First results with charmless two-body B-decays at LHCb and future prospects

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on behalf of the LHCb Collaboration

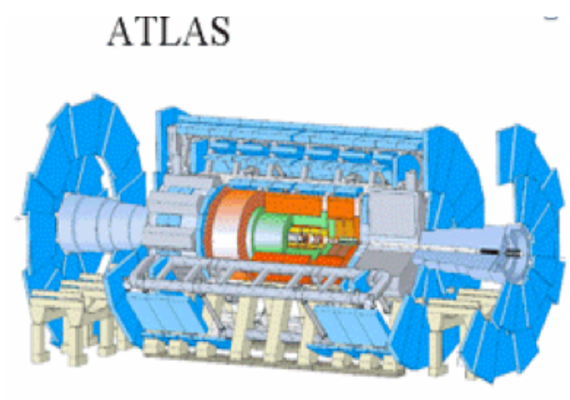
Joint EP/PP/LPCC seminar
CERN, 22 February 2011

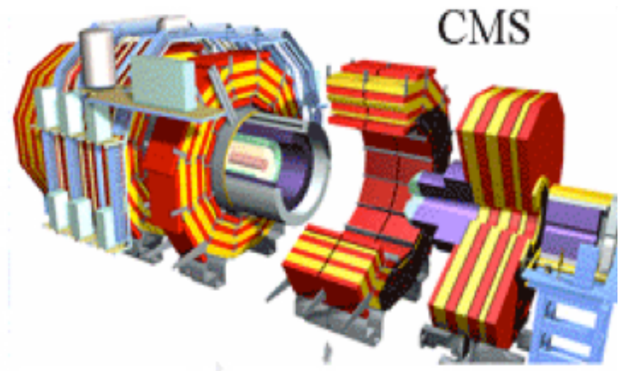
LHCb experiment and 2010 data taking

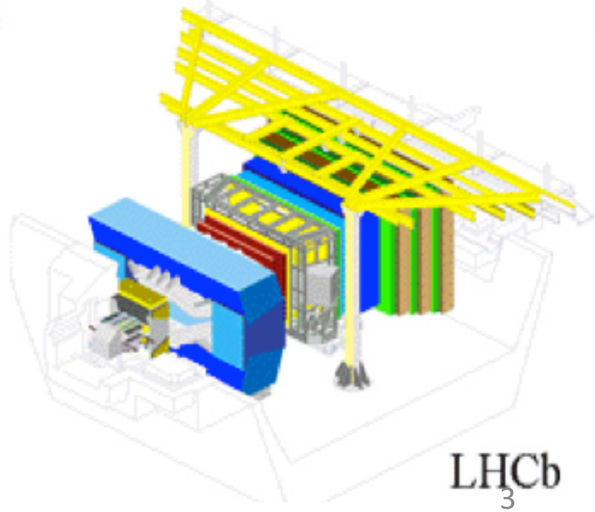
LHCb mission

- LHC experiments aim to discover New Physics beyond the Standard Model
- **Direct searches** of new particles produced at the LHC energy are performed by general purpose detectors: **Atlas and CMS**
- **LHCb** is specialized for **indirect searches**
  - Look for discrepancies in Standard Model predictions due to the presence of new heavy particles in loop diagrams

  - Perform **precision measurements of CP violation** and rare decays of heavy hadrons
  - **Beauty (and Charm) decays are an ideal place to search for such effects**





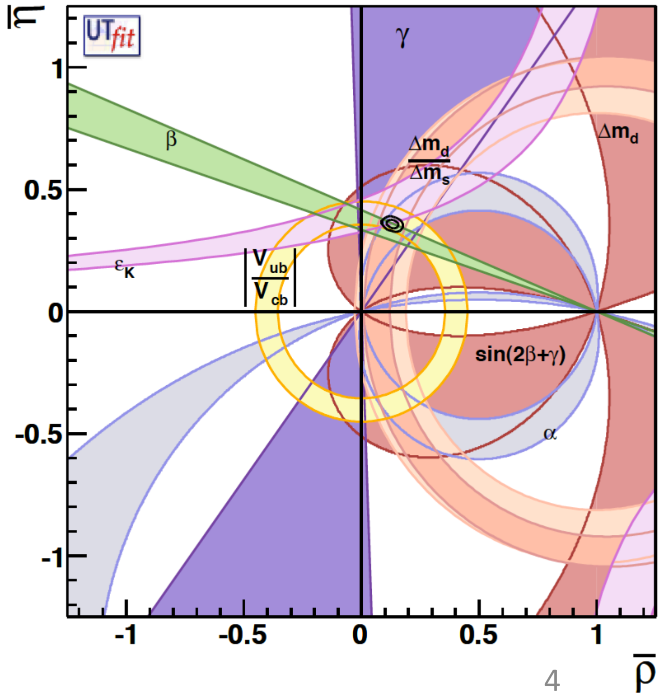


Sometimes indirect searches pay good dividends…


A third family of quarks is necessary to accomodate CP violation in weak interactions

M. Kobayashi and T. Maskawa
CP Violation in the Renormalizable Theory of Weak Interaction
Prog. Theor. Phys. **49** (1973) 652
Cited 6231 times

CP violation in B system at BaBar and Belle
B. Aubert *et al.*, Phys. Rev. Lett. **87** (2001) 091801
K. Abe *et al.*, Phys. Rev. Lett. **87** (2001) 091802



2008: Nobel prize in physics

"for the discovery of the origin of the broken symmetry which predicts the existence of at least three families of quarks in nature"

…but don't forget Prof. Cabibbo

I have some favoured decays…

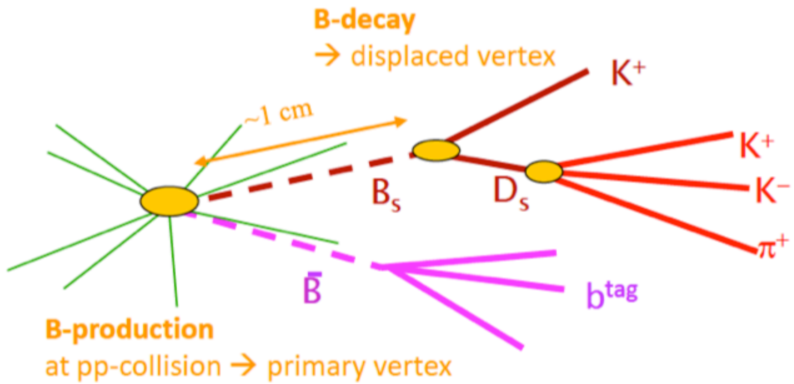
N. Cabibbo
Unitary Symmetry and Leptonic Decays
Phys. Rev. Lett. **10** (1963) 531
Cited 3399 times

2010: Dirac Medal

for his **"fundamental contributions to the understanding of weak interactions and other aspects of theoretical physics"**

LHC as hadronic B factory

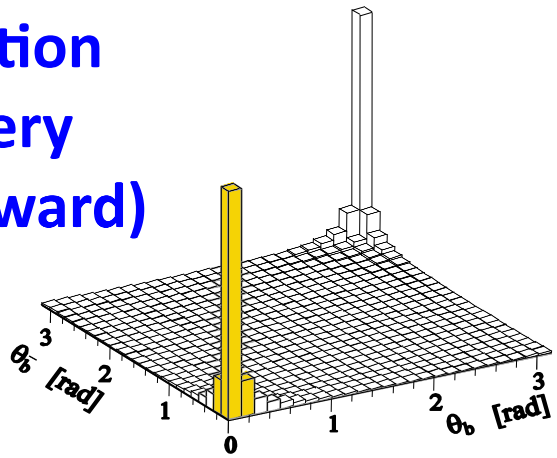
- **Large cross-section** for producing beauty hadrons
  - About 10^{12} B-hadron pairs produced per year at the full LHC energy
  - In contrast to e^+e^- B factories, **all B-hadron species** are produced in the primary proton-proton collisions
    - B^+, B^0, B_s, B_c, Λ_b, …
- B hadrons have **large distance of flight** → about 1 cm
  - Important signature to disentangle B decays from huge combinatorial background arising from primary p-p vertices
  - Crucial for B_s time-dependent CP violation studies to resolve fast oscillations

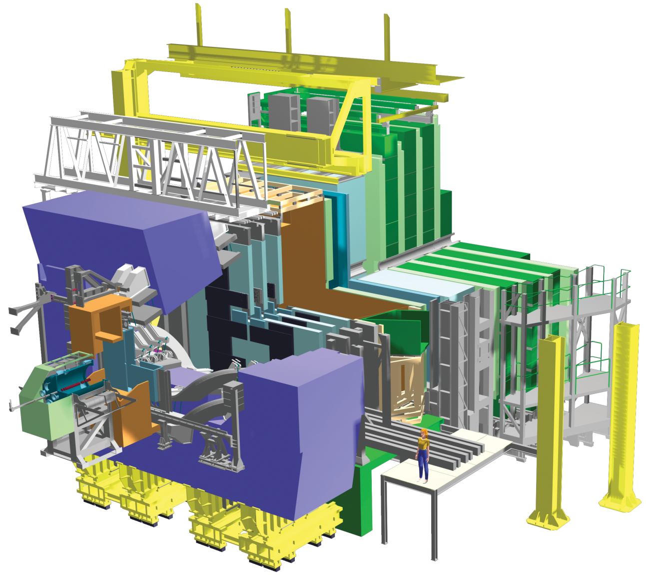


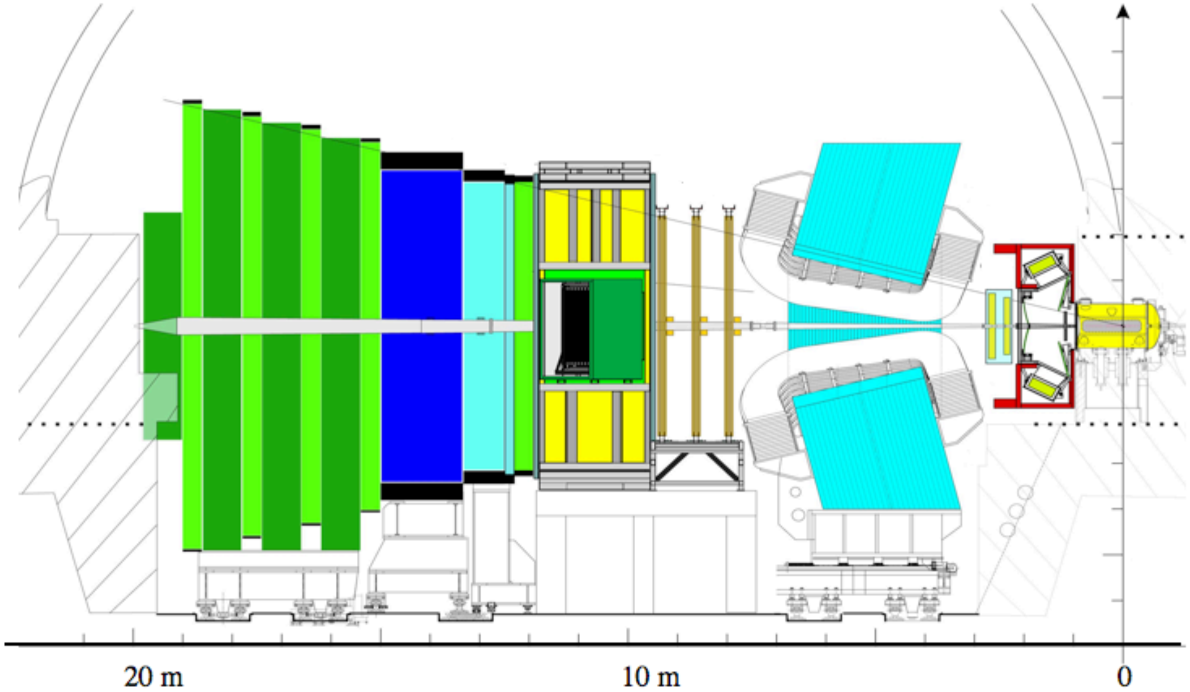
- Beauty cross-section is less than 1% of total inelastic cross-section and relevant B decays have branching fractions at the level of 10^{-5} or less
  - **Highly selective trigger is needed**

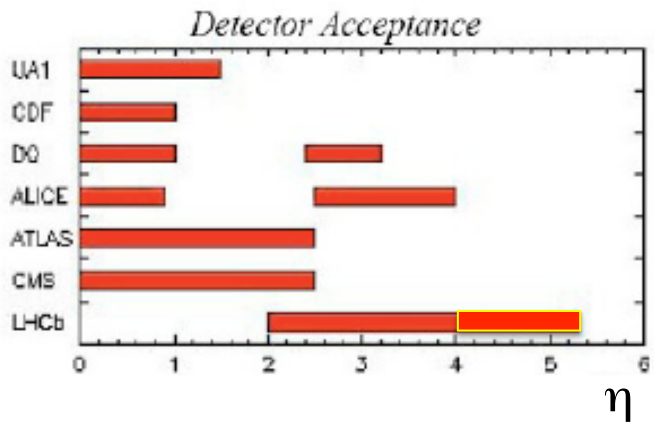
The LHCb detector is a forward spectrometer

