J/ψ production and polarization in CMS

F.Fiori (INFN, Pisa),

On behalf of the CMS collaboration

J/ψ production

- Two main categories:
  - prompt J/ψ : direct J/ψ production or indirect from heavier states ψ(2S), χc, X.
  - non-prompt J/ψ : from B hadrons decay
- Examples of theoretical models for prompt production (based on NRQCD):
  - **CSM (Color Singlet Model)**
  - **COM (Color Octet Mechanism)**
  - **CEM (Color Evaporation Model)**
- Prompt J/ψ Puzzles:
  - COM can explain the CDF cross section, but not polarization (discussed later)
- Despite recent theory progress, no satisfactory models fit cross section and polarization for prompt J/ψ.
- The B hadron component however is well described by QCD and can be used as a test
- LHC data could clarify this situation
- J/ψ is fundamental to tune the detector (pT calibration) and for data driven efficiencies

J/ψ inclusive Xsection in CMS

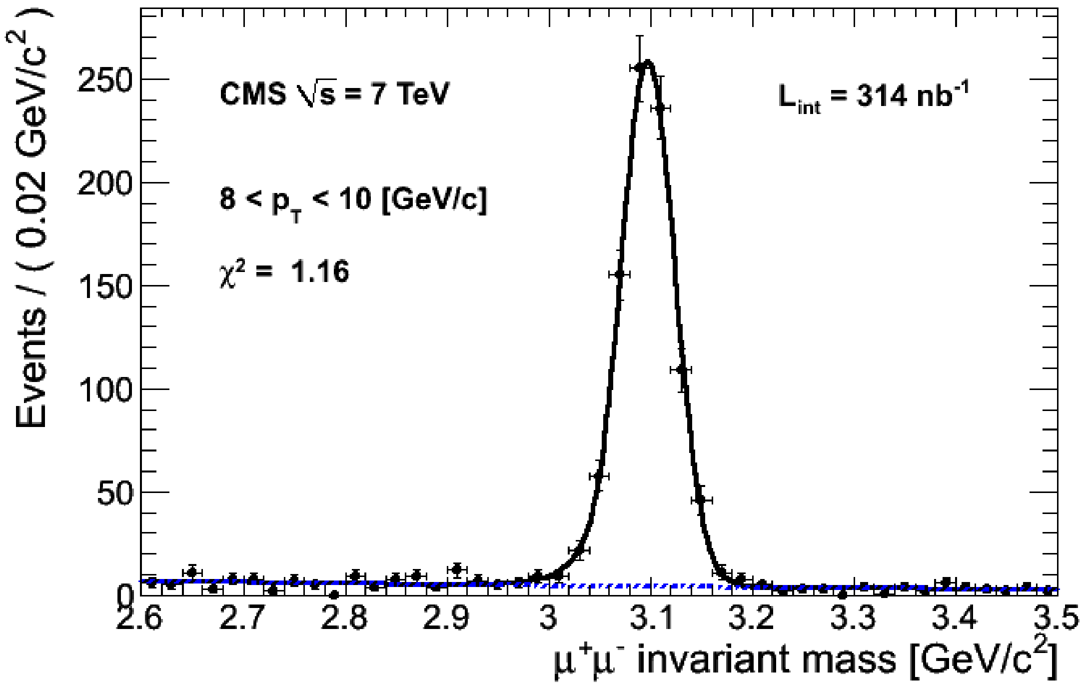
$$\frac{d^2\sigma}{dp_T\,dy} \times B(J/\psi \to \mu\mu) = \frac{N_{fitted}}{L \cdot A \cdot \varepsilon_{trigger} \cdot \varepsilon_{reco} \cdot \Delta p_T \cdot \Delta y}$$

From fit to data (MLL)

Acceptance from MC

From data , T&P

- Use J/ψ -> $\mu^+ \mu^-$ decay channel
- 314 1/nb of 2010 data
- Trigger on two muons at L1
- Good primary vertex and secondary vertex by the two muons (prob. > 0.1%)
- Quality cuts (n° of hits, χ2 fit ...) (backup)
- Acceptance from MC
- Efficiencies from data (T&P)
- Yields: MLL unbinned fit (CB+Exp.)

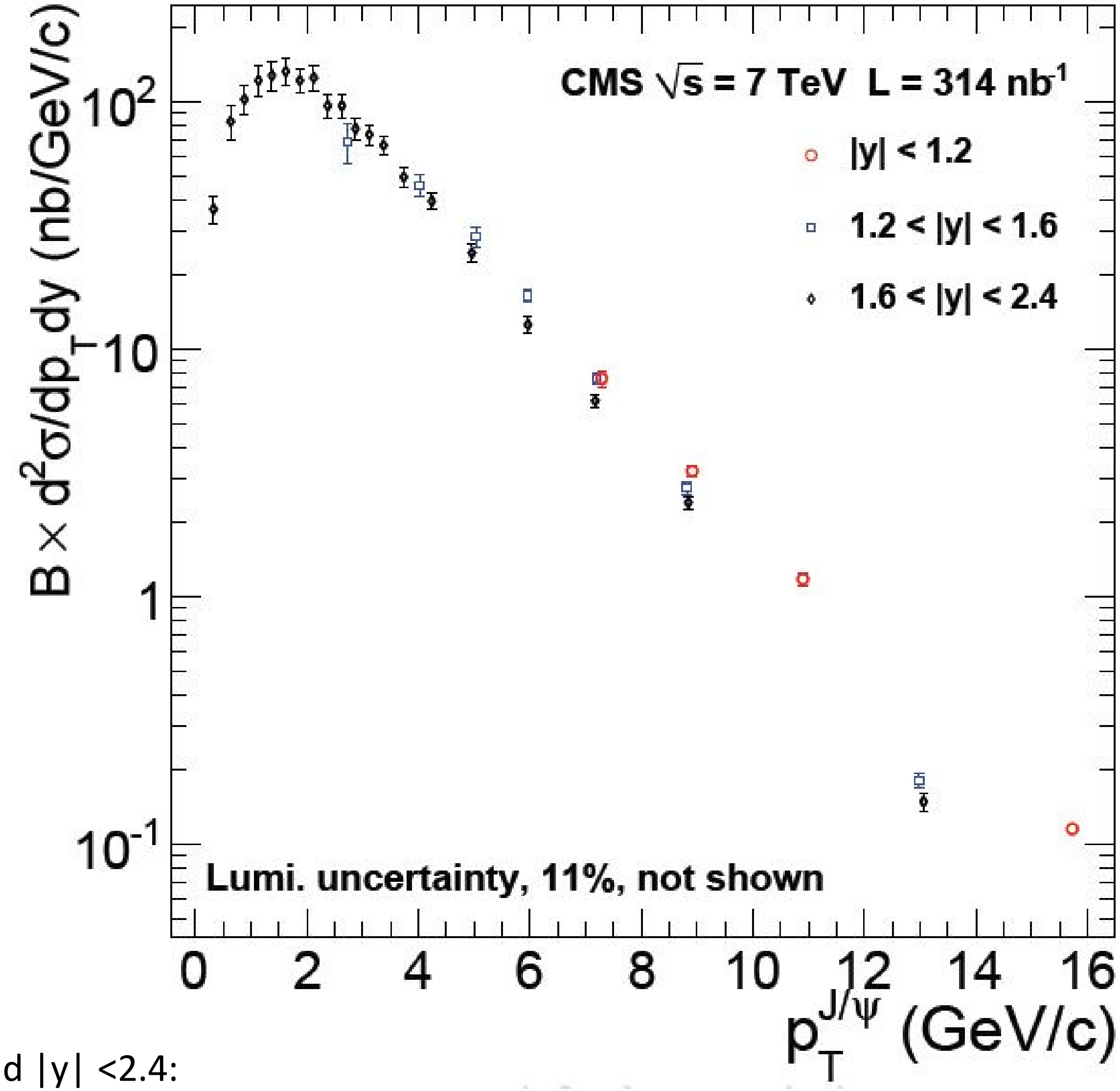


Results

- Published on EPJC (March 2011)
  - *Eur. Phys. J. C (2011) 71: 1575*
- First CMS B-Physics paper
- About 90k J/psi in total
- Measurement in 30 pT and rapidity bins (from 0 to 30 GeV/c), in 3 regions of rapidity

