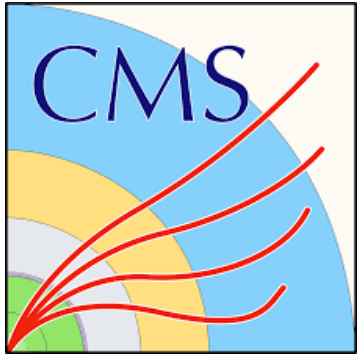


Hard Probes in heavy ion physics at ATLAS and CMS

Timothy Rinn for the
ATLAS and CMS collaborations

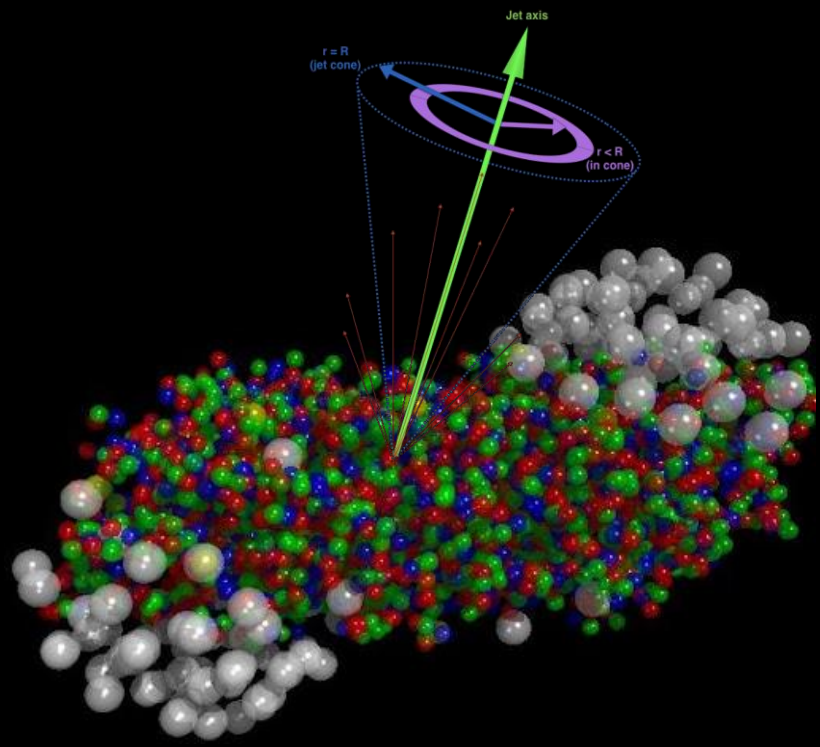
ILLINOIS

Hard Probes in Heavy Ion Collisions

- Heavy Ion collisions can produce a state of deconfined nuclear matter called the Quark Gluon Plasma (QGP)

- Hard probes allows us to study the properties of the QGP through comparisons to *pp collisions*

- Key hard probes discussed today:
  - Jets
  - Z-tagged particles
  - Heavy Flavor and quarkonia



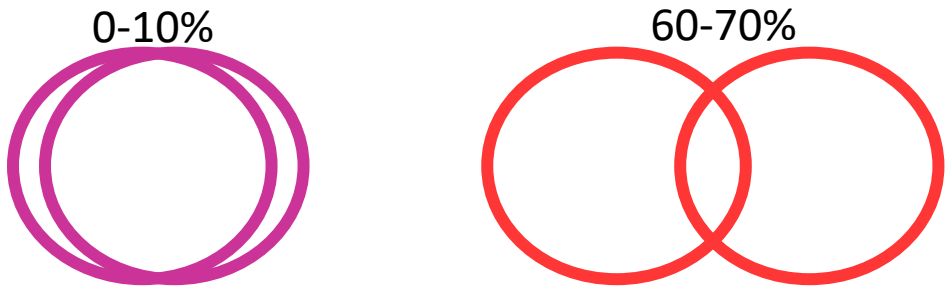
PhysLetB.2018.10.076

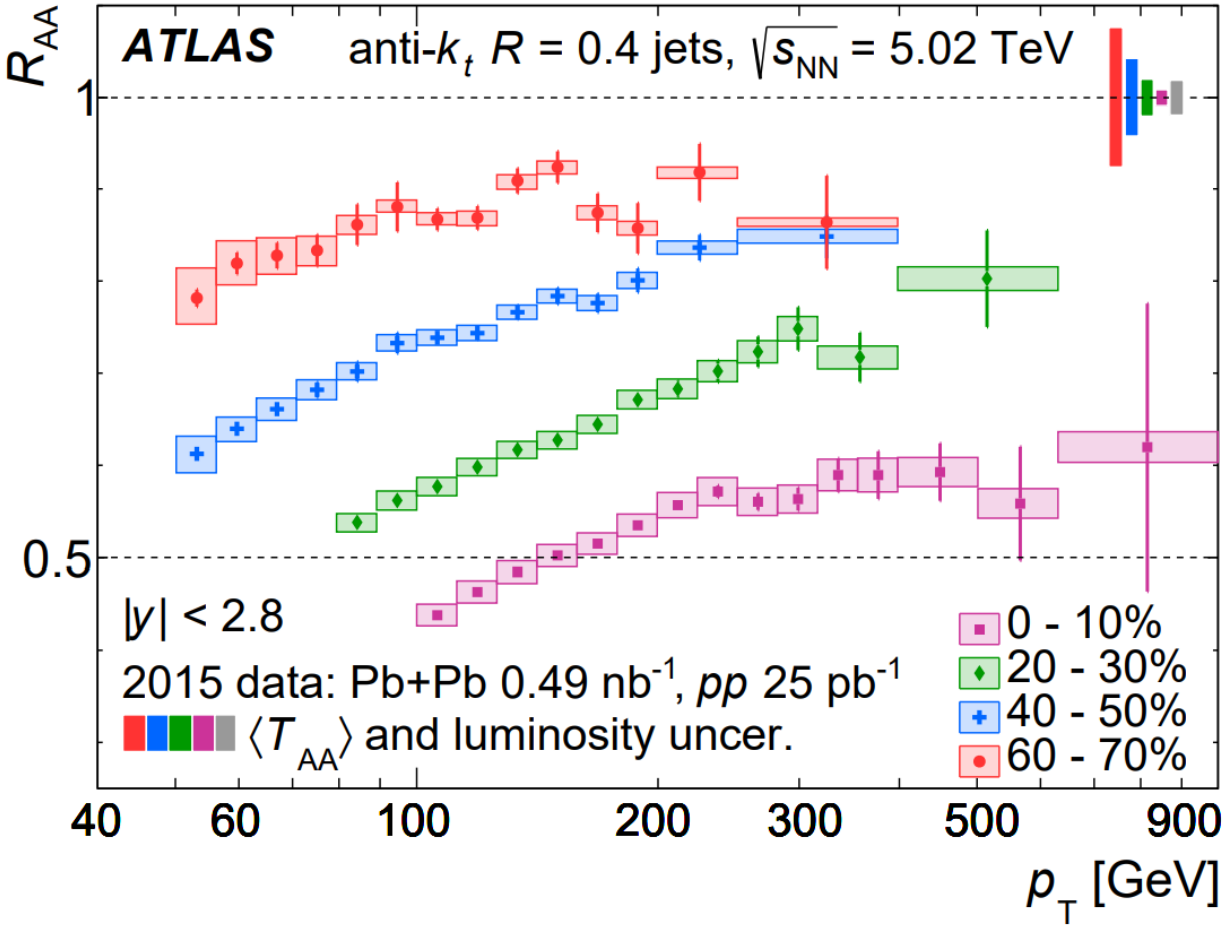
$$R_{AA} = \frac{\frac{1}{N_{evt}}\frac{dN_{PbPb}}{dp_T dy}}{\langle T_{AA}\rangle \frac{d\sigma_{pp}}{dp_T dy}}$$

Nuclear Modification of jet production

Partons produced in hard scattering lose energy as they traverse the nuclear medium resulting in 'jet quenching'

