Physics at LHC, Perugia 6-11 June 2011

B decays, CKM, spectroscopy, B and charm at LHCb

or

"the brilliant start-up of LHCb"

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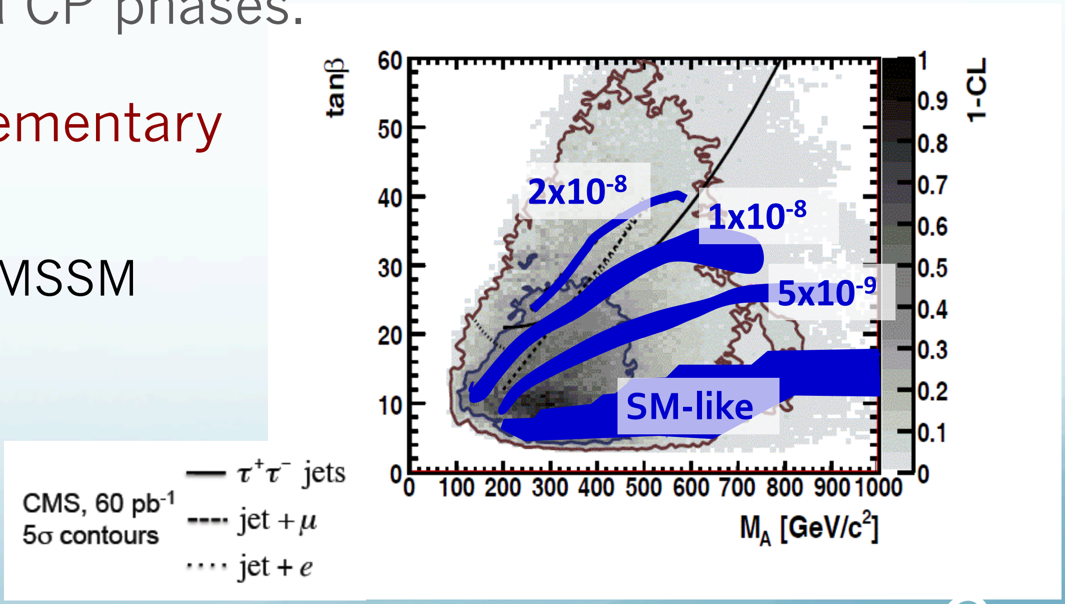
On behalf of the LHCb Collaboration

The LHCb Physics Program

- The Large Hadron Collider beauty experiment: for precise measurements of CP violation and rare decays.
- Search for evidence of New Physics through indirect effects: new particles of high mass can give measurable contribution in box and loops diagrams.
- Open puzzle: the flavour structure of NP. Will have to measure masses, spins, coupling constants and CP phases.
- Measurements can be complementary to direct searches.

  Eg. Large $\mathcal{B}(B_s \rightarrow \mu\mu)$ limits MSSM (NUHM1 in the plot)

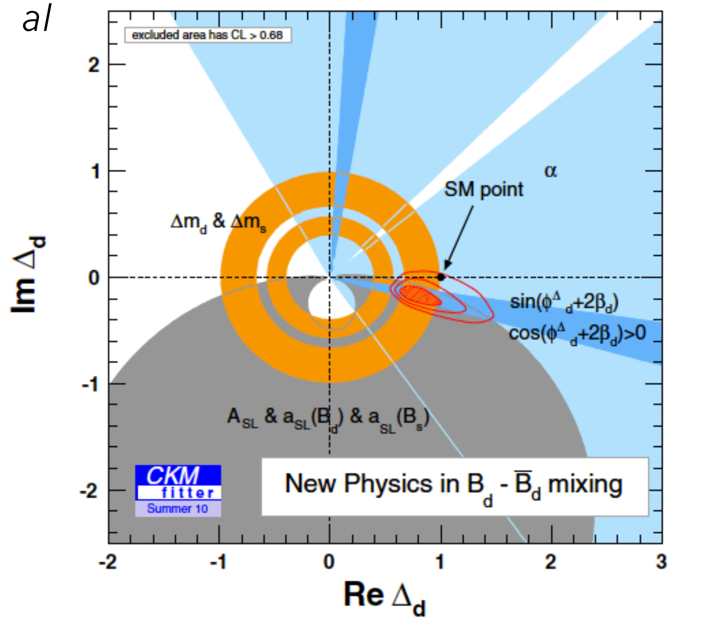


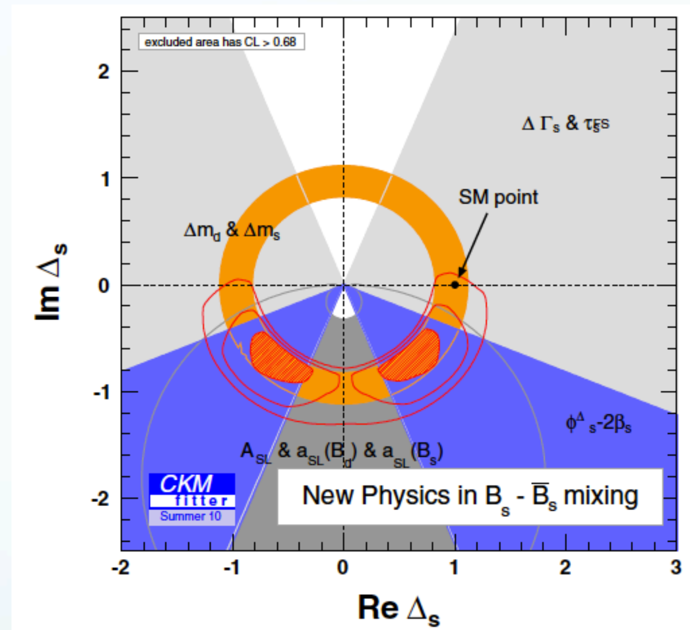
New physics in B_d and B_s mixing?

- CKM global analysis: combined fit to Δ_d and Δ_s

$$\frac{M_{12}^{q}}{M_{12}^{\mathrm{SM},q}} = 1 + \frac{M_{12}^{\mathrm{NP},q}}{M_{12}^{\mathrm{SM},q}} = \Delta_q = 1 + h_q e^{i2\sigma_q}$$

A. Lenz et al PHYSICAL REVIEW D **83**, 036004 (2011)





SM hypothesis $\Delta_d = \Delta_s = 1$ disfavoured a 3.6 σ

- Mainly for tension between measurements of $B \rightarrow \tau\nu$, $\sin 2\beta$, V_{ub} and deviations in ϕ_s and a_{sl}

The brilliant start-up of LHCb

- Heavy flavour production: cross sections, B_c , fragmentation fractions, H_b masses and first observation of new B decay modes
- B_s mixing and ϕ_s
- Towards a γ determination from charmed and charmless B decays
- Charm: towards CPV measurements
- NP in rare decays: $B_s \rightarrow \mu\mu$ and more

See also:
→Talk by G.Cowan

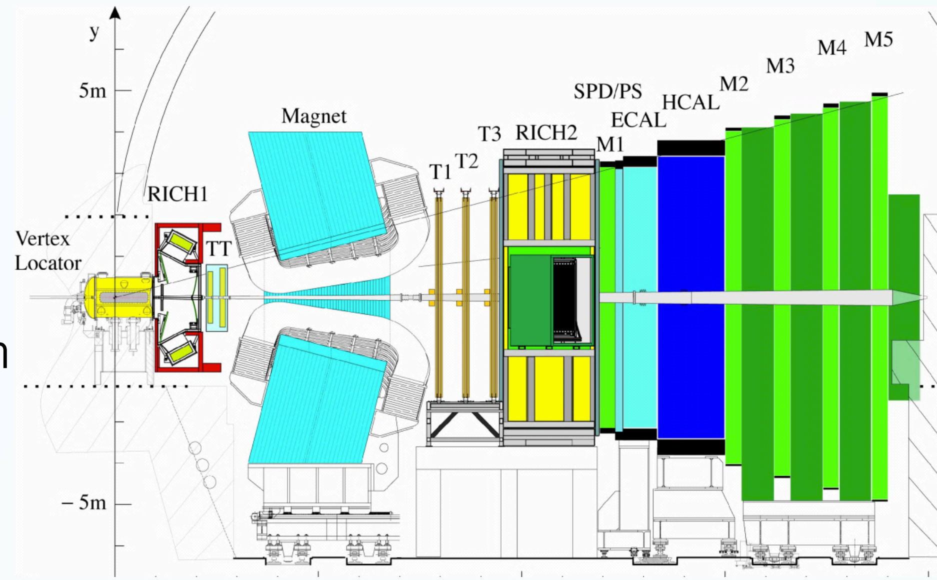
→Talk by L.Eklund

→Talk by V.Gligorov

→Talk by J.Albrecht

Onia results covered in G.Manca's talk

LHCb



→ *A.Shopper talk on Monday*

Single arm forward detector: $2<\eta<6$

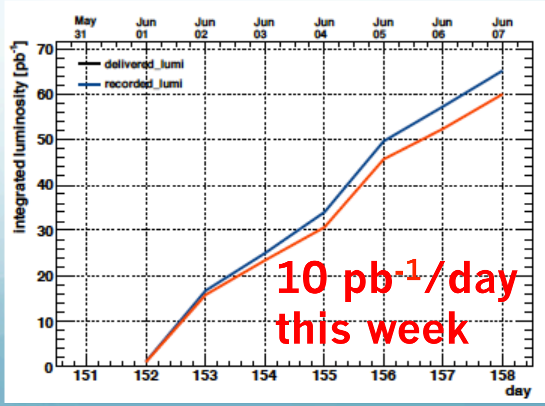
High $b\bar{b}$ production in the forward region in pp collisions at $\sqrt{s}$=7TeV: $\sigma_{b\bar{b}} \approx 290\ \mu b$

LHCb detector performance:

- Efficient trigger for leptonic and hadronic decays (ε^{trig}~94%-60%)
- Excellent resolution for tracking and vertexing ($\sigma_{IP}^{x} \approx 15\ \mu m$)
- Good mass resolution and proper-time resolution
- Good particle identification: π/K/p (RICHs), π/e/γ (ECAL), μ (MUON)

In this talk preliminary results from analysis of ~37 pb^{-1} 2010 data

Expectation for 2011 ~1 fb^{-1}, at today ~230 pb^{-1}

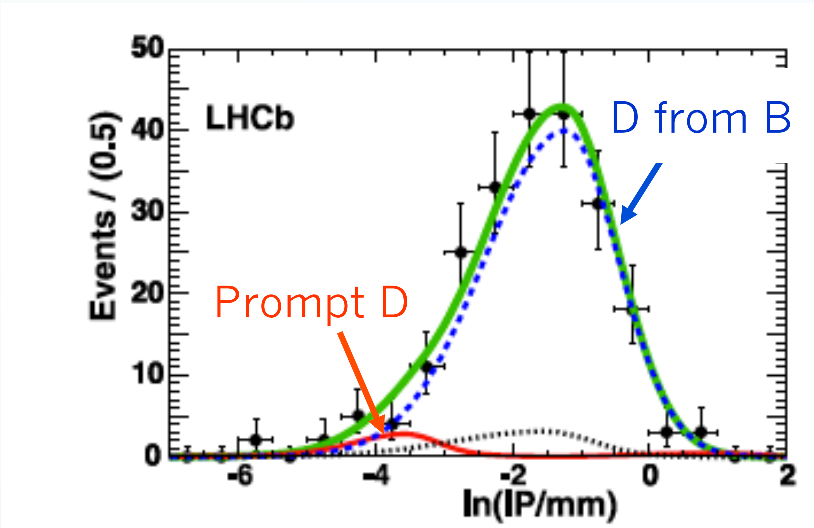


Heavy Flavour production and spectroscopy

Phys Lett B 694 (2010) 209–216

Heavy flavour production: open beauty

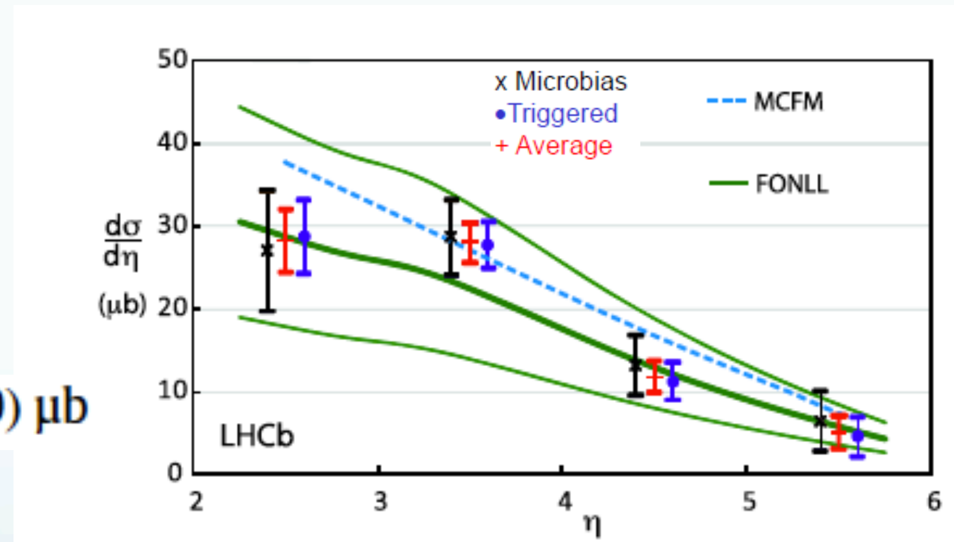
- Cross section measurement with semi-leptonic decays $b \rightarrow D^0(K\pi)\,\mu\nu X$



D^0 impact parameter w.r.t. primary vertex to separate $b\bar{b}$ and $c\bar{c}$ events

$$\sigma(pp \rightarrow H_b X) = (75.3 \pm 5.4 \pm 13.0)\ \mu b$$

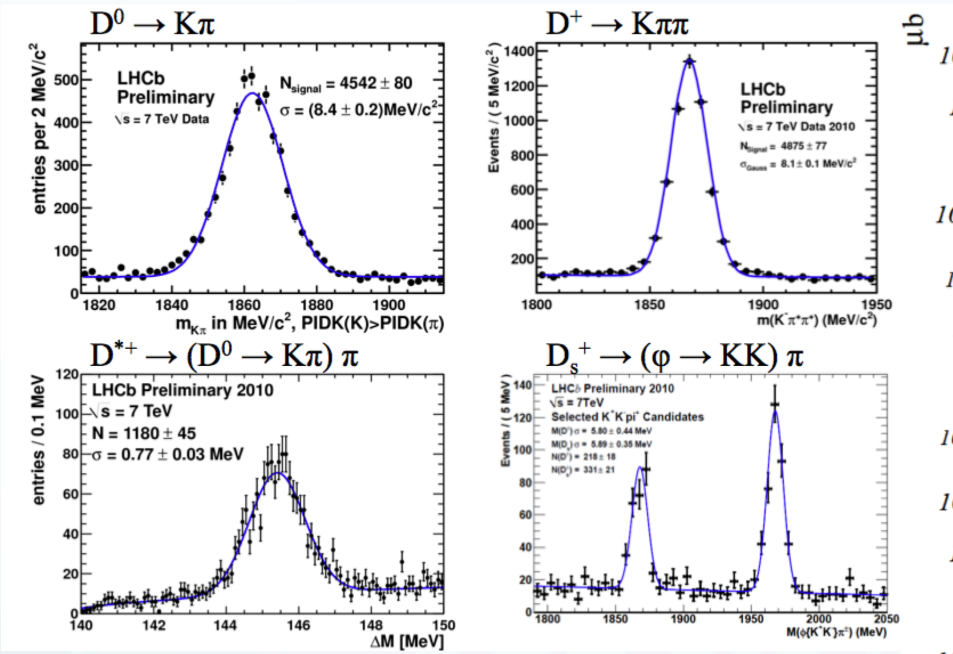
$$2 < \eta < 6.$$

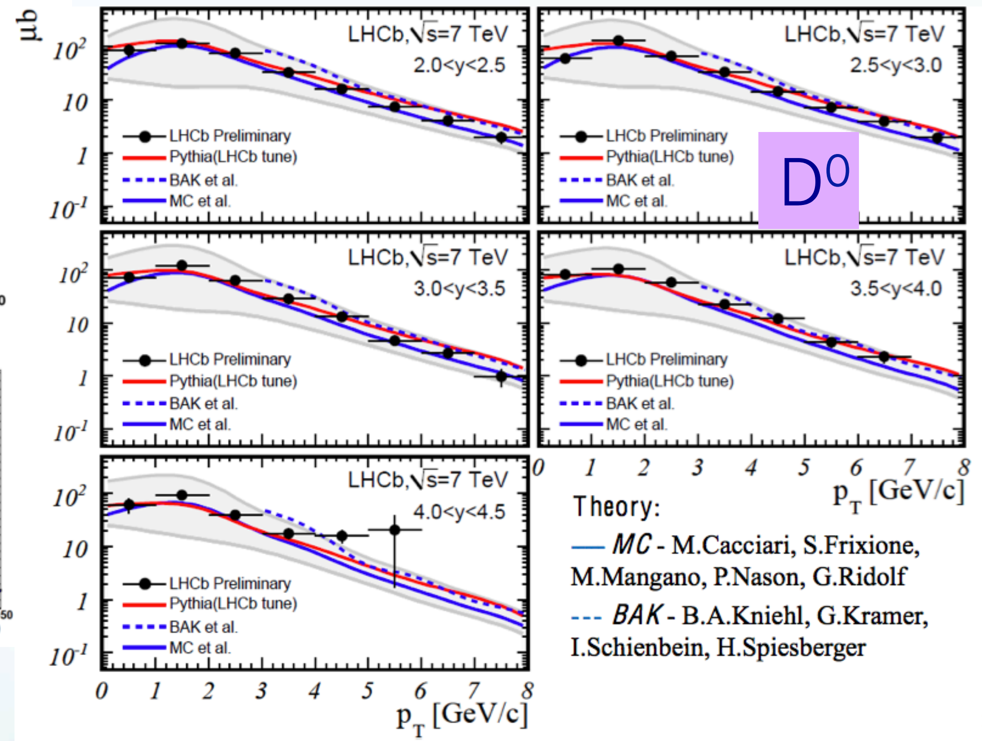


- Extrapolating to 4π with PYTHIA 6.4: $\sigma(pp \rightarrow b\bar{b}X) = 284 \pm 20 \pm 49\ \mu b$
- Agreement with expectations validate QCD predictions at LHC energy

Heavy flavour production: open charm

- Cross section measured for D^0, D^+, D^{*+}, D_s mesons production.



