High p_T/hard processes in small systems

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Jetscape workshop

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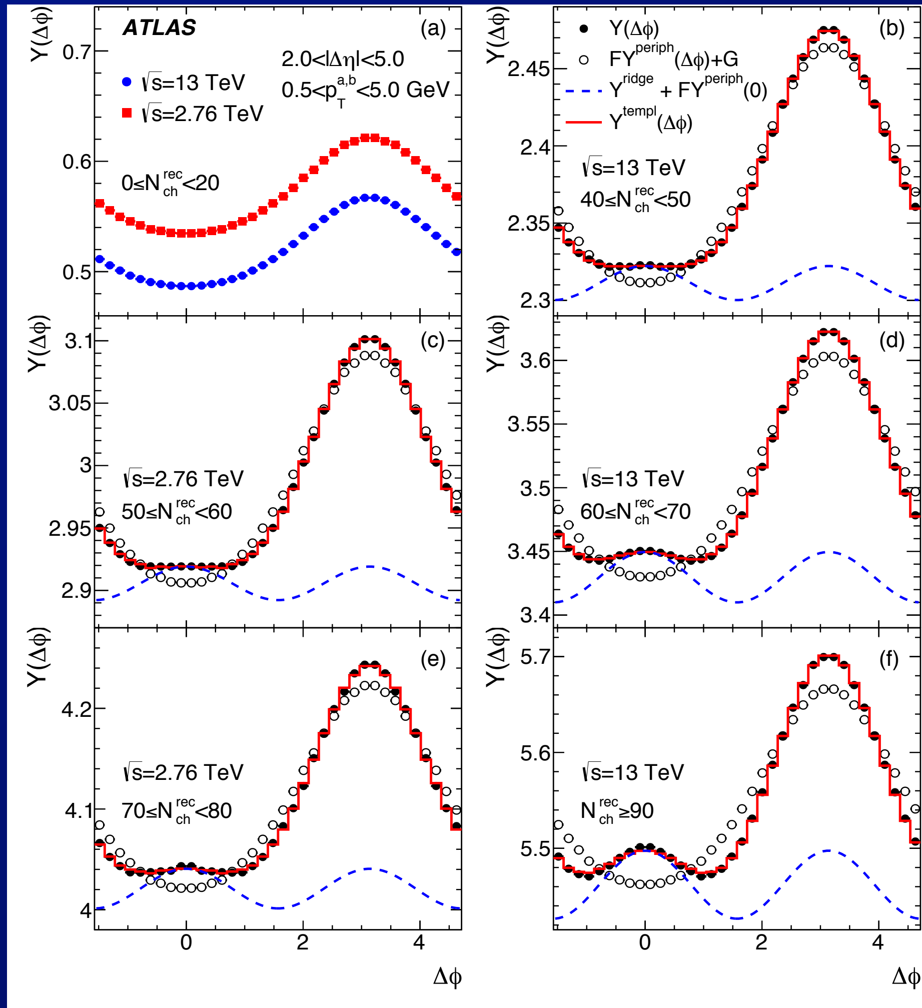
Overview

- Like Gunther, I am going to take the prerogative of a senior (grizzled, grey haired & bearded) physicist to:
  - not attempt a comprehensive summary of data
  - not be “fair” in what data I select
  - talk about what I want to talk about
- What do I want to talk about?
  - MPI in (e.g.) pp
    - ⇒ experimental evidence?
  - jet quenching/lack thereof in p+Pb collisions
    - ⇒ why this might not be surprising
  - hard-soft correlations beyond Glauber/WN
    - ⇒ why these should not be surprising
  - pose some answerable (I hope) questions.

MPI in pp collisions

MPI in pp collisions?

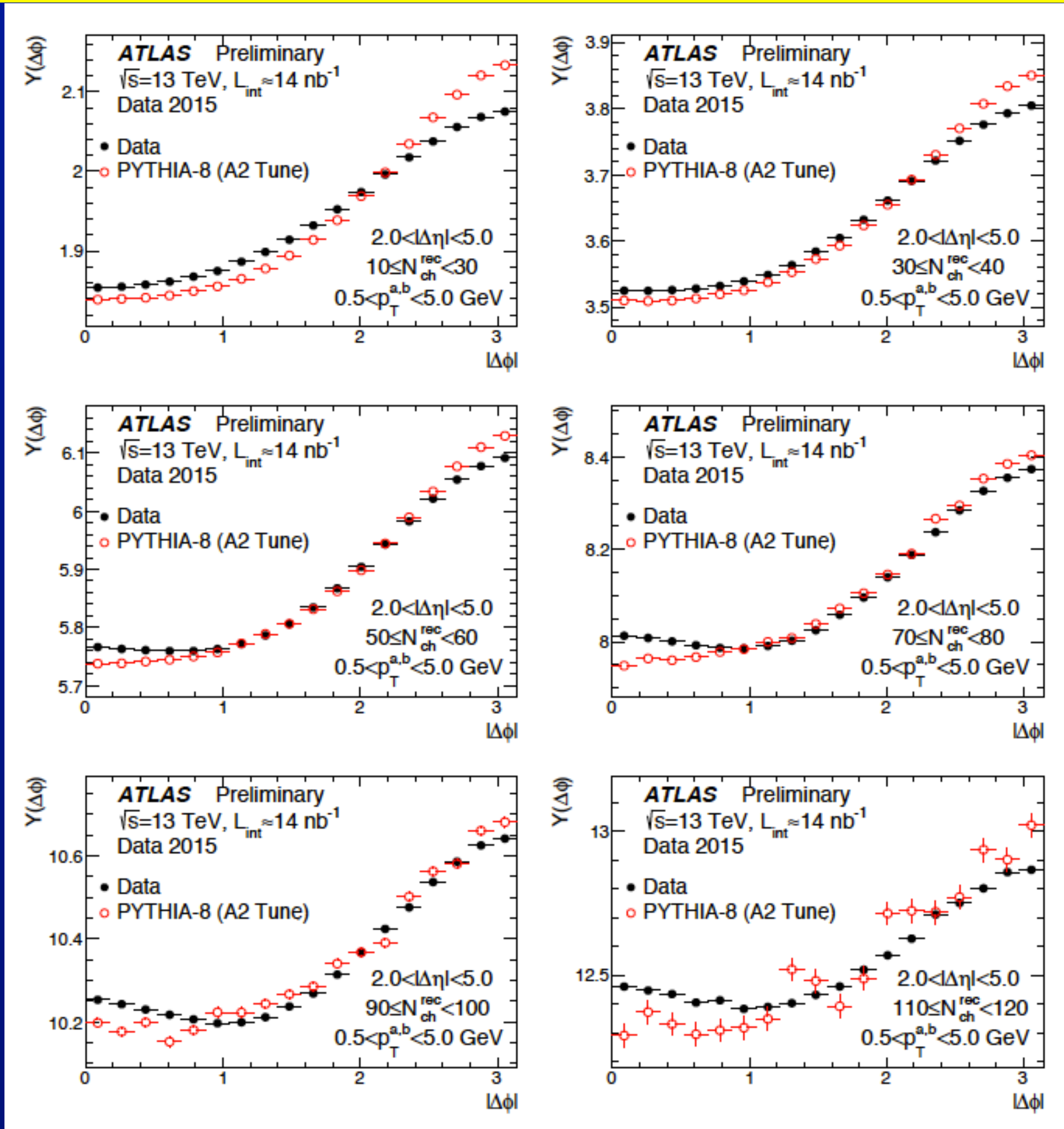
- To what extent does hard physics contribute to low-p_T / "minimum-bias" physics
  - e.g. in Pythia, MPI important at LHC energies
    - ⇒consistent with data?
    - ⇒go back to ATLAS analysis of 2-particle correlations in pp



- Implicit assumption:
  - 2-particle correlation for given multiplicity a sum of scaled "hard" component + v_2 term
    - ⇒empirically: works well, better than it should(?)

Compare data to Pythia

From ATLAS conf note, didn't make it into paper …



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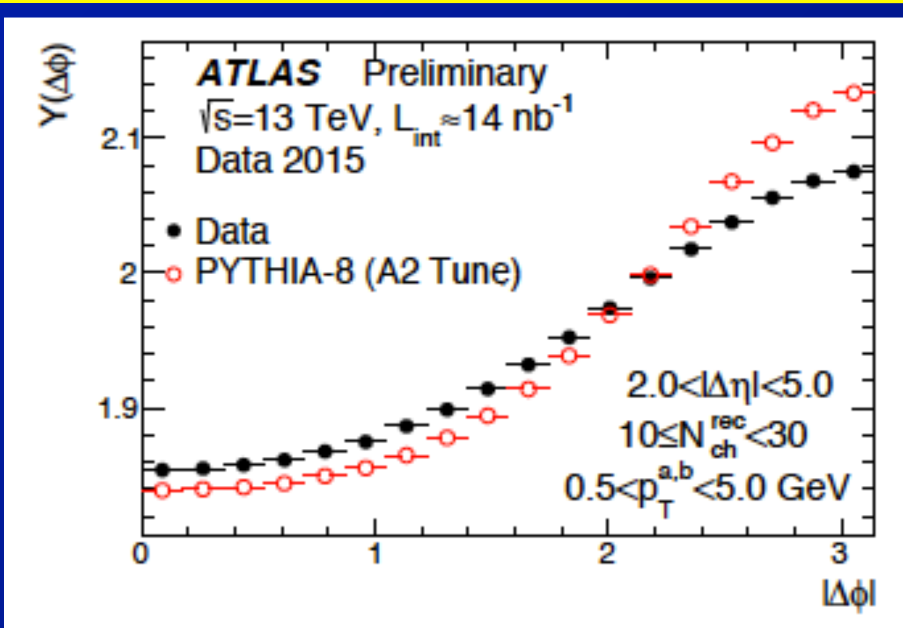
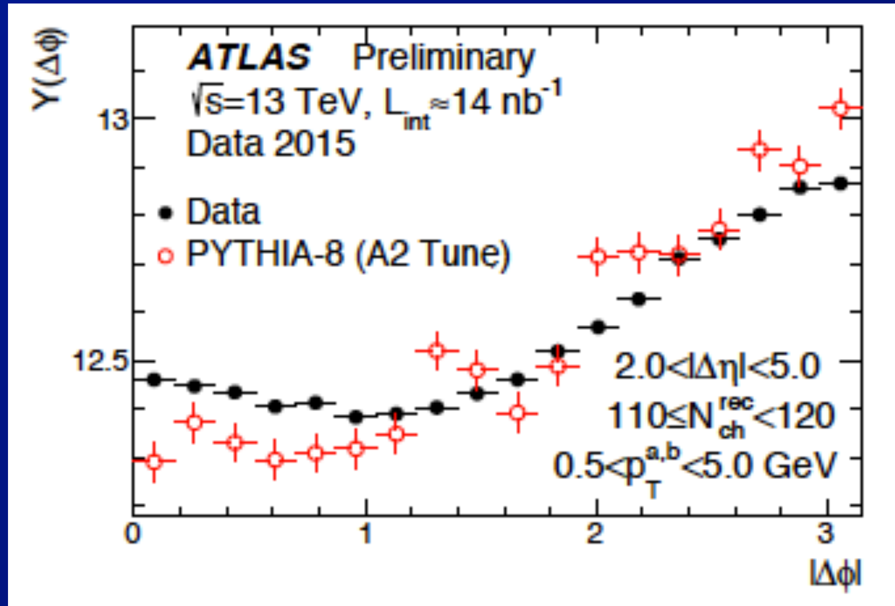
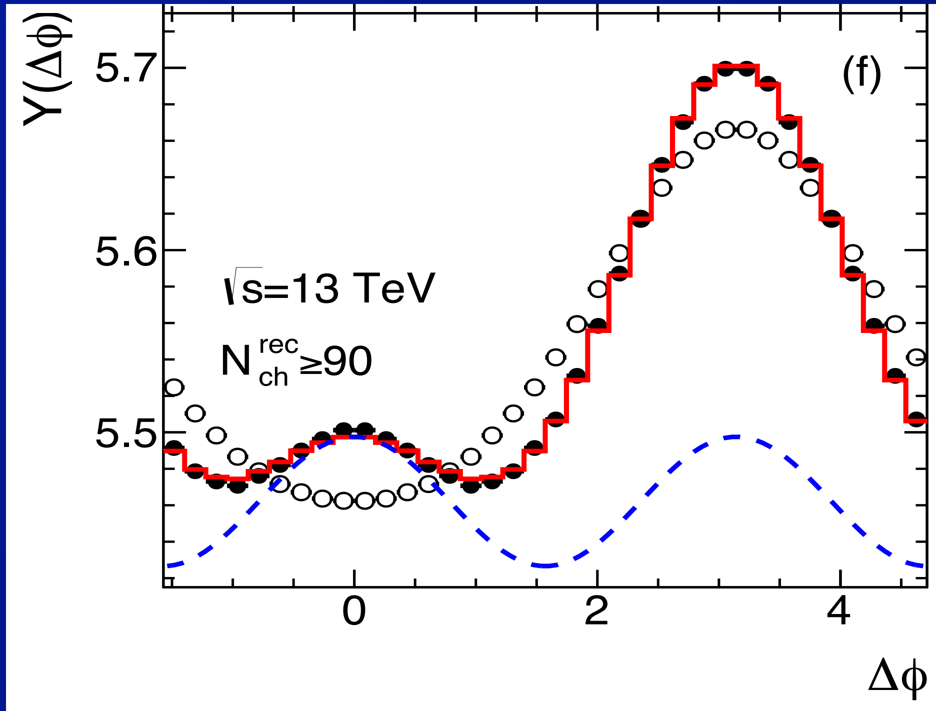




