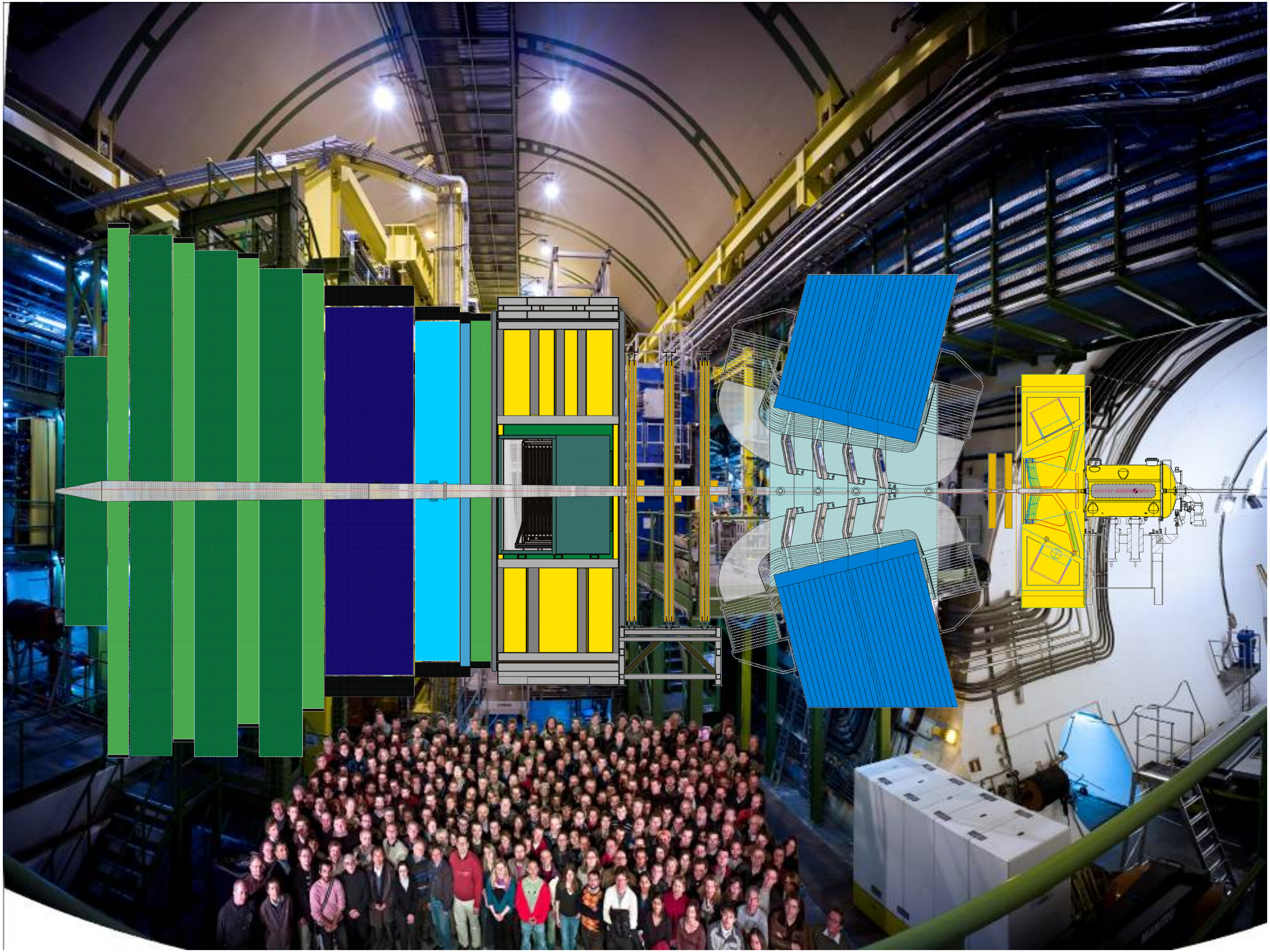
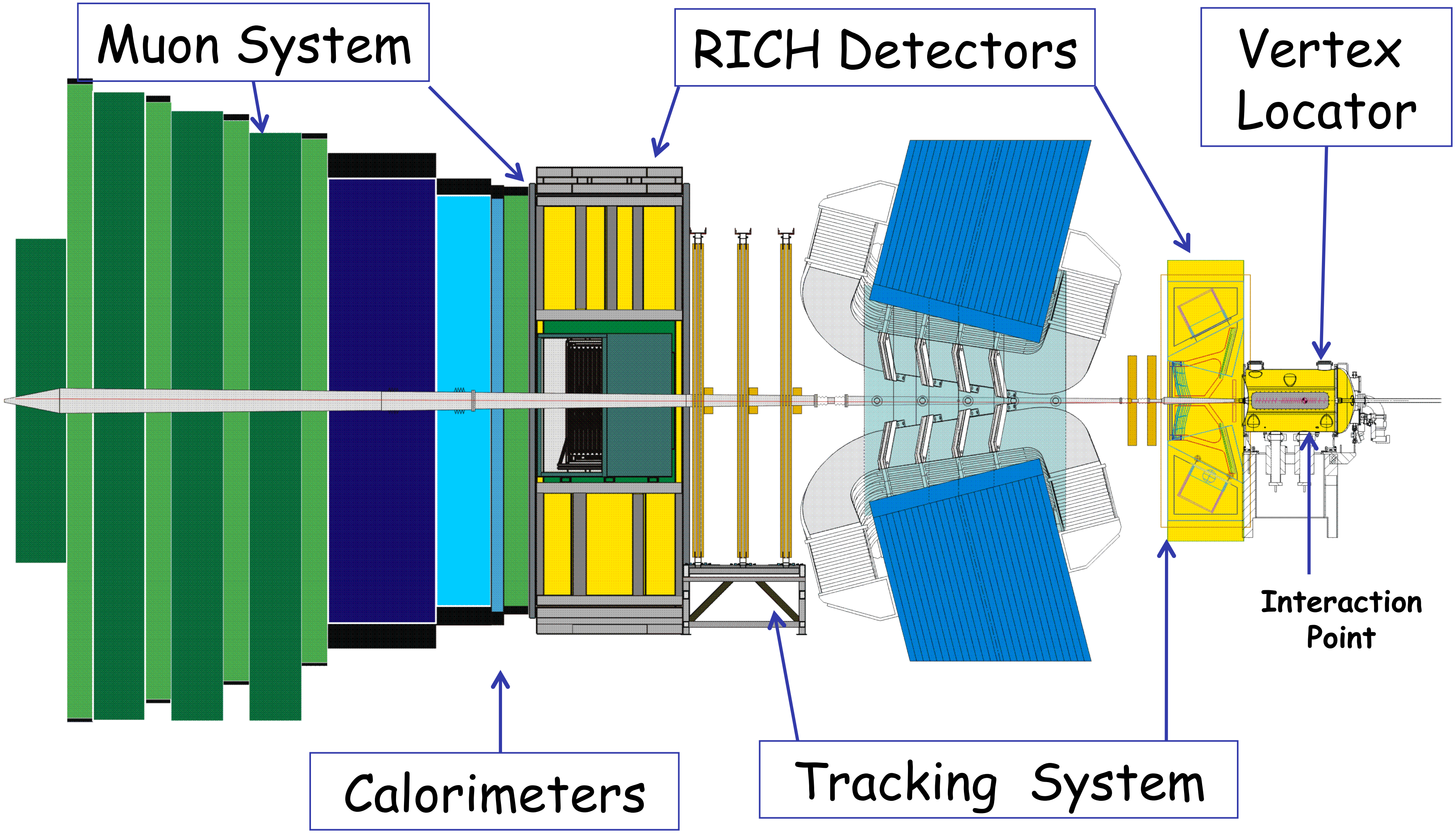
University of Glasgow | Experimental Particle Physics

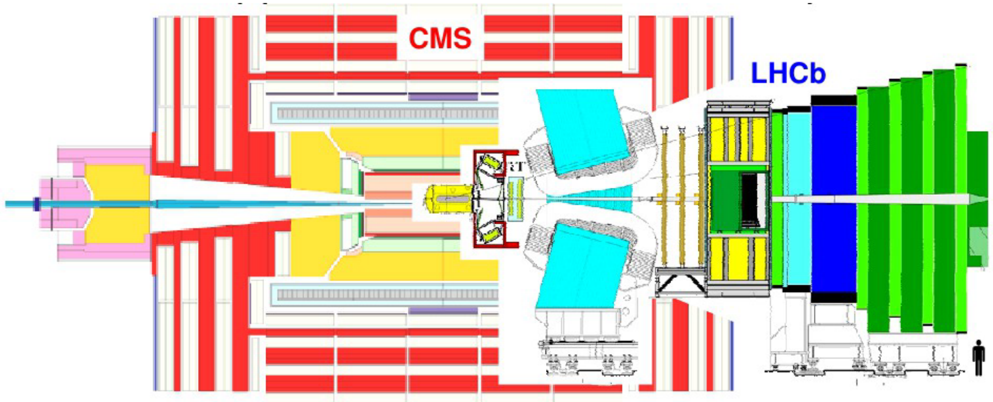
First LHCb Results: A new Era in Flavour Physics

Chris Parkes, IOP, University of Glasgow, April 2010




Muon System
RICH Detectors
Vertex Locator
Interaction Point
Calorimeters
Tracking System

Part 1:
Introducing LHCb



UK: Birmingham, Bristol, Cambridge, Edinburgh, Glasgow, Liverpool, Manchester, Imperial, Oxford, STFC, Warwick

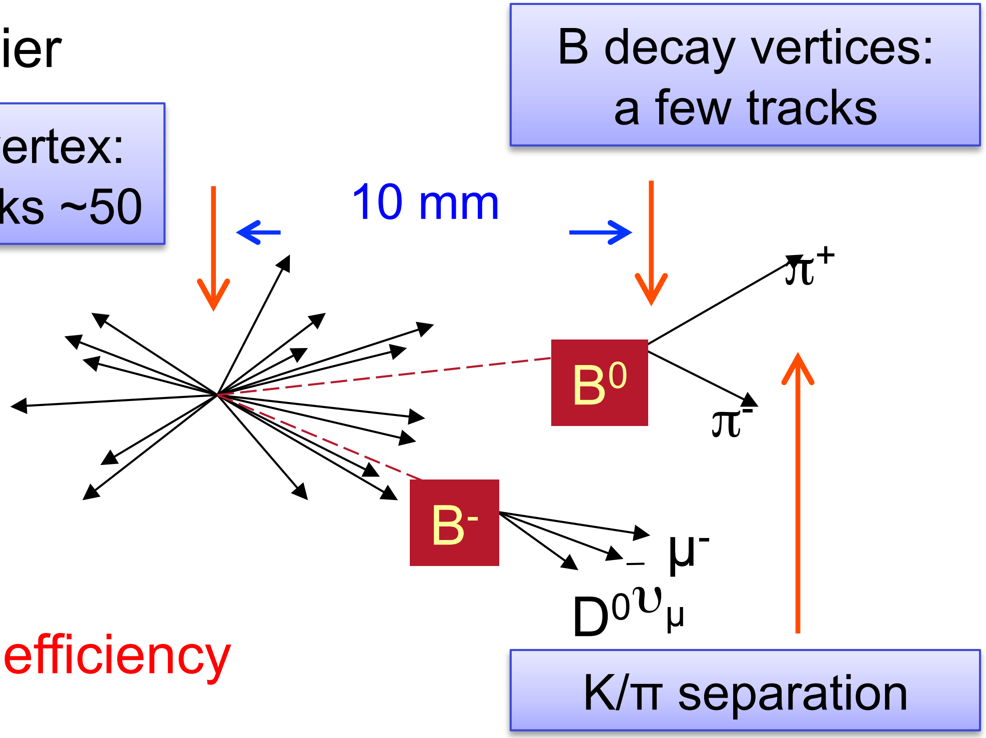
- ~**20%** of Collaboration
- Major contributors both key detectors (**VELO/RICH**)

- Key Responsibilities include
  - Spokesperson
  - Physics Co-ordinator
  - VELO Project Leader
  - Editorial Board Chair

Introducing LHCb

LHCb is a dedicated experiment to study flavour physics at the LHC

- Search for New Physics in quantum loop processes
- CP violation and rare decays allowing to probe beyond the LHC energy frontier

