

**LHC Days in Split**  
4 - 9 October 2010

# Perpectives for the LHCb physics reach (CP violation and rare decays in B and D mesons at LHCb)

José Ángel Hernando Morata  
*Universidade de Santiago de Compostela, Spain*  
(on behalf of the **LHCb collaboration**)



# LHCb objectives

**"poeta novus versus ut nauta novos portus quaerit"**

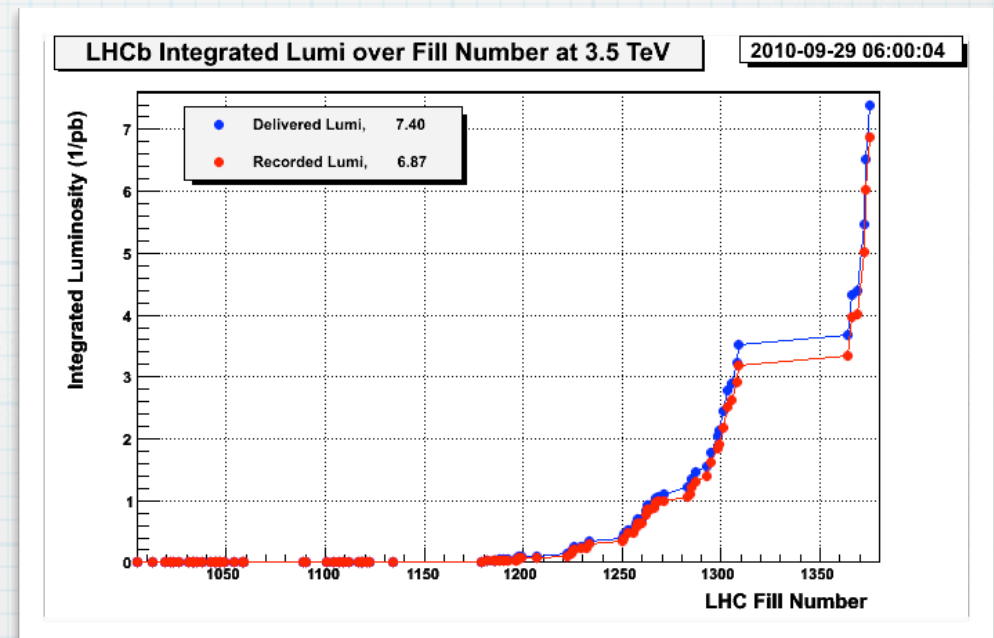
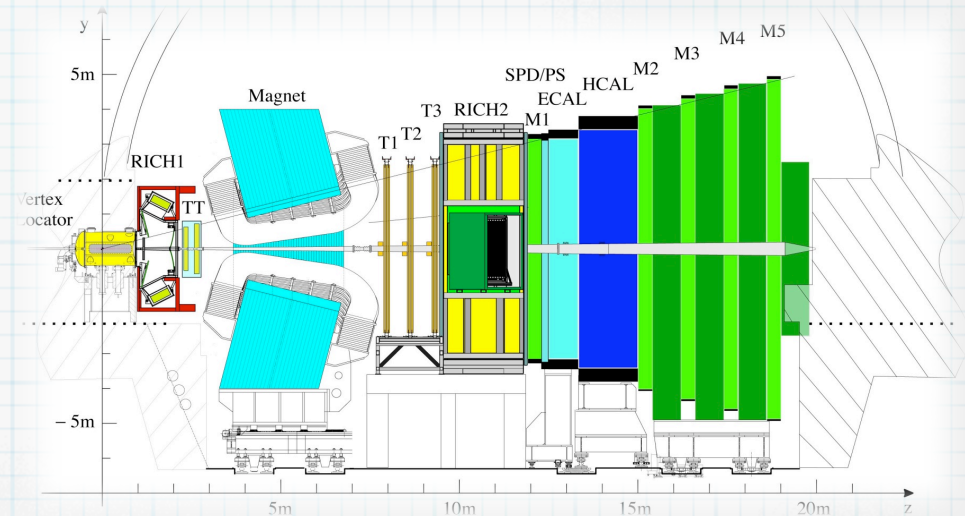
VIII century manuscript by an anonymous monk of the St. Gallen Abbey

- ◆ New Physics (NP) introduces new particles at higher energy scale that enter in the loop processes and can modify the SM predictions of observable
- ◆ FCNC
  - $B_s$  phase of the mixing:  $\beta_s$
  - Rare Decays:  $BR(B_s \rightarrow \mu\mu)$ ,  $A_{FB}(B \rightarrow K^* \mu\mu)$
  - D phase of the mixing:  $\Phi_D$
- ◆ CKM 'precision' measurements
  - Compare two measurements of the same quantity sensitive and not to the NP (tree vs loop)
  - $\gamma : B_{(s)} \rightarrow D_{(s)}K, B_{(s)} \rightarrow hh$



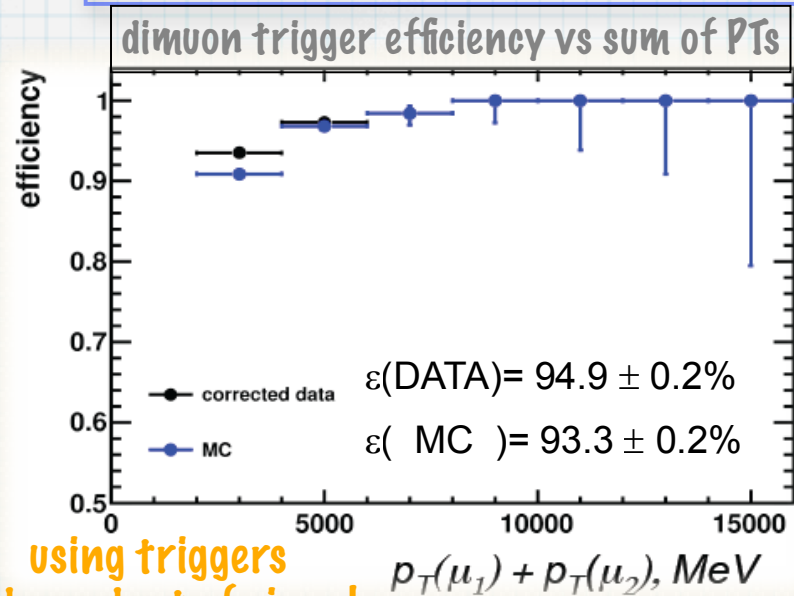
# LHCb experiment

- ◆ A forward spectrometer [2,5] in  $\eta$
- ◆ Large  $bb$  xsection T. Skwarnicki talk
  - $\sigma(pp \rightarrow bbX) = (284 \pm 20 \pm 49) \mu b$ ;
  - $\sigma(pp \rightarrow Hb X) = (75.3 \pm 5.4 \pm 13.0) \mu b$  [2,6]  $\eta$
- ◆ The LHCb physics program does not suffer much for running at 3.5 TeV!
- ◆ Trigger based on lepton and hadrons in the B final state with 'soft' PT cut
  - $PT > 1.4$  GeV for muons,  $ET > 3.6$  GeV for hadrons
- ◆ Good particle separation  $e/\mu/\pi/K$
- ◆ Good momentum ( $\sigma_p/p = 0.4\%$ ) and vertex resolution
- ◆ 071010  $12 \text{ pb}^{-1}$  collected.  $50 \text{ pb}^{-1}$  expected by end 2010 and  $1 \text{ fb}^{-1}$  end 2011?
  - Harder conditions than nominal:
    - interactions/xing 1.6

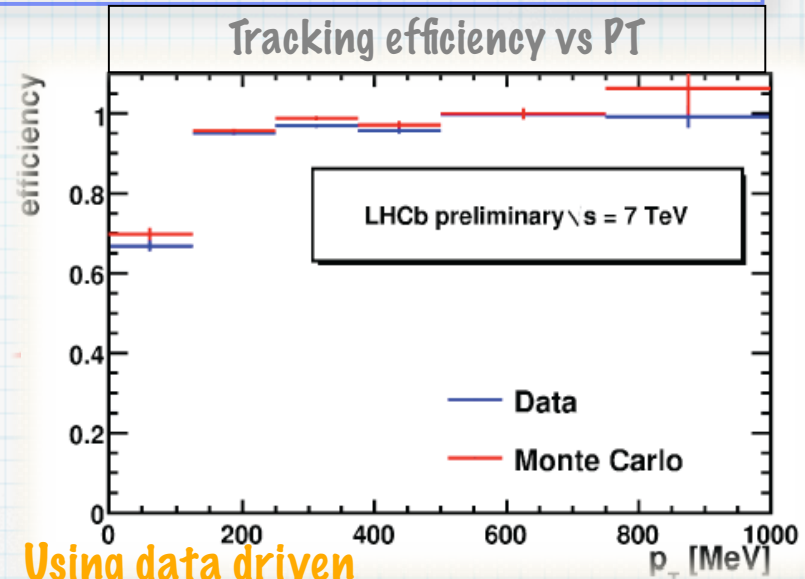


# LHCb performance

Poster (Sebastian)

