Status and First Results from LHCb

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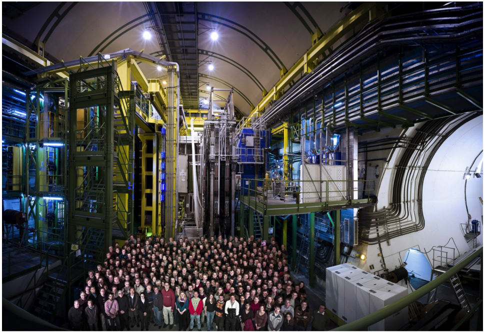
Outline

The LHCb Collaboration



- 730 members
- 54 institutes
- 15 countries

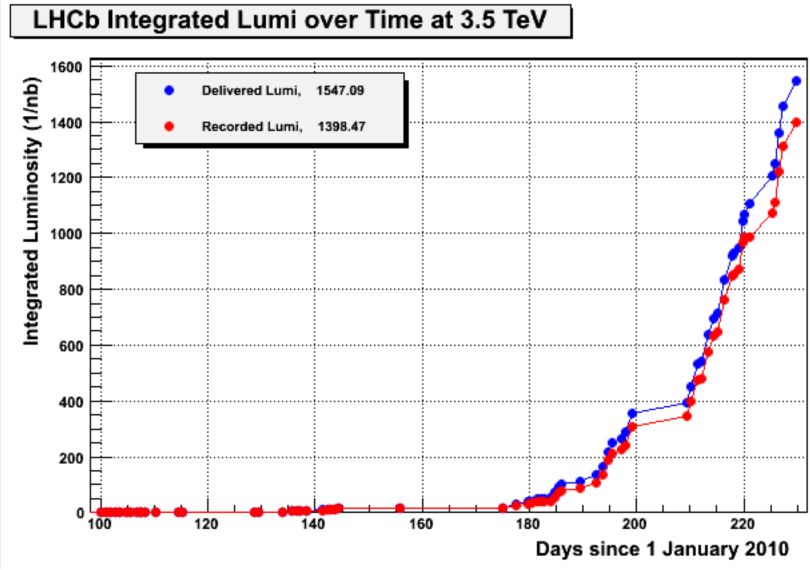
Swiss institutes involved are EPFL and Uni.ZH.

Design Goals

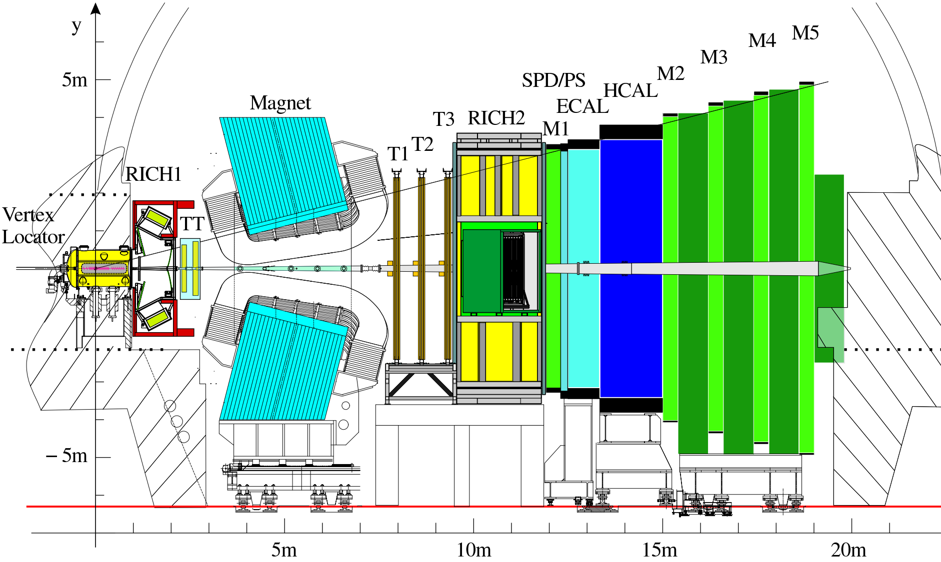
"The Large Hadron Collider beauty (LHCb) experiment is a forward one-arm spectrometer dedicated to the study of $\mathcal{CP}$ violation and other rare phenomena in the decay of hadrons containing b-quarks at the LHC."

In order to perform this task, it must provide excellent:

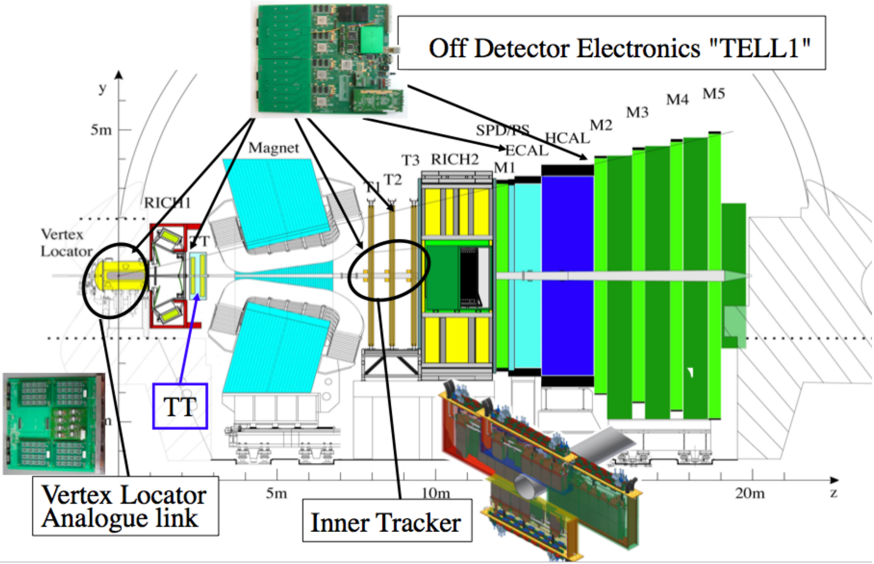
- Track Reconstruction Efficiency
- Momentum Resolution
- Particle Identification
- Vertex Resolution
- Trigger Efficiency


