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

Kurt Jung
[Purdue University]
for the CMS Collaboration

Quark Matter 2014: Darmstadt, Germany

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…

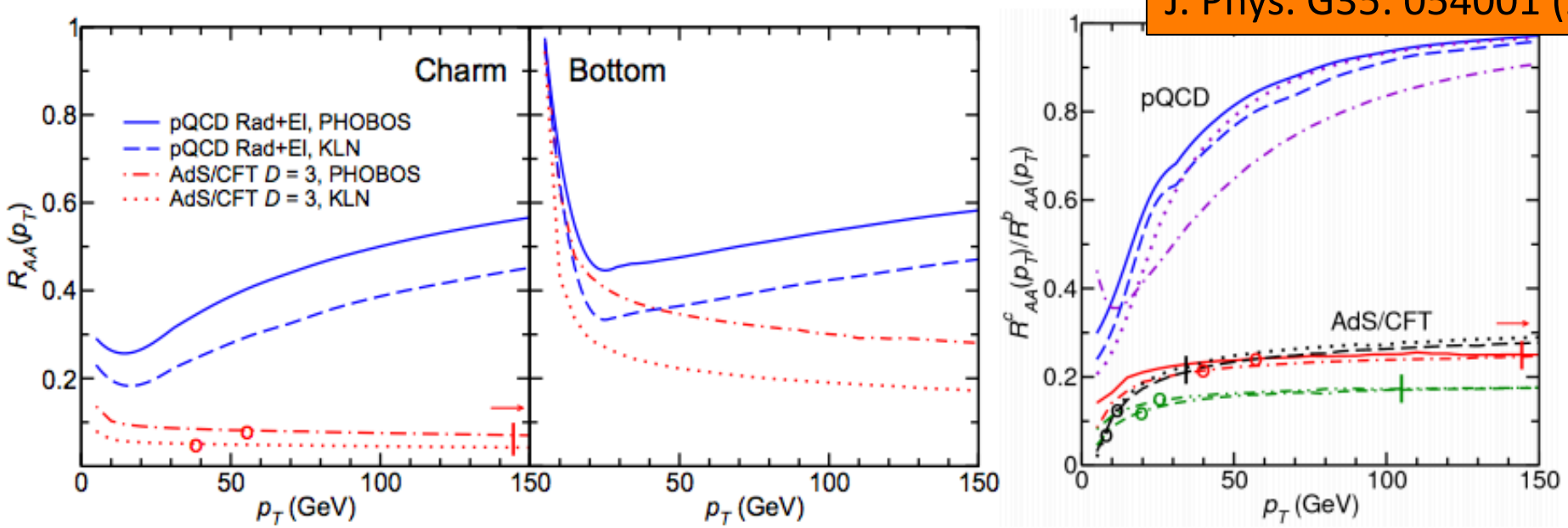
- Enhanced pp statistics
- Fully unfolded and corrected spectra
- R_{AA} measurements
- R_{pA} measurements

Additional details found in CMS PASes HIN-12-003, HIN-14-007

Motivation for Heavy Flavor Studies

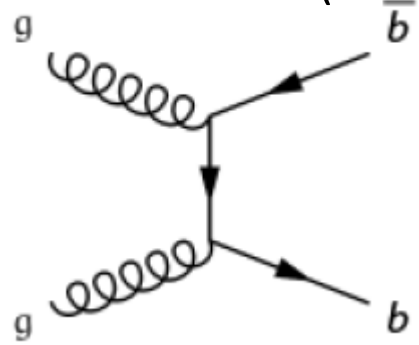
- Heavy quark measurements give a deeper understanding of the in-medium energy loss mechanisms
- pA in particular allows assessment of ***cold nuclear matter effects***, independent of HI medium quenching
- Jets in particular are extremely useful:
  - ✓ Provide a high-p_T heavy flavor probe
  - ✓ Complementary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

J. Phys. G35: 054001 (2008)

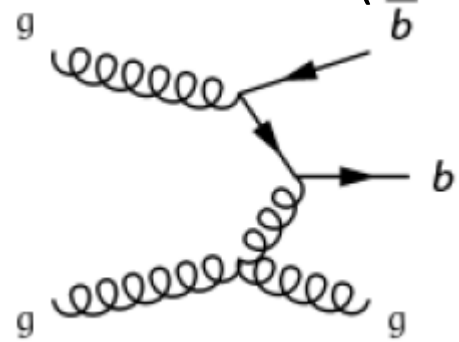


b-jet Production Mechanisms

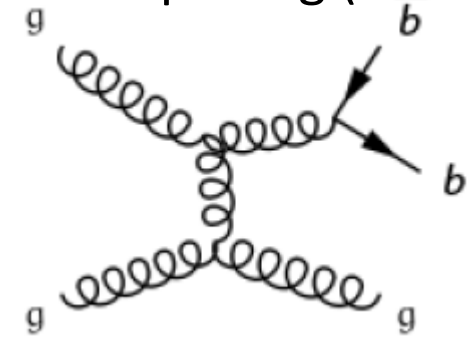
Flavor Creation ("FCR")



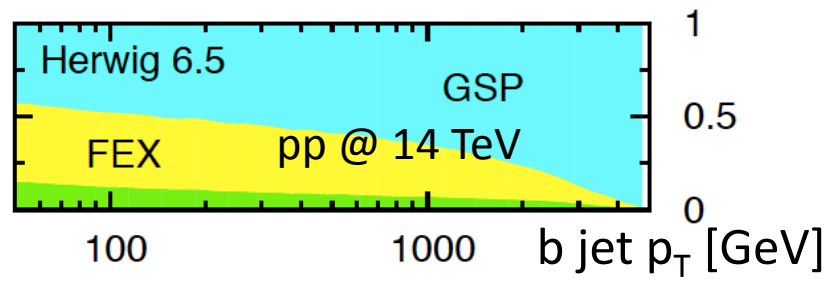
Flavor Excitation ("FEX")



Gluon Splitting ("GSP")

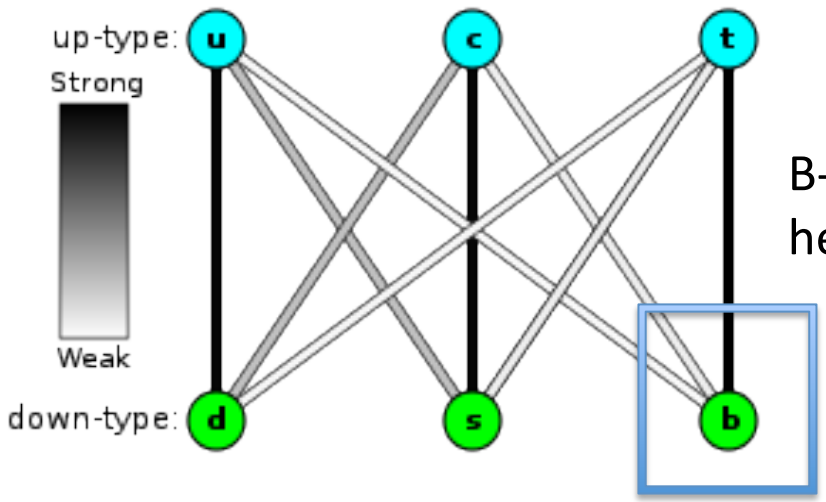


arXiv:0704.2999

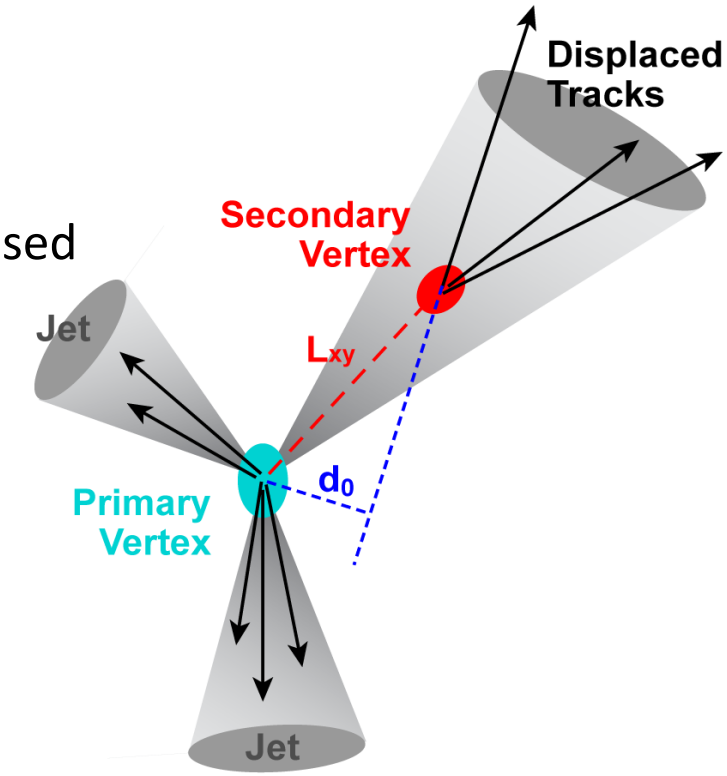


- This b jet measurement does not distinguish between different b-jet production mechanisms
- NLO (through Herwig) predicts non-negligible contributions from all three production mechanisms in the p_T range that we measure
  - Gluon can split anywhere from early to late in the collision -> convolutes 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



B-quark decays are heavily CKM-suppressed
-> Long lifetimes

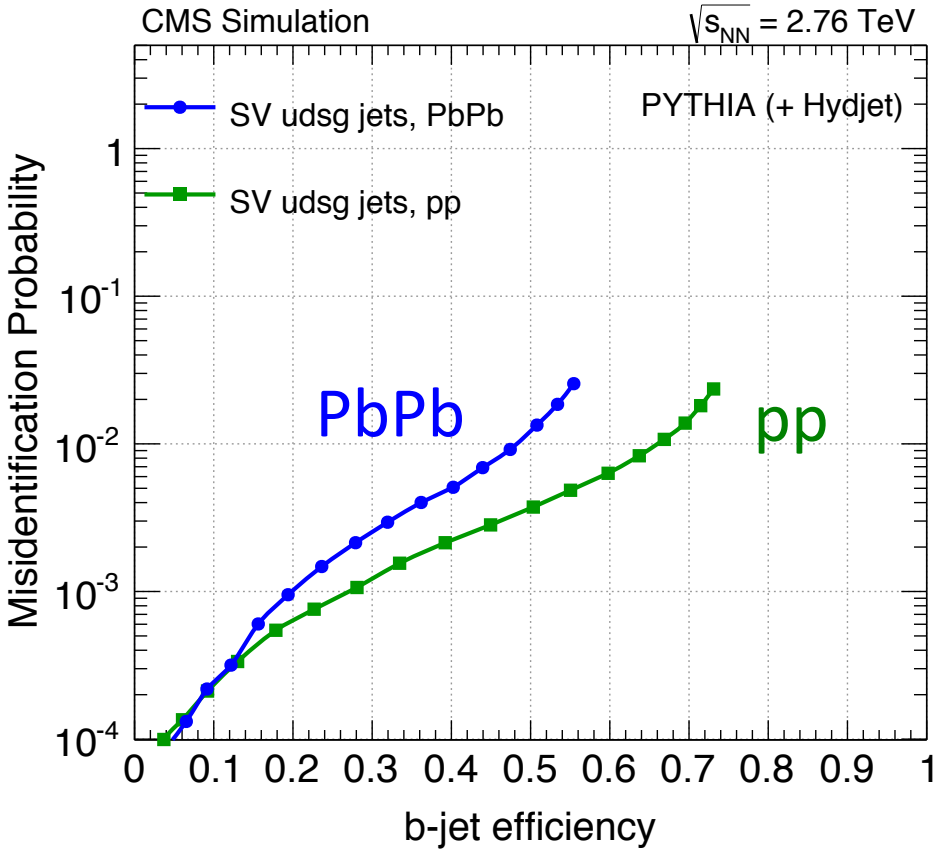


- Primary identification method is using a **Secondary Vertex**
  - Long lifetime of b = mm or cm vertex displacement
- Flight distance (L_{xy}) of the secondary vertex used as a discriminating variable
- Tagging methods independent of secondary vertex reconstruction used as cross-check

