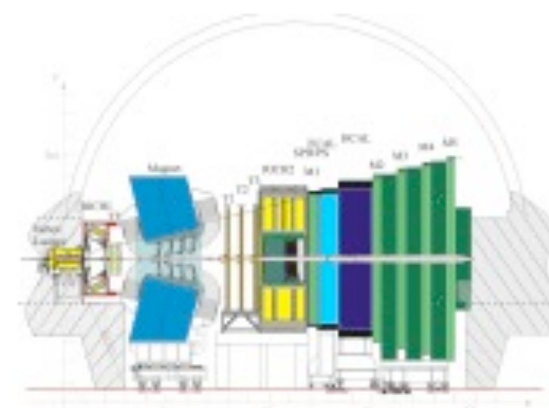
CP violation measurements at LHCb and searches for New Physics



Fred Blanc
EPFL

on behalf of the LHCb Collaboration

23rd Rencontres de Blois
(Particle Physics and Cosmology)
Blois, May 29th - June 3rd, 2011

Introduction

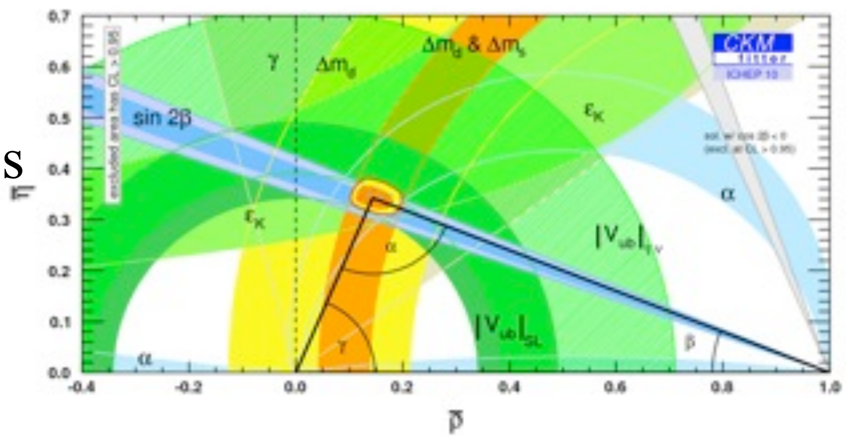
- LHCb physics goals:
  - precision tests of the Standard Model and search for New Physics
- Phenomena under study
  - *CP* violation in B and D decays (this talk)
  - rare decays (see talk by O. Deschamps)
  - direct searches for New Physics in the forward region

Indirect searches for New Physics

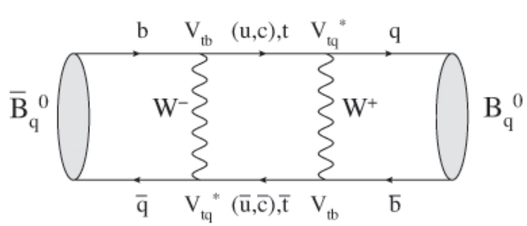
- Finding New Physics (NP) at low energy
  - heavy NP particles can alter amplitude of loop processes
- New Physics can either:
  - be discovered in precision measurements and then confirmed with direct searches (e.g. @ ATLAS and CMS)
  - or NP particles are first observed at the energy frontier, and their properties then studied in precision measurements at ‘low’ energy

CP violation measurements

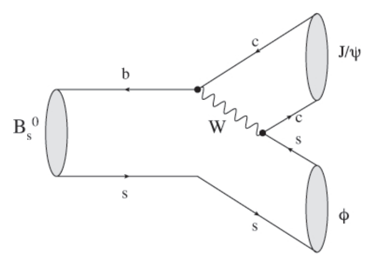
- Unitarity Triangle (B^0 decays)
  - β is very well measured at B factories
    - LHCb will also measure β
  - γ from hadronic B decays at LHCb



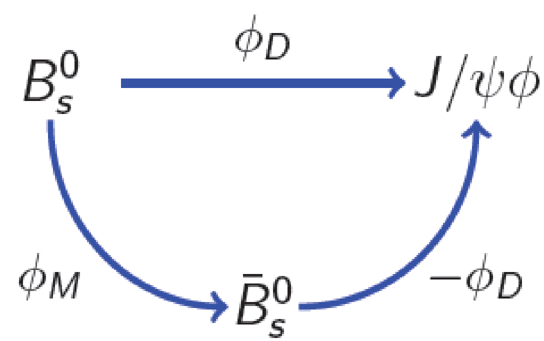
- In B_s system, probe phase of CKM element V_{ts}
  - measure interference between decay and mixing



$\phi_M^{SM} = -2\arg(V_{ts}V_{tb}^*) \approx -2\beta_s$



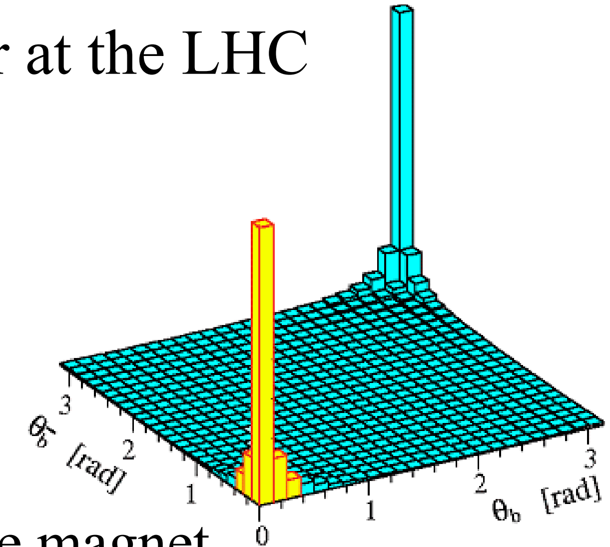
$\phi_D^{SM} = -2\arg(V_{cs}V_{cb}^*) \approx 0$

