Recent LHCb Results

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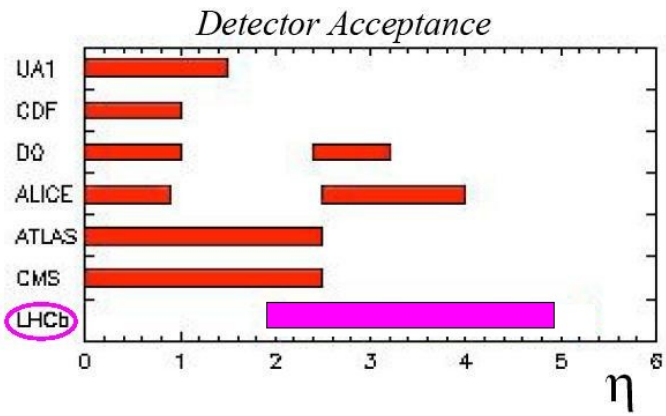
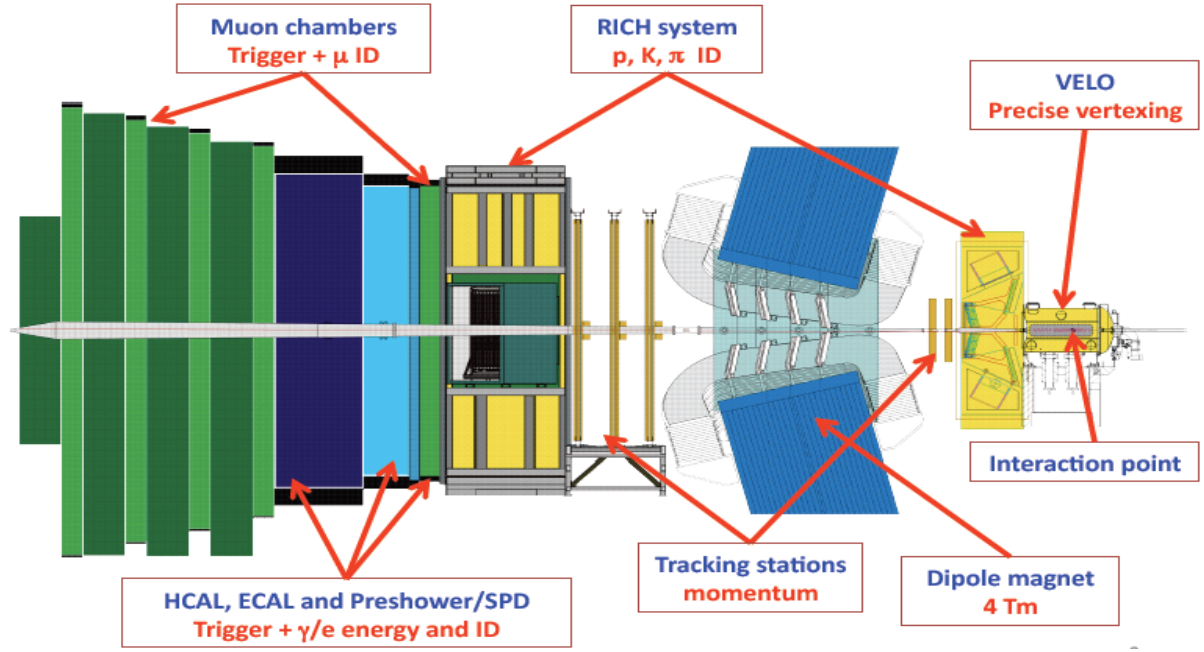
on behalf of the
LHCb Collaboration

DIS 2011
April 11th, 2011

The LHCb experiment was conceived for CP violation and rare decays in heavy flavors

The detector is a forward spectrometer with unique coverage in rapidity and p_T of triggered particles at hadron colliders



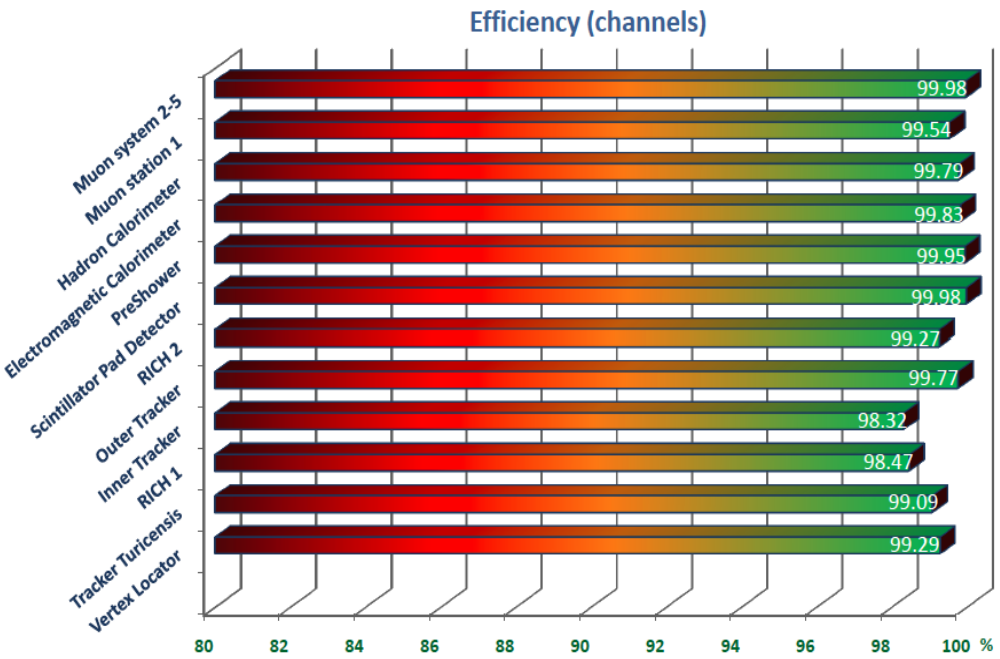


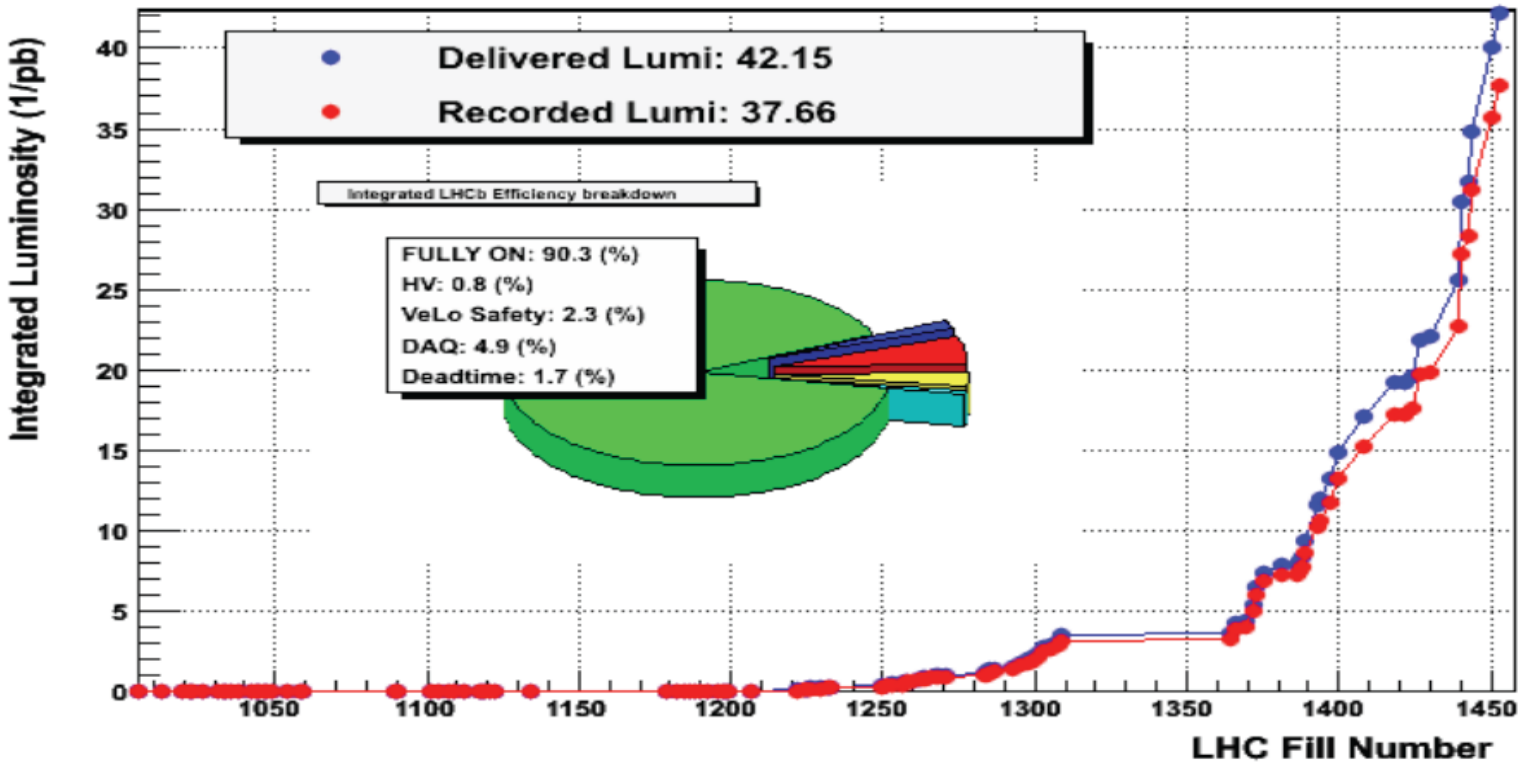
Outline

- The 2010 run
- Demonstrating performances with selected results from the core (B) physics program
- Results from non-B forward physics

2010 run

- Fully working detector
- LHC almost reached design LHCb luminosity ($2x10^{32}$ $cm^{-2}s^{-1}$)
- 90% DAQ efficiency overall

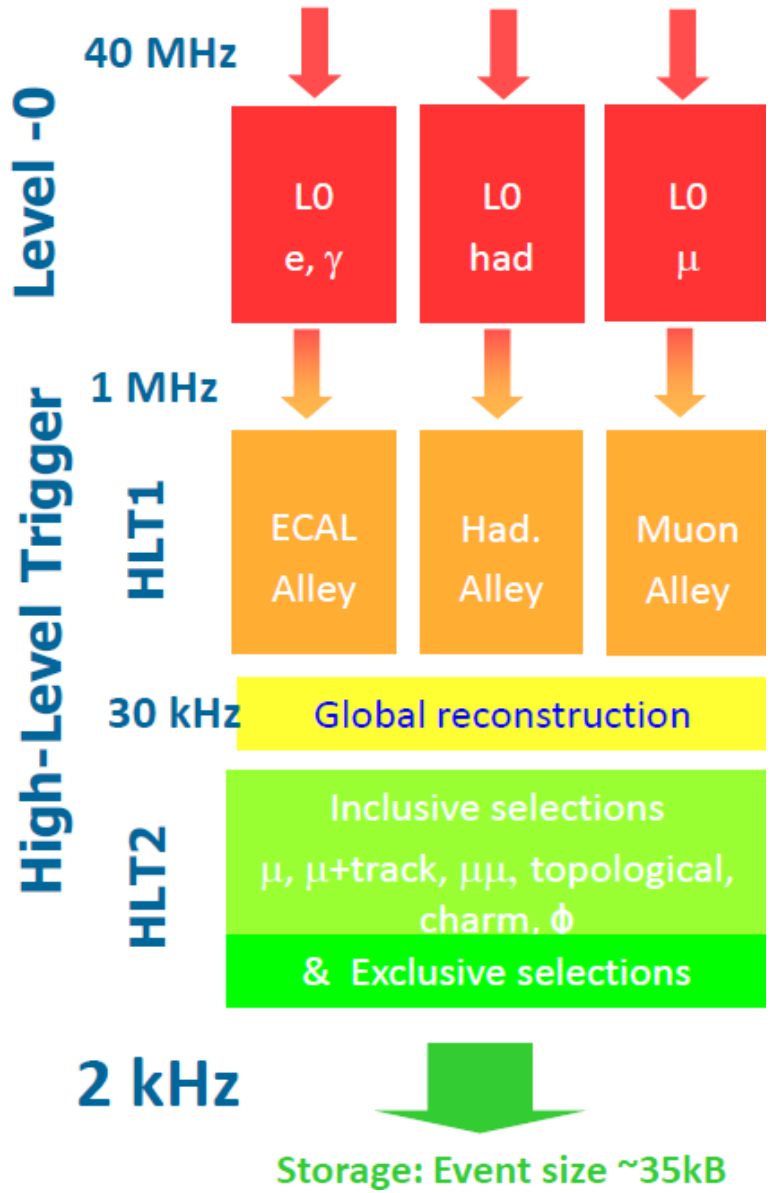




~ **11G $b\bar{b}$ pairs** produced!

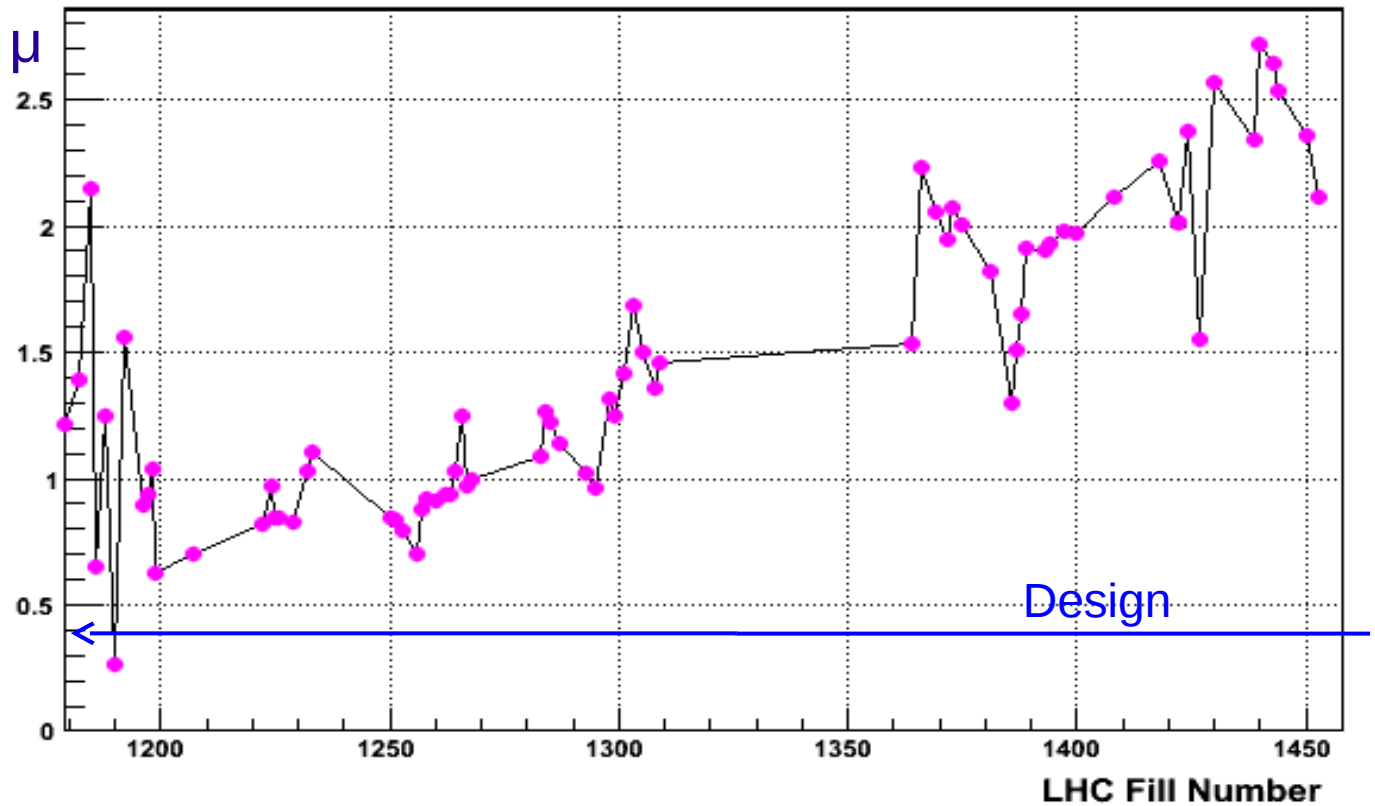
~ **5G b events** in detector acceptance

