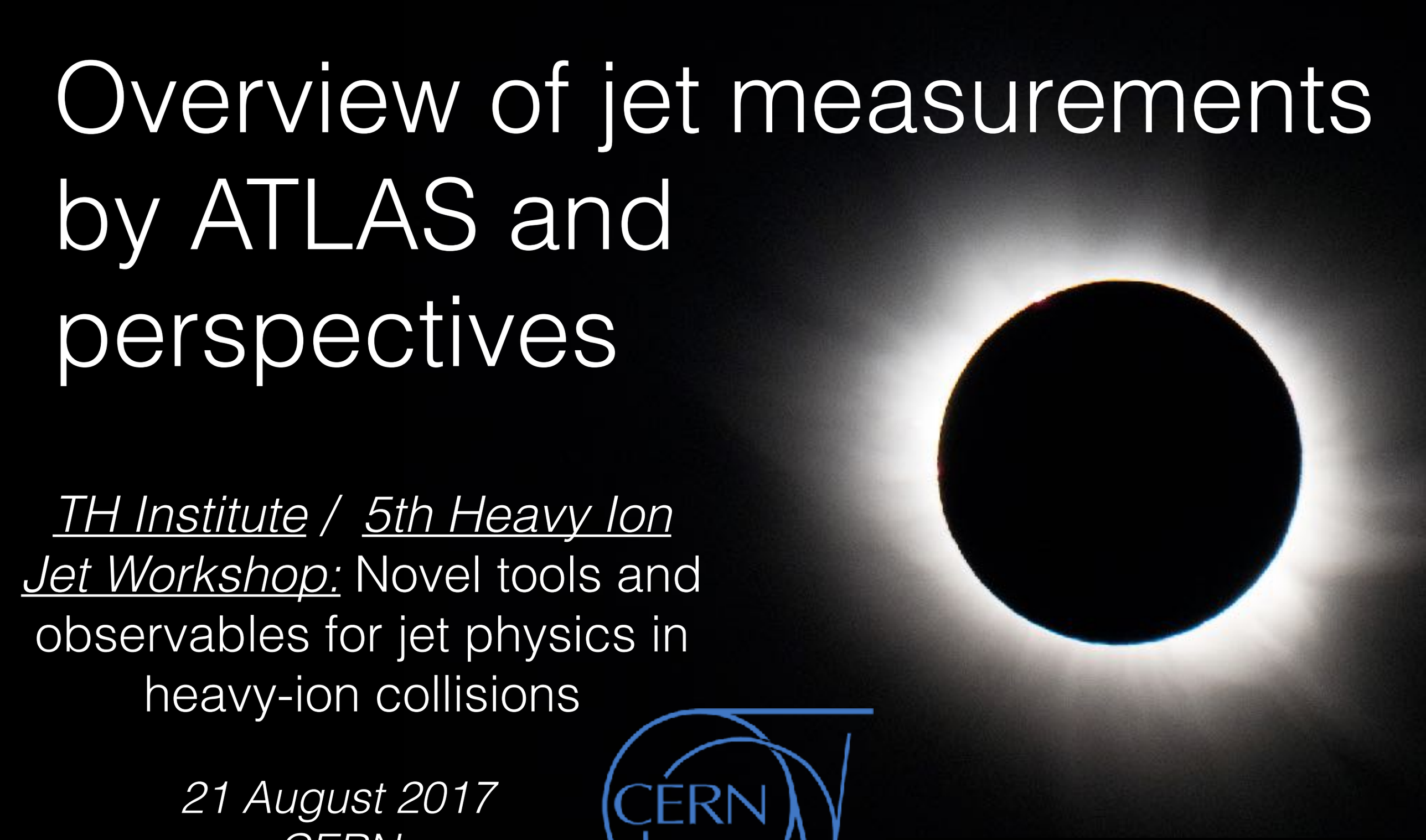
Overview of jet measurements by ATLAS and perspectives

TH Institute / *5th Heavy Ion Jet Workshop:* Novel tools and observables for jet physics in heavy-ion collisions

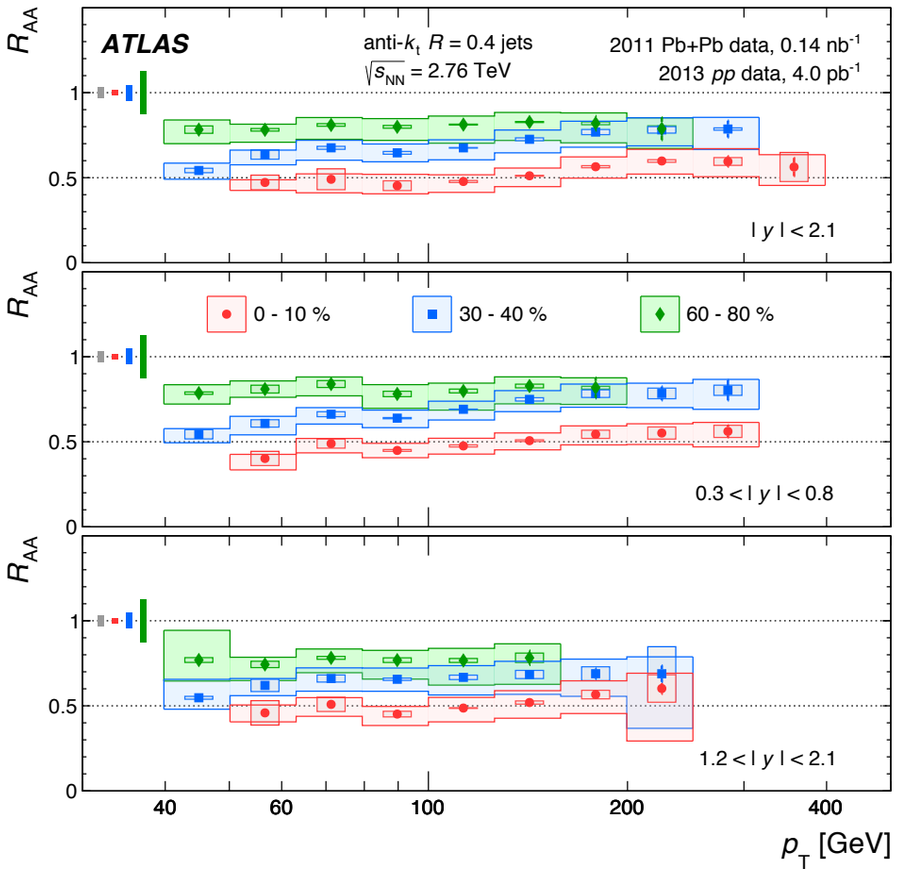
21 August 2017
CERN



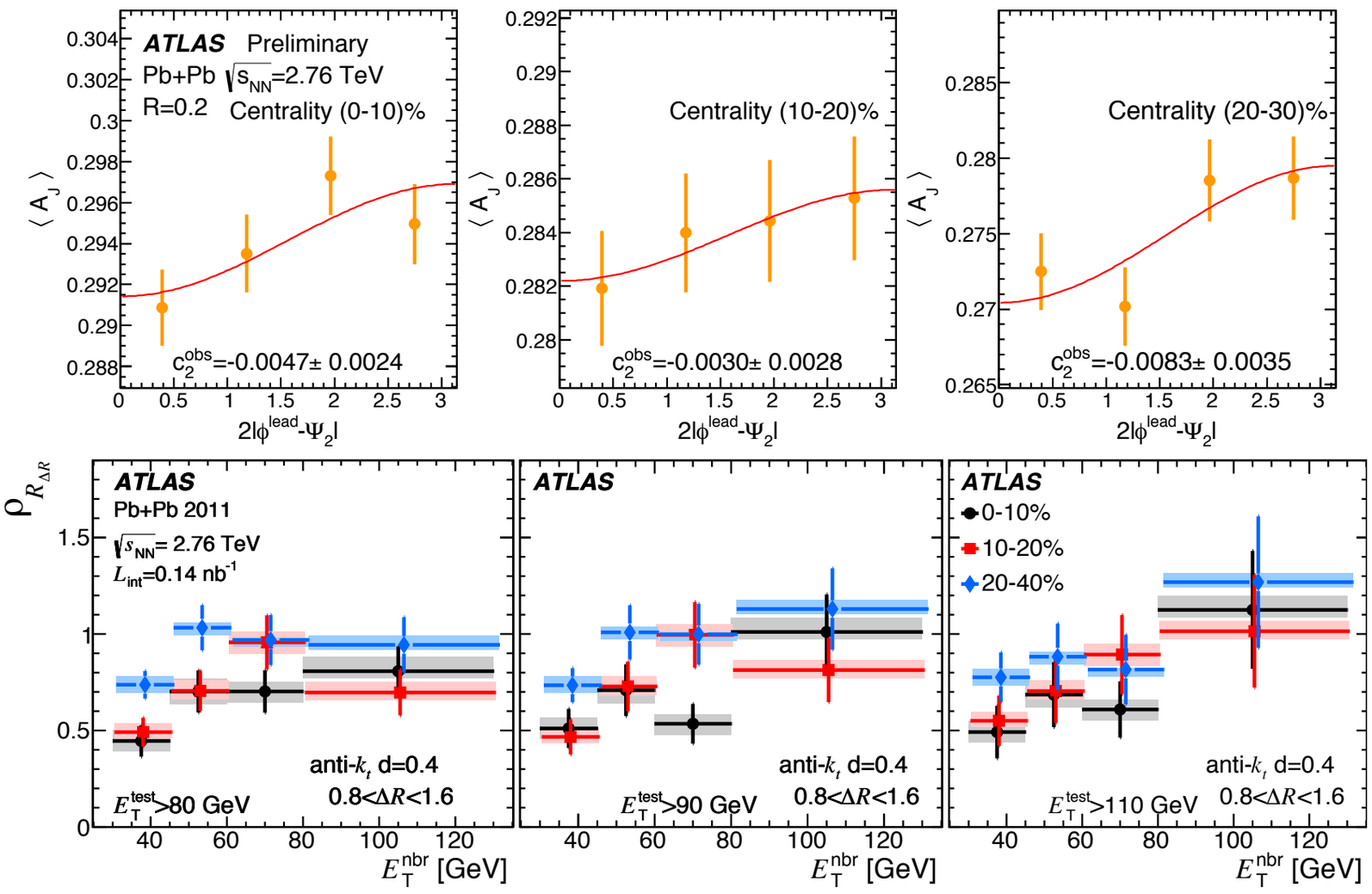
Dennis V. Perepelitsa
University of Colorado Boulder

ATLAS Jet Quenching in LHC Run 1

dijet asymmetry vs. reaction plane



inclusive jet suppression

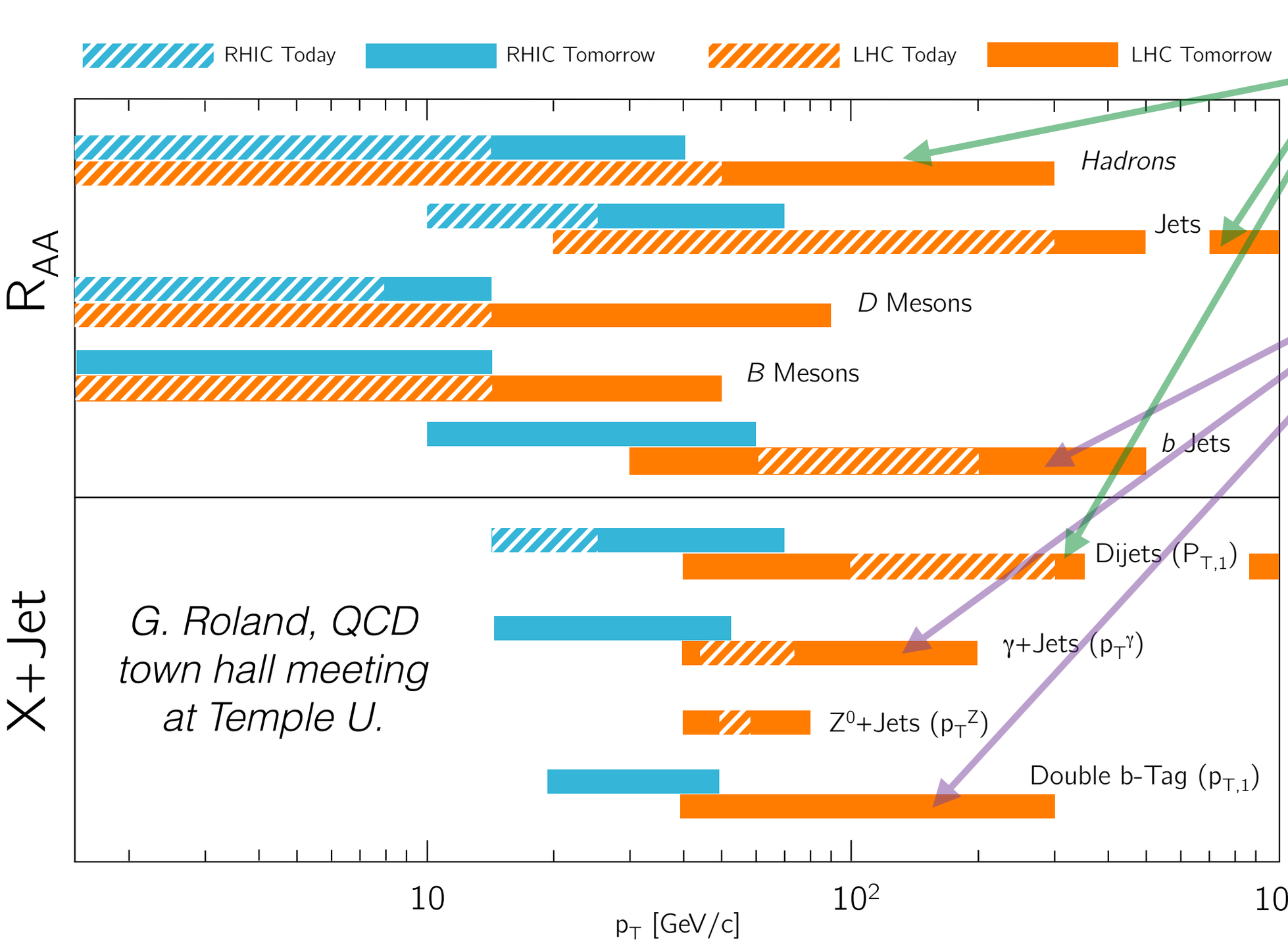


modification of multi-jet correlations

- Broad program of jet suppression and modification
  - ➡ *how do we best make progress in Run 2?*

⇒ *https://twiki.cern.ch/twiki/bin/view/AtlasPublic/HeavyIonsPublicResults*

Jet physics during LHC Run 2

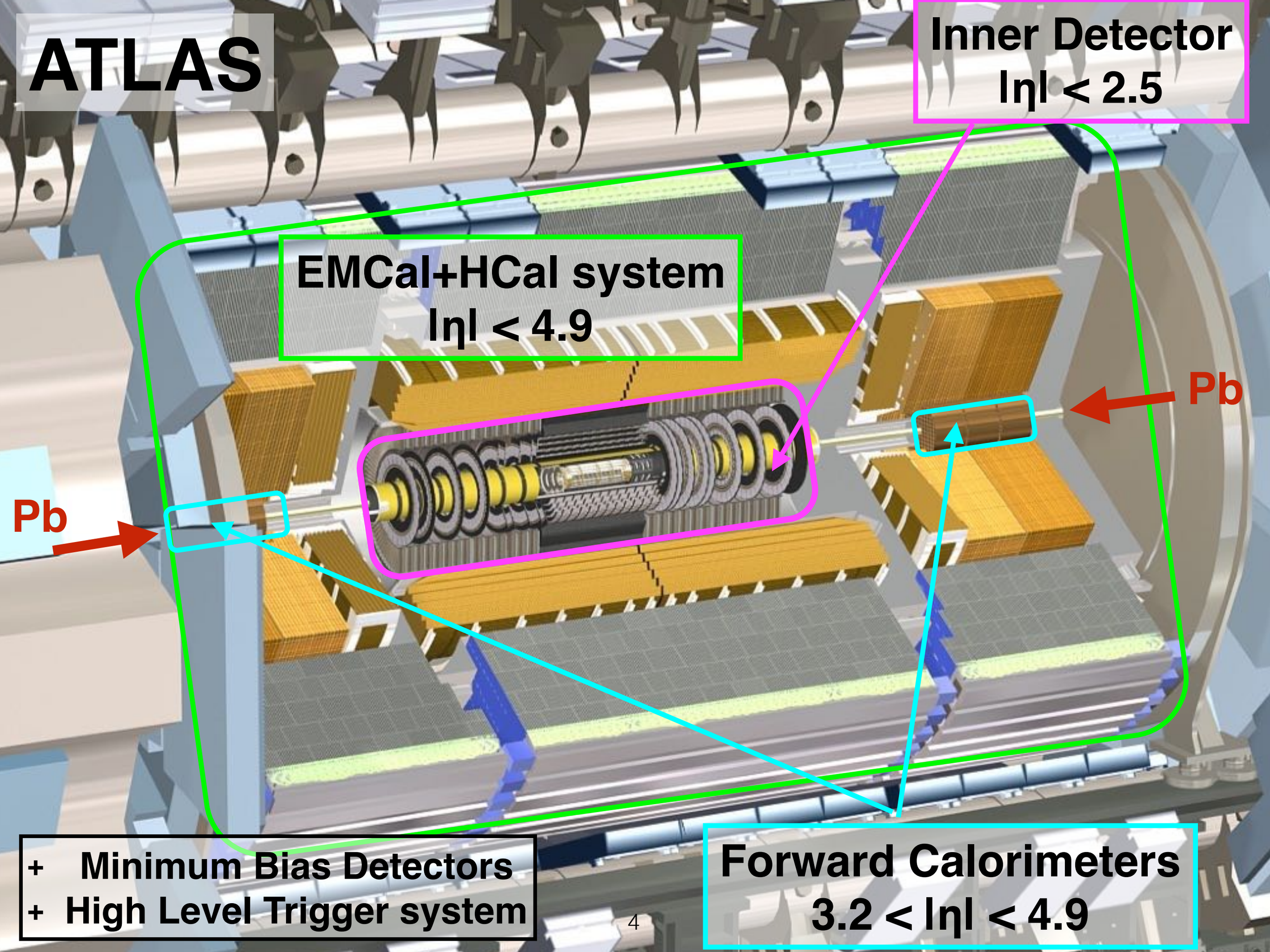


expanded kinematic reach

HF + EW probes

frag. funcs & (sub-) structure

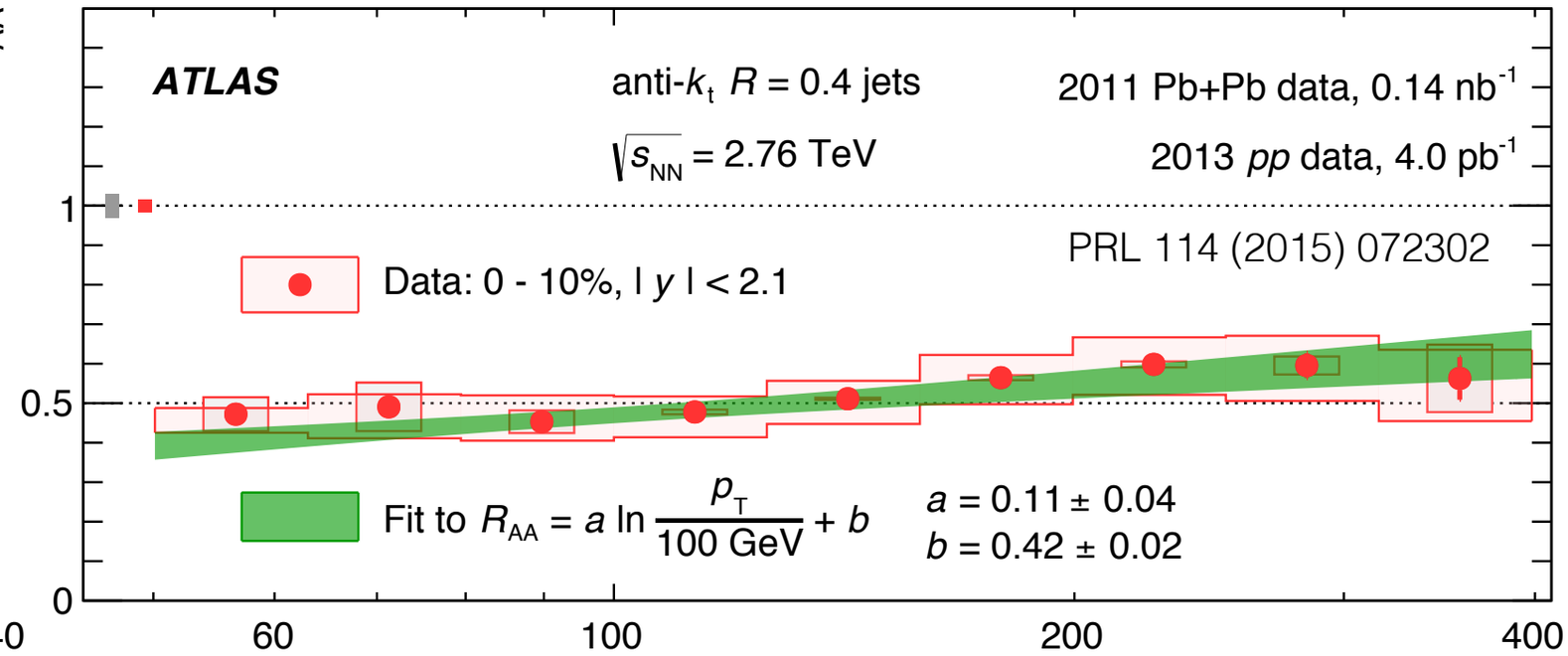
+ p+A / UPC

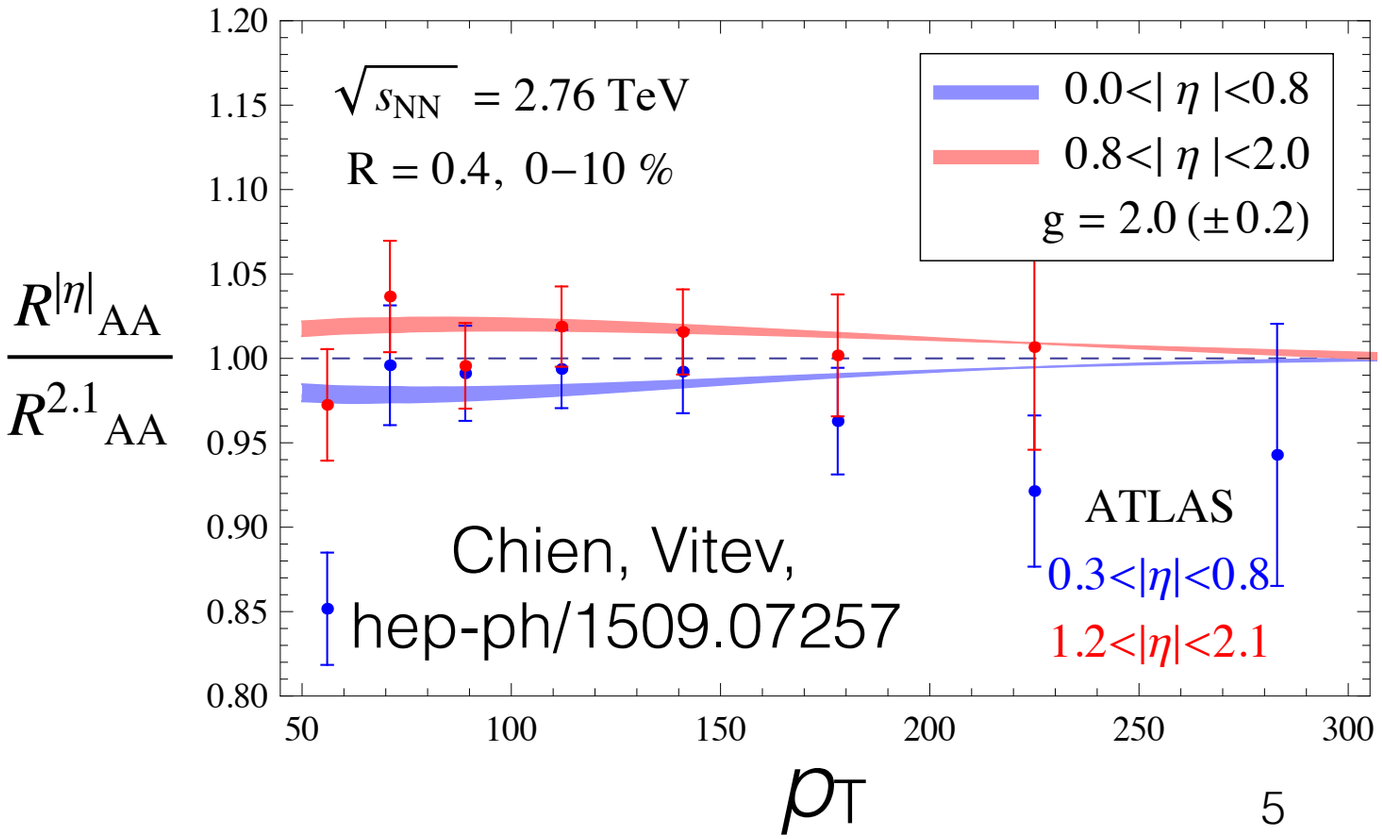

ATLAS
Inner Detector
|η| < 2.5
EMCal+HCal system
|η| < 4.9
Pb
Pb
+ Minimum Bias Detectors
+ High Level Trigger system
Forward Calorimeters
3.2 < |η| < 4.9

