# Quarkonia Measurements by the CMS Experiment in pp and PbPb Collisions

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#### for the CMS Collaboration



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# **Quarkonia in Heavy Ion Collisions**

- Good candidates to probe the QGP in HIC
  - Large masses and (dominantly) produced at the early stage of the collision via hard-scattering of gluons
  - Strongly bound resonances



The start : quarkonia should melt in the QGP T. Matsui & H. Satz PLB178, 416 (1986) Color Screening





# **A Complex Production**

#### Production mechanism not completely understood



The NNLO\* is not a complete NNLO  $\rightarrow$  possibility of (large) uncanceled logs ! If NNLO\*  $\approx$  NLO, problem with polarization

#### Many effects altering production in nuclear reactions

- In pA, cold nuclear matter (CNM) effects
  - Extensively studied at the SPS and RHIC
  - But different at the LHC ?
- In AA, hot medium effects





# RHIC J/ $\psi$ Suppression Puzzles

- No increase of the suppression with local density  $R_{AA}$  (|y|<0.35) >  $R_{AA}$  (1.2<|y|<2.2)
- Similar suppression at SPS and RHIC energies  $P_{\text{NA50, Scomparin's talk at QM06, 0 < y < 1}}$





#### **Compact Muon Solenoid**





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# Quarkonia in CMS

- Precision quarkonia physics
  - High statistics run pp  $\sqrt{s}$ =7 TeV L<sub>int</sub>=40 pb<sup>-1</sup>

Nuclear modification factor

− PbPb 
$$\sqrt{s_{NN}}$$
=2.76 TeV L<sub>int</sub>=7.28  $\mu$ b<sup>-1</sup>

- pp  $\sqrt{s}$ =2.76 TeV L<sub>int</sub>=225 nb<sup>-1</sup>
  - Similar hard probes statistics
  - Good reference
  - Same reconstruction algorithm











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## Di-muons from CMS pp √s=7 TeV





#### **Inclusive** J/ψ pp √s=7 TeV









#### $B \rightarrow J/\psi$

# pp √s=7 TeV



- Simultaneous fit
  - Invariant mass

J/ψ

 $L_{xy}$ 

°⊖3500 — CMS √s = 7 TeV → data ⊕3000 — signal+

8<sub>2500</sub>

)/2000 Events/

1000

500

2.6

Pseudo-proper decay length





В

2.9

3

signal+background

background-only

 $\sigma = 48 \text{ MeV/c}^2$ 

2.7 2.8



# J/ψ Cross Section pp √s=7 TeV

PROMPT

NON PROMPT



- **Prompt J**/ $\psi$  production not well reproduced
- Models describe non-prompt J/ $\psi$  production better





## Y States

# pp √s=7 TeV



- Very good dimuon mass resolution  $\rightarrow$  separation of the 3  $\Upsilon$  states





# Y Cross Section pp √s=7 TeV



# Quarkonia in pp

- Summary of the 7 TeV run
  - Differential charmonia and bottomonia
    - Constrain production mechanisms
  - In progress
    - $\chi_{c},\,\psi^{'},\,quarkonium$  polarization

#### • Heavy ion reference run $\sqrt{s}=2.76$ TeV





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# PbPb COLLISIONS



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## **Di-muons by CMS in PbPb**





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# Inclusive $J/\psi$

#### Similar resolution as in pp





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PbPb

6

TeV



## First Non-Prompt J/ψ



CMS

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PbPb



## Corrections

#### PbPb √s<sub>NN</sub>=2.76 TeV





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# $J/\psi R_{AA}$ vs. $p_T$ : Comparison



#### High $p_T J/\psi$ 's tendency to survive at RHIC (and SPS) is not seen at the LHC







# Prompt J/ $\psi$ R<sub>AA</sub> vs. y PbPb



- Less suppression at forward rapidity for high  $p_T$
- Anti-shadowing ?
  - CMS@p<sub>T</sub>=10 up to  $x_1 \sim 0.02 (x_2 \sim 5.10^{-4})$





# $J/\psi R_{AA}$ vs. y : Comparison



- CMS : opposite trend than PHENIX but different  $p_T$
- Increasing R<sub>AA</sub> going towards ALICE y range
  - Watch out for anti-shadowing :
- CMS@p<sub>T</sub>=10 GeV/c up to  $x_1 \sim 0.02 (x_2 \sim 5.10^{-4})$ ALICE@p<sub>T</sub>=0 GeV/c up to  $x_1 \sim 0.06 (x_2 \sim 2.10^{-5})$







Central 0-10%  $R_{AA} = 0.20 \pm 0.03 \pm 0.01$ Peripheral 50-100%  $R_{AA} = 0.59 \pm 0.12 \pm 0.10$ 





