Jets in *Heavy Ion Collisions*

7th Workshop of the APS Topical Group on Hadronic Physics

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Washington, D.C.

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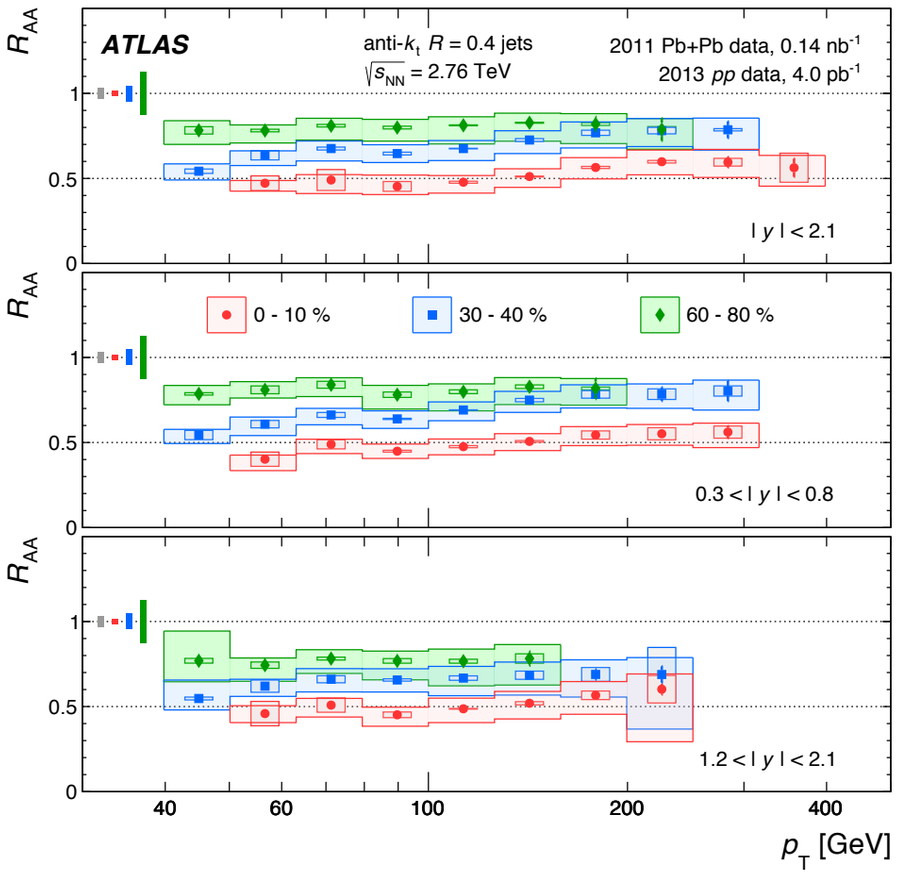
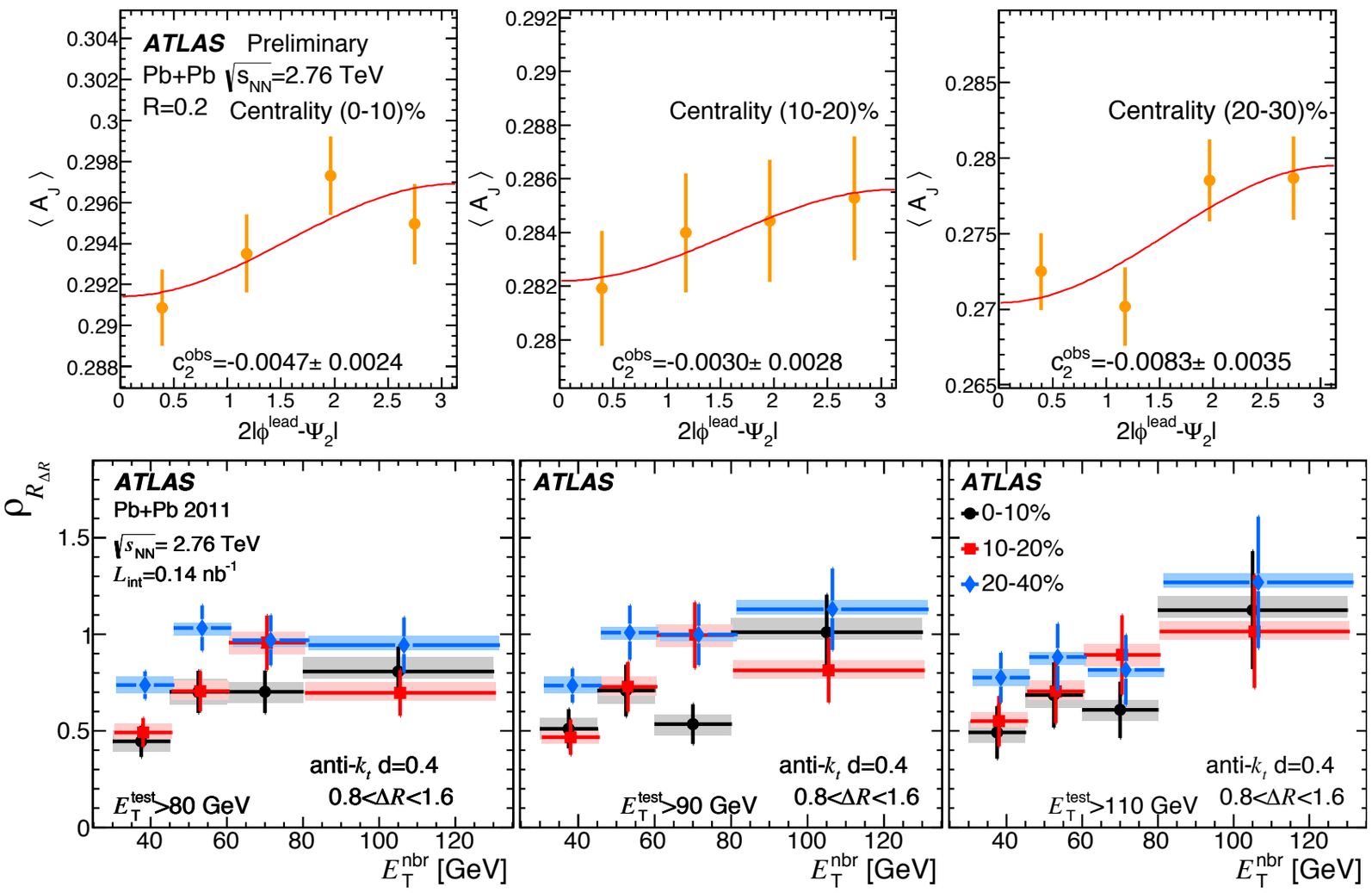
University of Colorado Boulder

Jets in LHC Run 1

dijet asymmetry vs. reaction plane



inclusive jet suppression

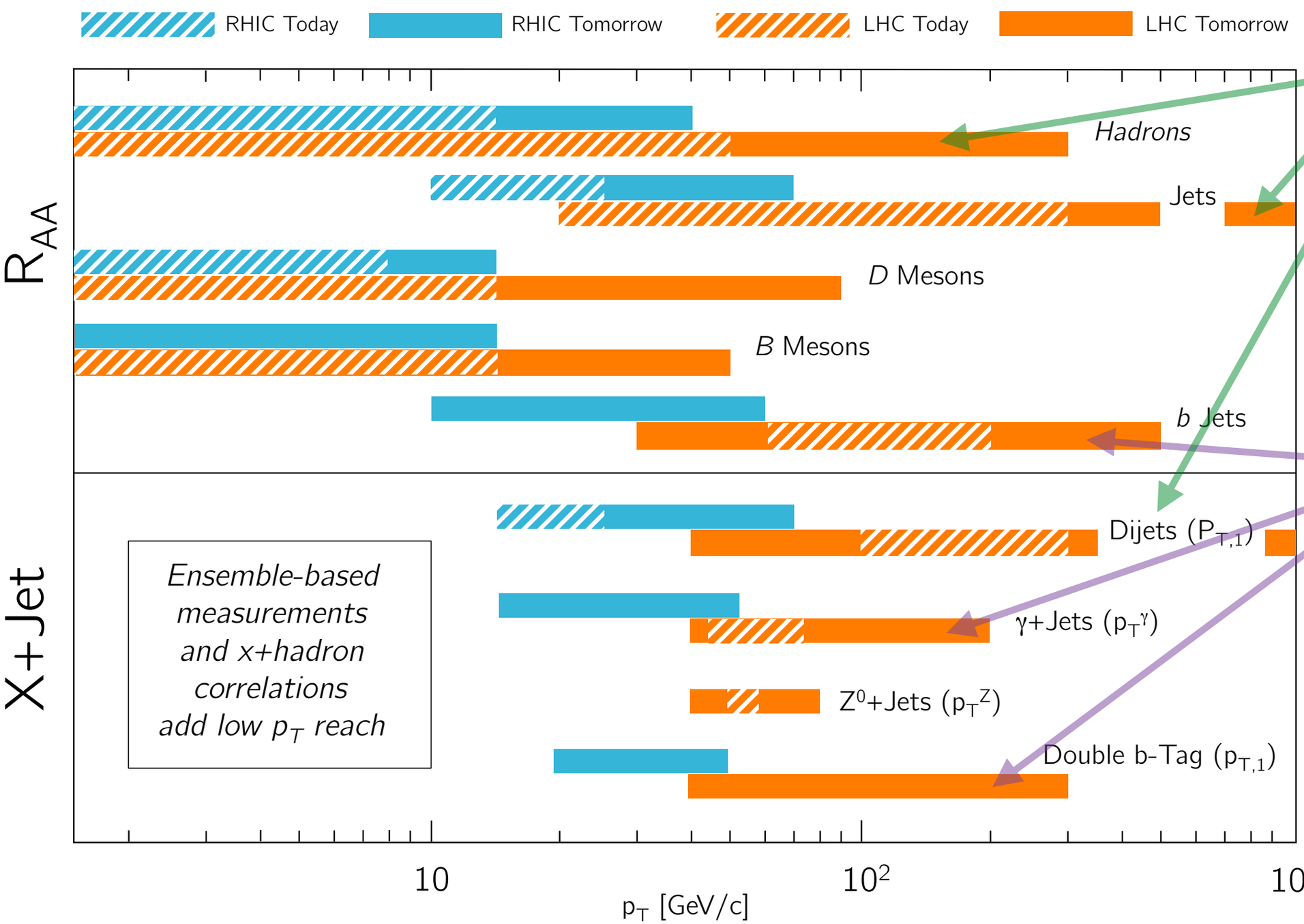


modification of multi-jet correlations

- Broad program of jet suppression and modification measurements since first dijet asymmetry in 2011