B-hadron production happens in the very forward (or backward) region

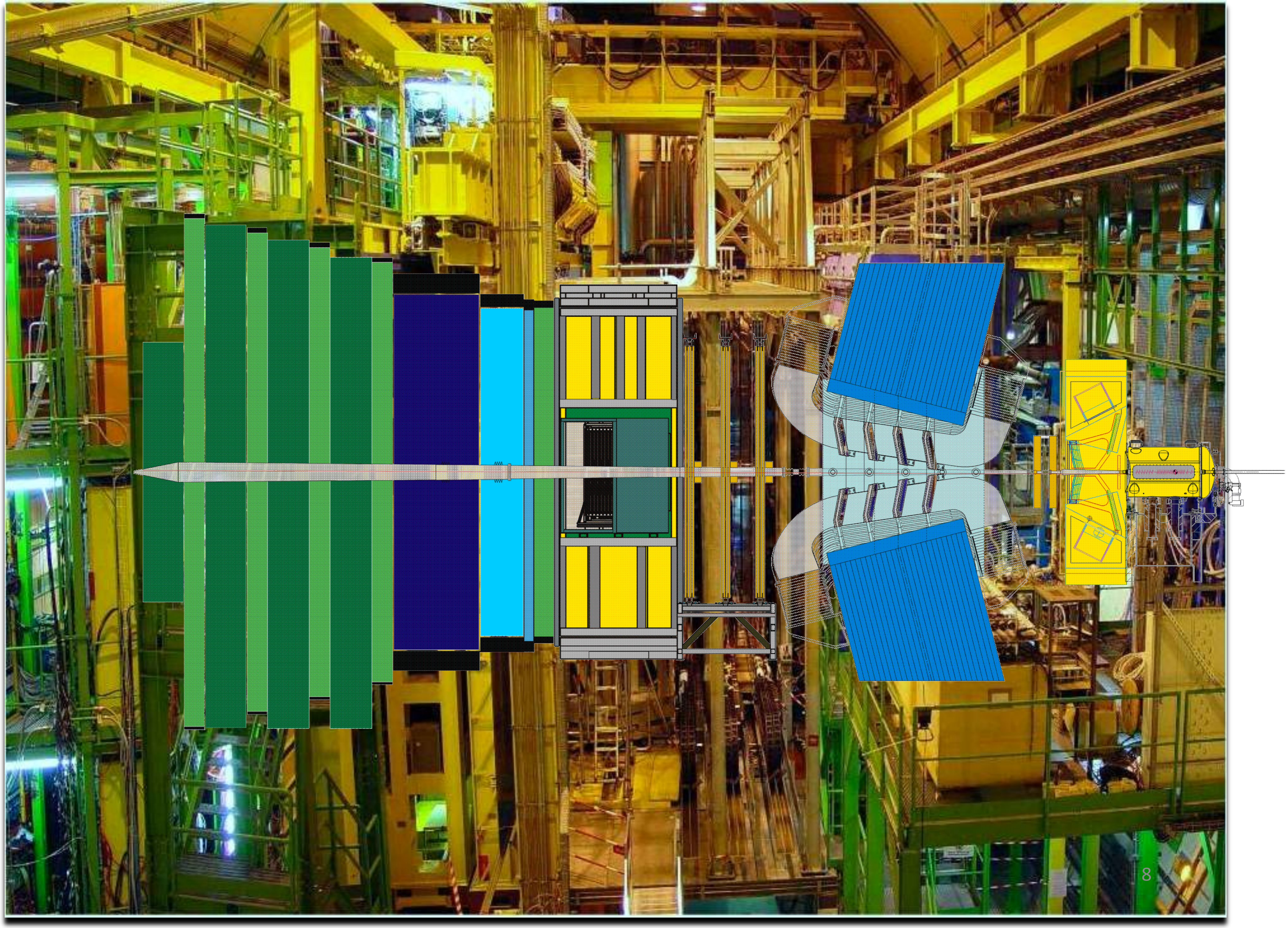




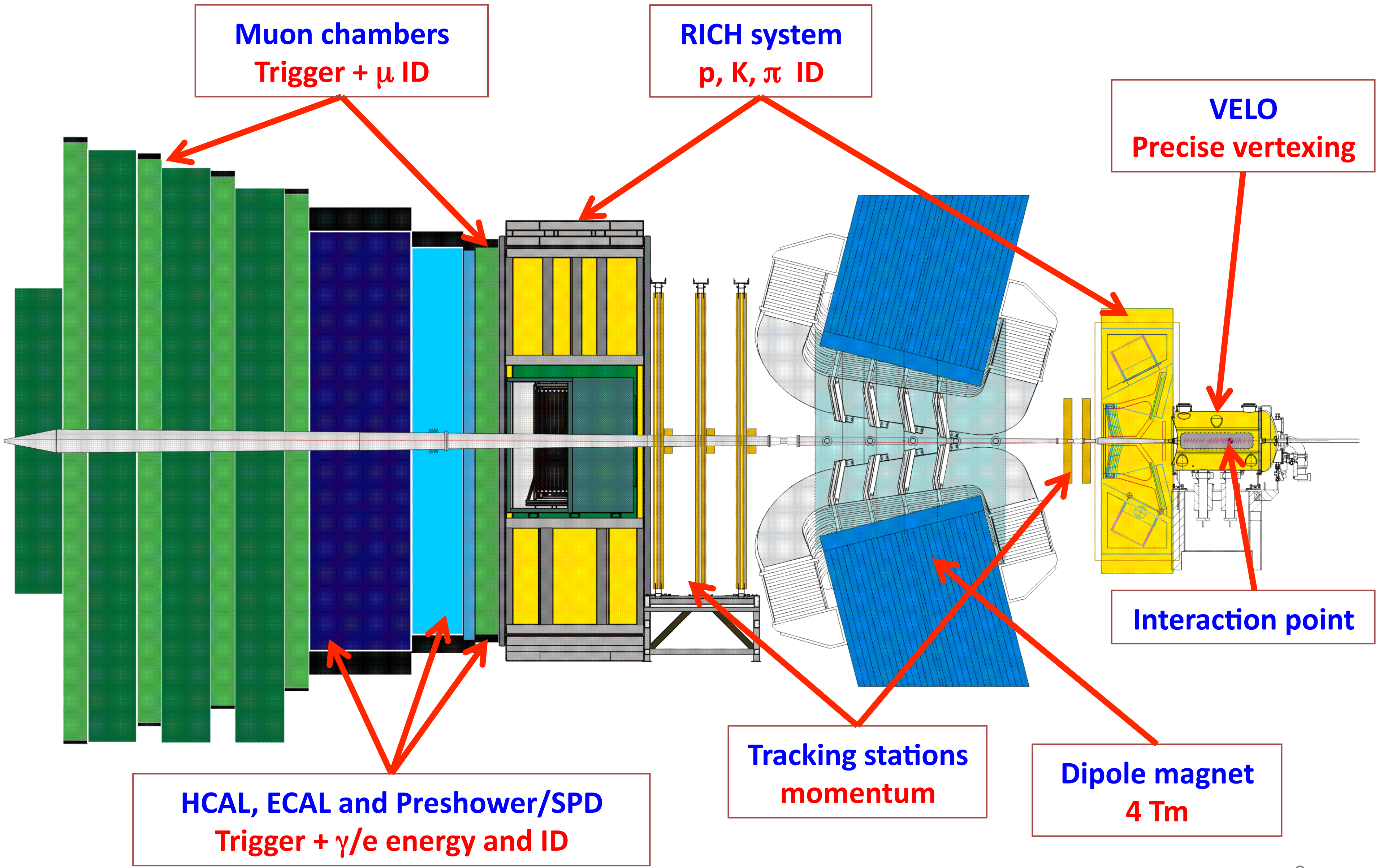




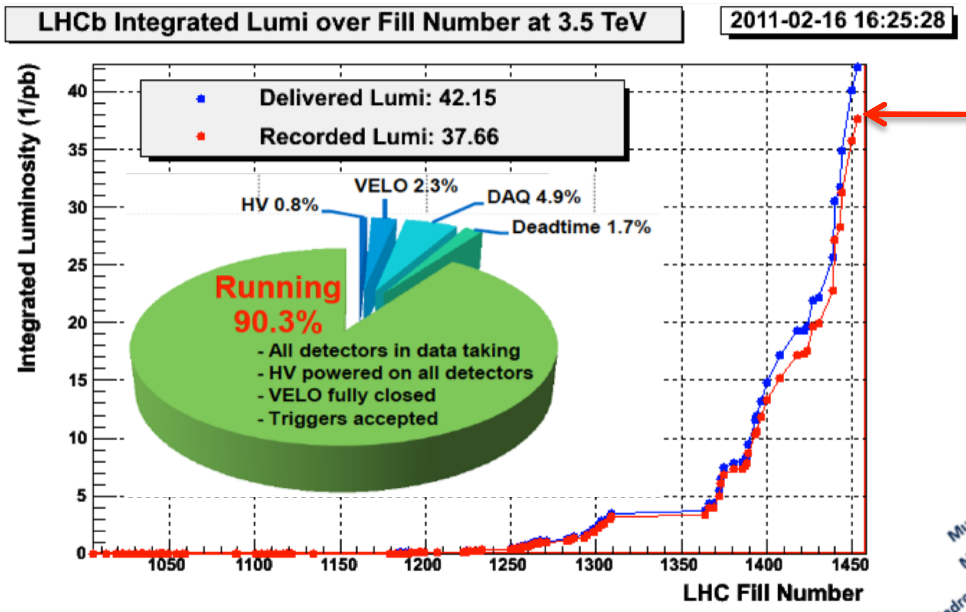
Unique acceptance capabilities



LHCb sub-detectors



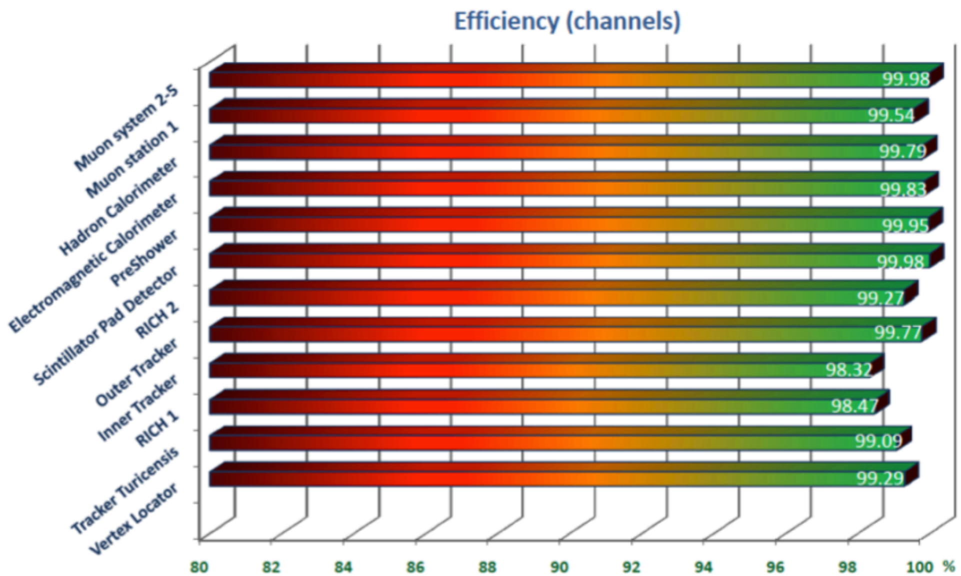
Performance of 2010 data taking



Recorded approximately 37 pb^{-1} in 2010 run with all detectors fully operational

Data taking efficiency around 90% over the year

Largest part of data taken during last month of running

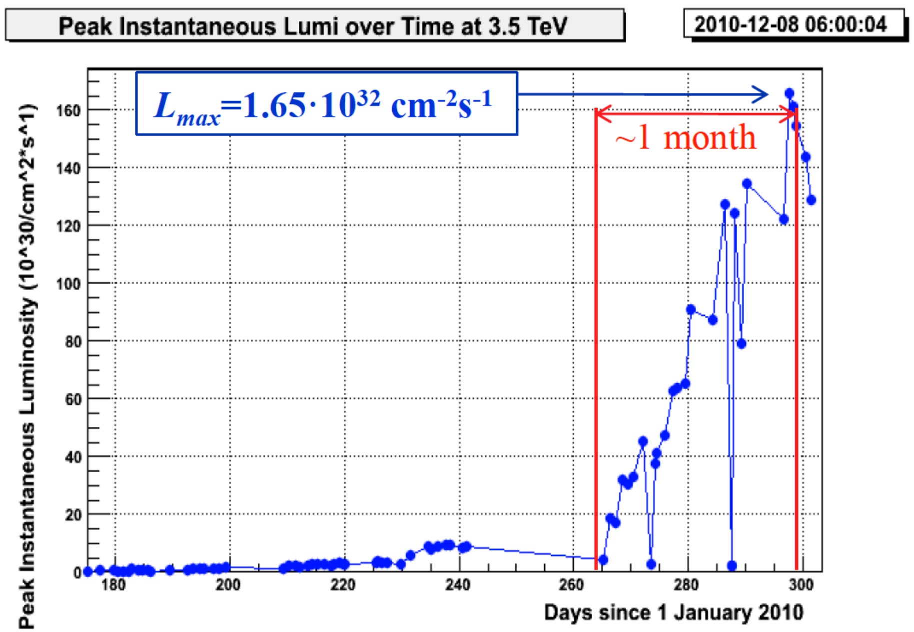


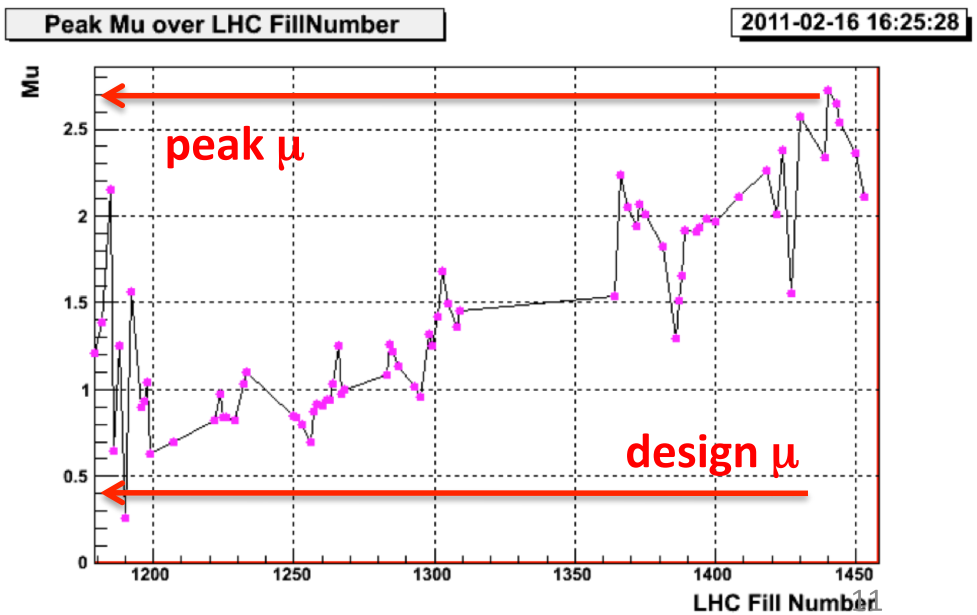
all sub-detectors >99% efficient

2010 running conditions

- Running conditions foreseen in LHCb design
  - number of interacting bunches at IP8: $N_{bunches} = 2622$
  - average number of visible proton-proton collisions per bunch crossing: $\mu \sim 0.4$
  - Istantaneous luminosity: $\mathcal{L} = 2\text{x}10^{32}\ \text{cm}^{-2}\text{s}^{-1}$
- Real conditions in 2010 run
  - $N_{bunches}$ up to 344
  - μ up to 2.7
  - $\mathcal{L}$ up to $1.6\text{x}10^{32}\ \text{cm}^{-2}\text{s}^{-1}$

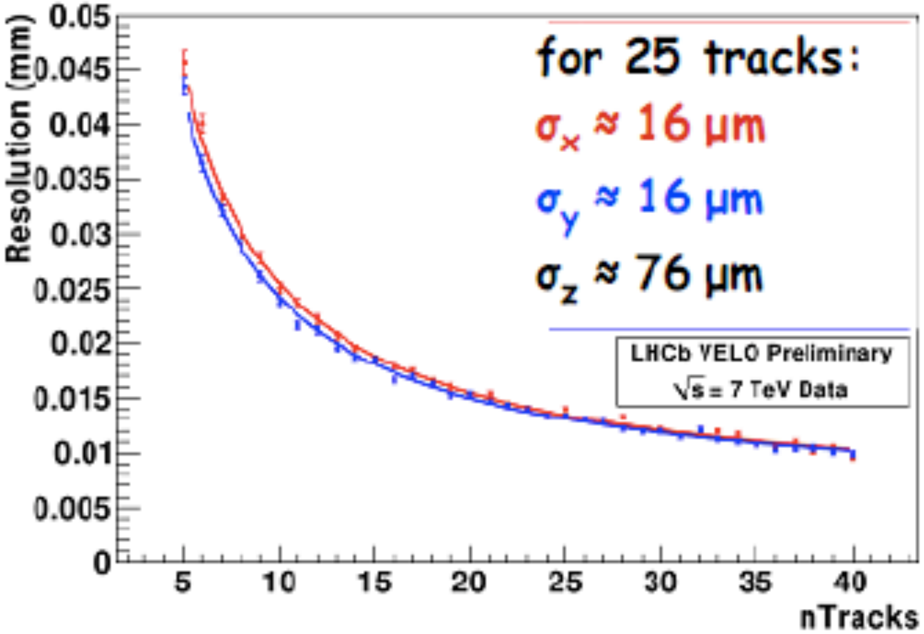
> 6 times than design!





Primary Vertex and Impact Parameter resolution

PV resolution evaluated in data using random splitting of the tracks in two halves and comparing vertices of equal multiplicity



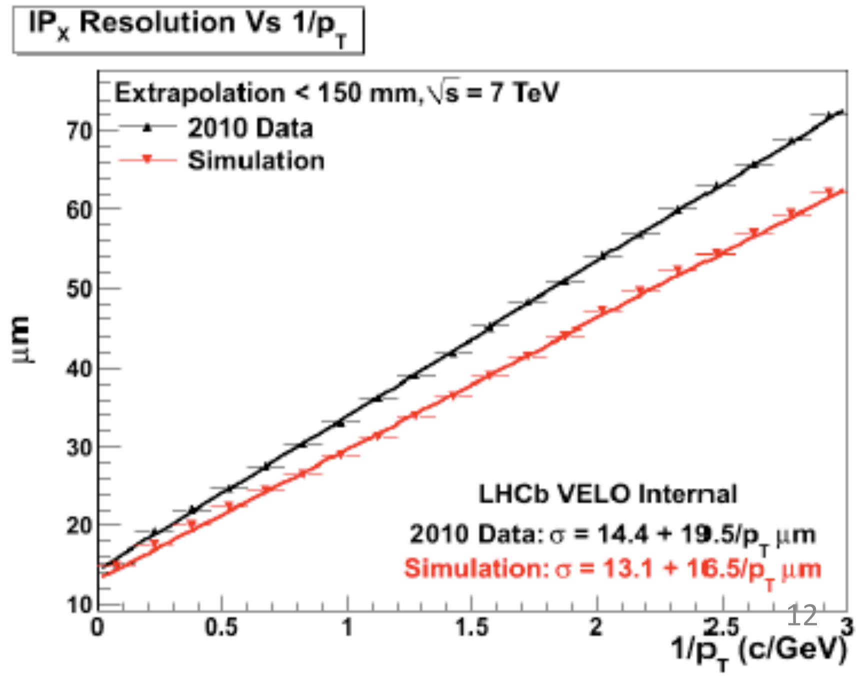
Resolution for PV with 25 tracks

Data: 16 μm for X and Y
76 μm for Z

MC: 11 μm for X and Y
60 μm for Z

IP resolution 15 μm for the highest p_T bins

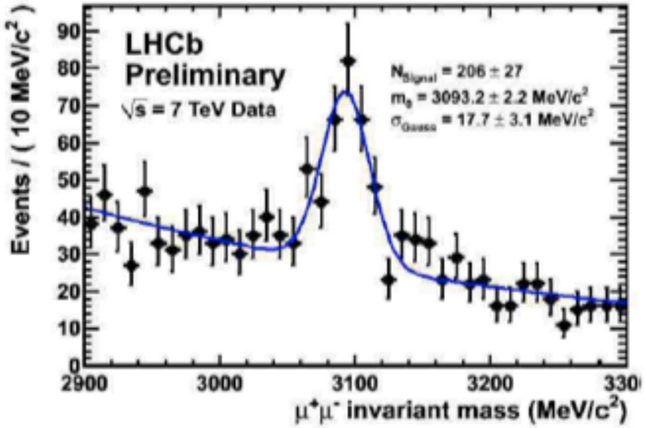
- slope determined by multiple scattering, not an alignment effect
- improvement of material description is ongoing



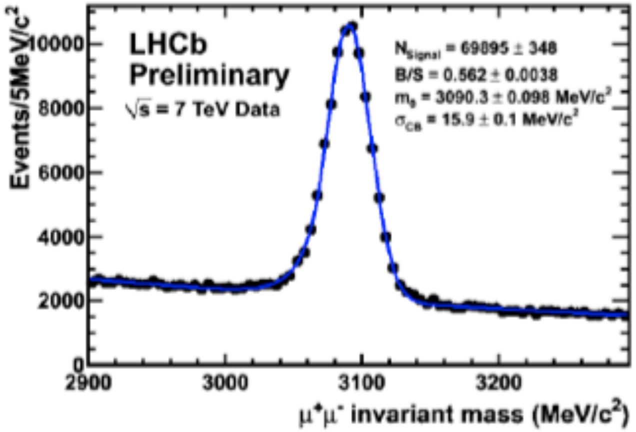
Mass resolution

Evolution of J/ψ → $\mu^+\mu^-$ mass resolution with time (MC ~ 12 MeV/c^2)

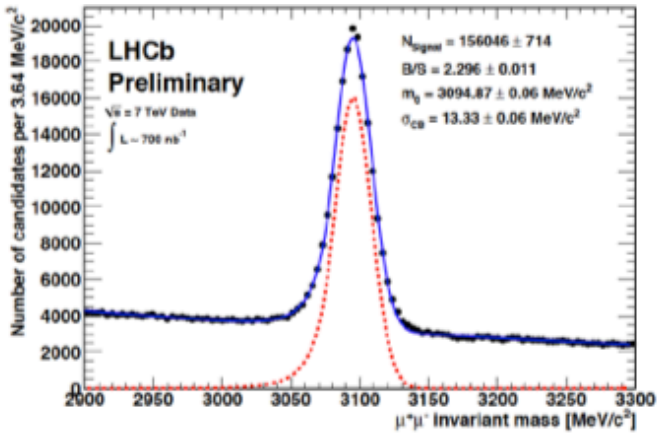
May: σ ~ 18 MeV/c^2



August: σ ~ 16 MeV/c^2

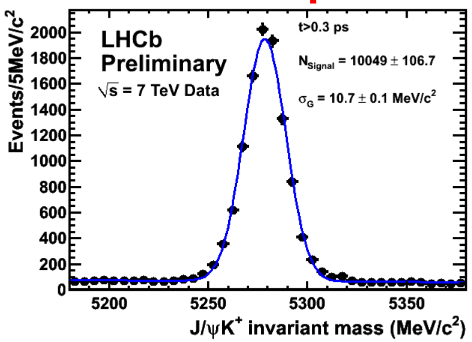


November: σ ~ 13 MeV/c^2



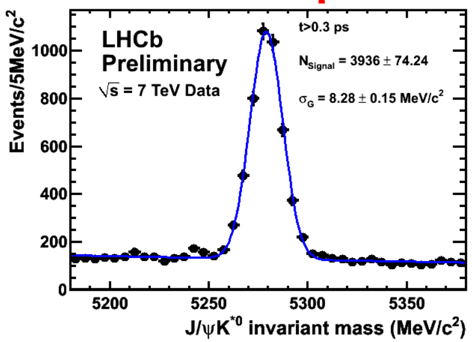
Different B hadron species in J/ψX final states

B^+ → $J/\psi K^+$



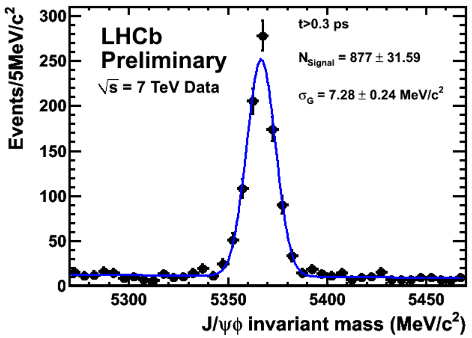
σ~11 MeV/c^2

B^0 → $J/\psi K^{*0}$



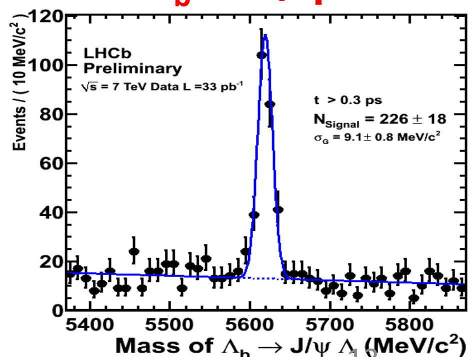
σ~8 MeV/c^2

B_s → $J/\psi\phi$



σ~7 MeV/c^2

Λ_b → $J/\psi\Lambda$

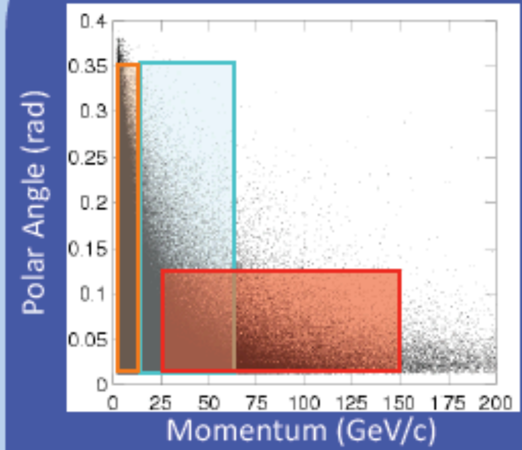


σ~9 MeV/c^2

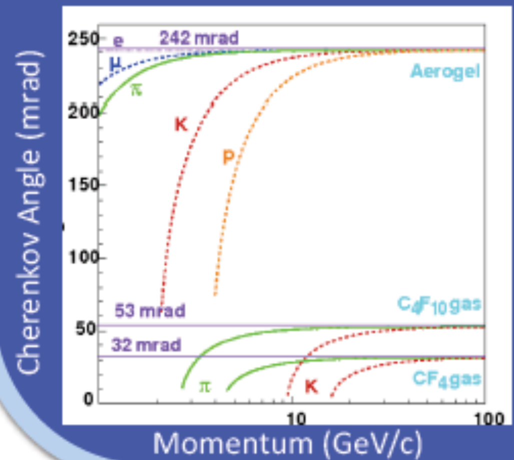
RICH particle identification

- To determine ID and mis-ID rated we need
  - pure sample of each particle type K/π/p
  - selected without use of any PID cut
- Exploit an array of standard candle decays
  - $K_s \rightarrow \pi^+\pi^-$
  - $\phi \rightarrow K^+K^-$
  - $\Lambda \rightarrow p\pi^-$
  - $D^{*+} \rightarrow D^0(K^-\pi^+)\pi^+$

- RICH unique to LHCb!

