Charmless two-body B-decays at LHCb

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on behalf of the LHCb Collaboration

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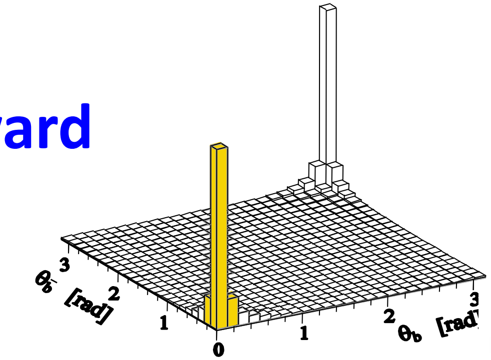
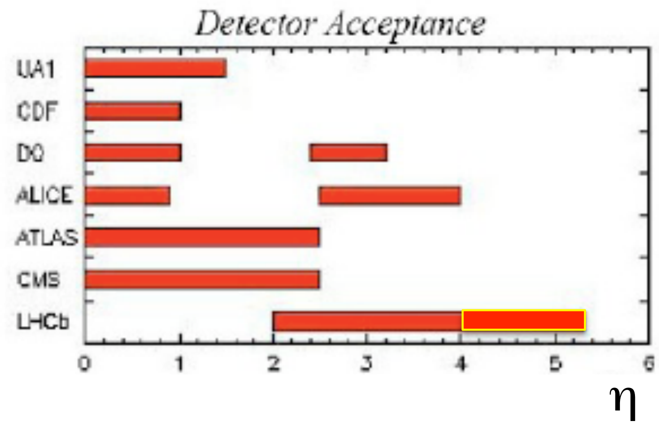
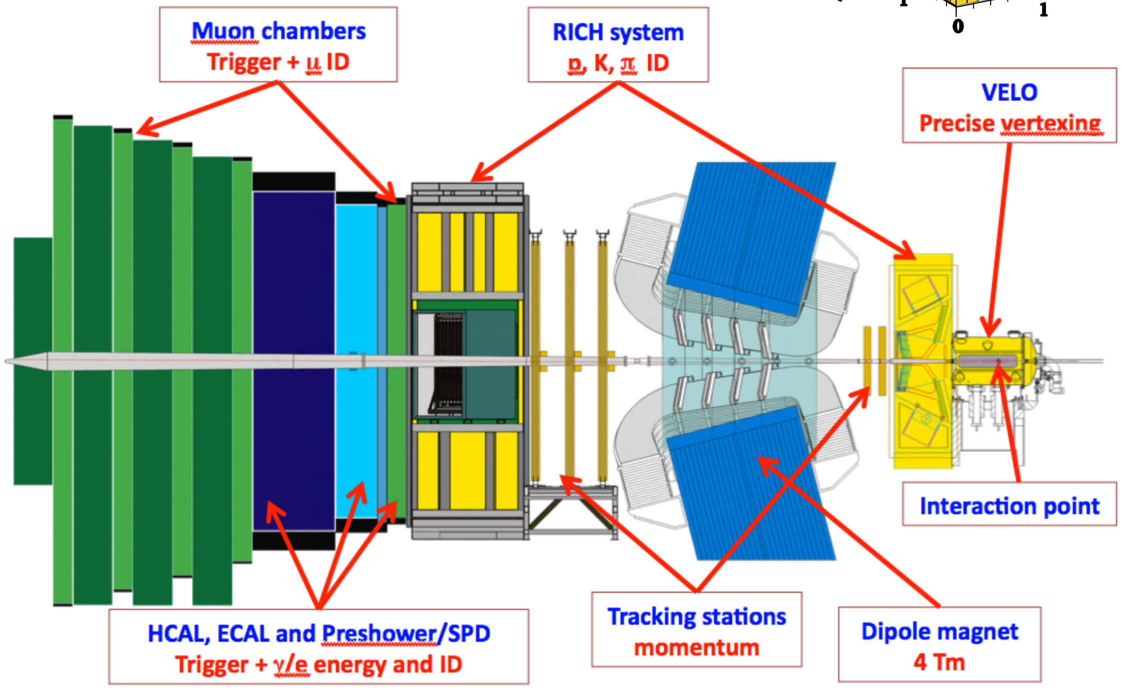
LHCb detector in brief

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



Fully instrumented forward spectrometer with unique acceptance capabilities at a hadronic collider





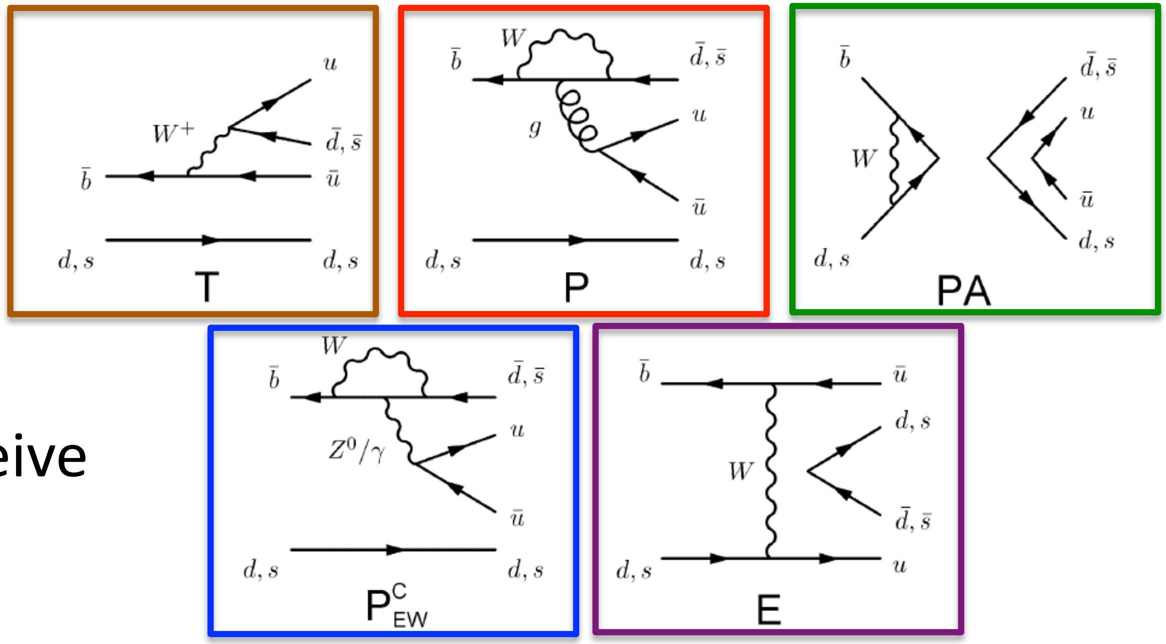
Possibility to invert magnetic field in order to control detector-induced charge asymmetries

so-called "magnet up" and "magnet down" data sets in this talk

For details on LHCb detector, trigger and overall performance see Neville Harnew's talk on Monday

