

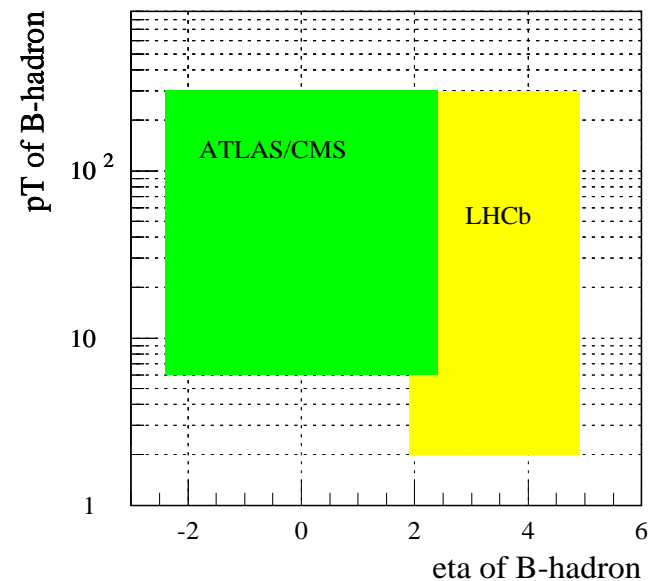
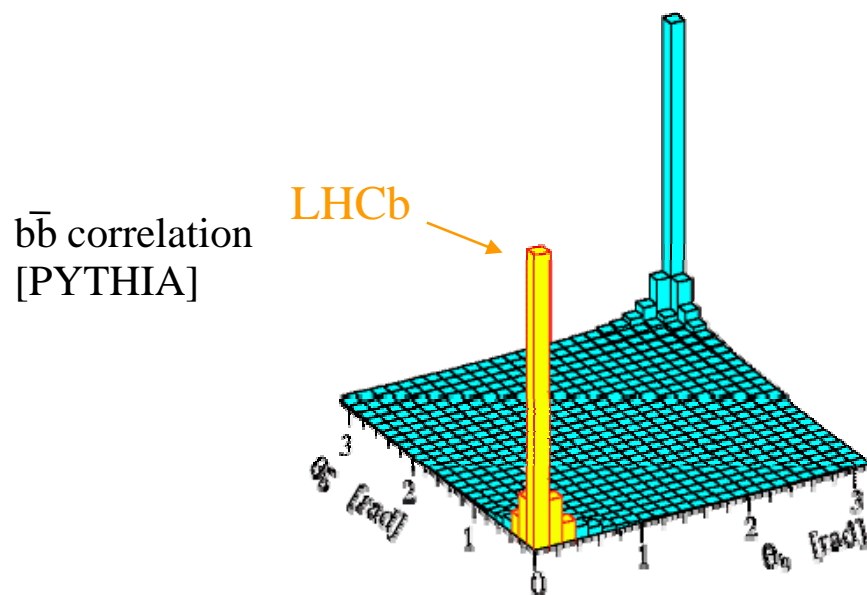


# LHC Perspectives for $b$ lifetimes, $\Delta m$ , $\Delta\Gamma$

*Patrick Robbe, LHCb Collaboration, LAL Orsay & CERN, 10 Sep 2008*

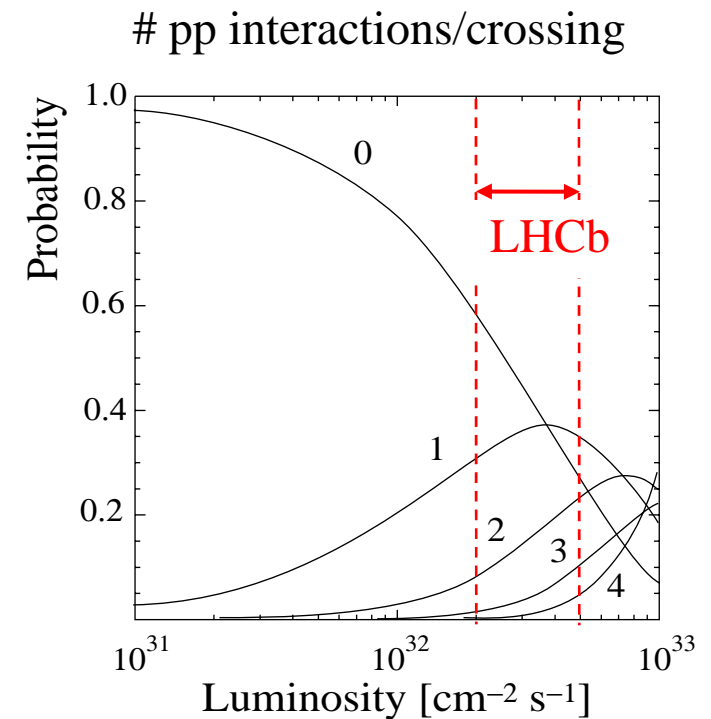
# B physics at LHC

- LHC designed for discoveries at high energies: high  $p_T$  central detectors, ATLAS and CMS
- But the  $b\bar{b}$  production cross section at LHC energy is large (estimated  $500 \mu\text{b}$ ), **100000 B hadrons** produced per second: LHCb experiment dedicated to B physics, and B physics program by ATLAS and CMS.
- All B hadrons produced:  $B^0, B^+$  and also  $B_s^0, B_c^+, \Lambda_b, \Xi_b, \dots$



# Luminosity

- At design LHC luminosity ( $10^{34} \text{ cm}^{-2}\text{s}^{-1}$ ), more than 20 pile-up interactions per crossing: *B* physics difficult (uses vertex structures).
- At LHCb, luminosity will be adjusted independently by less beam focussing than ATLAS/CMS. Baseline is  $2 \times 10^{32} \text{ cm}^{-2}\text{s}^{-1}$  where most collisions will contain only 1 interaction.
- At early running of LHC (starting today!), luminosity will be lower than design: phase favorable for *B* physics at ATLAS and CMS. LHCb ready for nominal luminosity.

