B meson production in pp and PbPb collisions at 5TeV

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on behalf of the CMS collaboration

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Flavor dependence parton energy loss

- Medium induced energy loose $E_{\text{loss}}$:
  - Collisional
  - Radiative

- Kinematics: “Dead cone effect” [1]: gluon radiation is suppressed at angle smaller than the ratio of quark mass to energy
  - $E_{\text{loss}}$ in light quarks $> E_{\text{loss}}$ in heavy quarks

- Suppression of induced radiation at low $p_T$ and the disappearance of this effect at high $p_T$
  - $R_{AA}^B > R_{AA}^D > R_{AA}^{\text{light}}$? ($R_{AA}^{\text{A}}$: Nuclear modification factor)

Strategy

- B meson life time $\rightarrow c\tau O(500) \mu m$ $\rightarrow$ secondary vertex
  - Secondary vertex reconstruction $\rightarrow$ full reconstruction of B meson decay chain $\rightarrow$
  - Target channel: $B^+ \rightarrow J/\psi + K^+$

- Complementary to non-prompt $J/\psi$ analysis
  (non-prompt $J/\psi$ and extra decay)
MVA optimization

To reach high signal to background significance (low production rate of b)

→ Multivariate analysis (MVA) for cut value optimization

Five variables are employed

• **track kinematic**: track $p_T$ and pseudorapidity

• **Probability of the vertex fit ($\chi^2$)**: $B^+$ secondary vertex fitting probability

• **Normalized $d_0$**: normalized distance between primary vertex and $B^+$ secondary vertex

• **Cosine($\theta$)**: angle between $B^+$ meson displacement vector and $B^+$ meson momentum

Maximize Figure of merit: $S/\sqrt{(S+B)}$

• **S**: signals from simulation (normalized to FONLL prediction)

• **B**: background from real data (sidebands of the $B^+$ mass spectrum)

• Optimization conducted independently for pp and PbPb
Mass fitting

CMS Preliminary

pp $\sqrt{s_{NN}} = 5.02$ TeV

Centrality 0-100%

- Signal:
  Double Gaussian with same mean

- Peaking BG:
  error function + two sided Gaussian

- Combinatorial BG:
  1st order polynomial

Selected B cand.

Mass spectrum

fitting!

Yield extractions

Efficiency correction

Cross section/R_{AA}

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Non-prompt contribution

Peaking structure from other types of B meson decay: \textit{two main contributions}

**B^+ \rightarrow J/\psi + \pi:** Two sided Gaussian

the pion track is identify as a K^+

**B^+ \rightarrow J/\psi + K^{*+} or B^0 \rightarrow J/\psi + K^{*0}, K^0:** Error function

tracks coming from the subsequent K^{*0} decay incorrectly assumed to be from genuine B^+ \rightarrow J/\psi + K^+
First direct reconstruction of B meson in PbPb collision

CMS-PAS-HIN-16-011

pp 5TeV

CMS Preliminary

\[ \chi^2/\text{nDOF}: 48.00/44 = 1.09 \]

PbPb 5TeV

CMS Preliminary

\[ \chi^2/\text{nDOF}: 60.84/44 = 1.38 \]
Systematic: results

Luminosity & branching ratio
- BR obtained from PDG

Signal extraction systematics \( \sim 3.9\% \)
- Estimated by varying the modeling PDF and the fitting procedure

Selection and correction \( \sim 12.6\% \)
- Selection variation
- B life-time / \( p_T \) modeling
- Tracking efficiency systematic (evaluated by 2 and 4 prongs \( D^0 \) decays)

Muon efficiency \( \sim 16.4\% \)
- Data-MC single muon efficiency
- Estimate via standard “tag & probe” method by reconstructing \( J/\psi \) candidates

