Measurements of Z- and jet-tagged fragmentation and medium response in Pb+Pb and p+Pb collisions by ATLAS

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Jets in QGP

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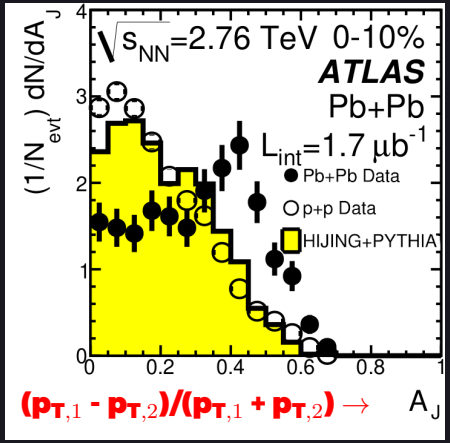
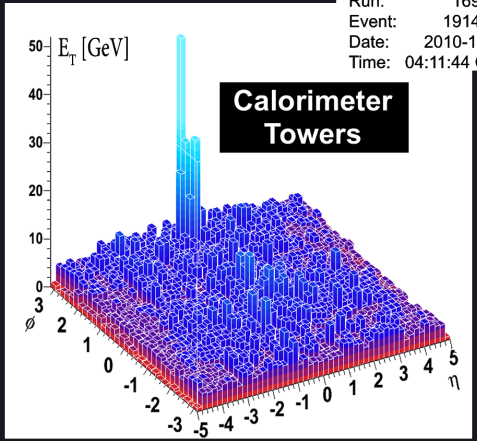




- **Observe significant modification to dijet asymmetry (A_J)!**
- **Interpret as jet energy 'lost' to medium interactions**
  - **For latest ATLAS dijet asymmetry measurements, see here**

Quenching in QGP: A Study and a Search

Study Jet Fragmentation

Quenching in QGP: A Study and a Search

Study Jet Fragmentation

Z-tagged Jet Fragmentation

Study QGP Energy Redistribution

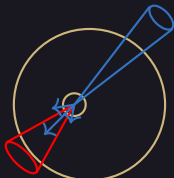
Quenching in QGP: A Study and a Search

Study Jet Fragmentation

Z-tagged Jet Fragmentation

Study QGP Energy Redistribution

Quenching Search in p+Pb



Constrain Fragmentation Modification

Quenching in QGP: A Study and a Search

Study Jet Fragmentation

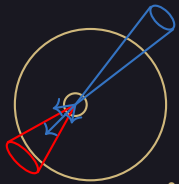
Z-tagged Jet Fragmentation

Quenching Search in p+Pb

Study QGP Energy Redistribution

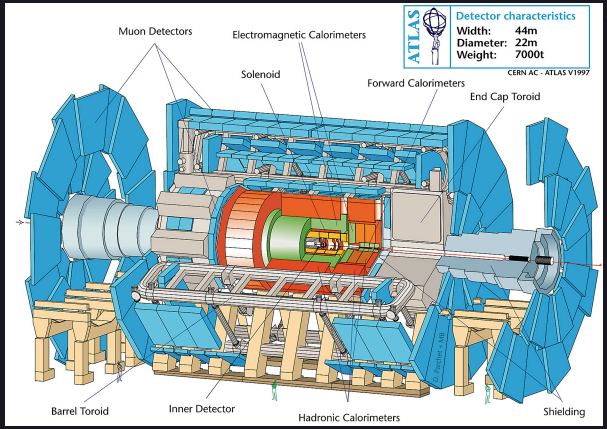
Note: Reconstructed jets are used as event tags only

Instead focus on modification of jet constituents



Constrain Fragmentation Modification

ATLAS Detector and Data



Via CDS

p p

p+p collected in 2017
2.6 - 260 pb^{-1} lumi.

Pb Pb

Pb+Pb collected in 2018
1.72 nb^{-1} lumi.