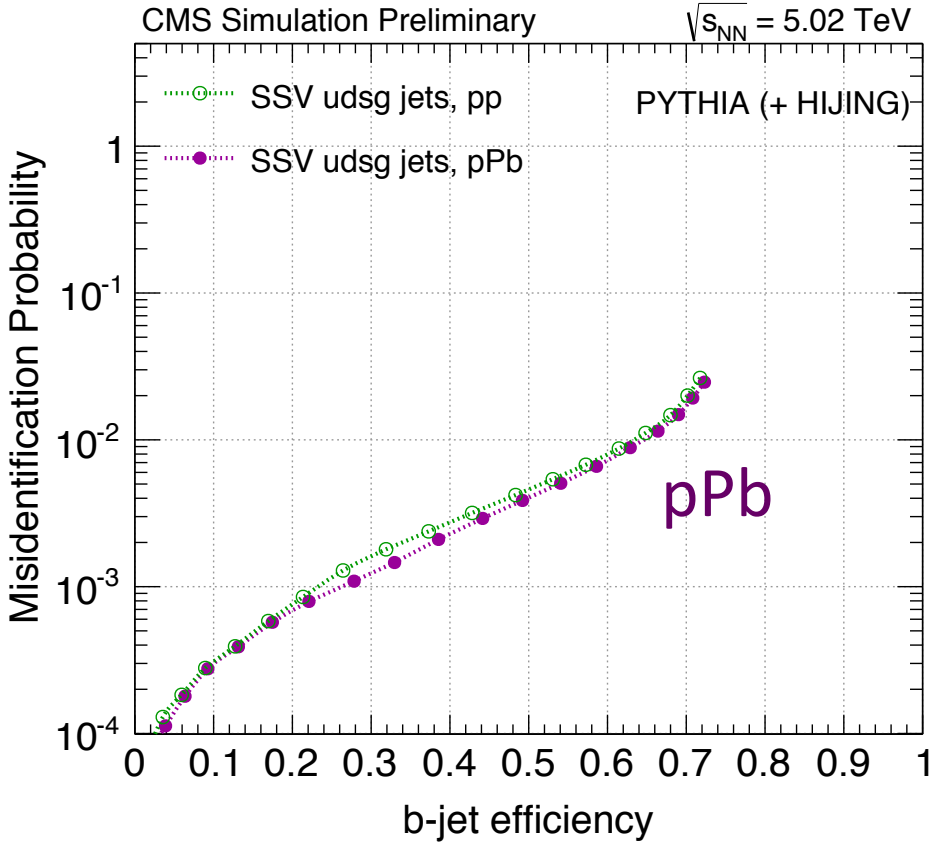
Algorithms described in:
JINST 8 (2013) P04013

Tagging Performance in Simulation

Performance in PbPb



Performance in pPb



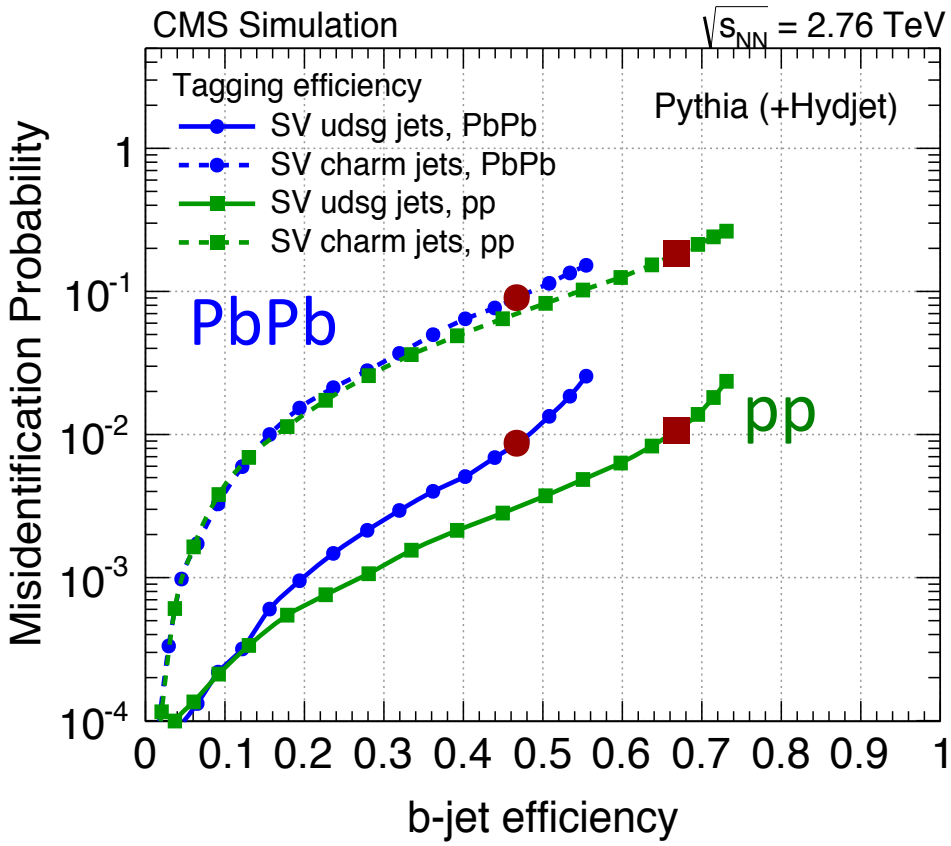
- B-jet efficiency plotted against probability of misidentifying a light jets as a b-jet

CMS PAS HIN-12-003

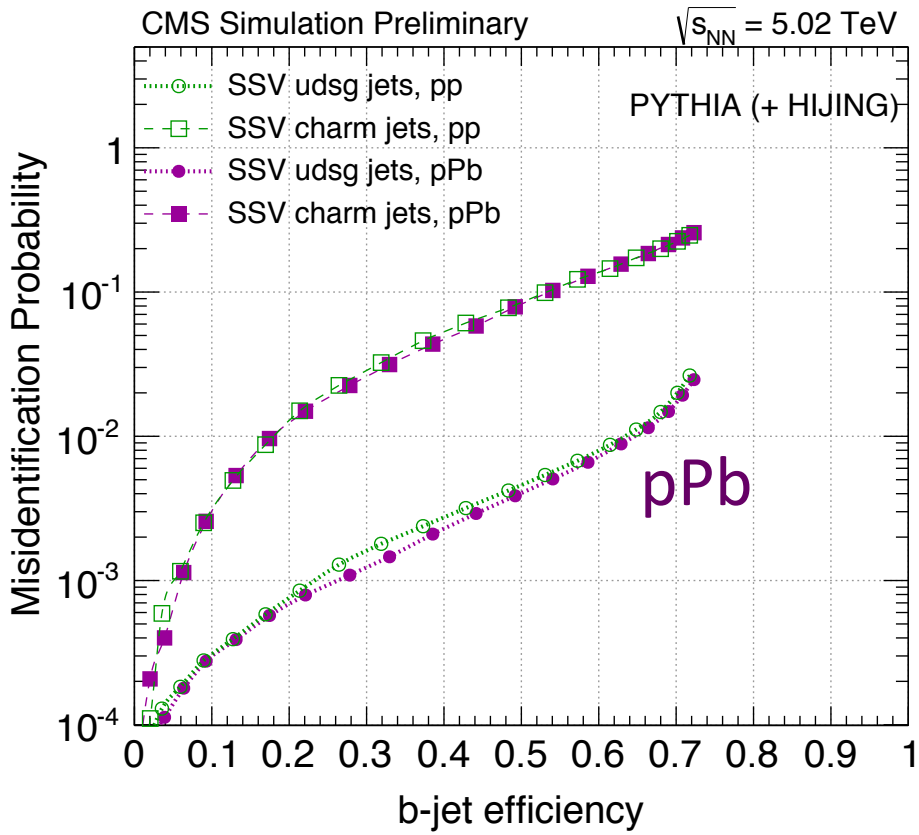
CMS PAS HIN-14-007

Tagging Performance in Simulation

Performance in PbPb



Performance in pPb



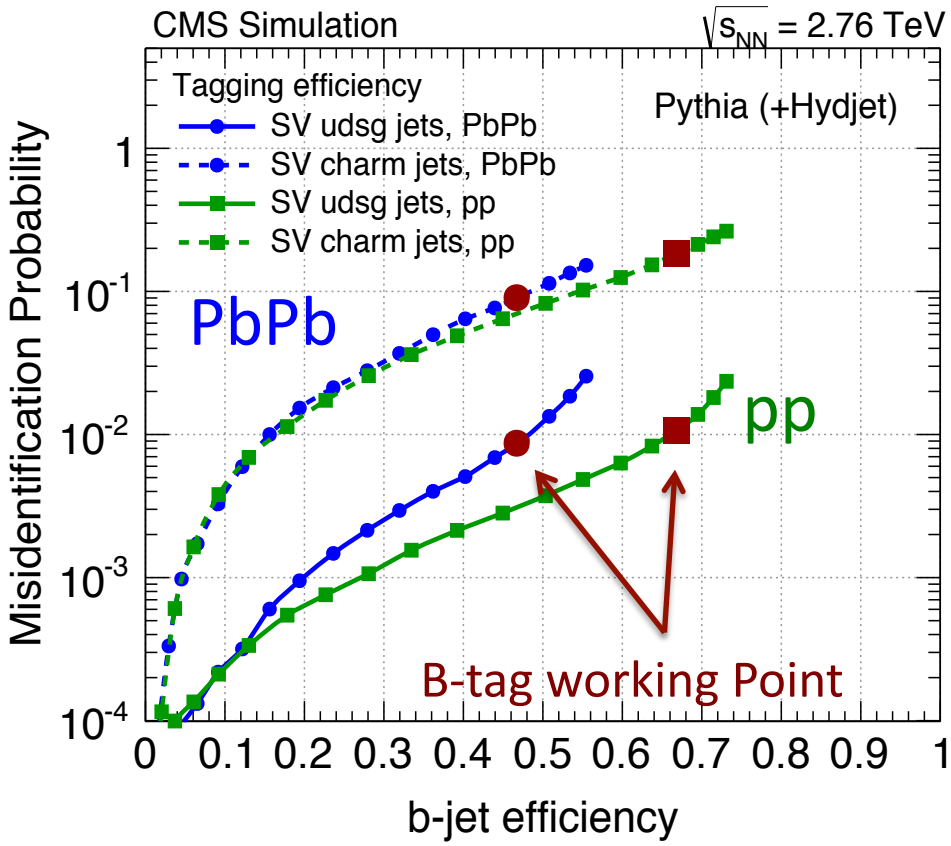
- B-jet efficiency plotted against probability of misidentifying a light/charm jet as a b-jet
- pPb and pp have identical reconstruction procedures ➔ very similar tagging performance

