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TEVATRON

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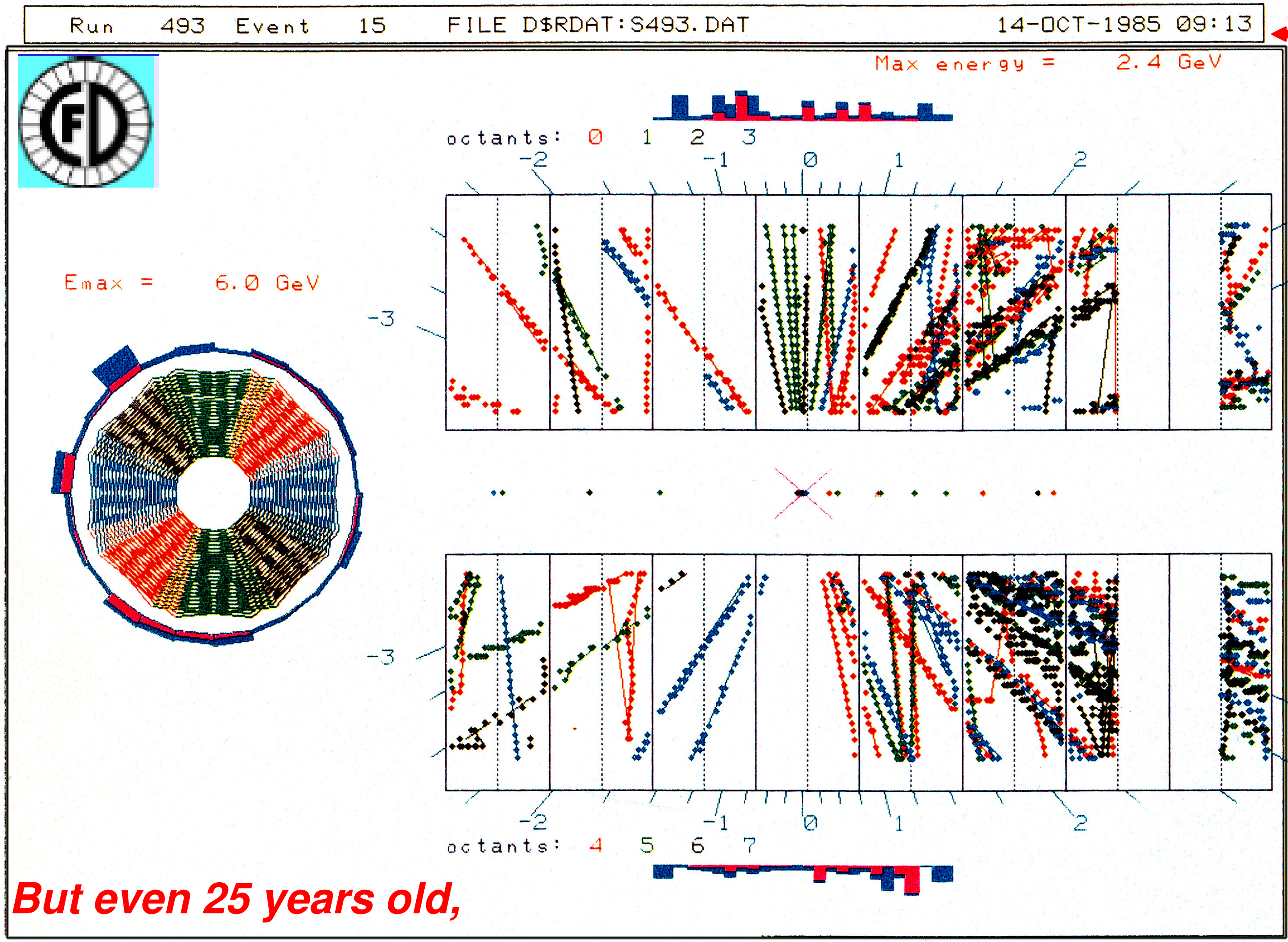
OUTLINE

- The Machine & the Detectors: CDF & D0
- Physics Menu
  - Tevatron Part I: Heavy Flavours
  - Tevatron Part II: EWK & Higgs sector
- Why and How long will Tevatron still run?

The lectures will concentrate on just a few among the many important Physics topics currently under analysis in the CDF and D0 Collaboration. This choice is of course biased but it intends to show the audience what are still the important researches ongoing at the Tevatron and competitiveness/complementariness with the forthcoming LHC results.

THE MACHINE and THE DETECTORS: CDF and D0

TEVATRON is an OLD PAL

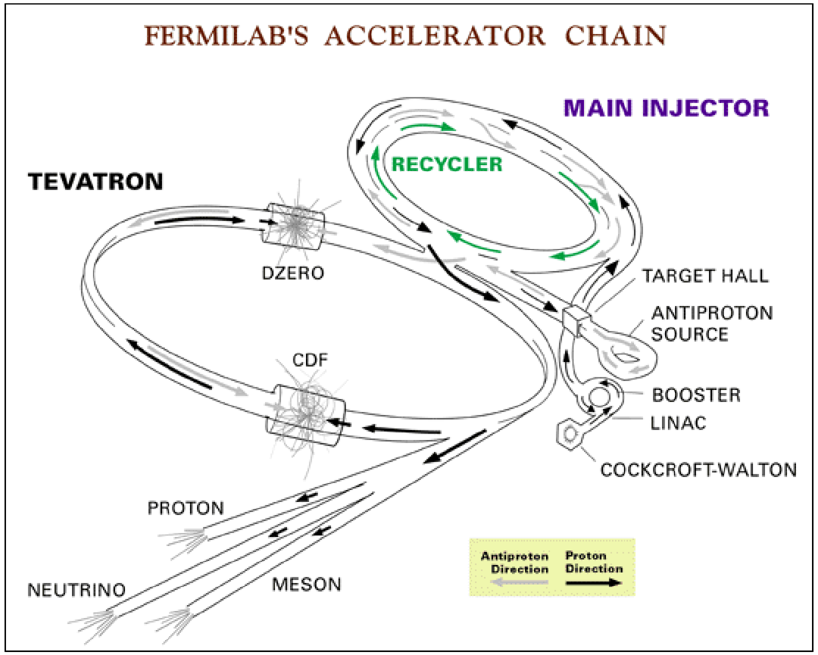


OCT. 15 1985!

First collisions at 1.6 TeV c.m., observed by CDF in the VTPC central innermost tracker
Courtesy of G.P. Yeh, the author of this online original Display…

But even 25 years old,

the Tevatron is running extremely well & still improving its performances

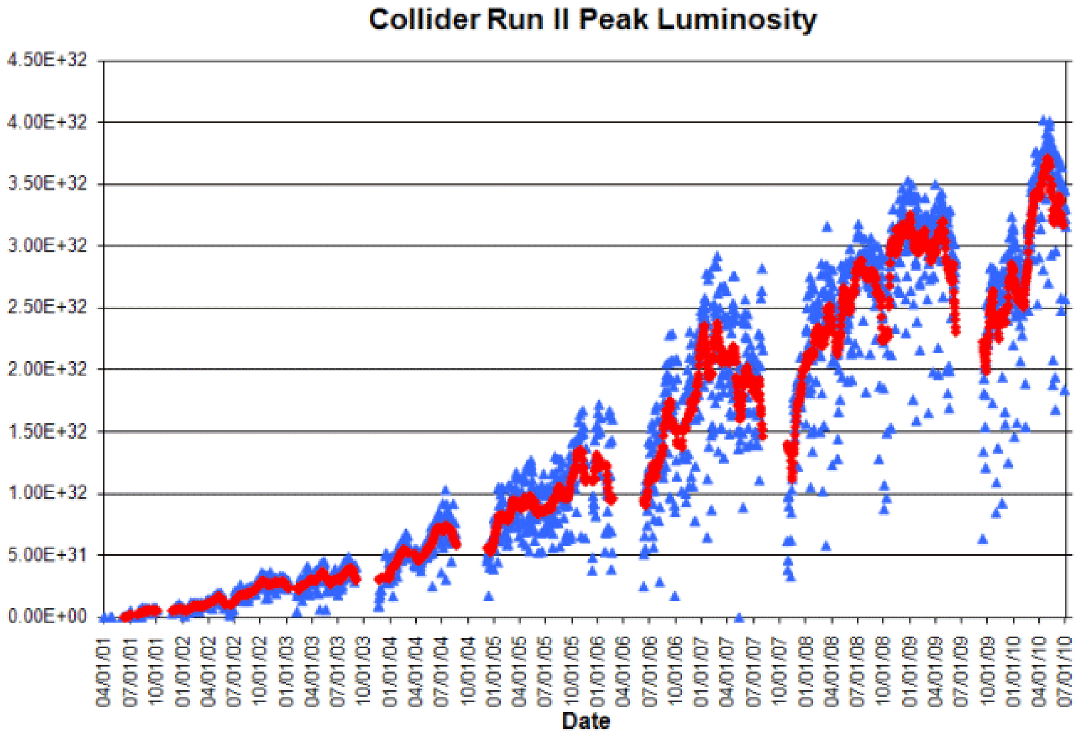


TEVATRON

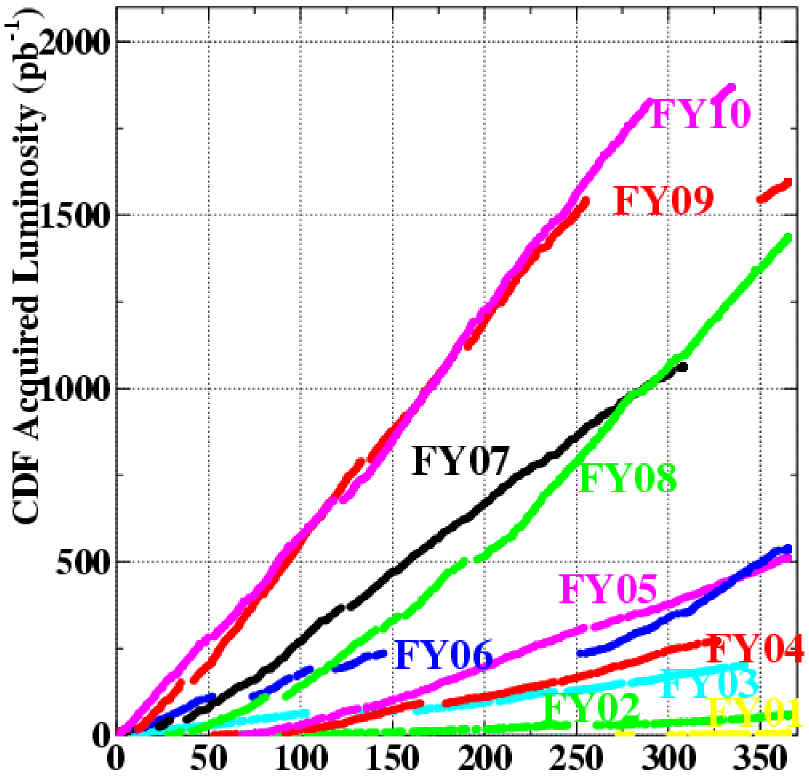
- proton – **anti**proton collider
- Center of mass energy in Run II: **E_{cms}=1.96 TeV**
- Run II machine cycle: **396 ns**
- Dominated by:
  quark-antiquark interactions (LHC: gluon-gluon)

-First collisions observed Oct 13, 1985 at 1.8 TeV
-CDF experiment observed these first collisions and the first top events in 1992 (first vertex detector in hadronic machine)

- D0 started at Run I in 1992
- Both CDF and D0 discover the top in 1995



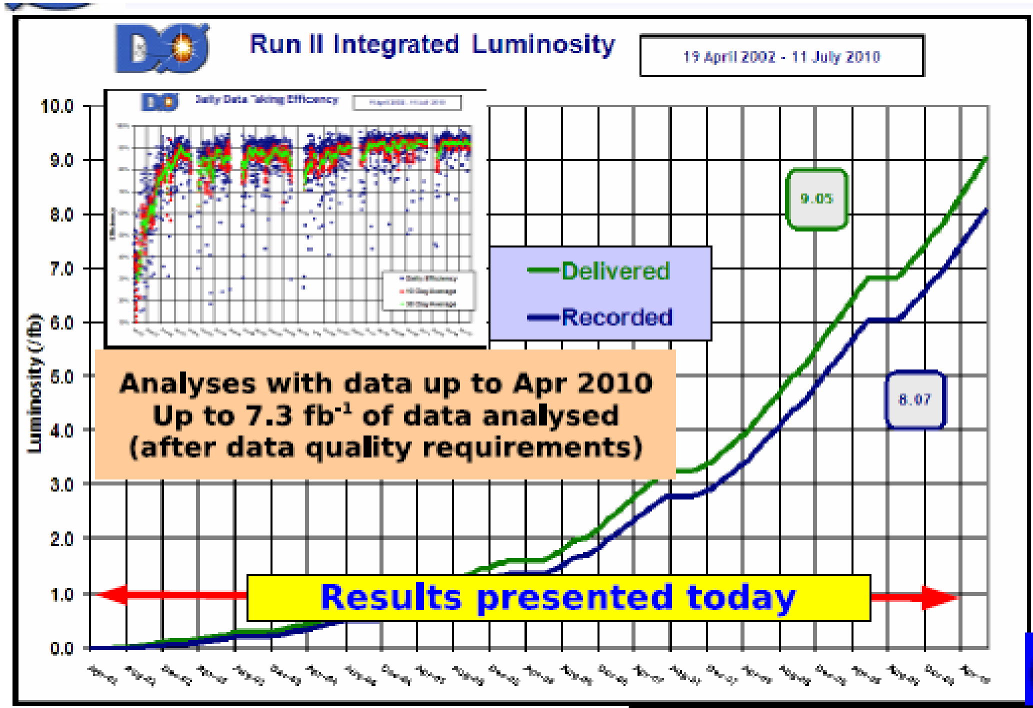
Tevatron Run II Luminosity



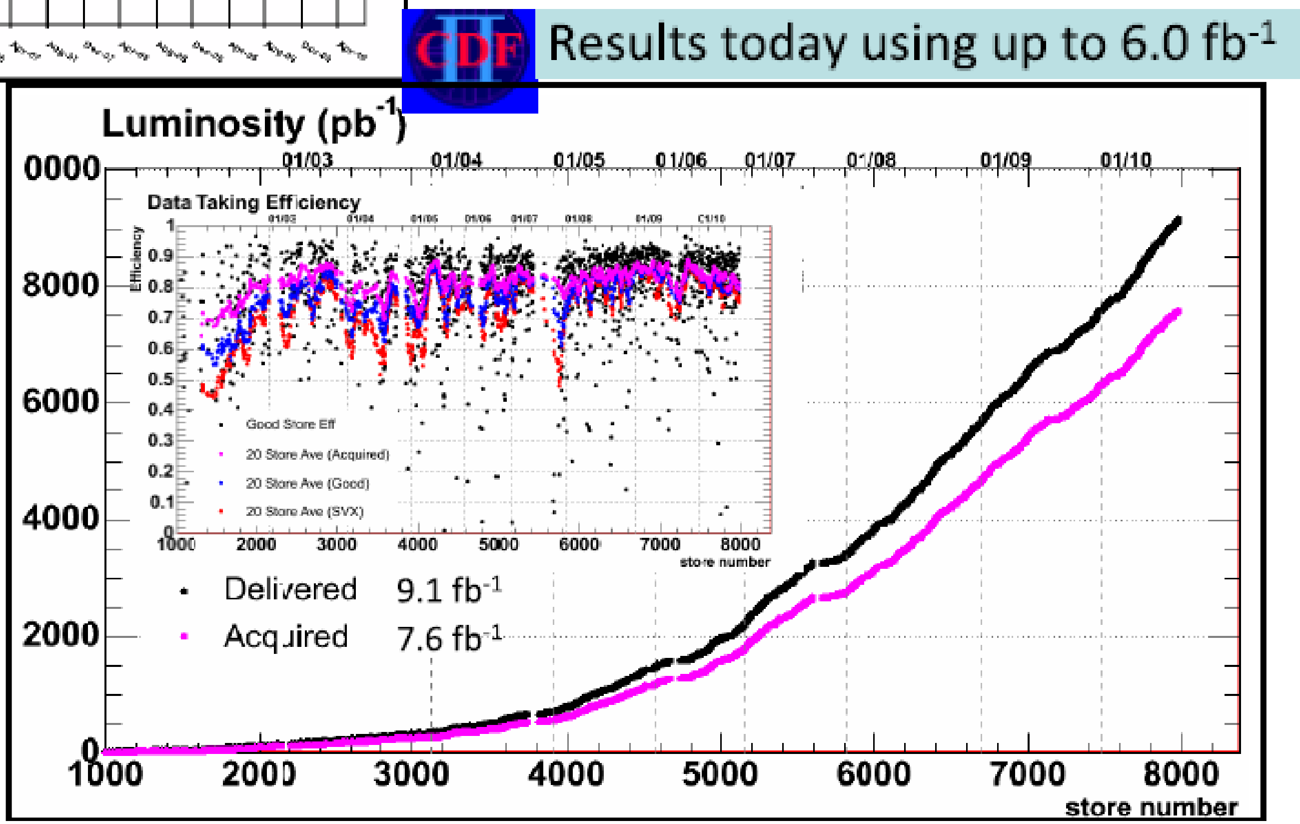
Delivered luminosity per year: still increasing, now about 2.5 fb^{-1}/year, about 50 pb^{-1} /week

Initial luminosity per shot still increasing, now: up to 4 x 10 ^{32} cm^{-2} s^{-1}

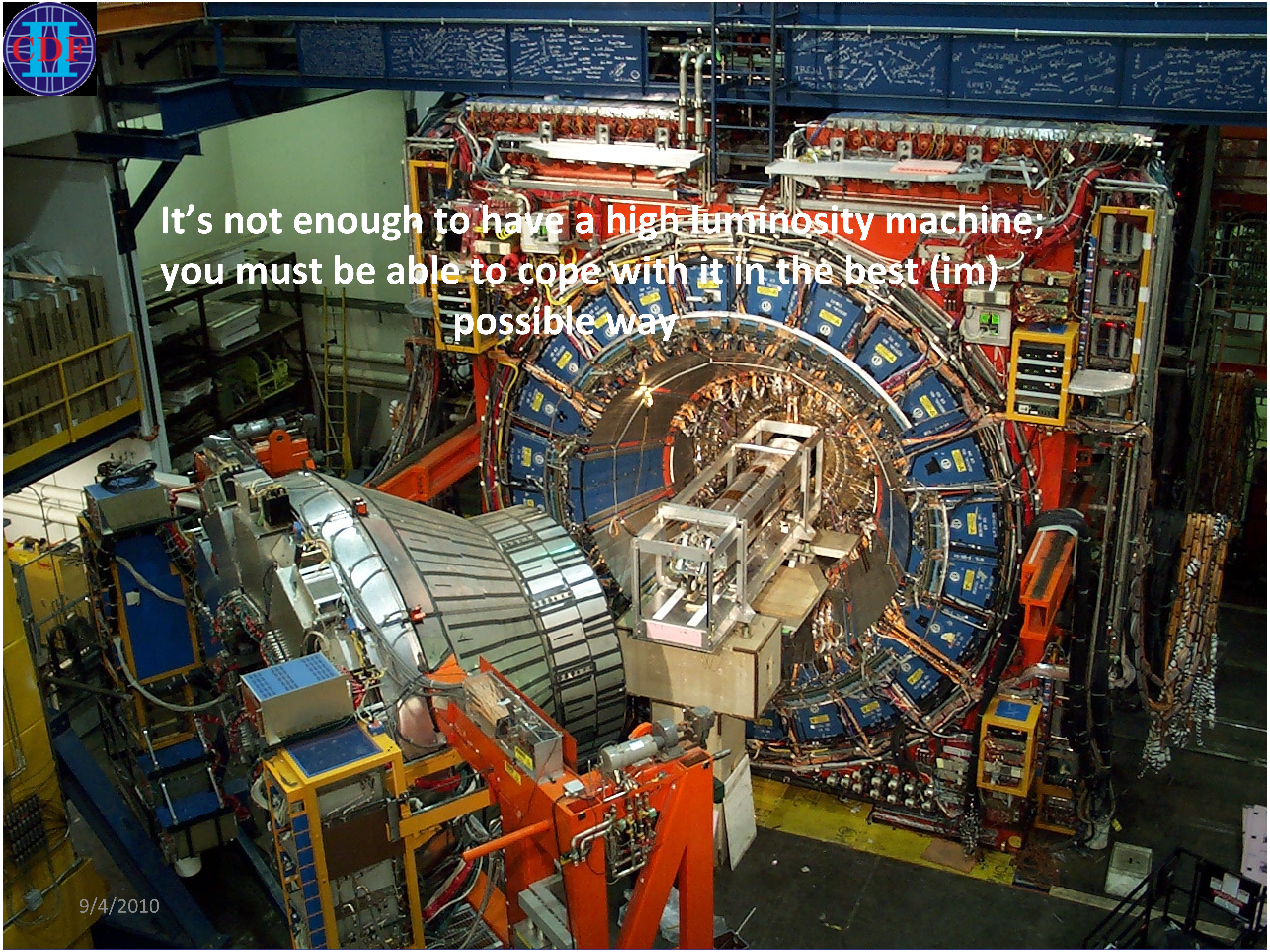
Therefore the Tevatron overpasses by about a factor 2 the scheduled maximum instantaneous luminosity for Run II.



Integrated Luminosity and Data taking efficiency per experiment since start of Run II

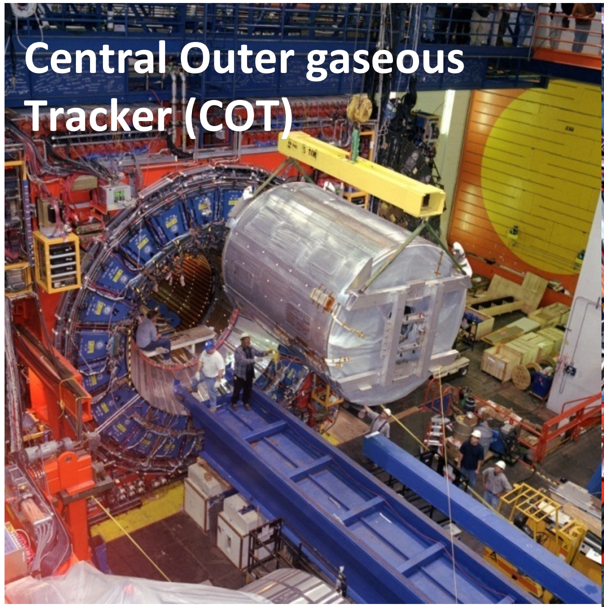


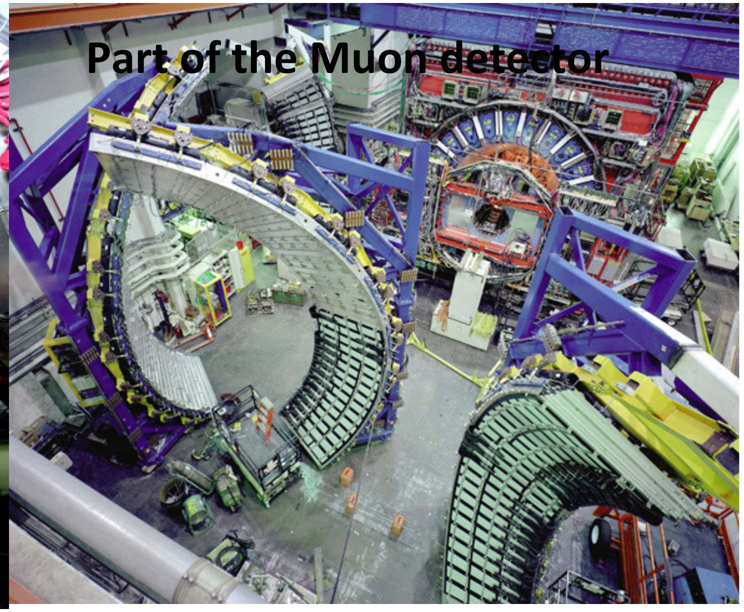
Up to July shut down:
9 fb^{-1} delivered/expt
7.6-8 fb^{-1} acquired. /expt
Data taking efficiency:
75 up to 90%

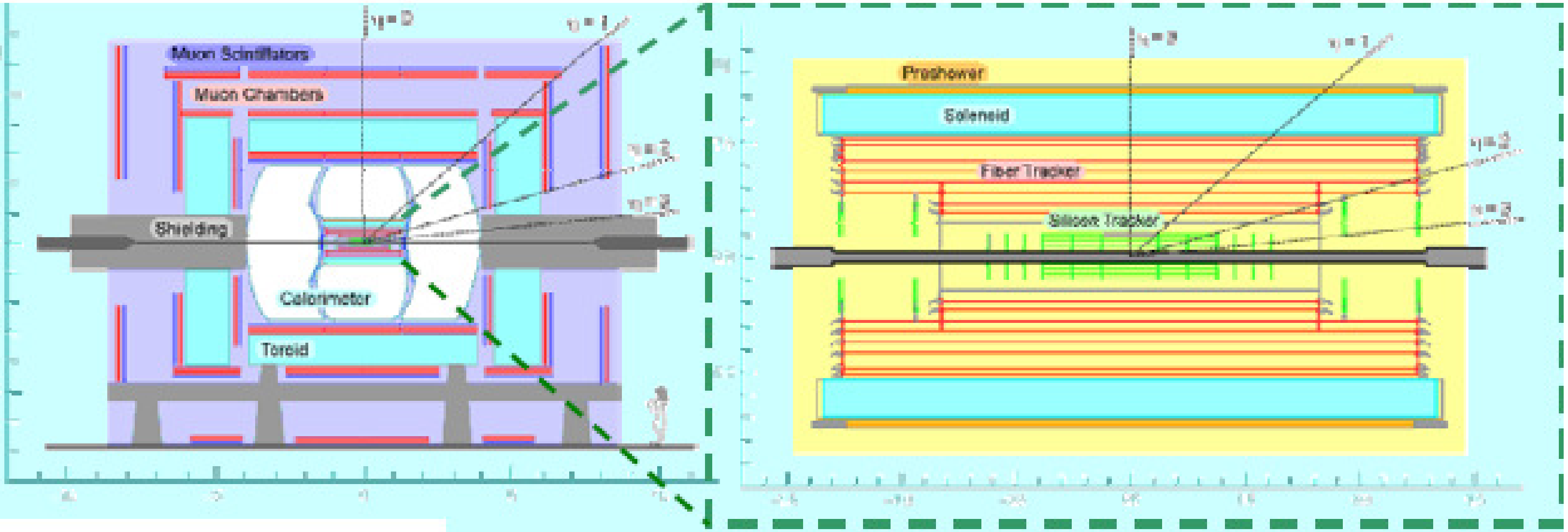


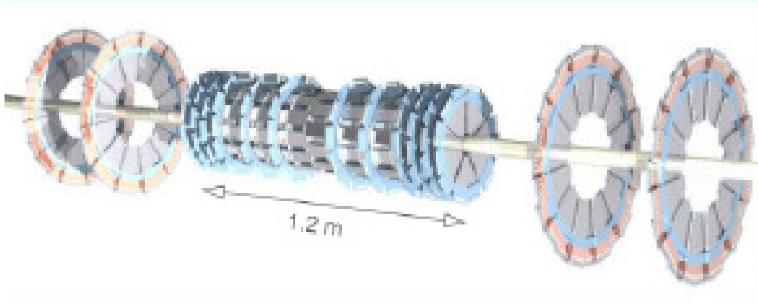
It’s not enough to have a high luminosity machine; you must be able to cope with it in the best (im) possible way

Since over about 3 decades (!!), several generations of experimentalists have worked on building and continuously upgrading CDF with innovative and pioneering ideas making it to be still today at the forefront and with various discoveries** (top, Bs mixing, single top & …)* ***plus important breakthroughs both in Physics and Detector techniques (2008'Panofsky award for SVX-SVT +impacts: A.Menzione +L.Ristori, Pisa)









- Excellent coverage of the Muon and tracking η <2
- Excellent calorimetry & electron ID
- High efficiency muon trigger with Pt measurement at Level 1 (toroid)
- 2T solenoid & 1.8 T toroidal reversed weekly (OK for μ asymmetry systematics)

Trigger	CDF	D0
2 Tracks	Pt> 2GeV/c Pt1+Pt2>5.5GeV/c 100μm<Id12I<1mm	No
1-muon	No	Pt(μ)>3, 4.5GeV/c
2-muon	Pt(μ's)>1.5GeV/c	Pt(μ's)>2.0 GeV/c

Triggering: an essential issue in hadron colliders

=> example of a continuously upgraded & sophisticated trigger system by CDF

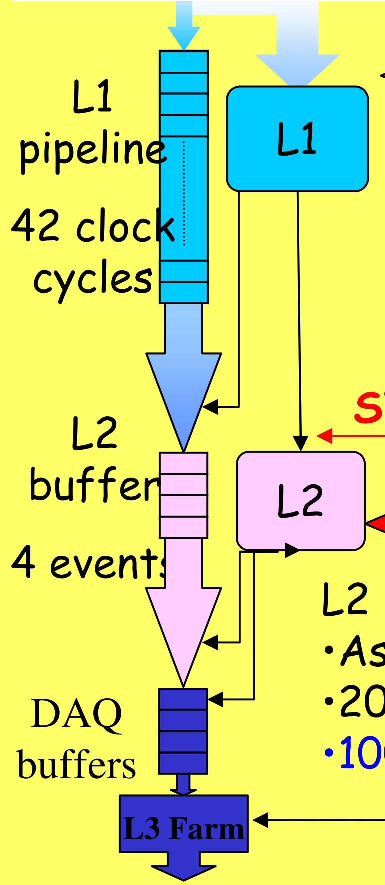
First time triggering on tracking system at first level (XFT)

First time triggering on vertex

Silicon tracker => Real time Physics

Very important contribution of Tracker in CDF Trigger Architecture

7.6 MHz Crossing rate



L1
- 7.6 MHz Synchromous Pipeline
- 5.5 μs Latency
- 30 kHz accept rate

SVX read out after L1

L2
- Asynchromous 2 Stage Pipeline
- 20 μs Latency
- 1000 Hz accept rate

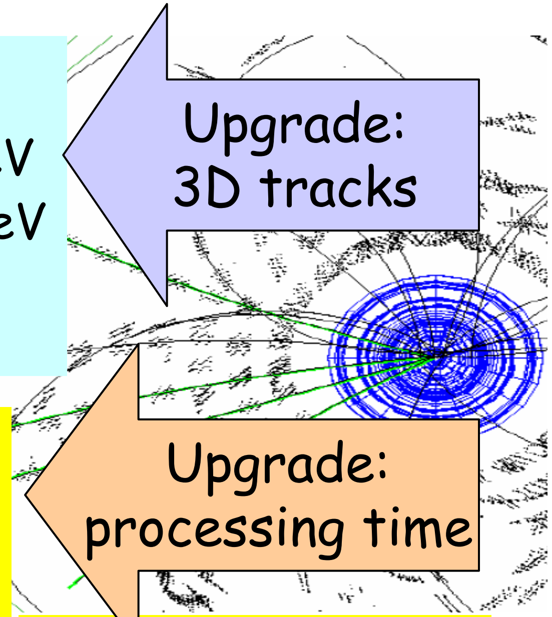
L3: CPU farm Full event Reconstruction Speed-optimized offline code

Mass Storage

(~100 Hz)

XFT – Level 1

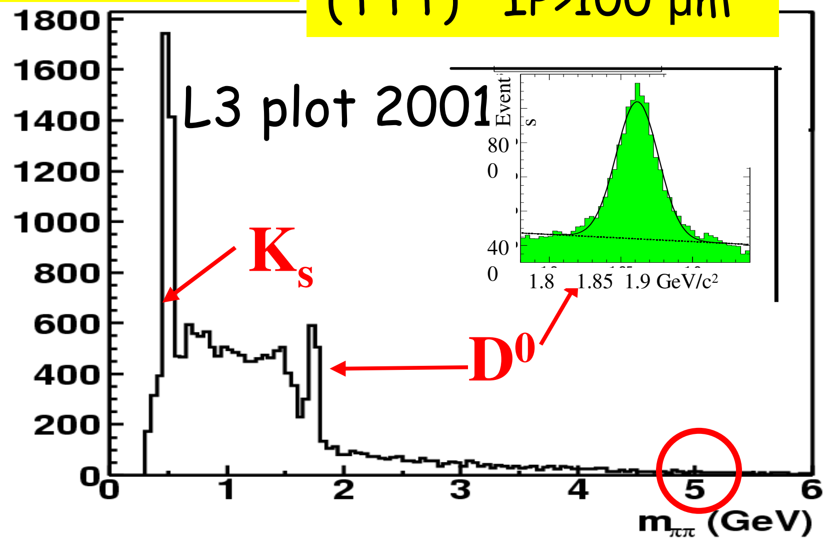
all trck pT>1.5 GeV
σ(1/pT) = 1.7%/GeV
σ(φ0) = 5 mrad
96% efficiency



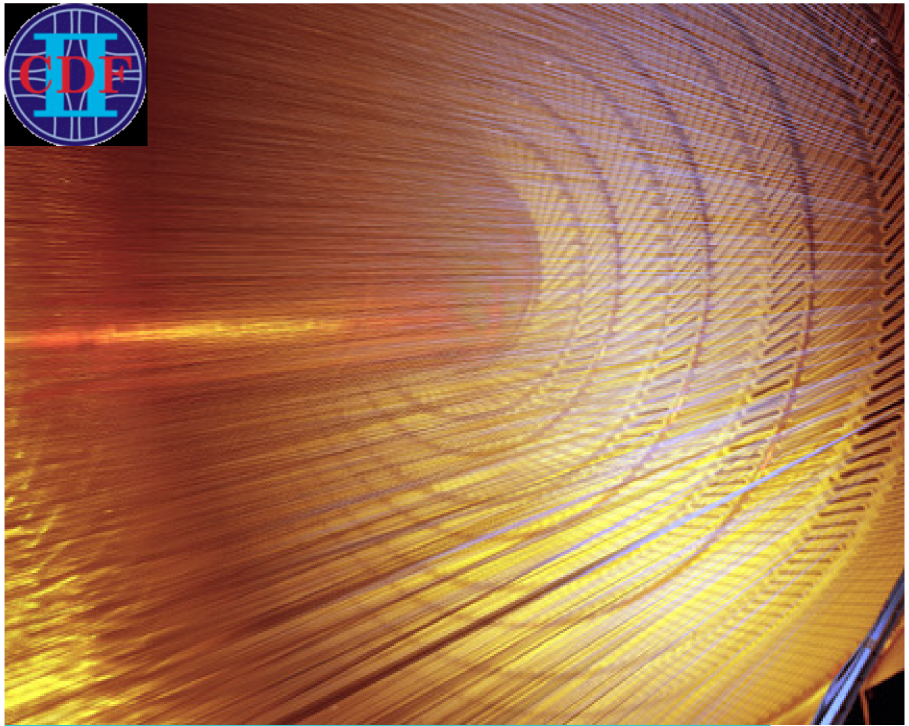
SVT – Level 2

all trck pT>2 GeV
σ(IP) = 35 μm,
σ(1/Pt) = 0.3 %
σ (φ0)=1 mrad

Two Track Trigger (TTT) IP>100 μm

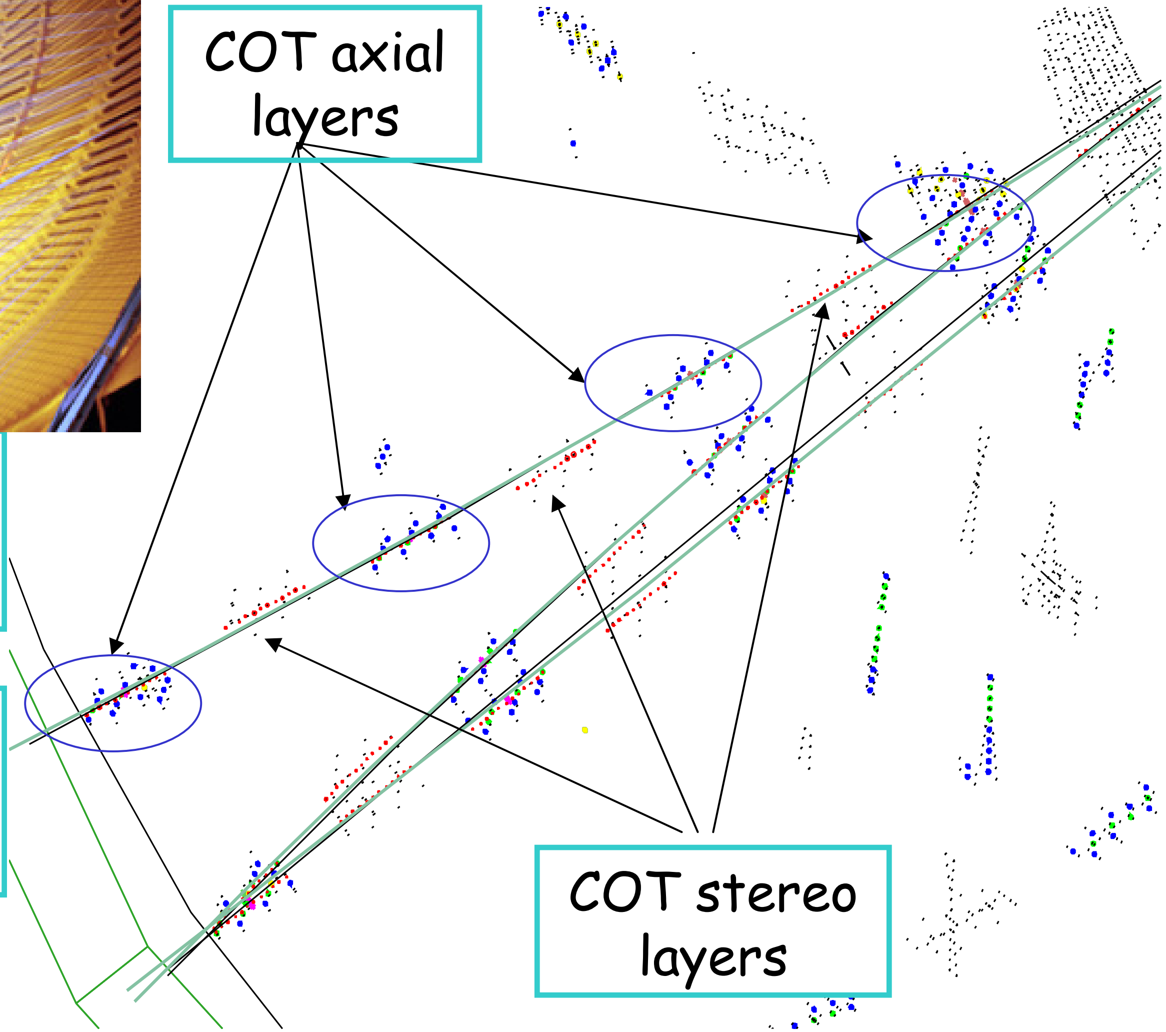


Upgrading the trigger to cope with the increase in luminosity is another crucial issue, well experienced at the Tevatron (see next). It will also be of course essential at the LHC when the luminosity is going to get to 10^{32} cm^{-2} s^{-1} and higher…



Gaseous tracking chamber rebuilt from run I to run II to cope with luminosity x100 and for the first time a tracking LV1 trigger:

eXtremelyFastTracker

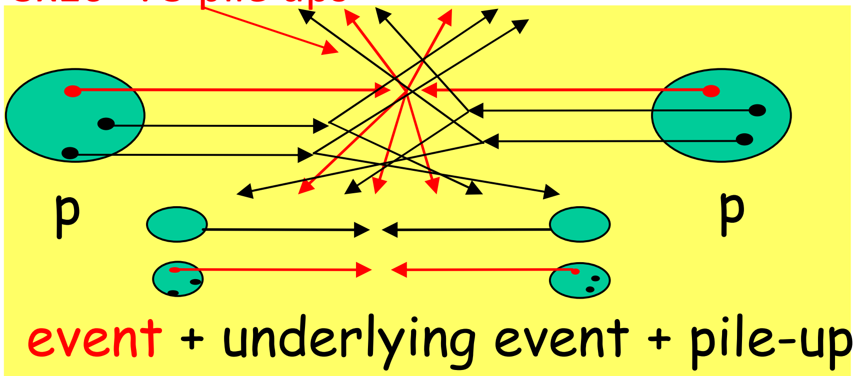


Good hit patterns are identified as segments, then segments are linked as tracks

XFT 3D upgrade:
Add info from stereo layers
Fake rejection ~8

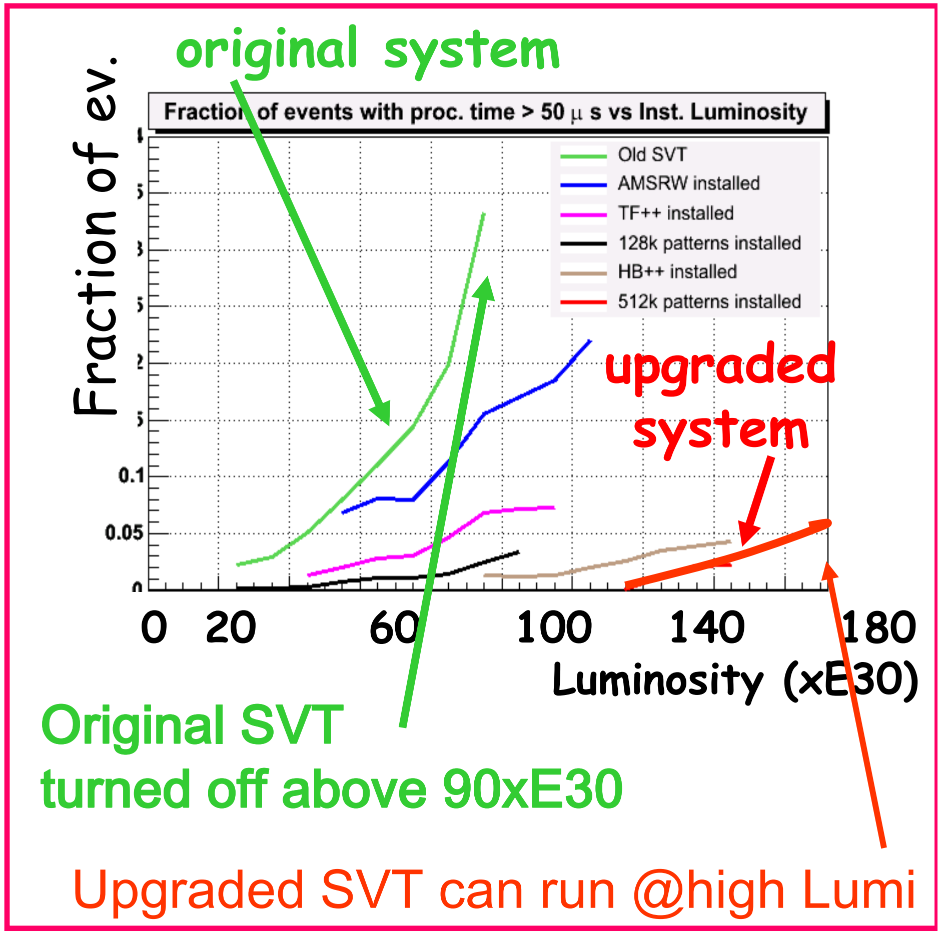
Upgrade SVT for luminosity

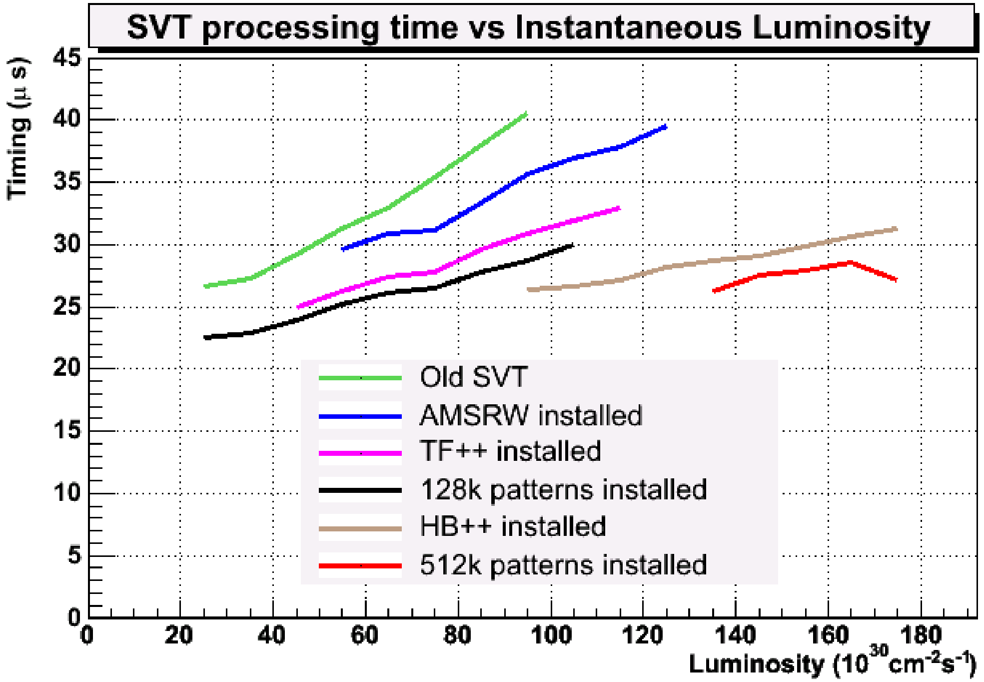
At $3x10^{32}$: 5 pile ups



Upgrade: Faster SVT components and:

32Kpatterns → 512Kpatterns new AM.





Good Data@ higher Luminosity
More Data @ lower Luminosity

TEVATRON
Part I

HEAVY FLAVOURS

Importance of triggers in B Physics

Di-Muon (J/ψ)	Displaced trk + lepton (e, μ)	2-Track Trig.
$Pt(\mu) > 1.5$ GeV	IP(trk) > 120μm	Pt(trk) > 2 GeV
J/ψ modes down to low $Pt(J/\psi)$ (~ 0 GeV)	Pt(lepton) > 4 GeV	IP(trk) > 100 μm
	Semileptonic modes	Fully hadronic modes

$X(3872) \rightarrow J/\psi\pi\pi$

β_s in $B_s \rightarrow J/\psi\,\phi$,

Ξ_b, Ω_b Observation

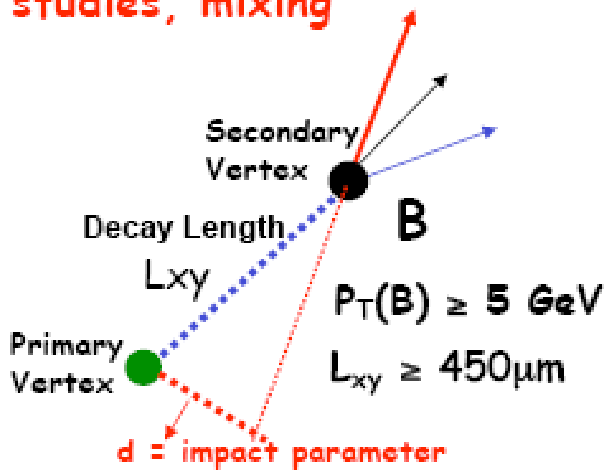
$\Lambda_b \rightarrow J/\psi\,\Lambda$ (masses, lifetimes)

$B^0_{s,d} \rightarrow \mu\mu$ (rare decays)

$Bc \rightarrow J/\psi\,\pi$ (J/ψ lX)

High statistics lifetime

Tagging studies, mixing



$B \rightarrow hh$ (CP)

B_s mixing

D^0 mixing

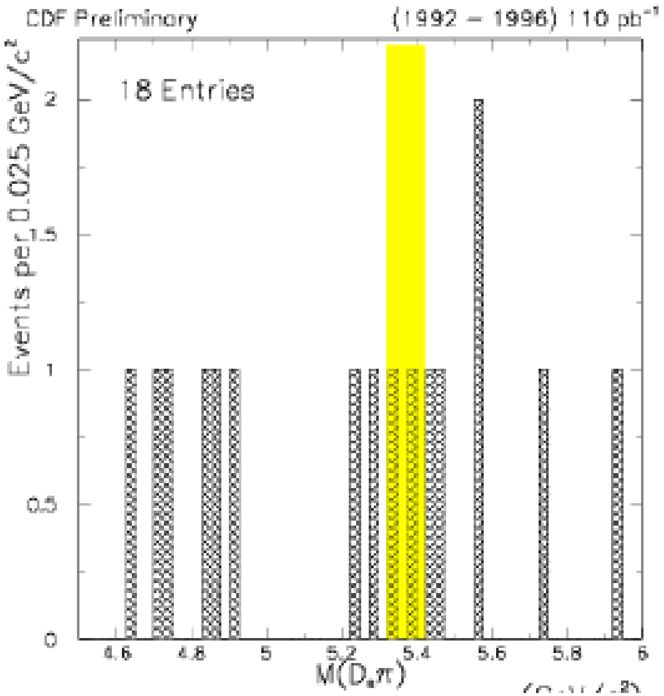
$\Sigma^{*+} \rightarrow \Lambda_b\,\pi$

$\Lambda_b \rightarrow \Lambda_c\,\pi$

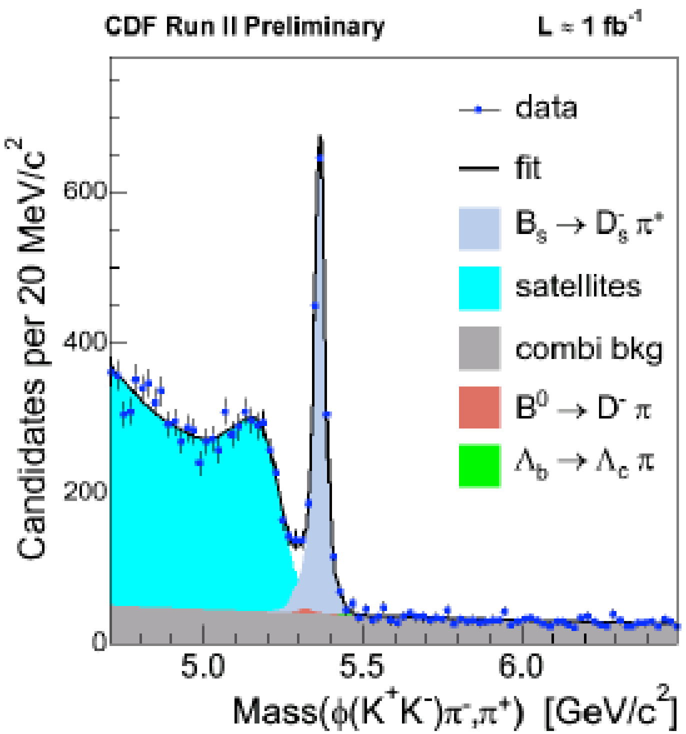
Hadronic B Trigger (II)

- Run I collected O(1) $B_s \rightarrow D_s\pi$ in 100 pb^{-1} (all D_s modes)
- Run II collected ~200/100 pb^{-1} $B_s \rightarrow D_s\pi$ (D_s--> $\phi[\rightarrow K^+K^-]\,\pi$)
- *Compare with only 10x integrated luminosity!*

Without SVT



With SVT



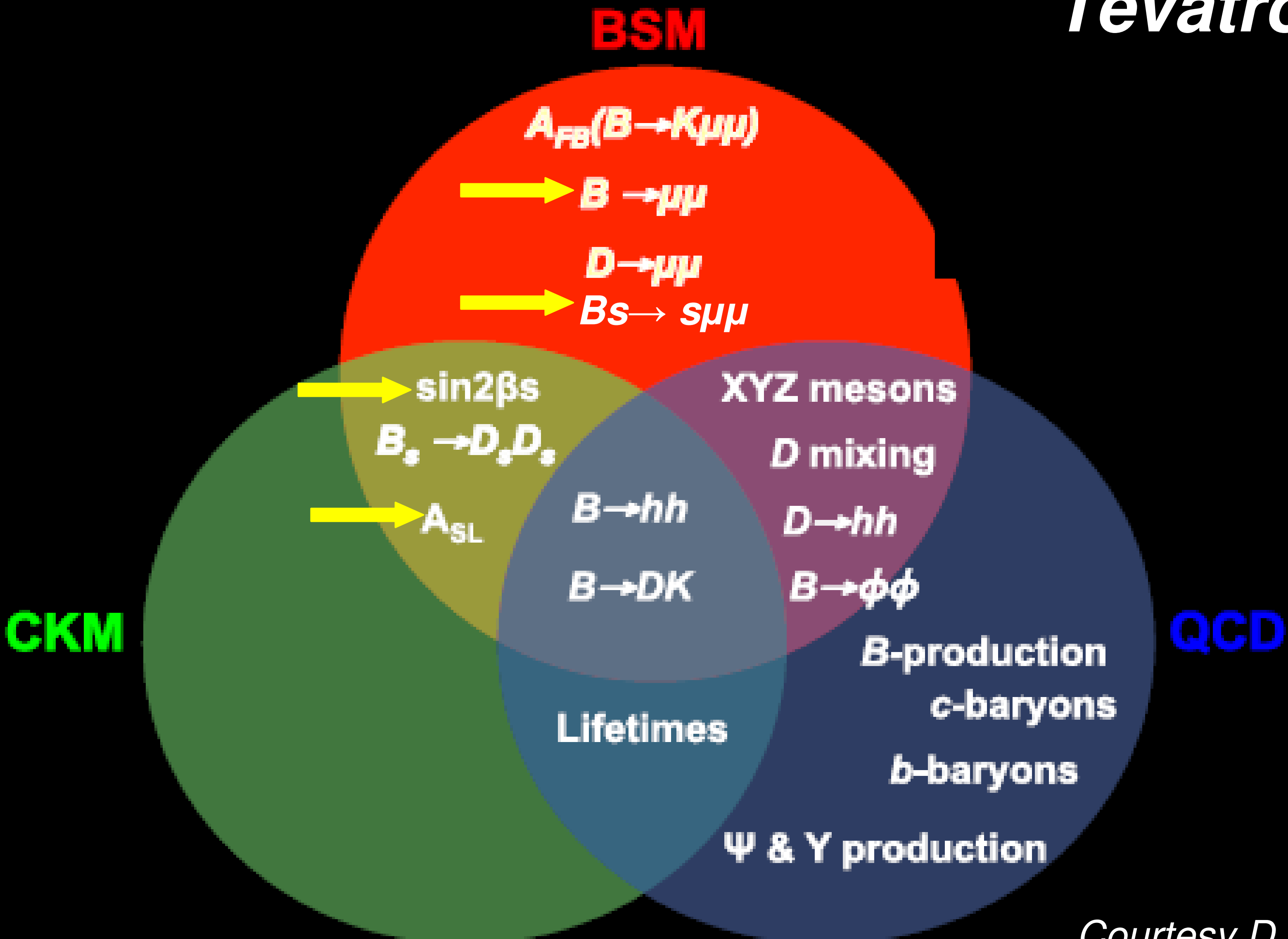
The Tevatron is a B and charm factory

- Bs **mesons**={b,s} are only produced in hadron colliders. By several aspects, they are unique probes for beyond standard model searches and CP violation phenomena.
Tevatron is fully exploiting the physics potential of Bs mesons.

- Tevatron gives access as well to b-baryons.

- CDF has the largest world's samples of B & charm with special thanks to SVX+SVT!! *(see previous slides). Important also the Particle ID with COT (dE/dX) and the TOF => π and K identification*
- CDF challenges B factories (on charged final states):
  40M J/ψ (about 20% from B)
  > 6K $B^0_s \to J/\psi\ \varphi$, 32 K $B^0 \to J/\psi\ K^*$
  50 M $D^0 \to K^-\pi^+$, 12 K $B^0 \to K^-\pi^+$ etc.