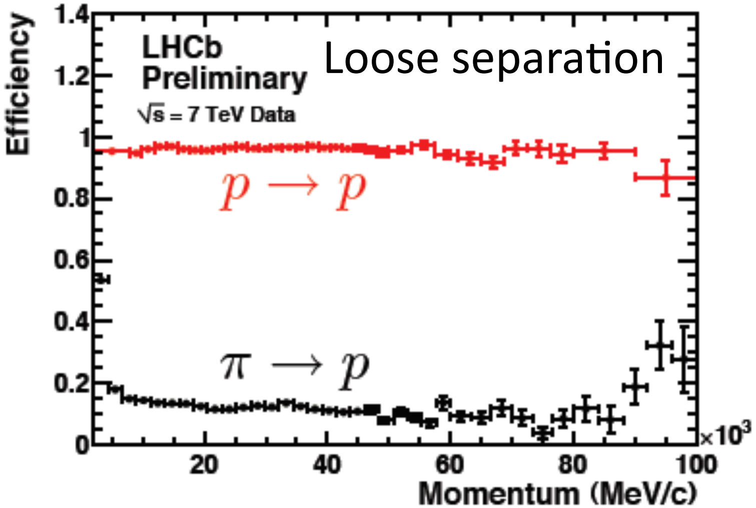


- Two detectors
- Three radiators
  - Silica Aerogel
  - C_4F_{10}
  - CF_4

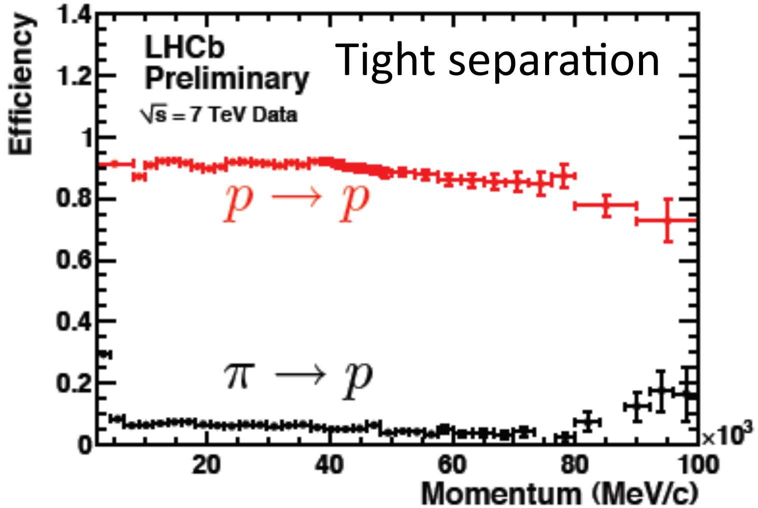


- Provides K/π separation between 2 – 100 GeV/c

$\Delta\log\mathcal{L}(p-\pi) > 0$

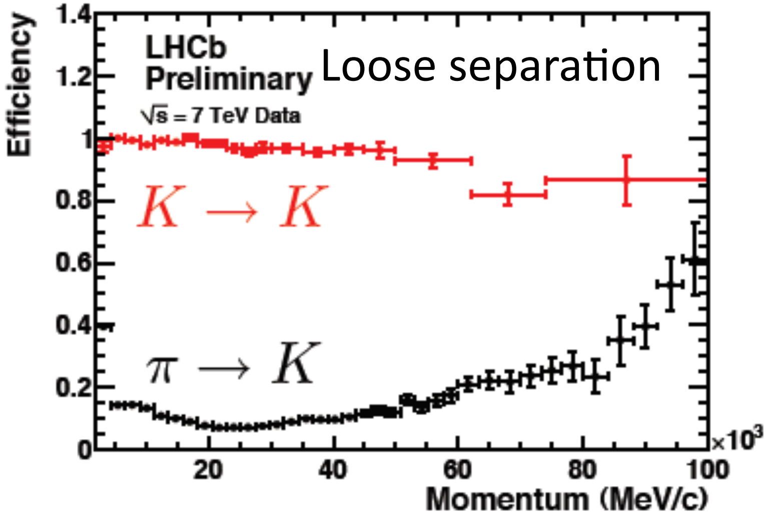


$\Delta\log\mathcal{L}(p-\pi) > 5$

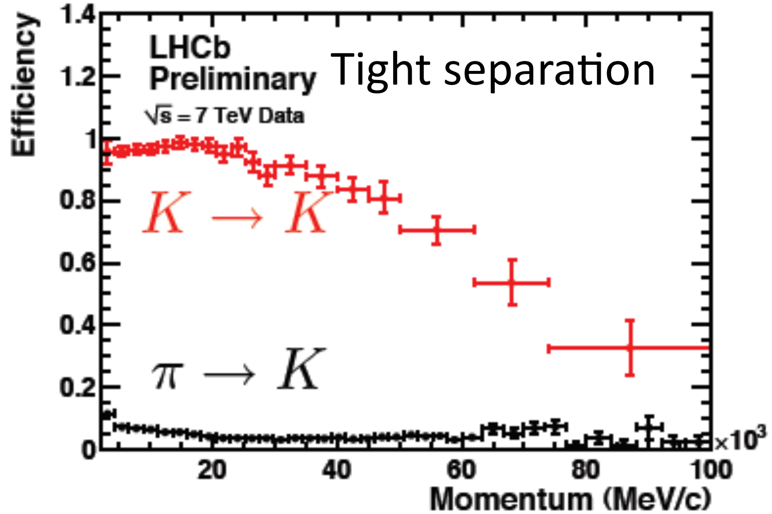


RICH proton-pion separation

$\Delta\log\mathcal{L}(K-\pi) > 0$



$\Delta\log\mathcal{L}(K-\pi) > 5$

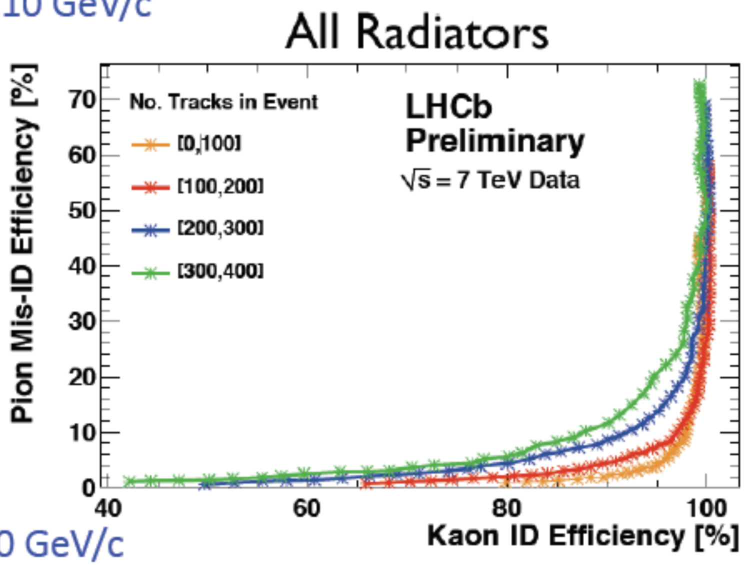


RICH kaon-pion separation

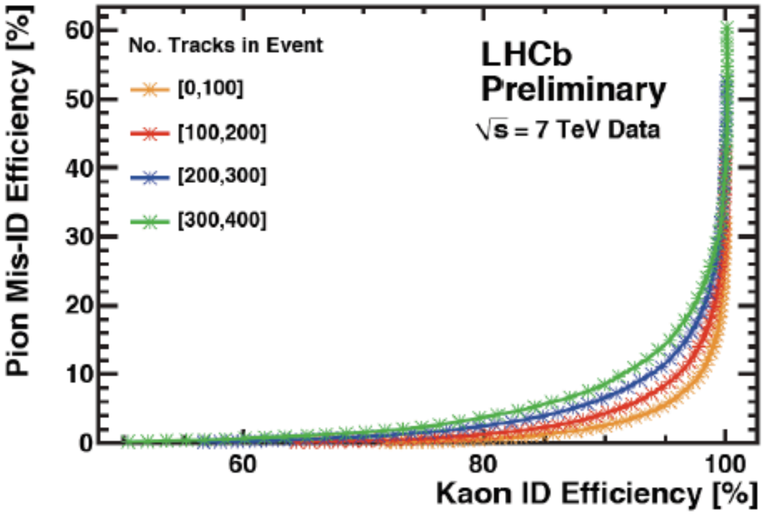
$\Delta\log\mathcal{L}$(i-j) = difference of the logarithms of likelihoods for i and j hypotheses

RICH PID robustness with increasing number of tracks per event

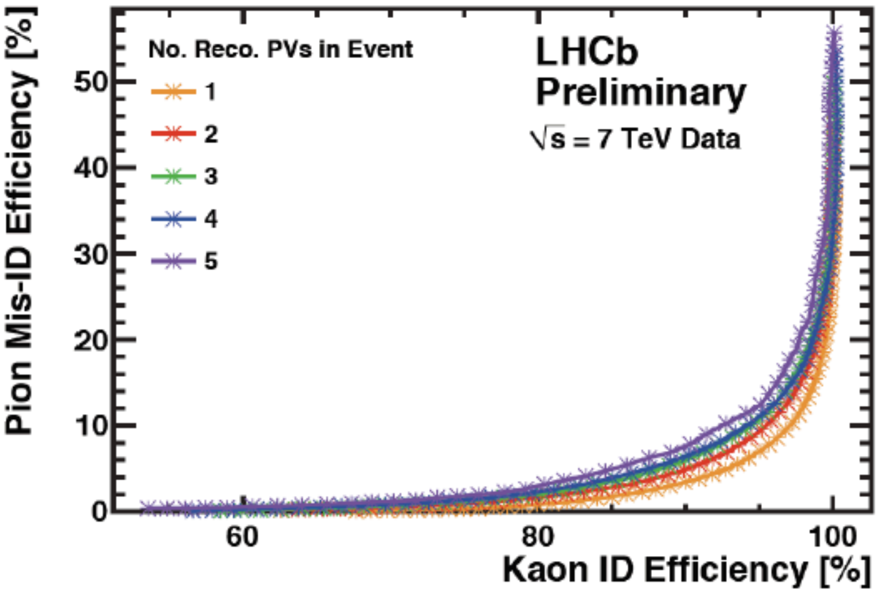
p<10 GeV/c



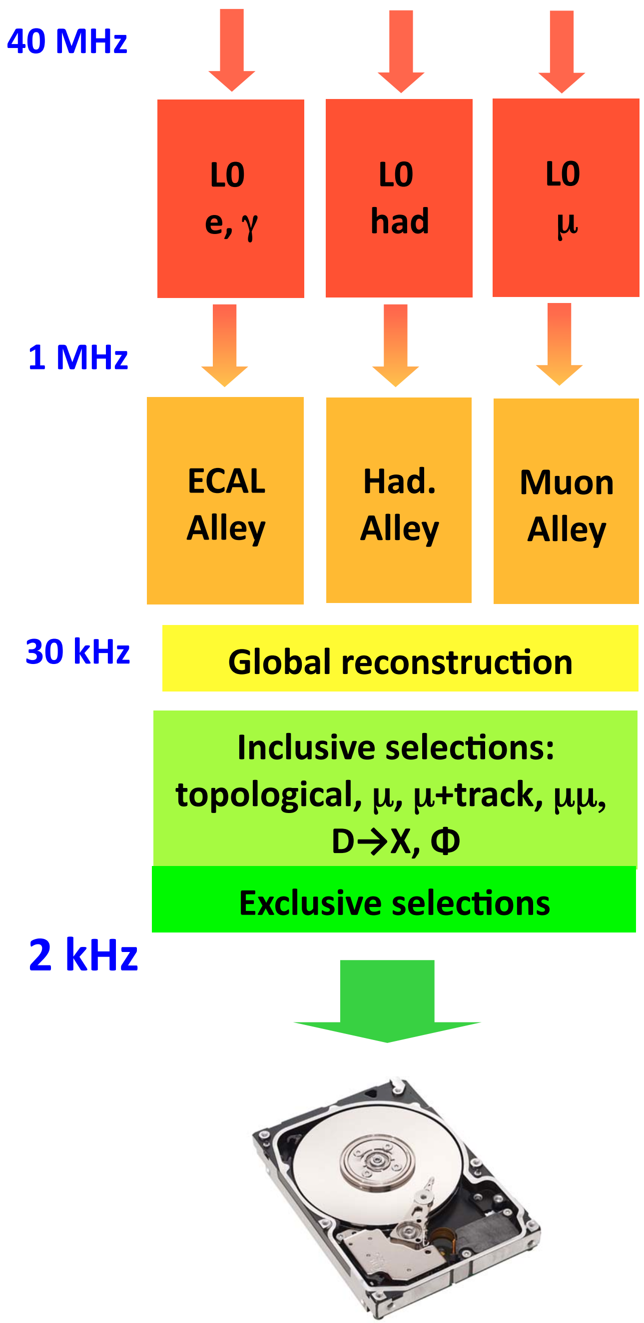
>10 GeV/c



Limited drop in PID capabilities with increasing track multiplicity



LHCb Trigger



Level-0

High-p_T signals in calorimeter
and muon systems

HLT1

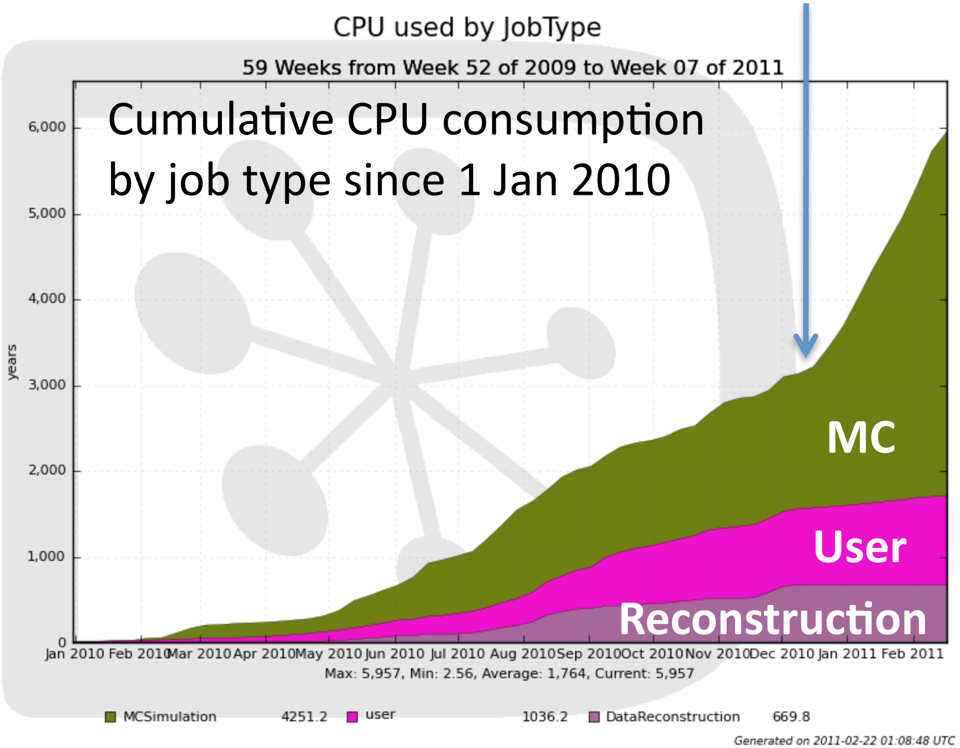
Associate L0 signals with
tracks, especially those
in VELO displaced from PV

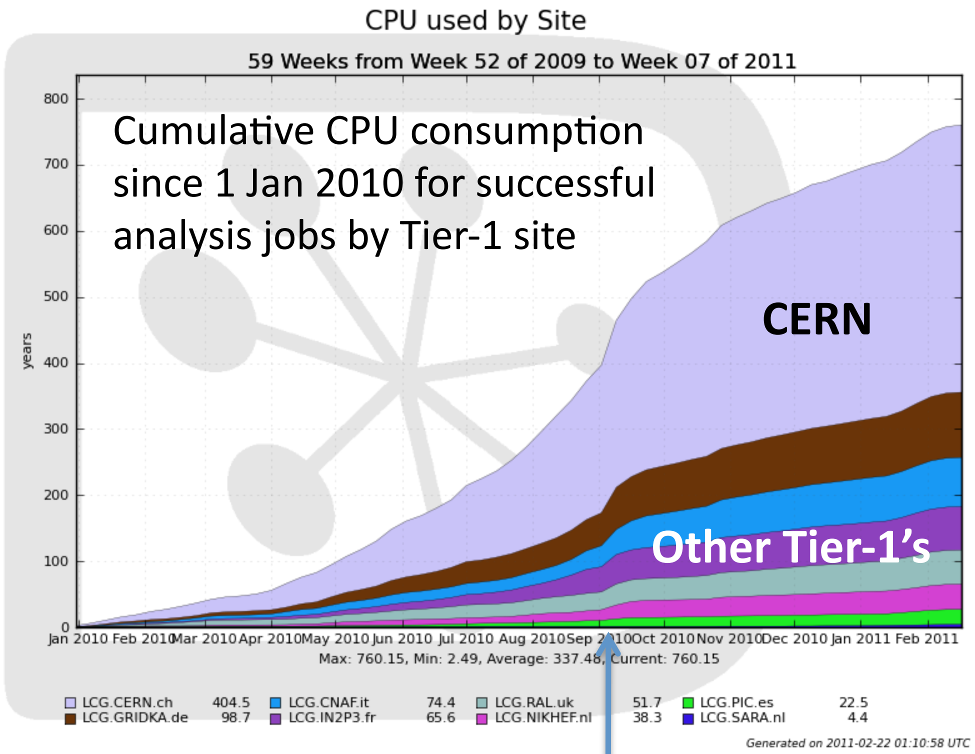
HLT2

Full detector information available
Continue to look for inclusive
signatures, augmented by exclusive
selections in certain key channels.