- Comparison of data, Pythia per-trigger yields in (left) low (10-30) and (right) high (110-120)
  - In Pythia, the away-side peak gets broader with increasing multiplicity — expected from MPI

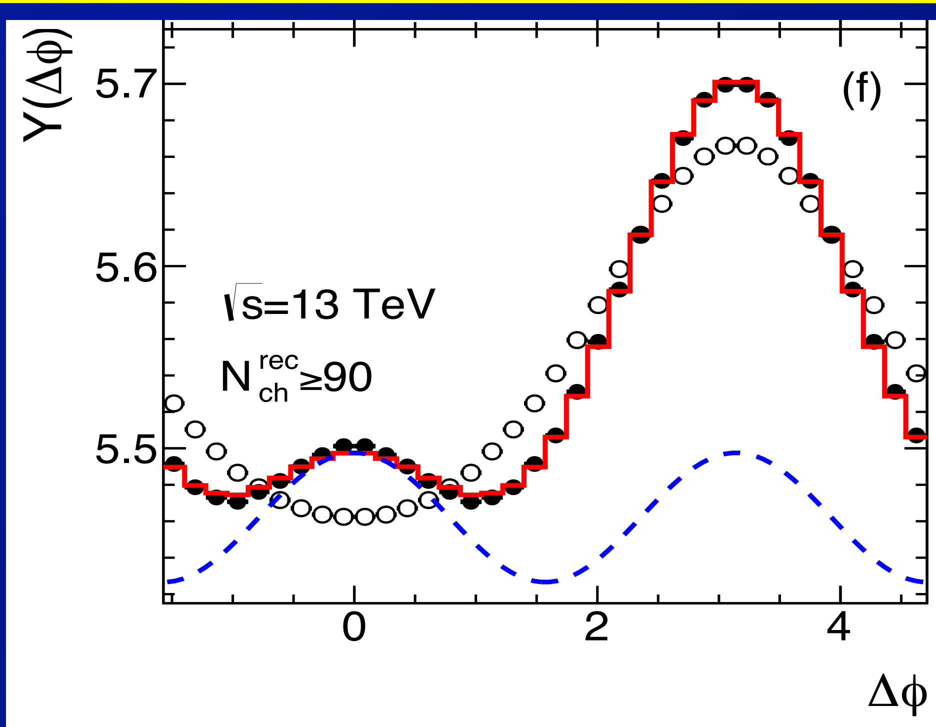
MPI in pp collisions?



- **But in the data, the away-side correlation gets narrower with increasing multiplicity**
  - we need to continually remind our high-energy colleagues that "flow" (for lack of better word) has a significant impact on the underlying event

⇒ not in any event generator

MPI in pp collisions?



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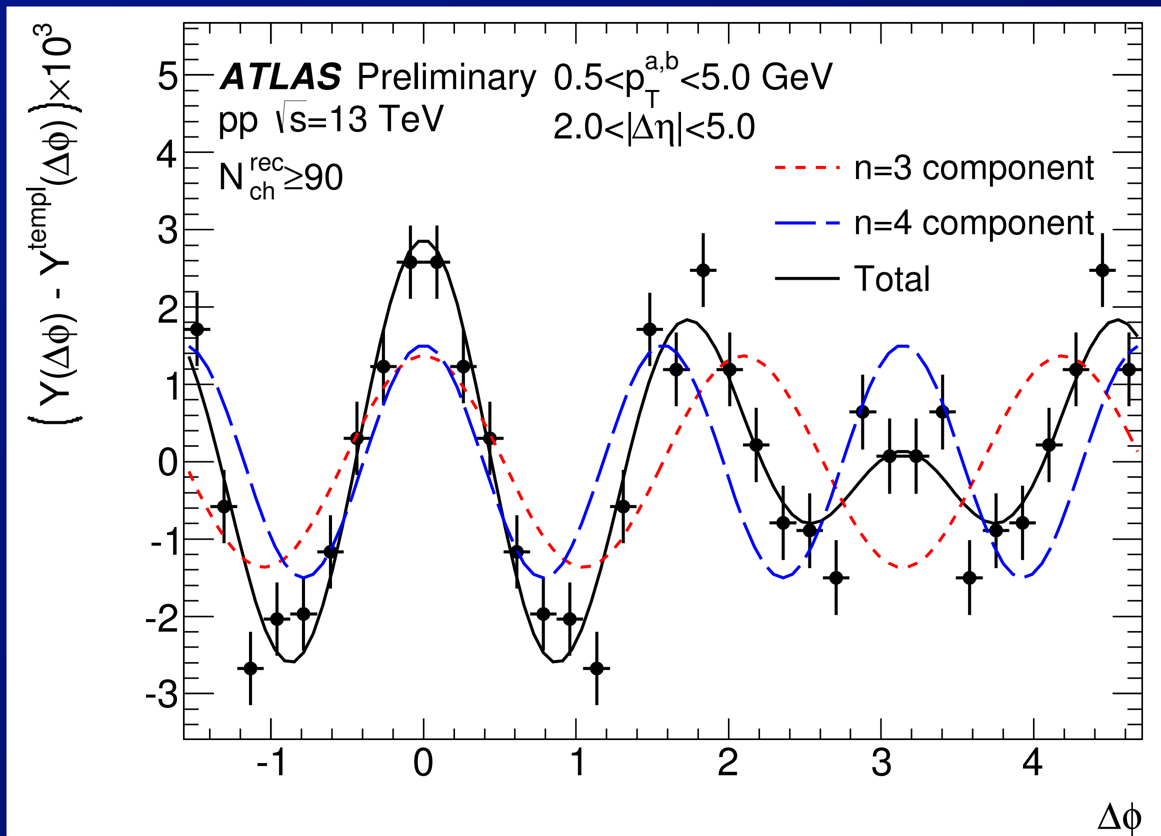
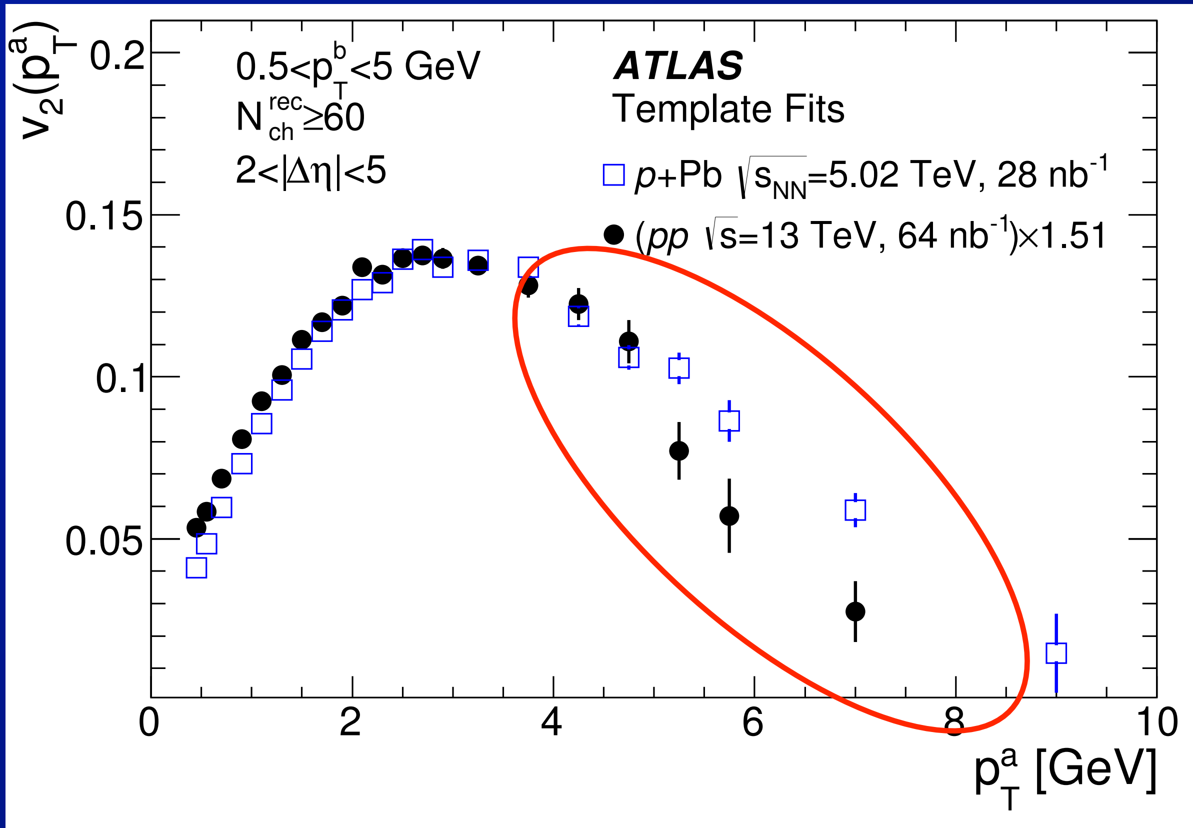
MPI in pp collisions?