  ➡ *how do we best make progress in Run 2?*

Jet physics during LHC Run 2

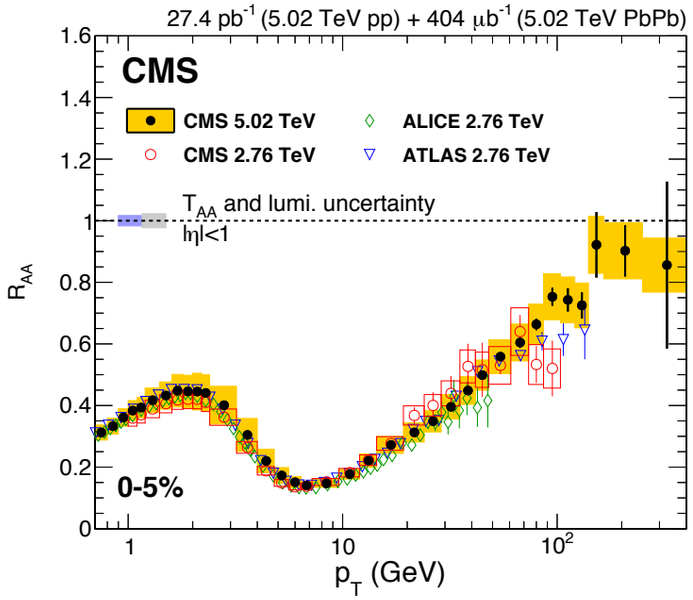


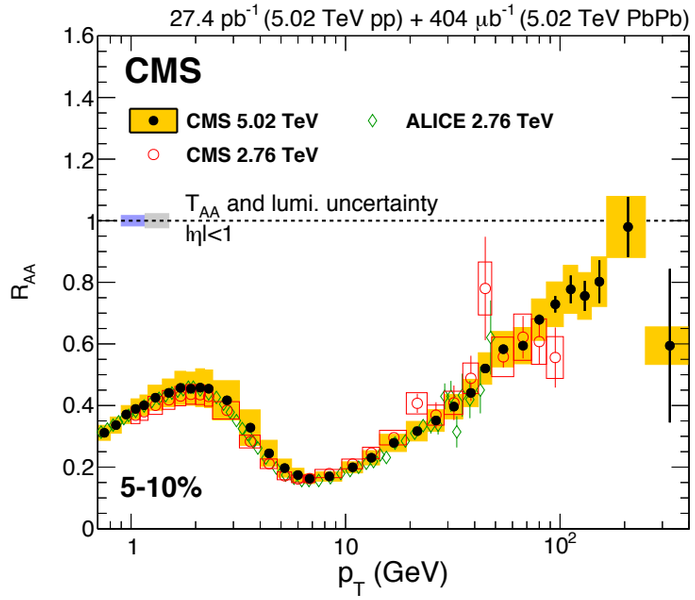
1. extreme kinematic reach

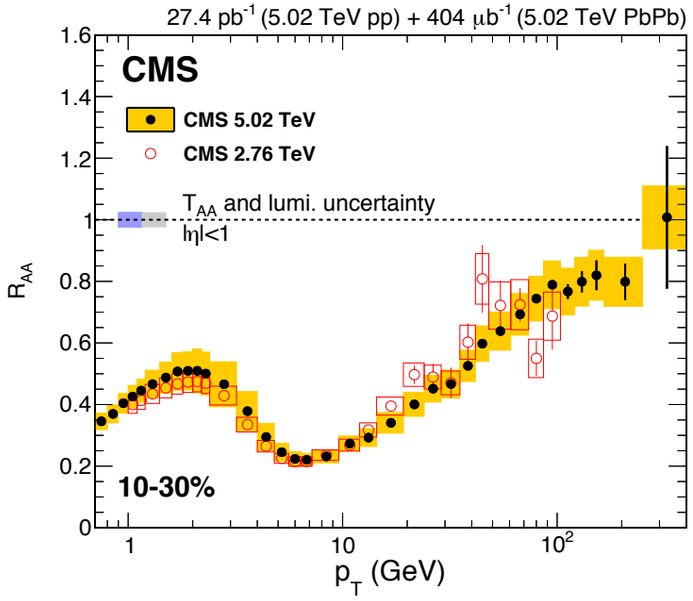
2. HF + EW probes

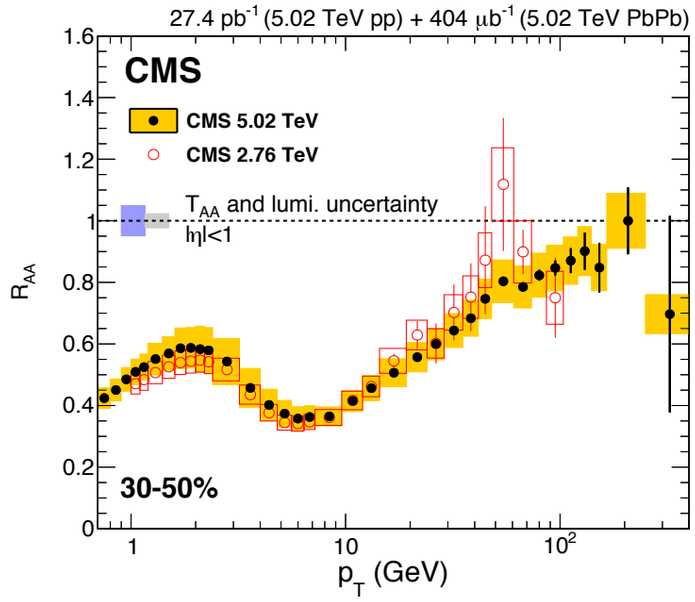
3. jet sub-structure

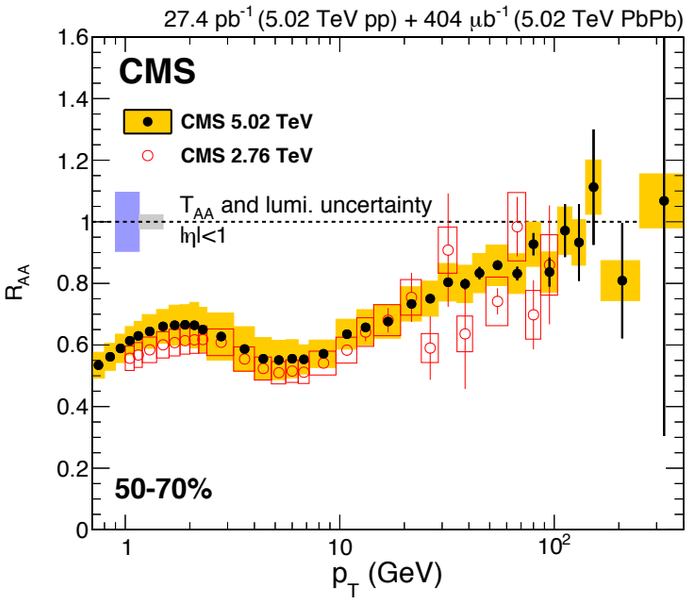
G. Roland, QCD town hall meeting at Temple U.

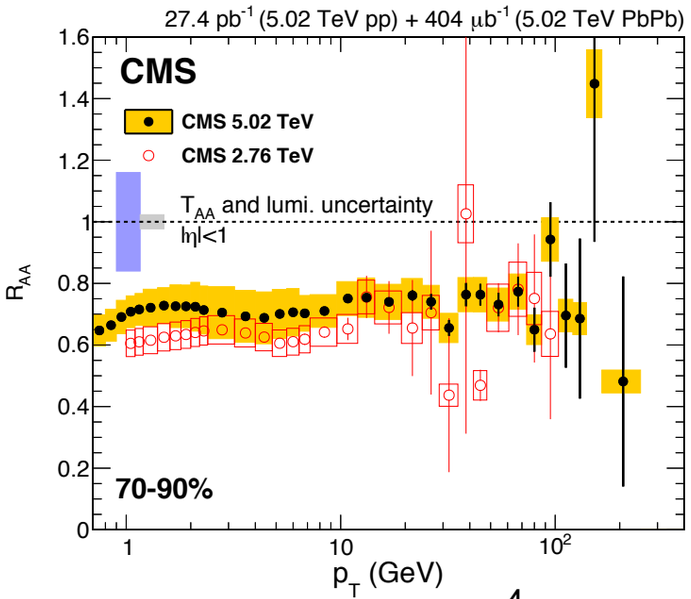












Extreme kinematic reach: *hadrons*

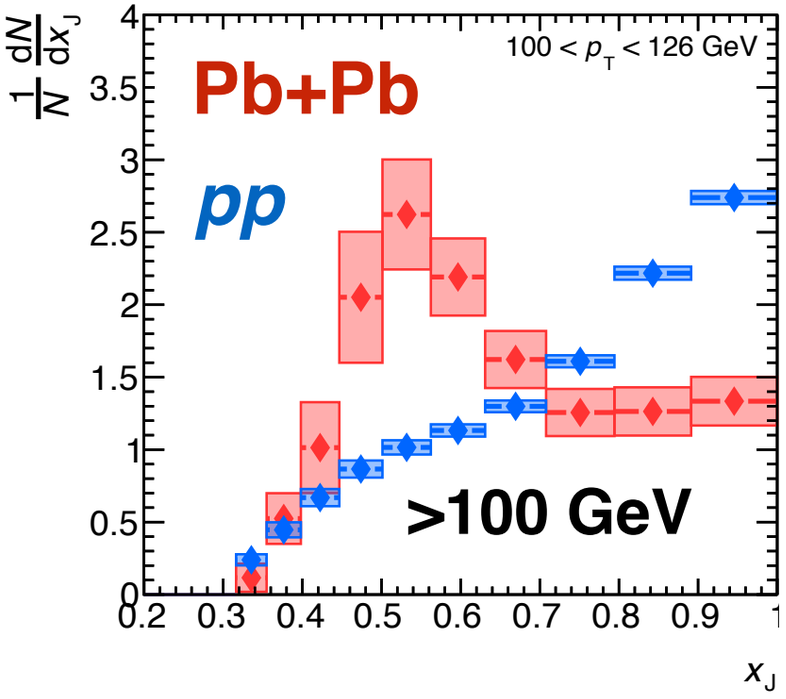
CMS charged hadron R_{AA} in Run 2 Pb+Pb

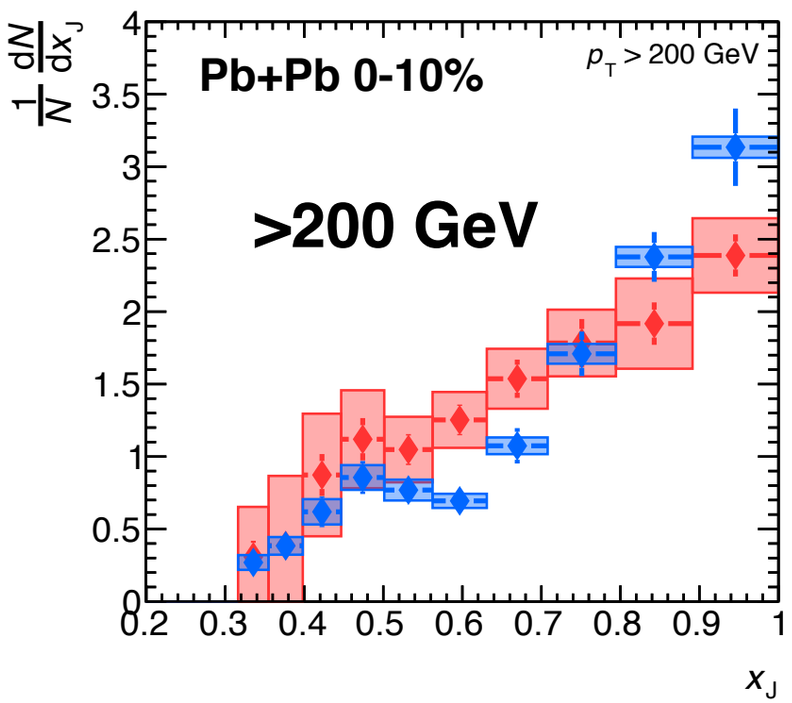
➡ $R_{AA} \rightarrow 1$ at $p_T > 200$ GeV?