LHCb Integrated Lumi over Time at 3.5 TeV
Delivered Lumi, 1547.09
Recorded Lumi, 1398.47
Integrated Luminosity (1/nb)
0
200
400
600
800
1000
1200
1400
1600
100
120
140
160
180
200
220
Days since 1 January 2010

The LHCb Detector

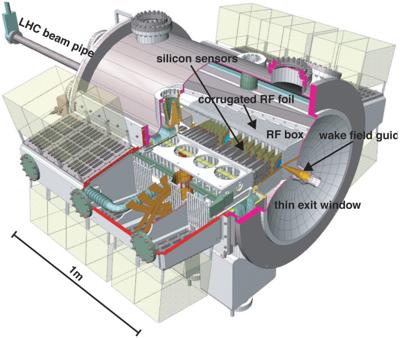


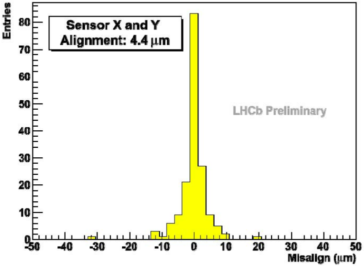
Swiss Responsibilities/Hardware Contribution in LHCb

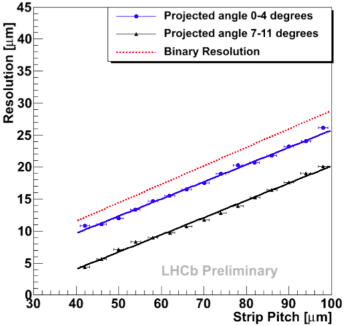


Also perform comissioning, calibration, alignment and tracking.

VErtex LOcator (VELO)

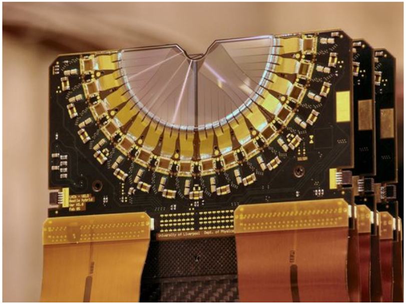


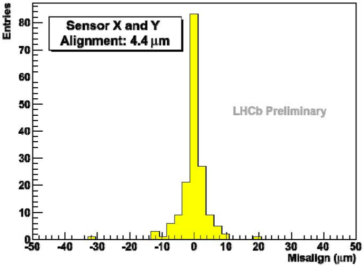


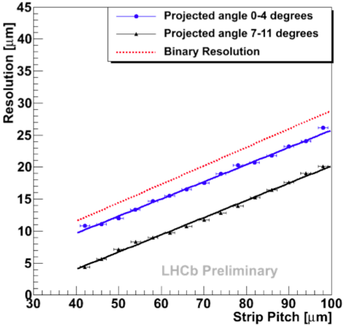


- Module and sensor alignment known to $< 5\,\mu$m
- VELO relative alignment better than $5\,\mu$m per fill
- Best hit resolution also $< 5\,\mu$m

VErtex LOcator (VELO)







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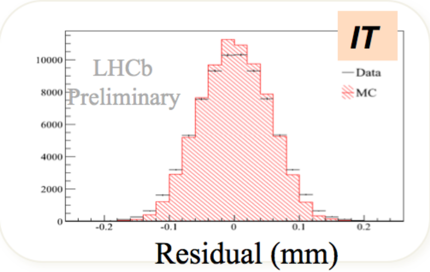
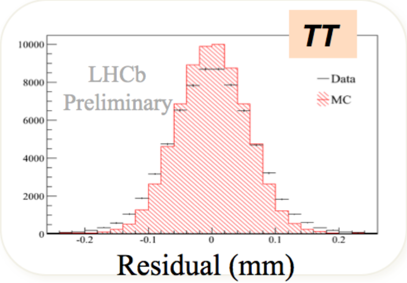
- VELO relative alignment better than $5\,\mu$m per fill
- Best hit resolution also $< 5\,\mu$m