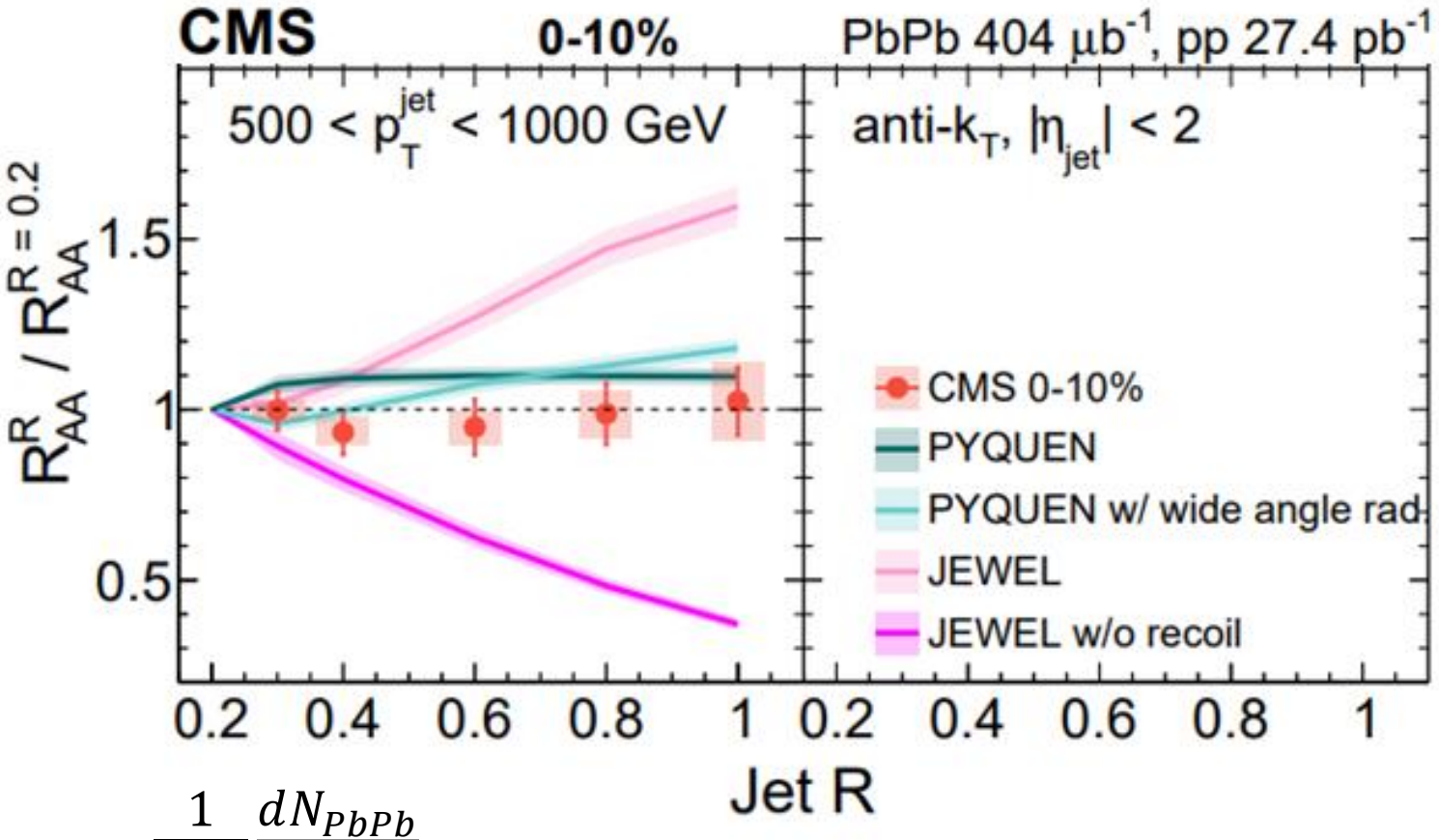
Significant energy loss for $R = 0.4$ jets is observed across centrality





arXiv:2102.13080

Nuclear modification factor: Radius Scan

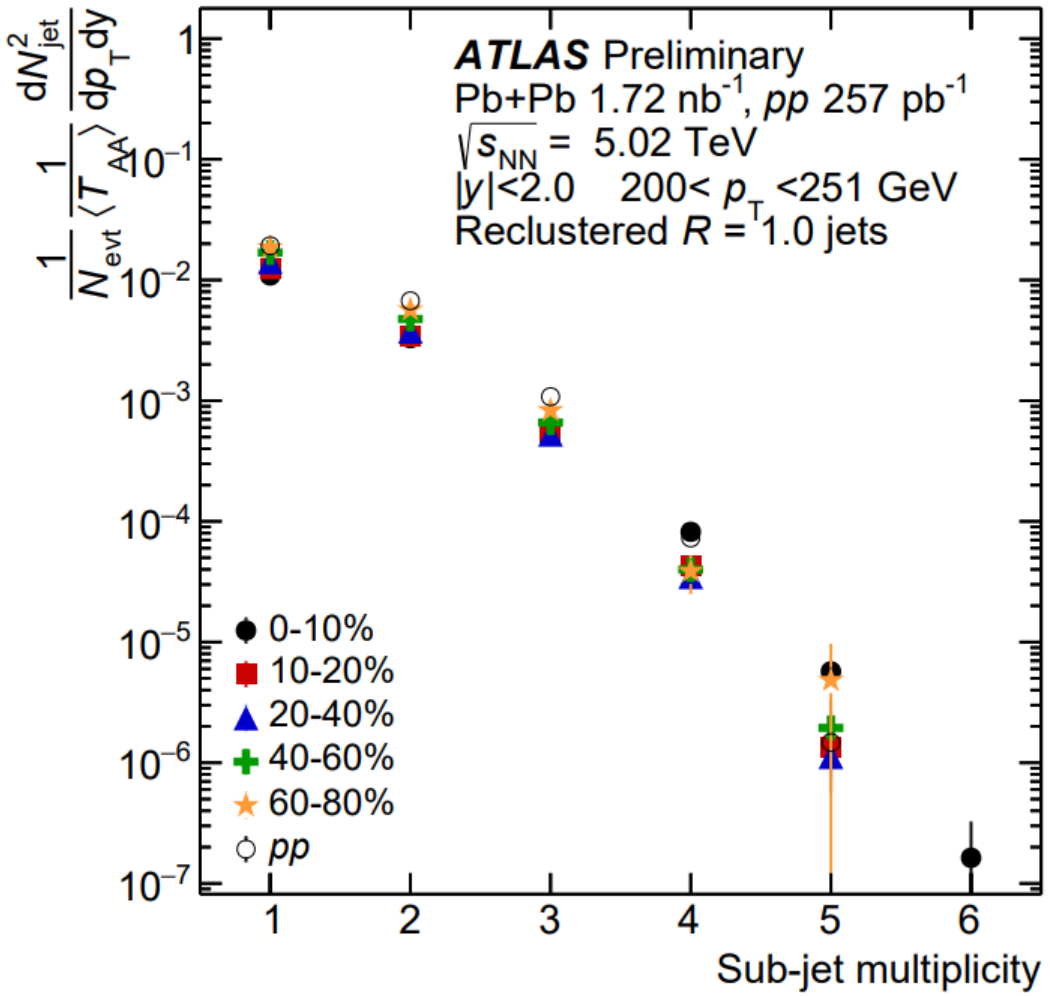


$$R_{AA} = \frac{\frac{1}{N_{evt}}\frac{dN_{PbPb}}{dp_T dy}}{\langle T_{AA}\rangle \frac{d\sigma_{pp}}{dp_T dy}}$$

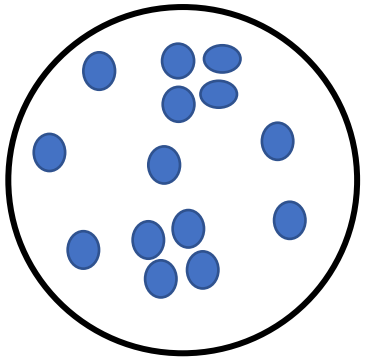
- Sensitive to balance between increasing radiative sources and recovering re-distributed energy
- Enables simultaneous comparisons of model calculations across jet Radii
- CMS observes no radius dependence to jet energy loss in central Pb+Pb for $500\ \mathrm{GeV} < p_{\mathrm{T}}^{Jet} < 1\ \mathrm{TeV}$

ATLAS-CONF-2019-056

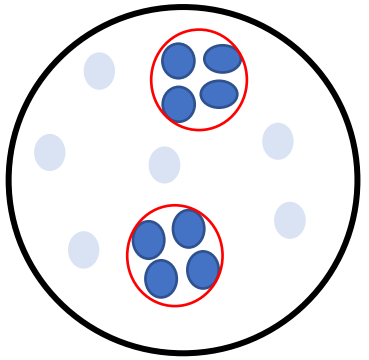
Reclustered Large R Jets:



Traditional R=1.0 Jet



Reclustered R=1.0 Jet



- R = 0.2 jets are reclustered using the anti-k_t algorithm to produce R = 1.0 jets
  - R = 0.2 jet $p_T > 35$ GeV
- Allows for the study of the jet quenching with respect to the macro structure.

