Quarkonia in dimuon final states and exclusive dimuon decays at LHC*b*

XIV International Conference on Hadron Spectroscopy
Munich 13-17 June 2011

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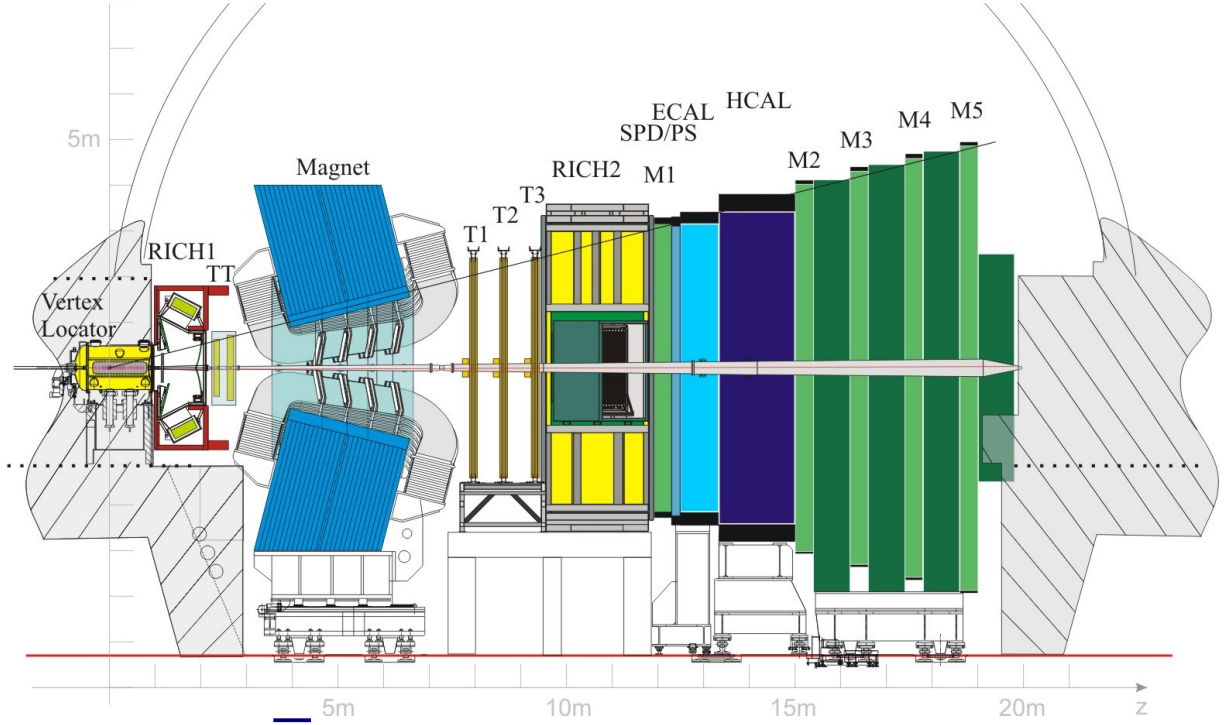
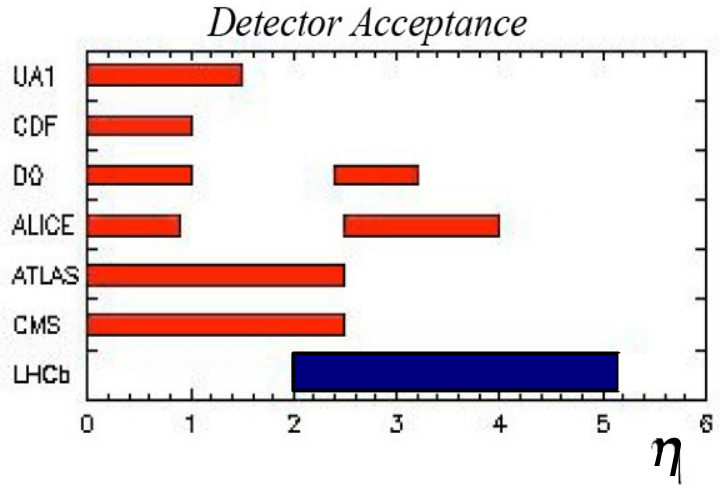
Outline

- The LHC*b* experiment
  - Detector description
- Quarkonia cross-section measurements: J/ψ, double J/ψ, ψ(2S), Υ
  - Selection criteria, efficiencies, systematic errors
  - Results and comparison to theory
- Exclusive dimuon production
- Prospects for polarisation measurements at LHC*b*
- Conclusions

The LHC*b* experiment

- An experiment at LHC dedicated to *b (c)* quark physics





angular acceptance $1.9<\eta<4.9$

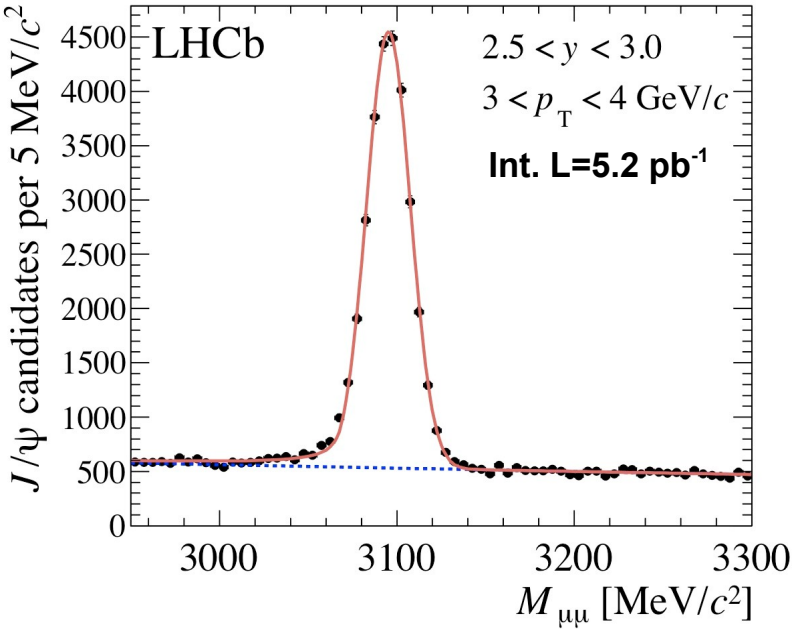
- b and $\bar{b}$ are both forward(backward) produced: detector geometry imposed by the kinematics
- 3 trigger levels reduce the event rate from 40 MHz to 2 kHz
- Stable data taking runs at $\sqrt{s} = 7$ TeV
- Instantaneous $L = 10^{31} - 10^{32}\ cm^{-2}s^{-1}$

