the origin of the modification of the z_g distribution in AA collisions

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WHY JET SUB-STRUCTURE?

- ‘1st generation’ jet observables [R_{AA}, A_J, boson-jet imbalance, …] sensitive to overall jet energy loss
  - limited information on dynamical details of jet-medium interaction
  - distinct approaches yield comparable agreement with data

- jet-substructure sensitive to a wide range of scales
  - observables reliant on particles [e.g. fragmentation functions] sensitive to ill-constrained hadronization dynamics
  - observables built from jet-like structures [sub-jets, prongs in clustering sequence] much more robust
  - as in all measurements [e.g. di-jet asymmetry] it is crucial to understand what any observable is sensitive to

general procedure outlined in Milhano and Zapp 1512.08107 [hep-ph]

- grooming techniques developed in pp based on analitycal understanding have proven very useful
  - grooming allows for the separation of soft and hard components

z_g : GROOMED SHARED MOMENTUM FRACTION

modified Mass Drop Tagger / Soft Drop [β=0]

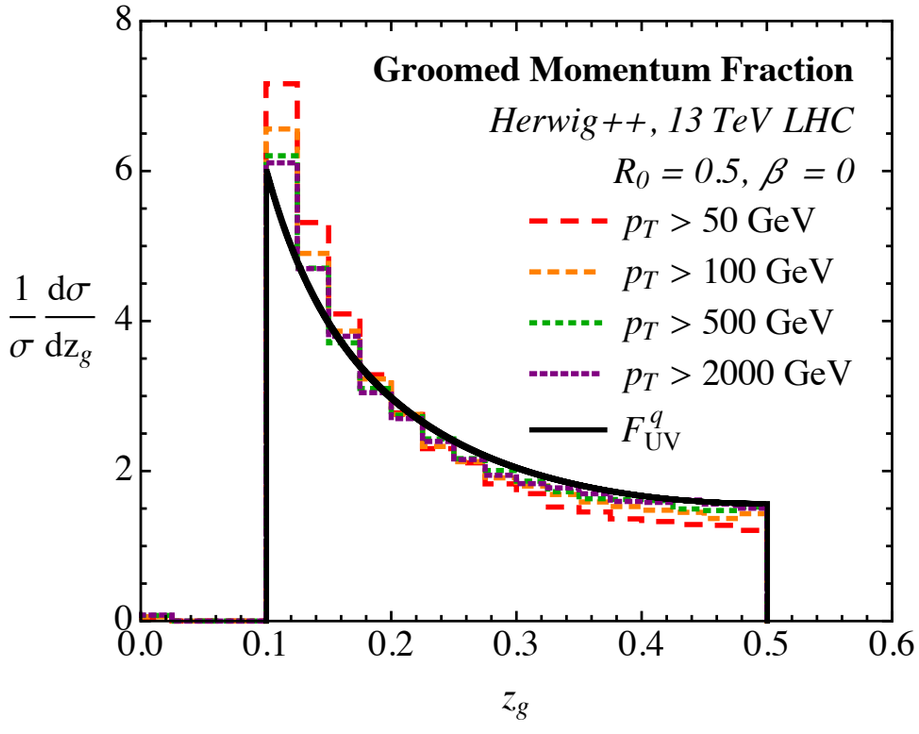
1. cluster jets with anti-k_t
2. re-cluster with Cambridge/Aachen [from closest to furthest in angle]
3. undo last clustering [jet as 2-prong object] step and compute z_g
4. if $z_g > z_{cut}$ stop,
   else discard softer prong and go back to 3

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

at LO

$$p(z_g) = \frac{P(z_g) + P(1 - z_g)}{\int_{z_{cut}}^{0.5} dz \left(P(z) + P(1 - z)\right)} \Theta(z_g - z_{cut})$$

➤ **in vacuum, the procedure measures the LO Altarelli-Parisi splitting function**



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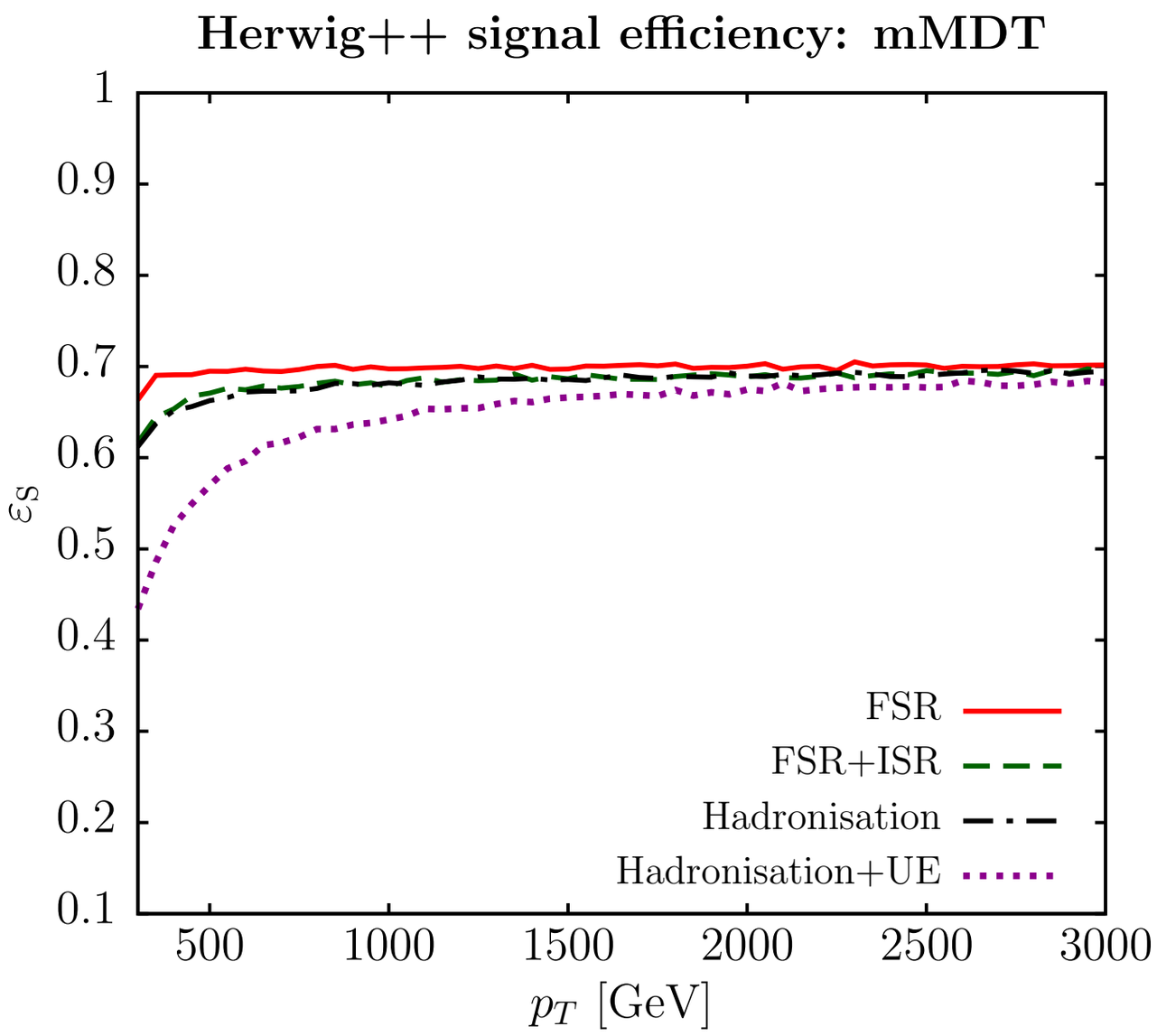

- **mMDT/Soft Drop in pp is sensitive to UE**
  - **worse for the lower $p_\perp$ in CMS [and STAR] measurements**

THE MEASUREMENT

:: carried out by both CMS and STAR [previous talks in the session]

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CMS

- angular ‘resolution’ cut
  - configurations where prongs are close [$\Delta R_{12}<0.1$] are removed from sample
  - removes ~50% of events
- strong modification of z_g distribution
- modification decreases and eventually vanishes for high $p_\perp$

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STAR

- no angular ‘resolution’ cut
- only jets with hard cores
- results consistent with no modification of z_g distribution

THE TOOL: JEWEL

Zapp, Krauss & Wiedemann, JHEP 1303 (2013) 080

- jet evolution and interaction with medium described within single formalism
  - jet evolution well understood in pp :: use standard tools from pp description
  - dynamical model of jet evolution anchored in analytical understanding of pQCD
- key assumptions
  - medium seen by jet as collection of quasi-free partons
  - use infra-red continued perturbation theory to describe all jet-medium interactions
  - formation times govern the interplay of different sources of radiation [vacuum-like and medium induced]
  - LPM effect encoded through eikonal limit analytical results

JEWEL: MEDIUM RESPONSE

Zapp and Kunnawalkam Elayavalli

- two possible operating modes in JEWEL

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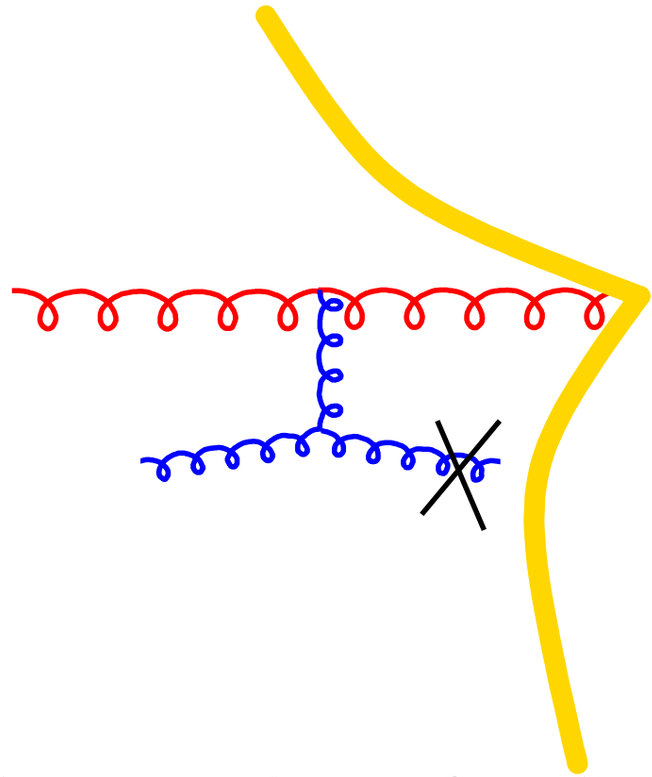

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  - medium partons **not included** in event record :: no tracking of medium response