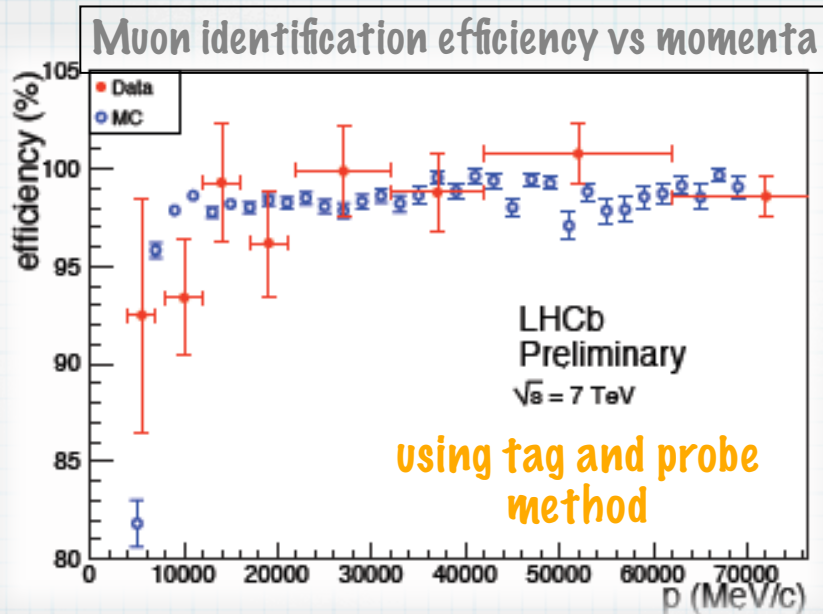


using triggers independent of signal



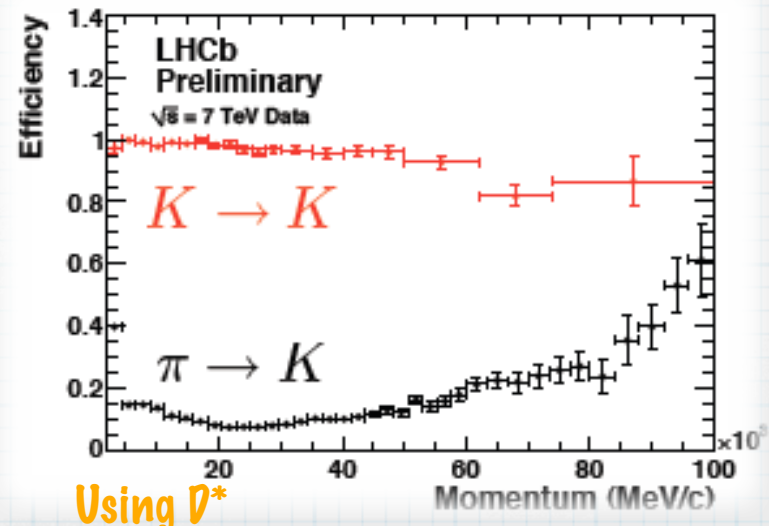
Using data driven methods

W. Witzeling talk



using tag and probe method

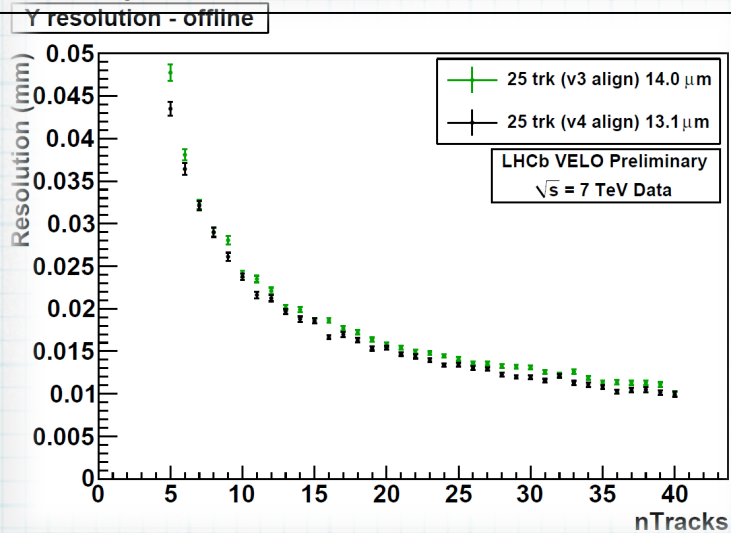
K/pi separation vs momenta ( $V_{LL} > 0$ )



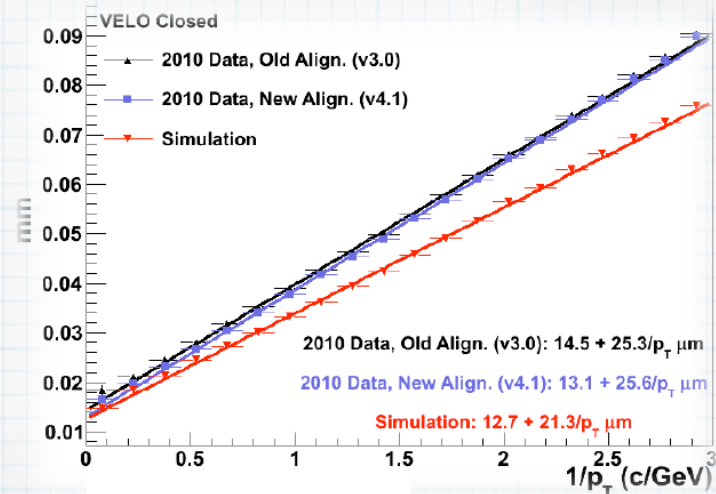
Using  $D^*$

# LHCb performance

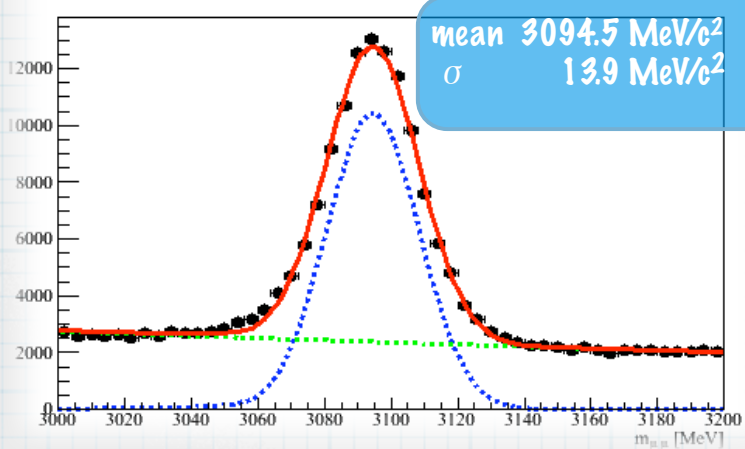
## $\Upsilon$ Primary Vertex resolution vs number of tracks



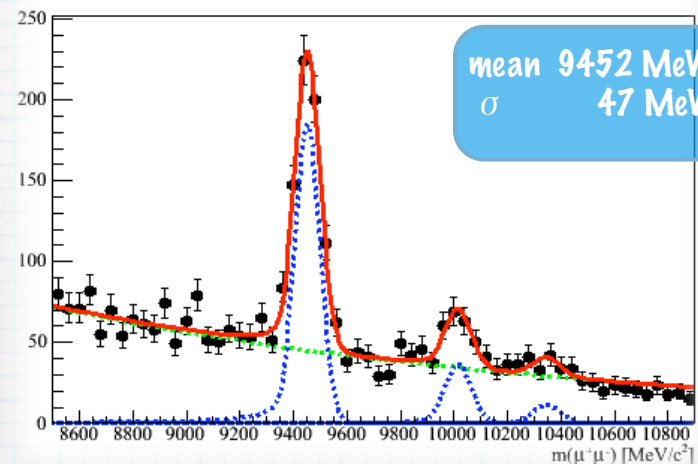
## $\Upsilon$ IP resolution vs $1/p_T$



## $J/\Psi$ mass



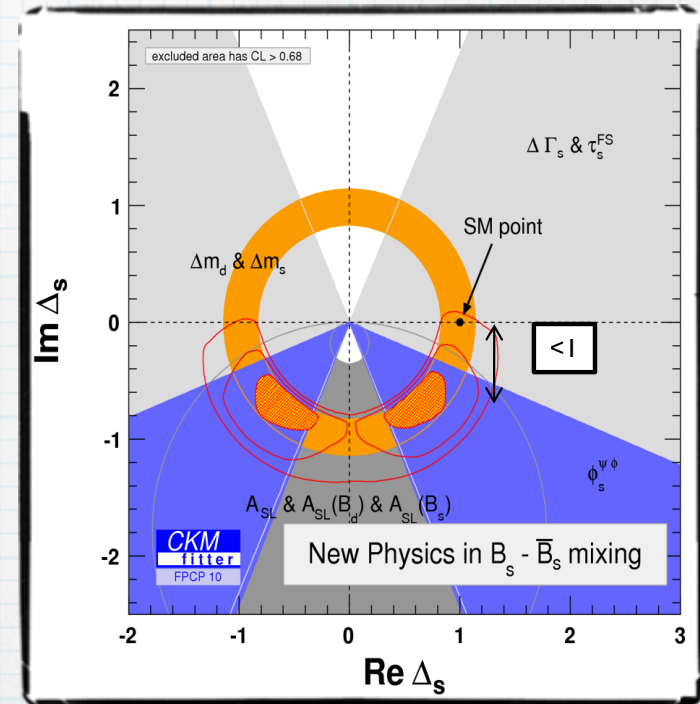
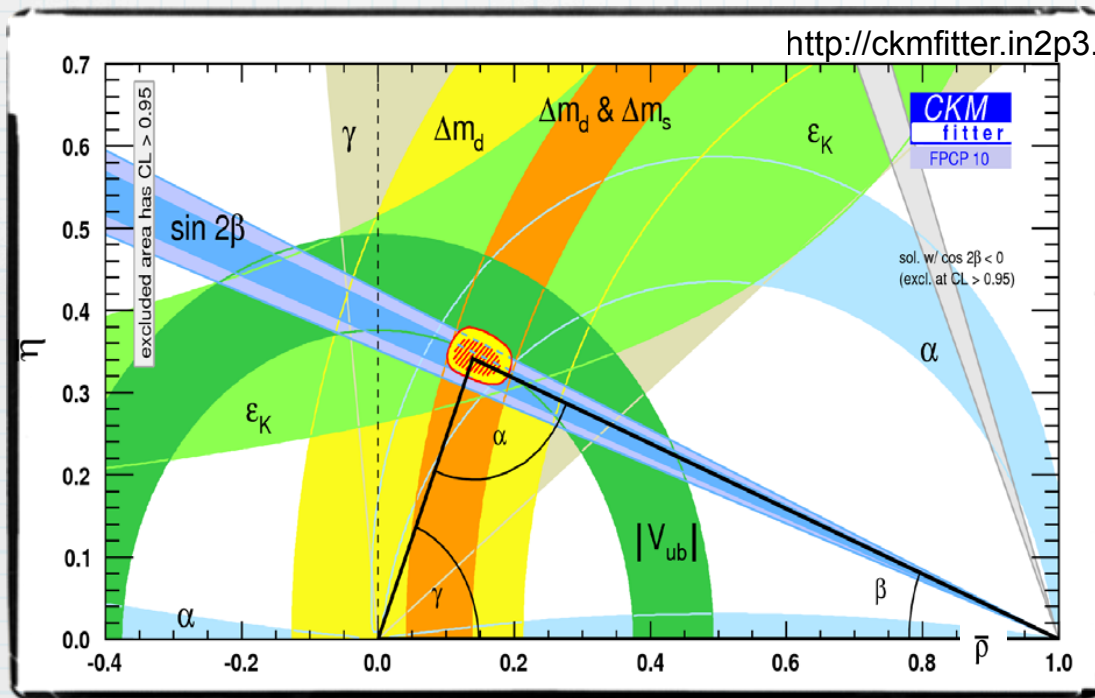
## $\Upsilon$ mass