Quarkonia cross-section measurements: J/ψ

- Double differential cross-section, as a function of p_T and y:
  - $p_T < 14$ GeV/c (14 bins), $2<y<4.5$ (5 bins)
  - separately for prompt J/ψ and for J/ψ from b
  - data sample: (5.2 ± 0.5) pb^{-1} collected during 2010, $\sqrt{s}=7$ TeV
  - J/ψ reconstructed in the μμ decay mode

- **Trigger and selection criteria**
  - single muon OR dimuon trigger: muon p_T cuts
  - off-line cuts:
    - muon track quality (χ^2/nDoF < 4)
    - muon $p_T > 700$ MeV/c
    - common vertex fit quality ($p(\chi^2)>0.5\%$)
    - N primary vertices ≥ 1

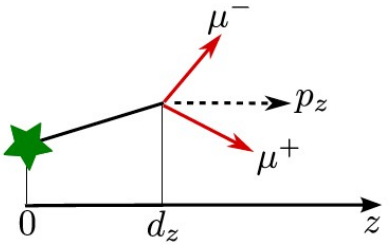
Quarkonia cross-section measurements: J/ψ



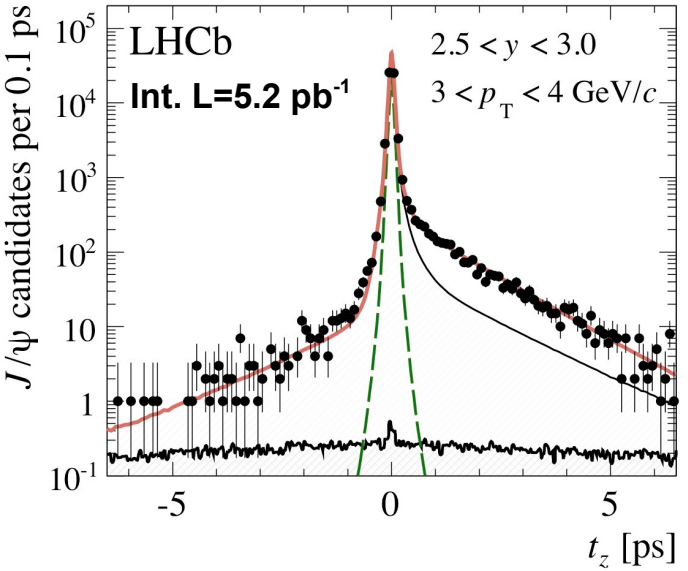
- Total number of J/ψ: 564603 ± 924
- Fit: Crystal Ball (signal) + Exponential (bg)

- Separation prompt/from *b* J/ψ

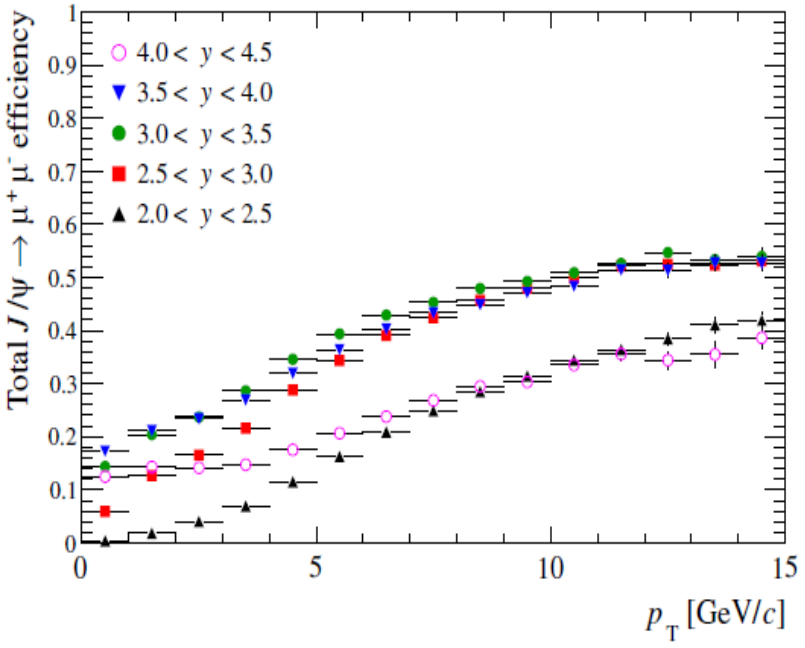
$$t_z(J/\psi) = \frac{d_z \times M_{J/\psi}}{p_z}$$



- Signal: prompt + from *b* + tail
- Background (shape from sidebands)
- Convolved by a resolution function: $\sigma(t_z)$=53 fs



Quarkonia cross-section measurements: J/ψ



- Efficiencies were computed from MC and were checked on data
- J/ψ polarisation (unknown) affects the efficiency. Polarisation scenarios simulated:
  - unpolarised J/ψ (figure)
  - fully transverse polarised J/ψ
  - fully longitudinal polarised J/ψ

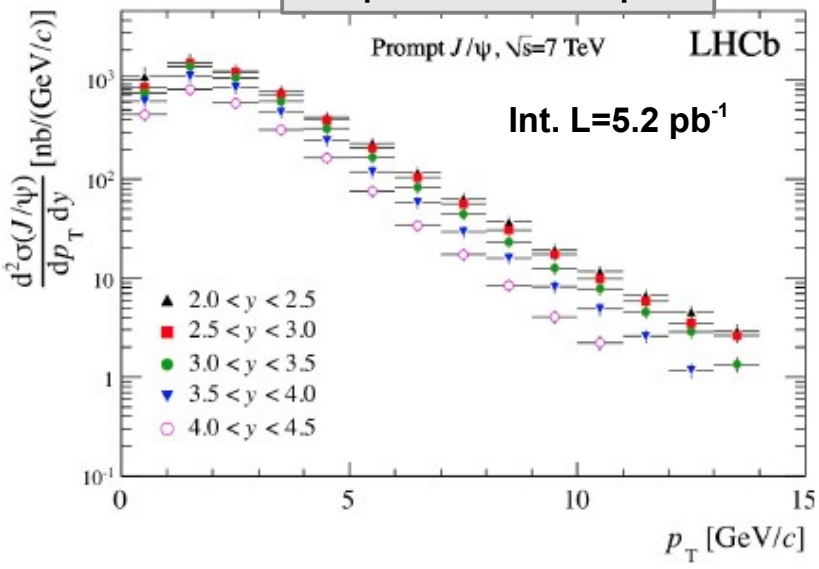
results were given in each of the three cases

