LHCb: Results and plans

Miami 2010

December 16th, 2010

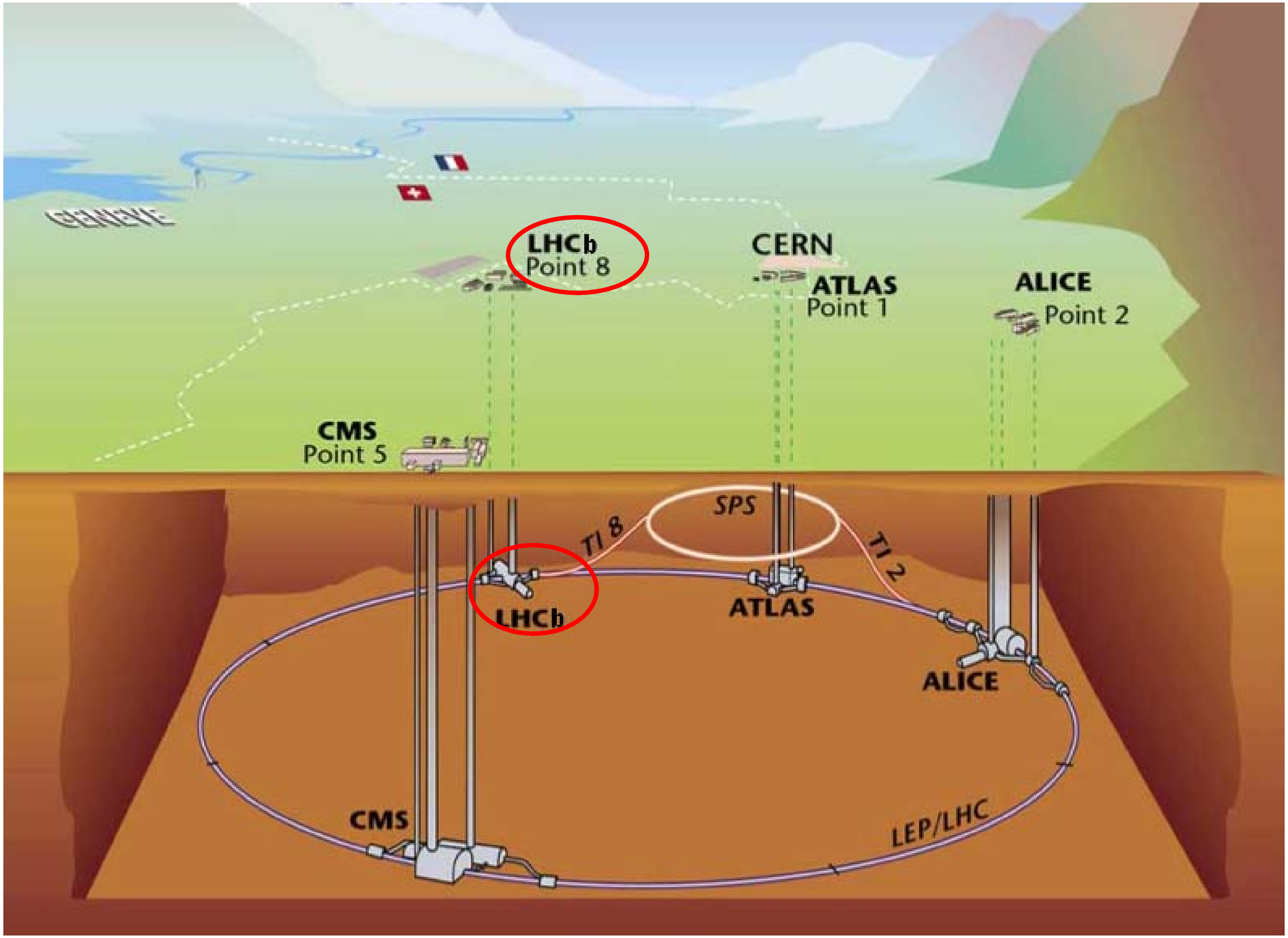
Xabier Cid Vidal
University of Santiago de Compostela,
on behalf of the LHCb collaboration

Outline

- Introduction to LHCb:
  - Our detector, trigger and reconstruction; and how they performed in 2010
- Early physics results
  - K_s, $b\bar{b}$ production cross sections
  - J/Ψ studies
  - Preliminary DCPV and $B^0\bar{B}^0$ oscillation
- Prospects for next year
  - Φ_s from $B_s \rightarrow J/\Psi\Phi$
  - Rare decays
  - Charm
- Conclusions

Introduction to LHCb

The LHCb experiment at CERN



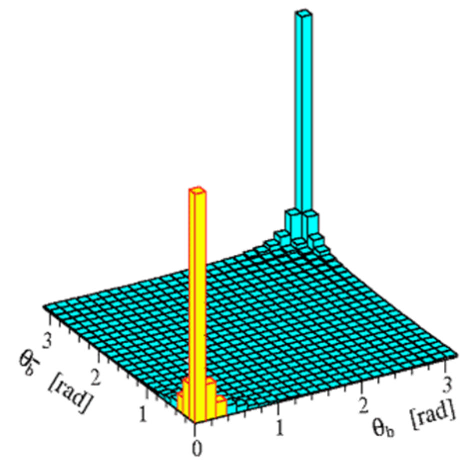
LHCb Overview (I)

- LHCb searchs indirectly for New Physics in the **b** (and c) sectors. This approach can access higher energy scales and **see NP effects earlier**. It has happened before in the history of physics…
- NP enters through contributions from virtual heavy particles in loop-mediated processes
- LHCb physics divided in two main categories:
  - **Study of FCNC**
    - Search for Φ_s angle ($B_s \rightarrow J/\Psi\Phi$)
    - Rare Decays: *BR*($B_s \rightarrow \mu\mu$), A_{FB}($B \rightarrow K^*\mu\mu$)
    - CP violation phase in charm mixing
  - **CKM "precision" measurements**
    - Compare two measurements of the same quantity sensitive and not to the NP (tree vs loop)

      γ: $B_{(s)} \rightarrow D_{(s)}K$, $B_{(s)} \rightarrow hh$

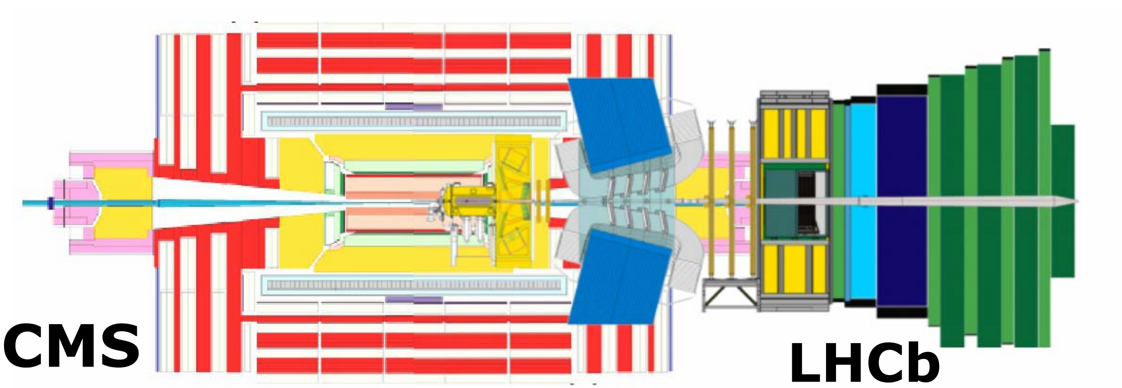
LHCb Overview (II)

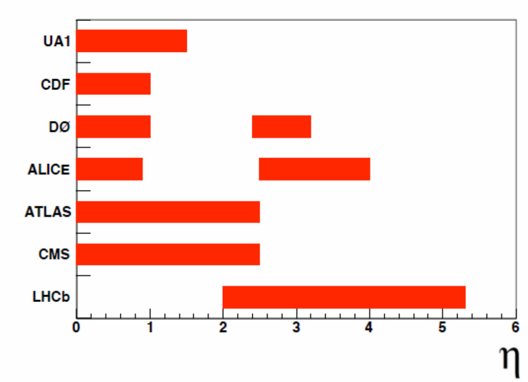
- LHCb designed for b physics. Some of its **strongest points** are:
  - Vertexing and IP
  - PID
  - Momentum and mass resolution
  - Flexible trigger
  - **Forward spectrometer**! Angular coverage 10-250 mrad (V) and 10-300 mrad (H)



$b\bar{b}$ are produced in the same region

- LHCb is complementary to the other LHC experiments!