The $H_b \rightarrow h^+h'^-$ family

- The family of $H_b \rightarrow h^+h'^-$ decays comprises several modes
  - H_b stands for B^0, B_s, Λ_b and h can be π, K, or p
- The decay amplitudes receive various contributions
  - **tree** diagrams
  - penguin diagrams, both **strong** and **electroweak**
  - also certain **penguin annihilation** and **exchange** topologies
- Relevant observables include
  - CP-averaged branching ratios
  - charge (direct) CP asymmetries in flavour-specific decays
  - time-dependent CP asymmetries in decays to CP eigenstates



~~CP~~ in $B^0 \to \pi^+\pi^-$ and $B_s \to K^+K^-$ decays

- The direct and mixing induced CP asymmetries in the $B^0 \to \pi^+\pi^-$ and $B_s \to K^+K^-$ modes are related to the angle γ and the B^0 and B_s mixing phases ϕ_d and ϕ_s **R. Fleischer, PLB 459 (1999) 306 … R. Fleischer and R. Knegjens EPJ C71 (2011) 1532**

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

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

where d, d', ϑ, ϑ' are hadronic quantities

- Diagrams of the decays $B^0 \to \pi^+\pi^-$ and $B_s \to K^+K^-$ differ only by the **interchange of the d and s quarks → U-spin symmetry**
  - predicts **d=d'** and **$\vartheta=\vartheta'$**
- By measuring time-dependent CP violation in these modes, within the validity of U-spin symmetry, the **angle γ and the mixing phase ϕ_s can be extracted**
  - sensitivity studies in the LHCb Roadmap document [arXiv:0912.4179]

$B^0 \rightarrow K^+\pi^-$ and $B_s \rightarrow \pi^+K^-$

- By U-spin symmetry and neglecting **penguin annihilation** and **exchange** topologies we also expect

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

  which can also **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 $B_s \rightarrow \pi^+\pi^-$

$B_s \rightarrow K^+K^-$ lifetime

- $B_s \rightarrow K^+K^-$ dominated by light mass eigenstate

$$\Gamma(t) \propto Ae^{-\Gamma_L t} + Be^{-\Gamma_H t}$$ → ***B* is small**

- Fitting a single exponential to the decay rate gives an effective lifetime

$$\tau(B_s^0 \to K^+K^-) = \frac{A/\Gamma_L^2 + B/\Gamma_H^2}{A/\Gamma_L + B/\Gamma_H}$$

- From the Standard Model $\tau(B_s^0 \to K^+K^-) \approx 1.39 \text{ ps}$

CP violation measurements in this talk

- We provide preliminary values of **direct CP violation** in $B^0 \rightarrow K^+\pi^-$ and $B_s \rightarrow \pi^+K^-$ decays obtained with about 37 pb^{-1} of integrated luminosity
  - no time dependence, hence no tagging, but…
  - must separate **many decay modes** sitting one on top of the other
    - peaking backgrounds due to mis-identified particles in the final state are present
  - must cope with **instrumental charge asymmetries** and with **B meson production asymmetries**
    - LHCb is a single-arm forward spectrometer at a p-p collider → flavour-asymmetric initial state and "beam-drag" effects

LHCb-CONF-2011-011

Experimental knowledge up to Beauty 2011

- 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, arXiv:1103.5762 [hep-ex]

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

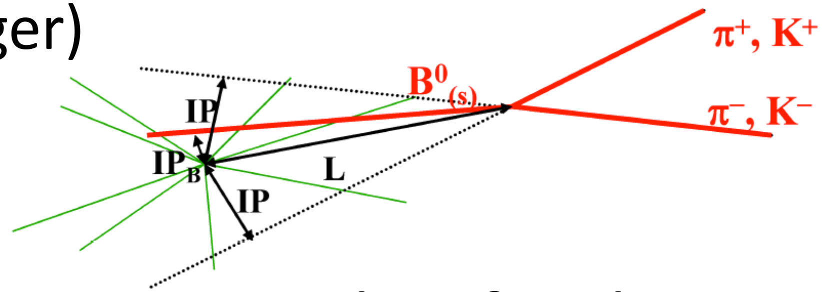
- CP violation established at ~9σ in $B^0 \rightarrow K^+\pi^-$ but **still an open issue** in $B_s \rightarrow \pi^+K^-$

CDF with 1 fb^{-1}

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

Trigger and event selection at LHCb

- **Excellent performance of the hadronic trigger**
  - Look for large E_T clusters in the hadronic calorimeter (Level-0) and high p_T tracks with large impact parameter with respect to the primary vertex (High Level Trigger)



- Then offline, we make use of **two sets of kinematic selection cuts**, optimized to get the best sensitivity either for the measurements of $A_{CP}(B^0 \to K^+\pi^-)$ or $A_{CP}(B_s \to \pi^+K^-)$