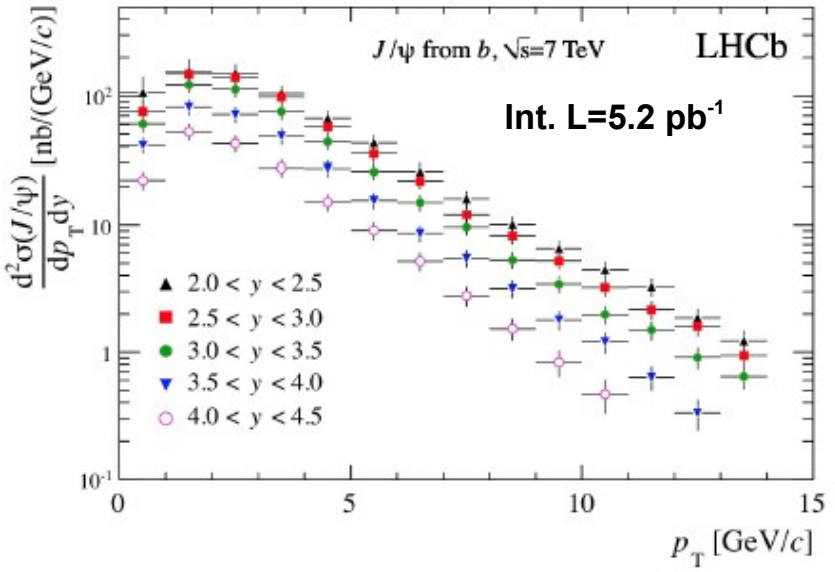
- Many systematic error sources have been studied mostly through MC-data comparison:
  - tracking efficiency: 4% per track (2010 runs, now improved at 1%)
  - luminosity: 10% (2010 runs, now improved at 3.5%)
  - trigger efficiency: 1.7-4.5%

Quarkonia cross-section measurements: J/ψ

$$\frac{d^2\sigma}{dy\,dp_{\mathrm{T}}} = \frac{N\left(J/\psi \to \mu^+\mu^-\right)}{\mathcal{L} \times \epsilon_{\mathrm{tot}} \times \mathcal{B}\left(J/\psi \to \mu^+\mu^-\right) \times \Delta y \times \Delta p_{\mathrm{T}}}$$

Unpolarized J/ψ



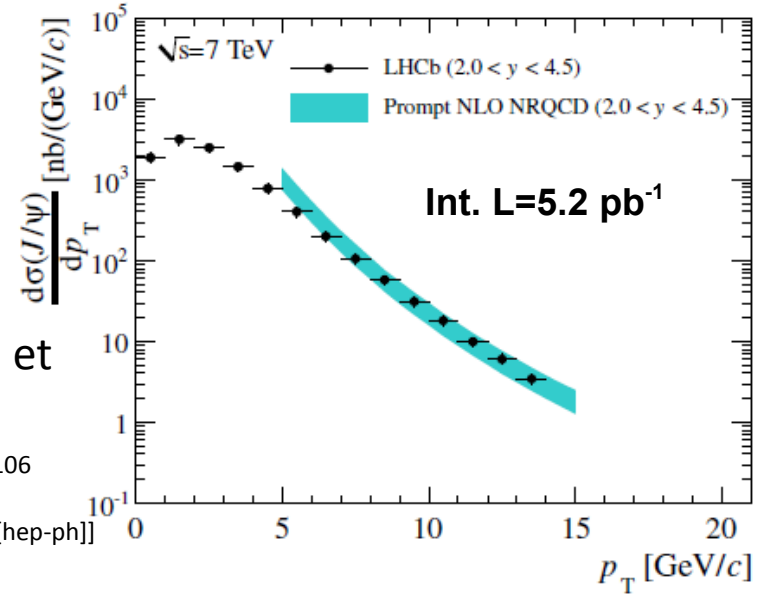


- Integrated over the acceptance:

$$\sigma\left(\text{prompt } J/\psi, p_{\mathrm{T}} < 14\ \mathrm{GeV}/c, 2.0 < y < 4.5\right) = 10.52 \pm 0.04 \pm 1.40^{+1.64}_{-2.20}\ \mu\mathrm{b}$$

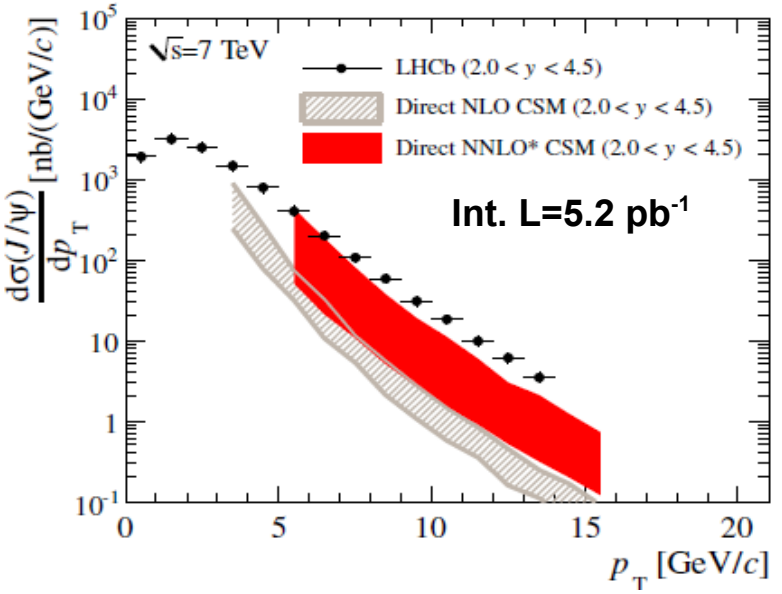
$$\sigma\left(J/\psi \text{ from } b, p_{\mathrm{T}} < 14\ \mathrm{GeV}/c, 2.0 < y < 4.5\right) = 1.14 \pm 0.01 \pm 0.16\ \mu\mathrm{b}$$

Quarkonia cross-section measurements: J/ψ



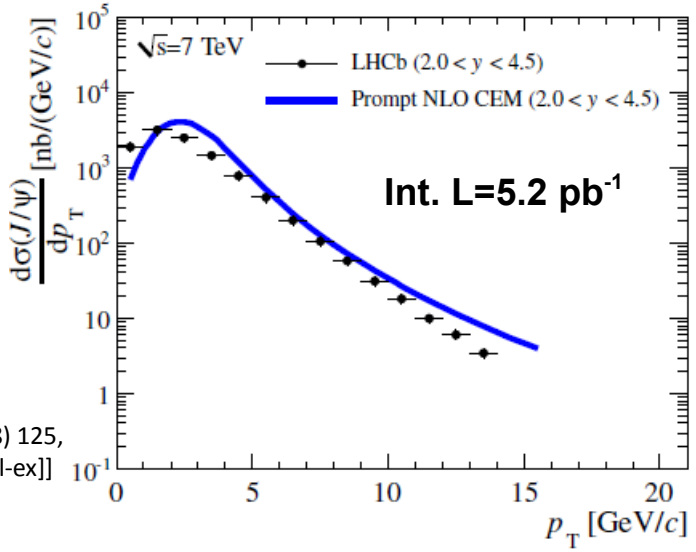
K. T. Chao et al.

