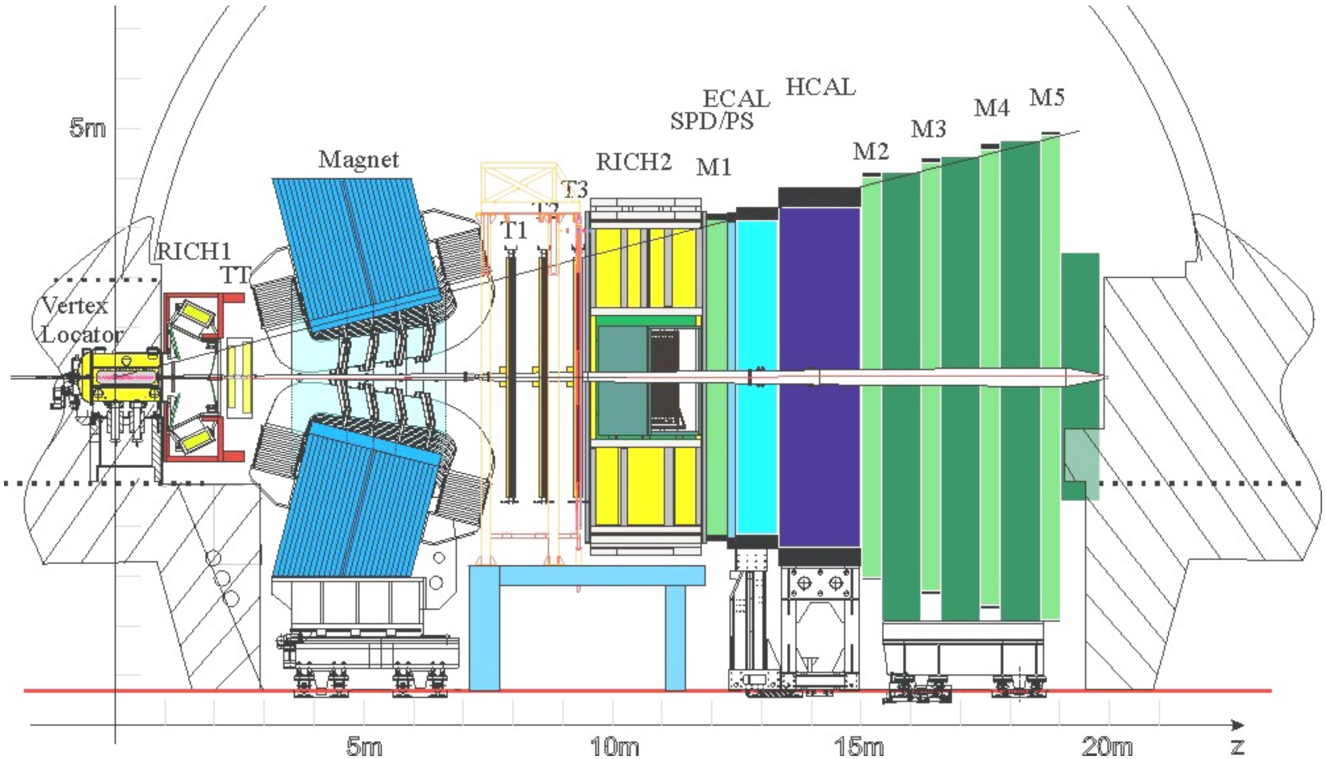
Prospects for quarkonium studies at LHCb

« Quarkonium Production at the LHC » workshop

Patrick Robbe, LAL Orsay, 19 Feb 2010

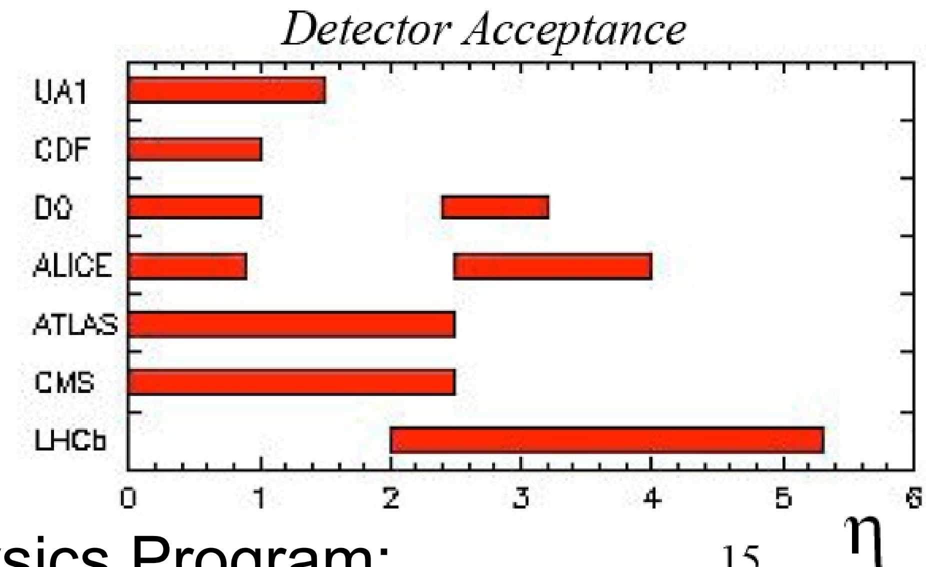
LHCb Detector



- Forward Spectrometer Geometry, with angular acceptance 15<θ<300 mrad
- Performance numbers relevant to quarkonium analyses:
  - Charged tracks $\Delta p/p$ = 0.35 % - 0.55%, $\sigma(m)$=12-25 MeV/c^2
  - ECAL $\sigma(E)/E = 10\% \, E^{-1/2} \oplus 1\,\%$ (E in GeV)
  - muon ID: $\varepsilon(\mu\rightarrow\mu)$ = 94 %, mis-ID rate $(\pi\rightarrow\mu)$ = 3 %
  - Vertexing: $\sigma(L)$=250 μm (Primary Vertex Resolution: 10μm in x/y, 60 μm in z)