Systematics:

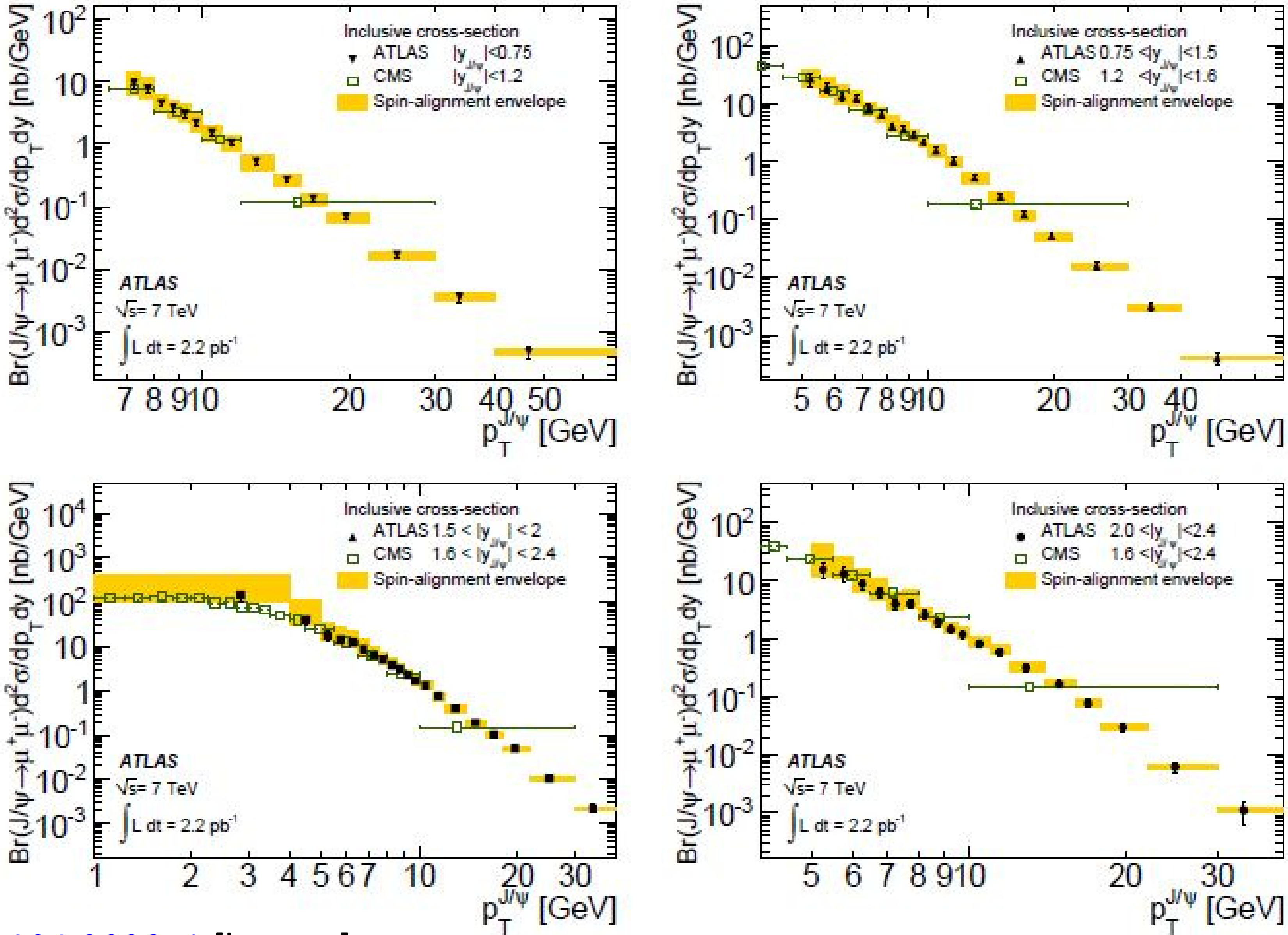
- Signal (background) PDF (1-9%)
- Single Mu efficiencies (2-12%)
- Momentum scale (1-2%)
- FSR (1-2%)
- Luminosity 11%



Total production cross section in 6.5 < pT < 30 and |y| <2.4:

$$\sigma(pp \to J/\psi + X) \cdot B(J/\psi \to \mu^+\mu^-) = 97.5 \pm 1.5(\text{stat.}) \pm 3.4(\text{syst.}) \pm 10.7(\text{luminosity})\ \text{nb}.$$

Comparison with ATLAS

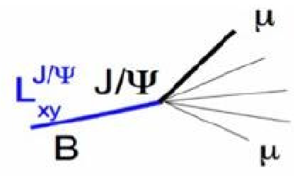


arXiv:1104.3038v1 [hep-ex]

