Suppression of open bottom at high $p_T$ via non-prompt J/$\psi$ decays in PbPb collisions at 2.76 TeV with CMS

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Outline

• Introduction
• Compact muon solenoid
• Signal extraction
  – Prompt and non-prompt $J/\psi$ separation
• Acceptance and efficiency
• Results
  – Non-prompt $J/\psi$ $R_{AA}$
  – $b$-jet $R_{AA}$
• Summary
Bottom quark in hot and dense medium

- Bottom quark is a sensitive probe of the medium energy loss
  - Created at an early stage of collision and has long lifetime
  → Interacts with medium and loses energy
- Inelastic scattering - radiative energy loss
- Elastic scattering - collisional energy loss
- Dead-cone effect
  - Reduces small-angle gluon radiation for heavy quarks with moderate energy-over-mass values

\[ R_{AA} = \frac{L_{pp}}{T_{AA} N_{MB}} \frac{N_{PbPb}(J/\psi)}{N_{pp}(J/\psi)} \frac{\varepsilon_{pp}}{\varepsilon_{PbPb}(\text{cent})} \]

\[ R_{AA}(\text{light hadrons}) < R_{AA}(D) < R_{AA}(B) \]


Non-photonic decays from D and B mesons

Au+Au @ \sqrt{s_{NN}} = 200 \text{ GeV}

BDMPS (D+B decays)  \hspace{1cm}  DGLV (D decay only)

Radi. E. loss (D+B decays)  \hspace{1cm}  Radi. E. loss + Coll. E. loss (D+B decays)
Compact Muon Solenoid

CMS Detector

Pixels Tracker ECAL HCAL Solenoid Steel Yoke Muons

**STEEL RETURN YOKE**
~13000 tonnes

**SUPERCONDUCTING SOLENOID**
Niobium-titanium coil carrying ~18000 A

**SILICON TRACKER**
Pixels (100 x 150 μm²) ~1m² ~65M channels
Microstrips (80-180 μm) ~200m² ~9.6M channels

**CRYSTAL ELECTROMAGNETIC CALORIMETER (ECAL)**
~76k scintillating PbWO₄ crystals

**PRESHOWER**
Silicon strips ~16m² ~137k channels

**FORWARD CALORIMETER**
Steel + quartz fibres ~2k channels

**HADRON CALORIMETER (HCAL)**
Brass + plastic scintillator ~7k channels

**MUON CHAMBERS**
Barrel: 250 Drift Tube & 480 Resistive Plate Chambers
Endcaps: 468 Cathode Strip & 432 Resistive Plate Chambers

Total weight: 14000 tonnes
Overall diameter: 15.0 m
Overall length: 28.7 m
Magnetic field: 3.8 T
Muon reconstruction in CMS

- Excellent muon identification and triggering (Muon system)
- High mass/momentum resolution (Tracker)
Dimuon spectrum in 2011 PbPb

CMS Preliminary
PbPb $\sqrt{s_{NN}} = 2.76$ TeV
$\Upsilon(1,2,3S)$

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

Events/(GeV/c$^2$)

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

$14$ Aug, $14:15$
Parallel 1D, D. Moon

$14$ Aug, $16:45$
Parallel 2D, B. Guillermo

$15$ Aug, $12:00$
Parallel 4C B. Lamia

$16$ Aug, $11:05$
Plenary, C. Mironov

$16$ Aug, $9:45$
Plenary, R. de Cassagnac

$p_T^\mu > 4$ GeV/c

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

10

100

1000

10000

100000

$Z$
Inclusive J/ψ

- Reconstruct $\mu^+\mu^-$ vertex
- 2-D unbinned maximum likelihood fit of $\mu^+\mu^-$ mass and pseudo-proper decay length $l_{J/\psi}$

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

$6.5 < p_T < 30 \text{ GeV/c}$
Cent. 0-100%

$|y| < 2.4$

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

Events / (0.035 mm)

$\ell_{J/\psi} = L_{xy} \frac{m_{J/\psi}}{p_T}$
Signal Extraction in PbPb

- Dimuon mass distributions
  - Signal shape: Crystal Ball + Gaussian
  - Background shape: Exponential