Silicon Tracker Alignment and Resolution

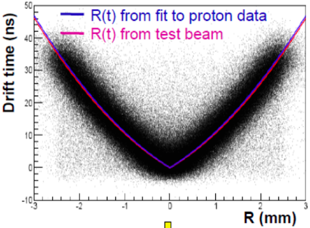


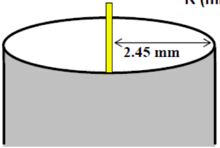


	Active Channels/%	Misalignment/μm	Hit Resolution/μm
IT	98.6	16	54
TT	99.6	35	55

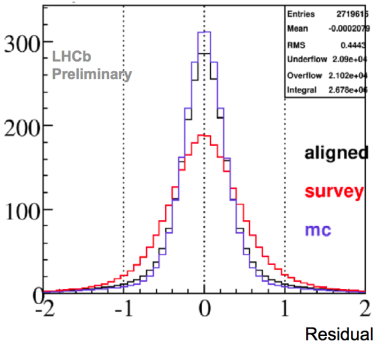
Outer Tracker

- Straw tubes
- 70% Ar : 28.5% CO_2 : 1.5% O_2 drift gas.
- Space-drift time relation as expected





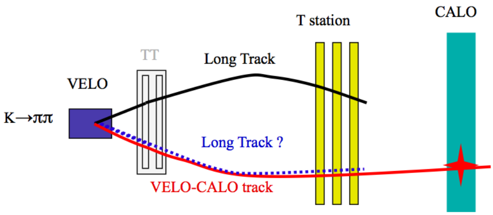
- 56 k channels
- 99.3% of channels are working
- OT resolution $\pm 270\,\mu m$, $\sim$ nominal



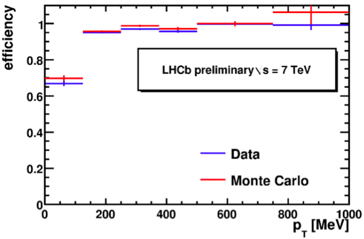
Tracking Efficiency

Using "Tag and Probe" method, efficiency defined as:

$$\epsilon = \frac{\text{Tracks}^{\text{VELO + IT/OT + CALO}}}{\text{Tracks}^{\text{VELO + CALO}}}$$

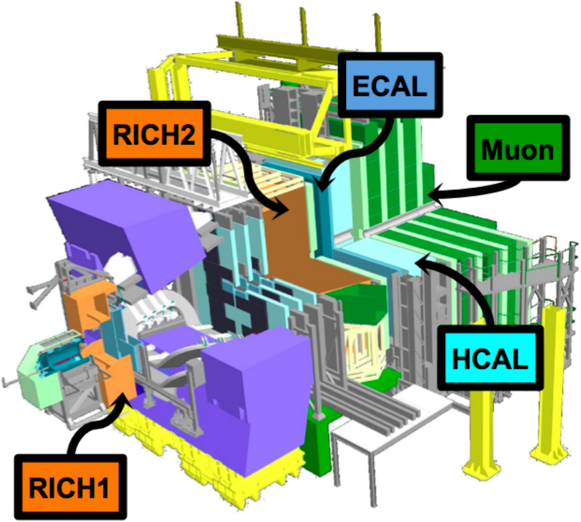


Method can also be used for J/ψ and Λ decays.



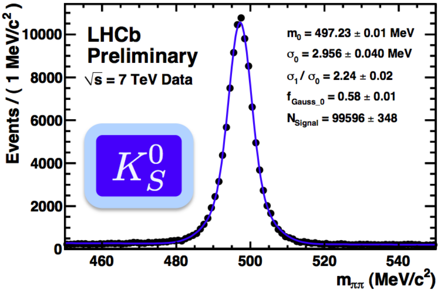
- Good agreement between data and MC.
- $\frac{\epsilon_{data}}{\epsilon_{MC}} = 0.99 \pm 0.02$ over all phase space.

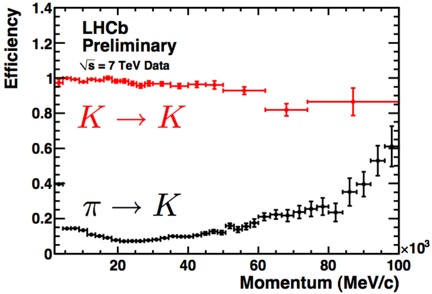
Particle Identification: Subdetectors



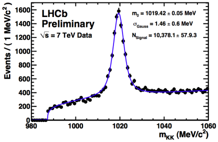
Particle Identification: General Method

- Need pure samples of each particle type $K^{\pm}$, $\pi^{\pm}$, p, $\overline{p}$, $\mu^{\pm}$, $e^{\pm}$ identified without the use of any PID at all
- V0:
  - $K^0_S \to \pi^+\pi^-$
  - $\Lambda \to p\pi^-$
  - Kinematic cuts only
- Resonances (one daughter identified with PID):
  - $\phi \to K^+K^-$
  - $J/\psi \to \mu^-\mu^+$

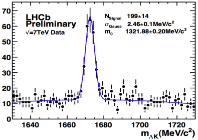




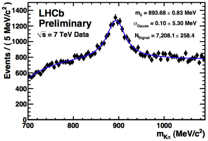
RICH Particle Zoo: Building Blocks of Future Analyses