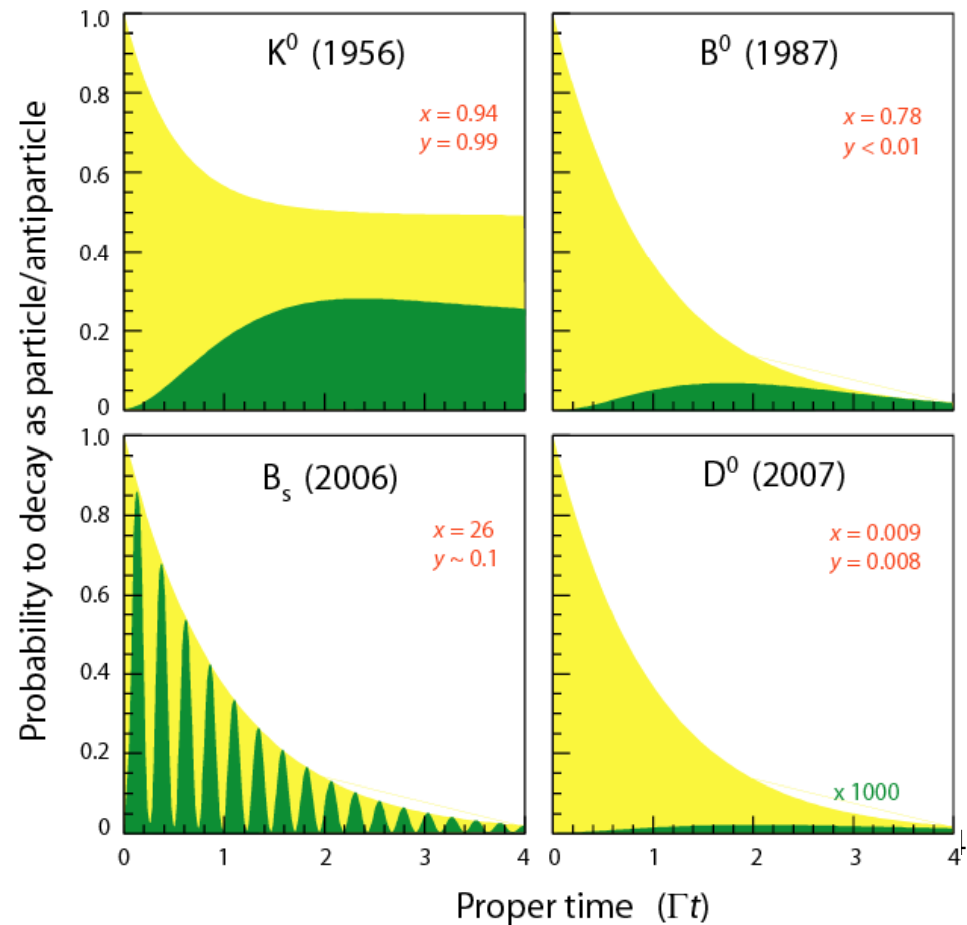


# Lifetimes and Mixing

- All mixing particles have been observed

$\tau(B^0) = (1.530 \pm 0.009) \text{ ps}$
$\tau(B^+) = (1.638 \pm 0.011) \text{ ps}$
$\tau(B_s^0) = (1.425 \pm 0.041) \text{ ps}$
$\tau(B_c^+) = (0.460 \pm 0.070) \text{ ps}$
$\tau(\Lambda_b) = (1.383 \pm 0.049) \text{ ps}$
$\tau(\Xi_b) = (1.420 \pm 0.280) \text{ ps}$

PDG2008

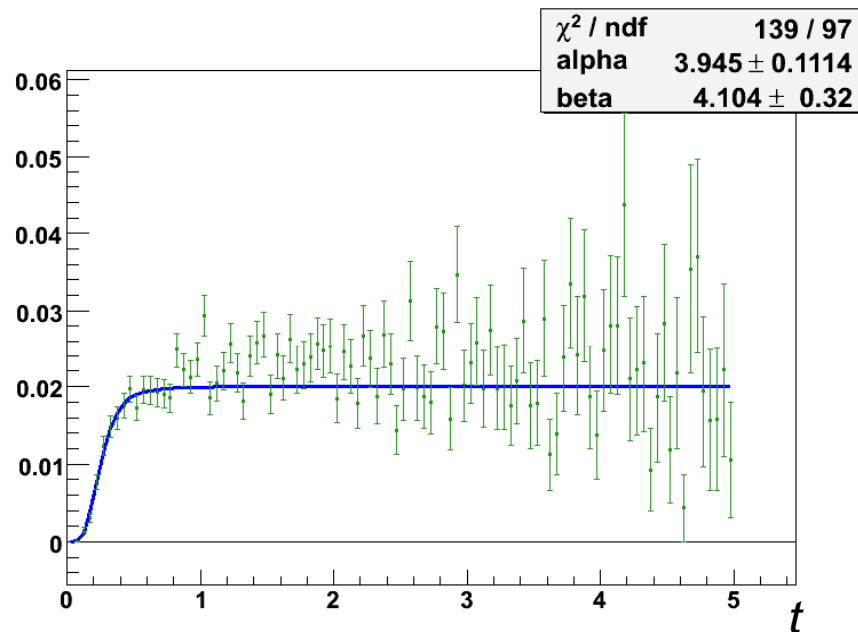


# Precision Lifetime Measurements

- Heavy quark expansion predicts the following hierarchy of  $B$  lifetimes:
  - $\tau(B_c^+) < \tau(\Lambda_b) < \tau(B_s^0) \approx \tau(B^0) < \tau(B^+)$
- PDG2008:
  - $\tau(B_s^0)/\tau(B^0) = 0.961 \pm 0.018$
  - $\tau(\Lambda_b)/\tau(B^0) = 0.904 \pm 0.021$
- HQET predictions (A. Deischer, Moriond 2008):
  - $\tau(B_s^0)/\tau(B^0) = 1.00 \pm 0.01$
  - $\tau(\Lambda_b)/\tau(B^0) = 0.86 \pm 0.05$
- Test of HQET with 1% precision on these ratios