- Dimuon $l_{J/\psi}$ distributions
  - Prompt $J/\psi$ component
    Prompt $J/\psi$ MC template modeled with resolution function includes the event-by-event uncertainty of $l_{J/\psi}$
  - Non-prompt $J/\psi$ component
    Non-prompt $J/\psi$ MC template uses $l_{J/\psi}$ distribution as a shape
  - Background component
    Fit events in mass sidebands to sum of 3 exponential decay functions
Efficiency and acceptance

- MC simulations with PYTHIA

- Acceptance
  - No acceptance for J/ψ at mid-rapidity with $p_T < 6.5$ GeV/c
  - At forward rapidity, acceptance for J/ψ with $p_T > 3$ GeV/c

- Efficiencies
  - Embedded signal in min-bias events simulated with HYDJET
  - Validated MC by comparing efficiencies measured with “Tag & Probe” in MC and data

|y| 0 0.2 0.4 0.6 0.8 1 1.2 1.4 1.6 1.8 2 2.2 2.4
Acceptance

|y| 0 0.2 0.4 0.6 0.8 1 1.2 1.4 1.6 1.8 2 2.2 2.4
Efficiency

CMS collaboration, JHEP 1205 (2012) 063
Non-prompt $J/\psi$ $R_{AA}$ vs. $N_{part}$

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

- Centrality dependent suppression of non-prompt $J/\psi$ is observed
- Non-prompt $J/\psi$ in the most central collision (0-10%) is suppressed by a factor of 2.5
Non-prompt J/ψ \( R_{AA} \) vs. \( p_T \) and \( |y| \)

- Low-\( p_T \) J/ψ is slightly less suppressed than high-\( p_T \) J/ψ
- Mid-rapidity J/ψ is slightly less suppressed than in forward rapidity
Non-prompt J/ψ $R_{AA}$ vs. $N_{\text{part}}$ & $p_T$, $N_{\text{part}}$ & $y$

- All rapidity bins show centrality dependent suppression
- Low-$p_T$ J/ψ is less suppressed than high-$p_T$ J/ψ
Non-prompt $J/\psi$ $R_{AA}$ comparison

$R_{AA}$

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

- Vitev: 0-10%, $y \sim 0$
  - Rad E loss+CNM
  - Rad E loss+CNM+Dissoc

- WHDG: 0-80%, $y \sim 0$
  - Rad+Coll E loss

- Buzatti: 0-100%, $y \sim 0$
  - CUJET preliminary

- He,Fries,Rapp: 0-100%, $y \sim 0$
  - HF transport

- b-quarks: 0-100% $|\eta|<2.4$
  (via secondary $J/\psi(\mu^+\mu^-)$)

- $R_{AA}$ of non-prompt $J/\psi$ is described with theory calculations
  - Non-prompt $J/\psi$ $p_T$ for measurement and $B$ $p_T$ for theory curves
b-jets in heavy-ion collisions

- Jets from b-quark fragmentation are identified for the first time in heavy ion collisions
  - Jets are tagged by their secondary vertices
  - b-quark contribution is extracted using template fits to their secondary vertex mass distributions
b-jets in heavy-ion collisions

At $100 < \text{jet } p_T < 120$ GeV/c,
- Inclusive jet $R_{AA} = 0.50 \pm 0.01(\text{stat.}) \pm 0.06(\text{syst.})$
- $b$-jet $R_{AA} = 0.48 \pm 0.09(\text{stat.}) \pm 0.18(\text{syst.})$
Summary

- Non-prompt J/$\psi$ is suppressed in PbPb collisions
- Distinct b-quark suppression pattern at low $p_T$ is observed
- b-jets at high-$p_T$ shows similar suppression

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIN
J/ψ separation

- $L_{xy}$: The most probable transverse $b$-hadron decay length in the laboratory frame
  - $u$: the unit vector in the direction of the J/ψ meson $p_T$
  - $S$: the sum of the primary and secondary vertex covariance matrices

$$L_{xy} = \frac{\hat{u}^T S^{-1} \hat{r}}{\hat{u}^T S^{-1} \hat{u}} \quad \ell_{J/\psi} = L_{xy} \frac{m_{J/\psi}}{p_T}$$
Dimuon mass distributions consist of
  - Signal shape: Crystal Ball + Gaussian
  - Background shape: Exponential

