Jets in p-Pb collisions

Raghav Kunnawalkam Elayavalli

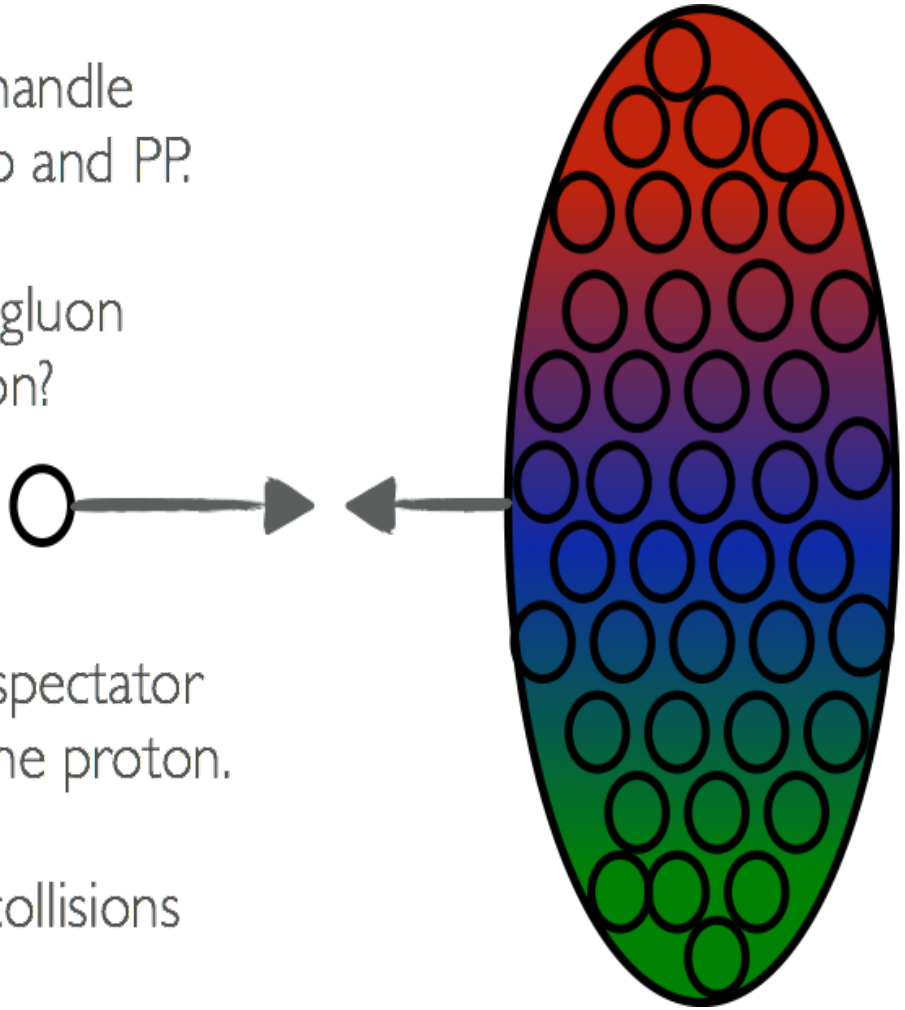
Rutgers University

(For the CMS Collaboration)

Proton Lead Collisions

Provides a handle between PbPb and PP.

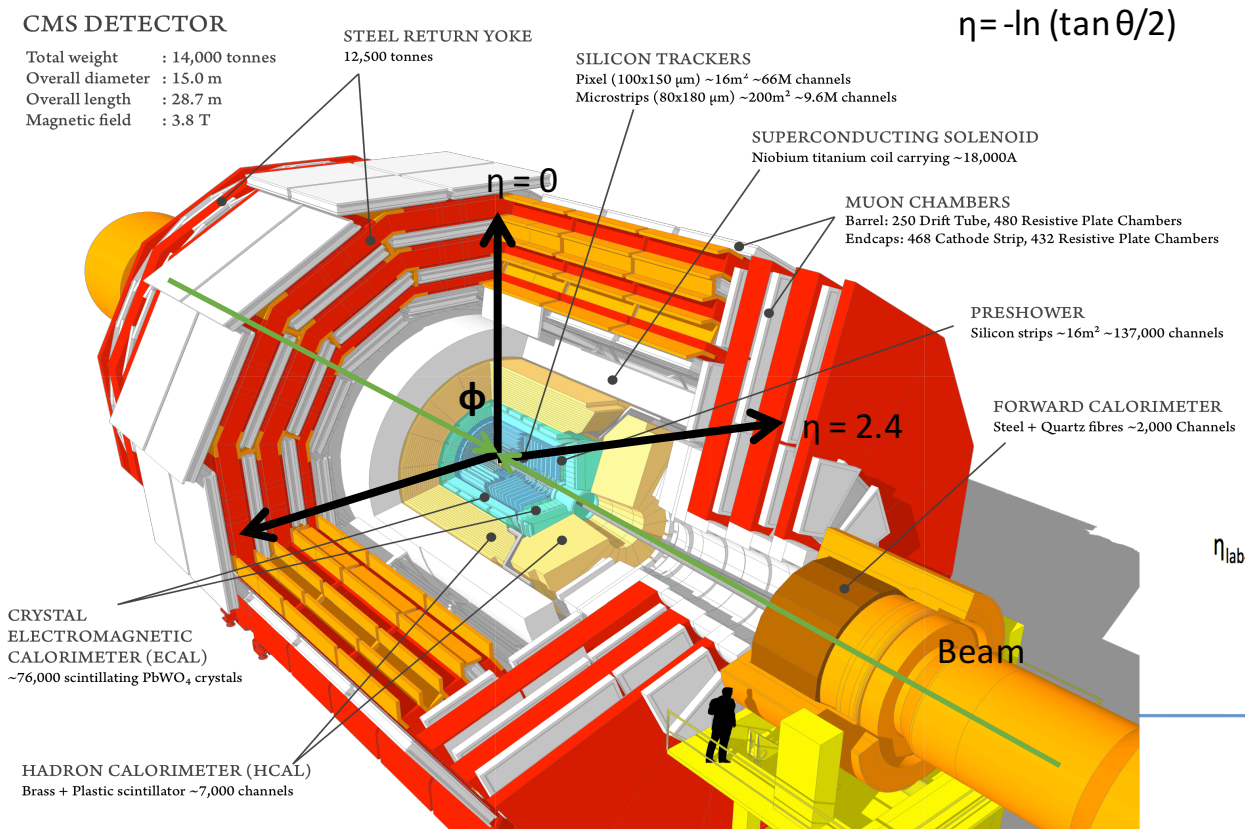
Initial state gluon saturation?



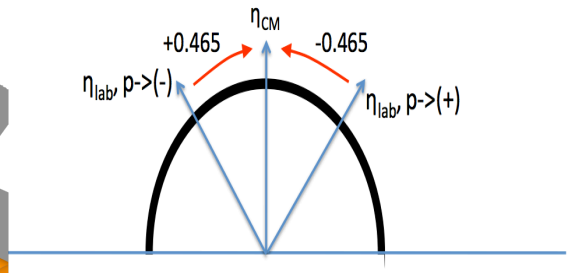
Interaction of spectator nucleons with the proton.

