Jet and Charged Hadron R_{AA}

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on behalf of the CMS Collaboration

4th Heavy-Ion Jet Workshop
École Polytechnique
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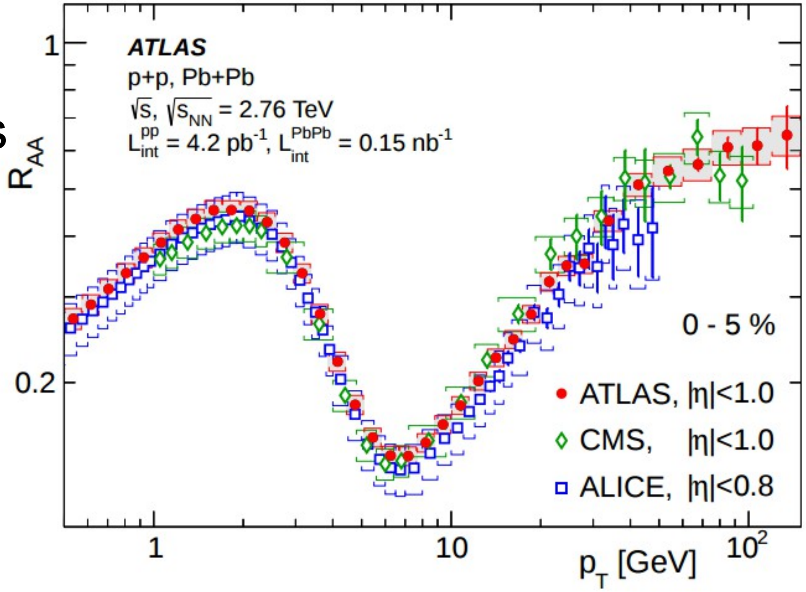
R_{AA} Motivation

- Jet R_{AA} - direct measurement of jet energy loss
  - Hides how the remaining energy is distributed among remaining jet constituents

$$R_{AA}(p_T) = \frac{d^2N_{ch}^{AA}/dp_T\,d\eta}{\langle T_{AA}\rangle\, d^2\sigma_{ch}^{pp}/dp_T\,d\eta}$$

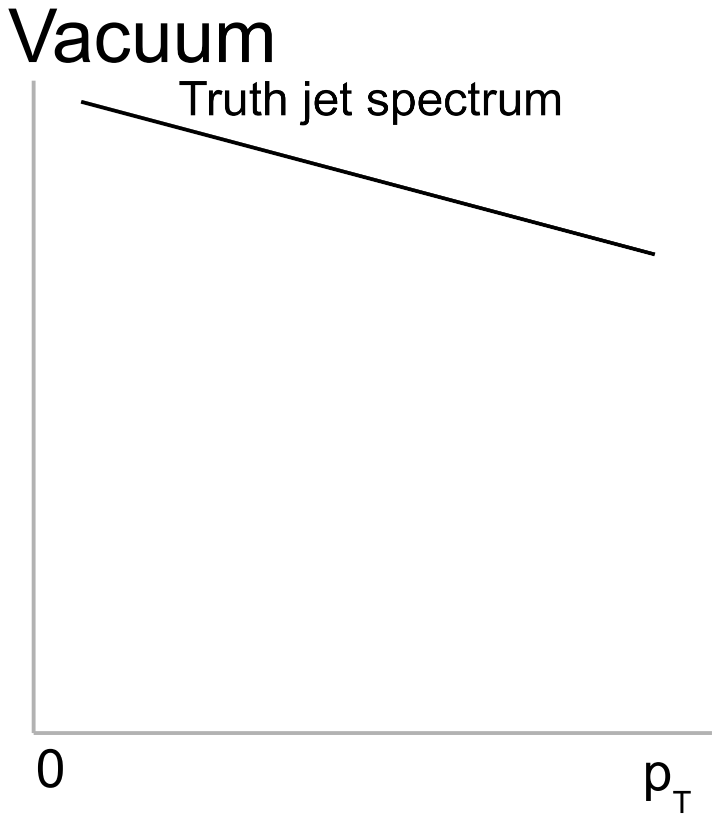
- Charged particle R_{AA} contains wealth of information
  - Initial state shadowing
  - Hydrodynamic flow
  - N_{coll} vs. N_{part} scaling
  - **Jet quenching**
  - Reference for heavy flavor measurements
    - (See Gian Michele's talk from Tues.)
- Both R_{AA}'s sensitive to path length, temperature, medium interaction strength
- Will focus on the high-p_T region to examine relationship with jet R_{AA} in this talk

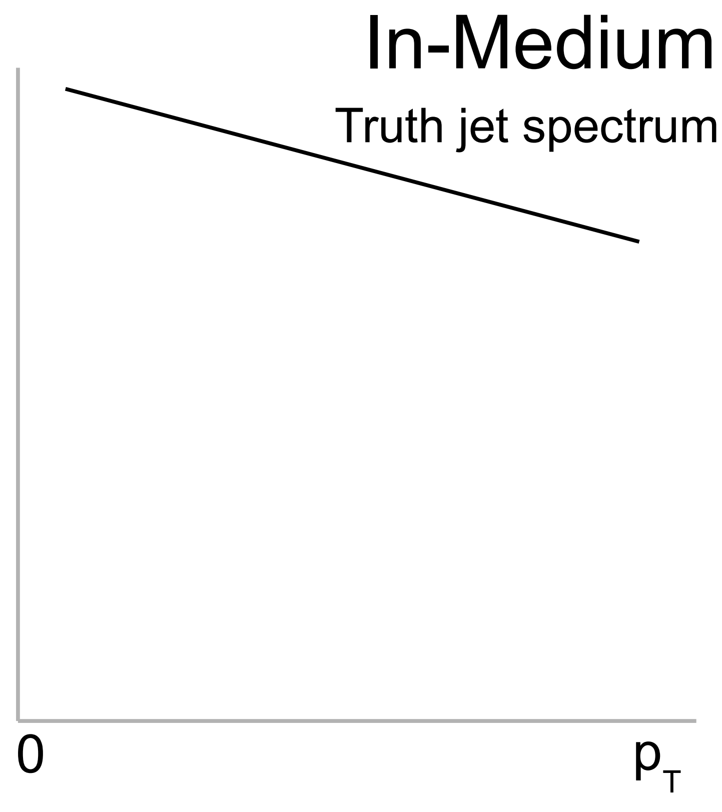
JHEP 1509 (2015) 050



R_{AA}'s and Energy Loss

- Interpreting both R_{AA}'s in terms of energy loss can be complicated:





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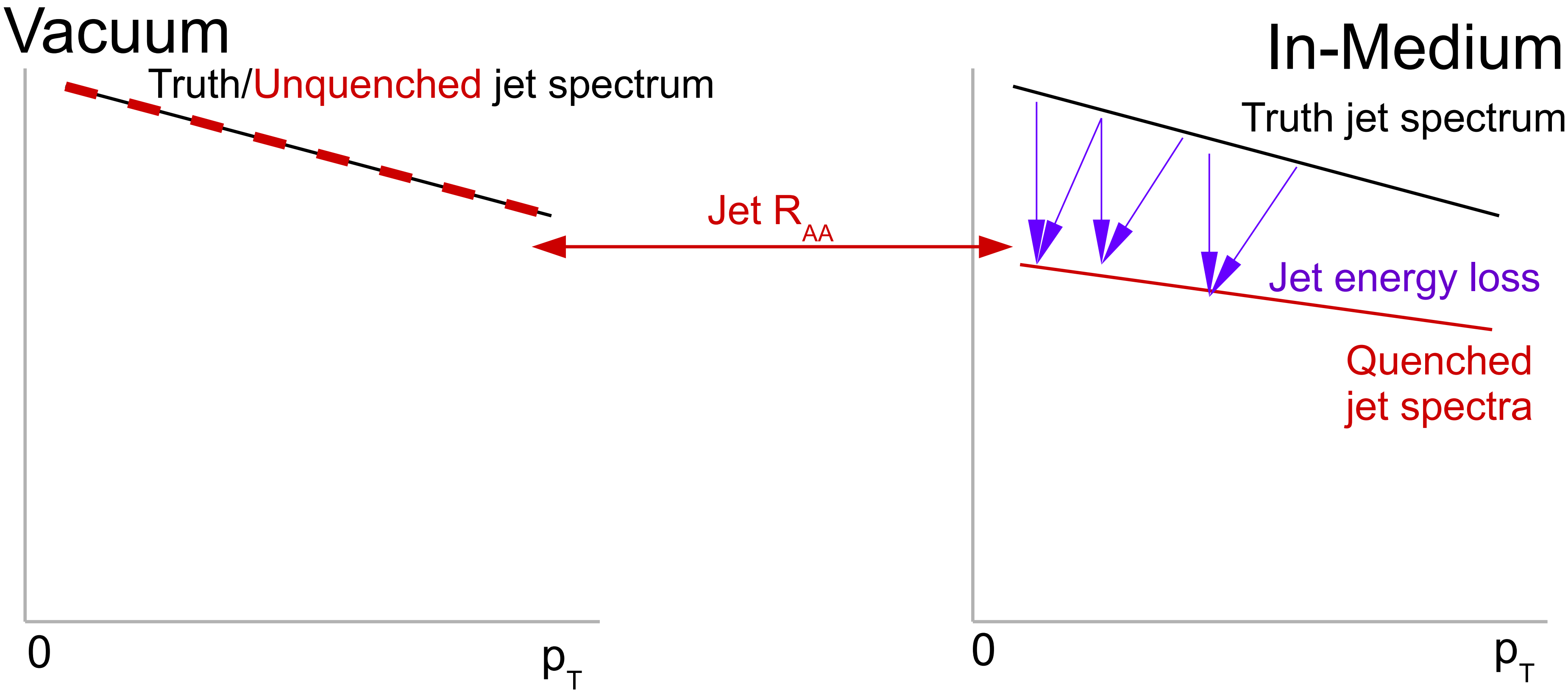