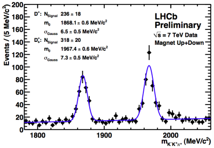
$\phi \rightarrow K^+K^-$



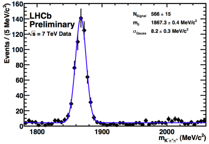
$\Omega \rightarrow \Lambda K^-$



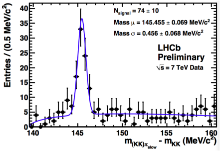
$K^{*0} \rightarrow K^{\pm}\pi^{\mp}$



$D^+ \rightarrow K^+K^-\pi^+$



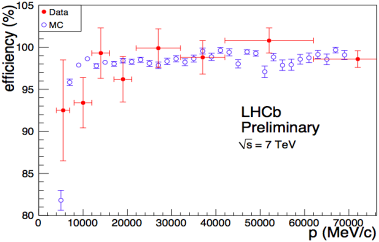
$D^+ \rightarrow K^+\pi^-\pi^+$

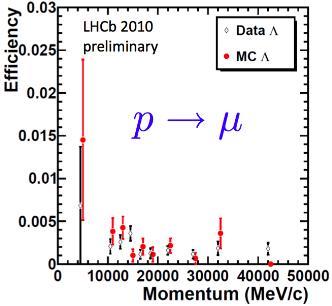


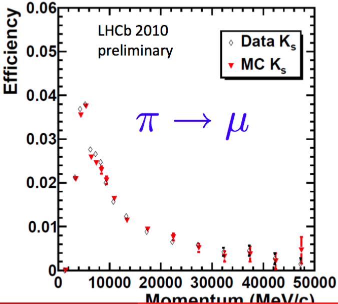
$D^{*+} \rightarrow K^+\pi^-\pi^+$

Muon PID

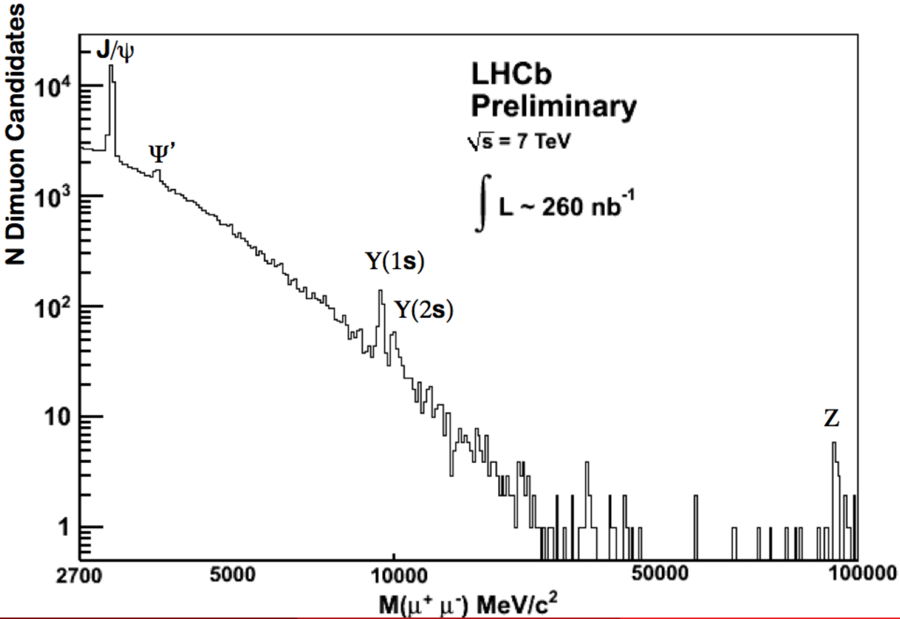
- Good agreement with MC.
- Integrated efficiency over full spectrum, $\epsilon(\mu) = 97.3 \pm 1.2\%$
- $\epsilon(\mathrm{p} \rightarrow \mu) = 0.21 \pm 0.05\%$
- $\epsilon(\pi \rightarrow \mu) = 2.35 \pm 0.04\%$
- $\epsilon(\mathrm{K} \rightarrow \mu) = 1.67 \pm 0.06\%$



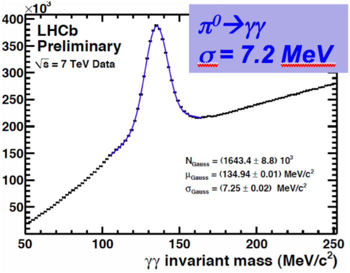


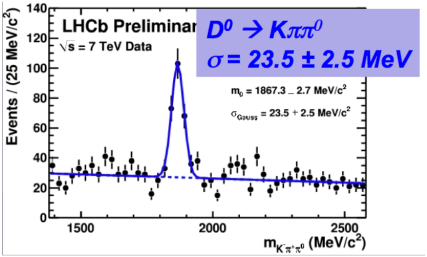


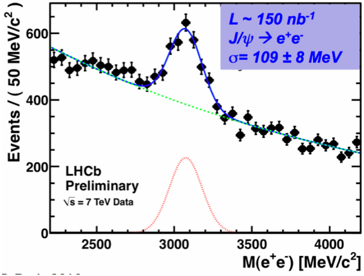
Particle Zoo: Dimuon Spectrum



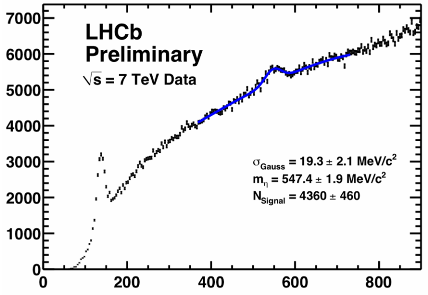
- ECAL calibrated to 2% level
- Reconstruction of D from neutrals
- Clear $J/\psi \to e^- e^+$ (including Bremsstrahlung recovery).