- **Maybe there's both MPI and "flow"?**
  - and maybe the MPI is hiding in the difference between data and the fit?
    - ⇒subtract …
    - ⇒basically, the difference is "v3" and "v4"

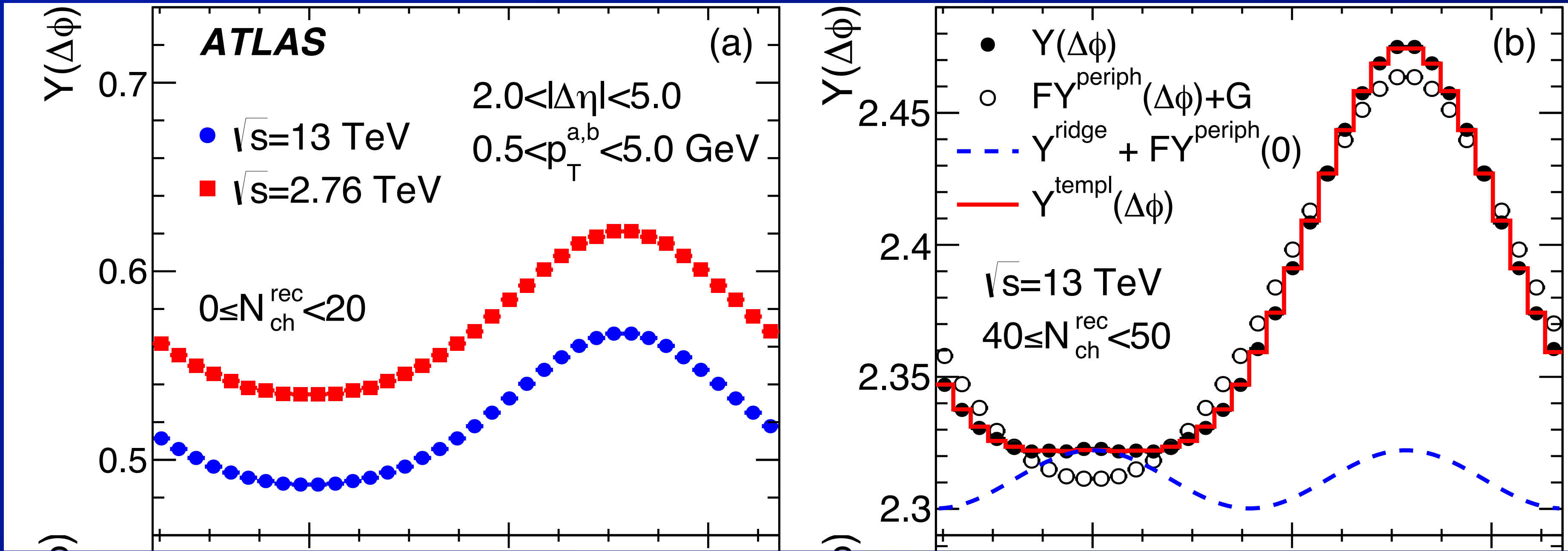


MPI in pp collisions?



- We do see away-side broadening w/ increasing multiplicity, for p_T > 5 GeV
  - In fact, for pT > 7 GeV, “v2” (not) < 0!
  - ⇒So, the hard phenomena are there, just not seen at low p_T …

Questions, thoughts



- To what extent is the 2-particle correlation in low-multiplicity pp collisions "hard"?
- Do soft jet fragments participate in "flow"?

⇒contrary to the assumption of template method

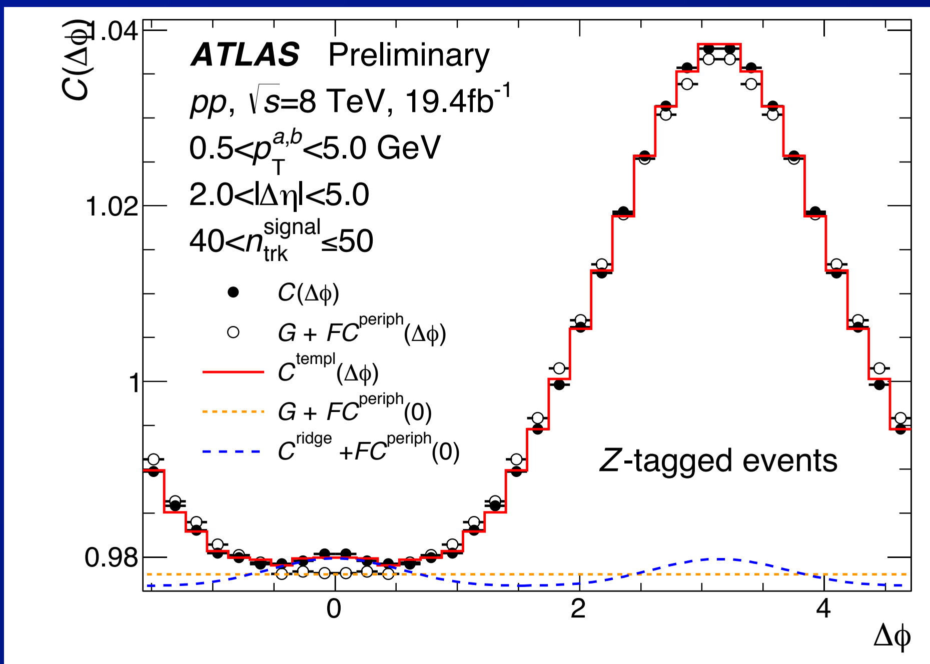
– Suppose they don't

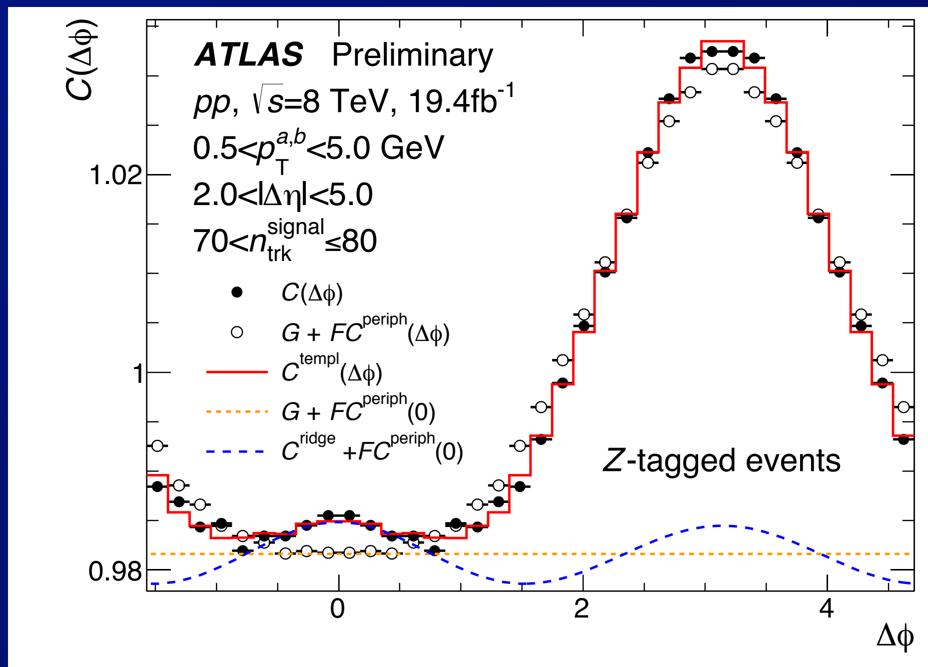
⇒then why should we expect to see jet quenching in small systems? (more on this later)

While we're at it …

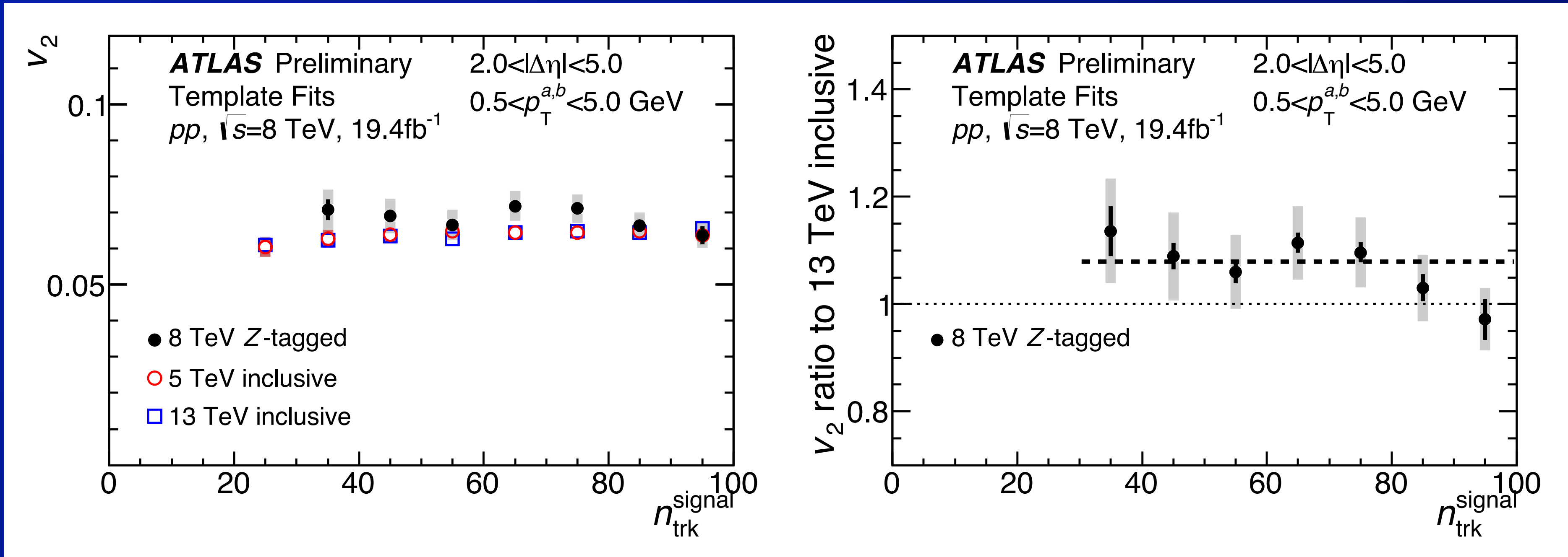
- 2-particle correlations in Z-tagged pp collisions
- Physics "question":
  - does the presence of a hard scattering change the behavior of the (soft?) 2-particle correlation's?

