Measuring $b\bar{b}$ (and charmonium) production with J/ψ decays at LHCb

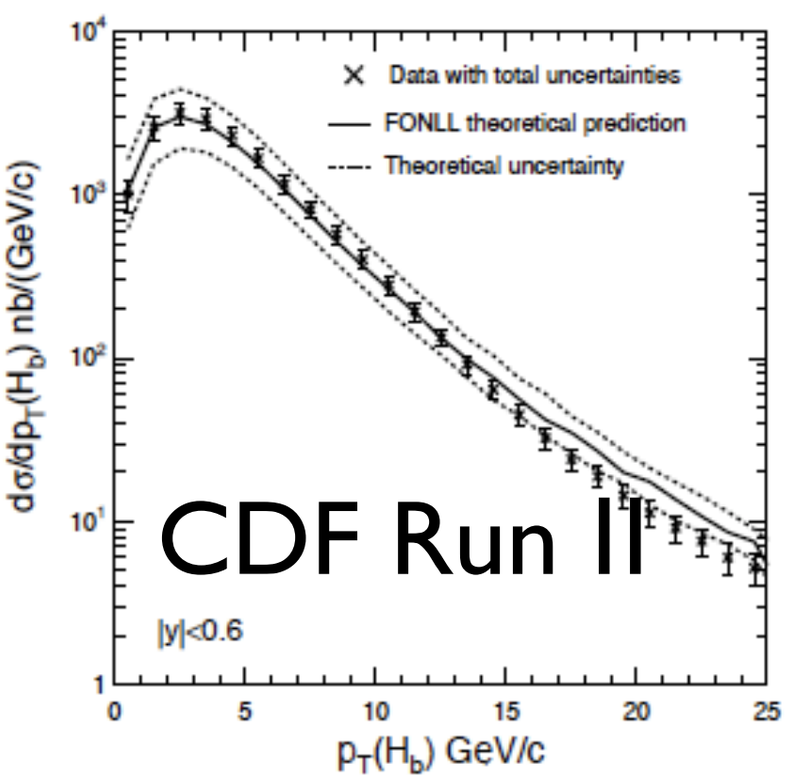
Wenbin Qian

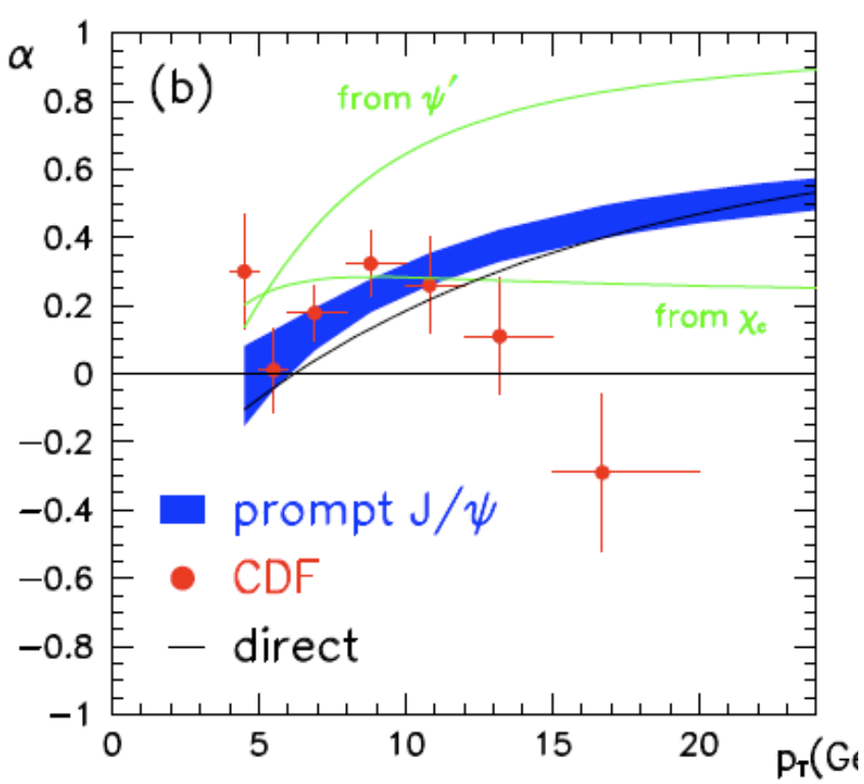
Marie-Helene Schune, Patrick Robbe
LaL, Orsay, France
Yuanning Gao
Tsinghua University, Beijing, China

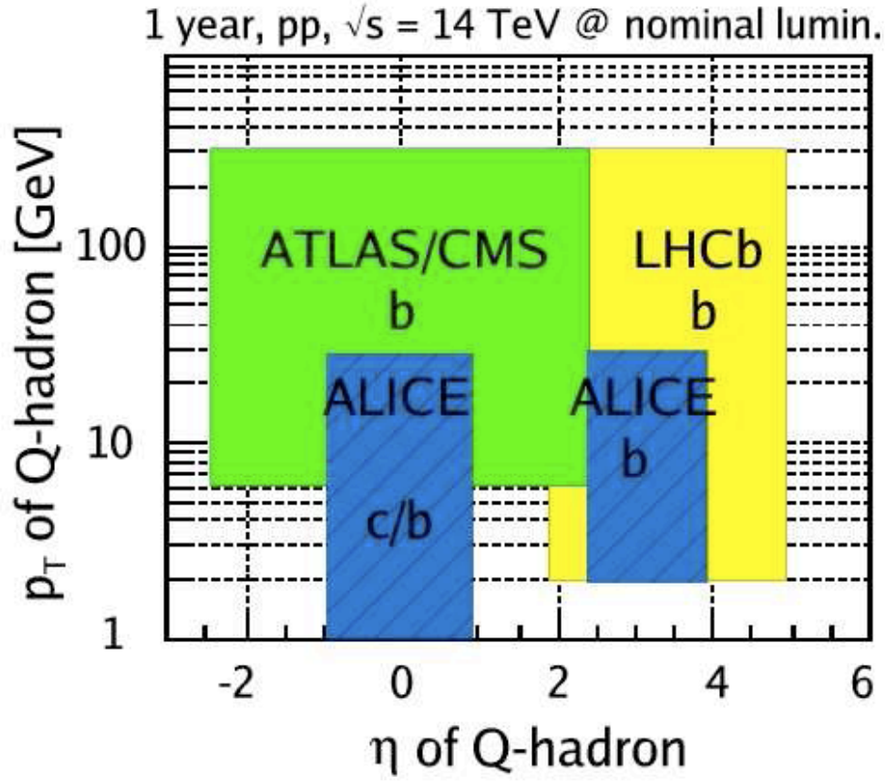
Motivation

- Facing at first results

- The long history of cross section measurement and theoretical calculation: Still not so satisfactory







- Special for LHC and LHCb: Higher Energy, larger η

- Important for later analysis: DiMu trigger, absolute Br etc

Braaten et al, Phys. Rev. D 62, (2000) 094005
The CDF Collaboration, Phys. Rev. Lett. 69, 3704 (1992)

