Prompt J/ψ and b → J/ψ X production in pp collisions at √s = 7 TeV

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Introduction I

- **J/ψ produced in abundance at LHC:** expect $\sigma(pp \to X + J/\psi) \approx O(0.1)$ mb $\Rightarrow$ enough statistics to study the production cross sections already with the first LHC data.

- Measurement very important:
  - ★ J/ψ production mechanism not well understood
  - ★ $b \to J/\psi X$ decays fundamental for the LHCb core physics program

- **3 main sources of J/ψ :**
  - ★ direct production in pp collisions
  - ★ feed down from heavier charmonium states (ψ(2S), $\chi_{c,\dots}$)
  - ★ J/ψ from b-hadron decay chains

$$\left.\begin{array}{l}\text{direct production in pp collisions}\\ \text{feed down from heavier charmonium states}\end{array}\right\}\ \text{Prompt } J/\psi \qquad \left.\text{J/ψ from b-hadron decay chains}\right\}\ J/\psi \text{ from b}$$

Introduction II

- I will discuss the measurement of the production cross section both for prompt J/ψ and for J/ψ from b, namely:

$$\sigma = \frac{N\left(J/\psi \rightarrow \mu^+\mu^-\right)}{L \times \varepsilon \times B\left(J/\psi \rightarrow \mu^+\mu^-\right)}$$

- Measurements restricted to:
  $2.5 < y^{J/\psi} < 4$
  $0 < p_T^{J/\psi} < 10$ GeV/c
  because of the small statistics available

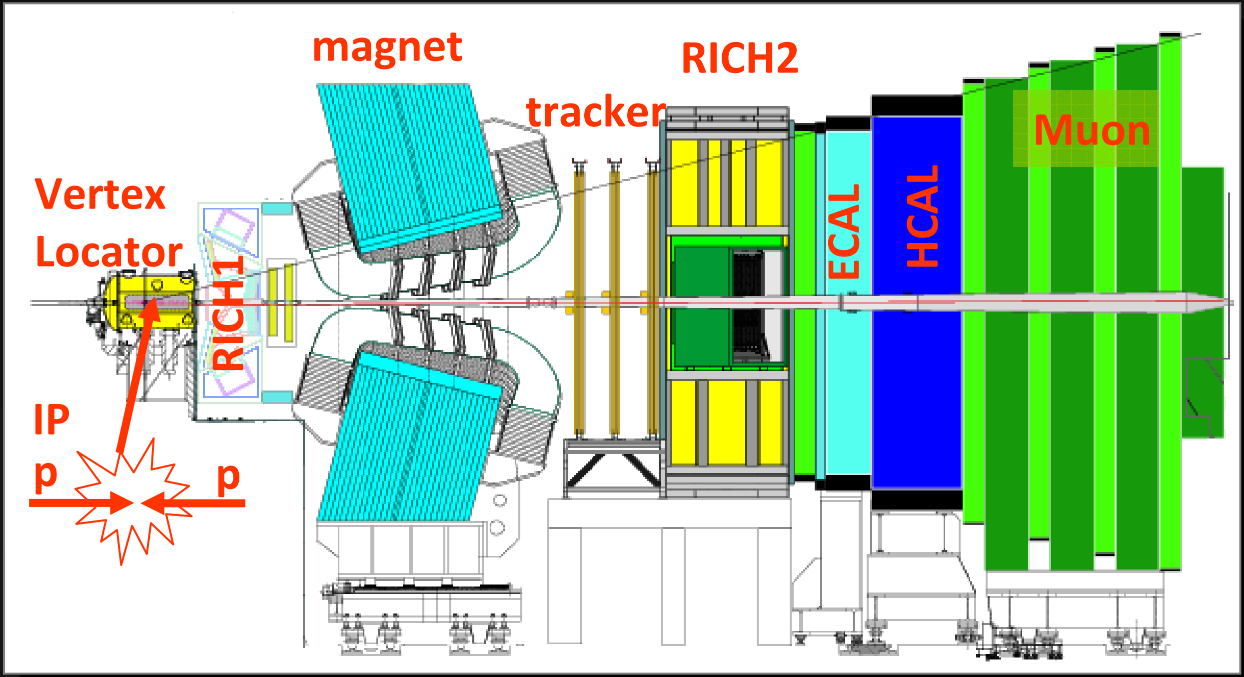
- Results on:
  - ★ $d\sigma/dp_T$ (incl. J/ψ) in 10 bins of $p_T^{J/\psi}$, $0 < p_T^{J/\psi} < 10$
  - ★ σ(incl. J/ψ)
  - ★ σ(J/ψ from b)

The LHCb experiment

Forward Spectrometer

- Angular acceptance : $15<\theta<300$ mrad
- Nominal luminosity: $L = 2 \times 10^{32} cm^{-2}s^{-1}$

Plenary talk on LHCb:
A. Golutvin, 26/07



Performance numbers relevant to J/ψ analysis

Charged tracks $\Delta p/p$ = 0.35 % - 0.55% (S. Borghi, Track1, 22/07, 11:35, Salle Maillot)

Excellent mass resolution

Muon ID: $\varepsilon(\mu\to\mu)$ = 94 %, mis-ID rate $(\pi\to\mu)$ = 1-3 % (A. Powell, Track1, 22/07, 14:00, Salle Maillot)

Vertexing: proper time resolution 30-50 fs

Trigger: 2 levels. L0: hardware, high p_T particles; HLT: software (E. Van Herwijnen, Track1, 22/07, Salle Maillot)

Cross section measurement

$$\sigma = \frac{N\left(J/\psi \to \mu^+\mu^-\right)}{L \times \varepsilon \times B\left(J/\psi \to \mu^+\mu^-\right)}$$

- N: select $J/\psi \to \mu^+\mu^-$ decays and extract the n. of signal events from a fit to the invariant mass distribution
- $\varepsilon = \varepsilon_{acc} \times \varepsilon_{rec} \times \varepsilon_{trig}$: taken from MC and extensively cross-checked with data
- Separation of prompt J/ψ and J/ψ from b: fit to the pseudo-proper time (t_z) distribution $$t_z = \frac{d_z \times M_{J/\psi}}{p_z}$$
- N.B. **for the central cross section values ε is estimated with simulated J/ψ with NO polarization. The effect of polarization will be discussed later**

Event selection

Data sample

- $14.2\ nb^{-1}$ collected between April and June 2010 with low pile-up conditions
  Luminosity used for the cross section measurement : $(14.15 \pm 1.42)\ nb^{-1}$
  (Details of the luminosity measurement method given by M. Ferro-Luzzi - Track 1, 22/07, 9:25, **Salle Maillot)**