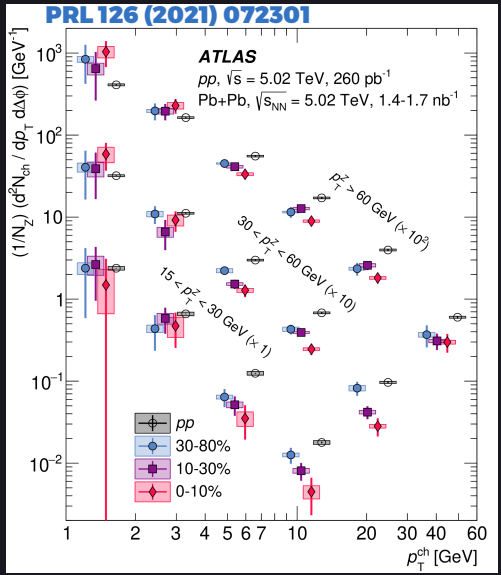
Pb p

p+Pb collected in 2016
0.36 nb^{-1} lumi.

- **Jets are reconstructed w/ EMCal and HCal**
- **Charged particles via inner tracking detectors**
- **Centrality (nuclear overlap) is determined by FCal/ZDC**
- **Z boson reconstructed w/ muon detectors and EMCal+track**

Z-Tag w/ Jet Fragments (I)

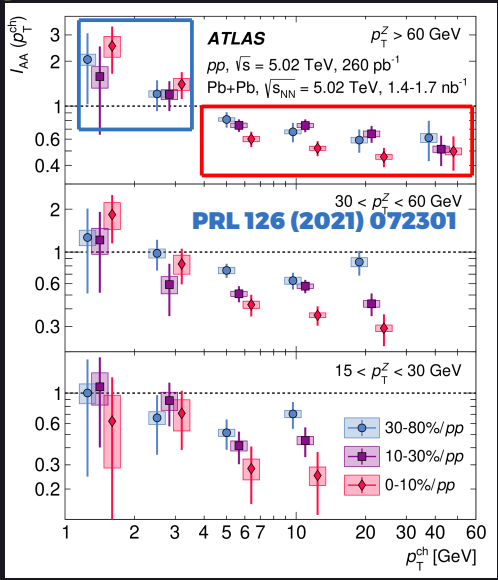
- Colorless tag (Z) unmodified by medium
  - Initial scattering proxy
- Study charged particles opposite the Z
  - These are produced by the jet
- Right: Charged particles produced in hemisphere opposite Z in Pb+Pb, p+p



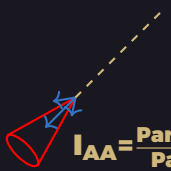
Z-Tag w/ Jet Fragments (II)

$$I_{AA} = \frac{\text{Particles per Z in Pb+Pb}}{\text{Particles per Z in p+p}}$$

- How does energy loss modify jet constituents?
- Observe suppression of high-p_T particles
- Excess of low p_T particles
- Medium interactions attenuate+redistribute