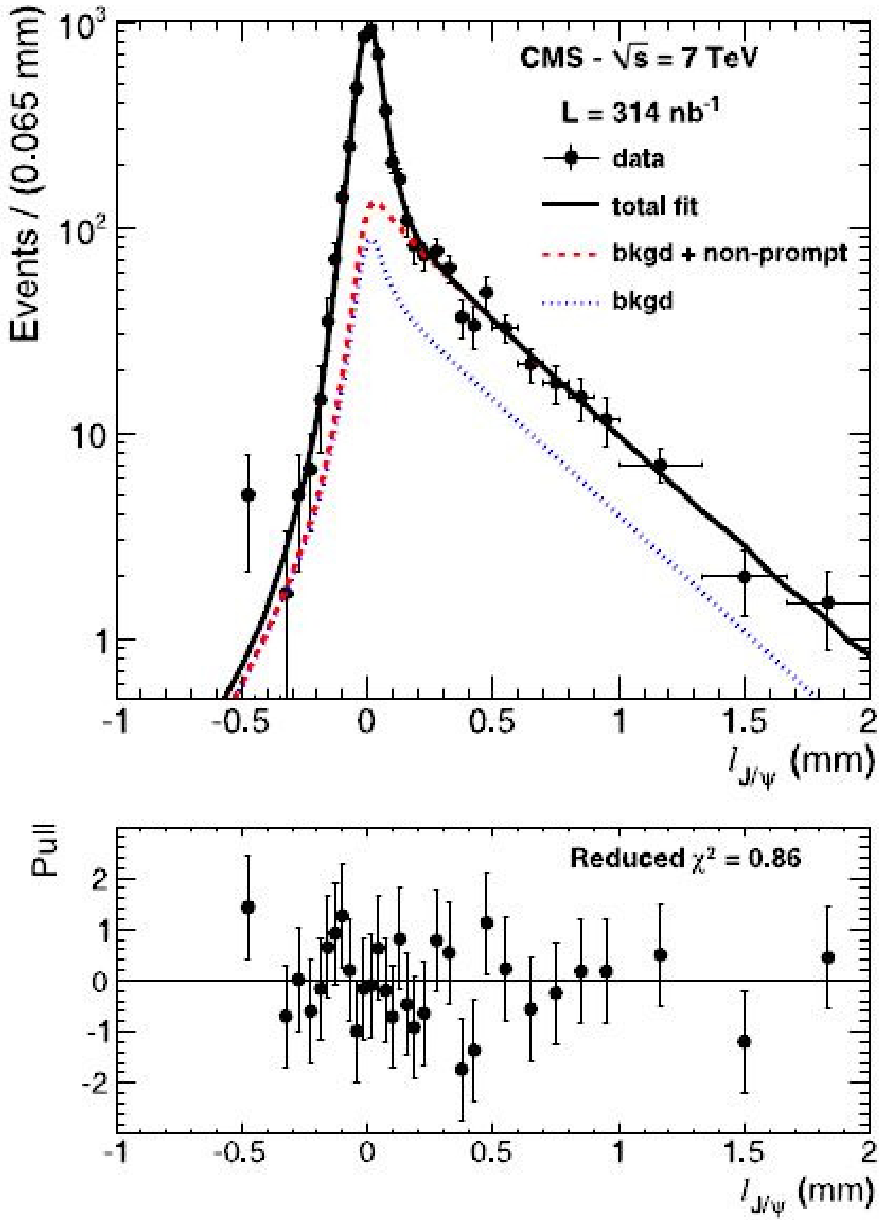
Prompt and non-prompt J/ψ

pseudo-proper decay length

$$\ell_{xy} = \frac{L_{xy}^{J/\psi} \cdot M^{J/\psi}}{p_T^{J/\psi}}$$



- ❑ Prompt J/ψ: triple Gaussian resolution function
- ❑ non prompt: MC template of true pseudo-decay length, convoluted with the same resolution function
- ❑ B-fraction extracted by simultaneus MLL fit to the mass and lifetime distributions

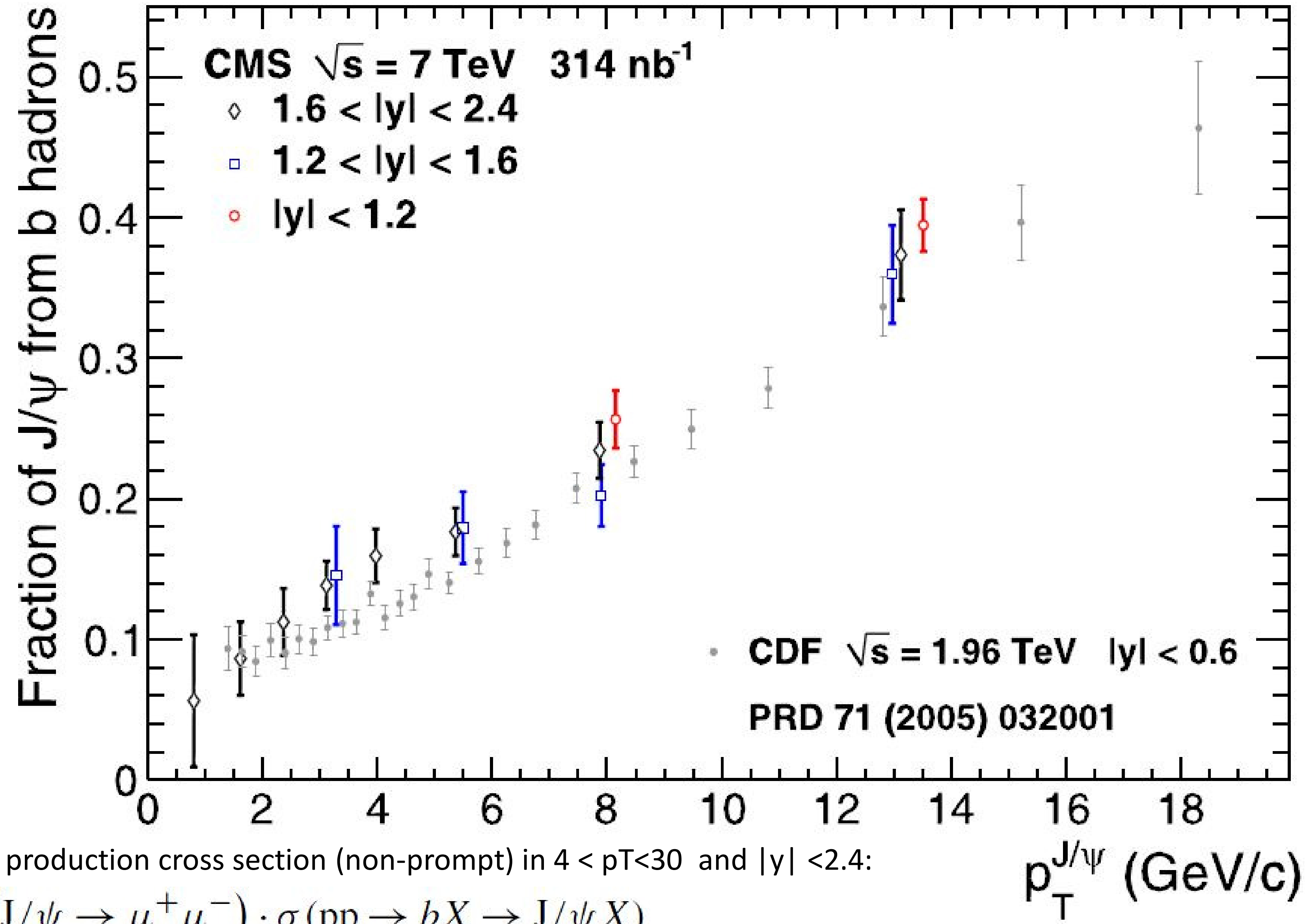


Systematics:

- Resolution function (1-30%)
- Difference prompt, non-prompt eff. (1-2%)
- Tracker Misalignment (< 9%)
- Lifetime and Bkg model (< 15%)