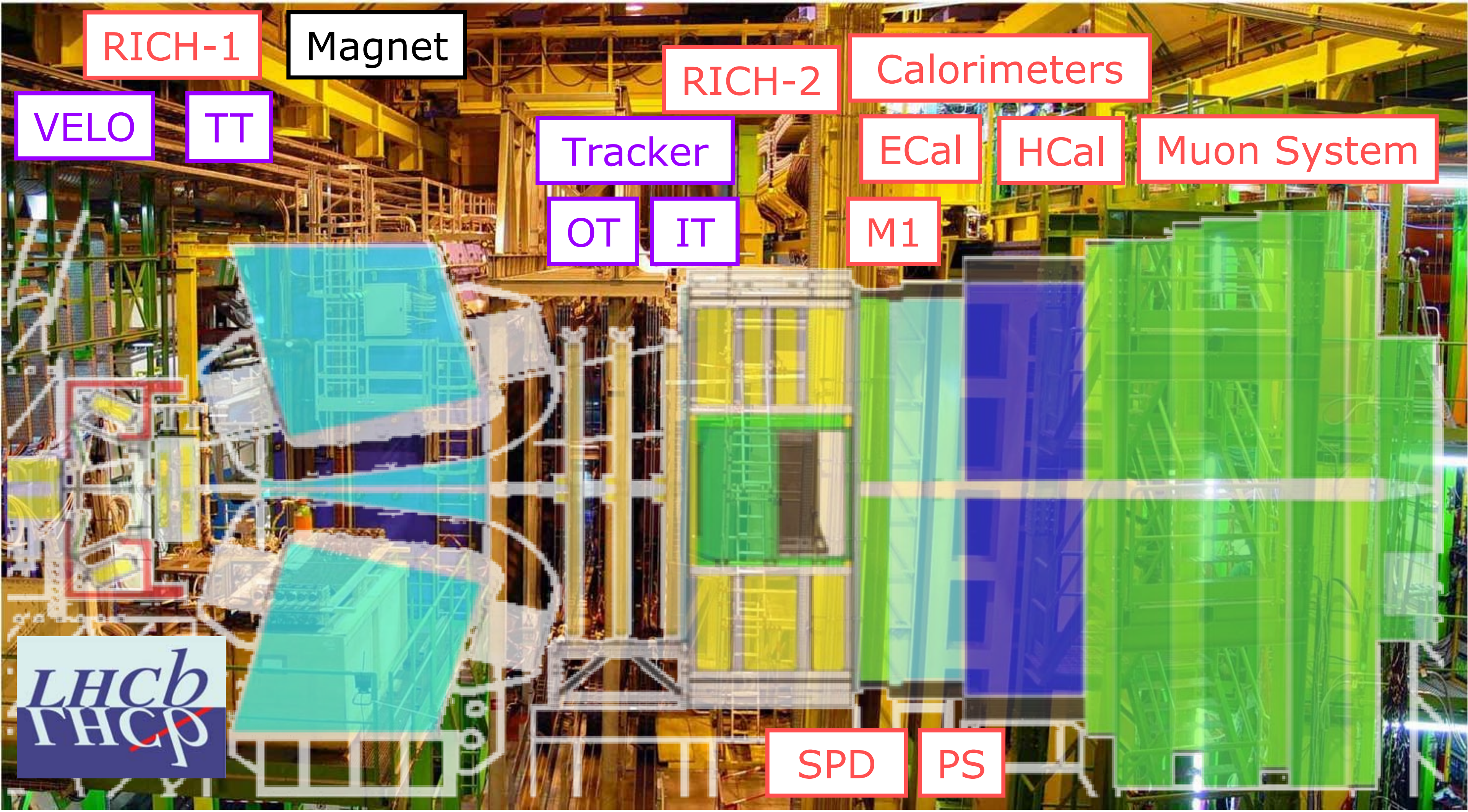




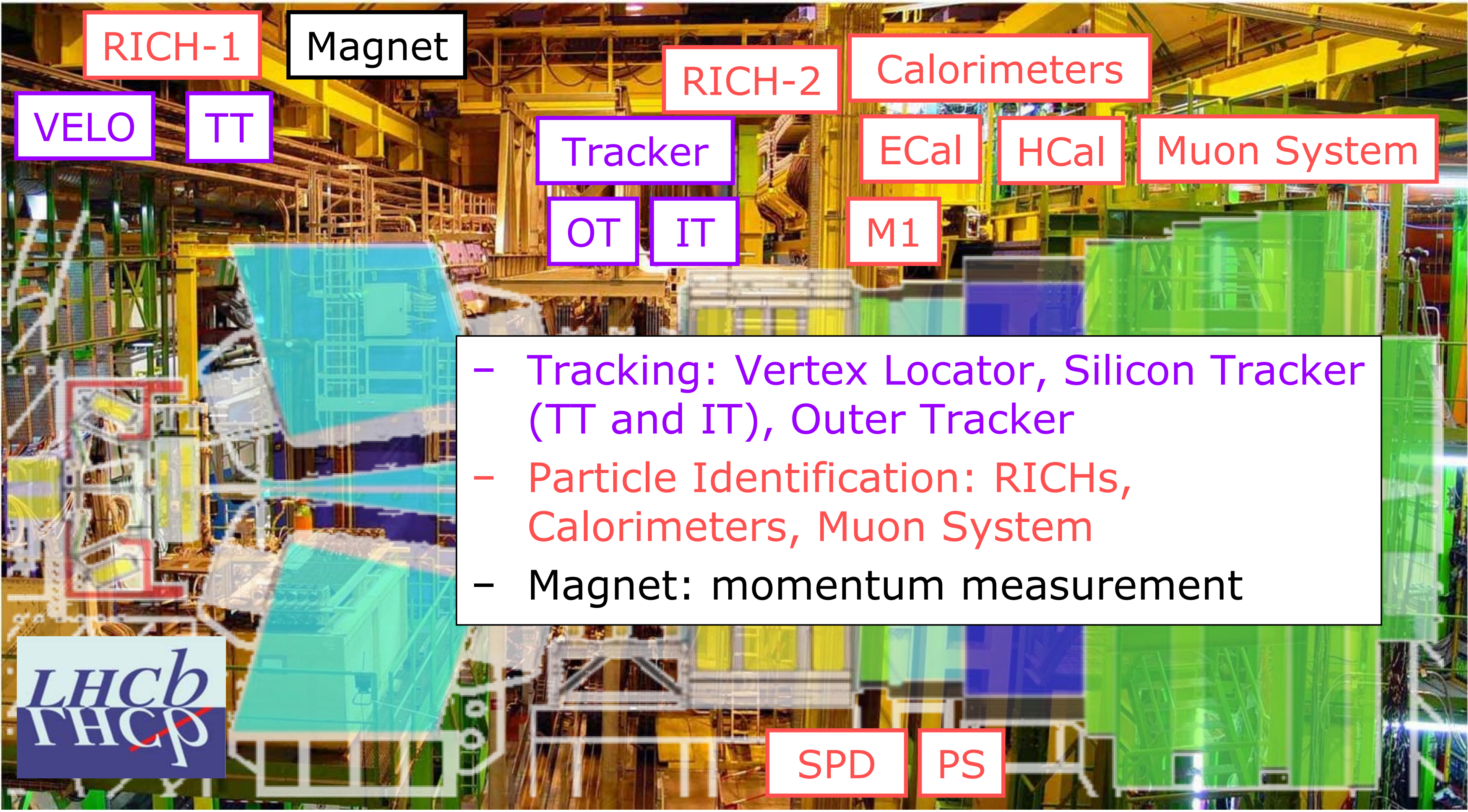
Introduction to LHCb

→ Our detector, trigger and reconstruction; and how they performed in 2010

LHCb detector



LHCb detector



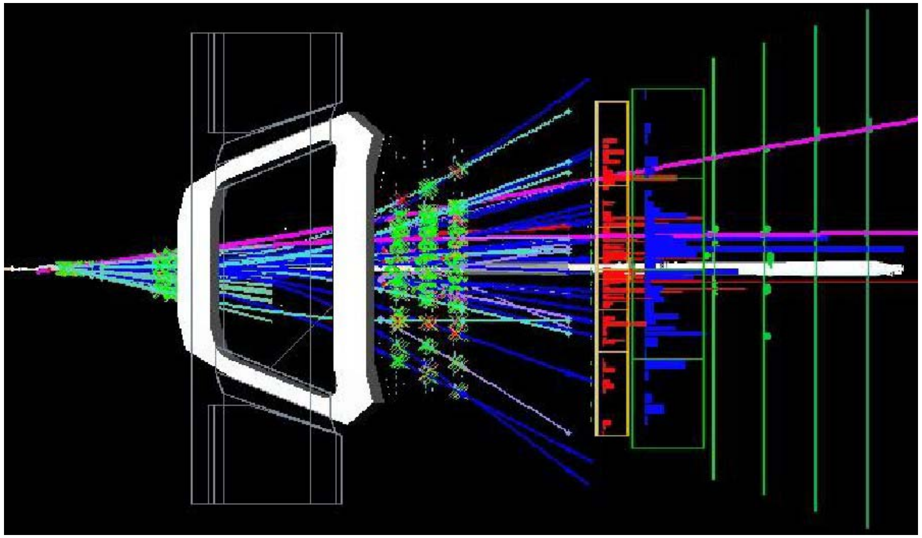
- Tracking: Vertex Locator, Silicon Tracker (TT and IT), Outer Tracker
- Particle Identification: RICHs, Calorimeters, Muon System
- Magnet: momentum measurement

LHCb 2010 data taking

- Excellent performance of the detector, trigger and reconstruction!