Physics Topics covered by B & Charm at Tevatron



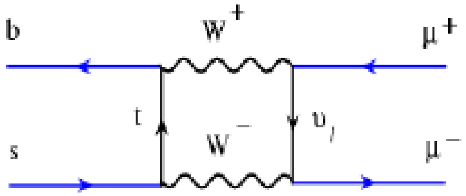
Courtesy D. Tonelli

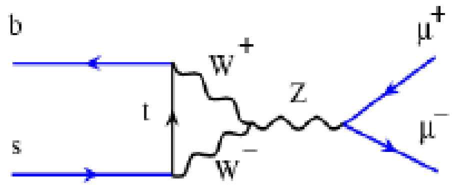
Among the many topics let's focus on the latest results of processes with the yellow arrow

RARE DECAYS

1) FCNC decays: very suppressed by SM

Forbiden at tree level, proceed through loop diagrams





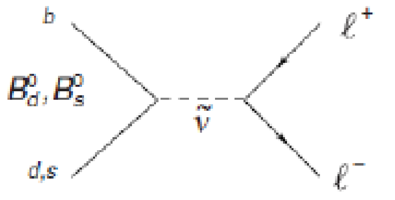
Recent rather precise BF predictions in SM:

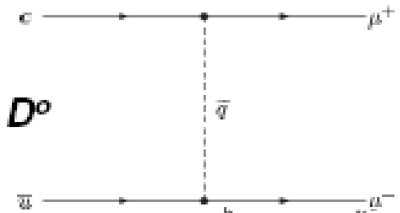
$$Br(B_s \to \mu^+\mu^-) = (3.6 \pm 0.3) \cdot 10^{-9}$$

$$Br(B_d \to \mu^+\mu^-) = (1.1 \pm 0.1) \cdot 10^{-10}$$

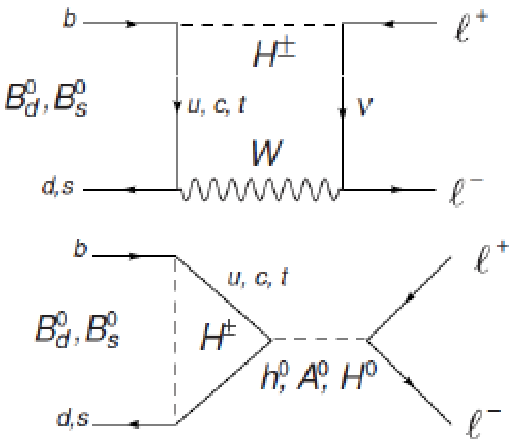
A. Buras

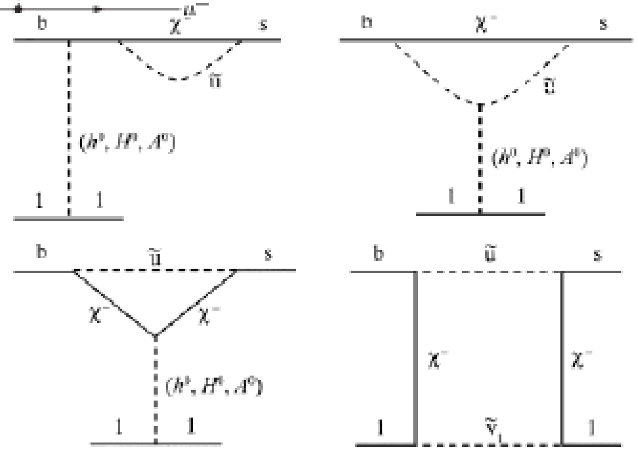
New Physics can appear in:





Look for B_s^0 or B_d^0 →ee, eμ or μμ and D^0→μμ





$\mathcal{B}^{SUSY}(B \to \mu\mu) \propto (\tan\beta)^6$

NP can appear at

- Tree level

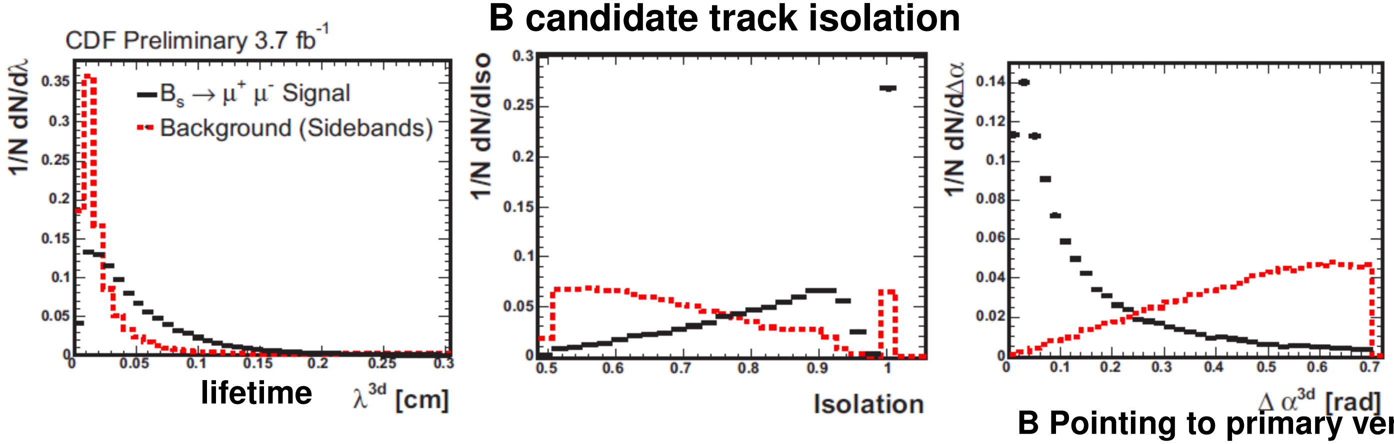
Or

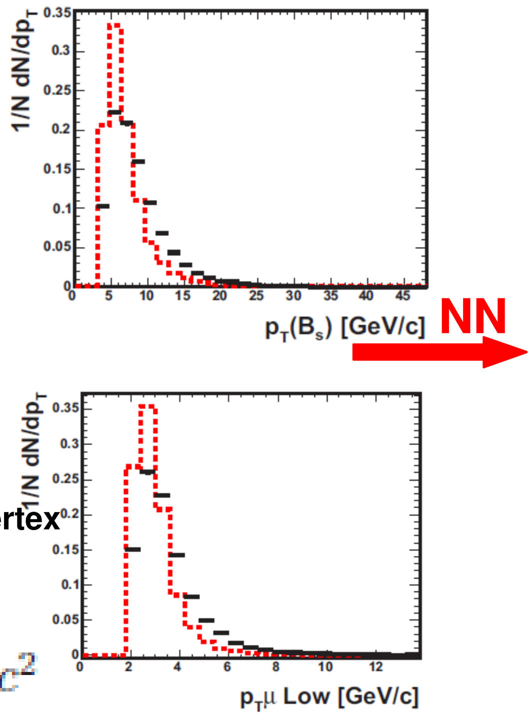
- through loops

▪MFV –SM extensions such as: 2 HDM or MSSM

Example of search for $B_s \to \mu\mu$ rare decay

The events are searched in a sample of dimuon triggered events
a set of discriminating variables, comparing data (sidebands, red) with MC generated events (black) are studied and trained in a NN:





Signal region determined by $5.169 < M\mu\mu$ (GeV/c^2)< 5.469
Sideband regions to estimate the background:

$$4.669 < M_{\mu\mu} < 5.169\,\mathrm{GeV}/c^2 \text{ and } 5.469 < M_{\mu\mu} < 5.969\,\mathrm{GeV}/c^2$$

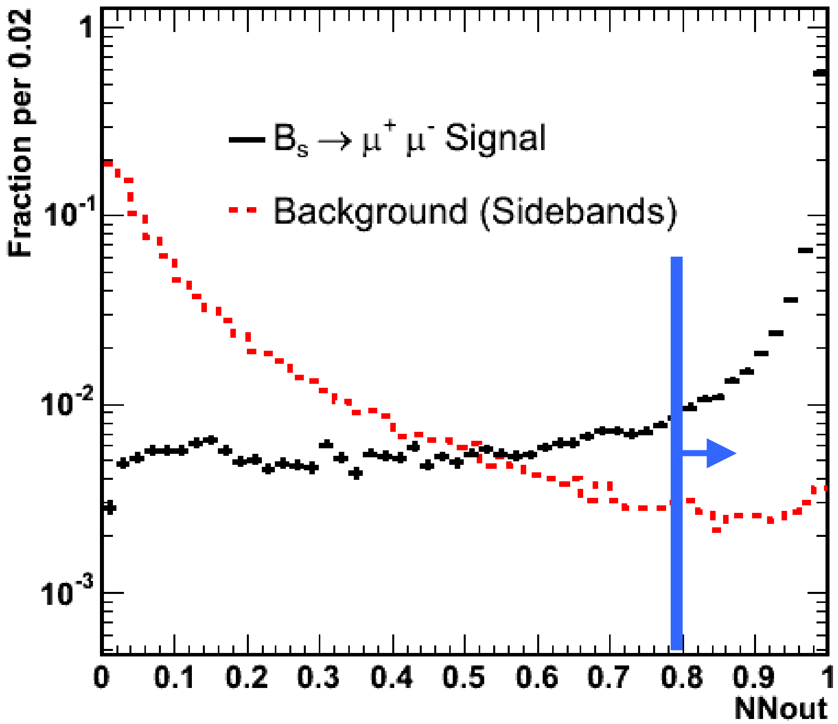
The Branching fraction is obtained by normalizing to the number of $B^+ \to J/\Psi K^+ \to \mu^+\mu^- K^+$

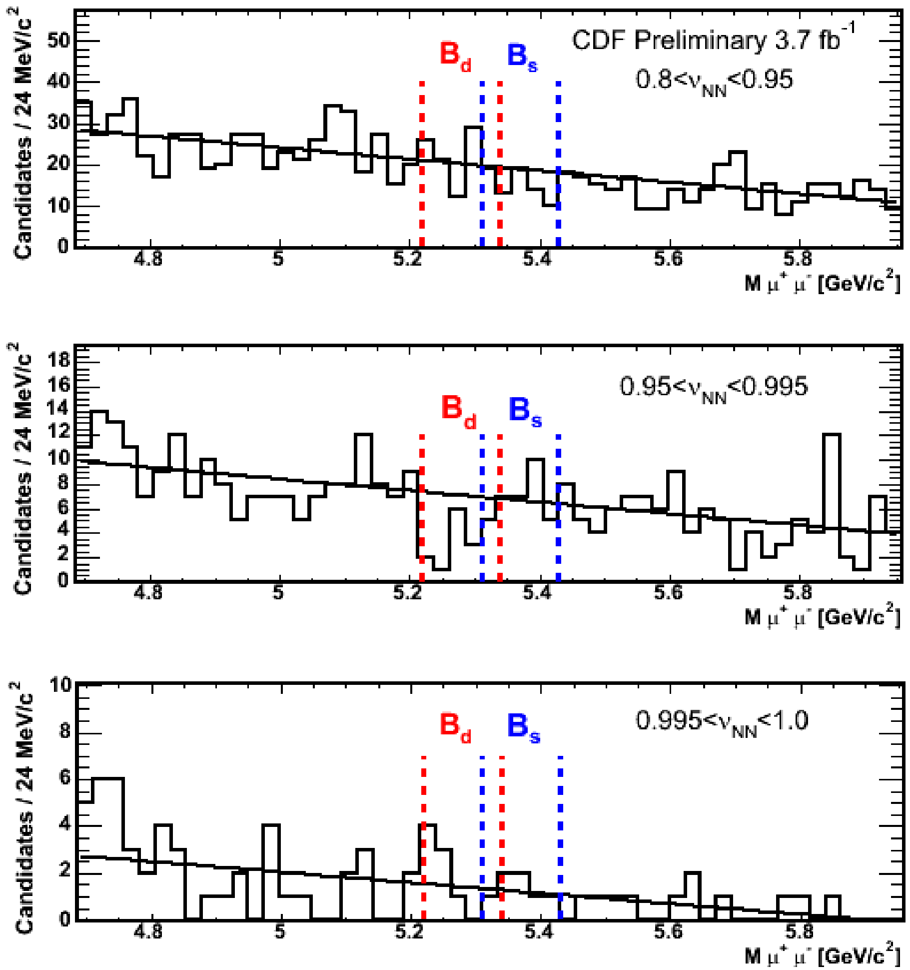
$$\mathcal{B}(B^0_{s,d} \to \mu^+\mu^-) = [N_{s,d}/N_+] \times [\alpha_+/\alpha_s] \times [\varepsilon_+/\varepsilon_{s,d}] \times [1/\varepsilon^{NN}_{s,d}] \times f_u/f_{s,d} \times \mathcal{B}(B^+ \to J/\Psi K^+)$$

Where N_s=number of $B^0_s \to \mu^+\mu^-$ at 95%CL for N observed and N_b expected backg.
α stands for the acceptance, ε for efficiency and f for fragmentation function

RESULTS:

Suppress background with NN trained on MC/sideband data



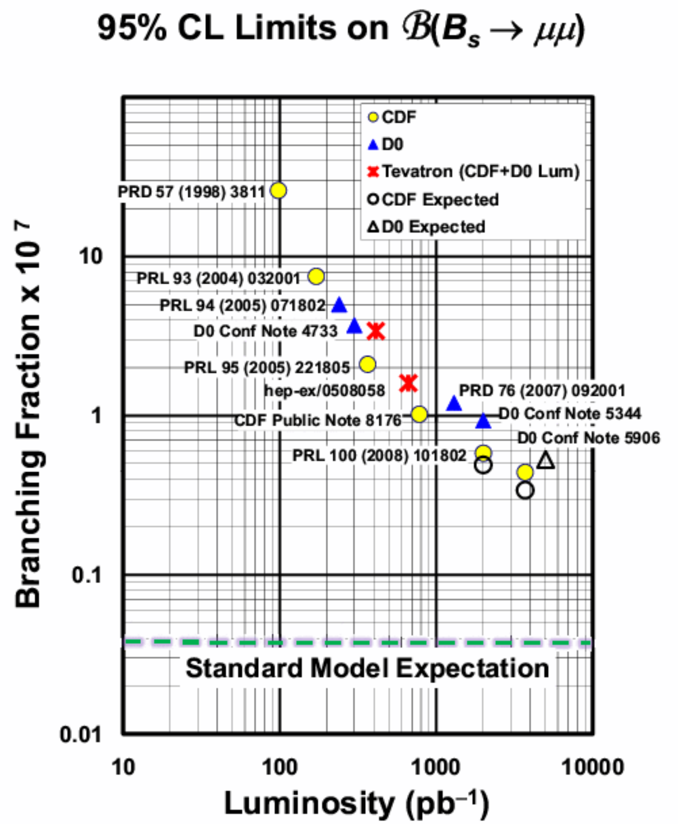


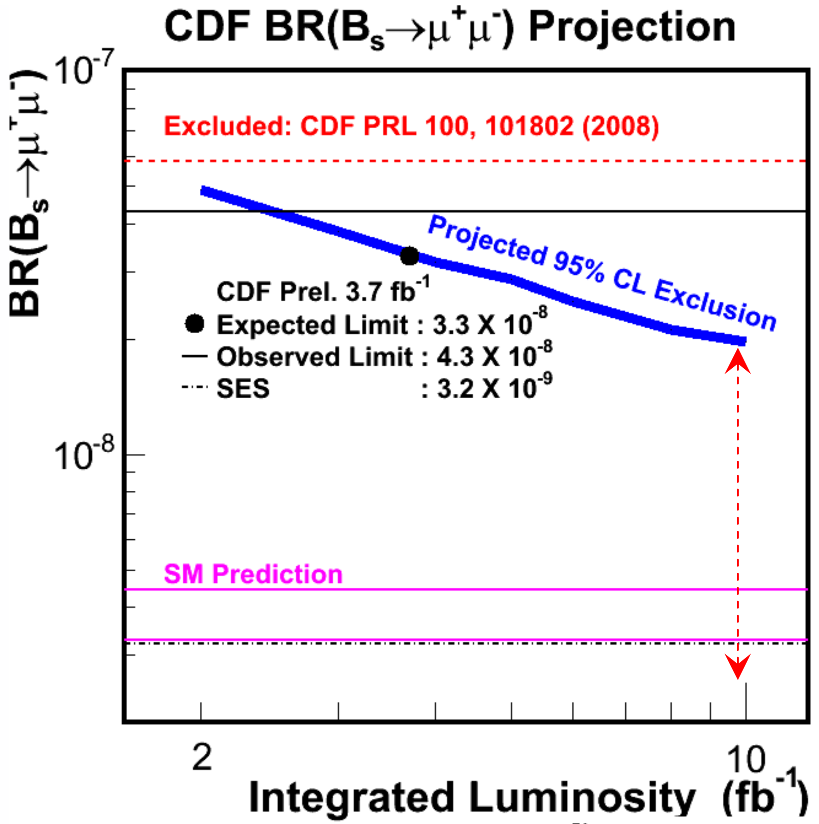
World best limit on 3.7 fb^{-1} of data:

CDF mass resolution allow separation of Bs and Bd signal regions

$$BR(B_s \to \mu^+\mu^-) < 4.3\times10^{-8} \; @\, 95\% \; C.L.$$

$$BR(B_d \to \mu^+\mu^-) < 7.6\times10^{-9} \; @\, 95\% \; C.L.$$

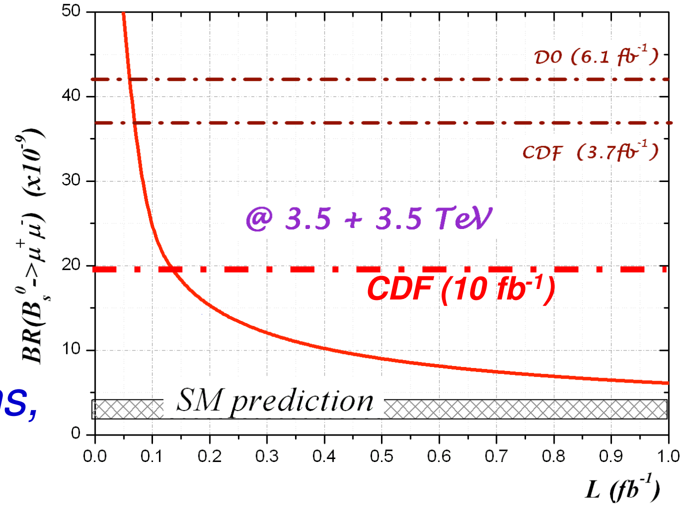




Bs→μ+μ-: Status and prospects

ATLAS & CMS should soon join

LHCb

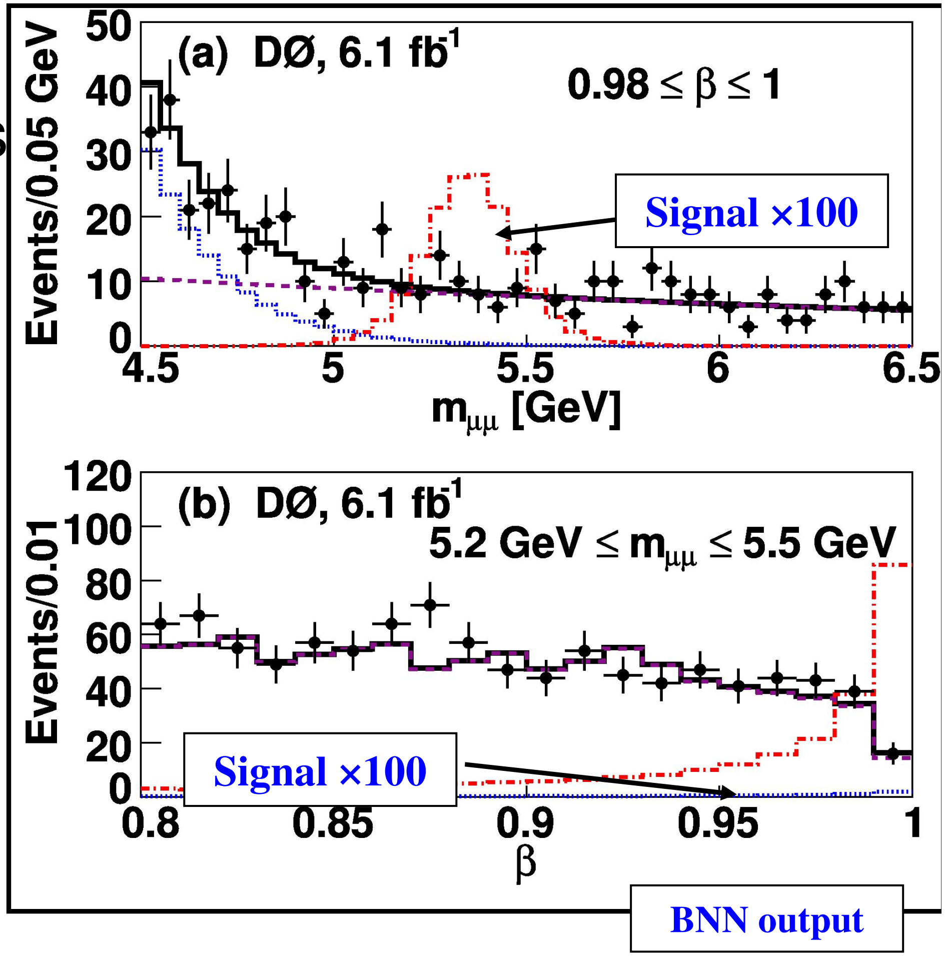


-CDF won already 2 orders of magnitude in RunII
Now still the last factor x10!
And competition with LHCb @ $1fb^{-1}$
- But already, constraining more and more BSM.
Several BSM models predict 1 up to 3 orders of magnitude deviation wrt SM and have relevance to explain deviation of the muon g-2, neutrino oscillations, Bs oscillations, dark matter/dark energy results

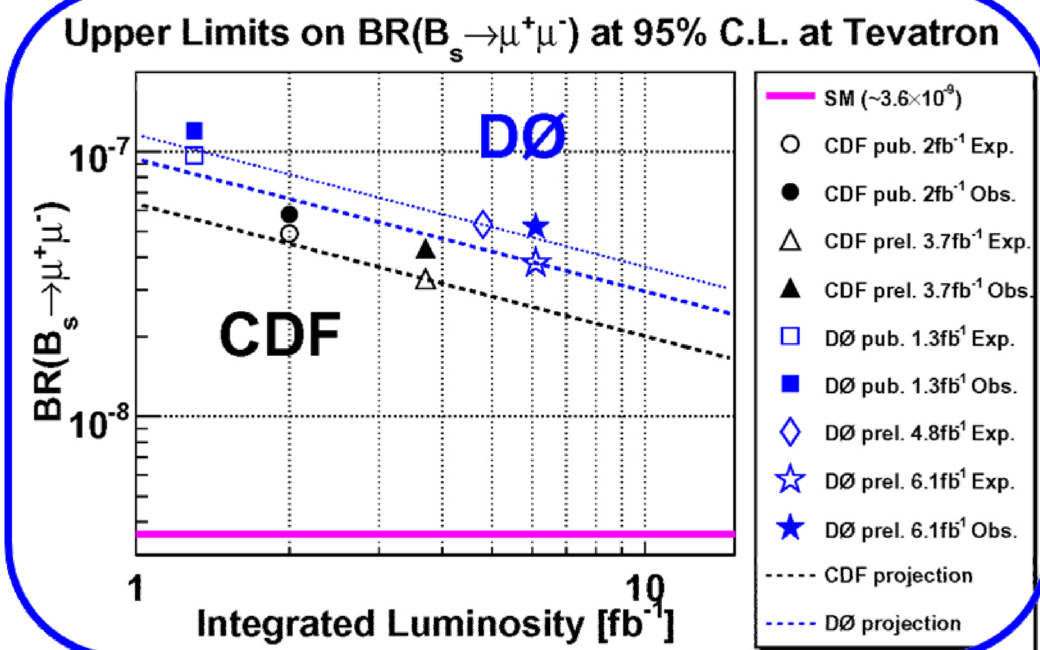
$B_s \rightarrow \mu^+\mu^-$

- 6.1 fb^{-1} of data analyzed
- Many improvements of analysis compared to previous published result
  - Improved muon identification and trigger selection
  - Bayesian NN is used instead of Likelihood ratio method
  - Limits are calculated in several bins of BNN variable and M(μμ)

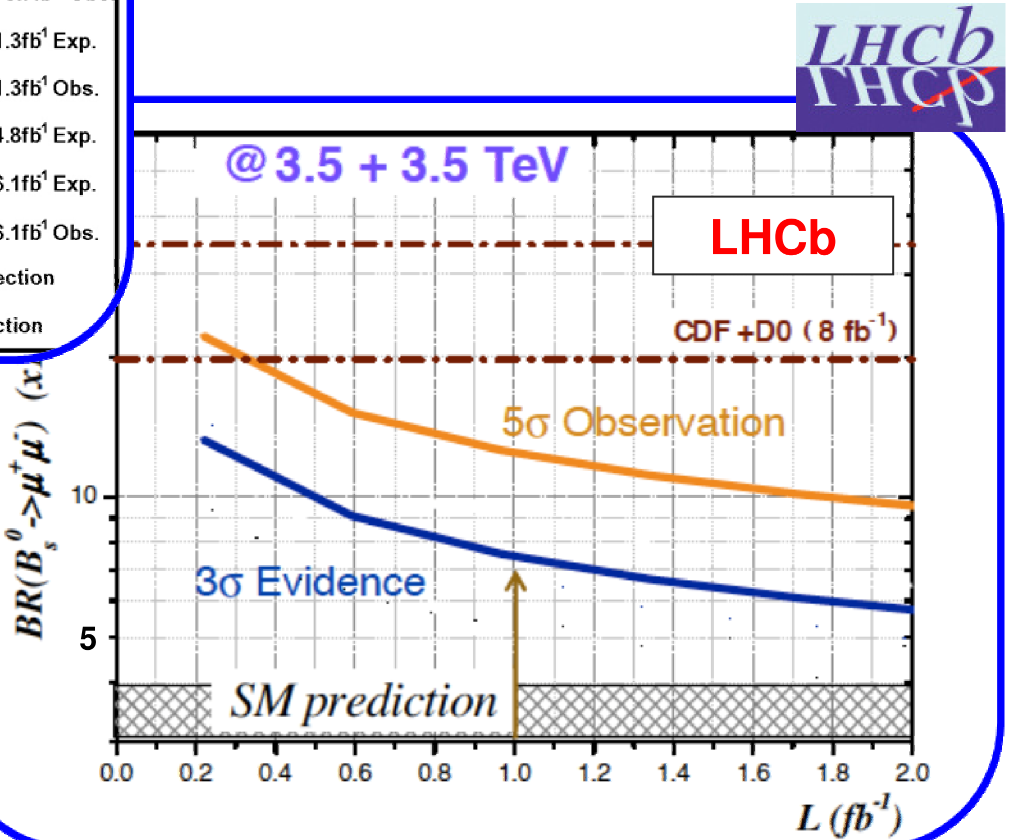
$$\mathrm{Br}(B_s \rightarrow \mu^+\mu^-) < 5.1\times10^{-8}(95\%\ C.L.)$$
$$\mathrm{Expected}: 4.2\times10^{-8}(95\%\ C.L.)$$



$B^0_s \rightarrow \mu^+\mu^-$ - year 2012



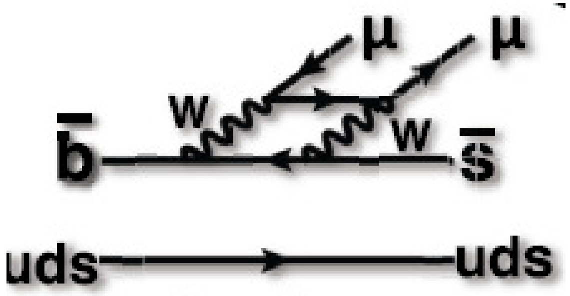
Competition may be tight. ATLAS and CMS may join



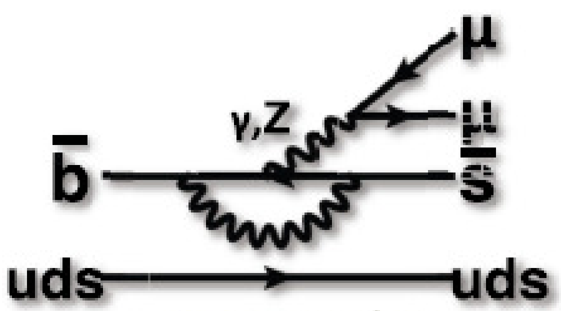
SM value won't be probed anytime soon, but eating-in last chunks of NP space.

$b \to s\mu^+\mu^-$

- Suppressed decays in SM: Br ~ O(10^{-6})
- New Physics in penguin or box diagrams modifies the decay-kinematics



W box diagram

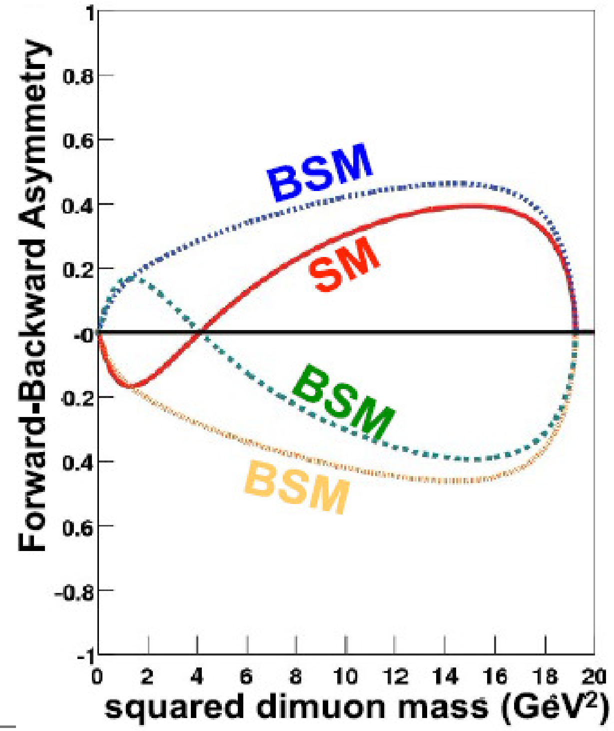


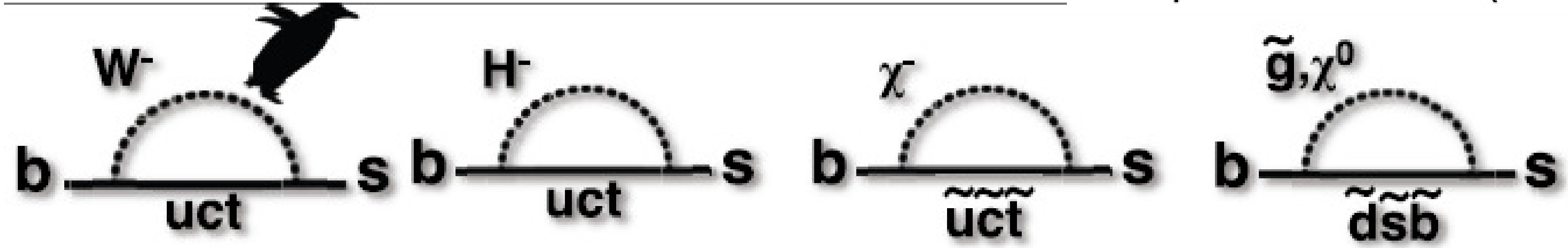
EW penguins

New results from CDF (see next slides)

➢First observation of $B_s \to \varphi\mu\mu$, the rarest B_s ever observed

➢First measurement of A_{FB} in hadron collider competitive with current best results





Exclusive $b \to s\mu^+\mu^-$

Current results from analysis based on 4.4 fb^{-1}:

- Trigger on dimuons (p_T^{μ}>1.5-2 GeV) forming a displaced vertex
- Look for:

  $B^+ \to K^+ \mu^+\mu^-$, $B_d \to K^{*0} \mu^+\mu^- \to [K^+\pi^-] \mu^+\mu^-$, $B_s \to \phi \mu^+\mu^- \to [K^+K^-] \mu^+\mu^-$

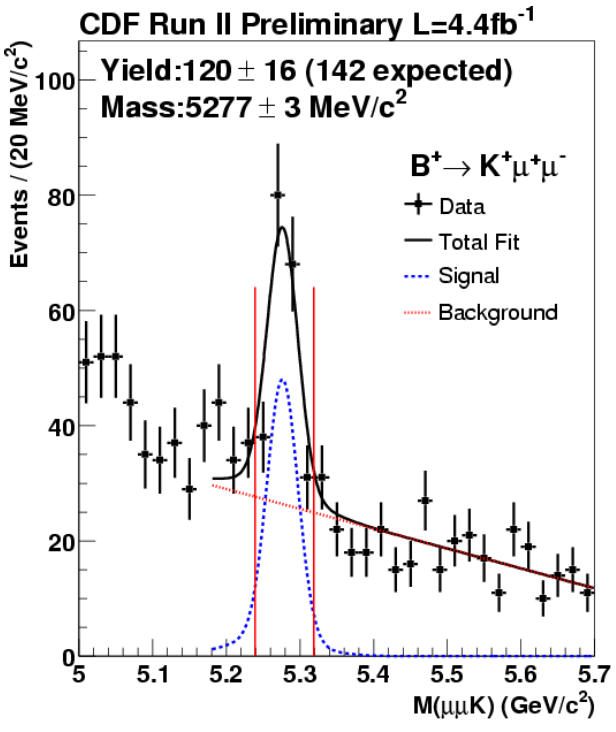
- To reject $B \to J/\psi$ (ψ') remove:

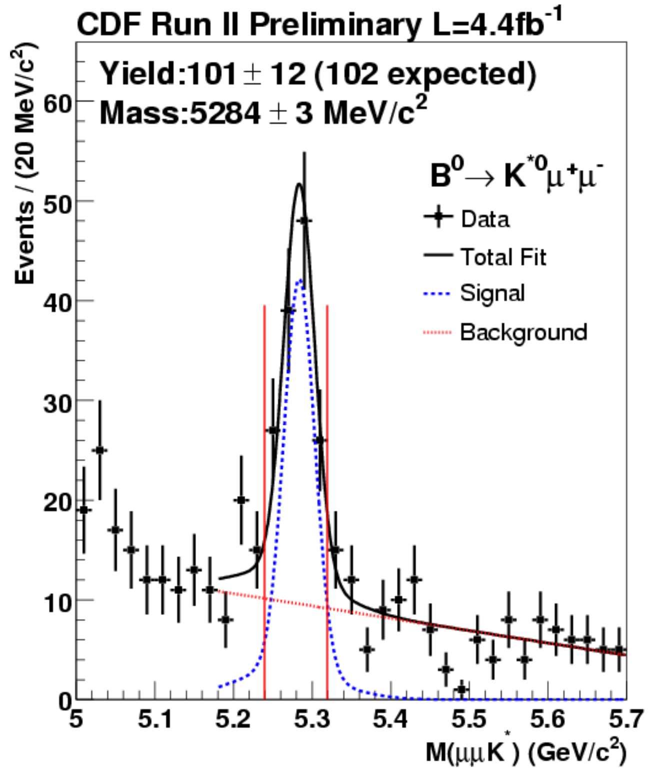
  $8.68 < M^2_{\mu+\mu-} < 10.09 \cup 12.86 < M^2_{\mu+\mu-} < 14.18$ GeV^2

- Vertex quality, PID (dE/dx and TOF) + kinematic variables combined in a Neural Network to optimize sensitivity:
  - $S/\sqrt{(S+B)}$ for known modes
  - $S/(2.5+\sqrt{B})$ for B_s mode

- Normalize rate to $B \to J/\psi\, h$ ($h=K,K^*,\phi$), used as 'reference' to obtain BR

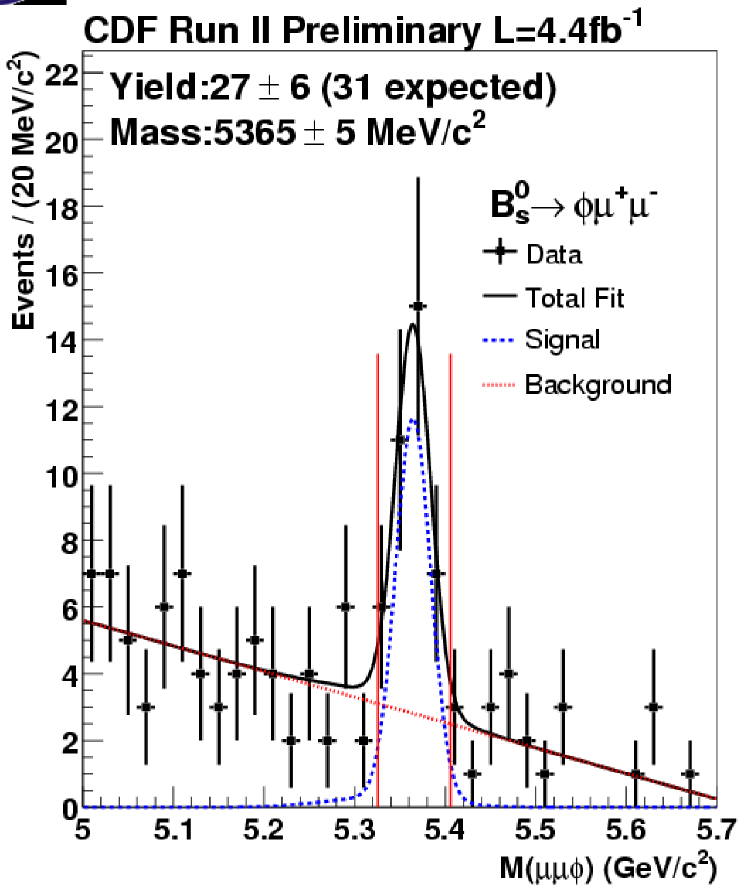
$B \rightarrow K(*)\ \mu^+\mu^-$ signals





	$B^+ \rightarrow K^+\mu^+\mu^-$	$B^0 \rightarrow K^{*0}\mu^+\mu^-$
CDF	$[0.38 \pm 0.05 \pm 0.03] \times 10^{-6}$	$[1.06 \pm 0.14 \pm 0.09] \times 10^{-6}$
Babar	$[0.41 \pm 0.16 \pm 0.02] \times 10^{-6}$	$[1.35 \pm 0.40 - 0.37 \pm 0.10] \times 10^{-6}$
Belle	$[0.53 \pm 0.08(+0.07-0.03] \times 10^{-6}$	$[1.06 + 0.19 - 0.14 \pm 0.07] \times 10^{-6}$

$B_s \to \phi\mu^+\mu^-$ First Observation

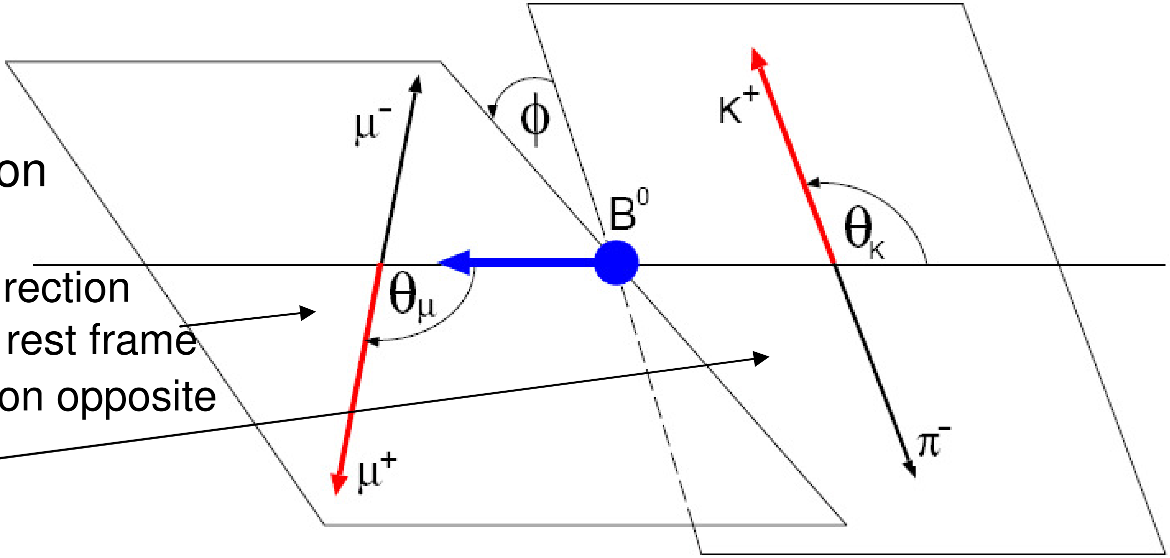


- Unbinned Max Likelihood fit to $B_s$candidate mass
  - Signal: double Gaussian from MC (width adjusted to data)
  - Background: linear shape
- 27±6 signal events (6.3 σ)
- Normalize measured rate to BR($B_s \to J/\psi\phi$)

$$BR(B_s \to \varphi\mu^+\mu^-) = (1.44 \pm 0.33(stat.) \pm 0.46(sys.)) \cdot 10^{-6}$$

Compare to $BR(B_s \to \varphi\mu^+\mu^-) \sim 1.6 \cdot 10^{-6}$ C. Q. Geng, C. C. Liu, J. Phys. G29, 1103 (2003)

$B_d \rightarrow K^{*0}\mu^+\mu^-$ angular analysis



A_{FB} and K^{*0} longitudinal polarization are extracted from:

- Θ_μ : helicity angle between μ+(μ-) direction & the opposite of B ($\bar{B}$) direction in μμ rest frame
- Θ_K: angle K direction and the direction opposite to the B meson in the K^{*0} rest frame

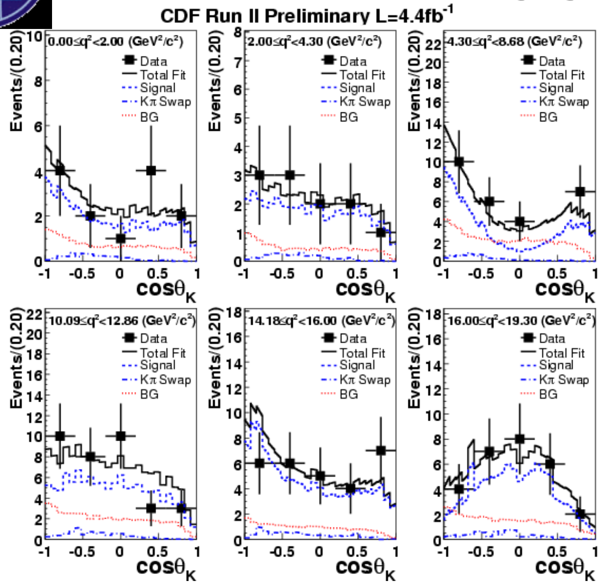
$$\frac{1}{\Gamma}\frac{d\Gamma(B^0 \to K^{*0}\mu^+\mu^-)}{d\cos\theta_K} = \frac{3}{2}\mathrm{F_L}\cos^2\theta_\mathrm{K} + \frac{3}{4}(1-\mathrm{F_L})(1-\cos^2\theta_\mathrm{K}),$$

Fit Parameters

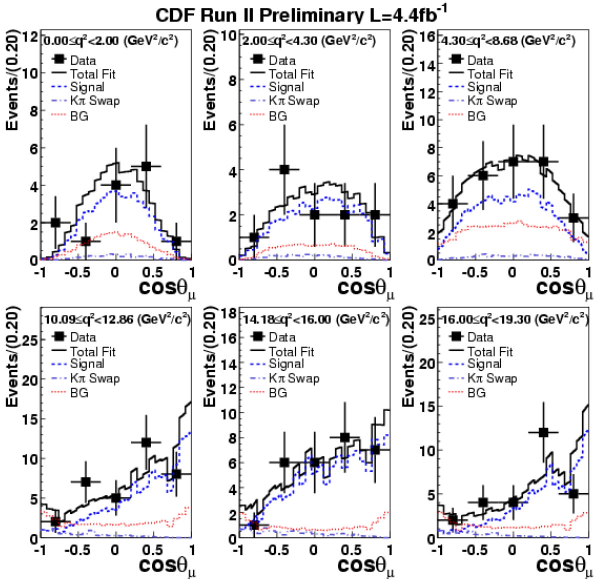
$$\frac{1}{\Gamma}\frac{d\Gamma(B^0 \to K^{*0}\mu^+\mu^-)}{d\cos\theta_\mu} = \frac{3}{4}\mathrm{F_L}(1-\cos^2\theta_\mu) + \frac{3}{8}(1-\mathrm{F_L})(1+\cos^2\theta_\mu) + \mathrm{A_{FB}}\cos\theta_\mu$$

- Correct for acceptance via detailed simulation
- 5 or 6 bin in $q^2=m_{\mu\mu}{}^2$ excluding ccbar resonances
- Cross check with $B \rightarrow J/\psi$ X (reference) samples

Decay Angle Analysis

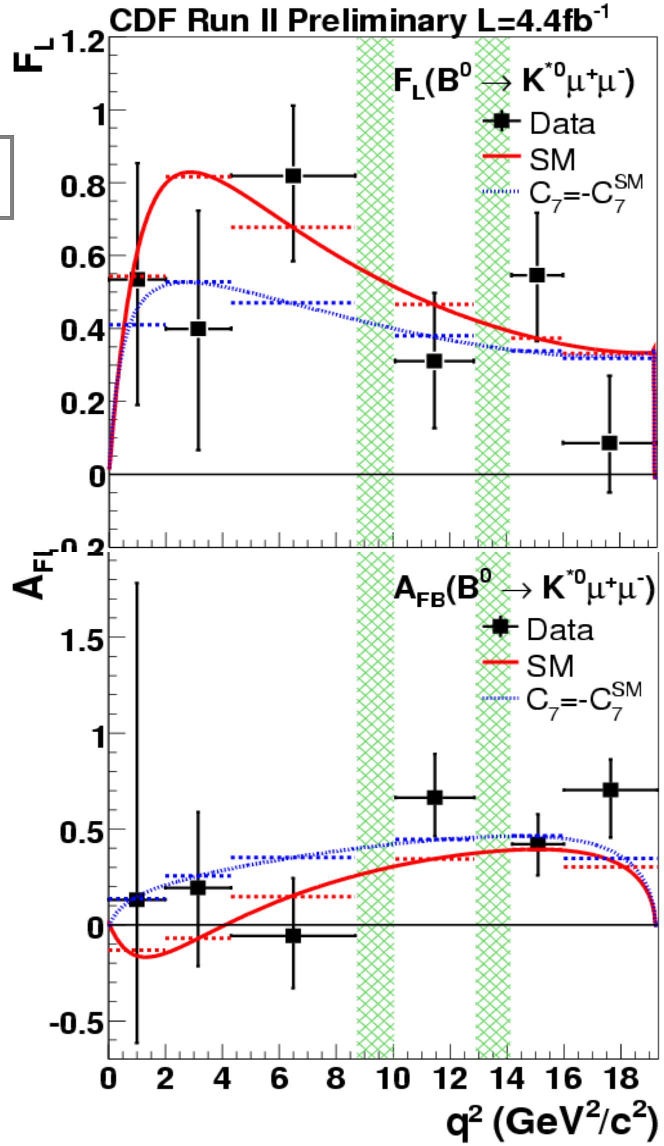


Fit $\cos(\theta_K)$

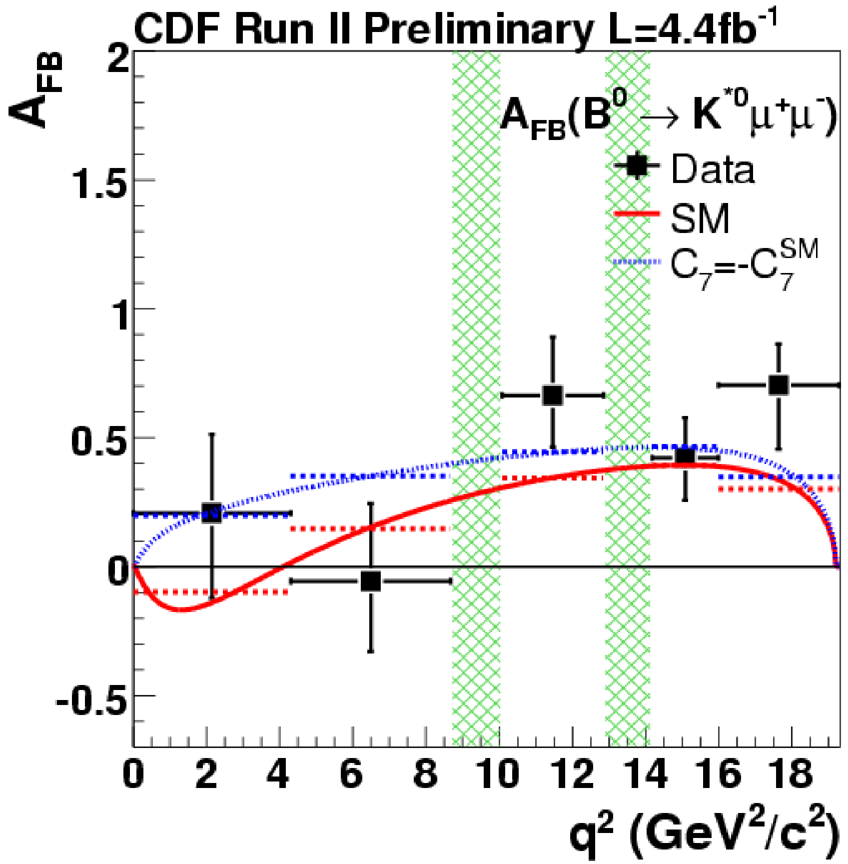


Fit $\cos(\theta_\mu)$

per q^2 bins
(q^2=$M_{\mu\mu}$ c^2)



A_{FB} result $B_d \rightarrow K^* \mu^+ \mu^-$



- CDF provides a measurement in 5 bin in the theoretically cleanest range:

  $1<q^2<6$

$$A_{FB}^{CDF}(1<q^2<6\,\mathrm{GeV}^2/\mathrm{c}^4) = 0.43^{+0.36}_{-0.37} \pm 0.06$$

- Compare to BELLE: 660x10^6 B

$$A_{FB}^{Belle}(1<q^2<6\,\mathrm{GeV}^2/\mathrm{c}^4) = 0.26^{+0.27}_{-0.30} \pm 0.07$$

First AFB measured in hadron collider: consistent & competitive with B factory

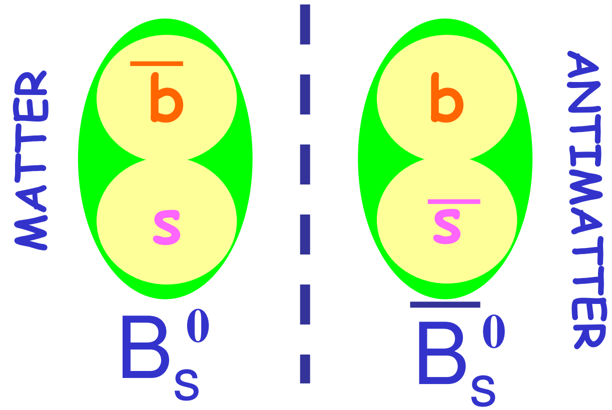
$$A_{FB}^{(th)}(1<q^2<6\,\mathrm{GeV}^2/\mathrm{c}^4) = -0.05^{+0.03}_{-0.04} \quad \text{C.Bobeth, et al. arXiv : 1006.5013}$$

Still inconclusive, wait for more data

Neutral B_s System

- Time evolution of B_s flavor eigenstates described by Schrodinger equation:

$$i\frac{d}{dt}\begin{pmatrix}|B_s^0(t)\rangle \\ |\bar{B}_s^0(t)\rangle\end{pmatrix} = \left(\mathbf{M} - \frac{i}{2}\mathbf{\Gamma}\right)\begin{pmatrix}|B_s^0(t)\rangle \\ |\bar{B}_s^0(t)\rangle\end{pmatrix}$$



-Diagonalize mass (M) and decay (Γ) matrices

→ mass eigenstates :

$$|B_s^H\rangle = p\,|B_s^0\rangle - q\,|\bar{B}_s^0\rangle \qquad |B_s^L\rangle = p\,|B_s^0\rangle + q\,|\bar{B}_s^0\rangle$$

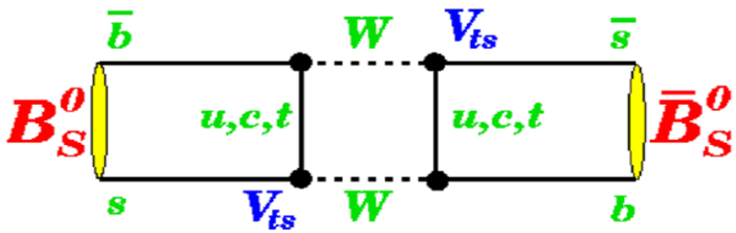
- Flavor eigenstates differ from mass eigenstates and mass eigenvalues are also different:

$\Delta m_s = m_H - m_L \approx 2|M_{12}|$

→ B_s oscillates with frequency Δm_s precisely measured by

CDF $\Delta m_s = 17.77 \pm 0.12\ ps^{-1}$

DØ $\Delta m_s = 18.56 \pm 0.87\ ps^{-1}$



- Mass eigenstates have different decay widths

$$\Delta\Gamma = \Gamma_L - \Gamma_H \approx 2|\Gamma_{12}|\cos(\Phi_s) \qquad \text{where} \quad \phi_s^{SM} = \arg\left(-\frac{M_{12}}{\Gamma_{12}}\right) \approx 4 \times 10^{-3}$$

β_s vs ϕ_s

- Up to now, introduced two different phases:

$\phi_s^{SM} = \arg\left(-\frac{M_{12}}{\Gamma_{12}}\right) \approx 4x10^{-3}$ and $\beta_s^{\rm SM} = \arg(-V_{ts}V_{tb}^*/V_{cs}V_{cb}^*) \approx 0.02$

- New Physics affects both phases by same quantity $\phi_s^{\rm NP}$

$$2\beta_s = 2\beta_s^{\rm SM} - \phi_s^{\rm NP}$$

$$\phi_s = \phi_s^{\rm SM} + \phi_s^{\rm NP}$$

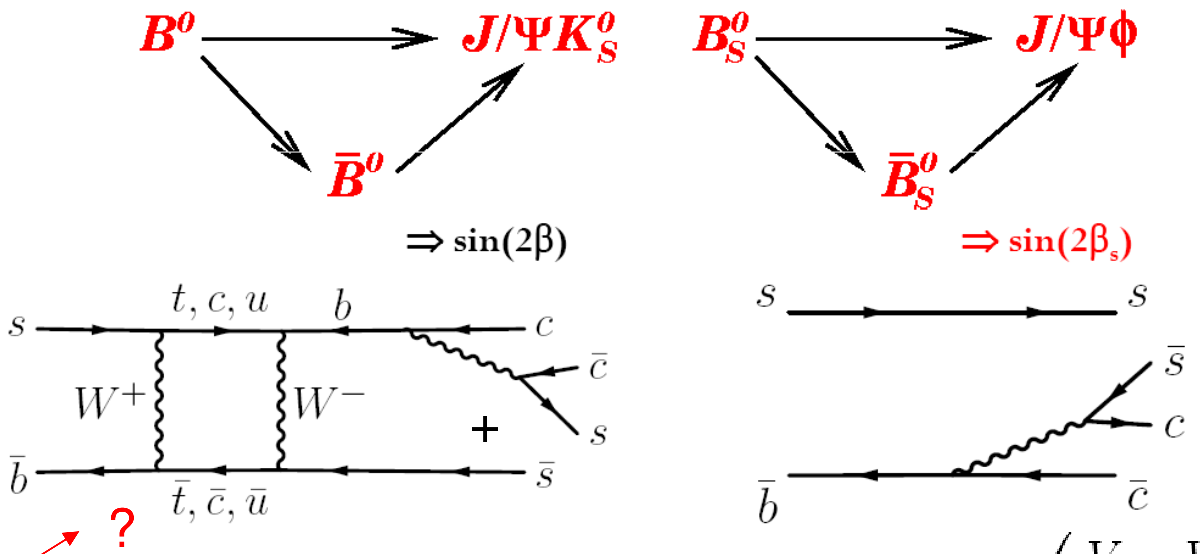
- If the new physics phase $\phi_s^{\rm NP}$ dominates over the SM phases $2\beta_s^{\rm SM}$ and $\phi_s^{\rm SM}$
→ neglect SM phases and obtain:

$$2\beta_s = -\phi_s^{\rm NP} = -\phi_s$$

CP Violation in $B_s \rightarrow J/\Psi\Phi$ Decays

- Analogously to the neutral B^0 system, *CP* violation in B_s system occurs through interference of decays with and without mixing:

dominant contribution from top quark



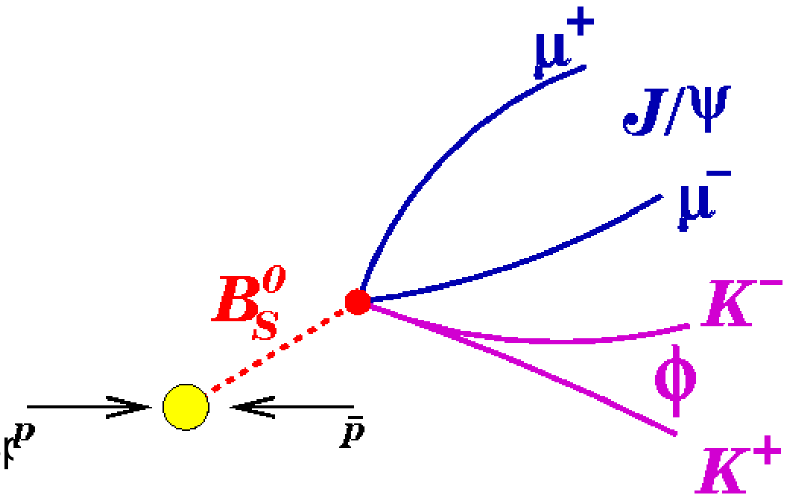
New Physics particles ?

$$\beta_s^{\mathrm{SM}} = \arg(-V_{ts}V_{tb}^*/V_{cs}V_{cb}^*) \approx 0.02$$

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

- *CP* violation phase β_s in SM is predicted to be very small, $O(\lambda^2)$
- New physics particles running in the mixing diagram may enhance β_s
    - large β_s $\rightarrow$ clear indication of New Physics !

$B_s \rightarrow J/\Psi\Phi$ Decays



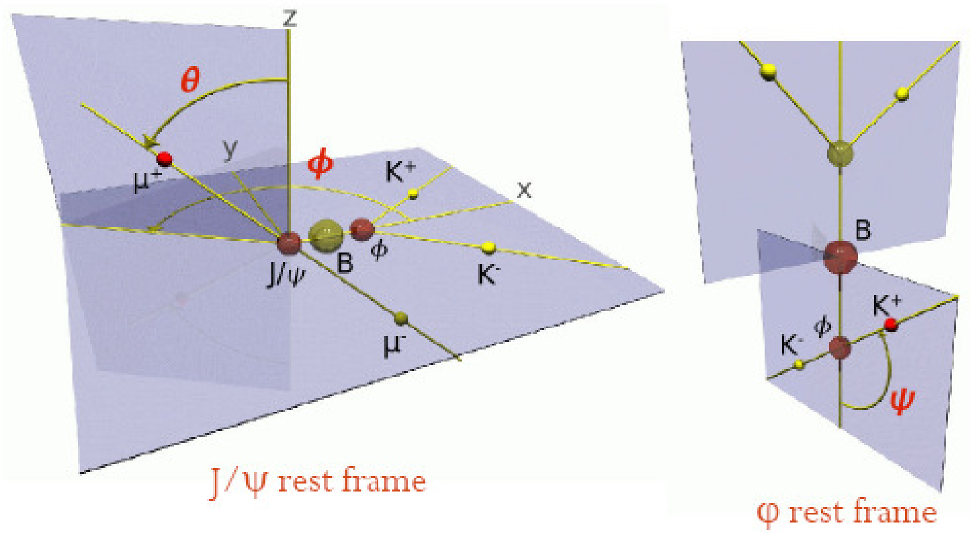
- Extremely physics rich decay mode

- Can measure lifetime, decay width difference $\Delta\Gamma$ and *CP* violating phase β_s

- Decay of B_s (spin 0) to J/Ψ (spin 1) and Φ (sp[...]
angular momentum final states:

$L = 0$ (s-wave), 2 (d-wave) → *CP even* (= short lived or light B_s if no *CPV*)

$L = 1$ (p-wave) → *CP odd* (= long lived or heavy B_s if no *CPV*)



- Three decay angles $\vec{\rho} = (\theta, \phi, \psi)$ describe directions of final decay products
$\mu^+ \mu^- K^+ K^-$

Finding New Physics in Φs

- Measurement of semileptonic CP asymmetry
  $\leftrightarrow A_{SL} = -|\Gamma_{12}/M_{12}| \sin\phi_s$

$\rightarrow$ Difficult due to smallness of the A_{SL}

- Measurement of $\Delta\Gamma \leftrightarrow \Delta\Gamma = \Gamma_L - \Gamma_H = 2|\Gamma_{12}|\cos(\phi_s)$

$\rightarrow$ Need input for $|\Gamma_{12}| \leftrightarrow$ can come from $\mathcal{B}(B_s \rightarrow D_s^{(*)} D_s^{(*)})$

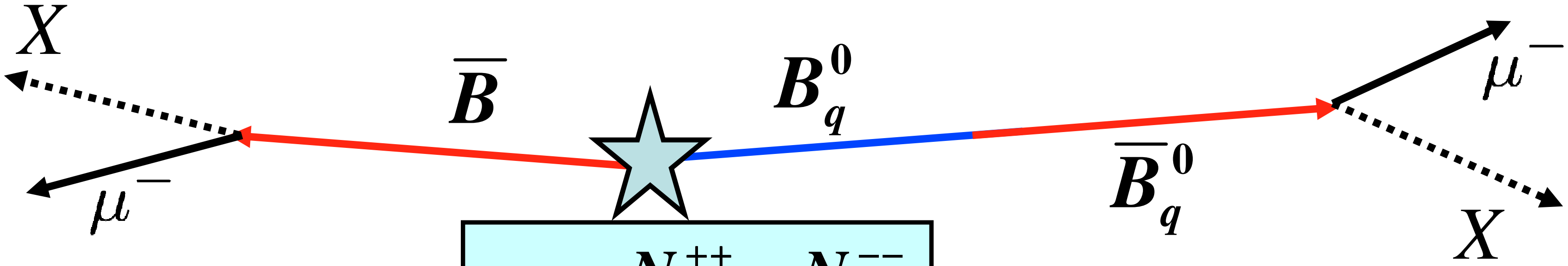
- Measurement of CP violation in CP modes

$\rightarrow$ Golden mode pursued currently is $B_s \rightarrow J/\psi\phi$

$\rightarrow$ ϕ_s not only phase entering here, but SM value small $\rightarrow$ search for sizable NP can neglect SM value

$$\Longrightarrow 2\beta_s = -\phi_s^{NP} = -\phi_s$$

Asymmetry in B decays



$$A_{sl}^b \equiv \frac{N_b^{++} - N_b^{--}}{N_b^{++} + N_b^{--}}$$

N_b^{++} (N_b^{--}) – number of same-sign $\mu^+\mu^+$ ($\mu^-\mu^-$) events from $B \to \mu X$ decay

- Both B_d and B_s contribute in A^b_{sl} at Tevatron :

$$A_{sl}^b = (0.506 \pm 0.043) a_{sl}^d + (0.494 \pm 0.043) a_{sl}^s$$

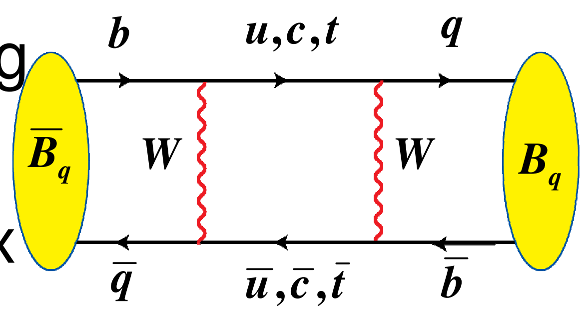
B_d contribution

B_s contribution

  – a^q_{sl} is the charge asymmetry of "wrong sign" semileptonic B^0_q ($q = d,s$) decays:

$$a_{sl}^q \equiv \frac{\Gamma(\overline{B}_q^0 \to \mu^+ X) - \Gamma(B_q^0 \to \mu^- X)}{\Gamma(\overline{B}_q^0 \to \mu^+ X) + \Gamma(B_q^0 \to \mu^- X)}; \quad q = d, s$$

CP violation in mixing



- Non-zero A^b_{sl} means CP violation in mixing
- Source of this type of CP violation –

 complex phase ϕ_q of B_q (q=d,s) mass matrix

$$\boxed{\begin{aligned} \Delta M_q &= M_H - M_L \approx 2\left|M_q^{12}\right| \\ \Delta\Gamma_q &= \Gamma_L - \Gamma_H \approx 2\left|\Gamma_q^{12}\right|\cos\phi_q \\ \phi_q &= \arg\left(-\frac{M_q^{12}}{\Gamma_q^{12}}\right) \end{aligned}}$$

$$\boxed{\left\|\mathbf{M}_q\right\| = \begin{bmatrix} M_q & M_q^{12} \\ (M_q^{12})^* & M_q \end{bmatrix} - \frac{i}{2}\begin{bmatrix} \Gamma_q & \Gamma_q^{12} \\ (\Gamma_q^{12})^* & \Gamma_q \end{bmatrix}}$$

- For B_q meson, a^q_{sl} is related to the CP-violating phase ϕ_q :

$$\boxed{a_{sl}^q = \frac{\Delta\Gamma_q}{\Delta M_q}\tan(\phi_q)}$$

SM prediction

- SM predicts very small values of ϕ_q and A^b_{sl}:

$$\boxed{\begin{aligned} \phi_d^{SM} &= -0.091^{+0.026}_{-0.038} \\ \phi_s^{SM} &= 0.0042 \pm 0.0014 \\ A_{sl}^{b,SM} &= (-2.3^{+0.5}_{-0.6}) \times 10^{-4} \end{aligned}}$$

A. Lenz, U. Nierste, J. High Energy Phys. 0706, 072 (2007)

  – These values are below current experimental sensitivity

- New physics contribution can significantly change these values

$$\boxed{\begin{aligned} \phi_d &= \phi_d^{SM} + \phi_d^{NP} \\ \phi_s &= \phi_s^{SM} + \phi_s^{NP} \end{aligned}}$$

Non-zero A^b_{sl} would indicate the presence of new physics

Measurement strategy

- Measure two raw asymmetries (include μ's from all sources):

raw dimuon charge asymmetry

$$A \equiv \frac{N(\mu^+\mu^+) - N(\mu^-\mu^-)}{N(\mu^+\mu^+) + N(\mu^-\mu^-)} = (0.564 \pm 0.053)\%$$

raw inclusive muon charge asymmetry

$$a \equiv \frac{n(\mu^+) - n(\mu^-)}{n(\mu^+) + n(\mu^-)} = (0.955 \pm 0.003)\%$$

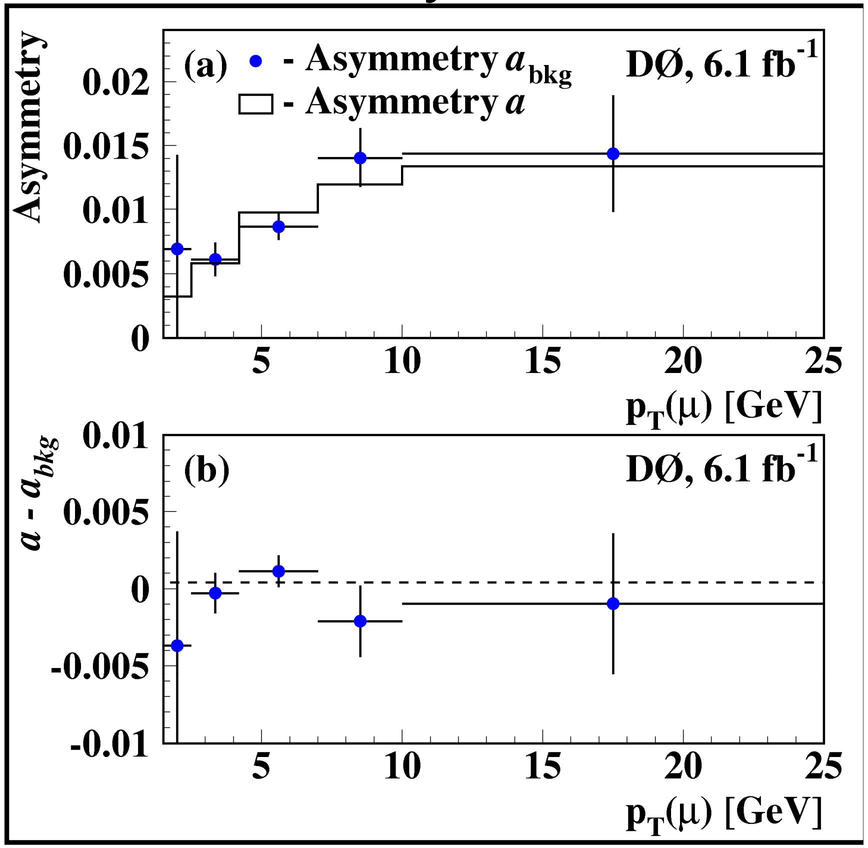
- Both asymmetries contain contributions from A^b_{sl} and detector-related background asymmetries

$$A = K\, A^b_{sl} + A_{bkg} \qquad a = k\, A^b_{sl} + a_{bkg}$$

  - contribution from A^b_{sl} to a is strongly suppressed by k=0.041±0.003
- Determine background contributions A_{bkg} and a_{bkg} using data with minimal input from simulation
- Exploit the correlation of background content in raw asymmetries to reduce the uncertainty on A^b_{sl}

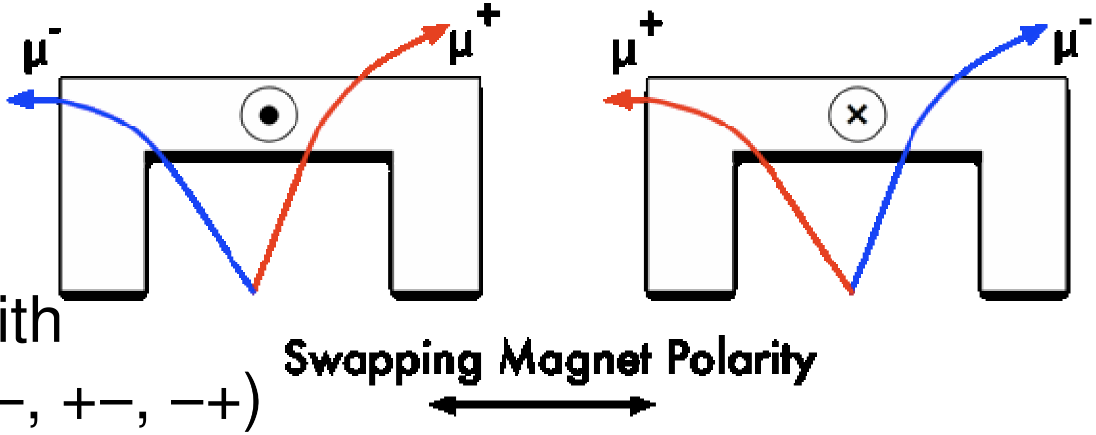
Test of background description

- Raw inclusive muon asymmetry a is dominated by the background asymmetry a_{bkg}
- a_{bkg} is measured in data
- Compare a and a_{bkg} to verify the background description
- This comparison is done as a function of muon p_T
- Good consistency between observed and expected asymmetries
  - χ^2/dof = 2.4/5 for the difference between these two distributions

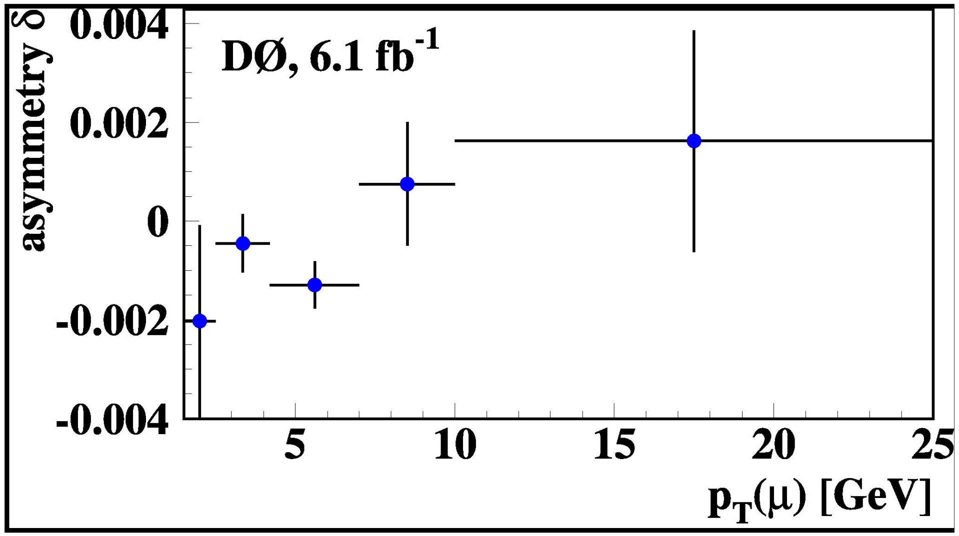


Original experimental technique

- Polarities of DØ solenoid and toroid are reversed every ~2 weeks
- 4 equal sized samples with different polarities (++, −−, +−, −+)
- difference in reconstruction efficiency between positive and negative particles minimized
- Reconstruction asymmetries reduced from ~1% to <0.1%
  - To be compared with raw dimuon asymmetry A= (0.564±0.053)%