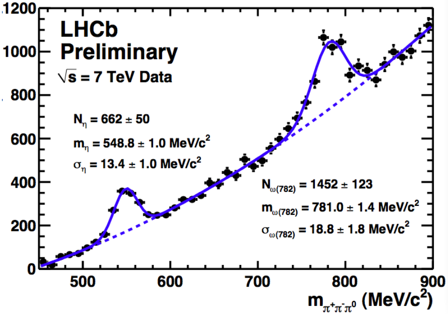




Calorimeter PID: Reconstructed Neutral States

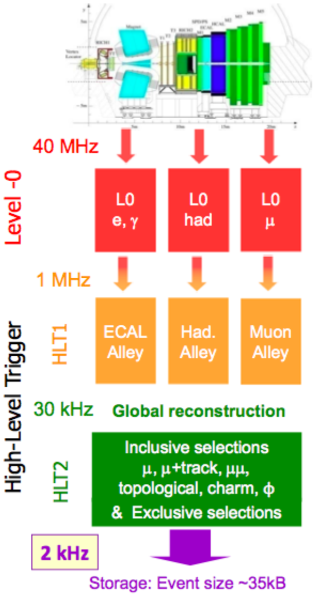


$\eta \to \gamma\gamma$



$\eta \to \pi^+\pi^-\pi^0$
$\omega \to \pi^+\pi^-\pi^0$

Trigger



LHCb trigger

Trigger is crucial:
- $\sigma_{b\bar{b}}$ is less than 1% of total inelastic cross section
- B decays of interest typically have BR < 10^{-5}

Customized Hardware Level Trigger (L0)
- random trigger
- high-p_t μ, e, γ and hadron candidates

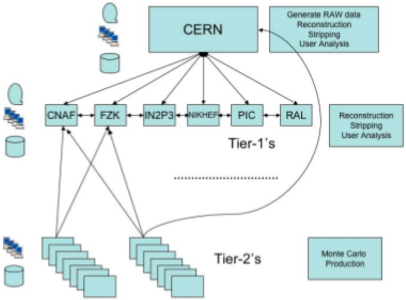
Software High Level Trigger (HLT1&HLT2)

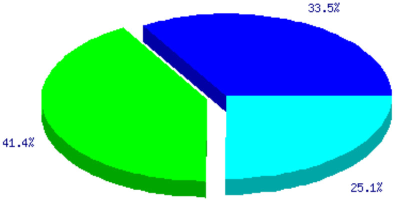
Farm with O(2000) multi-core processors

HLT1:
- minimum bias: no bias & micro bias (at least one track)
- c & b physics: L0 confirmation with more complete info, add impact parameter and lifetime cuts

HLT2:
- inclusive and exclusive selections

Computing





CSCS.ch CPU usage by LCG last year.
Key: CMS ATLAS LHCb

- Grid-based analysis, storage and MC production.
- Data reprocessed (stripped) several times a year, 9 times so far in 2010.
- Swiss Tier 2 site, CSCS.ch, well-used in the last year, in line with fairshare policy.

First LHCb Paper (Submitted to Phys Lett B)

arXiv:1008.3105v1 [hep-ex] 18 Aug 2010

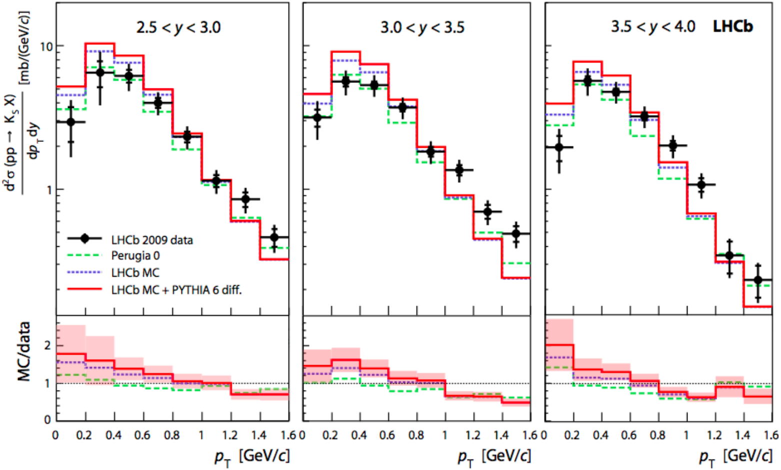
Prompt K^0_S production in pp collisions at $\sqrt{s} = 0.9$ TeV

The LHCb Collaboration[1]

Abstract

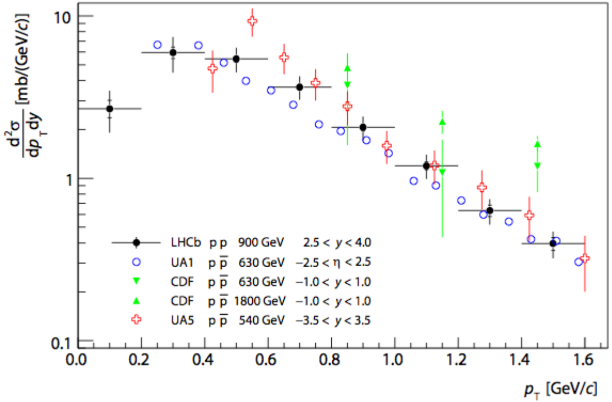
The production of K^0_S mesons in pp collisions at a centre-of-mass energy of 0.9 TeV is studied with the LHCb detector at the Large Hadron Collider. The luminosity of the analysed sample is determined using a novel technique, involving measurements of the beam currents, sizes and positions, and is found to be $6.8 \pm 1.0\ \mu b^{-1}$. The differential prompt K^0_S production cross-section is measured as a function of the K^0_S transverse momentum and rapidity in the region $0 < p_T < 1.6$ GeV/c and $2.5 < y < 4.0$. The data are found to be in reasonable agreement with previous measurements and generator expectations.