# CPV: $\gamma$

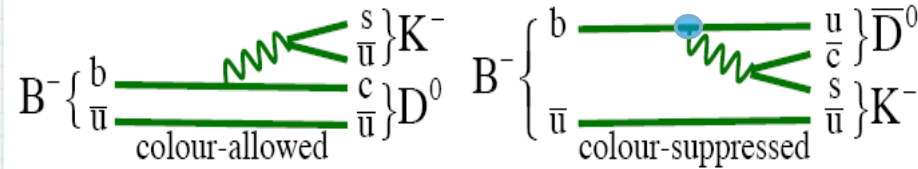
- ◆ Direct measurement of  $\gamma$  have large errors  $(70^{+21}_{-25})^\circ$  compared with indirect measurements
- ◆ Still a region of NP to explore in  $B_s$  mixing

$$\langle B_q^0 | M_{12}^{SM+NP} | \bar{B}_q^0 \rangle \equiv \Delta_q^{NP} \cdot \langle B_q^0 | M_{12}^{SM} | \bar{B}_q^0 \rangle$$



- ◆ LHCb expect to reach  $\sigma(\gamma) \sim 8^\circ \text{ fb}^{-1}$ ,  $[1.2, 2.7]^\circ$  with  $10 \text{ fb}^{-1}$

# CPV: $\gamma$ by trees

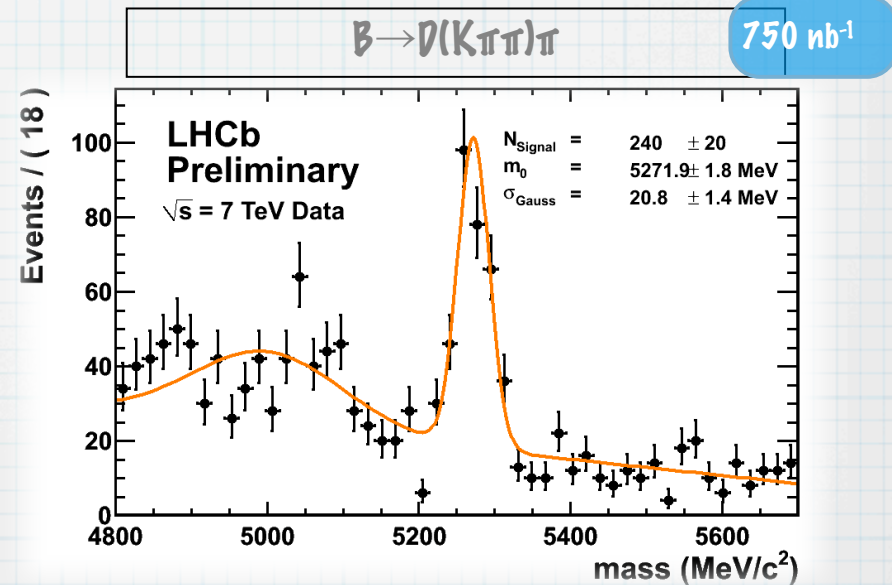
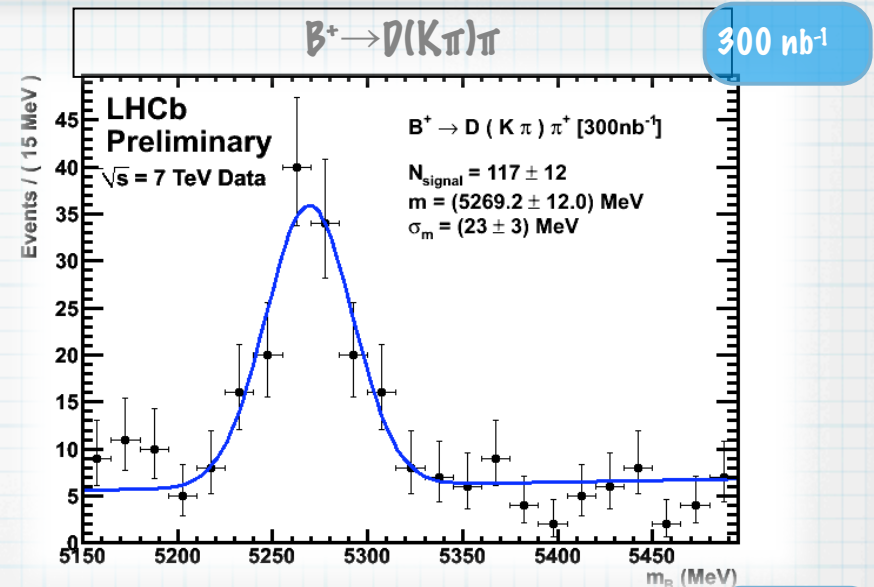


- ◆ Amplitudes interfere in the decay of  $D^0$  to common final states
- ◆ Time integrated measurement and selftagging
- ◆ Measure the ratio of the decays modes
  - $B^- \rightarrow D^0(\bar{D}^0)K^-$ ,  $B^0 \rightarrow D^0(\bar{D}^0)K^{*0}$
- ◆ Extract:  $r_B \sim 0.1$ ,  $\delta_B, \gamma$

With  $r_B = 0.1$  (0.4) for  $B^\pm$  ( $B^0$ )

$\sigma(\gamma) \sim 8^0$  with  $1 \text{ fb}^{-1}$

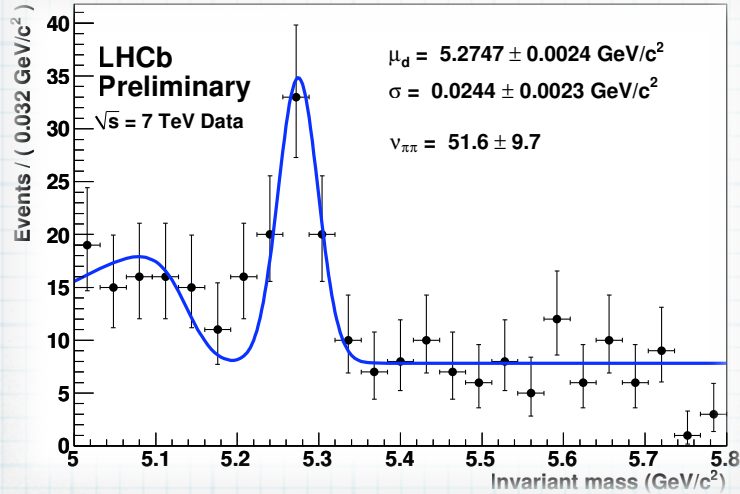
Channel	Expected event yield	Channel	Expected event yield
$B^- \rightarrow D(KK)K^-$	2000	$B^0 \rightarrow D(KK)K^{*0}$	70
$B^- \rightarrow D(\pi\pi)K^-$	750	$B^0 \rightarrow D(\pi\pi)K^{*0}$	25
$B^- \rightarrow D(K\pi)K^-$ favoured	20000	$B^0 \rightarrow D(K\pi)K^{*0}$ favoured	800
$B^- \rightarrow D(K\pi)K^-$ suppressed	400	$B^0 \rightarrow D(K\pi)K^{*0}$ suppressed	70



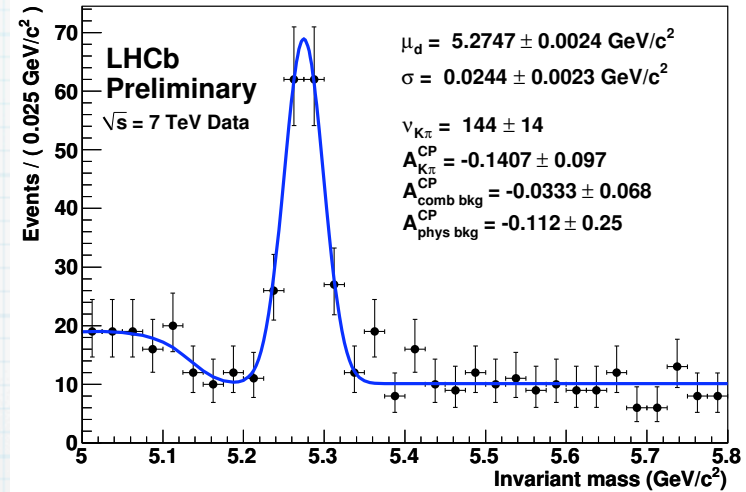
# LHCb: $\gamma$ in loops, $B_{(s)} \rightarrow hh$

