ATLAS-CMS Physics Program I

Standard Model Measurements

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Presentation

I. Introduction
II. Proton-Proton collisions
III. Differential Inclusive Jet Cross-Section
IV. Electroweak Sector

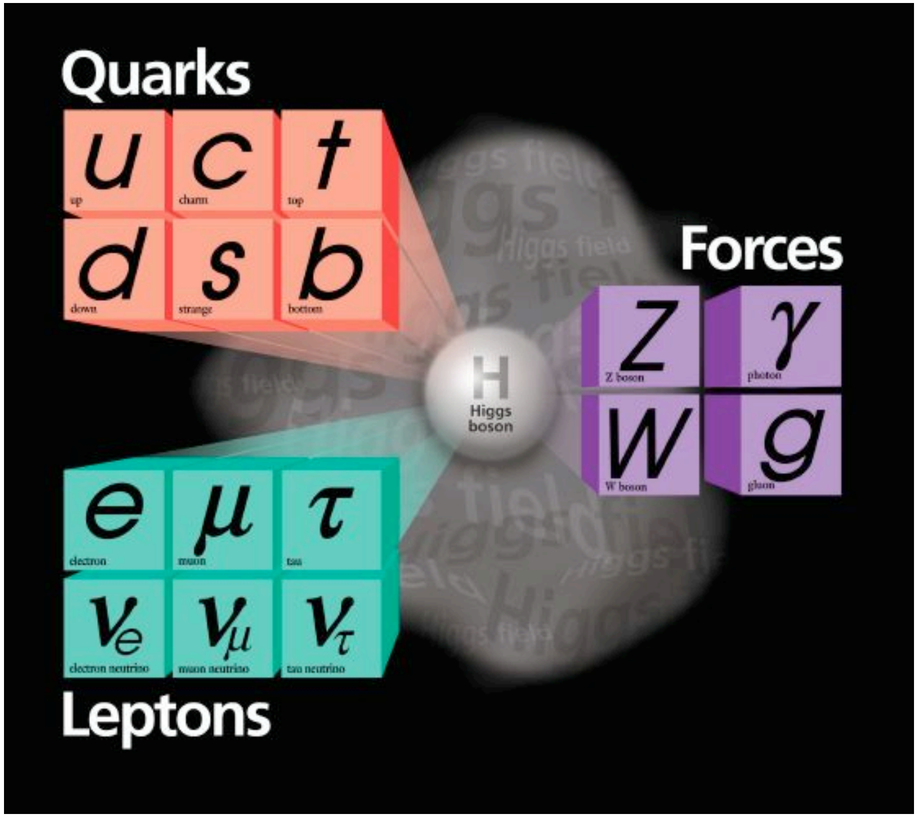
V. The Higgs Search (this afternoon)
VI. Beyond the Standard Model
in Albert De Roeck's lecture

Credits

- Most of the figures/plots presented here are mainly taken from the two
  physics books of ATLAS & CMS
  Expected Performance of the ATLAS Experiment Detector, Trigger, Physics
  CMS Physics TDR

- I was inspired by the lectures/presentations prepared by
  - Beate Heinemann (CERN summer students)
  - Mohamed Aharrouche (Gomel summer school 2009)
  - Fabiola Gianotti
  - Lucia di Ciaccio, Nathalie Besson, Marco Delmastro, Louis Fayard
  - and many more

Introduction: Fundamental Particles & Forces



- Matter
  - made out of fermions
- Forces
  - mediated by bosons
- Higgs boson
  - breaks the electroweak symmetry and gives mass to fermions and weak gauge bosons
- All colliders experiments data are very well described by the Standard Model (SM) but the Higgs boson has not been observed

Introduction: The Standard Model Lagrangian

$$\mathcal{L} = -\frac{1}{4}F^a_{\mu\nu}F^{a\mu\nu} + i\bar{\psi}D\psi$$
$$+ \psi_i\lambda_{ij}\psi_j h + \text{h.c.}$$
$$+ |D_\mu h|^2 - V(h)$$
$$+ \frac{1}{M}L_i\lambda^\nu_{ij}L_j h^2 \text{ or } L_i\lambda^\nu_{ij}N_j$$

gauge sector

flavour sector

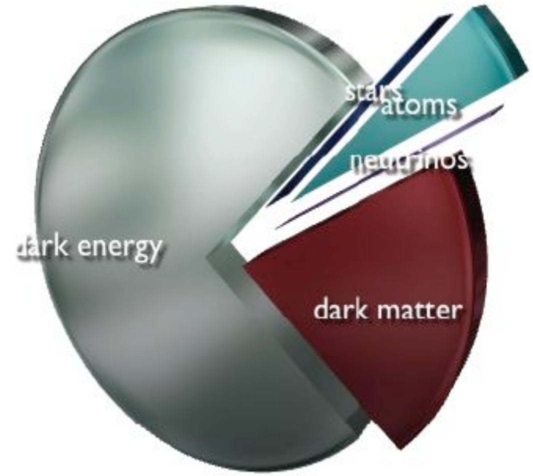
EWSB sector

ν mass sector

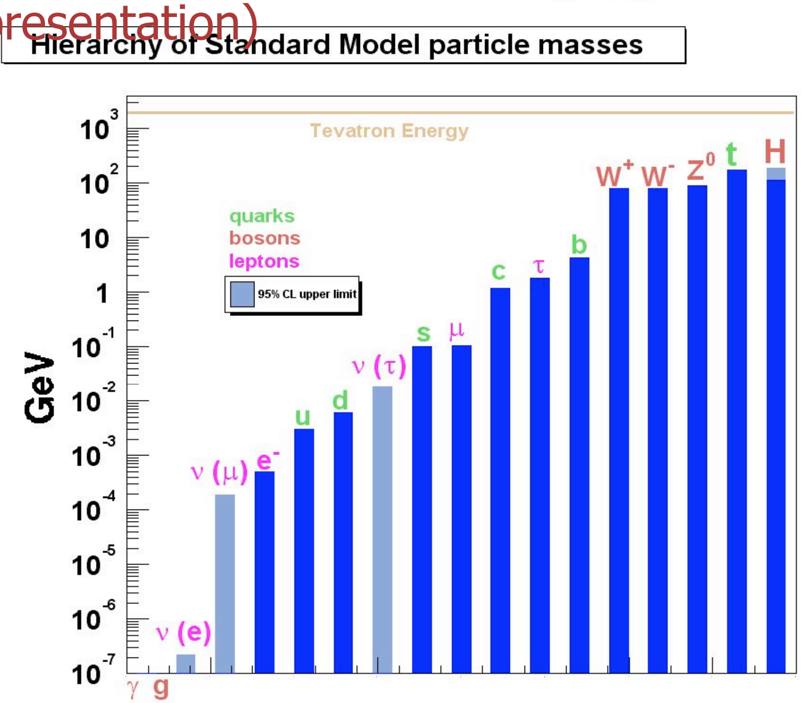
… and beyond?

supersymmetry (many variants)
extra spacetime dimensions
compositeness
strong electroweak symmetry breaking
…
something new?!

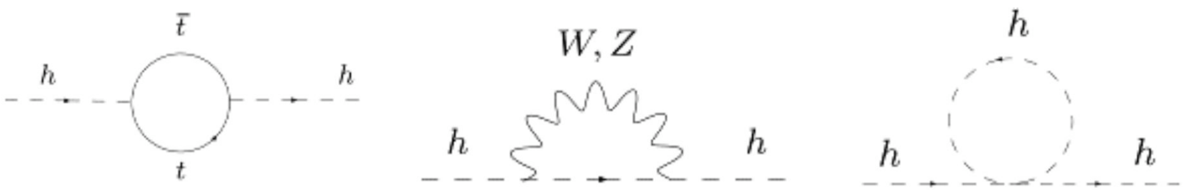
Introduction: What is not described by SM ?



- Where is the Higgs boson?
- SM only account for 20% of the matter in the universe
- Only matter in the universe; where has anti-matter gone ?
  - SM can only account for a small fraction of the observed CP violation (See M. Pepe's presentation)
- Hierarchy problem
- And more
  - number of fermions generations
  - particles mass spectrum
  - EW & strong interactions do not unify inside the SM
  - SM has no gravity
  - What is dark energy?



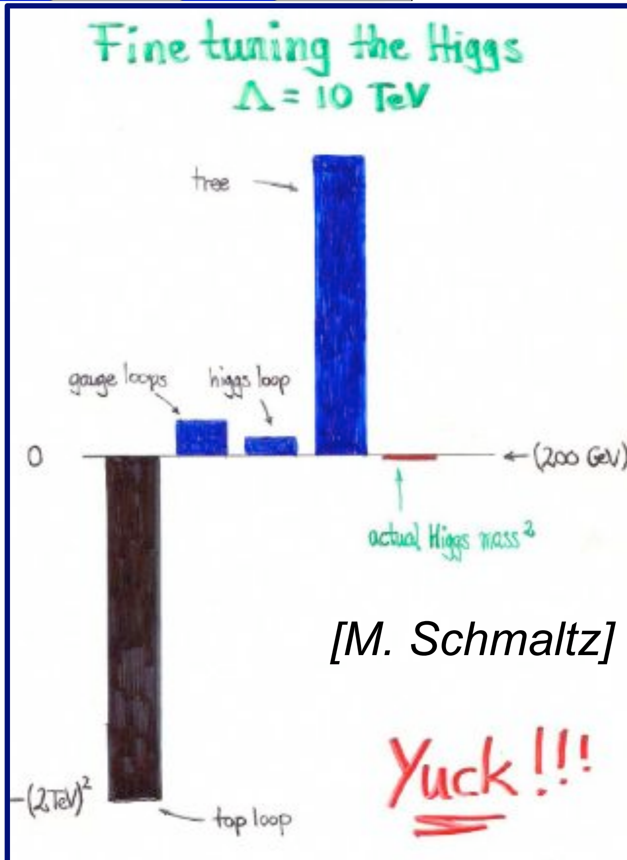
Hierarchy problem



$$m^2_H \approx (200\ \mathrm{GeV})^2 = m^2_{H}{}^{tree} + \delta\, m^2_{H}{}^{top} + \delta\, m^2_{H}{}^{gauge} + \delta\, m^2_{H}{}^{higgs}$$

$v^2 = (\sqrt{2}\cdot G_F)^{-1} \Longrightarrow v \sim 246\ \mathrm{GeV}$

- Why is gravity so weak?
  - $M_W/M_{Planck} \sim 10^{16}$ or $G_F/G_N \sim 10^{32}$
- Free parameter $m^2_{H}{}^{tree}$ needs to be fine-tuned to cancel huge corrections
- Can be solved by presence of new particles at M~1 TeV



[M. Schmaltz]

Introduction

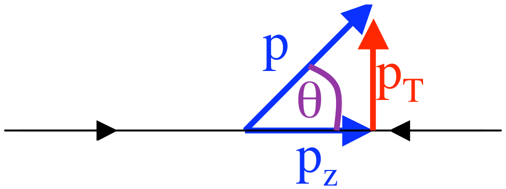
- LHC was invented in the 80's to find the Higgs boson and probe the physics beyond the Standard Model
- CMS & ATLAS were conceived, designed & built to detect everything:
  - e, μ, γ, jets
  - E_T^{miss}

  and reconstruct particles such as
  - W&Z, SM Higgs
  - SUSY particles (neutralino, Higgsino)
  - Compositness
- But, a final state (such as a γγ pair) does not come with a label such as
  - Higgs
  - double bremsshtralung
  - or $q\bar{q}\rightarrow\gamma\gamma$
- The work consists in identifying the particles, rejecting & measuring the background

Introduction

- The experimental method follows the successive steps like:
  - Understanding of the detector (see Peter Jenni’s presentation for ATLAS)
  - Measuring simple variables and comparing them to expectations
  - Reconstructing known physics objects such as:
    - e, μ, jets, E_T^{miss}
    - pairs of leptons: Z, J/ψ, ϒ
    - leptons + E_T^{miss}
    - top events: leptons+jets+ E_T^{miss}
  - Looking outside the fence for new signatures

Usual variables used to describe events in hadrons colliders



- Transverse momentum p_T is a Lorentz invariant
  - Particles flowing along the beam pipe ($\theta<3^o$) have $p_T \sim 0$
  - Visible transverse momentum is conserved $\sum_i p_T^i \sim 0$
    - Very useful variable
- Longitudinal momentum and energy p_Z and E
  - Particles that escape detection have large p_Z
  - Visible p_Z is not conserved
    - This is not a very useful variable
- Polar angle, rapidity & pseudo-rapidity: θ, y, η
  - θ is not Lorentz invariant
  - y is an invariant
  - $\eta = y(M=0)$

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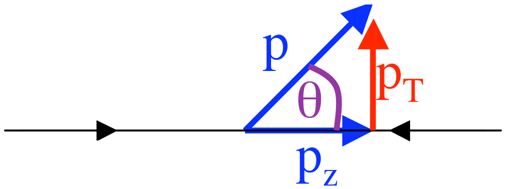

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$$\boxed{y = \frac{1}{2}\log\frac{E + p_z}{E - p_z}}$$

$$\boxed{\eta = -\log\tan\frac{\theta}{2}}$$

Usual variables used to describe events in hadrons colliders

- Cone ΔR
  - Solid angle often used to define a region around a particle (or a jet of particle) direction
    - Jet reconstruction
    - Isolation around leptons, photons,…….

- E_T^{miss}
  - Important variable: measures the transverse momentum carried by neutrinos (or any non interacting particle)
  - Very sensitive to noise in the detector

$$\boxed{\not{E}_{x,y}^{\mathrm{Calo}} = - \sum_{\mathrm{TopoCells}} E_{x,y}.}$$

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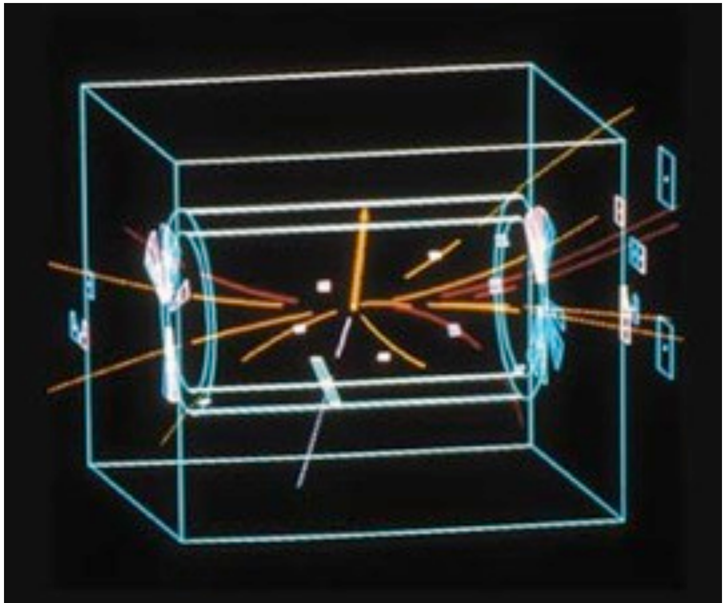


Collider luminosity $\mathscr{L}$

- Luminosity is given by the beam optics:

$$\boxed{L = \frac{N_b^2 n_b f_{rev} \gamma_r}{4\pi \epsilon_n \beta^*} F}$$

- $N_{events} = \mathscr{L} \times \sigma$
  - Experiments count the number of events
  - $\mathscr{L}$ has to be known to be able to measure cross sections
    - At first, use $\mathscr{L}$ provided by LHC (±10%)
    - Dedicated detectors, measuring events from known cross-section will be used, will ultimately provide a measurement of the luminosity to ±2-3%

The road

1000 evts/pb

Higgs discovery sensitivity (M_H=130~500 GeV)

Explore SUSY & NP to m ~ TeV

SM Precision measurements

√s=14 TeV

100 evts/pb

Understand SUSY and Higgs background from SM

More accurate alignment & EM/Jet/ETmiss calibration

Early discoveries

10 evts/pb

Initial detector & trigger synchronization, commissioning, calibration & alignment, material