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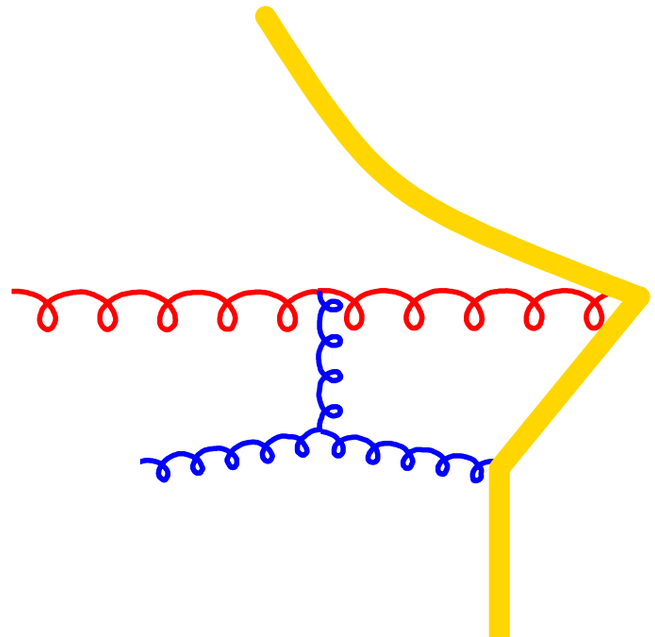
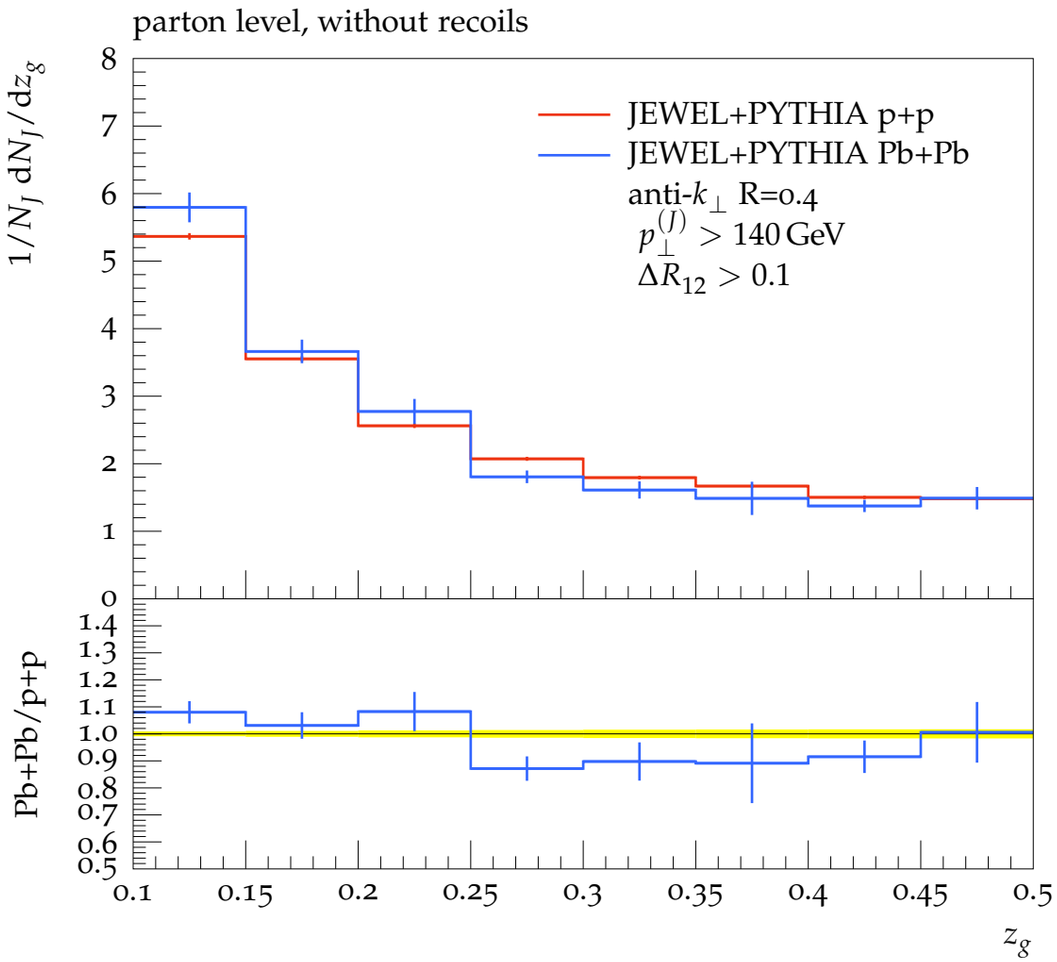


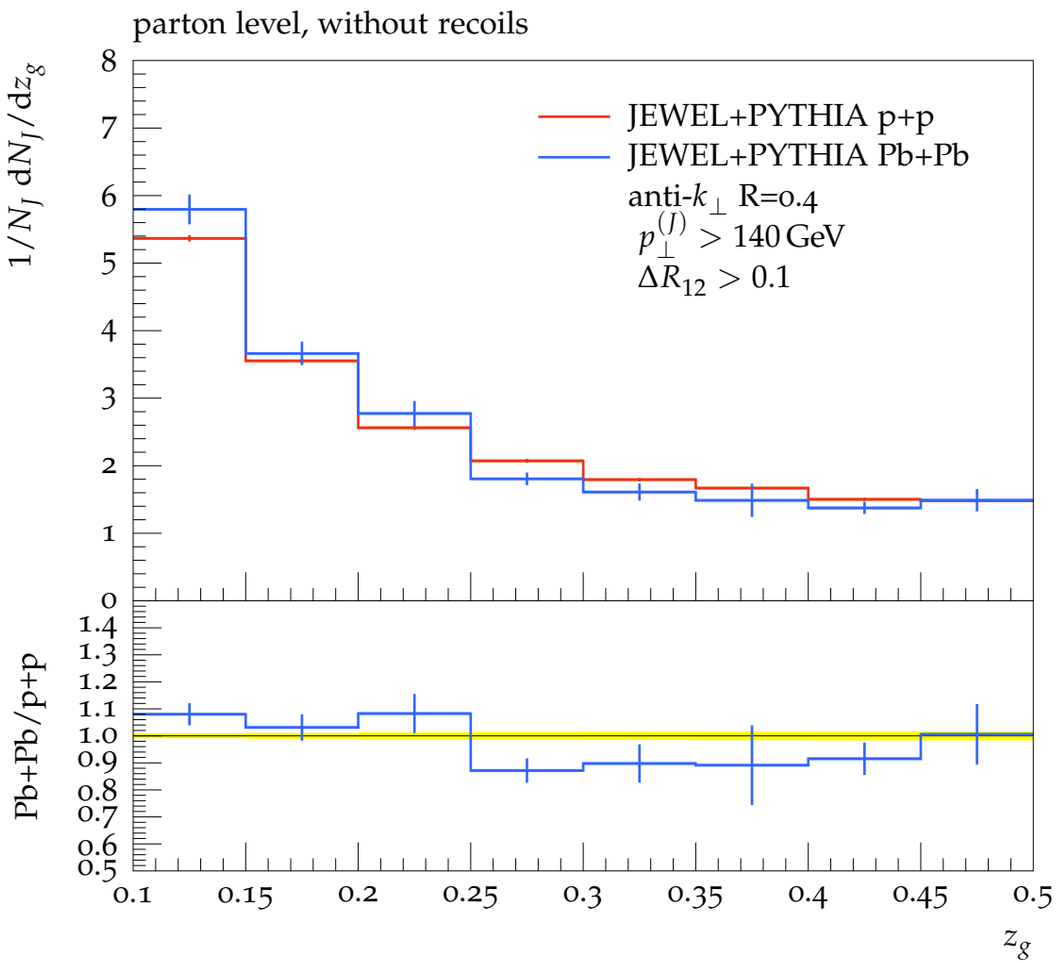
- two possible operating modes in JEWEL
  - medium partons **not included** in event record :: no tracking of medium response
  - medium partons that interact with jet **included** in event record
    - part of the medium becomes correlated with jet and thus part of jet
    - requires subsequent background subtraction :: only 4-momentum acquired by medium partons should survive
    - no further re-scattering of medium partons :: jet-correlated medium arguably too hard

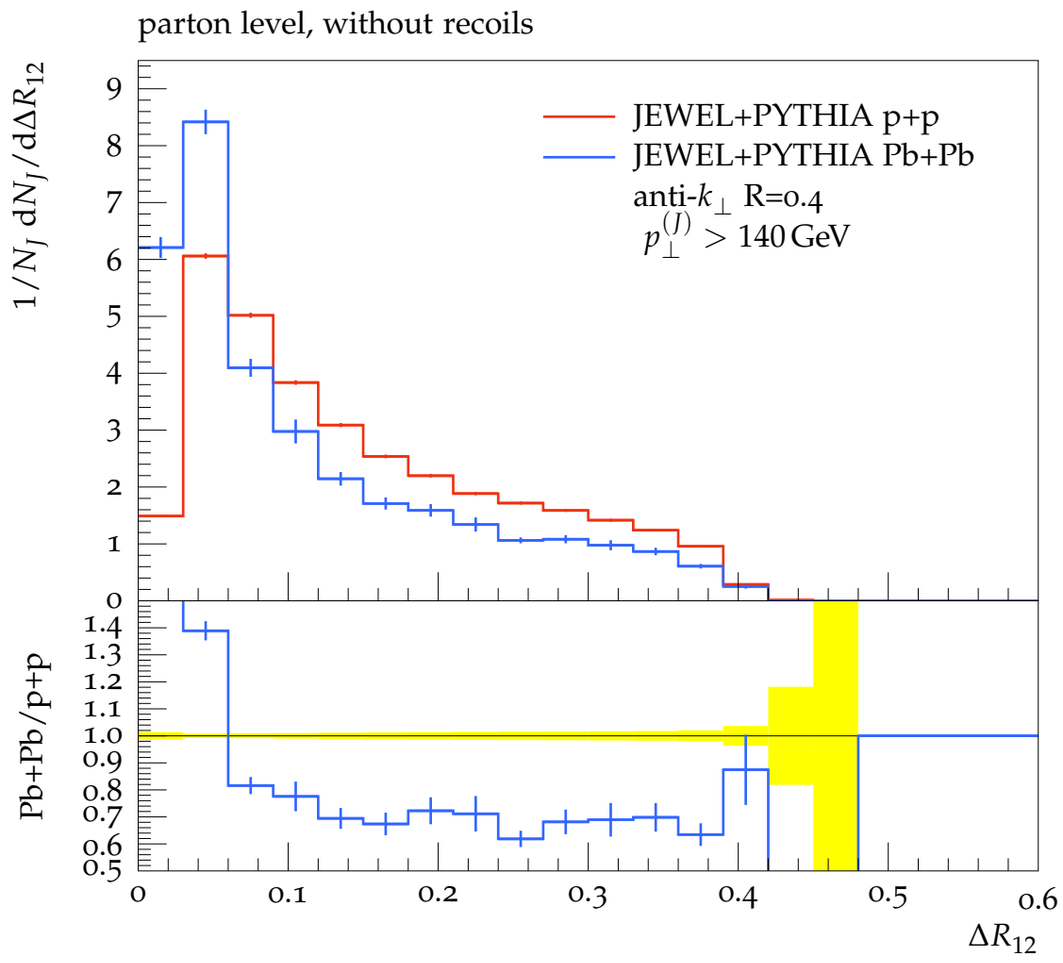
z_g WITHOUT JET-CORRELATED MEDIUM



- small modification of z_g distribution from ‘additional splittings’ and ‘energy loss’

z_g WITHOUT JET-CORRELATED MEDIUM





- small modification of z_g distribution from ‘additional splittings’ and ‘energy loss’
- angular distribution narrower in AA [prongs are closer together]