# b Lifetimes

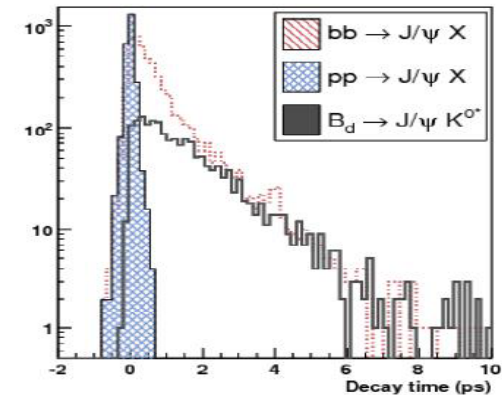
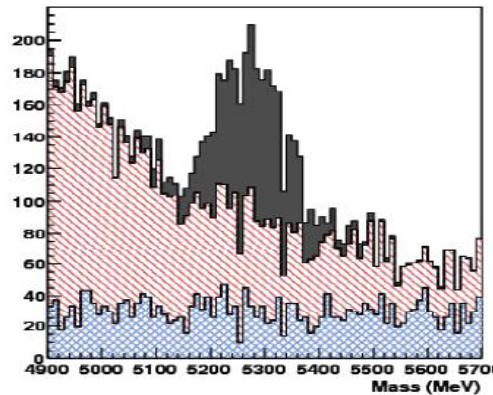
- $B$  are long-lived compared to large combinatorial background at 0 lifetime: impact parameter cuts used in trigger and/or selections, which affect lifetime distributions.
- Example of acceptance as a function of  $t$ :



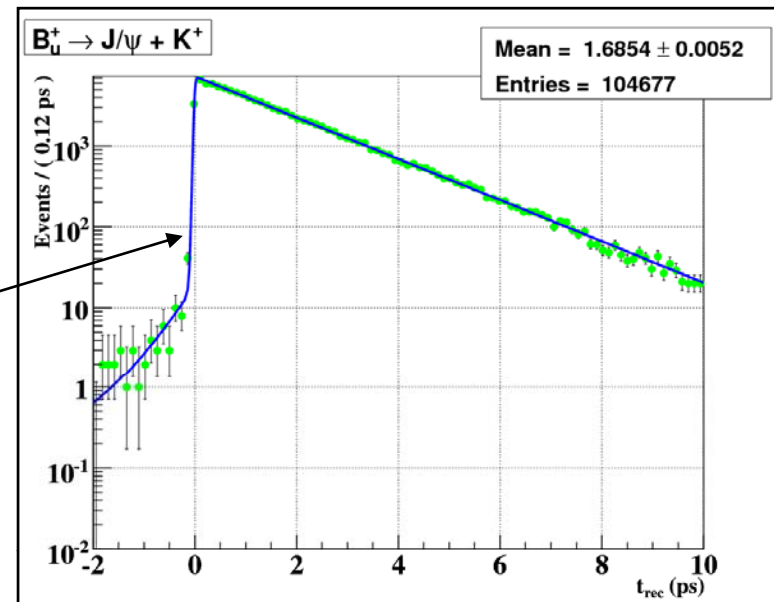
- Error dominated by  $B$  vertex, primary vertex is precisely determined.

# B lifetimes as calibration

- $B^0 \rightarrow J/\psi K^{*0}$  in ATLAS:
  - Yield: 1024 for  $10 \text{ pb}^{-1}$  (ie the next months)
  - Precision of 10% on lifetime reached for  $10 \text{ pb}^{-1}$

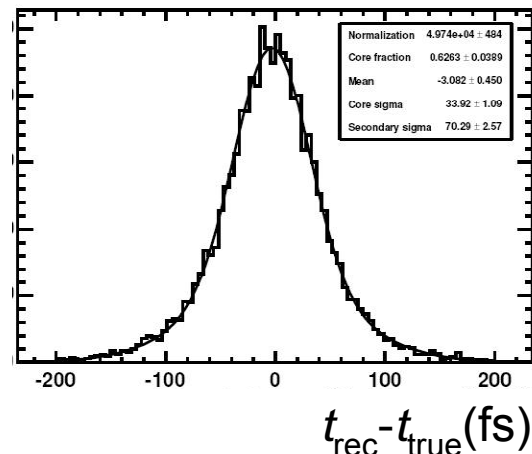
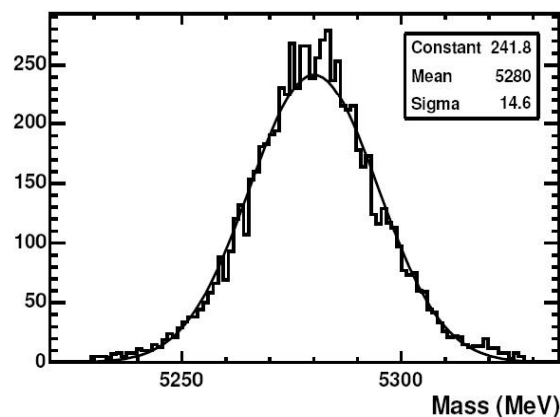


- $B^+ \rightarrow J/\psi K^+$  in LHCb:
  - Yield: 1735000 for  $2 \text{ fb}^{-1}$
  - Selection does not use lifetime cuts: unbiased lifetime distribution which allows to determine lifetime resolution functions (region at  $t \sim 0$ )



# $B$ lifetimes as calibration

- *Hadronic Decay Mode (with lifetime cuts for selection):*  
 $B^0 \rightarrow D^-(K\pi^+\pi^-)\pi^+$  in LHCb:
  - Yield: 1340000 for  $2 \text{ fb}^{-1}$
  - S/B:  $\sim 5$
  - Mass Resolution:  $14.6 \text{ MeV}/c^2$
  - Proper time resolution:  $33.9 \text{ fs}$
  - Current ( $0.009 \text{ ps}$ )  $B^0$  lifetime statistical precision reached with 60000 events.

