Westfälische Wilhelms-Universität Münster

CERN

Jet Structure

Leticia Cunqueiro

Münster University & CERN

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Jet Structure

-**How is the jet shower modified in a Heavy Ion Collision**

-relate observed jet modifications to quenching

-Understand mechanisms of parton energy loss in medium

-complex, multiscale problem

-Infer fundamental properties like density, T, or degrees of freedom of the medium

-clean connection to the theory, well defined observables

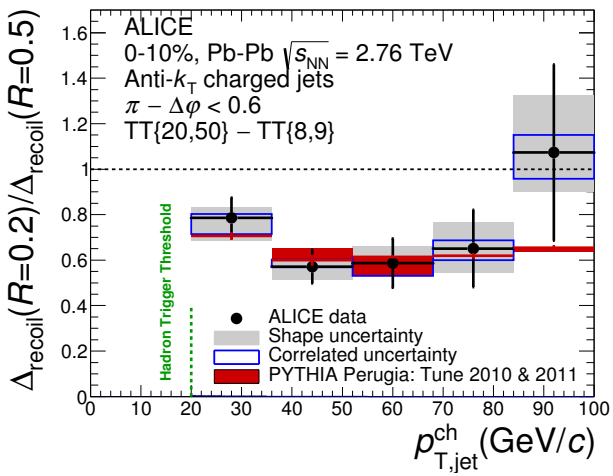
Jet Structure

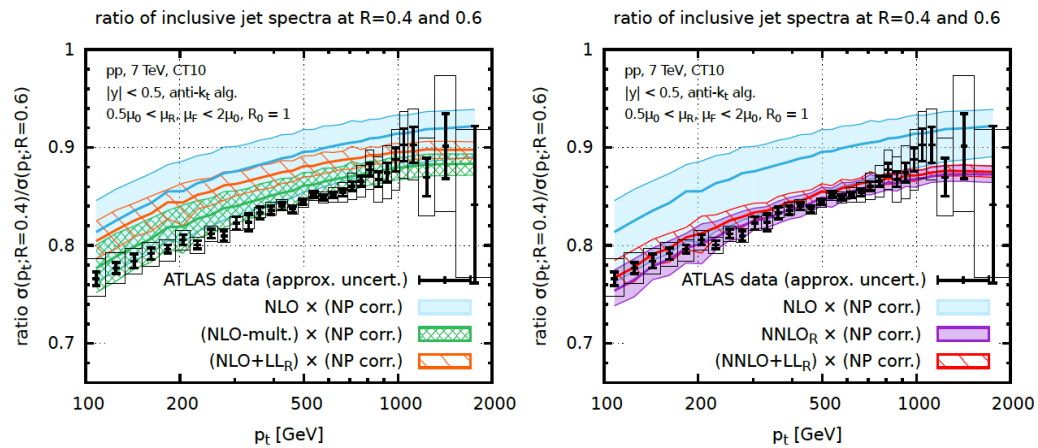
- Requirements: clean connection to the theory, calculable from first principles
- Essentially two types of jet shapes:

  -**uses the clustering history**
  -**computes a function of the constituents**

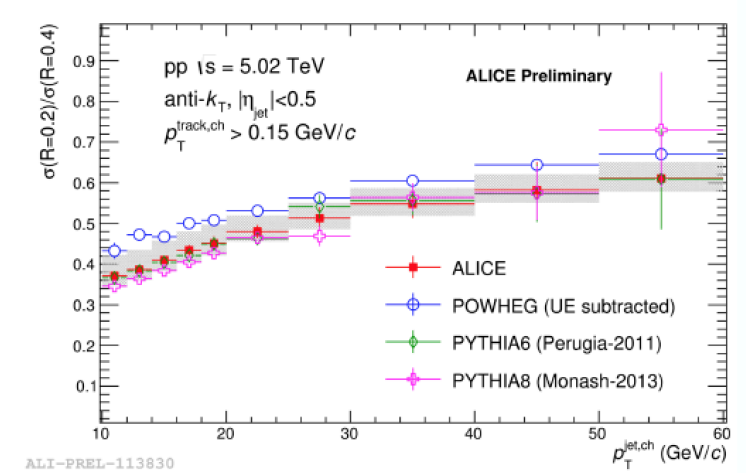
- Probe different aspects of jet quenching:
  -energy redistribution
  -intrajet broadening/collimation
  -color coherence
  -flavour hierarchy

Jet Structure





Dasgupta et al, arXiv:1602.01110v1



Hiroki Yokoyama, ALICE

Fully inclusive measurement of the radial profile of the jets: ratios of jet cross section with different resolution R

Jet mass

$$M = \sqrt{p^2 - p_T^2 - p_z^2}$$

$$p = \sum_{i=1}^{n} p_{T_i} \cosh \eta_i$$

$$p_z = \sum_{i=1}^{n} p_{T_i} \sinh \eta_i$$

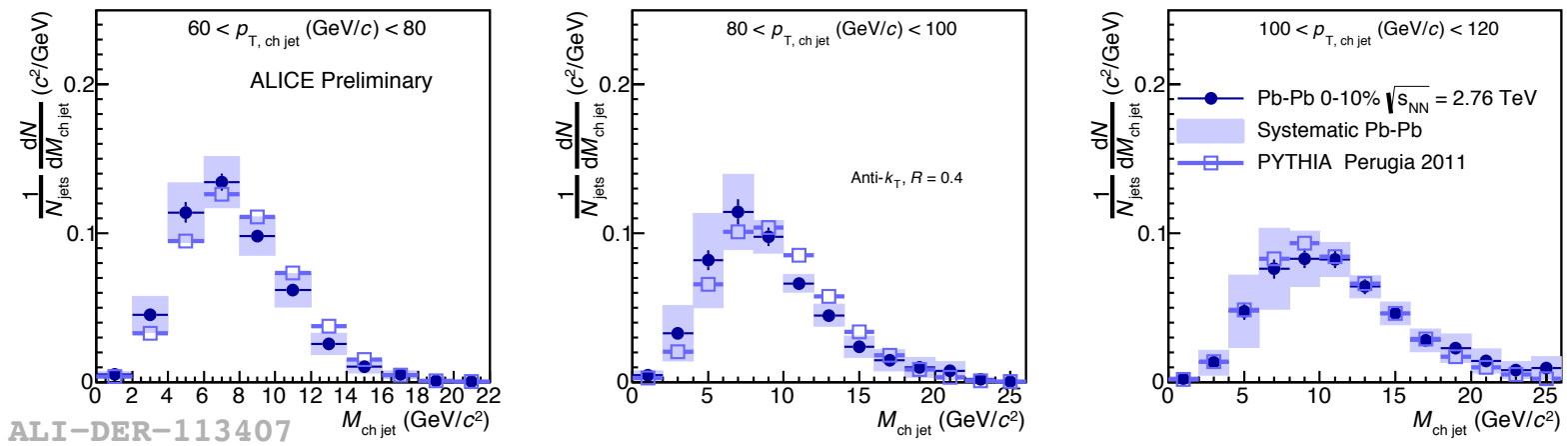
-Mixes **longitudinal and transverse** components