Extreme kinematic reach: *jets*

<u>ATLAS inclusive jet R_{AA} slowly increases from 50-400 GeV</u>

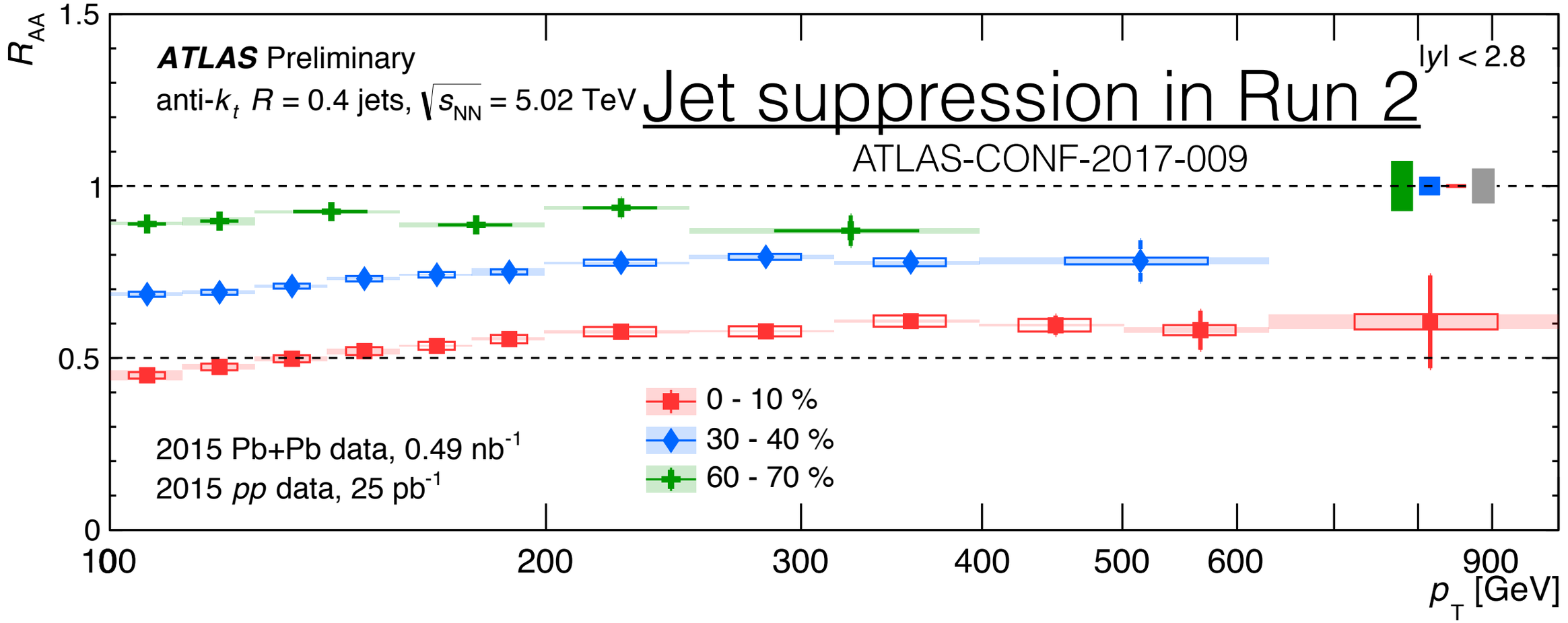
➡ *quenching for TeV-scale jets in Run 2?*





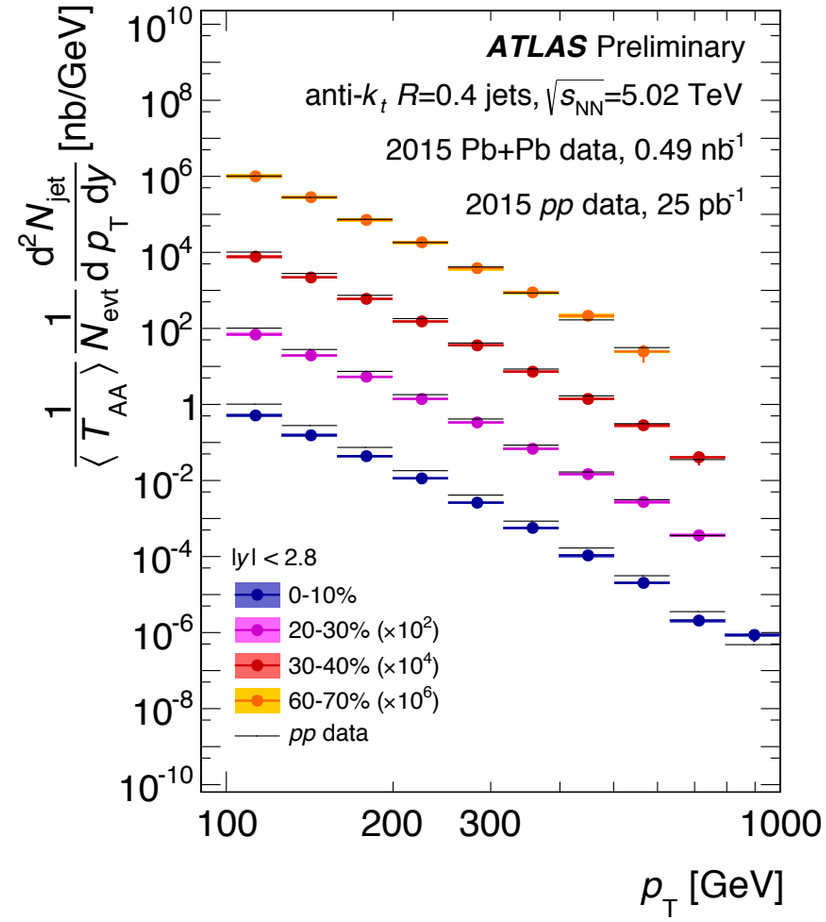
<u>Only modest rapidity-dependence for <300 GeV jets within |y| < 2.1</u>

➡ *expand to larger p_T / y ?*

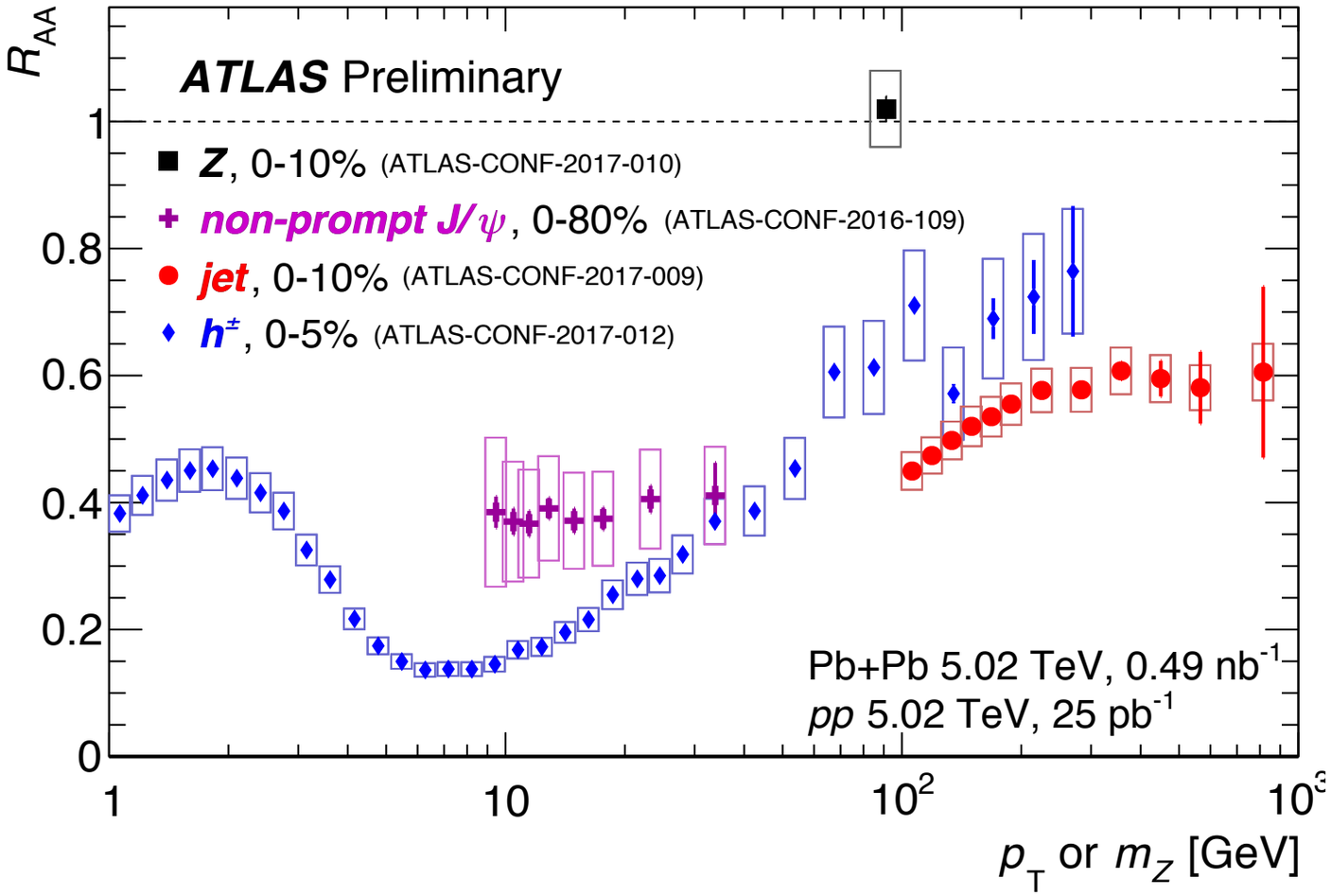


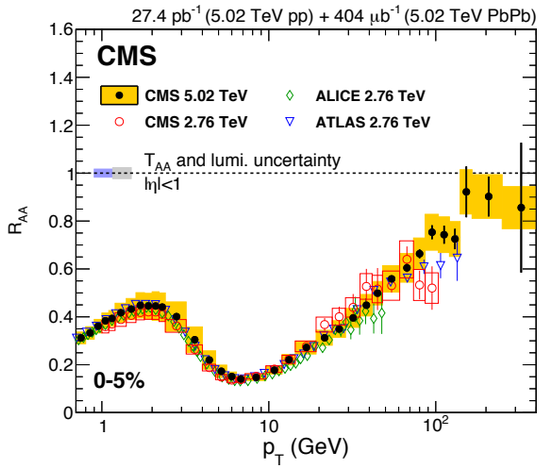
Within uncertainties, R_{AA} ~ 0.6 from 0.2-1 TeV

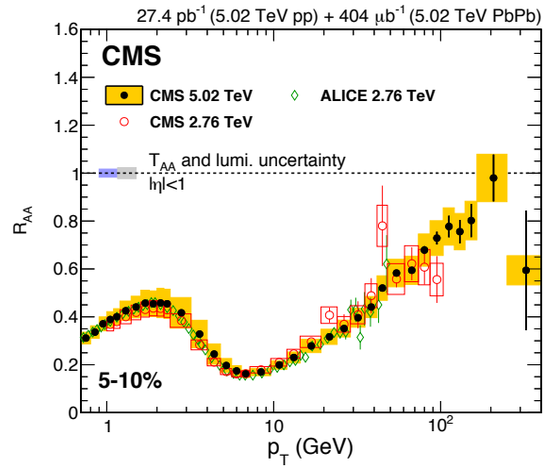
- ➡ *constant spectral shape*
- ➡ *in a fraction "shift" picture, ~1 TeV jets losing 100 GeV(!)*
  - ➡ *will be very interesting to dissect p_T > 500 GeV jet events…*

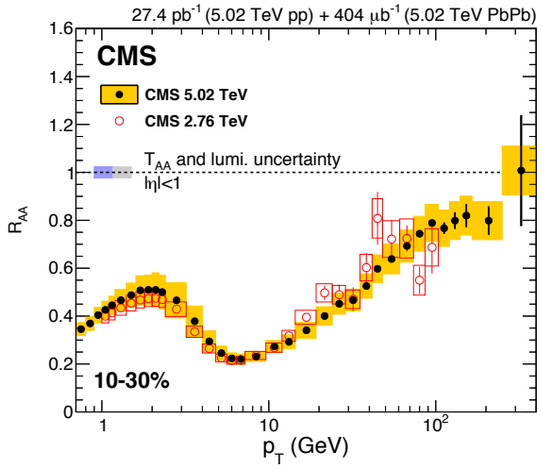


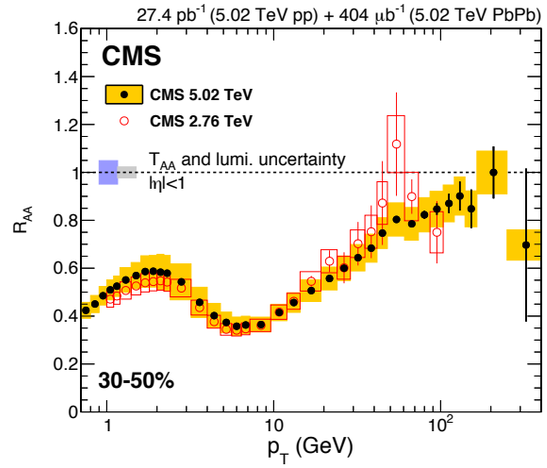
Inclusive charged particles





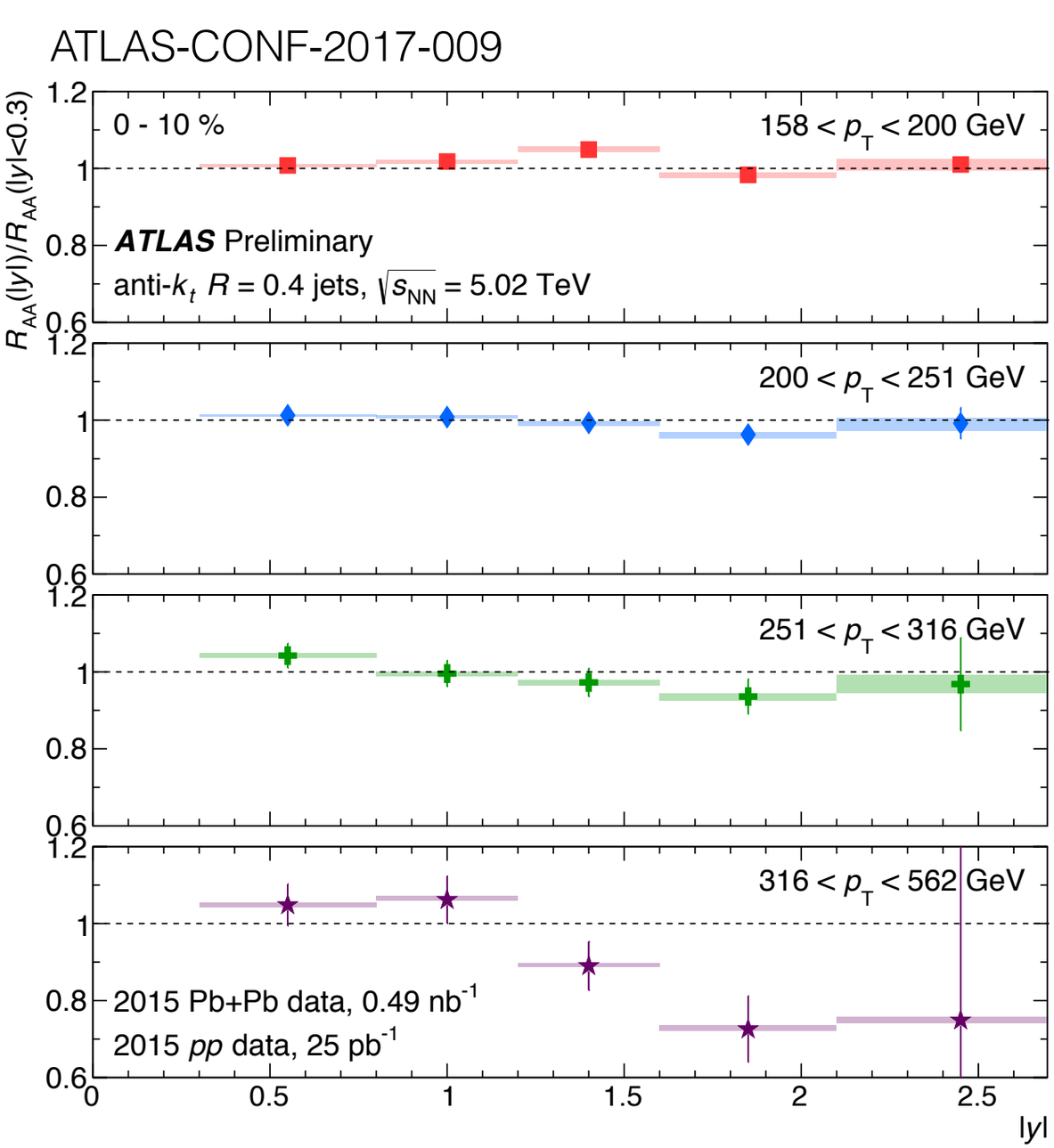




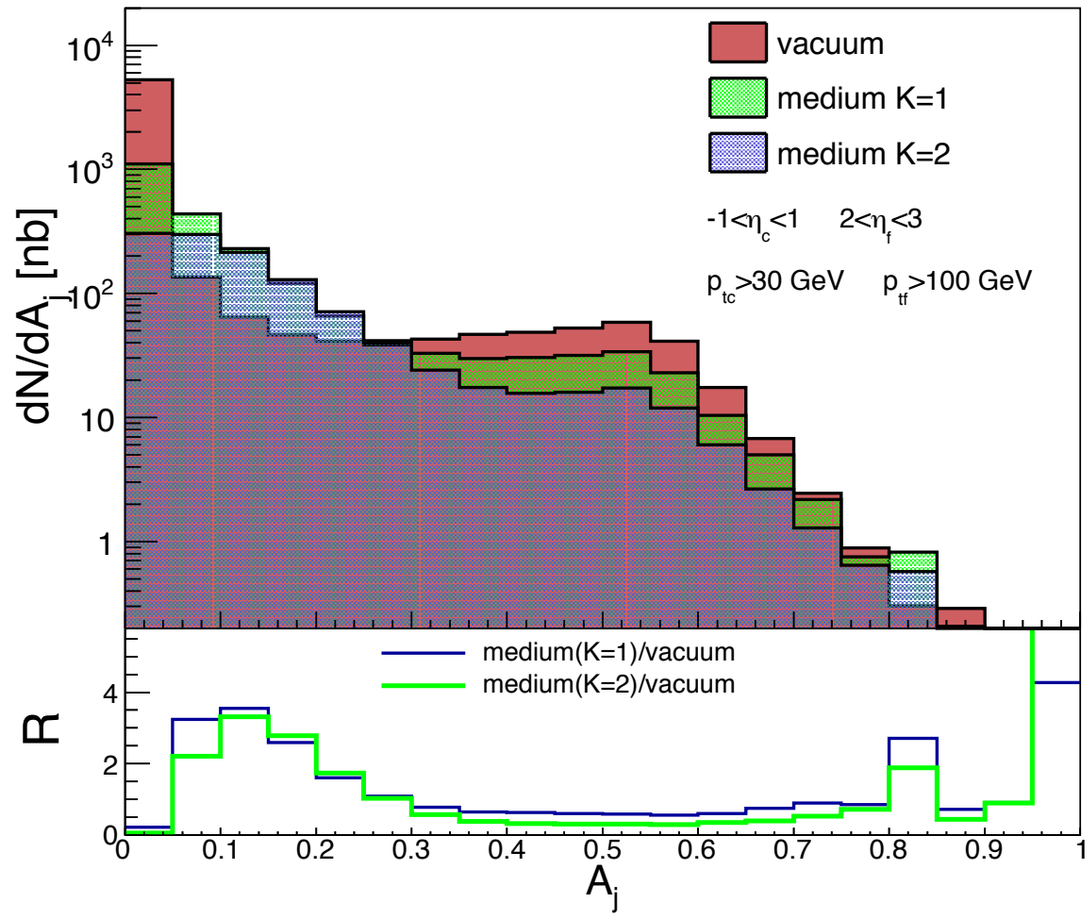


Charged particle R_{AA} *~ 0.75±0.10 in the >100 GeV region*

- *qualitatively consistent with* ***Jet R_{AA}***
- *no indication that quenching "turns off" at some large E scale*
  - *important: check CNM effects in data…*



increasing p_T^{jet}



➡ *proposal for central + forward dijet corr.*

Deak, Kutak, Tywoniuk, hep-ph/1706.08434

$R_{AA}(|y|) / R_{AA}(|y|<0.3)$, measured out to $|y| = \pm 2.7$

➡ *visible y-dependence for p_T > 300 GeV jets*

➡ *interplay of (1) path length, (2) spectral shape, (3) flavor?*

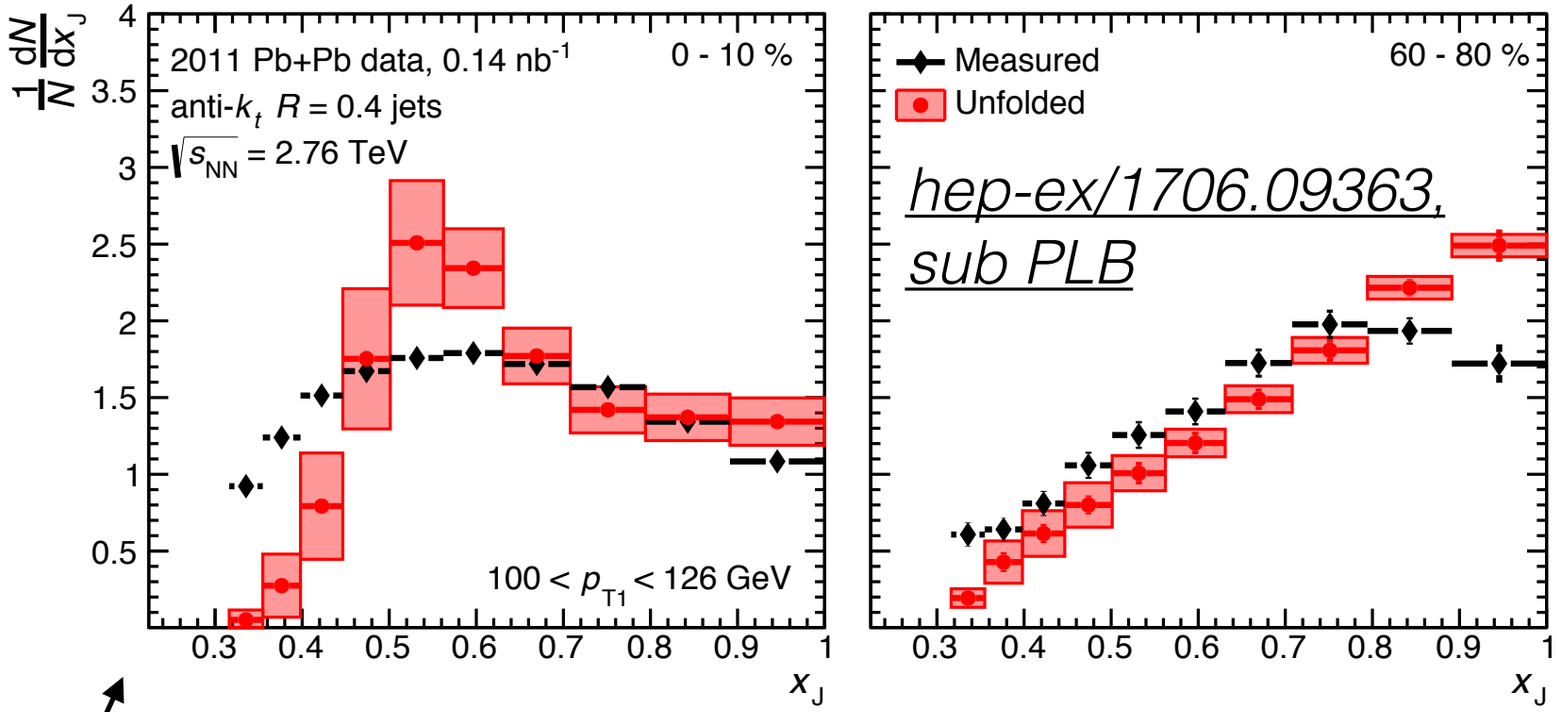
Dijet p_T balance

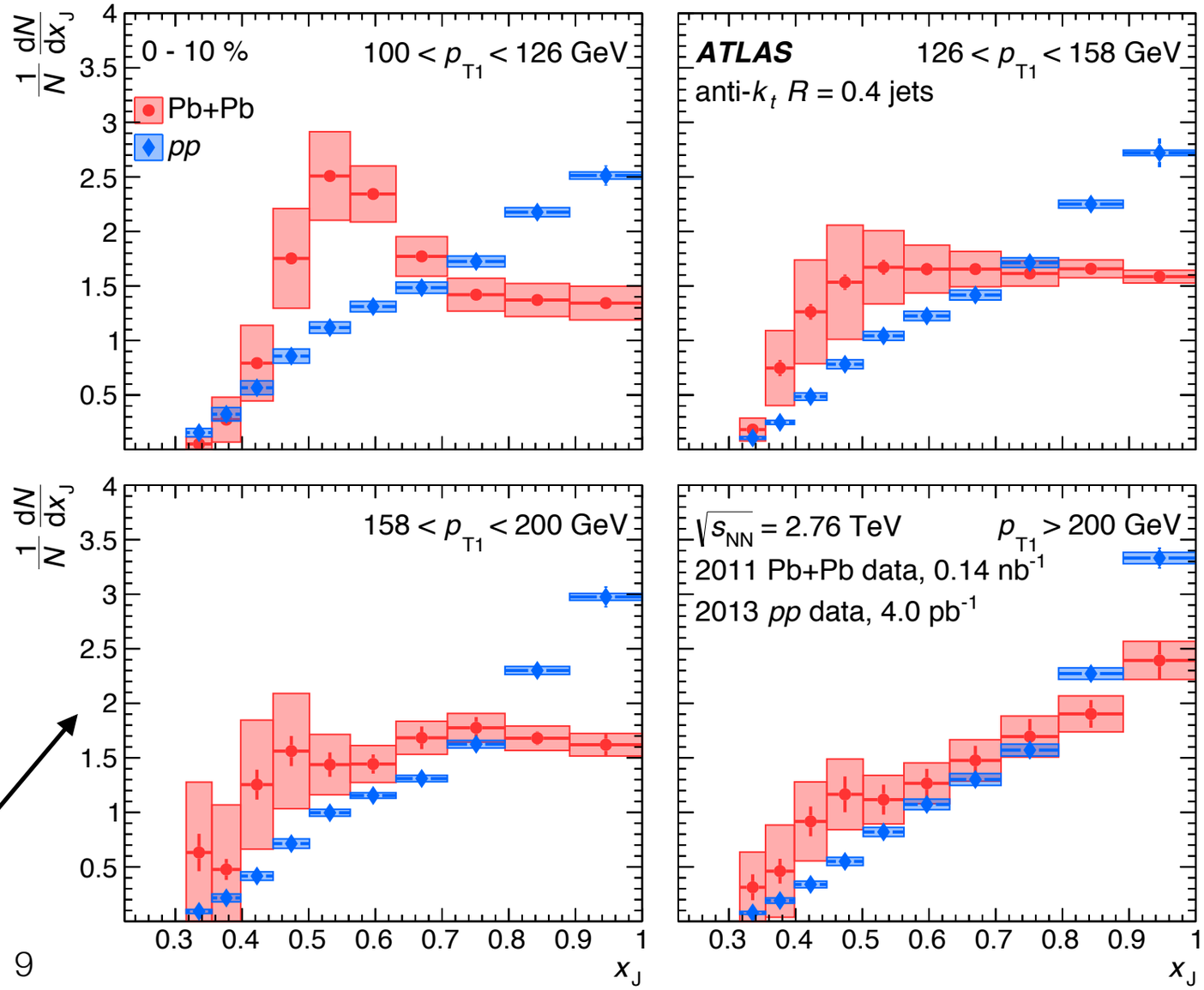
Full ("2-D") unfolding to generator-level