LHCb Trigger



- L0 trigger (the only hardware level) selects up to 1 MHz of "high" (>~1GeV) p_T particles
- High Level Trigger (HLT): software level running on massive computing farm
  - Confirmation of L0 candidates with tracking information
  - Inclusive selections based on IP, p_T, dimuon invariant mass; exclusive selection for key channels

	ε(L0)	ε(HLT1)	ε(HLT2)
Electromagnetic	70 %	> ~80 %	> ~90 %
Hadronic	50 %		
Muon	90 %		

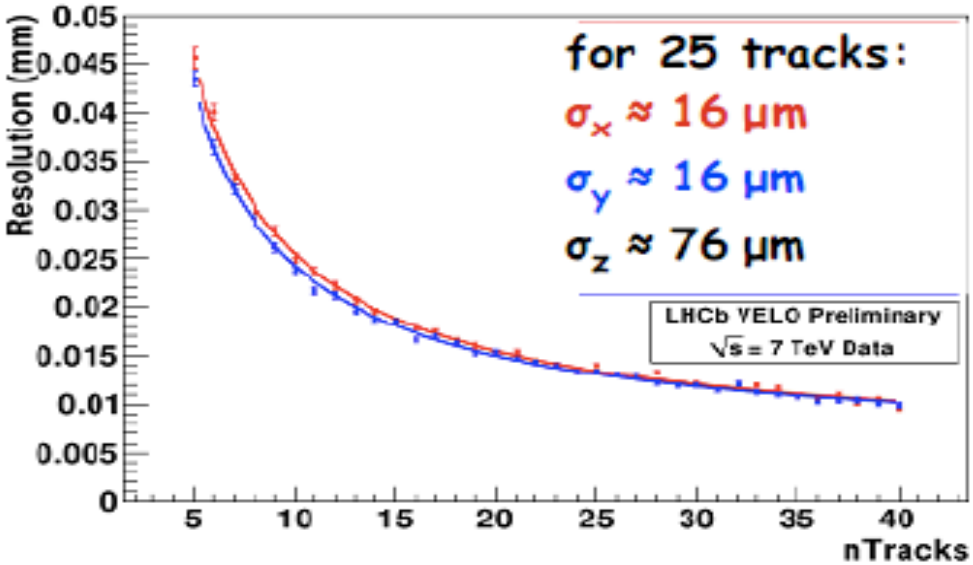


- 10^{32} $cm^{-2}s^{-1}$ luminosity reached with 344 bunches instead of nominal 2622: average number of interactions per crossing (μ) up to 6 x design value
- Larger luminosity preferred to low pile-up conditions:
  - relevant gain in statistics for a wide range of measurements: rare decays, charm physics, production studies...
- DAQ and triggers flexible enough to follow beam conditions

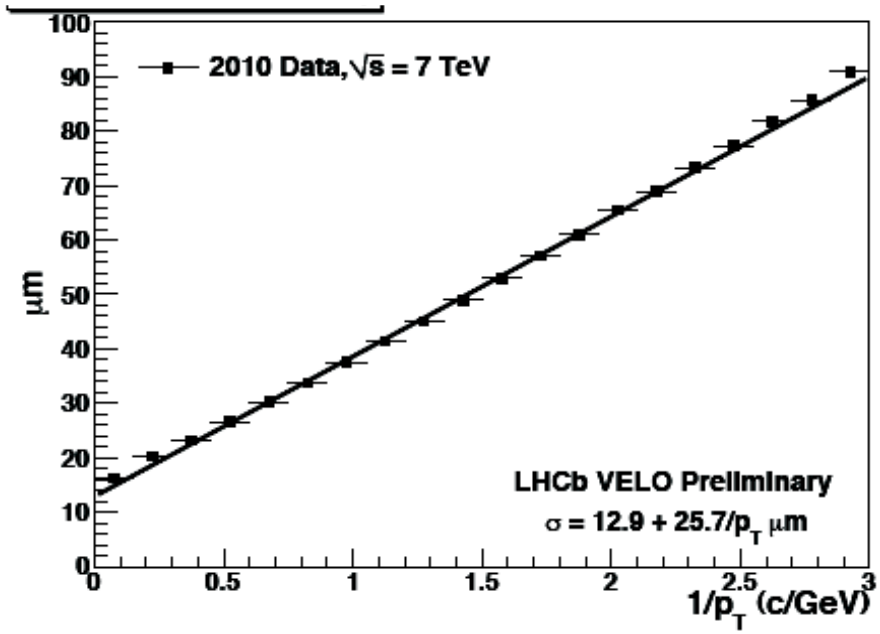
The VErtex LOcator

- Geometry optimized for forward tracks: sensors perpendicular to the beam
- Two retractable half stations, 8 mm from beam axis!

Vertex Resolution

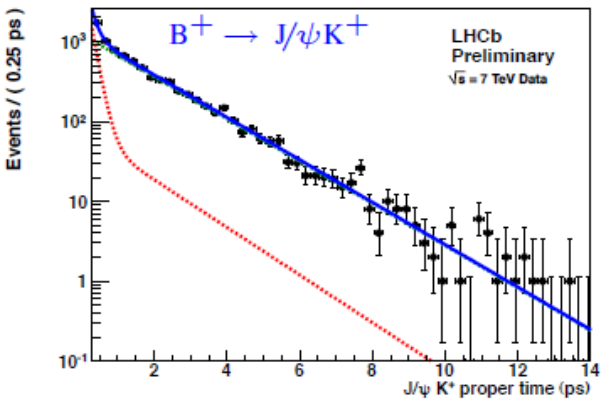


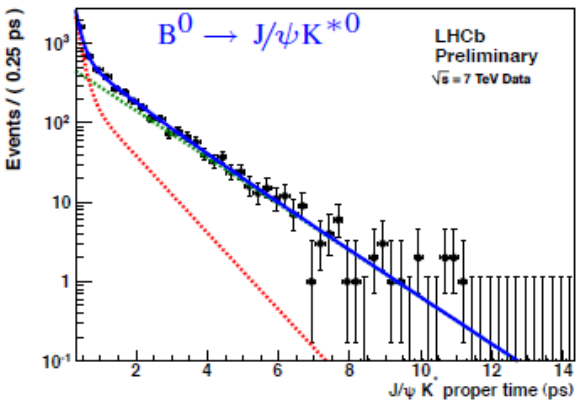
Impact Parameter Resolution

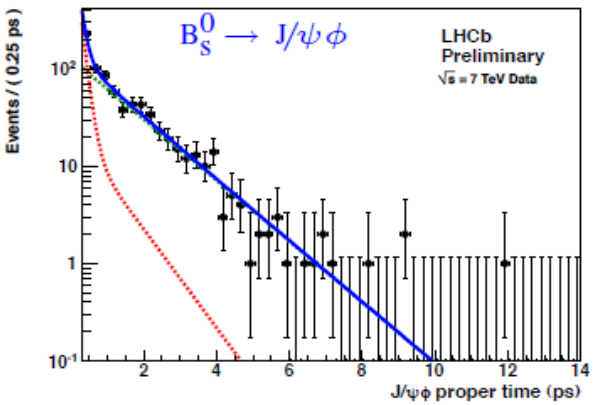


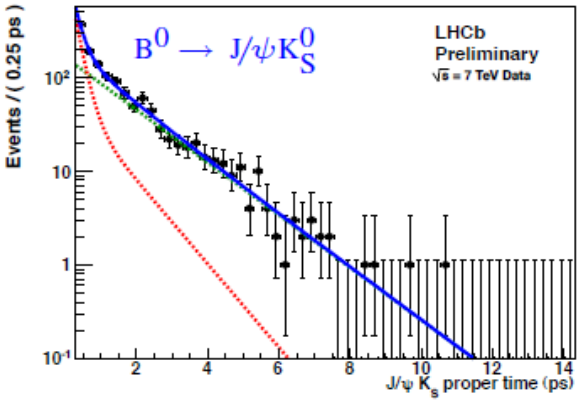
- Typical proper time resolution for B decays: 50 fs

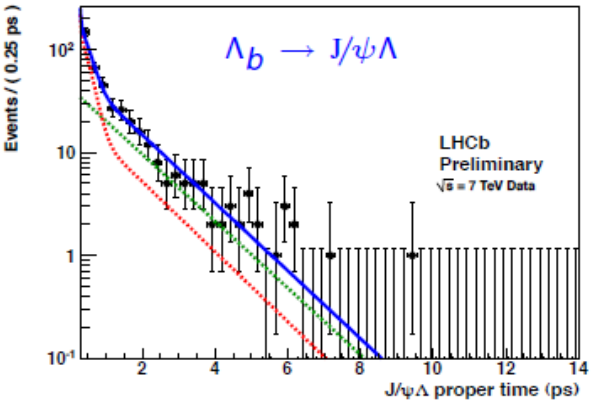
VELO visiting card: beauty lifetime











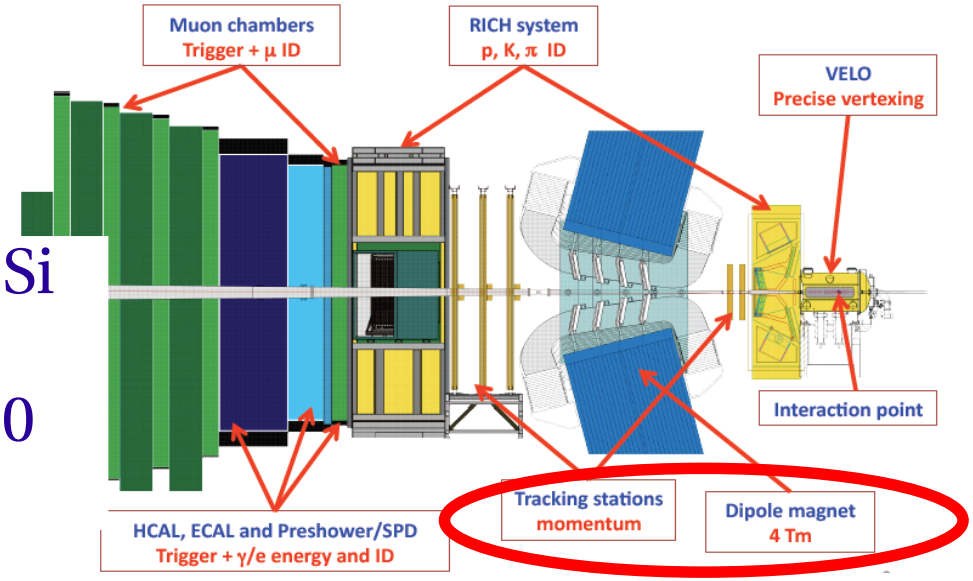
Channel	LHCb yield	LHCb "lifetime"(*) stat. and sys. (ps)	PDG (ps)
$B^+ \to J/\psi K^+$	$6\,741 \pm 85$	$1.689 \pm 0.022 \pm 0.047$	1.638 ± 0.011
$B^0 \to J/\psi K^{*0}$	$2\,668 \pm 58$	$1.512 \pm 0.032 \pm 0.042$	1.525 ± 0.009
$B^0 \to J/\psi K_S^0$	838 ± 31	$1.558 \pm 0.056 \pm 0.022$	1.525 ± 0.009
$B_s^0 \to J/\psi \phi$	570 ± 24	$1.447 \pm 0.064 \pm 0.056$	1.477 ± 0.046
$\Lambda_b \to J/\psi \Lambda$	187 ± 16	$1.353 \pm 0.108 \pm 0.035$	$1.391^{+0.038}_{-0.037}$

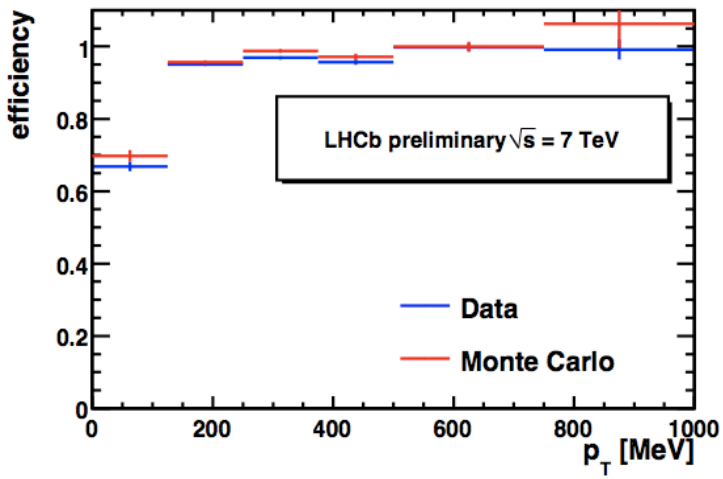
using only lifetime unbiased trigger and $t \in [0.3,\ 14]$ ps

Preliminary
36 pb^{-1}

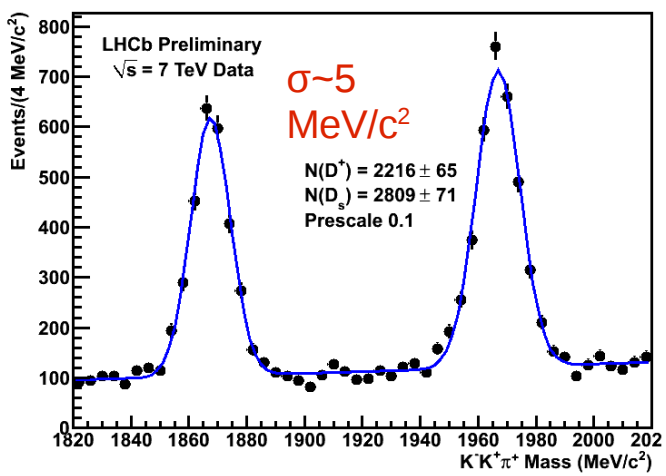
Tracking

- Charged particles tracked through Si μstrips (inner part, σ ~ 60 μm) or drift straw tubes (outer part, σ ~ 250 μm)