➡ *confirmation of high-p_T behavior from ATLAS at QM?*

Extreme kinematic reach: *jets*

ATLAS-CONF-2015-052





ATLAS dijet balance

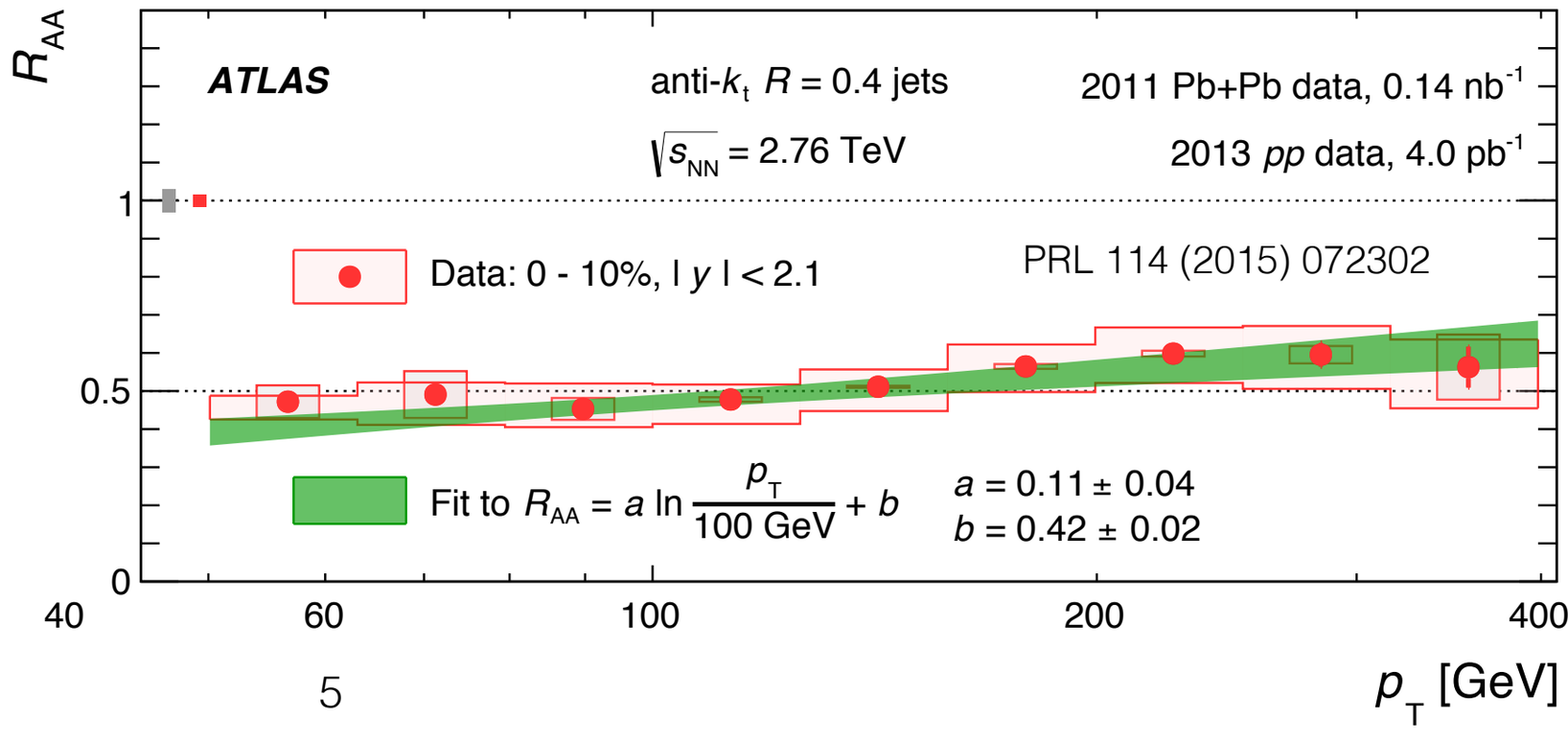
$x_J = p_{T,2}/p_{T,1}$

in Run 1 Pb+Pb data

➡ *x_J(Pb+Pb) → x_J(pp) at $p_{T,1}$ > 200 GeV?*

ATLAS inclusive jet R_{AA} is finite up to 400 GeV

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



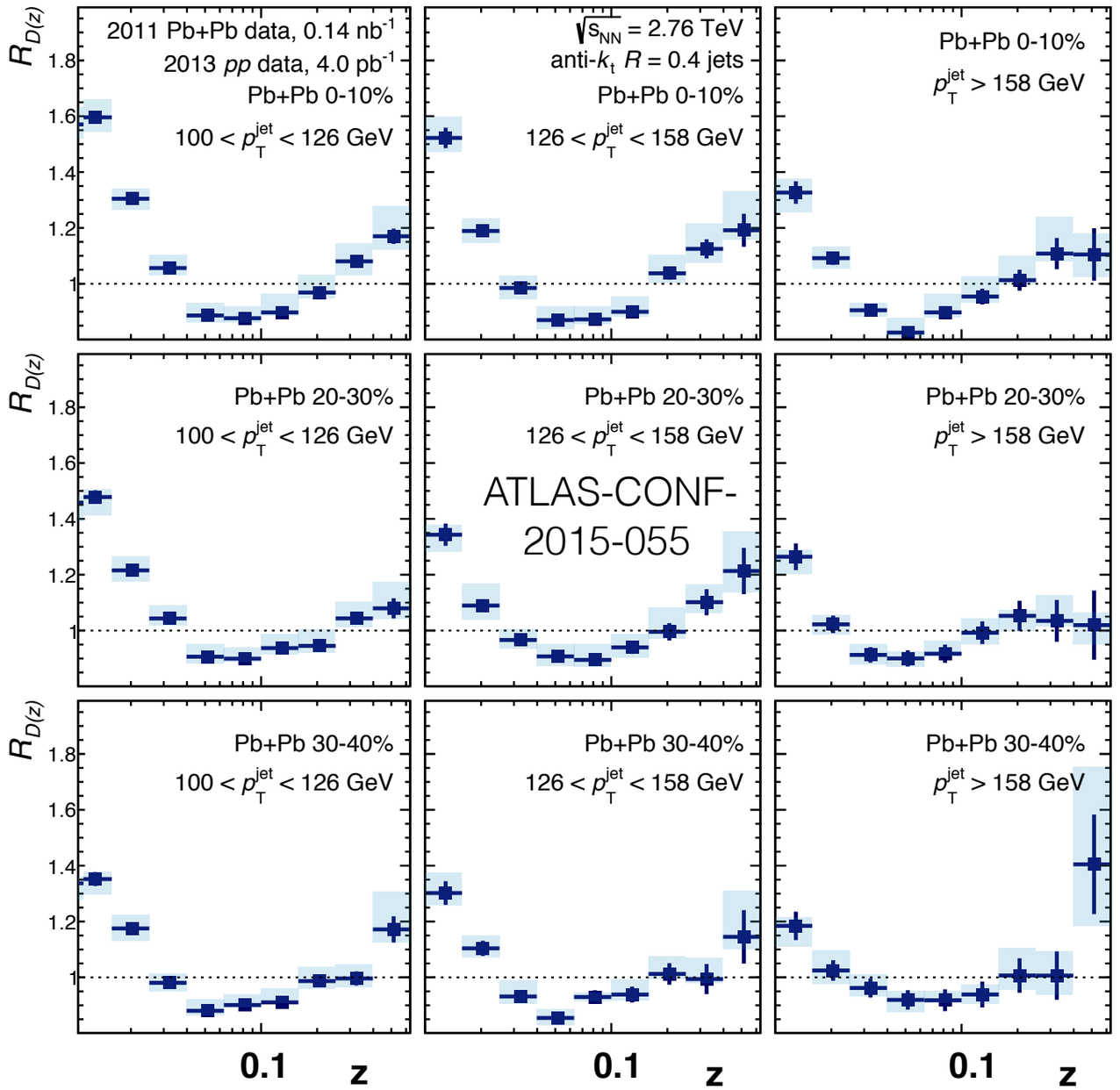
Extreme kinematic reach: *FF*

increasing p_T

central

semi-central

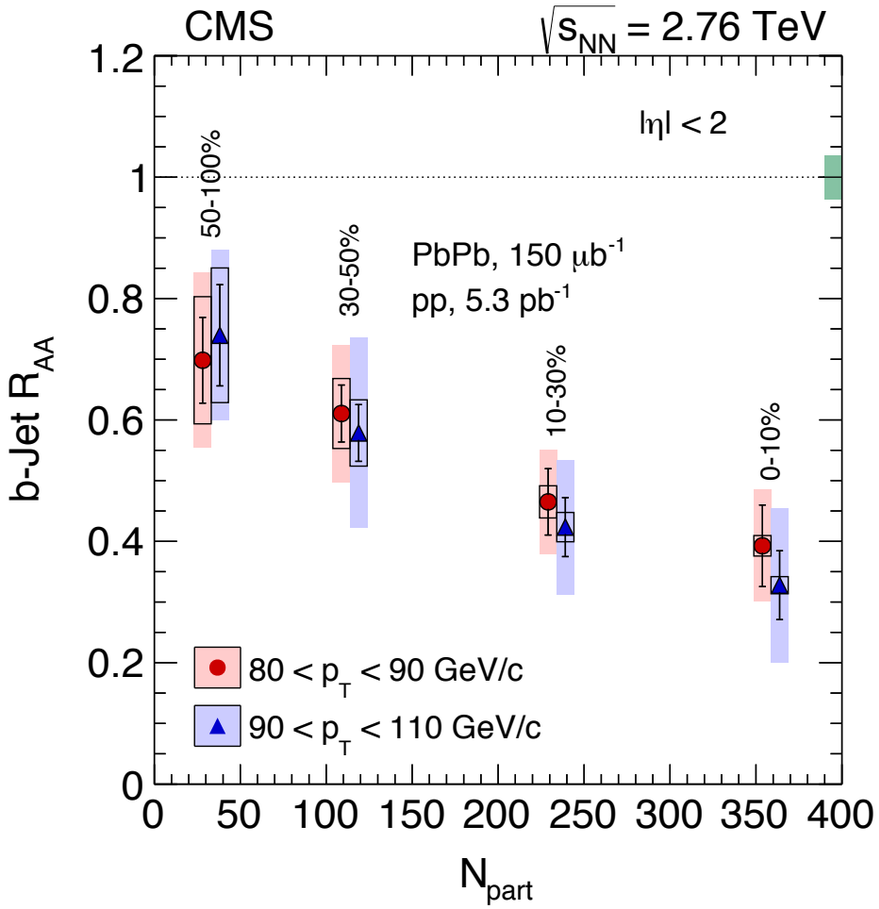
$$R_{D(z)} = \frac{D(z;\ \text{Pb+Pb})}{D(z;\ pp)}$$

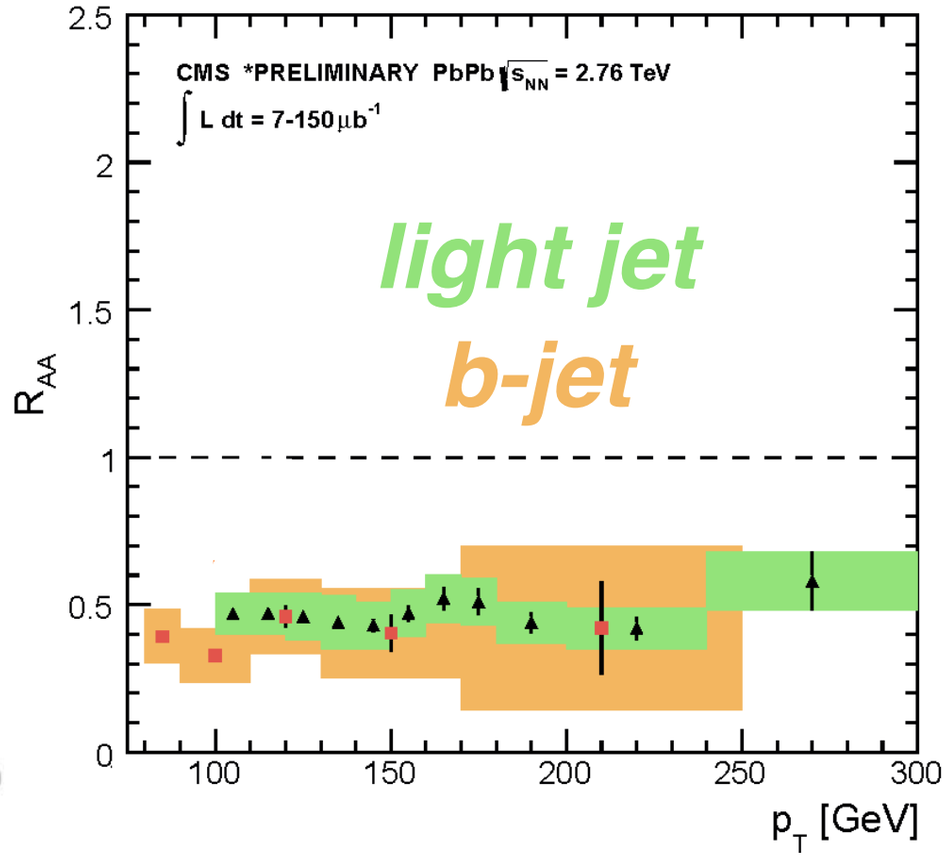


Low and high-z excess becomes <u>*systematically smaller*</u> with p_T…

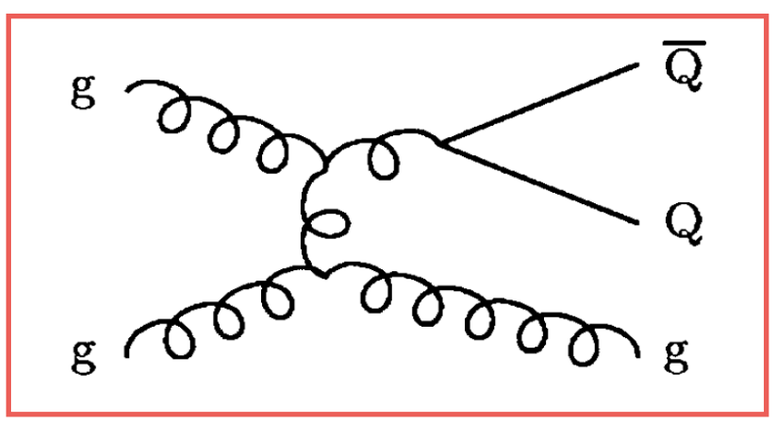
➡ *fragmentation functions for multi-hundred-GeV jets?*