First LHC collisions at 3.5 TeV
30 March 2010 – around 1pm

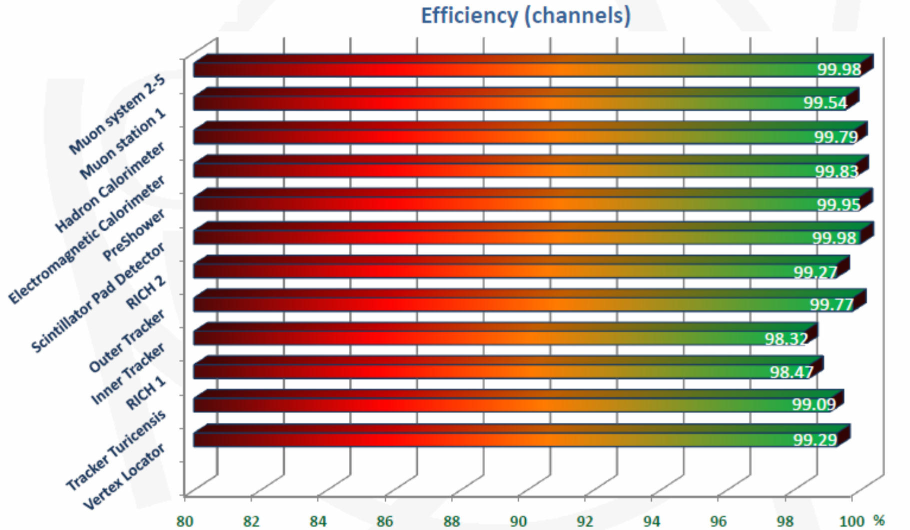
First $B^+ \rightarrow J/\Psi K^+$ Candidate
5 April 2010 – around 1am



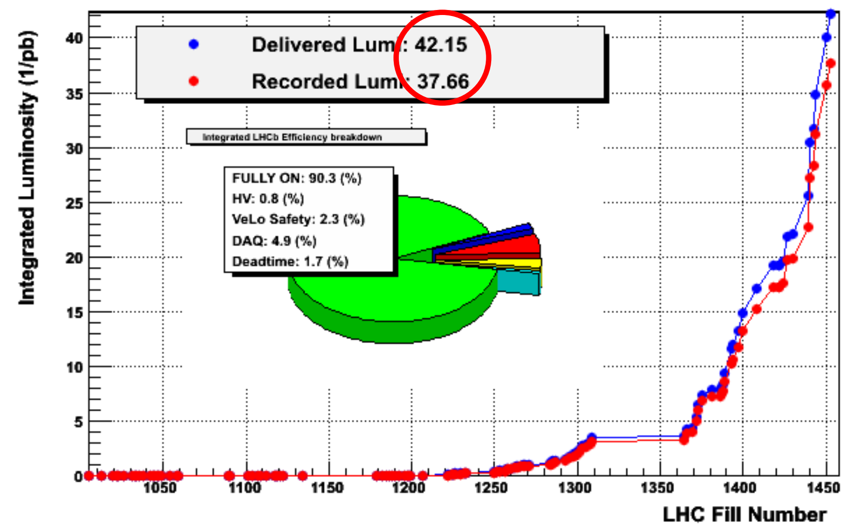
LHCb 2010 data taking

- Excellent performance of the detector, trigger and reconstruction!

Efficiency of the different channels (total number 544063)

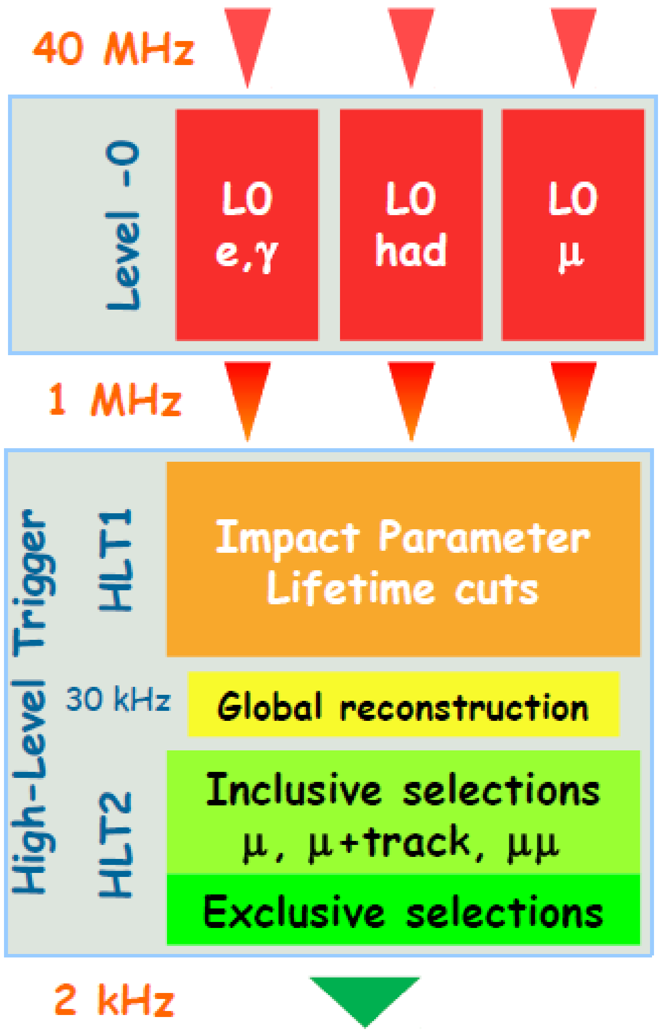


LHCb integrated luminosity (~37 pb^{-1} recorded out of ~42 →90% eff.)



And this in spite of up to more than **2.5 interactions per crossing** on average (**nominal ~0.4**). Significantly harsher conditions than design:
- multiple primary vertices
- high occupancies, track multiplicities

LHCb trigger

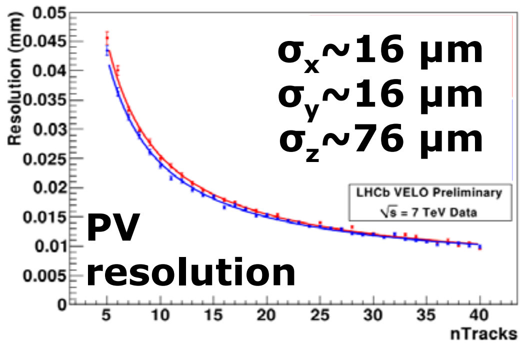


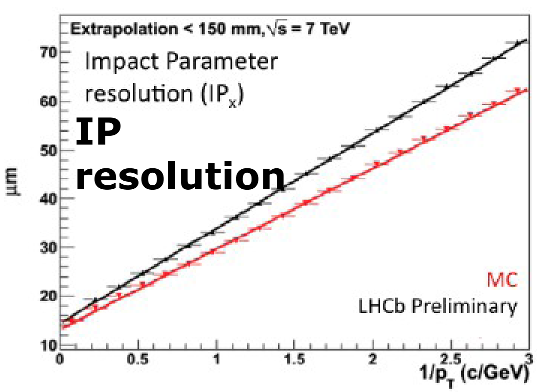
- LHCb trigger has two levels:
  - **L0** (hardware)
  - **HLT** (software)
- The trigger has been changed continously to cope with the different running conditions
- Trigger efficiencies determined on data **in good agreement with simulation**

	Muon trigger (J/Ψ)	Hadron Trigger (D^0, p_T>2.6 GeV/c)
Data	(94.9 ± 0.2) %	(60 ± 4) %
Simulation	(93.3 ± 0.2) %	66 %

Vertexing, tracking and PID (I)

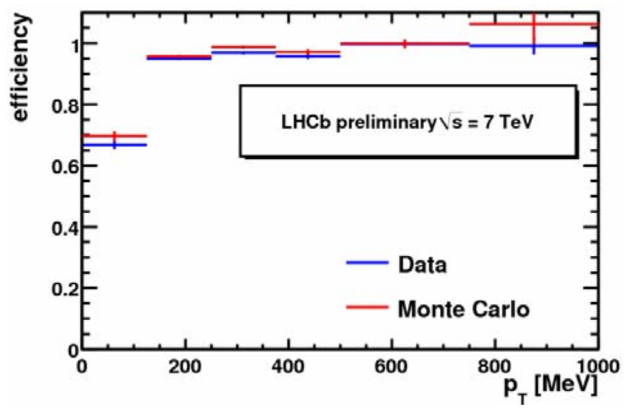
- **Vertexing:**
  - good vertex resolution crucial for high-level triggers and most physics analysis





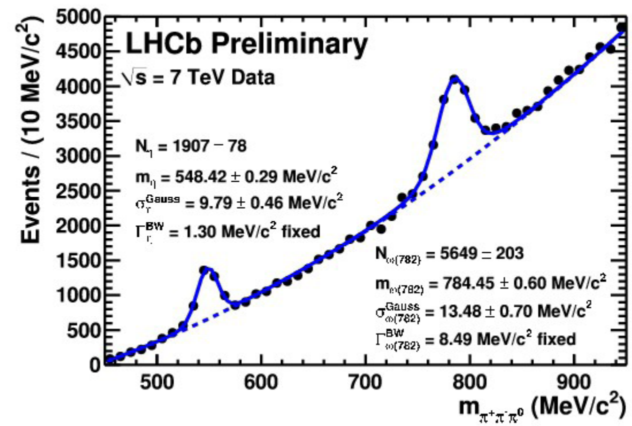
- **Tracking:**
  - excellent momentum resolution for invariant mass resolution, rejection of combinatorial backgrounds

Tracking efficiency vs p_T



- **Calorimeters:**
  - trigger on hadronic decay channels
  - reconstruction of final states with e, γ, π^0

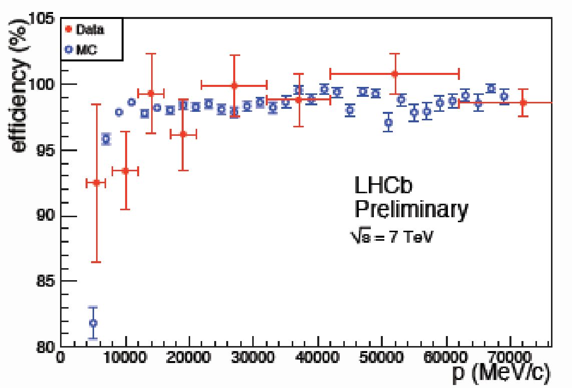
$\eta,\omega \to \pi^+\pi^-\pi^0$



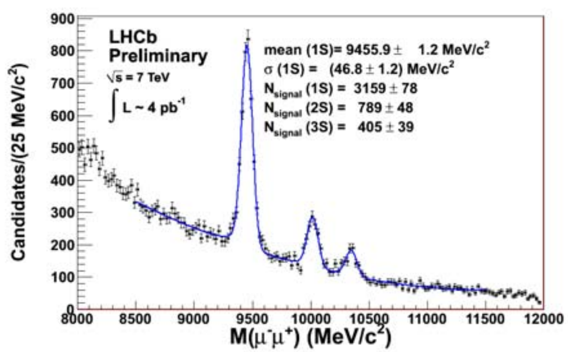
Vertexing, tracking and PID (II)

- **Muon identification:**
  - Extrapolate tracks to muon system and obtain associated hits

Muon ID efficiency vs mom.