- Details of feed down due to energy loss affects jet R_{AA}

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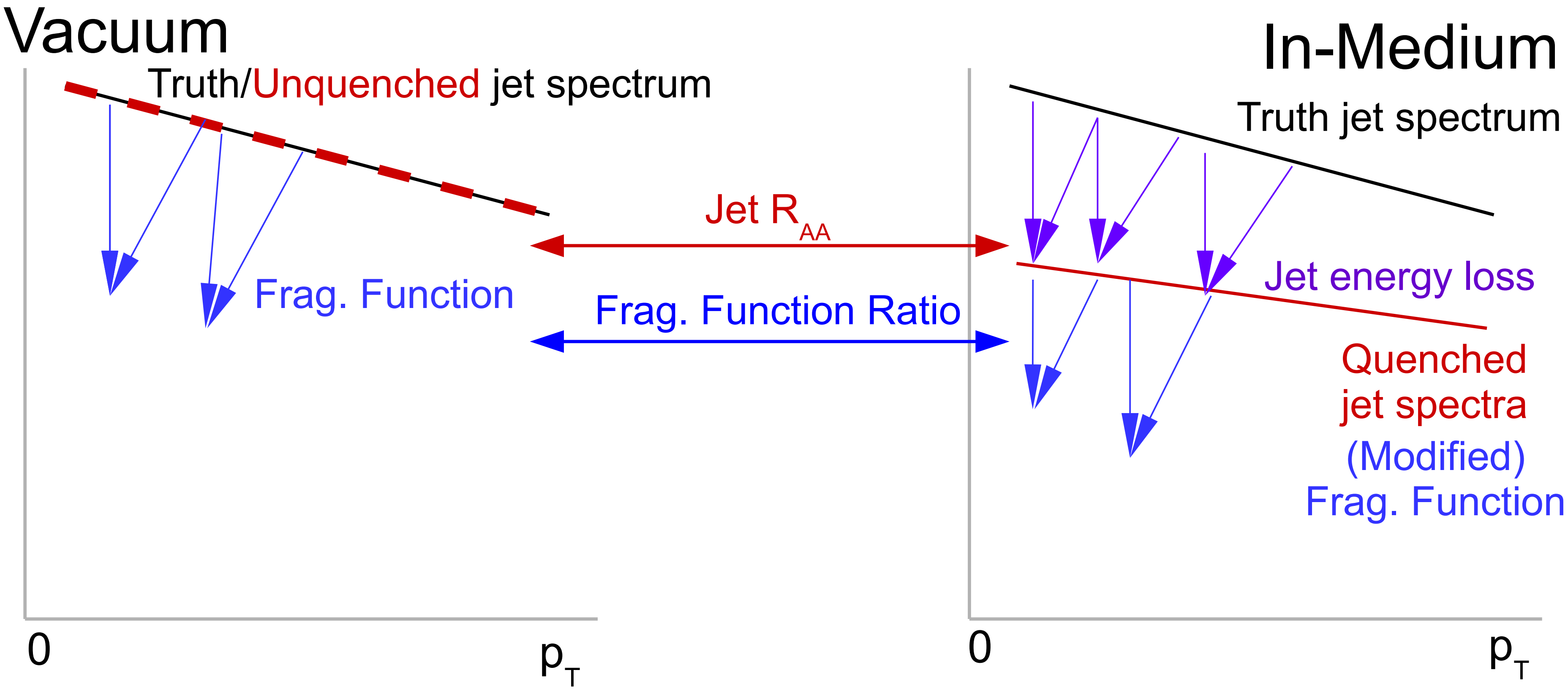

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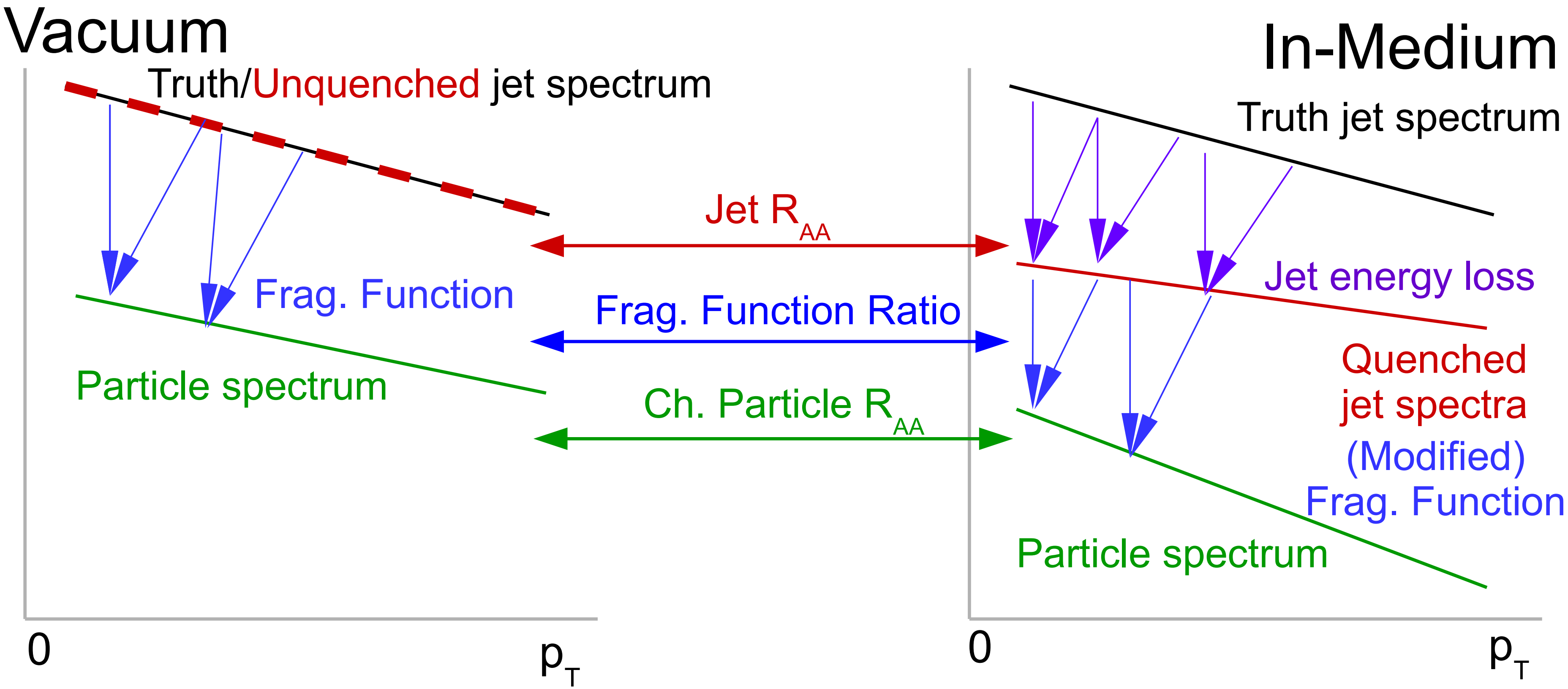
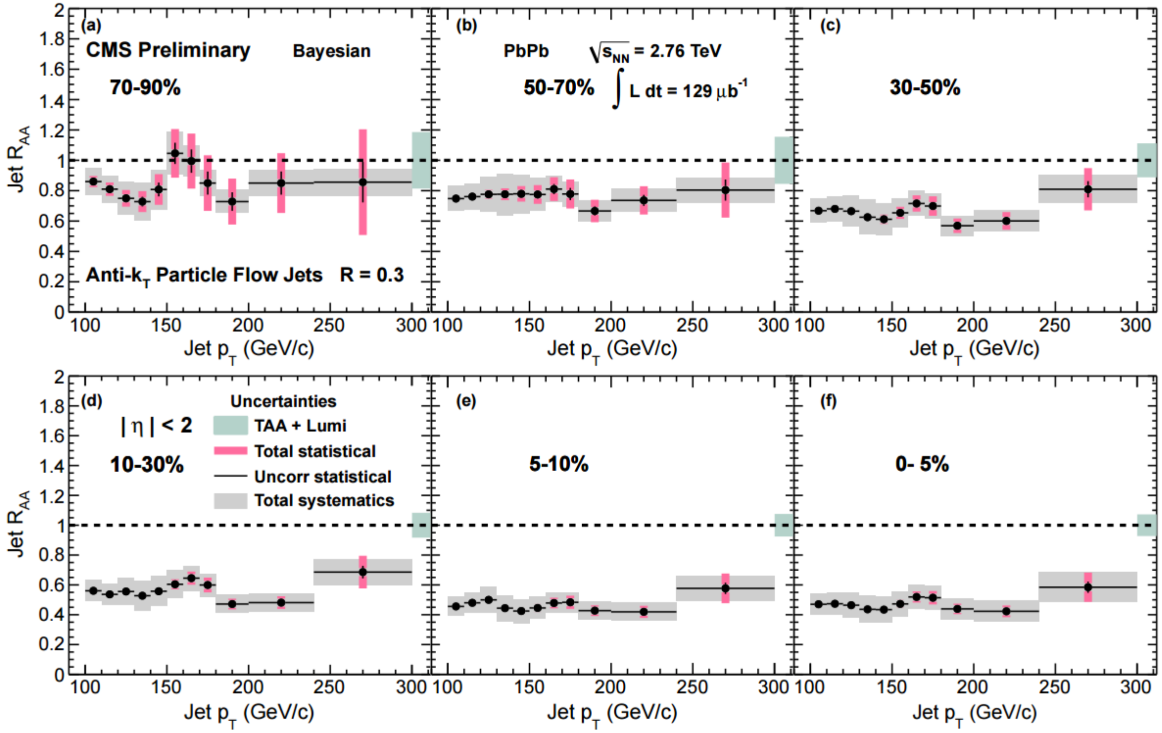
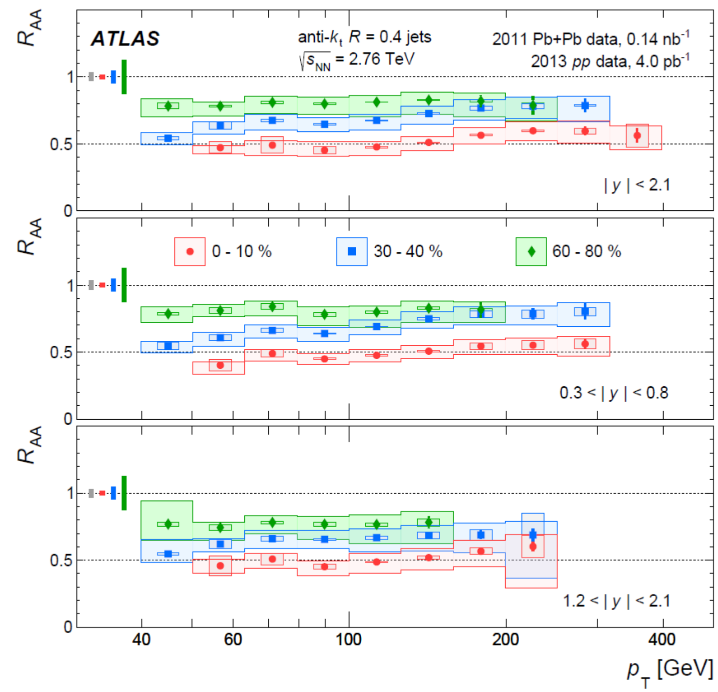