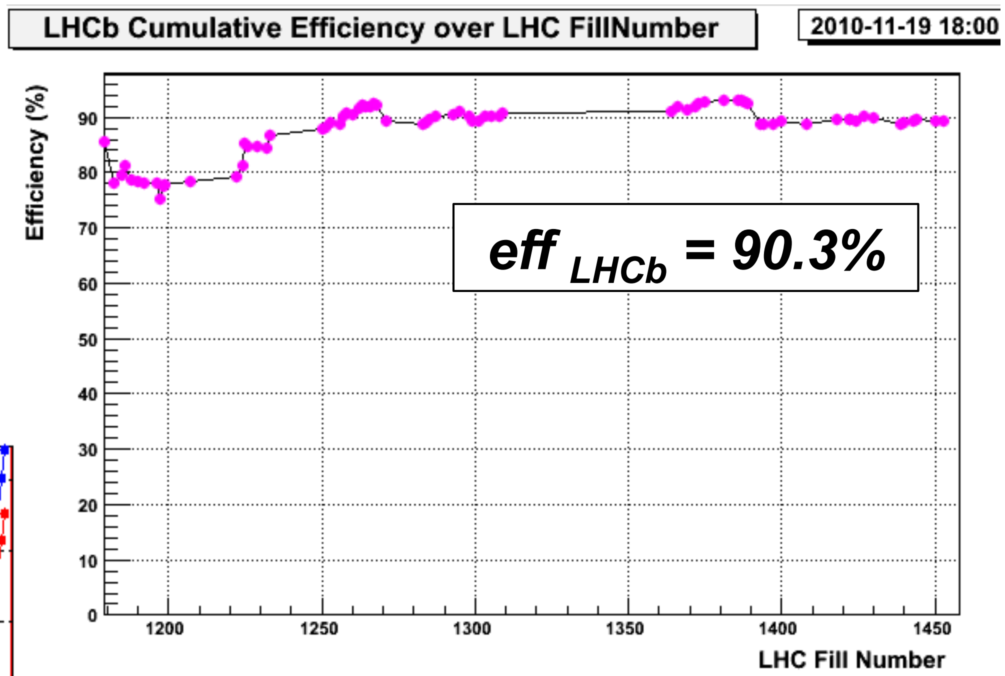


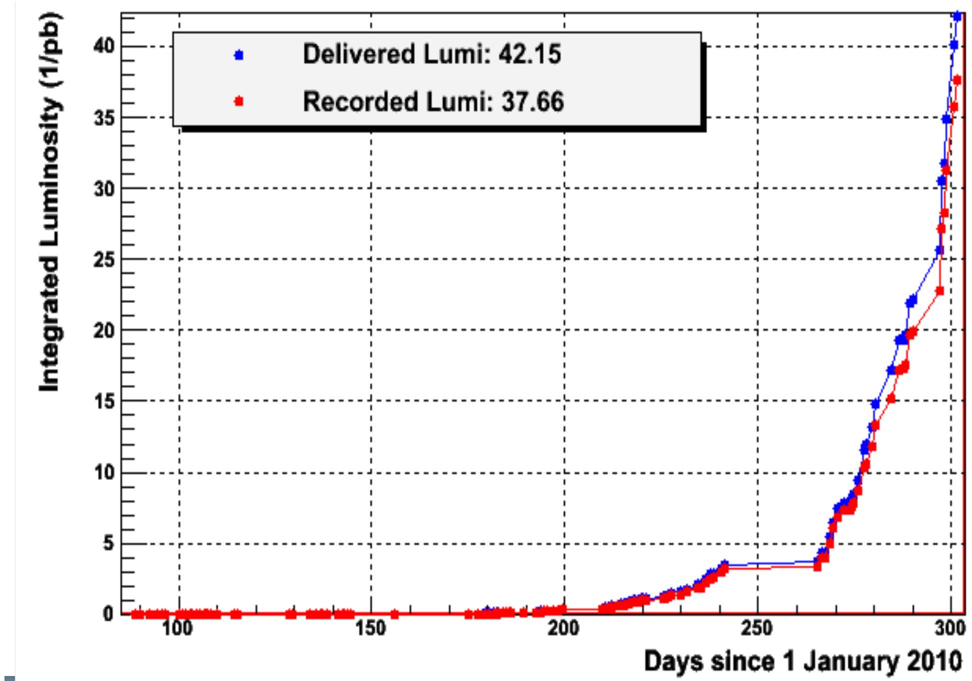
Detector requirements

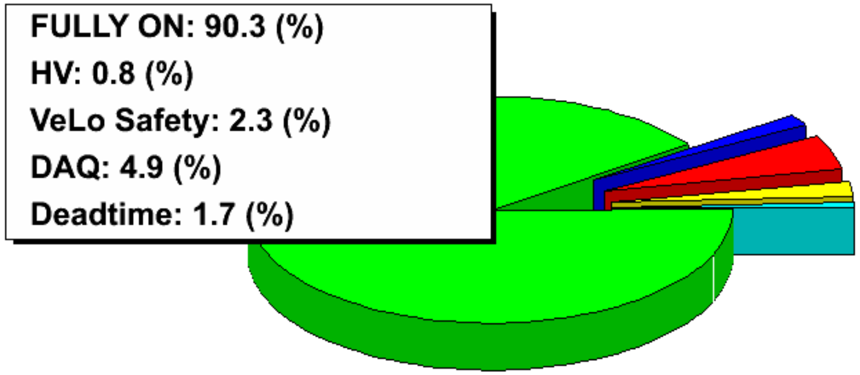
- Efficient trigger for both leptonic and hadronic final states
- Excellent vertex finding and tracking efficiency
- Outstanding particle identification

LHC and LHCb performance

- LHC and LHCb show excellent performance
- Recorded 38 pb^{-1} in 2010
- 10^{10} bb-pairs produced

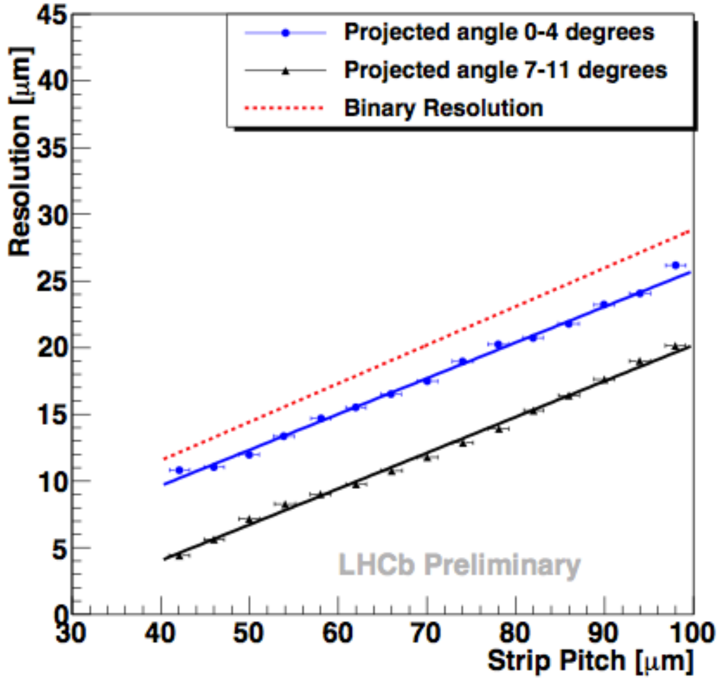


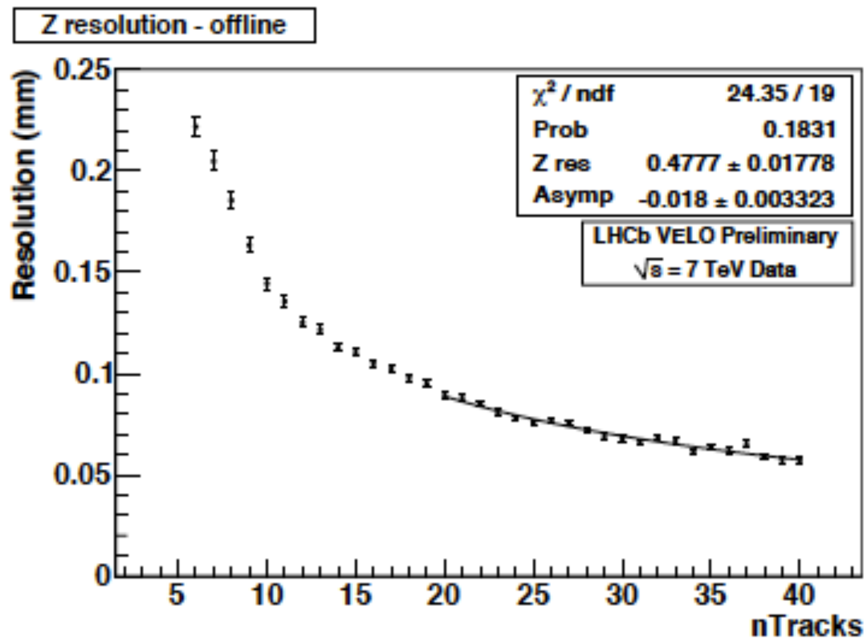


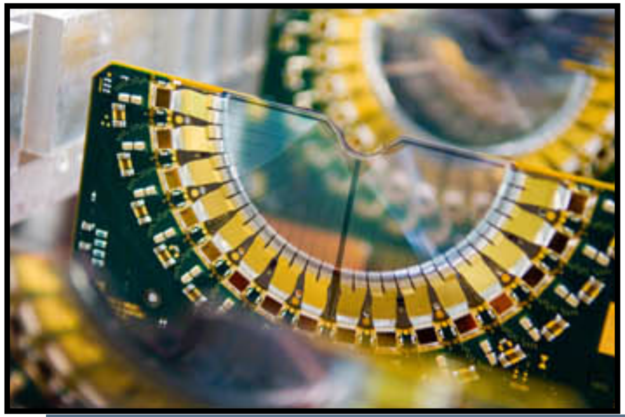


Vertex Resolution

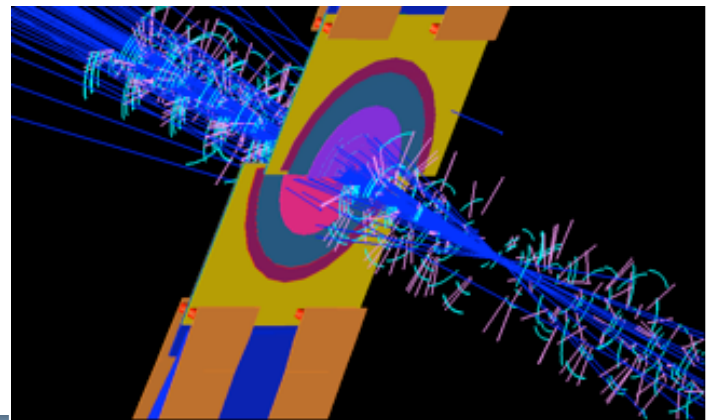
VELO - Highest Resolution Vertex Detector at LHC





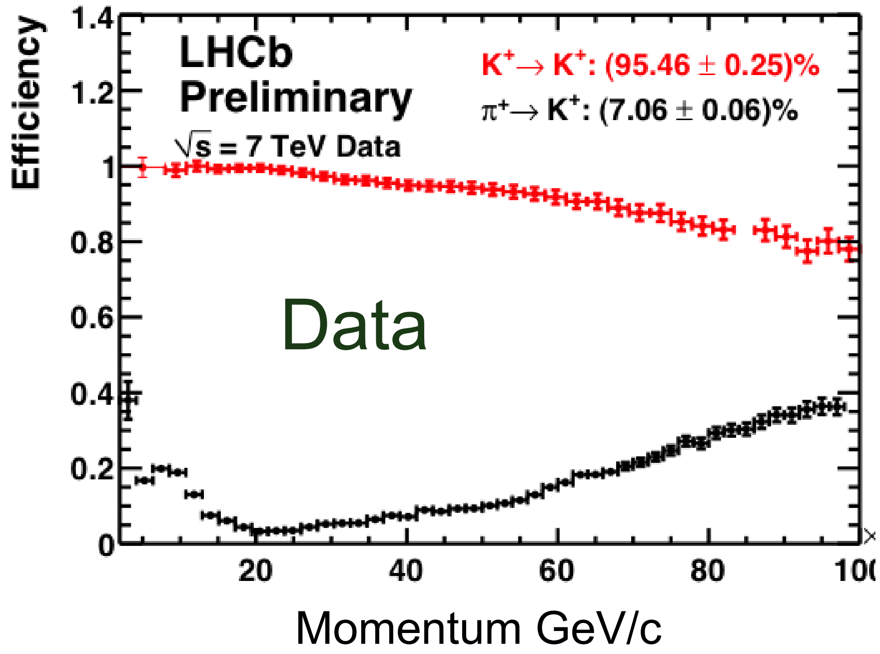


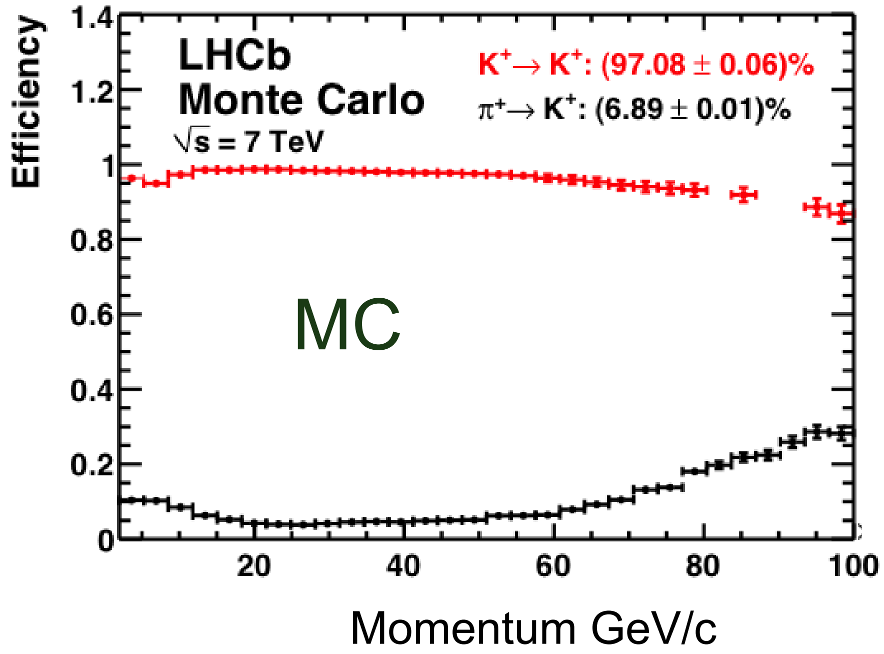
Identification of beauty and charm from displaced vertices critical to LHCb physics

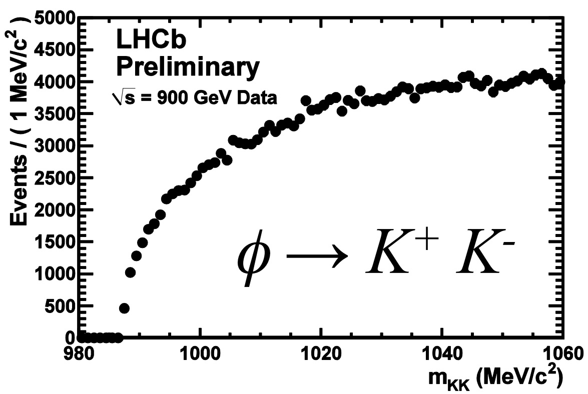


Particle Identification

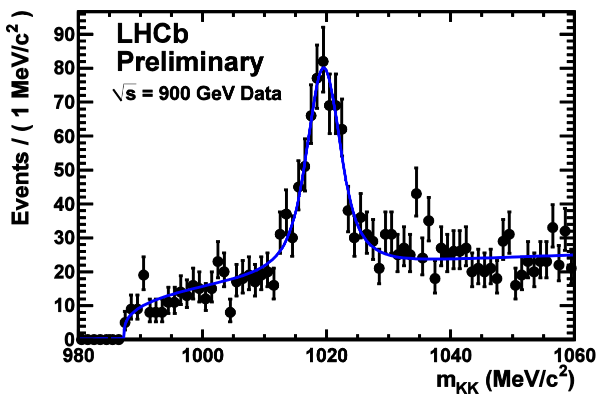
RICH PID close to MC expectations across full momentum range



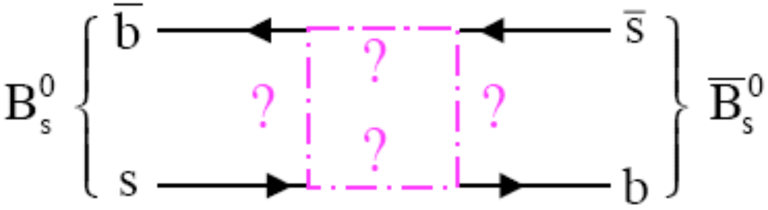




Clean reconstruction of hadronic decays critical to many of following physics results



LHCb: Beyond the Energy Frontier



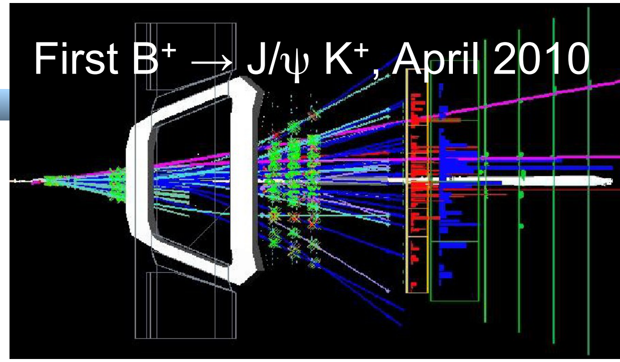
B_s–$\bar{B}_s$ oscillations: “Box” diagram