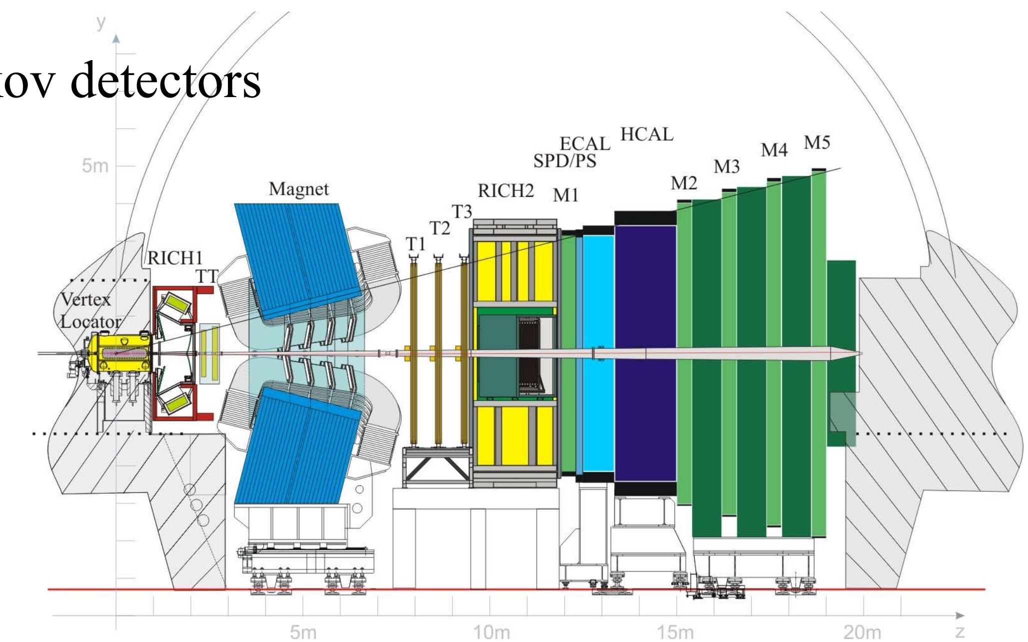


  - in SM, $\phi_s^{SM} = \phi_M - 2\phi_D = -0.0363 \pm 0.0017$ rad [CKM fitter]
  - NP contribution can modify this parameter: $\phi_s = \phi_s^{SM} + \Delta\phi_s^{NP}$

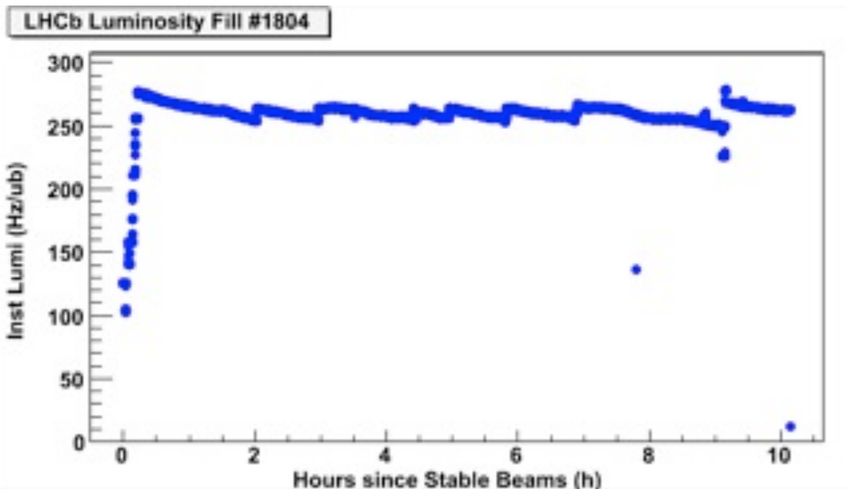
The LHCb detector

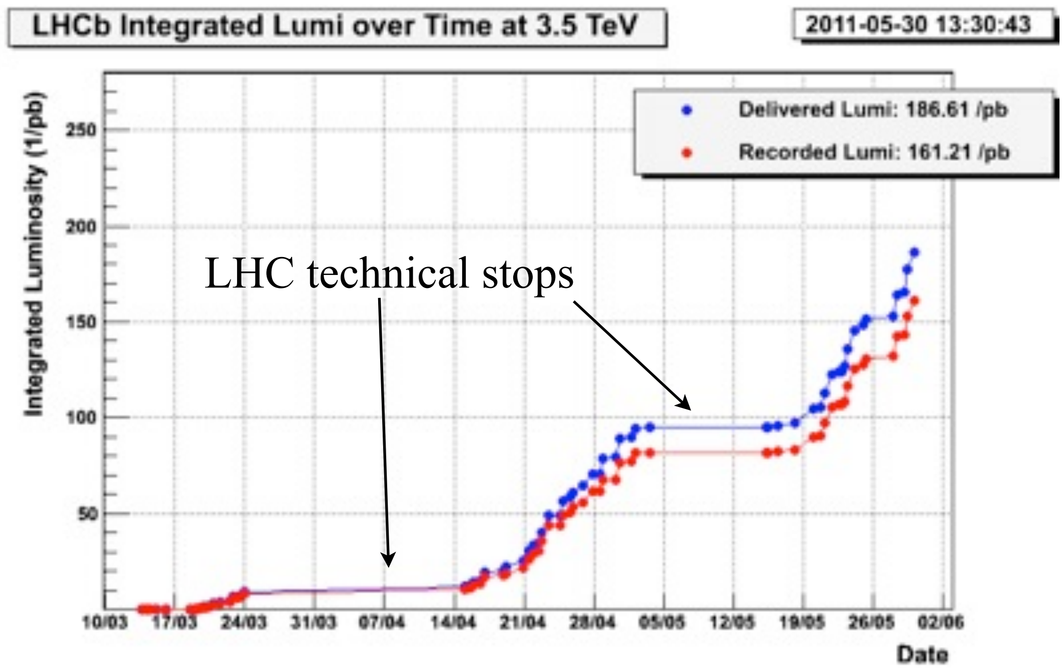
- LHCb is a single-arm forward spectrometer at the LHC
  - rapidity range: $1.9 < \eta < 4.9$
- Fully instrumented in the forward region
  - excellent vertex resolution (+boost)
    → ~50fs lifetime resolution
  - tracking stations before and after 4Tm dipole magnet
  - particle identification with
    - two ring-imaging Cherenkov detectors
    - calorimetry
    - muon detectors