3.1 pb<sup>-1</sup>

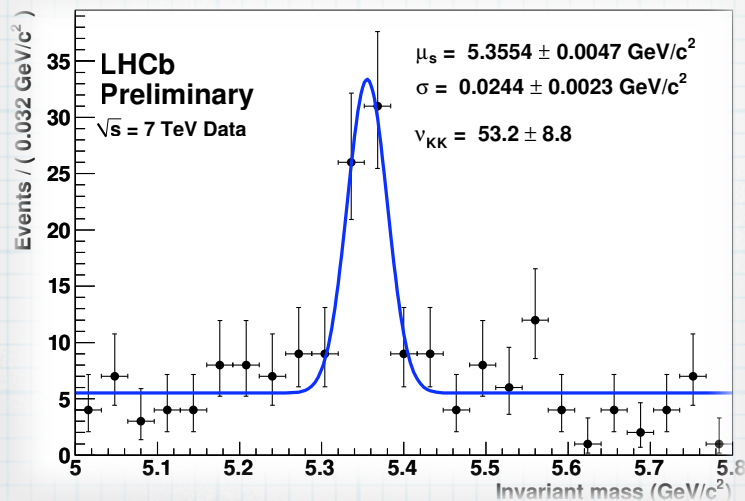
$B^0 \rightarrow \pi\pi$



$B \rightarrow K\pi$



$B_s \rightarrow KK$

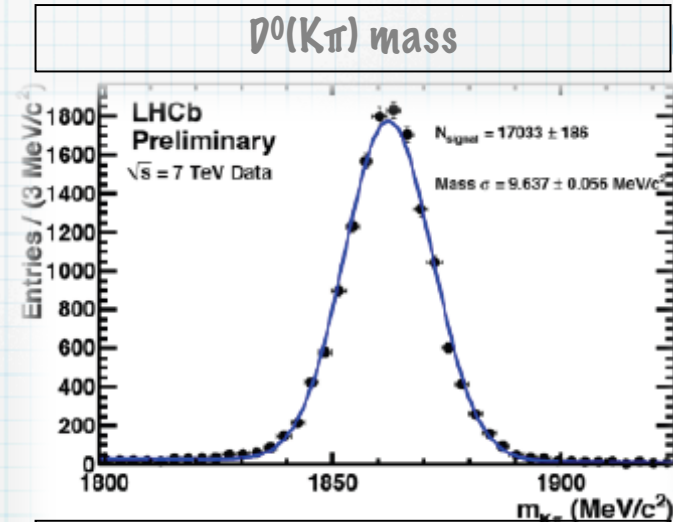
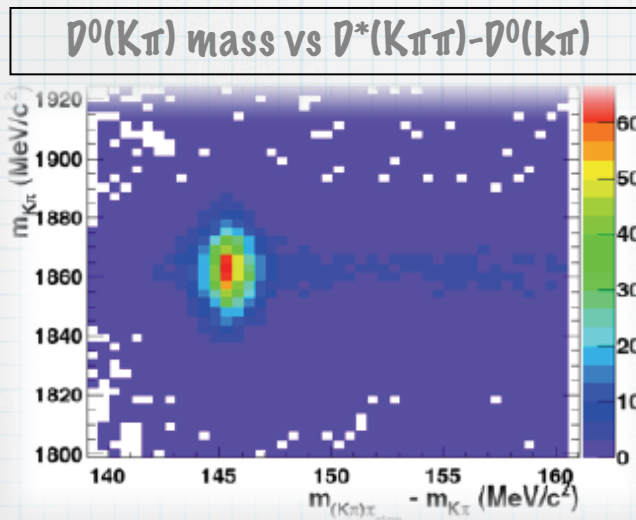
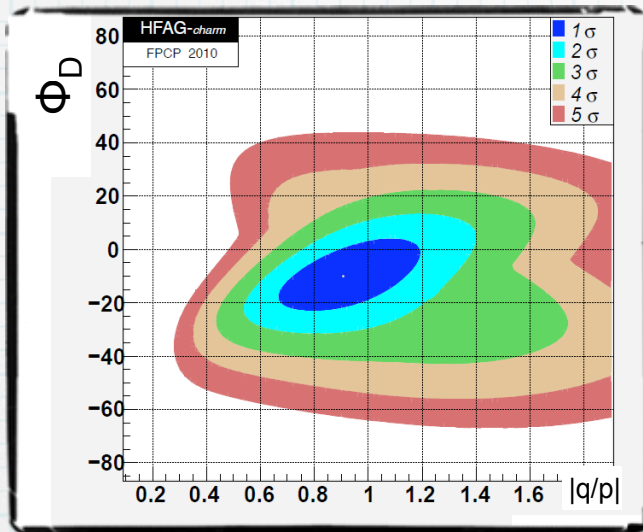


- ◆ Separate different  $B_{(s)} \rightarrow hh$  contributions in the mass distributions requires PID
- ◆ Possible 2010 measurements:
  - ◆ Direct CP asymmetry in  $B_{(s)} \rightarrow K\pi$
  - ◆ Relative BR
  - ◆  $B_s \rightarrow KK$  lifetime
- ◆ Time dependent CP asymmetries perspectives  $\sigma(\gamma) \sim 7^\circ 2\text{fb}^{-1}$

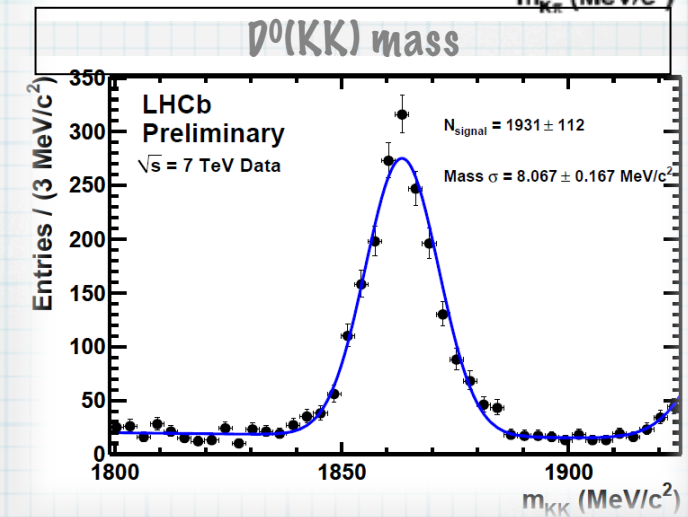


# LHCb: CPV in charm decays

- ◆ Weak constraints in  $\Phi_D, |q/p|$
- ◆ LHCb will surpass B factory statistics in 2010



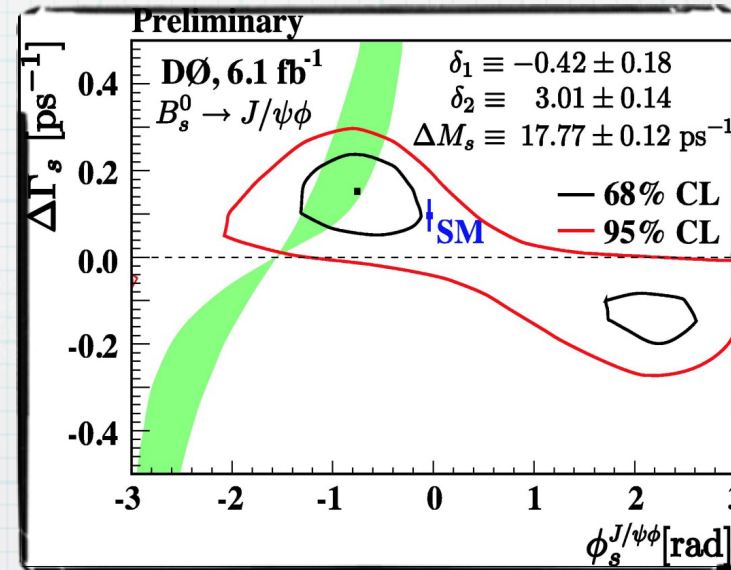
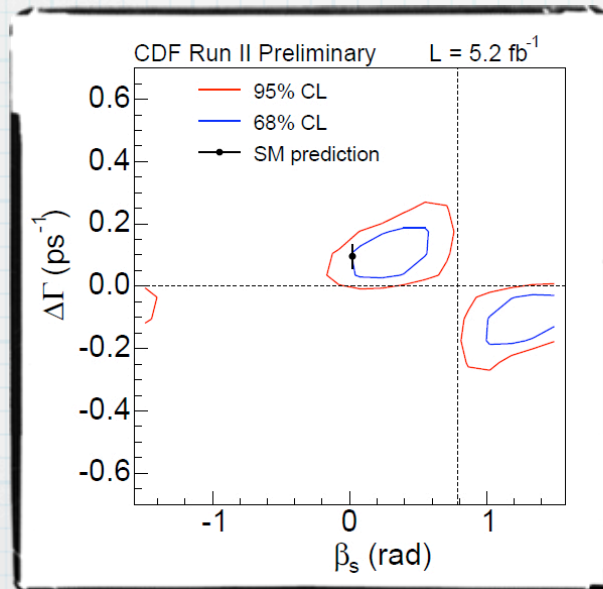
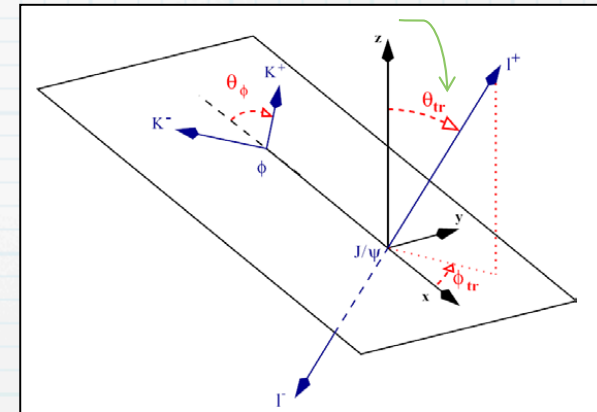
120 nb<sup>-1</sup>



# $\beta_s$ from $B_s \rightarrow J/\psi \Phi$

- Tantalizing hints from the time dependent CPV analysis of D0/CDF and D0 measurement of the anomalous dimuon charge asymmetry.
- LHCb Yield  $\sim 3.4 \text{ k}/0.1 \text{ fb}^{-1}$
- Time dependent CP violation asymmetry requires angular analysis as  $J/\psi\Phi$  is not a pure CP state, tagging the initial flavour and good proper time resolution
- Fit  $B_s$  differential decays rates with 9 physics and 15 detectors parameters

$$\frac{d^4\Gamma(B_s^0 \rightarrow J/\psi\phi)}{dt d\cos\theta d\phi d\cos\psi}$$



