Bundesministerium
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# Measurement of J/Ψ $\rightarrow \mu^+\mu^-$ and $\Upsilon \rightarrow \mu^+\mu^-$ cross sections with first CMS data at $\sqrt{7}$ TeV


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4th Annual Workshop of the Helmholtz Alliance "Physics at the Terascale"
2. Dezember 2010

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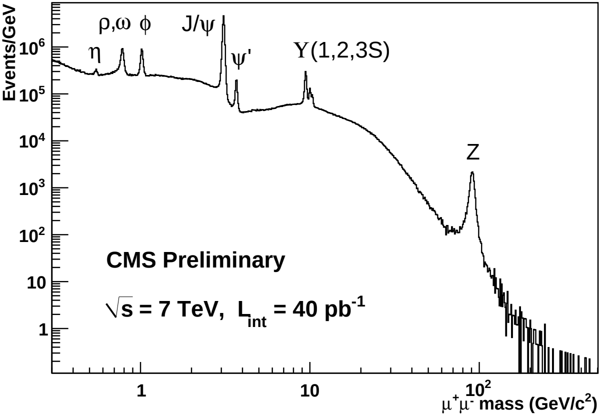
## Overview

- Motivation and Definitions
- Data and Event Selection
- Acceptance and Efficiency
- Results

The analysis presented here is performed with the first LHC data:

*BPH-10-002* *J/Ψ prompt and non-prompt cross sections in pp collisions at* $\sqrt{s}$ *= 7 TeV* - $L_{int}$ **= 314/nb**
*BPH-10-003* *Upsilon production cross section in pp collisions at* $\sqrt{s}$ *= 7 TeV* - $L_{int}$ **= 3.1/pb**

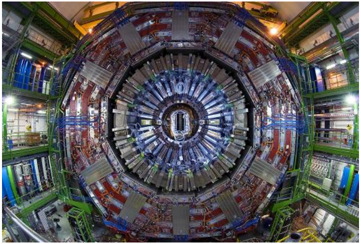
# Dimuon Spectrum with $L_{int}$=40/pb




CMS can even observe $\eta \rightarrow \mu\mu$ (BR $\simeq$ 5.8 $\cdot 10^{-6}$)

# Motivation

- $J/\Psi$ and $\Upsilon$ are standard candles, used for efficiency measurements and detector calibration
- high $J/\Psi$ and $\Upsilon$ $p_T$ regions were not accessible at previous experiments
- none of existing theories explains differential cross section and the polarization simultaneously (measured at Tevatron)
  - expectation: improvements from data collected at higher energies, extending to larger $p_T$
  - clarify production mechanism for $\Upsilon$ and $J/\Psi$ in hadronic collisions



# Cross section Definition

**inclusive differential production cross section for $Q\bar{Q}$ = J/Ψ resp. Υ**

$$\frac{d^2\sigma(pp \to Q\bar{Q}X)}{dp_T dy} \cdot \mathcal{B}\left(Q\bar{Q} \to \mu^+\mu^-\right) = \frac{N^{\text{fit}}_{Q\bar{Q}}(p_T; \mathcal{A}, \epsilon_{\text{track}}, \epsilon_{\text{id}}, \epsilon_{\text{trig}})}{\int L \cdot \Delta p_T \Delta y}$$

- $N^{\text{fit}}_{Q\bar{Q}} = \frac{N^{\text{fit,uncorr}}_{Q\bar{Q}}}{\epsilon\mathcal{A}}$ corrected signal yield in given $p_T$ bin obtained from a weighted 1-D fit to $M_{\mu^+\mu^-}$ distribution
  - $\mathcal{A}$ = geometrical and kinematical acceptance for J/Ψ, Υ
  - $\epsilon_{\text{track}}$ = tracking reconstruction efficiency
  - $\epsilon_{\text{trig}}, \epsilon_{\text{id}}$ = trigger and muon identification efficiencies
- $\int L$ = integrated luminosity
- $\Delta p_T, \Delta y$ = $J/\Psi, \Upsilon$ transverse momentum, rapidity bin size