Prompt K^0_S Production: (http://arxiv.org/abs/1008.3105)



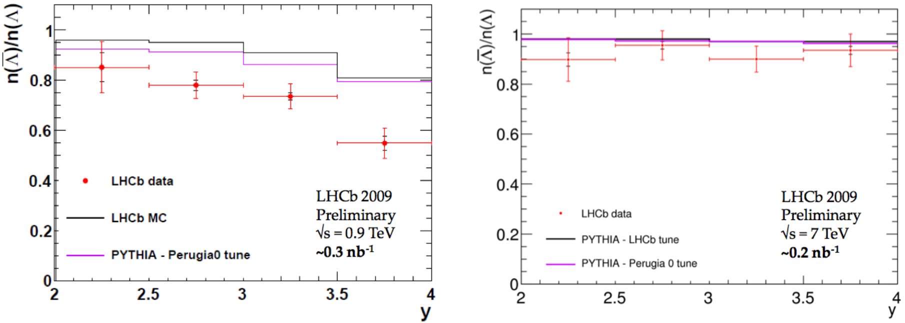
- Prompt K^0_S produced in the LHCb pilot run at $\sqrt{s} = 900\,\text{GeV}$
- Reasonable agreement with MC, but MC not tuned on data.
- First input from LHCb for tuning MC.

Prompt K^0_S Production: (http://arxiv.org/abs/1008.3105)



- Unique measurement at high rapidity and low p_T at $\sqrt{s} = 0.9\,\text{TeV}$
- Novel method of measuring luminosity by measuring the beam profile with the beam-gas and beam-beam interactions.

$\Lambda/\overline{\Lambda}$ ratio



- Unique measurement at high rapidity in $\mathrm{p\,p}$ collisions at $\sqrt{s} = 0.9\,\mathrm{TeV}$ and $7\,\mathrm{TeV}$.
- $\Lambda/\overline{\Lambda}$ ratio differs from expected values at 0.9 TeV
- Important input for understanding the hadronization modes.
- $\mathrm{p}/\overline{\mathrm{p}}$ is also being studied.

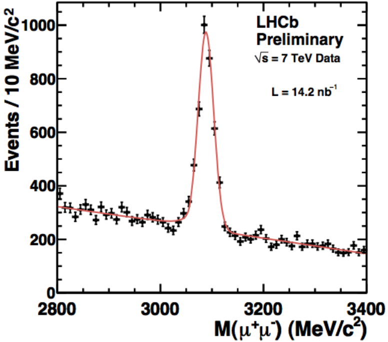
b Cross Section Measurement using inclusive $J/\psi \to \mu\mu$

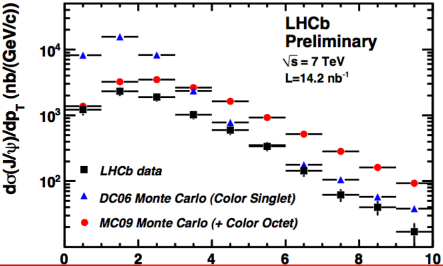
Interesting because heavy quarkionia production mechanism not completely understood.

- $J/\psi \to \mu^-\mu^+$ selected.
- J/ψ yield calculated from mass fit, 15 MeV/c^2 resolution.

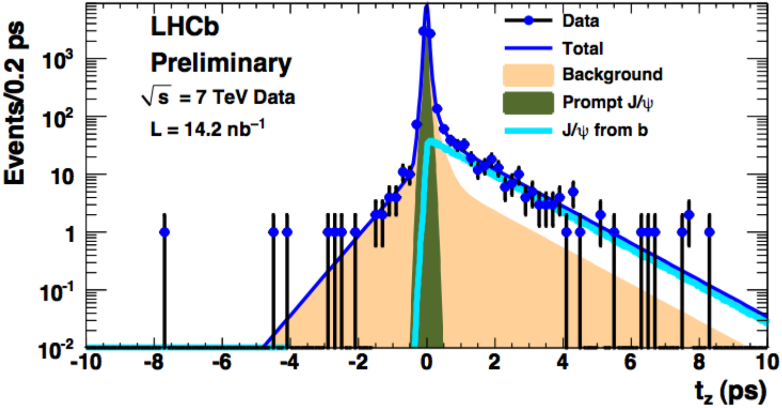
$$\sigma = \frac{N\left(J/\psi \to \mu^-\mu^+\right)}{\mathcal{L} \cdot \epsilon \cdot \mathcal{B}\left(J/\psi \to \mu^-\mu^+\right)}$$