-Related to the virtuality of parton initiating the shower

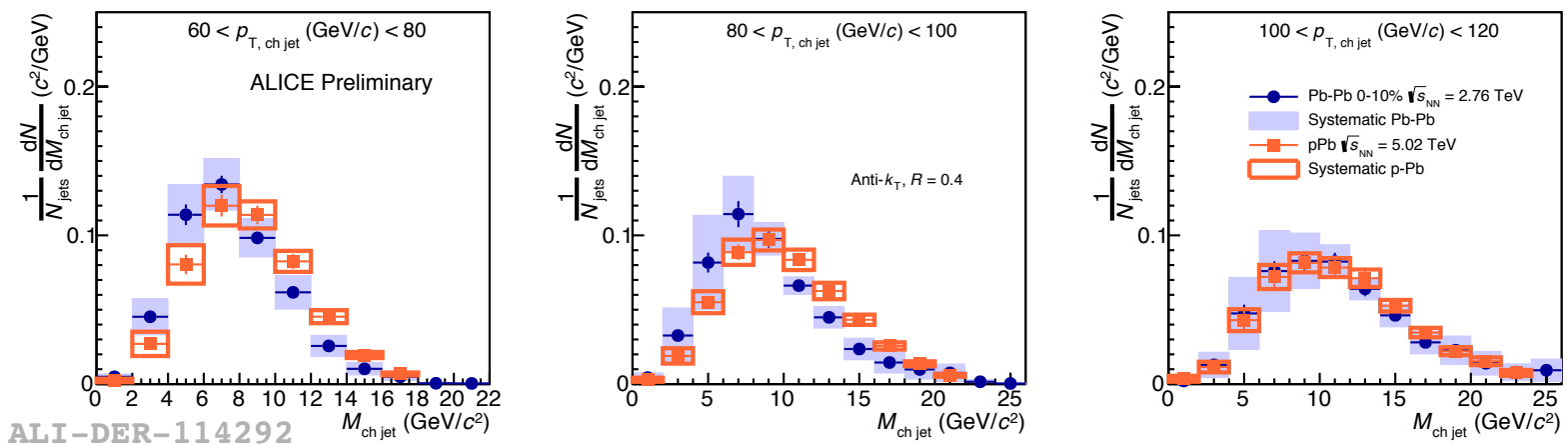
-Interactions of the projectile parton with the medium increase the radiation at large angles and this leads to an increase in the jet mass if the radiated angle is recovered within the jet cone.

Fully corrected observable: constituent and derivative subtraction for the pedestal background plus 2D unfolding for the residual background fluctuations and detector effects

Jet mass



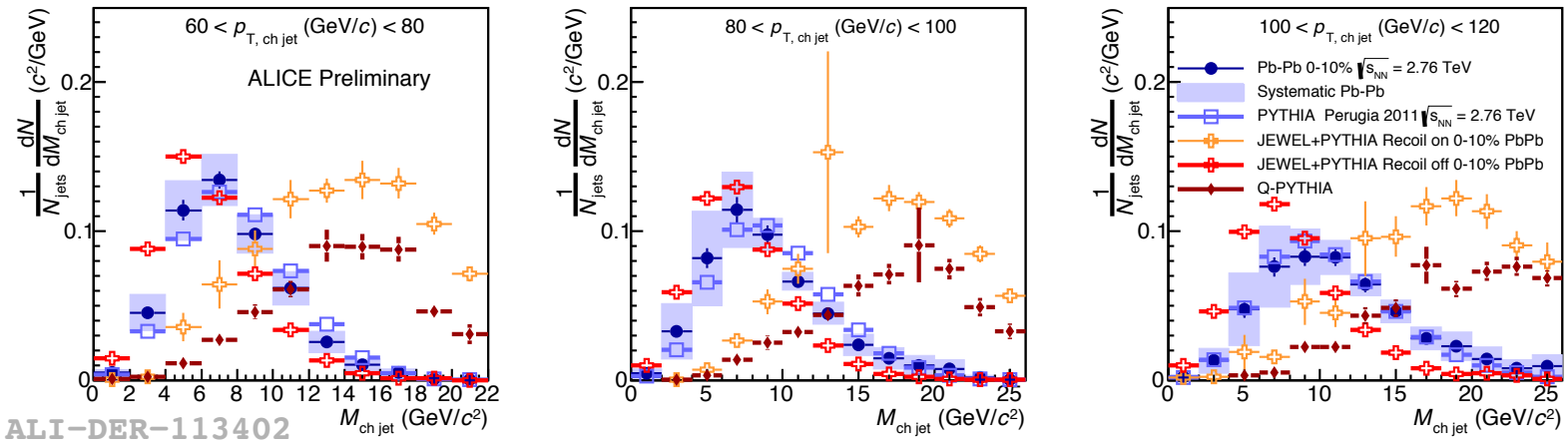
Fully corrected measurement of the (charged) jet mass compared to Pythia (up) and pPb (down)



Chiara Bianchin, ALICE

Jet mass

The PbPb mass compared to models



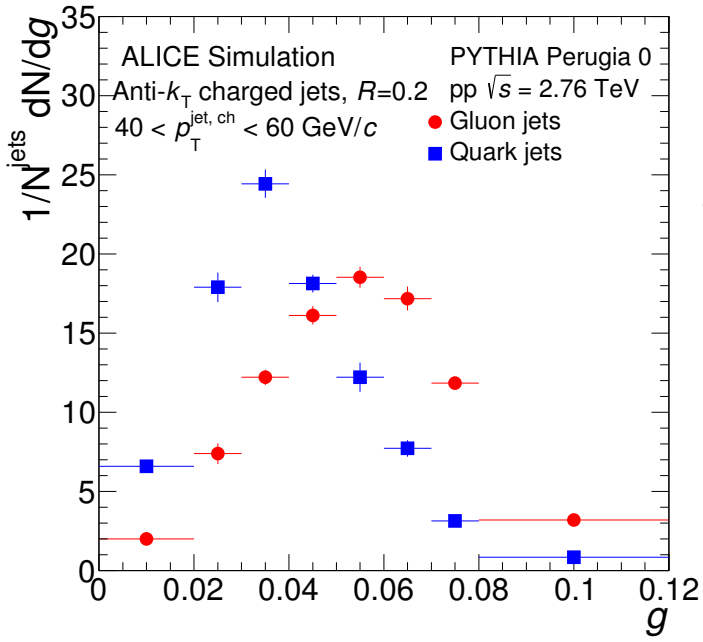
-Intrajet broadening as happens in qPythia (all partons in the shower radiate) leads to higher masses

