Beauty measurements with CMS in PbPb and pp @ 2.76TeV

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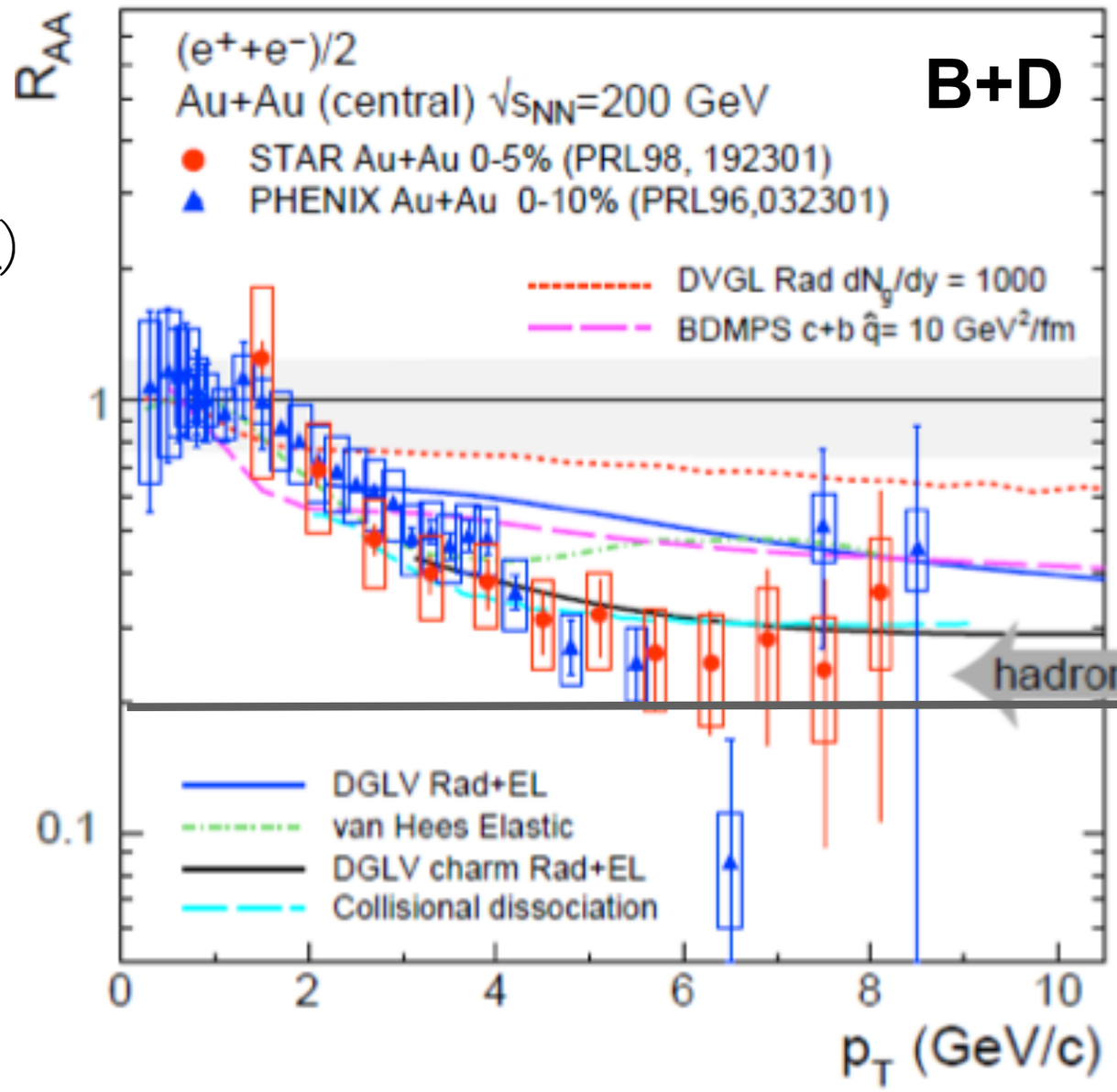
Etretat

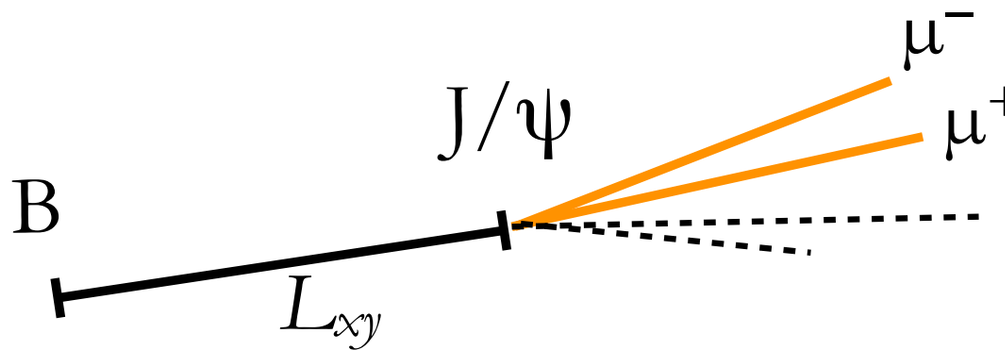
Open heavy-flavor in heavy-ion collisions

- **Theoretically**:
  - ➡ radiative (and collisional) energy loss
  - ➡ $R_{AA}^{light} < R_{AA}^{D} < R_{AA}^{B}$

- **Experimentally** at RHIC (AuAu@0.2TeV)
  - ➡ non-photonic electrons
    - low-p_T: $R_{AA}^{light} < R_{AA}^{e(D+B)}$
    - high-p_T: $R_{AA}^{light} \sim R_{AA}^{e(D+B)}$

- **Essential:**
  - ➡ separate charm from bottom:
    - 2011: ALICE: D, CMS: B→J/ψ
  - ➡ look at low-p_T and high-p_T
    - 2012: CMS: B→J/ψ, CMS: B-jets