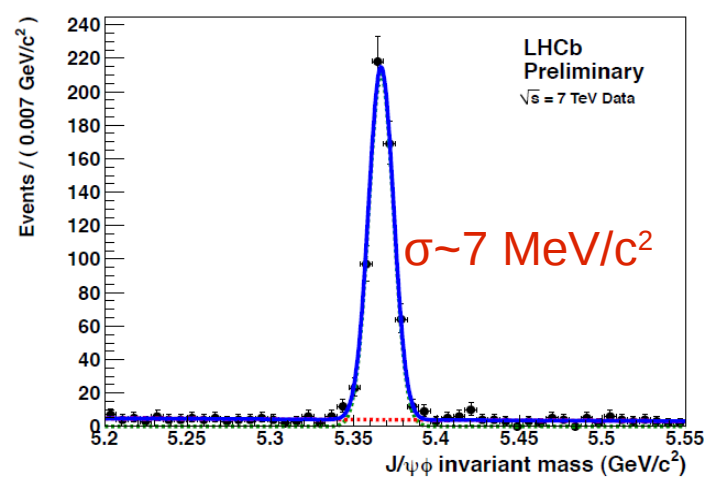




$D^+, D_s^+ \to K^- K^+ \pi^+$



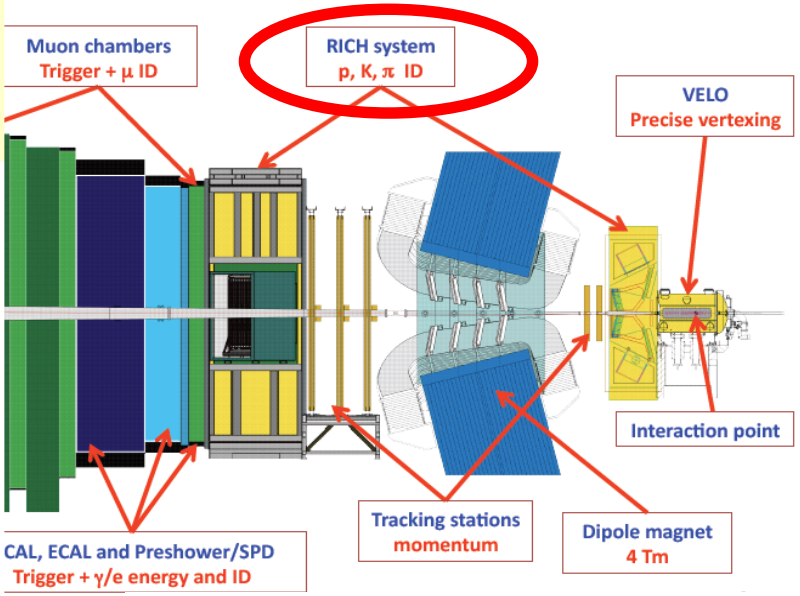
$B_s \to J/\psi\phi$

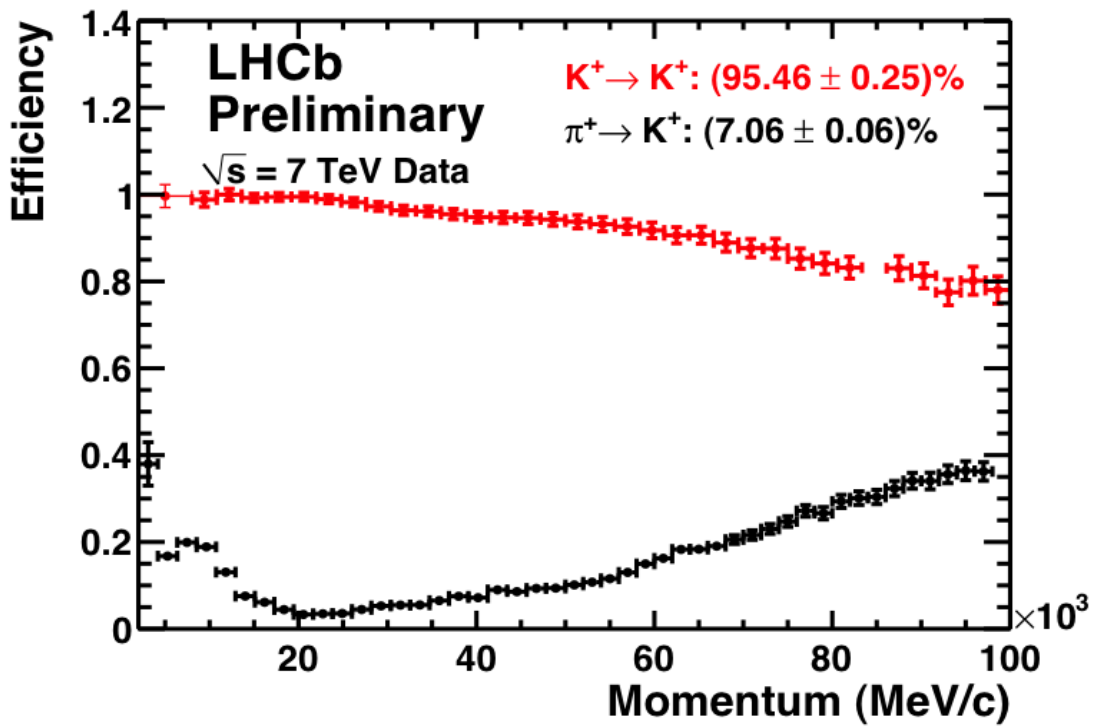


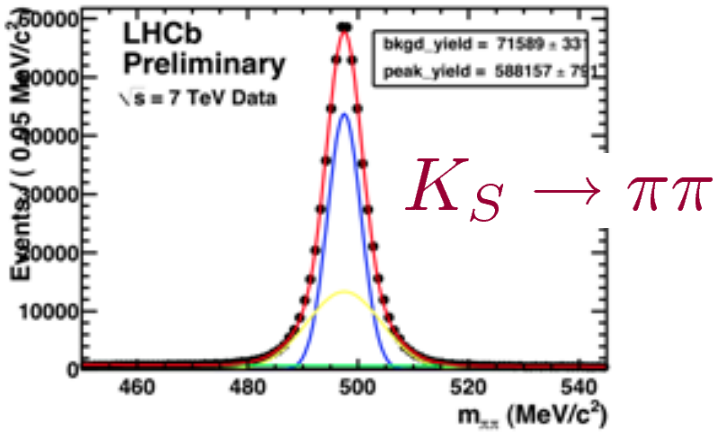
See talk by M. De Cian for new world-class mass measurements!

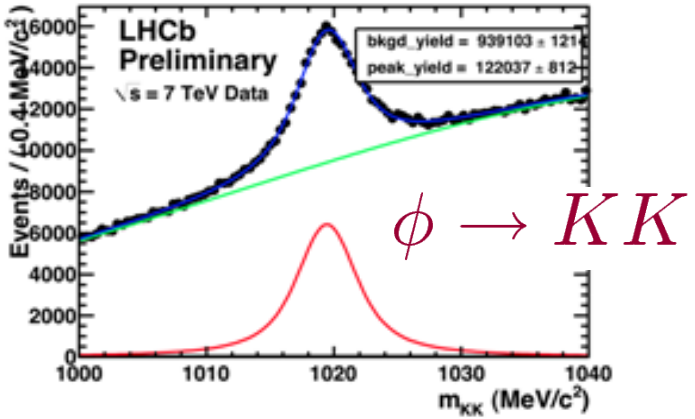
Particle ID:RICHs

- π/K separation essential for clean reconstruction of exclusive decays
- 2 RICH detectors (using 3 radiators), to cover momenta from 0.5 to 100 GeV/c







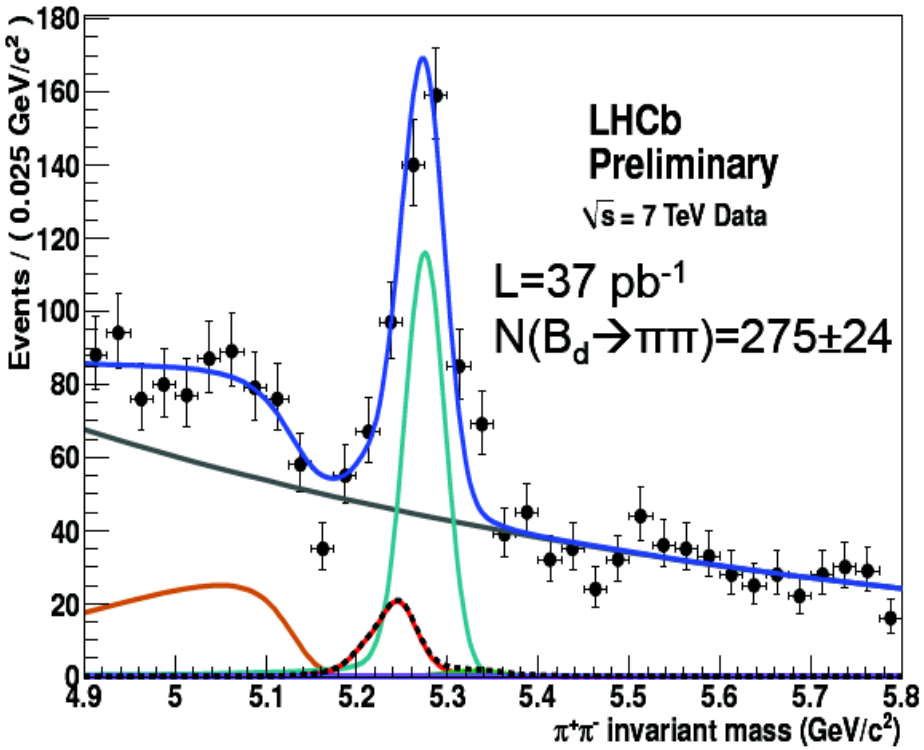


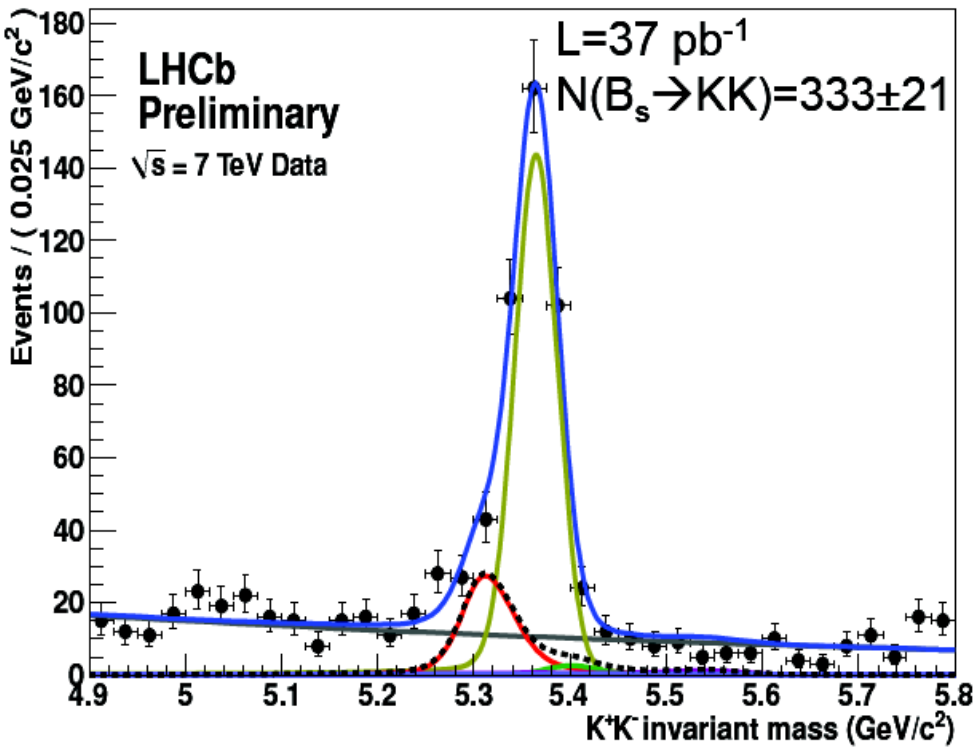
RICH visiting card: B → hh

- Disentangle all main charmless 2 body decays of B hadrons:

$$B^0 \to \pi^+\pi^-, B^0 \to K^+\pi^-, B_s^0 \to K^+K^-, B_s^0 \to \pi^+K^-, \Lambda_b \to pK^-, \Lambda_b \to p\pi^-$$

- Time dependent CP asymmetry in $B^0 \to \pi\pi$ and $B_s \to KK$ will allow to measure CKM angle γ from loops: very promising yields from 2010 sample:

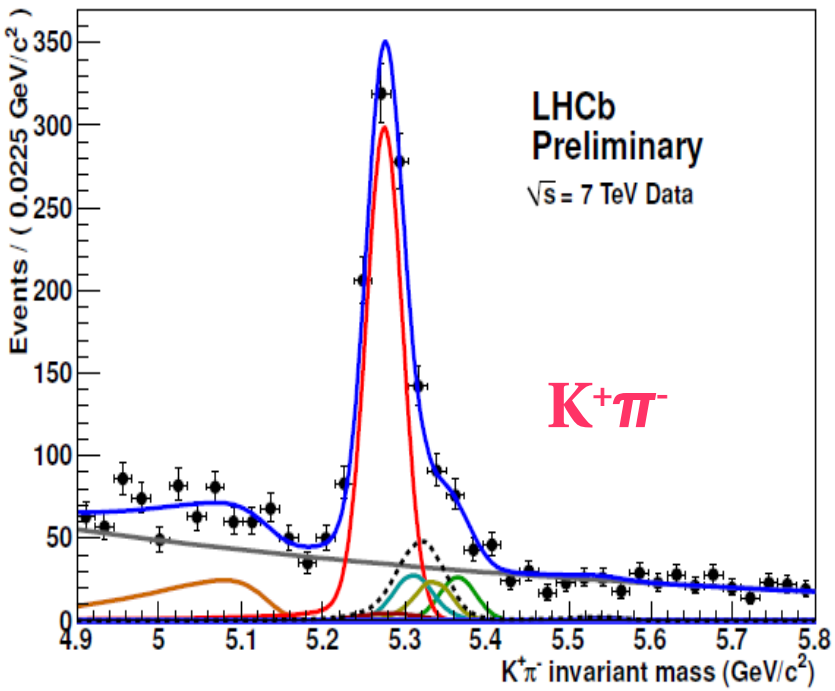


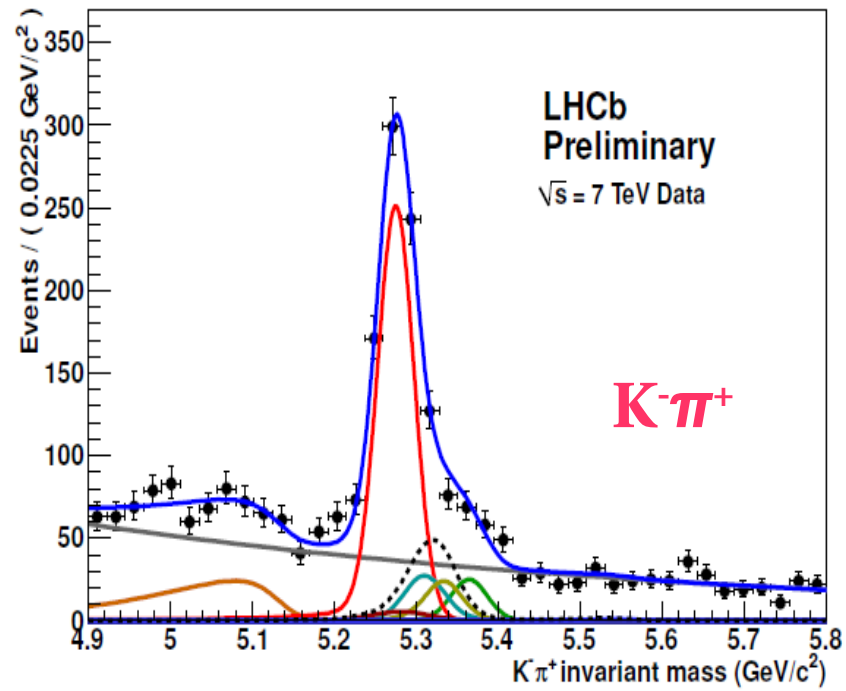


cmp CDF: 1100 B_d and 1300 B_s in 1 fb^{-1}

Direct CP violation in $B \to K\pi$

- Established by B factories for B^0, not yet in B_s, measuring $A_{CP}=(\overline{N}-N)/(\overline{N}+N)$
- Fit invariant mass shape for signal rates and cross-feeds using PID calibration (from data)
- Detector asymmetry estimated from D, $D^* \to K\pi$: $A_D=-0.004\pm0.004$
- Production asymmetry estimated from $B^\pm \to J/\psi K^\pm$: $A_P= 0.009\pm0.008$





LHCb preliminary:

$$A_{CP}(B^0 \to K^+\pi^-) = -0.077 \pm 0.033 \pm 0.007$$

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

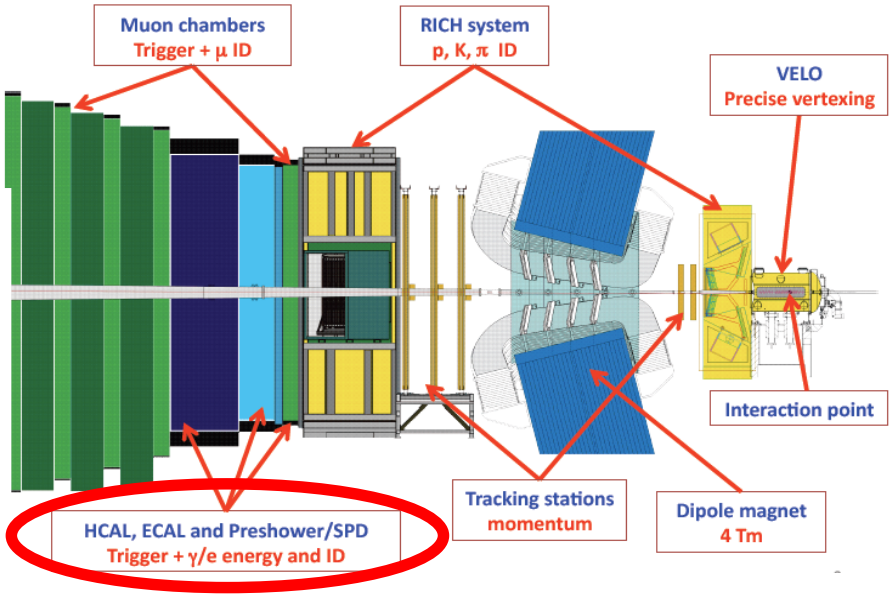
HFAG average:

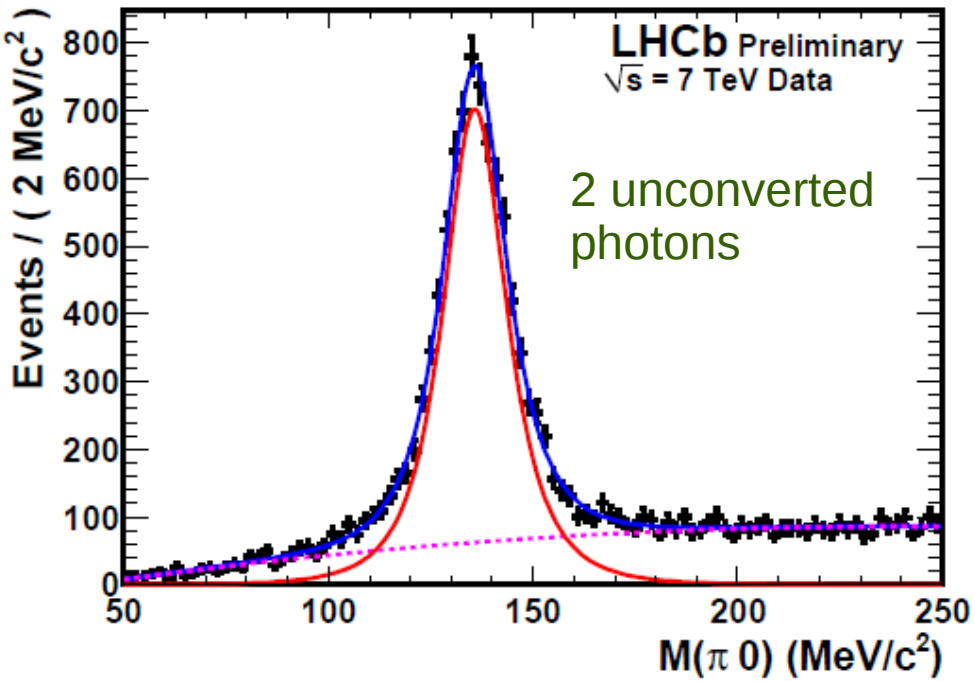
$$A_{CP}(B^0 \to K^+\pi^-) = -0.098^{+0.012}_{-0.011}$$

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

Calorimeters

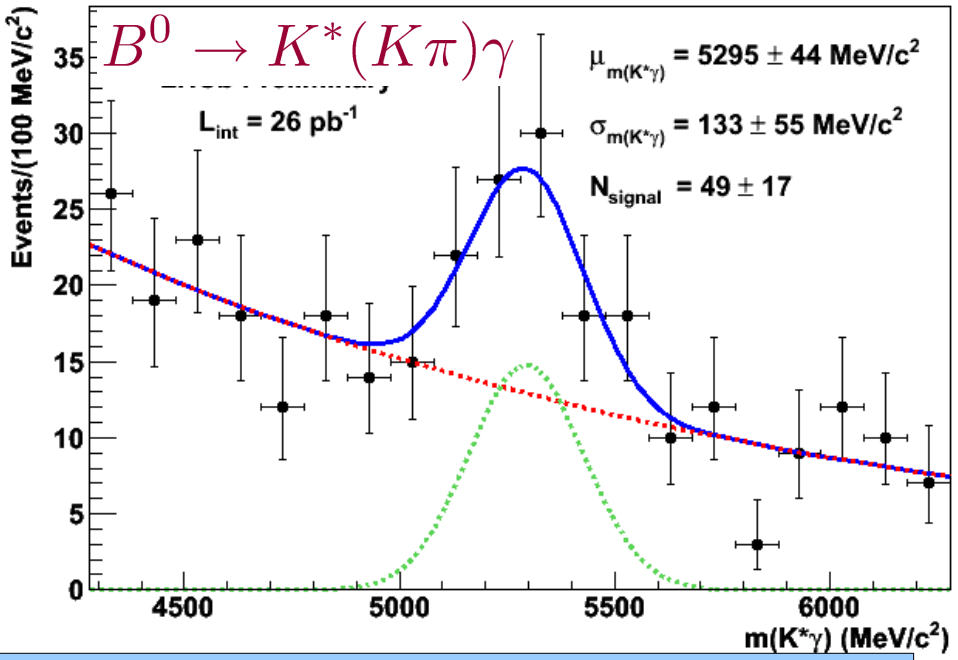
- Provide trigger and energy reconstruction for e, γ, hadrons
- Resolutions agree perfectly with simulations: $\sigma(m_{\pi^0}) = 7.2$ MeV/c^2





Nice prospects for b!sγ !

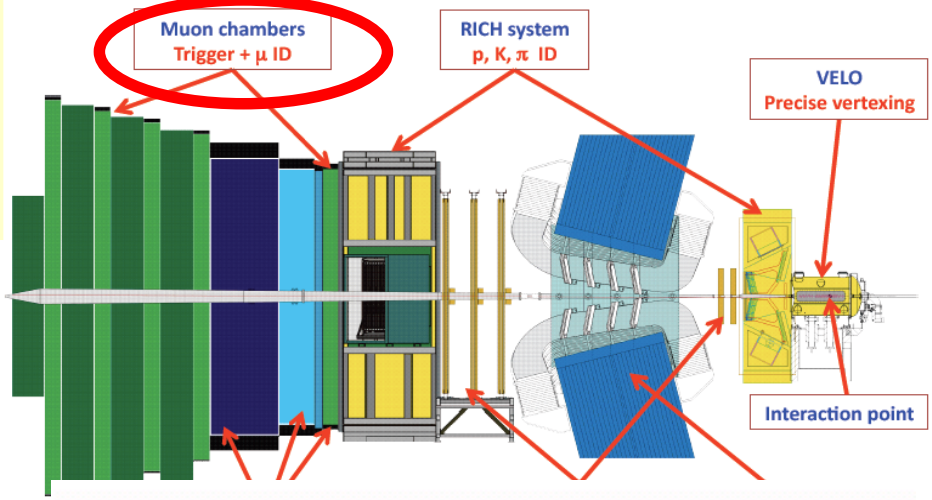
- Observation of B radiative decays:

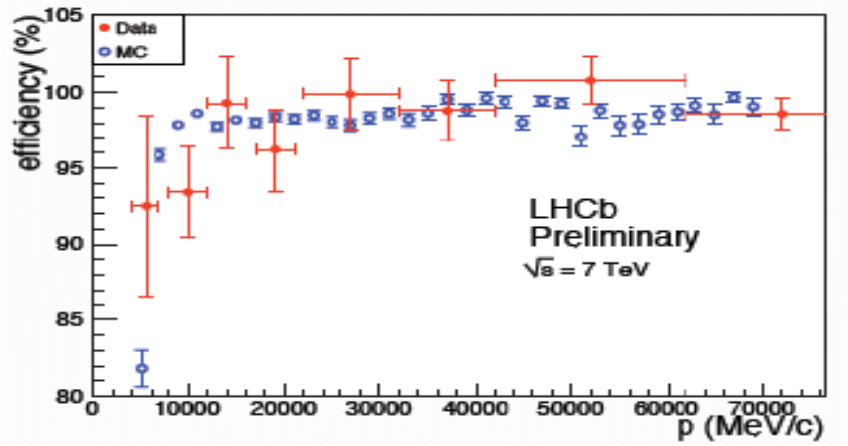


See also talk by U. Kerzel on χ_c ! J/Ψ γ

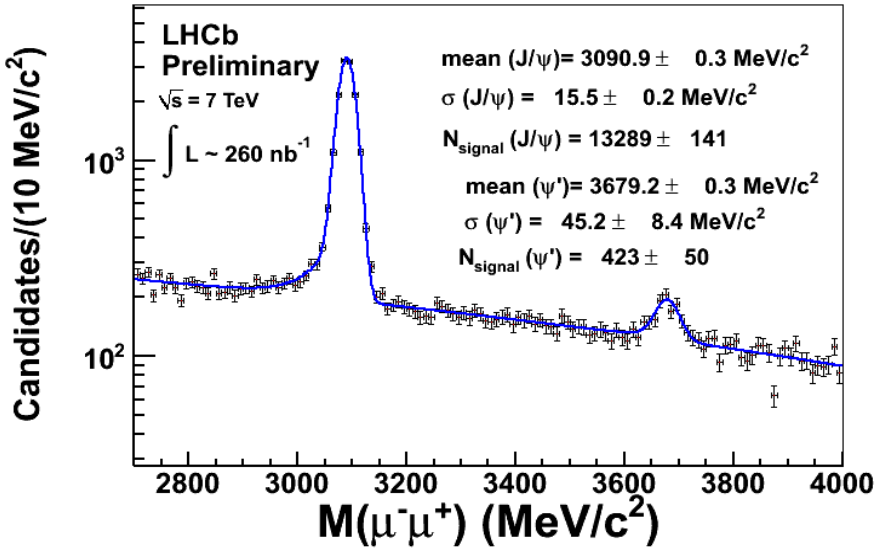
Muon Chambers

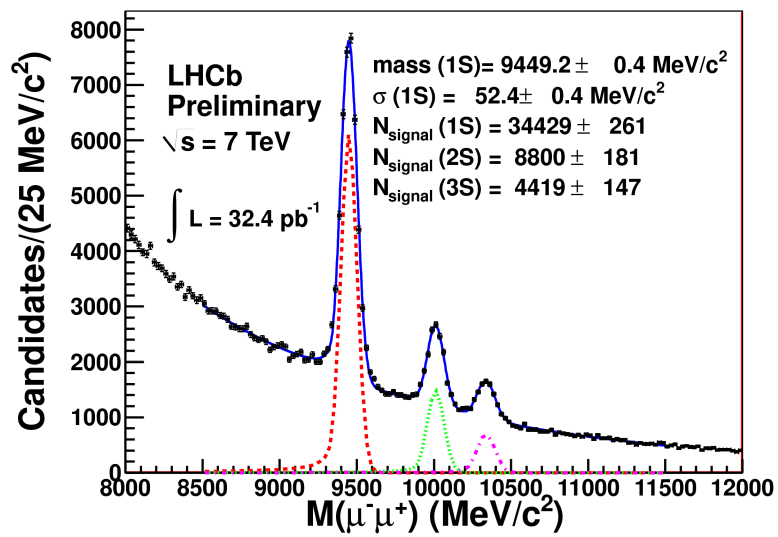
- Trigger (p_T>~1 Gev/c) and identify muons with efficiency > 95% for p>6 GeV/c



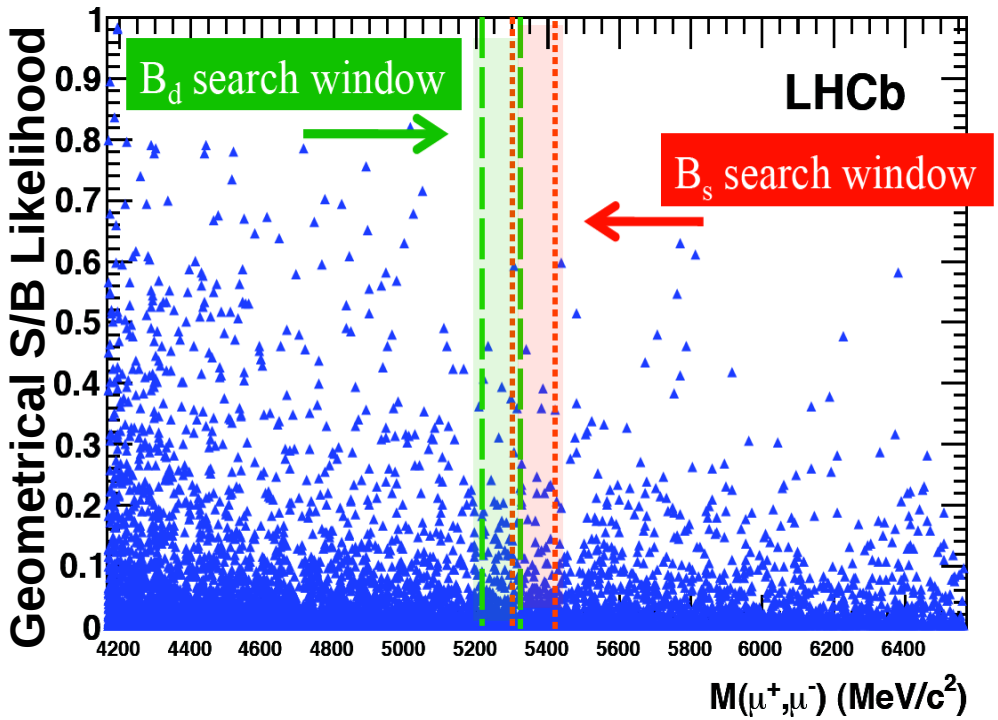


Dimuon mass spectra for charmonia and bottonomia states

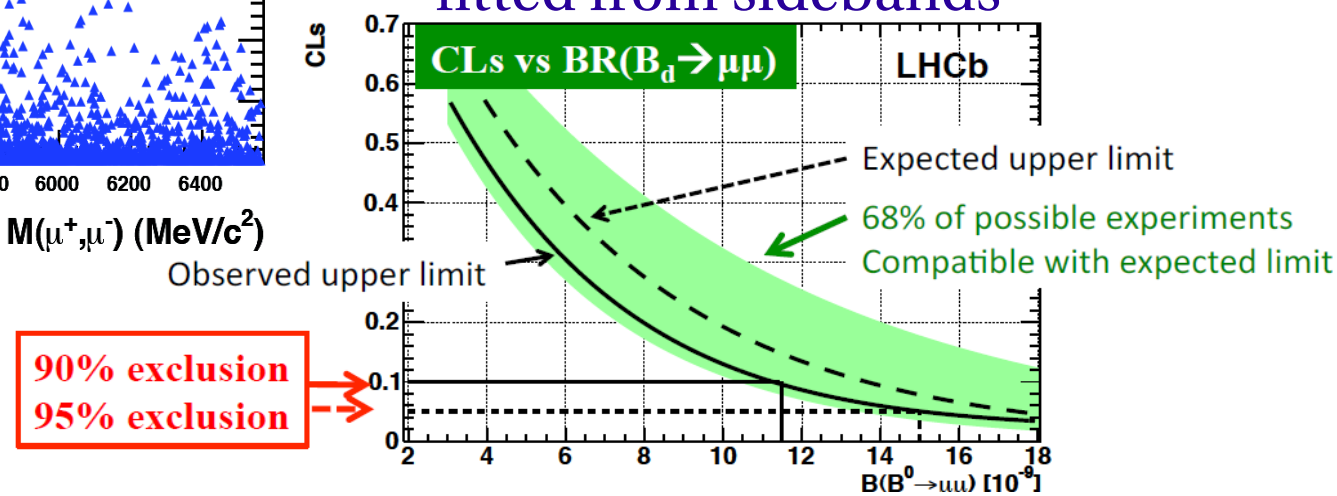




$B_{d,s} \to \mu\mu$



- doubly suppressed FCNC, very cleanly predicted by SM:
  $BR(B_s \to \mu^+\mu^-) = (3.2 \pm 0.2) \times 10^{-9}$
  $BR(B_d \to \mu^+\mu^-) = (1.0 \pm 0.1) \times 10^{-10}$
- High sensitivity to new physics in (pseudo)scalar sector
- Very clean experimentally: main background is combinatorial (not peaking) $B \to \mu^+\mu^- X$ background, fitted from sidebands



LHCb result with 37 pb^{-1}:

arXiv:1103.2465
subm. to Phys.Lett.B

$BR(B_s \to \mu^+\mu^-) < 5.6 \times 10^{-8}$ @ 95% CL (expected 6.5×10^{-8})

$BR(B_d \to \mu^+\mu^-) < 1.5 \times 10^{-8}$ @ 95% CL (expected 1.8×10^{-8})

