# J/ψ Production in pp and in Heavy-Ions Collisions in ATLAS

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On behalf of the ATLAS Collaboration

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# Motivations & Outline

- **Motivations:**
  No unified mechanism exists to consistently explain the heavy quarkonium production and spin-alignment in e+e-, hadron and heavy-ion colliders. J/Ψ production measurements provide constraint to physics models.

- **J/Ψ Cross-Section Measurement in 7 TeV pp Collisions**
  - New results with 2.4 $pb^{-1}$ data
  - Part of the results - related to $b\bar{b}X \rightarrow J/\Psi X'$ production, presented Tuesday, in ATLAS b-production overview by Ilektra Christidis
  - More details in Nir Amram's poster

- **J/Ψ Production in 2.76 TeV pb pb Collisions**
  - PLB 697, 294-312, 2011 (accepted in Jan 2011)
  - More details in Camilla Maiani's poster

# ATLAS Detector

## Key Elements for J/Ψ Analysis

### Trigger:

Minimum Bias, Muon

### Inner Detectors:

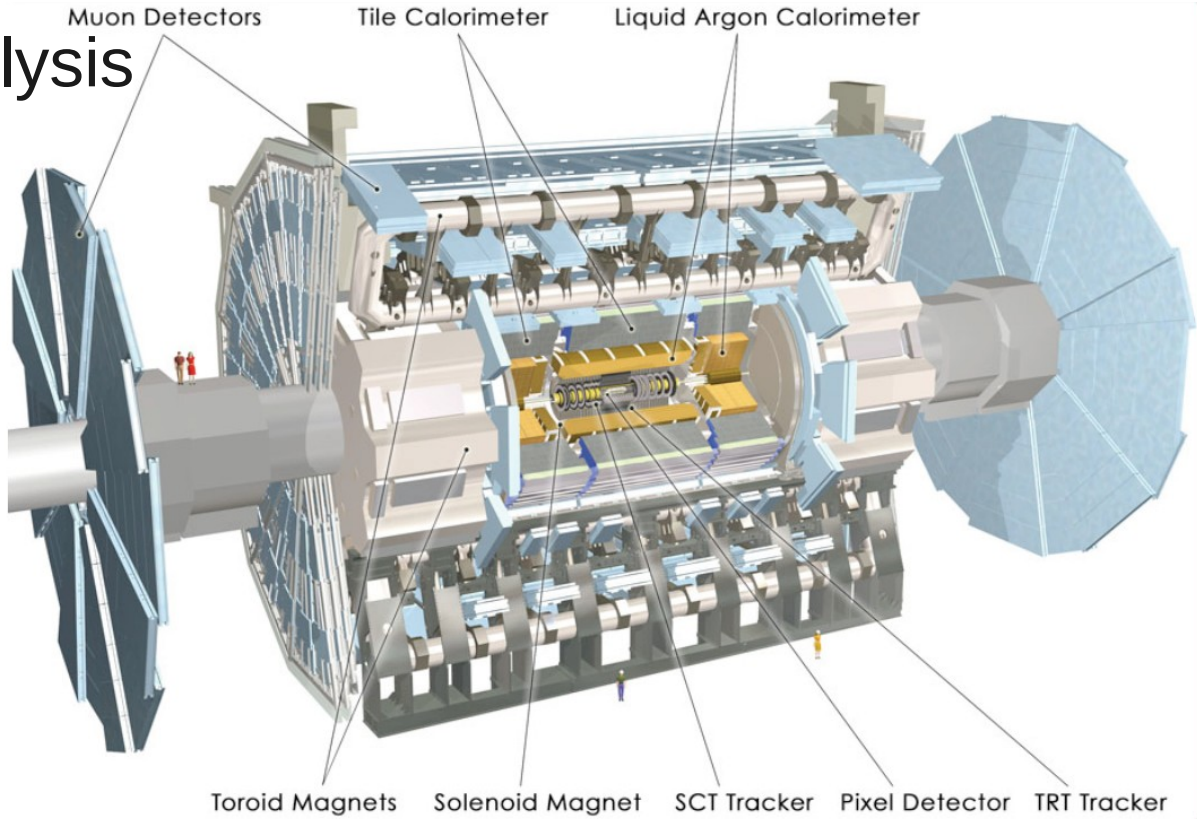
Designed resolution

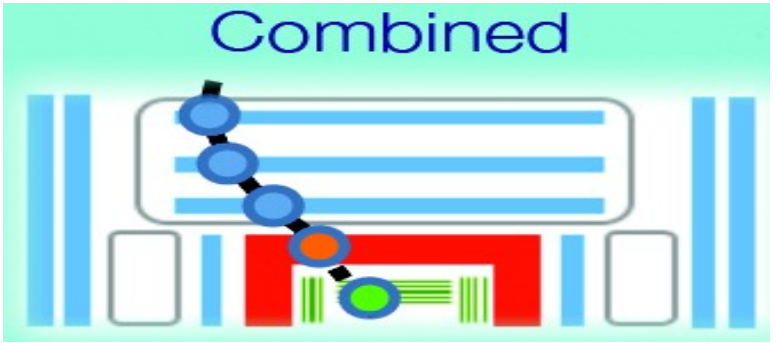
$\sigma(p_T)/p_T = 0.05\%\ p_T\ [\text{GeV}] \oplus 1\%$

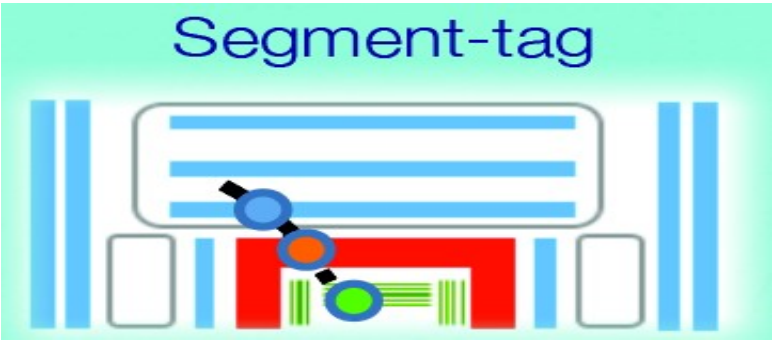
Impact parameter $(0.25<|\eta|<0.5)$

$\sigma(d_0) = 10\mu\text{m} \oplus 140\mu\text{m} / p_T\ [\text{GeV}]$

### Muon Spectrometer






More details in Rosy Nicolaidou's talk: ATLAS detector performance

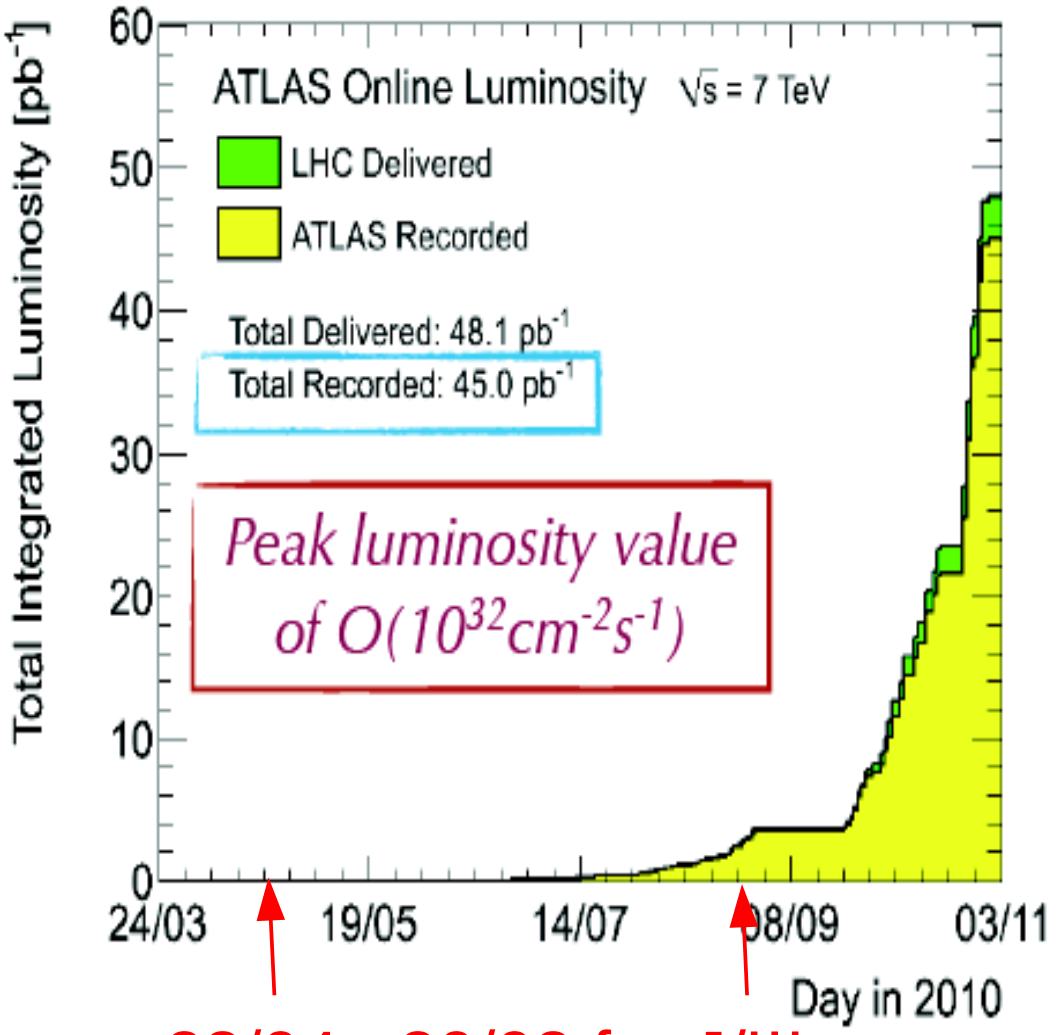
# Triggers, Dataset, Selections

**Trigger:**

- Single muon trigger
- Un-prescaled trigger for inclusive production **2.27 pb$^{-1}$**
- Include prescaled trigger for non-prompt **2.44 pb$^{-1}$**

**Selections:**

- >=3 tracks in Primary Vertex to veto Cosmics
- At least one combined muon
- Muon pT>3GeV and |eta|<2.5
- For Non-prompt fraction study
  → Both tracks associated to the same Event Vertex



# Inclusive Cross-Section Measurement

Measure Double Differential Cross-section as function of J/Ψ transverse momentum and rapidity

$$\frac{d^2\sigma(J/\psi)}{dp_T dy} \cdot Br(J/\psi \to \mu^+\mu^-) = \frac{N_{corr}^{J/\psi}}{\mathcal{L} \cdot \Delta p_T \Delta y} \qquad N_{corr}^{J/\psi} = N_{J/\psi} \cdot w$$

Event-by-event weight is applied to retrieve true number of J/Ψ

$$w^{-1} = \mathcal{A} \cdot M \cdot \mathcal{E}_{\text{trk}}^2 \cdot \mathcal{E}^+{}_{\mu}(p_T^+, \eta^+) \cdot \mathcal{E}^-{}_{\mu}(p_T^-, \eta^-) \cdot \mathcal{E}_{\text{trig}}$$

$$\mathcal{E}_{\text{trig}} = 1 - \left(1 - \mathcal{E}_{\text{trig}}^+(p_T^+, \eta^+)\right) \cdot \left(1 - \mathcal{E}_{\text{trig}}^-(p_T^-, \eta^-)\right)$$

A: geometrical acceptance depends on spin-alignment
M: Bin migration factor to account for resolution effect
$\varepsilon_{trk}$: ID tracking efficiency 99.0+-0.5 %
ε(pt,eta): single muon offline reconstruction efficiency
$\varepsilon_{trig}$ : Charge dependent muon trigger efficiency

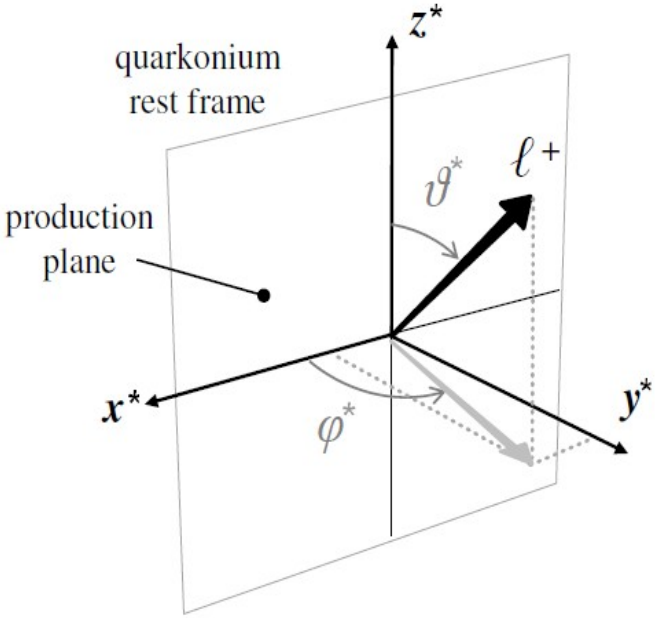
Efficiency measurement is described in Massimo Corradi's talk