Asymmetric collisions

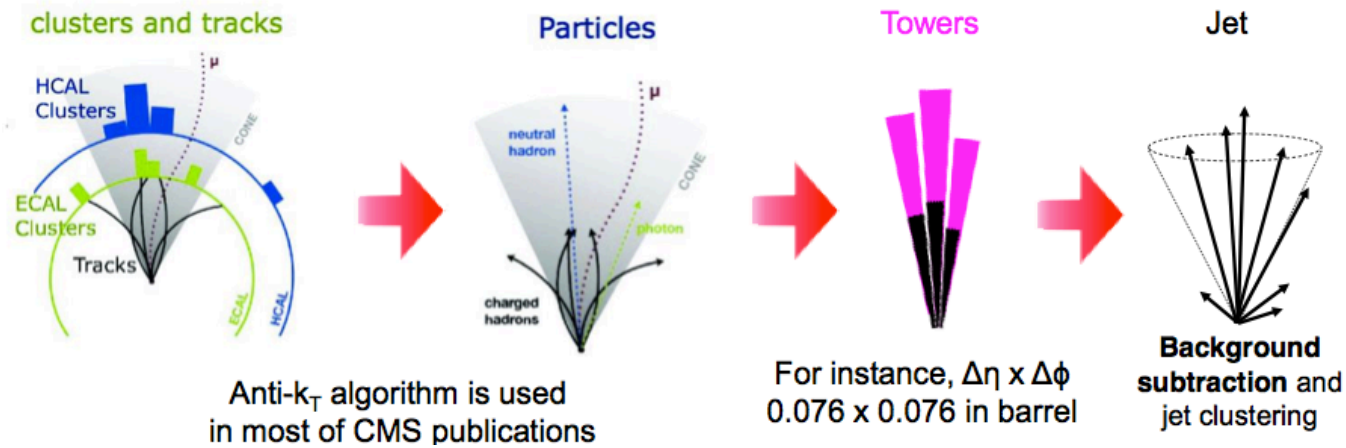
CMS detector and p-Pb system

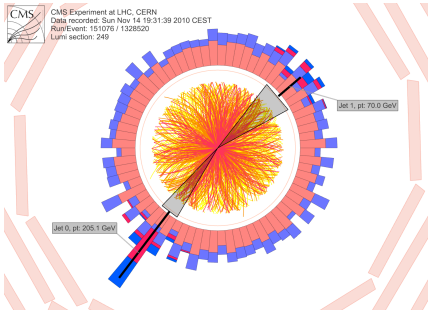


$\eta = -\ln(\tan\theta/2)$



Jets in CMS

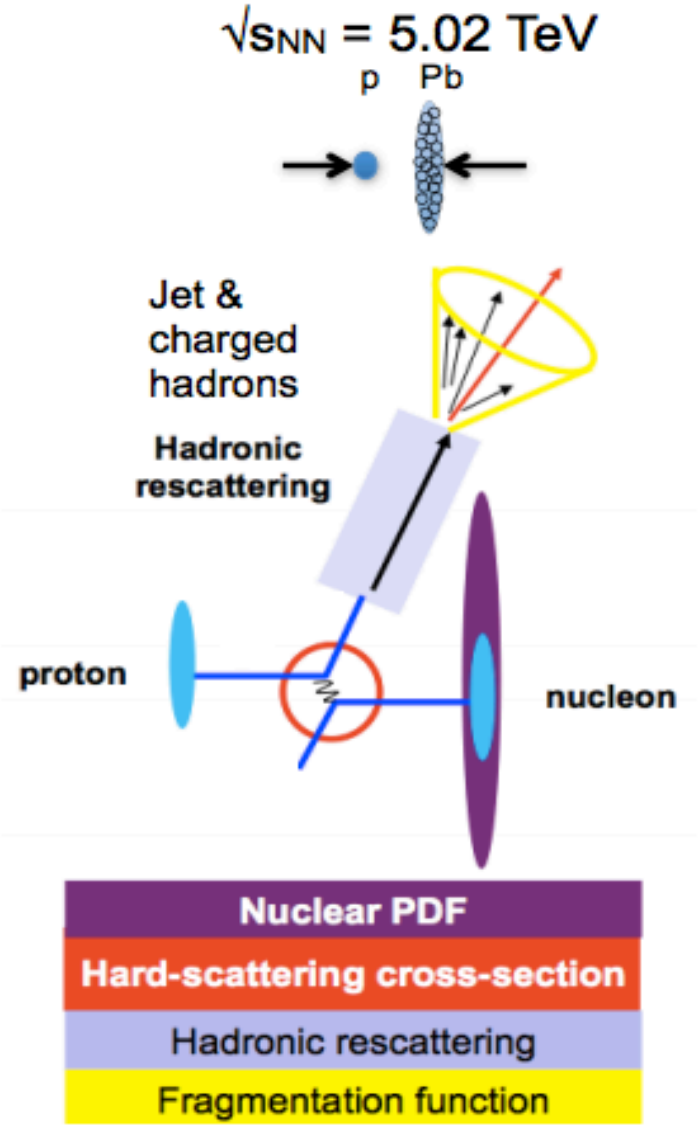




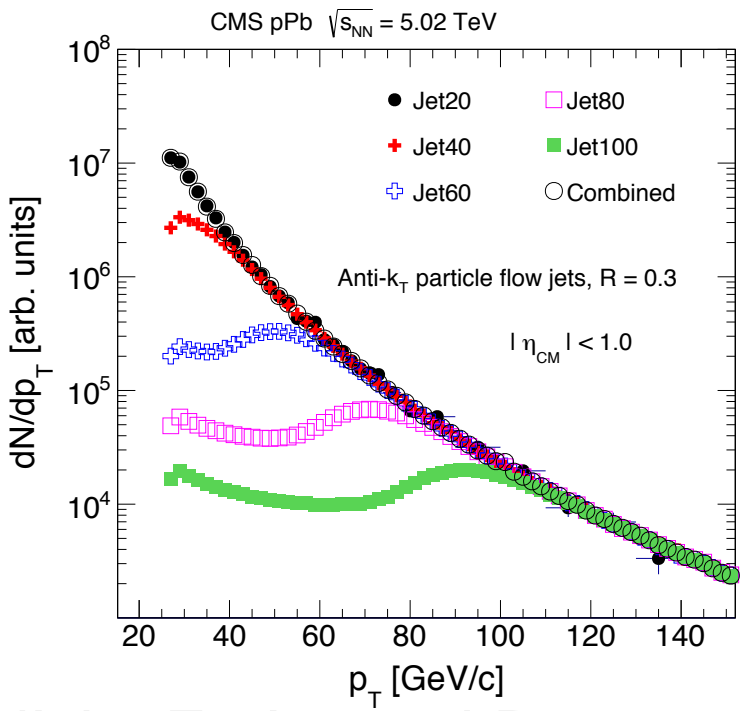
Calorimeter (CALO) Jets: Using Calorimeter energy deposits.
Particle Flow (PF) Jets: Combines information from all sub detectors to make PF candidates, which are then clustered.

Starring Jets!

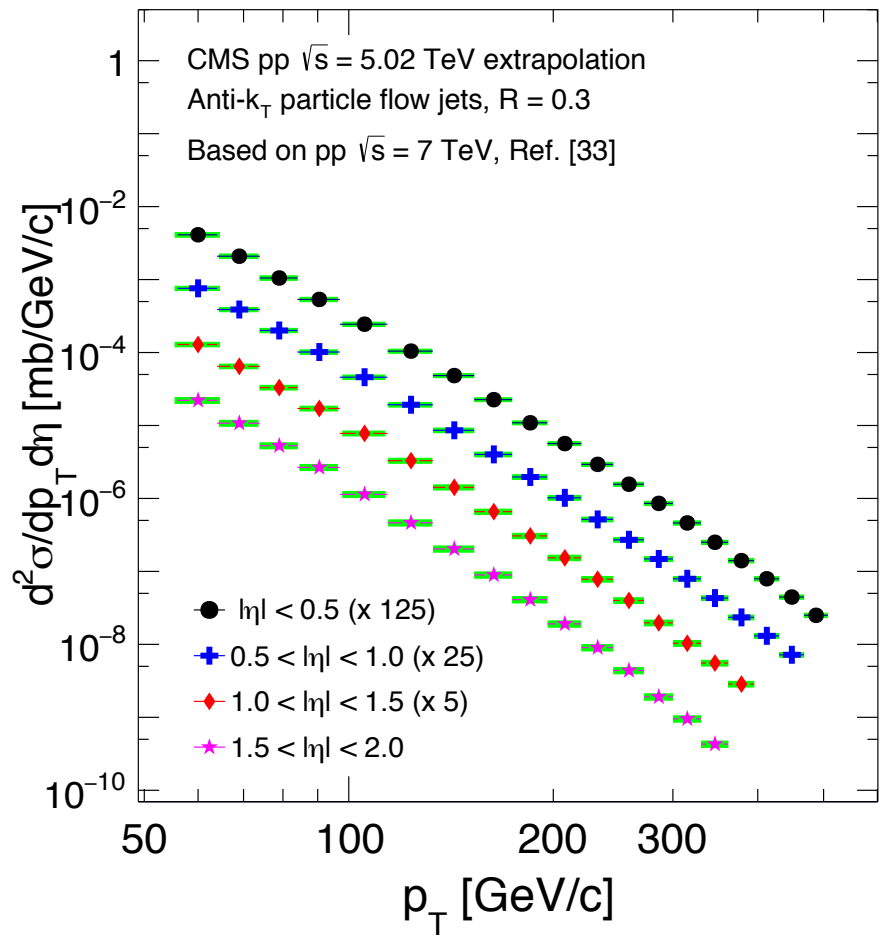
- Asymmetry in jet production (nPDF contribution)
- Initial State vs Final State effects in the RpA
- Fragmentation function effects
- Does mass play a role? (Heavy Flavor jets)