Muon reconstruction asymmetry



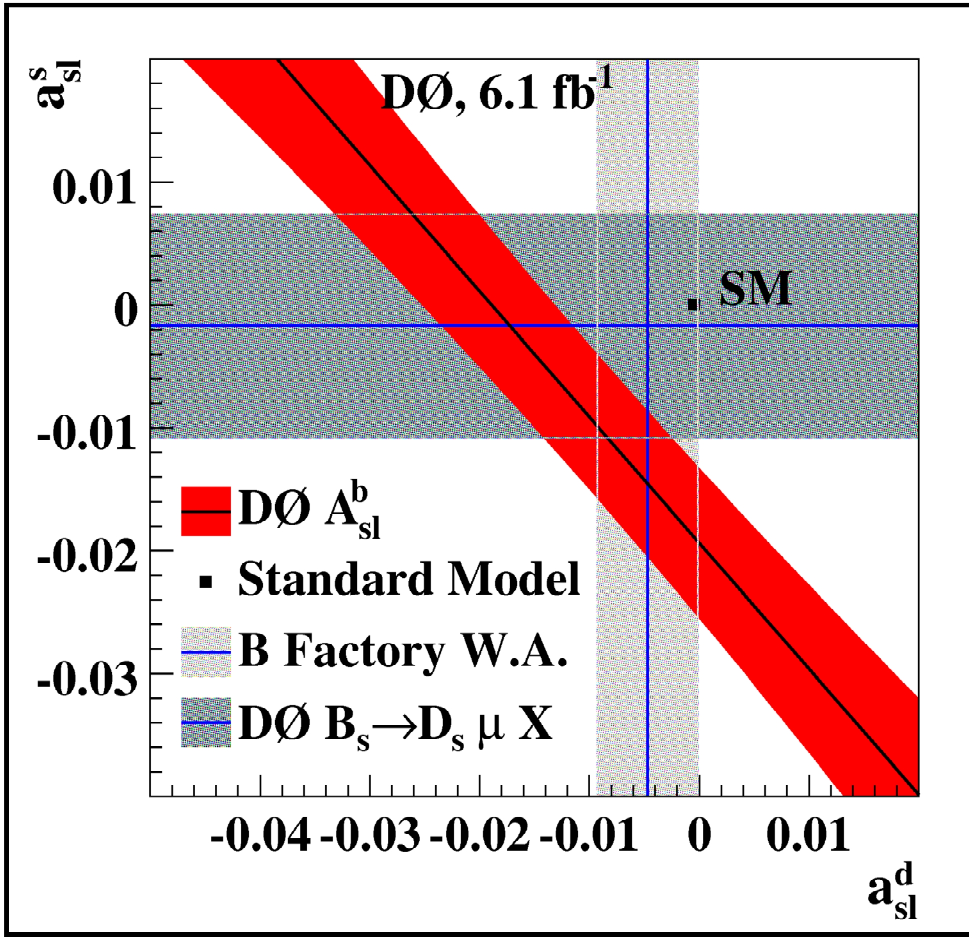
Evidence for an anomalous like-sign charge asymmetry

$$A_{sl}^{b} = (-0.957 \pm 0.251\,(\mathrm{stat}) \pm 0.146\,(\mathrm{syst}))\,\%$$

- This result differs from the SM prediction by ~3.2 σ
- A^{b}_{sl} produces a band in a^{d}_{sl} v.s. a^{s}_{sl} plane:

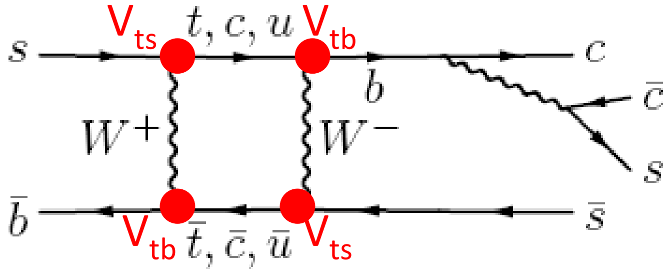
$$A_{sl}^{b} = (0.506 \pm 0.043)\,a_{sl}^{d} + (0.494 \pm 0.043)\,a_{sl}^{s}$$

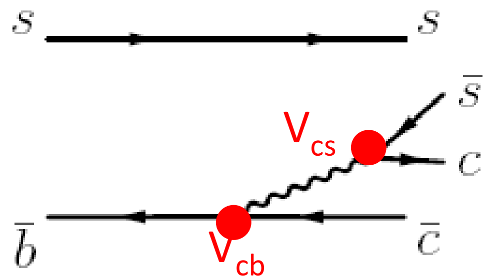
- Obtained result agrees well with other measurements of a^{d}_{sl} and a^{s}_{sl}



Bs mixing phase: Bs→J/ψφ best testing Lab

B_s mixing phase (or V_{ts} phase) is the last experimentally unconstrained part of CKM

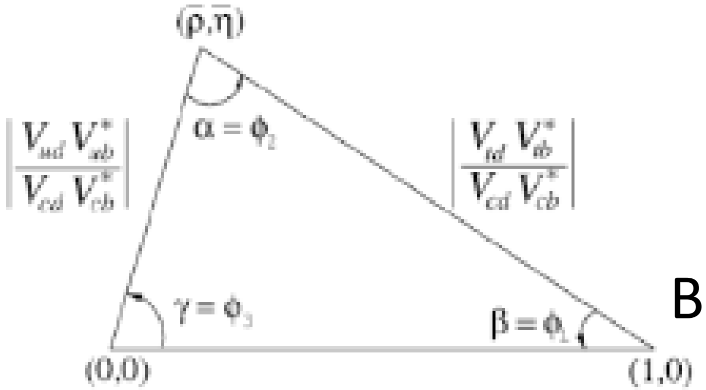


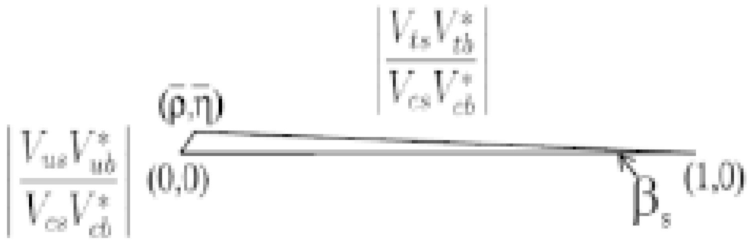


$B_s \to J/\psi\varphi$ allows measuring phase between B_s mixing and $b \to ccs$

$$\boxed{2\beta_s = -\varphi^{NP}_s = -\varphi_s}$$

N.B. Mixing phase: B^0 analogy





$B_s \to J/\psi\varphi$ for $\sin 2\beta_s$ ↔ $B^0 \to J/\psi K^0_s$ for $\sin 2\beta$

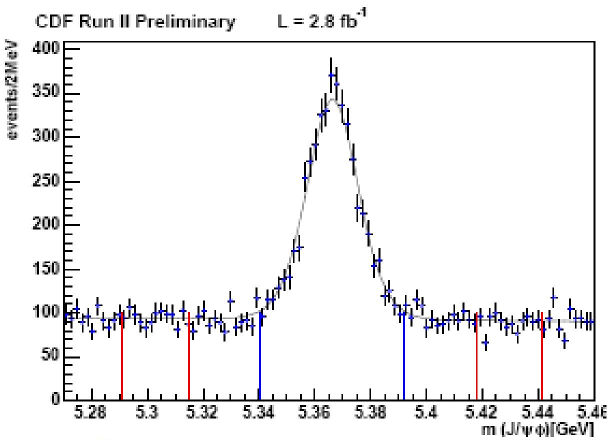
BUT, additional experimental complications:

$J/\psi\varphi$: a mix of CP-even and CP-odd eigenstates, treat them separately

B_s oscillates ~ 35 times faster than B^0

$\sin 2\beta$~0.7, $\sin 2\beta_s$ expected about 20 times smaller

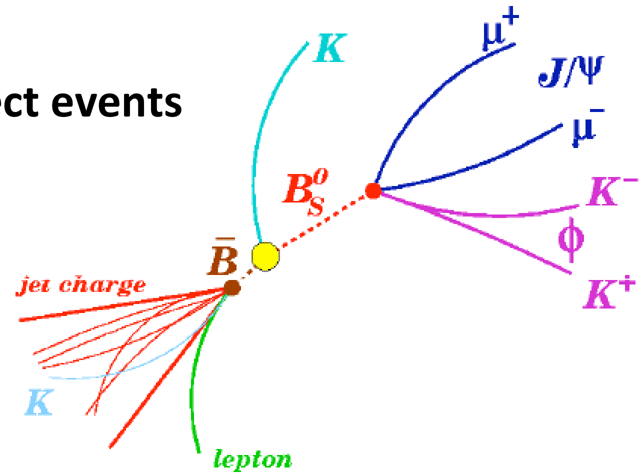
Bs mixing phase in Bs→J/ψφ: analysis outline



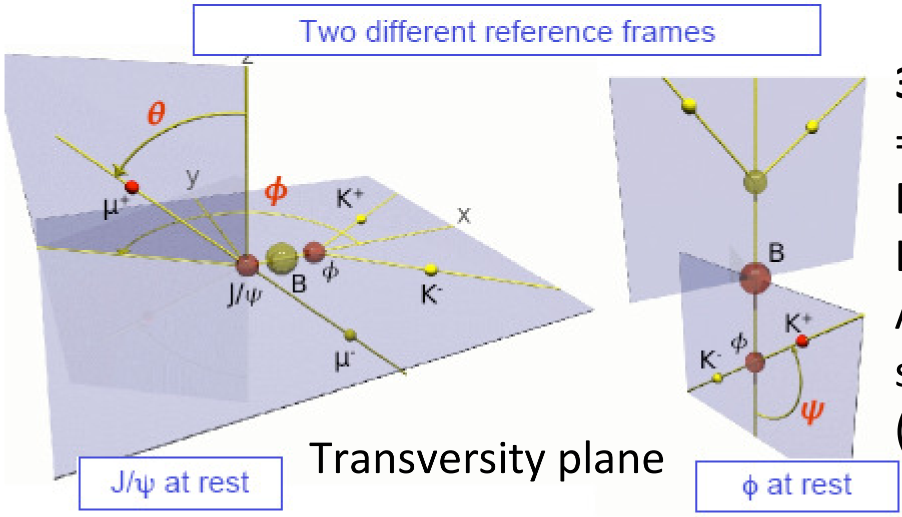
1. **Reconstruct data and select events**

   Control sample:

   $B_d \rightarrow J/\psi(\mu^+\mu^-)\ K^{*0} \rightarrow (K^+\pi^-)$



2. **Measure lifetime cτ**



Transversity plane

3. **Disentangle CP even and CP odd**

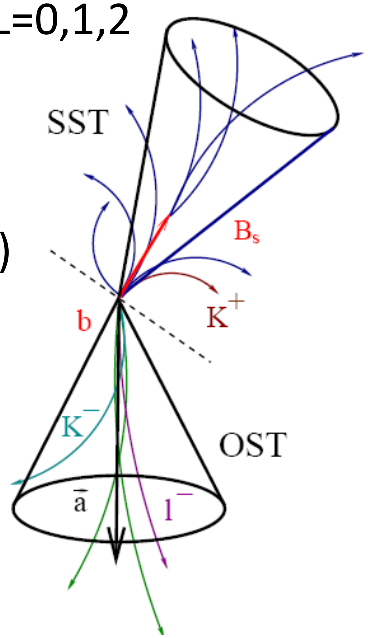
   => perform angular analysis:

   Bs(pseudoscalar)→J/ψ(V) φ(V)=>L=0,1,2

   L=0,2 are CP-even; L=1 CP-odd

   Angular analysis can statistically separate CP-even and CP-odd

   (usually done in transversity basis)



4. **Determine flavour at production time**

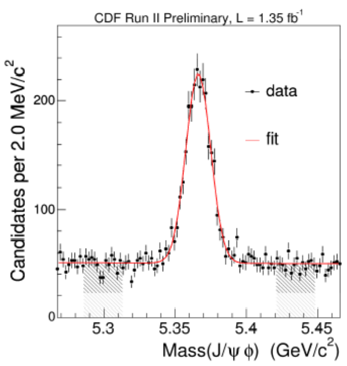
N.B. All based on quantities directly derived from data!!

Mixing phase - *fit overview*

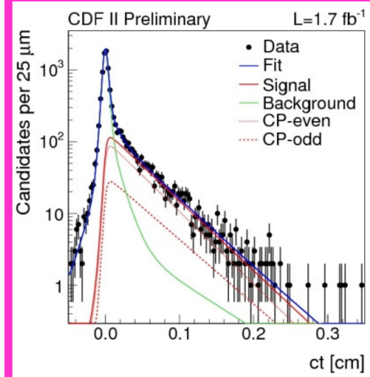
Courtesy of Diego Tonelli

5. Perform unbinned maximum likelyhood fit to extract interesting quantities

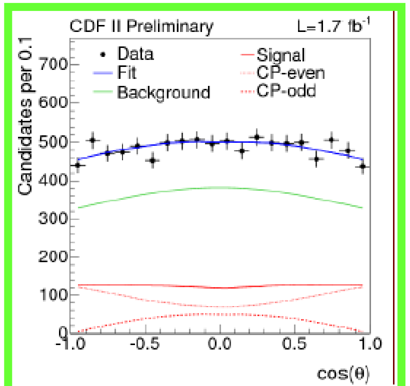
$$f_s P_s(m|\sigma_m) P_s(t,\vec{\rho},\xi|\mathcal{D},\sigma_t) P_s(\sigma_t) P_s(\mathcal{D})$$



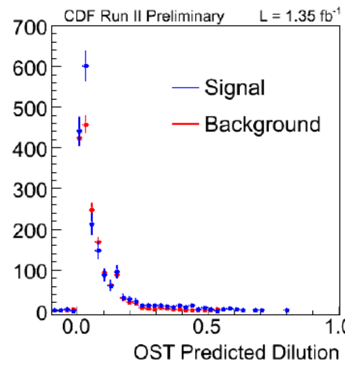
Mass
discriminate signal against background



Decay-time
Determine lifetime of each CP and flavor state

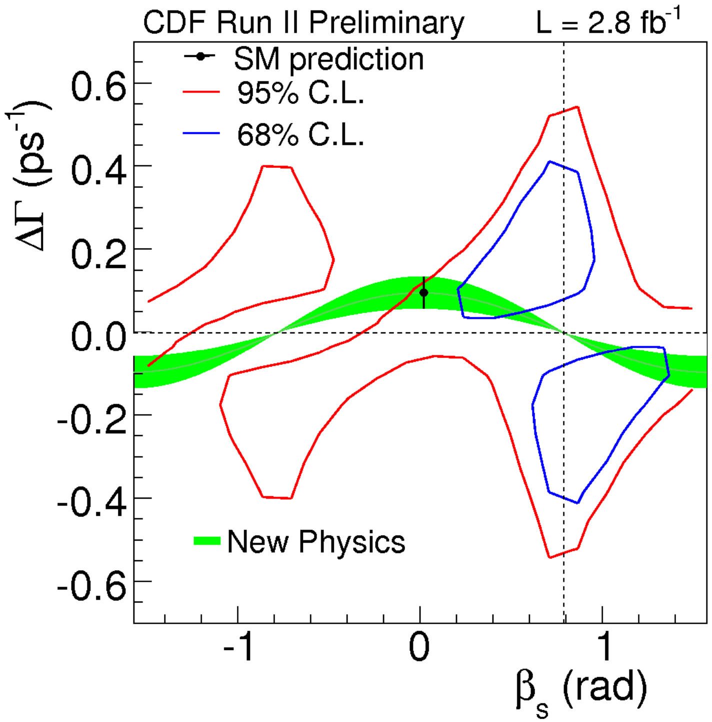


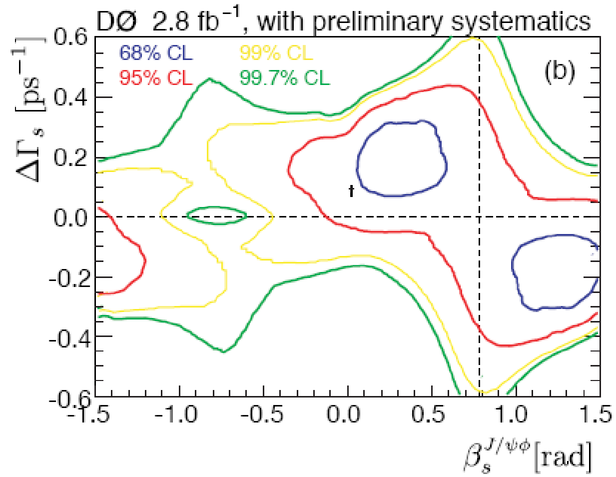
Angles
Separate CP-even from CP-odd final states



Tagging
Determines flavor of initial state

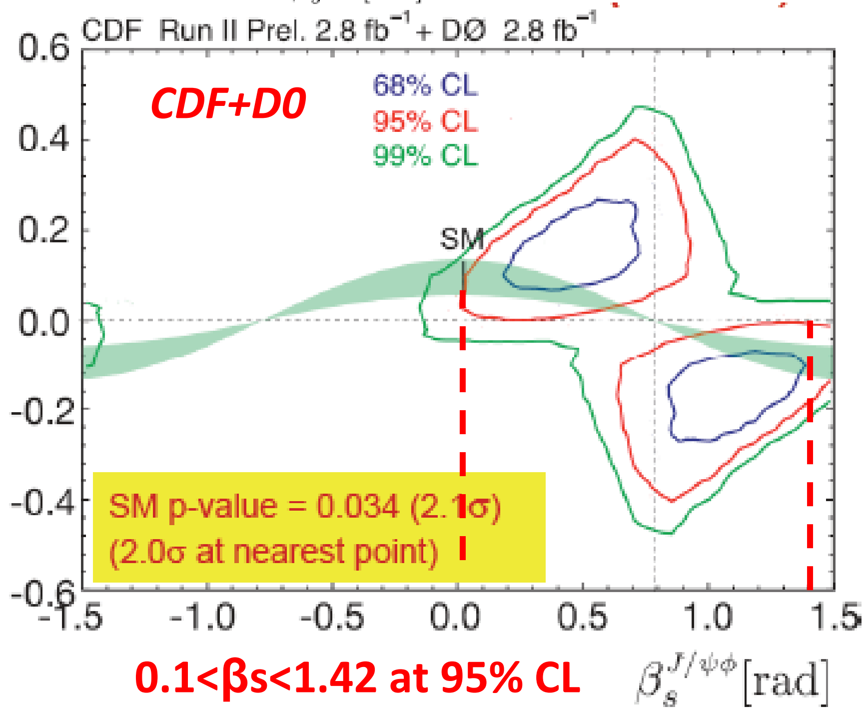
Mixing phase – *results & prospects*





Results in 2009

CDF only: SM p-value: 7% (1.8σ)



0.1<βs<1.42 at 95% CL

CDF and D0 combined =>
Assuming SM the probability of observing a fluctuation as or larger than observed in the data is 3.4% (2.1σ)

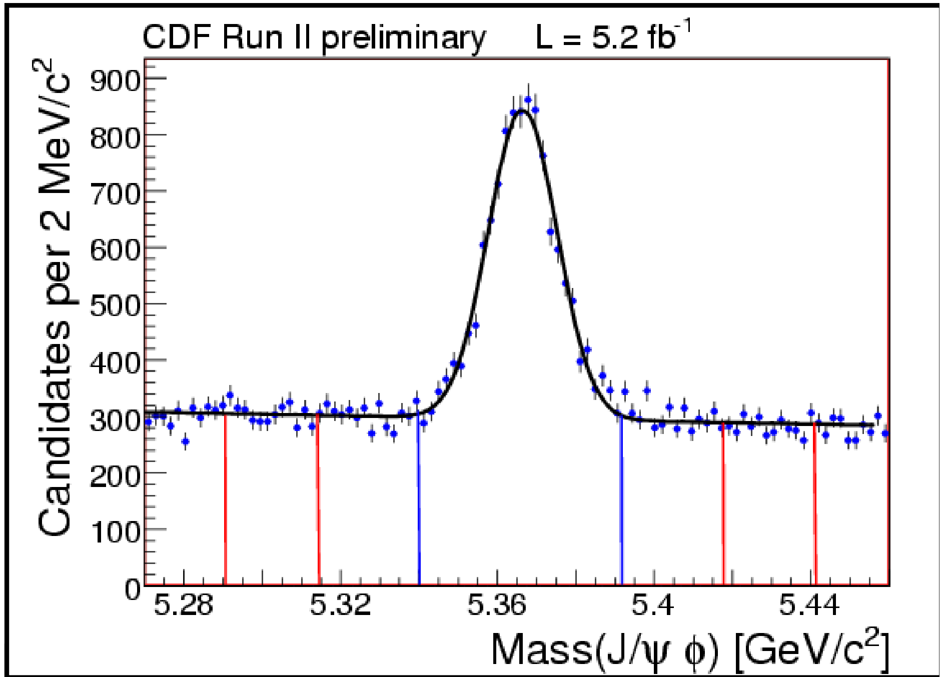
%

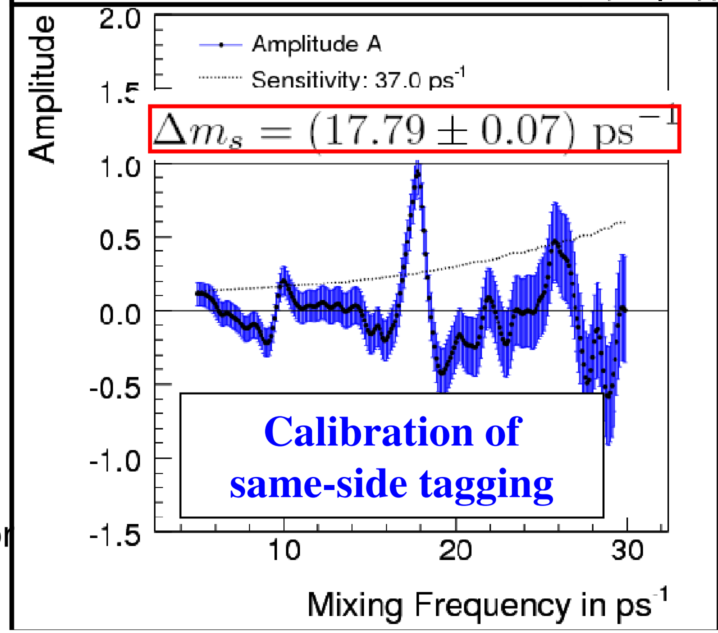
New measurement of $B_s \to J/\psi\ \varphi$ (2010)

- 5.2 fb^{-1} of data analyzed
- ~6500 signal events
- New trigger will be soon added (increase of stat.)
- Same side flavour tagging calibrated in data
- Strong phases are free
- S wave included in the fit < 6.5% at 95% CL

$$\tau_s = \mathbf{1.529 \pm 0.025\,(stat) \pm 0.012\,(syst)\ ps}$$
$$\Delta\Gamma_s = \mathbf{0.075 \pm 0.035\,(stat) \pm 0.01\,(syst)\ ps^{-1}}$$

Most precise measurements of $\tau(B_s)$ and $\Delta\Gamma_s$





Evolution of the Results with increased data set

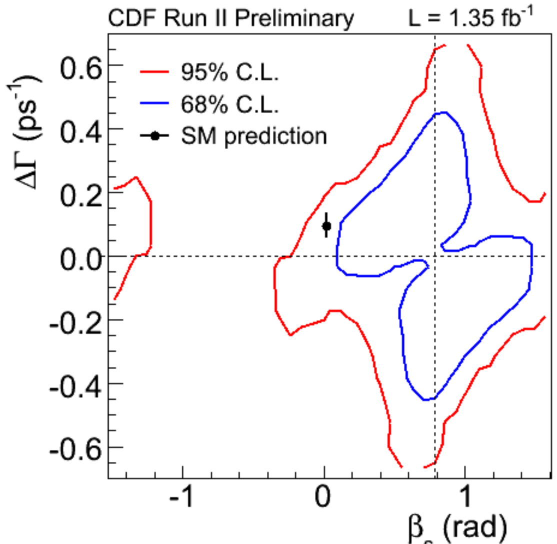
- Agreement with SM expectation increases with higher statistics

- β_s and $\Delta\Gamma$ allowed parameter space greatly reduced

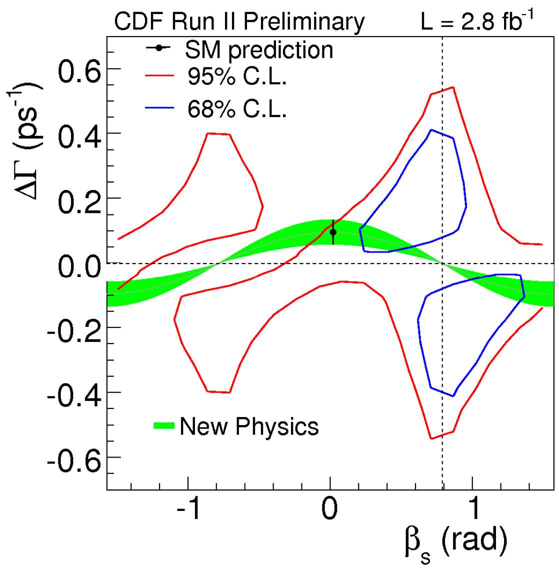
Initial result released at the end of 2007, ~2000 signal events

2008 ICHEP update with sub-optimal PID and tagging ~3150 signal events

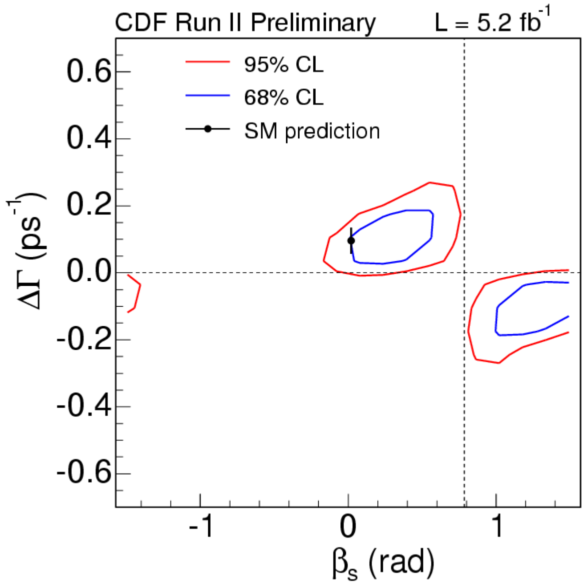
ICHEP 2010 update
With improved analysis
~6500 signal events



0.16 < βs < 1.41 at 68% CL



0.28 < βs < 1.29 at 68% CL



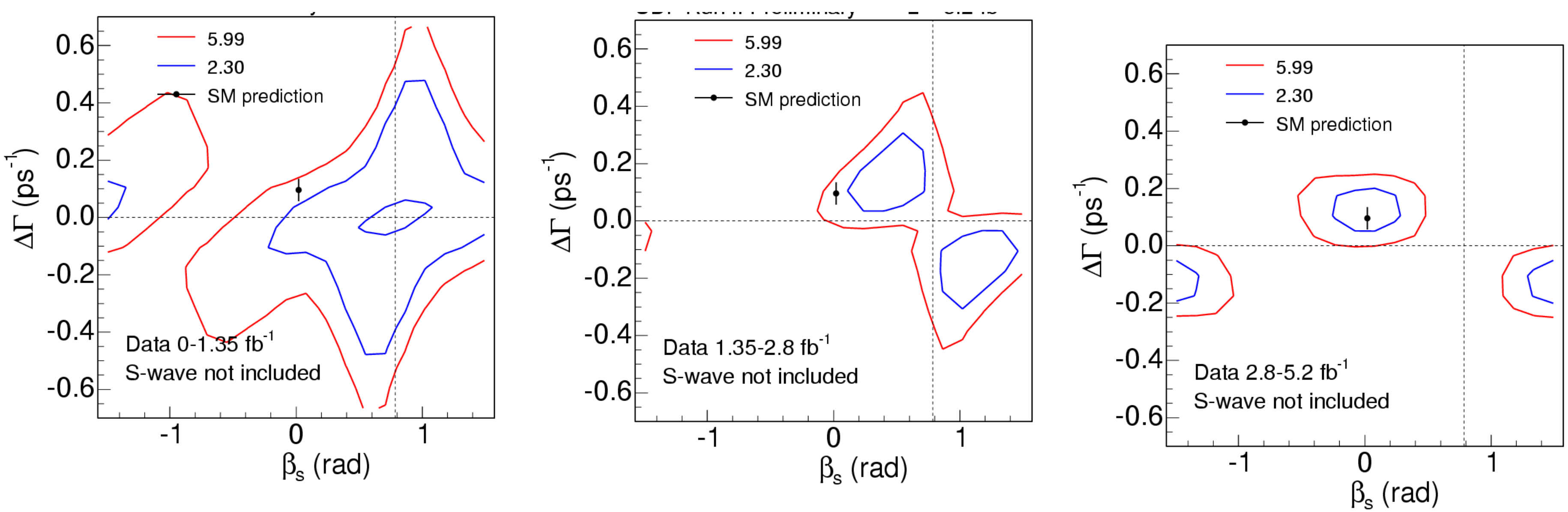
[0.02, 0.52] U [1.08, 1.55] at 68% CL

Agreement with SM: → **15% (1.5σ)** → **7% (~1.8σ)** → **44%~0.8σ**

Comparison Between Different Data Periods

- Divide 5.2 fb^{-1} sample in three sub-samples corresponding to three public releases:
  - 0 - 1.4 fb^{-1} (initial result released at the end of 2007, PRL 100, 161802 (2008)
  - 1.4 - 2.8 fb^{-1} (added for 2008 ICHEP update)
  - 2.8 - 5.2 fb^{-1} (added for this update)

- Previous results reproduced with updated analysis
- Clearly, improved agreement with the SM expectation comes from the second half of data (2.8 – 5.2 fb^{-1})



B_s Lifetime and Decay Width Difference

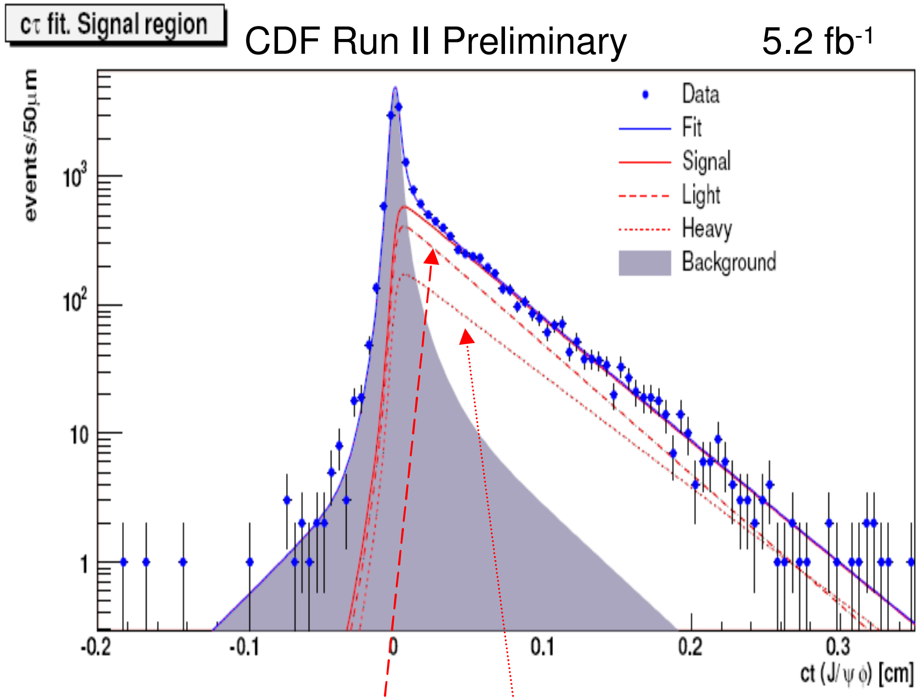
- Assuming no *CP* violation ($\beta_s = 0$) obtain most precise measurements of lifetime τ_s and decay width difference $\Delta\Gamma_s$:

$$c\tau_s = 458.6 \pm 7.5\ (\text{stat.}) \pm 3.6\ (\text{syst.})\ \mu m$$
$$\tau_s = 1.53 \pm 0.025\ (\text{stat.})\ \pm 0.012\ (\text{syst.})\ \text{ps}$$
$$\Delta\Gamma = 0.075 \pm 0.035\ (\text{stat.}) \pm 0.01\ (\text{syst.})\ ps^{-1}$$

PDG average:

$$\tau = (1.472^{+0.024}_{-0.026}) \times 10^{-12}\ \text{s}$$

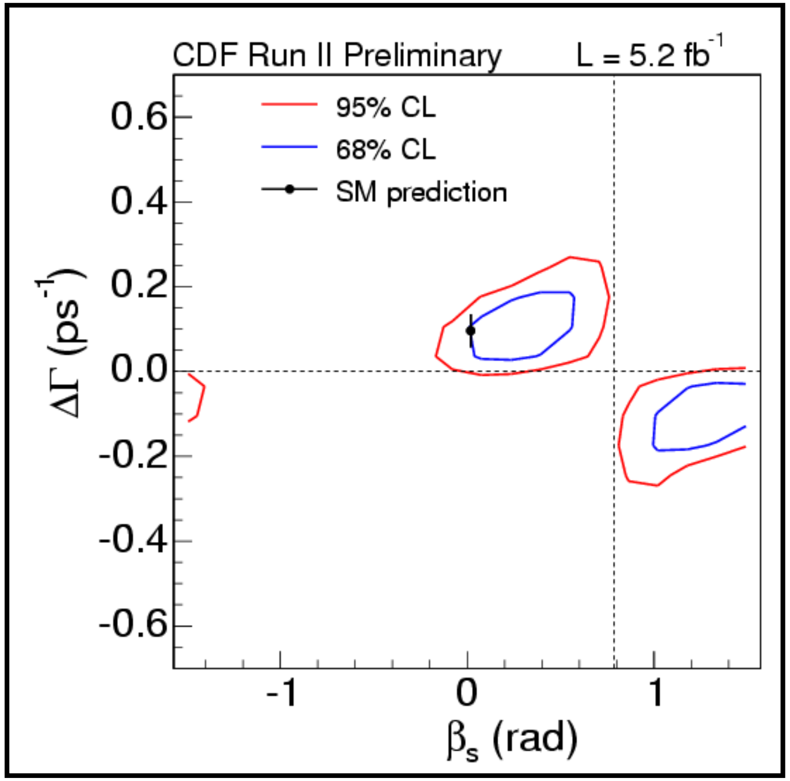
Systematic	$\Delta\Gamma$	$c\tau_s$
Signal efficiency:		
Parameterisation	0.002	0.13
MC reweighting	0.001	0.44
Signal mass model	0.001	0.52
Background mass model	0.001	1.4
Resolution model	0.001	1.0
Background lifetime model	0.004	2.0
Background angular distribution:		
Parameterisation	0.001	0.22
$\sigma(c\tau)$ correlation	0.0005	0.26
Non-factorisation	0.0001	0.42
$B^0 \to J\psi K^*$ crossfeed	0.004	0.26
SVX alignment	0.001	2.0
Mass error	0.0004	0.84
$c\tau$ error	0.0003	0.72
Pull bias		0.54
Totals	0.01	3.6



CP-even (B_s^{light}) and CP-odd (B_s^{heavy}) components have different lifetimes

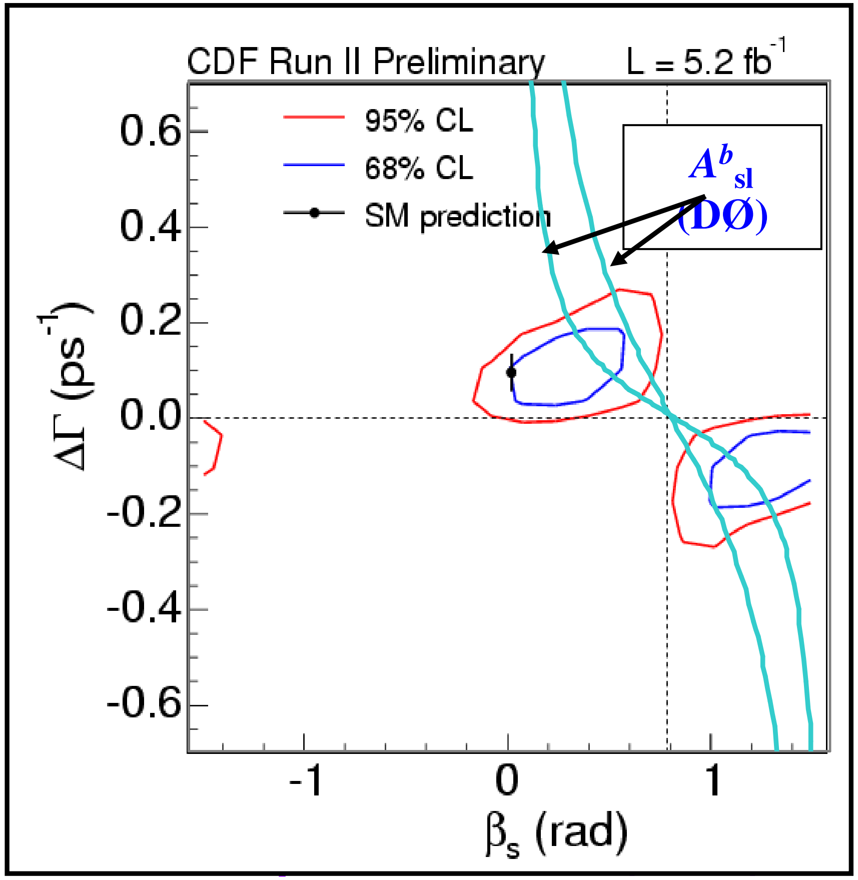
$\rightarrow \Delta\Gamma \neq 0$

Mixing phase – *results & prospects*



NEW: p-value is 44% (0.8 σ)

Mixing phase – *results & prospects*



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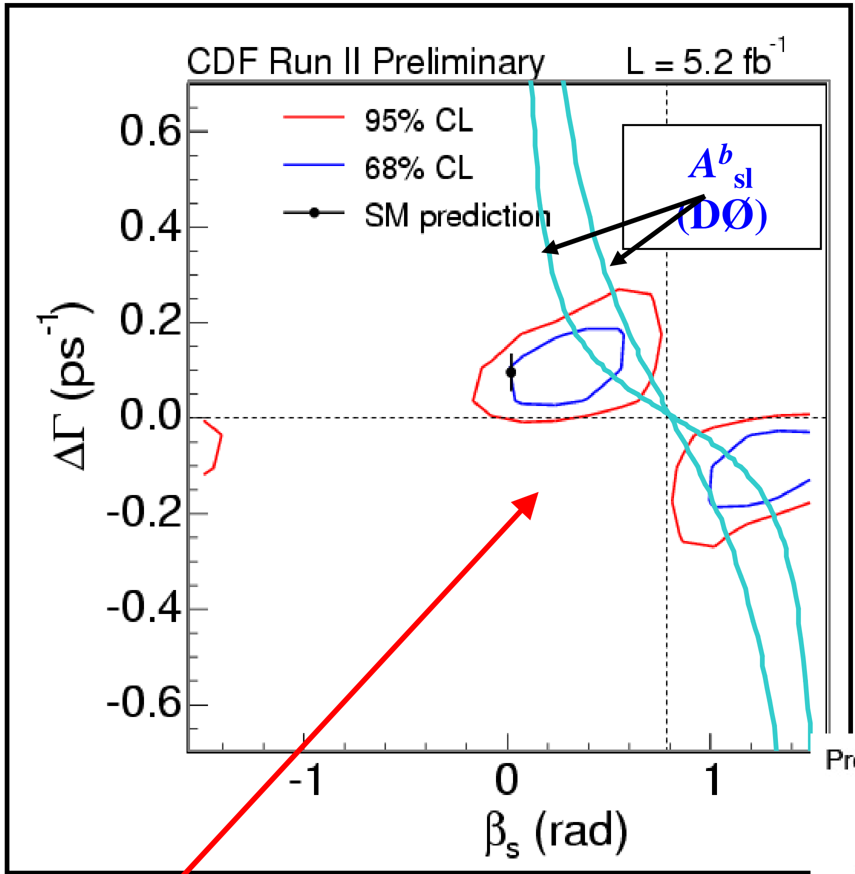
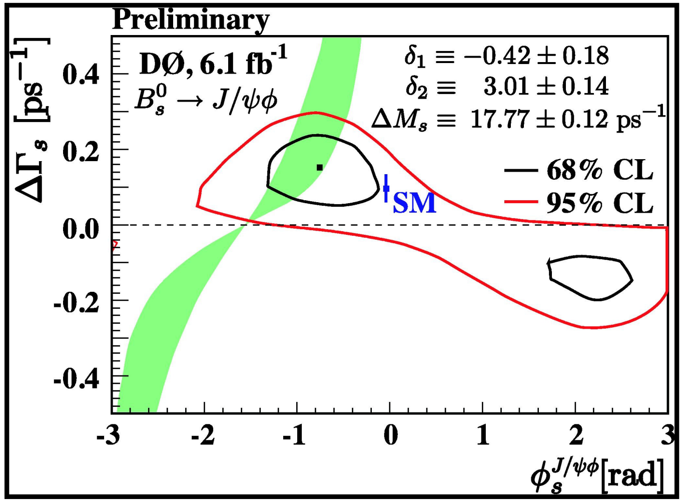
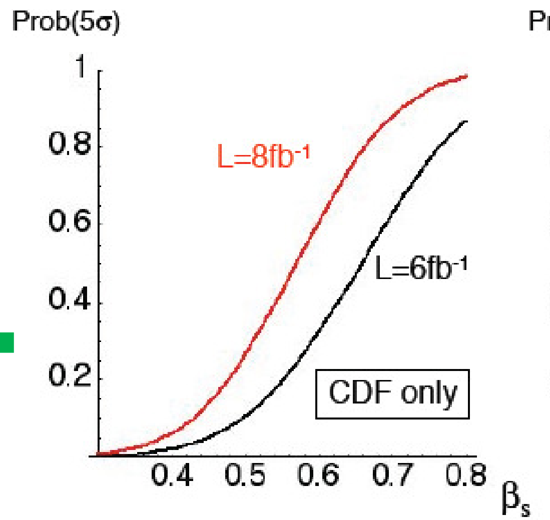
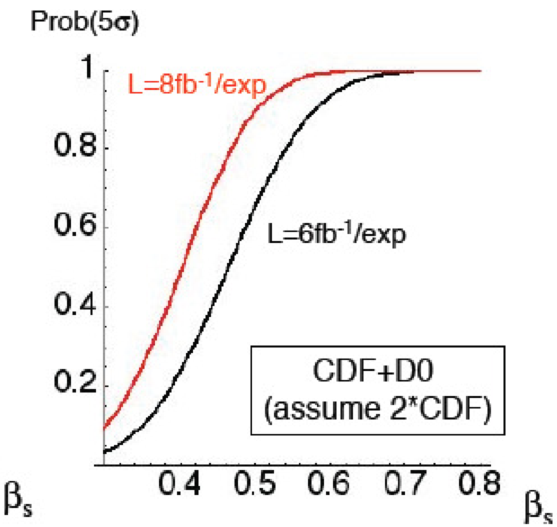




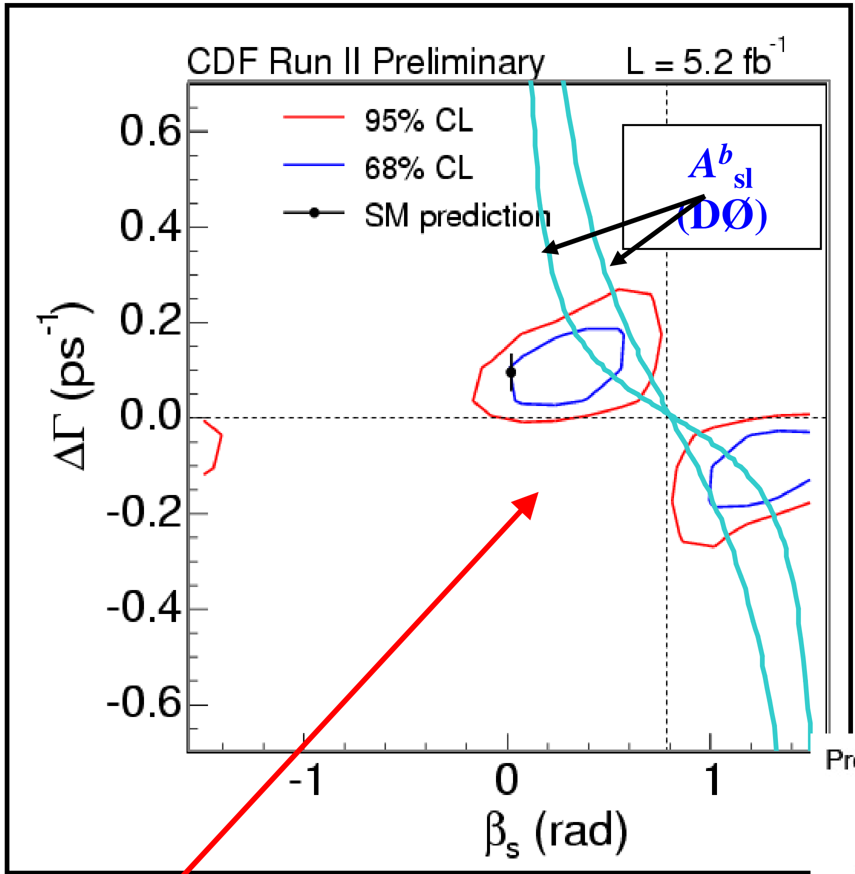
Results of CDF and DØ are consistent within ~1σ

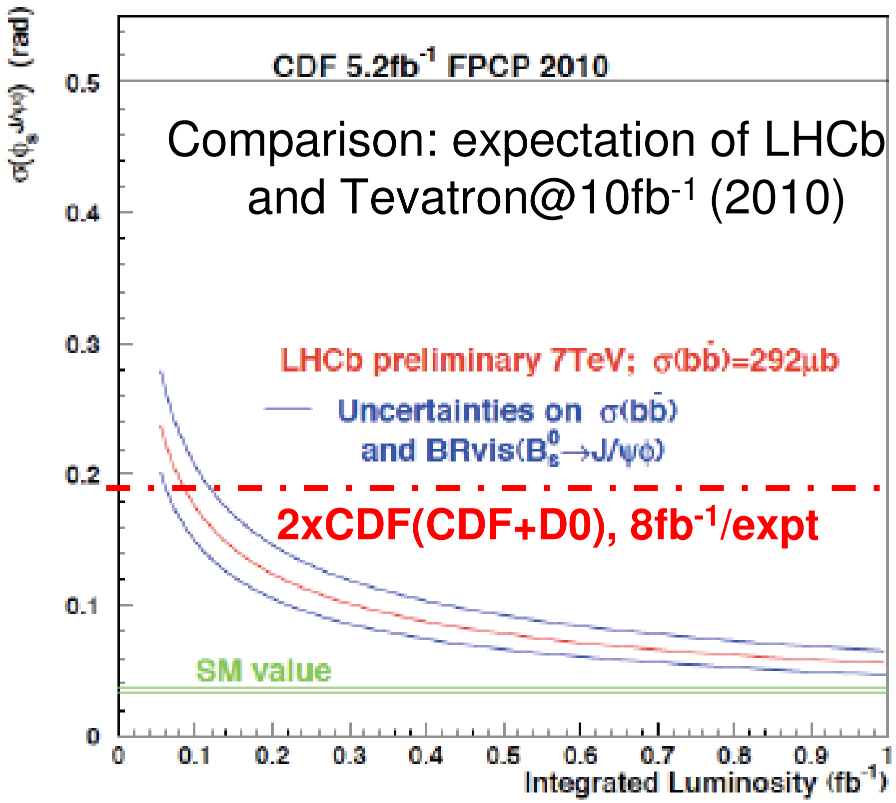


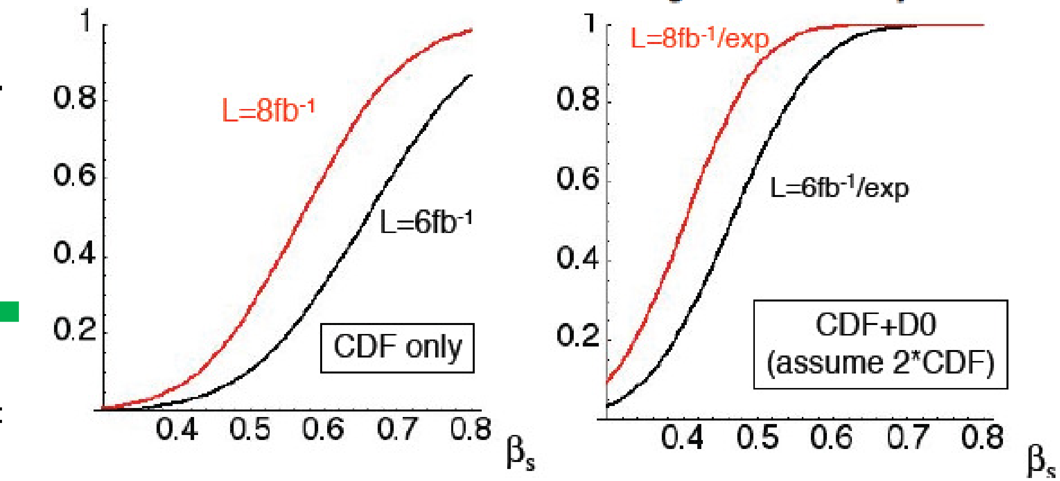


High probability of 5σ evidence over an interesting βs range

Mixing phase – *results & prospects*







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High probability of 5σ evidence over an interesting βs range

CONCLUDING REMARKS and
WHY we became interested in B Physics at Hadron Colliders

- HF Physics at Hadron colliders: UA1 = precursor
- HF Physics at Hadron Colliders: CDF = pioneer:
  - 1^{st} microvertex in hadronic colliders
  - 1^{st} trigger on displaced tracks

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Important breakthroughs and much more still to come...

About 2 times more data to be analyzed by 2011 and more if RunIII

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  (provided the right detector & trigger!!!!!), and:

  SM picture of CPV satisfactory at least at tree level in B0 and B+ decays. NP Physics at at the level of ≤ 10% effect.

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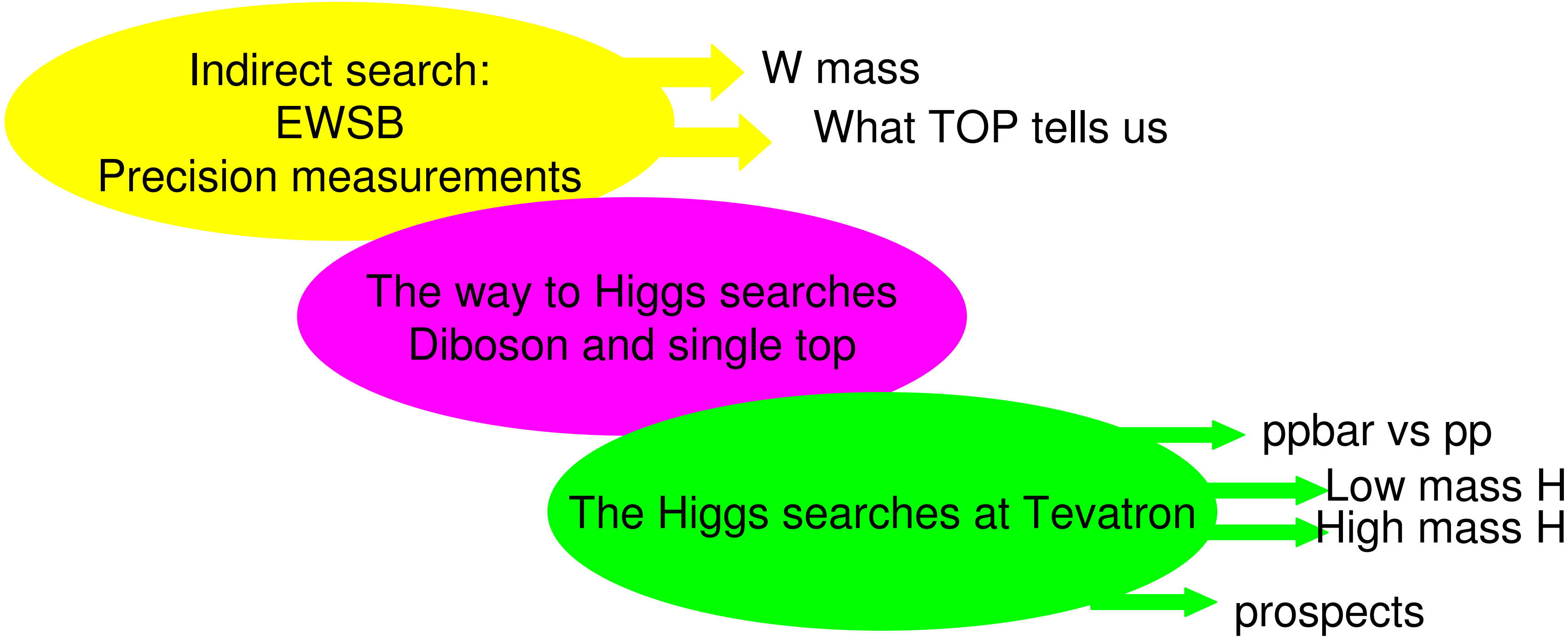
- To keep NP-scale in the TeV range, Physics BSM should have a highly fine-tuned Flavour structure: Flavour problem ???

TEVATRON
Part II

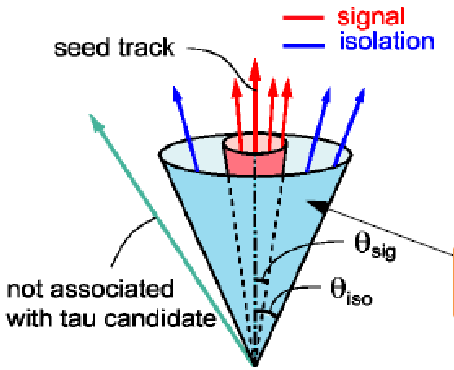
REVEALING THE HIGGS SECTOR

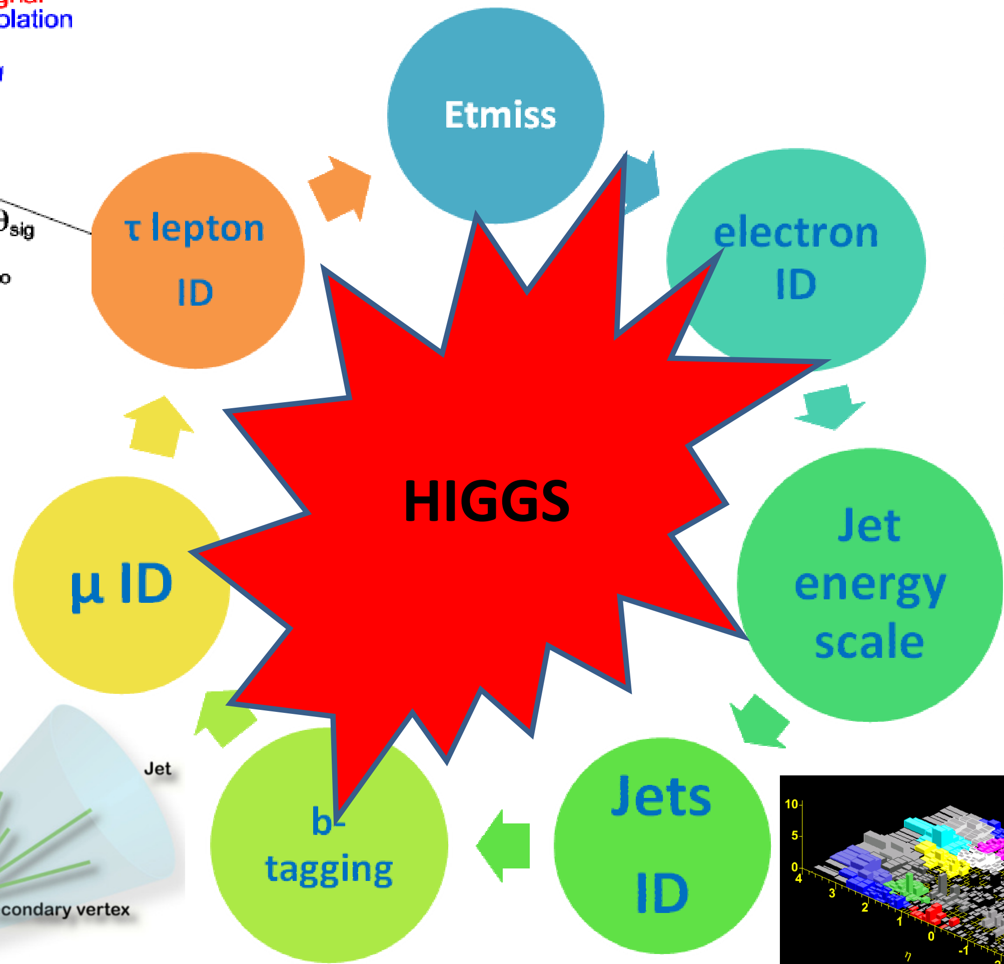
REVEALING THE HIGGS SECTOR

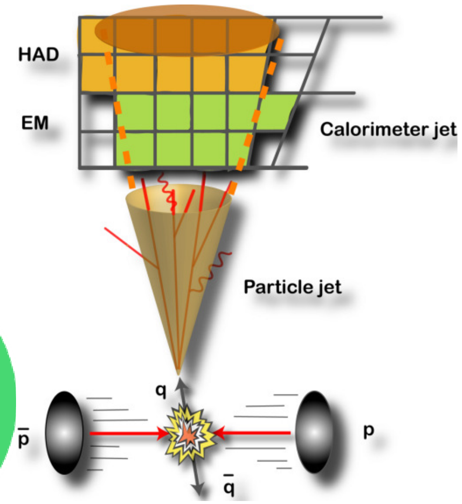


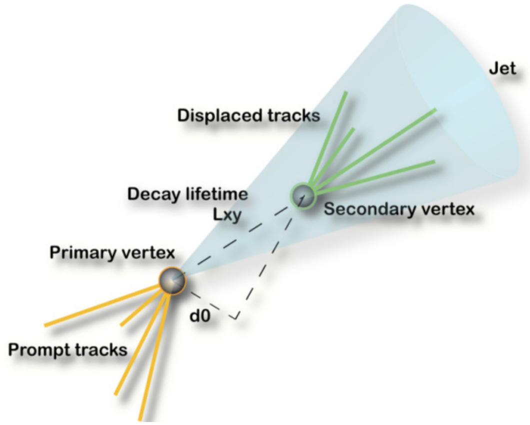
This part presents some of the instrumental searches and breakings
in the exploration of the Higgs sector at the Tevatron

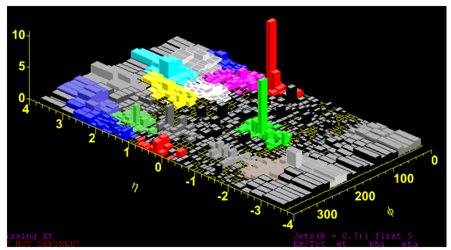
Higgs sector demands it all from the detectors







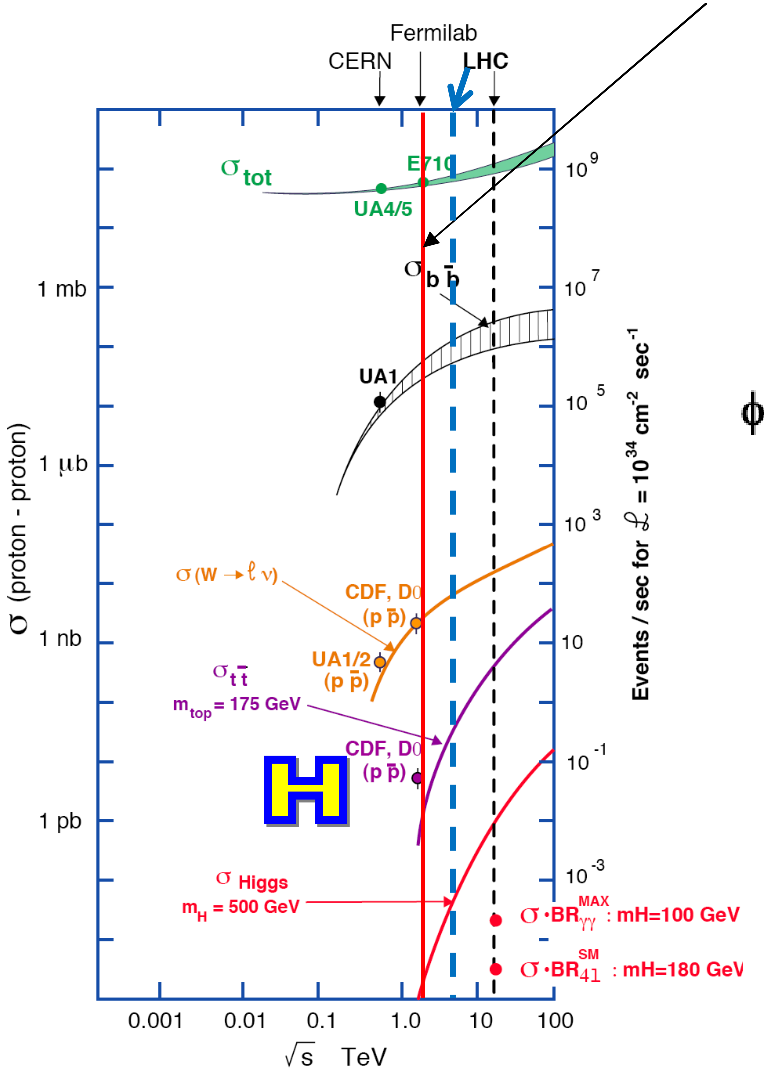




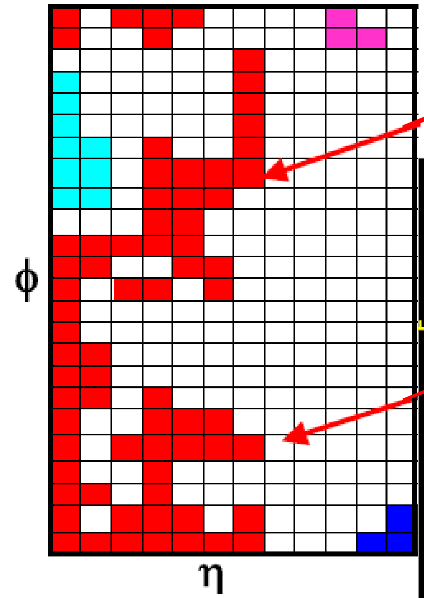
WITH STRONG TRIGGERING POWER

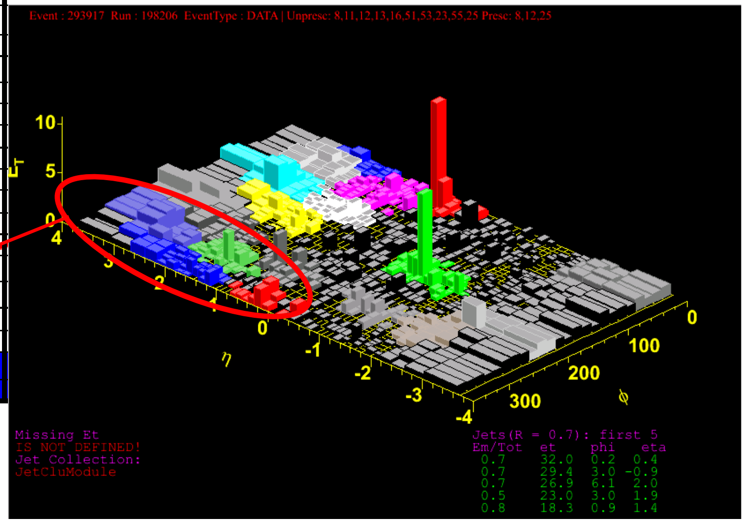
A dedicated new Higgs trigger & N.P. searches

Ten orders of magnitude to fight against!!



