LHCb STATUS AND PHYSICS PROSPECTS

Monica Pepe-Altarelli (CERN)

Corfu Summer School 2010

Outline

- Introduction to the LHCb Experiment
- Physics motivations
- Detector Overview and Performance
- First results
- Prospects
- Conclusions

Many thanks to G.Wilkinson and many others for (un)knowingly helping me!

The LHCb Experiment

- **LHCb**: dedicated b-physics experiment at LHC searching for NP beyond the SM through the study of very rare decays of b-flavoured (and c) hadrons and precision measurements of CP-violating observables

- Enormous progress in recent years from the B factories and Tevatron, far beyond expectations.

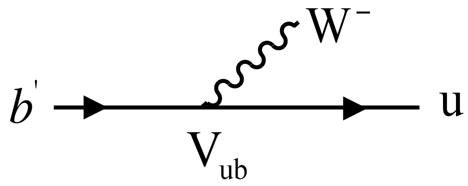
- Clear demonstration of the SM CKM mechanism as dominant source of CP violation.

CKM Matrix

- The Cabibbo-Kobayashi-Maskawa matrix $\mathbf{V_{CKM}}$ describes rotation between flavour (d',s',b') and mass (d,s,b) eigenstates

Flavour eigenstates / Mass eigenstates

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

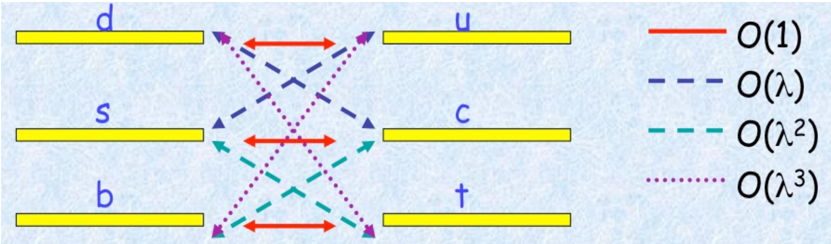


V_{ij} proportional to transition amplitude from quark i to quark j
→V_{CKM} quark mixing matrix

- V_{CKM} depends on 3 mixing angles and 1 phase, which is the only source of CP violation in SM
- Phase only present with N ≥ 3 generations (Nobel prize 2008)
  - With N=2, all phases can be removed → matrix real → no CPV
- These 4 parameters (3 angles and 1 phase) must be determined experimentally

Wolfenstein parametrization

Reflects hierarchy of strengths of quark transitions



$$V_{CKM} \approx \begin{pmatrix} 1 & \lambda & \lambda^3 \\ \lambda & 1 & \lambda^2 \\ \lambda^3 & \lambda^2 & 1 \end{pmatrix}$$

$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{pmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} + O(\lambda^4)$$

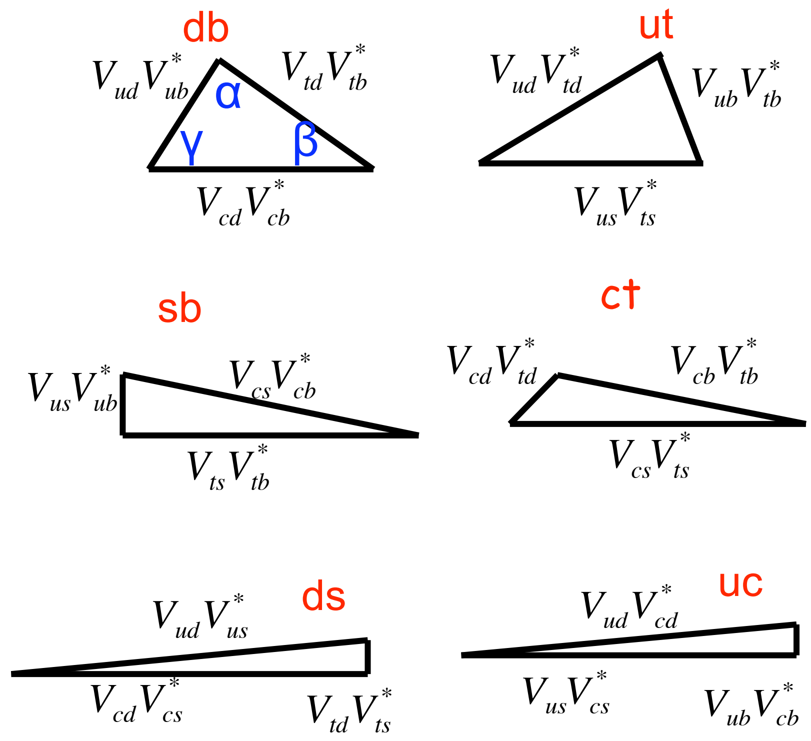
- $\lambda = \sin\theta_c$
- η induces CP Violation
- $O(\lambda^4) \to (\bar{\rho}, \bar{\eta}) \equiv (1-\lambda^2/2)\,(\rho,\eta)$

$$\boxed{\begin{aligned} A &= 0.812^{+0.013}_{-0.027} \\ \lambda &= 0.22543 \pm 0.00077 \\ \bar{\rho} &= 0.144 \pm 0.025 \\ \bar{\eta} &= 0.342^{+0.016}_{-0.015} \end{aligned}}$$

CKM fitter:
ICHEP 2010
(see also UTfit)

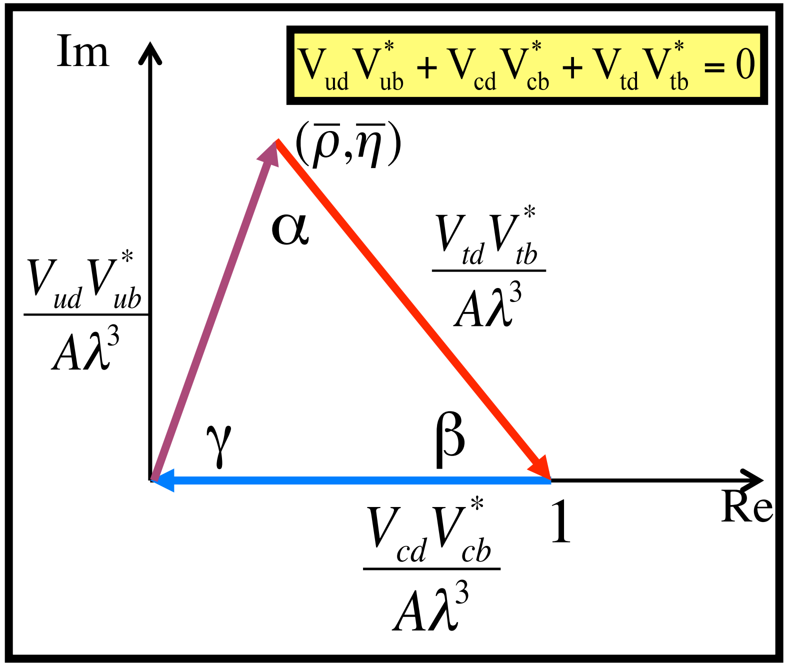
CKM Matrix

- Unitarity of CKM matrix implies $\Sigma\, V_{ij}\, V_{ik}^* = 0$ $(j \neq k)$
- Each of these 6 unitarity constraints can be seen as sum of 3 complex numbers closing a triangle in complex plane
- All triangles have same area a → measure of CPV in SM $\quad J_{CP} = 2a = \lambda^6 A^2 \eta \approx 10^{-5}$
- Only db and ut triangles have sides of same order (λ^3)
- db triangle → used to define angles α, β, γ
- ut triangle of special relevance for physics of B_s mesons

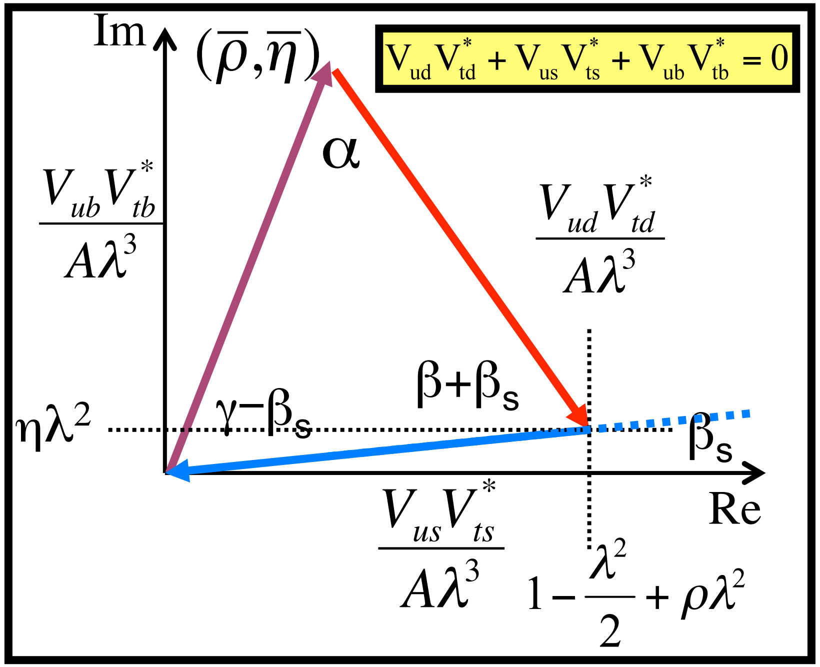


Unitarity triangles

db triangle



ut triangle



$$\gamma \equiv \arg\left[-\frac{V_{ub}^* V_{ud}}{V_{cb}^* V_{cd}}\right] = \tan^{-1}\frac{\eta}{\rho} \sim 70^\circ$$

$$\beta \equiv \arg\left[-\frac{V_{cb}^* V_{cd}}{V_{tb}^* V_{td}}\right] = \tan^{-1}\frac{\bar{\eta}}{1-\bar{\rho}} \sim 22^\circ$$

$$\alpha \equiv \pi - \beta - \gamma \sim 88^0$$

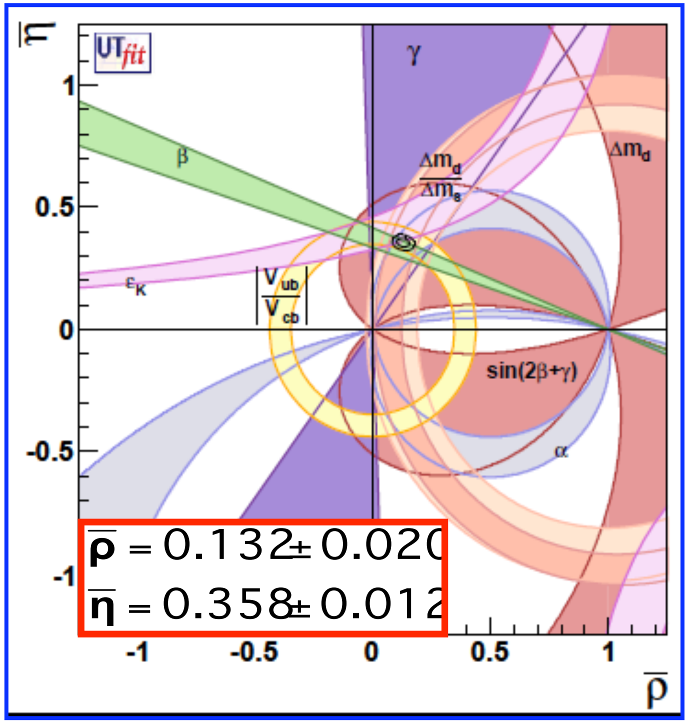
Higher λ-orders in CKM introduce small shift → $\gamma-\beta_s$ $\beta+\beta_s$

$$\beta_s \equiv \arg\left[-\frac{V_{cb}V_{cs}^*}{V_{tb}V_{ts}^*}\right] \sim \eta\lambda^2 \sim 1^\circ$$

Status of CKM parameters

- Measurements of many processes are consistent with the SM and fix a rather restricted domain for the CKM parameters

- Coordinates of apex of unitarity triangle:
  - $\overline{\eta} = 0$ → CP conservation
  - imaginary part $\overline{\eta}$ measured at **~3%** (measurements of $\varepsilon_{K,}$ sin(2β), V_{ub} ,..)
  - real part $\overline{\rho}$ measured at **~16%** (Δm_d , Δm_s, α, V_{ub}….)



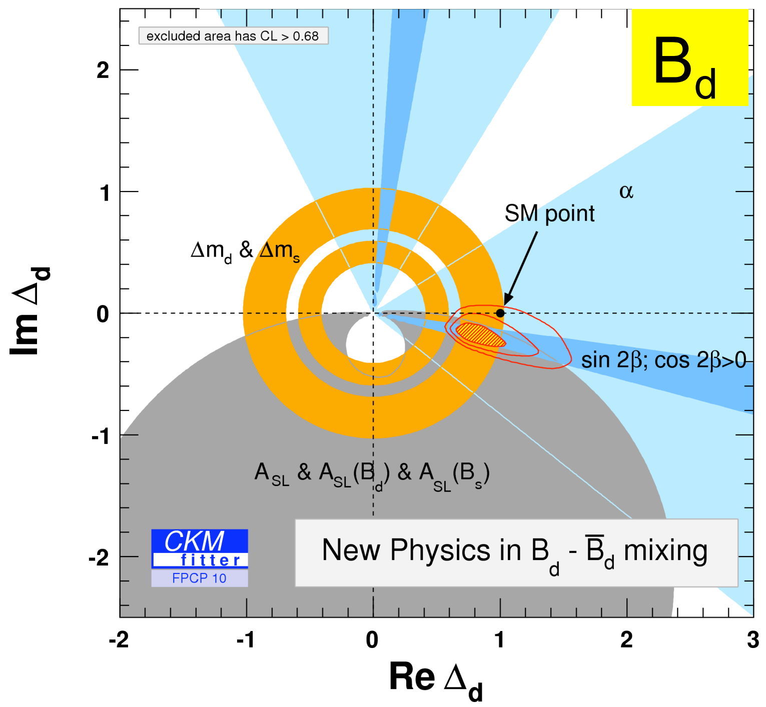
ICHEP 2010

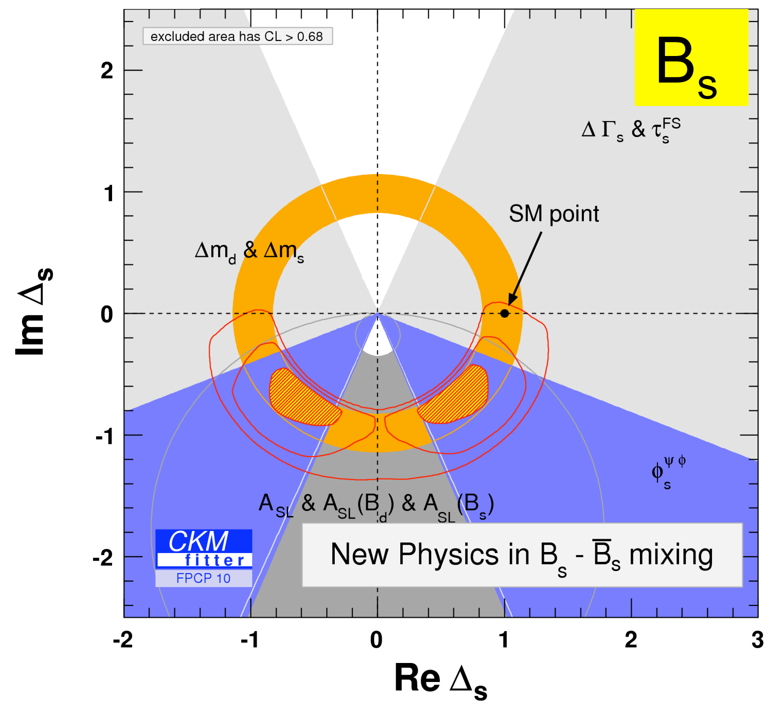
Is there still room for NP?

The effect of New Physics in B mixing can be parameterized as:

$$\langle B_q | H^{SM+NP}_{\Delta B=2} | \overline{B_q} \rangle \equiv \langle B_q | H^{SM}_{\Delta B=2} | \overline{B_q} \rangle \times \left[\mathrm{Re}\Delta_q + i\,\mathrm{Im}\Delta_q \right] \qquad \Delta_q = |\Delta_q| e^{2i\phi_q^{NP}}$$

$$\text{In SM} : \mathrm{Re}\Delta_q = 1,\ \mathrm{Im}\Delta_q = 0$$

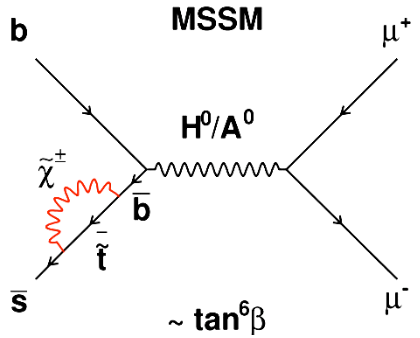


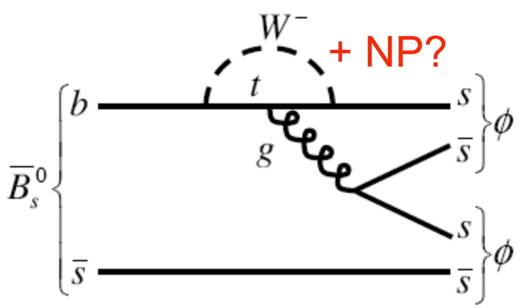


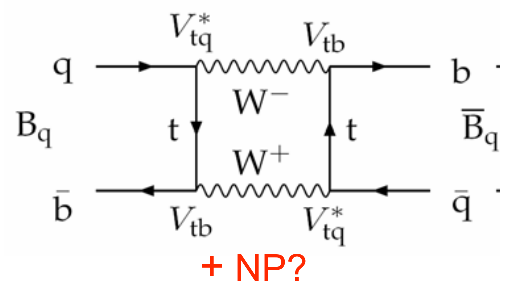
There are effects which need investigating! Still a lot of room for NP, particularly in B_s

The LHCb roadmap

- Focus has shifted: from seeking to verify the CKM picture to searching for signs of New Physics beyond the Standard Model in the flavour sector
- Measure processes that are strongly suppressed in the SM and poorly constrained by existing data, but that have sensitivity to new particles at high mass scales via their virtual effects in loop diagrams (complementary approach to direct searches):



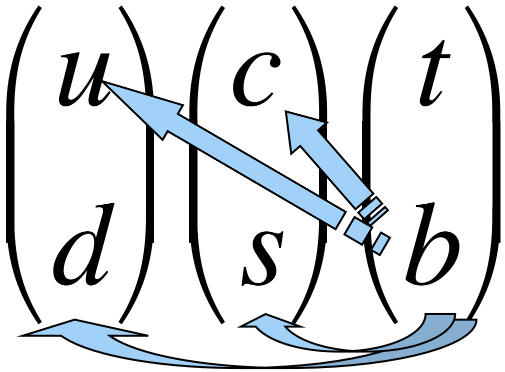




- Search for possible inconsistencies in measurements of angles and sides of unitarity triangles: compare results from decays dominated by tree-level diagrams with those that start at loop level to probe validity of SM

Why the b quark?