Offline computing

Start of massive Monte Carlo production for winter conferences





Quite smooth computing activities during first year of data taking considering the complexity of the challenge

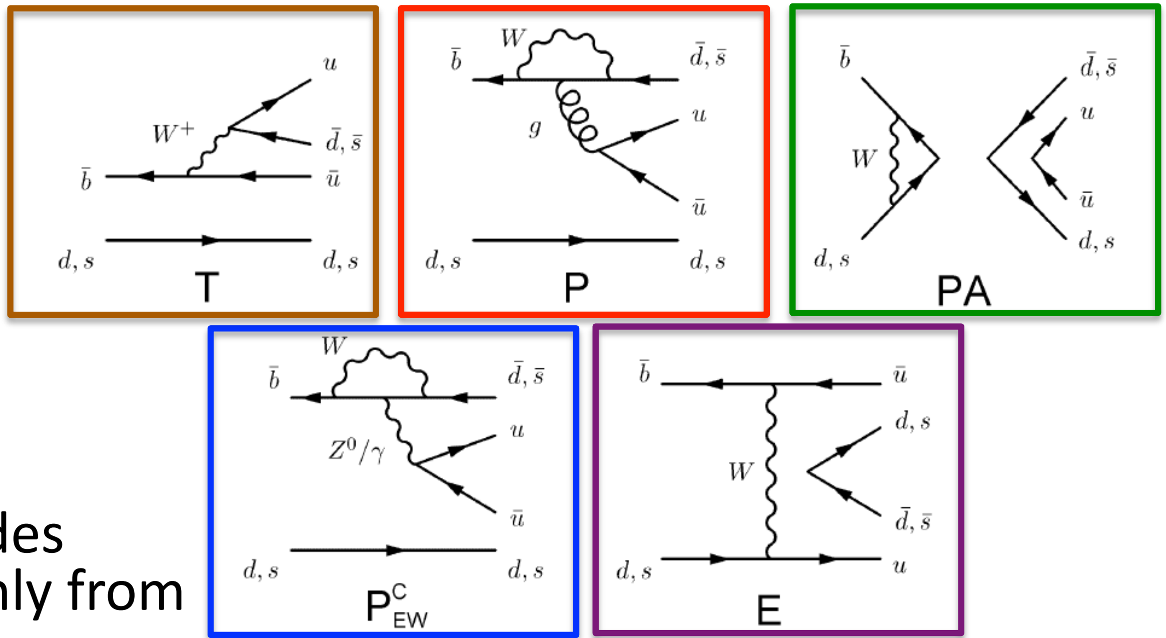
50% of data analysis done outside CERN

End of summer 2010, when significant data samples became available for analyses

Charmless charged two-body B decays at LHCb

Why $H_b \to h^+h'^-$ decays are important

- The family $H_b \to h^+h'^-$ decays comprises several modes, providing many different ways for testing the Standard Model picture of CP violation
  - H stands for B^0, B_s, Λ_b and h can be π, K, or p



- The corresponding amplitudes receive contributions not only from **tree** diagrams, but also from loop (penguin) diagrams, both **strong** and **electroweak**, hence measurements in this sector can be sensitive probes of New Physics
- Also certain **penguin annihilation** and **exchange** topologies can be probed via rare decays
- Relevant observables include branching ratios, charge (direct) CP asymmetries and, in the case of neutral B mesons, time dependent CP asymmetries

CP violation in $B^0 \rightarrow \pi^+\pi^-$ and $B_s \rightarrow K^+K^-$ decays

- The direct and mixing induced CP asymmetries in the $B^0 \rightarrow \pi^+\pi^-$ and $B_s \rightarrow K^+K^-$ modes are related to the angle γ and the B^0 and B_s mixing phases ϕ_d and ϕ_s

$$\mathcal{A}^{dir}_{\pi^+\pi^-} = \frac{2d\sin(\vartheta)\sin(\gamma)}{1-2d\cos(\vartheta)\cos(\gamma)+d^2} \qquad \mathcal{A}^{mix}_{\pi^+\pi^-} = -\frac{\sin(\phi_d+2\gamma)-2d\cos(\vartheta)\sin(\phi_d+\gamma)+d^2\sin(\phi_d)}{1-2d\cos(\vartheta)\cos(\gamma)+d^2}$$

$$\mathcal{A}^{dir}_{K^+K^-} = -\frac{2\tilde{d}'\sin(\vartheta')\sin(\gamma)}{1+2\tilde{d}'\cos(\vartheta')\cos(\gamma)+\tilde{d}'^2} \qquad \mathcal{A}^{mix}_{K^+K^-} = -\frac{\sin(\phi_s+2\gamma)+2\tilde{d}'\cos(\vartheta')\sin(\phi_s+\gamma)+\tilde{d}'^2\sin(\phi_s)}{1+2\tilde{d}'\cos(\vartheta')\cos(\gamma)+\tilde{d}'^2}$$

where d, d’, ϑ, ϑ’ are hadronic quantities

- CP violation in these decays is thus **sensitive to New Physics** in decay and mixing

R. Fleischer, PLB 459 (1999) 306

U-spin symmetry

- Diagrams of the decays $B^0 \rightarrow \pi^+\pi^-$ and $B_s \rightarrow K^+K^-$ differ only by the **interchange of the d and s quarks**
  – their strong interaction dynamics are connected by the so-called U-spin symmetry
- Within the validity of U-spin symmetry the **angle γ and the mixing phase ϕ_s can be extracted**
  – detailed studies were presented in the Roadmap document
- By U-spin symmetry and neglecting **PA** and **E** topologies we also expect

$$A_{CP}(B_s^0 \to \pi^+ K^-) \approx \mathcal{A}^{dir}_{\pi^+\pi^-}$$
$$A_{CP}(B^0 \to K^+ \pi^-) \approx \mathcal{A}^{dir}_{K^+K^-}$$

  which can **provide a sensitive check of U-spin**
  – **PA** and **E** topologies will be constrained by measuring the BR of the rare decays $B^0 \rightarrow K^+K^-$ and $B_s \rightarrow \pi^+\pi^-$, as they can only proceed via such diagrams
    - Albeit **PA** and **E** are expected to be small, they could be enhanced by rescattering effects $\rightarrow$ **BR($B^0 \rightarrow K^+K^-$) and BR($B_s \rightarrow \pi^+\pi^-$) are relevant**

Aims of this analysis

- Provide preliminary measurements of **direct CP violation** in $B^0 \rightarrow K^+\pi^-$ and $B_s \rightarrow \pi^+K^-$ decays
  - no time dependence, hence no tagging, but…
  - must separate **many decay modes** sitting one on top of the other
    - peaked backgrounds due to mis-identified particles in the final state are present
  - must cope with **instrumental charge asymmetries**
  - must cope with **B meson production asymmetries**

Current experimental knowledge

- Direct CP asymmetries in charmless two body B decays have been measured by the B-factories and CDF
  - BaBar, arXiv:0807.4226 [hep-ex]
  - Belle, PRL 98 (2007) 211801
  - CLEO, PRL 85 (2000) 525
  - CDF, PRL 97 (2006) 211802

	$A_{CP}(B^0 \to K^+\pi^-)$
BaBar	$-0.107 \pm 0.016^{+0.006}_{-0.004}$
Belle	$-0.094 \pm 0.018 \pm 0.008$
CLEO	$-0.04 \pm 0.16 \pm 0.02$
CDF	$-0.086 \pm 0.023 \pm 0.009$
Average	$-0.098^{+0.012}_{-0.011}$

- CP violation established at ~9σ in $B^0 \to K^+\pi^-$ but **still an open issue** in $B_s \to \pi^+K^-$

CDF with 1 fb^{-1}

$$A_{CP}(B_s^0 \to \pi^+ K^-) = 0.39 \pm 0.15 \pm 0.08$$

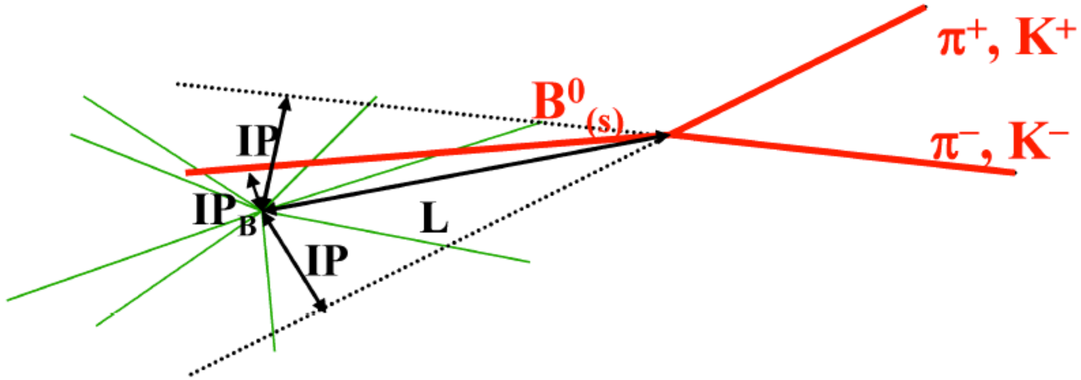
Analysis main steps

- Offline event selection
  - Choice of optimal cuts
- Calibration of **RICH PID**
  - Charm two-body decays are a  mine for this analysis
- Determination of **instrumental asymmetries** from D* tagged and untagged $D \rightarrow h^+h'^-$ control samples
  - a.k.a. 
- Determination of **B meson production asymmetry** from $B^+ \rightarrow J/\psi(\mu^+\mu^-)K^+$ decays
- Maximum likelihood fit of $B \rightarrow h^+h'^-$ mass spectra
- Systematical errors and final results

Optimization of kinematic selection cuts

- Parameterized the sensitivity on A_{CP} as a function of the fraction of signal events p=S/(S+B)
- Determined **two score functions** of p, one for $A_{CP}(B^0 \rightarrow K^+\pi^-)$ and one for $A_{CP}(B_s \rightarrow \pi^+K^-)$
- Score functions used to determine **two sets of cuts** optimized for the best sensitivities on the two CP asymmetries
- In order to avoid biases, the optimization has been performed using **Monte Carlo signal** events, while **combinatorial background** events were taken from the **signal-free right invariant mass sideband** $M_{K\pi}>5.6$ GeV/c^2
- Optimization technique makes sense if distributions of variables for signals in **MC and data agree** well

Optimal cuts for kinematic selection

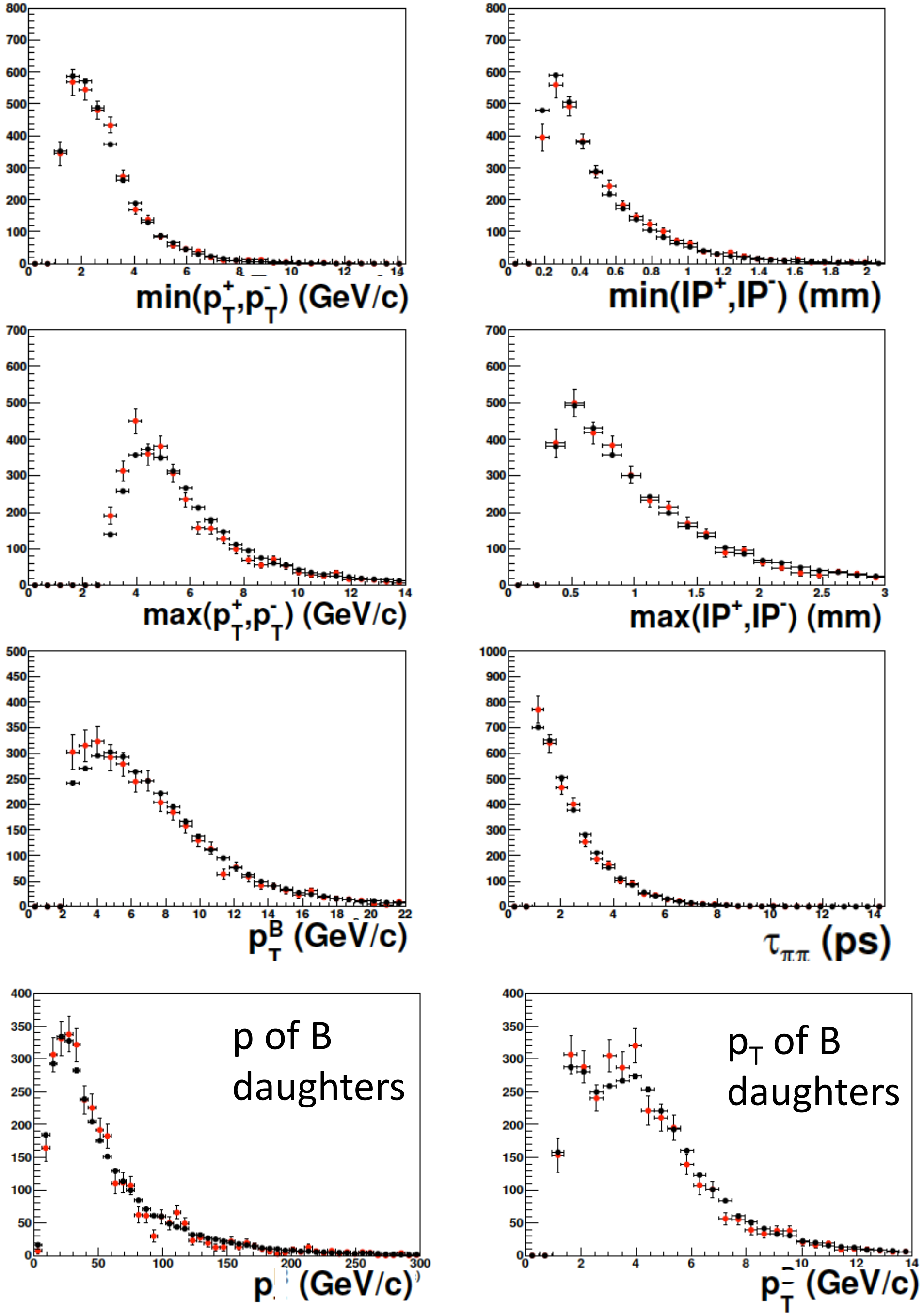


Cuts optimized for $A_{CP}(B^0 \rightarrow K^+\pi^-)$

Cut type	Accepted regions
Track p_T [GeV/c]	> 1.1
Track IP [μm]	> 150
Track χ^2/d.o.f.	< 3
$\max(p_T^{h^+}, p_T^{h'^-})$ [GeV/c]	> 2.8
$\max(IP^h, IP^{h'^-})$ [μm]	> 300
p_T^B [GeV/c]	> 2.2
$\tau_{\pi\pi}^B$ [ps]	> 0.9

Cuts optimized for $A_{CP}(B_s \rightarrow \pi^+K^-)$

Cut type	Accepted regions
Track p_T [GeV/c]	> 1.2
Track IP [μm]	> 200
Track χ^2/d.o.f.	< 3
$\max(p_T^{h^+}, p_T^{h'^-})$ [GeV/c]	> 3
$\max(IP^h, IP^{h'^-})$ [μm]	> 400
p_T^B [GeV/c]	> 2.4
$\tau_{\pi\pi}^B$ [ps]	> 1.2



Comparison of MC and data

Remarkable agreement between LHCb Monte Carlo (using Pythia) and data for selected events

Note: raw distributions not corrected for acceptance

Black dots ($B^0 \rightarrow K^+\pi^-$ MC) and **red dots (data)**

PID cuts

- Events passing kinematic selection are separated into different final states using PID
- Guiding principle to identify the two appropriate sets of PID cut values for $A_{CP}(B^0 \to K^+\pi^-)$ and for $A_{CP}(B_s \to \pi^+K^-)$
  - **limit the total amount of cross-feed backgrounds** present under the $B^0 \to K^+\pi^-$ and $B_s \to \pi^+K^-$ mass peaks to the **same level** of the corresponding **combinatorial background** → will show this later when talking of the $B \to h^+h'^-$ mass fits

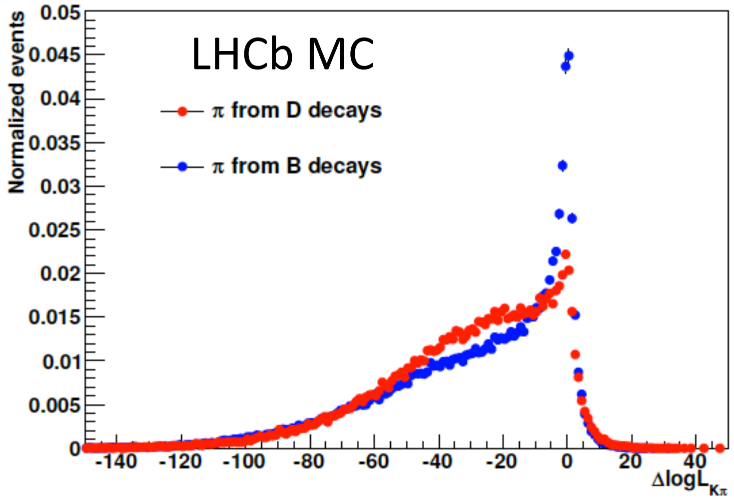
$K^+\pi^-$ PID cuts for $A_{CP}(B^0 \to K^+\pi^-)$	π^+K^- PID cuts for $A_{CP}(B_s^0 \to \pi^+K^-)$
$\Delta \log \mathcal{L}_{K\pi}(h^+) > 0$	$\Delta \log \mathcal{L}_{K\pi}(h^+) < -7$
$\Delta \log \mathcal{L}_{K\pi}(h^-) < 0$	$\Delta \log \mathcal{L}_{K\pi}(h^-) > 7$
$\Delta \log \mathcal{L}_{pK}(h^+) < 5$	$\Delta \log \mathcal{L}_{pK}(h^+) < 5$
$\Delta \log \mathcal{L}_{p\pi}(h^-) < 5$	$\Delta \log \mathcal{L}_{p\pi}(h^-) < 5$

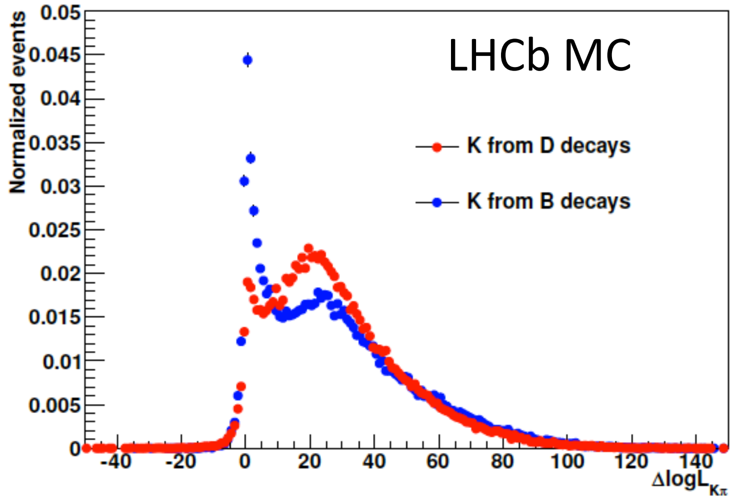
$\pi^+\pi^-$	K^+K^-	pK^-	$p\pi^-$
$\Delta \log \mathcal{L}_{K\pi}(h^+) < -3$	$\Delta \log \mathcal{L}_{K\pi}(h^+) > 3$	$\Delta \log \mathcal{L}_{pK}(h^+) > 5$	$\Delta \log \mathcal{L}_{pK}(h^+) > 10$
$\Delta \log \mathcal{L}_{K\pi}(h^-) < -3$	$\Delta \log \mathcal{L}_{K\pi}(h^-) > 3$	$\Delta \log \mathcal{L}_{K\pi}(h^-) > 3$	$\Delta \log \mathcal{L}_{K\pi}(h^-) < -3$
$\Delta \log \mathcal{L}_{p\pi}(h^+) < 5$	$\Delta \log \mathcal{L}_{pK}(h^+) < 5$	$\Delta \log \mathcal{L}_{p\pi}(h^+) > 5$	$\Delta \log \mathcal{L}_{p\pi}(h^+) > 10$
$\Delta \log \mathcal{L}_{p\pi}(h^-) < 5$	$\Delta \log \mathcal{L}_{pK}(h^-) < 5$	$\Delta \log \mathcal{L}_{pK}(h^-) < 5$	$\Delta \log \mathcal{L}_{p\pi}(h^-) < 5$

Adopted cuts identify mutually exclusive samples for each mass hypothesis

PID calibration

- Crucial aspect of this analysis
  - Relative PID efficiencies needed to determine yields of cross-feed backgrounds
- $\Delta\log\mathcal{L}$ distributions from $D^* \rightarrow D^0(K\pi)\pi$ and $\Lambda \rightarrow p\pi$ decays can be used, but their phase space is different with respect to $B \rightarrow h^+h'^-$ decays
- Different momentum distributions lead to different $\Delta\log\mathcal{L}$ distributions