High luminosity gives large calorimeter occupancy (pile up) that generates fake clusters/ cluster merging (ex: red towers seen as one single cluster)

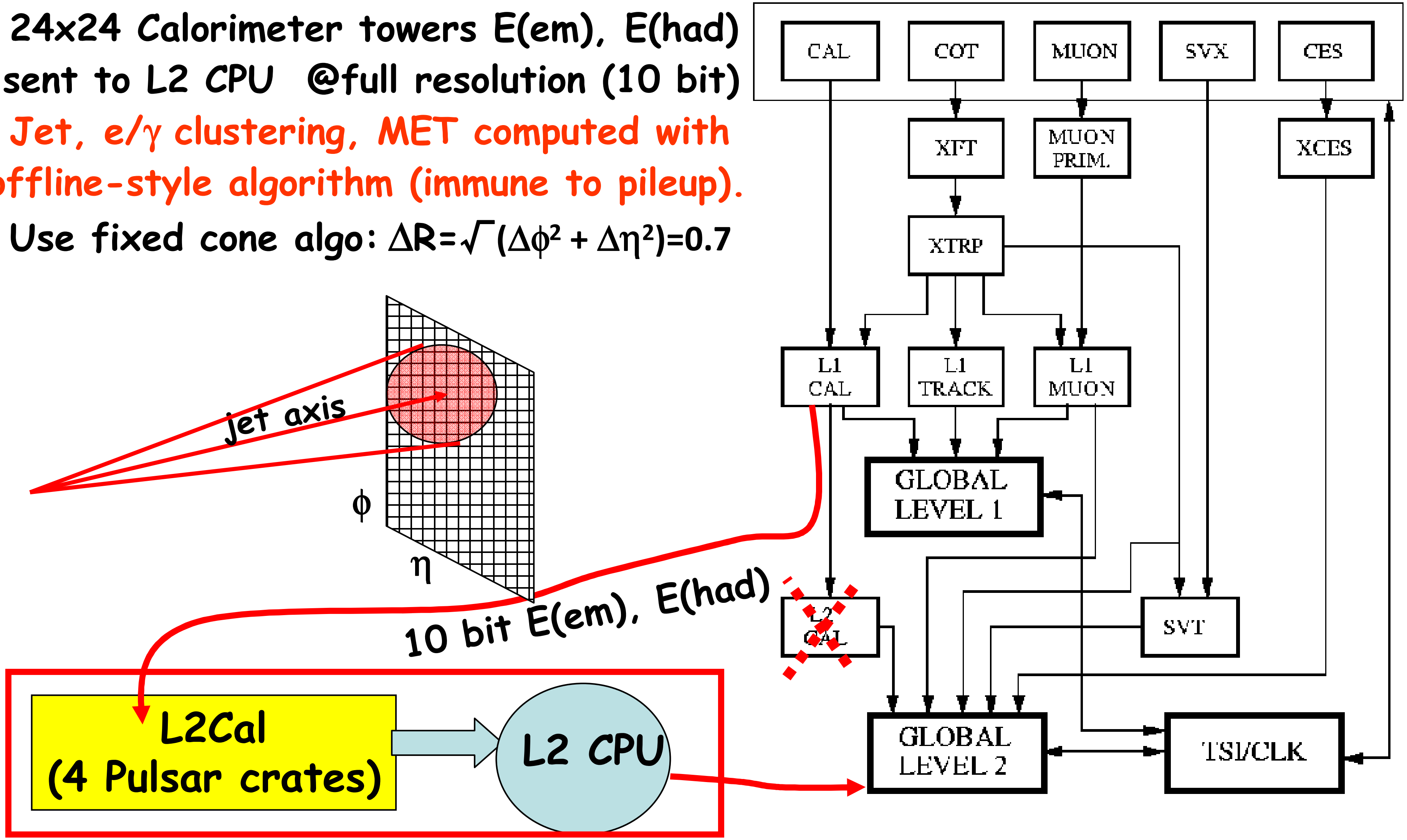




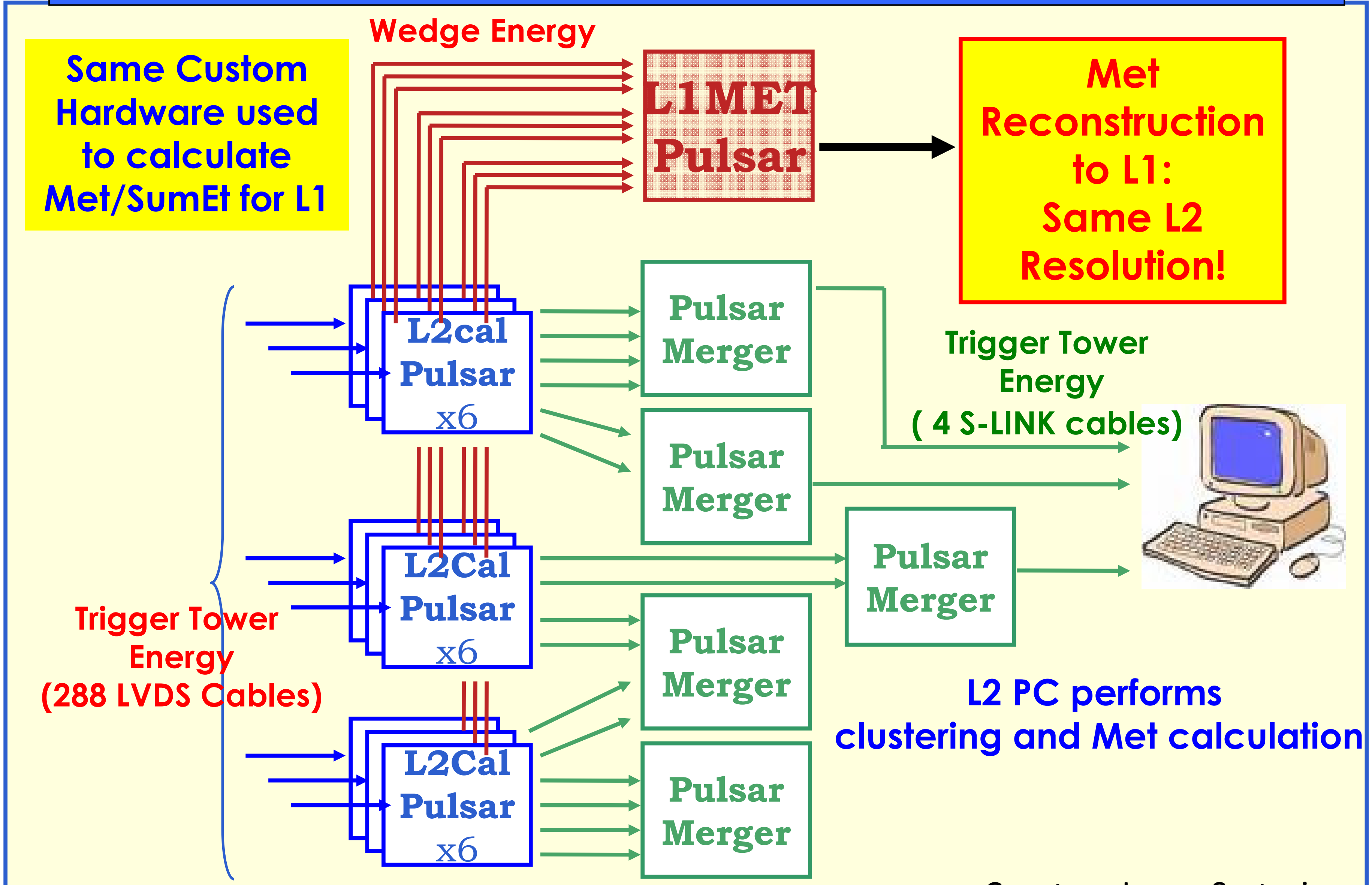
The upgraded Calorimeter Trigger

courtesy of Simone Donati

- 24x24 Calorimeter towers E(em), E(had) sent to L2 CPU @full resolution (10 bit)
- Jet, e/γ clustering, MET computed with offline-style algorithm (immune to pileup).
- Use fixed cone algo: $\Delta R=\sqrt{(\Delta\phi^2 + \Delta\eta^2)}=0.7$

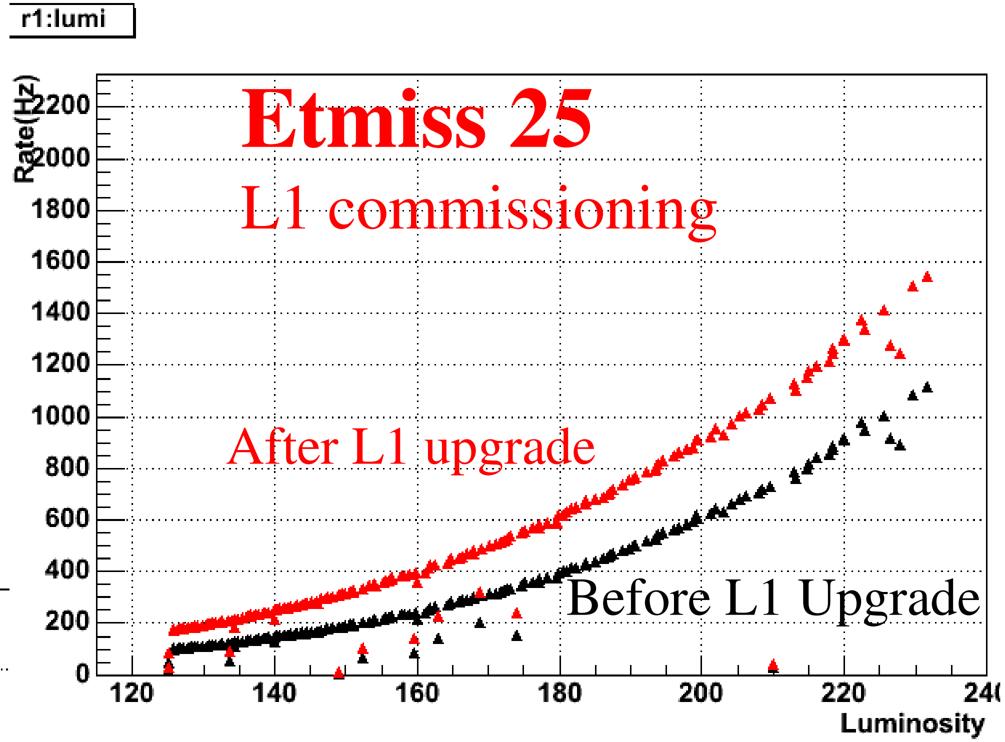


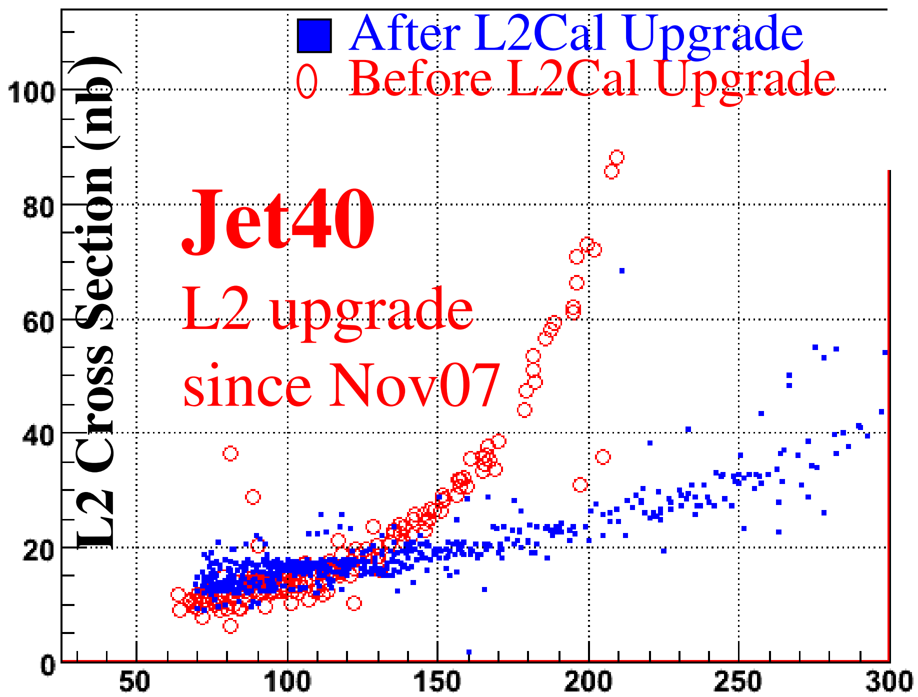
The L1MET Upgrade



Courtesy Laura Sartori

Effects of latest trigger upgrades on L1 and L2: 2 examples





This impacts also on the

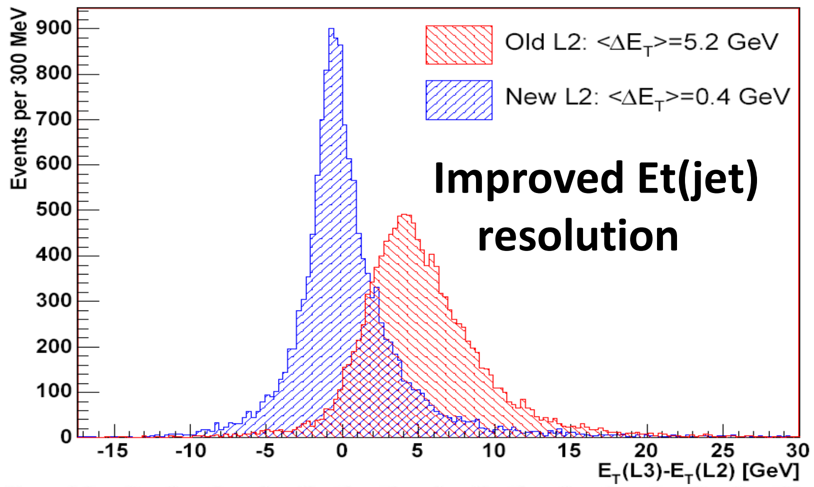
τ- triggers

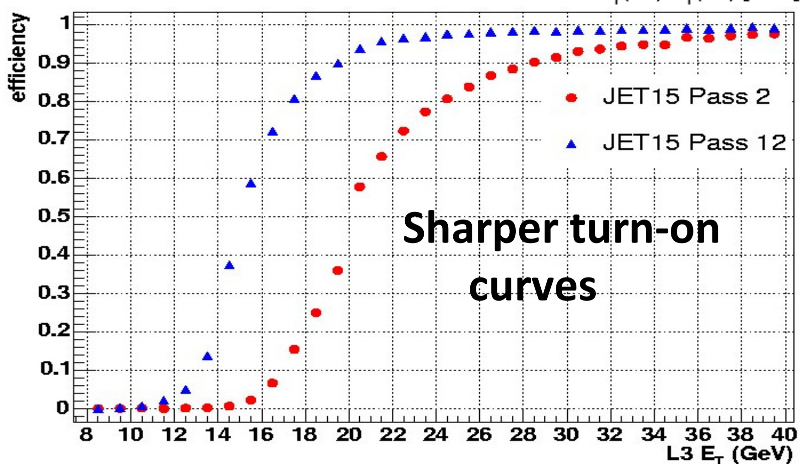
Courtesy Laura Sartori

New trigger strategies for the Higgs

The calorimeter trigger upgrade together with XFT-3D, SVT upgrades significantly improves CDF reach for the Higgs (and lots of Physics topics)

Ex: New Jet clustering provides





Mode	Acceptance increase
WH → eνbb	+97 %
WH → μνbb	+110 %
ZH → e+e-bb	+27 %
ZH → μ+μ-bb	+60 %
ZH → ννbb	+30 %
H → lνlν	+24 %

triggers at CDF

e/μ+ track

primarily designed to detect e/μ- τ_{had} events

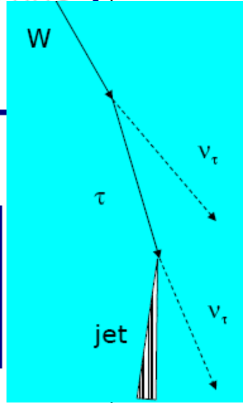
Primarily designed to trigger low Pt multileptons Including τ's

L1
- a single calorimetric trigger tower with Et > 8 GeV OR muon hits in muon chambers
- a matching track

L2
- electron cluster Et > 8 GeV / muon Pt > 8 GeV
- a second track of Pt > 5 GeV 10 degrees in φ apart from the electron/muon track

L3
- Tighter electron/muon id
- charged track isolation (for tau)

N.B. Also included:
Tau+Missing Energy Trigger
and
Di-Tau Trigger



$\tau \to \pi^- \nu_\tau$

$\tau \to \pi^- \nu_\tau \geq 1\pi_0$

$\tau \to \pi^- \pi^- \pi^+ \nu_\tau$

$\tau \to \pi^- \pi^- \pi^+ \nu_\tau \geq 1\pi_0$

Hadronic Tau

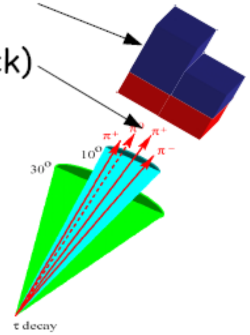
$\cancel{\tau \to e \bar{\nu}_e \nu_\tau}$

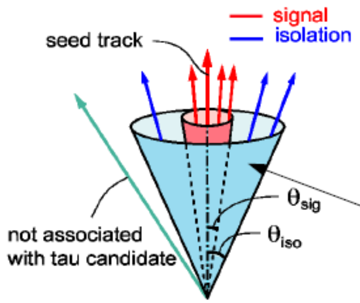
$\cancel{\tau \to \mu \bar{\nu}_\mu \nu_\tau}$

~~BR ≅ 36%~~

1 - find a narrow cluster in the calorimeters

2 - find a track pointing to it (seed track)





3 - define signal and isolation cones

4 - match π_0s

Designed and installed by: Davis, LPNHE, PISA, Rutgers, TA&M in 2002

SM Consistency Check: M_W, M_{top}, M_H

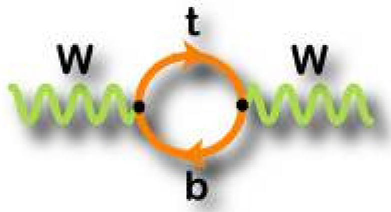
- ***The W boson mass is derived from precisely measured EWK quantities***

known to 0.015%

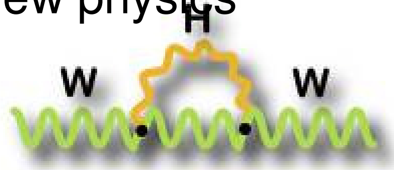
$$M_W^2 = \frac{\pi\alpha(M_Z^2)}{\sqrt{2}G_F}\frac{1}{1-M_W^2/M_Z^2}\frac{1}{1-\Delta r}$$

known to 0.0009% M_Z known to 0.002%

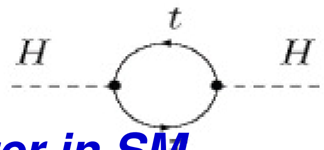
- ***Δr: - large radiative corrections***
  - dominated by *tb* and Higgs loops
  - sensitive to new physics

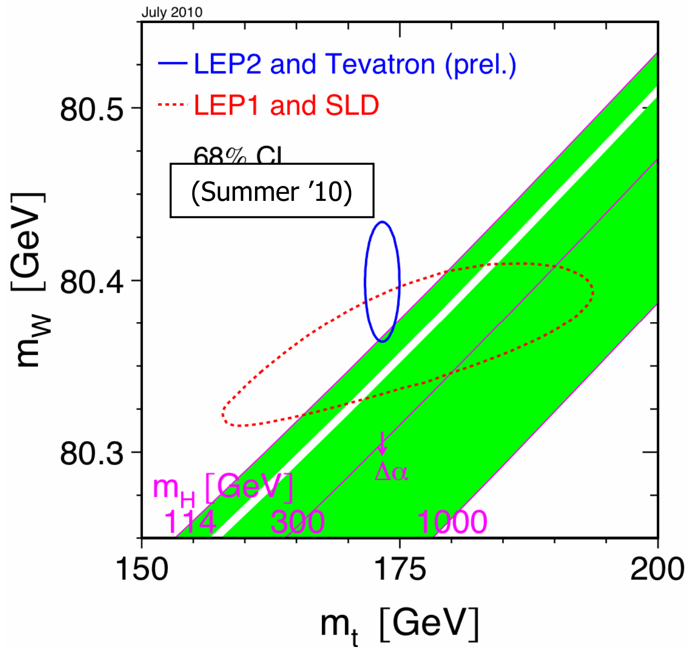


$\Delta M_W \sim M_t^2$



$\Delta M_W \sim \log(M_H)$

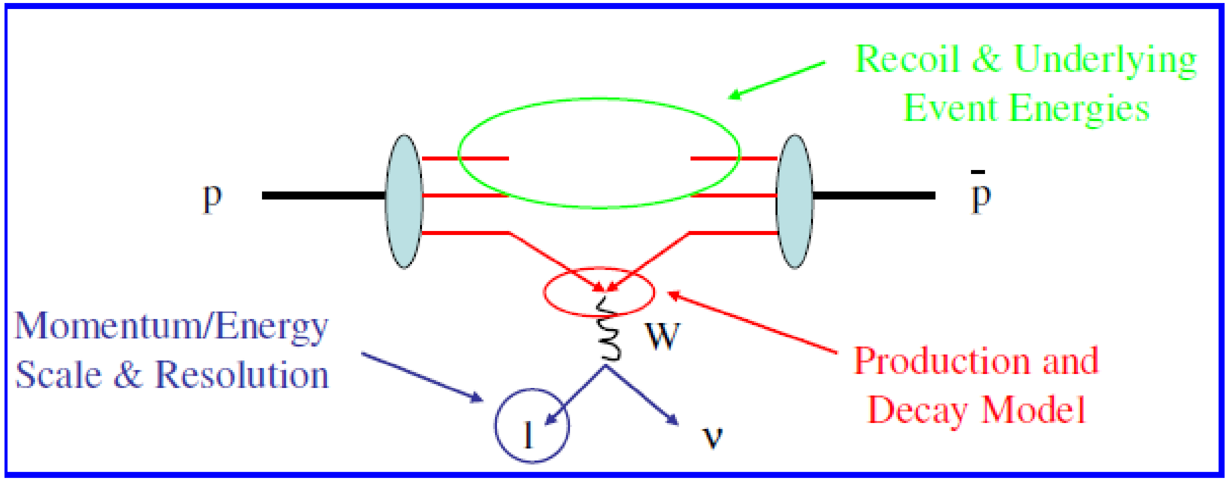




- ***Top mass: free parameter in SM***
  Strongly related to W and H mass

Top and W mass:
=> Consistency check of the SM
=> Prediction of the Higgs mass

W detection at Tevatron

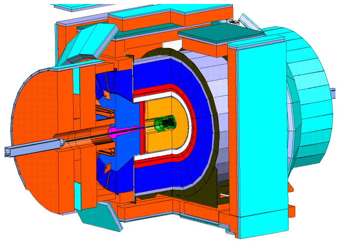


On tape ~ 7.5 fb^{-1} /expt
=> ~6 Mio W's per expt

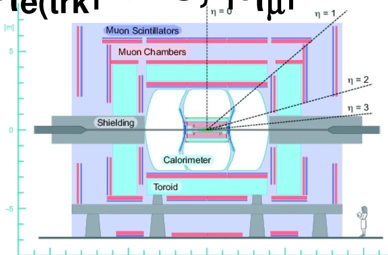
W events:

- single charged lepton
  - high p_T
  - isolated
- missing E_T from neutrino
  ($W \rightarrow \mu\nu$ or $e\nu$).
  - p_T^{ν} is inferred

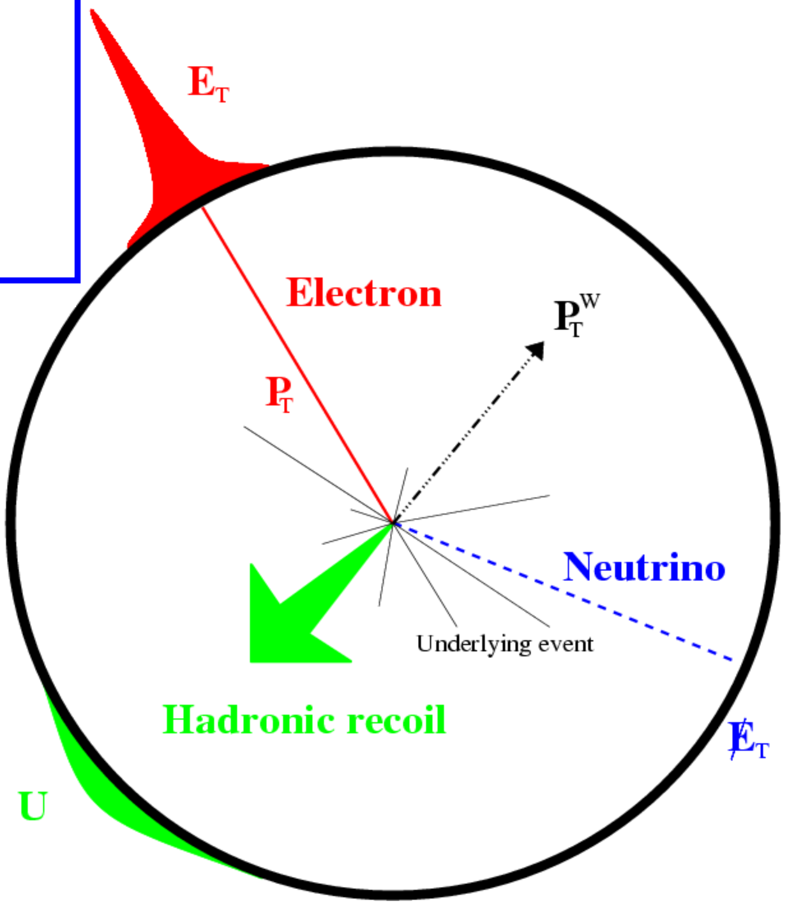
.



$|\eta_{e(trk)}|<2.8$, $|\eta_\mu|<1$



$|\eta_{e(trk)}|<3.2$, $|\eta_\mu|<2$

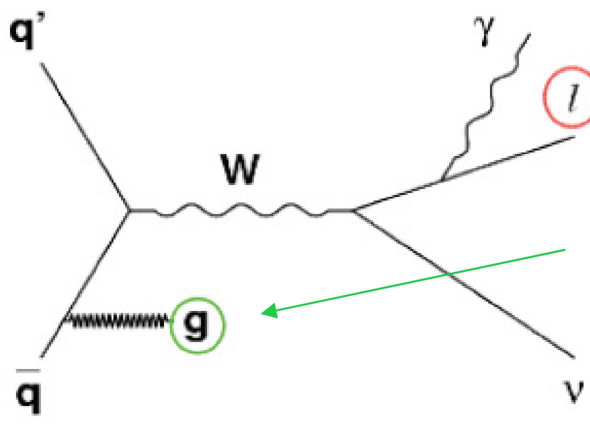


- Muons: central tracker + muon detectors
- Electrons: central tracker + calorimeter

Detailed understanding (~10MeV) of all aspects of W is required.

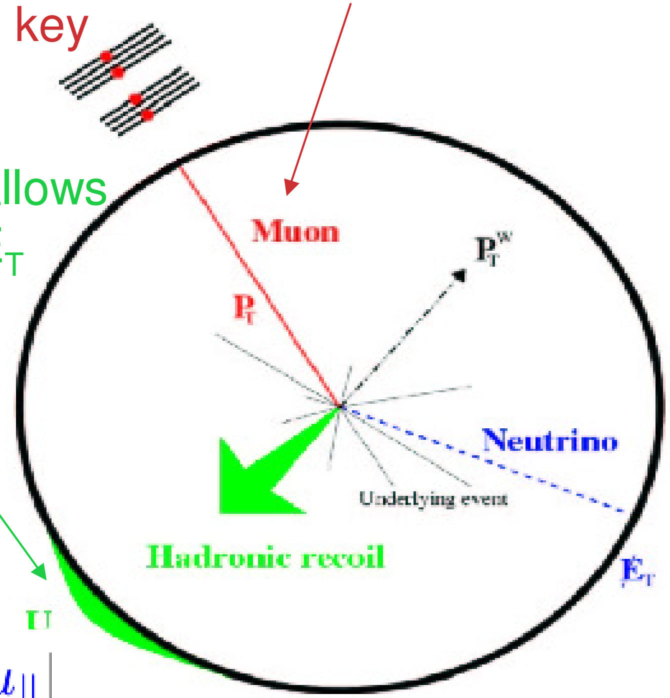
W-Mass Measurement at the Tevatron

•Tevatron: mainly $\bar{q}q'$ annihilation



precise charged lepton measurement is the key

Recoil measurement allows inference of neutrino E_T



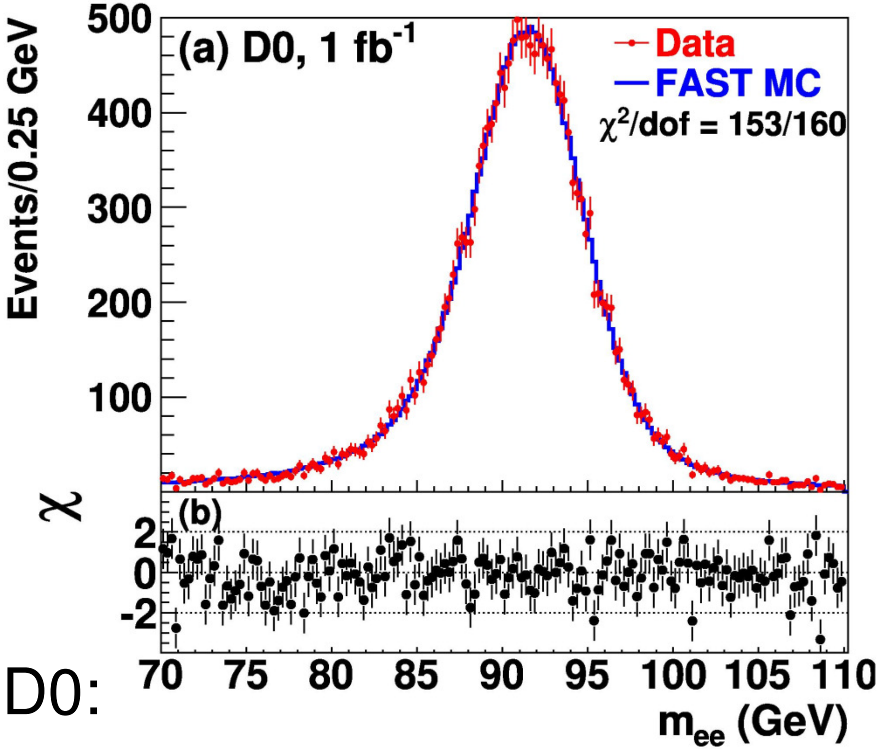
• Main ingredients lepton p_T (~10^{-4}) and hadronic recoil (~1%) parallel to lepton $u_{||}$

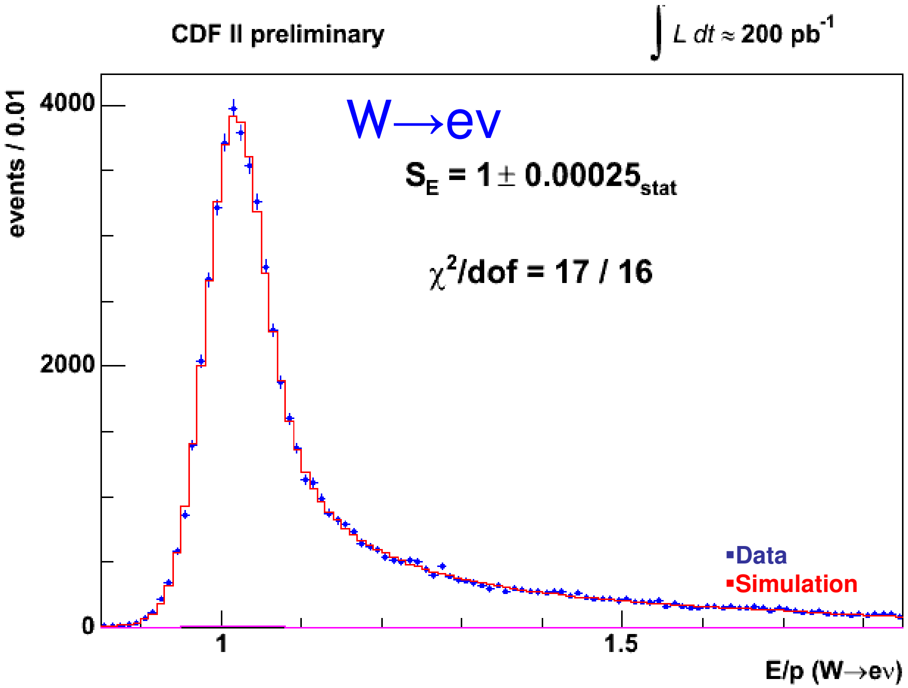
$$m_T = \sqrt{2 p_T^l p_T^\nu (1 - \cos\Delta\phi)}; \quad p_T^\nu \approx |p_T^l + u_{||}|$$

Z decay into leptons provide an excellent calibration sample:

- $Z \to \mu\mu$ (CDF) and $Z \to ee$ (CDF, D0) events to derive recoil model
- most systematic uncertainties limited by size of Z sample (10x less Z than W)

Lepton Energy/Momentum Scale





D0:

- Calibrate calorimeter using precisely known M_Z from LEP
- Detailed corrections for non instrumented regions
- Reduce higher order corrections due to ratio W/Z

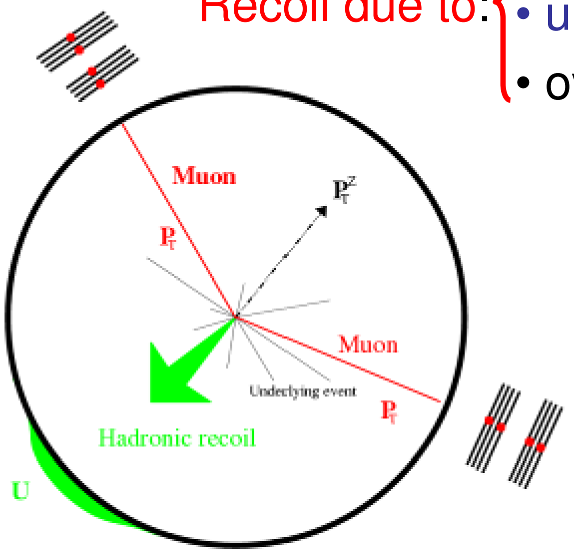
CDF:

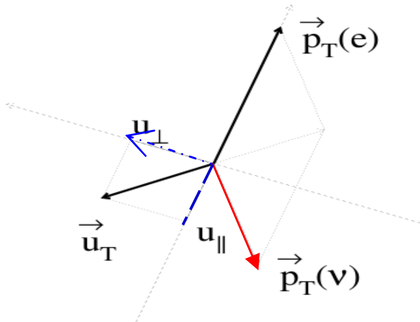
- Calibrate lepton momentum scale using Υ, J/ψ, Z data
- Calibrate calorimeter against precision tracker (E/p) and M_Z

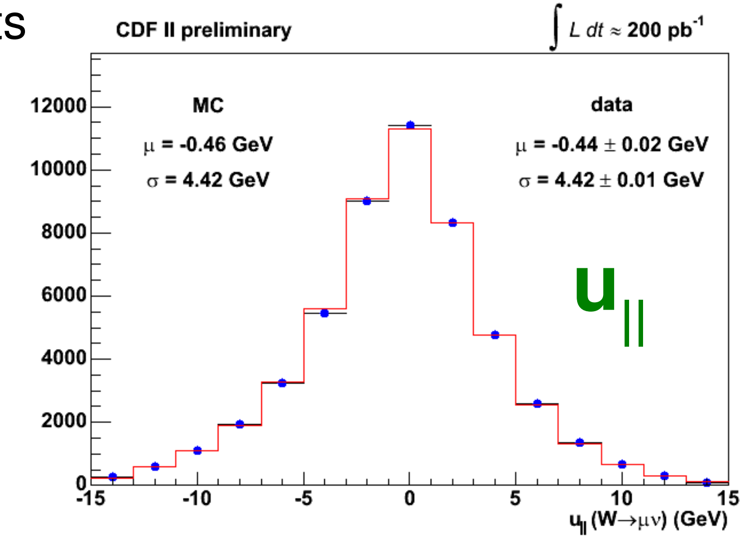
Dominant systematic uncertainty (D0: 34 MeV, CDF: 17/30 MeV e/μ)

W-Mass: Recoil Model

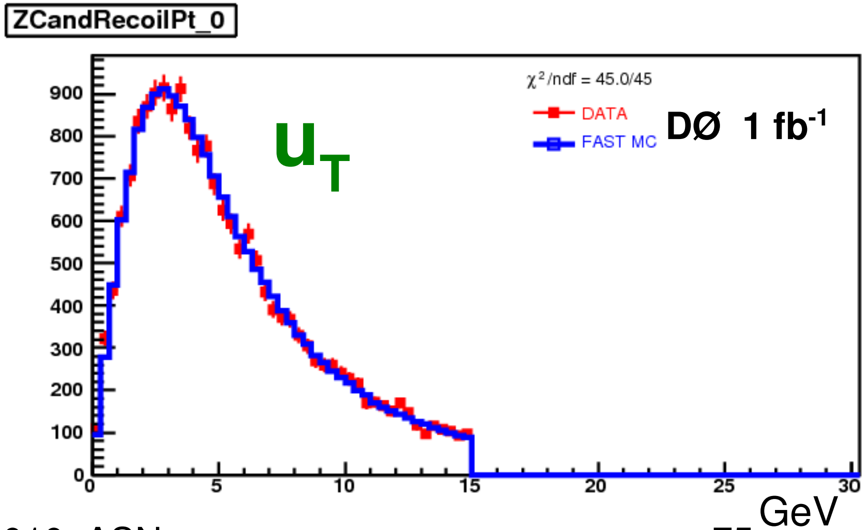
Recoil due to:
- QCD radiation "recoiling" against W
- • underlying event
- • overlapping min bias events







Use $Z \to ee$ (D0 and CDF) + $Z \to \mu\mu$ (CDF) balancing to calibrate recoil energy scale and to model resolution

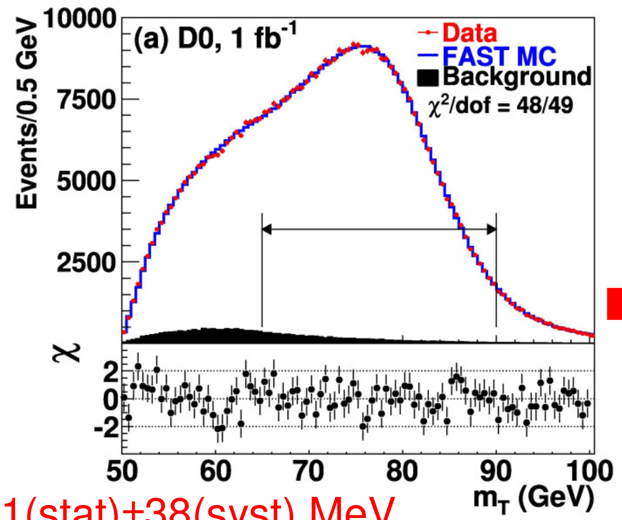


systematic uncertainty on M_W :

D0: 6 MeV m_T, 12 MeV p_T

CDF:9 MeV m_T, 17 MeV p_T

W-Mass Results



D0 (1 fb^{-1}):

m_W=80401±21(stat)±38(syst) MeV

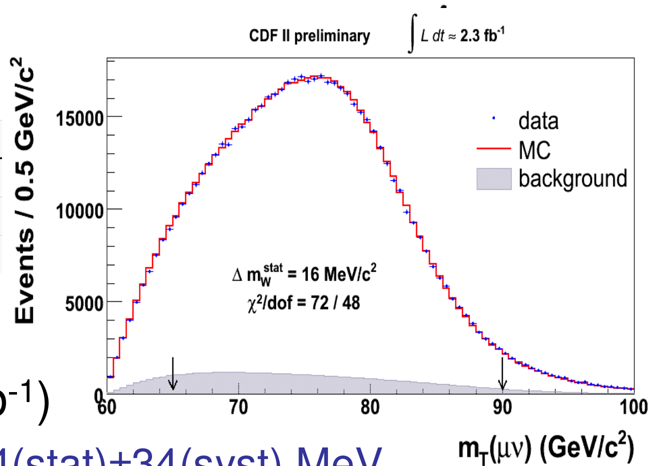
→Single most precise result

SystematicSource	δm_W(MeV)
Electron energy scale	34
Electron energy resolution model	2
Electron energy nonlinearity	4
W and Z electron energy loss differences	4
Recoil model	6
Electron efficiencies	5
Backgrounds	2
PDF	9
QED	7
Bosonp_T	2
Total	**37**

Improve w/ statistics

Ultimately limit precision

	Δm_W^{stat}
published (200pb^{-1})	54 MeV/c^2
expected (2.3fb^{-1})	16 MeV/c^2
fit (2.3fb^{-1})	16 MeV/c^2



CDF (200 pb^{-1})

m_W=80413±34(stat)±34(syst) MeV

→ update w/ 2.4 fb^{-1}

Tevatron Run II precision goal:

Δm_W < 25 MeV/experiment

Tevatron W Mass Combination

- **New Tevatron combination**:

  m_W=80420±31MeV (0.038%)

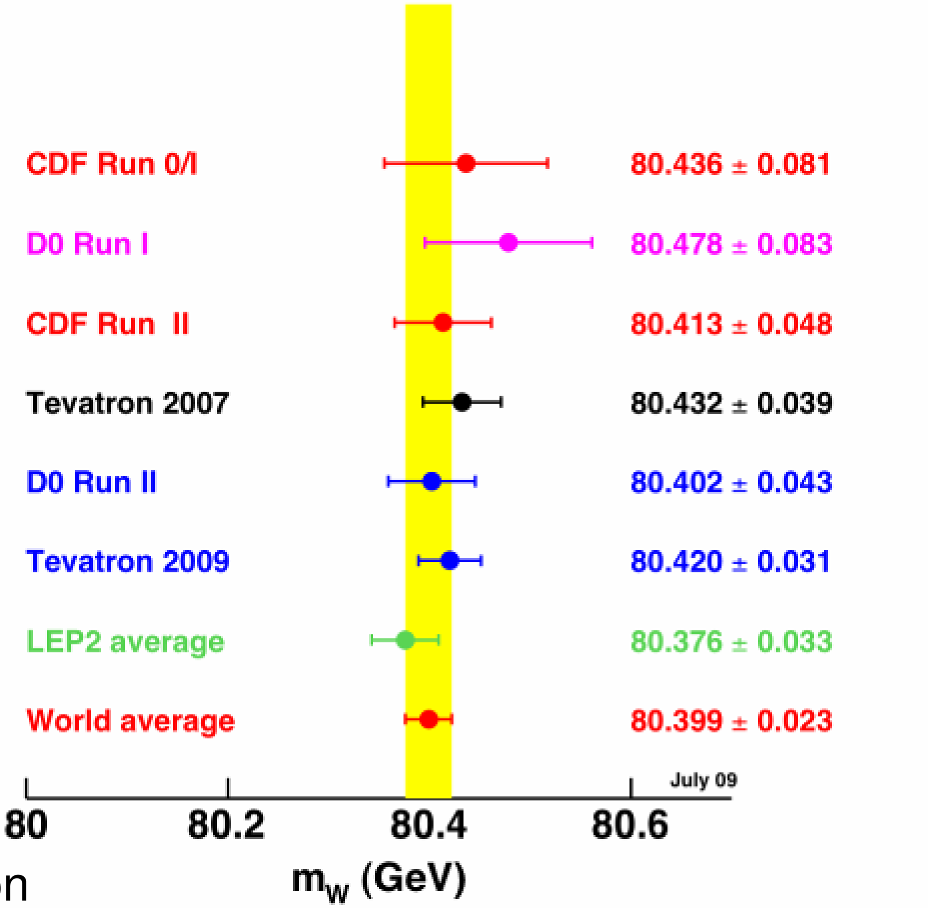
  – Update previous CDF result to modern PDFs
  – Correct to same Γ_W
  – PDF, QED, Γ_W uncertainties correlated

- **More precise than LEPII legacy**:

  80.367±0.033 GeV (0.04%)

- **New world average (2009):**

  m_W=80399 ± 23 MeV



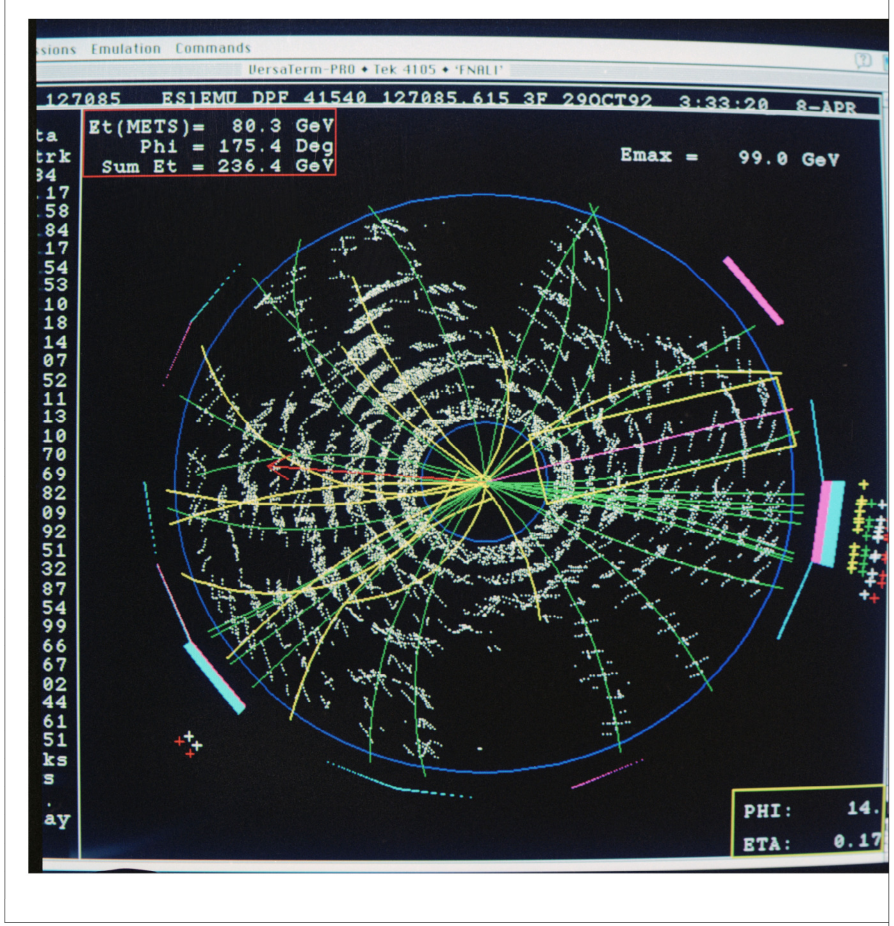
CDF (2.4 fb^{-1}) and D0 (5fb^{-1}) are working on updates with improved analysis
=> expected to go ≤ 25 MeV per experiment

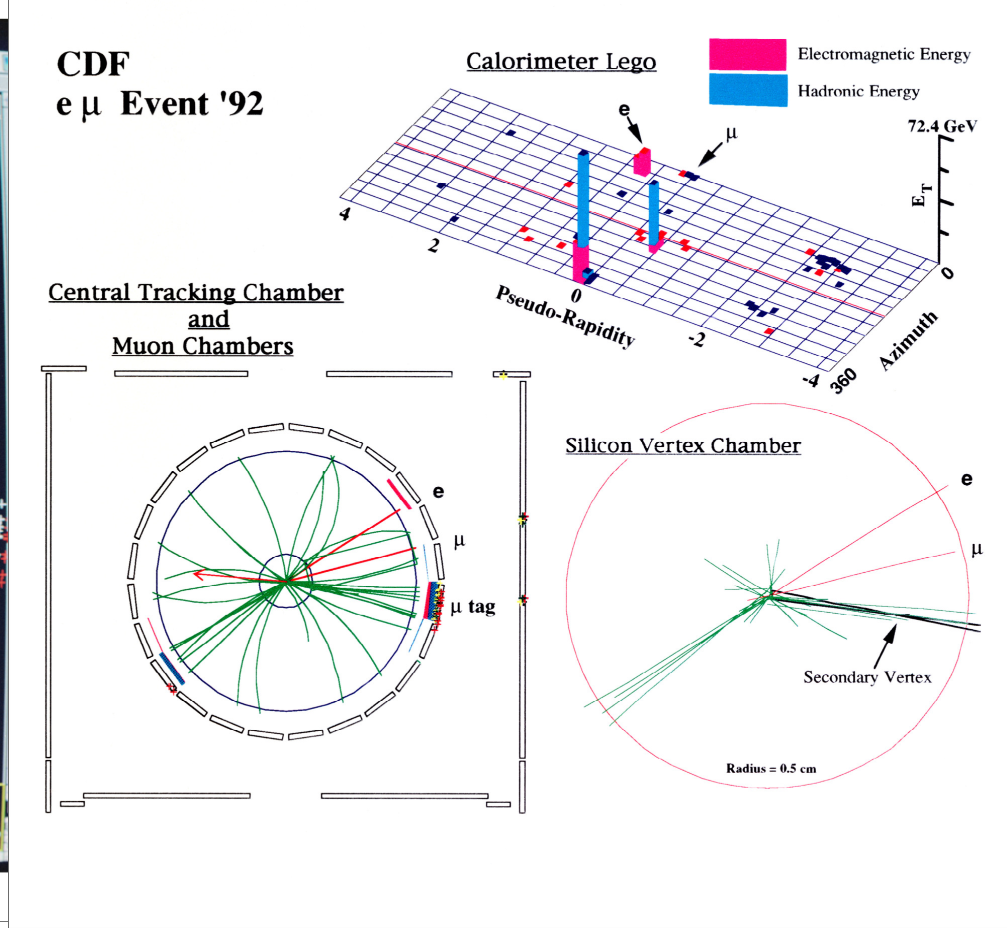
=> W-MASS: ONE of the OUTSTANDING LEGACY OF THE TEVATRON

The Top in itself and as a window to New Physics

TOP: A little bit of history…

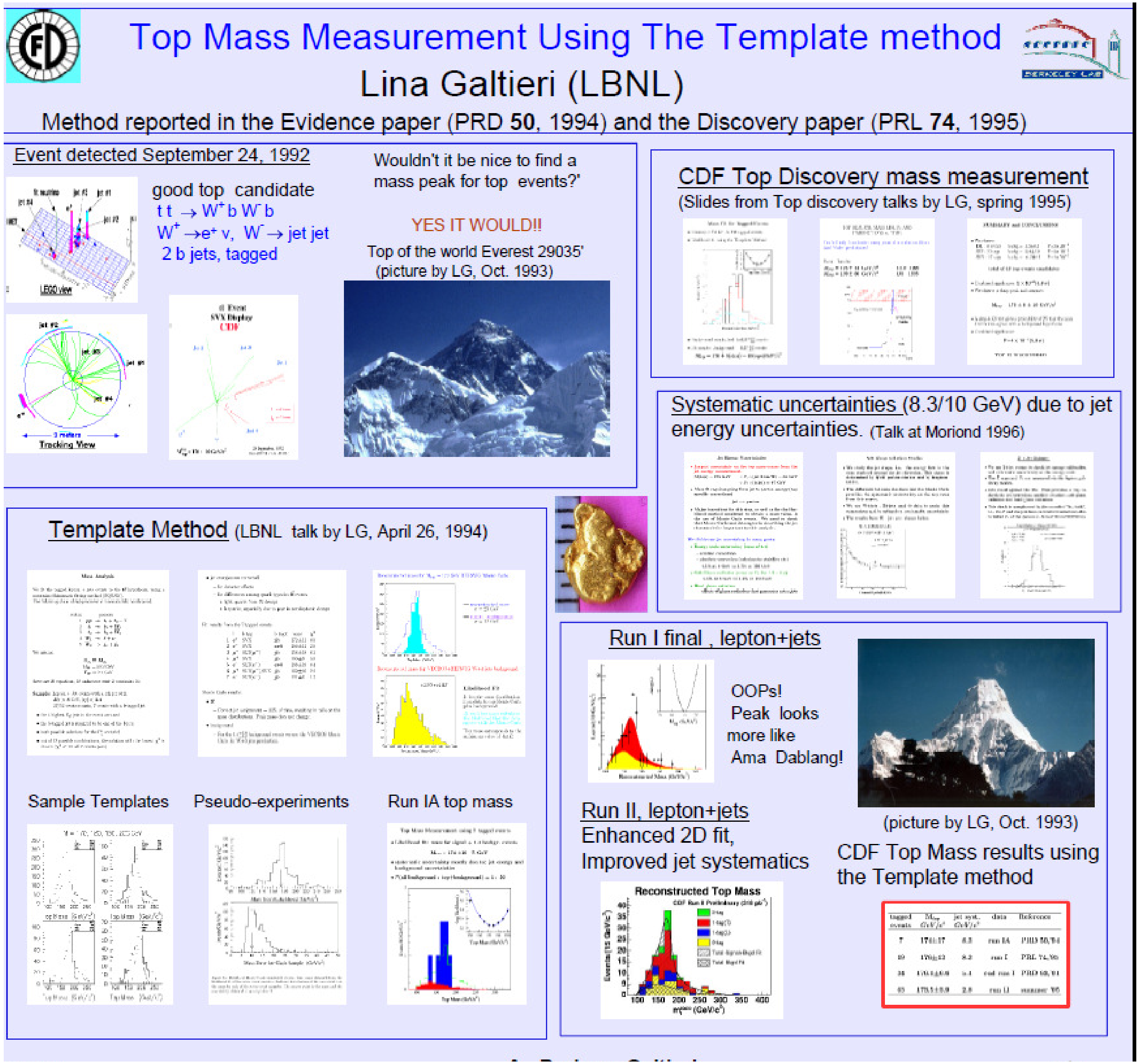
1992: FIRST OBSERVATIONS!





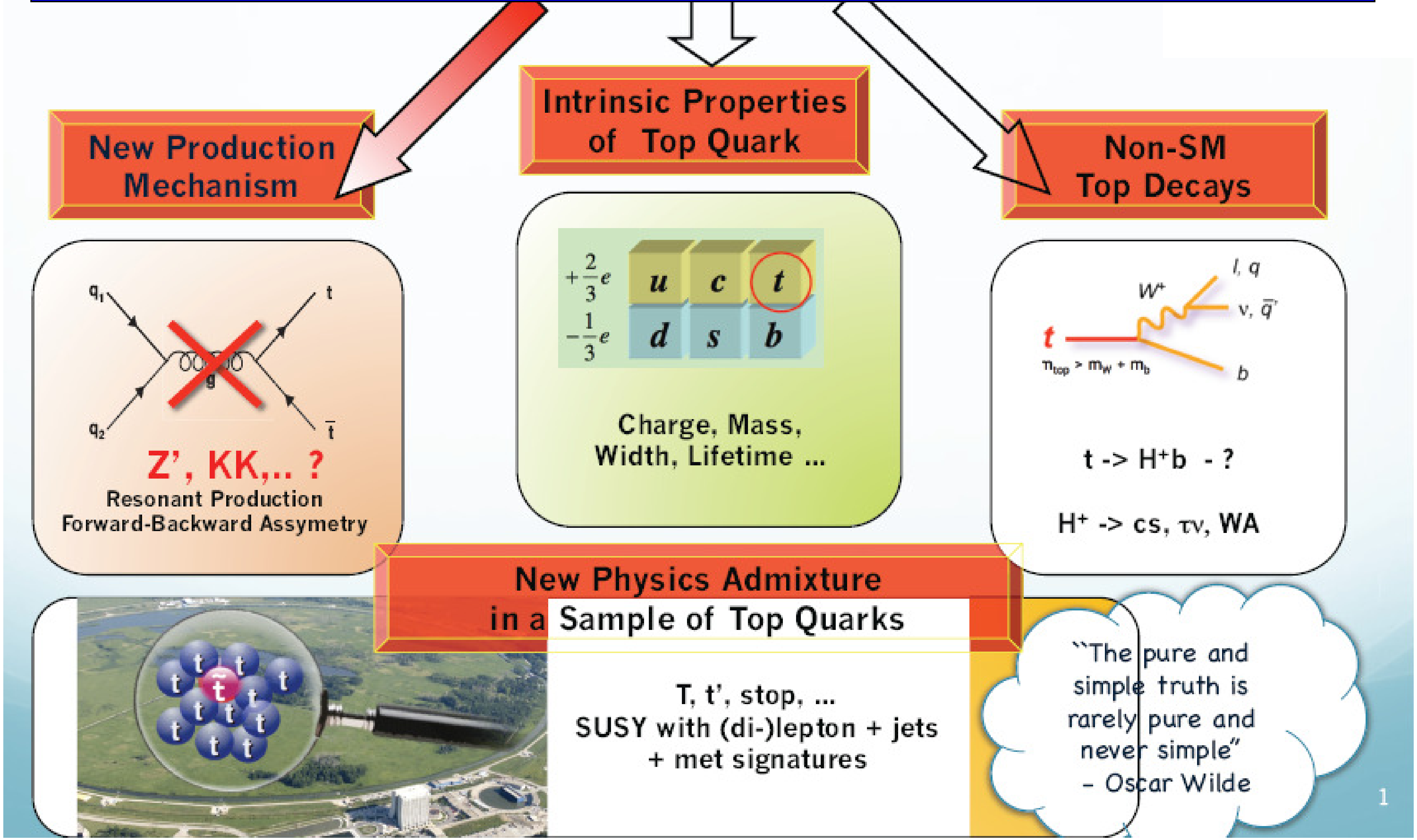
29 Oct 1992, first observation of TOP by CDF in the Run I in a golden e μ event and the vertex detector signing b-jet!