# Acceptance & Spin-Alignment

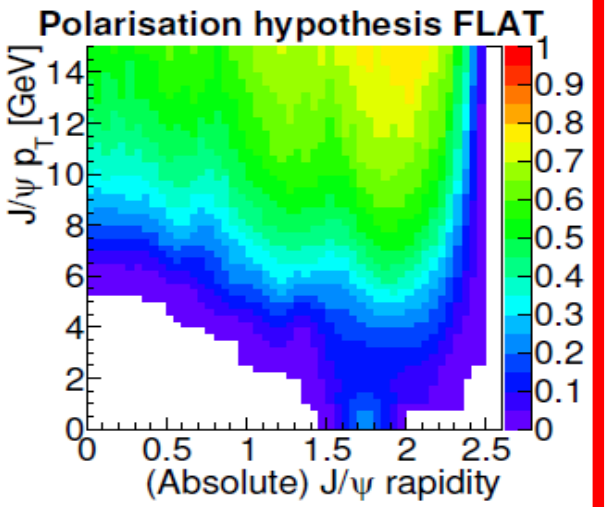
Unknown spin alignment of J/Ψ production in LHC

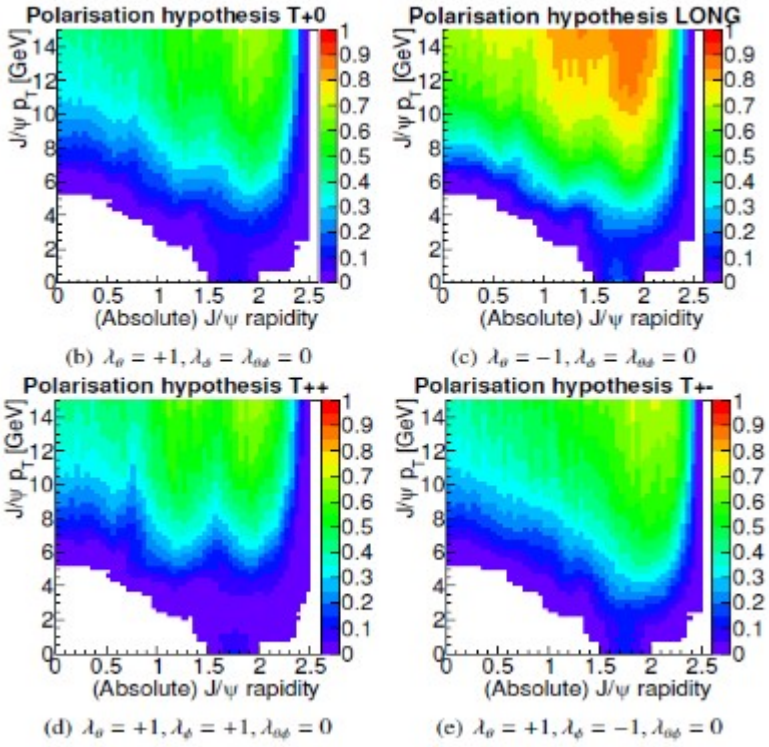
$$\frac{d^2N}{d\cos\theta^\star d\phi^\star} \propto 1 + \lambda_\theta \cos^2\theta^\star + \lambda_\phi \sin^2\theta^\star \cos 2\phi^\star + \lambda_{\theta\phi} \sin 2\theta^\star \cos\phi^\star$$

Central values are reported with un-polarized acceptance
Spin-alignment envelopes are maximal variations from four polarization schemes




Central Value

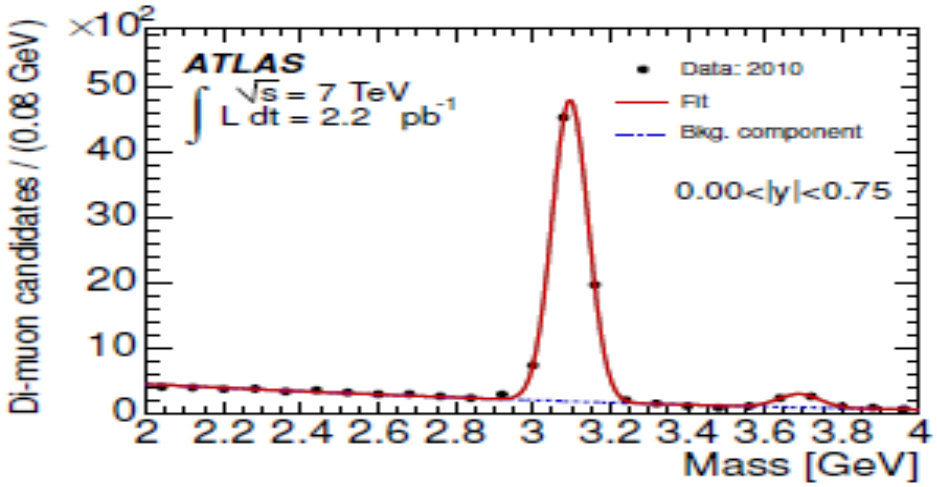


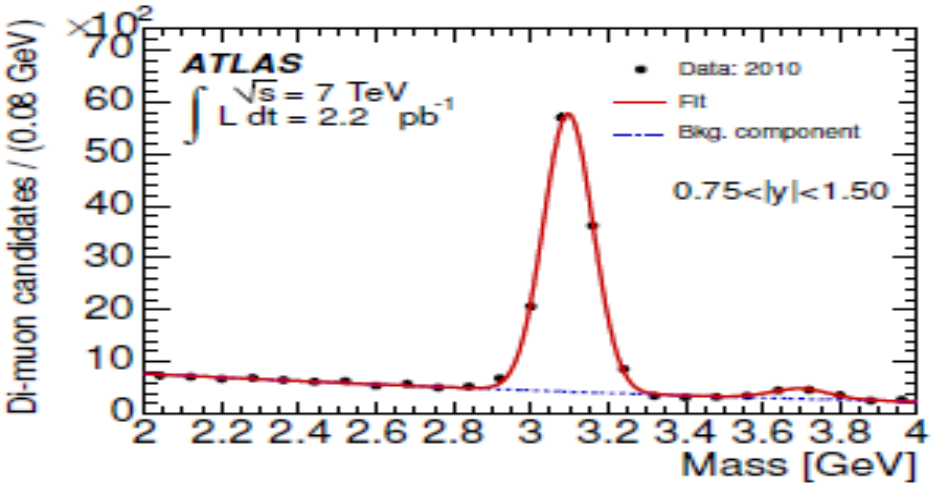



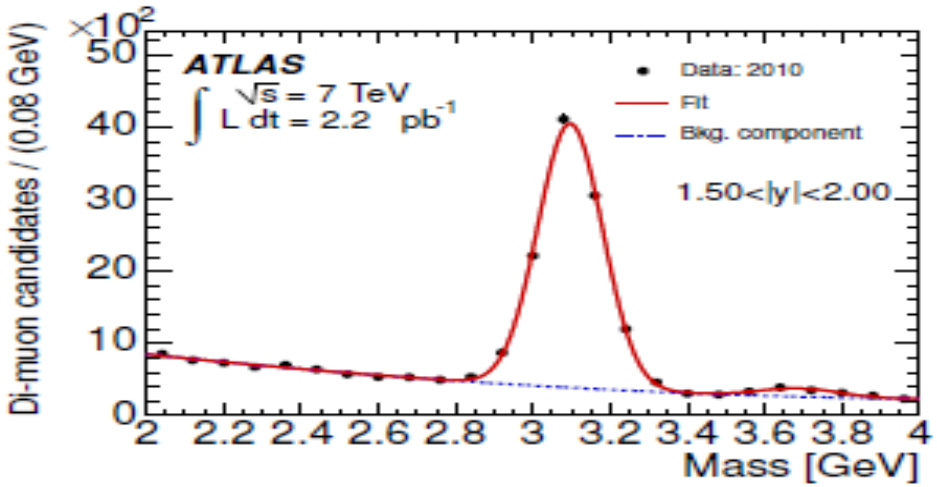

Spin-alignment envelopes

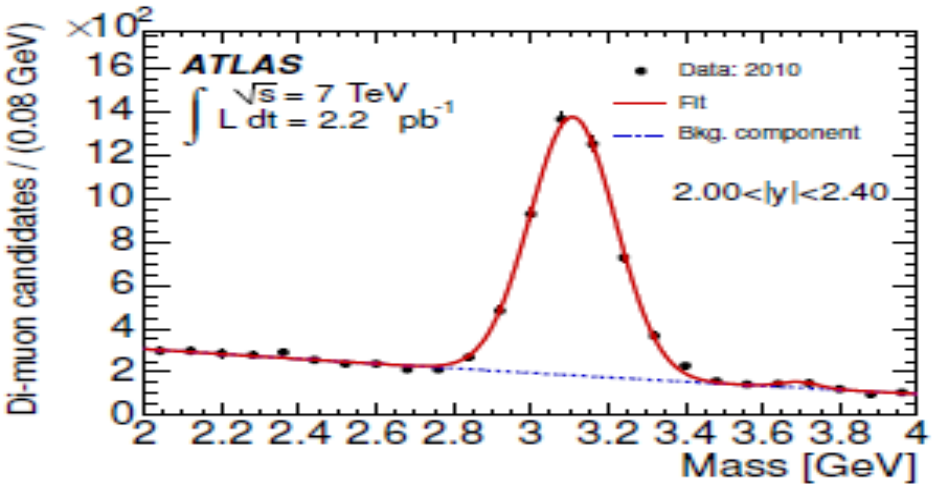
# Inclusive J/Ψ in pp Collisions

There are total ~31k J/Ψs used for double differential cross-section measurements in four rapidity bins. Mass resolution is 40~110 MeV