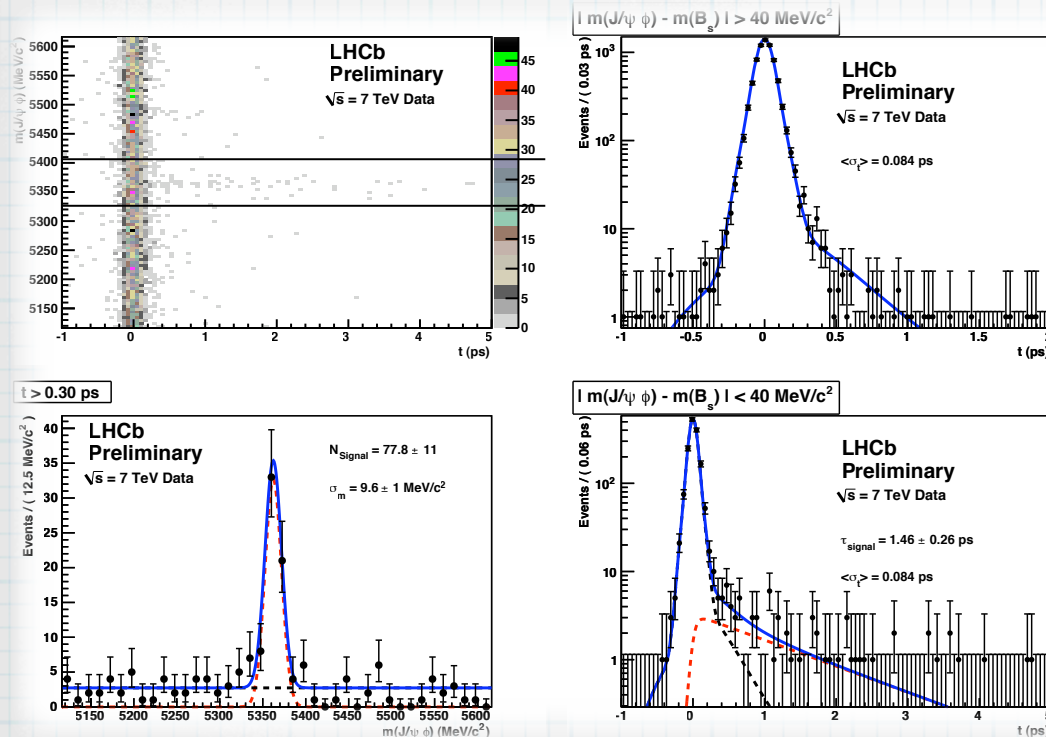
band: dimuon charge asymmetry

# $\beta_s$ from $B_s \rightarrow J/\psi \Phi$

- Yield similar to MC speciations  $(77.8 \pm 11)/2\text{pb}^{-1}$
- Proper time resolution expected to be  $\sim 50$  fs with latest alignment compared with 38 fs in MC (it implies a -20% decrease in sensitivity)

2 pb<sup>-1</sup>

$B_s \rightarrow J/\psi \Phi$  mass ( $t > 0.3$  ps)



$B_s \rightarrow J/\psi \Phi$  proper time (mass and sidebands)

- Tagging performance 'out of the box' (60% of expected performance!) calibration on going

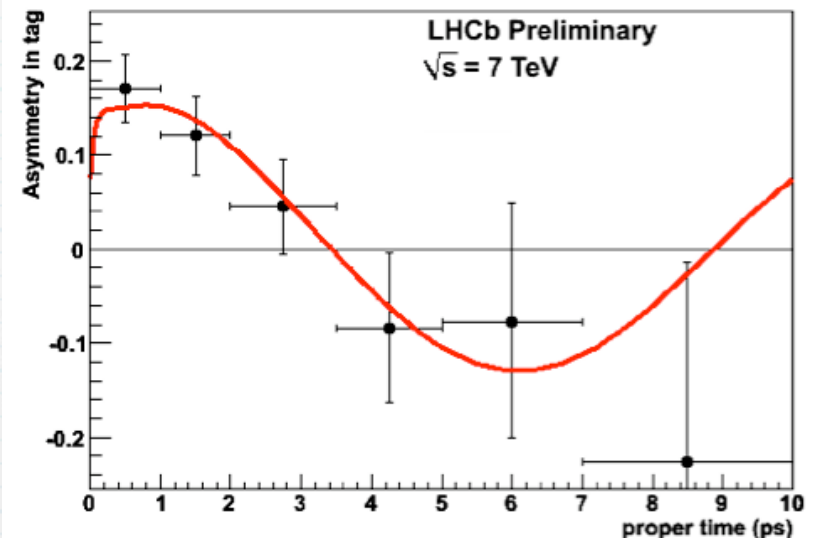
Oscillation of  $B^0 \rightarrow D^{*-}(D^0\pi)\mu^+\nu$

- Selection and trigger defined to minimize bias in proper time and angular acceptance

- Use as control samples:

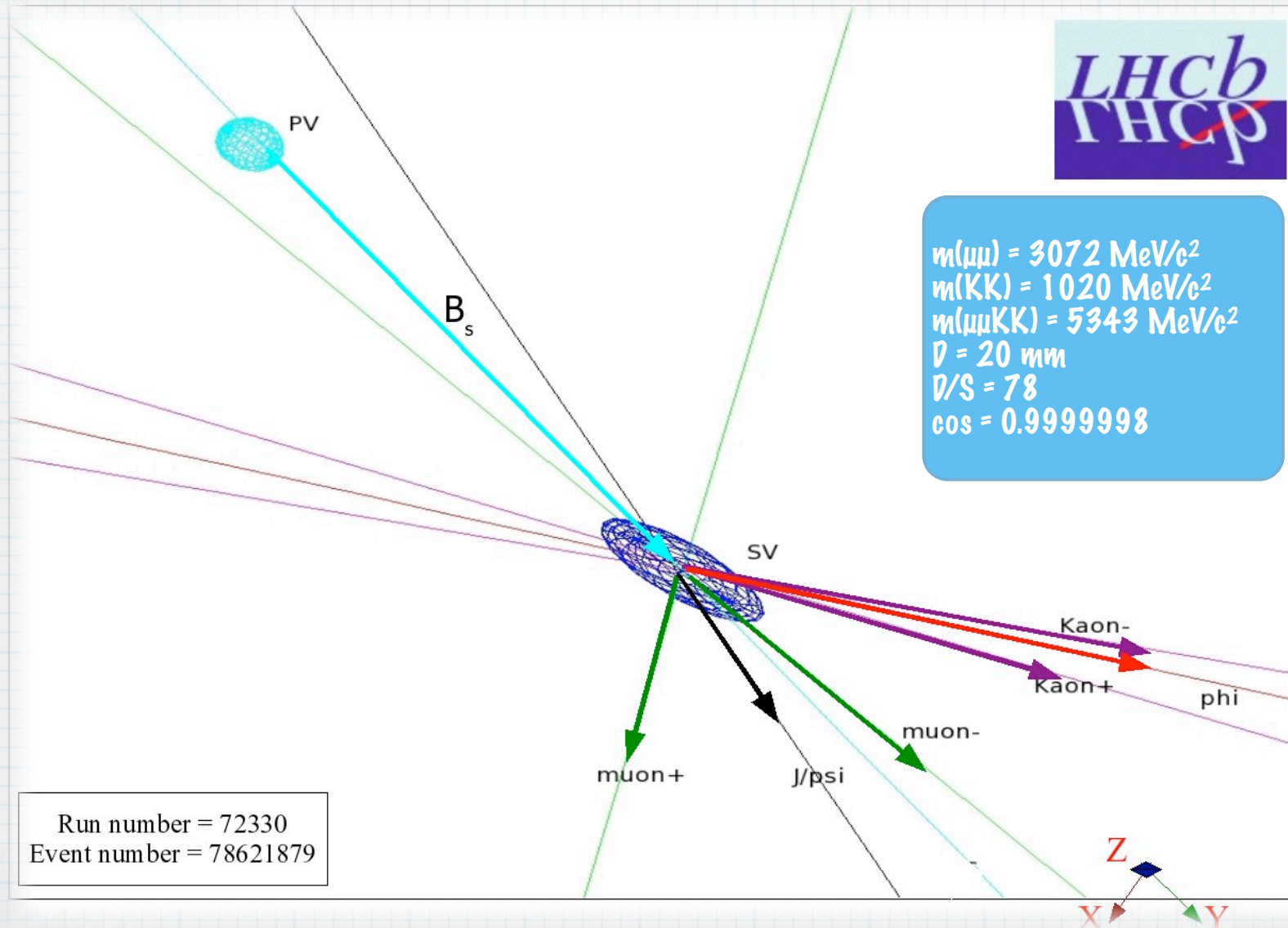
$B^+ \rightarrow J/\psi K^+$ ,  $B^- \rightarrow J/\psi K^-$