Also found in e+jets channel (see next slide)



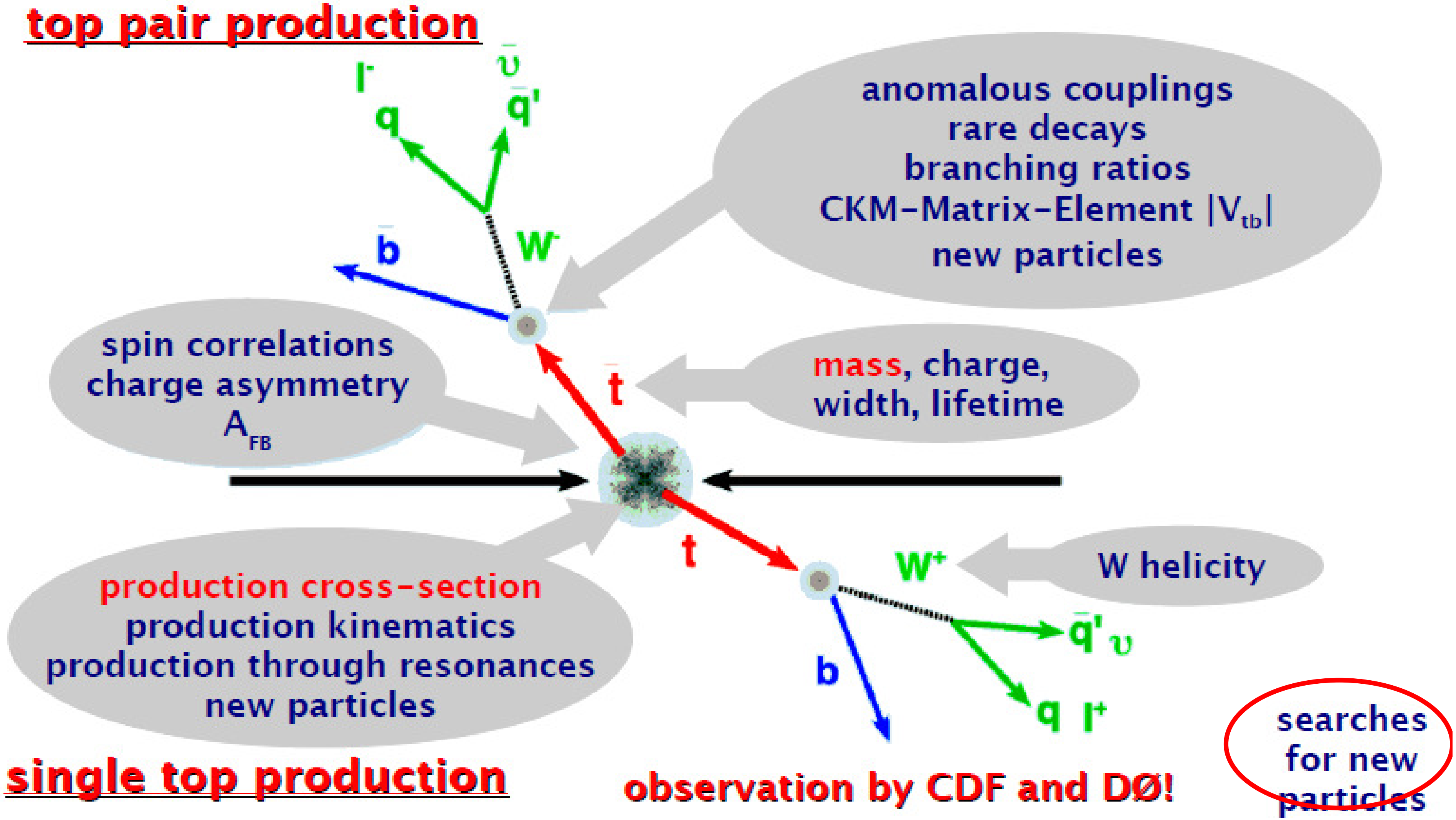
Top Mass Measurement Using The Template method
Lina Galtieri (LBNL)
Method reported in the Evidence paper (PRD 50, 1994) and the Discovery paper (PRL 74, 1995)
Event detected September 24, 1992
good top candidate
t t → W+ b W- b
W+ → e+ ν, W- → jet jet
2 b jets, tagged
Wouldn't it be nice to find a mass peak for top events?'
YES IT WOULD!!
Top of the world Everest 29035'
(picture by LG, Oct. 1993)
CDF Top Discovery mass measurement
(Slides from Top discovery talks by LG, spring 1995)
Systematic uncertainties (8.3/10 GeV) due to jet energy uncertainties. (Talk at Moriond 1996)
Template Method (LBNL talk by LG, April 26, 1994)
Sample Templates
Pseudo-experiments
Run IA top mass
Run I final , lepton+jets
OOPs!
Peak looks more like Ama Dablang!
(picture by LG, Oct. 1993)
Run II, lepton+jets
Enhanced 2D fit,
Improved jet systematics
Reconstructed Top Mass
CDF Top Mass results using the Template method

The Many ways to find New Physics with the Top

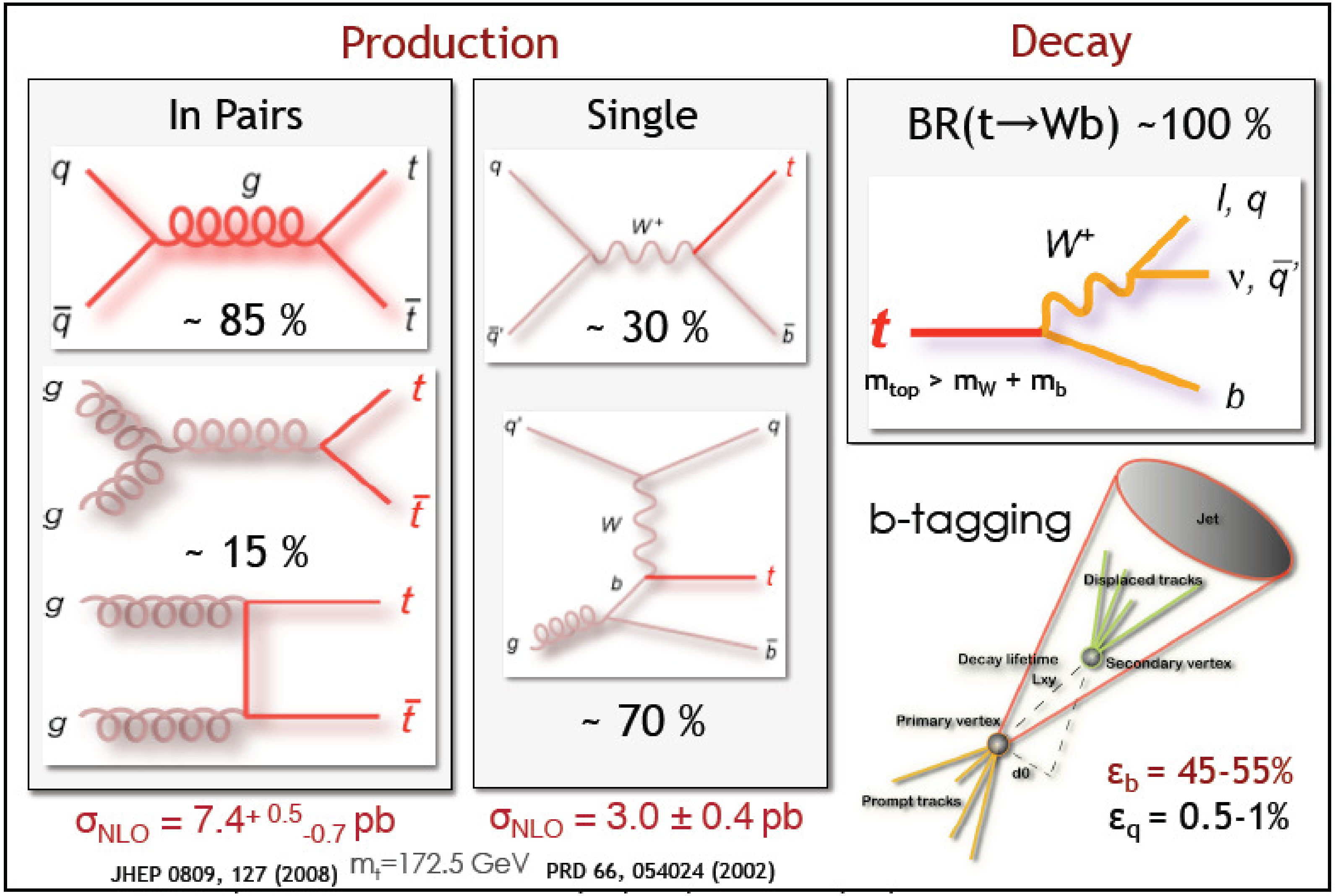


ONGOING TOP ANALYSIS AT THE TEVATRON

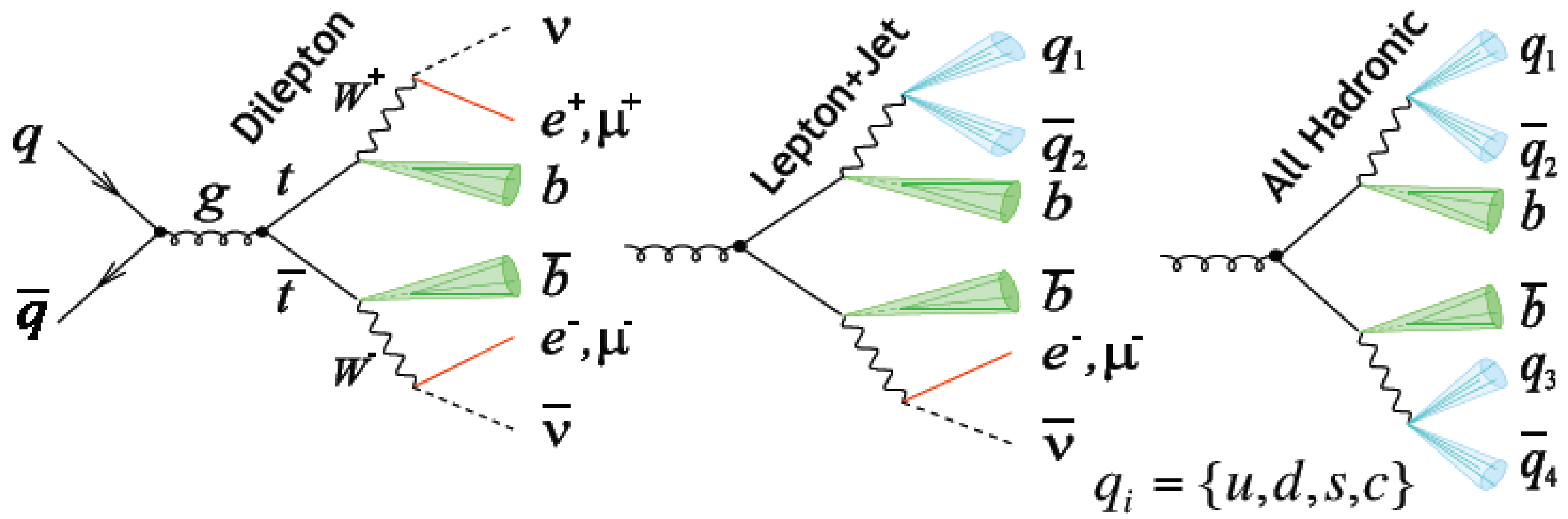
analyses with up to 5 fb^{-1} of data:
several thousand top candidate events per experiment



Top Production at the Tevatron: dominated by q qbar

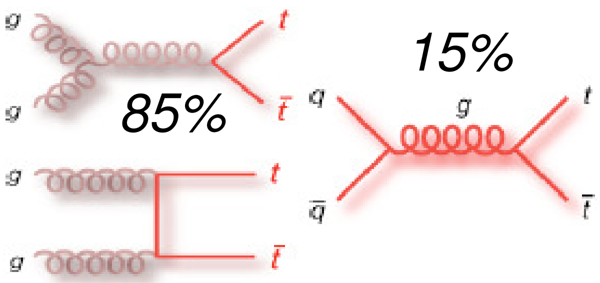


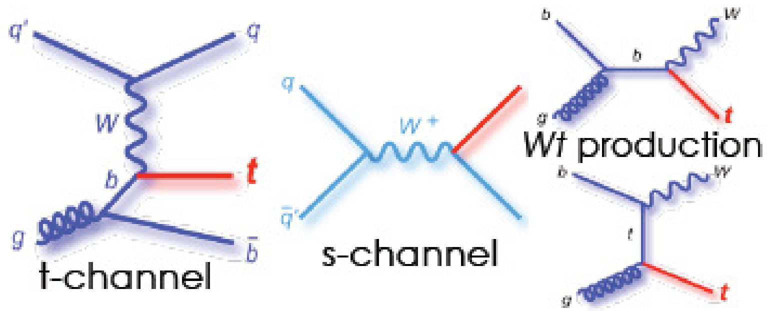
TOP Quark Pair Production at Tevatron

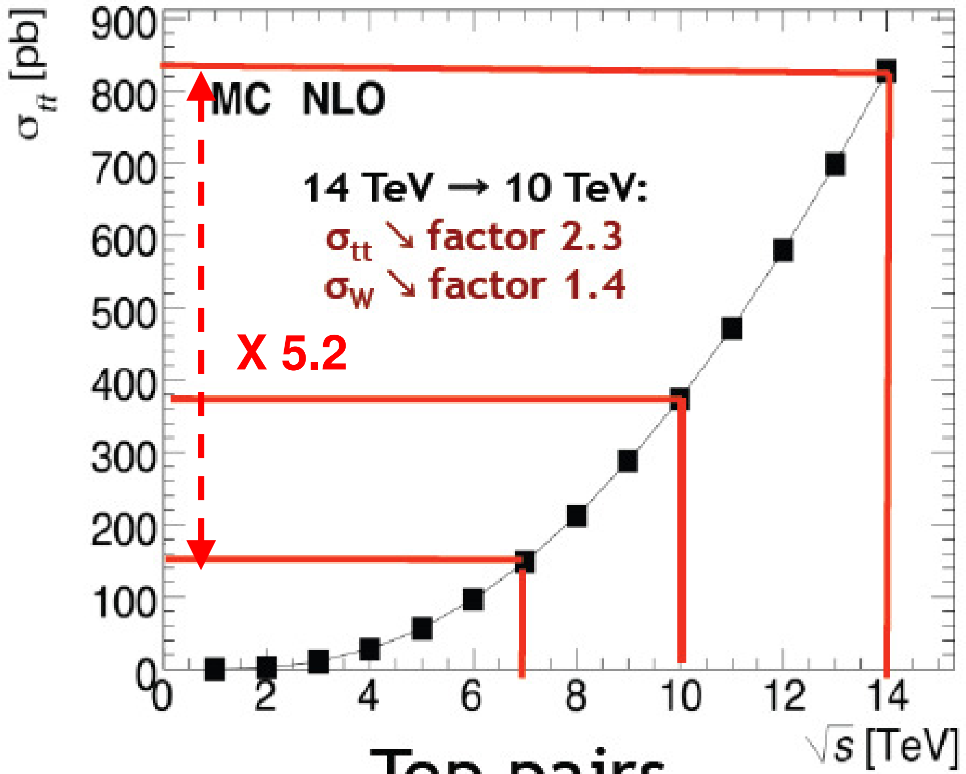


- **Dilepton** (lepton = e or μ) (6%)
  - Small rate, small backgrounds
  - Main background: Drell-Yan
  - *Highest purity*
- **Lepton+Jets** (lepton = e or μ) (34%)
  - Good rate and manageable backgrounds
  - Main background: W+jets,
  - *Good purity "Golden Channel"*
- **All-hadronic (46%)**
  - Large rate, large background
  - Main background: QCD multijet
  - *Least purity*
- **Hadronic Taus** (tau+lepton, tau+jets) (14%)
  - Small rate and large backgrounds
  - Main background: Multijets, W+jets
  - *Challenging purity*

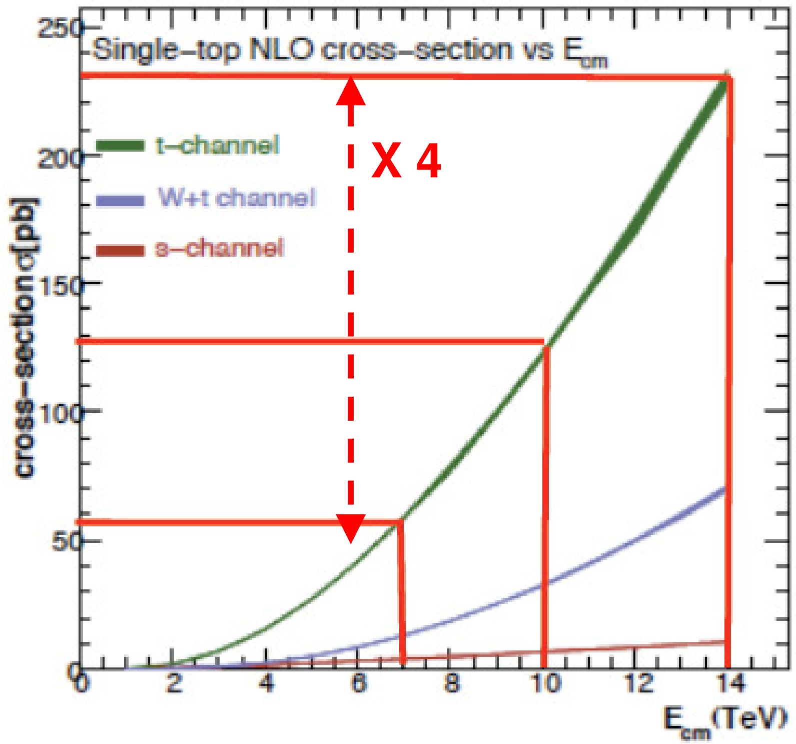
Top cross section at the LHC at 14 TeV: x100 Tevatron







Top pairs



Single Top

Z. Sullivan, arXiv: hep-ph 0408049 (2004).

REMINDER SEE ATLAS & CMS TALKS

TOP MASS Measurement Methods

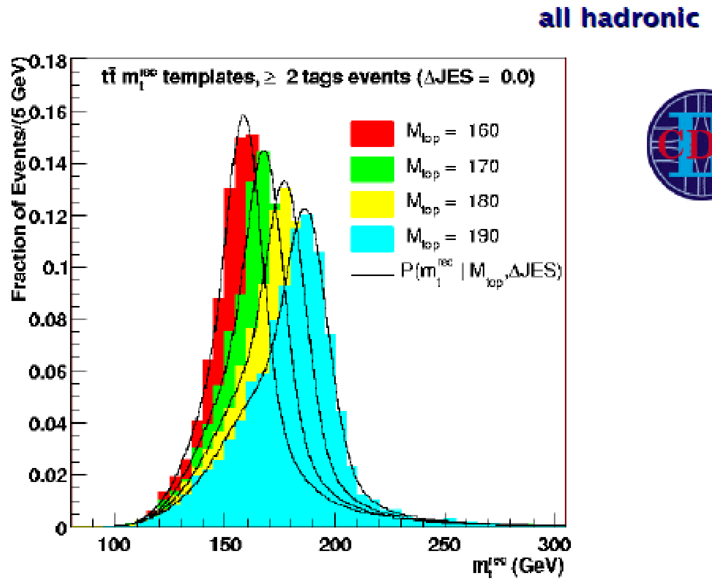
Two main approaches:

➤ ***The Template Method***

- Choose an observable x, sensitive to m_{top}
- Predict x-distribution = $f(m_{top})$ using MC (templates)
- For each event evaluate a Likelihood for each m_{top} value
- Maximize the likelihood for the entire sample

Exemple of variables used:

o m_{top} after kinematic reconstruction
o Lepton P_t
o Lxy: decay length of b-quarks in the event



➤ ***The Matrix Element Method (ME)***

Uses all information from the event, integrating over the least known variables

➤ ***Systematics are somewhat different for different methods***

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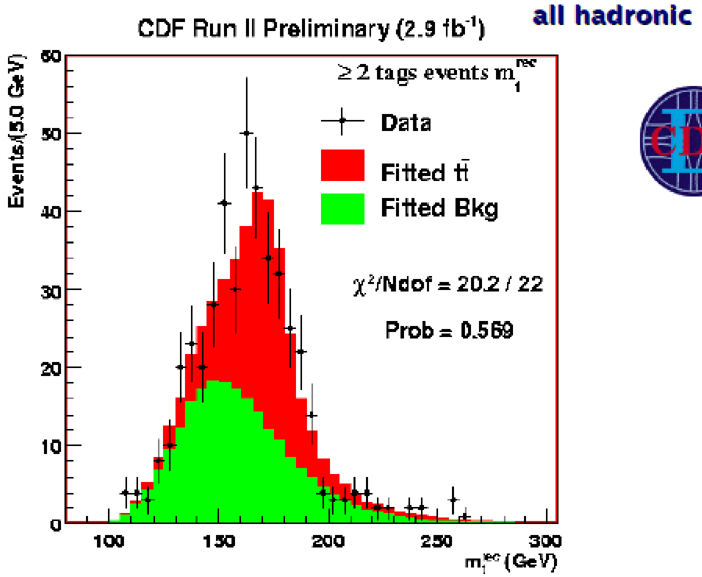


- ***The Matrix Element Method (ME)***

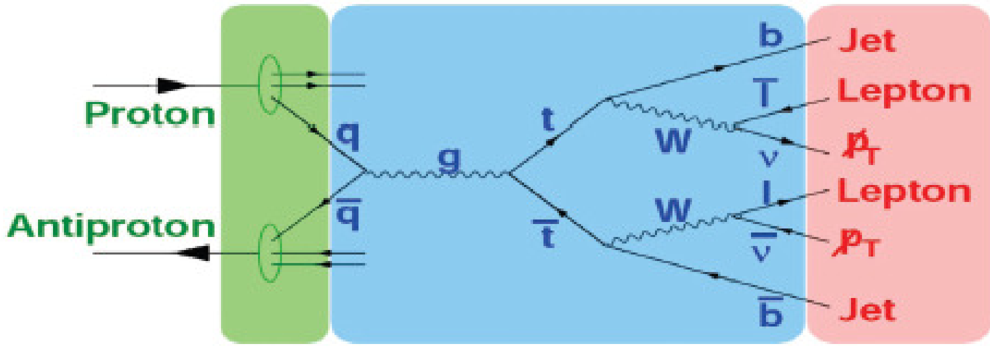
  Uses all information from the event, integrating over the least known variables

- ***Systematics are somewhat different for different methods***

Top mass extraction with ME method

- ME Method is based on a full LO calculation of top pair production + detector effects
- Per event, the probability to be produced under assuming a given top mass via signal process is:

$$P_{sgn}(x, m_{top}) = \frac{1}{\sigma^{obs}_{ttbar}} \int_{q1q2y} \sum_{flavor} \boxed{dq_1\, dq_2\, f_{PDF}(q_1) f_{PDF}(q_2)} \boxed{\frac{(2\pi)^4 |M_{ttbar}(y)|^2}{q_1 q_2 s}} \boxed{d\phi_6\, w(x, y)}$$



parton distribution functions $f_{PDF}(q)$

leading order matrix element $|M_{ttbar}(y)|^2$

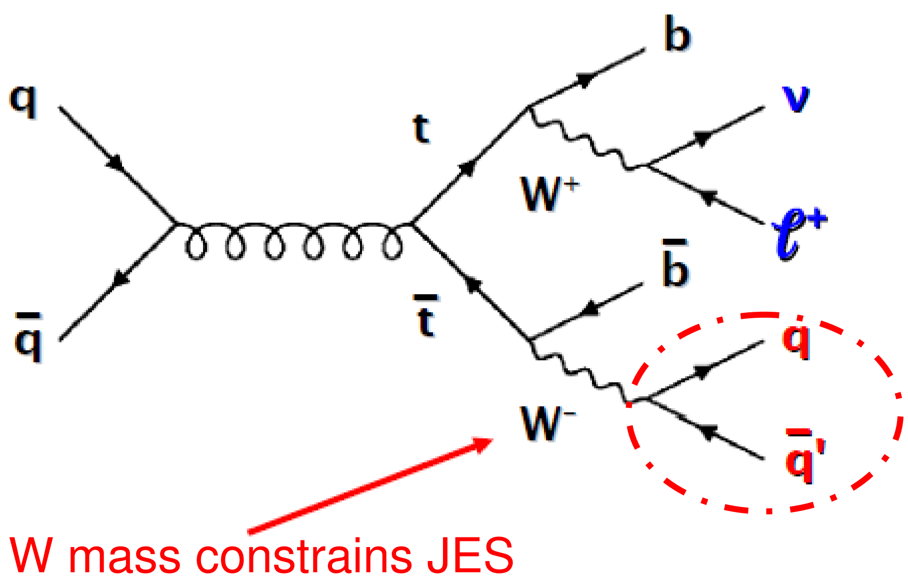
transfer functions W(x,y): mapping from parton y to measured object x

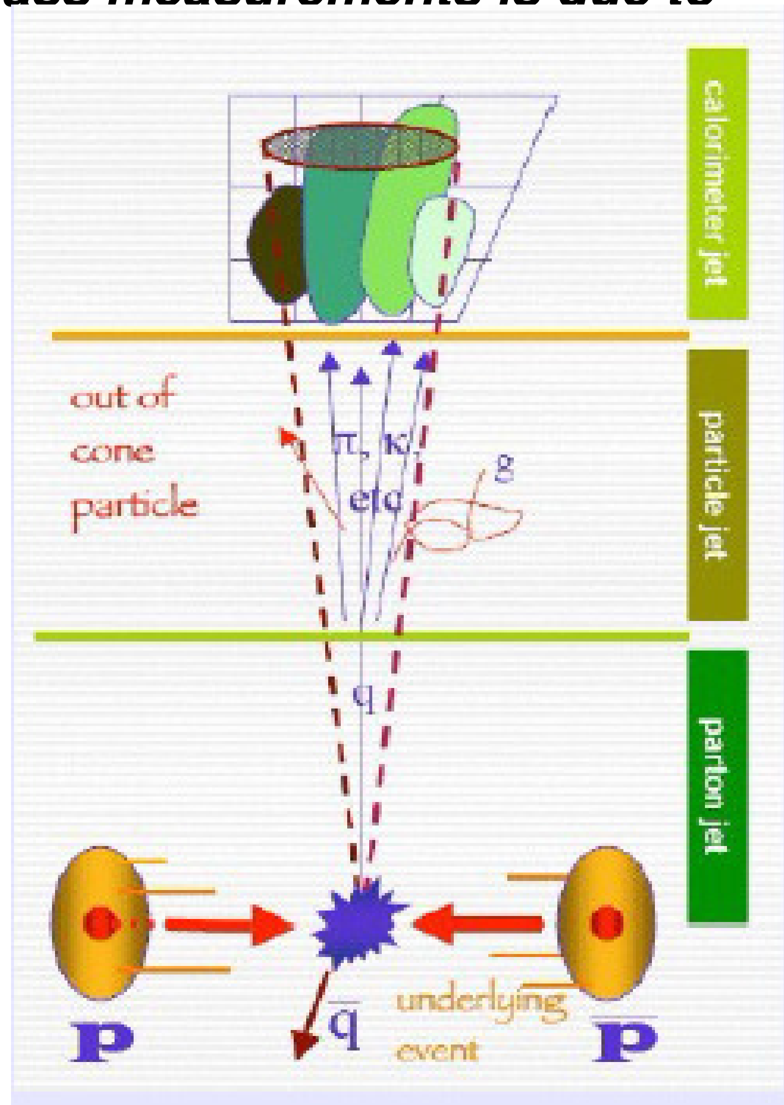
- Calculate main background probability in a similar way
- Build event probability by adding: normalized signal + background probabilities
- Determine top mass from likelihood fit of the event probabilities

Top Mass example: ME applied to lepton +jets

The largest uncertainty on all Top quark mass measurements is due to JET ENERGY SCALE (JES) uncertainties

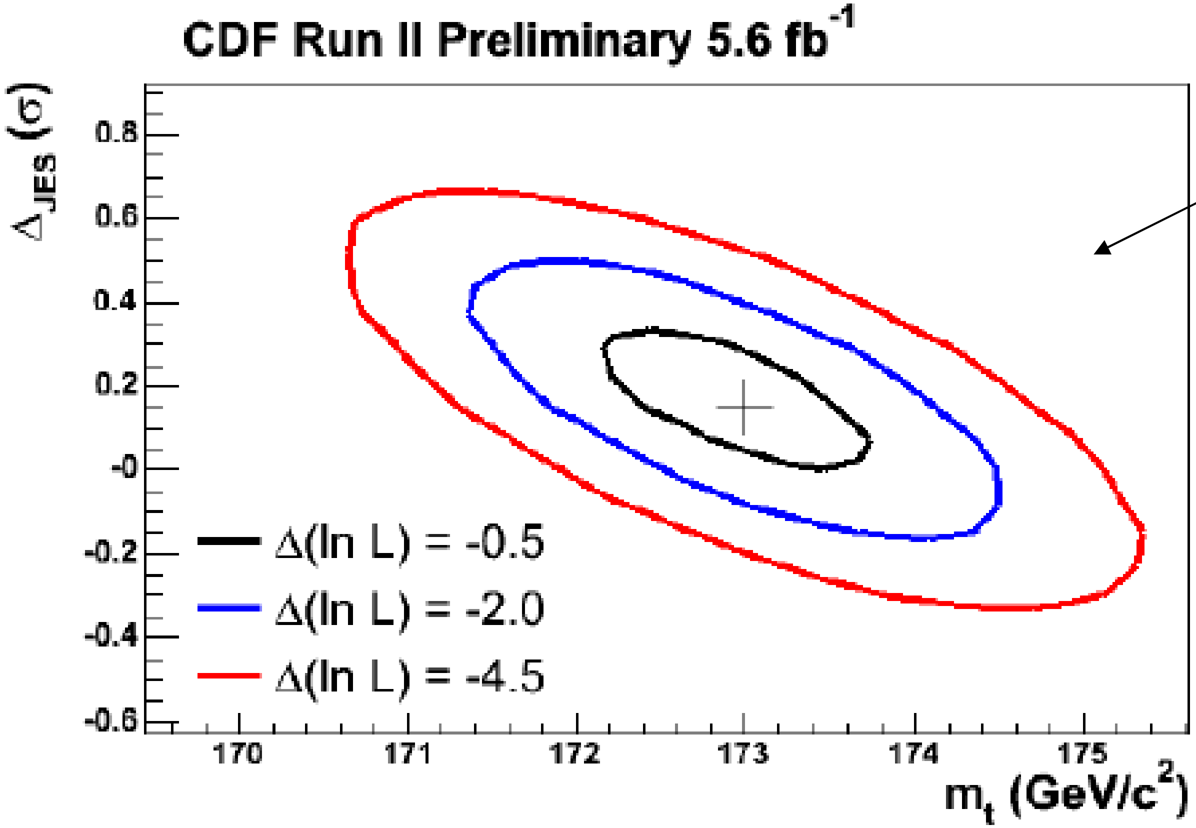
The measurement of an overall jet energy scale correction **JES** on top of the standard corrections in lepton+jets is possible because of well known W mass





Best present result in a single experiment

Measurement at CDF on lepton + jets data with 5.6 fb^{-1} analyzed data

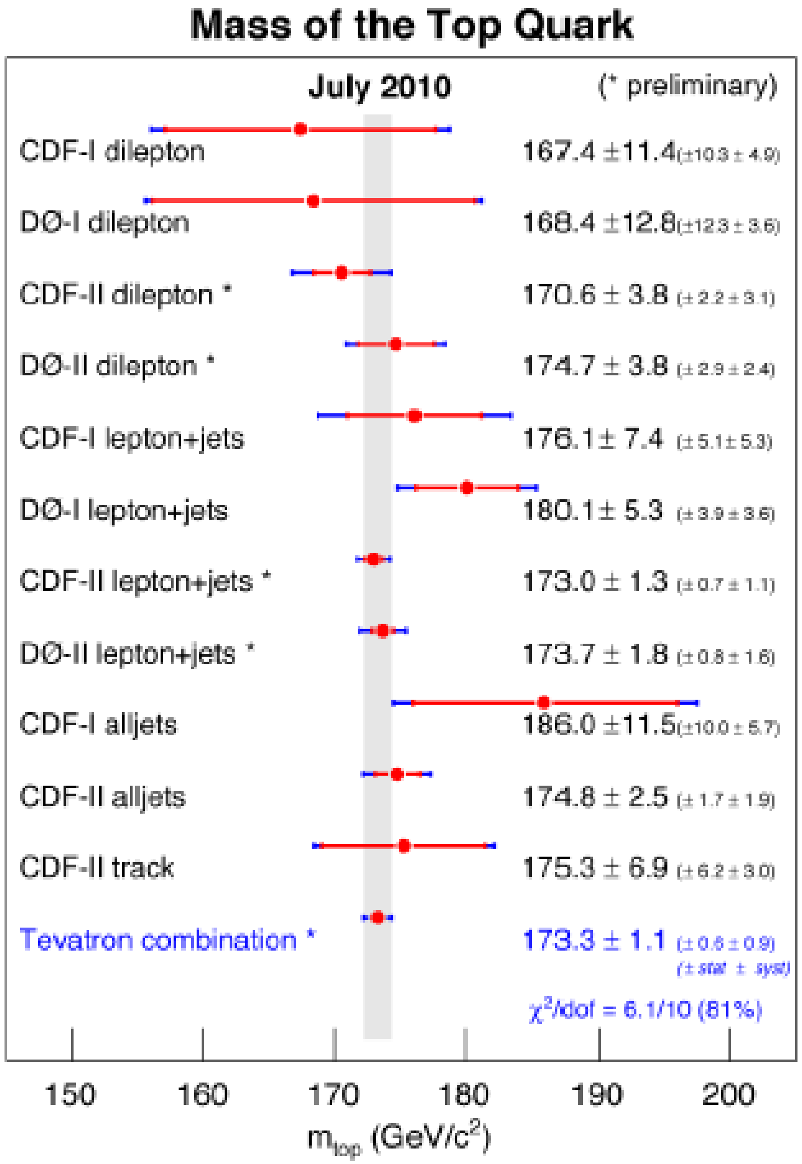


JES translates Jet into parton energy

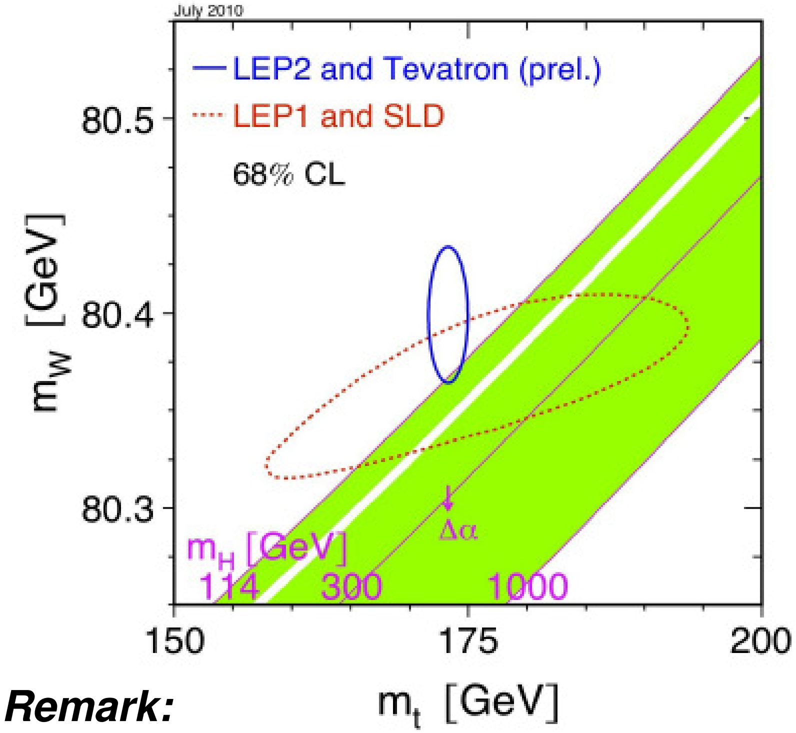
m_{top} = 173.0 ± 0.7 (stat) ± 0.6 (JES) ± 0.9 (syst) GeV
= 173.0 ± 1.2 GeV

±0.7%

Top Mass: Tevatron Combination, July 2010



$m_{top} = 173.3 \pm 1.1$ GeV **±0.6%**



Remark:

m_{top}=(173.3 ± 1.1) GeV (0.6%)

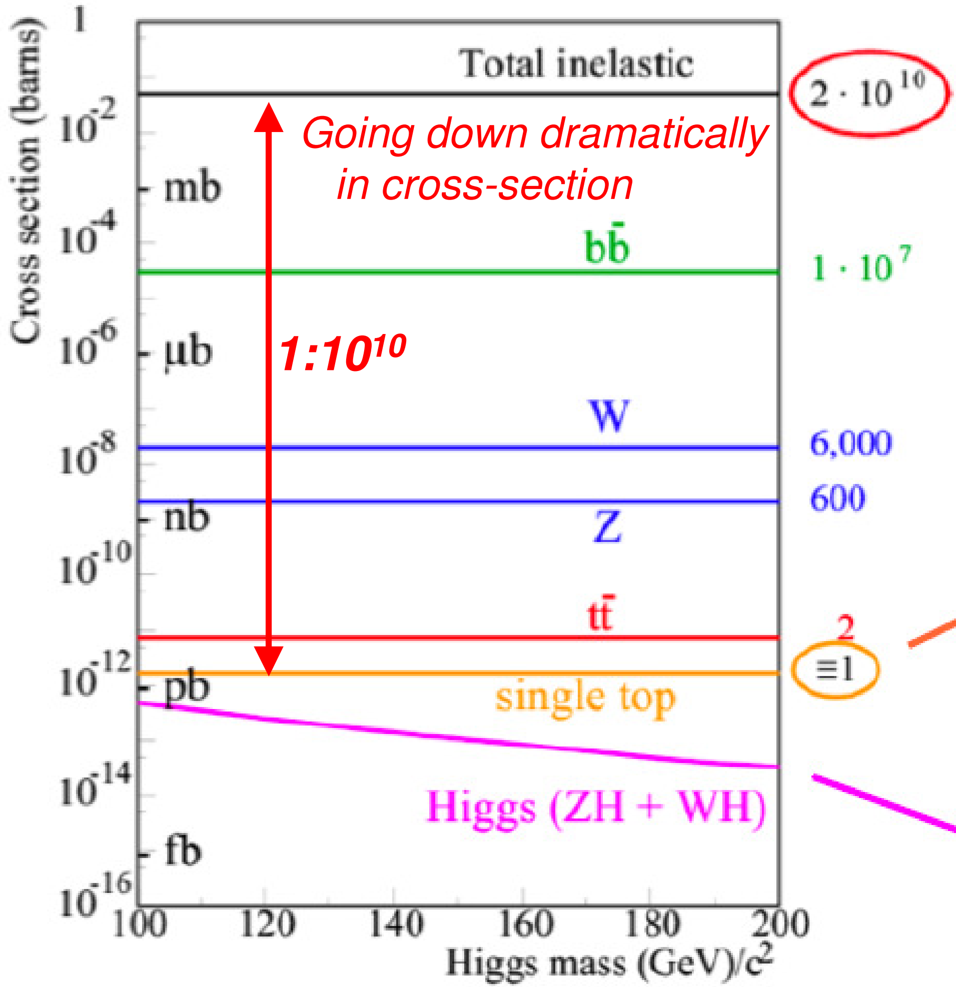
m_W=(80.399±0.023) GeV (0.028%)

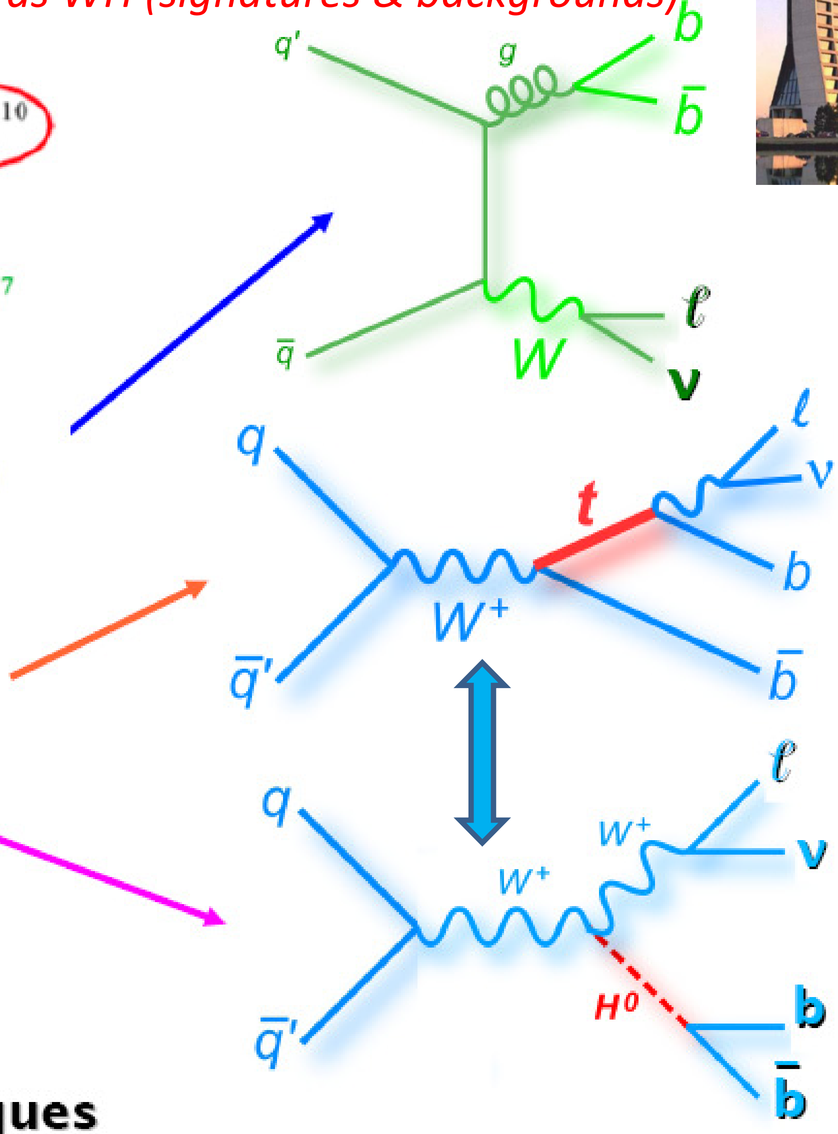
$\Delta m_W \sim 0.006 \times \delta m_{top} \sim 7$ MeV

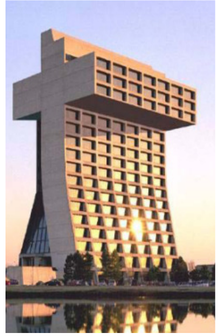
for equal weights in Higgs limits

Single top: after 15 years of search...

Experimentally very challenging and same as WH (signatures & backgrounds)







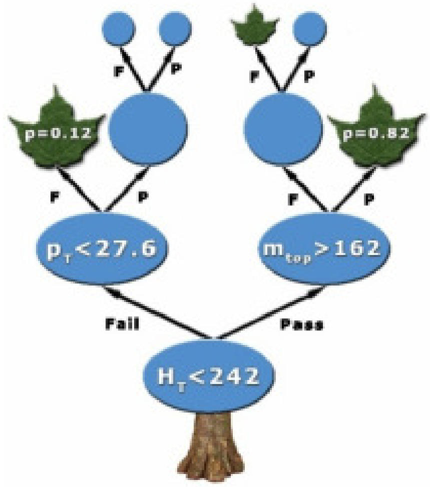
⇒ **multivariate analysis techniques**

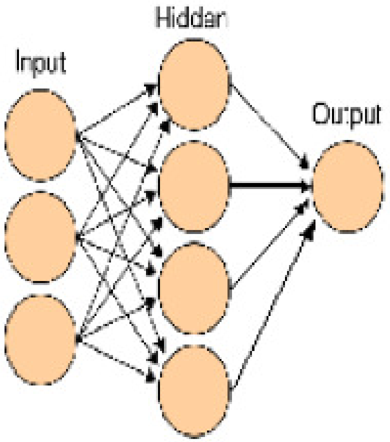
Multivariate Analyses: BDT & BNN

Use common Object and Event Kinematics, Angular Correlations, Jet Reconstruction and Top Quark Reconstruction variables

Boosted Decision Trees (BDT)

- Recover events that fail criteria in cut-based analysis
- Boosting averages the results over many trees, improving the performance
- Uses highest ranked common 64 variables



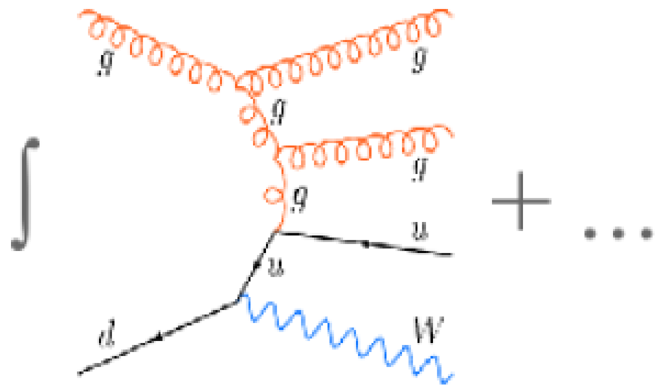


Bayesian Neural Network (BNN)

- NN train on signal and background, producing one output discriminant
- Bayesian NN average over many networks, improving the performance
- Uses highest ranked 18-28 variables in each channel

Multivariate analysis: Matrix Element (ME)

- Use the 4-vectors of all reconstructed leptons and jets
- Use Feynman diagrams to compute an event probability density for signal and background hypotheses

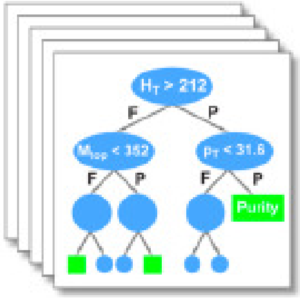


- Uses events with 2 and 3 jets only
- ME for signal (tb & tqb) and background
- Split the sample in high and low H_T (W+jets and top quark pair dominated regions) improves the performance

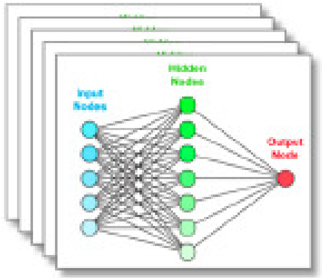
Without forgetting maximum Likelihood.....

⇒Training for Higgs searches; most of the developed tools were then applied to the search for Higgs(ses): see later

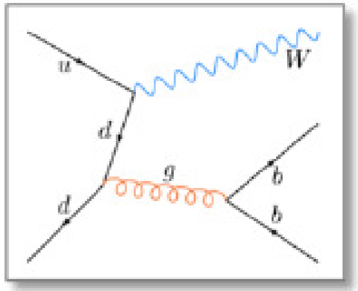
Boosted Decision Trees



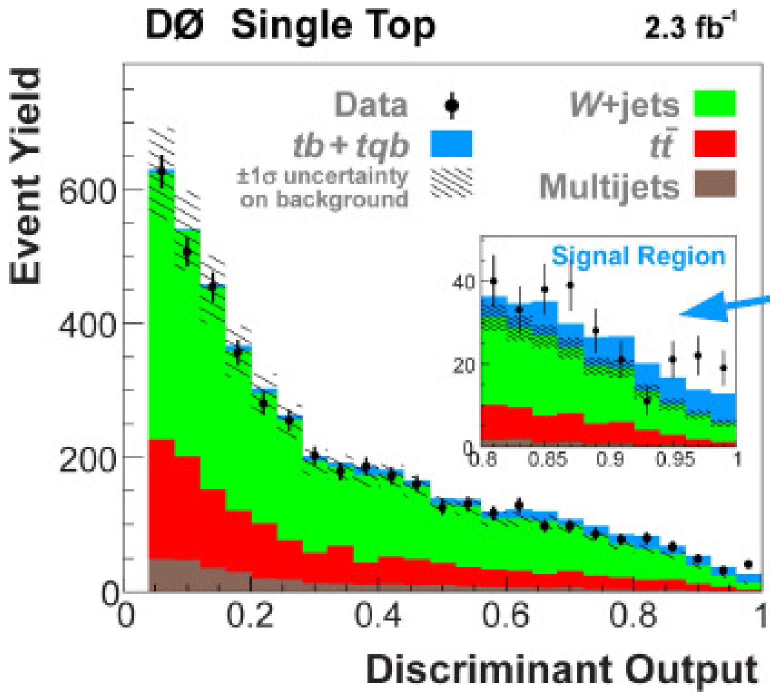
Boosted Neural Networks



Matrix Elements

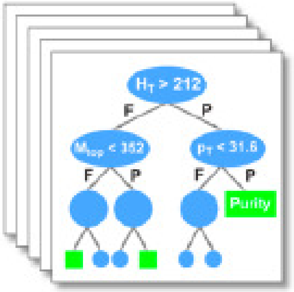


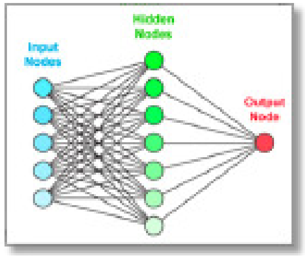
combine up to 12 different analysis channels:

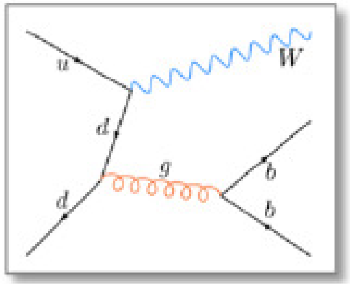


single top

Boosted Decision Trees | **Neural Networks** | **Matrix Elements** | **Likelihood**







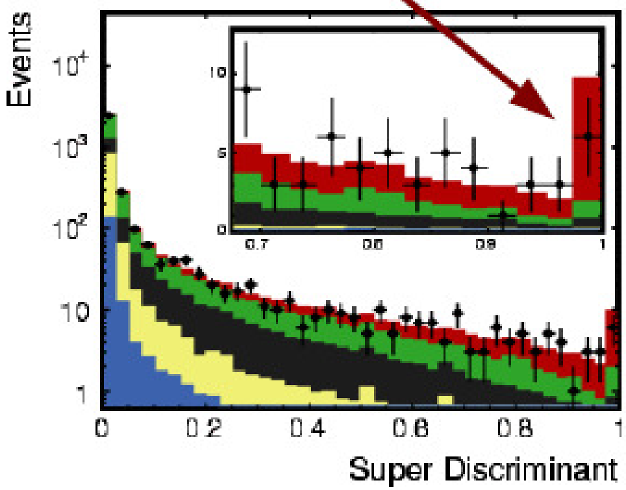
$$p_{ik} = \frac{f_{ij_ik}}{\sum_{m=1}^{5} f_{ij_im}},$$

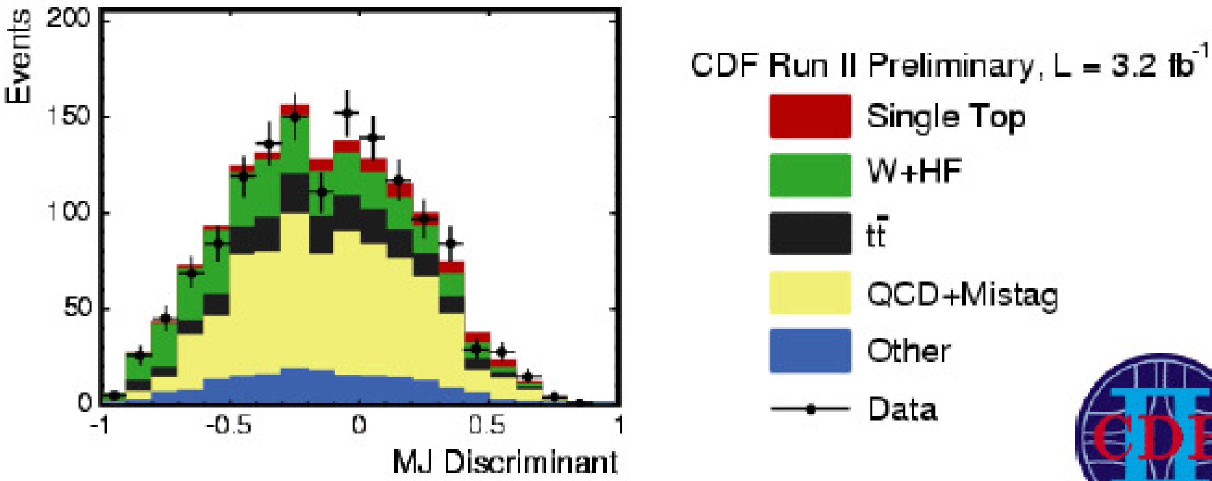
$$\mathcal{L}_k(\{x_i\}) = \frac{\prod_{i=1}^{n_{var}} p_{ik}}{\sum_{m=1}^{5} \prod_{i=1}^{n_{var}} p_{ik}}.$$

combine up to 8 different analysis channels:

single top

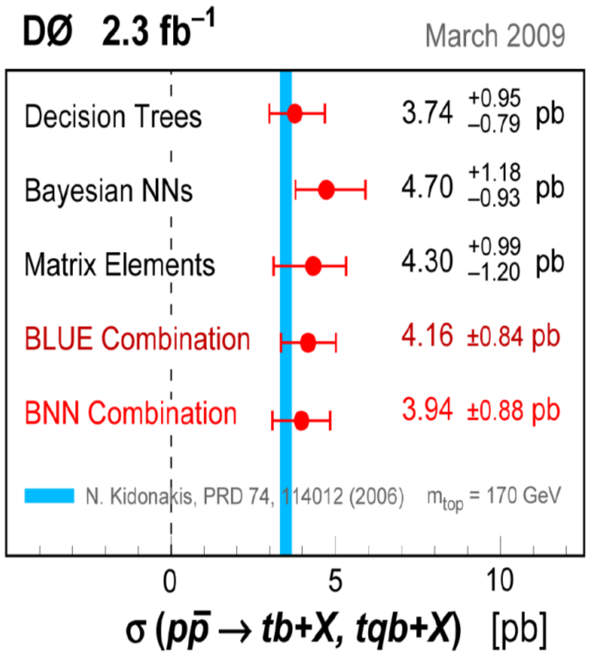
- $\not{E}_T$+jets selection :
  recover badly reconstructed e, μ; include τ



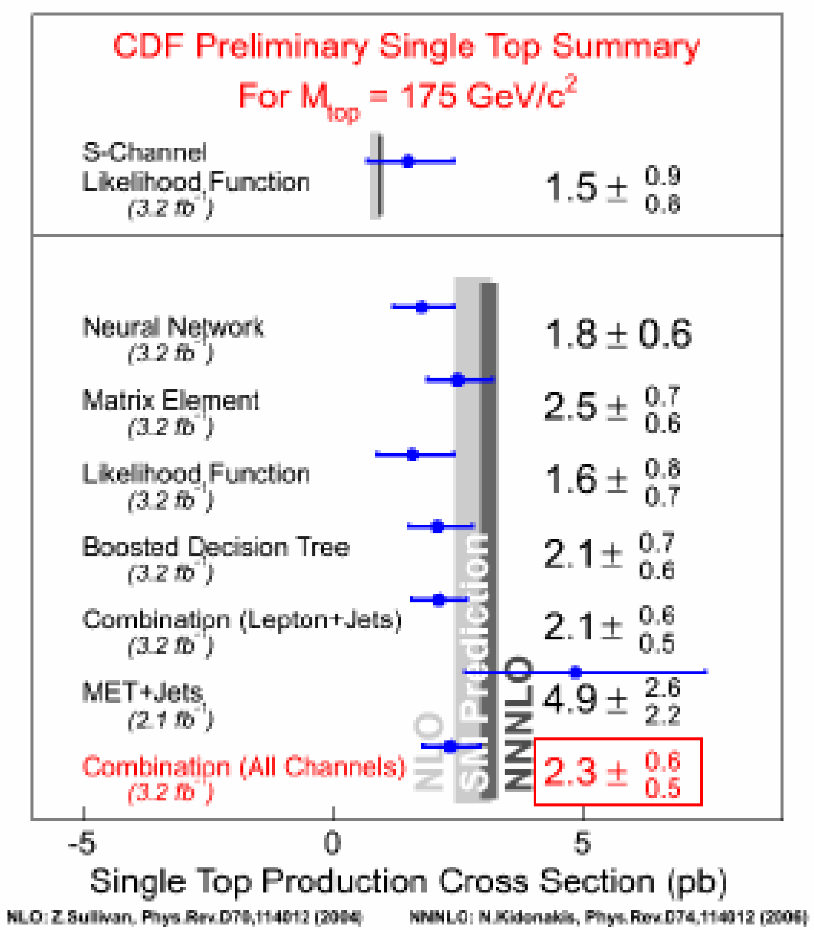


Single top results

Significance	CDF (3.2 fb^{-1})		DØ (2.3 fb^{-1})	
	Exp.	Obs.	Exp.	Obs.
ME	4.9	4.3	4.1	4.9
BDT	5.2	3.5	4.3	4.6
NN	5.2	3.5	4.1	5.2
LF	4.0	2.4	—	—
LF s-chan	2.0	1.1	—	—
$\not\!\!E_T$+jets	1.4	2.1	—	—
Comb.	5.9	**5.0**	4.5	**5.0**



THE result of the year 2009



$|V_{tb}|$ = 0.91±0.11 (exp)±0.07(theory) (CDF)

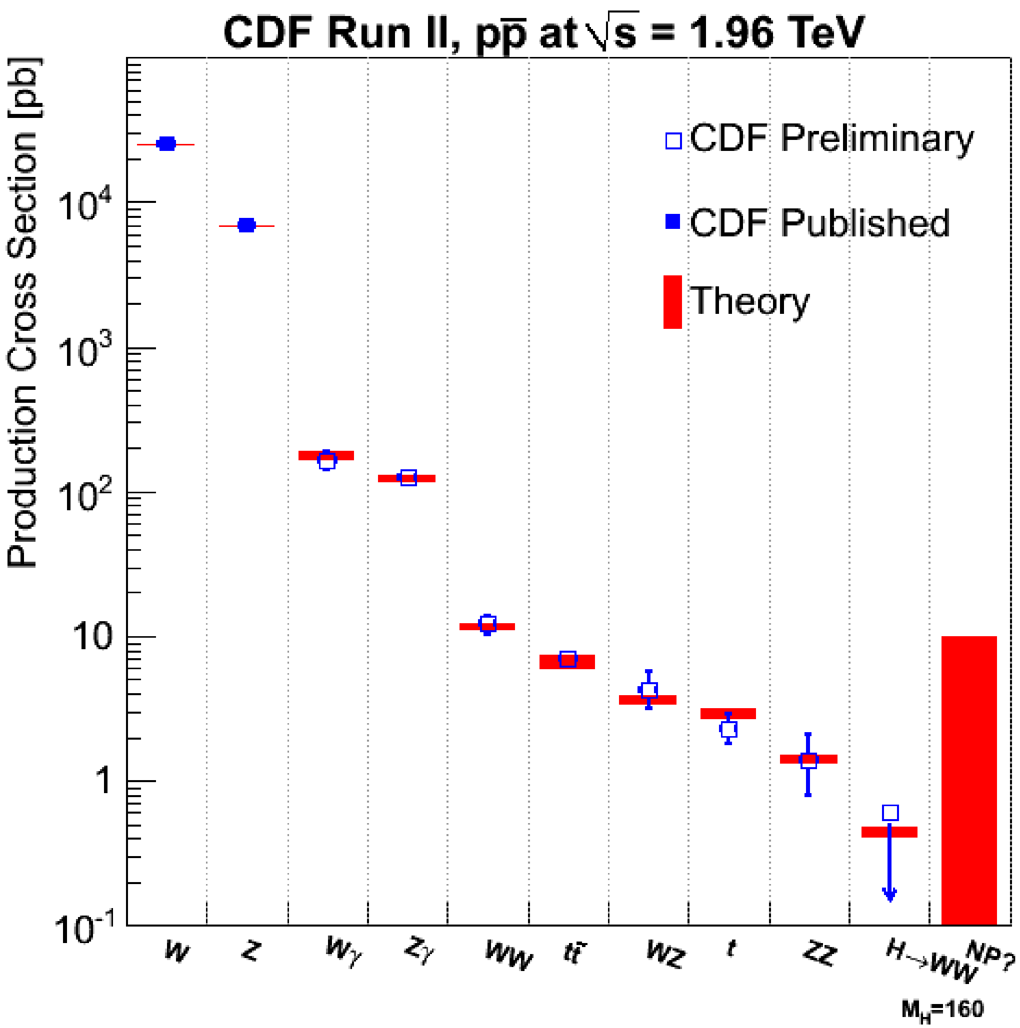
$|V_{tb}|$=1.07±0.12 (D0)

Going down to smaller cross section processes (cont'd)

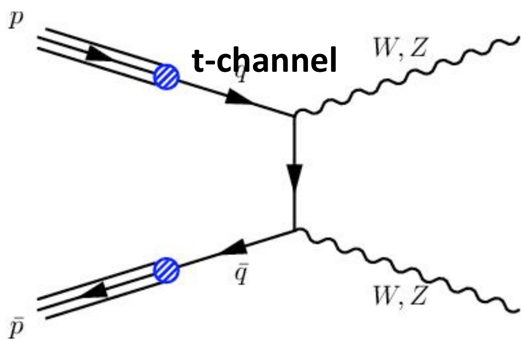
- High luminosity samples allow for measurements of low cross section processes
- provided also sophisticated triggers & analyses.

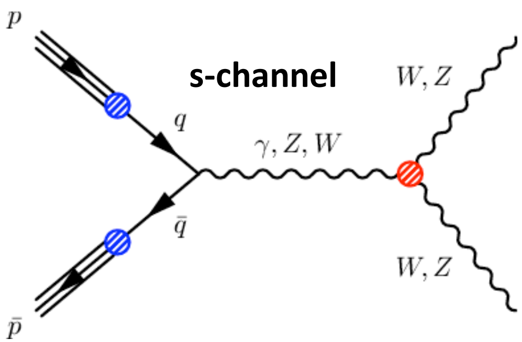
DIBOSON PRODUCTION:

- CDF & D0 have observed WW,WZ, and ZZ production via leptonic decay channels
- First observations of WW/WZ production in the semi-leptonic decay channel
- These measurements are critical for validating our Higgs search techniques



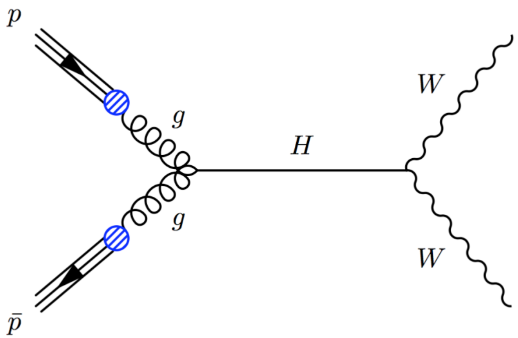
Triple Gauge Coupling (TGC) interest per se and as background for Higgs searches



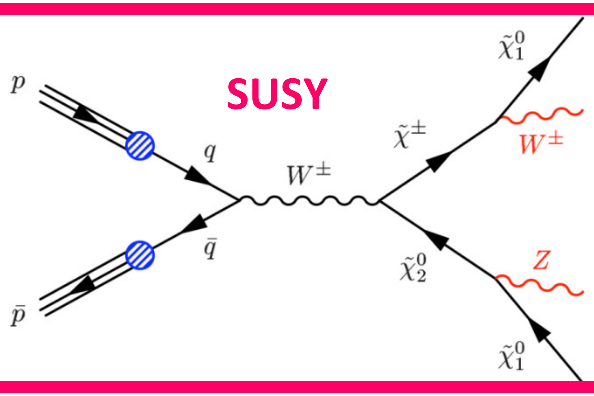


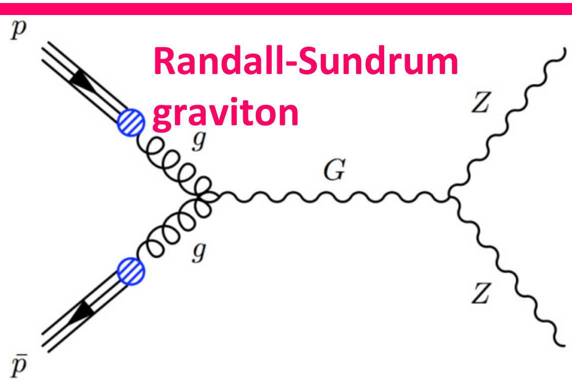
$$
\begin{array}{lll}
q\bar{q}\,' \to W^{(*)} & \to W\gamma : & WW\gamma \\
q\bar{q}\,' \to W^{(*)} & \to WZ : & WWZ \\
q\bar{q} \to Z/\gamma^{(*)} & \to WW : & WW\gamma, WWZ \\
q\bar{q} \to Z/\gamma^{(*)} & \to Z\gamma : & \boxed{ZZ\gamma, Z\gamma\gamma} \\
q\bar{q} \to Z/\gamma^{(*)} & \to ZZ : & \boxed{ZZ\gamma, ZZZ}
\end{array}
$$

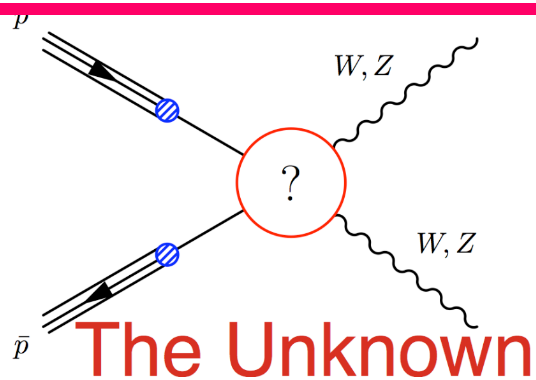
SM



- s-ch. prod. probes non-Abelian structure of SU(2)L⊗U(1)Y
- Tevatron sensitive to different TGCs than LEP higher s
- Important background for Higgs Searches!
- New physics => enhanced rate of diboson production!








g g s
hunting....