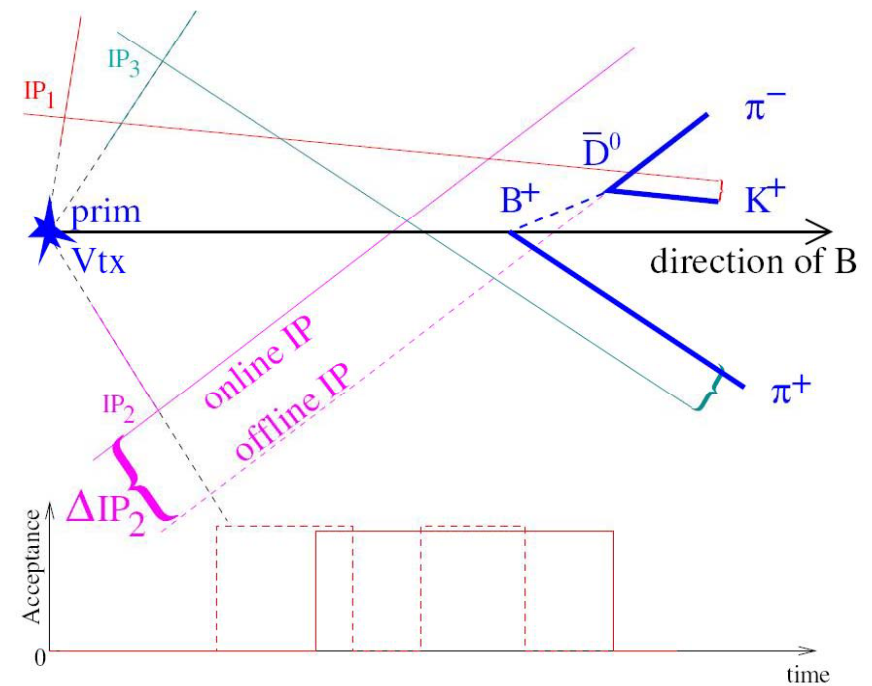
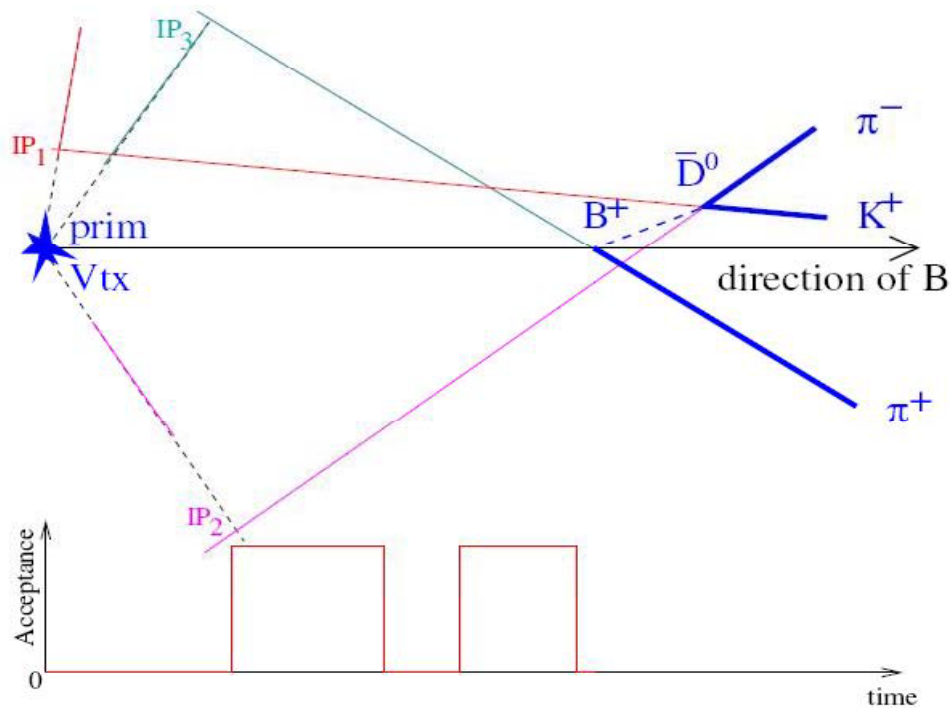


Very rapidly, large samples of  $B$  hadrons available to demonstrate detectors capabilities for time related  $B$  analyses.