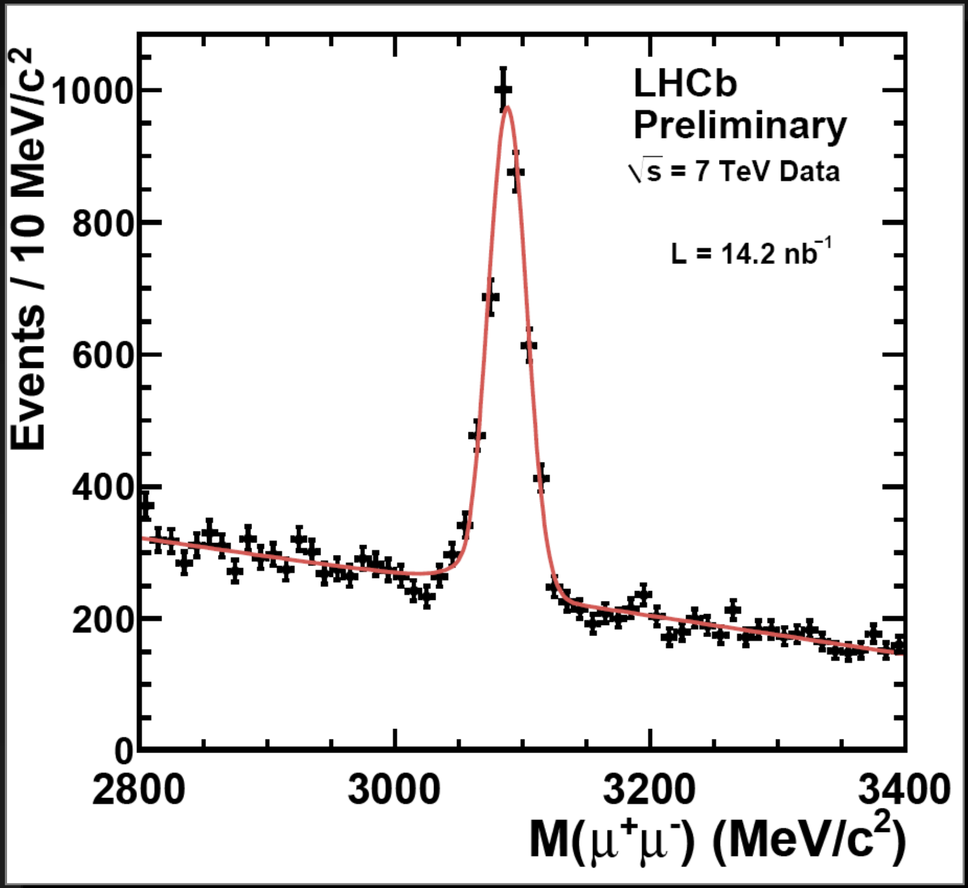
Event selection

- 2 muons
  - ★ with fully reconstructed tracks (VELO + Tracker)
  - ★ identified by the muon system (hits in muon stations inside fields of interest)
  - ★ making a good vertex
  - ★ $p_T > 700$ MeV/c
  - ★ Mass window for signal definition: $(M_{J/\psi} \pm 390)$ MeV/c^2
- Trigger L0:
  - ★ single muon, $p_T > 480$ MeV/c
- HLT:
  - ★ single muon, $p_T > 1.3$ GeV/c .OR. muon pair with $M_{\mu\mu} > 2700$ MeV/c^2

Mass fit

Mass fit with Crystal Ball function and 1st order polynomial for background

$$f(x;\mu,\sigma_M,\alpha,n) = \begin{cases} \dfrac{\left(\frac{n}{|\alpha|}\right)^n e^{-\frac{1}{2}\alpha^2}}{\left(\frac{n}{|\alpha|} - |\alpha| - \frac{x-\mu}{\sigma_M}\right)^n} & \dfrac{x-\mu}{\sigma_M} < -|\alpha| \\ \exp\left(-\dfrac{1}{2}\left(\dfrac{x-\mu}{\sigma_M}\right)^2\right) & \dfrac{x-\mu}{\sigma_M} > -|\alpha| \end{cases}$$



Fit results (2.5<y<4, p_T<10 GeV/c):

