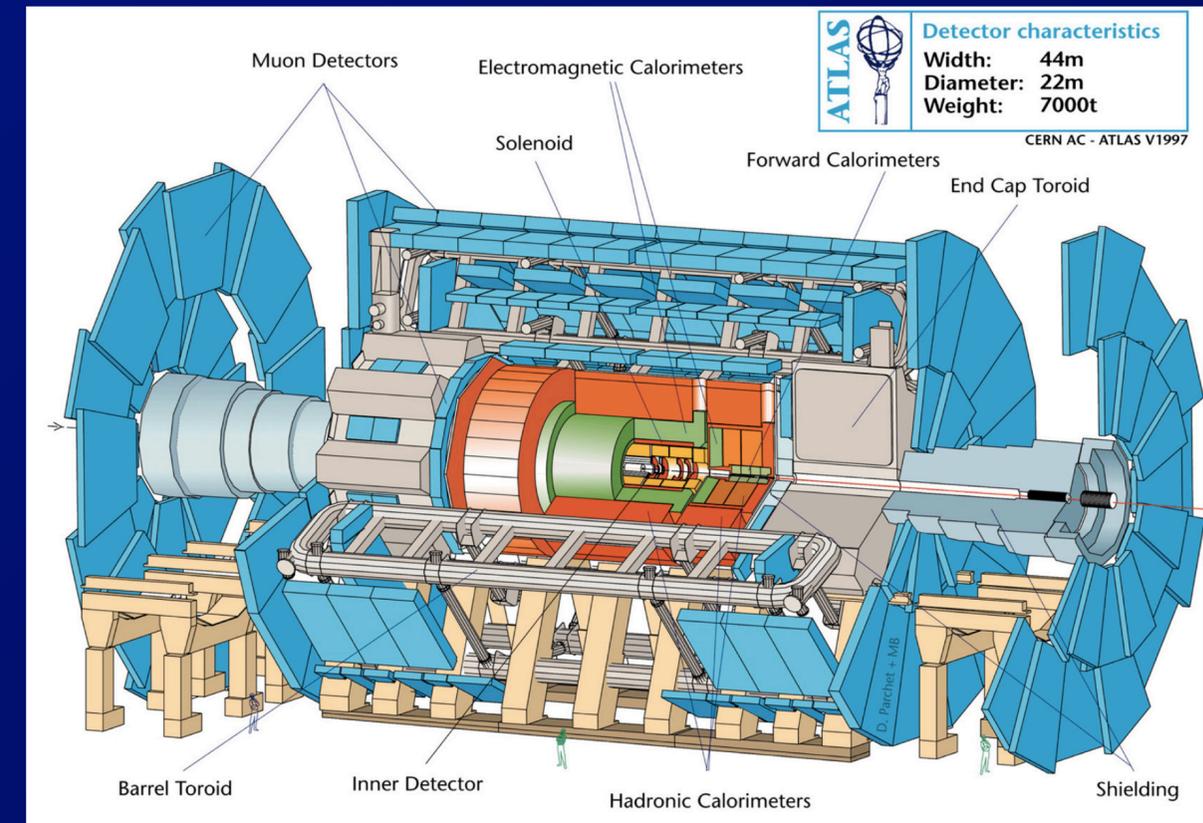


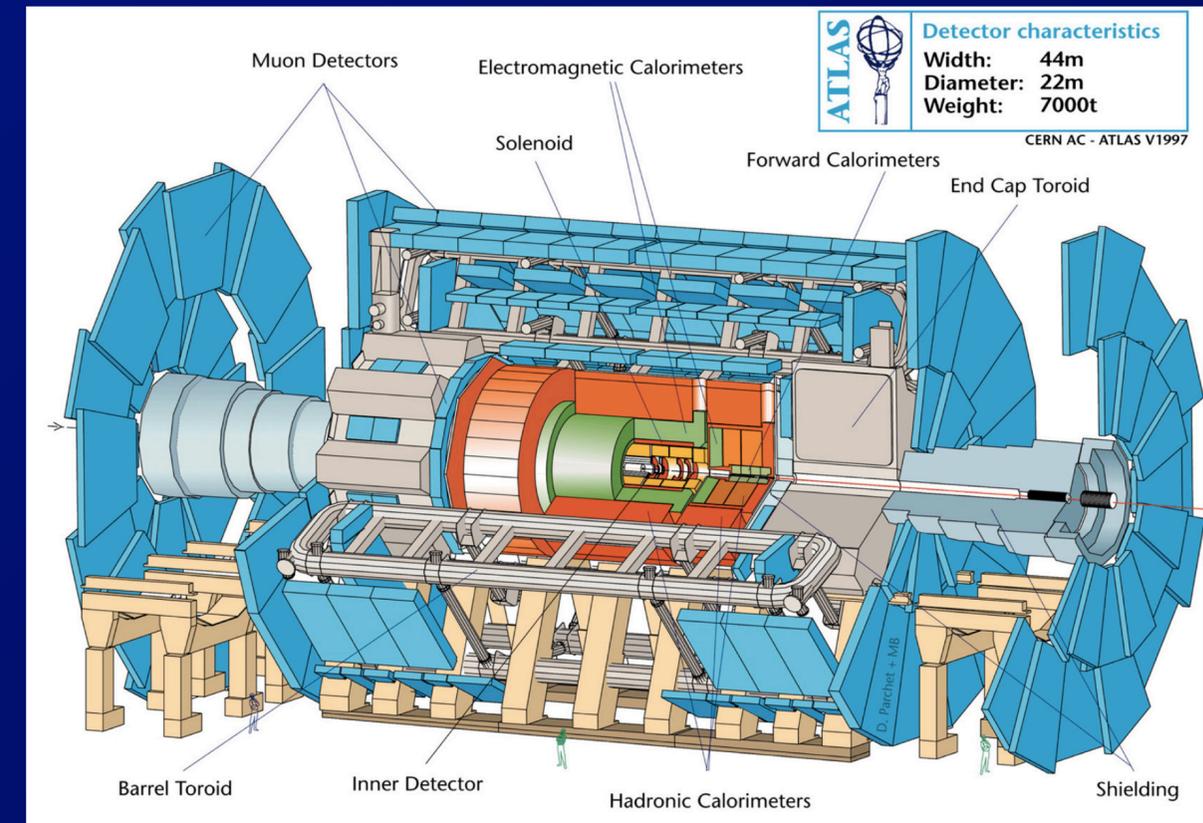
Jet Measurements in Heavy Ion Collisions with the ATLAS Experiment

Prof. Brian Cole
Columbia University
for the ATLAS collaboration



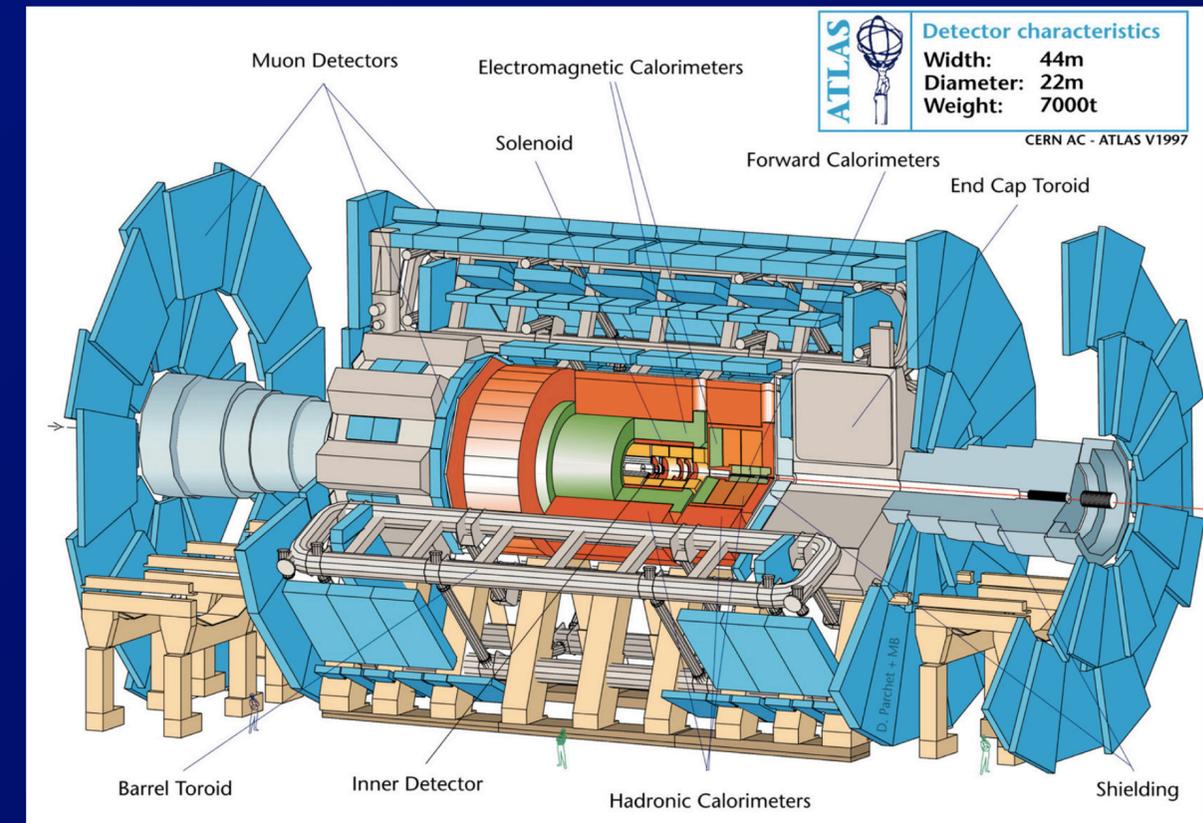
Jet and dijet probes of the quark-gluon plasma in Pb+Pb collisions with the ATLAS Experiment

Prof. Brian Cole
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quark and gluon probes of the quark-gluon plasma in Pb+Pb collisions with the ATLAS Experiment

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- The phenomenon of “jet quenching” is now well-established

- energy loss of hard-scattered quarks and gluons in the quark-gluon plasma

⇒ but still much to understand

- In this talk:

- probing quark vs gluon dE/dx

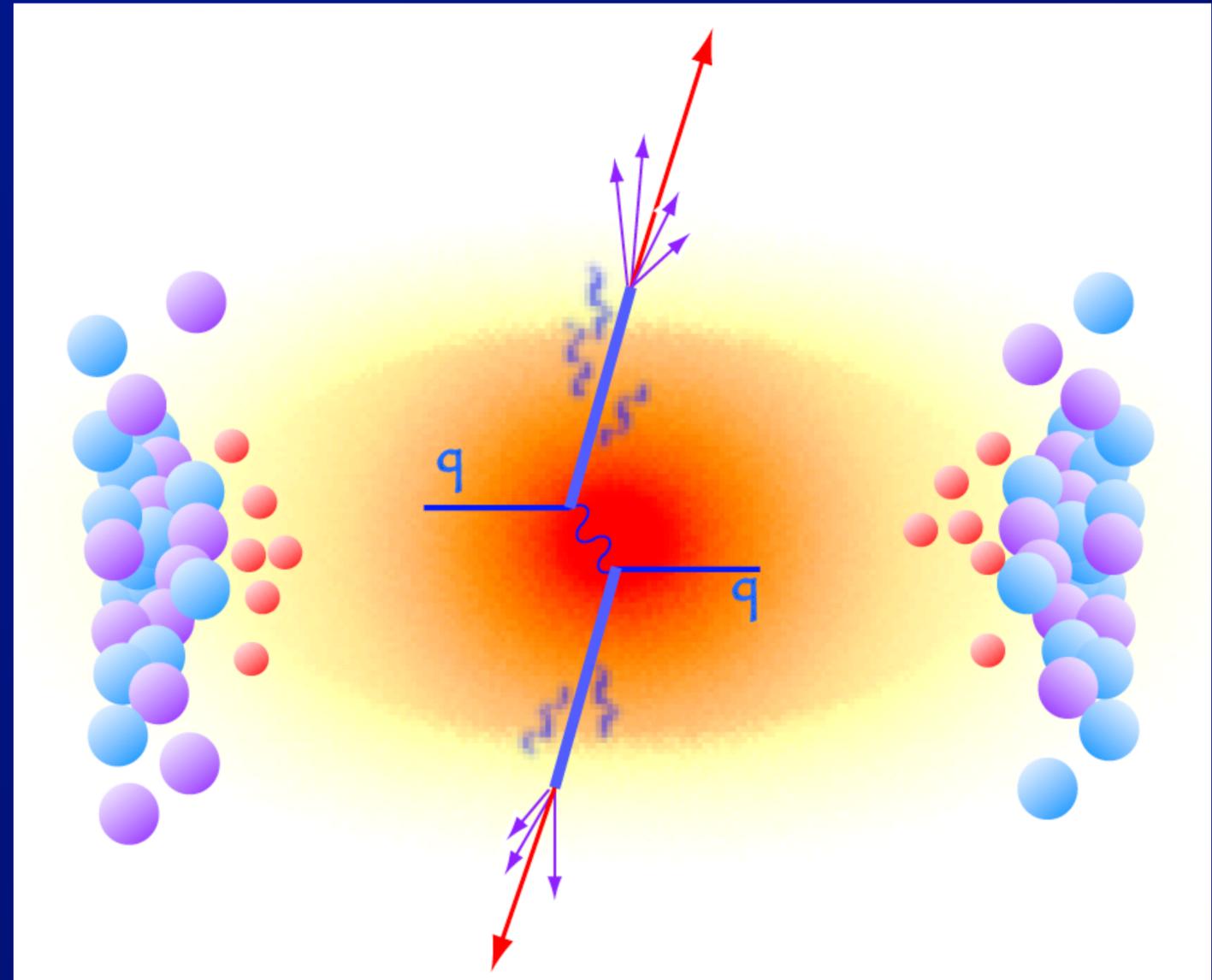
⇒ is weakly-coupled description OK?

- differential energy loss

⇒ dependence on initial-state geometry & for pairs of jets

- dependence on jet sub-structure

⇒ (how) does the medium resolve multiple color charges?