Largest effects are in the forward low pT bin

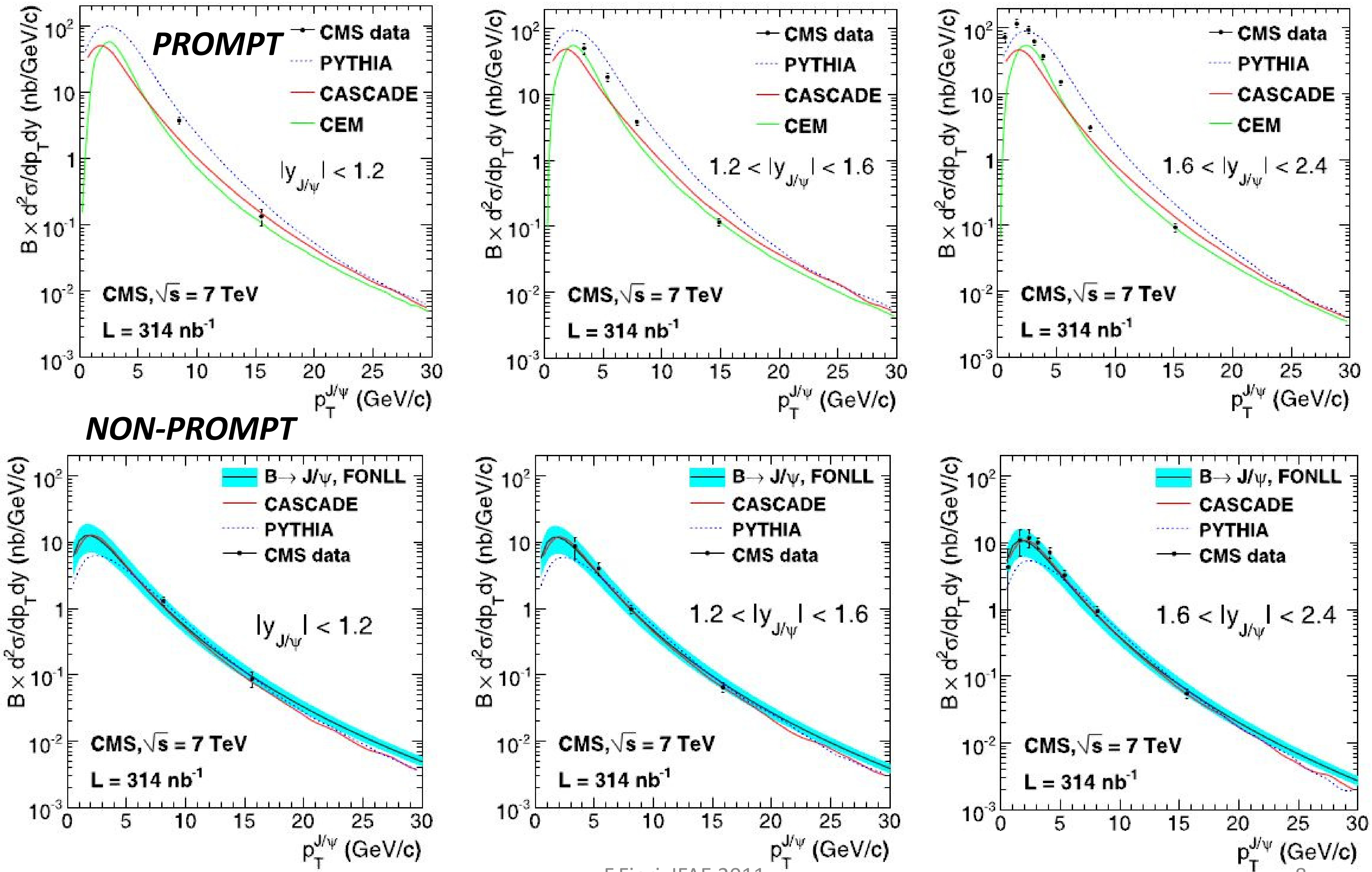
Results and comparison with CDF



Total production cross section (non-prompt) in 4 < pT<30 and |y| <2.4:

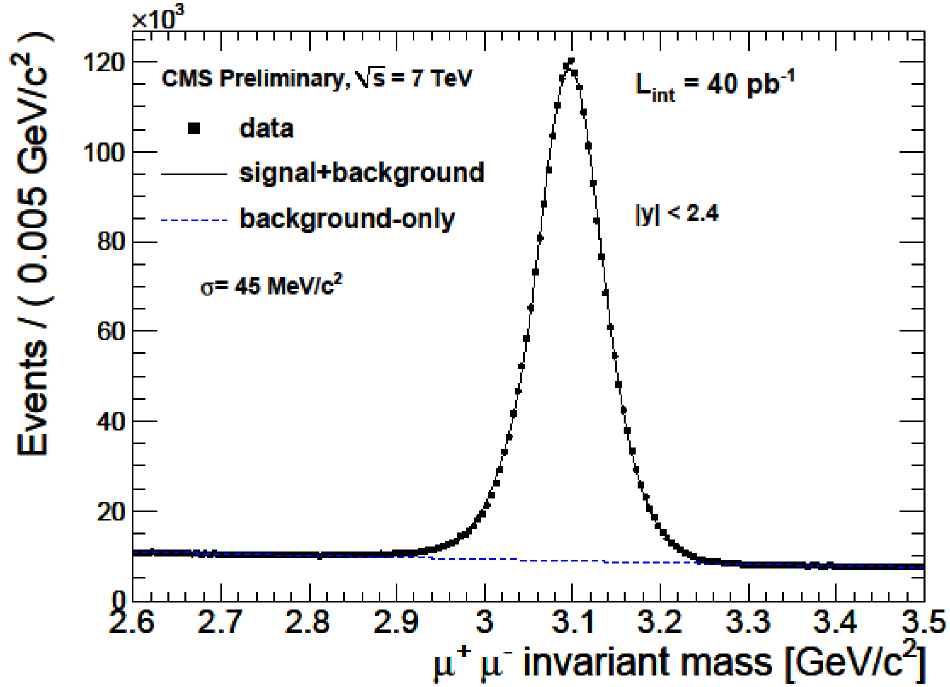
$$B\left(J/\psi \to \mu^+\mu^-\right) \cdot \sigma\left(pp \to bX \to J/\psi X\right)$$
$$= 26.0 \pm 1.4 \pm 1.6 \pm 2.9 \text{ nb}$$