⇒apply the same analysis applied to minimum-bias





2-part correlations in Z-tagged pp



- **See barely significant increase in v_2 in Z-tagged pp collisions relative to minimum-bias**
  - but, beware, the <p_T> is slightly larger

    ⇒p_T dependence under analysis
  - however, the presence of a hard scattering does not radically change modulation in the UE.

Quenching in p+Pb collisions?

Jet quenching in p+Pb

- In the last 4-5 years, many (nearly every?) talk on "flow" in small systems asks the question?
  - if there is collectivity in small systems, why don't we see jet quenching?

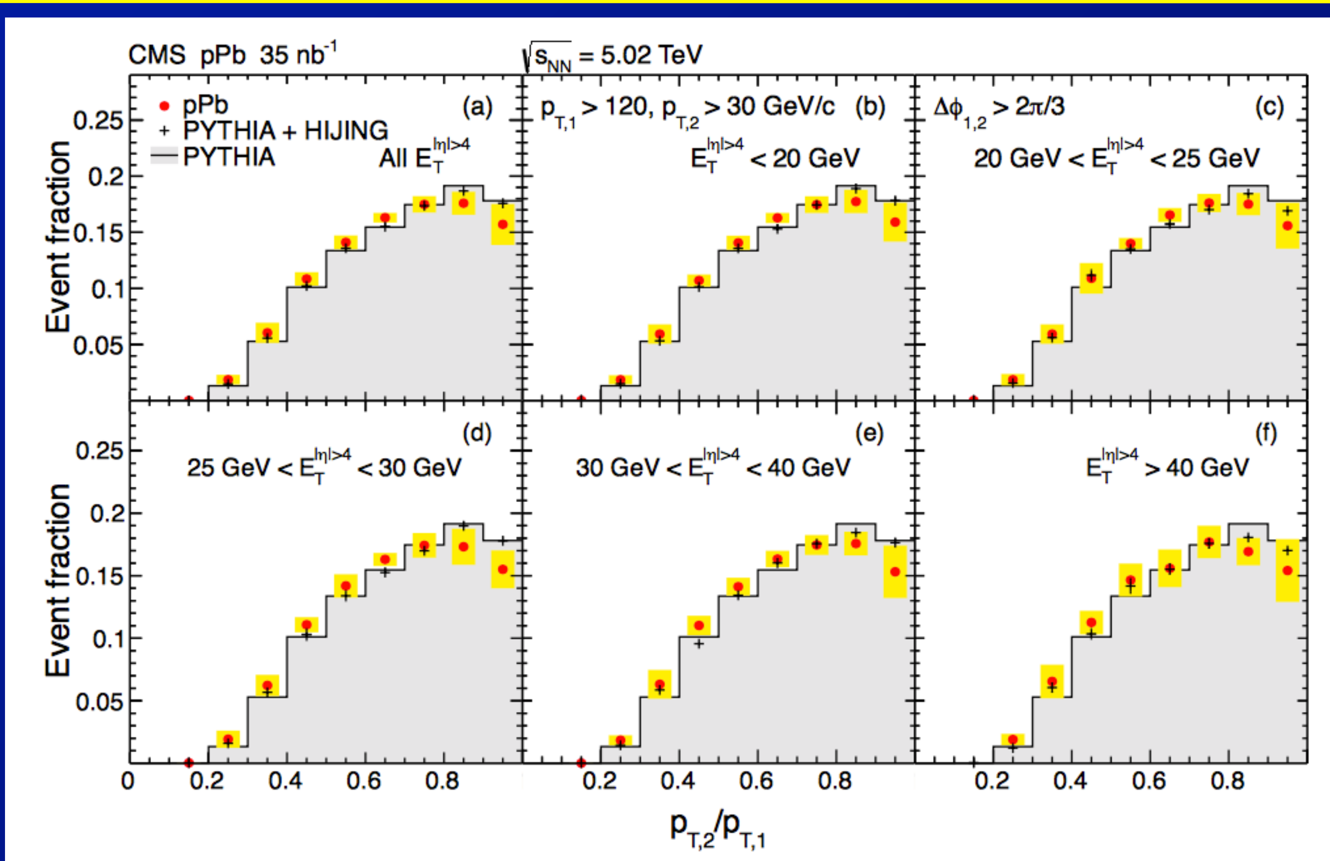
    ⇒ Note to students:

    » repeating a question that has been asked many times over without refining or attempting to answer it doesn't make you look "smart".
- So, let's review the relevant experimental data
  - CMS paper on dijets: Eur. Phys. J. C 74 (2014) 2951
- In particular, dijet balance

  ⇒ Self-normalized.

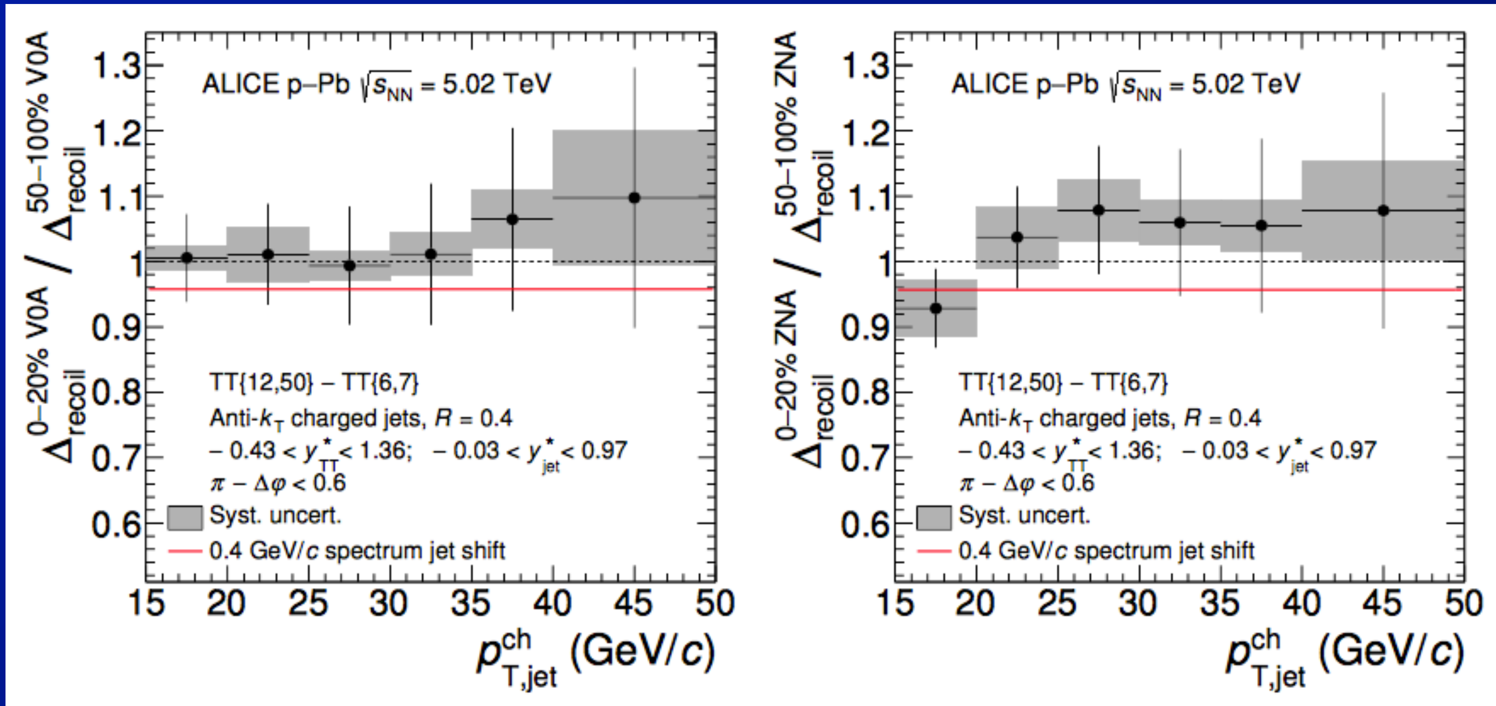
  ⇒ Important in p+Pb (below).

CMS dijet balance



- **Dijet balance distributions for different forward E_T intervals (centrality)**
  - ⇒no evidence for chance in balance distributions
  - ⇒should probably be repeated with (much) lower leading jet pT, but why no quenching?

Alice p+Pb h-jet correlation



$$\Delta_{\mathrm{recoil}}\left(p_{\mathrm{T,jet}}^{\mathrm{ch}}\right) = \frac{1}{N_{\mathrm{trig}}} \frac{\mathrm{d}^2 N_{\mathrm{jets}}}{\mathrm{d}p_{\mathrm{T,jet}}^{\mathrm{ch}}}\bigg|_{p_{\mathrm{T,trig}} \in \mathrm{TT_{Sig}}} - c_{\mathrm{Ref}} \cdot \frac{1}{N_{\mathrm{trig}}} \frac{\mathrm{d}^2 N_{\mathrm{jets}}}{\mathrm{d}p_{\mathrm{T,jet}}^{\mathrm{ch}}}\bigg|_{p_{\mathrm{T,trig}} \in \mathrm{TT_{Ref}}}$$

- **Short summary:**
  - no evidence for jet quenching

So why?

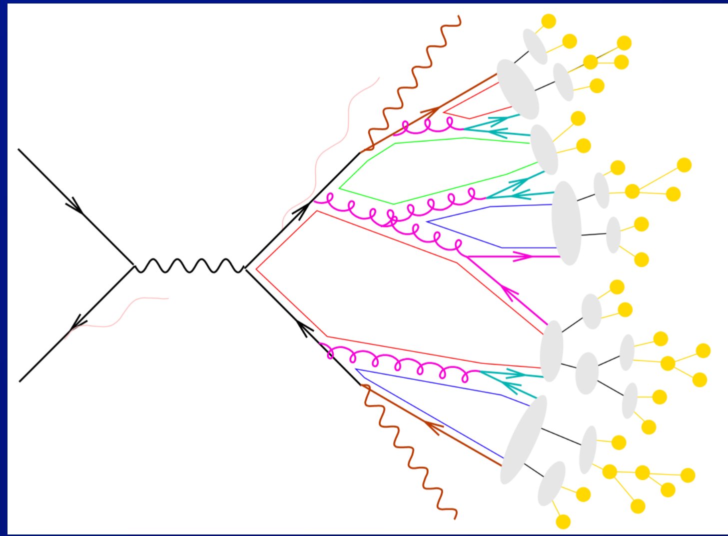
- First
  - analyses (e.g. by Konrad) that suggest that the combination of transverse size + smaller energy density/T yields small quenching effects (5% on R_{pA})

  ⇒but would still expect to see broader jet p_T balance distribution.

