b-jet Nuclear Modification Factors in Heavy-Ion Collisions with CMS

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Outline

• Motivation for heavy flavor analyses
• B-jet identification
• B-tagging performance
• B-jet $R_{AA}$ measurements
• B-jet $R_{pA}^{PYTHIA}$ measurements
  – Jet energy suppression?
  – Measurements of nuclear PDF?
• Conclusions

Since QM12...
• Enhanced pp statistics
• Fully unfolded and corrected spectra
  • $R_{AA}$ measurements
  • $R_{pA}$ measurements

Additional details found in CMS PASes HIN-12-003, HIN-14-007
Motivation for Heavy Flavor Studies

- Heavy quark measurements give a deeper understanding of the in-medium energy loss mechanisms
- pA in particular allows assessment of cold nuclear matter effects, independent of HI medium quenching
- Jets in particular are extremely useful:
  ✓ Provide a high-$p_T$ heavy flavor probe
  ✓ Complementary to B-meson measurements

• This b jet measurement does not distinguish between different b-jet production mechanisms.
• NLO (through Herwig) predicts non-negligible contributions from all three production mechanisms in the $p_T$ range that we measure:
  – Gluon can split anywhere from early to late in the collision -> convolutes energy loss measurements!
• This first LHC b-jet measurement is a critical starting point for the future:
  – di-b-jet and b jet-track correlations can shed additional light.
Identifying B-Jets

- Primary identification method is using a **Secondary Vertex**
  - Long lifetime of \( b = \text{mm or cm vertex displacement} \)
- Flight distance \( (L_{xy}) \) of the secondary vertex used as a discriminating variable
- Tagging methods independent of secondary vertex reconstruction used as cross-check

B-quark decays are heavily CKM-suppressed \( \rightarrow \) Long lifetimes

Algorithms described in: *JINST 8 (2013) P04013*
• B-jet efficiency plotted against probability of misidentifying a light jets as a b-jet
Tagging Performance in Simulation

- B-jet efficiency plotted against probability of misidentifying a light/charm jet as a b-jet
- pPb and pp have identical reconstruction procedures ➔ very similar tagging performance
• Tagger working point is chosen such that the light jet rejection is approx. 99% for all collision species
Calculating the b-jet Fraction

\[ \varepsilon_b = \frac{C_b f_b^{b\text{tag}} N_b^{b\text{tag}}}{f_b^{\text{untagged}} N_{\text{jets}}^{\text{untagged}}} \]  

(1)

\[ N_{\text{jets}}^{b\text{tag}} = N_{\text{jets}}^{\text{total}} f_b \frac{f_b}{\varepsilon_b} \]  

(2)

- **Purity** \( (f_b) \) is found via fitting two very different distributions:
  - Distribution of SV mass is primary extraction method
  - Track impact parameter used as data-driven cross-check
- **Efficiency** \( (\varepsilon_b) \) is found via the tagging and anti-tagging purity [eq. 1]

\[ f_b = \text{purity from template fit} \]
\[ \varepsilon_b = \text{efficiency of b-tagger} \]
\[ C_b = \text{Fraction of jets with JP information} \]
PbPb B-Jet Spectra

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

- Fully corrected and unfolded spectra plotted for both PbPb and pp
- B jets in PbPb scaled by $T_{AA}$ → normalized to pp spectra
- Clear indication of suppression seen

B-jet suppression already indicated from this plot

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• First measurement of heavy flavor jet $R_{AA}$
• Clear suppression of $b$-jets
  – $R_{AA}$ shows clear trend as a function of centrality
• Suppression favors pQCD model with stronger jet-medium coupling
“$\eta_{CM}$” in pPb

- pPb collisions are natively asymmetric
  - $E(\text{proton}) = 4 \text{ TeV}, E(\text{Pb}) = 1.58 \text{ TeV}/N$
  - Distributions of jets are centered around $\pm 0.465$ units in $\eta$
- $\eta$ distributions are corrected to the center-of-mass eta
- Pbp $\eta$ distribution is “mirrored” ($\eta \rightarrow -\eta$)
  - This ensures consistency when pPb and Pbp results are used together
pPb B-jet Spectra