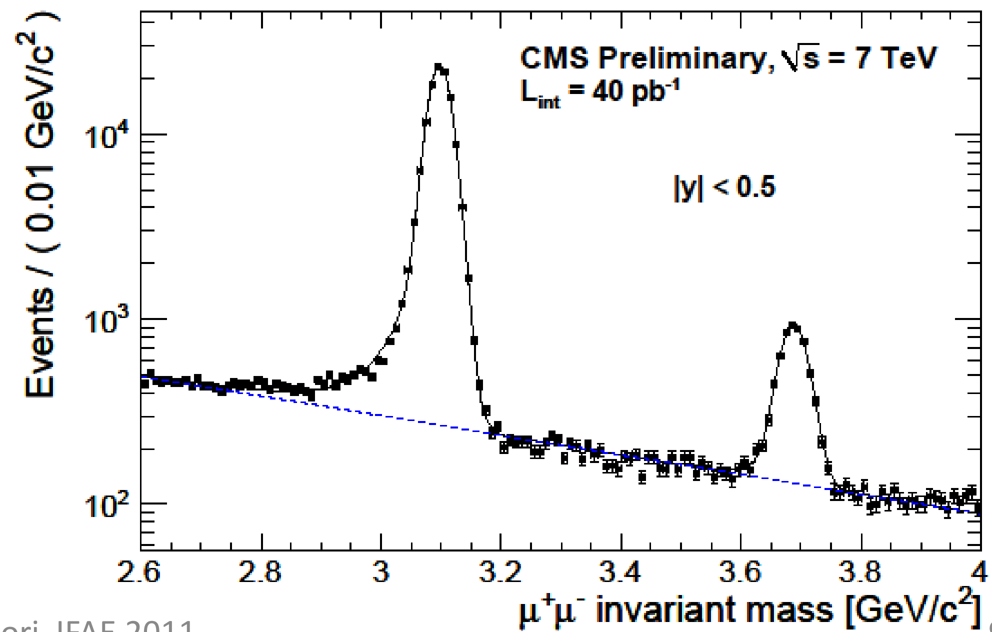
Comparison with predictions



Current status

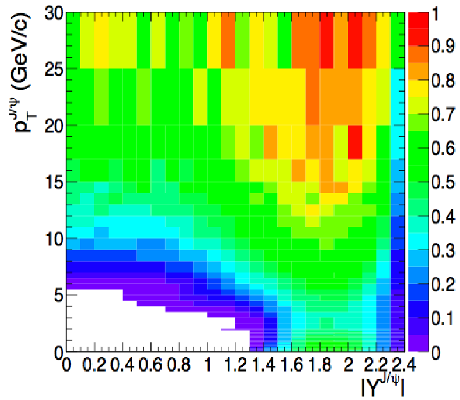
- The full 2010 dataset contains more than 2M J/ψ's
- The J/ψ cross section measurement is going to be updated with the full 2010 stat
- The ψ(2S) cross section will be also measured (inclusive, prompt and non-prompt)
- ... and the ratio σ(ψ')/σ(J/ψ)
- The analysis is in a good shape (the strategy and tools are almost the same as for the paper) and is expected to be released before half May



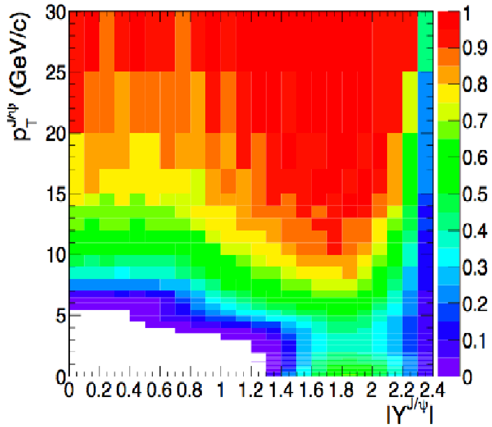


The polarization issue

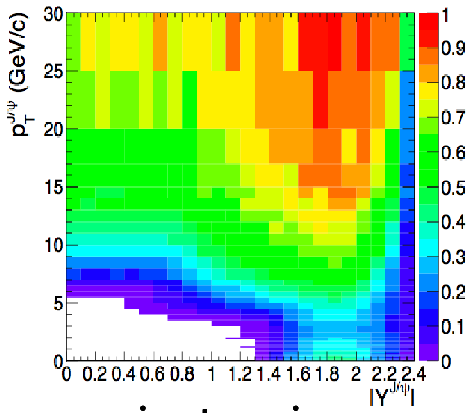
- The cross section is strongly dependent by the (unknown) polarization of the J/ψ
- At present no reliable mesurement of promptJ/ψ polarization is available
- The acceptance variation with polarization are huge
- For the J/ψ paper we gave five different values of σ corresponding to extreme cases
- A J/ψ polarization measurement at CMS can greatly improve the Physics content this analysis



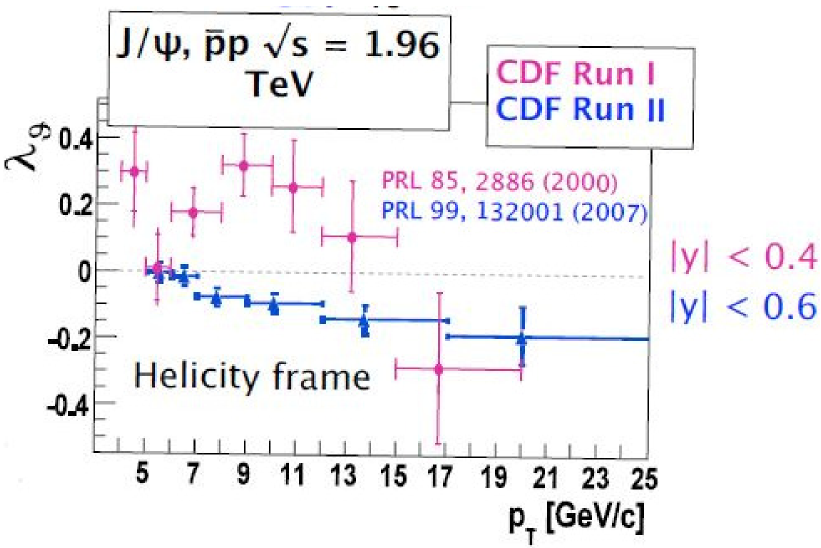
Collins-Soper fully long.

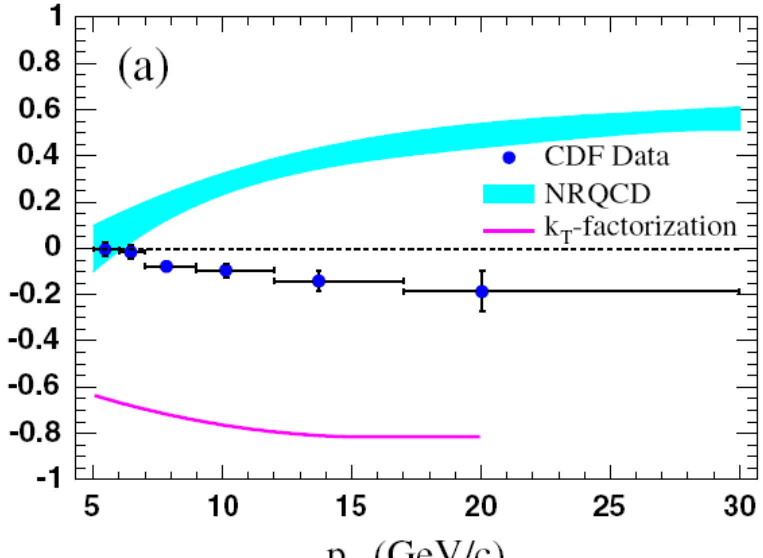


Helicity fully long.

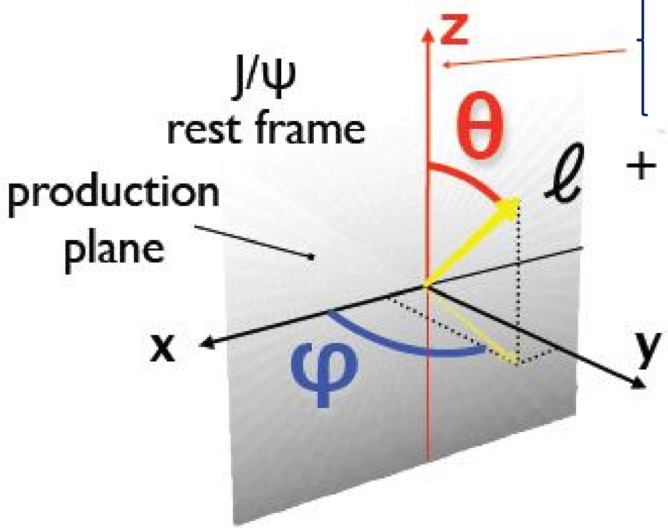


isotropic



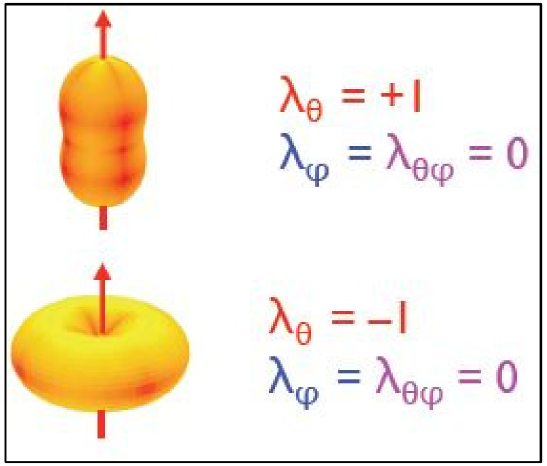


Frames and Parameters



Collins-Soper axis (CS) ≈ bisect. of dir. of colliding partons
Helicity axis (HX) = dir. of J/ψ lab momentum

$$\frac{dN}{d\Omega} \propto 1 + \lambda_\theta \cos^2\theta + \lambda_\varphi \sin^2\theta \cos 2\varphi + \lambda_{\theta\varphi} \sin 2\theta \cos\varphi$$