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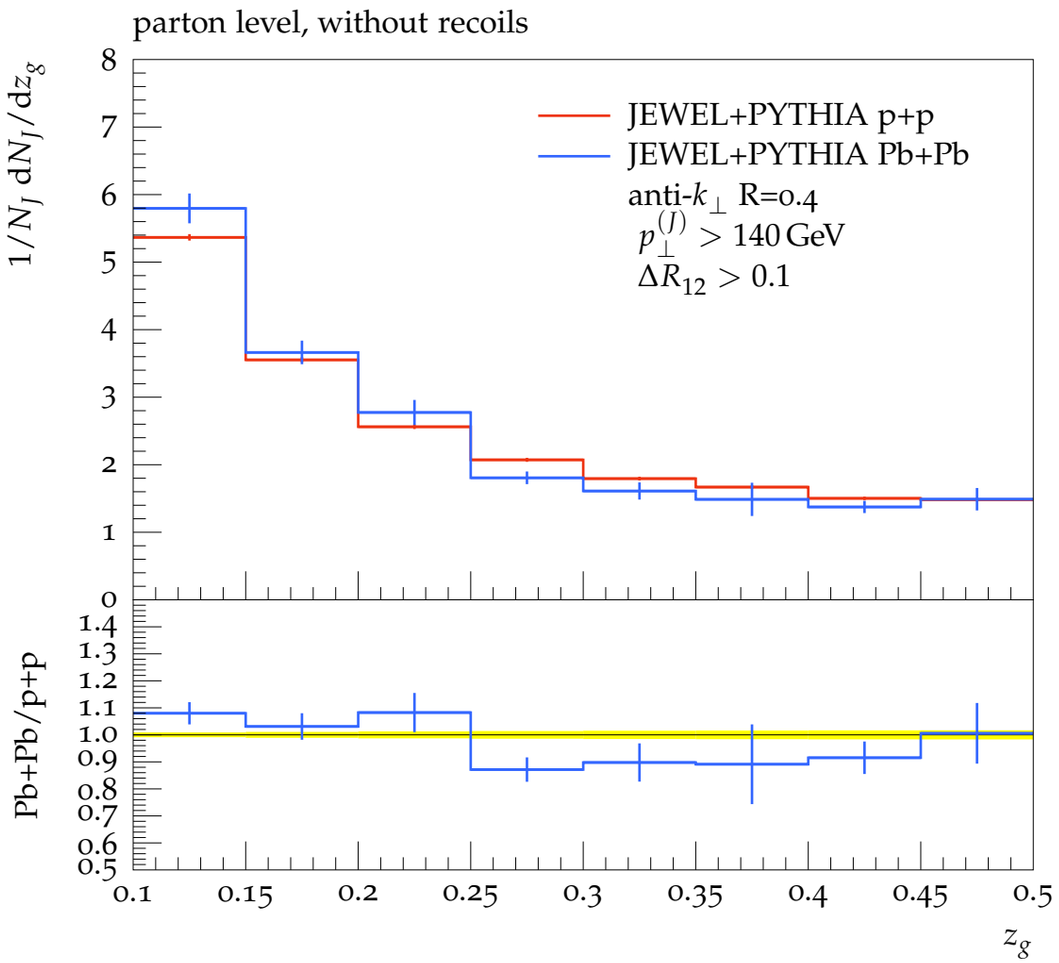
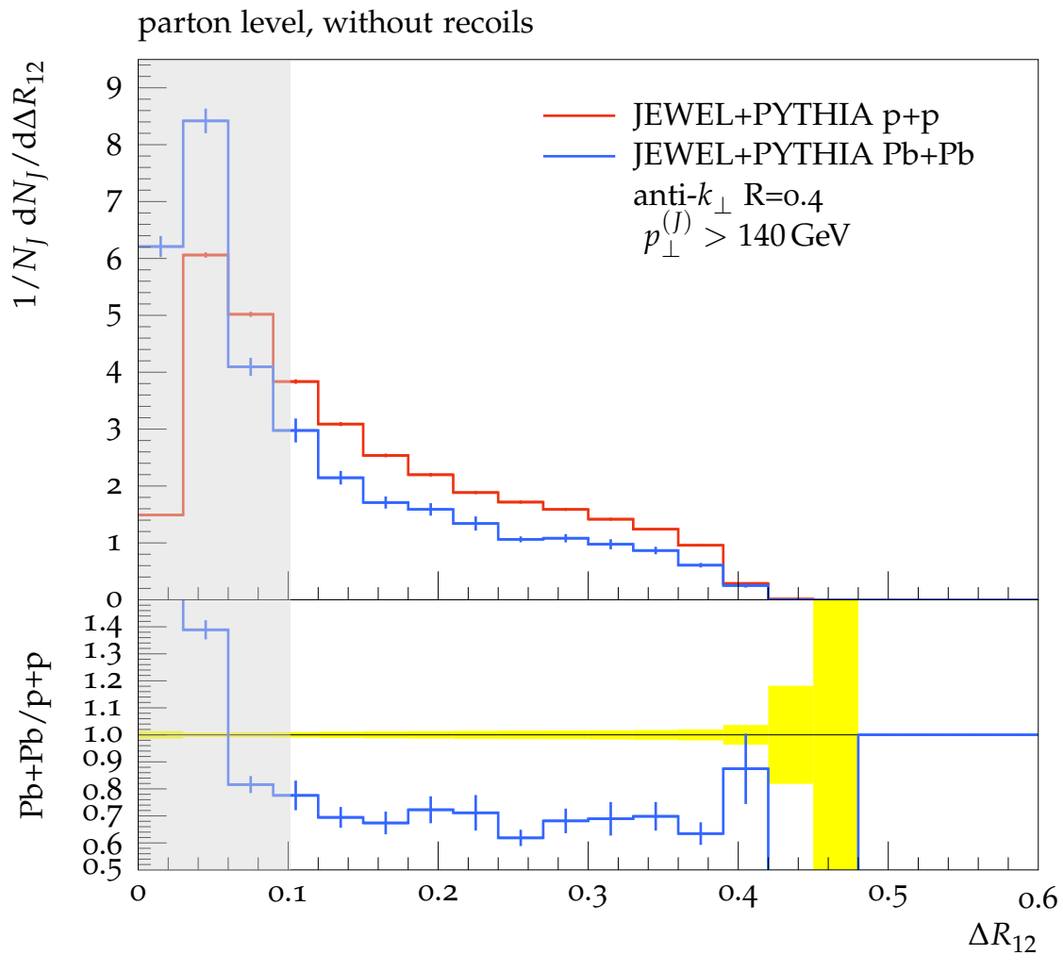


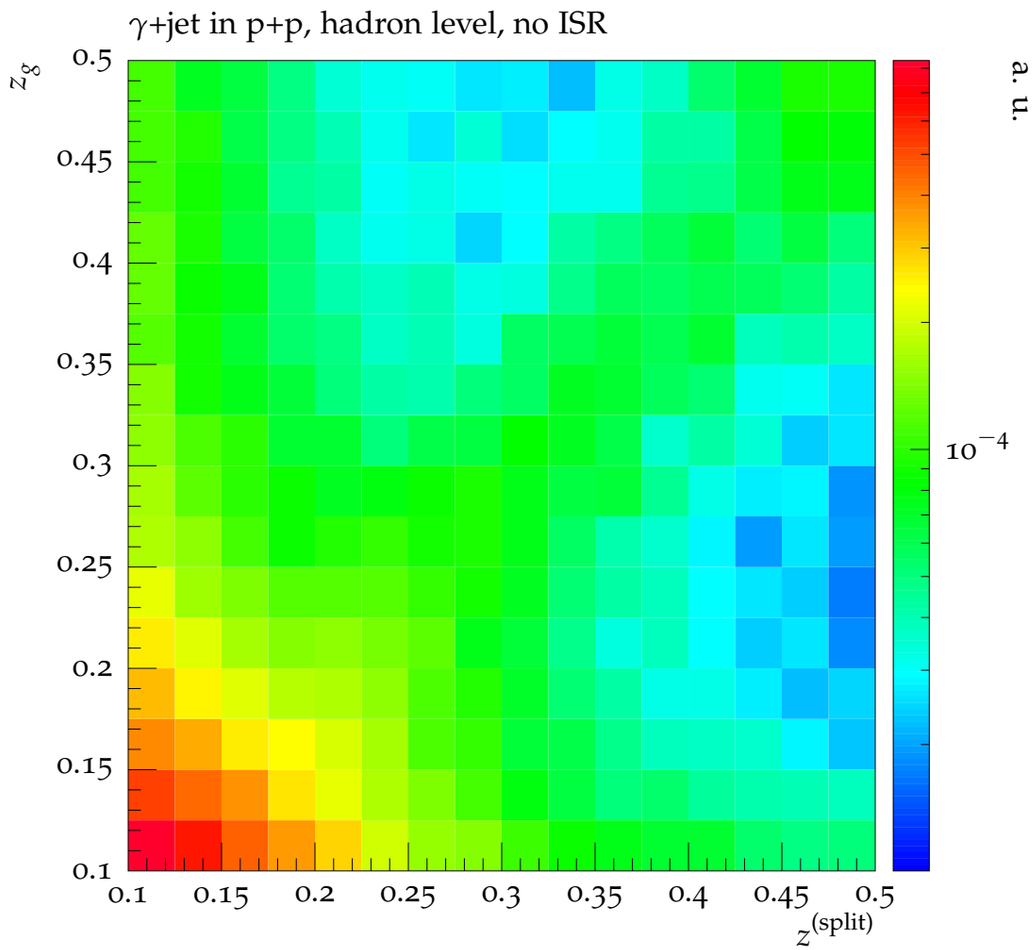


- small modification of z_g distribution from ‘additional splittings’ and ‘energy loss’
- angular distribution narrower in AA [prongs are closer together]
  - jets with softer fragmentation more affected by the medium :: lost from sample :: also seen elsewhere [di-jet asymmetry]

THE LOST JETS

- γ-jet without ISR as cleanest possible environment

THE LOST JETS



- γ-jet without ISR as cleanest possible environment
- z_{split} [the energy sharing of first FSR] well correlated with z_g

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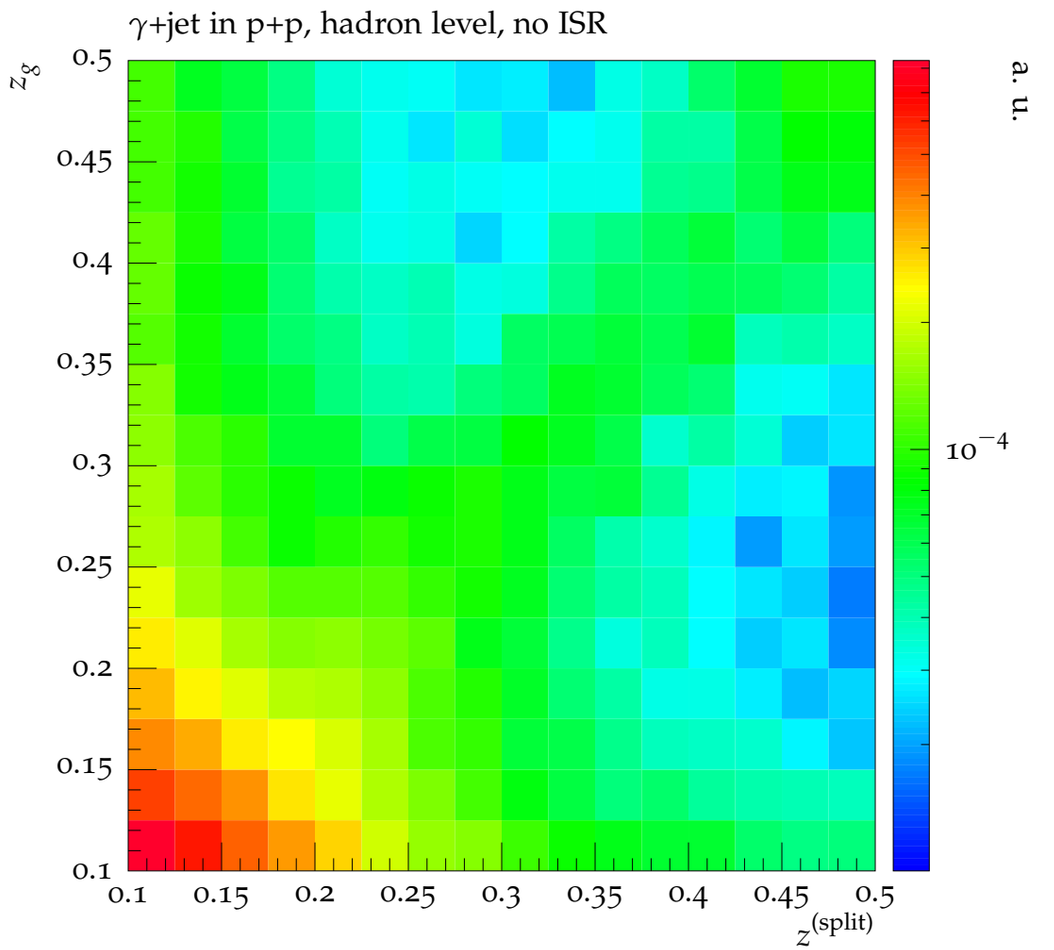