[Phys. Rev. Lett. 106 (2011) 042002, arXiv:1009.3655 [hep-ph]]



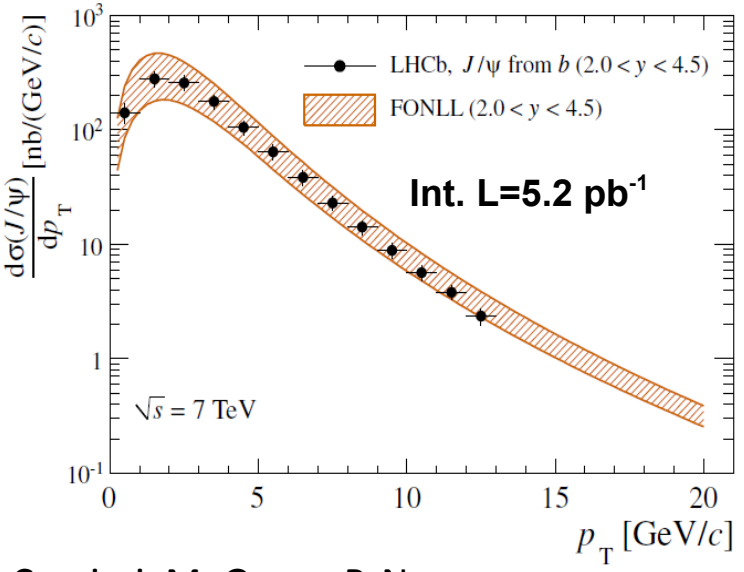
J.-P. Lansberg

[Eur. Phys. J. C 61 (2009) 693, arXiv:0811.4005 [hep-ph]]



R. Vogt

[Phys. Rep. 462 (2008) 125, arXiv:0806.1013 [nucl-ex]]



M. Cacciari, M. Greco, P. Nason, J. High Energy Phys. 9805 (1998) 007 hep-ph/9803400

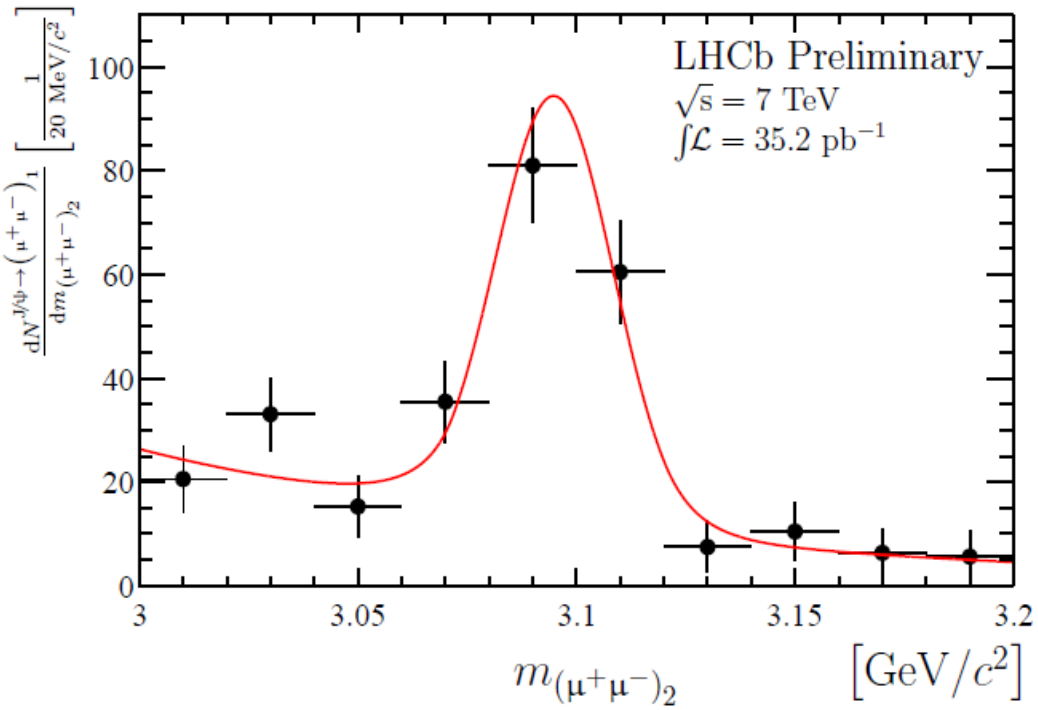
M. Cacciari, S. Frixione, P. Nason, J. High Energy Phys. 0103 (2001) 006 hep-ph/0102134

Quarkonia cross-section measurements: double J/ψ

- LO QCD makes predictions of $\sigma(pp \rightarrow J/\psi\, J/\psi + X)$ at the LHC energies
- Analysis performed in the range
  - p_T<10 GeV/c
  - 2<y<4.5

  with the full 2010 dataset

- **Strategy**
  - 4 muons from the same vertex
  - fit $M(\mu^+\mu^-)_1$ in bin of $M(\mu^+\mu^-)_2$
  - 140 ± 18 double J/ψ



Quarkonia cross-section measurements: double J/ψ

- Events are weighted with the inverse of tot. eff: $1/\varepsilon^{tot}_{J/\psi J/\psi}$
- Systematic errors (most important):
  - trigger efficiency: 8%
  - tracking efficiency: 4% per track (now improved at 1%)
  - luminosity: 10% (now improved at 3.5%)

$$\sigma^{J/\psi\,J/\psi} = \frac{1}{\mathcal{L} \times \mathcal{B}^2_{\mu^+\mu^-}} \times N^{corr}_{J/\psi\,J/\psi} = 5.6 \pm 1.1 \pm 1.2 \text{ nb}$$

- To compare with QCD calculation:
  - $\sigma(pp \rightarrow J/\psi\ J/\psi + X) = 4.15 - 4.34$ nb