LHCb detector performance

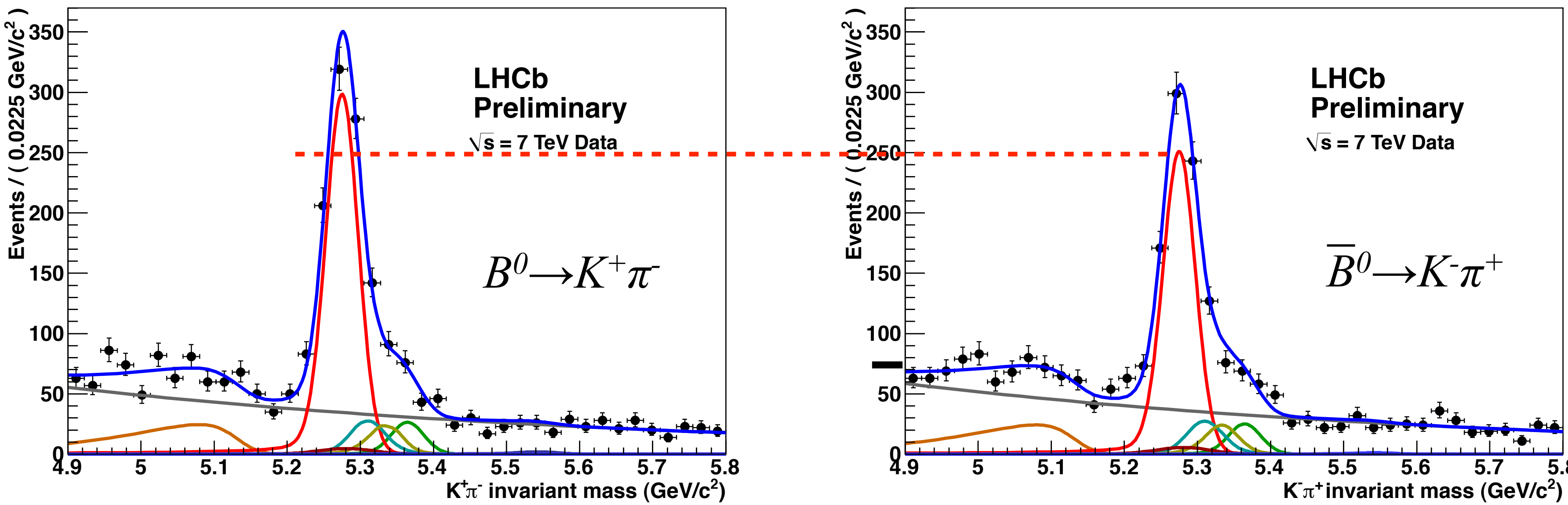




- All subsystems working at design specifications
- LHCb collecting data >85% of stable beam time
- Pile up from multiple pp collisions from LHC bunch crossing to be tuned to maximize performance
  - increasing pile up => more b hadrons... ✔
    ...but more combinatorial background ✖
- Solution: luminosity "leveling" during LHC spill
  => keep approximately constant pile up over spill lifetime
- Recorded 37pb^{-1} at 7TeV in 2010, and >160pb^{-1} since March 2011
- Expect ≈1fb^{-1} in 2011

Direct CP violation at LHCb

- Measured direct CP asymmetry in $B \to K^+\pi^-$
  - based on 37pb^{-1} collected in 2010 at 7TeV
- Kinematic and particle identification (PID) variables used for selection optimizing sensitivity to CP violation



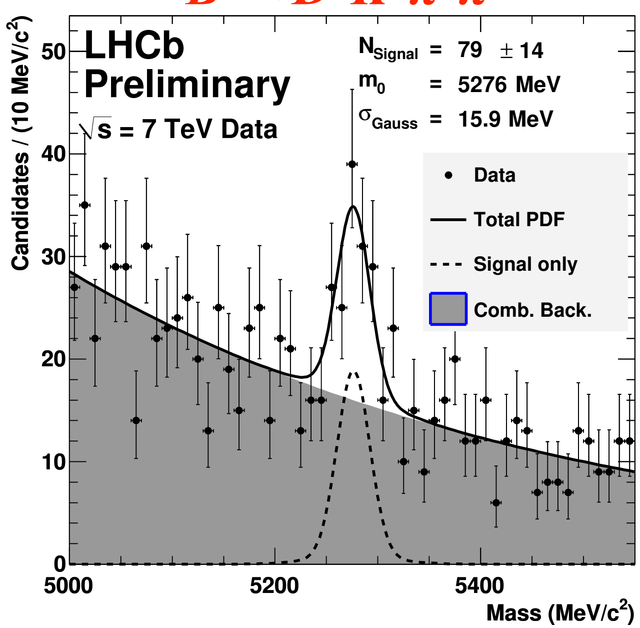
	LHCb [PRELIMINARY]	HFAG
$A_{CP}(B^0 \to K^+\pi^-)$	$-0.074 \pm 0.033_{stat} \pm 0.008_{syst}$	-0.098 ± 0.012
$A_{CP}(B_s \to \pi^+K^-)$	$0.15 \pm 0.19 \pm 0.02$	0.39 ± 0.17

Measuring angle γ at LHCb

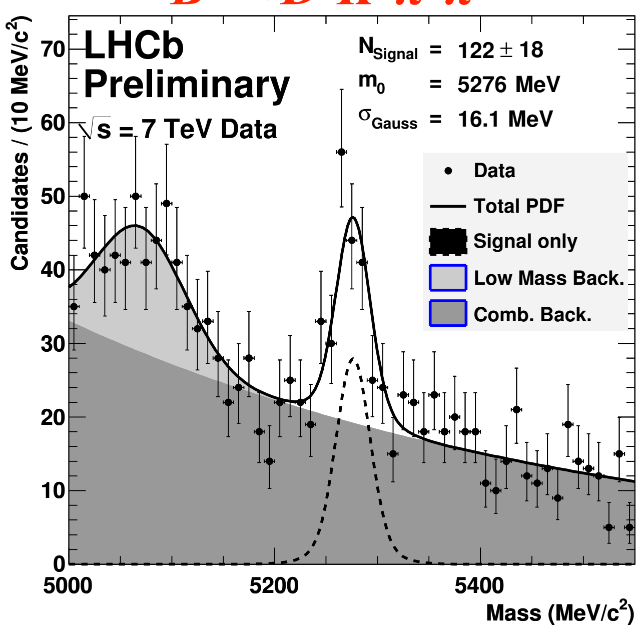
- Angle γ from interference between tree and penguin decays
- LHCb can measure γ with U-spin related decays $B_d \to K\pi$, $\pi\pi$, $B_s \to K\pi$, KK, $\Lambda_b \to p\pi$, pK (analysis is in preparation)
- LHCb also observes the Cabibbo-suppressed decays $B \to DK\pi\pi$, which will add 30-40% statistics to the measurements of γ