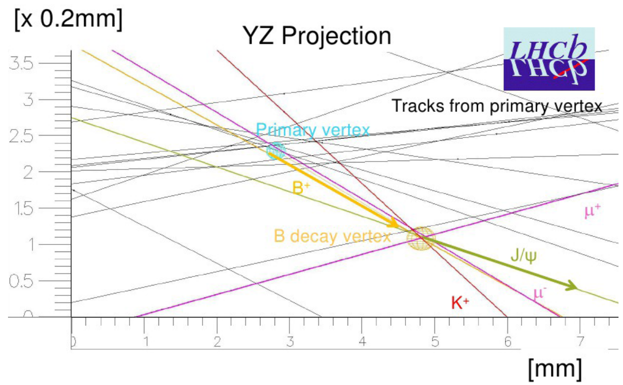
Discovering New Physics through indirect effects: sensitive far beyond direct particle production reach

- Precision Measurements
  - Need events !
  - Need detailed understanding of detector & systematics
- Competitive Tevatron?
  - CDF/D0 >6000 pb-1
  - LHCb ~ 40 pb-1
    - Cross-section: factor 3,
    - Acceptance, Trigger, Vertex Resolution, Particle ID

Key LHCb Targets:
CP violation in B_s system
New physics in rare decays
CKM angle γ

Part 2: Production Studies





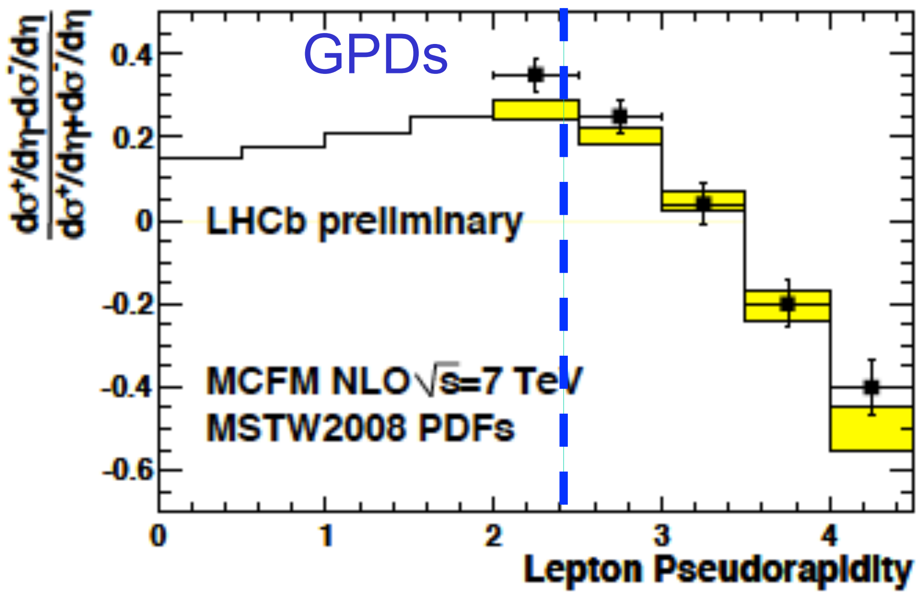
- Measuring the branching fraction ratio between B_s->ψ'ϕ and B_s->J/ψϕ: P Schaack
- The observation of the $D^{*+} \rightarrow D^0(K3\pi)\,\pi^+$ decay and a charm production cross section measurement at LHCb: P Hunt
- Prompt hadron production at LHCb: A Contu
- Measuring σ(Z→μμ) at LHCb: E Hicks

W and Z Production

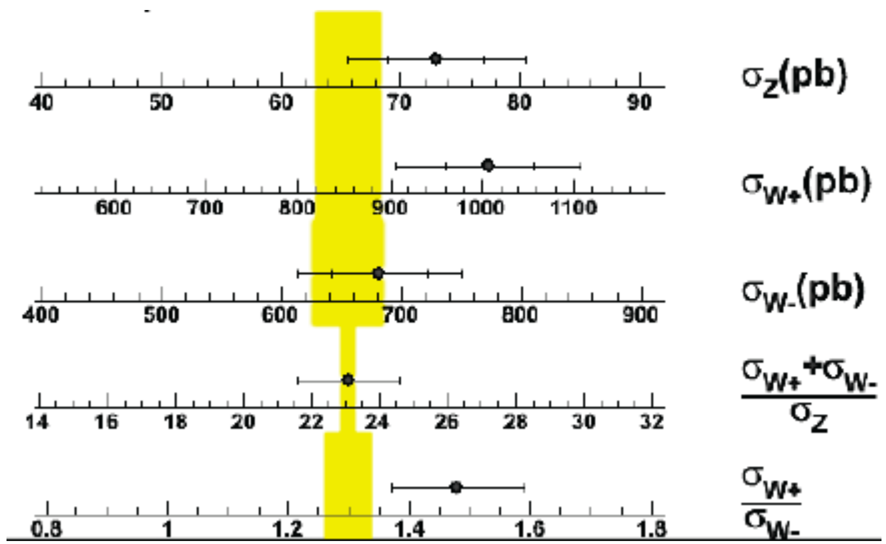
LHCb-CONF-2011-012

E. Hicks, session 2.4

- W/Z cross-section ratio
  - sensitive test of SM at LHC
- W Charge Asymmetry $\frac{\sigma_{W^+} - \sigma_{W^-}}{\sigma_{W^+} + \sigma_{W^-}}$
  - changes **sign** in LHCb region: constraints on the **low x quark content of the** protons at **high q^2.**



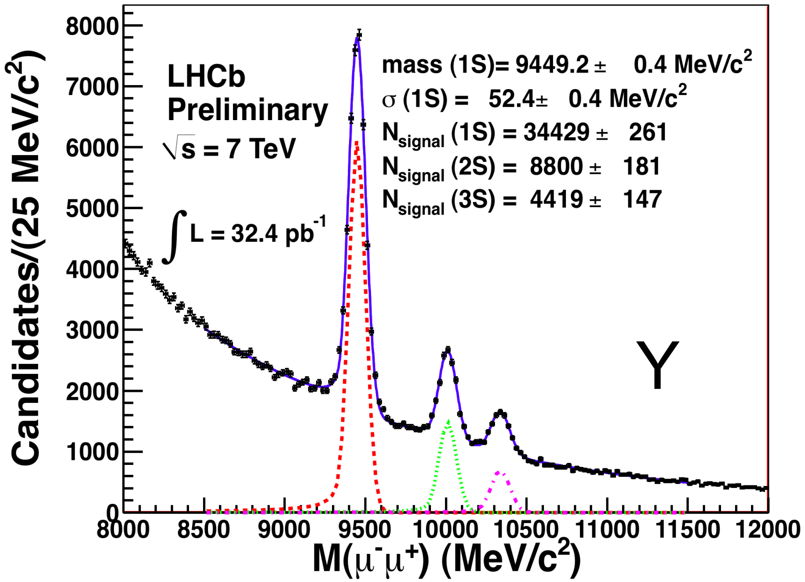
16.5 pb^{-1}, muon decays



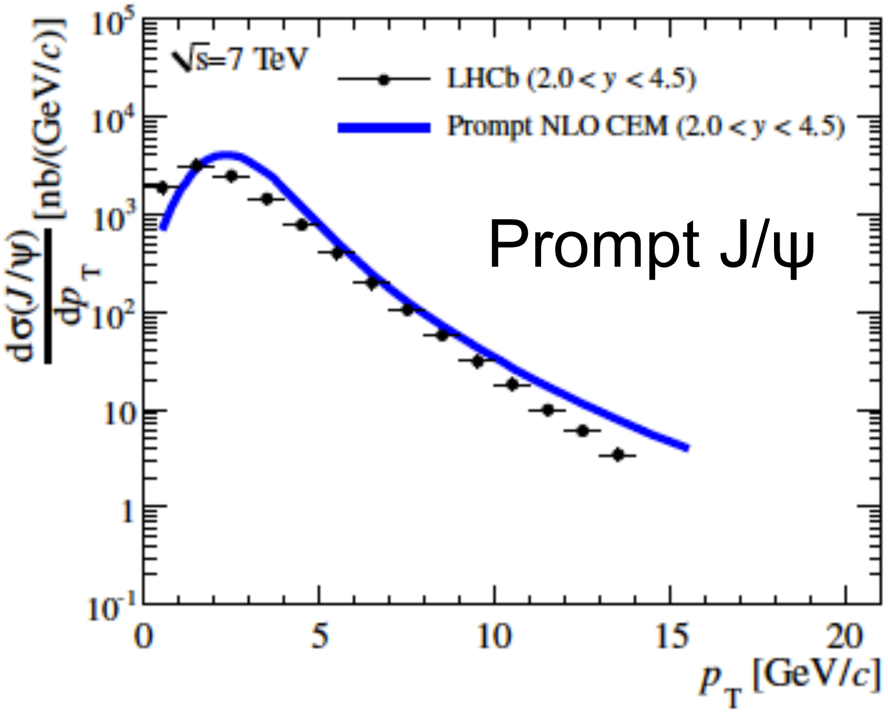
J/ψ, Y, B_c^+ Production

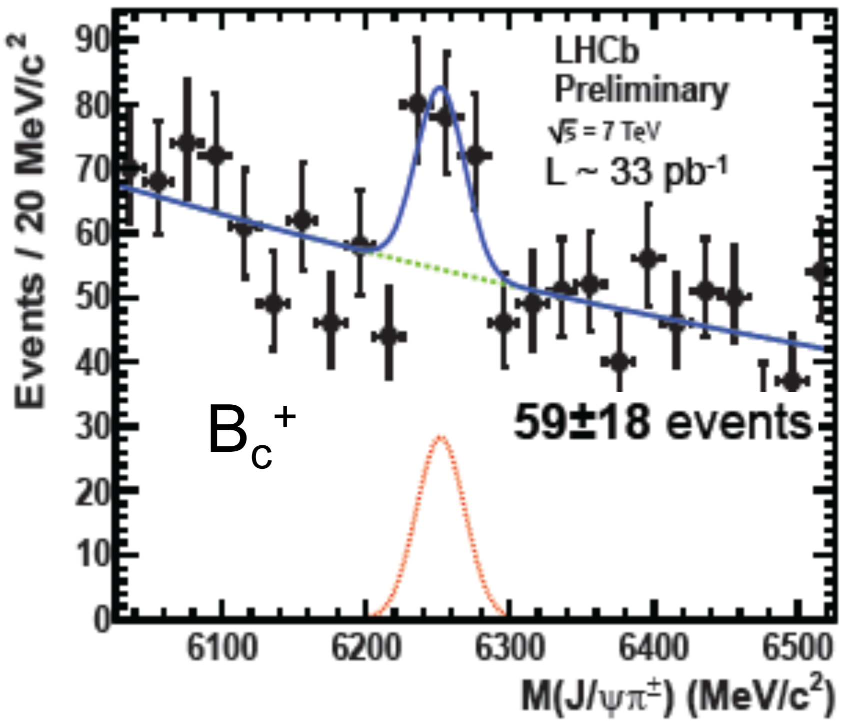
ArXiv: 1103.0423 ,EPJC
LHCb-CONF-2011-009
LHCb-CONF-2011-016
LHCb-CONF-2011-017

A. Contu, session 2.1



- Test QCD in unique forward region





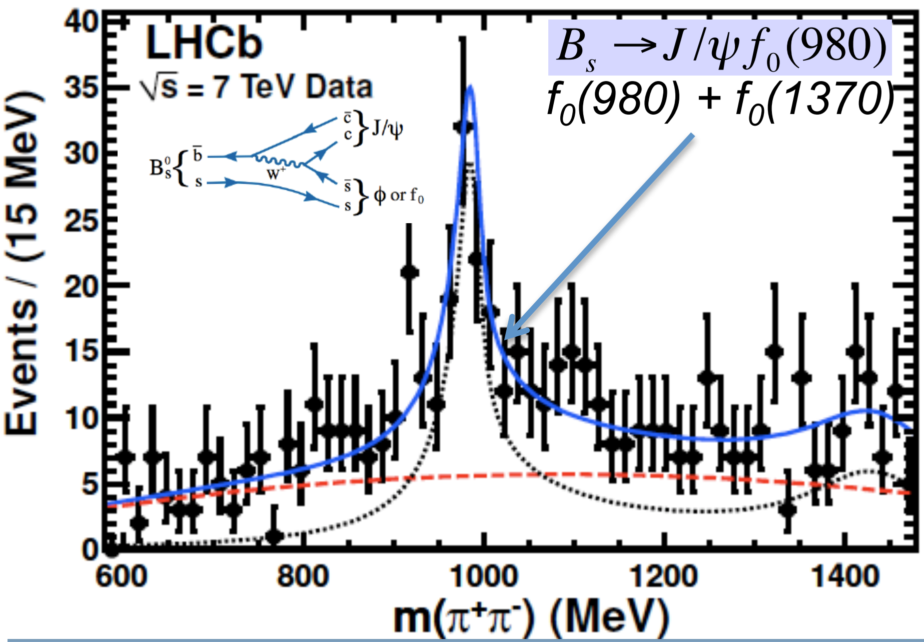
- Also first obs. J/ψJ/ψ

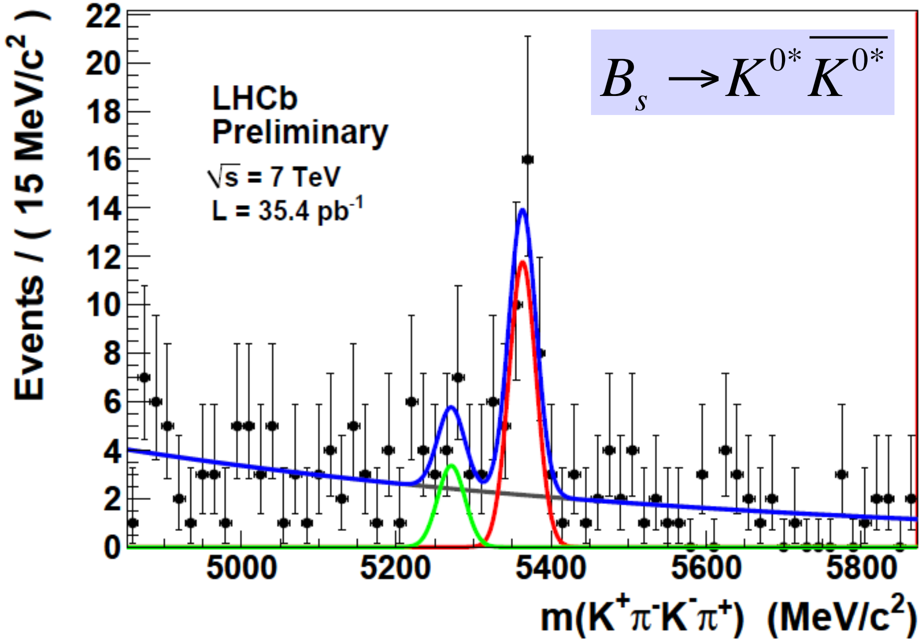
FIRST

New B_s Decays

PLB 698 (2011) 115
LHCb-CONF-2011-019
LHCb-CONF-2011-008
PLB 698 (2011)14

- Observation of:
  - The new CP eigenstate for β_s: $B_s \to J/\psi f_0(980)$
  - NP in penguin explorer: $B_s \to K^{0*}\overline{K^{0*}}$
  - Background for γ angle: $B_s \to D^0 K^{*0}$
  - Exploring semi-leptonics: $\overline{B_s} \to D_{s2}^{*+} X \mu^- \overline{\upsilon}$