MC Input Numbers

Process considered

$$pp \to X + (\psi(2s), \chi_{c0,1,2} + ... \to X) J/\psi$$

$$\sigma(\text{prompt } J/\psi, 14TeV) = 0.266mb \pm 0.002mb$$

$$pp \to X + b\bar{b}(b/\bar{b} \to X + J/\psi)$$

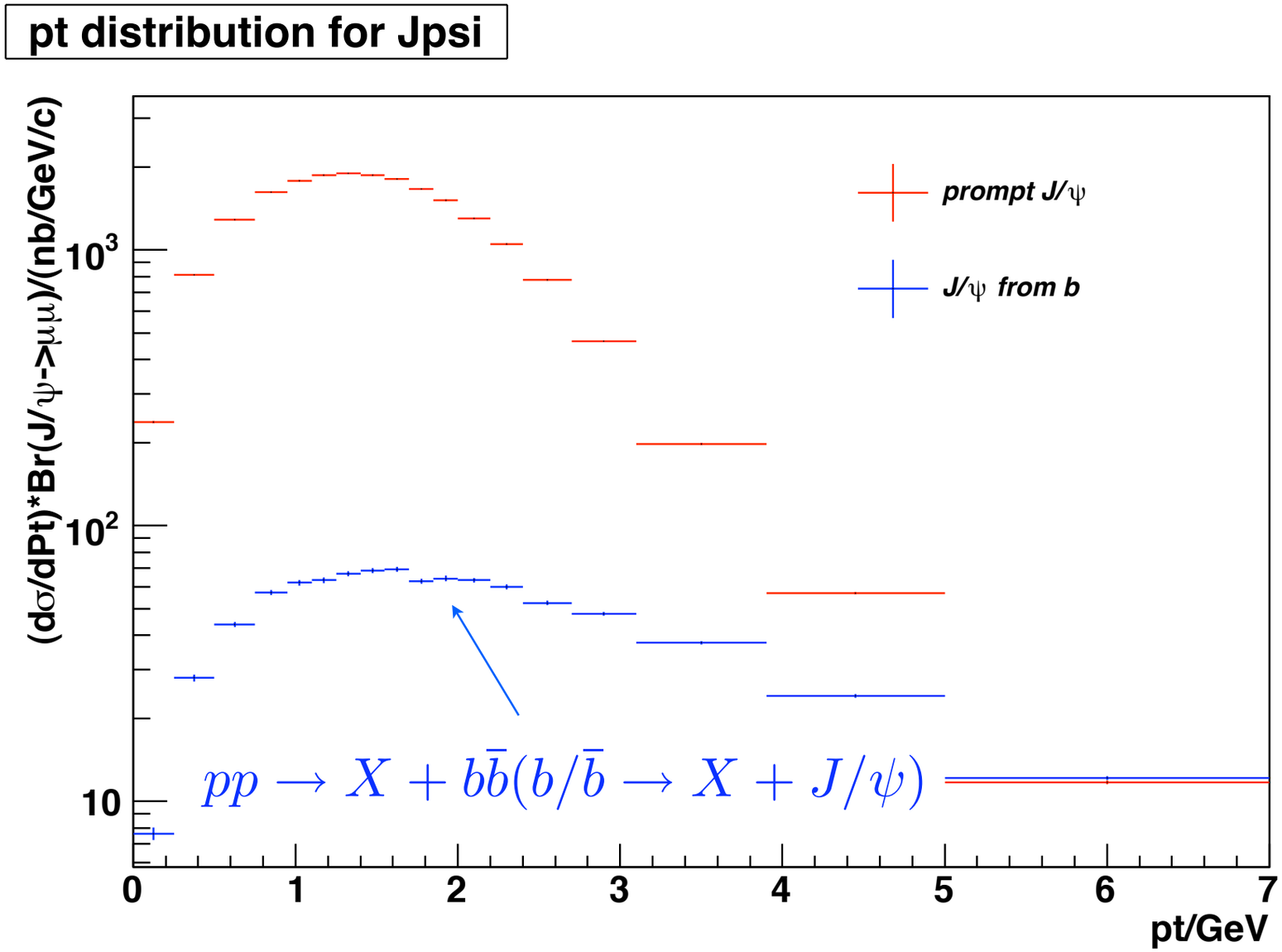
$$\sigma(b\bar{b}) = 0.698mb \pm 0.001mb$$

Branching ratio considered

$$\text{Br}(b \to J/\psi + X) = (1.16 \pm 0.10)\%$$
$$\text{Br}(J/\psi \to \mu^+\mu^-) = (5.93 \pm 0.06)\%$$

$$\text{Br}(\psi(2s) \to J/\psi + X) = (57.4 \pm 0.9)\%$$
$$\text{Br}(\chi_{c0} \to J/\psi + \gamma) = (1.28 \pm 0.11)\%$$
$$\text{Br}(\chi_{c1} \to J/\psi + \gamma) = (36.0 \pm 1.9)\%$$
$$\text{Br}(\chi_{c2} \to J/\psi + \gamma) = (20.0 \pm 1.0)\%$$

Generator Level Information



GenLevel dist. for J/Ψ→μ⁻μ⁺ with J/Ψ Pt<7GeV and η∈(2.5,5.5)

Cross sections for above graph:

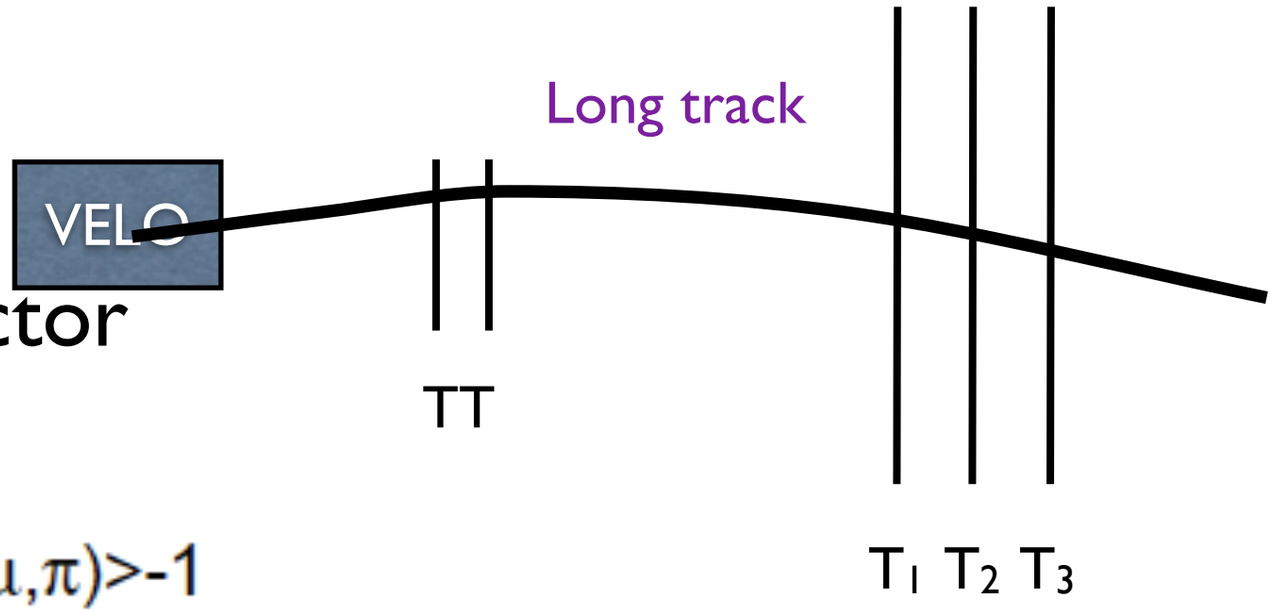
Prompt J/Ψ(μμ), 3102±5.5 nb

J/Ψ(μμ) from b, 235.7±1.5 nb

b fraction:~7%

Selections and Efficiency

- μ^+, μ^-:
  - Long track && muon detector
  - One muon with p_t>1.5 GeV/*c*
  - One muon with μ PID: Δln L(μ,π)>-1
- J/ψ vertex: $\chi^2/n_{DOF}< 6$