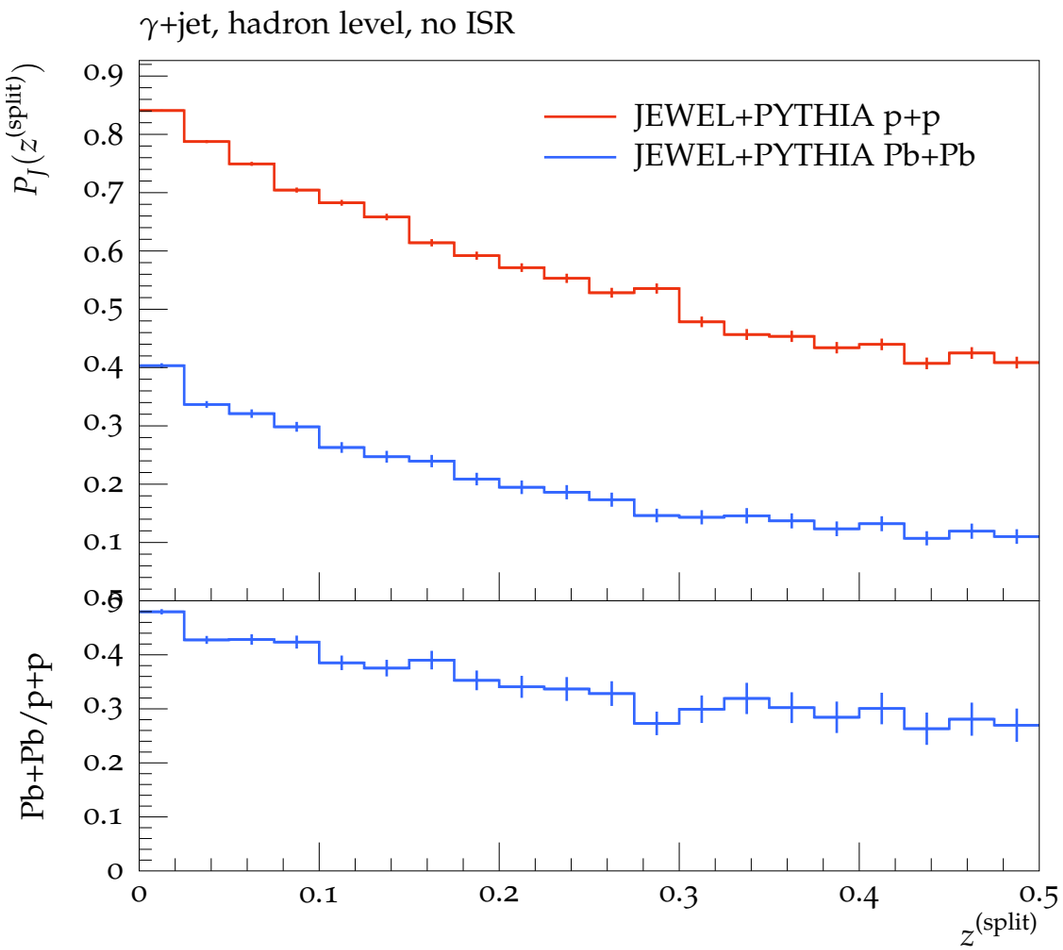

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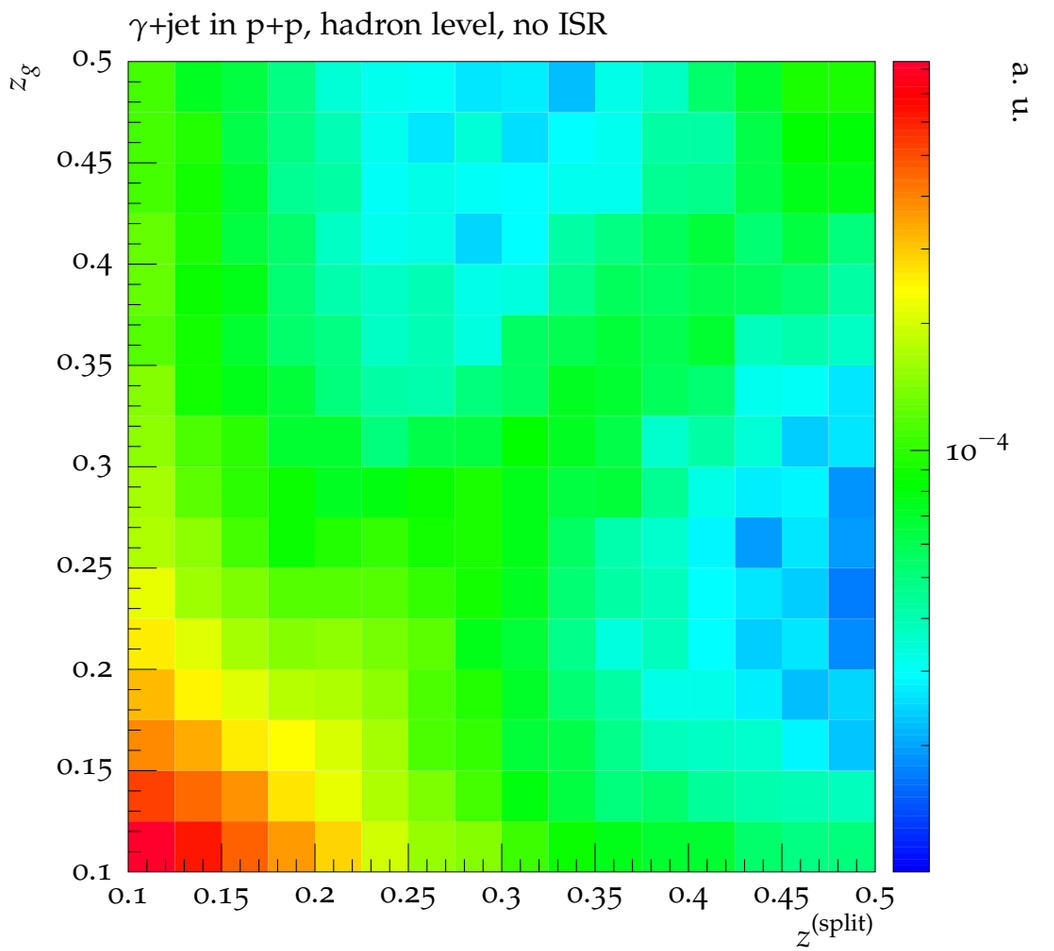
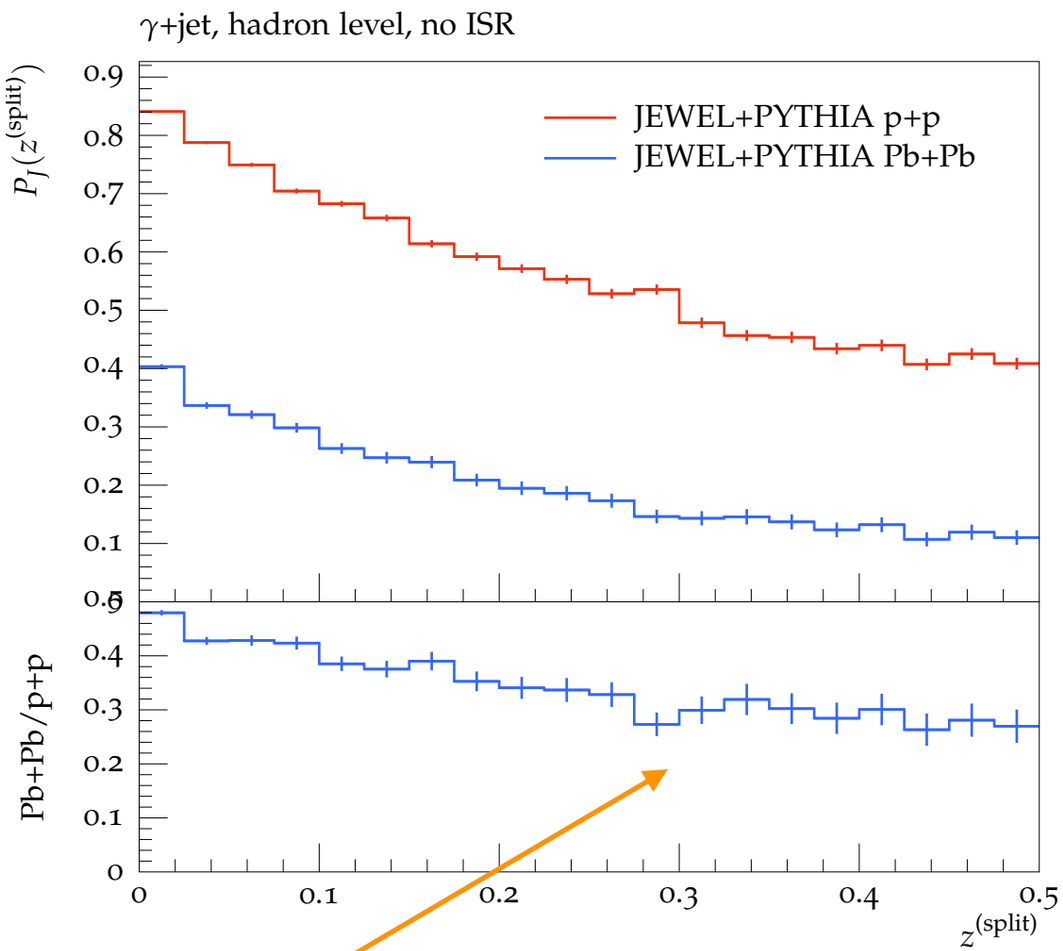
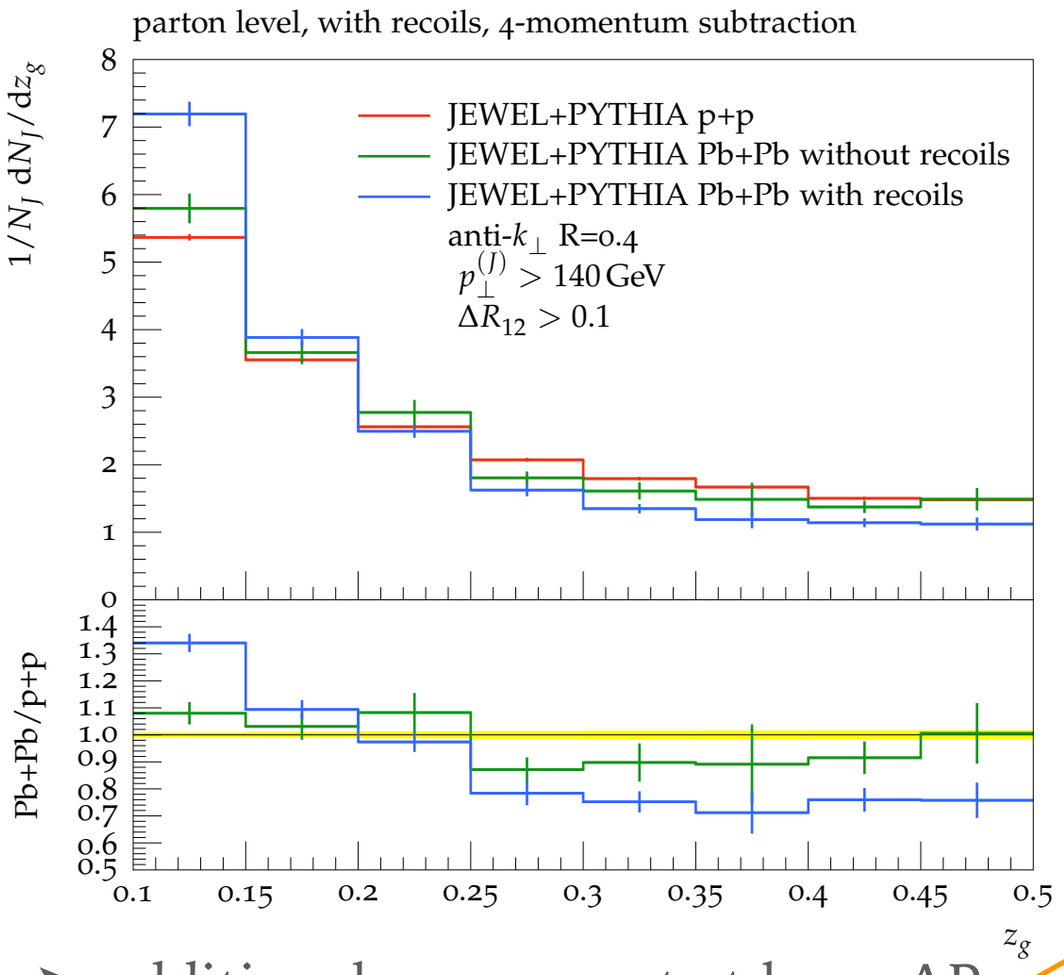
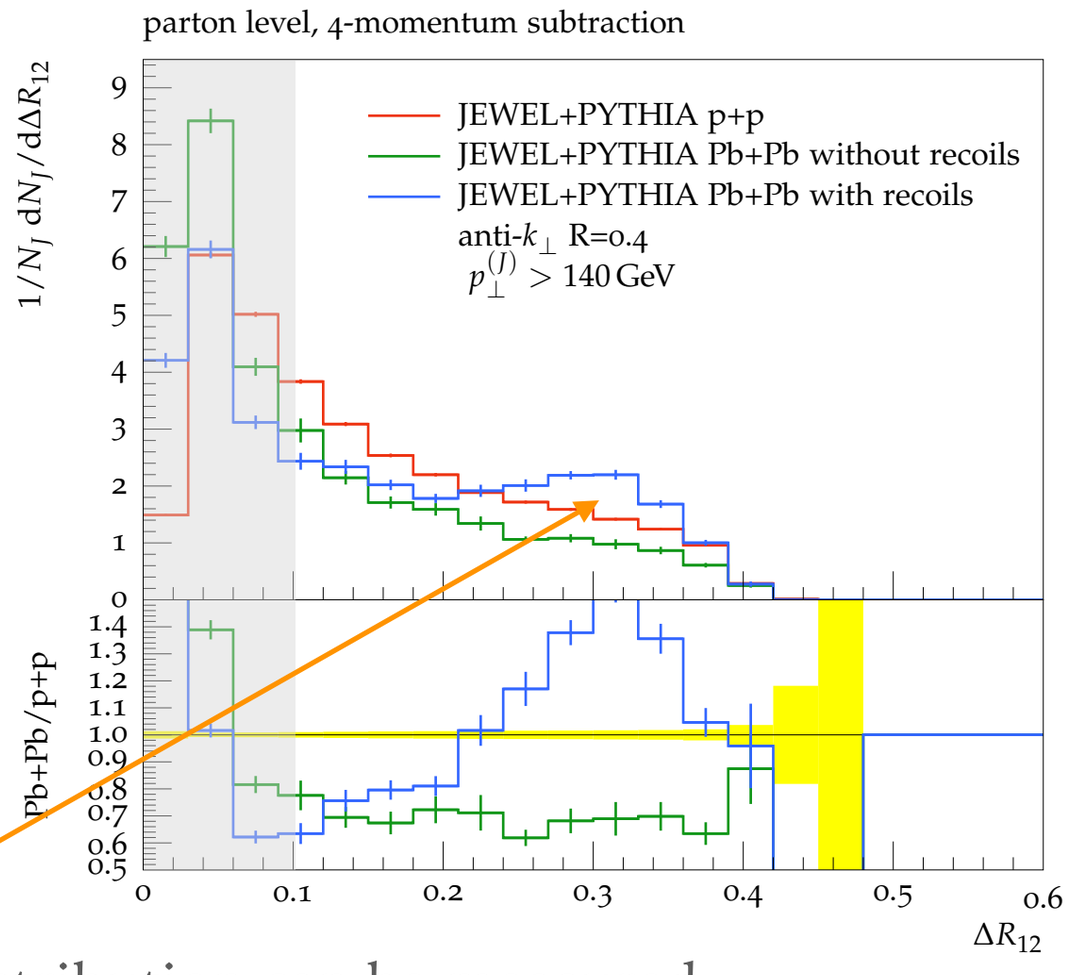