Introduction

- Unique acceptance amongst LHC experiments:

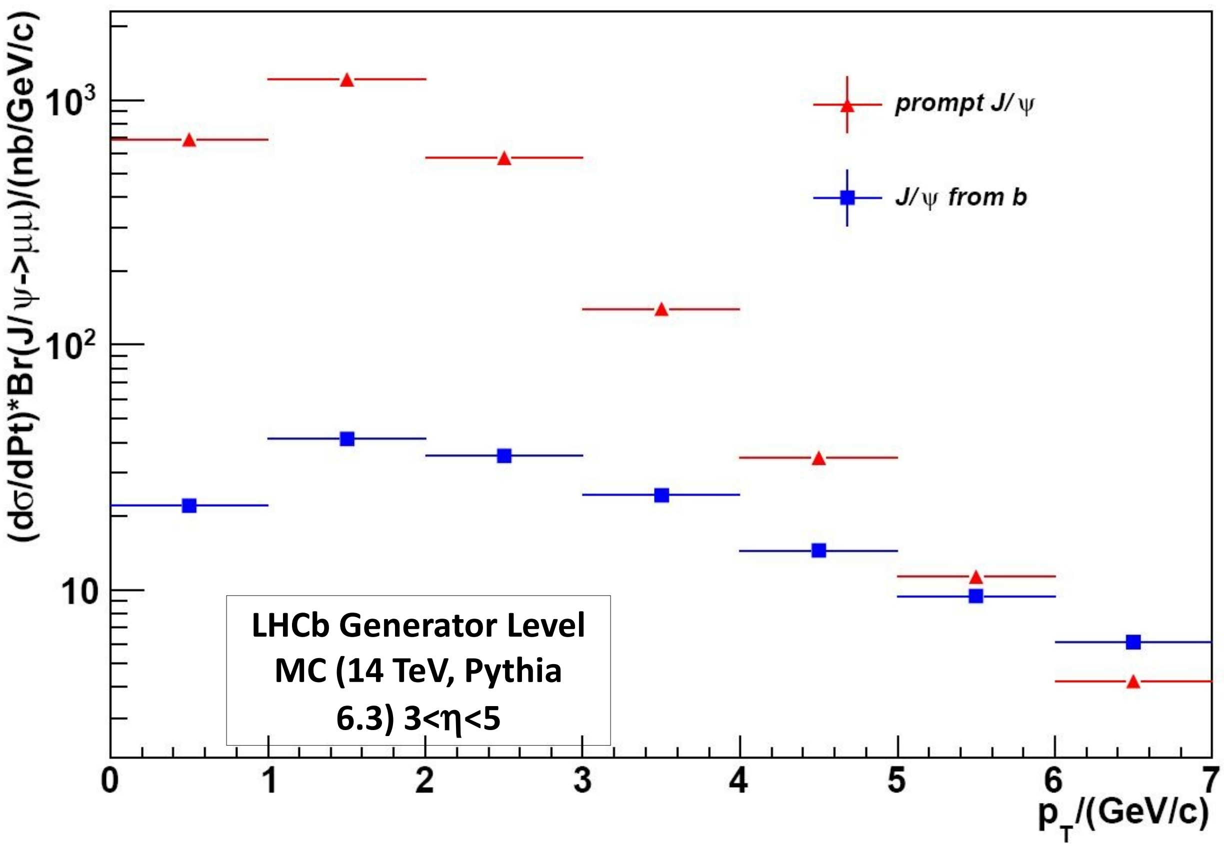


- <u>Quarkonium Physics Program</u>:
  - Measurement of J/ψ production cross-section in LHCb acceptance ($3<\eta<5$, $p_T<7$ GeV/c),
  - Measurement of J/ψ polarization
  - Similar measurements with ψ(2S), Υ(1S), Υ(2S), Υ(3S).
  - Production of χ_c, h_c
  - Extensive studies of B_c, X(3872)

Monte Carlo Tools

- PYTHIA 6.3 for the studies shown here:
  - Production of J/ψ through ***Color Single Model***.
- PYTHIA 6.4 for the current Monte Carlo productions:
  - With ***Color Octet Model*** added, tuned to reproduce CDF measurements see note CERN-LHCb-2007-042.
- EvtGen for decays:
  - Generator package which allows to have a detailed description of **$b \to J/\psi\ X$ decays**.
  - Also allows correct **angular correlations** in decays of polarized particles.
- PHOTOS for **radiative corrections**.

Monte Carlo J/ψ Samples



In LHCb acceptance ($3<\eta<5$, $p_T<7$ GeV/c):

- $\sigma(pp \to \text{prompt } J/\psi\ X) \times Br(J/\psi \to \mu^+\mu^-) = 2.7\ \mu b$
- $\sigma(pp \to (b \to J/\psi\ X)\ X') \times Br(J/\psi \to \mu^+\mu^-) = 0.15\ \mu b$