b & c cross-sections

ArXiv: 1103.0423 ,EPJC
PLB 694 (2010) 209
LHCb-CONF-2010-013

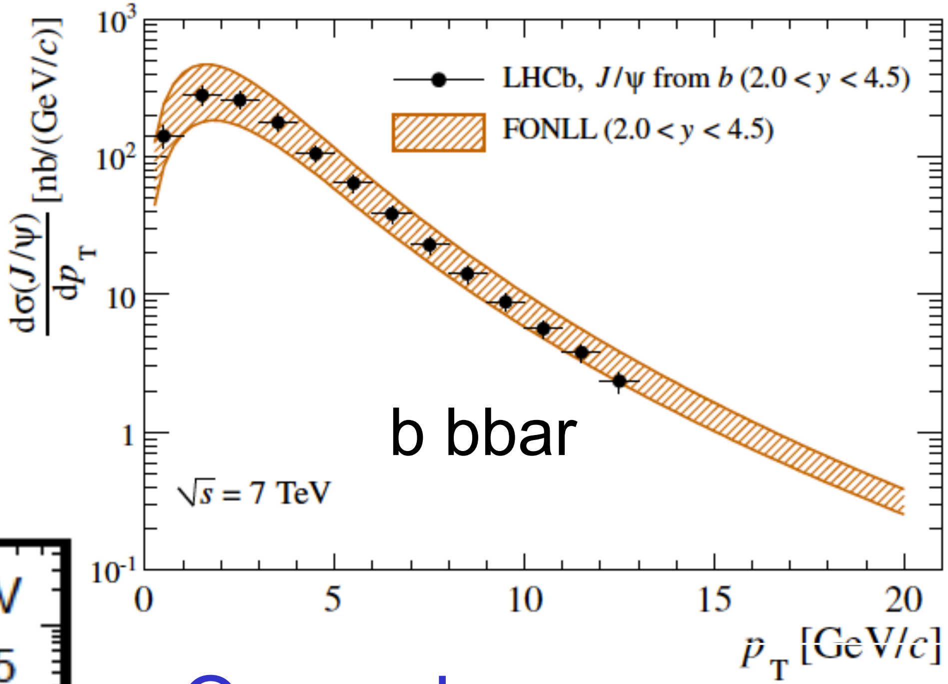
P. Hunt, session 1.1

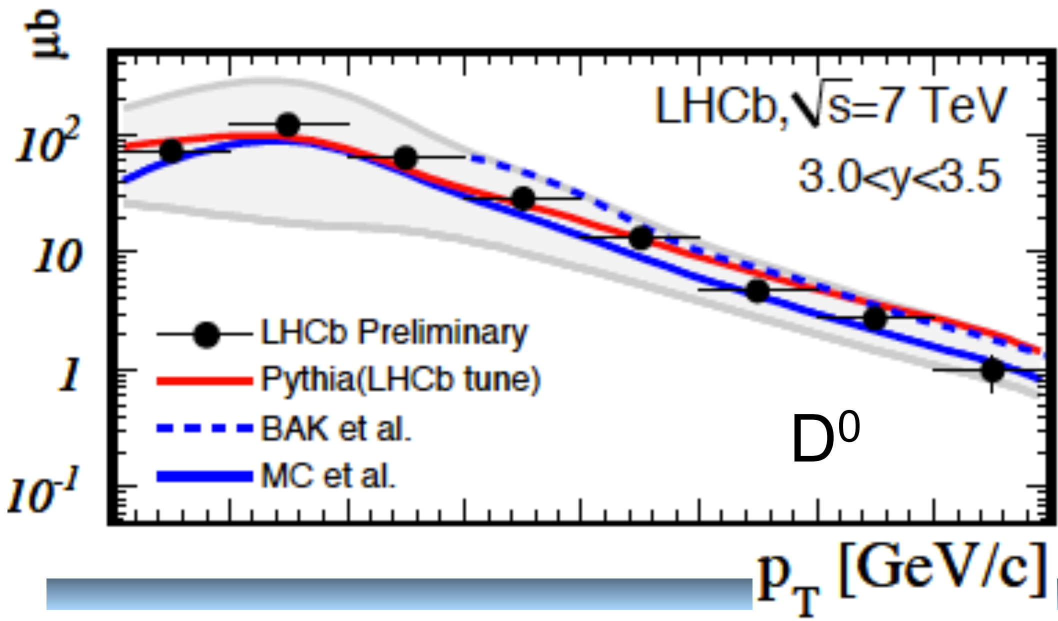
- bbar: two measurements
  - b➔J/ψ 5.2 pb^{-1}

    σ(pp→b bbar X) = 288±4±48 μb

  - b➔$D^0\mu^-\upsilon X$ 12.2 nb^{-1}

    σ(pp→b bbar X) = 284±20±49 μb





- Open-charm: 1.8 nb^{-1}
  - D^0, D^+, D^{*+}, D_s^+

$$\sigma(pp \to c\bar{c}X) = 6.10 \pm 0.93\,\text{mb}$$

Fragmentation Functions

LHCb-CONF-2011-013

$$\frac{f_s}{f_d} \propto \frac{N(B_s \to D_s^{\pm}\pi^{\mp})}{N(B_d \to D^{\pm}K^{\mp})} \quad , \quad \frac{N(B_s \to D_s^{\pm}\pi^{\mp})}{N(B_d \to D^{\pm}\pi^{\mp})}$$

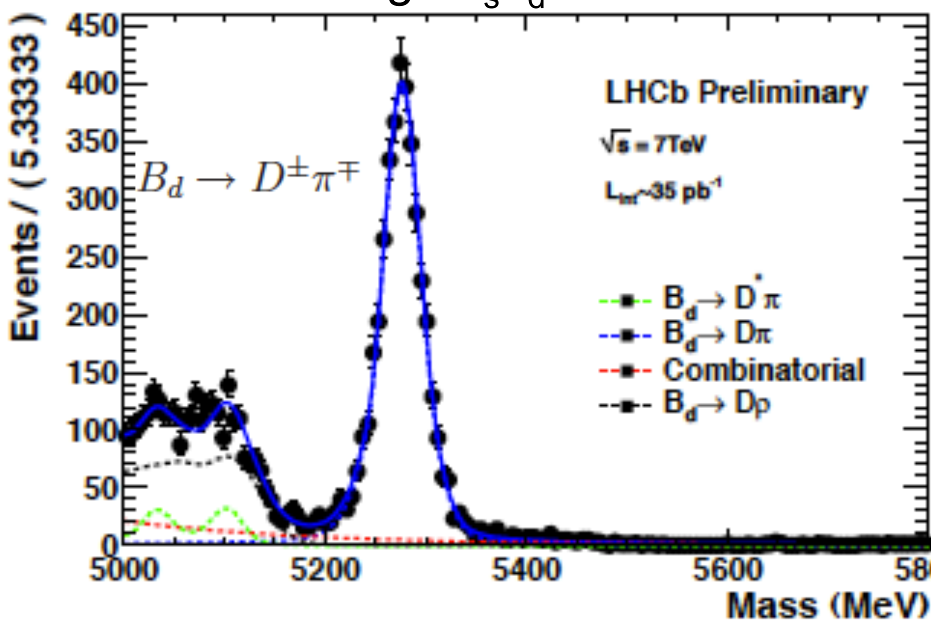
Theoretically cleaner (7%) , Additional Exchange Diagram (9%)

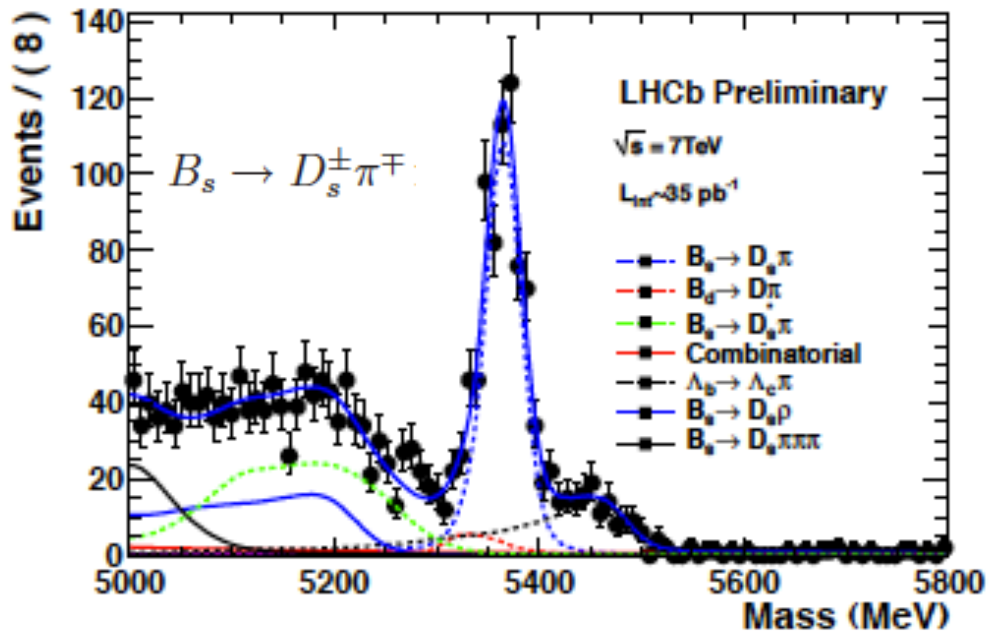
Same 4 particle final state , More events

$$\left(\frac{f_s}{f_d}\right)_1 = 0.242 \pm 0.024^{\rm stat} \pm 0.018^{\rm syst} \pm 0.016^{\rm theor},$$

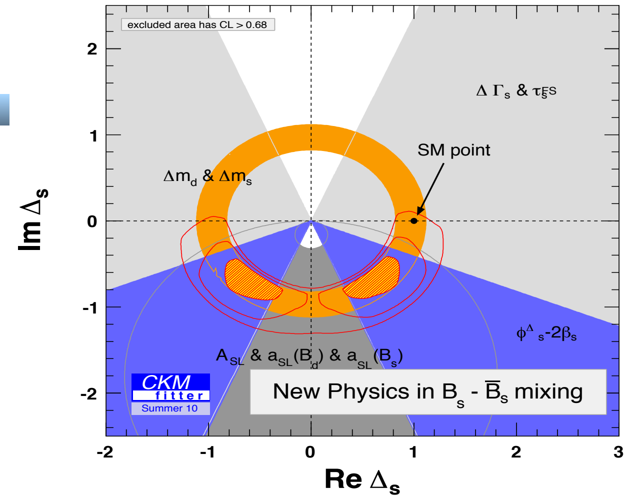
$$\left(\frac{f_s}{f_d}\right)_2 = 0.249 \pm 0.013^{\rm stat} \pm 0.020^{\rm syst} \pm 0.022^{\rm theor}.$$

HFAG average: f_s/f_d = 0.270±0.034 LEP: 0.256±0.026 new CDF(La Thuile): 0.269±0.03





Part 3:
Search for New Physics in CP violation and mixing

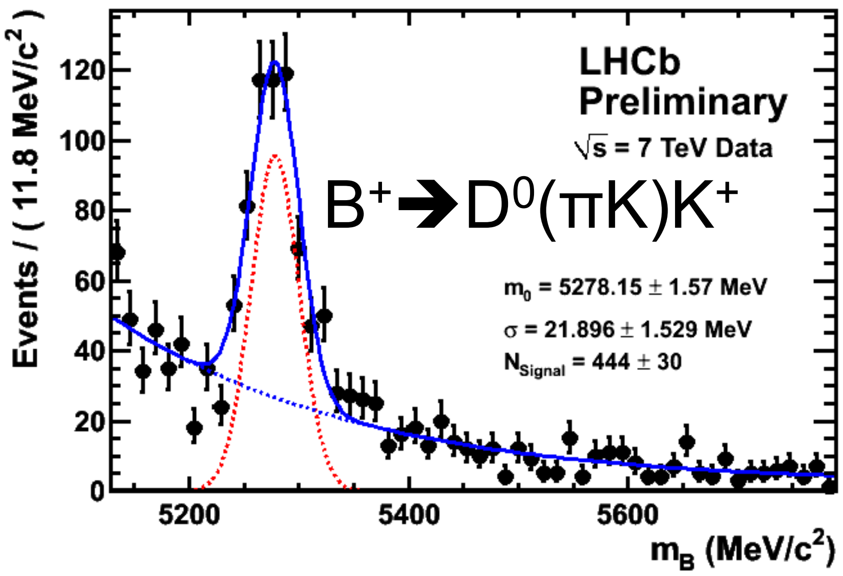


- Analysis of B_d->J/Ψ K* at LHCb: A Sparkes
- Early measurements of the decay B_s->J/Ψϕ at LHCb: C Fitzpatrick
- Δm_d and Δm_s measurements from LHCb: T Bird
- CP violation and lifetime measurement in B_s->KK: L Eklund
- B->DK* studies at LHCb: M Whitehead
- Measurement of y_{CP} and A_Γ via direct lifetime measurements: M Alexander
- Model-independent determination of the (D0,D0bar) -> $K_{(S,L)}K^+K^-$ strong phase difference and its impact on the measurement of the CKM angle γ: C Thomas

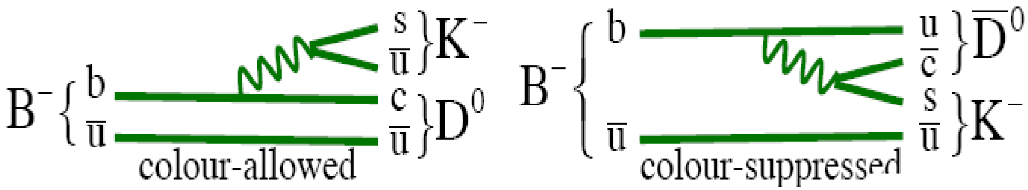
Towards measuring CKM γ

M. Whitehead, session 1.1
C. Thomas, session 1.1

- Tree diagram measurements B➔Dh and others
  - SM value of γ
- Loop diagram measurements B➔hh
  - New physics sensitive
- Example Tree Method B➔DK



LHCb yield: 444 ± 30 / 34 pb^{-1}
CDF yield: 516 ± 37 / fb^{-1}



Expect to measure γ with a combined precision of ~5° from 2011/2012 data

New States for Tree γ

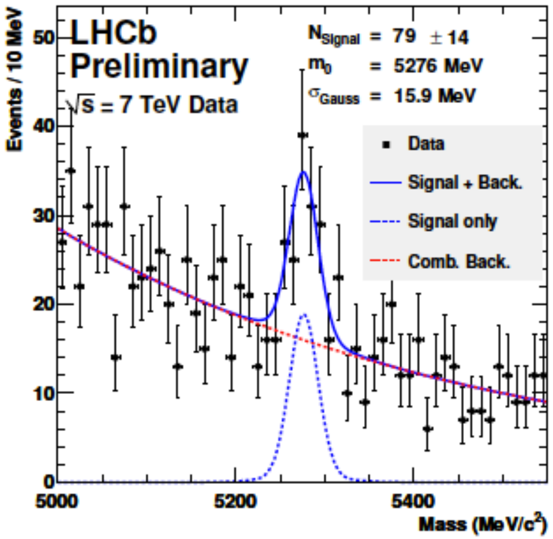
LHCb-CONF-2011-018
LHCb-CONF-2011-007
LHCb-CONF-2011-004