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

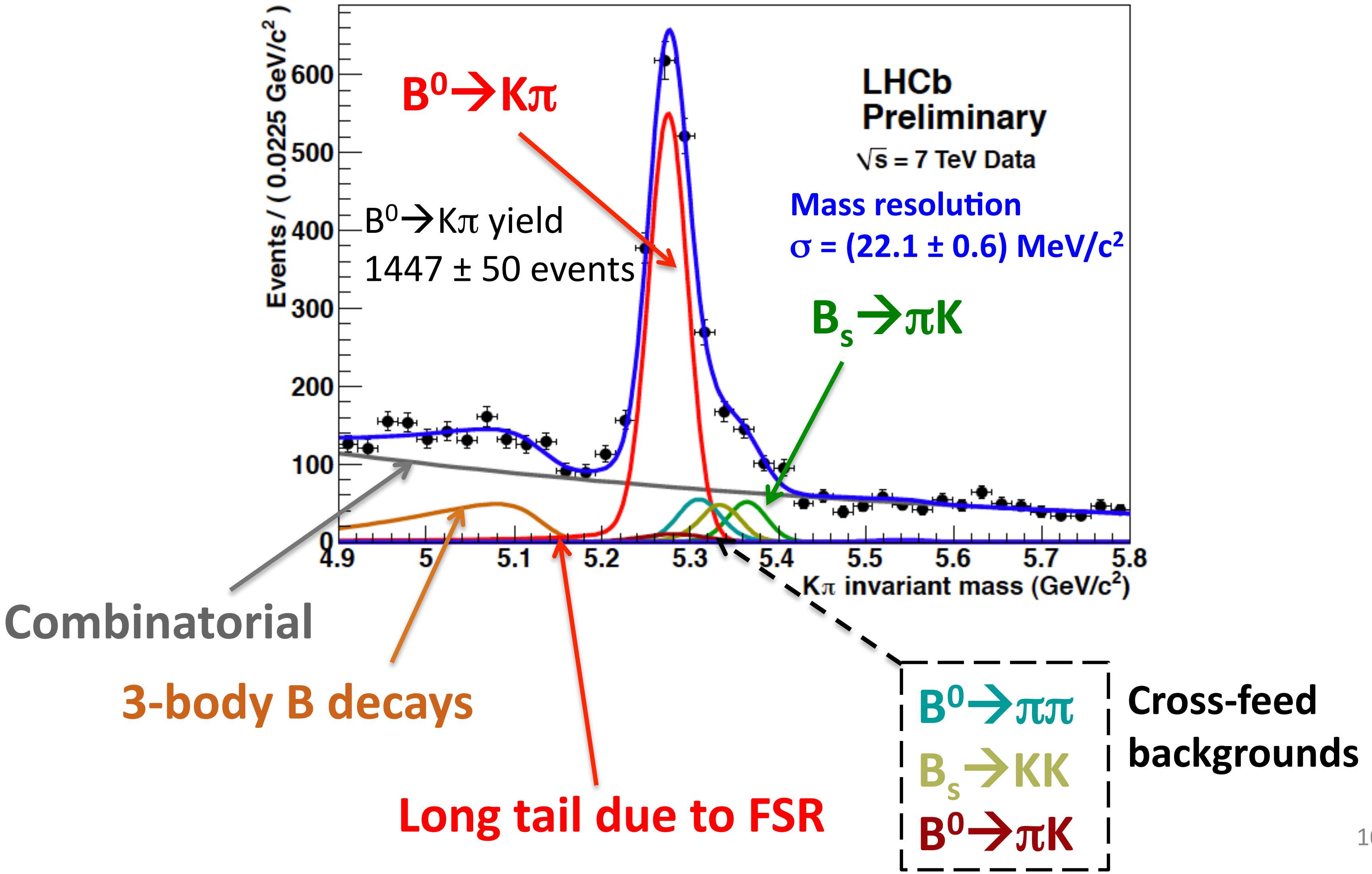
Cut type	Accepted regions
Track p_T [GeV/c]	> 1.2
Track IP [μm]	> 200
Track χ^2/d.o.f.	< 3
$\max(p_T^{h^+}, p_T^{h'^-})$ [GeV/c]	> 3
$\max(IP^h, IP^{h'^-})$ [μm]	> 400
p_T^B [GeV/c]	> 2.4
$\tau_{\pi\pi}^B$ [ps]	> 1.2

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

RICH particle identification

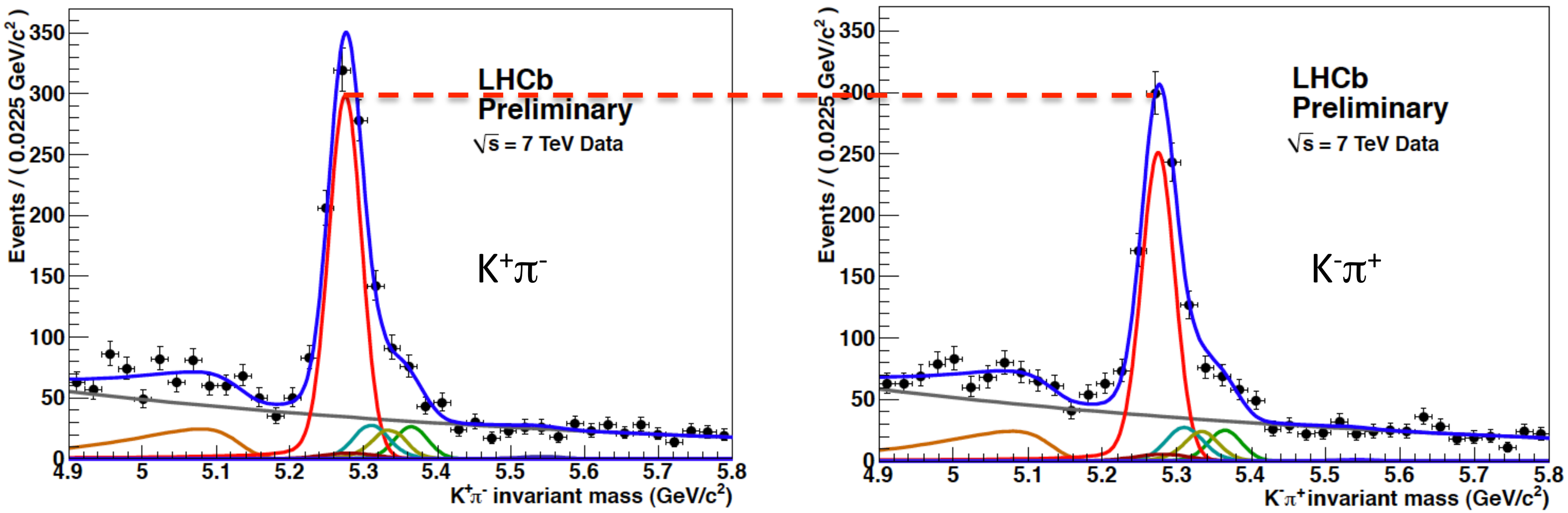
- **Crucial aspect of this analysis**
  - Events passing the kinematic selection are separated into different final states using RICH PID capabilities
- PID calibration
  - made using $D^* \to D^0(K\pi)\pi$ and $\Lambda \to p\pi$ decays
    - their phase space is different with respect to $B \to h^+h'^-$ decays
  - **RICH performance depends on phase space**
    - need event reweighting in momentum and transverse momentum to achieve good match
- PID criteria are able to identify mutually exclusive samples for each mass hypothesis of interest
  - $K^+\pi^-$, $K^-\pi^+$, $\pi^+\pi^-$, K^+K^-, pK^-, $\bar{p}K^+$, $p\pi^-$, $\bar{p}\pi^+$