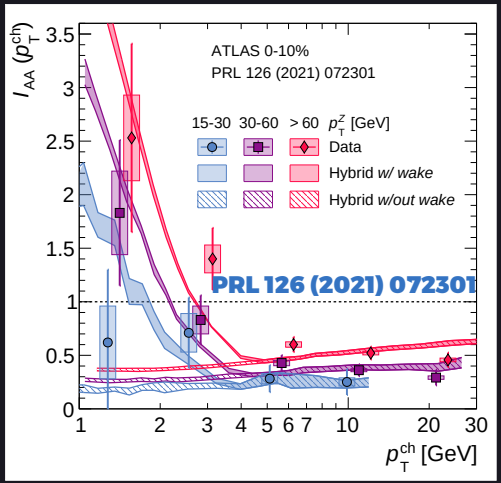


Z+hadrons Theory Comparison

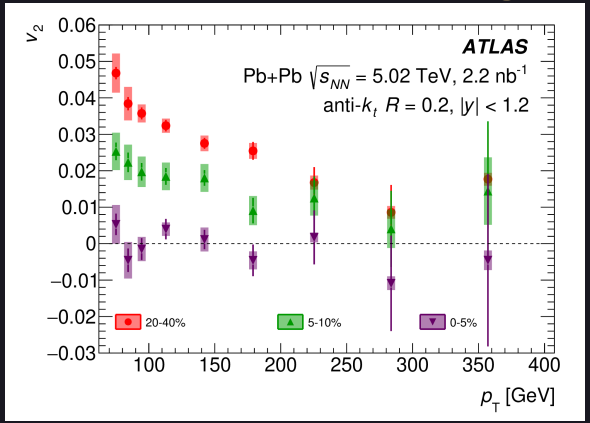


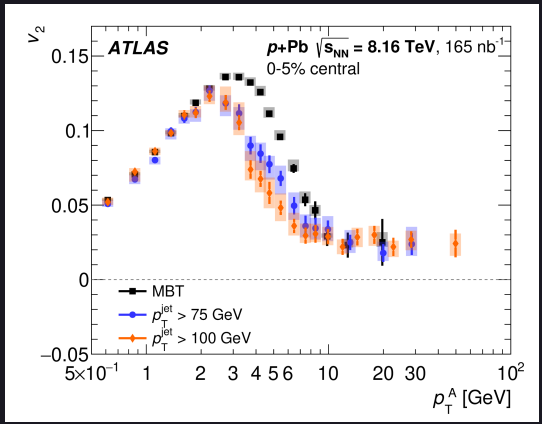
$$I_{AA} = \frac{\text{Particles per Z in Pb+Pb}}{\text{Particles per Z in p+p}}$$

- Does a jet in medium leave a wake?
- Check in Hybrid model - jet quenching theory with strong-coupling
- Hybrid model does not describe low-p_T excess in data w/o such a backreaction



Motivating a Search in p+Pb





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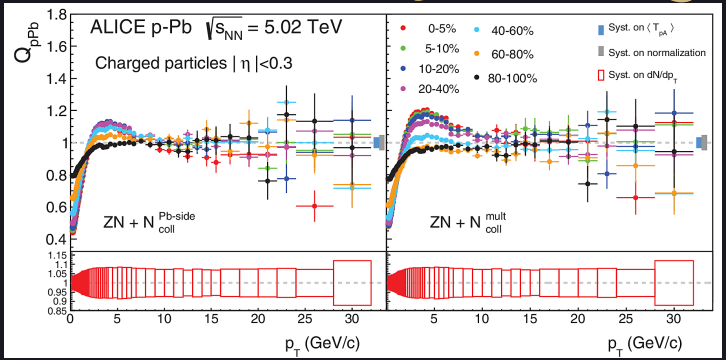
- Left: ATLAS measurement of jet v_2 persistent to high-p_T in Pb+Pb
  - Generally understand as a product of differential jet energy loss
- Right: ATLAS measurement of v_2 persistent to high-p_T in p+Pb!
  - No existing observations of quenching in p+Pb

Other Searches for Quenching in p+Pb



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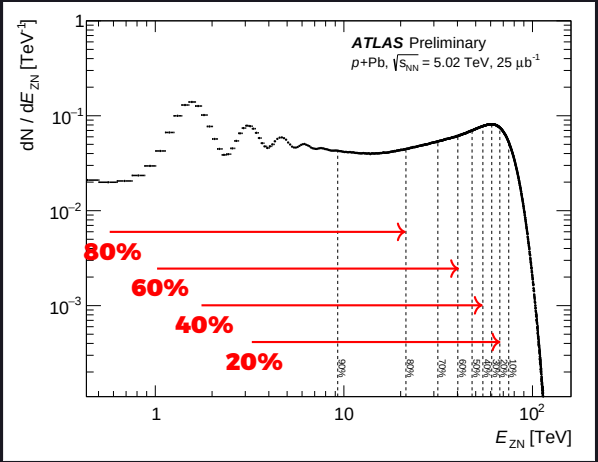
- ALICE measurement using ZDC centrality to search for quenching in p+Pb
- Restricts any p+Pb quenching effects to a ~10% level at high-p_T
- We will adopt the ZDC centrality approach but restrict to jet-tagged events
  - No errors associated w/ N_{coll}