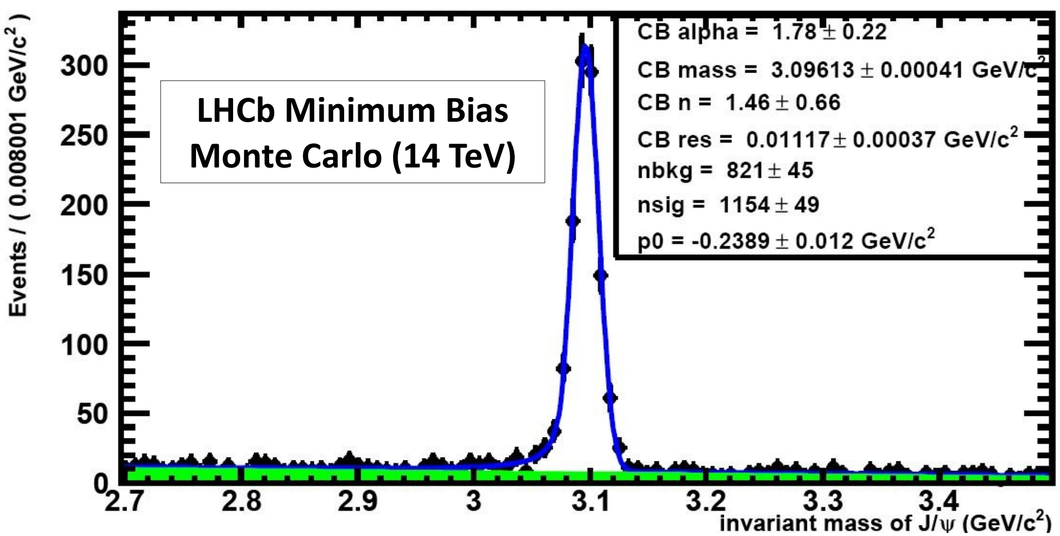
<u>NB</u>: *the analysis presented here does not depend on the exact spectrum of the J/ψ.*

$J/\psi \rightarrow \mu^+ \mu^-$ Reconstruction

• Selection based on positive muon identification of the two μ, cut on the μ transverse momentum p_T>0.7 GeV/c and on the quality of the $\mu^+\mu^-$ vertex.

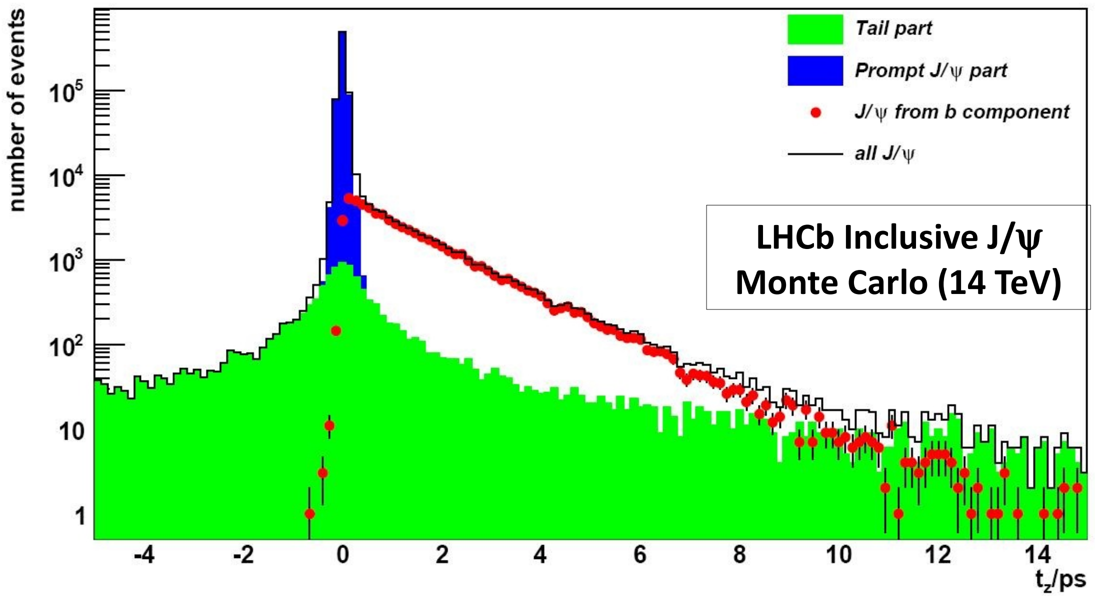
• Invariant mass plot on fully simulated minimum bias events (with ***all background included***):

- Mass resolution: **11.0 ± 0.4 MeV/c^2**,
- S/B=**17.6 ± 2.3** in ±3σ mass window,
- 1.3x10^9 reconstructed after L0 trigger J/ψ for 1 fb^{-1} ($\sqrt{s}$=14 TeV)
- Or **0.65x10^6 for 1 pb^{-1}** at $\sqrt{s}$ = 7 TeV



Separating prompt J/ψ from J/ψ from b

- Use pseudo-propertime: $$t = \frac{dz}{p_z^{J/\psi}} \times m_{J/\psi}$$



- Prompt component characterized by ***peak at 0***,
- ***Exponential decay*** for J/ψ from b component,
- ***Long tail*** due to association of the J/ψ to a not-related primary vertex.