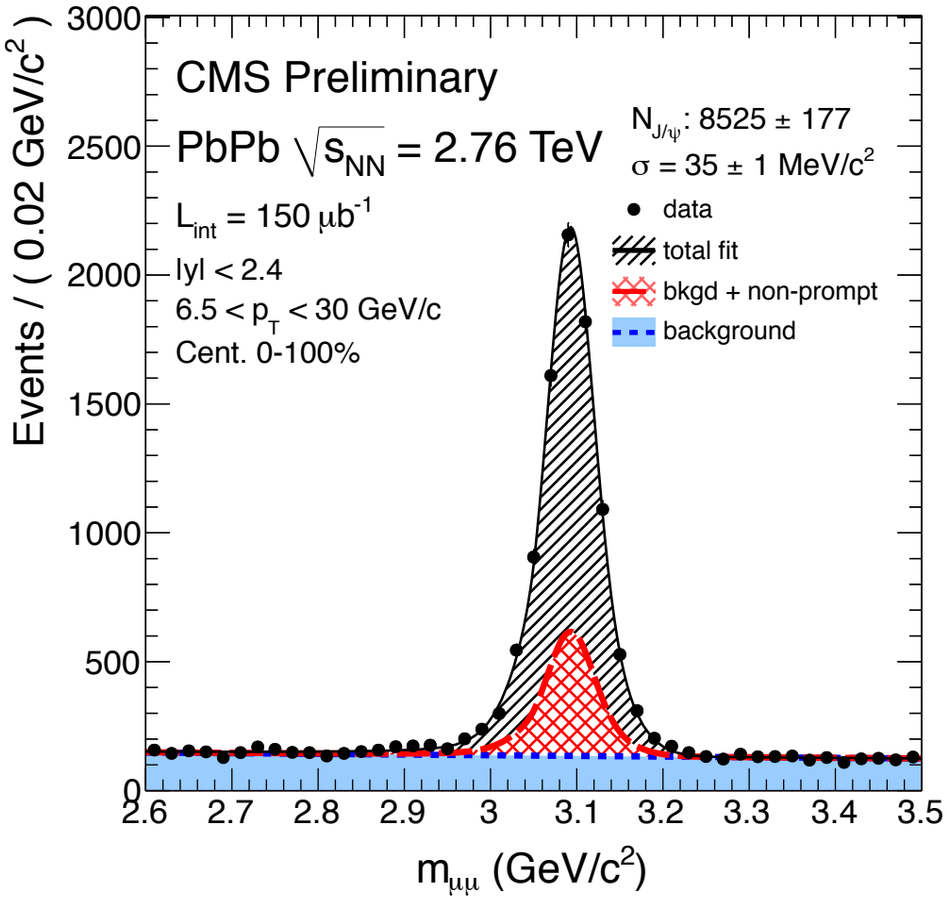


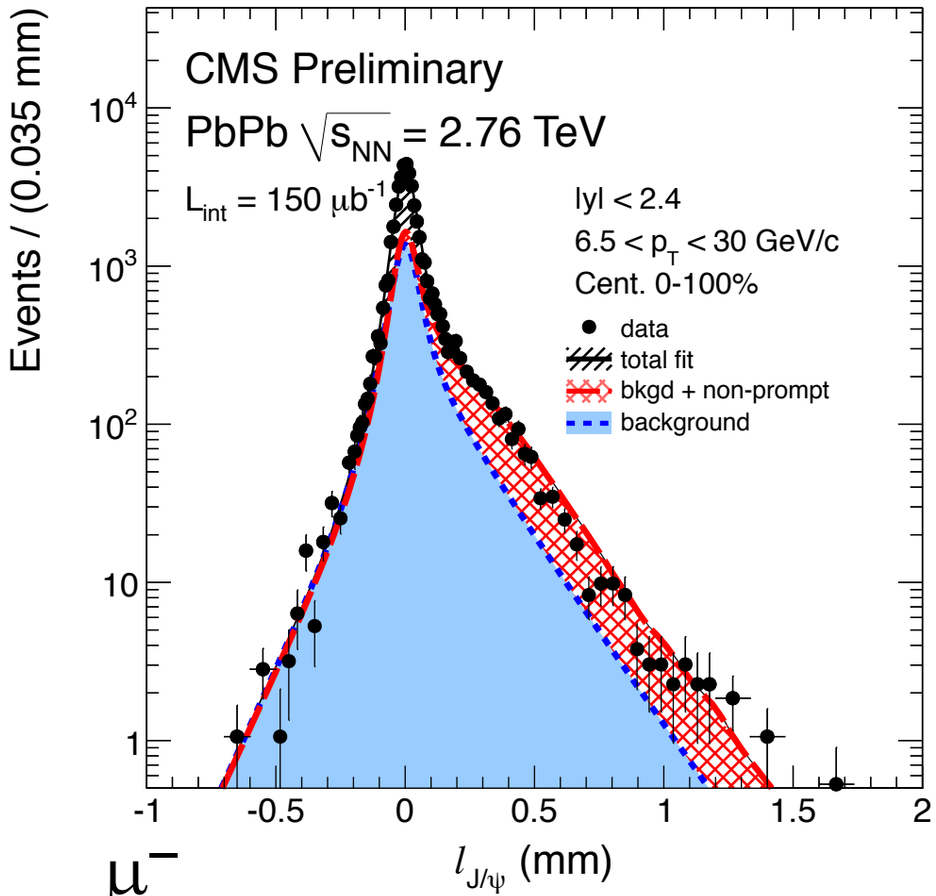
Low-p_T B: $p_T < 30$GeV/c

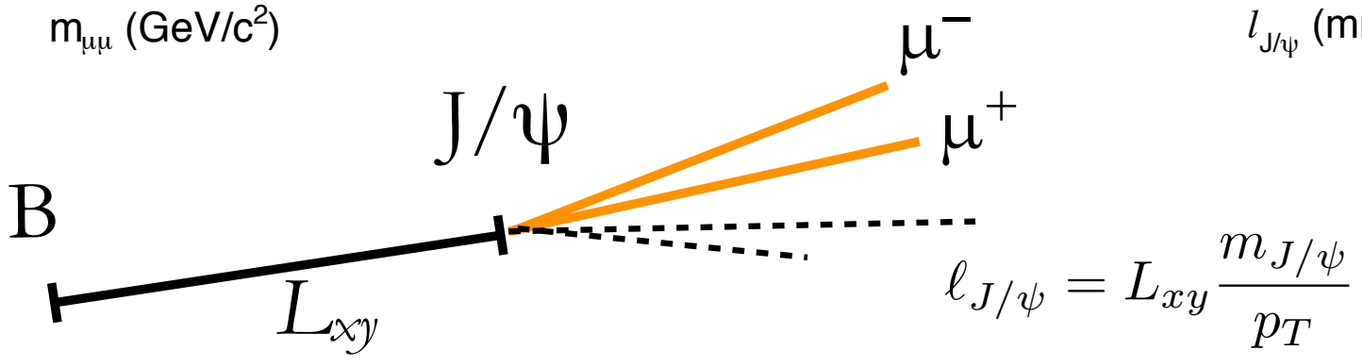
$B \to J/\psi \to \mu\mu$: R_{AA} vs p_T, y and centrality

$B \rightarrow J/\psi \rightarrow \mu\mu$

CMS-PAS HIN-12-014



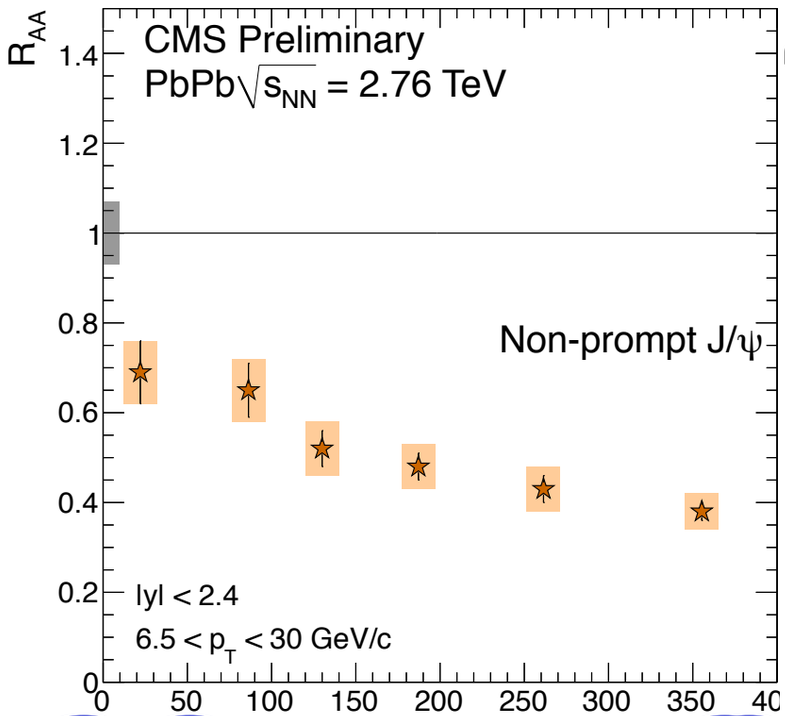


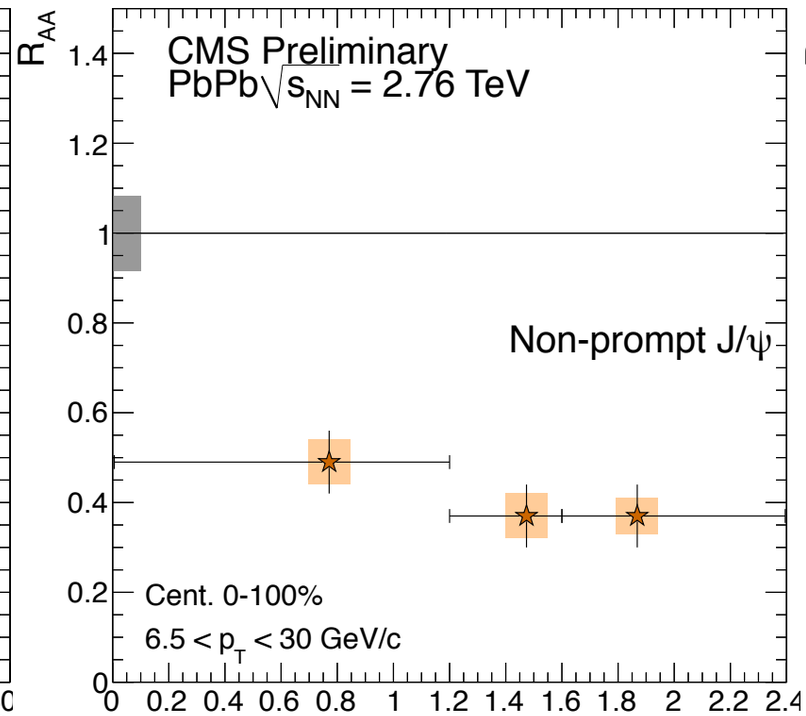


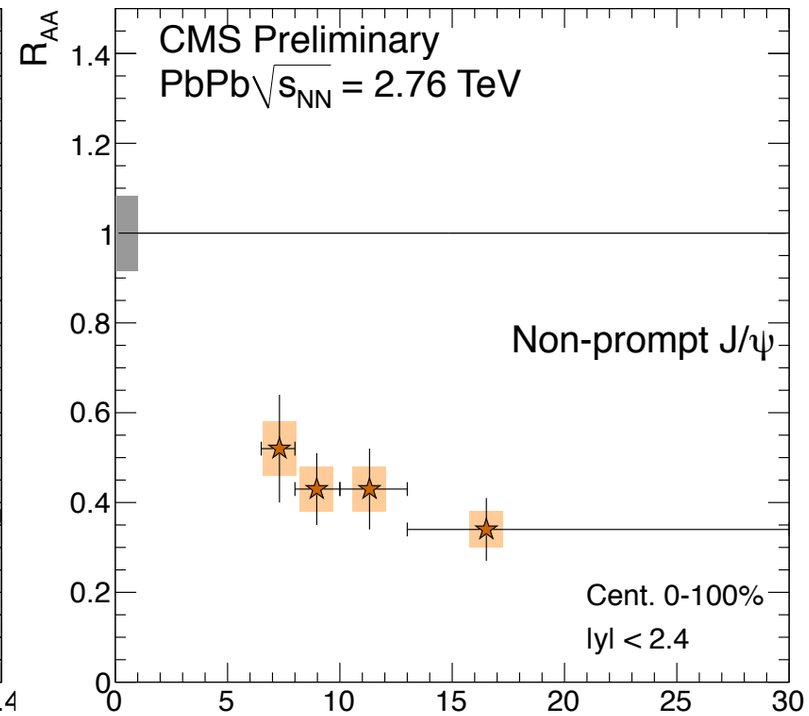
- Same procedure in both pp and PbPb:
  - ➡ Reconstruct the $\mu^+\mu^-$ secondary vertex
  - ➡ 2D fit of invariant mass and $l_{J/\psi}$ → b-fraction in each p_T, y, centrality bin→ yield

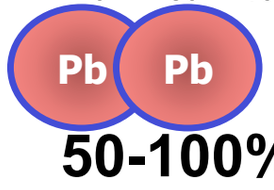
$b \rightarrow B \rightarrow J/\psi \rightarrow \mu\mu$ R_{AA}