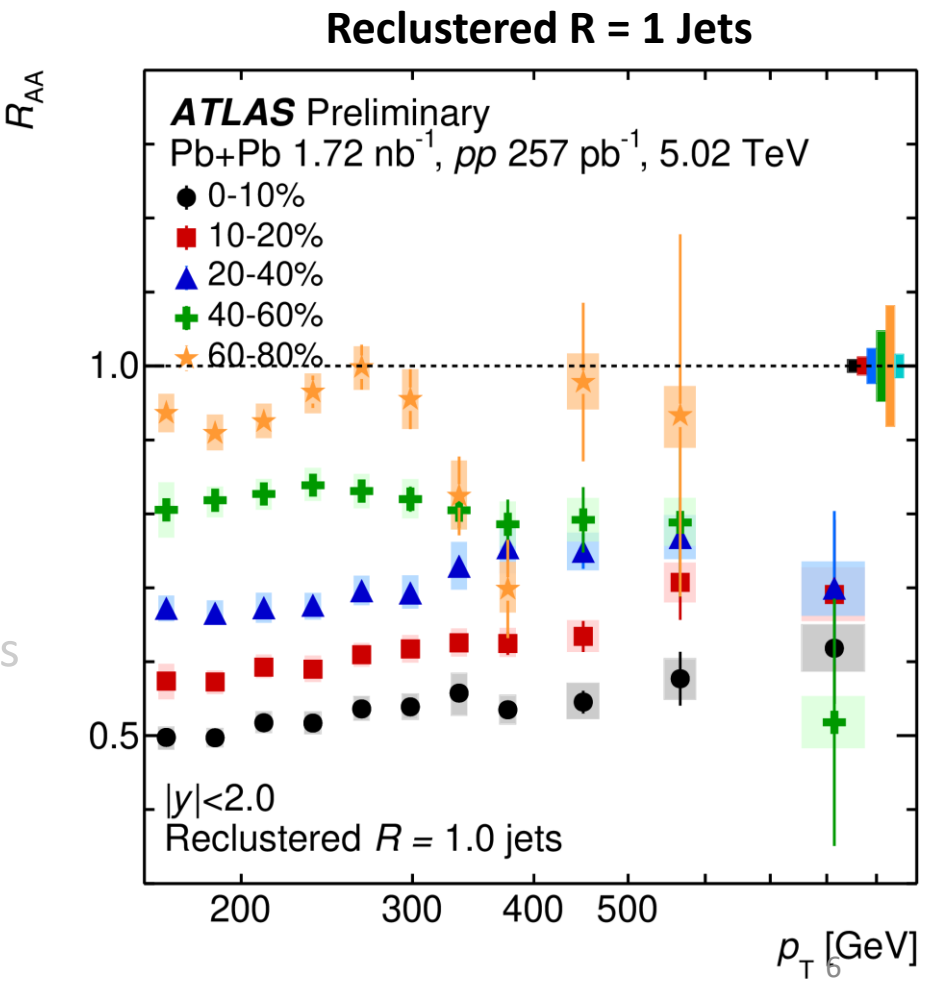
Nuclear Modification of Reclustered Jets

Observe Suppression out to 1 TeV for reclustered R = 1 jets

$\sqrt{d_{12}} = \min(p_{T,1}, p_{T,2}) \times \Delta R_{12}$

Jets with **single subjet** observe less suppression compared to multi subjects

No evidence for strong $\sqrt{d_{12}}$ dependence



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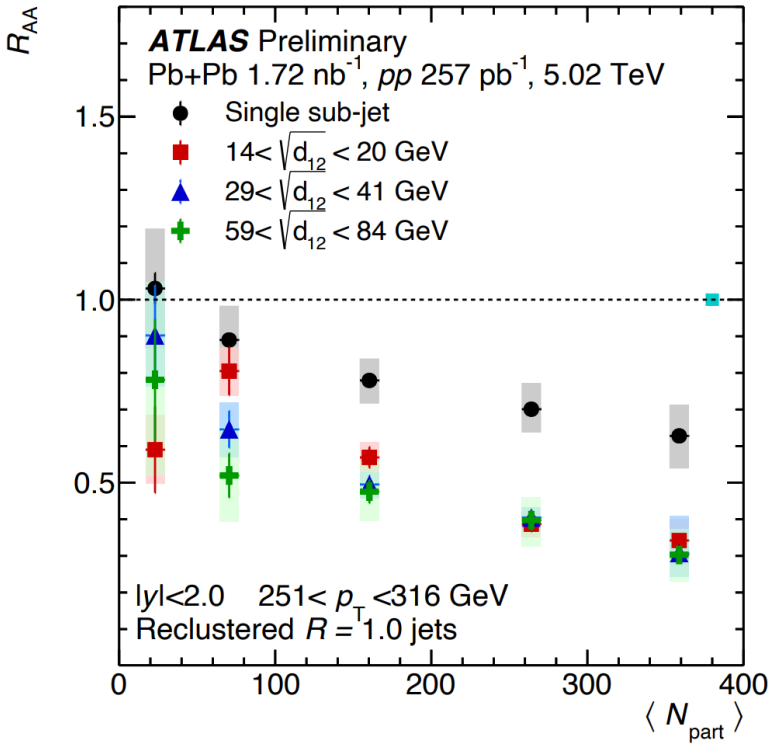