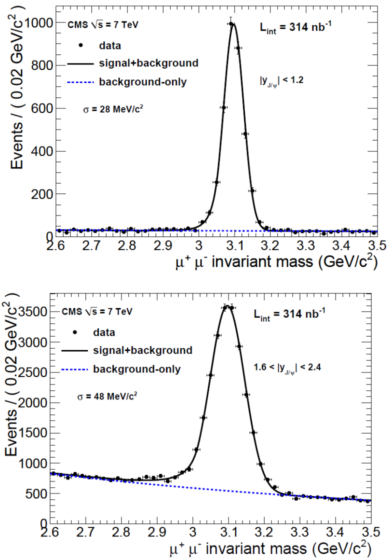
# Data and Event Selection for J/Ψ

L = $314 \pm 34$ nb$^{-1}$

- Trigger: 2 Muons
- Track Quality Cuts:
  - 12 hits in Tracker detector
  - 2 hits in pixel layer
  - $\chi^2$/ndf<4
- Muon Acceptance Cuts:

$$|\eta^\mu| < 1.3 \; p_T^\mu > 3.3 \text{ GeV/c}$$
$$1.3 < |\eta^\mu| < 2.2 \; p_T^\mu > 2.9 \text{ GeV/c}$$
$$2.2 < |\eta^\mu| < 2.4 \; p_T^\mu > 0.8 \text{ GeV/c}$$

- $|y_{J/\psi}| < 2.4$
- Yield extraction:
  Unbinned ML fit to dimuon mass: Crystal Ball function for signal + exponential for background



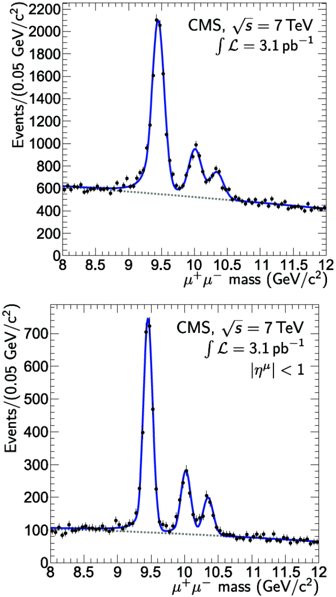
# Data and Event Selection for $\Upsilon$

L = $3.1 \pm 0.3$ pb$^{-1}$

- Trigger: 2 Muons
- Track Quality Cuts:
  - 12 hits in Tracker detector
  - 1 hits in pixel layer
  - $\chi^2$/ndf<5
- Muon Acceptance Cuts:

$$|\eta^\mu| < 1.6 \; p_T^\mu > 3.5 \text{ GeV/c}$$
$$1.6 < |\eta^\mu| < 2.4 \; p_T^\mu > 2.5 \text{ GeV/c}$$

- $|y_\Upsilon| < 2.0$
- Yield extraction:
  Unbinned ML fit to dimuon mass: 3 Crystal Ball function for signal + 2nd order polynomial for background

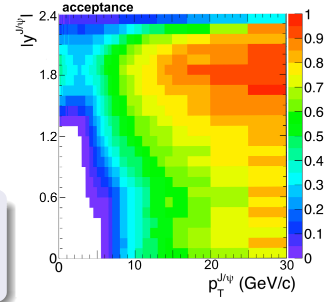


# Acceptance

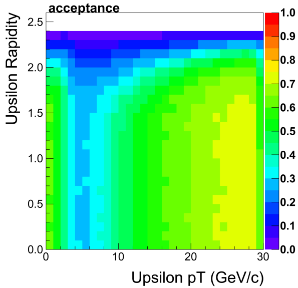
- probability each $\mu$ leaves a detectable track limited via geometrical and kinematical acceptance
- obtained via Monte Carlo Simulations

$$\mathcal{A}(p_T, y) = \frac{N_{Det}(p_T, y)}{N_{Gen}(p_T, y)},$$

$N_{\mathrm{Det}}(p_T, y)$ = number of detectable events in given $p_T$, $y$ bin
$N_{\mathrm{Gen}}(p_T, y)$ = corresponding number of generated events in MC simulation




- acceptance dependent on polarization of J/Ψ, ϒ:
  - affects muon kinematic properties ($p_T, \eta$)
  - extreme polarization scenarios are used: unpolarized, polarized longitudinally, transversely with respect to diff. reference frames
- use unpolarized scenario for results