  ⇒though would like to see the balance distribution for lower-p_T jets …
- But, there is another reason that the smaller transverse size in p+Pb collisions matters
  - (perturbative) QCD!

  ⇒evolution of the outgoing states

Final-state evolution



- **Understanding of outgoing parton showers**
  - as implemented in (e.g.) Pythia event generators
- **Evolution from hard to soft (smaller to larger effective charge) via angular-ordered radiation**
  - not instantaneous, necessarily introduces a dependence on the transverse system size, Q^2 or p_T

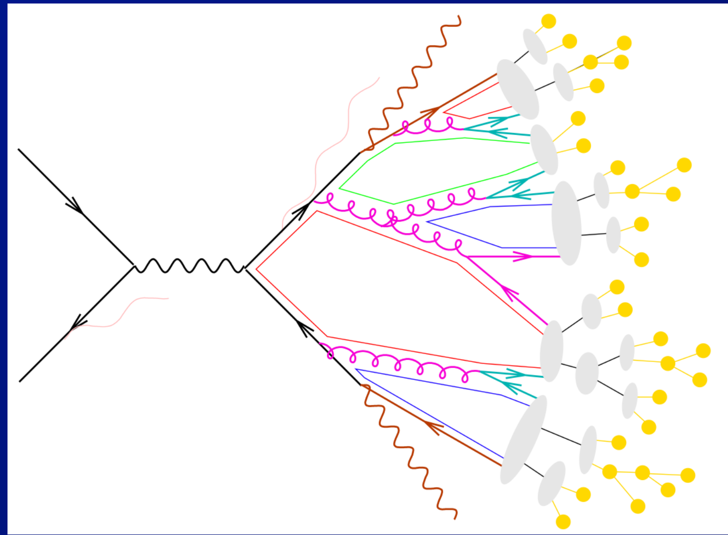
    ⇒ beyond that of usual path length in medium

    ⇒ also relevant to jet quenching in AA collisions
  - needs theoretical attention …

    ⇒ but, we shouldn't be surprised at the lack of p+Pb quenching until we're sure it should be there.

Final-state evolution

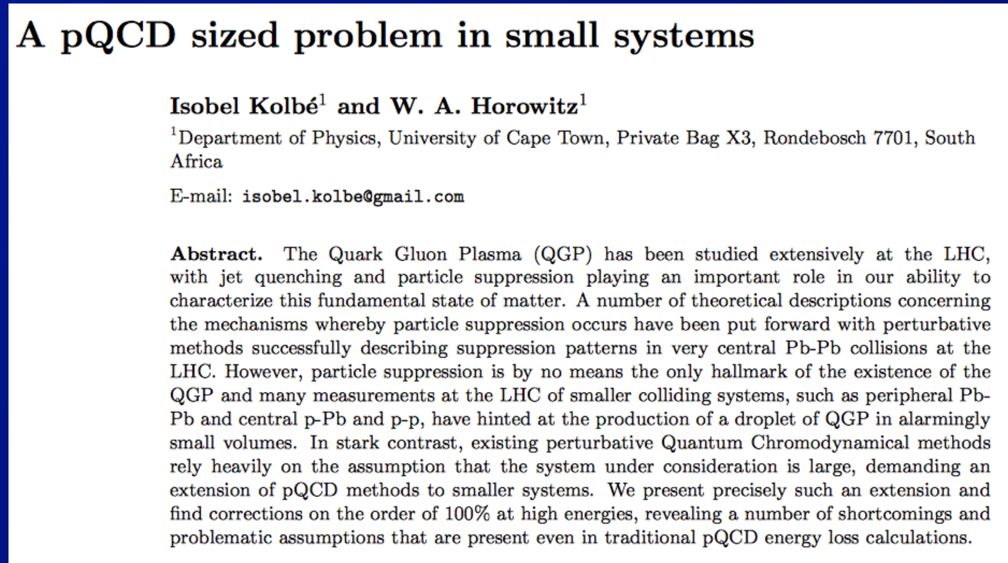
- Can we address the above question experimentally?
  - i.e. can we test whether components of a PS/jet couple to the "medium" in p+A collisions?



- A question that can maybe answered:
  - do the fragments of jets couple to the "flow"?
    - ⇒as a function of the hadron p_T
    - ⇒as a function of the jet p_T
  - requires measuring two-particle correlations selecting one of the particles to be in the angular range of the jet

Yet another problem …

- Forgotten(?) feature of GLV and BDMPS energy loss
  - for thin media, the interactions with the medium result in energy gain not loss
    - ⇒destructive interference w/ vacuum radiation
    - ⇒One of the reasons for lack of quenching in p+A?



A pQCD sized problem in small systems

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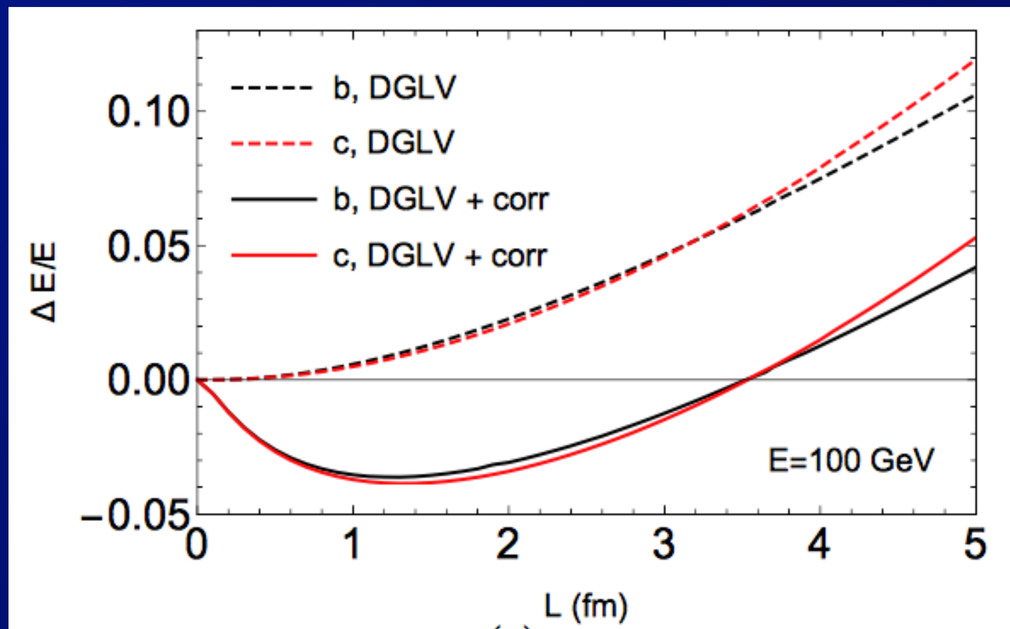
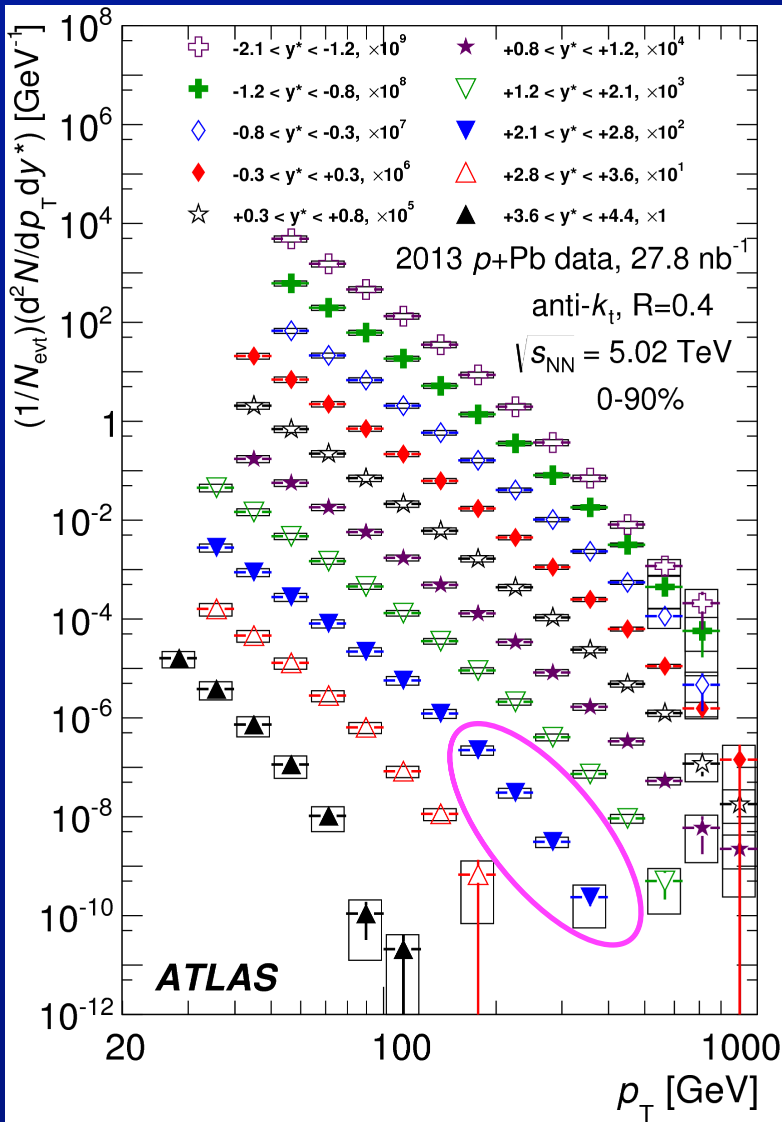
Abstract. The Quark Gluon Plasma (QGP) has been studied extensively at the LHC, with jet quenching and particle suppression playing an important role in our ability to characterize this fundamental state of matter. A number of theoretical descriptions concerning the mechanisms whereby particle suppression occurs have been put forward with perturbative methods successfully describing suppression patterns in very central Pb-Pb collisions at the LHC. However, particle suppression is by no means the only hallmark of the existence of the QGP and many measurements at the LHC of smaller colliding systems, such as peripheral Pb-Pb and central p-Pb and p-p, have hinted at the production of a droplet of QGP in alarmingly small volumes. In stark contrast, existing perturbative Quantum Chromodynamical methods rely heavily on the assumption that the system under consideration is large, demanding an extension of pQCD methods to smaller systems. We present precisely such an extension and find corrections on the order of 100% at high energies, revealing a number of shortcomings and problematic assumptions that are present even in traditional pQCD energy loss calculations.