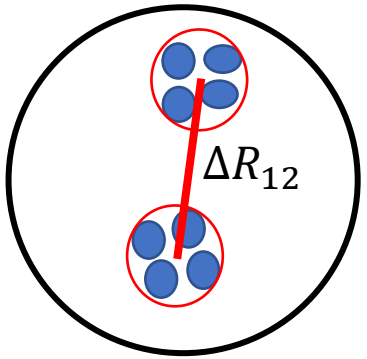

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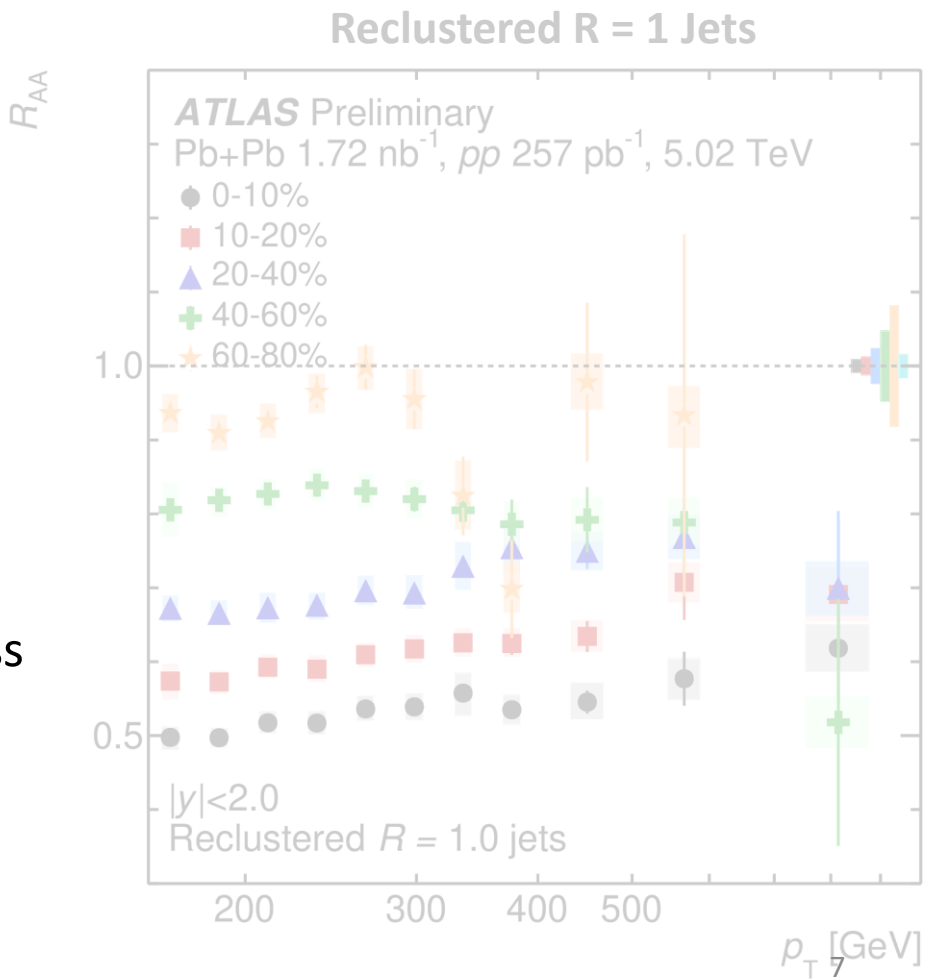
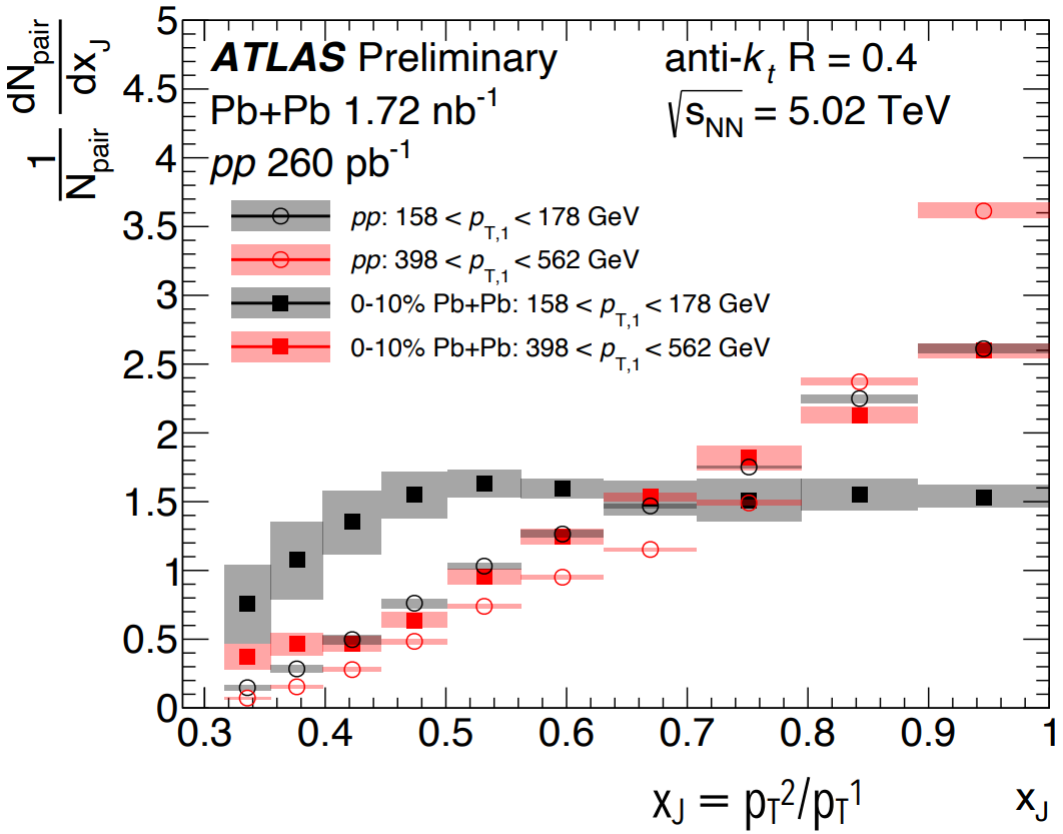
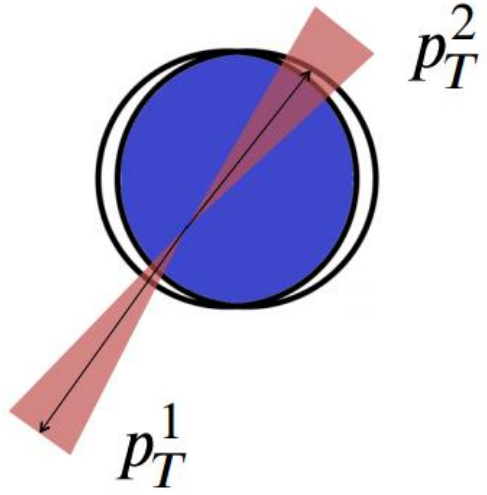
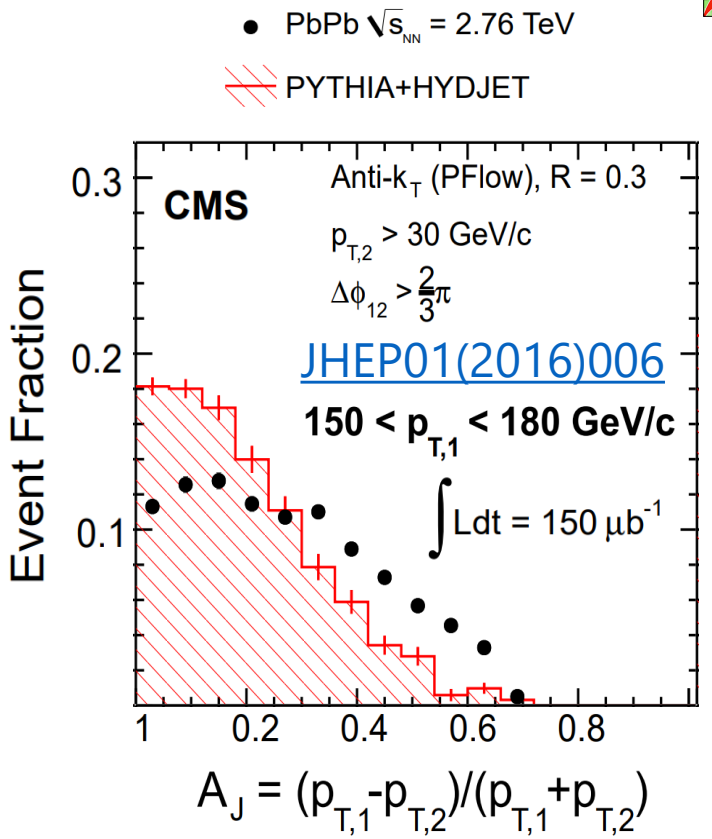


Dijet Momentum Balance

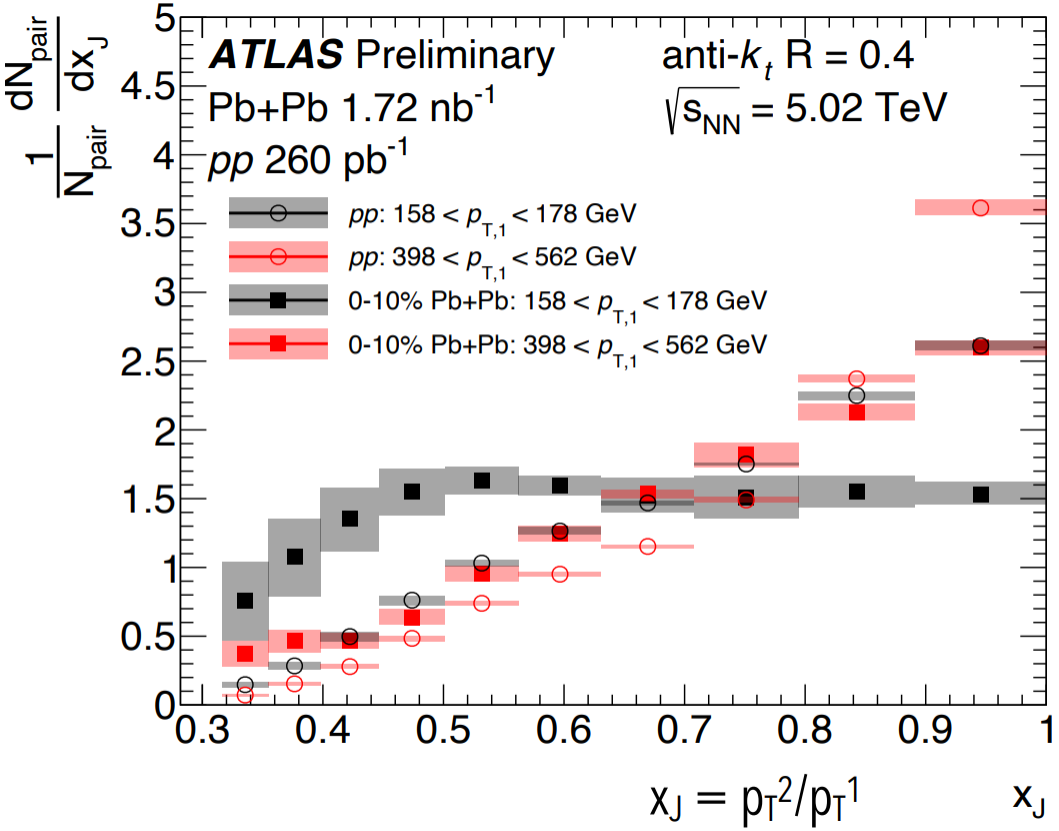






Dijet momentum balance is sensitive to energy loss fluctuations and path length dependent energy loss