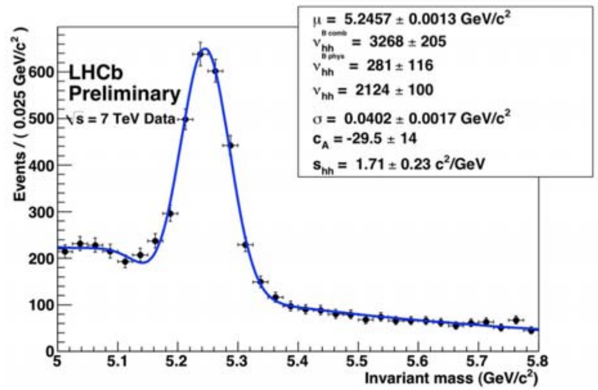


Y(1s),(2s),(3s) → $\mu^+\mu^-$



- **RICH**
  - K/π identification very important for separation of B decays with identical topology, as B→hh

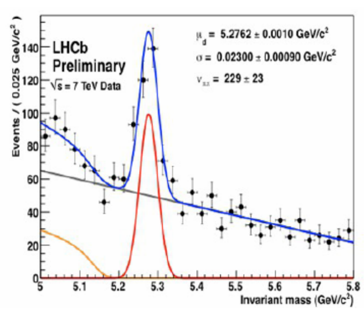
no PID, π mass assumed for both decay particles

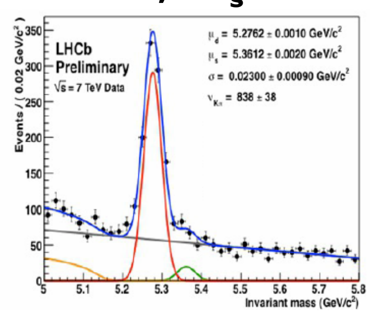


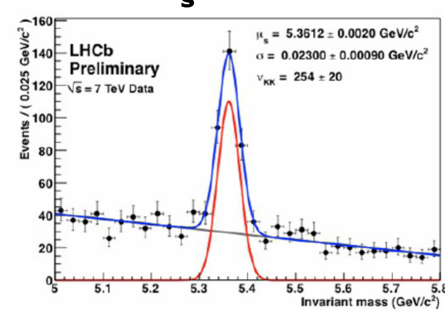
B→hh

apply PID cuts

$B^0 \to \pi^+\pi^-$ **$B^0 \to K^\pm\pi^\pm$, $B^0_s \to K^\pm\pi^\pm$** **$B^0_s \to K^+K^-$**



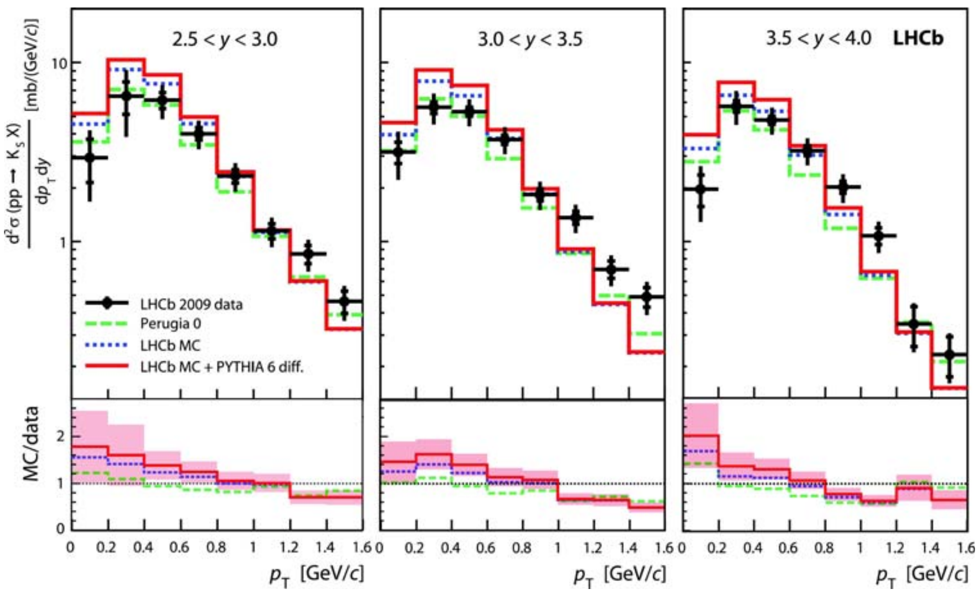




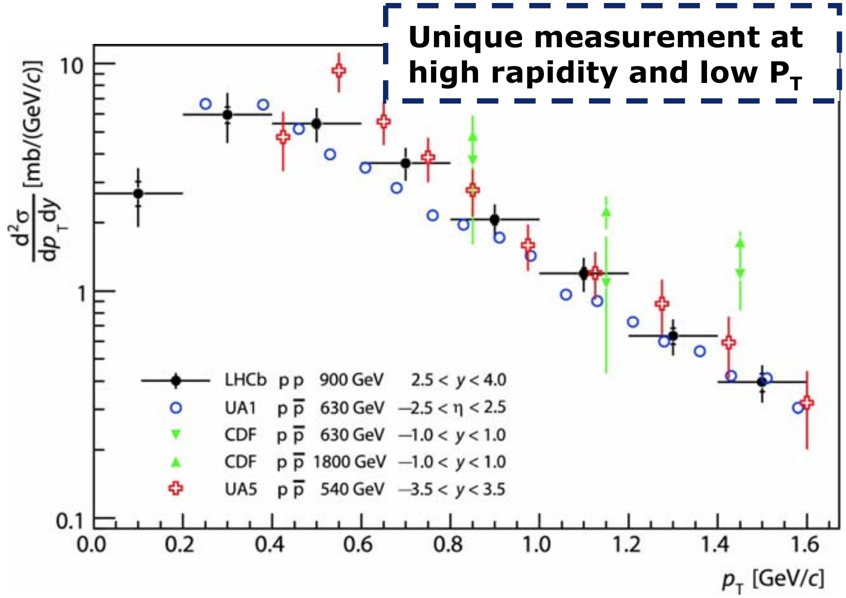
Early physics results

K_S production cross section

- First measurement for LHCb with 2009 run data ($\sqrt{s}=0.9$ *TeV*)
  - $K_S \rightarrow \pi^+\pi^-$ selection based on tracking and impact parameters



K_s production differential cross section vs p_T
(in bins of rapidity)



K_s production differential cross section vs p_T
(comparison with other experiments)

- First LHCb publication: *Phys. Lett. B 693 (2010) 69-80*

$b\bar{b}$ production cross section

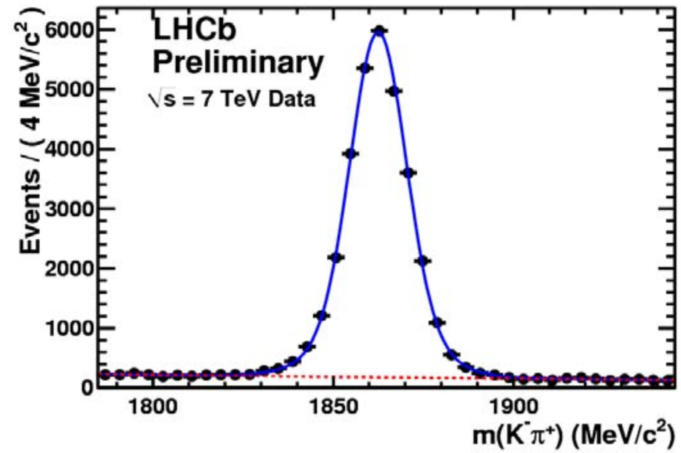
- Obtained with the decay **$B^0 \rightarrow D^0 \mu^- \nu X^+$**
  - reconstruct $D^0 \rightarrow K^- \pi^+$ decay mode
  - reconstruct $D^0\mu^-$ pairs from a common vertex, and D^0 from B by large impact parameter
  - use wrong-sign $D^0\mu^+$ pairs to estimate background

- Measured **$\sigma(pp \rightarrow b\bar{b}X)$**

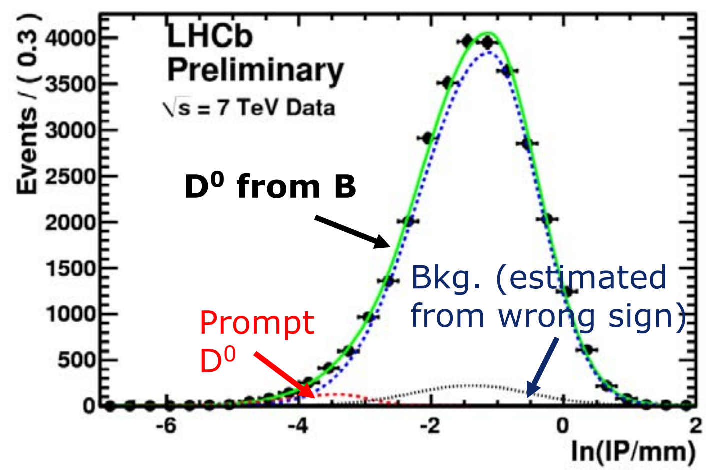
	Within LHCb acceptance (2<η<6)	Total (estimated with Pythia to full phase space)
σ (μb)	75 ± 5.4 ± 13	284 ± 20 ± 49

~in agreement with MC used in sensitivity studies (~250 μb).