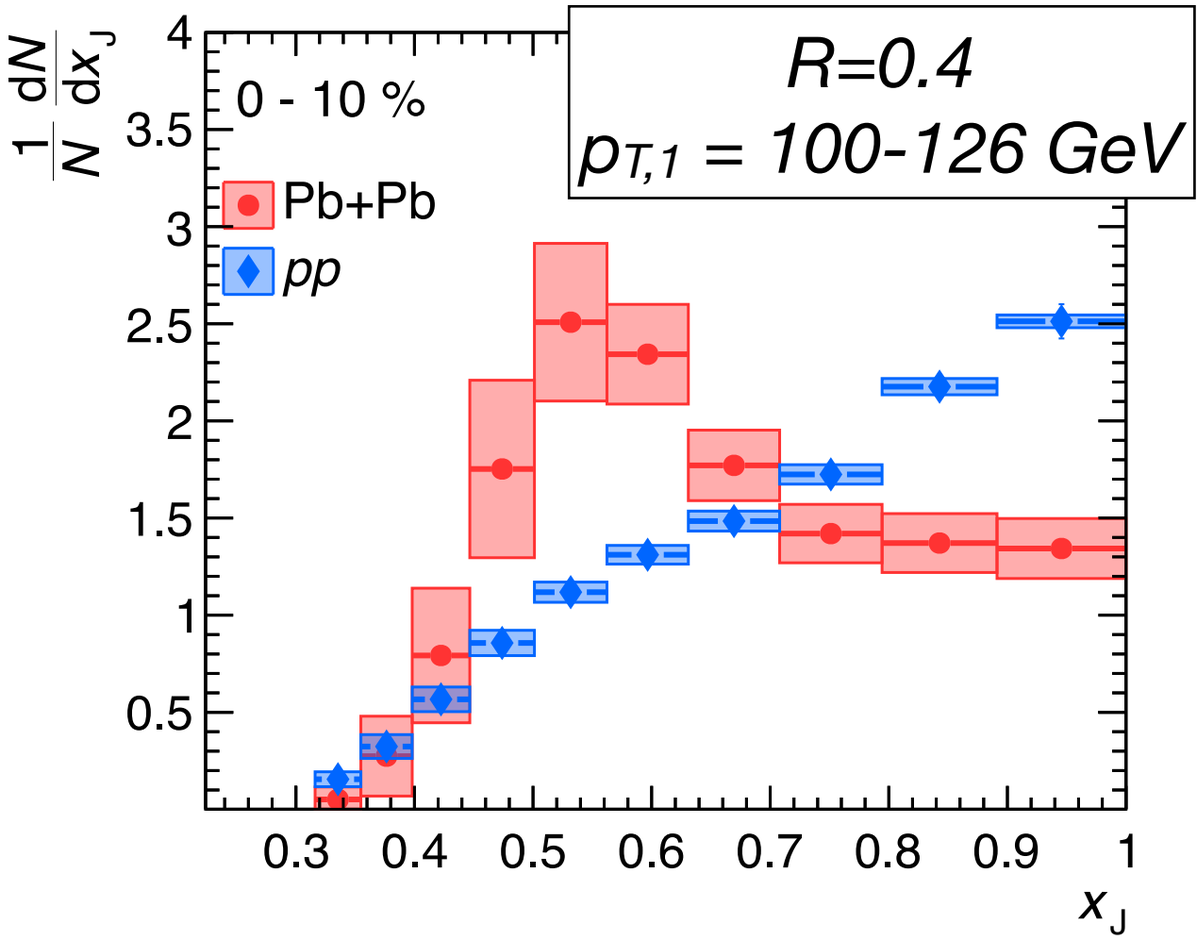
➡ *uncovers non-obvious* ***features*** *from* ***reco. distributions***

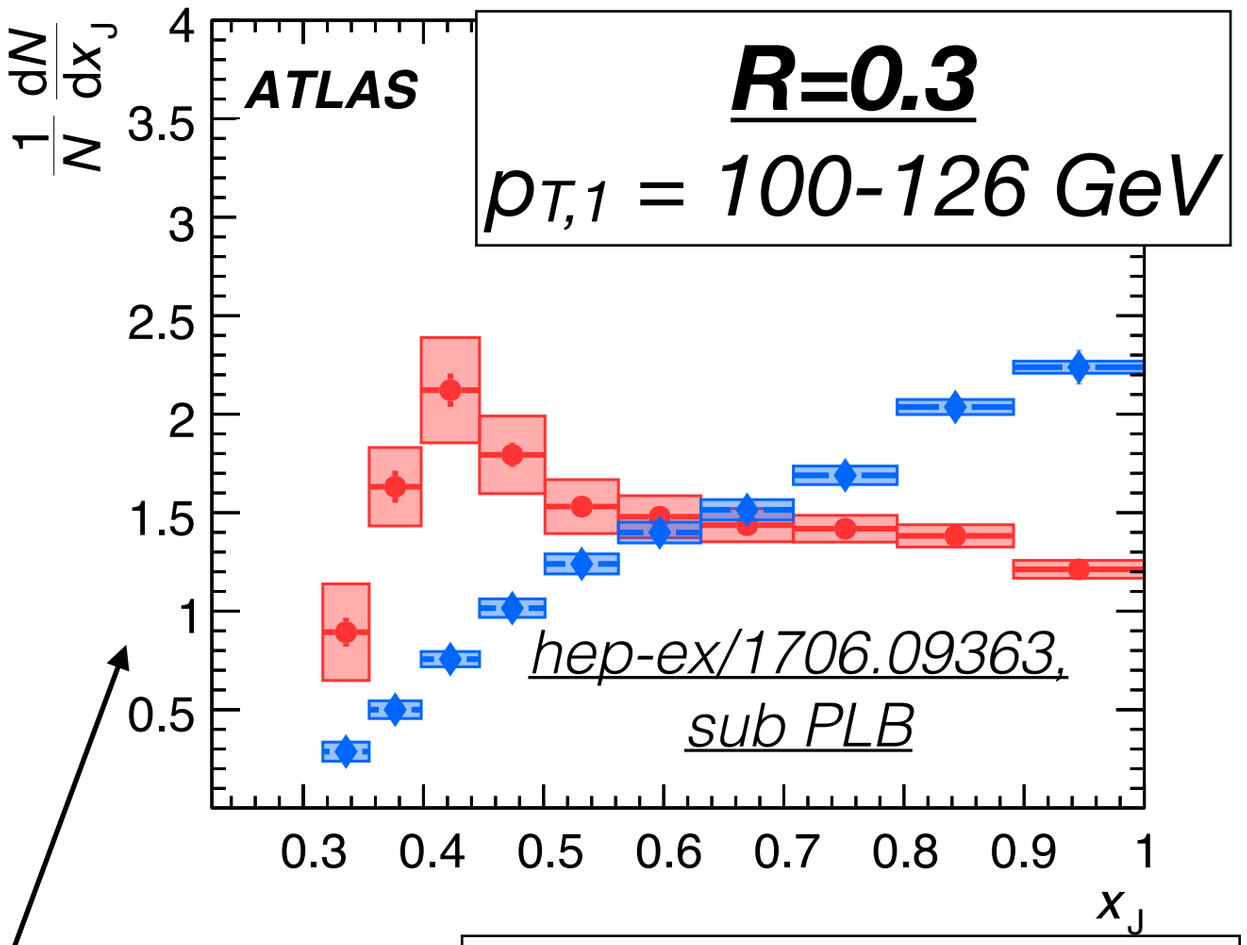
➡ *direct comparisons to theory, other expts (w/o addtl' modeling)*

➡ *surprising p_T evolution…*





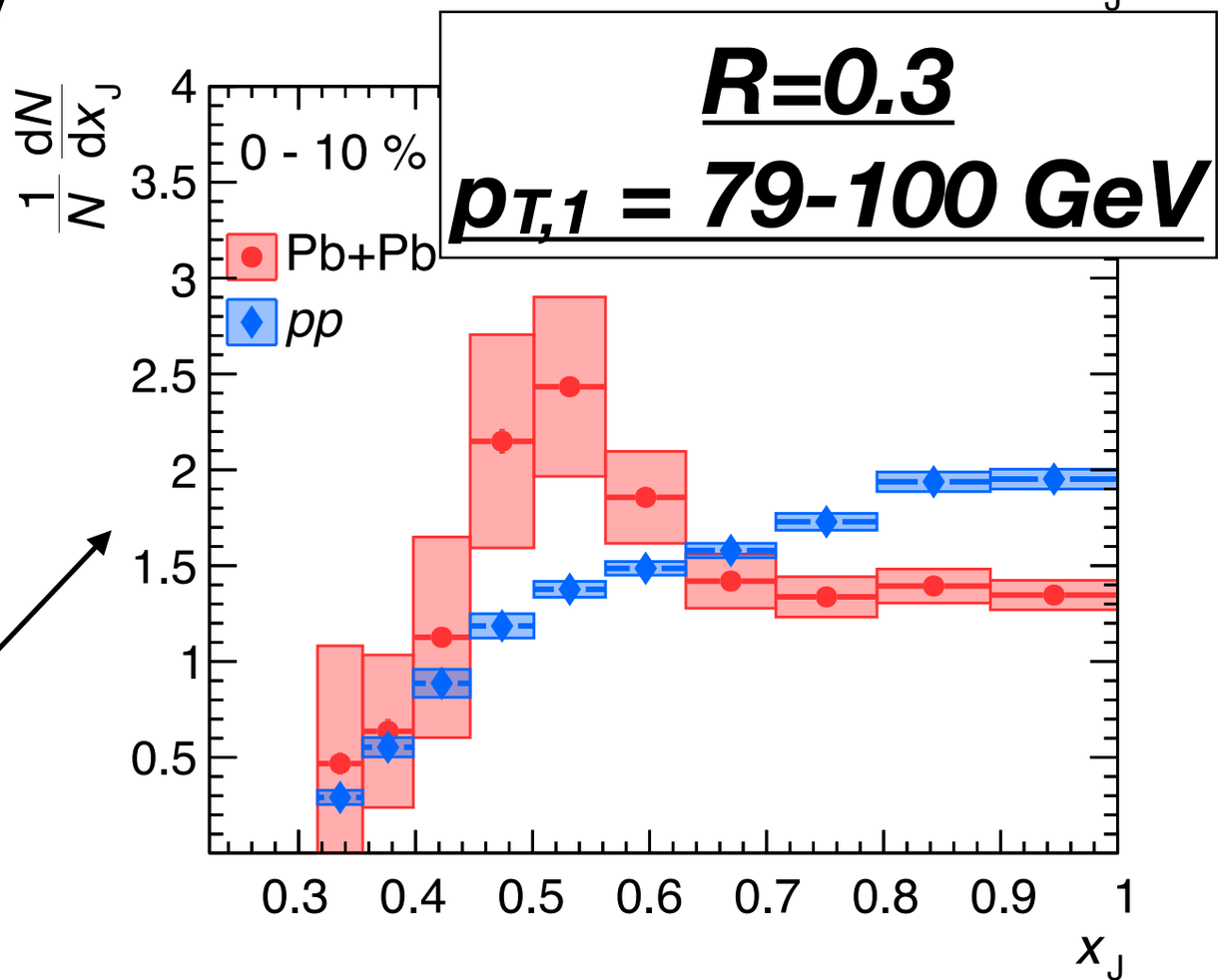




Great handle on UE-related effects: move to smaller cone size R=0.4 → R=0.3

➡ *same feature in same p_T bin, even more significant*

➡ *also visible in a lower jet p_T selection*



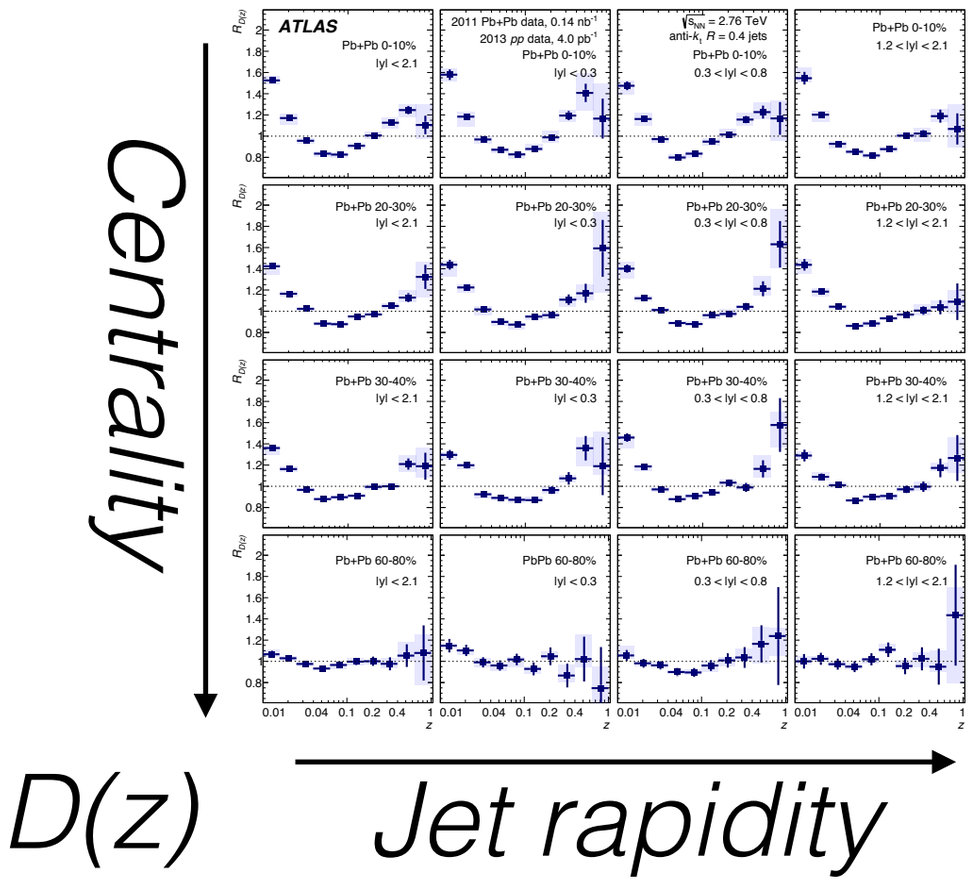
Jet longitudinal momentum structure

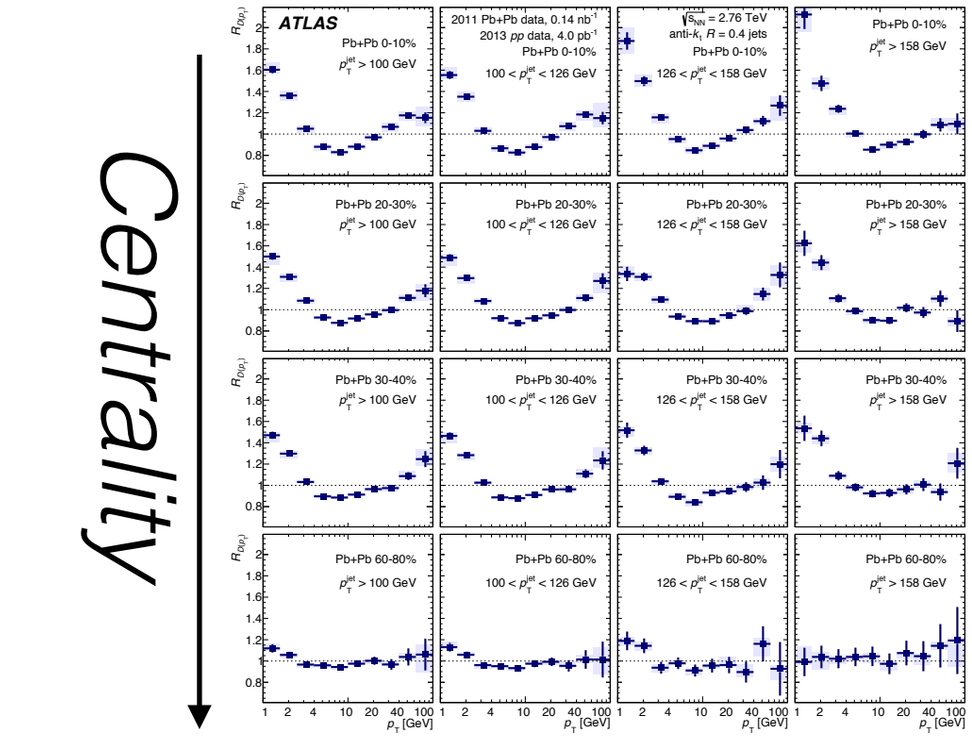
Comprehensive measurement, vs. kinematics / centrality / √s