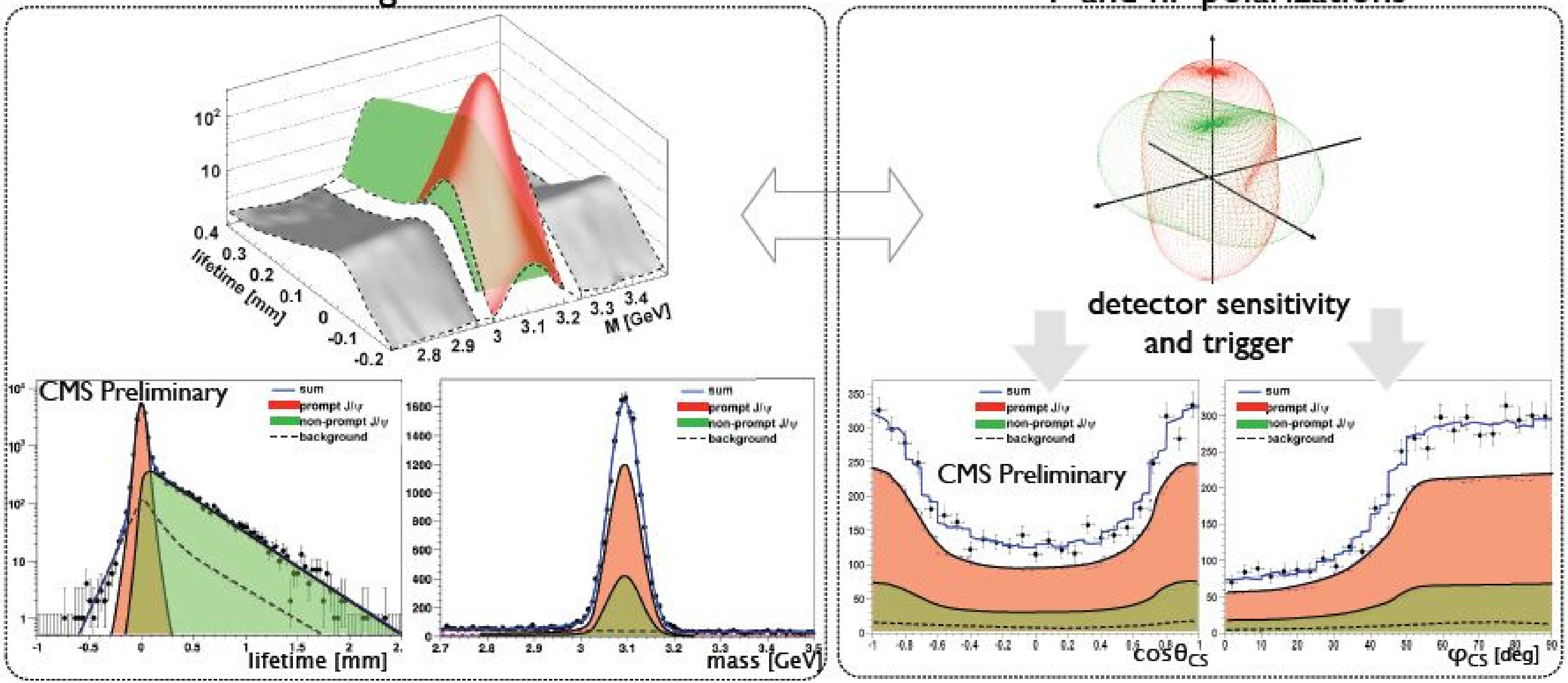
- λ parameters represent the degree of anisotropy in the measured angular distribution for a given frame
- All frames (CS, HX, ...) define their polarization axes in the J/ψ rest frame so, all frames are related by rotations and **both polarization angles** can contain information about J_Z *(CDF measured only* λ_θ) ... see back-up
- For the first time in hadron collider all the three polarization parameters will be measured
- Am extreme case:
  - $J_z = \pm 1 \rightarrow \lambda_\theta = 1$ **transverse pol.** (photon like)
  - $J_z = 0 \rightarrow \lambda_\theta = -1$ **longitudinal pol.**

The measurement

- Prompt and non-prompt J/ψ polarizations determined *simultaneously*
- One max likelihood fit for each dilepton pT-rapidity cell
- 9 free parameters: f_p , f_{np} , f_{BKG} , $\lambda_{\theta p}$, $\lambda_{\varphi p}$, $\lambda_{\theta\varphi p}$, $\lambda_{\theta np}$, $\lambda_{\varphi np}$, $\lambda_{\theta\varphi np}$
- Only a preliminary study of systematics available (max about 20%)

invariant mass & pseudo-lifetime
→ P / nP / bkg discrimination

cosθ & φ (CS, HX)
→ P and nP polarizations



Conclusions

- A first paper on J/ψ production croos section has been published by EPJC
- Results are in good shape with previsions and other experiment
- A new paper is in preparation for the full 2010 statistics, it will include also the ψ(2S) cross section
- The J/ψ polarization analysis is in advanced state, the strategy is established and the needed tools are in place

(see EPJC (2010) 69: 657–673 for more details)

Back-Up

Selection I

- **Event selection:**
  - Good Vertex, Anti Scraping [+L1 tech bits (only for runs<136086)]
- **Mu selection:**
  - Use GlobalMuons and TrackerMuons
    - see next slide for selection details
    - No Mu cleaning (does not affect x-section once using trigger bits)
- **Triggers used:**
  - **HLT_L1DoubleMuOpen (pT<4 GeV/c) + HLT_Mu3 (pT>4 GeV/c)**
    - strategy: keep the loosest unprescaled trigger path and that gives the smallest systematics
- **Analysis is performed on GG+GT+TT**
  - In case more than a combination use the GG; if both are GG, GT or TT take the one with larger p_T
    - Given the small number of events the three categories are lumped into a single category.