- Second LHCb publication: *Phys. Lett. B 694 (2010) 209*



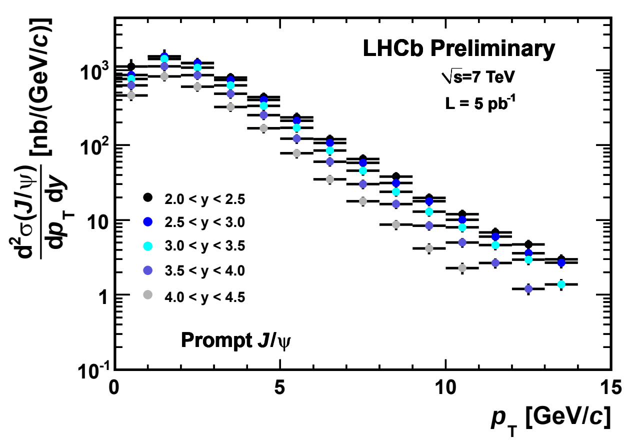
Mass of K⁻π⁺ pairs making a good vertex with a μ⁻

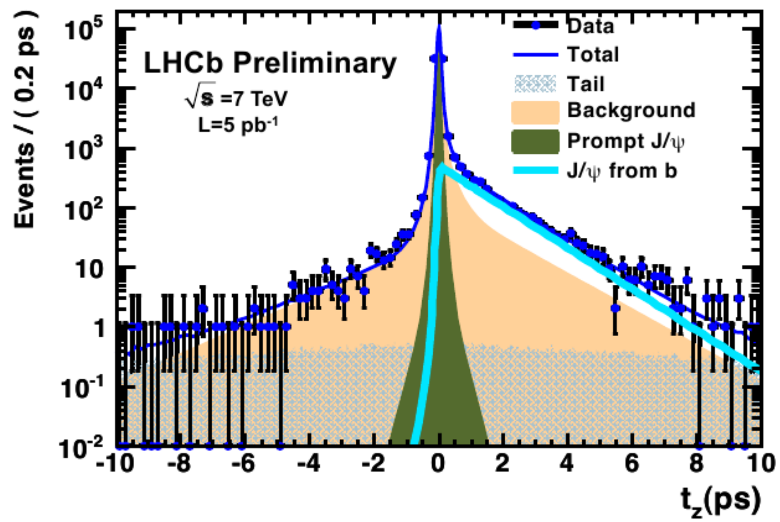


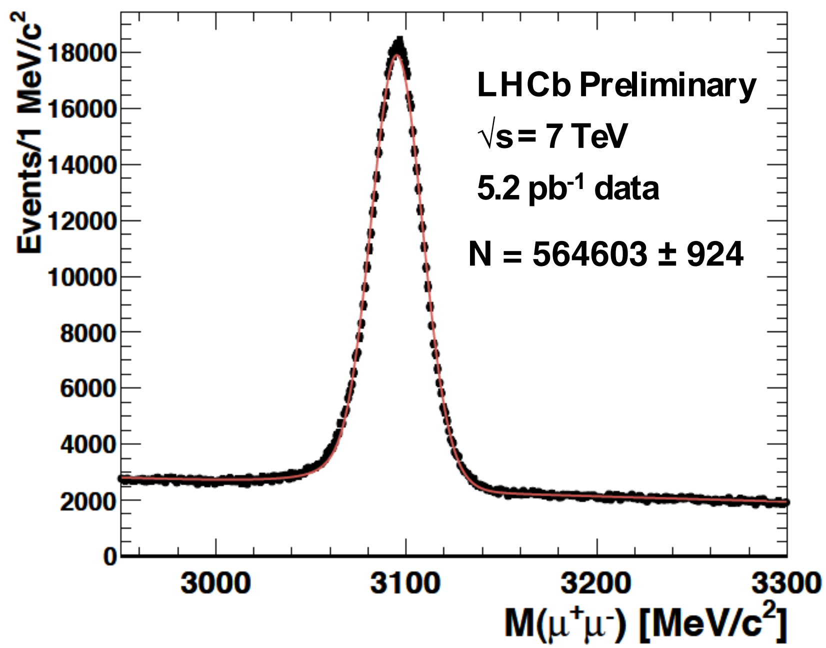
IP of K⁻π⁺ pairs making a good vertex with a μ⁻

Prompt J/Ψ and b→J/ΨX

- Use distribution of "pseudo proper time", t_z, to identify J/Ψ from b
  - Can measure **prompt and "from b" production cross sections**!
- For **prompt production**, measurement uncertainties dominated by unknown J/Ψ polarization, will eventually be measured.
  - **Prompt J/Ψ differential cross section:**





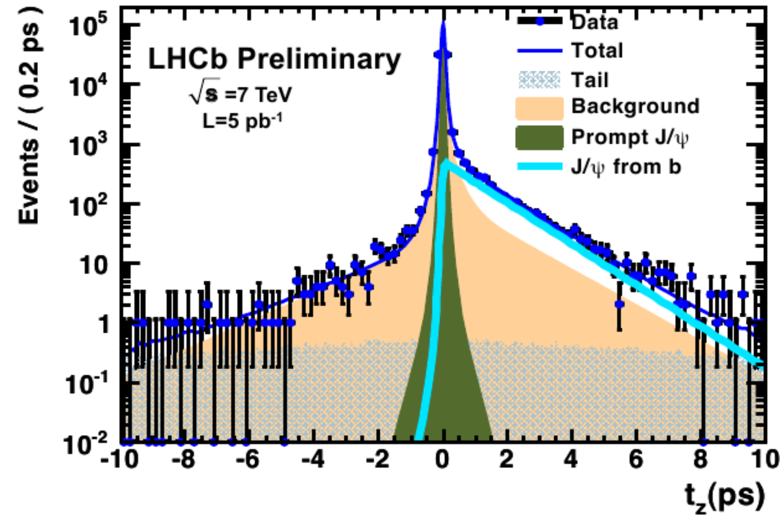


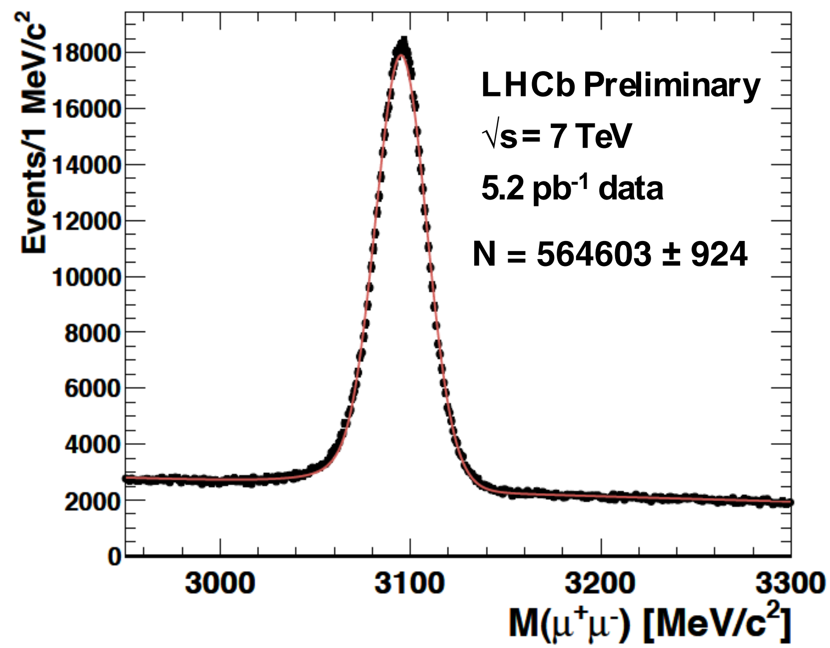
Prompt J/Ψ and b→J/ΨX

- Use distribution of "pseudo proper time", t_z, to identify J/Ψ from b
  - Can measure **prompt and "from b" production cross sections**!
- For **J/Ψ from b**, measurement can be use to obtain the bb production cross section.
  - **$\sigma(pp \to b\bar{b}X)$**:

	Within LHCb acceptance (2<η<6)	Total (estimated with Pythia to full phase space)
σ (μb)	1.16 ± 0.01 ± 0.17	295 ± 4 ± 48