Acceptance efficiency

$$\epsilon_{acc/full} = (19.8 \pm 0.1)\%$$

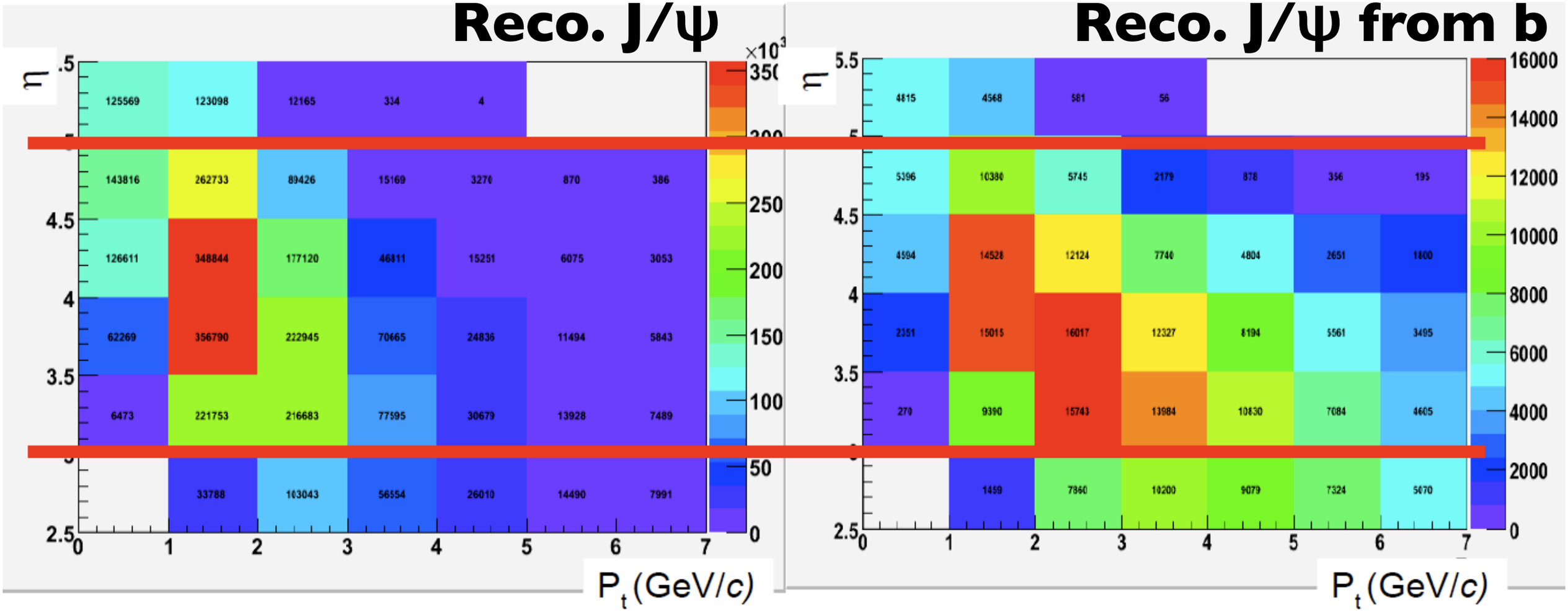
Reconstruction and selection efficiency

$$\epsilon_{sel/acc} = (40.4 \pm 0.1)\%$$

L0 trigger efficiency

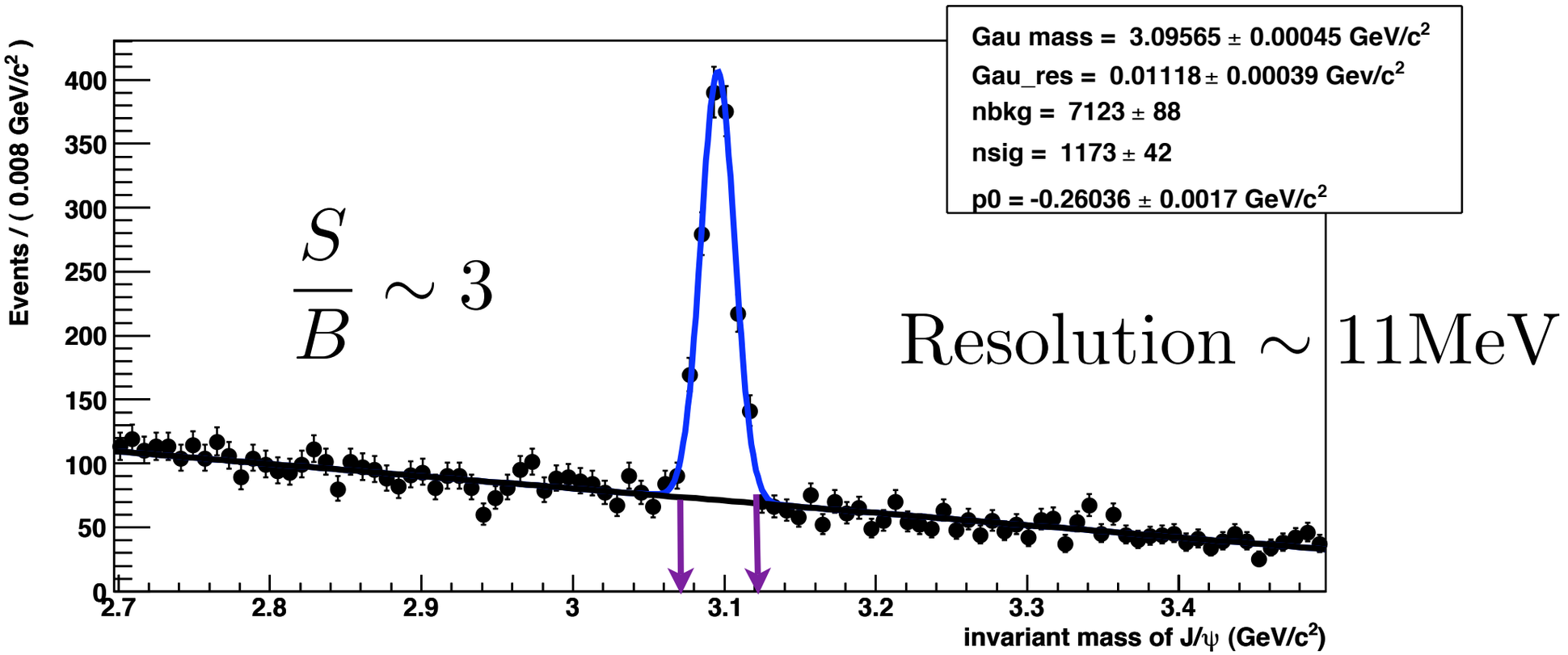
$$\epsilon_{L0/sel} = (78.6 \pm 0.1)\%$$

- 5pb^{-1}, 8 TeV, after L0 and selection cuts



- Current study based on η in 3~5
- Joint region with CMS/ATLAS could be studied but may be not for low pt bins.
- Efficiency differences largely due to acceptance cut

LHCb J/ψ Yield



5.5M Minibias Events passing L0 trigger

2 fb^{-1}

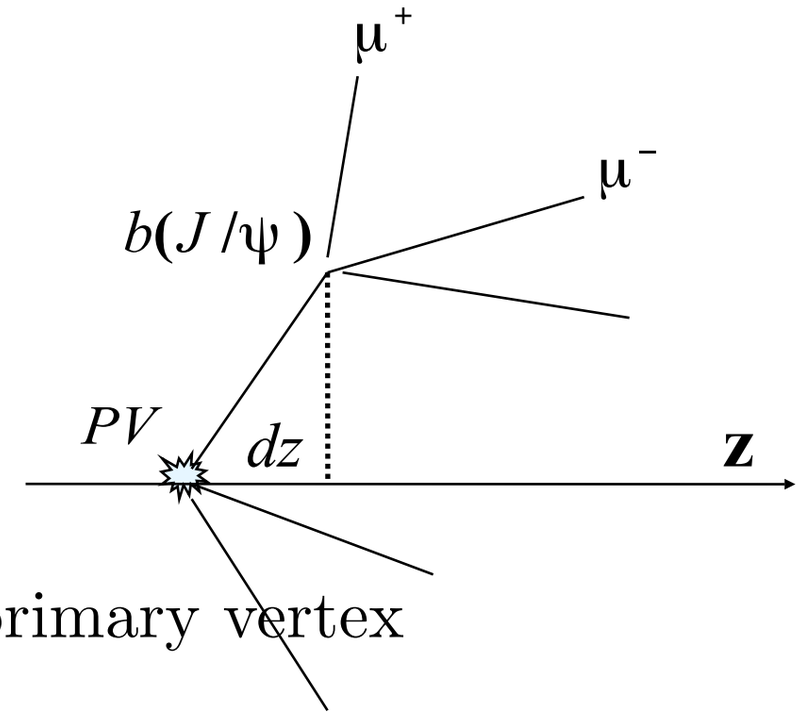
5s → 1173 J/ψ Reco.

14TeV → $2 \times 10^9 J/\psi$ Reco.

3.2x10⁶ for 5 pb⁻¹ at 8 TeV

How to Distinguish between Prompt and J/ψ from b

$$t_z = \frac{d_z}{P_z^{J/\psi}} \times M^{J/\psi}$$

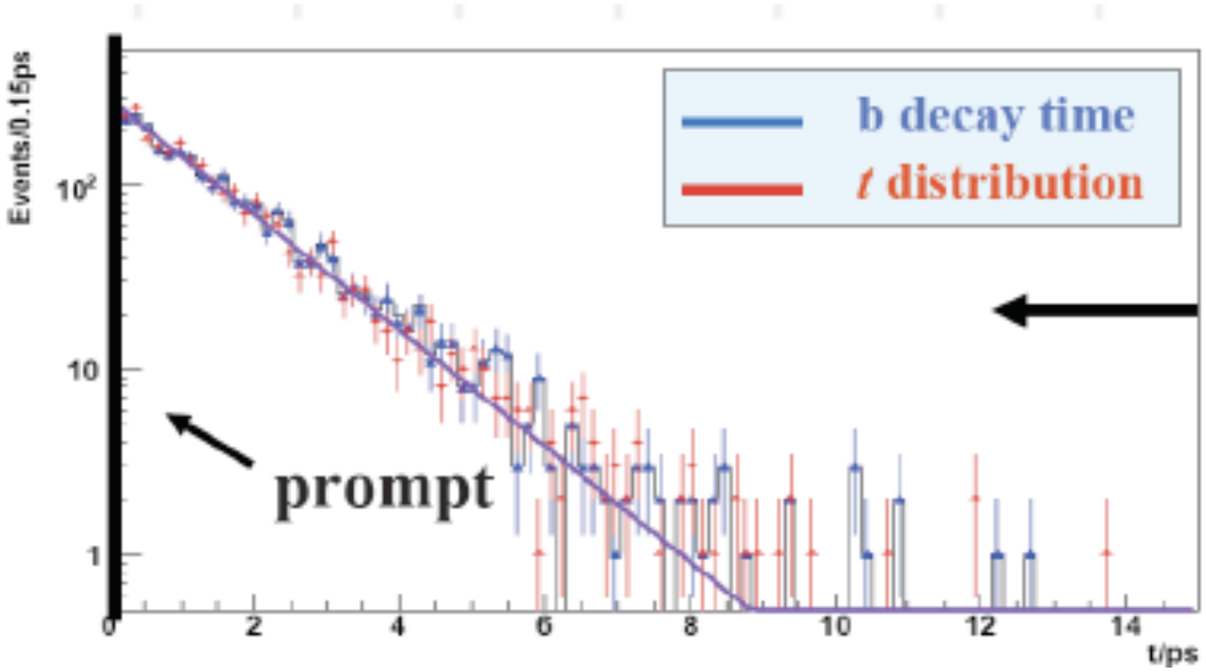


d_z is the distance between reconstructed J/ψ and primary vertex

P_z is the momentum of J/ψ in z direction

$M^{J/\psi}$ is the mass of reconstructed J/ψ

- Simple approximation of « b quark » lifetime:



t distribution at generator level

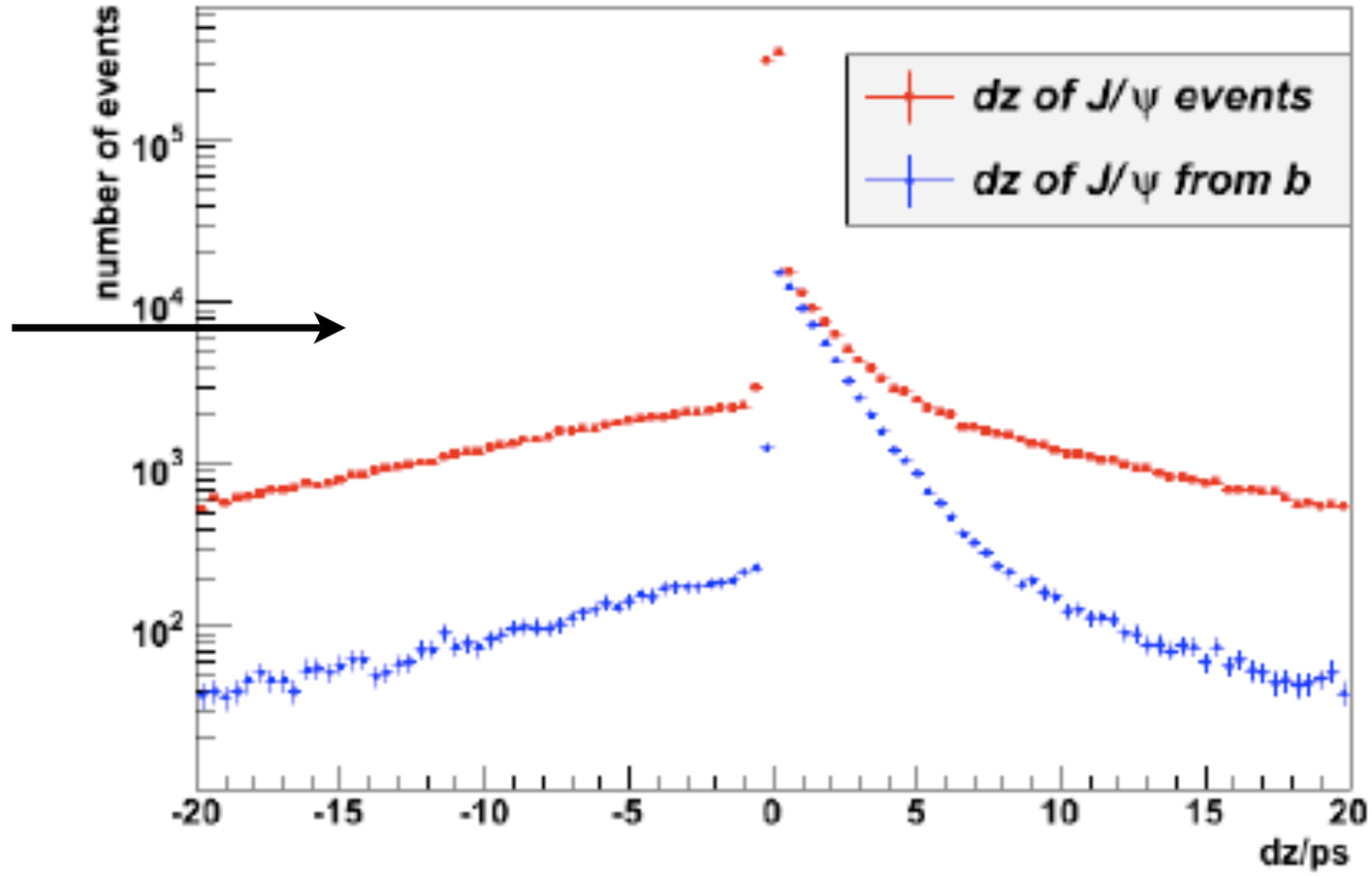
How to measure differential cross-section

- Divide in J/ψ p_t and η (pseudo-rapidity) bins
- Fit mass distribution to measure number of reconstructed J/ψ
- Use *t* distribution to measure number of reconstructed prompt J/ψ and J/ψ from b
- Use efficiency per p_t and η bin to compute original number of J/ψ
- Bins definition:
  - $0 \le p_t \le 7$ GeV/c, 7 bins
  - $3 \le \eta \le 5$, 4 bins

t distribution

- *t* distribution has 4 components:
  - Prompt J/ψ: peak at 0 ps
  - J/ψ from B: exponential decay
  - J/ψ background
  - Long tail, due to association between J/ψ and wrong primary vertex.

Background not included

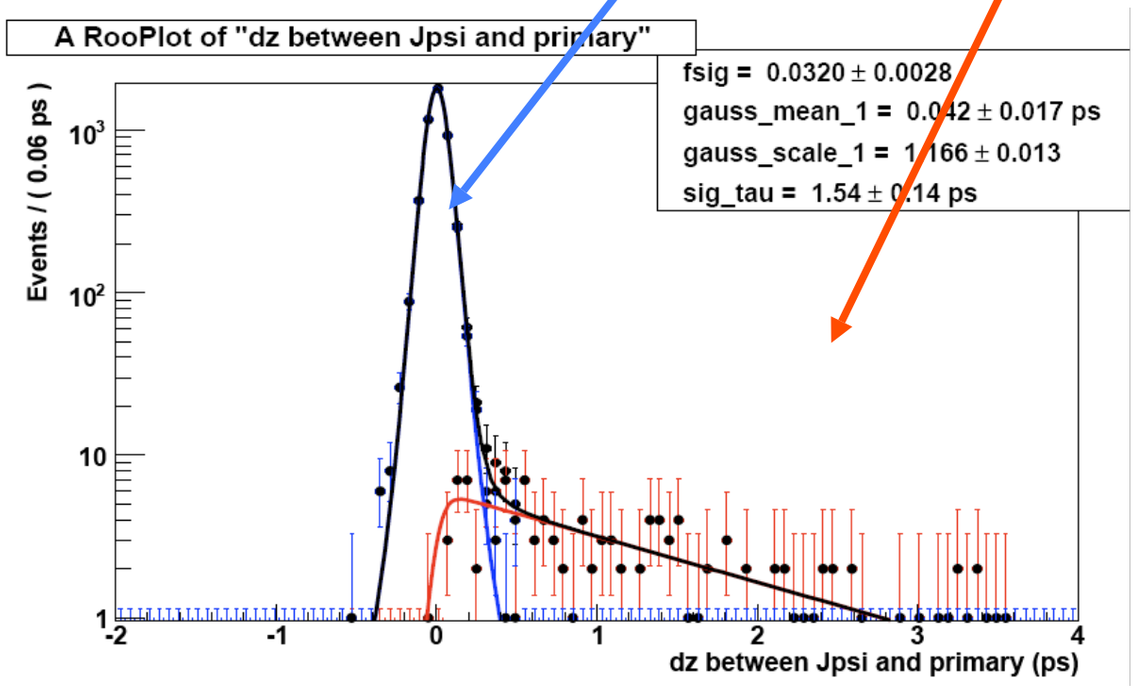


0.8 pb^{-1}, after L0

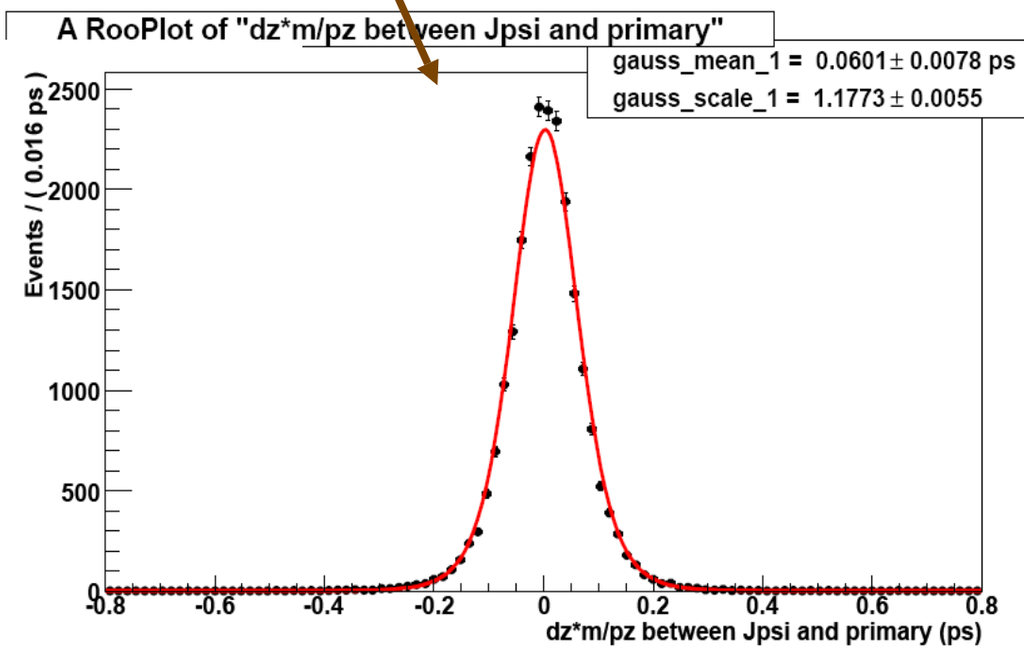
Combined Fit Function:Signal Fit

$$\text{Fit Function} = f_{J/\psi} \times F_{J/\psi}(t) G_{J/\psi}(m) + (1 - f_{J/\psi}) F_{bkg}(t) G_{bkg}(m)$$