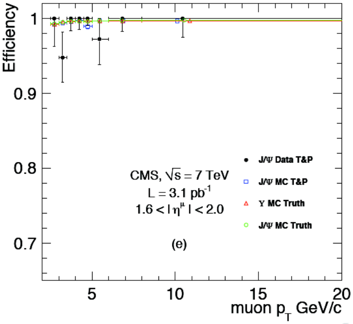


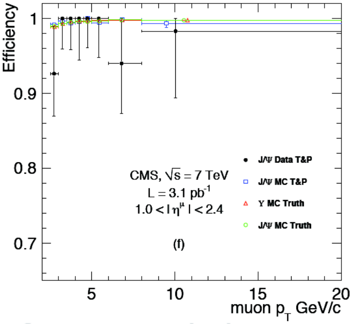
# Efficiency

- related to instrumental effects

$$\epsilon_\mu = \epsilon_{trig} \cdot \epsilon_{id} \cdot \epsilon_{track}$$

- obtained via data driven tag and probe method
- only obtained for J/Ψs due to low statistics
- for ϒ: J/Ψ efficiencies are used



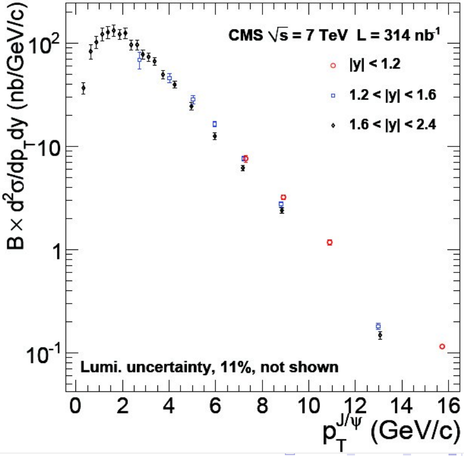
# inclusive J/Ψ Cross section

$$\sigma\,(pp \to J/\Psi X) \cdot \mathcal{B}\left(J/\Psi \to \mu^+\mu^-\right) = (97.5 \pm 1.5(\text{stat.}) \pm 3.4(\text{syst.}) \pm 10.7(\text{lumi.}))\text{nb}$$

**6.5<$p_T$<30 GeV/c**, $|y|$<2.4, L = 314/nb, *CMS PAS BPH-10-002*

$$\mathcal{B}\left(J/\Psi \to \mu^+\mu^-\right) = (5.88 \pm 0.10)\%$$

**extreme polarization scenarios** (unpolarized, polarized longitudinally, transversely with respect to diff. reference frames) **lead to additional changes in cross section by about 20 % for J/Ψ and ϒ results**

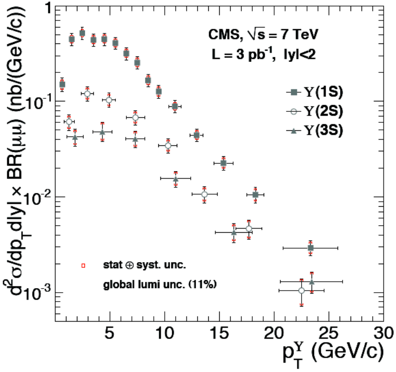


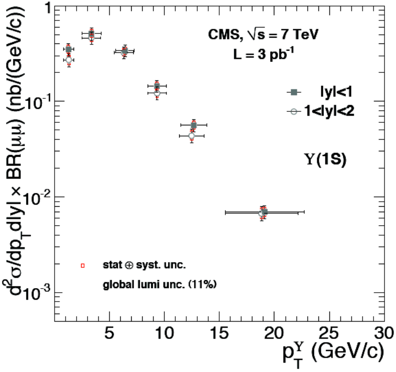
# Υ Cross section

$$\sigma\,(pp \rightarrow \Upsilon(1S)X) \cdot \mathcal{B}\left(\Upsilon(1S) \rightarrow \mu^+\mu^-\right) = (7.52 \pm 0.07(\text{stat.})^{+0.69}_{-0.48}(\text{syst.}) \pm 0.83(\text{lumi.}))\text{nb}$$

$|y|$<2.0, L = 3.1/pb, *CMS PAS BPH-10-003*

$$\mathcal{B}\left(\Upsilon(1S) \rightarrow \mu^+\mu^-\right) = (2.48 \pm 0.05)\%$$