- Heaviest quark that forms hadronic bound states
- All decays are CKM suppressed
  - Long lifetime (~1.6 ps)
  - Favourable experimental conditions
- High mass: many accessible final states with different expected rates
  - Dominant decay process: “tree” b→c transition
  - Very suppressed “tree” b→u transition
  - FCNC: “penguin” b→s,d transition
- CP violation – expect large CP asymmetries in some B decays
- Theoretical predictions can be precisely compared with experimental results

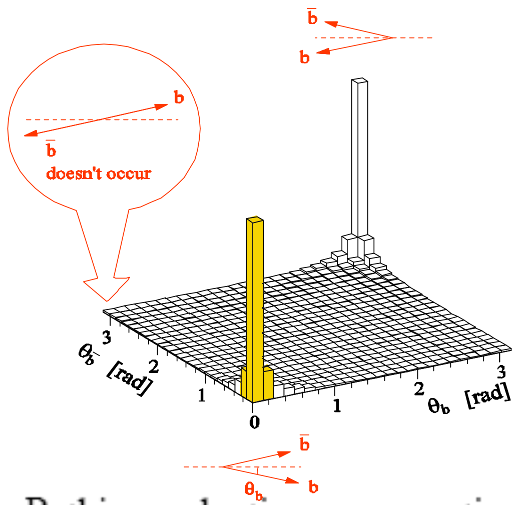


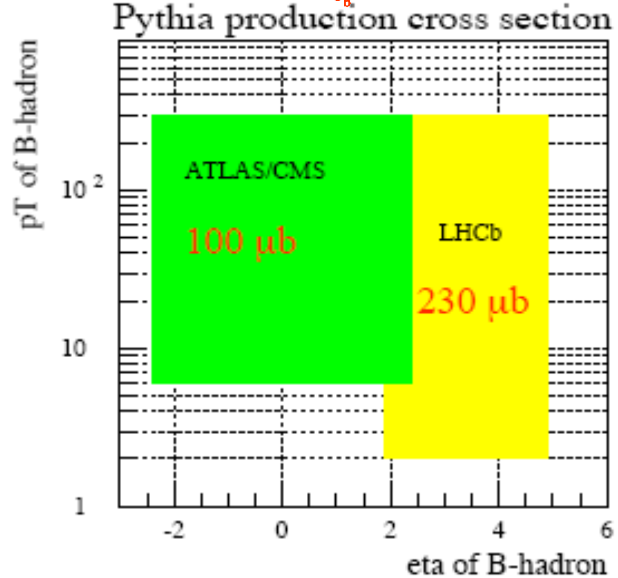
b production at LHC

- Advantages of beauty physics at hadron colliders:
  - High value of beauty cross section expected at LHC:
    - σ_{bb} ~0.3 – 0.5 mb @$\sqrt{s}$=7-14 TeV (e^+e^- cross section at Y(4s) is 1 nb)
    - σ_{cc} ~ 5 mb
  - Access to all b-hadrons: $B^\pm$, B^0, B_s, B_c, b-baryons
    - In particular can study the B_s (bs) system, not studied at the B factories, but measured by CDF/D0
- The challenges
  - Rate of background events: σ_{inel}~ 60 mb @$\sqrt{s}$=7 TeV
    - → Trigger is essential!
  - Multiplicity of tracks (~30 tracks per rapidity unit)

LHCb Acceptance

- Detector designed to maximize b acceptance (against cosθ)
- Forward spectrometer 1.9<η<4.9
  - b-hadrons produced at low angle
  - Single arm OK as b quarks are produced in same fwd or backward cone
- Rely on much softer, lower P_T triggers, efficient also for purely hadronic decays
- ATLAS/CMS: |η|<2.5
  - Will do B-physics using high P_T μ triggers, mostly with modes involving di-μ
  - Purely hadronic modes triggered by tagging μ.



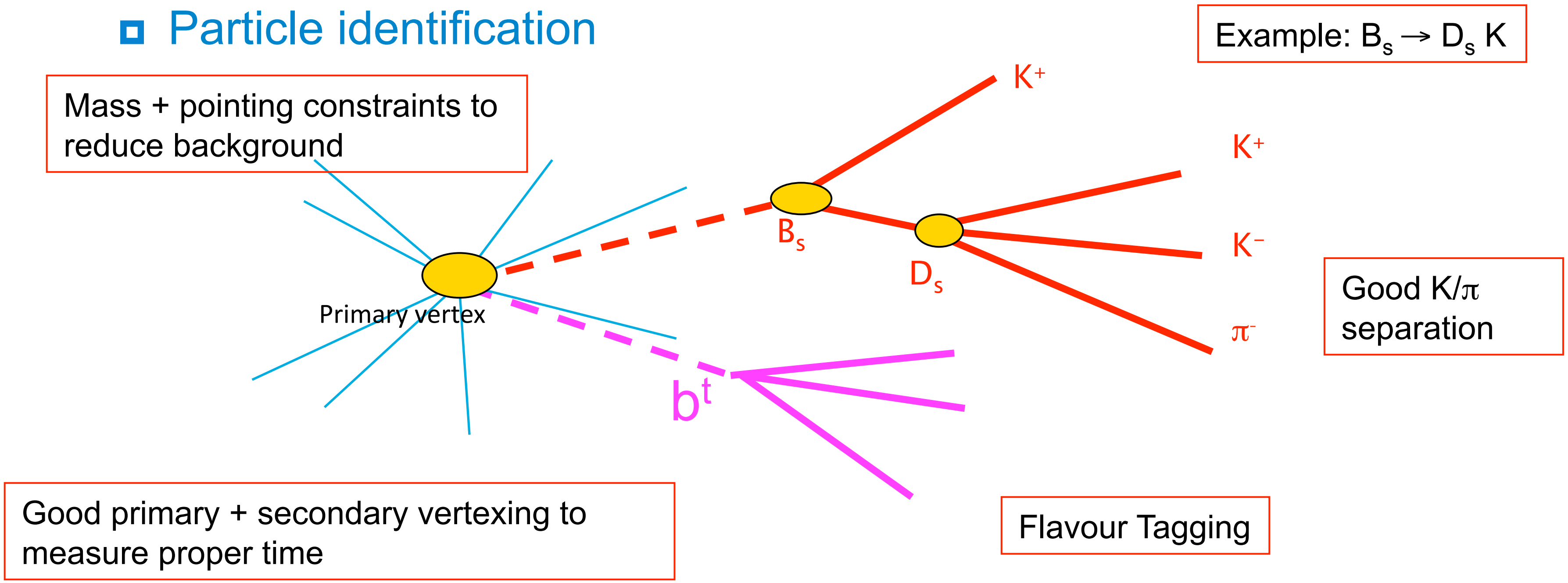


LHCb running conditions

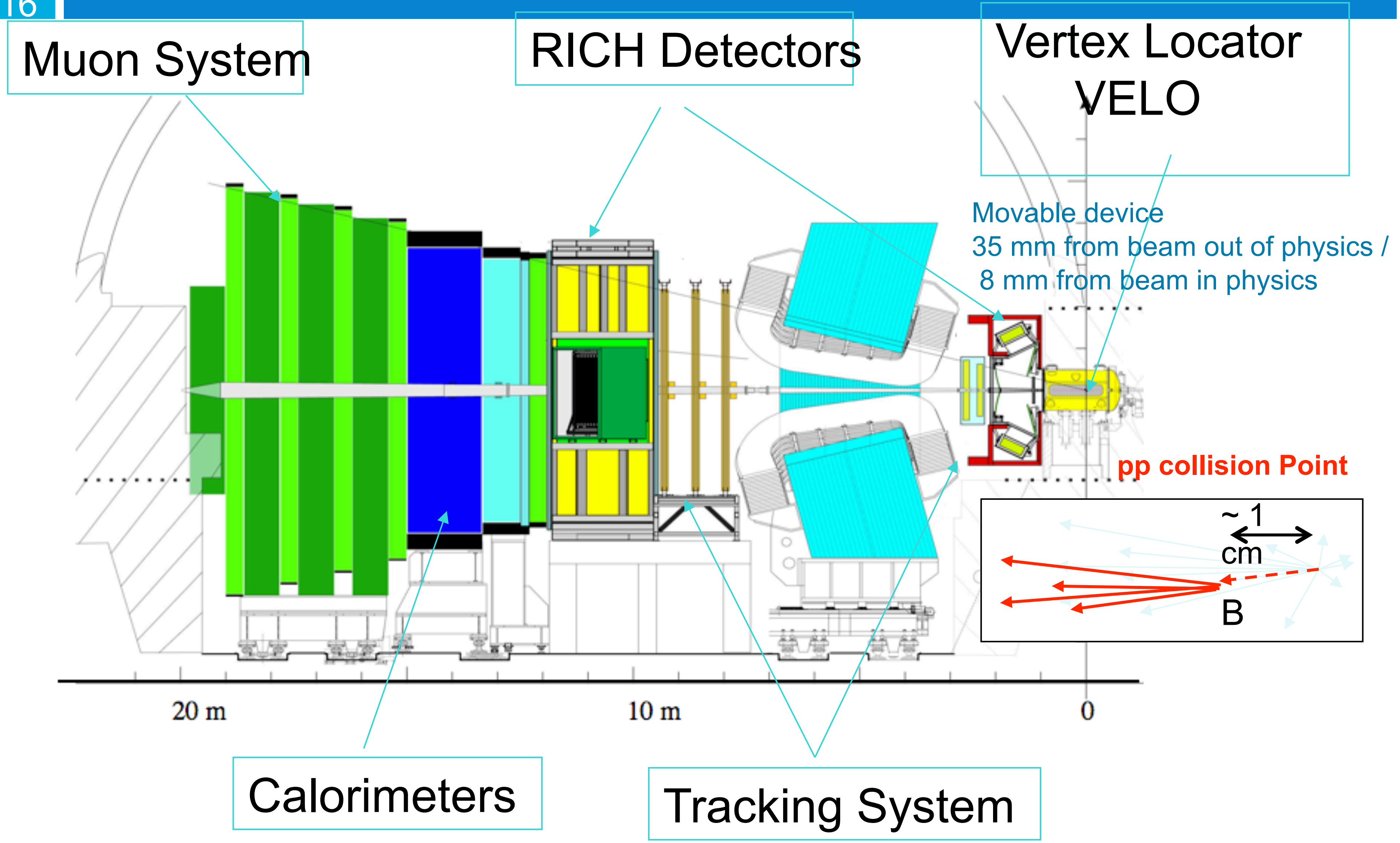
- L limited to ~2-5 10^{32} cm^{-2} s^{-1} by not focusing the beam as much as ATLAS and CMS
  - Can maintain this luminosity even when ATLAS/CMS run at high L
  - Currently conditions same for all experiments
- Maximize the probability of single interaction per bunch crossing
  - At LHC design luminosity pile-up of >20 pp interactions/bunch crossing
- Makes is simpler to identify B decays from their vertex structure
- Less radiation damage
- LHCb L reached already at the end of 2010
- $2fb^{-1}$ per nominal year (10^7s)
  - ~ 10^{12} bb pairs produced per year
- The B and D physics program does not suffer much from running at half the nominal energy, given the enormous cross-sections.

Detector Requirements

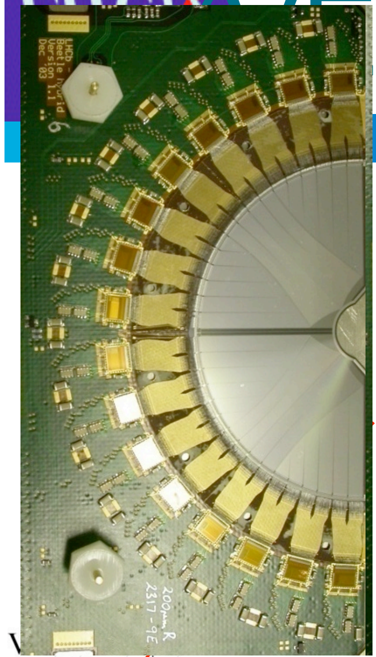
- Key features:
  - Highly efficient trigger for both hadronic and leptonic final states to enable high statistics data collection
  - Vertexing for secondary vertex identification
  - Mass resolution to reduce background
  - Particle identification

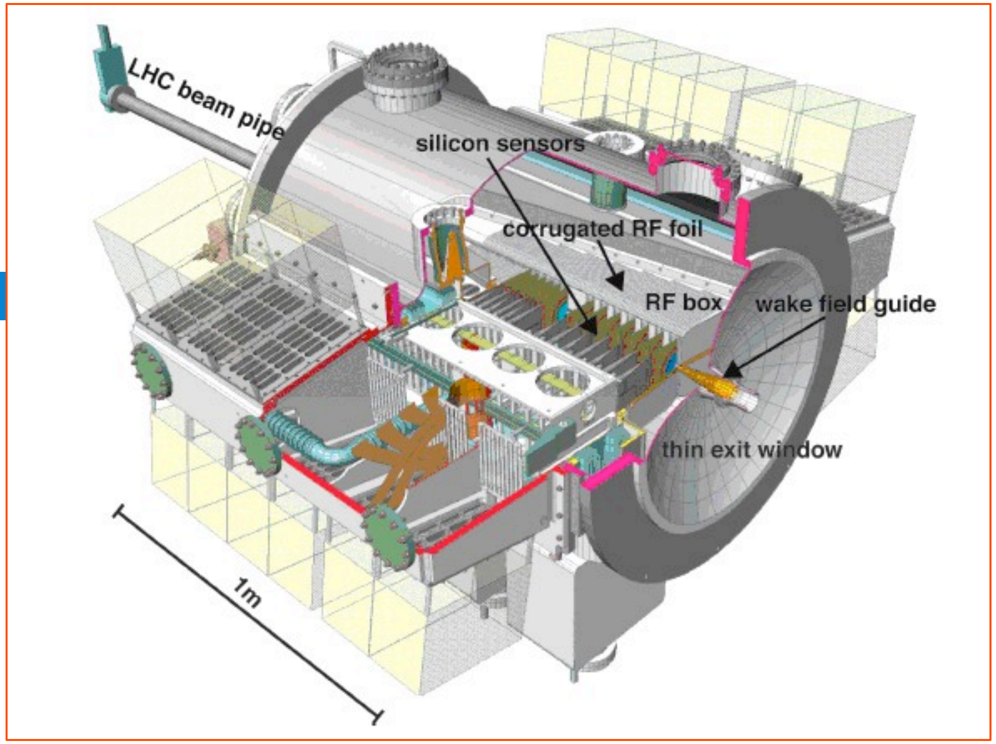


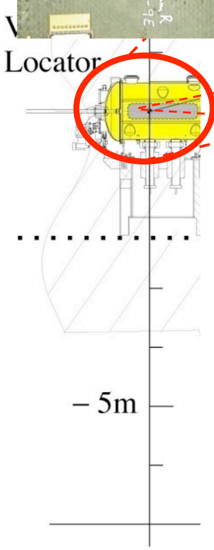
The LHCb Detector



Vertex Locator (VELO)

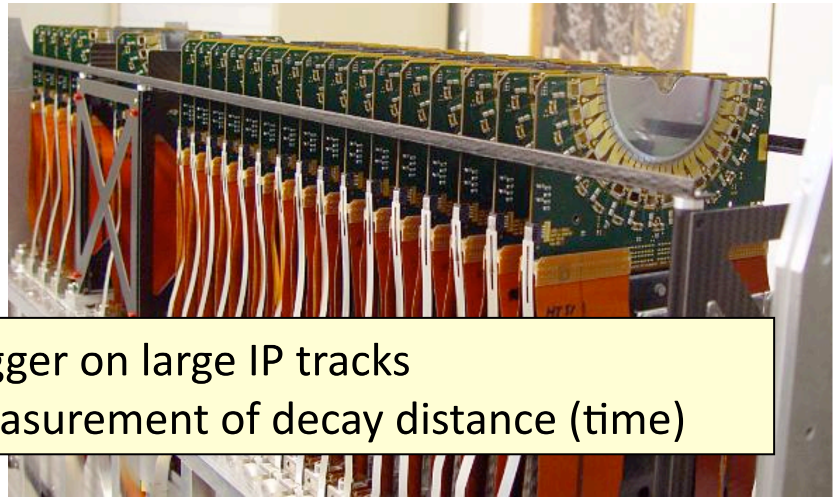






Vertex Locator (Velo)

21 stations of silicon strip detectors (r-ϕ)

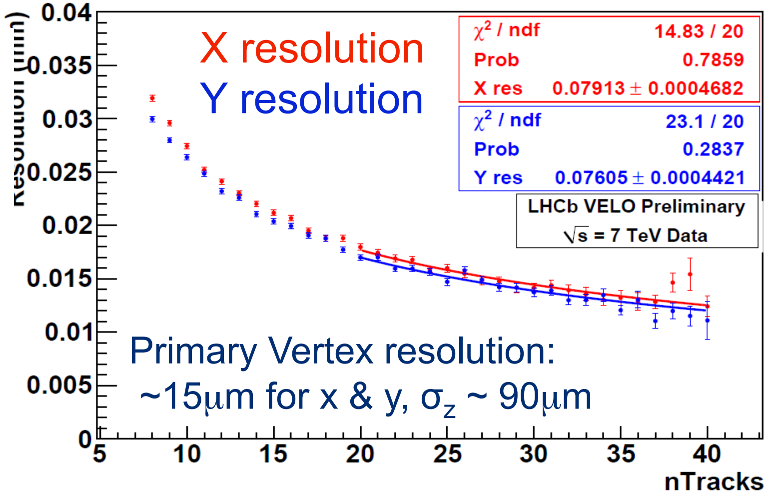


- Trigger on large IP tracks
- Measurement of decay distance (time)

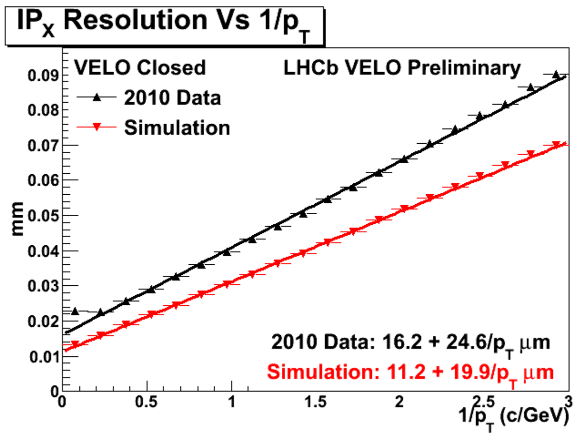
VELO Performance

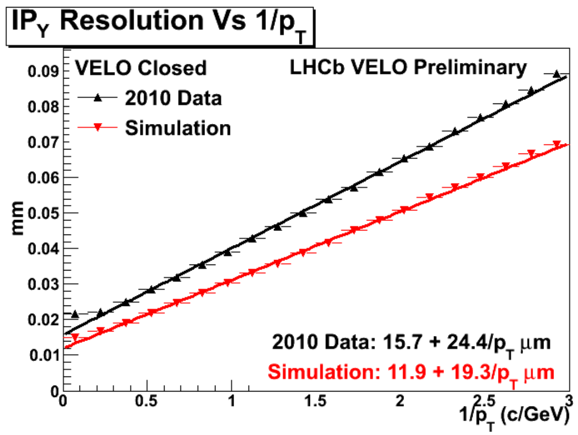
- Cluster finding efficiency 99.7%
- Excellent hit resolution (down to ~4 μm !)
- Module and sensor alignment better than 5 μm
- Fill-to-fill variation of alignment < 5 μm

  (➔ VELO moves every fill!)