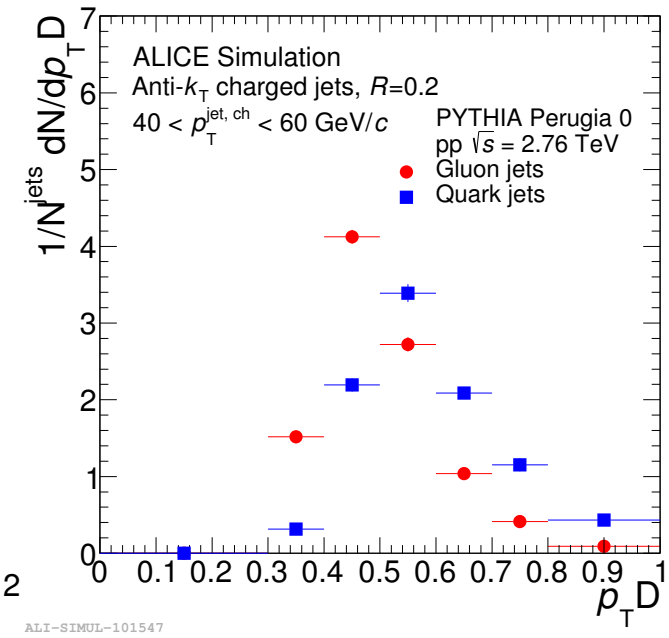
-Jewel r"ecoils off" leads to a collimation of the jet (particles transported out of the cone by elastic scattering)

-Jewel "recoils on" overshoots the data

Chiara Bianchin, ALICE

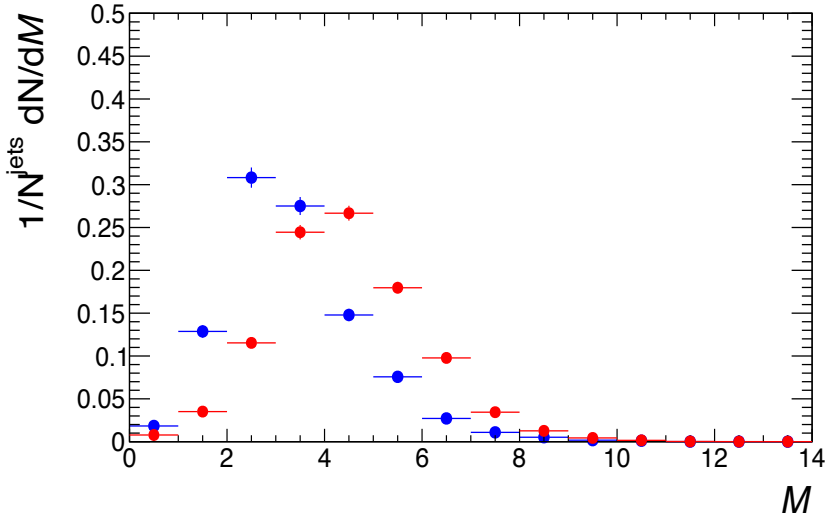
Qualitative remarks





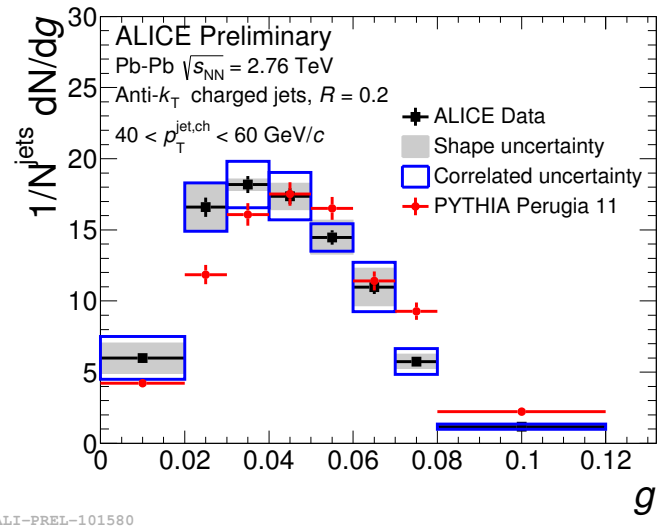
$$p_T D = \frac{\sqrt{\sum_i p_{T,i}^2}}{\sum_i p_{T,i}}$$

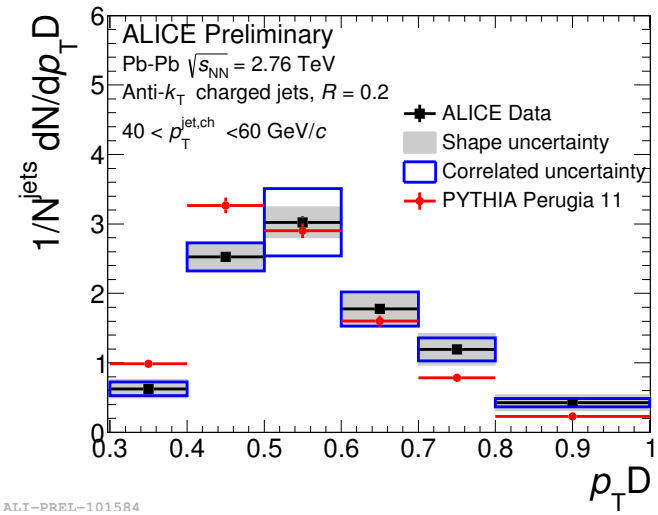
$$g = \sum_{i \in \text{jet}} \frac{p_T^i}{p_T^{jet}} |r_i|$$

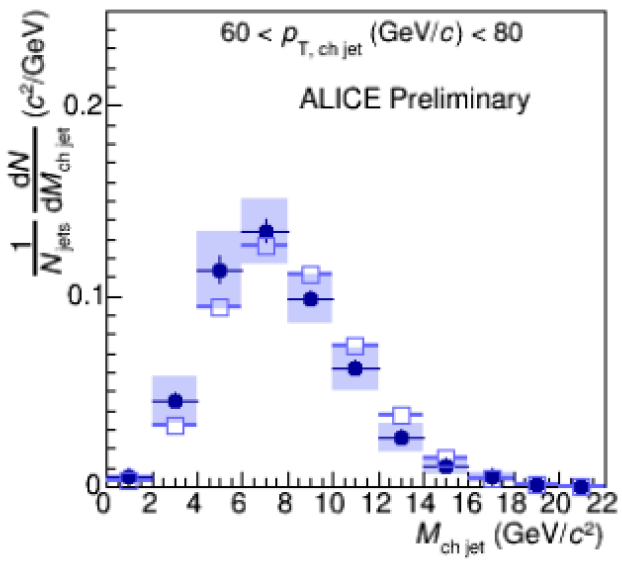


An accelerated shower (ie gluons compared to inclusive) leads to larger mass, higher angularities (broader) and smaller p_TD (more constituents)