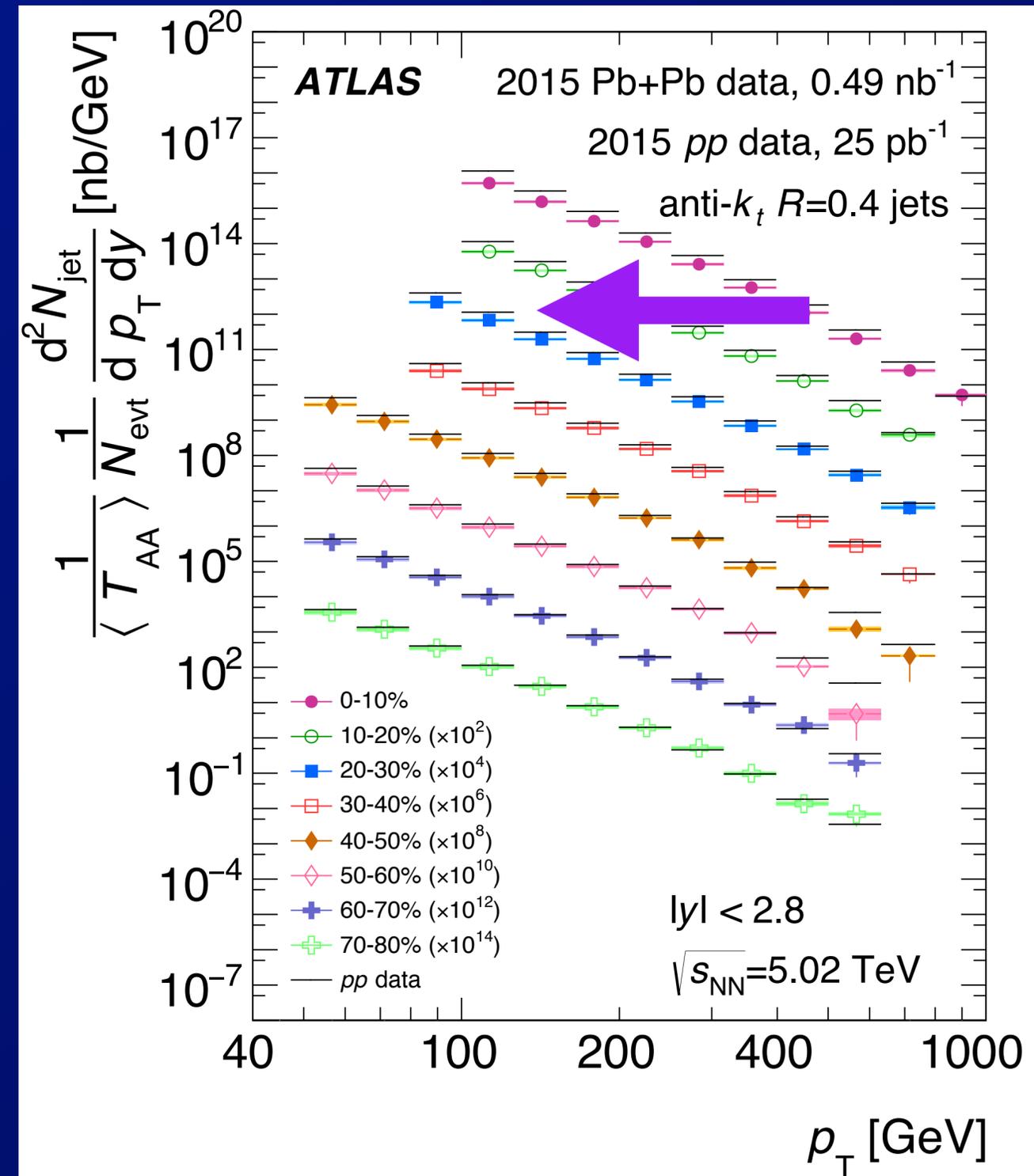
- One way to probe the energy loss of jets in the plasma

- measure reduction in jet yield vs p_T

- calibrated by pp jet cross-section

⇒ jet “ R_{AA} ”

$$R_{AA} = \frac{\frac{1}{N_{\text{evt}}} \frac{dN^{AA}}{dp_T}}{\frac{1}{T_{AA}} \frac{d\sigma^{pp}}{dp_T}}$$



- One way to probe the energy loss of jets in the plasma

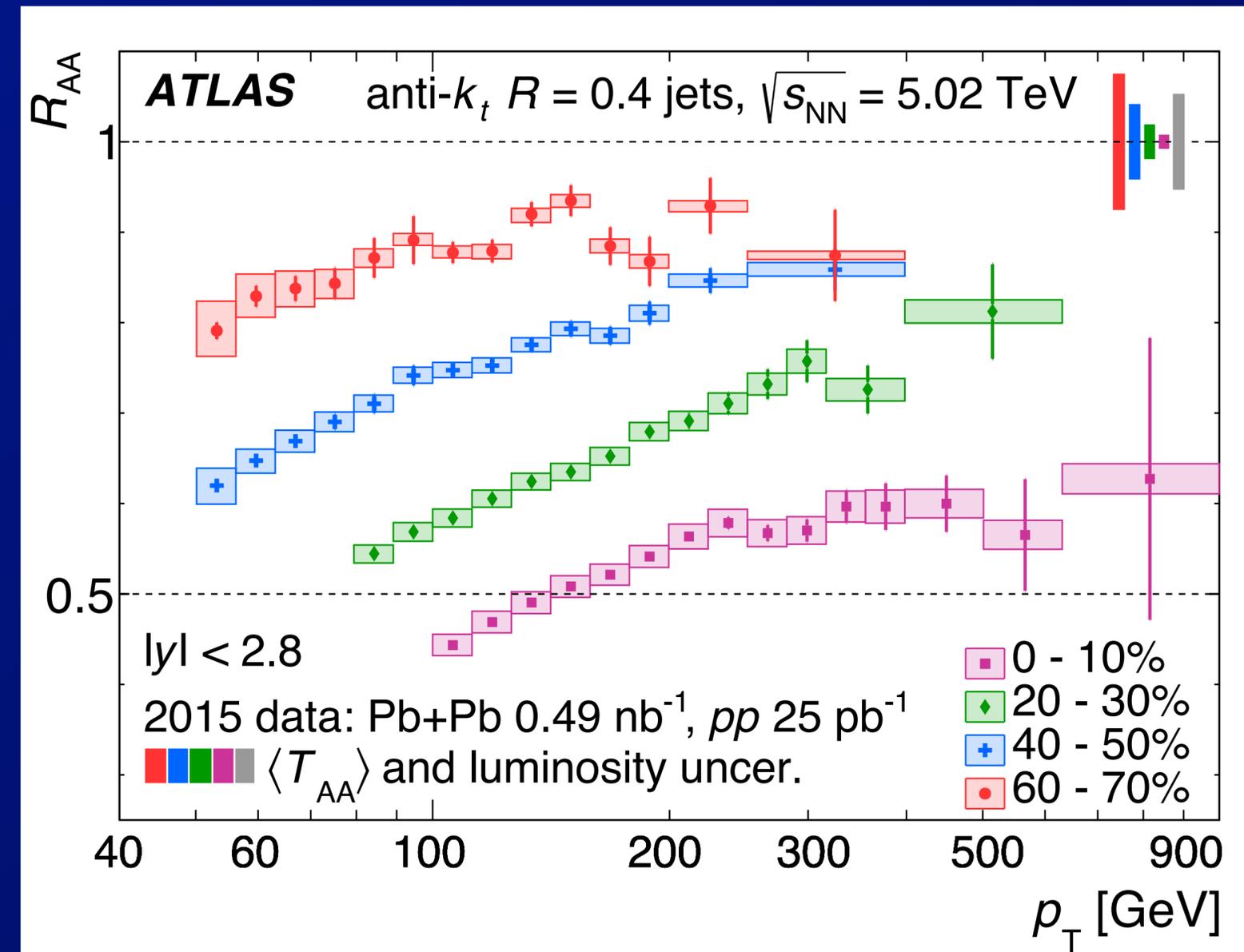
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⇒ jet “ R_{AA} ”

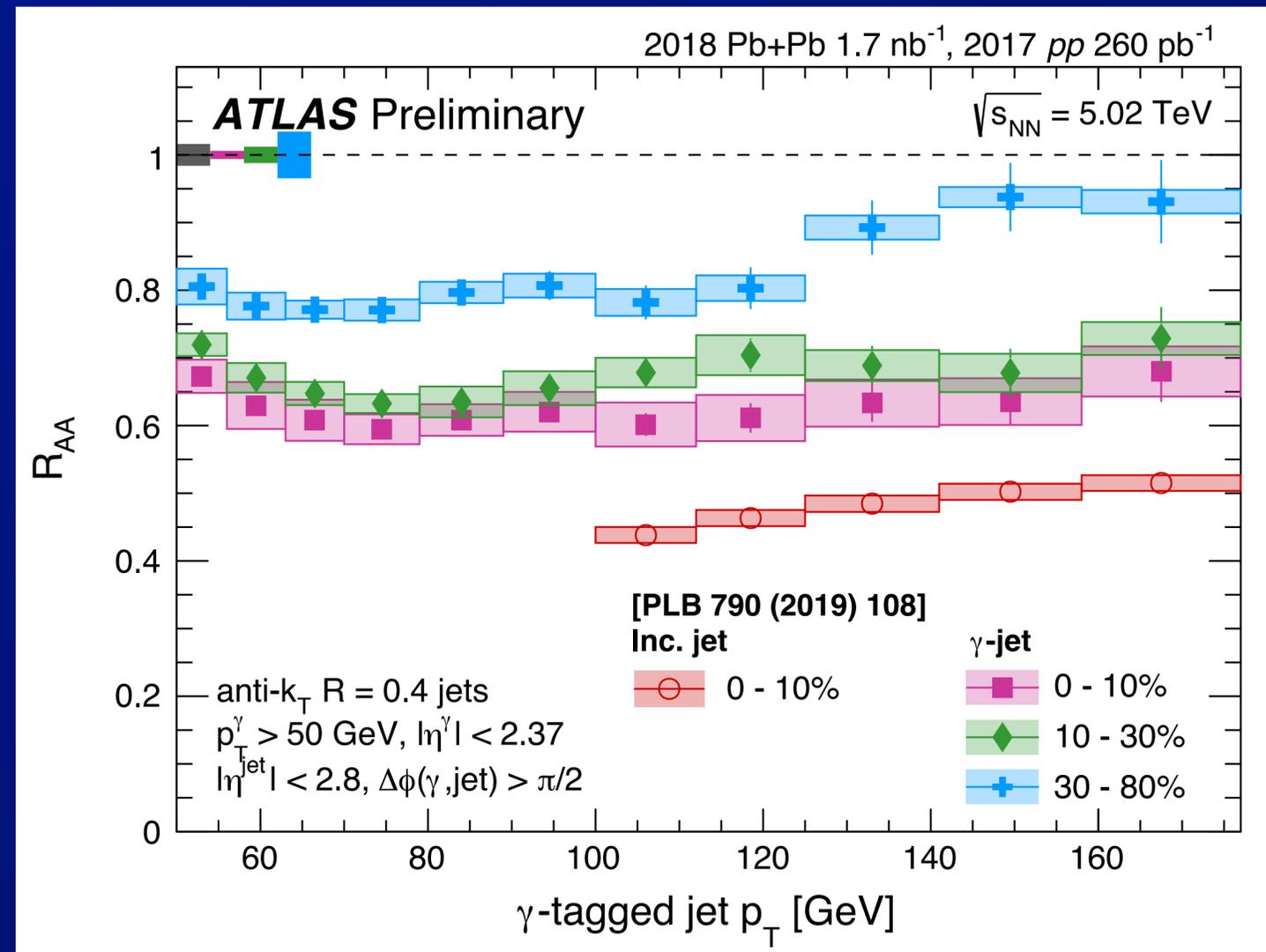
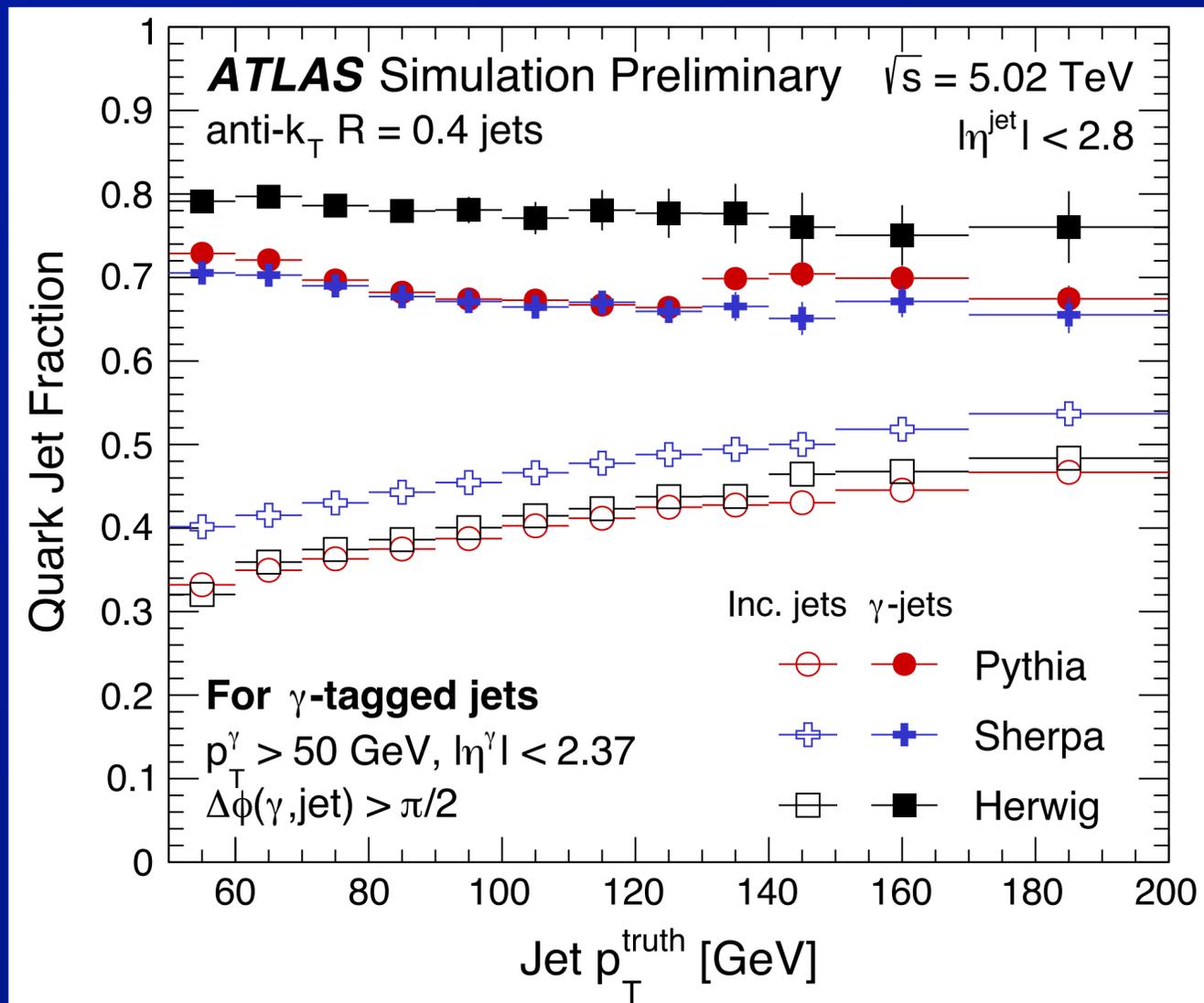
$$R_{AA} = \frac{1}{N_{evt}} \frac{dN^{AA}}{dp_T} \bigg/ \frac{1}{T_{AA}} \frac{d\sigma^{pp}}{dp_T}$$