Dimuon $J/\psi$ distributions consist of
  - Prompt $J/\psi$ component
    Prompt $J/\psi$ MC template modeled with resolution function includes the event-by-event uncertainty of $J/\psi$
  - Non-prompt $J/\psi$ component
    Non-prompt $J/\psi$ MC template $J/\psi$ distribution as a shape
  - Background component
    Fit events in mass sidebands to sum of 3 exponential decay functions
Signal Extraction
Signal Extraction in separated rapidity

B-fraction = 0.233 ± 0.008

- Poor pseudo-proper decay length distribution originates from y<0
  - B-fraction does not affected

B-fraction = 0.234 ± 0.009
Single muon acceptance

\[ p_T^\mu > 3.4 \text{ GeV/c} \]
\[ p_T^\mu > (5.8 - 2.4 \times |\eta^\mu|) \text{ GeV/c} \]
\[ p_T^\mu > (3.4 - 0.78 \times |\eta^\mu|) \text{ GeV/c} \]

for \( |\eta^\mu| < 1.0 \),
for \( 1.0 < |\eta^\mu| < 1.5 \),
for \( 1.5 < |\eta^\mu| < 2.4 \).
Trigger efficiency correction

- Different dimuon trigger was used in 2011 PbPb collisions because of High luminosity
- Difference between MC and data is corrected with Tag & Probe method
Reconstruction Efficiency

![Graph 1: CMS Simulation](image1)

- CMS Simulation
- $\sqrt{s} = 2.76$ TeV
- PYTHIA + EvtGen: $B \rightarrow J/\psi$
- Events / (0.03 mm)
- $l_{\text{true}}^{J/\psi}$ (mm)

![Graph 2: Efficiency](image2)

- Efficiency
- Cent. 0-100%
- $|y| < 2.4$
- CMS Simulation
- PbPb $\sqrt{s_{\text{NN}}} = 2.76$ TeV

- PYTHIA+EvtGen+HYDJET
- $Y(1S)$
- Prompt $J/\psi$
- Non-prompt $J/\psi$
Systematic Uncertainties

• Signal extraction
  – Mass distribution
    • Alternative shapes for signal, backgrounds are tested
    • Uncertainties of fixed parameters are tested
  – Pseudo-proper decay length distribution
    • Alternative shapes for resolution functions

• Efficiency
  – Tag & probe method for reconstruction efficiency validation
  – Tag & probe method for trigger efficiency correction

<table>
<thead>
<tr>
<th></th>
<th>prompt J/ψ (%)</th>
<th>non-prompt J/ψ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PbPb yield extraction</td>
<td>0.2–1.7</td>
<td>0.6–4.5</td>
</tr>
<tr>
<td>pp yield extraction</td>
<td>0.3–1.6</td>
<td>1.7–8.4</td>
</tr>
<tr>
<td>T&amp;P_{recoValidation}*(1−ε_{PbPb}/ε_{pp})</td>
<td>1–9</td>
<td>1–10</td>
</tr>
<tr>
<td>T&amp;P_{triggerCorrection}</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>$T_{AA}$</td>
<td>4.1–18</td>
<td>4.3–15</td>
</tr>
<tr>
<td>Total</td>
<td>10.8–23</td>
<td>11.1–22.7</td>
</tr>
</tbody>
</table>
- 231 nb$^{-1}$ data reconstructed by heavy-ion algorithm
- Different trigger condition (HLT_L1DoubleMu0 – slightly higher quality)
- Same acceptance and efficiency condition as heavy-ion analysis
b-jet $R_{AA}$

CMS Preliminary

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

100 < $p_T$ < 120 GeV/c

b-tagged sample
- PbPb data
- b-jet template
- c-jet template
- usdg-jet template

$\chi^2$/NDF = 16.8 / 11

100 < $p_T$ < 120 GeV/c

CMS PAS HIN-12-003