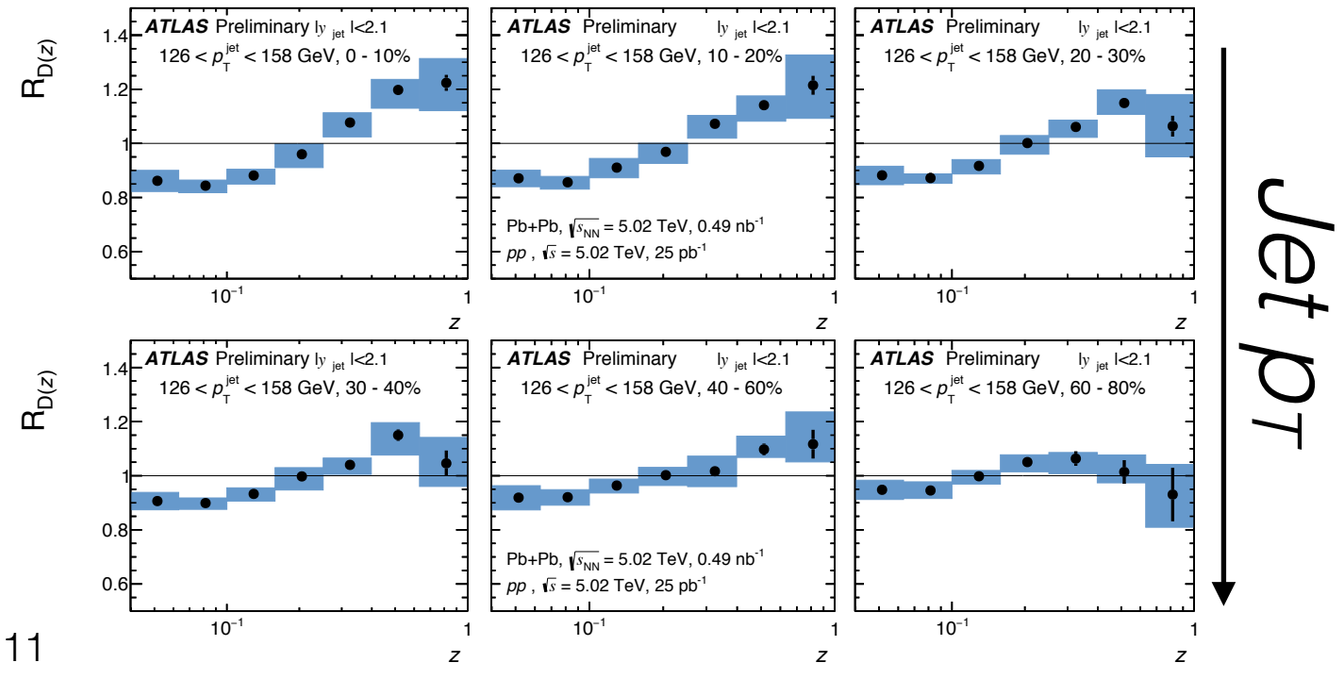
➡ *2.76 TeV: EPJC 77 (2017) 379*

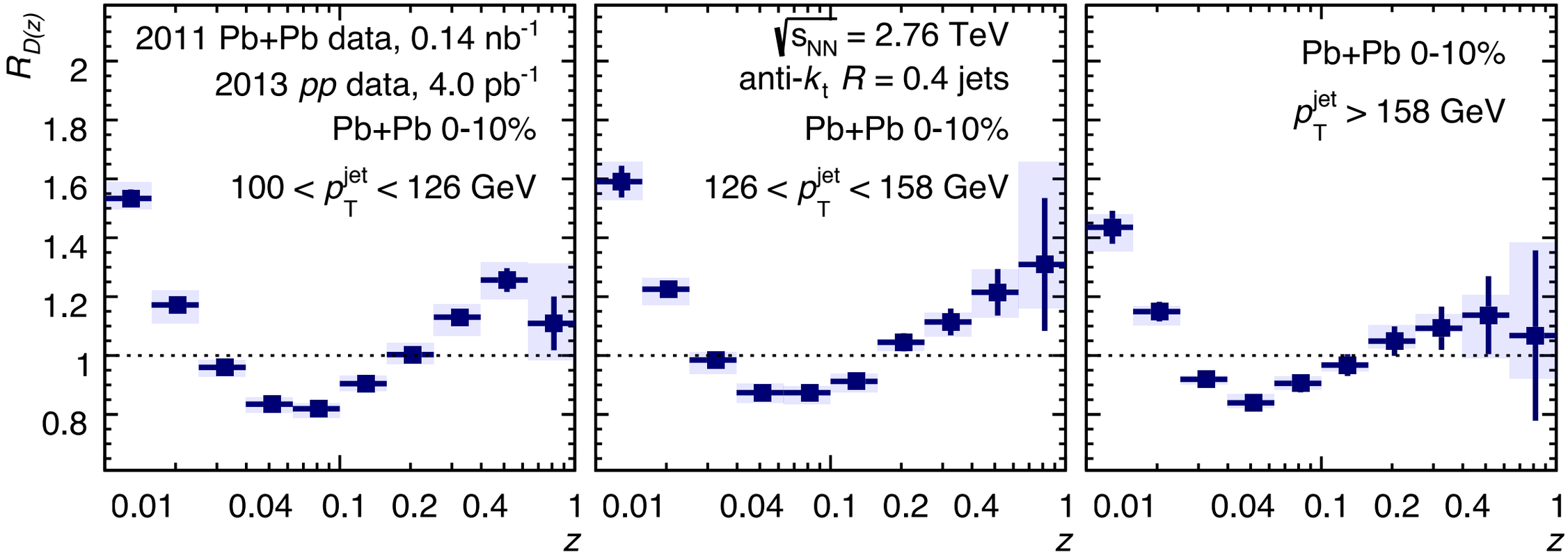
➡ *5.02 TeV: ATLAS-CONF-2017-005*

➡ *will summarize salient features*





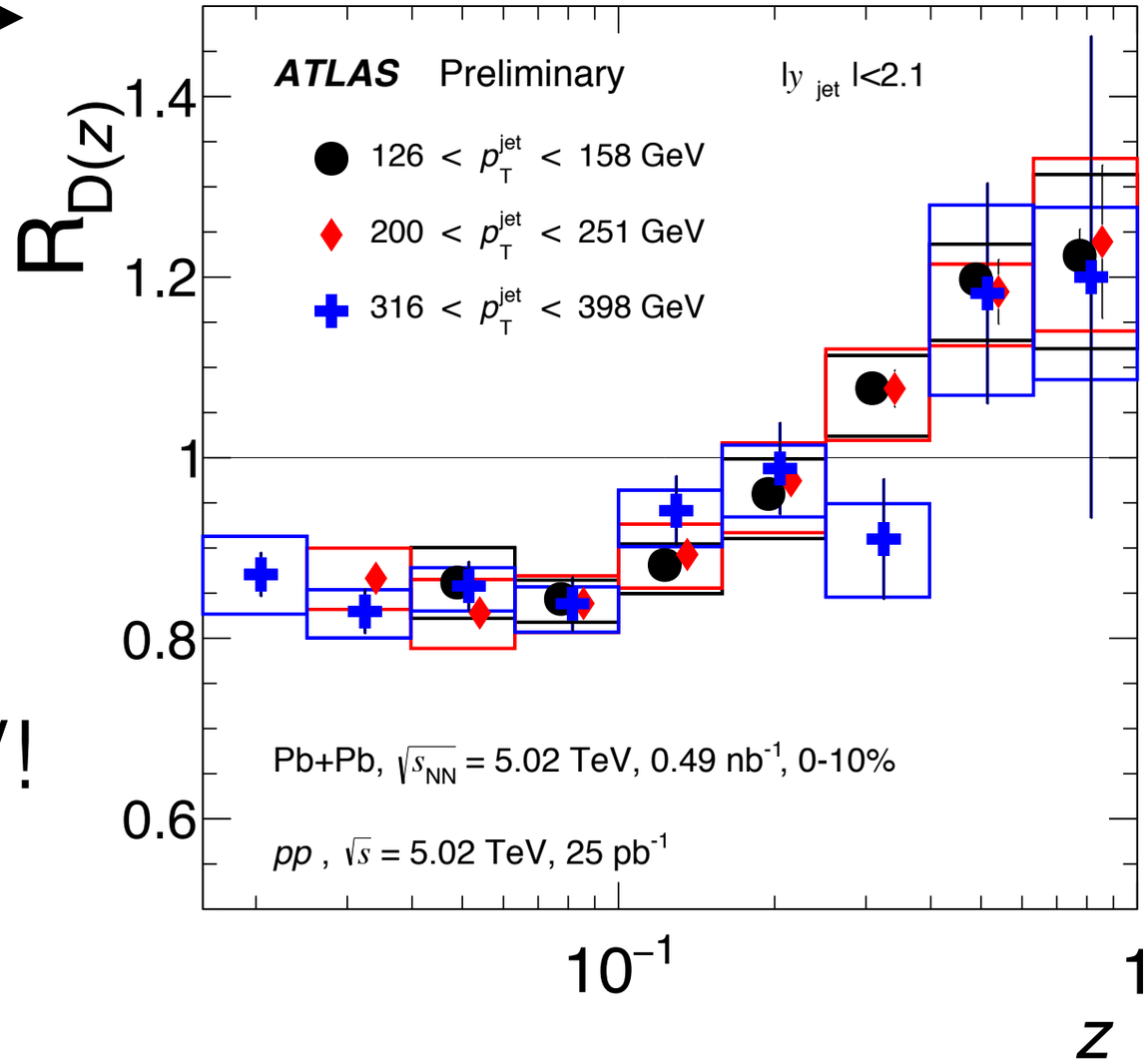


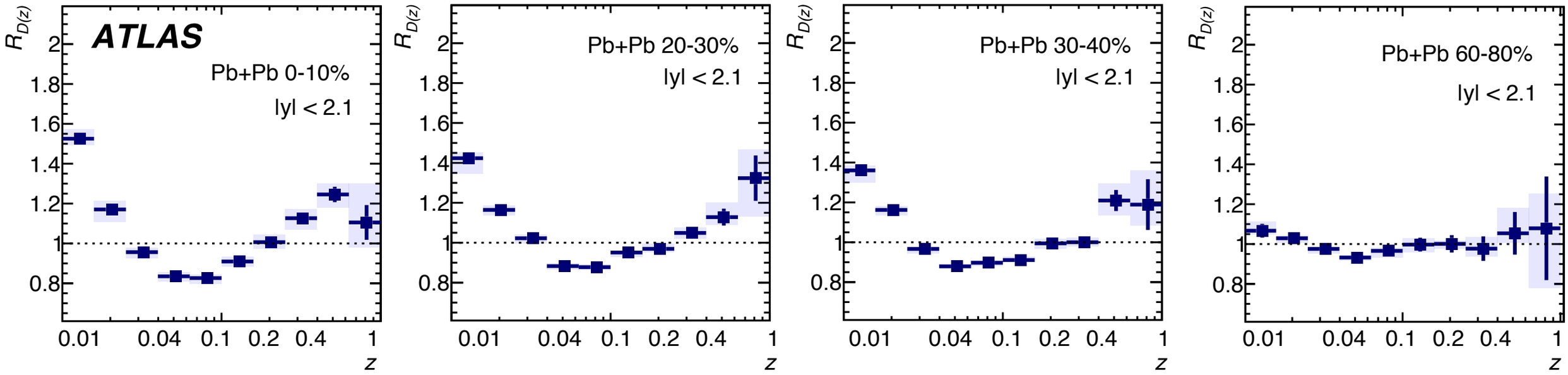


Jet p_T

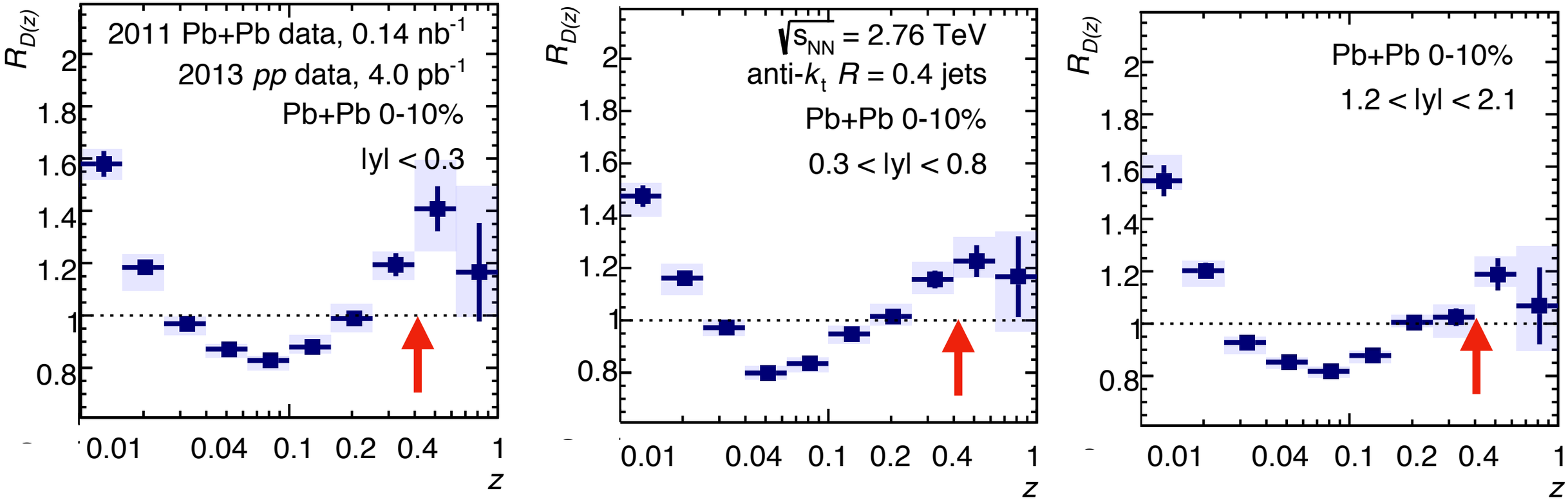
Modifications seemingly constant with jet p_T

➡ large-z enhancement persists out to 300-400 GeV!