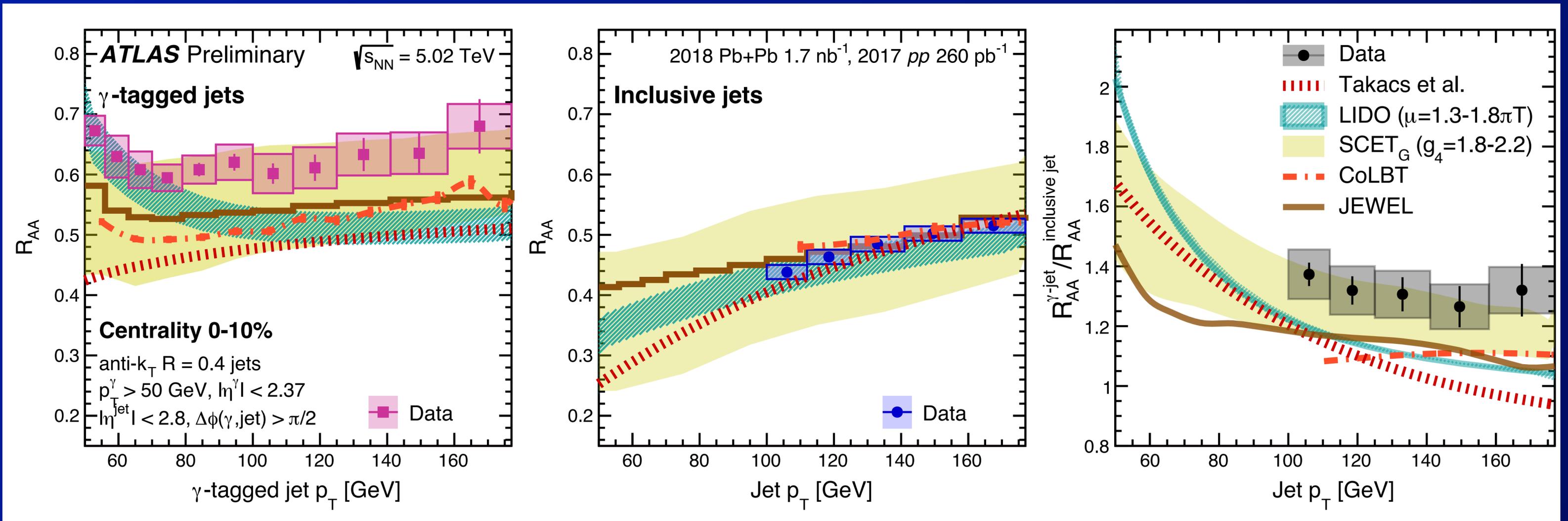
⇒ result for inclusive jets



(mostly) quark probes of the
quark-gluon plasma:
 γ -tagged jet production

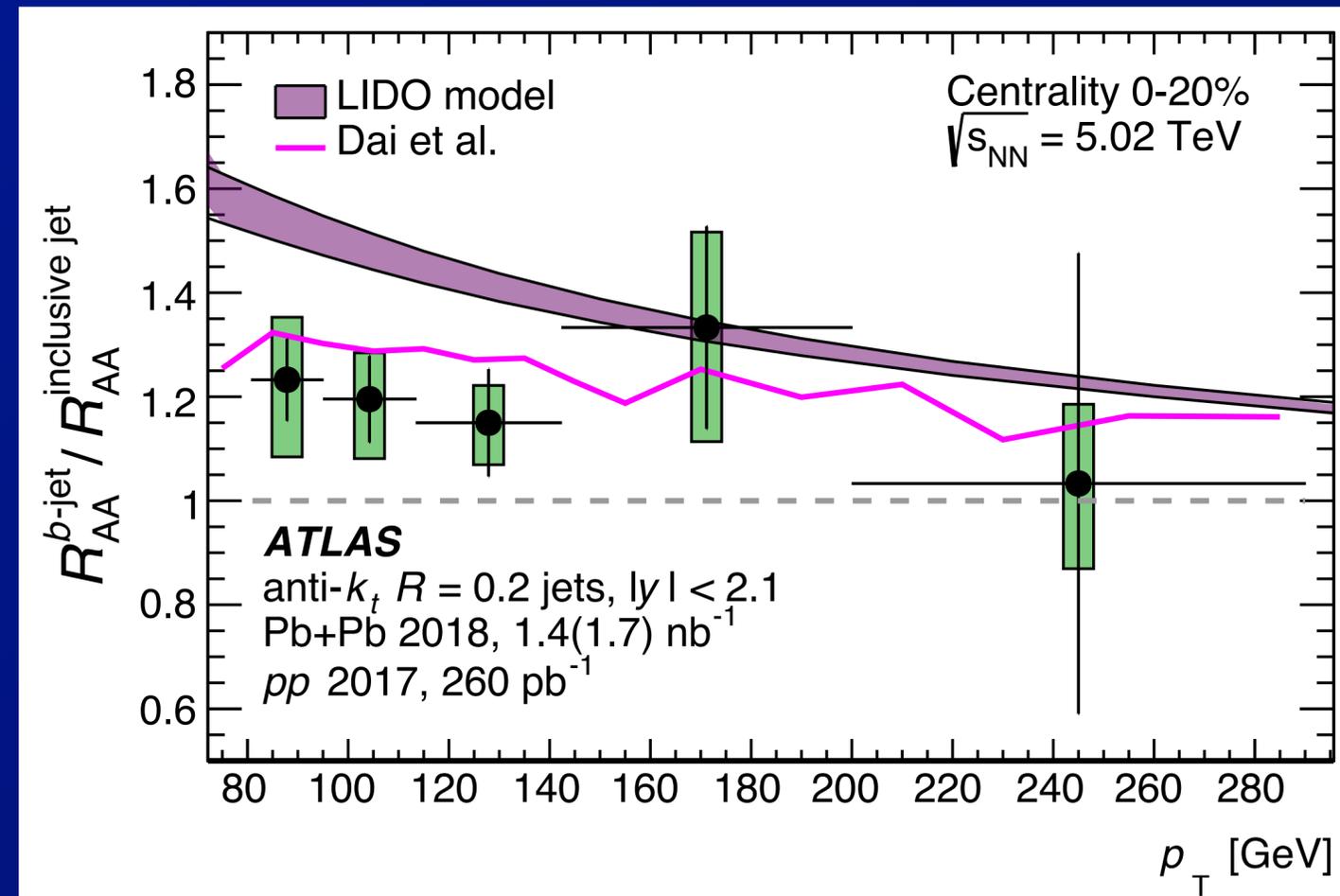
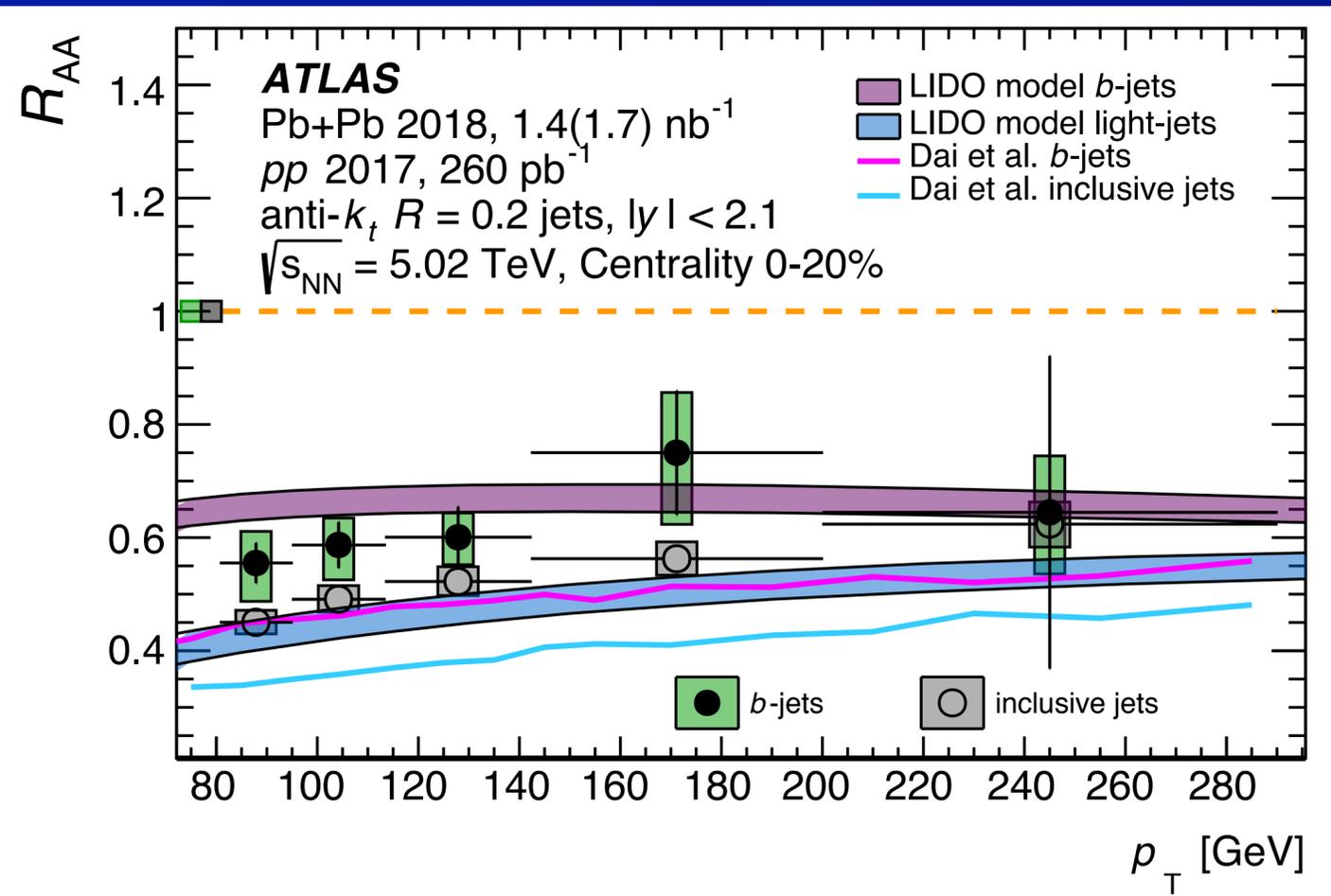
- Measure jet spectra opposite $p_T > 60$ GeV photons
 - larger quark fraction than for inclusive jets
 - ⇒ test weak-coupling expectation: quarks lose less energy than gluons





- γ -tagged jet R_{AA} is unambiguously larger than inclusive jet R_{AA}
- Most energy loss calculations under-predict difference
 - difference is larger than it appears in R_{AA} ratio
 - $\Rightarrow 1 - R_{AA}$ is more directly related to energy loss

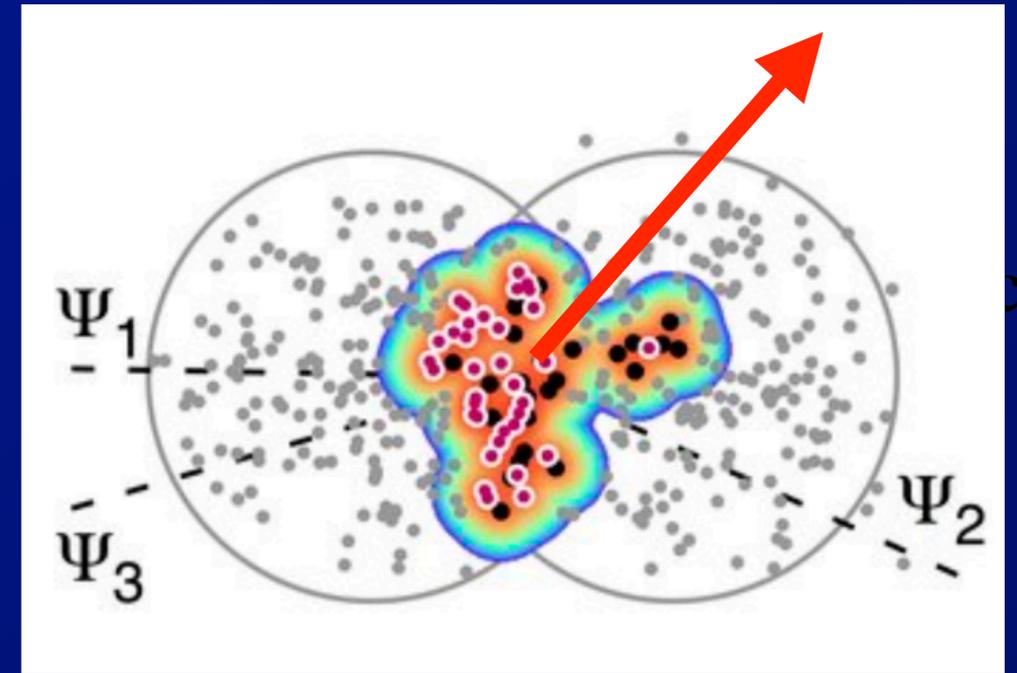
b-tagged jets (c.f. W Zou talk this AM)