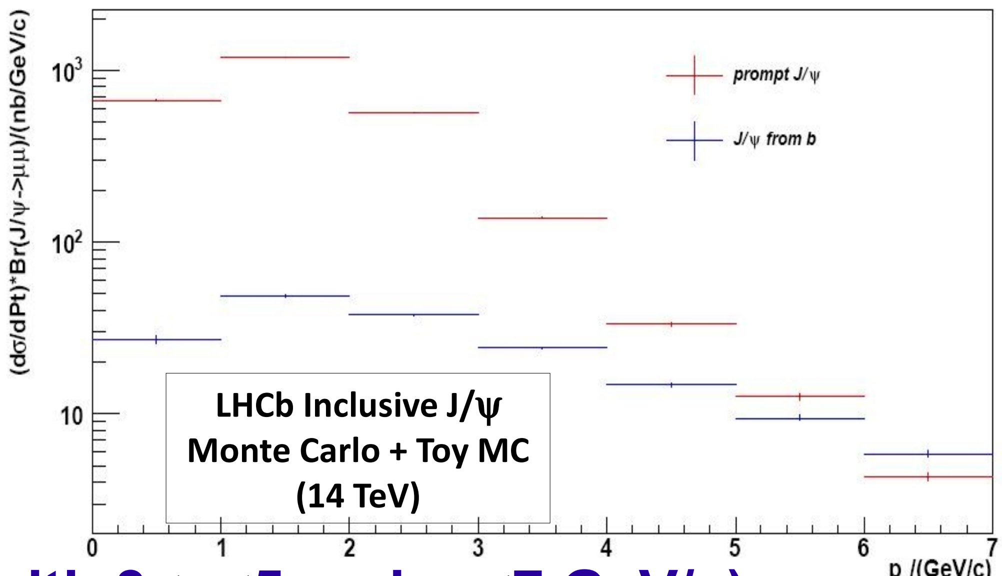
- Combined mass/pseudo-propertime fit will allow to measure both prompt and J/ψ from b production cross sections in η and p_T bins:
  - 4 pseudorapidity η bins, **$3 < \eta < 5$**.
  - 7 transverse momentum p_T bins , **p_T<7 GeV/c**.

Example: fit on MC at $\sqrt{s}$ = 14 TeV

Sample corresponding to 0.8 pb^{-1}, $\sqrt{s}$ = 14 TeV

Signal: Inclusive J/ψ sample

Background: toy Monte-Carlo reproducing behaviour (mass and pseudo-lifetime) seen on the Minimum Bias sample.



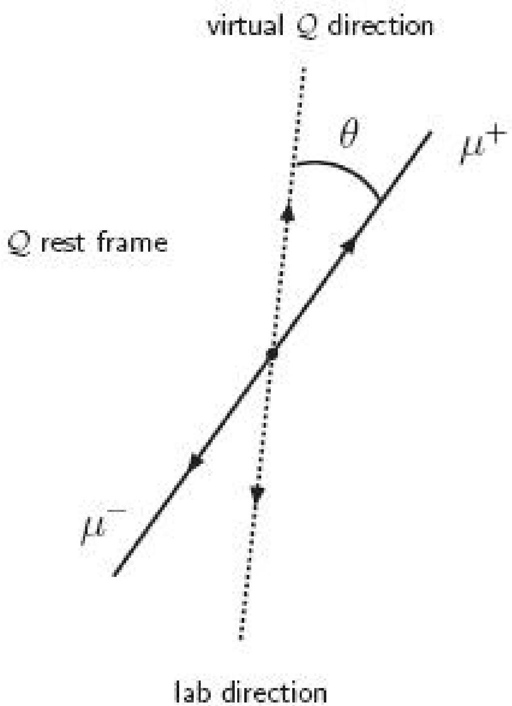
Results (J/ψ with 3<η<5 and p_T<7 GeV/c):

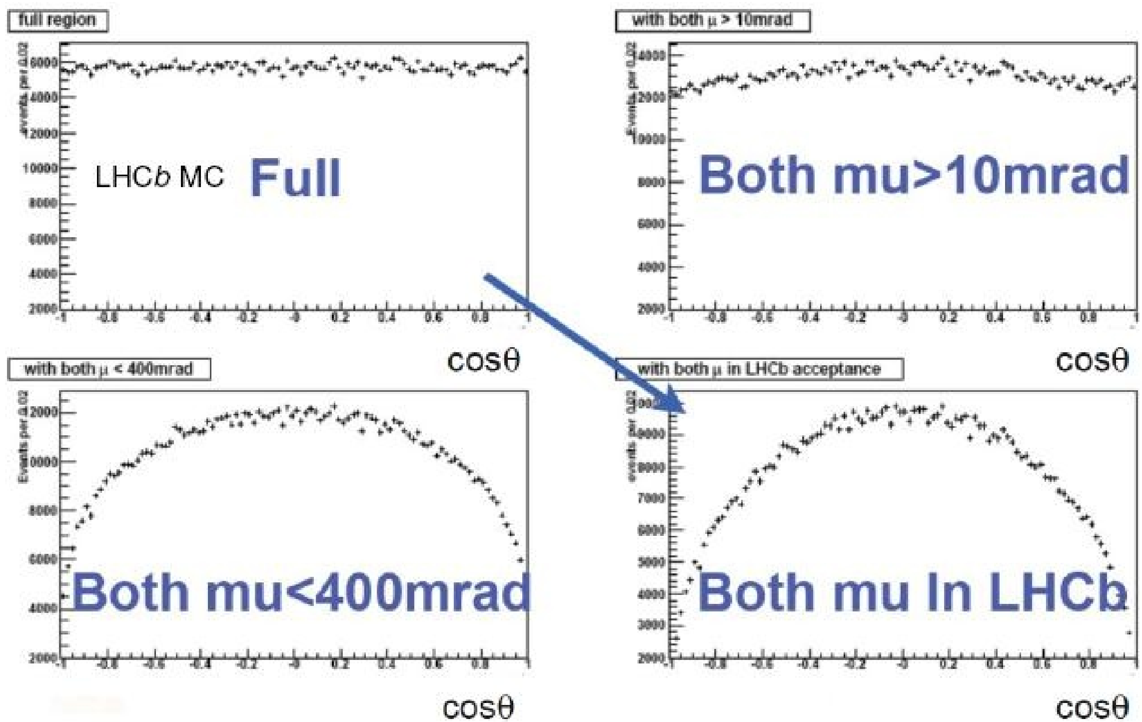
- σ(prompt J/ψ) x Br(J/ψ → $\mu^+ \mu^-$) = 2597 ± 12 (stat) ± 24 (eff) nb [Input: 2667 nb]
- σ(J/ψ from b) x Br(J/ψ → $\mu^+ \mu^-$) = 161 ± 4 (stat) ± 2 (eff) nb [Input: 153 nb]

Statistical error at maximum 10% in each of the analysis bin, for 5pb^{-1} of data at $\sqrt{s}$ = 7 TeV.