HF jets: *Run 1 status*

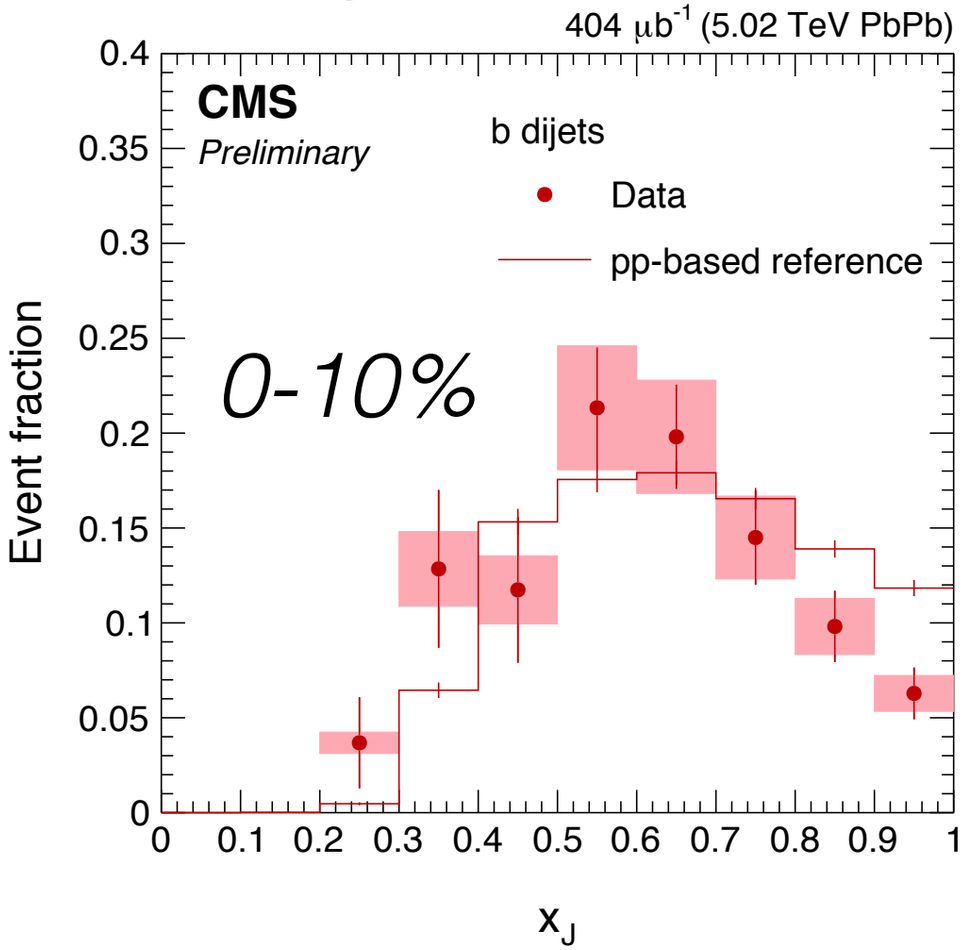




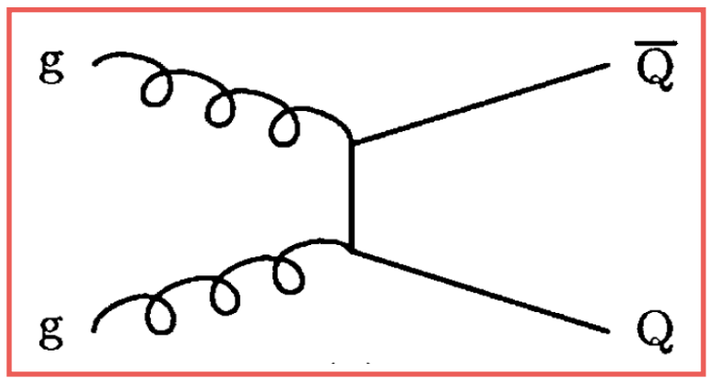
- Demonstration of *b*-jet tagging in HI collisions by CMS, but:
  - ➡ Run 1 statistics → measurement of inclusive yield only
  - ➡ non-trivial contribution from *gluon-splitting* late in parton shower

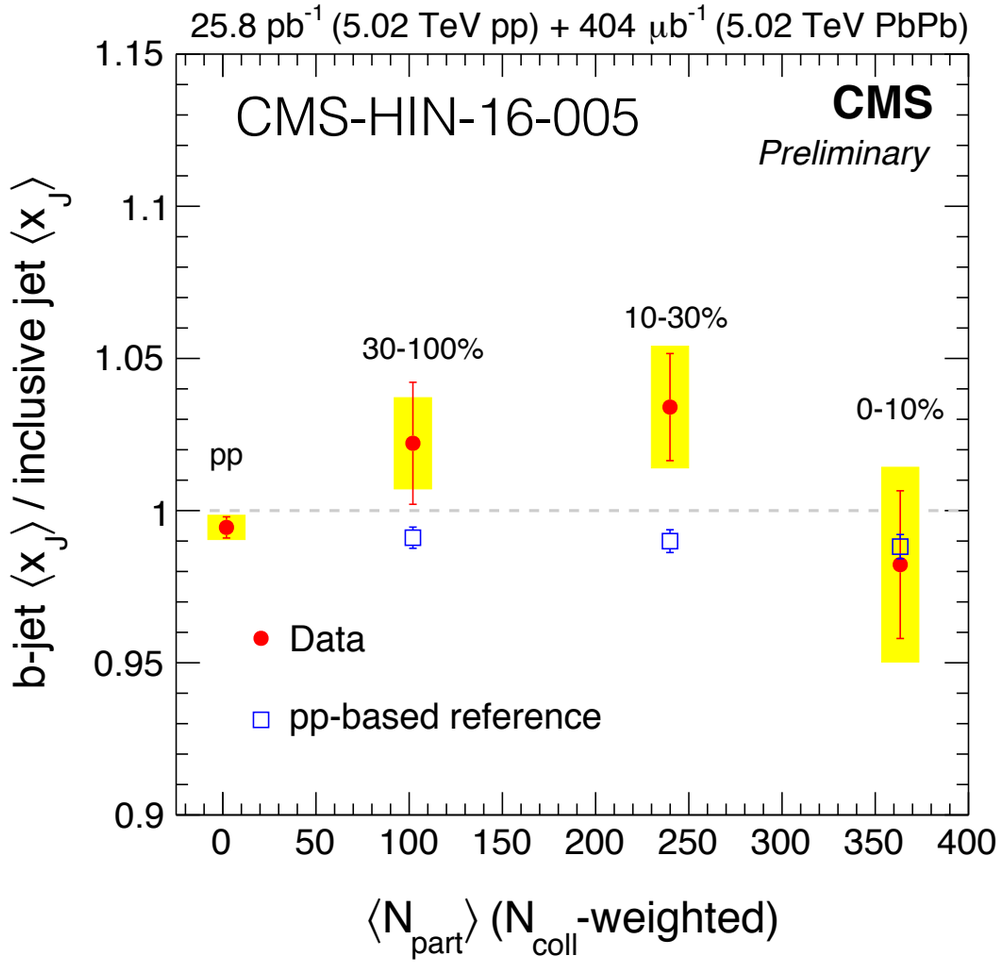


HF jets in Run 2: *di-b-jet*



Angularly-balanced b-jets favor flavor creation processes:

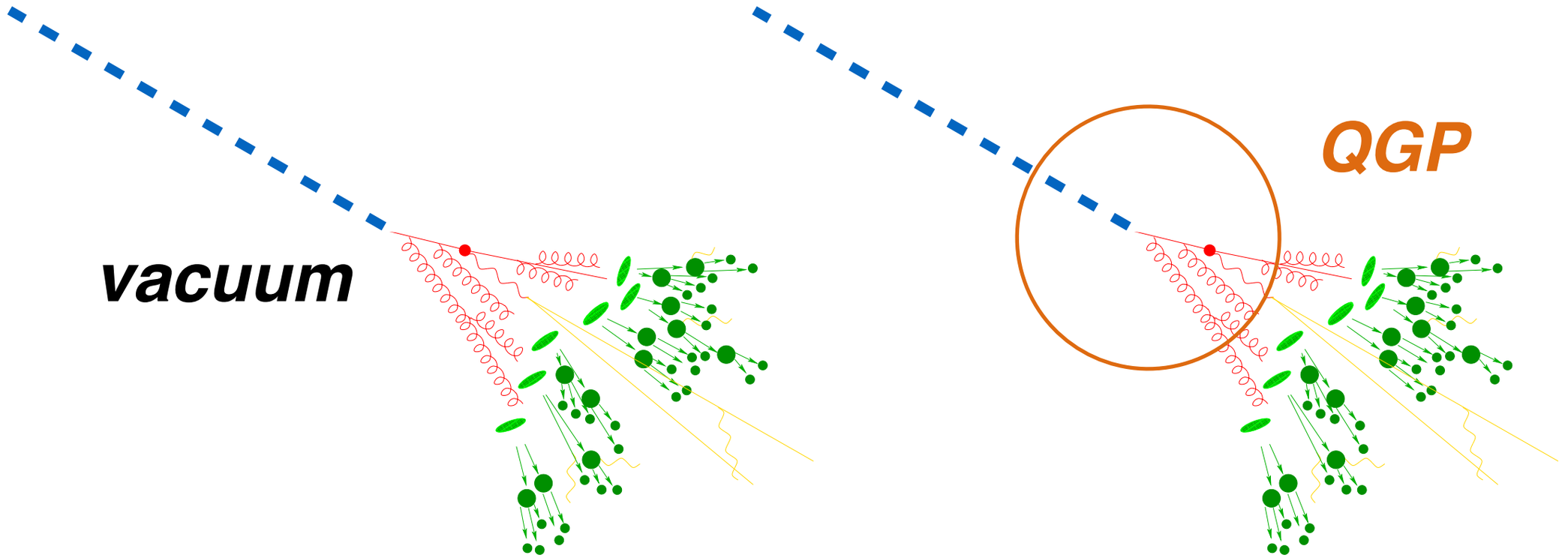




Indication of more balanced pairs relative to inclusive jets?

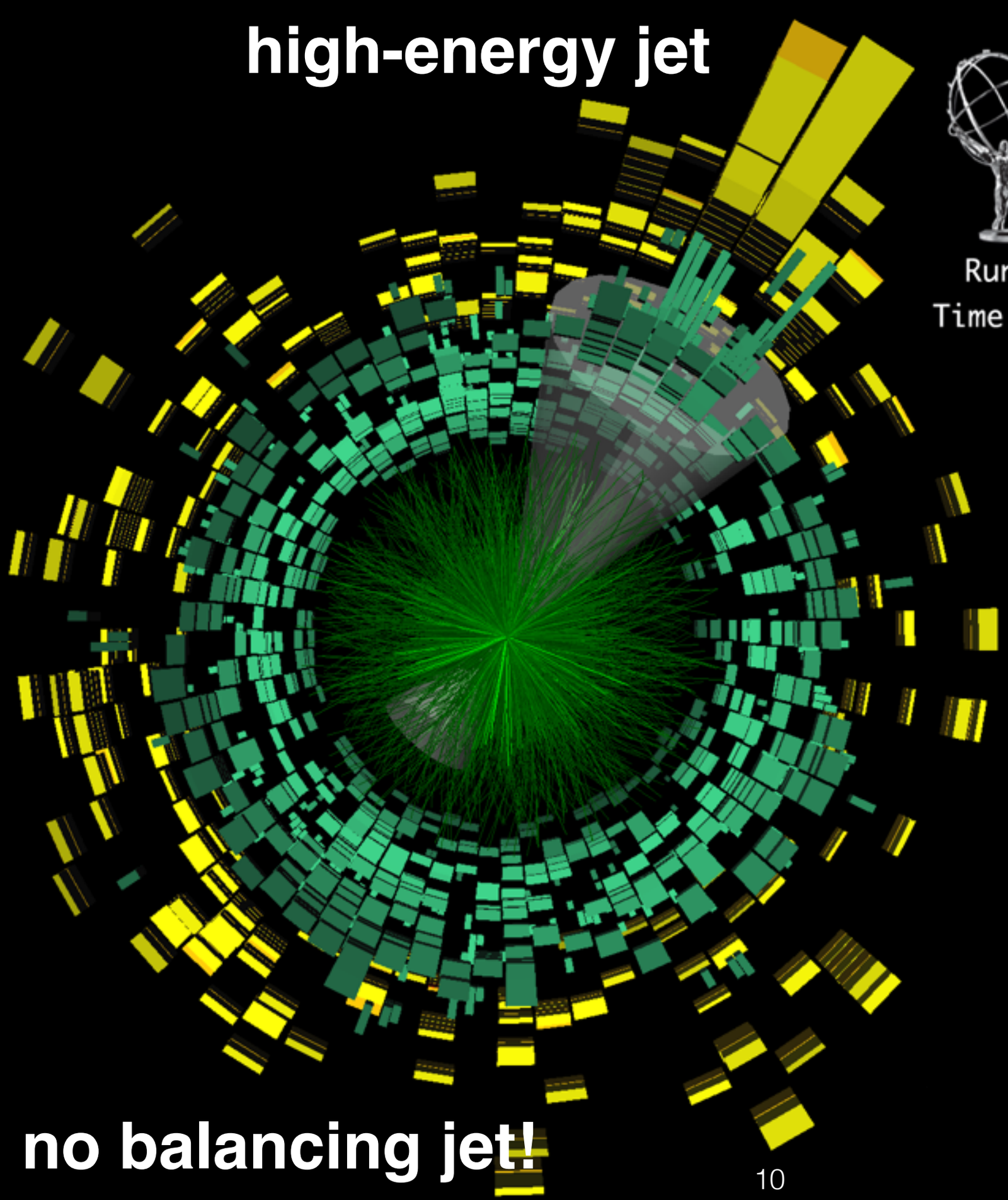
➡ *Run 2 data will allow differential studies of b-jets*

EW probes: γ+jet and *Z*+jet



- Photon / *Z* grants external handle on initial hard scattering
  - ➡ tests absolute *E*-loss of balancing jet
  - ➡ can make “apples to apples” *pp* to Pb+Pb comparisons
  - ➡ selects quark-enhanced jet sample (flavor dependence)
  - ➡ no “surface bias”

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

no balancing jet!