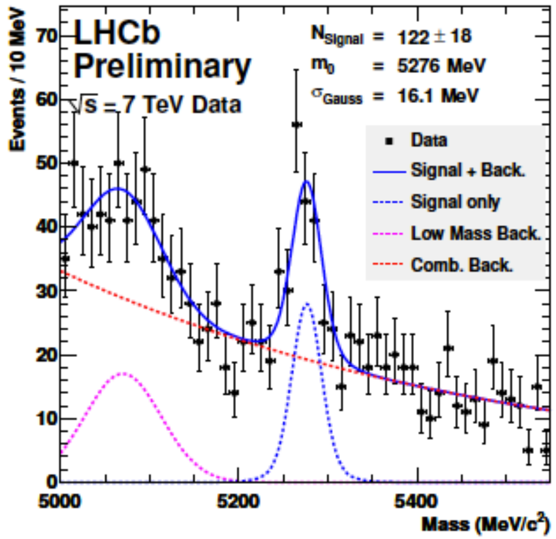
NEW

FIRST

- First Observation

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





- BRs on other states
  - – Up to six track final states

BEST

$$\frac{\mathcal{B}(\bar{B}^0 \to D^+\pi^-\pi^+\pi^-)}{\mathcal{B}(\bar{B}^0 \to D^+\pi^-)} = 2.35 \pm 0.11(\mathrm{stat}) \pm 0.24(\mathrm{syst})$$

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

$$\frac{\mathcal{B}(\bar{B}^0_s \to D^+_s\pi^-\pi^+\pi^-)}{\mathcal{B}(\bar{B}^0_s \to D^+_s\pi^-)} = 2.22 \pm 0.41(\mathrm{stat}) \pm 0.25(\mathrm{syst})$$

$$\frac{\mathcal{B}(\Lambda^0_b \to \Lambda^+_c\pi^-\pi^+\pi^-)}{\mathcal{B}(\Lambda^0_b \to \Lambda^+_c\pi^-)} = 1.32 \pm 0.15(\mathrm{stat}) \pm 0.14(\mathrm{syst})$$

Direct CP violation in $B_s \rightarrow K^-\pi^+$

LHCb-CONF-2011-011

- Production asymmetry (see also D➔hh slide)
  - Controlled from $B^\pm \rightarrow J/\Psi K^\pm$ (A_P=-0.024±0.016).
- Detector asymmetry
  - Magnet up/down with D* and $D^0 \rightarrow K\pi$ (A_D=-0.004±0.004)

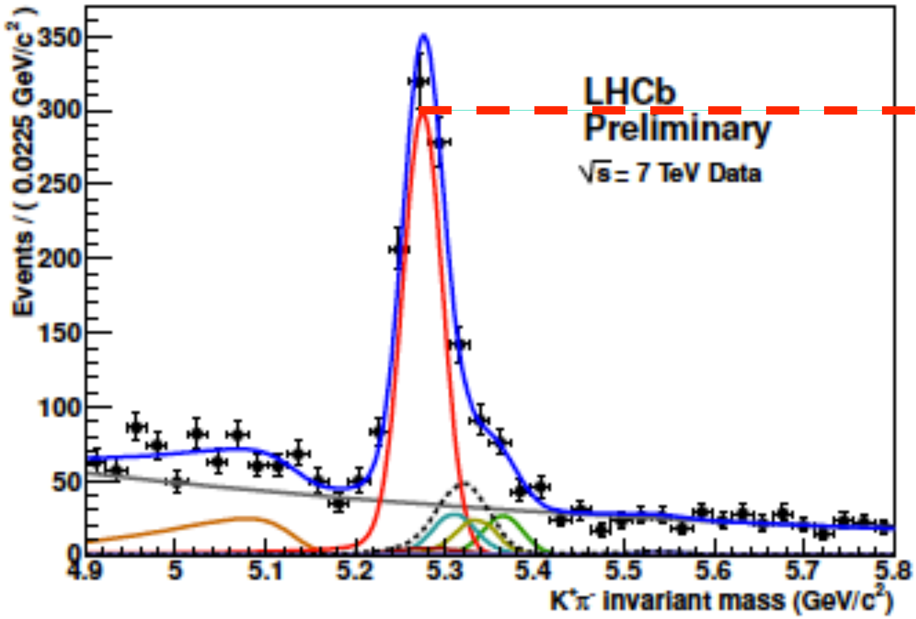
$$A_{CP}(B^0 \rightarrow K^+\pi^-) = -0.074 \pm 0.033 \pm 0.008$$

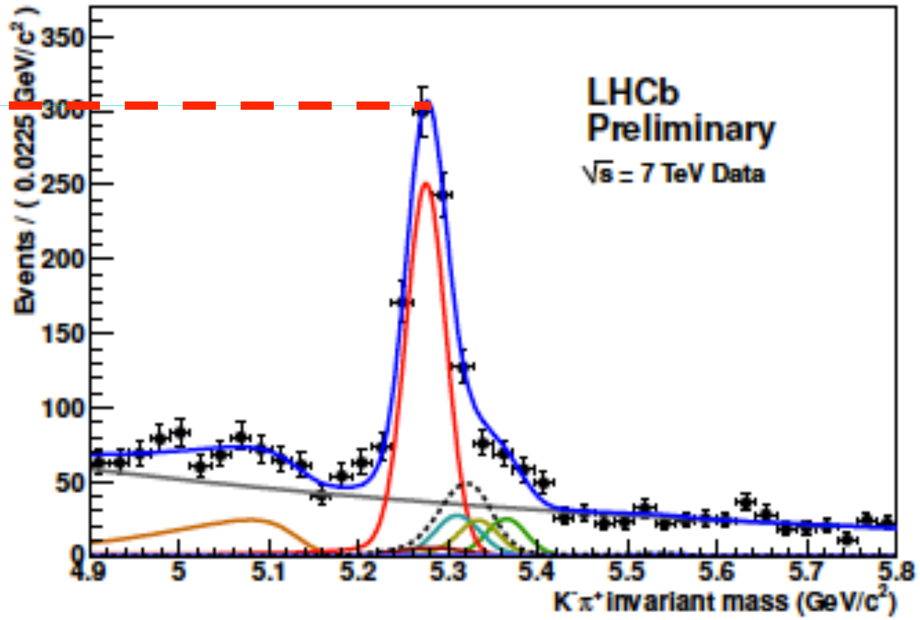
$$A_{CP}(B^0_s \rightarrow \pi^+K^-) = 0.15 \pm 0.19 \pm 0.02.$$

HFAG average:

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

$$A_{CP}(B^0_s \rightarrow \pi^+K^-) = 0.39 \pm 0.17$$





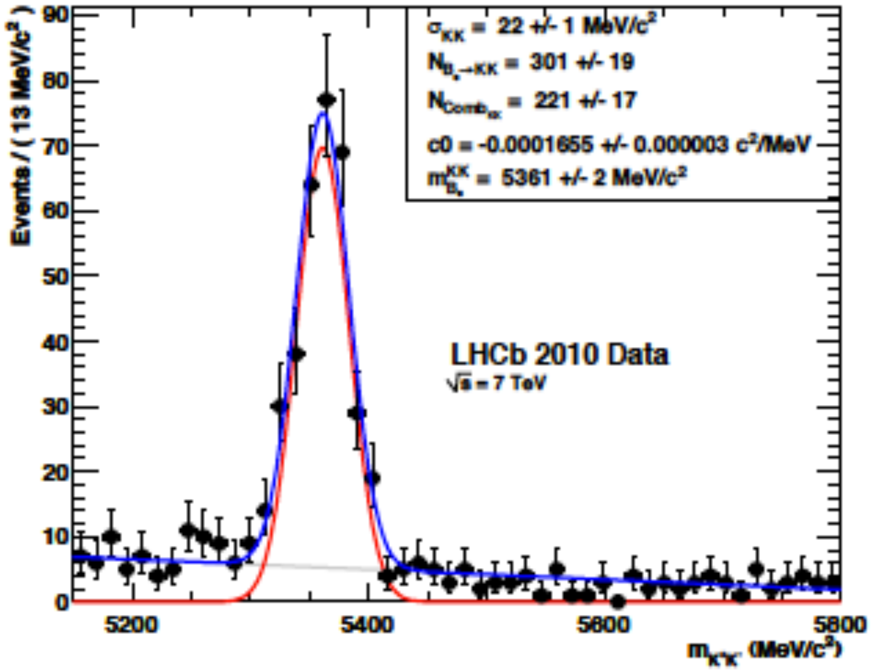
$B_s \to K^+K^-$ lifetime

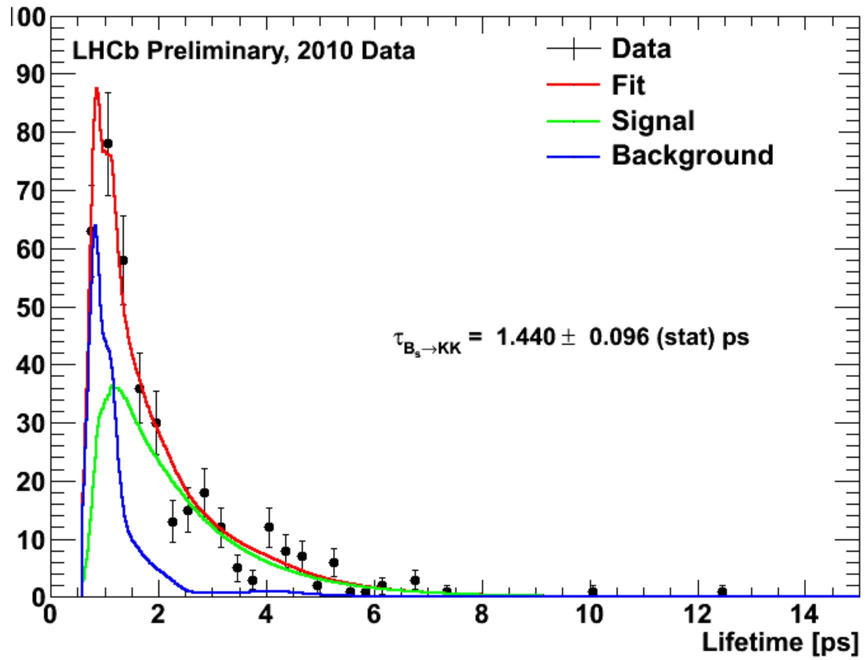
LHCb-CONF-2011-018

NEW BEST

L. Eklund, session 2.1

- Two independent analyses in agreement
  - proper-time acceptance from data



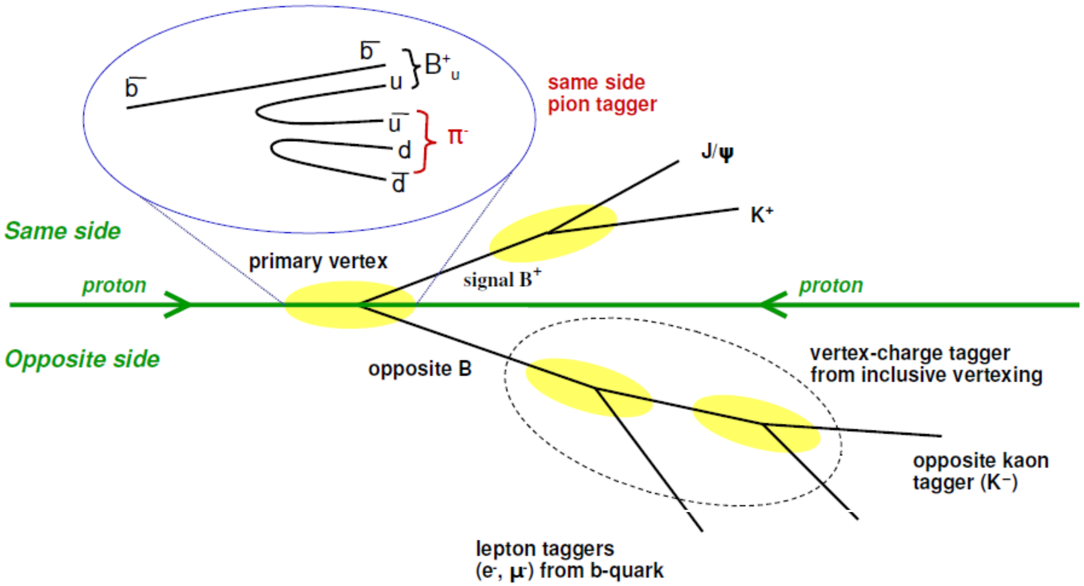


~ measurement of light B_s state in absence of New Physics

$\tau(B_s \to K^+K^-)$ = 1.440 ± 0.096 (stat) ± 0.010 (syst) [c.f. CDF ±0.18]

Flavour Tagging - B mixing: Δm_d

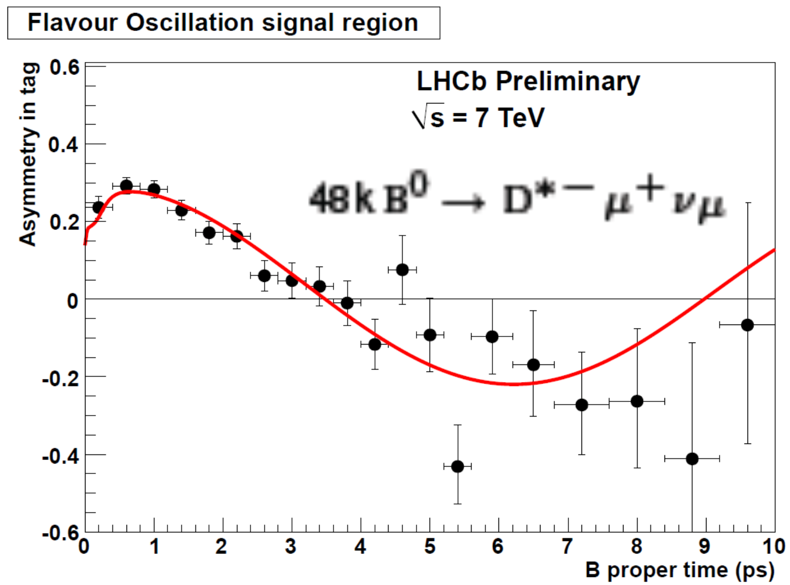
LHCb-CONF-2011-03
LHCb-CONF-2011-10



At present, opposite side kaon, lepton, vertex charge and same-side pion studied

$$e_{eff} = e_{tag} (1-2w)^2$$

- Study in flavour specific calibration channel
- Current measured tagging power (1.97±0.18)% using OS tagging only
- **Δm_d = 0.499 +/- 0.032(stat) +/- 0.03 (syst) ps^{-1}**
  - Measured in $B^0 \rightarrow D^-(K^+\pi^-\pi^-)\,\pi^+$
  - World average 0.507 +/- 0.05