Flavour Oscillation signal region



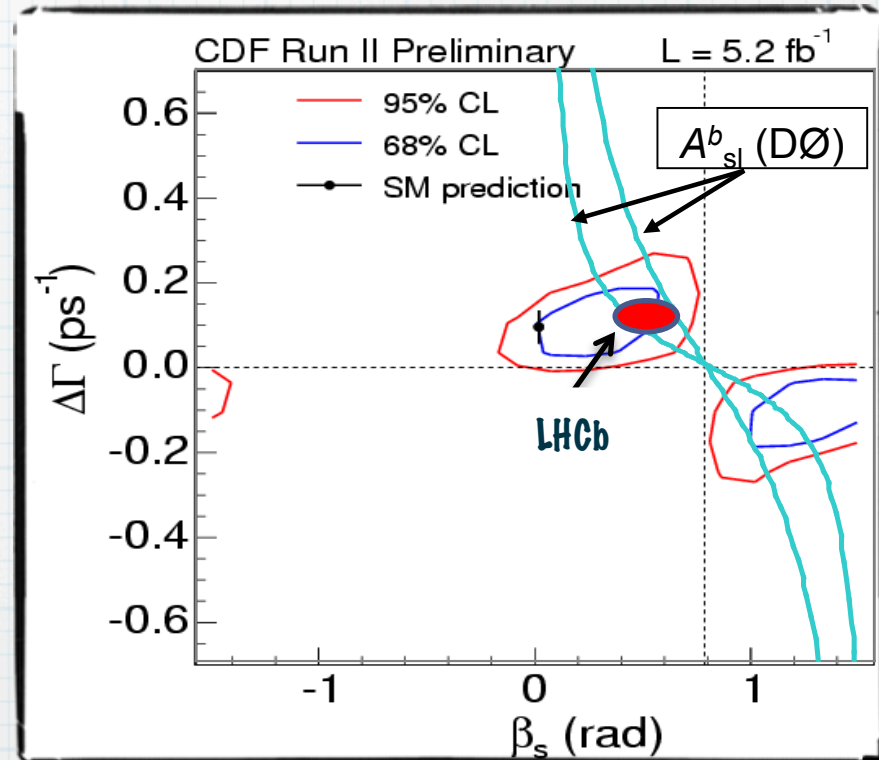
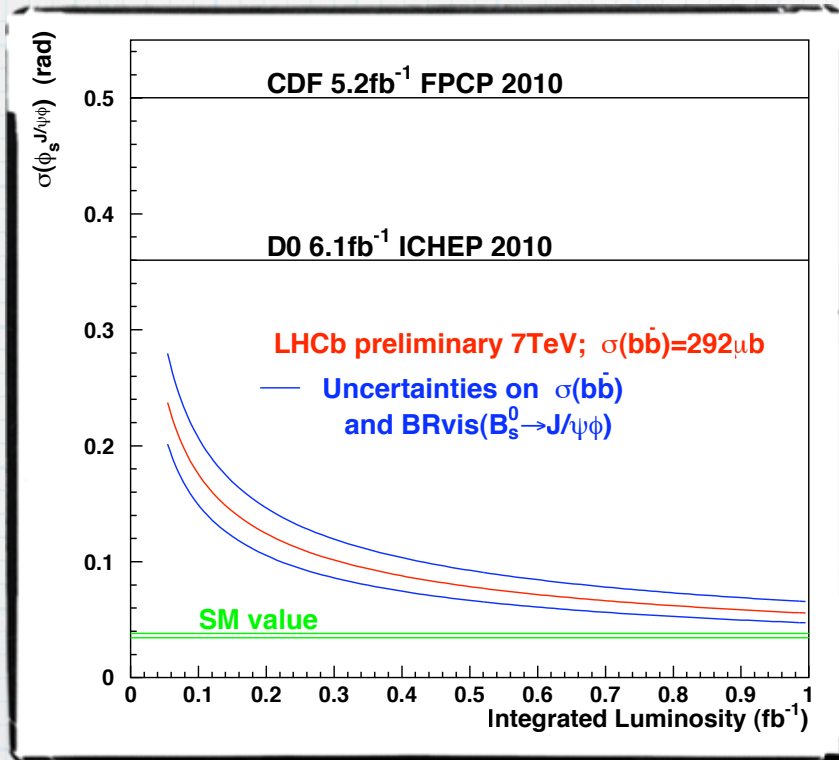
Asymmetry  $B^0 \rightarrow D^{*}(D^0\pi)\mu^+\nu$  vs time

# $B_s \rightarrow J/\psi \Phi$ candidate



# Perspectives for $\beta_s$

- xsection and yields consistent with expectations
- Work on progress for alignment, tracking and tagging
- Sensitivity on  $\beta_s$  depends on
  - $\omega$  wrong tag fraction,  $\sigma$  proper time resolution



$$\varepsilon_{\text{tag}}(1 - 2\omega)^2 = 6.2\%, \sigma(t) = 38 \text{ fs}$$

# Flavour specific asymmetry: $a_{fs}$

- ◆ D0 charge asymmetry measurement, using  $bb \rightarrow \mu\mu X$  event

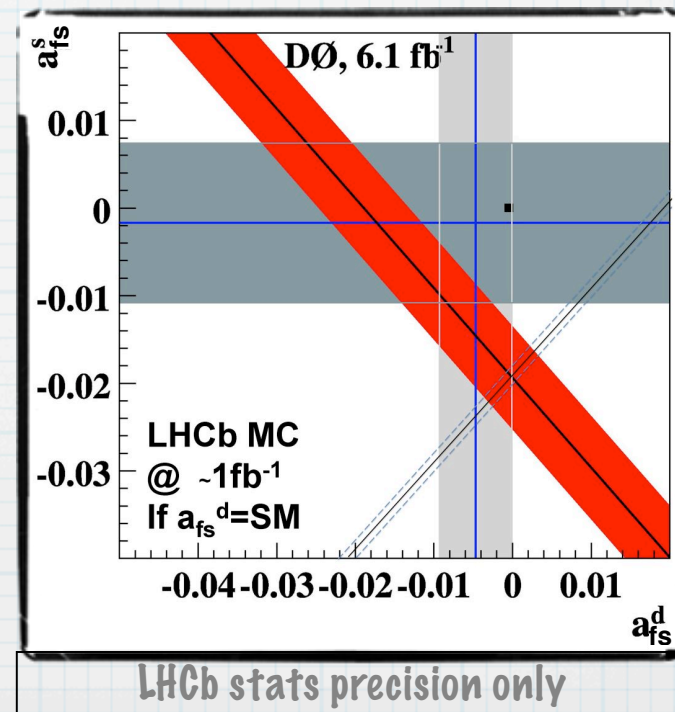
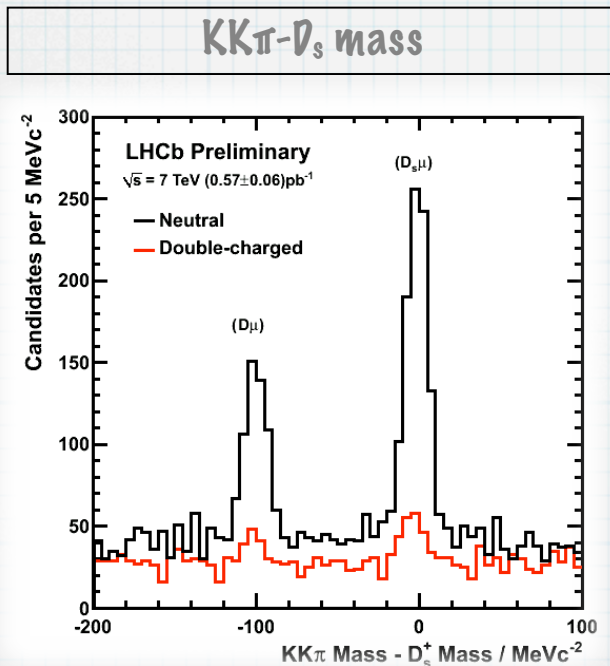
$$A^b = \frac{N^{++} - N^{--}}{N^{++} + N^{--}} = (0.494)a_{fs}^s + (0.506)a_{fs}^d$$

$$a_{fs}^s = \frac{\Delta\Gamma^s}{\Delta M^s} \tan \phi_s$$

$$A_{fs}^q(t) = \frac{\Gamma(f) - \Gamma(\bar{f})}{\Gamma(f) + \Gamma(\bar{f})}$$

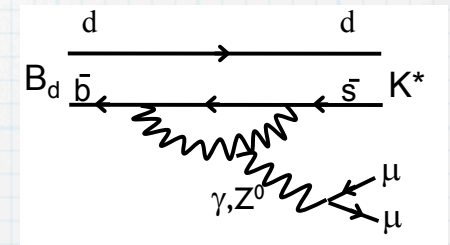
- ◆ LHCb plans to measure exclusive rates  $B_{(q)} \rightarrow D_{(q)} \mu\nu$  in pp
- ◆ Ignore time dependent part to remove production asym ( $\sim 10^{-2}$ )
- ◆ Compute the difference in the Asymmetry between  $B_s, B^0$  to remove detector asymmetries ( $\sim 10^{-2}$ )

0.57 pb<sup>-1</sup>



# $A_{FB} B \rightarrow K^* \mu \mu$

- ◆ The  $BR(B \rightarrow K^* \mu \mu) = (1.15^{+0.16}_{-0.15}) 10^{-6}$  is in 20% with SM
- ◆ The photon/Z penguin introduces a forward-backward asymmetry in the SM that can be affected by NP
- ◆ Expect 1.4 k events/ $1 \text{ fb}^{-1}$
- ◆ Study the forward-backward asymmetry vs the  $q^2$  of the muons
  - Control of the angular and muon acceptances
- ◆  $\sigma(A) \sim 0.2$  at  $0.1 \text{ fb}^{-1}$  (similar to B-factories) and 0.07 at  $1 \text{ fb}^{-1}$



$$A_{FB}(s = m_{\mu^+\mu^-}^2) = \frac{N_F - N_B}{N_F + N_B}$$

$\theta$  = angle between  $\mu^+$  &  $B$  in the dilepton rest frame  
 $q^2$  = dilepton invariant mass



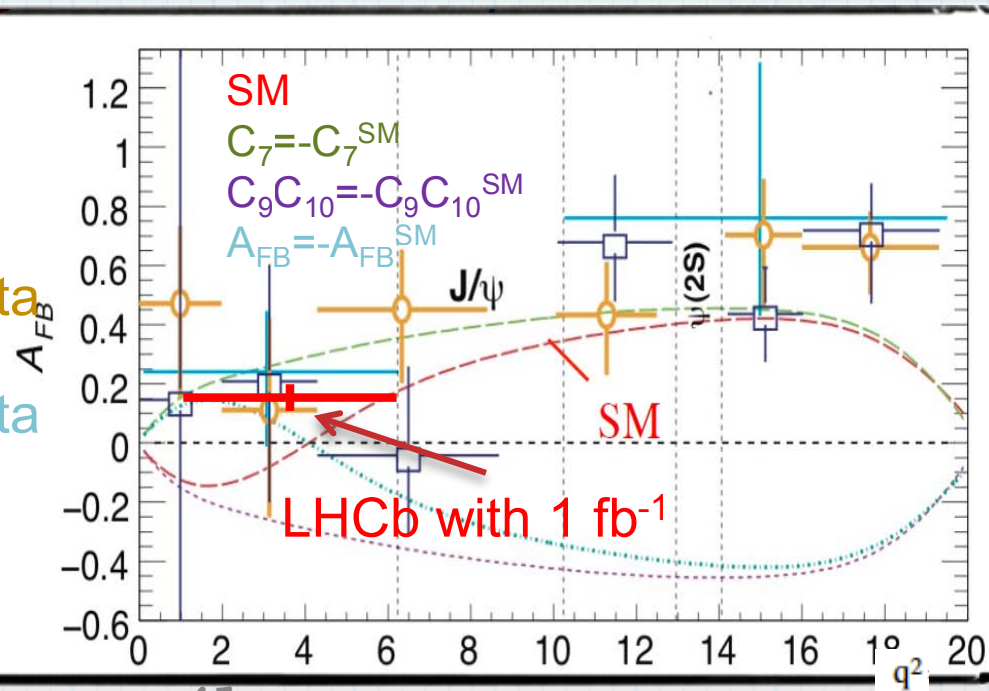
80% of data



75% of data



4.4  $\text{fb}^{-1}$



# $B_s \rightarrow \mu\mu$

◆ Very rare decay (FCNC+helicity suppress)

