Two-particle correlations in 13 TeV pp collisions and their sensitivity to jets / hard scatterings

Prof. Brian Cole
Columbia University and ATLAS collaboration

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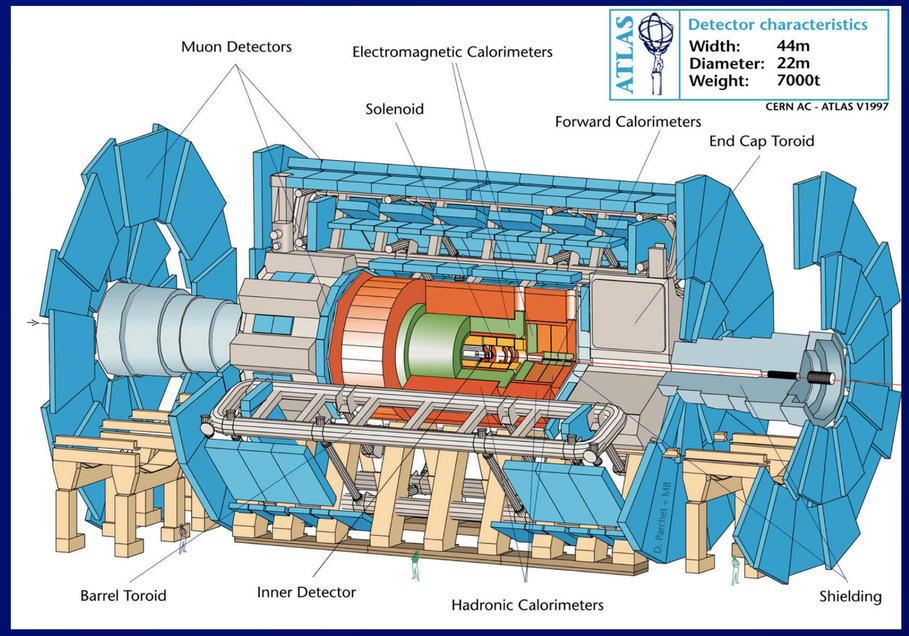
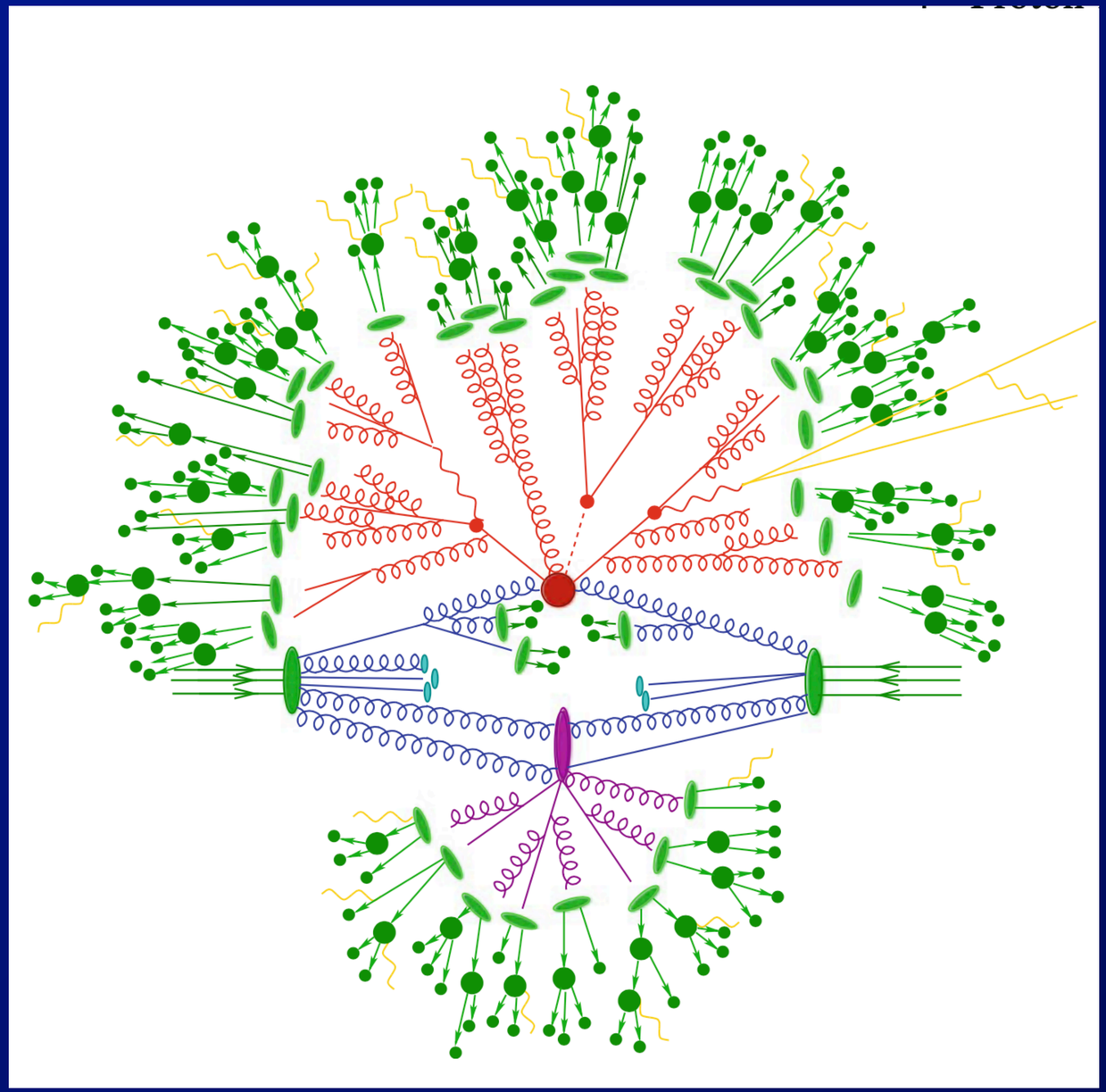