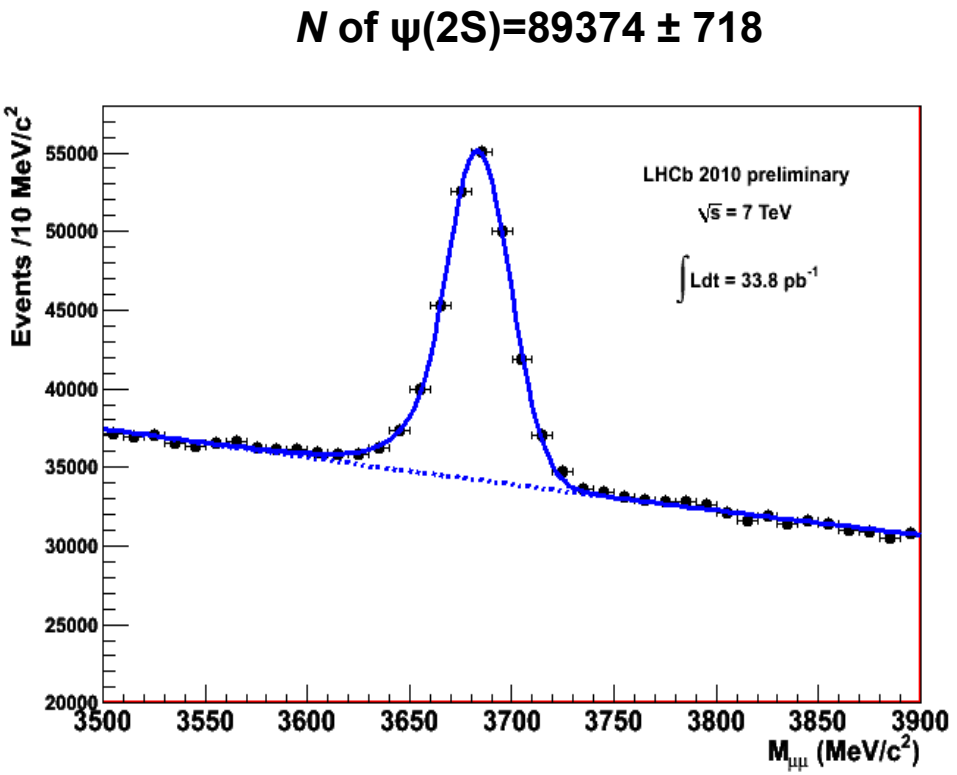
A.V. Berezhnoy, et al., arXiv:1101.5881v1 [hep-ph]

  - Theoretical calculation does not include non-direct J/ψ J/ψ

Quarkonia cross-section measurements: ψ(2S)

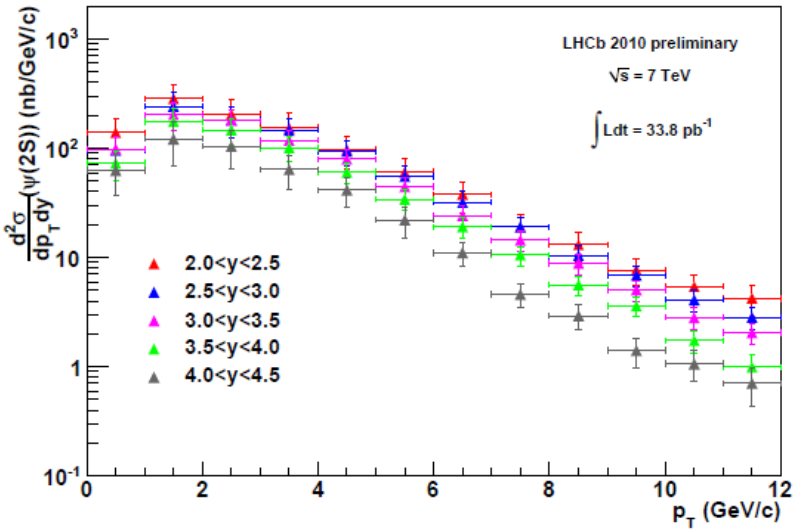
- $\psi(2S) \rightarrow \mu^+\mu^-$ B.R. = $7.7 \pm 0.8\ 10^{-3}$
- Measured also in $\psi(2S) \rightarrow J/\psi(\mu^+\mu^-)\ \pi^+\pi^-$
  (see Bo Liu's talk at quarkonia session on thursday)

- Selection similar to the $J/\psi \rightarrow \mu^+\mu^-$ one
  - harder cut on muon p_T (p_T>1200 MeV/*c*)
- Fit: CB + exponential



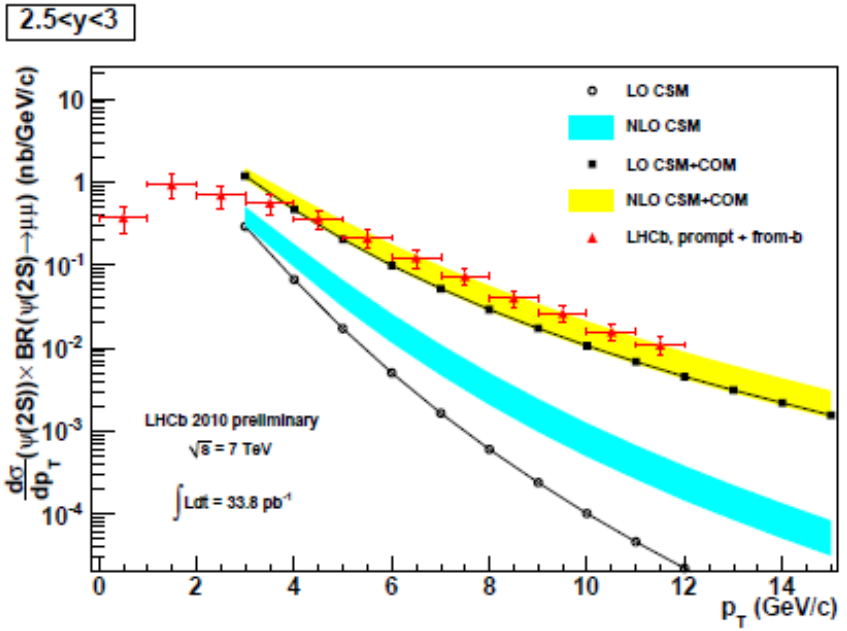
Quarkonia cross-section measurements: ψ(2S)

- Efficiencies estimated from MC and checked (trigger) with real data
- Systematic errors: luminosity, trigger, tracking, polarisation, ...



$$\sigma(0 < p_T \leq 12\ \text{GeV}/c, 2 < y \leq 4.5) \;=\; 1.88 \pm 0.02 \pm 0.31^{+0.25}_{-0.48}\ \mu\text{b}$$

