J/ψ production and polarization in CMS

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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

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

Acceptance from MC

From data, T&P

- Use $J/\psi \rightarrow \mu^+ \mu^-$ 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, $\chi^2$ fit ...)(backup)
- Acceptance from MC
- Efficiencies from data (T&P)
- Yields: MLL unbinned fit (CB+Exp.)
Results

- Published on EPJC (March 2011)
- 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 $6.5 < p_T < 30$ and $|y| < 2.4$:

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

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Comparison with ATLAS

arXiv:1104.3038v1 [hep-ex]
Prompt and non-prompt J/ψ

pseudo-proper decay length

\[ \ell_{xy} = \frac{L_{xy}^{J/ψ} \cdot M_{xy}^{J/ψ}}{P_{T}^{J/ψ}} \]

- 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 simultaneous 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 $4 < p_T < 30$ and $|y| < 2.4$:

$$B(J/\psi \rightarrow \mu^+ \mu^-) \cdot \sigma(pp \rightarrow bX \rightarrow J/\psi X)$$

$$= 26.0 \pm 1.4 \pm 1.6 \pm 2.9 \text{ nb}$$

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Comparison with predictions

**PROMPT**

CMS, $\sqrt{s} = 7$ TeV
L = 314 nb$^{-1}$

$|y_{J/\psi}| < 1.2$

$1.2 < |y_{J/\psi}| < 1.6$

$1.6 < |y_{J/\psi}| < 2.4$

**NON-PROMPT**

CMS, $\sqrt{s} = 7$ TeV
L = 314 nb$^{-1}$

$|y_{J/\psi}| < 1.2$

$1.2 < |y_{J/\psi}| < 1.6$

$1.6 < |y_{J/\psi}| < 2.4$
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 $\sigma(ψ')/\sigma(J/ψ)$

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 measurement of prompt J/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
Frames and Parameters

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

- 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 $\lambda_\theta$) ... 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 $J/\psi$ polarizations determined simultaneously
- One max likelihood fit for each dilepton $pT$-rapidity cell
- 9 free parameters: $f_p$, $f_{np}$, $f_{bkg}$, $\lambda_p$, $\lambda_{np}$, $\lambda_{bkg}$, $\lambda_{np}$, $\lambda_{bkg}$
- Only a preliminary study of systematics available (max about 20%)

**Invariant mass & pseudo-lifetime**

$\rightarrow$ P / NP / bkg discrimination

**Cos$\theta$ & $\varphi$ (CS, HX)**

$\rightarrow$ P and NP polarizations

CMS Preliminary
Conclusions

- A first paper on J/ψ production cross 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 (p_T<4 GeV/c) + HLT_Mu3 (p_T>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:
  - $\chi^2$/ndof < 4.0
  - $|d_{0}|$ < 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 $\geq$ 2
- Global muons:
  - $\chi^2$/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 $P(\chi^2) > 0.1\%$

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Determined by T&P (single muon)

\[ \varepsilon_{\text{reco}} = \varepsilon_{\text{track}} \cdot \varepsilon_{\text{id}} \]

- From single mu to J/ψ:

\[ \varepsilon_{J/ψ} = \varepsilon_{\text{reco}}(\mu^+) \cdot \varepsilon_{\text{reco}}(\mu^-) \cdot \varepsilon_{\text{Trigger}} \cdot \rho \cdot \varepsilon_{\text{Vertex}} \]

\[ \varepsilon_{\text{Trigger}} = \varepsilon_{\text{Trigger}}(\mu^+) \cdot \varepsilon_{\text{Trigger}}(\mu^-) \]

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

LHC $\sqrt{s} = 7$ TeV

Preliminary

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Importance of $\lambda_\phi$

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

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

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\[
\sqrt{s} = 7 \text{ TeV}, \quad L_{\text{int}} = 40 \text{ pb}^{-1}
\]
J/ψ production

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  - prompt J/ψ:
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