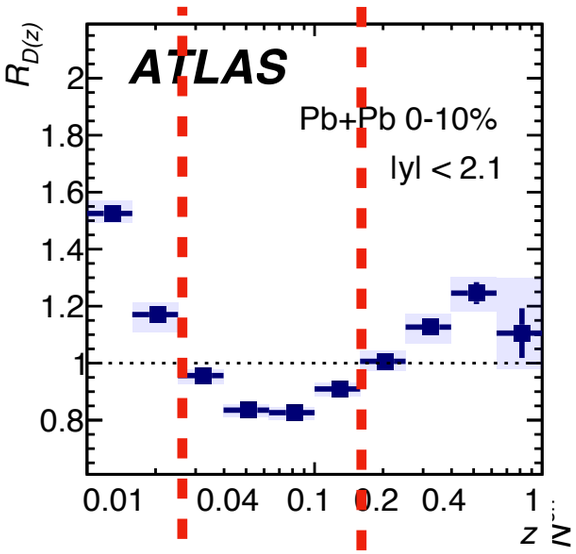




Modifications turn on and off with centrality



At fixed jet p_T, hint of a rapidity dependence

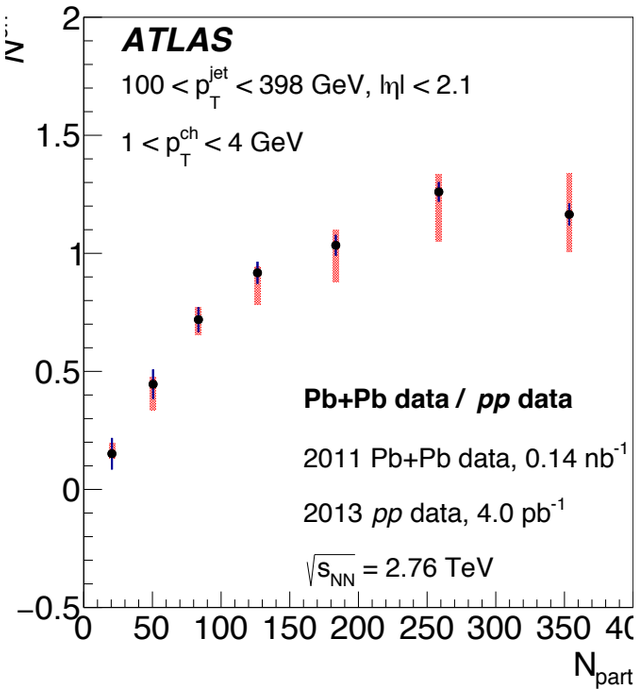


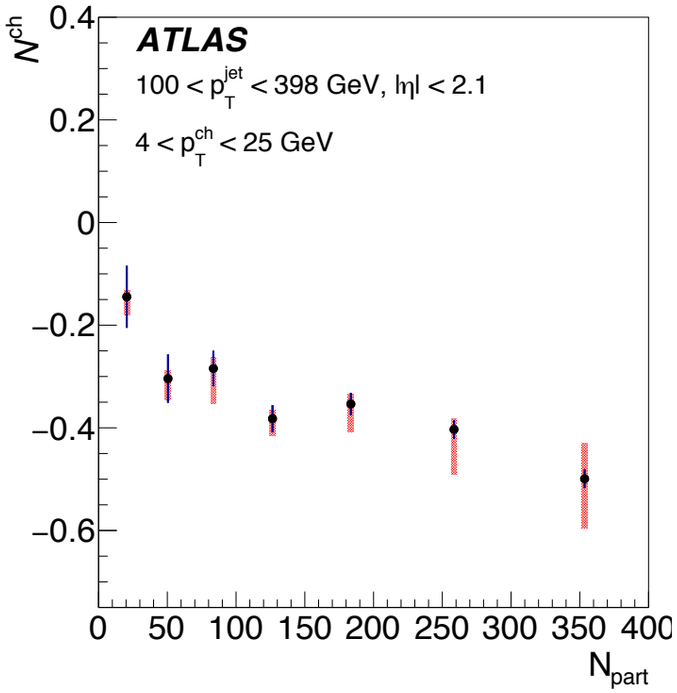
low z/p_T^{ch} excess

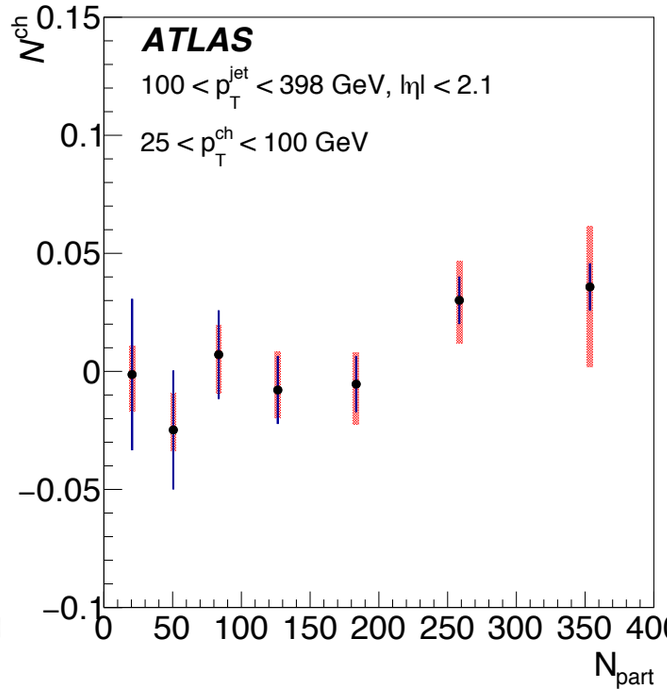
mid z/p_T^{ch} depletion

high z/p_T^{ch} excess

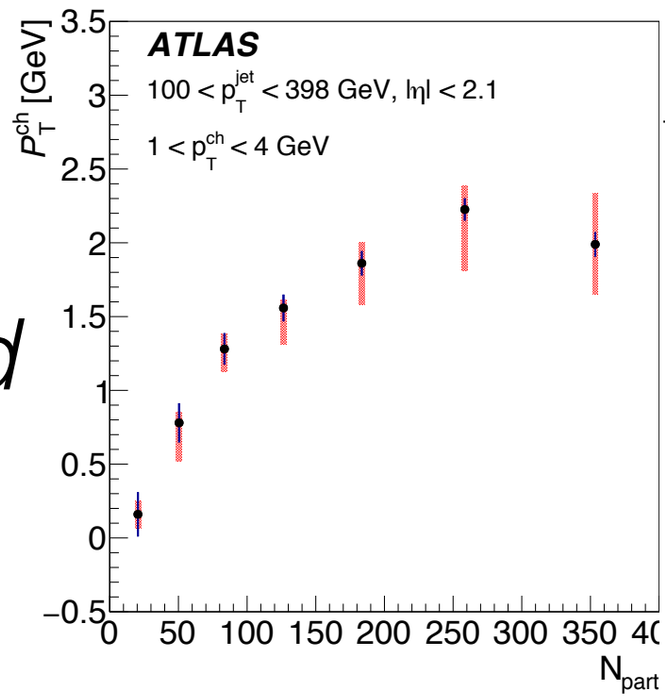
# of charged particles

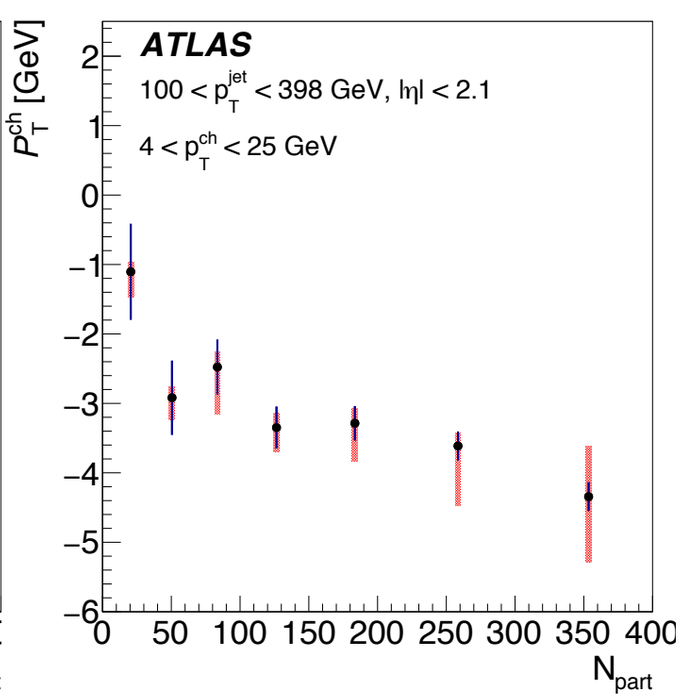


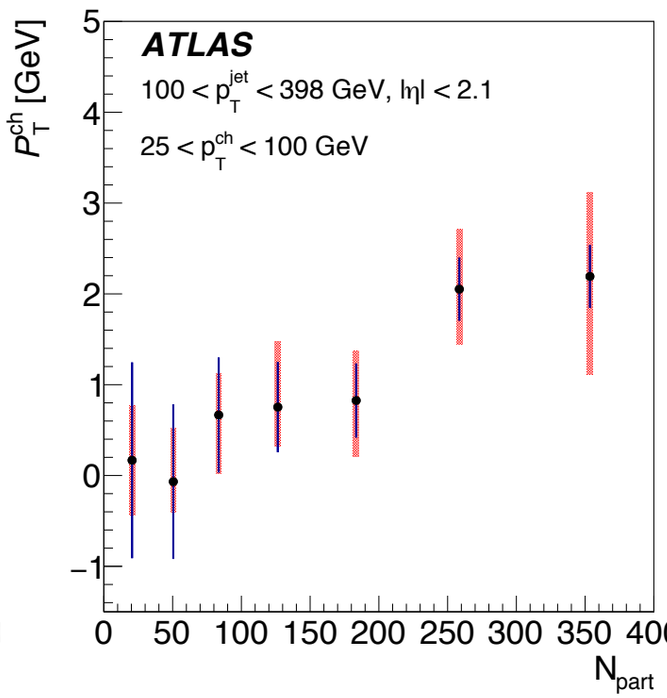


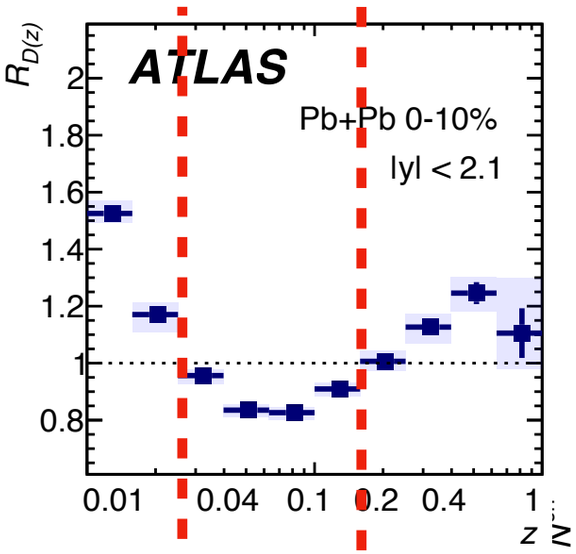


p_T carried by charged particles







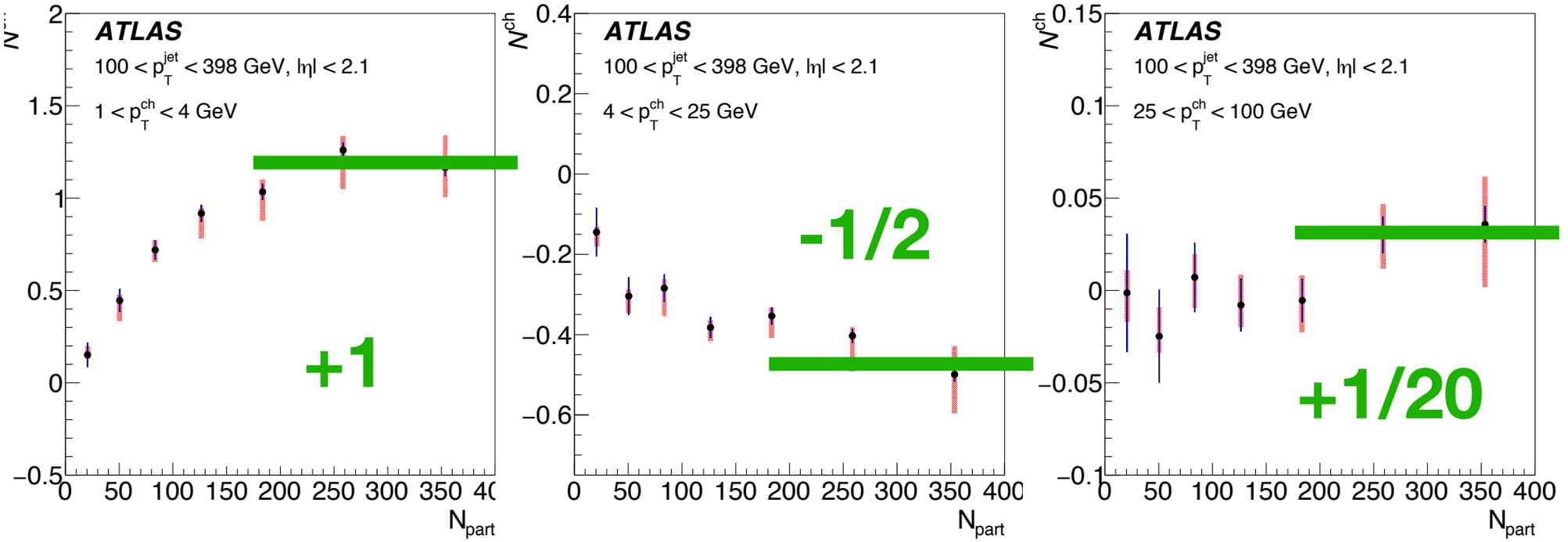


low z/p_T^{ch} excess

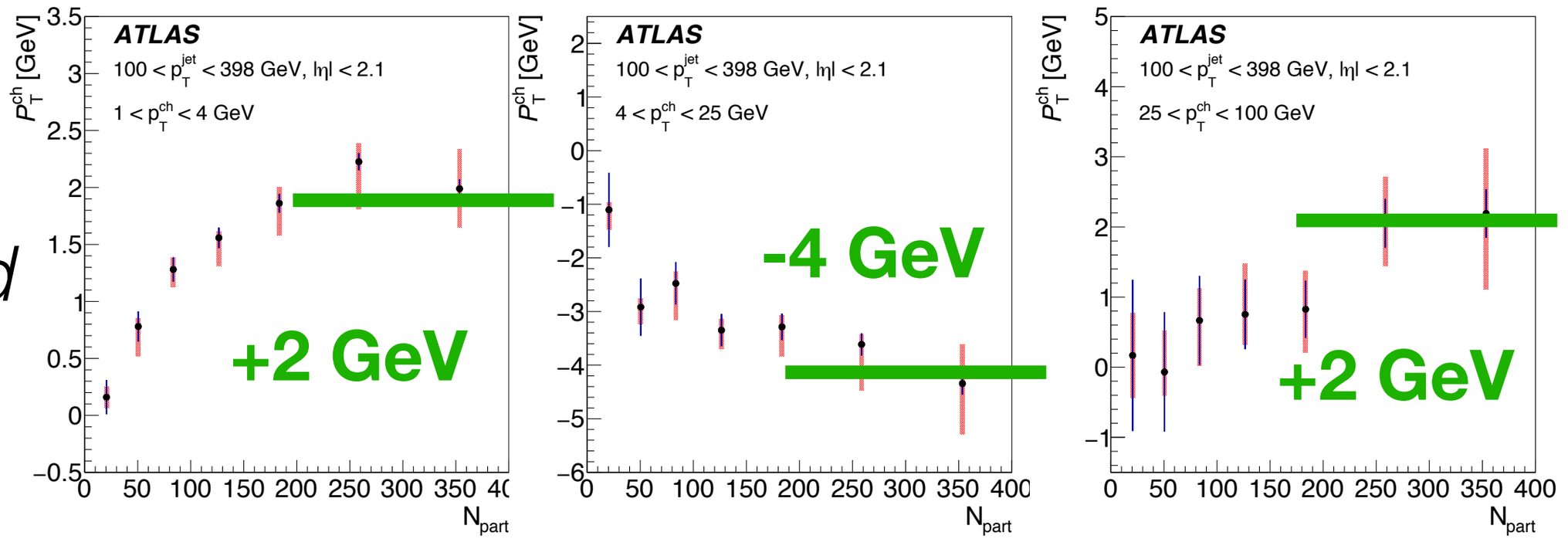
mid z/p_T^{ch} depletion

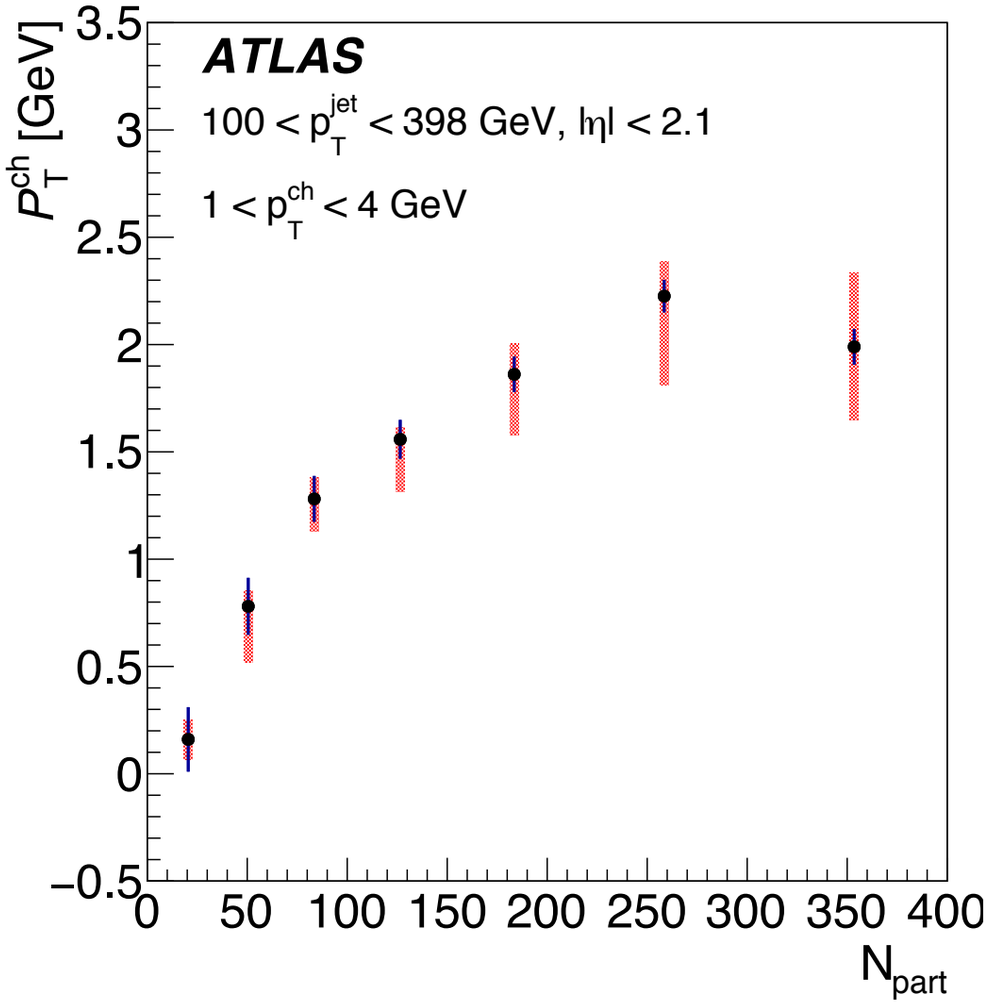
high z/p_T^{ch} excess

# of charged particles

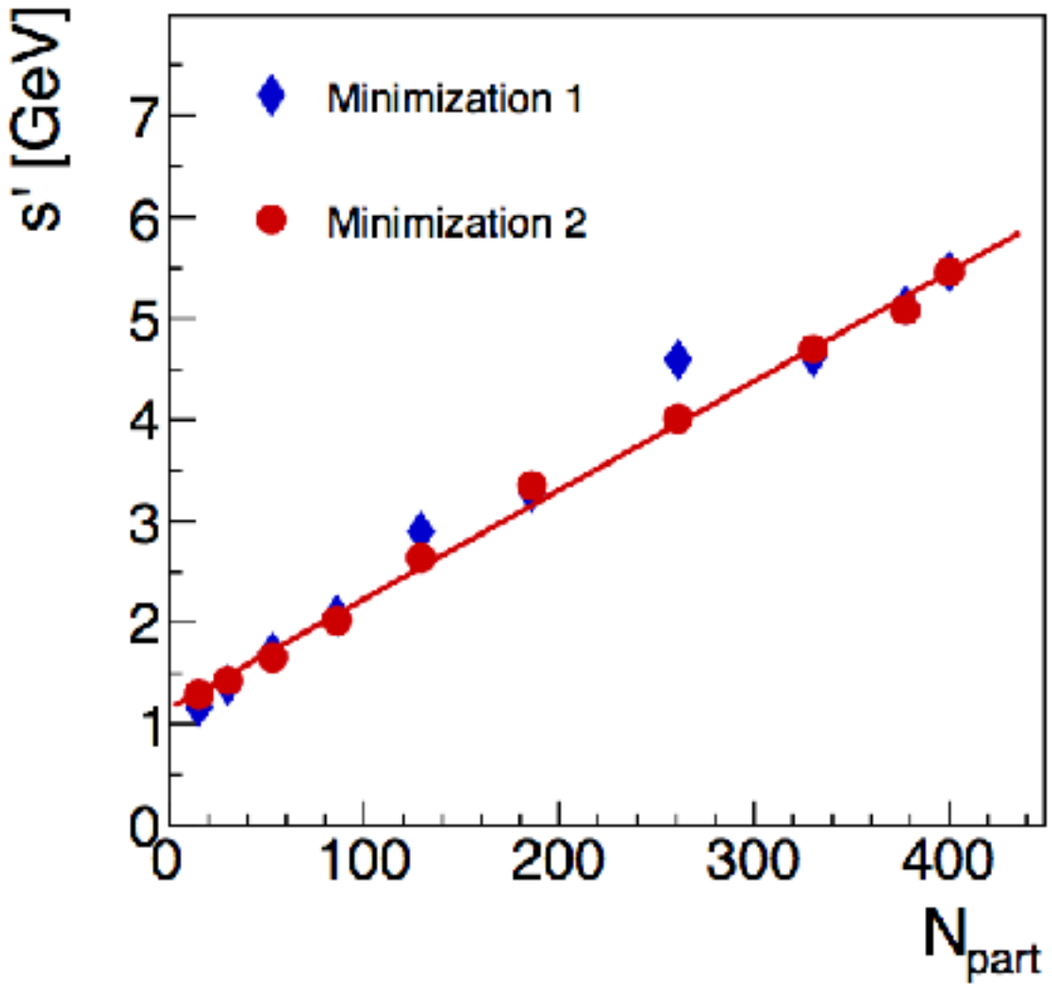


p_T carried by charged particles





excess p_T carried by soft particles "saturates"…



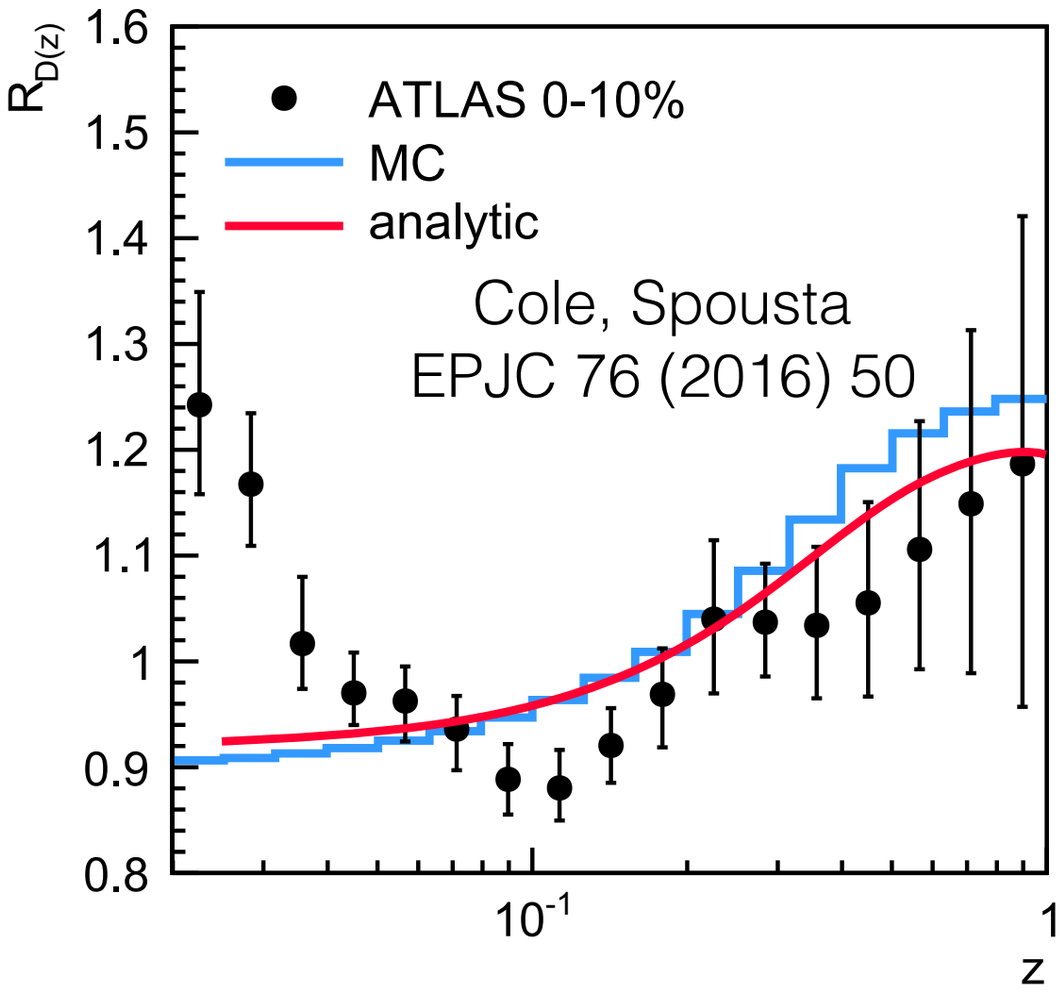
… but jets lose more and more energy

after quenching

$$\frac{D(z;\ \boldsymbol{p_T^{jet}}) \text{ in } \mathbf{A+A}}{D(z;\ \boldsymbol{p_T^{jet}}) \text{ in } \boldsymbol{p+p}}$$

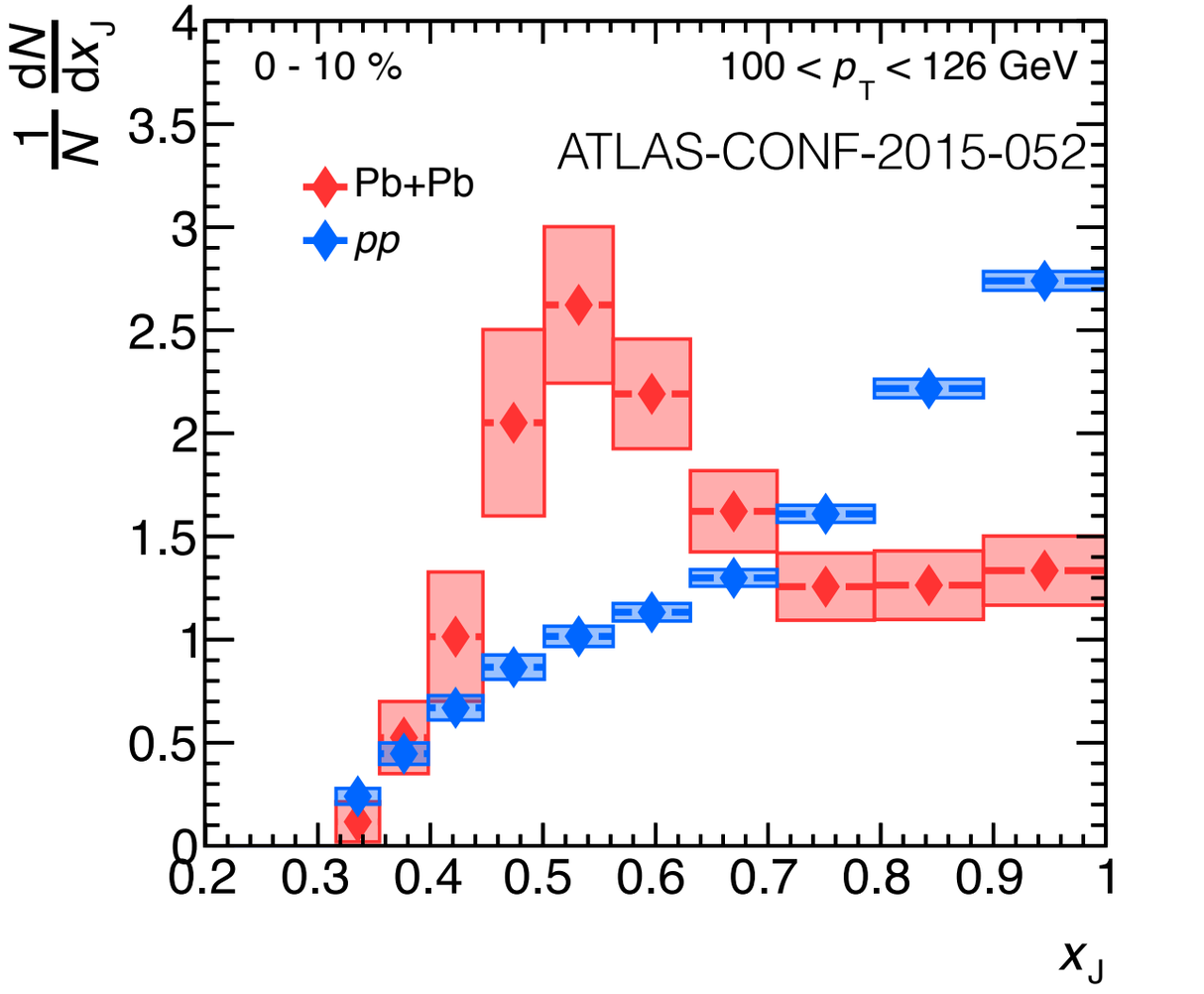
are some jets quenched so strongly they <u>leave</u> their final-state p_T bin?

a general feature of inclusive measurements…



after quenching

$$\frac{D(z;\ p_T^{jet}) \text{ in } \mathbf{A+A}}{D(z;\ p_T^{jet}) \text{ in } \mathbf{p+p}}$$



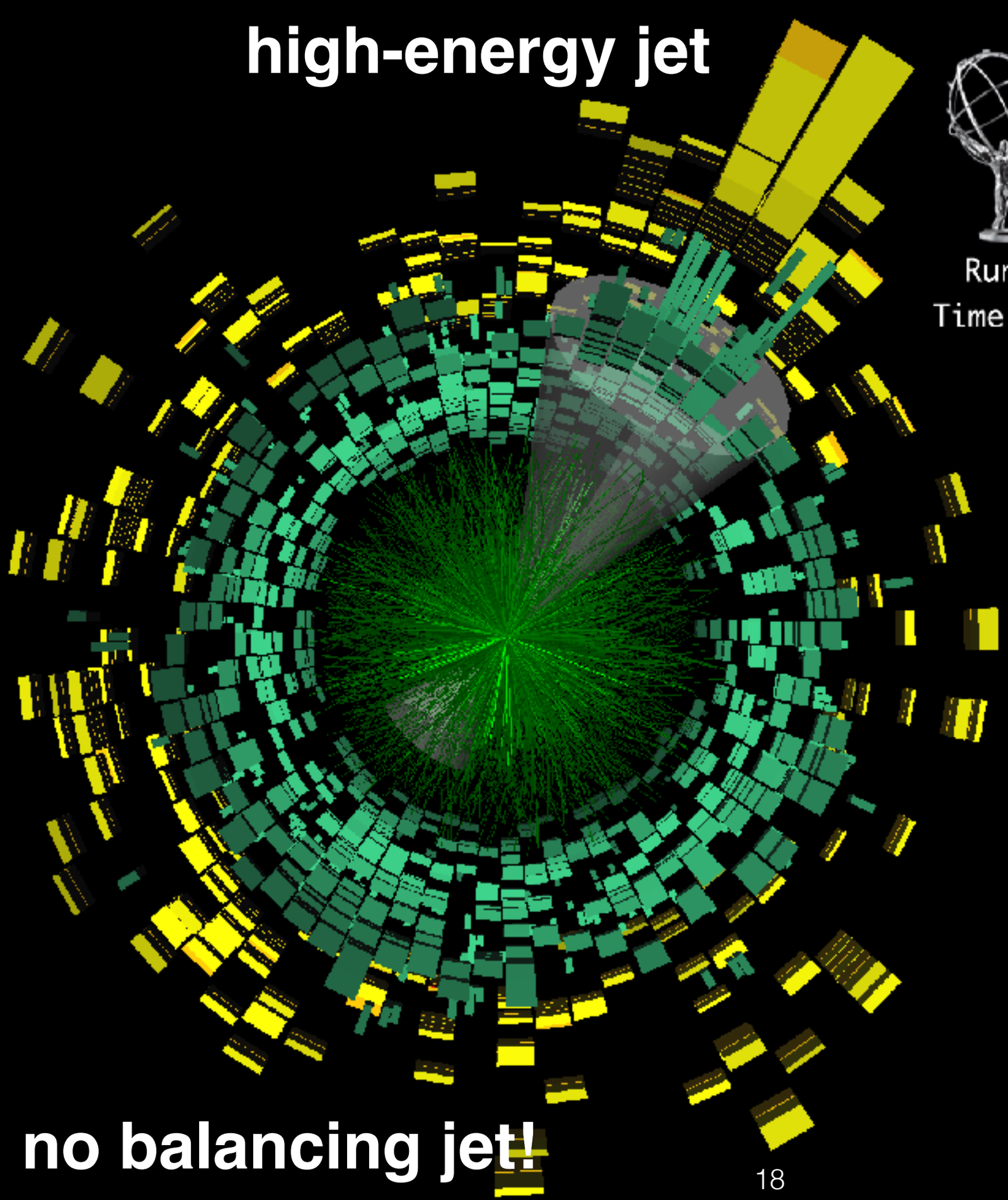
after quenching

$p_{T,2} / p_{T,1}$ in **A+A**

vs.

$p_{T,2} / p_{T,1}$ in **p+p**

high-energy jet



ATLAS EXPERIMENT

Run 168795, Event 7578342

Time 2010-11-09 08:55:48 CET

Pb+Pb 2.76 TeV

LHC Run 1

beams going into/ out of the page

see for example: Milhano, Zapp hep-ph/1512.08107

no balancing jet!

ATLAS EXPERIMENT

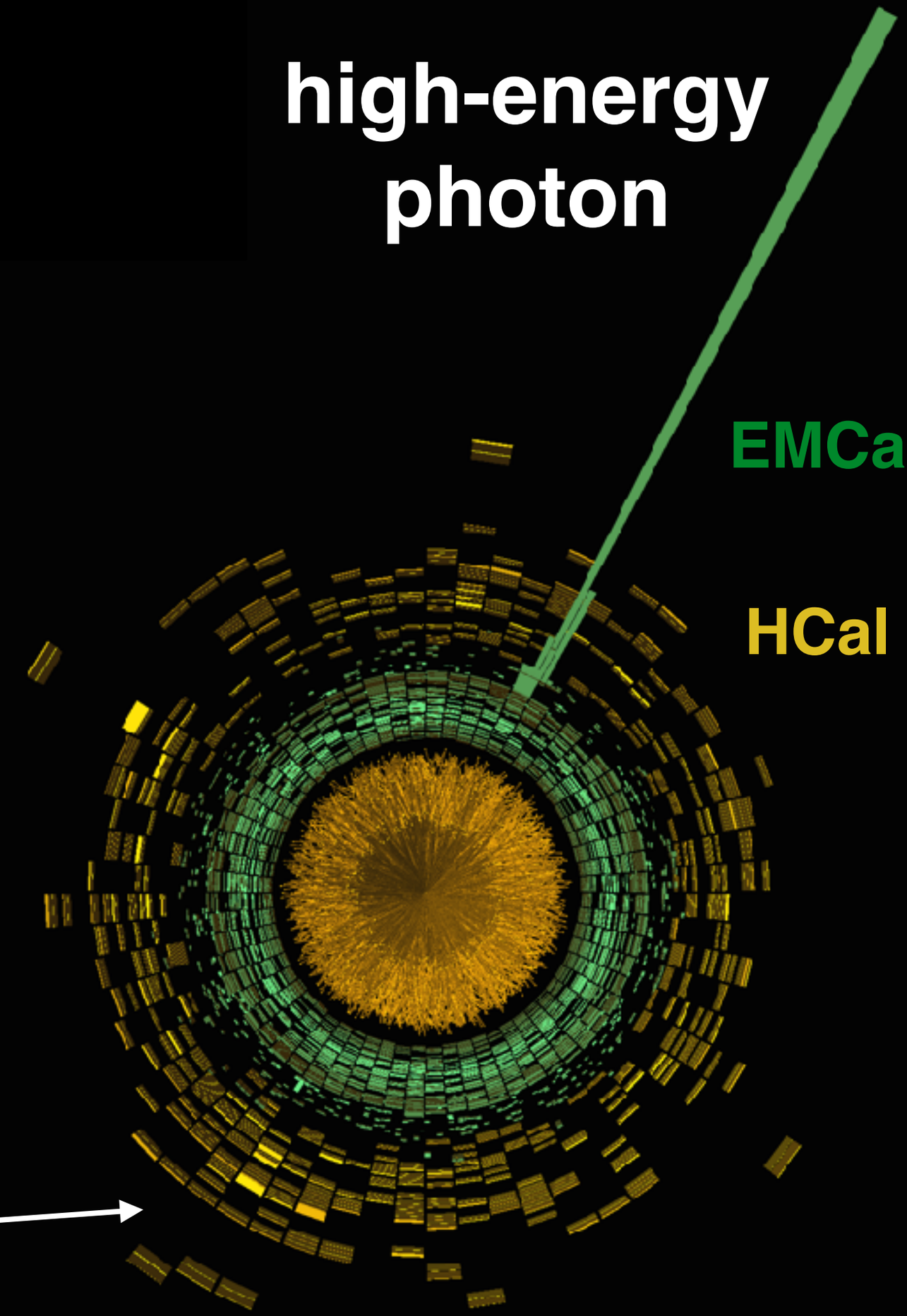
Run: 286834
Event: 124877733
2015-11-28 01:15:42 CEST

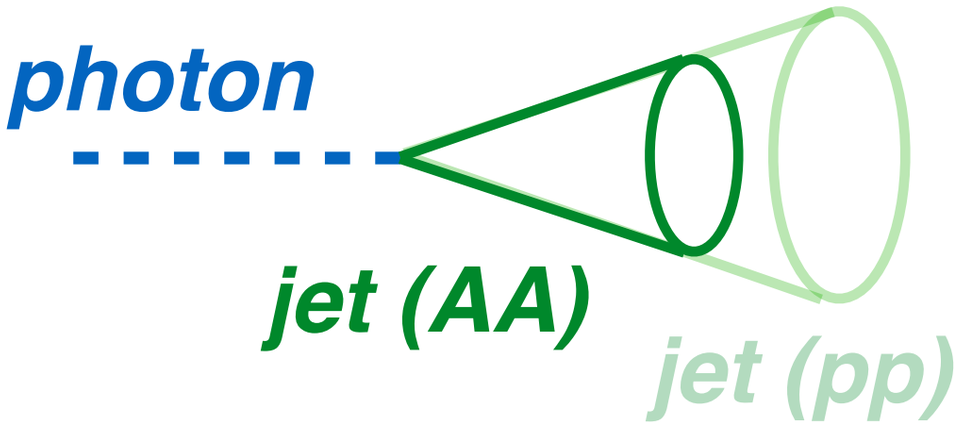
Pb+Pb $\sqrt{s_{NN}}$ = 5.02 TeV
photon + multijet event
ΣE_T^{FCal} = 4.06 TeV

Pb+Pb 5.02 TeV
LHC Run 2

high-energy photon

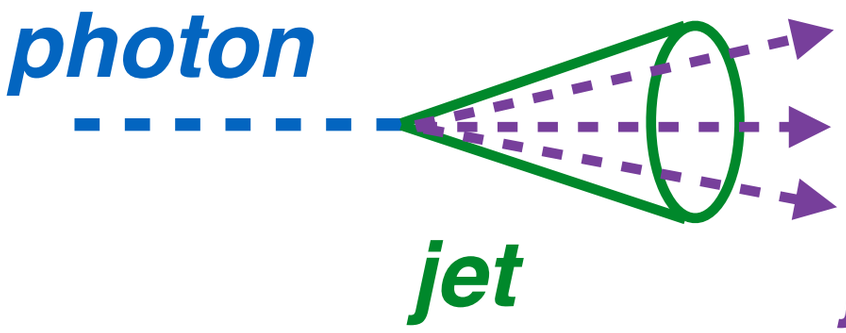
balancing jet?





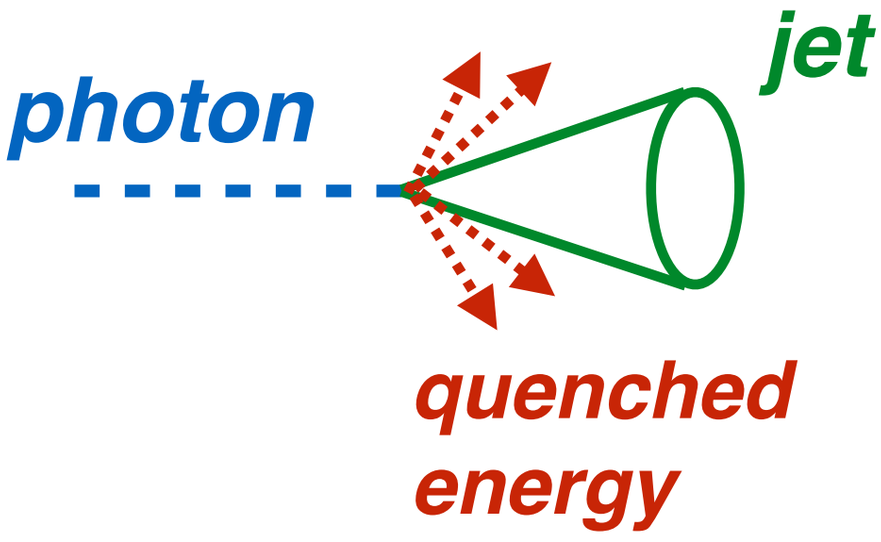
1. What is the (absolute) amount of energy lost in cone?