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



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

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

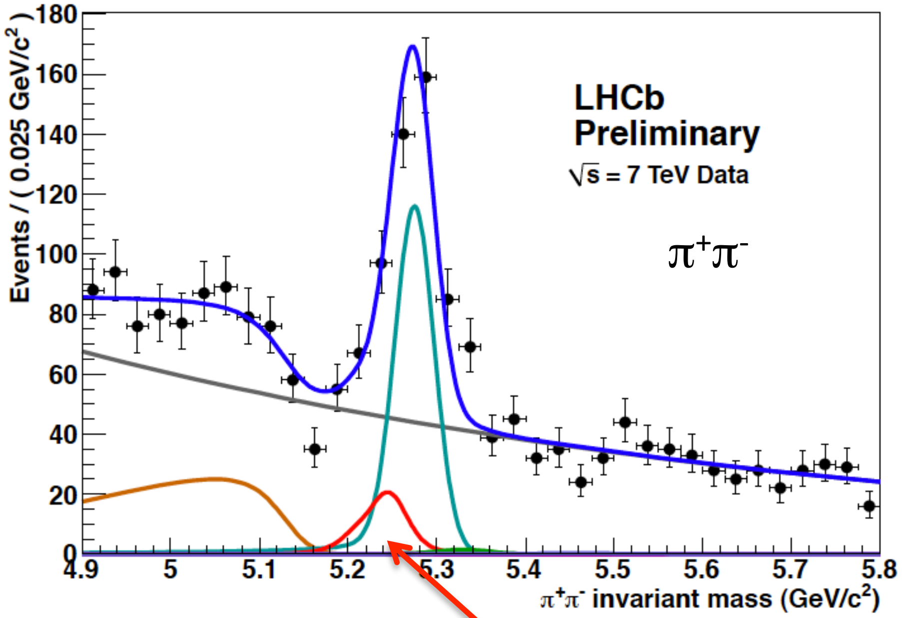


Raw CP asymmetry clearly visible from the plots

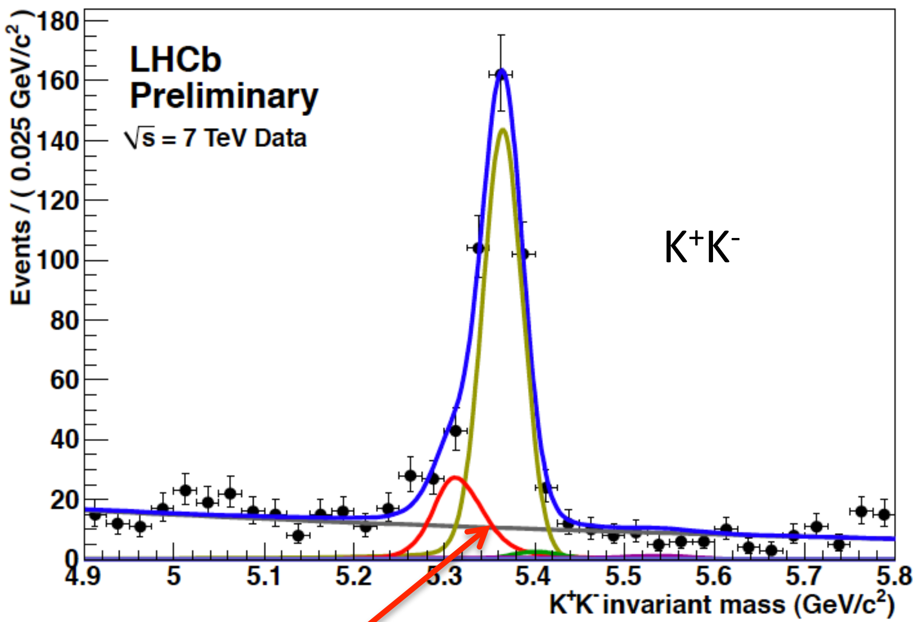
$\pi^+\pi^-$ and K^+K^- mass spectra

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

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



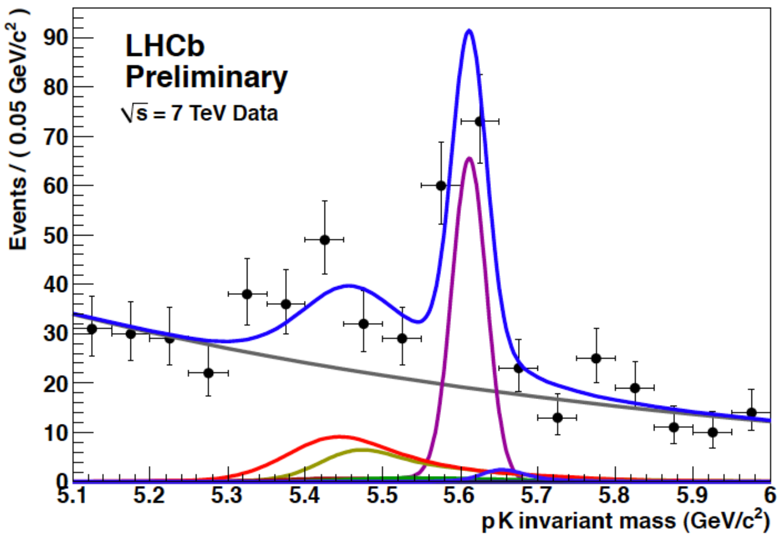
$B_s \rightarrow KK$ yield: 333 ± 21 events