Constraints on the SM Higgs Boson

What we know from:

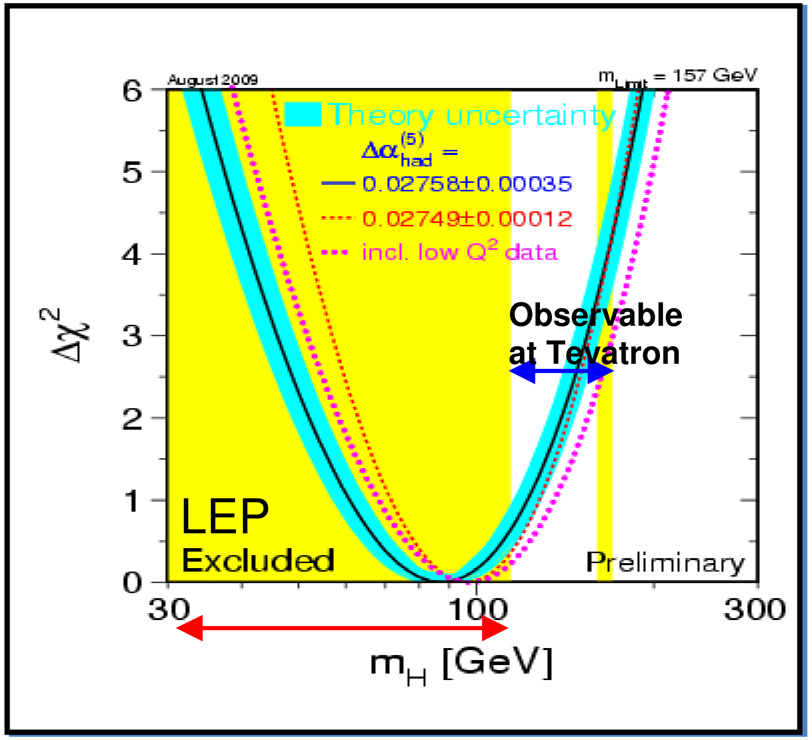
•Direct search at LEPII:

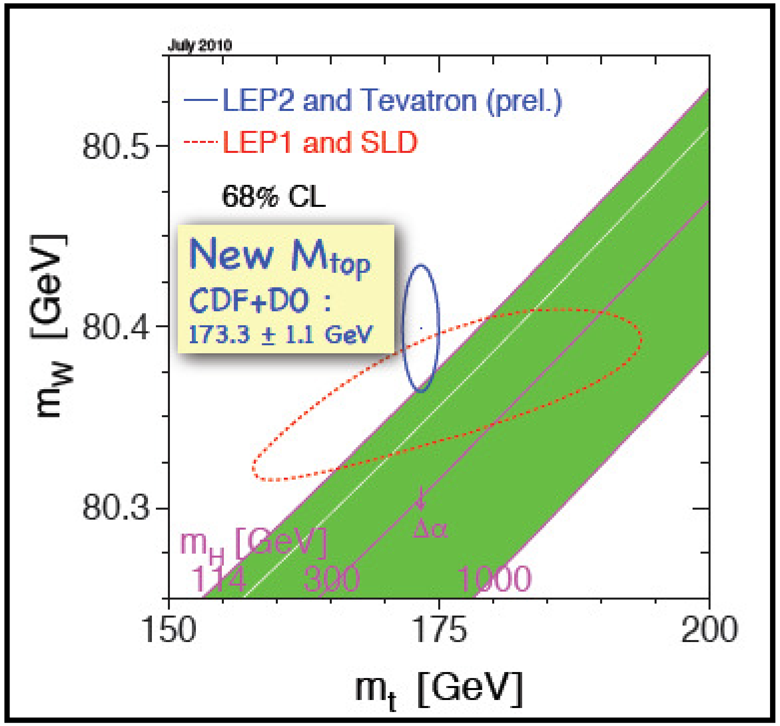
Mh > 114 GeV/c2 @95% CL

•Precision EWK meaurements (top mass, W mass, etc):

$M_h = 89.0^{+35}_{-26}$ GeV/c^2

$M_h < 158$ GeV/c^2 @95% CL

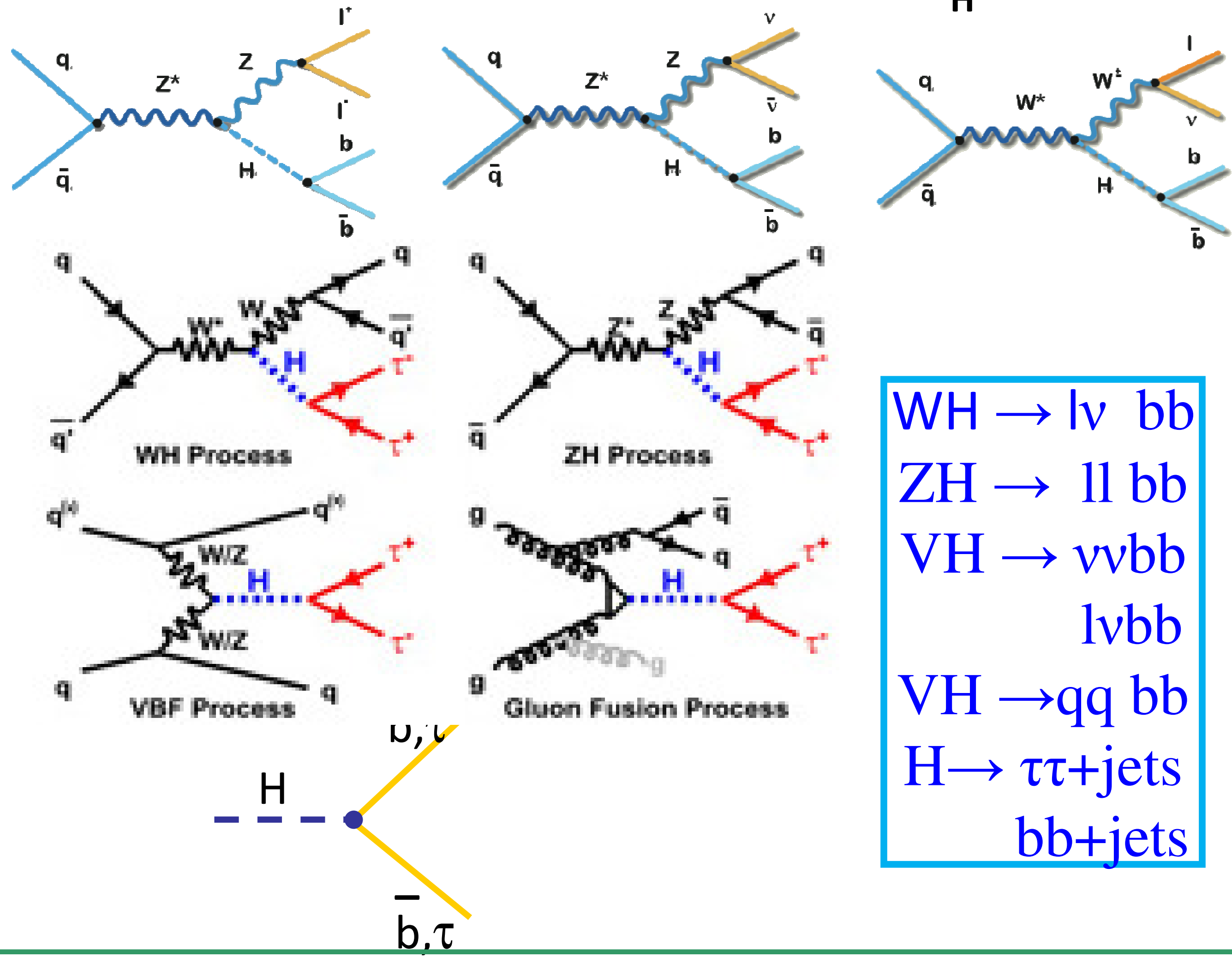




The many ways to produce a light Higgs at the Tevatron

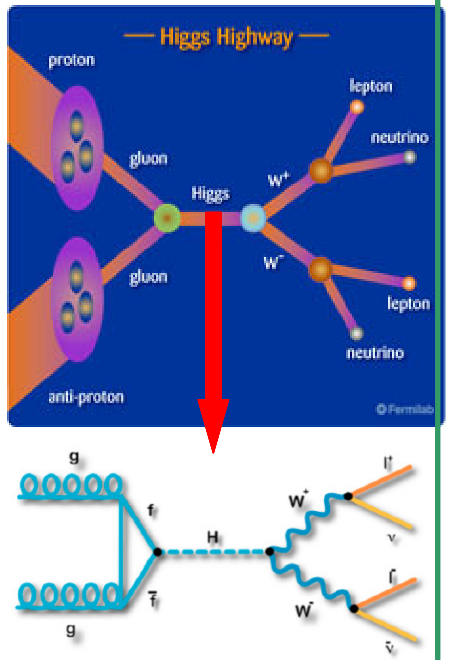
gg→H→bb => close to IMPOSSIBLE

m_H<135GeV

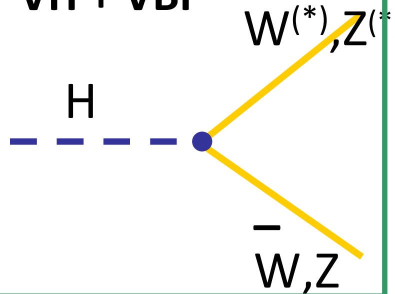


WH → lν bb
ZH → ll bb
VH → ννbb
lνbb
VH →qq bb
H→ ττ+jets
bb+jets

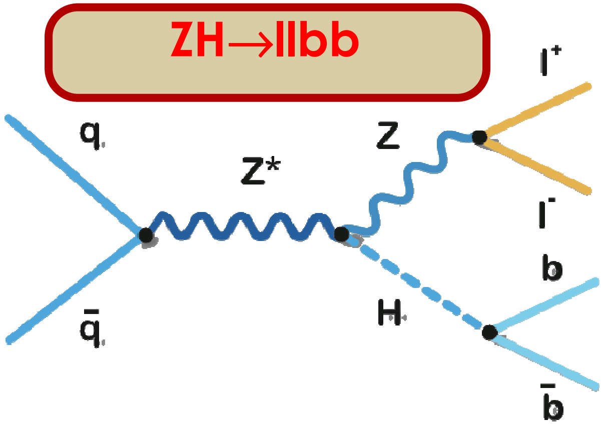
m_H>135GeV

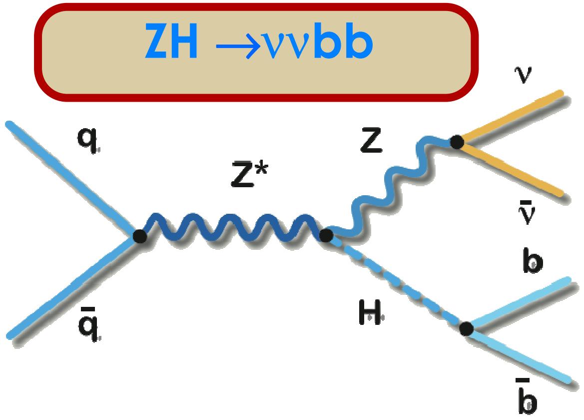


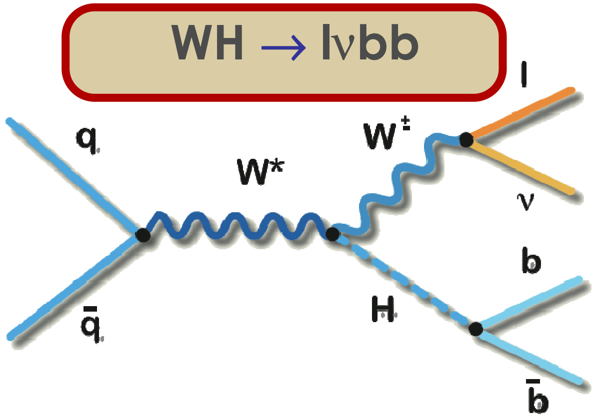
+ VH + VBF



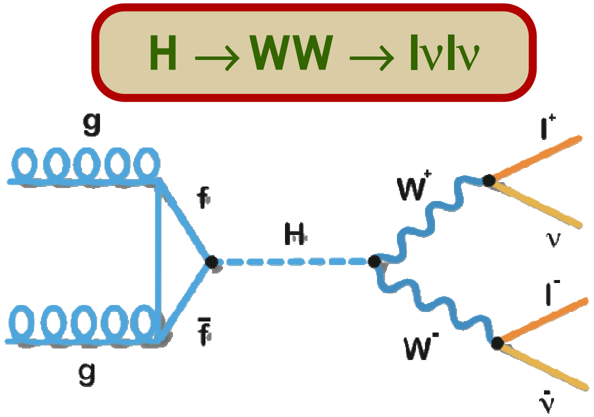
Higgs Production at the Tevatron: *the main channels*



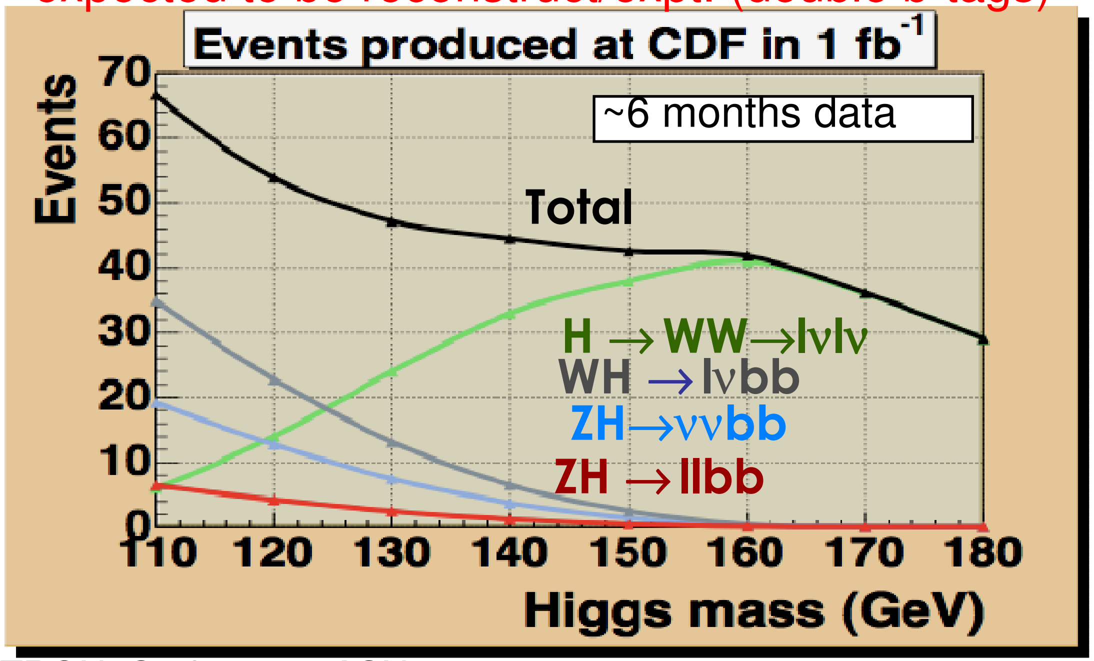




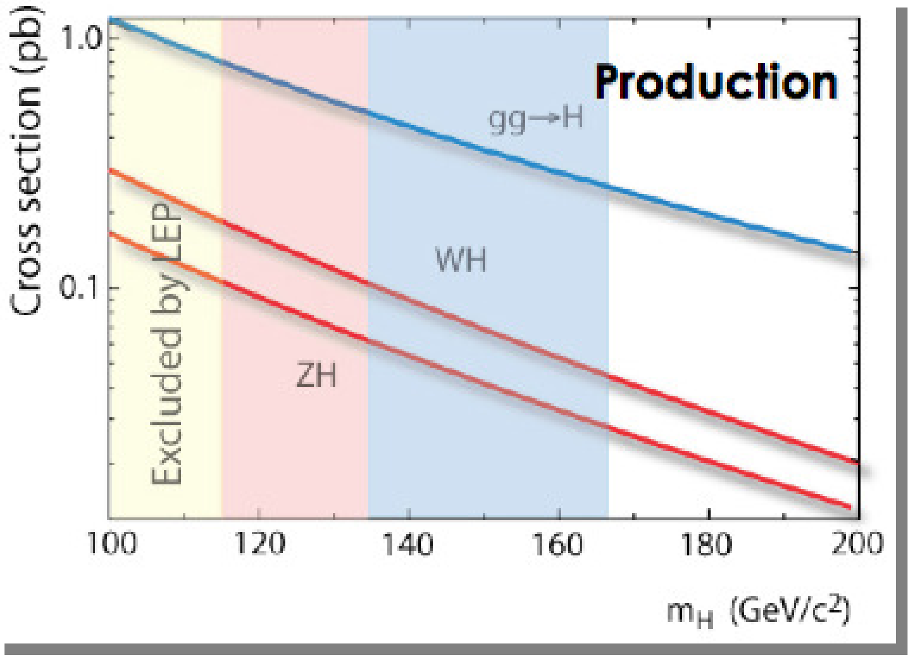
For m_H = 115 GeV/c², ~3.5 events/fb⁻¹ expected to be reconstruct/expt. (double b-tags)

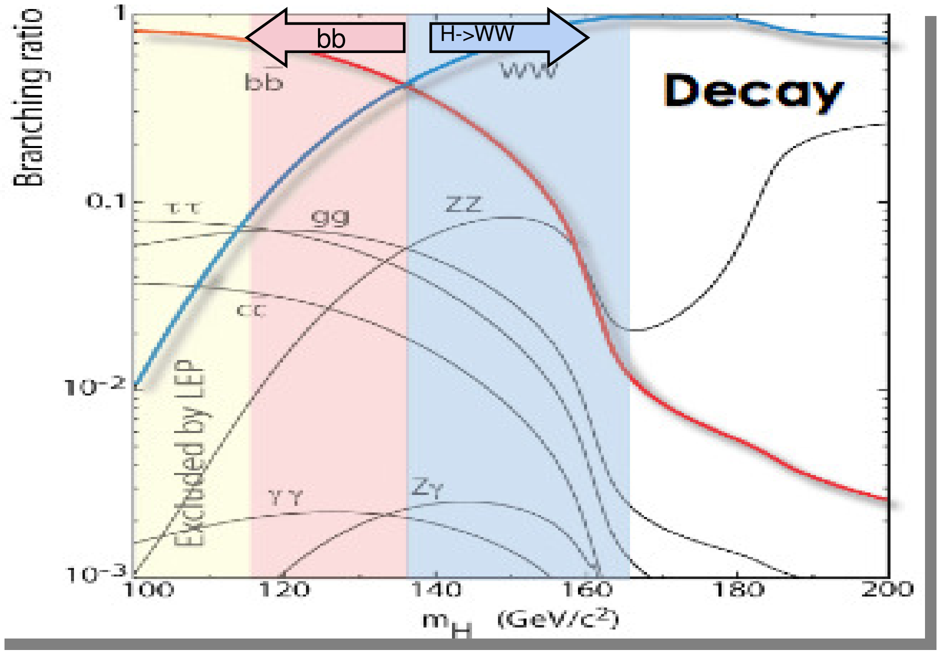


For m_H = 165 GeV/c², ≥7 events/fb⁻¹ expected to be reconstruct/expt.



LOW MASS HIGGS: Production and Decay





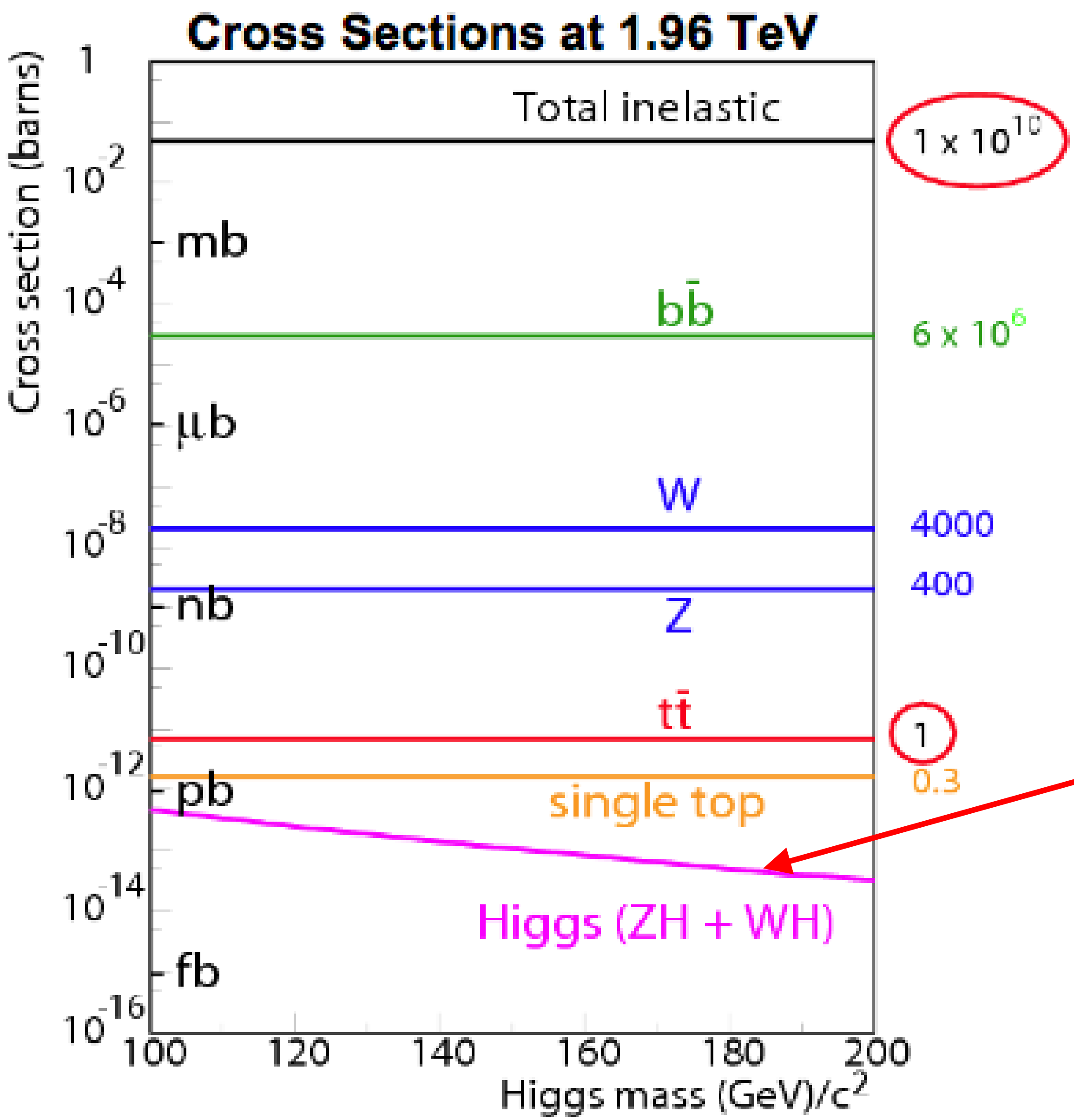
Low Mass Final States

$WH \to \ell\nu b\bar{b}$ → 1 High P_T Lepton + $\not{E}_T$ + b jets

$ZH \to \ell\ell b\bar{b}$ → 2 High P_T Leptons + b jets

$ZH \to \nu\nu b\bar{b}$
$WH \to (\ell)\nu b\bar{b}$ → 0 High P_T Leptons + $\not{E}_T$ + b jets

Efficiency for tagging b-quark jets is critical as well as rate for mis-tagging light quark jets



CHALLENGE:
Separate Signal
from Background

S/B: $1/10^{11}$

The Strategy

Attack at every opportunity! And use all means!

1) *Maximize acceptance*

"Tight"cuts on final state objects (leptons,jets, etc.) are too costly Valuable signal efficiency is available at the cost of additional hard work! Includes triggers as well.

2) Minimize backgrounds

- **Often a good model of the backgrounds are needed to do this - some may come from the data itself**

3) Maximize measurement resolution

- **Improvements in jet energy resolution directly impact acceptance, backgrounds, and many other aspects of the analyses**

4) Extract the most from the resulting events

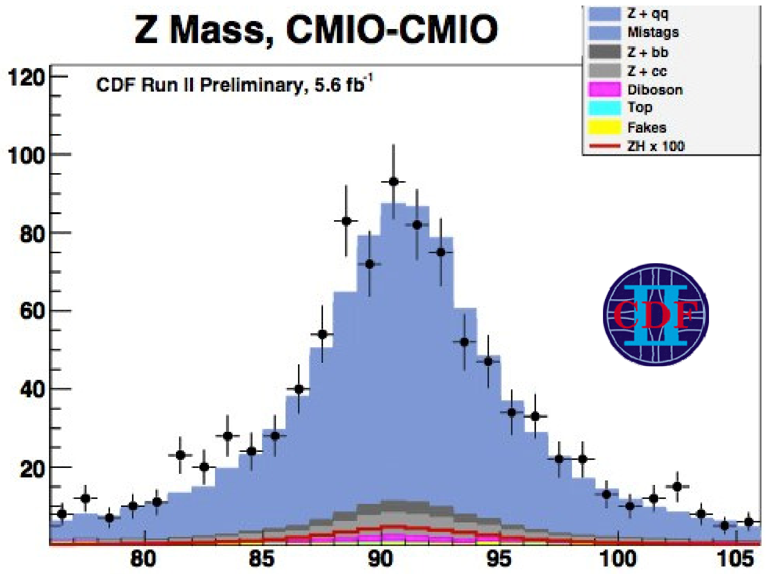
- **Use advanced algorithms like decision tree, neural networks, matrix elements, etc**

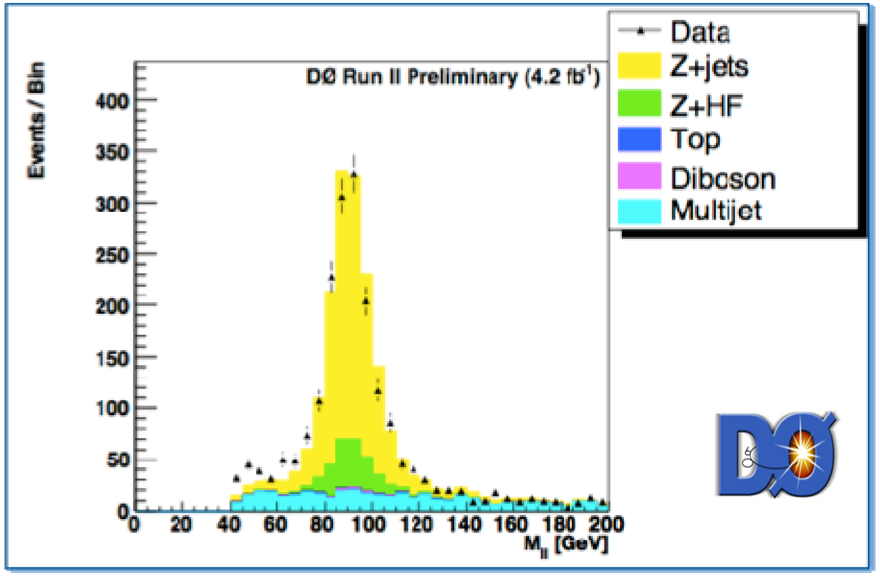
Maximizing Acceptance

Example: $ZH \rightarrow \ell\ell b\bar{b}$

Reconstruct Z candidate using two loose muons AND non-muon trigger!

Reconstruct Z candidate using a μ and an isolated track

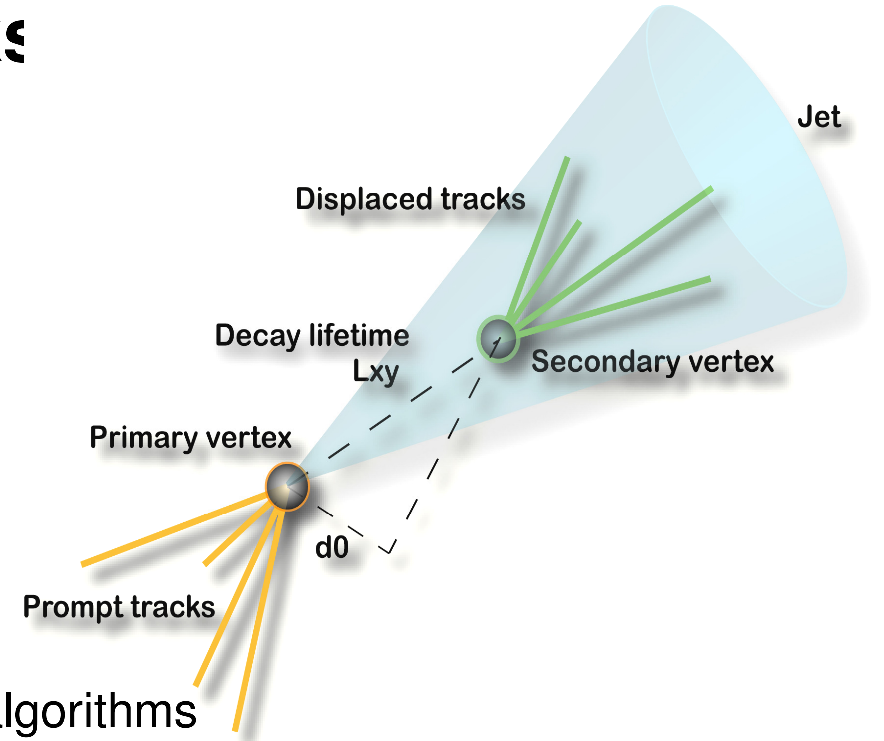




Typical gain from increased lepton ID ~15%

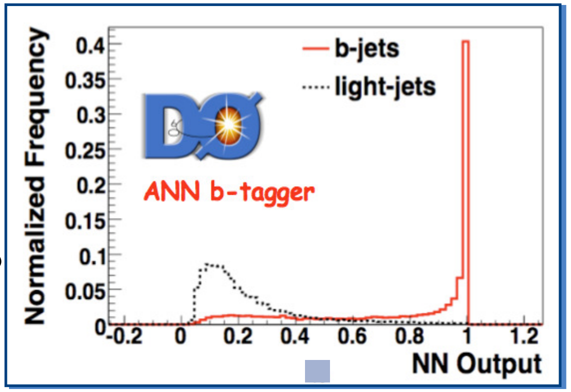
Tagging Jets from b-quarks

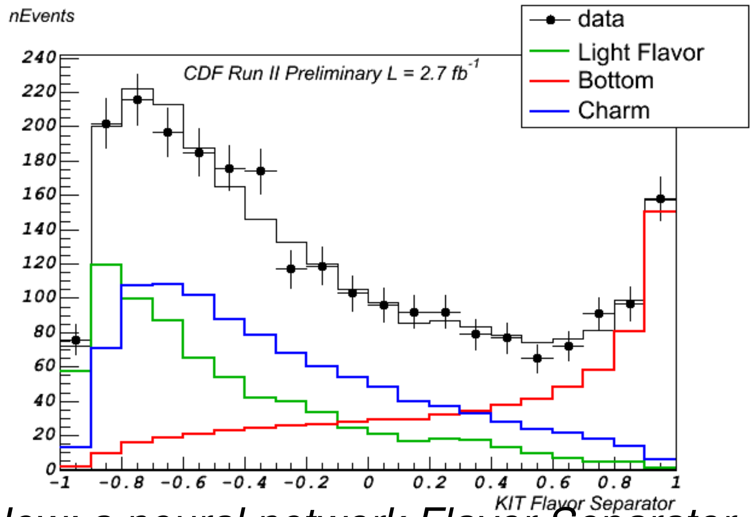
- Idea is to pick out jets consistent with having originated from long-lived b-quark (typically involves reconstruction of secondary track vertex within jet)
- More sophisticated tools incorporating both jet shape and track variables are used to obtain additional discrimination between different flavor quark jets



- CDF uses a variety of secondary vertexing algorithms
- D0 uses NN tagger based on 7 discriminating B-lifetime variables

- Btagging eff: ~ 50-70%
- Depends on Jet(ET& η)
- Mistag rates ~0.3 - 6.0%
- Loose tagging if double tag

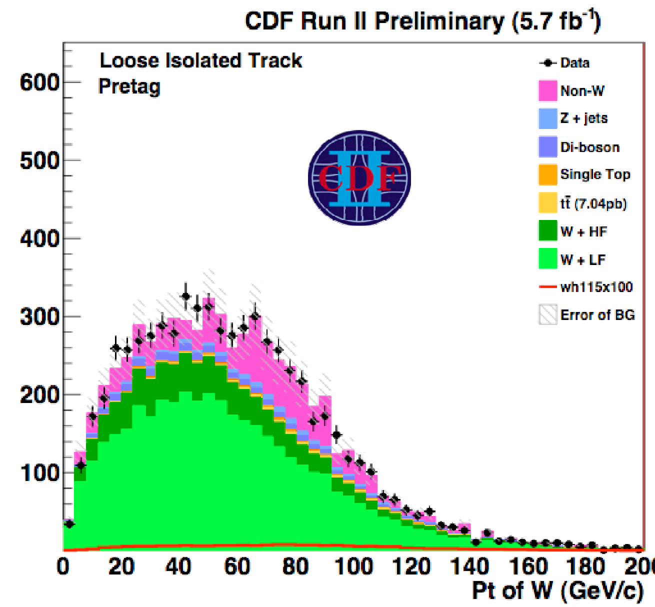


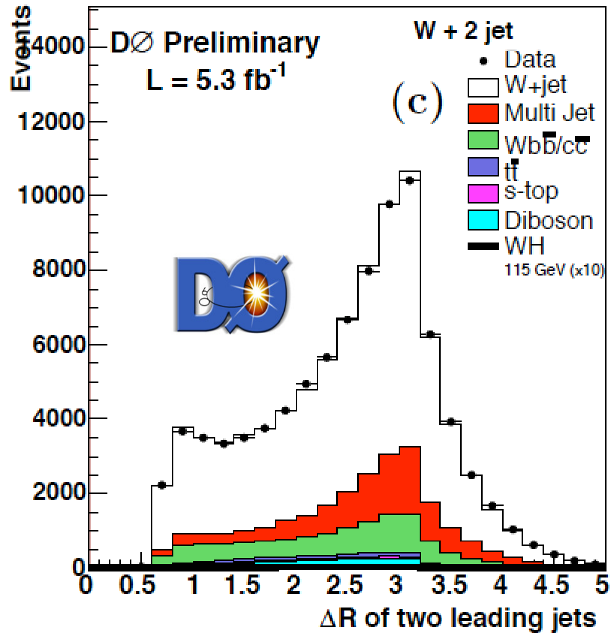


New: a neural network Flavor Separator

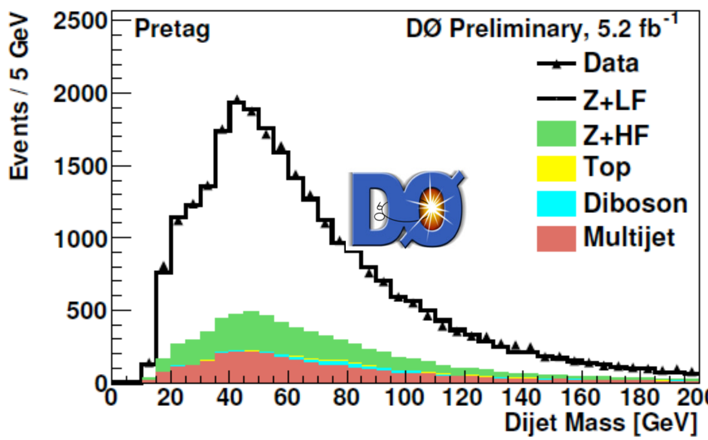
Modeling of Backgrounds

- ❖ Pre-tag W+jets loose isolated tracks (mostly electrons)





- ❖ Pre-tag W+jets

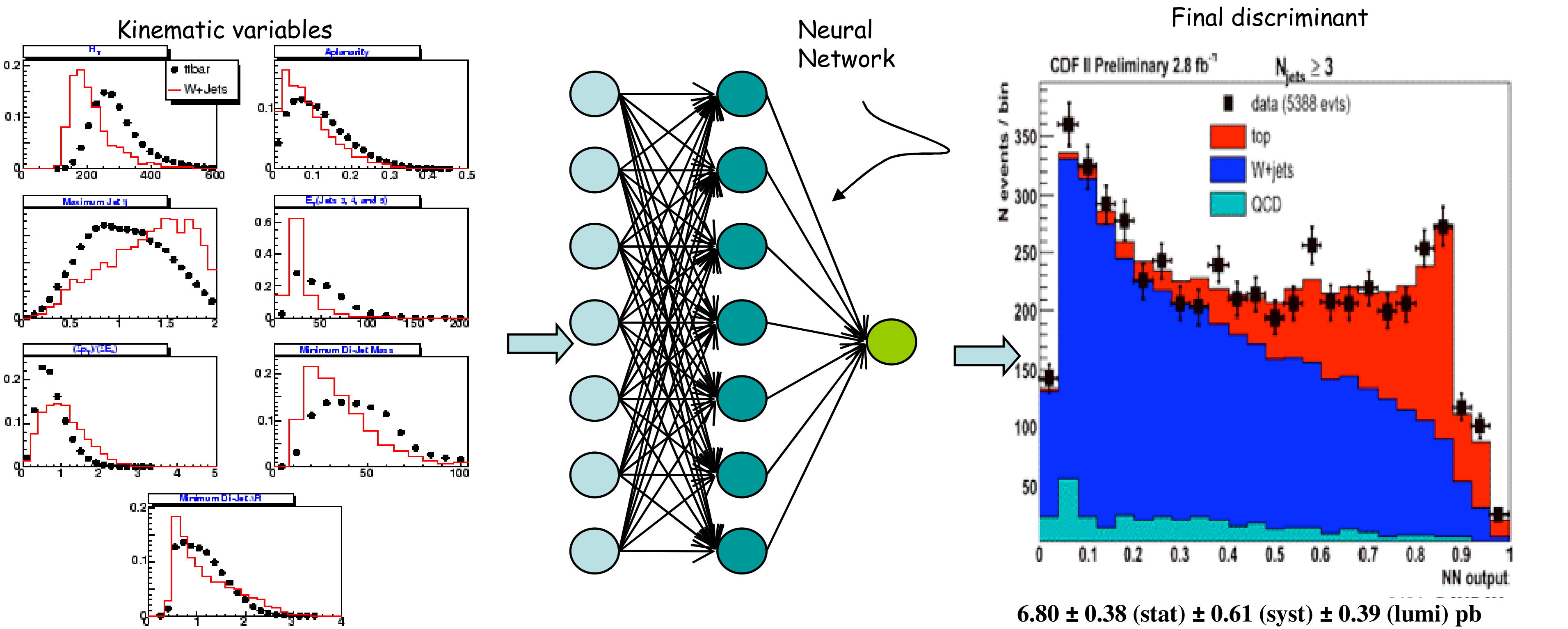


- ❖ Pre-tag Z+jets

Using Advanced Algorithms

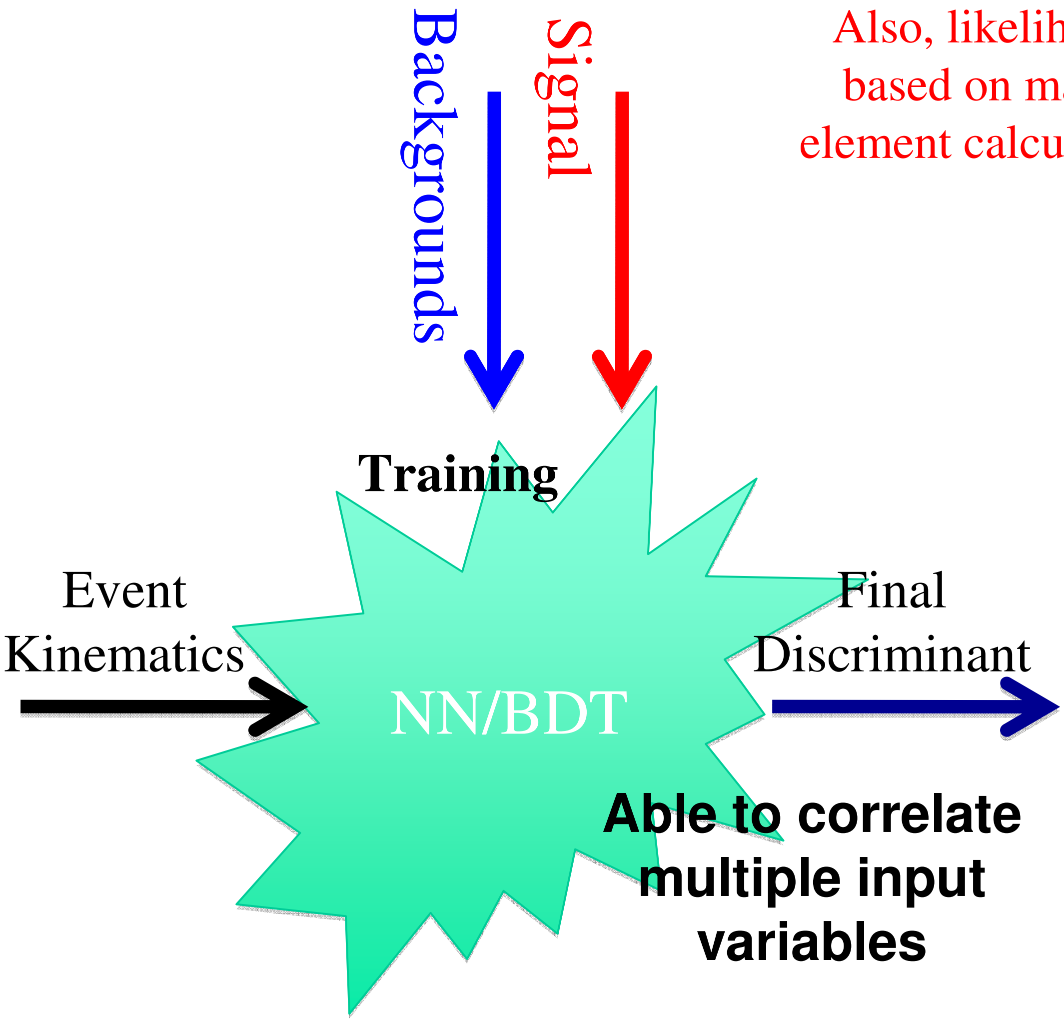
Artificial Neural Networks (ANN), Boosted Decision Trees (BDT), Matrix Element:ME

- Ex: ANN used to combine information from different kinematic variables both Energy-based and Shape-based
- Improved discrimination and less sensitive to systematic effects
- Tested using already observed physics processes: identification of top in Lepton+ jets



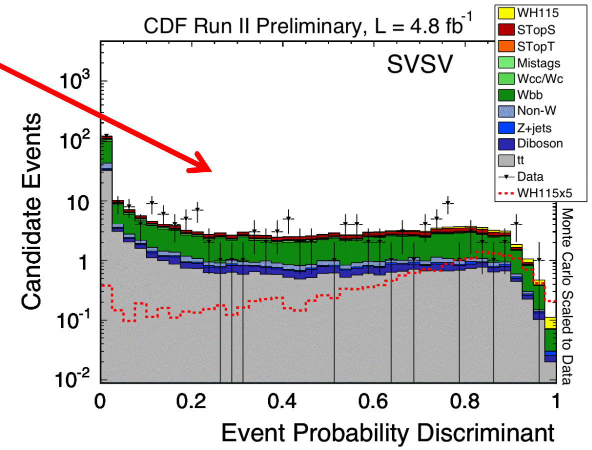
6.80 ± 0.38 (stat) ± 0.61 (syst) ± 0.39 (lumi) pb

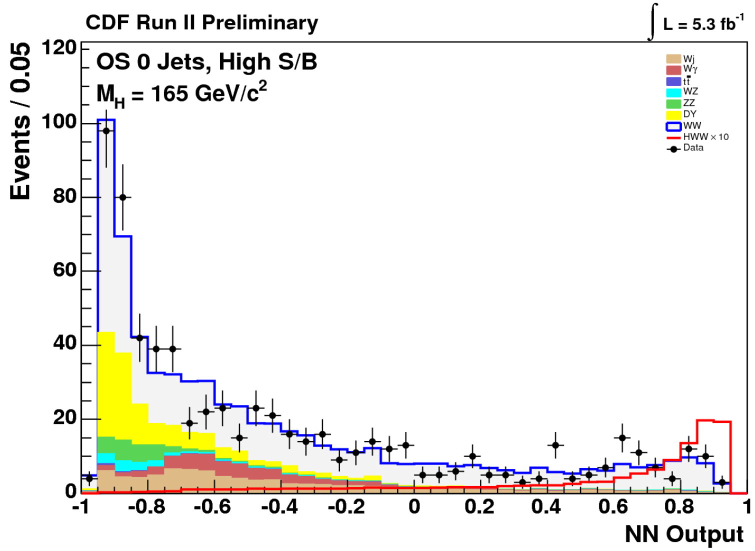
Final Discriminants



Able to correlate multiple input variables

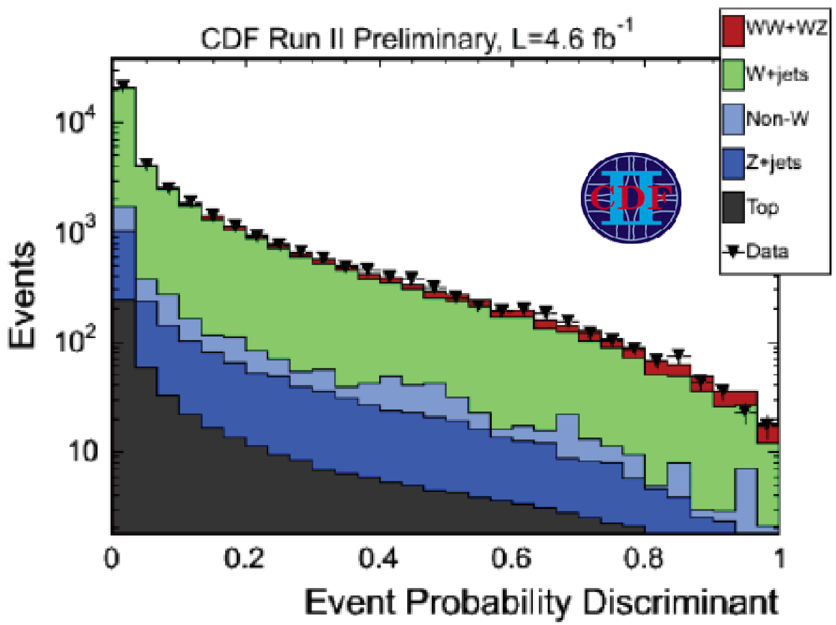
Also, likelihoods based on matrix element calculations



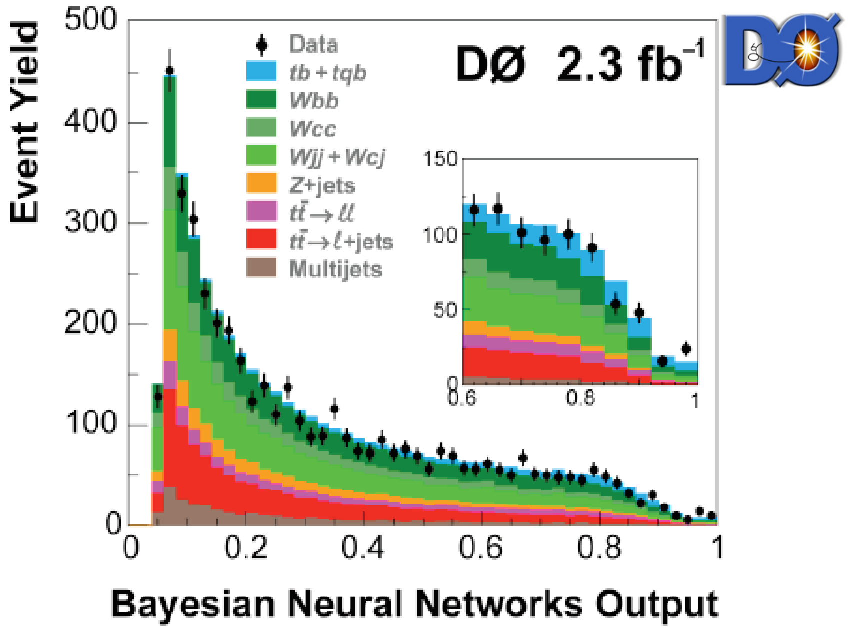


Applications of Advanced Algorithms

Diboson observation :
WW + WZ ➞ lvjj
Similar to WH → lvbb
Matrix Element :
Us: σ(WW+WZ) = 16.6+3.5-3.0 pb
SM : σ = 15.1 ± 0.8 pb

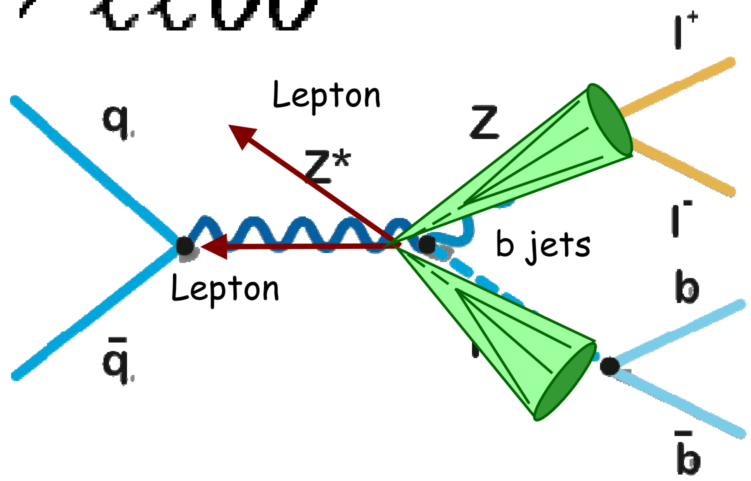


Single top observation
t+q ➞ lvb+j (with b-tag)
Similar to WH → lvbb
Neural Network :
Us : σ(t) = 4.70 +1.18 -0.93 pb
SM : σ = 3.46 ± 1.8 pb



$ZH \rightarrow \ell\ell b\bar{b}$

- Two High P_T Leptons
- No (direct) Missing E_T
  - >=2 jets
  - Split up 1 and 2 b-tags



Features:

1. Small σ◊BR
2. Several tight constraints

i. $M_{ll} \cong M_Z$

ii. "$\cancel{E_T}$" $\rightarrow$ improve jet resol.

1. ~1 evt/6 fb^{-1} (dbl tags)

Primary Backgrounds

$Zbb,\ Zc\bar{c},\ Zqq'$

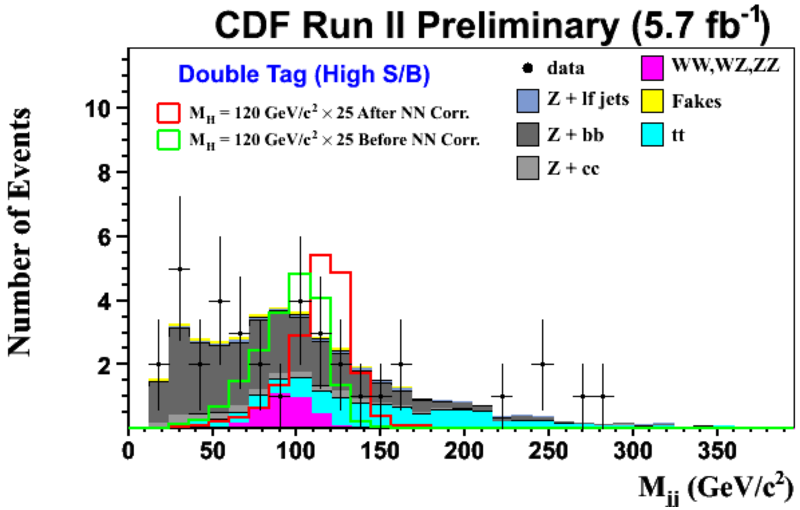
$t\bar{t}$

$WW + jj,\ WZ,\ ZZ$

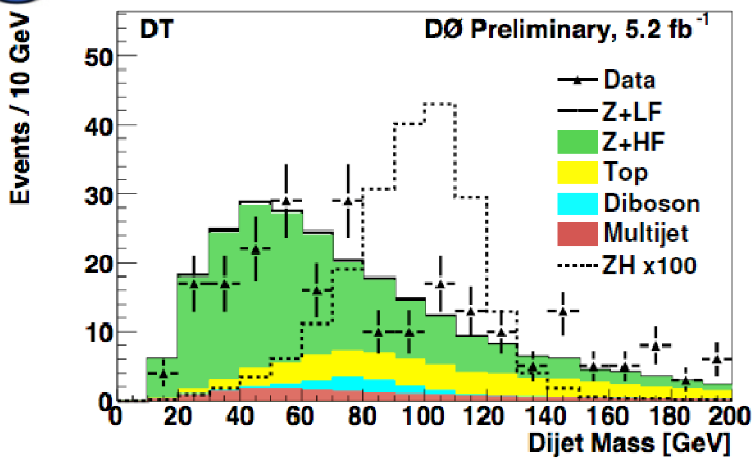
$Z \rightarrow \tau\tau$

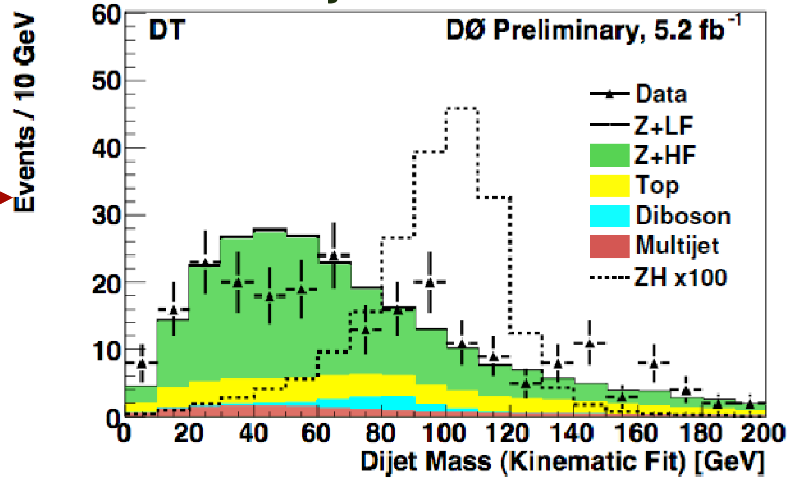
$ZH \to \ell\ell b\bar{b}$ Dijet Mass Improvements

Use of a NN, with inputs of observed jet energies and directions, MET magnitude and direction, to correct the two highest Et jets



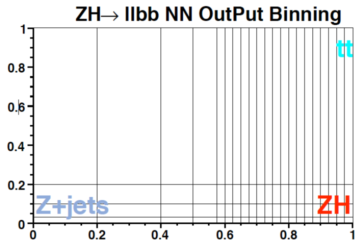
Use of a kinematic fit, adjusting lepton and jet energies to obtain the correct M_Z and P_t of the llbb system



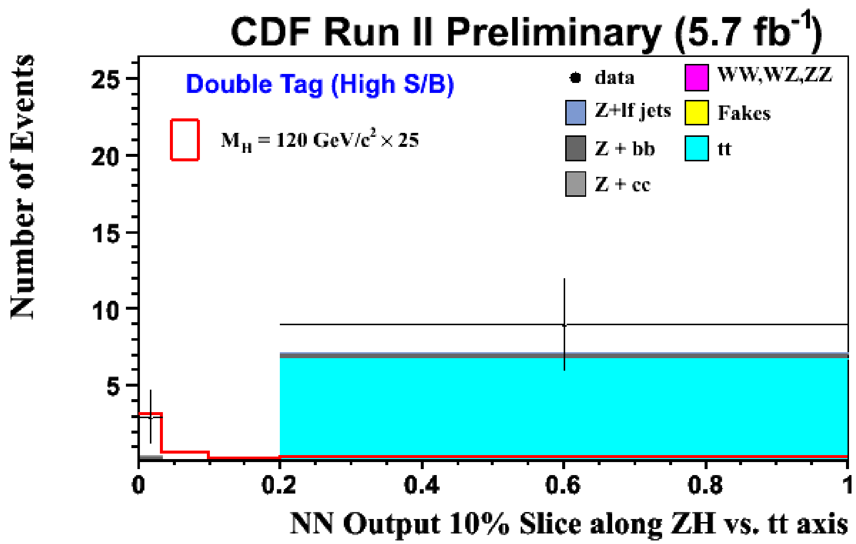


$ZH \rightarrow \ell\ell b\bar{b}$ Event Discriminants

uses a 2D NN:

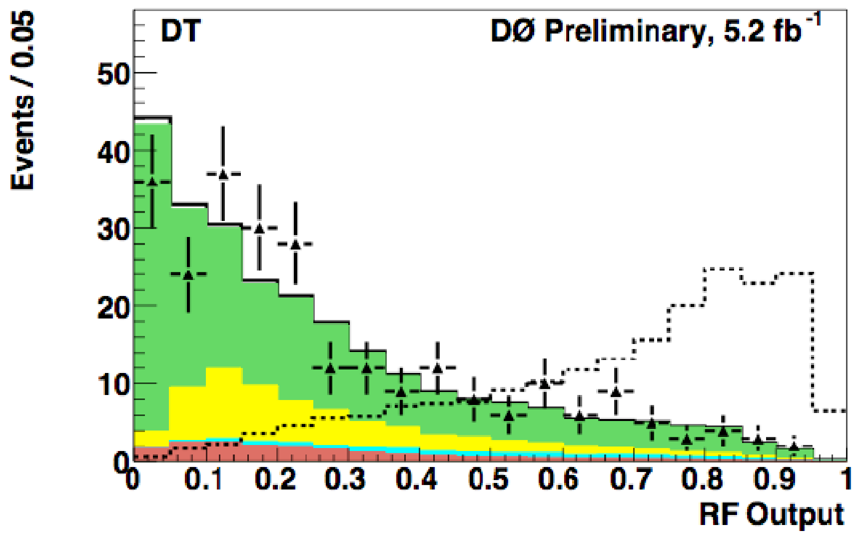


- one axis is ZH vs Z+jets
- one axis is ZH vs ttbar
- A 10% slice along the ZH vs ttbar is for display (full 2D is used in limit)

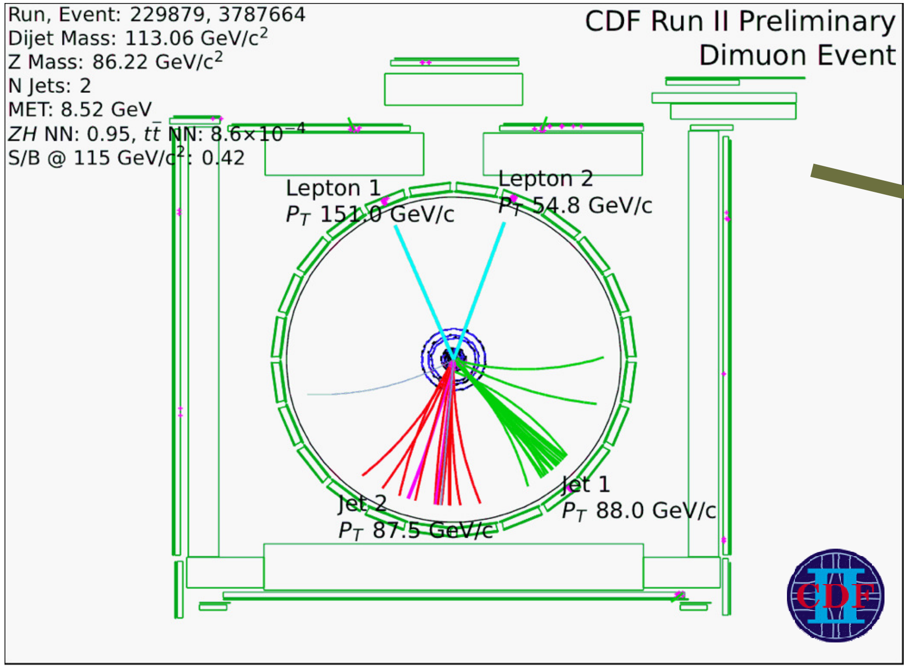


uses a Random Forest Decision Tree method:

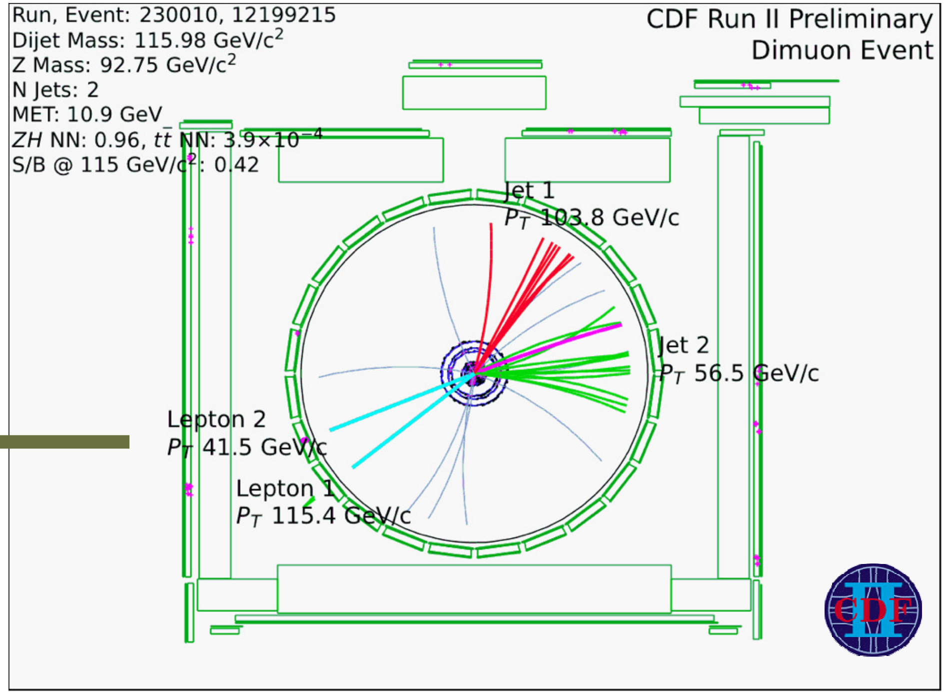
- 20 well modeled inputs chosed
- 200 trees are trained, using a random subset of 10 inputs
- RF Output is the performance weighted result of all 200 trees



$ZH \rightarrow \ell\ell b\bar{b}$ Event Displays

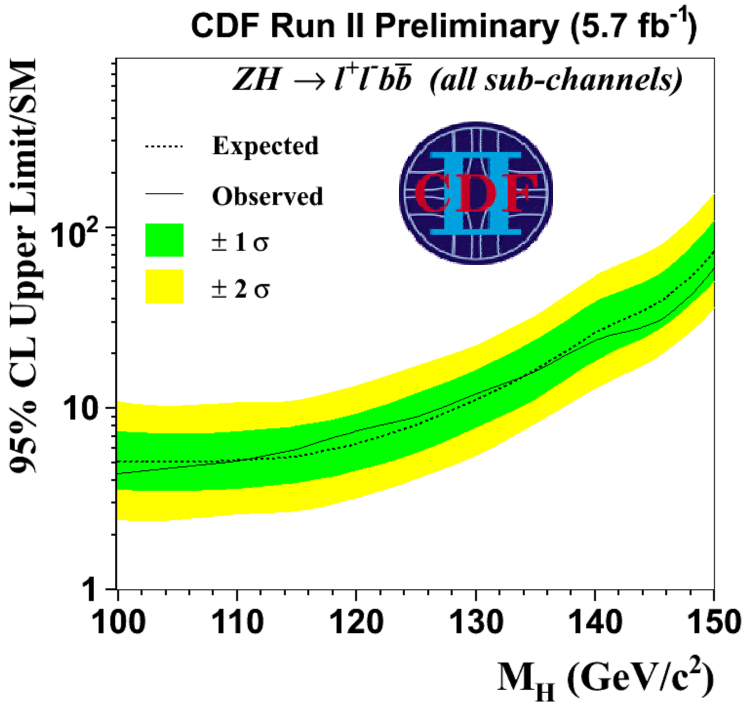


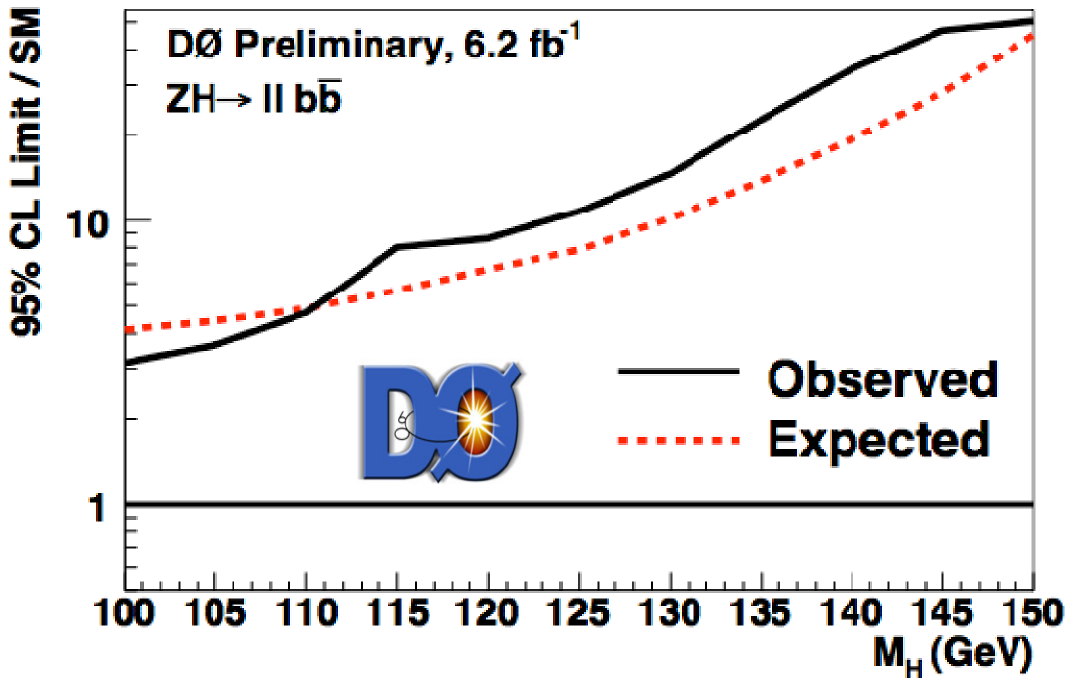
Dijet Mass = 113 GeV/c^2
Z Mass = 86.2 GeV/c^2
MET = 8.5 GeV



Dijet Mass = 116 GeV/c^2
Z Mass = 92.8 GeV/c^2
MET = 10.9 GeV

$ZH \to \ell\ell bb$ Results



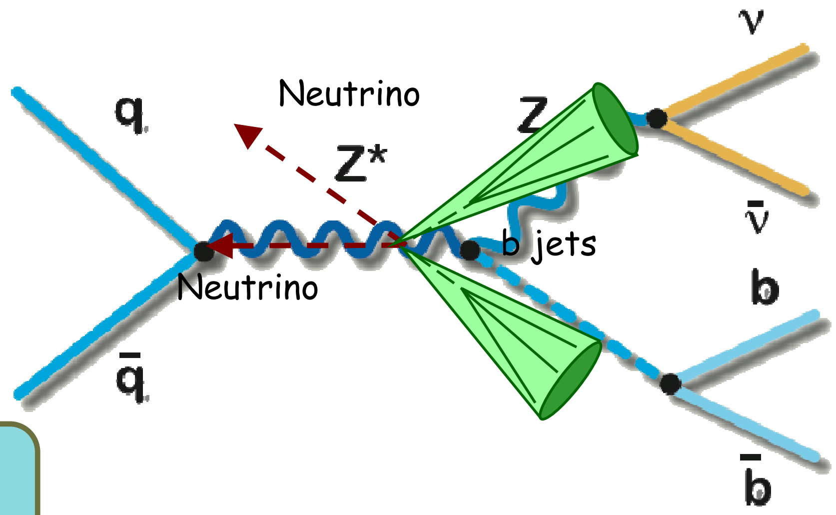


$M_h = 115\ GeV/c^2$

Experiment	Luminosity	Obs/SM	Exp/SM
D0	6.2 fb^{-1}	8.0	5.7
CDF	5.7 fb^{-1}	6.0	5.5

$ZH \rightarrow \nu\nu b\bar{b}$

- No High P_T Leptons
- Large Missing E_T
- D0: 2 jets 2 b-tags
- CDF: 2/3 Jets, 1/2 b-tags



Features:

1. Trigger is more challenging
2. Large QCD/Fake Bkg: Difficult to simulate: *use data*
- **Use tracks to help bkg identification.**
- **Large contribution ~50% from WH**
- **~10 evts/ 6fb^{-1} (double tags)**

Primary Backgrounds

QCD Heavy Flavor,

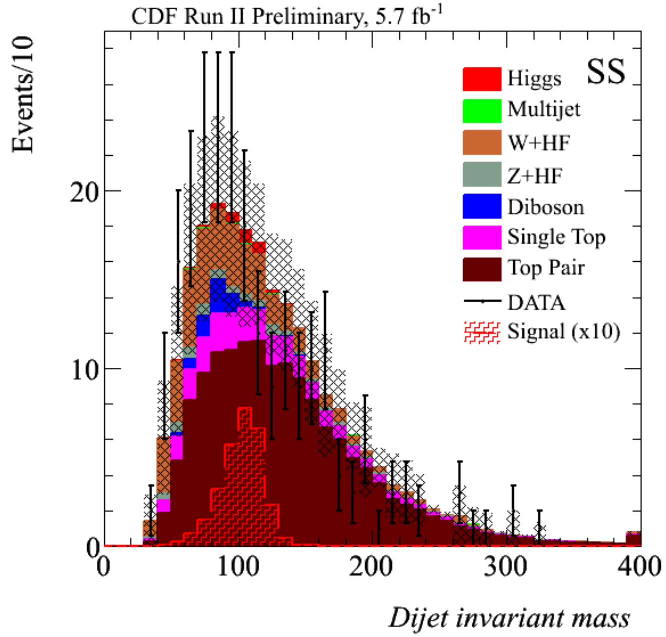
$t\bar{t}$, $W/Z + b\bar{b}/c\bar{c}$,

Single Top,

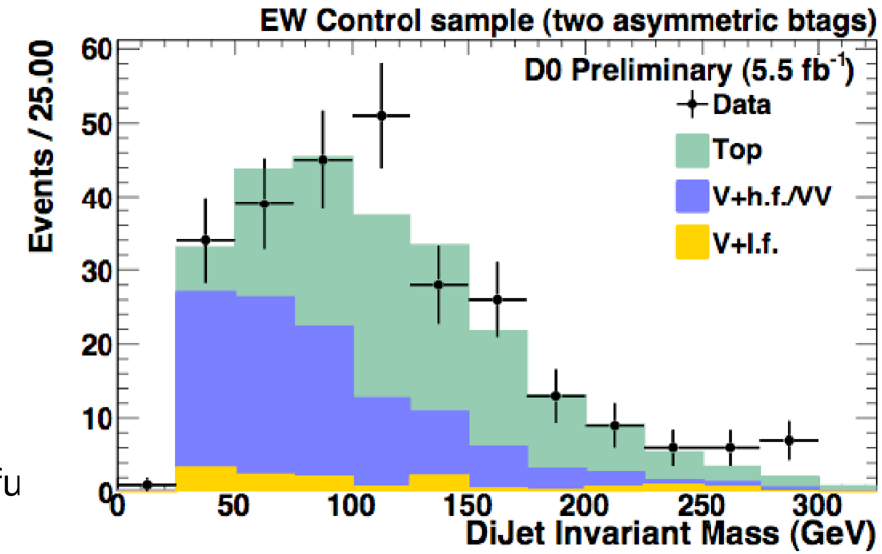
ZZ, WZ, WW

$ZH \rightarrow \nu\nu b\bar{b}$ *Background Modeling*

divides data into 5 subsamples:
- •Signal used to search for Higgs
- •QCD Region for systematic studies
- •EWK region for modeling ewk processes
- •QCD Regions (2) to check normalization of MultiJet (MJ)



divides data into 4 subsamples:
- •Signal used to search for Higgs
- •MJ-model for modeling MJ background in signal sample
- •MJ-control to validate MJ-modeling
- •EWK control, enhanced in W->μν