pPb Inclusive Jet Spectra



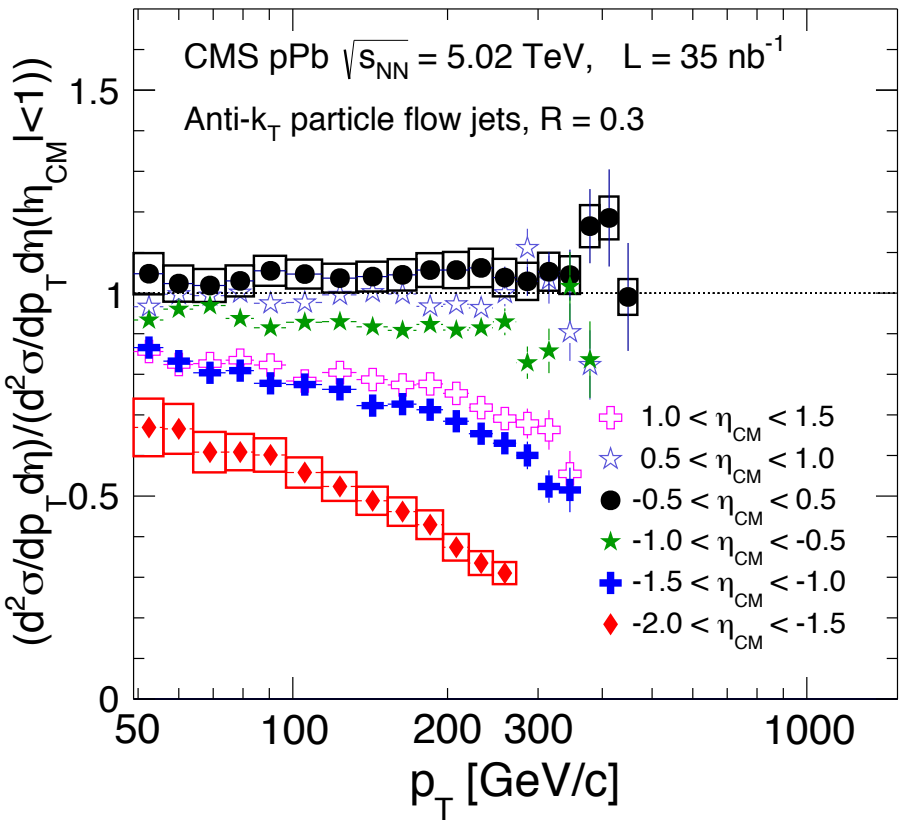
arXiv:1601.02001, Submitted to EPJC

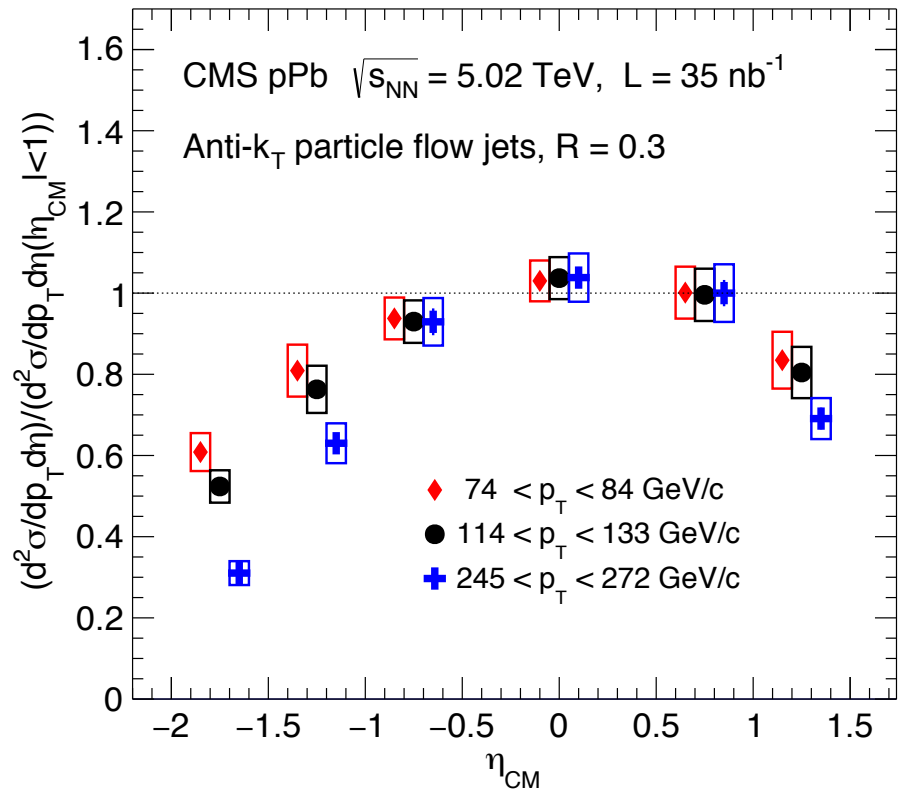


- High pT triggered Dataset combined and unfolded using Iterative Bayesian technique.