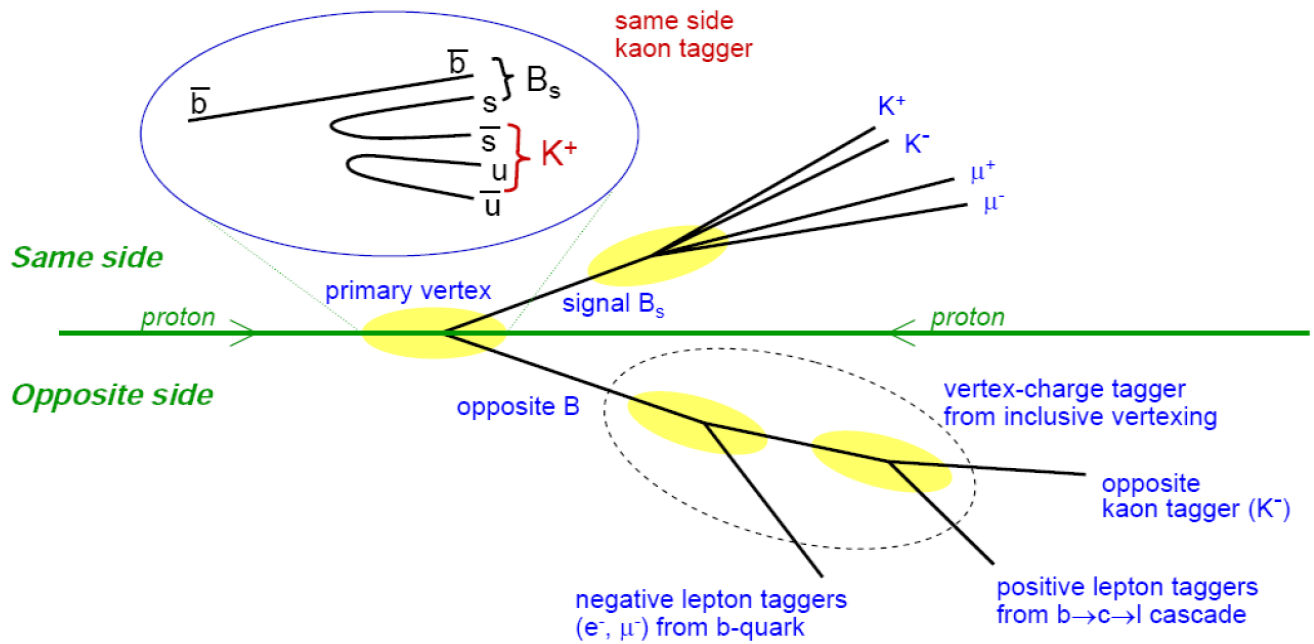
best limits from CDF (3700 pb^{-1}):

$< 4.3 \times 10^{-8}$ @ 95% CL

$< .76 \times 10^{-8}$ @ 95% CL

Tagging performances

- NN based tagging algorithms calibrated from real data, using self-tagging modes; accuracy still limited by statistics
- tagging power evaluated event-by-event
- checked with MC



- Results for calibration channels:

Mistag fraction

Tagging efficiency

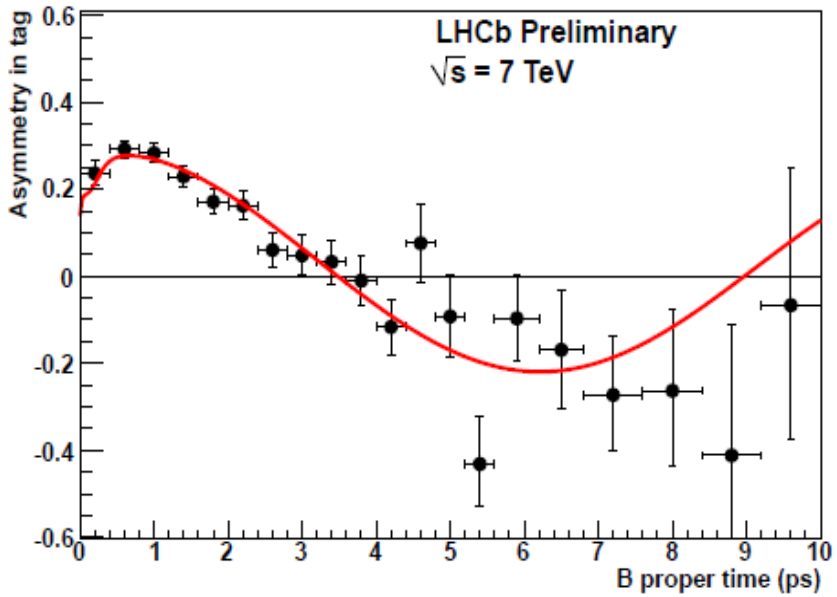
Tagging power= $\epsilon_{tag}(1-2\omega)^2$

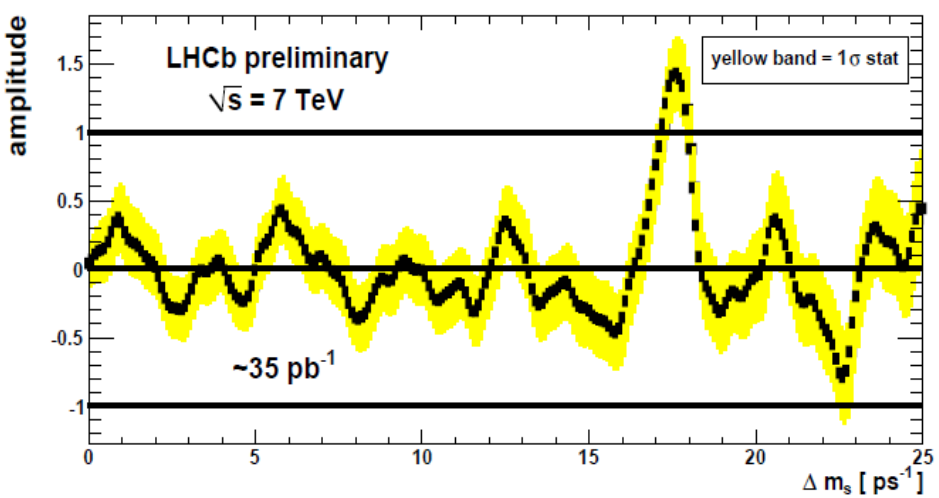
OS+SS-π	ε_{tag}(%)	ω(%)	ε_{eff}(%)
$B^0 \to D^{*-}\mu^+\nu_\mu$	28.9 ± 0.2	34.2 ± 0.8	2.87 ± 0.32
$B^+ \to J/\psi K^+$	23.0 ± 0.5	33.9 ± 1.1	2.38 ± 0.33
$B^0 \to J/\psi K^{*0}$	26.1 ± 0.9	33.6 ± 5.1	2.82 ± 0.87

Proof of principle: B_0 oscillations

$B^0 \to D^{*-}\mu^+\nu_\mu$ (48k events)

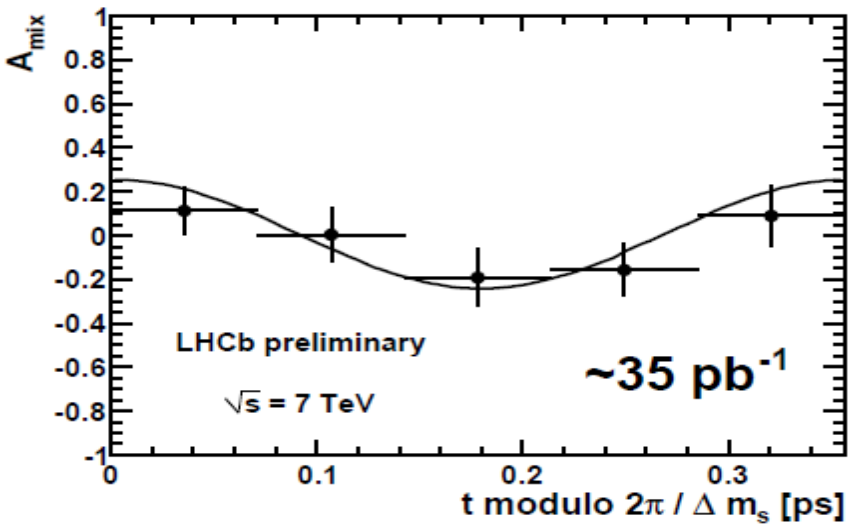
Effective tagging power: $\epsilon_{eff}^{SS\pi+OS} = 4.3 \pm 1.0\%$





$B_s^0 \to D_s\pi, D_s3\pi$ (1400 candidates)

$\epsilon_{eff}^{OS} = 3.8 \pm 2.1\%$



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

  cfr CDF: 17.77 ± 0.10 (stat) ± 0.07 (syst)
- Using $B^0 \to D^-(K^+\pi^-\pi^-)\pi^+$

  $\Delta m_d = 0.499 \pm 0.032$ (stat) ± 0.003 (syst) ps^{-1}

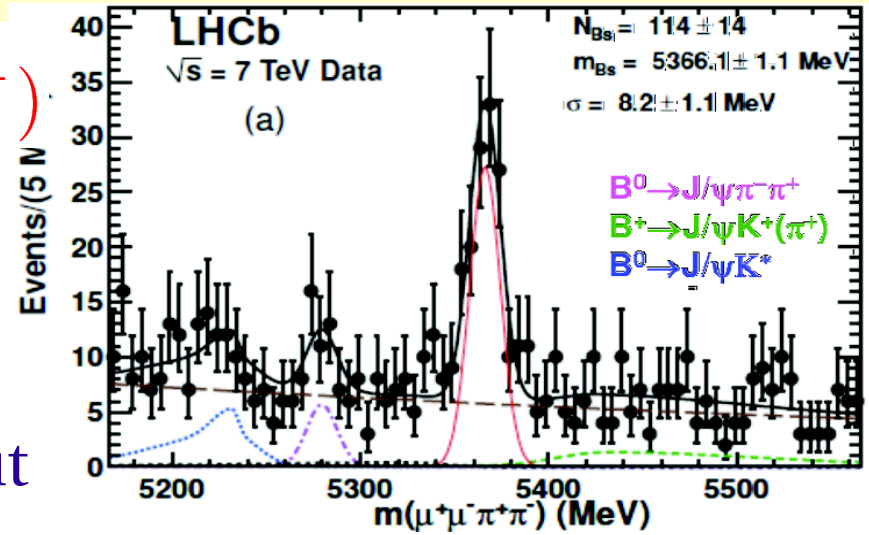
  cfr PDG: 0.507 ± 0.005 (syst) ps^{-1}

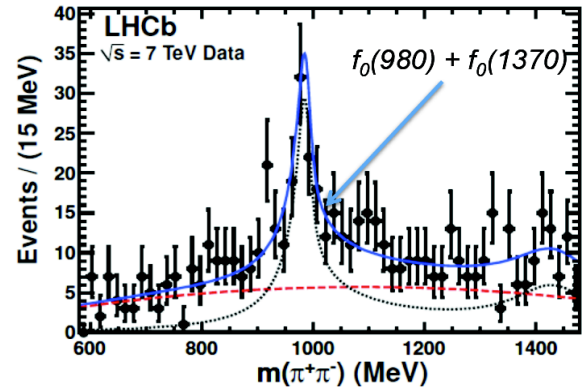
Preliminary, 35 pb^{-1}

First observations

$B_s \to J/\psi f_0(\pi^+\pi^-)$

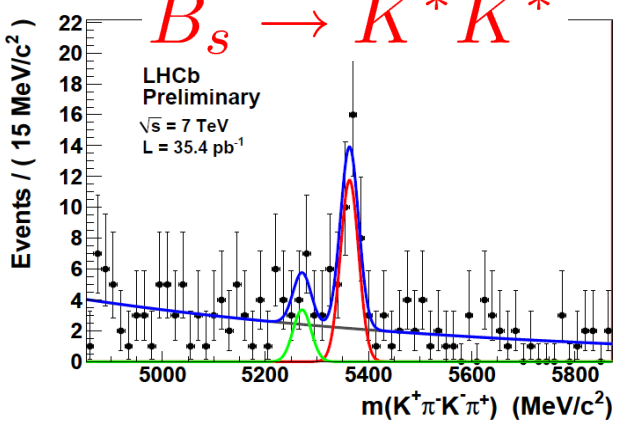
- Will contribute to measurement of mixing phase in B_s
- BR ¼ wrt $J/\Psi\ \varphi$, but is pure CP eigenstate



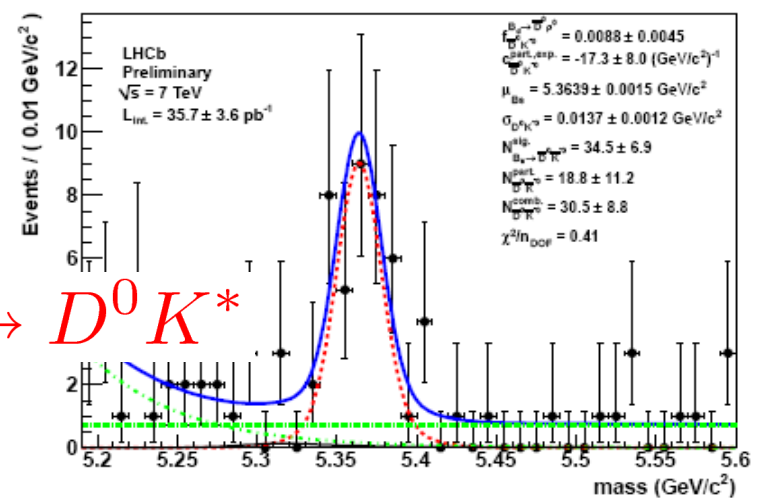


$$\frac{\Gamma(B_s \to J/\psi f_0,\ f_0 \to \pi^+\pi^-)}{\Gamma(B_s \to J/\psi\phi,\ \phi \to K^+K^-)} = 0.252^{+0.046+0.027}_{-0.032-0.033}$$

$B_s \to K^*K^*$



$B_s \to D^0 K^*$



- and list still growing: $B_s \to D_{s2} X \mu\nu,\ \overline{B}^{0,-} \to D^{+,0} K^- \pi^+ \pi^-, \ldots$

LHCb as general purpose forward detector

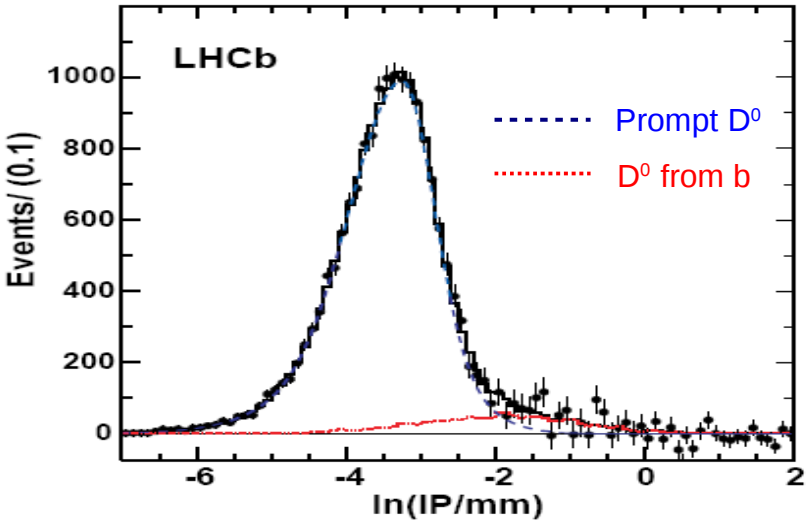
- Production studies can be performed in unique rapidity/p_T range in LHCb !! complement studies at other LHC detectors
- Test QCD predictions in very forward region
- W and Z measurements can constrain parton PDFs
- The excellent PID capabilities allow to select many exclusive channels: study quarkonia, X(3872) and other new states recently discovered

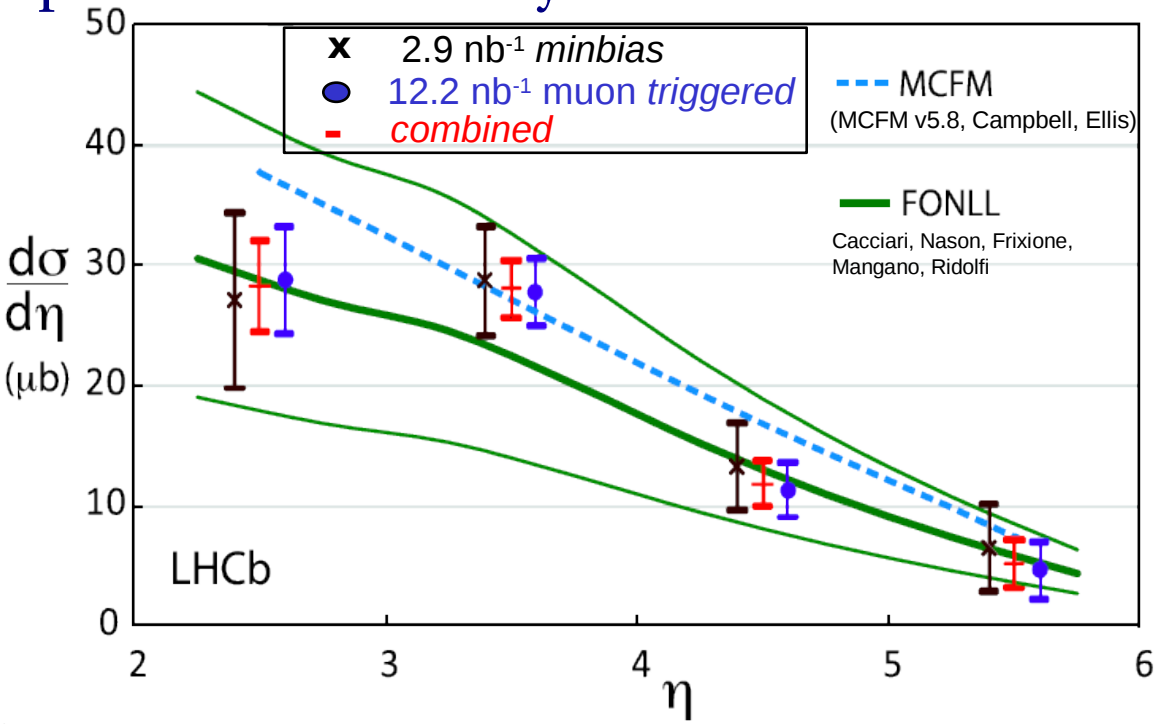
Some highlights here. More results and details in the talks by:
K. Hennessy (WG1)
D. Moran (WG2)
M. Adinolfi and J. Merkel (WG4)
L. Zhang, U. Kerzel and M. De Cian (WG5)