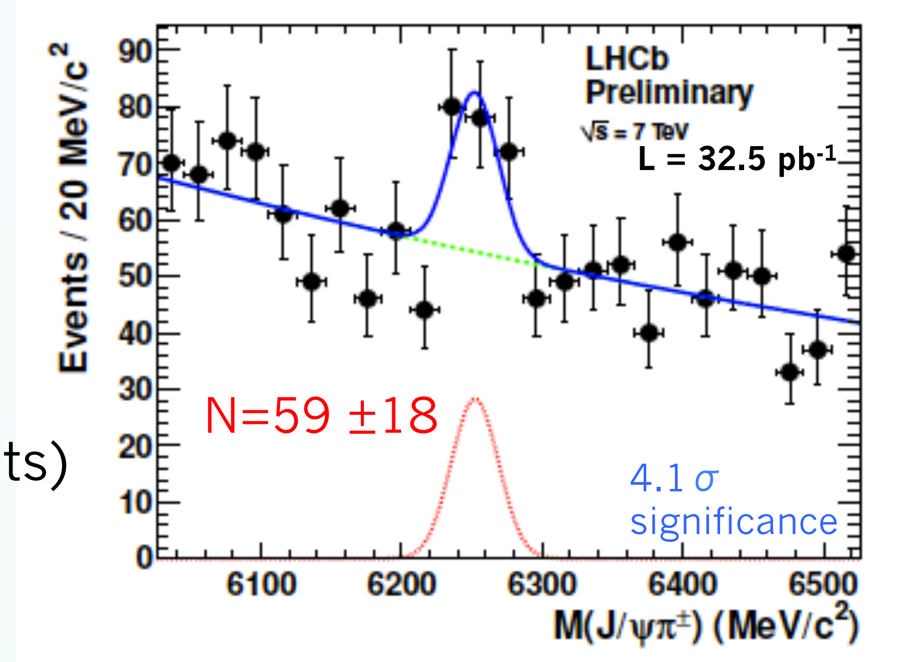


- Total production cross section in 4π, combined average:

$\sigma(pp \rightarrow c\bar{c}X) = 6100 \pm 930\ \mu b$ → 20 x $b\bar{b}$ cross section

B_c production

- B_c^+ is the heaviest meson ($\bar{b}c$) rich filed for studies giving insight into QCD.
- Only seen in 3 decay modes so far:
  $B_c^+ \rightarrow J/\psi\, \pi^+$ (~100 events)
  $B_c^+ \rightarrow J/\psi\, \mu^+\nu$, $J/\psi\, e^+\nu$, (~1000 events)
- LHCb for $p_T(B_c) > 4$ GeV/c, $2.5<\eta<4.5$:



LHCb preliminary

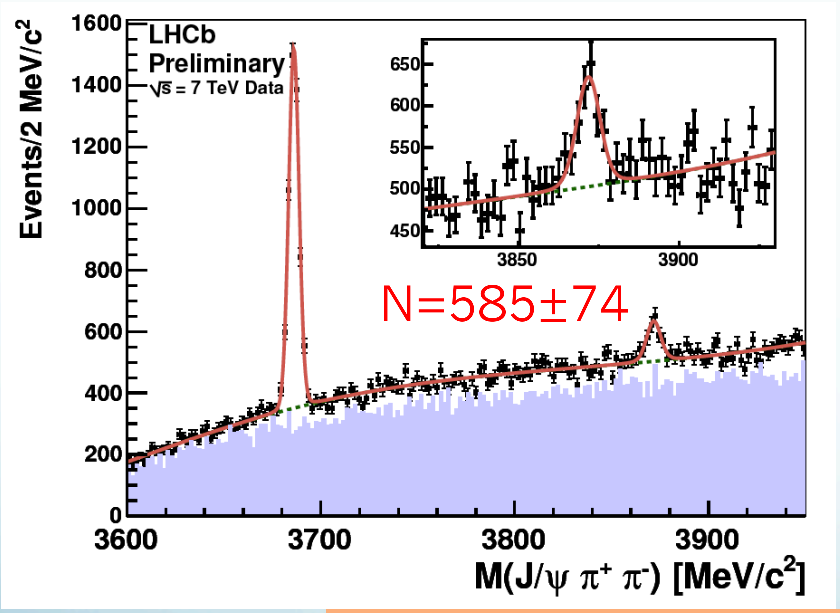
$$R_{c+} = \frac{\sigma(B_c^+)\times\mathcal{B}(B_c^+ \to J/\psi\pi^+)}{\sigma(B^+)\times\mathcal{B}(B^+ \to J/\psi K^+)} = (2.2 \pm 0.8 \pm 0.2)\%$$

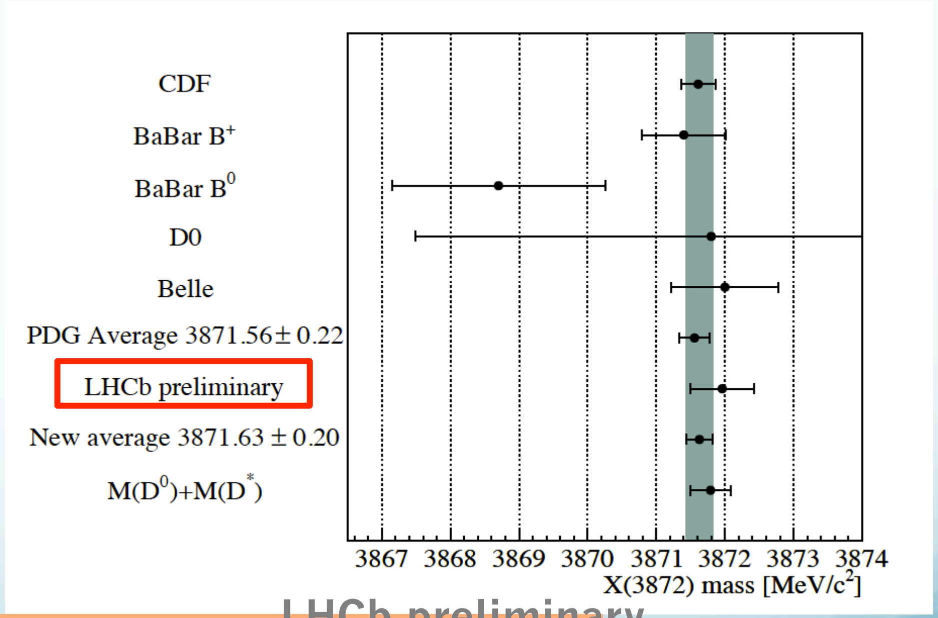
Promising for LHCb program on B_c physics

LHCb-CONF-2011-021

X(3872)

- Exotic meson discovered in 2003 by Belle, but its nature still unclear: $\eta_{c2}(1D)$ charmonium state, bound $D^0\bar{D}^{0*}$ molecule, tetraquark…?
- Mass measurement in $X(3872) \to J/\psi(\mu\mu)\,\pi^+\pi^-$
- Momentum scale calibration verified with $\psi(2S) \to J/\psi\,\pi^+\pi^-$

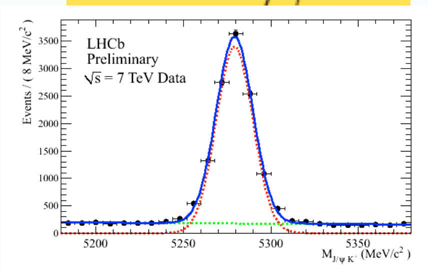




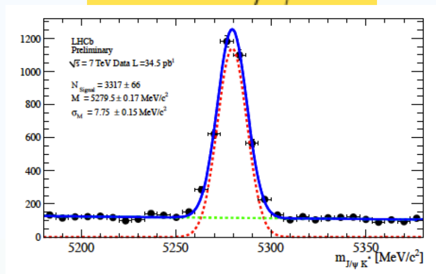
$$M_{X(3872)} = 3871.96 \pm 0.46 \pm 0.10\ \mathrm{MeV}/c^2$$

Precise measurement of b-hadron masses

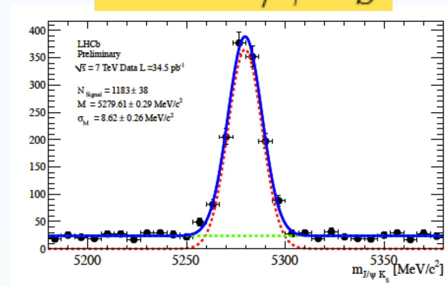
$B^+ \rightarrow J/\psi K^+$



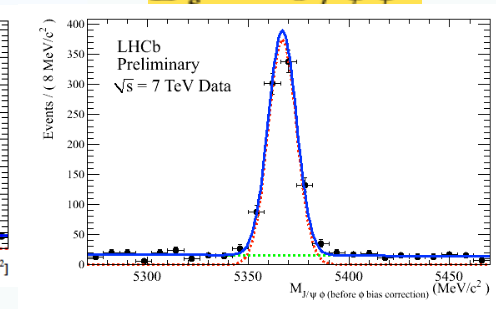
$B^0 \rightarrow J/\psi K^*$



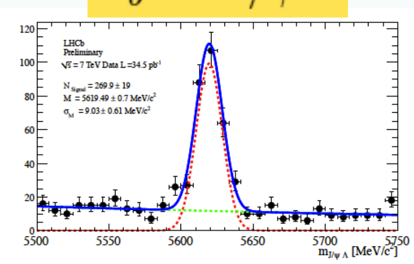
$B^0 \rightarrow J/\psi K_S$



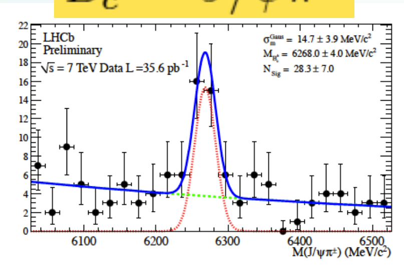
$B^0_s \rightarrow J/\psi \phi$



$\Lambda_b \rightarrow J/\psi \Lambda$



$B_c \rightarrow J/\psi \pi^+$



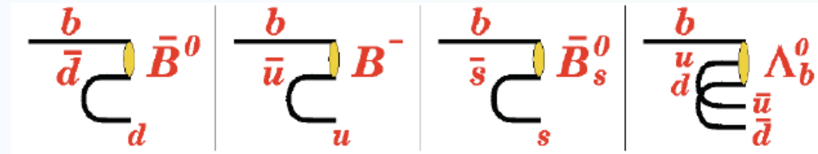
Momentum scale known to ~10^{-4}

	LHCb preliminary (MeV/c^2)	PDG
$B^+ \rightarrow J/\psi K$	$5279.27 \pm 0.11\,(\mathrm{stat}) \pm 0.19\,(\mathrm{syst})$	5279.17 ± 0.29
$B^0 \rightarrow J/\psi K^*$	$5279.54 \pm 0.15\,(\mathrm{stat}) \pm 0.15\,(\mathrm{syst})$	5279.50 ± 0.30
$B^0 \rightarrow J/\psi K_S$	$5279.61 \pm 0.29\,(\mathrm{stat}) \pm 0.20\,(\mathrm{syst})$	
$B^0_s \rightarrow J/\psi \phi$	$5366.60 \pm 0.28\,(\mathrm{stat}) \pm 0.21\,(\mathrm{syst})$	5366.3 ± 0.60
$\Lambda_b \rightarrow J/\psi \Lambda$	$5619.49 \pm 0.70\,(\mathrm{stat}) \pm 0.19\,(\mathrm{syst})$	5620.2 ± 1.6
$B^+_c \rightarrow J/\psi \pi$	$6268.0 \pm 4.0\,(\mathrm{stat}) \pm 0.5\,(\mathrm{syst})$	6277 ± 6

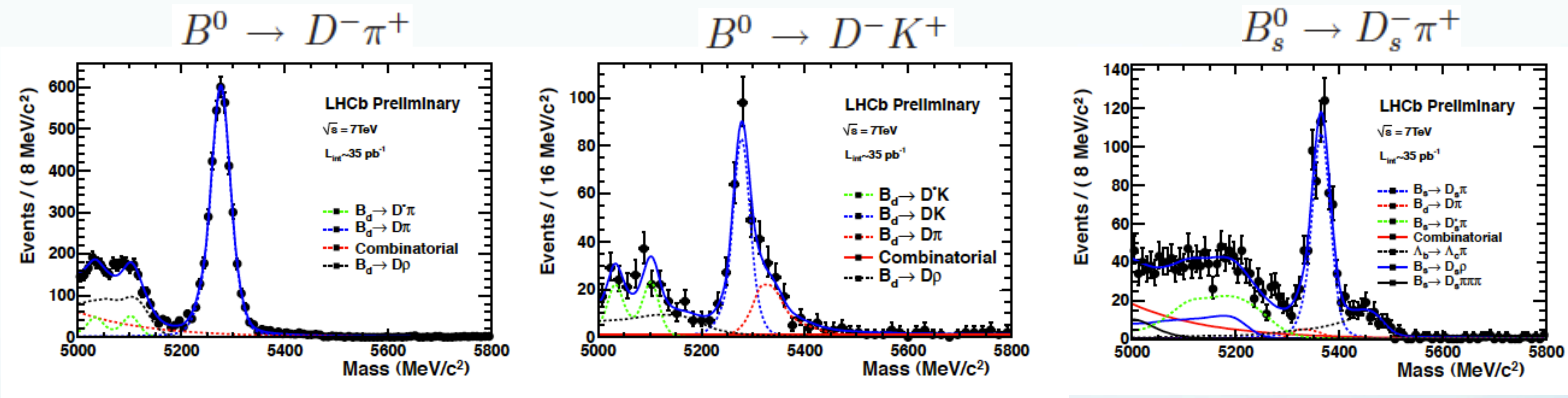
World best mass measurement already with 36 pb^{-1} of data! (except B_c)

B fragmentation fractions: hadronic

- Probability that a b quark hadronize into a $B_{u,d,s}$ meson or a Λ_b baryon.



- f_s/f_d needed to normalize B_s to B^0 decays in branching ratio determination.
- Measurement in hadronic modes from ratio $B_s \to D_s\pi$ to $B^0 \to D^-\pi$ or D^-K:



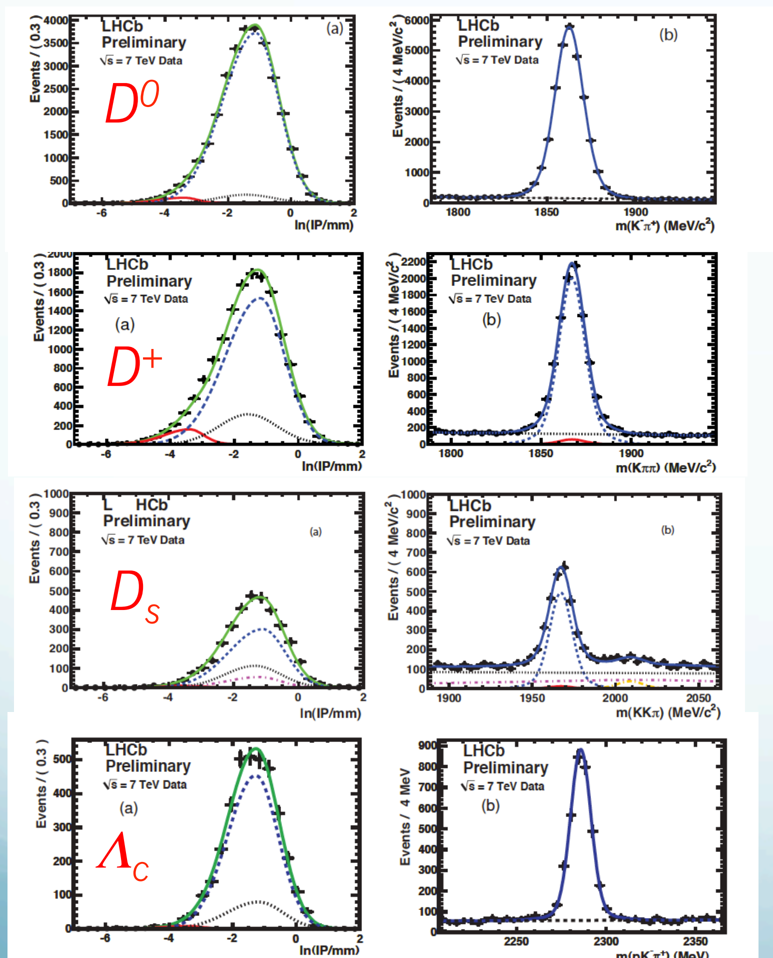
$$\frac{f_s}{f_d} = 0.245 \pm 0.017^{\text{stat}} \pm 0.018^{\text{syst}} \pm 0.018^{\text{theor}}$$

LHCb preliminary

HFAG at the Z: 0.256 ±0.022
CDF (LaThuile): 0.269 ±0.033

B fragmentation fractions: semi-leptonic

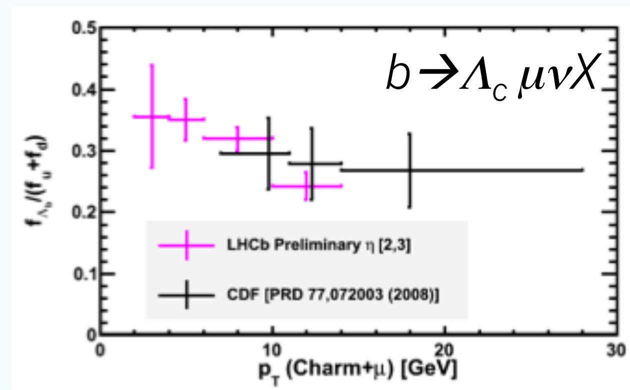
- LHCb measurement in semi-leptonic decays: $b \rightarrow (D^0, D^+, D_s^+, \Lambda_c)\, X\mu\nu$



$$\frac{f_s}{f_d} = 0.272 \pm 0.008^{+0.024}_{-0.022}$$

LHCb preliminary

p_T dependence observed in baryon fraction



LHCb preliminary

$$\frac{f_{\Lambda_b}}{f_u + f_d} = (0.401 \pm 0.019 \pm 0.106) - (0.0120 \pm 0.0025 \pm 0.0012) \times p_T / \text{GeV}$$

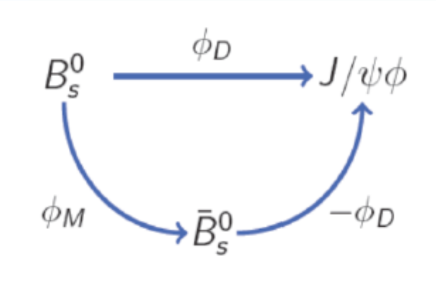
CDF value $(0.281 \pm 0.012^{+0.011}_{-0.056}{}^{+0.128}_{-0.086})$ $\langle p_T \rangle_{CDF} \approx 14.1\,\text{GeV}$

LEP value 0.112 ± 0.031 $\langle p_T \rangle_{LEP} \approx 40\,\text{GeV}$

Search for New Physics in CPV and CKM precision measurements

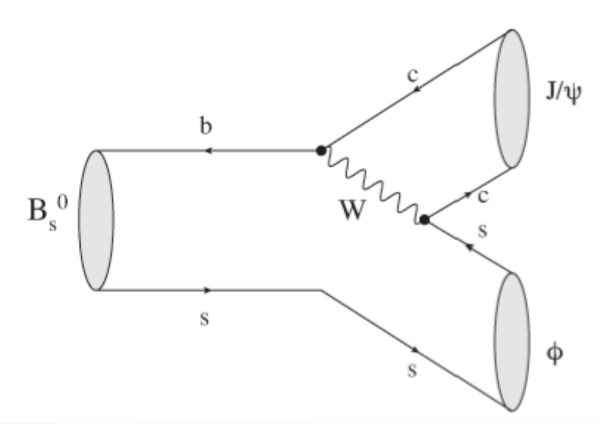
B_s mixing and CP violation

A CP violating phase can arise in the B_s system, from interference between decay with and without mixing.



$\phi_s = \Phi_M - 2\Phi_D$

$B_s \rightarrow J/\psi(\mu\mu)\ \phi(KK)$ is the golden mode.