CMS-PAS HIN-12-014









Centrality

50-100%

0-10%

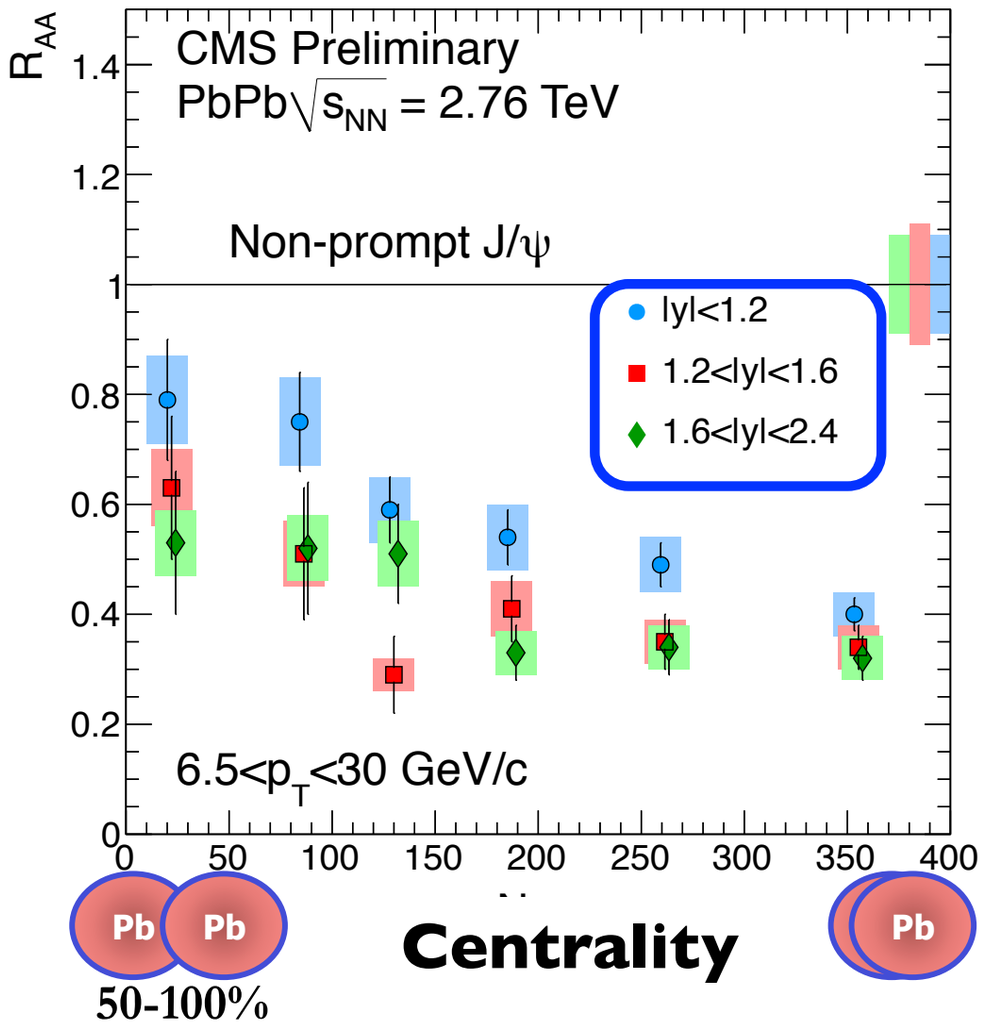
$|y^{J/\psi}|$

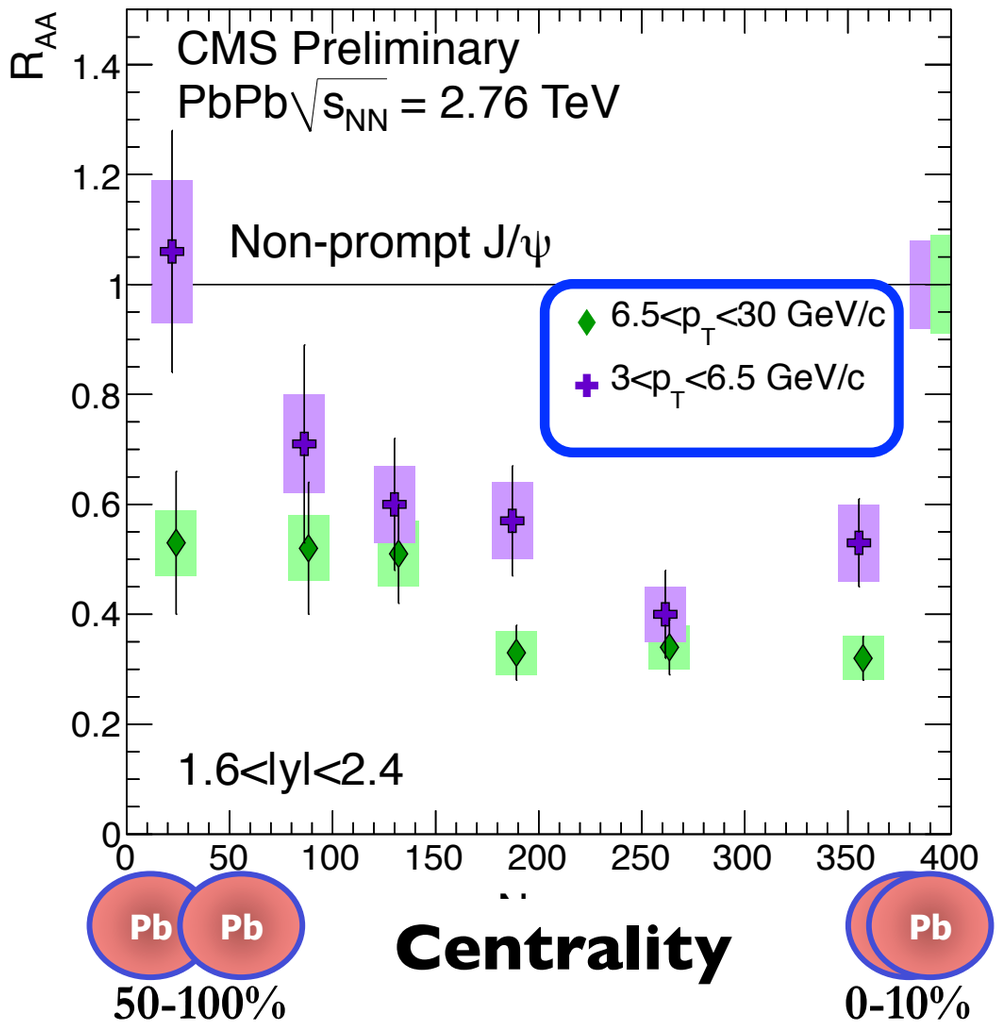
$p_T^{J/\psi}$ [GeV/c]

- **Centrality** (p_T, y integrated): slow decrease of suppression
  - ➡ 50-100%: factor ~1.4
  - ➡ 0-10%: factor 2.5
- **y** (p_T, centrality integrated):
  - ➡ hints of less suppression at mid-rapidity (surprising: not seen for other particles)
- **p_T** (y, centrality integrated):
  - ➡ hints of increasing suppression at high-p_T

$b \rightarrow B \rightarrow J/\psi \rightarrow \mu\mu$ R_{AA}

CMS-PAS HIN-12-014

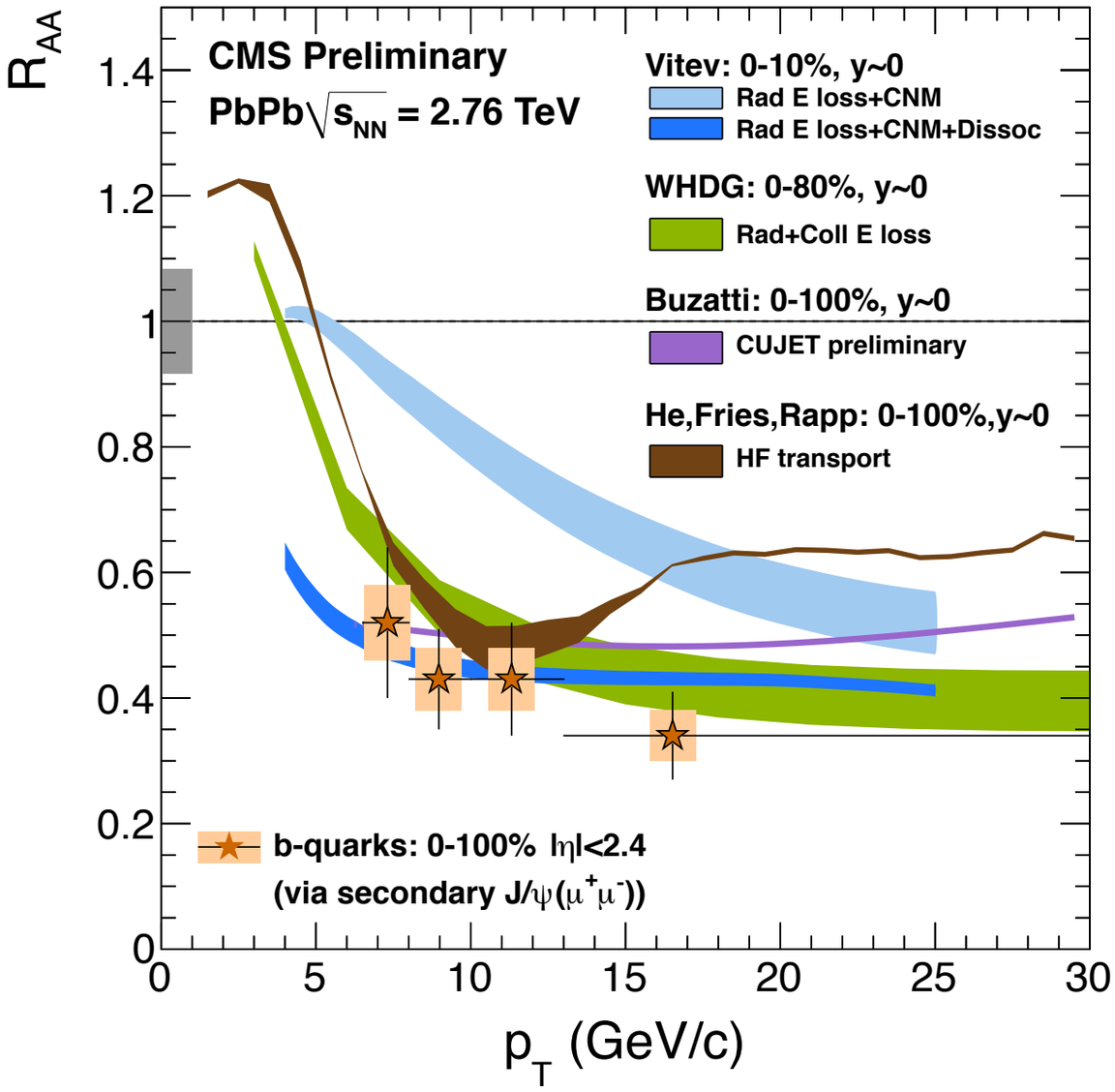




- **high-p_T: 6.5< p_T < 30GeV/c**
  - ➡ hints of less suppression at mid-rapidity
- **forward: 1.6< | y | <2.4**
  - ➡ hints of less suppression at lower-p_T