- Details of feed down due to energy loss affects jet R_{AA}
- Feed down through modified Frag. Functions affects ch. particle R_{AA} as well

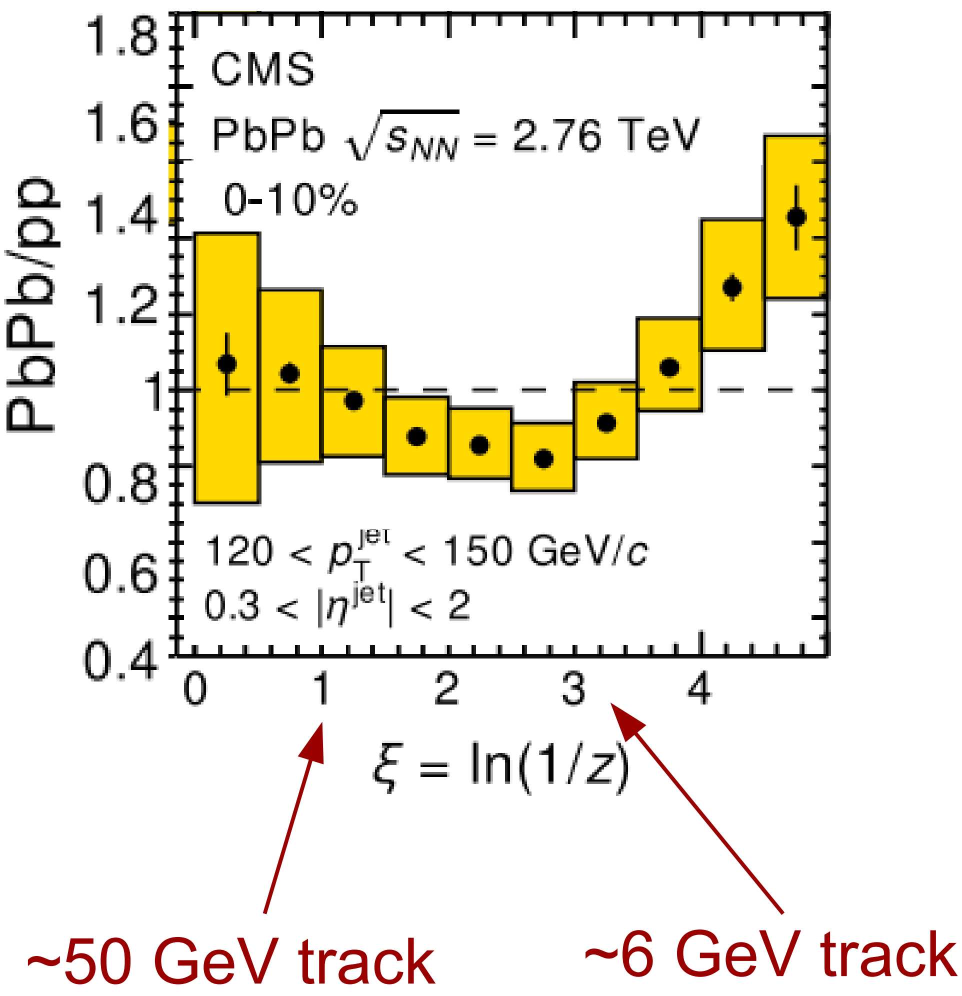
2.76 TeV Jet R_{AA}



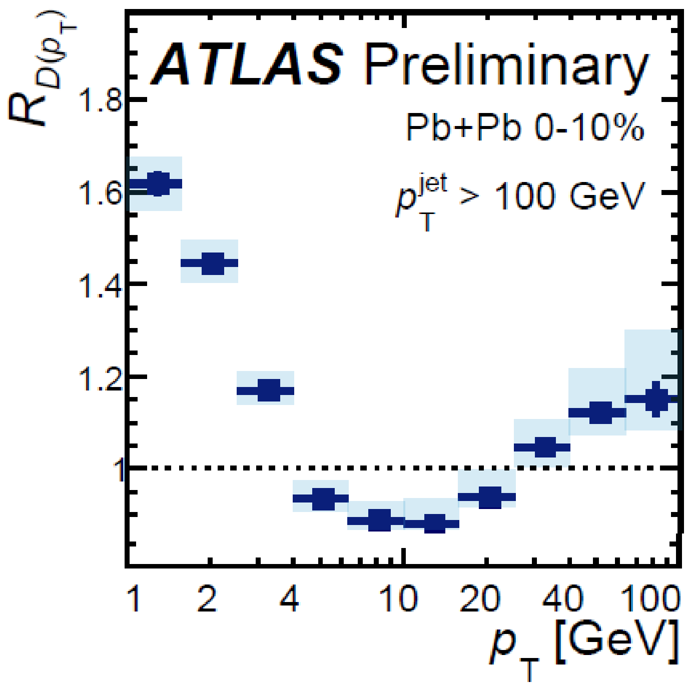


- CMS R_{AA} scales from 0.8 to 0.5 with centrality
  - Roughly flat last bin higher
- ATLAS - similar scaling with centrality
  - Slight increasing slope seen with p_T

2.76 TeV Fragmentation Function Ratio



- Fragmentation function ratio within +/- 20% of unity
  - Expect charged particle R_{AA} to be similar in magnitude to jet R_{AA}



2.76 TeV Charged Particle R_{AA}

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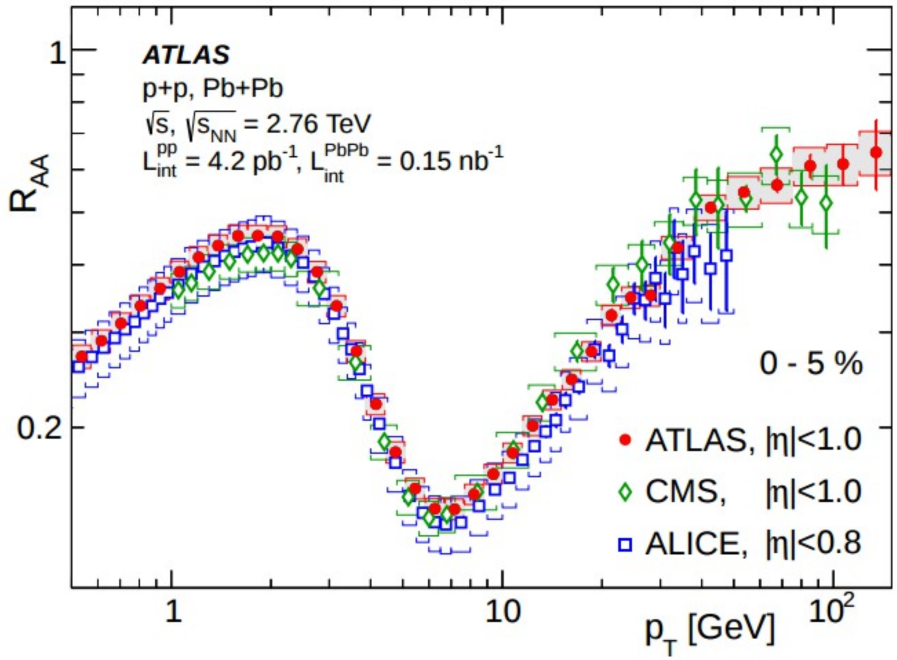


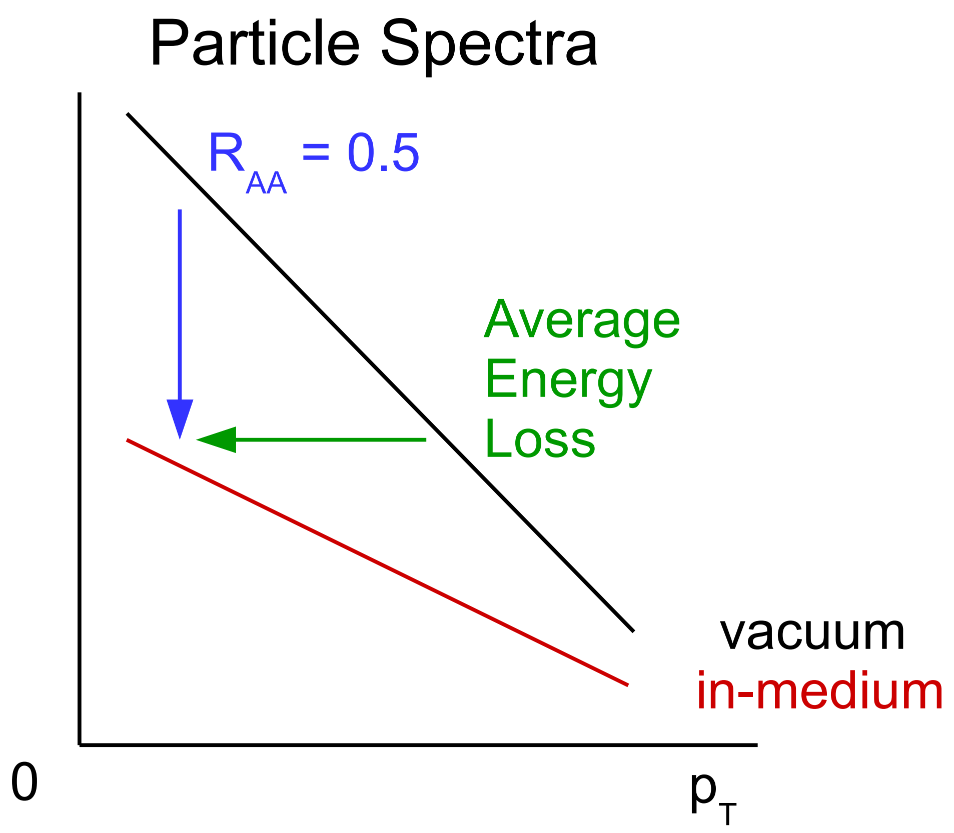
- High pT observed to be 0.5-0.6 with slowly rising slope
  - Approximately the same as the jet R_{AA} value

- Does the distribution plateau at 0.6 or keep rising?
- What is the dependence on collision energy?
  - … and are models fit to 2.76 TeV able to predict it?