Systematics from J/ψ polarization

- Acceptance as a function of cosθ, θ = helicity angle





- Large LHCb detector acceptance dependance on assumed initial polarization of J/ψ.

Systematics from J/ψ polarization

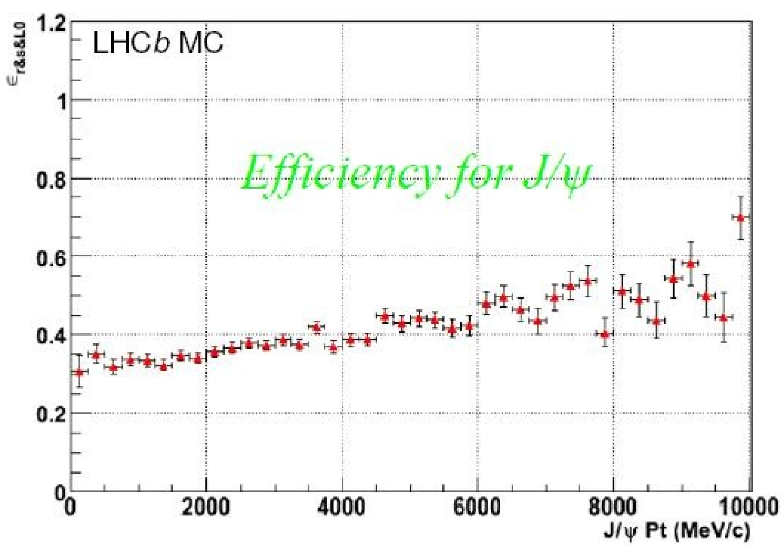
- Study the effect of ignoring the polarization dependance of the efficiency (J/ψ are not polarized in the LHCb Monte Carlo)

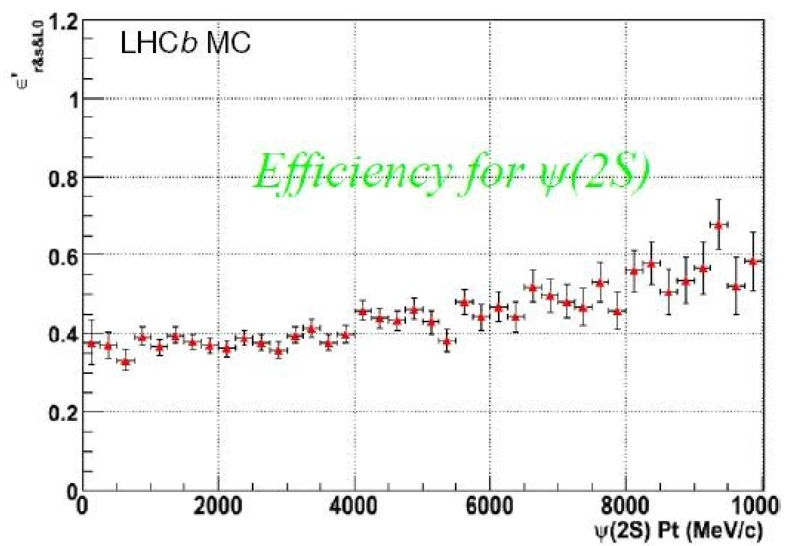
$\alpha_{«data»}$	Measured cross-section, assuming α=0	Input $\sigma_{«data»}$
0	2758 nb ± 27 nb	2820 nb
+1	2738 nb ± 27 nb	3190 nb
-1	2787 nb ± 28 nb	2286 nb

- Systematic error up to **25 %** when ignoring polarization.
- Polarization will be measured (in a second step):
  - in bins of η and p_T,
  - separating prompt and J/ψ from b,
  - With full angular analysis, in different reference frames.

$\psi(2S) \to \mu^+ \mu^-$

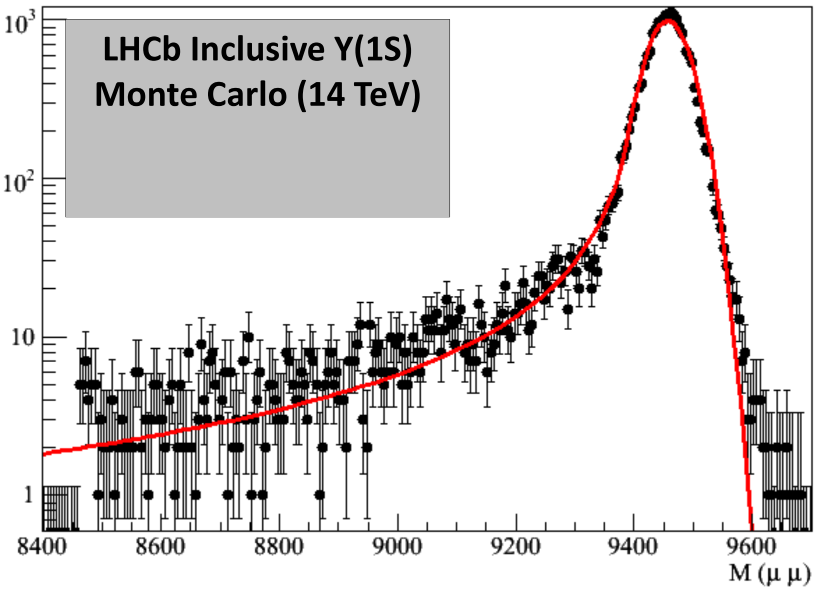
- Similar performances than J/ψ:
  - Mass resolution: **13 MeV/c²**
  - S/B = **2**
  - Number of reconstructed ψ(2S) = **2-4 %** of the number of reconstructed J/ψ.
- Measurement of the ratio σ(ψ(2S))/σ(J/ψ), as a function of p_T, separating prompt and from b.
- Polarization effects complicate also the measurement: systematic error up to 22% on the cross section ratio.