Pb cross section ratio to mid rapidity

arXiv:1601.02001, Submitted to EPJC

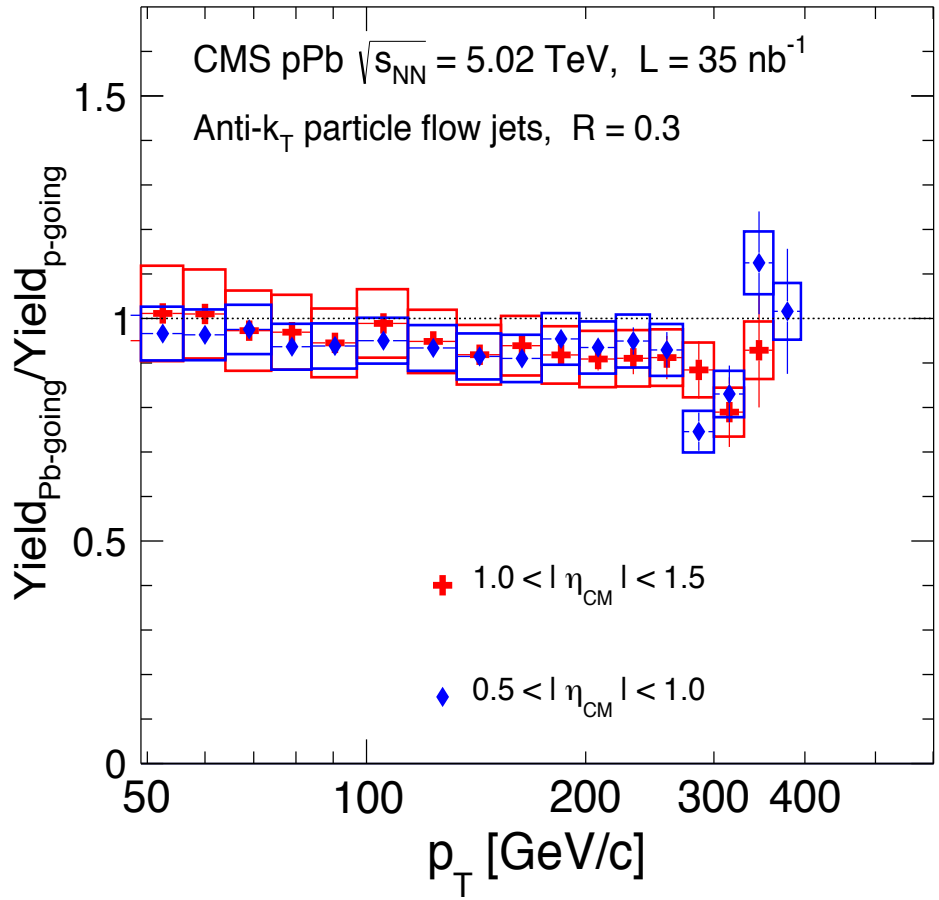




Yield Asymmetry

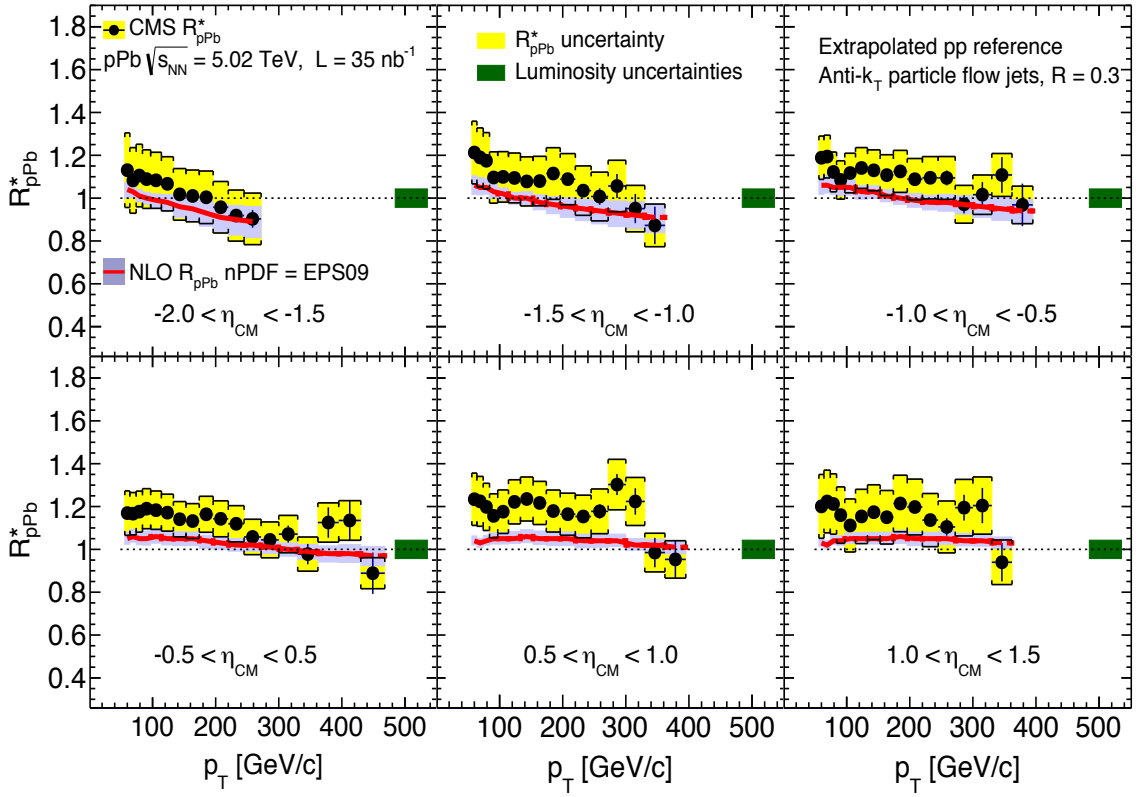
- Lead going side vs proton going side yield ratio
- There is no significant asymmetry observed in the jet production within the covered pseudorapidity range, although a small effect at high p_T cannot be excluded with the present systematic uncertainties.

arXiv:1601.02001, Submitted to EPJC



Inclusive Jet R_{pPb}

arXiv:1601.02001, Submitted to EPJC



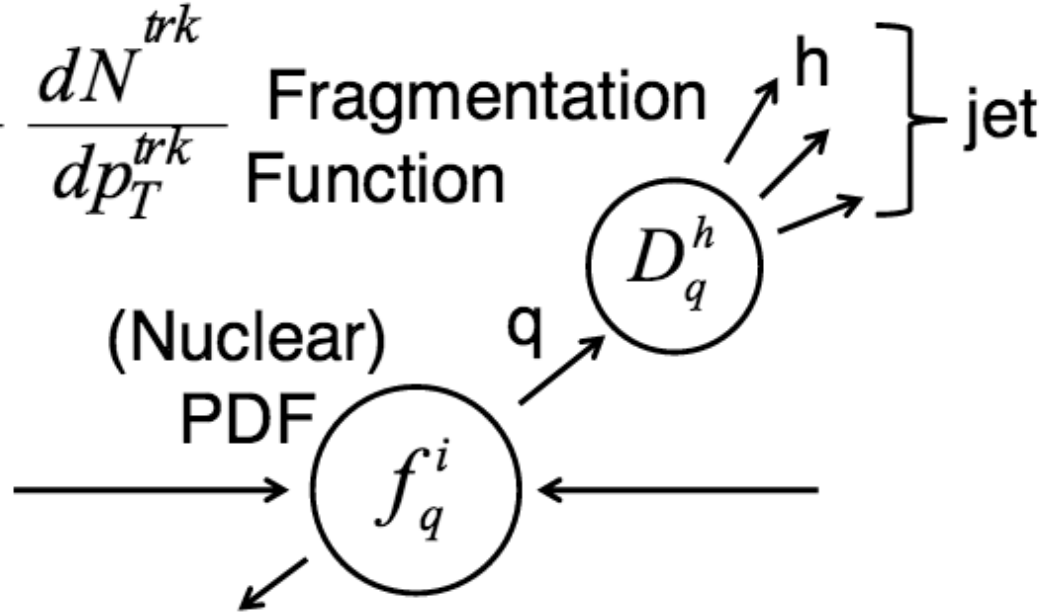
- Data slightly above EPS09 prediction (but still consistent within the uncertainties)

Fragmentation Functions (FF)

- FF are the jet yield normalized track yield inside a jet of specified radius for each jet pT bin

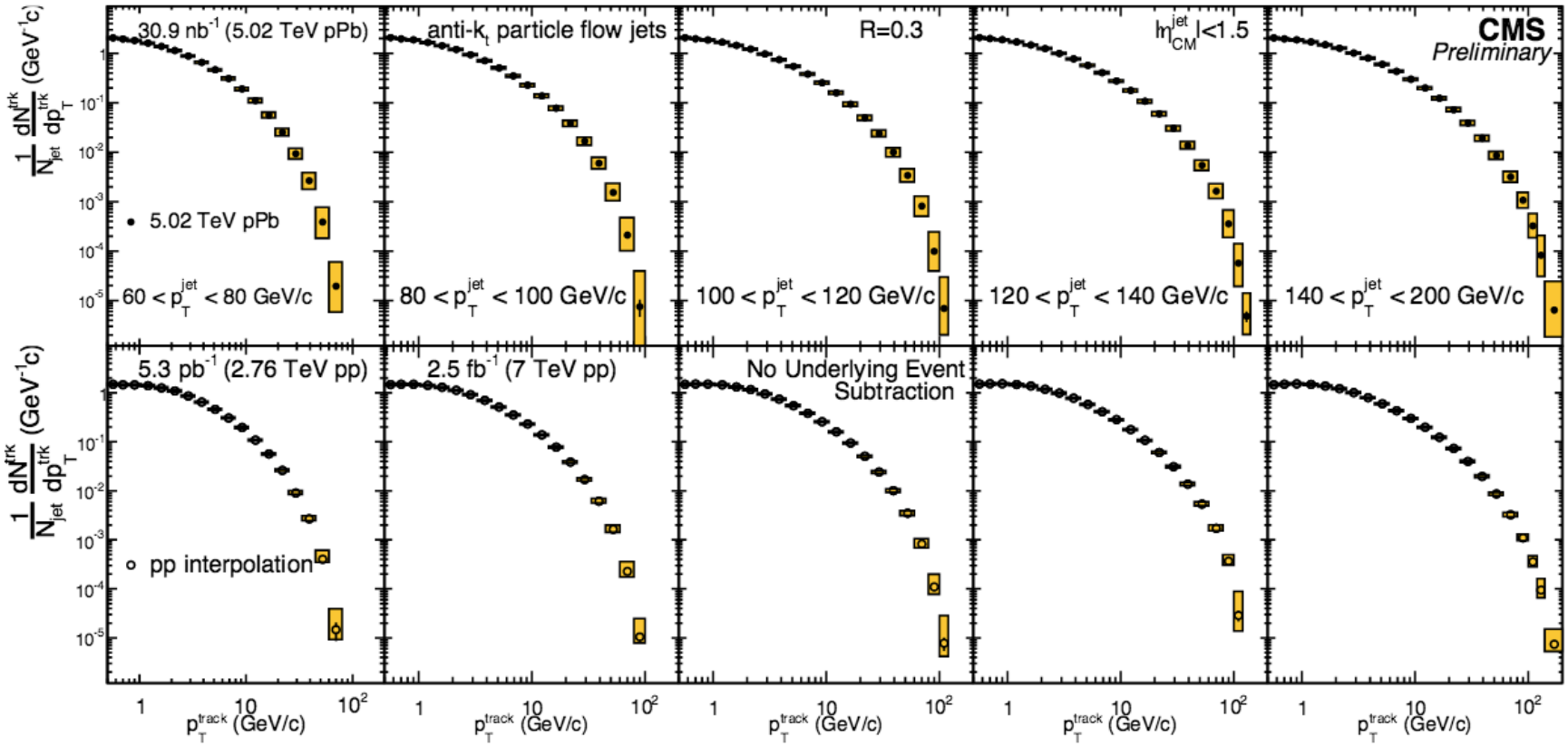
$$D(p_T) = \frac{1}{N_{jet}} \frac{dN^{trk}}{dp_T^{trk}}$$