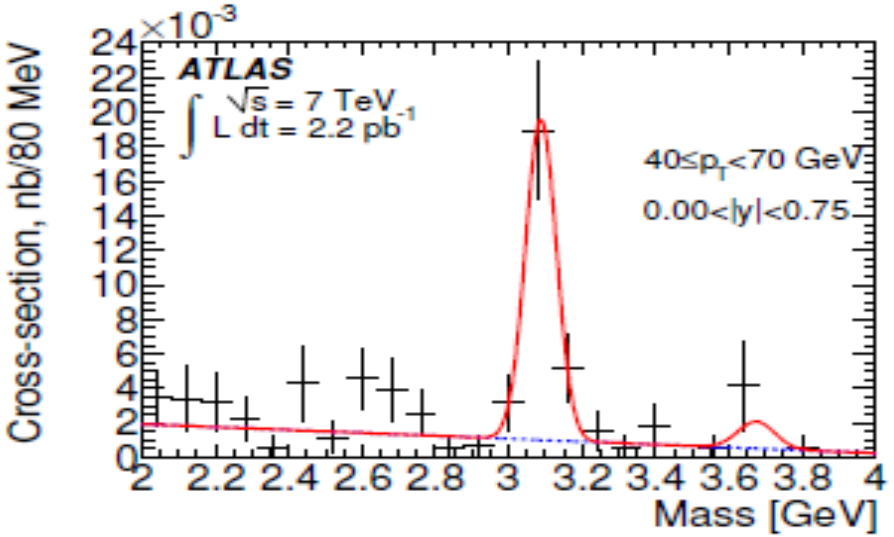



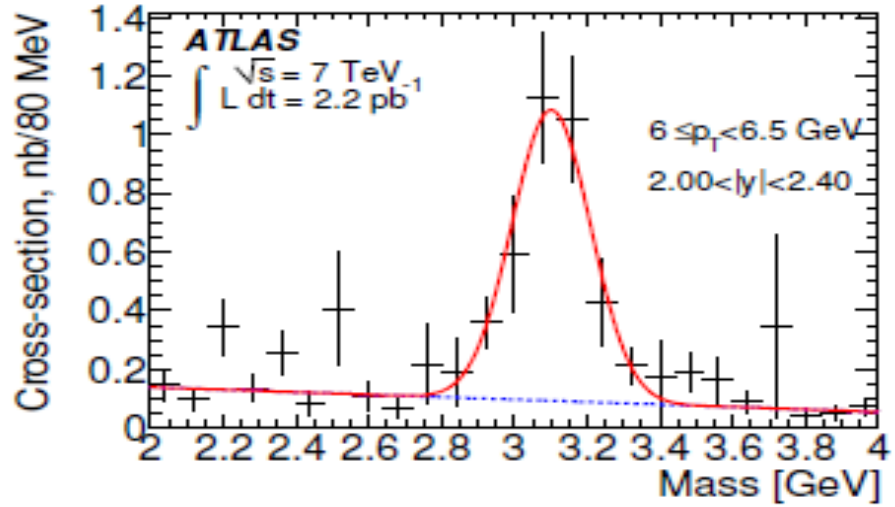



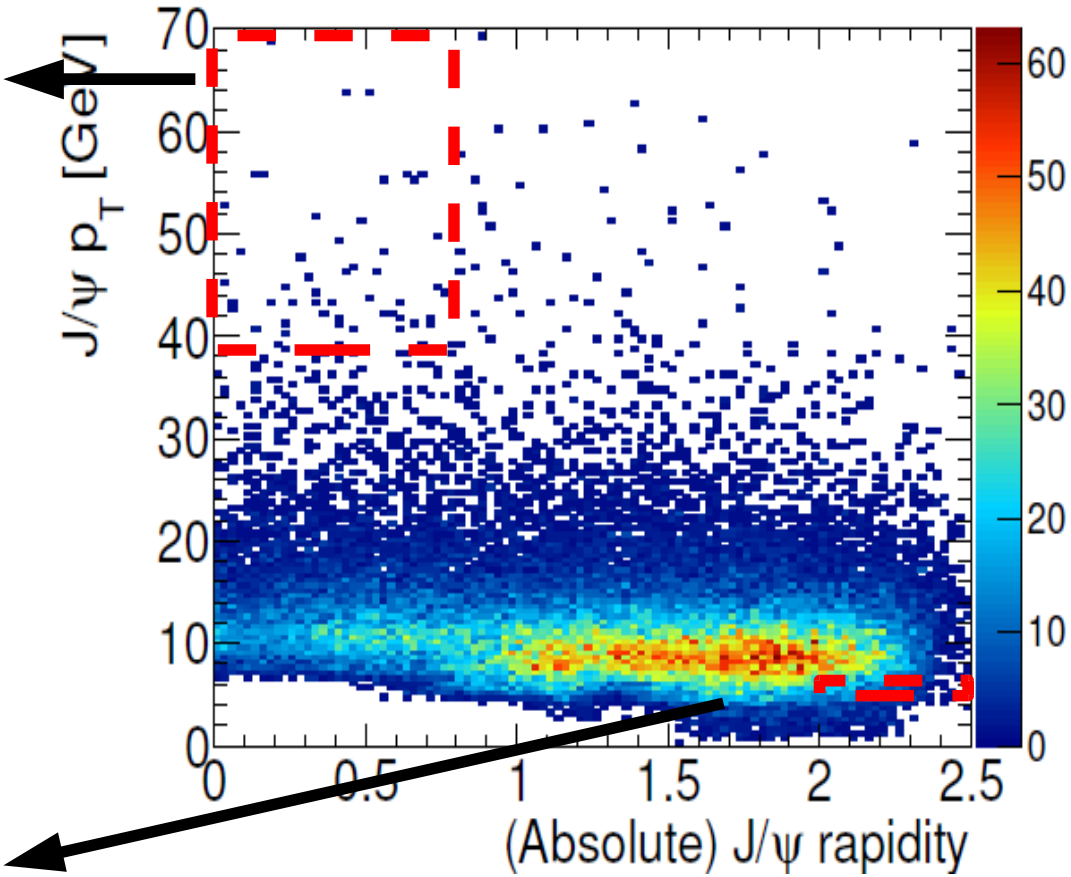



# Yield & Cross-section Extraction

Signal P.D.F. is one Gaussian with scaled event-by-event mass errors while background P.D.F. is the first order polynomial

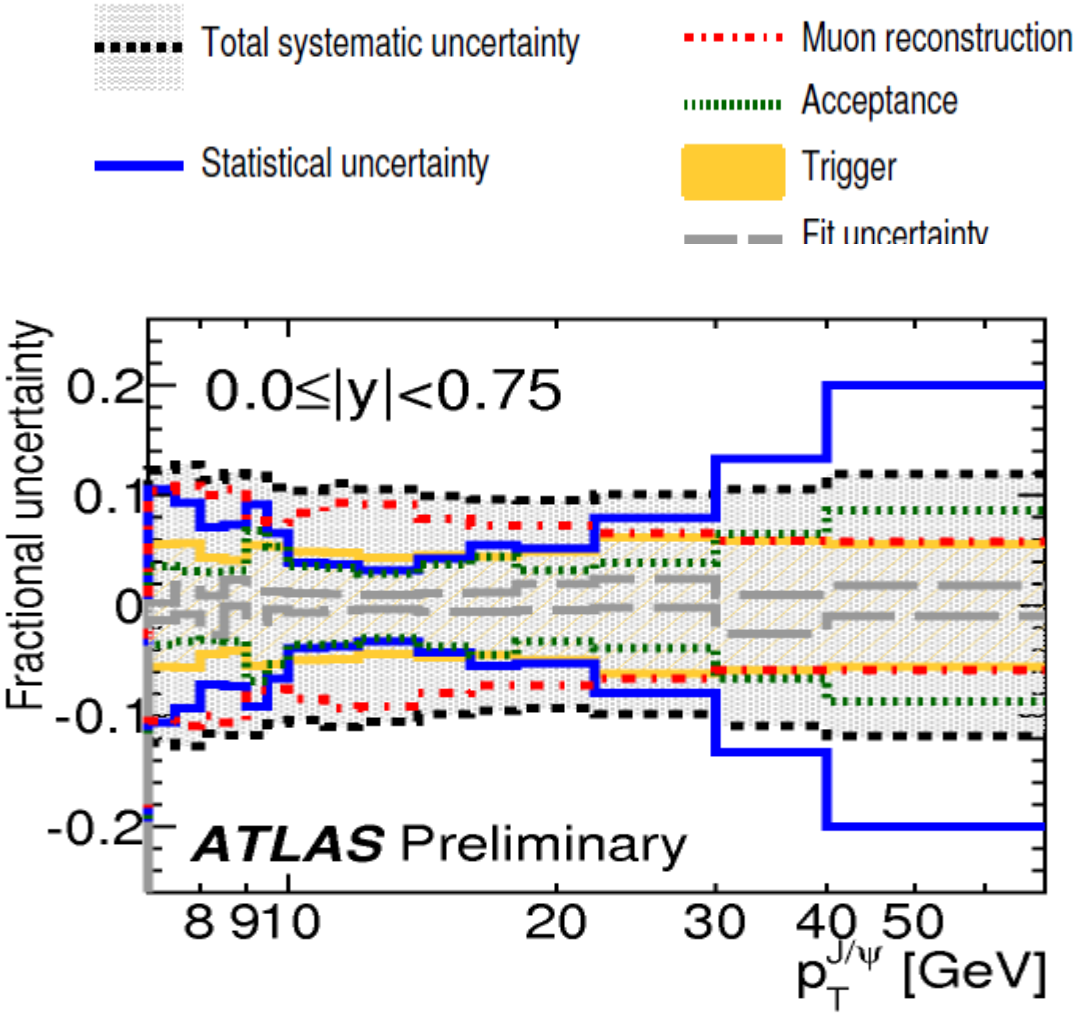


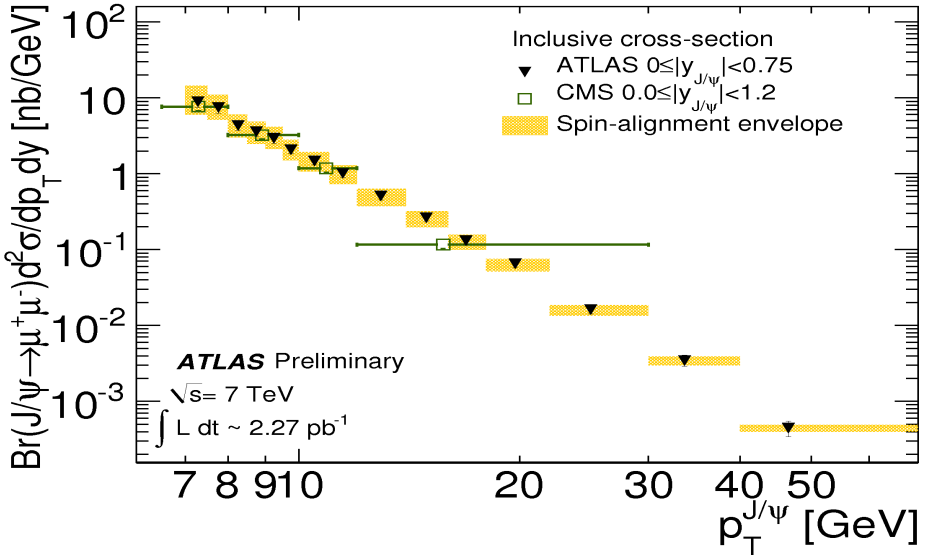



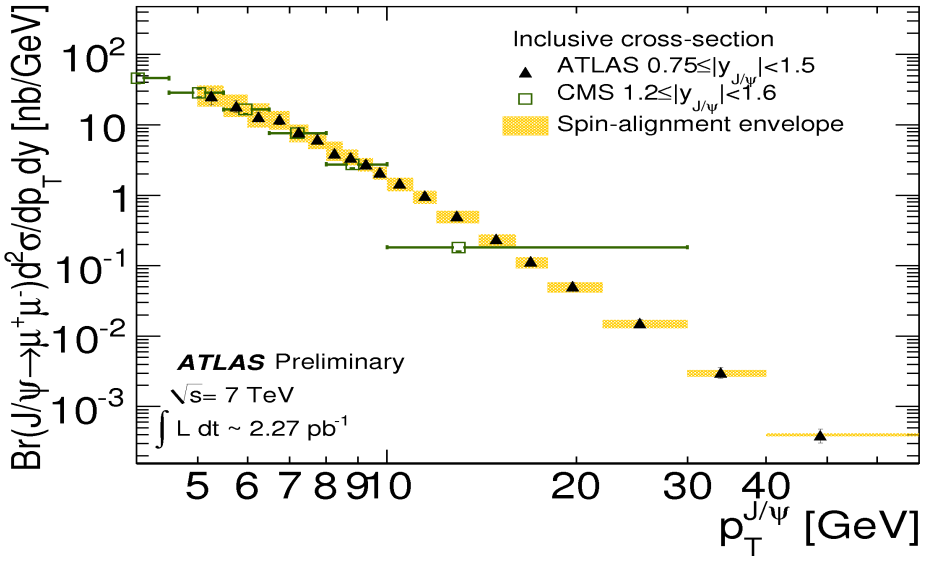
# Systematics Uncertainties

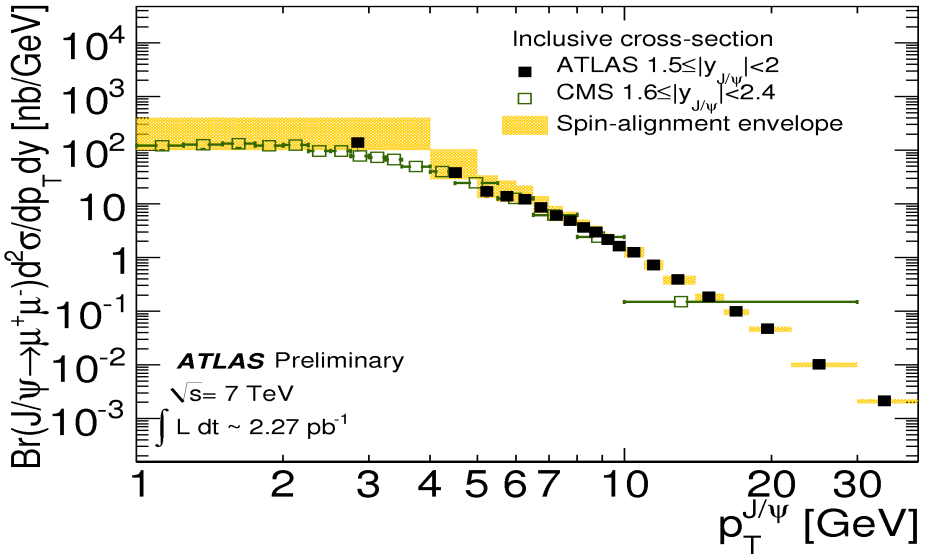
- Muon Reconstruction
  - Muon/ID efficiency
- Acceptance
  - Bin Migration
  - Vertexing
- Trigger
- Fit uncertainty
- Total
  - Above
  - Luminosity (3.4%)
  - MC model dependence
  - Final State Radiation
- Spin-alignment envelopes are separate uncertainties (5~200%)