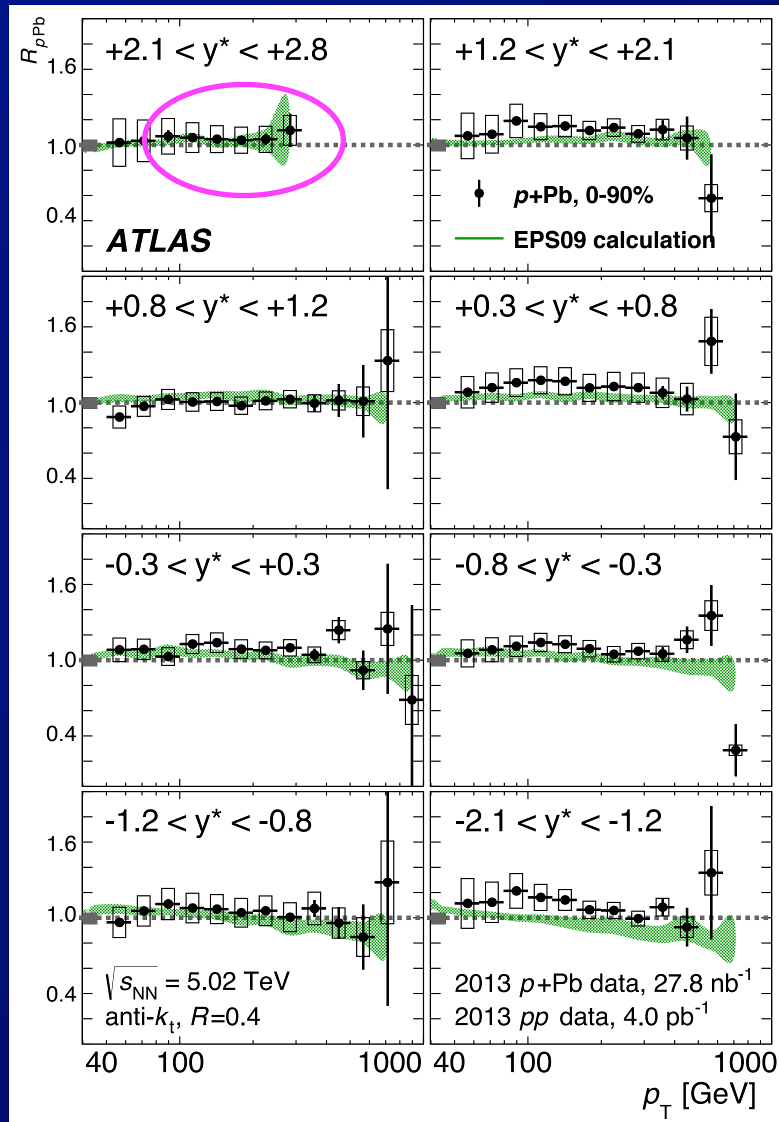


Yet another problem/question

- where is the initial-state dE/dx?
  - at forward rapidity & high p_T accessing x ~ 0.4

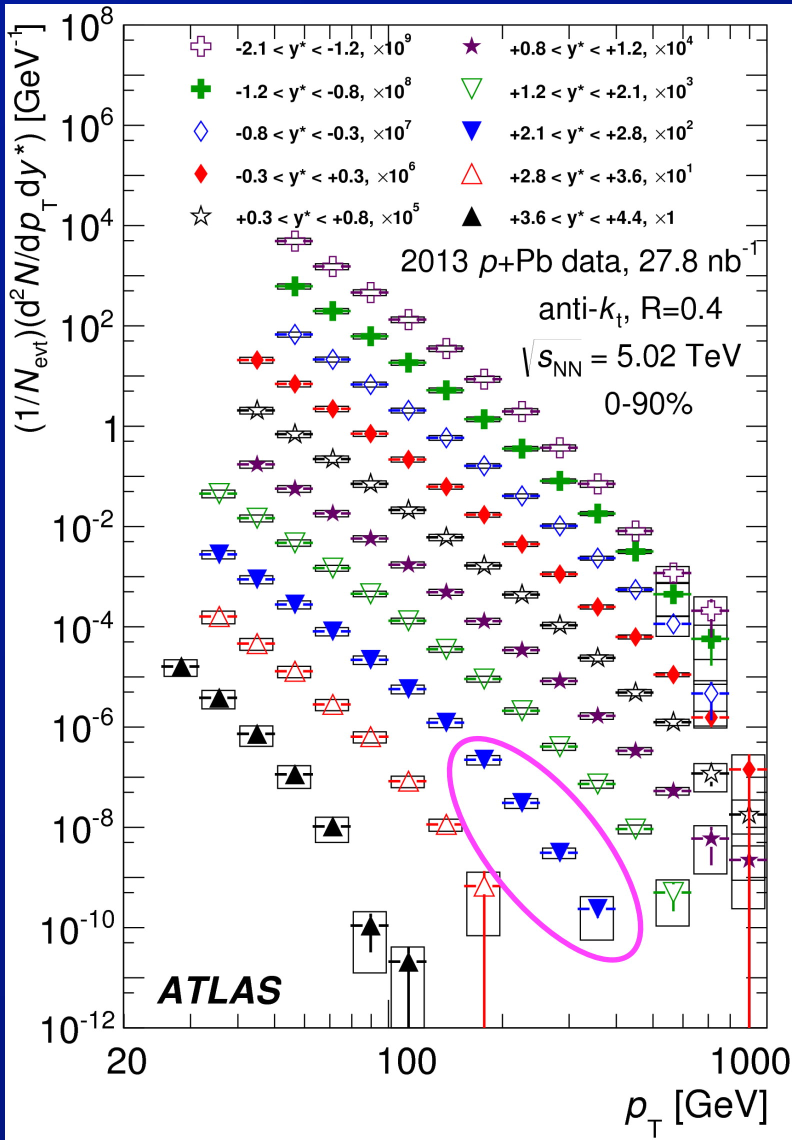
  ⇒shouldn't we be seeing effects of initial state dE/dx?

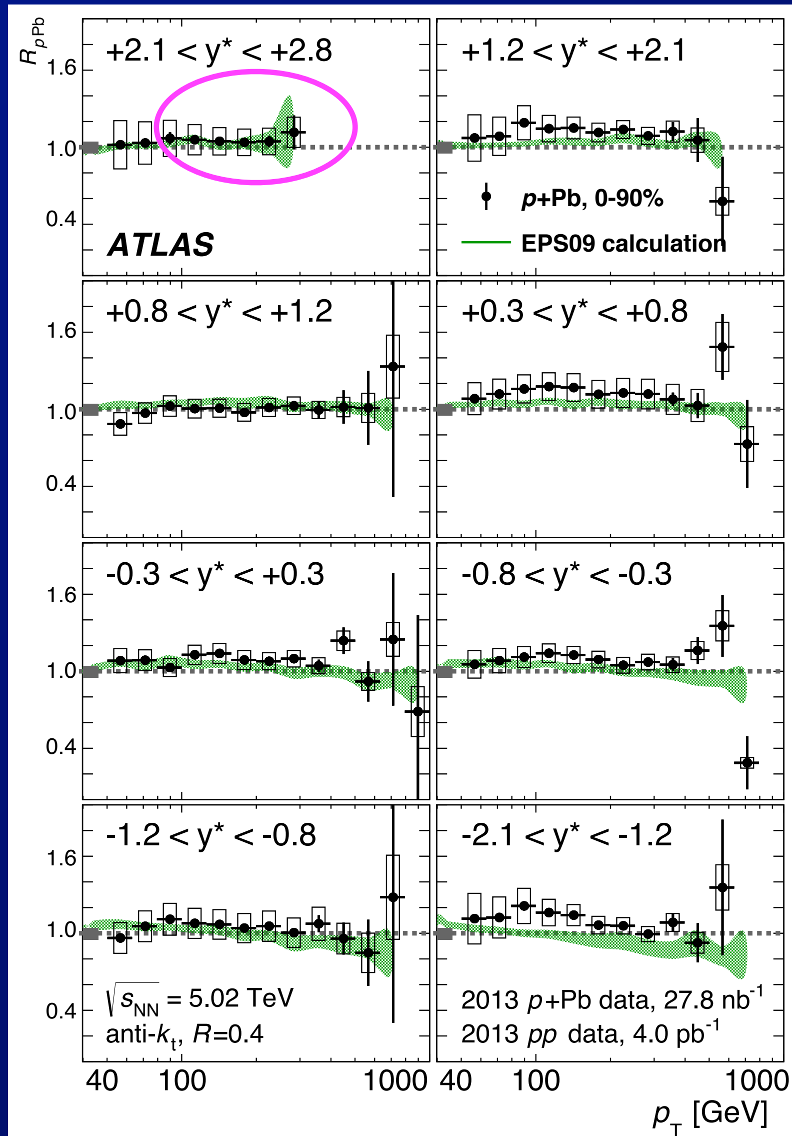




Yet another problem/question

- Is there significant initial-state dE/dx?
  - ⇒how can we have a precision jet quenching program without knowing the answer to this question?