ATLAS EXPERIMENT

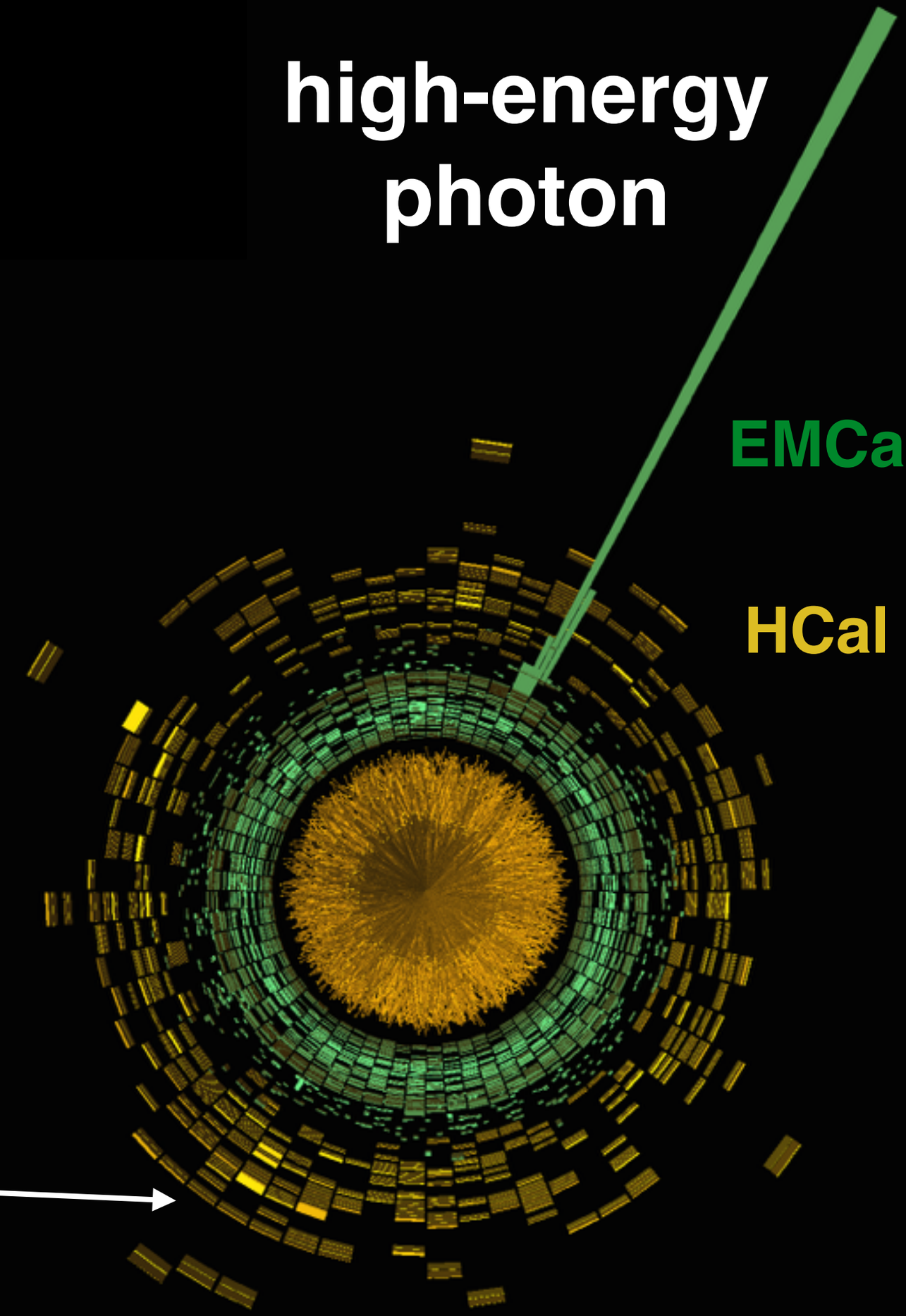
Run: 286834
Event: 124877733
2015-11-28 01:15:42 CEST

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

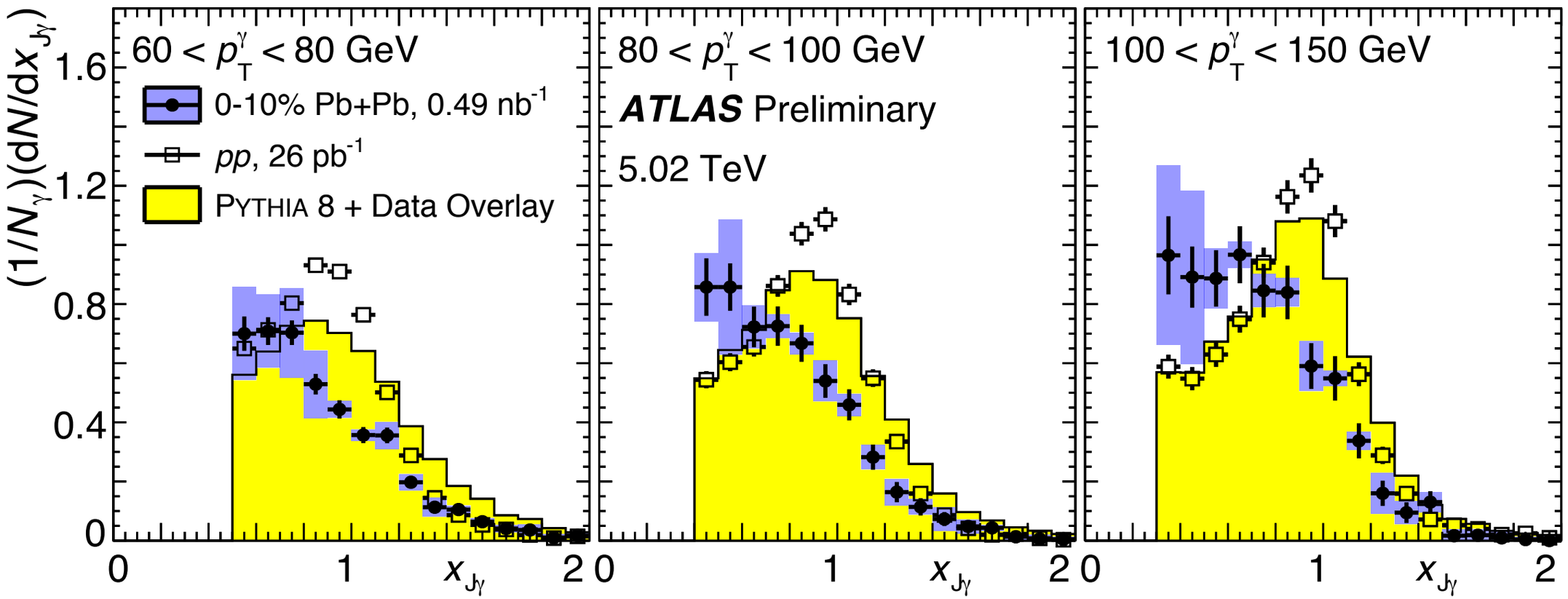
high-energy photon

balancing jet?



γ+jet: p_T balance (central events)

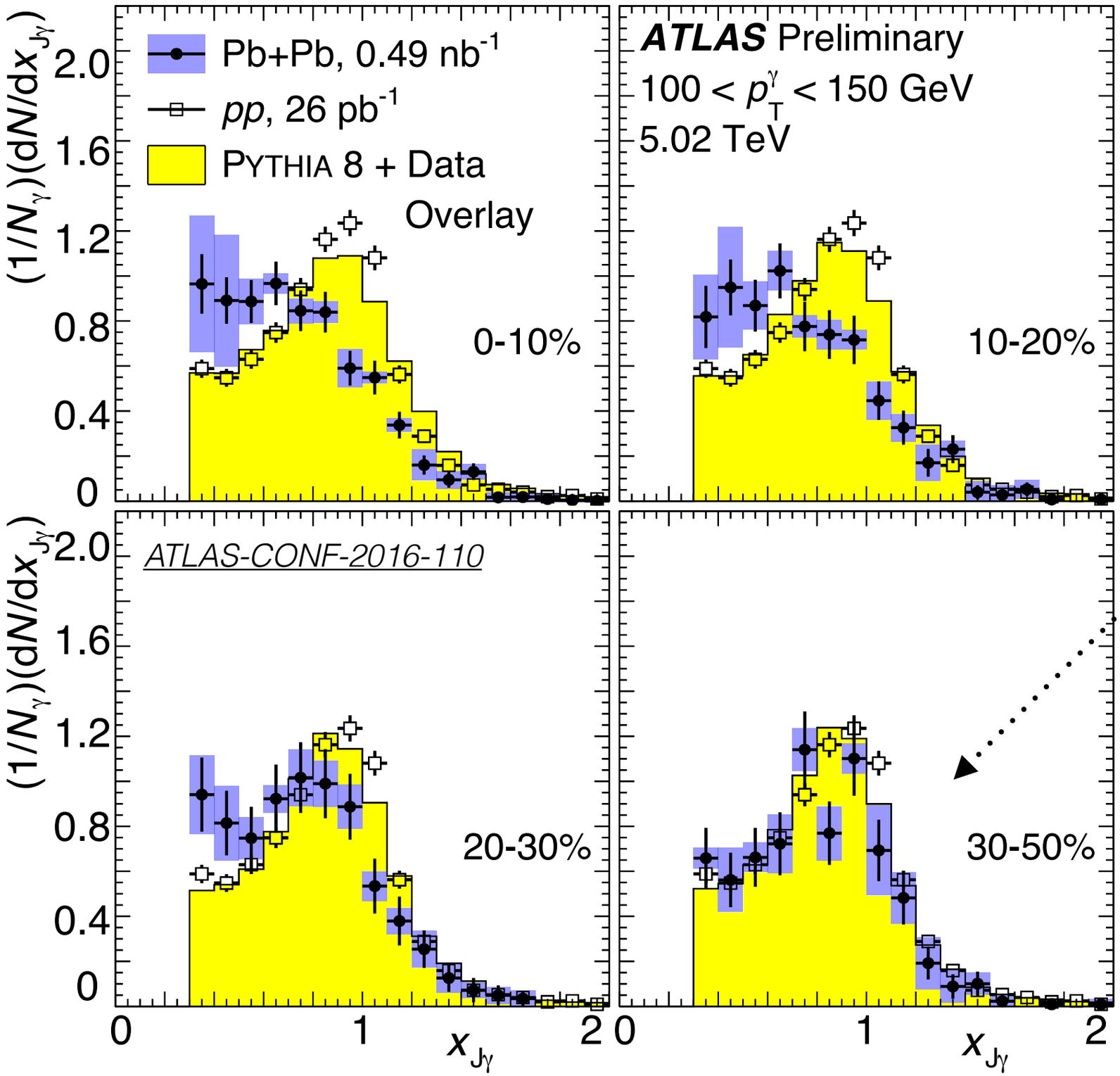
ATLAS-CONF-2016-110



increasing photon p_T

- Measurements of $x_{J\gamma} = p_T^{jet} / p_T\gamma$ with large Run 2 statistics
  - ➡ systematic depletion of balancing jet p_T distribution
  - ➡ insight into absolute *E*-loss

γ+jet: p_T balance (at large p_T^{γ})



for 100-150 GeV photons, $x_{J\gamma}$ in peripheral events *similar to vacuum…*

…indicates that *fractional energy lost decreases*?