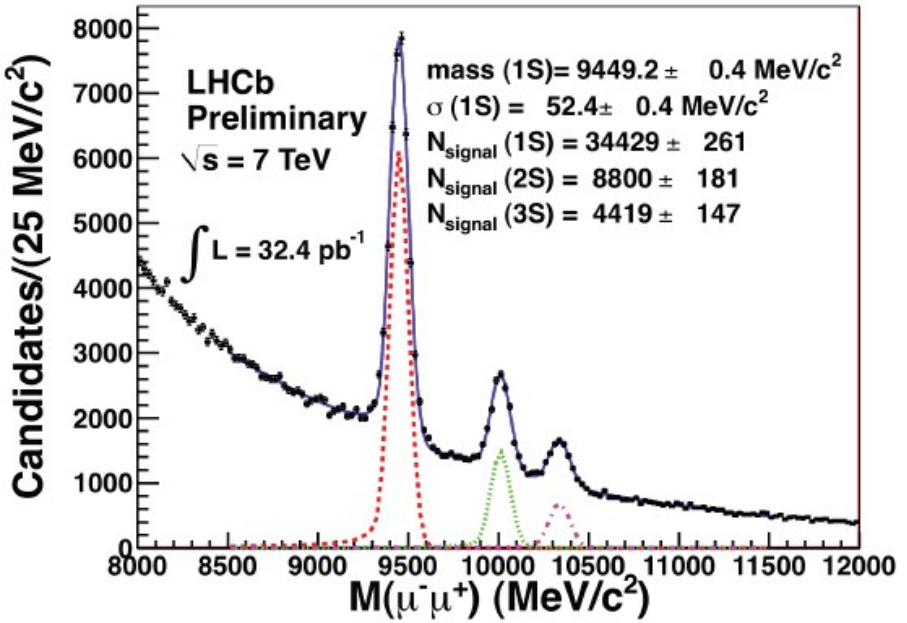
- **Our preliminary measurement includes ψ(2S) from *b* also: *b* fraction expected to be 10% at low p_T and 40% at large p_T**



M. Butenschoen and B. A. Kniehl, Phys. Rev. Lett. **106**, 022003 (2011) and private communication

Quarkonia cross-section measurements: Y(1S)

- Measurement of the Y cross-section: same strategy already discussed for J/ψ
- Selection:
  - 2 muon tracks
  - muon p_T cut (>1 GeV/*c*)
  - track fit quality cut (χ^2/nDoF < 4)
  - vertex fit quality cut (p(χ^2)>0.01%)



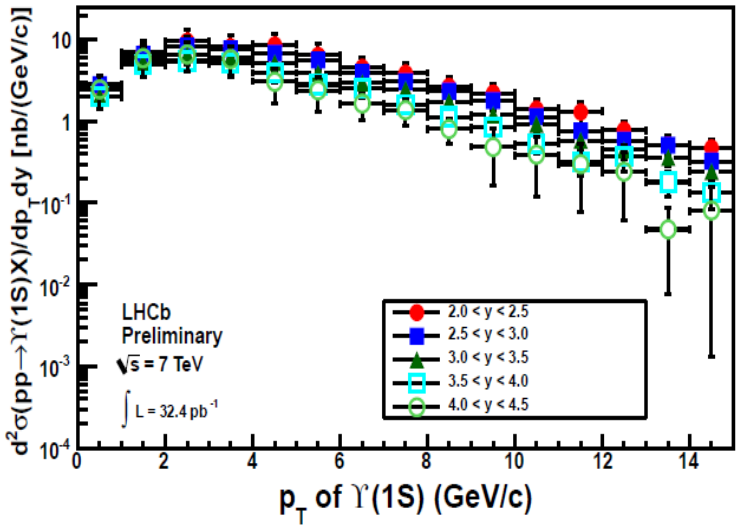
- Fit: three CB for signal + exponential for background
- 2S, 3S masses and widths fixed
- Only Y(1S) is considered for cross-section measurement

Quarkonia cross-section measurements: Υ(1S)

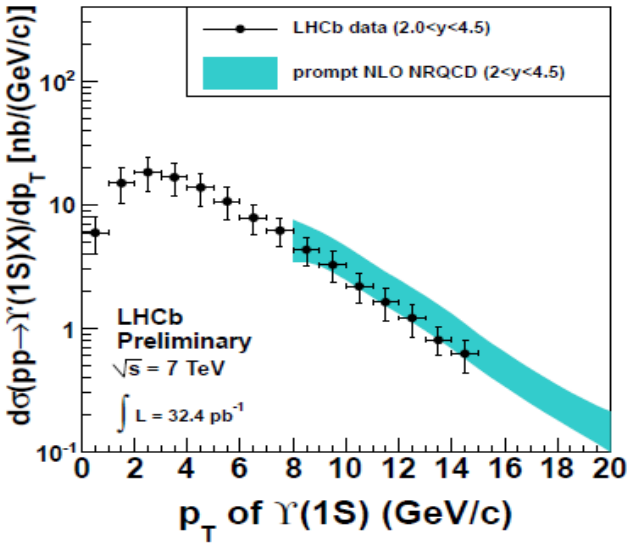
- Efficiencies computed from Monte Carlo
- Polarisation effect evaluated

Integrated value over p_T<15 GeV/*c* and 2<*y*<4.5

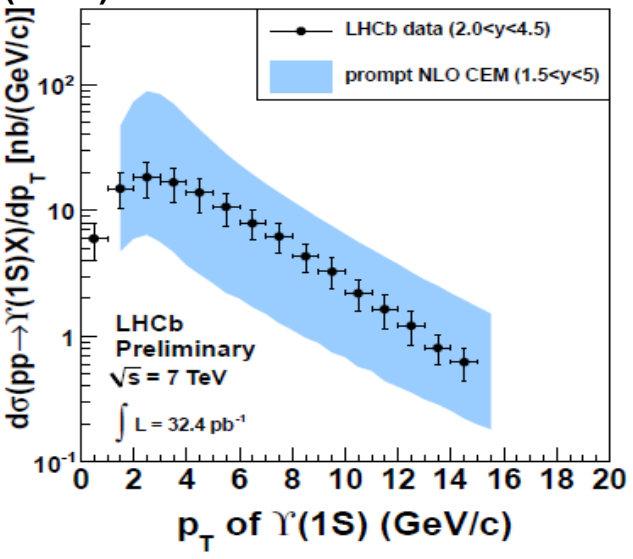
$$\sigma = 108.3 \pm 0.7 \pm {}^{+30.9}_{-25.8} \text{ nb}$$