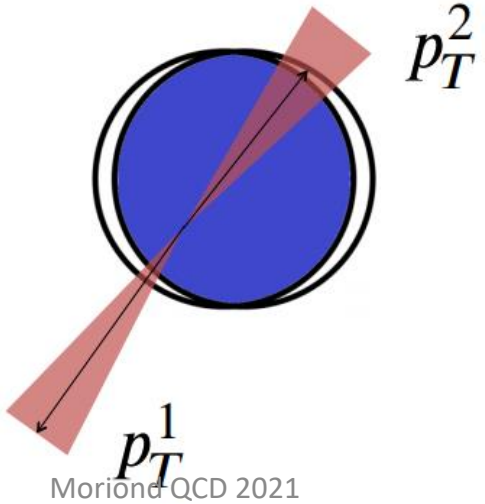
Dijet Momentum Balance

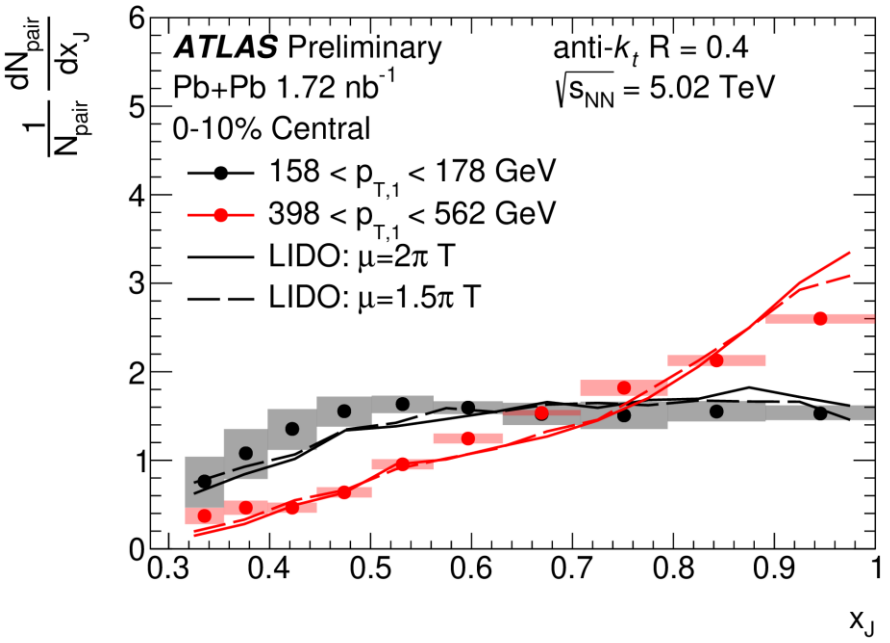


Significant modification from *pp* observed for $p_{T,1} < 562$ GeV

Predictions from LIDO are consistent with the results across jet $p_{T,1}$

- Linearized transport model with a jet-induced hydrodynamic response





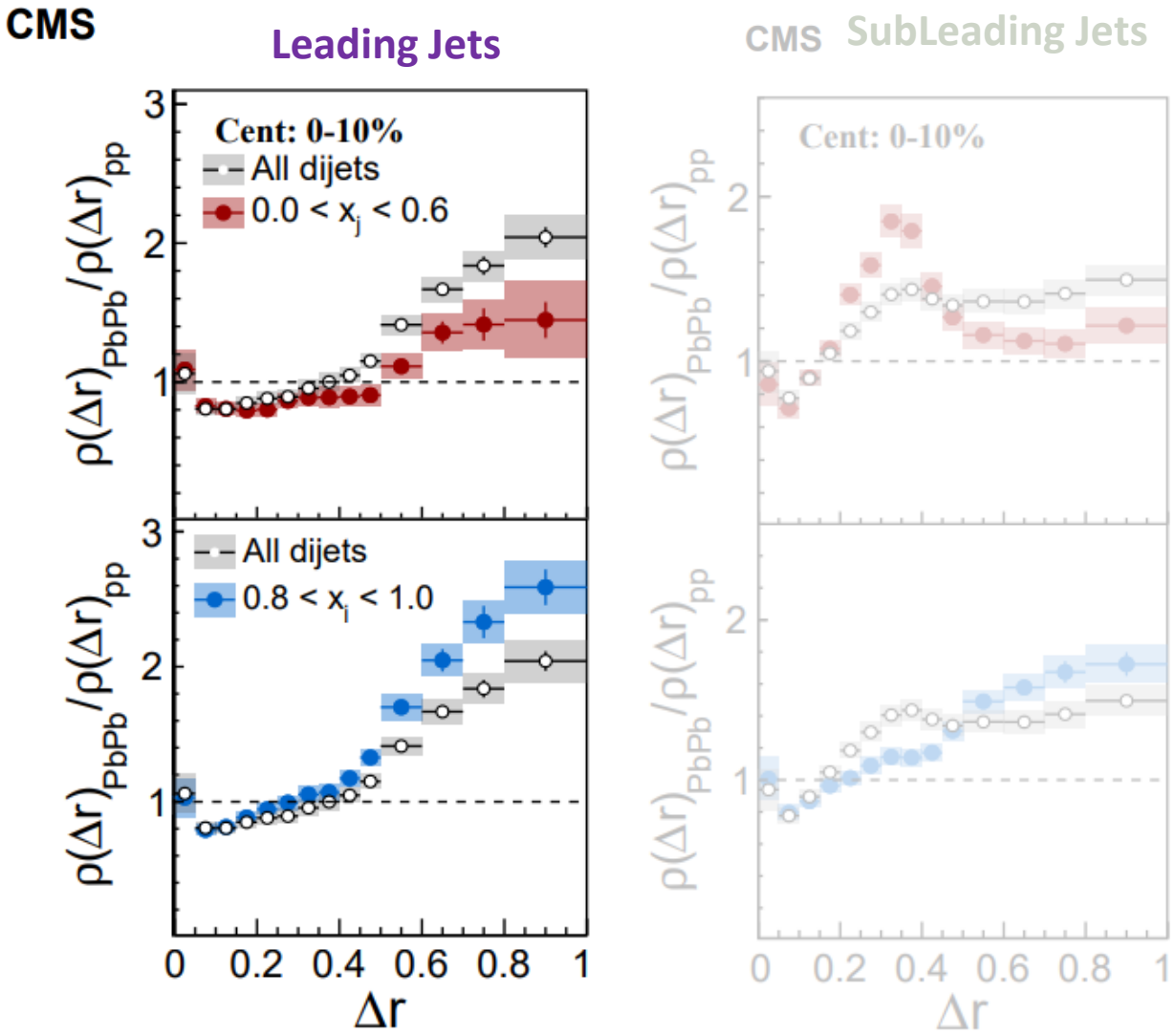
arXiv:2101.04720

ρ is proportional to track momentum density in a radius window

Leading Dijet Fragmentation

5.02 TeV pp 320 pb^{-1} PbPb 1.7 nb^{-1}

anti-k_T R = 0.4, $|\eta_{jet}| < 1.6$, $p_{T,1} > 120$ GeV, $p_{T,2} > 50$ GeV, $\Delta\varphi_{1,2} > \frac{5\pi}{6}$



No significant modification from **inclusive** dijets to the jet shape of the **leading jet** for highly **asymmetric** dijets

arXiv:2101.04720

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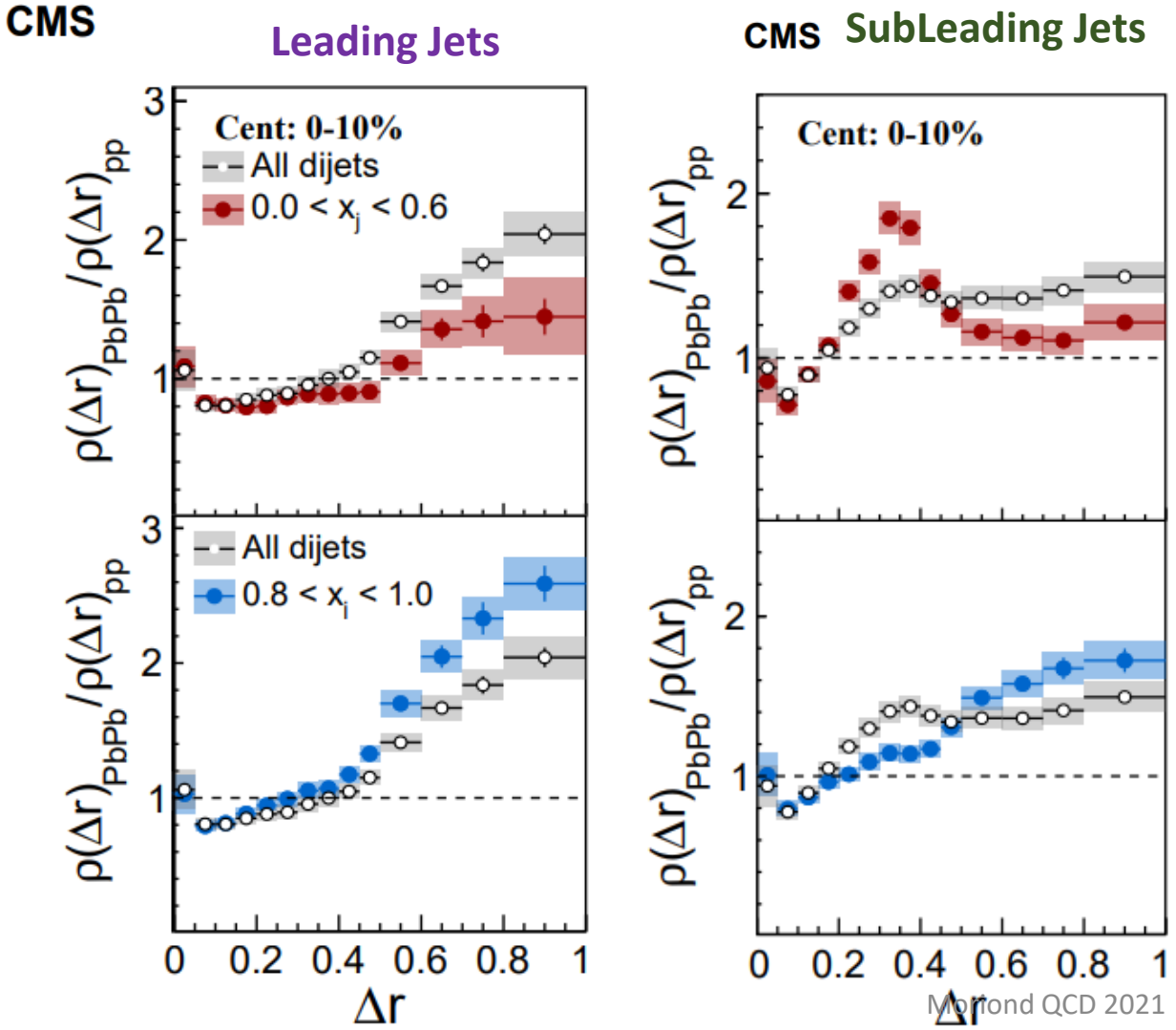