➡ ***photon*+*jet*** *p_T-balance*



2. How is the parton shower in cone modified by medium?

➡ ***photon***-tagged ***frag. function*** (w.r.t. ***jet***)



3. Where does the lost energy end up?

➡ ***photon*-*hadron*** corr. broadly in angle / momentum

$x_{J\gamma} = p_T^{jet} / p_{T\gamma}$

vary system size

ATLAS-CONF-2016-110

vary initial *E* before quenching

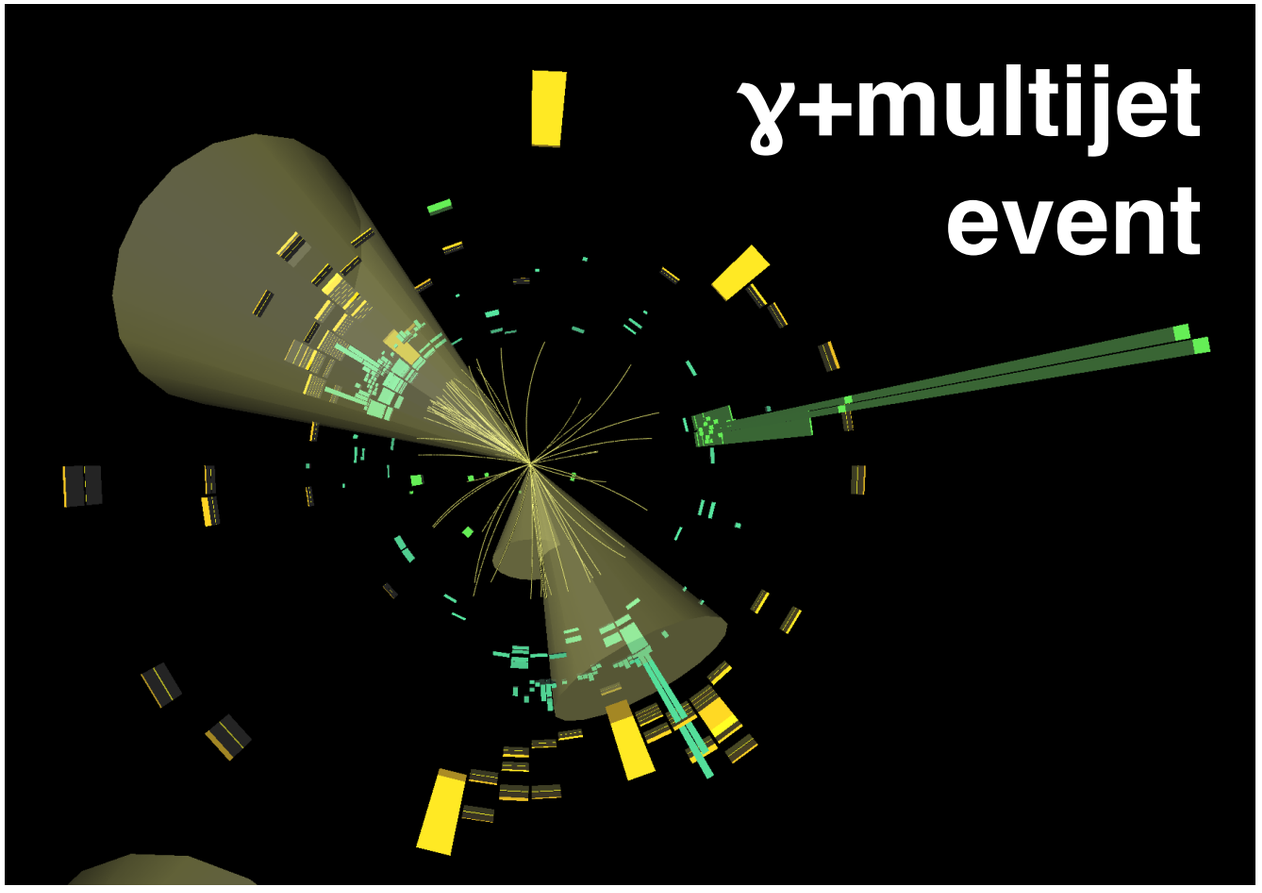
pp | 50-80% Pb+Pb | 30-50% Pb+Pb | 20-30% Pb+Pb | 10-20% Pb+Pb | 0-10% Pb+Pb

ATLAS Preliminary
5.02 TeV
Pb+Pb, 0.49 nb^{-1}
pp, 26 pb^{-1}
Simulation
Data

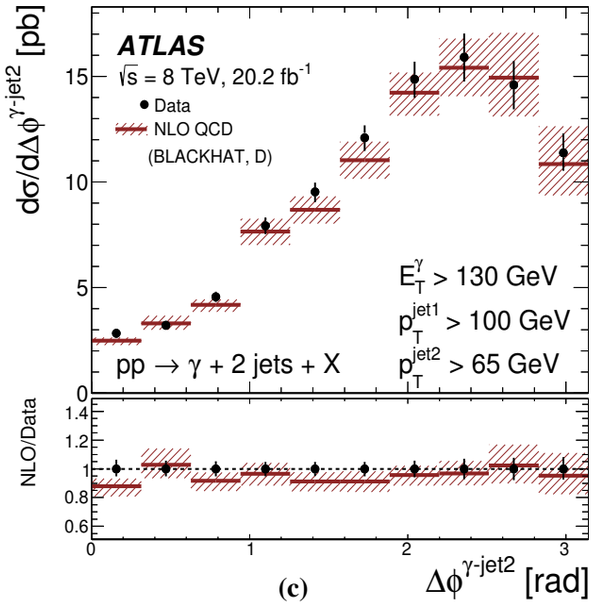
$(1/N_{J\gamma})(dN/dx_{J\gamma})$

$60 < p_T^{\gamma} < 80$ GeV
$80 < p_T^{\gamma} < 100$ GeV
$100 < p_T^{\gamma} < 150$ GeV
$150 < p_T^{\gamma} < 200$ GeV

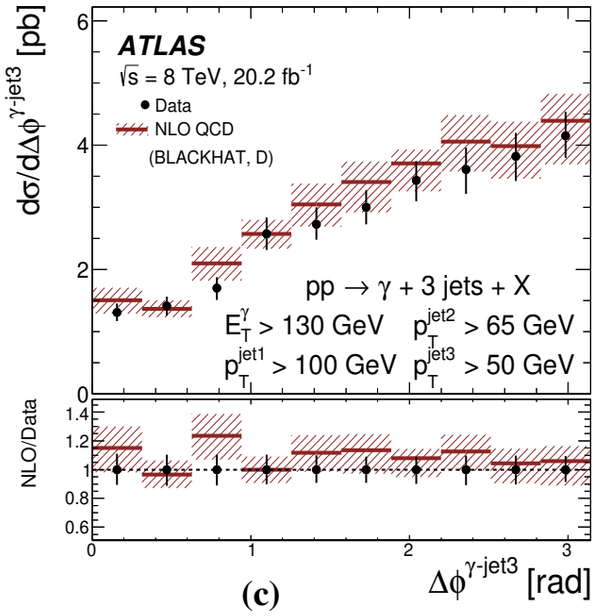
$x_{J\gamma}$



Measured in detail by HEP community, e.g.

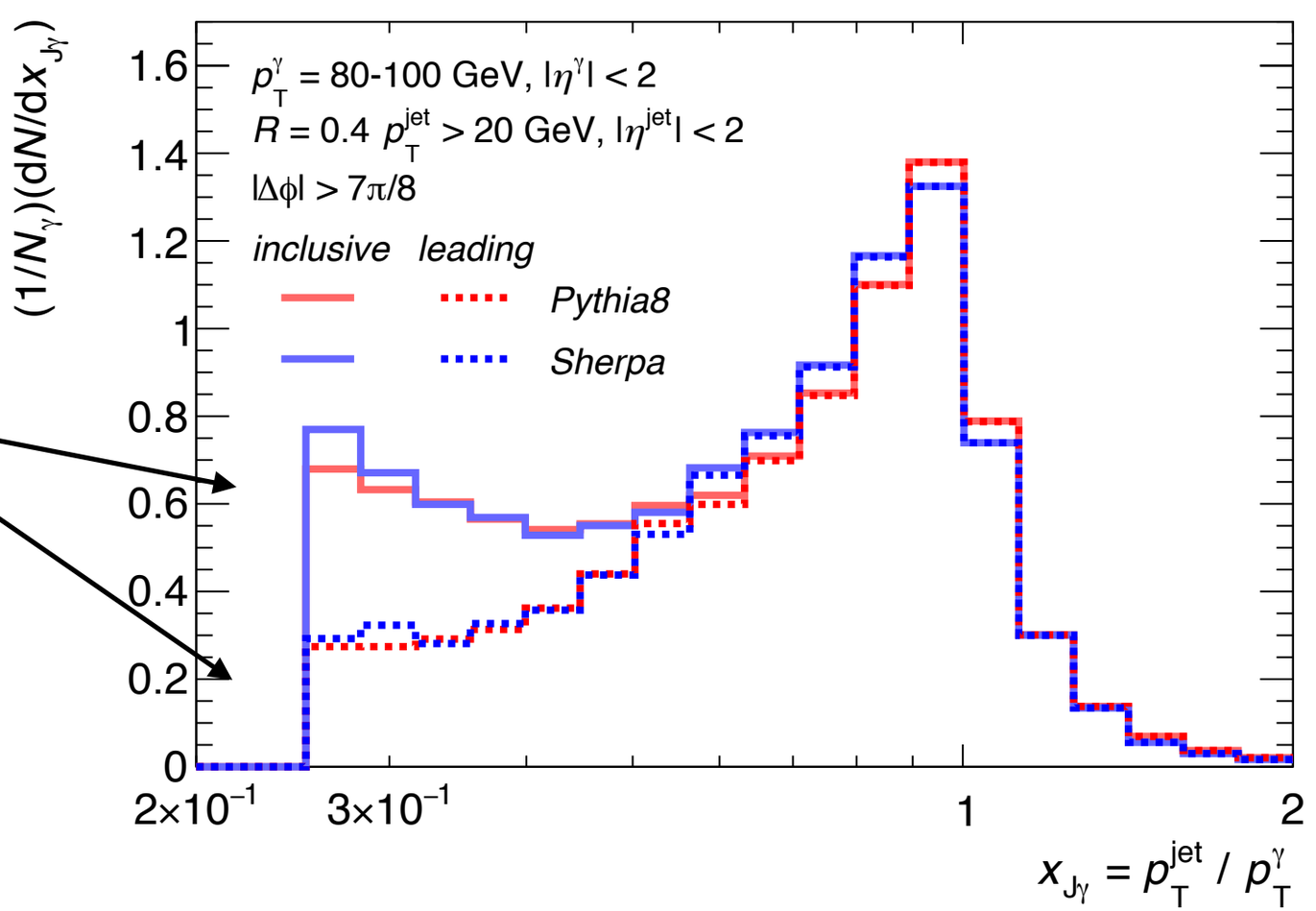


dσ/dΦ(γ+jet2)



dσ/dΦ(γ+jet3)

Large differences for inclusive vs. leading at low-$x_{J\gamma}$…

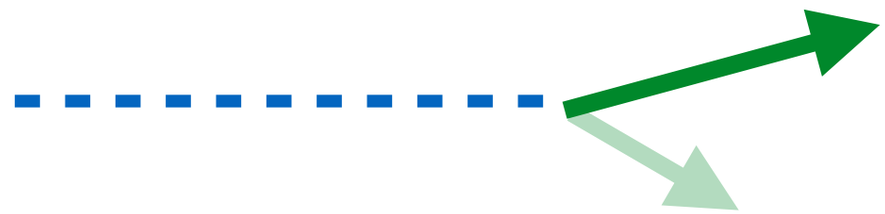


Sensitivity to analysis choices…

1. Photon + *inclusive* jets

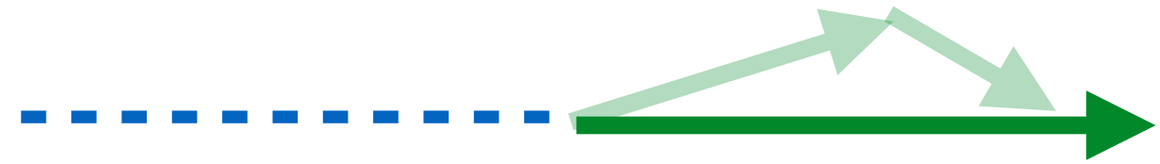
➡ experimentally easy, but can't extract per-jet $\langle E_{loss} \rangle$

2. Photon + *leading* jet



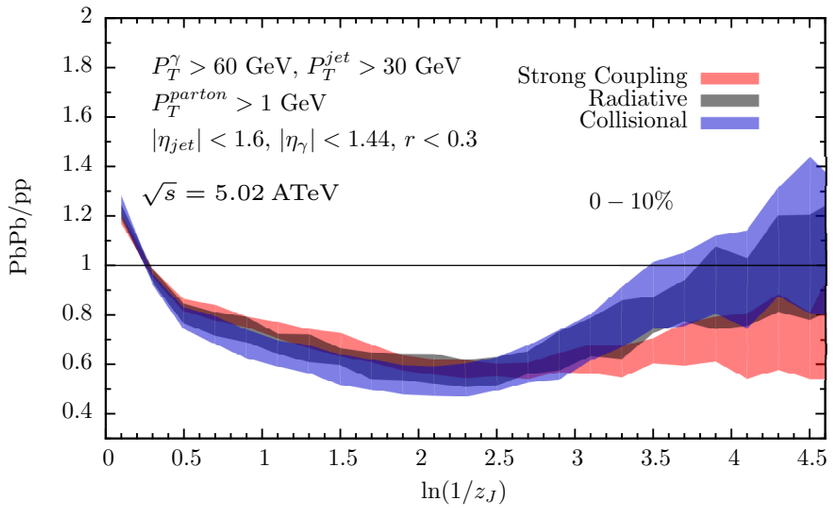
➡ better-defined "leading quark" probe

3. Photon + $\Sigma\vec{p}_T$ of high-p_T jets

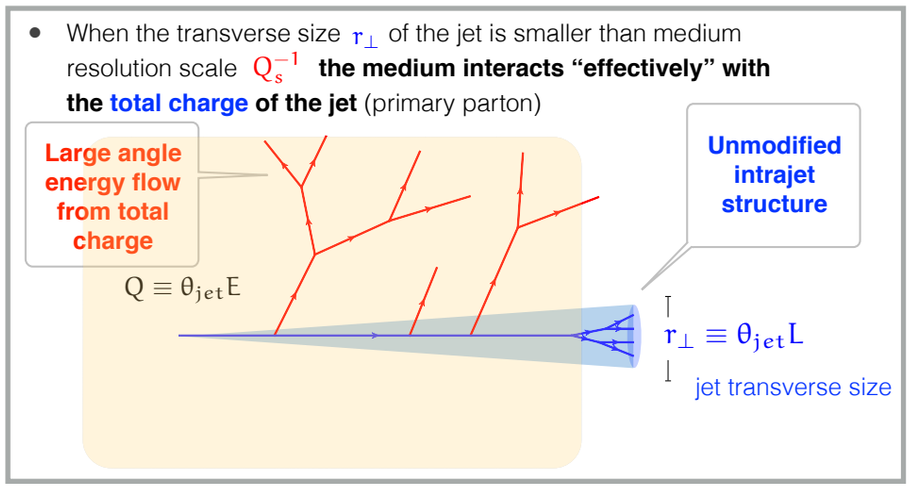


➡ *E*-loss of entire recoiling hadronic system

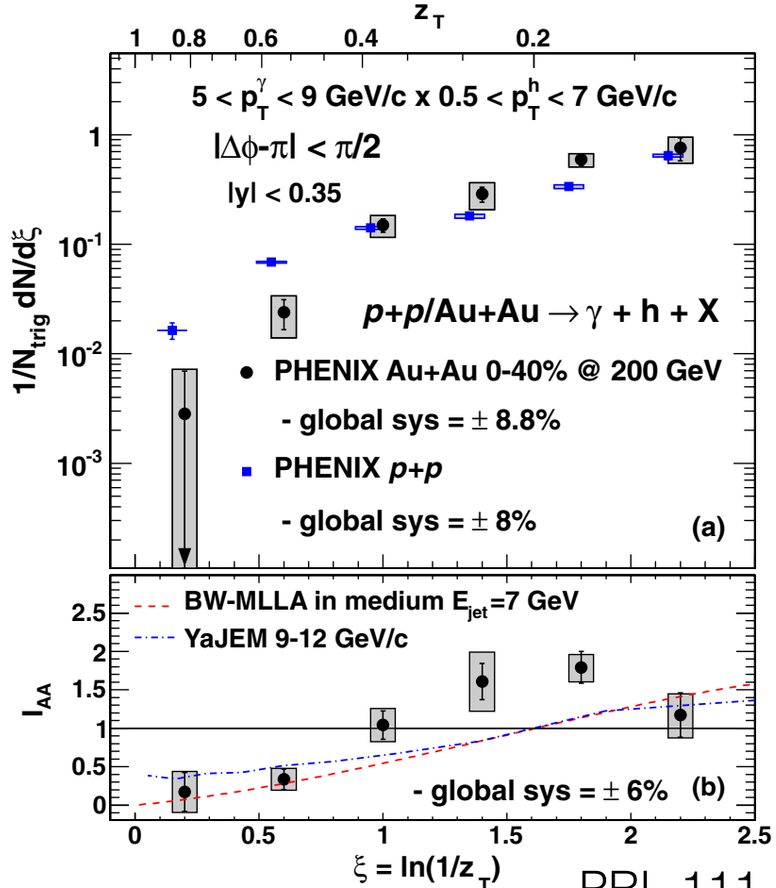
Photon-tagged fragmentation functions



Casalderrey-Solana, Gulhan, Milhano, Pablos, Rajagopal, hep-ph/1508.00815



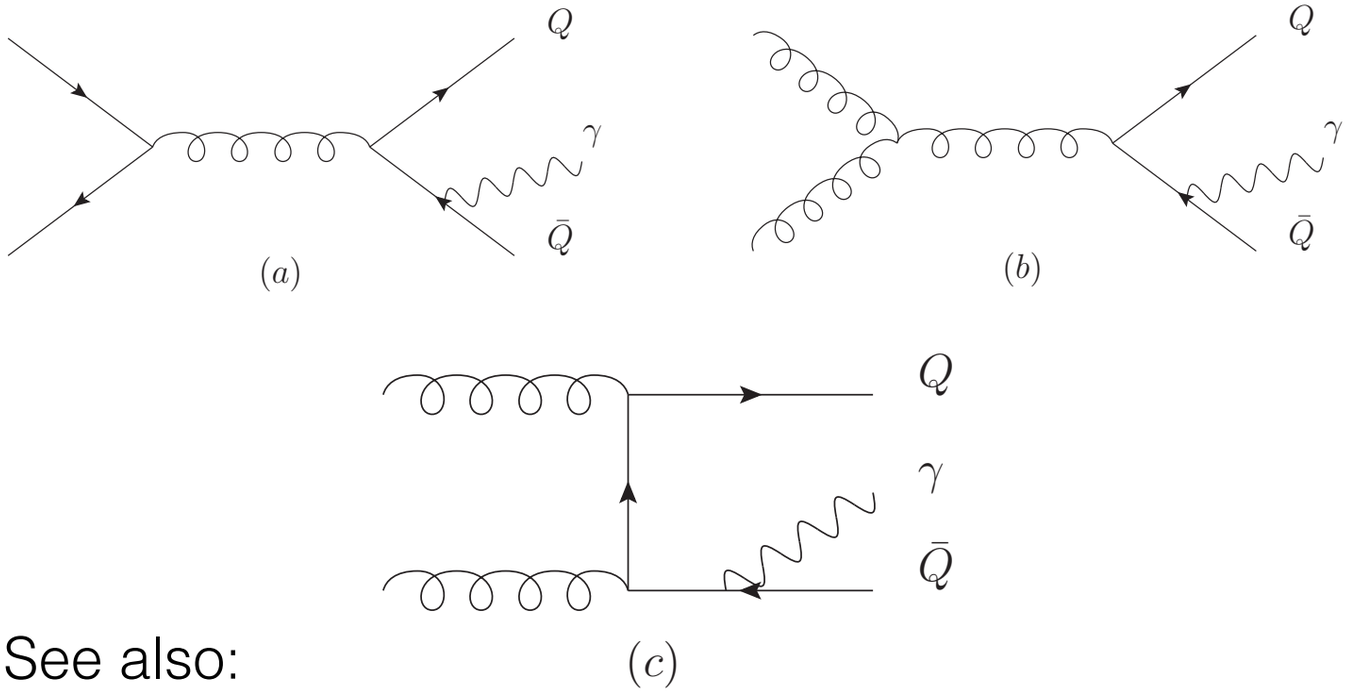
Casalderray-Solana, Mehtar-Tani, Salgado, Tywoniuk, hep-ph/1210.7765



PRL 111 (2013) 032301

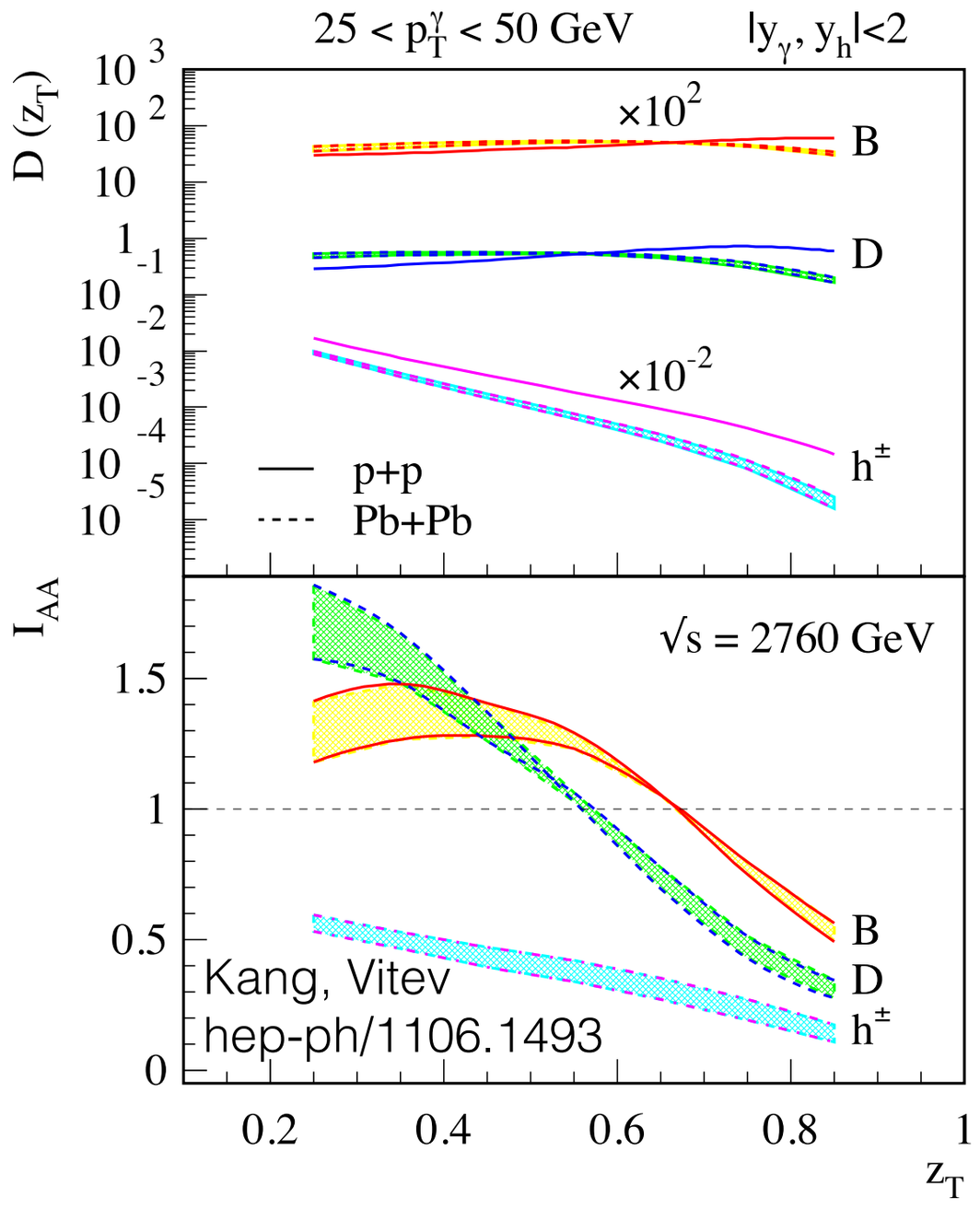
- Separately with respect to the *jet* and the *photon*
  - ➡ *flavor* dependence of parton shower modification
  - ➡ γ-tag: clean sample of jets at lower p_T (e.g. w/o fake jet rejection)
  - ➡ avoid "artificial" features due to final-state selection (e.g. change in q/g mixture, Spousta, Cole hep-ph/1504.05169)

Photons + heavy flavor quarks



See also:

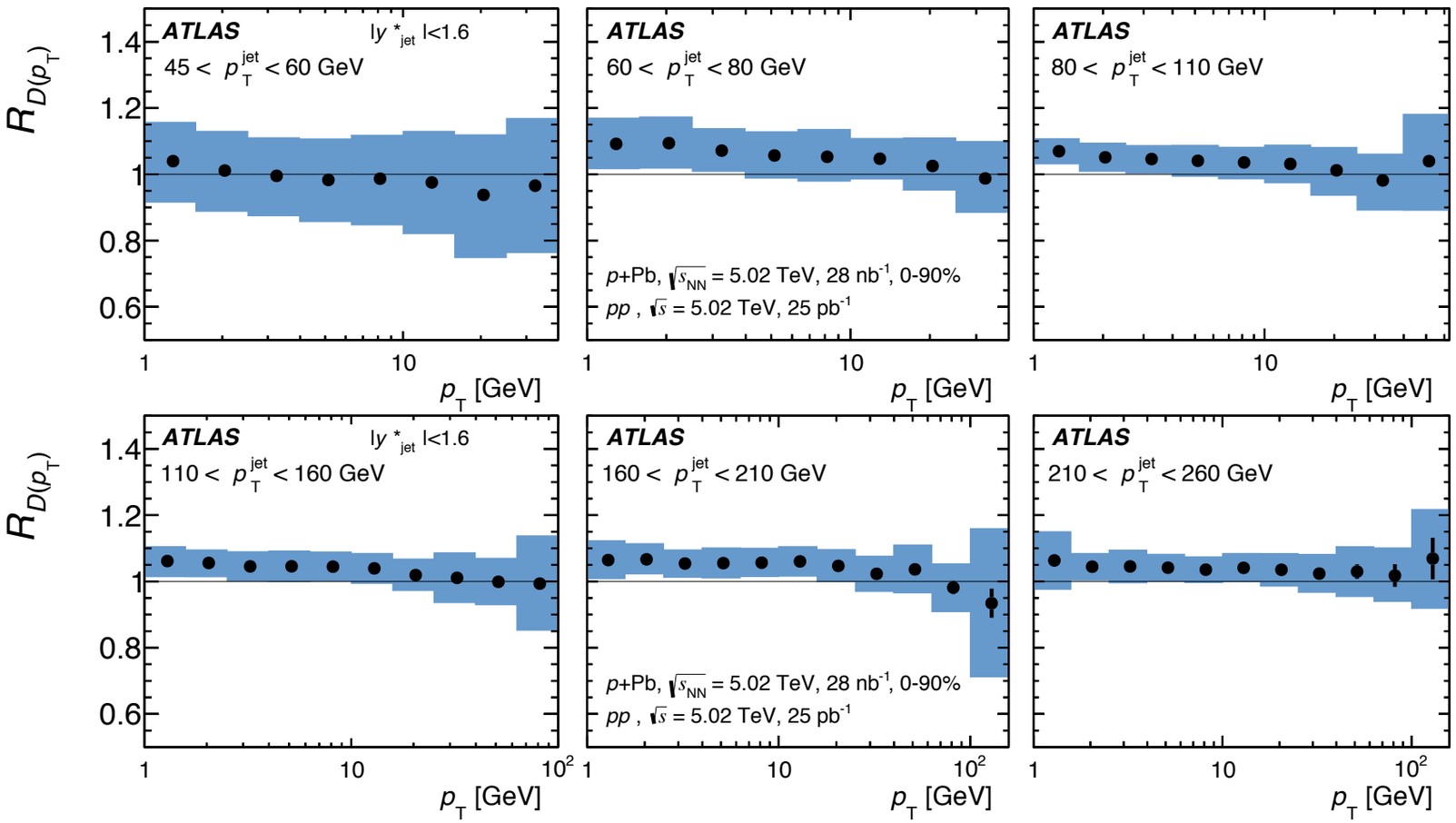
- ➡ Stavreva, Arleo, Schienben, hep-ph/1211.6744
- ➡ Huang, Kang, Vitev, Xing hep-ph/1505.03517