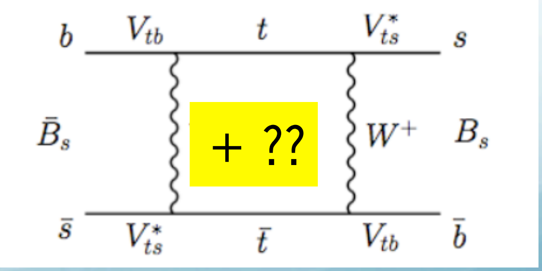
In the Standard Model ϕ_s is dominated by a single weak phase: $\phi_s^{SM} \cong -2\beta_s$

$$\beta_s = \arg\left(-\frac{V_{ts}V_{tb}^*}{V_{cs}V_{cb}^*}\right)$$

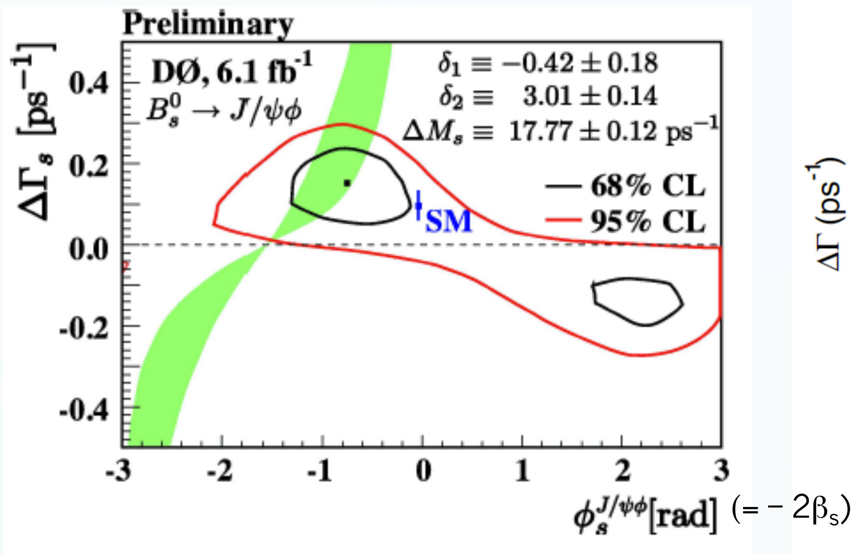
Well predicted:
$2\beta_s = 0.0363 \pm 0.0017$ rad
Additional penguin contribution ~10^{-4} -10^{-3}

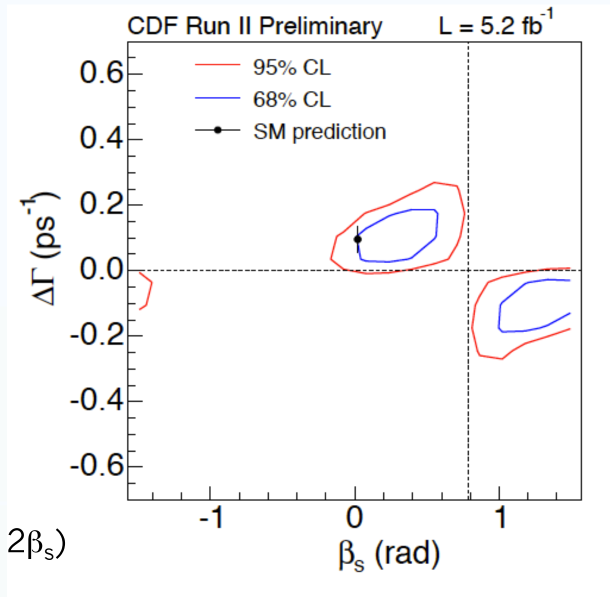
New Physics in mixing can enhance the measured ϕ_s :

$$\phi_s = \phi_s^{SM} + \phi^{NP}$$



ϕ_s from $B_s \to J/\psi(\mu\mu)\phi(KK)$





Still much space for NP to appear

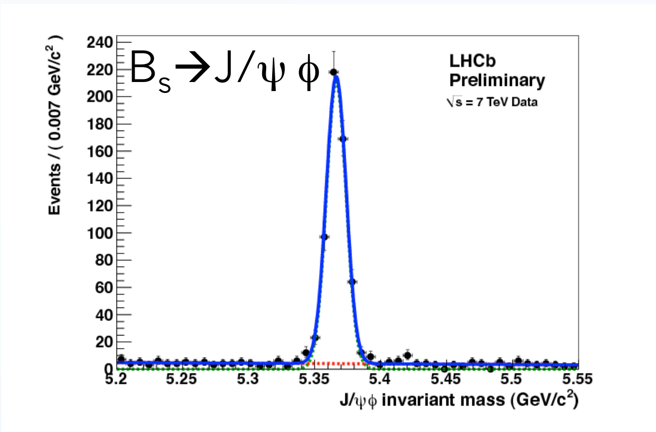
- The roadmap for a new ϕ_s measurement at LHCb requires several intermediate steps, and to demonstrate good control on:
  - Signal and control channels selection
  - Proper-time measurement
  - Angular distributions
  - Flavour tagging

LHCb-CONF-2011-001, 002,003,004,005,006,010

B→J/ψX samples

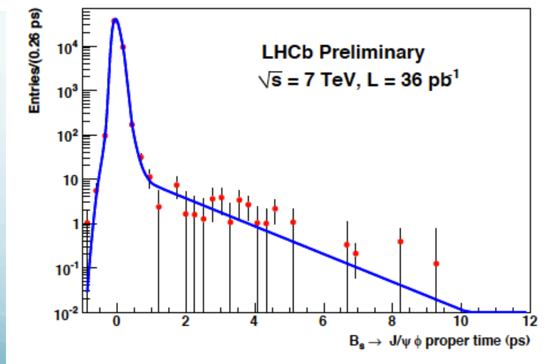
Similar selection for all $H_b \to J/\psi(\mu\mu)X$ channels, use "decay time unbiased" di-muon trigger.

Increase sample (~ 30%) with events from displaced track trigger "decay time biased".



Excellent mass resolution: σ_m = 7 MeV/c^2

Very low background (S/B=12.5)
after proper-time cut t>0.3 ps removing prompt $J/\psi \to \mu\mu$.

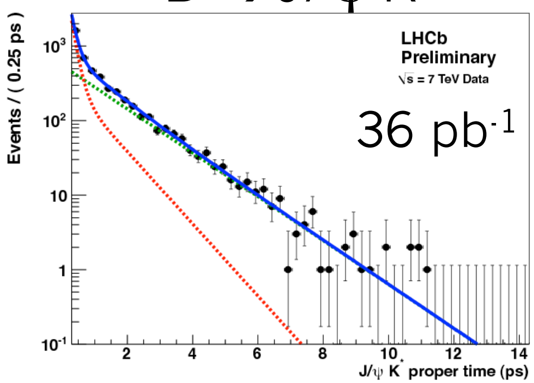


Excellent proper-time resolution: $\sigma \approx$ 50 fs
Triple Gaussian resolution model determined from data, using prompt $J/\psi \to \mu\mu$.

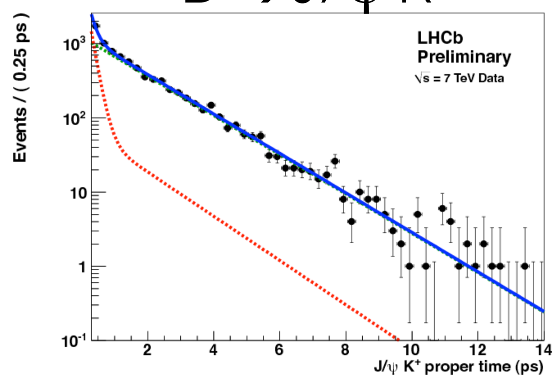
Measurement of lifetimes

Use "decay time unbiased" sample.

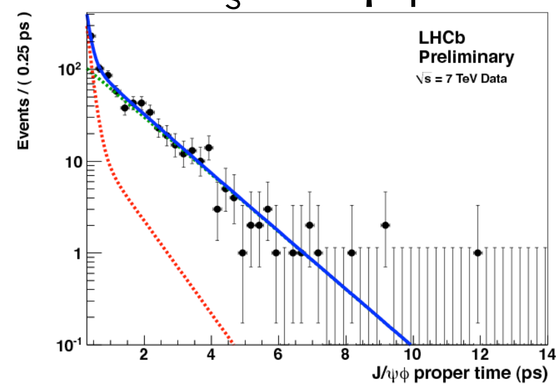
$B^+ \to J/\psi\, K^+$



$B^0 \to J/\psi\, K^{0*}$



$B_s \to J/\psi\, \phi$



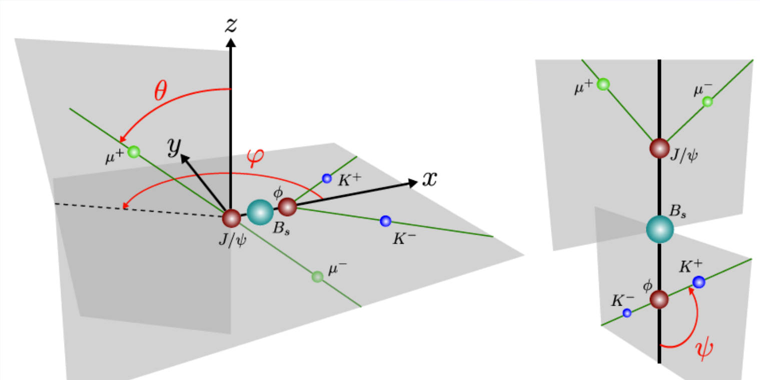
Yields for t>0.3 ps

Decay channel	Yield	LHCb result τ[ps]* (preliminary)	PDG τ[ps]
$B^+ \to J/\psi K^+$	6741 ± 85	$1.689 \pm 0.022_{stat.} \pm 0.047_{syst.}$	1.638 ± 0.011
$B^0 \to J/\psi K^{*0}$	2668 ± 58	$1.512 \pm 0.032_{stat.} \pm 0.042_{syst.}$	1.5252 ± 0.009
$B^0 \to J/\psi K^0_S$	838 ± 31	$1.558 \pm 0.056_{stat.} \pm 0.022_{syst.}$	1.525 ± 0.009
$B^0_s \to J/\psi \phi$ (*)	570 ± 24	$1.447 \pm 0.064_{stat.} \pm 0.056_{syst.}$	1.477 ± 0.046
$\Lambda_b \to J/\psi \Lambda$	187 ± 16	$1.353 \pm 0.108_{stat.} \pm 0.035_{syst.}$	$1.391^{+0.038}_{-0.037}$

Will become competitive with 2011 data sample. Current systematic dominated by time dependence of reconstruction efficiency, conservative estimate.

(*) Fit to a single exponential

Time dependent angular analysis



Transversity basis

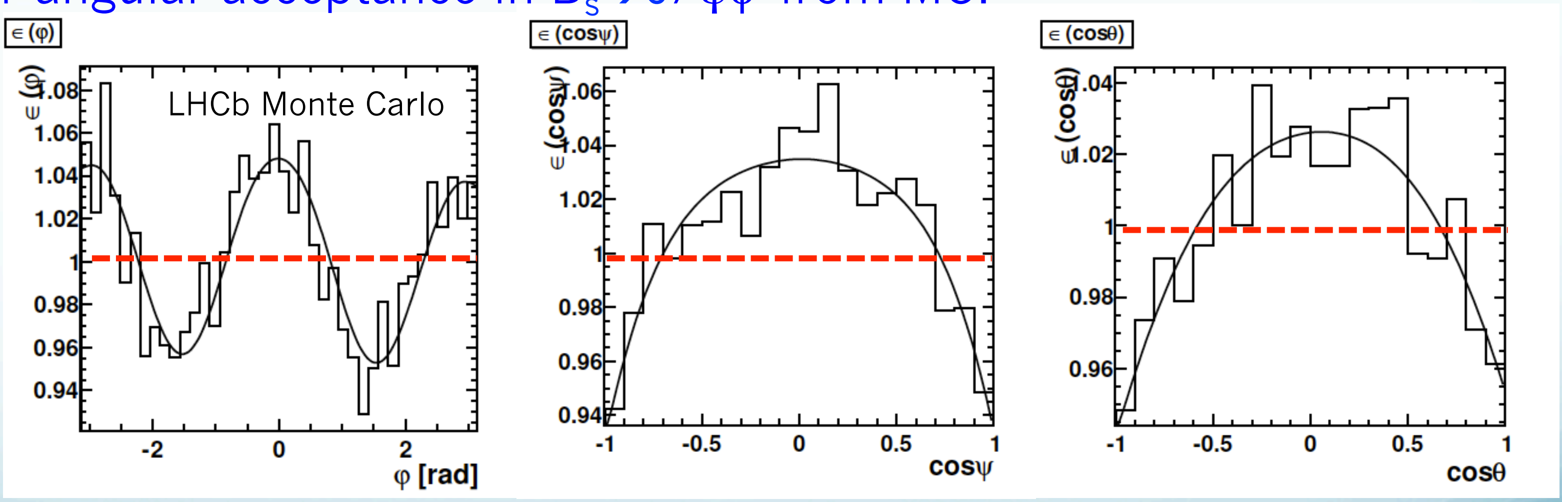
$B_s \to J/\psi\phi$ decay (P→VV) requires full angular analysis to statistically separate CP-even (ℓ=0,2) and CP odd (ℓ=1) final states.

Use θ,ϕ,ψ angles in the transversity basis.

Corrections for angular acceptance in $B_s \to J/\psi\phi$ from MC:

Normalized 1D projections of the 3D distributions

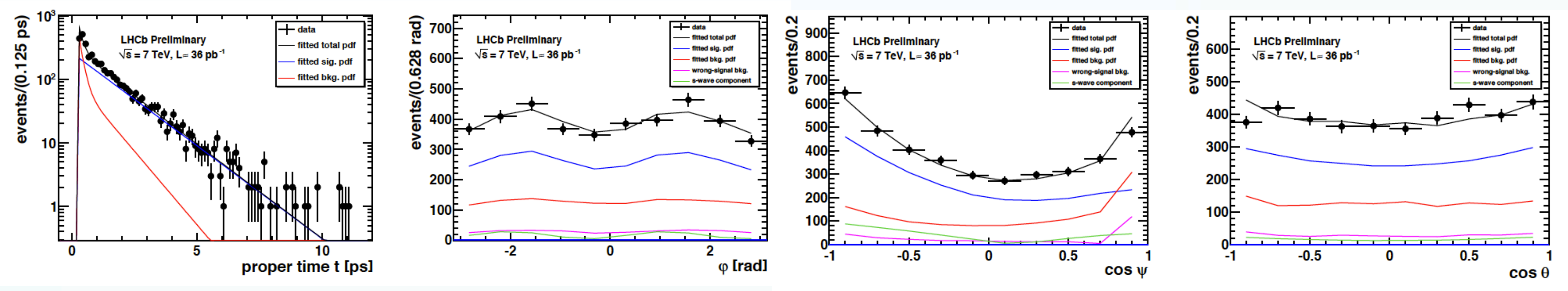
zero suppressed→



Angular acceptance effects induced by LHCb geometry are within ±5%

Polarization amplitudes for $B^0 \rightarrow J/\psi K^{0*}$

Same $P \rightarrow VV$ structure in $B^0 \rightarrow J/\psi(\mu\mu)\ K^{0*}(K\pi)$ decay.
Analysis used as a cross-check of the full 5D fit $(m, t, \phi, \psi, \theta)$.



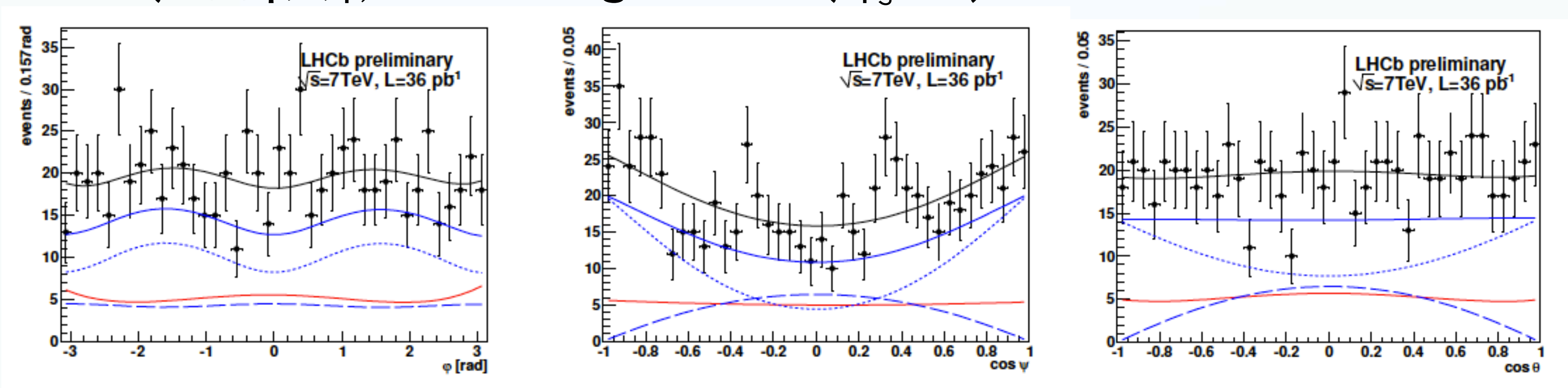
Background shape from sidebands. Non resonant S-wave $K\pi$ contribution 5±2 %.

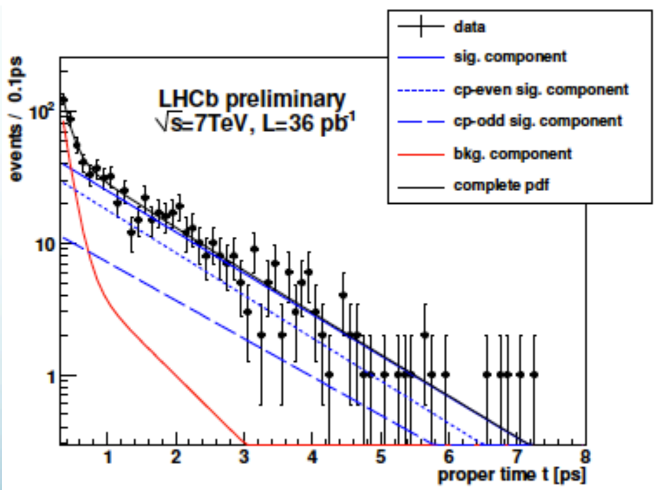
Parameter	LHCb result (preliminary)	BaBar PRD 76, 031002
$\lvert A_{\parallel}\rvert^2$	$0.252 \pm 0.020 \pm 0.016$	$0.211 \pm 0.010 \pm 0.006$
$\lvert A_{\perp}\rvert^2$	$0.178 \pm 0.022 \pm 0.017$	$0.233 \pm 0.010 \pm 0.005$
$\delta_{\parallel}$ [rad]	$-2.87 \pm 0.11 \pm 0.10$	$-2.93 \pm 0.08 \pm 0.04$
$\delta_{\perp}$ [rad]	$3.02 \pm 0.10 \pm 0.07$	$2.91 \pm 0.05 \pm 0.03$

Good agreement with previous measurements, but not yet competitive.

$B_s \to J/\psi\phi$ untagged analysis

5D fit (m,t,ψ,θ,ϕ) assuming no CPV ($\phi_s = 0$) .