5.02 TeV Charged Particle R_{AA}

R_{AA} and Collision Energy

- Increasing energy loss and collision energies have opposite effects on R_{AA}



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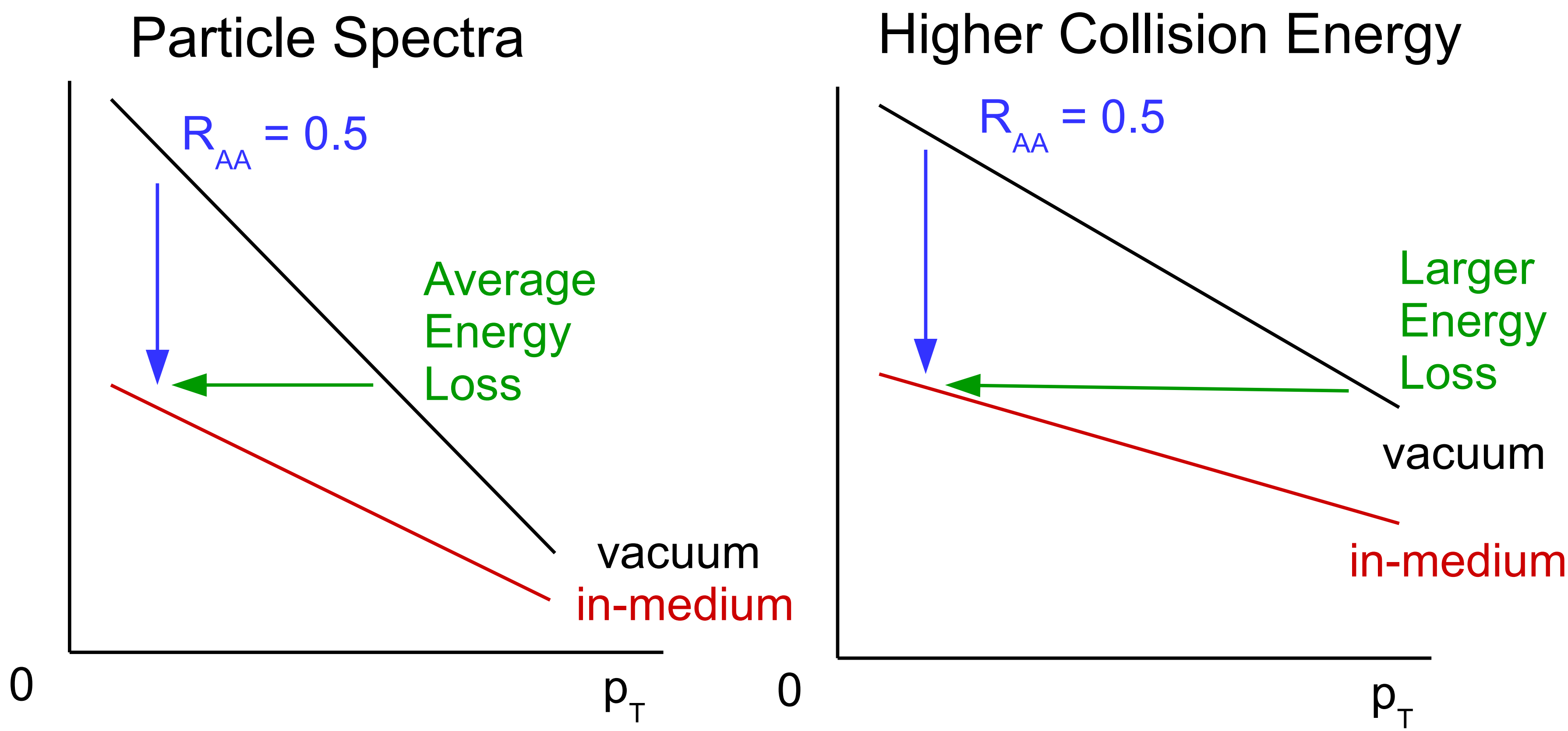
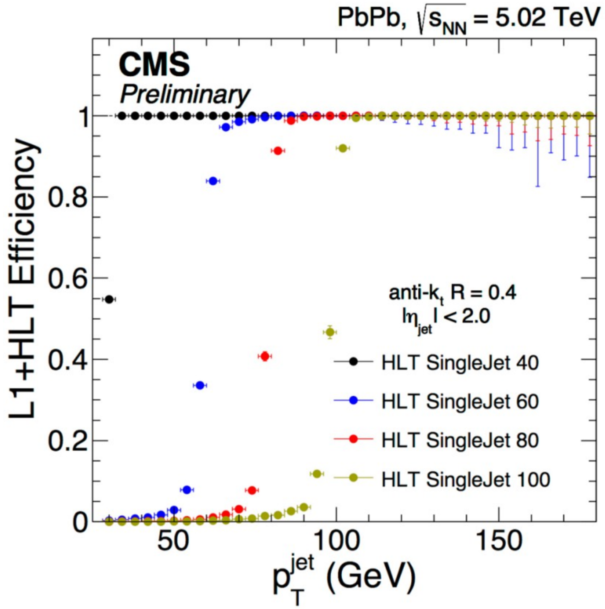


- Different energy losses can lead to same R_{AA} if spectrum shape changes

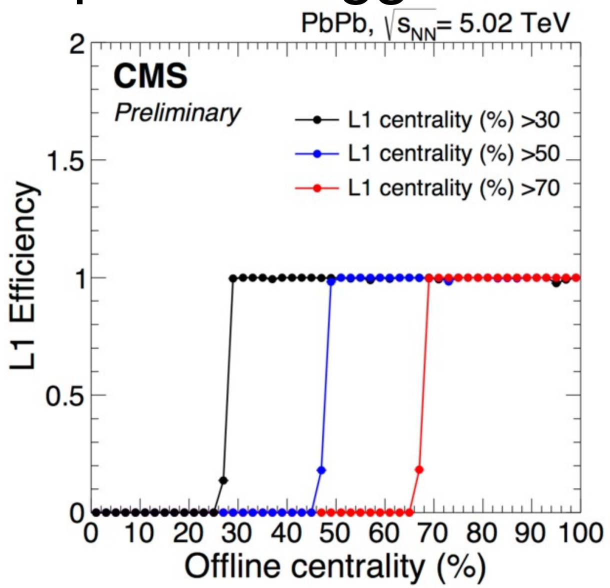
Dataset

- 404 μb-1 (PbPb) and 25.8 pb-1 (pp) from Fall 2015
  - Previously 150 μb^{-1} (PbPb) and 0.23 pb^{-1} (pp) at 2.76 TeV
- Minimum Bias and Jet Triggers
  - Peripheral triggers boost statistics in 30-100% and 50-100%
- Checked with high-pT track triggers
- 28 triggers total – High statistics; reach up to 400 GeV

Jet Triggers



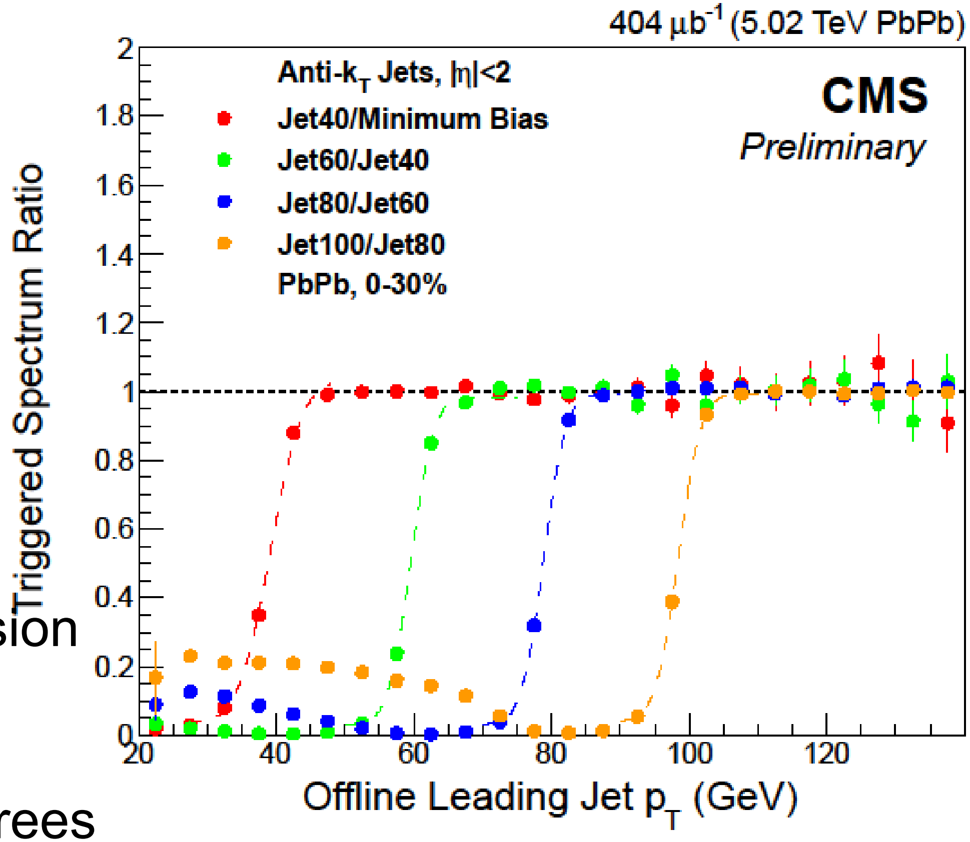
Peripheral Triggers



Trigger Combination

- Take distributions of leading jet pT with |η|<2
- Ratio of number of jets from each trigger in pT region of constant efficiency

$$Scale|_{jet40} = \frac{N^{MB}_{pt>60}}{N^{jet40}_{pt>60}}$$



- Compare jet 60 with jet 40, etc.
- Done for 0-30%, 30-50%, 50-100%
  - Scale factors different due to inclusion of peripheral triggers