■  $BR(B_s \rightarrow \mu\mu) = (3.35 \pm 0.32) 10^{-9}$  (SM prediction)

◆ High sensitivity to NP with new scalar or pseudoscalar interactions (i.e MSSM)

■  $BR \propto \tan^6 \beta$

◆ Current limits by Tevatron:

■  $BR < 3.6 10^{-8}$  @ 90% CL (CDF 3.7 fb<sup>-1</sup>)

■  $BR < 4.2 10^{-8}$  @ 90% CL (D0 6.1 fb<sup>-1</sup>)

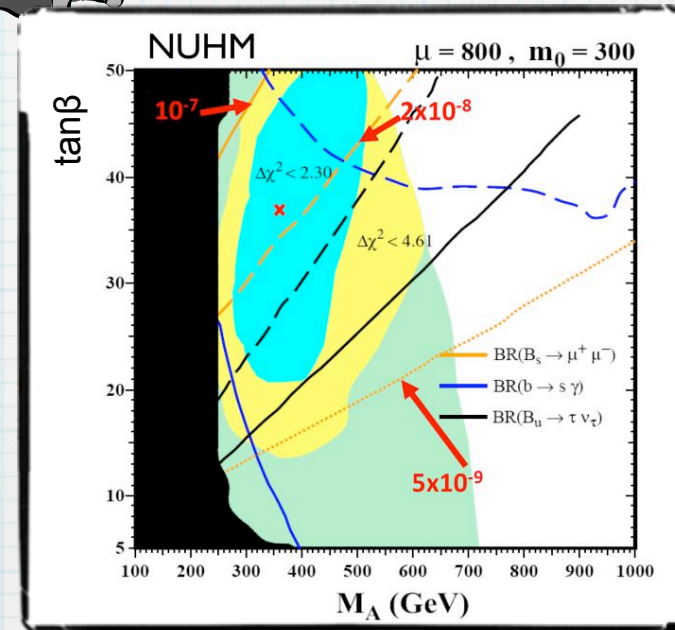
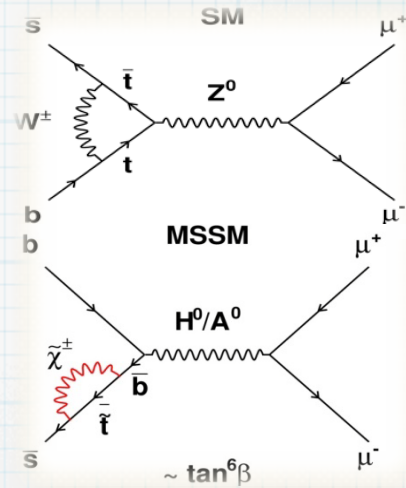
◆ LHCb performance (see prev. transp.)

■ High efficient trigger

■ Good muon identification

■ Good mass resolution

■ Good vertex capabilities



JHEP 0710:092,2007



# $B_s \rightarrow \mu\mu$

## ◆ 3 Axis space divided in bins:

- Muon Identification
- Geometrical Likelihood (lifetime, IPS of  $B_s, \mu$ , isolation,...)
- Invariant Mass

## ◆ Calibration channels

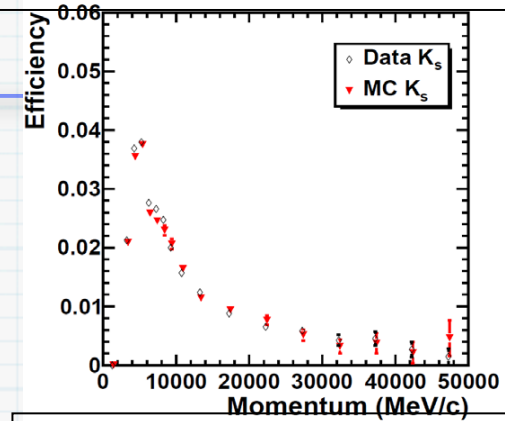
- muon ID:  $J/\Psi, \Lambda, K_s$
- GL:  $B_{(q)} \rightarrow hh$
- mass:  $B_s \rightarrow KK$

$$BR = BR_n \frac{\epsilon_n}{\epsilon} \cdot \frac{P(b \rightarrow B_n)}{P(b \rightarrow B_s)} \cdot \frac{N}{N_n}$$

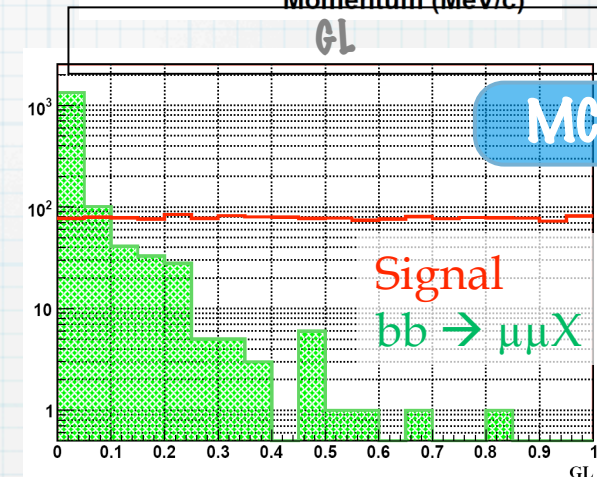
## ◆ Normalization

- Use:  $B^+ \rightarrow J/\Psi K^+, B_s \rightarrow J/\Psi \Phi, B_{(q)} \rightarrow hh$
- production fraction is the larger systematic (13%)
  - Measure ratios of  $B_{(q)} \rightarrow D_{(q)} X$  (expected 5-7%)

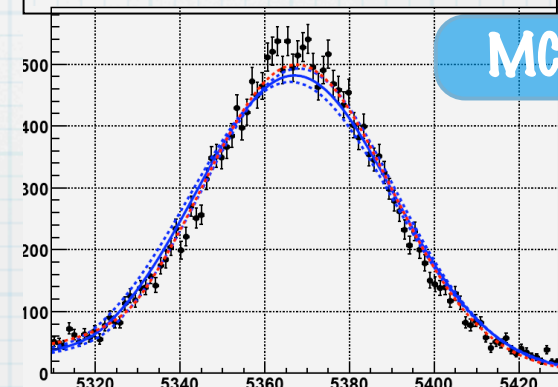
mis ID ( $\pi \rightarrow \mu$ ) vs momenta



GL



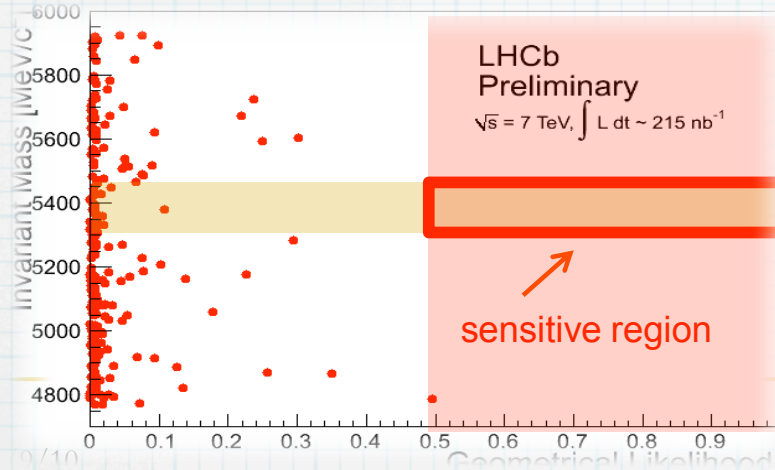
Mass  $B_s \rightarrow KK, B_s \rightarrow \mu\mu$