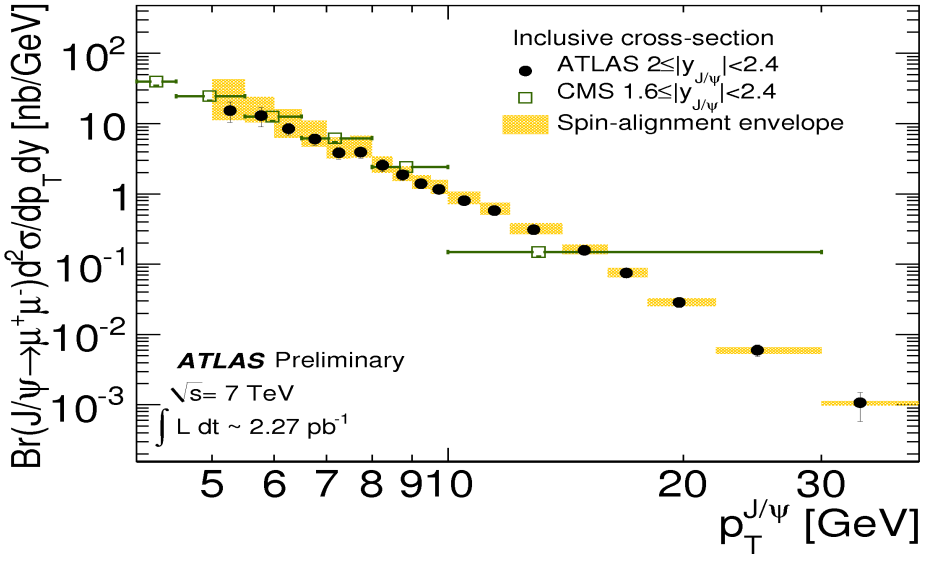


# Inclusive Cross-Section



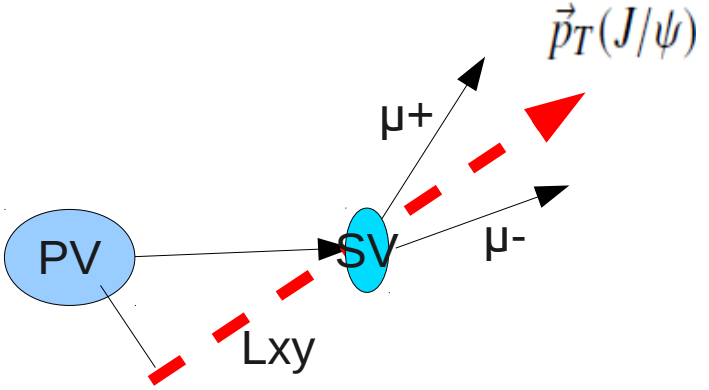




ATLS results are consistent with CMS results where overlap

# Extraction of Non-prompt fractions

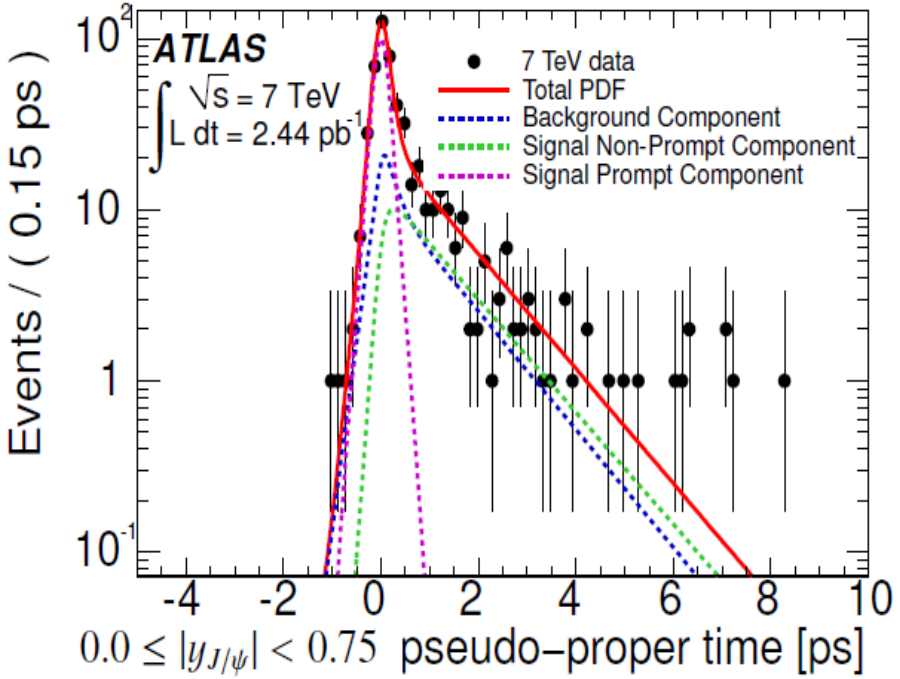
Non-promt fraction $f_B$ is defined as:

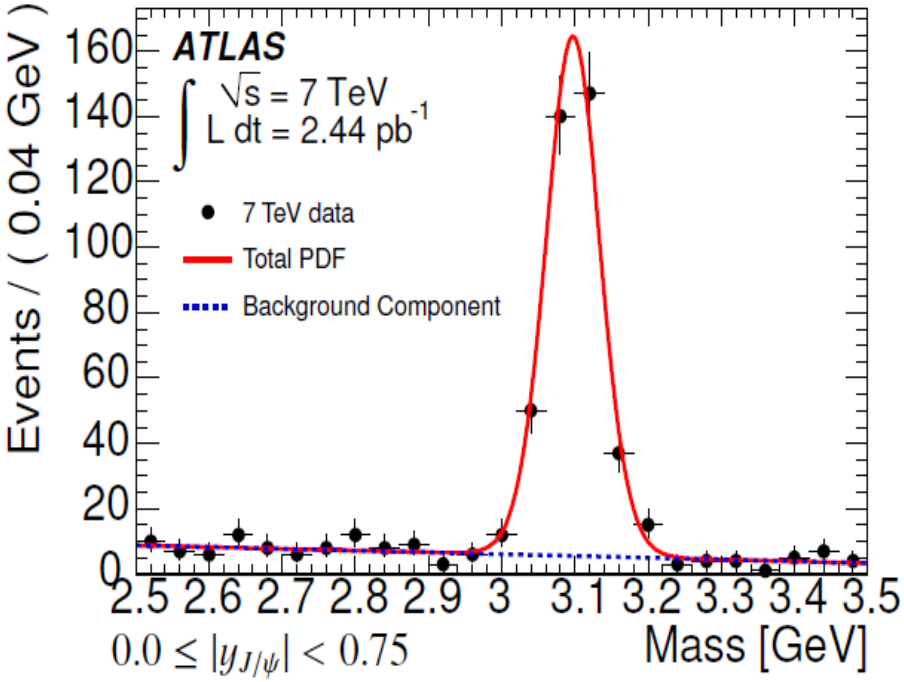
$$f_B \equiv \frac{d\sigma(pp \to b\bar{b}X \to J/\psi\, X')}{d\sigma(pp \to J/\psi\, X'')}$$



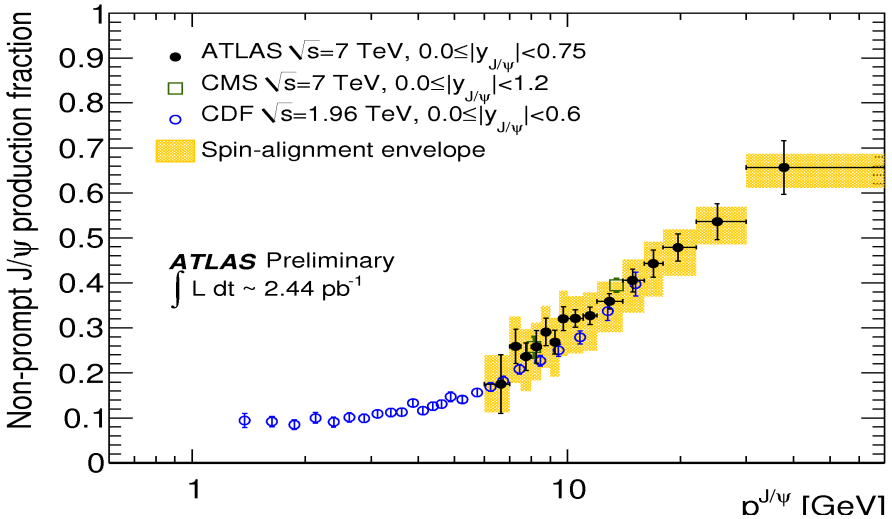

Simultaneous mass-lifetime unbinned likelihood fit was used to extract $f_B$ in multiple J/Ψ $p_T$ and rapidity

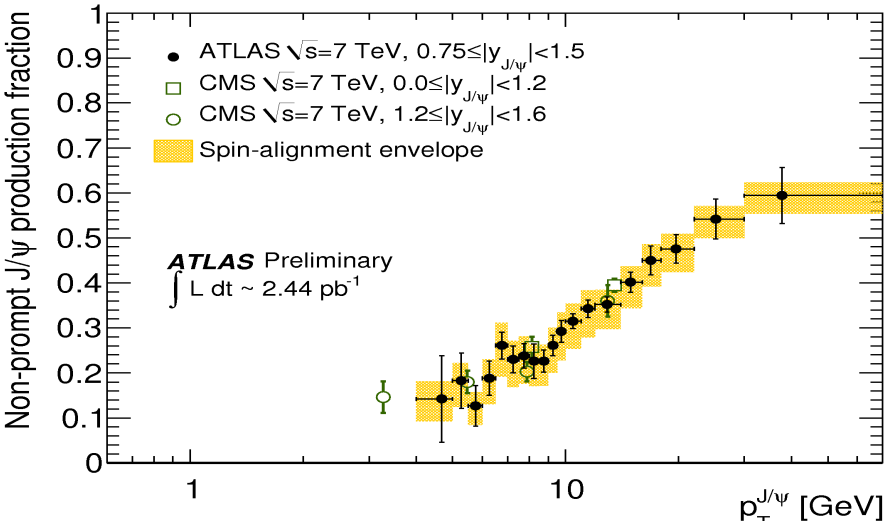
$$\tau = \frac{L_{xy}\, m_{\mathrm{PDG}}(J/\psi)}{p_T(J/\psi)}$$