Production studies: $b\bar{b}$

- Beauty production is a QCD testbench, also crucial for backgrounds in many key channels at LHC (Higgs, CPV, ...)
- First measurement of $\sigma(pp \to b\bar{b}X)$ via

  $b \to \bar{D}^0 X \mu^- \nu$, $\bar{D}^0 \to K^- \pi^+$
- Signature is high IP D^0 and muon in same vertex
- Error dominated by luminosity (10%), published with only 15 nb^{-1}





- Result:

$$\sigma(b\bar{b}X) = (75.3 \pm 5.4 \pm 13.0)\mu b$$

(2<η<6)

$$\sigma(b\bar{b}X) = (284 \pm 20 \pm 49)\mu b$$

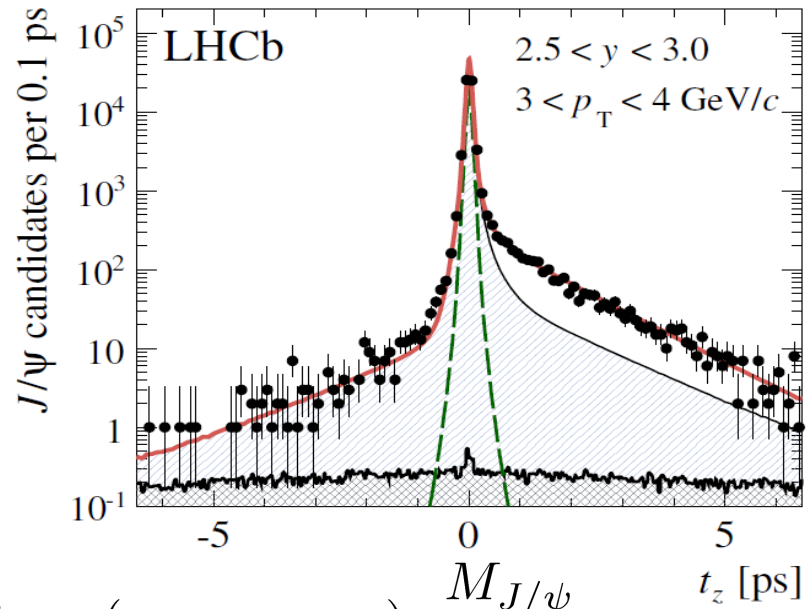
(full η range)

- Good agreement with theoretical predictions

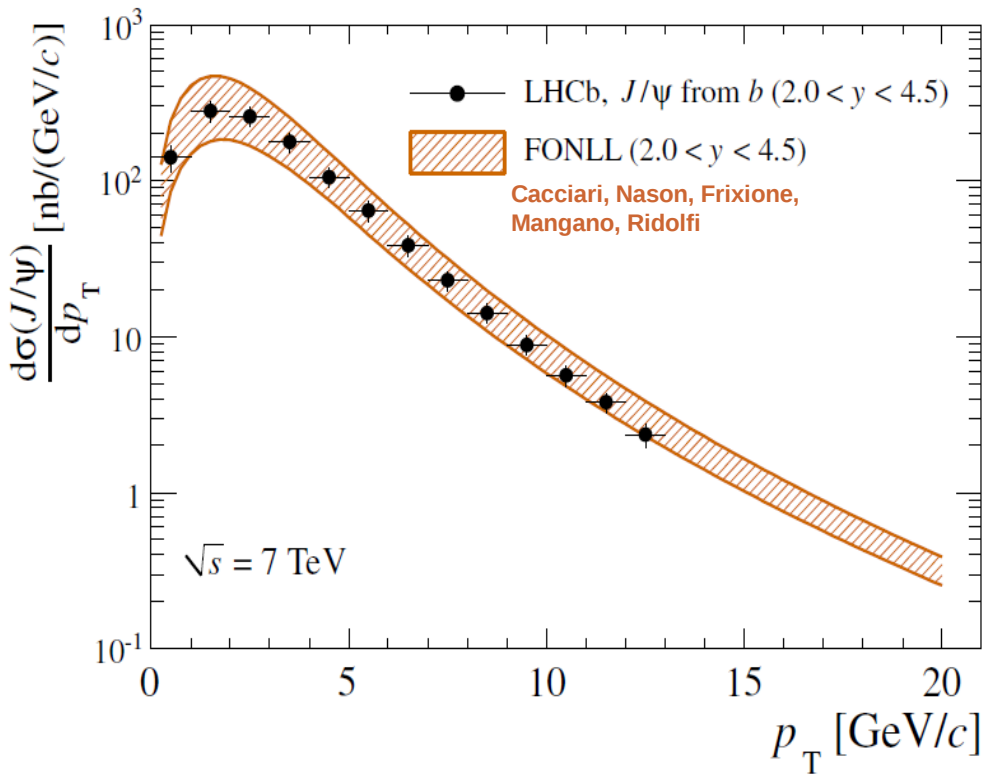
LHCb Collaboration, R.Aaij et al., PLB694:209-216,2010

$b\bar{b}$ from J/Ψ

- Similar accuracy reached from b! J/Ψ(μμ) X using 5 pb^{-1} of data
- B signal disentangled from prompt component using b pseudo proper time



$$t_z = (z_{J/\psi} - z_{PV})\frac{M_{J/\psi}}{c(p_z)_{J/\psi}}$$



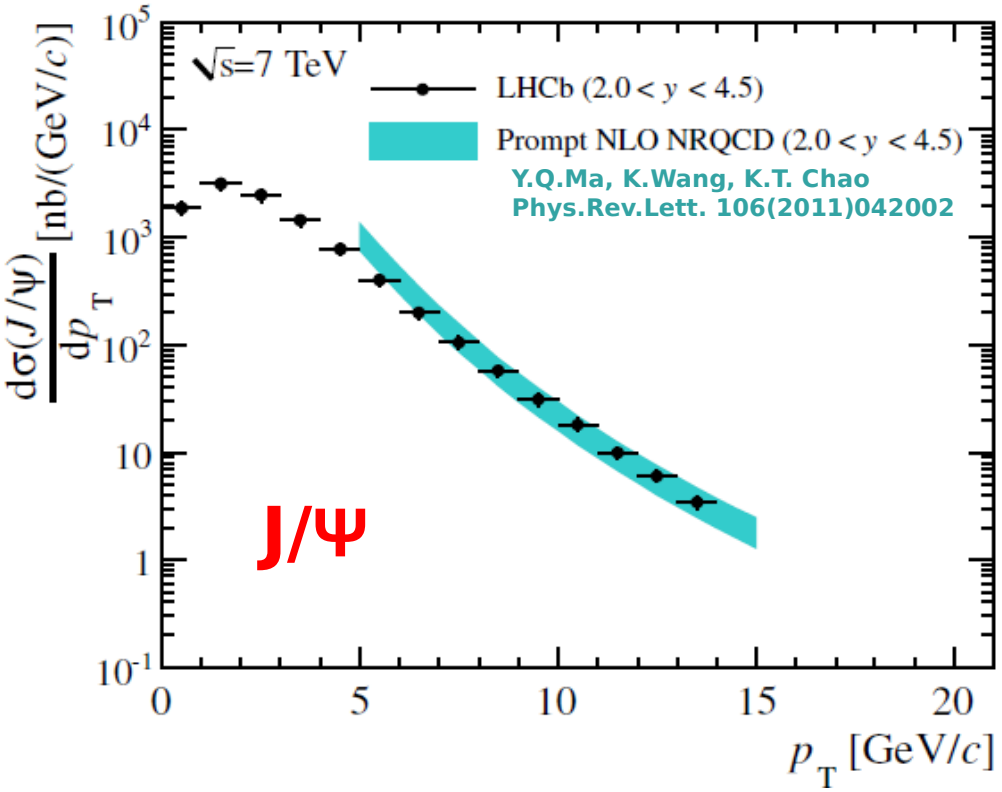
- Result:
  $\sigma(b\bar{b}X) = (288 \pm 4 \pm 48)\mu b$

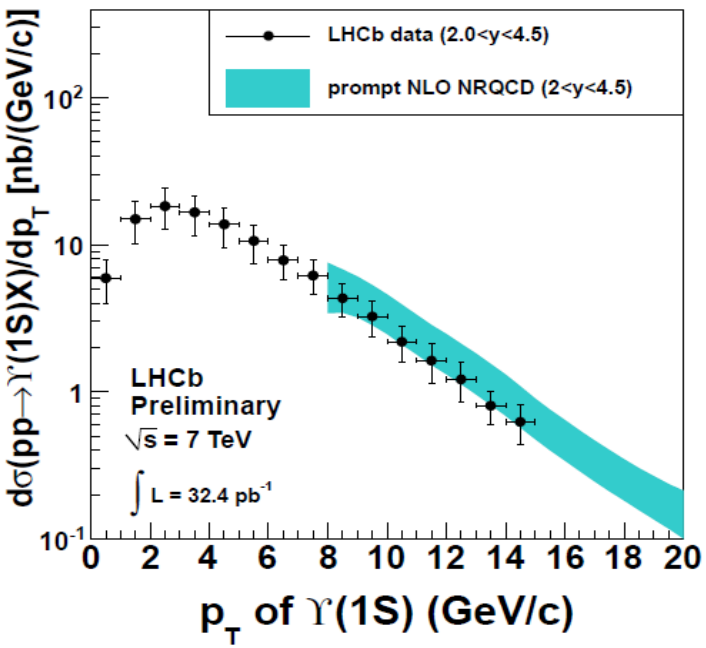
  arXiv:1103.0423, subm. to Eur.Phys.J. C
- Nice agreement with the semileptonic result and the FONNL prediction

Quarkonia

- cross sections results for prompt J/Ψ, χ_c, Υ(1S), double J/Ψ , B_c (J/Ψ π^+)
- Others to come soon: Ψ(2S), X(3872), polarizations...
- Data available below p_T thresholds of most predictions!

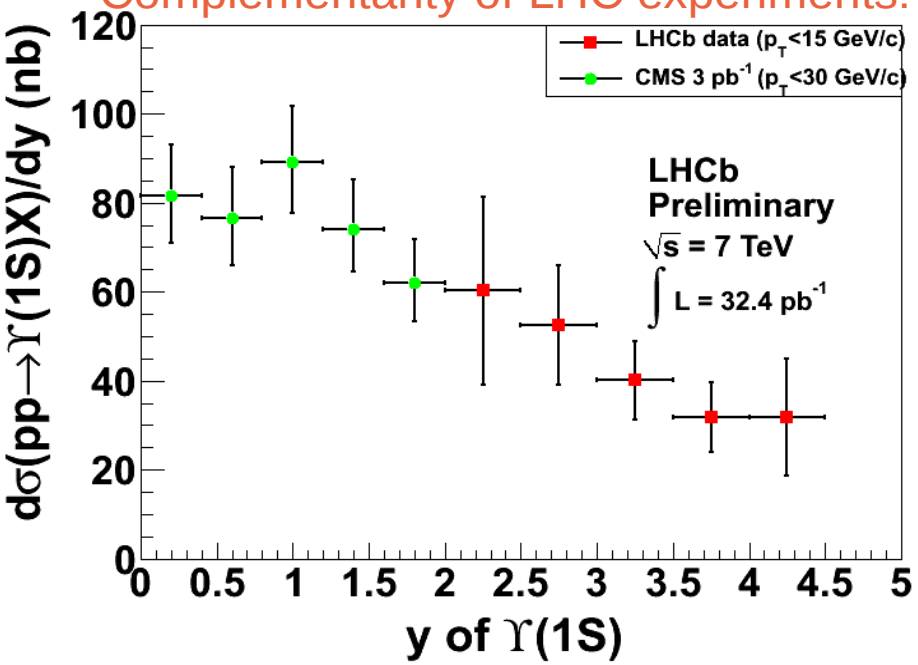
Full results in talk by U. Kerzel





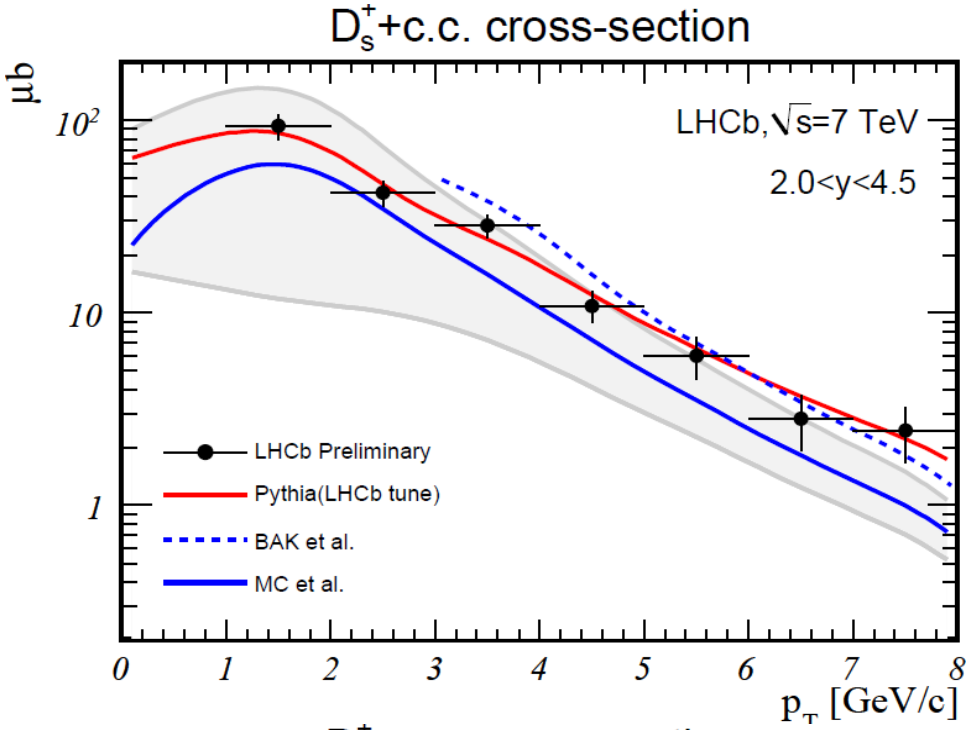
Υ(1S)

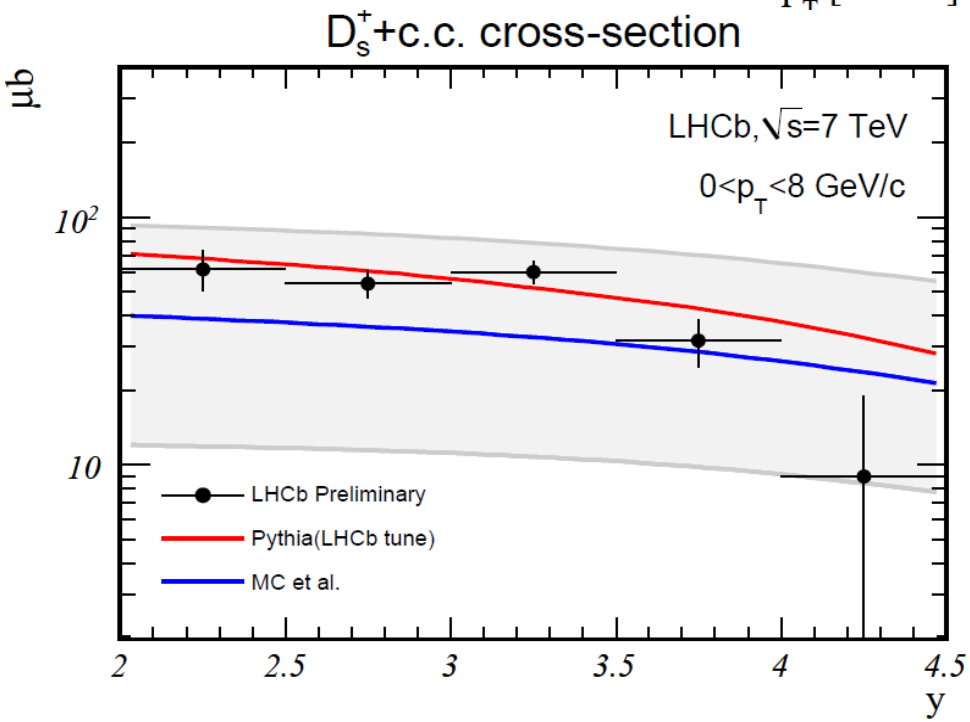
Complementarity of LHC experiments!