b energy loss --- Theory

CMS-PAS HIN-12-014

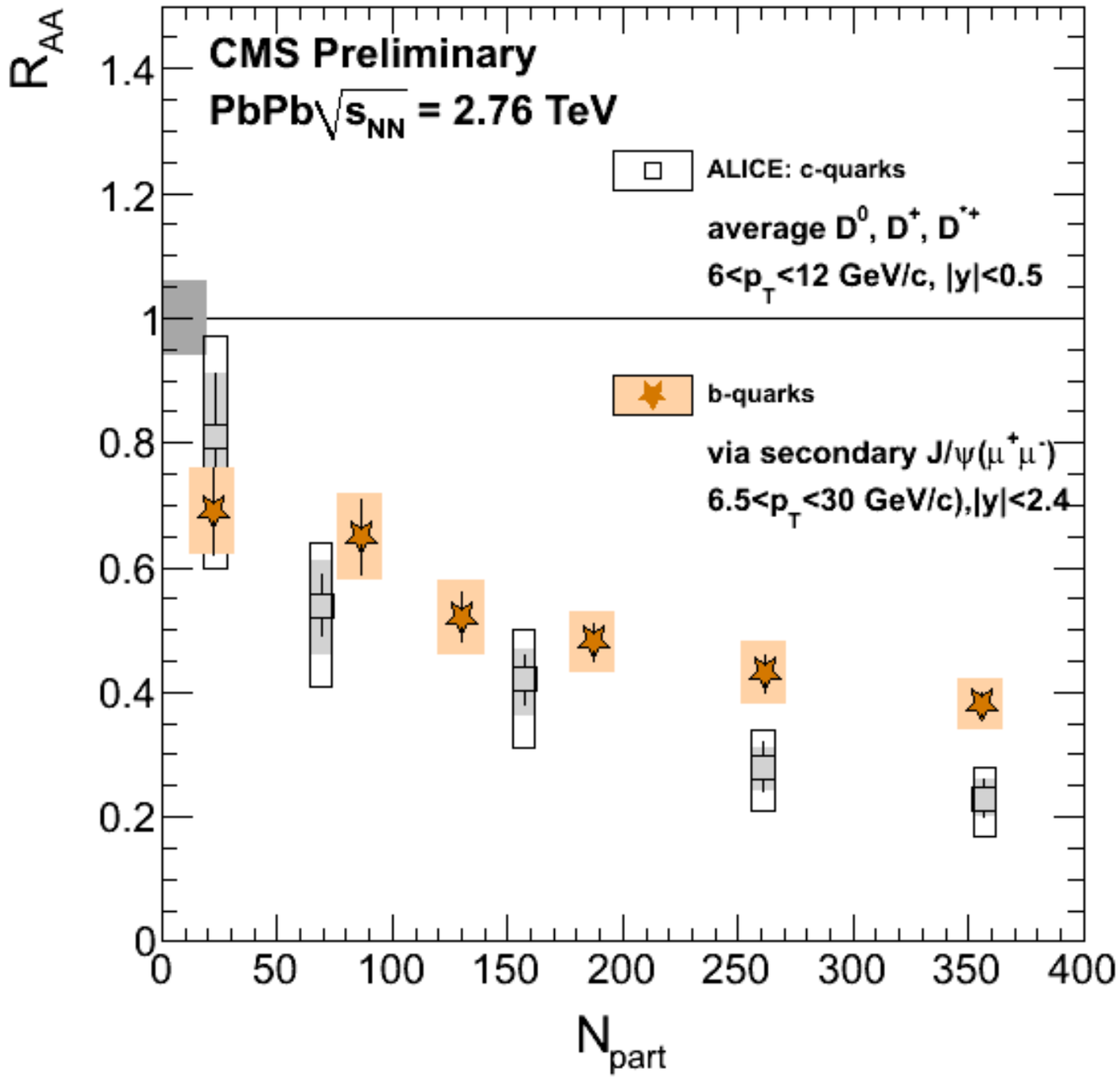


Vitev:
J. Phys.G35 (2008) 104011 + private communications
Horowitz:
arXiv:1108.5876 + private communications
Buzzatti, Gyulassy:
arXiv: 1207.6020+ private communications
He, Fries, Rapp:
PRC86(2012)014903+ private communications

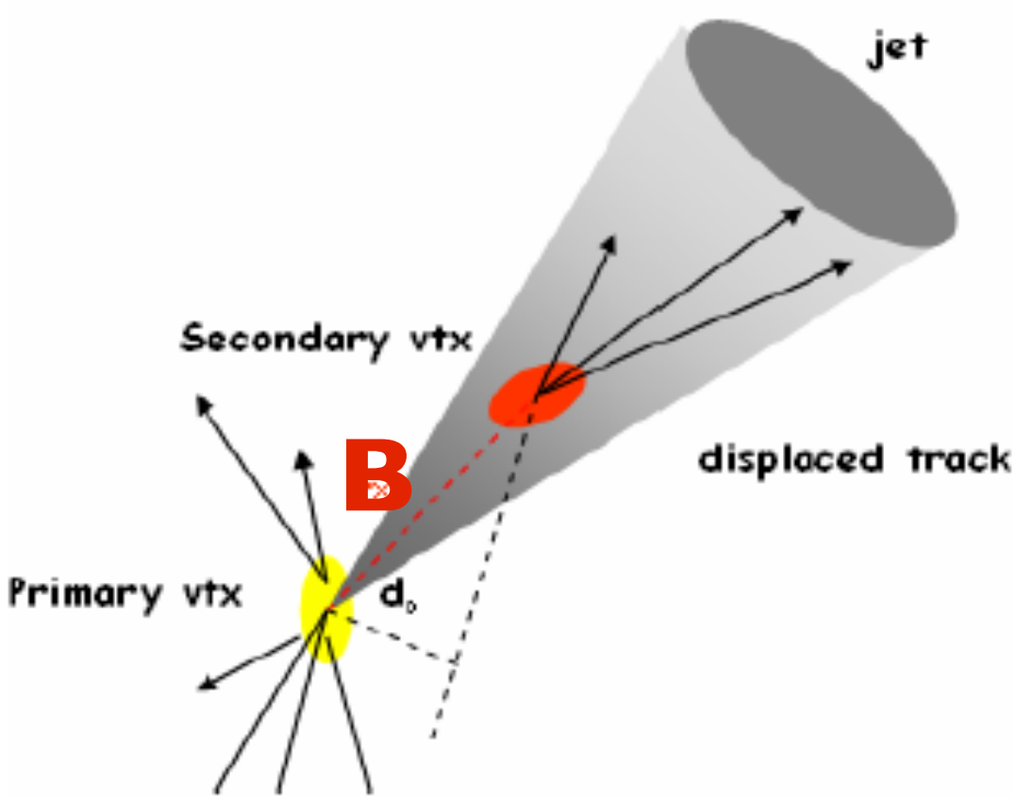
Note:
all calculations provided for p_T of B not J/ψ

- Many models, different inputs and approaches... But ...
- Radiative energy loss NOT enough to describe the B-en loss

Beauty(ful) CMS and Charm(ing) ALICE



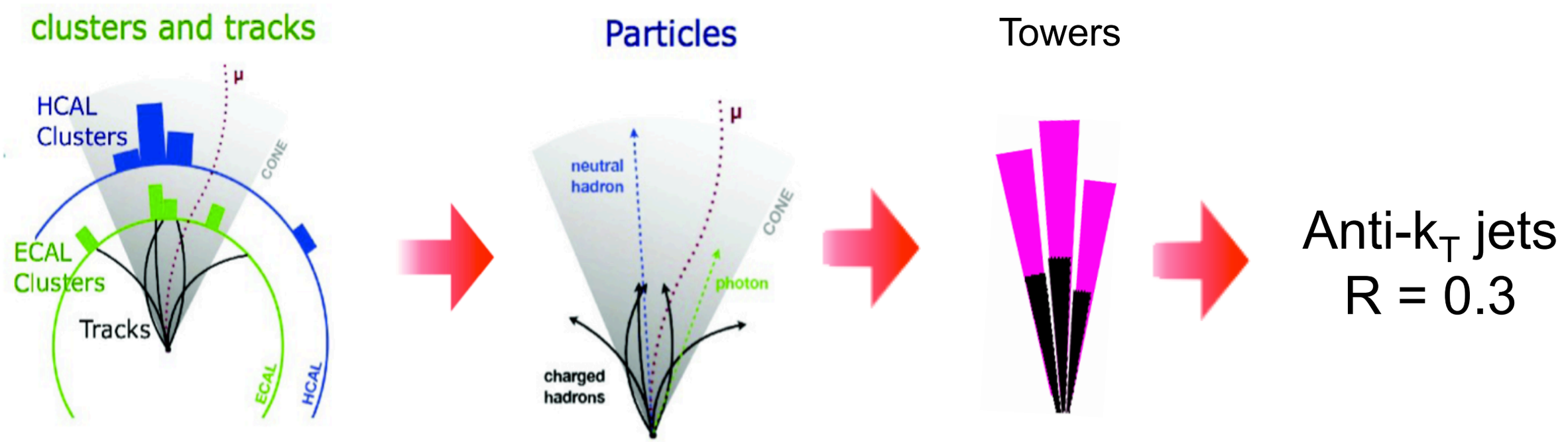
- In central PbPb collisions, there are Law&Order: $R_{AA}^{charm} < R_{AA}^{beauty}$



High-p_T B: $p_T > 80$GeV/c

B-tagged jets: b-jet fraction (and b-jet R_{AA})