LHCb-CONF-2011-024

$\bar{B}^0 \to D^+ K^- \pi^+ \pi^-$



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



- Expect to measure angle γ with 5-6° accuracy with 2011 data

Towards time-dependent *CP* measurements

- Ingredients for measuring ϕ_s in $B_s \rightarrow J/\psi\phi$

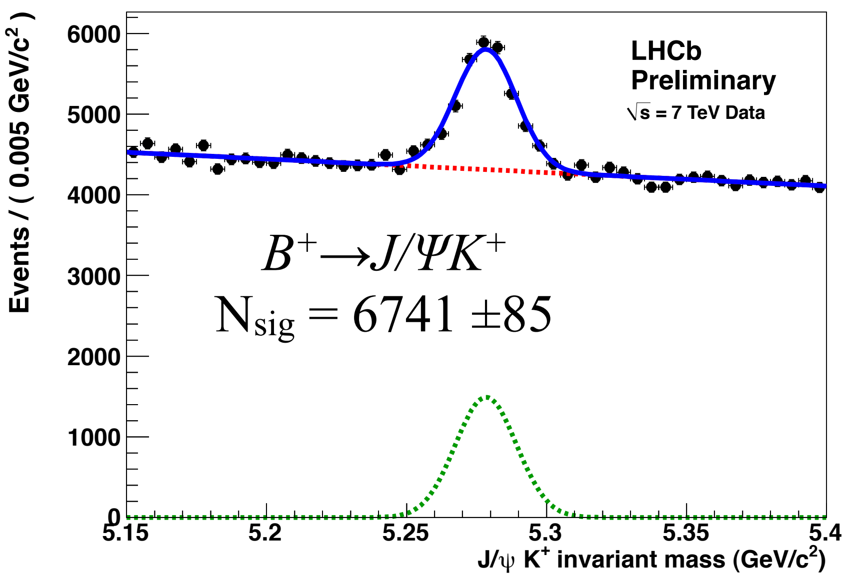
1. measure B_d, B_u, B_s, and Λ_b lifetimes
2. angular analysis of $B_s \rightarrow J/\psi\phi$
   => untagged measurement of ϕ_s
3. flavor tagging calibration
4. measure Δm_s
5. measure sin2β in $B^0 \rightarrow J/\psi K_S$

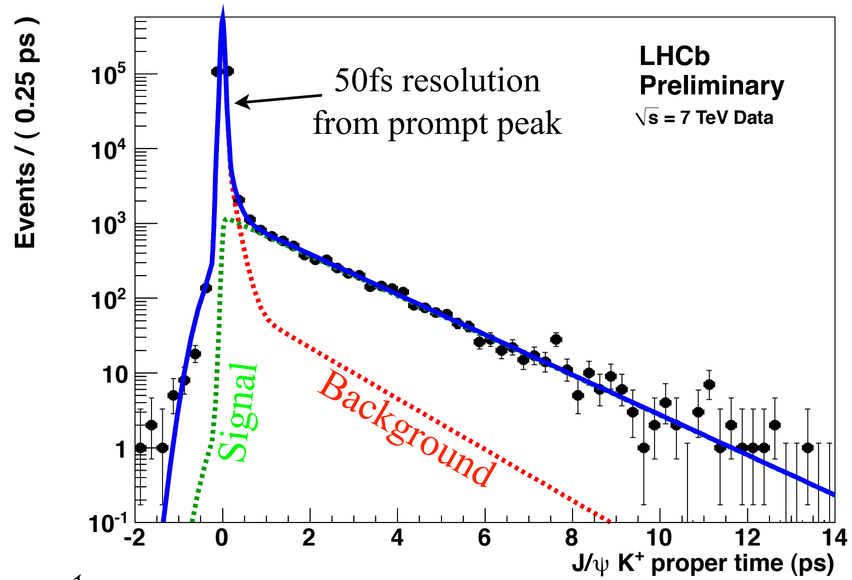
   and, finally,

6. apply tagged time-dependent angular analysis
   to $B_s \rightarrow J/\psi\phi$ to measure ϕ_s

Proper time reconstruction

- Lifetime measured for B_d, B_u, B_s, and Λ_b
- Define event selection criteria used in following analyses
- Detailed studies of resolution and acceptance





- All results compatible with world averages → validation of proper time measurement at LHCb

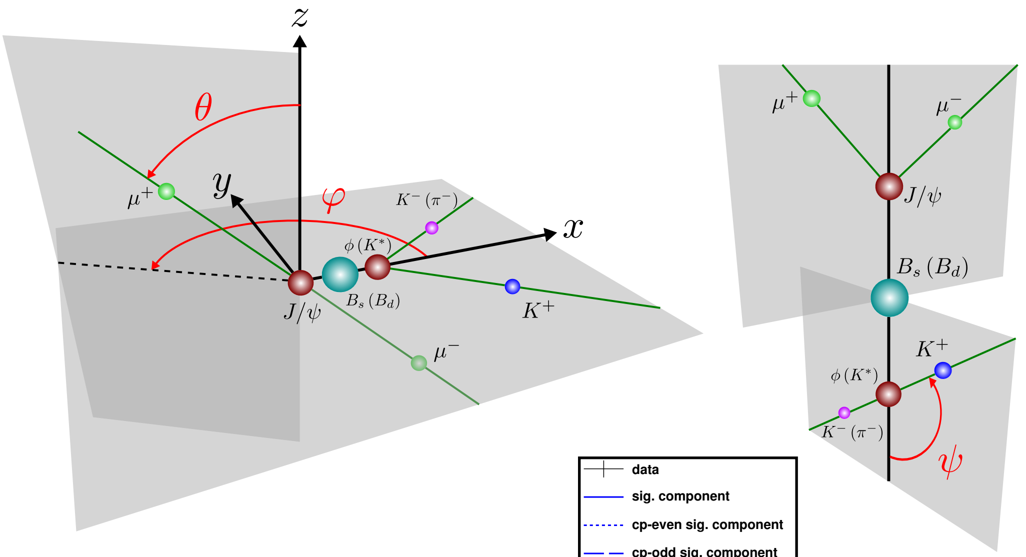
LHCb PRELIMINARY

$$\begin{aligned}
\tau(B^+ \to J/\psi K^+) &= 1.689 \pm 0.022 \pm 0.047 \text{ ps} \\
\tau(B^0 \to J/\psi K^{*0}) &= 1.512 \pm 0.032 \pm 0.042 \text{ ps} \\
\tau(B^0 \to J/\psi K^0_S) &= 1.558 \pm 0.056 \pm 0.022 \text{ ps} \\
\tau^{\text{single}}(B^0_s \to J/\psi \phi) &= 1.447 \pm 0.064 \pm 0.056 \text{ ps} \\
\tau(\Lambda_b \to J/\psi \Lambda) &= 1.353 \pm 0.108 \pm 0.035 \text{ ps}
\end{aligned}$$

Systematics dominated by proper time acceptance uncertainties

Angular analysis

- Final state in $B_s \to J/\psi\phi$ is a mixture of *CP* eigenstates
  - depends on angular momentum configuration ($P \to VV$ decay)
- Use transversity angles to disentangle $A_{||}$, A_0 and $A_\perp$ amplitudes