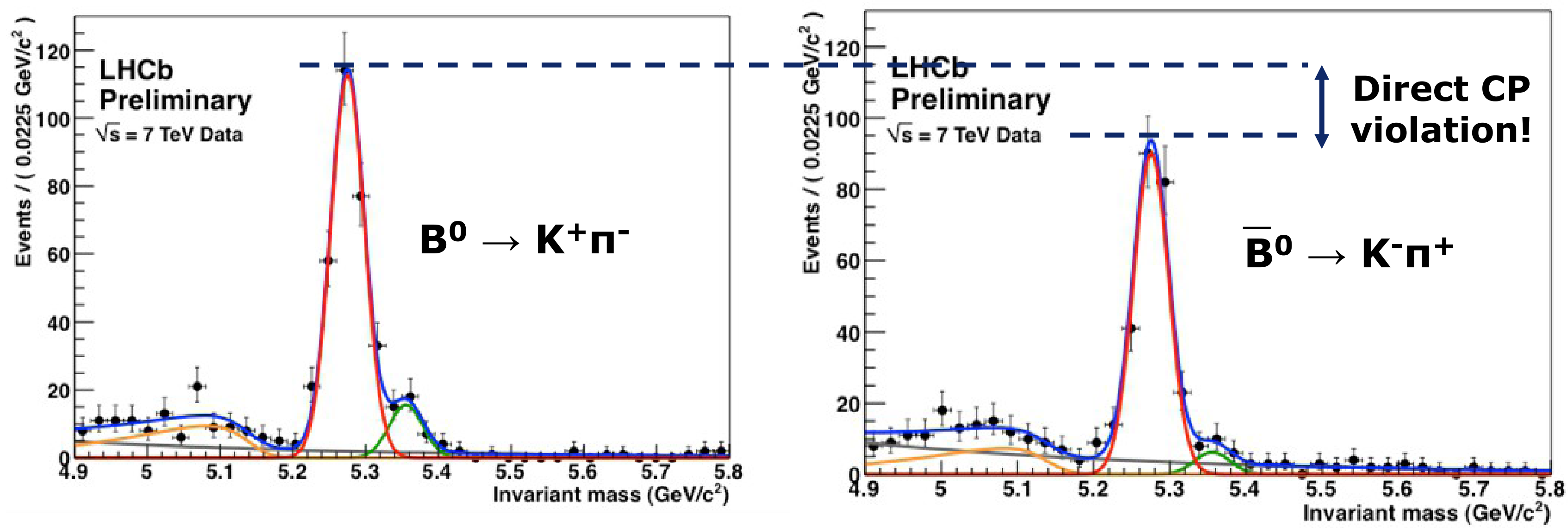
  - In agrement with measured in published result (σ= 284 ± 20 ± 49 μb)





CP Violation in $B \to K\pi$

- Separate into B^0 and $\bar{B}^0$ using particle identification
  - Raw asymmetry shows CP Violation at 3σ
  - **Preliminary!** Small corrections from production and detector asymmetry still to be corrected!

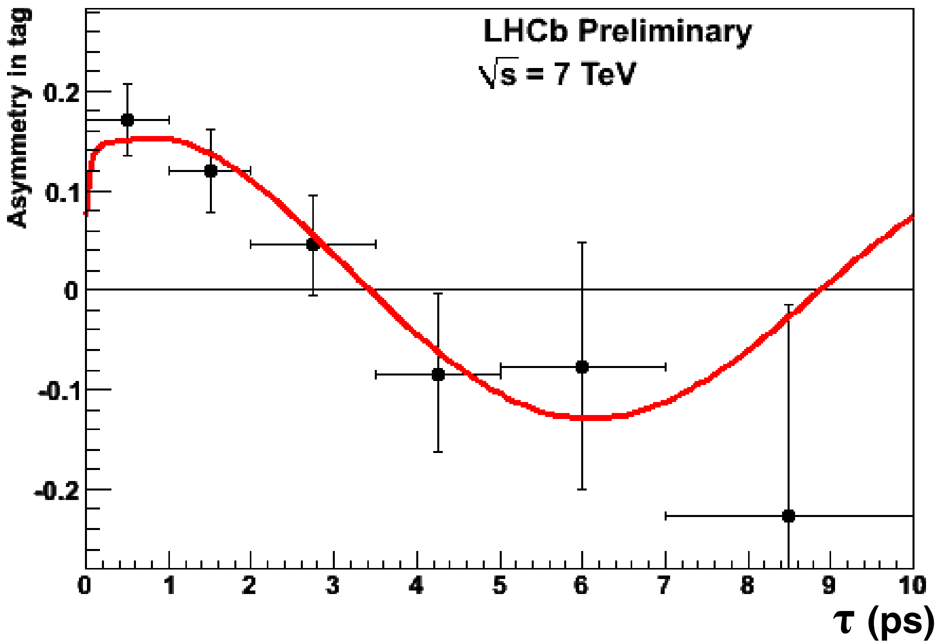


$$A_{CP} \equiv \frac{\Gamma\left(\bar{B}^0 \to K^-\pi^+\right) - \Gamma\left(B^0 \to K^+\pi^-\right)}{\Gamma\left(\bar{B}^0 \to K^-\pi^+\right) + \Gamma\left(B^0 \to K^+\pi^-\right)}$$

A_{CP} Belle	-0.094 ± 0.020
A_{CP} Babar	-0.107 ± 0.019

$B^0\overline{B}^0$ oscillation

- First oscillation signal seen in:
  $\mathbf{B^0 \rightarrow D^{*-}(D^0\pi^-)\mu^+\nu_\mu}$



b tagging is crucial for several LHCb analysis!

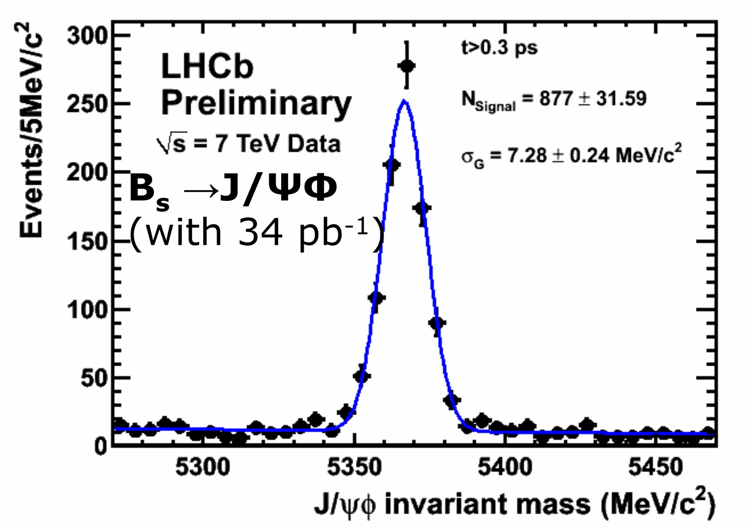
- lepton tag and opposite-side Kaon tags used to **tag initial flavour of B meson**
- performance currently at ~50 % of expectation, calibration on data ongoing

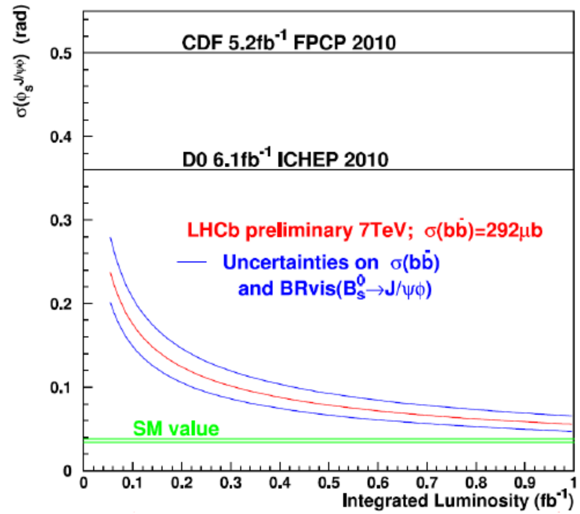
Prospects for next year

Φ_s from $B_s \to J/\Psi\Phi$

- B_s-$\bar{B}_s$ mixing phase Φ_s: small in the Standard Model, can be enhanced by New Physics. Some hints from CDF/D0 but not significant
- *Golden channel* for Φ_s: **time - dependent CP asymmetry in $B_s \to J/\Psi\Phi$**.
  - requires **large statistics** for angular analysis to separate CP even and CP odd final states. Fit to B_s differential decays rates with **9 physics and 15 detectors parameters**
  - requires **flavour tagging** to tag initial B_s
  - requires **excellent proper-time resolution** to resolve fast B_s-$\bar{B}_s$ oscillation (Δm_s = 17.8 ps^{-1}). Currently ~60 fs where 38 fs expected (we are trying to understand why)

35k selected events expected per fb^{-1}
(CDF: 7k events with 5.2 fb^{-1})

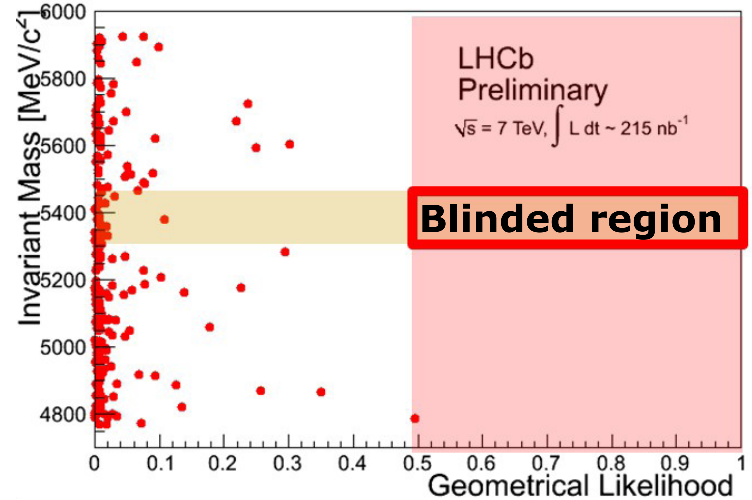


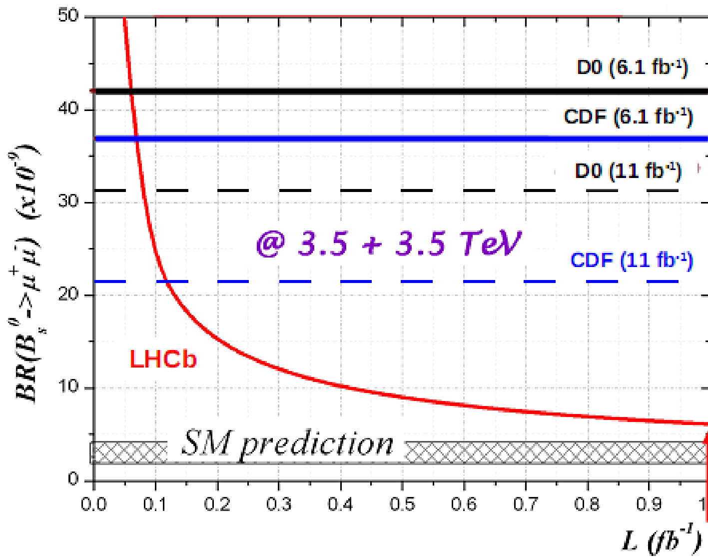


LHCb prospects

BR($B_s \rightarrow \mu^+\mu^-$)

