Overview of results on heavy flavour and quarkonia from the CMS collaboration

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Outline

• Heavy quarks and QGP

• CμS

• 2nd year of PbPb@LHC
  – J/ψ, ψ(2S), Υ(1S,2S,3S)
  – B→J/ψ

• The big picture

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIN
Heavy quarks and QGP

• Produced early in the collision
  – They map the evolution of the medium
  – Their measurements reflect the medium characteristics
Open heavy flavour (HF)

• Theoretically:
  – $R_{AA}^{\text{light}} < R_{AA}^{D} < R_{AA}^{B}$
  – Interplay of collisional and radiative energy loss

• Experimentally:
  – high-$p_T$ non-photonic electrons as suppressed as light hadrons

• Essential to separate charm from bottom
LHC: First unambiguous separation in heavy-ion collisions of charm and bottom

- One giant step for HI, one (first) small step for understanding heavy vs light parton energy loss differences
Hidden heavy flavours

Onia state in a deconfined, colour charged medium: Debye screening

- if $\lambda_D(T) < r_0 \Rightarrow$ screening $\Rightarrow$ melting of the bound state $\Rightarrow$ yields suppressed
- Screening at different $T$ for different states $\Rightarrow$ sequential melting

Onia: thermometer for the QGP
Charmonia: status before 2nd PbPb@2.7TeV

• All suppressed, but no clear pattern/picture

• Interplay of hot and cold medium effects
  – Shadowing, nuclear absorption
  – Regeneration, colour screening
  – feed-down ($p_T$-dependent)

• Quarkonium production in pp is not fully understood theoretically
Bottomonia: status before 2$^{\text{nd}}$ PbPb@2.76 TeV

- Ground state suppressed
  - $\sim$50% feed-down contribution above $p_T>8$ GeV/c
- Excited states more suppressed than ground state
C μ S
Muons: silicon tracker + muon subdetectors

- Tracker $p_T$ resolution: 1-2% up to $p_T \sim 100$ GeV/c
  - Separation of quarkonium states
  - Displaced tracks for heavy-flavour measurements
(di)Muon acceptance

- **Single muons**: $p_{\text{min}} \sim 3\text{-}5 \text{ GeV}/c$ for muon stations
  - $J/\psi$: $p_{T\text{min}} \sim 3 \text{ GeV}/c$ for $|y| > 1.6$
  - $\Upsilon$: $p_{T\text{min}} = 0 \text{ GeV}/c$ for $|y| < 2.4$
2\textsuperscript{nd} PbPb run at the LHC
Dimuons with muon $p_T > 4$ GeV/c

CMS Preliminary
PbPb $\sqrt{s_{NN}} = 2.76$ TeV

$\psi(1,2,3S)$
$\Upsilon(1,2,3S)$
$J/\psi$
$\rho$, $\omega$, $\phi$

$\int L_{\text{int}} (\text{PbPb}) = 147 \, \mu b^{-1}$

Events/(GeV/c$^2$)

$10^4$
$10^3$
$10^2$
$10$
$1$

$Z$

$D. Moon$
Tuesday

$M. Jo$
Friday

$L. Benhabib$
Wednesday

$R. GdeCassagnac$
Thursday

$\rho^\mu > 4$ GeV/c

$m_{\mu\mu}$ (GeV/c$^2$)

$1$
$10$
$10^2$
CMS Preliminary
PbPb $\sqrt{s_{NN}} = 2.76$ TeV
\[ \gamma(1,2,3S) \]
$\rho, \omega, \phi$
$\psi(2S)$
$\psi(1,2,3S)$
$\Upsilon(1,2,3S)$

$\text{L}_{\text{int}} \text{(PbPb)} = 147 \mu b^{-1}$

$p_{T}^{\mu} > 4 \text{ GeV/c}$

Events/(GeV/c$^2$)

$10^4$

$10^3$

$10^2$

$10$

$1$

$m_{\mu\mu} \text{ (GeV/c}^2\text{)}$

$10^2$

$10^3$

$10^4$
$R_{AA}$ prompt $J/\psi$

- Centrality ($p_T$, $y$ integrated): smooth increase of $R_{AA}$
  - 0-5% factor $\sim$ 5 suppression
  - 60-100% factor $\sim$ 1.4 suppression