$$(1 - f_{\text{tail}})[(1 - f_{\text{b}})\delta(t) + f_{\text{b}} e^{-t/\tau}] \otimes \textbf{Resolution} + f_{\text{tail}} \rho_{\text{tail}}(t)$$



t/ps



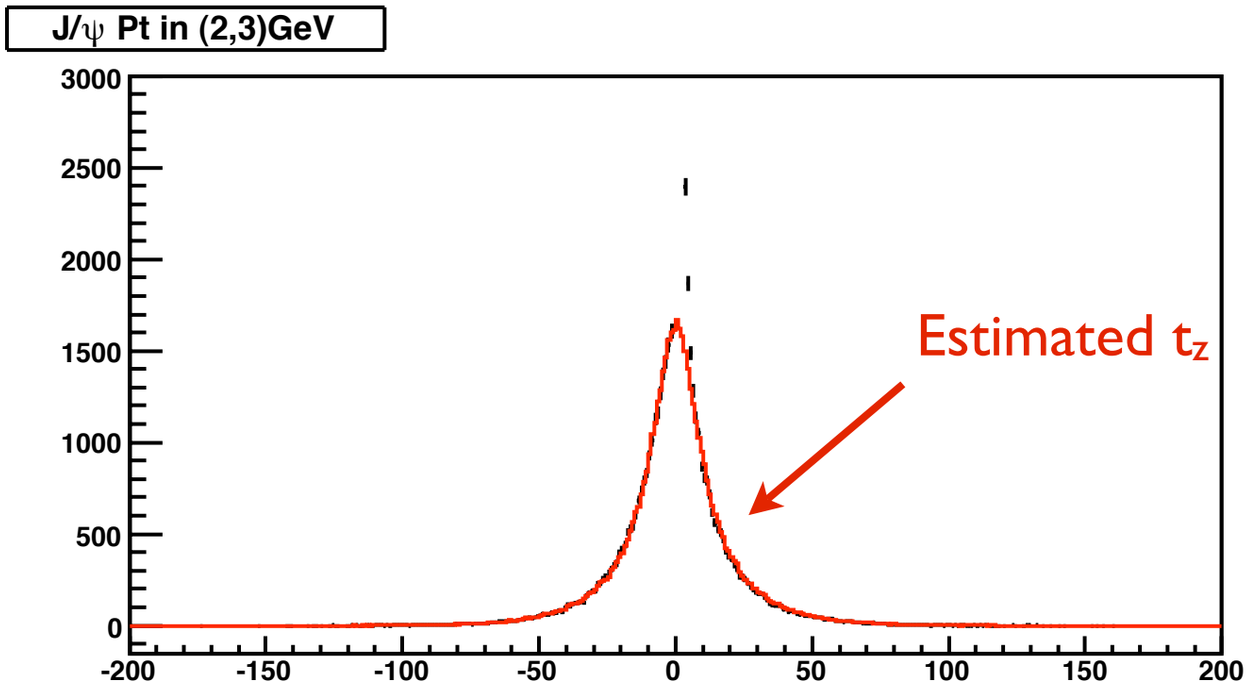
t/ps

$$Gauss(mean, scale \times error)$$

Method for Tail Function

$$F_{J/\psi} = (1 - f_{\text{tail}})[(1 - f_b)\delta(t) + f_b e^{-t/\tau}] \otimes \text{Resolution} + f_{\text{tail}}\rho_{\text{tail}}(t)$$

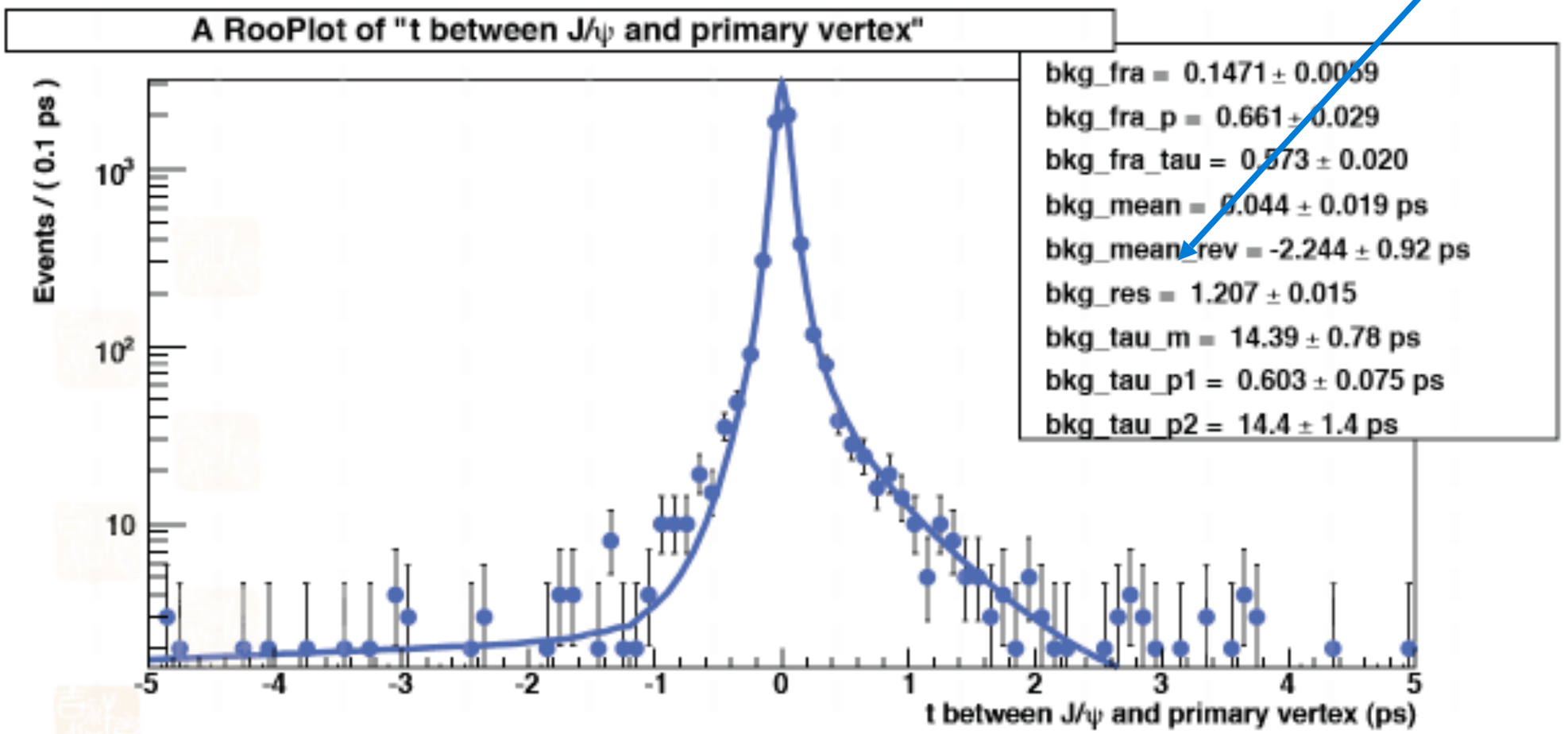
$$t_z = \frac{(J/\psi_z - PV_z^{next}) \times M_{J/\psi}}{P_z(J/\psi)}$$



- Tail distribution could be got from Real data
- Using J/ψ vertex and primary vertex in the next events
- For multi-primary vertex case, it is weighted as t

Combined Fit Function:Background Fit

$$\text{Fit Function} = f_{J/\psi} \times F_{J/\psi}(t) G_{J/\psi}(m) + (1 - f_{J/\psi}) F_{bkg}(t) G_{bkg}(m)$$