- γ-jet without ISR as cleanest possible environment
- z_{split} [the energy sharing of first FSR] well correlated with z_g
- high z_{split} parton configurations less likely to result in jet with pt>100 GeV
  - effect stronger in AA

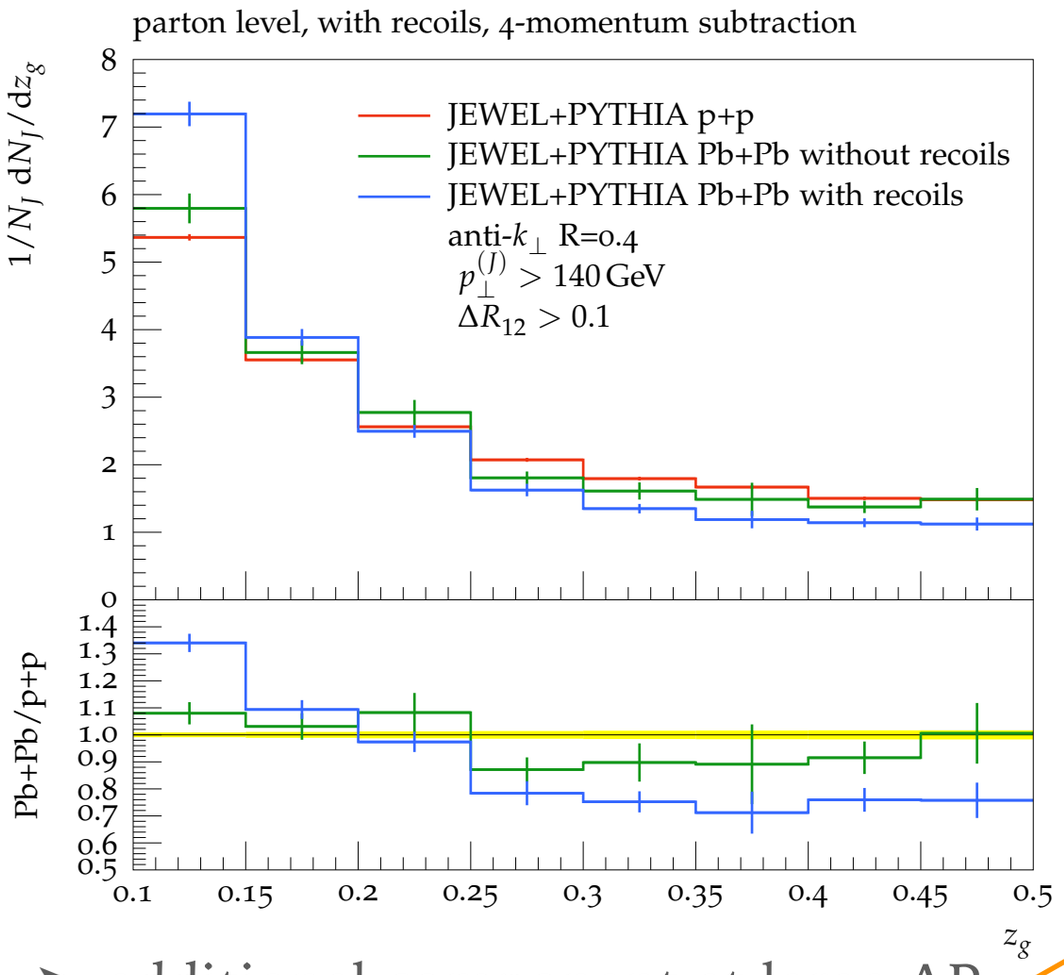
WITH JET-CORRELATED MEDIUM

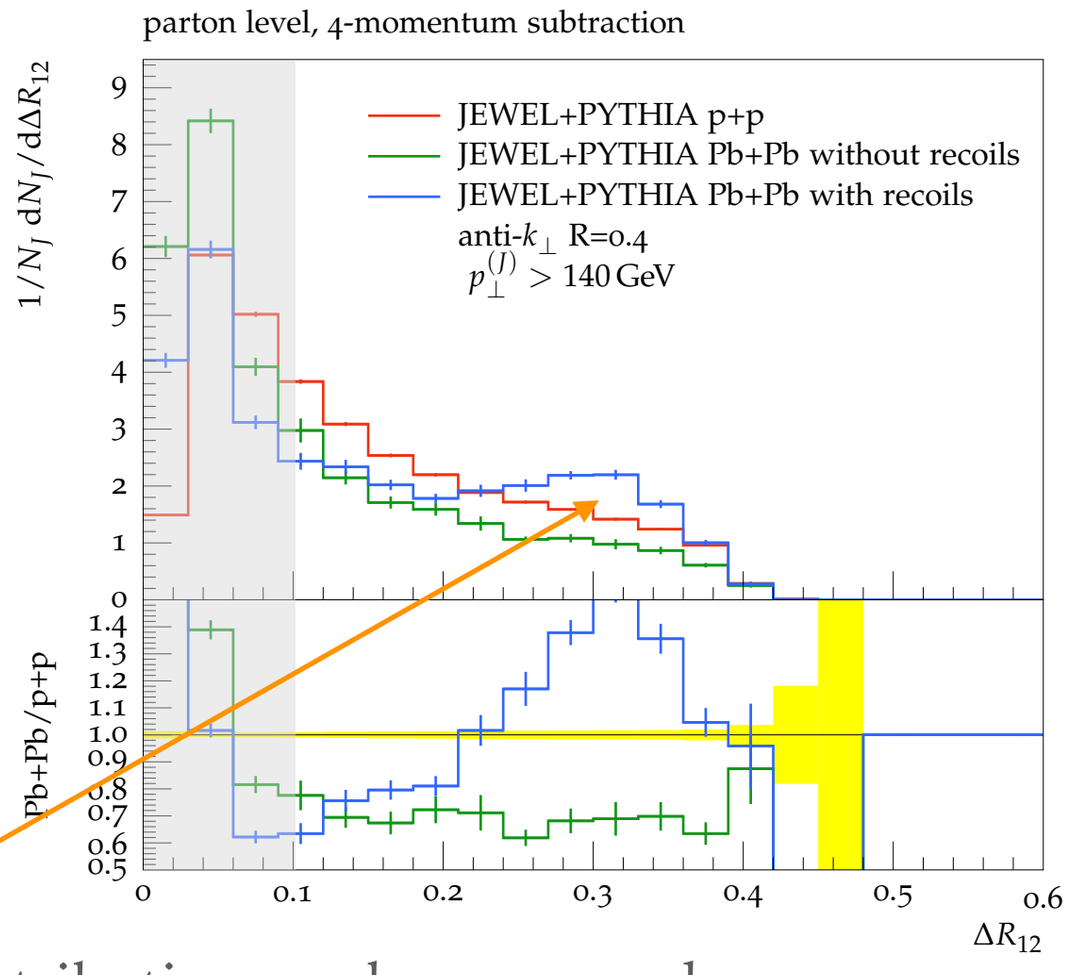




- additional component at large ΔR_{12} :: this distribution can be measured

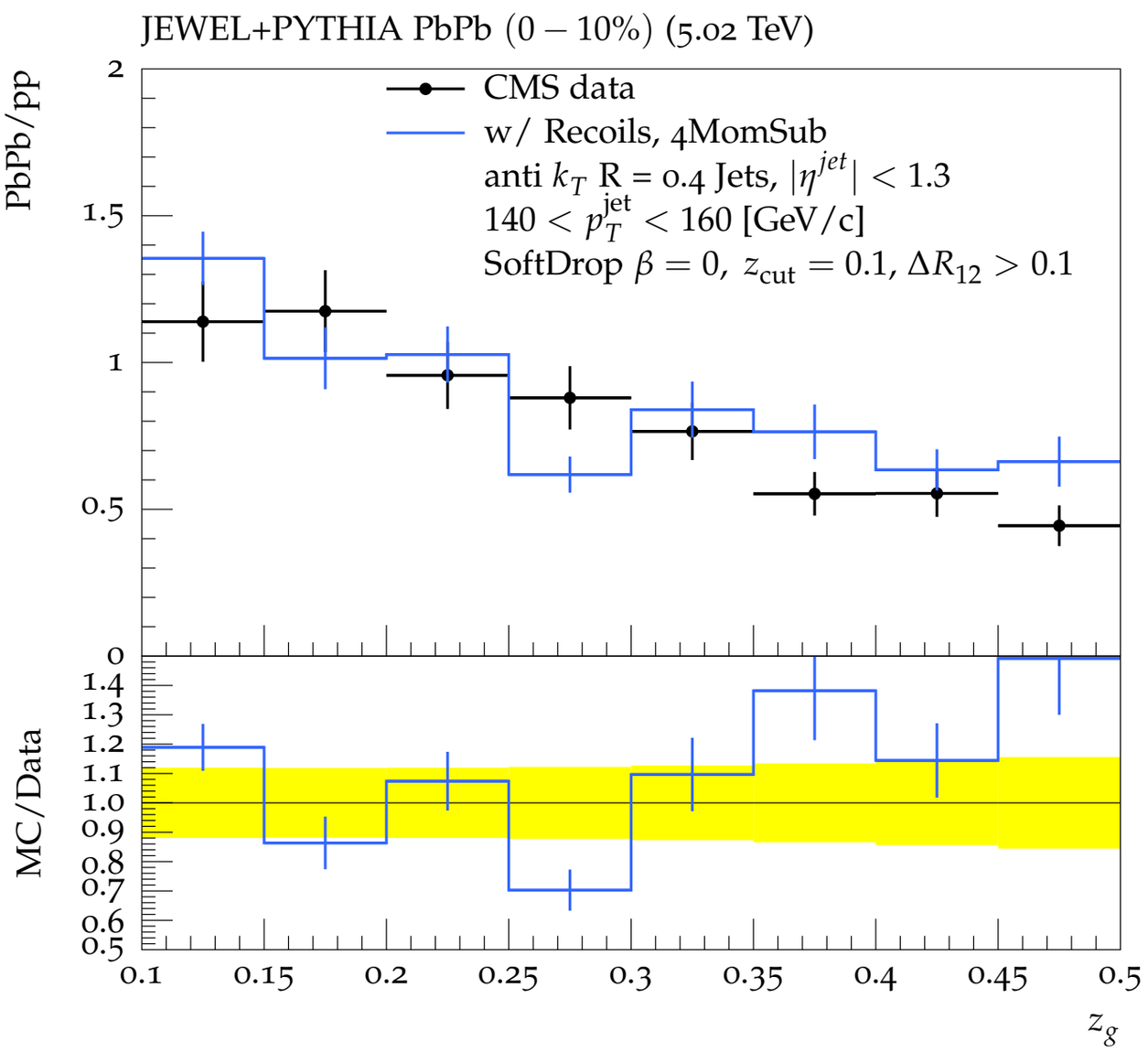
WITH JET-CORRELATED MEDIUM





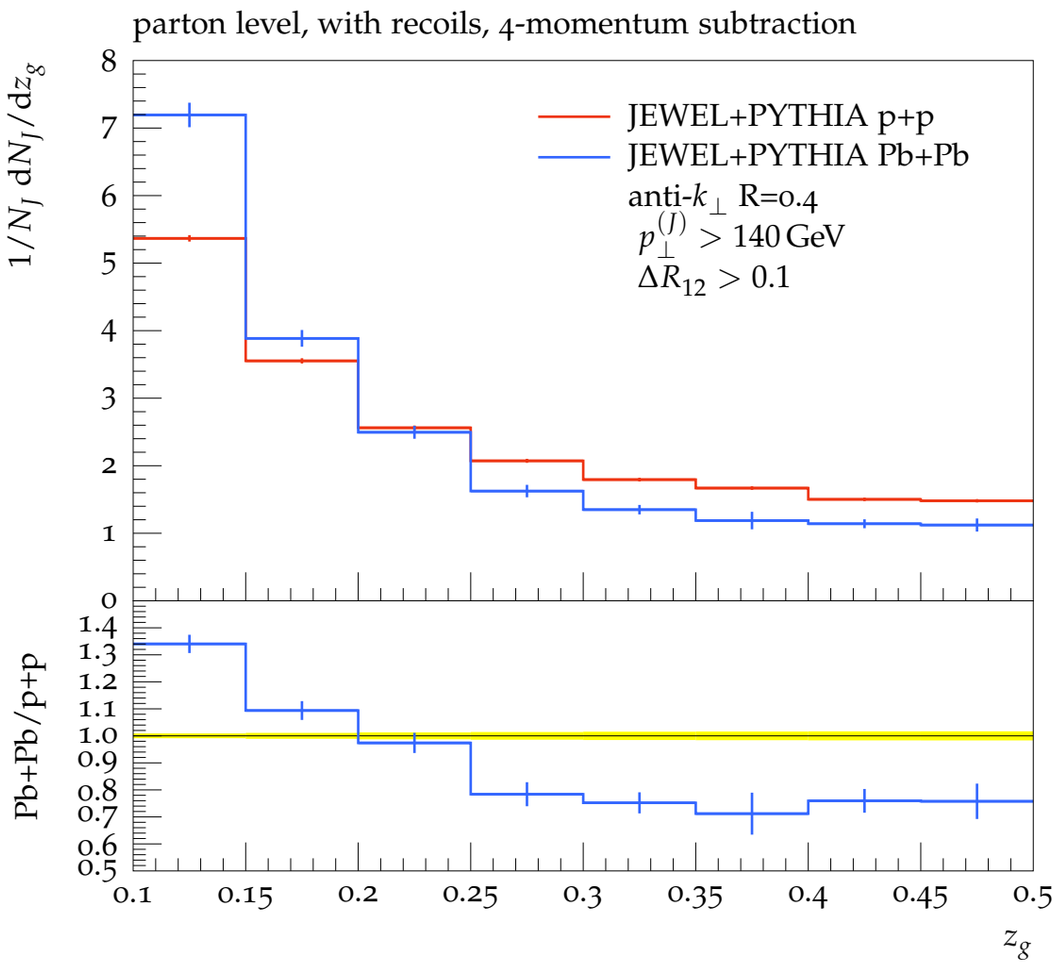
- additional component at large ΔR_{12} :: this distribution can be measured
  - predominantly low z_g
    - correlated background [medium response] spread out over large angles
    - **z_g distribution is steeply falling, additional $p_\perp$ from correlated background [recoils] in sub-leading prong promotes configurations above z_{cut}**

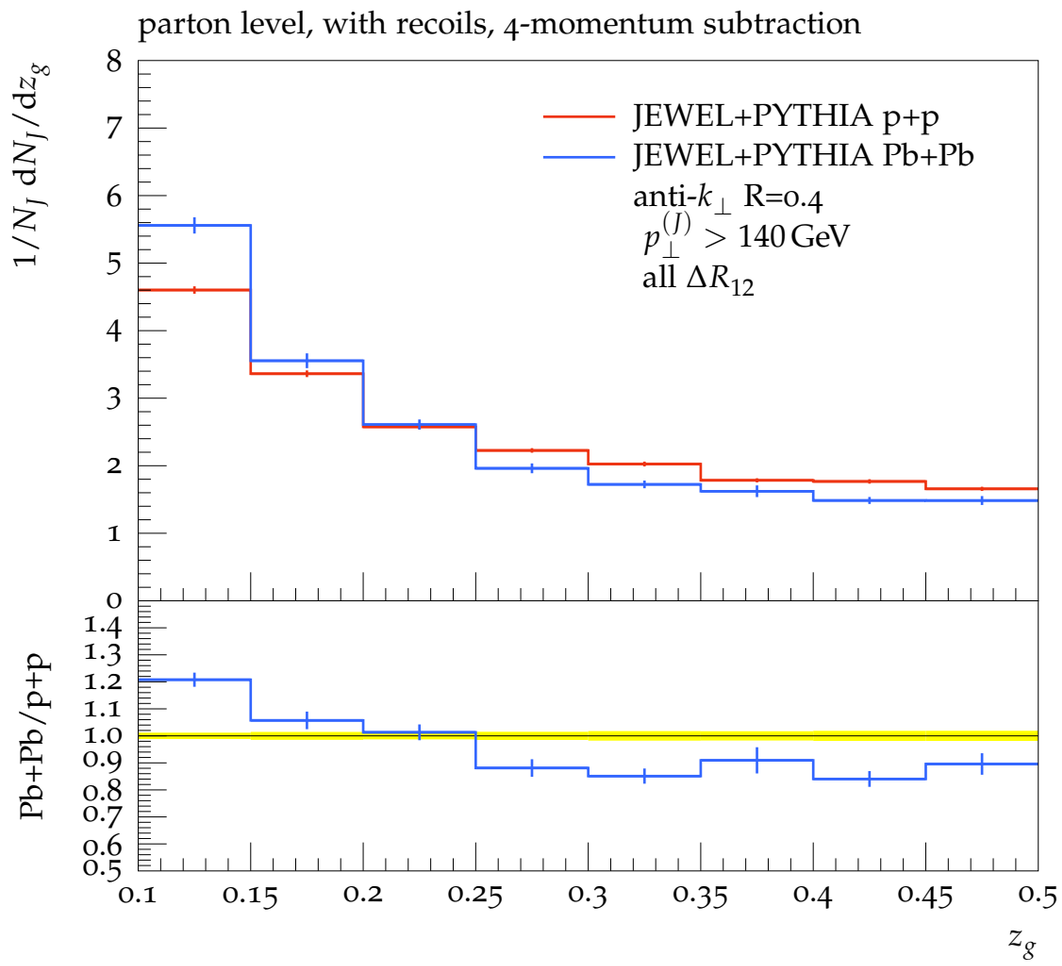
WITH JET-CORRELATED MEDIUM