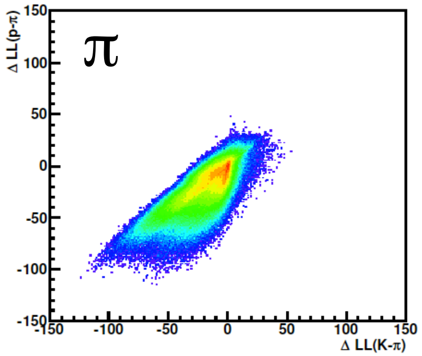


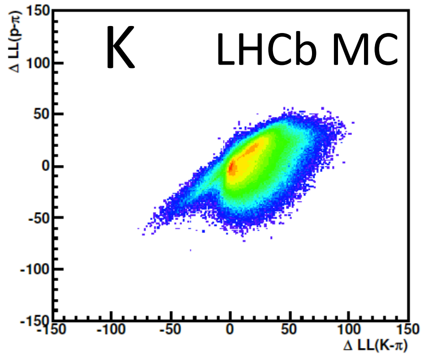


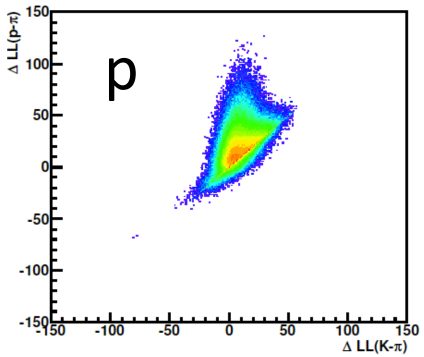
- Needs reweighting in momentum at least, but we reweighted simultaneously also in transverse momentum

PID reweighting

- Additional complication
  - $\Delta\log\mathcal{L}_{K\pi}$ and $\Delta\log\mathcal{L}_{p\pi}$ distributions are strongly correlated → need to reweight both at the same time







$\Delta\log\mathcal{L}_{p\pi}$
vs
$\Delta\log\mathcal{L}_{K\pi}$

$$f\left(\Delta\log\mathcal{L}^{+}_{K\pi},\ \Delta\log\mathcal{L}^{+}_{p\pi},\ \Delta\log\mathcal{L}^{-}_{K\pi},\ \Delta\log\mathcal{L}^{-}_{p\pi},\ p^{+},\ p^{-},\ p^{+}_{T},\ p^{-}_{T}\right) =$$
$$= \boxed{g^{+}\left(\Delta\log\mathcal{L}^{+}_{K\pi},\ \Delta\log\mathcal{L}^{+}_{p\pi}\ \middle|\ p^{+},\ p^{+}_{T}\right)} \cdot \boxed{g^{-}\left(\Delta\log\mathcal{L}^{-}_{K\pi},\ \Delta\log\mathcal{L}^{-}_{p\pi}\ \middle|\ p^{-},\ p^{-}_{T}\right)} \cdot$$
$$\cdot \boxed{h\left(p^{+},\ p^{-},\ p^{+}_{T},\ p^{-}_{T}\right)}$$

Conditional $\Delta\log\mathcal{L}$ distributions from real data calibration samples

Joint p and p_T distributions from MC

PID efficiencies

- By integrating the joing p.d.f.
  $f\left(\Delta \log \mathcal{L}_{K\pi}^{+},\ \Delta \log \mathcal{L}_{p\pi}^{+},\ \Delta \log \mathcal{L}_{K\pi}^{-},\ \Delta \log \mathcal{L}_{p\pi}^{-},\ p^{+},\ p^{-},\ p_T^{+},\ p_T^{-}\right)$
  we get the PID cut efficiencies, for events passing the two sets of optimal kinematic cuts
- The efficiencies will be used to determine the yields of cross-feed backgrounds in maximum likelihood mass fits

From raw to physical asymmetries

- The $A_{CP}(B^0 \to K^+\pi^-)$ and $A_{CP}(B_s \to \pi^+K^-)$ values measured in data need correction factors

$$A_{CP} = \boxed{A_{CP}^{RAW}} - \boxed{A_D(K\pi)} - \kappa \boxed{A_P}$$

Raw asymmetry measured in data

Production asymmetry

Instrumental $K^+\pi^-/K^-\pi^+$ charge asymmetry

- κ is a selection dependent factor

Acceptance as function of the proper decay time

$$\kappa = \frac{\int \left(e^{-\Gamma t'} \cos \Delta m t'\right) \boxed{\varepsilon(t)} dt}{\int \left(e^{-\Gamma t'} \cosh \frac{\Delta\Gamma}{2} t'\right) \boxed{\varepsilon(t)} dt}$$

- Using acceptance function determined from MC with
  - Γ_d, Γ_s, Δm_d, Δm_s from PDG
  - $\Delta\Gamma_d$=0 and $\Delta\Gamma_s$=0.1Γ_s

Channel	κ
$B^0 \to K^+\pi^-$	0.33
$B_s^0 \to \pi^+K^-$	0.015

Fast B_s oscillation cancel effects of production asymmetry

Instrumental asymmetry

- Asymmetry due to various effects
  - Different probabilities of $K^+\pi^-$ and $K^-\pi^+$ pairs to have **strong interactions with the detector material**
    - B daughter momenta are quite large, but an asymmetry due to kaons in particular can be present
  - Possible presence of a **left-right asymmetry** of detector efficiencies and possibly other left-right differences due to reconstruction
    - Effect of the latter can be investigated by comparing data acquired with opposite magnet polarities

Instrumental asymmetry (II)

- Studied using $D^* \rightarrow D^0(K\pi)\pi_s$, $D^* \rightarrow D^0(KK)\pi_s$ $D^* \rightarrow D^0(\pi\pi)\pi_s$ and untagged $D^0 \rightarrow K\pi$ decays
  - The combination of these modes is necessary to disentangle various components
- Decomposition of raw asymmetries

$$A_{CP}^{RAW}(K\pi)^* = \boxed{A_{CP}(K\pi)} + \boxed{A_D(\pi_s)} + \boxed{A_D(K\pi)} + \boxed{A_P(D^*)}$$

$$A_{CP}^{RAW}(KK)^* = \boxed{A_{CP}(KK)} + \boxed{A_D(\pi_s)} + \boxed{A_P(D^*)}$$

$$A_{CP}^{RAW}(\pi\pi)^* = \boxed{A_{CP}(\pi\pi)} + \boxed{A_D(\pi_s)} + \boxed{A_P(D^*)}$$

$$A_{CP}^{RAW}(K\pi) = \boxed{A_{CP}(K\pi)} + \boxed{A_D(K\pi)} + \boxed{A_P(D^0)}$$

A_{CP} → physical asymmetries

A_D → instrumental asymmetries

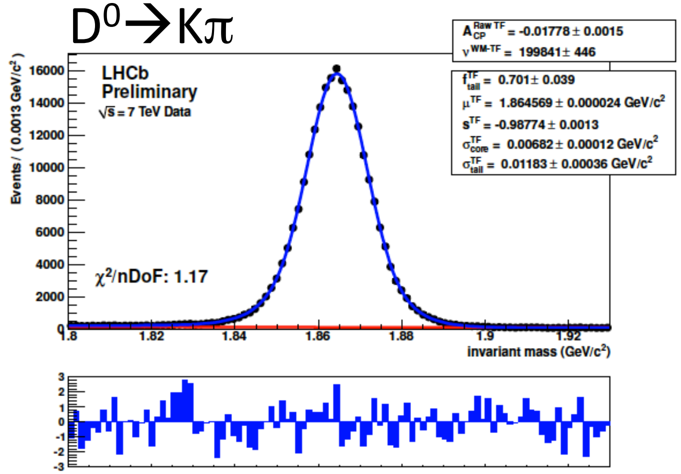
A_P → production asymmetries

The "*" identifies the D* tagged modes

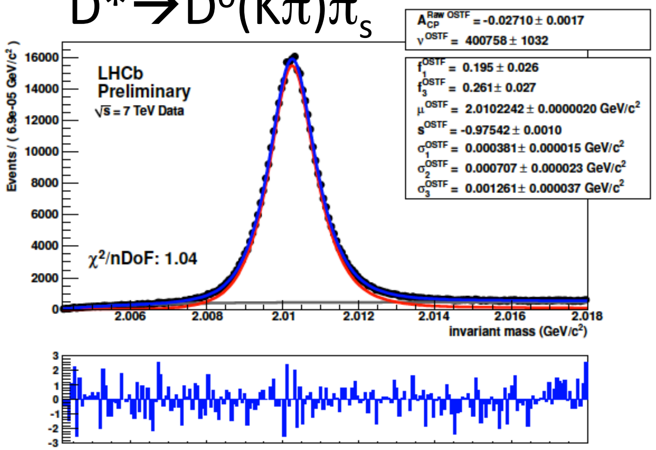
Instrumental asymmetry (III)

- Maximum likelihood fits made in **M(D^0)** for D^0→Kπ and **M(D*)-M(D^0)+M(D^0)$_{PDG}$** for D* modes
  - integrated raw CP asymmetries returned by the fits

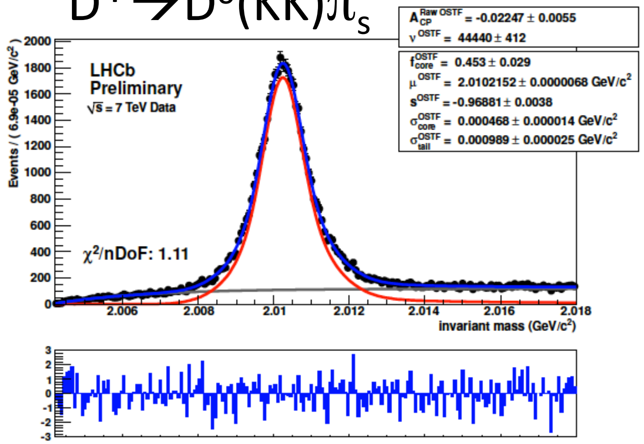
D^0→Kπ



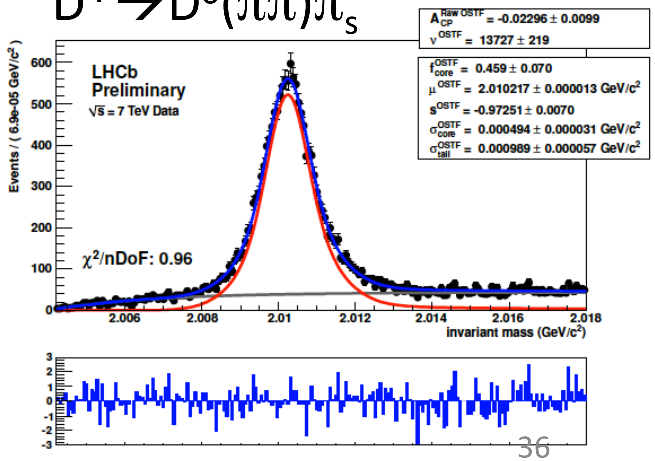
D*→D^0(Kπ)π_s



D*→D^0(KK)π_s

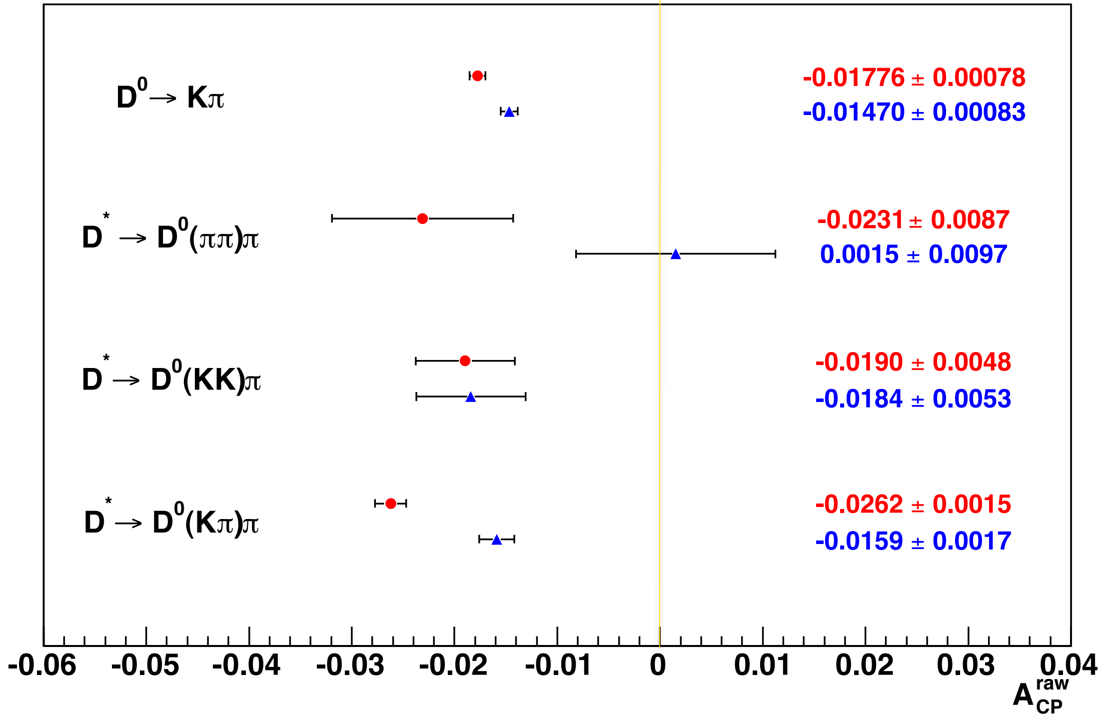


D*→D^0($\pi\pi$)π_s



Instrumental asymmetry (IV)

- All raw asymmetries have been measured separately for **magnet up** and **magnet down** data

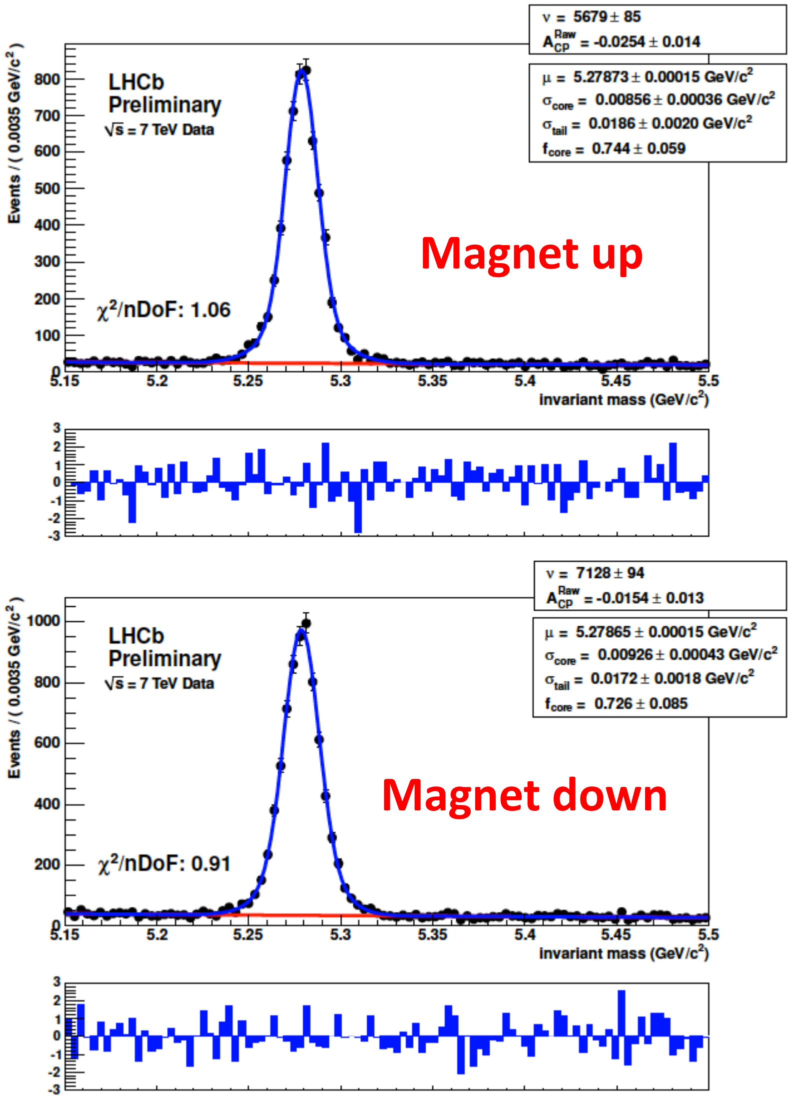


- Using world averages of the corresponding physical asymmetries we can solve and extract the instrumental asymmetry $A_D(K\pi)$

$$A_D(K\pi) = -0.004 \pm 0.004$$

averaged between magnet up and magnet down

Production asymmetry



- B meson production asymmetry has been studied following a similar approach using $B^+ \to J/\psi(\mu^+\mu^-)K^+$ decays

	Magnet up	Magnet down
$B^\pm \to J/\psi(\mu^+\mu^-)K^\pm$ event yield	5679 ± 85	7128 ± 94
$A_{CP}^{RAW}(B^+ \to J/\psi(\mu^+\mu^-)K^+)$	-0.025 ± 0.014	-0.015 ± 0.013

- Averaging between magnet up and magnet down, correcting for instrumental asymmetries and taking into account the current world average of the direct CP asymmetry in $B^+ \to J/\psi(\mu^+\mu^-)K^+$ decays, we get the production asymmetry for charged B mesons

$$A_P(B^+) = -0.025 \pm 0.014$$

- We assumed the production asymmetry $A_P(B^0)$ to differ from $A_P(B^+)$ by 1% at most, i.e.