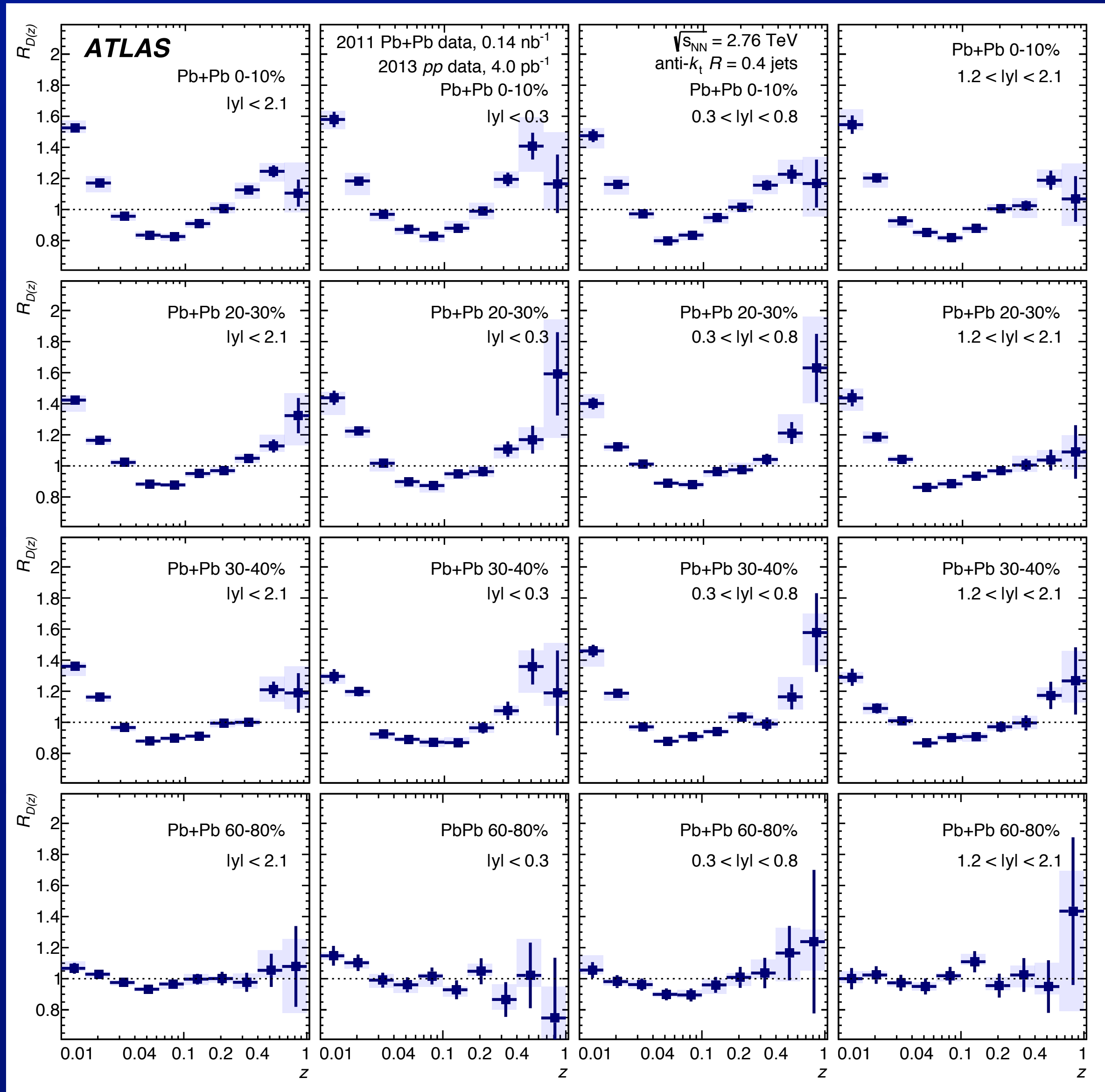


Other self-normalizing probes?

- ATLAS jet fragmentation in Pb+Pb collisions
  - modifications observed even in 60-80% centrality

  ⇒close to E_T or N_{ch} accessible in p+Pb

  ⇒should also measure jet FF in very high E_T/N_{ch} p+Pb collisions

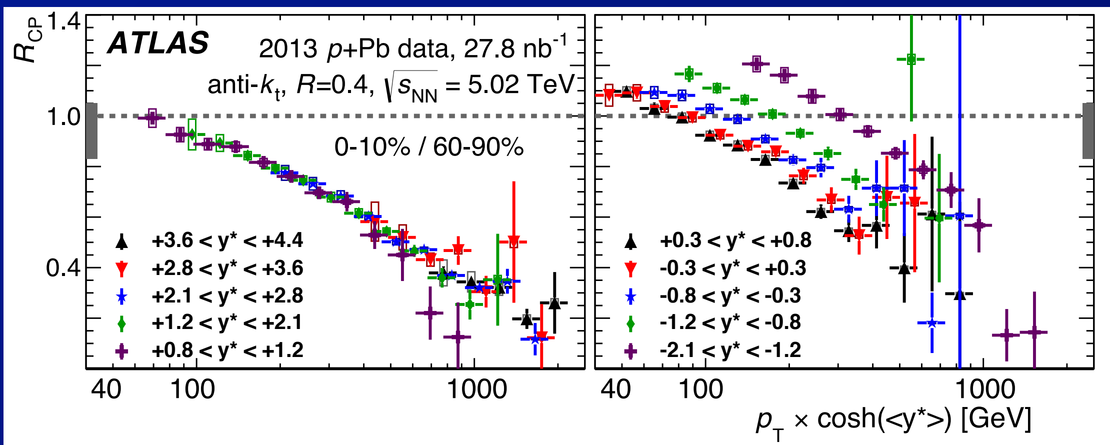


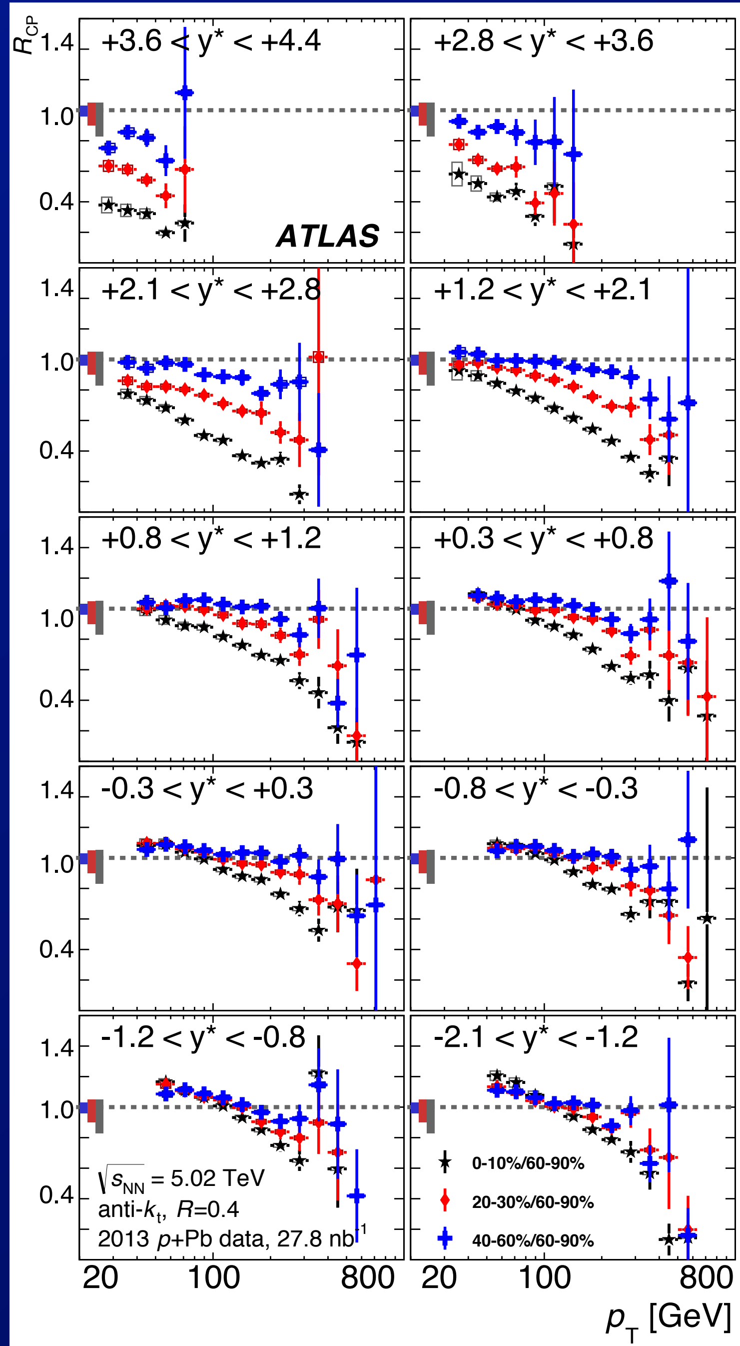
initial state and soft-hard non-factorization

- old news re: p+Pb jet yields vs centrality @ high p_T and forward rapidity
  - and the observation that the modification scales vs energy

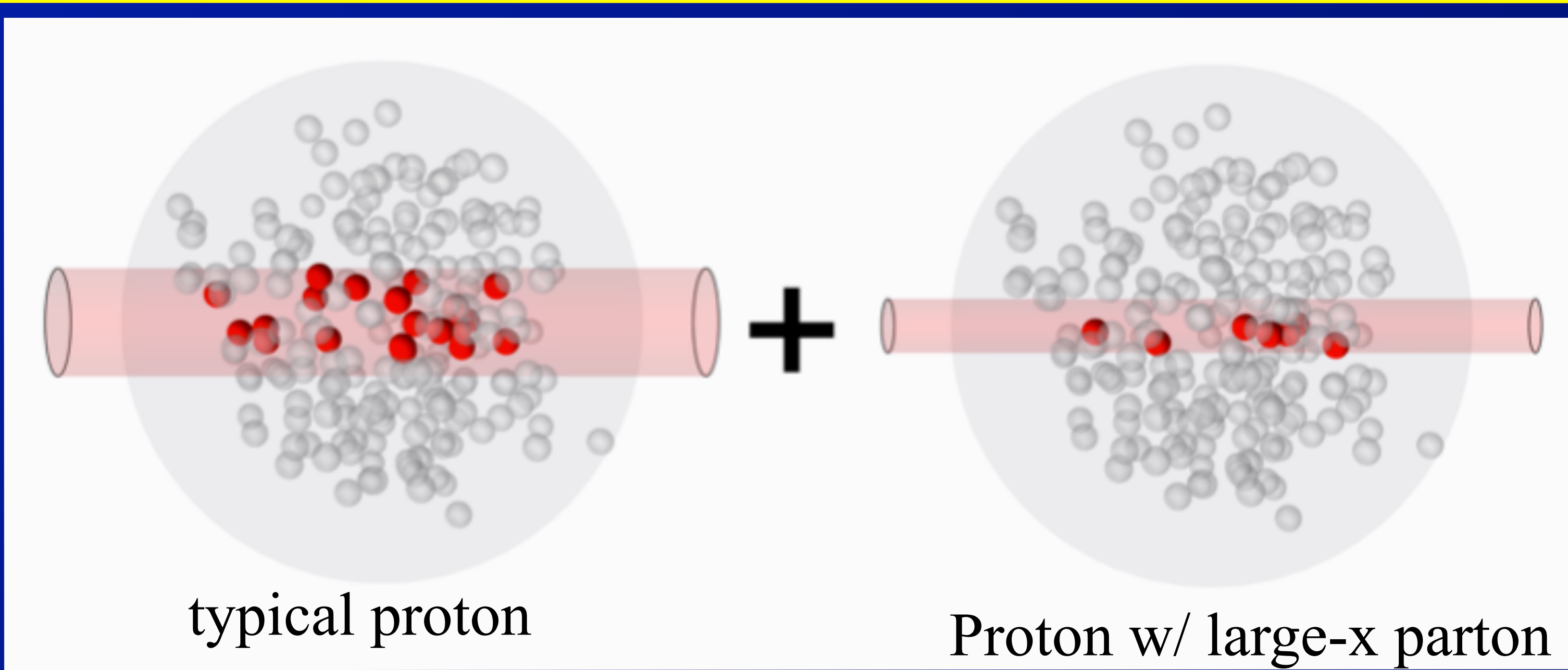
  ⇒ @ forward rapidity

  ⇒ but not @ backward rapidity where energy conservation effects are most important