Defining Centrality in p+Pb w/ ZDC

- Centrality defined using Zero Degree Calorimeter (ZDC)
- Count number of spectator neutrons remaining after nuclear breakup
- Minimizes potential bias to centrality from jet production
  - At cost of coarser centrality bins
- Results are reported in 20% centrality bins and inclusive



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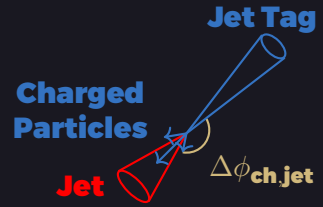
Jet-tagged Charged Particle Spectra



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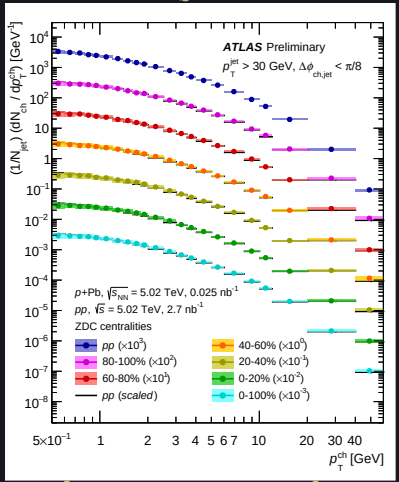
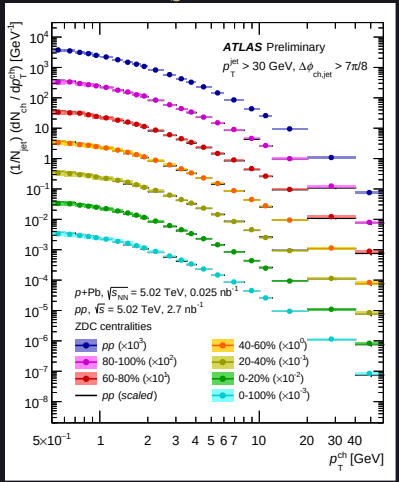
$\Delta\phi_{ch,jet} < \pi/8$



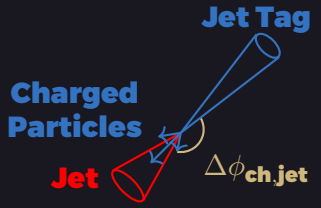
$\Delta\phi_{ch,jet} > 7\pi/8$



- **Measure near and away-side charged particles from 0.5-60 GeV**
- **See backup for corresponding p_T^{Jet} > 60 GeV**

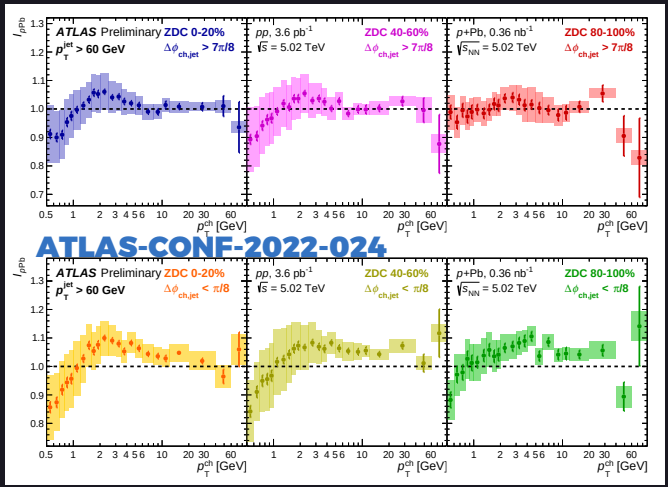
Jet-tagged $I_{p\mathrm{Pb}}$

$\longrightarrow$
$\Delta\phi_{\mathrm{ch,jet}} > 7\pi/8$



$\longrightarrow$
$\Delta\phi_{\mathrm{ch,jet}} < \pi/8$

$$I_{\mathrm{pPb}} = \frac{\text{Particles per jet in p+Pb}}{\text{Particles per jet in p+p}}$$