No significant modification from **inclusive** dijets to the jet shape of the **leading jet** for highly **asymmetric** dijets

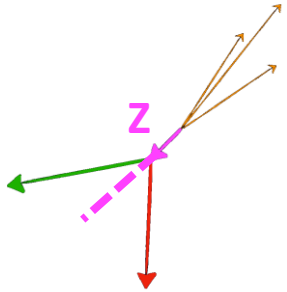
The **subleading** jet for $x_J < 0.6$ observes significant enhancement of fragment momentum between $0.2 < \Delta R < 0.4$

For **symmetric jets** similar modification is seen for the leading and **subleading** jet

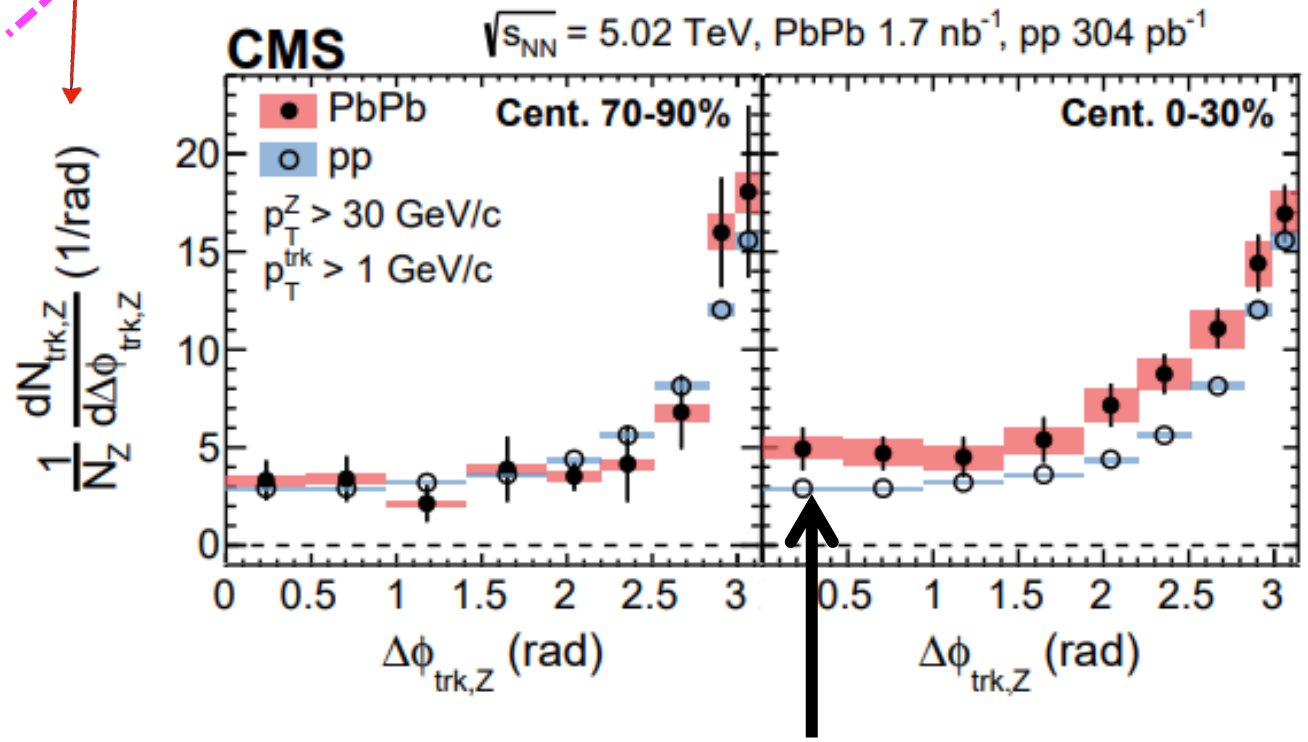
arXiv:2103.04377

Phys. Rev. Lett. 126 (2021) 072301

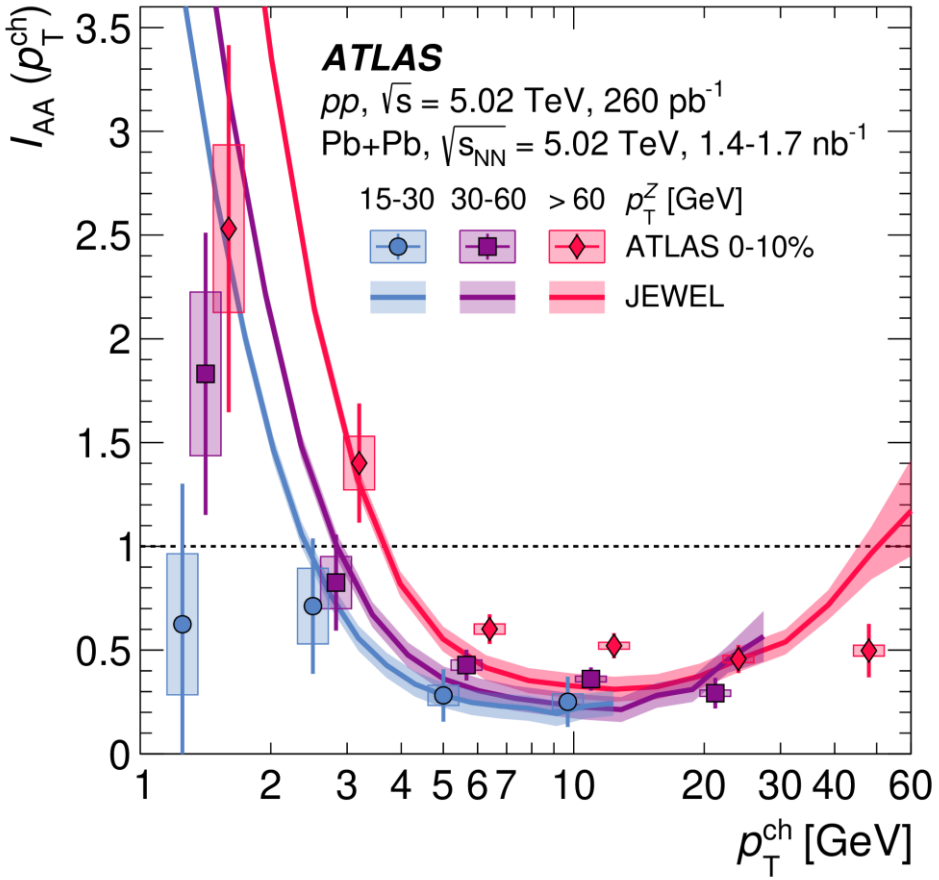
Z-Tagged Particles:



Z-tagging allows for study of particles with an unquenched tag



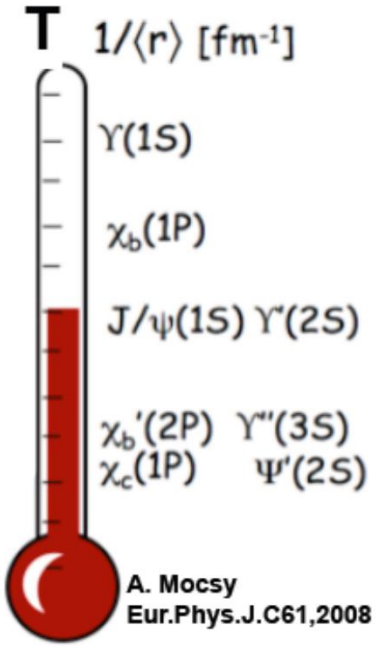
Excess of particle yield in Pb+Pb compared to *pp* in central Pb+Pb