- FCNC very suppresed in the SM:
  - **BR($B_s \rightarrow \mu\mu$) = $(3.35 \pm 0.32)\cdot 10^{-9}$**
- Current experimental upper limit (CDF) ~10 times higher!
- NP can modify the BR from smaller SM up to current experimental upper limit → **Any measured value will constraint NP searches!**
- Analysis with 3-dimensions binned likelihood:
  - Invariant mass of muon pair
  - Muon identification
  - Geometrical Likelihood or GL (combines lifetime, IP, DOCA…)
- Use control channels to calibrate likelihoods from data and normalize: $B^+ \rightarrow J/\Psi K^+$, $B \rightarrow hh$, $B_s \rightarrow J/\Psi\Phi$





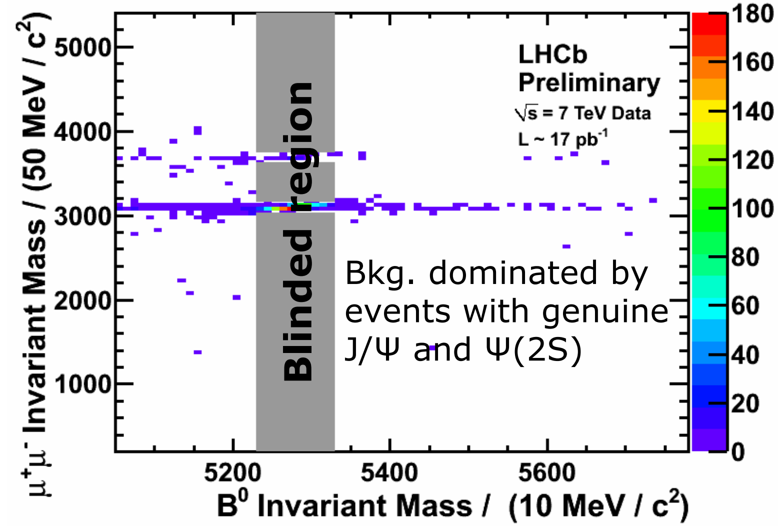
LHCb exclusion limit

A_{FB} in $B^0 \to K^*\mu^+\mu^-$

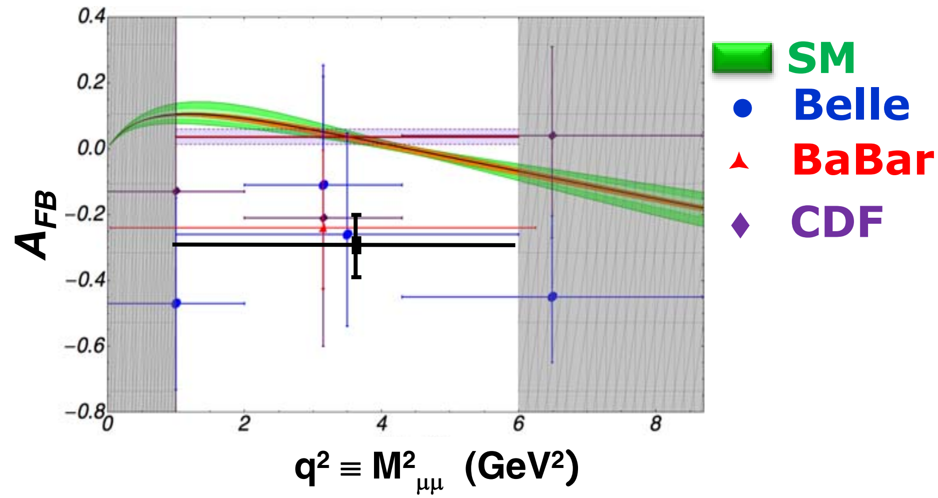
- The γ/Z penguin diagram of $B^0 \to K^*\mu^+\mu^-$ introduces a **forward-backward asymmetry** in the B rest frame. This asymmetry **can be affected by NP**!
  - Study the forward-backward asymmetry vs the q^2 of the muons
  - **Yields:**

LHCb (expected per fb^{-1})	**1.4 k**
Belle (85% of data)	250
Babar (75% of data)	100
CDF (4.4 fb^{-1})	100

- Most critical part of the analysis: understand biases from acceptance, trigger, selection, PID.

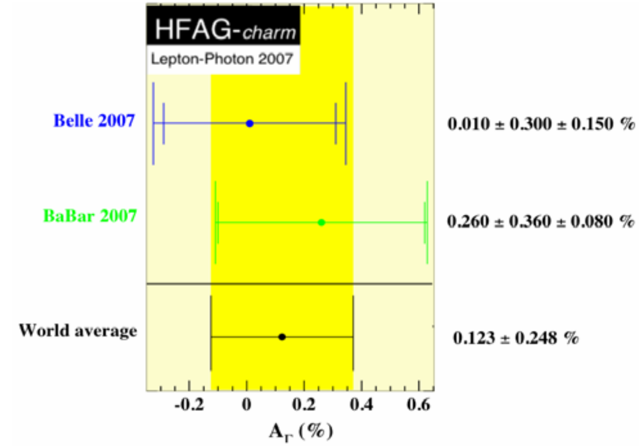


LHCb prospects with 1fb^{-1}
(asuming Belle central value)



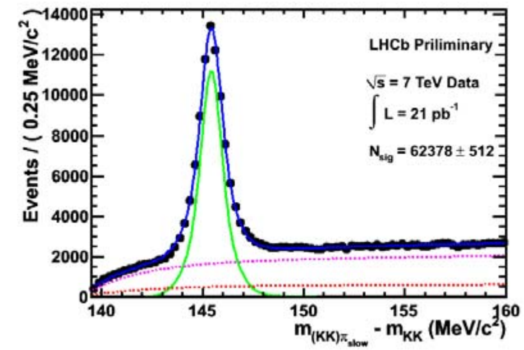
Prospects in the charm sector

- The charm sector has **high sensitivity** to New Physics. LHCb is ideal for charm physics: we have already **overtaken B factories yields**!

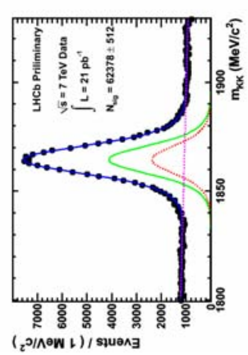


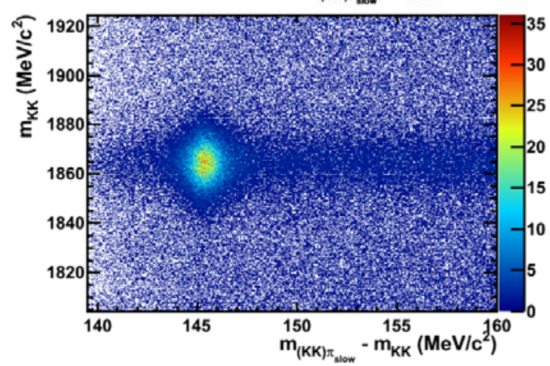
- Physics example: **CP violation in D^0-$\overline{D}^0$ lifetime assymetries**:

$$A_\Gamma \equiv \frac{\tau(\overline{D}^0 \longrightarrow K^+K^-) - \tau(D^0 \longrightarrow K^+K^-)}{\tau(\overline{D}^0 \longrightarrow K^+K^-) + \tau(D^0 \longrightarrow K^+K^-)}$$



  - Use slow pion from $D^{*+} \rightarrow D^0\pi^+$ to tag D^0 flavour
  - **Competitive measurement** expected very soon!





and the best is yet to come…

Conclusions

Conclusions

- LHCb designed to search for **new physics through the loops** → access higher energy scales and do it earlier!
- **The experiment is working really fine**. Data approaching MC in tracking, vertexing and PID.
- **First physics results** obtained in 2010 showing the potential of LHCb (e.g. $b\bar{b}$ cross section measurement, observation of direct CP violation).
- 2011 will be (hopefully) our year. **We have a very nice chance of seeing new physics** (if it is there!)
  - Φ_s from $B_s \to J/\Psi\Phi$
  - $BR(B_s \to \mu^+\mu^-)$