- effect seen in CMS data compatible with promotion of below z_{cut} configuration into the sample

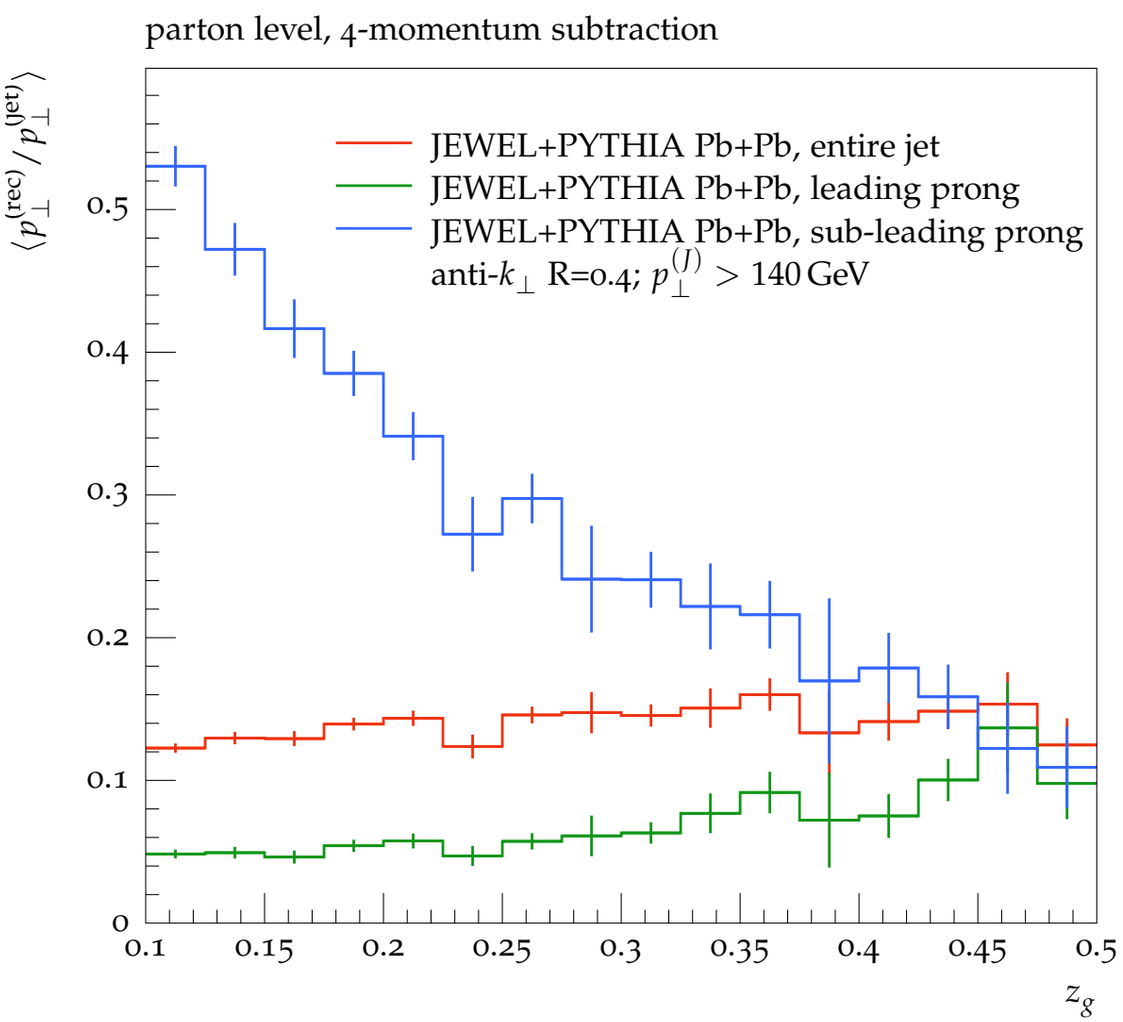
EFFECT OF ANGULAR CUT





- ΔR_{12} cut responsible for significant part of the modification
  - removes ~50% of events from sample
  - jets with narrower configurations [harder fragmentation] less modified
  - STAR does not impose cut [is that why no modification is seen?]

MOMENTUM FRACTION DUE TO JET-CORRELATED MEDIUM



- much more important for sub-leading prong and for low z_g
- absolute $p_\perp$ due to jet correlated medium weakly dependent on z_g [not shown]
- consistent with modification of z_g distribution being due to promotion of below z_{cut} configurations

A CROSS-CHECK: GIRTH

$$g = \sum_i \frac{p_{\perp,i}\,\Delta R_{ij}}{p_\perp^J}$$

first radial moment of the intra-jet $p_\perp$ distribution

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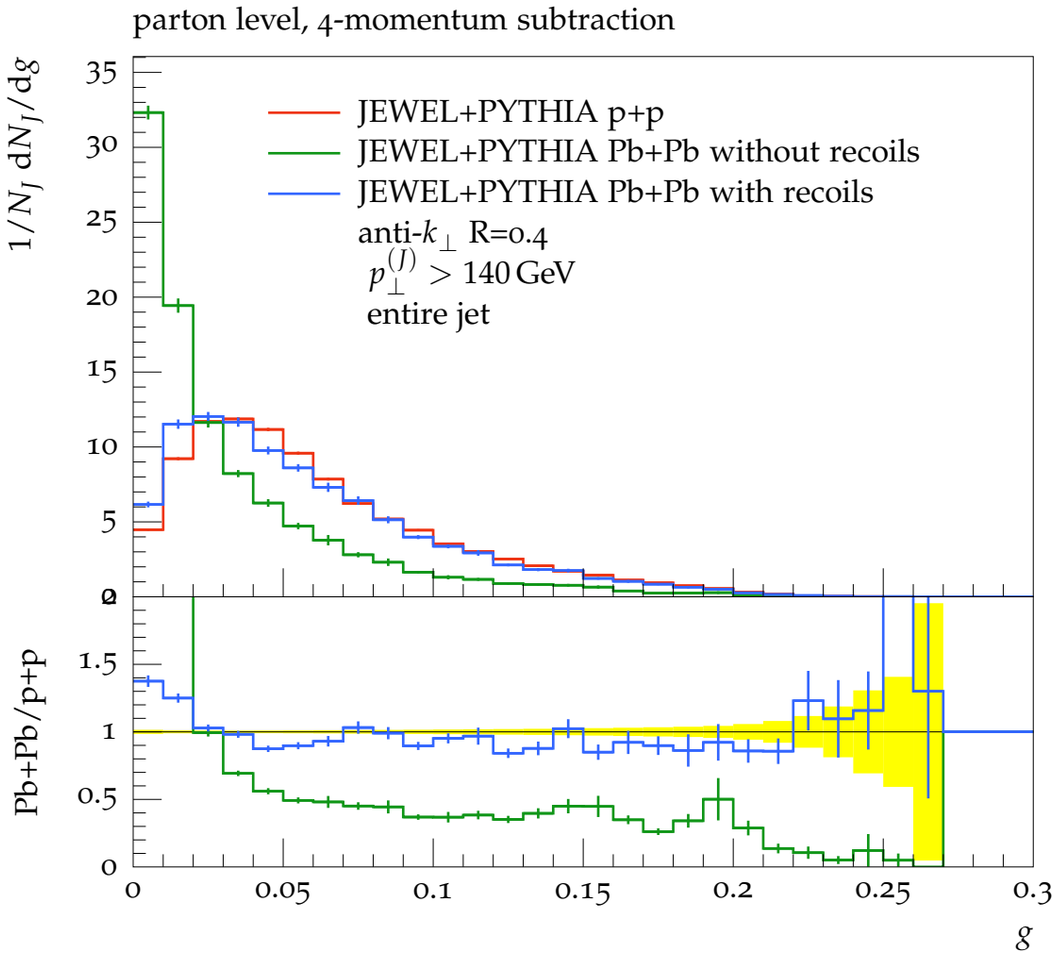