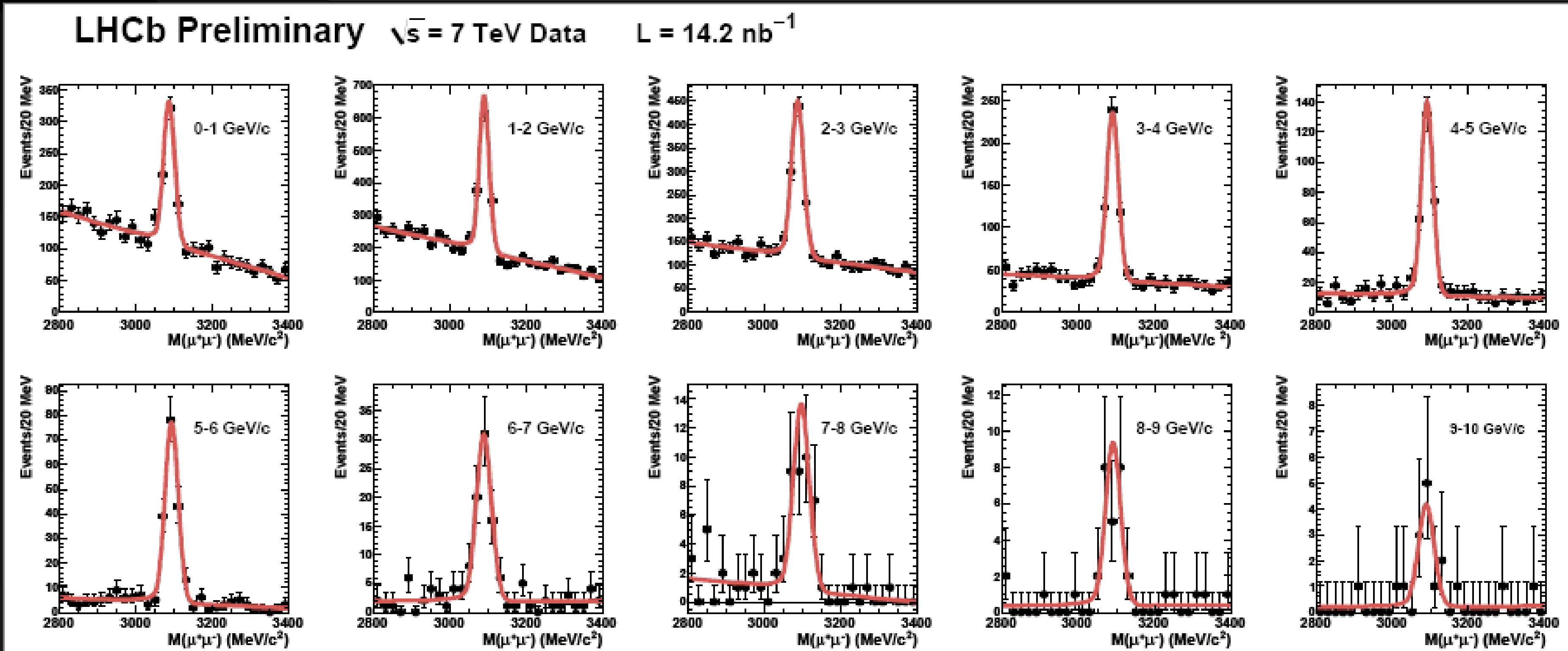
Signal = **2872 ± 73**

S/B = **1.3**

Mean = **(3088 ± 0.4) MeV/c²**

σ = **(15.0 ± 0.4) MeV/c²**

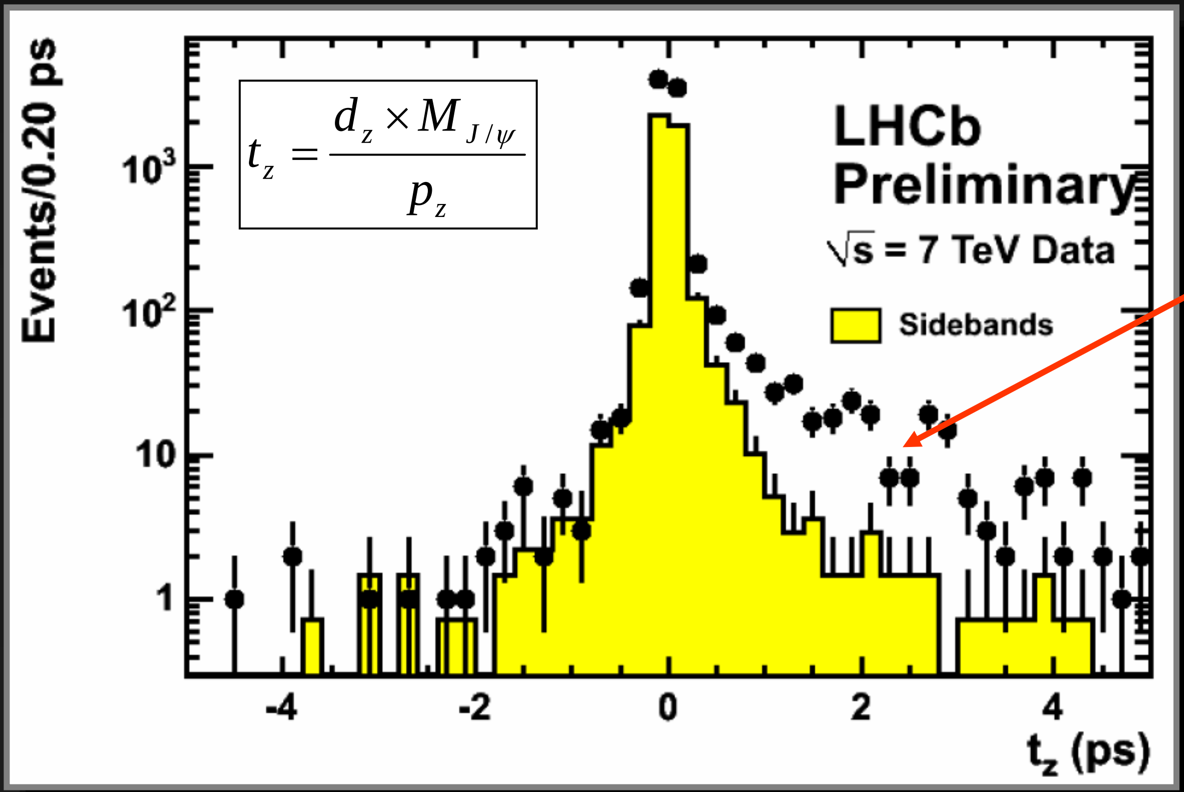
Mass fits in p_T bins



p_T (GeV/c)	total	0 – 1	1 – 2	2 – 3	3 – 4	4 – 5
N	2872 ± 73	427 ± 31	823 ± 40	687 ± 36	398 ± 24	259 ± 18
background	2273 ± 166	520 ± 61	907 ± 79	568 ± 64	182 ± 36	55 ± 20
σ_M (MeV/c^2)	15.0 ± 0.4	14.7 ± 1.2	13.1 ± 0.7	16.0 ± 0.9	15.6 ± 1.0	15.5 ± 1.1
p_T (GeV/c)		5 – 6	6 – 7	7 – 8	8 – 9	9 – 10
N		163 ± 13	74 ± 9	34 ± 6	23 ± 5	10 ± 3
background		18 ± 11	9 ± 8	4 ± 5	1 ± 3	0 ± 2
σ_M (MeV/c^2)		17.2 ± 1.3	19.9 ± 2.5	21.0 ± 1.3	20.0 ± 3.1	21.0 ± 26.2

Prompt/delayed separation

- Use pseudo-proper time t_z to distinguish prompt from B decay-produced J/ψ
- **Extract f_b = fraction of J/ψ from b decays with an unbinned maximum likelihood fit to t_z**



J/ψ from b component clearly visible

Fit results

- n_p ,n_b ,n_{bkg} : number of prompt J/ψ, J/ψ from b and background events
- μ, σ_1 , σ_2 , β: mean, resolutions and fraction for the 2 gaussians for signal resolution function
- τ_b : pseudo b life time
- Background from invariant mass sidebands

Fit results :