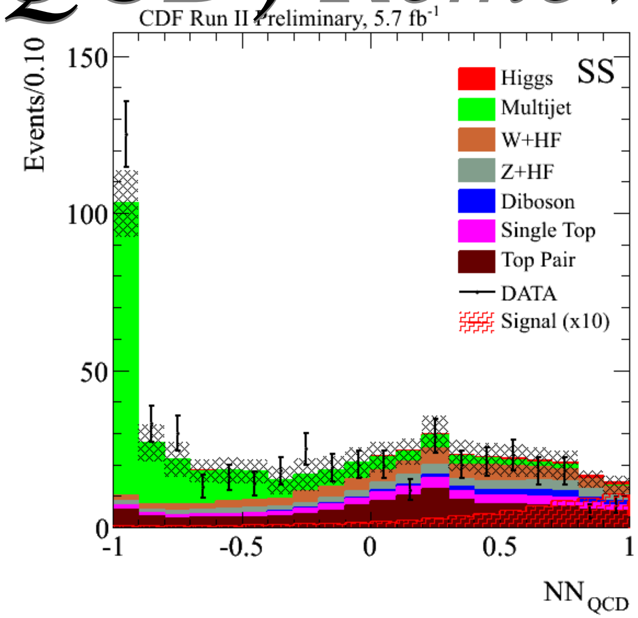
$ZH \rightarrow \nu\nu b\bar{b}$ MultiJet (QCD) Removal

uses a QCD NN:

•Based on Jet kinematics as well as "track missing transverse momentum"

•Removes 87% of MJ, 50-70% of non-MJ background

•Preserves 90-95% of signal

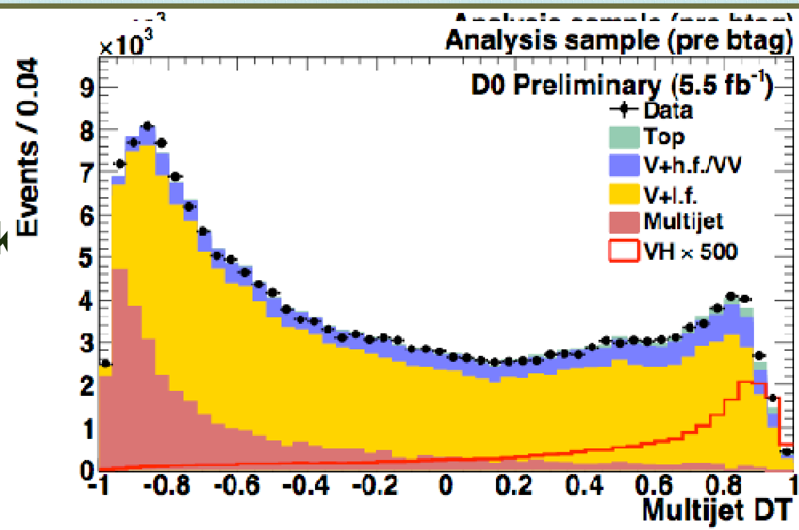


employs a Multijet Discriminant:

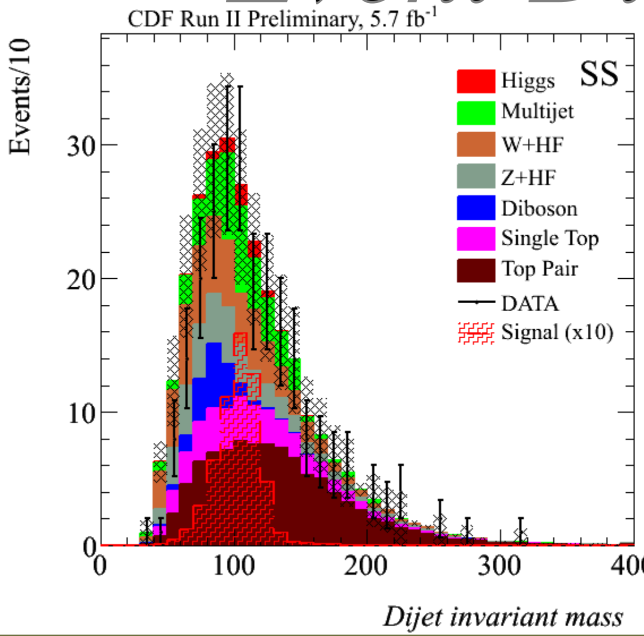
•Based on jet kinematics (after cut on "track based missing transverse momentum")

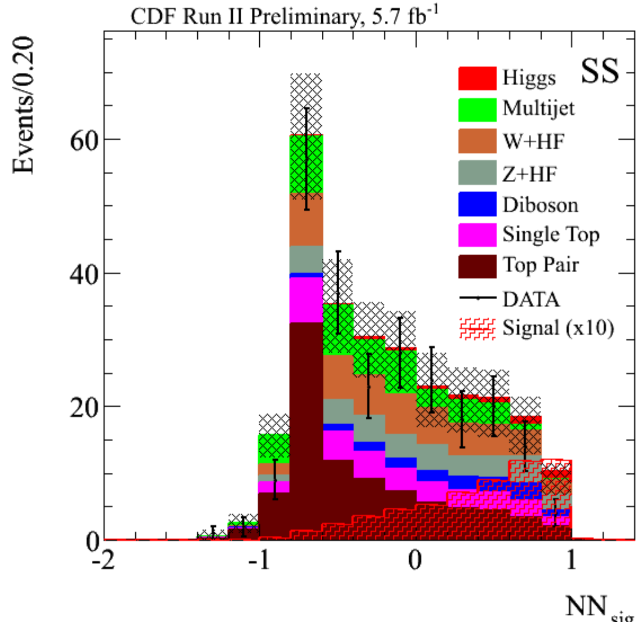
•Removes 95% of MultiJet and 65% of non-MultiJet background

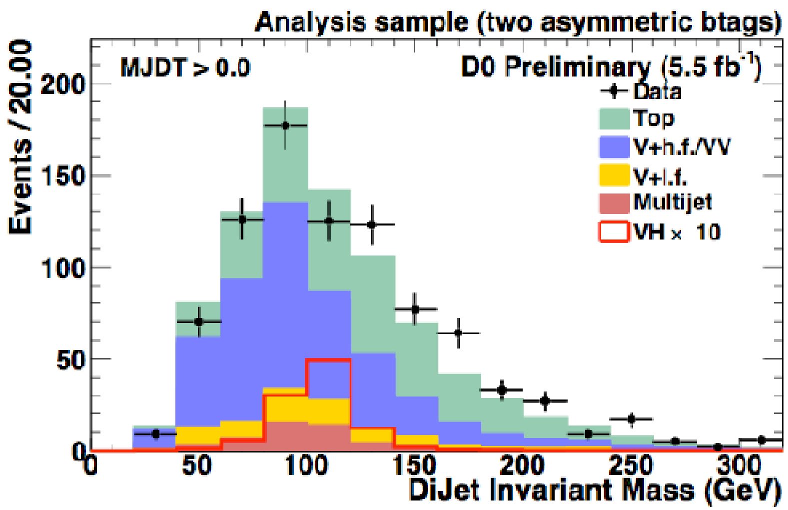
•Preserves 70% of signal

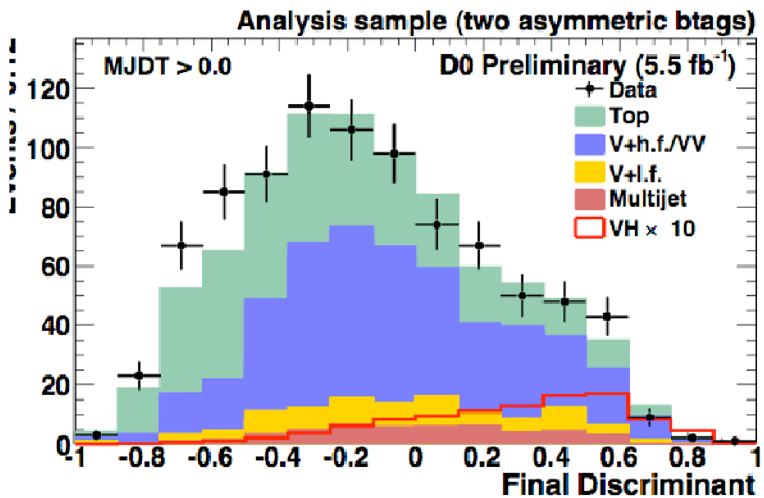


$ZH \rightarrow \nu\nu b\bar{b}$ Event Discriminants

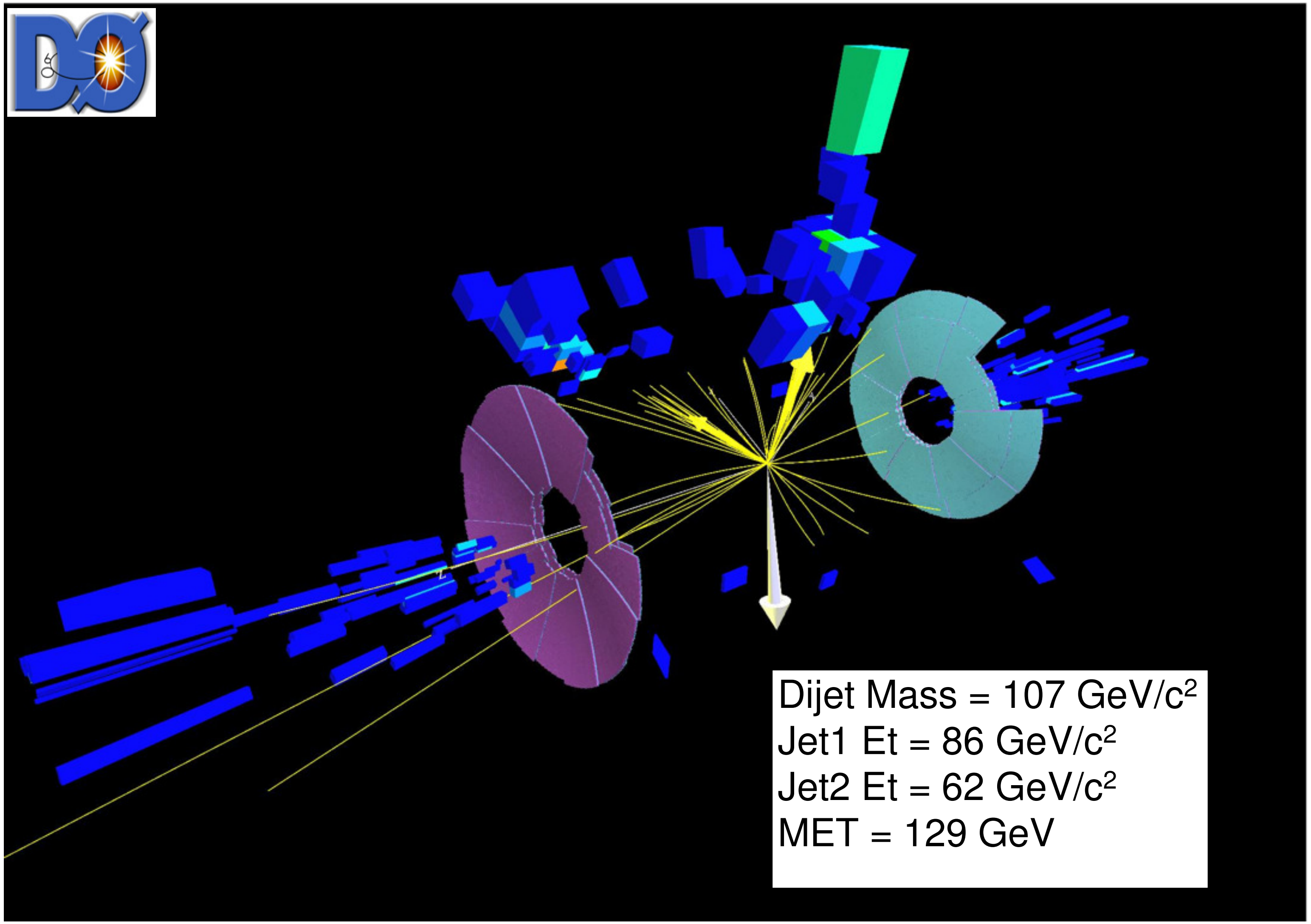




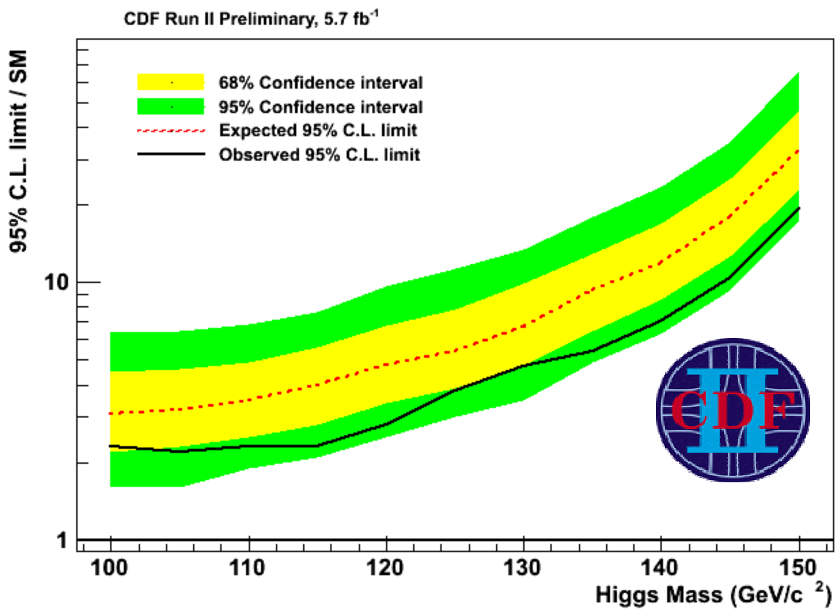


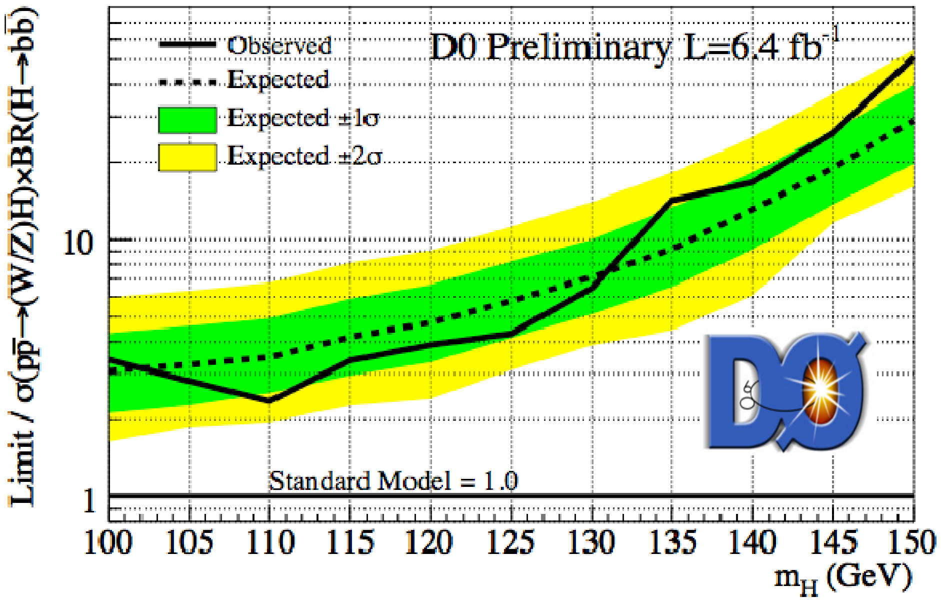


$ZH \to \nu\nu b\bar{b}$ *Event Display*



$ZH \to \nu\nu b\bar{b}$ Results



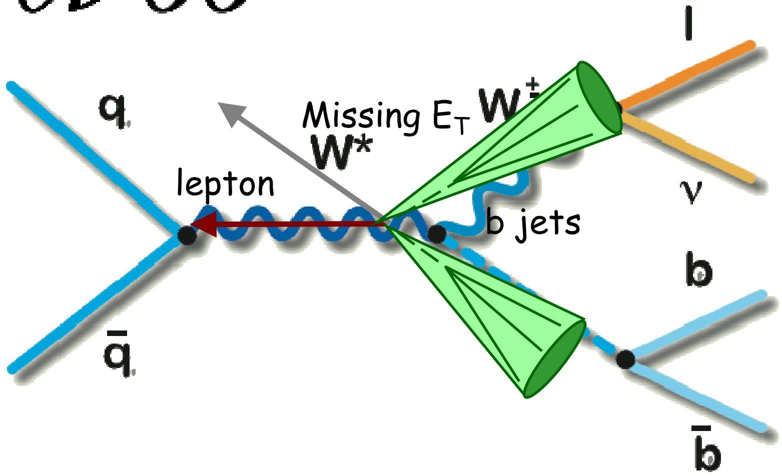


Experiment	Lum	Obs/SM	Exp/SM
CDF	5.7 fb^{-1}	2.3	4.0
D0	6.4 fb^{-1}	3.4	4.2

M_h = 115 GeV/c^2

$WH \rightarrow \ell\nu bb$

- **High P_T Lepton**
- **Missing E_T**
- **2/3 Jets, 1/2 b-tags**



Features:

1. **Good Acceptance**
2. **Final state similar to single top production**
3. **~5 evts/ 6 fb^{-1} (dbl tags)**

Primary Backgrounds

$Wb\bar{b}$, $Wc\bar{c}$, Wqq'

$t\bar{t}$

Single top

non − W QCD

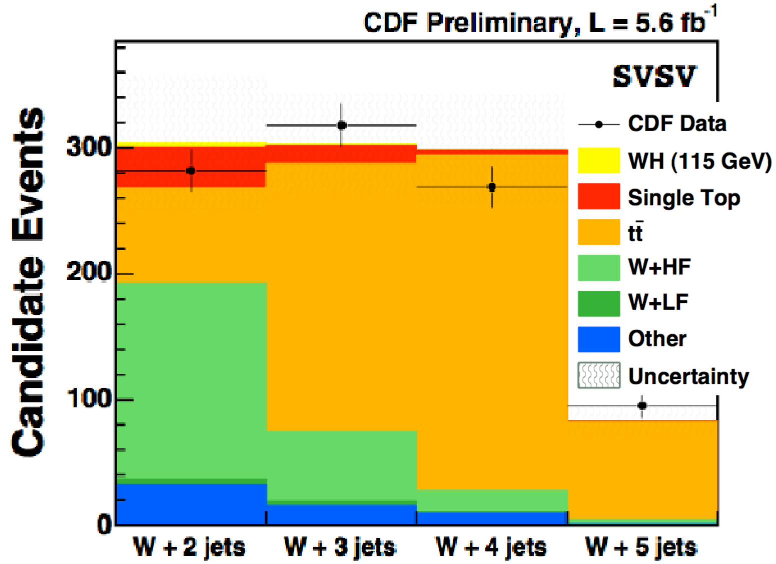
WZ, WW

$Z \rightarrow \tau\tau$

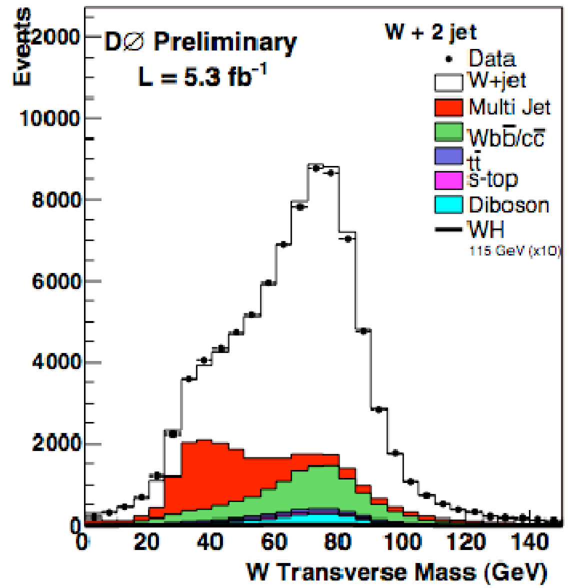
$WH \to \ell\nu bb$ Procedure

CDF uses 2 methods:
- e/μ MET, 2/3 jets
- double loose or single tight tagging
- Flavor separator for single tags
- Two discriminants

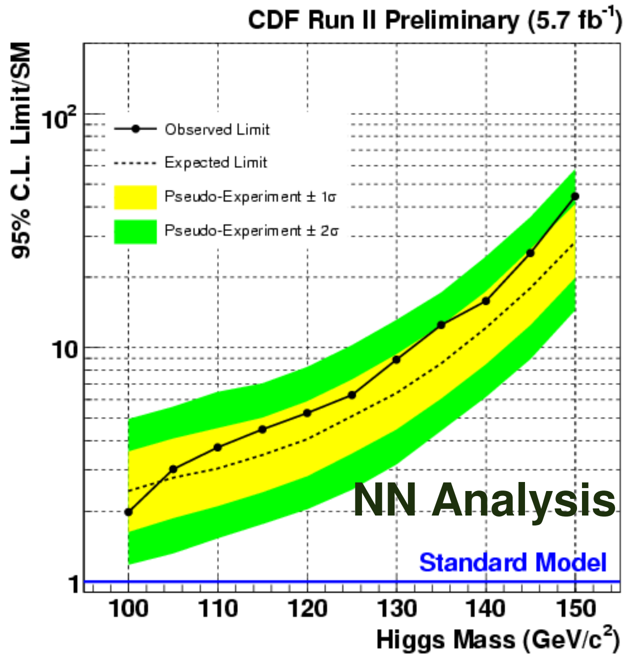
1) Matrix Element
2) Bayesian Neural Network (adds in single isolated tracks as well)

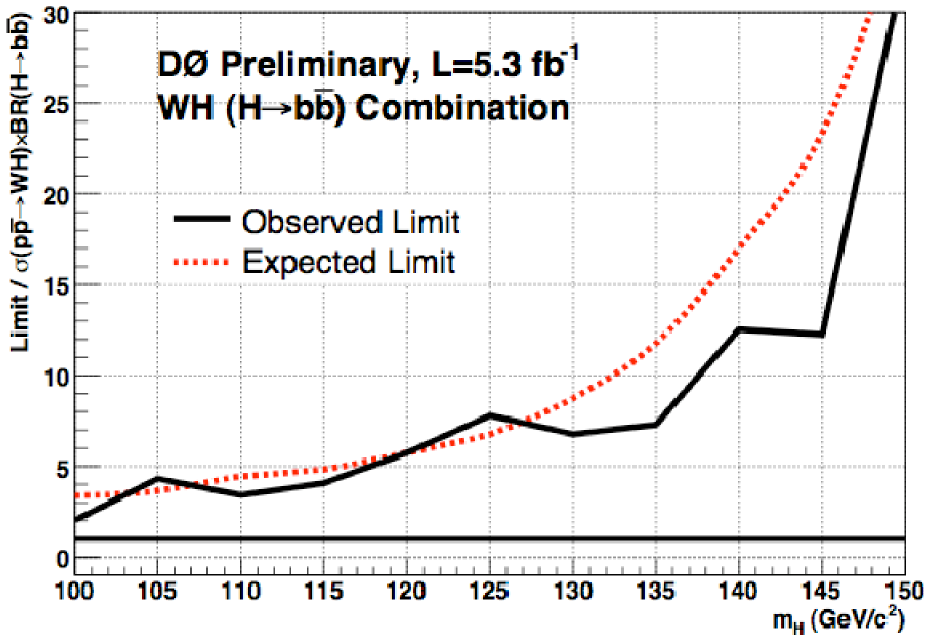


D0 method:
- e/μ MET, 2/3 jets
- Double loose or single tight tagging
- Random forest discriminant



$WH \to \ell\nu bb$ Results

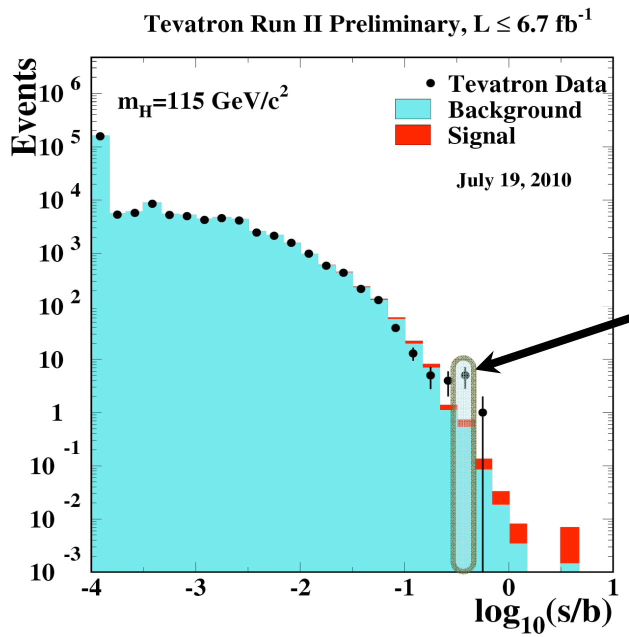




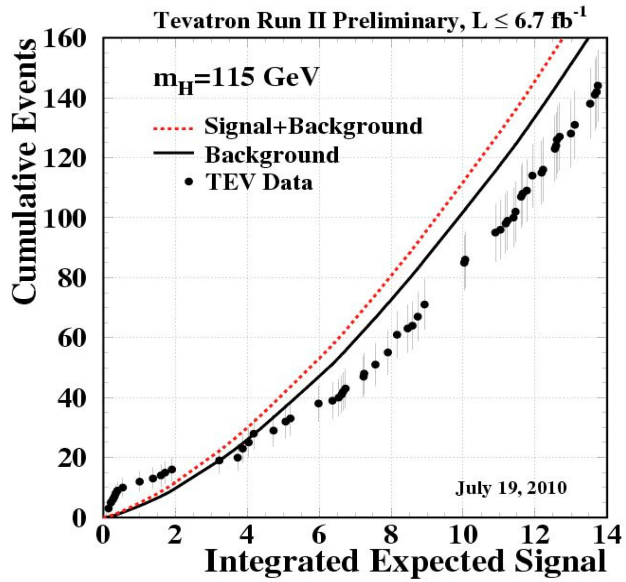
Experiment	Lum	Obs/SM	Exp/SM
CDF	5.7 fb^{-1}	3.6/4.5	3.5/3.4
D0	5.3 fb^{-1}	3.7	4.7

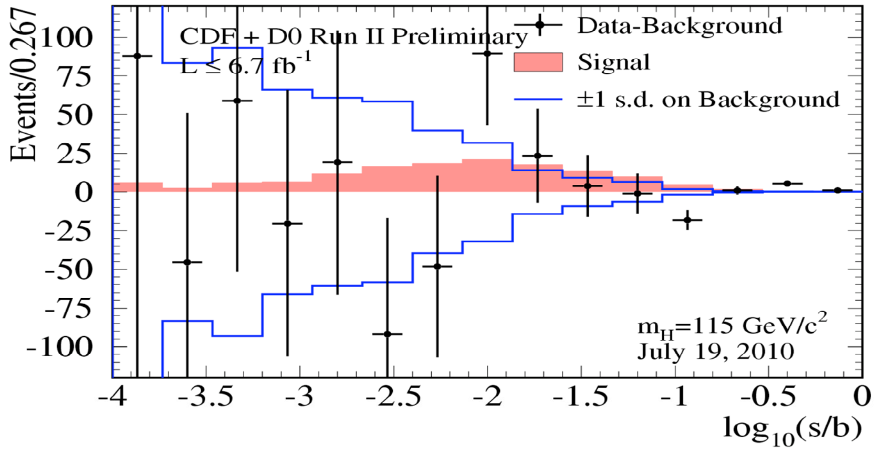
$M_h = 115\ GeV/c^2$

Tevatron Candidate Summary, m_H=115 GeV



Data: 5 events
Backgnd: 0.8 events
S:B ~ 1:2





Fluctuations: Excess and deficit average out :
Expected limit 1.45*SM
Observed limit 1.56*SM

“HIGH” MASS LIGHT HIGGS

H->WW decay in:

$gg \to H \to WW$ (OS leptons)

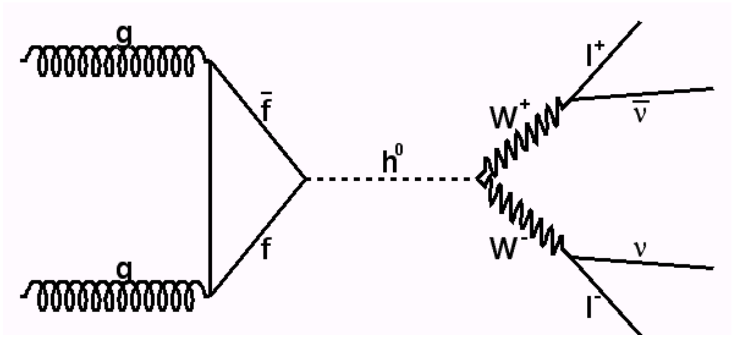
$VBF \to VWW$

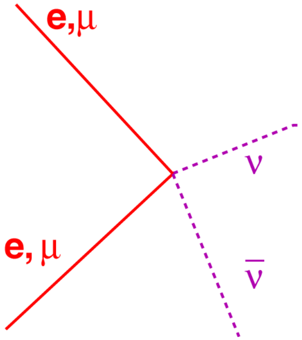
$VH \to VWW$ (SS leptons)

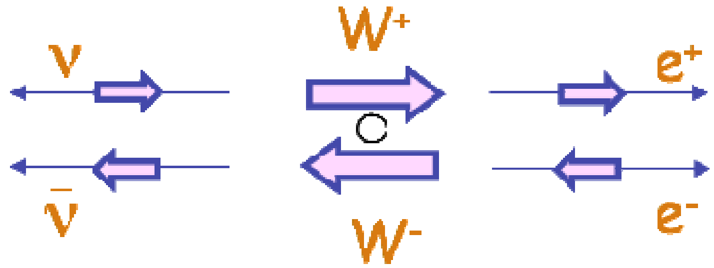
$VH \to VWW \to l^{\pm}\nu l^{\pm}\nu + X$

Both CDF and D0:

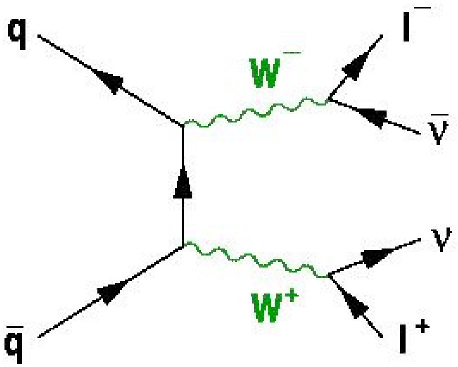
Selection: 2 opposite –signed, isolated high Pt leptons, Plus missing energy and m(ll)>15 GeV

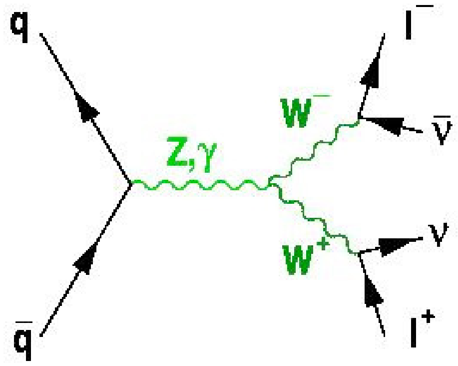






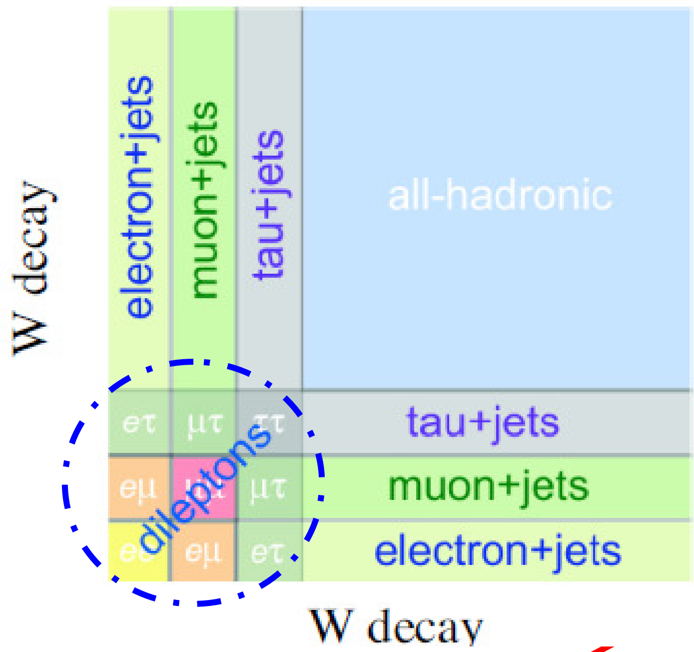
Dominant difficult background: $q\bar{q} \to W^+W^-$





Z!Z! Higgs is a scalar => Angular correlations are different from SM background WW: The signal leptons come out collinear ($\Delta\Phi_{ll}$)

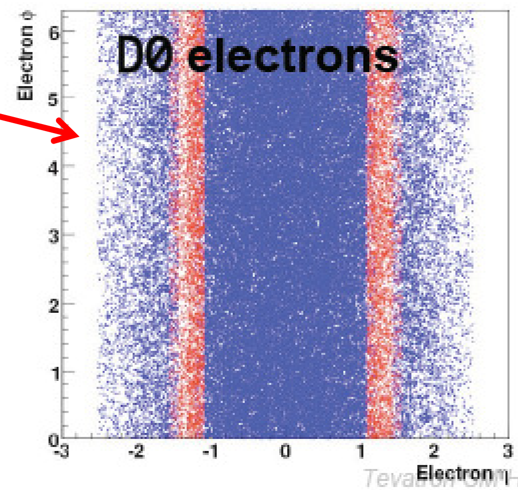
Why W leptonic decays?



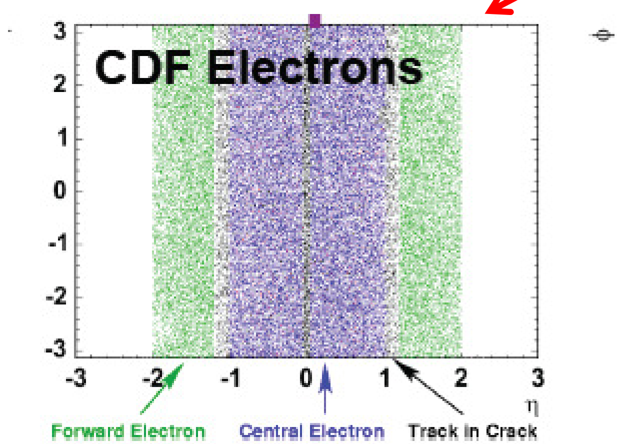
W+jets and multijet background prohibit using
W⟶ hadron decays

Br(WW →ee, eμ, μμ)≈ 6%, but:

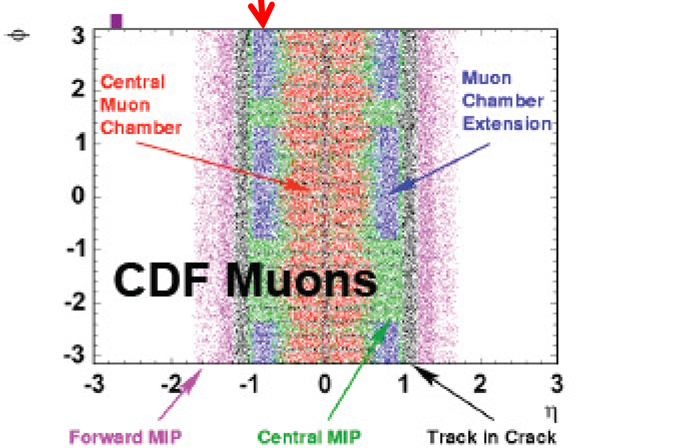
- Manageable background
- Lepton trigger are easier
- Missing Et is a good signature too
- Include also some W⟶τ ν_τ decays
- Leptons acceptance:



Inter calorimeter e-:
10% gain in D0 e- acceptance

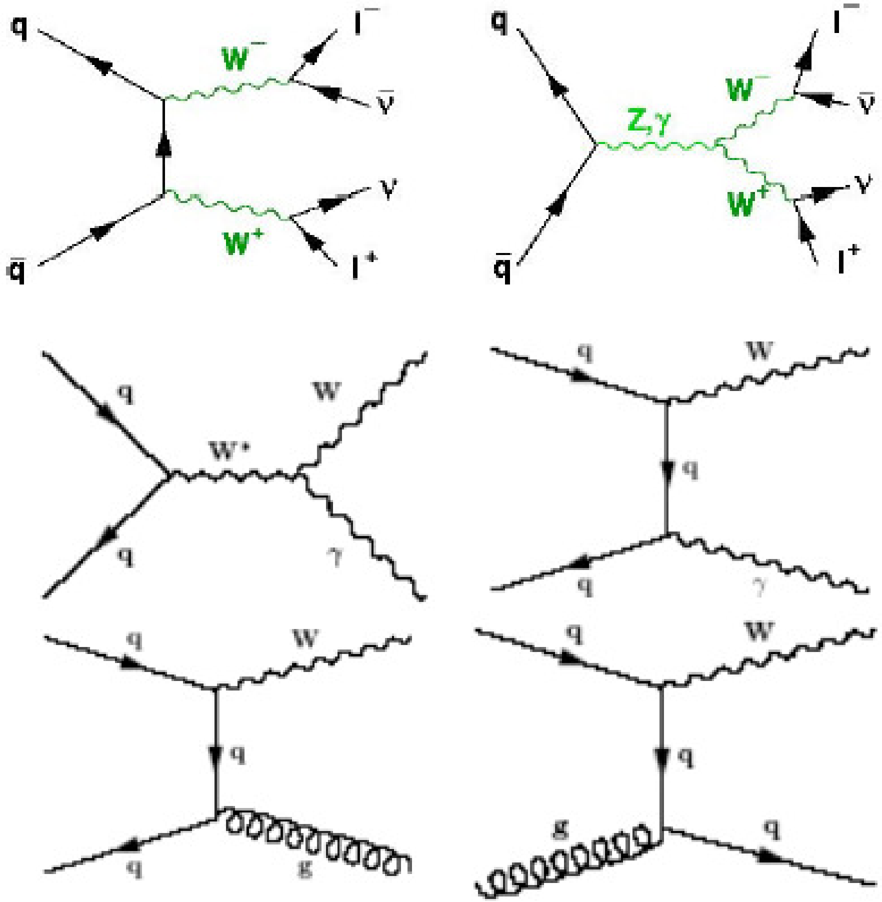


10% gain in CDF electron acceptance

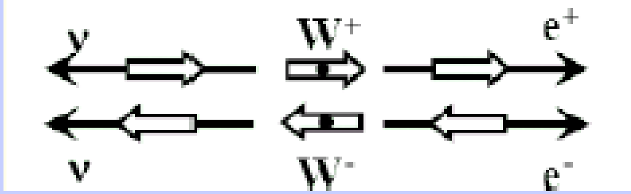


30% gain in CDF single-muon acceptance

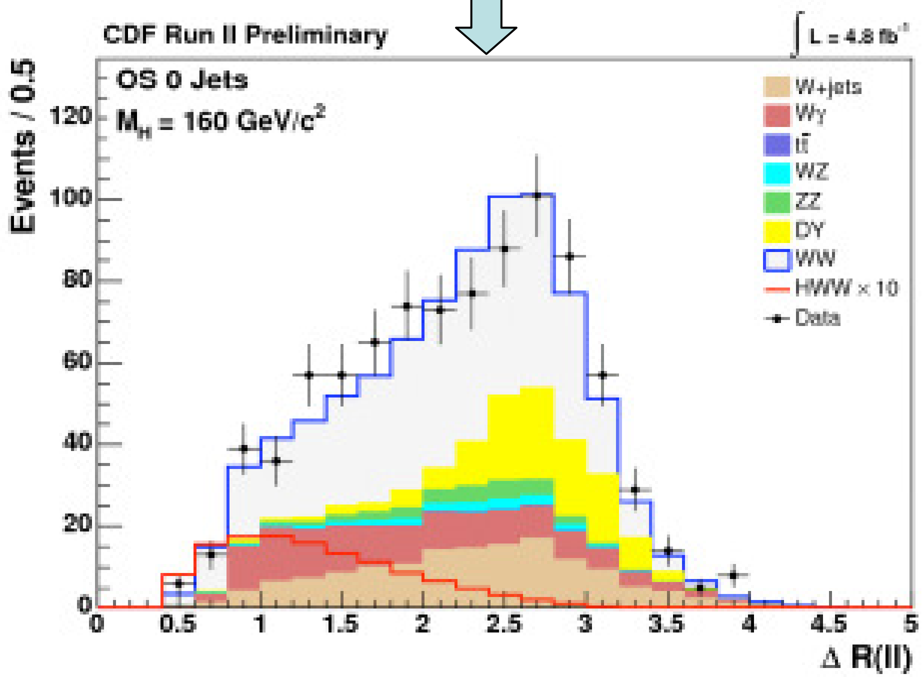
H→WW BACKGROUNDS:
- WW/WZ
- W+Jets/γ
- Drell-Yan
- $t\bar{t}$, single top
- Multijet with jet faking lepton



- Kinematic Discriminants
  - ll opening angle



  - kinematics input MVA



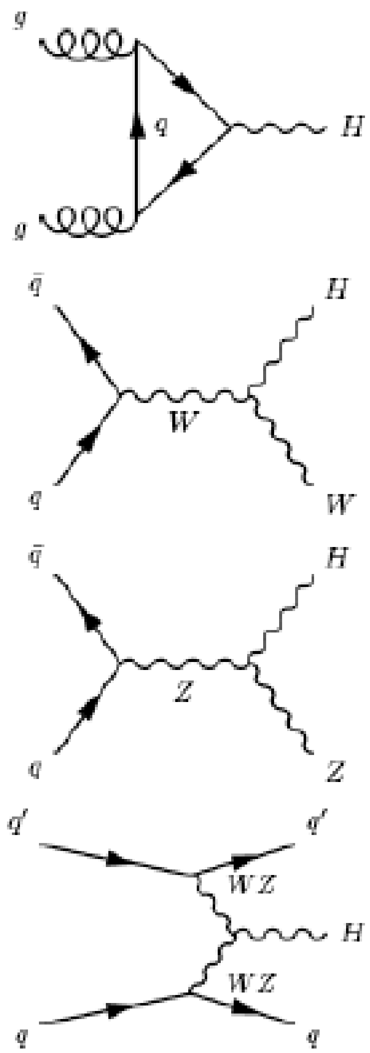
All backgrounds were measured

CDF Analysis Strategy

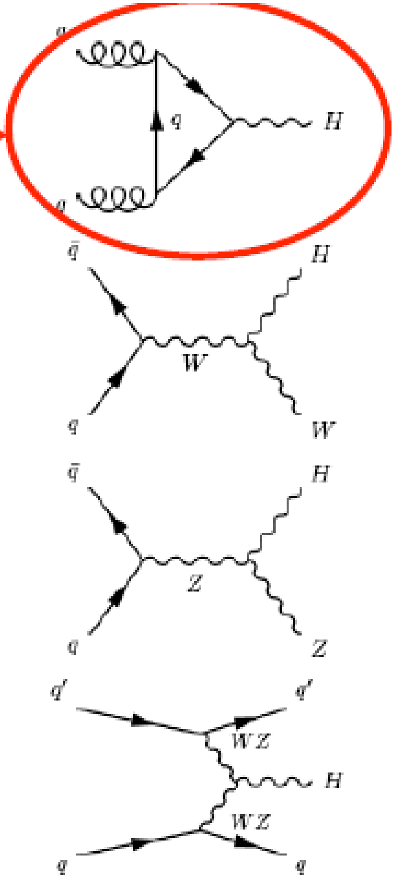
0 Jet Events

1 Jet Events

2+ Jet Events

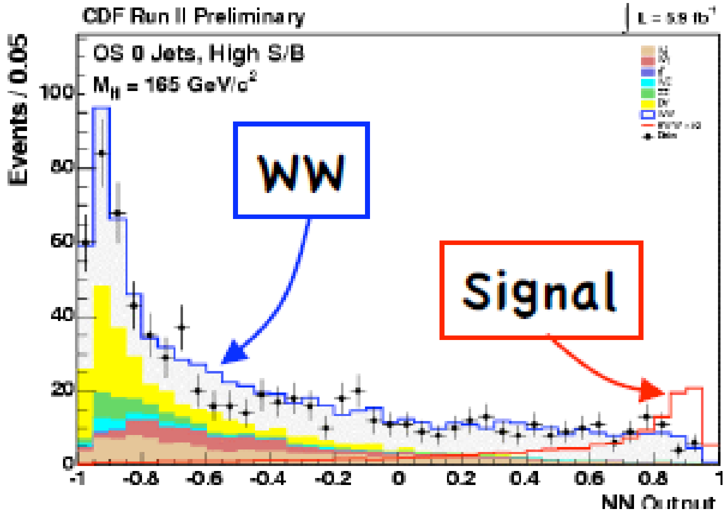


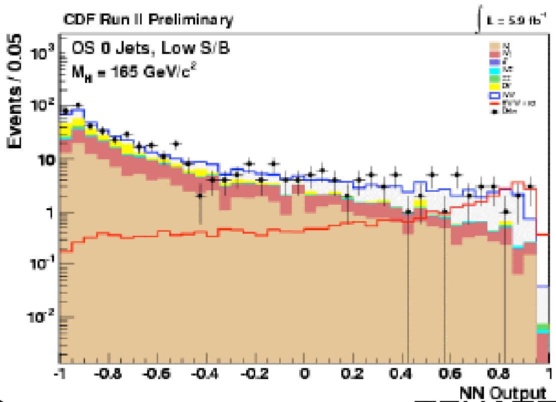
0 Jet Events



CDF Run II Preliminary	$\int \mathcal{L} = 5.9\ \mathrm{fb}^{-1}$		
$M_H = 165\ \mathrm{GeV}/c^2$			
$t\bar{t}$	2.23	$\pm$	0.66
DY	227	$\pm$	62
WW	563	$\pm$	56
WZ	25.5	$\pm$	3.8
ZZ	38.3	$\pm$	5.4
W+jets	215	$\pm$	51
$W\gamma$	155	$\pm$	22
Total Background	1226	$\pm$	120
$gg \to H$	16.9	$\pm$	3.0
WH	0.410	$\pm$	0.070
ZH	0.416	$\pm$	0.059
VBF	0.140	$\pm$	0.028
Total Signal	17.8	$\pm$	3.1
Data	1230		

OS 0 Jets





Inputs into Neural Network

- $\Delta R(l,l)$, $\Delta\phi(l,l)$, H_T(all)

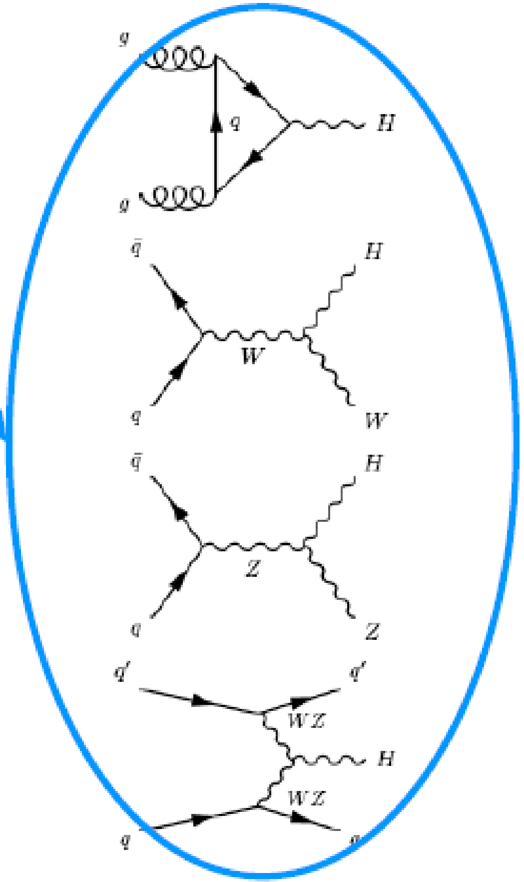
Matrix Element Likelihood Ratios

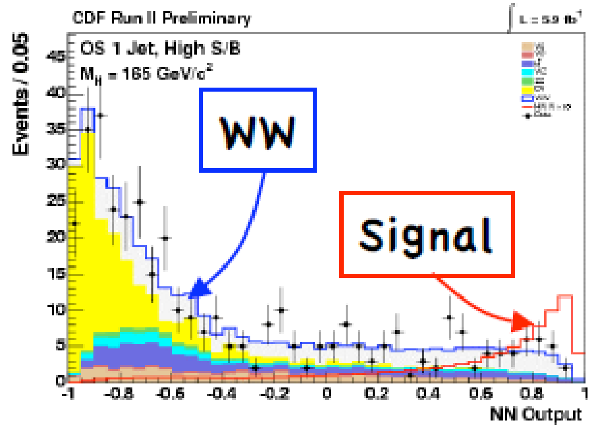
- LR_{HWW}, LR_{WW}

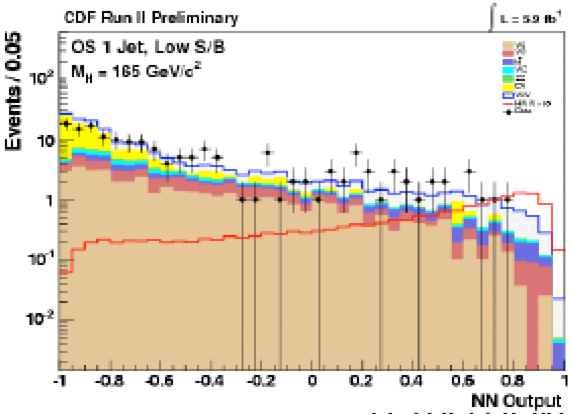
1 Jet Events

CDF Run II Preliminary	$\int \mathcal{L} = 5.9\ \mathrm{fb}^{-1}$		
$M_H = 165\ \mathrm{GeV}/c^2$			
$t\bar{t}$	56	$\pm$	11
DY	218	$\pm$	49
WW	151	$\pm$	18
WZ	25.4	$\pm$	3.5
ZZ	10.3	$\pm$	1.5
W+jets	77	$\pm$	20
$W\gamma$	25.1	$\pm$	4.3
Total Background	563	$\pm$	69
$gg \rightarrow H$	8.0	$\pm$	2.4
WH	1.13	$\pm$	0.18
ZH	0.439	$\pm$	0.066
VBF	0.74	$\pm$	0.13
Total Signal	10.3	$\pm$	2.5
Data	533		

OS 1 Jet







Neural Net Inputs

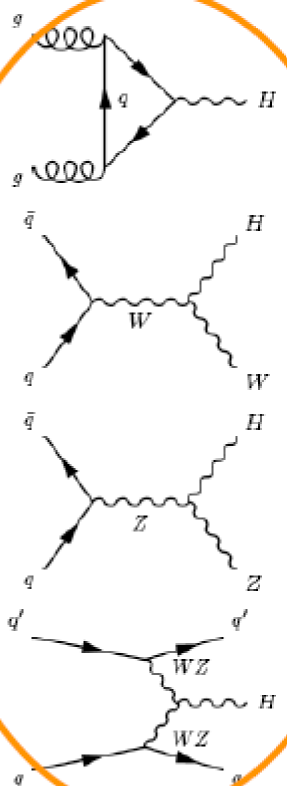
$\Delta R(l,l)$, $M_T(ll,\not{E}_T)$, M_{ll}, $\not{E}_t^{spec}$

$E(l_1)$, $P_T(l_1)$, $P_T(l_2)$, H_T

2+ Jet Events

CDF Run II Preliminary		$\int \mathcal{L} = 5.9$ fb^{-1}	
$M_H = 165$ GeV$/c^2$			
$t\bar{t}$	169	$\pm$	24
DY	80	$\pm$	31
WW	33.6	$\pm$	6.1
WZ	6.8	$\pm$	1.3
ZZ	3.10	$\pm$	0.57
W+jets	26.7	$\pm$	7.5
$W\gamma$	4.4	$\pm$	1.2
Total Background	324	$\pm$	50
$gg \to H$	2.6	$\pm$	1.8
WH	2.50	$\pm$	0.35
ZH	1.28	$\pm$	0.17
VBF	1.37	$\pm$	0.23
Total Signal	7.8	$\pm$	2.0
Data	307		

AllSB-2JOS



VH and VBF dominant

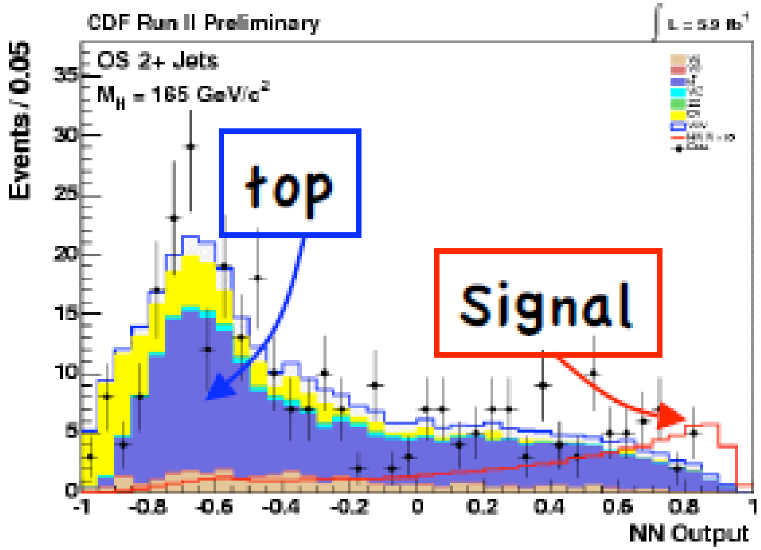
VH and VBF contribution dominant 60% (~3.5 evts)

Anti-b-tag cut suppresses $t\bar{t}$

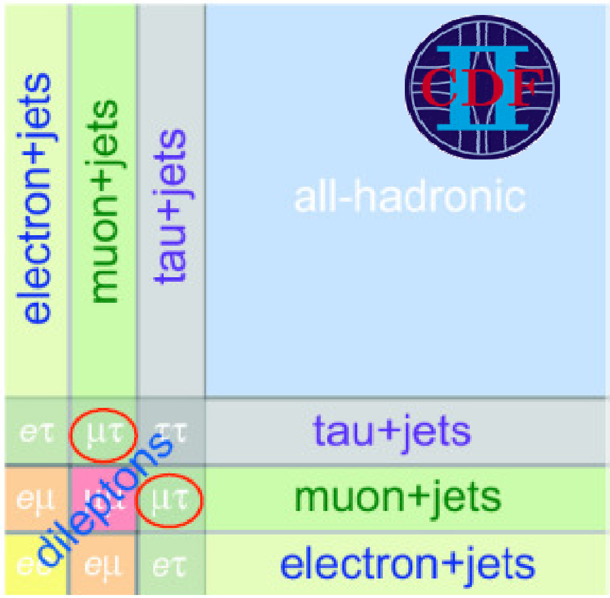
Neural Net Inputs

$\Delta R(l,l)$, $\Delta\phi(l,l)$, M_{ll}, ΣP_T^{jets}

$\Delta\phi(E_T^{ll}, E_T)$, $E_T(l_1)$, $E_T(l_2)$, H_T



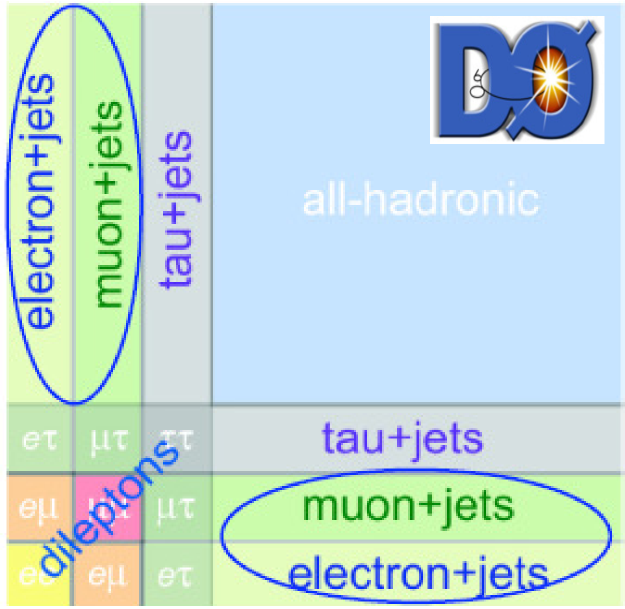
Adding new channels (2010)



- $H \to WW^* \to \mu\nu\tau\nu$ - CDF

And also extend to lower M(ll)

- extend the opposite sign analysis
- $M(ll) < 15$ GeV

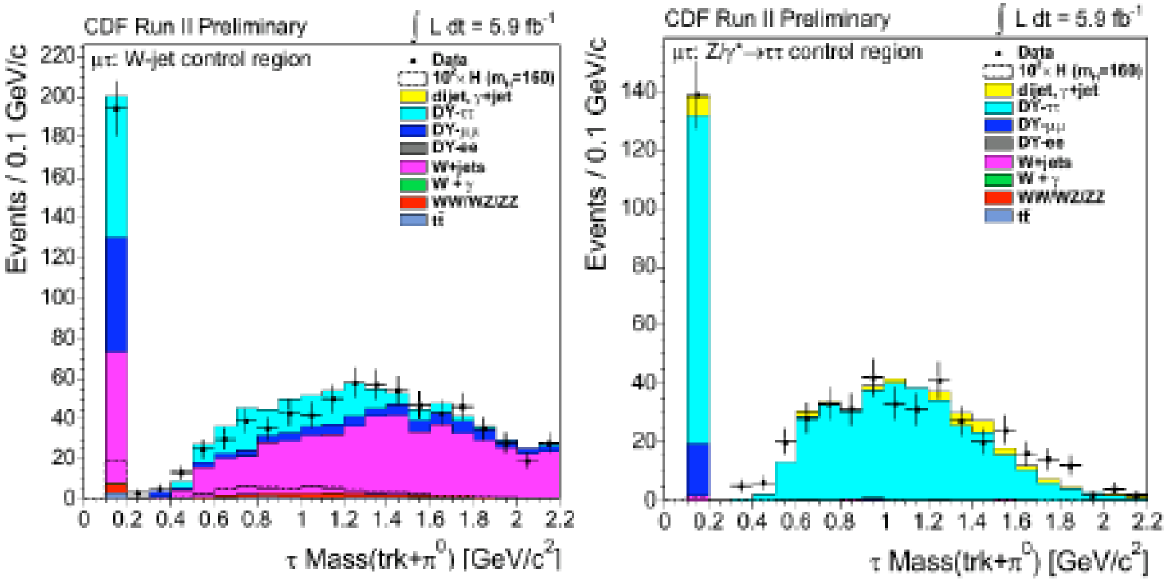


- $H \to WW^* \to l\nu jj$ - D0

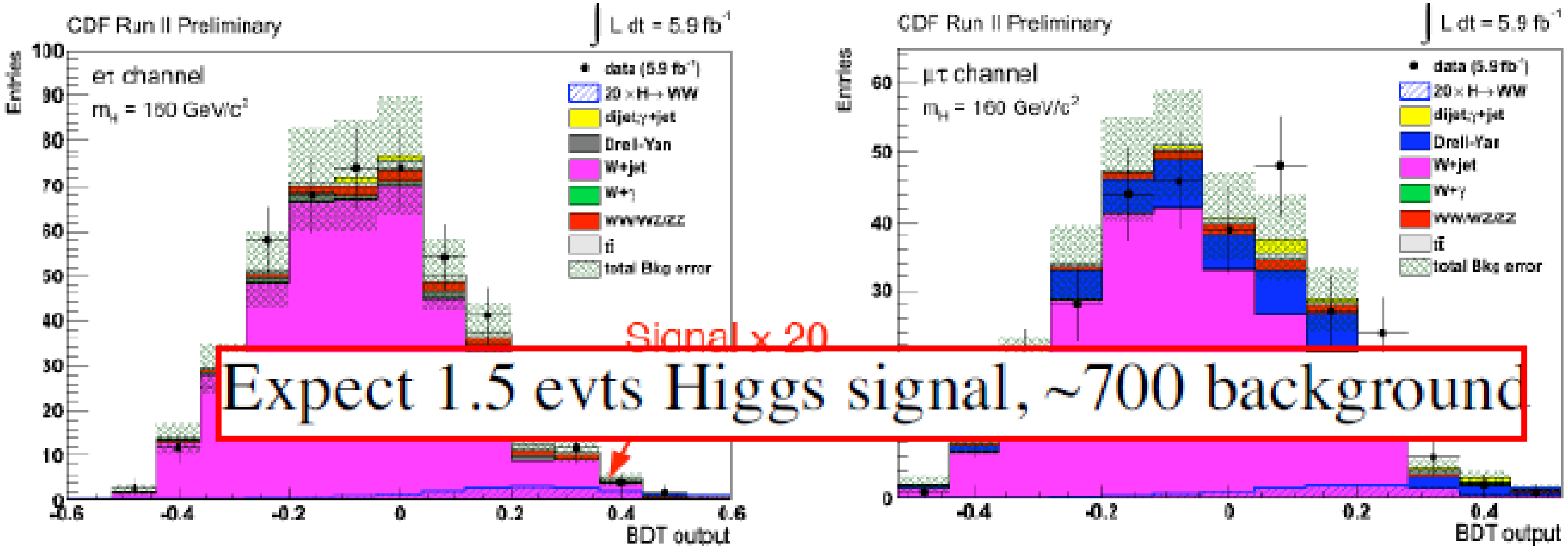
DO add the lepton+ jet(s)
Channels already included
In the CDF 2009 analysis

$H \rightarrow WW \rightarrow l\nu\tau\nu$

- backgrounds very different for τ samples
- Multijet and $Z \rightarrow \tau\tau$ dominate
- Control samples allow for cross checks of τ kinematic and ID variables
  - W+jets ($e\tau$ & $\mu\tau$)
  - Mulijet ($e\tau$)
  - $Z \rightarrow \tau\tau$ ($\mu\tau$)



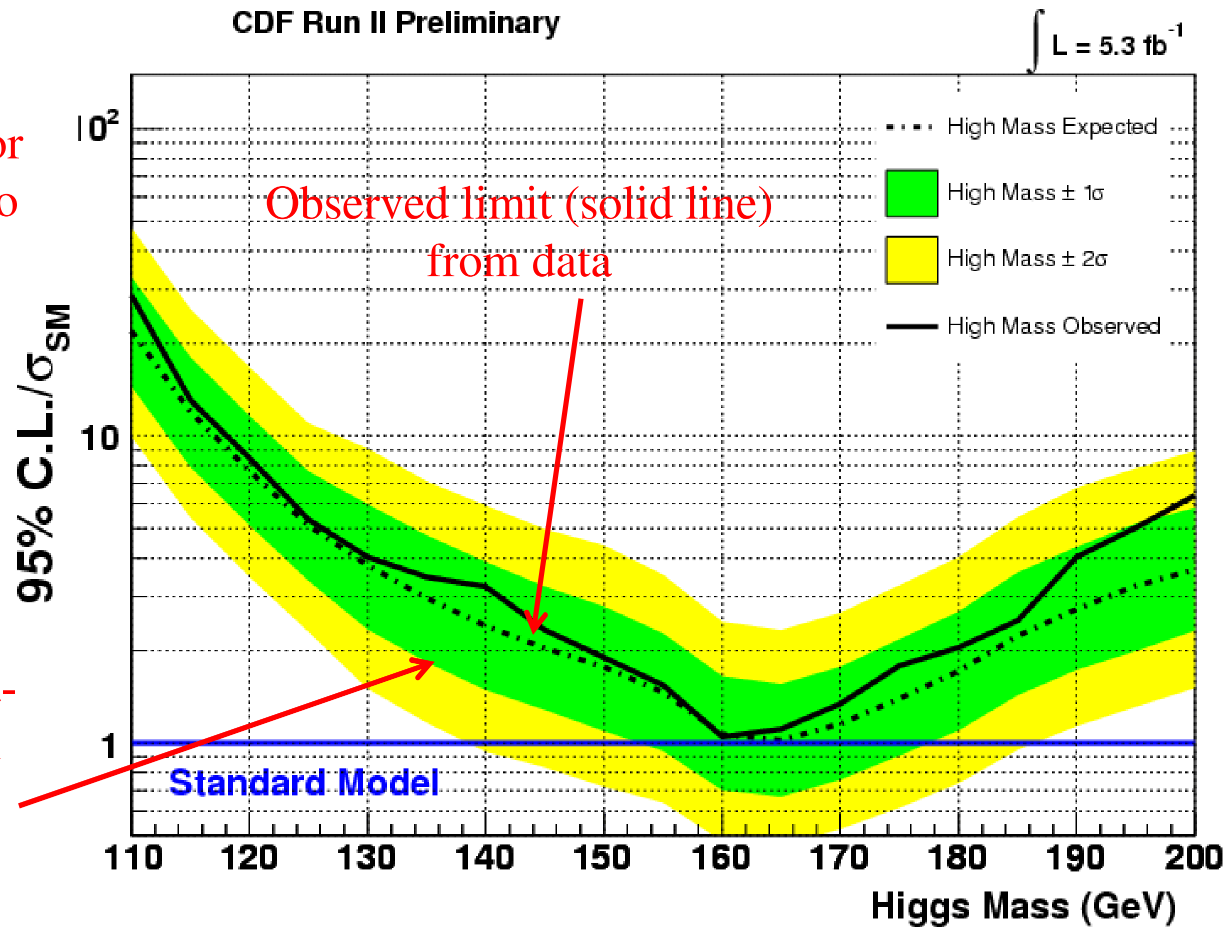
Use BDT discriminant



Expect 1.5 evts Higgs signal, ~700 background

Explaining Limit Plot

Upper cross section limit for Higgs production relative to SM prediction



Observed limit (solid line) from data

Median expected limit (dot-dashed line) and predicted 1 σ /2 σ (green/yellow bands) excursions from background only pseudo-experiments