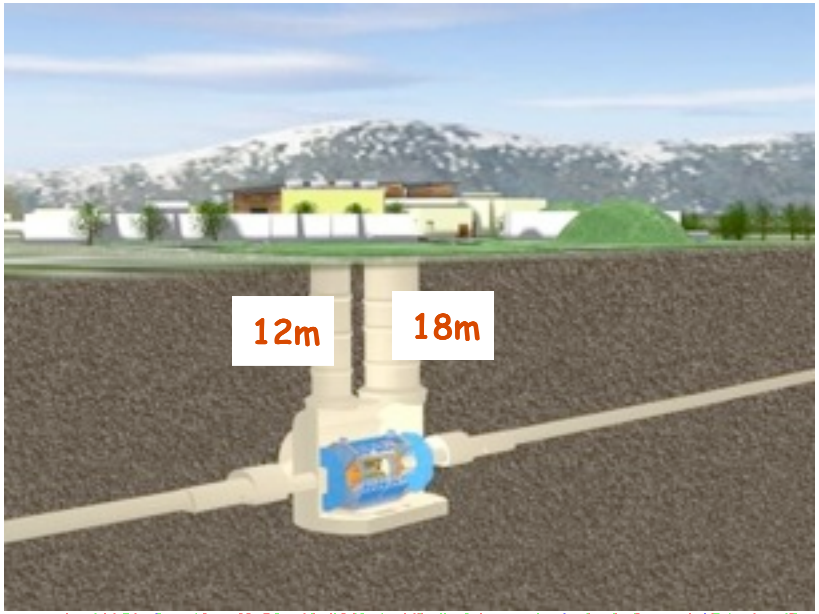
Rediscover SM processes

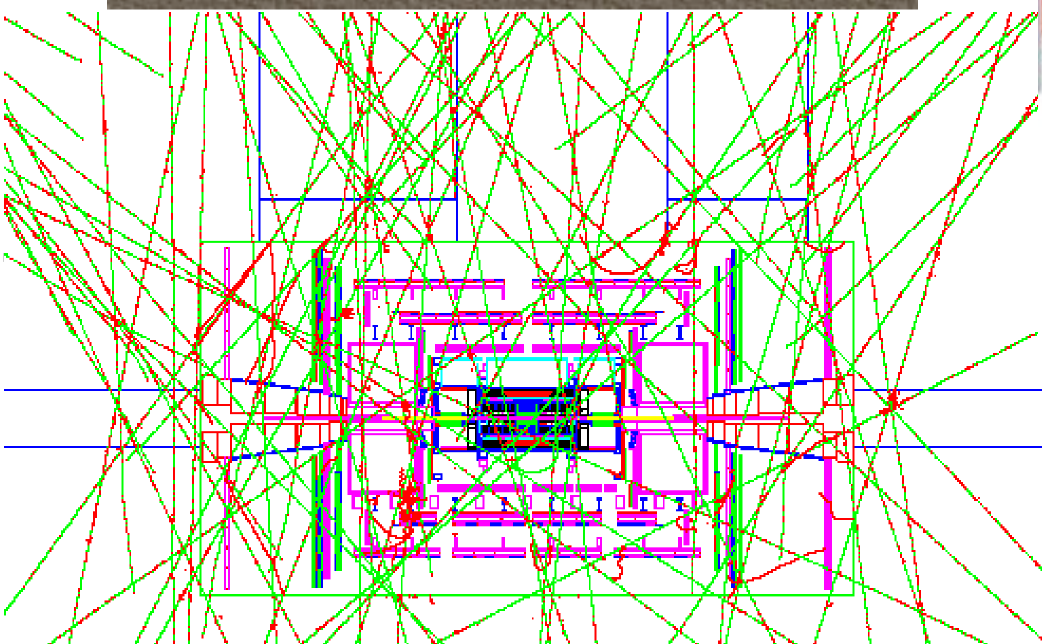
√s~7 TeV

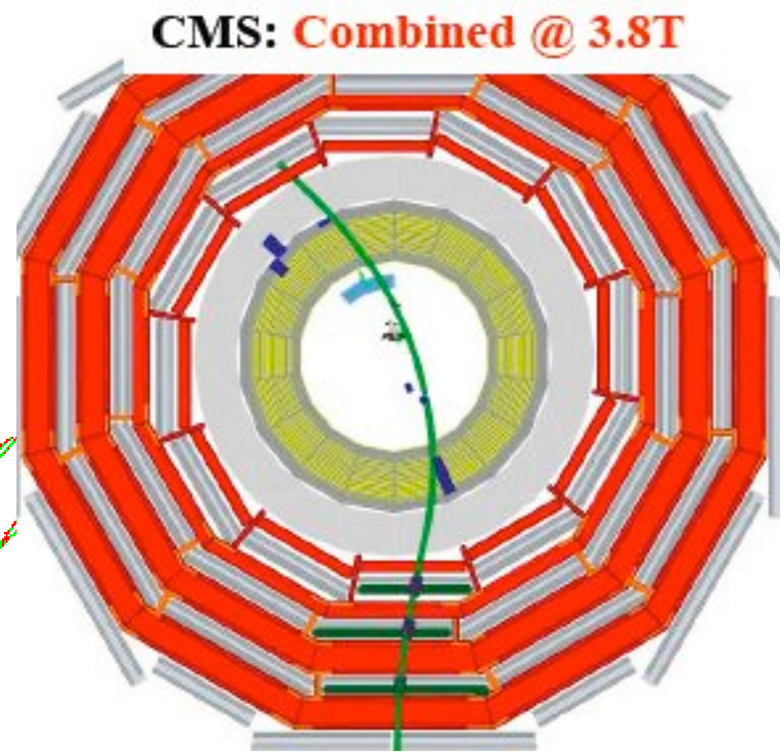
Cosmic muons - calibration

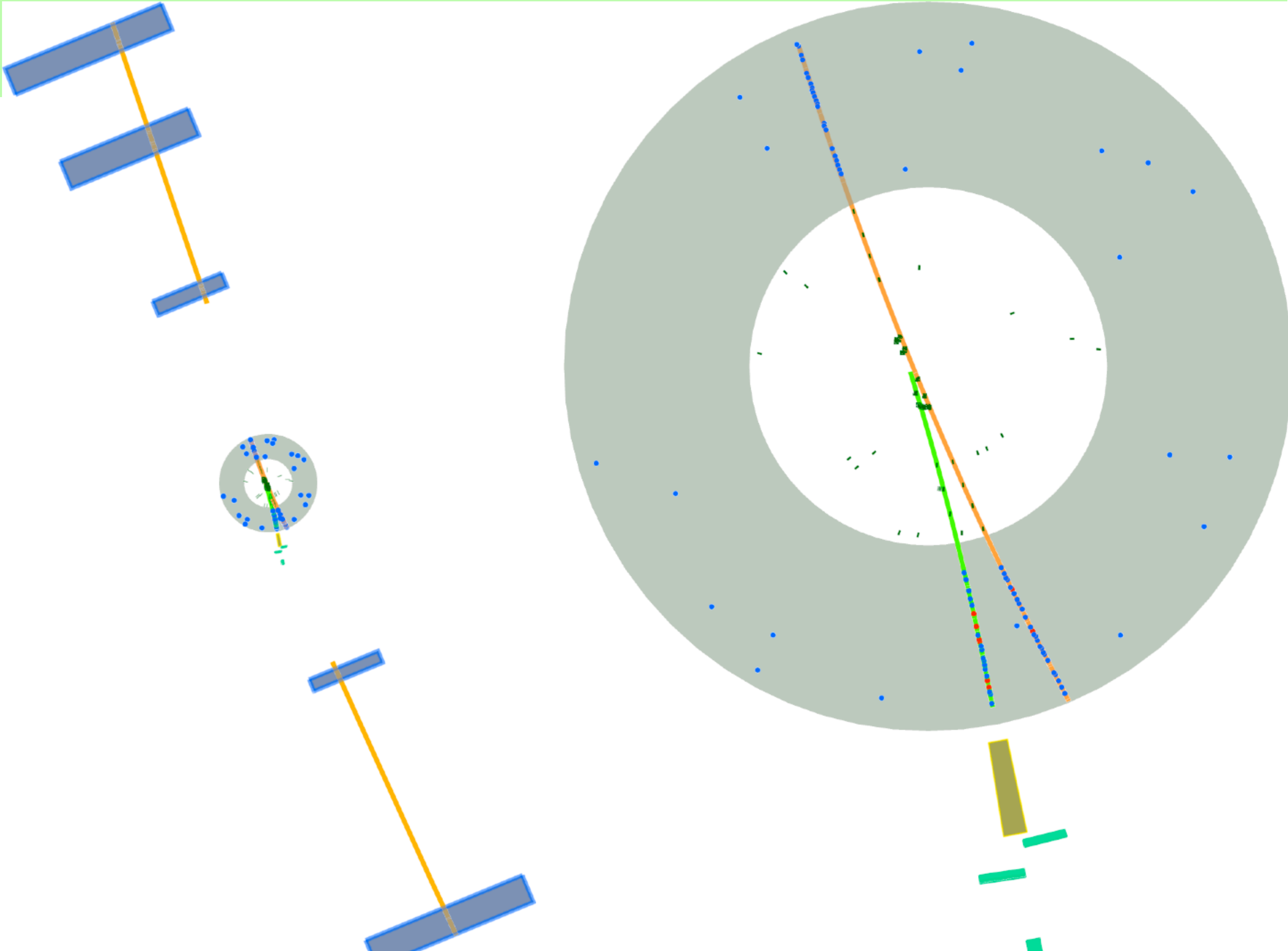
time

Cosmic muons in ATLAS & CMS



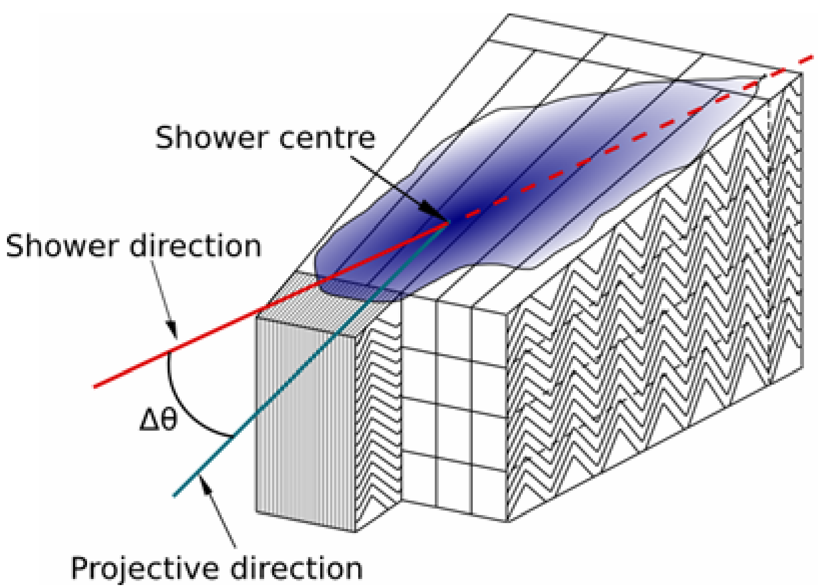


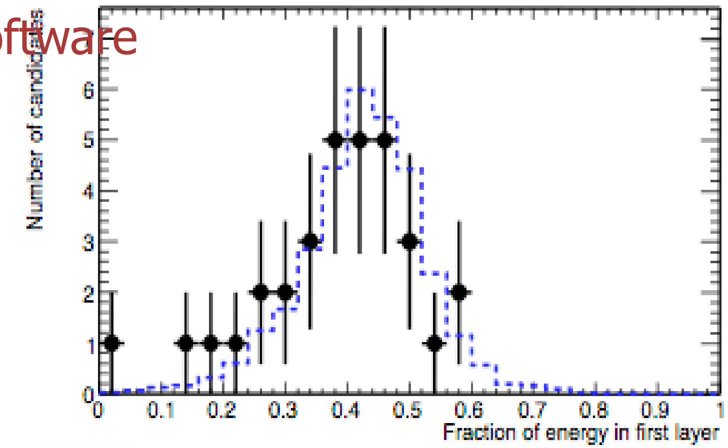


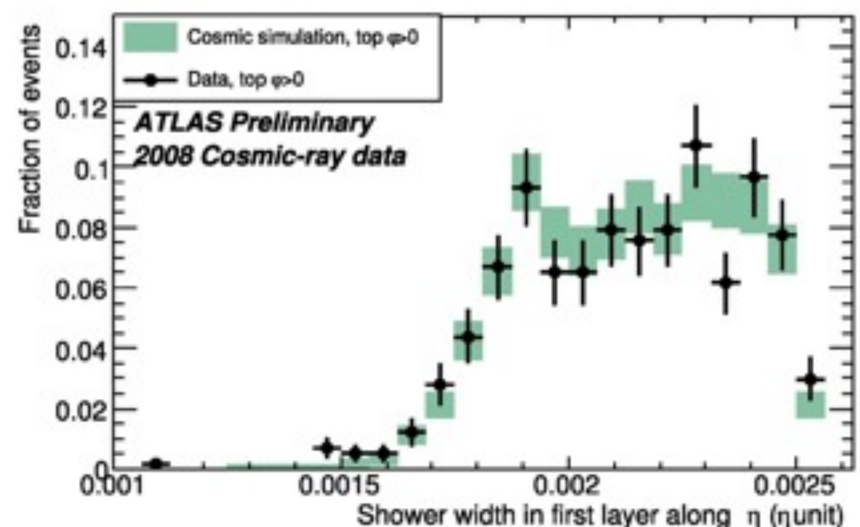


Detector performance

- Detector commissioning is prior to any analysis; ATLAS & CMS have been running since installed (2006-2008) and have mainly collected cosmic muons
  - Check detector readout & reconstruction software
  - Adjust timing alignment

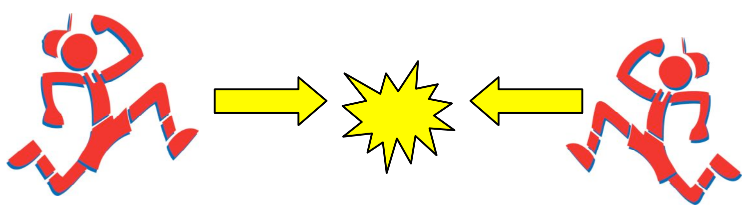




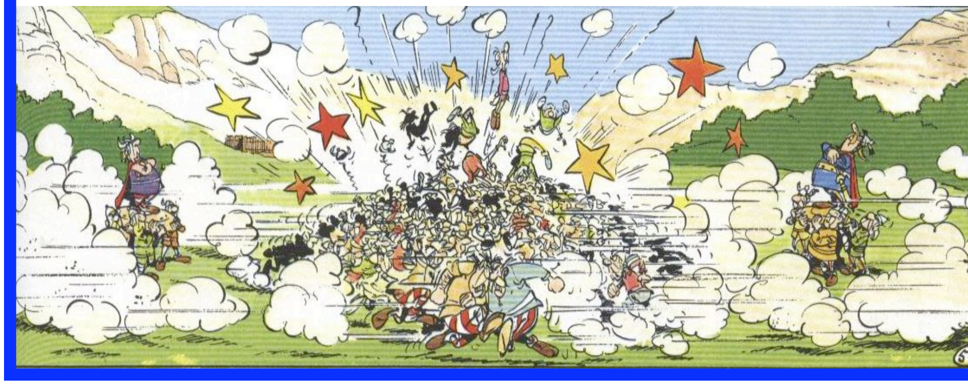


Colliders

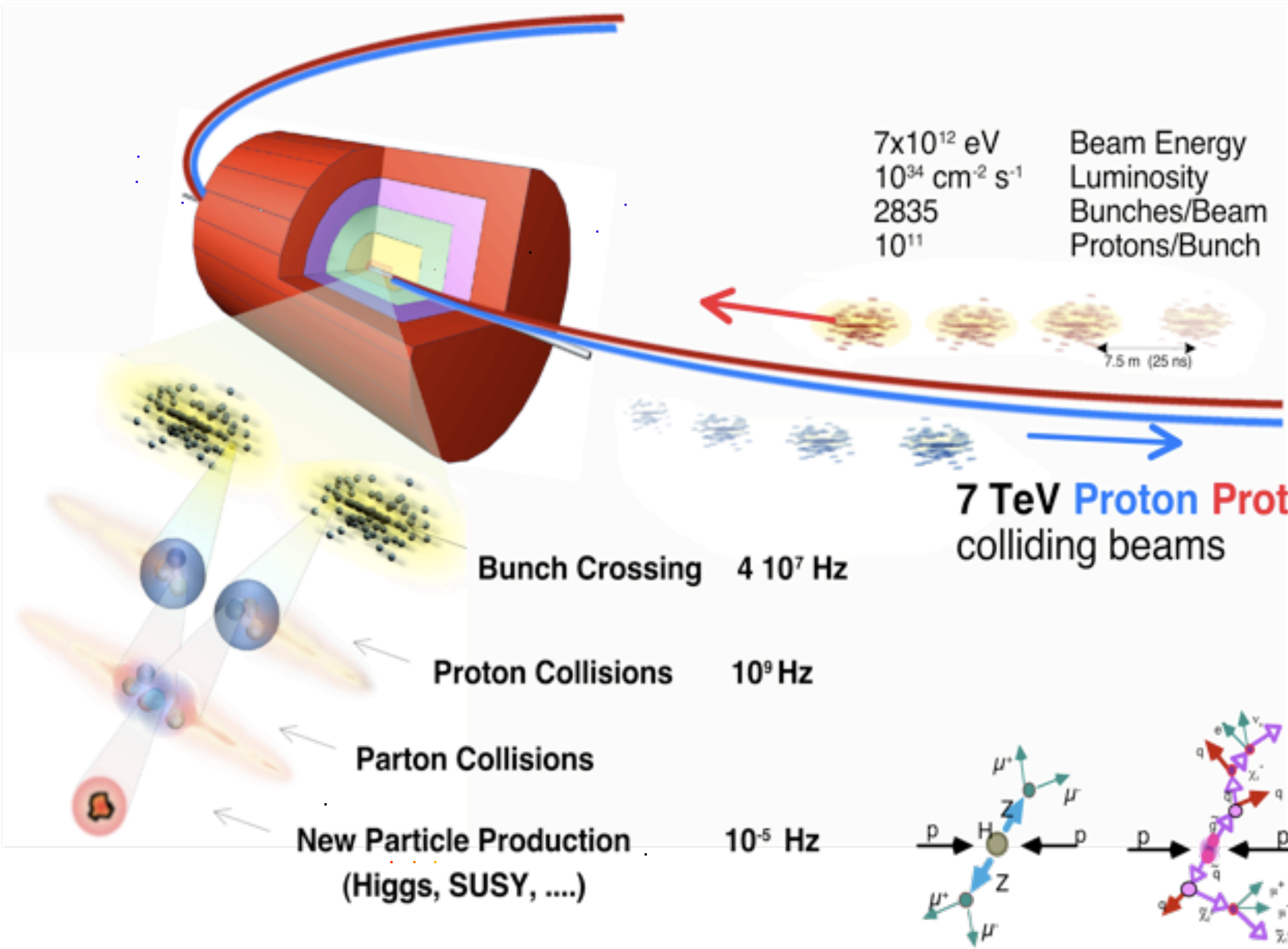
Lepton Collider
(collision of two point-like particles)



Hadron collider
(collision of ~50 point-like particles)



[Karl Jakobs] 14



Selection of 1 event in 10,000,000,000,000

J. Virdee

From cosmic muons to collisions: LHC

	LHC design	LHC 2009-2010	Tevatron
$\sqrt{s}$	14 TeV	~ 7-10 TeV	1.96 TeV
Number of bunches	2808	40-400	36
Bunch spacing	25 ns	50 ns	396 ns
Energy stored in beam	360 MJ		1 MJ
Peak Luminosity	10^{33}-10^{34} cm^{-2}s^{-1}	10^{28}-10^{32} cm^{-2}s^{-1}	$3 \cdot 10^{32}$ cm^{-2}s^{-1}
$\int \mathcal{L} \cdot dt$- one year	10-100 evts.fb^{-1}	0.1 evts$\cdot$fb^{-1}	~2 evts$\cdot$fb^{-1}

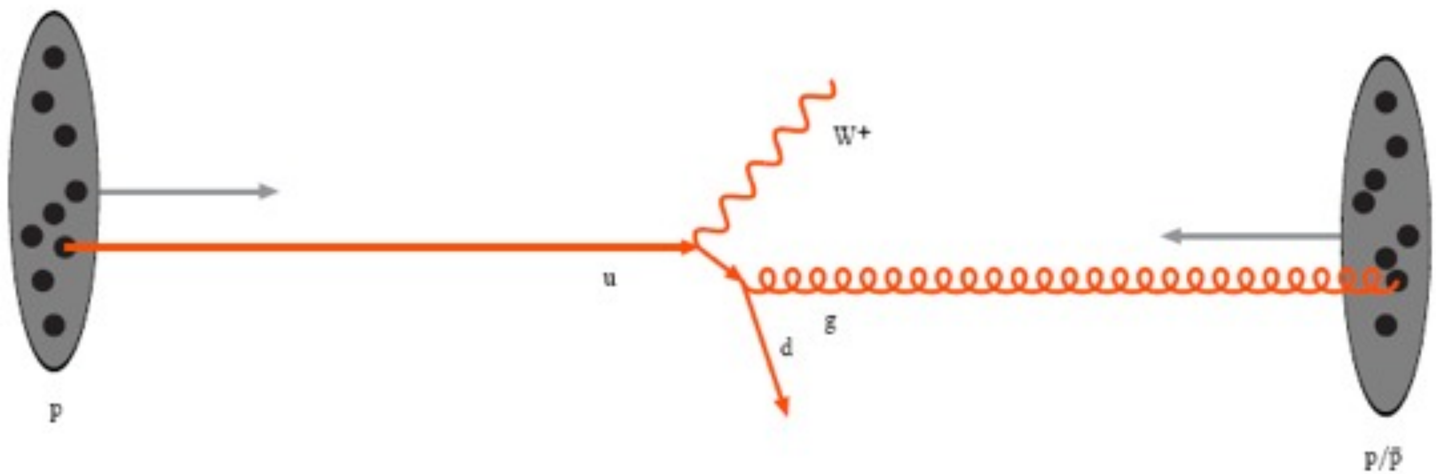
- With nominal parameters: LHC is a factor ~1000 more powerful than Tevatron
  - Energy: $E_{LHC} = 7 \cdot E_{Tevatron}$
  - Luminosity: $L_{LHC} = 3\text{-}30 \cdot L_{Tevatron}$
  - Physics cross sections factor 10-1000 larger
- First collision expected by end of the year
  - $\sqrt{s}$ = 900 GeV & 7 TeV