n_p = **2527 ± 74**

n_b = **316 ± 24**

n_{bkg} = **28500 ± 180**

μ = **(-8.5±1.5) fs**

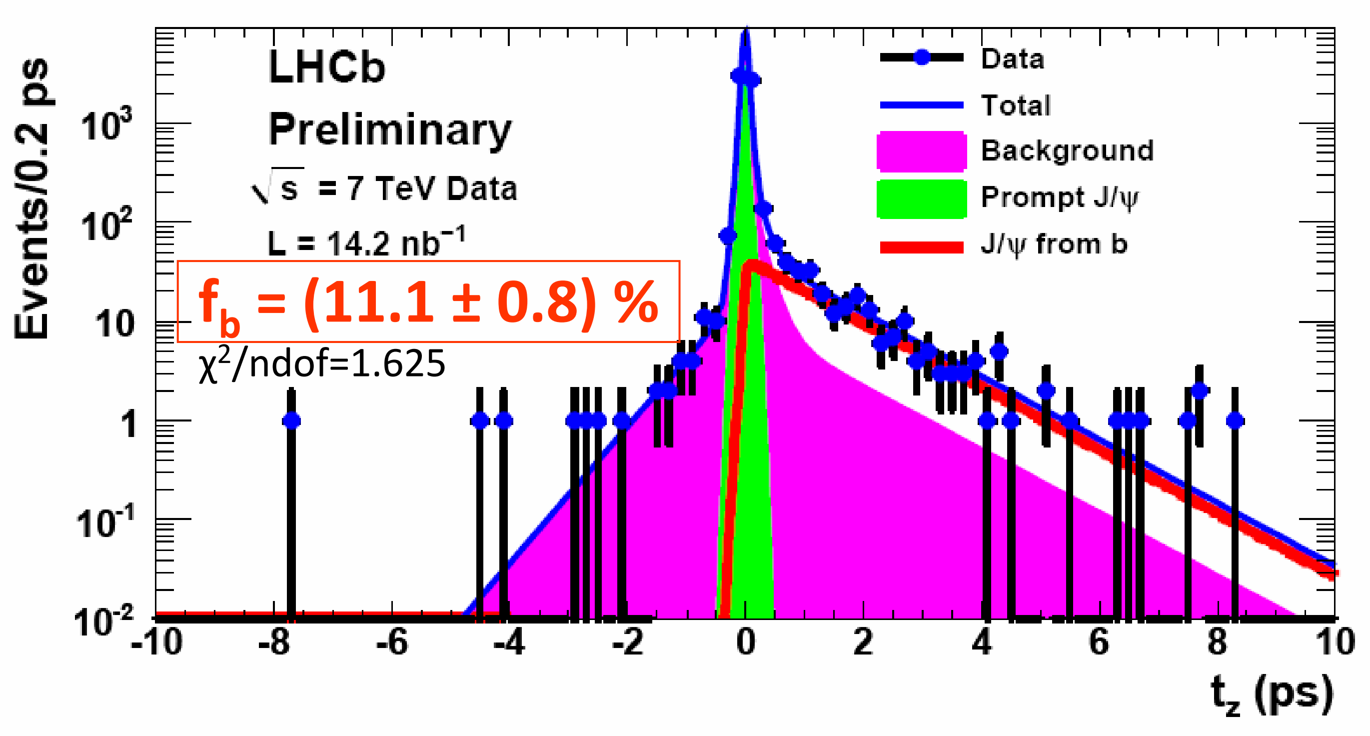
σ_1 = **(111±13) fs**

σ_2 = **(40 ±3) fs**

β = **0.26 ± 0.06**

τ_b = **(1.35 ± 0.10) ps**

$f_b = n_b/(n_p+n_b)$ = **(11.1 ± 0.8)%**

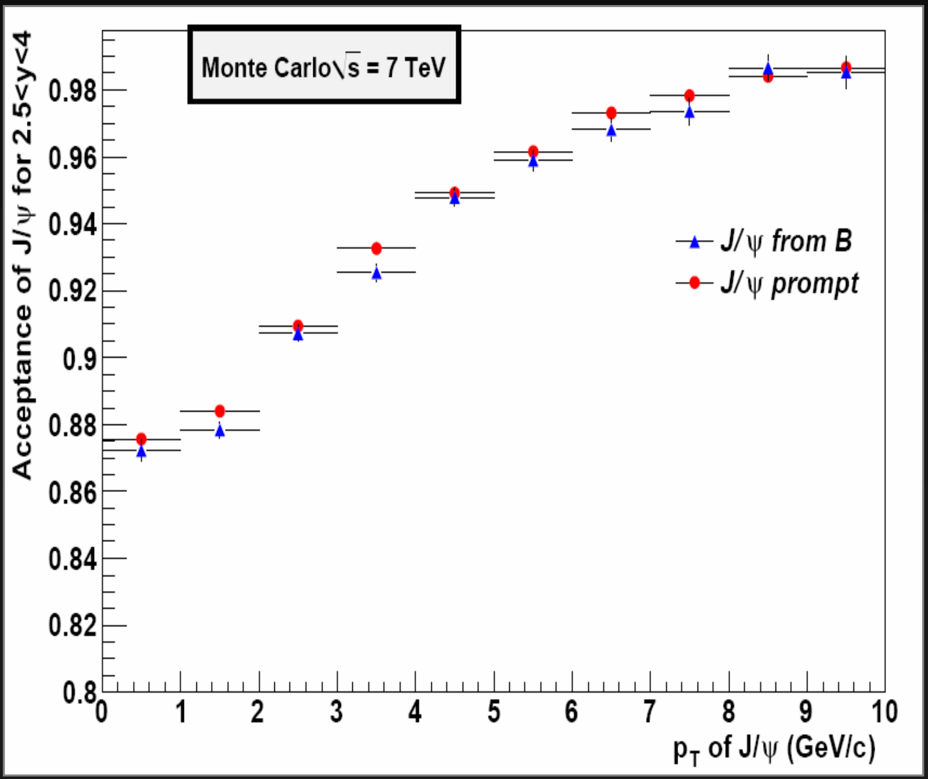


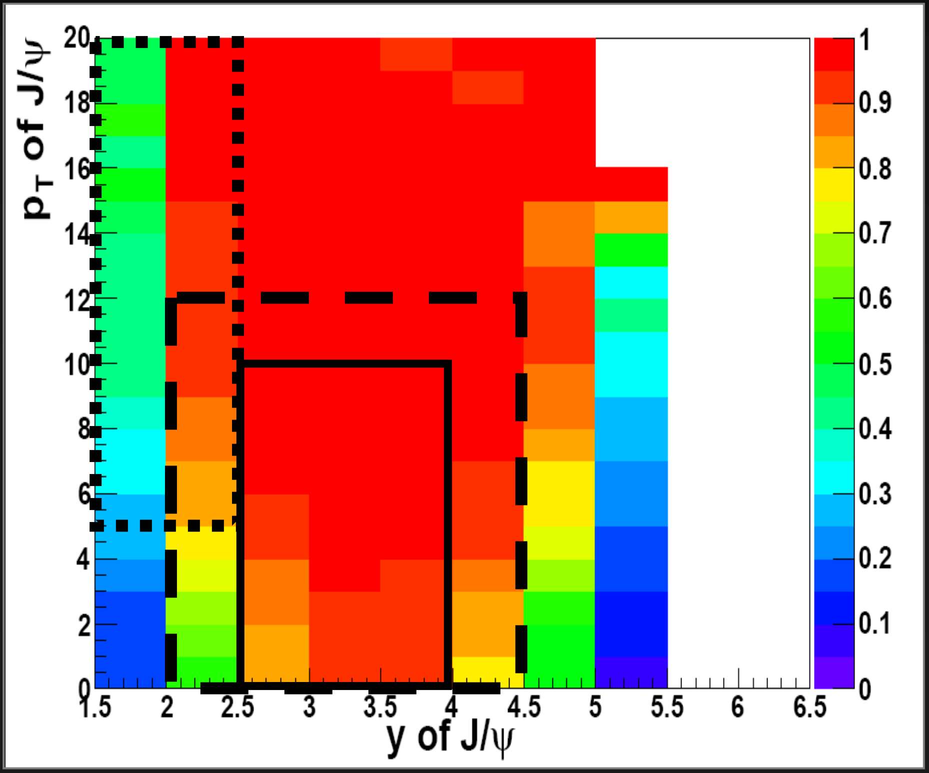
A crosscheck with a binned fit gives consistent results

Statistical errors only

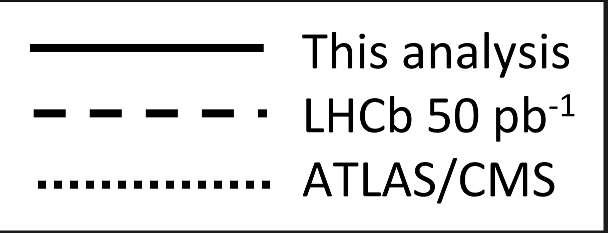
Efficiencies: $\varepsilon = \varepsilon_{acc} \times \varepsilon_{rec} \times \varepsilon_{trig}$

$$\text{Acceptance } (\varepsilon_{acc}) = \frac{J/\psi \text{ in each } p_T \text{ bin with both } \mu \text{ in LHCb}}{J/\psi \text{ generated in each } p_T \text{ bin}}$$