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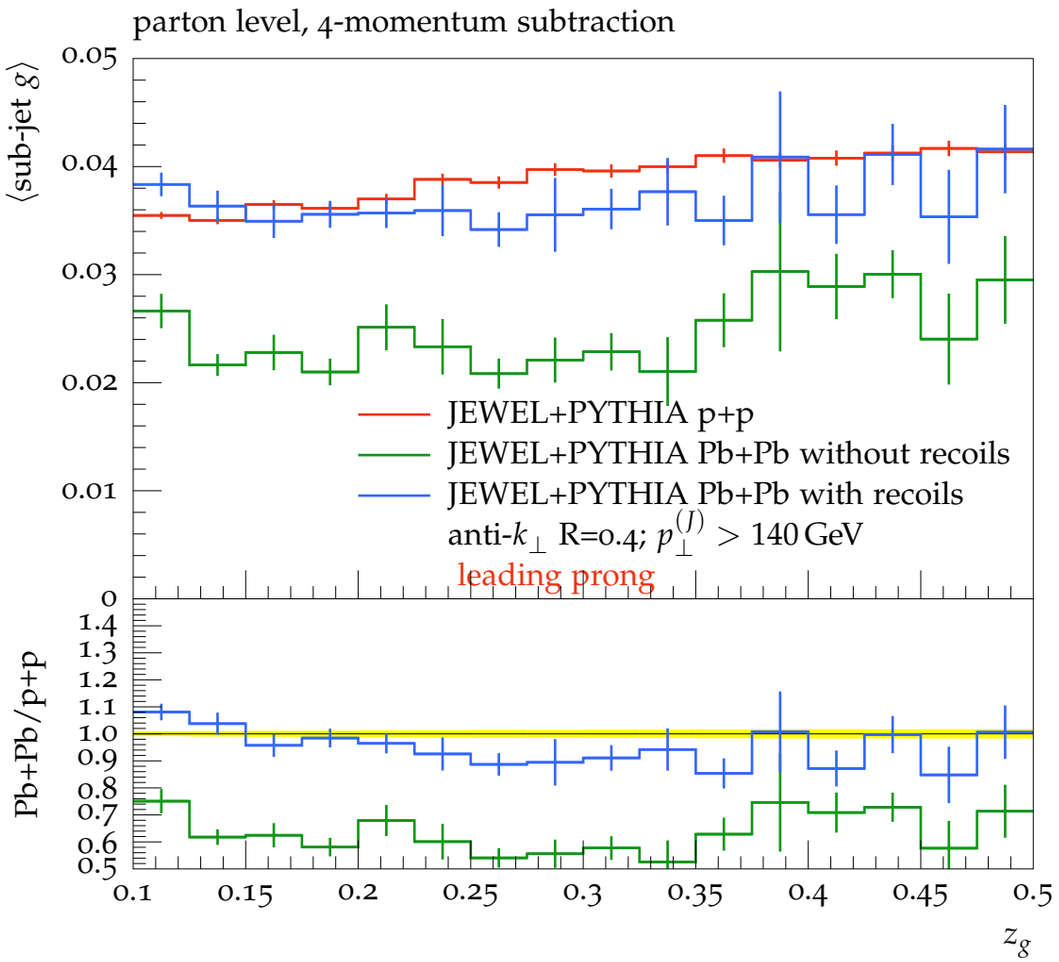
first radial moment of the intra-jet $p_\perp$ distribution

- negligible modification of whole jet girth [ALICE QM 2015] is compound effect of narrowing and re-population with jet-correlated background

A CROSS CHECK: THE GIRTH OF PRONGS



- girth of leading prong [jet core] unmodified and z_g independent :: narrowing and re-population as for whole jet

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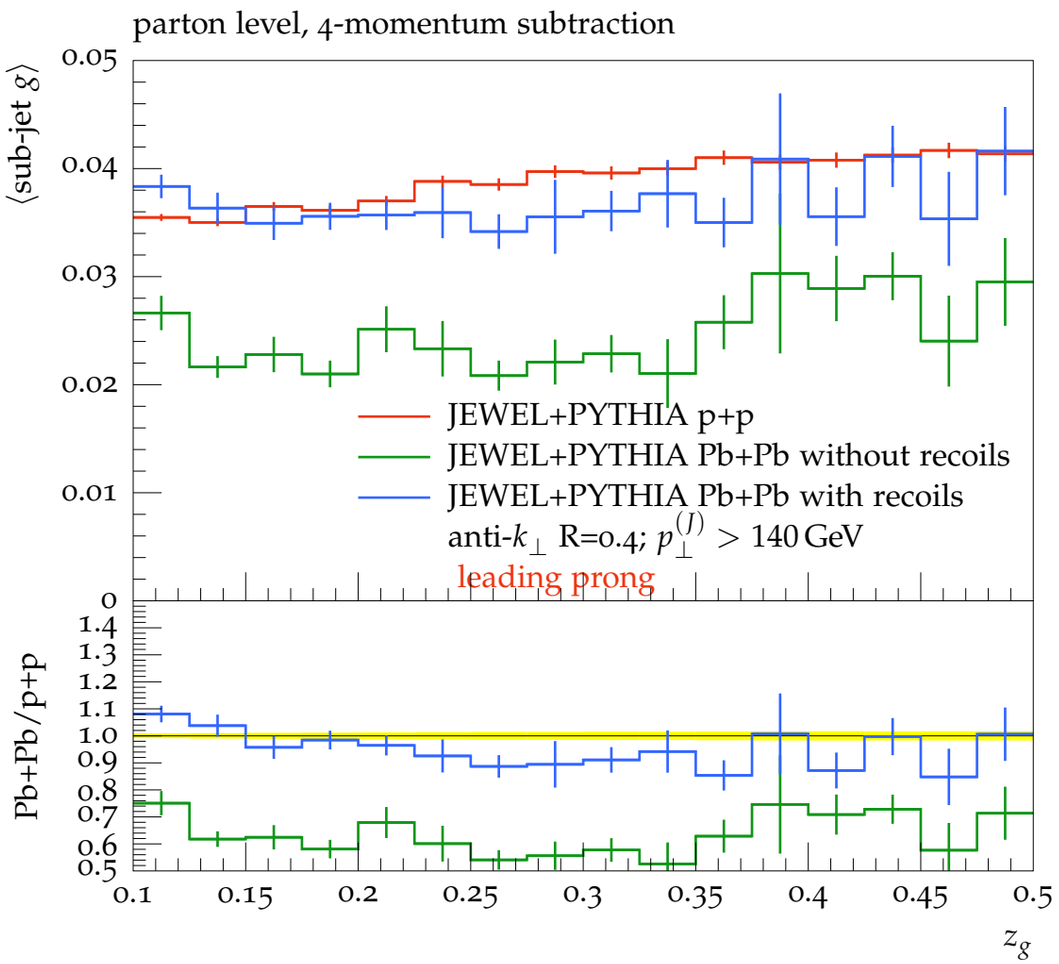

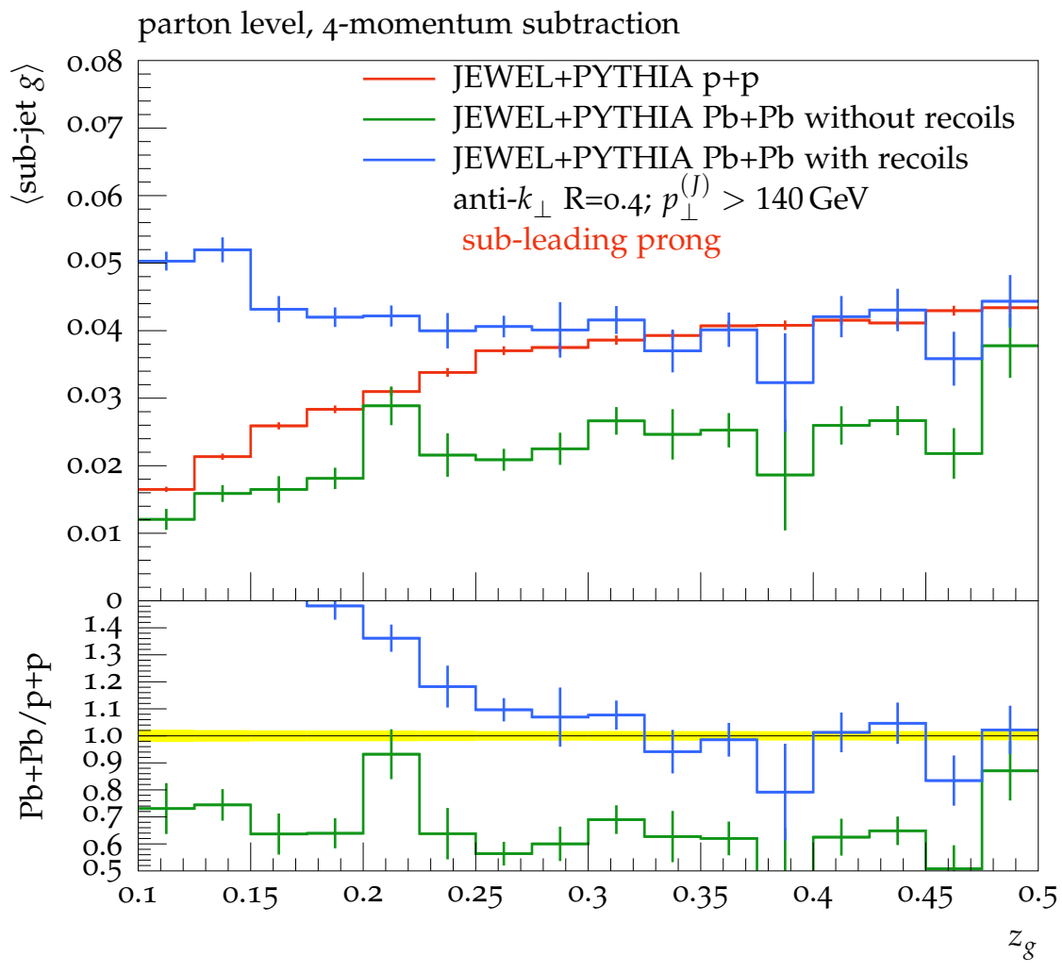

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- girth of sub-leading prong z_g-dependent in pp