Nuclear modification factor
- normalization \( \sim 9\% \)
- total systematic \( \sim 25\% \)
\[ \frac{d\sigma}{dp_T} \bigg|_{|y| < 2.4} = \frac{1}{2} \frac{N(p_T)|y| < 2.4}{\Delta p_T \text{Acc } |y| < 2.4 \text{ BR } \mathcal{L}}. \]

- **N**: raw yields of the mass fitting
- **Acc \(\epsilon\)**: selection efficiency estimated from simulation
- **BR**: branching ratio obtained from PDG
- **\(\mathcal{L}\)**: Luminosity of the pp 5 TeV data

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\[
\left. \frac{d\sigma}{dp_T} \right|_{|y| < 2.4} = \left[ \frac{1 \cdot N(p_T)_{|y| < 2.4}}{2 \cdot \Delta p_T \cdot (Acc \cdot e)_{|y| < 2.4}} \right] \cdot BR \cdot \mathcal{L}.
\]

- Result derived in 5 $B^+$ $p_T$ bins, from 7 to 50 GeV in $|y| < 2.4$
- Consistent with the upper bound of FONLL predictions [1]

pp cross section

pp 13 and 7 TeV results

arXiv:1609.00873

CMS Preliminary

25.8 pb⁻¹ (5.02 TeV pp)

Data
FONLL pp ref.
|y| < 2.4
Global uncert. 12.4%

CMS (13 TeV)

Ratios to FONLL

Data (13 TeV, |y|<1.45)
Data (13 TeV, |y|<2.1)
FONLL (13 TeV)
PYTHIA (13 TeV)

Data (7 TeV, scaled to |y|<1.45)
Data (7 TeV, scaled to |y|<2.1)
FONLL (7 TeV)
PYTHIA (7 TeV)

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• Result derived in 5 $B^+ p_T$ bins, from 7 to 50 GeV in $|y| < 2.4$ inclusive centrality (0~100%)

• Suppression of $B$ meson production rate is observed in PbPb collision

• $B$ meson $R_{AA} \sim 0.3$ to 0.6 with no obvious trend observed within statistical and systematic uncertainty
Nuclear modification factor

CMS-PAS-HIN-12-014

• $B^+ p_T^{10\sim15 \text{ GeV}} \rightarrow J/\psi p_T^{8\sim10 \text{ GeV}}$

• Results compatible with each other within uncertainty
Nuclear modification factor

- Comparison with the $D^0$ meson [1] and charge hadron [2] $R_{AA}$

![Graph showing $R_{AA}$ vs. $p_T$ (GeV/c)]

[1] CMS-PAS-HIN-16-001
Nuclear modification factor

- Comparison with different theory model
  - M. Djordjevic [1]
    - pQCD calculations in a finite size optically thin dynamical QCD medium
  - M. He et al. [2]
    - consistent strong-coupling treatment with hydrodynamic bulk evolution and nonperturbative T-matrix interactions
  - X. Jiechen et al. [3]
    - jet quenching model based on DGLV opacity expansion theory

- Compatible with theory prediction within statistical and systematic uncertainty

![CMS Preliminary graph]

$25.8 \text{ pb}^{-1} (5.02 \text{ TeV pp}) + 350.68 \text{ \mu b}^{-1} (5.02 \text{ TeV PbPb})$

$R_{AA}$ and lumi. uncertainty

Centrality 0-100%

$T_{AA}$

$p_T (\text{GeV/c})$

Summary

- The first fully reconstructed B meson $R_{AA}$ measurement in PbPb collision
- pp cross section matched (at the upper edge) with FONLL prediction within uncertainty
- A suppression of production rate is observed for B meson $p_T$ from 7 to 50 GeV in $|y| < 2.4$ inclusive centrality (0~100%)
- $R_{AA}$ range from 0.3 to 0.6 for B meson with no obvious trend observed

Thank you very much for your attention
Back Up
Basic Selections

Event selections
- Remove beam scraping events.
- Forward hadronic calorimeter coincidence.
- Primary vertex reconstruction

Muon object Selections
- Muon acceptance (e.g., muon $p_T > 3.5$ GeV for pseudorapidity $< 1.2$)
- Reconstructed with both information from tracker and muon chamber
- Muon track quality (e.g., number of hits in tracker)
- Distance between primary vertex and muon track

Track object Selections
- Remove overlap with muon track (track cleaning)
- Basic kinematic selections (baseline $p_T$ and pseudorapidity cut)
- Track quality selections
List of systematic sources...