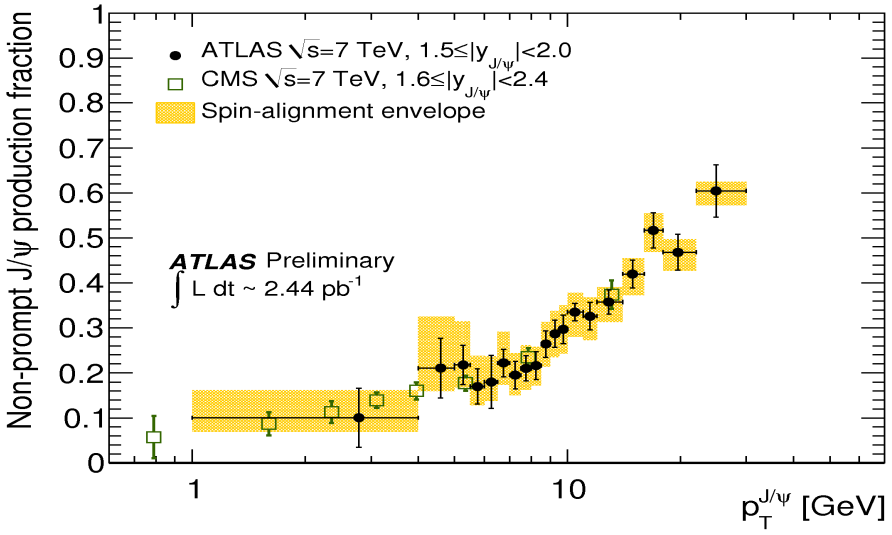


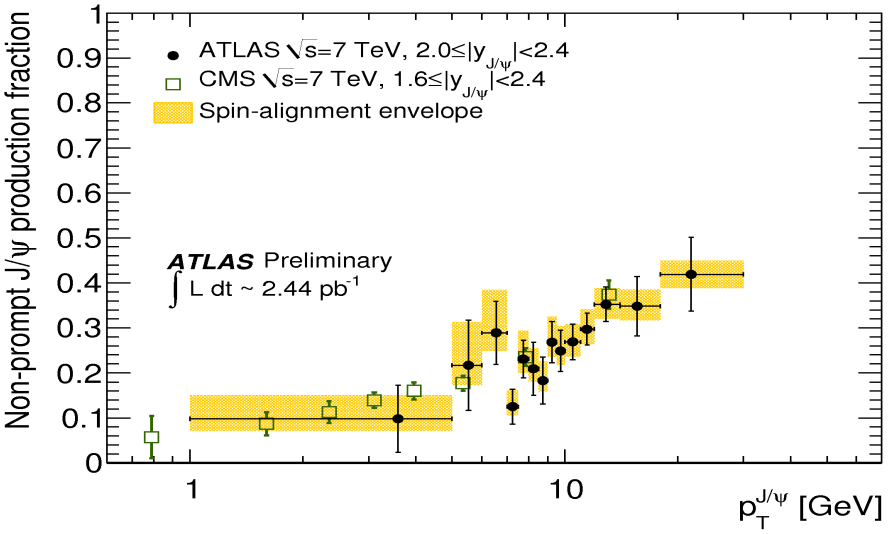



# Non-prompt fraction Results



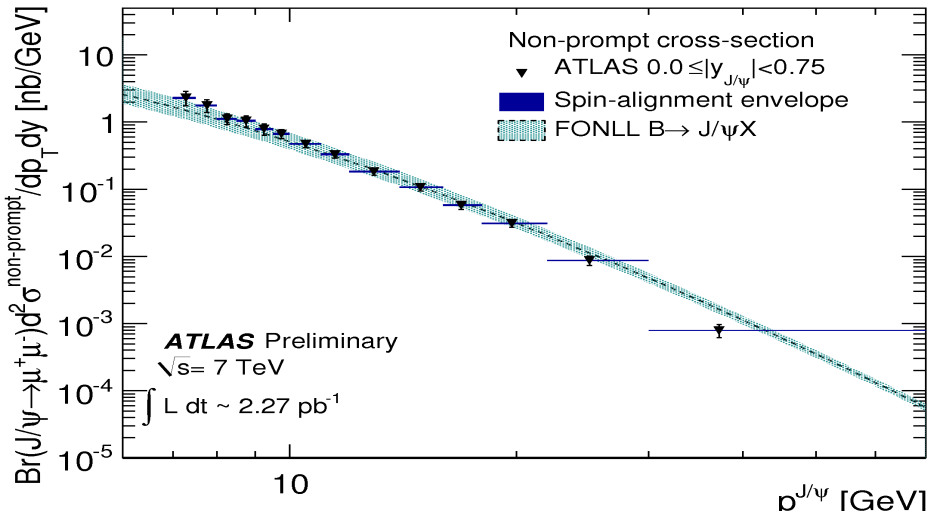



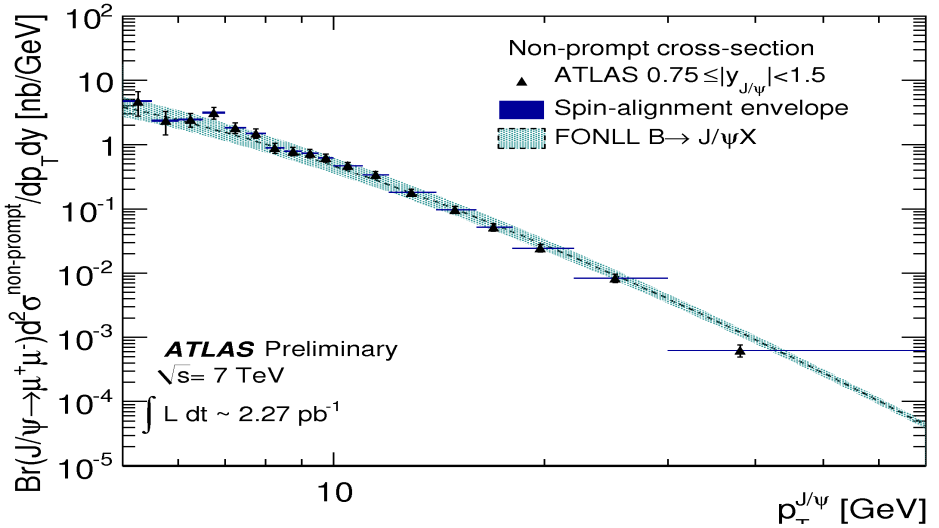



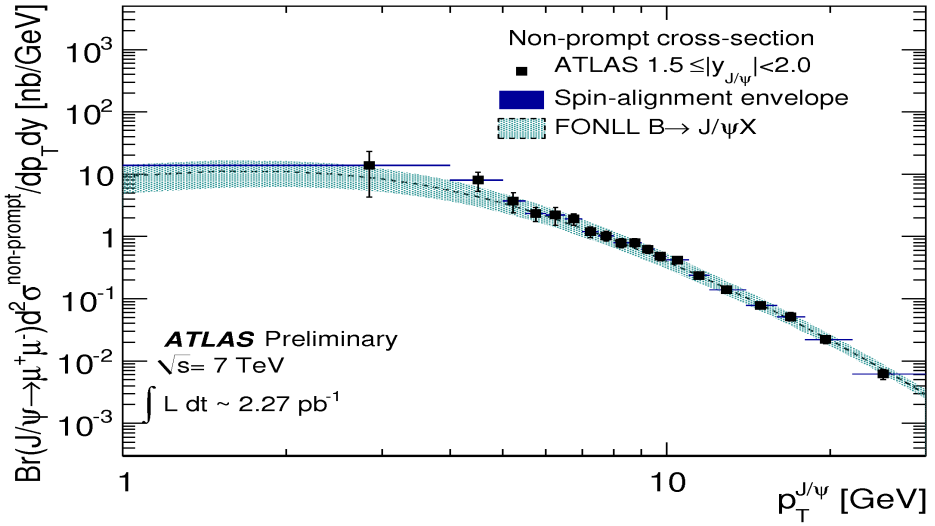



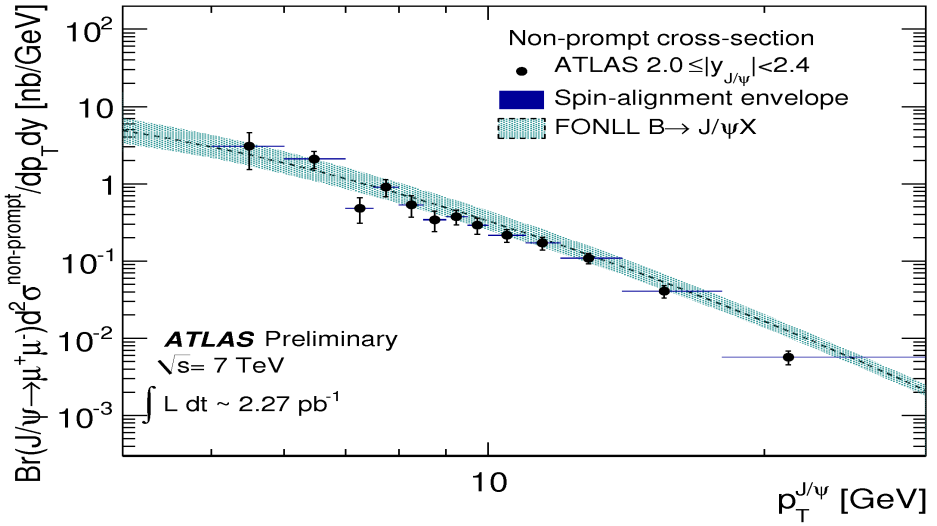

ATLAS extends further to higher pT not covered by any of previous measurements.

# Non-prompt Cross-Section



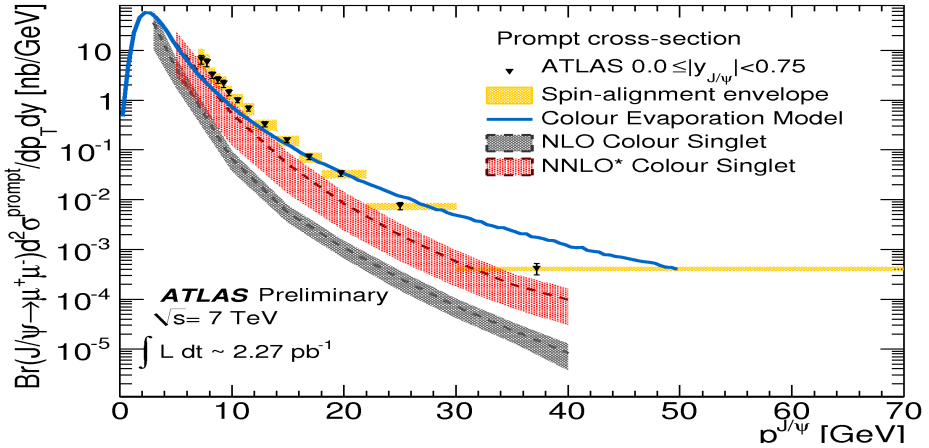



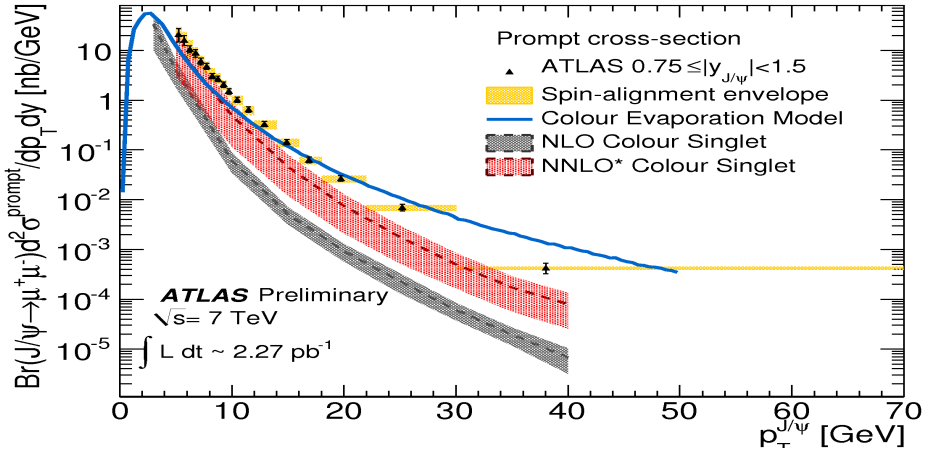



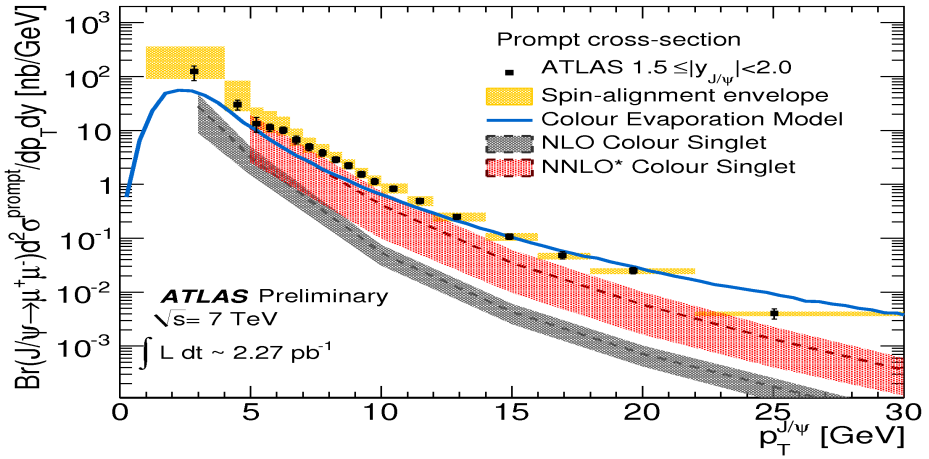



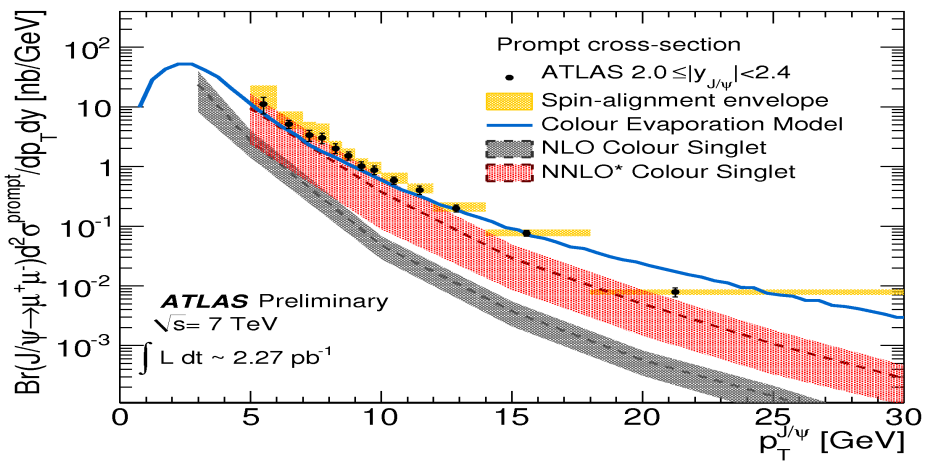

Good agreement is found to Fixed Order Next-to-leading-logarithm calculation. JHEP 9805 (1998) 007, JHEP 0103 (2001) 006

# Prompt Cross-Section



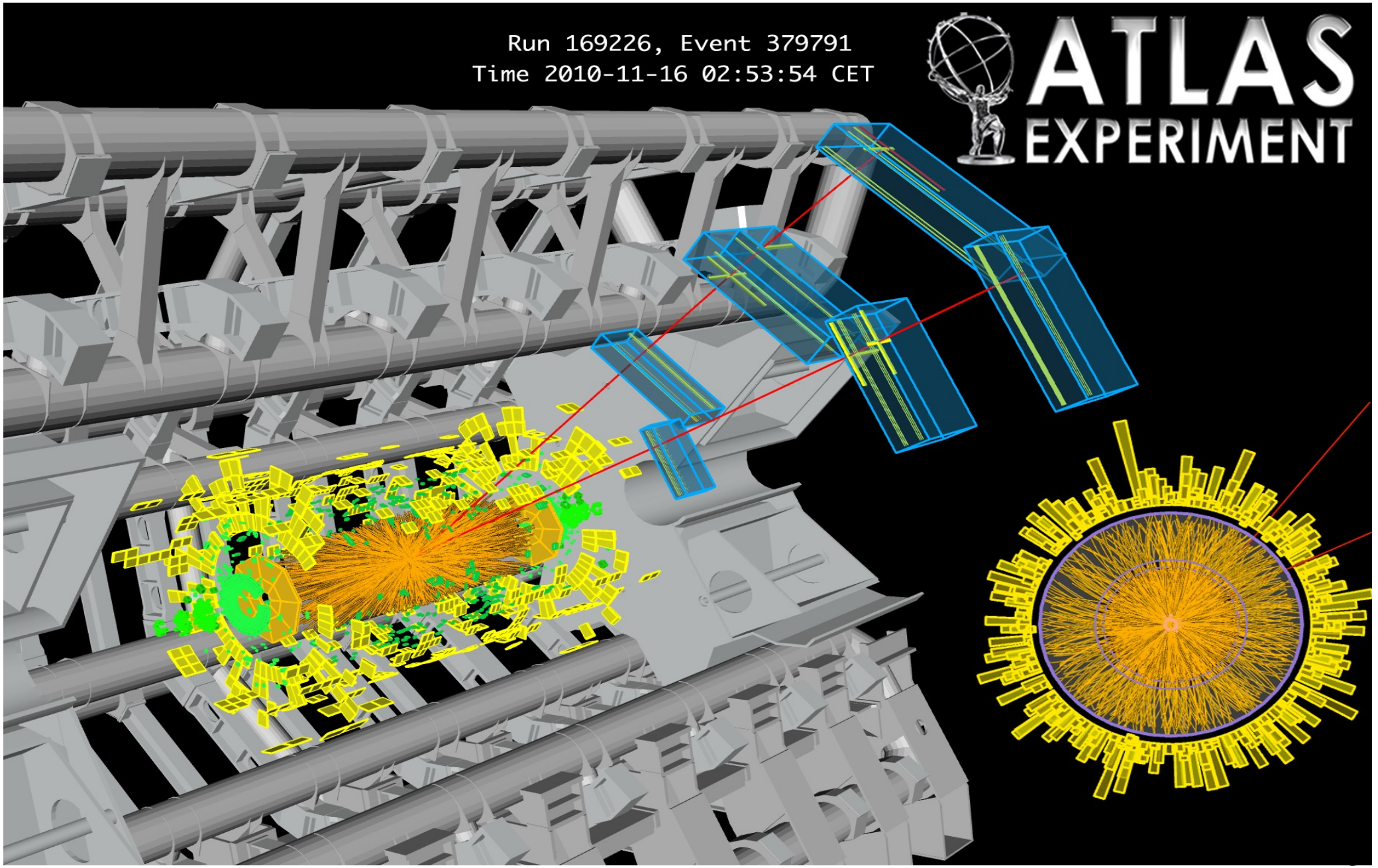




**Comparisons include J/ψ feed-down from higher states**
**Theoretical predictions have issues to describe both shapes and normalization**