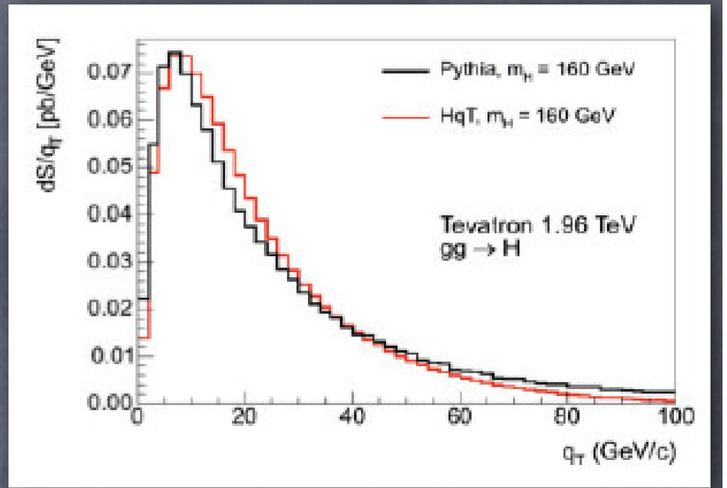
Analysis repeated using different signal templates for each m_H between 100 and 200 GeV in 5 GeV steps

Theory & uncertainties

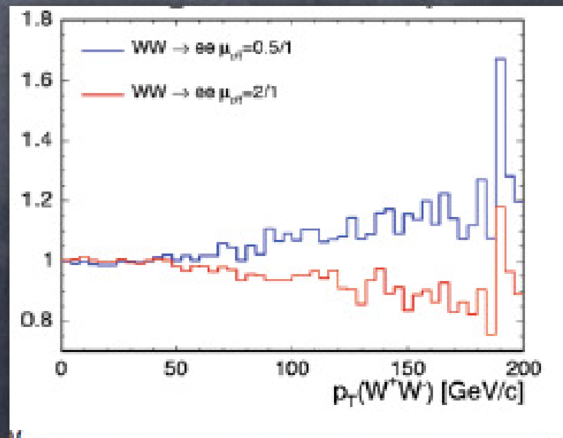
An(other) important topic & no time to discuss it

- We make use of well-motivated and state of the art gluon fusion cross-section calculations and uncertainties
  - gg → H uses NNLL + NNLO calculations
    - "Next to Next to Leading Log/Order"
  - de Florian & Grazzini (Phys.Lett.B674:291-294, 2009)
    - Soft-gluon resummation treatment
    - MSTW2008 Parton Density Function
  - Anastasiou, Boughezal, Petriello (JHEP:0904:003, 2009)
    - Proper treatment of b-quarks at NLO
    - Inclusion of two-loop electroweak effects
- For those interested in a detailed explanation of our choices and comparison with more extreme approaches :

http://tevnphwg.fnal.gov/results/SMHPubWinter2010/gghtheoryreplies_may2010.html



Reweight PYTHIA Higgs kinematics to full NNLL calculation



Consider same variations for dominant WW bkg

Courtesy of Ben Kilmenster

SM HIGH MASS HIGGS combination

- combine all 18 high mass channels
- use bayesian approach
- weighted by sensitivity, average integrated luminosity
  - 5.90 fb^{-1} @ 165 GeV

CDF SM Higgs limit @165 GeV

σ/σ_{SM} (obs) = 1.13

σ/σ_{SM} (exp) = 1.00

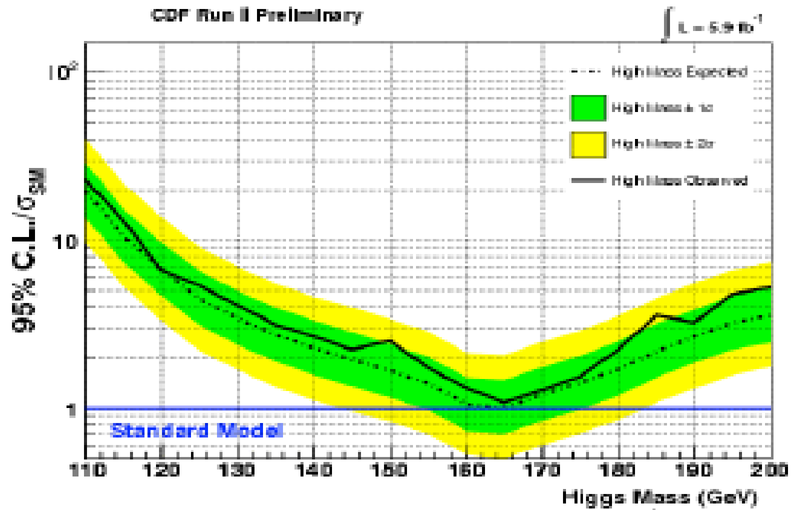
- combine all 10 high mass channels
- modified frequentist approach with log likelihood ratio test statistic
- weighted by sensitivity, average integrated luminosity
  - 6.10 fb^{-1} @ 165 GeV

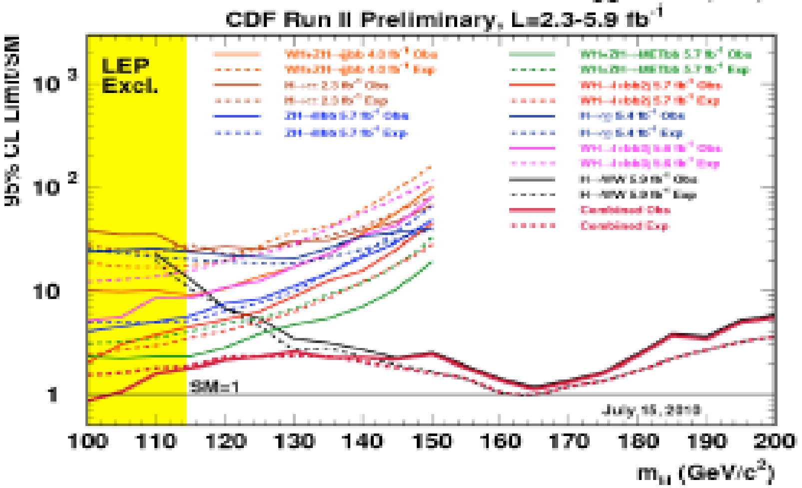
D0 SM Higgs limit @165 GeV

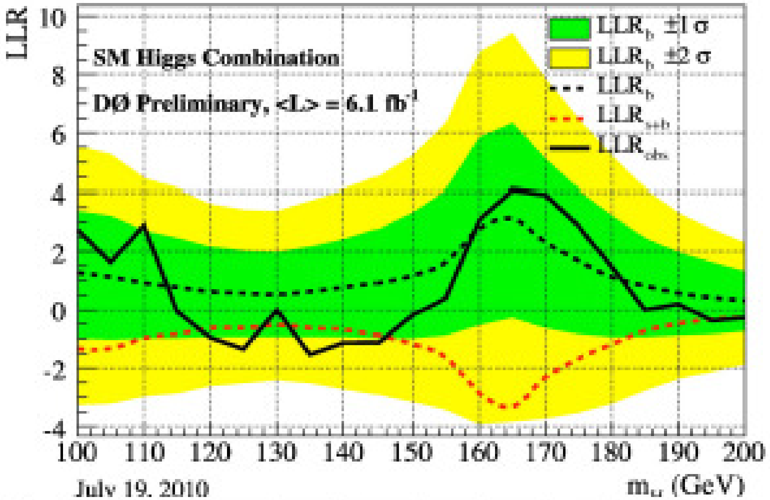
σ/σ_{SM} (obs) = 1.03

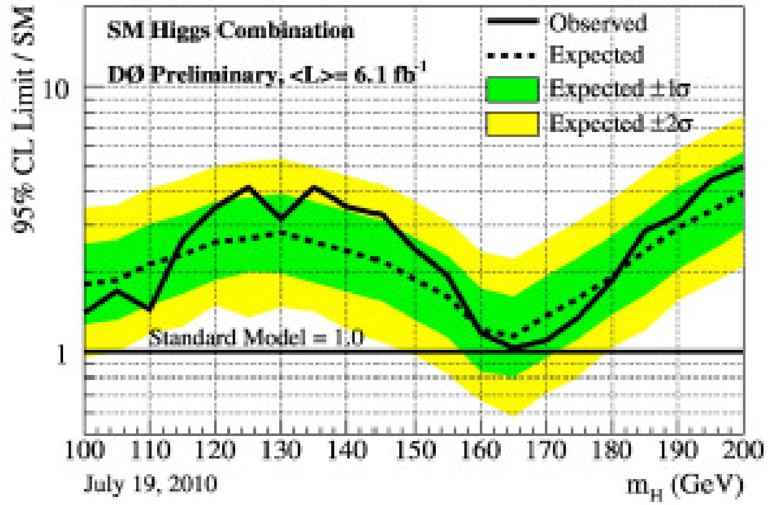
σ/σ_{SM} (exp) = 1.14

SM HIGH MASS HIGGS combination

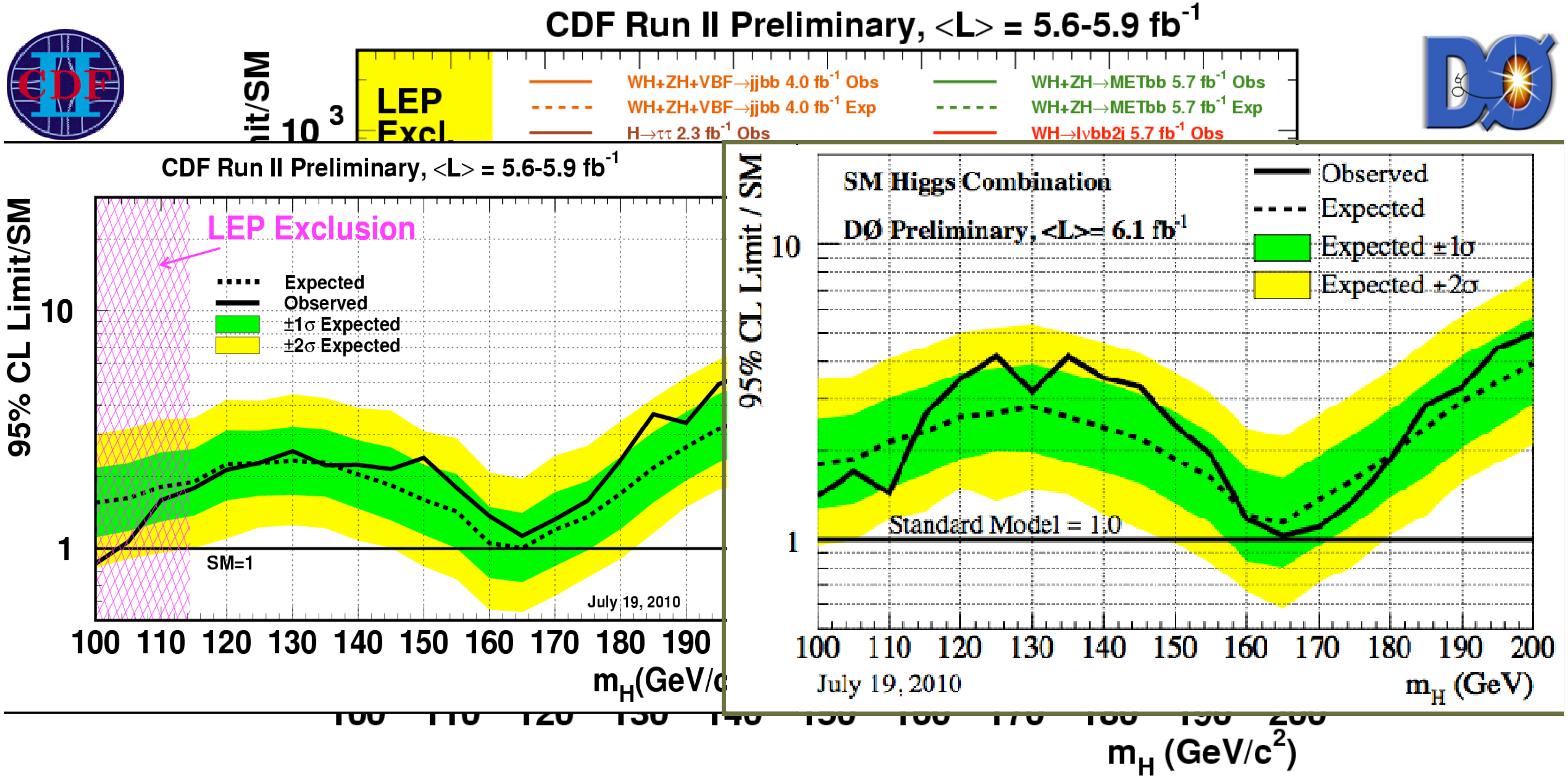




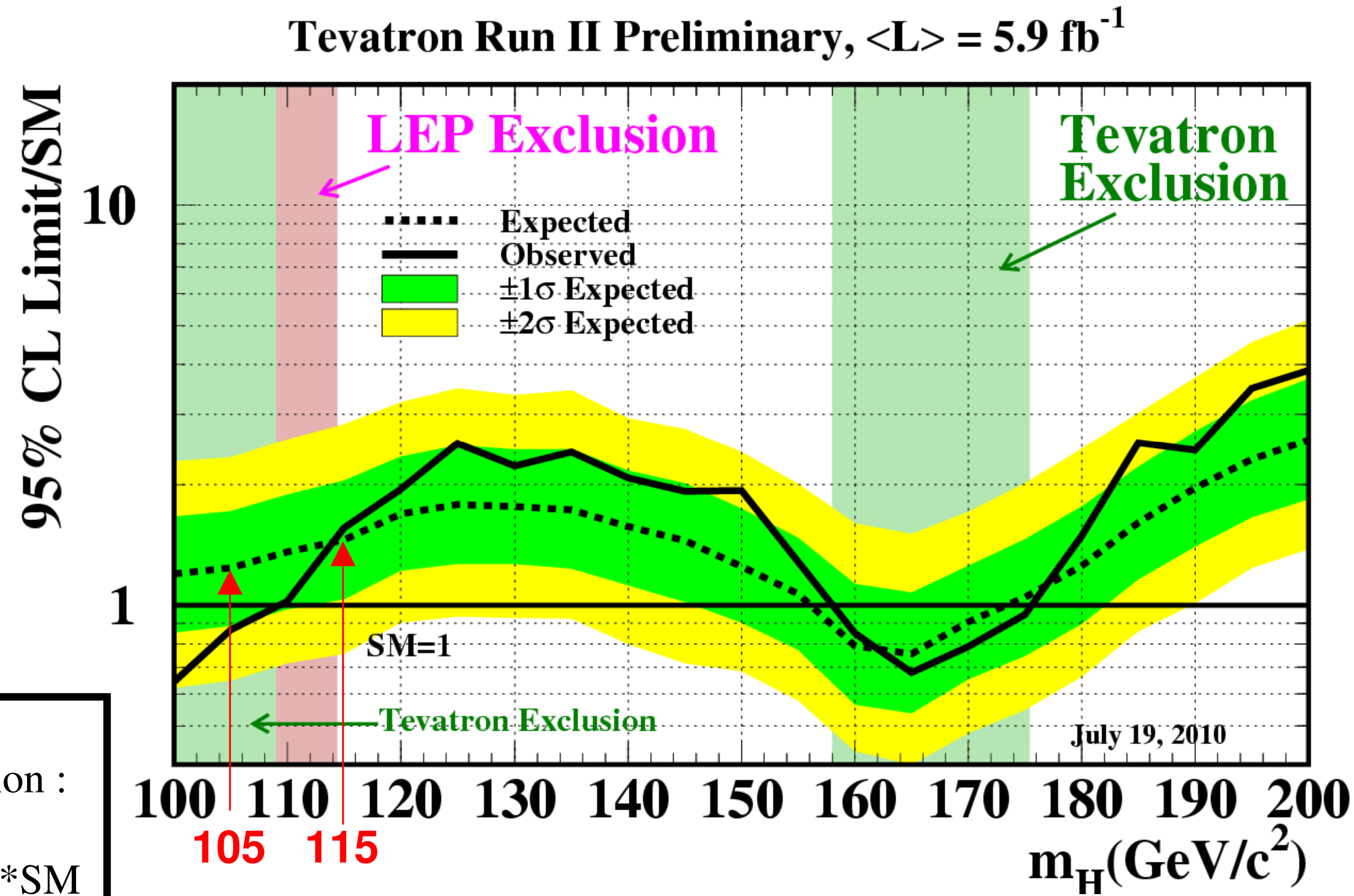




CDF/D0 Combinations



TEVATRON COMBINATION SUMMER 2010



Low mass sensitivity approaching LEP exclusion :

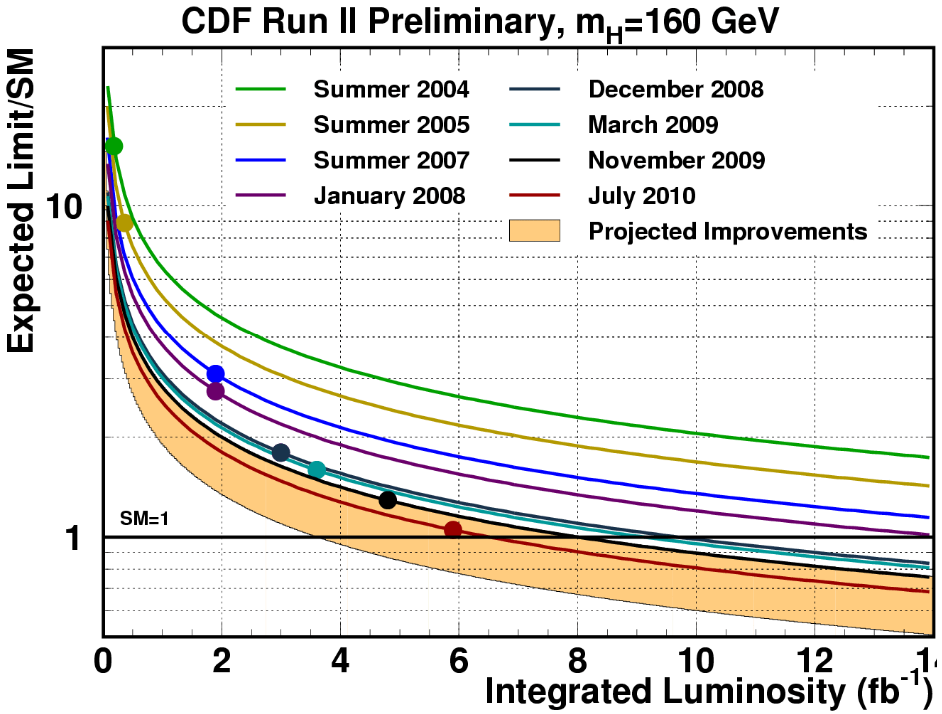
At M_H 105 GeV:

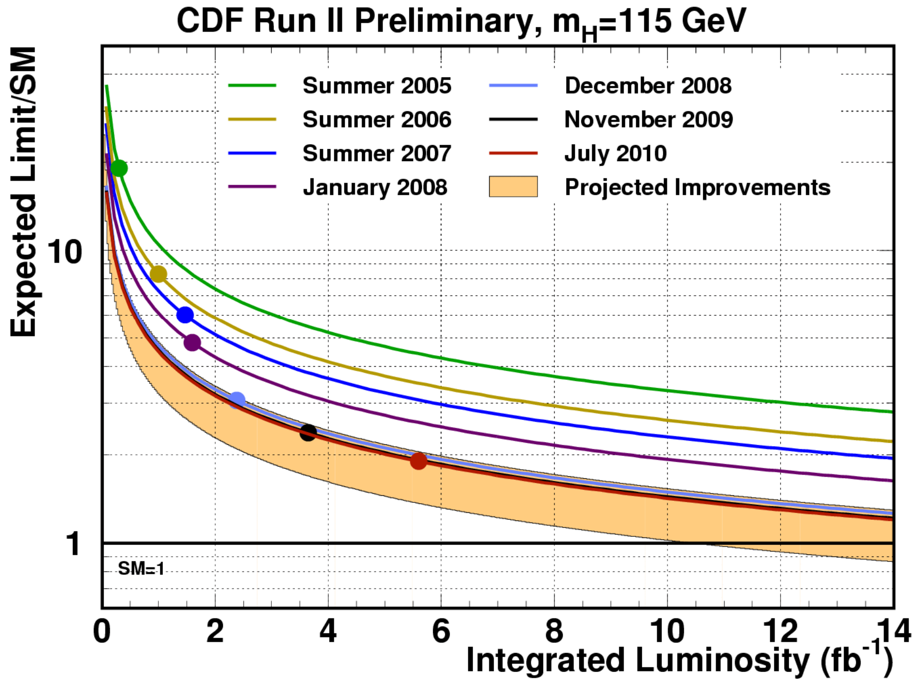
Expected Limit 1.24*SM

At M_H 115 GeV:

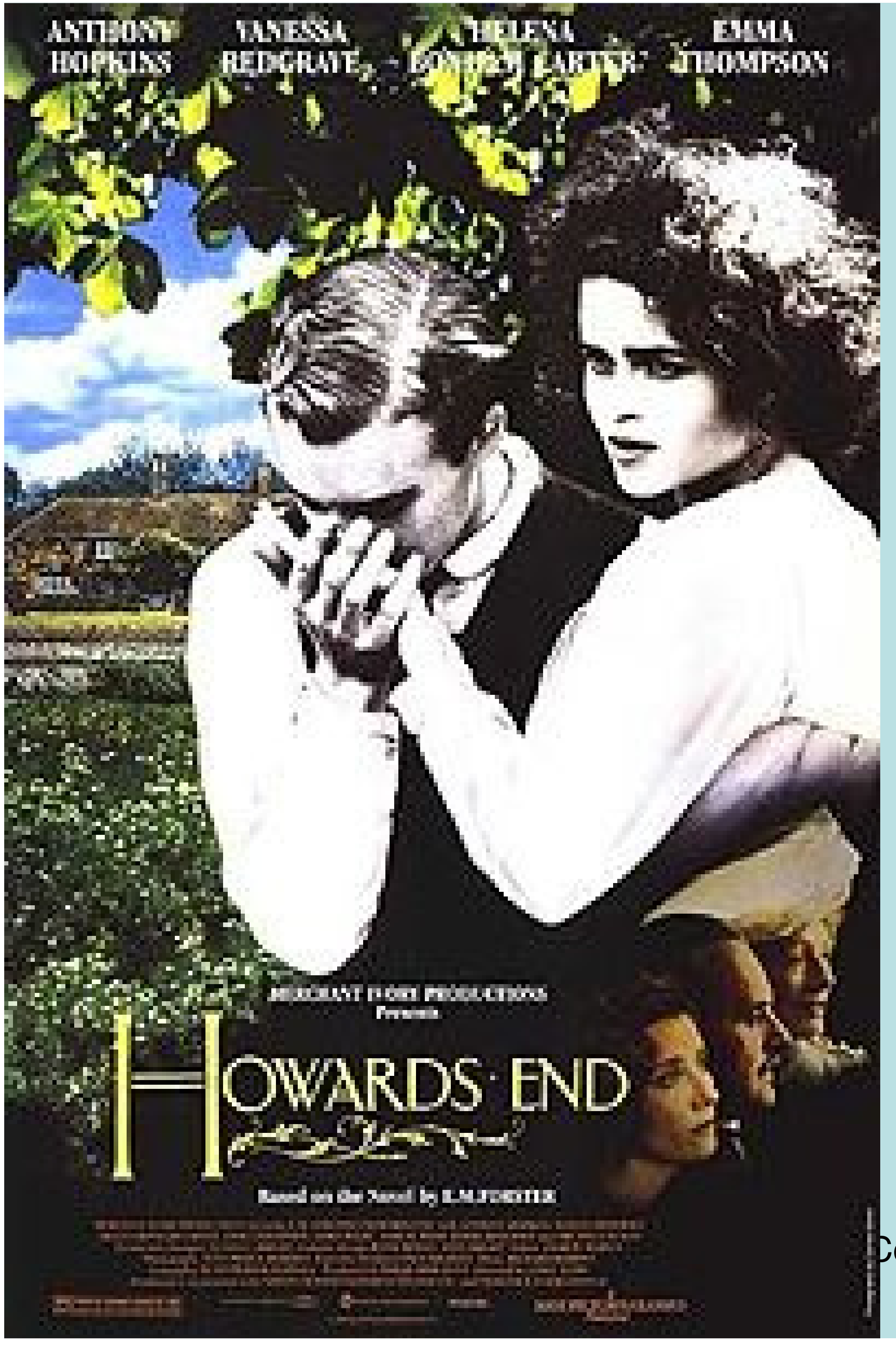
Expected Limit 1.45*SM

Perspectives high/low mass Higgs by end Run II





Delivered luminosity now ~8.5 fb^{-1} per experiment
Tevatron will deliver ~11 fb^{-1} per experiment by end of 2011



Finance issues

Scientific motivations

Politics

Si

TevatrOn Run III

No?

Manpower

Impact on the FNAL future

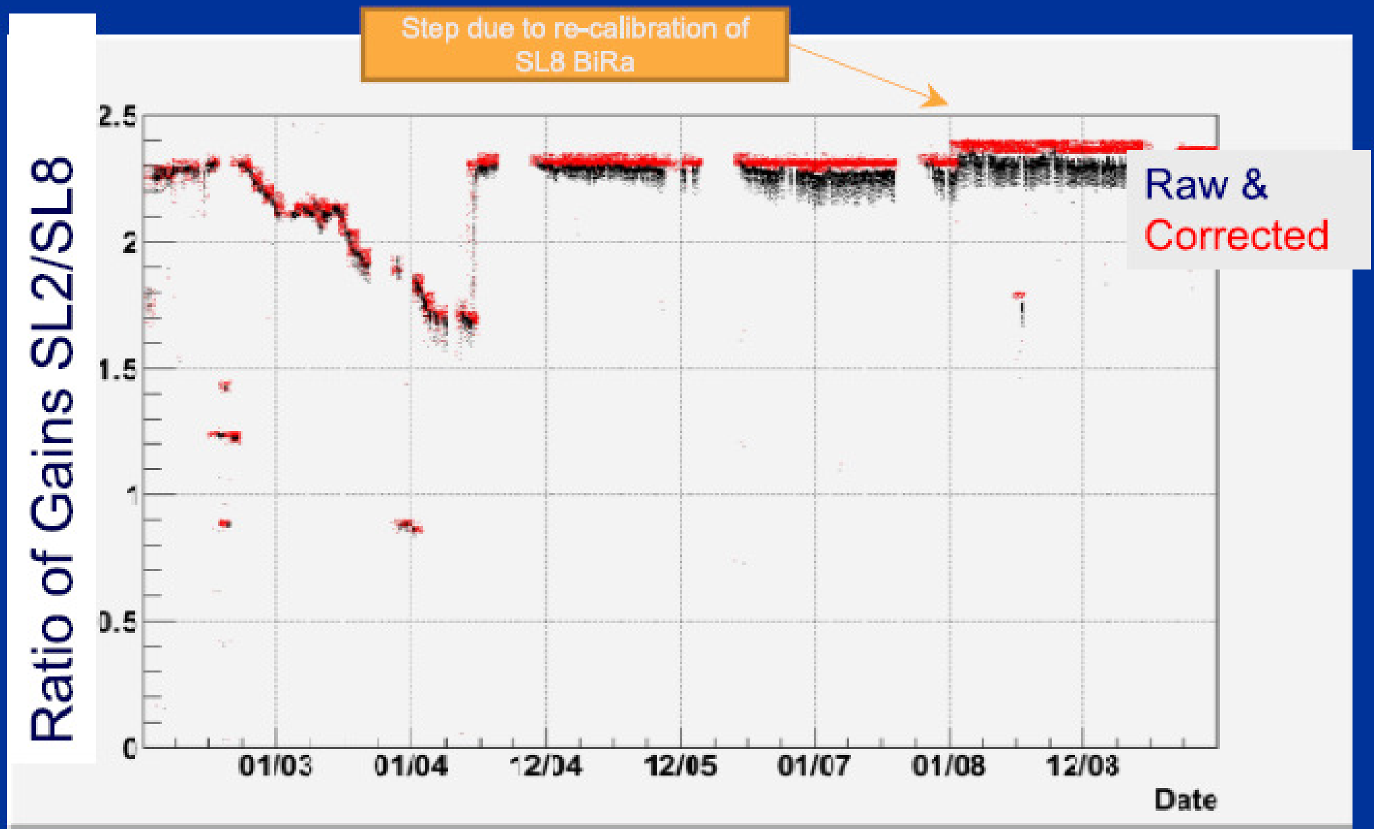
Detector aging

AGING

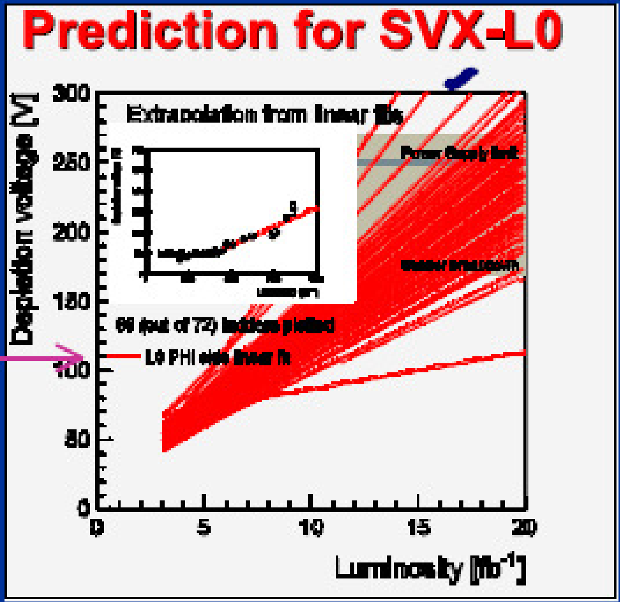
Courtesy G. Punzi (PAC Augst 2010)

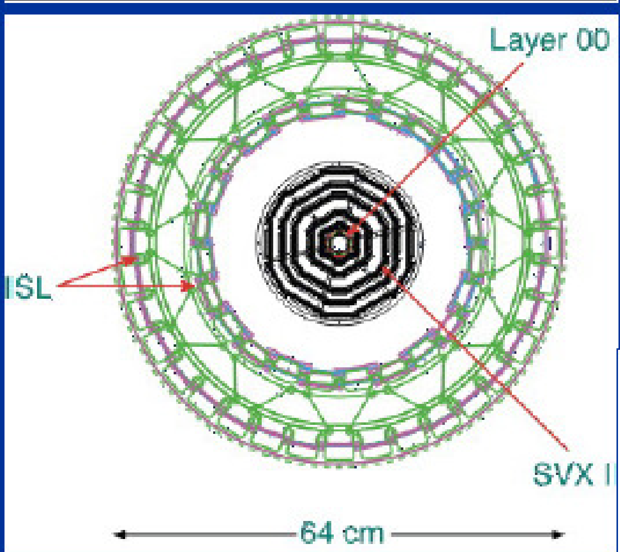
Wire aging in COT (main drift chamber)

- Since the recovery after adding O_2, the gain is steady.
- Example of the many things that are running well



we are here



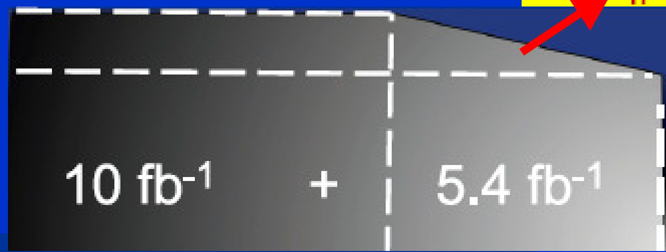


1. Accumulated radiation damage to Layer-0 of the SVX may prevent us to fully deplete silicon.
   - Loss in efficiency - Loss in b-tag - Lost Higgs efficiency
   - ACTION: EVALUATED IMPACT ON HIGGS SENSITIVITY

Overall sensitivity loss

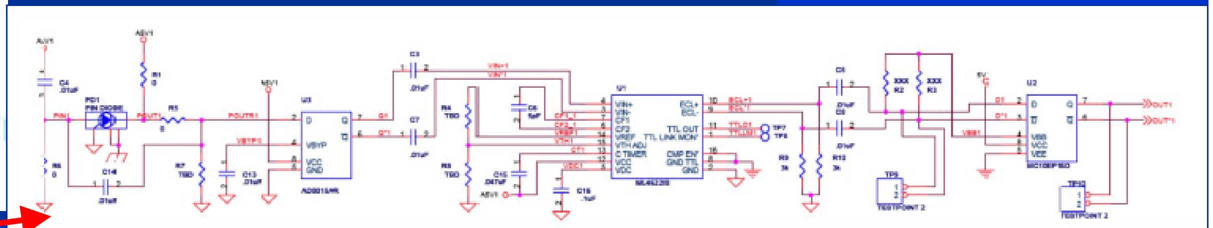
at m_H = 115 GeV : 2%
at m_H = 135 GeV : < 1%
at m_H = 160 GeV : ~0%

NO degrad.
20% loss



2. Radiation Damage to digital optical transmitters (DOIM) may prevent reading out some parts of the detector
   - ACTION: STUDIED IN MORE DETAIL AND PLANNED A FIX

Courtesy G. Punzi (PAC Augst 2010)



New amplifier board with more sensitive light receivers has been prepared as backup => no loss of ladders up to 20 fb-1

July 28, 2010

Dr. Steven Chu
Secretary of Energy
U.S. Department of Energy
1000 Independence Ave., SW
Washington, DC 20585

Cc: Dr. Steven E. Koonin,
DOE Under Secretary for Science
Cc: Dr. William F. Brinkman,
Director, DOE Office of Science
Cc: Dr. Dennis Kovar,
DOE Associate Director of Science for High Energy Physics
Cc: Dr. Joseph L. Dehmer,
NSF Associate Director, Physics Division
Cc: Dr. Pier Oddone,
Director, Fermilab

Dear Dr. Chu,

We are writing to alert you to an urgent and exceptional opportunity for U.S.-based high energy physics. Given the outstanding current performance of the Tevatron at Fermilab, coupled with the delays in the Large Hadron Collider at CERN, extended running of the Tevatron beyond the planned shutdown in 2011 offers an unanticipated opportunity for American science. The Tevatron has the potential to discover new phenomena – most notably the Higgs boson – more quickly than the LHC, and has unique features that complement LHC experiments. A premature shutdown would rob the U.S. program of valuable discovery opportunities.

Running the Tevatron through 2014 could produce the first direct evidence of a Higgs boson, a remarkable triumph for U.S. HEP and one of the most exciting scientific developments of this decade. The current plan to shut down the Tevatron at the end of FY11 was formulated some years ago, before the unanticipated delays at the LHC. The Tevatron now has the unique capacity to detect the expected low mass Higgs boson during the next few years. Even after LHC experiments find evidence for the Higgs boson, combining a bottom quark decay signal from the Tevatron with complementary decay signals from the LHC would help determine the properties of the Higgs particle, testing if it agrees with the simplest predictions, and furthermore help confirm the case for the Higgs particle interpretation.

July 28, 2010

Dr. Steven Chu
Secretary of Energy
U.S. Department of Energy
1000 Independence Ave., SW
Washington, DC 20585

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Prof. Frank Wilczek
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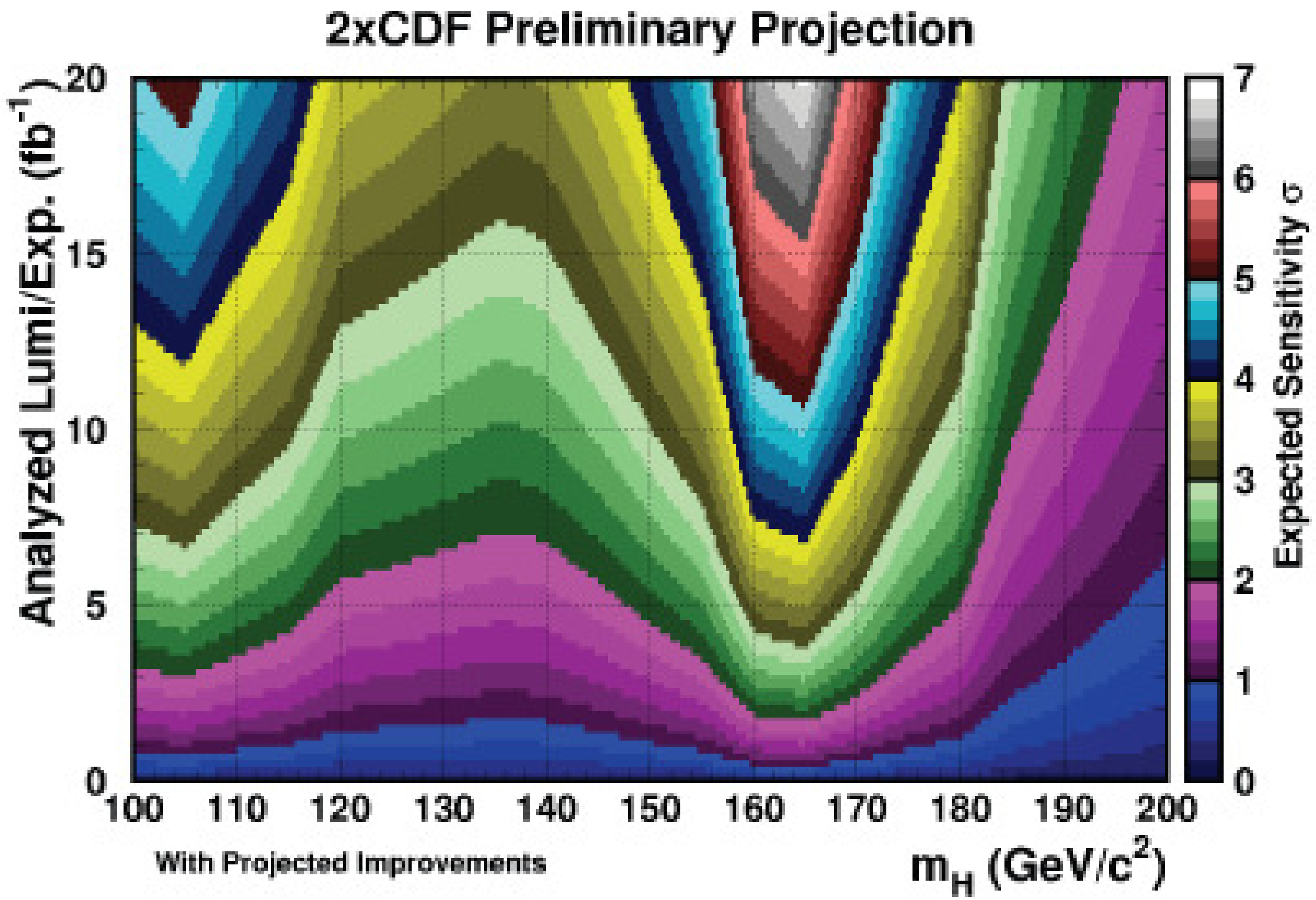
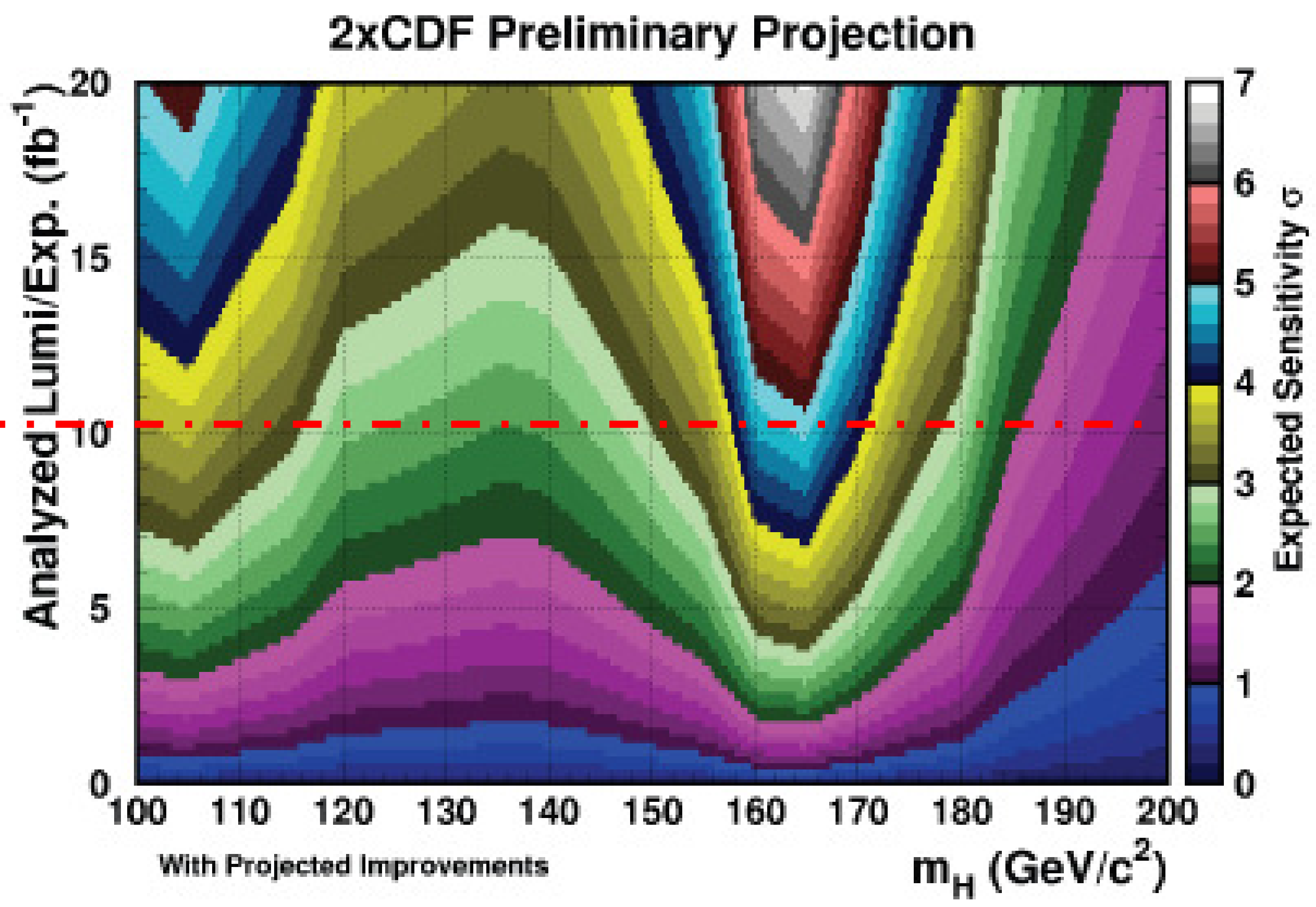
Prof. Edward Witten
Institute for Advanced Study

If there is only one reason to pursue…



If there is only one reason to pursue…

End of 2011:
>2.4σ expected sensitivity across mass range
3σ at 115 GeV

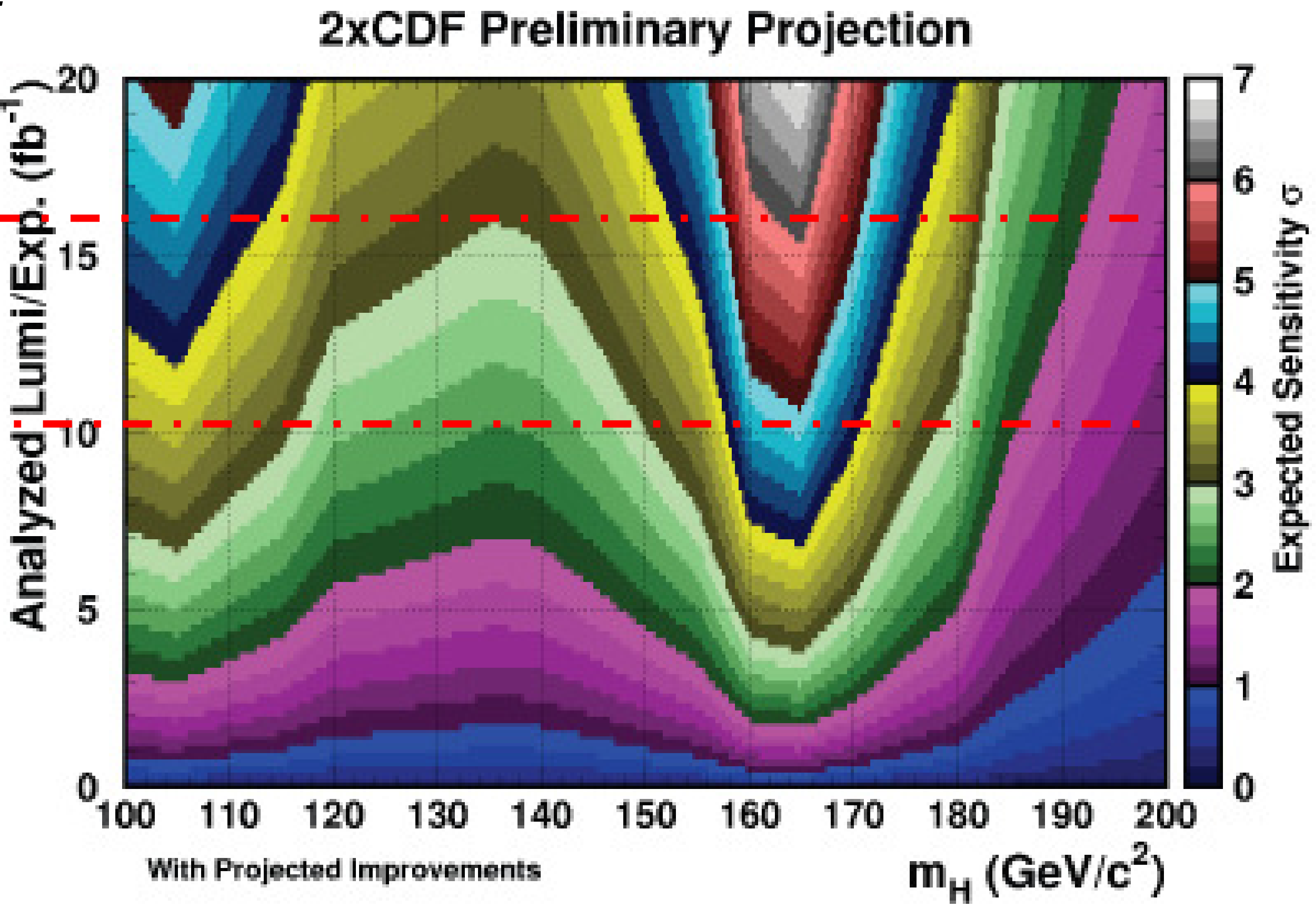


If there is only one reason to pursue…

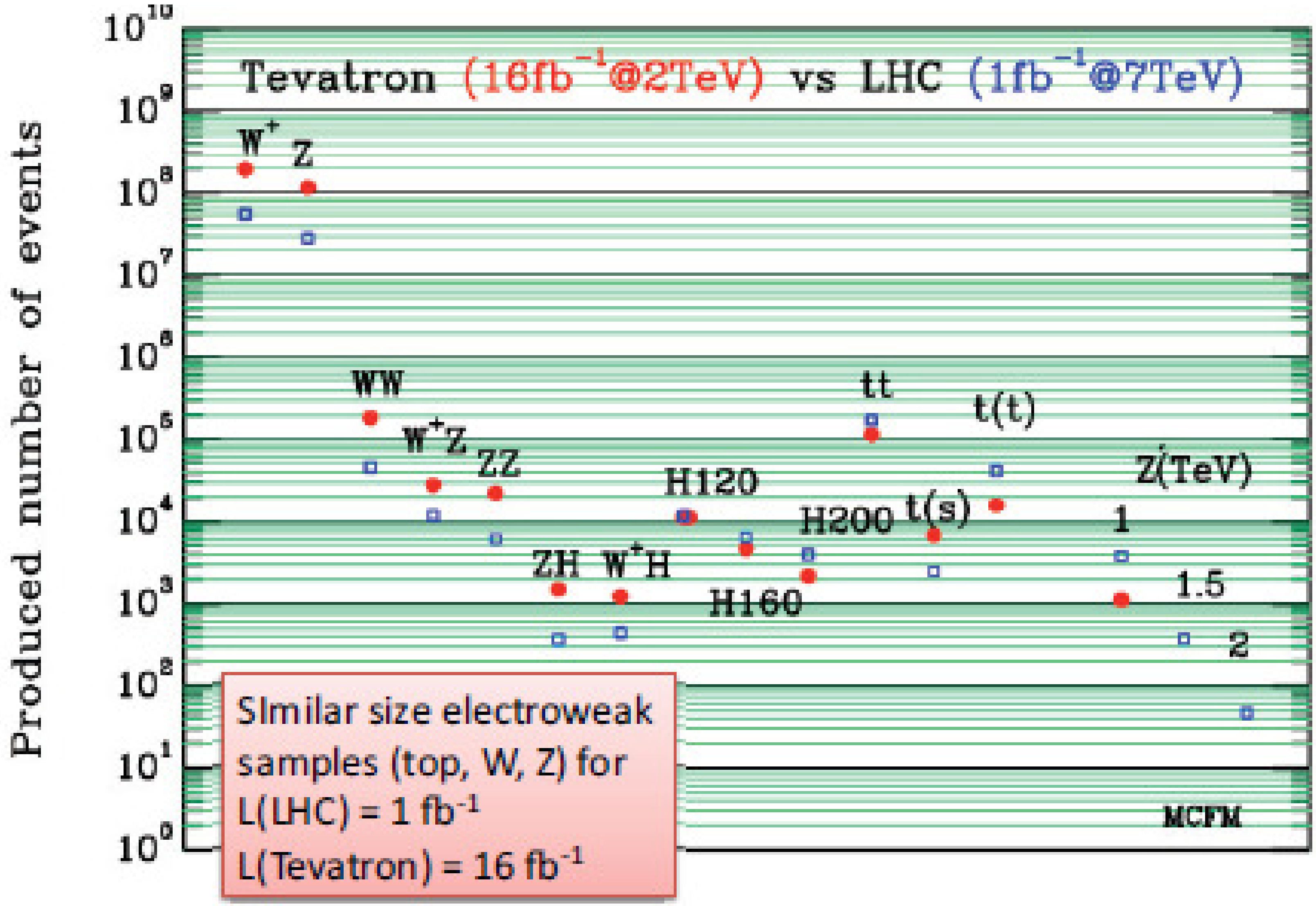
N.B. 16 fb-1 is the total expected registered luminosity per experiment with 3 more years of Tevatron run.

About 16 fb-1(*)
>3σ expected sensitivity from 100-185 GeV
4σ @ 115 GeV

End of 2011:
>2.4σ expected sensitivity across mass range
3σ at 115 GeV



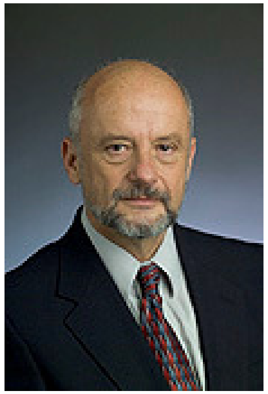
Tevatron vs LHC: complementarity & competition



Fermilab Today

September 1st 2010

Director's Corner



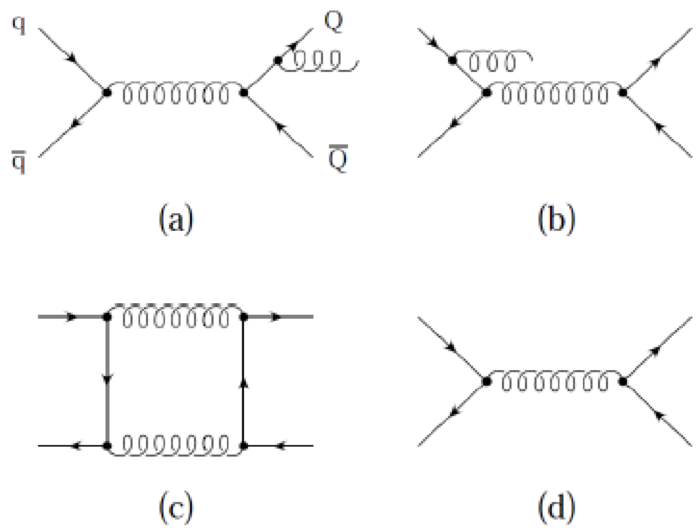
Last Friday we had a special meeting of the Physics Advisory Committee to address just one question: whether to recommend a proposed three-year extension of the Tevatron run. The Tevatron is now scheduled to close in September 2011. The PAC's recommendation was very strong. They recommended that we run the Tevatron in each of two proposed scenarios, one with additional funding in Fermilab's budget for Tevatron operations and one with no such extra funding. The committee's recommendation recognizes the extraordinary performance of the Tevatron and its remaining promise for the future. Extended running, combined with the predicted improvement in data analysis, would allow the Tevatron to make critical contributions to the discovery of the Higgs boson and our understanding of electroweak symmetry breaking. The combined potential of the Tevatron extension and early LHC running would constitute the optimal campaign to solve the central issue of particle physics. Many eminent members of the U.S. particle physics community have written to Secretary of Energy Steven Chu to express their support for more Tevatron running. The extension also motivates the collaborations to retain physicists and add new ones to carry out this program.

I have a dream….

Backup slides

AFB (TOP): backup

- Proton antiproton initial state is charge asymmetric, but strong interaction is not sensitive to the charge:
  - LO: kinematic distributions in production are charge symmetric
  - NLO 2→2, LO 2→3: expect (5—10)% asymmetry (higher order corrections are small)
  - NLO 2→3: reduce expected asymmetry significantly ⇒ strong dependence from phase space region
- SM asymmetry is small, so asymmetry is a sensitive variable to test the new physics contribution.
- A charge asymmetry can be observed as forward-backward asymmetry defined as



See e.g.:

- J. H. Kuhn and G. Rodrigo, Phys. Rev. D 59, 054017 (1999)
- O. Antunano, J. H. Kuhn and G.Rodrigo, Phys. Rev. D 77, (2008)

TOP A_{FB} at Tevatron: motivation

- In QCD Leading Order, top production is symmetric.
- In NLO the soft Coulomb field of an incoming light quark repels the quark top to larger rapidity, while attracting the antitop quark to smaller rapidities, creating a positive asymmetry at large rapidity, as defined by the quark direction.

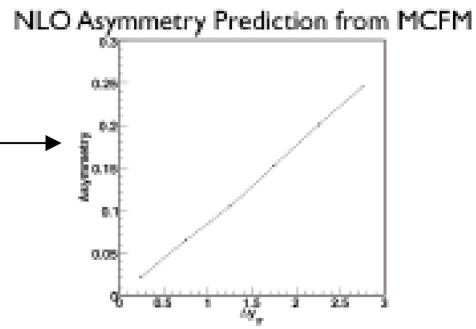
The MCFM NLO parton level MC (K. Ellis et al.) predicts:

$$A_{lab}=0.038\pm0.006 \text{ and } A_{ttbar}=0.058\pm0.009$$

The QCD terms responsible for the QCD asymmetry are proportional to the β of the top/antitop quarks in the center of mass, so the asymmetry increases with the rapidity separation of the two quarks:

MCFM predicts a linear rise of Afb from:

0.05 at $|\Delta y|=0.5$ up to 0.23 at $|\Delta y|=2.5$.



A number of models BSM predicts much higher asymmetries ex: Z', extra dimension Etc..

Importance of A_{FB} at Tevatron: dominated by qqbar process

TOP Forward-Backward Asymmetry

Compare the number of top and antitop produced with momentum in a given direction:

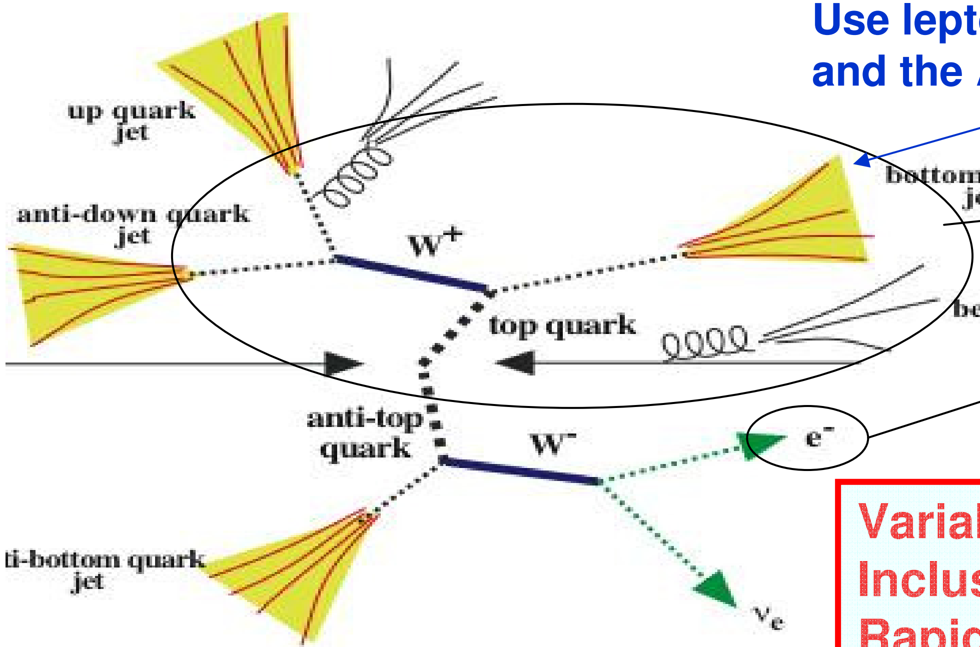
$$A_{fb} = \frac{N_t(p) - N_t(\bar{p})}{N_t(p) + N_t(\bar{p})}$$

Top (antitop) moving against or in the same direction in the Lab or the ttbar rest frames

$$A_{fb} = \frac{N_t(\cos(\theta) > 0) - N_t(\cos(\theta) < 0)}{N_t(\cos(\theta) > 0) + N_t(\cos(\theta) < 0)}$$

Choose to express it with θ the angle between the Top momentum and the p beam direction.

Use lepton +jet to distinguish between the Top and the Antitop signature in the same event



Use the hadronic side to measure top rapidity. → Y_{had}

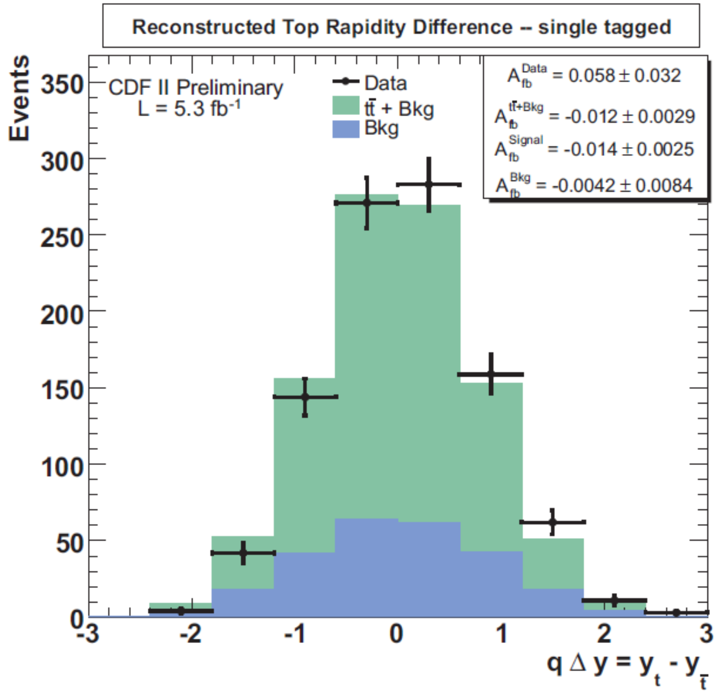
Tag top vs tbar with lepton charge. → Q_l

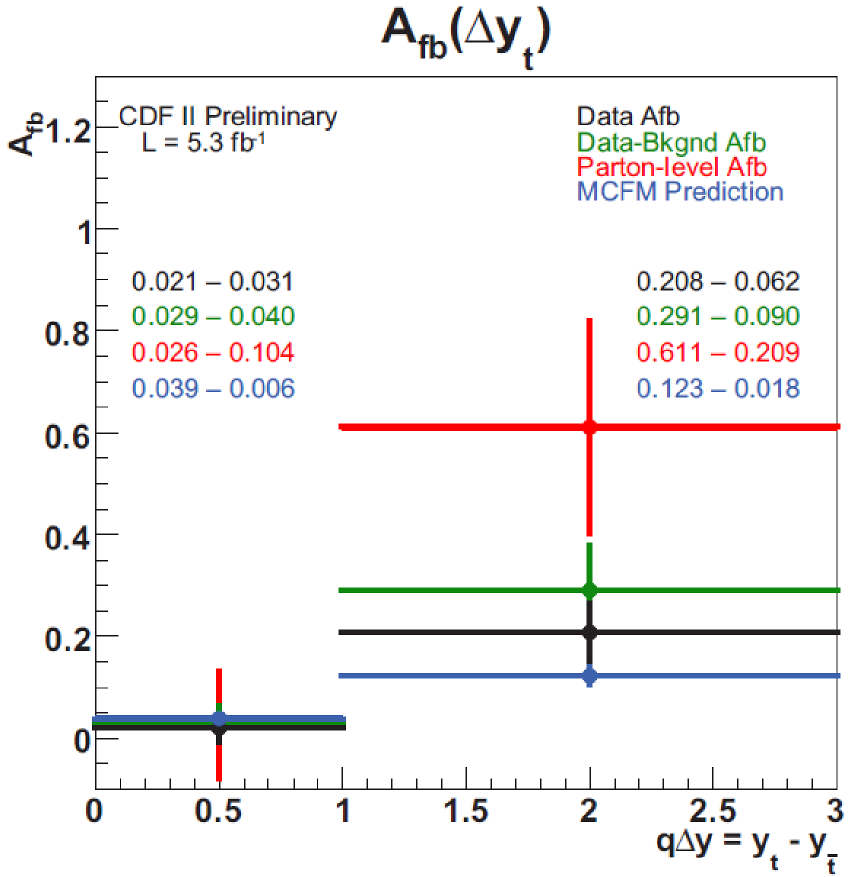
q_l	t_{lep}	t_{had}
$+$	t	$\bar{t}$
$-$	$\bar{t}$	t

Variables => calculate A_{FB}
Inclusive: $-QY_{had} = Y_{top} = -Y_{antitop}$
Rapidity-dependent:
$Q(Y_{lep} - Y_{had}) = Q\Delta Y = Y_{top} - Y_{antitop}$

N.B.The new results from CDF, with 5.3fb^{-1} data distinguishes between top & anti-t Afb

ALL NEW RESULTS:



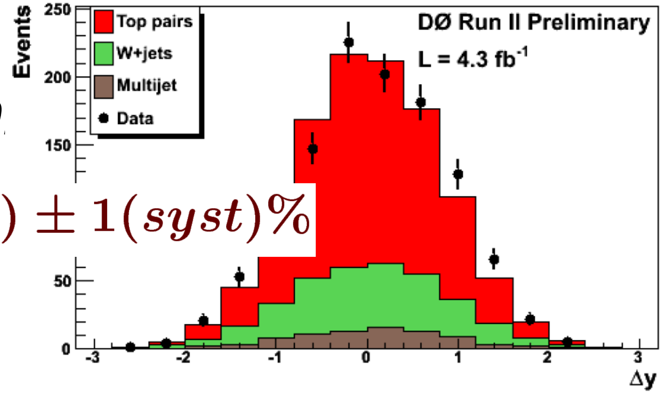


A_{FB} (ppbar) = 0.150 ± 0.050stat ± 0.024syst

A_{FB} (ttbar) = 0.158 ± 0.072stat ± 0.017syst

Results from D0

$$A_{fb}^{obs} = 8 \pm 4(stat) \pm 1(syst)\%$$



For |Δy|<1.0, A_{FB}ttbar=

= 0.026 ± 0.104stat ± 0.055syst

For |Δy|>1.0 A_{FB}ttbar=

= 0.611 ± 0.210stat ± 0.141syst

Currently about 2.7σ dev./SM

More data needed!!