# Correcting for trigger bias

- HLT Trigger cuts introduce bias in lifetime distributions, because of IP cuts.
- Compute an event by event acceptance function:

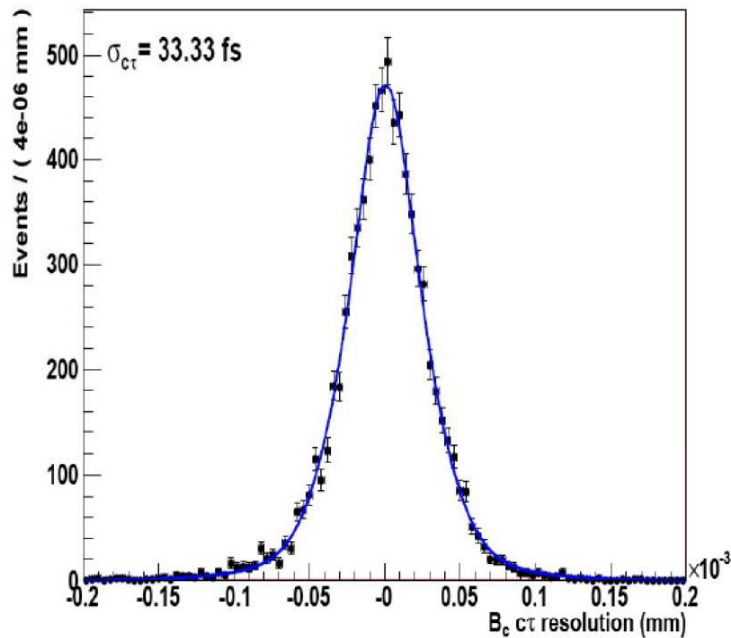


- Difference between online and offline reconstructions taken into account (shift of the acceptance function)

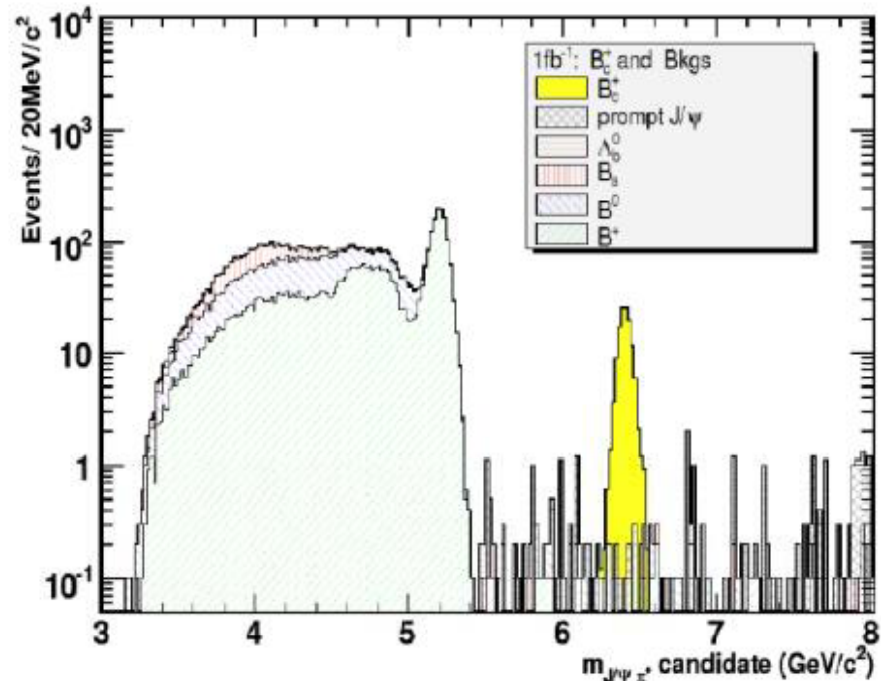
# $B_c$ lifetime

- $B_c$  observed at Tevatron experiments, production cross at LHC will be 20 times larger: the  $B_c$  sample size and knowledge will be increased largely:  $O(10^9)$   $B_c$  produced per year, in LHCb.
- Two kinds of flavour,  $b$  and  $c$ : unique physical properties, such as 3 types of decay mechanisms ( $b$ ,  $c$  decay or annihilation)
- $B_c$  reconstructed in the decay channel  $B_c^+ \rightarrow J/\psi \pi^+$ .
- Assuming cross-section of  $0.4 \mu\text{b}$  and  $\text{BR}(B_c^+ \rightarrow J/\psi \pi^+) = 1.3 \times 10^{-3}$ , expect:
  - 700 events for  $2 \text{ fb}^{-1}$  in LHCb,
  - 80 events for  $10 \text{ fb}^{-1}$  in CMS.