Fragmentation Function



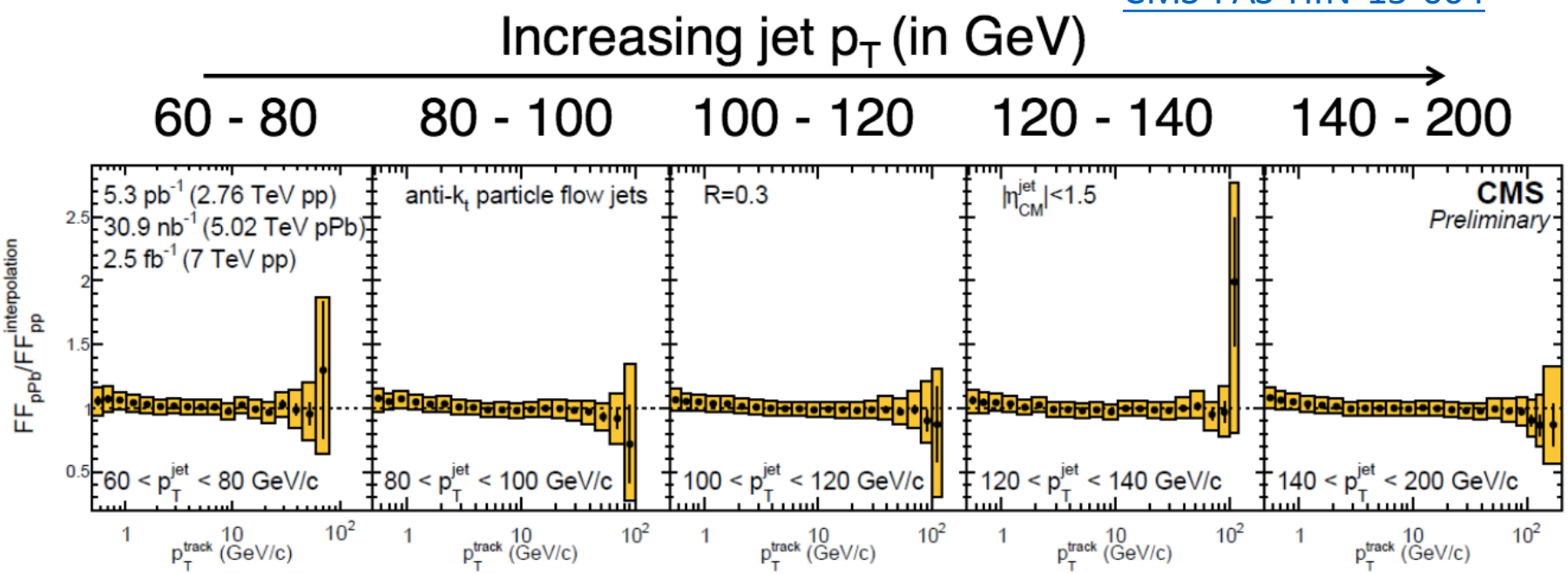
FF for pPb and PP (interpolated)

CMS-PAS-HIN-15-004



Ratio of FF pPb/pp

CMS-PAS-HIN-15-004

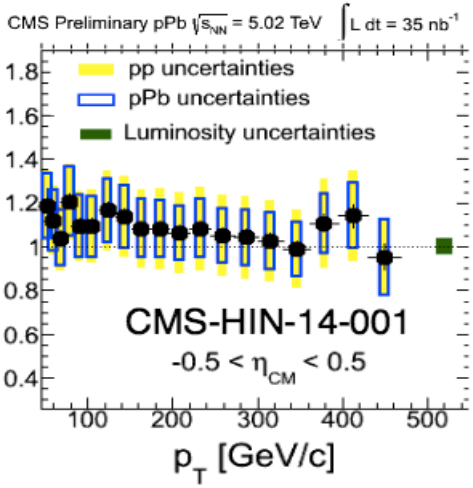


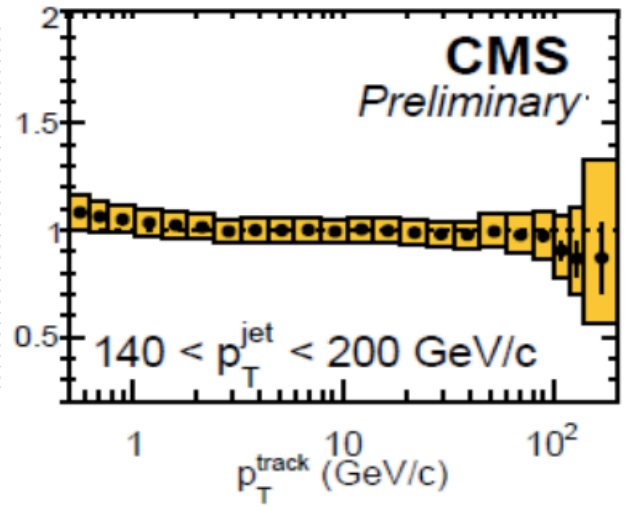
- No observed modification of the fragmentation function relative to our constructed pp reference

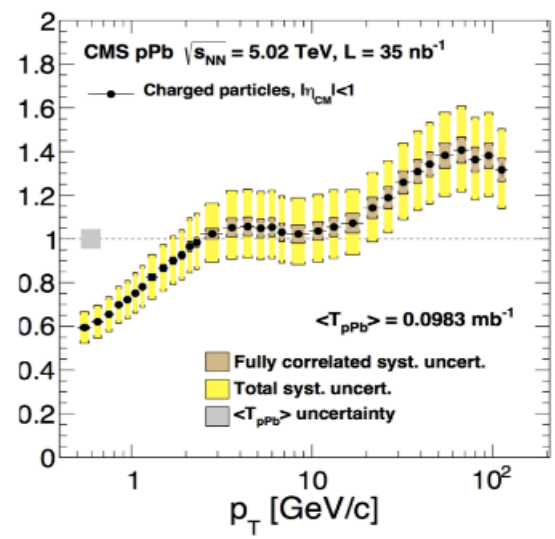
Relationship to R_{pPb} Measurements

- Expected that the jet R_{pPb} convolved with the fragmentation function ratio gives the high p_T charged particle R_{pPb}

$$R^{jet}_{pPb} * \left(\frac{D_{pPb}}{D_{pp}} \right) = R^{track}_{pPb}$$

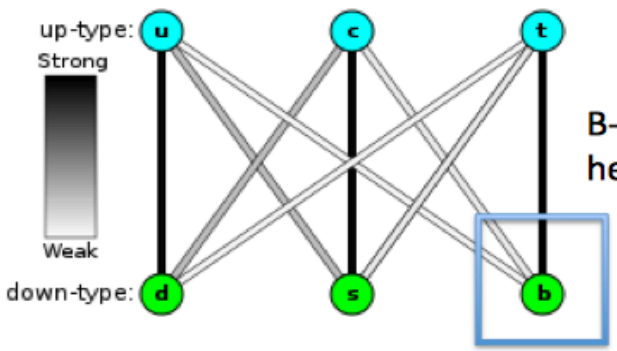




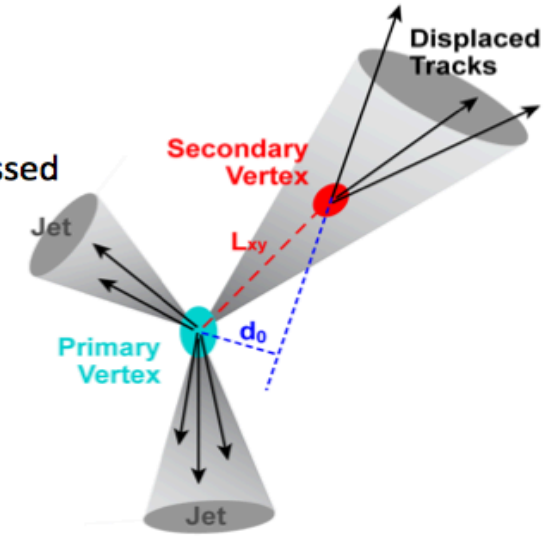


- **pPb data agrees for all three analysis**
- pp reference method differs for all three analysis
- **Tension due to pp reference and still under investigation**