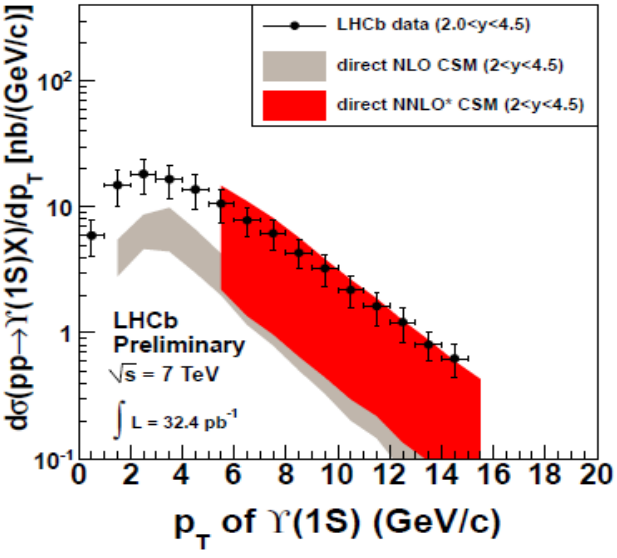
Y.Q. Ma, et al., PRL106 (2011) 042002



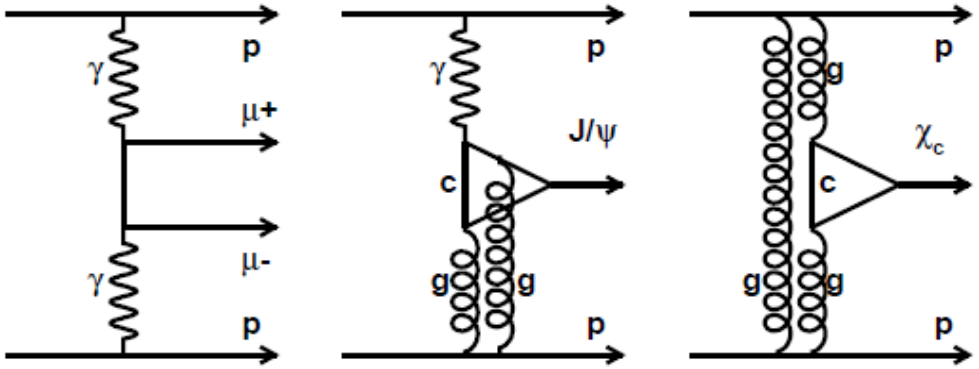
A. D. Frawley et al., Phys Rep.462 (2008) 125



J.F. Lansberg, Eur. Phys. J. C 61 (2009) 693



Exclusive dimuon production

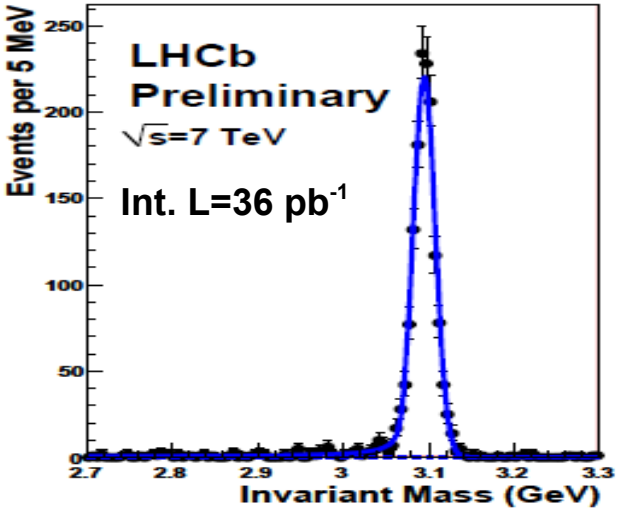


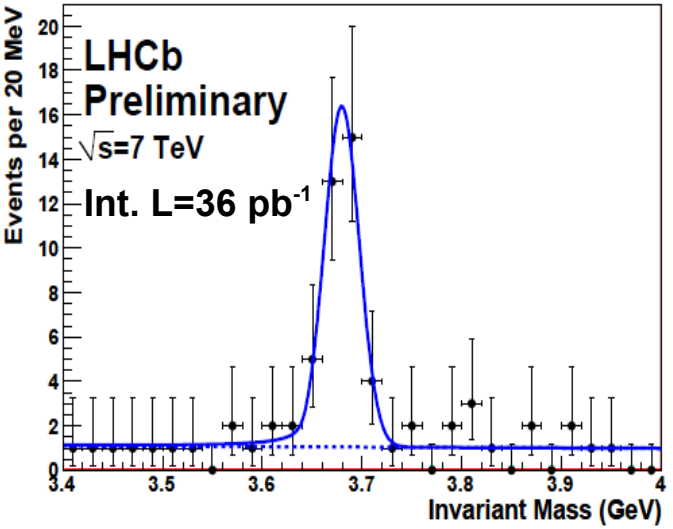
- two muons in the final state: non resonant or resonant through J/ψ, ψ(2S) or χ_c
- pomeron (gg) and odderon (ggg) predicted by QCD can be studied in a clean environment

- **Selection**
  - 36 pb^{-1}
  - No backward tracks (from VeLo)
  - Only two forward muons
  - $p_T(\mu\mu)<900$ MeV/*c* to reduce contamination from inelastic (diffractive) prod.
  - No photons (one photon for χ_c)