- Differential cross section calculated in bins of p_T assuming non-polarised J/ψ.
- $\sigma\,(J/\psi$ from b) in acceptance: $7.65 \pm 0.19 \pm 1.10^{+0.87}_{-1.27}$ μb





b Cross Section Measurement using inclusive $J/\psi \to \mu\mu$

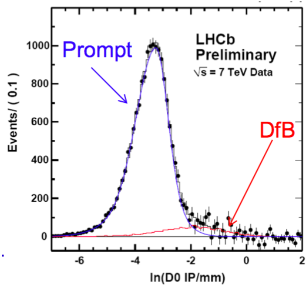


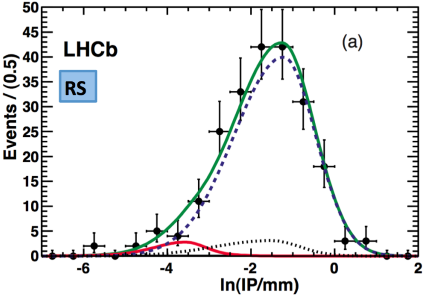
$$t_z = d_z \cdot M_{J/\psi} / p_z$$

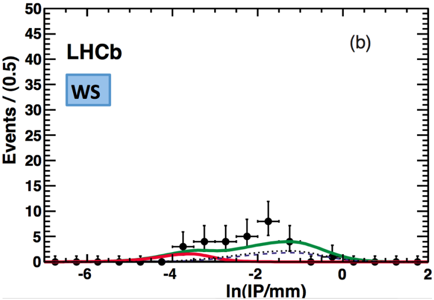
- Prompt and $b \to J/\psi$ contributions from fit to propertime distribution.
- Bkg calculated from mass sidebands.

b Cross Section Measurement from $B^0 \to D^0 \mu \bar{\nu}_\mu X$

- $D^0 \to K^- \pi^+$ selected.
- Combination with μ reduces prompt D^0 bkg.
- Statistical separation of prompt D^0 and DfB using IP.

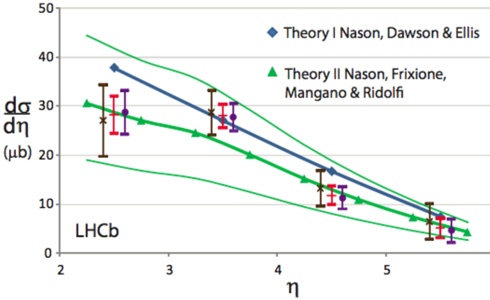






b Cross Section Measurement from $B^0 \to D^0\mu\overline{\nu}_\mu X$

- Yields of DfB are calculated, knowing $\mathcal{B}\left(b \to D^0 X \mu^- \overline{\nu}\right)$ and efficiencies, $\sigma\left(pp \to b\overline{b}X\right)$ is calculated.
- Main systematic errors from Luminosity, Tracking efficiency and b-Branching Ratios:
  - 10% from $\mathcal{L}$, beam-current dominated.
  - 8% (J/ψ), 10% (dimuon) tracking efficiency determined by comparing to MC.
  - 9% (J/ψ), 5% (dimuon) b Branching Ratio.



Channel	$\sigma\left(pp \to b\overline{b}X\right)/\mu b$
$J/\psi \to \mu\mu$	$319 \pm 24 \pm 59$
$D^0\mu^-\overline{\nu}_\mu X$	$282 \pm 20 \pm 49$
Combined	$292 \pm 15 \pm 43$
$D^{*-}\mu^-\overline{\nu}_\mu X \to$	$275 \pm 44 \pm 66$

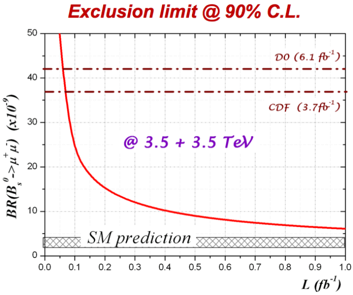
Physics Prospects with 1 fb^{-1}

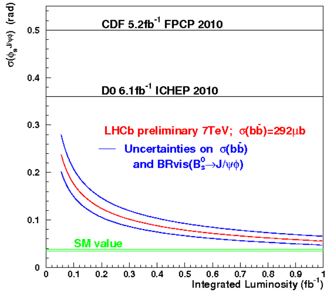
$B_s^0 \to \mu\mu$:

- Rare decay, $\mathcal{B} \sim \mathcal{O}\left(10^{-9}\right)$.
- 0.1 fb^{-1} improve on Tevatron limit.
- 1 fb^{-1} exclude $\mathcal{B}$ down to $7 \cdot 10^{-9}$ or observe 5σ signal with $\mathcal{B} = 3.5 \cdot \mathrm{SM}$

$B_s^0 \to J/\psi\phi$:

- $\phi_s = -2\beta_s$, SM value small & precise.
- 50 k events/fb^{-1} consistent with observed data.
- Sensitivity better than Tevatron with $0.1 fb^{-1}$.

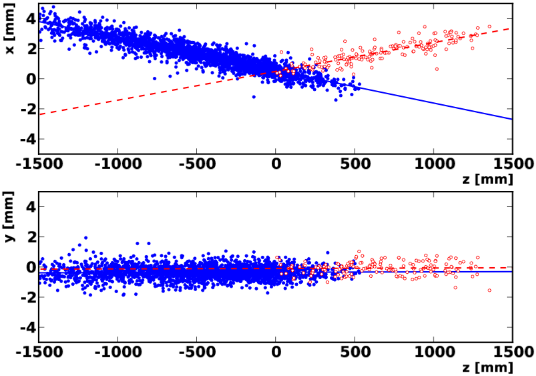




Summary

- Detector understood and performing well.
- Charm resonances and B-mesons have been reconstructed.
- The foundations of the LHCb physics program have been firmly established.
- Unique measurements of production cross sections at $\sqrt{s} = 7\,\text{TeV}$
- LHCb is in good form to analyse the $1\,\text{fb}^{-1}$ expected in 2011.