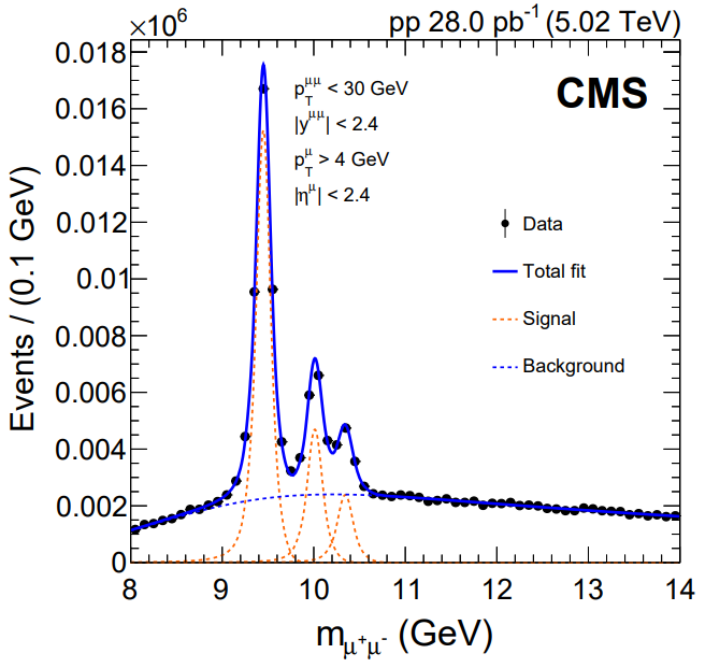


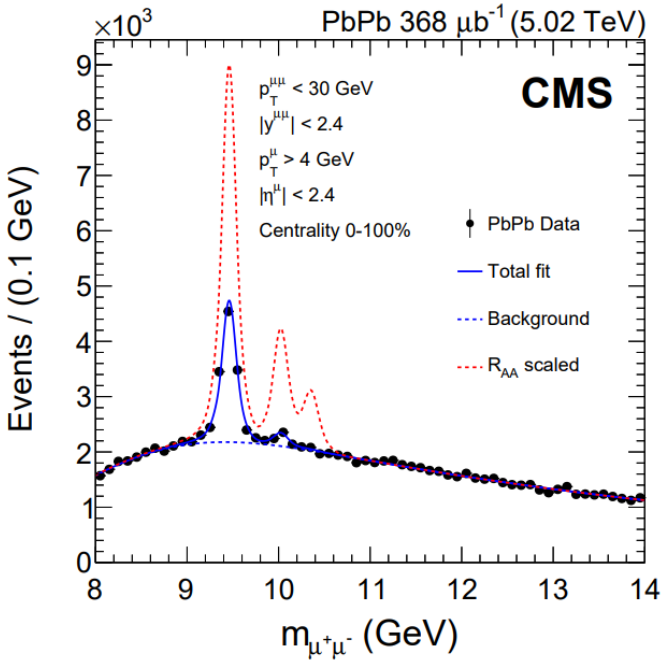
Enhancment of low p_T particles seen in central Pb+Pb compared to *pp*

physletb.2019.01.006

Υ(nS) Mesons





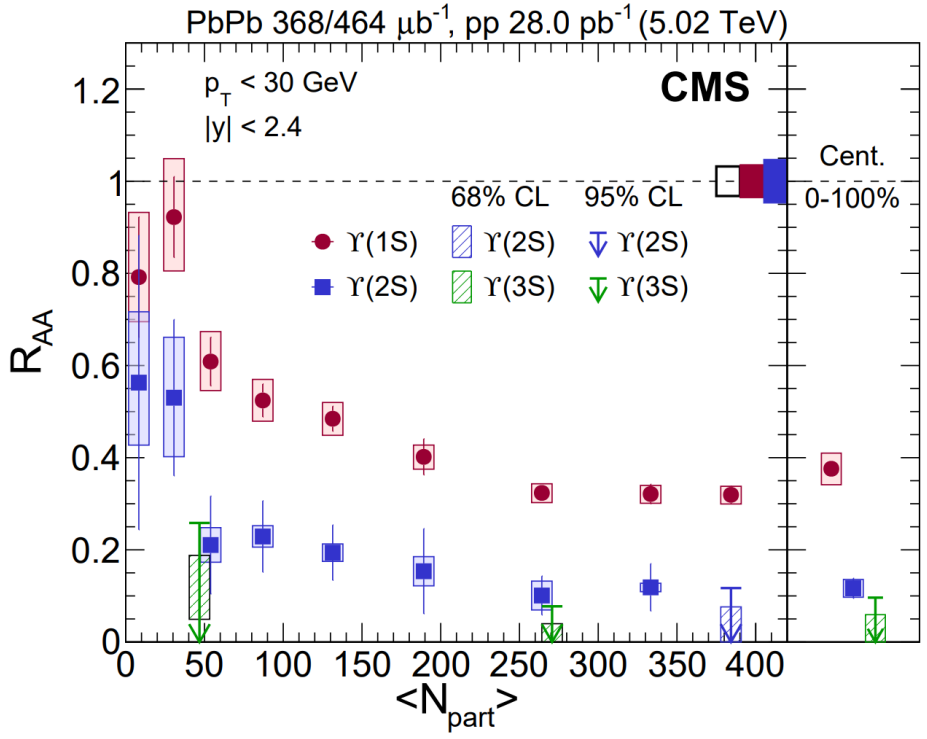


The high-temperature medium induces melting of quarkonia states

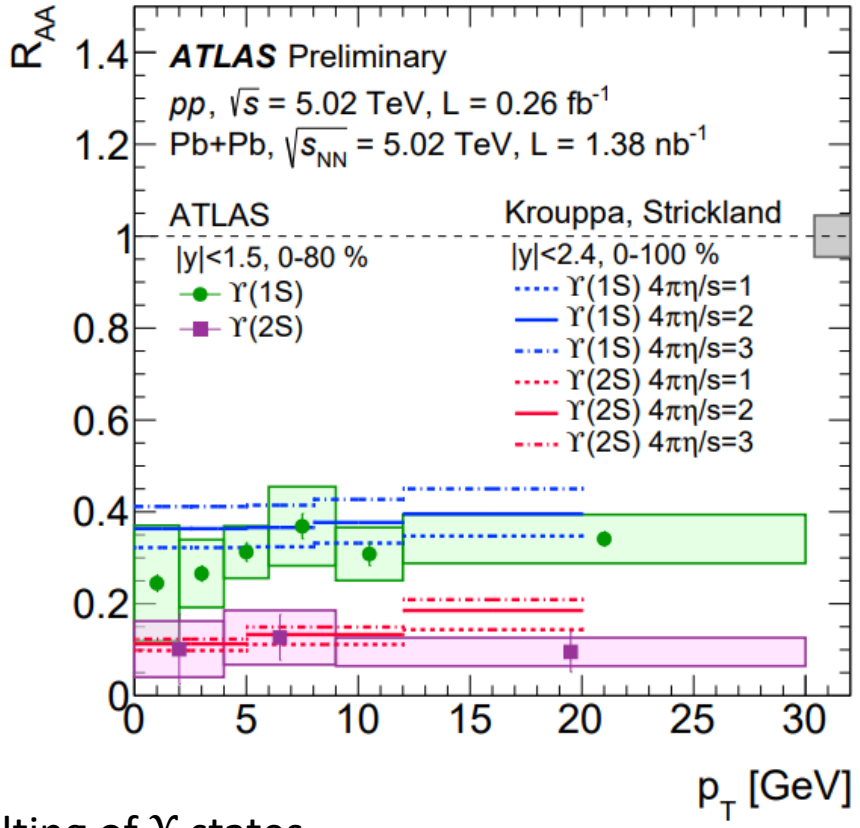
Higher-mass quarkonia states melt more readily at a fixed medium temperature

Υ(nS) Nuclear Modification

physletb.2019.01.006



ATLAS-CONF-2019-054



- Clear signal of sequential melting of Υ states
- Suppression is observed to be independent of p_T