Structure of an event

from T. Sjoestrand

Structure of an event

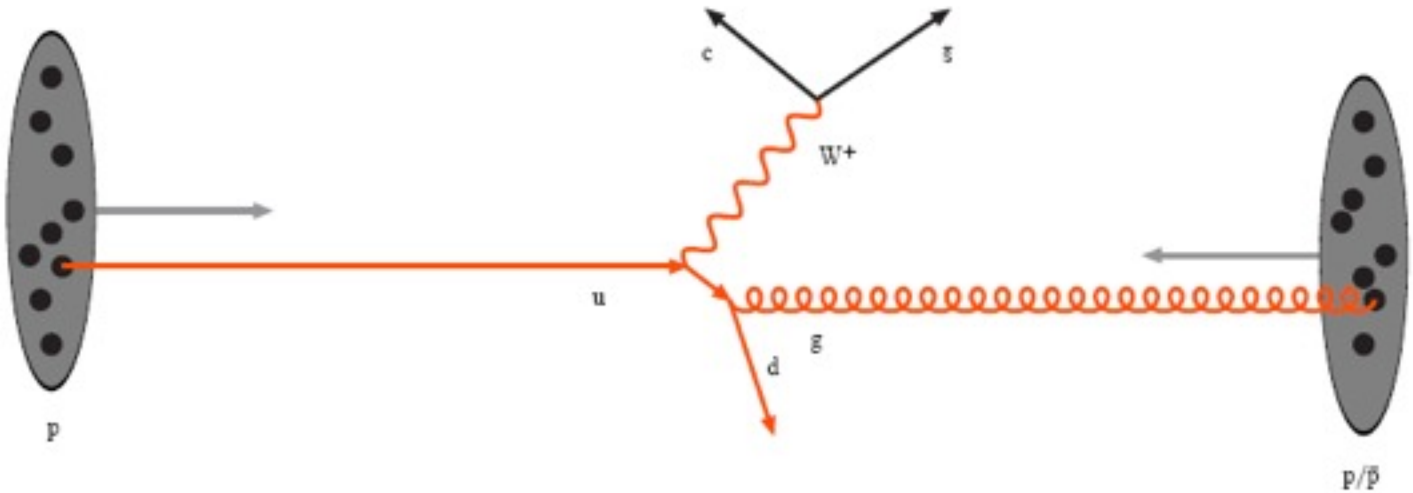
The hard sub-process



from T. Sjoestrand

Structure of an event

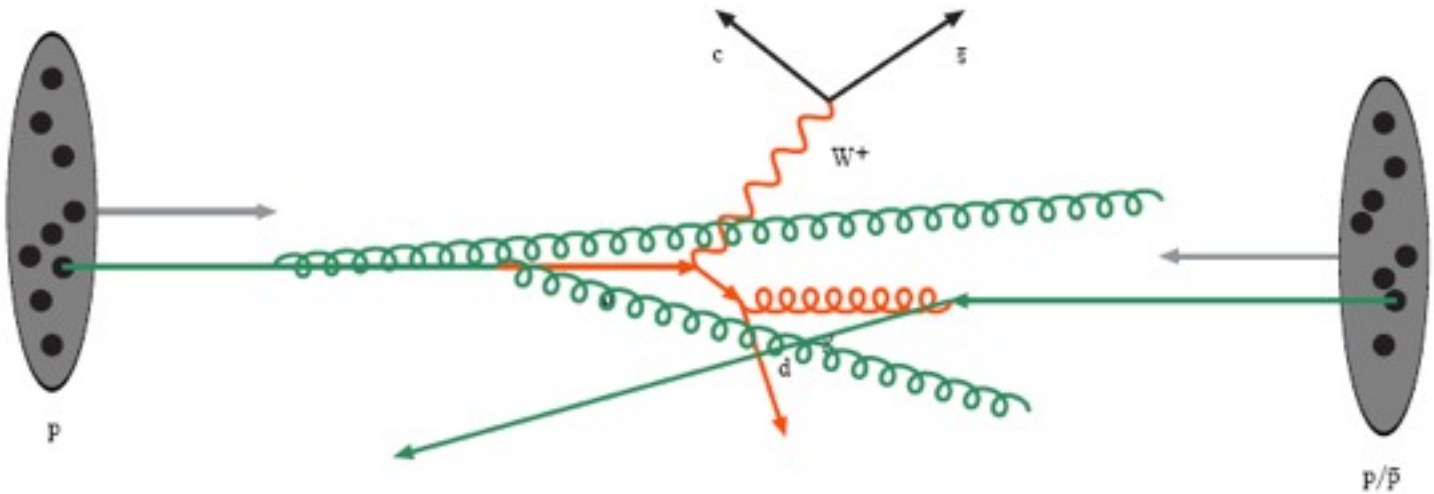
Resonnance decays



from T. Sjoestrand

Structure of an event

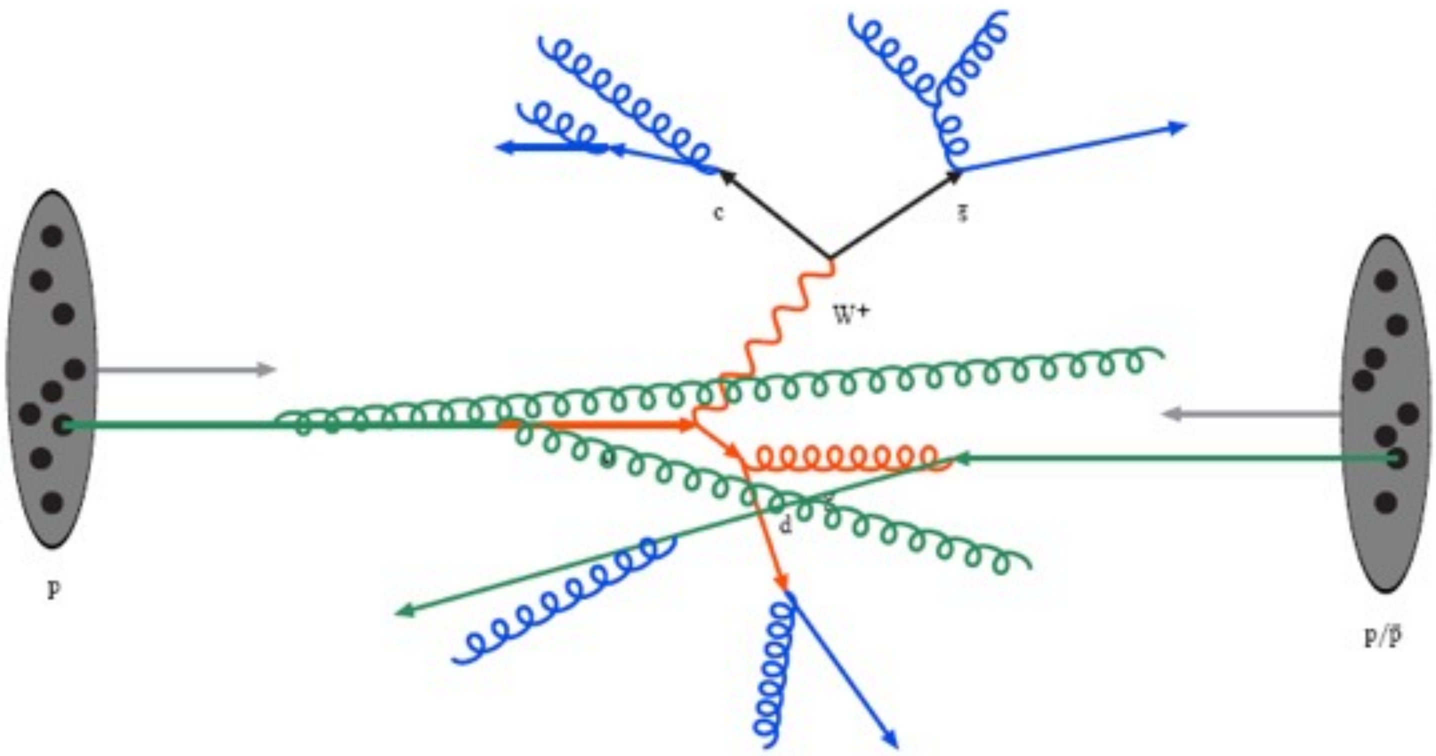
Initial state radiation



from T. Sjoestrand

Structure of an event

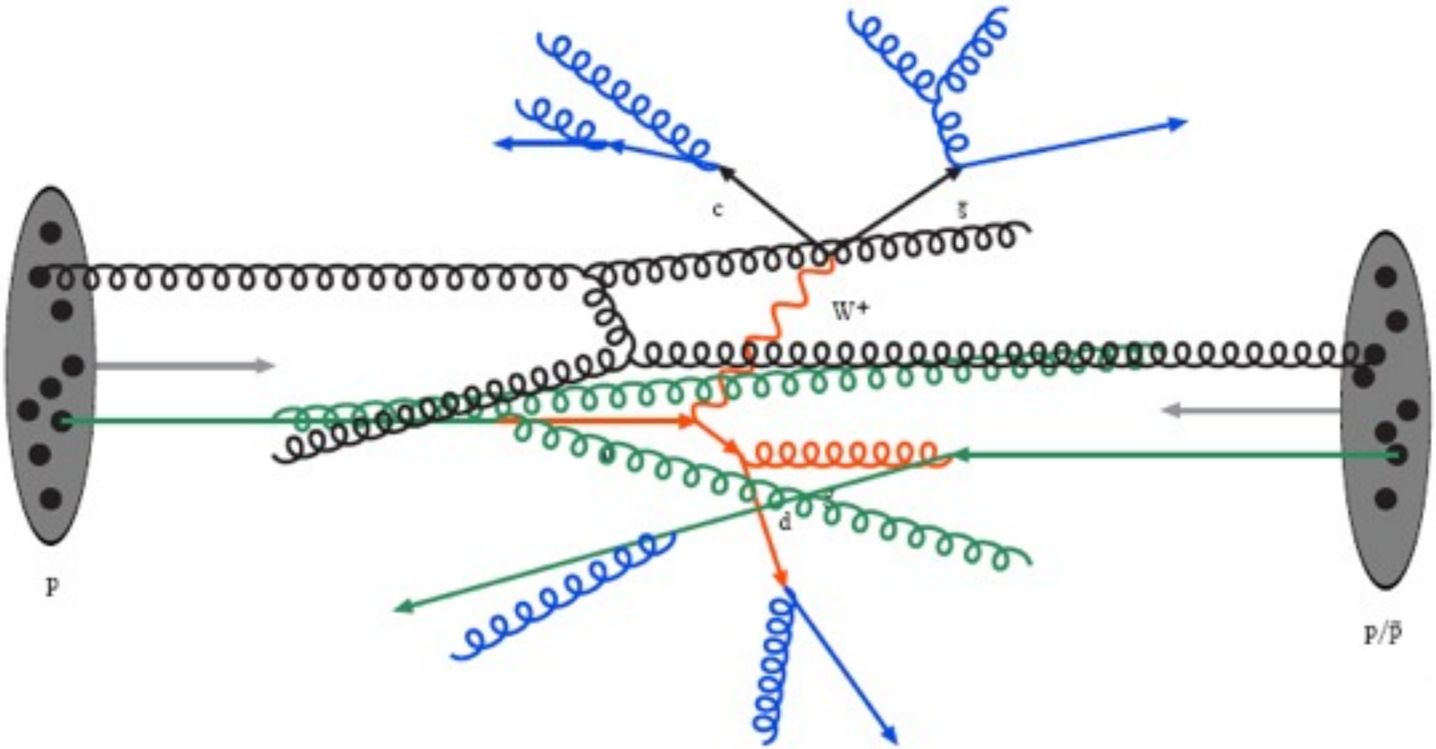
Final state radiation



from T. Sjoestrand

Structure of an event

Multiple parton-parton interactions



from T. Sjoestrand

Calculating a cross-section

Physical cross section

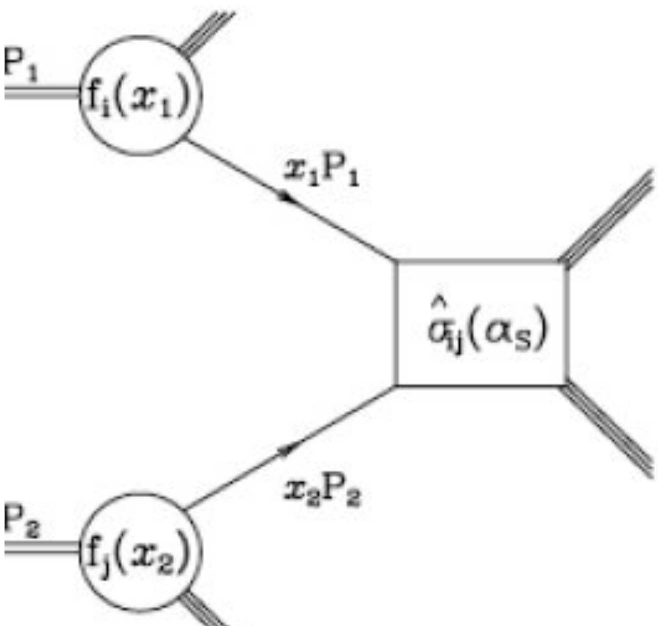
Parton distribution function

Renormalization scale μ_R

$$\sigma(P_1, P_2) = \sum_{i,j} \int dx_1 dx_2\, f_i(x_1, \mu_F) f_j(x_2, \mu_F)\, \hat{\sigma}_{ij}(p_1, p_2, \alpha_S(\mu_R), Q^2, \mu_R, \mu_F).$$

Factorization scale μ_F

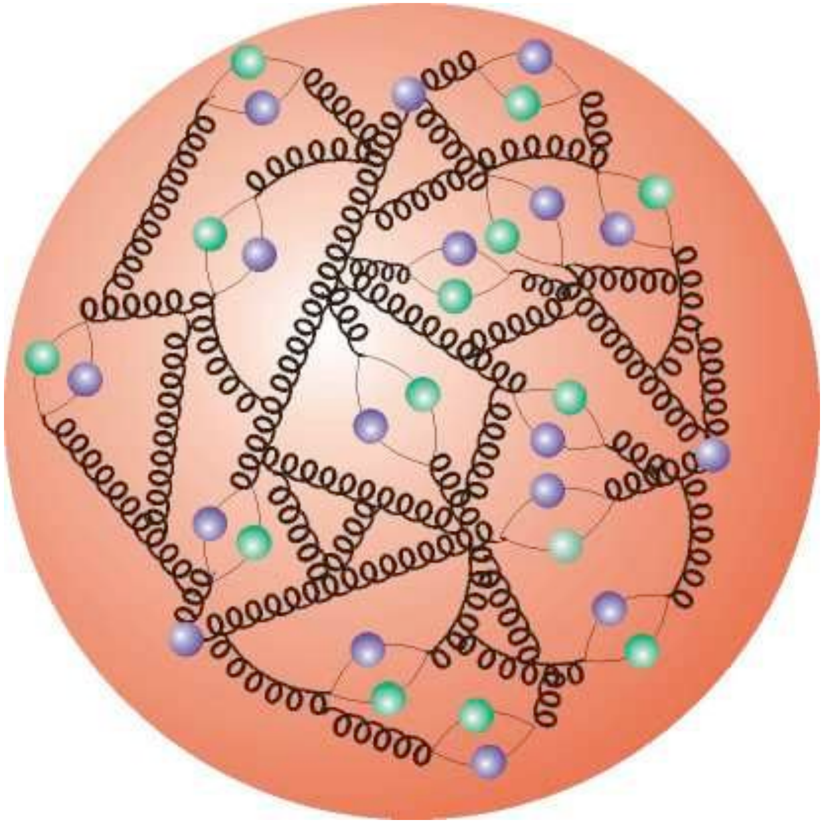
Short distance cross section, calculated as a perturbation series in α_S



- Calculations are done in pertubative QCD
  - Possible due to the factorization of hard ME & pdf's
    - Can be treated independently
  - Strong coupling (α_S) is large
    - Higher order needed
    - Calculations complicated

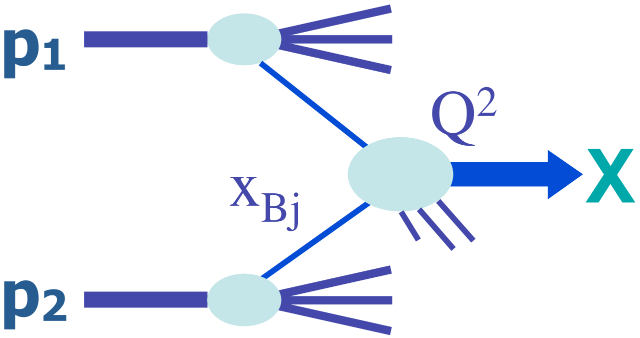
Proton composition

- It is complicated:
  - Valence quarks, gluons, sea quarks
- Exact mixture depends on:
  - Q^2: $\sim(M^2+p_T^2)$
  - Björken-x:
    - fraction of the proton momentum carried by the parton

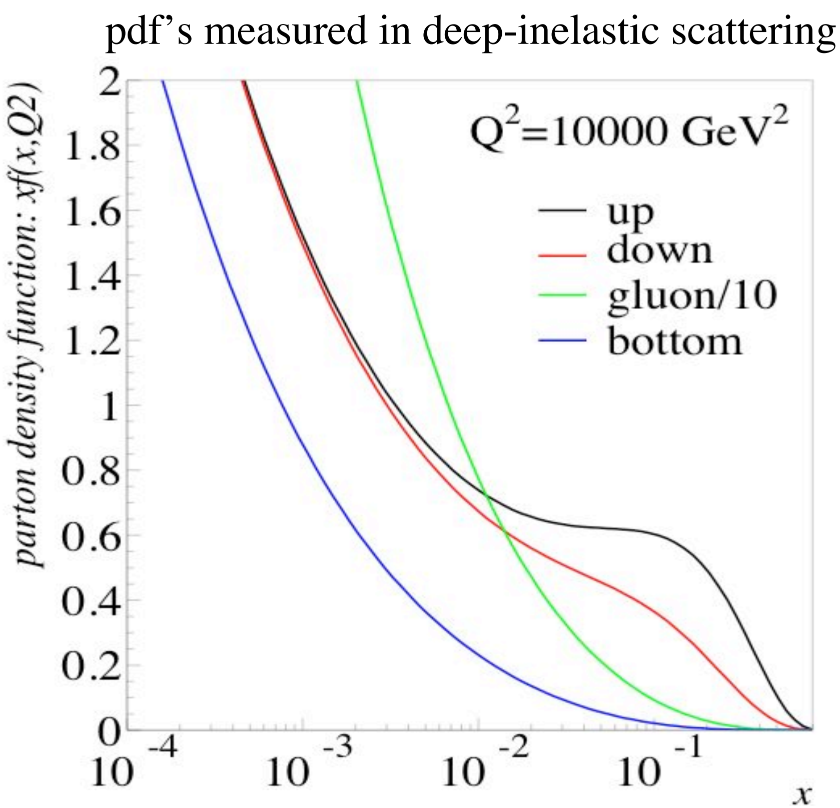


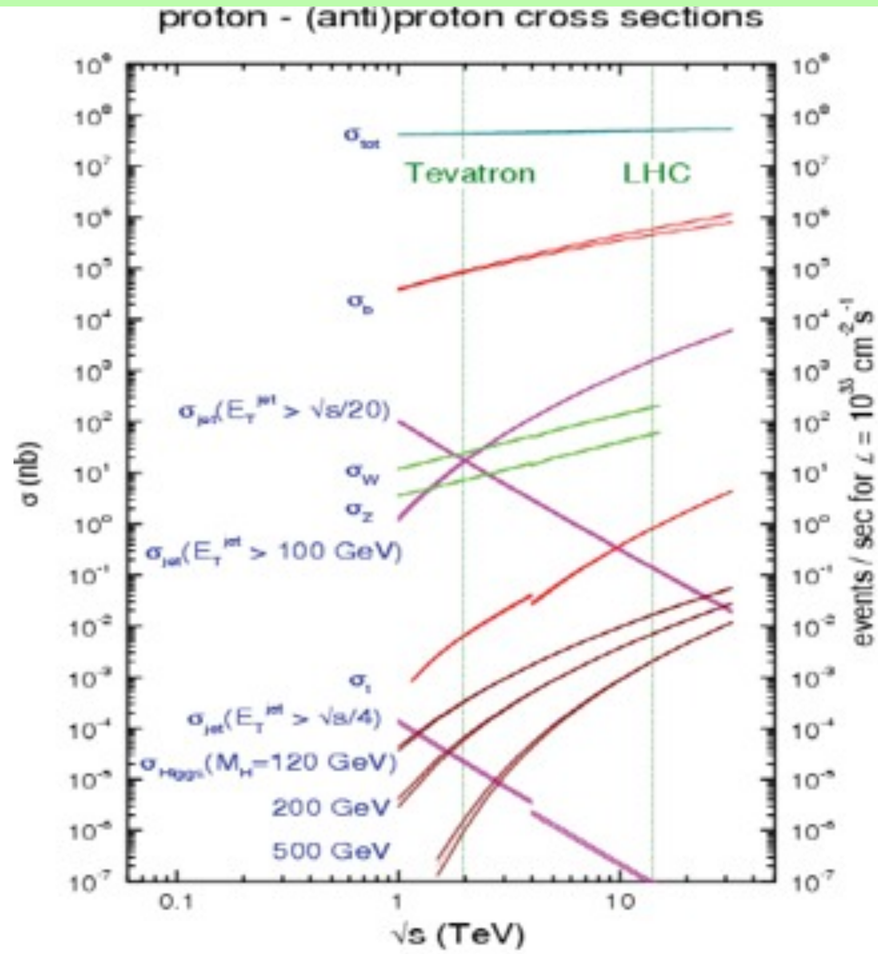
- Energy of parton collision:

$$\hat{s} = x_1 \cdot x_2 \cdot s$$
$$M_X = \sqrt{\hat{s}}$$



LHC vs previous hadron colliders





(Campbell, Huston, Stirling, hep-ph/0611148)

Factor
- 1000 for gluinos
- 40 for Higgs
- 10 for W's

Cross section at LHC: ~10 × x.s. at Tevatron

New (x,Q^2) regime

Gluons play a dominant role at high Q^2

LHC start

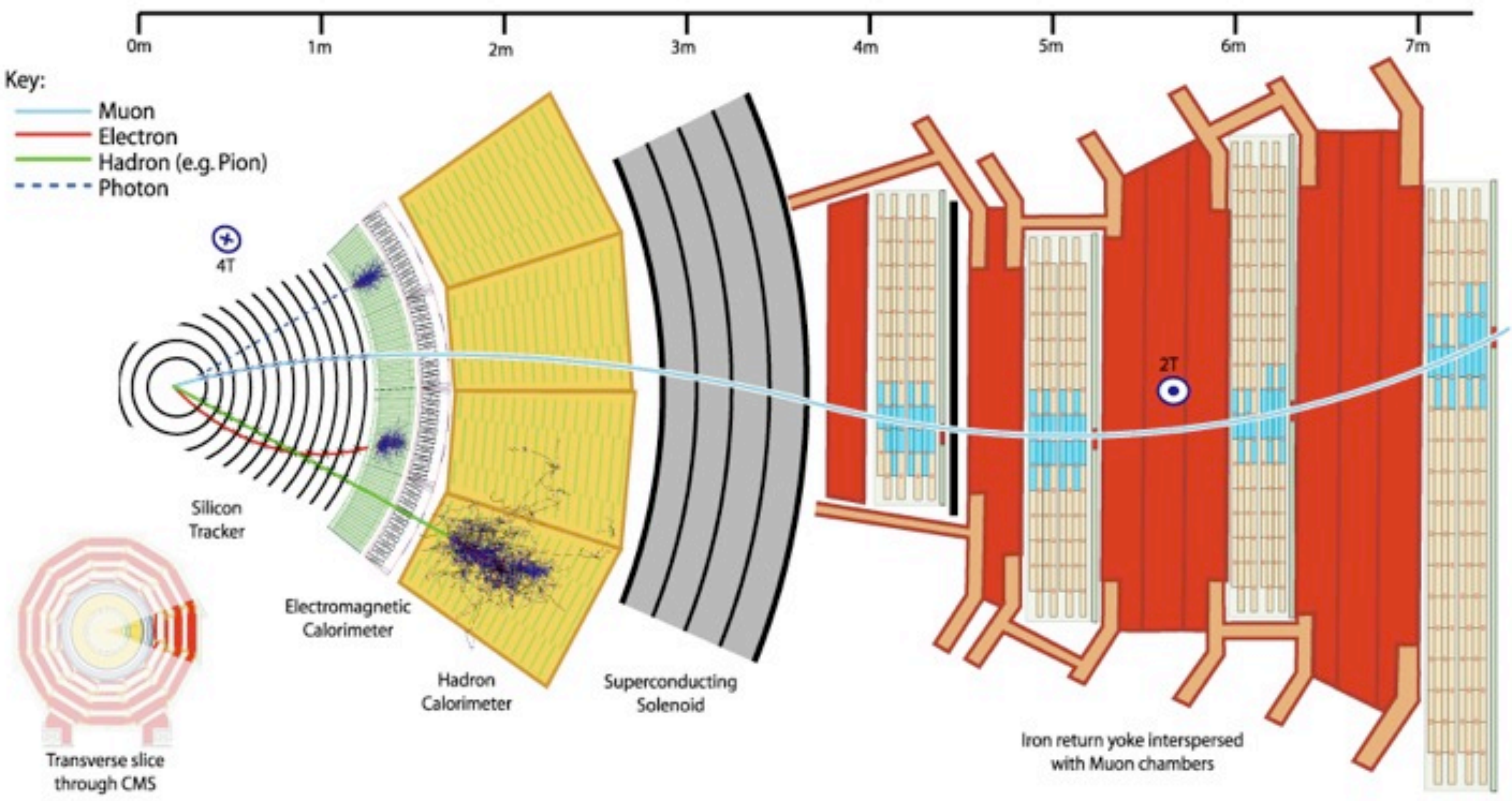
- LHC should start mid-November 2009 with single beams.
- Collisions at $\sqrt{s}=2\times450$ GeV expected by mid-December
- Increase to $\sqrt{s}=2\times3.5$ - 2×5 TeV
- Run for 2010, accumulating ~100 evts/pb

Channels (examples ...)	Expected events in ATLAS after cuts $\sqrt{s}$= 10 TeV, 100 pb^{-1}
$J/\psi \rightarrow \mu\mu$	$\sim 10^6$
$\Upsilon \rightarrow \mu\mu$	$\sim 5\ 10^4$
$W \rightarrow \mu\nu$	$\sim 3\ 10^5$
$Z \rightarrow \mu\mu$	$\sim 3\ 10^4$
$tt \rightarrow WbWb \rightarrow \mu\nu + X$	~ 350
QCD jets $p_T > 1$ TeV	~ 500
$\tilde{g},\tilde{q}$ m ~ 1 TeV	~ 5