Selection II

- **Both muons in acceptance**
- **Muon tracker tracks:**
  - $\chi2/ndof < 4.0$
  - $|d0| < 3.0$ cm (calculated w.r.t. PV)
  - $|dz| < 15.0$ cm (calculated w.r.t. PV)
  - number of valid hits (pixel + strips) > 11
  - number of pixel layers with hits ≥ 2
- **Global muons:**
  - $\chi2/ndof$ (global fit) < 20.0
  - number of valid muon hits > 0
  - also tracker muons arbitrated and passing TMLastStationAngTight selector
- **Tracker muons**:
  - arbitrated and passing TMLastStationAngTight
- **a secondary vertex must be found with $P(\chi2) > 0.1\%$**

Efficiencies

- Determined by T&P (single muon)

$$\varepsilon_{reco} = \varepsilon_{track} \cdot \varepsilon_{id}$$

- From single mu to J/ψ:

$$\varepsilon_{J/\psi} = \varepsilon_{reco}(\mu^{+}) \cdot \varepsilon_{reco}(\mu^{-}) \cdot \varepsilon_{Trigger} \cdot \rho \cdot \varepsilon_{Vertex}$$ ← From data

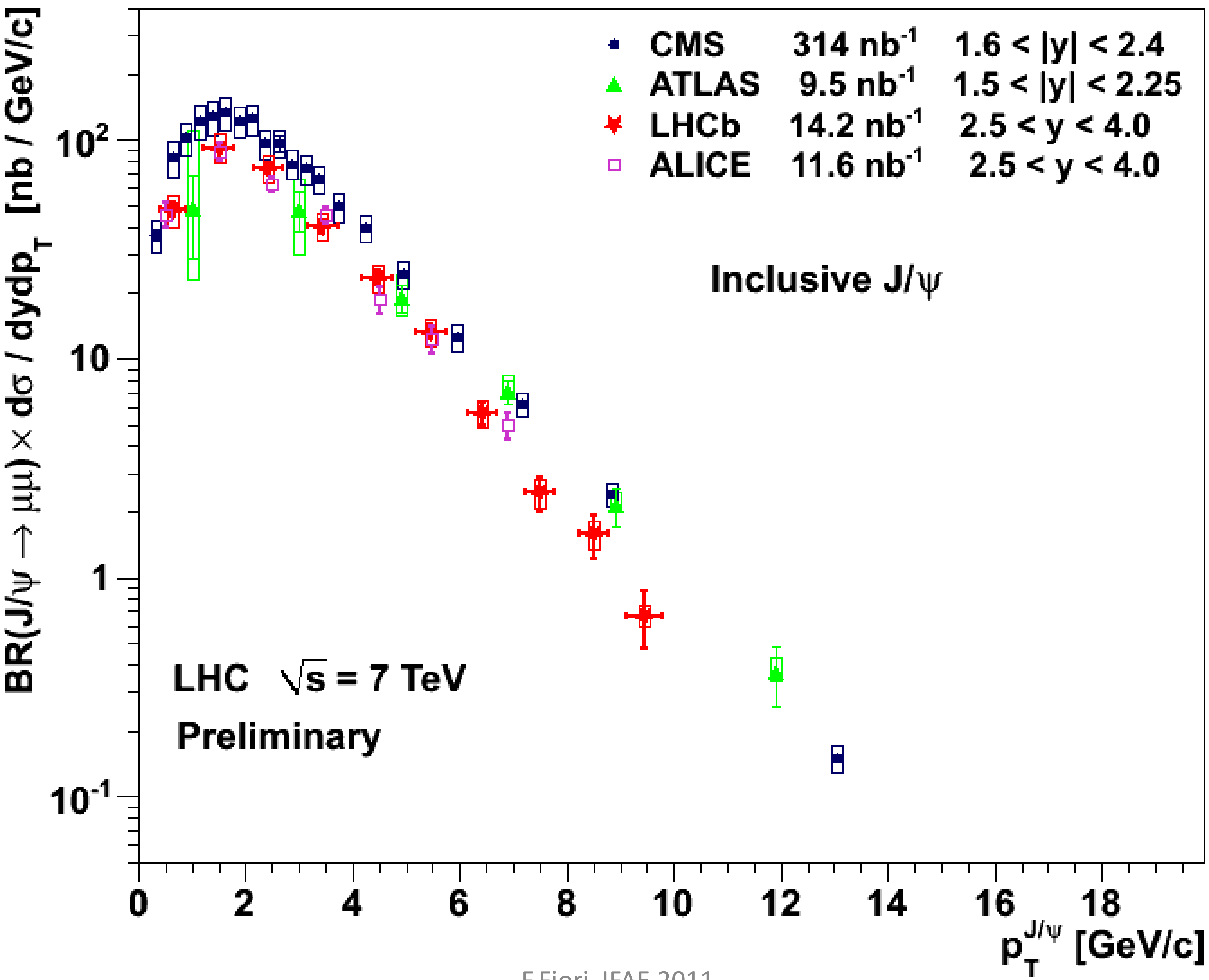
$$\varepsilon_{Trigger} = \varepsilon_{Trigger}(\mu^{+}) \cdot \varepsilon_{Trigger}(\mu^{-})$$ ← For double Mu trigger

$$\varepsilon_{Trigger} = \varepsilon_{Trigger}(\mu^{+}) + \varepsilon_{Trigger}(\mu^{-}) - \varepsilon_{Trigger}(\mu^{+}) \cdot \varepsilon_{Trigger}(\mu^{-})$$ ← For single Mu trigger

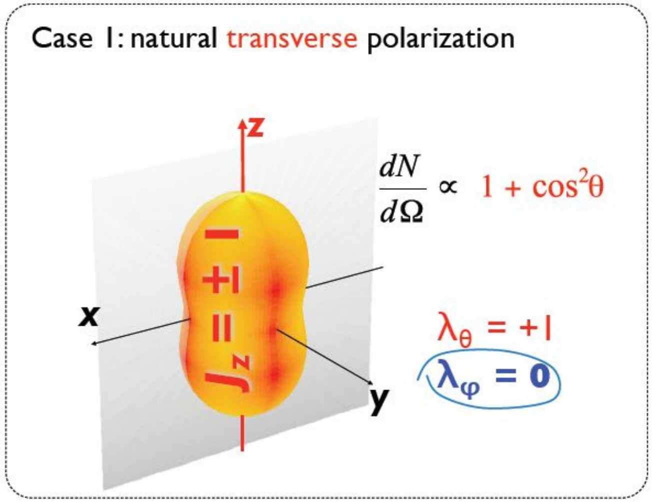
All the single muon efficiency computed on data

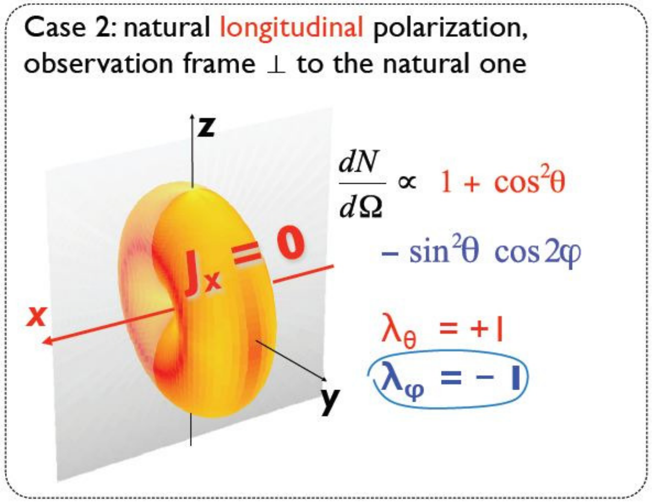
- Triggers used:
  - L1DoubleMuOpen (Forward region for pT<4 GeV/c)
  - HLT_Mu3 (For pT>4 GeV/c, gives a better S/B)