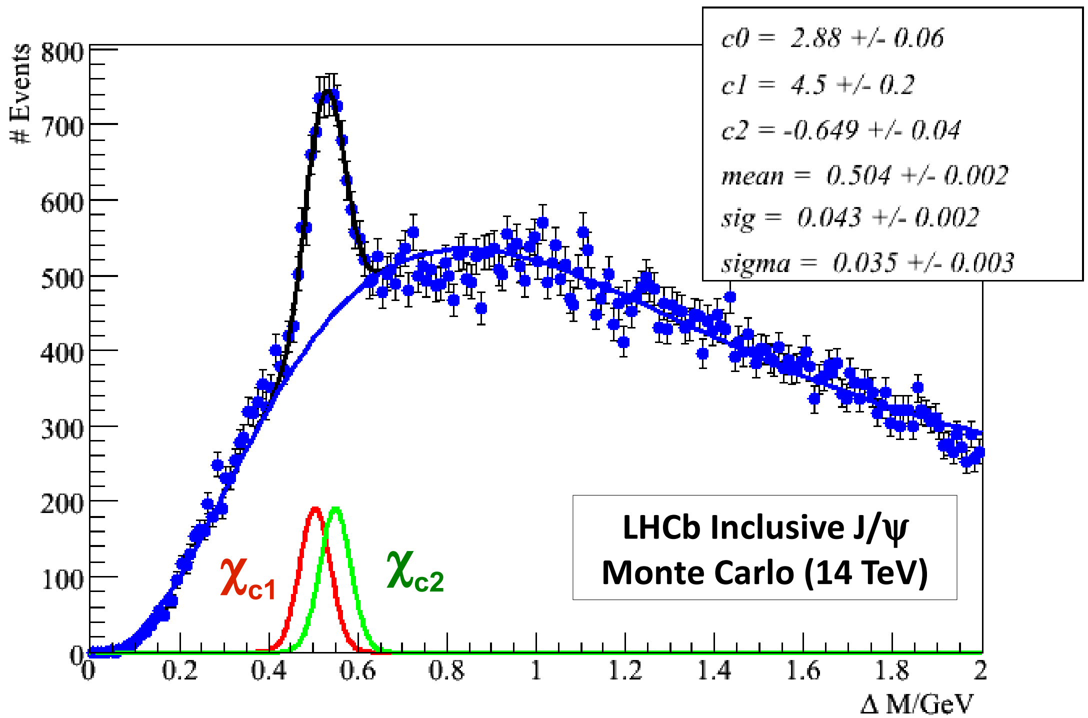
$\Upsilon(1S) \rightarrow \mu^+ \mu^-$

- Loose muon ID selection, and transverse momentum requirement ($p_T(\mu)$>1.5 GeV/c).
- L0 trigger efficiency: 96 %
- Mass resolution: **37 MeV/c^2**
- Similar reconstruction and resolutions will be obtained for the Y(2S) and Y(3S) states: this will allow to separate the 3 Upsilon states.
- Goal is to measure cross-sections and polarization for all di-muon states, as a function of p_T.