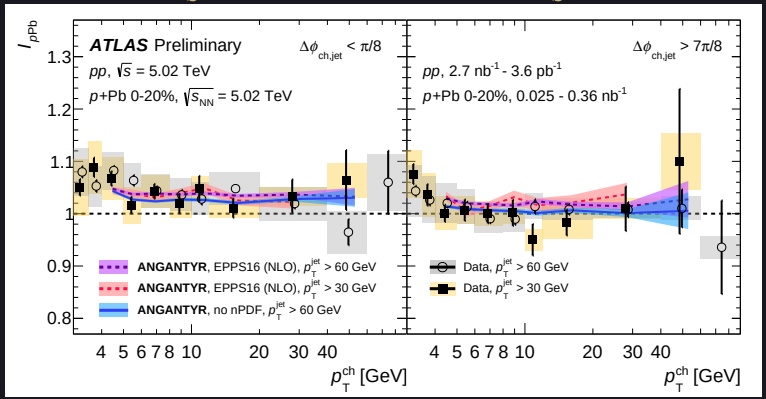


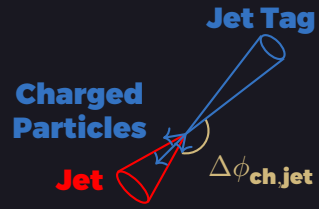
ZDC 0-20% 40-60% 80-100%

- No observable quenching effect at high-p_{T}, across ZDC centrality

Model Comparison

$\Delta\phi_{\text{ch.jet}} < \pi/8$ $\Delta\phi_{\text{ch.jet}} > 7\pi/8$





$$I_{\text{pPb}} = \frac{\text{Particles per jet in p+Pb}}{\text{Particles per jet in p+p}}$$

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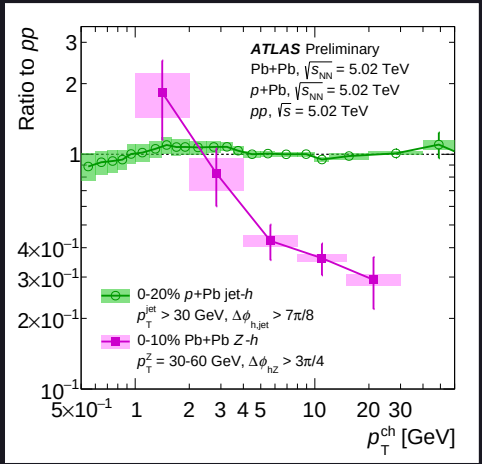
- Observe a general excess in near-side particle production
- Angantyr (model w/o quenching effects) captures this behavior

Comparing w/ Known Quenching Signal

- **Overlaid on p+Pb search is Z-tagged Pb+Pb**
- **Even peripheral Pb+Pb tends to show quenching effects > 10%**
- **Yet high-p_T v_2 is observed in both systems**



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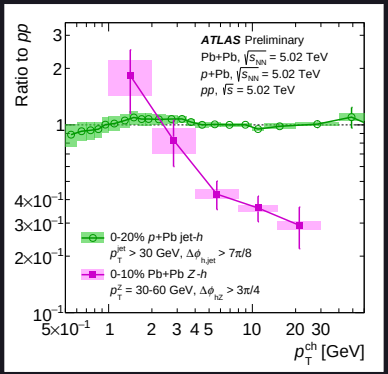
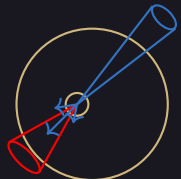
Conclusion

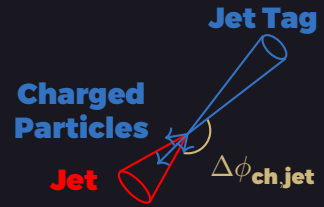




- **Jet constituents are preferentially softer in Pb+Pb**
- **Observation of high-p_T v_2 in p+Pb suggests we should find quenching**
- **No quenching effects observed in p+Pb jet constituent study!**
  - **Do we understand high-p_T v_2?**
- **For these and more results, see ATLAS HI Public Results TWiki**