Mass, angularity and $p_T D$

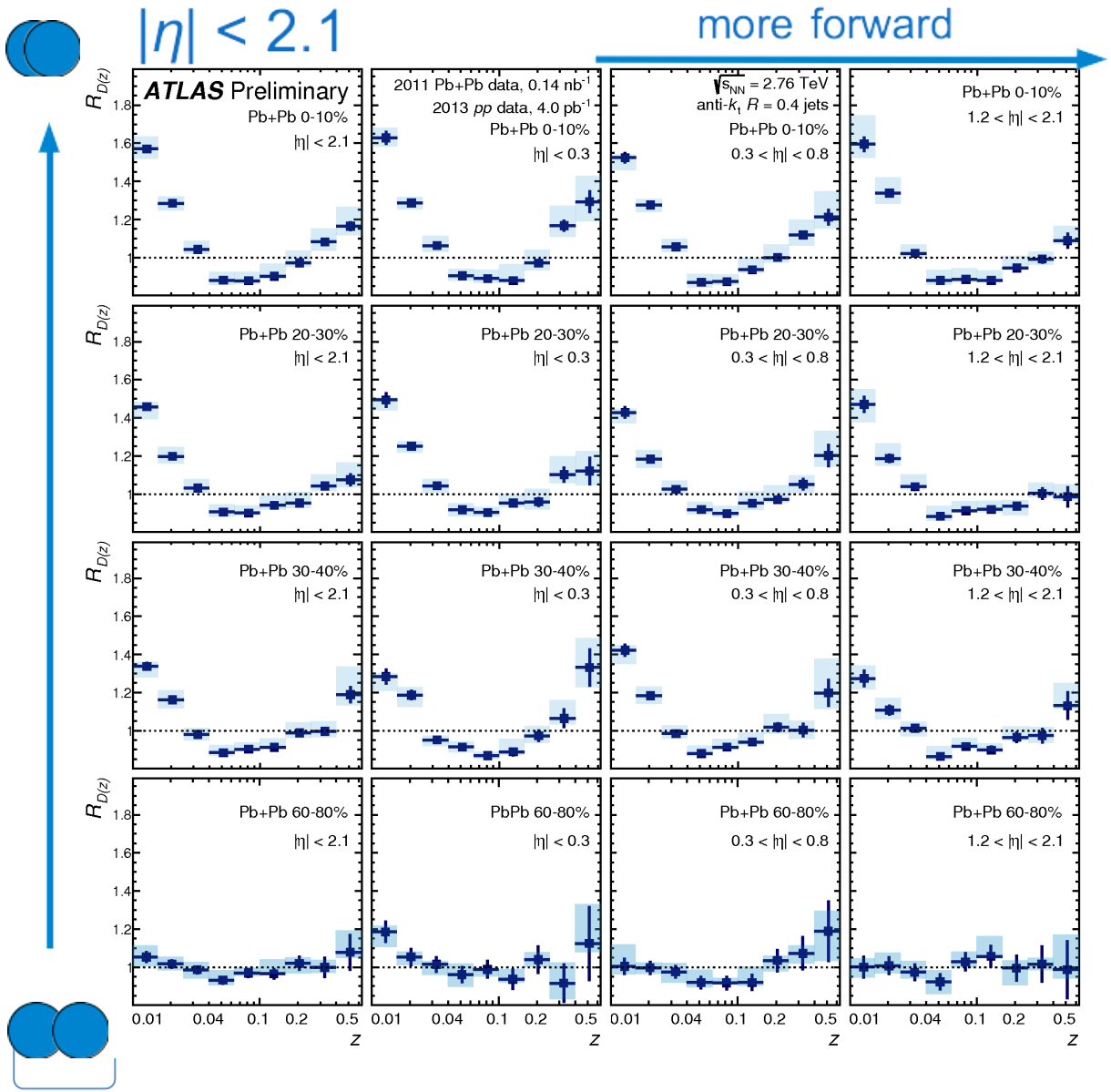






Picture qualitatively consistent with collimation of the jet core

Fragmentation function



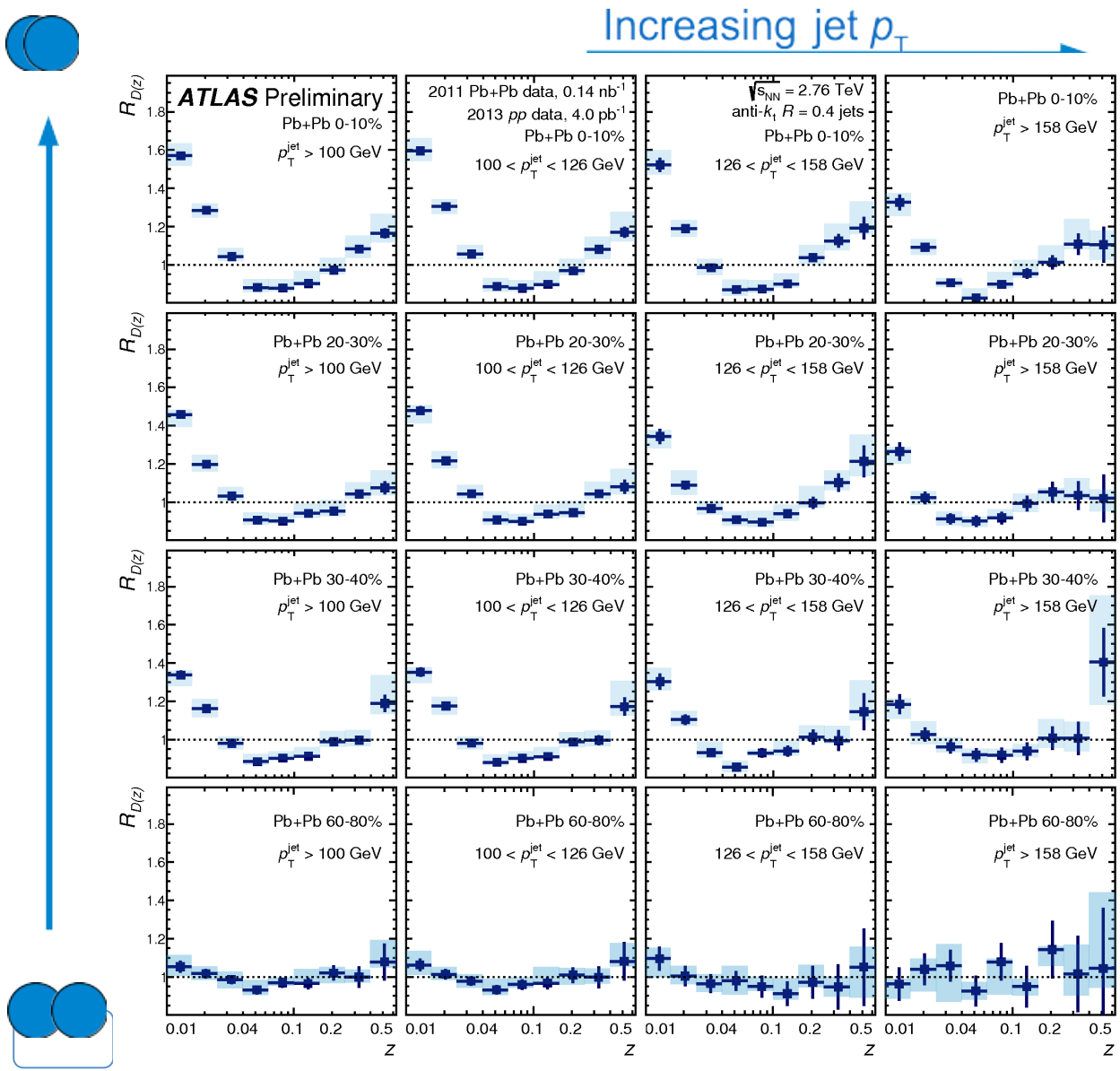
$$D(z) \equiv \frac{1}{N_{\mathrm{jet}}} \frac{1}{\varepsilon} \frac{\Delta N_{\mathrm{ch}}(z)}{\Delta z}$$

Probes longitudinal energy redistribution within the jet

Change with pseudorapidity, change of flavour composition?