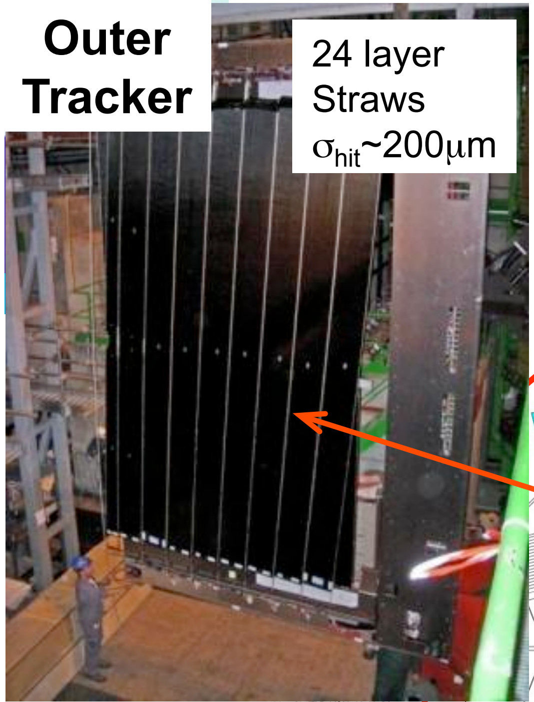


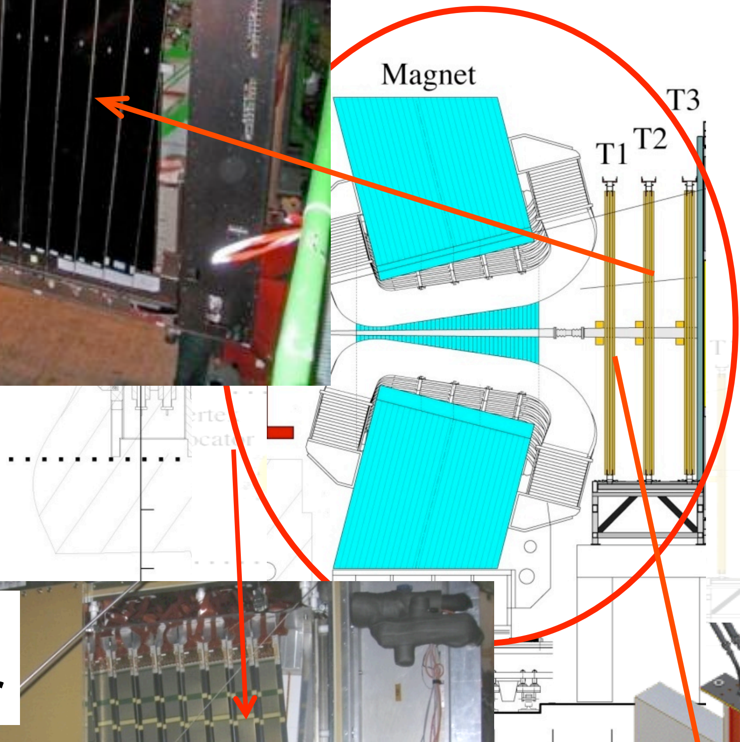
- ~20μm Impact Parameter resolution @ high p_T
- Further improvement expected with better alignment and material description

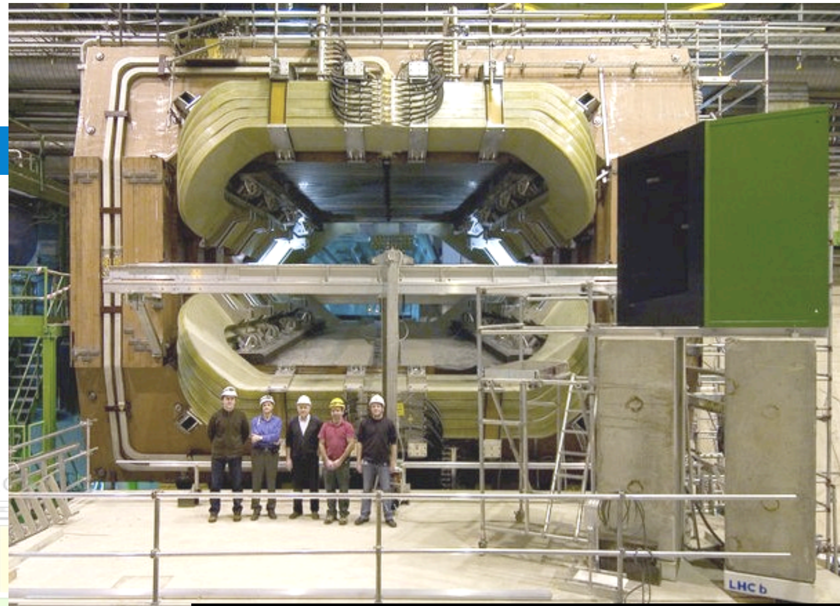


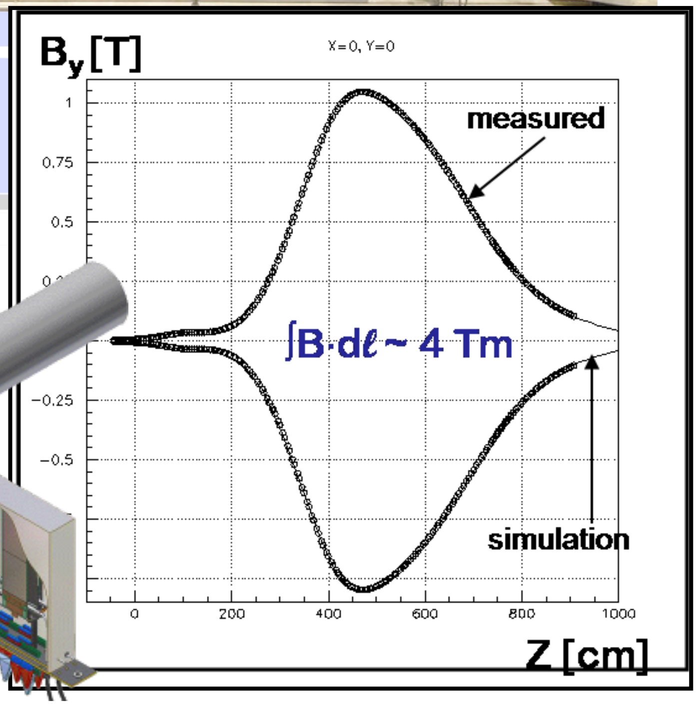


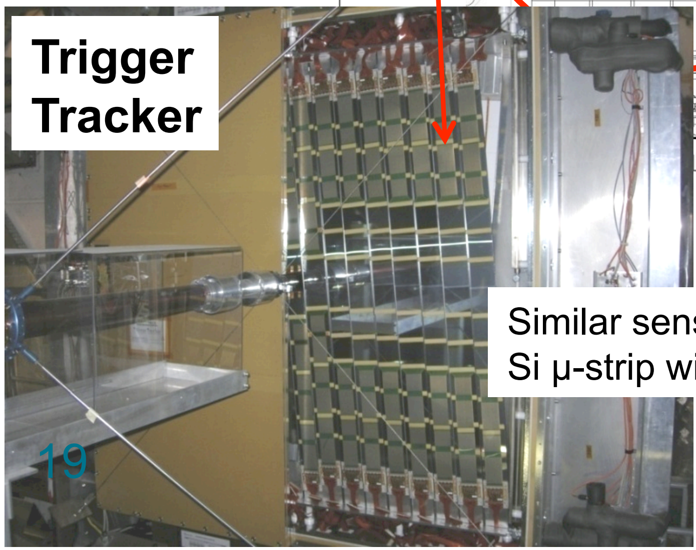
Momentum measurement

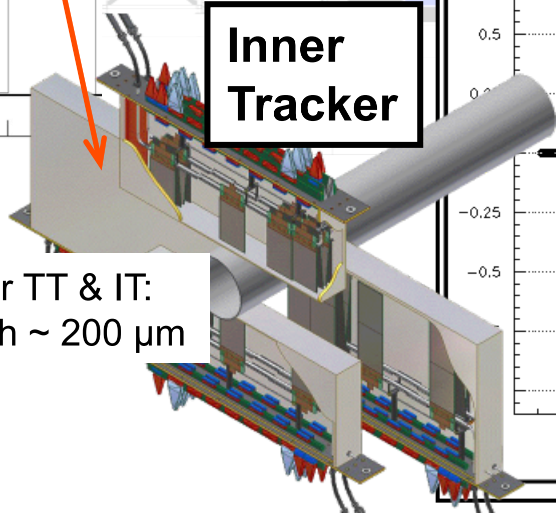






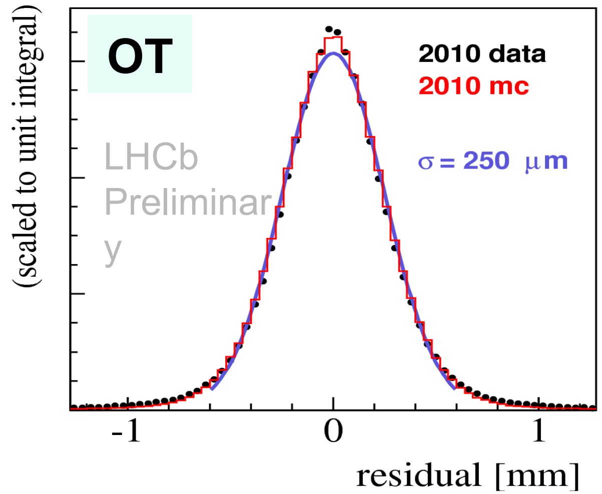


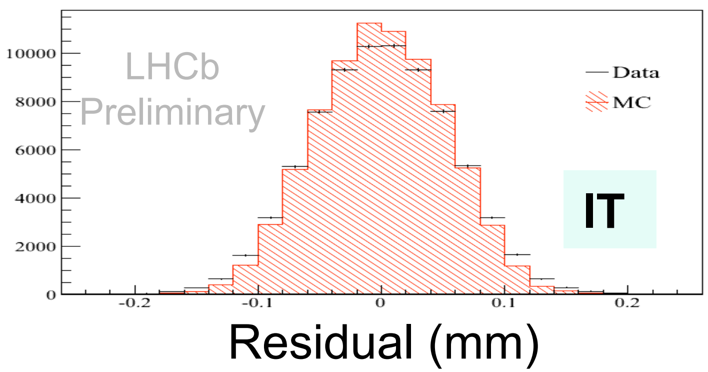


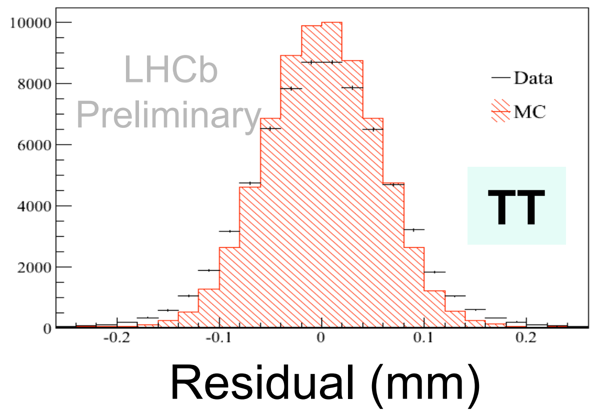


Silicon Trackers (IT/TT) and Outer Tracker (OT) performance

- Hit resolution close to expectation
  - IT: 54 µn
  - IT: 55 µn
  - IT: 250 µn
- Expected to improve with better alignment





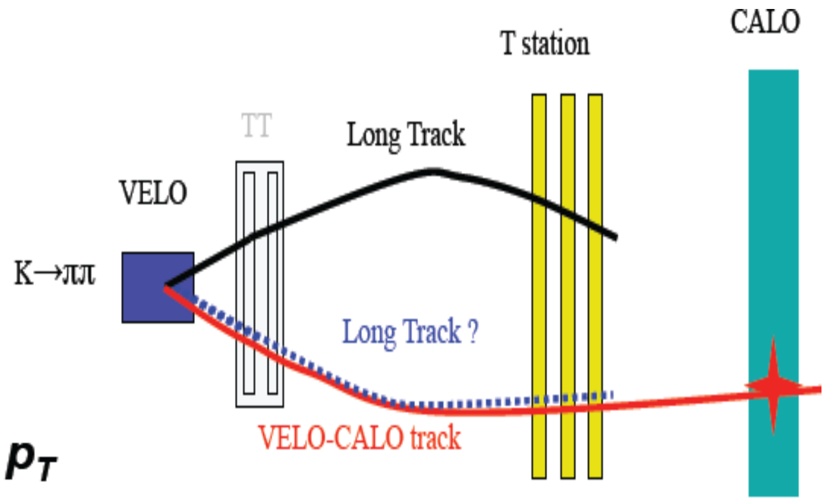


Tracking Performance

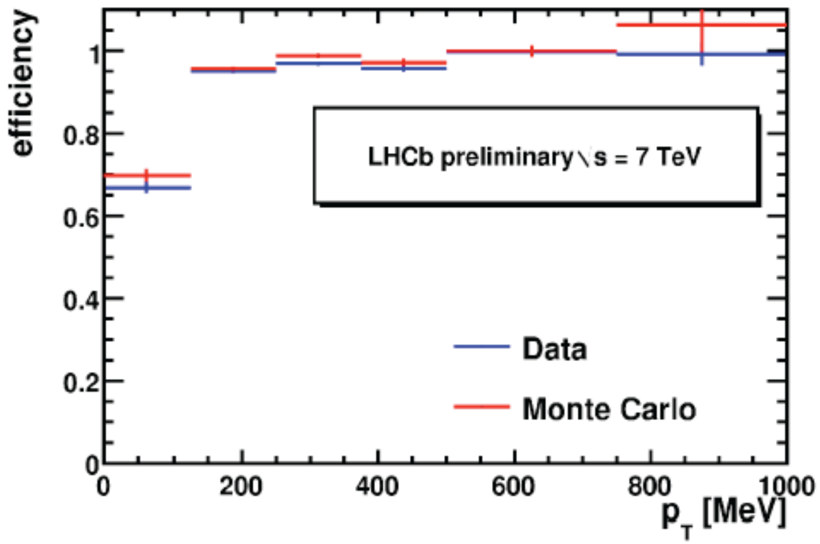
- Tracking Efficiency

Obtained using K_S candidates:

$$\varepsilon = \frac{Tracks^{(VELO + IT/OT+CALO)}}{Tracks^{(VELO + CALO)}}$$



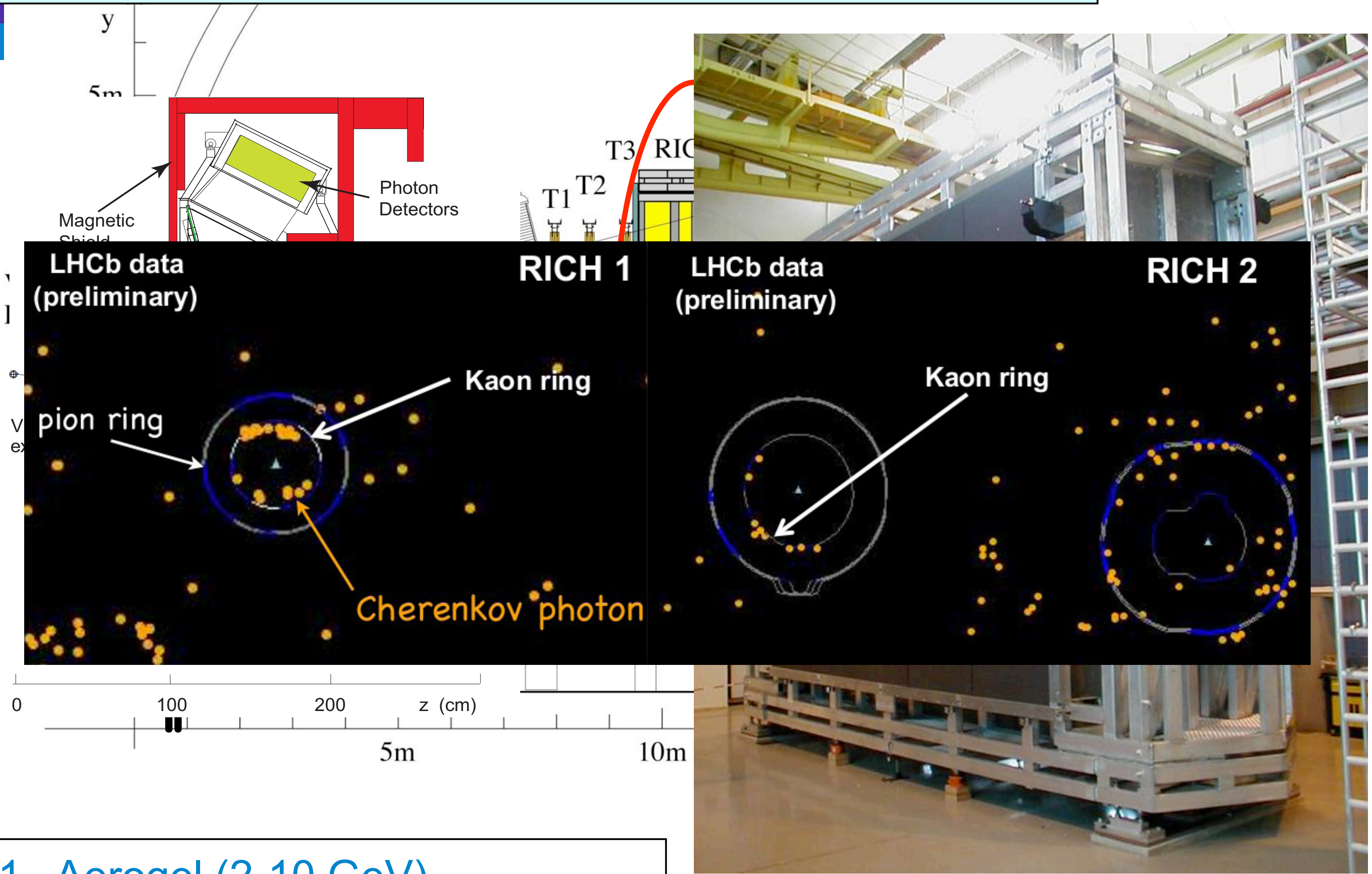
Efficiency as a function of p_T



Tracking efficiency evaluated with data driven methods agrees ~well with MC

RICH Particle Identification

RICH: K/π identification using Cherenkov light emission angle

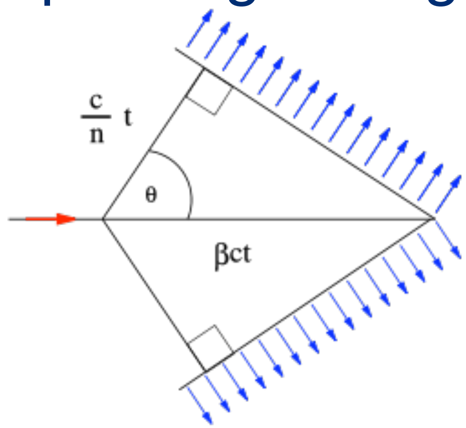


RICH1 Aerogel (2-10 GeV),
C_4F_{10} (10-60 GeV)

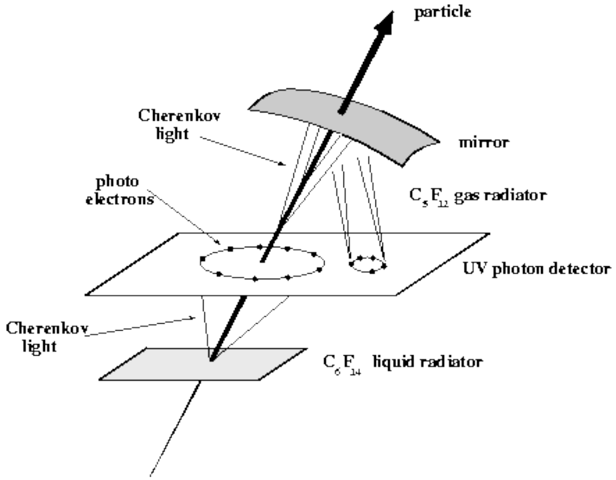
RICH2 CF_4 (16-100 GeV)

Cherenkov light

- Radiation produced when a charged particle travels faster than the speed of light in the medium it is passing through ($\beta c > c/n$, with n=refractive index)

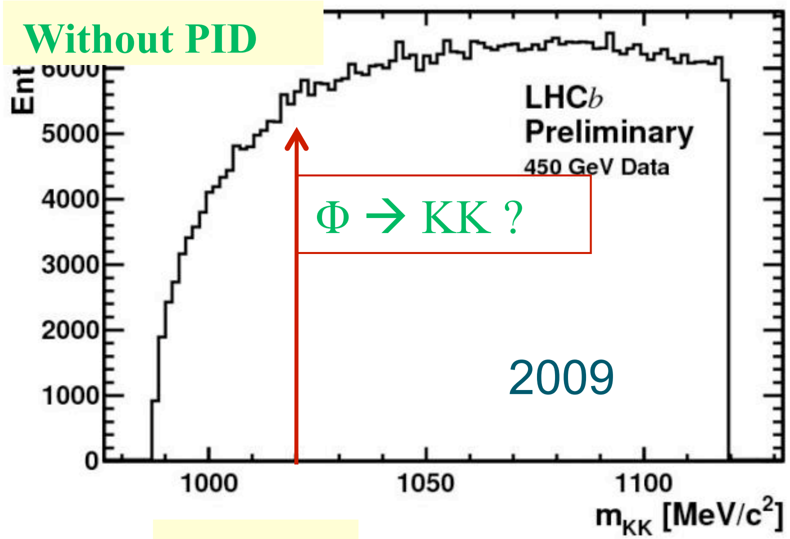


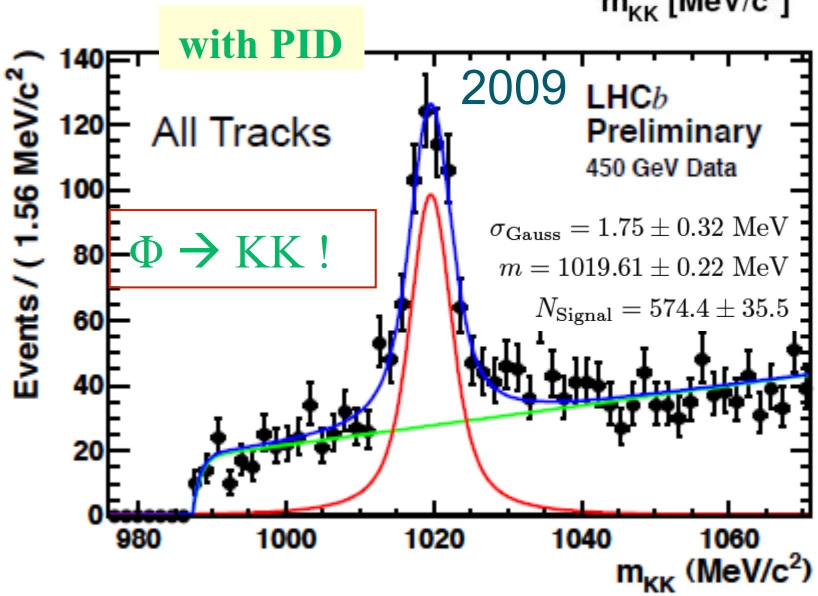
- Light produced in a cone with $\cos\theta_c = 1/\beta n$ can be detected as a ring image