CMS PAS HIN-12-003

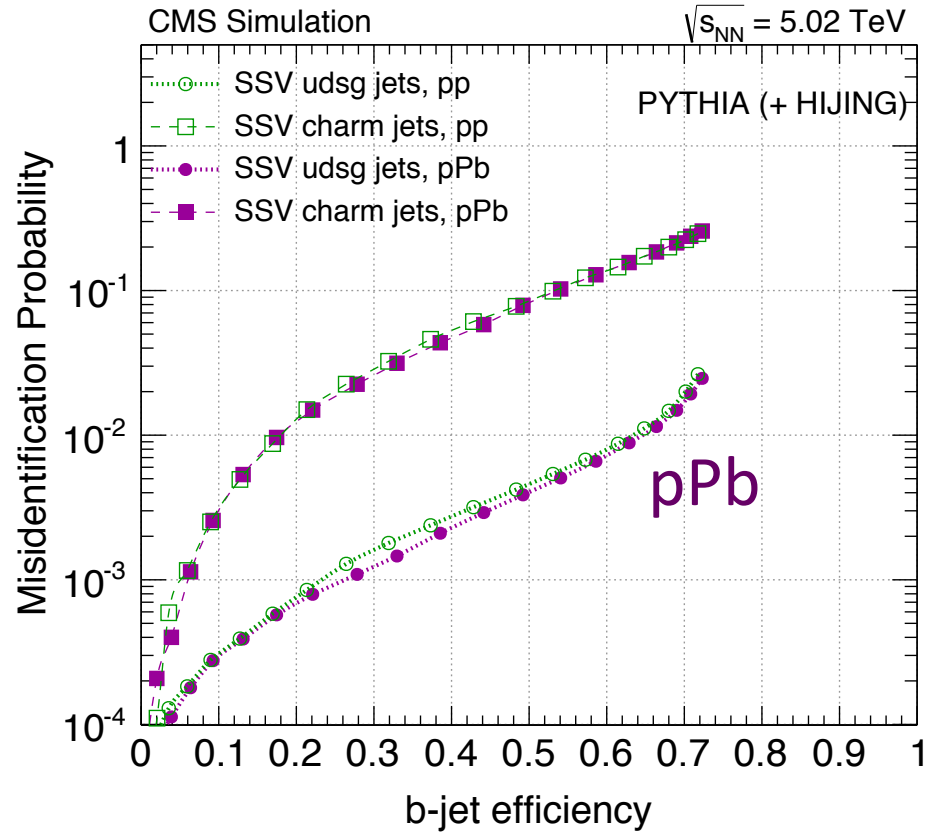
CMS PAS HIN-14-007

Tagging Performance in Simulation

Performance in PbPb



Performance in pPb



- Tagger working point is chosen such that the light jet rejection is approx. 99% for all collision species

CMS PAS HIN-12-003

CMS PAS HIN-14-007

Calculating the b-jet Fraction

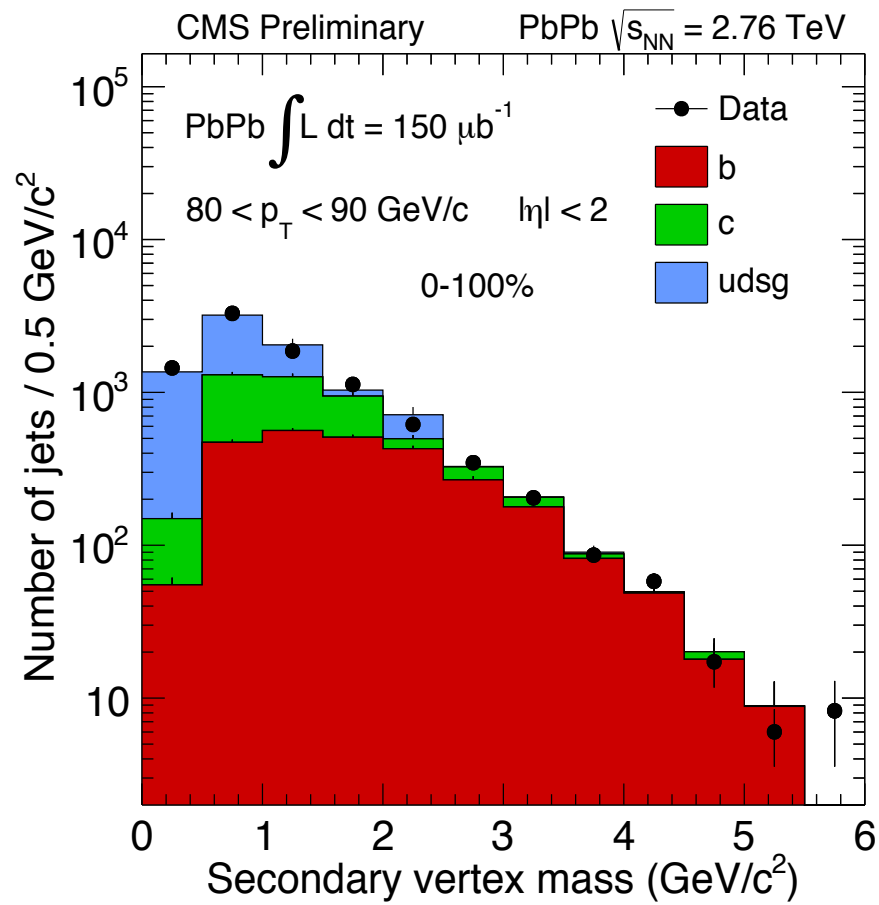
$$\varepsilon_b = \frac{C_b f_b^{btag} N_{jets}^{btag}}{f_b^{untagged} N_{jets}^{untagged}} \quad (1)$$

$$N_{jets}^{btag} = N_{jets}^{total} \frac{f_b}{\varepsilon_b} \quad (2)$$

f_b = purity from template fit
ε_b = efficiency of b-tagger
C_b = Fraction of jets with JP information

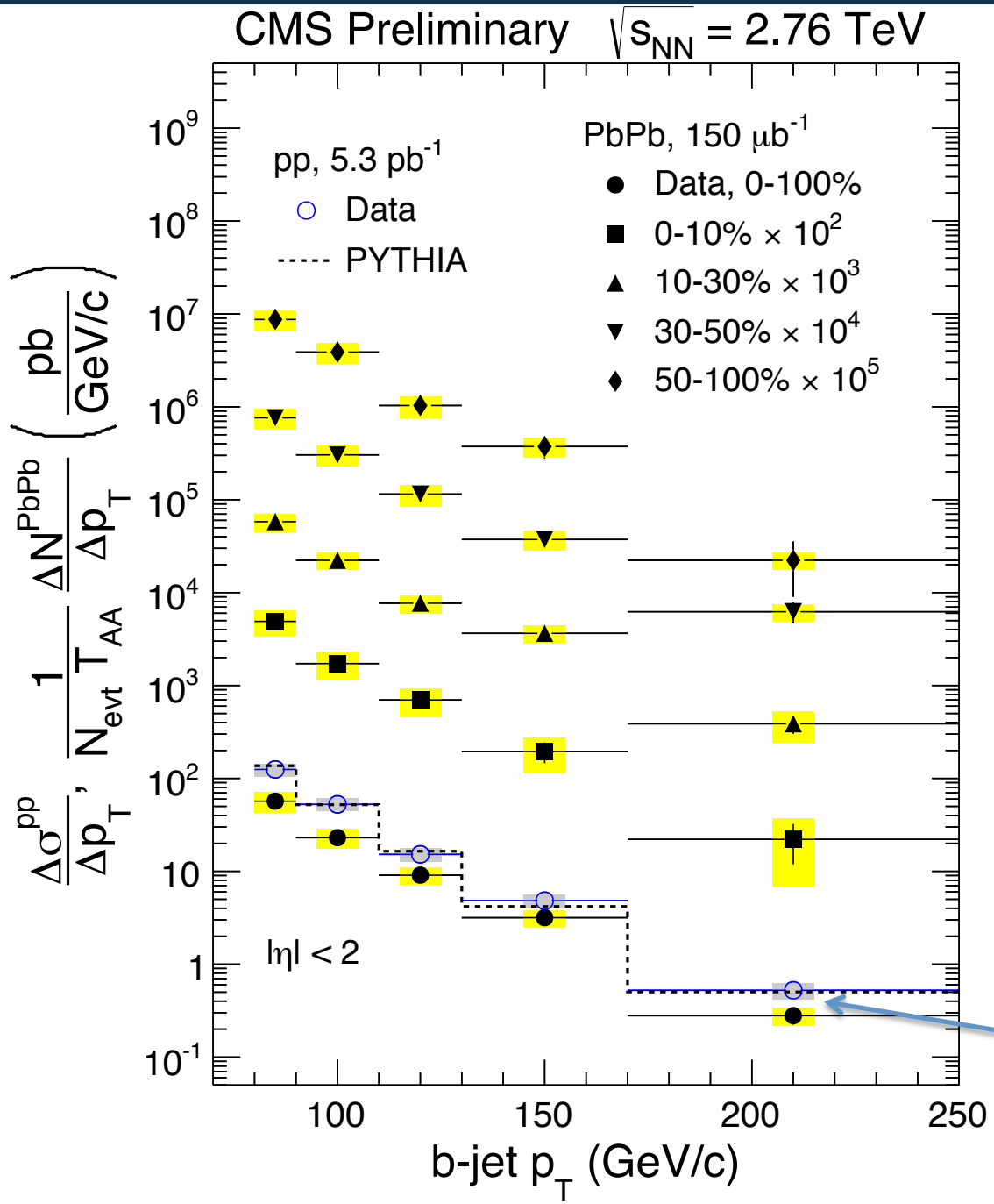
$N^{untagged}$ = Jets that do not pass the tagger
$f_b^{untagged}$ = Purity of anti-tagged jets

- 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 (ε_b) is found via the tagging and anti-tagging purity [eq. 1]