- $y$ and $p_T$ (centrality integrated): no significant dependence
$R_{AA}$ prompt J/ψ: double-differential

CMS Preliminary
PbPb $\sqrt{s_{NN}} = 2.76$ TeV

Prompt J/ψ

- 6.5 < $p_T$ < 30 GeV/c: no rapidity dependence
- 1.6 < $|y|$ < 2.4: low-$p_T$ little less suppressed than high-$p_T$

$N_{\text{part}}$

- 50-100%
- 0-10%

CMS-PAS HIN-12-014
**$R_{AA}$ prompt $J/\psi$: theory**

CMS Preliminary
$PbPb \sqrt{s_{NN}} = 2.76$ TeV

- **Prompt $J/\psi$**
- **R. Rapp & X. Zhao**
- **Prompt $J/\psi$ (V=U)**
- **Shadowing**
- **Cronin**
- **Formation time**

- $l_y < 2.4$
- $6.5 < p_T < 30$ GeV/c
- $N_{part}$

NPA 859 (2011) 114 + private communication

- **High-$p_T$: no need for regeneration to describe data**
- **Treatment of onia energy loss similarly as open heavy flavour energy loss, without colour-octet included, is not supported by data**

arXiv:1203:0329 + private communication
We do see $\psi$ (2S) at high-$p_T$ and low-$p_T$ in PbPb.
\textbf{\(\psi (2S)\) vs \(J/\psi\) : \(pp\) vs \(\text{PbPb} (0-20\%)\)}

- \textbf{Raw ratios:} \(R_{\psi (2S)} = \frac{N_{\psi (2S)}}{N_{J/\psi}}\)
  - \textbf{High-}\(p_T\): \(R_{\psi (2S)}^{\text{PbPb}} \approx 0.5 \times R_{\psi (2S)}^{\text{pp}}\)
  - \textbf{Low-}\(p_T\): \(R_{\psi (2S)}^{\text{PbPb}} \approx 5 \times R_{\psi (2S)}^{\text{pp}}\) (low significance)

\[\text{CMS Preliminary}\]
\[pp \quad \sqrt{s} = 2.76\ \text{TeV}\]
\[L_{\text{int}} = 231\ \text{nb}^{-1}\]
\[
\begin{align*}
N_{J/\psi} & : 741 \pm 36 \\
R_{\psi (2S)} & : 0.049 \pm 0.010 \\
\sigma & : (32 \pm 1)\ \text{MeV/c}^2
\end{align*}
\]

\[\begin{array}{c}
\text{data} \\
\text{total fit} \\
\text{background} \\
\text{with } R_{\psi (2S)}^{0-20\%}(\text{PbPb})
\end{array}\]

- \(6.5 < p_T < 30\ \text{GeV/c}\)
- \(1.6 < |y| < 2.4\)

\[\text{CMS Preliminary}\]
\[pp \quad \sqrt{s} = 2.76\ \text{TeV}\]
\[L_{\text{int}} = 231\ \text{nb}^{-1}\]
\[
\begin{align*}
N_{J/\psi} & : 1046 \pm 34 \\
R_{\psi (2S)} & : 0.020 \pm 0.007 \\
\sigma & : (51 \pm 1)\ \text{MeV/c}^2
\end{align*}
\]

\[\begin{array}{c}
\text{data} \\
\text{total fit} \\
\text{background} \\
\text{with } R_{\psi (2S)}^{0-20\%}(\text{PbPb})
\end{array}\]

- \(3 < p_T < 30\ \text{GeV/c}\)
- \(1.6 < |y| < 2.4\)
3 < \( p_T \) < 30 GeV/c
1.6 < \( |y| \) < 2.4

High-\( p_T \):

\[
R_{AA}^{0-100\%}(\psi(2S)) = 0.11 \pm 0.03 \text{(stat)} \pm 0.02 \text{(syst)} \pm 0.02 \text{(pp)}
\]