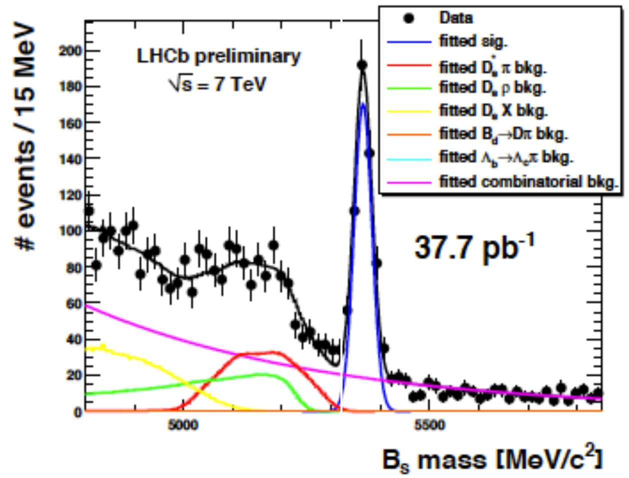
BEST

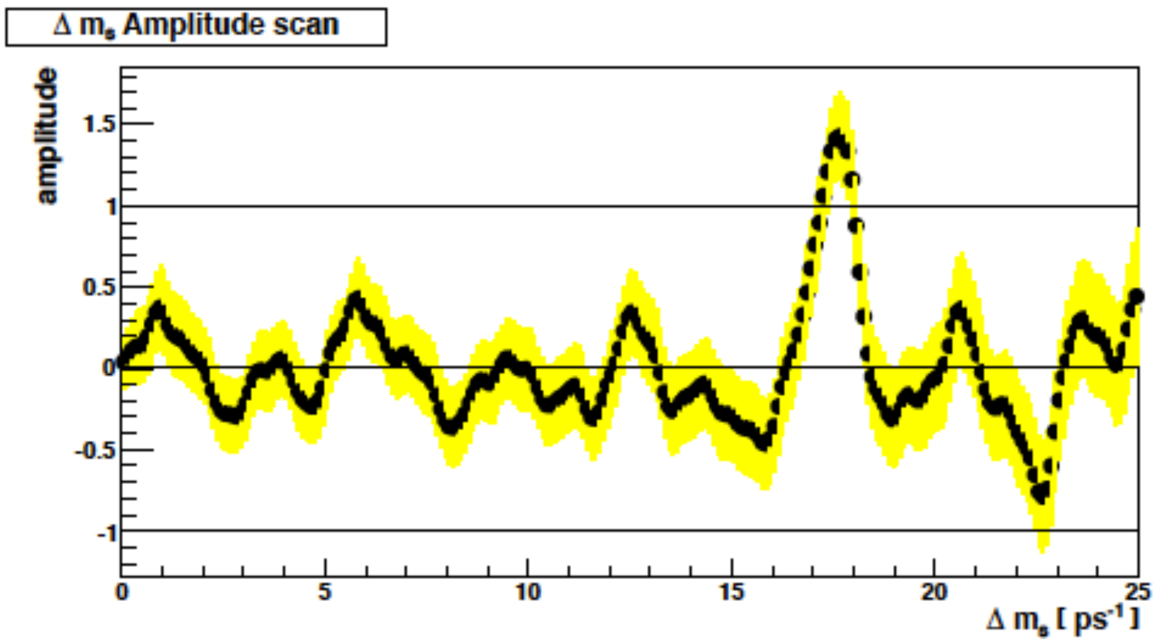
B mixing: Δm_s

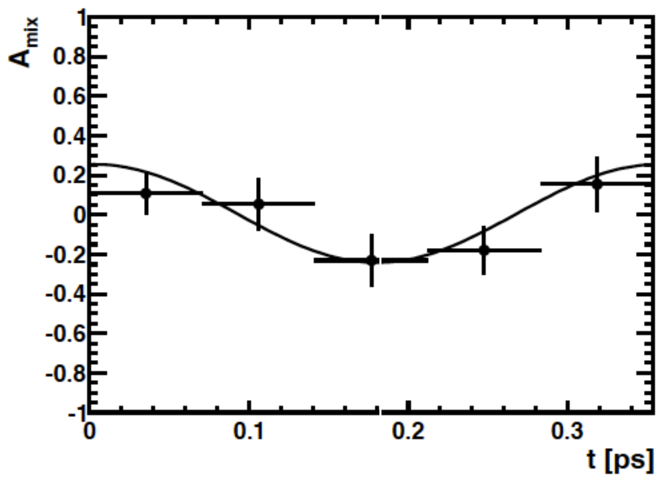
LHCb-CONF-2011-005

- $B_s \rightarrow D_s^- \pi^+$ (primarily), total ~1400 signal events
  - Proper-time resolution (50 fs)
  - Tagging power

T. Bird, session 1.1







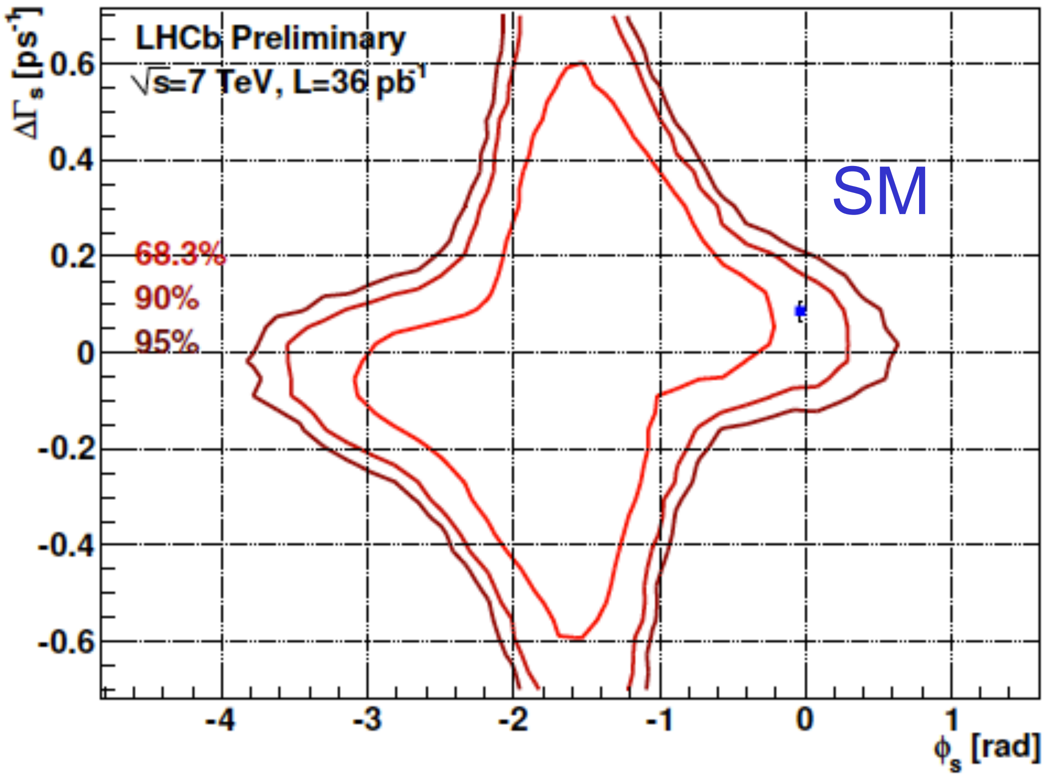
- $\Delta m_s = 17.63 \pm 0.11(\mathrm{stat}) \pm 0.04(\mathrm{sys})\ \mathrm{ps}^{-1}$ (4.6σ stat. significance)
- CDF: $\Delta m_s = 17.77 \pm 0.10$ (stat) ± 0.07 (sys) ps^{-1}

NEW Flavour Tagged ϕ_s

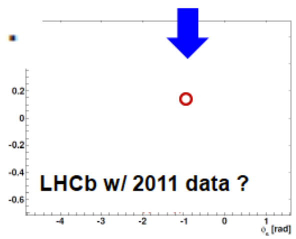
LHCb-CONF-2011-01…
LHCb-CONF-2011-06

C Fitzpatrick, session 1.1
A. Sparkes, session 1.1

- B_s->$J/\psi\phi$: Golden Mode for B_s CP Violating phase ϕ_s



$\phi_s \in [-2.7, -0.5]$ rad at 68% CL .

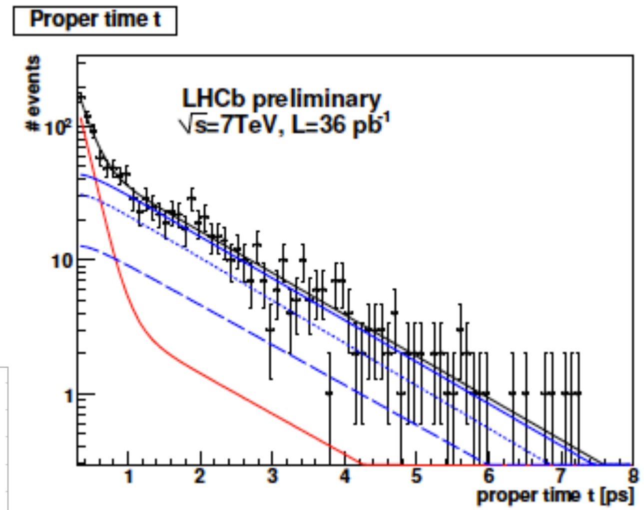


– Excellent prospects for 2011 sample

Lifetime measurements in agreement with PDG

$\tau(B^+ \to J/\psi K^+)$	=	1.689 ± 0.022 (stat.) ± 0.047 (syst.) ps ,
$\tau(B^0 \to J/\psi K^{*0})$	=	1.512 ± 0.032 (stat.) ± 0.042 (syst.) ps ,
$\tau(B^0 \to J/\psi K^0_S)$	=	1.558 ± 0.056 (stat.) ± 0.022 (syst.) ps ,
$\tau^{\text{single}}(B^0_s \to J/\psi\phi)$	=	1.447 ± 0.064 (stat.) ± 0.056 (syst.) ps ,
$\tau(\Lambda_b \to J/\psi\Lambda)$	=	1.353 ± 0.108 (stat.) ± 0.035 (syst.) ps ,

- Flavour tagged fit to mass, time, and angular distributions



NEW

CP violation in D→hh

LHCb-CONF note soon

M. Alexander, session 2.1

- Direct CP violation $D^0 \to \pi^+\pi^-/K^+K^-$
  - Cancellation of production/detection asymmetries

$$\begin{aligned} A_{RAW}(K^-K^+)^* &= A_{CP}(K^-K^+) + A_D(\pi_s) + A_P(D^{*+}) \\ A_{RAW}(\pi^-\pi^+)^* &= A_{CP}(\pi^-\pi^+) + A_D(\pi_s) + A_P(D^{*+}) \\ \Rightarrow A_{RAW}(K^-K^+)^* - A_{RAW}(\pi^-\pi^+)^* &= A_{CP}(K^-K^+) - A_{CP}(\pi^-\pi^+) \end{aligned}$$

$$A_{CP}(KK) - A_{CP}(\pi\pi) = (-0.275 \pm 0.701 \pm 0.25)\%$$

  - Same technique, extract production asymmetry

$$A_P(D^0) = (-1.08 \pm 0.32 \pm 0.12)\%.$$

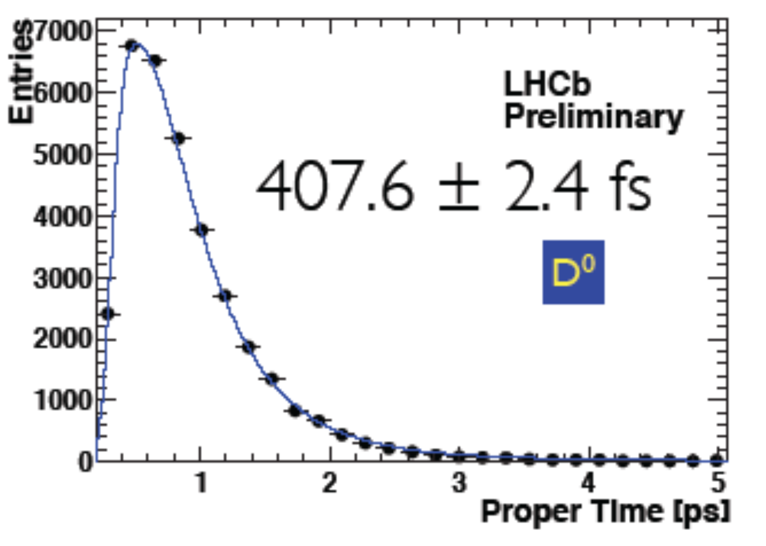
    - LHC pp collider, important for CP violation measurements

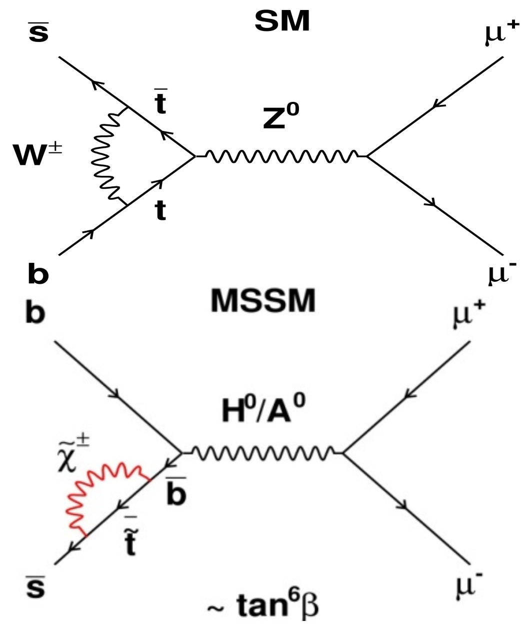
- CP violation in D^0 mixing

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

•Method cross-check in Kπ

$$A_\Gamma^{K\pi,eff} = (-2.1 \pm 4.2) \times 10^{-3}.$$



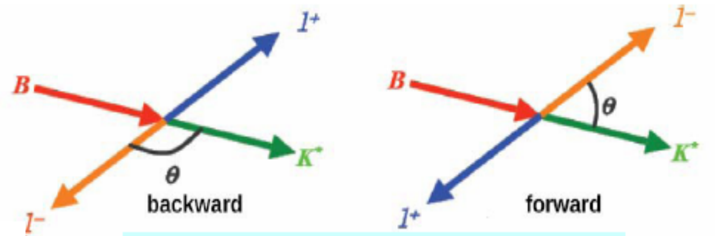


Part 4:
Search for New Physics in rare B Decays

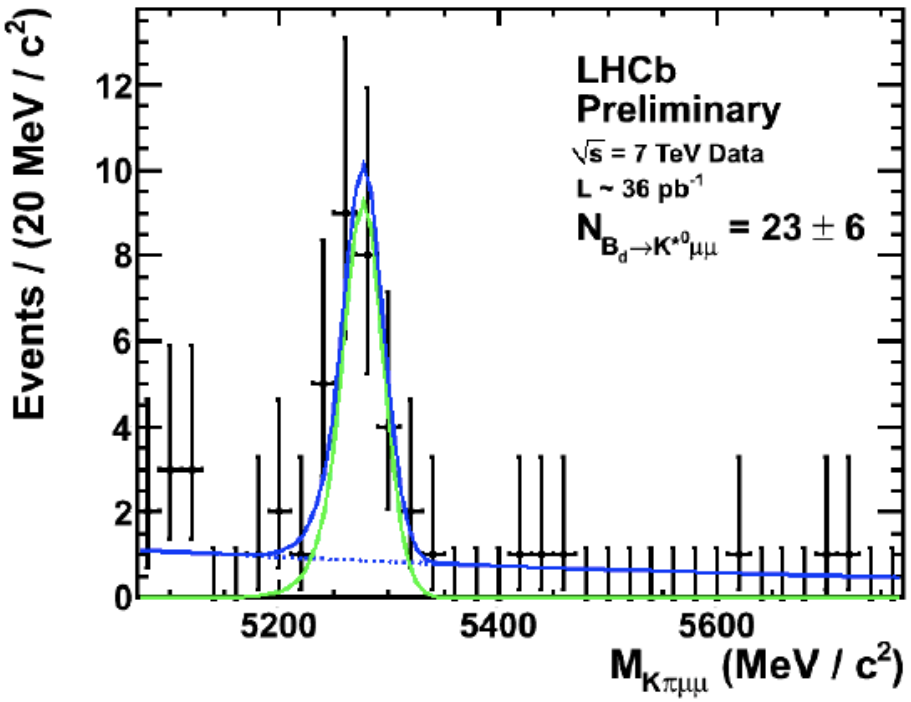
- Search for Bs->$D_s^+D_s^-$ at LHCb: J Mylroie-Smith