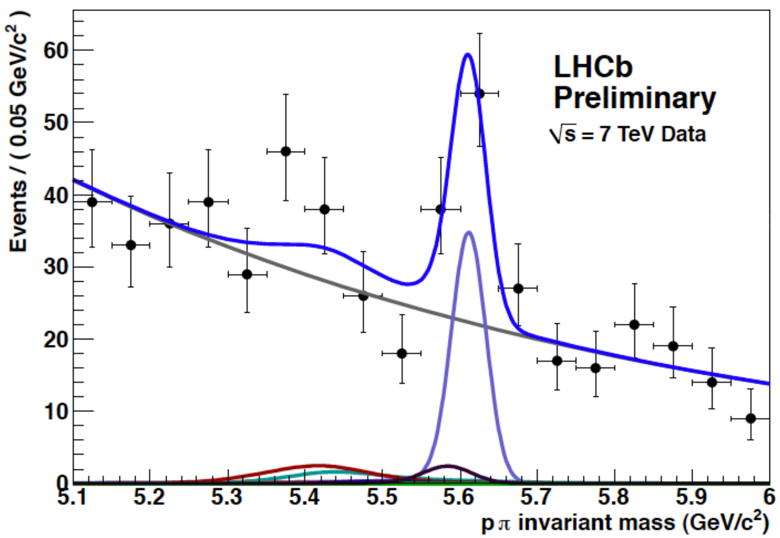
Cross feed background dominated by $B^0 \rightarrow K\pi$ decays

$\Lambda_b \rightarrow pK$ 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



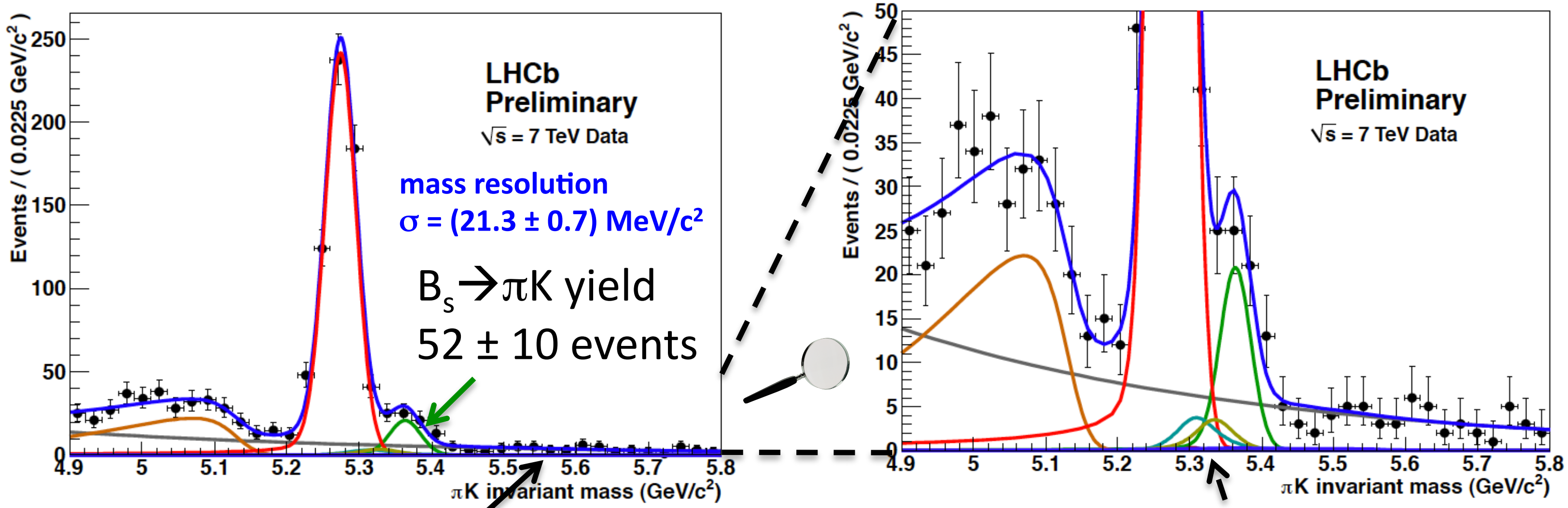
$\Lambda_b \rightarrow p\pi$ yield: 41 ± 10 events



Selection not optimized for best sensitivity on yields of these modes, but clear signals are observed