Jet reconstruction



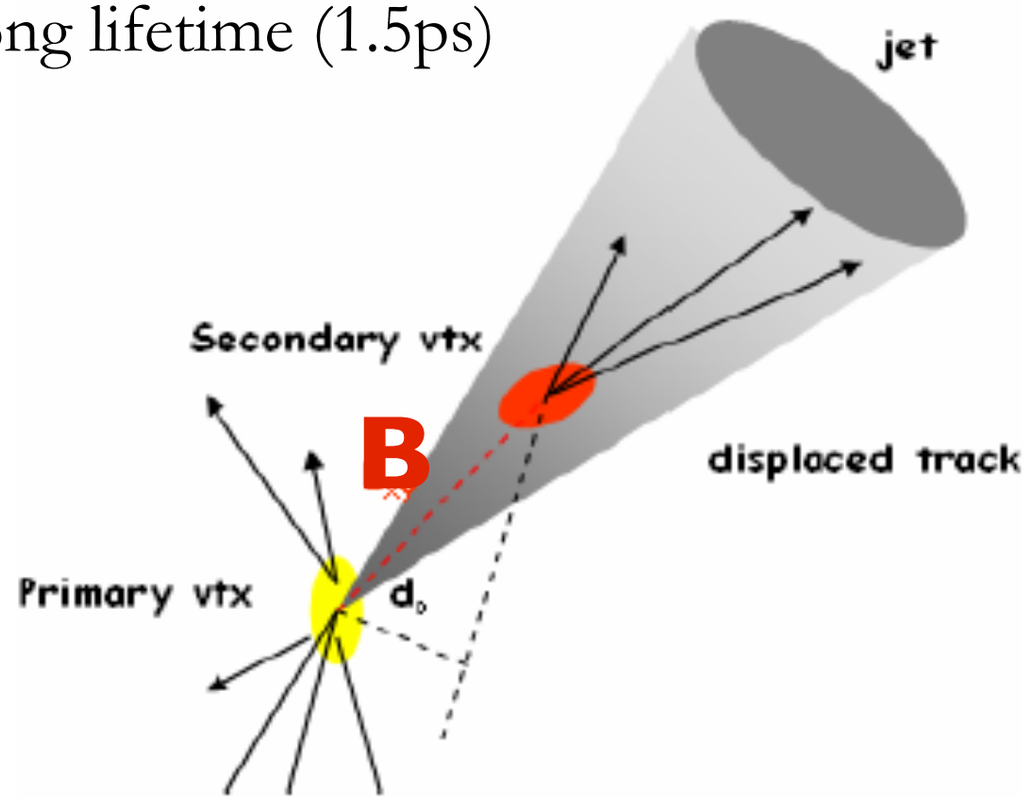
- Info from all sub-detectors combined into 'particle candidates' -> 'Particle flow'
  - ➡ allows to exploit the excellent resolution of the tracker for the charged hadron component of the jet
  - ➡ includes full treatment of electrons and muons inside the jet

- Particle candidates are combined into towers in order to subtract the HI background

b-tagging

CMS-HIN-12-003
CMS-BTV-11-004

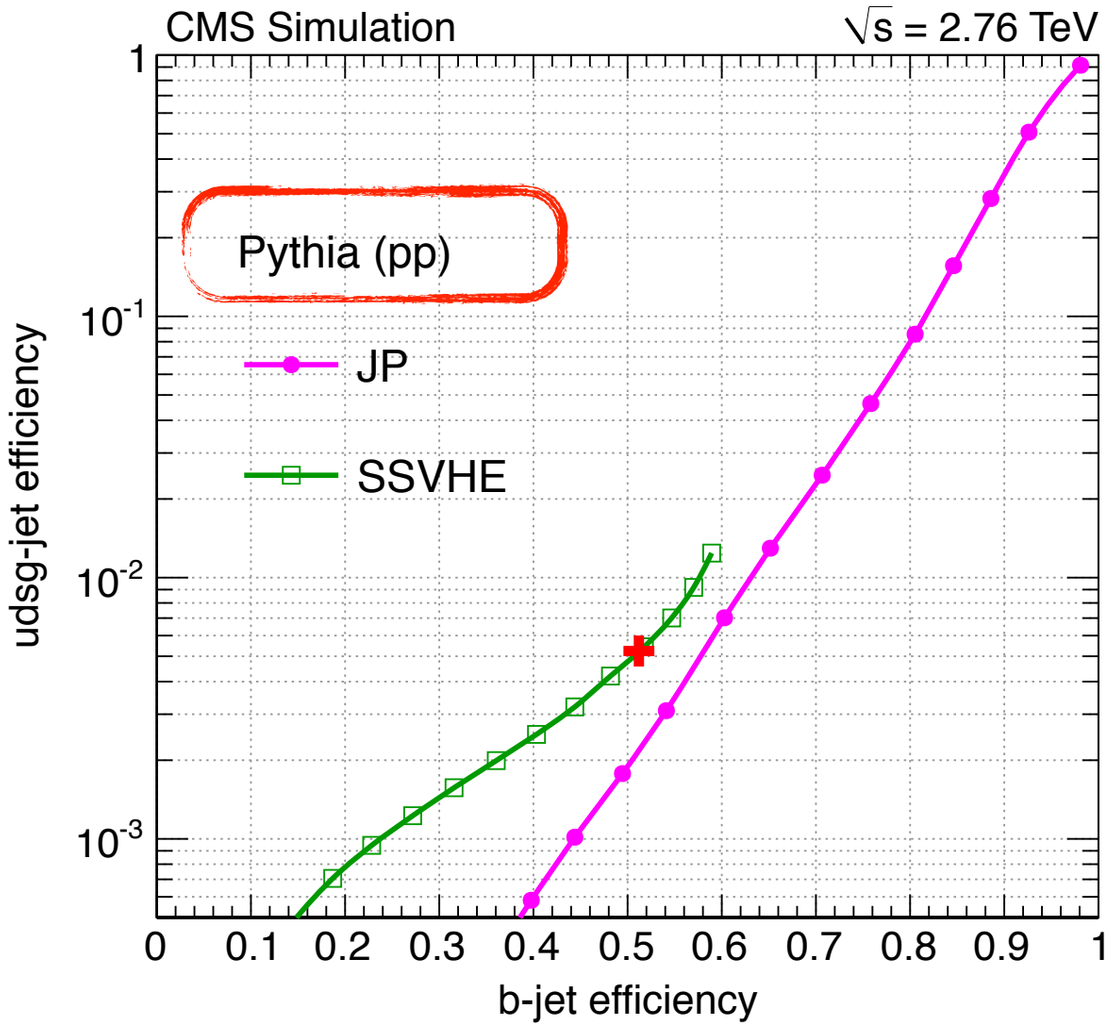
- Characteristics of B which the tagging exploits: long lifetime (1.5ps)
  - displaced secondary vertices (SV)
  - large-impact parameter tracks
    - run iterative tracking, inside the jet

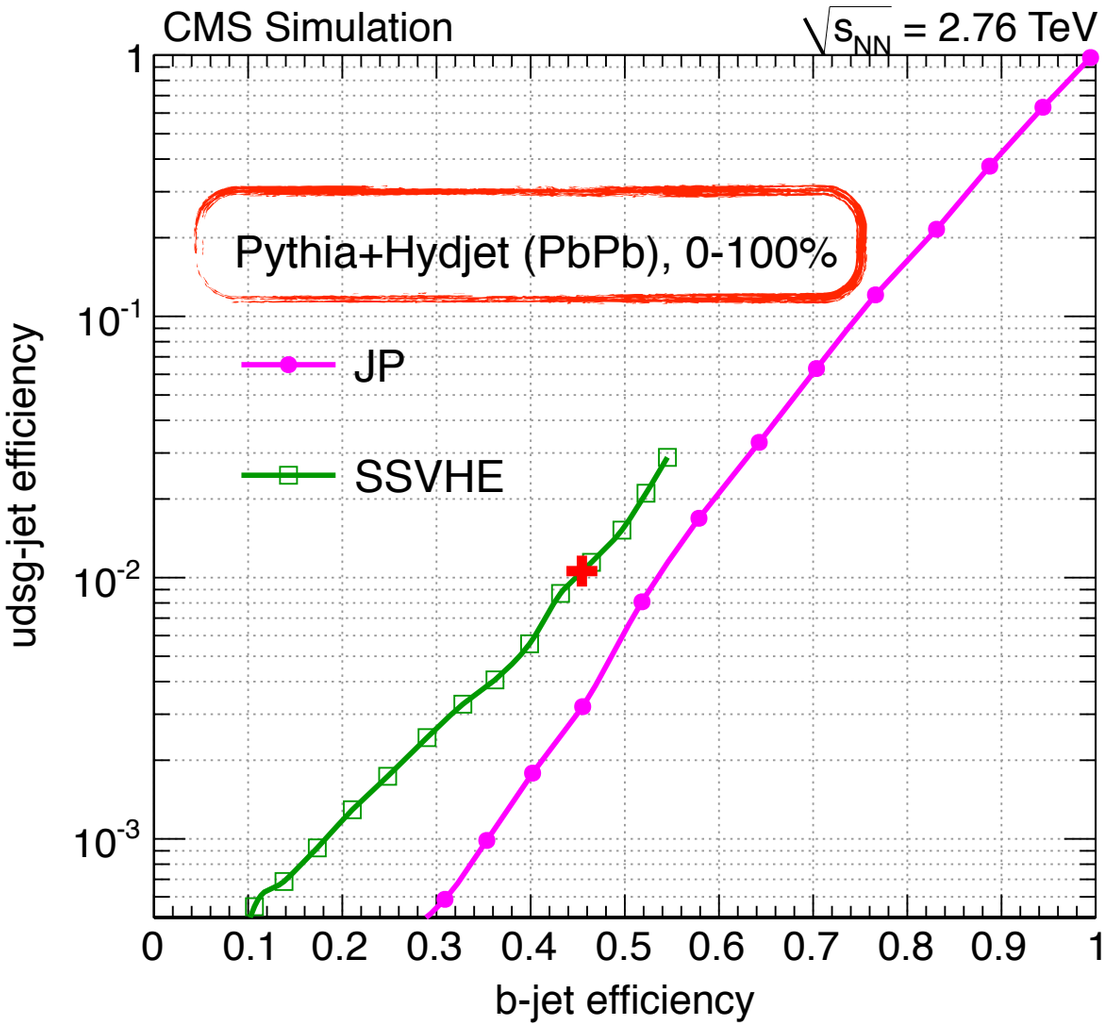


- B-tagging used in HI
  - Simple Secondary Vertex High Efficiency (SSVHE)
    - reconstructed SV, using the flight distance of the SV as a discriminant
    - fit to the SV mass → b-jet fraction
  - Jet probability (JP)
    - used as an alternative tagger to corroborate the SV performance
    - uses large impact parameter tracks, estimate a likelihood they come from the primary vertex