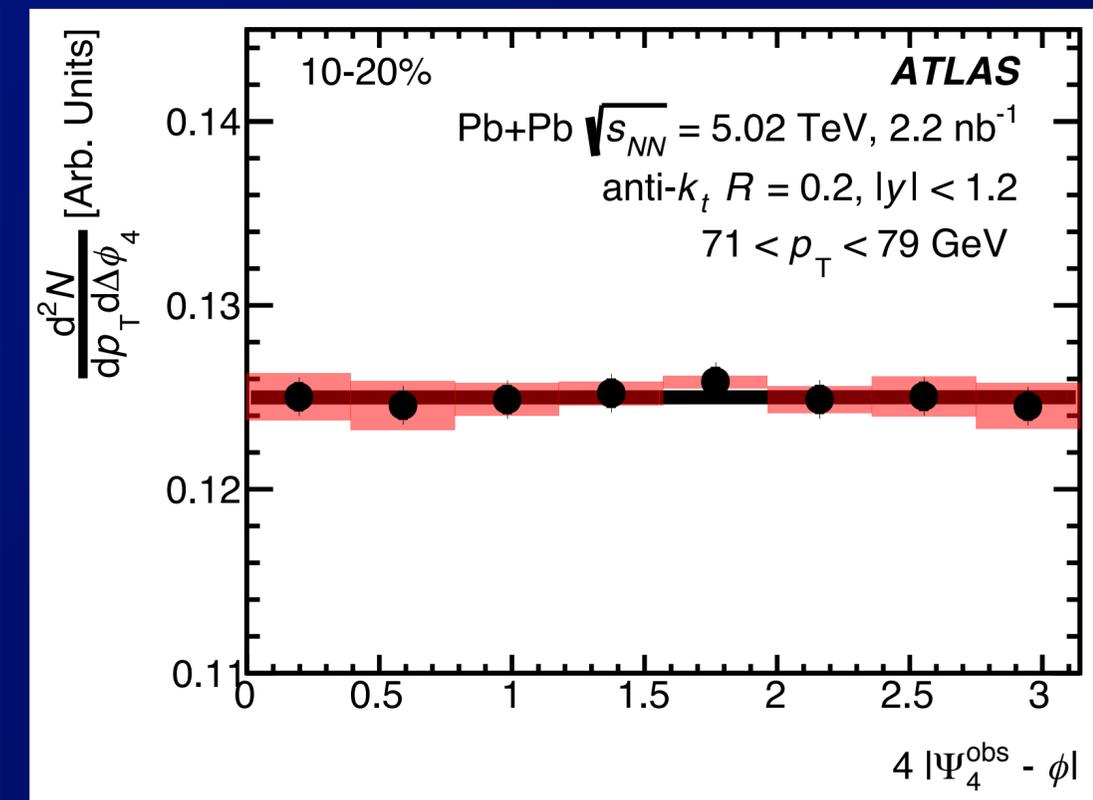
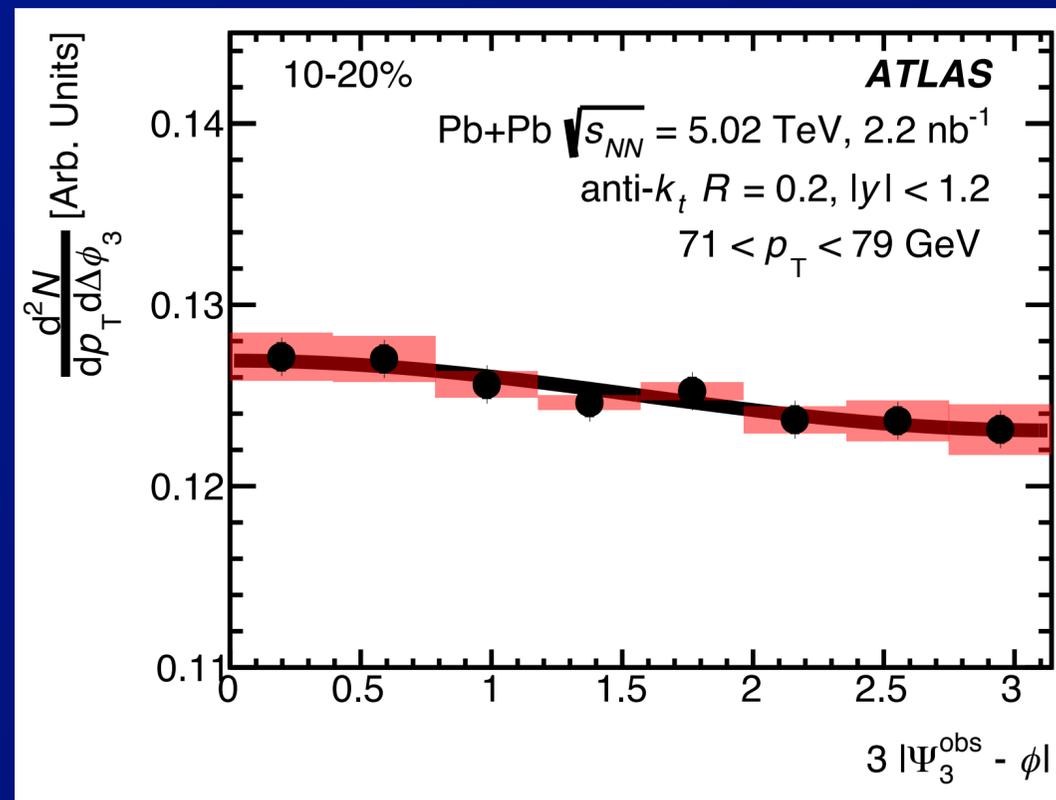
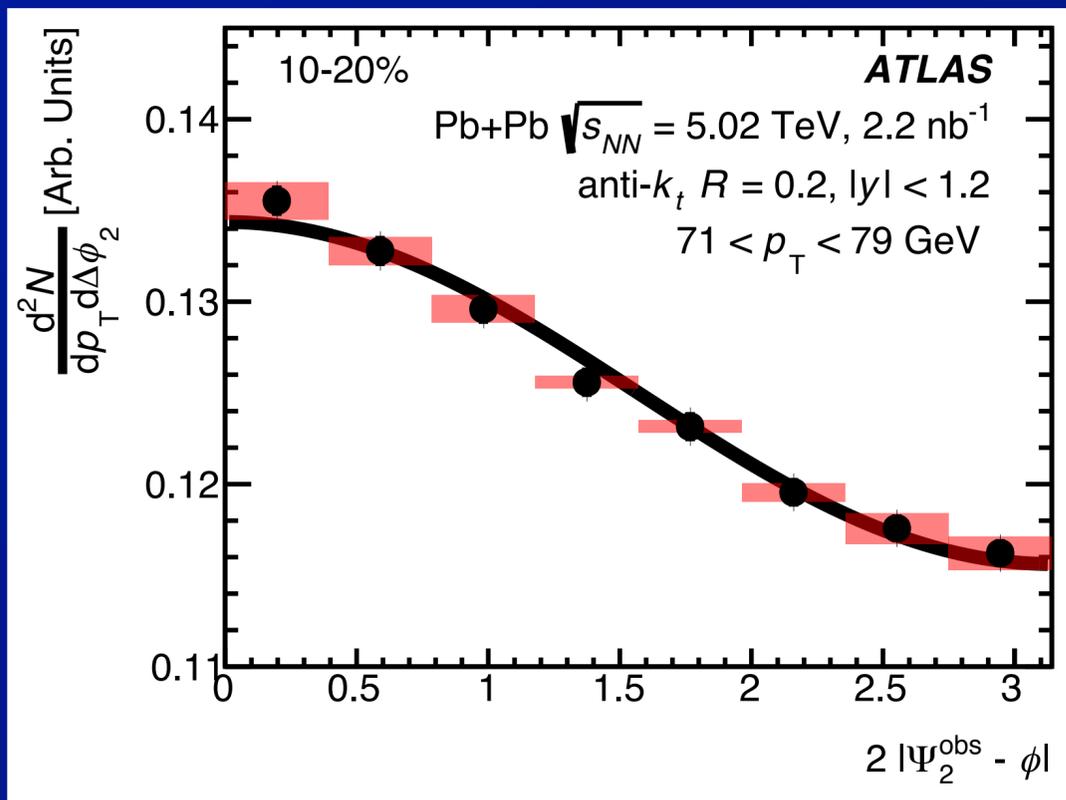
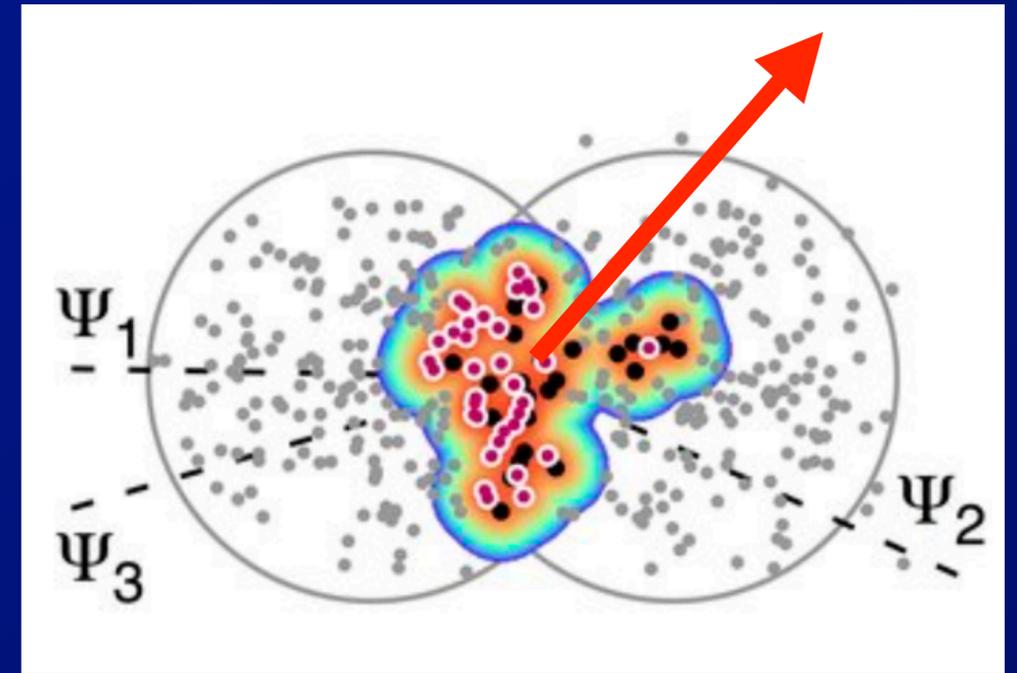
- **Observe that b-tagged jet $R_{AA} >$ inclusive jet**
 - but no significant p_T -dependence ... role of b quark mass?
- **but b-tagged jets a mixture of leading b and $g \rightarrow b\text{-}b\bar{b}$**
 - gluon fraction varies by 23-45% over p_T range [80, 250] GeV
 - ⇒ can disguise role of b quark mass @ lower p_T (?)

**differential quark and gluon probes
of the quark-gluon plasma:
jet v_2 and v_3**

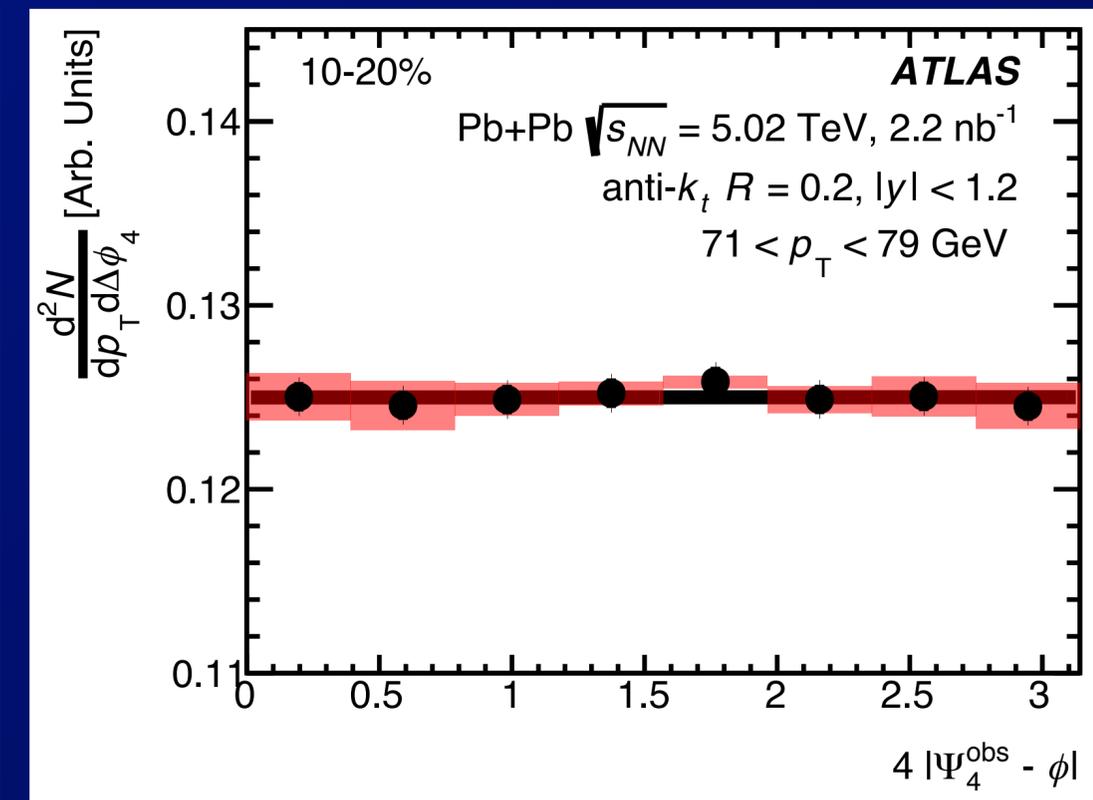
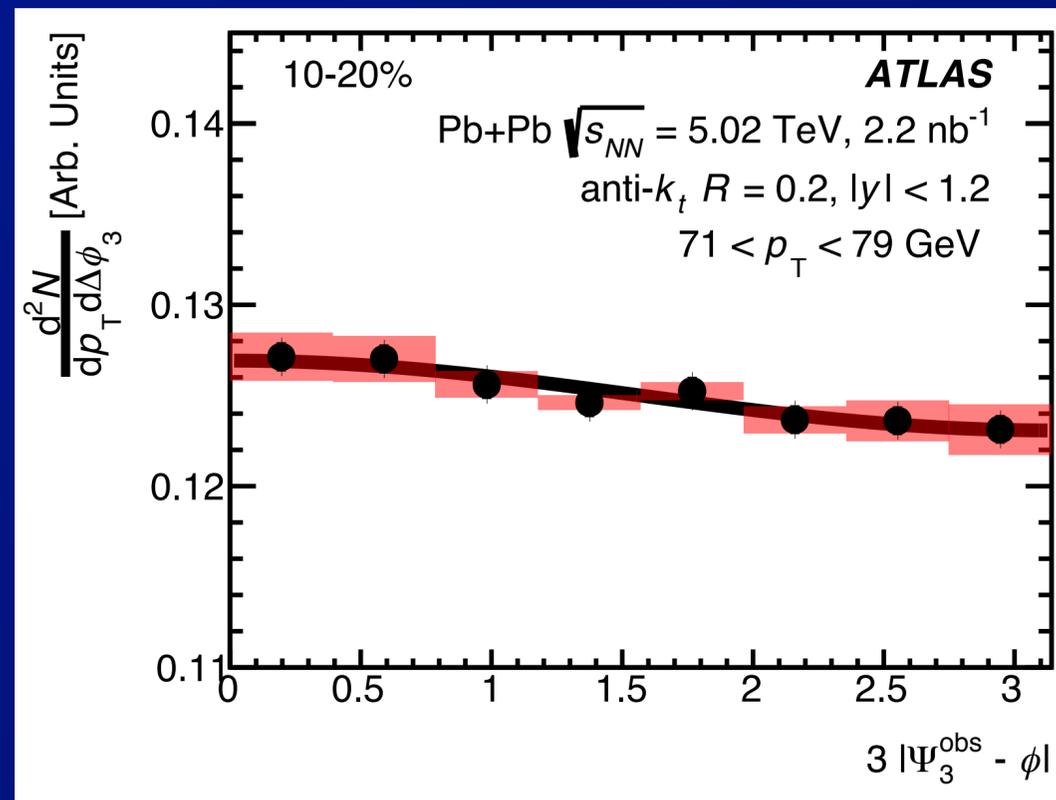
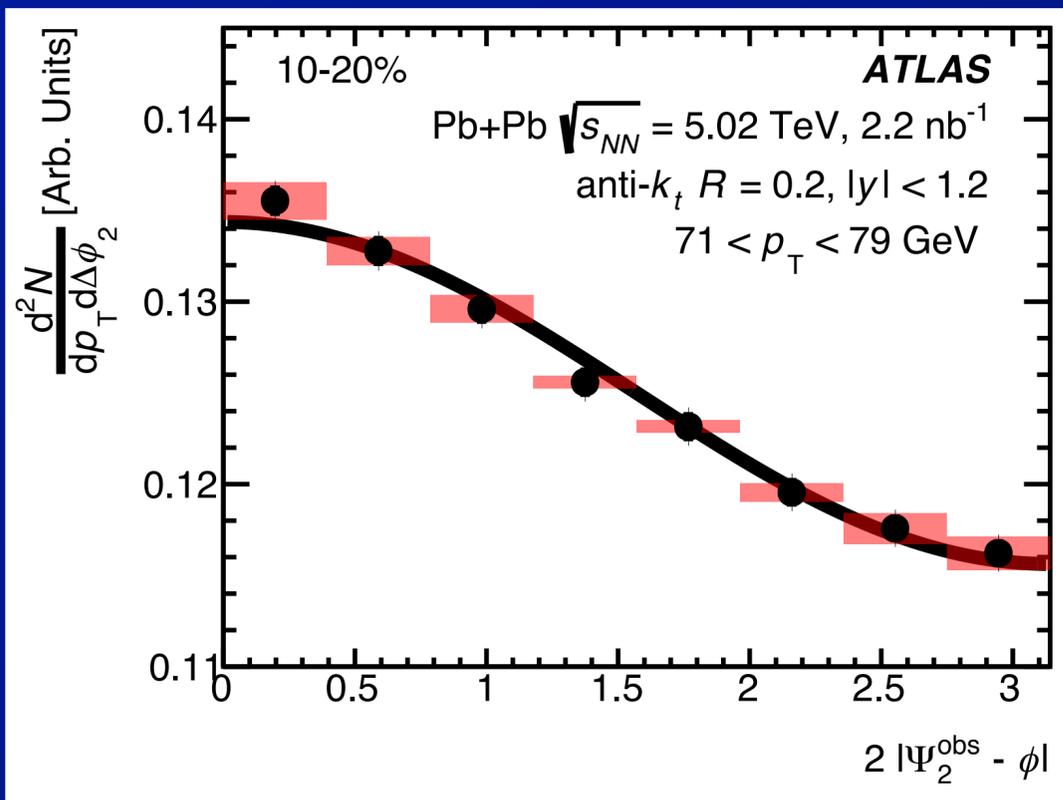
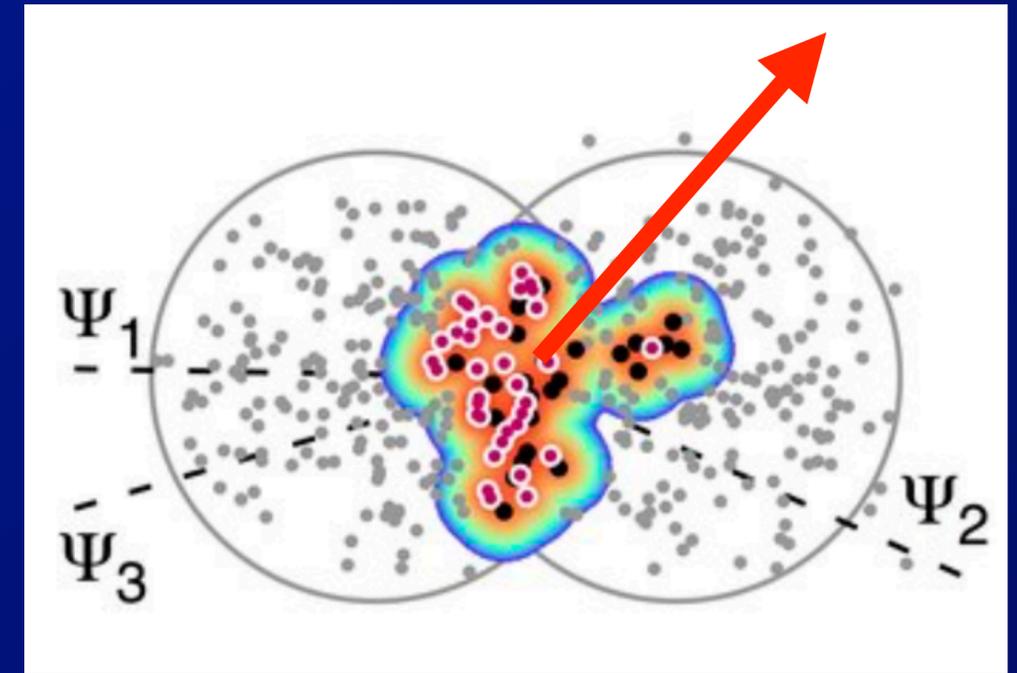
- Measure jet yield as a function of angle *wrt* n th-order event plane: $\Delta\varphi_n = n|\varphi - \Psi_n|$