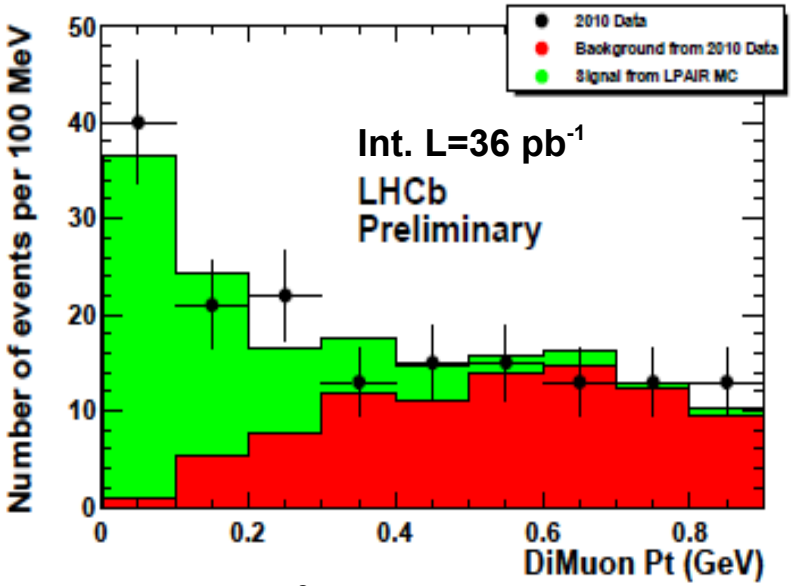
Exclusive dimuon production

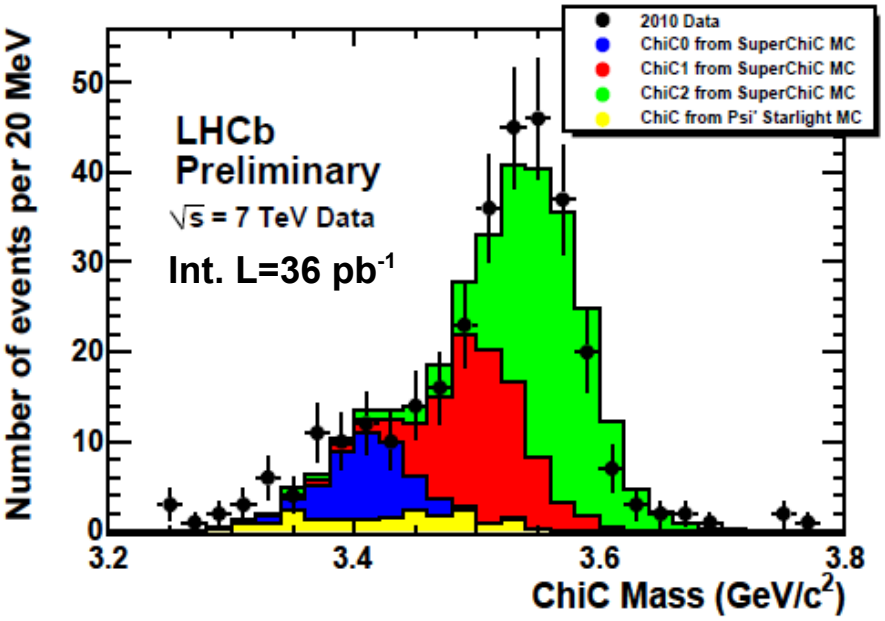
J/ψ





ψ(2S)





inv mass > 100 MeV/c^2 away from J/ψ and ψ(2S)

Exclusive dimuon production

$$\sigma_{J/\psi\to\mu^+\mu^-}(2<\eta_{\mu+},\eta_{\mu-}<4.5) = 474 \pm 12 \pm 51 \pm 92 \text{ pb}$$

$$\sigma_{\psi(2S)\to\mu^+\mu^-}(2<\eta_{\mu+},\eta_{\mu-}<4.5) = 12.2 \pm 1.8 \pm 1.3 \pm 2.4 \text{ pb}$$

$$\sigma_{\chi_{c0}\to J/\psi\gamma\to\mu^+\mu^-\gamma}(2<\eta_{\mu+},\eta_{\mu-},\eta_\gamma<4.5) = 9.3 \pm 2.2 \pm 3.5 \pm 1.8 \text{ pb}$$

$$\sigma_{\chi_{c1}\to J/\psi\gamma\to\mu^+\mu^-\gamma}(2<\eta_{\mu+},\eta_{\mu-},\eta_\gamma<4.5) = 16.4 \pm 5.3 \pm 5.8 \pm 3.2 \text{ pb}$$

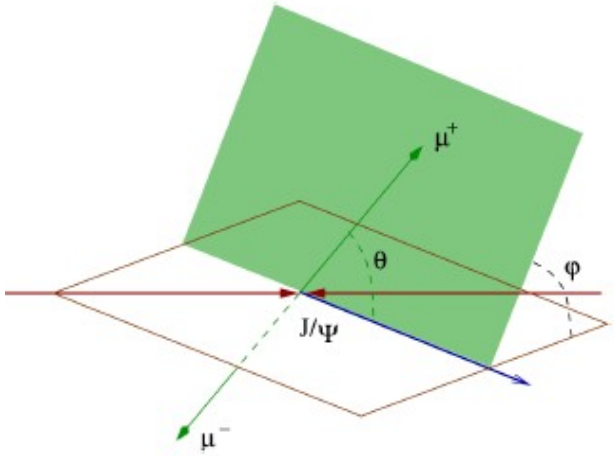
$$\sigma_{\chi_{c2}\to J/\psi\gamma\to\mu^+\mu^-\gamma}(2<\eta_{\mu+},\eta_{\mu-},\eta_\gamma<4.5) = 28.0 \pm 5.4 \pm 9.7 \pm 5.4 \text{ pb}$$

$$\sigma_{pp\to p\mu^+\mu^- p}(2<\eta_{\mu+},\eta_{\mu-}<4.5; m_{\mu+\mu-}>2.5 \text{ GeV/c}^2) = 67 \pm 10 \pm 7 \pm 15 \text{ pb}$$

- Predictions are rather uncertain and vary a lot
- Exclusive J/ψ
  - Starlight generator: 292 pb
  - SuperChic generator: 330 pb
  - L. Motyka et al., PR D78 (2008) 014023: 330 pb
  - W. Schäfer et al., PR D76 (2007) 094014: 710 pb
- Exclusive ψ(2S)
  - Starlight generator: 6.1 pb
  - W. Schäfer: 17 pb

Prospects for polarisation measurements

- Theories give clear predictions of prompt J/ψ polarisation
- Polarisation knowledge helps to decrease the error on the cross-sections measured



$$\frac{d^2N}{d\cos\theta\, d\phi} \propto 1 + \lambda_\theta \cos^2\theta + \lambda_{\theta\phi} \sin 2\theta \cos\phi + \lambda_\phi \sin^2\theta \cos 2\phi$$

Coming soon: polarisation measurement (λ_θ, $\lambda_{\theta\varphi}$, λ_φ) in the helicity frame, in 15 p_T bins, $0<p_T<15$ GeV/c

Expected statistical sensitivity

challenge: systematic due to the detector effect on the angular distributions

Parameter	min	max
λ_θ	0.01	0.16
$\lambda_{\theta\varphi}$	0.006	0.06
λ_φ	0.004	0.06

Conclusions

- Quarkonia results have been presented: cross-sections for
  - J/ψ (separately prompt and non-prompt)
  - double J/ψ
  - ψ(2S) (not yet separated prompt from non-prompt)
  - Υ(1S)
  - Exclusive dimuon

- Comparison with the theoretical models: experimental error is lower than the theoretical one

- Other interesting informations will come from quarkonium polarisation measurements: results expected soon