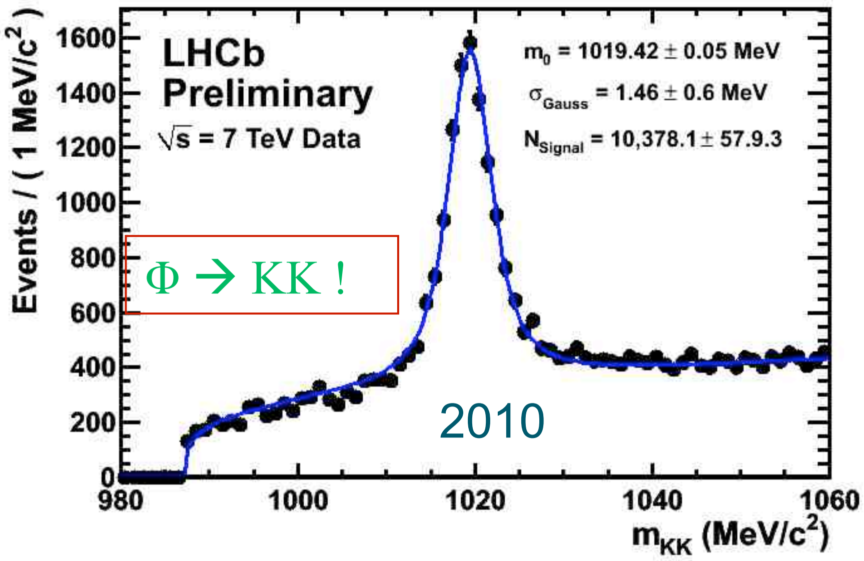


- By measuring θ_c ($\propto$ radius of ring) the velocity β of the particle is found
  Then with knowledge of its momentum the mass of the particle can be found

RICH PID performance



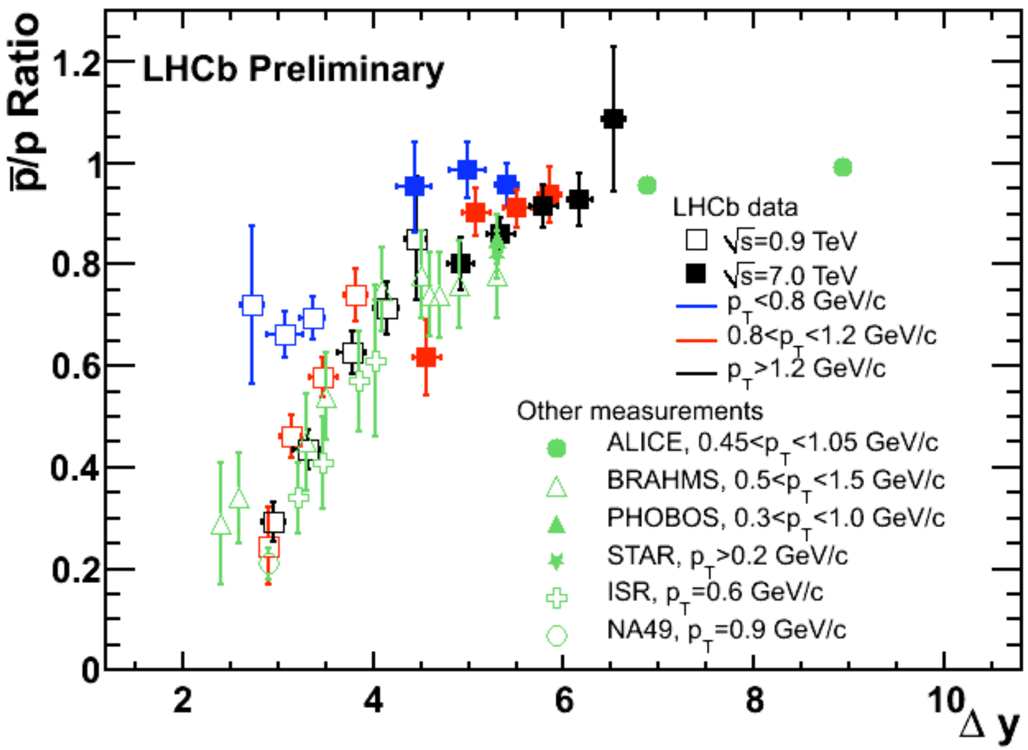




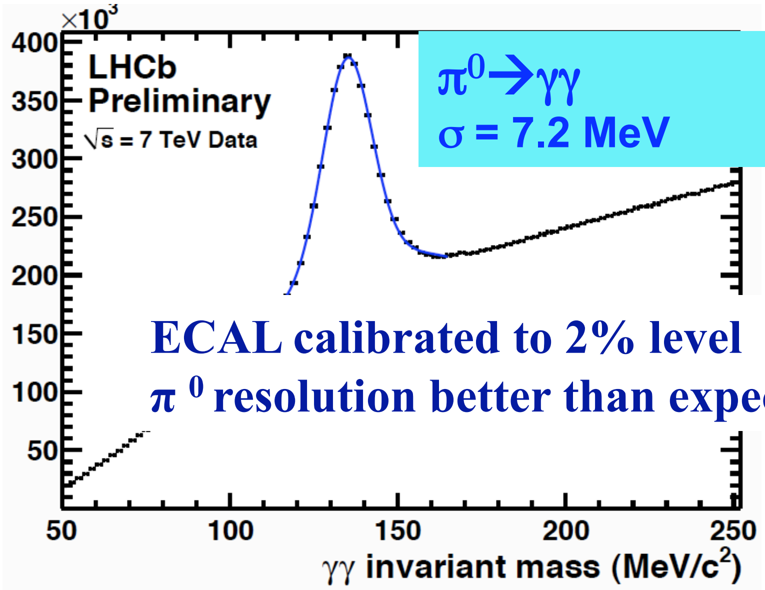
RICH PID performance: Baryon number transport with $\bar{p}/p$

- Baryon number conservation requires the destroyed beam particles in inelastic non-diffractive collisions must be balanced by creation of baryons elsewhere → baryon-number transport
- Probe this baryon-number transport by measurements of $\bar{p}/p$ ratio vs (pseudo)rapidity and p_T. Isolate pure samples with RICH likelihood.

  - Results expressed in energy independent way vs Δy (rapidity interval w.r.t. beam) for different p_T bins →some p_T dependence observed
  - Consistent with results from previous measurements

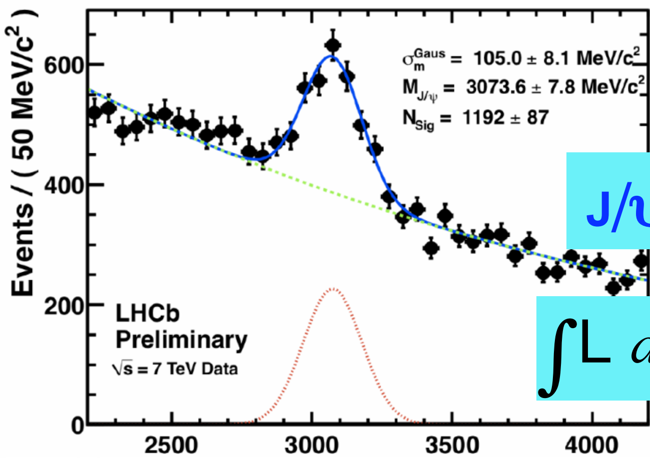


PID with Calorimeters
Identification of electrons and photons



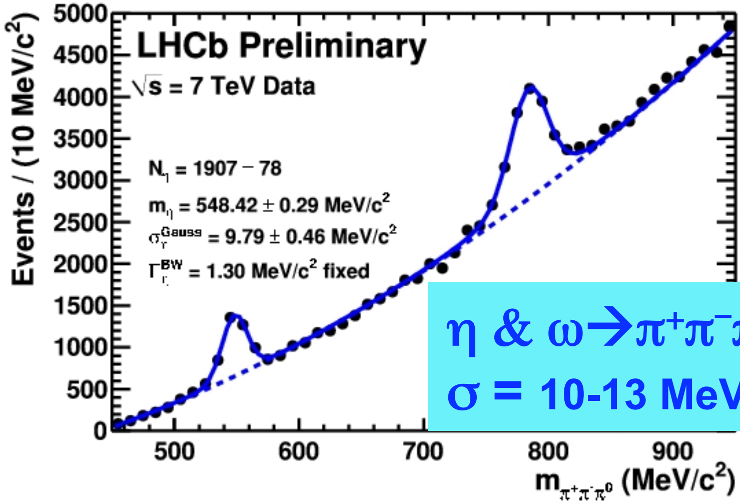
$\pi^0 \rightarrow \gamma\gamma$
σ = 7.2 MeV

ECAL calibrated to 2% level
π^0 resolution better than expected!

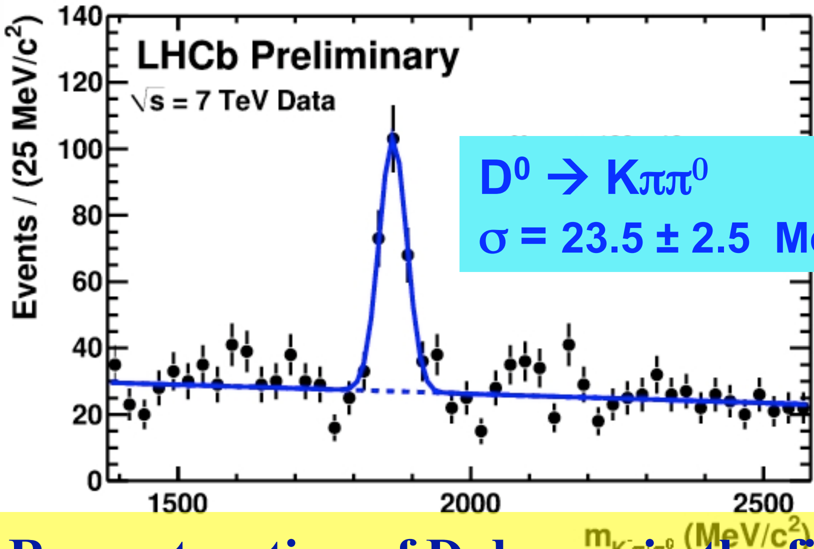


$J/\psi \rightarrow e\, e$

$\int L\, dt \approx 150\ \mathrm{nb}^{-1}$



η & $\omega \rightarrow \pi^+\pi^-\pi^0$
σ = 10-13 MeV

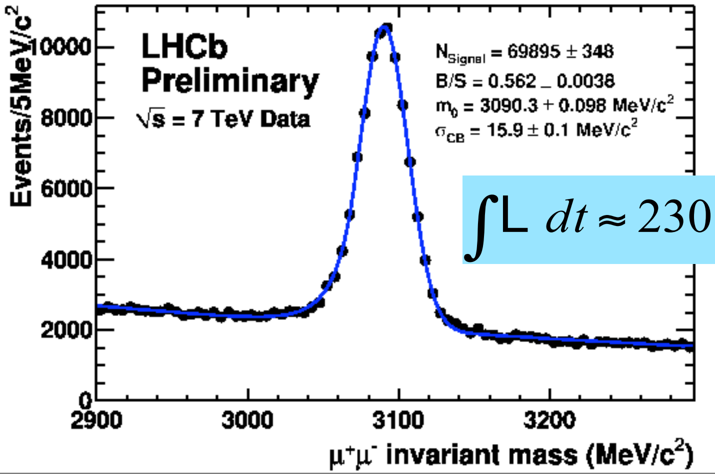


$D^0 \rightarrow K\pi\pi^0$
σ = 23.5 ± 2.5 MeV

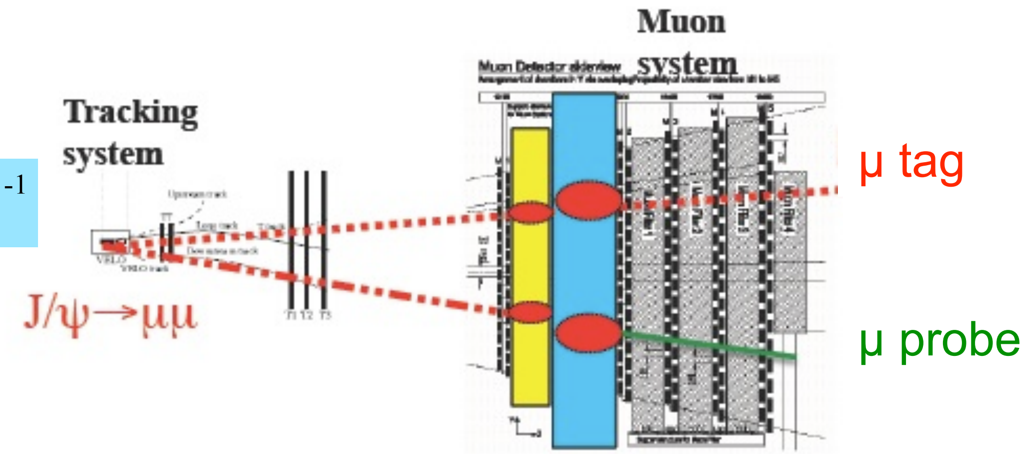
Reconstruction of D decays in the final states with neutrals looks promising !

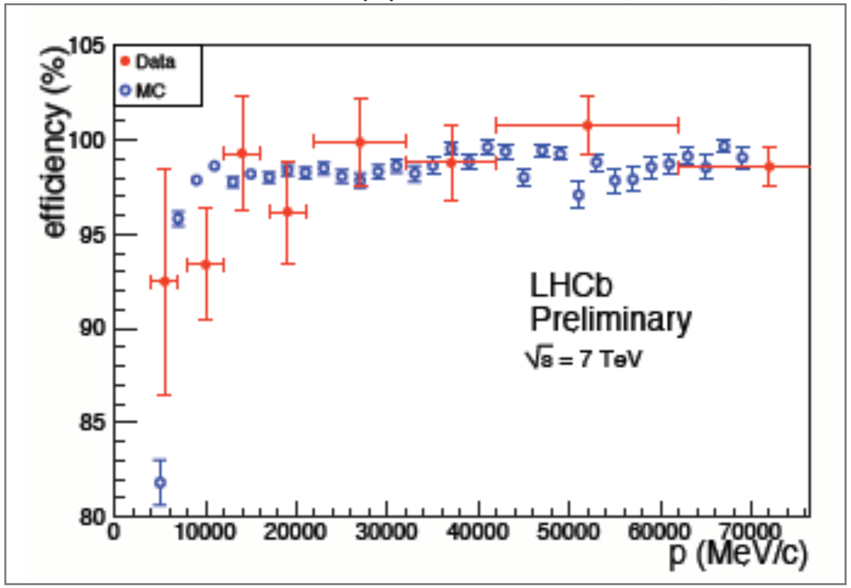
Muon ID performance

- $B_s \to \mu\mu$, $D \to \mu\mu$ sensitivity relies on good performance of muon ID



$\int L\, dt \approx 230\ \mathrm{nb}^{-1}$





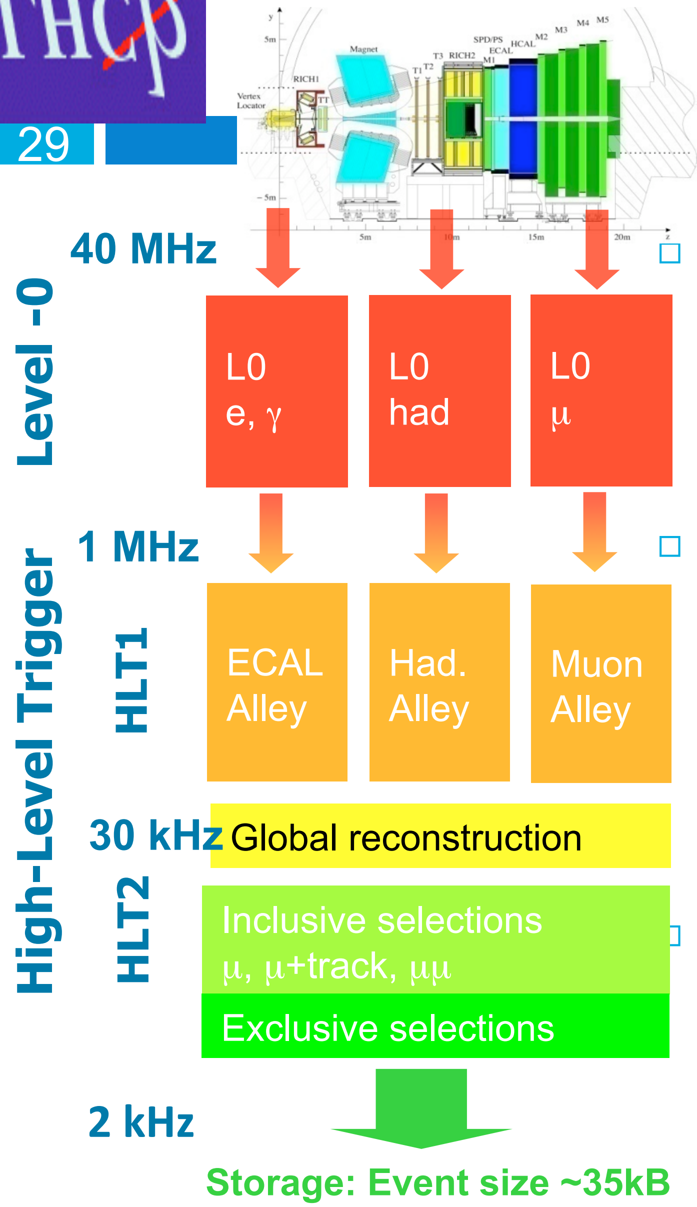
- $\varepsilon(\mu) = 97.3 \pm 1.2$ %
  - from $J/\psi \to \mu\,\mu$
- Mis-ID efficiency
  - $P(\pi \to \mu) = (2.35 \pm 0.04)\%$ [$K_s \to \pi\pi$]
  - $P(p \to \mu) = (0.21 \pm 0.05)\%$ [$\Lambda \to p\pi$]
  - $P(K \to \mu) = (1.67 \pm 0.06)\%$ [$\phi \to KK$]

LHCb Trigger

- Trigger is crucial as σ_{bb} is less than 1% of total inelastic cross section and B decays of interest typically have BR < 10^{-5}

- b hadrons are long-lived →
  - Well separated primary and secondary vertices
- Have a ~large mass→
  - Decay products with large p_T

LHCb Trigger

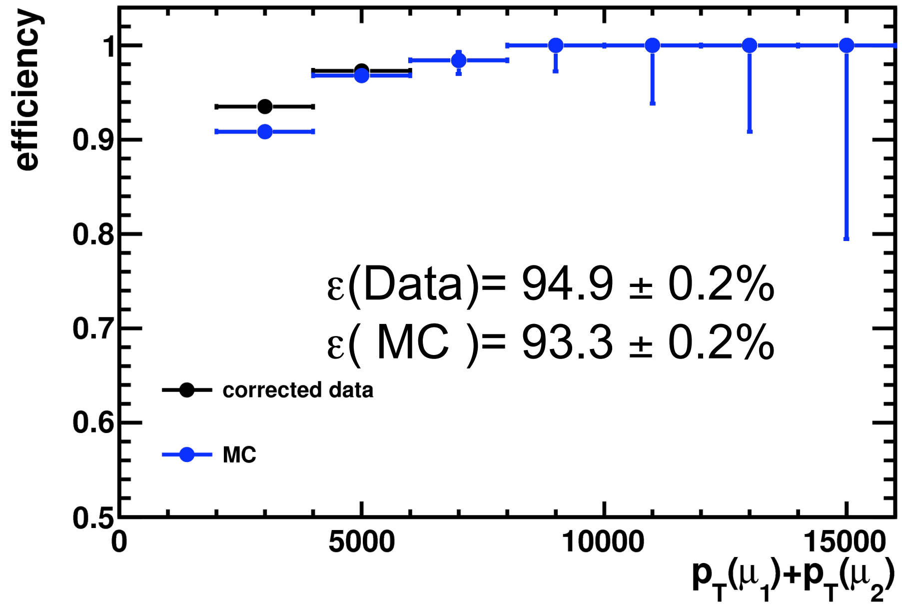


- Hardware level (L0)
  - High-p_T μ, e, γ, hadron candidates (ECAL, HCAL, Muon)
  - L0 output is large!→ ~1 MHz
- Software level (**H**igh **L**evel **T**rigger, HLT)
  - Access all detector data
  - Farm with O(2000) multi-processor commodity boxes
  - **HLT1**: Confirm L0 candidate with more complete info, add impact parameter and lifetime cuts → ~30 kHz
  - **HLT2**: global event reconstruction + selections → ~2 kHz
- Flexible design to follow evolution of physics objectives
  - Loose HLT requirements applied in 2010
  - Since beginning of July, LHC is running with higher Pileup than expected at nominal conditions →
  - Trigger settings adapted to this configuration