Color Evaporation Model: Phys. Rept. 462 (2008) 125, Phys. Lett. B 91 (1980) 253
Color Singlet Model: Phys. Rev. D 81 (2010), Eur. Phys. J. C 61 (2009) 693

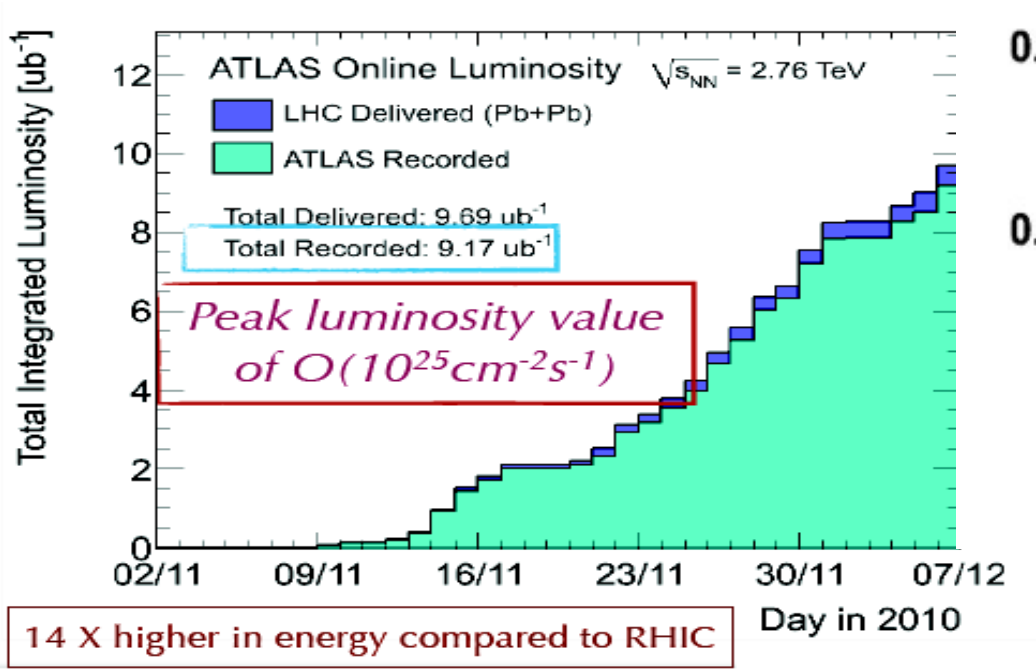
# J/Ψ Candidate in Heavy Ion



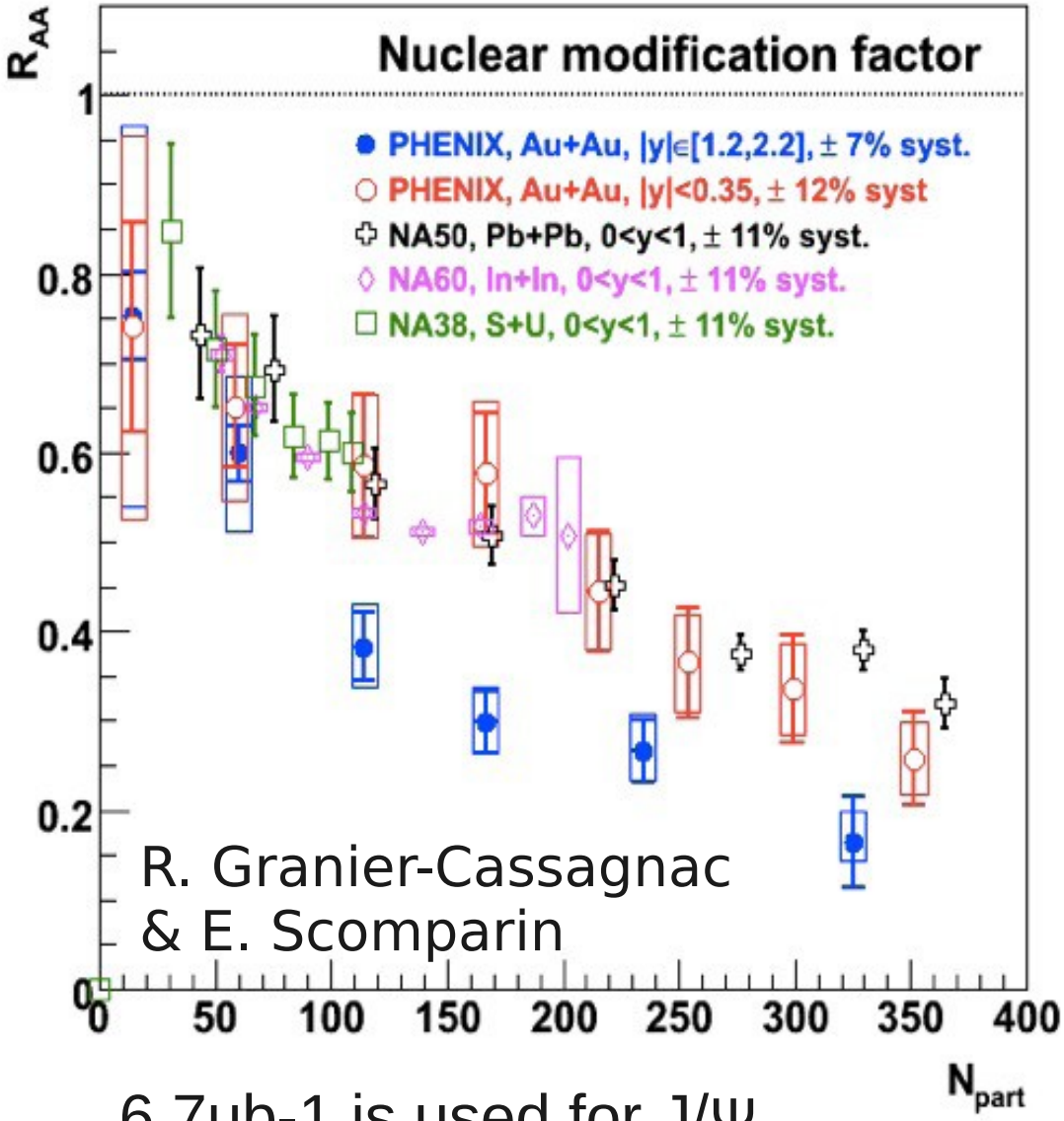
# Heavy Ion Collisions

**Observation of Suppression**
~2 between central and peripheral collisions.

Quarkonium suppression could be due to color screening effect. However, J/ψ recombination might happen at higher density




14 X higher in energy compared to RHIC




R. Granier-Cassagnac & E. Scomparin

6.7ub-1 is used for J/Ψ and Z Analysis

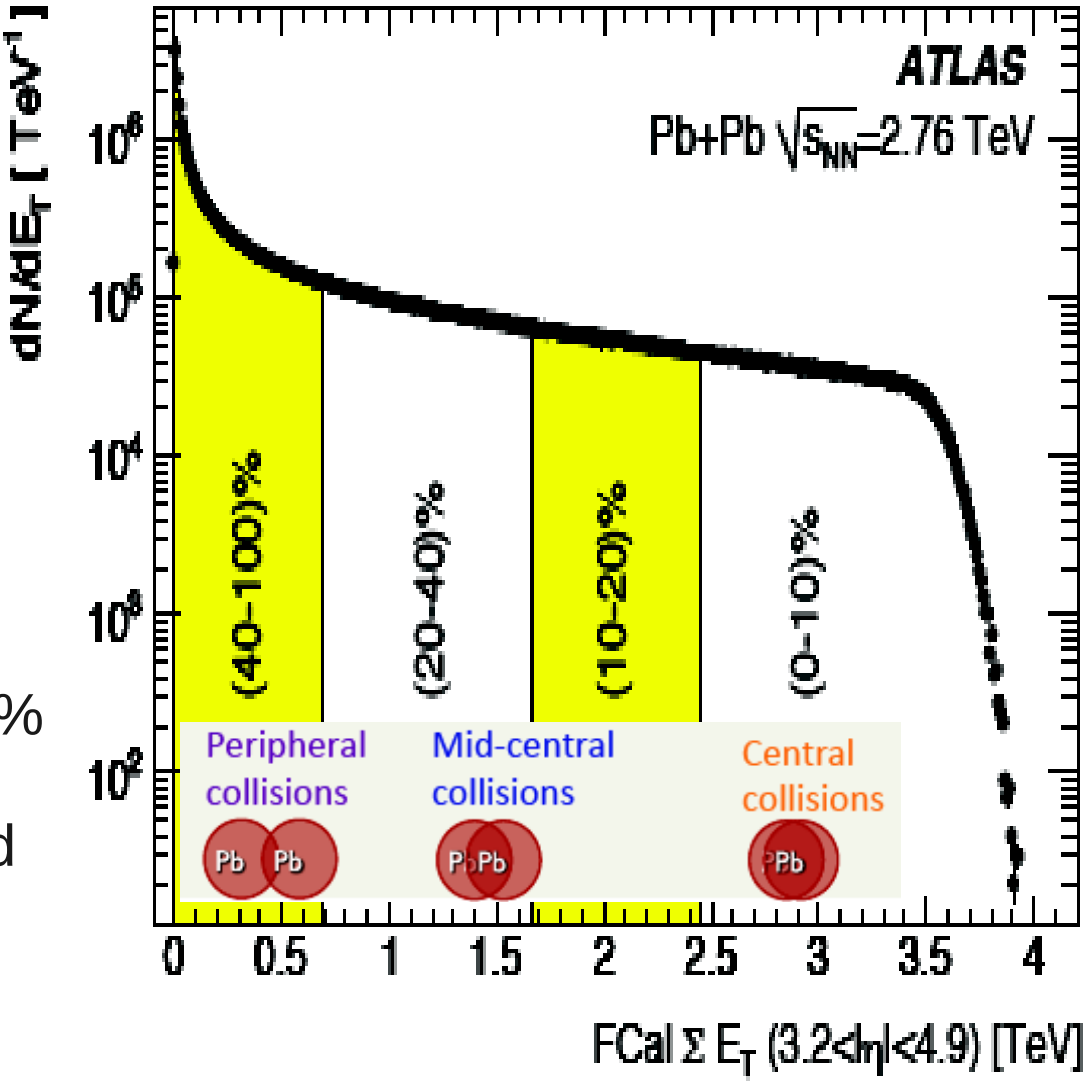
# Trigger & Centrality

**Trigger**
Minimum Bias Trigger

**Centrality**
characterized by percentage of total cross-section using the forward calorimeter (Fcal) transverse energy sum: $\Sigma E_T$ ($3.2 < |\eta| < 4.9$)

- Four centrality bins:
  0-10%, 10-20%, 20-40%, 40-80%

- Range between 80-100% excluded due to larger systematics in determining Ncoll, the number of nucleon-nucleon collisions