Motivation

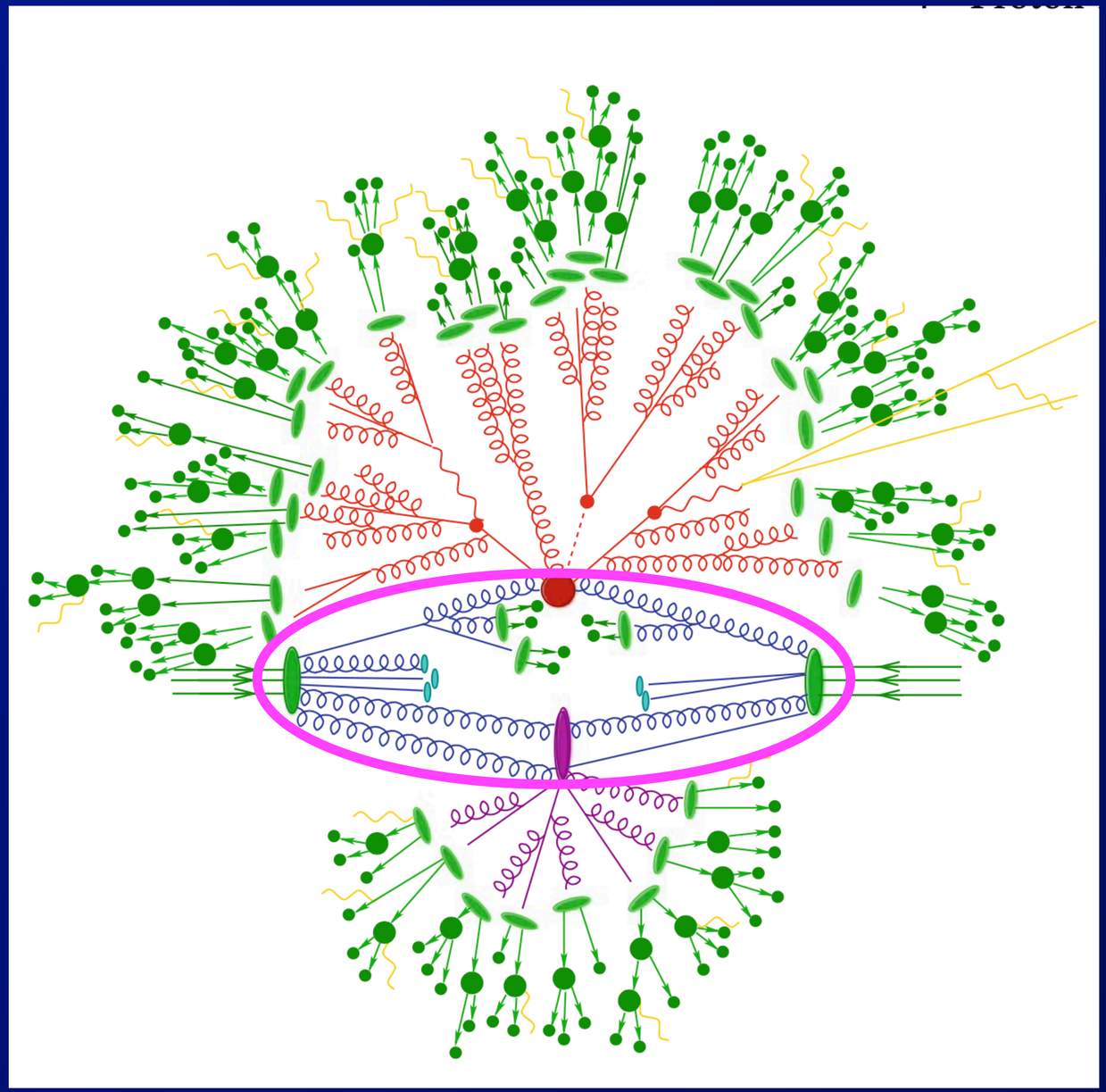
- Cartoon of pp collision



Motivation

Key question

- To what extent does the soft(?) underlying event decouple from hard scattering processes?



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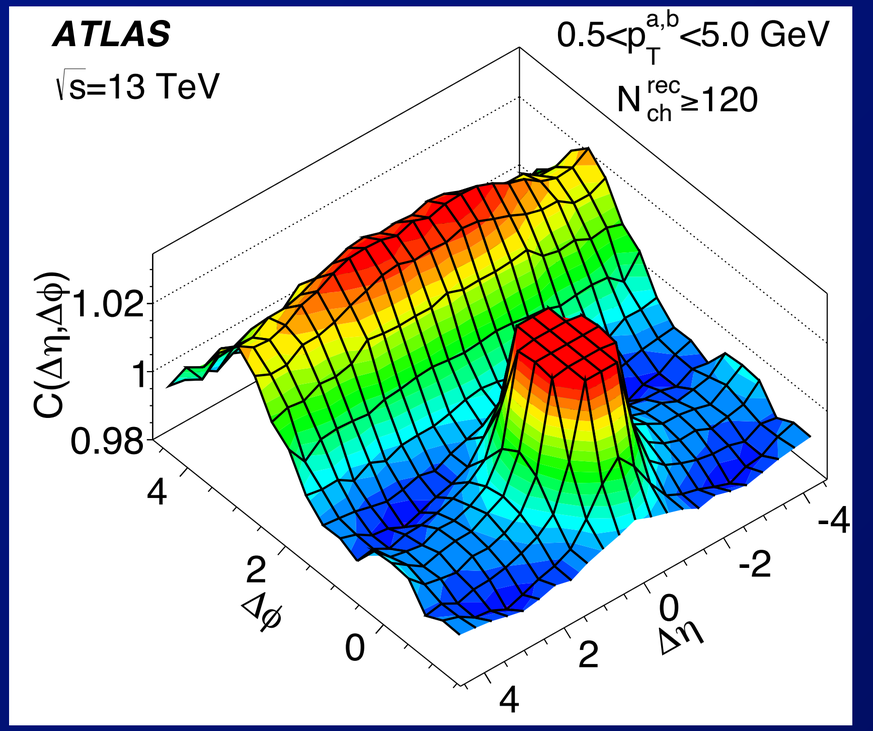
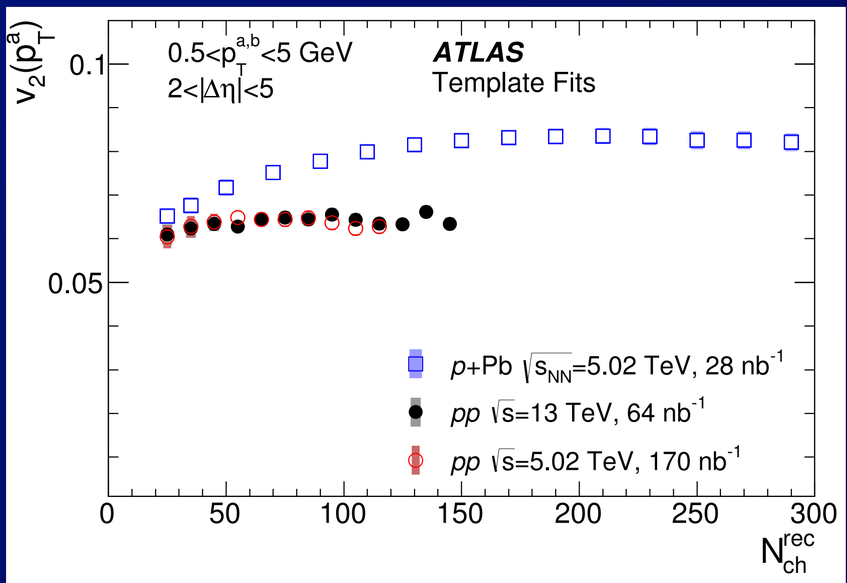
⇒At least, as seen via the “ridge”