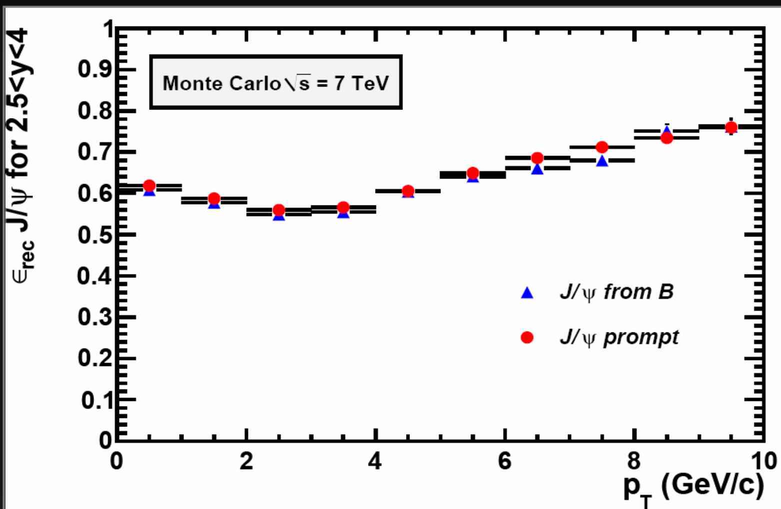


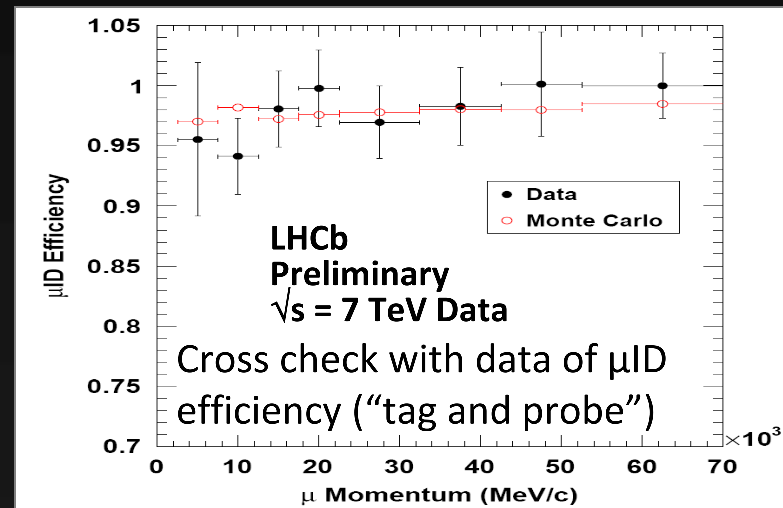
- With more statistics (~50 pb^{-1}) can explore a larger phase space and overlap with ATLAS/CMS acceptance

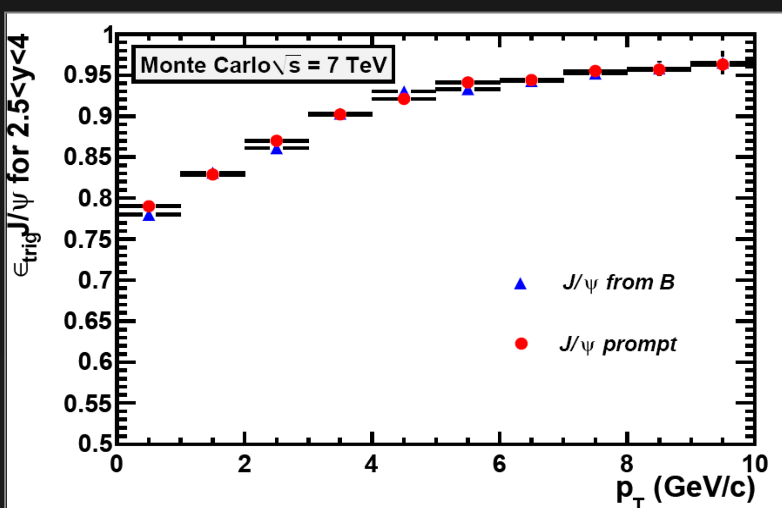


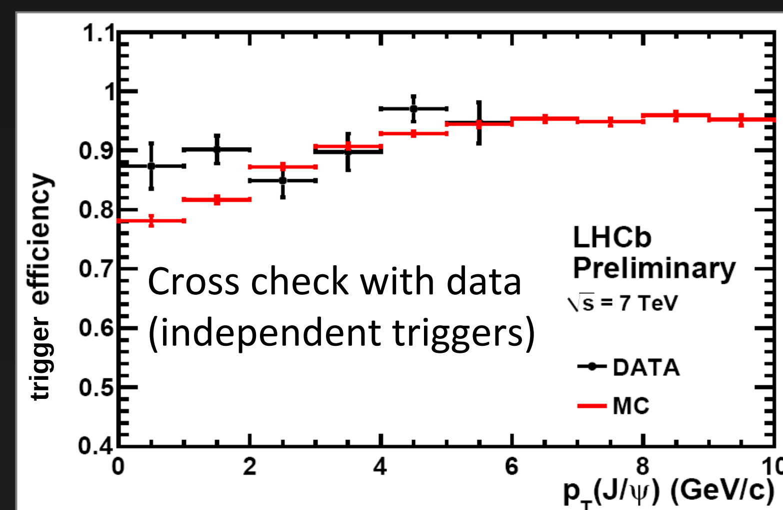
Efficiencies: $\varepsilon = \varepsilon_{acc} \times \varepsilon_{rec} \times \varepsilon_{trig}$

- ε_{rec}: (reconstructed J/ψ) / (J/ψ in acceptance)
- ε_{trig}: (triggered J/ψ) / (reconstructed J/ψ)



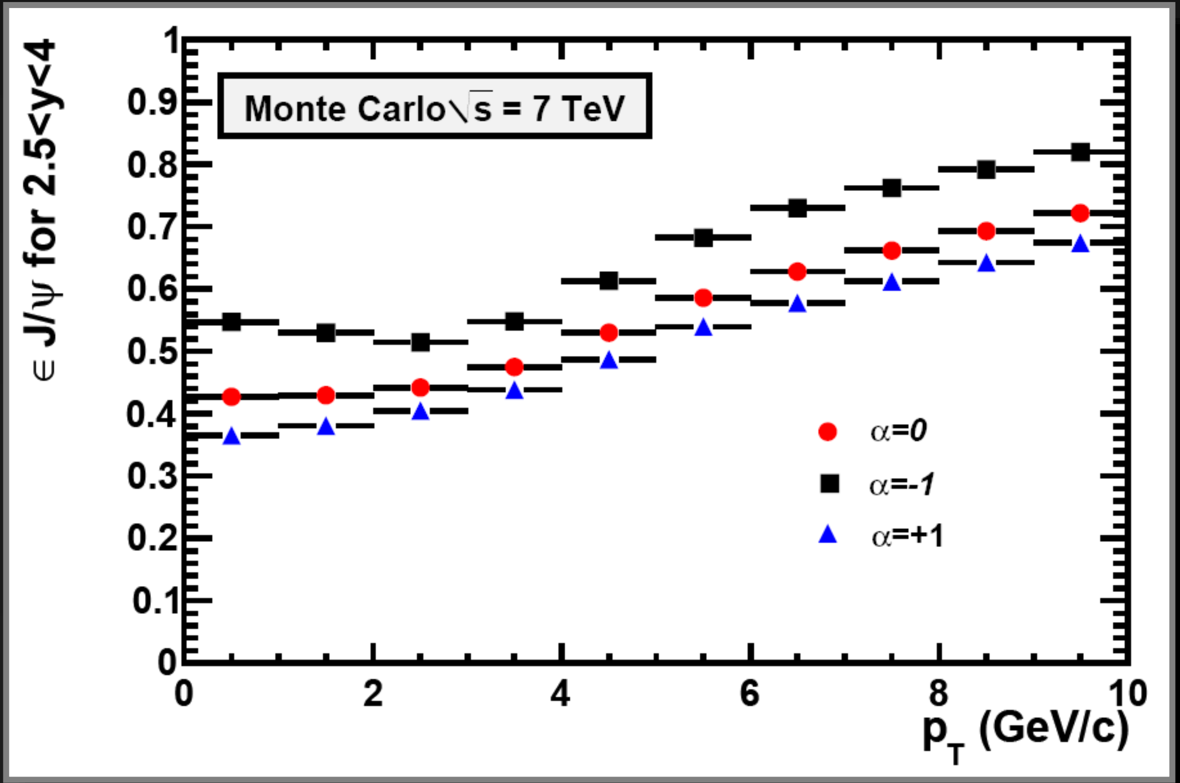






Total efficiency

- ε depends strongly on the polarization
- Three polarization scenarios ($\alpha = \lambda_\theta$ = 0,-1,+1; angular distribution in the helicity reference frame; azimuthal part ignored) considered
- ε evaluated in the 3 polarization cases. Deviation of $\sigma(\alpha = -1,+1)$ wrt $\sigma(\alpha = 0) \Rightarrow$ systematic error