Low-\( p_T \) (<2 \( \sigma \)):

\[
R_{AA}^{0-100\%}(\psi(2S)) = 1.54 \pm 0.32 \text{(stat)} \pm 0.22 \text{(syst)} \pm 0.76 \text{(pp)}
\]
CMS Preliminary

PbPb $\sqrt{s_{NN}} = 2.76$ TeV

$\gamma(1,2,3S)$, $\Upsilon(1,2,3S)$, $\psi(2S)$, $J/\psi$, $\rho$, $\omega$, $\phi$

$p_T^\mu > 4$ GeV/c

Events/(GeV/c$^2$)$^2$
$R_{AA}^{\Upsilon(1S), \Upsilon(2S), \Upsilon(3S)}$

- First $R_{AA}^{\Upsilon(2S)}$ measurement

- Centrality integrated:
  - $\Upsilon(1S)$: $0.56\pm0.08\pm0.07$
  - $\Upsilon(2S)$: $0.12\pm0.04\pm0.02$
  - $\Upsilon(3S)$: $<0.10$ at 95% CL

- $R_{AA}^{\Upsilon(3S)} < R_{AA}^{\Upsilon(2S)} < R_{AA}^{\Upsilon(1S)}$

- Ordered suppression $\Rightarrow$ sequential melting
**Against religion**: regeneration for the excited state, absorption/shadowing to be considered
Transition slide …
**b-quark energy loss: non-prompt $J/\psi$**

![Diagram showing muons and $J/\psi$ particles](image)

**CMS Preliminary**

- **PbPb $\sqrt{s_{NN}} = 2.76$ TeV**
- $L_{int} = 150 \mu b^{-1}$
- $|y| < 2.4$
- $6.5 < p_T < 30$ GeV/c
- Cent. 0-100%

- $N_{J/\psi} = 8525 \pm 177$
- $\sigma = 35 \pm 1$ MeV/c$^2$

**Events / (0.035 mm)**

![Graph showing muon mass distribution](image)

**CMS Preliminary**

- **PbPb $\sqrt{s_{NN}} = 2.76$ TeV**
- $L_{int} = 150 \mu b^{-1}$
- $|y| < 2.4$
- $6.5 < p_T < 30$ GeV/c
- Cent. 0-100%

- $\psi_{J/\psi} = L_{xy} \frac{m_{J/\psi}}{p_T}$

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Mihee Jo, Friday
Parallel 6A
**R_{AA}: Non-prompt J/\psi (B \rightarrow J/\psi)**

- **Centrality \((p_T, y \text{ integrated})\):** slow decrease of \(R_{AA}\)
  - 50-100\%: factor \(~1.4\)
  - 0-5\%: factor \(~2.5\)
- **y \((p_T, \text{centrality integrated})\):** hints of less suppression at mid-rapidity
- **p_T \(J/\psi\) \((y, \text{centrality integrated})\):** hints of increasing suppression at high-\(p_T\)
Non-prompt J/\psi: double-differential

- $6.5 < p_T < 30 \text{ GeV}/c$: hint of more suppression at forward $y$
- $1.6 < |y| < 2.4$: hint of less suppression for lower $p_T$
Light vs Heavy partons energy loss

- At low-\(p_T\): different suppression pattern than light
- At high-\(p_T\): b and light similar suppression
**B → J/ψ : theory**

- Data points: $p_T$ of $J/\psi$
- Theory: $p_T$ of $B$

- Radiative energy loss not enough to describe data

Horowitz: arXiv:1108.5876 + private communications
Buzzatti, Gyulassy: arXiv: 1207.6020+ private communications
He, Fries, Rapp: PRC86(2012)014903+ private communications
Summary: there is order ...
1) Closed charm and beauty: Yes, we can!

- The sequential melting map is experimentally drawn
  - Map includes: hot and cold effects (feed-down, nuclear absorption (pPb run), etc)
  - Looser bound states are more suppressed than the tighter bound states
2) Open charm and beauty: Yes, it does!

- In central collisions, $R_{AA}$ hierarchy

\[ R_{AA}^{\text{charm}} < R_{AA}^{\text{bottom}} \]

CMS-PAS HIN-12-014

arXiv:1205.6443