CMS Preliminary $\sqrt{s_{NN}} = 5.02$ TeV $L = 35$ nb$^{-1}$

- B-jet spectra shown for various selections in $\eta_{CM}$
- Spectra scaled by $T_{pA}$ such that pp & pPb are directly comparable
- Minimal suppression or enhancement is observed

100 200 300 400
b-jet $p_T$ [GeV/c]
• Result is *consistent with a small Cronin enhancement* from *but effects are quite minimal*

• Systematic uncertainties from b-tagging and spectrum unfolding dominate

• pPb b-jet fraction is consistent with PYTHIA at high $p_T$
Comparison of $b$-Jet $R_{pA}$ [PYTHIA] and $R_{AA}$

CMS Preliminary

$pPb$ L = 35 nb$^{-1}$; PbPb L = 150 μb$^{-1}$

- Nuclear Modification Factor

- $b$-jet $R_{AA}$, (0-100%), $|\eta|<2$
- $b$-jet $R_{pA}^{PYTHIA}$, $-2.4<\eta_{CM}<1.6$

- $pPb$ Luminosity Unc.
- $pPb$ Reference Unc.

- $b$-Jet $R_{AA}$ is heavily suppressed compared to $R_{pA}$ indicative of strong in-medium effects

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CMS PAS HIN-12-003 CMS PAS HIN-14-007
Global Jet Energy Modification

- Dramatic energy loss for jets in PbPb collisions
- Virtually no modification seen in pPb collisions
- We observe virtually no modification as a function of jet flavor

CMS PAS HIN-12-003  CMS PAS HIN-14-007  CMS PAS HIN-12-004  CMS PAS HIN-14-001
B Mesons vs b jets

• Measurements in conjunction with B mesons show consistency with over a very wide range in $p_T$!
• B Mesons in pPb show similar suppression w.r.t. pp simulation as do the b jets
• $\eta$-dependent jet production is generally a result of nPDF effects, due to $\eta$/bjorken-$x$ correlations

• Plotting $R_{pA}(\text{PYTHIA})$ vs $\eta$ shows no such trend
Summary

• b-jet $R_{pA}$ (PYTHIA) consistent with unity within large systematic uncertainties

• b-jet $R_{AA}$ shows increased suppression with increased centrality

• All b-jet suppression effects are consistent with inclusive-jet effects
  – No indication of flavor-dependent energy loss mechanisms within systematics at high-$p_T$
A distortion in the secondary vertex \( p_T \) spectrum would indicate suppression dependence between gluon and quark jets.

- This is not observed as the SV \( p_T \) spectrum in data.
Efficiency and Purity of b-Tagging

- Purity is calculated first from fits to SV mass distributions
- Efficiency calculated from MC using purity values extracted for samples with and without the b-tagger applied
\( R_{AA} \) is closest to unity for the peripheral collisions and shows increasing suppression with increasing centrality.
Additional Fits to JP Tagger

- Before tagging, b-fraction is approx. 3%
- After tagging, b-fraction is approx. 50%
b-jet Production at the LHC

• 2011 PbPb Run: 150 $\mu$b$^{-1}$ integrated lumi
• Corresponding # of b-jets is $\sim$15k
• Golden measurement: double b-tagged dijets
  – Removes gluon splitting component
  – Allows to obtain a high purity sample of b-jets
  – Small systematics w.r.t. inclusive jet measurement
• However:
  – Double b-tagging efficiency $\sim 0.5^2 = 0.25$
  – LO flavor creation mode only contributes $\sim 15$

• LESS THAN 1000 tagged di-b-jets (leading jet $p_T > 80$ GeV/c)
PYTHIA agrees with the b-jet fraction calculation within 20% systematic uncertainties for both 2.76 TeV (not shown) and 7 TeV.

Additional PYTHIA tuning uncertainty applied: 8% between D6T and Z2 tunes.

Scale factor of $0.99 \pm 0.02\text{(stat)} \pm 0.21\text{(syst)}$.