$B_d \rightarrow K^*\mu^+\mu^-$ & $B^+ \rightarrow K^+\mu^+\mu^-$

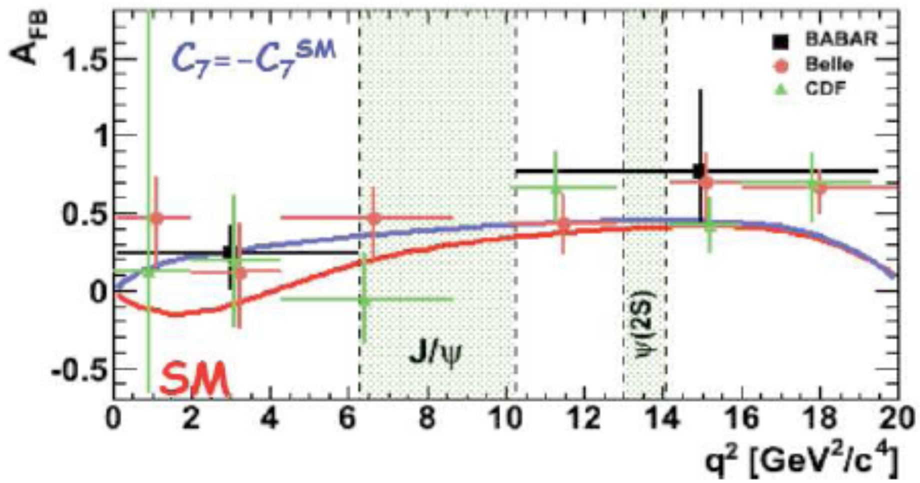
- $B^+ \rightarrow K^+\mu^+\mu^-$: Most rare decay yet observed at LHCb
  - BR ~ 5×10^{-7}
- $B_d \rightarrow K^*\mu^+\mu^-$: Future-Sensitive probe of New Physics with Forward-Backward Asymmetry



$$A_{FB}\left(s=m^2_{\mu^+\mu^-}\right)=\frac{N_F-N_B}{N_F+N_B}$$



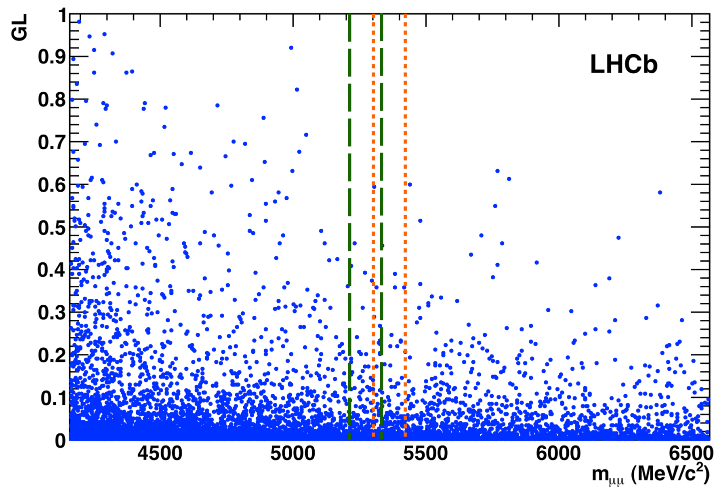
Forward-backward asymmetry



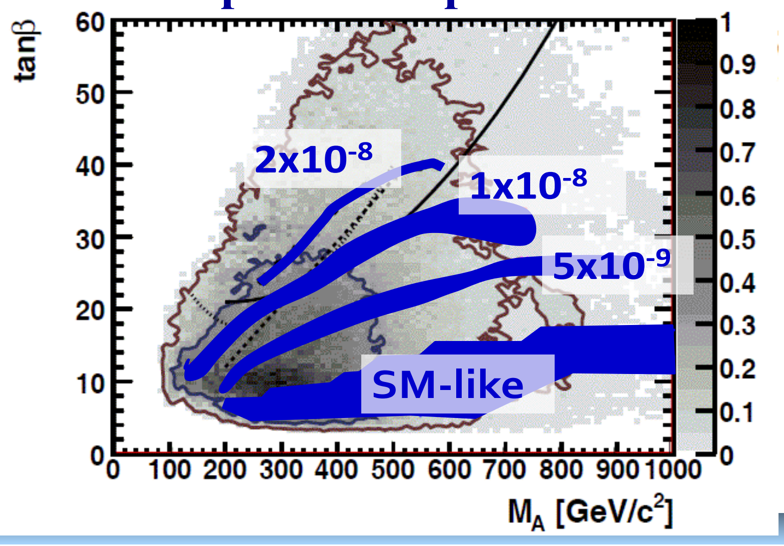
$B_s \rightarrow \mu^+\mu^-$

arXiv:1103.2465, PLB

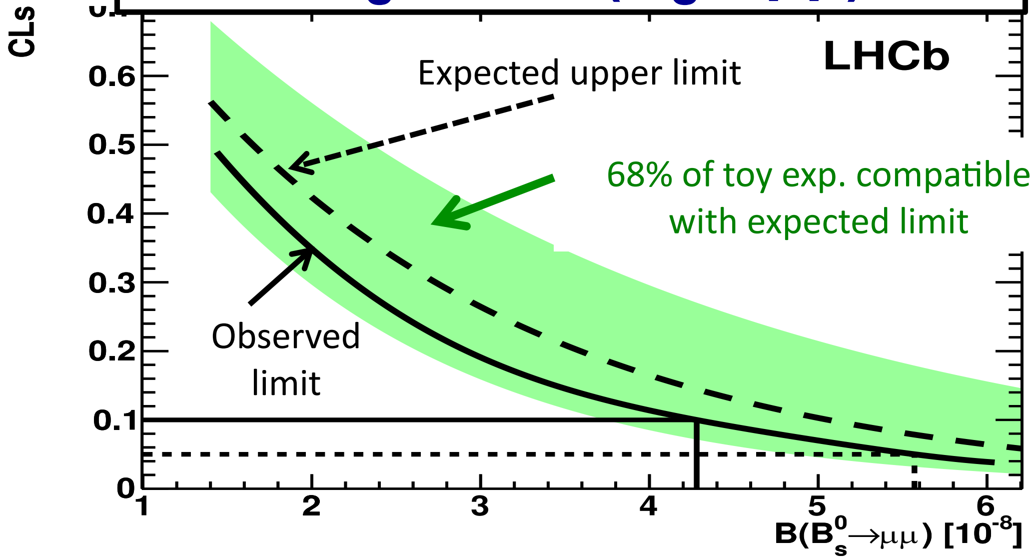
- Very sensitive to new scalar/ pseudoscalar interactions



37 pb^{-1} 500 pb^{-1} 1 fb^{-1}



CL$_S$ vs BR($B_S \rightarrow \mu\mu$)



LHCb 37pb^{-1}

BR($B_s \rightarrow \mu^+\mu^-$) < 5.6×10^{-8}

@ 95% CL

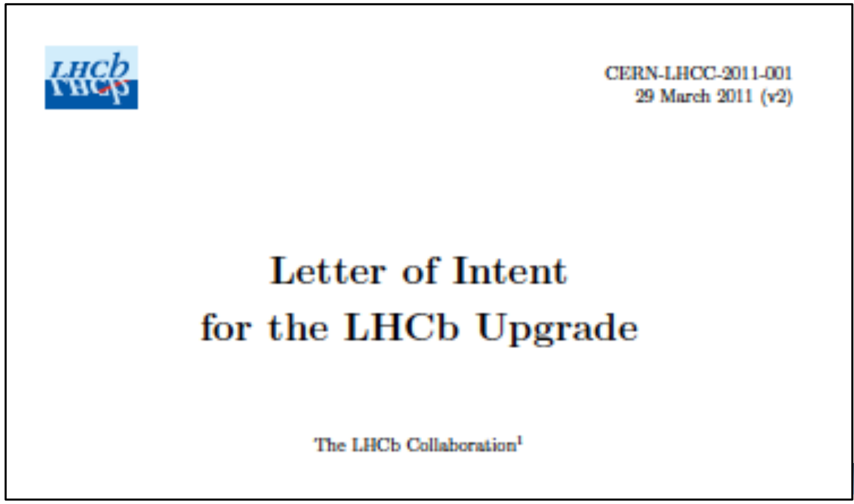
CDF 3.7 fb-1 : < 4.3×10^{-8} @95% CL

SM from Lattice: 3.2 ± 0.2 10^{-9}

E. Gamiz et al: Phys.Rev.D 80 (2009) 014503

Summary: First Results from LHCb

- In this talk:
- 6 world's best measurements
- 6 first observations of decay channels
- 5 new results shown for first time this week
  - Competitive Tevatron 150 x less *L*
  - Will dominate with 2011 sample
- Major UK Involvement


CERN-LHCC-2011-001
29 March 2011 (v2)

Letter of Intent
for the LHCb Upgrade

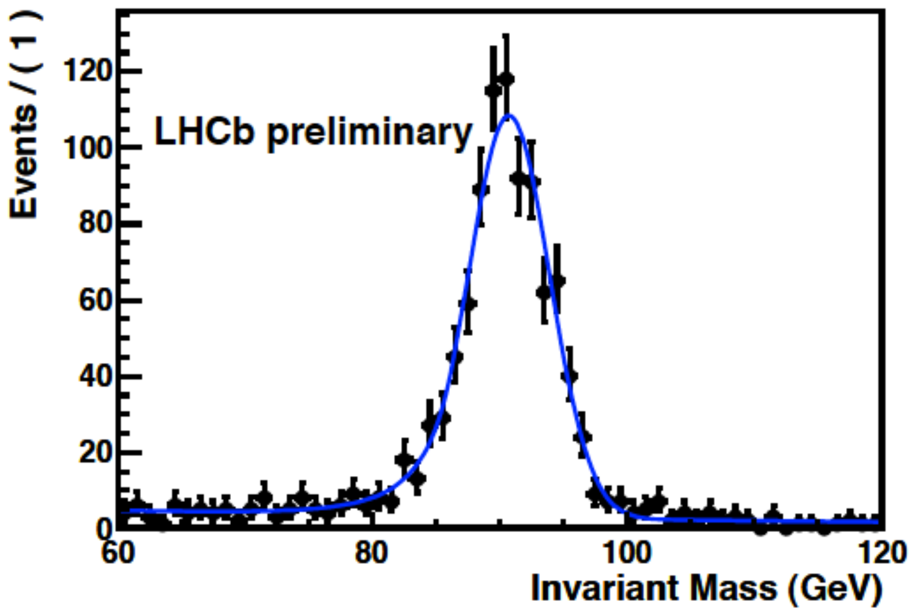
The LHCb Collaboration[1]