CMS PAS HIN-12-003

PbPb B-Jet Spectra

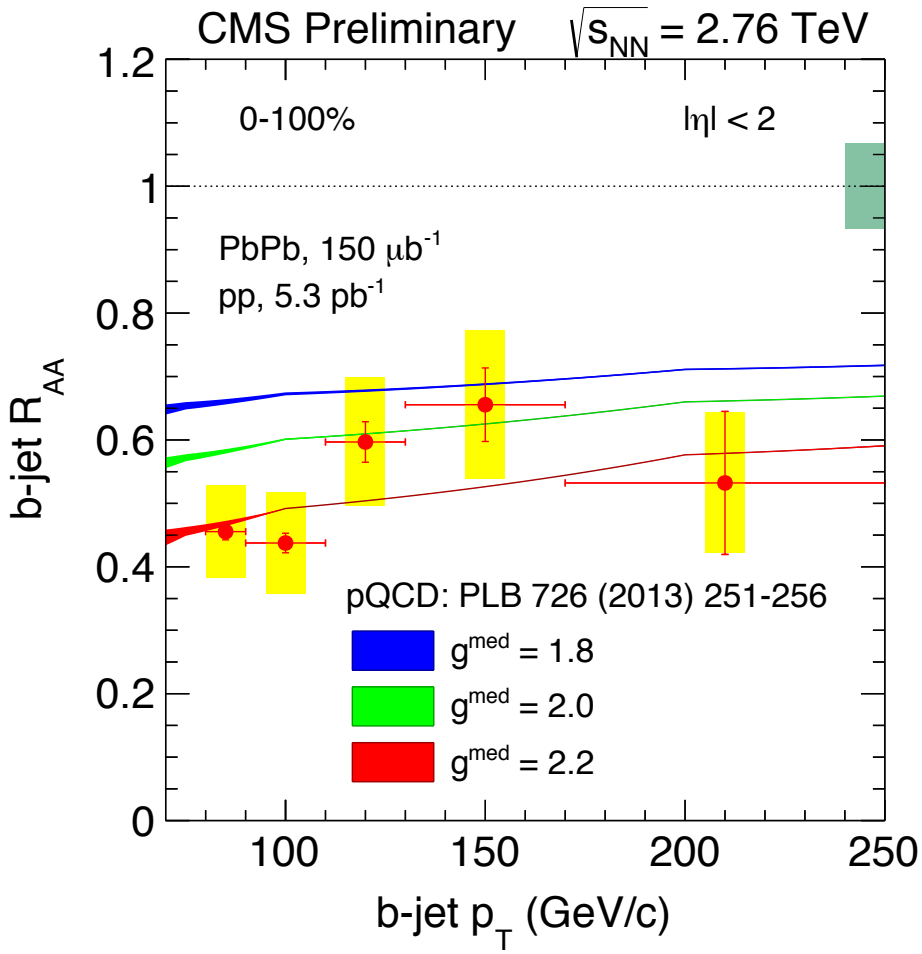


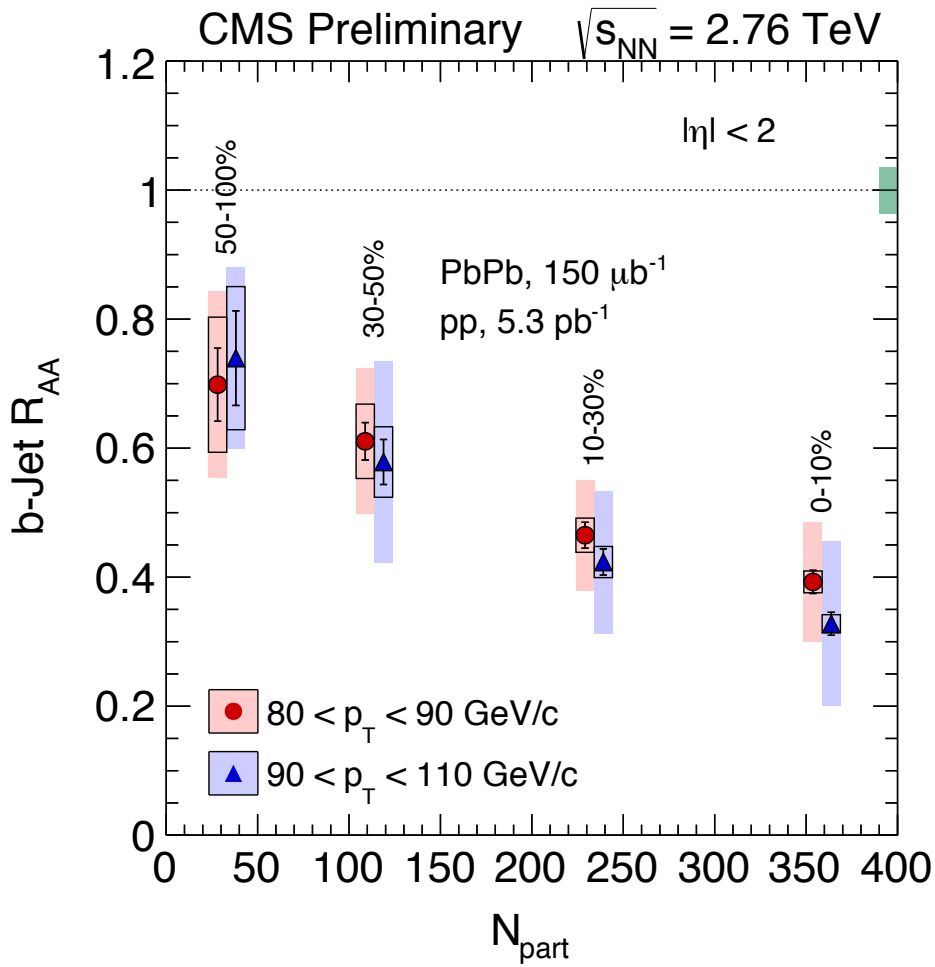
- Fully *corrected* and *unfolded* spectra plotted for both PbPb and pp
- B jets in PbPb scaled by T_{AA} ➔ normalized to pp spectra
- Clear indication of suppression seen

B-jet suppression already indicated from this plot

CMS PAS HIN-12-003

B-Jet R_{AA}

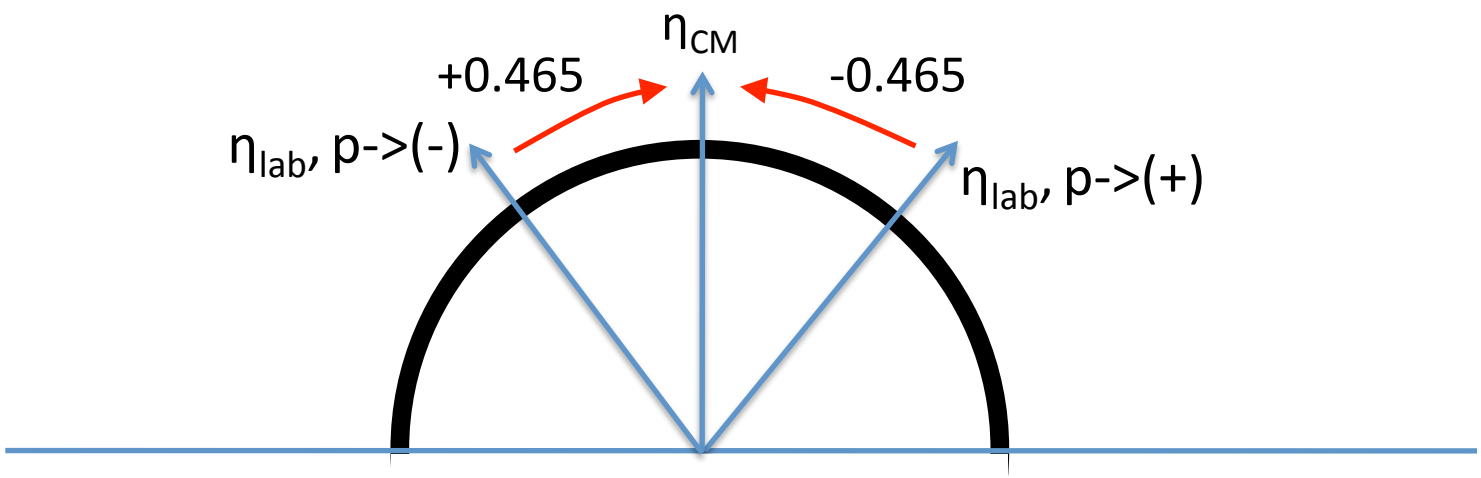




- First measurement of heavy flavor jet R_{AA}
- Clear suppression of b-jets
  - R_{AA} shows clear trend as a function of centrality
- Suppression favors pQCD model with stronger jet-medium coupling

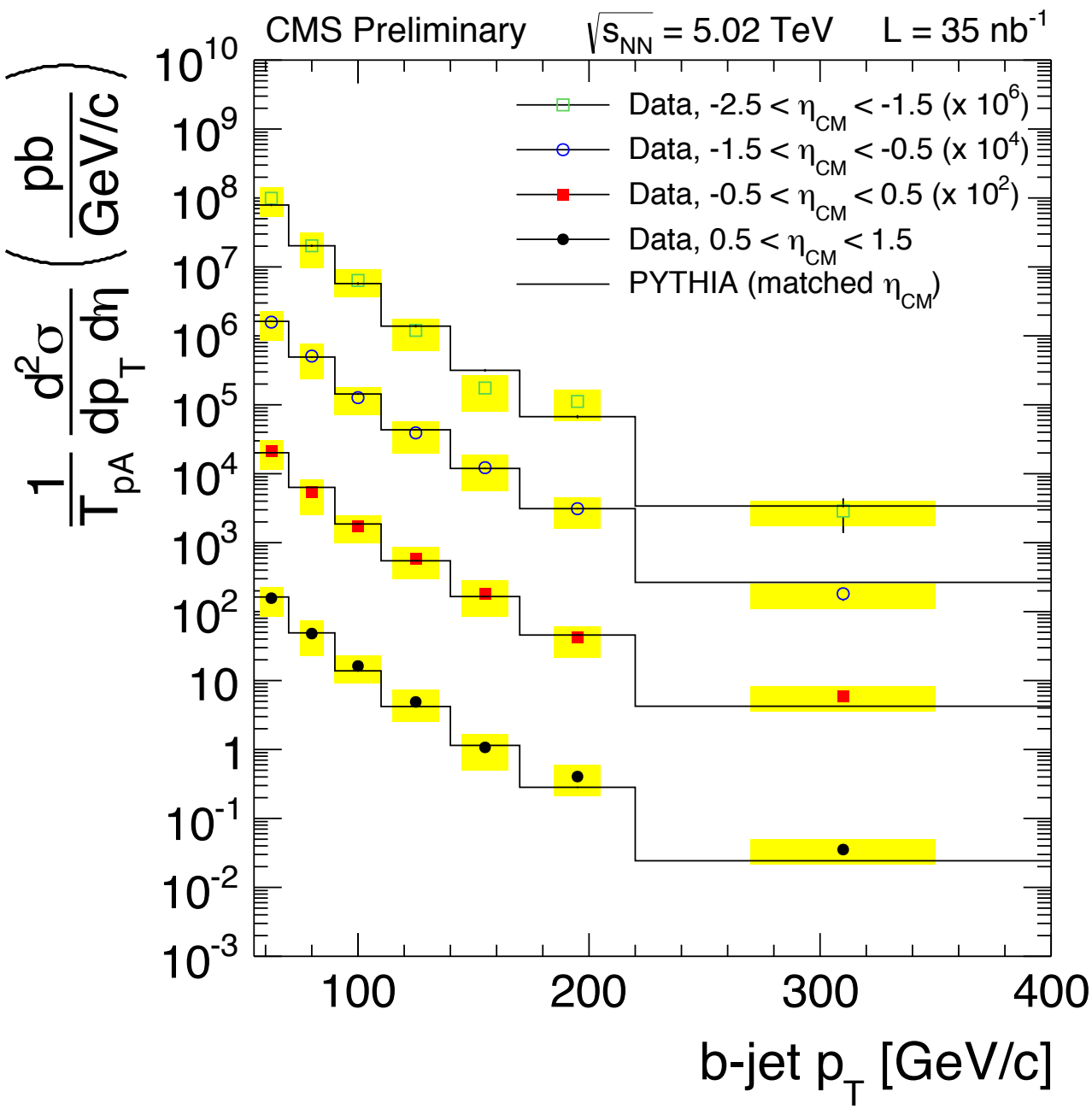
CMS PAS HIN-12-003

"η_{CM}" in pPb



- pPb collisions are natively asymmetric
  - E(proton) = 4 TeV, E(Pb) = 1.58 TeV/N
  - Distributions of jets are centered around ±0.465 units in η
- η distributions are corrected to the center-of-mass eta
- Pbp η distribution is "mirrored" (η -> -η)
  - This ensures consistency when pPb and Pbp results are used together