Backup

Jet-tagged Charged Particle Spectra



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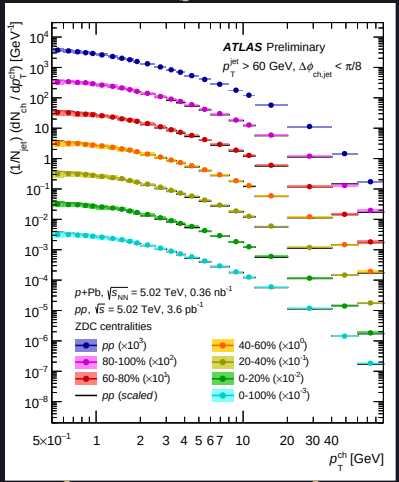
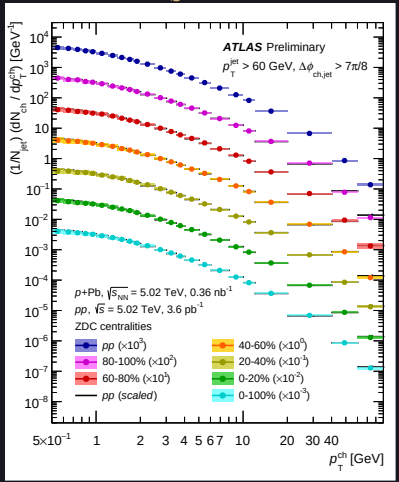
$\Delta\phi_{\text{ch,jet}} < \pi/8$

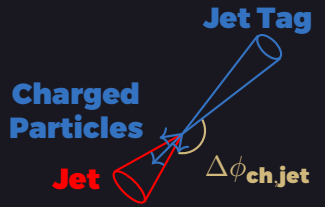


$\Delta\phi_{\text{ch,jet}} > 7\pi/8$



- **Measure near and away-side charged particles from 0.5-60 GeV**
- **See body for corresponding p_T^{Jet} > 30 GeV**

AMPT Model Comparison



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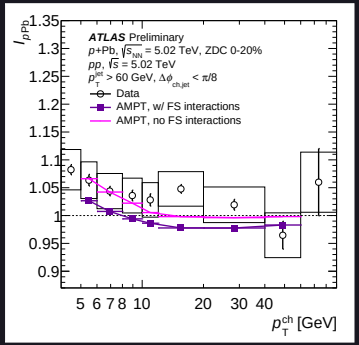
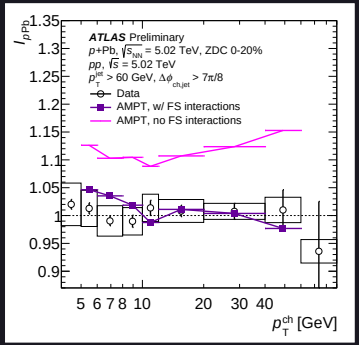


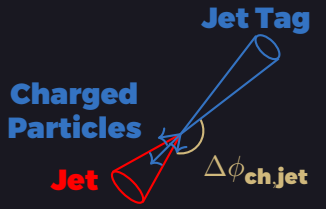
$\Delta\phi_{\text{ch,jet}} < \pi/8$



$\Delta\phi_{\text{ch,jet}} > 7\pi/8$

- Final state effects necessary to capture away-side behavior

Comparison with ATLAS $R_{\mathbf{D}(p_T)}$ $I_{p\mathbf{Pb}}$ (I)



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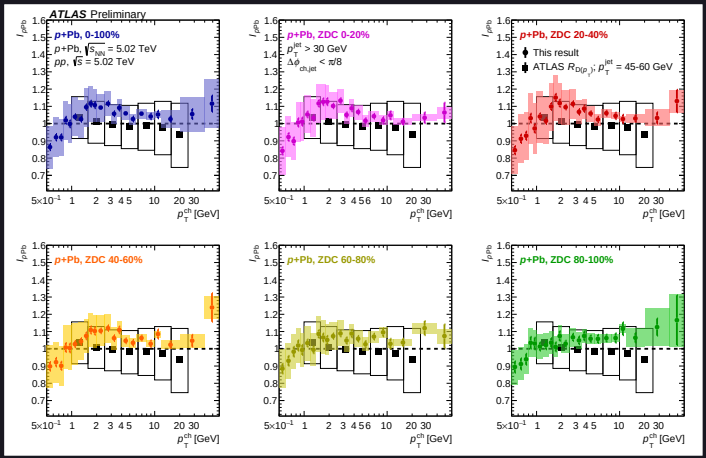
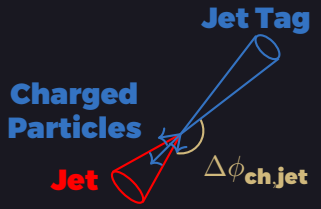