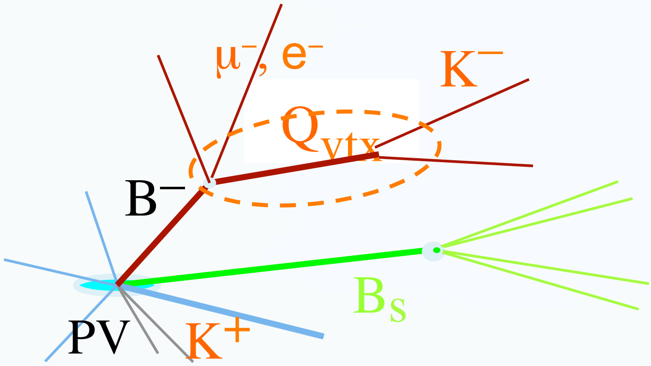


LHCb preliminary

Parameter		Result ± stat. ± syst.
Γ_s	$=$	$0.680 \pm 0.034 \pm 0.027\,\mathrm{ps}^{-1}$
$\Delta\Gamma_s$	$=$	$0.084 \pm 0.112 \pm 0.021\,\mathrm{ps}^{-1}$
$\lvert A_0(0)\rvert^2$	$=$	$0.532 \pm 0.040 \pm 0.028$
$\lvert A_\perp(0)\rvert^2$	$=$	$0.279 \pm 0.057 \pm 0.014$
$\cos\delta_{\parallel}$	$=$	$-1.24 \pm 0.27 \pm 0.09$

CDF 5.2 fb^{-1}: $\Delta\Gamma = 0.075 \pm 0.035(\mathrm{stat}) \pm 0.01(\mathrm{syst})\ \mathrm{ps}^{-1}$

Flavour tagging



B flavour at production determined by several algorithms

- Opposite Side (tag all b hadrons): μ, e, K, charge of inclusive secondary vertex
- Same Side: K (for B_s), π (for B_d,B_u)

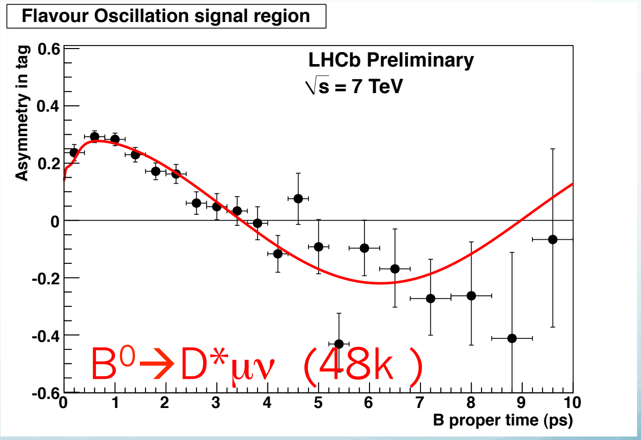
Algorithms optimized on data for maximum tagging power: $\varepsilon_{tag}(1\text{-}2\omega)^2$ using control channels.

OS and SSπ :

- $B^0 \rightarrow D^{*-}\mu^+\nu$, $B^+ \rightarrow J/\psi K^+$, $B^0 \rightarrow J/\psi K^{0*}$

SSK:

- $B_s \rightarrow D_s^-\pi$ (≈1.3k) too small sample to calibrate on data



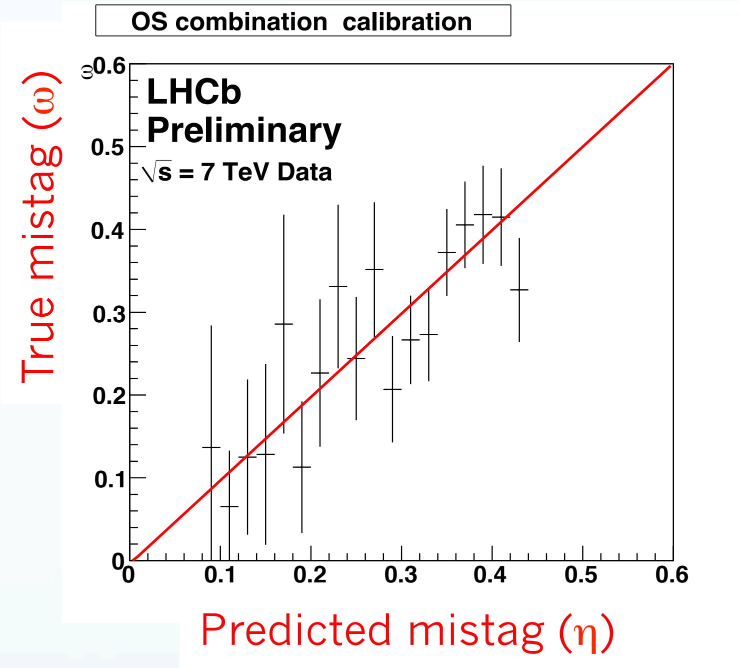
Flavour tagging calibration

- Tagging power enhanced using per-event mistag probability calculated from taggers and event properties.

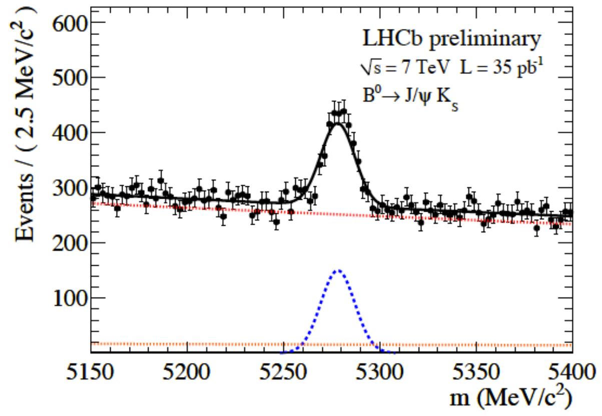
- Calibrated on data with $B^+ \rightarrow J/\psi K^+$.
  Validated on $B^0 \rightarrow J/\psi K^{0*}$.
  Uncertainty dominated by sample size.

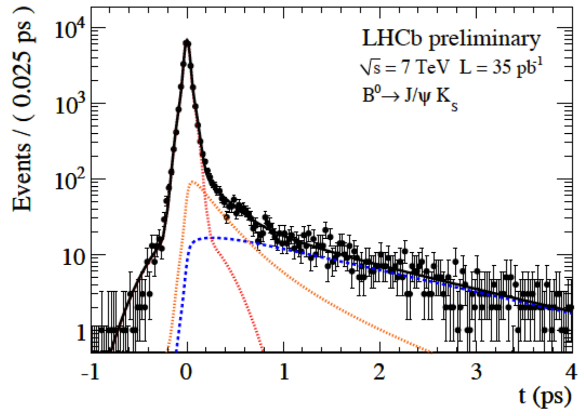
- Performance on $B_s \rightarrow J/\psi\phi$ (OS only)

  ε_{tag} = 17.6 ± 1.4 %
  ω = 32 ± 2 %
  $\varepsilon_{tag}(1\text{-}2\omega)^2$ = 2.2 ± 0.5 %



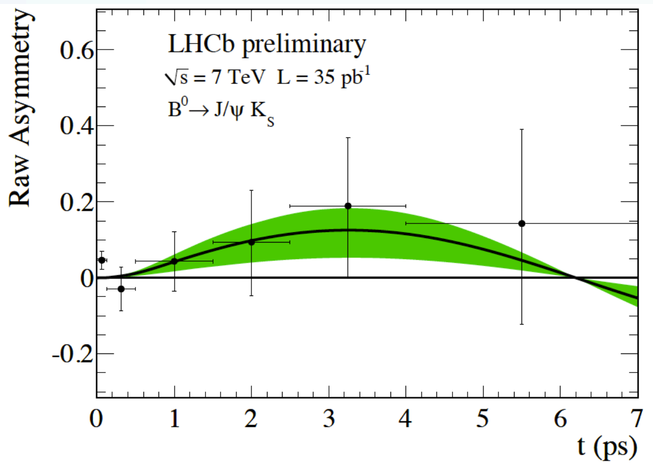
sin2β from $B^0 \to J/\psi K^0_S$





1330 events in 35 pb^{-1}
Unbiased+biased trigger.
Use OS and SSπ tag
$\varepsilon_{tag}(1-2\omega)^2 \approx 2.8\%$

Too small data sample for a measurement competitive with B-factories, but valid demonstration of LHCb capability in time dependent CPV analysis.



$$\mathcal{A}_{J/\psi K^0_S}(t) \equiv \frac{\Gamma(\overline{B}^0(t) \to J/\psi K^0_S) - \Gamma(B^0(t) \to J/\psi K^0_S)}{\Gamma(\overline{B}^0(t) \to J/\psi K^0_S) + \Gamma(B^0(t) \to J/\psi K^0_S)}$$
$$= S_{J/\psi K^0_S}\cos(\Delta m_d t) - C_{J/\psi K^0_S}\sin(\Delta m_d t)$$

LHCb preliminary

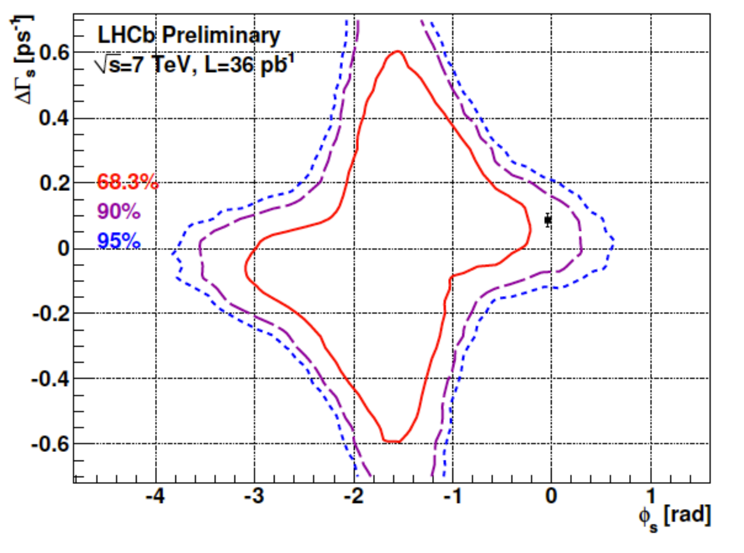
$$S_{J/\psi K^0_S} = 0.53^{+0.28}_{-0.29}(\text{stat}) \pm 0.07(\text{syst})$$

Main systematic from tagging calibration.

LHCb-CONF-2011-006

$B_s \rightarrow J/\psi\phi$ tagged analysis

- 757±28 events (t>0.3ps) from unbiased+biased trigger. 7D fit (m,t,tag,ω, ϕ,ψ,θ)
- No point-estimate, CL contours (Feldman-Cousins) in $\Delta\Gamma_s$- ϕ_s plane.



SM p-value 22% (1.2 σ)

Projection on ϕ_s:

LHCb preliminary

$$\phi_s \in [-2.7, -0.5]\,\text{rad at } 68\%\ \text{CL}$$

Include statistical uncertainty and systematic from tagging and Δm_s floated in the fit.
All other syst. uncertainties negligible wrt stat.

	LHCb $36\,\text{pb}^{-1}$	CDF $5.2\,\text{fb}^{-1}$
$B_s \rightarrow J/\psi\,\phi$	836	6500
Proper time resolution	50 fs	100 fs
OS tagging power	$2.2 \pm 0.5\%$	$1.2 \pm 0.2\%$
SS tagging power	work ongoing	$3.5 \pm 1.4\%$

- Improvements expected with 2011 data: larger event sample and addition of SSK tag.

Preparing for world best measurement!

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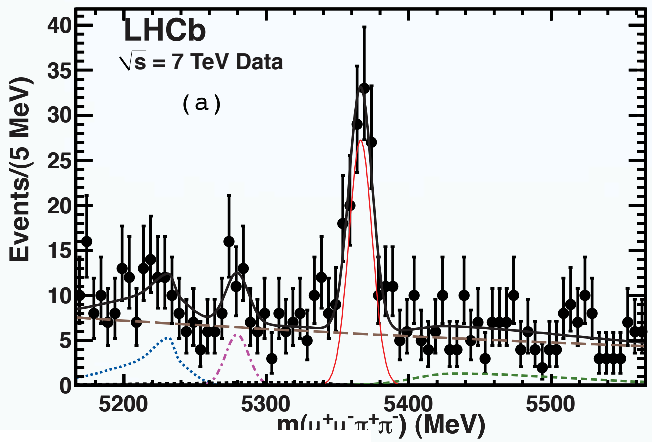
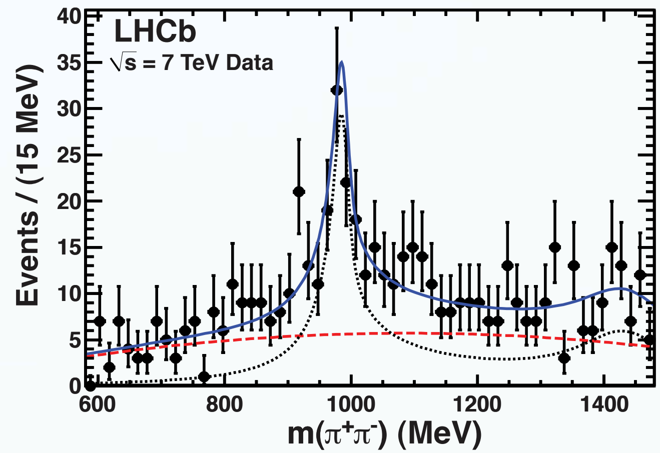
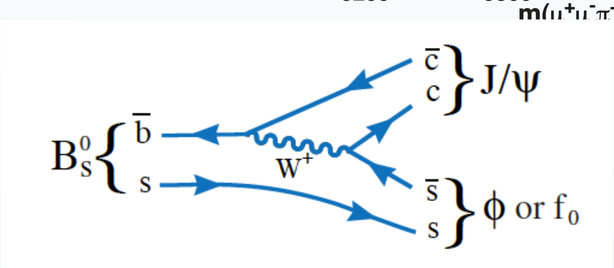
$B_s \to J/\psi f_0$

- First observation of $B_s \to J/\psi f_0$ at LHCb. Now measured also by Belle and CDF







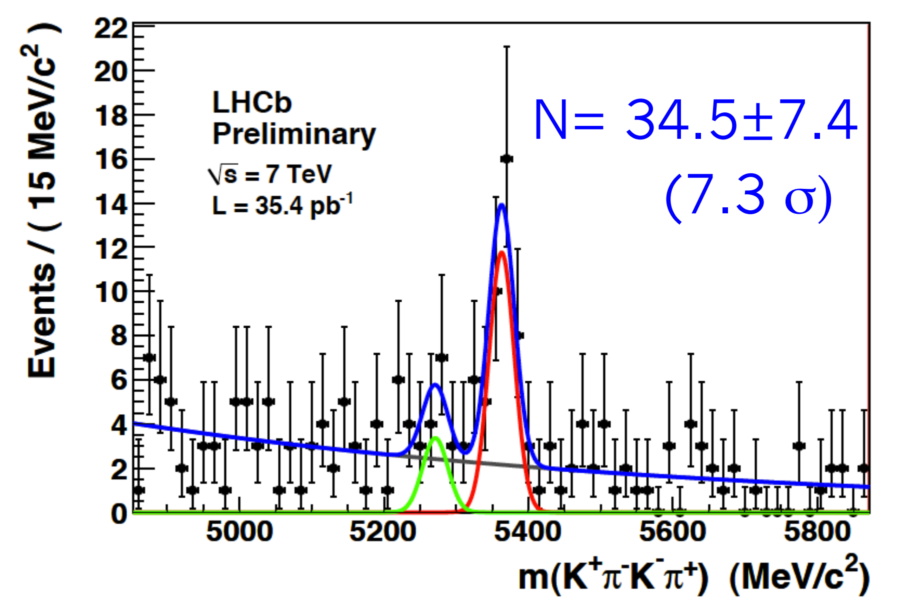
$$\frac{\Gamma(B_s^0 \to J/\psi f_0,\ f_0 \to \pi^+\pi^-)}{\Gamma(B_s^0 \to J/\psi \phi,\ \phi \to K^+K^-)} = 0.252^{+0.046+0.027}_{-0.032-0.033}$$

- Will allow another measurement of ϕ_s. Pure CP state, no angular analysis need, but less clean.

- Other CP modes under study for ϕ_s determination: $B_s \to J/\psi\eta'$, $B_s \to D_s^- D_s^+$

CPV in penguins
First evidence of $B_s \to K^{0*}\overline{K^{0*}}$

- $B_s \to K^{0*}(K^+\pi^-)\ \overline{K^{0*}}(K^-\pi^+)$ only from penguin decay. First evidence at LHCb with 35 pb^{-1}
- Future measurement of time-dependent CP asymmetries will probe New Physics in $b \to s$ transitions.



- Branching fraction with $B^0 \to J/\psi\ K^{0*}$ as normalization channel.
- In agreement with predictions from QCD factorization: $(7.9^{+4.3}_{-3.9}) \times 10^{-6}$

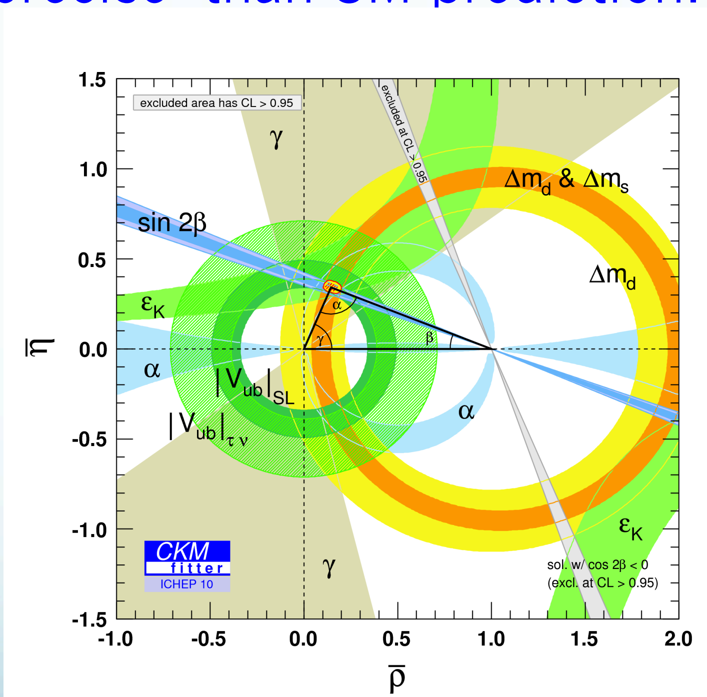
$$\mathcal{B}\left(B_s^0 \to K^{*0}\overline{K}^{*0}\right) = (1.95 \pm 0.47(stat.) \pm 0.51(syst.) \pm 0.29\,(f_d/f_s)) \times 10^{-5}$$

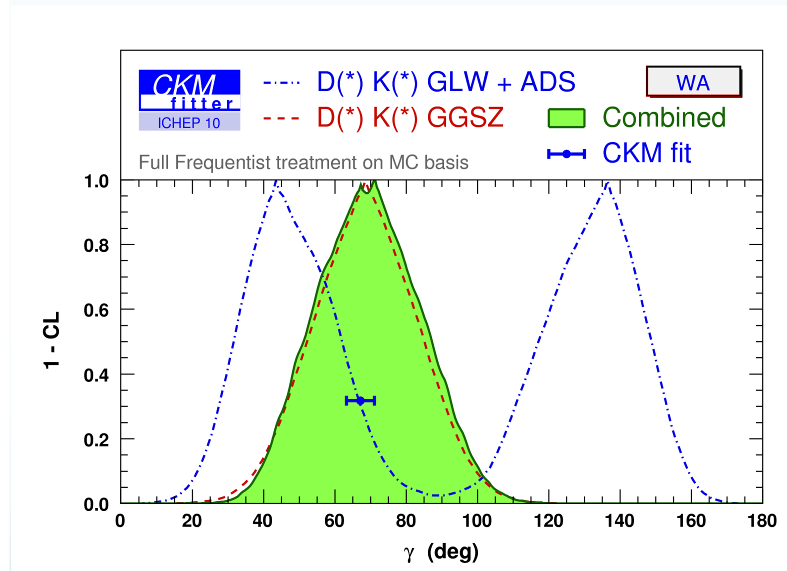
Gamma at LHCb

- Gamma angle from interference between b→c and b→u transition amplitudes

$$\gamma / \phi_3 = \arg\left(-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right)$$

- Most poorly measured angle of the UT, direct measurement much less precise than SM prediction.