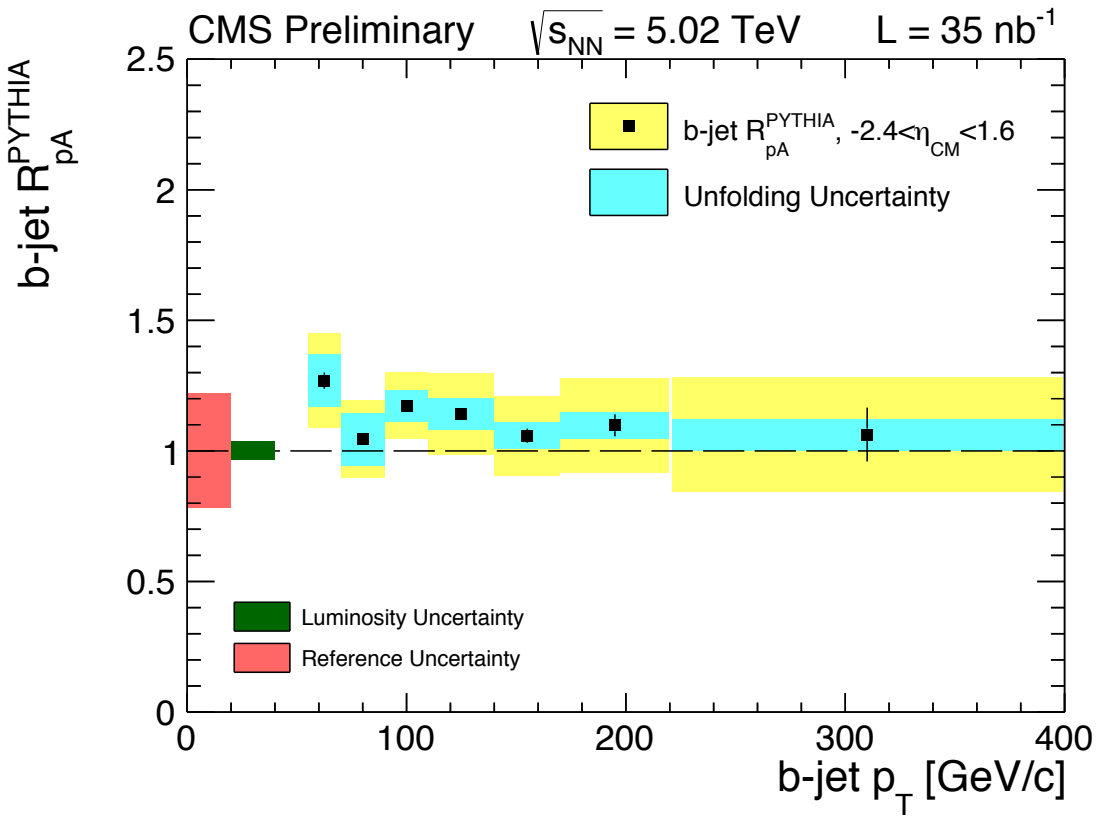
pPb B-jet Spectra

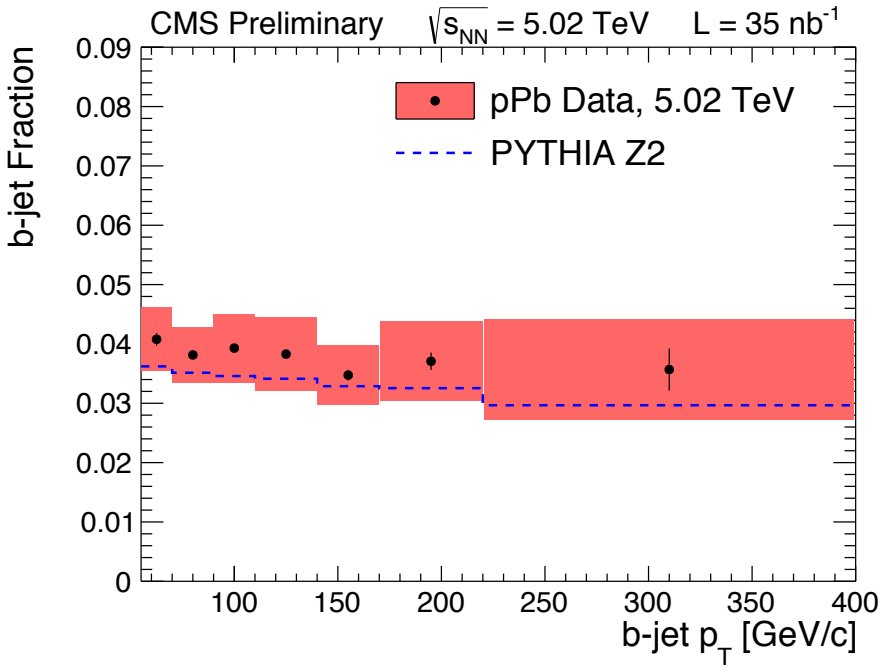


- B-jet spectra shown for various selections in η_{CM}
- Spectra scaled by T_{pA} such that pp & pPb are directly comparable
- Minimal suppression or enhancement is observed

CMS PAS HIN-14-007

B-Jet R_{pA}[PYTHIA]

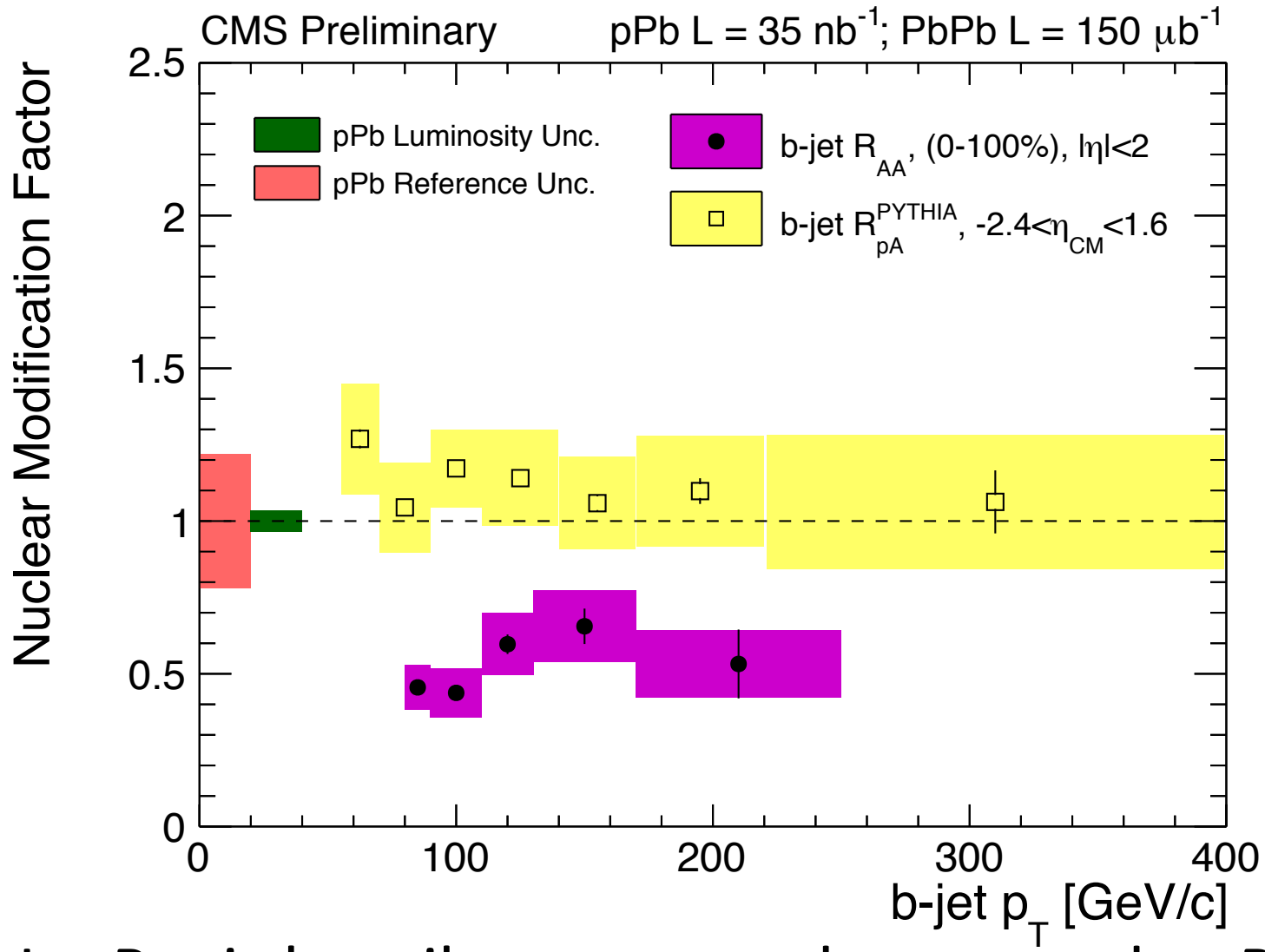




- Result is ***consistent with a small Cronin enhancement*** from *but effects are quite minimal*
- Systematic uncertainties from b-tagging and spectrum unfolding dominate
- pPb b-jet fraction is consistent with PYTHIA at high p_T