- **Luminosity:** $pp \sim 4\%$, $PbPb \sim 2\%$, $T_{AA} \sim 8.9\%$
- **Branching ratio (from PDG):** $\sim 3.07\%$
- **Signal extraction:** $\sim 3\%$, estimated via varying signal and background modeling of the mass fitting procedure.
- **Monte Carlo sample statistic:** $pp$ from $0.8 \sim 2.2\%$, $PbPb$ from $2.0 \sim 7.1\%$
- **Alignment:** $\sim 2.8\%$, alignment modeling of simulation
- **Life time:** $\sim 0.3\%$ life time modeling of simulation
- **B pT shape modeling:** $\sim 2\%$, B meson pT spectrum modeling of simulation
- **Tracking efficiency:** $pp \sim 4\%$ and $PbPb \sim 5\%$. From reconstruction ratio the $D^* 3$ and 5 prong decay ($k+2^*\pi$, $k+4^*\pi$)
- **B meson selection:** $pp \sim 3.8$ and $PbPb \sim 12.0\%$, estimated by variation of selection cut values
- **Muon reconstruction efficiency:** $pp \sim 10\%$ and $PbPb \sim 13\%$, estimated via the standard tag&probe method
Systematic: results

**pp cross section**
- normalization ~ 4%
- total systematic ~ 15%

**Nuclear modification factor**
- normalization ~ 9%
- total systematic ~ 25%
Nuclear modification factor

\[
R_{AA}(p_T) = \frac{1}{T_{AA}} \frac{dN_{B^+}^{PbPb}}{dp_T} / \frac{d\sigma_{B^+}^{pp}}{dp_T}
\]

- **$T_{AA}$**: Nuclear overlap function

\[
\frac{1}{T_{AA}} \frac{dN}{dp_T} \bigg|_{|y|<2.4} = \frac{1}{T_{AA}} \frac{1}{2 \Delta p_T} \frac{N_{B^+}^{PbPb}}{|y|<2.4} (\text{Acc} \cdot \text{BR} \cdot N_{\text{events}})
\]

- **$N_{\text{event}}$**: Numbers of minimum bias event correspond to the PbPb 5TeV data

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CMS

Preliminary

B$^+$ $|y| < 2.4$

T$_{AA}$ and lumi.
uncertainty

Centrality 0-100%

25.8 pb$^{-1}$ (5.02 TeV pp) + 350.68 µb$^{-1}$ (5.02 TeV PbPb)

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Nuclear modification factor

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- $B^+ p_T$ 10~15 GeV $\rightarrow$ J/$\psi$ $p_T$ 8~10 GeV

- Results compatible with each other within uncertainty
$R_{AA}$
D meson Run1, 2.76 TeV result

- $p_T$: 2-100 GeV/c
Non-prompt $J/\psi$ $R_{AA}$

$R_{AA}$: binning in $p_T$, rapidity and centrality

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• pp reference: FONLL prediction (no pp data yet at this energy)
• Measurement of $B^+$ $B^0$ and $B^0_s$
• Function of $p_T$
• Function of rapidity


CMS

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

0-100% $|\eta| < 2$

PbPb, 150 $\mu$b$^{-1}$

pp, 5.3 pb$^{-1}$

$b$-jet $R_{AA}$ vs $p_{T}$ (GeV/c)

pQCD: PLB 726 (2013) 251-256

$g_{med} = 1.8$

$g_{med} = 2.0$

$g_{med} = 2.2$

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