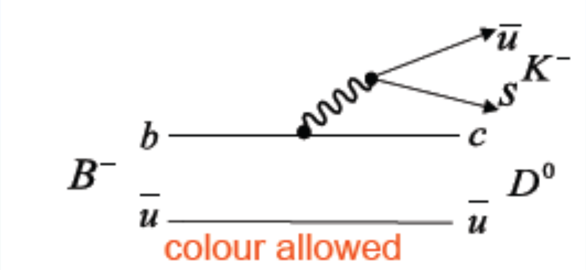


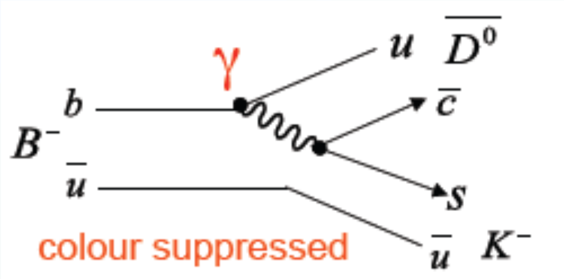
γ = (71+21−25)°

CKMfitter Group (J. Charles et al.)

Gamma from tree-level decays

- Theoretically cleanest way to γ via the interference between $B^{\pm}\rightarrow D^0K^{\pm}$, $B^{\pm}\rightarrow \overline{D}^0K^{\pm}$ in decays with final states common to $D^0,\overline{D}^0$ (only affected by possible NP in D^0 mixing).





Several time-integrated measurements are possible:

- Decays to CP modes $D^0 \rightarrow \pi^+\pi^-$ $D^0\rightarrow K^+K^-$ (GLW)
- CF ($K^-\pi^+$) and DCS ($K^+\pi^-$) decay modes (ADS)
- Dalitz analysis $D^0\rightarrow K_S\pi^+\pi^-$,$D^0\rightarrow K_SK^+K^-$ (most precise result from B-Factories)

But also time-dependent measurements, unique to LHCb:

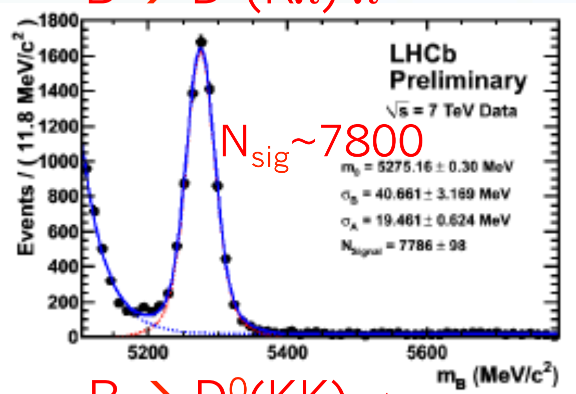
- $B_s\rightarrow D_sK$ sensitive to $\gamma - \phi_s$

No significant constraint on γ from 2010 data, many studies started:

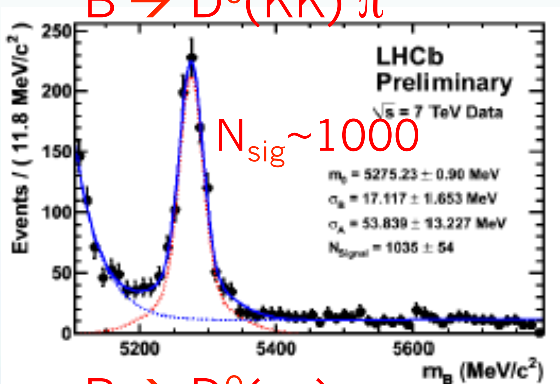
expected sensitivity on γ at the end of 2012 ~5 degrees.

$B^\pm \to D^0 h^\pm$

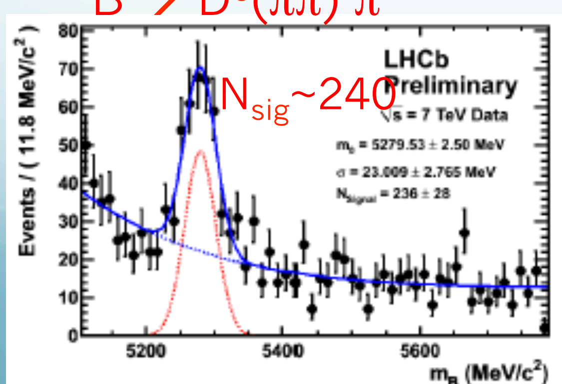
$B \to D^0(K\pi)\,\pi$



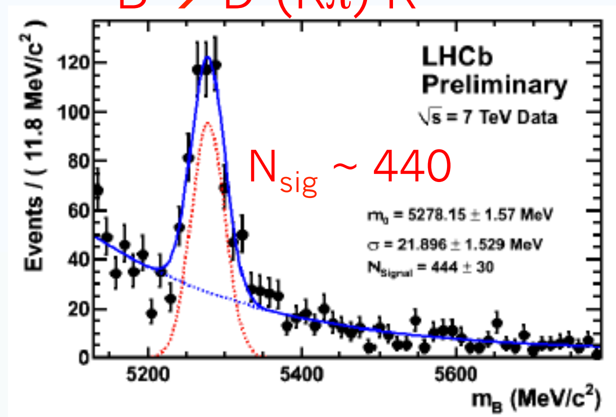
$B \to D^0(KK)\,\pi$



$B \to D^0(\pi\pi)\,\pi$



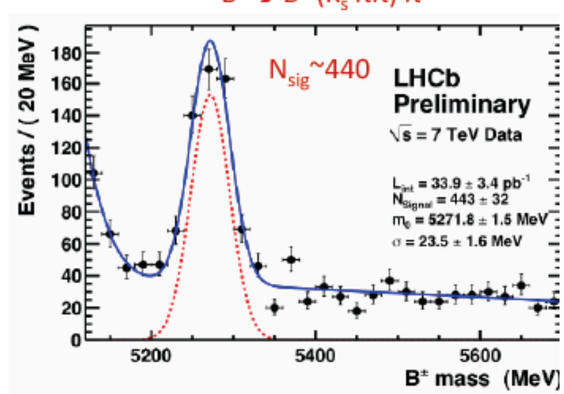
$B \to D^0(K\pi)\,K$



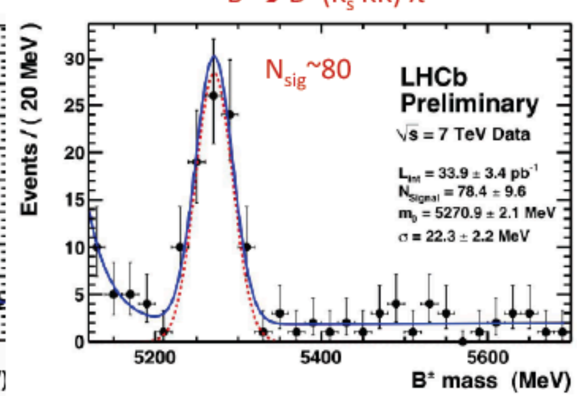
Statistics comparable to CDF in 1 fb^{-1}
(eg. ~300 $B \to D^0(K\pi)K$)

And also $D^0 \to K_S hh$ modes for Dalitz plot:

$B^- \to D^0(K_s\,\pi\pi)\,\pi$



$B^- \to D^0(K_s\,KK)\,\pi$



Expect ~1000 $B^- \to D^0(K_S\pi^+\pi^-)K$ in $1fb^{-1}$, about the same sample as BaBar and Belle.

LHCb-CONF-2011-007
LHCb-CONF-2011-024

$H_b \to H_c hhh$

- Can add multi-body $B^{\pm} \to D^0 K^{\pm} \pi^+ \pi^-$ to measure γ.
- LHCb has the first observation of CS modes:

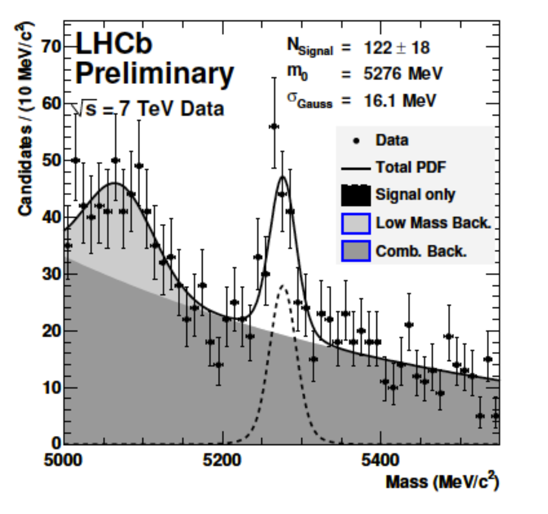
$$\frac{\mathcal{B}(B^- \to D^0 K^- \pi^+ \pi^-)}{\mathcal{B}(B^- \to D^0 \pi^- \pi^+ \pi^-)} = (9.6 \pm 1.5(\text{stat}) \pm 0.8(\text{syst})) \times 10^{-2}$$

LHCb preliminary

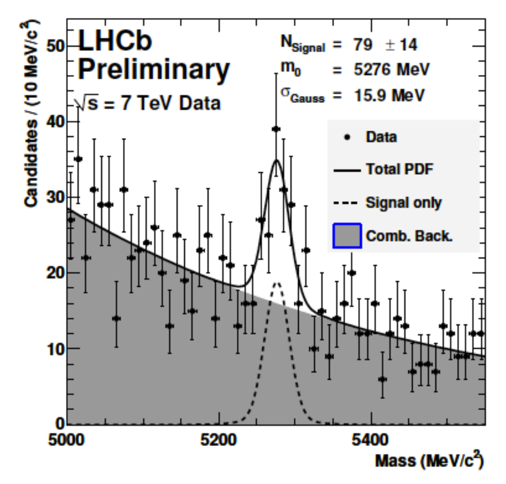
$$\frac{\mathcal{B}(\bar{B}^0 \to D^+ K^- \pi^+ \pi^-)}{\mathcal{B}(\bar{B}^0 \to D^+ \pi^- \pi^+ \pi^-)} = (5.2 \pm 0.9(\text{stat}) \pm 0.5(\text{syst})) \times 10^{-2}$$

- Also measured several multi-body CF modes.
- With 2011 data expect also $B_s \to D_s^+ K^- \pi^+ \pi^-$

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

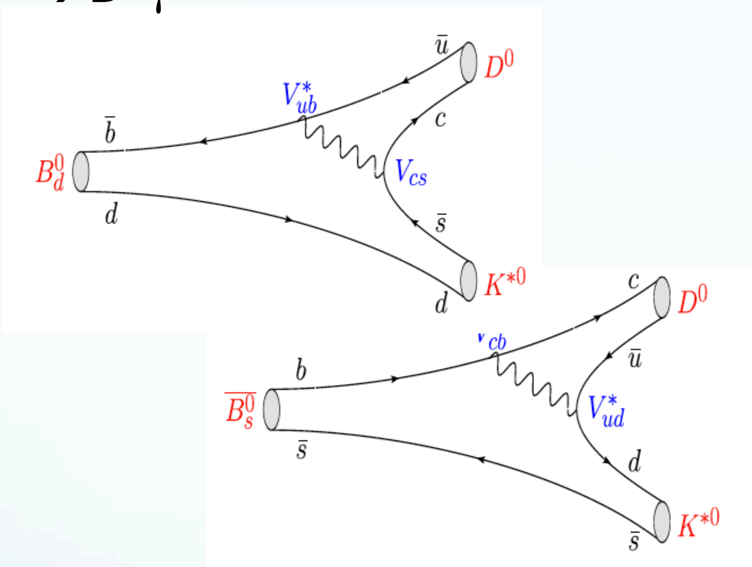


$B^0 \to D^+ K^- \pi^+ \pi^-$

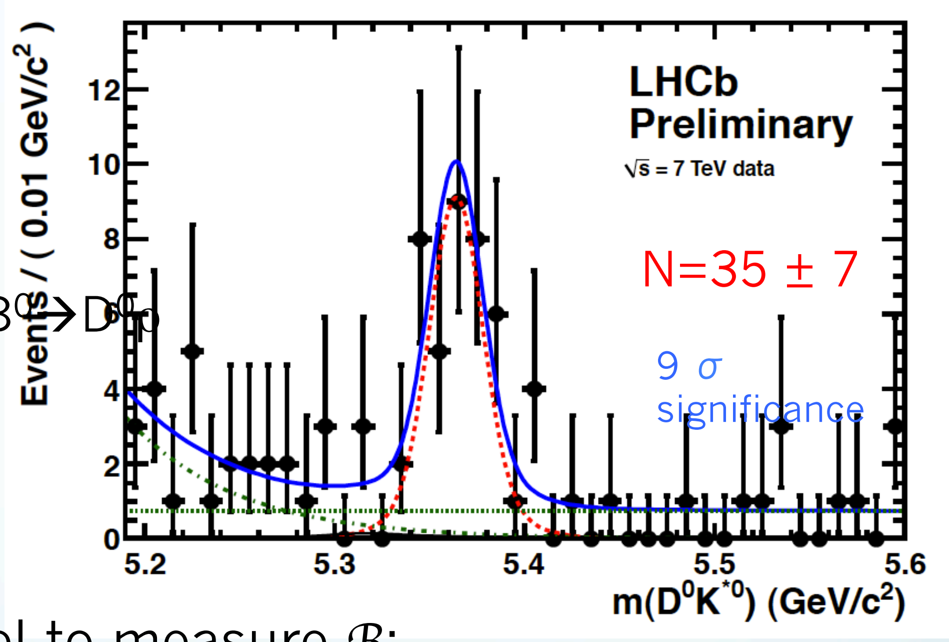


$\overline{B}_s \rightarrow D^0 K^{0*}$

Dangerous background for the measurement of γ in $B_d \rightarrow D^0 K^*$, when $D^{0*} \rightarrow D^0 \gamma$



First observation at LHCb.



Use $B^0 \rightarrow D^0 \rho$ as reference channel to measure $\mathcal{B}$:

LHCb preliminary

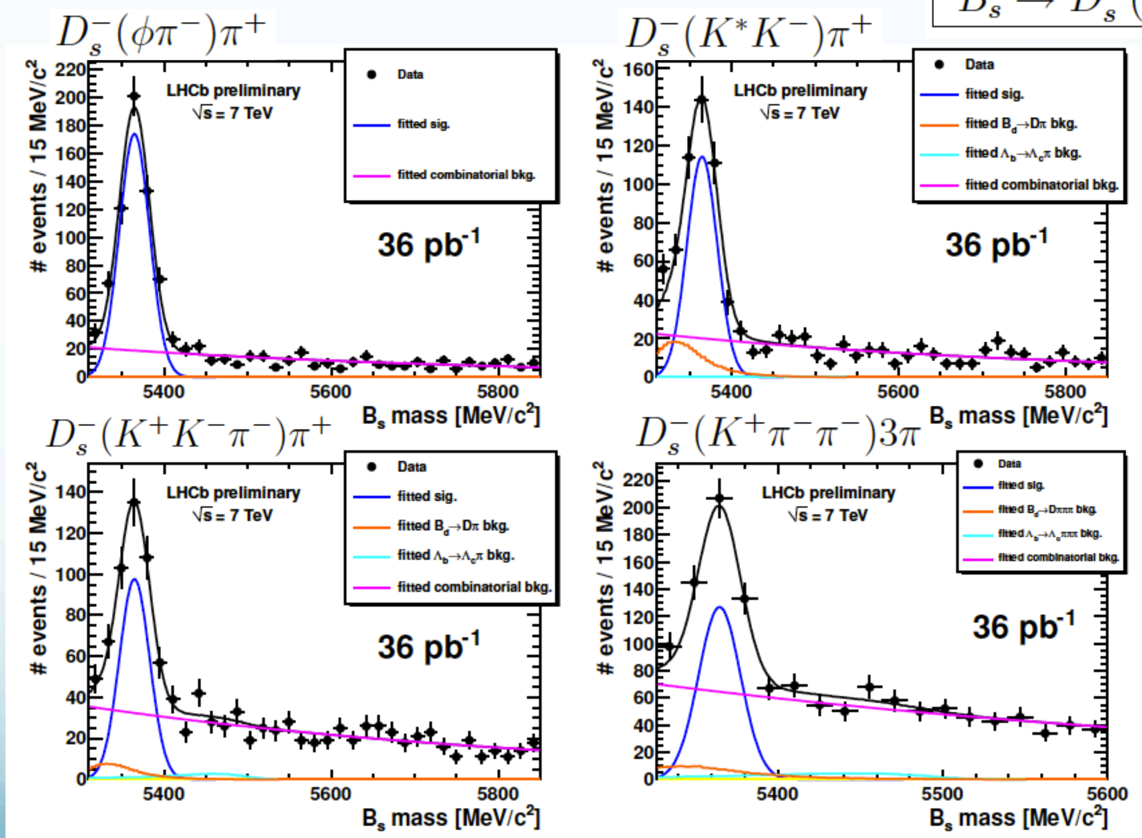
$$\mathcal{B}\left(\overline{B}_s^0 \rightarrow D^0 K^{*0}\right) = (4.44 \pm 1.00 \pm 0.55 \pm 0.56 \pm 0.69)\ 10^{-4}$$

f_d/f_s $\mathcal{B}(B^0 \rightarrow D^0 \rho)$

B_s mixing in $B_s \rightarrow D_s^-(3)\pi^+$

- Combine four decay modes for a total of ~1300 signal events:

decay mode	# signal candidates
$B_s \to D_s^-(\phi\pi^-)\pi^+$	515 ± 25
$B_s \to D_s^-(K^*K)\pi^+$	338 ± 27
$B_s \to D_s^-(K^+K^-\pi^-)\pi^+$	283 ± 27
$B_s \to D_s^-(K^+K^-\pi^-)3\pi$	245 ± 46