Open charm

- Use first low-luminosity data with minimum bias trigger
- Measure production cross sections for D^0, D^+, D^{*+}, D_s^+, and D^+/D_s^+ ratio
- New result for D^0 production asymmetry: important fro QCD test and backgrounds in CP asymmetries
- First results on mixing and CPV also released!

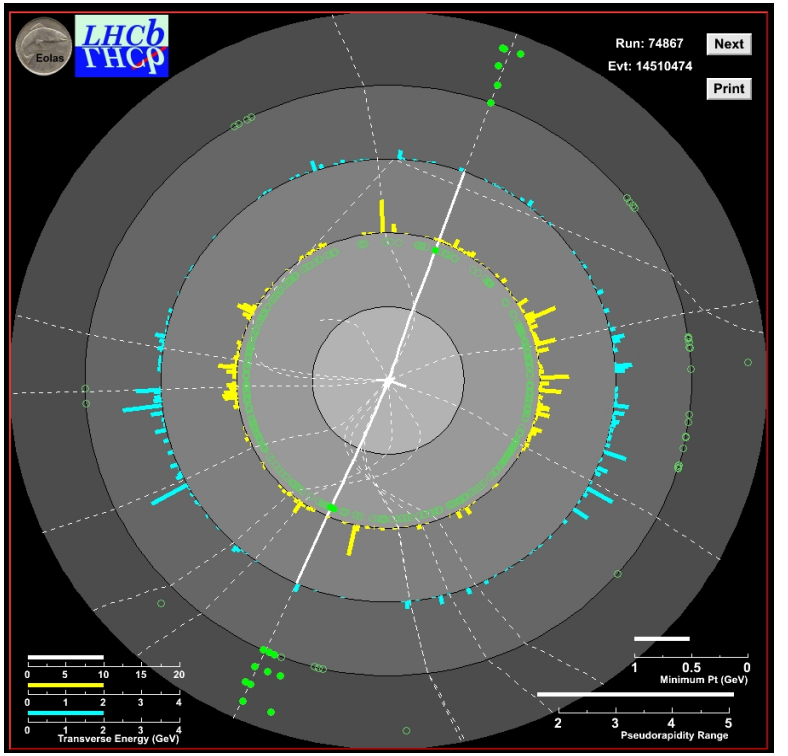


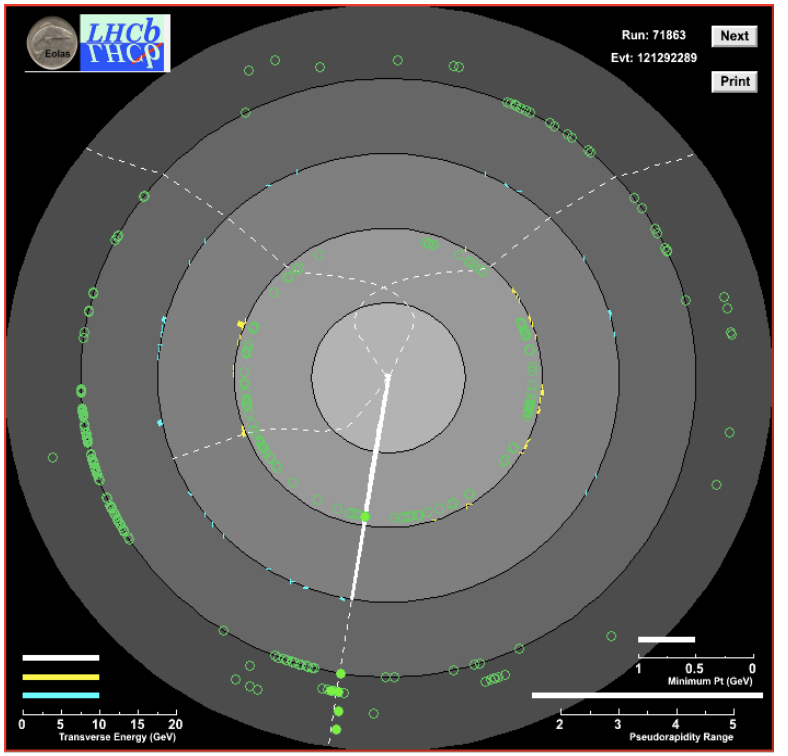


Detailed results in talk by L. Zhang

W/Z production

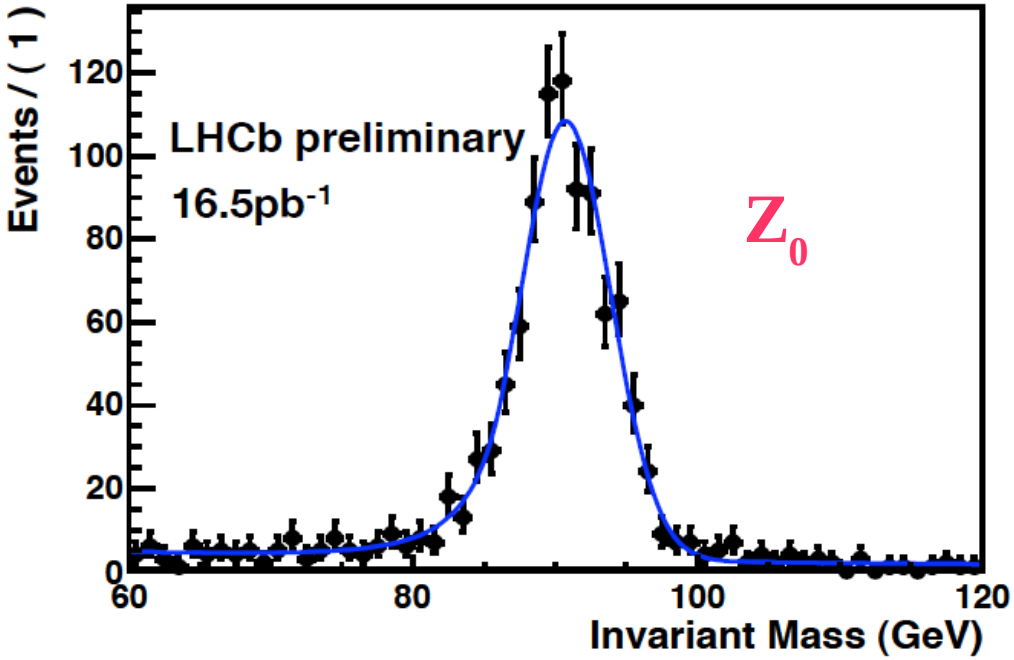
- Cross sections for W and Z production predicted at 3-10 % level, main uncertainty from parton PDFs
- Sensitive to previously unexplored region $x \sim 10^{-4}$ ($Q^2 = M_{W,Z}^2$)
- Clean samples can be easily selected for Z!μμ
- High purity W!μX sample selected requiring a high (>20 GeV/c) pT muon from PV and little other activity in event
- Many systematics cancel in W charge asymmetry and W/Z ratio

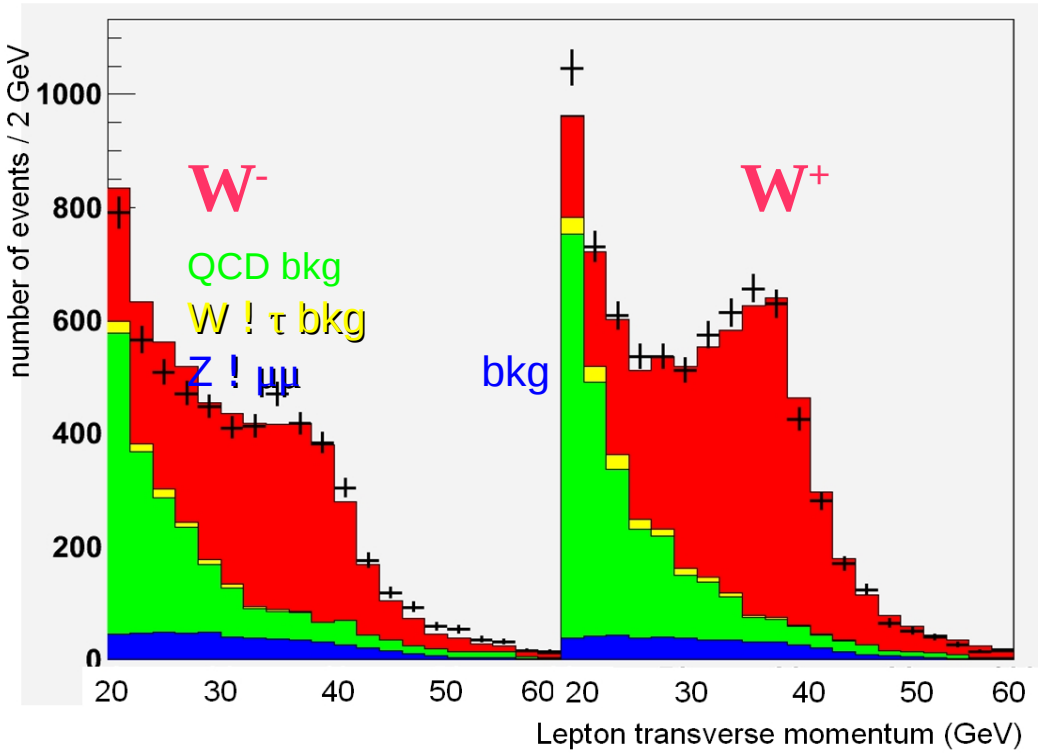




W/Z results

- Yields with 16 pb^{-1} (preliminary):
  ~800 Z, ~13k $W^{\pm}$
- Error on cross section limited by luminosity uncertainty (10%)
- Error on W charge asymmetry similar to PDF uncertainty, we will constrain PDFs with 2011/2012 data!





Detailed results in talk by K. Hennessy

b fragmentation fractions

$$B_s^0 \to D_s^- \pi^+ / B^0 \to D^- K^+$$

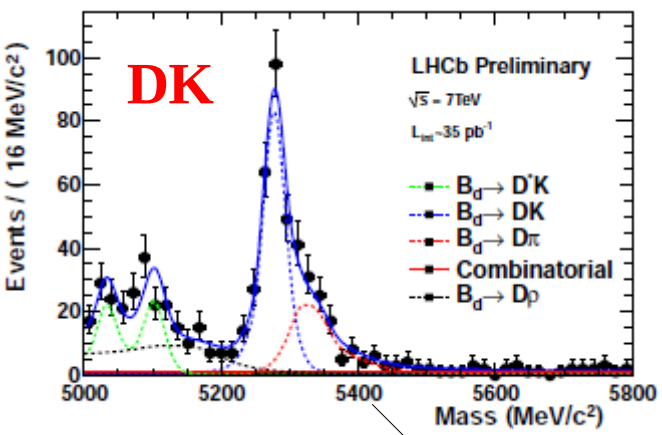
- Tree dominated, color allowed decays, theory under control

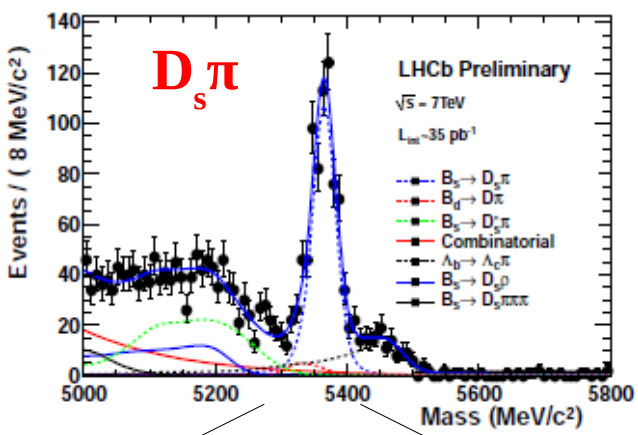
$$\frac{f_s}{f_d} = 0.0743 \times \frac{\tau_{B^0}}{\tau_{B_s^0}} \times \left[\frac{1}{\mathcal{N}_a \mathcal{N}_F} \frac{\epsilon_{DK}}{\epsilon_{D_s\pi}} \frac{N_{D_s\pi}}{N_{DK}} \right]$$

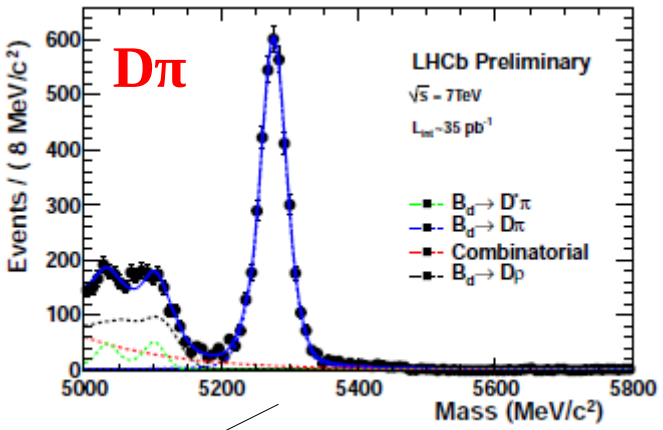
$$B_s^0 \to D_s^- \pi^+ / B^0 \to D^- \pi^+$$

- B0 decay more abundant, but less clean theoretically

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







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

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

Preliminary, 35 pb^{-1}

- No evidence for difference wrt LEP (0.256±0.026) and latest CDF (0.269 ±0.03)
- Expect to crosscheck and improve accuracy using semileptonic decays

Conclusions

- LHCb operated successfully in 2010, demonstrating its expected capabilities with the first 37 pb^{-1}...
- ...and announcing the first world-class measurements:

  Δm_s, new limit on $B_s \to \mu\mu$, new B_s decay modes
- Handing on the baton from the Tevatron on B physics

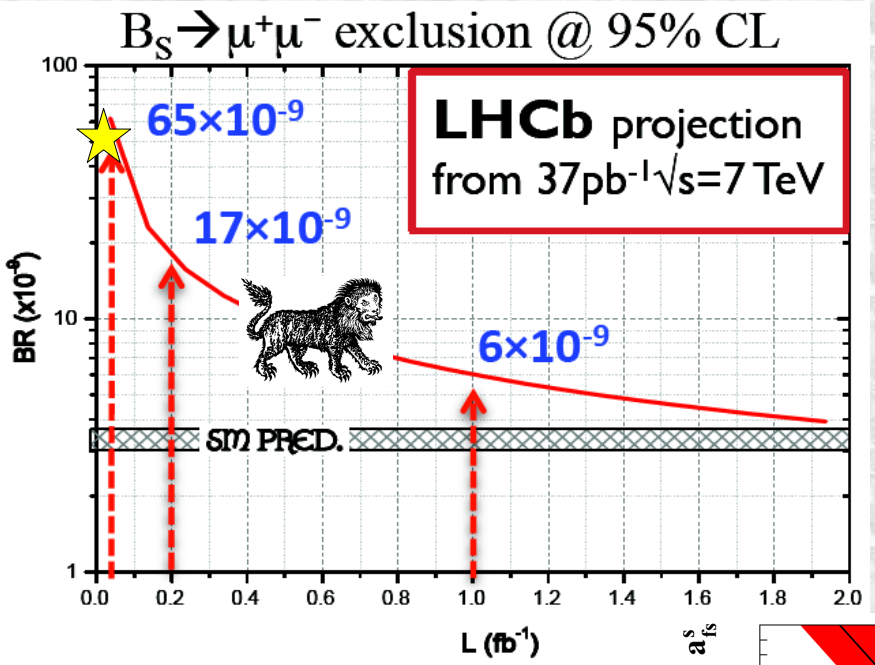
- Many more results than CPV and rare decays:

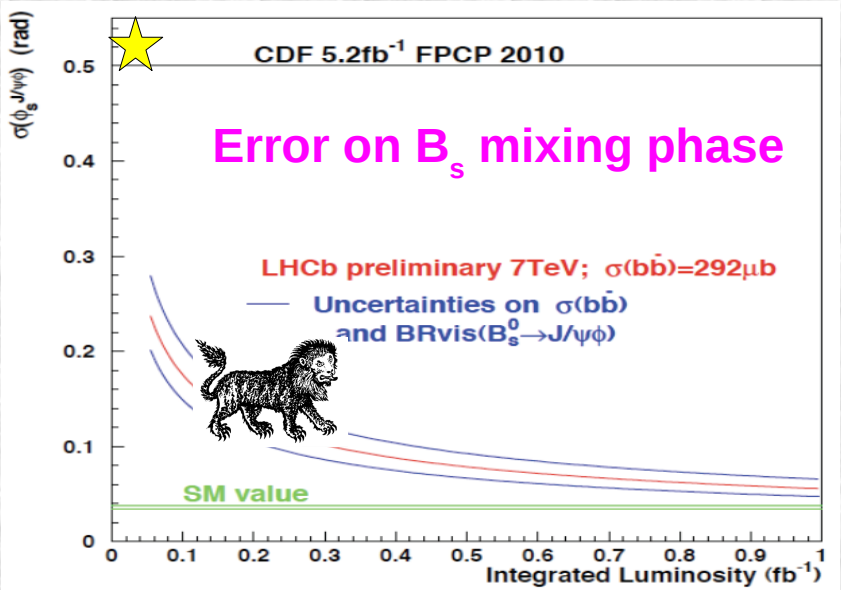
  8 parallel talks at this conference
- And this is just the beginning...