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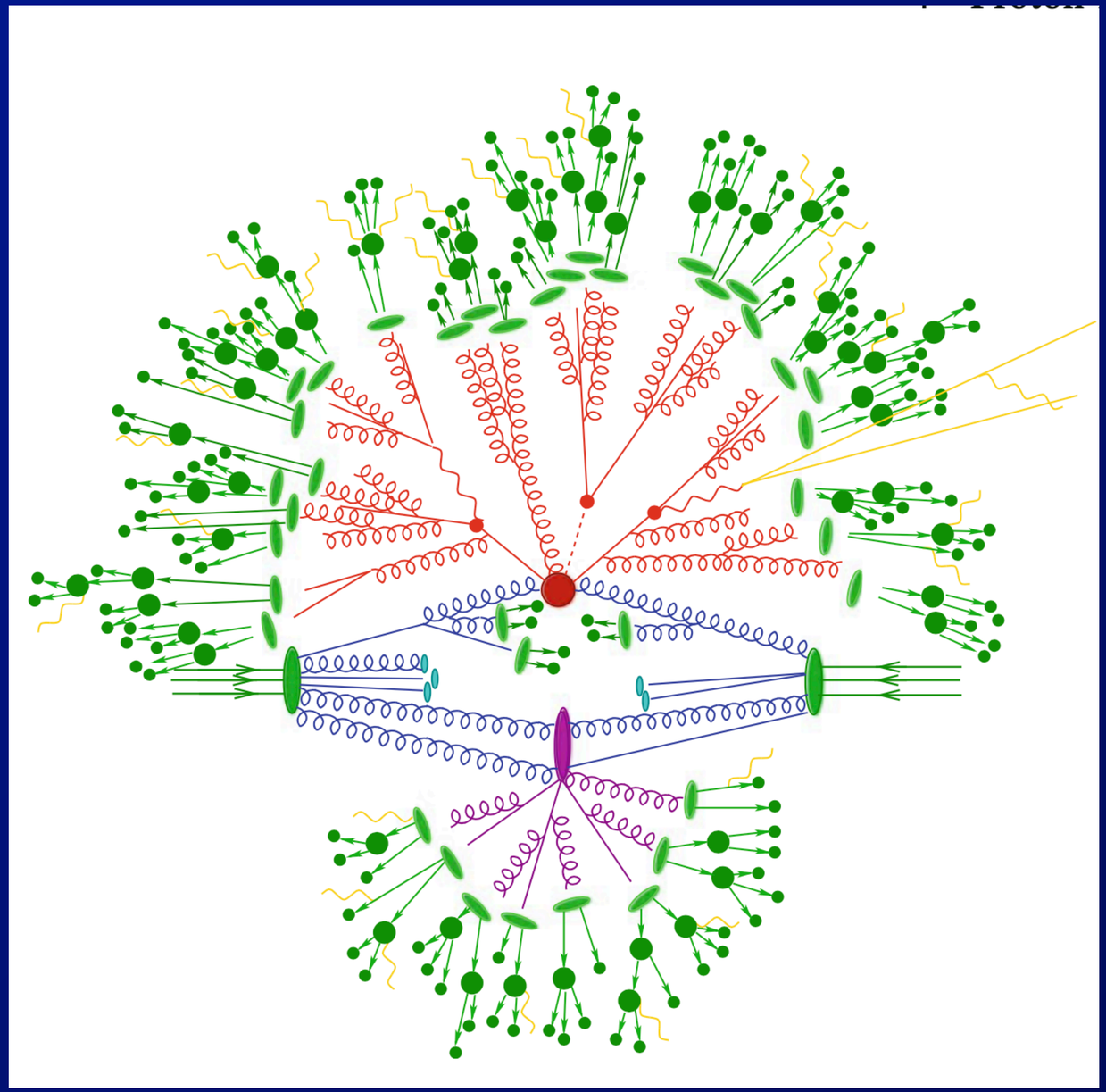
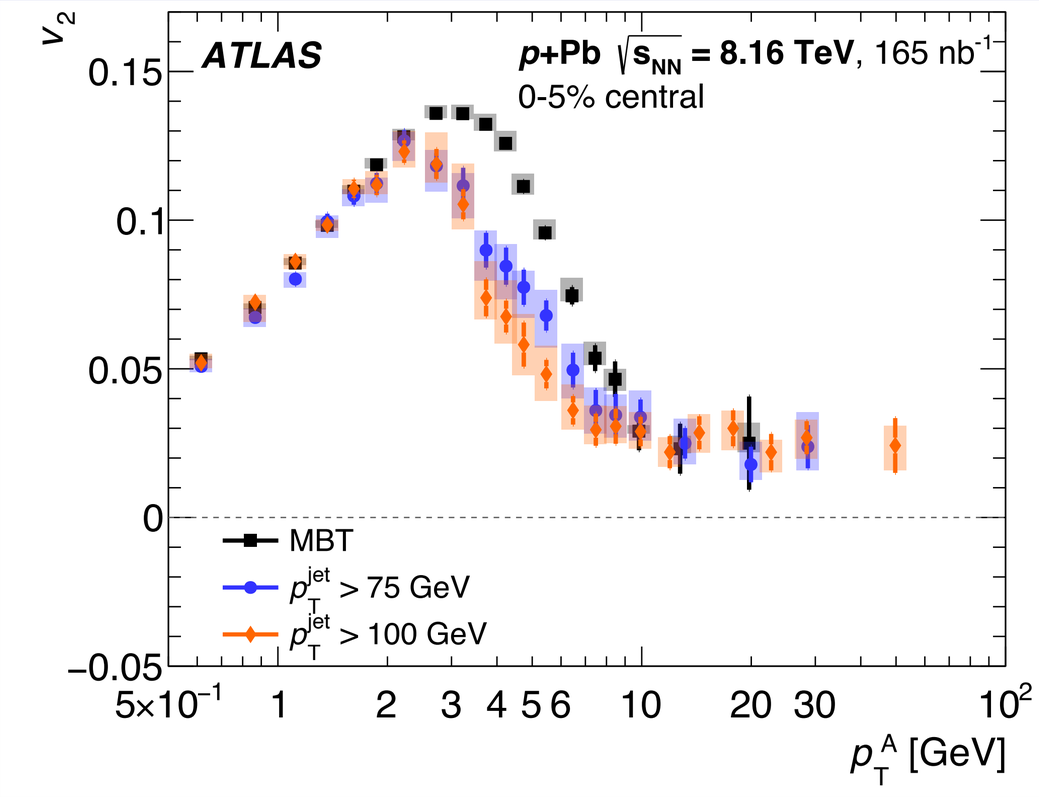
- Suppose the ridge is from “flow”:
  - With small transverse distance scales, can fragments of jets couple to the collective expansion?
- Suppose ridge is glasma-driven:
  - Can we directly see correlation between (semi)hard processes and the ridge?