Martin Rybar,ATLAS

Fragmentation function



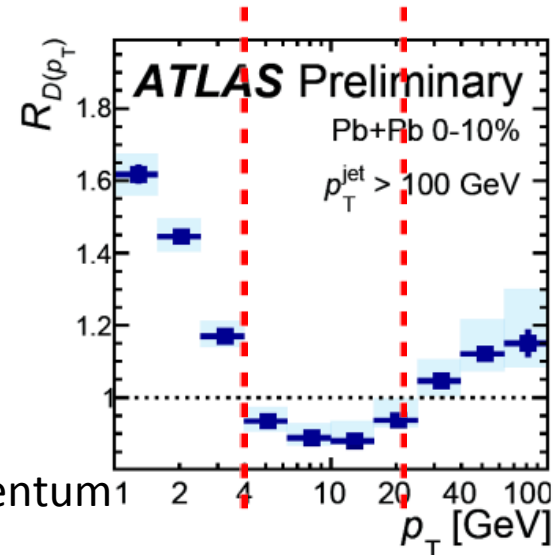
$$D(z) \equiv \frac{1}{N_{\rm jet}} \frac{1}{\varepsilon} \frac{\Delta N_{\rm ch}(z)}{\Delta z}$$

Mild p_T dependence

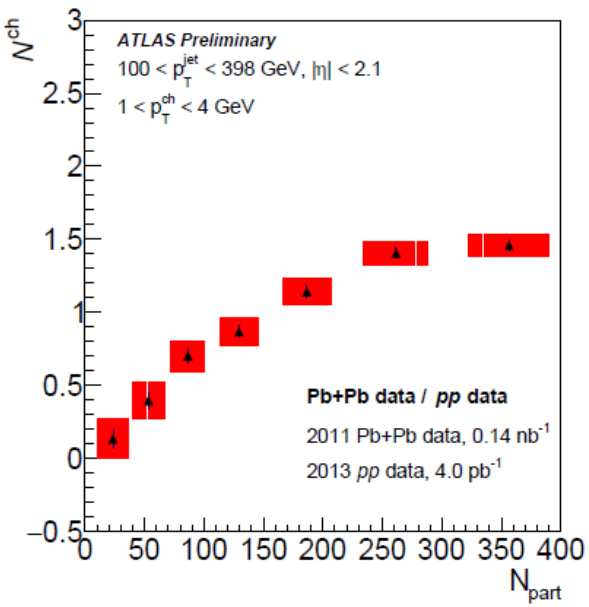
Martin Rybar,ATLAS

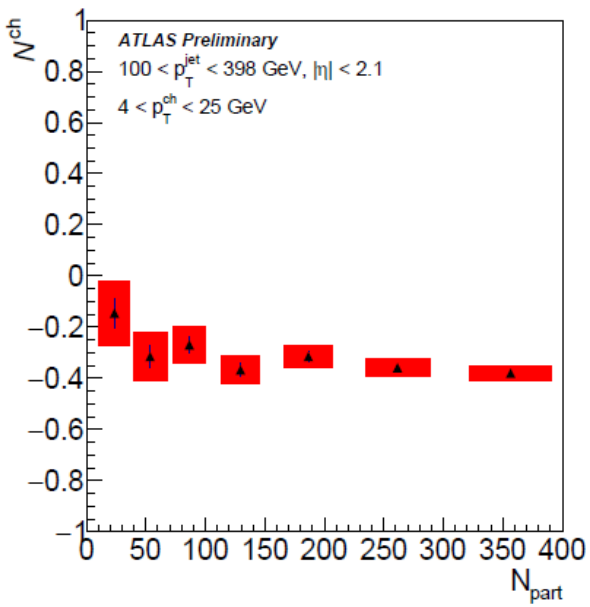
Fragmentation Function

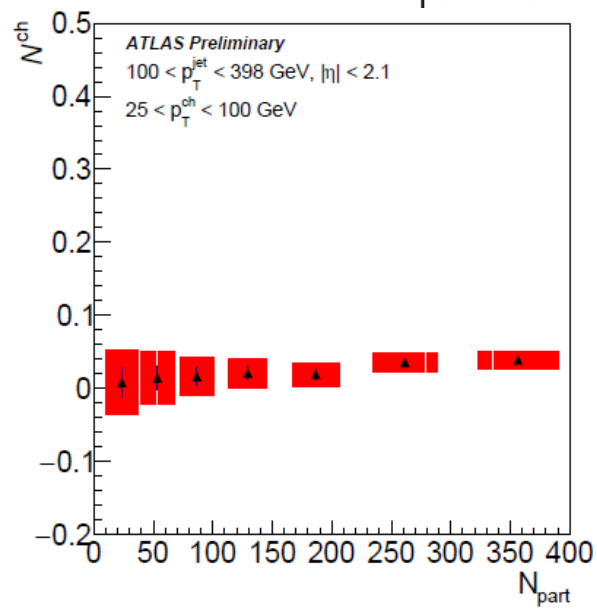
$$N^{\mathrm{ch}} \equiv \int_{p_{\mathrm{T,min}}}^{p_{\mathrm{T,max}}} \left(D(p_{\mathrm{T}})|_{\mathrm{cent}} - D(p_{\mathrm{T}})|_{\mathrm{pp}} \right) \mathrm{d}p_{\mathrm{T}}.$$



Modifications translate into ~1.5 excess of particles at low momentum







Martin Rybar,ATLAS

Jet Substructure: probing coherence

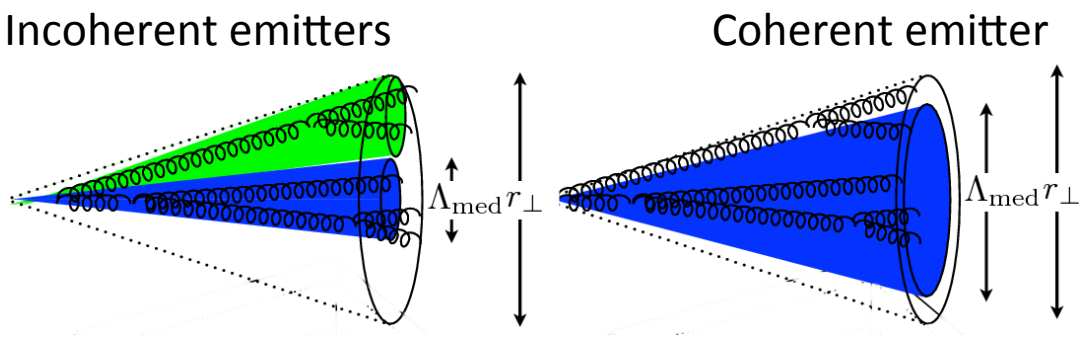


Fig. from *Phys.Lett.B* **725** (2013) 357–360

Partons that are separated less than the characterisitc scale of the medium, Δ_{med}, won't be resolved as independent emitters.
To probe color coherence we would like to:

- **Find the antenna or first splitting** in the jet
- Measure the opening angle
- Measure **suppression of jet yields relative to pp differentially as function of the antenna opening angle** in the search of a threshold behaviour
- Look for **asymmetries in the momentum sharing** of the antenna

Finding the hardest (and earliest) splitting

1. Soft drop: reclusters the jet constituents (C-A) and goes through the clustering history**, grooming away the soft branch** at each step until (for β=0)

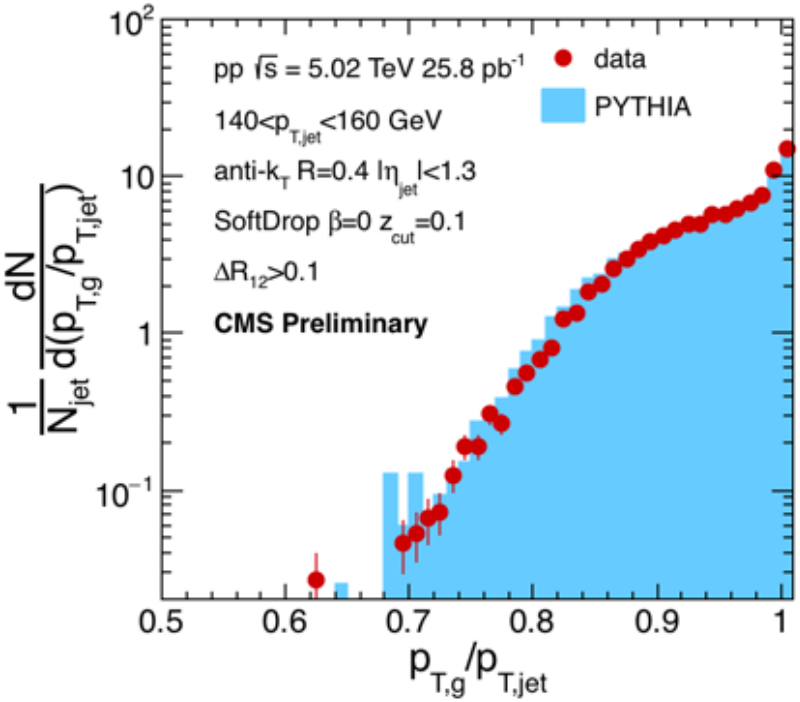
$$z_{cut} < \frac{\min(p_{T_1}, p_{T_2})}{p_{T_1} + p_{T_2}} \equiv z_g$$

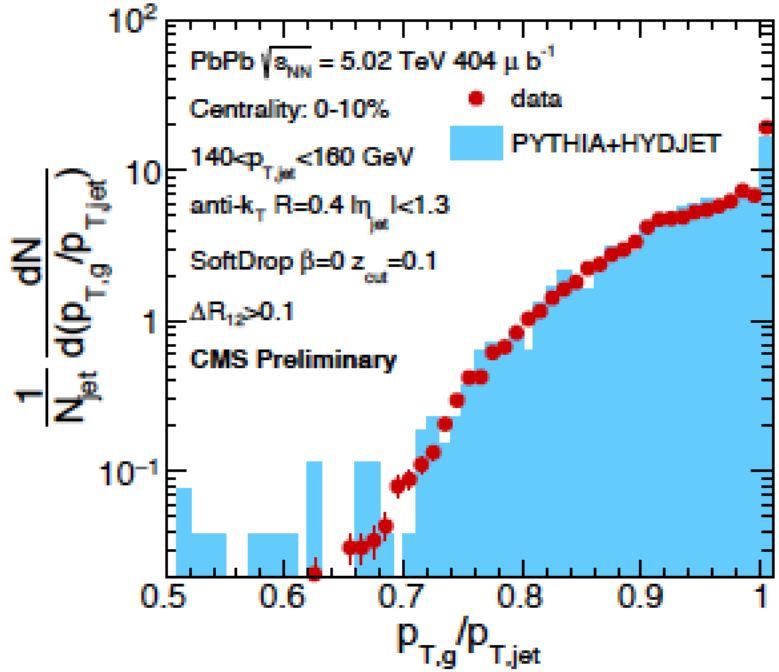
2. Color factors cancel, **and $P(z_g)$~$1/z_g$, weak p_T dependence**

3. Depending on opening angle and on k_T of the splitting, different splitting times are probed (t_f~$2\omega/k_T$)

4. Also, note that no scale R_{subjet} is needed as input

Effect of grooming in heavy ions

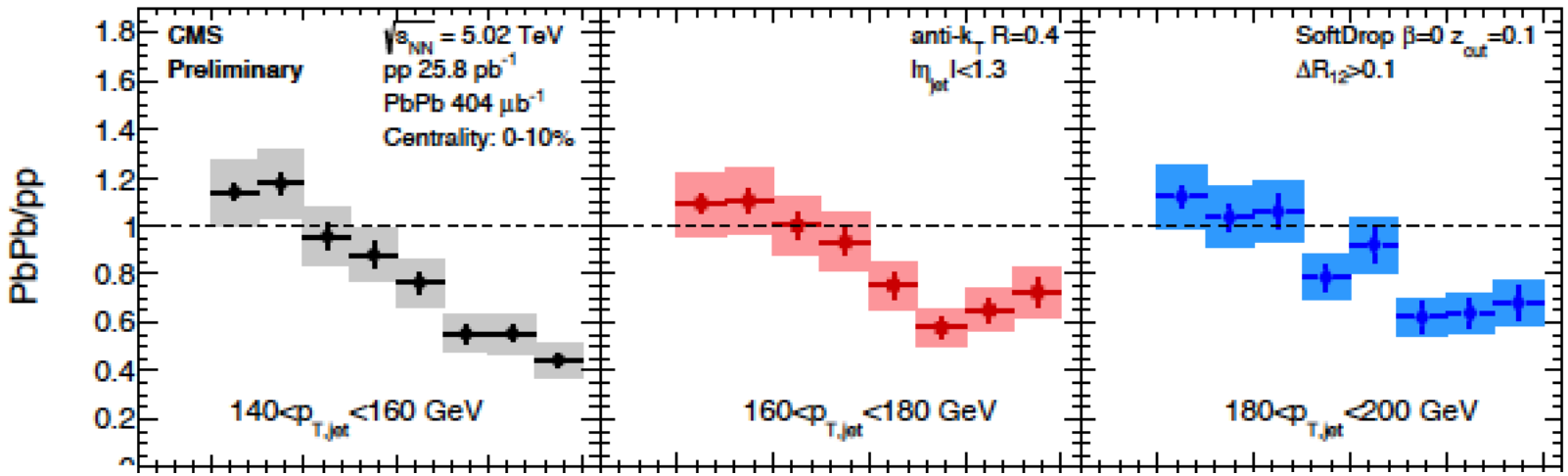




-What are we cutting away when grooming quenched jets?
-Interesting physics message here: distribution of fraction of groomed energy in data is similar to vacuum (pp+bkg).
-What room for fragmentation differences?