Backup

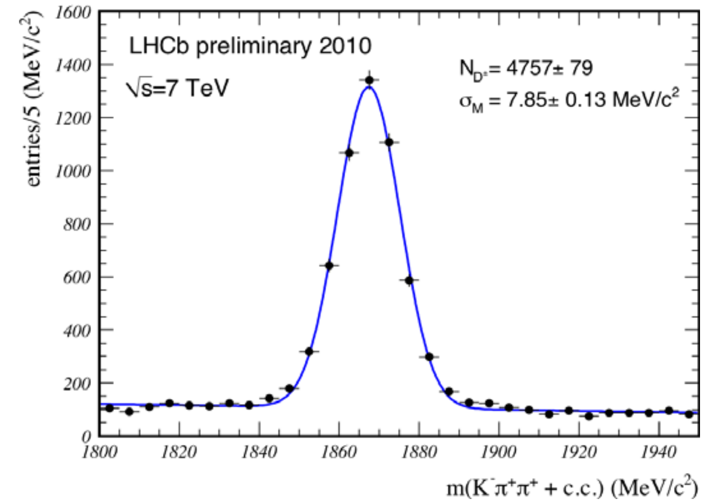
Open charm cross sections

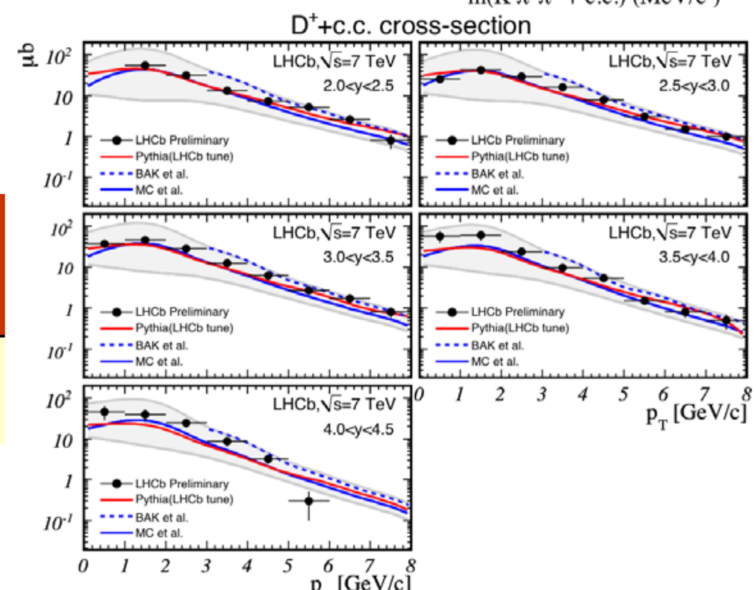
- Measure differential cross sections in bins of pseudo-rapidity up to η=4.5 and transverse momentum down to p_T=0
  - large uncertainties on theory predictions
  - use impact parameter to reject "D from B"
  - separate measurements for D^0, D^{*+}, D^+ , D_s^+
- Use published fragmentation fractions to calculate also open charm cross-section for each analysis and take least-squares fit, **measured $\sigma(pp \rightarrow c\bar{c})$**

	Within LHCb acceptance (2<η<6)	Total (estimated with Pythia to full phase space)
σ (mb)	1.23 ± 0.19	6.10 ± 0.93

~in agreement with expected
$\sigma(pp \rightarrow c\bar{c}) \sim 20 \times \sigma(pp \rightarrow b\bar{b})$

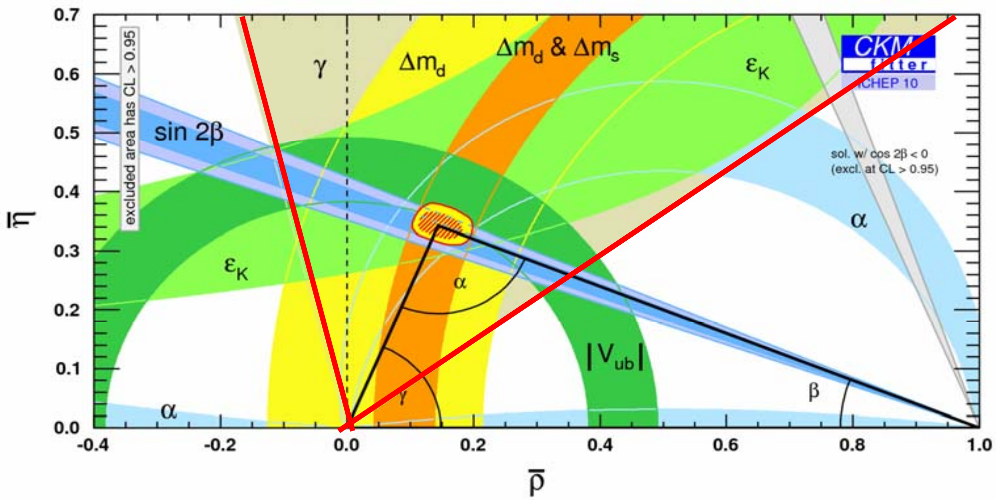
Example: $D^+ \rightarrow K^-\pi^+\pi^+$



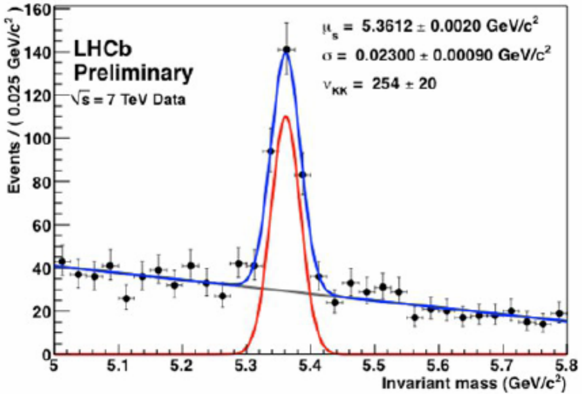


γ angle

- Direct measurement of γ has large errors $(70^{+21}_{-25})^{o}$ compared with indirect measurements



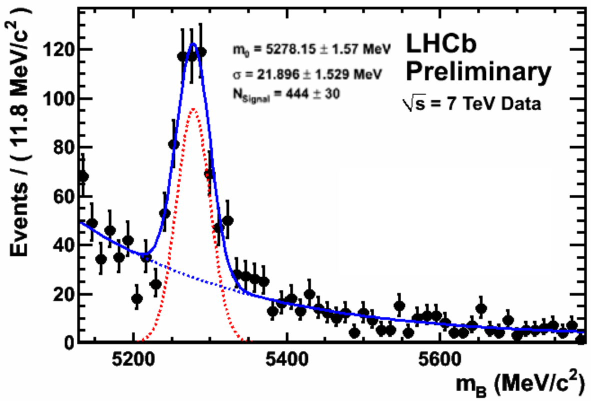
γ from loops: $B^0_s \rightarrow K^+K^-$



- LHCb **expected sensitivities**:

	From trees	From loops
σ (γ) (1 fb⁻¹)	8º	-
σ (γ) (2 fb⁻¹)	-	7º
σ (γ) (~10 fb⁻¹)	1.2º - 2.7º	

γ from trees: $B^\pm \rightarrow D^0(K\pi)K^\pm$



a_{fs} in LHCb

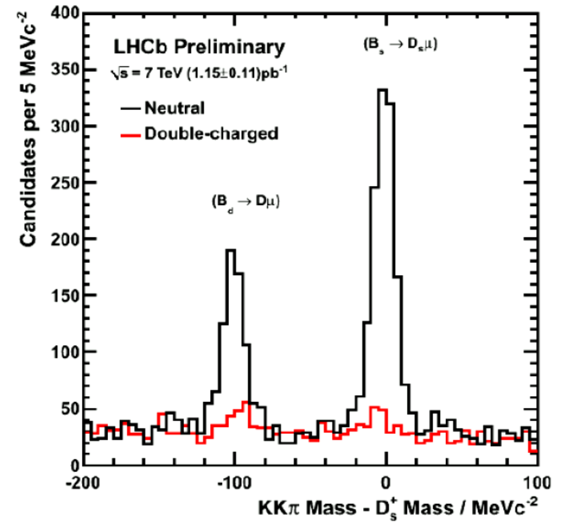
- **Inclusive method** (similar to the one of D0) **is difficult at LHCb** due to the ~10^{-2} production asymmetry in pp collisions and control of detector asymmetry
- **Subtraction method** in semi-leptonic modes used instead
  - **$B^0 \rightarrow D^- \mu^+ \nu$ and $B^0_s \rightarrow D_s^- \mu^+ \nu$** (same final state $K^+K^-\pi^-\mu^+$)
  - Measure the difference between B^0_s and B^0, substract non time dependent part of A^d_{fs} and A^s_{fs}:

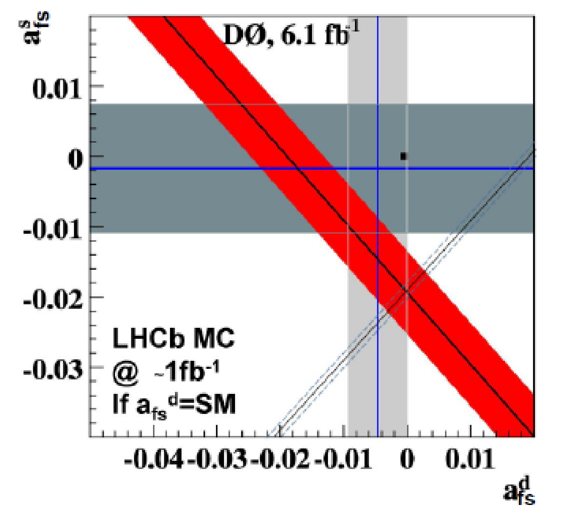
$$\Delta A_{fs}^{s,d} \sim \frac{a_{fs}^s - a_{fs}^d}{2}$$

→ difference suppresses production asymmetry

→ same final state suppresses detector biases

KKπ, D_s^+ mass difference





LHCb: MC stat. uncertainty only