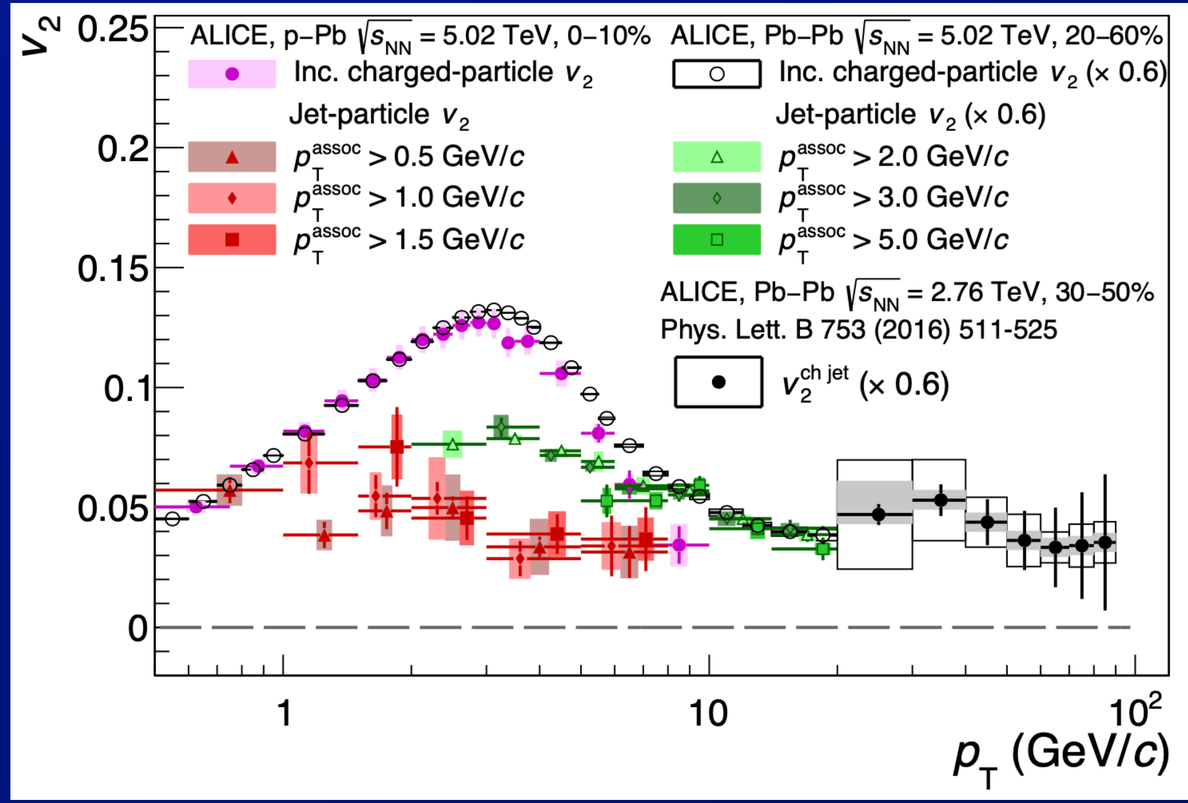


hard-scattering - UE flow correlation in p+Pb

ATLAS, EPJC 80 (2020) 1



arXiv:2212.12609



- Measurements by ATLAS and CMS in p+Pb collisions show correlations between jet particles and the underlying event

⇒But unlike Pb+Pb collisions not due to jet quenching

New ATLAS measurement

Measure correlation of v_2 in pp collisons w/ jets

Method (originally)

- Reconstruct jets in pp collisions using particle-flow algorithm
  - Goal to go as low in p_T as possible, $p_T > 15$ GeV, $|\eta| < 4.5$

$\Rightarrow$Then, measure 2PC, excluding particles within $|\Delta\eta| < 1$ of jet

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  ⇒Then, measure 2PC, excluding particles within $|\Delta\eta| < 1$ of jet
- Also directly measure correlation between jet fragments and UE
  - Require trigger jet ($|\eta| < 2.1$) to have balance jet

  ⇒ reduce non-flow (away-side) effects in 2PC
  - Apply isolation cut on the trigger jet

  ⇒ Remove potential distortion of 2PC

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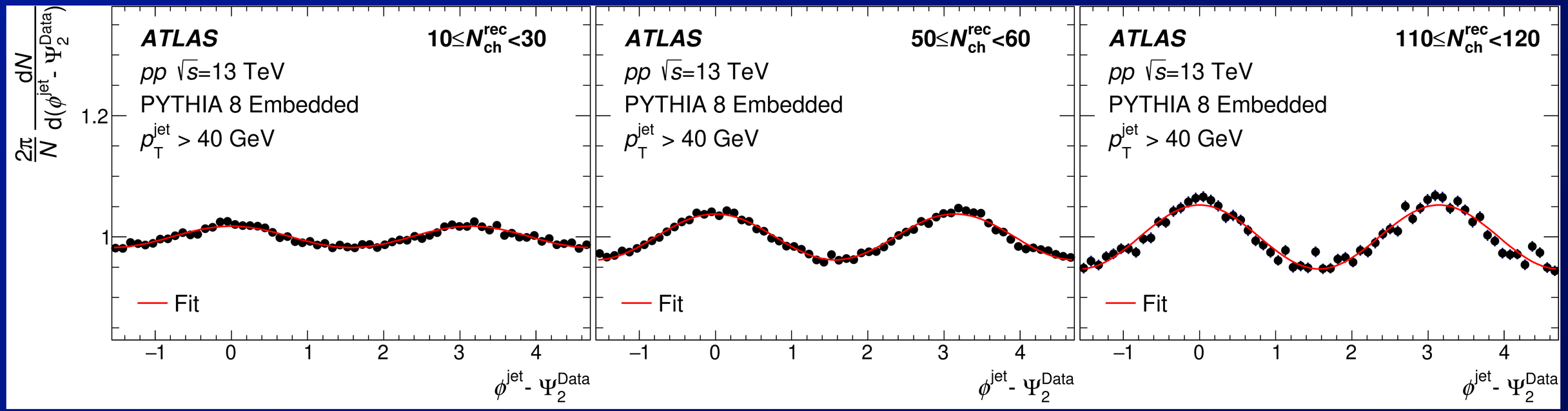
  ⇒ Remove potential distortion of 2PC
- Evaluate the impact on 2PC of requiring or excluding jet in event
- Separately: directly test whether jet fragments (and thus jets) have azimuthal correlations with the underlying event.

The problem

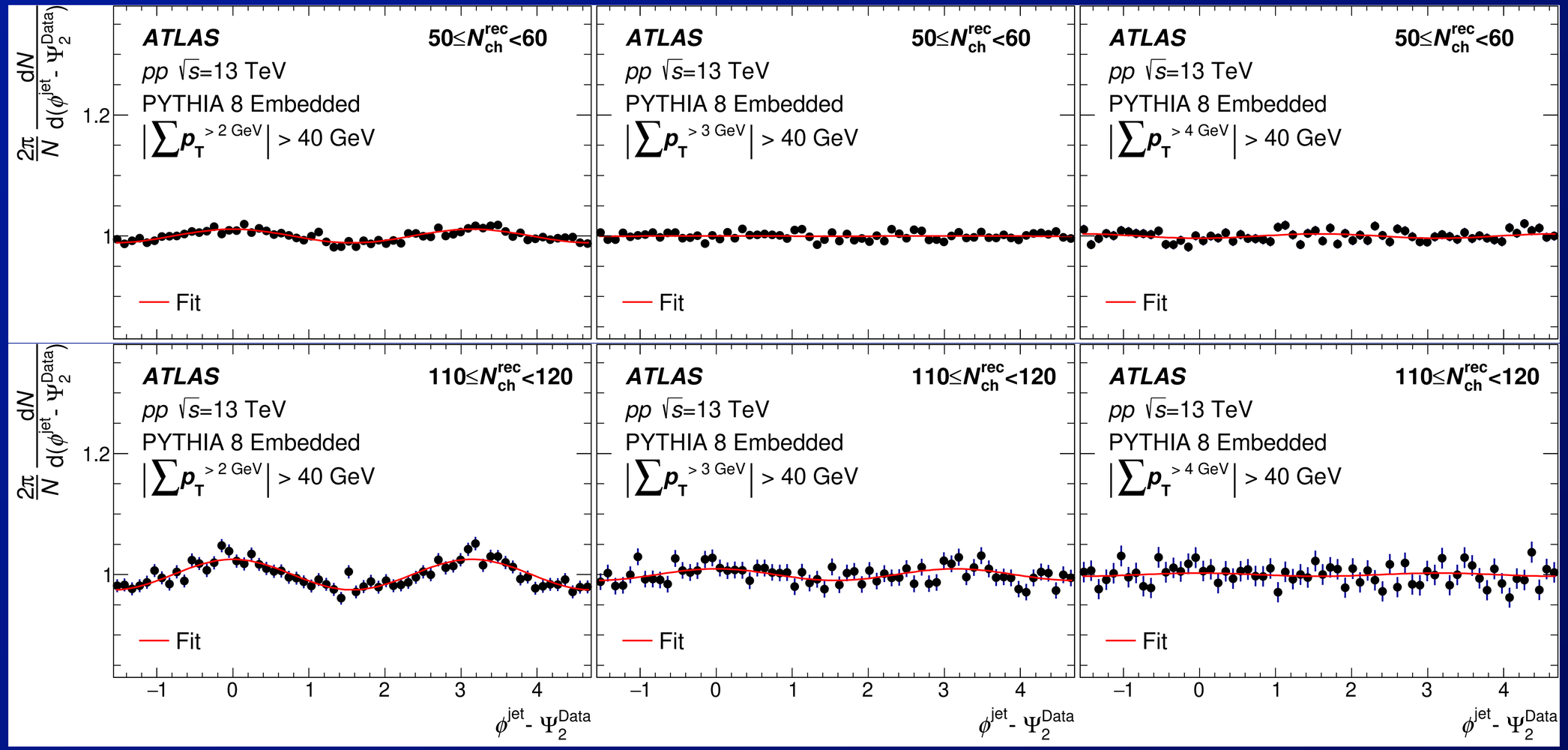
- We observed a strong correlation between jets and the soft UE
  - ⇒ But it was unphysical, due to modulation of the pp UE ➛ jet p_T bias
- The UE bias was confirmed by overlaying Pythia8 events onto pp minimum-bias (except for multiplicity selection) data
  - Measure the pp event plane angle Ψ_2 in the data before overlay
  - ⇒See strong modulation of jet yield vs ϕ - Ψ_2, even for jet p_T > 40 GeV
  - ⇒In spite of poor Ψ_2 resolution