Marta Verweij, CMS

Hardest splitting momentum imbalance

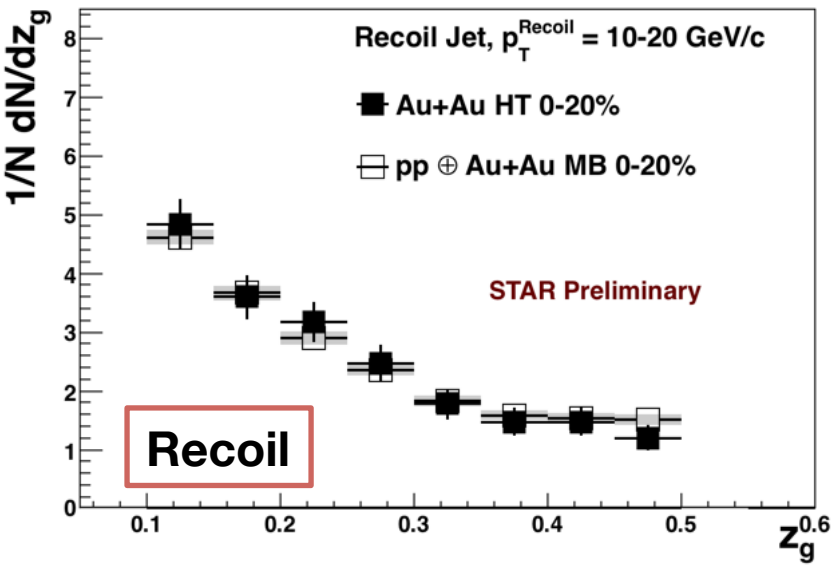


$$z_g = \frac{\min(p_{T,1}, p_{T,2})}{p_{T,1} + p_{T,2}}$$

-Asymmetric longitudinal momentum share in the hardest splitting within the jet
-Energy dependent?
-Bkg fluctuations need to be under total control, since there are critical: the subleading subjet can be pumped up by a fluctuation. Smearing based on Hydjet, tuned to event bkg.
-Semihard large angle medium-induced gluons might not be groomed and contribute to the asymmetry?

Marta Verweij, CMS

Hardest splitting momentum imbalance at STAR



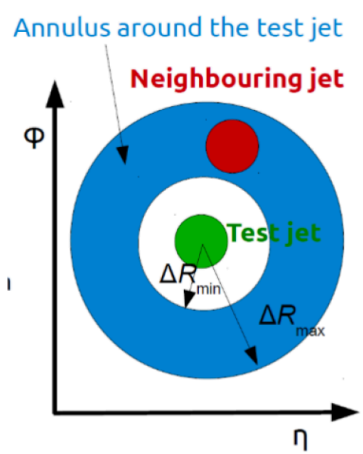
-Jet selection not inclusive: require a trigger jet (>20 GeV/c) plus a recoil jet (>10 GeV/c)
-HT trigger (E_T>5.4 GeV)
-const. cutoff of 2 GeV/c

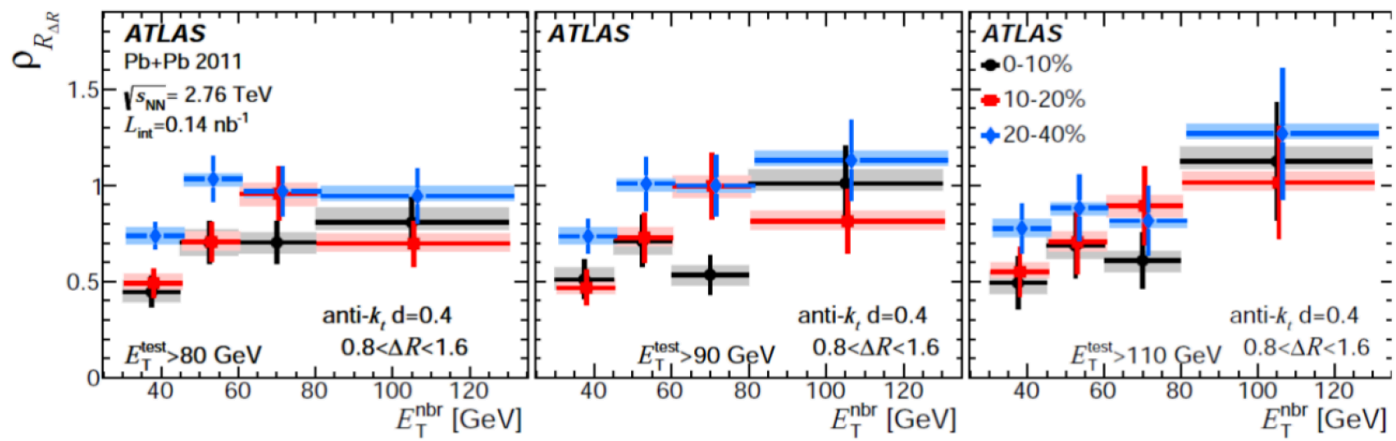
Results compatible with no modifications:
-Selection bias (tangential)
-large splitting time t_f for the given kinematics

Kolja Kauder, STAR

Jet structure at large ΔR

- To probe jet structure at large ΔR, difficult as an **intrajet or shape** measurement due to large fluctuation background within
- Possible via **interjet correlations**->example ATLAS neighbouring jet or CMS missing p_T
- Event shapes?





Radim Slovak,ATLAS

Consistent picture for all jet shape measurements?

-Need a systematic MC study of all available (independent) observables.

-Perhaps agreements/standards from pp can be adopted in PbPb community?