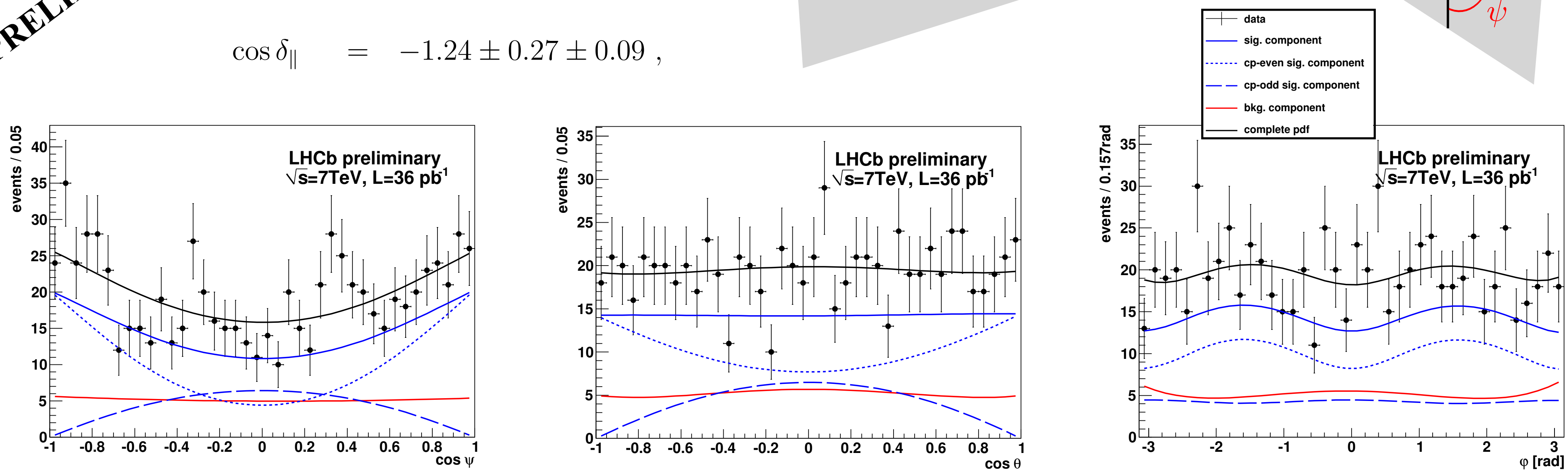


LHCb PRELIMINARY

$$|A_\perp(0)|^2 = 0.279 \pm 0.057 \pm 0.014 \ ,$$

$$|A_0(0)|^2 = 0.532 \pm 0.040 \pm 0.028 \ ,$$

$$\cos\delta_{||} = -1.24 \pm 0.27 \pm 0.09 \ ,$$



Untagged measurement of ϕ_s

- Extract Γ_s, $\Delta\Gamma_s$, and amplitudes from 4-D fit to angles and proper time

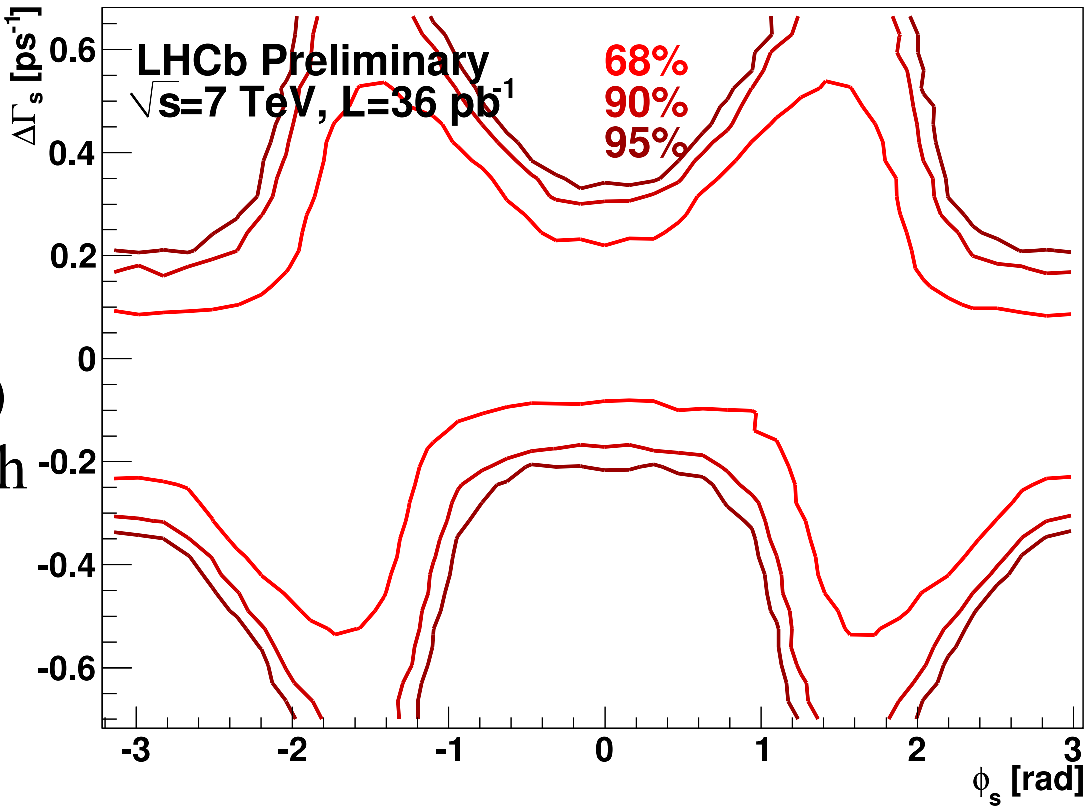
$$\frac{d^4\Gamma}{dt d\Omega} \propto |A_0(t)|^2 \cdot f_1(\Omega) + |A_\parallel(t)|^2 \cdot f_2(\Omega) + |A_\perp(t)|^2 \cdot f_3(\Omega) + \Im\left(A_\parallel^*(t)A_\perp(t)\right) \cdot f_4(\Omega) + \Re\left(A_0^*(t)A_\parallel(t)\right) \cdot f_5(\Omega) + \Im\left(A_0^*(t)A_\perp(t)\right) \cdot f_6(\Omega)$$

  - $A(t)$ functions depend on Γ_s, $\Delta\Gamma_s$, and ϕ_s
  - $f_i(\Omega)$ functions depend on transversity angles

- Fit with ϕ_s fixed at 0 to determine Γ_s and $\Delta\Gamma_s$

- Likelihood scan in ($\Delta\Gamma_s$, ϕ_s) plane (contour obtained with Feldman-Cousins method)