Heavy quark Jets at the CMS



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

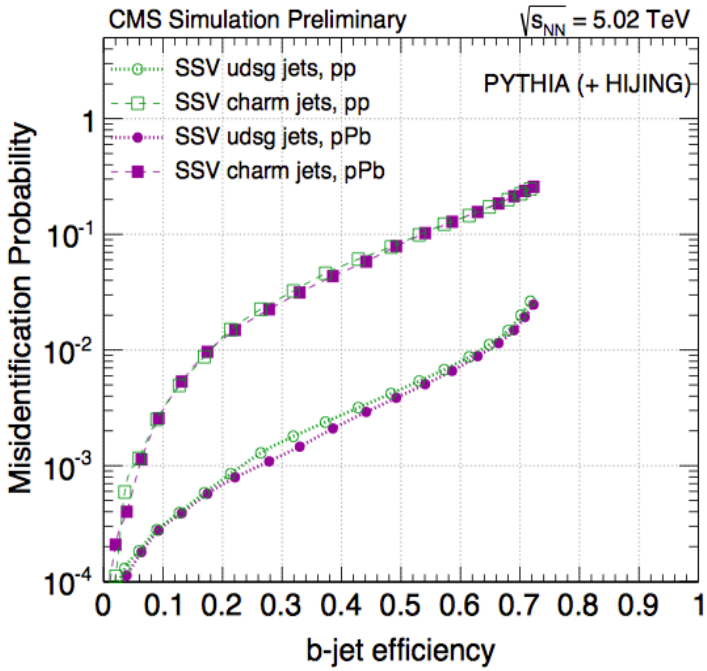


- Primary identification method is using a **Secondary Vertex**
  - Long lifetime of b = mm or cm vertex displacement
- Flight distance (L_{xy}) of the secondary vertex used as a discriminating variable
- Tagging methods independent of secondary vertex reconstruction used as cross-check

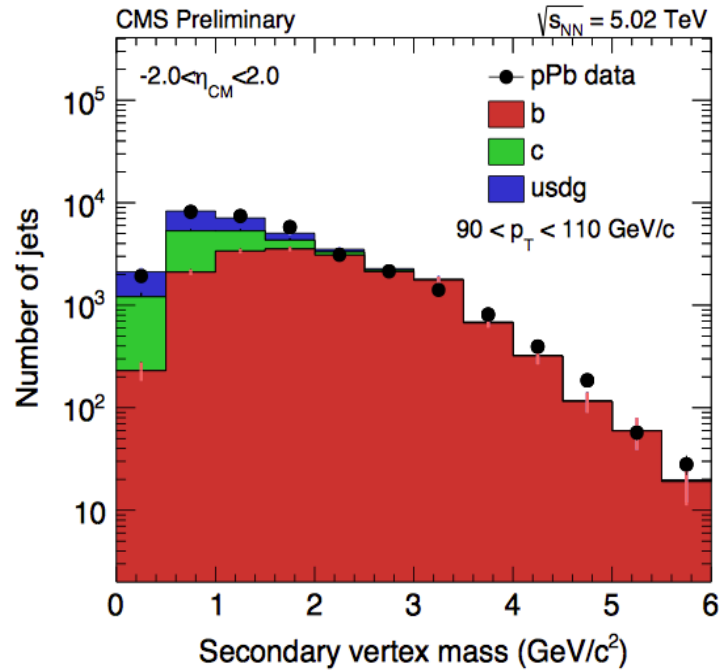
Algorithms described in:
JINST 8 (2013) P04013

b-Jet tagging

arXiv:1510.03373, Submitted to PLB



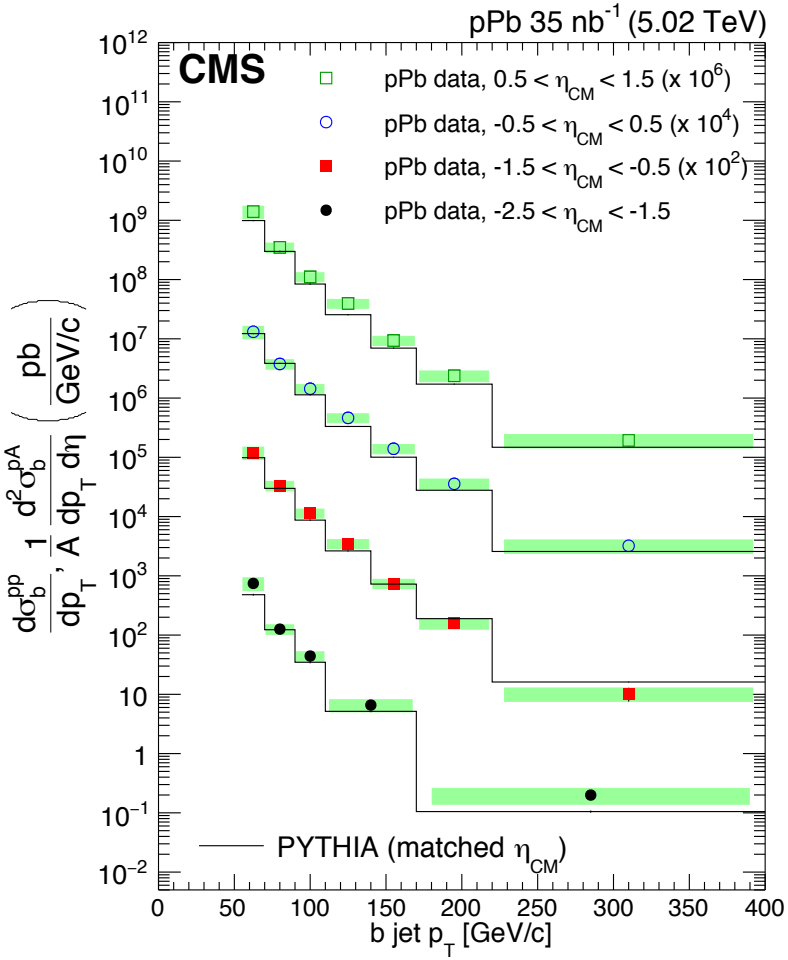
The SSV tagger is more robust against a combinatorial background due to the secondary vertex requirement

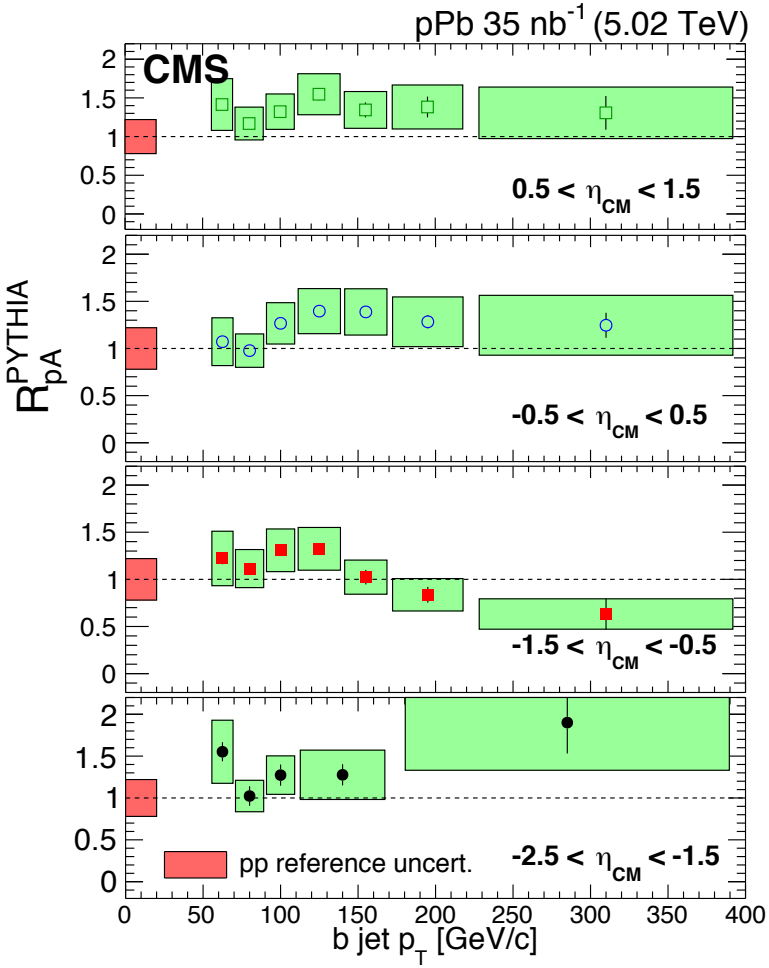


Template fits to the SV invariant mass distribution in pPb collisions for jets of $90 < p_T < 110$ GeV/c, where b-jets dominate after 2 GeV/c^2