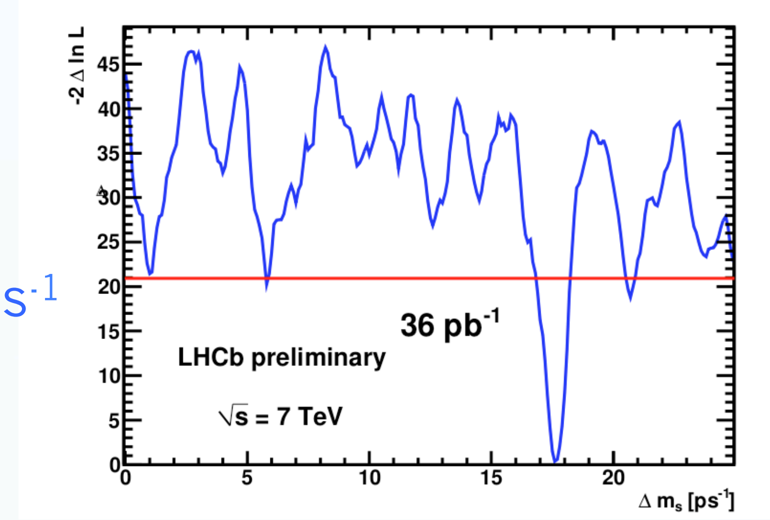


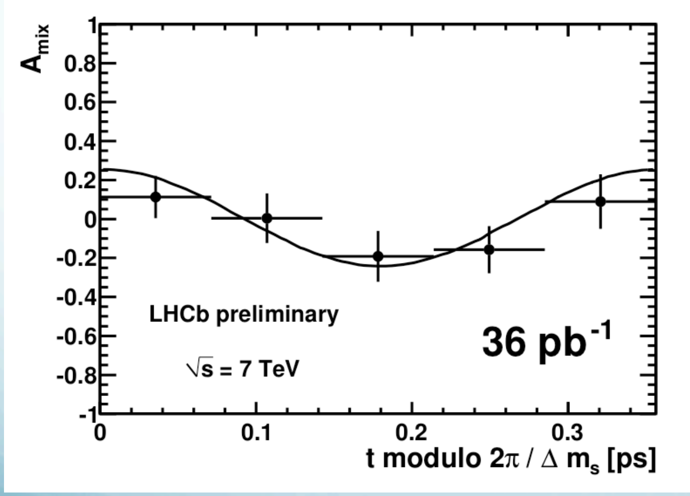
σ_m=18 MeV/c^2 ($D_s\pi$)

σ_m=12.7 MeV/c^2 ($D_s3\pi$)

B_s mixing in $B_s \to D_s^-(3)\pi^+$

- Per-event proper-time resolution calibrated on data with prompt D_s and π^+ : $\langle\sigma_t\rangle$ = 44 fs ($D_s\pi$), 36 fs ($D_s 3\pi$)
- Per-event mistag probability re-calibrated with $B^0 \to D^-\pi^+$: εD^2 = 3.8 ±2.1 % (OS tag)
- Minimum in the likelihood at $\Delta m_s \sim 17.6\,ps^{-1}$ with 4.6 σ statistical significance





LHCb preliminary

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

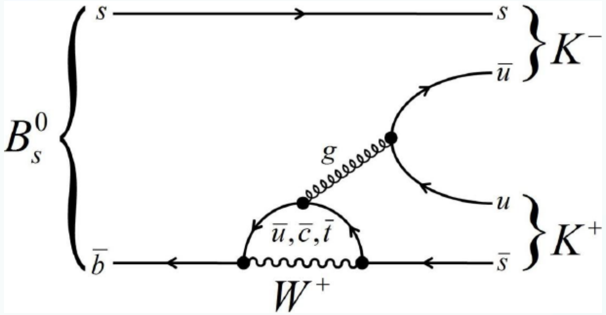
Competitive with world best (CDF, 1 fb^{-1}):

$$\Delta m_s = 17.77 \pm 0.10\ (\mathrm{stat.})\ \pm 0.07\ (\mathrm{syst.})\ \mathrm{ps}^{-1}$$

Gamma from loops

- Two body charmless decays $B_{d,s} \rightarrow \pi K, \pi\pi$, KK, pp have significant contribution of penguin diagrams: NP effects can be large.

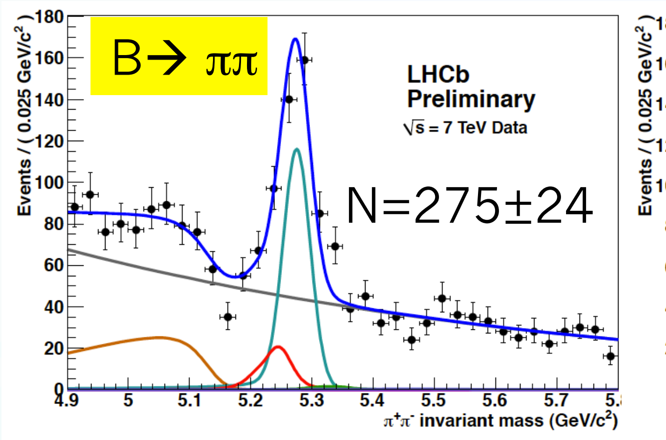
- First measurements on 2010 data:
  - ✓ Direct CP asymmetry (counting)
  - ✓ Lifetimes of $B_s \rightarrow KK$

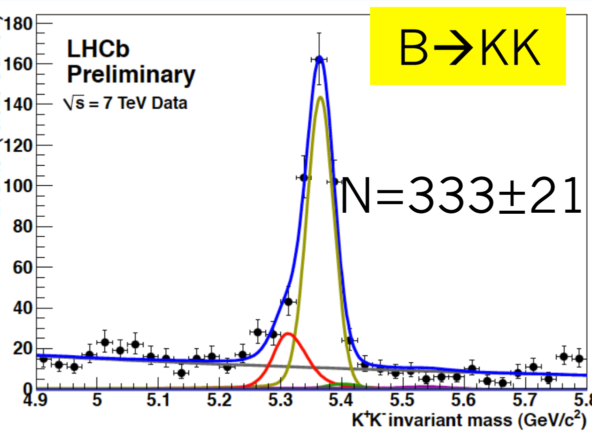


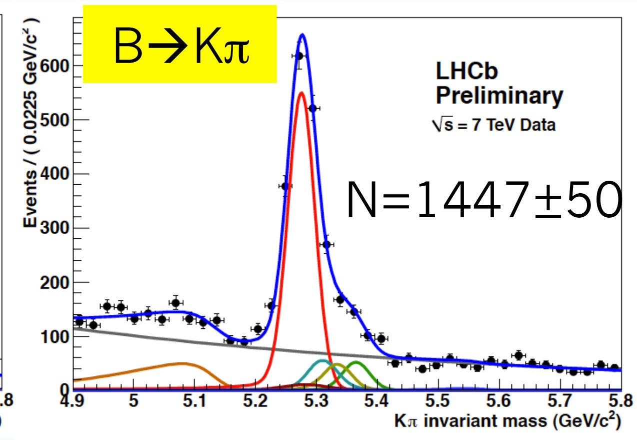
- Upcoming: γ angle (time dependent tagged analysis)

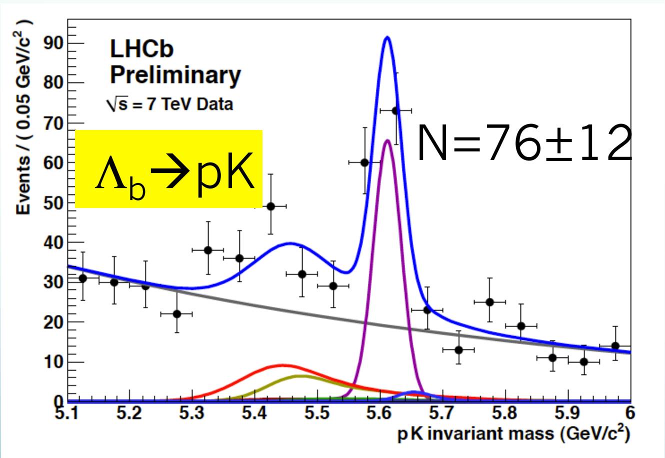
Experimentally rely on good performance of hadron trigger and RICH system and good mass resolution.

Charmless B decays

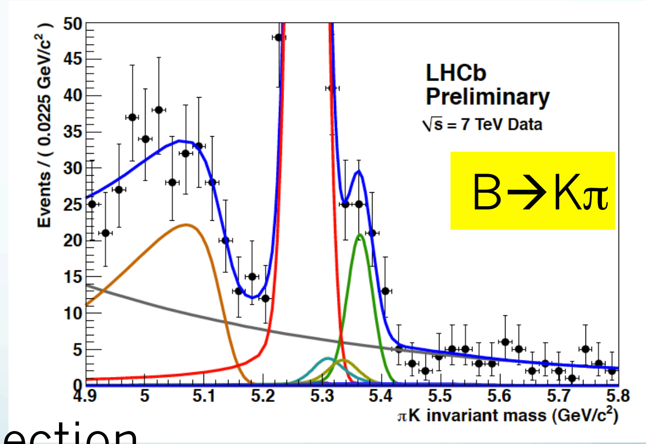








σ_m = 22 MeV/c^2
(B→Kπ)



Tighter selection
to enhance the B_s→πK signal

CP Asymmetries in B→Kπ

- Observation of direct CPV in B→Kπ decays.

$$A_{CP} = [\Gamma(\bar{B} \to \bar{f}) - \Gamma(B \to f)]/[\Gamma(\bar{B} \to \bar{f}) + \Gamma(B \to f)]$$

- Raw asymmetries corrected for:

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

  - ✓ detector asymmetries from $D^* \to D^0(K\pi, KK, \pi\pi)\pi$: $A_D(K\pi) = (-0.4 \pm 0.4)\%$
  - ✓ production asymmetries from $B^+ \to J/\psi K^+$: $A_P(B^0) = (-2.4 \pm 1.6)\%$

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

LHCb preliminary

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

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

already competitive with CDF ($1 fb^{-1}$): $A_{CP}(B_s^0 \to \pi^+K^-) = 0.39 \pm 0.15 \pm 0.08$

- New observation from CDF: $B^0 \to K^+K^-$ (2σ) and $B_s^0 \to \pi^+\pi^-$ (3.7σ)
  Will be soon explored by LHCb also. Rates compatible with expectations is good news for γ measurement.

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

- Lifetime provide information on decay width difference, sensitive to NP

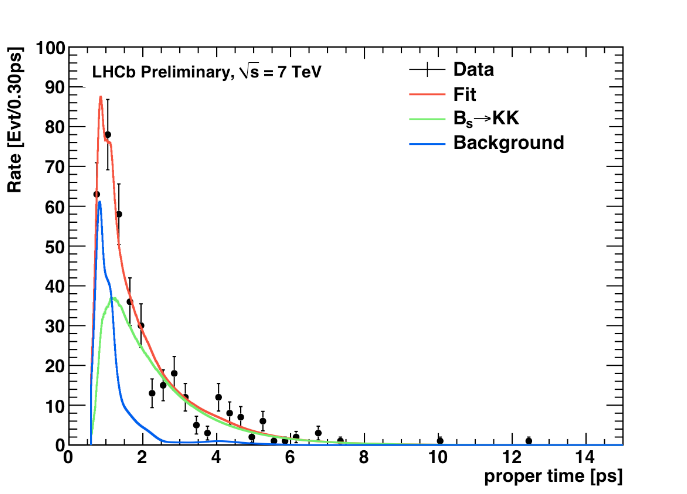
$$\Delta\Gamma_s = \Gamma_L - \Gamma_H \cong \Delta\Gamma_s^{SM} \cos(\phi^{NP})$$

Single exponential fit measures an effective lifetime:
$B_s \rightarrow K^- K^+$ nearly pure light state.

$$\tau^{-1}_{B\rightarrow KK} = \frac{R_L/\Gamma_L + R_H/\Gamma_H}{R_L/\Gamma_L^2 + R_H/\Gamma_H^2}$$

Two complementary measurements to control time-acceptance:

- Relative lifetime: use the ratio to the kinematically similar decay $B_d \rightarrow K\pi$, and B_d lifetime.
- Absolute lifetime: acceptance determined from data on event-by event basis



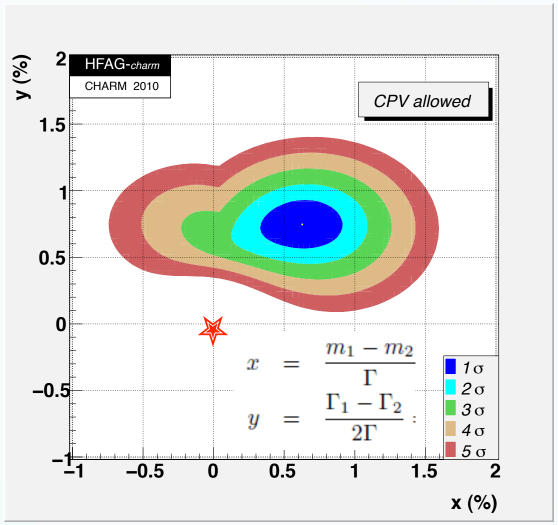
LHCb preliminary

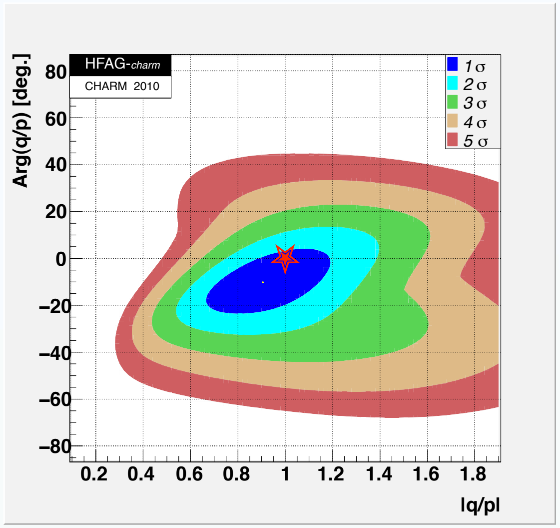
$$\tau_{B_s^0} = 1.440 \pm 0.096\ (\mathrm{stat}) \pm\ 0.010\ (\mathrm{syst})\ \mathrm{ps}$$

CDF: τ = 1.53±0.18±0.02 ps

Already world best. With 2011 data will give interesting NP constraints

CPV in charm





No mixing point excluded at 10.2σ by combination of several measurements. But no single experiment with 5σ evidence.

No CPV consistent at 1σ.

Forthcoming measurements at LHCb on y_{CP} and A_Γ (time dependent):

$$y_{\rm CP} = \frac{\tau(D^0 \to K^-\pi^+)}{\tau(D^0 \to K^-K^+)} - 1$$

$$A_\Gamma = \frac{\tau(\bar{D}^0 \to K^+K^-) - \tau(D^0 \to K^+K^-)}{\tau(\bar{D}^0 \to K^+K^-) + \tau(D^0 \to K^+K^-)}$$

$$y_{\rm CP} = y\cos\phi - \tfrac{1}{2}A_M \sin\phi$$

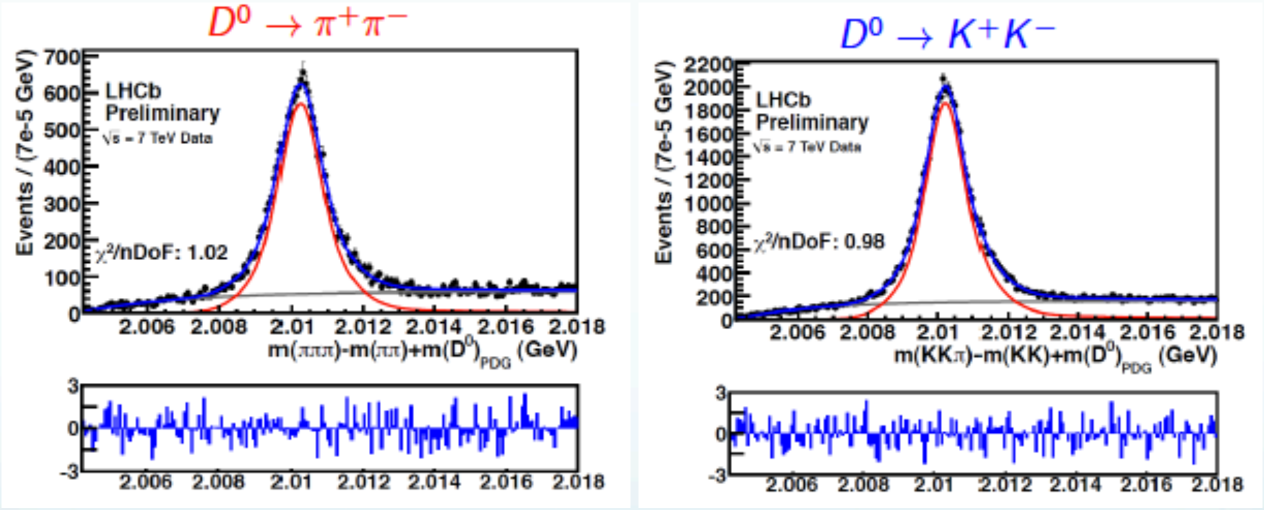
$$A_\Gamma = \tfrac{1}{2}A_M y\cos\phi - x\sin\phi.$$

Many intermediate measurement on the way.

Time-integrated CP Asymmetry in $D^0 \rightarrow \pi^+\pi^-, D^0 \rightarrow K^+K^-$

- Search for direct CPV. Use $D^{*+} \rightarrow D^0\pi^+$ tagged events and difference between two decay channels to cancel effects of detector and production asymmetries:

$$\Delta A_{CP} = A_{CP}(K^+K^-) - A_{CP}(\pi^+\pi^-) = A_{CP}^{raw}(K^+K^-) - A_{CP}^{raw}(\pi^+\pi^-)$$



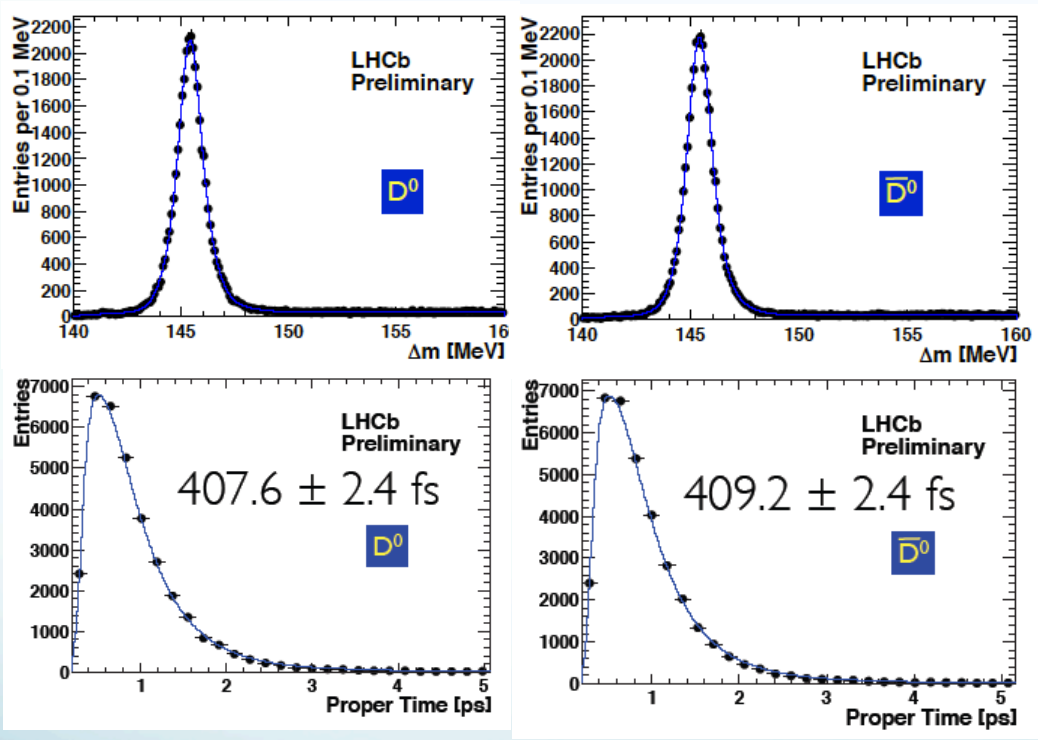
LHCb preliminary

$$\Delta A_{CP} = (-0.28 \pm 0.70 \pm 0.25)\%$$

Expect statistical sensitivity ~0.1% with $1 fb^{-1}$.