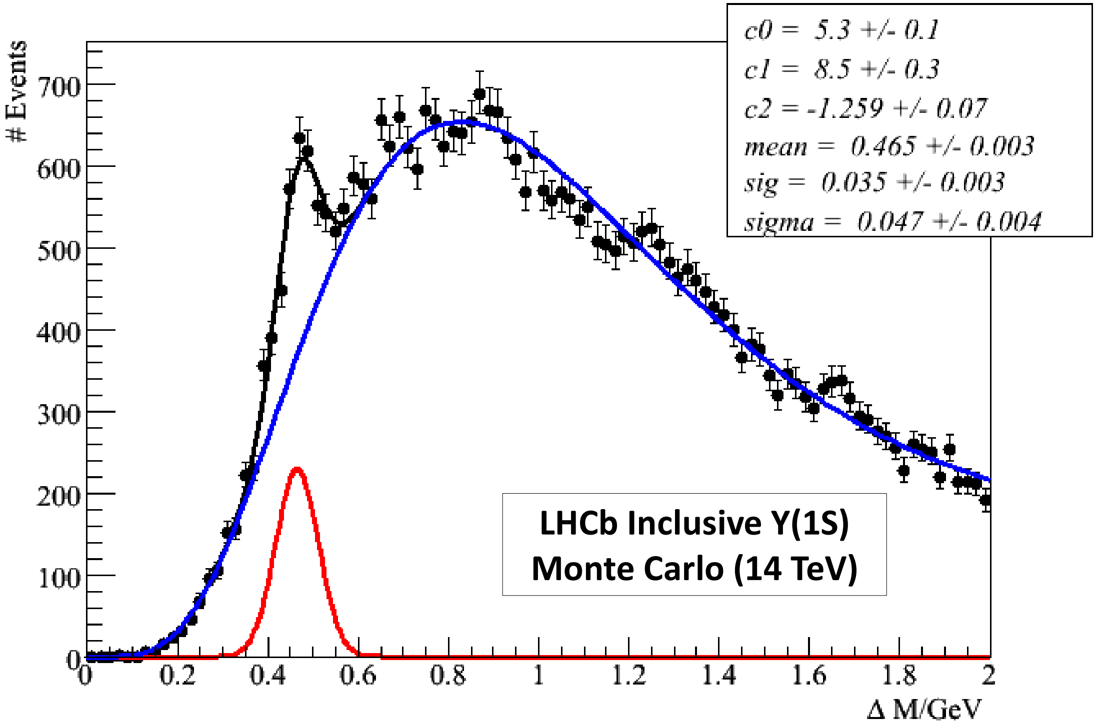
χ_c reconstruction

- J/ψ selection, adding a photon detected in the ECAL with $p_T(\gamma)>500$ MeV/c.
- $\Delta m = m(J/\psi\ \gamma) - m(J/\psi)$ distribution obtained on fully simulated events containing one J/ψ. Since the J/ψ background is very low, the plot contains a large fraction of the total background.
- <u>Δm resolution</u> = **27 MeV/c²**.



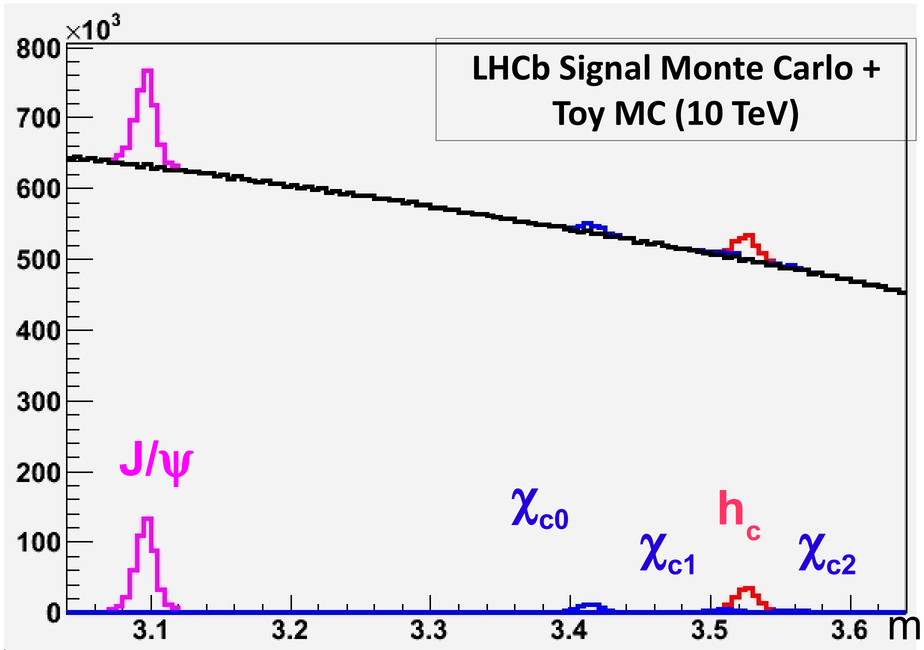
χ_{b2} reconstruction

- Reconstruction of $\chi_{b2}(1P) \rightarrow Y(1S)\,\gamma$
- Photon detected in ECAL, with $p_T(\gamma) > 500$ MeV/c
- Mass resolution: **47 MeV/c²**



h_c reconstruction

- Besides di-muon states, LHCb detector performances will allow to study other states though hadronic decay modes.
- Reconstruction of $h_c \rightarrow \eta_c \gamma$ is difficult (E(γ)~500 MeV in the h_c rest frame).
- Hadronic decay channels look promising: $h_c \rightarrow p\bar{p}$, $h_c \rightarrow \phi K^+ K^-$, $h_c \rightarrow \phi \pi^+ \pi^-$.
  - In particular, $h_c \rightarrow p\bar{p}$ probably visible with first year data, which will give access to $\sigma(h_c)$xBr($h_c \rightarrow p\bar{p}$) relative to $\sigma(J/\psi)$xB($J/\psi \rightarrow p\bar{p}$).