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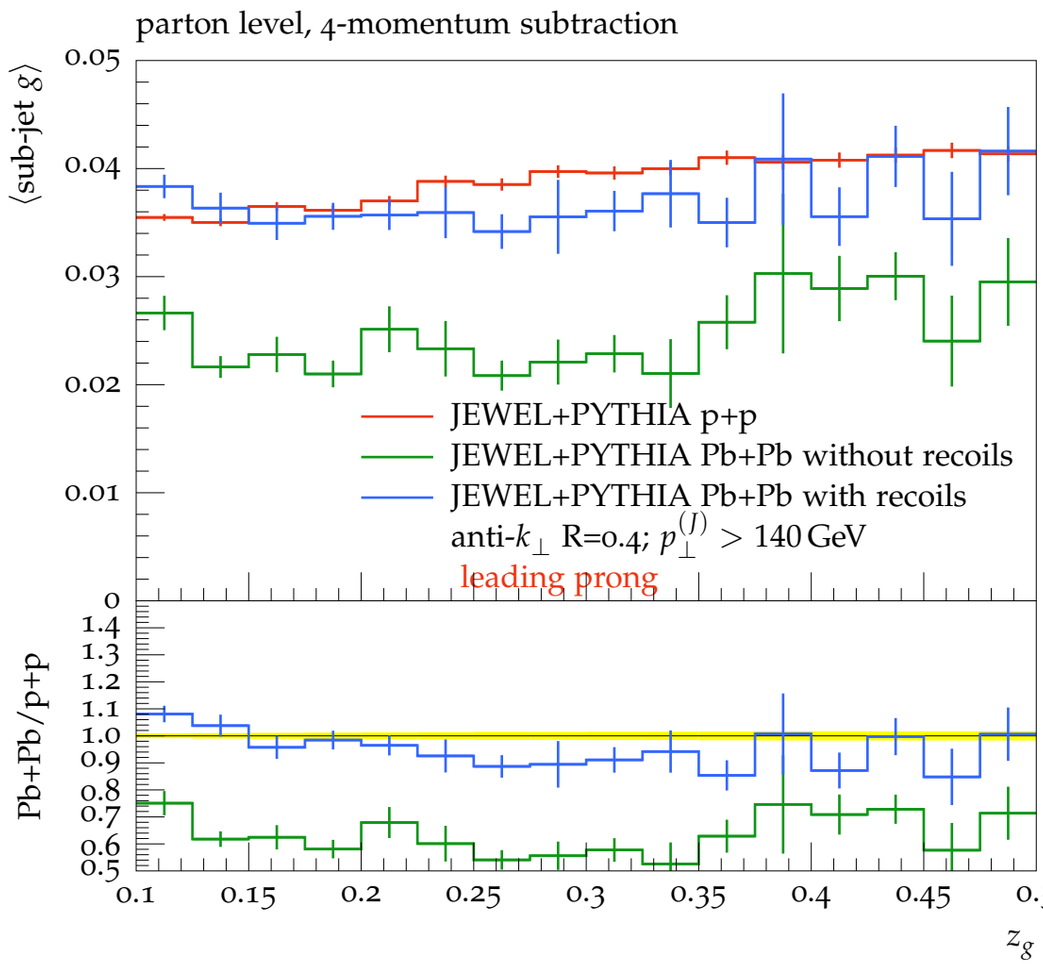

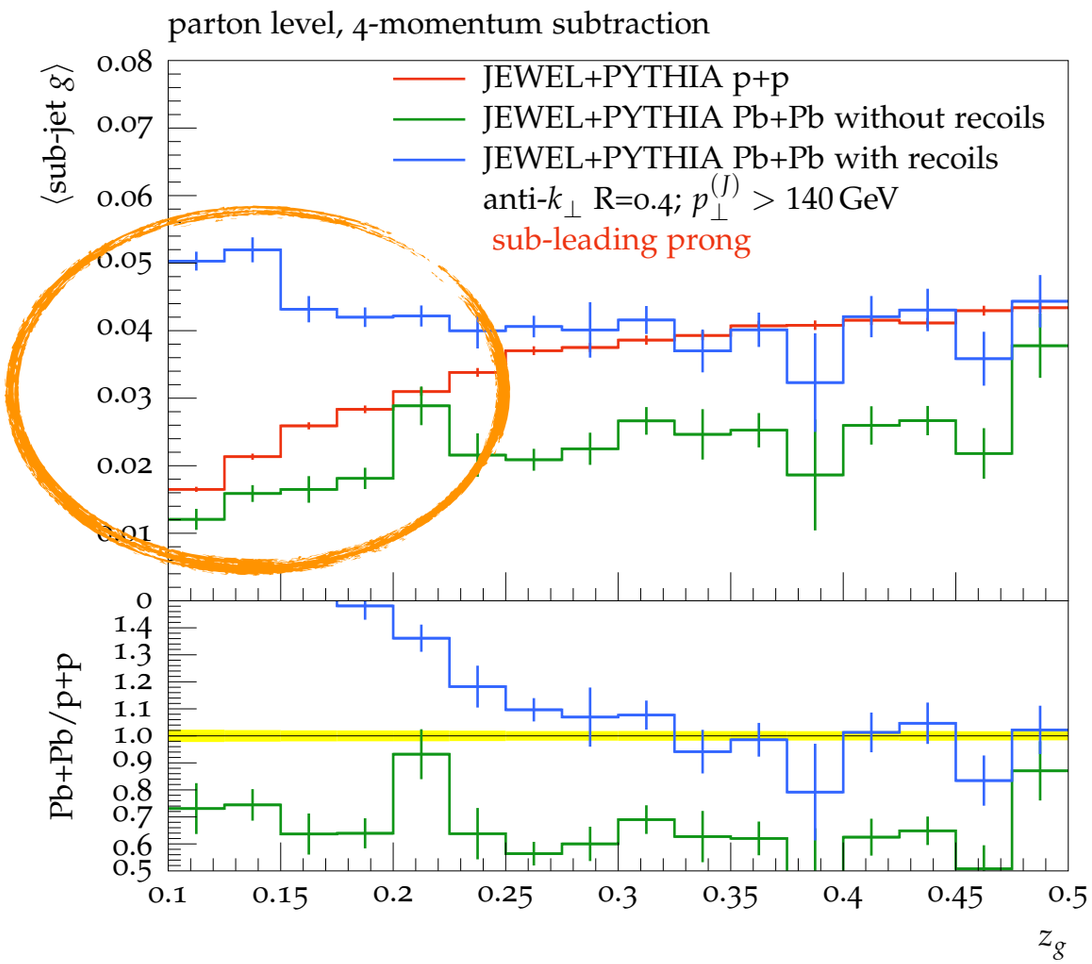

- girth of leading prong [jet core] unmodified and z_g independent :: narrowing and re-population as for whole jet
- girth of sub-leading prong z_g-dependent in pp
  - re-population a very large effect for low z_g

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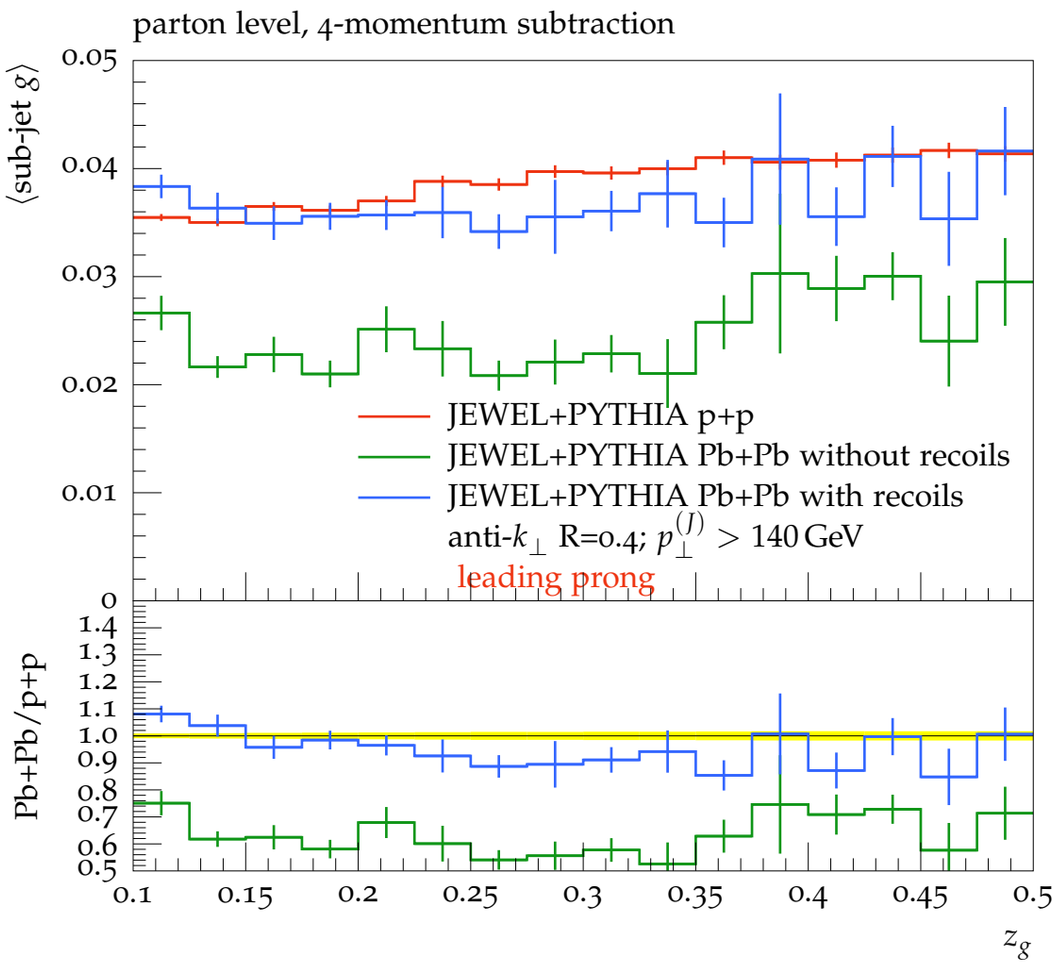

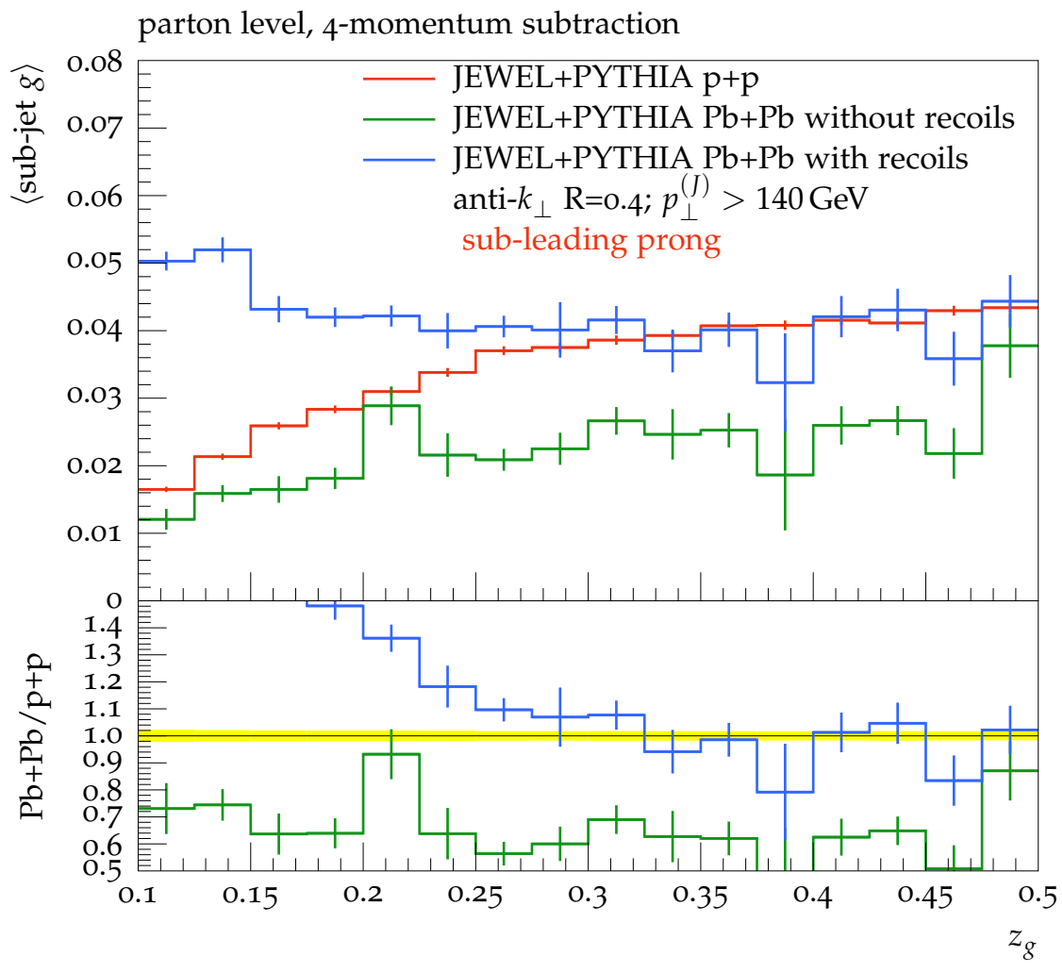

- this can be measured…
- modification of girth distribution of sub-leading prong should be unique to jet-correlated medium mechanism

OUTLOOK

- understanding of sensitivity of observables crucial for success of QGP probing program with jets
- jet sub-structure observables sensitive to dynamical details of jet-medium interaction
- grooming techniques will likely prove invaluable in jet quenching studies
- z_g arguably sensitive to response of medium to interaction with jet
  - first example of direct sensitivity to medium details
- importance of correlated medium contribution to jet sub-structure observables is testable