  => 4-fold ambiguity and weak sensitivity to ϕ_s

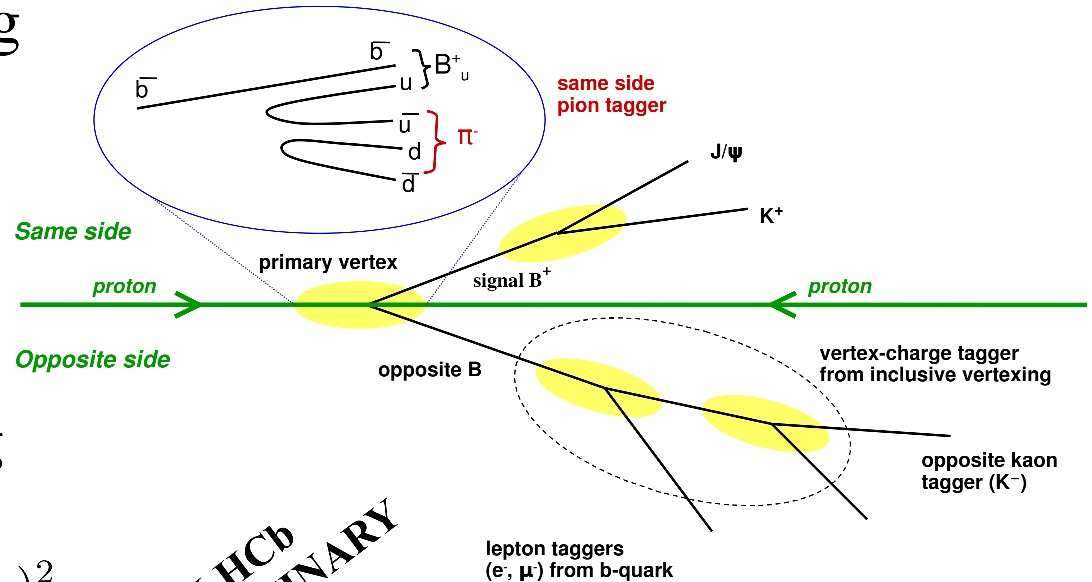


Tagging

- Tagging decision and mistag probability from neural network trained on MC
- Calibrated on real data using self tagging decays
- Determine effective tagging efficiency ε_{eff}

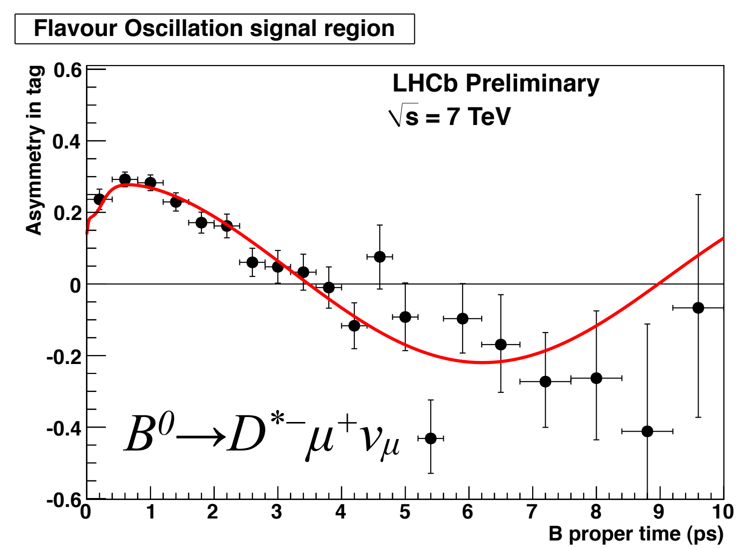
$$\varepsilon_{\text{eff}} = \varepsilon_{\text{tag}} D^2 = \varepsilon_{\text{tag}}(1-2\omega)^2$$

tagging efficiency (ε_{tag}), dilution (D), mistag probability (ω)



LHCb PRELIMINARY

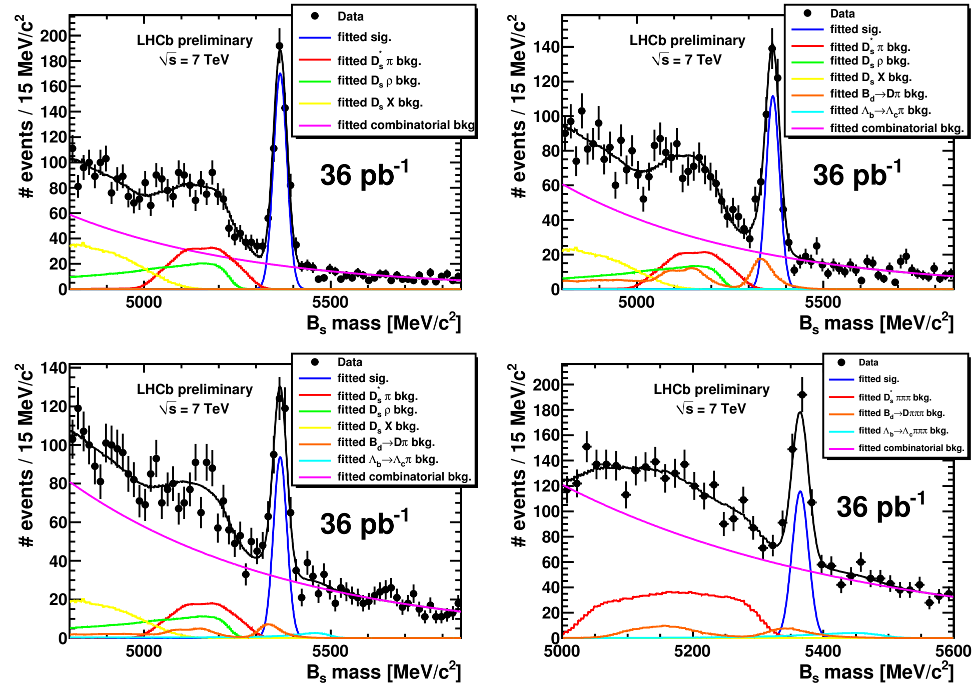
OS+SS-π	ε_{tag}(%)	ω(%)	ε_{eff}(%)
$B^0 \to D^{*-}\mu^+\nu_\mu$	28.9 ± 0.2	34.2 ± 0.8	2.87 ± 0.32
$B^+ \to J/\psi K^+$	23.0 ± 0.5	33.9 ± 1.1	2.38 ± 0.33
$B^0 \to J/\psi K^{*0}$	26.1 ± 0.9	33.6 ± 5.1	2.82 ± 0.87

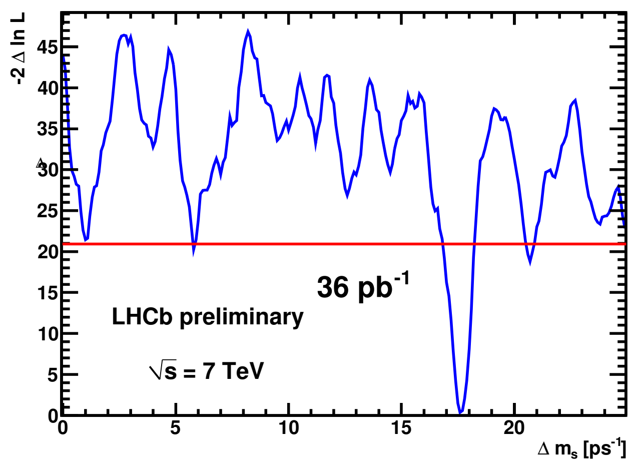


- OS tagging used for ϕ_s result
- Improvements expected from same-side kaon tagging (work in progress)