Beyond inclusive jet shapes

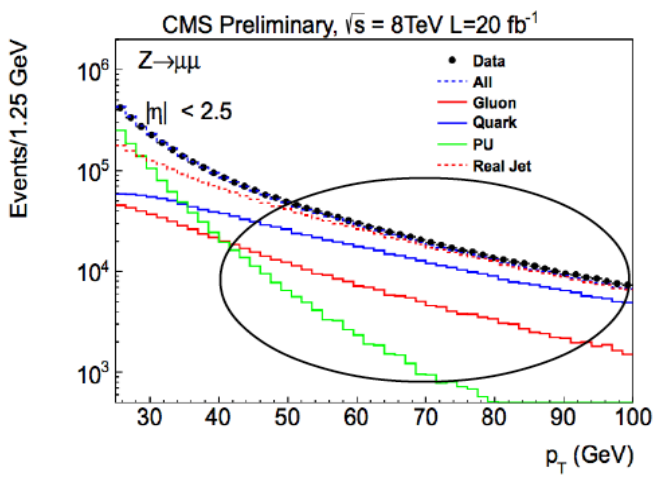
- Coincidence measurements to suppress combinatorial bkg and to be able to measure shapes at **low jet p_T and large R**

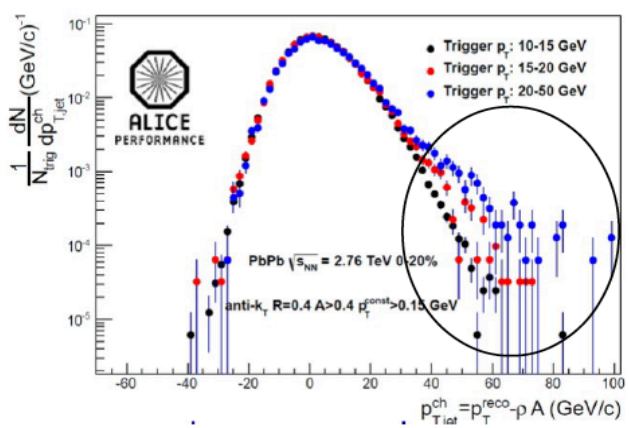
07/11/14 Philip Harris Heavy Ion Jet Workshop 2

Pileup Jets or "Fake" Jets

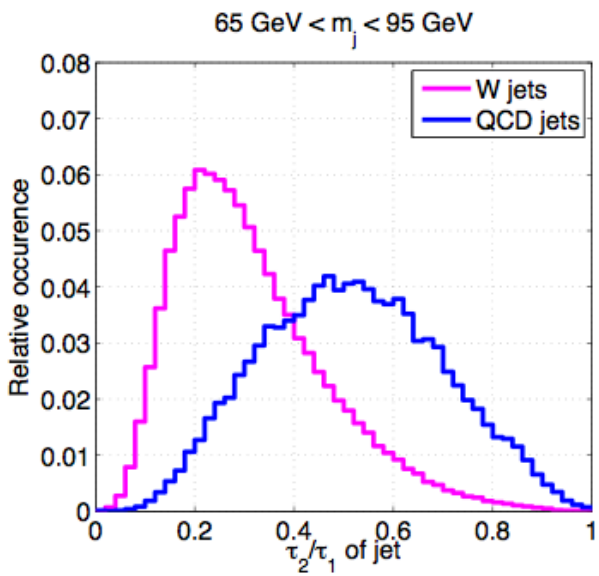
- For all classical purposes
  - Pileup jet can be viewed as overlapping low p_T jets
    - **Consider the Jet substructure of such an object?**

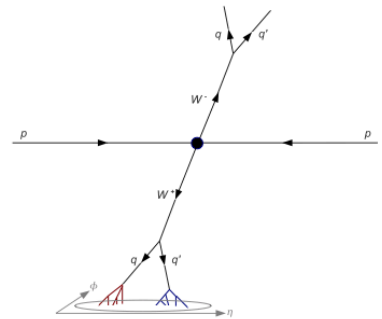
$P(\text{overlap}|pT) \approx C\, N^2_{pu}\, a^2_{jet}\, pT^{-6.2}$ Real Jets $\approx pT^{-5}$

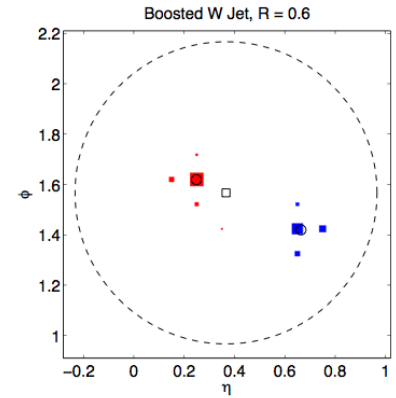




Other ideas to probe coherence: Nsubjettiness







$$\tau_N = \frac{1}{d_0} \sum_k p_{T,k} \min\{\Delta R_{1,k}, \Delta R_{2,k}, \cdots, \Delta R_{N,k}\}$$

Thaler et al: arXiv:1011.2268v3

-2 pronged jets have low tau2/tau1->0

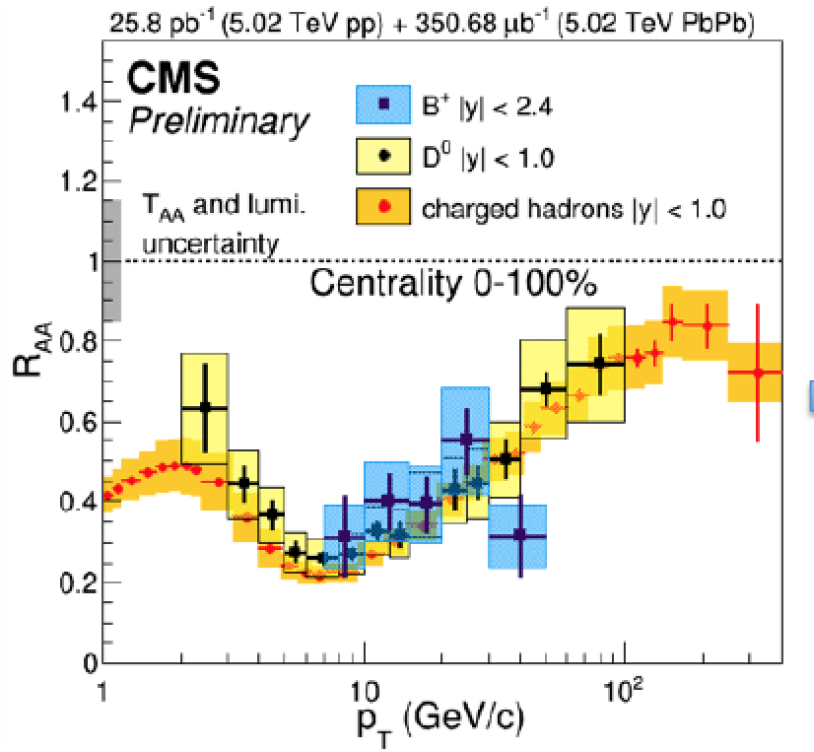
-**use this shape to tag 2-pronged jets (small subsample)**

-Find the hardest splitting.

-Calculate nsubjetiness relative to the obtained hard splitting

-Explore change of rate of 2 pronged jets as function of opening angle

Other ideas: heavy quark jet shapes



The dependence of R_{AA}^{jets} on resolution R as well as jet shapes as function of R for heavy flavours could allow to study intrajet modifications for fixed quark flavour

For inclusive jets, the change of the energy profile with R mixes up with the change of q/g fractions with R

Thanks for the interesting conference!