The solution

- **After trying a number of grooming/pruning/correction methods**
  - **best suppression of UE bias was obtained with p_T cut on jet constituents**

  ⇒Particle flow object (track, cluster) p_T > 4 GeV



Measure correlation of v_2 in pp collisons w/ jets

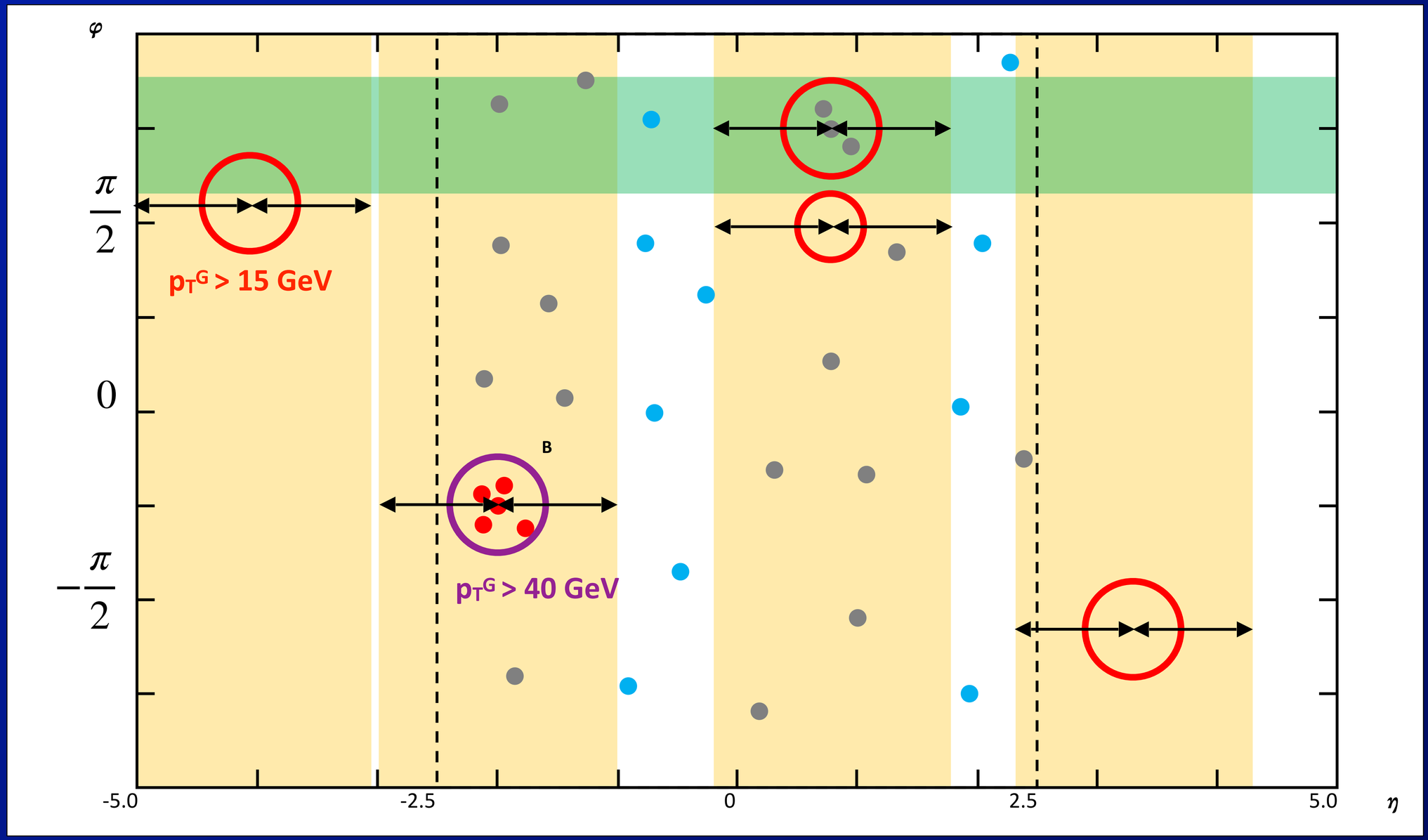
Method (actual)

- Reconstruct jets in pp collisions using particle-flow algorithm
  - Define *groomed* jet p_T,

$$p_{\mathrm{T}}^{\mathrm{G}} = \left| \sum_{\text{constituents}} \boldsymbol{p}_{\mathrm{T}}^{> 4\ \mathrm{GeV}} \right|$$

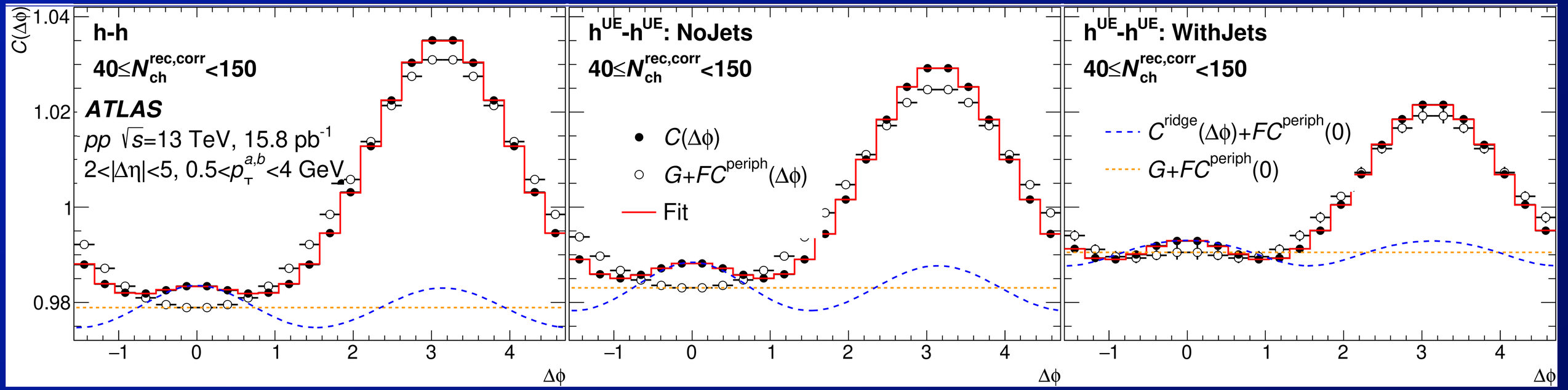
- For excluding particles in jets, balance jets, isolation
  - require $p_{\mathrm{T}}^{\mathrm{G}} > 15$ GeV
- For jet-triggered 2PC (for statistics) need to use jet triggered events
  - $p_{\mathrm{T}}^{\mathrm{G}} > 40$ GeV
- Evaluate impact on 2PC of requiring/excluding $p_{\mathrm{T}}^{\mathrm{G}} > 15$ GeV jets
- Separately: directly test whether jet fragments (and jets) with $p_{\mathrm{T}}^{\mathrm{G}} > 40$ GeV have azimuthal correlations with the UE.