Kπ mass spectrum

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



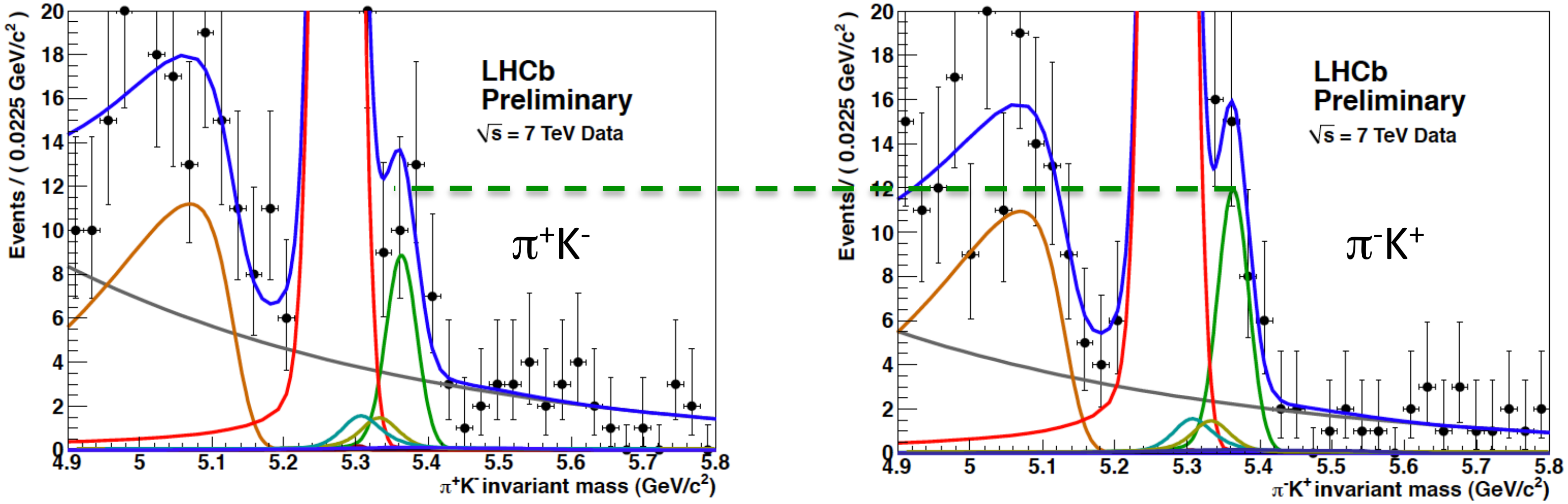
Tighter kinematic and PID selection cuts provide strong suppression of combinatorial background events

$B^0 \rightarrow \pi\pi$

$B_s \rightarrow KK$

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

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

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

Raw asymmetry measured in data

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

Production asymmetry

- κ is a selection dependent factor

Acceptance as function of the proper decay time

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

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

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 (method)

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

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

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

$A_{CP} \to$ physical asymmetries

$A_D \to$ instrumental asymmetries

$A_P \to$ production asymmetries

The "*" identifies the D* tagged modes

Same formalism is used to determine the D^0 production asymmetry at LHCb
See talk by Alexandr Kozlinskiy

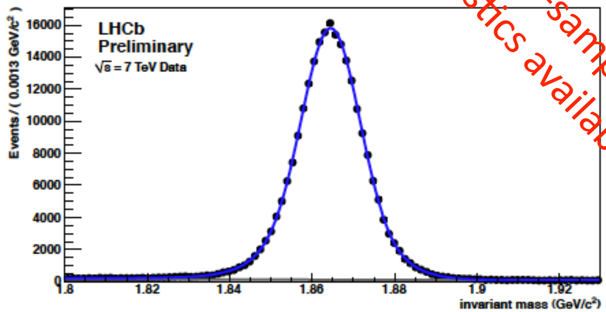
Instrumental asymmetry (results)

- Integrated raw CP asymmetries are extracted by means of maximum likelihood fits made in **M(D^0)** for D^0→Kπ and **M(D*)-M(D^0)+M(D^0)$_{PDG}$** for D* tagged modes

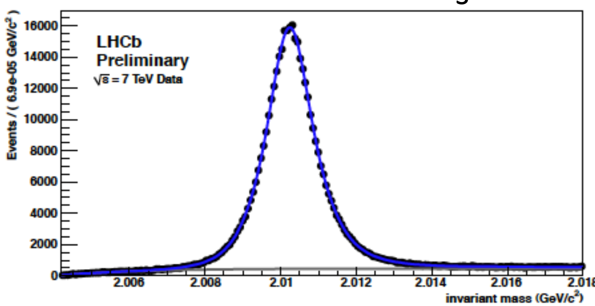
Plots for sub-samples of total statistics available

Mode	Yield [10^6]	Mode	Yield [10^6]
Untagged D^0→Kπ	~4.5	D*→D^0(KK)π_s	~0.1
D*→D^0(Kπ)π_s	~0.9	D*→D^0($\pi\pi$)π_s	~0.03