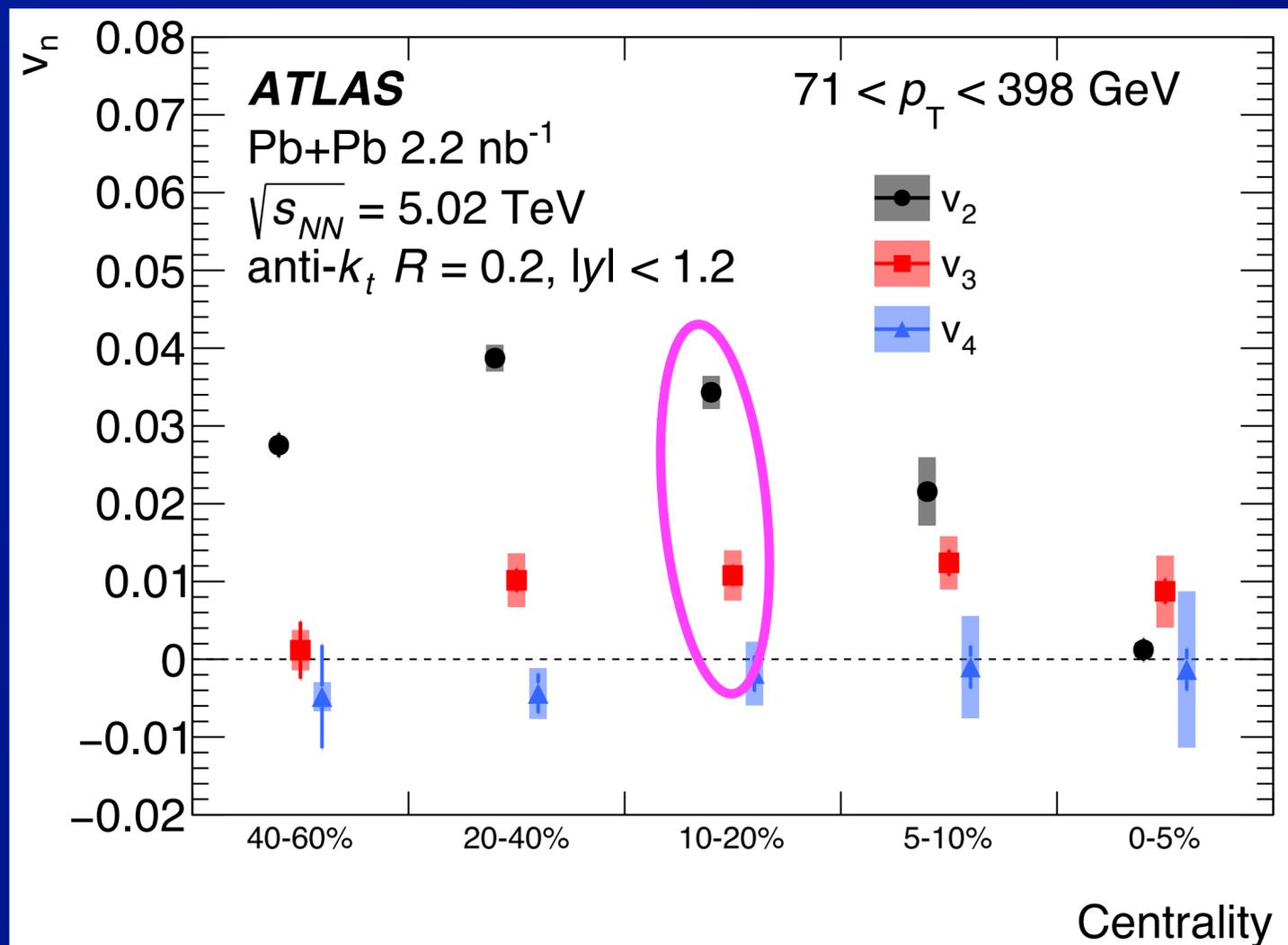
- Measure jet yield as a function of angle wrt nth-order event plane: $\Delta\varphi_n = n|\varphi - \Psi_n|$



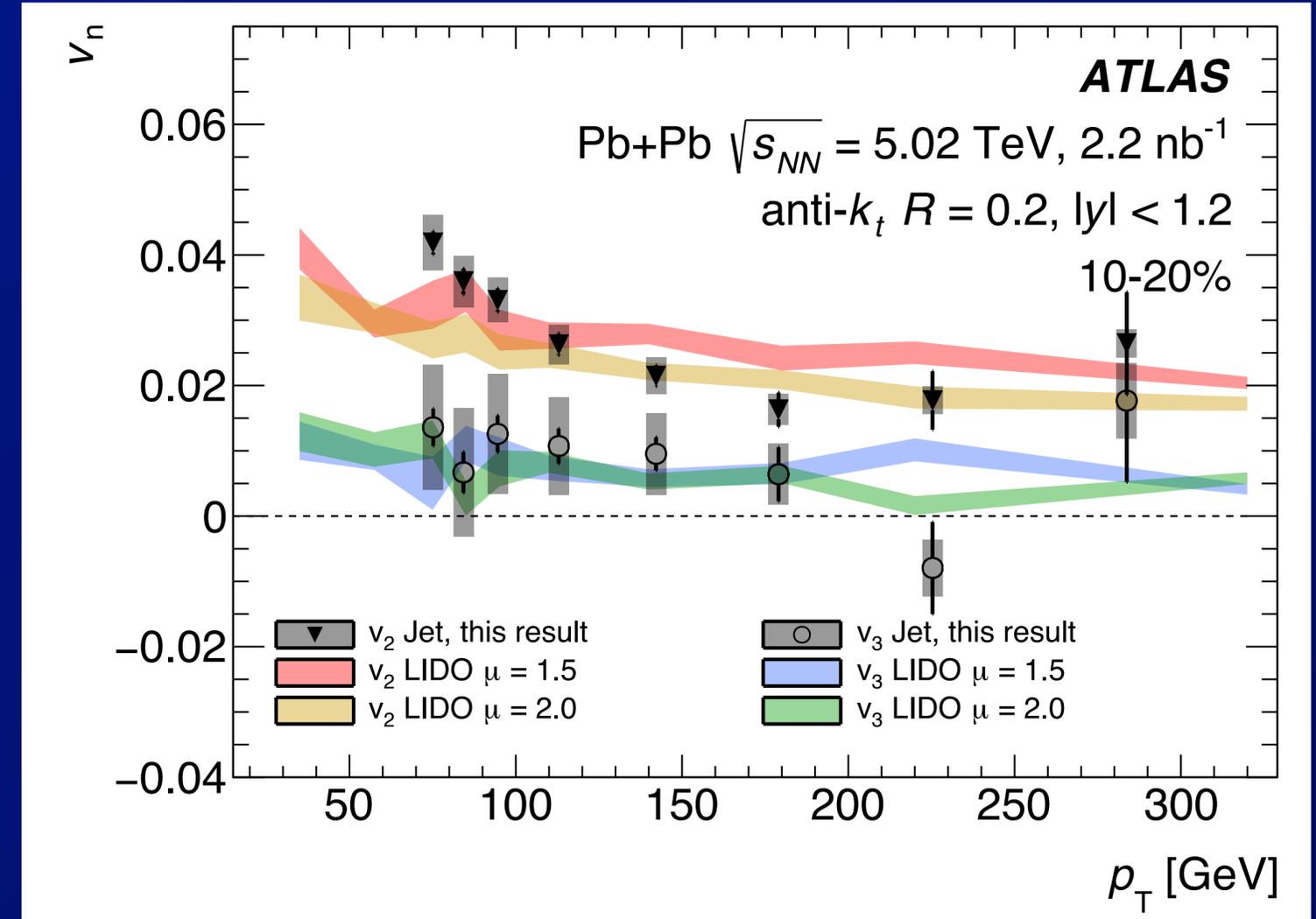
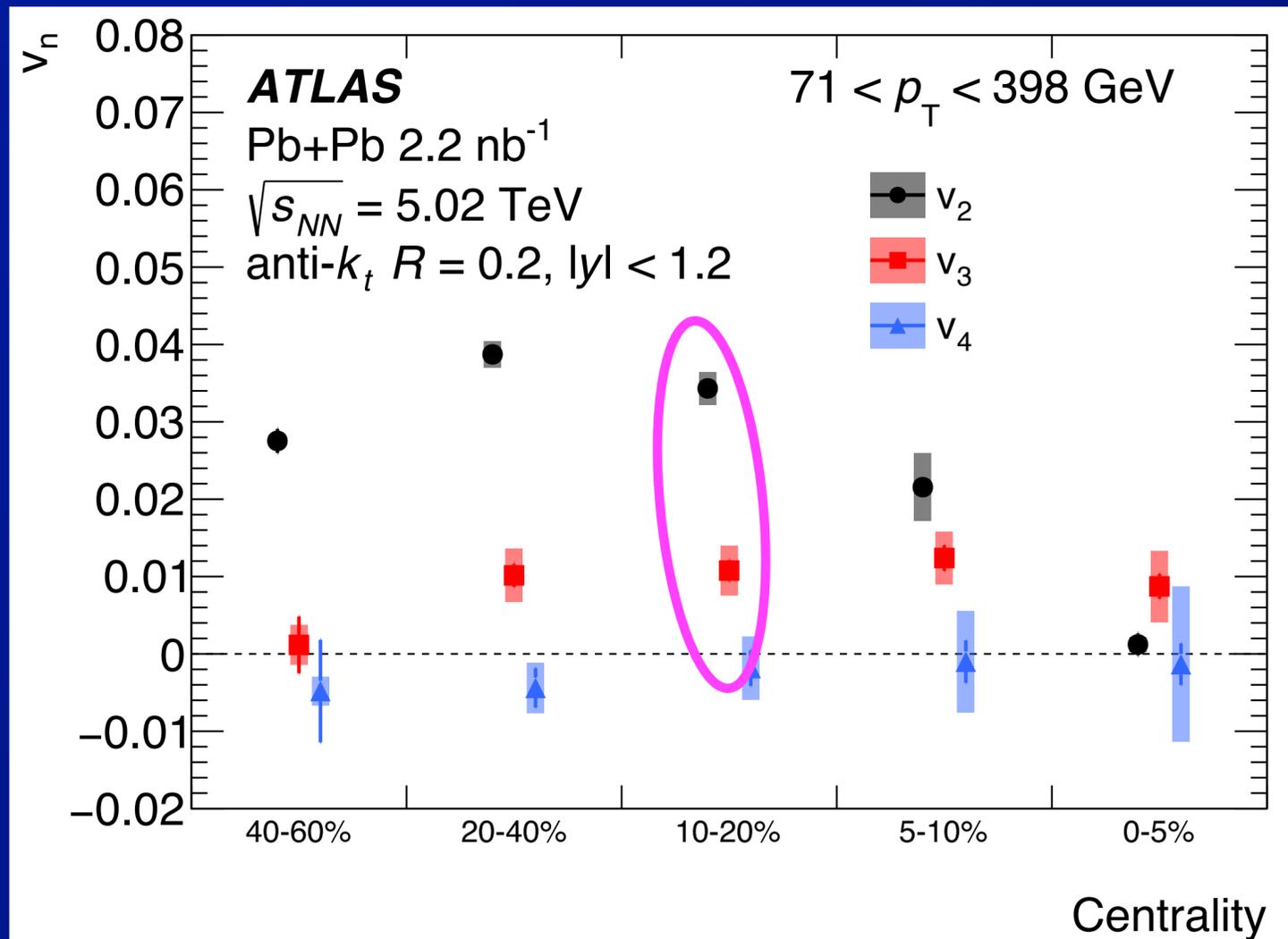
- Measure jet yield as a function of angle *wrt* n th-order event plane: $\Delta\varphi_n = n|\varphi - \Psi_n|$
- observe clear variation with $\Delta\varphi_2$ and $\Delta\varphi_3$
- no significant dependence on $\Delta\varphi_4$



- Measure jet yield as a function of angle *wrt* n th-order event plane
 - observe clear variation with $\Delta\varphi_2$ and $\Delta\varphi_3$
- Characterize w/ Fourier coefficients: $dN/d\Delta\varphi_n = A [1 + 2v_n \cos(\Delta\varphi_n)]$



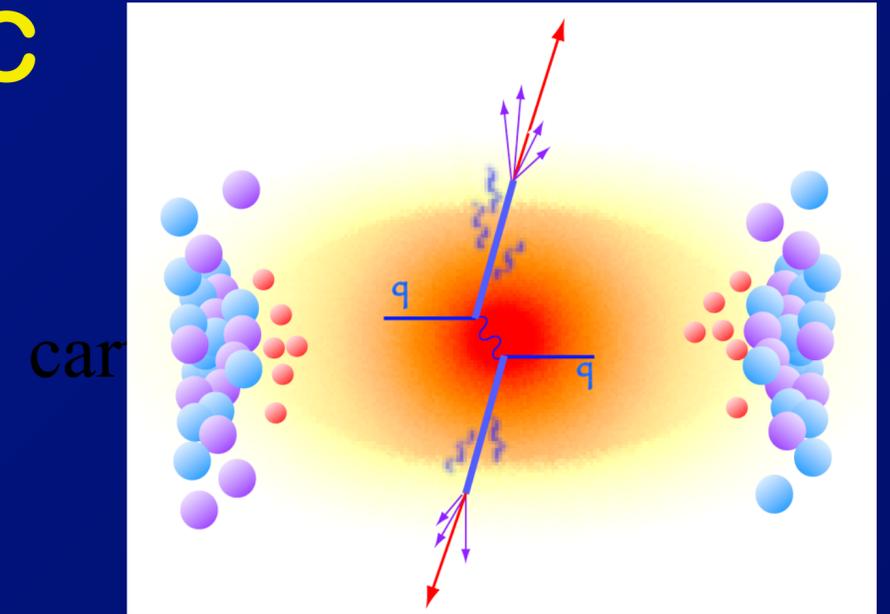
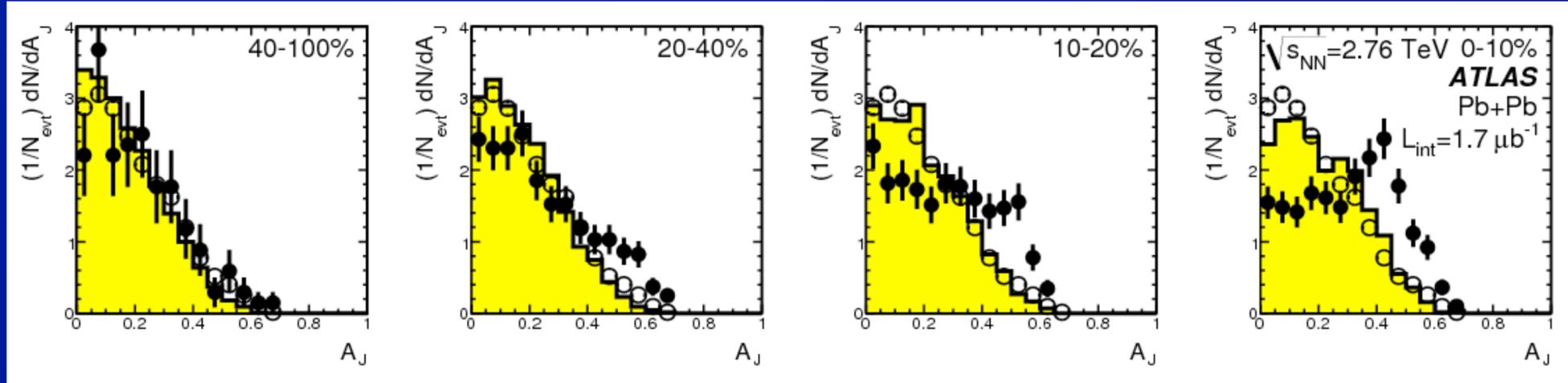
- Measure jet yield as a function of angle *wrt* n th-order event plane:
- Characterize w/ Fourier coefficients: $dN/d\Delta\varphi_n = A [1 + 2v_n \cos(\Delta\varphi_n)]$
 - compare to theoretical energy loss calculations
 - ⇒ good description of data