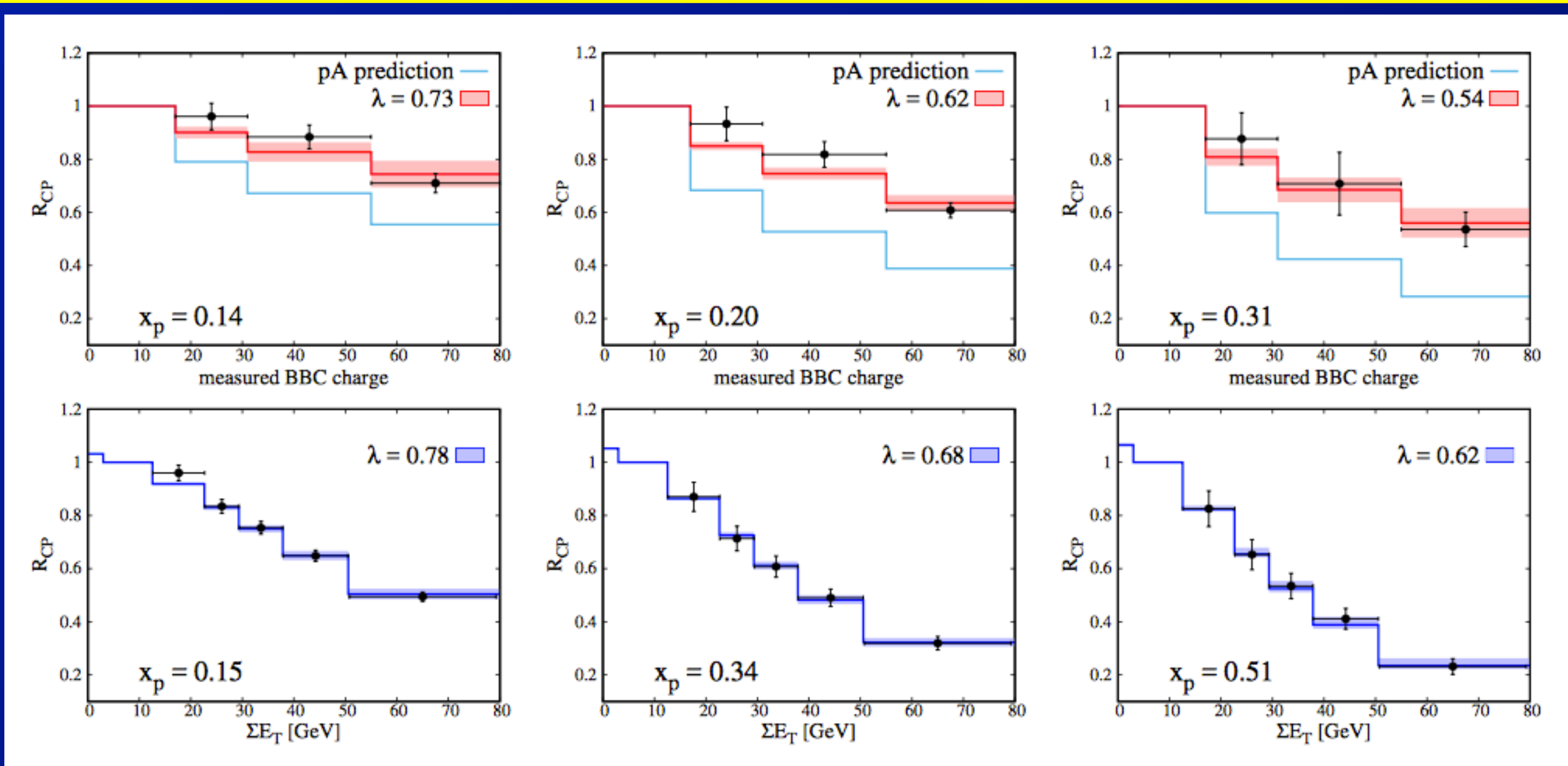
initial state and soft-hard non-factorization



- Picture by Strikman et al for origin of the soft-hard correlation that produces the effect
  - by now, it's becoming accepted(?) that shape/color fluctuations in the proton may be important …

  ⇒IMHO, it would be surprising if there wasn't a correlation between proton configuration and valence quark x distribution for x > ~ 0.3

initial state and soft-hard non-factorization



- single parameter controls the "centrality" evolution of the R_{cp} $\lambda(x_p) = \langle \sigma_{NN}^{MB}(x_p) \rangle / \sigma_{NN}^{MB}$.
  - testable prediction for p+Au @ RHIC given fit to the d+Au data.

soft-hard correlations

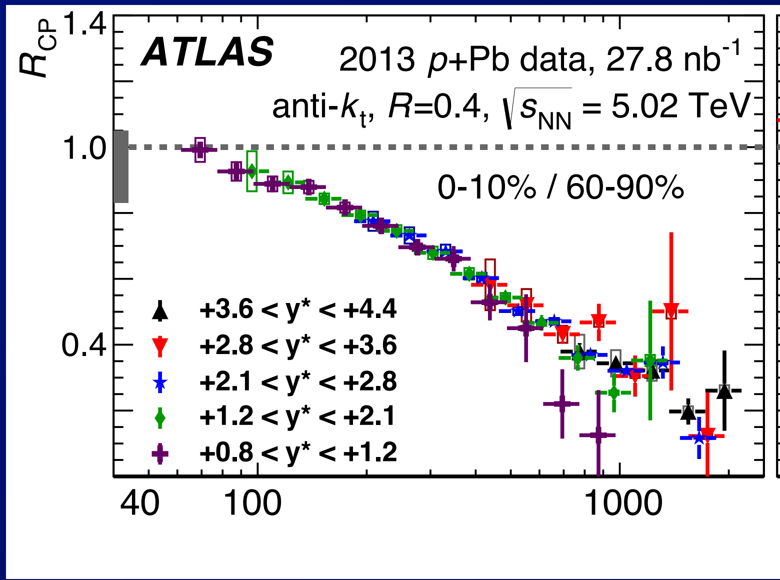
initial state and soft-hard non-factorization

- The wounded nucleon model (maybe) augmented to wounded constituent quark picture works well in nucleus-nucleus collisions
  - but it was extremely naive to think that it was "right"
- But on the other hand, it's useful to ask "how could it be wrong"
  - the basic reason WN works is timescales
    - ⇒the multiple scatterings in (e.g.) p+A happen ~ simultaneously in the proton rest frame
    - ⇒proton responds the same to 1, 2, … scatterings(?)
  - but should it always interact with same σ ?
    - ⇒the literature said "no"
    - ⇒basic physics (QM) also says "no"
- we should not have been surprised by this …

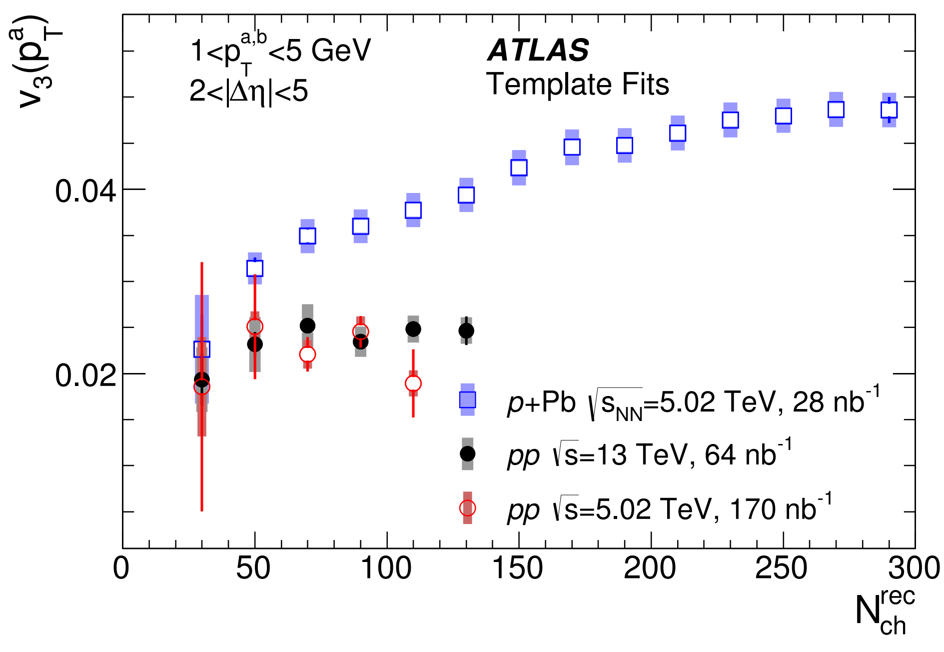
A challenge and an opportunity

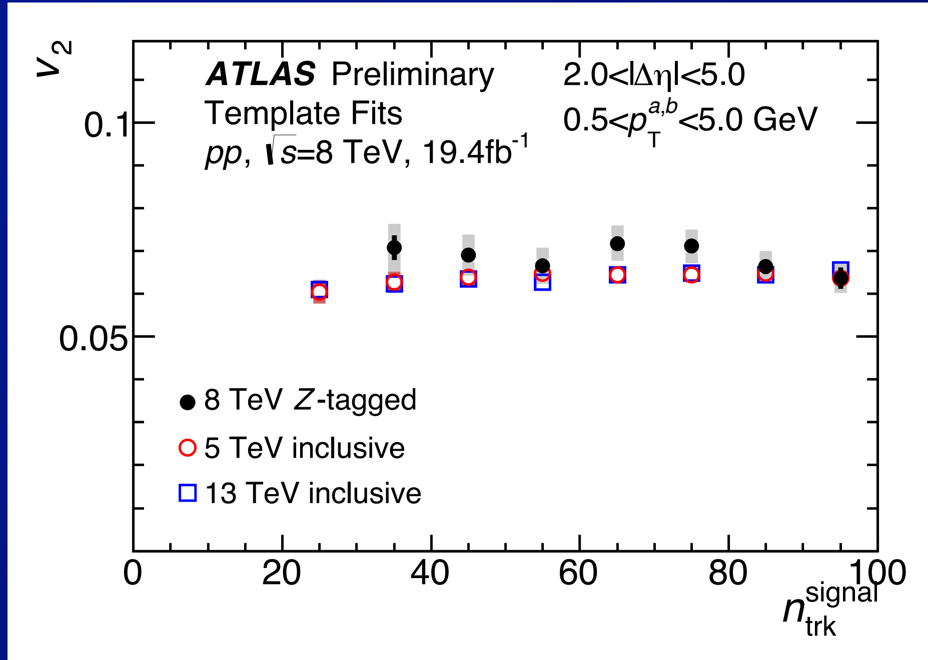
- The fluctuations in the nucleon configuration adds complexity to the understanding of p+Pb AND pp collisions
  – lots of theoretical ideas that need to be tested
  – but we have experimental observables sensitive to the initial transverse energy density distribution

  ⇒ "flow"
- So, for example, suppose we could collect enough events at "large" x
  – even 0.15 is large
- Then measure v_2, v_3, v_4
  – should be able to predict how they will change if Strikman et al are correct.



Back to pp collisions





- Where does the v_3 come from in pp?
  - MPI, valence quark position fluctuations, …
- But we can do the same test in pp
  - select hard processes with large enough x_P and look for differences in v_n’s

  ⇒ in this respect, the Z events probably weren’t hard enough …