With more statistics, a direct measurement of the polarization with full angular analysis, in different reference frames and in bins of y and p_T is foreseen

systematic errors

- Systematic errors mainly coming from the discrepancy data/MC. Dominant contributions from trigger and tracking efficiencies.
- Large systematic uncertainty from luminosity
- The p_T spectrum of J/ψ from b is not measured (low statistics) $\Rightarrow$ additional systematic errors on σ due to ε dependence on p_T

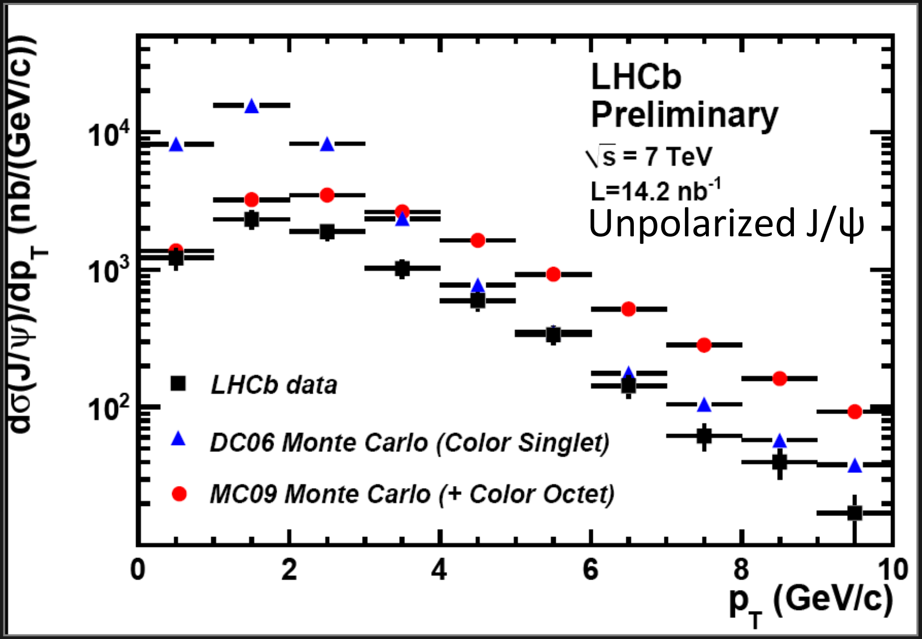
Quantity	Systematic error	Comment
Trigger	2.8 % to 9.4 %	Correlated between bins
Muon identification	2.5%	Correlated between bins
Tracking efficiency	8%	Correlated between bins
Track χ^2	2%	Correlated between bins
Vertexing	1%	Correlated between bins
Bin size	1.3% to 3.9%	Bin dependent
Inter-bin cross-feed	0.5%	Correlated between bins (not applied to the total cross section)
Mass fit procedure	3%	Correlated between bins
Loss of events due to the radiative tail	1%	Correlated between bins
$\mathcal{B}(J/\psi \to \mu^+\mu^-)$	1%	Correlated between bins
Luminosity	10%	Correlated between bins
b momentum spectrum	4 %	Applies only to J/ψ from b cross section
b hadronization fractions	2%	Applies only to extrapolation of $b\bar{b}$ cross section
$\mathcal{B}(b \to J/\psi X)$	9%	Applies only to extrapolation of $b\bar{b}$ cross section

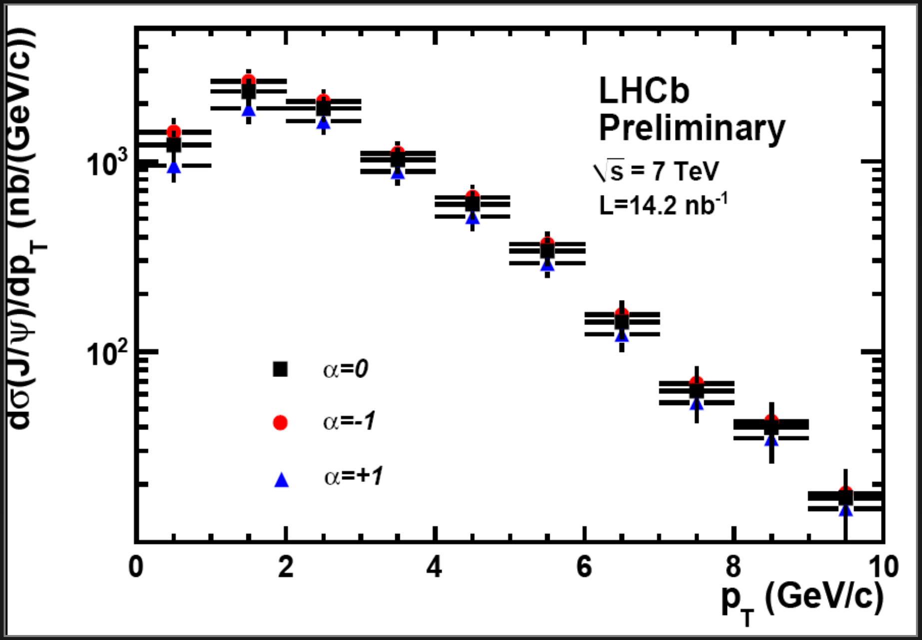
Preliminary results

polarization

- σ(incl. J/ψ, $p_T^{J/\psi} < 10$ GeV/c, $2.5 < y^{J/\psi} < 4$) = $(7.65 \pm 0.19 \pm 1.10\boxed{^{+0.87}_{-1.27}})$ μb

- $d\sigma/dp_T$(incl. J/ψ, $2.5 < y^{J/\psi} < 4$):





- σ(J/ψ from b, $p_T^{J/\psi} < 10$ GeV/c, $2.5 < y^{J/\psi} < 4$) = $(0.81 \pm 0.06 \pm 0.13)$ μb

Preliminary results: extrapolated cross sections

- Extrapolations with PYTHIA 6.4 (LEP hadronization fractions assumed)

1. ½ production cross section for b or $\bar{\text{b}}$ in LHCb acceptance

$$\frac{\sigma(pp \to H_b X, 2 < \eta(H_b) < 6)}{2} = 84.5 \pm 6.3 \pm 15.6\,\mu\text{b}$$

2. Total b$\bar{\text{b}}$ production cross section

$$\sigma(pp \to b\bar{b}X) = 319 \pm 24 \pm 59\,\mu\text{b}$$

An independent σ(bb) measurement by LHCb presented by S. Stone (Track 1, 23/07, 10:00, Salle 191) with results in excellent with the above ones. Averaging:

$$\frac{\sigma(pp \to H_b X,\, 2 < \eta(H_b) < 6)}{2} = 77.4 \pm 4.0 \pm 11.4\,\mu\text{b}$$

$$\sigma(pp \to b\bar{b}X) = 292 \pm 15 \pm 43\,\mu\text{b}\,.$$

LEP b hadronization fractions

$$\frac{\sigma(pp \to H_b X,\, 2 < \eta(H_b) < 6)}{2} = 88.3 \pm 4.5 \pm 13.0\,\mu\text{b}$$

$$\sigma(pp \to b\bar{b}X) = 333 \pm 17 \pm 49\,\mu\text{b}\,.$$

TeVatron b hadronization fractions

Conclusions and perspectives

- **J/ψ production cross section measured on 14.2 nb^{-1} showing an excellent performance of LHCb**