# $B_c$ lifetime



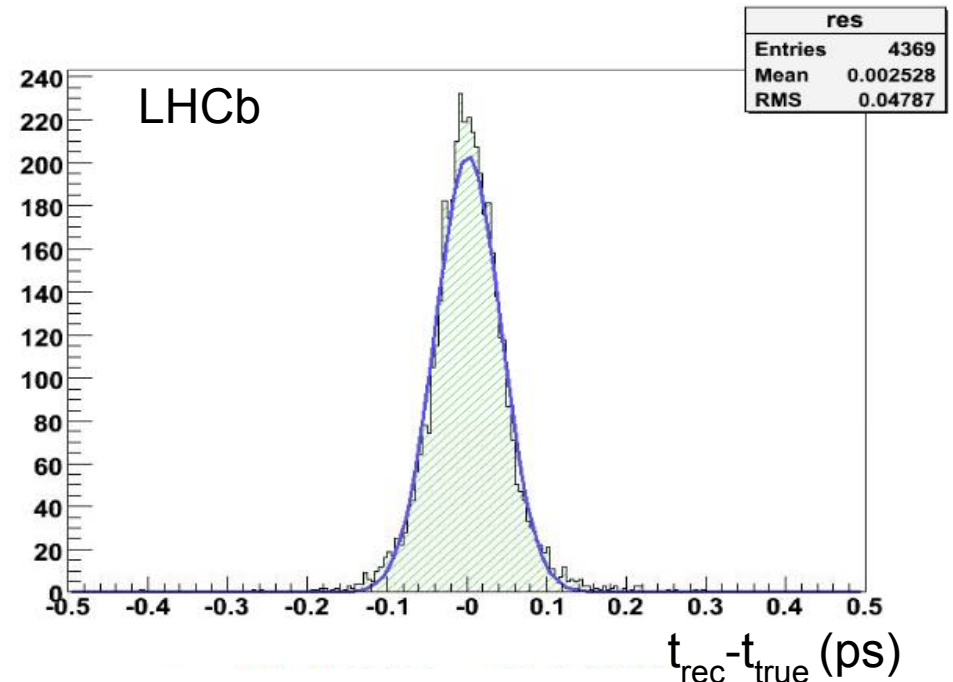
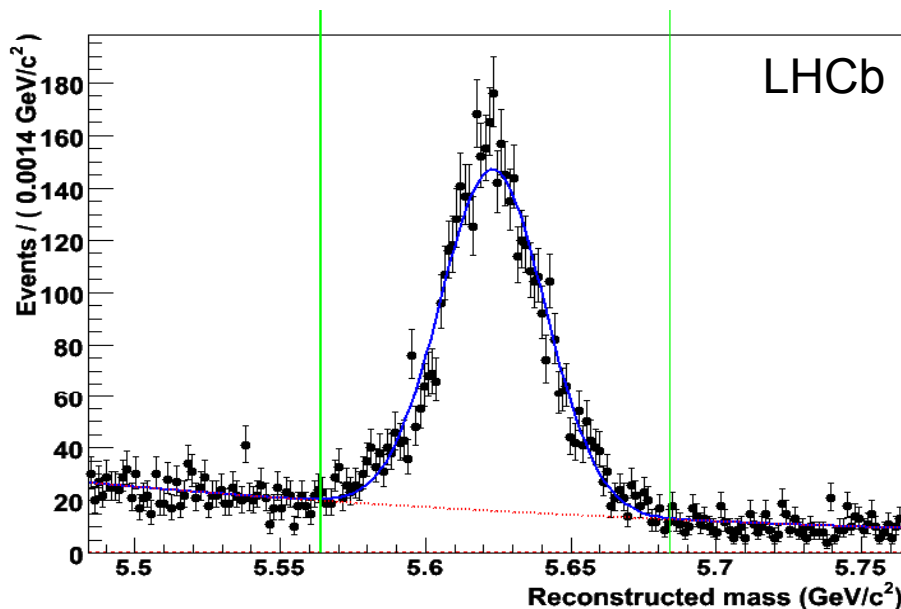
Preliminary precision on  $B_c$  lifetime is **0.026 ps** (statistical only) for LHCb, for  $2 \text{ fb}^{-1}$   
Mass resolution:  $25 \text{ MeV}/c^2$   
Proper time resolution:  $33 \text{ fs}$   
B/S:  $[1.15, 2.15]$  (90 %CL)



Precision on  $B_c$  lifetime is **0.055 ps** (statistical only) for CMS, for  $10 \text{ fb}^{-1}$   
Mass resolution:  $15 \text{ MeV}/c^2$

# $\Lambda_b$ reconstruction

- Reconstructed in the decay mode  $\Lambda_b \rightarrow J/\psi (\mu^+\mu^-) \Lambda (p\pi)$ .



LHCb: 23000 events for 2 fb<sup>-1</sup>

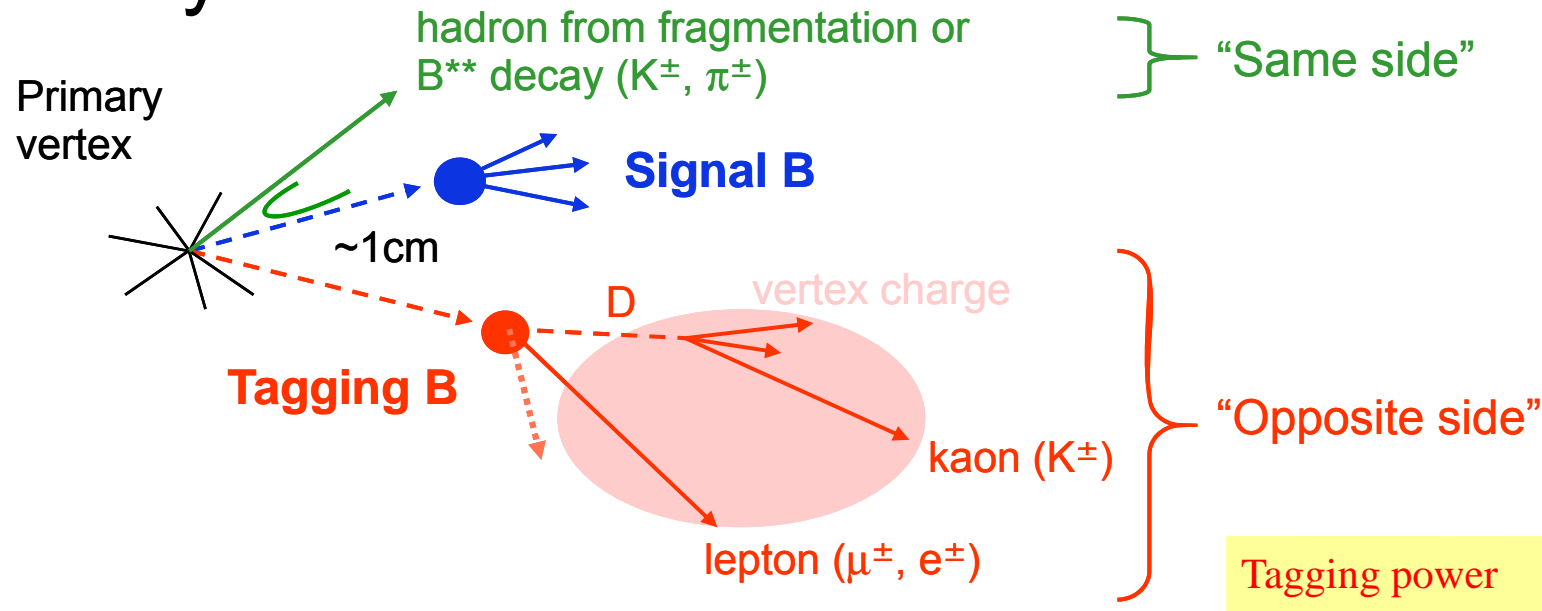
- Statistical precision estimate on lifetime from Full Monte-Carlo: **0.027 ps**
- Mass resolution: 18 MeV/c<sup>2</sup>
- Proper time resolution: 0.0415 ps
- B/S: 0.3

ATLAS: in the same decay mode, 4500 events for 10 fb<sup>-1</sup>

B-Baryons can be reconstructed at LHC detectors: a lot of possible measurements there.