Illustration of the analysis



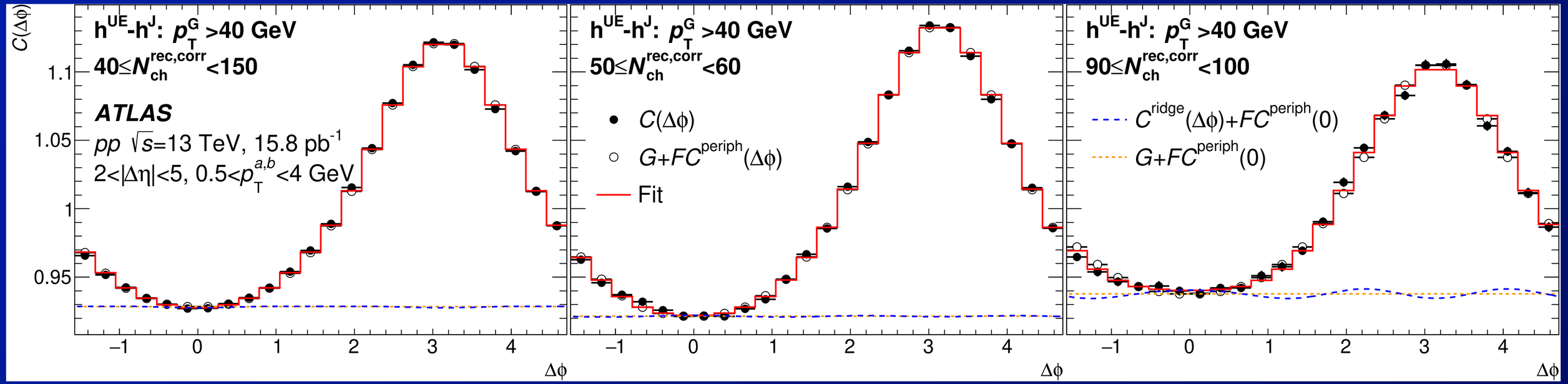
By Pengqi (Bill) Yin, Columbia University

Two-particle correlation functions



- **Charged particle multiplicity measured excluding all jet constituents.**
  - ⇒i.e. only the soft UE multiplicity
- **h-h (no jet excl) (left), exclude events w/jets (middle), require jet (right)**
  - ⇒Observe "typical" ridge
- **v_2 measured using ATLAS template fit method (Phys. Rev. Lett. 116 (2016) 172301)**

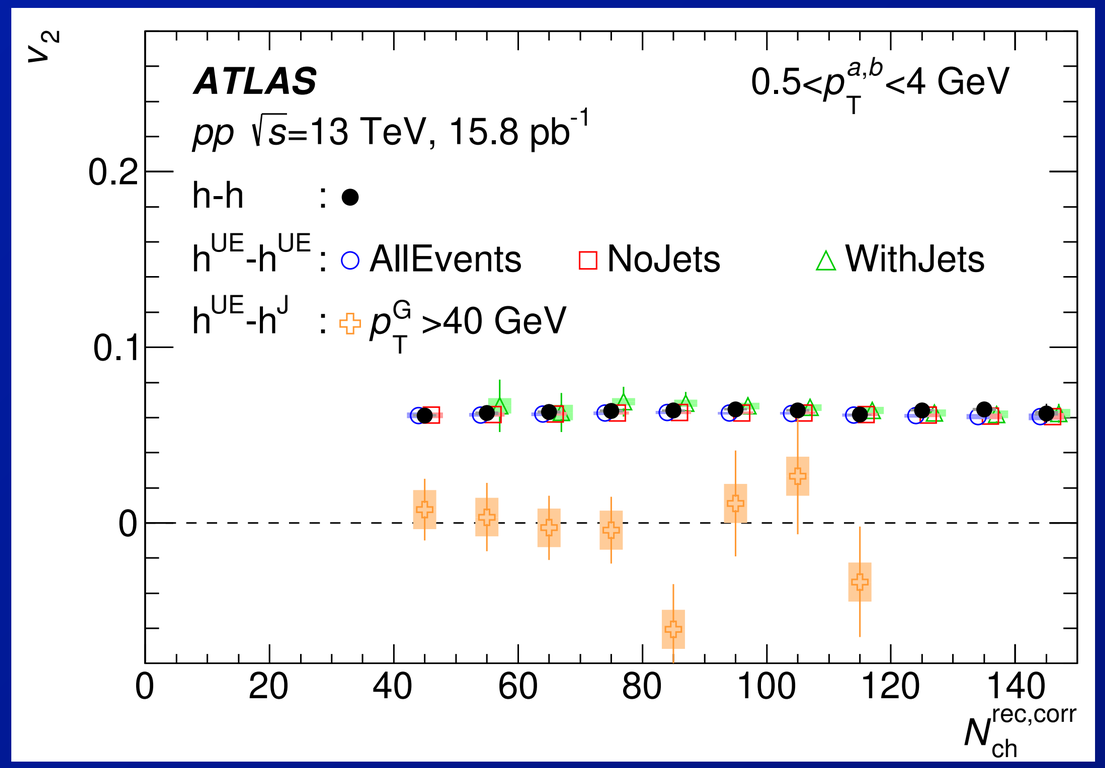
Two-particle correlation functions: jet-triggered