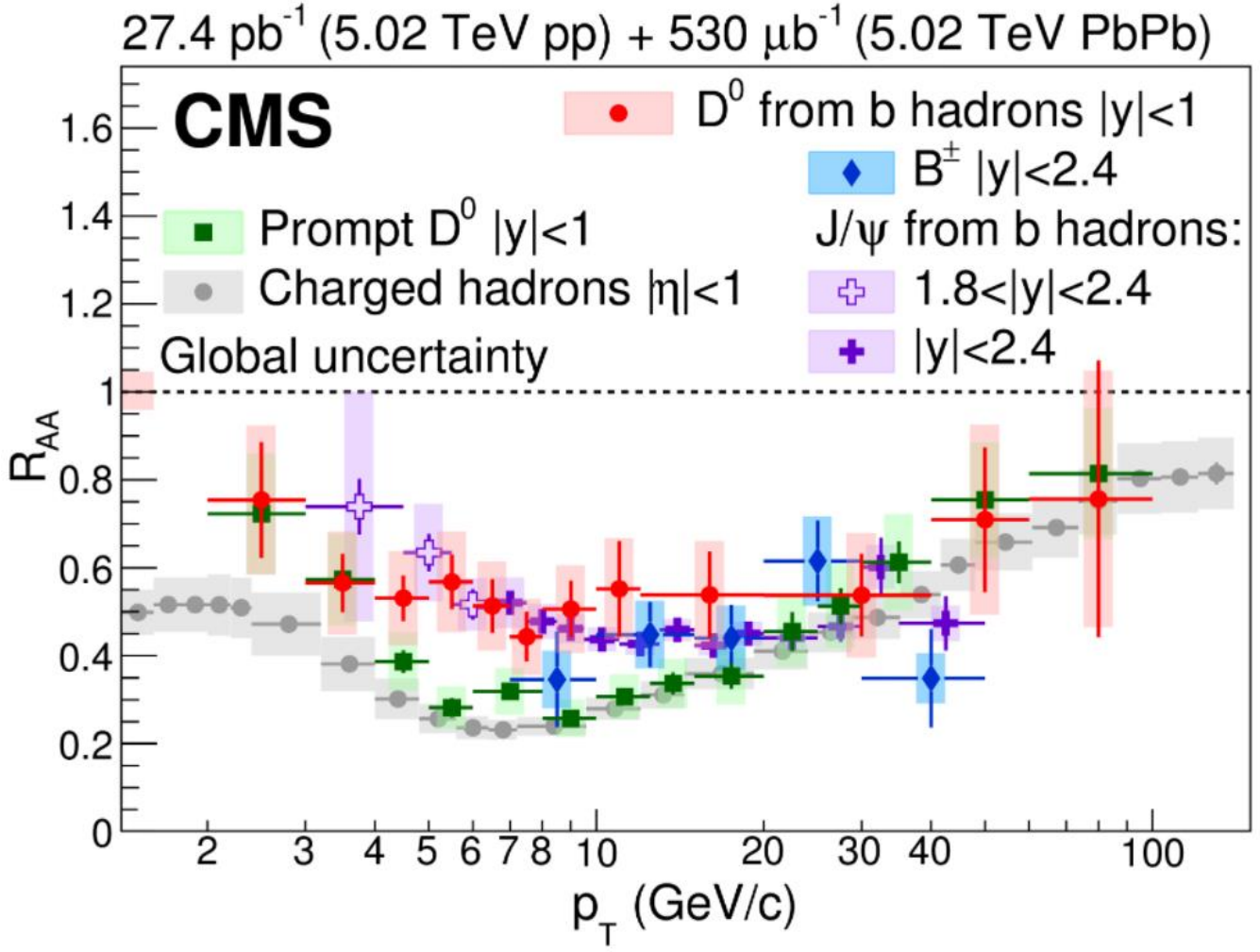
Phys. Rev. Lett. 123 (2019) 022001

Open Heavy Flavor

Dead cone effect expected to reduce radiative energy loss for heavier mass quarks

Prompt D^0 similarly suppressed to light hadrons

Evidence of mass hierarchy to energy loss observed between B and D hadrons below 20 GeV

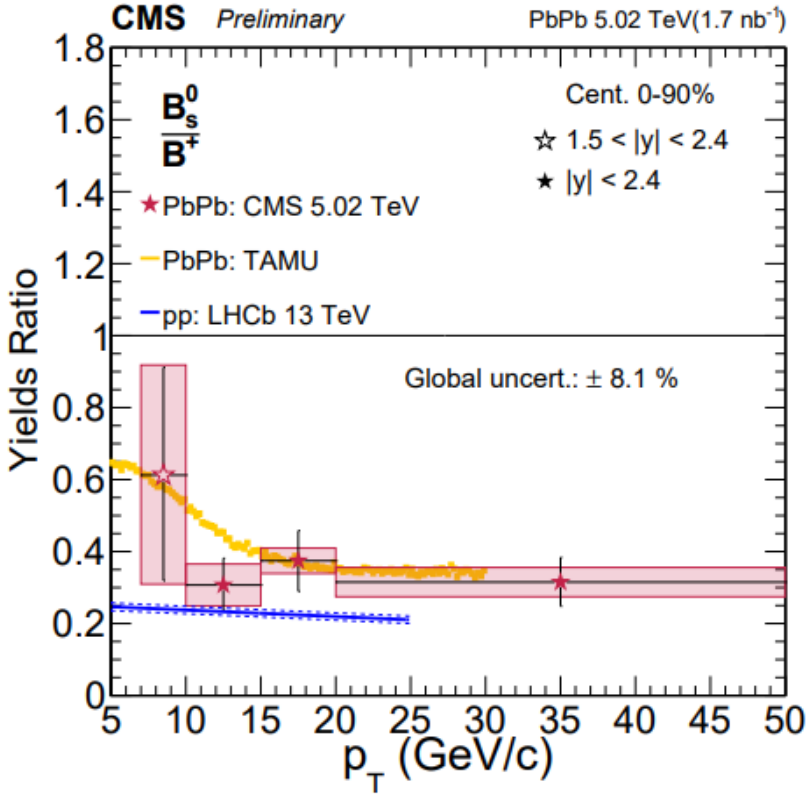


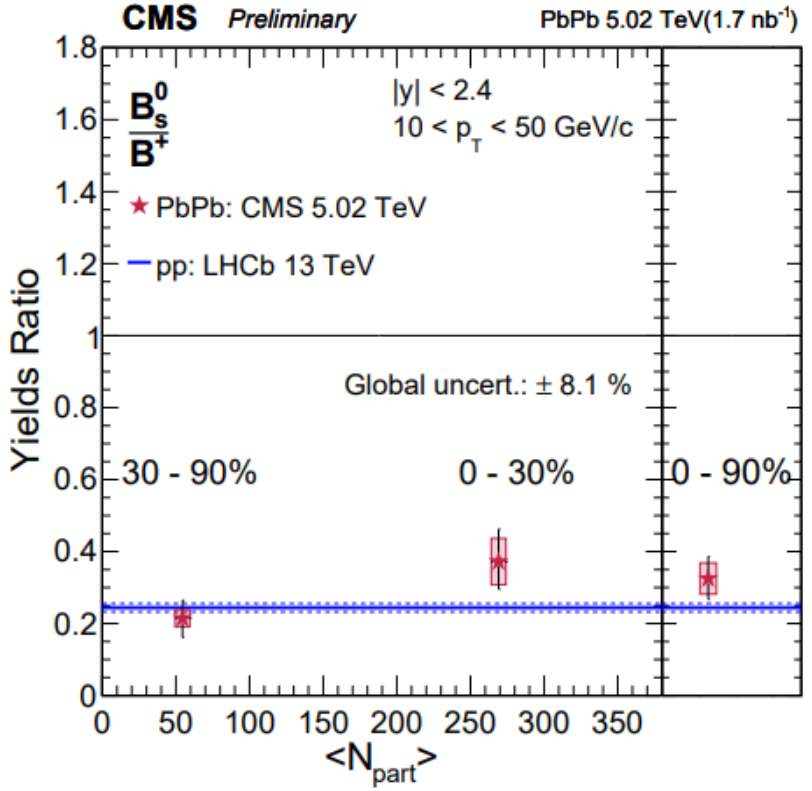
B^+ and B_s^0 Yields

Measurement of B_s^0/B^+ probes hadronization in medium with enhanced strangeness content

Observe an enhancement of the B_s^0 fraction compared to pp@13 TeV

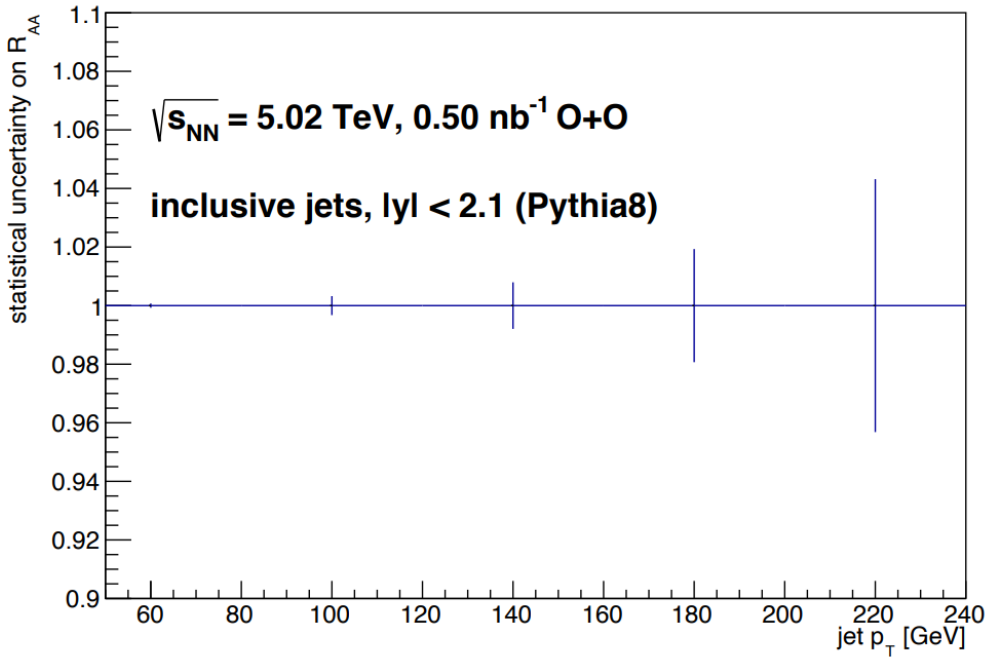
Predictions from TAMU are consistent with the relative production of B_s^0/B^+





Conclusions

- Lots of exciting results coming out from both ATLAS and CMS!!
  - Too many to include here
    - https://twiki.cern.ch/twiki/bin/view/AtlasPublic
    - http://cms-results.web.cern.ch/cms-results/public-results/publications/HIN/index.html
- Ongoing developments and improvements in theory allows for comparisons providing insight to the properties of interactions with the QGP
- Look forward to results using high luminosity from run 3 that will allow for studies with rare probes
  - Potential data from light ion collisions to allow for studying the QGP across a variety of system sizes!!



Great jet statistics out to 240 GeV