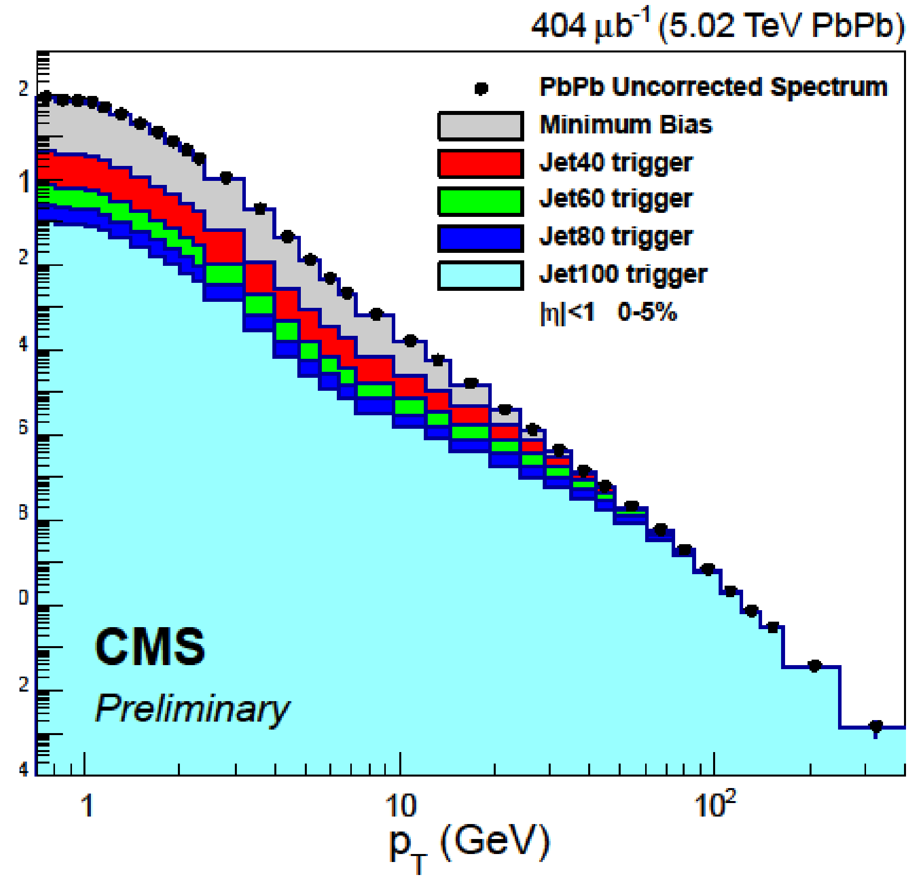
- Scaled leading jet pT distribution agrees

Building PbPb Spectra

- At given leading jet pT, count tracks originating only from the highest fully efficient trigger
  - Require track |η|<1
- Repeated using leading track pT and track triggers in both PbPb and pp

- Normalization
  - PbPb – Number of MB events
  - pp – luminosity
    - Inelastic event class
    - Scaled by TAA from Glauber

- Spectra corrected for efficiency and misreconstruction track-by-track



R_{AA} Systematics

Sources	Uncertainty [%]
Event-selection correction	<1
Momentum resolution	1.5
Particle species composition	1.5–15.5
Fraction of misreconstructed tracks	3
Tracking correction non-closure	5
Tracking efficiency	6.5
Track selection	4
Pileup	3
Trigger combination	0–2.5
Luminosity	12
Glauber-model uncertainty	1.7–16
R_{AA} uncertainty	10–17

- CMS track momentum resolution is very good – no unfolding is applied

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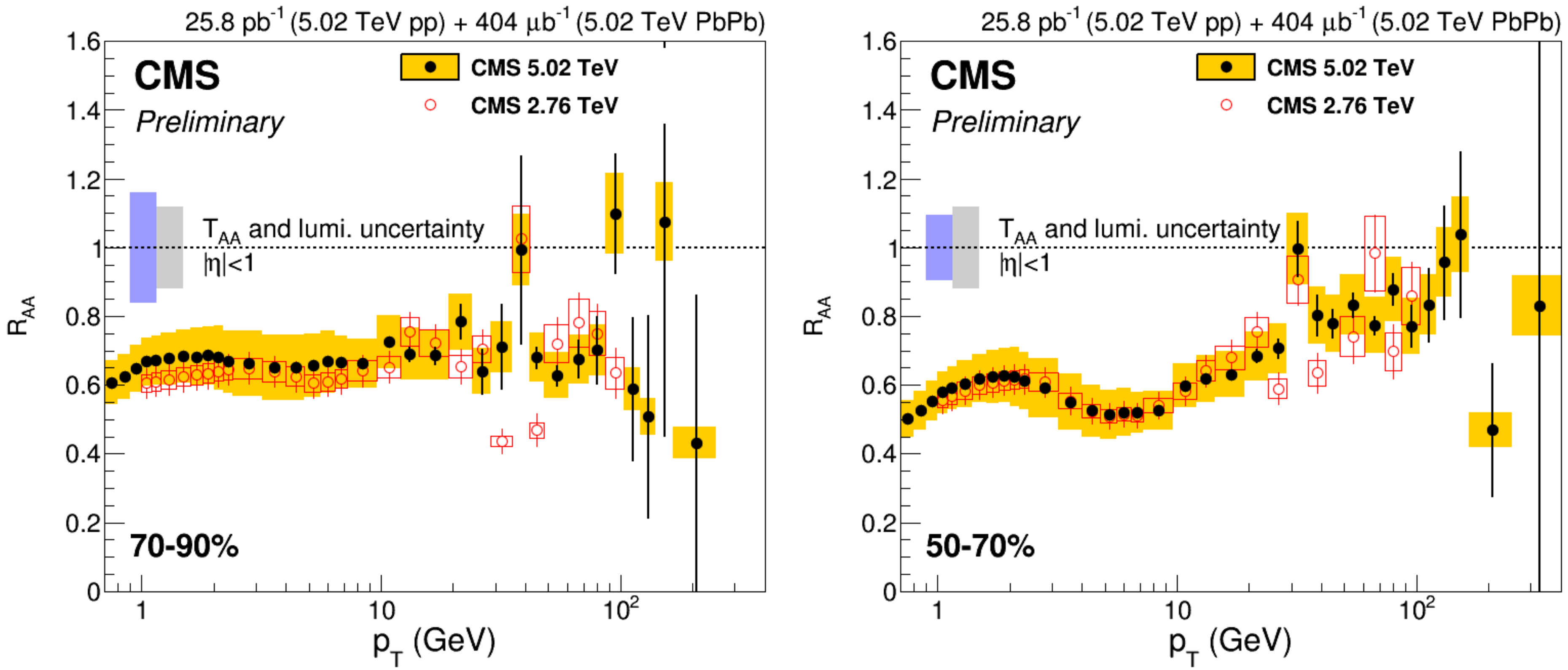
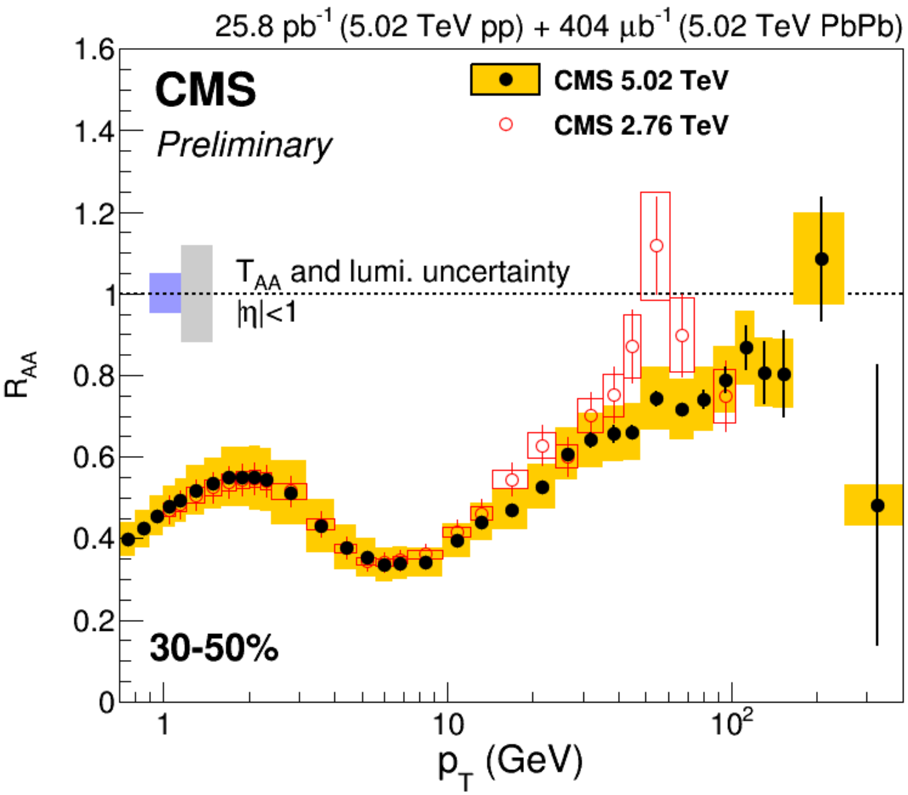
- CMS track momentum resolution is very good – no unfolding is applied
- 6.5% uncertainty from data-driven studies of tracking efficiency using decays from D* mesons in pp and variation of track selections in PbPb
- R_{AA} uncertainty: 10-17% not including 12% from pp luminosity (expected to improve in the future) and Glauber uncertainty