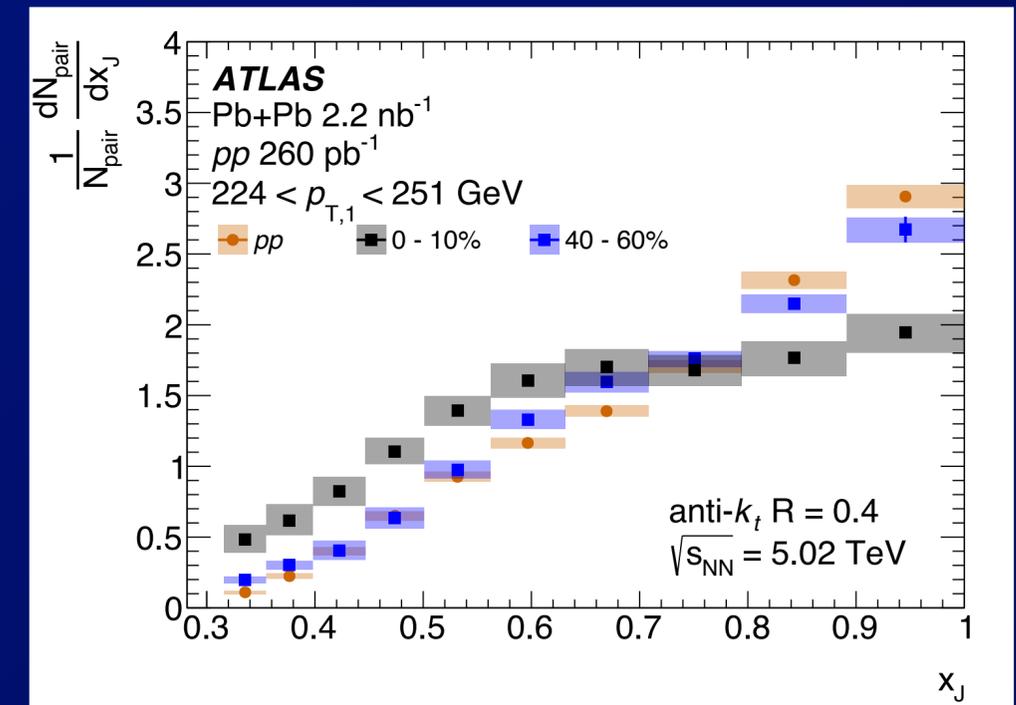
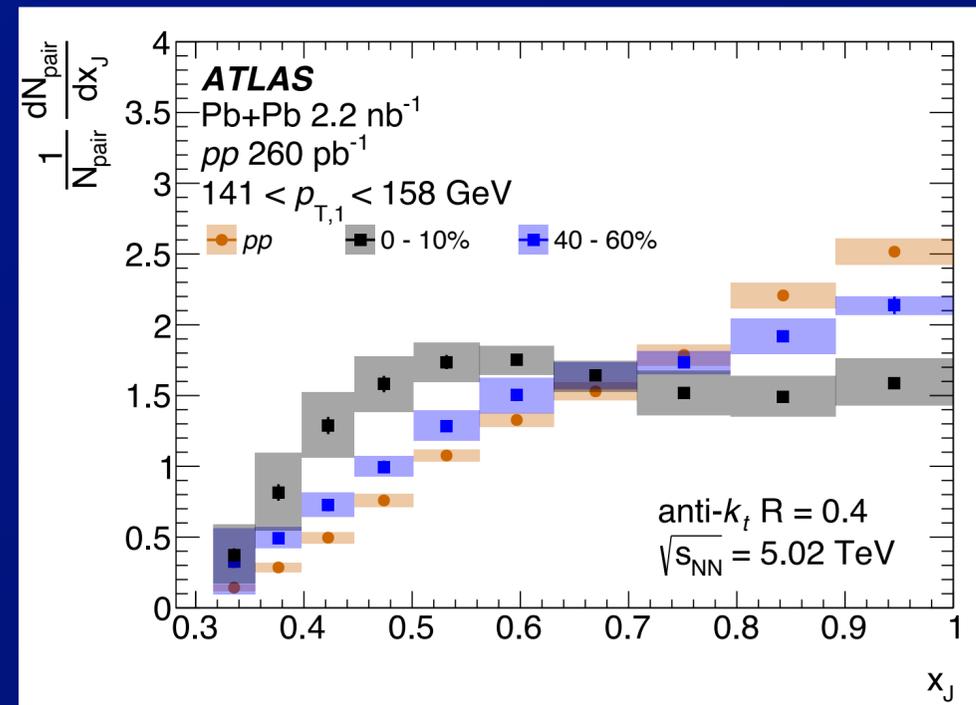
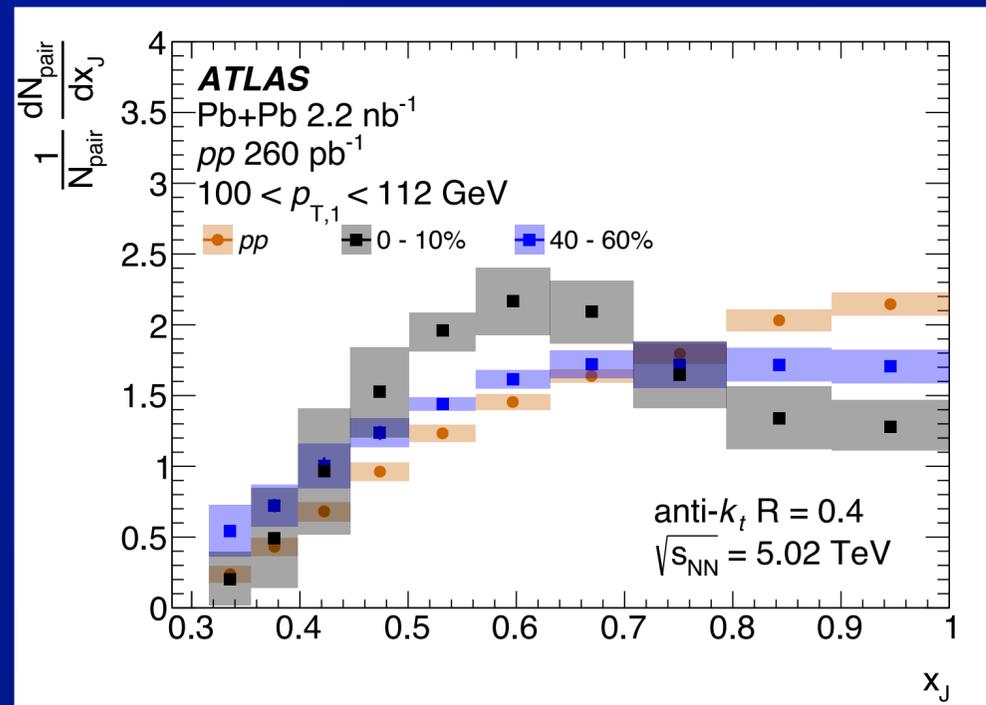
**differential jet quenching:
dijet balance**

Measure p_T balance in dijet pairs

- First direct observation of jet quenching @ LHC



- Fast-forward 12 years (Phys.Lett.B 774 (2017) 379 and [arXiv:2205.00682](https://arxiv.org/abs/2205.00682))
– much higher statistics, higher p_T , unfolded for jet response

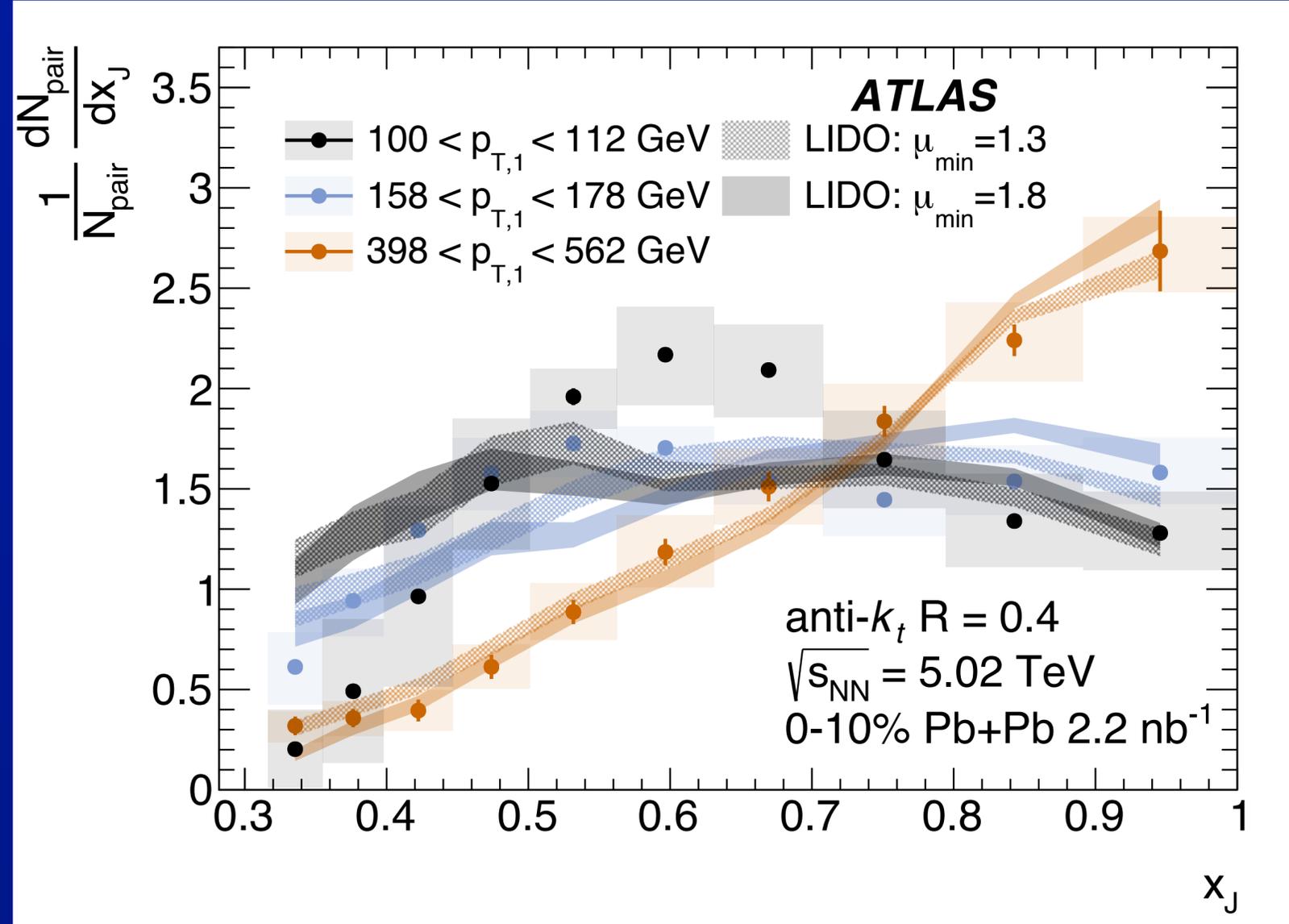
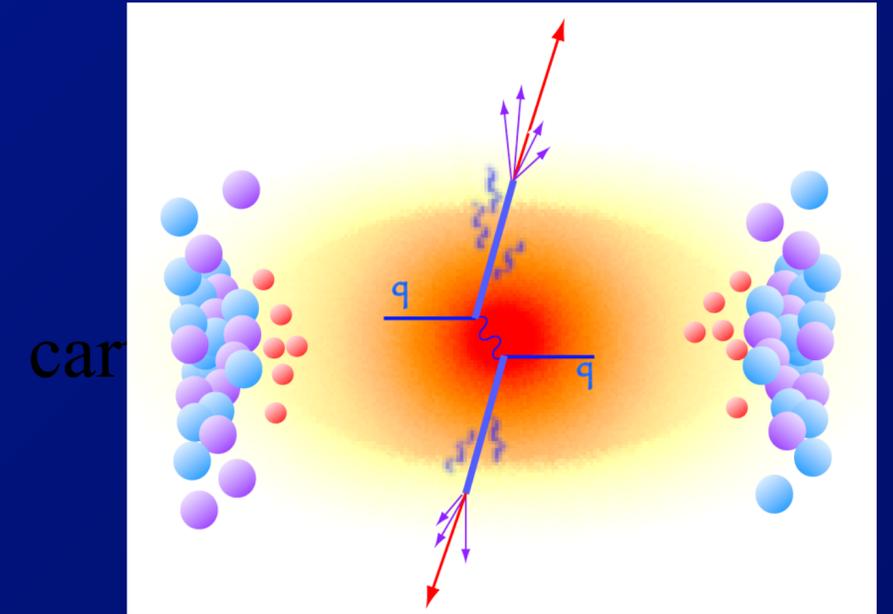


Measure p_T balance in dijet pairs

- Compare x_J distributions to theory (LIDO)

- qualitative agreement

- ⇒ but theoretical calculations unable to explain peaking @ $x_J \sim 0.6$ in the data