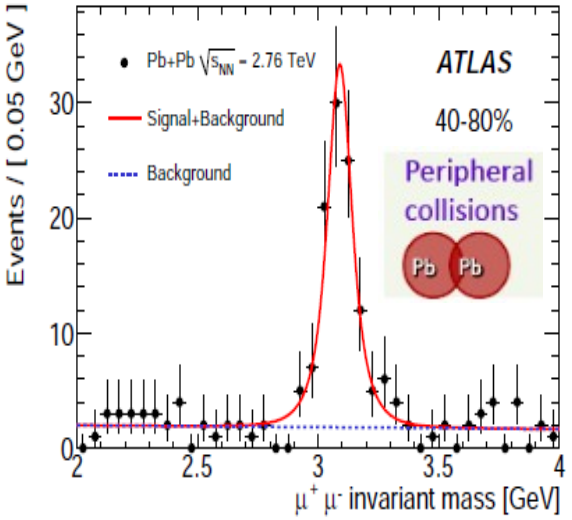


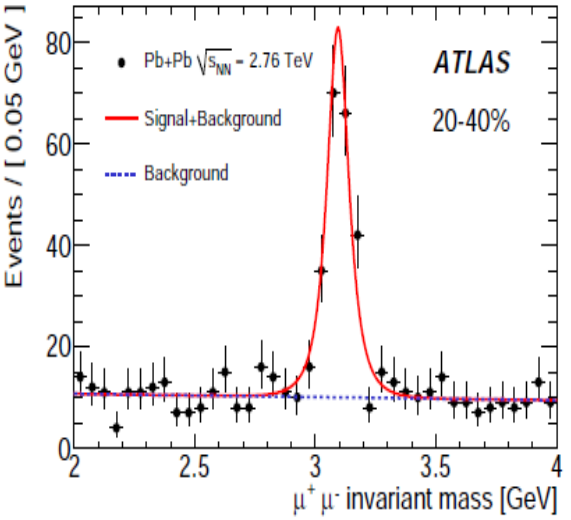
# Signal Yield Extraction

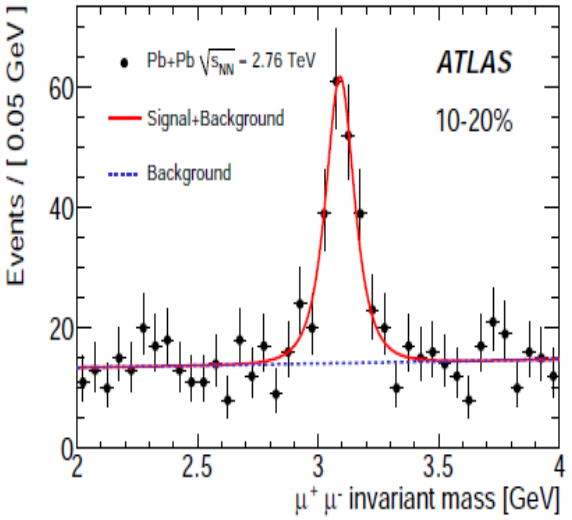
**Selections**
2 Combined Muons with opposite signed
pT> 3 GeV |eta|<2.5
Total ~600 J/Ψ

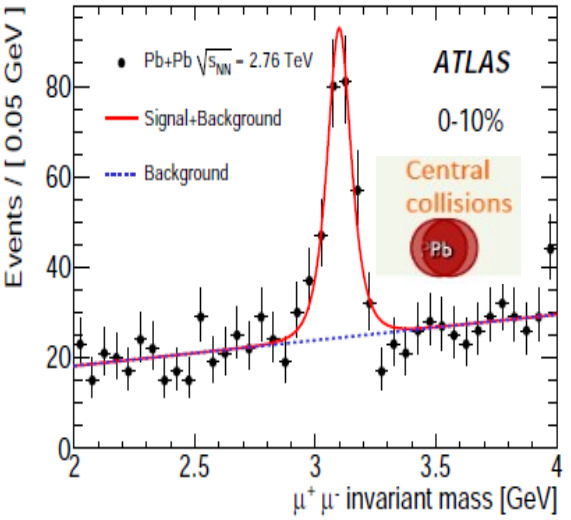
**Yields Extractions:**
Sideband subtraction to extract the J/Ψ Yields

Unbinned maximum likelihood fit for cross-check
→ good agreement



# Reconstruction & Systematics

**Results are normalized to the most peripheral bin**

| Centrality | $N^{\mathrm{meas}}(J/\psi)$ | $\epsilon(J/\psi)_c/\epsilon(J/\psi)_{40-80}$ | Systematic Uncertainty | | |
|---|---|---|---|---|---|
| | | | Reco. eff. | Sig. extr. | Total |
| 0-10% | $190 \pm 20$ | $0.93 \pm 0.01$ | 6.8 % | 5.2 % | 8.6 % |
| 10-20% | $152 \pm 16$ | $0.91 \pm 0.02$ | 5.3 % | 6.5 % | 8.4 % |
| 20-40% | $180 \pm 16$ | $0.97 \pm 0.01$ | 3.3 % | 6.8 % | 7.5 % |
| 40-80% | $91 \pm 10$ | 1 | 2.3 % | 5.6 % | 6.1 % |

**Major centrality dependent systematics:**

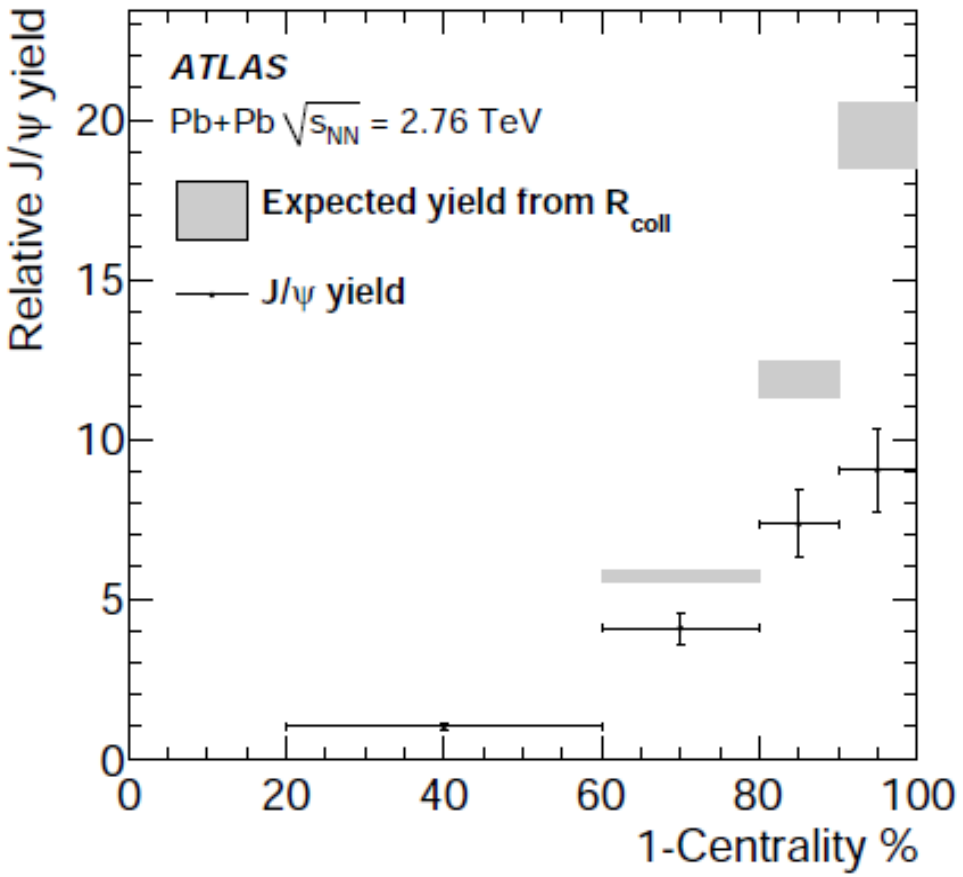
- Inner Detector efficiency due to high occupancy environments.
- Theoretical uncertainty of the mean number of binary nucleon-nucleon collisions

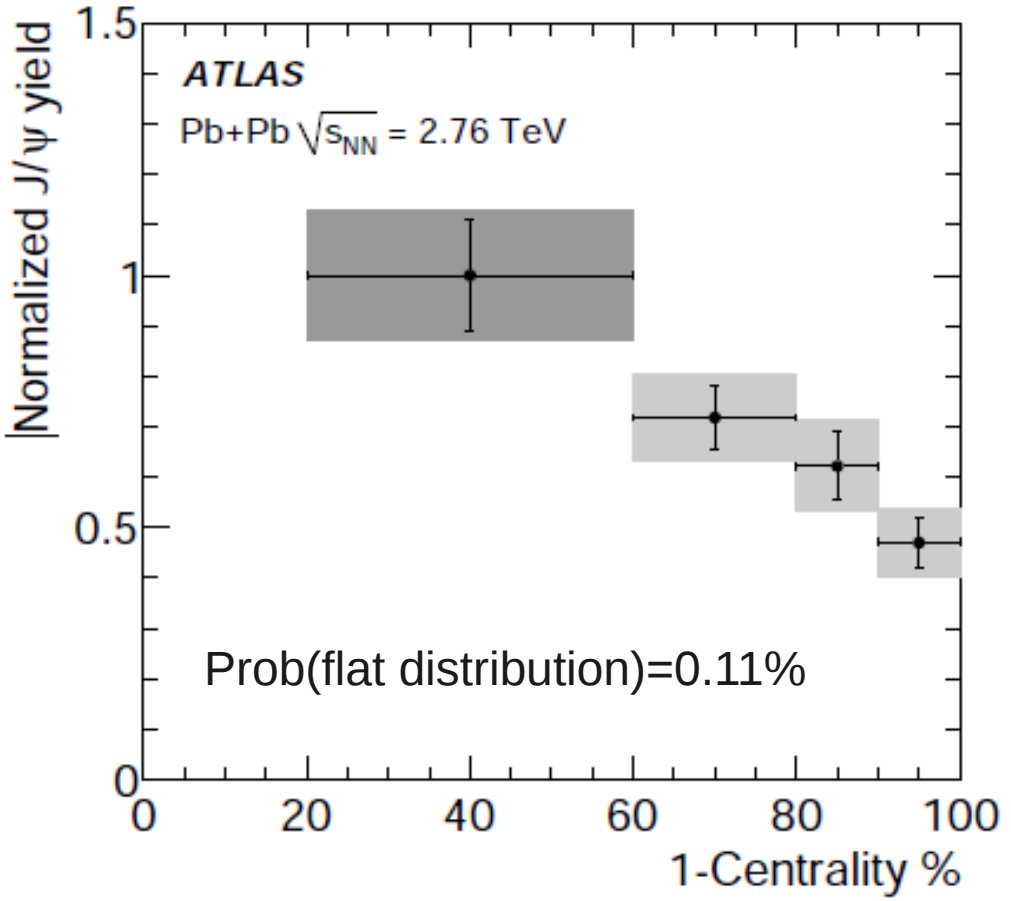
| Centrality | $R_{\mathrm{coll}}$ | Uncertainty |
|---|---|---|
| 0-10% | 19.5 | 5.3 % |
| 10-20% | 11.9 | 4.7 % |
| 20-40% | 5.7 | 3.2 % |
| 40-80% | 1.0 | – |