b-tagging performance

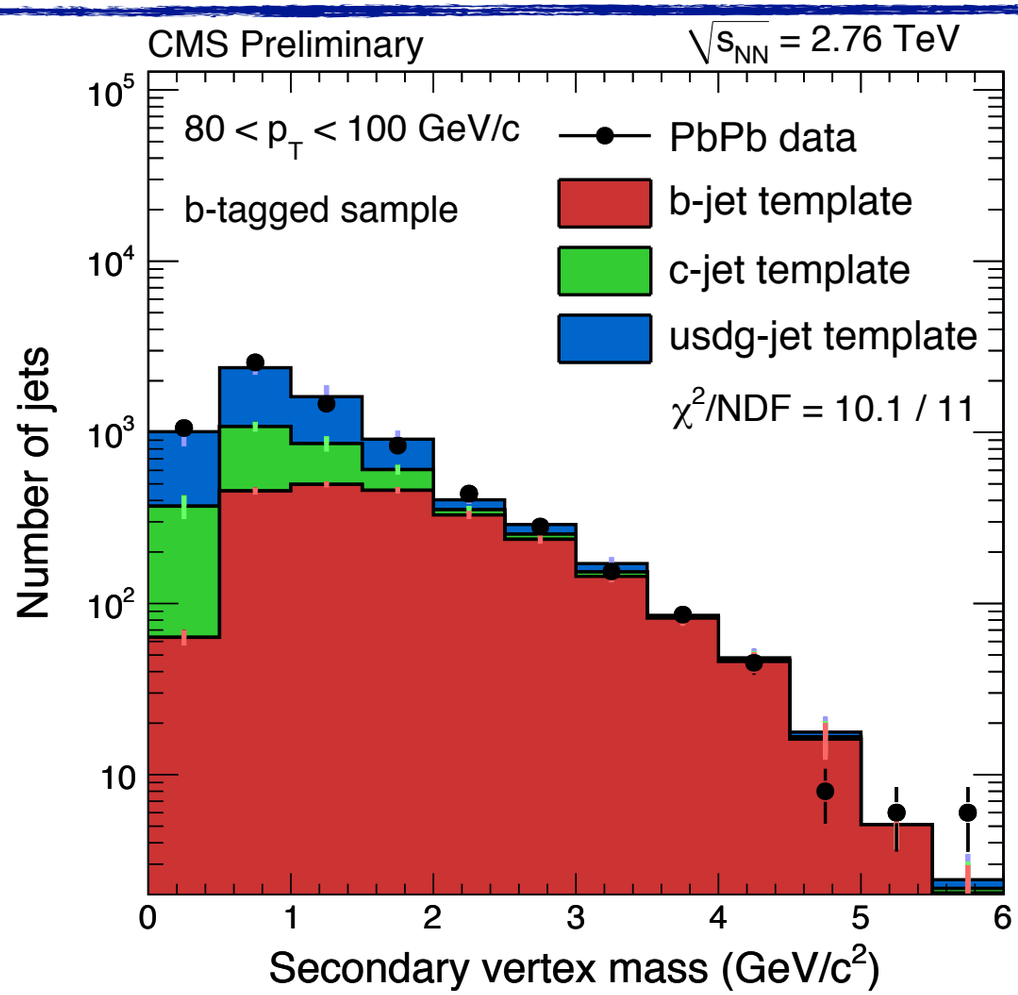
CMS-HIN-12-003
CMS-BTV-11-004





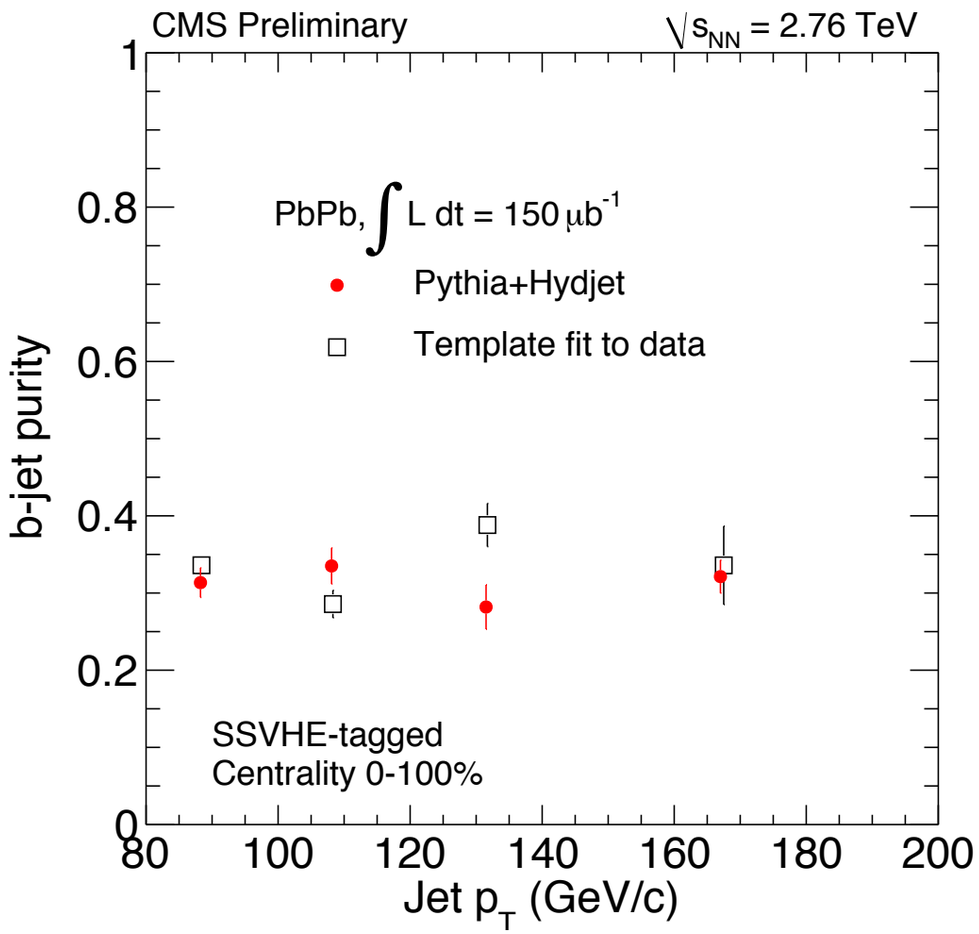
- Performance benchmarked by comparing b-tagging and light mis-tagging efficiency
- Some degradation of performance in PbPb compared to pp, but still a factor of ~100 light jet rejection for 45% b-jet efficiency

SecondaryVertex mass fits

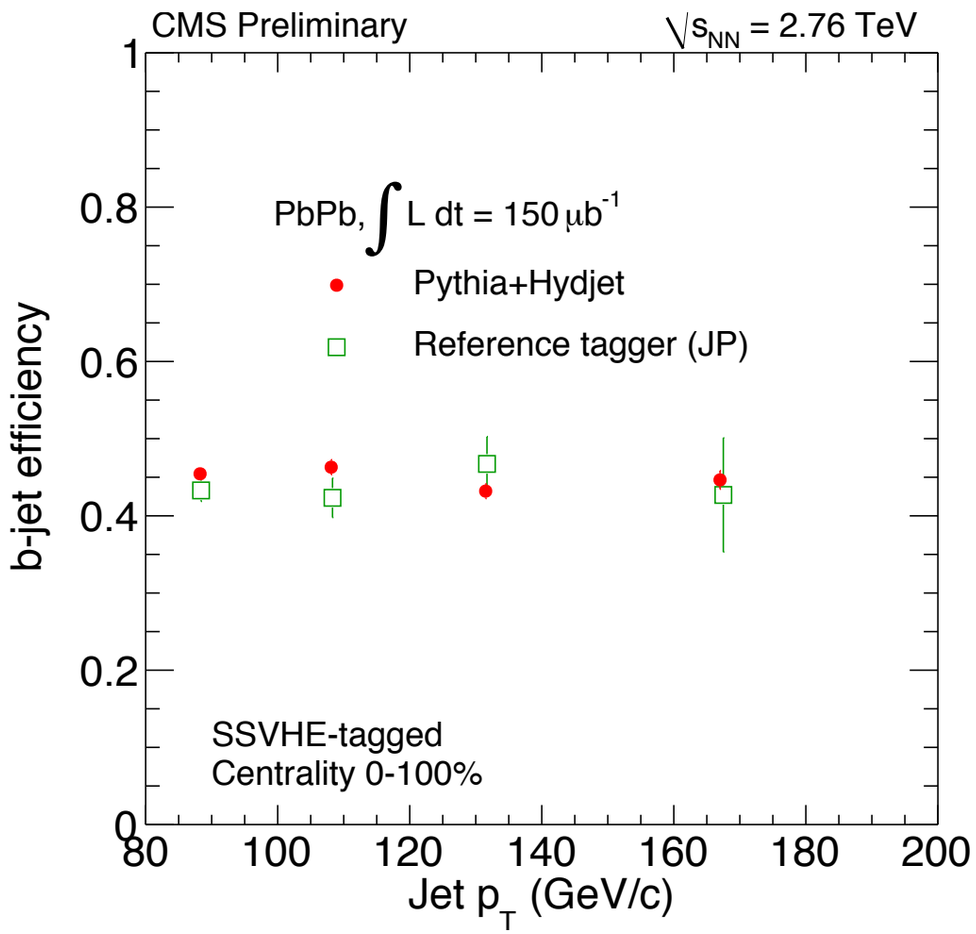


- After selecting the enriched b-jet sample with the SSVHE tagger, fit the SV mass distribution
- Shapes of b and non-b templates fixed in MC, normalizations allowed to float, c to light normalization fixed
- The shapes of non-b templates are cross-checked with a data-driven method
- The stability of the fits and the shapes of the templates are the dominant sources of systematic uncertainties