Numbers to be scaled down to $\sqrt{s}=7$ TeV

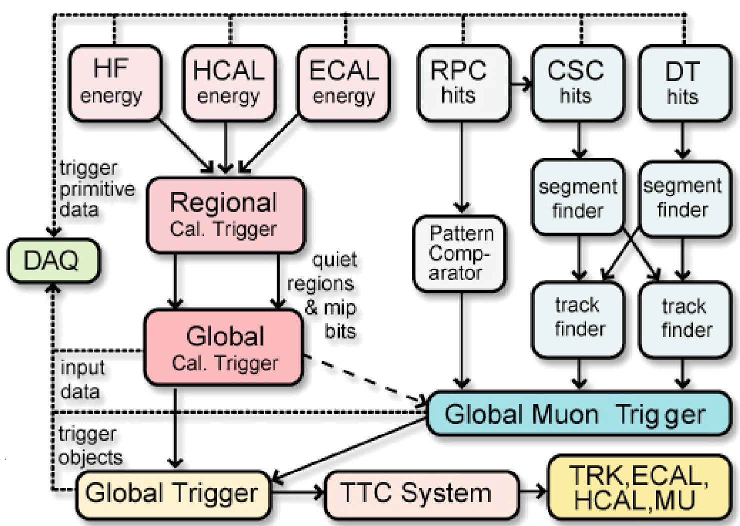
F. Gianotti

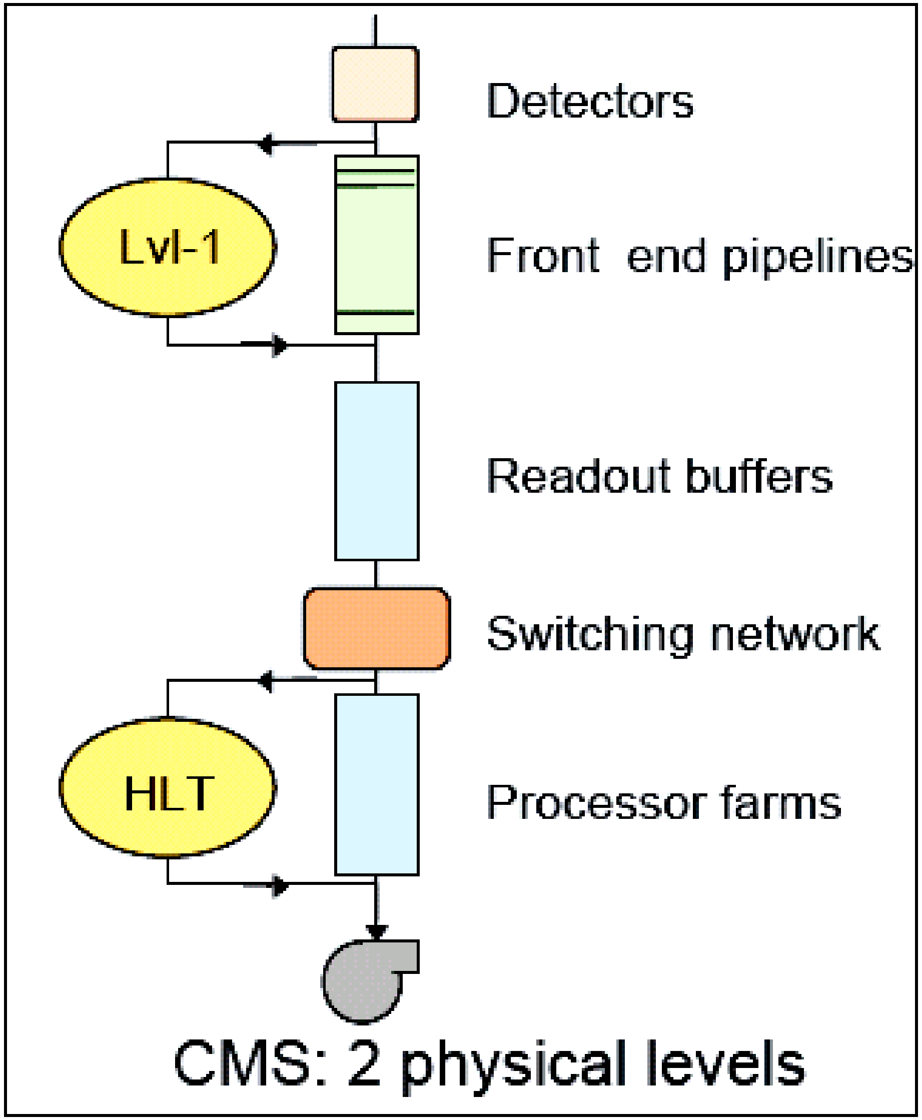
Typical hadron collider detector



Triggering on events

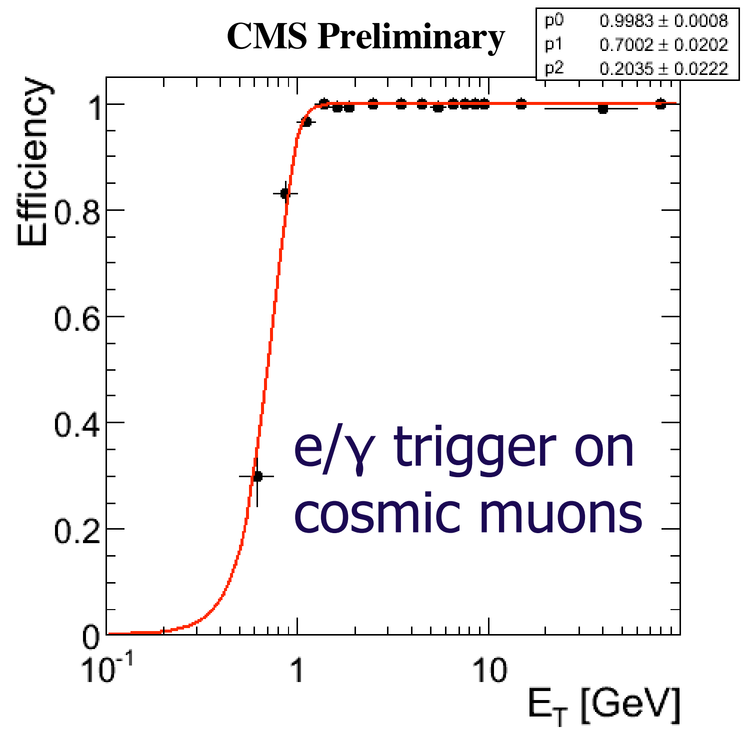
- First level of triggering (Level 1) is based on detectors with fast signals: calorimeters & Muon trigger chambers
  - Input rate 40MHz
  - Output rate 100 kHz
  - Custom made HW processors
- High level trigger (L2 & L3) make use of more detectors & correlations between them
  - Input rate 100 kHz
  - Output rate ~100 Hz
  - PCs & fast switches





Trigger: you get what you ask for

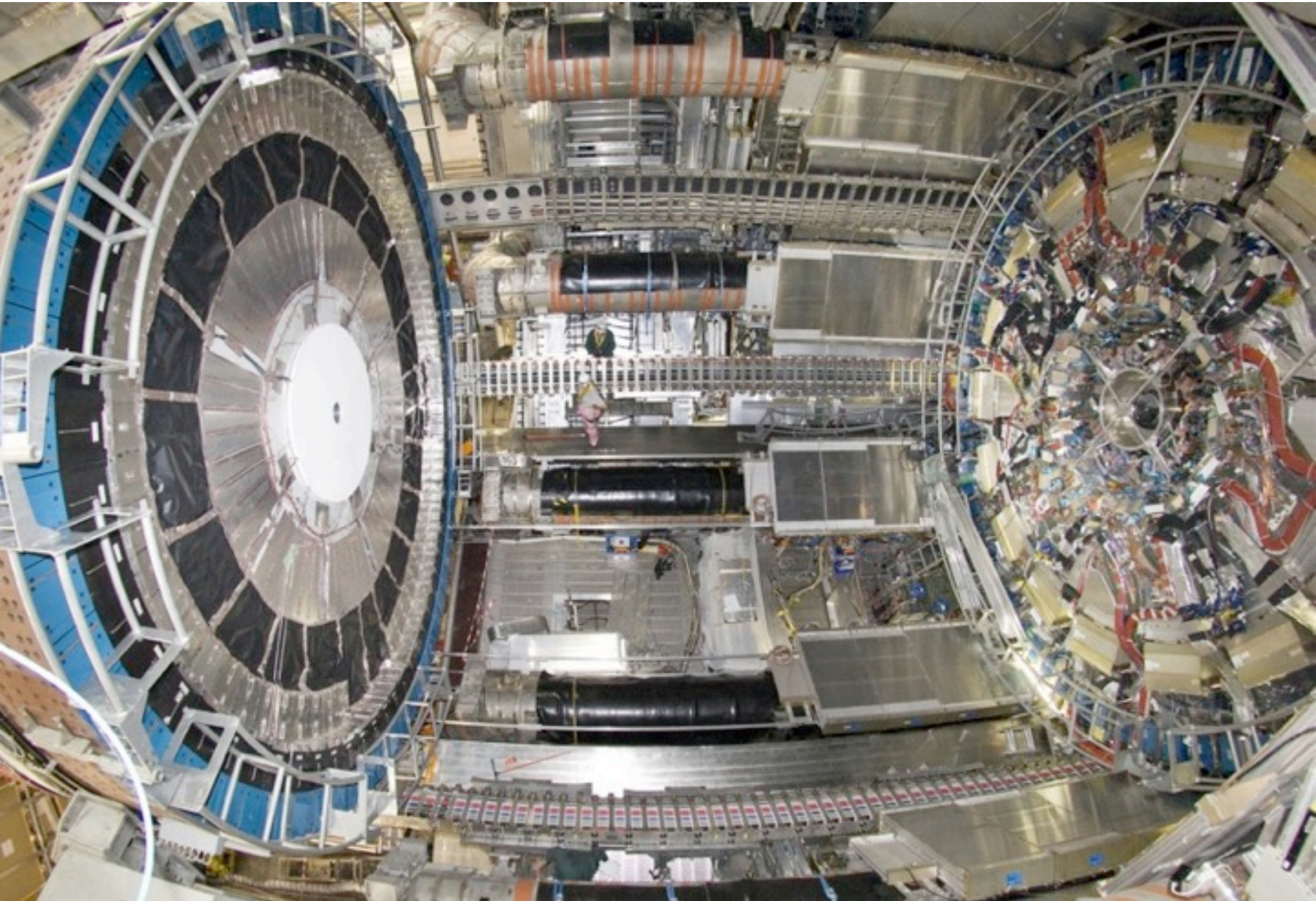
- At LHC (Tevatron), the trigger determines the quality of the physics you can do (not true at e^+e^- colliders)
- The trigger is made of multiple steps (2 in CMS, 3 in ATLAS)
- The possibility to re-configure the trigger, to adjust it, to implement new algorithm is probably the key to success
- The trigger efficiency needs to be measured
  - Need for un-biased samples
- Triggers were designed for high energy objects; both ATLAS and CMS have to adjust their strategy to cope with low p_T events (Minimum Bias)



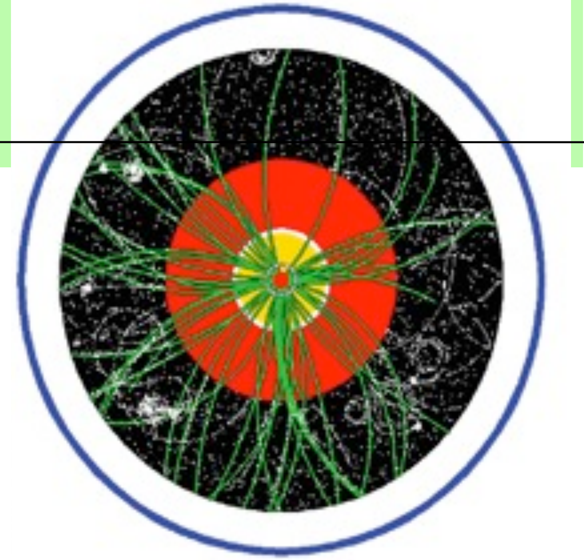
Cosmic Muons Events triggered by the Muon system

Reconstruct e/γ cluster & check that μ track is close

Measure the efficiency



Minimum Bias events

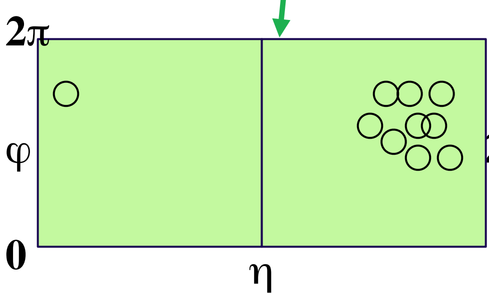


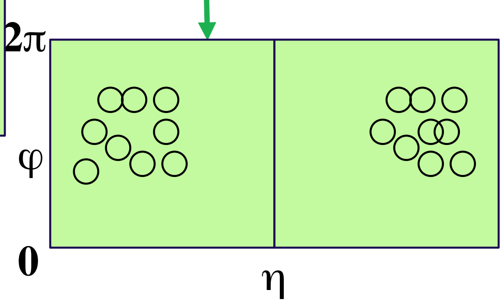
- Inelastic events with no or as little as possible trigger bias
- Bias depends on the trigger acceptance of the experiment

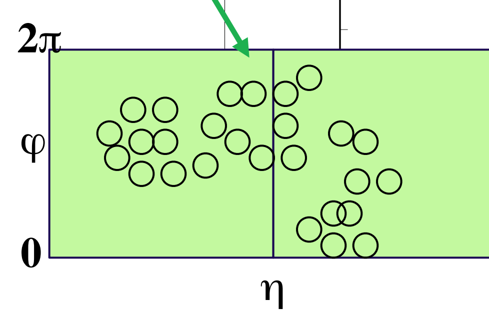
$\sigma_{\text{inelastic}} \approx$ 80-85 mb

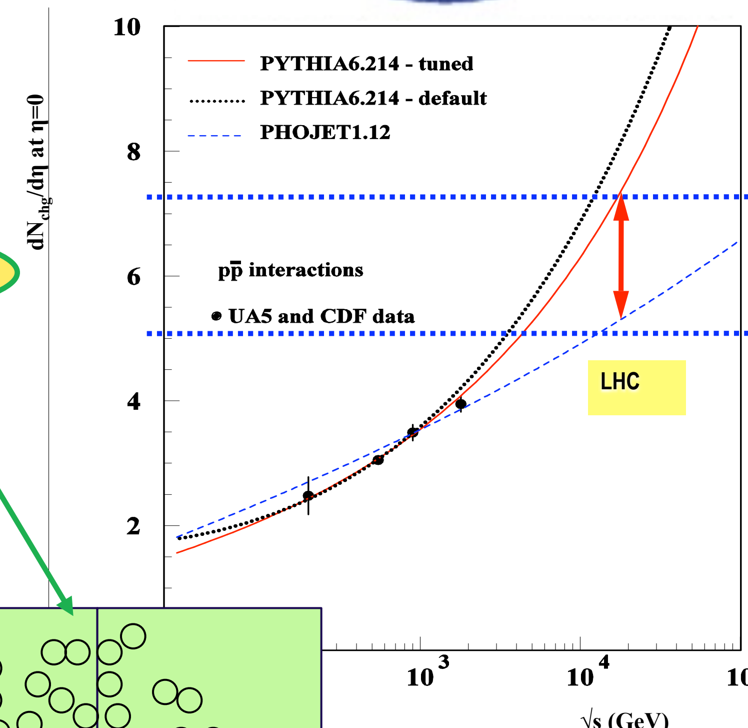
$\sigma_{\text{Single Diffractive}} + \sigma_{\text{Double Diffractive}} + \sigma_{\text{Non Diffractive}}$

$\sigma_{\text{NSD}} \approx$ 65-75 mb



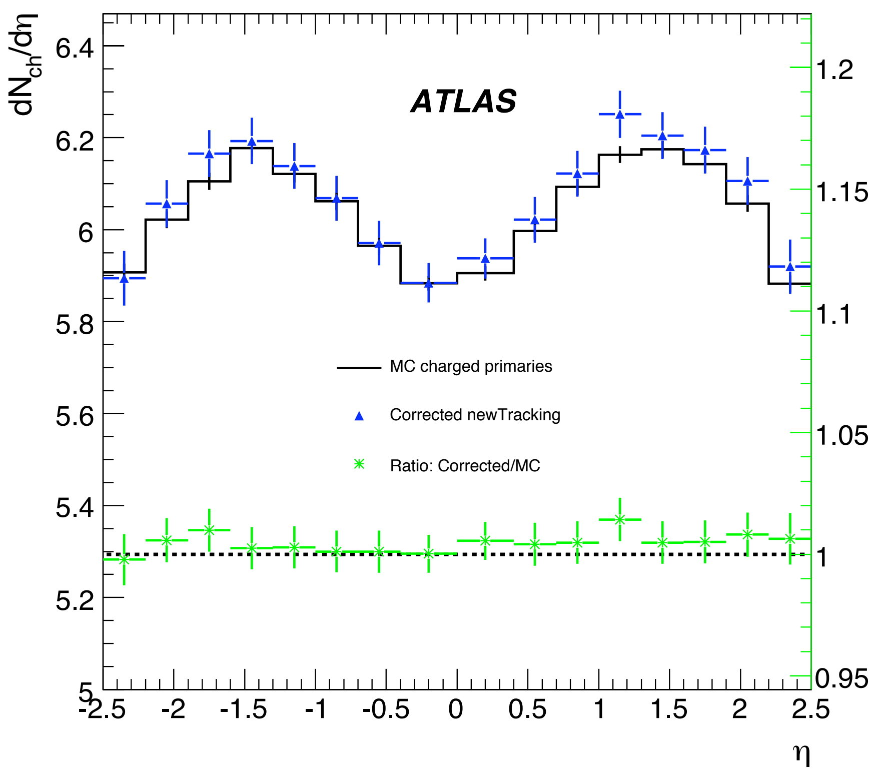






Understanding the low p_T events

MC charged primaries & track p_T > 150MeV



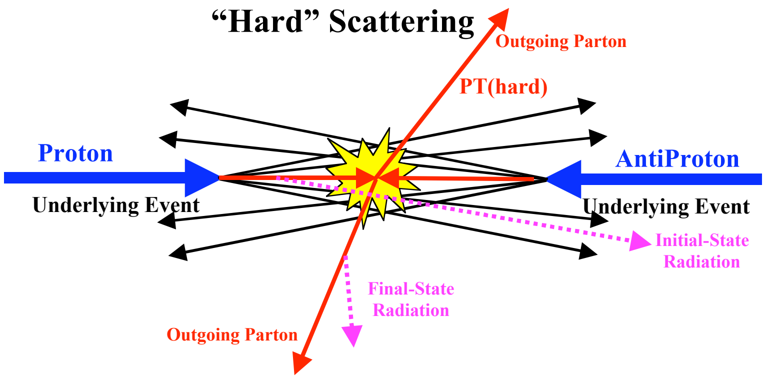
- Reconstructed distribution for non-single diffractive inelastic events (for p_T > 150MeV)
- This can be directly compared to previous measurements from UA5 and CDF for example.

Summary of systematic uncertainties

Track selection cuts	2%
Mis-estimate of secondaries	1.5%
Vertex reconstruction	0.1%
Mis-alignment	6%
Beam-gas & pile-up	1%
Particle composition	2%
Diffractive cross-sections	4%
Total:	**8%**

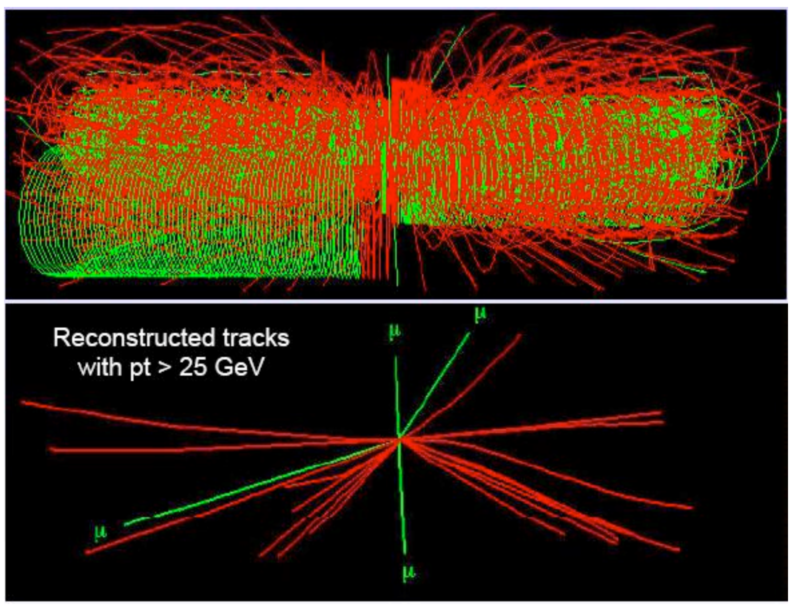
Underlying Event & Pileup Events

- In proton-(anti)proton interaction, remaining partons from the protons produce activity in the event



- Events produced & triggered in ATLAS & CMS are the results of multiple proton-proton interactions
  - Number of bunches, protons/bunch, time between two bunches

$H \rightarrow ZZ \rightarrow \mu^+\mu^-\mu^+\mu^-)$



Inclusive Jet Cross Section

- At LHC, the dominant process is pp→gluon-gluon
- ATLAS-CMS will trigger on single jets with typically E_T>15 GeV (pre-scale)
- Large cross section ~ mb
- Why?
  - Jets are contributing to most backgrounds
  - Direct confrontation of QCD predictions

trigger	p_T threshold (GeV)	pre-scale
$HLT\_L1Jet15$	15	10000
HLT_Jet30	30	2500
HLT_Jet50	50	50
HLT_Jet80	80	10
HLT_Jet110	110	1

- Ingredients for data
  - Understand basic detector performance
    - Coherent noise
    - Noisy cells
  - Jet algorithm reconstruction
  - Jet energy scale
  - Jet energy resolution
  - Luminosity

- Ingredients for Monte Carlo
  - Higher order corrections
    - Non perturbative corrections
  - Structure functions
  - Renormalisation scale

Total Cross-section Measurement

- Differential cross section: $d\sigma/d\Omega$
  - Probability of a scattered particle in a given quantum state per solid angle $d\Omega$
    - e.g. Rutherford scattering experiment
- Other differential cross sections
  - $d\sigma/dE_T^{jet}$ probabilty of a jet with given E_T^{jet}
- Integrated cross-section
  - $\sigma = \int d\sigma/d\Omega \, d\Omega$
  - Measurement:

$$\sigma = \frac{\overbrace{N_{obs.}}^{\text{Number of selected evts}} - \overbrace{N_B}^{\text{Number of background evts}}}{\underbrace{\varepsilon}_{\text{Selection efficiency}} \times \underbrace{\mathcal{L}}_{\text{Luminosity}}}$$

Differential Inclusive Jet Cross Section

Resolution un-smearing correction factor

Number of jets in a bin

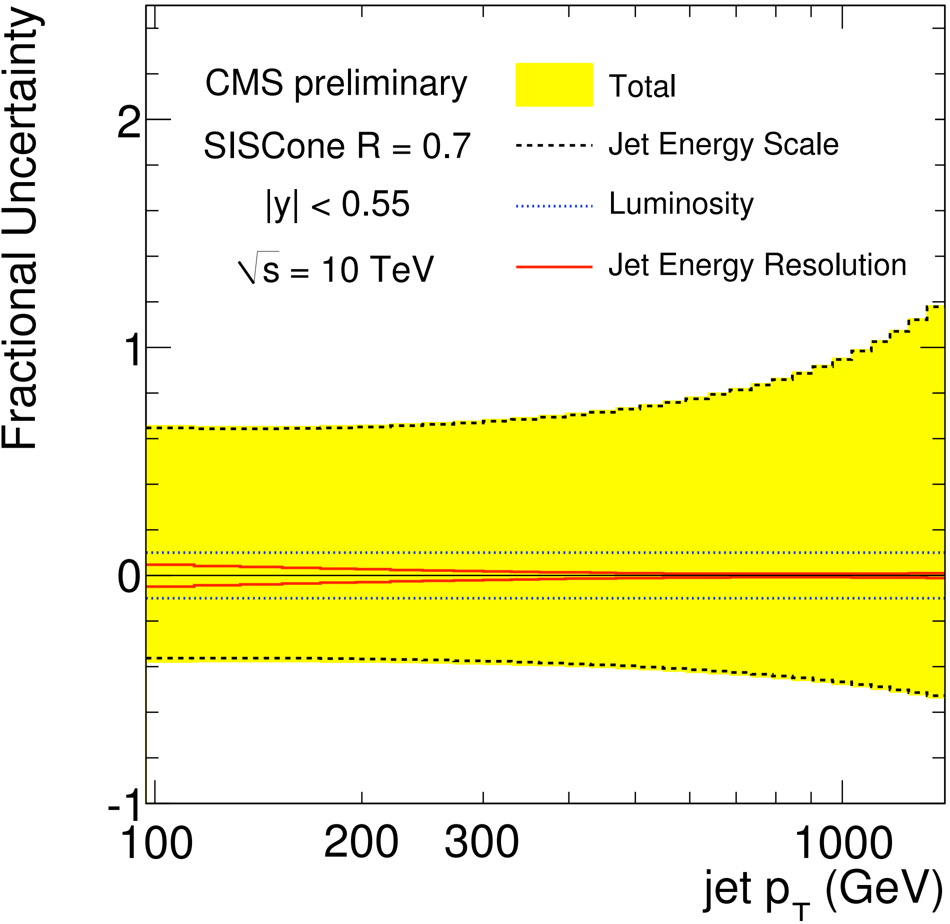
$$\frac{d^2\sigma}{dp_{\mathrm{T}}dy} = \frac{C_{\mathrm{res}}}{\mathcal{L}\cdot\varepsilon}\cdot\frac{N_{\mathrm{jets}}}{\underbrace{\Delta p_{\mathrm{T}}\cdot\Delta y}}$$