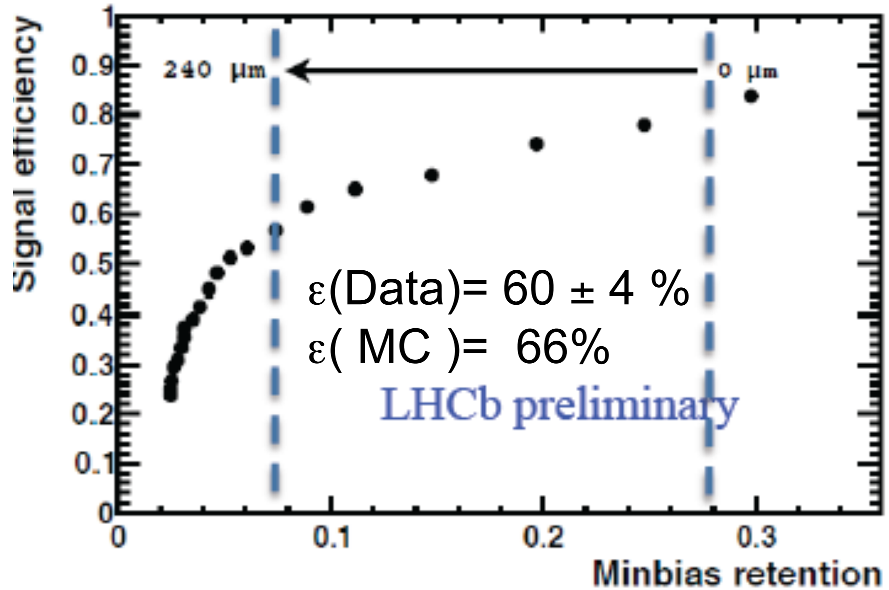
LHCb Trigger Validation

- Selected samples of $J/\psi \rightarrow \mu^+\mu^-$ and $D^0 \rightarrow K^+\pi^-$ have been used to evaluate the trigger efficiencies in Data and MC

Muon Trigger
L0xHLT Efficiency for J/Psi

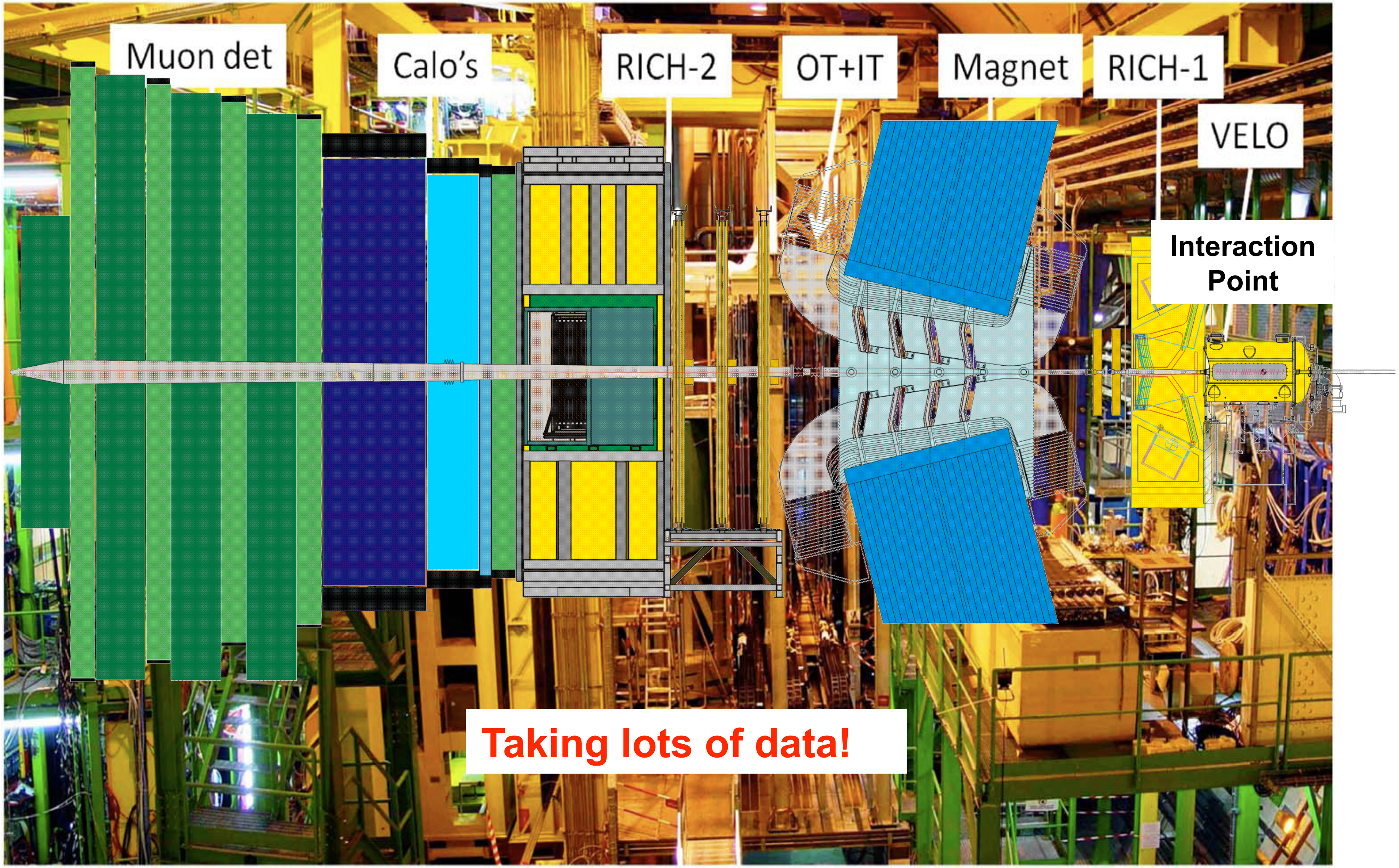


Hadron Trigger
L0xHLT Efficiency for D^0

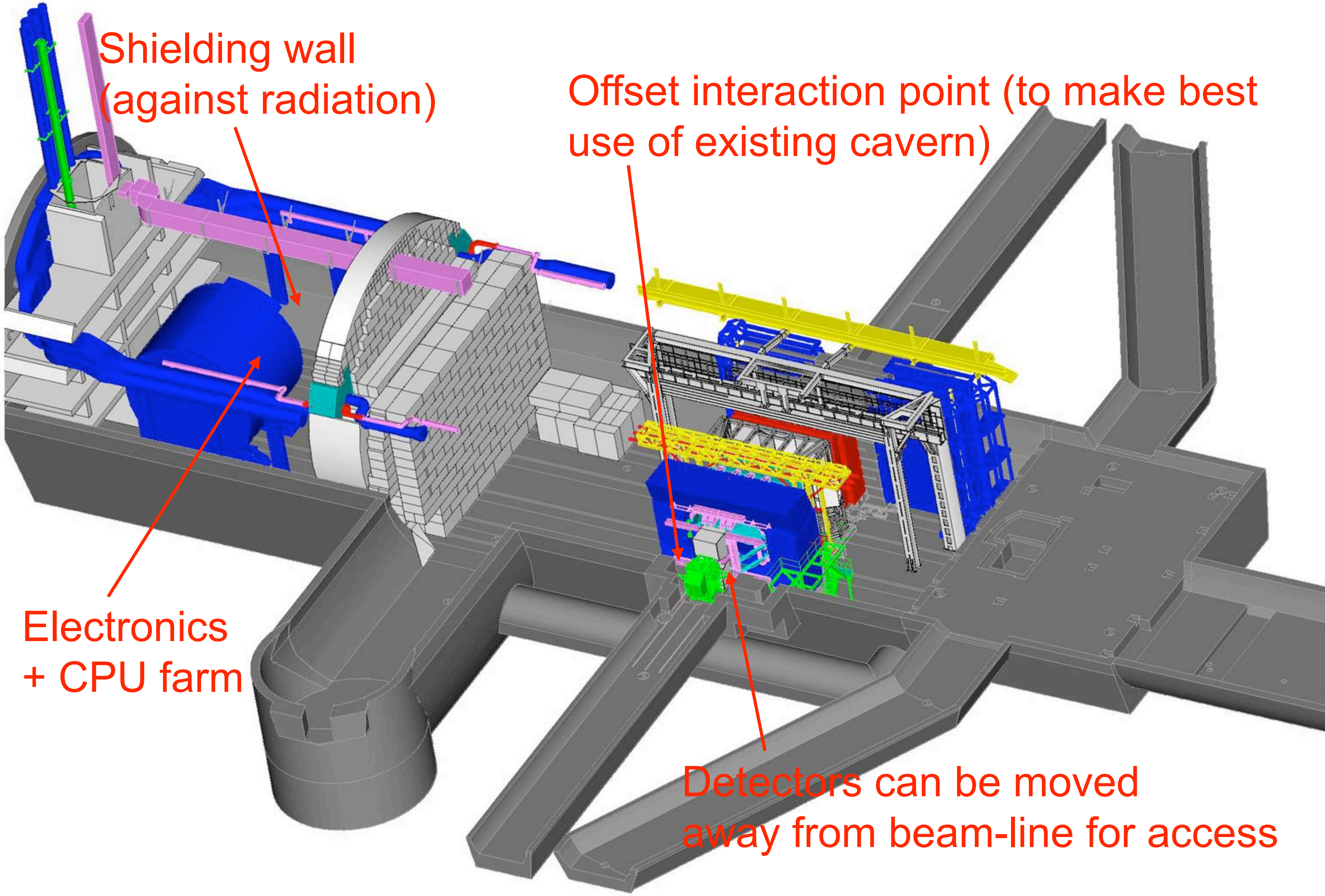


Data agree well with MC
LHCb trigger concept has been validated by data !!!

The LHCb Detector



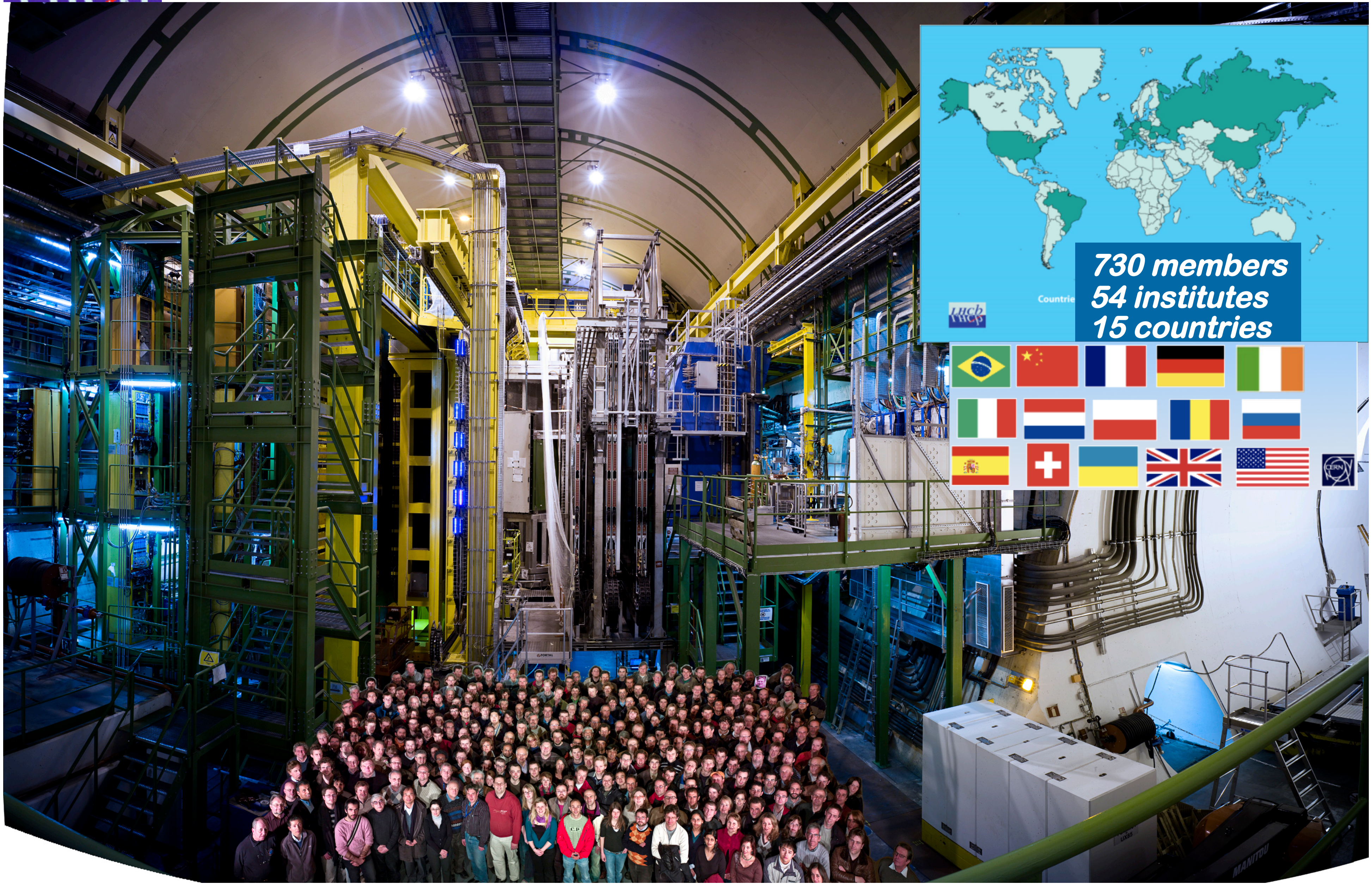
LHCb in its cavern (~100 m deep)



A lot of progress!

February 2002
Cavern ready for detector installation

LHCb



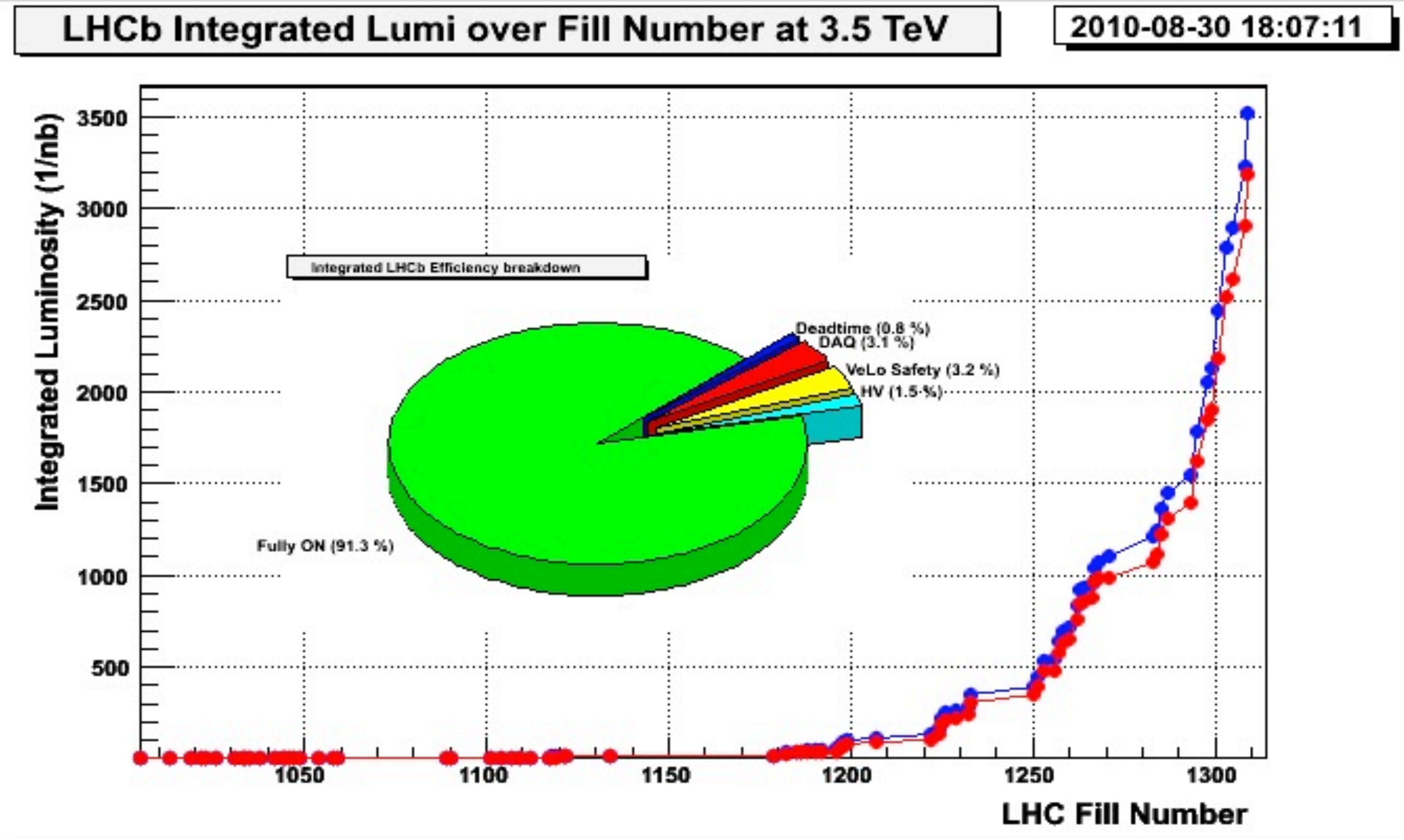
Accumulated statistics and data-taking efficiency

- **LHC**
  - Currently operating with 50X50 bunches, of which 35 colliding. L_{peak} of $>10^{31}cm^{-2}sec^{-1}$ reached for a short time!
  - Plan is to operate LHC with bunch trains in Sept.→ increase total number of bunches in successive steps
  - Goal: Integrated **L of ≥1fb^{-1} by end of 2011** → must reach ~$10^{32}cm^{-2}sec^{-1}$ in 2010 (~50 pb^{-1} by end of 2010?)

$$\boxed{\mathcal{L} = \frac{N^2 n_b f_{\mathrm{rev}}}{4\pi\sigma_x\sigma_y} F}$$

	Nominal
N = bunch population	1.15 10^{11} (0.9-1.1 achieved)
n_b = number of bunches	2808
f_{rev} = revolution frequency	
$\sigma_{x,y}$ = colliding beam sizes	
F = geometric factor	

Accumulated statistics and data-taking efficiency

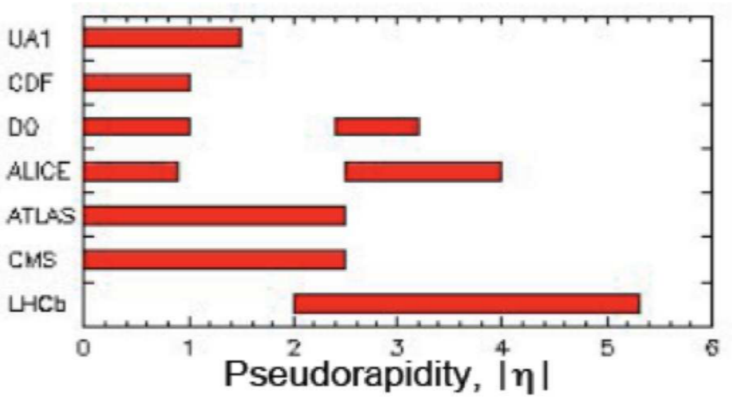


LHCb shift

Typically two shifter and many experts on call

Very First Measurements
(some examples)

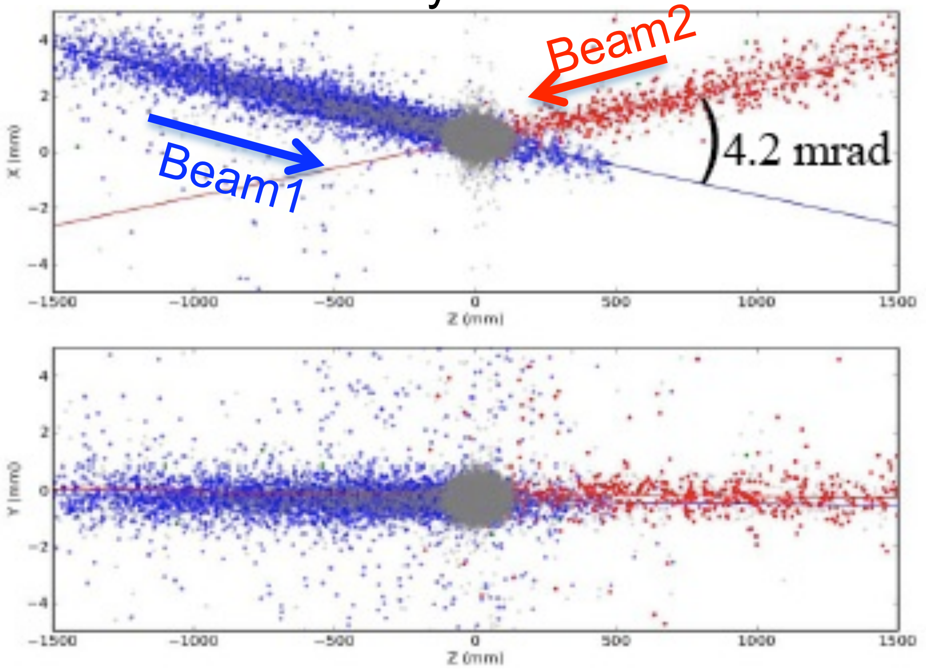
- Cross sections and particle multiplicity/ratios
  - K_s cross sections vs p_T and η
  - $\overline{\Lambda}/\Lambda,\ \overline{\Lambda}/K_S,\ \overline{\mathrm{p}}/\mathrm{p}$ vs y and p_T
  - J/Ψ cross section (prompt and from b)
  - bb cross section
  - D, D*, D_S cross sections
- LHCb covers a unique rapidity range 2<η<5