b-jet Spectra/R_{pPb} in η_{cm} bins

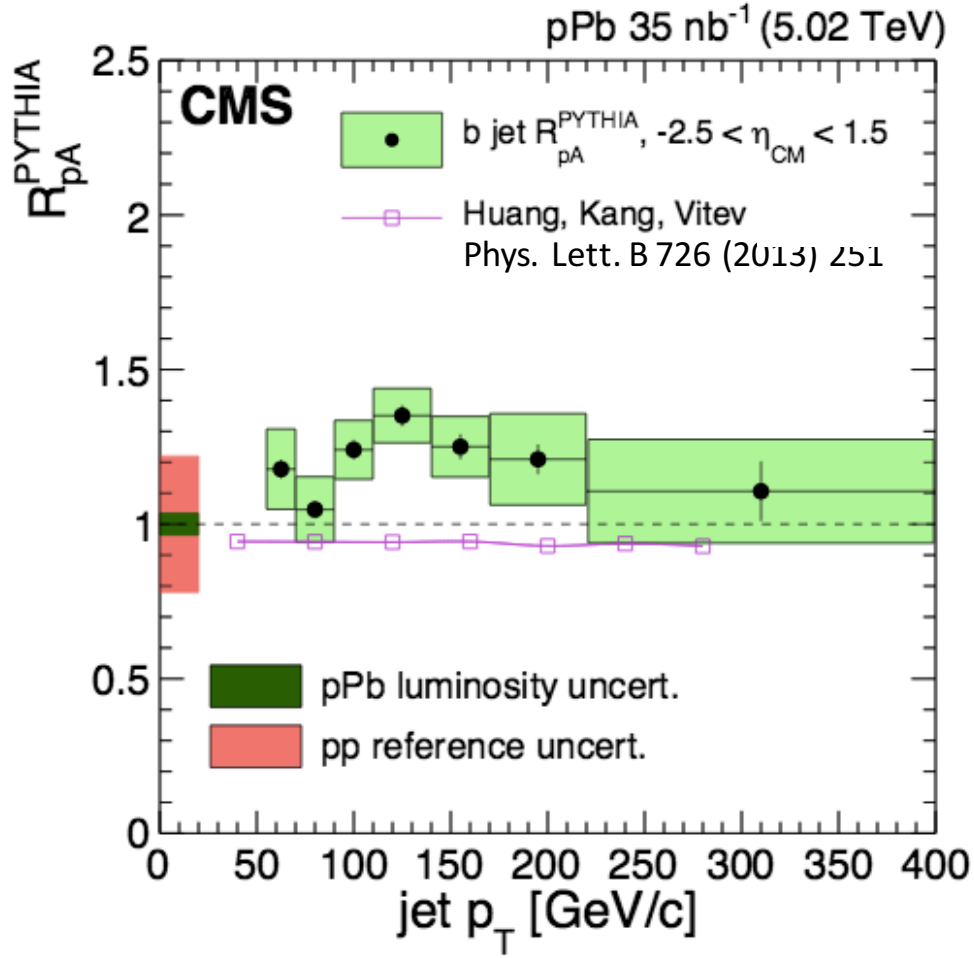
arXiv:1510.03373, Submitted to PLB





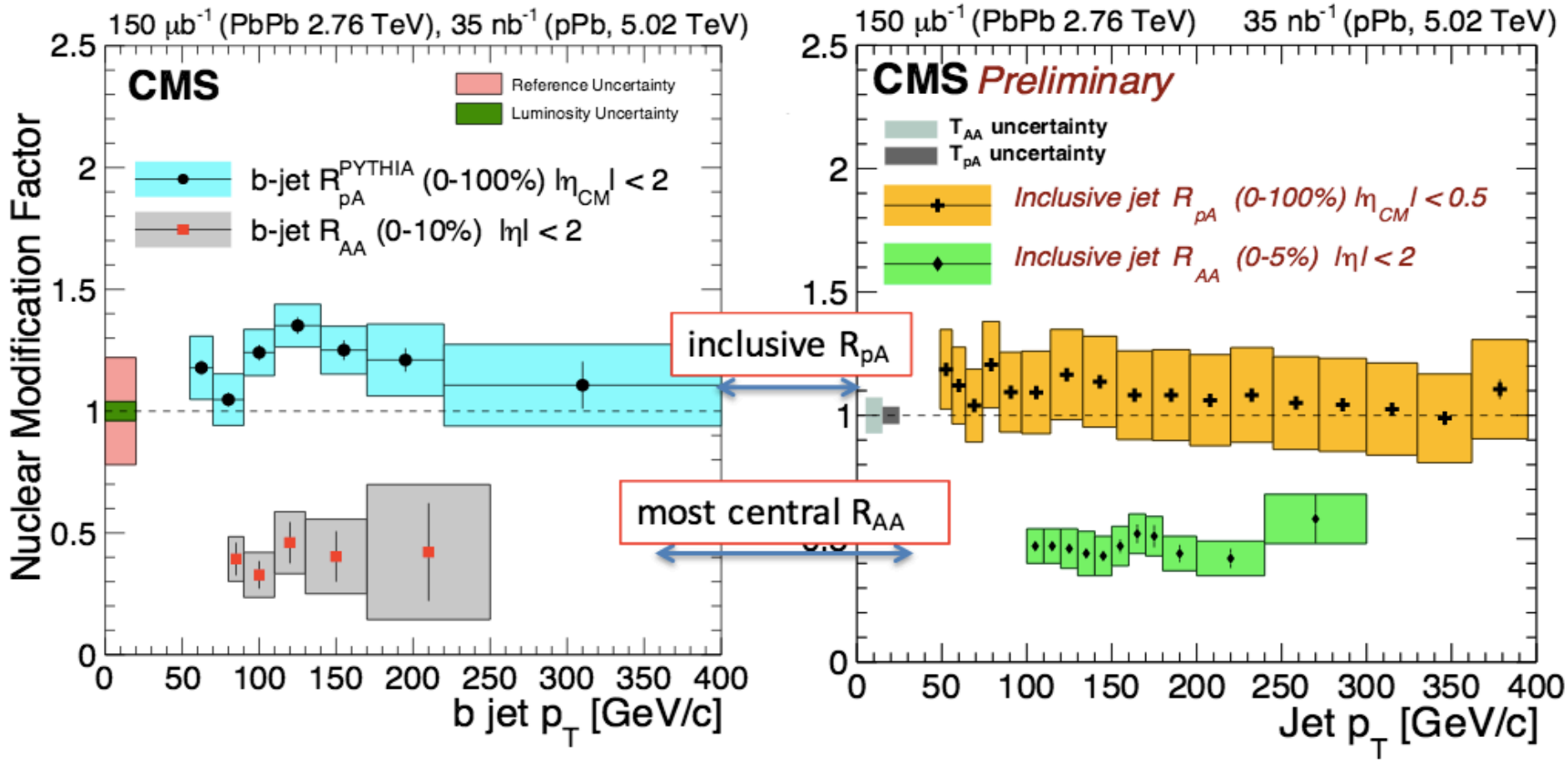
Comparison to theory (mid rapidity)

arXiv:1510.03373, Submitted to PLB



- Comparison to pQCD model including modest initial-state energy-loss effects

b-Jets vs Inclusive Jets

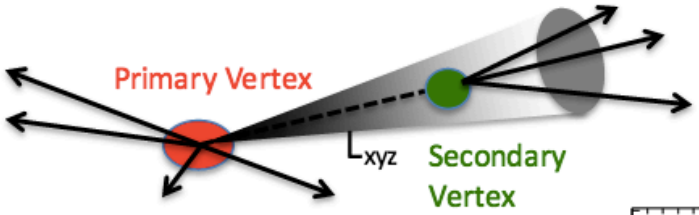


- CMS showed b-jets in PbPb (and pPb) are modified to a similar extent as light jets