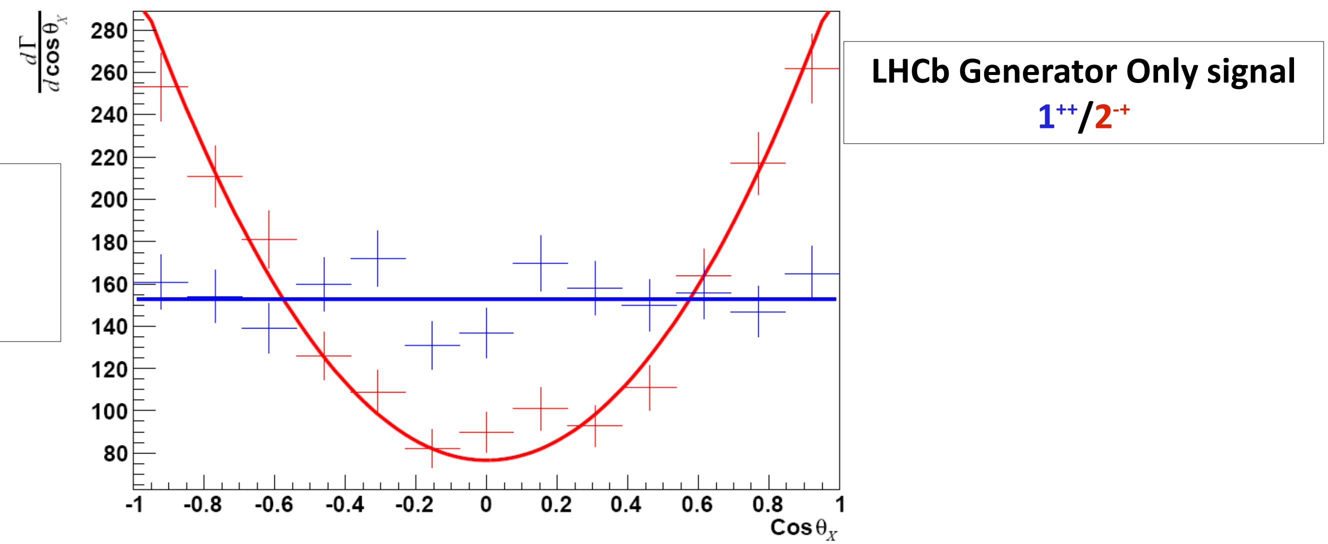


Expected $p\bar{p}$ mass distribution:
- Assuming Br($h_c \rightarrow p\bar{p}$) = 0.12 %,
- Toy Monte Carlo for background, reproducing background seen on fully simulated minimum bias events,
- 100 pb^{-1} at $\sqrt{s}$ = 10 TeV

X(3872) and Z(4430)$^{\pm}$

- Reconstruction of **X(3872) → J/ψ π$^+$ π$^-$** (and the control channel ψ(2S) → J/ψ π$^+$ π$^-$), prompt or from b: systematic study of this state.
- Expect **1800** reconstructed B$^{\pm}$ → X(3872) K$^{\pm}$, with 2 fb^{-1} at $\sqrt{s}$ = 14 TeV, allowing to disentangle unknown quantum number J^{PC}: 1^{++}/2^{-+}.

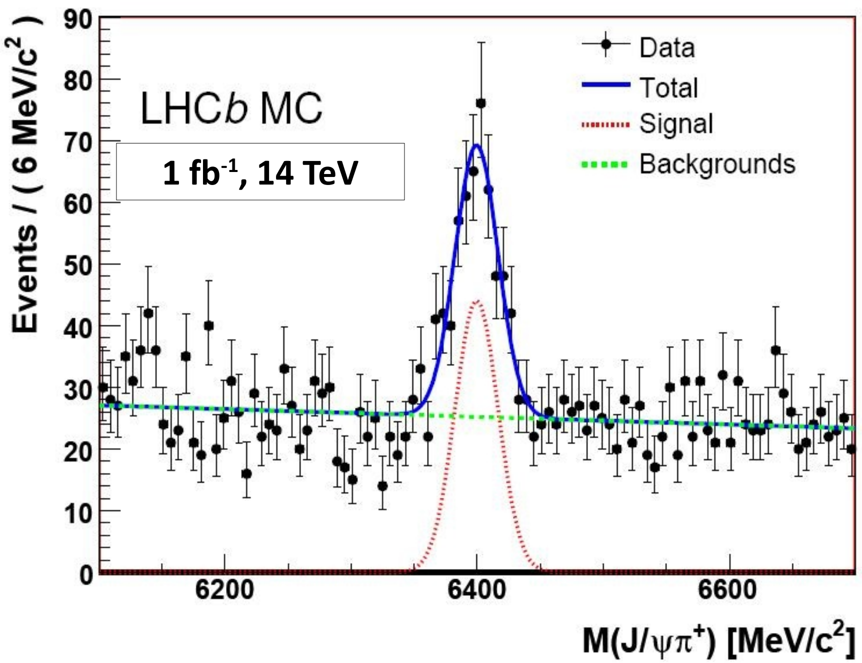
The decay B$^{\pm}$ → X(3872) K$^{\pm}$ forces the X(3872) to have helicity 0



- Similar studies for **B^0 → Z(4430)$^+$(→ ψ(2S)π$^+$)K$^-$**
  - About **6200** signal events can be selected from 2 fb^{-1} of data at $\sqrt{s}$ =14 TeV, assuming B(B^0 → Z(4430)$^+$ K$^-$)xB(Z(4430)$^+$→ψ(2S)π$^+$) = 4.1x10^{-5}
  - Possible to confirm the Belle discovery with about 100 pb^{-1} of data at $\sqrt{s}$ = 7 TeV.

$B_c^{\pm}$

- Measurement of mass, lifetime and production cross section using the decay modes:
  - **$B_c^+ \rightarrow J/\psi\ \pi^+$** assuming $\sigma(B_c^+)$=0.4 μb, and $Br(B_c^+ \rightarrow J/\psi\ \pi^+)$ =0.13 %, expect **310** signal events for 1 fb^{-1} of data at $\sqrt{s}$ = 14 TeV.
    - Production cross section relative to $B^+(\rightarrow J/\psi\ K^+)$
  - **$B_c^+ \rightarrow J/\psi\ \mu^+\ X$**: signal yield one order of magnitude larger, production cross section measurement possible with 2010 data.



Conclusions

- LHCb will measure production cross sections and polarization of di-muon states, in the LHCb acceptance: $3 < \eta < 5$, p_T<7 GeV/c.
- Other quarkonium states will also be looked at: h_c, χ_c, χ_b, B_c.
- LHCb performances will allow to also study associate productions: J/ψ+J/ψ, J/ψ+$c\bar{c}$, either reconstructing D or tagging it with a displaced e or μ.
- Study of « exotic » states: X(3872) and Z(4430).
- Similar states can also be searched in (Quarkonium $\pi^+ \pi^-$) mass spectra: $Y_b \rightarrow Y(1S)\, \pi^+ \pi^-$, $B_c^{**} \rightarrow B_c^+ \pi^+ \pi^-$.