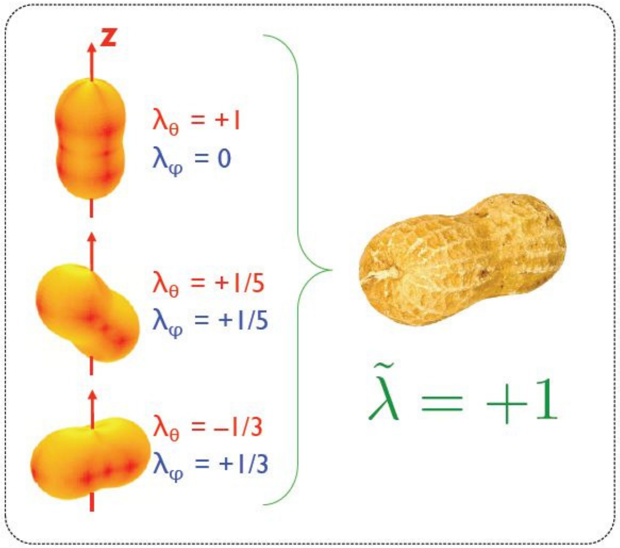
From other LHC experiments

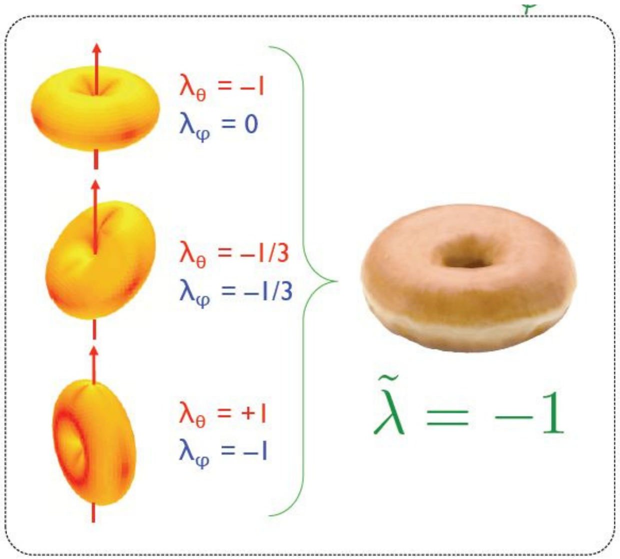


Importance of λ_φ





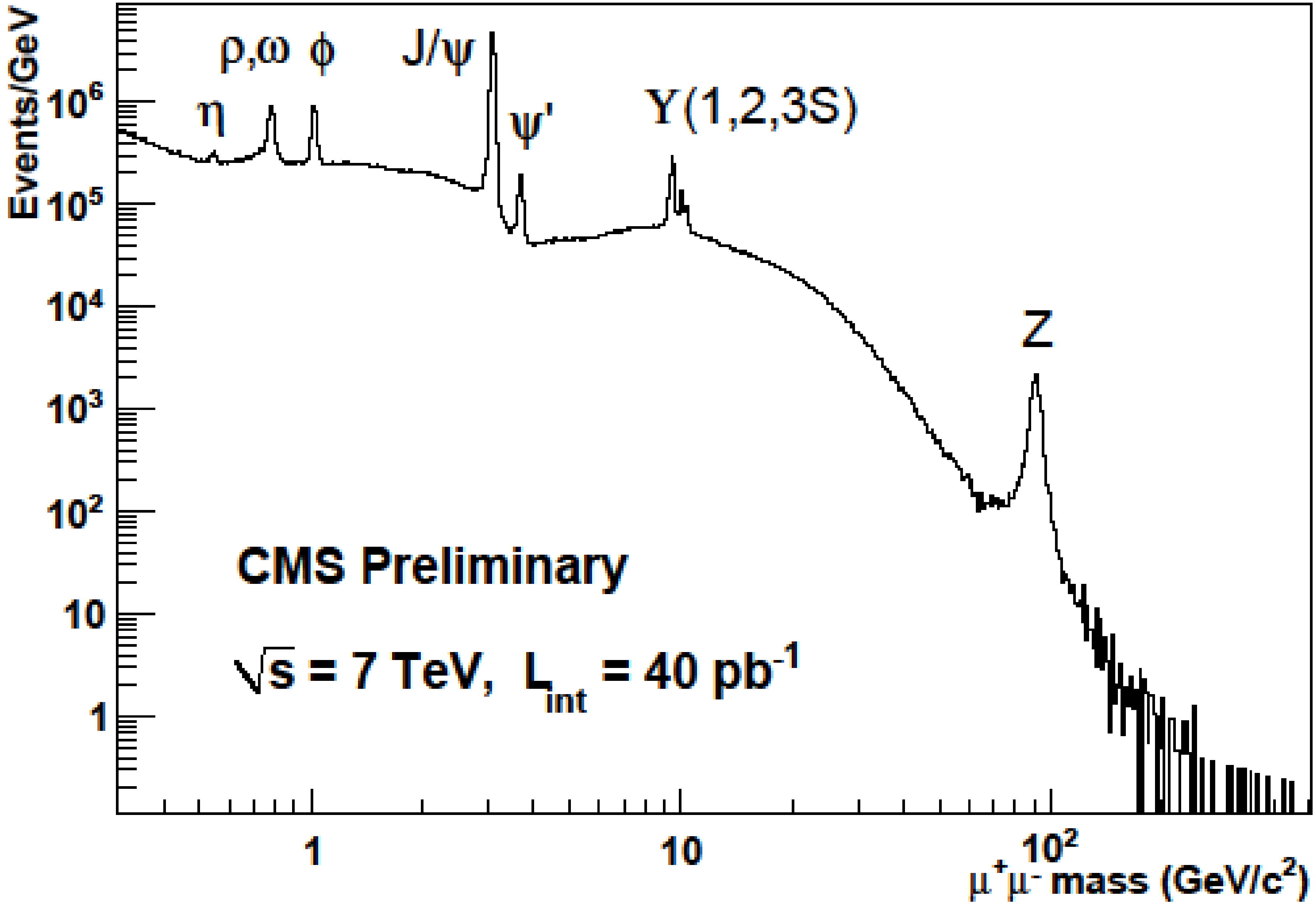




- Two opposite physical cases are look the same without a measure of λ_φ
- The intrinsic shape of the distribution is rotationally invariant (i.e. it can be characterized by a frame independent parameter)

$$\tilde{\lambda} = \frac{\lambda_\theta + 3\lambda_\varphi}{1 - \lambda_\varphi}$$

PRL 105, 061601; PRD 82, 096002; PRD 83, 056008


Events/GeV
η
ρ,ω
φ
J/ψ
ψ'
Υ(1,2,3S)
Z
CMS Preliminary
√s = 7 TeV, L_int = 40 pb^-1
μ+μ- mass (GeV/c2)
10^6
10^5
10^4
10^3
10^2
10
1
1
10
10^2

J/ψ production

- The J/ψ production has two components:
  - prompt J/ψ :
    - direct J/ψ production
    - indirect from heavier states ψ(2S), χc, X.
  - non-prompt J/ψ : from B hadrons decay
- Examples of theoretical models for prompt production:
  - **CSM (Color Singlet Model)** : LO, NLO, NNLO
  - **COM (Color Octet Mechanism)**
- Prompt J/ψ Puzzles:
  - COM can explain the CDF cross section, but not polarization (discussed later)
- Despite recent theory progress, no satisfactory models fit cross section and polarization for prompt J/ψ. The B hadron component however is well described by QCD and can be used as a test