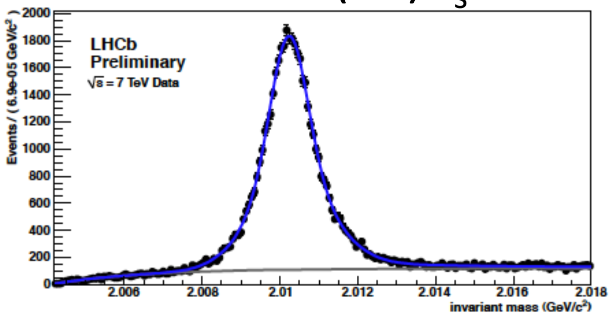
D^0→Kπ



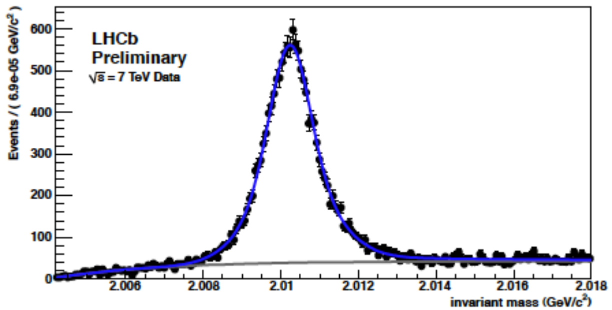
D*→D^0(Kπ)π_s



D*→D^0(KK)π_s



D*→D^0($\pi\pi$)π_s

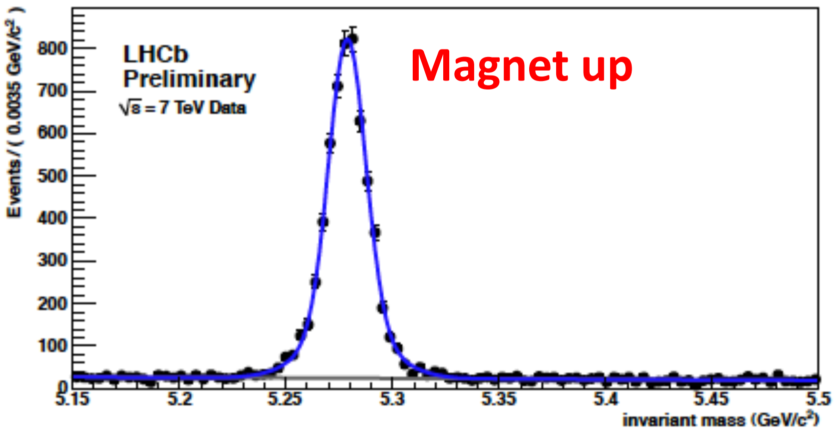


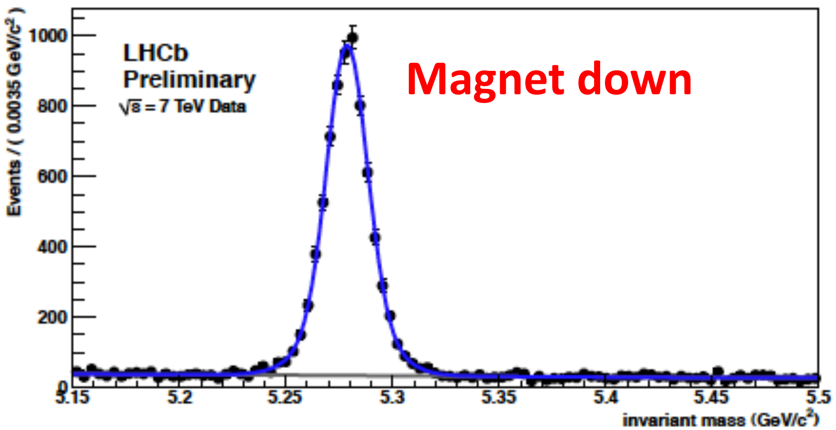
- Using world averages of the physical asymmetries we can solve the system of equations for the instrumental asymmetry A$_D$(Kπ)

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

averaged between magnet up and magnet down data

Production asymmetry





- B meson production asymmetry has been studied using **$B^+ \rightarrow J/\psi(\mu^+\mu^-)K^+$ decays**

- 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 $B^+ \rightarrow J/\psi(\mu^+\mu^-)K^+$ decays, we get a **preliminary value for the production asymmetry for charged B mesons**

$$A_P(B^+) = -0.024 \pm 0.013$$

- With the aid of Monte Carlo fragmentation models we estimate the production asymmetry **$A_P(B^0)$ to differ from $A_P(B^+)$ by 1% at most**, i.e.

$$A_P(B^0) = -0.024 \pm 0.013 \pm 0.010$$

Preliminary

Correcting the raw 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

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

$A_P(B^0) = -0.024 \pm 0.017$

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 2.4%, the **central values of $A_{CP}(B_s \to \pi^+K^-)$ is practically unaffected**

Systematic uncertainties and results

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

Systematic uncertainty	$A_{CP}(B^0 \to K^+\pi^-)$	$A_{CP}(B_s^0 \to \pi^+K^-)$
PID calibration	0.0021	0.001
Final state radiation	0.0034	0.011
Signal model	0.0019	0.009
Combinatorial background model	negligible	0.013
Cross-feed background model (shift)	0.0009	0.005
Cross-feed background model (smearing)	0.0006	0.006
Instrumental asymmetry	0.0042	0.004
Production asymmetry	0.0054	negligible
Total	0.0082	0.021

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

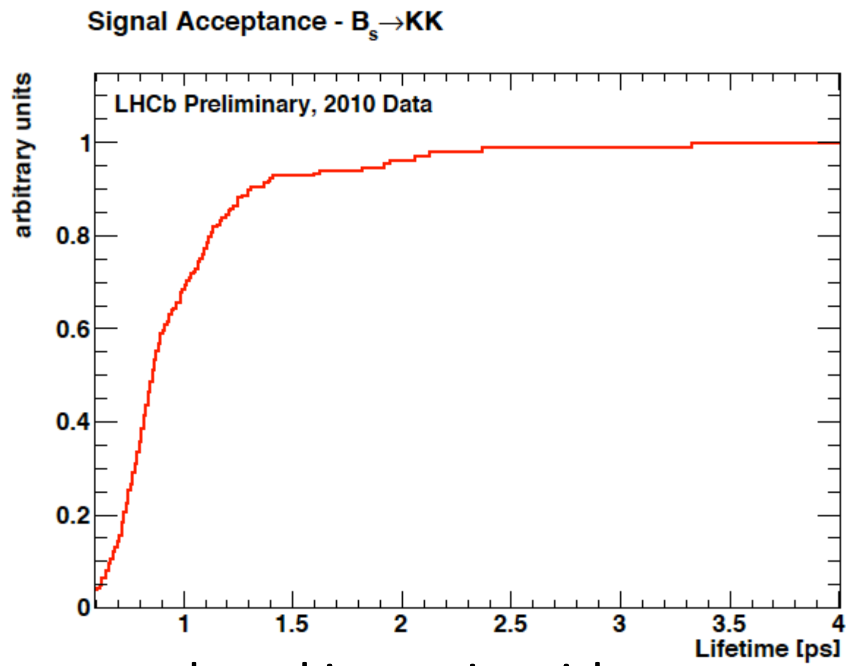
$$A_{CP}(B_s^0 \to \pi^+K^-) = 0.15 \pm 0.19 \pm 0.02$$

Preliminary

$B_s \rightarrow K^+K^-$ lifetime measurement

NEW

- Trigger and offline selection sculpt the measured proper decay time distribution
  - low proper time values are suppressed by impact parameter cuts etc., needed to reject huge combinatorial background from primary vertices
  - this **"acceptance" as a function of the proper decay time** must be corrected for



- Two methods used at LHCb
  - **Relative measurement**: cancels acceptance by taking ratio with kinematically similar decay
  - **Absolute measurement**: uses data-driven technique to calculate acceptance, then accounted for in the lifetime fit