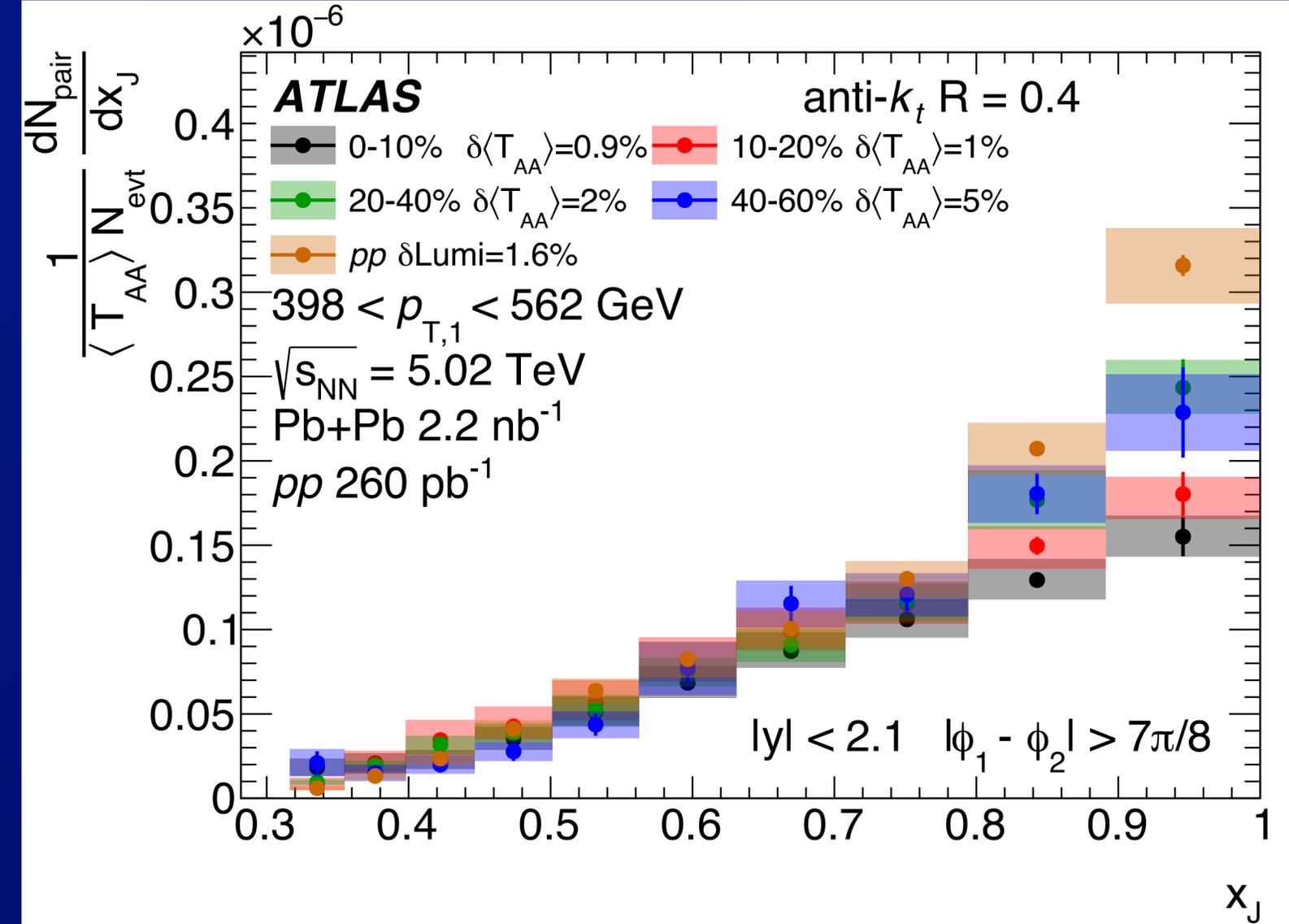
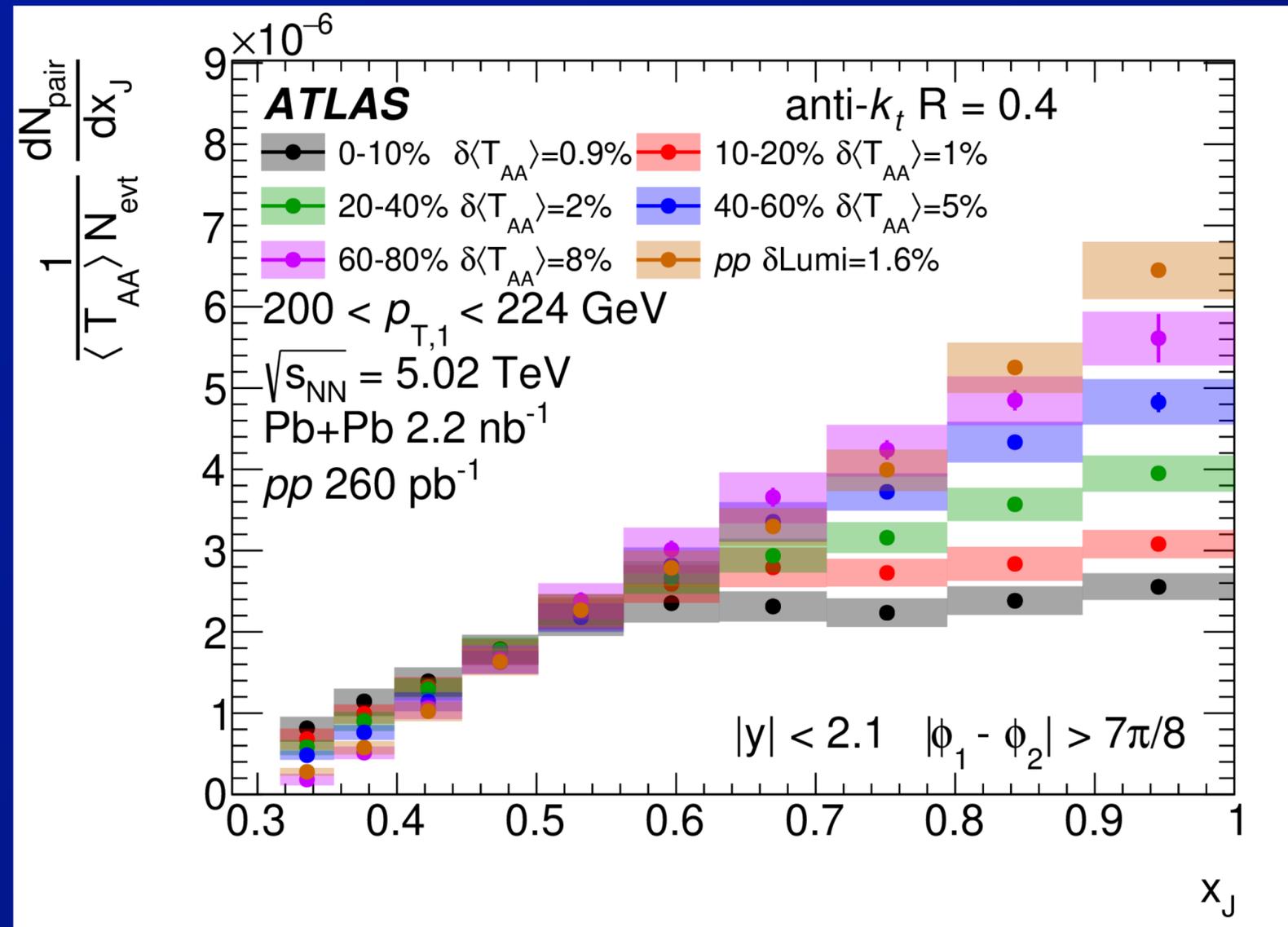


Measure p_T balance in dijet pairs

- **New: absolute pair yields vs x_J**

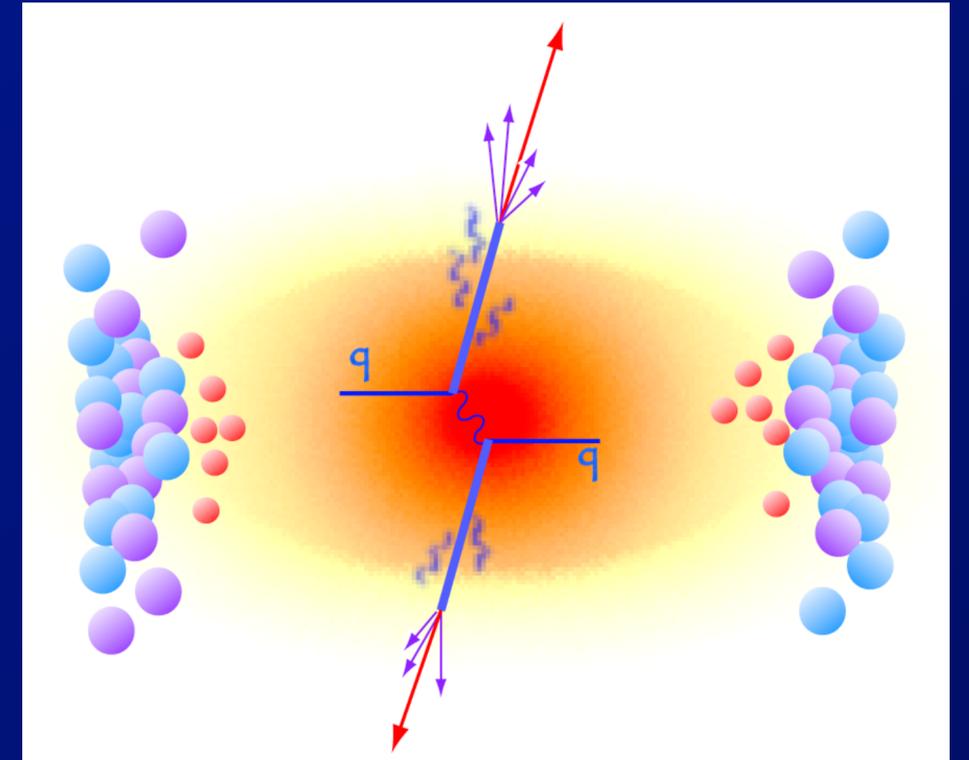
– complicated because it combines suppression of leading jet + effects of leading-sub-leading imbalance

⇒ **greatest suppression for balanced pairs: energy loss fluctuations?**



**color-coherence of in-medium
jet quenching: jet sub-structure**

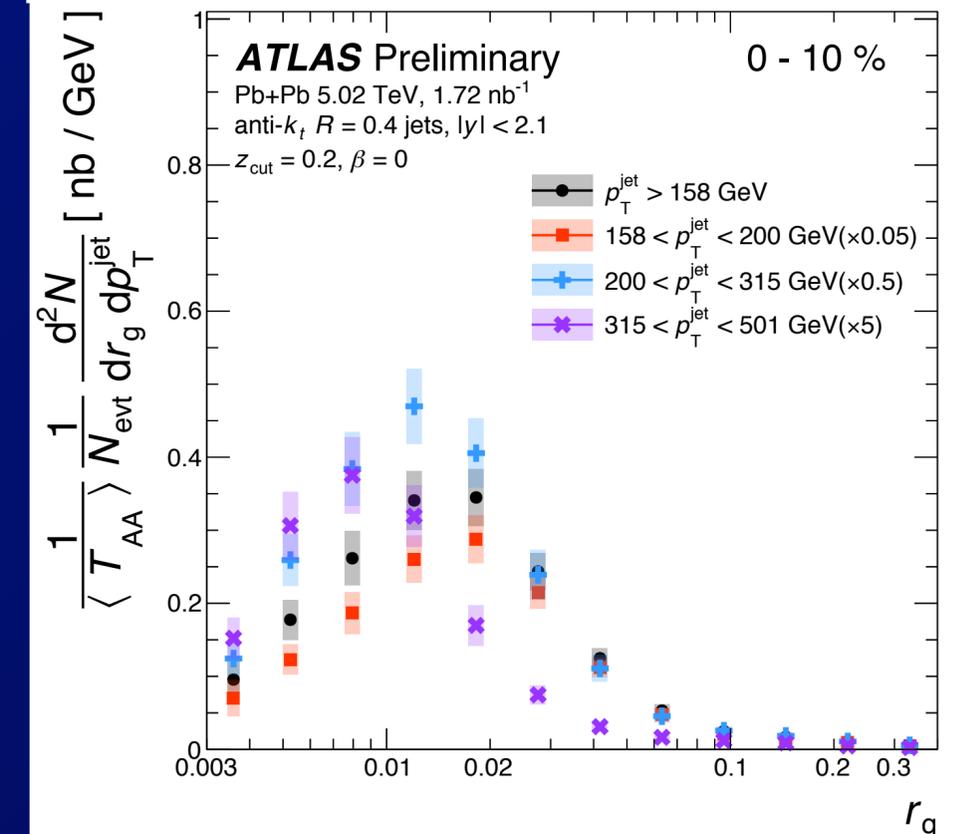
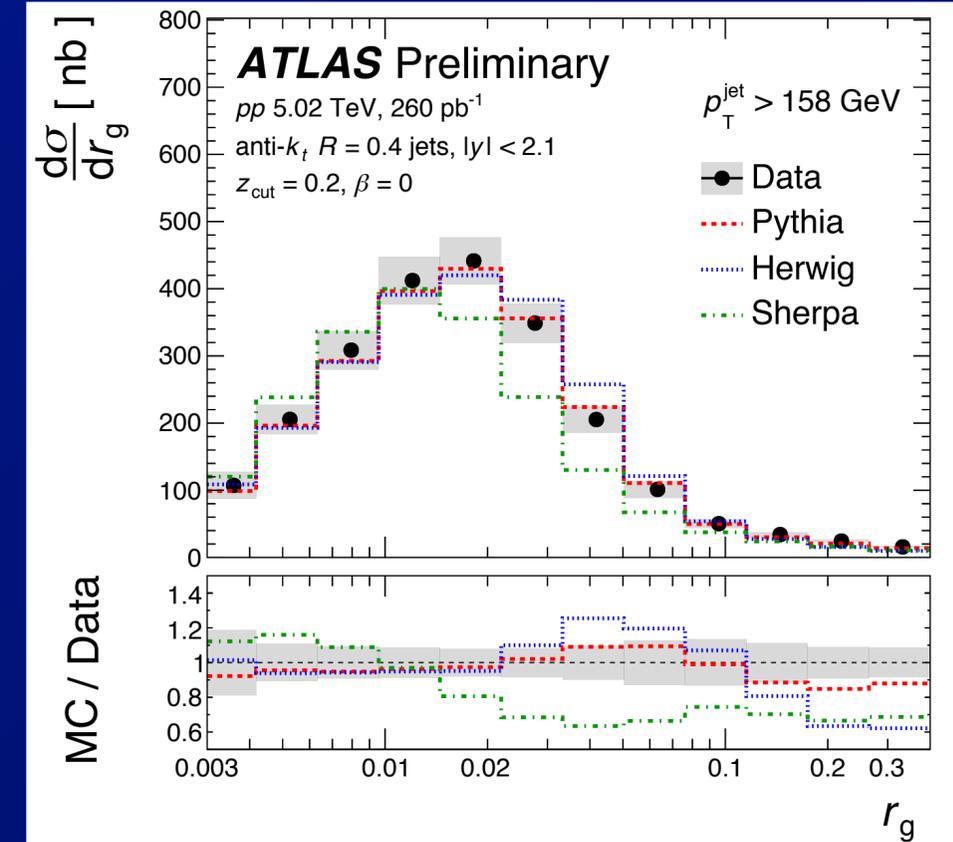
- $R = 0.4$ anti- k_T jets reconstructed from matched tracks and calorimeter clusters
 - re-clustered using C/A + soft-drop
 - $\Rightarrow \beta = 0, z_{\text{cut}} = 0.2$
 - r_g from the last splitting
 - \Rightarrow hardest angular splitting in the jet