Time-dependent CP Asymmetry

- Control measurement of lifetime asymmetry performed with tagged $D^0 \rightarrow K^-\pi^+$ events. Expect $A_\Gamma^{K\pi,eff} = 0$.



$$A_\Gamma^{K\pi,eff} = \frac{\tau^{eff}(\overline{D}^0) - \tau^{eff}(D^0)}{\tau^{eff}(\overline{D}^0) + \tau^{eff}(D^0)}$$

LHCb preliminary

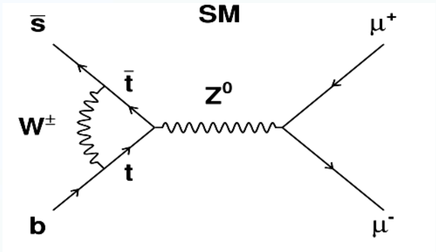
$A_\Gamma^{K\pi,eff} = (-2 \pm 4) \times 10^{-3}$

- Proves good control of proper time acceptance and modelling of secondary charm decays, statistical sensitivity on A_Γ –like measurement at 0.4%.

Search of New Physics in Rare Decays

Search for $B_{s,d} \to \mu^+\mu^-$

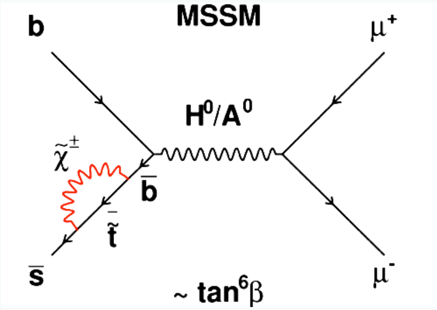
Very rare FCNC decay in the SM, precise predictions

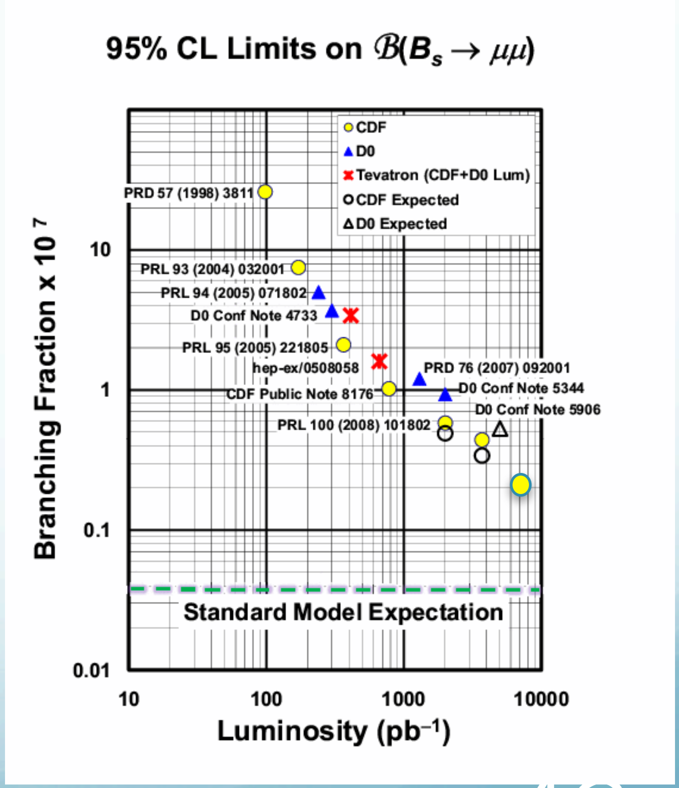


$$\mathcal{B}(B_s \to \mu\mu) = (3.2 \pm 0.2)\ \text{x}10^{-9}$$
$$\mathcal{B}(B_d \to \mu\mu) = (0.10 \pm 0.01)\ \text{x}10^{-9}$$

A.J.Buras: arXiv:1012.1447
E. Gamiz et al: Phys.Rev.D 80 (2009) 014503

Strong enhancements possible from NP eg. in MSSM





Best current limit (CDF 3.7 fb^{-1}):

$\mathcal{B}(B_s \to \mu\mu) < 43\ \text{x}10^{-9}$ @ 95%CL

$\mathcal{B}(B_d \to \mu\mu) < 7.6\ \text{x}10^{-9}$ @ 95%CL

Still one order of magnitude above SM.

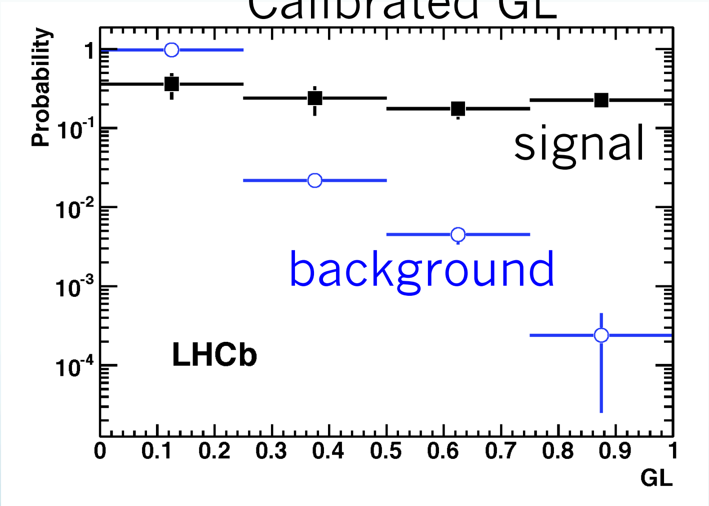
With 7fb^{-1} CDF expect for B_s ~$20\text{x}10^{-9}$ @ 95%CL

PLB 699 (2011) 330-340

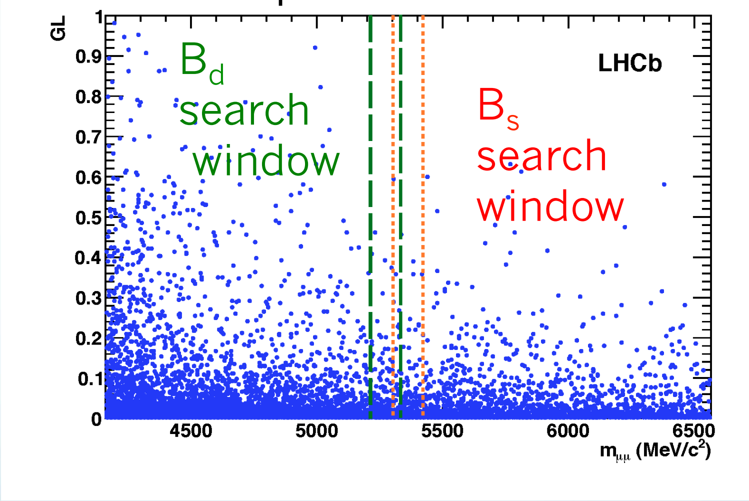
Search for $B_{s,d} \rightarrow \mu^+\mu^-$@LHCb

- Can get to low limit already with ~37 pb^{-1} thanks to:
  high trigger efficiency also at low p_T, good mass resolution, good μ PID
- Signal and background separation with geometrical likelihood calibrated on data with B→hh' events.
  300 events after pre-selection, about all in first GL bin.

Calibrated GL



Open max box

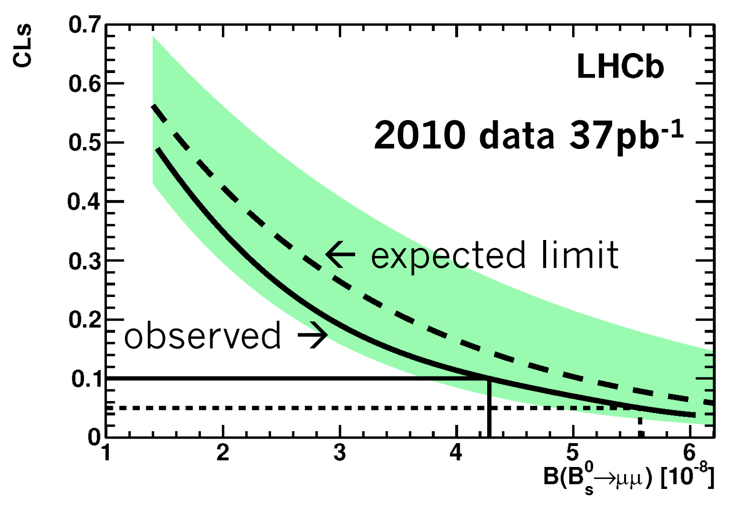


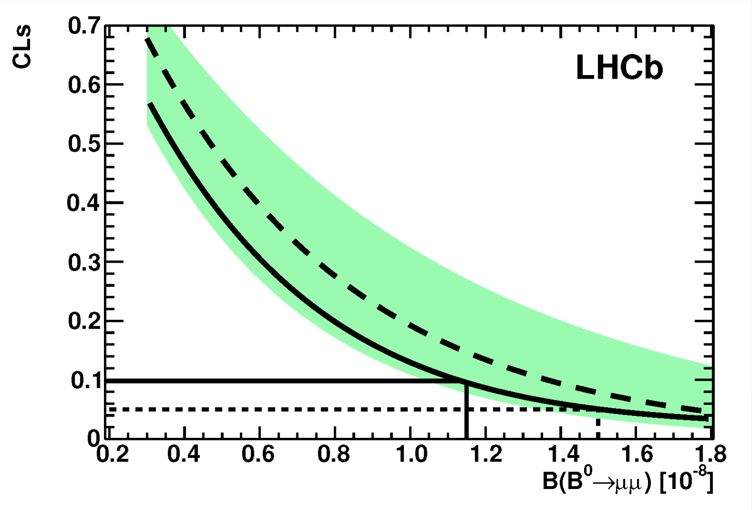
Branching ratio calculated with normalization from: B→J/ψK ,B→J/ψφ, B→πK

Search for $B_{s,d} \to \mu^+\mu^-$

- Observed limits:

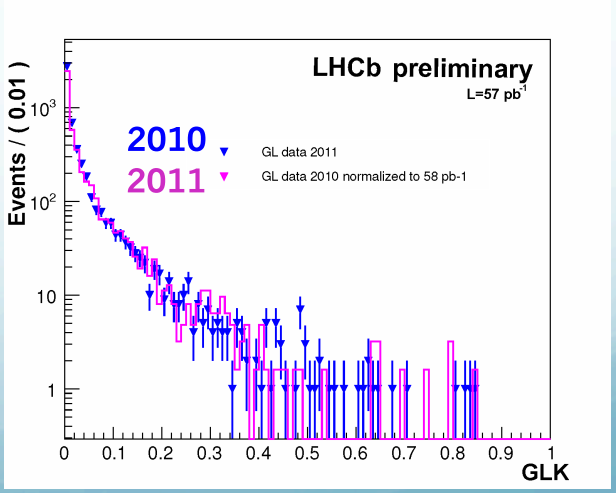
  $\mathcal{B}(B_s \to \mu\mu) <$ 56 x10^{-9} @ 95%CL $\mathcal{B}(B^0 \to \mu\mu) <$ 15 x10^{-9} @ 95%CL



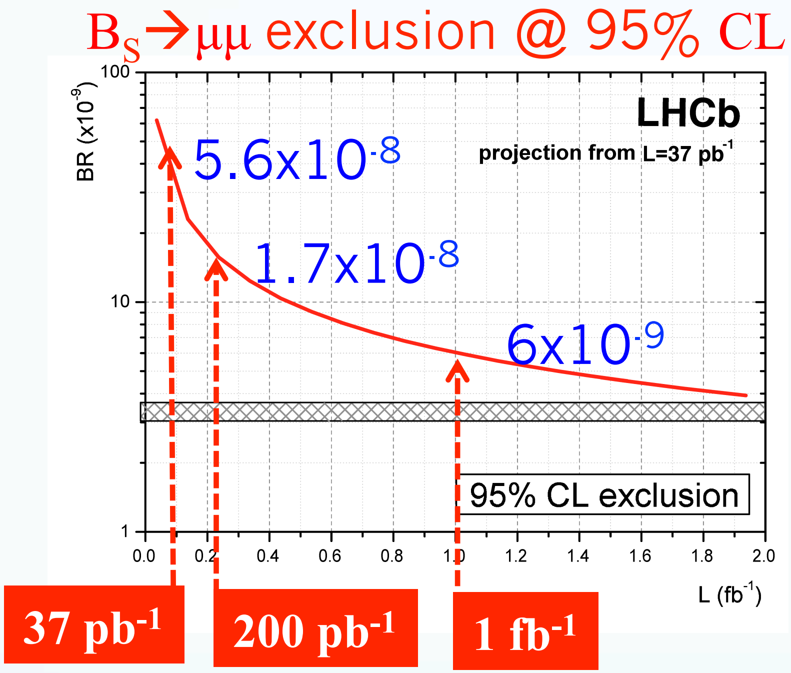


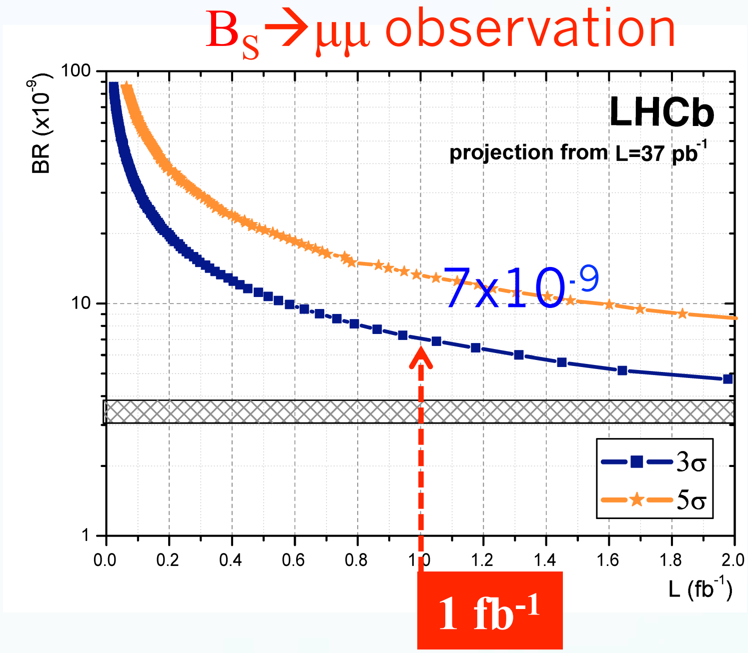
- Prospects for update with 2011 data: background still very low

GL shape in signal mass sidebands



Prospect for $B_{s,d} \to \mu^+\mu$

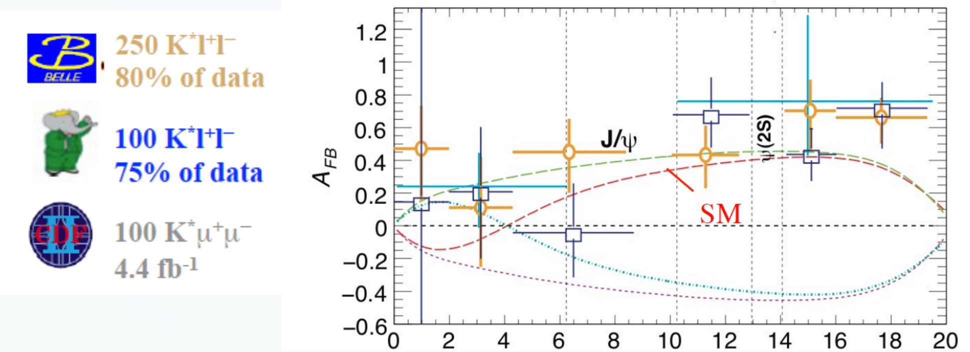




LHCb will either find signs of NP or exclude most of the tan β vs MA plane with 2011 data.
Strong impact on viable SUSY scenarios.

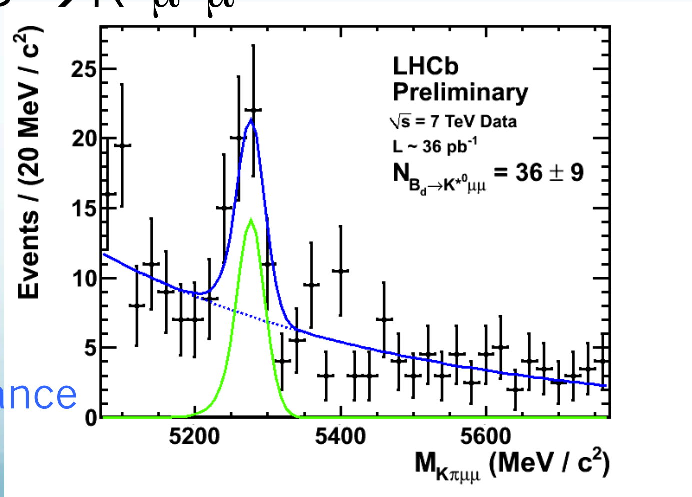
Prospect for $B^0 \to K^* \mu^+ \mu^-$

- FCNC $b \to s$ observed with $\mathcal{B} \sim 10^{-6}$, sensitive to C_7, C_9, C_{10} Wilson coeff.
- Sensitivity probe to NP from forward-backward asymmetry A_{FB}

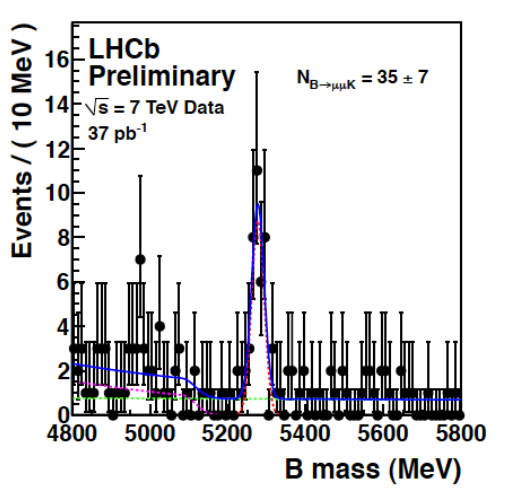


$C_7 = -C_7^{SM}$ favoured ?
Hints of anomaly to be confirmed by more data.