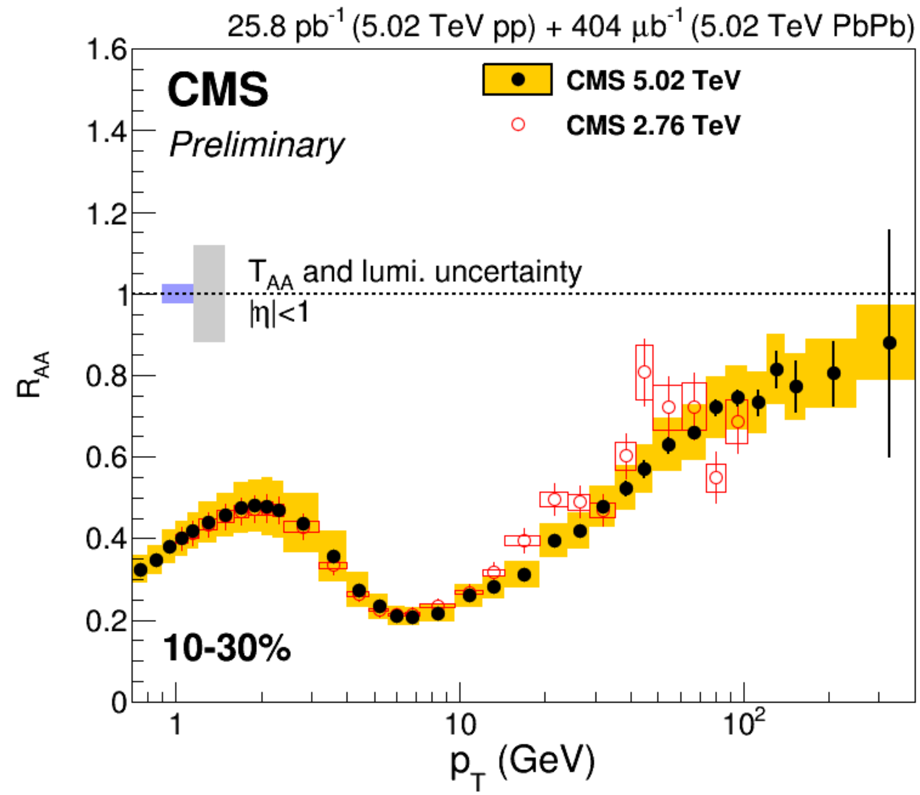
Peripheral R_{AA}



- Peripheral RAA is fairly flat at ~0.65 up to ~100 GeV
  - Same value as previous CMS measurement at 2.76 TeV
  - Large Glauber uncertainty

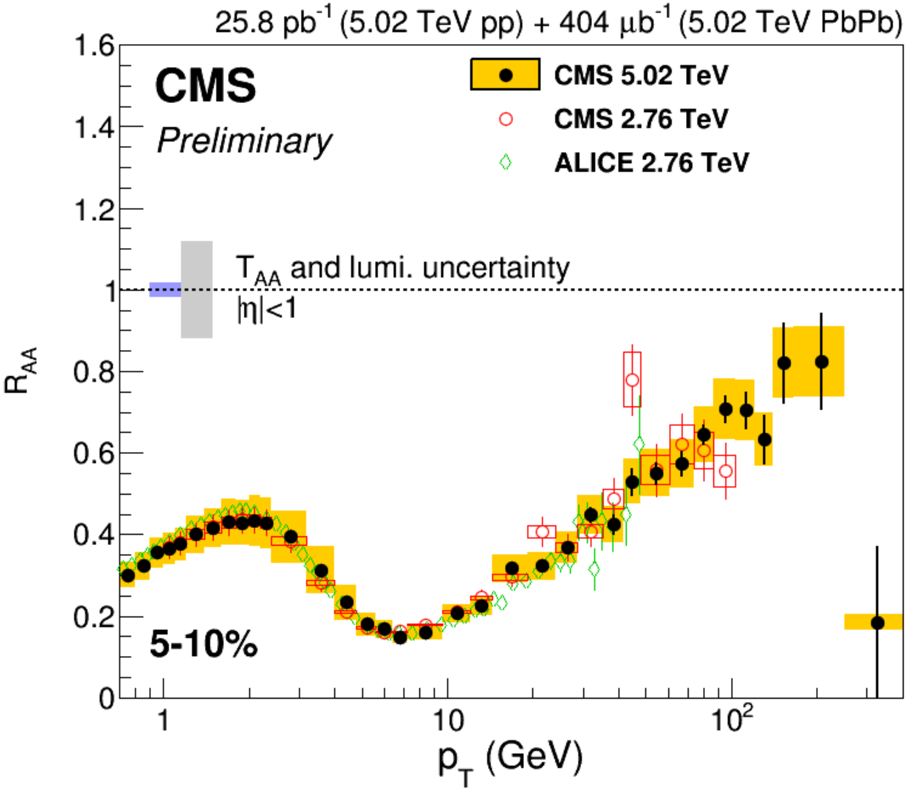
Mid-Central R_{AA}

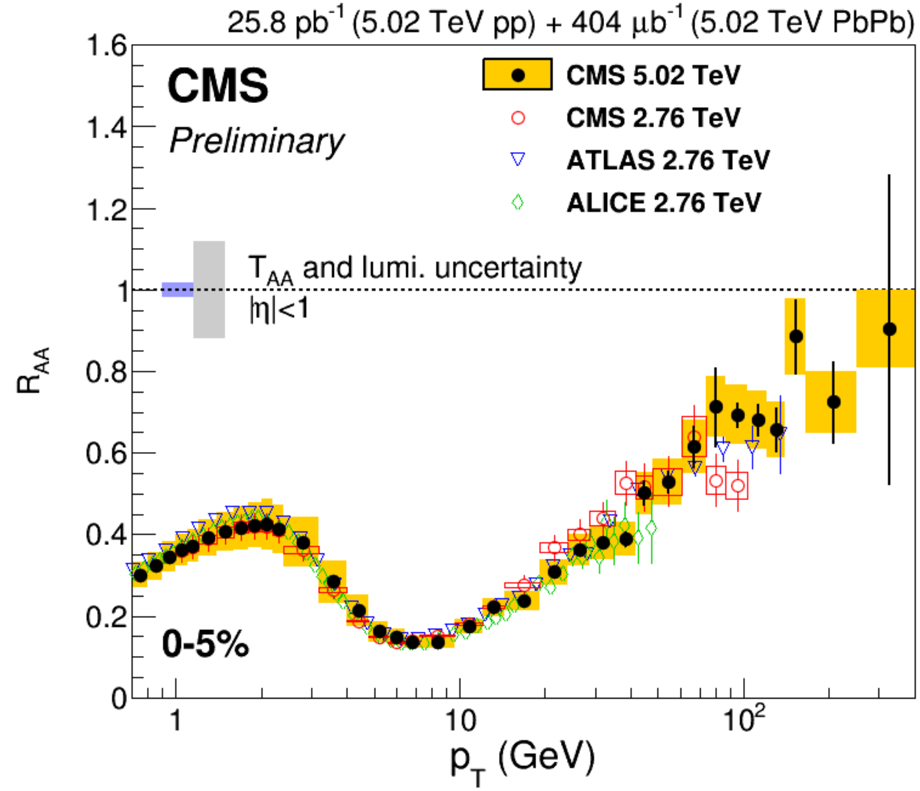




- Slightly more suppression seen than in 2.76 TeV
- 10-30% suppressed by a factor of ~5 at 10 GeV, but only 1.2 at 400 GeV