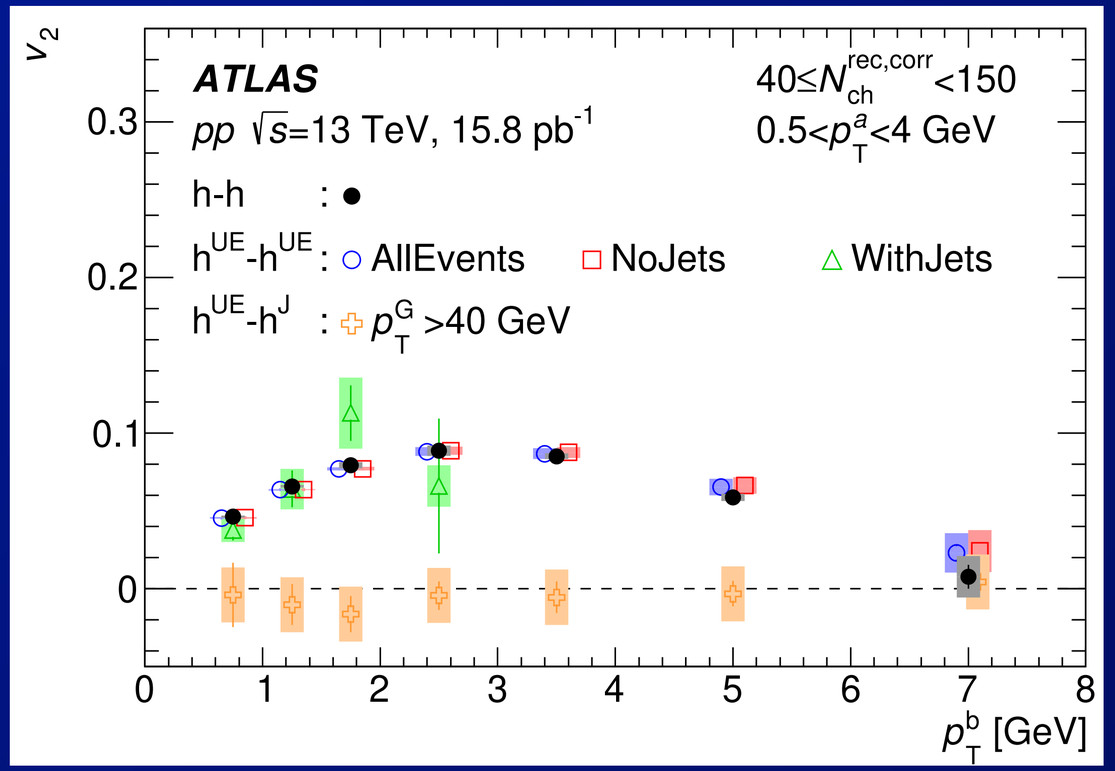


- **Jet-trigggered 2PC for different multiplicities**

⇒**Ridge not evident in the 2PC for any multiplicity interval**

2PC, v_2 using template fit method



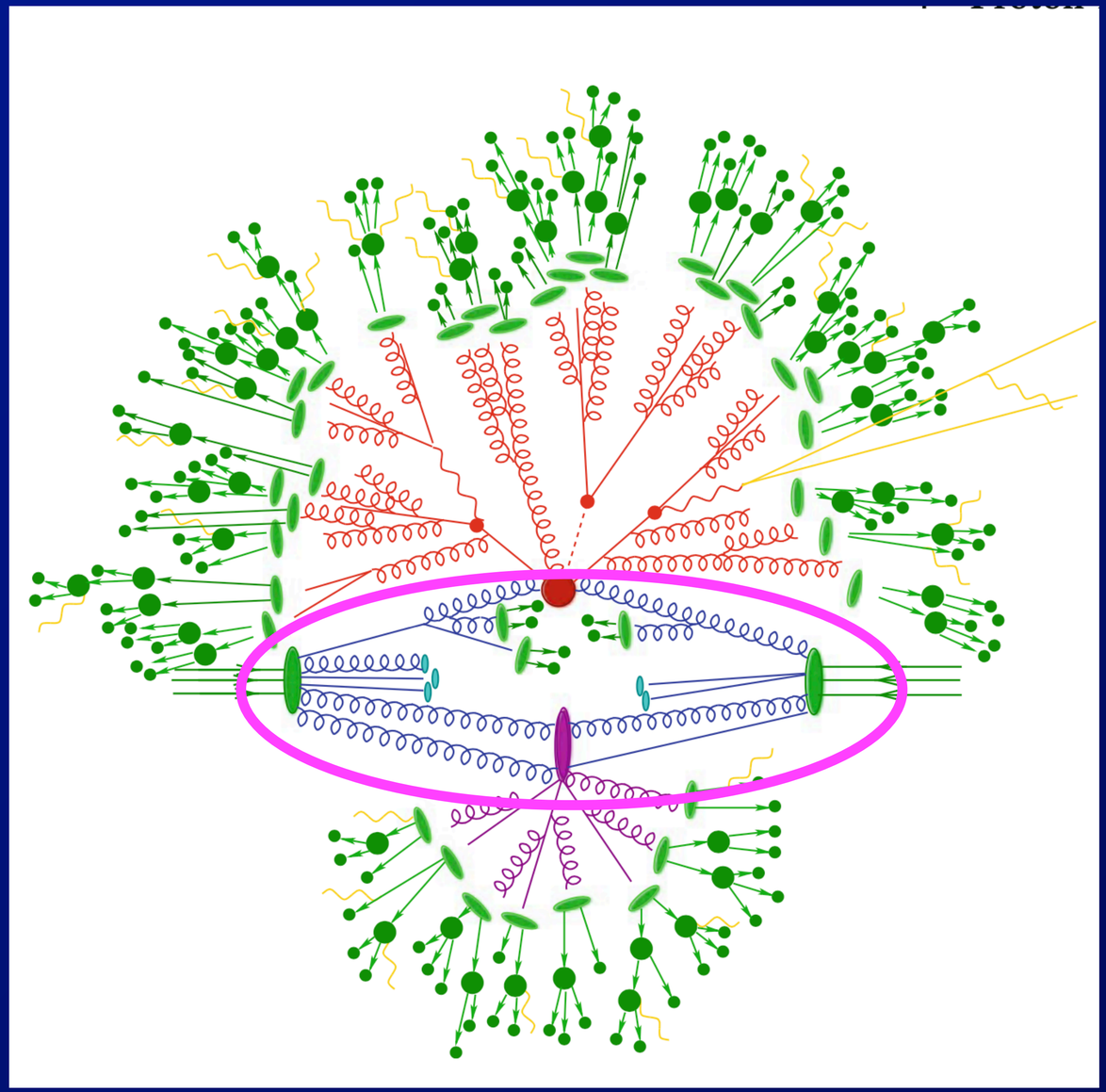


- **Compare results of this analysis with jet blind results (h-h)**
  - Requiring a jet or excluding a jet in the pp event has negligible impact
- **Jet-triggered ($p_{\mathrm{T}}^{\mathrm{G}}$ > 40 GeV) v_2 consistent w/ zero**
  - Both p_T - integrated and as a function of p_T of jet-selected particle (p_T^b)

⇒Fake correlation due to UE modulation bias has sharp rise at low p_T

Summary

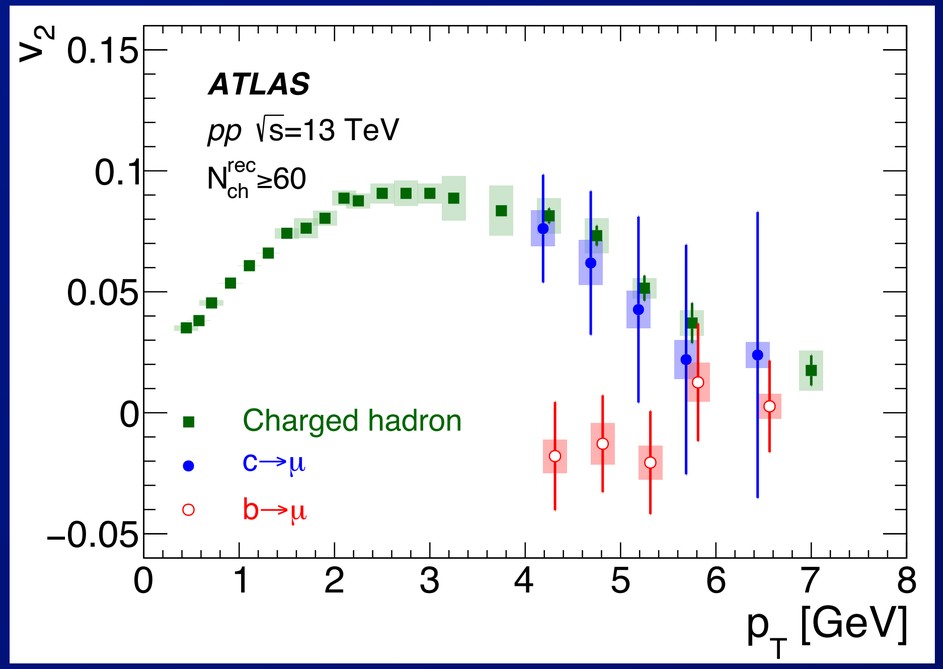
- In pp collisions, jet p_T values are biased by modulation in the UE
  - Indirect evidence that ridge is a global property of the UE ?
- Applying a p_T threshold to jet constituents can suppress bias
  - Here $p_T > 4$ GeV
- Excluding or requiring $p_{\mathrm{T}}^{\mathrm{G}} > 15$ GeV jet in pp collision has negligible impact on soft, UE v_2
  - Consistent with previous Z-tagged 2PC
- Jet-triggered 2PC v_2 consistent with zero, within uncertainties