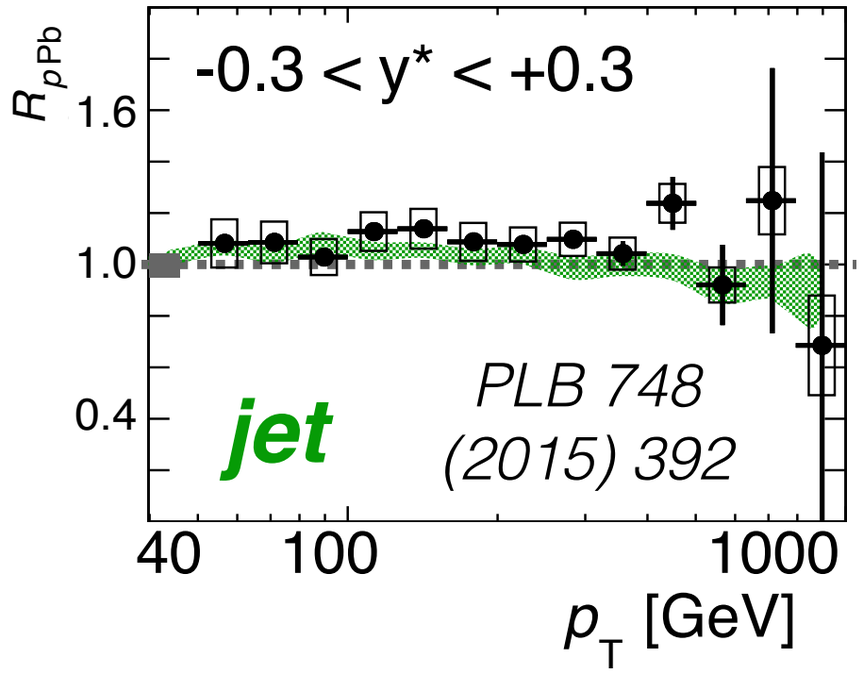
- Absolute energy loss & mod. fragmentation for *c*, *b*?
  - ➡ since *Q* is not incoming parton, lose back-to-back photon + “leading quark” picture
  - ➡ but still pick out consistent initial kinematics in *pp* & AA?

p+Pb & ultra-peripheral Pb+Pb

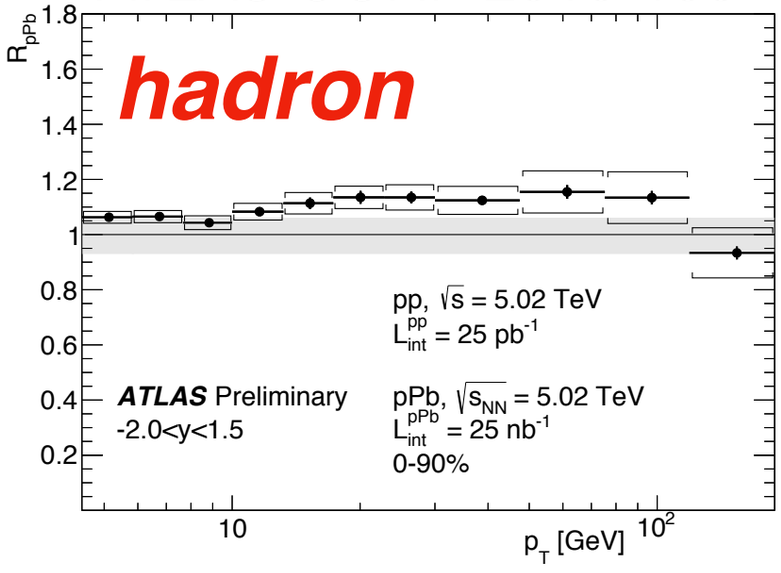
Inclusive jet and charged particles



hep-ex/1706.02859, sub. to PLB



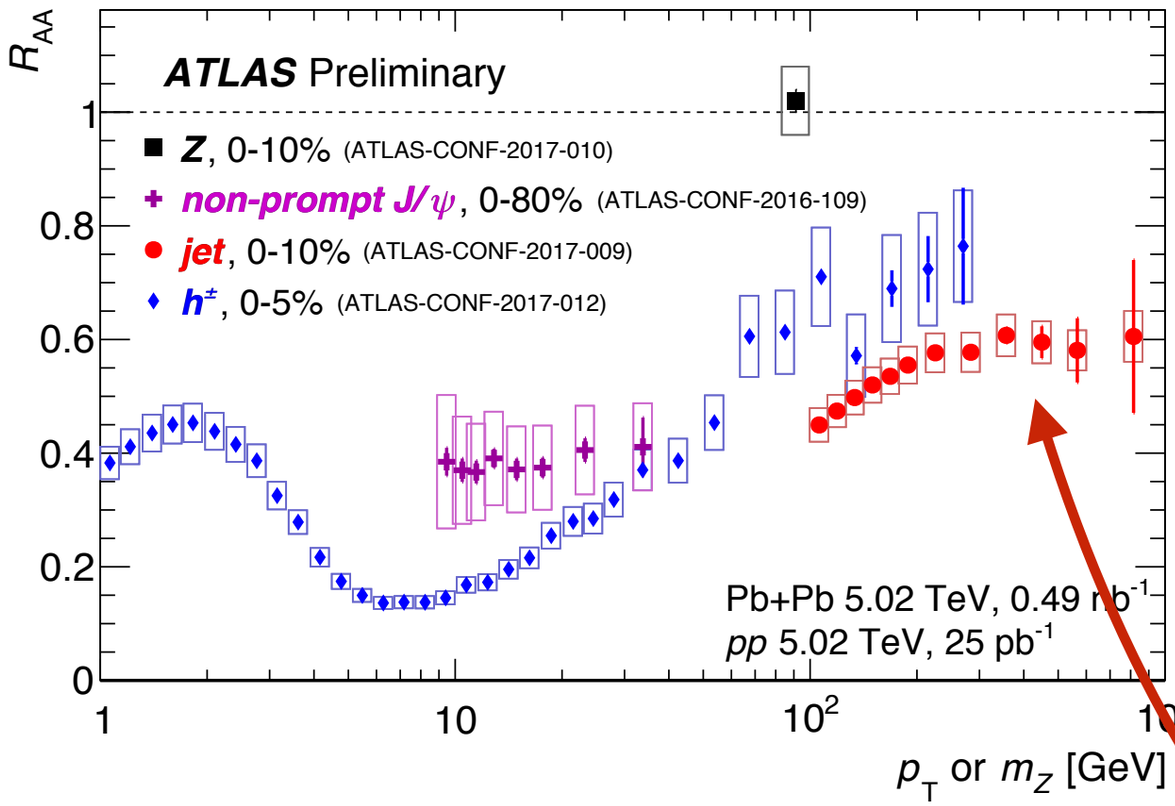
ATLAS-CONF-2016-108

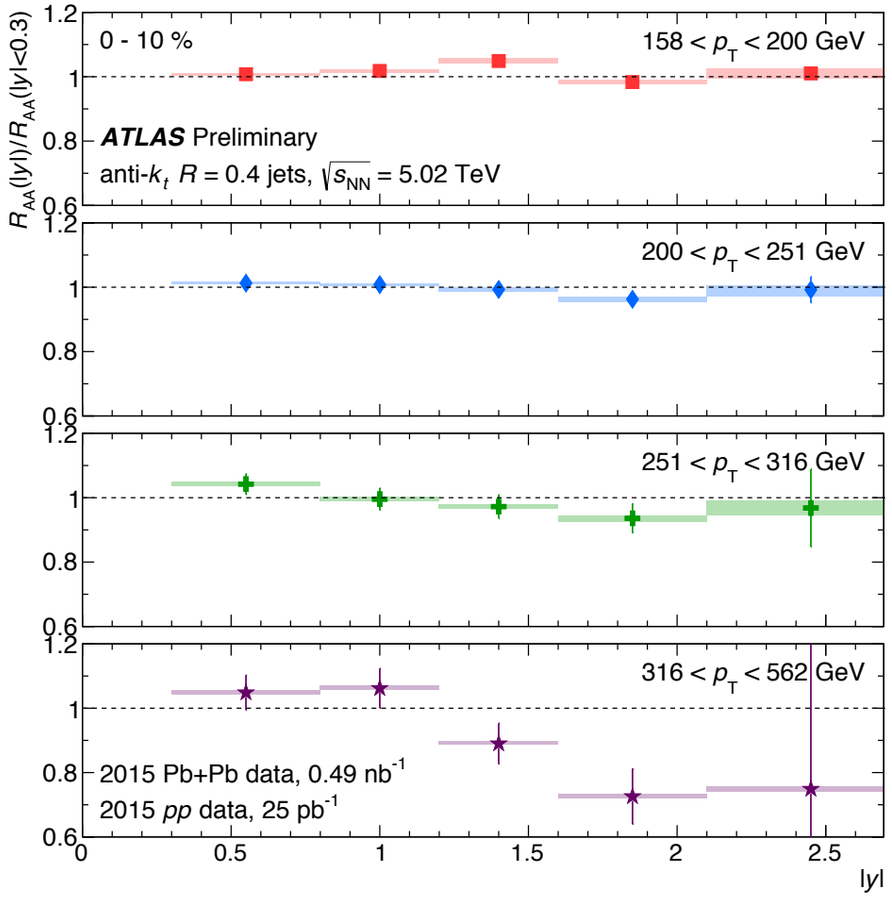


Measurement of *p*+Pb / *pp* jet **fragmentation functions**

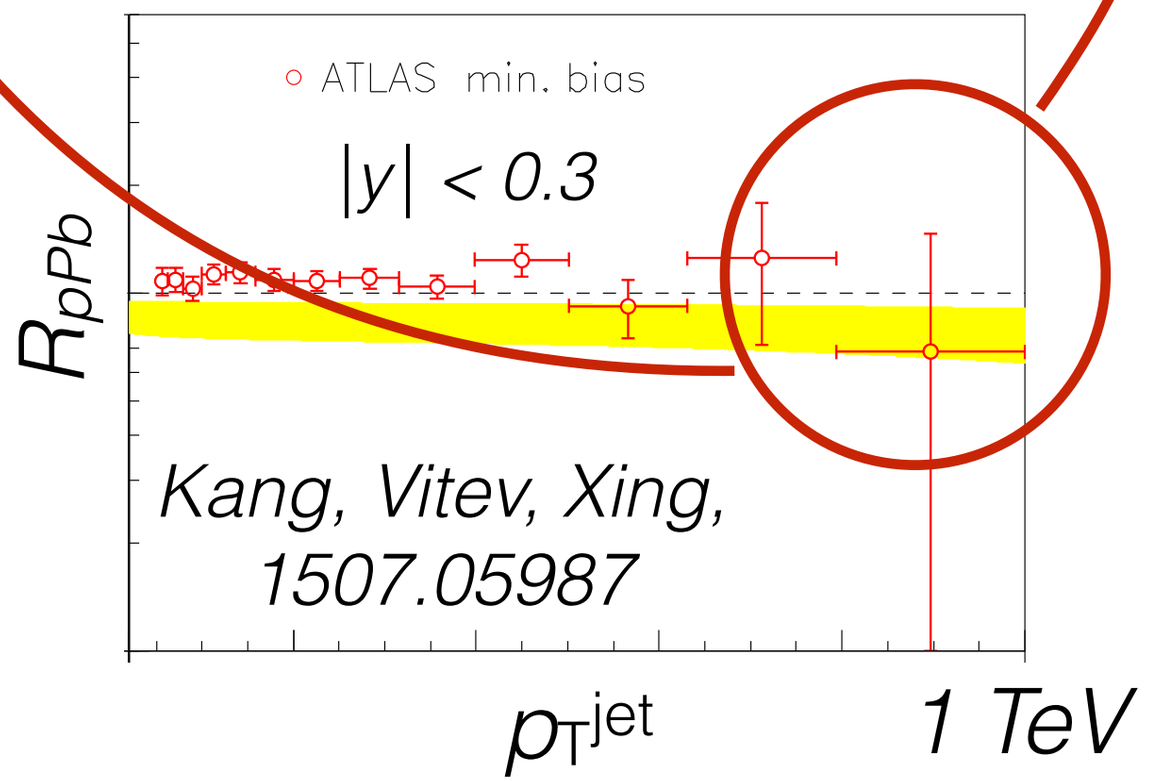
- ➡ *data-to-data ratio, identical collision energy*
- ➡ *ties together (unmodified)* ***jet*** *and* ***hadron*** *measurements*

Calibrating initial-state effects





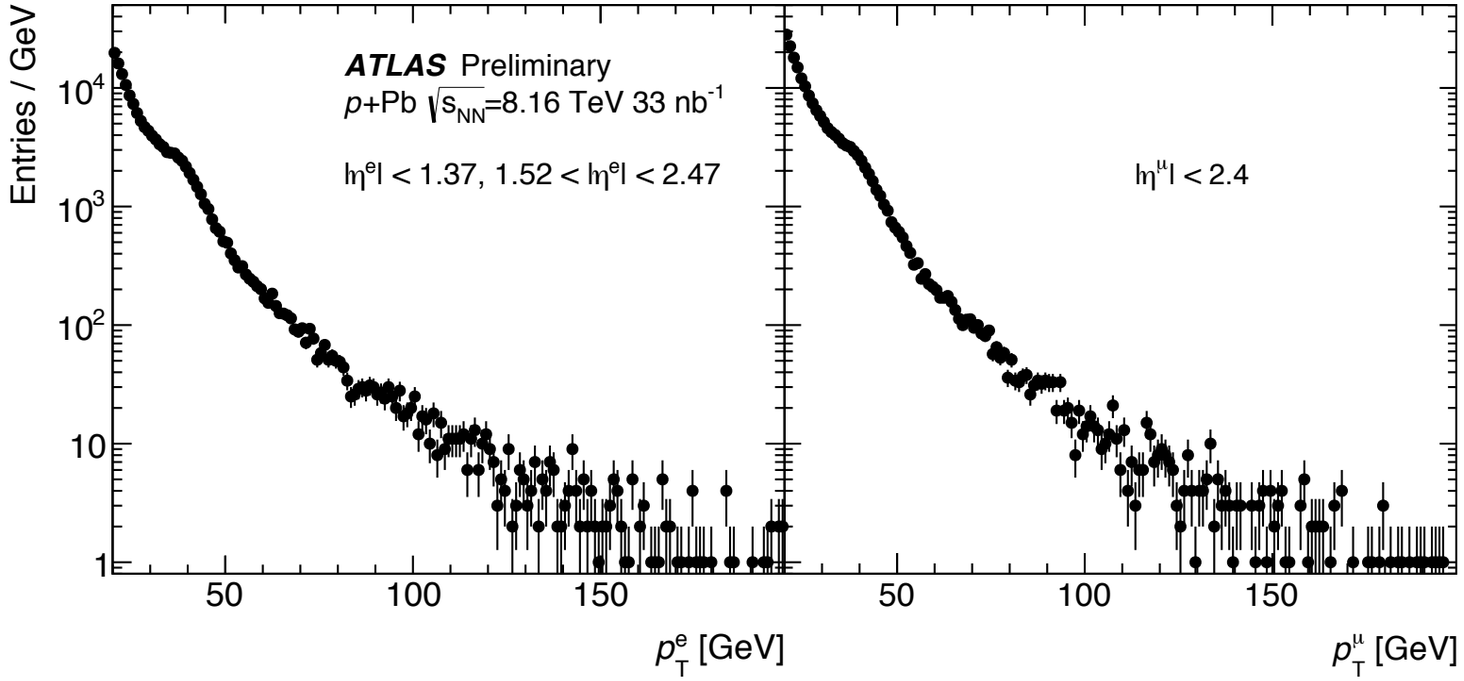
- $E_{T,jet}$ = 1 TeV @ y = 0
- $E_{T,jet}$ = 0.3 TeV @ y = 2
  - ➡ $x_A = 0.4(!)$
- Need constraints on possible initial state effects, ideally in data



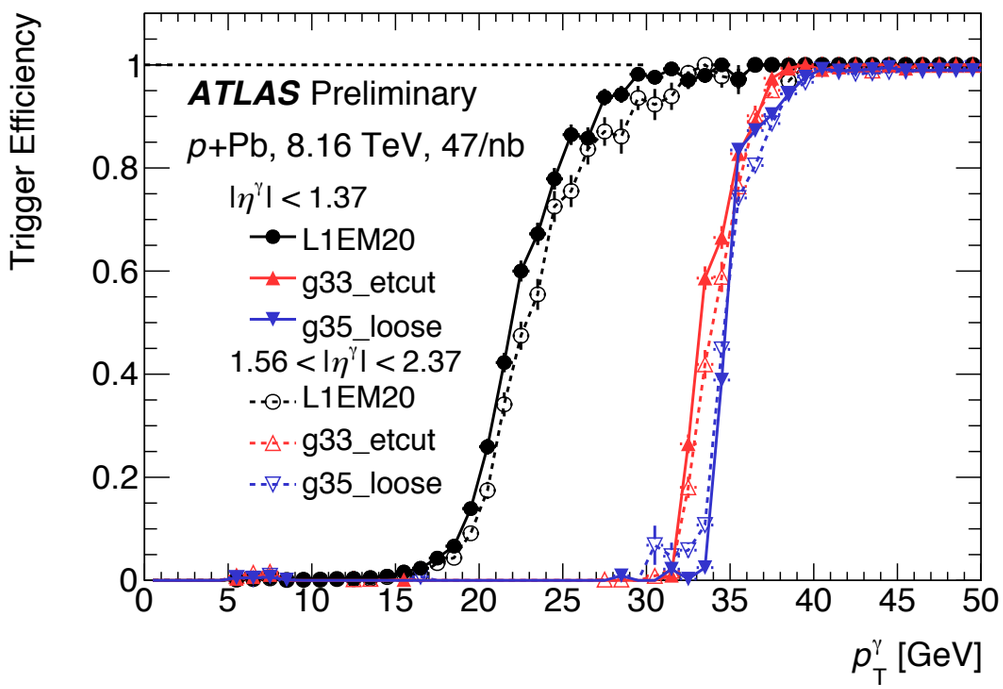
EW bosons in *p*+Pb…

Tremendous γ/*W*±/Z yields

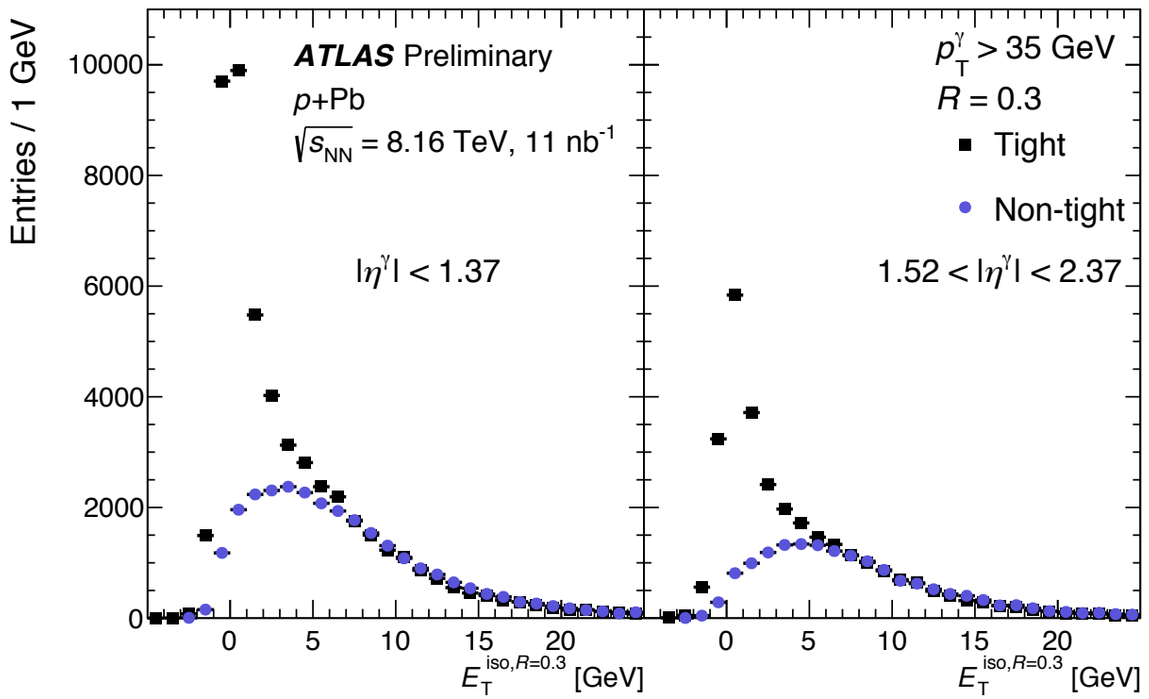
- *8 TeV comparison data readily available*
- *analyses in progress*



Single e± and μ± spectra



forward photon trigger

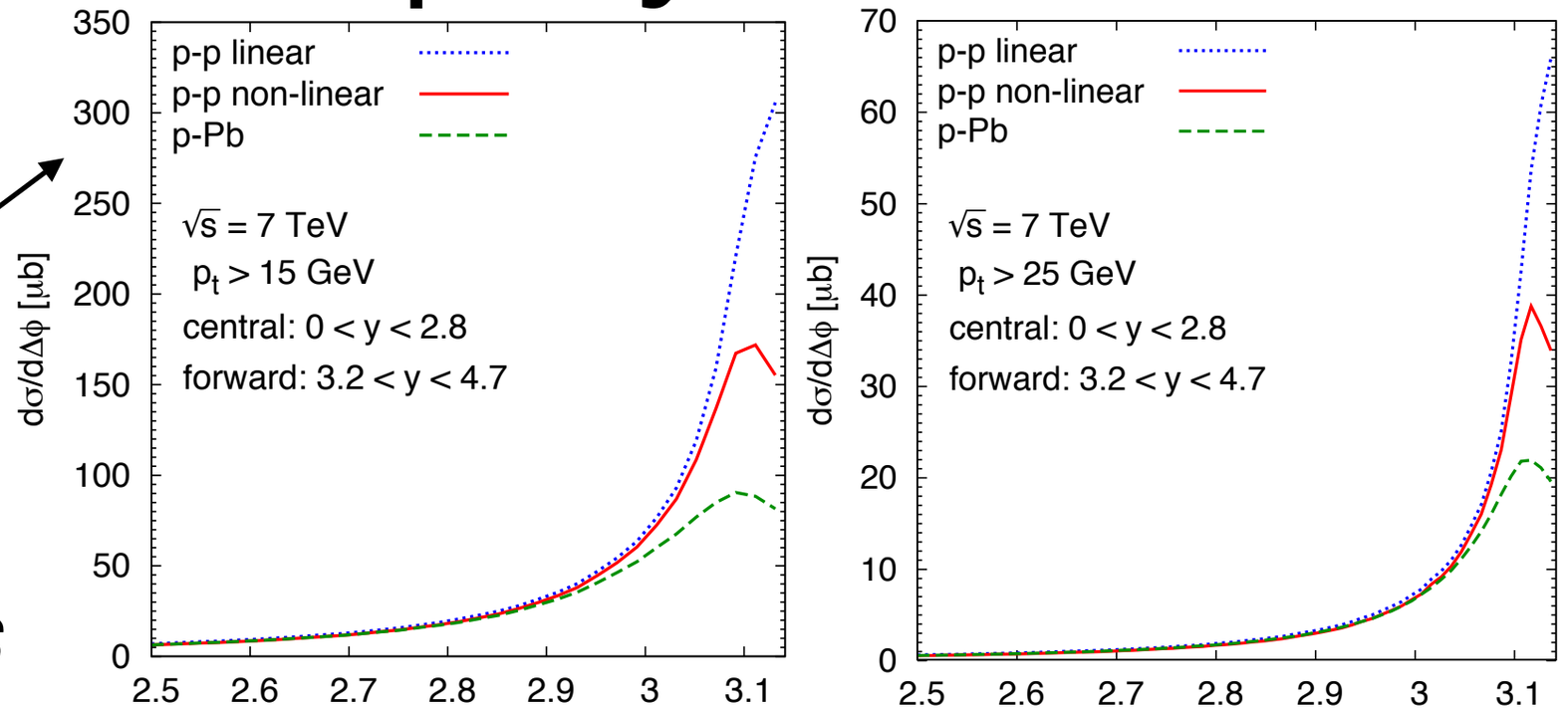


photon isolation

Saturation physics?

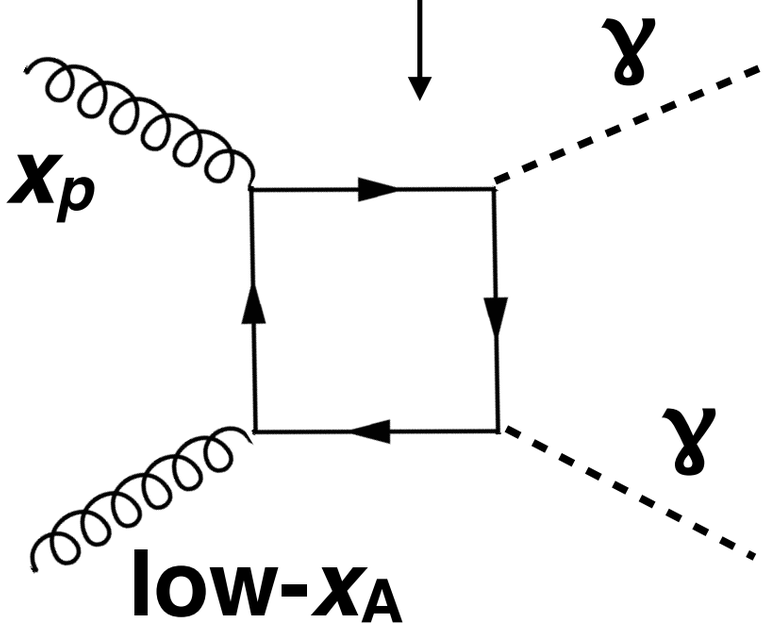
Low-p_T central + forward dijet corr.