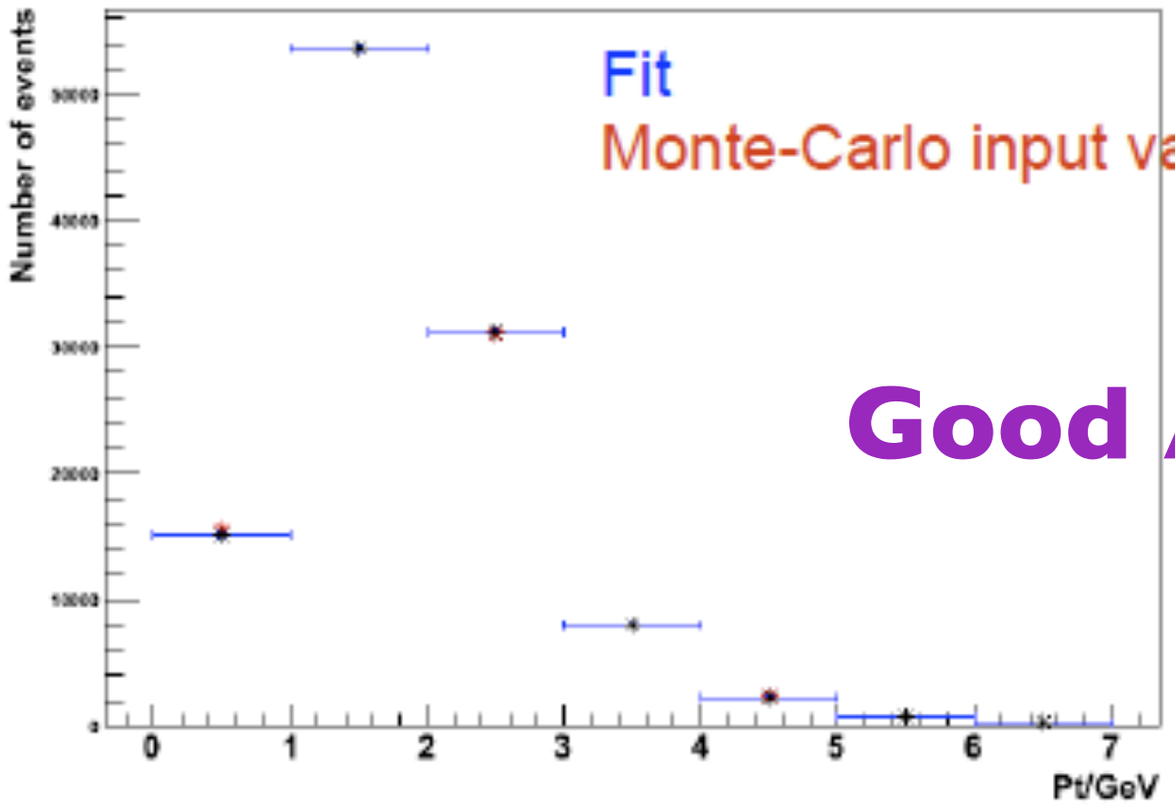


- Could be determined from mass sidebands

- For current study, background are generated by toy MC using sidebands of Mini-bias sample passing L0 trigger

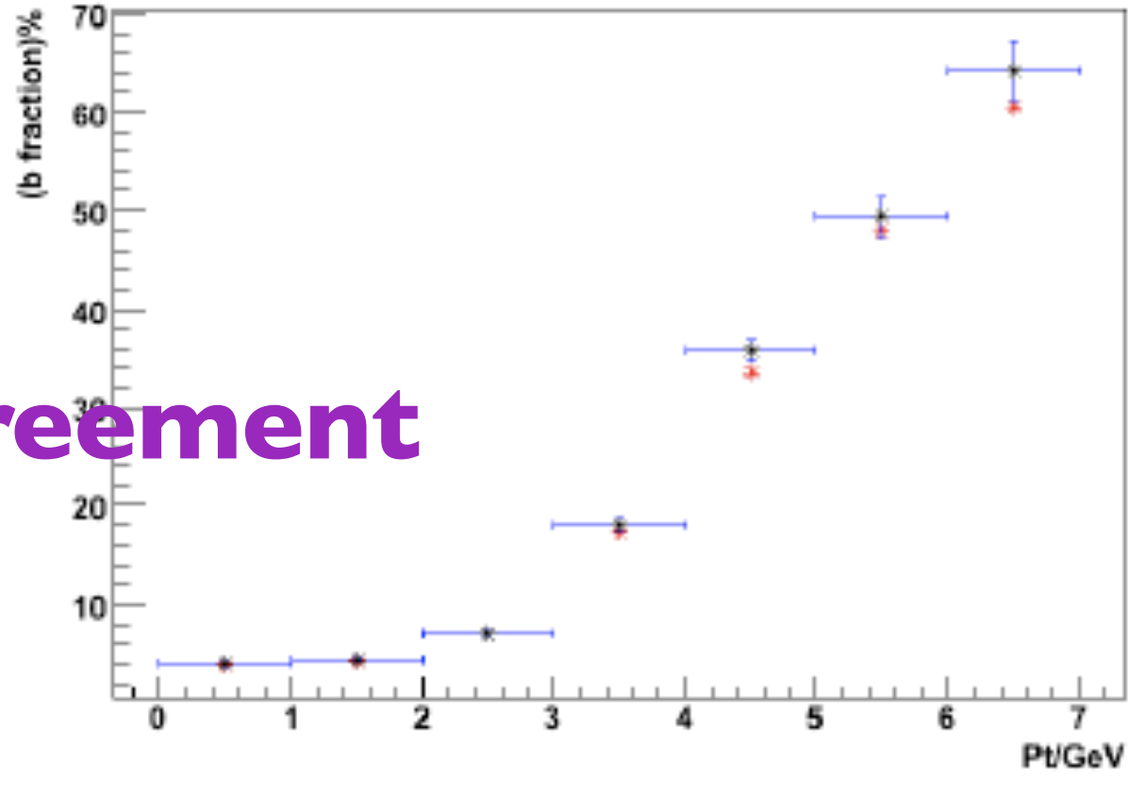
Fit Results

- Corresponds to 0.145 pb^{-1}, 14 TeV
- Signal: part of the inclusive J/ψ sample
- Background: toy Monte-Carlo reproducing behaviour seen on Minimum Bias sample (S/B~3)