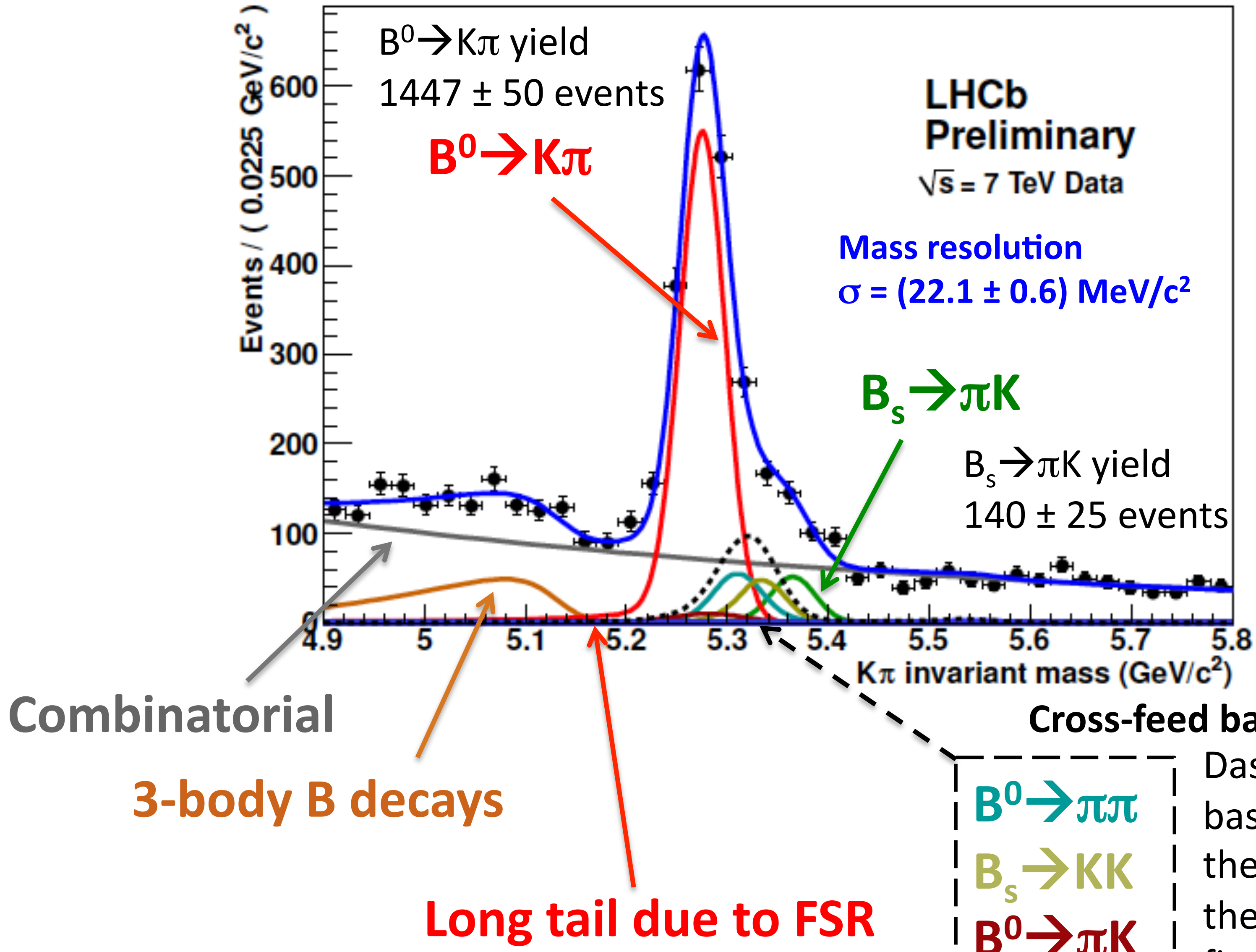
$$A_P(B^0) = -0.025 \pm 0.014 \pm 0.010$$

Maximum likelihood fits of $H_b \rightarrow h^+h'^-$ mass spectra

- A **simultaneous unbinned maximum likelihood fit** to all the mass spectra was done
- Separated fits were done using events which passed either the selection optimized for $A_{CP}(B^0 \rightarrow K^+\pi^-)$ or $A_{CP}(B_s \rightarrow \pi^+K^-)$
  - Each fit featured **34 free parameters**

Kπ mass spectrum

selection optimized for $A_{CP}(B^0 \to K\pi)$



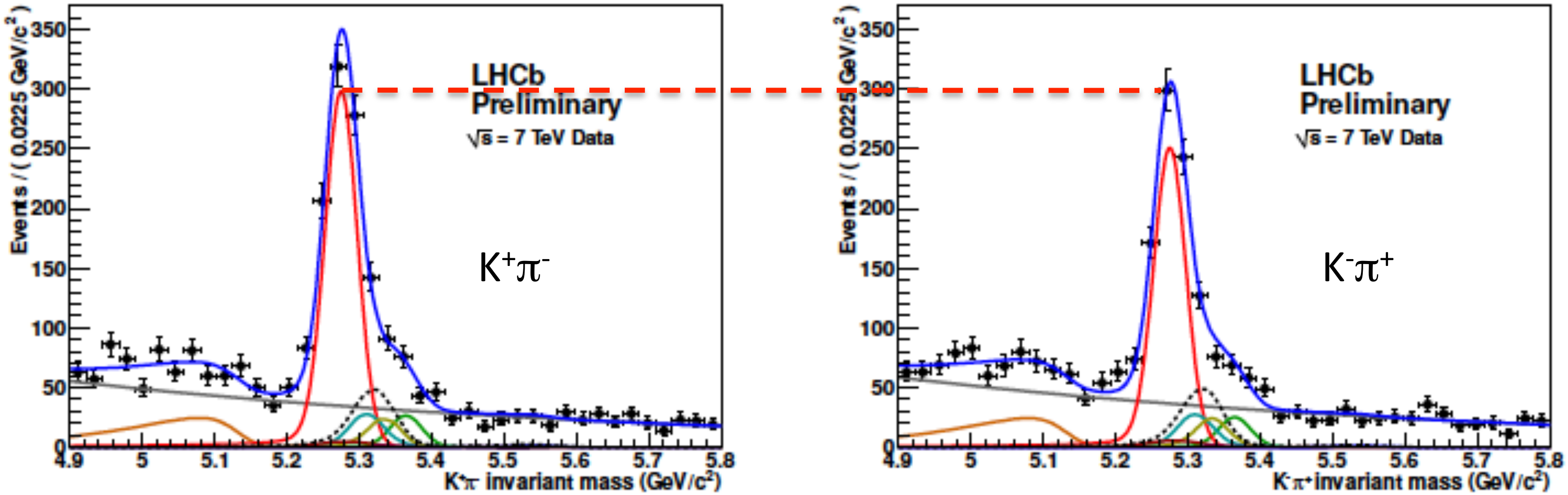
Cross-feed backgrounds

$B^0 \to \pi\pi$
$B_s \to KK$
$B^0 \to \pi K$

Dashed curve is basically the sum of these three modes: their lineshapes are fixed from MC

$K^+\pi^-$ and $K^-\pi^+$ mass spectra
selection optimized for $A_{CP}(B^0 \to K\pi)$

Raw CP asymmetry in $B^0 \to K\pi$ decays: -0.086 ± 0.033

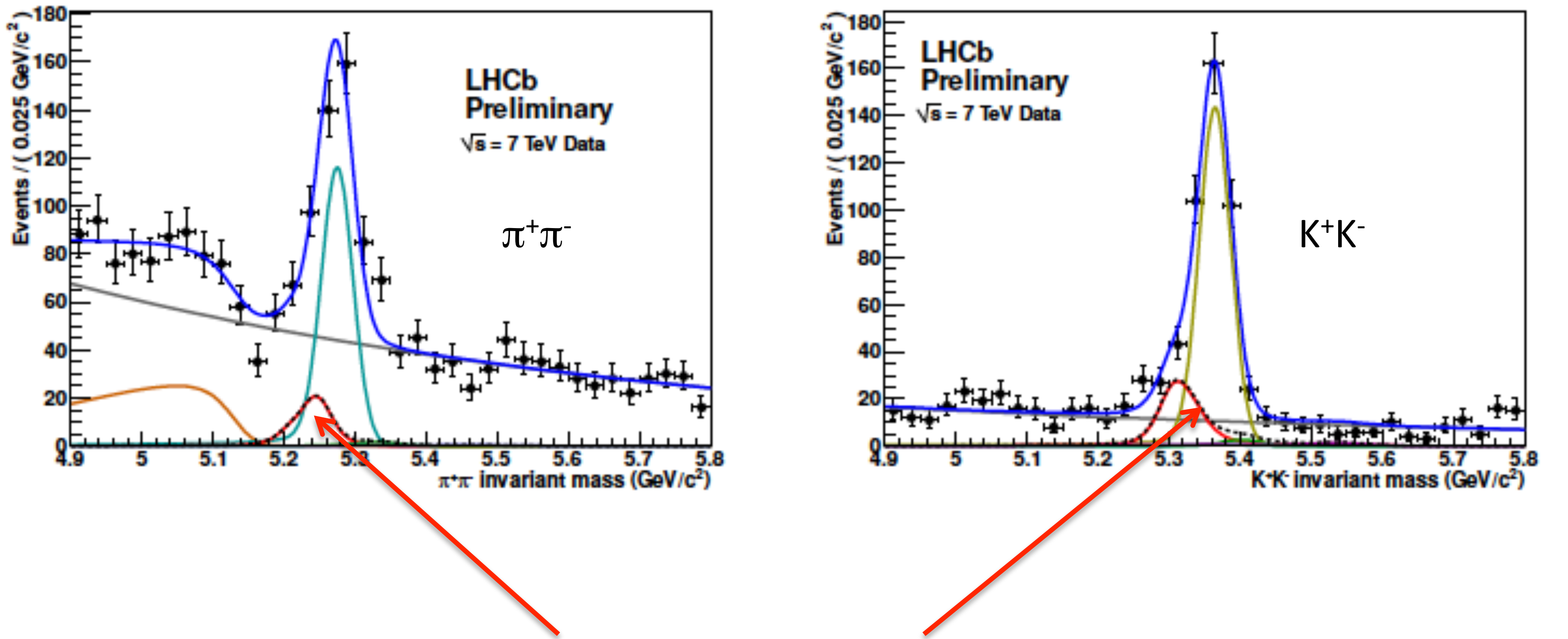


Raw CP asymmetry clearly visible from the plots

$\pi^+\pi^-$ and K^+K^- mass spectra
selection optimized for $A_{CP}(B^0 \rightarrow K\pi)$

$B^0 \rightarrow \pi\pi$ yield: 275 ± 24 events

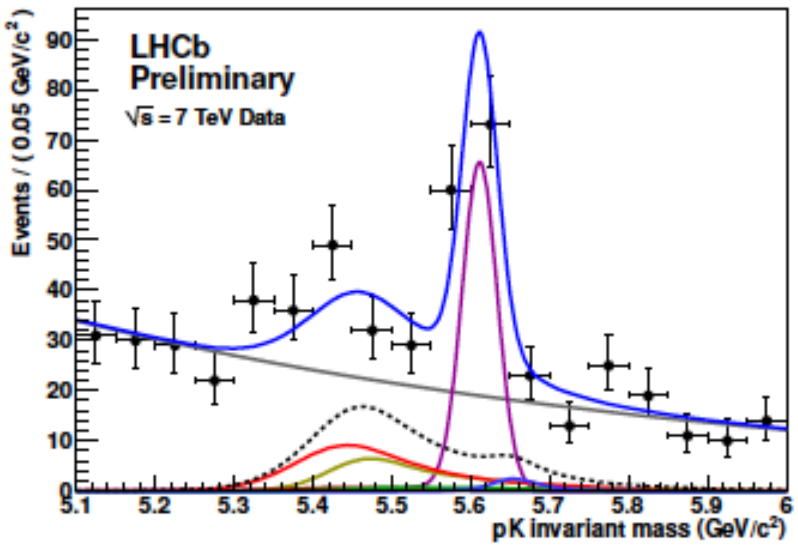
$B_s \rightarrow KK$ yield: 333 ± 21 events



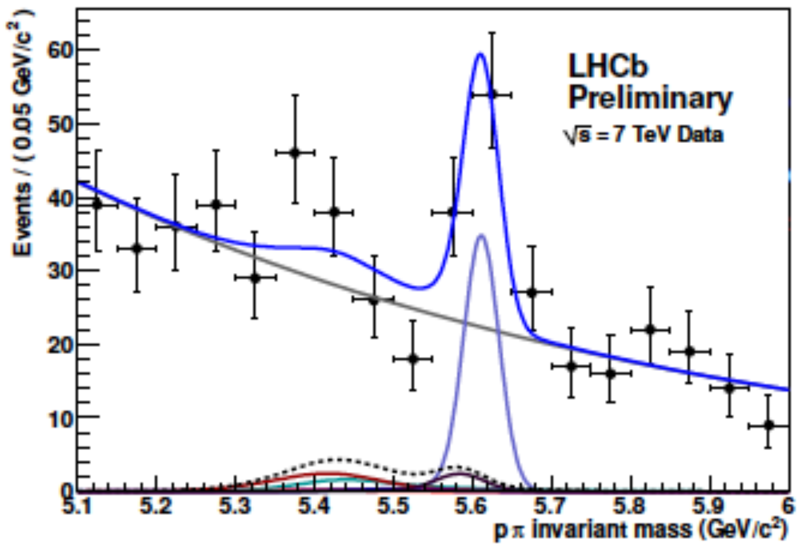
Cross feed background dominated by $B^0 \rightarrow K\pi$ decays

$\Lambda_b \rightarrow pK$ and $\Lambda_b \rightarrow p\pi$ mass spectra selection optimized for $A_{CP}(B^0 \rightarrow K\pi)$

$\Lambda_b \rightarrow pK$ yield: 76 ± 12 events



$\Lambda_b \rightarrow p\pi$ yield: 41 ± 10 events

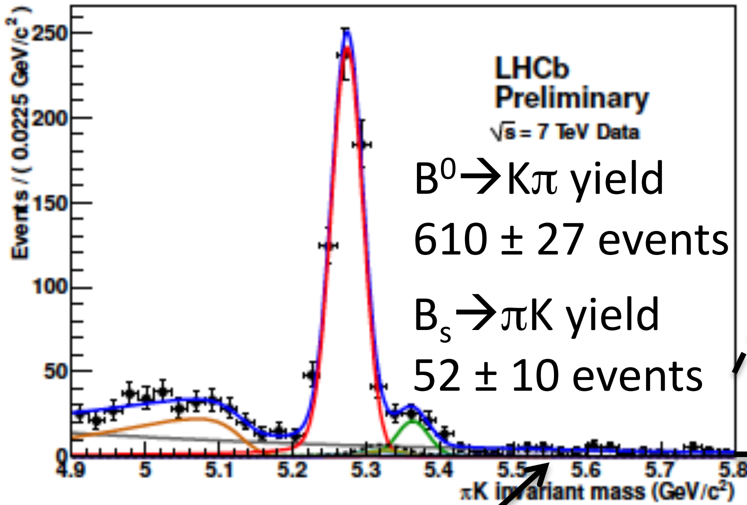


Selection not optimized for best sensitivity on yields of these modes, but clean mass peaks clearly observed

Kπ mass spectrum

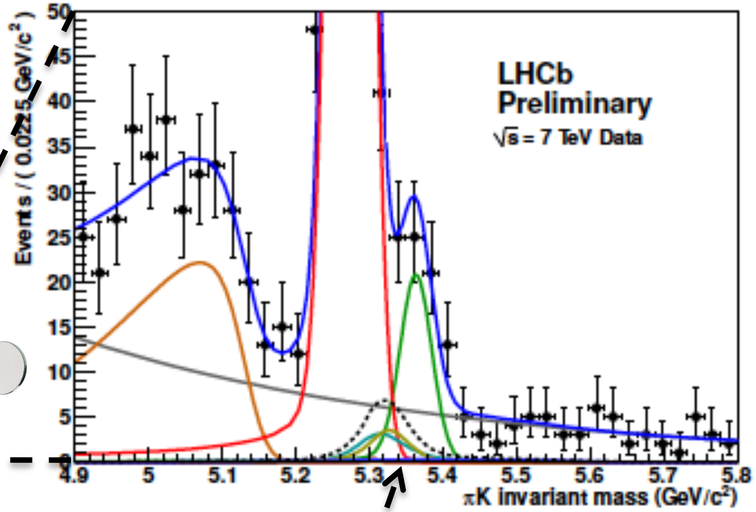
selection optimized for $A_{CP}(B_s \rightarrow \pi K)$

mass resolution
σ = (21.3 ± 0.7) MeV/c^2



$B^0 \rightarrow K\pi$ yield
610 ± 27 events

$B_s \rightarrow \pi K$ yield
52 ± 10 events



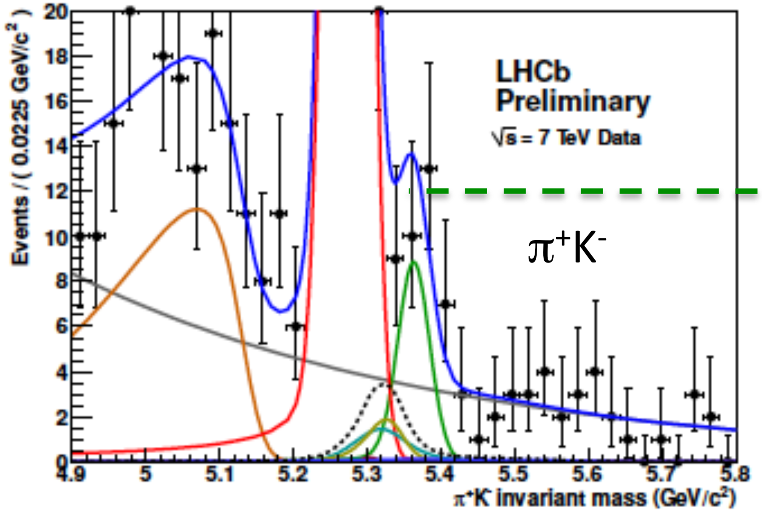
Tighter kinematic and PID selection cuts provide strong suppression of combinatorial background events

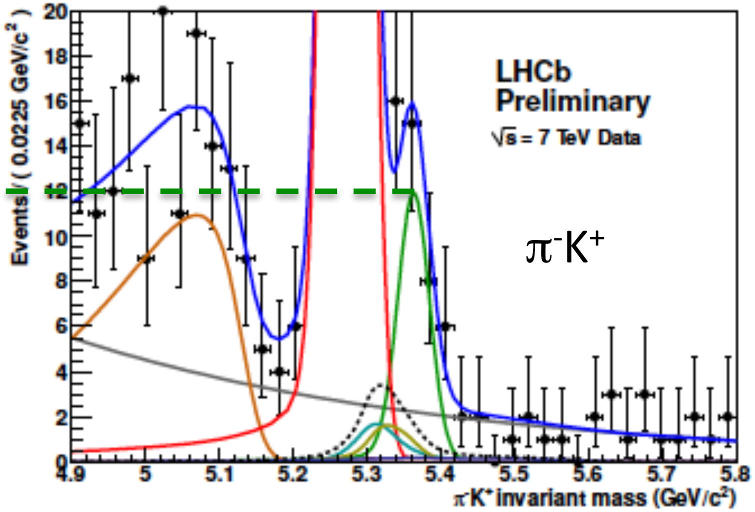
$B^0 \rightarrow \pi\pi$
$B_s \rightarrow KK$

Dashed curve is basically the sum of these two modes: their lineshapes are fixed from MC

π^+K^- and π^-K^+ mass spectra selection optimized for $A_{CP}(B_s \rightarrow \pi K)$

Raw CP asymmetry in $B_s \rightarrow \pi K$ decays: 0.15 ± 0.19





Raw CP asymmetry still visible in the plots, but significance is much lower

Systematic uncertainties

- We identified three main categories of systematic errors affecting $A_{CP}(B^0 \rightarrow K^+\pi^-)$ and for $A_{CP}(B_s \rightarrow \pi^+K^-)$
  - **PID calibration**
  - **modelling of signal and background** components in maximum likelihood fits
  - **instrumental and production asymmetries**

Systematics due to instrumental and production asymmetries

- Remember that the physical CP asymmetry is related to the observed asymmetry by

$$A_{CP} = A_{CP}^{RAW} - A_D(K\pi) - \kappa A_P$$

where we have determined

$A_D(K\pi) = -0.004 \pm 0.004$

$A_P(B^0) = -0.025 \pm 0.017$

Channel	κ
$B^0 \to K^+\pi^-$	0.33
$B_s^0 \to \pi^+K^-$	0.015

- The **corrected central value of $A_{CP}(B^0 \to K^+\pi^-)$** becomes

$$A_{CP}(B^0 \to K^+\pi^-) = -0.074$$

while even assuming that the B_s production asymmetry is as large as 2.5%, the central values of $A_{CP}(B_s \to \pi^+K^-)$ is practically unaffected

- The corresponding systematic errors on A_{CP} are obtained by propagating to A_{CP} the uncertainties on $A_D(K\pi)$ and $A_P(B^0)$

Summary of systematics

Reason	$A_{CP}(B^0 \to K^+\pi^-)$	$A_{CP}(B_s^0 \to \pi^+K^-)$
PID calibration	0.002	0.001
Final state radiation	0.003	0.01
Signal model	0.002	0.01
Combinatorial background model	0.0001	0.01
Cross-feed background model (shift)	0.0009	0.005
Cross-feed background model (smearing)	0.0006	0.006
Instrumental asymmetry	0.004	0.004
Production asymmetry	0.006	0.0003
Total	0.008	0.02