Measurement of B_s oscillations

- Determine Δm_s from $B_s \to D_s^- \pi^+$ and $B_s \to D_s^- 3\pi$
- Tagged time-dependent fit to extract Δm_s

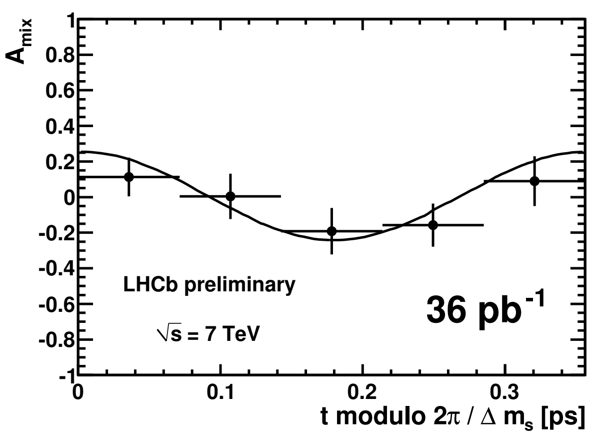




LHCB PRELIMINARY

$$\Delta m_s = 17.63 \pm 0.11_{stat} \pm 0.04_{syst}\ \mathrm{ps}^{-1}$$

CDF $\Delta m_s = 17.67 \pm 0.10_{stat} \pm 0.07_{syst}\ \mathrm{ps}^{-1}$



- With $36\mathrm{pb}^{-1}$ result already competitive with CDF
- Demonstrates the importance of the excellent LHCb proper time resolution

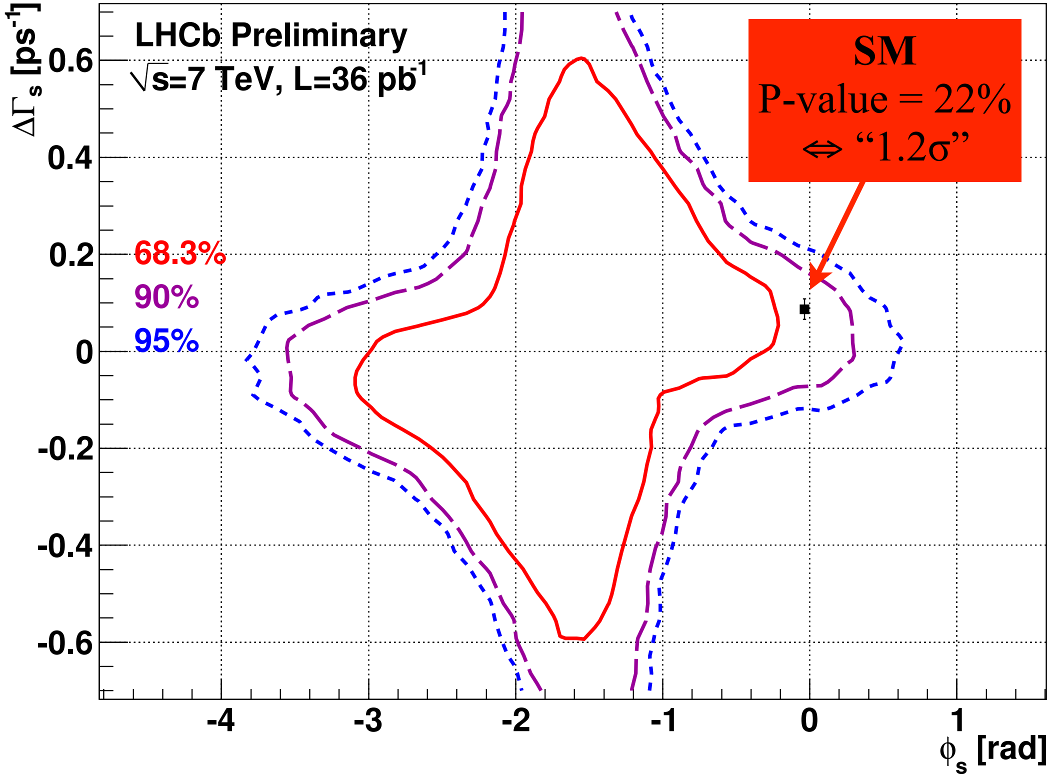
ϕ_s from $B_s \to J/\psi\phi$

- Tagged time-dependent fit to extract ϕ_s in $B_s \to J/\psi\phi$ decays
- First LHCb constraint on ϕ_s using 36pb^{-1} (2010 dataset)
- LHCb results:
  $\phi_s \in [-2.7, -0.5]$ @ 68% C.L.
  $\phi_s \in [-3.5, +0.2]$ @ 95% C.L.

LHCb PRELIMINARY

Standard Model:
$\Delta\Gamma_s$=0.087±0.021 ps^{-1}
ϕ_s=-0.0363±0.0017 rad

- Confidence contour from Feldman-Cousins method
  - contour includes systematics on tagging and Δm_s ; other systematics are negligible
- 2-fold ambiguity remaining
- Prospect for 1fb^{-1}
  $\to \sigma(\phi_s) \approx 0.13$ rad



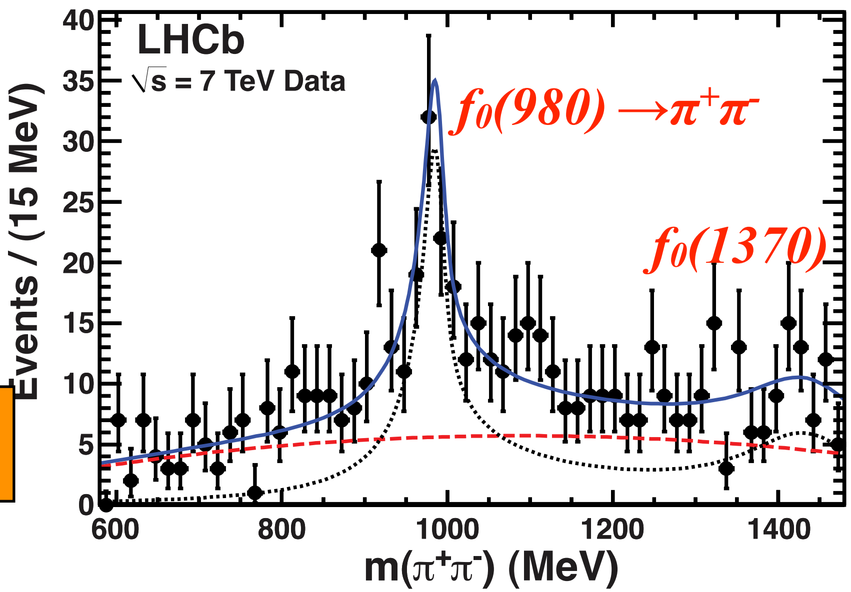
Projected 1fb^{-1} error

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

- $B_s \to J/\psi\, f_0(980)$ has been observed at LHCb with 33pb^{-1}
- 111±14 signal events (12.8σ)
- Measure ratio to $B_s \to J/\psi\phi$