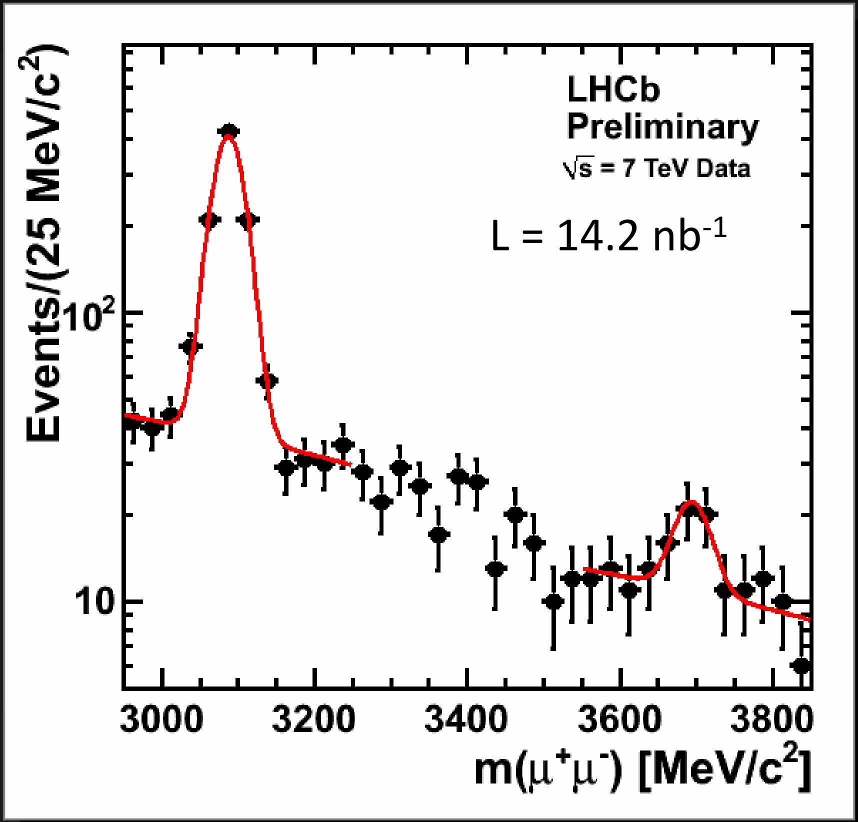
- The measurements discussed are very important for the LHCb core physics program (B physics with J/ψ in final state, tuning of b-hadron spectra in MC, etc.)

With more statistics:

- Aim at a measurement in 5 bins of y (2<y<4.5) and 12 bins of p_T ($0<p_T<12$GeV/c) with 10% accuracy in each bins (need ~50 pb^{-1}) separating in each bin the prompt and the delayed component

- Extend the analysis to ψ(2S) and other quarkonia

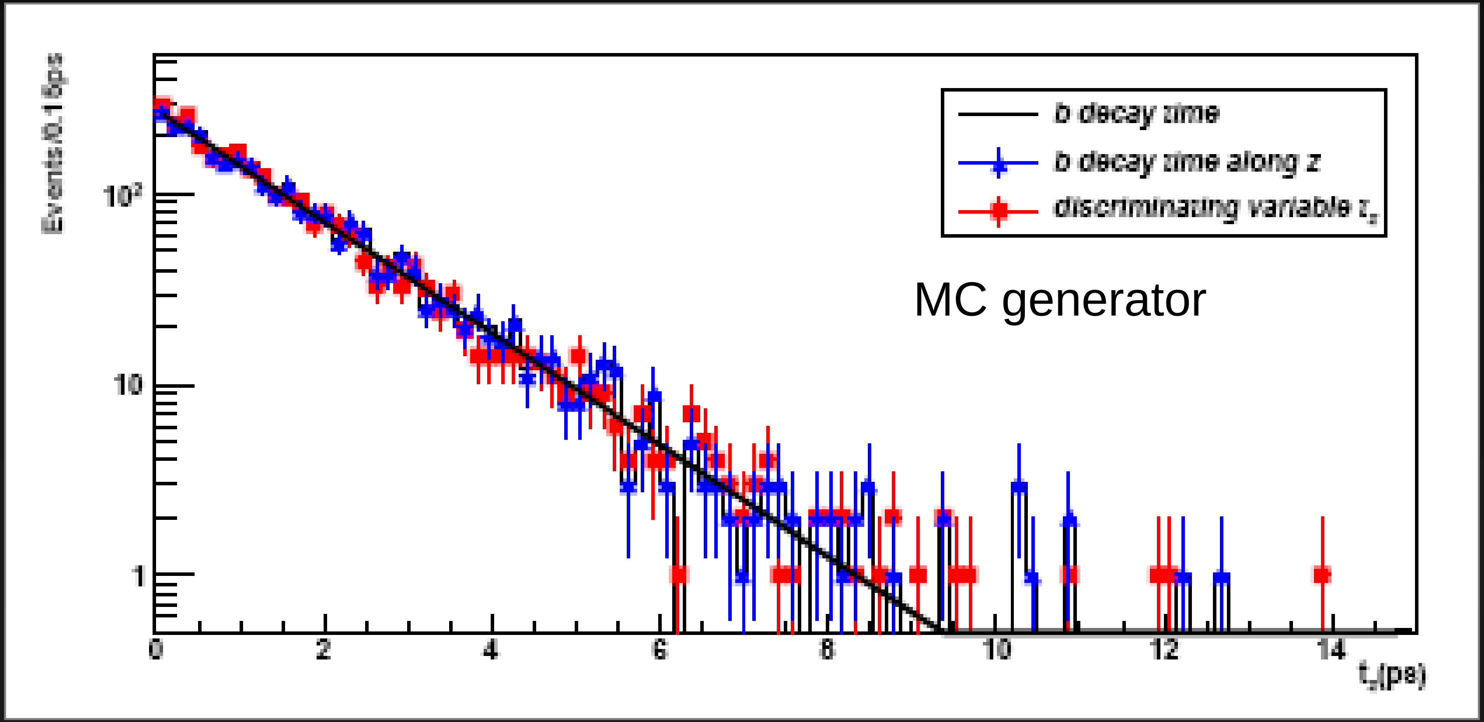
- Measure the polarization with full angular analysis and in bins of y and p_T



Thank you!