b-Tagging Purity and Efficiency



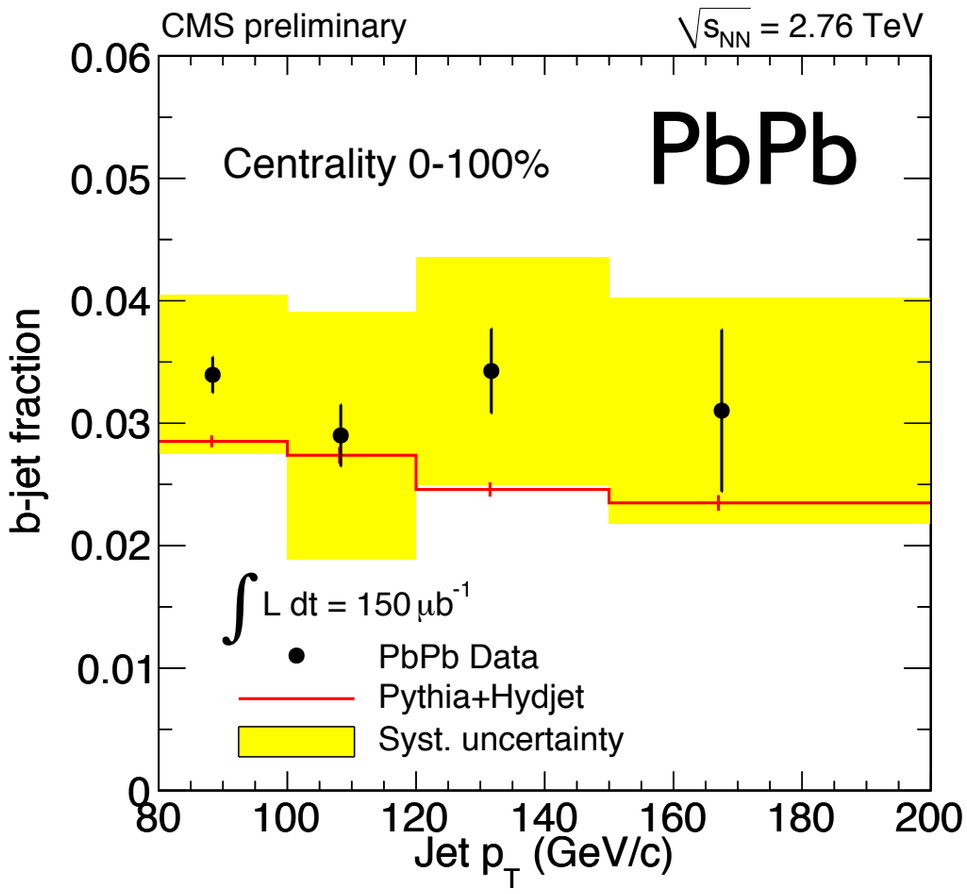
Purity: b-jet fraction in SSVHE-tagged sample extracted from SV mass fit

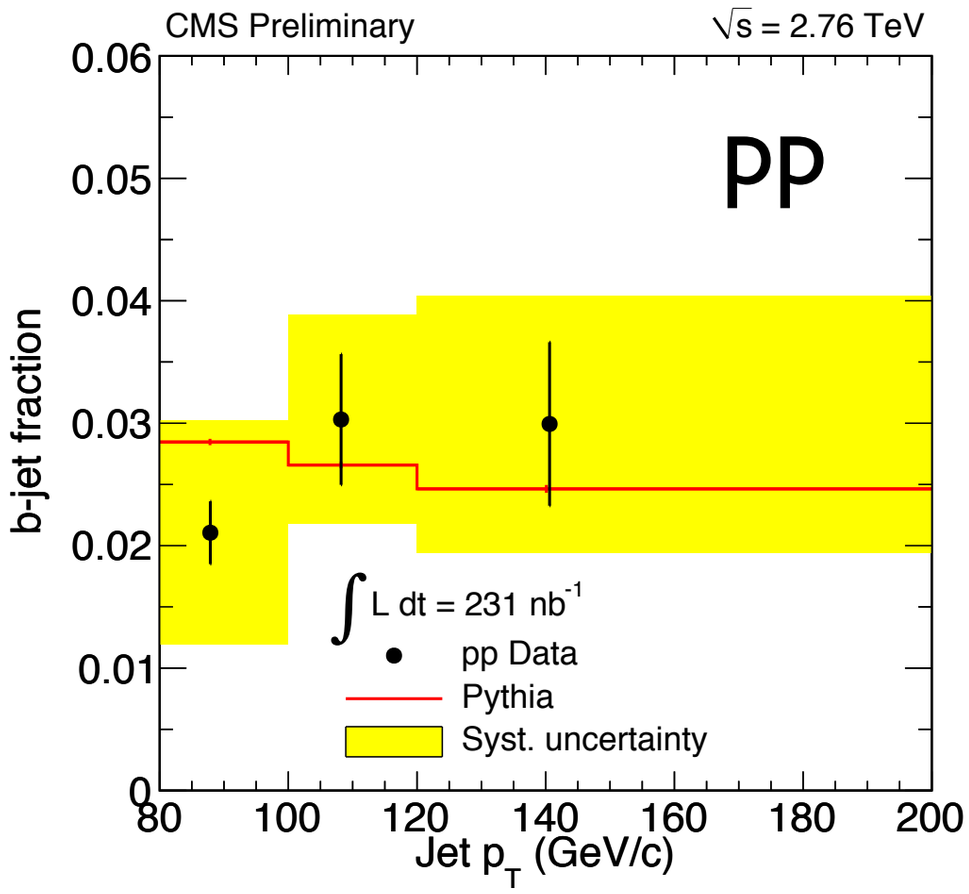


Efficiency: fraction of b-jets which are tagged by their SV

- Efficiency is extracted from simulation and with a data-driven method using the JP tagg (i.e., w/o requiring a SV)
- For both efficiency and purity, MC is fairly closed to data