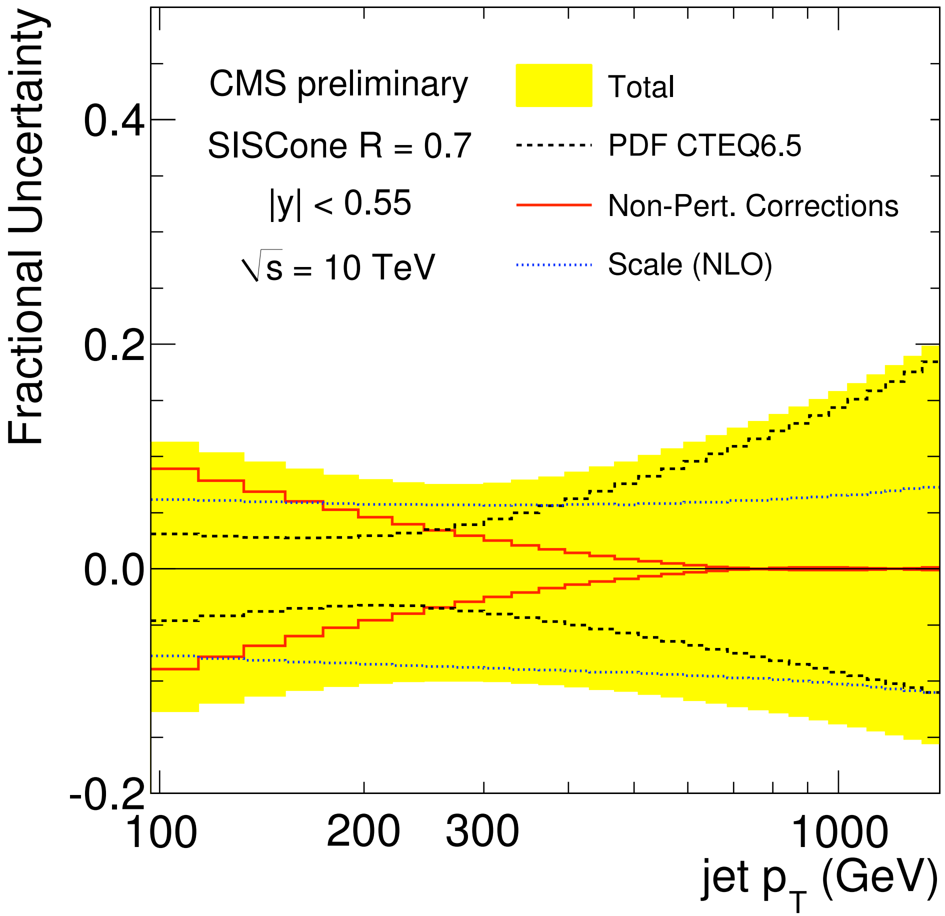
Luminosity

Efficiency:
- jet clean-up
- identification

Bin sizes:
- pT
- pseudo-rapidity

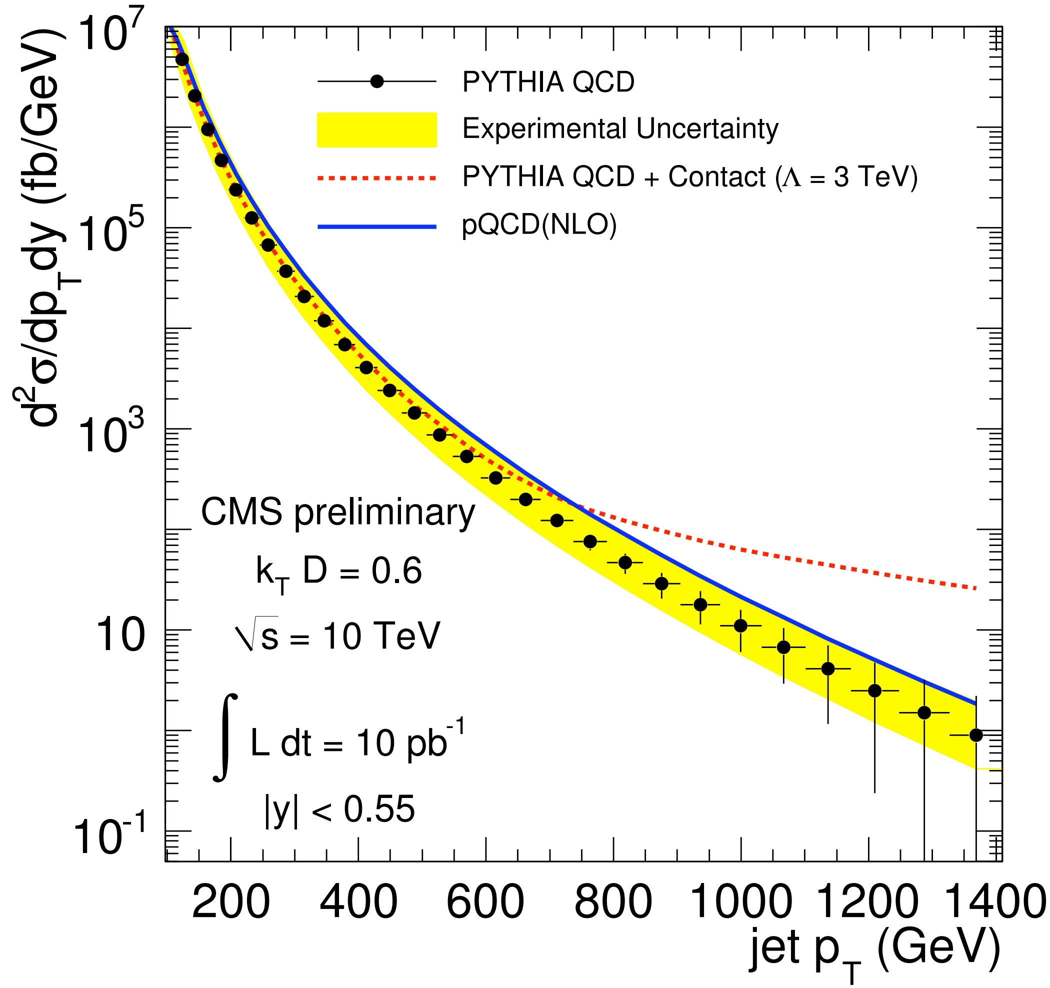
Experimental & theoretical uncertainty





"Measured" QCD jet spectrum

- From first 10pb^{-1} of data, the differential inclusive cross-section can be measured
  - 100 GeV < p_T^{jet} < 1.4 TeV
  - central rapidity
- Systematic errors will go down as more events are collected
- Any large deviation from QCD prediction
  - will be studied carefully
  - may be sign for new physics

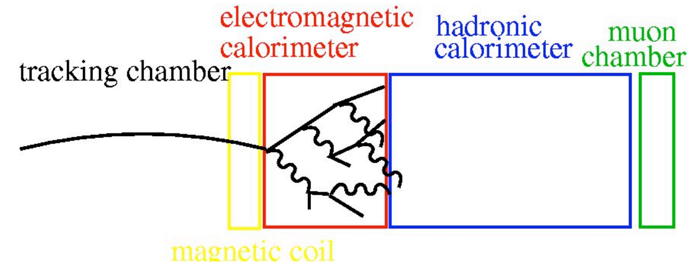


Conclusion on Jet Analysis

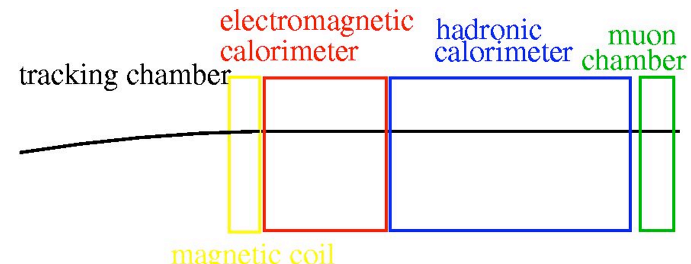
- Jets cross-section is high
- Inclusive jets cross-sections will be one of the first measurements made at LHC
  - Requires a good detector understanding
  - Prior to any search analysis
- Allows to confront theoretical predictions to data
  - Gives a handle on MC
  - Essential for further background prediction
- More detailed & refined analysis than presented here will be pursued
  - 1/2/3/multi-jets comparisons
  - Angular distributions
  - …..

Identifying leptons

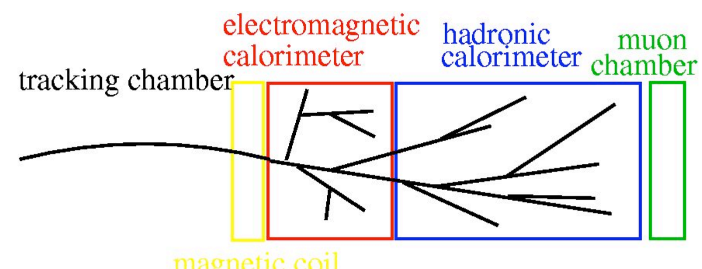
- Electrons:
  - compact electromagnetic cluster in calorimeter
  - Matched to track



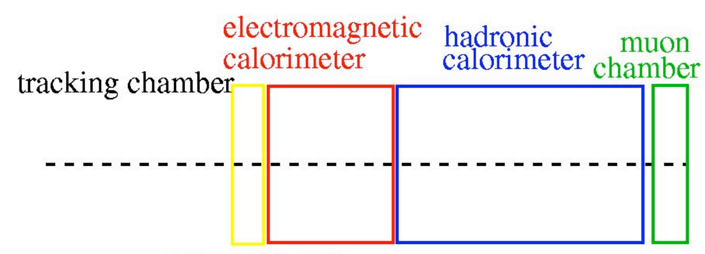
- Muons:
  - Track in the muon chambers
  - Matched to track



- Taus:
  - Narrow jet
  - Matched to one or three tracks



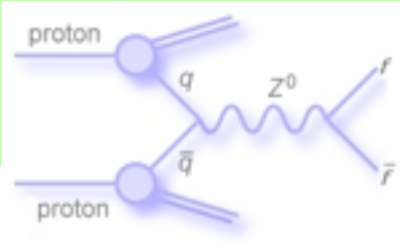
- Neutrinos:
  - Imbalance in transverse momentum
  - Inferred from total transverse energy measured in detector



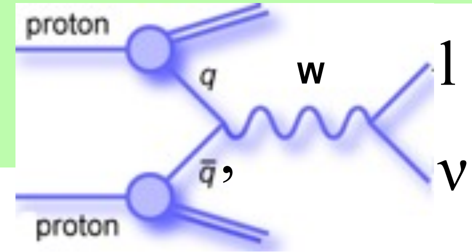
Electroweak Physics

- Current Electroweak theory thoroughly tested (and never “broken”) until now (LEP, Hera, TeVatron, μ & neutron magnetic moments,…)
- Aim at LHC:
  - Finally break it!
  - Deeper understanding to:
    - tighten indirect constraints
    - find deviations
  - Detector calibration

- Presented today:
  - Z&W cross-sections
  - Top mass
  - W Mass
  - F/B asymmetry
  - Associated production of gauge bosons



Z & W productions



- Z production
  - $15 \cdot 10^6$ evts in one year at $d\mathscr{L}/dt = 10^{33}$ evts/cm^2/s
  - $q\bar{q}$ annihilation
  - $x_q \cdot x_{\bar{q}} \sim 4 \cdot 10^{-5}$
  - $p_L = 0.5 \cdot \sqrt{s} \cdot (x_q - x_{\bar{q}})$
- Z decay
  - To 2 energetic fermions of opposite charge
  - 70% are quark pairs
    - jet-jet distributions are dominated by QCD background
  - Study lepton pairs: cleaner
    - electrons
    - muons
    - taus
- W production
  - $\sigma_Z \sim 10 \cdot \sigma_W$
  - $\sigma_{W^+} > \sigma_{W^-}$ (quark content of the proton)
  - W^+ peaked at high rapidity; W^- in central rapidity
- W decay
  - 32% to one energetic fermion & one neutrino
  - 68% to two quarks

Selection of Z events

Electron/μ trigger p_T>10 GeV

Two isolated lepton p_T^{lep} > 15 GeV

$|\eta|$ < 2.4

$|M_{ll} - M_Z|$<20 GeV

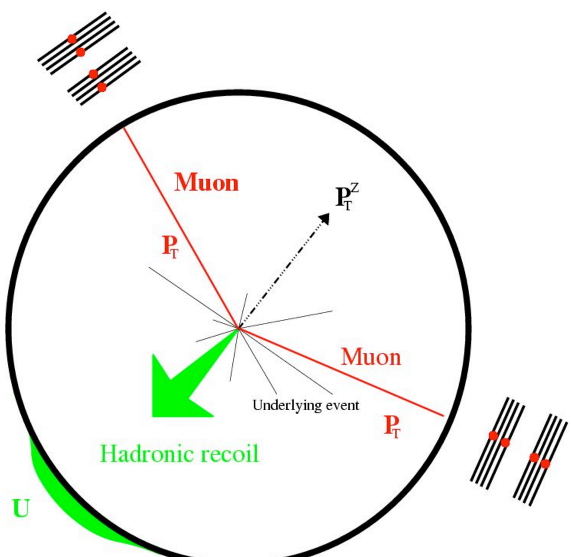
Backgrounds

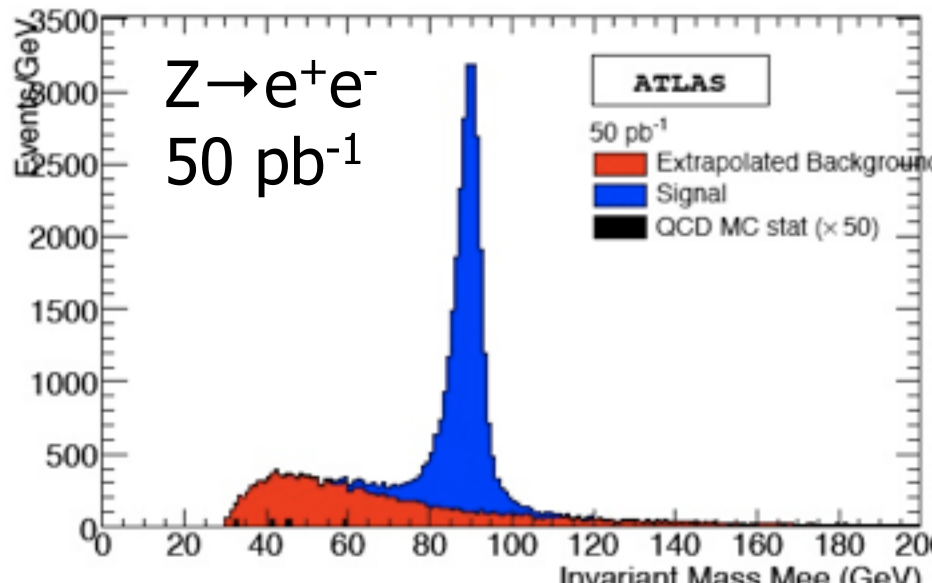
Electron channel:

signal and background fraction are simultaneously estimated via a fit that leads to (8.5±1.5)% of background rate, with the uncertainty coming from modeling the shape

Muon channel:

the dominant background is t-tbar and the total uncertainty on this background is 20%





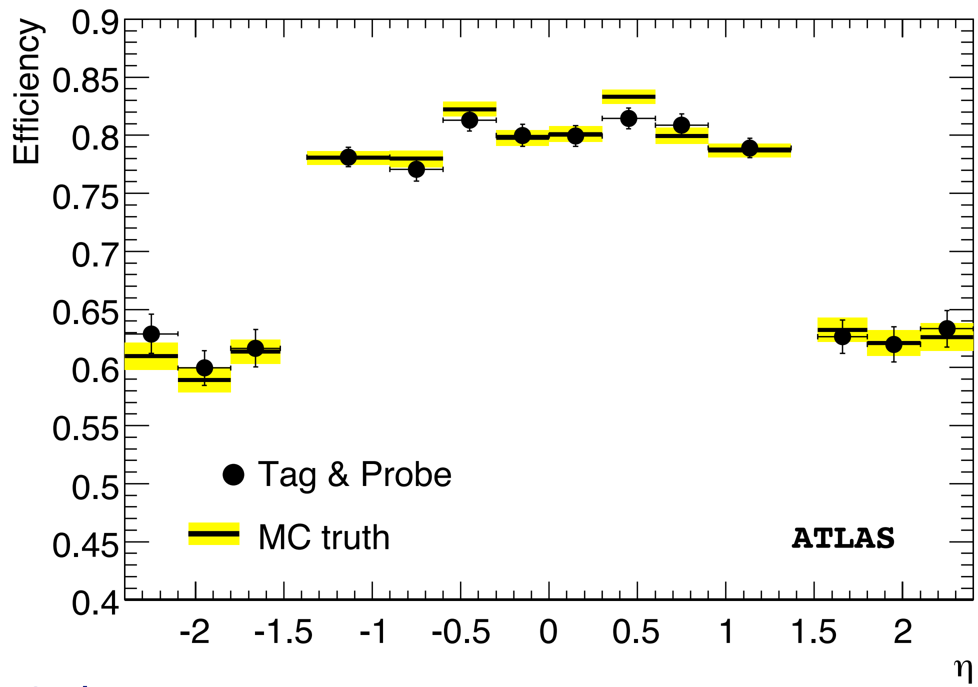
Tag & Probe (or FYFMC*) Method

One good electron

$P_T > 15$ GeV
$|\eta| < 2.5$, no $|\eta|$ cracks (1.3-1.6)
track associated & matched
Electromagnetic properties

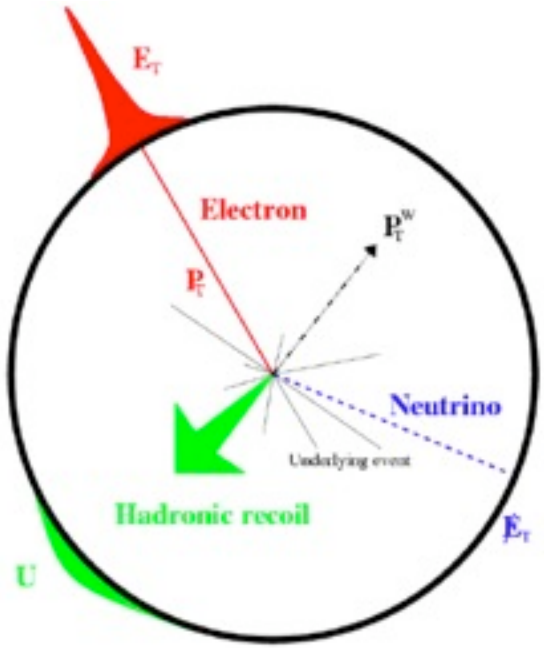
One electromagnetic cluster

$P_T > 15$ GeV
$|\eta| < 2.5$, no $|\eta|$ cracks (1.3-1.6)
No requirement on track
Electromagnetic properties



(*) Free Yourself From MonteCarlo

Selection of W events



Backgrounds

Electron channel:

jet fraction estimated with a data driven method to be (0±4)%, and the W->τν with an uncertainty of 3%

Muon channel:

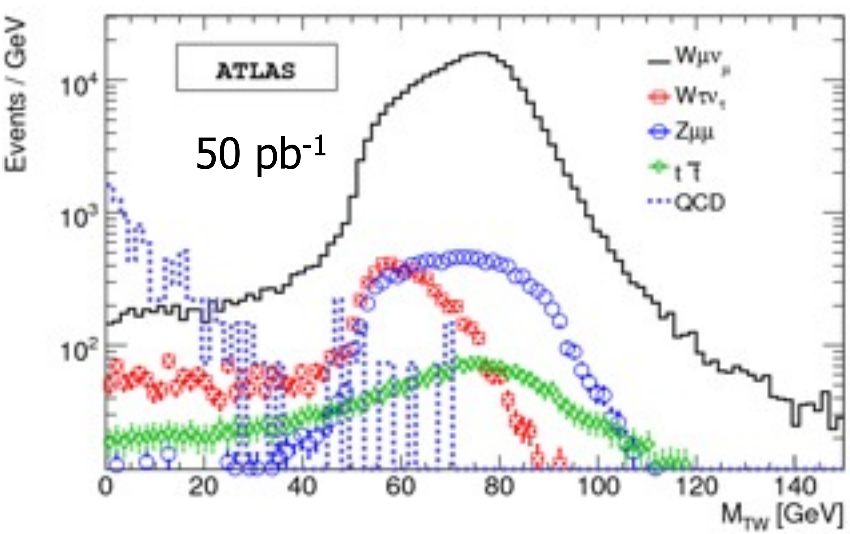
a theoretical uncertainty of 15% is assumed on t-tbar background, plus a 10% one on the rejection of the isolation cut that is a total 20% on this background rate