$\Delta\phi_{\mathbf{ch,jet}} < \pi/8$

$\mathbf{p}_T^{Jet} > 30$ **GeV**

Comparison with ATLAS $R_{D(p_T)}I_{pPb}$ (II)



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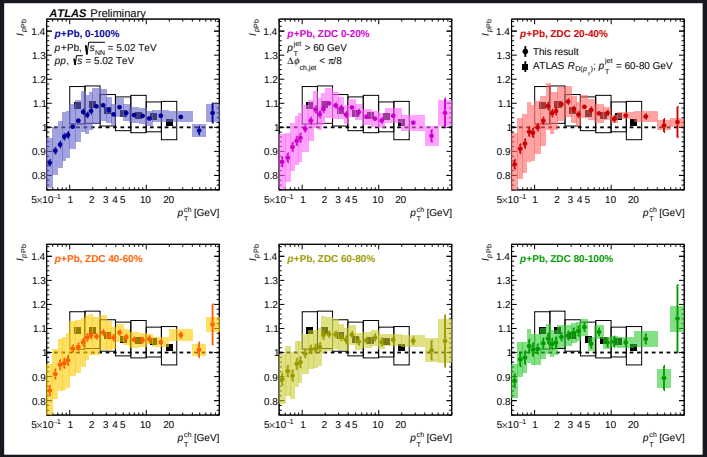
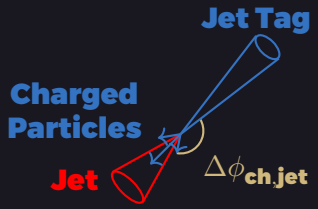


$\Delta\phi_{ch,jet} < \pi/8$

$p_T^{Jet} > 60$ GeV

Comparison with Angantyr of $I_{p\text{Pb}}$ (I)



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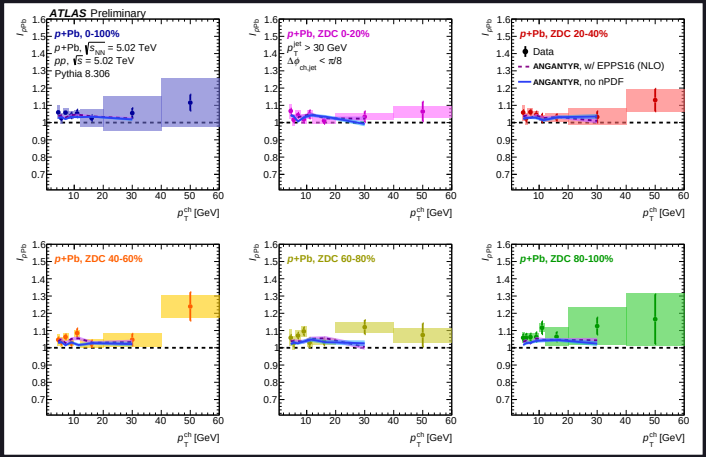
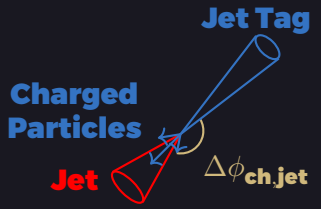


$\Delta\phi_{\text{ch,jet}} < \pi/8$

$p_T^{Jet} > 30$ GeV

Comparison with Angantyr of $I_{p\mathrm{Pb}}$ (II)