A new Era in Flavour Physics has begun

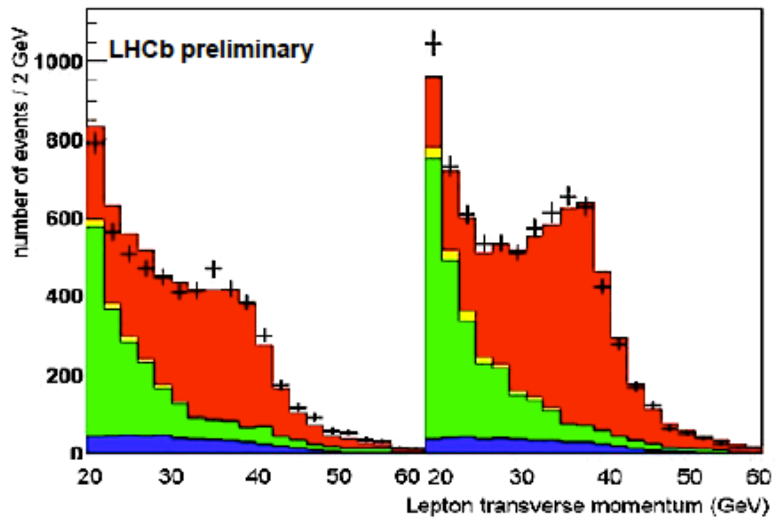
Backup W/Z

- 16.5pb-1
- NLO theory, uncertainty from NLO & MSTW2008 90%

Z



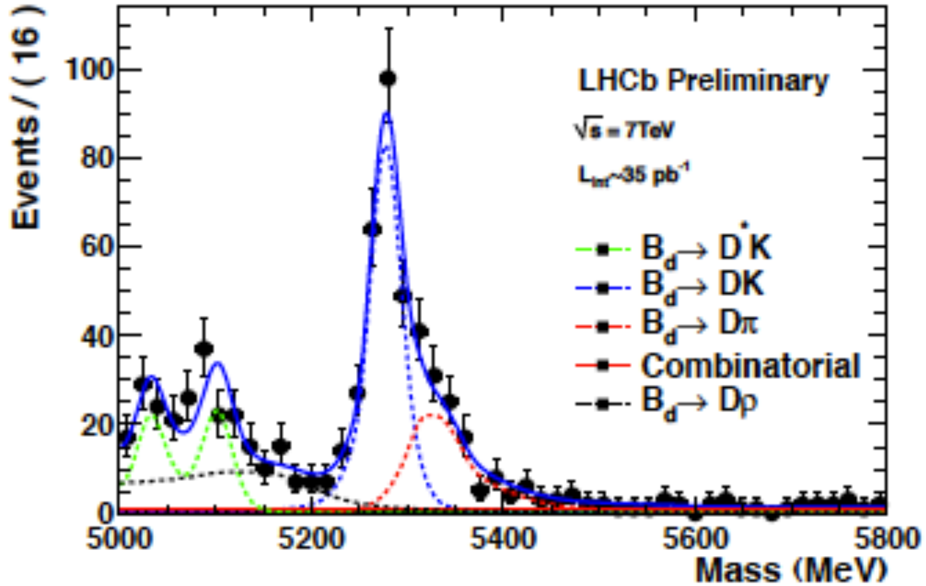
W



Fragmentation Functions

LHCb-CONF-2011-013

- fd/fs



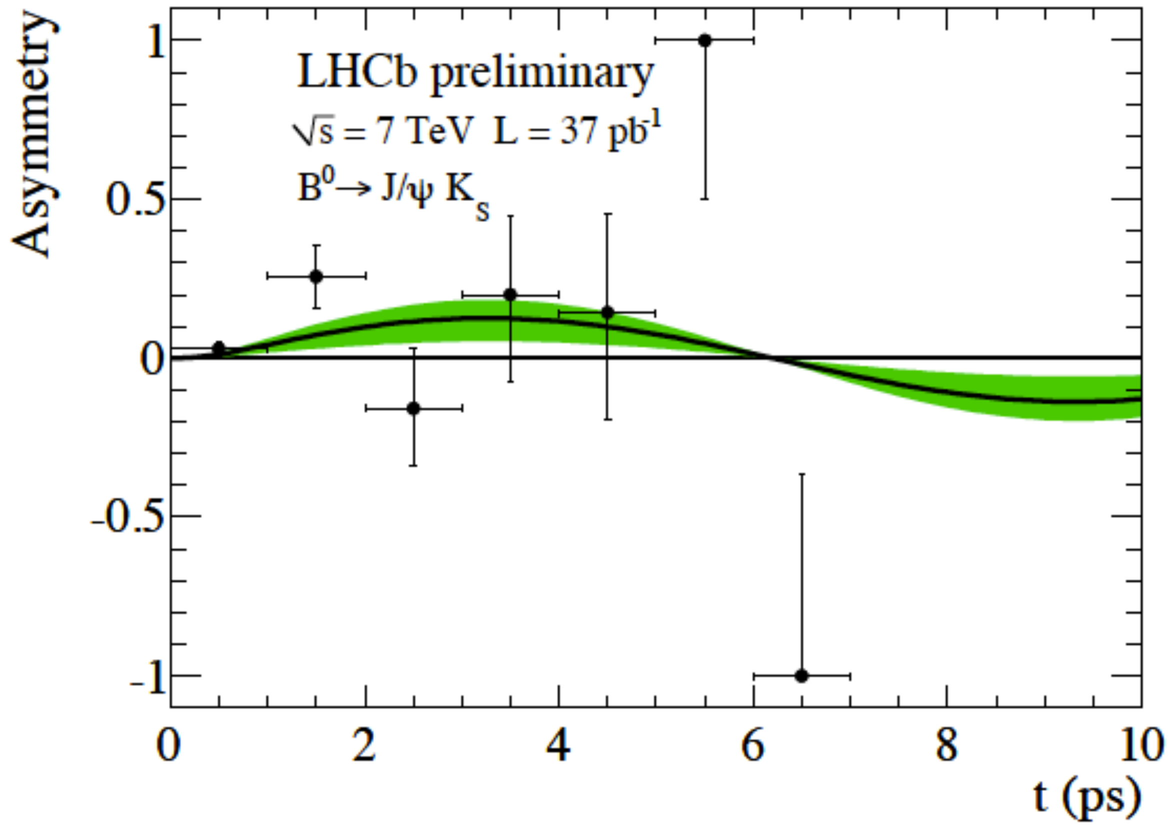
$$\frac{f_d}{f_s} = 13.45 \times \frac{\tau_{B_s}}{\tau_{B_d}} \times \left[\mathcal{N}_a \mathcal{N}_F \frac{\epsilon_{D_s\pi}}{\epsilon_{DK}} \frac{N_{DK}}{N_{D_s\pi}} \right]$$

$$\frac{f_d}{f_s} = 1.018 \times \frac{\tau_{B_s}}{\tau_{B_d}} \times \left[\tilde{\mathcal{N}}_a \mathcal{N}_F \mathcal{N}_E \frac{\epsilon_{D_s\pi}}{\epsilon_{D\pi}} \frac{N_{D\pi}}{N_{D_s\pi}} \right]$$

Na NF: non-factorisable corrections, form factors
NE: exchange diagrams

sin2β

$$S_{J/\psi K^0_S} = 0.53^{+0.28}_{-0.29}(\text{stat}) \pm 0.02(\text{syst}) \ .$$



Production Asymmetry

Assume no real CPV in $D^0 \to K^-\pi^+$, i.e.

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

Then:

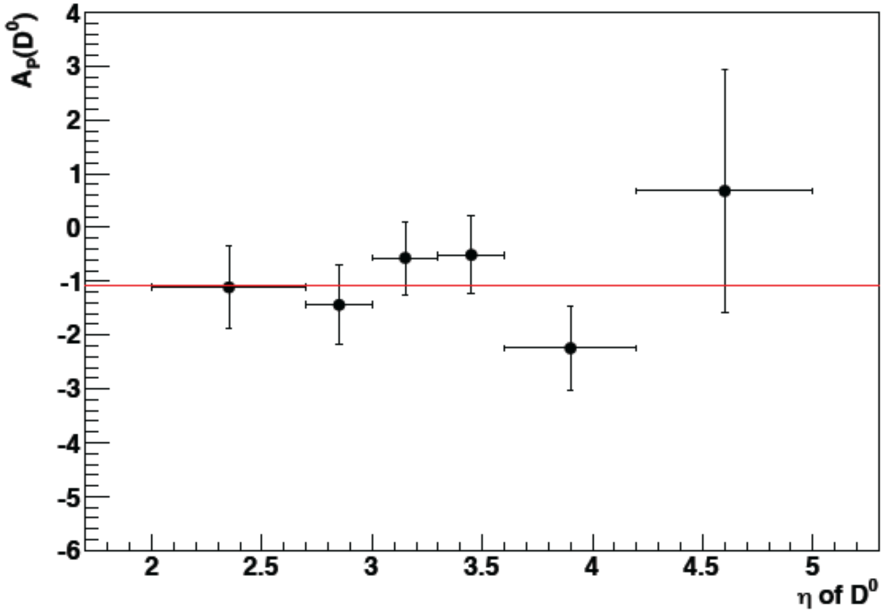
cancel

cancel

$$
\begin{aligned}
A_{RAW}(K^-\pi^+) &= A_D(K^-\pi^+) + A_P(D^0) \\
A_{RAW}(K^-\pi^+)^* &= A_D(K^-\pi^+) + A_D(\pi_s) + A_P(D^{*+}) \\
A_{RAW}(K^-K^+)^* &= A_{CP}(K^-K^+) + A_D(\pi_s) + A_P(D^{*+}) \\
\Rightarrow A_{RAW}(K^-\pi^+) - A_{RAW}(K^-\pi^+)^* + A_{RAW}(K^-K^+)^* &= A_P(D^0) + A_{CP}(K^-K^+)
\end{aligned}
$$

... so if we use measurements of $D^0 \to K^-K^+$ CP asymmetry from other experiments as input, we can extract D^0 production asymmetry at LHCb.

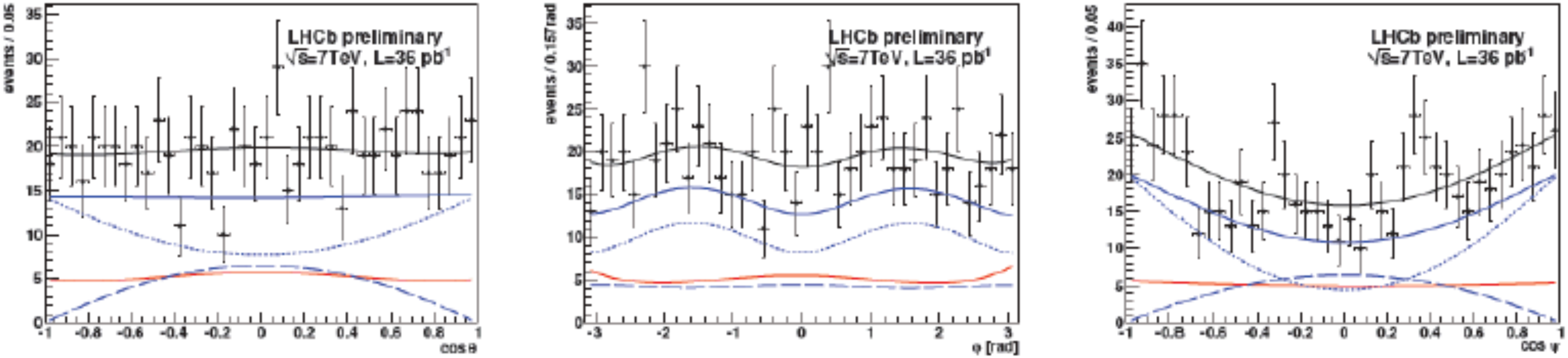
- Use cancellations in D->hh

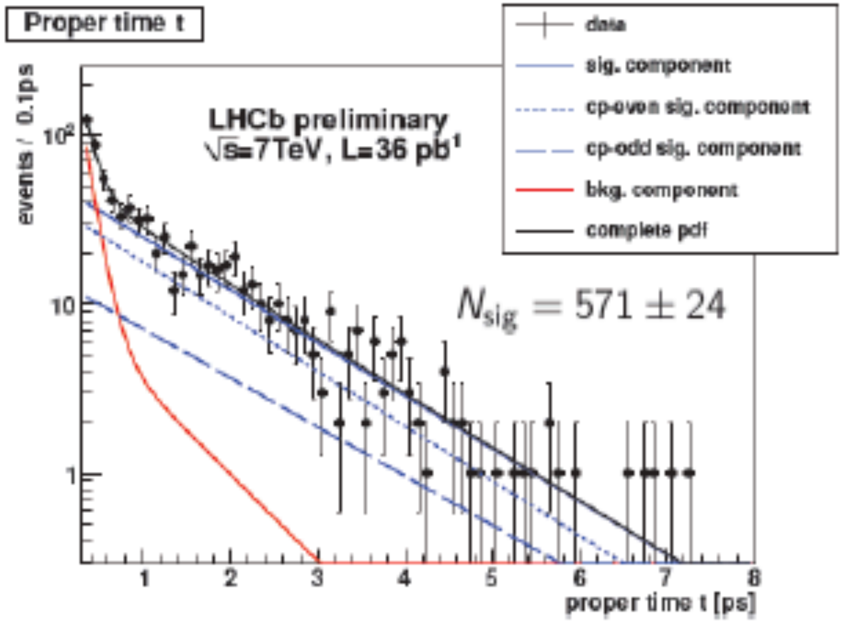


Untagged analysis of $B_s \to J/\psi\phi$

LHCb-Conf-2011-002

Assuming $\phi_s = 0$





Parameter	Result ± stat. ± syst.
$\Gamma_s\,[\mathrm{ps}^{-1}]$	$0.679 \pm 0.036 \pm 0.027$
$\Delta\Gamma_s\,[\mathrm{ps}^{-1}]$	$0.077 \pm 0.119 \pm 0.021$
$\lvert A_0(0)\rvert^2$	$0.528 \pm 0.040 \pm 0.028$
$\lvert A_\perp(0)\rvert^2$	$0.263 \pm 0.056 \pm 0.014$

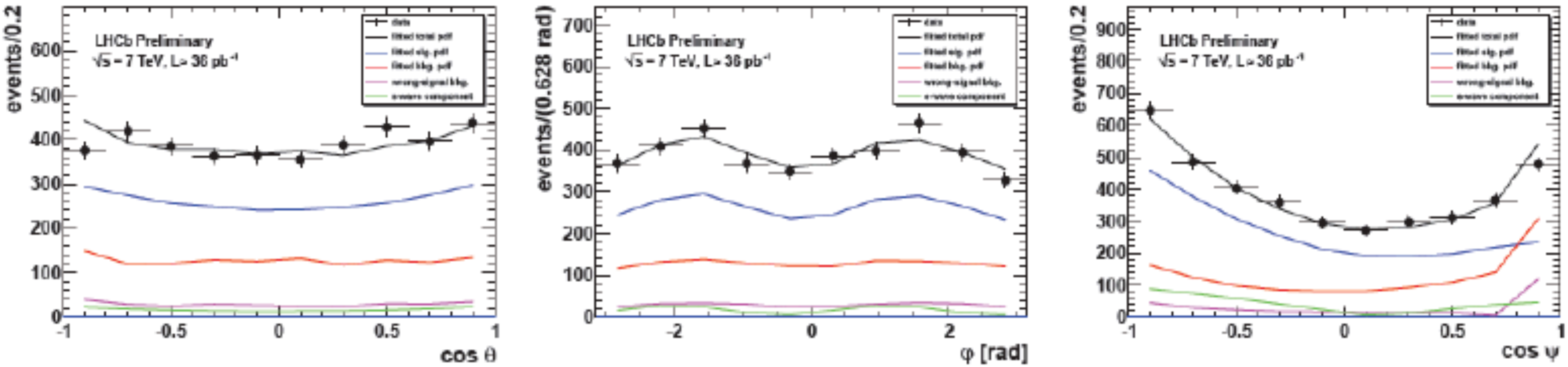
CDF note 10206, $L = 5.2\,\mathrm{fb}^{-1}$

$\Delta\Gamma_s = (0.075 \pm 0.035 \pm 0.010)\,\mathrm{ps}^{-1}$

Polarization amplitudes for $B^0 \to J/\psi K^*$

LHCb-Conf-2011-002

- Angular analysis ⇒ angular acceptance taken from MC simulation
- 3dim. background from sidebands (important: S/B ~ 3.5).
- Add non-res. Kπ component (S-wave) to signal PDF: 5±2 %



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

Systematics:

- S-wave
- Background
- Angular accept.

- Good agreement with previous measurements (here: BABAR)
- Not yet competitive!

What about the flavour specific asymmetry measured at D0?

$$a^q_{fs} \propto A^q_{fs}(t) = \frac{\Gamma\left(B^0_q \text{ or } \overline{B}^0_q \to \overline{f}\right) - \Gamma\left(B^0_q \text{ or } \overline{B}^0_q \to f\right)}{\Gamma\left(B^0_q \text{ or } \overline{B}^0_q \to \overline{f}\right) + \Gamma\left(B^0_q \text{ or } \overline{B}^0_q \to f\right)}$$

$$a^q_{fs} = \mathrm{Im}\left\{\frac{\Gamma^q_{12}}{M^q_{12}}\right\}$$

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

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

D0 measurement using bb→μμX events:

$$A^b = \frac{N^{++} - N^{--}}{N^{++} + N^{--}} = (0.494)a^s_{fs} + (0.506)a^d_{fs}$$

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

~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:

$$\Delta A^{s,d}_{fs} \approx \frac{a^s_{fs} - a^d_{fs}}{2}$$

Stat. Error	100 pb^{-1}	1fb^{-1}
a_{fs}^s (D_s π)	2 x10^{-2}	6.8x10^{-3}
ΔA_{fs} (D_q μν)	2 x10^{-3}	6.3 x10^{-4}