One Electron/μ trigger p_T>20 GeV

Isolated lepton p_T^{lep} > 25 GeV - |η| < 2.4

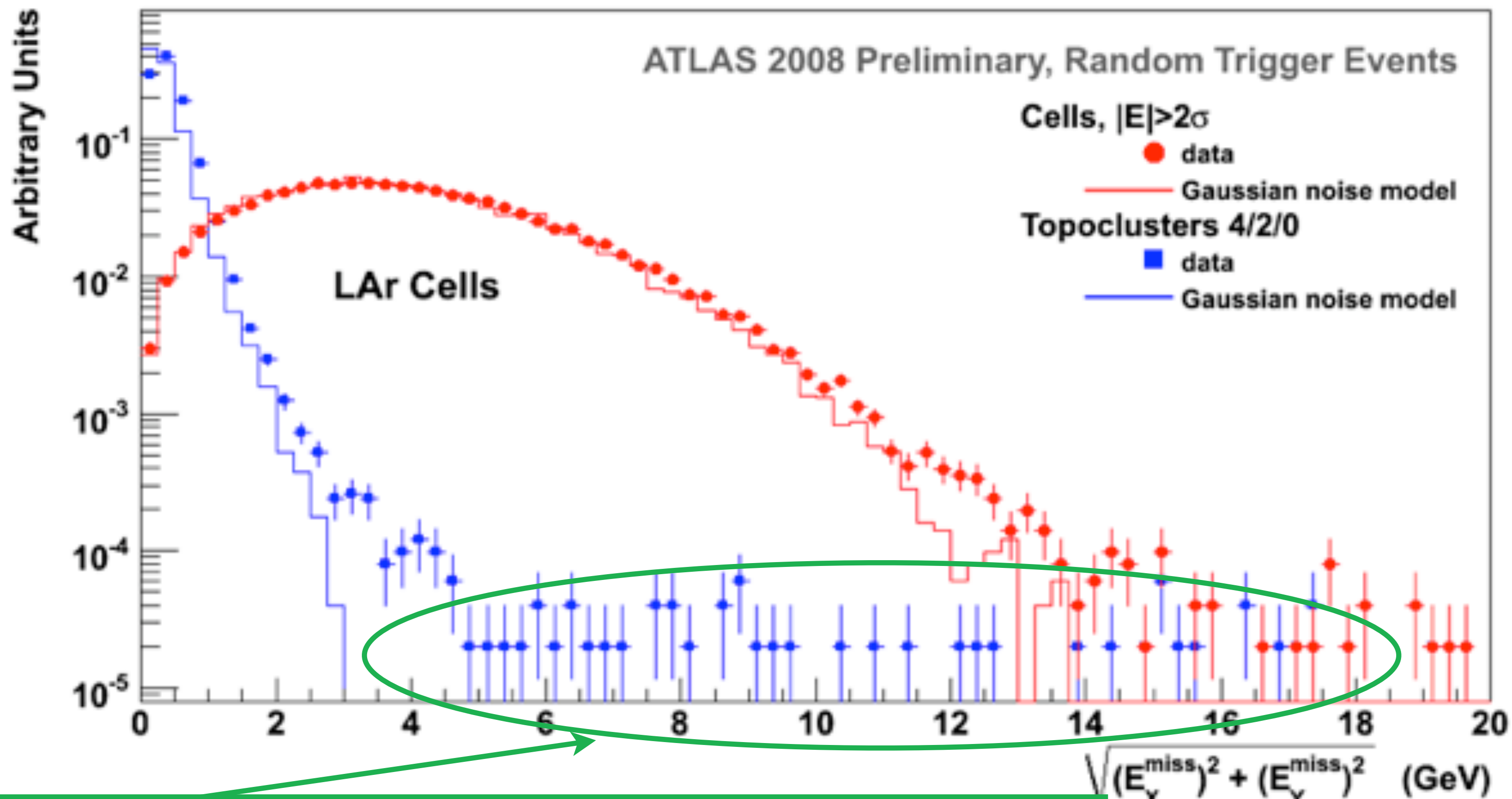
E_T^{Miss} > 25 GeV

M_T > 40 GeV



The detector: measuring E_T^{miss}

- Noisy cells?
- Dead region
- Coherent noise



identified as damaged HV cable inducing coherent noise on the presampler detector: replaced & fixed

Z & W Cross-sections

Number of selected evts

Number of background evts (from data)

$$\sigma = \frac{N_{obs.} - N_B}{\varepsilon \times \mathcal{L}}$$

Signal acceptance × selection efficiency

Luminosity
Large uncertainty in early data

Not accounted for in this table

Expectations for 50 pb^{-1}

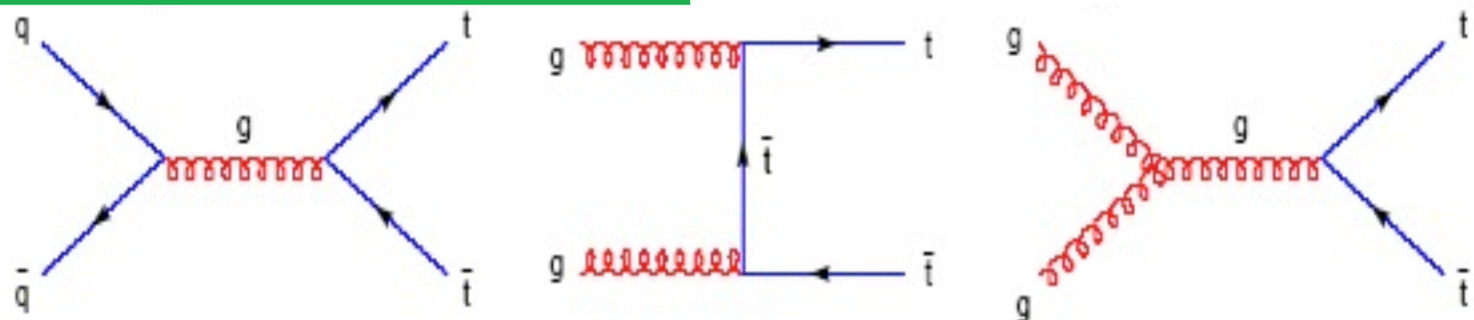
Process	$N(\times 10^4)$	$B(\times 10^4)$	$A \times \varepsilon$	$\delta A/A$	$\delta\varepsilon/\varepsilon$	σ (pb)
$W \to e\nu$	22.67 ± 0.04	0.61 ± 0.92	0.215	0.023	0.02	$20520 \pm 40 \pm 1060$
$W \to \mu\nu$	30.04 ± 0.05	2.01 ± 0.12	0.273	0.023	0.02	$20530 \pm 40 \pm 630$
$Z \to ee$	2.71 ± 0.02	0.23 ± 0.04	0.246	0.023	0.03	$2016 \pm 16 \pm 83$
$Z \to \mu\mu$	2.57 ± 0.02	0.010 ± 0.002	0.254	0.023	0.03	$2016 \pm 16 \pm 76$

Expectations for 1 fb^{-1}

Process	$N(\times 10^5)$	$B(\times 10^5)$	$A \times \varepsilon$	$\delta A/A$	$\delta\varepsilon/\varepsilon$	σ (pb)
$W \to e\nu$	45.34 ± 0.02	1.22 ± 0.41	0.215	0.023	0.004	$20520 \pm 9 \pm 516$
$W \to \mu\nu$	60.08 ± 0.02	4.02 ± 0.05	0.273	0.023	0.004	$20535 \pm 7 \pm 480$
$Z \to ee$	5.42 ± 0.01	0.46 ± 0.02	0.246	0.023	0.007	$2016 \pm 4 \pm 49$
$Z \to \mu\mu$	5.14 ± 0.01	0.02 ± 0.001	0.254	0.023	0.007	$2016 \pm 4 \pm 49$

Top production

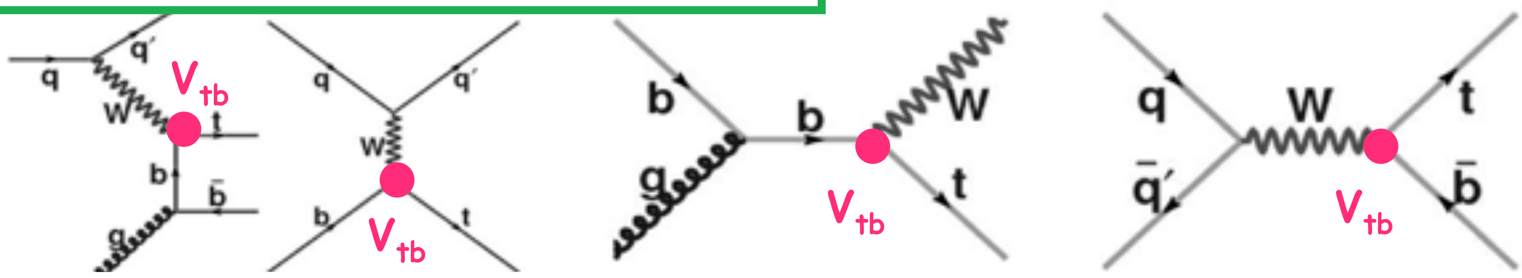
Paire production $\sigma_{tt} \sim 830$ pb



$q\bar{q} \rightarrow t\bar{t} \sim 10\%$

$gg \rightarrow t\bar{t} \sim 90\%$

Single top production $\sigma \sim 330$ pb



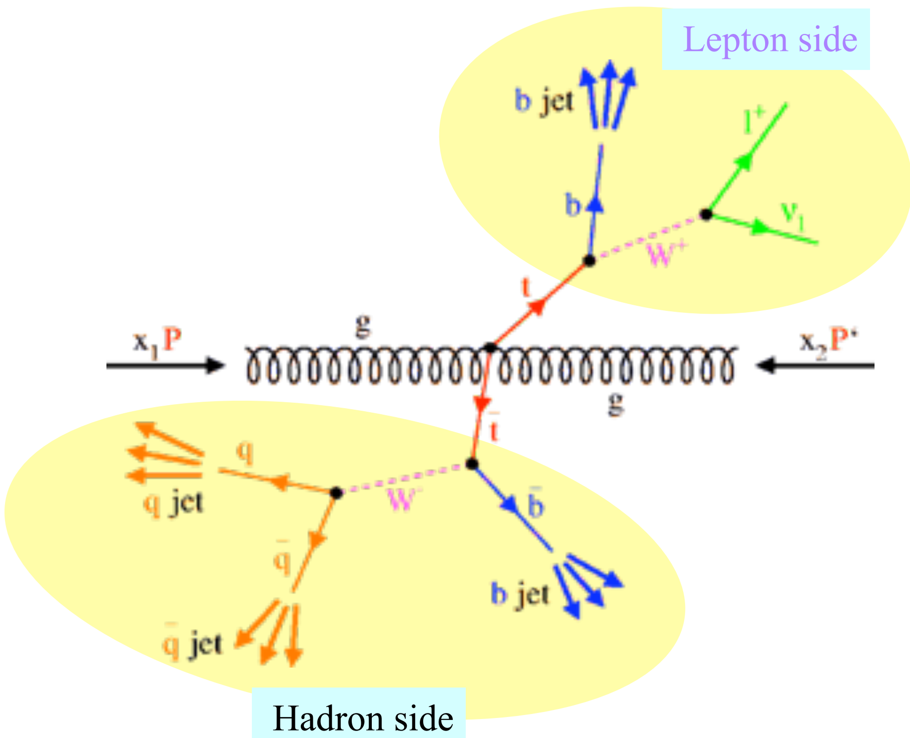
t-channel
$\sigma \sim 250$ pb

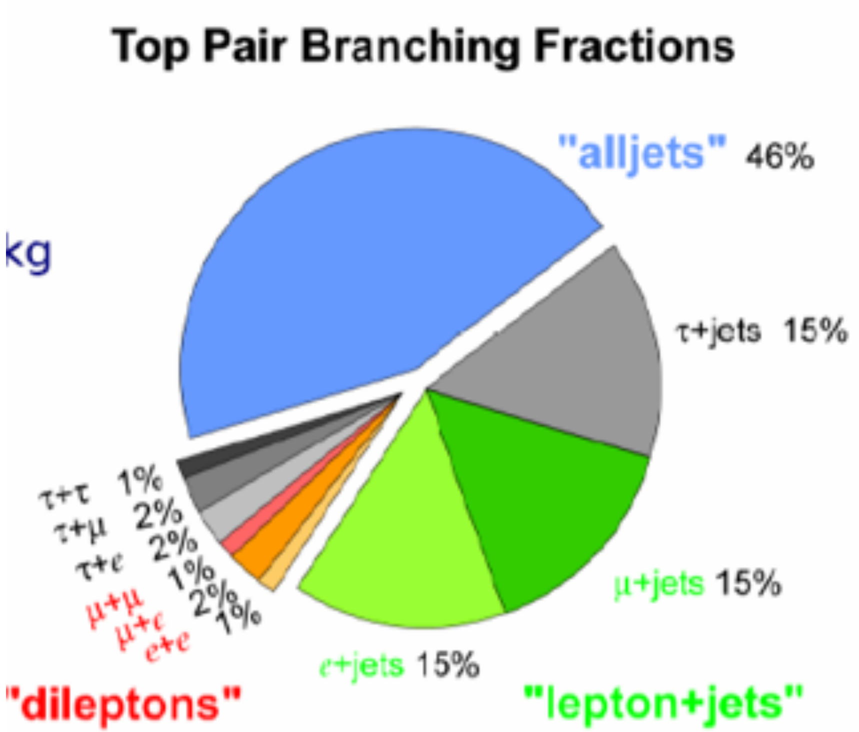
Wt channel
$\sigma \sim 70$ pb

W* (s-channel)
$\sigma \sim 10$ pb

Top Decays

- In the Standard Model, the decay of top quarks takes place almost exclusively through the t→Wb. W-boson decays in about 1/3 of the cases into a charged lepton and a neutrino and in 2/3 of the cases, decays into a quark-antiquark pair





Top Studies

- LHC is sometimes presented as a top factory
  - 1 evt/s produced at $d\mathcal{L}/dt = 10^{33}\ cm^{-2}s^{1}$
- Top production mechanism
  - Production cross section
  - V_{tb}
  - Spin correlations

- Top properties
  - Mass
  - Charge
  - Decay properties
    - EW vertex (V-A), W helicity
    - Rare top decays
- Search for new physics with 1 evt/fb with heavy flavours ?

Top Pair selection for semi-leptonic channels

Electron Trigger E_T>10 GeV

Two isolated lepton $p_T^{lep} > 20$ GeV $|\eta| < 2.4$

Four jets $p_T^{jet} > 20$ GeV & three jets $p_T^{jet} > 40$ GeV

$E_T^{Miss} > 20$ GeV

Top: 3 jets with highest p_T sum

No b-tag

W constraint ±10 GeV for one of the jet-jet comb.

Backgrounds

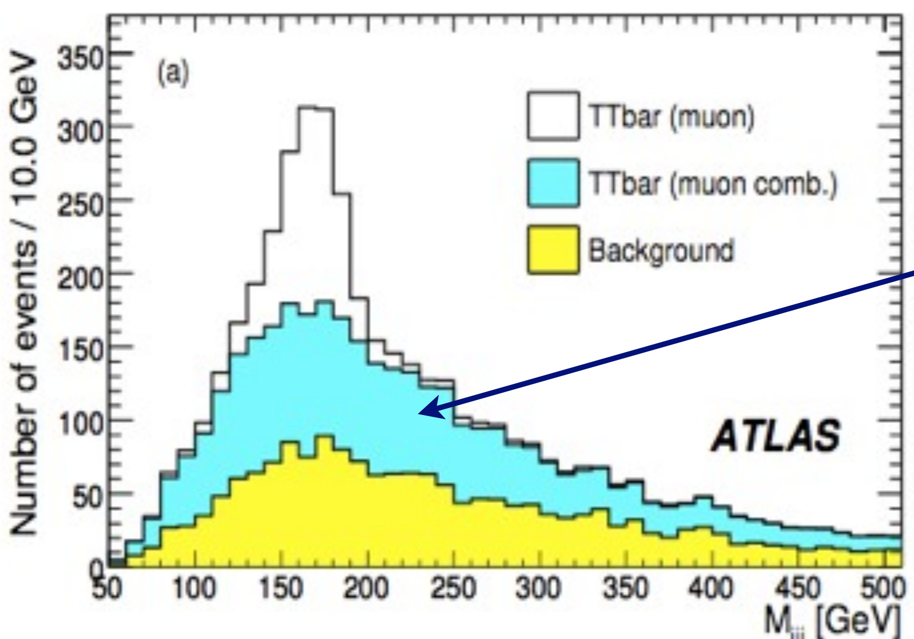
Dominant W+jets

Single top

$Z \rightarrow ll$ + jets

QCD with fake leptons and E_T^{Miss}

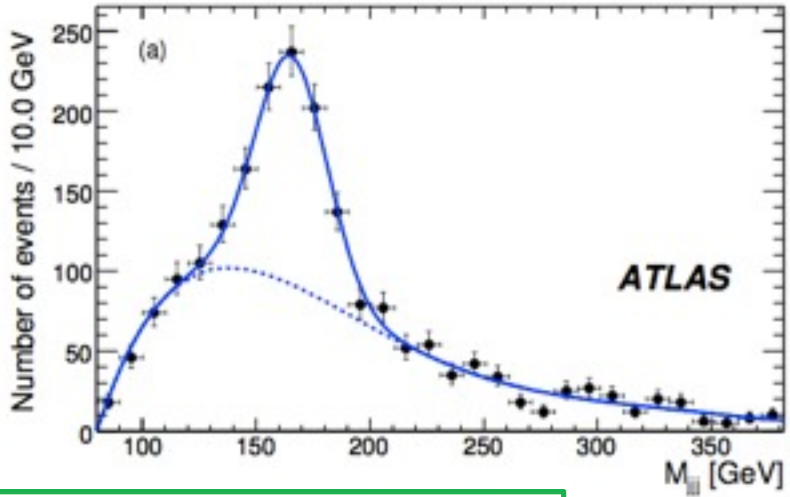
Dibosons: WW,WZ,ZZ



Combinatorial background

Top Pair Cross-Section Measurement

- 2 methods
  - Maximum likelihood fit on three jet invariant mass distribution
  - Counting events satisfying selection cuts & then subtracting background



100pb^{-1}

$$\text{Likelihood method:} \quad \Delta\sigma/\sigma = \left(7(\text{stat}) \pm 15(\text{syst}) \pm 3(\text{pdf}) \pm 5(\text{lumi})\right)\%$$

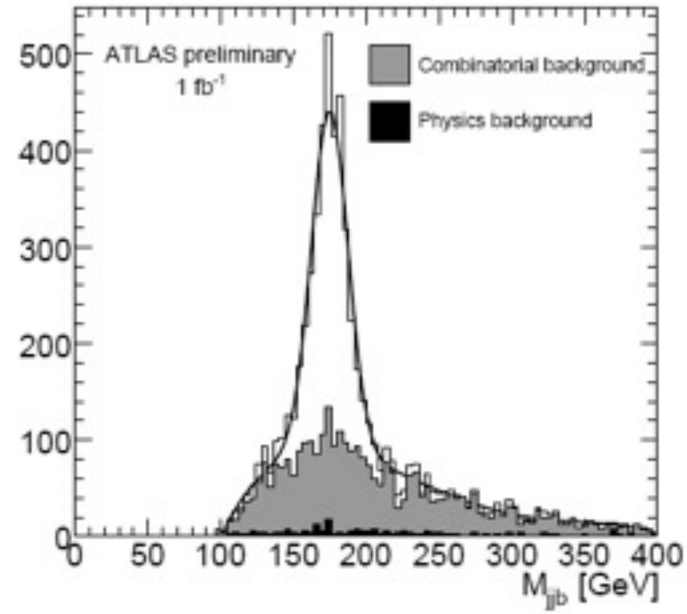
$$\text{Counting method:} \quad \Delta\sigma/\sigma = \left(3(\text{stat}) \pm 16(\text{syst}) \pm 3(\text{pdf}) \pm 5(\text{lumi})\right)\%$$

Source	Likelihood fit Electron (%)	Likelihood fit Muon (%)	Counting method (elec) Default (%)	Counting method (elec) W const. (%)
Statistical	10.5	8.0	2.7	3.5
Lepton ID efficiency	1.0	1.0	1.0	1.0
Lepton trigger efficiency	1.0	1.0	1.0	1.0
50% more W+jets	1.0	0.6	14.7	9.5
20% more W+jets	0.3	0.3	5.9	3.8
Jet Energy Scale (5%)	2.3	0.9	13.3	9.7
PDFs	2.5	2.2	2.3	2.5
ISR/FSR	8.9	8.9	10.6	8.9
Shape of fit function	14.0	10.4	-	-

Top Quark Mass Measurement

- Same cuts as before but p_T^{jet} > 40 GeV (calibration)
- 2 b-tag
- Use X^2 method to reconstruct W mass by minimizing, over all light jets pairs:

$$\chi^2 = \frac{(M_{jj}(\alpha_{E_{j_1}}, \alpha_{E_{j_2}}) - M_W^{PDG})^2}{(\Gamma_W^{PDG})^2} + \frac{(E_{j1}(1-\alpha_{E_{j_1}}))^2}{\sigma_1^2} + \frac{(E_{j2}(1-\alpha_{E_{j_2}}))^2}{\sigma_2^2}$$



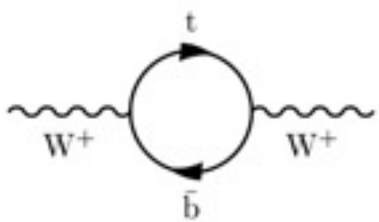
Systematic uncertainty	χ^2 minimization method	geometric method
Light jet energy scale	0.2 GeV/%	0.2 GeV/%
b jet energy scale	0.7 GeV/%	0.7 GeV/%
ISR/FSR	$\simeq$ 0.3 GeV	$\simeq$ 0.4 GeV
b quark fragmentation	$\lesssim$ 0.1 GeV	$\lesssim$ 0.1 GeV
Background	negligible	negligible
Method	0.1 to 0.2 GeV	0.1 to 0.2 GeV

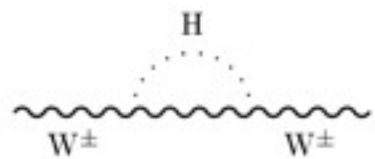
Tevatron
$M_{top} = 172.4 \pm 0.7_{stat} \pm 1.0_{sys}$ GeV

M_{top} = 175.0 ± 0.2GeV(stat)

Systematic error ($1fb^{-1}$)~ 1 GeV

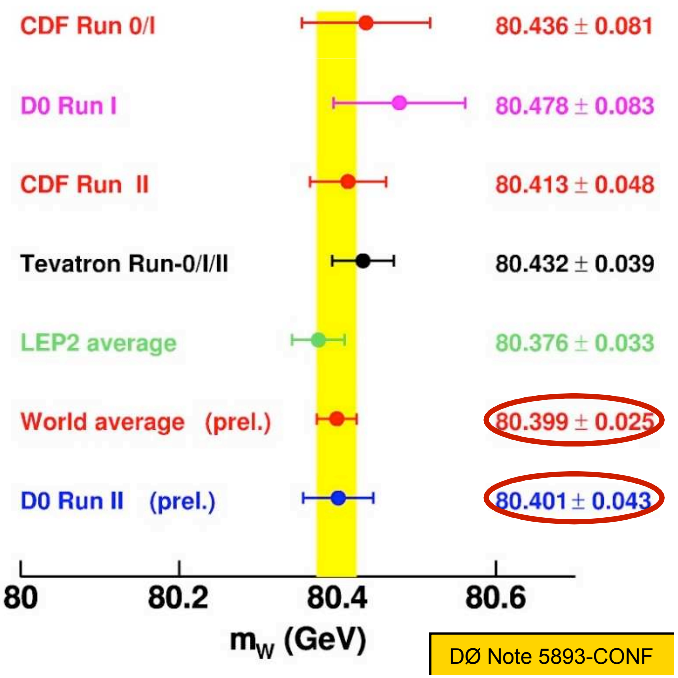
W Mass Measurement





$$M_W = 4\sqrt{\frac{\pi^2\alpha^2}{2G_F^2}}\,\frac{1}{\sin\theta_W\left(1-\Delta R\right)}$$

$$M_{top}^2, \log M_H$$



0. 3‰

World average: M_W = 80399 ± 25 MeV

ATLAS & CMS aims at a measurement of M_W with a precision of ~10 MeV.