CMS PAS HIN-14-007

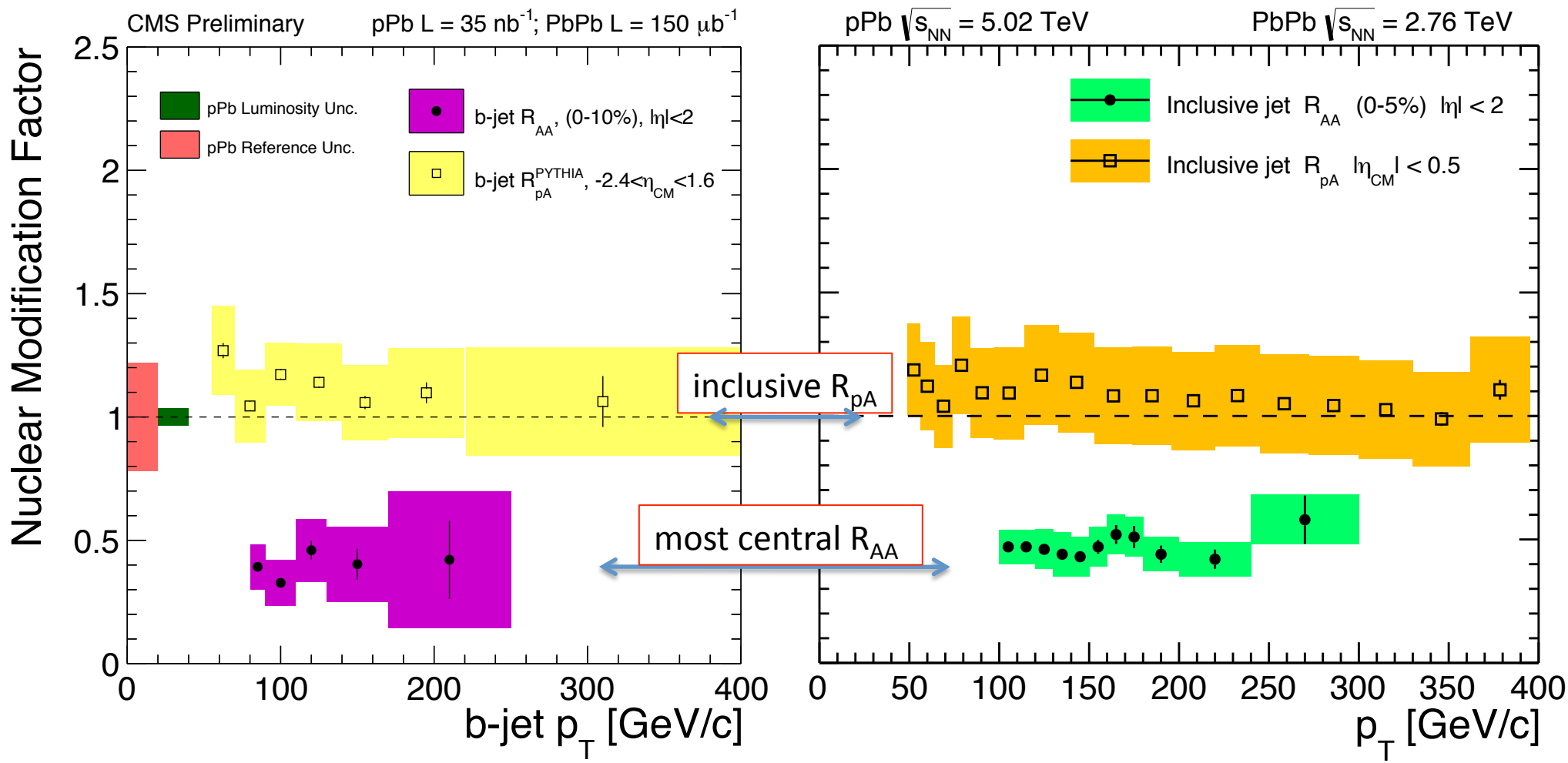
Comparison of b-Jet R_{pA}[PYTHIA] and R_{AA}



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

CMS PAS HIN-12-003 | CMS PAS HIN-14-007

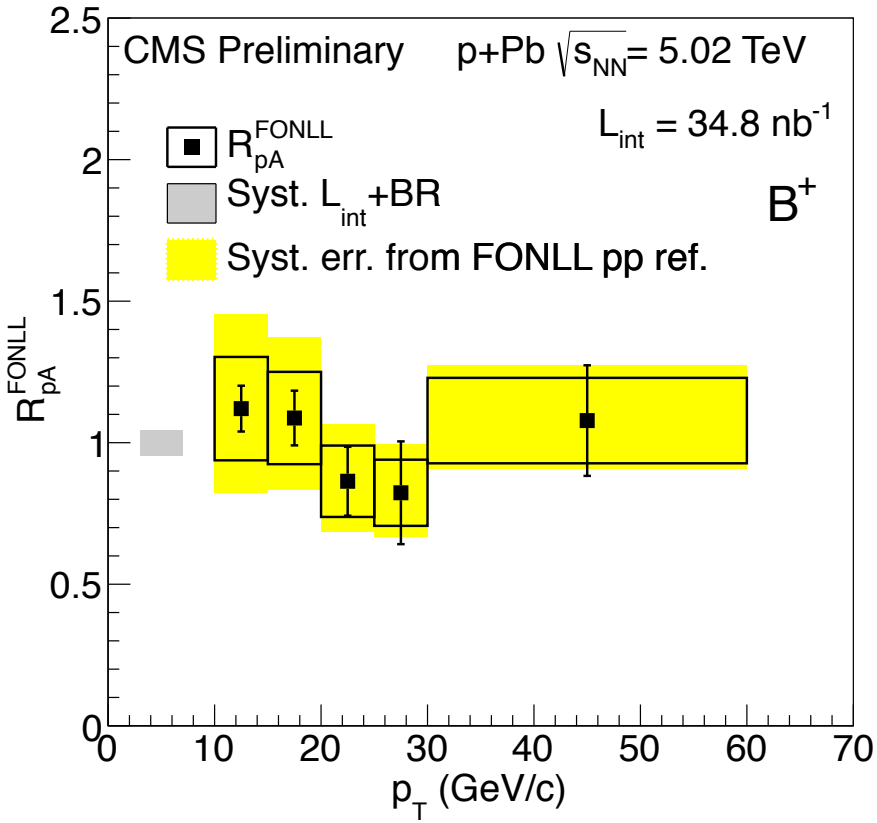
Global Jet Energy Modification

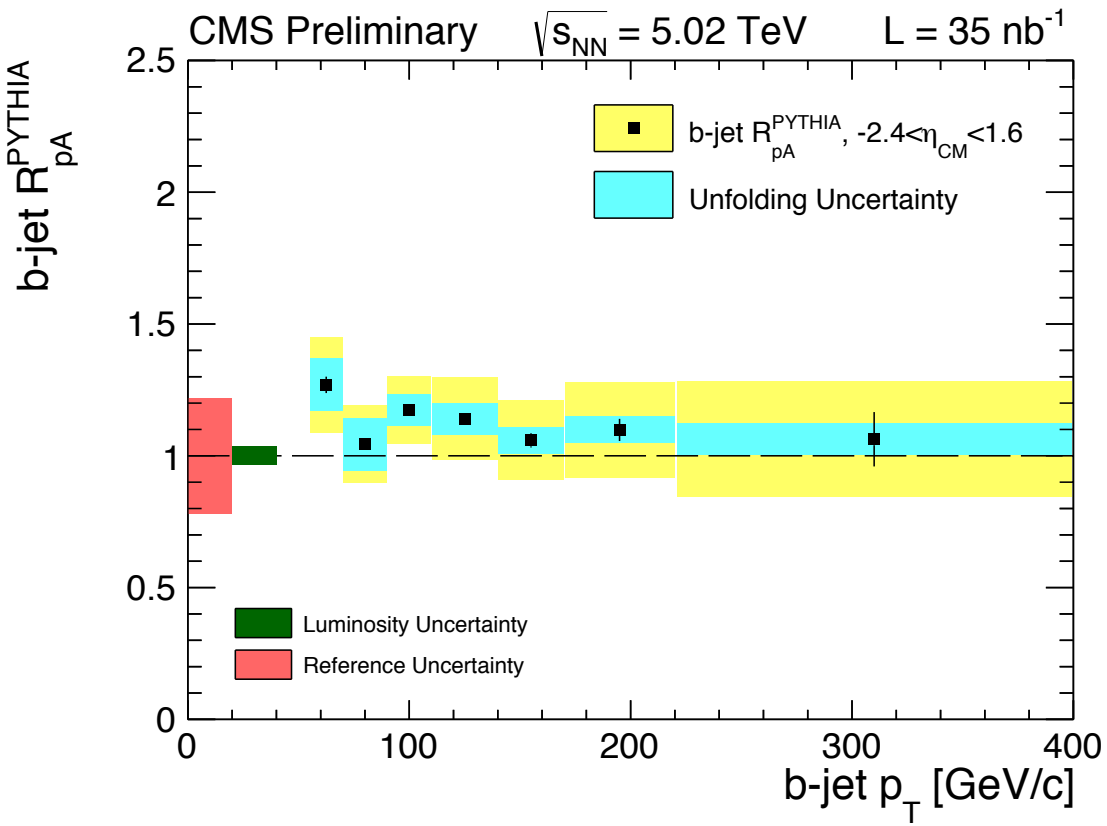


- Dramatic energy loss for jets in PbPb collisions
- Virtually no modification seen in pPb collisions
- ***We observe virtually no modification as a function of jet flavor***

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



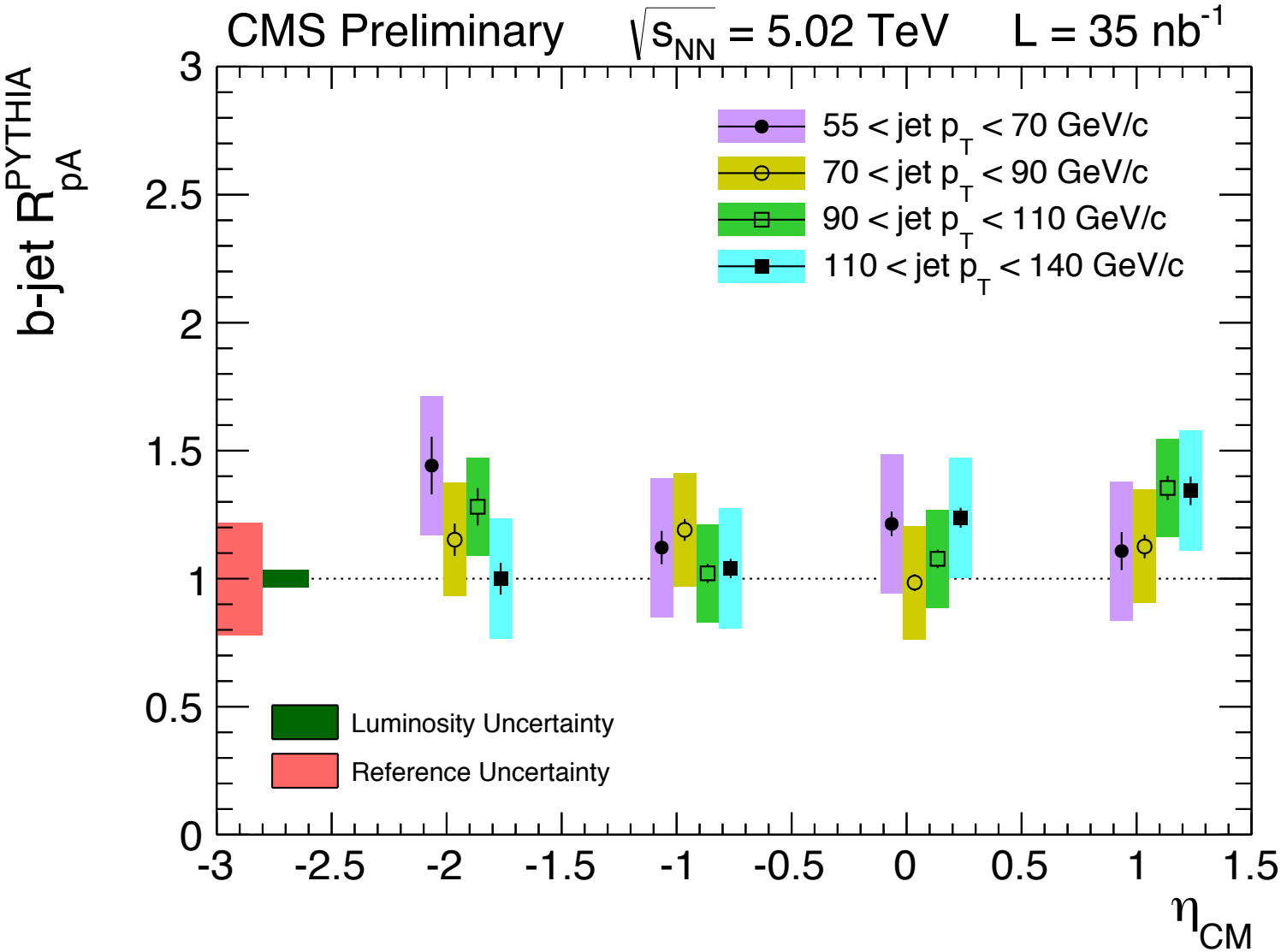


- Measurements in conjunction with B mesons show consistency with over a very wide range in p_T!
- B Mesons in pPb show similar suppression w.r.t. pp simulation as do the b jets