Number of prompt J/ψ

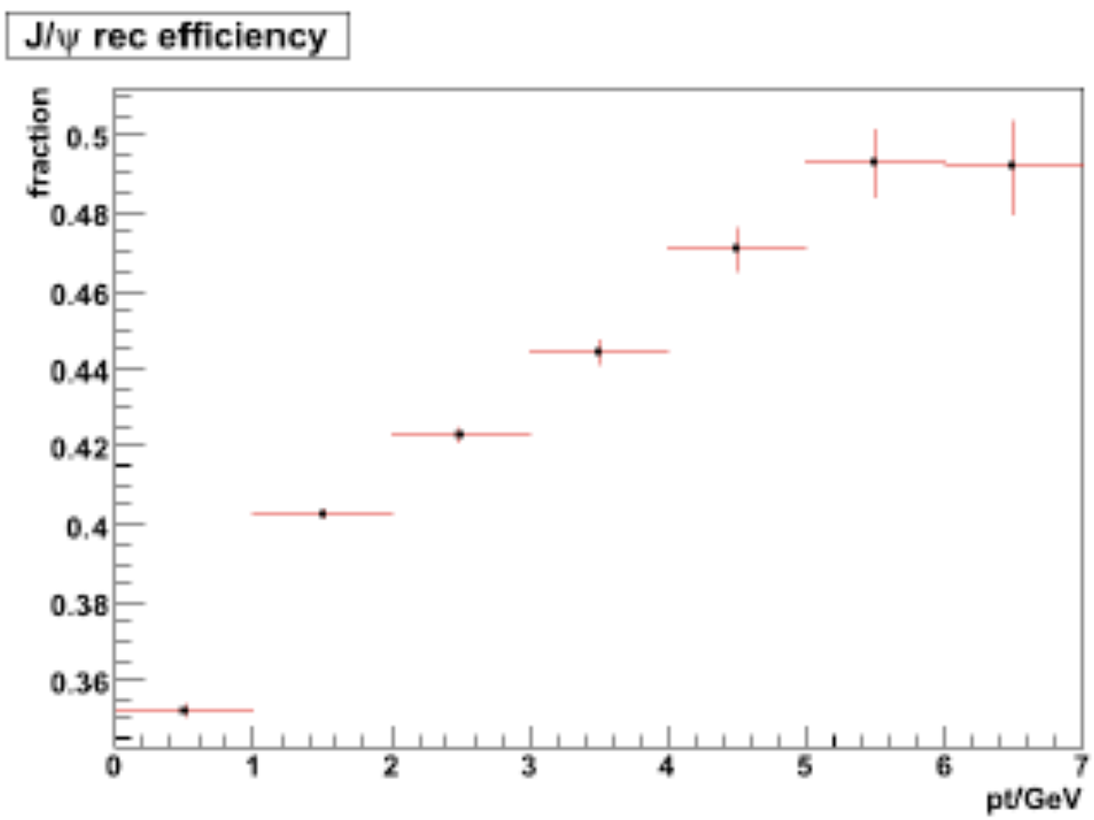
Good Agreement



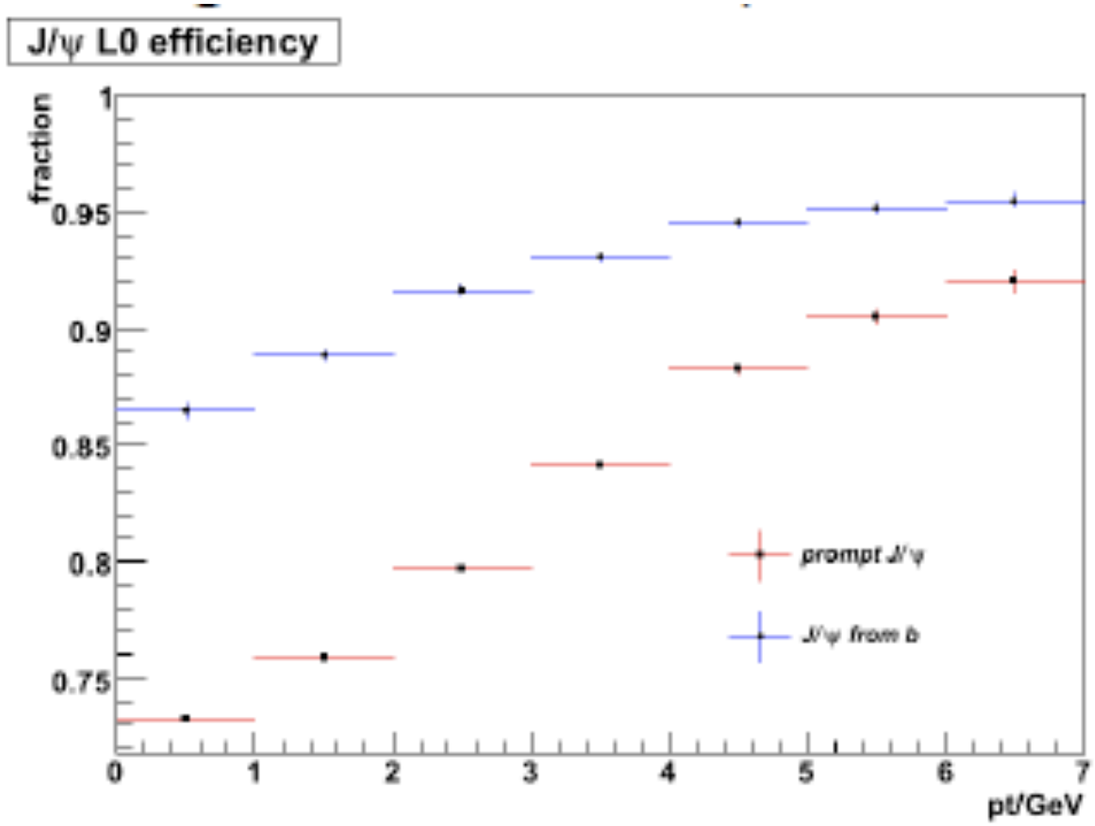
Fraction of J/ψ from b

Efficiencies

- Assuming efficiency independent of t(True for MC)
- Efficiency depends on Pt and η (need to know for each bin)
- For current study, efficiency comes from MC