γ+jet: Δφ balance, differential data

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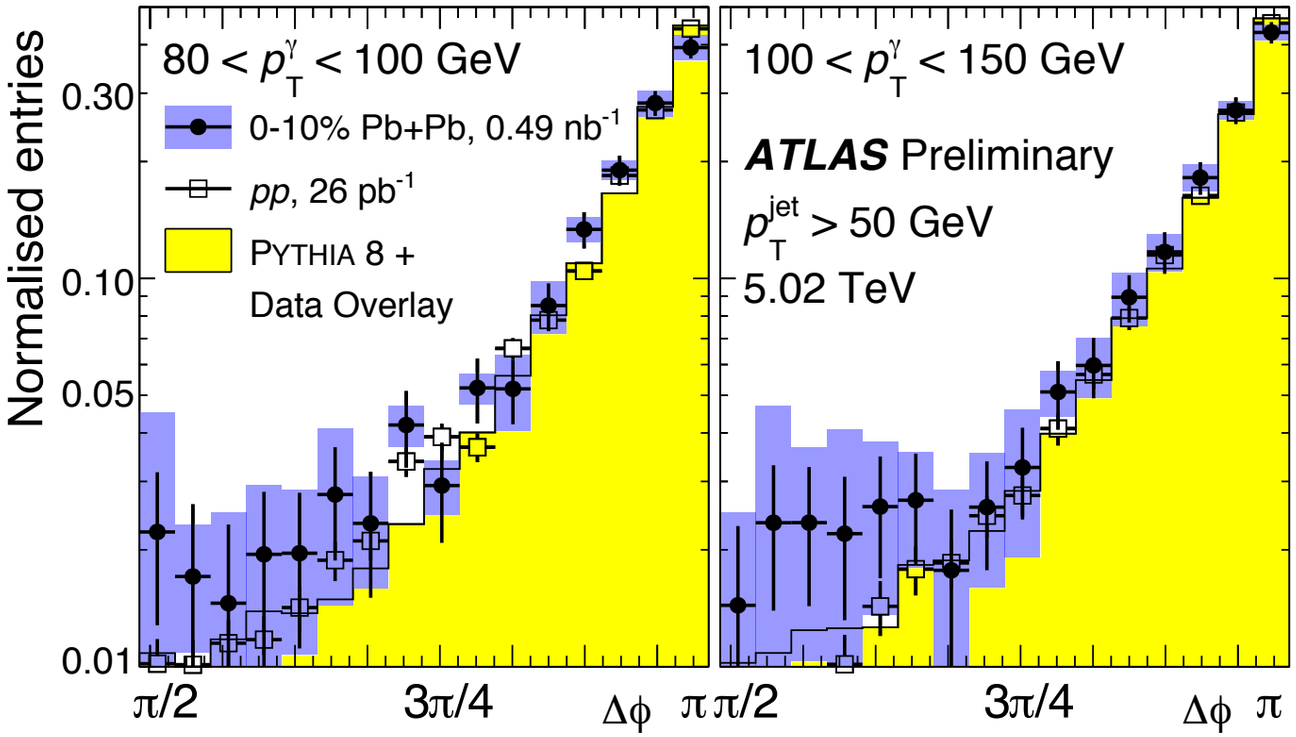
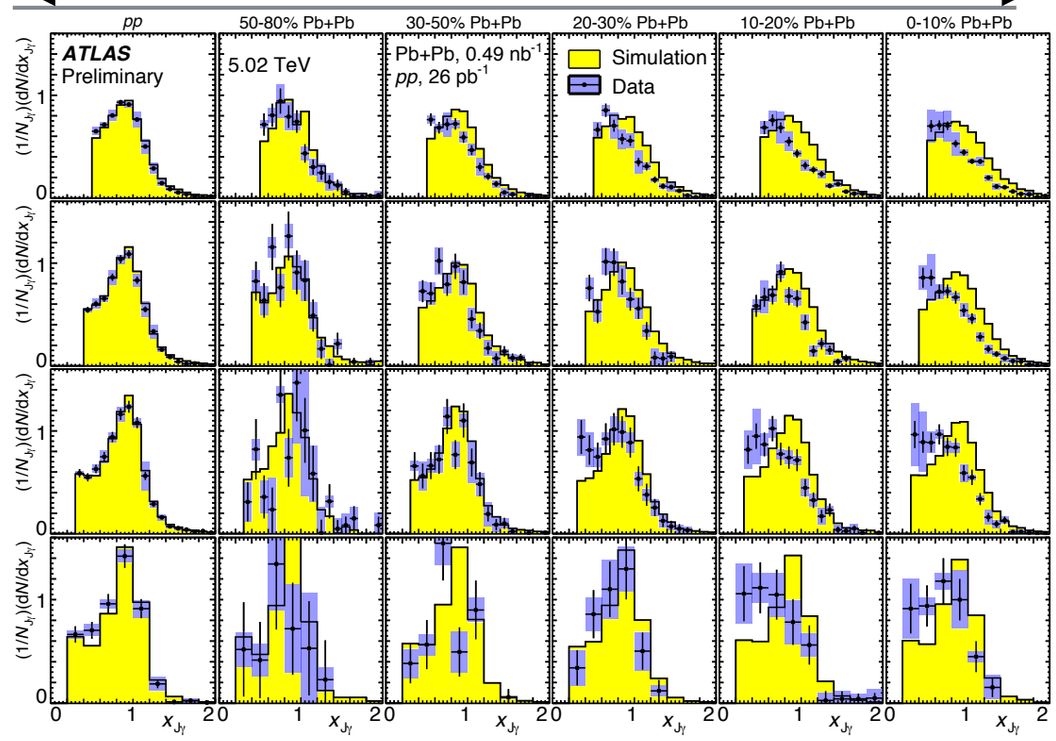


vary system size

vary initial E_T^γ



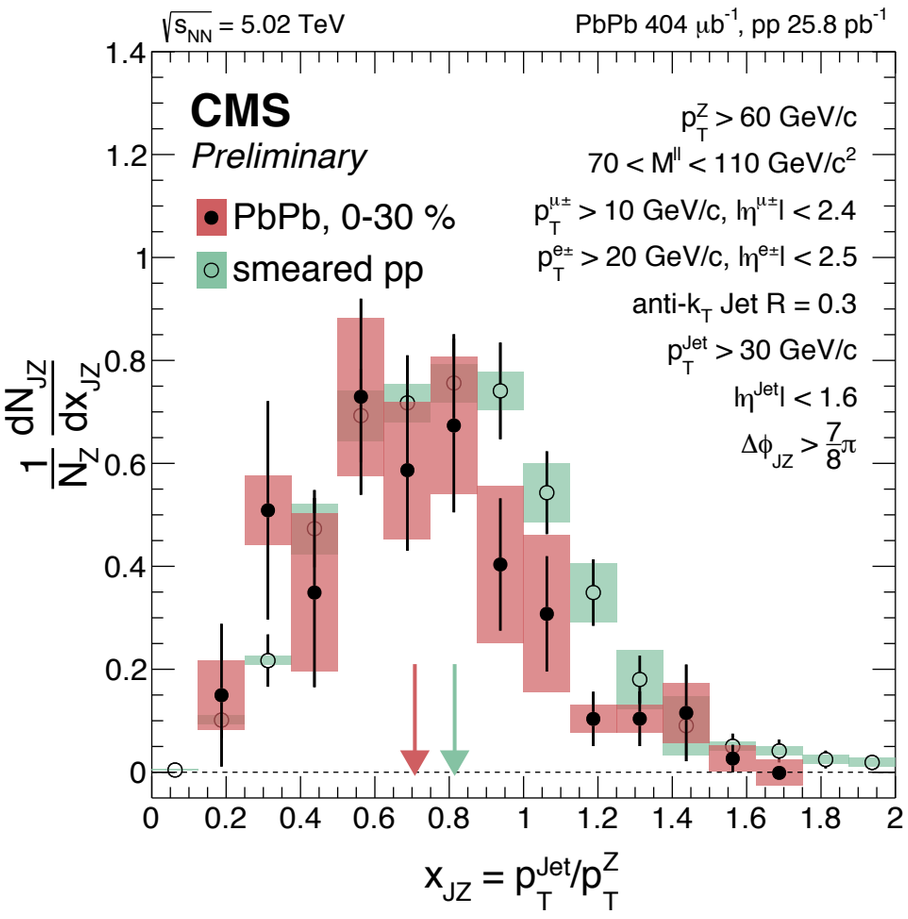
Δφ balance sensitive to large-angle (Rutherford) scattering off QGP quasi-particles

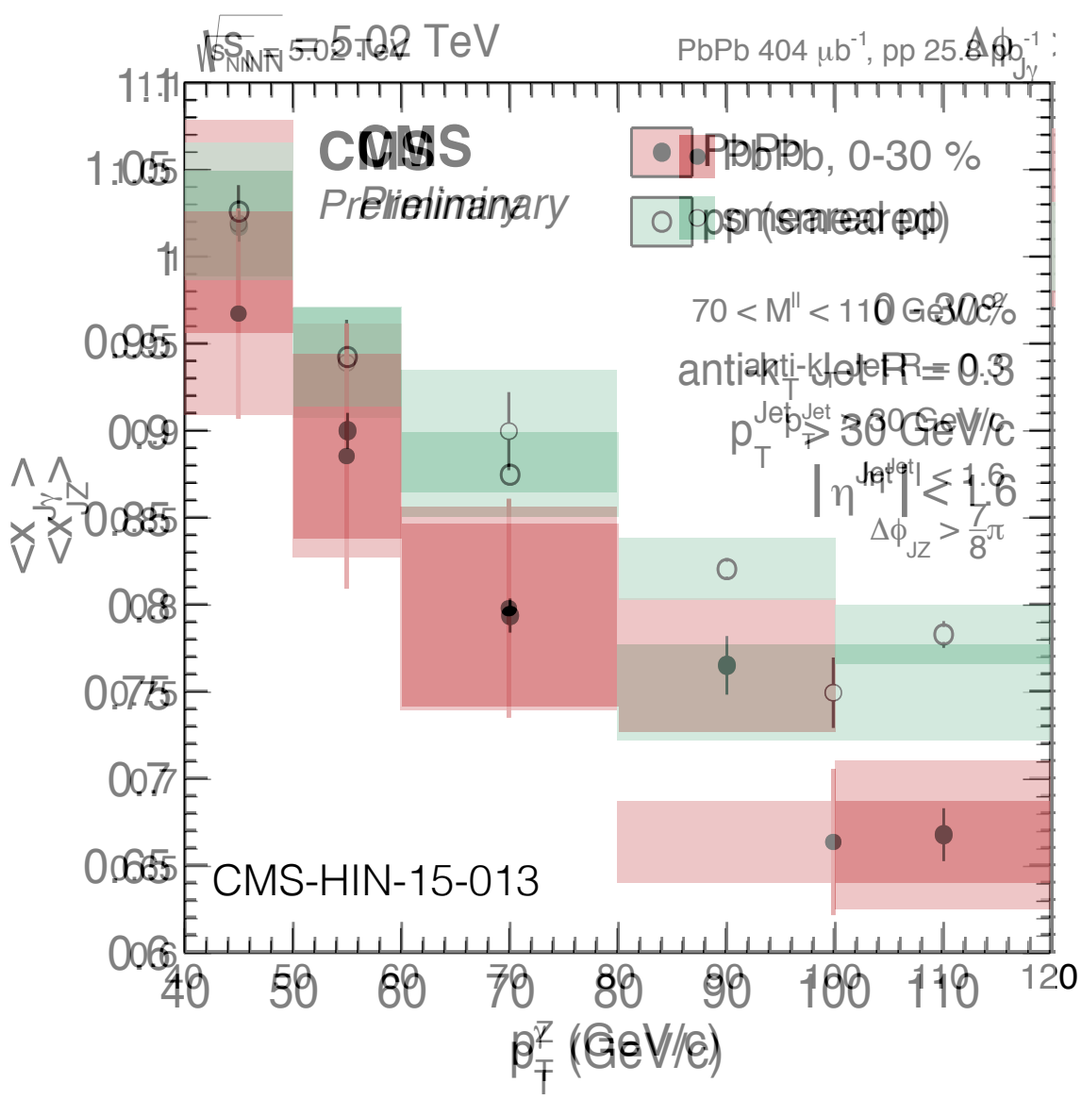
➡ *no evidence of deflection (for p_T^{jet} > 50 GeV)*

Full suite of results vs. centrality and p_T^γ

➡ *differential constraints on energy loss models*

Z+jet





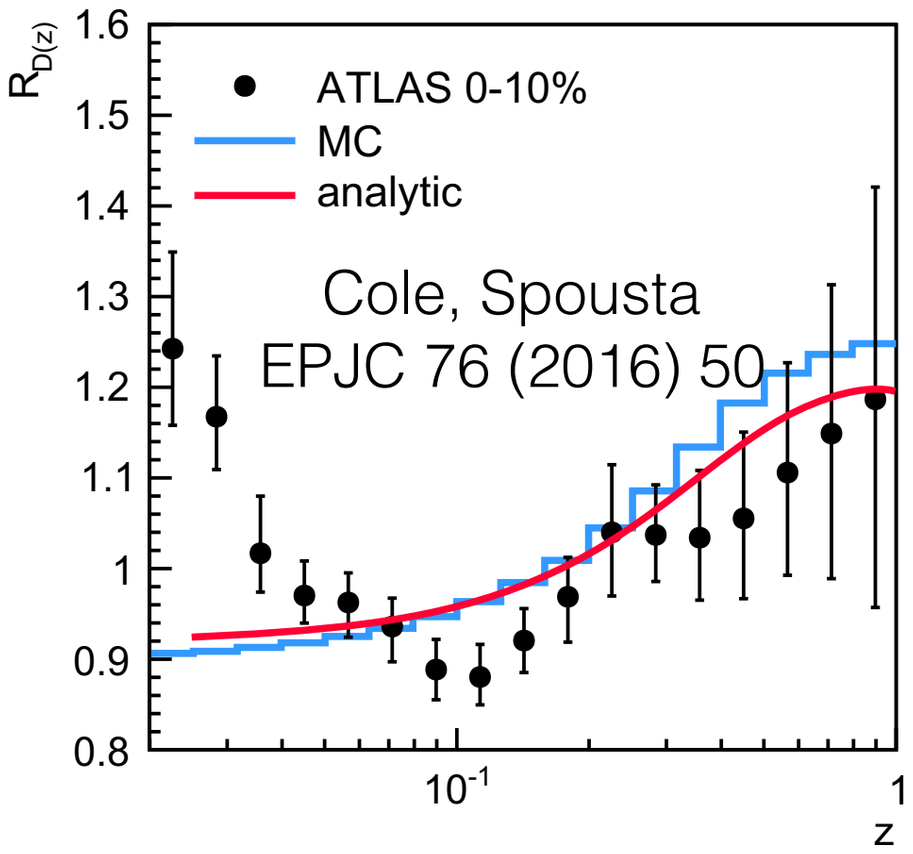
<x_{JZ}> vs. p_T^Z overlaid onto <$x_{J\gamma}$> vs. $p_{T\gamma}$