Jet sub-structure via C/A + soft-drop

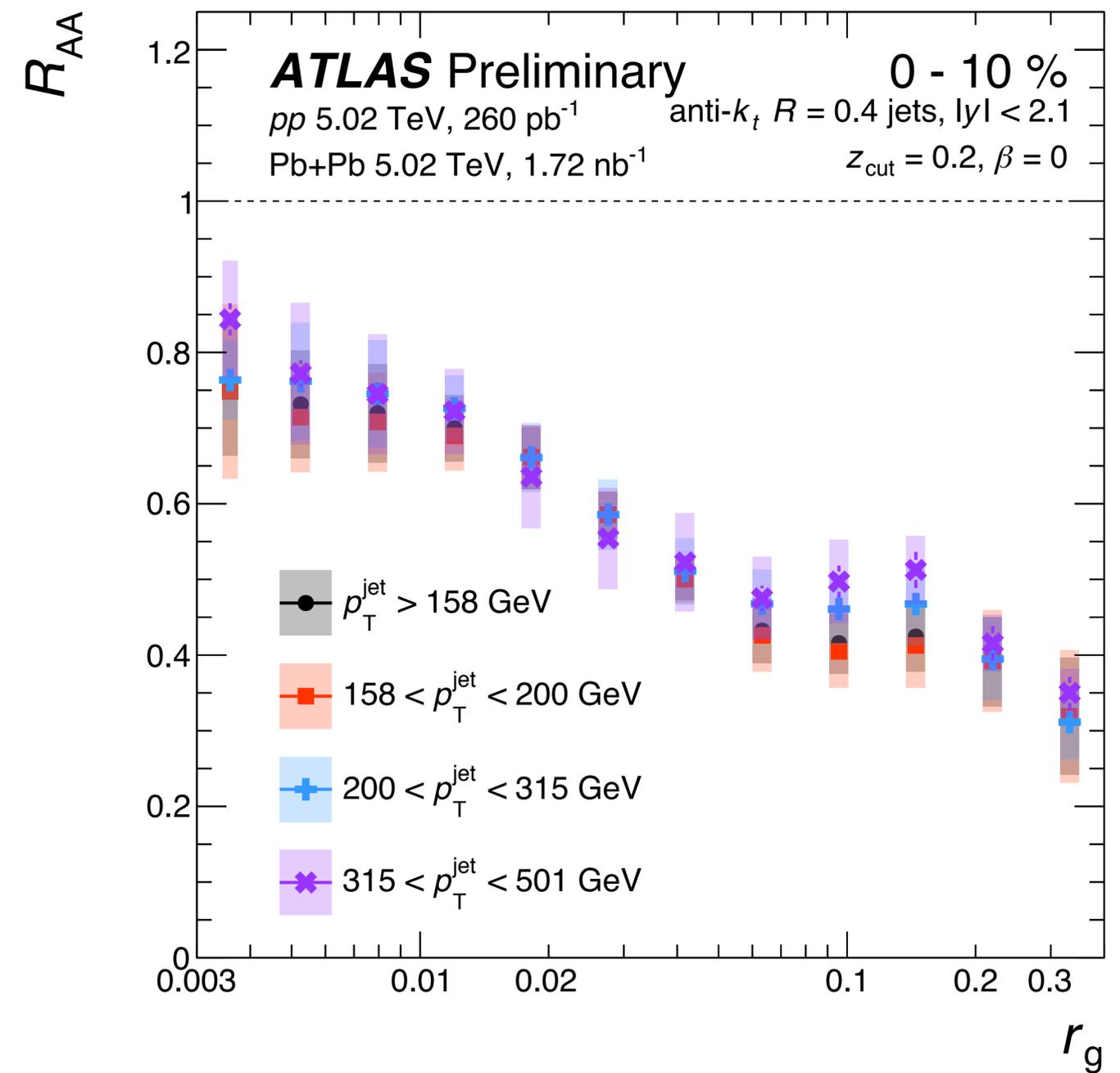
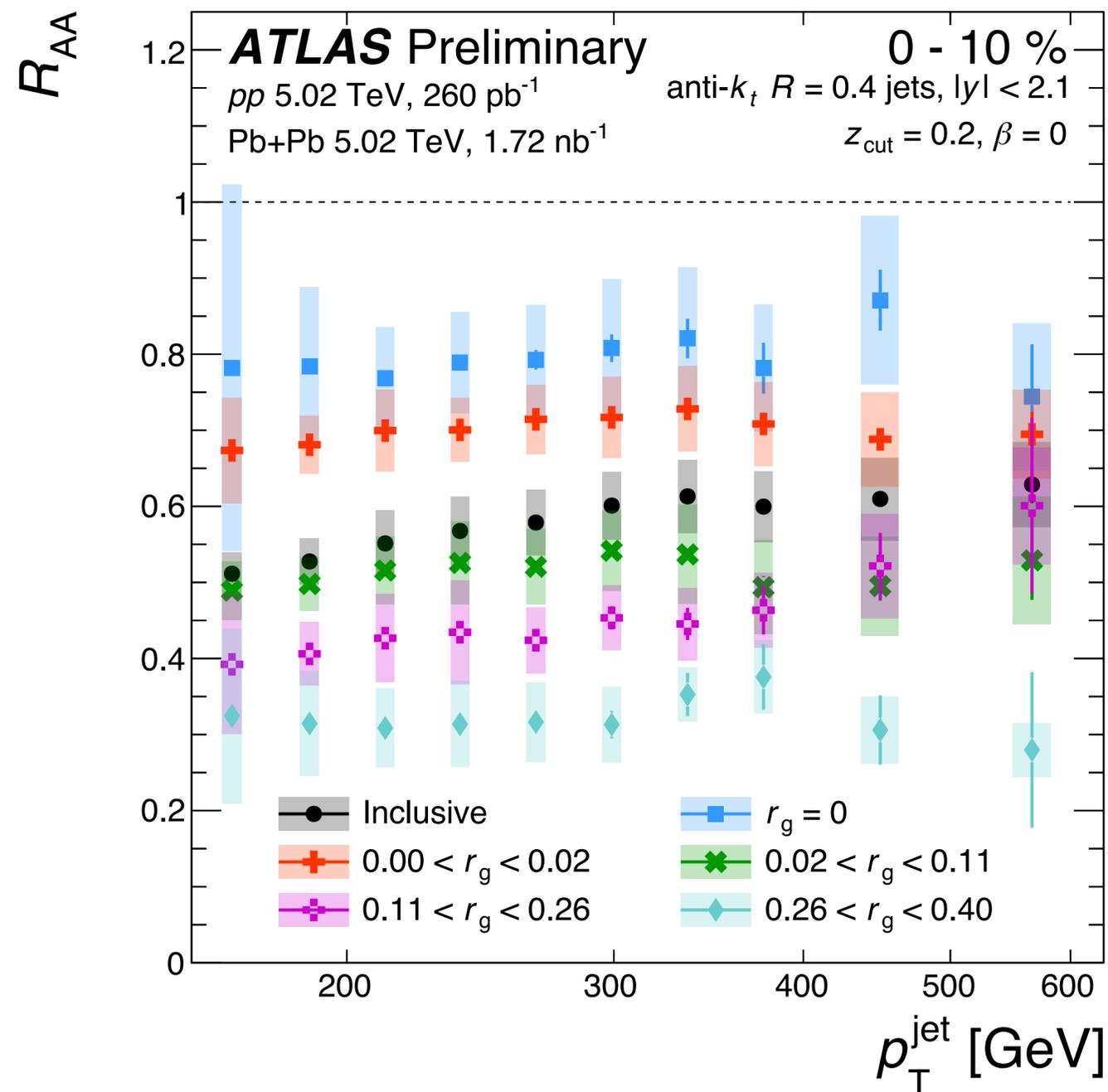
23

- $R = 0.4$ anti- k_T jets reconstructed from matched tracks and calorimeter clusters
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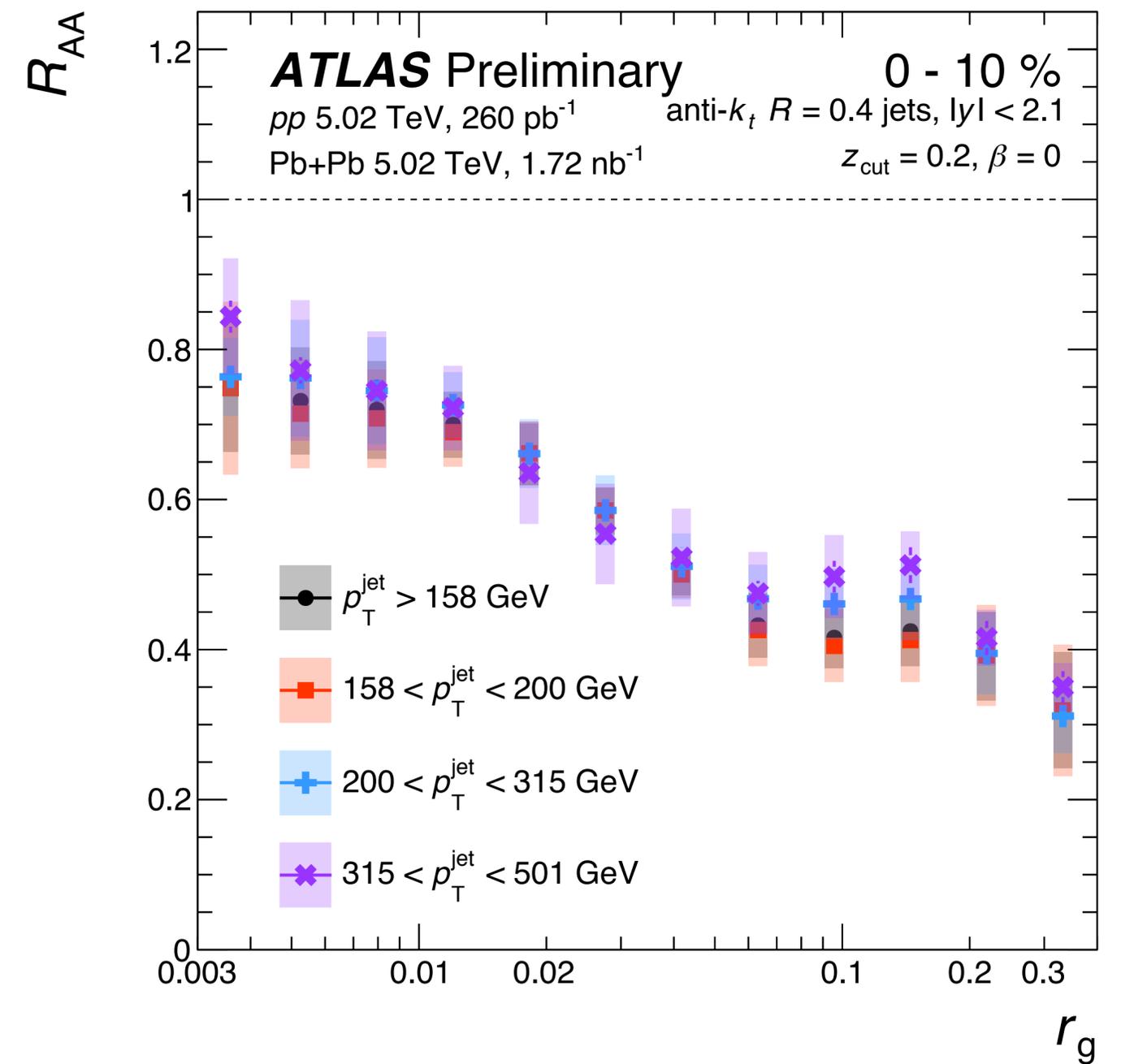
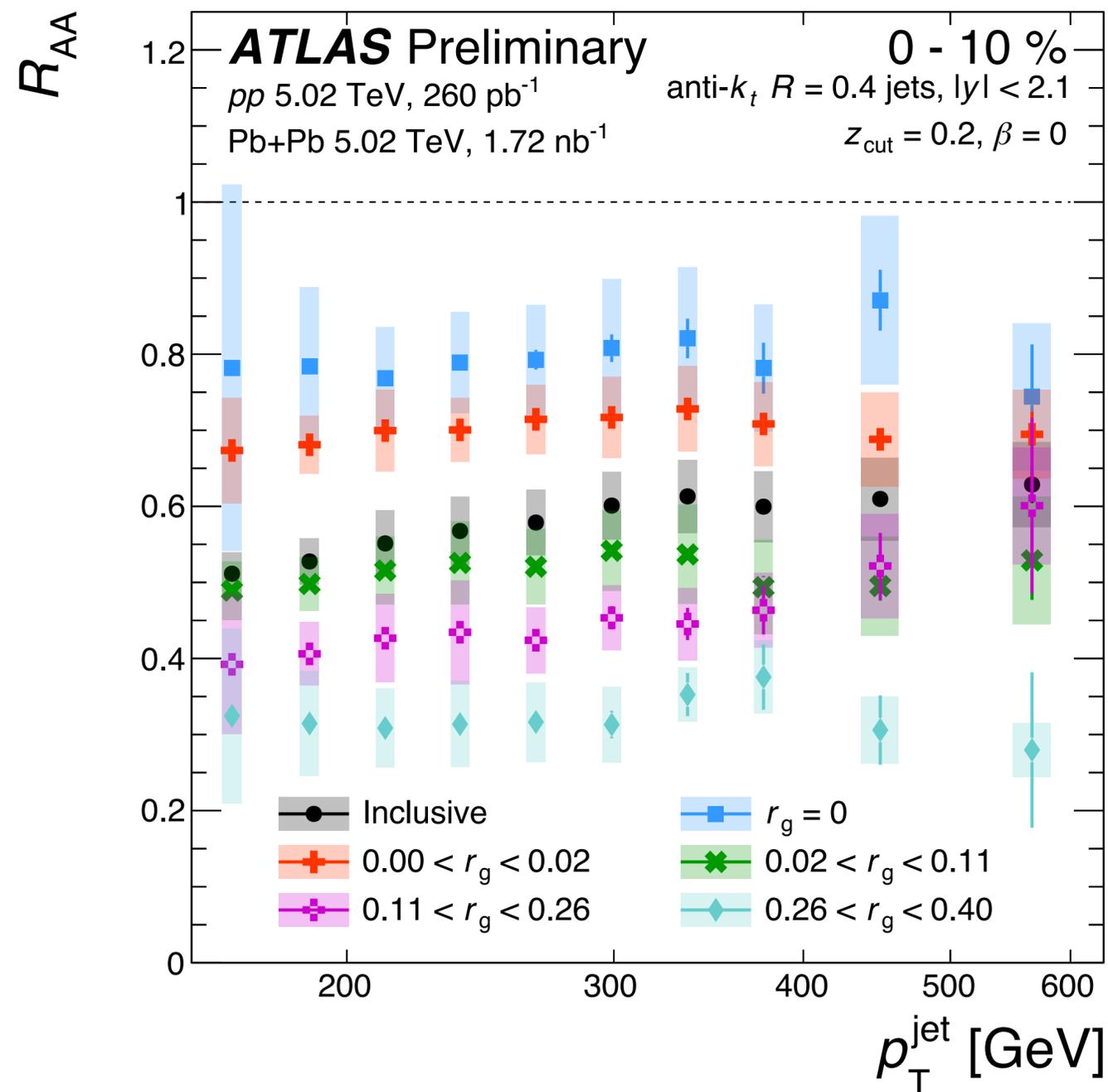
Jet sub-structure via C/A + soft-drop

- $R = 0.4$ jets re-clustered using C/A + soft-drop
- ⇒ $\beta = 0$, $z_{\text{cut}} = 0.2$, r_g from the last splitting



Jet sub-structure via C/A + soft-drop

⇒ Observe a clear increase in jet suppression / energy loss with increasing r_g . Consistent with expectations from color-coherence



- Have shown results from ATLAS of multiple jet measurements
 - using jet flavor and differential probes of energy loss:
dijets, jet v_n , jet-substructure
 - ⇒ probe how energetic partons lose energy in the quark-gluon plasma
- Clear evidence for the difference between quarks & gluons
 - photon-tagged jets & b-jets
 - ⇒ appears to be consistent with weak-coupling expectations
- Jet v_n measurements: parton energy loss sensitive to geometry
 - ⇒ even the transverse energy density fluctuations that cause v_3
- Dijet asymmetry shows effects of fluctuating energy loss
- Jet sub-structure measurements probe dependence of energy loss on hard (and soft!?!) splitting in jets
 - ⇒ dependence of energy loss on r_g even for very small r_g scale?
 - ⇒ flavor (quark/gluon) at small r_g

Backup

Jet yield vs $\Delta\varphi_n$ and v_n

- Measure jet yield as a function of angle wrt nth-order event plane: $\Delta\varphi_n = n|\varphi - \Psi_n|$
 - \Rightarrow observe clear variation with $\Delta\varphi_2$ and $\Delta\varphi_3$
 - \Rightarrow no significant dependence on $\Delta\varphi_4$ (not shown)
- Characterize using Fourier coefficients

$-v_2$ & v_3