# $J/\psi R_{AA}$ vs. $N_{part}$ Comparison



#### STAR $\sqrt{s}$ =200 GeV, J/ $\psi$ 5 < p<sub>T</sub> < 8 GeV/c Stronger suppression seen in CMS than at STAR





### (PARENTHESIS FROM QUARKONIA : b-QUARK ENERGY LOSS)



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#### Minimum bias $R_{AA} = 0.37 \pm 0.07 \pm 0.03$ Central 0-20% $R_{AA} = 0.36 \pm 0.08 \pm 0.03$





# High p<sub>T</sub> Suppression PbPb



#### Same level of suppression as hadrons



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**2.76 TeV** 



# BACK TO QUARKONIA : BOTTOMONIA



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## **Y** States

# PbPb





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# $\Upsilon(1S) R_{AA}$

# PbPb



- Minimum bias  $R_{AA} = 0.62 \pm 0.11 \pm 0.10$
- High  $p_T$  not as suppressed ?
  - Need more statistics





# $\Upsilon(1S) R_{AA}$



- **Comparison with STAR** 
  - CMS Y(1S)  $R_{AA}(0-100) = 0.62 \pm 0.11 \pm 0.10$
  - R. Reed - STAR  $\Upsilon$ (1+2+3S) R<sub>AA</sub>(0-60) = 0.56 ± 0.11 +0.02 -0.10 (poster)





#### Y(2S+3S) Suppression **PbPb**



- $\Upsilon(2S+3S)$  production relative to  $\Upsilon(1S)$  in pp and PbPb
- Compare pp and PbPb through a simultaneous fit





# Υ(2S+3S) Suppression PbPb

(0.14 GeV/c<sup>2</sup>

Events /

$$\frac{\Upsilon(2S+3S)/\Upsilon(1S)\big|_{PbPb}}{\Upsilon(2S+3S)/\Upsilon(1S)\big|_{pp}}$$

- Pros of a double ratio
  - Acceptance cancels
  - Efficiency cancels

#### Potential differences

 Remaining systematics 9%, from line shapes

 $\frac{\Upsilon(2S+3S)/\Upsilon(1S)\Big|_{PbPb}}{\Upsilon(2S+3S)/\Upsilon(1S)\Big|_{pp}} = 0.31^{+0.19}_{-0.15} \pm 0.03$ 



arXiv : <u>1105.4894</u> Submitted to PRL

#### Hypothesis: no suppression $\Rightarrow$ p-value 1% Significance of the suppression 2.4 $\sigma$



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# $\Upsilon$ Suppression

- Large fraction of  $\Upsilon(1S)$  come from excited states
  - Feed down ~50% from  $\chi_b$  for  $p_T(\Upsilon)$  >8 GeV/c

CDF: PRL84 (2000) 2094

PbPb

<mark>6 TeV</mark>

- 40% suppression of Y(1S)
- Relative suppression of Y(2S+3S) vs. Y(1S)
  - Observation consistent with melting of the excited states only ?

- What about cold nuclear matter effects ?
  - Smaller  $\sigma_{\text{abs}}$  than at lower energy and for J/ $\psi$  (smaller size)

R. Vogt, hep-ph/1003.3497

- Shadowing cancelling in the  $\Upsilon(2S+3S)/\Upsilon(1S)$  ratio
  - pA run ?





# **Quarkonia Production with CMS**



#### Sequential melting accessible with CMS resolution









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# $\Upsilon \rightarrow e^+e^- @ RHIC$

- PHENIX
- **Au+Au collisions**
- High mass correlated  $\bullet$ di-electrons are suppressed

- **STAR** lacksquare
  - Au+Au collisions 0-60%
  - 93 Υ(1,2,3S)







#### **Pseudo-proper decay length**





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#### **Quarkonia Acceptance**





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### $B \to J/\psi$ Fraction in PbPb and pp







## **B** $\rightarrow$ J/ $\psi$ Fraction pp $\sqrt{s=7}$ TeV







# $R_{AA} J/\psi$ vs. $p_T$ Predictions

- Range of predictions
  - Less suppression
    - Zhao, Rapp: Due to finite J/ψ formation time, B feed down and Cronin effect
  - Stronger suppression
    - « Hot wind » model cc pair in motion w.r.t. hot ≃ medium ⇒ decrease of screening length.







# pp Comparison

Same pp reconstruction, including low  $p_T J/\psi$ Agreement of the Y(2S+3S)/Y(1S) ratio

#### • pp 2.76 TeV







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#### p-value

# Could background fluctuation produce a result as extreme as observed in data?

- Generate pseudo-experiments following the *null-hypothesis* (i.e. no suppression)
- Fit pseudo-data samples with nominal fit
- Count fraction of occurrences for which the ratio (taken as test statistic) is same or lower than observed:
  - p-value: 0.9%
  - 2.4 $\sigma$  (1-sided Gaussian test)







# J/ψ R<sub>AA</sub> Comparison PbPb



- **PHENIX**  $\sqrt{s}$ =200 GeV, inclusive J/ $\psi$ , p<sub>T</sub><sup>J/ $\psi$ </sup><5 GeV/c
- SPS, PHENIX, LHC: similar centrality dependence
  - But different  $p_T$ , systems and energies