- Nominal experimental advantages:
  - ➡ lower photon-p_T reach limited by finite purity
  - ➡ probe quenching with fixed-p_T but large Q^2 jets
- However: existing Z+ and γ+tagged results are consistent within uncertainties…

Substructure: γ-tagged jet FF

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

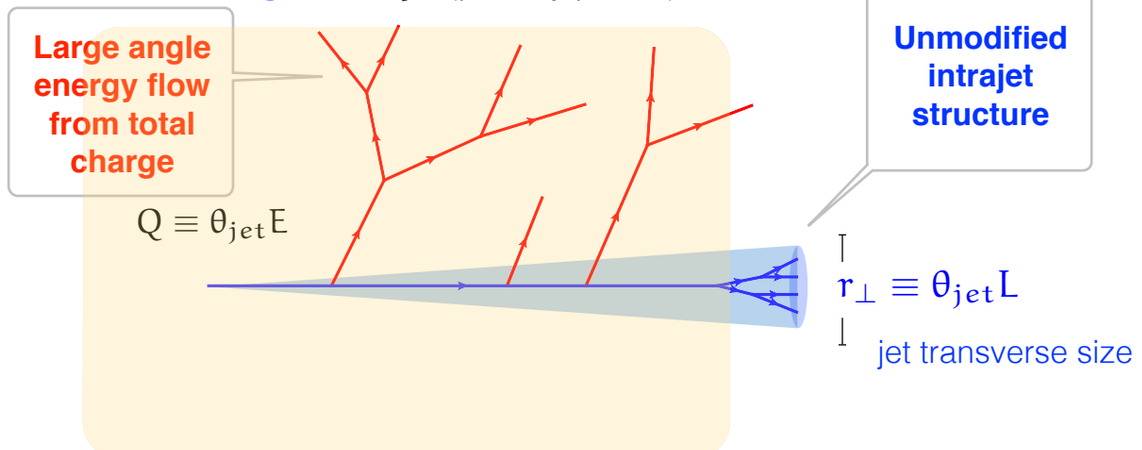
after quenching



- Large γ+jet statistics open many opportunities, e.g.
  - ➡ implicit flavor difference between jets in the numerator and denominator
  - ➡ causes artificial features in, e.g. D(z) ratio
- Run 2 possibility: measure distribution of p_T^{hadron}/p_T^{jet}, but in photon-containing events

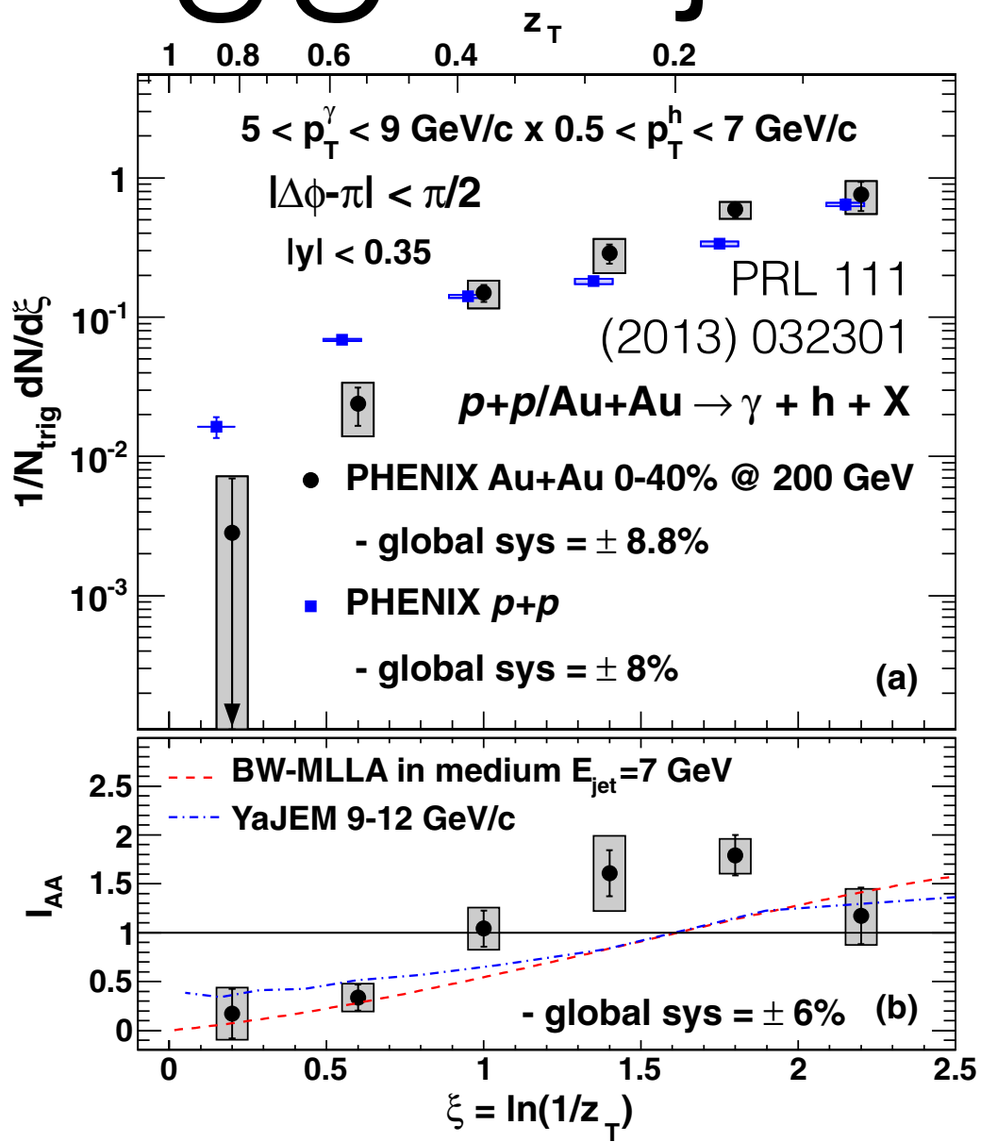
Substructure: γ-tagged jet FF

- When the transverse size $r_\perp$ of the jet is smaller than medium resolution scale Q_s^{-1} **the medium interacts "effectively" with the total charge of the jet** (primary parton)



(Y. Mehtar-Tani, QM'15 talk)
PLB 725 (2013) 357

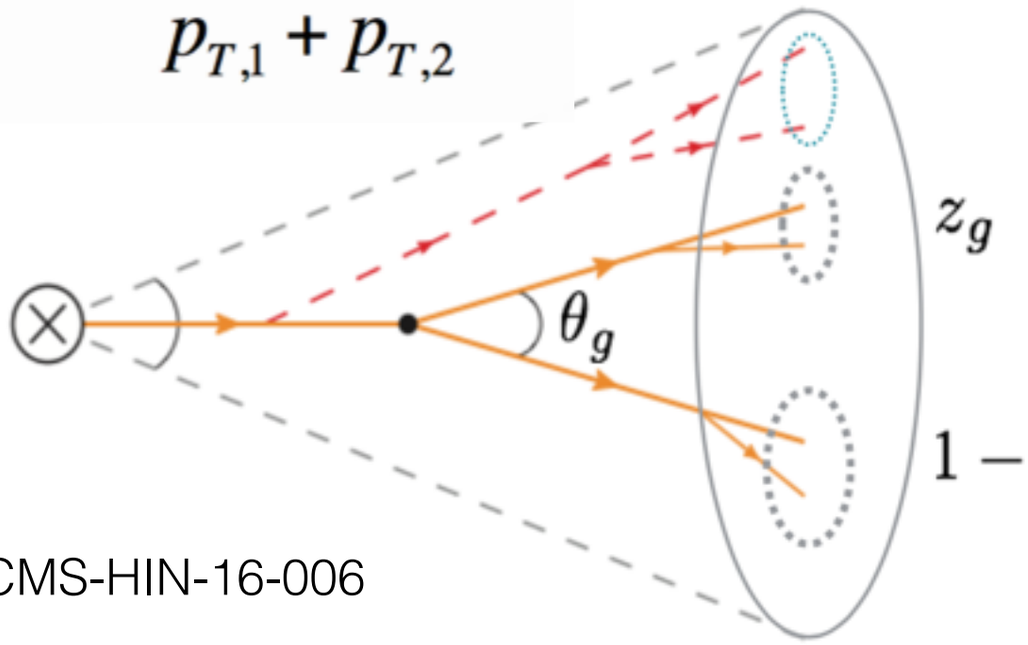
Test of color coherence picture: *e.g. what if entire parton shower loses energy, but structure unmodified?*



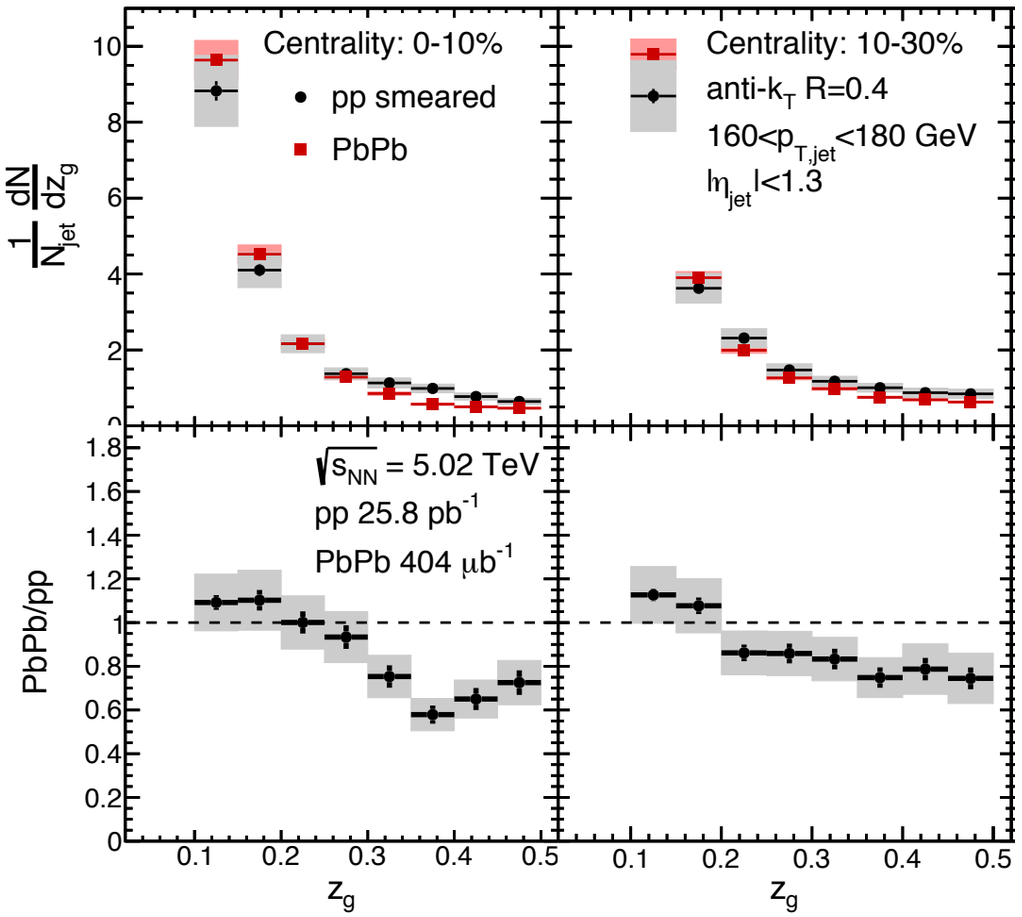
γ+*<u>hadron</u> measurements can't distinguish E-loss from modification of fragmentation…*