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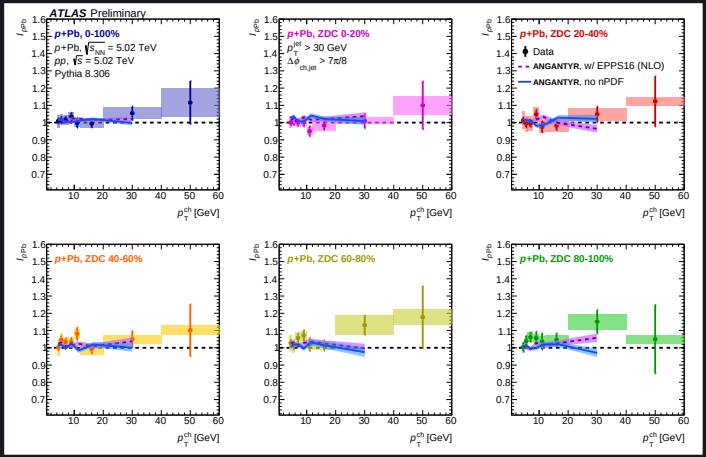
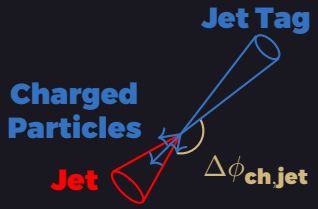


$\Delta\phi_{\mathrm{ch,jet}} > 7\pi/8$

$p_T^{Jet} > 30$ GeV

Comparison with Angantyr of $I_{p\text{Pb}}$ (III)



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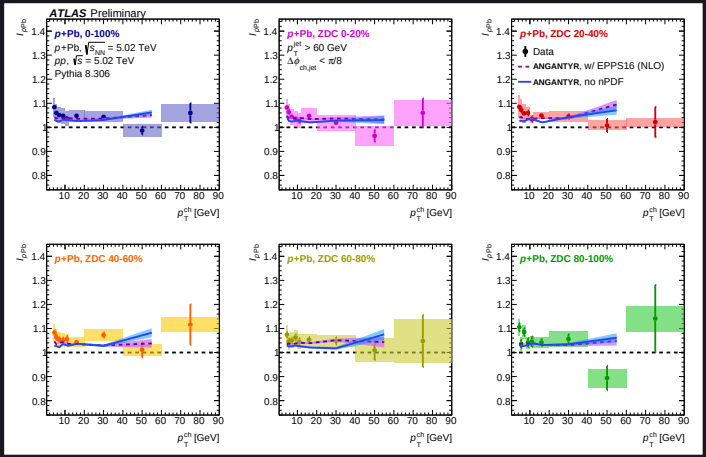
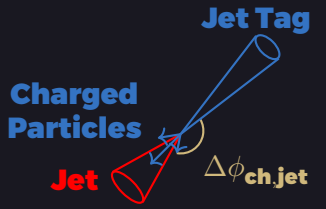


$\Delta\phi_{\text{ch,jet}} < \pi/8$

$p_T^{Jet} > 60$ GeV

Comparison with Angantyr of $I_{p\mathrm{Pb}}$ (IV)



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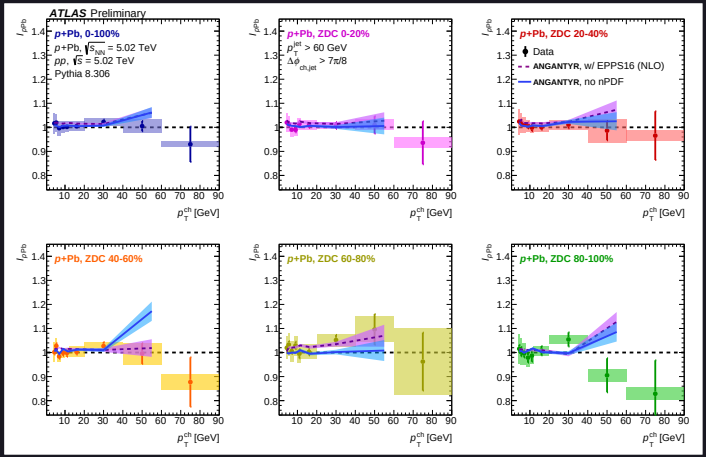

$\Delta\phi_{\mathrm{ch,jet}} > 7\pi/8$

$p_T^{Jet} > 60$ GeV