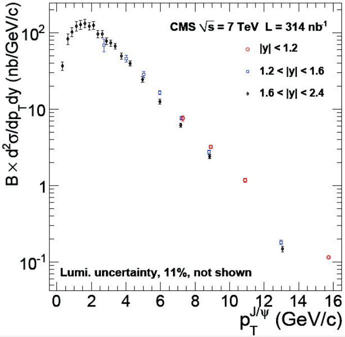


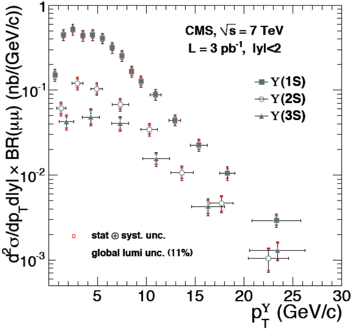



# Summary

**first results for CMS were presented:**

- inclusive production cross section for J/Ψ and ϒ
  - $\sigma\,(pp \rightarrow J/\Psi X) \cdot \mathcal{B}\left(J/\Psi \rightarrow \mu^+\mu^-\right) = (97.5 \pm 1.5(\text{stat.}) \pm 3.4(\text{syst.}) \pm 10.7(\text{lumi.}))\text{nb}$
    **6.5<$p_T$<30 GeV/c**, $|y|$<2.4, L = 314/nb
  - $\sigma\,(pp \rightarrow \Upsilon(1S)X) \cdot \mathcal{B}\left(\Upsilon(1S) \rightarrow \mu^+\mu^-\right) = (7.52 \pm 0.07(\text{stat.})^{+0.69}_{-0.48}(\text{syst.}) \pm 0.83(\text{lumi.}))\text{nb}$
    $|y|$<2.0, L = 3.1/pb
- differential cross section in transverse momentum for J/Ψ and ϒ



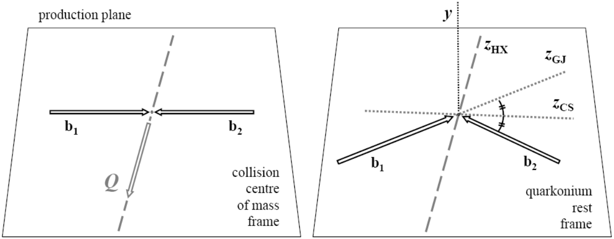



**BACKUP**

# Quarkonium Polarization

- alignment of the decaying particle spin with its direction of motion
  $\Rightarrow$ two muons get emitted in different angular configurations:

$$W(cos\theta, \varphi) \propto \frac{1}{3+\lambda_\theta}(1 + \lambda_\theta cos^2\theta + \lambda_\varphi sin^2\theta cos2\varphi + \lambda_{\theta\varphi} sin2\theta cos\varphi)$$




different reference frames:

- Helicity frame (HX): own flight/momentum direction of the quarkonium
- Collins-Soper frame (CS): bisecting angle between one beam and the opposite of the other beam
- Gottfried-Jackson frame (GJ): direction of the momentum of one of the two colliding beams *(not used in analysis)*

# Fit function

## Maximum Likelihood Method

$L(p) = \prod_i F(x_i, p) \quad \Leftrightarrow \quad ln(L(p)) = \sum_i ln(F(x_i, p))$

- parameters are estimated by maximizing the likelihood
- no information lost due to binning; works also at low statistics

## Crystal Ball function (PDF)

$$f(x;\alpha,n,\bar{x},\sigma) = N \cdot \begin{cases} \exp(-\frac{(x-\bar{x})^2}{2\sigma^2}), & \text{for } \frac{x-\bar{x}}{\sigma} > -\alpha \\ A \cdot (B - \frac{x-\bar{x}}{\sigma})^{-n}, & \text{for } \frac{x-\bar{x}}{\sigma} \leqslant -\alpha \end{cases}$$

- $A = \left(\frac{n}{|\alpha|}\right)^n \cdot \exp\left(-\frac{|\alpha|^2}{2}\right)$,
- $B = \frac{n}{|\alpha|} - |\alpha|$,
- $N$ is a normalization factor
- $\alpha$, $n$, $\bar{x}$ and $\sigma$ are parameters which are fitted with the data