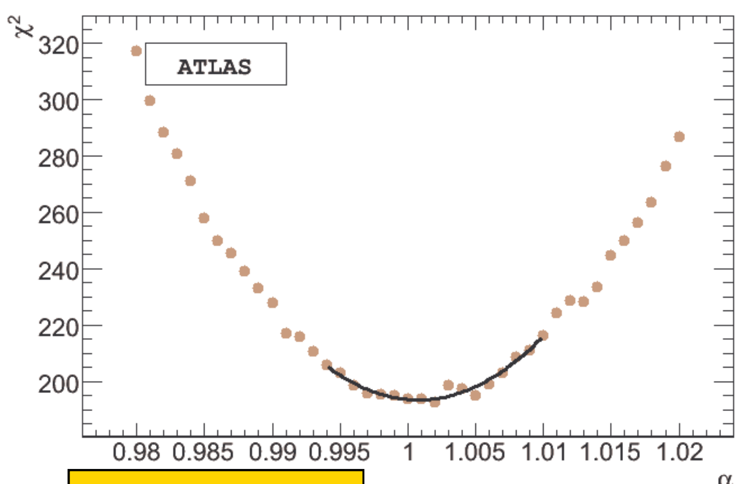
0. 1‰

Measuring M_W

- Aim at $2 \cdot 10^{-4}$ precision on the energy scale (going from M_Z to M_W) i.e.
  10 MeV at 50 GeV:
  - Electronics noise in strips compartment of LAr calorimeter
  - ~2 ADC counts in the middle compartment
  - A change of 0.01 degree of LAr or CMS crystal temperature
  - Effect of empty Bunch Crossings ?
    - The protons packets are not uniformly distributed inside the LHC
    - Effect of pile-up is different depending on the packet
    - Careful treatment of this effect is necessary
  - Good tradition in Geneva for "clock-work" skills
- Many (careful) steps have to be taken to reach the goal
  - Z^0 to fix the energy scale at ~ M_Z/M_W
  - Detector acceptance
  - Description of variables by MC (templates)
  - ....

Template method

- Use knowledge of Z^0
  - mass
  - kinematics (ratio M_W/M_Z)
- Response parameters
  - determined in-situ using Z events
  - then used to produce templates of p_T^e, tested against the data
- Study shows that M_W is measured with no bias, using this method
  - M_W^{true} = 80.405 GeV
  - M_W^{fit} = 80.466 ± 0.110 GeV



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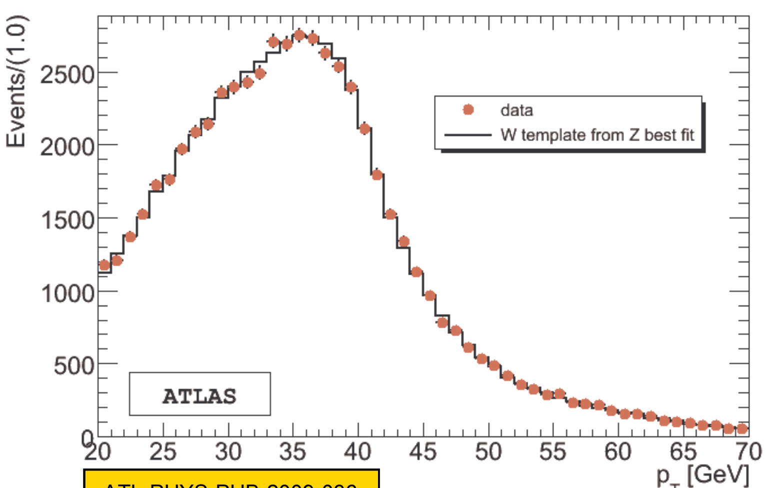

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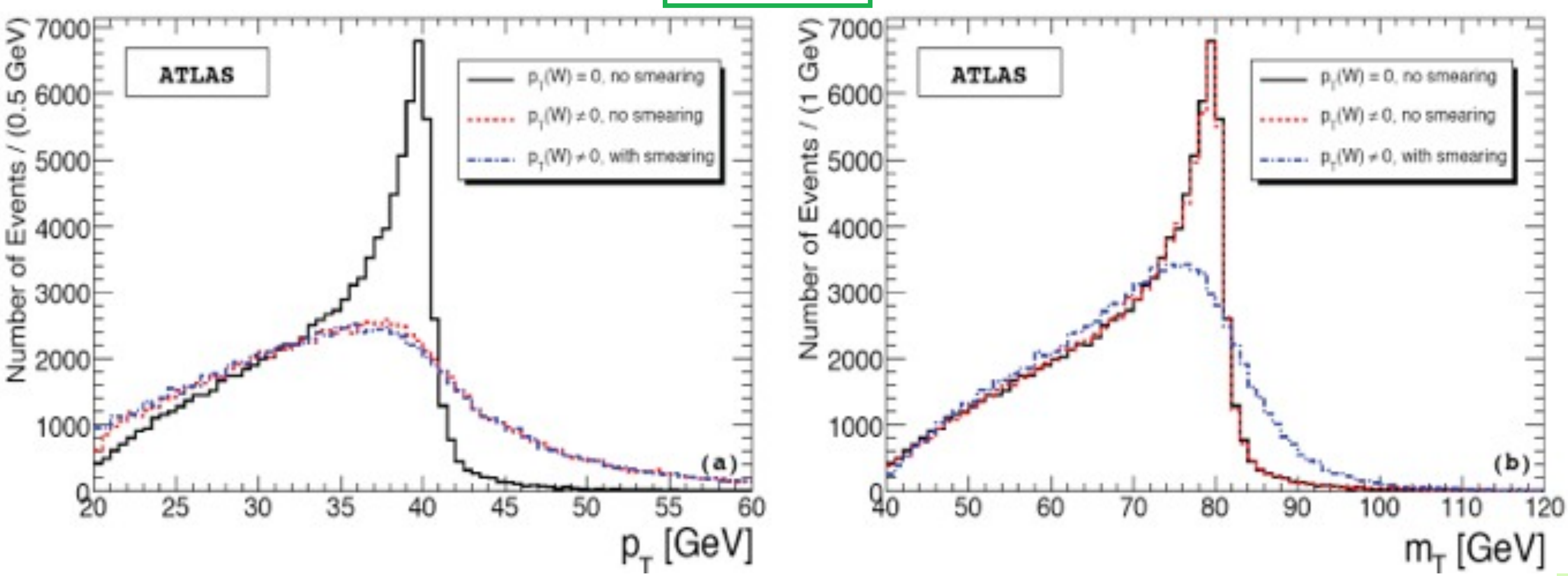
W Mass Measurement

- Select W candidate events
- Observable sensitive to M_W
  - p_T leptons
  - Transverse mass: M_T

$$m_T^W = \sqrt{2 p_T^l p_T^\nu (1 - \cos \Delta\phi)}$$

- Build template for these observables $p_T(M_W)$, $M_T(M_W)$

15 pb^{-1}



W Mass Measurement

15 pb^{-1}

Method	p_T (e) [MeV]	p_T (μ) [MeV]	m_T (e) [MeV]	m_T (μ) [MeV]
δM_W (stat.)	120	106	61	57
δM_W (scale)	110	110	110	110
δM_W (resol)	5	5	5	5
δM_W (tails)	28	<28	28	<28
δM_W (eff.)	14	-	14	-
δM_W (recoil)	-	-	200	200
δM_W (bkg)	3	3	3	3
δM_W (PDF)	25	25	25	25

p_T leptons $\delta M_W = 110\ (\text{stat}) \oplus 114\ (\text{exp.}) \oplus 25\ (\text{PDF})\ \text{MeV}$

Transverse mass M_T $\delta M_W = 60\ (\text{stat}) \oplus 230\ (\text{exp.}) \oplus 25\ (\text{PDF})\ \text{MeV}$

High Statistic Measurement of M_W

- With $1 fb^{-1}$
  - $45\ 10^6$ W boson per leptonic channel
  - $4.5\ 10^6$ Z boson per leptonic channel
- Examples of systematic studies:
  - Experimental
    - Lepton energy scale, linearity, resolution
    - Reconstruction efficiency
  - Theory
    - W distribution, y^W, p_T^W
    - FSR
  - Environment
    - Underlying event
    - Pile-up
    - Background

W Mass: Ultimate Measurement

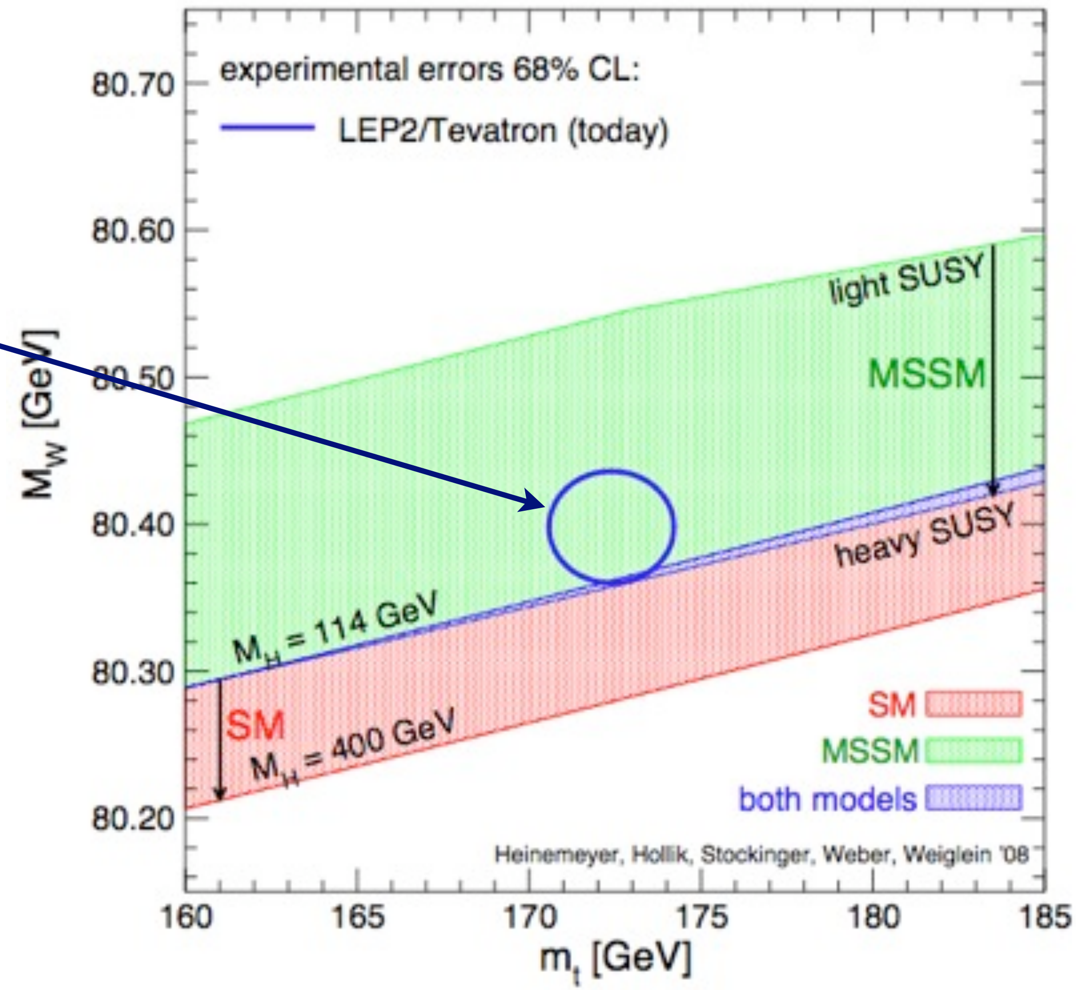
source	effect	δm_W (MeV)
Theoretical model	Γ_W	0.5
	y_W	1
	p_{tW}	3
	QED radiation	<1
Lepton measurement	linearity and scale	4
	resolution	1
	efficiency	3 (e); <1 (μ)
Backgrounds	$W \rightarrow \tau\nu$	0.4
	$Z \rightarrow l\ (l)$	0.2
	$Z \rightarrow \tau\tau$	0.1
	Jet events	0.5
Pile-up and UE		<1 (e); ~0 (μ)
Beam crossing angle		<0.1
total		~7

One channel (e) and one study (p_T)

From M_W to M_{Higgs}

today $\sigma(M_{W}) \sim 0.3‰$

LHC aims at 0.1‰

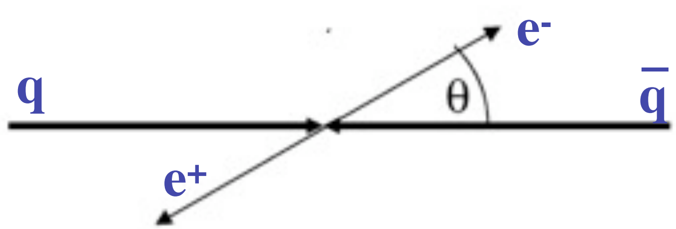


Measurement of A_{FB} in γ^*/Z decays

Parity violation in neutral currents $\Longrightarrow$

$$J_\mu^{NC} = J_\mu^3 - \sin^2\theta_W J_\mu^{em}$$

$$\frac{1}{\sigma}\frac{d\sigma}{d\cos\theta} = \left[\frac{3}{8}(1+\cos^2\theta) + A_{FB}(s)\cos\theta\right]$$



$$A_{FB} = \frac{1}{\sigma}[\sigma(\cos\theta > 0) - \sigma(\cos\theta < 0)]$$

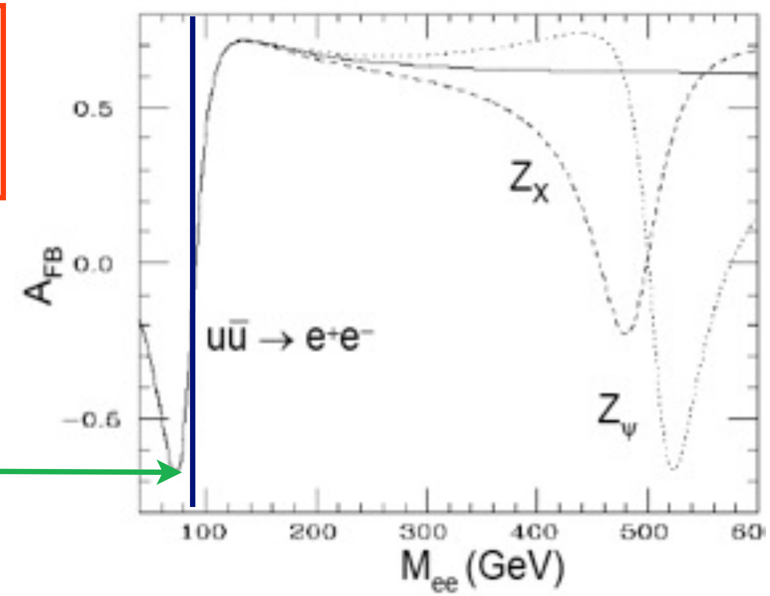
$A_{FB}(s) = f(g_V^{lq}, g_A^{lq}, Q^{lq}) \Longrightarrow$ probe V-A

extraction of the weak mixing angle $\sin^2(\theta_W)$

Study A_{FB} at the Z pole, using forward electrons.

At Tevatron, meast dominated by statistical error

Systemtatic errors come from PDF, detector resolution



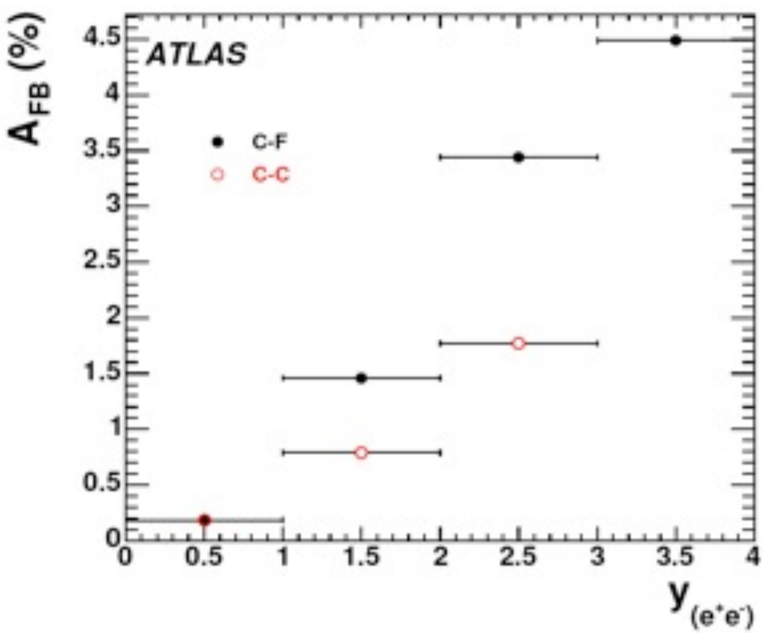
From theory: $A_{FB} = b\,(a - \sin^2\vartheta_{eff}^{lept})$

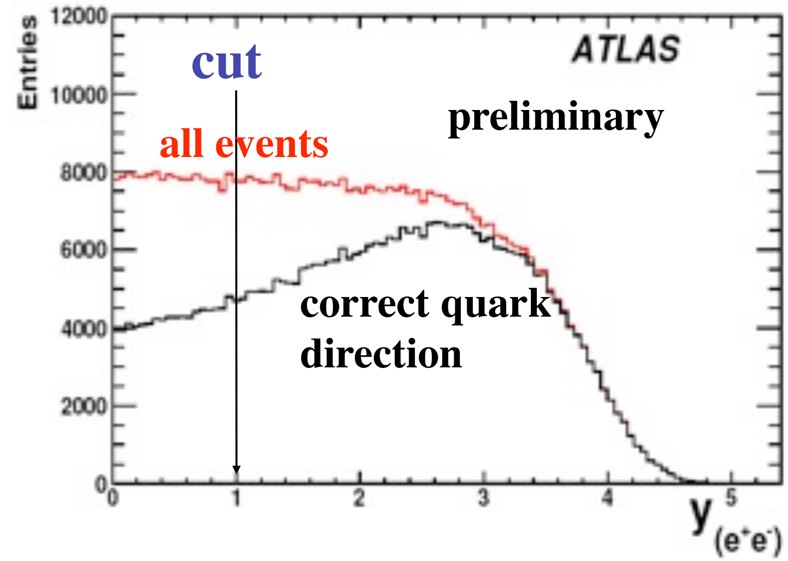
($a = 0.23 \pm 0.03$ $b = 1.8 \pm 0.3$)

Forward-Backward Asymmetry in Z decay

- At LHC: quark direction not known
  - take Z direction
  - cut on y_Z improves the assumption

C: central electron(|η|<2.5)
F: fw electron (|η|<4.9)





Forward electron identification important !!
($\varepsilon_{fw\ ele}$~ 50% R_{ject} = 100 → $\Delta A_{FB}(stat) = 1.5\ 10^{-4}$)
Electron channel favored w.r.t. to μ channel because of the acceptance up to η=4.9

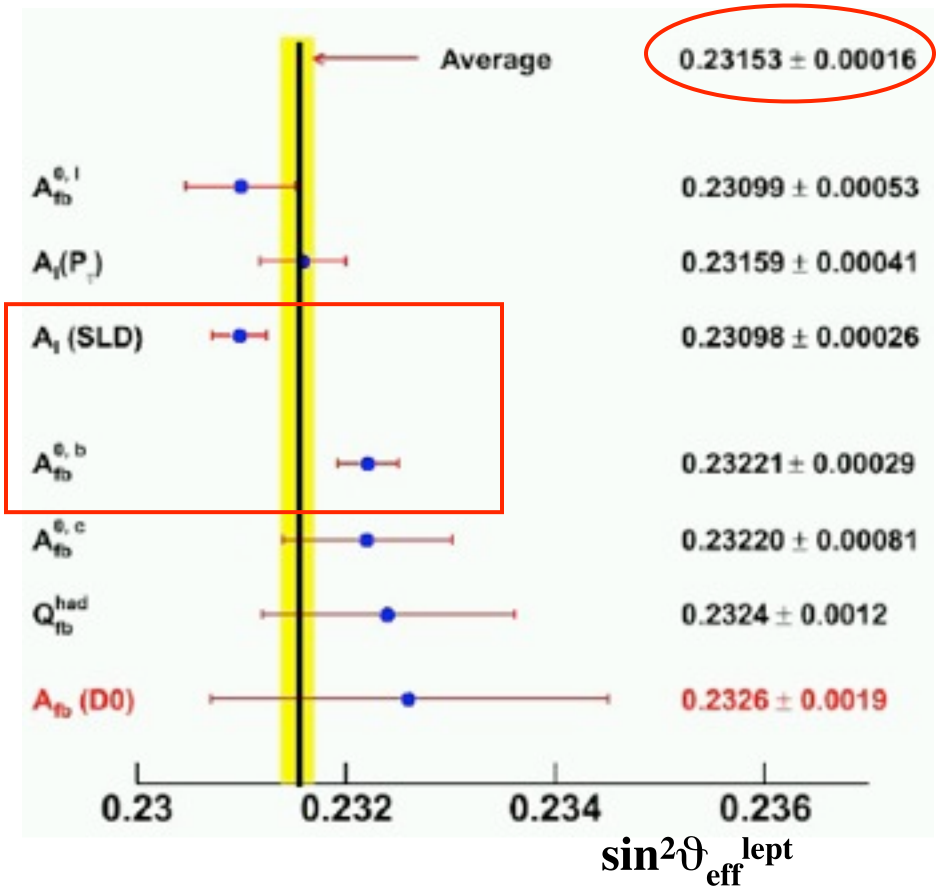
Prediction for measurement of $\sin^2\theta_W$

Uncertainties	$\delta \sin^2_{eff}$
Energy scale	1.5×10^{-5}
Reco. Efficiency	1.9×10^{-5}
Energy resolution	1.1×10^{-6}
Charge ID	1.4×10^{-5}
Bkg. subtraction	$<10^{-5}$
Theory(PDF)	2.4×10^{-4}
a and b parameters	3×10^{-5}
Statistical error	1.5×10^{-4}