$$R_{coll} = \frac{N_{coll}\,(C)}{N_{coll}(40\text{-}80\%)}$$

Ncoll is Glauber prediction of the number of nucleon-nucleon collisions

# Final Results

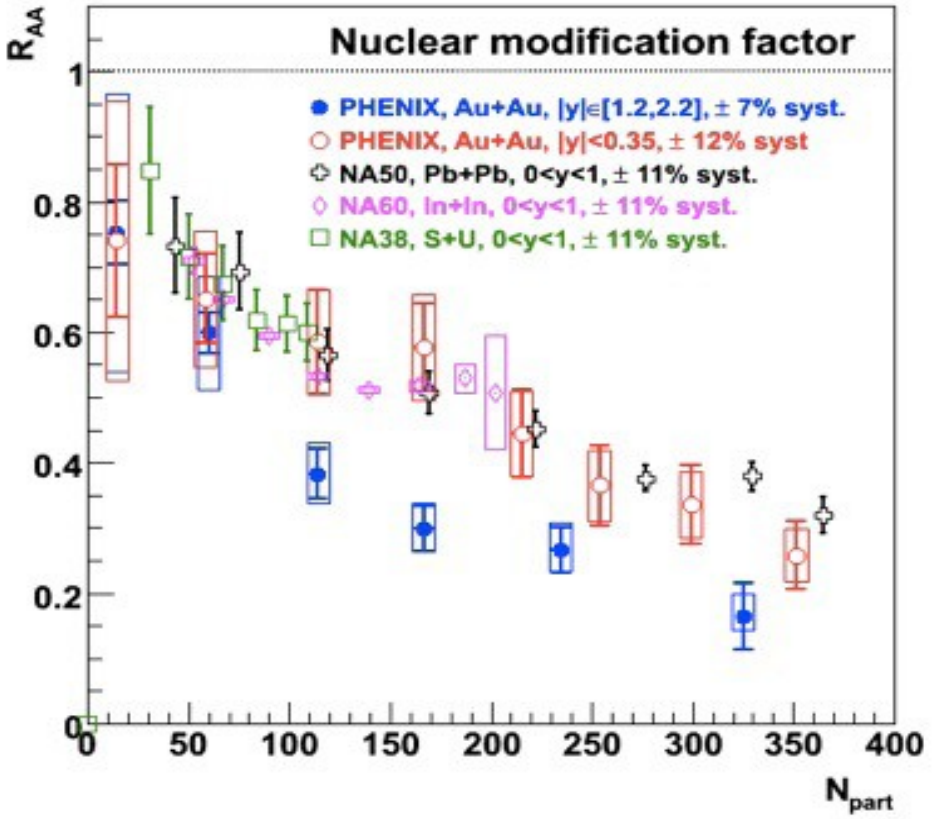


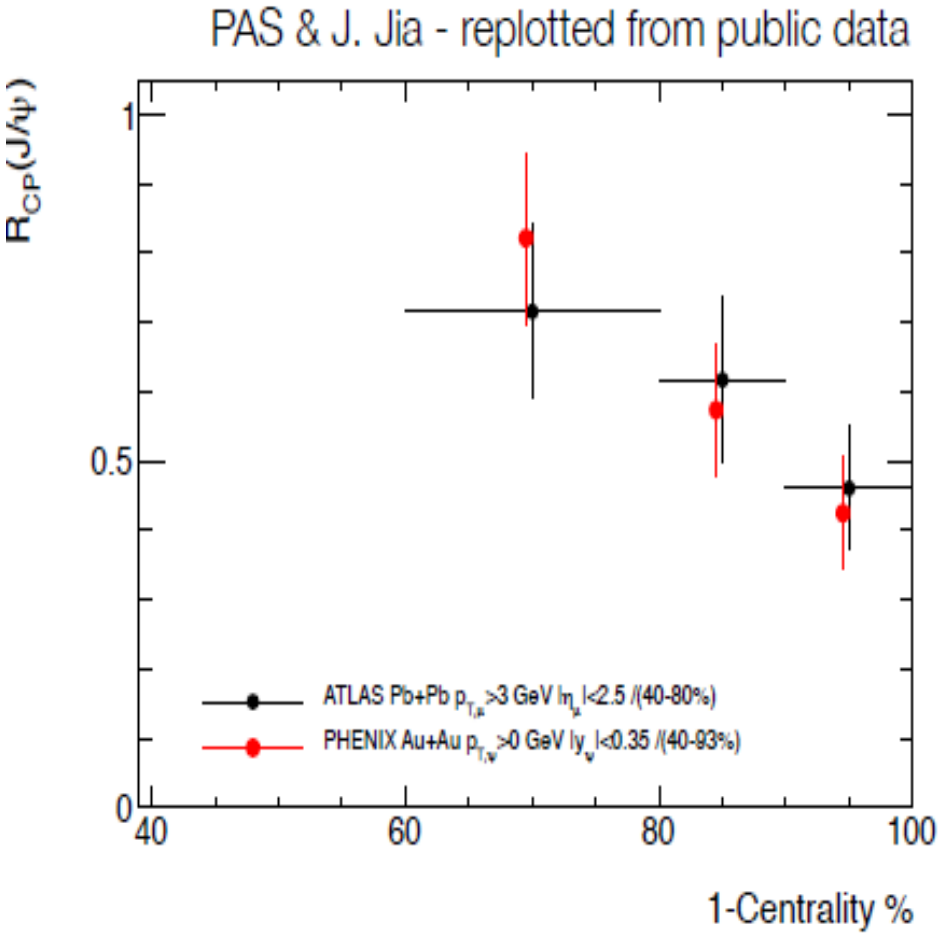




Relative yields, Rc, is normalized to the most peripheral bin

Normalized yields Rcp is Rc further corrected by the Rcoll

# Results Comparison




PHENIX data on $R_{AA}$ (relative to p-p) is recombined and ratio is taken from 40-93% bin, errors including uncertainties of the number of nucleon-nuclueon collisions, Ncoll

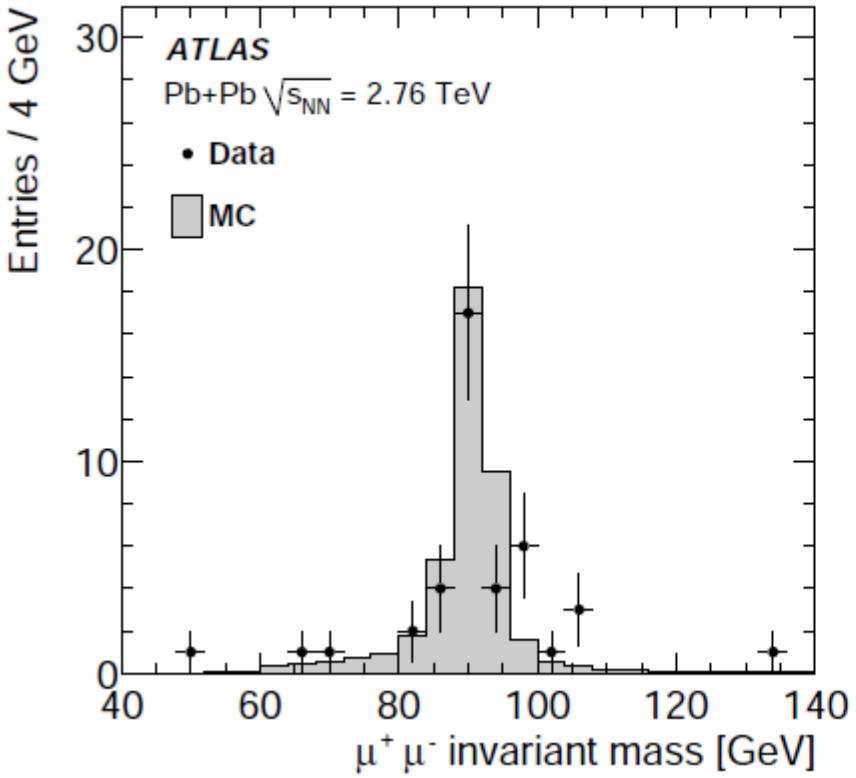


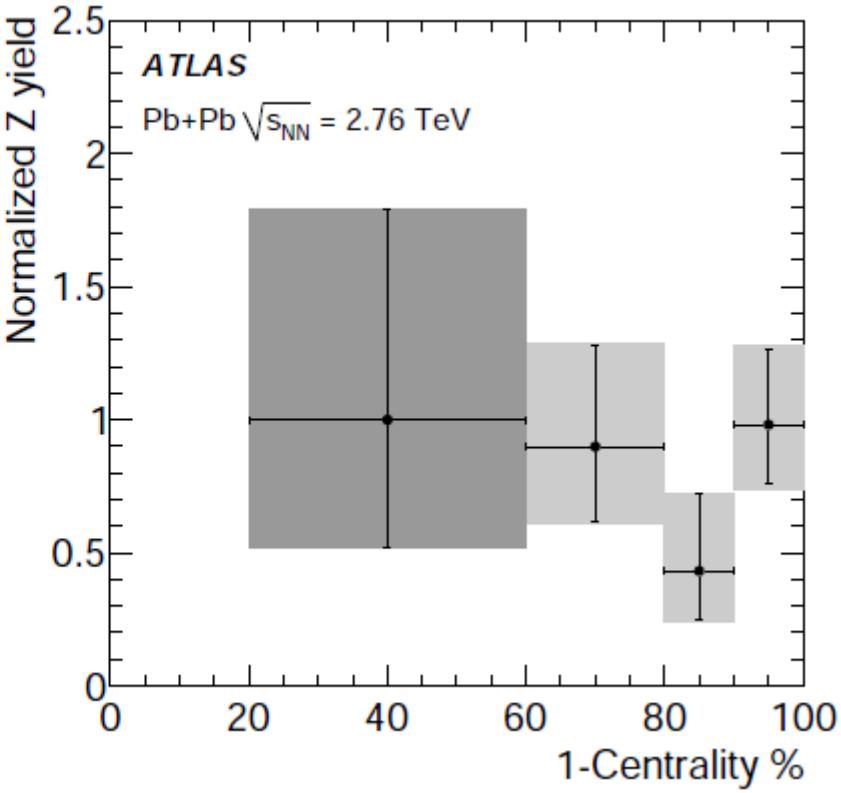
Centrality suppression appears no beam energy dependence!

# Z Observation in Heavy Ion

**Observation of 38 Z pairs:**

- |η|<2.5, pT>20 GeV, |η1+η2|>0.01 (cosmics rejection)
- No conclusive centrality dependence effect due to limited statistics
- First Z production results in heavy ion collision history



# Summary

- **Present new ATLAS results of J/Ψ production in 7 TeV pp collisions with 2.4 $pb^{-1}$ data**
  - consistent with CMS and CDF where overlaps
  - ATLAS extends results to higher pT range (30~70 GeV)
  - theory predictions are in good agreement to non-prompt results but have issues in non-prompt results in both shapes and normalizations

- **Present the first J/Ψ and Z production results in 2.76 TeV lead-lead collisions with 6.7 $\mu b^{-1}$ data**
  - Observe a centrality dependent suppression in the normalized J/Ψ yield
  - Centrality suppression is consistent to PHENIX Au+Au collision

# Backup

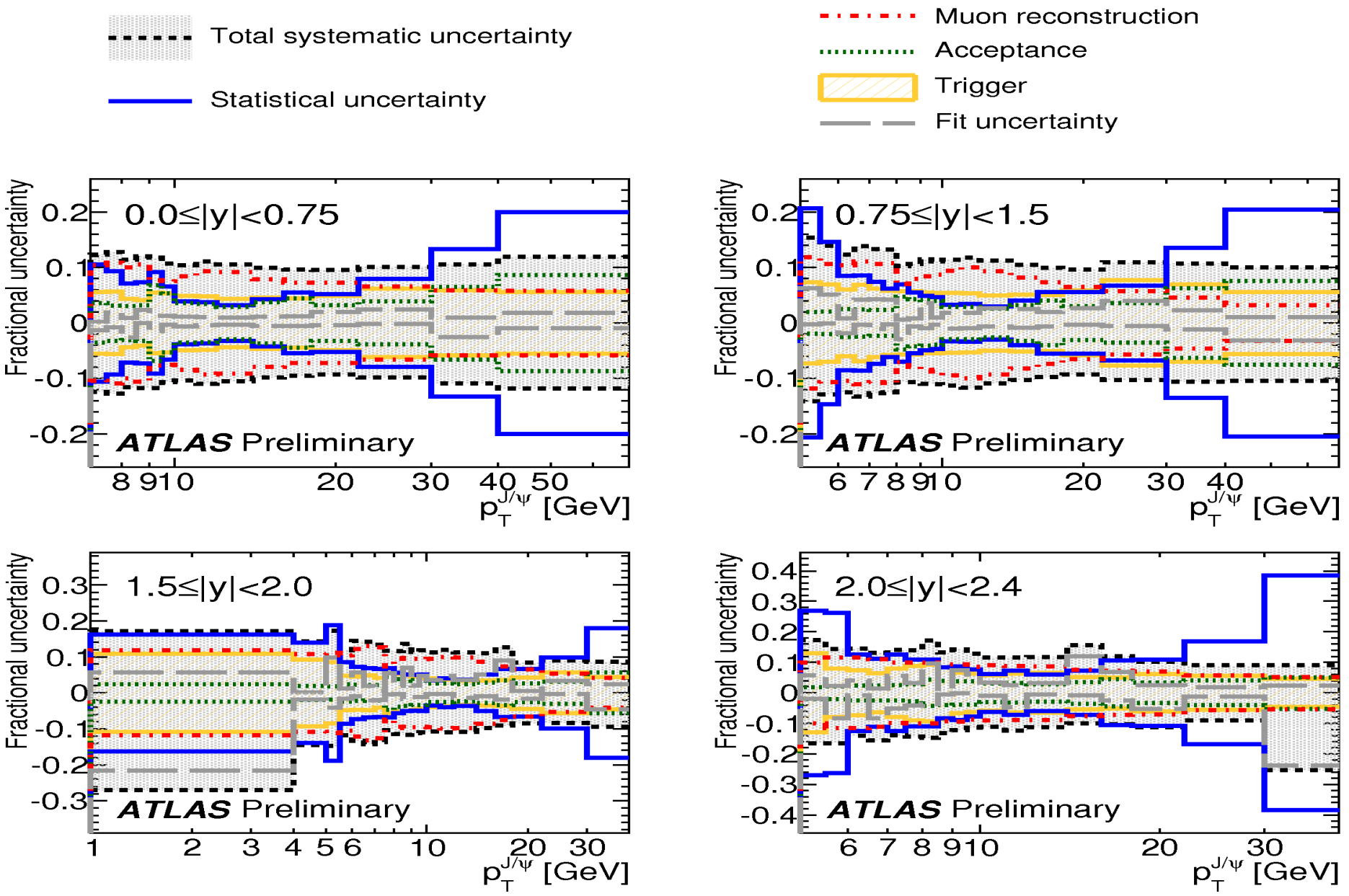
# J/Ψ Trigger in pp Collisions

**Trigger:**
**Inclusive Cross-section**
Level1 Muon
Event Filter Muon pT > 4GeV, 6GeV
**2.27 $pb^{-1}$ (no pre-scale trigger)**

**Non-prompt fraction**
Above triggers and additional
Minimum Bias
Event Filter Muon pT>10 GeV
**2.44 $pb^{-1}$ (include pre-scale trigger)**

**Trigger in 2011 B-physics:**
Topological 2muon trigger

# J/Ψ Systematics



# Inner Detector Tracking in Heavy Ion Collisions

#SiHits>=9. #Missing Pix Hits=0, #Missing SCT Hits <=1
Tracking systematic uncertainties are determined from the comparisons of associated/missing hits distributions between MC/Data.