Backup Slides



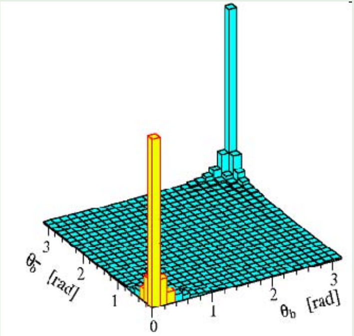
n_i = number of protons,
$f = 11.245\,\text{kHz}$,
θ is half-crossing angle,
ρ is bunch density,
number of p from LHC machine.
Bunch shapes well-described by gaussian.

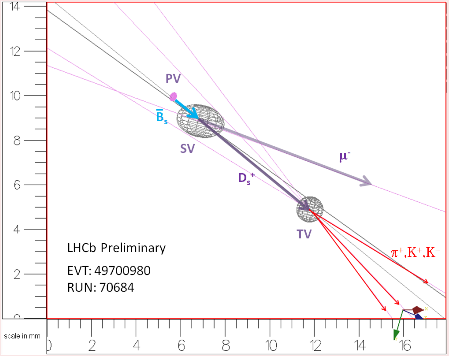
$$L = 2cn_1 n_2 f \cos^2\theta \int \rho_1(x,y,z,t)\,\rho_2(x,y,z,t)\,dx\,dy\,dz\,dt$$

Beam-gas tracks reconstructed in VELO, beam directions and crossing angle determined from beam-gas vertex distribution.

Physics Environment

- At the LHC, b-quarks are produced strongly peaked in the forward direction.

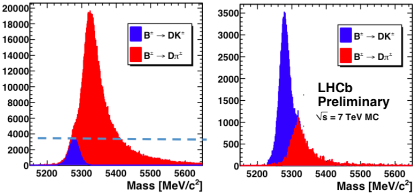


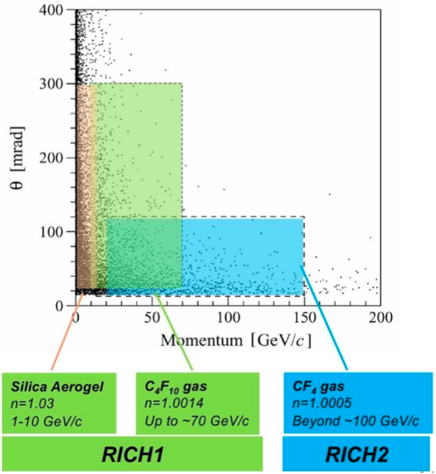


- Large Lorentz boost corresponding to $\sim 7\,\text{mm}$ decay distance.

Particle Identification: RICHes

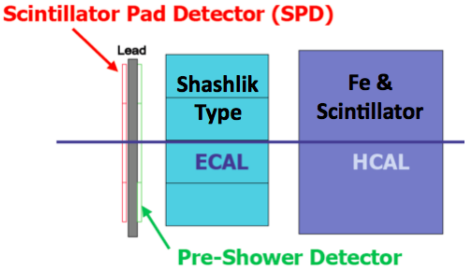
- Need good $\pi/\mathrm{K}/\mathrm{p}$ separation in momentum range between 1 and 100 GeV and good coverage of angular acceptance.
- Two RICH detectors and three radiators.

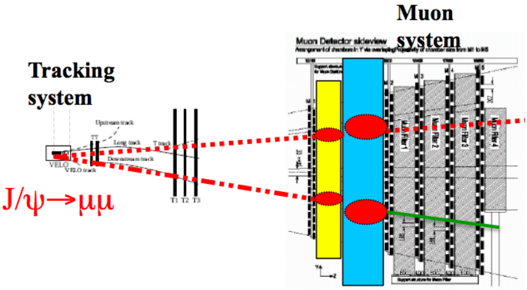




Particle Identification: Calorimeters and Muon

- Calorimeters:
  - Provides PID for e, γ & neutral particles.
  - Position and energy information.
  - Electron/Pion separation.
- Muon:
  - Provides μ ID with high purity
  - Multi-wire Proportional Chambers
  - Gas Electron Multipliers





Flavour-specific Asymmetry (A_{fs})

$D0$ measures like-sign dimuon asym

$$N^{++} = N\left(b\bar{b} \rightarrow X l^+ l^+\right)$$

$$A^b = \frac{N^{++} - N^{--}}{N^{++} + N^{--}} = (0.494)a_{fs}^s + (0.506)a_{fs}^d$$

$$A^b = [-9.57 \pm 2.51 \pm 1.46] \cdot 10^{-3} \approx (-1 \pm 0.3)\,\%$$

Orthogonal LHCb measurement:

$$\Delta A_{fs}^{s,d} = \frac{a_{fs}^s - a_{fs}^d}{2}$$

Resolution comparable to $D0$ after $100\ pb^{-1}$

Also via untagged $\mathrm{B_s^0} \rightarrow \mathrm{D_s}\pi$:

$$A_{fs}^s = \frac{a_{fs}^s}{2}\frac{\cos \Delta m_s t}{\cosh \Delta\Gamma_s t/2} + \mathcal{O}\left(a_{fs}^2\right)$$