Final results

Using data collected by the LHCb detector during the 2010 run we provide preliminary measurements of the direct CP asymmetries

$$A_{CP}(B^0 \to K^+\pi^-) = -0.074 \pm 0.033 \pm 0.008$$

$$A_{CP}(B_s^0 \to \pi^+K^-) = 0.15 \pm 0.19 \pm 0.02$$

These results can be compared with the current HFAG averages

$$A_{CP}(B^0 \to K^+\pi^-) = -0.098^{+0.012}_{-0.011}$$

$$A_{CP}(B_s^0 \to \pi^+K^-) = 0.39 \pm 0.17$$

By including our results the new world averages become

$$A_{CP}(B^0 \to K^+\pi^-) = -0.095^{+0.011}_{-0.010}$$

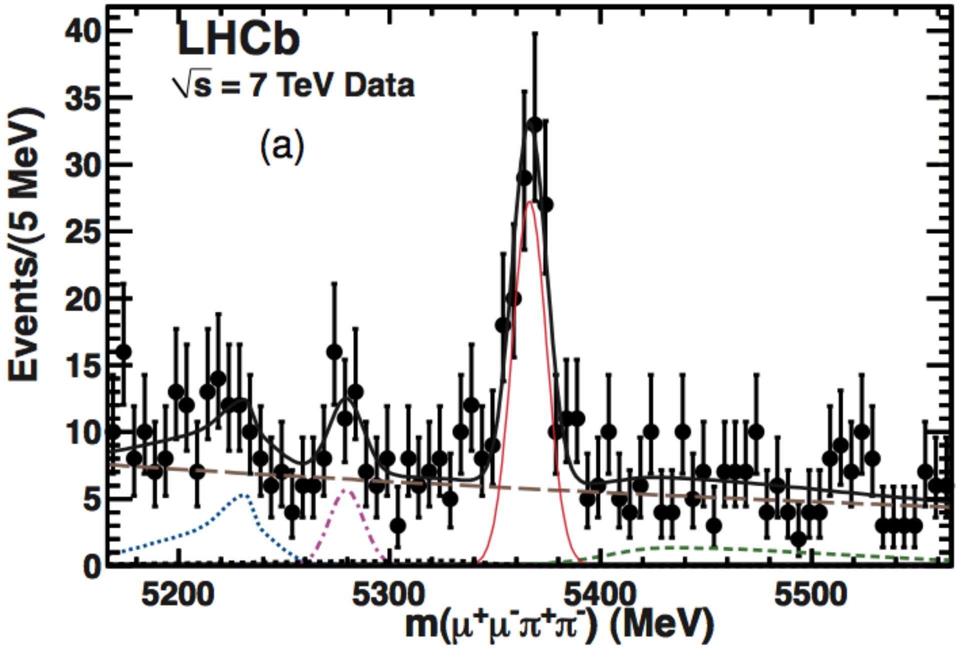
$$A_{CP}(B_s^0 \to \pi^+K^-) = 0.28 \pm 0.13$$

Roadmap for evolutions of this analysis

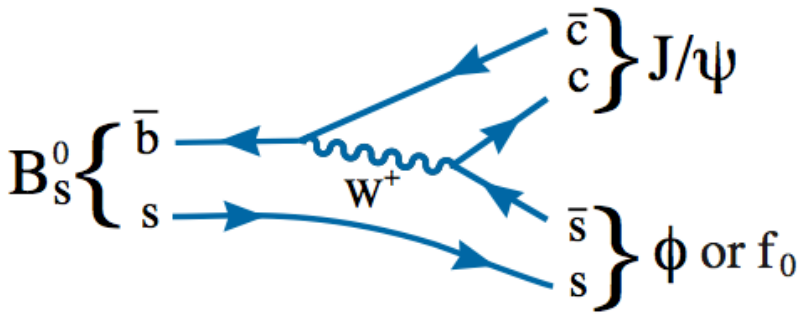
- Even with existing data
  - **Measure relative branching fractions**
- With new data for 2011 summer conferences
  - **Remake CP and BR measurements with larger statistics**
    - Will start dominating world averages at ~0.3 fb^{-1}
  - **Measure BR of rare modes $B_s \rightarrow \pi^+\pi^-$ and $B^0 \rightarrow K^+K^-$**
  - Possibly measure direct CP asymmetries in $\Lambda_b \rightarrow p\pi^-$ and $\Lambda_b \rightarrow pK^-$
- By the end of 2011
  - Include proper time and tagging and **measure time-dependent CP violation** in $B^0 \rightarrow \pi^+\pi^-$ and $B_s \rightarrow K^+K^-$ decays

Brief overview of other selected LHCb measurements and prospects

First observation of $B_s \rightarrow J/\psi f_0(980)$



arXiv:1102.0206 [hep-ex]

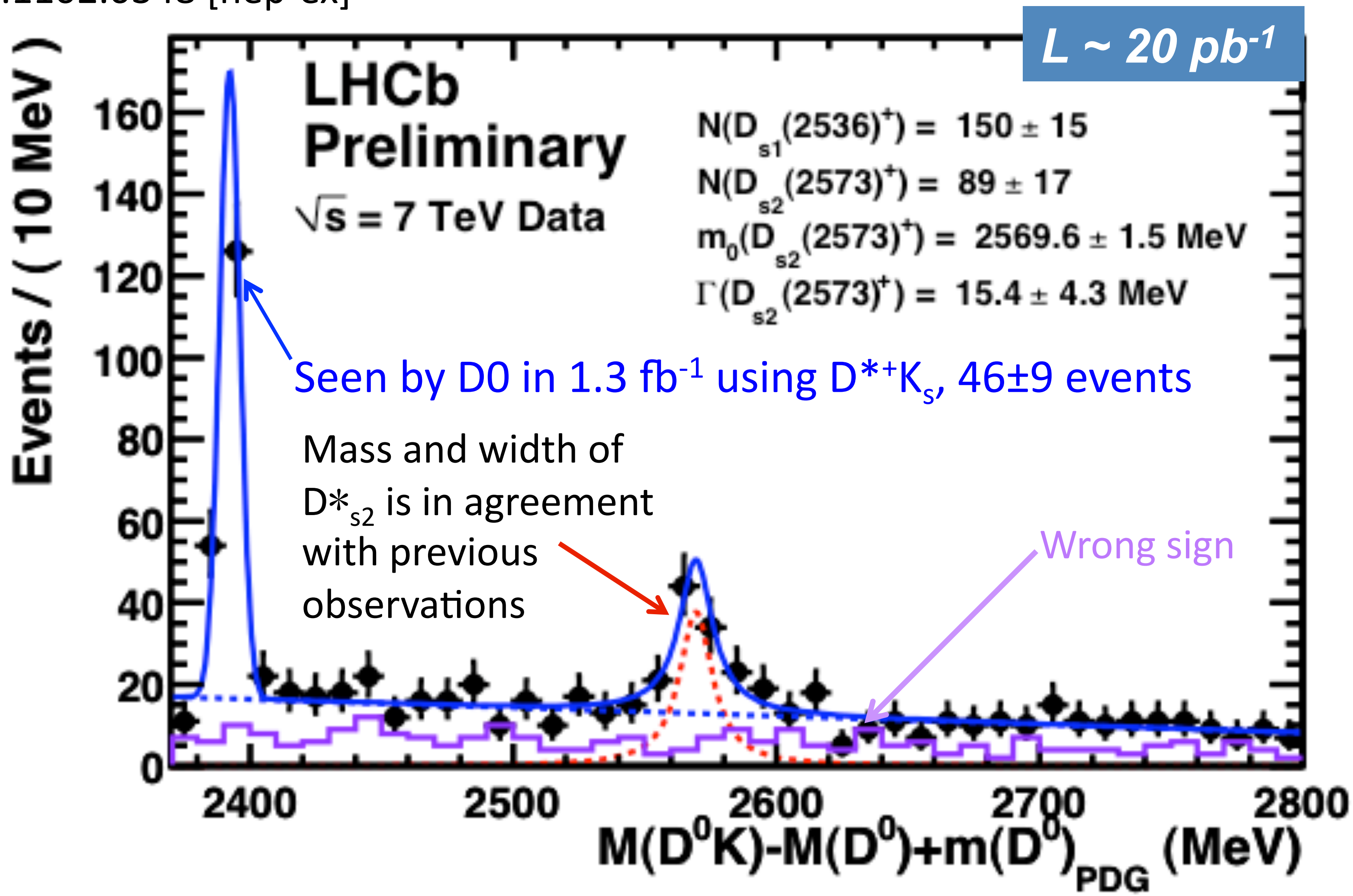


$$R_{f_0/\phi} \equiv \frac{\Gamma(B_s^0 \to J/\psi f_0,\ f_0 \to \pi^+\pi^-)}{\Gamma(B_s^0 \to J/\psi \phi,\ \phi \to K^+K^-)} = 0.252^{+0.046+0.027}_{-0.032-0.033}$$

This is a CP eigenstate mode and can be used to measure the B_s mixing phase without the need of an angular analysis

Observation of new semileptonic decay $\overline{B}_s \rightarrow D_{s2}^{*+} X \mu^- \nu$

arXiv:1102.0348 [hep-ex]

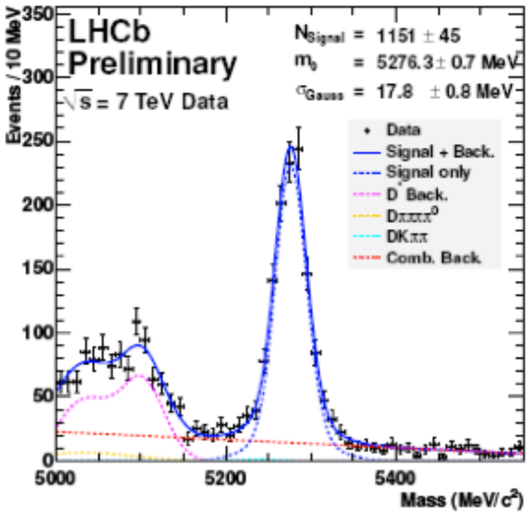


Also a clear demonstration of LHCb capabilities in reconstructing final states with missing particles

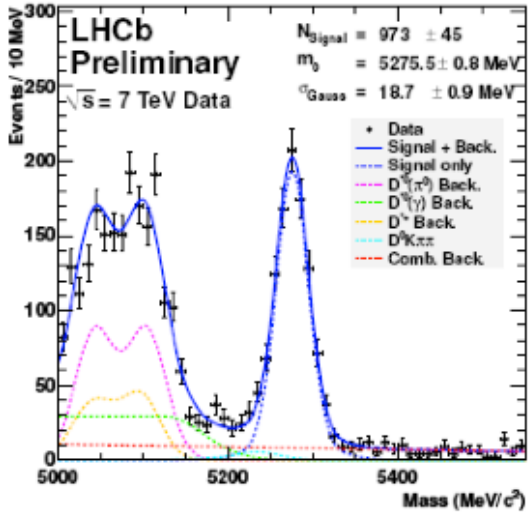
$$\frac{\mathcal{B}(\overline{B}_s^0 \to D_{s2}^{*+} X \mu^- \overline{\nu})}{\mathcal{B}(\overline{B}_s^0 \to X \mu^- \overline{\nu})} = (3.3 \pm 1.0 \pm 0.4)\%$$

Measurement of the Cabibbo-favoured Decays $X_b \to X_c\pi\pi\pi$

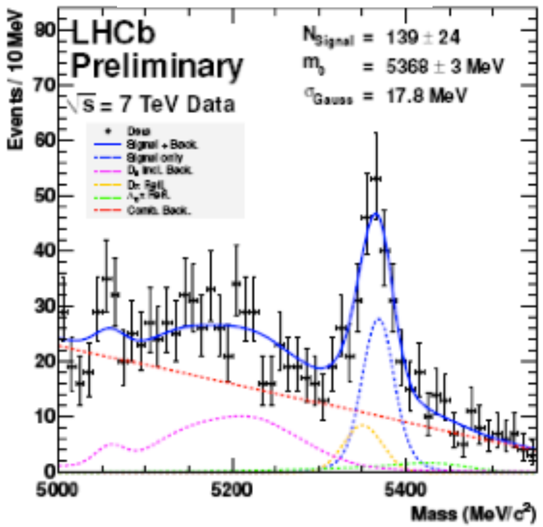
$B^0 \to D^-\pi^+\pi^-\pi^+$



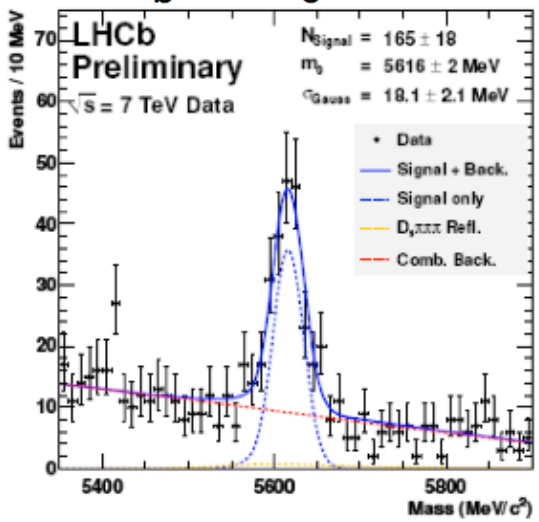
$B^+ \to D^0\pi\pi\pi$



$B_s \to D_s\pi\pi\pi$



$\Lambda_b \to \Lambda_c\pi\pi\pi$



$$\frac{BF(B^0 \to D^-(\pi^+\pi^-\pi^+))}{BF(B^0 \to D^-\pi^+)} = 2.36 \pm 0.11 \pm 0.24$$

$$\frac{BF(B^+ \to D^0(\pi^+\pi^-\pi^+))}{BF(B^+ \to D^0\pi^+)} = 1.26 \pm 0.07 \pm 0.12$$

$$\frac{BF(B_s \to D_s(\pi^+\pi^-\pi^+))}{BF(B_s \to D_s\pi^+)} = 2.22 \pm 0.41 \pm 0.25$$

$$\frac{BF(\Lambda_b^0 \to \Lambda_c^+(\pi^+\pi^-\pi^+))}{BF(\Lambda_b^0 \to \Lambda_c^+\pi^+)} = 1.33 \pm 0.15 \pm 0.14$$

Knowledge of branching fractions greatly improved over current PDG

Yields are 25-40% of the single π bachelor yields, helpful to increase statistics in some measurements, e.g. use $B_s \to D_s\pi\pi\pi$ to measure Δm_s

Cabibbo-suppressed decays to come soon…

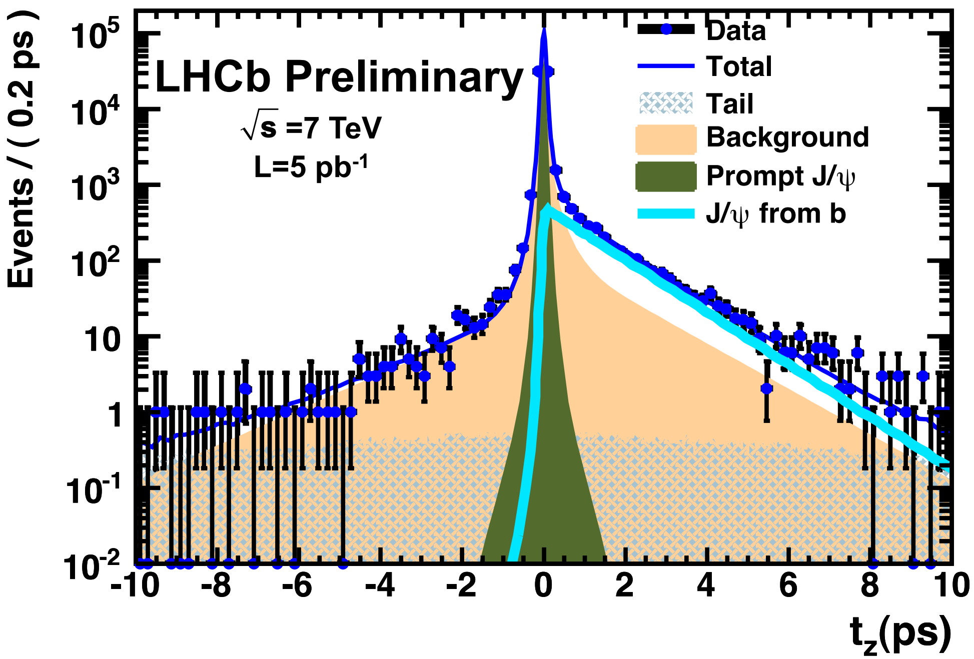
J/ψ cross-section measurement

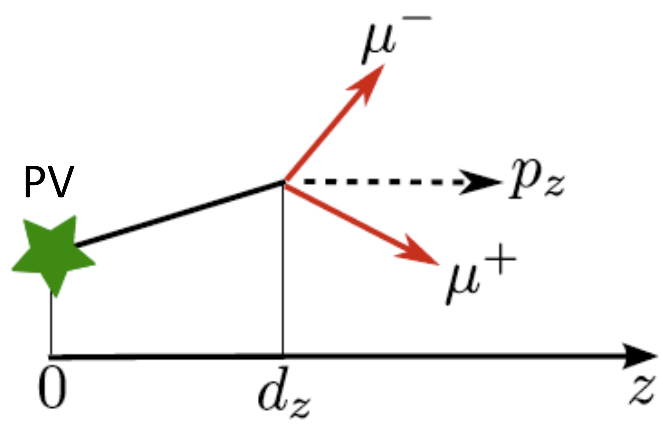
- Measured double differential cross-section as a function of the transverse momentum p_T and of the rapidity y
  - 14 p_T bins, $p_T < 14$ GeV/*c*
  - 5 y bins, $2 < y < 4.5$
- Measurement made separately for
  - Prompt J/ψ = direct J/ψ plus J/ψ from χ_c feed-down
  - J/ψ from *b* decays
- Used (5.2±0.5) pb^{-1} of data collected by end of September 2010

Separation of prompt J/ψ and J/ψ from B decays

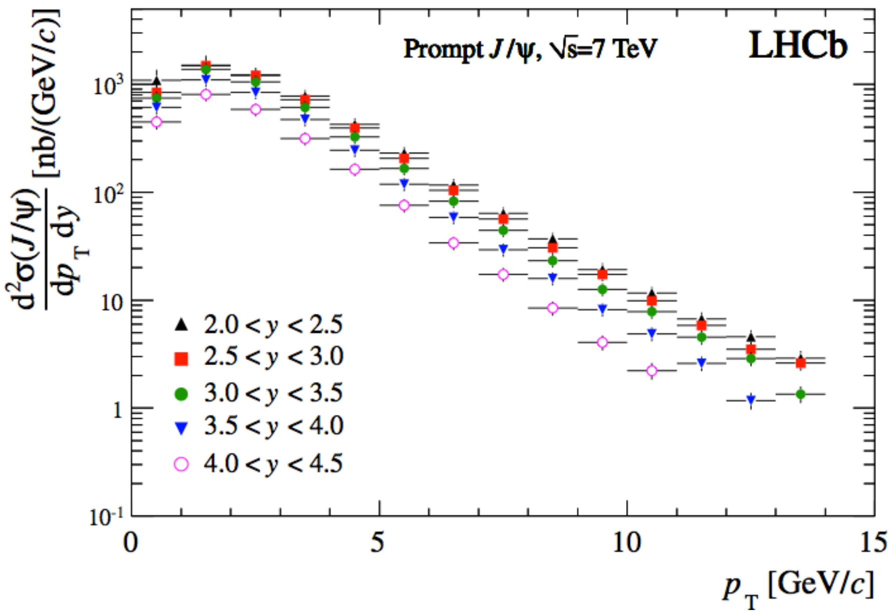
- Fraction of J/ψ from *b* is given by fit to the "pseudo propertime" t_z

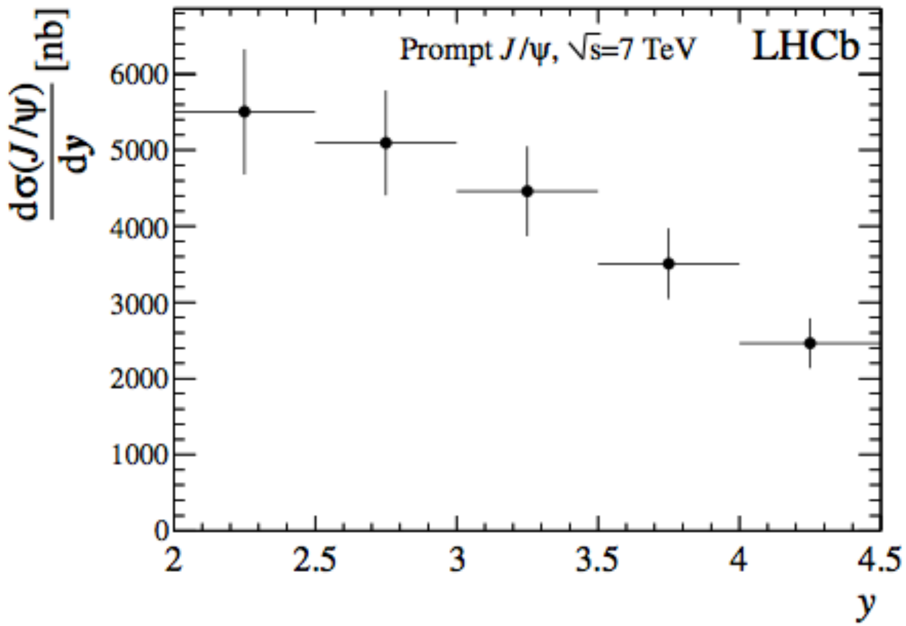
$$t_z(J/\psi) = \frac{\left(z_{J/\psi} - z_{PV}\right) \times M_{J/\psi}}{p_z}$$