b-jet fraction

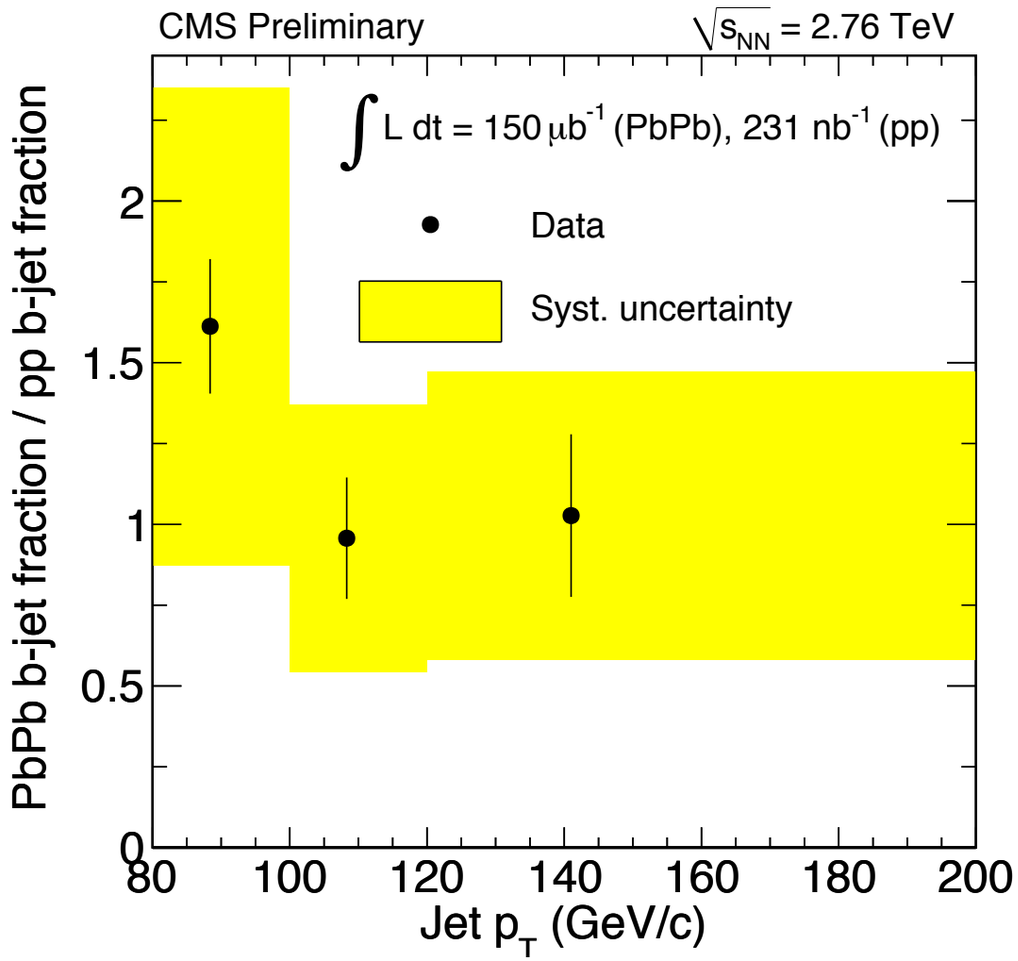




b-jet fraction = N_{jets}^{tagged} * purity/efficiency

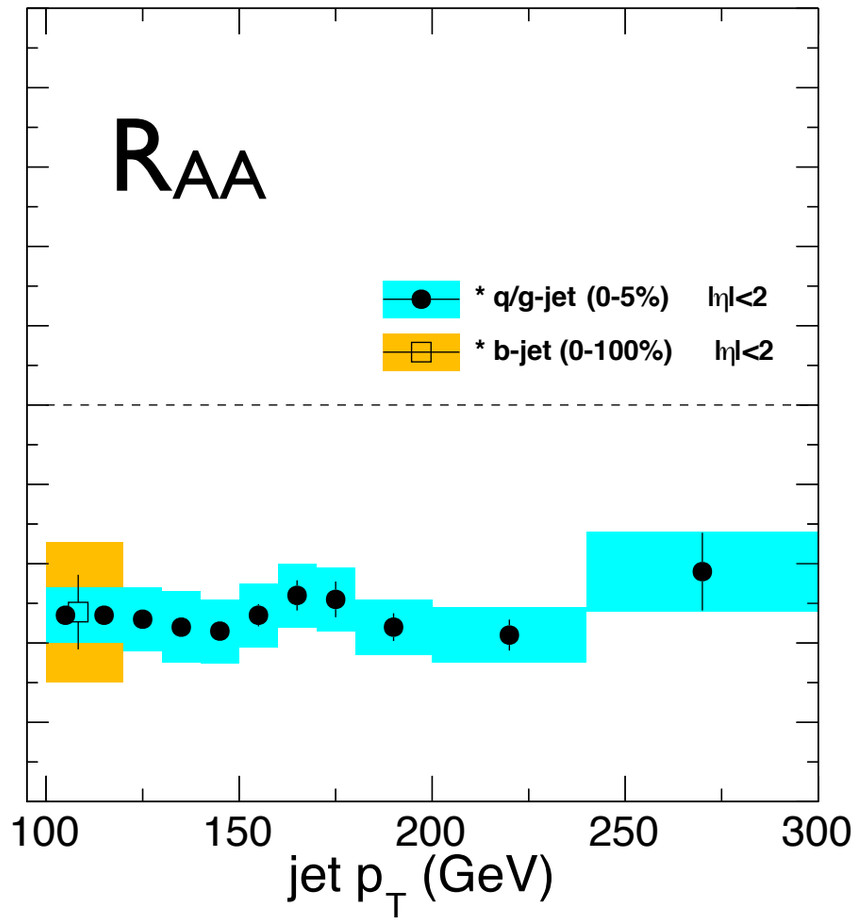
- PbPb:
  - ➡ hints of larger fraction in data, but overall consistent within uncertainties
  - ➡ no significant p_T dependence
- pp:
  - ➡ consistent with MC

b-jet R_{AA}



b-jet double_ratio =

b-fraction in PbPb / b-fraction in pp

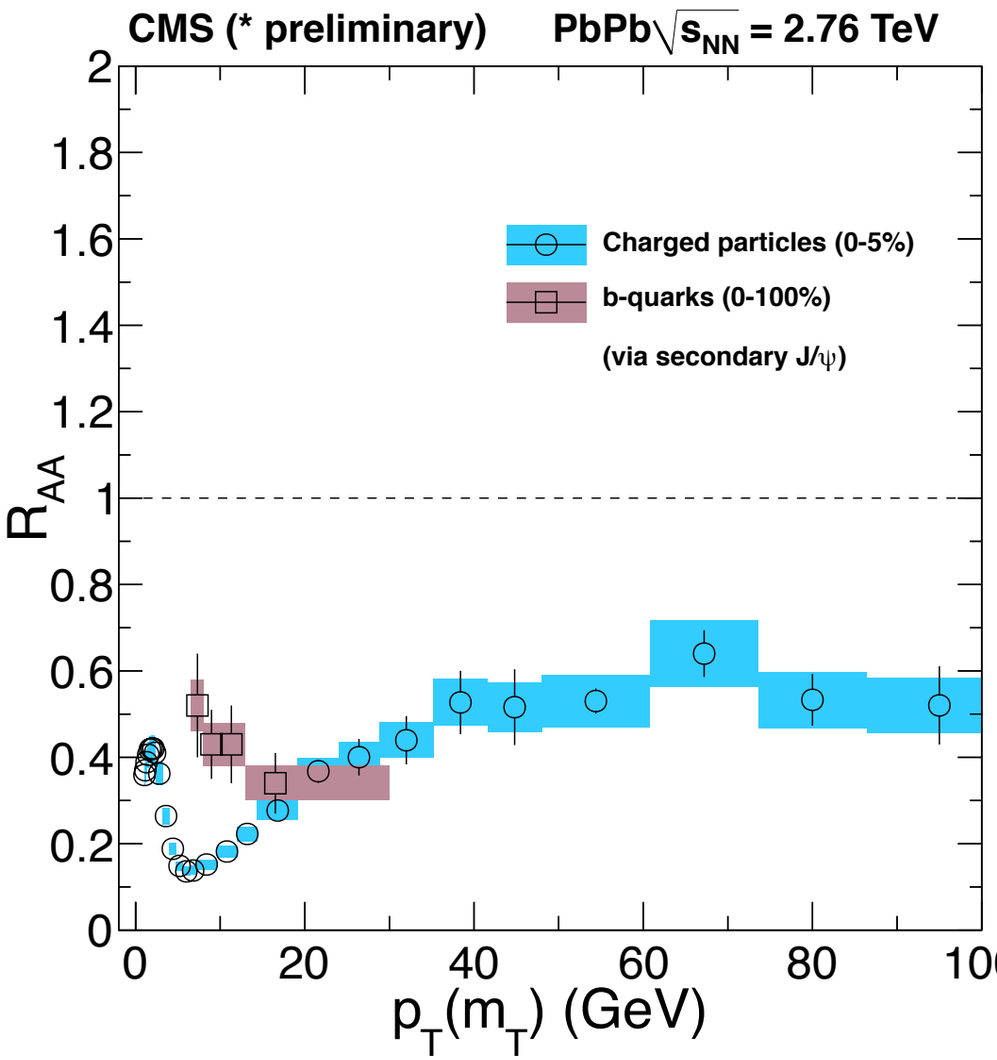


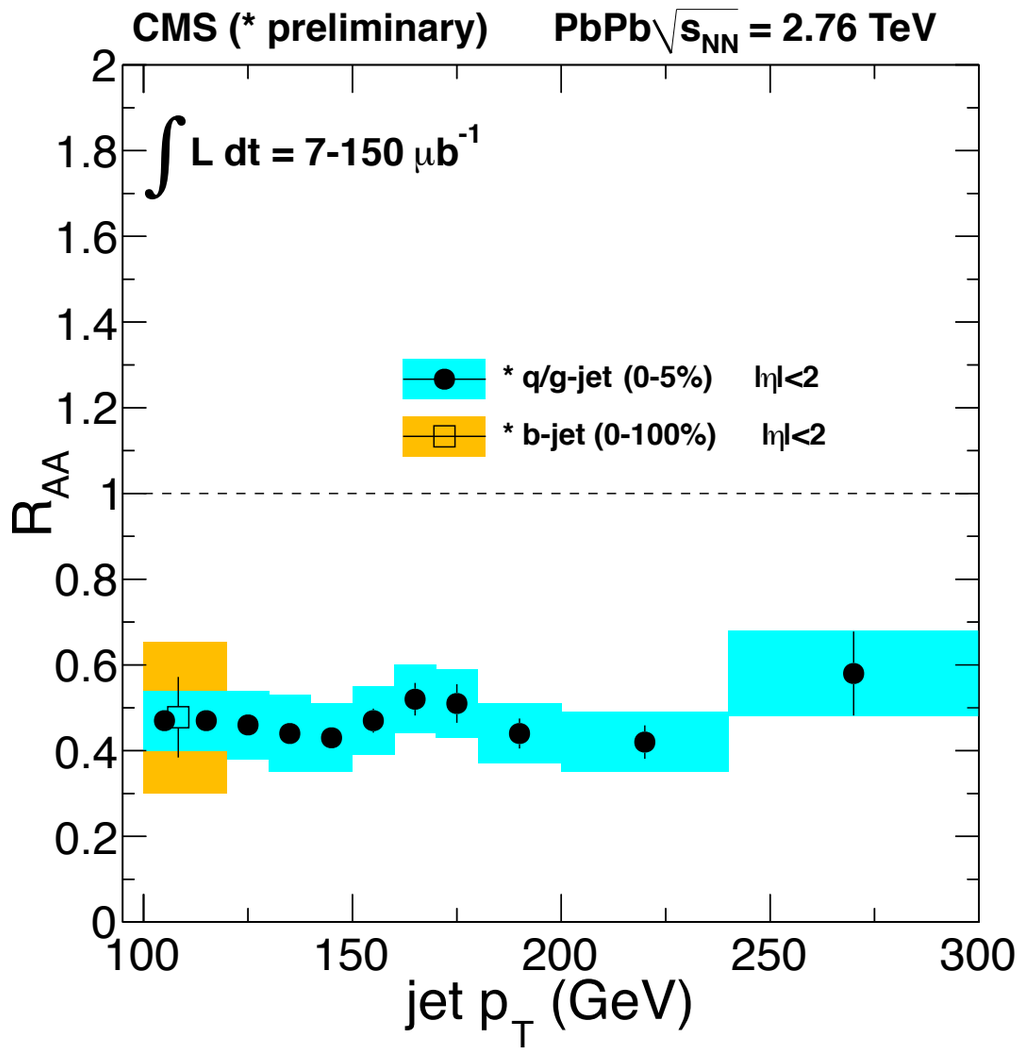
b-jet R_{AA} =

inclusive-jet R_{AA} * b-jet double_ratio

- For p_T [100, 120] GeV/c
  - $R_{AA}^{\text{b-jet}} = 0.48 \pm 0.09\ (\text{stat}) \pm 0.18\ (\text{syst})$
  - $R_{AA}^{\text{inclusive-jet}} = 0.50 \pm 0.01\ (\text{stat}) \pm 0.06\ (\text{syst})$
- Data disfavor a scenario in which b-jets suffer no energy loss in PbPb (p_T>100 GeV/c)

Beauty energy loss with CMS in PbPb





- At low-p_T: different suppression pattern
- At high-p_T: similar suppression

- Note: gluon jets dominant at LHC --- energy loss gluon > energy loss light quark --- not there yet for mass dependence of en loss

Summary

- Low-p_T : $b \rightarrow B \rightarrow J/\psi$
  - ➡ detailed beauty measurement in HIC (many bins in p_T, y and N_{part})
  - ➡ hint of very interesting (and unique) features: need more data (pp and PbPb)
  - ➡ there is order: $R_{AA}^{D} < R_{AA}^{B}$, in most central 0-20% PbPb@2.76TeV collisions

- High-p_T: b-tagged jets
  - ➡ fully reconstructed b-jets have been identified for the first time in HIC
  - ➡ b-jet fraction in PbPb is consistent with PYTHIA and pp data-fairly sizable uncertainties