$B^0 \to K^* \mu^+ \mu^-$



4.8 σ significance

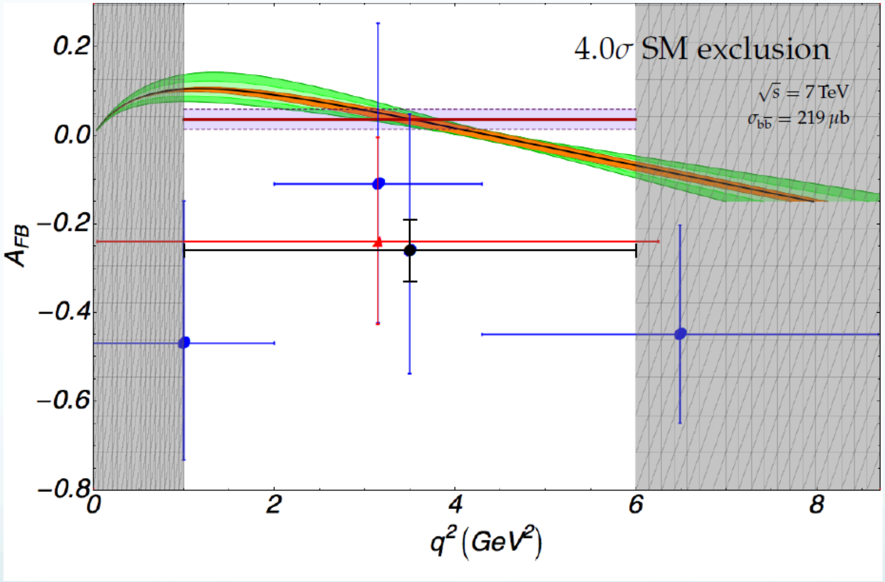


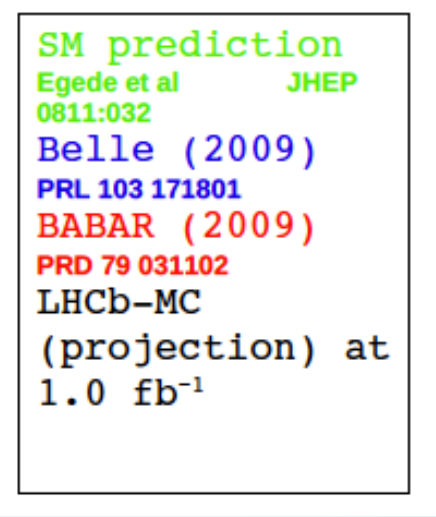
$B^+ \to K^+ \mu^+ \mu^-$ control channel, no A_{FB} expected.

$\mathcal{B} \sim 5 \times 10^{-7}$

Prospect for $B^0 \to K^* \mu^+ \mu^-$

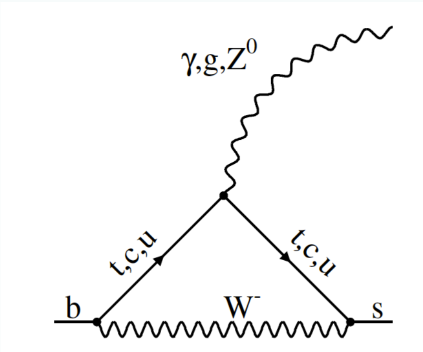
- Estimated error on A_{FB} in most sensitive bin (1–6 GeV^2), assuming Belle's central value
  - L=0.2 fb^{-1}(summer): $\sigma(A_{FB}) = 0.14$
  - L=1.0 fb^{-1}(end of 2011): $\sigma(A_{FB}) = 0.07$





- Future: also full angular analysis and use of other sensitive variables in addition to A_{FB}.

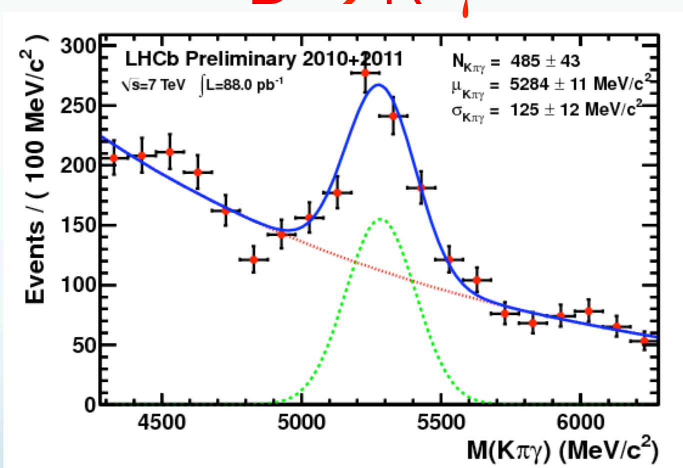
Prospects for radiative decays



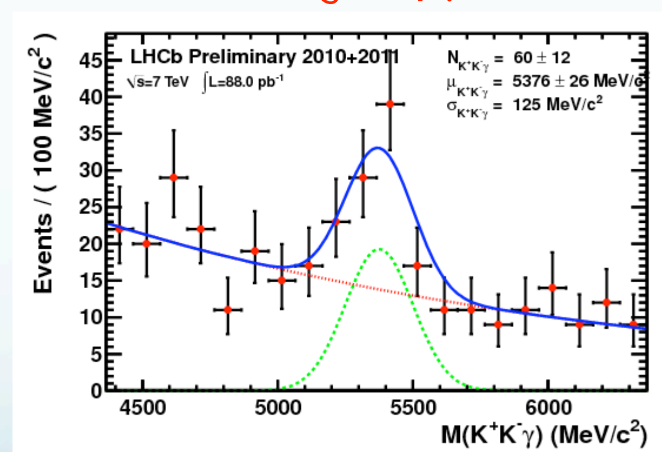
- Radiative $b \rightarrow s\gamma$ decays from FCNC penguins. LHCb will measure the polarisation of the emitted photon: $\left| \frac{\mathcal{A}(B \rightarrow \Phi\gamma_R)}{\mathcal{A}(B \rightarrow \Phi\gamma_L)} \right|$

- Enhancement of "wrong" polarization in LR symmetric models

$B^0 \rightarrow K^*\gamma$



$B_s \rightarrow \phi\gamma$



- Expect ~6000 $B^0 \rightarrow K^*\gamma$ and ~600 $B_s \rightarrow \phi\gamma$ with 1 fb^{-1}.

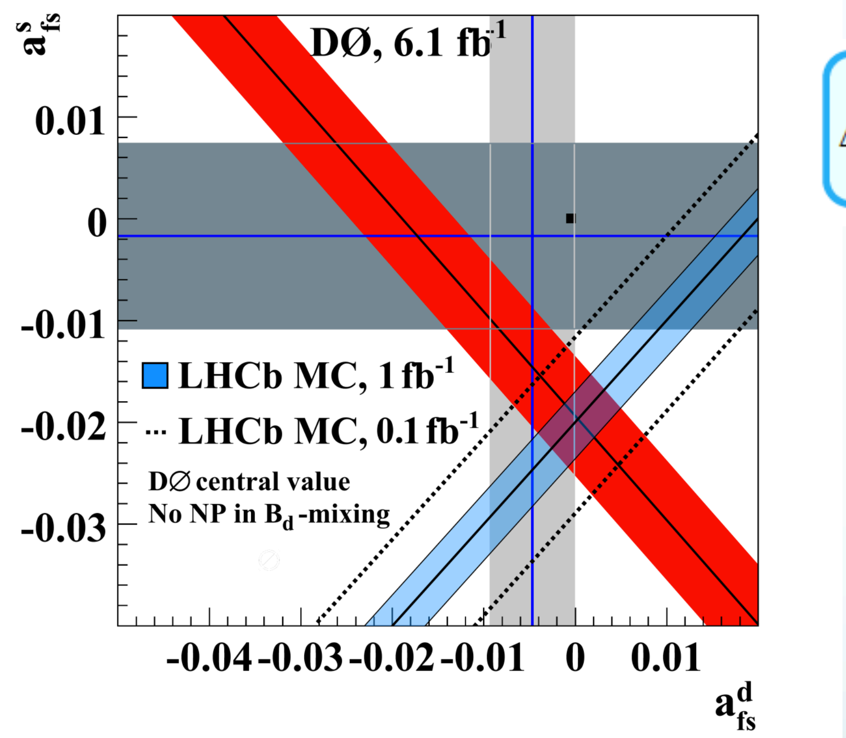
Conclusions

- Excellent performance of LHCb proved on 2010 data.
- Very clean signal measured in all "roadmap" channels and new decay modes observed.
- Preliminary result on Δm_s in $B_s \rightarrow D_s\pi$ oscillations with 36 pb^{-1} competitive with world best.
- Successfully completed all steps towards a ϕ_s measurement in $B_s \rightarrow J/\psi\phi$. Will allow world best result to be reached with 2011 data.
- Preliminary measurements of CP asymmetries in hadronic channels, more results from charmed mode underway.
- Limits on $\mathcal{B}(B_s \rightarrow \mu\mu)$ with 36 pb^{-1} close to world best, will become close to SM with 2011 data.
- Charm physics at LHCb will soon provide competitive results.

Backup

A_{sl}

Di-muon charge asymmetry measured by D0, giving hints of anomalous CPV in the mixing of neutral B mesons.



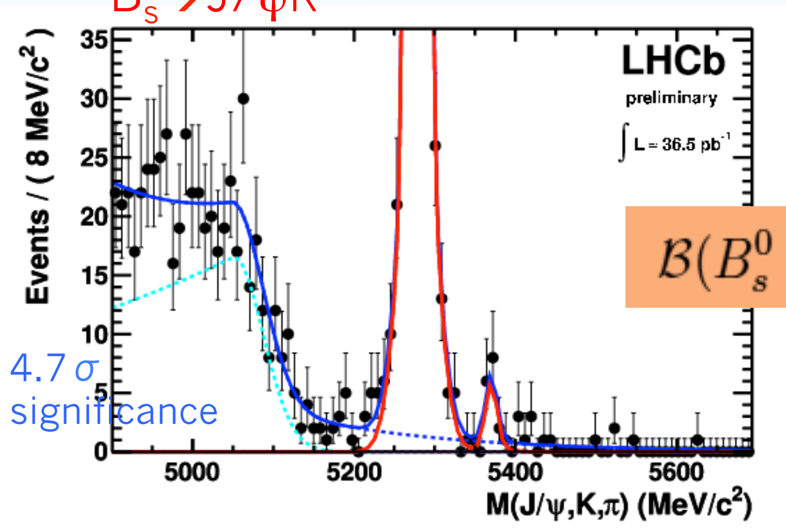
$$\Delta A_{fs} = \frac{a^s_{fs} - a^d_{fs}}{2} \rightarrow (2.1 \pm 0.3) \times 10^{-4} [S.M.]$$

- LHCb will measure $a^s_{sl} - a^d_{sl}$ from difference in asymmetry in $B_s \rightarrow D_s(KK\pi)\mu\nu$, $B^0 \rightarrow D^+(KK\pi)\mu\nu$.
- Orthogonal constraint to D0.

If there is NP in B_s mixing it will be seen by LHCb also in the ϕ_s measurement

$B_s \to J/\psi \overline{K}^{*0}$, $B_s \to \psi(2S)\phi$

$B_s \to J/\psi K^{*0}$



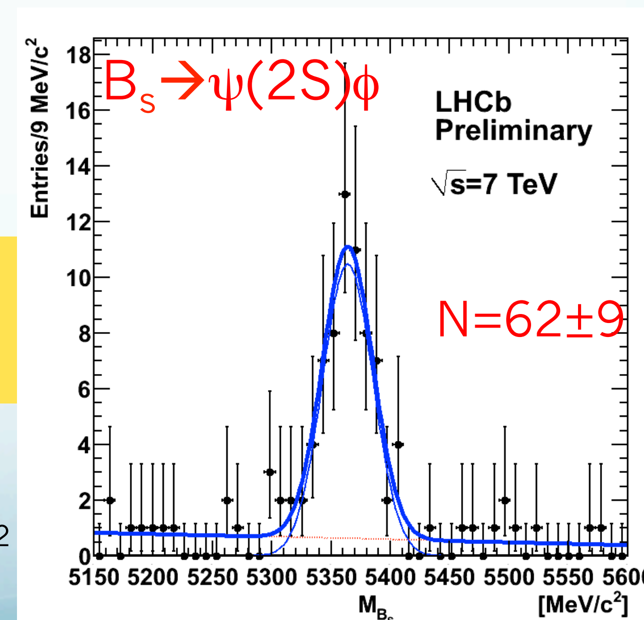
Will allow to control penguin effects in the ϕ_s determination from $B_s \to J/\psi\phi$

$$\mathcal{B}(B_s^0 \to J/\psi \overline{K}^{*0}) = (3.5^{+1.1}_{-1.0}(stat.) \pm 0.9(syst.)) \times 10^{-5}$$

Assuming all $K\pi$ from K^*

CDF: $\mathcal{B}(B_s^0 \to J/\psi \overline{K}^{*0}) = (8.3 \pm 3.8) \times 10^{-5}$

$$\frac{\mathcal{B}(B_s^0 \to \psi(2S)\phi)}{\mathcal{B}(B_s^0 \to J/\psi\,\phi)} = 0.68 \pm 0.10(\mathrm{stat}) \pm 0.09(\mathrm{syst}) \pm 0.07(\mathcal{B})$$



B_s mass for events with $3630 < M_{\mu\mu} < 3740$ MeV/c^2

Systematic $B^0 \to J/\psi K^{0*}$ and $B_s \to J/\psi\phi$ untagged

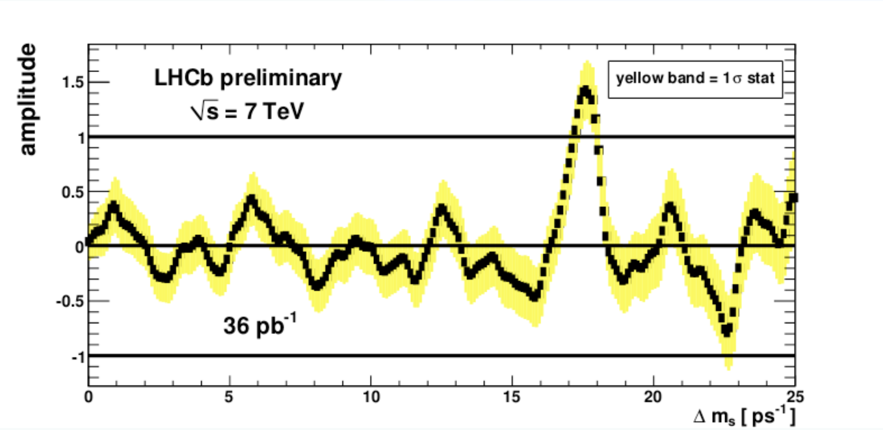
$B^0 \to J/\psi K^{0*}$

Systematic effect	$\|A_\parallel\|^2$	$\|A_\perp\|^2$	$\delta_\parallel$	$\delta_\perp$
proper time acceptance	-	-	-	-
data/MC differences	0.008	0.006	0.07	0.05
statistical error of acceptance	0.002	0.001	-	0.01
wrong-signal fraction	0.004	0.001	-	0.01
background treatment	0.002	0.008	0.04	0.01
statistical error of background	0.008	0.005	0.02	0.01
mass model	0.010	0.002	0.01	0.01
s-wave treatment	0.001	0.013	0.05	0.05
sum	0.016	0.017	0.10	0.07

$B_s \to J/\psi\phi$

Systematic effect	Γ_s [ps^{-1}]	$\Delta\Gamma_s$ [ps^{-1}]	$\|A_\perp(0)\|^2$	$\|A_\parallel(0)\|^2$	$\cos\delta_\parallel$
Proper time resolution	0.0001	-	-	-	-
Angular acceptance	-	-	-	0.0007	-
Acceptance parametrisation	0.0002	0.001	0.0017	0.0013	-
Proper time acceptance	0.0272	0.001	0.0003	0.0002	-
S-wave treatment	0.003	0.003	0.013	0.028	0.09
Background treatment	0.0002	0.02	0.0016	0.0012	-
Mass model	0.0004	0.004	0.0032	0.0006	-
Total (quadratic sum)	0.0274	0.0206	0.0136	0.0281	0.09

Systematic B_s mixing in $B_s \rightarrow D_s^-(3)\pi^+$



Amplitude scan: A =1.41 ± 0.26 (stat) for Δm_s =17.6 ps^{-1}

Systematic uncertainties on Δm_s	
source	$\Delta_{\Delta m_s}[ps^{-1}]$
proper time resolution $S_{\sigma_t} = [1.2 - 1.4]$	0.006
proper time resolution model	0.001
proper time acceptance function	0.000
fixed parameters floating	0.003
diff. background shape in mass fit	0.010
phys. bkg mass templates	0.002
variation of η and σ_t PDFs	0.026
z-scale (0.1%)	0.018
momentum scale (0.1%)	0.018
$\Delta\Gamma_s = [0 - 0.2] \times \Gamma_s$	0.002
total systematic uncertainties	**0.038**

Systematic sin2β from $B^0 \to J/\psi K^0_S$

$$\mathcal{A}^{\text{meas}}_{J/\psi K^0_S}(t) = (1-2\omega)\mathcal{A}_{J/\psi K^0_S}(t) \otimes \mathcal{R}(t)$$

Table 3: Systematic uncertainties to $S_{J/\psi K^0_S}$ in absolute terms.

Source	uncertainty
tagger calibration	0.067
per-event mistags p.d.f.	0.012
Δm_d uncertainty, z scale	0.0017
proper time resolution	0.0085
high propertime acceptance	0.00065
biased events acceptance	0.0042
biased TIS events acceptance	0.0063
production asymmetry	0.024
total (sum in squares)	0.073

New WA: sin2β = 0.678 ± 0.020

Systematic f_s/f_d

$$\frac{\mathcal{B}(B_s^0 \to D_s^- \pi^+)}{\mathcal{B}(B^0 \to D^- K^+)} = \frac{\tau_{B_s^0}}{\tau_{B^0}} \left|\frac{V_{ud}}{V_{us}}\right|^2 \left(\frac{f_\pi}{f_K}\right)^2 \left[\frac{F_0^{(s)}(m_\pi^2)}{F_0^{(d)}(m_K^2)}\right]^2 \left|\frac{a_1(D_s^- \pi^+)}{a_1(D^- K^+)}\right|^2$$

$$\frac{f_s}{f_d} = 0.0743 \times \frac{\tau_{B^0}}{\tau_{B_s^0}} \times \left[\frac{1}{\mathcal{N}_a \mathcal{N}_F} \frac{\epsilon_{DK}}{\epsilon_{D_s\pi}} \frac{N_{D_s\pi}}{N_{DK}}\right]$$

$$\frac{f_s}{f_d} = 0.242 \pm 0.024^{\mathrm{stat}} \pm 0.018^{\mathrm{syst}} \pm 0.016^{\mathrm{theor}}$$

$$\frac{f_s}{f_d} = 0.982 \times \frac{\tau_{B^0}}{\tau_{B_s^0}} \times \left[\frac{1}{\mathcal{N}_a \mathcal{N}_F \mathcal{N}_E} \frac{\epsilon_{D\pi}}{\epsilon_{D_s\pi}} \frac{N_{D_s\pi}}{N_{D\pi}}\right]$$

$$\frac{f_s}{f_d} = 0.249 \pm 0.013^{\mathrm{stat}} \pm 0.020^{\mathrm{syst}} \pm 0.025^{\mathrm{theor}}$$

Source	Using $D_s^- \pi^+ / D^- K^+$	Using $D_s^- \pi^+ / D^- \pi^+$
Specific BG vetos in B^0 fit	2%	2%
PID calibration	1.5%	1.5%
B^0 fit model	1%	1%
B_s^0 fit model	3%	3%
Tracking efficiency $K^\mp/\pi^\mp$	1.5%	3.5%
Trigger simulation	2%	2%
$\mathcal{B}(D_s^\pm \to KK\pi)$	5%	5%
$\mathcal{B}(D^\pm \to K\pi\pi)$	2%	2%
$\frac{\tau_{B_s}}{\tau_{B_d}}$	1.5%	1.5%
Total	7.3%	8.0%