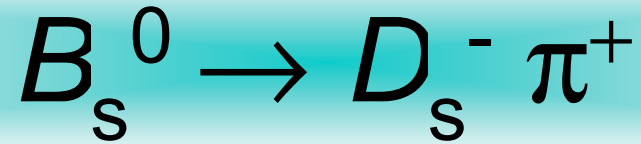
# B Tagging

- *B* Flavour Tagging necessary for mixing analyses.

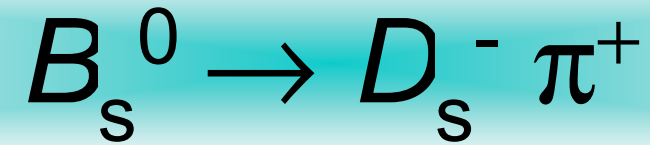


- Kaon tagging most powerful for LHCb using RICH detectors.
- Combined power is 7% for  $B_s^0$  (LHCb), 5% for  $B^0$  (LHCb).

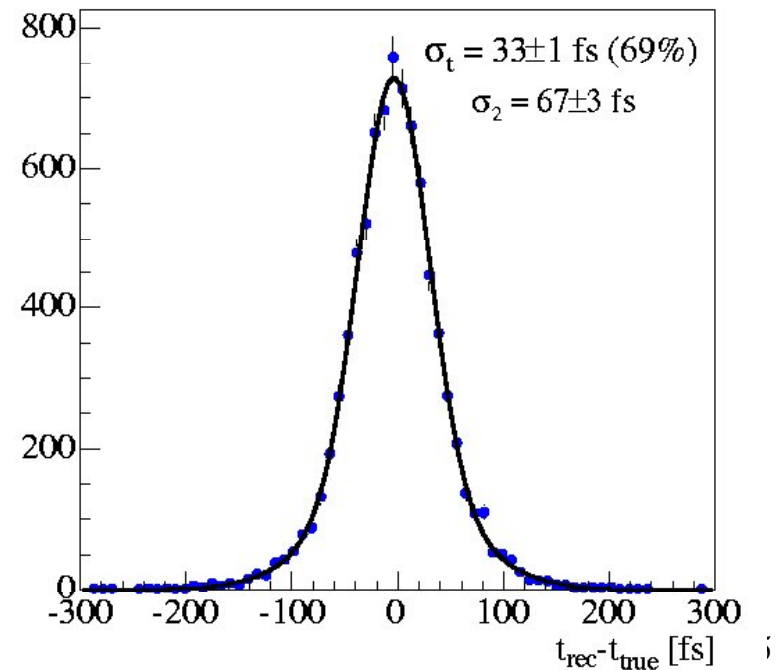
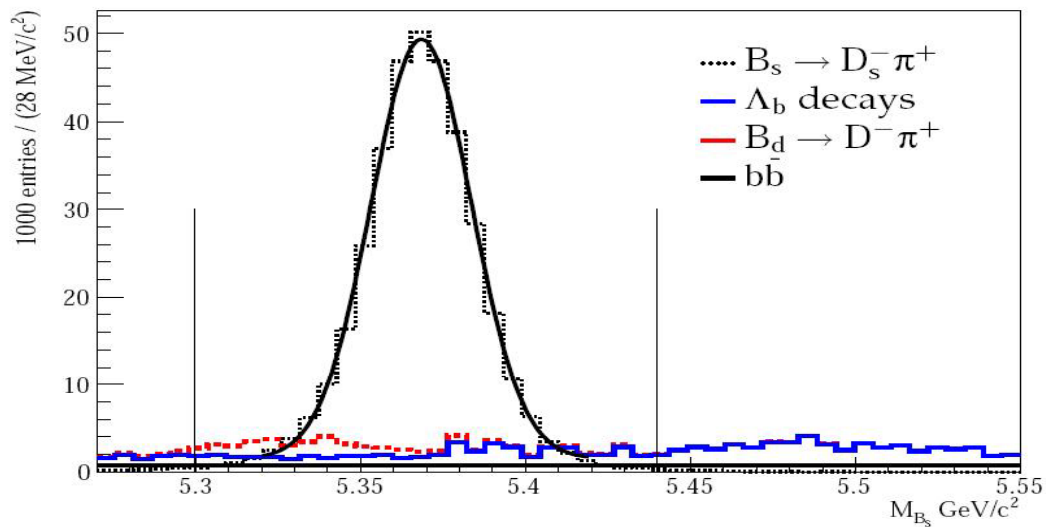
	LHCb
Tagging power	$\epsilon D^2$ (%)
Muon	1.0
Electron	0.4
Kaon	2.4
Jet/vertex charge	1.0
Same side	2.1