Results: prompt J/ψ cross-section





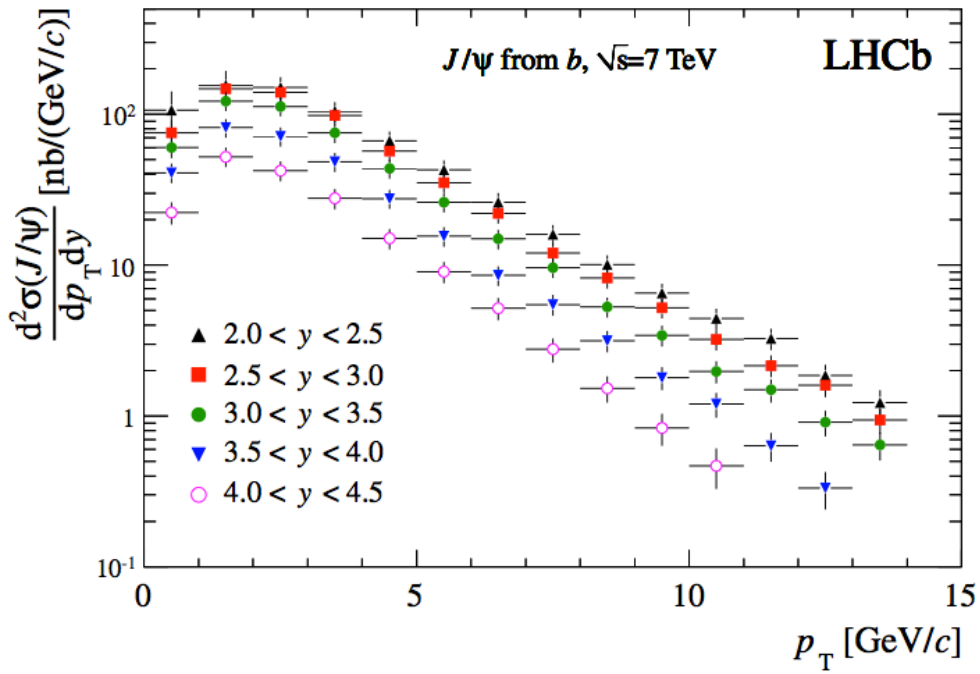
- Cross-section integrated over all bins

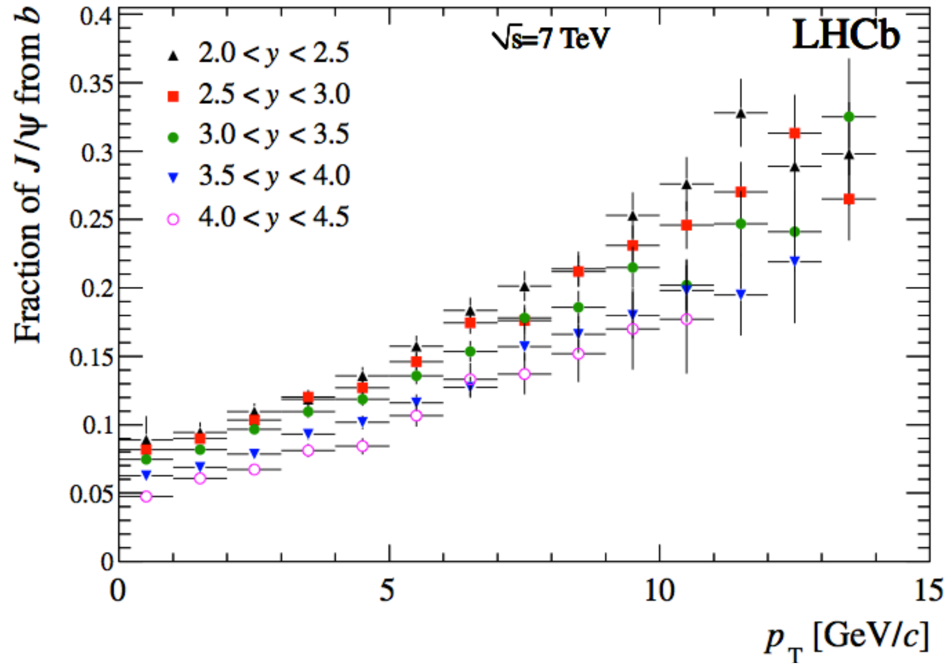
Stat. Syst.

$$\sigma\,(\text{prompt } J/\psi\,, p_T < 14\ \text{GeV}/c,\ 2.0 < y < 4.5) = 10.52 \pm 0.04 \pm 1.40^{+1.64}_{-2.20}\ \mu\text{b}$$

Last error takes into account the assumption of no J/ψ polarization

Results: J/ψ from *b* cross-section

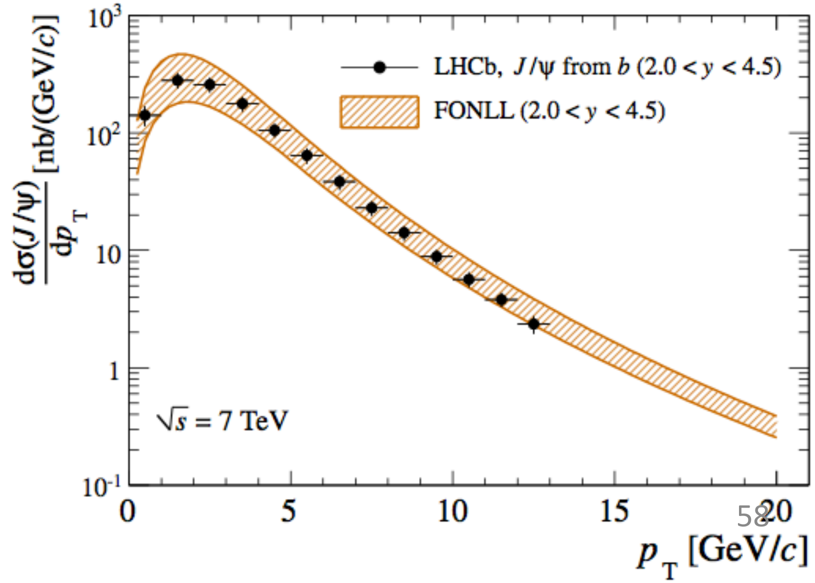




- Cross-section integrated over all bins

$$\sigma\,(J/\psi \text{ from } b,\, p_{\mathrm{T}} < 14\ \mathrm{GeV}/c,\, 2.0 < y < 4.5)$$

$$1.14 \pm 0.01 \pm 0.16\,\mu\mathrm{b}$$



Results: $b\bar{b}$ cross-section

- From the J/ψ from *b* cross-section, extrapolate to the total $b\bar{b}$ cross-section in 4π

$$\boxed{\sigma(pp \to b\bar{b}X) = 288 \pm 4 \pm 48\,\mu\text{b}}$$

- Excellent agreement with LHCb published value from $b \to D^0 \mu\nu X$, Phys. Lett. **B694** (2010) 209

$$\sigma(pp \to b\bar{b}X) = 284 \pm 20 \pm 49\,\mu\text{b}\,.$$

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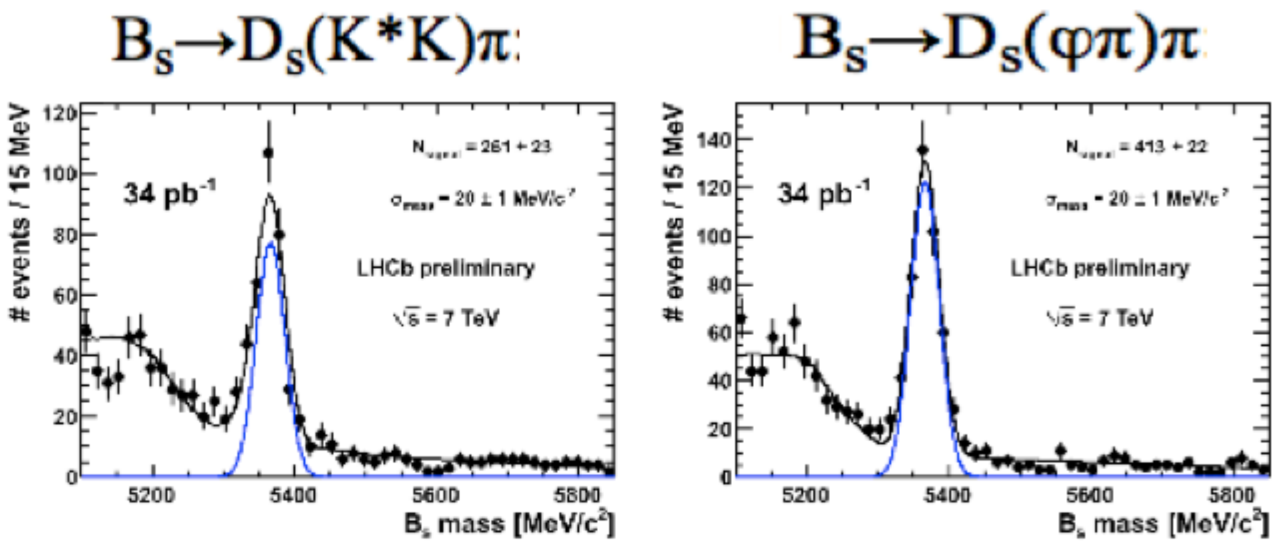
Prospects for γ measurement in $B_s \rightarrow D_s K$

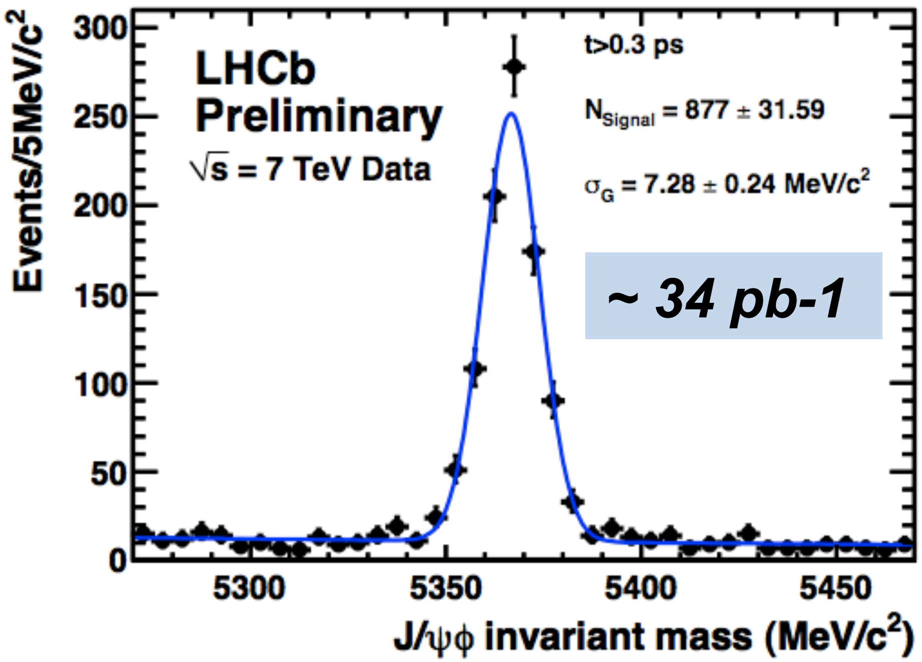
Large signals for $B_s \rightarrow D_s\pi$ useful for Δm_s measurement

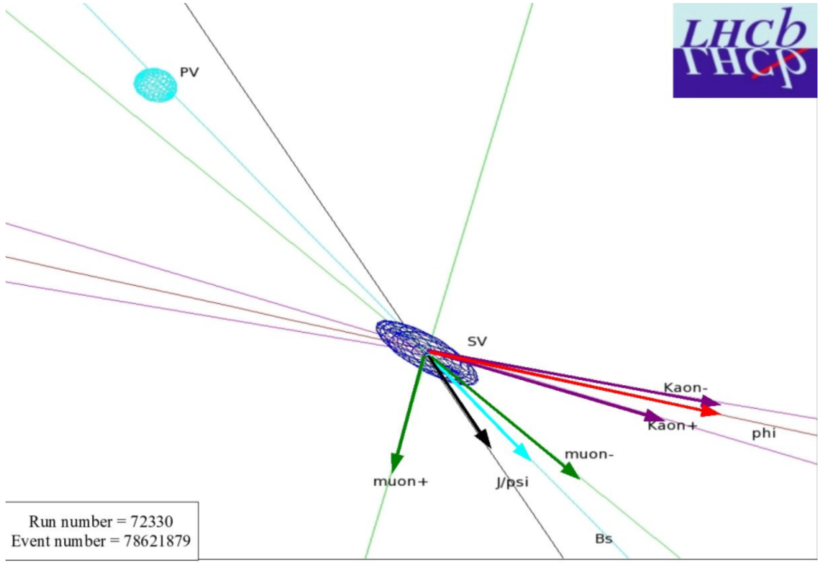


Expect world's first time-dependent CP violation analysis with $B_s \rightarrow D_s K$ in 2011

Combined sensitivity for γ in 2011/2012 run is ~7°

Very clean $B_s \rightarrow J/\psi\phi$ signal



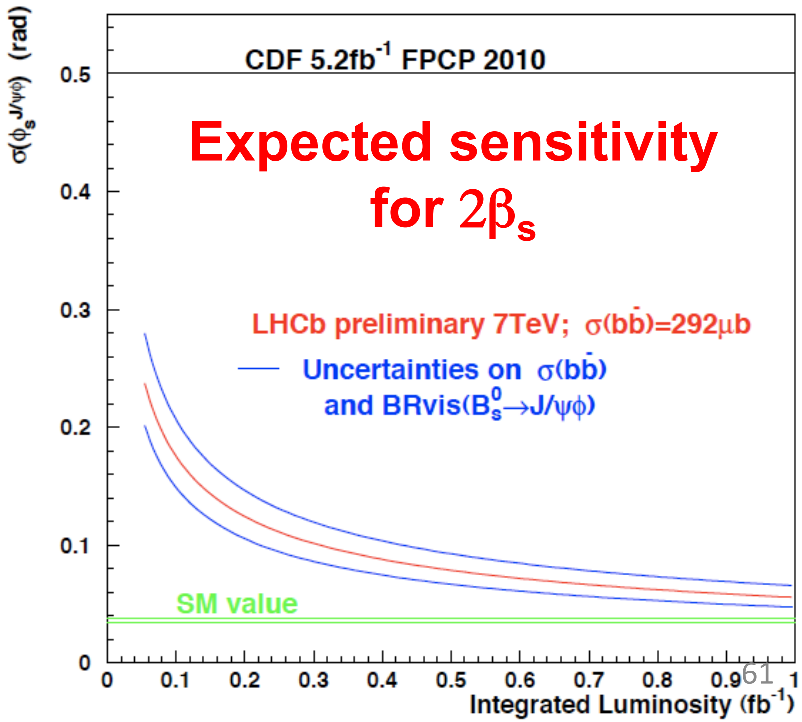


50k events / fb^{-1}: consistent with number of $B_s \rightarrow J/\psi\phi$ candidates seen in data

$<\sigma_t>$ = 0.040 ps: present time resolution worse in data but sufficient for Δm_s ~ 17.7/ps

Top secret

Δm_s and ϕ_s analyses will be unveiled at forthcoming conferences. Stay tuned!

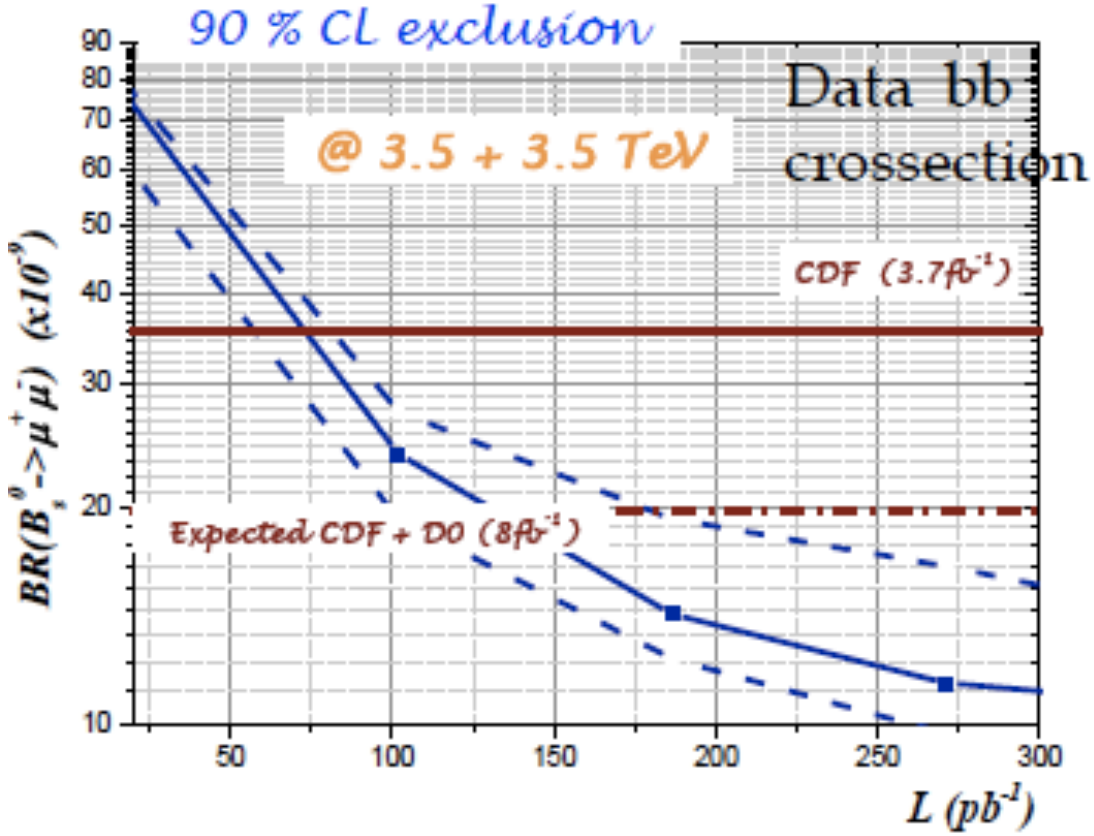


Prospects for $B_s \rightarrow \mu\mu$

For the SM prediction LHCb expects 10 signal events in 1 fb^{-1}

Background expected from MC is in good agreement with data

Very interesting sensitivity possible even with 37 pb^{-1} !!!



Top secret

See you in La Thuile/Moriond!

Conclusions

- In this seminar we have seen that already with the luminosity recorded during the 2010 run we have been able to
  - **Perform a complex CP violation analysis, with sensitivities close to current world averages**
  - **Reconstruct for the first time new decay modes, even inclusively, in the harsh hadronic environment of LHC**
  - **Reconstruct exclusive many-body hadronic B decays**
  - **Measure hidden charm and open beauty cross-sections**
- More to come at forthcoming conferences
  - $B_s \rightarrow \mu\mu$, Δm_s, ϕ_s and many others! Stay tuned!!!
- **We wish to thank colleagues in the CERN accelerator departments for the fantastic performance of the accelerator complex**
  - We will repay their work with best world precision measurements with 2011 data!

Ready for a new adventure!!!