Heavy flavour production measurements at √s=7TeV

- **First preliminary results on**
  - **J/Ψ production cross-section**
  - **bb production cross-section**
- Cross sections normalized using Luminosity L
- L determined from:
  - Van der Meer scan
    - based on beam separation scans
  - Beam-gas imaging method (only possible @LHCb)
    - can run parasitically during physics running
    - non disruptive
    - → potentially smaller systematic

x-z and y-z vertices



Luminosity: $\mathcal{L} = n_1 \cdot n_2 \cdot f / \mathcal{A}_{eff}$

n: protons/bunch

f: collision frequency

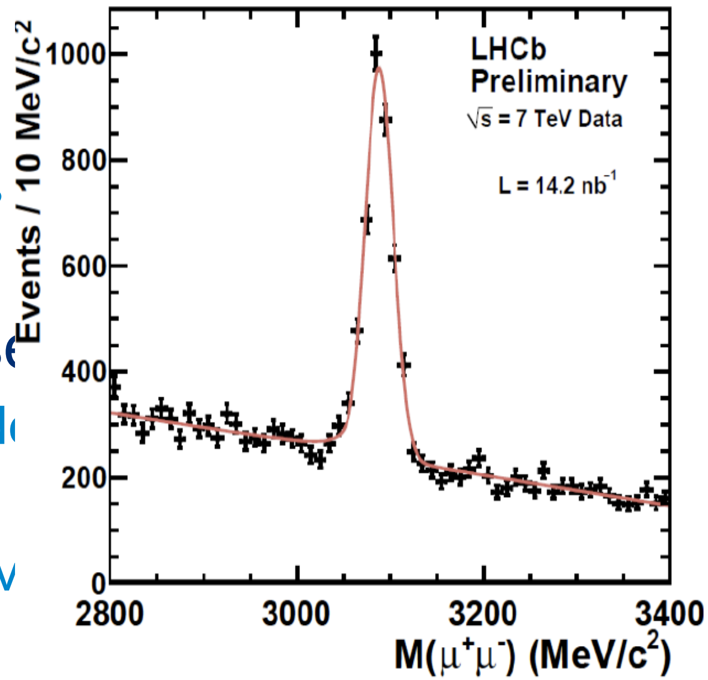
$\mathcal{A}_{eff}$: effective area calculated from beam size and position

→From LHC measurements

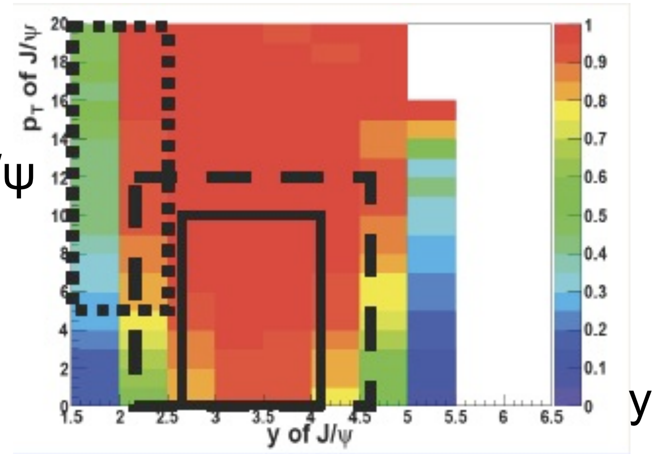
→ From VELO measurement of beam sizes, position and angles in beam-gas interactions

J/ψ production studies with 14 nb^{-1}

- Three main sources of J/ψ
  - direct production in pp collisions
  - feed down from heavier charmonium states
  - J/ψ from b hadrons decays
- J/ψ measurements of interest becaus
  - Prompt production mechanism not well und
  - Secondary J/ψ provide convenient b-tag
  - Di-muons central to many of core LHCb flav



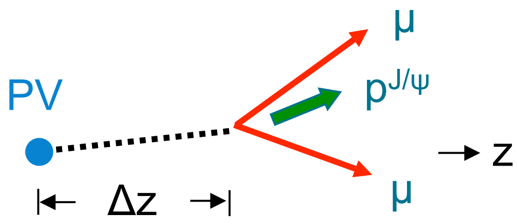
p_T of J/ψ



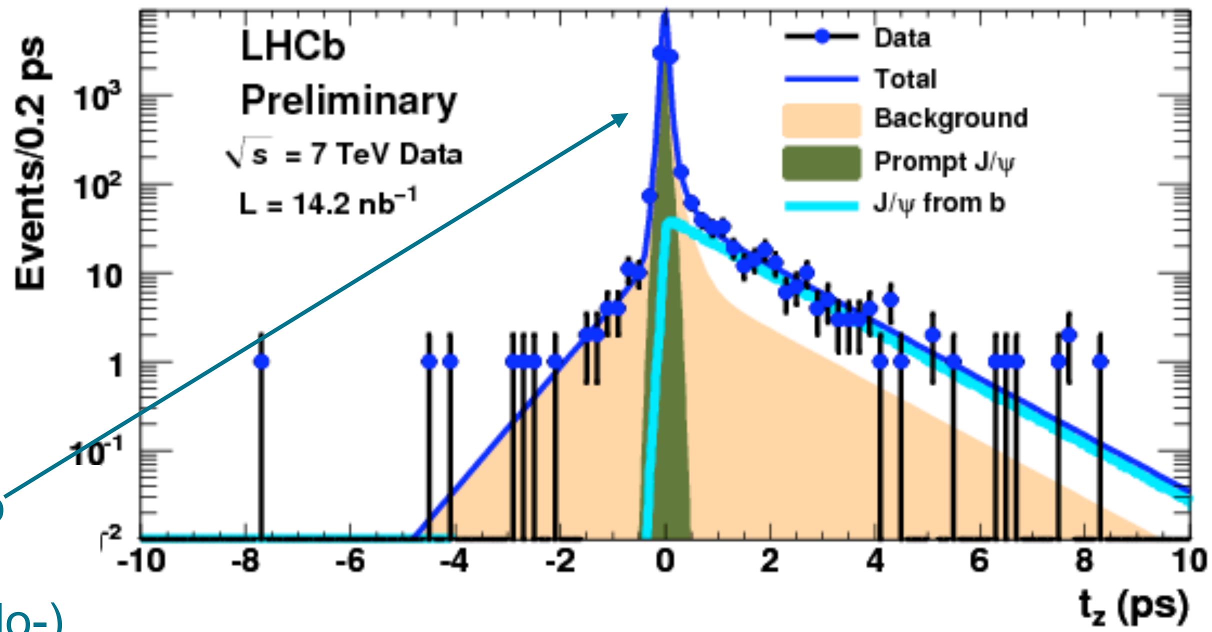
y of J/ψ

Secondary J/ψ from B

- Fit pseudo-propertime t_z of sample in four p_T bins (here shown integrated)



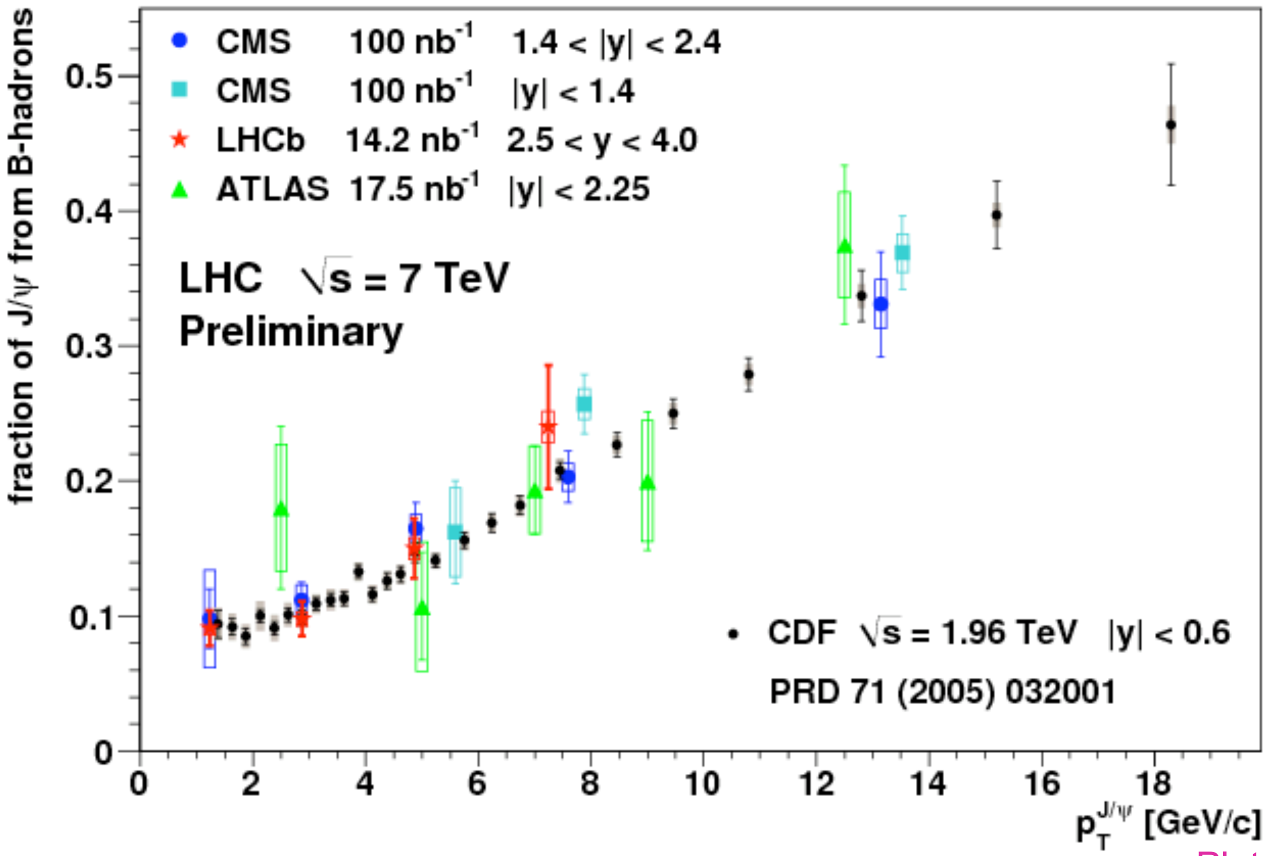
$$t_z = \frac{\Delta z}{p_z^{J/\psi}} m_{J/\psi}$$



Core gaussian fit to prompt component yields 40 fs (pseudo-) proper time resolution

$f_b = (11.1 \pm 0.8)\ \%$

Compilation of preliminary LHC results for J/ψ from B fractions



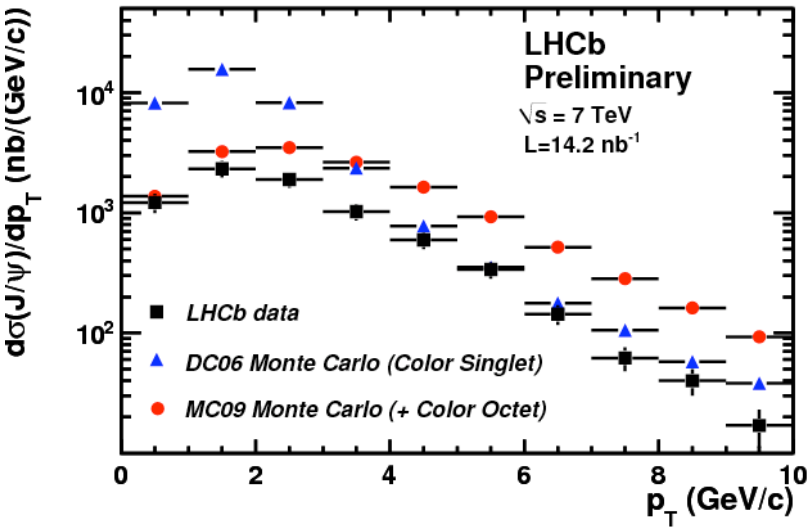
Plot by H.Woehri & C.Lourenco

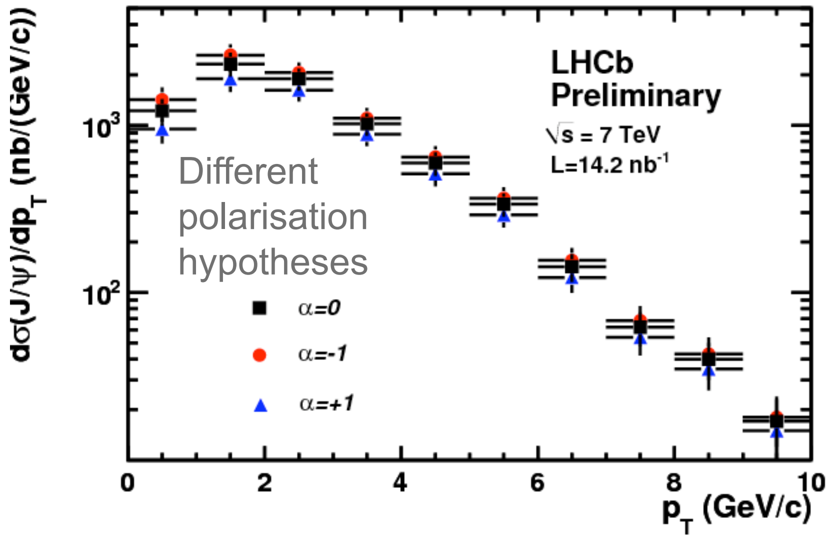
J/ψ cross section preliminary results

σ(incl. J/ψ, $p_T^{J/\psi} < 10$ GeV/c, $2.5 < y^{J/\psi} < 4$) = $(7.65 \pm 0.19 \pm 1.10^{+0.87}_{-1.27})$ μb

uncertainty from polarisation

$d\sigma/dp_T$(incl. J/ψ, $2.5 < y^{J/\psi} < 4$):



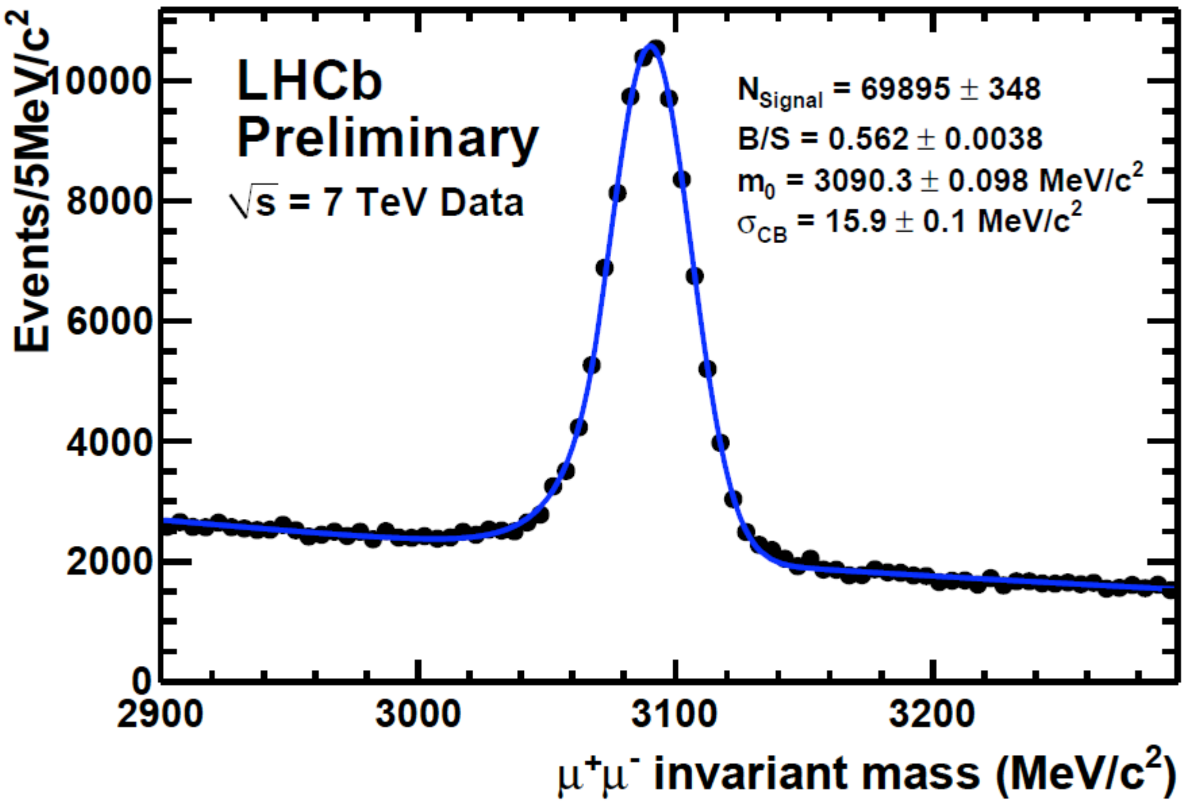


Scale and shapes not well described by either colour singlet or colour octet models as implemented in LHCb Pythia

Polarisation will eventually be measured !

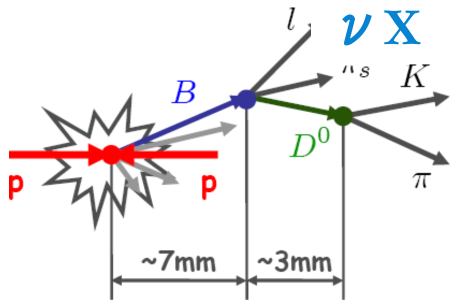
σ(J/ψ from b, $p_T^{J/\psi} < 10$ GeV/c, $2.5 < y^{J/\psi} < 4$) = $(0.81 \pm 0.06 \pm 0.13)$ μb

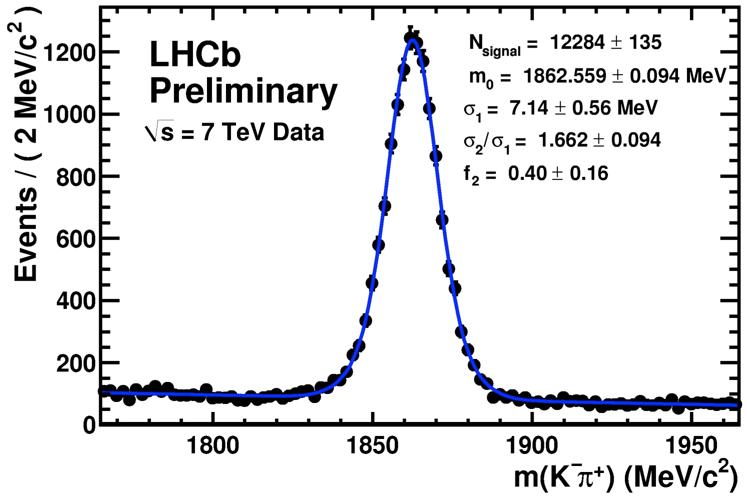
J/ψ update with ~230 nb^{-1}



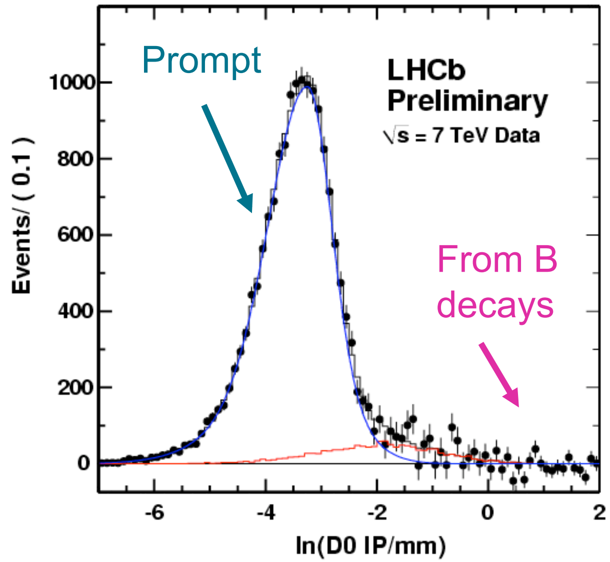
several 100k events / pb^{-1}

b production cross-section from $b \rightarrow D^0 \mu \nu X$ events





- Take clean $D^0 \rightarrow K\pi$ sample
- Use Impact Parameter of D^0 direction wrt primary vertex to separate prompt and from B decays
- Look for μ with correct charge correlation to suppress background (sign of μ charge same as K charge: RS)