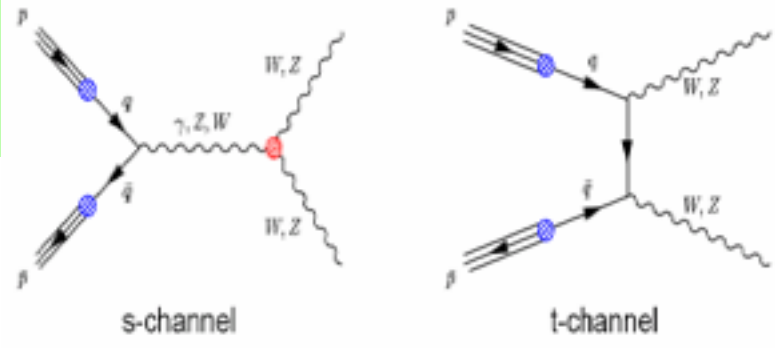
ATLAS preliminary : 100 fb^{-1}

Main uncertainty PDF

Conversely can be used to constrain PDF



Dibosons

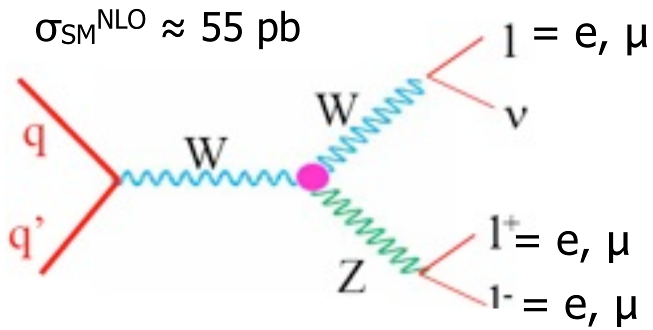


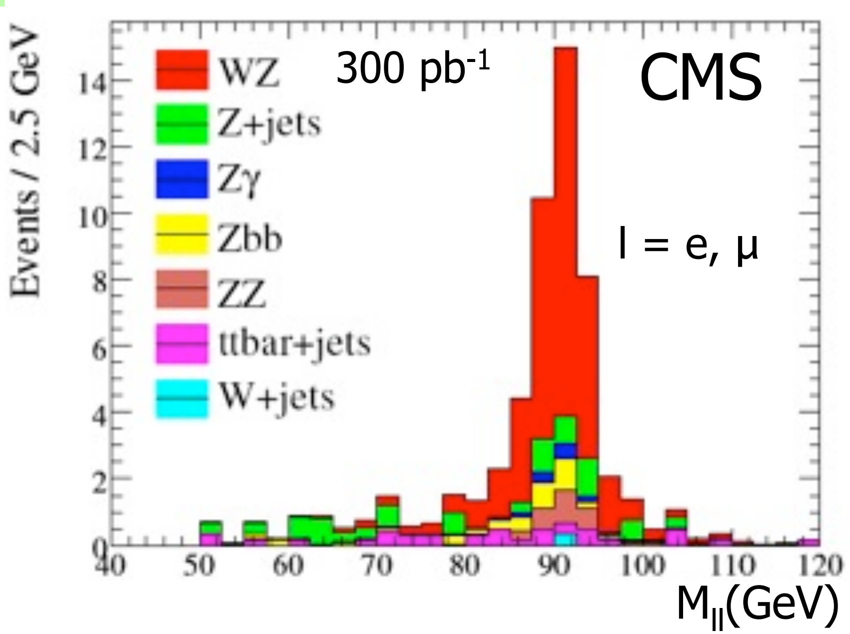
$$q\bar{q}'\to W^{(*)} \to W\gamma : WW\gamma$$
$$q\bar{q}'\to W^{(*)} \to WZ : WWZ$$
$$q\bar{q} \to Z/\gamma^{(*)} \to WW : WW\gamma, WWZ$$
$$q\bar{q} \to Z/\gamma^{(*)} \to Z\gamma : ZZ\gamma, Z\gamma\gamma$$
$$q\bar{q} \to Z/\gamma^{(*)} \to ZZ : ZZ\gamma, ZZZ$$

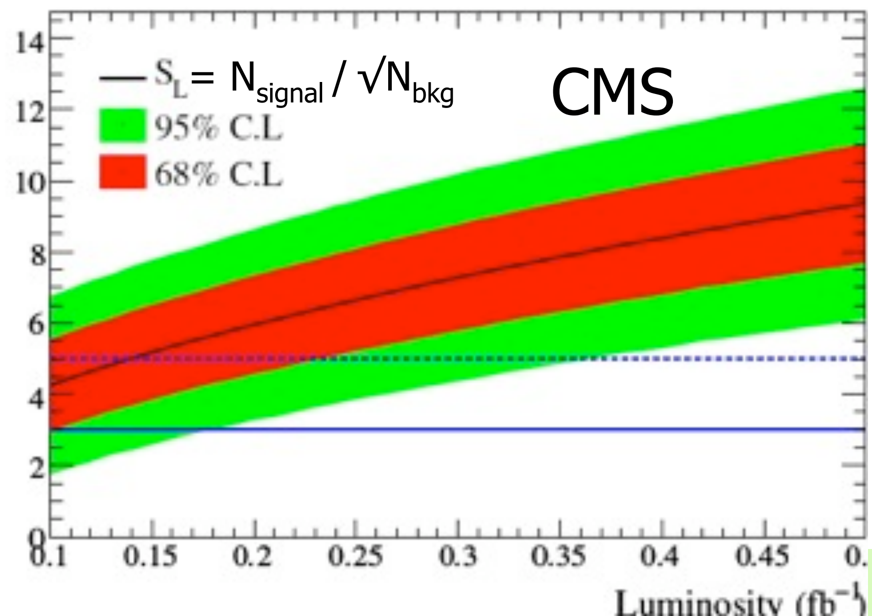
Not permitted in SM

- Diboson production cross-section
  - expect increase of factor 10 in xs at LHC
  - 10-100 evts in first fb^{-1}
- Anomalous charged Triple Gauge Boson Coupling
  - Self interactions among three gauge bosons
  - Deviation from SM
    - $\Delta g_1^Z = g_1^Z - 1$, $\Delta\kappa_Z = \kappa_Z - 1$, $\Delta\kappa_\gamma = \Delta\kappa_\gamma - 1$, $\lambda_\gamma \neq 0$, $\lambda_Z \neq 0$
- Anomalous neutral Triple Gauge Boson Coupling
  - neutral TGC forbidden in SM
    - $f_4^\gamma \neq 0, f_5^\gamma \neq 0, f_4^Z \neq 0, f_5^Z \neq 0$
- New Physics control sample
  - If no Higgs boson, di-bosons are important to understand EWSB
  - Background for Higgs & New Physics

Associated production of Gauge Bosons W&Z



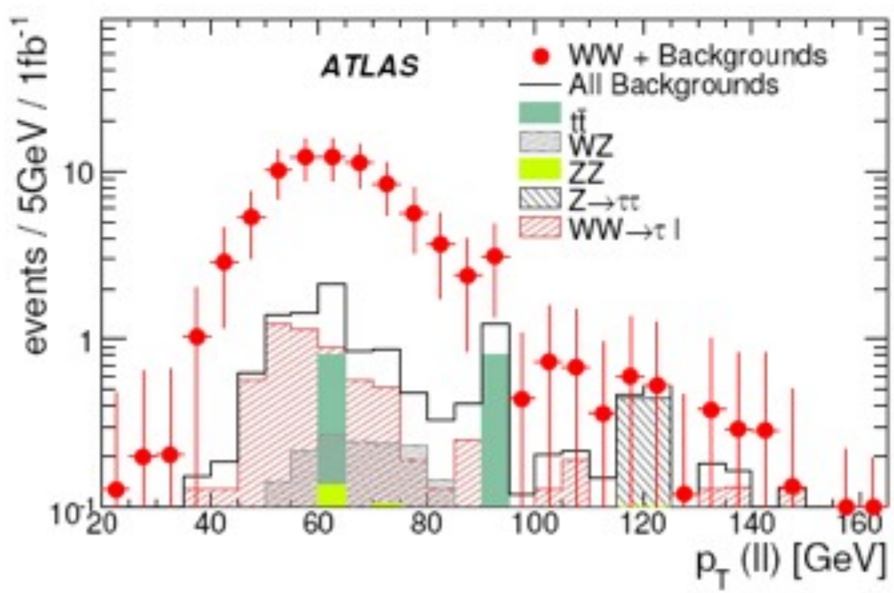




Charged di-bosons

$$L/g_{WWV} = ig_1^V (W^*_{\mu\nu} W^\mu V^\nu - W_{\mu\nu} W^{*\mu} V^\nu) + i\kappa^V W^*_\mu W_\nu V^{\mu\nu} + \frac{\lambda^V}{M_W^2} W^*_{\rho\mu} W^\mu_\nu V^{\nu\rho}$$

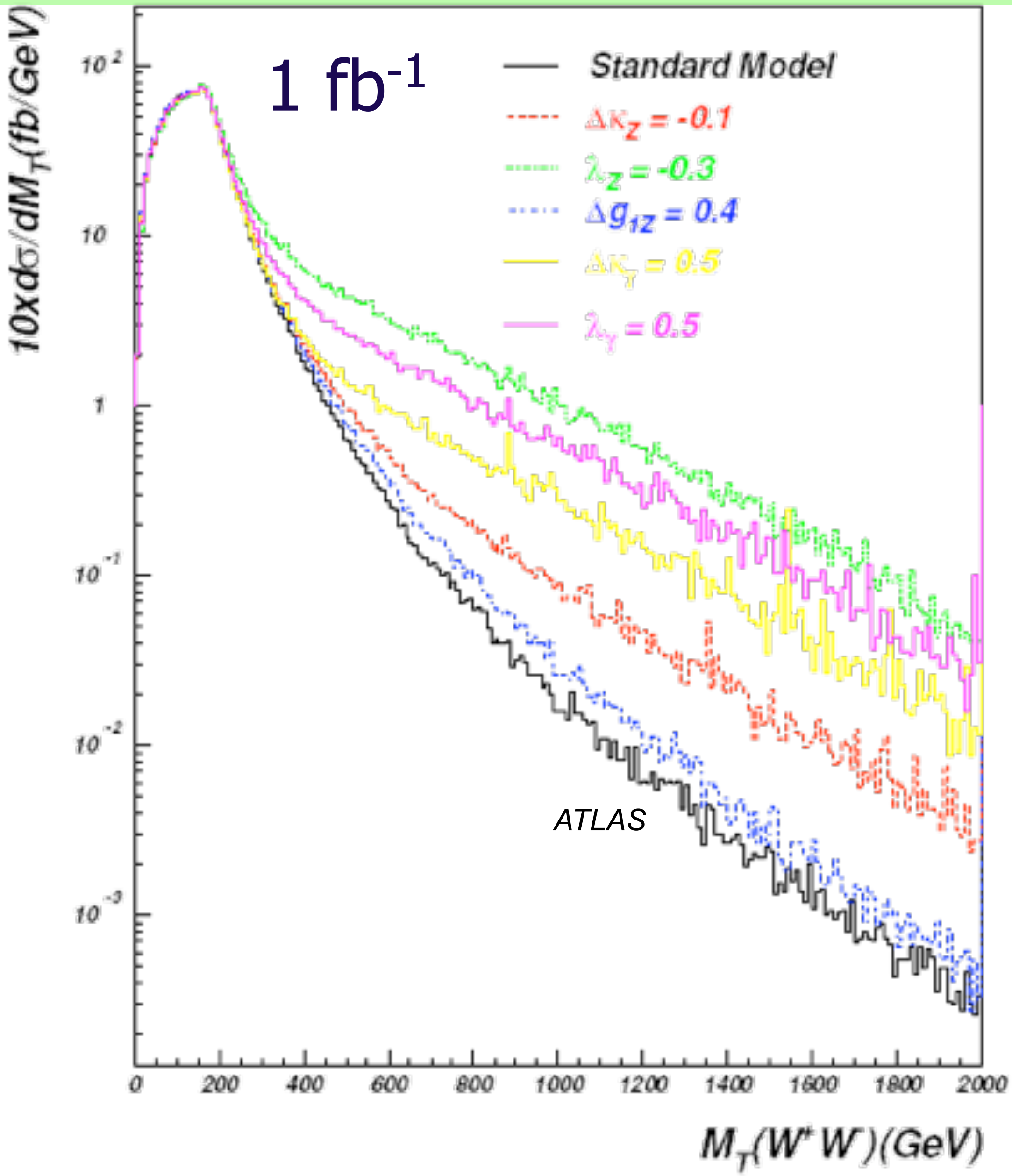
- Select WW events
  - Electrons: 2 isolated el. ($|\eta|<2.5$) with opposite charges; associate tracks-clusters, isolation $E_T<8$GeV in a cone $\Delta R=0.45$ (discriminate WW, ttbar, DY)
  - Muons: $p_T>5$GeV, isolation $E_T<5$GeV in a cone $\Delta R=0.45$
  - Jet veto: $E_T>20$GeV, $|\eta_{jet}|<3$
  - $E_T^{miss} > 50$ GeV
  - M_Z veto $|M_{ll}-M_Z|>15$ GeV
  - $\Delta\varphi(p_{T(ll)}, E_T^{miss}) > 175^0$



Diboson rates for 1 fb^{-1}

Diboson mode	Signal	Background	Signal eff.	σ_{stat}^{signal}	p-value	Sig.
$W^+W^- \to e^{\pm}\nu\mu^{\mp}\nu$	347 ± 3	64 ± 5	12.6% (BDT)	5.4%	3.6×10^{-166}	27.4
$W^+W^- \to \mu^+\nu\mu^-\nu$	70 ± 1	17 ± 2	5.2% (BDT)	12.0%	8.8×10^{-30}	11.3
$W^+W^- \to e^+\nu e^-\nu$	52 ± 1	11 ± 2	4.9% (BDT)	13.9%	1.9×10^{-24}	10.1
$W^+W^- \to \ell^+\nu\ell^-\nu$	103 ± 3	17 ± 2	2.0% (cuts)	9.9%	1.4×10^{-54}	15.5
$W^{\pm}Z \to \ell^{\pm}\nu\ell^+\ell^-$	128 ± 2	16 ± 3	15.2% (BDT)	8.8%	3.0×10^{-76}	18.4
	53 ± 2	8 ± 1	6.3% (cuts)	13.7%	3.1×10^{-30}	11.4
$ZZ \to 4\ell$	17 ± 0.5	2 ± 0.2	7.7% (cuts)	24.6%	6.0×10^{-12}	6.8
$ZZ \to \ell^+\ell^-\nu\bar{\nu}$	10 ± 0.2	5 ± 2	2.6% (cuts)	31.3%	7.7×10^{-4}	3.2
$W\gamma \to e\nu\gamma$	1604 ± 65	1180 ± 120	5.7% (BDT)	2.5%	significance > 30	
$W\gamma \to \mu\nu\gamma$	2166 ± 88	1340 ± 130	7.6% (BDT)	2.1%	significance > 30	
$Z\gamma \to e^+e^-\gamma$	367 ± 12	187 ± 19	5.4% (BDT)	5.2%	1.2×10^{-91}	20.3
$Z\gamma \to \mu^+\mu^-\gamma$	751 ± 23	429 ± 43	11% (BDT)	3.6%	5.9×10^{-171}	27.8

Anomalous couplings



Expectations for TGC Anomalous couplings with ATLAAS

95% CL limit on AC (Λ=2 TeV) 10 fb^{-1} (~ 10 x better than present CDF 2 fb^{-1})

Diboson,	λ_Z	$\Delta\kappa_Z$	Δg_1^Z	$\Delta\kappa_\gamma$	λ_γ
WZ, (M_T)	[-0.015, 0.013]		[-0.011, 0.034]		
$W\gamma$, (p_T^γ)					[-0.05, 0.02]
WW, (M_T)		[-0.035, 0.073]		[-0.088, 0.089]	
WW, (LEP)			[-0.051,0.034]	[-0.105,0.069]	[-0.059,0.026]

95% CL limit on AC (Λ=2 TeV) 10 fb^{-1}

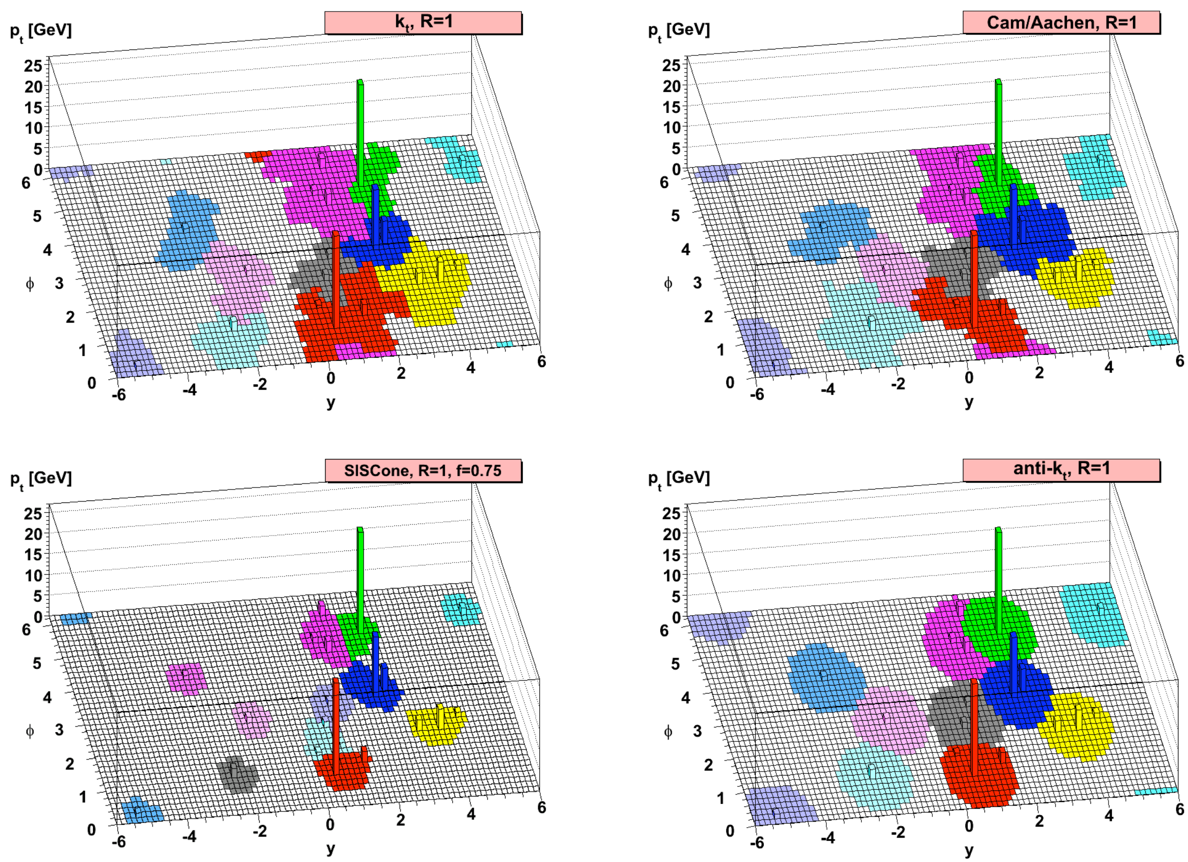
$ZZ \to \ell\ell\ell\ell$	f_4^Z	f_5^Z	f_4^γ	f_5^γ
$ZZ \to \ell\ell\nu\nu$	$[-0.009, 0.009]$	$[-0.009, 0.009]$	$[-0.010, 0.010]$	$[-0.011, 0.010]$
LEP Limit	$[-0.30, 0.30]$	$[-0.34, 0.38]$	$[-0.17, 0.19]$	$[-0.32, 0.36]$

Conclusions

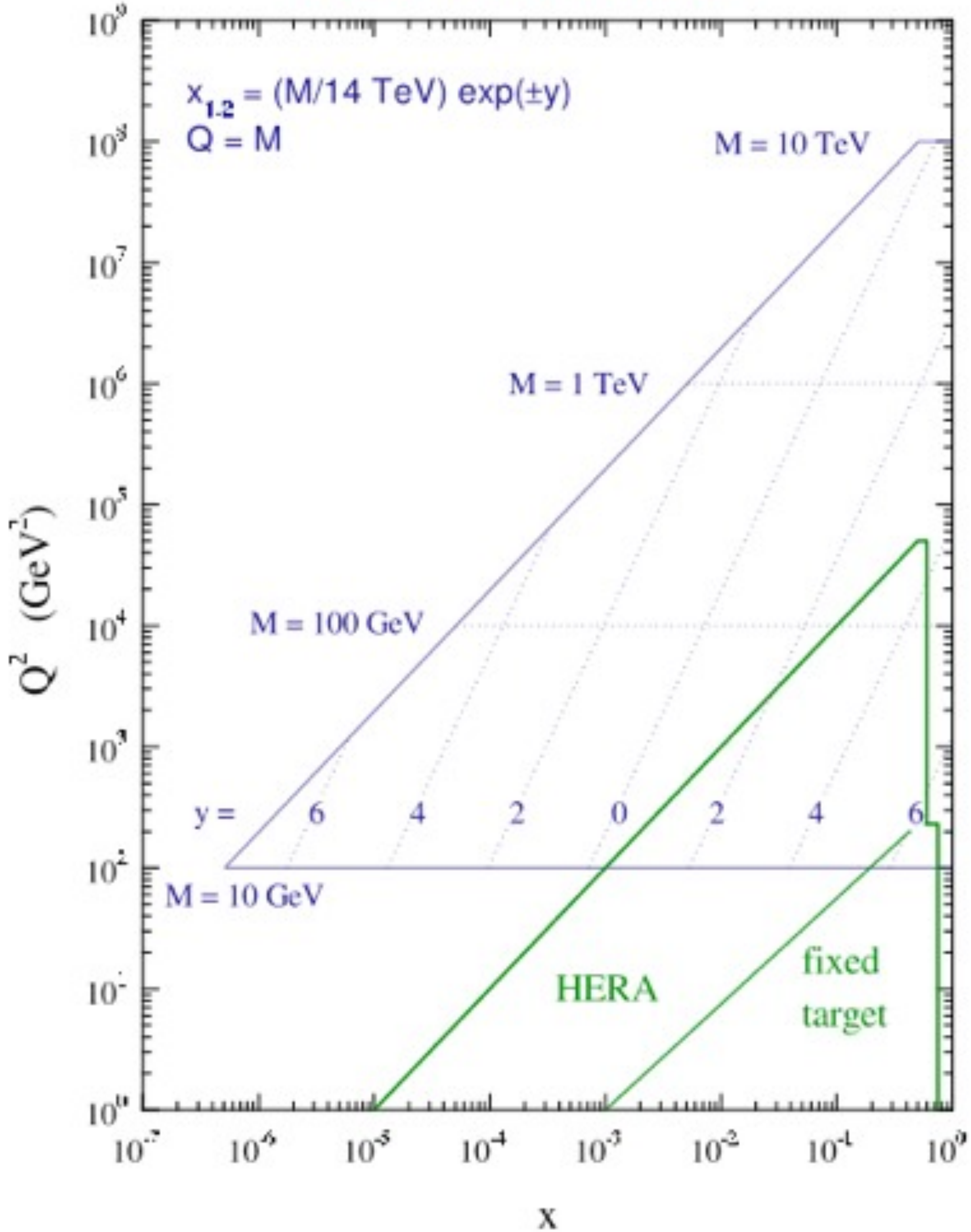
- Known processes from SM will be measured at LHC
  - Understand detector & machine performance
  - Make first comparison with theoretical predictions
- Even with a small integrated luminosity, ATLAS & CMS will be able to make physics measurements
  - Minimum Bias cross-section
  - W & Z cross sections, W mass
  - Inclusive jet cross sections
  - Top
- The ultimate goals w.r.t. to SM measurements require to control the detector with high precision
  - W mass wiyh 0.01% precision
  - Triple gauge coupling
  - Top properties
- Looking forward analyzing data from the LHC & making measurements and discovery(ies ?)

Jet reconstruction

- New developments on jet algorithms



LHC parton kinematics



Jet Energy Scale