- Large branching fraction:  $(3.3 \pm 0.5) \times 10^{-3}$
- Flavour specific decay mode: ideal candidate for  $B_s^0$  lifetime,  $\Delta m_s$  and  $\Delta \Gamma_s$  measurements.
- Reconstructed with the decay mode  $D_s^+ \rightarrow K^- K^+ \pi^-$
- LHCb:
  - Selection based on IP of the  $B$  candidate, Particle ID of the  $\pi$  candidate, and  $D_s$  impact parameter.
  - Total reconstruction efficiency: 0.41 %
  - Expected signal yield from full Monte Carlo: 155000 for  $2\text{fb}^{-1}$
  - B/S in [0.06-0.4] (90% CL)
  - Tagging power  $\varepsilon_{\text{eff}} = (6.31 \pm 0.17) \%$



- LHCb:
  - Mass resolution: 17 MeV
  - Time resolution: 33 fs



# $B_s$ lifetime, mixing, $\Delta\Gamma$

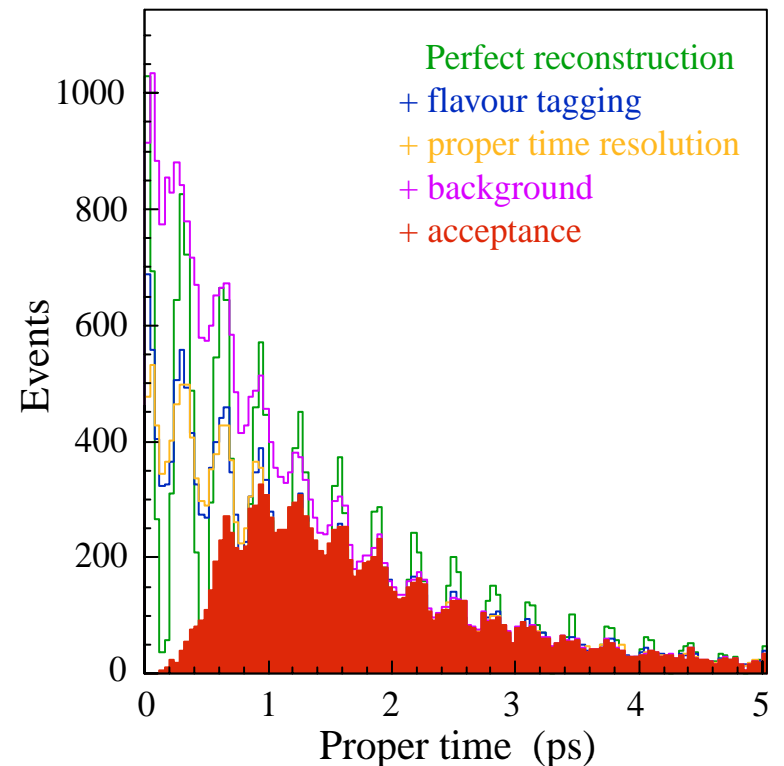
- Mass eigenstates of the  $B_s$  system,  $B_{sH}$  and  $B_{sL}$  have different masses and lifetimes.
- $\Delta\Gamma = \Gamma_L - \Gamma_H$ ,  $\Delta m_s = m_H - m_L$ , average lifetime:  $\Gamma = (\Gamma_H + \Gamma_L)/2$ .
- Lifetime distributions of *tagged*  $B_s$  decays to  $D_s \pi$ :
  - $\Gamma_{\text{unmixed}}(t) = e^{-\Gamma t/2} [\cosh(\Delta\Gamma t/2) + D \cos(\Delta m_s t)]$
  - $\Gamma_{\text{mixed}}(t) = e^{-\Gamma t/2} [\cosh(\Delta\Gamma t/2) - D \cos(\Delta m_s t)]$
- Where  $D$  is the dilution factor, due to mistags.
- Fit of both distributions gives access to  $\Gamma$ ,  $\Delta m$  and  $\Delta\Gamma$ .



# $B_s$ lifetime, mixing, $\Delta\Gamma$ sensitivities

- Estimated from toy Monte-Carlo using resolutions, efficiencies, tagging from full Monte-Carlo simulation, with  $\omega=0.37$
- Mistag will be evaluated from data using control channels ( $B^0 \rightarrow J/\psi K^{*0}$ ,  $B^+ \rightarrow J/\psi K^+$ )
- Sensitivities (stat only):
  - $\sigma(\tau_s) = 0.013$  ps
  - $\sigma(\Delta m_s) = 0.008$  ps $^{-1}$
  - $\sigma(\Delta\Gamma_s) = 0.03$  ps $^{-1}$  (Input = 0.068 ps $^{-1}$ )

Lifetime and mixing will be dominated by systematic errors



# $\Delta\Gamma$ from $B_s^0 \rightarrow J/\psi \phi$

- By-product of  $\beta_s$  measurement, see Gaia Lanfranchi's talk for more details.
- Full angular analysis, this decay channel provides  $\Delta\Gamma$  measurement with better precision than  $B_s^0 \rightarrow D_s^- \pi^+$ .
- Expected statistical precisions for  $10 \text{ fb}^{-1}$  (ATLAS/CMS) and  $2 \text{ fb}^{-1}$  (LHCb)
- Tagging power: 4.6 % (ATLAS), 6.2 % (LHCb), untagged analysis for CMS.

	ATLAS	CMS	LHCb
$\sigma(\Delta\Gamma_s)$	0.021 ps <sup>-1</sup>	0.010 ps <sup>-1</sup>	0.008 ps <sup>-1</sup>
Input Value	0.1 ps <sup>-1</sup>	0.142 ps <sup>-1</sup>	0.1 ps <sup>-1</sup>

# Conclusions

- Lifetime measurements with precision of existing measurements can be obtained during the first weeks of LHC nominal running (2009), and will be used to demonstrate the detector performances for time dependant analyses.
- Knowledge of  $B_s^0$  sector will reach similar precision than  $B^0$  and  $B^+$ .
- Precise studies of other  $B$  hadrons:  $B_c$ ,  $\Lambda_b$ , etc... will also be possible.