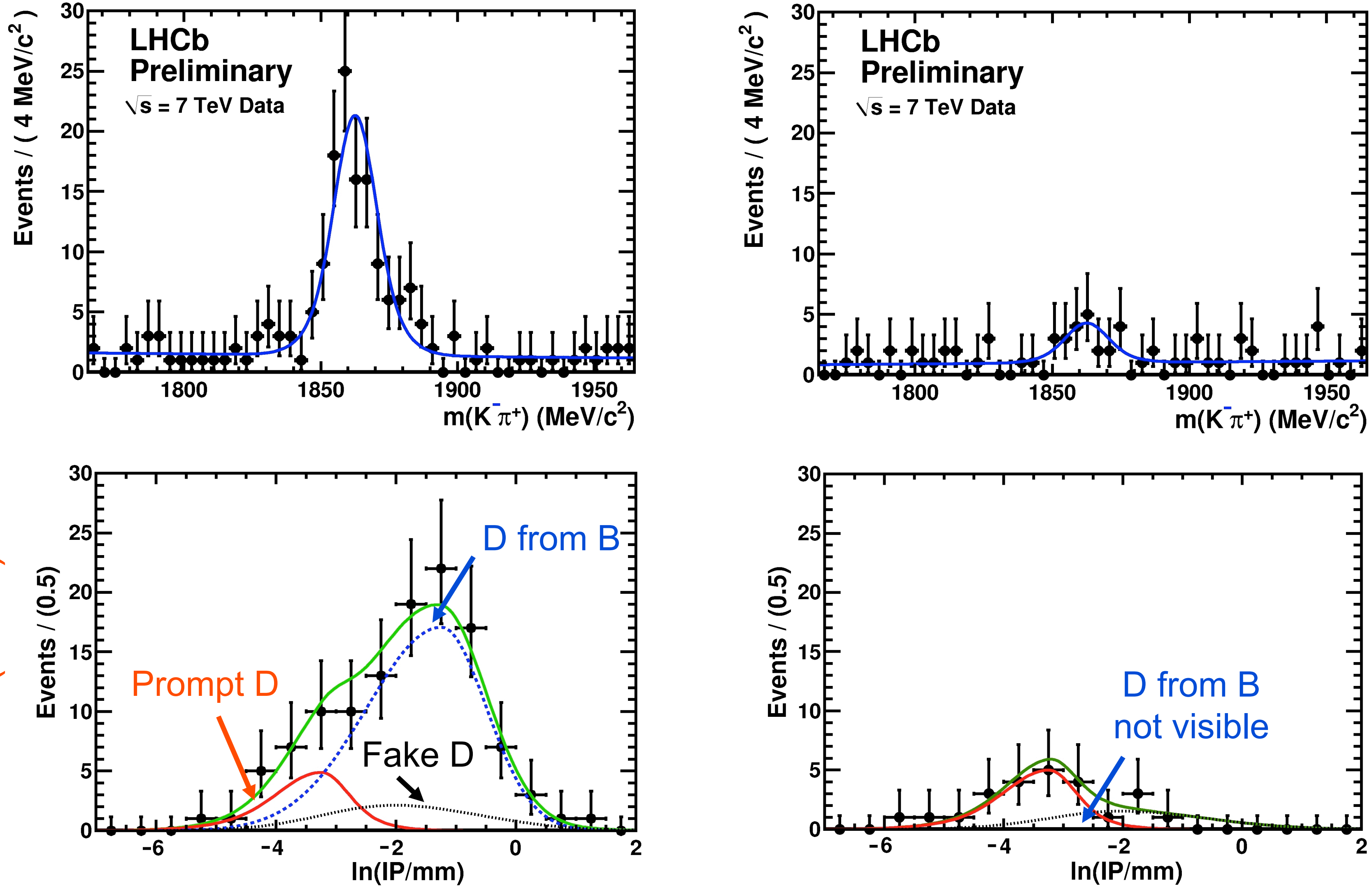


$b \rightarrow D^0 \mu \; \nu$ X events

Right sign correlation | **Wrong sign correlation**

D^0 mass

ln (IP D^0)

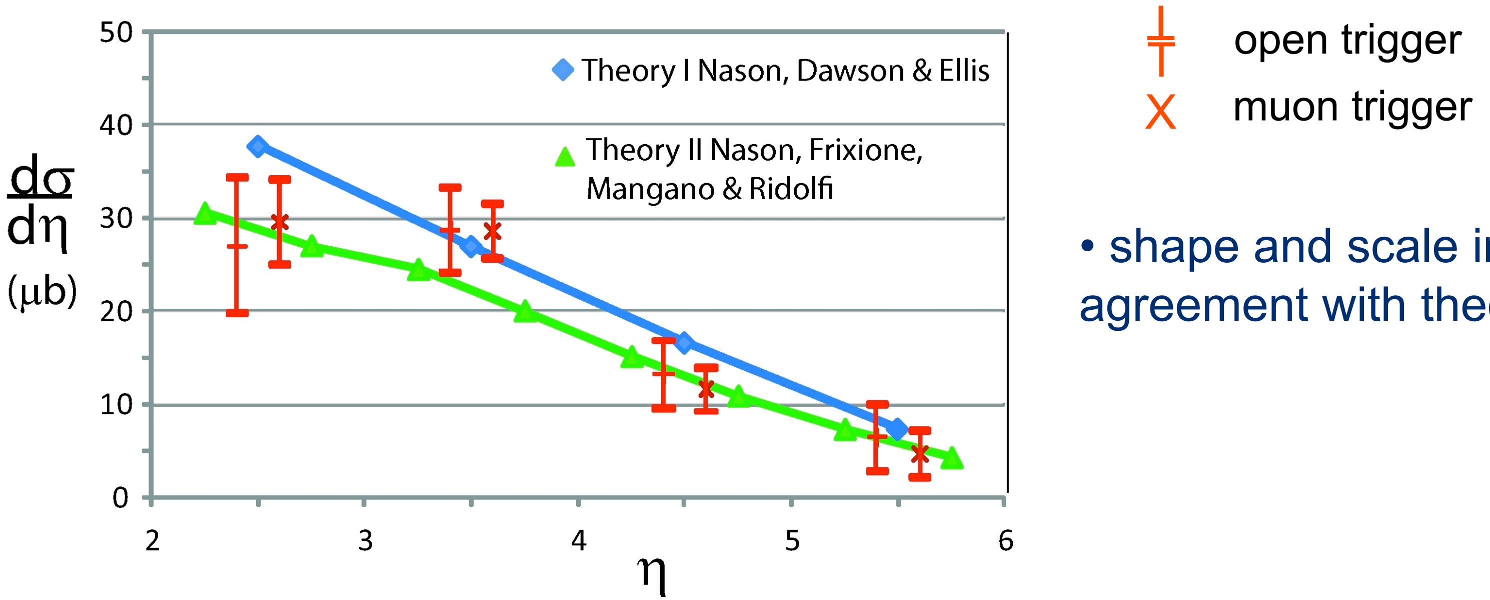


$b \rightarrow D^0 \mu\ \nu$ X preliminary results

- Measure cross sections in four η bins

$$\sigma(pp \rightarrow H_b X) = \frac{\#\text{ of detected } D^0\mu^- \text{ and } \overline{D}^0\mu^+ \text{ events}}{\mathcal{L} \times \text{efficiency} \times 2}.$$

- Compare with theory predictions for $b\bar{b}$ production



• shape and scale in good agreement with theories

$\sigma(pp \rightarrow H_b X;\ 2 < \eta < 6) = (74.9 \pm 5.3 \pm 12.9)\ \mu b$

Averaging preliminary $b\bar{b}$-production results

- Determine weighted average of J/ψ and $D^0\mu\nu X$ results
- Use MC and Pythia to extrapolate to 4π

	LHCb preliminary	Theory 1	Theory 2
$\sigma_T(pp \to b\bar{b}X)$ [μb]	$297 \pm 15 \pm 43$	332	254

Theory 1: Nason, Dawson, Ellis
Theory 2: Nason, Frixione, Mangano and Ridolfi

➔All $\sqrt{s}$ = 7 TeV LHCb sensitivity studies until now assumed ~ 250 μb!

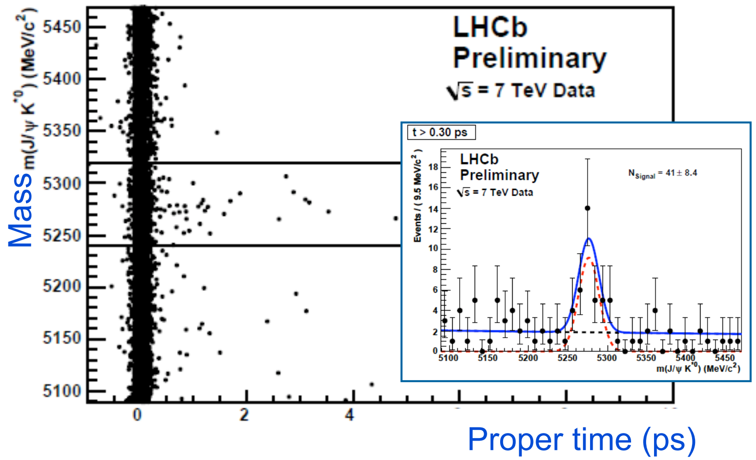
Exclusive final states with ~120-230 nb^{-1} and prospects for remainder of 2010-2011 run

Some other selected items from a rich physics programme:

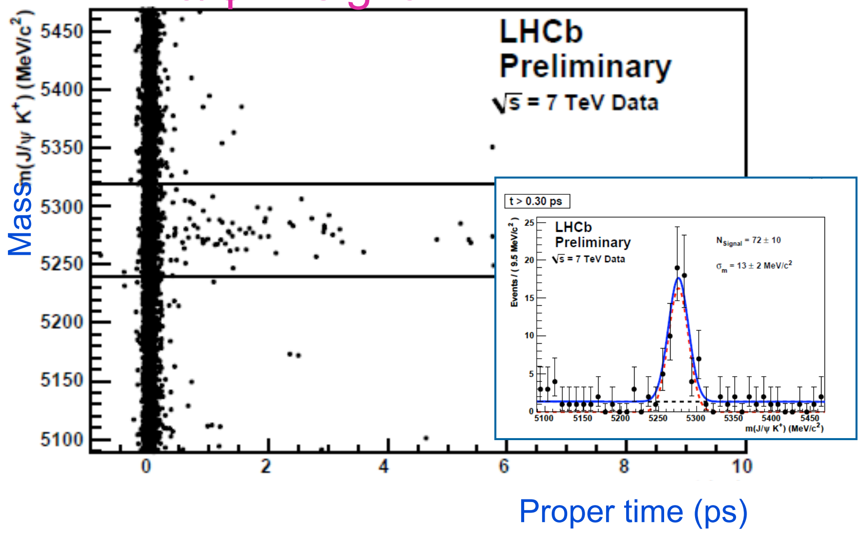
- $B \rightarrow J/\psi X$
- CP-violation in $B_s \rightarrow J/\psi \Phi$
- a^s_{sl} (and a^d_{sl})
- $B_s \rightarrow \mu\mu$

More B → J/ψ X signals

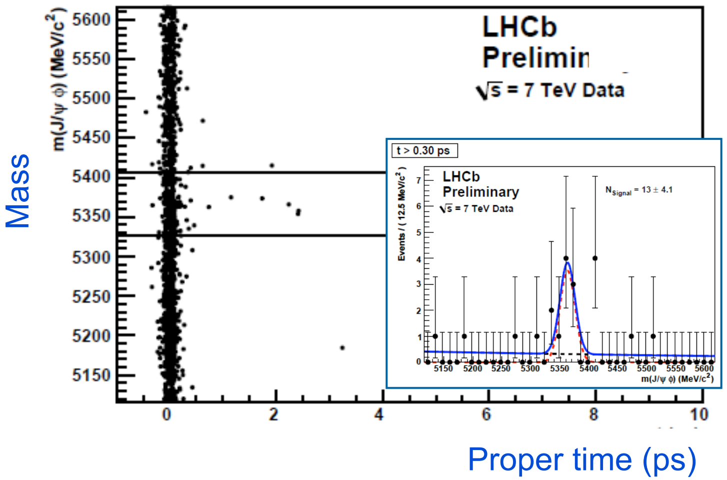
Clear $B^0 \to J/\psi K^*$ signal…



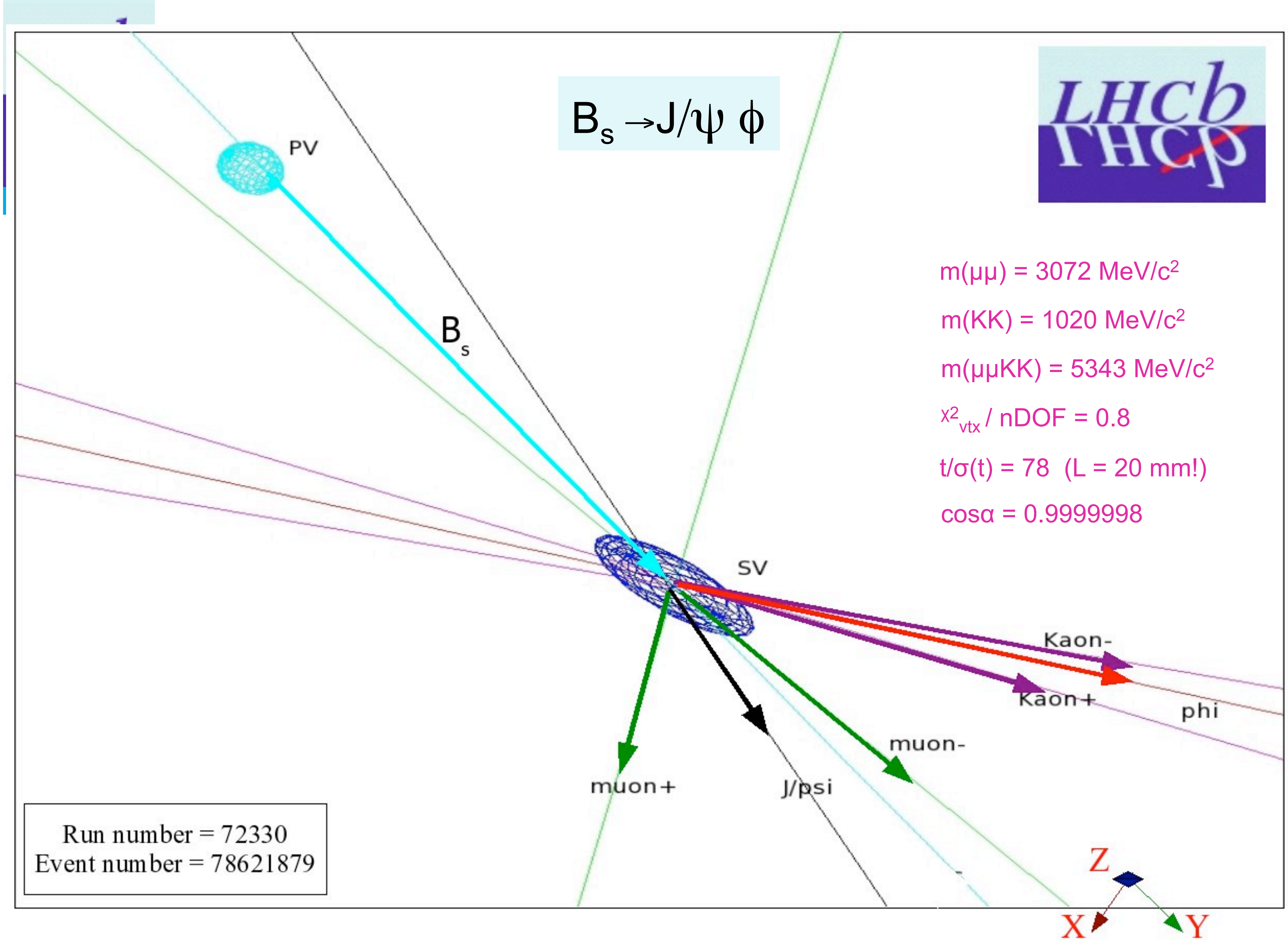
$B^+ \to J/\psi K^*$ signal



…and $B_s \to J/\psi \Phi$ beginning to show itself.

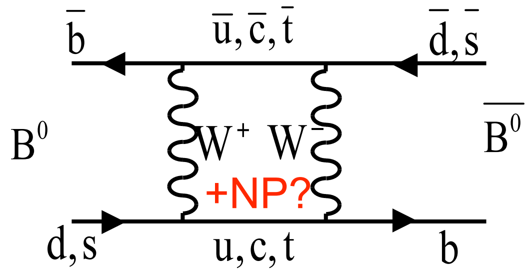


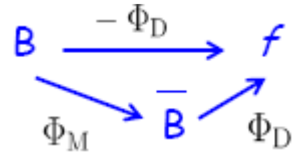
~ 230 nb^{-1}

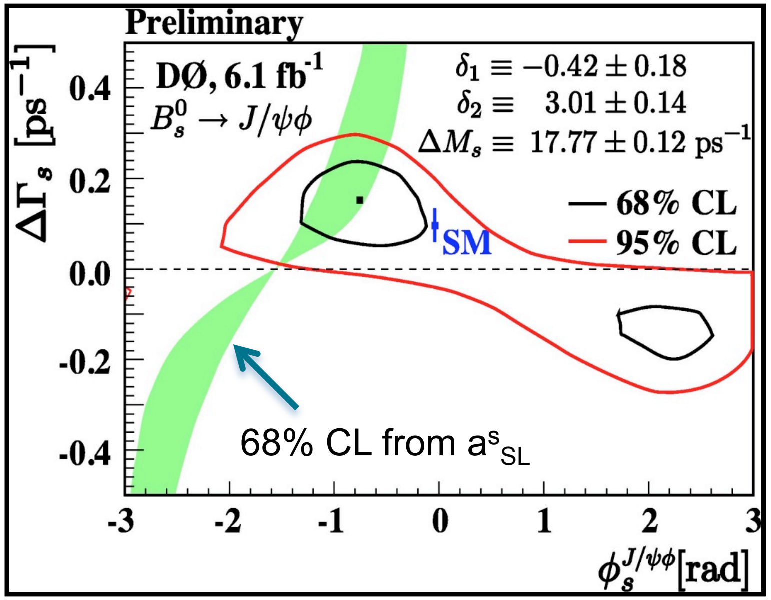

$B_s \rightarrow J/\psi\ \phi$
PV
B_s
SV
Kaon-
Kaon+
phi
muon-
muon+
J/psi
$m(\mu\mu)$ = 3072 MeV/c^2
$m(KK)$ = 1020 MeV/c^2
$m(\mu\mu KK)$ = 5343 MeV/c^2
χ^2_{vtx} / nDOF = 0.8
$t/\sigma(t)$ = 78 (L = 20 mm!)
$\cos\alpha$ = 0.9999998
Run number = 72330
Event number = 78621879
Z
X
Y

$\phi(J/\psi\phi)$ measurements from $B_s \rightarrow J/\psi\,\phi$

- Measure of B_s-B_s mixing phase $\phi(J/\psi\phi)$ in $B_s \rightarrow J/\psi(\mu\mu)\phi$ sensitive to NP effects in mixing
  - The phase arises from interference between B decays with and without mixing
  - $\phi^{SM}(J/\psi\phi) = -2\beta_s = -2\lambda^2\eta \sim -0.036\pm0.002$ rad
  - $\phi(J/\psi\phi) = -2\beta_s + \phi^{NP}$
- First measurements from CDF/D0 show some interesting hints (but significance reduced at ICHEP)
- Recent D0 measurement of an anomalous di-muon charge asymmetry points in the same direction
- The probability that SM is consistent with all these observations at few percent level.