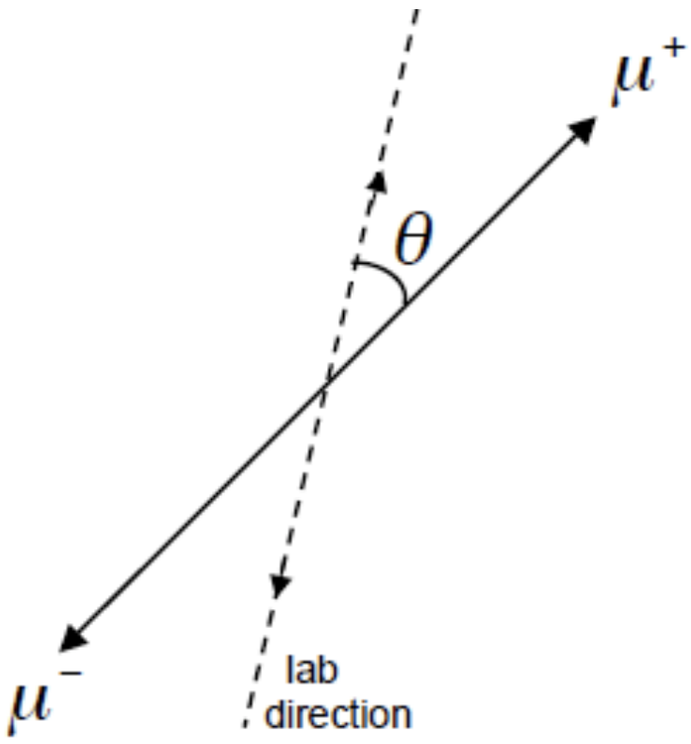
Reconstruction Efficiency vs p_t

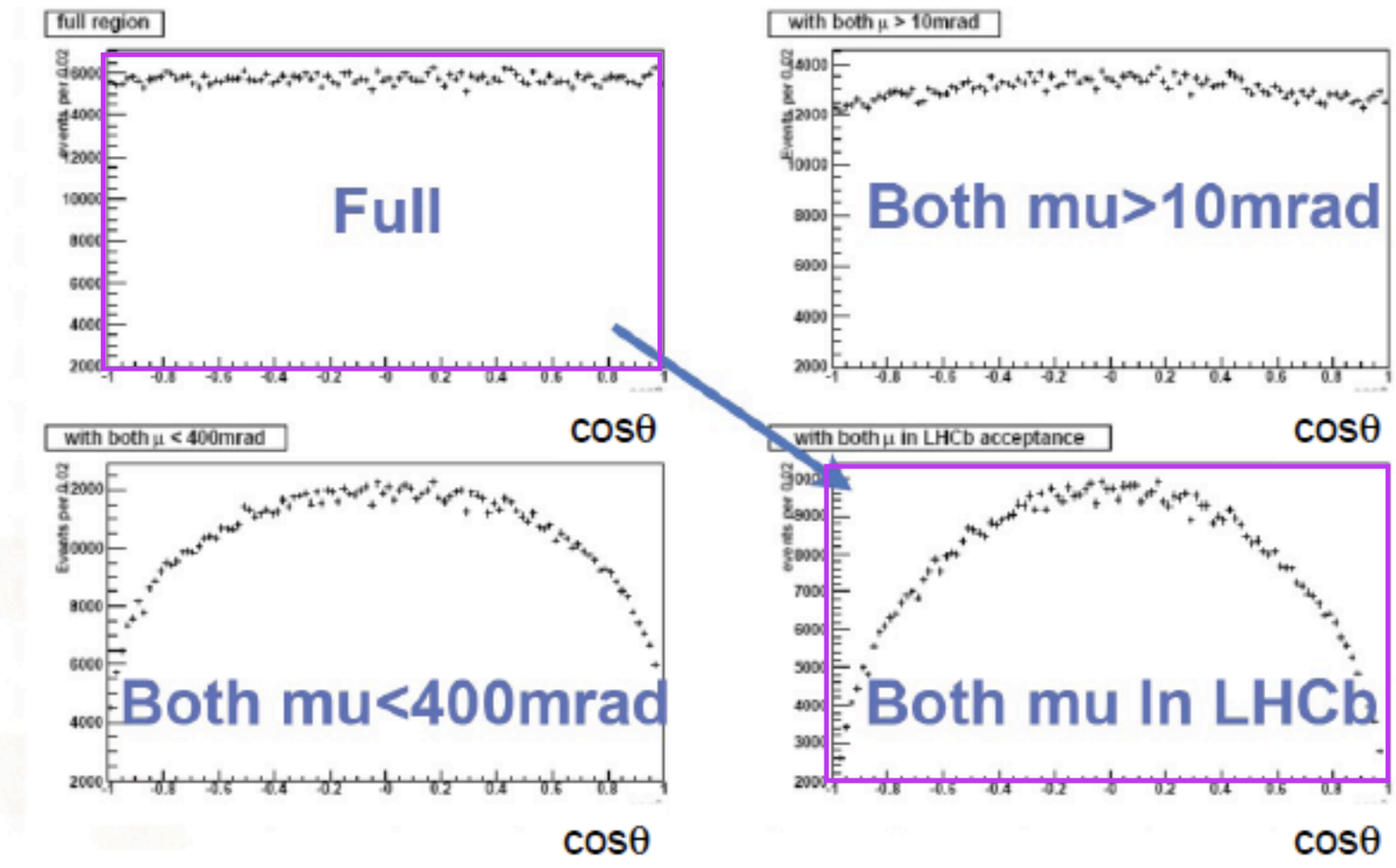


L0 Efficiency vs p_t

Further about Efficiencies: Polarisation dependent

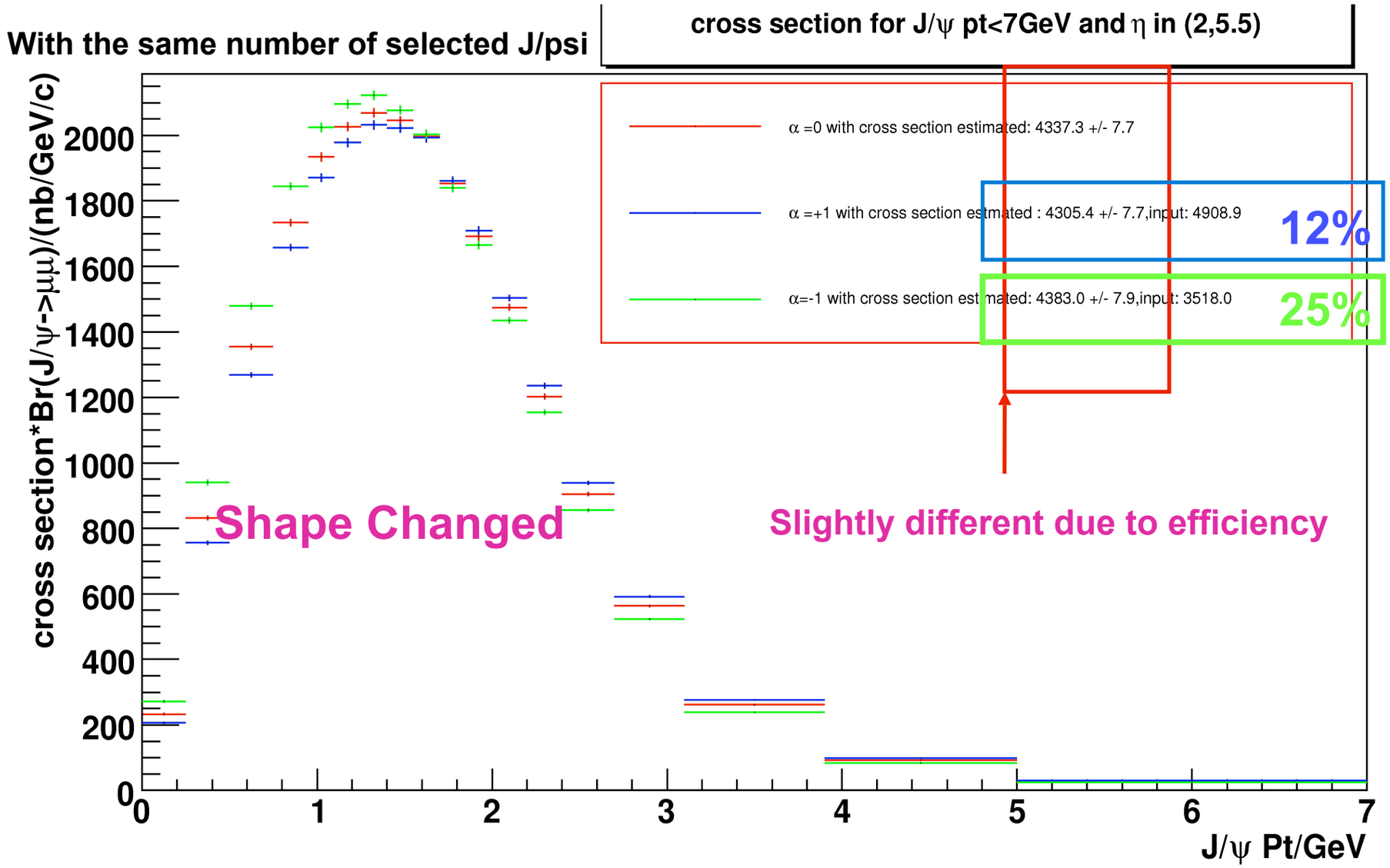
$$\frac{dN}{d\cos\theta^*} \propto 1+\alpha\cos^2\theta^*, \quad \text{where } -1\le\alpha\le+1 \quad \begin{cases}\alpha=+1: & \text{transverse polarization}\\ \alpha=-1: & \text{longitudinal polarization}\\ \alpha=0: & \text{no polarization}\end{cases}$$





- LHCb geometry induces fake J/ψ polarisation
- L0 efficiency also depends on polarisation

Polarisation Effect on Measurement



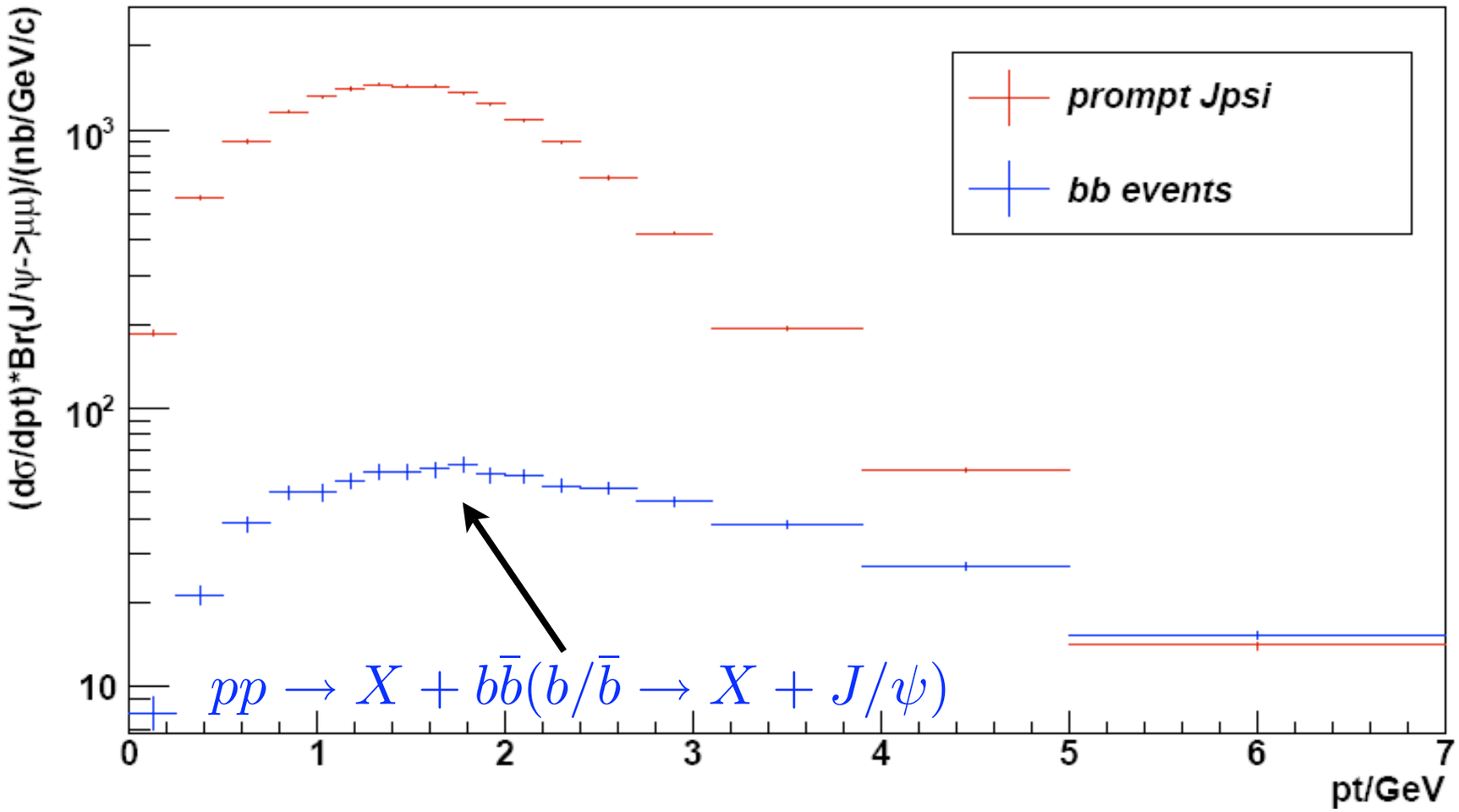
- The total cross section difference may be up to 25%
- The differential cross section shape may be changed
- For some pt and η bins, the effect is much larger than average

Polarization Fit

- Fit also the polarization α, ideally per p_t and η bin.
- Function: $$F(\cos^2\theta) = \frac{1+\alpha\cos^2\theta}{1+\alpha\times r}$$
- 3 components: prompt, from b and background. With small statistics, assume only a p_t dependance of α.
- r=b/a, with $a = \int \epsilon(\cos\theta)d\cos\theta$, $b = \int \epsilon(\cos\theta)\cos^2\theta\, d\cos\theta$, ε the efficiency as a function of cosθ.
- Need to know the efficiency shape:
  - could be extracted from data from a sample of J/ψ with known zero polarization, such as $B^+ \rightarrow J/\psi\, K^+$, reconstructed event number with $5pb^{-1}$ at 8 TeV will be small (~2000) but will allow check of Monte Carlo efficiency shape.

Preliminary Results

- A total fit with polarisation are nearly finished for each Pt and η bins
- A simplified fit results over pt without polarisation



In range 0~7GeV with two μ in LHCb acceptance:

prompt J/ψ(μμ): 3104.2±2.2(fit)±7.3(eff)nb

pp → bb → J/ψ(μμ)X: 233.6±1.7(fit)±2.(eff)nb

Input:

prompt J/ψ, 3102.0±5.5nb

b → J/ψ, 235.7±1.5nb

Uncertainties

- Statistical error <10% per Pt and η bin with 5pb^{-1} at 8TeV
- Need real data to understand tracking, muon PID, vertexing etc
- Error on luminosity: ~10%
- Error on Br(b->J/ψX): 9%
- Error on fit: possible errors from fit function etc

Conclusions

- The measurement is interesting and could be one of the first publications of LHCb
- Selections and fit procedures established for the two measurements
- Part of the distributions can be determined from data
- Works still in progress

Thank You Very Much for Your Attention