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

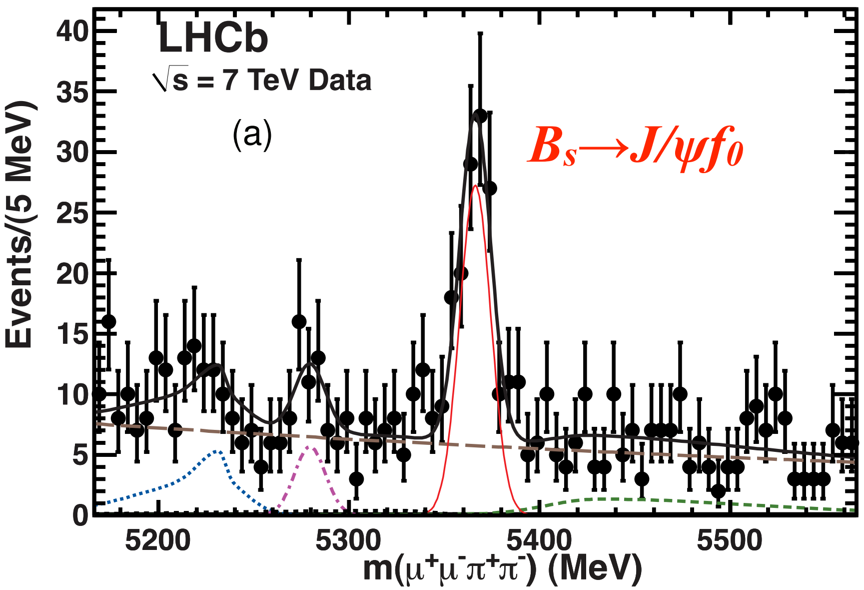
R. Aaij et. al. (LHCb Collaboration)
Phys. Lett. B 698 (2011) 115



- Important mode to study:

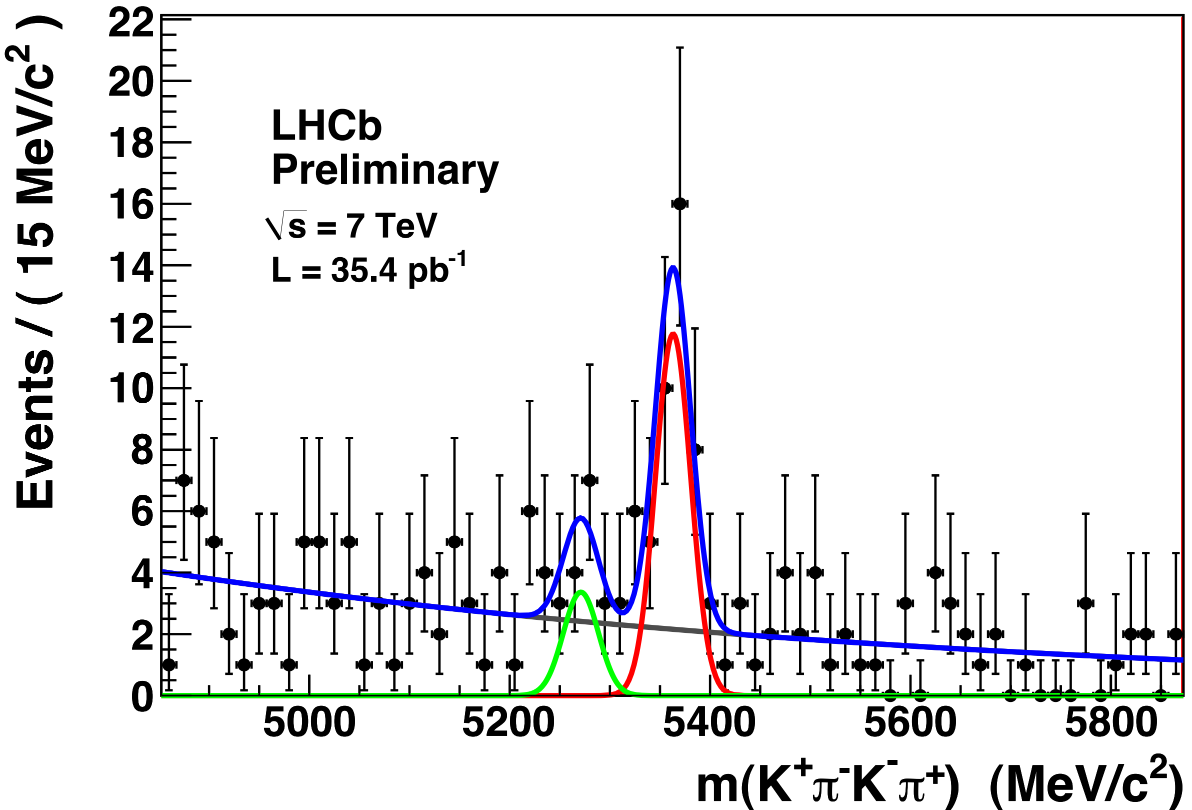
  A. $P \to PV$ decay with CP-odd final state
  => ϕ_s without angular analysis

  B. s-wave background to $B_s \to J/\psi\phi$; allows to remove remaining 2-fold ambiguity



ϕ_s in charmless B_s decays

- ϕ_s will be measured in $B_s \to \phi\phi$ decays (in preparation)
- ϕ_s can also be measured with other penguin decays
- $B_s \to K^{*0}\overline{K}^{*0}$ is observed at LHCb with 35pb^{-1}
- $N_{sig} = 34.0 \pm 7.4$ (7σ significance)



- Branching fraction obtained by normalizing to $B^0 \to J/\psi\, K^{*0}$

$$\mathcal{B}(B_s^0 \to K^{*0}\overline{K}^{*0}) = (1.95 \pm 0.47(\text{stat.}) \pm 0.51(\text{syst.}) \pm 0.29\,(f_d/f_s)) \times 10^{-5}$$

LHCb PRELIMINARY

Conclusion

- 2010 dataset ($\approx$36pb^{-1}) was used to demonstrate the excellent LHCb performance for
  - tagging,
  - angular, and
  - time-dependent analyses
- LHCb has obtained its first CP violation measurements
- Several new decay modes are being discovered

- CP violation measurements at LHCb on known and new decay modes will soon contribute significantly to constraining the Standard Model
- Expect world best measurements of ϕ_s and γ with 2011 dataset