# Perspectives for $B_s \rightarrow \mu\mu$

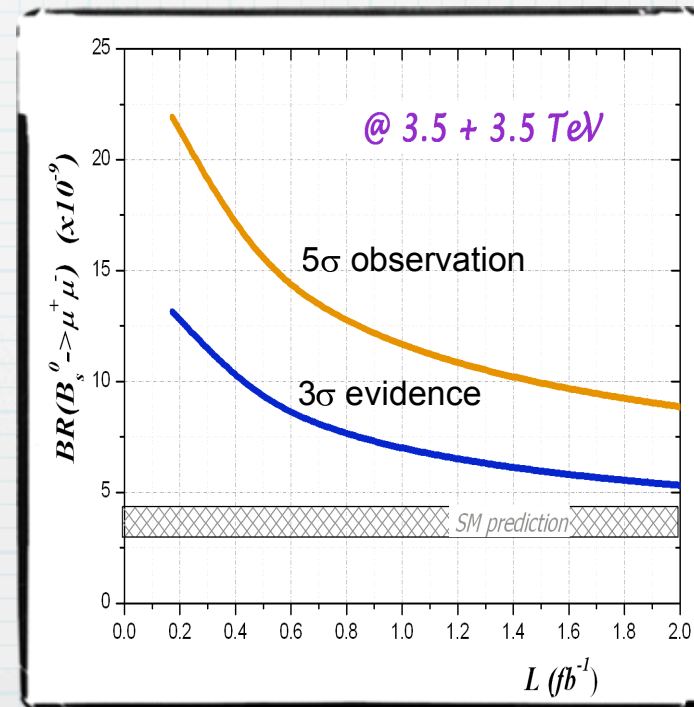
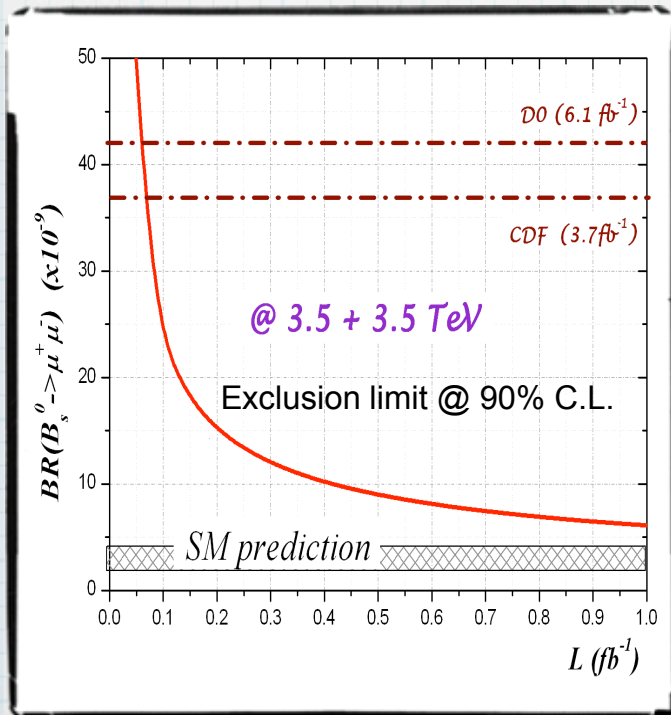
215 nb<sup>-1</sup>

Mass vs GL



## ◆ Perspectives:

- background levels  $\sim (1.5 \pm 0.5)$  MC
- dominated by real muons
- Calibrating the signal GL distribution from  $B \rightarrow hh$
- A chance to improve present limits 50-100 pb<sup>-1</sup>



# Conclusions



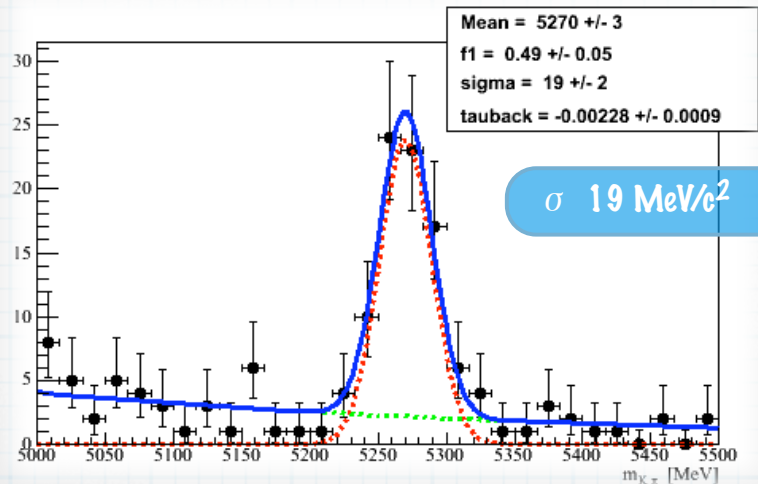
- ◆ LHCb detector working 'beautifully'
  - thanks to the work and dedication of the people that constructed, commissioned the detector and conduct the data taking and processing
- ◆ LHCb performing well
  - in trigger, reconstruction, particle identification.
  - and constantly improving alignment, mass resolution, proper time, tagging
- ◆ LHCb has chances to improve some relevant measurements in search for NP in B and D mesons with  $50\text{-}100 \text{ pb}^{-1}$ 
  - $BR(B_s \rightarrow \mu\mu)$ ,  $\beta_s$  from  $B_s \rightarrow J/\Psi\Phi$ , ...

# LHCb performance

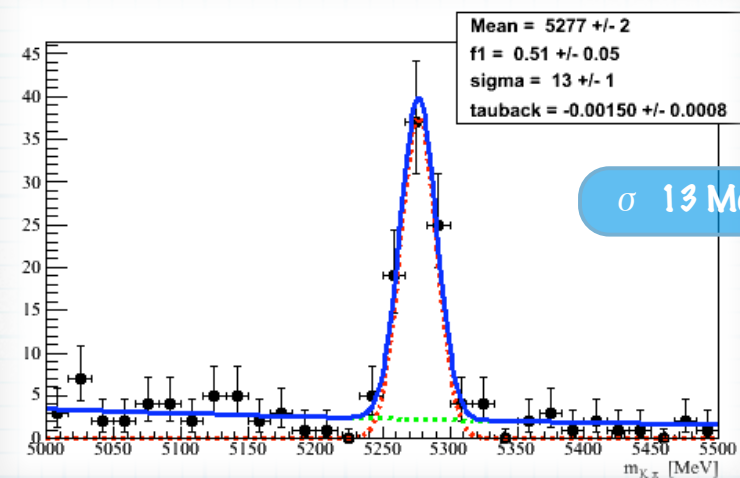
Marta LCC  
Lumi?

- ◆ Trigger performing well in harder circumstances
- ◆ tracking reconstruction and muon identification ok
- ◆ Improvements in the alignment gives mass resolution and impact parameters for high PT tracks close to MC
  - but still some work,
- ◆ Now commissioning the tagging

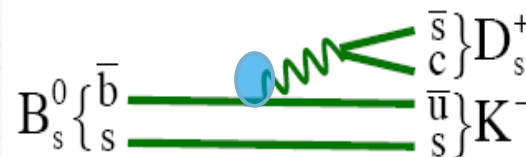
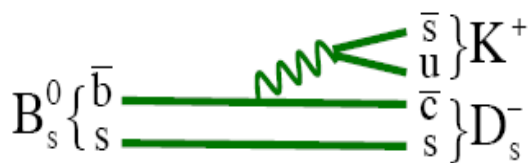
Data,  $B^+ \rightarrow J/\psi K^+$  mass



MC,  $B^+ \rightarrow J/\psi K^+$  mass



# CPV: $\gamma$ by trees

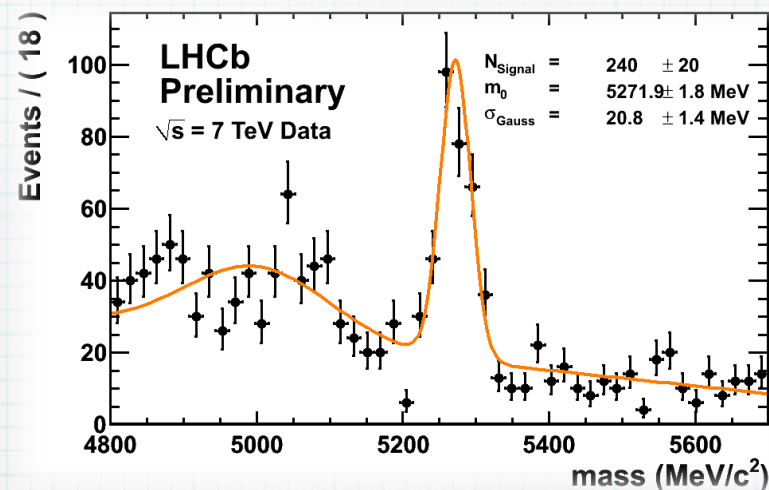


- ◆ CPV in the interference via mixing
- ◆ Fit to time distribution of decays
  - $B_s \rightarrow D_s^+ K^-$   $B_s \rightarrow D_s^+ \pi$
- ◆ Extract:  $\Delta m_s$ ,  $\Delta \Gamma_s$ ,  $\omega$  (wrong tag rate),  $\delta$  (strong phase difference)

Using  $\beta_s$  obtained from  $B_s$  to  $J/\psi\phi$ ,  
 $\sigma(\gamma) \sim 14^\circ$  with  $1 \text{ fb}^{-1}$

$B_s \rightarrow D_s(KK\pi)\pi$

750 nb<sup>-1</sup>



Channel	Expected event yield
$B_s^0 \rightarrow D_s^+ K^-$	3500
$B^0 \rightarrow D^+ \pi^-$	300000

# Flavour specific asymmetry: $a_{fs}$

- ◆ D0 charge asymmetry measurement, using  $bb \rightarrow \mu\mu X$  event

$$a_{fs}^s = \frac{\Delta\Gamma^s}{\Delta M^s} \tan \phi_s$$

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

$$A_{sl}^b(\text{SM}) = (-2.3_{-0.6}^{+0.5}) \times 10^{-4}$$

$$A_{sl}^b = -0.00957 \pm 0.00251(\text{stat}) \pm 0.00146(\text{sys})$$

- ◆ LHCb plans to measure exclusive rates  $B_{(q)} \rightarrow D_{(q)} \mu \nu$

- ◆ To deal with production asymmetries ( $\sim 10^{-2}$ )

- ◆  $\Delta A_{fs}^{s,d}$  cancel detector asymmetries

$$\Gamma(f) = N e^{-\Gamma t} \left[ (1 + x_1) \cosh\left(\frac{\Delta\Gamma t}{2}\right) + (x_2 + x_3) \cos(\Delta m t) \right]$$

$$\Gamma(\bar{f}) = N e^{-\Gamma t} \left[ (1 - x_1) \cosh\left(\frac{\Delta\Gamma t}{2}\right) + (x_2 - x_3) \cos(\Delta m t) \right]$$

where:  $x_1 = A_c + a_{fs}$      $x_2 = 2A_c A_p$      $x_3 = 2A_p - a_{fs}$

$$\Delta A_{fs}^{s,d} = \frac{\chi_1^s - \chi_1^d}{2} = \frac{a_{fs}^s - a_{fs}^d}{2} \text{ SM} = \left( +2.5_{-0.6}^{+0.5} \right) \times 10^{-4}$$

1.15 pb<sup>-1</sup>