Even Trickier – c Jets

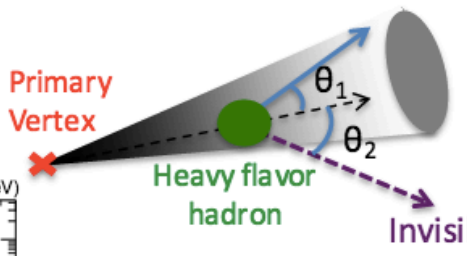
- b-jets tagged at CMS by selecting on displaced vertices
- Charm jets have smaller displacement, therefore trickier to tag
  - Developed a set of variables that provide discrimination power to extract c-jets

3+ Body Secondary Vertex Tagging

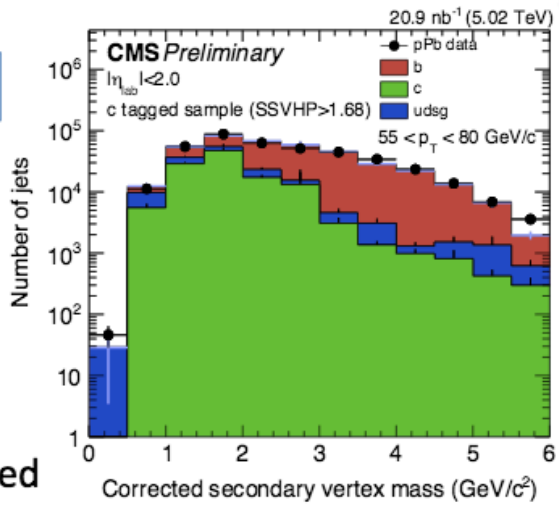


Separation of Charm + Light

Corrected Secondary Vertex Mass



Separation of Charm + Bottom

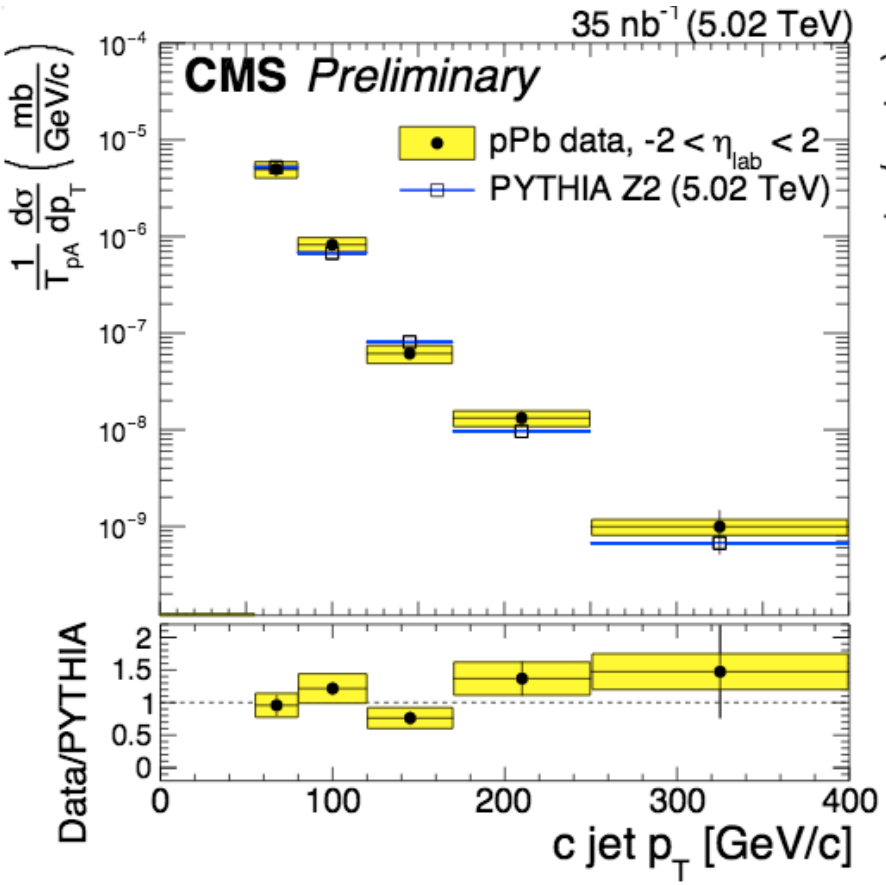


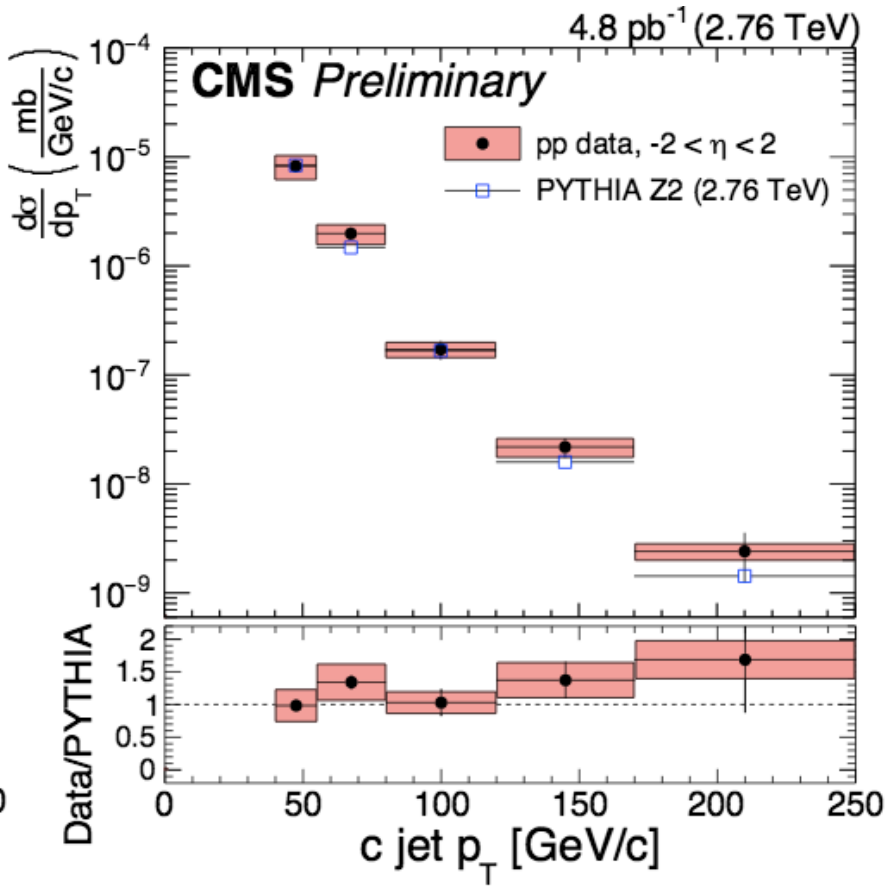
Feed into template shapes – charm jet contribution extracted

CMS-PAS-HIN-15-012

C-Jet R_{pA}!!!

CMS-PAS-HIN-15-012





- First charm jet measurement in heavy-ion collisions!
  - pPb and pp tackled so far – both consistent with PYTHIA predictions
    1.00 +/- 0.19 (stat.+syst. pPb) 1.15 +/- 0.27 (stat.+syst. pp)
  - Charm jet fraction (not shown) also consistent with PYTHIA

Conclusion

- Data doesn't show siginificant deviation with existing nPDF and pQCD calculations
- Changes to the PbPb FF doesn't appear to be a cold nuclear matter effect. pPb FF consistent based on q/g based interpolation
- In the high pT range observed, parton flavor doesn't affect the nuclear modification factor (compared to PYTHIA)
- Results checks in progress with latest pp data @ 5.02 TeV (look forward to new results very soon!)

Backup Slides