Jet substructure: z_g

$$z_g = \frac{\min(p_{T,1}, p_{T,2})}{p_{T,1} + p_{T,2}}$$

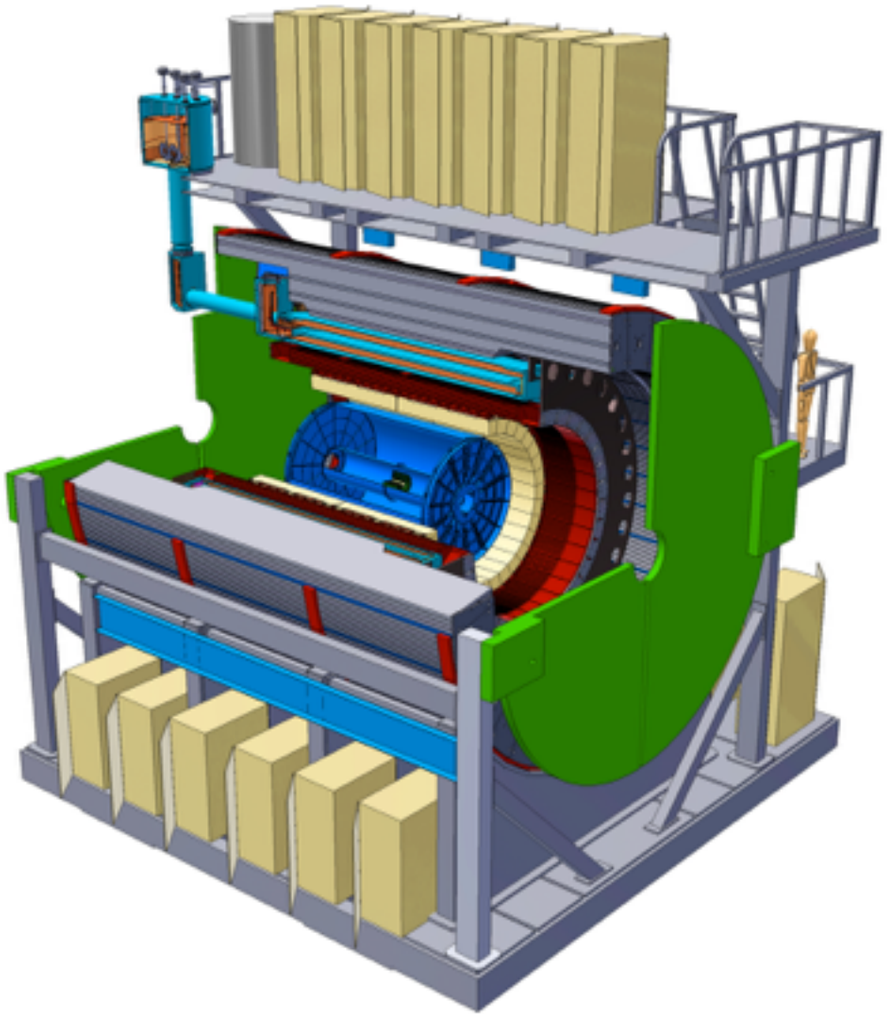


CMS-HIN-16-006

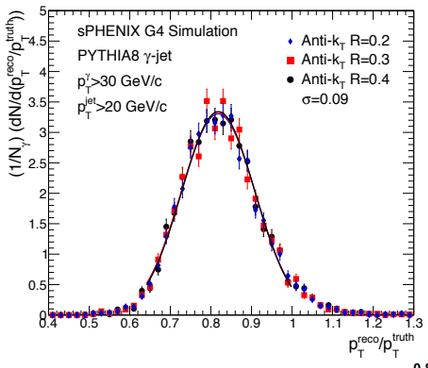


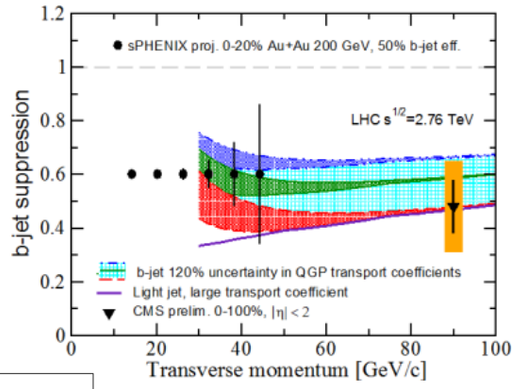
- Measurement of z_g quantity, which in vacuum is sensitive to first branching in the parton shower
  - ➡ sensitive to coherent or de-coherent energy loss of parton shower in medium
  - ➡ systematic modification vs. centrality at the LHC

Jets in sPHENIX

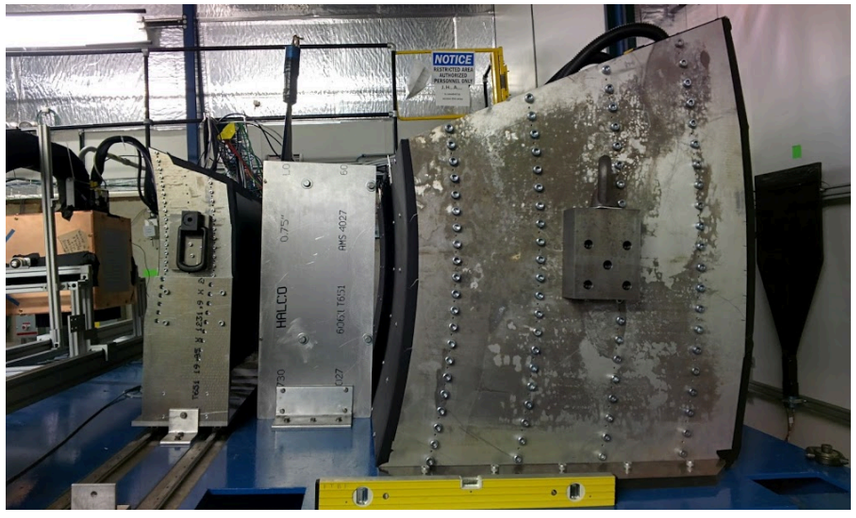


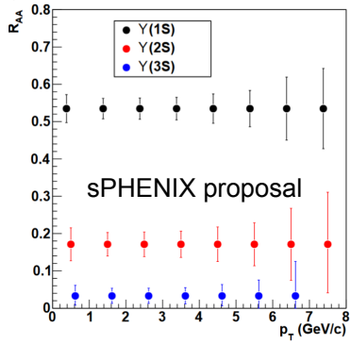
CAD drawing of sPHENIX detector





EMCal + IHCal + "solenoid" + OHCal slice at Fermilab for beam tests



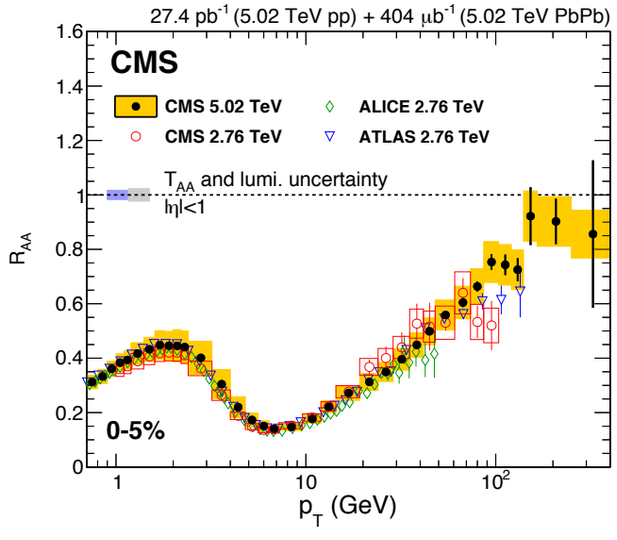


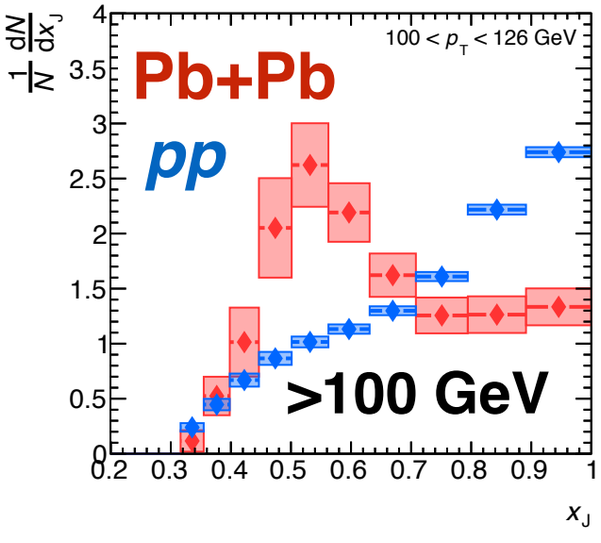
performance / projections for: γ+jet, Upsilons, *b*-tagged jets

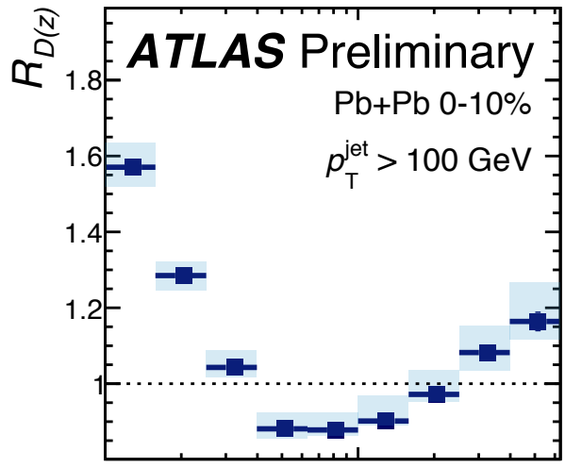
- Collab. formed December 2015, Expt. received CD-0 in Fall 2016
  - ➡ extensive R&D and beam tests of core subsystems
  - ➡ physics goal: make analogous measurements at RHIC kinematics, where QGP is closer to transition temperature

thank you!

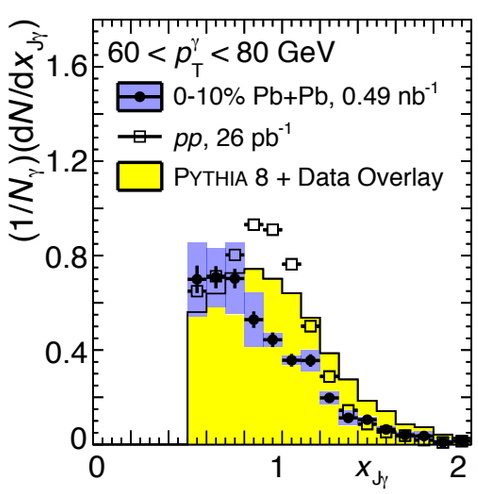
1. extreme kinematic reach

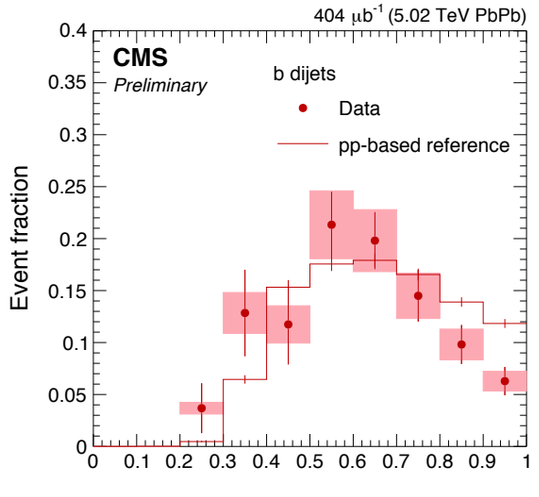


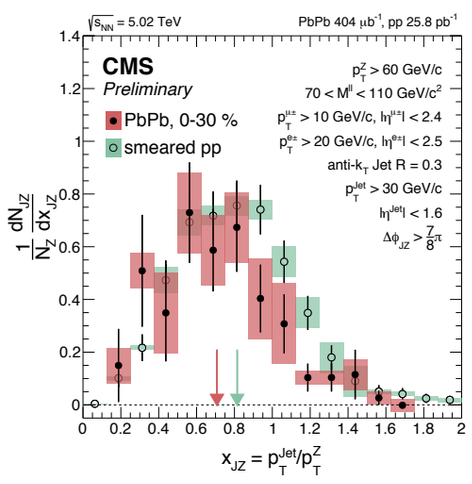




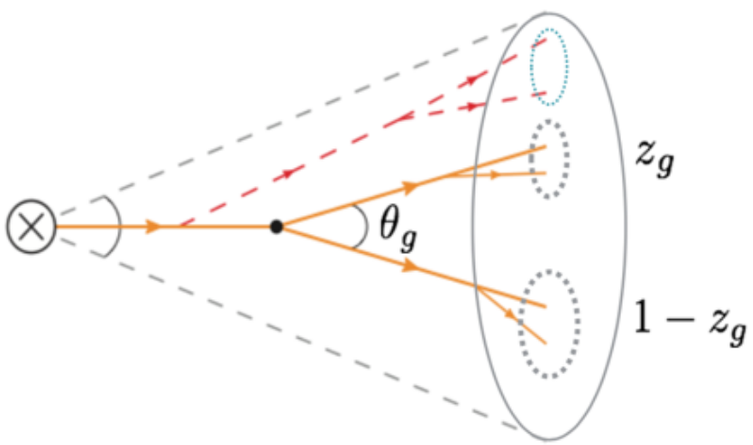
2. HF + EW probes

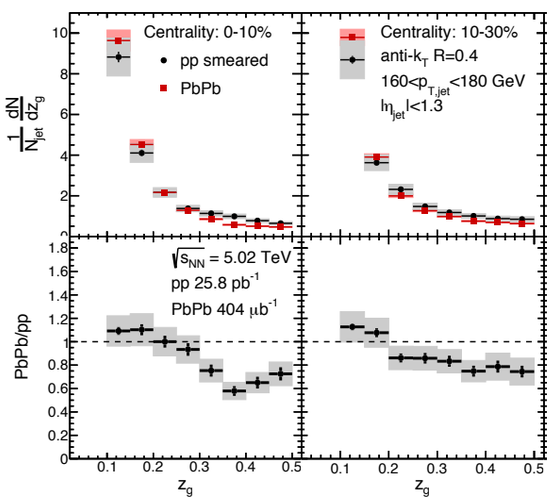






3. jet sub-structure





4. sPHENIX