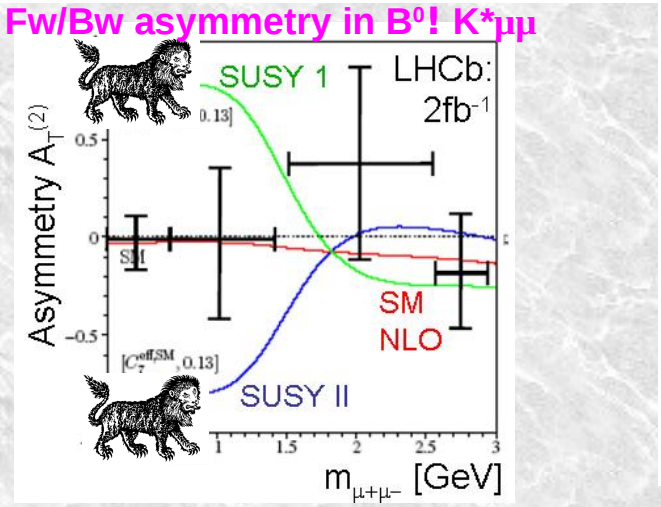
Orientation Table

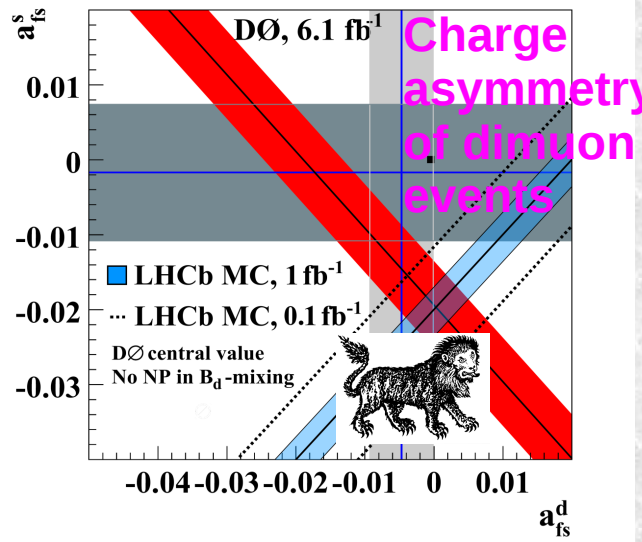
★ You are here

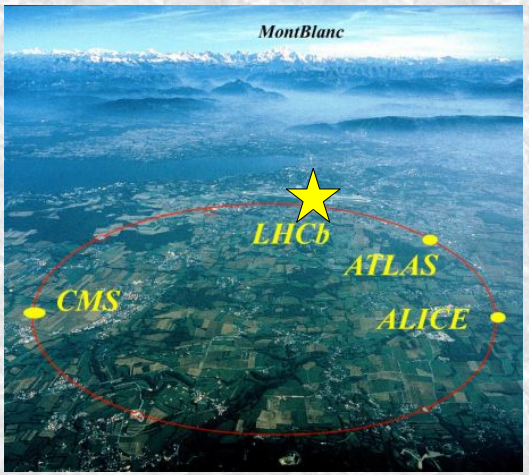
Hic sunt leones









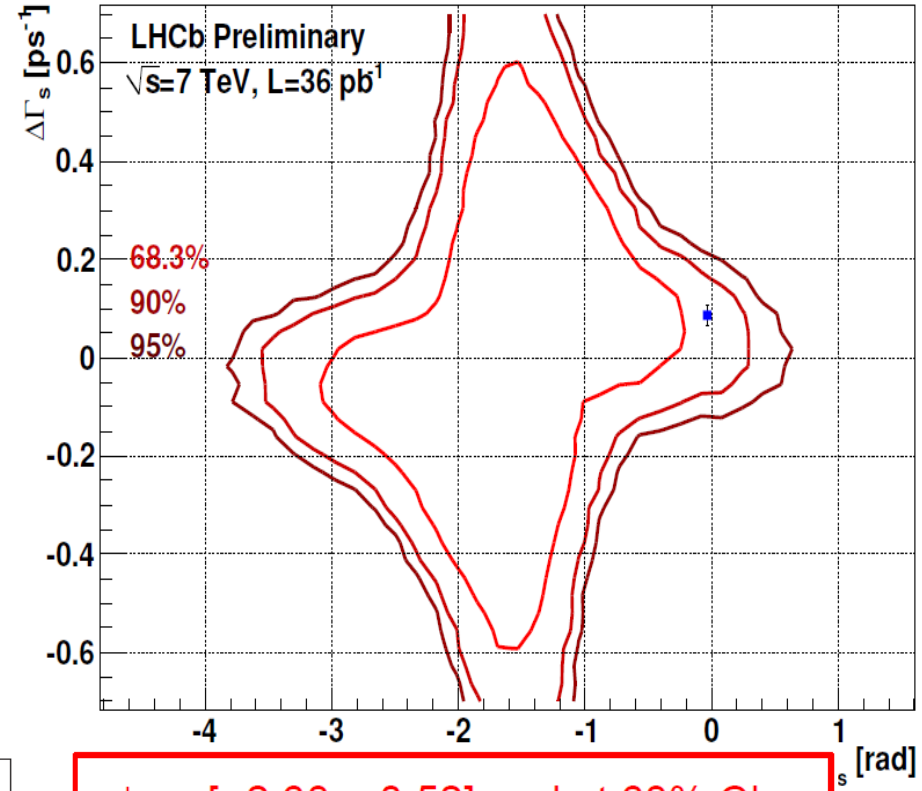


2011/2012: run at L<~3x10^{32} Hz/cm^2, μ < 2.5, expect **1 fb^{-1}** within 2011

Backup Slides

First J/ψ φ result

- Gold plated channel for the measurements of B_s mixing phase from time dependent CP asymmetry
- Concept of angular analysis (to disentangle CP eigenstates) proved



$\phi_s \in [-2.68, -0.52]$ rad at 68% CL
$\phi_s \in [-3.5, 0.2]$ rad at 95% CL

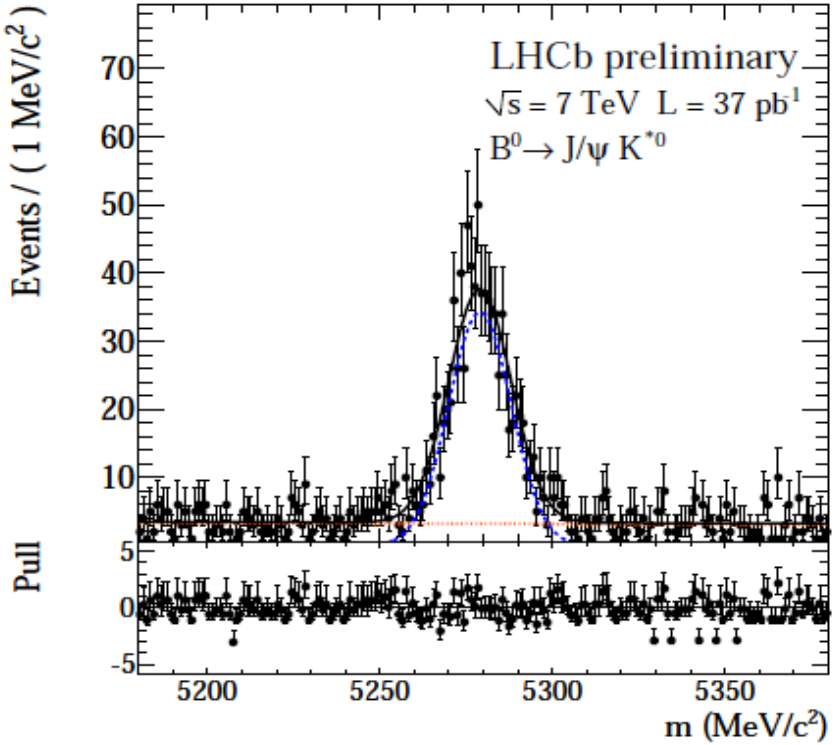
Parameter	LHCb result	BaBar PRD 76, 031002
$\lvert A_\parallel \rvert^2$	$0.252 \pm 0.020 \pm 0.016$	$0.211 \pm 0.010 \pm 0.006$
$\lvert A_\perp \rvert^2$	$0.178 \pm 0.022 \pm 0.017$	$0.233 \pm 0.010 \pm 0.005$
$\delta_\parallel$ [rad]	$-2.87 \pm 0.11 \pm 0.10$	$-2.93 \pm 0.08 \pm 0.04$
$\delta_\perp$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

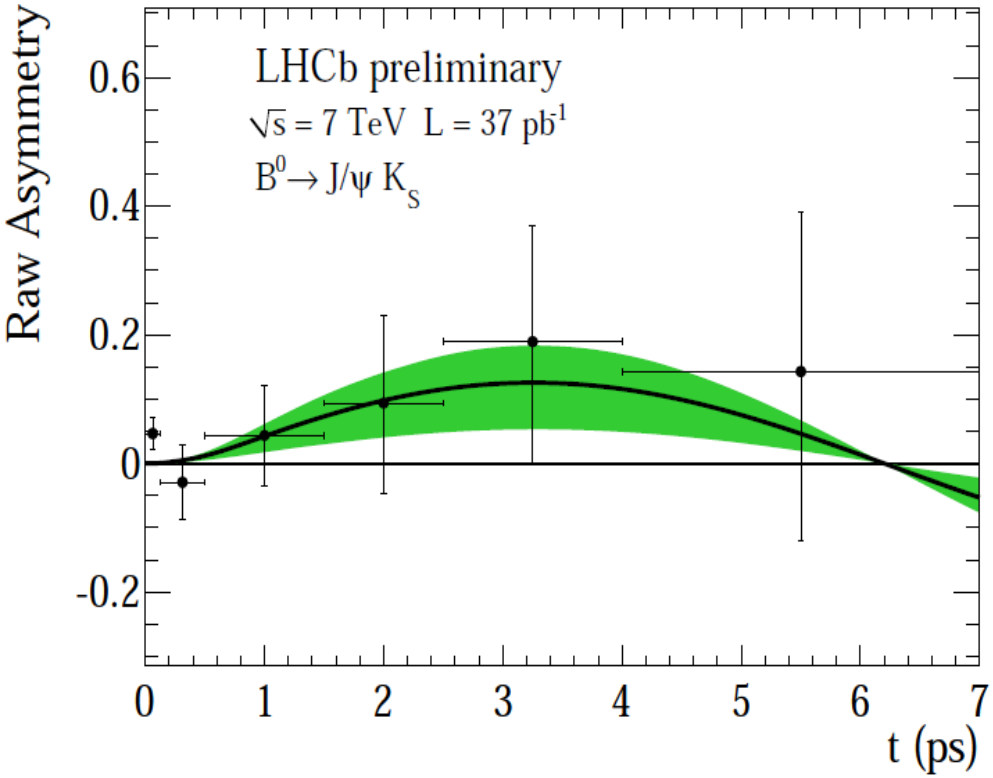
- First constraints from 2010 data
- Very good prospects for 2011

	LHCb 36 pb^{-1}	CDF 5.2 fb^{-1}
$B_s \to J/\psi\,\phi$	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	$3.5 \pm 1.4\%$

J/ψ K_s

- Testbench for all time dependent CPV analysis: check proper time, tagging
- 1300 candidates from 2010 run, needs more statistics
- First result presented at Beauty2011





$$S_{J/\psi K^0_S} = 0.53^{+0.28}_{-0.29}(\text{stat}) \pm 0.08(\text{syst})$$

- First measurement of sin(2β) at hadron machines
- agrees with world average

D0 flavor specific asymmetry

$$a_{fs}^q \propto A_{fs}^q(t) = \frac{\Gamma\left(B_q^0 \text{ or } \overline{B}_q^0 \to \overline{f}\right) - \Gamma\left(B_q^0 \text{ or } \overline{B}_q^0 \to f\right)}{\Gamma\left(B_q^0 \text{ or } \overline{B}_q^0 \to \overline{f}\right) + \Gamma\left(B_q^0 \text{ or } \overline{B}_q^0 \to f\right)}$$

$$a_{fs}^q = \mathrm{Im}\left\{\frac{\Gamma_{12}^q}{M_{12}^q}\right\}$$

$$\left(a_{fs}^d\right)^{SM} = -(5.0 \pm 1.1)\times 10^{-4}$$

$$\left(a_{fs}^s\right)^{SM} = (2.1 \pm 0.4)\times 10^{-5}$$

D0 measurement using bb→μμX events:

$$A^b = \frac{N^{++} - N^{--}}{N^{++} + N^{--}} = (0.494)a_{fs}^s + (0.506)a_{fs}^d$$

$$\left(a_{fs}^s\right)^{\text{using b-fact}} = -(1.46 \pm 0.75)\times 10^{-2}$$

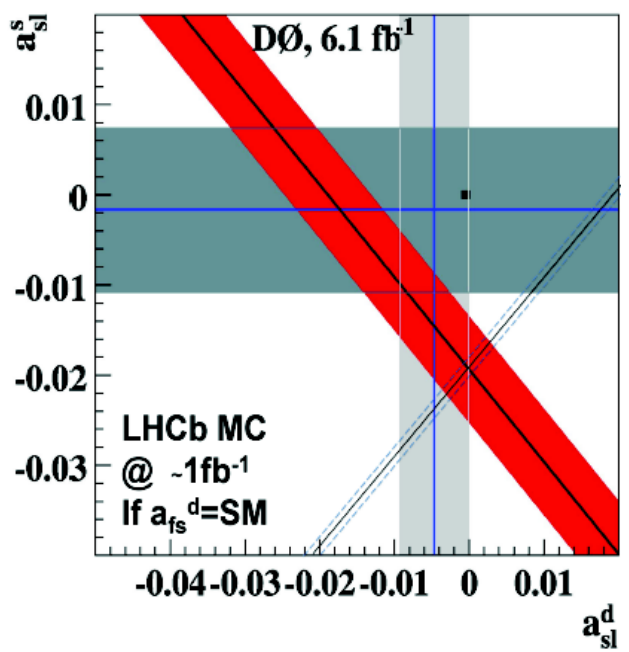
~2σ

Inclusive method using bb→μμX is difficult at LHCb due to the ~10^{-2} production (pp collider) and detector asymmetry.

More promising looks fitting simultaneously the production asymmetry using the exclusive method either with $B_s \to D_s\pi$ decays, or using the B_s and B_d semileptonic decays and subtracting them, such that the detector asymmetry cancels and we are left with:

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

Stat. Error	100 pb^{-1}	1 fb^{-1}
a_{fs}^s ($D_s\,\pi$)	2×10^{-2}	6.8×10^{-3}
ΔA_{fs} ($D_q\,\mu\nu$)	2×10^{-3}	6.3×10^{-4}



Wenesday, March 23, 2011 Fre