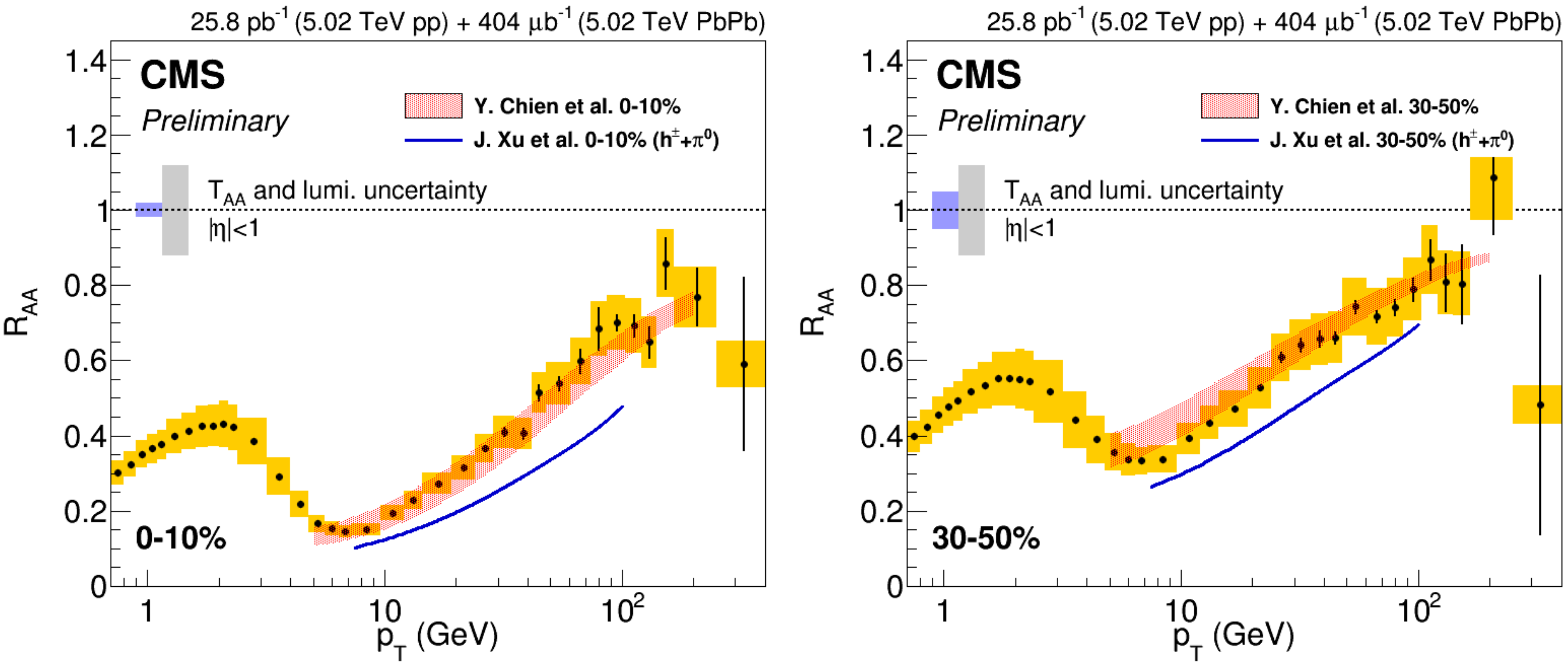
Central R_{AA}





- Rising trend in central events continues well past 80 GeV
- No strong increase in suppression as compared to 2.76 TeV data in central events
  - Doesn't necessarily mean energy loss is the same!

Comparison with Models

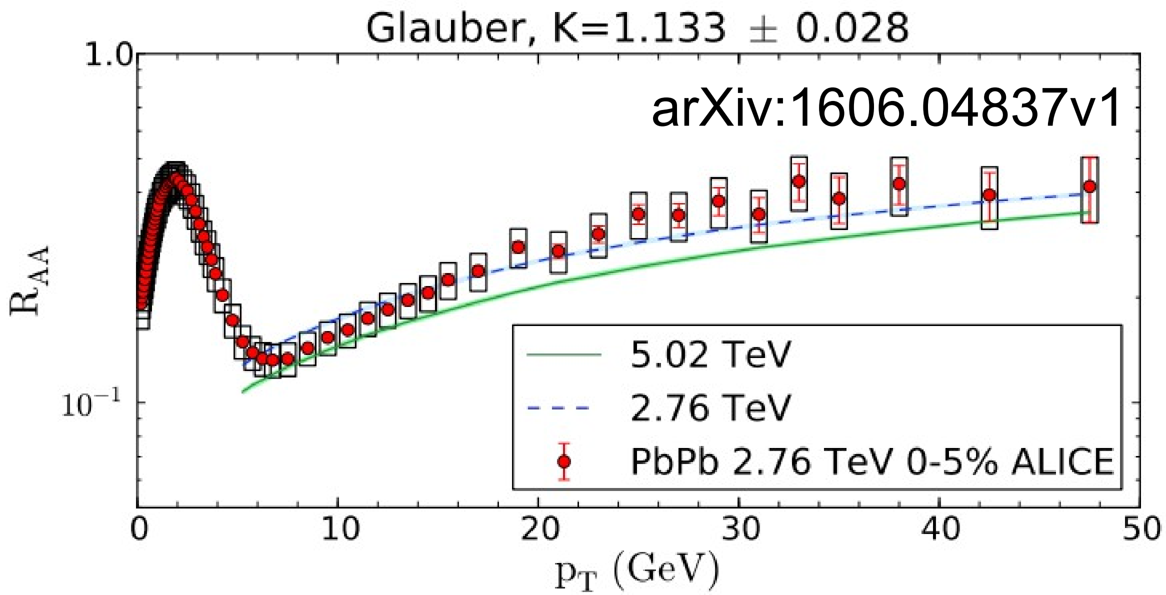


- $SCET_G$ - QCD evolution with in-medium splitting functions
  - Y. Chien et al. arXiv:1509.02936 (with cold nuclear matter effects)
- CUJET 3.0 Model
  - J. Xu et al. JHEP 1602 (2016) 169

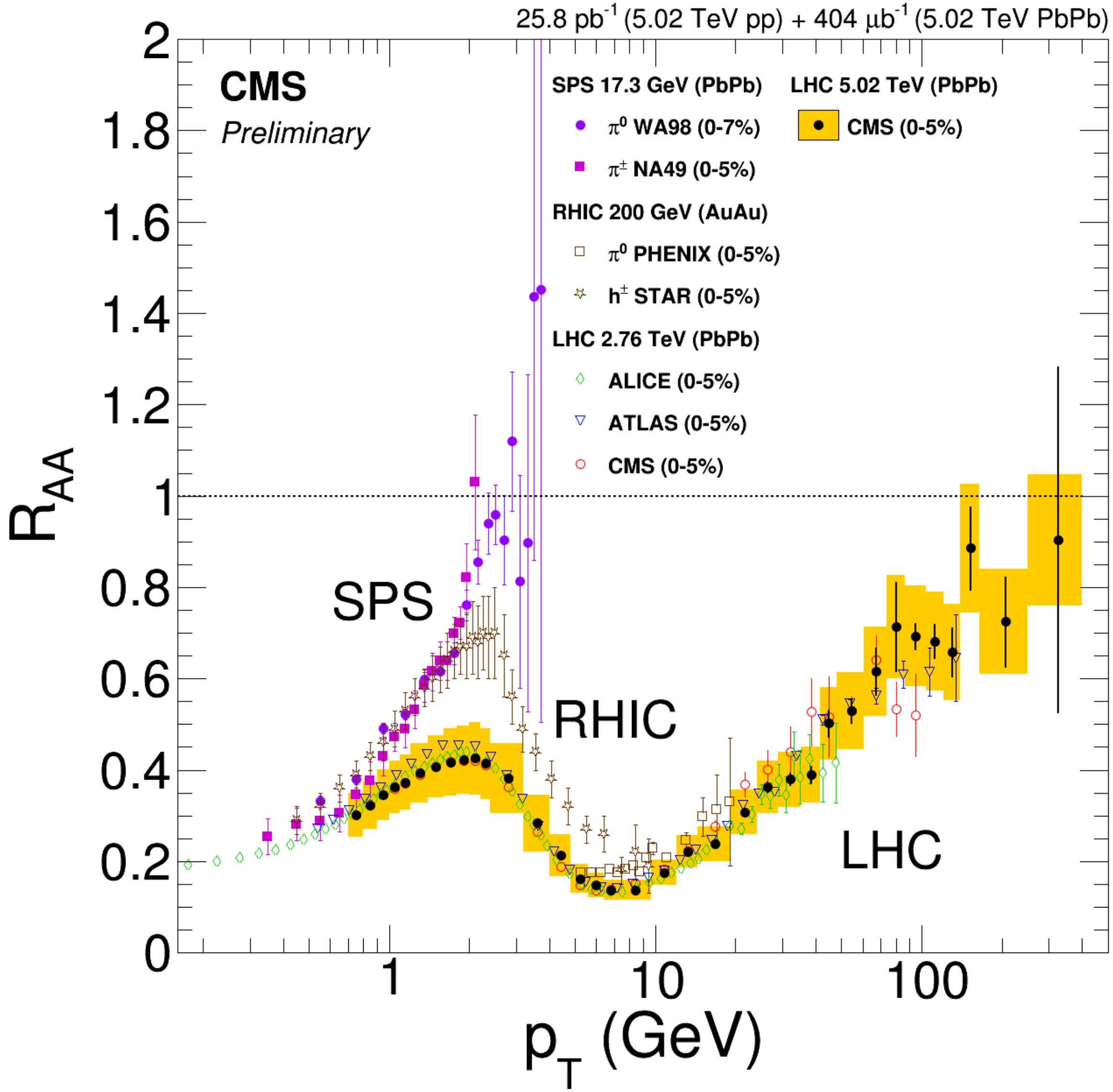
Comparison with Models (II)

- Andrés C. et al. Model:
  - Define jet quenching parameter: $\hat{q} = 2K\,\epsilon^{3/4}$
  - Fit K for each beam energy, centrality bin (RHIC and LHC data)

- "K-factor does not seem to depend on the medium parameters, e.g., the temperature, but instead on the center of mass energy..."
- Undershoots our new R_{AA} measurement
- Authors noted that increasing K by 10% would produce better agreement