CMS PAS HIN-14-004

CMS PAS HIN-14-007

B-Jet R_{pA}[PYTHIA] vs Pseudorapidity



- η-dependent jet production is generally a result of nPDF effects, due to η/bjorken-x correlations
- Plotting R_{pA}(PYTHIA) vs η shows no such trend

CMS PAS HIN-14-007

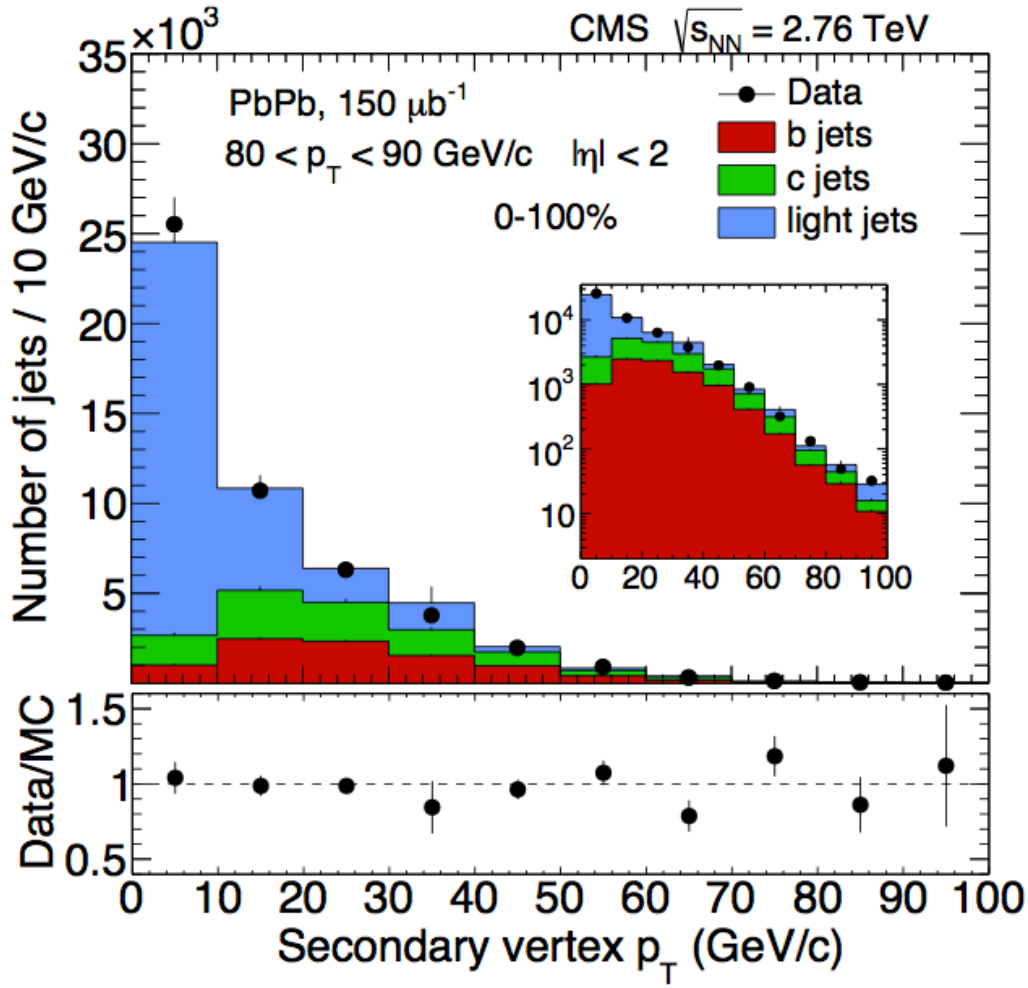
Summary

- 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

BACKUP SLIDES

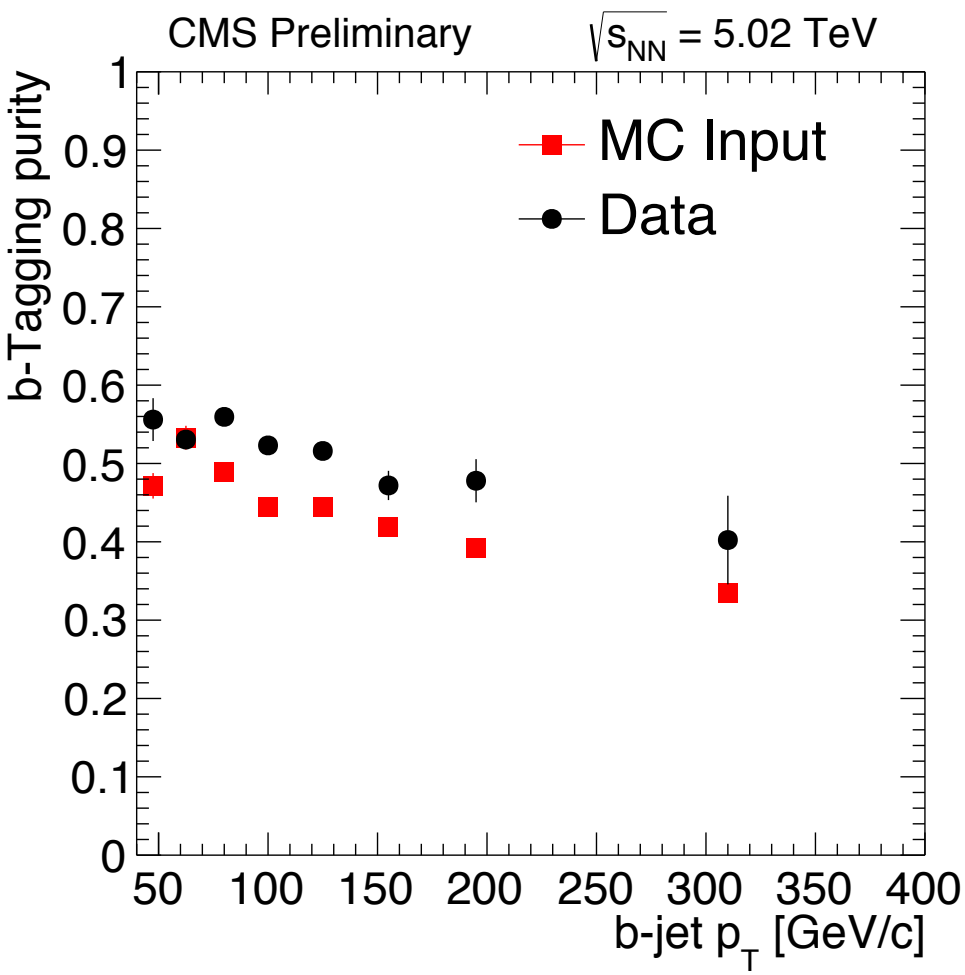
Secondary Vertex pT Fittings

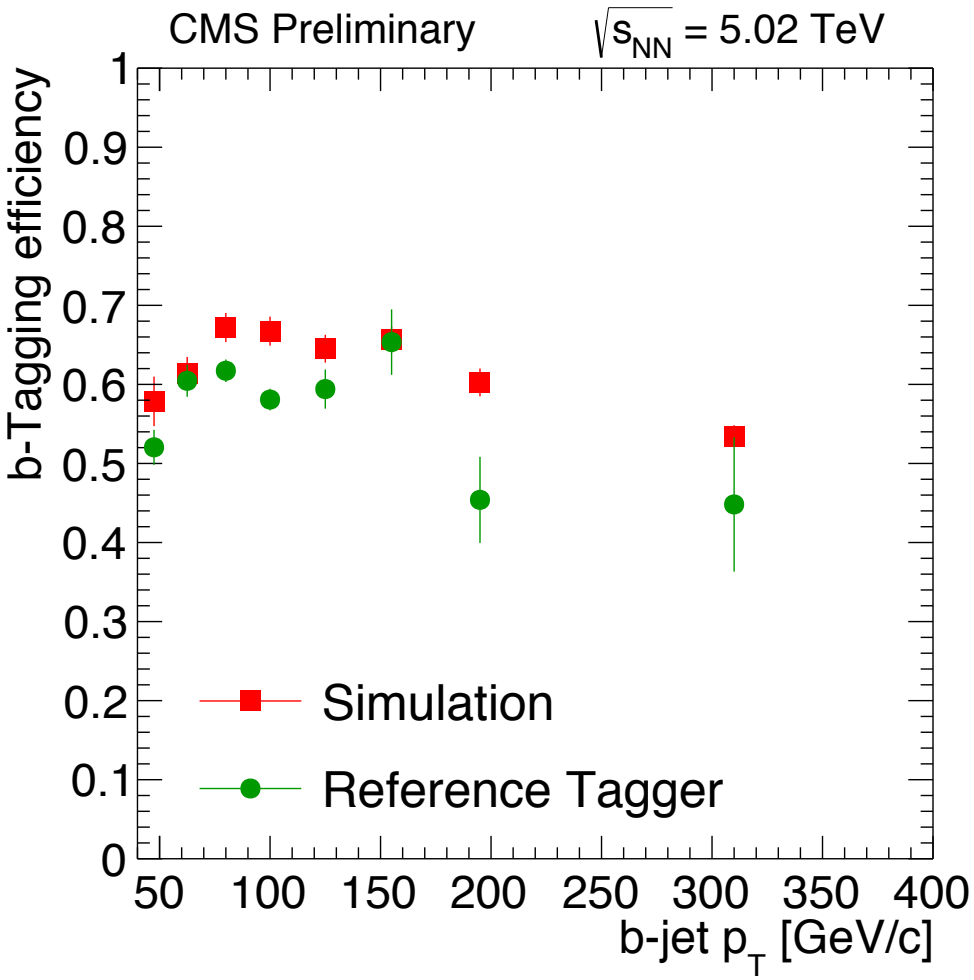
CMS PAS HIN-12-003



- A distortion in the secondary vertex pT spectrum would indicate suppression dependence between gluon and quark jets
  - This is not observed as the SV pT spectrum in data