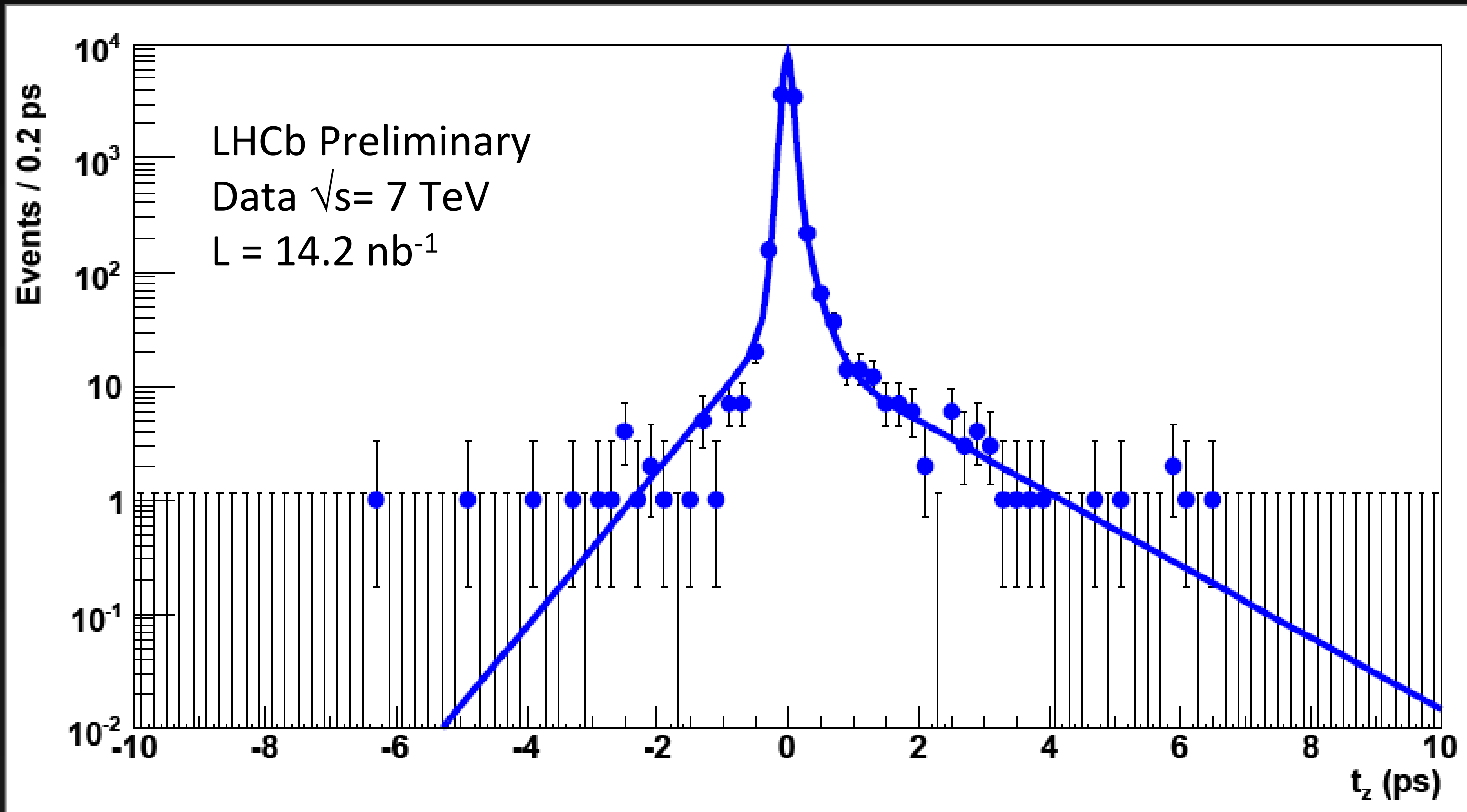
Back up slides

Pseudo-proper time description



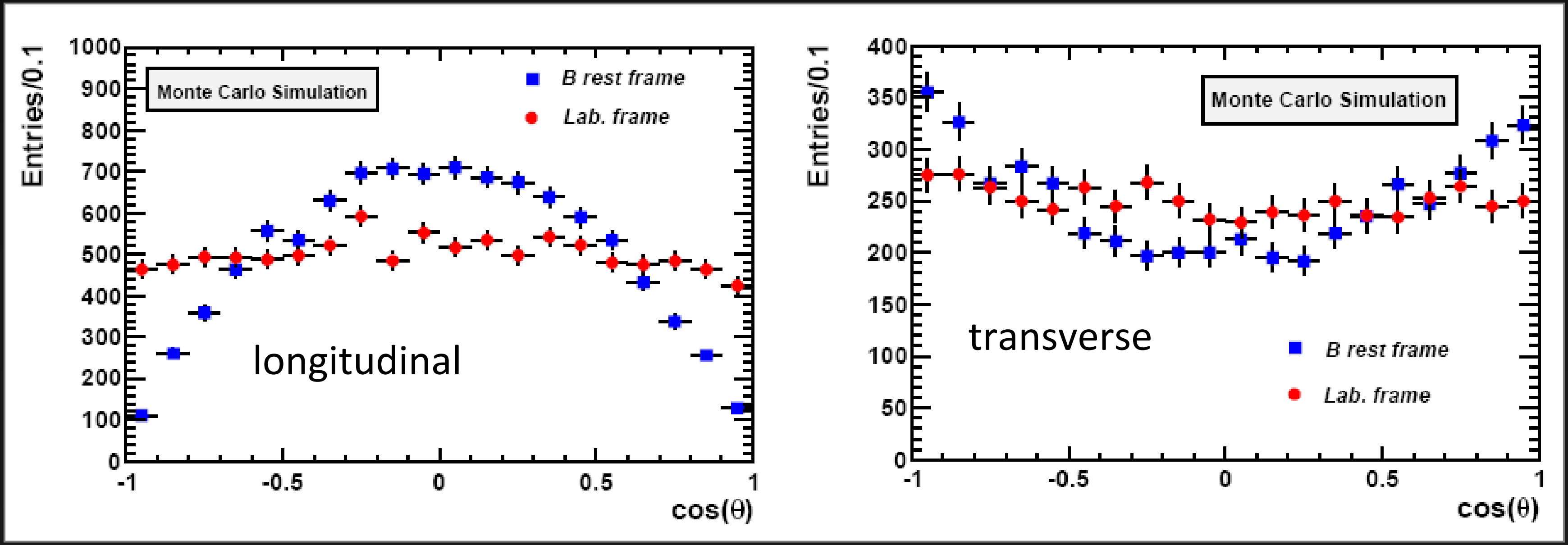
- Describing the t_z distribution with an exponential assumes that the average lifetime of the B-hadron admixture can be well described with a single exponential

Background parametrization in t_z fit



Background is described by a gaussian and 3 exponetials (2 for t_z>0 and 1 for t_z<0)

Polarization dependence for J/ψ from b



J/ψ from b cosθ distribution

Hadronization fractions

Species	Z^o fraction (%)	Tevatron fraction (%)
B^-	40.3 ± 0.9	33.3 ± 3.0
B^0	40.3 ± 0.9	33.3 ± 3.0
B_s	10.4 ± 0.9	12.1 ± 1.5
Λ_b	9.1 ± 1.5	21.4 ± 6.8

Definition of extrapolated cross sections

- Definitions (α_{LHCb}, $\alpha_{4\pi}$ = extrapolation factors)

$$\frac{\sigma(pp \to H_b X, 2 < \eta(H_b) < 6)}{2} = \alpha_{\mathrm{LHCb}} \frac{\sigma\,(J/\psi \text{ from } b,\ p_{\mathrm{T}} < 10\ \mathrm{GeV}/c,\ 2.5 < y < 4)}{2\mathcal{B}(b \to J/\psi X)}$$

α_{LHCb} = 2.42 (PYTHIA 6.4)

$$\sigma(pp \to b\bar{b}X) = \alpha_{4\pi} \frac{\sigma(pp \to H_b X, 2 < \eta(H_b) < 6)}{2}$$

$\alpha_{4\pi}$ = 3.77 (PYTHIA 6.4)

Extrapolated cross sections

PRELIMINARY RESULTS

- σ_{bb} (2<η<6) = (84.5±6.3±15.6) μb (LEP)
- σ_{bb} (2<η<6) = (86.2±6.4±16.0) μb (Tevatron)

- σ_{bb} (319±24±59) μb (LEP)
- σ_{bb} (325±24±60) μb (Tevatron)