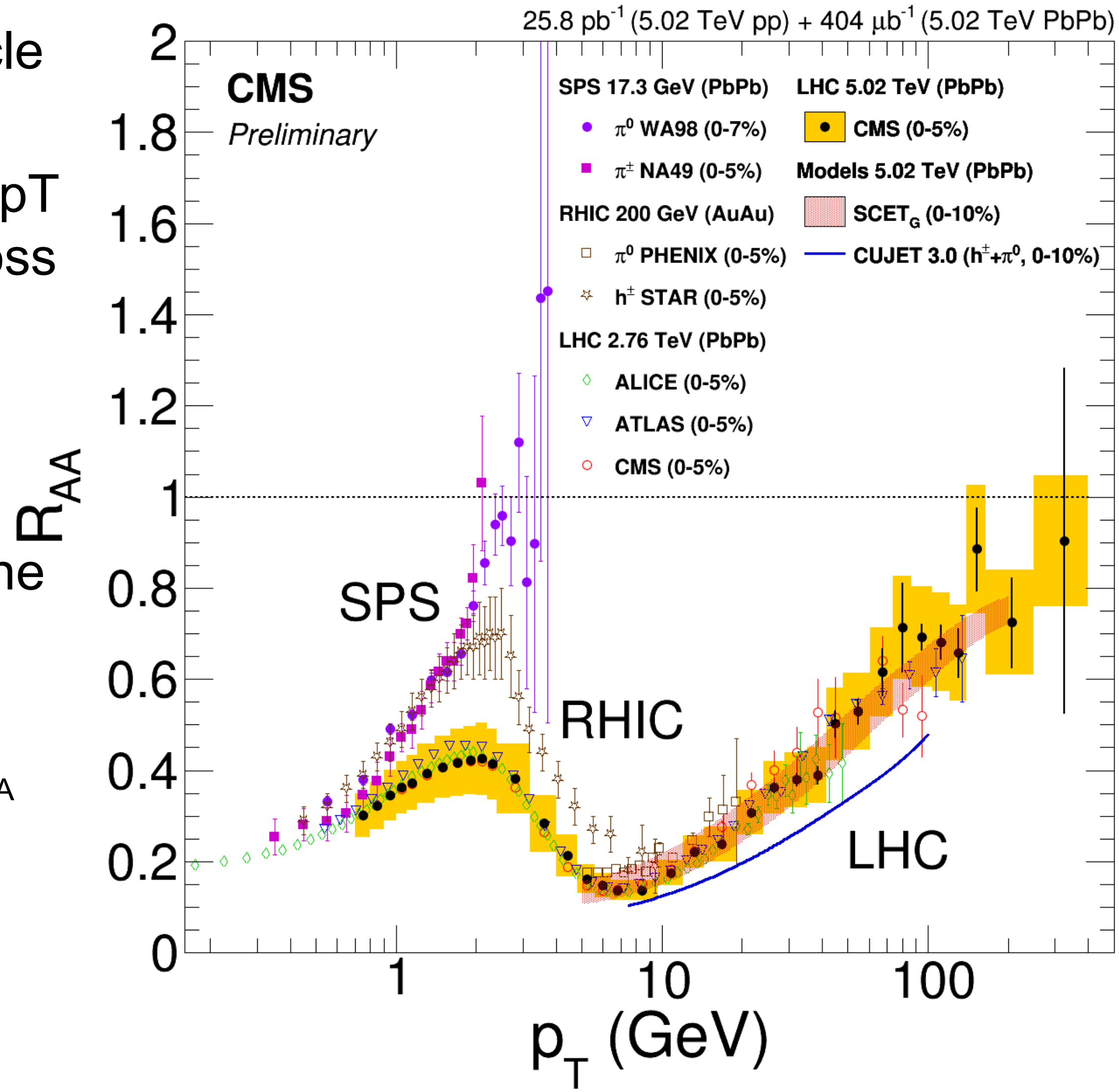


R_{AA} Compilation



5 TeV R_{AA} Conclusions

- CMS measured first ch. particle R_{AA} at 5 TeV to 400 GeV
  - Significant increase in high-pT reach to constrain energy loss models
- Central suppression at 5 TeV looks similar to 2.76 TeV
  - Doesn't necessarily mean the energy loss is the same!
- Comparison with 5 TeV jet R_{AA} (and FF) will be interesting to see if high p_T also trends to 1

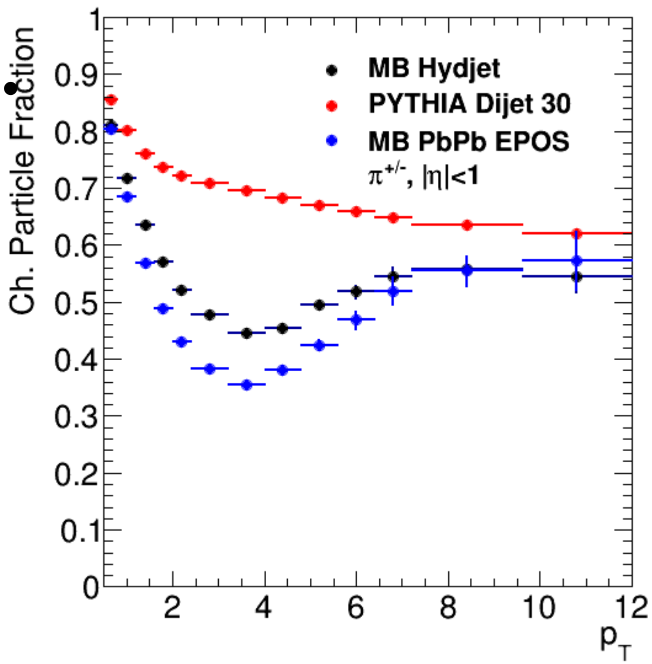


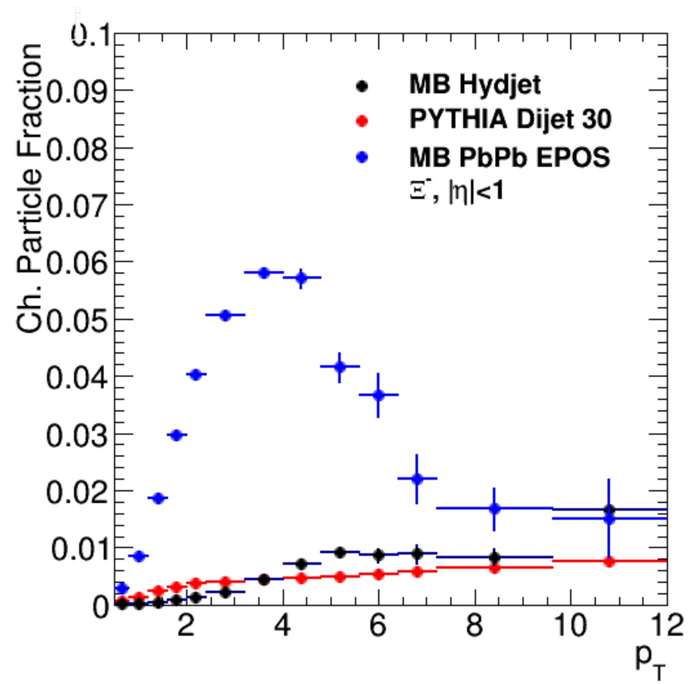
CMS-PAS-HIN-15-015

Thank You!

Corrections

- Efficiency, misreconstruction corrections applied on track-by-track basis
  - PYTHIA or PYTHIA+Hydjet
- Correct for changing primary particle composition as a function of centrality
  - □,□□,□□have a much lower efficiency than □,K, p
  - Few data-based constraints on strangeness enhancement vs. centrality
    - Correction reweighted halfway between PYTHIA and EPOS
    - Affects the 3-6 GeV region where models differ the most





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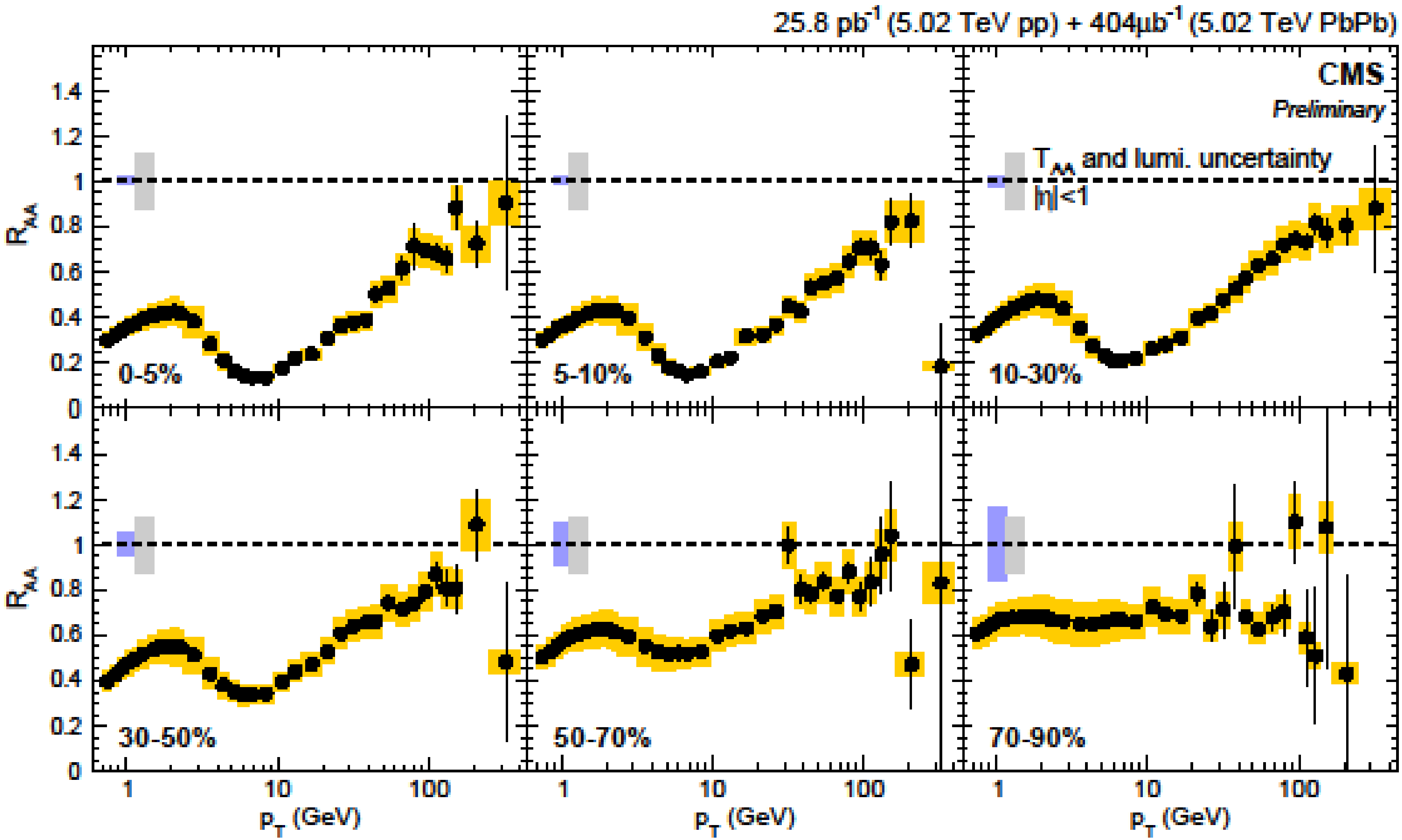
- Particle species correction is the leading systematic in 3-6 GeV range

All Centrality Bins



With Comparisons