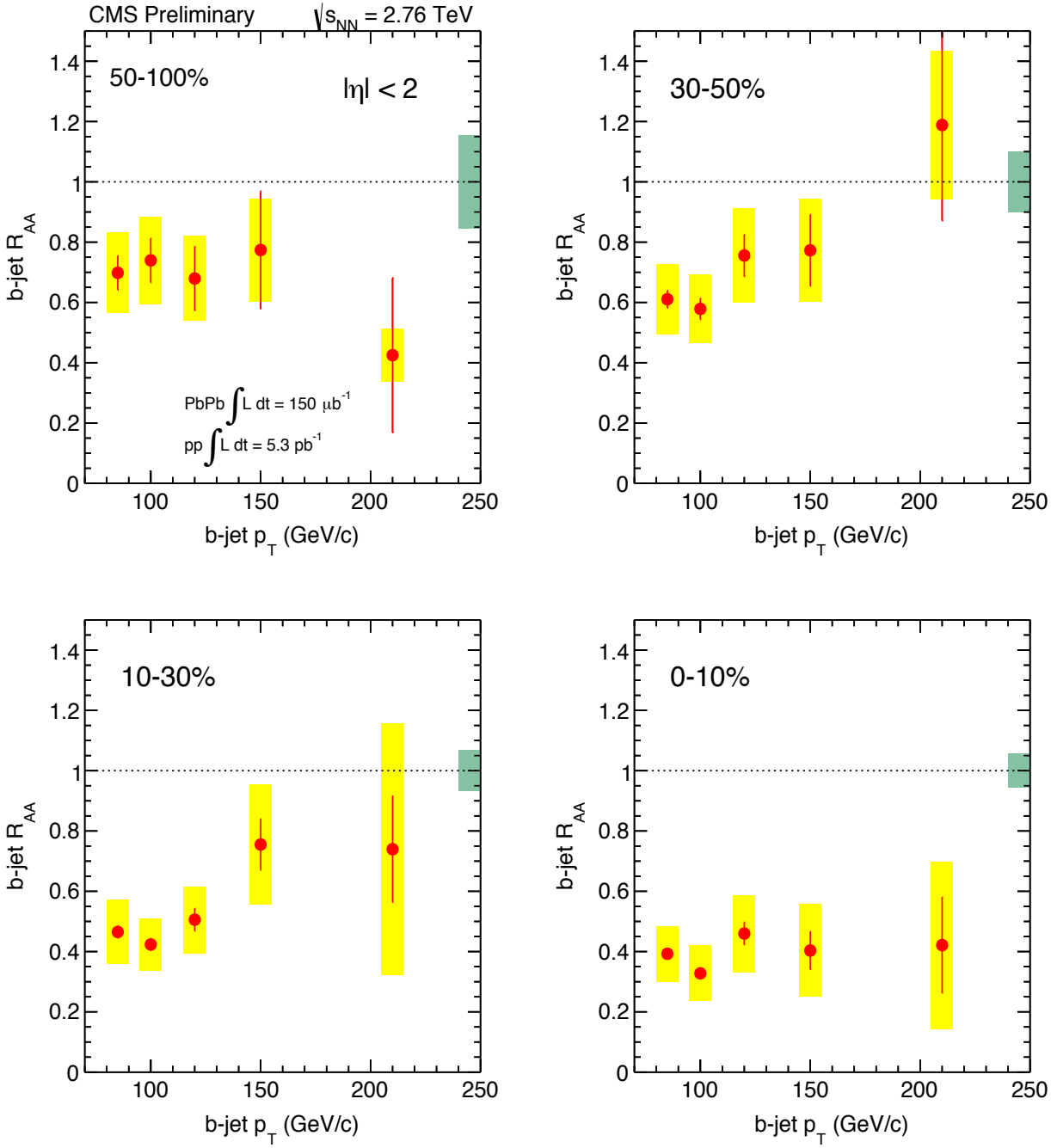
Efficiency and Purity of b-Tagging





- 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

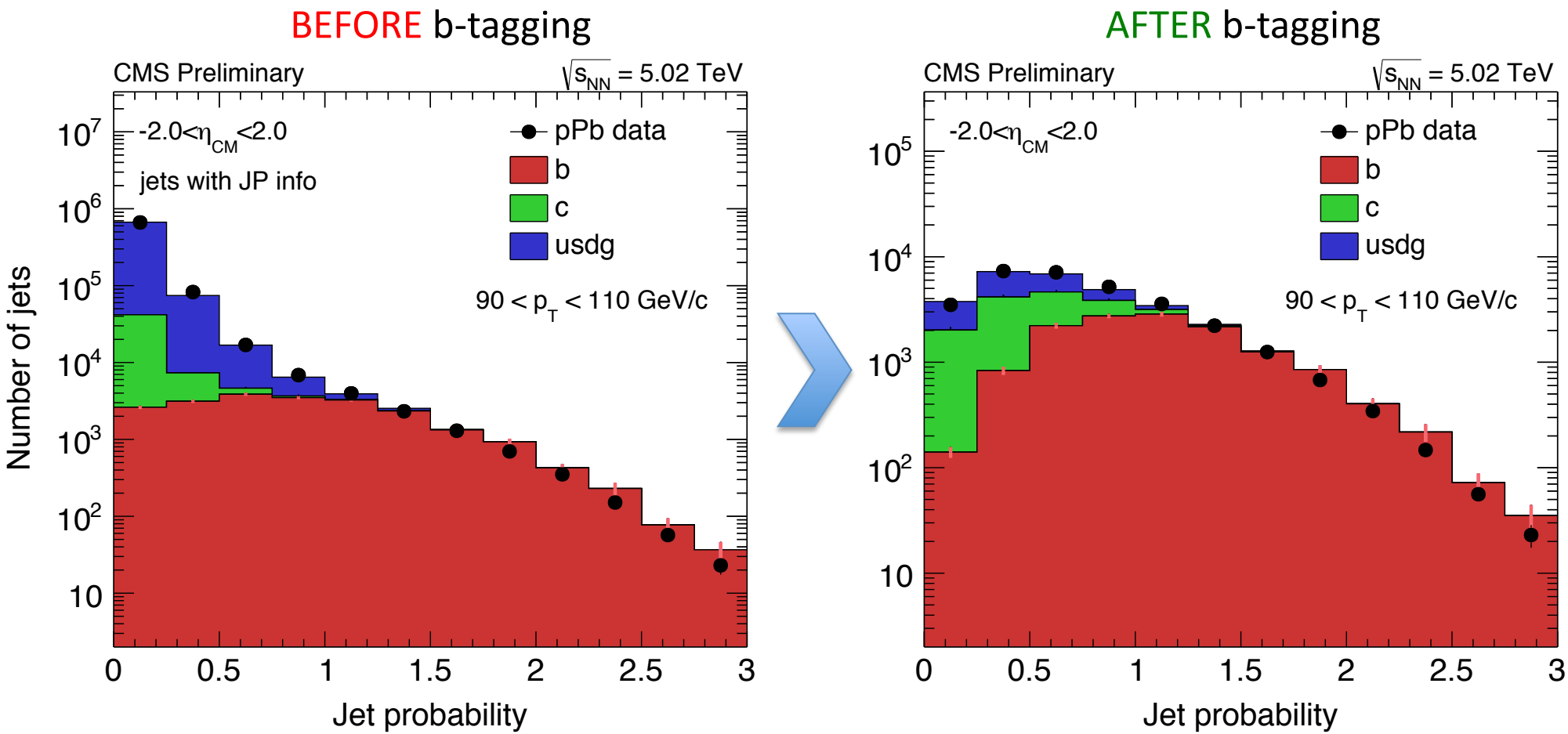
B-jet R_{AA} (centrality)



- R_{AA} is closest to unity for the peripheral collisions and shows increasing suppression with increasing centrality

CMS PAS HIN-12-003

Additional Fits to JP Tagger

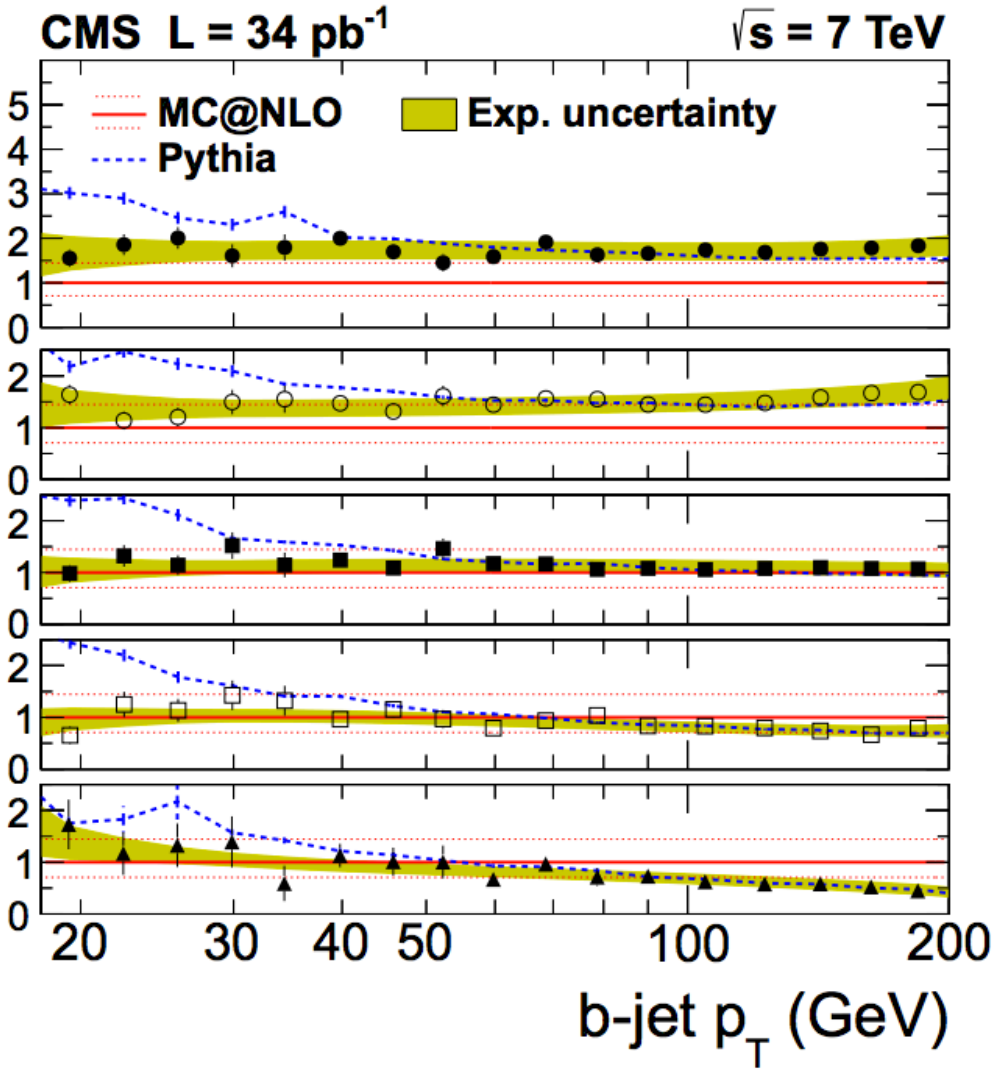


- Before tagging, b-fraction is approx. 3%
- After tagging, b-fraction is approx. 50%

b-jet Production at the LHC

- 2011 PbPb Run: 150 μb^{-1} integrated lumi
- Corresponding # of b-jets is ~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 ~ $0.5^2 = 0.25$
  - LO flavor creation mode only contributes ~ 15%
- LESS THAN 1000 tagged di-b-jets (leading jet p_T > 80 GeV/c)

b jet pp Reference at 5 TeV



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

JHEP 04 (2012) 084
arXiv: 1202.4617

- 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