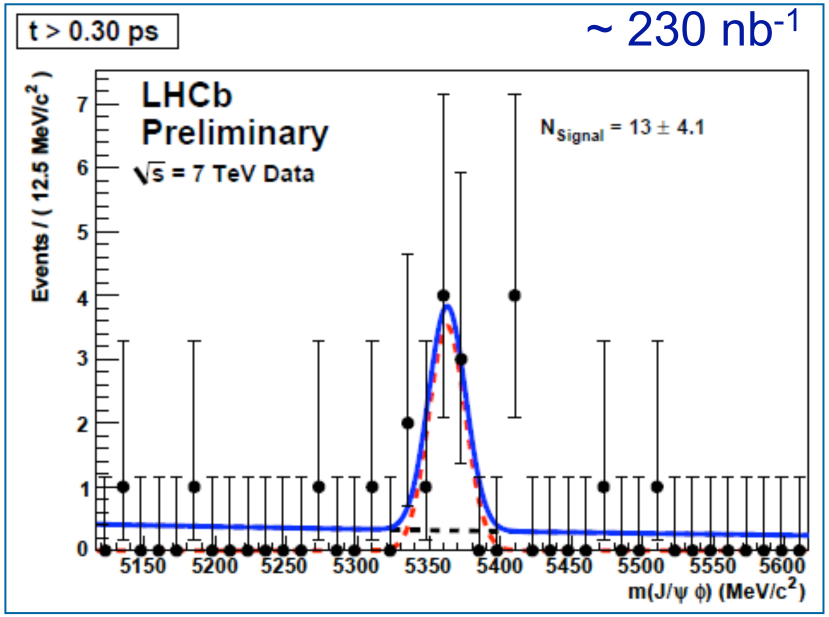


$\phi(J/\psi\phi)$ measurements from $B_s \rightarrow J/\psi\ \phi$

- P→VV decay:
  - B_s pseudoscalar (spin=0), J/ψ and Φ vectors mesons ($J^{PC}=1^{--}$)
  - Total angular momentum conservation implies ℓ=0,1,2
- $CP|J/\psi\ \phi\rangle = (-1)^\ell\ |J/\psi\ \phi\ \rangle$ →
  - Mixture of CP-even (ℓ=0,2) and CP odd (ℓ=1) final states
  - Need to fit angular distributions of decay final states as function of proper time
- Analysis strategy
  - Trigger and select $B_s \rightarrow J/\psi\phi$
  - Measure proper time
  - Measure 3 'transversity angles'
  - Tag initial B_s flavour
  - Likelihood fit of proper time and angular B decay rates
    - 6 observables: proper time, 3 angles, q (=0,-1,+1 for untagged, B_s, B_s) and mass
    - 8 physics parameters: Φ, $\Delta\Gamma_s$, Γ_s, Δm_s, $R_\perp$, R_0, δ_1, δ_2
    - many detector parameters (resolutions, acceptances, tagging, …)

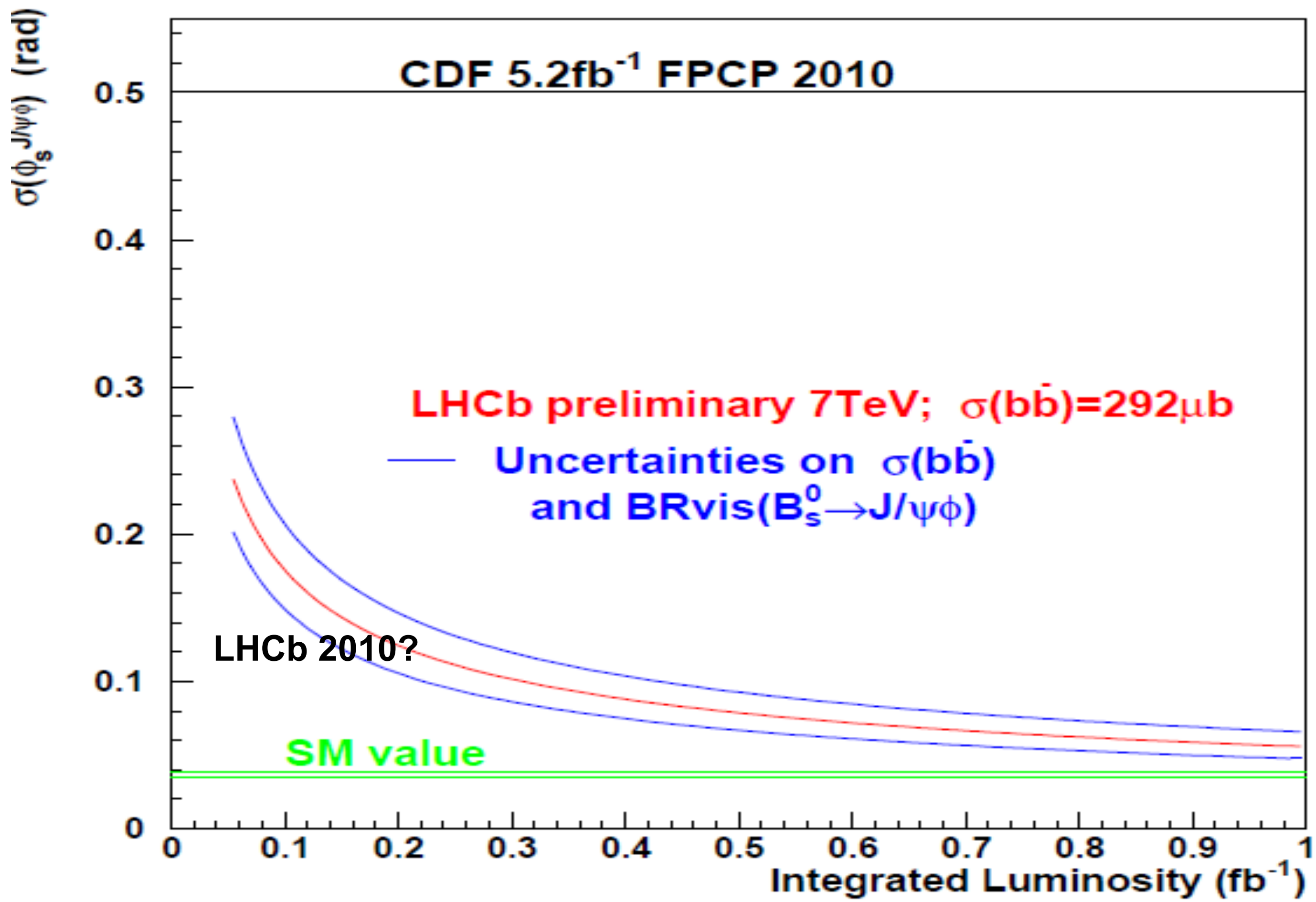
$\phi(J/\psi\phi)$ measurements from $B_s \rightarrow J/\psi\ \phi$

- Challenging measurement
  - Most critical parameters:
    - mis-tag
    - proper time resolution
- Reality check-list:
  - Measured cross section → consistent with expectations
  - Rate of signal events → consistent with expectations
  - Proper time resolution a bit worse than MC
  - Tagging performance: we will know about this soon, as we now have enough statistics in the control channels



- LHCb: yield for 100 pb^{-1}: ~ 6000
- CDF: 5.2 fb^{-1} data analysed→ ~5200 events

Perspectives for $\phi(J/\psi\phi)$ measurements from $B_s \to J/\psi\ \phi$



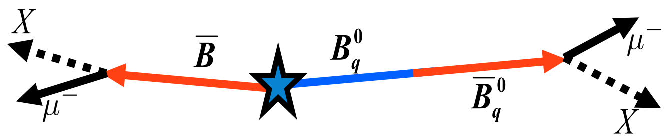
New Physics in di-muon charge asymmetry?

- If NP enhances CPV in $B^0_S \to J/\psi\Phi$, it will likely also enter in semi-leptonic asymmetry

- D^0 measures:

$$\boxed{A^b_{sl} \equiv \frac{N_b^{++} - N_b^{--}}{N_b^{++} + N_b^{--}}}$$

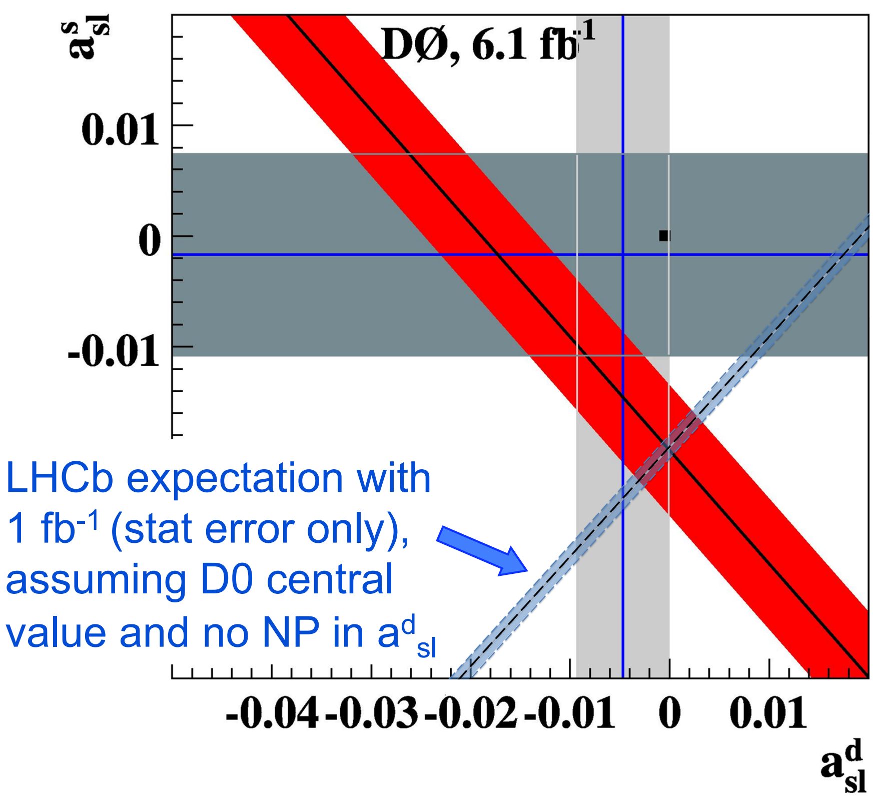
N_b^{++} (N_b^{--}) – number of same-sign $\mu^+\mu^+$ ($\mu^- \mu^-$) events from $B \to \mu X$ decay



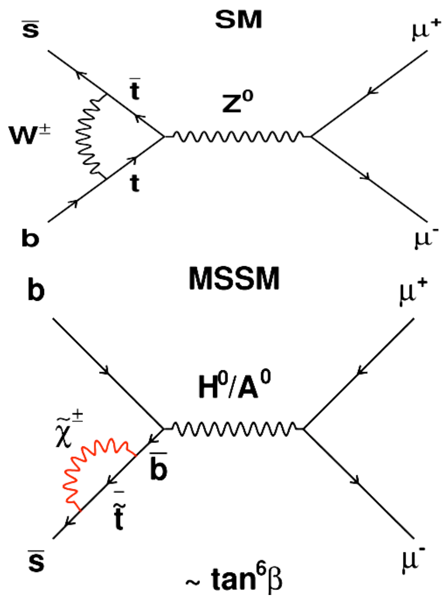
  - Both B_d and B_s contribute to A^b_{sl}
  - $A^b_{sl} = (0.506 \pm 0.043)a^d_{sl} + (0.494 \pm 0.043)a^s_{sl}$
  - $a^q_{sl} \equiv \dfrac{\Gamma(\overline{B}{}^0_q \to \mu^+ X) - \Gamma(B^0_q \to \mu^- X)}{\Gamma(\overline{B}{}^0_q \to \mu^+ X) + \Gamma(B^0_q \to \mu^- X)}; \quad q = d, s$

New Physics in di-muon charge asymmetry?

- D^0 result ~3.2 σ away from SM (arXiv:1007.0395)
- @LHCb
  - pp collider → production asymmetry (N(b)≠N(anti-b))
  - Measure: $\mathbf{a^s_{sl} - a^d_s}$ from difference in asymmetry in $B_s \to D_s(KK\pi)\mu\nu$ & $B^0 \to D^+(KK\pi)\mu\nu$
  - Same final state suppresses detection asymmetry
  - Provides orthogonal constraint to D^0 di-leptons

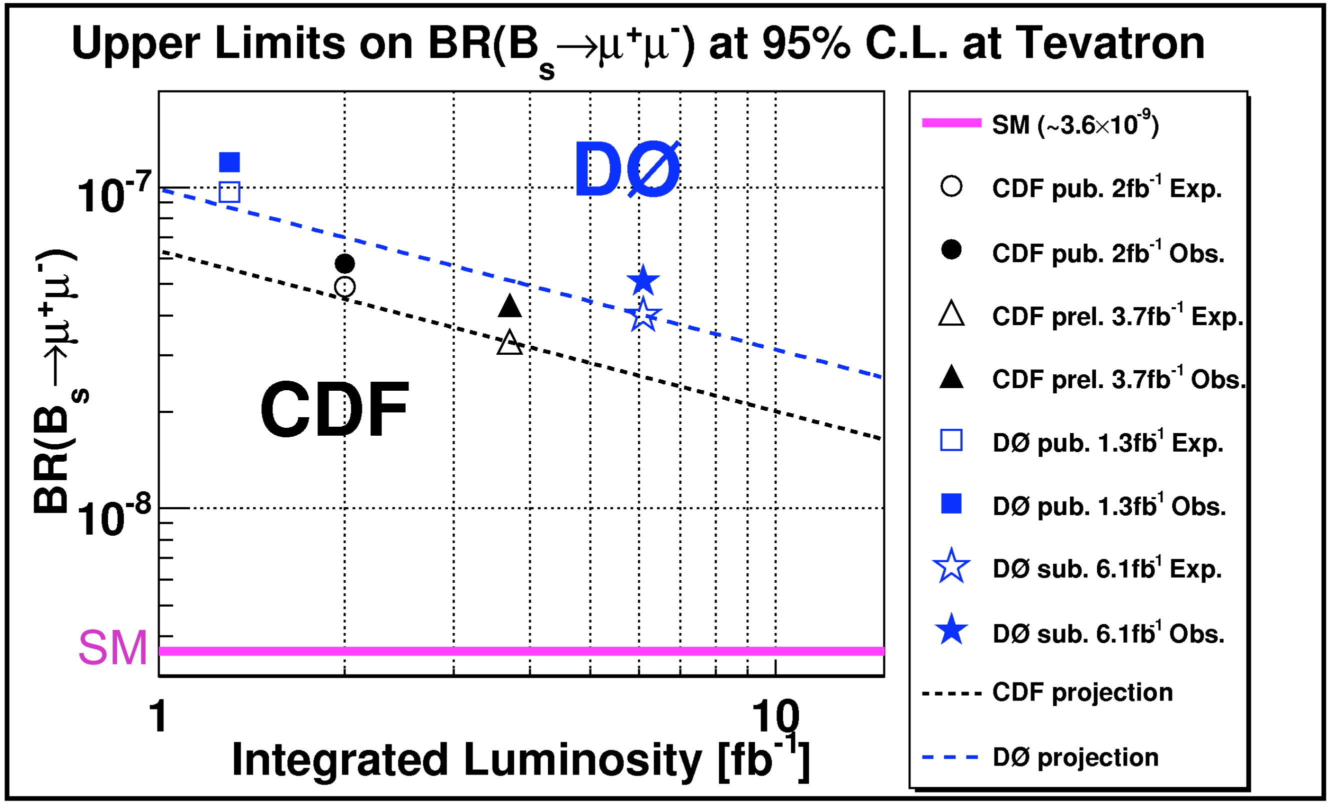


New Physics in $B_s \to \mu^+\mu^-$



- Small BR in SM: $(3.6 \pm 0.3) \times 10^{-9}$

  (Buras arXiv:0904.4917v1)
- Sensitive to NP
  - could be strongly enhanced in SUSY
  - In MSSM scales like $\sim\tan^6\beta$



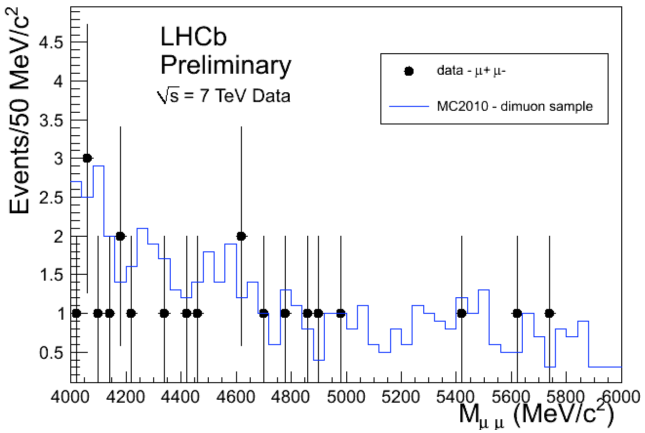
M. Aoki, FPCP-2010

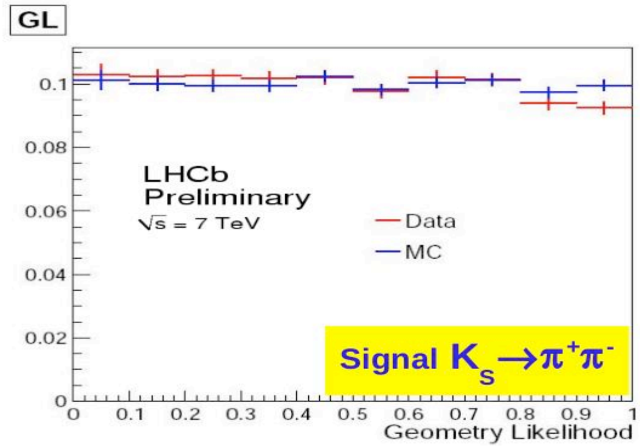
New Physics in $B_s \to \mu^+\mu^-$

- LHCb key features
  - high stat. & high trigger efficiency for signal
  - main issue is background rejection
  - dominated by $B \to \mu^+ X$, $B \to \mu^- X$ decays
    - (two real muons fom different B decays)
  - good mass resolution crucial
  - use of control channels to minimize dependence on MC simulation

New Physics in $B_s \to \mu^+\mu^-$

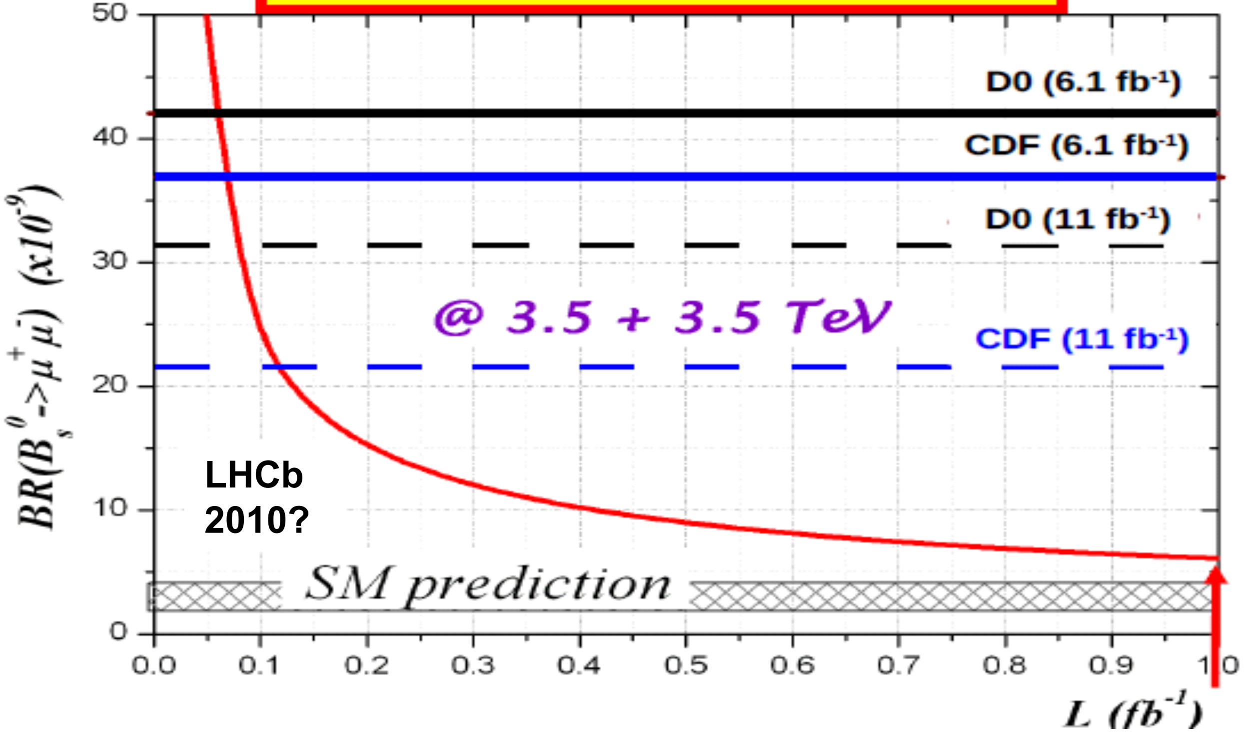
- Reality check
  - Trigger efficiency and μ-ID
    - Excellent agreement data/MC
  - First data indicate that the background estimate is reasonable
  - Geometrical likelihood GL based on decay topology
    - Good agreement data/MC
  - Mass and IP resolution still 30 to 50% off from design values, but expected to improve with better alignment
  - Overall good data/MC agreement





Physics reach for BR($B_s^0 \rightarrow \mu^+\mu^-$) as function of integrated luminosity (and comparison with Tevatron)

Exclusion limit at 90% CL at √s=7 TeV



CMS and ATLAS will certainly be competitive!

Conclusions

- LHCb successfully taking data
- Many charm and beauty peaks!
- First measurements of production cross-sections at $\sqrt{s}$ = 7 TeV for J/ψ and bb
- $B_s \rightarrow \mu\mu$ and $B_s \rightarrow J/\psi\varphi$ will reach new sensitivity regime with ~ 100 pb^{-1}
- Exciting prospects and rich physics programme with full 1 fb^{-1} expected by the end of 2011