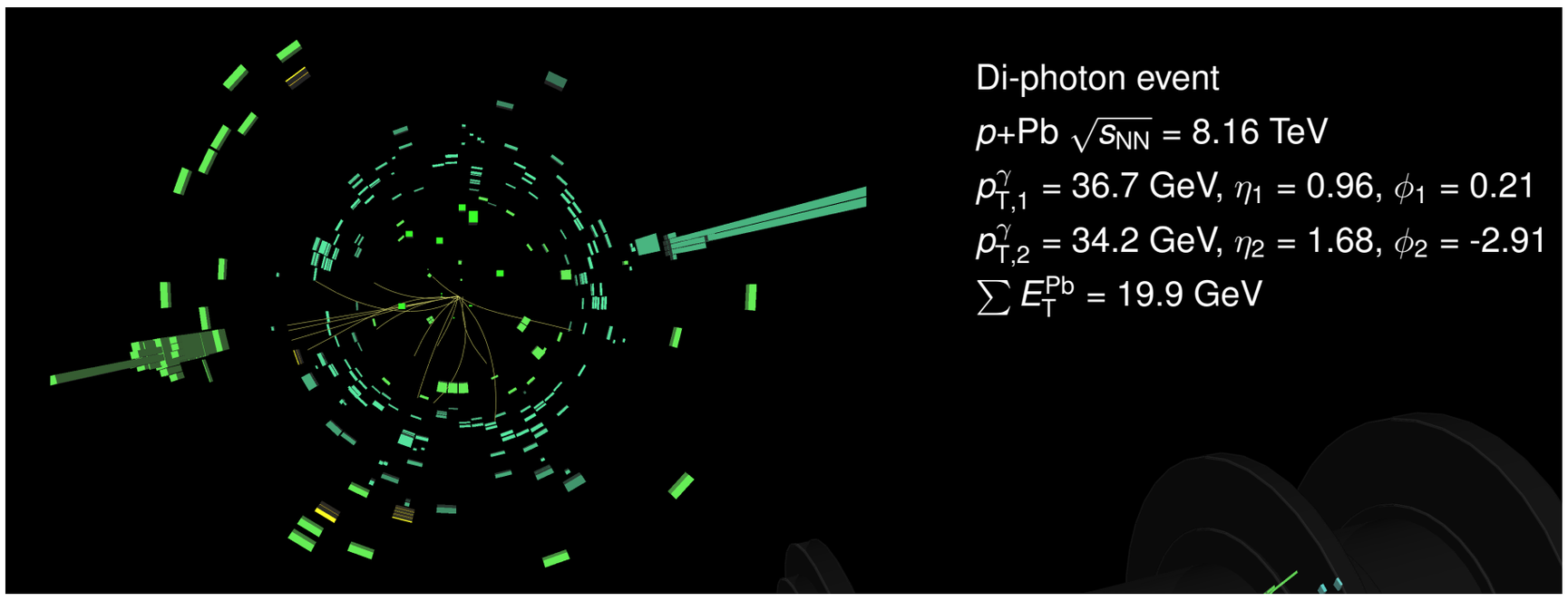
- *5.02 TeV p+Pb vs. pp data*
- *analysis in progress*



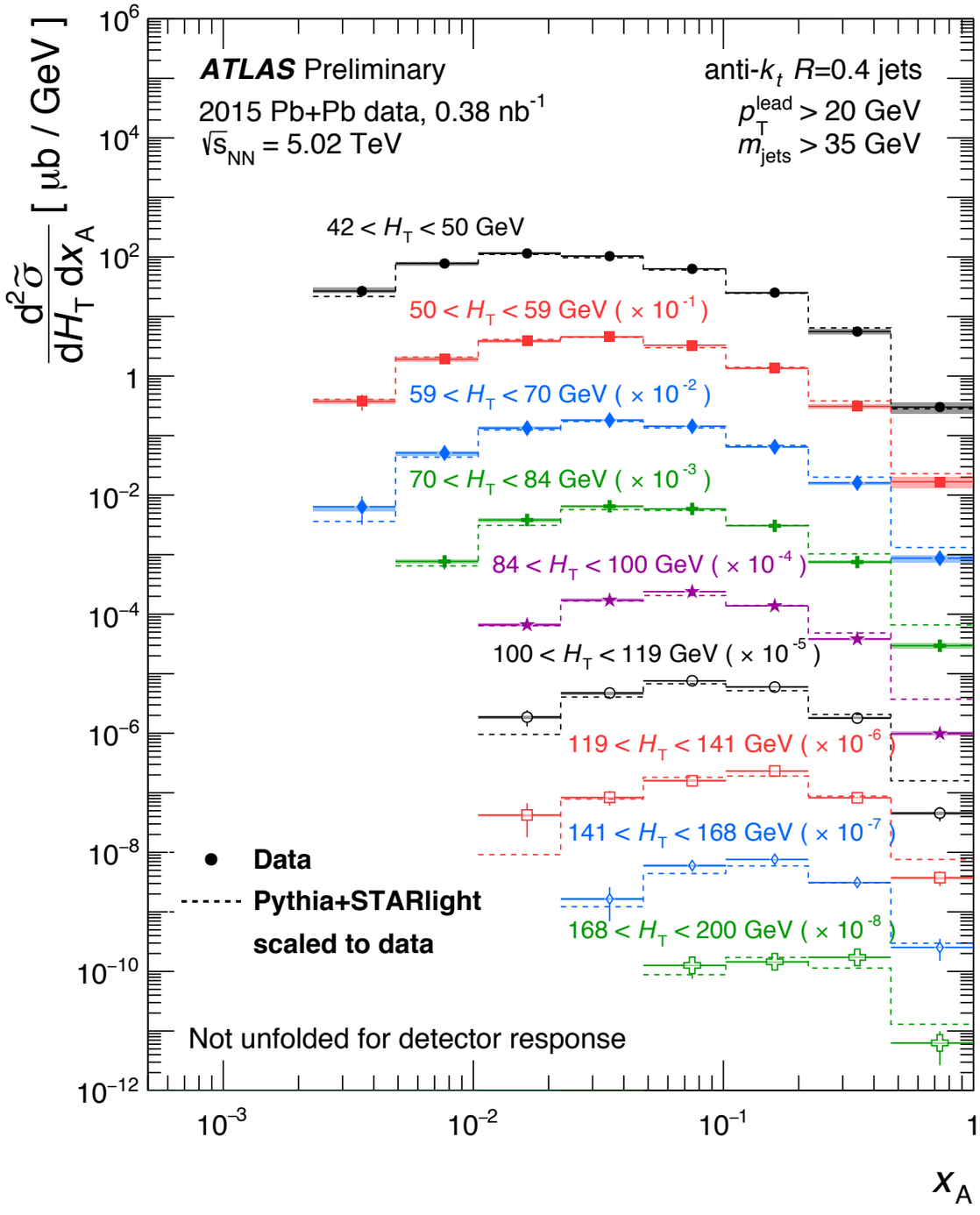
Kutak, Sapeta, hep-ph/1205.5035 (& other papers)

Di-photon production





dijets in γ+Pb



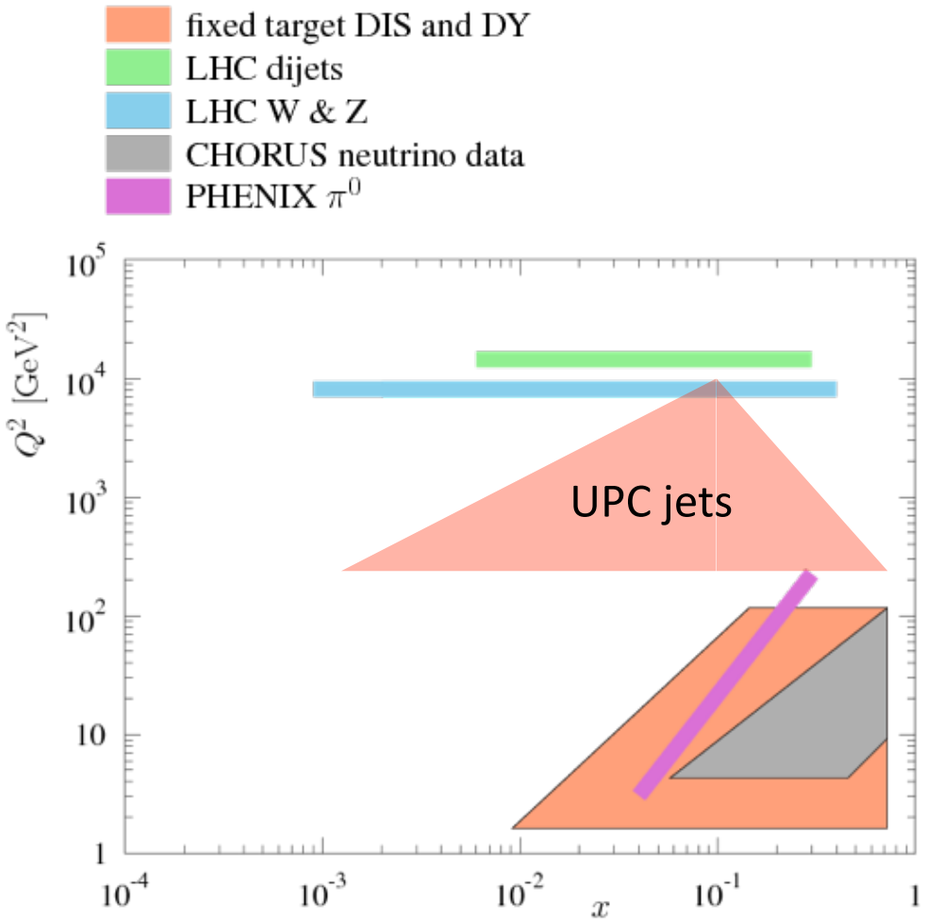
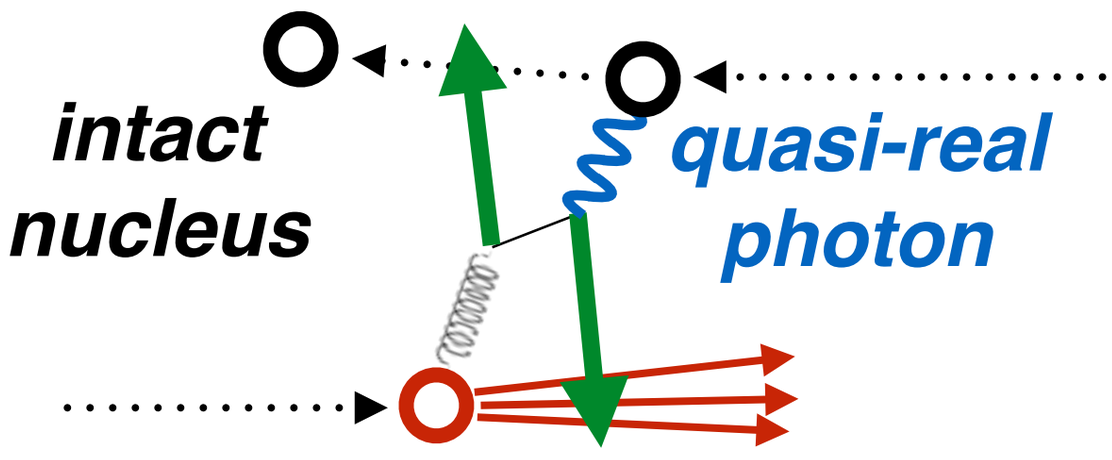


Figure adapted from EPPS16
1612.05741 [hep-ph]

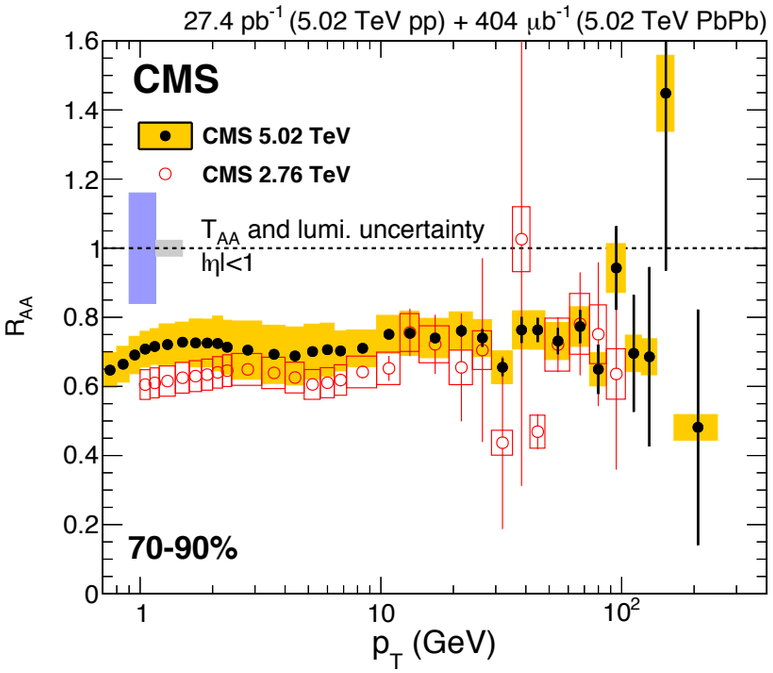


cleanly access nPDF effects in entirely new (x_A, Q^2) range

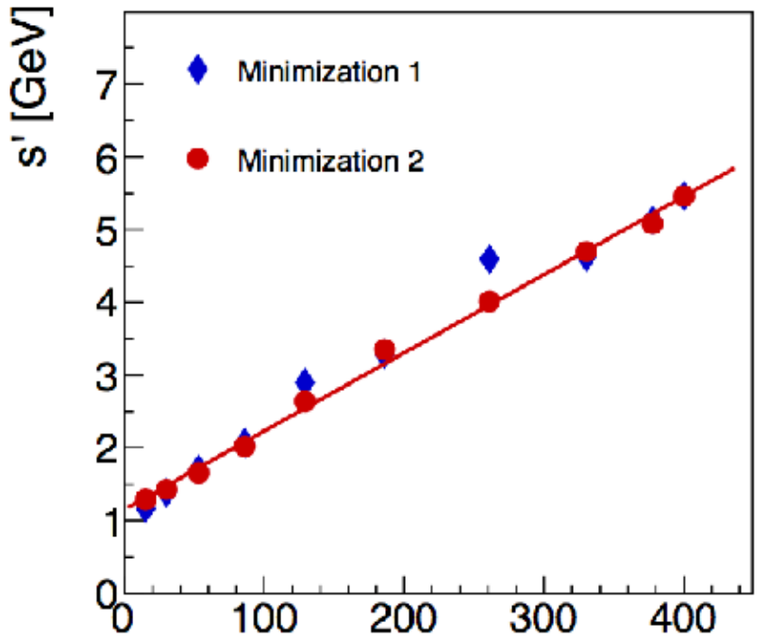
photo-nuclear dijets

nuclear breakup

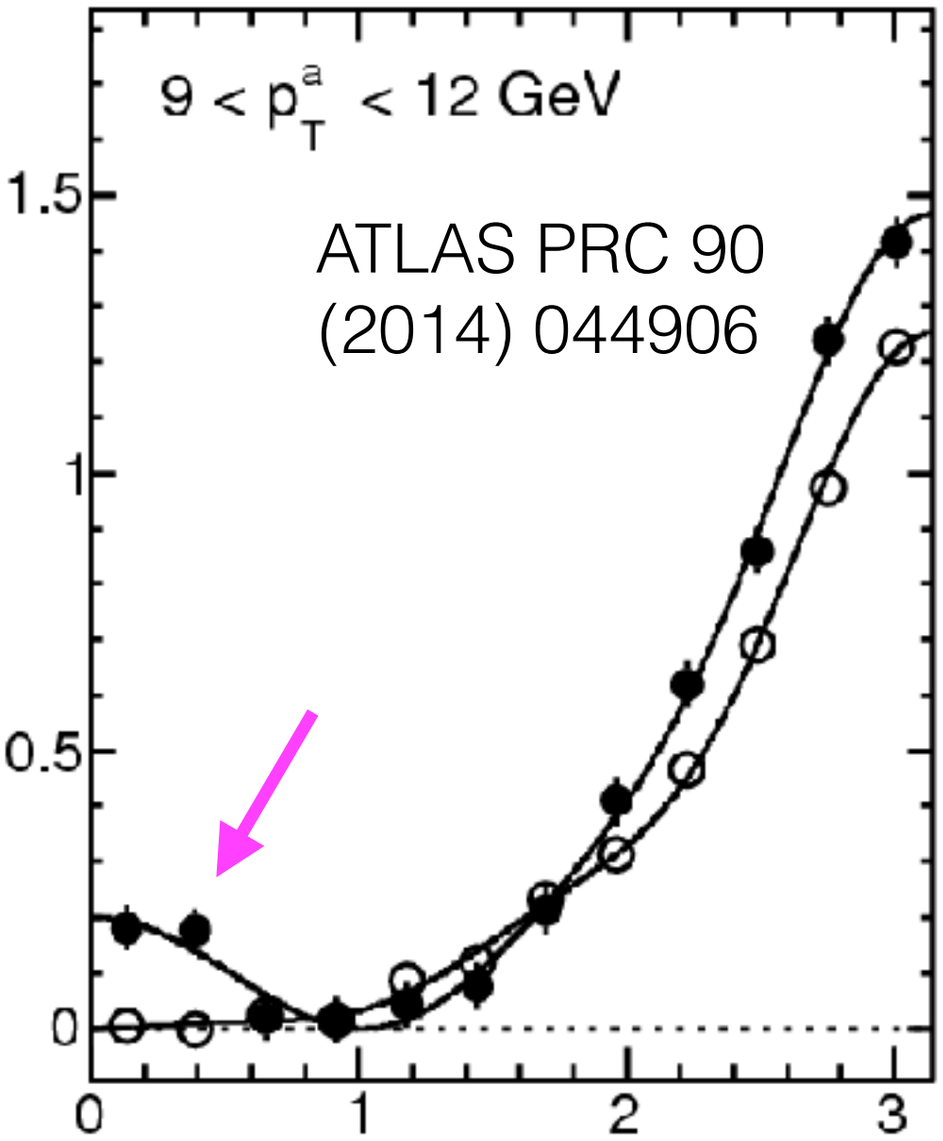
Energy loss in small systems?



F. Arleo



M. Spousta



high-p_T near-side $\Delta\phi$ ridge in <1% p+Pb

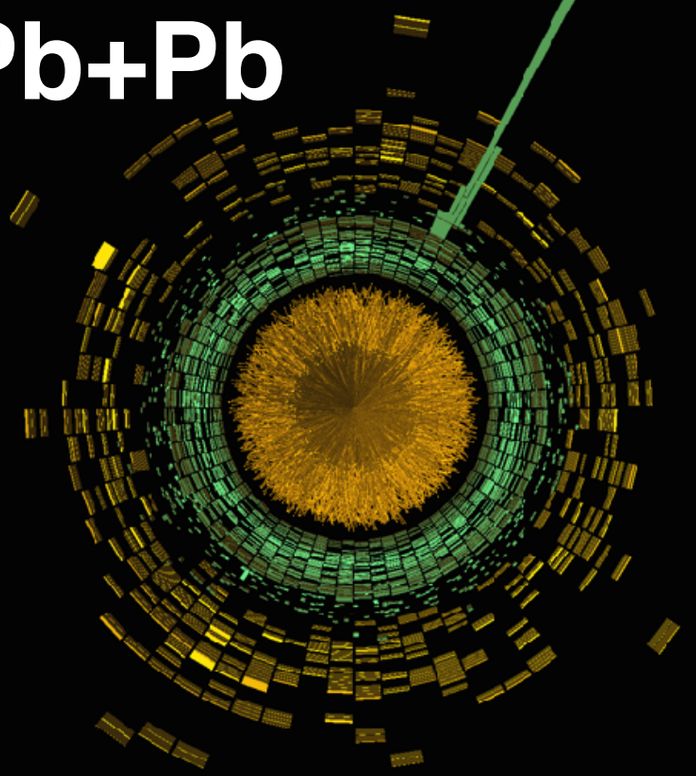
➡ *see also Morsch, Loizides nucl-ex/1705.08856*

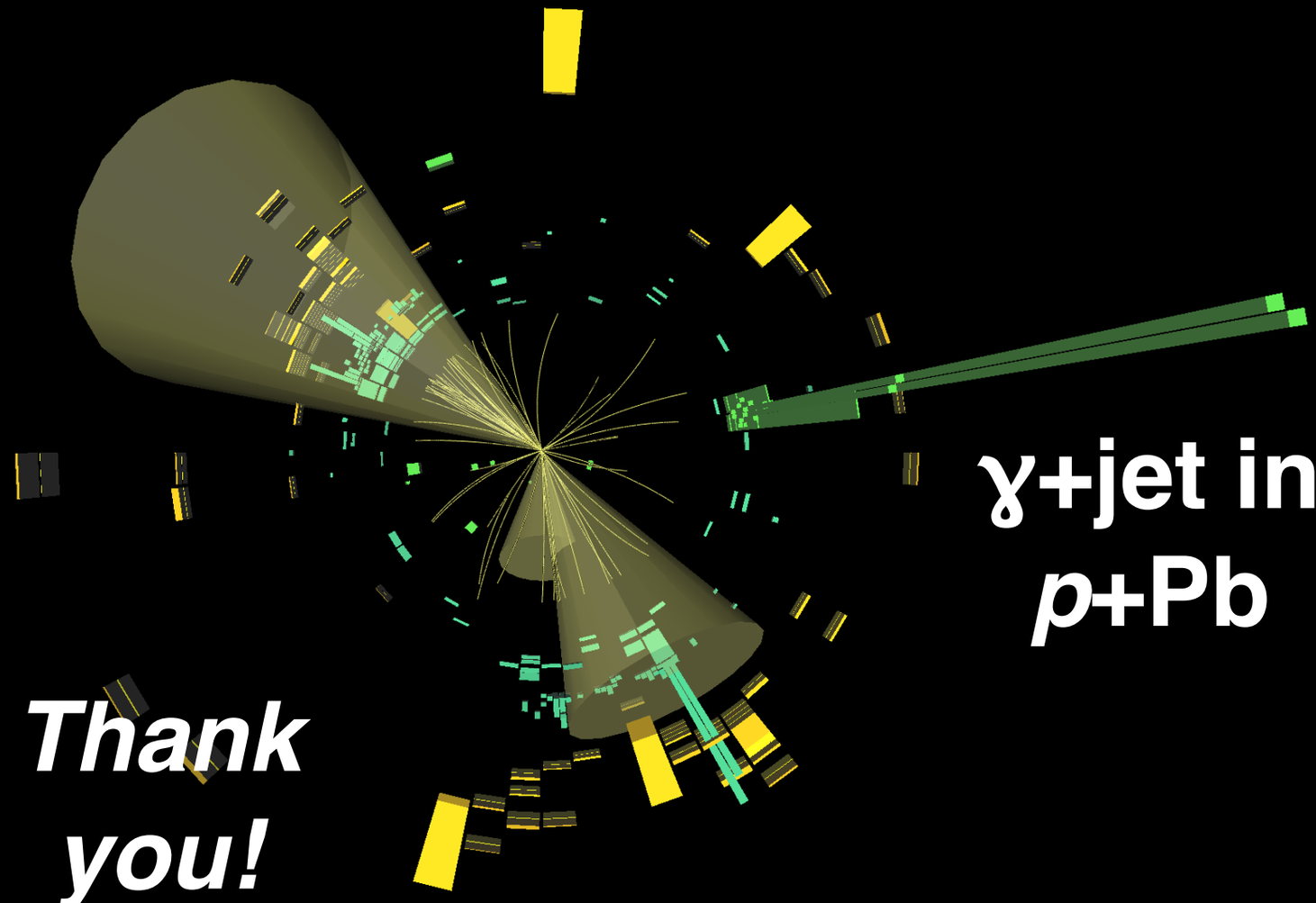
➡ Search for energy loss-like signatures with intra-event momentum correlations…

➡ guidance from peripheral Pb+Pb data and theory?

⇒ ***https://twiki.cern.ch/twiki/bin/view/AtlasPublic/HeavyIonsPublicResults***

γ+jet in Pb+Pb

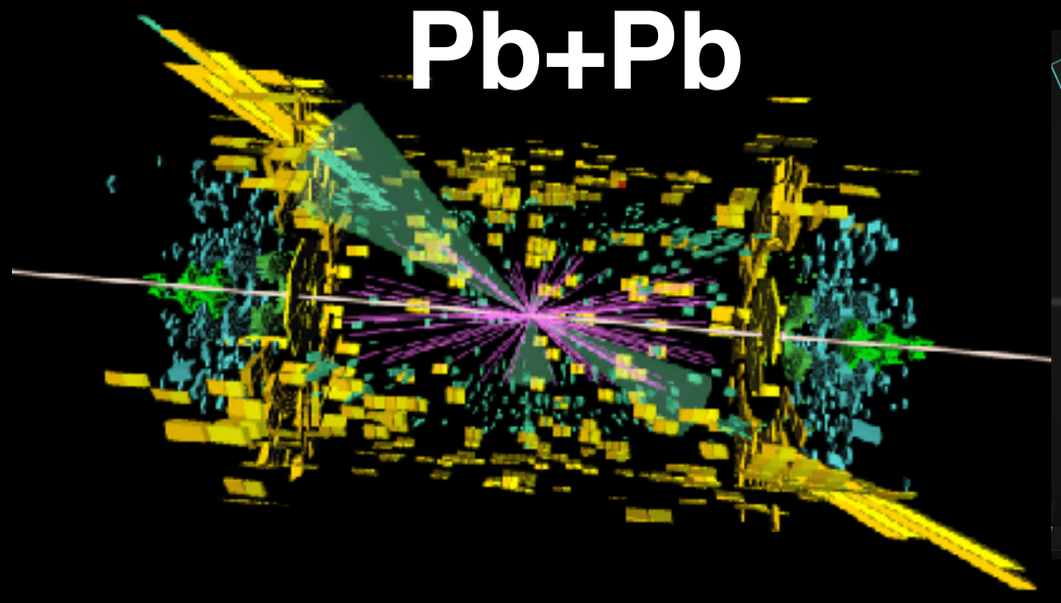




γ+jet in *p*+Pb

Thank you!

dijet in Pb+Pb



dijet in UPC (γ+A)