LHCb-CONF-2011-018

Relative Lifetime method

- Observed decay rate as a function of the proper time

$$\Gamma_{obs}(t) = [\Gamma(t') \otimes R(t-t')] \cdot \varepsilon(t)$$

- $B^0 \rightarrow K^+\pi^-$ and $B_s \rightarrow K^+K^-$ have very similar kinematics and acceptances are the same with good accuracy
  - $B^0 \rightarrow K^+\pi^-$ is used as reference mode since it has the largest yield amongst the $H_b \rightarrow h^+h'^-$ decays

$$R(t) = \frac{[\Gamma_{B_s^0 \to K^+K^-}(t') \otimes R(t-t')] \cdot \cancel{\varepsilon_{B_s^0 \to K^+K^-}(t)}}{[\Gamma_{B^0 \to K^+\pi^-}(t') \otimes R(t-t')] \cdot \cancel{\varepsilon_{B^0 \to K^+\pi^-}(t)}}$$

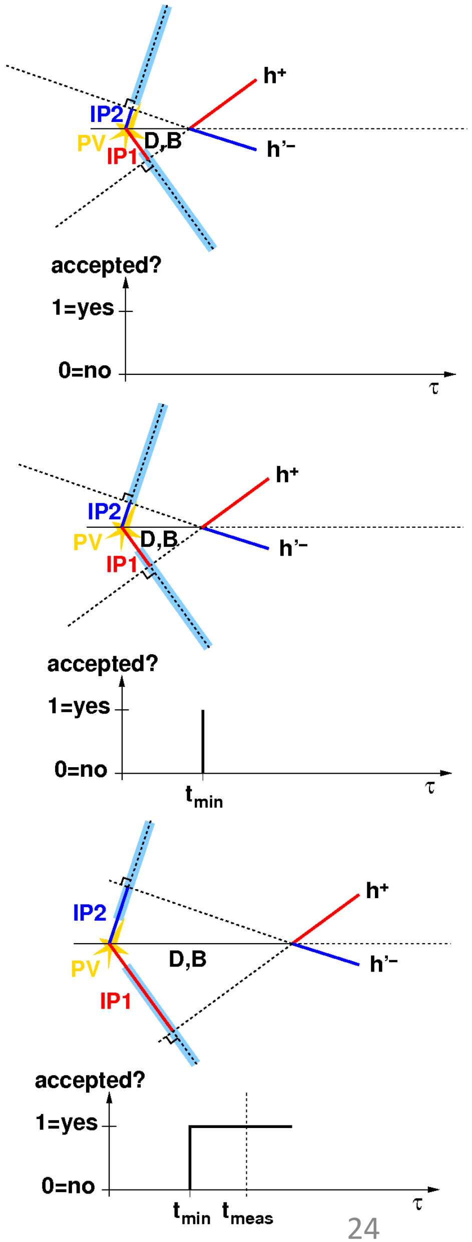
- To a good approximation this ratio becomes

$$R(t) = e^{-\left(\Gamma_{B_s^0 \to K^+K^-} - \Gamma_{B^0 \to K^+\pi^-}\right)t}$$

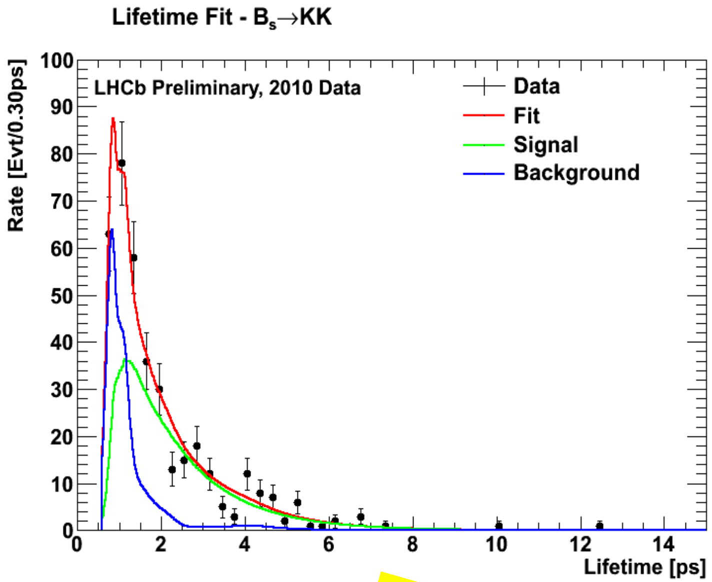
- By using the world knowledge of the B^0 lifetime one can extract the $B_s \rightarrow K^+K^-$ lifetime

Absolute Lifetime Method

- Acceptance determined on an event-by-event basis
  - move primary vertex along the B_s momentum vector
  - acceptance decision determined for all hypothetical lifetimes
- Non-parametric description of background lifetime p.d.f.
  - weighted sum of Gaussian "kernels"
- Completely data-driven analysis → no MC input



The two methods independently give consistent results with very similar sensitivities within the present statistics



$\tau(B_s \rightarrow K^+K^-) = (1.440 \pm 0.096 \pm 0.010)$ ps

Preliminary

Conclusions

Using an integrated luminosity of **~37 pb^{-1}** collected during the 2010 run we provide **preliminary** values of the **direct CP asymmetries**

$$A_{CP}(B^0 \to K^+\pi^-) = -0.074 \pm 0.033 \pm 0.008 \quad A_{CP}(B_s^0 \to \pi^+K^-) = 0.15 \pm 0.19 \pm 0.02$$

Our results are in agreement with current world knowledge (HFAG)

$$A_{CP}(B^0 \to K^+\pi^-) = -0.098^{+0.012}_{-0.011} \qquad A_{CP}(B_s^0 \to \pi^+K^-) = 0.39 \pm 0.17$$

In 2011 we expect ~1 fb^{-1} → **will dominate the world averages for the time integrated asymmetries** (relevant improvements expected already for the summer conferences) and will be able to provide first measurements of time-dependent CP asymmetries in $B^0 \to \pi^+\pi^-$ and $B_s \to K^+K^-$

We also measure the **$B_s \to K^+K^-$ lifetime** using two complementary methods yielding consistent results

Our **preliminary** value is

$$\tau(B_s \to K^+K^-) = (1.440 \pm 0.096 \pm 0.010)\ ps$$

NEW