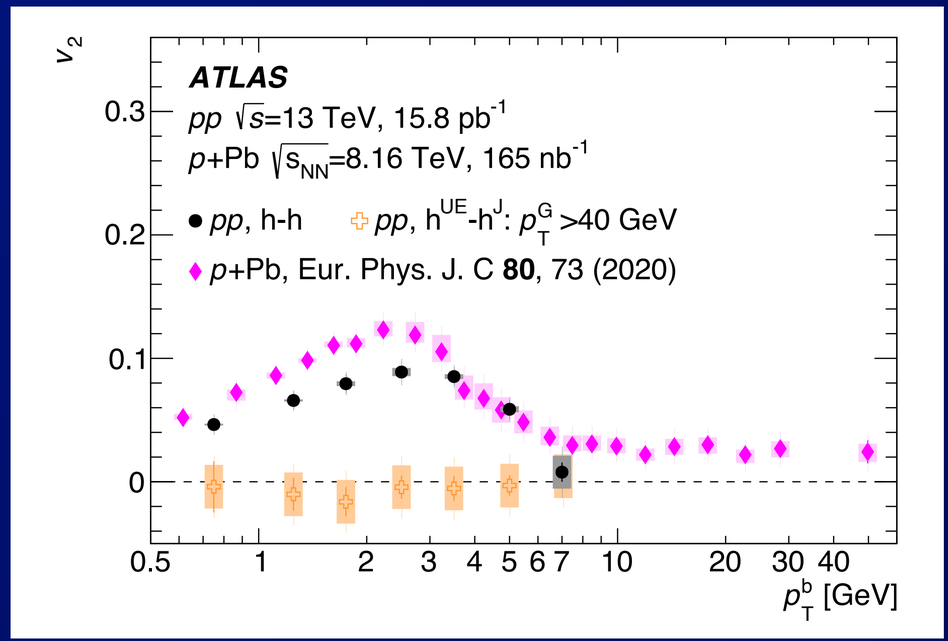


⇒ Apparently, soft & hard physics completely decoupled

Comments

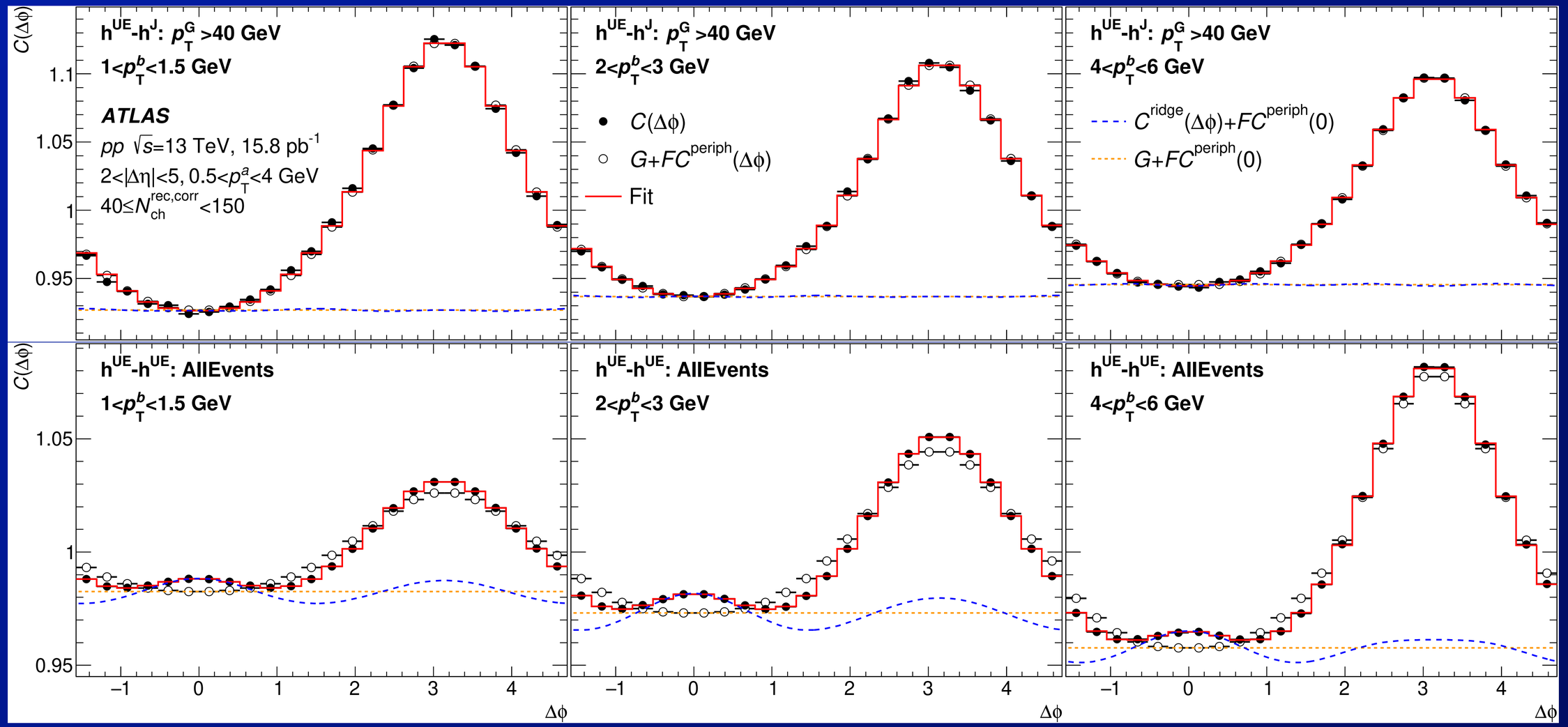
- This is a step in long program of studying the relationship of the (soft) ridge and hard-scattering processes
  - charm has non-zero v_2, but not bottom
  - ⇒Inclusive open charm "hard" or not?
- How do we understand p+Pb results?
  - Different systems
  - ⇒physics?
  - This analysis focused on lower fragment p_T
  - ⇒Also quite different techniques
- Multiplicity integrated jet-triggered v2:
  - $v_2^{int} = -0.009 \pm 0.010$ (stat) $\pm$ 0.014 (syst)
  - ⇒ 2σ difference from p+Pb high-p_T v_2





Backup

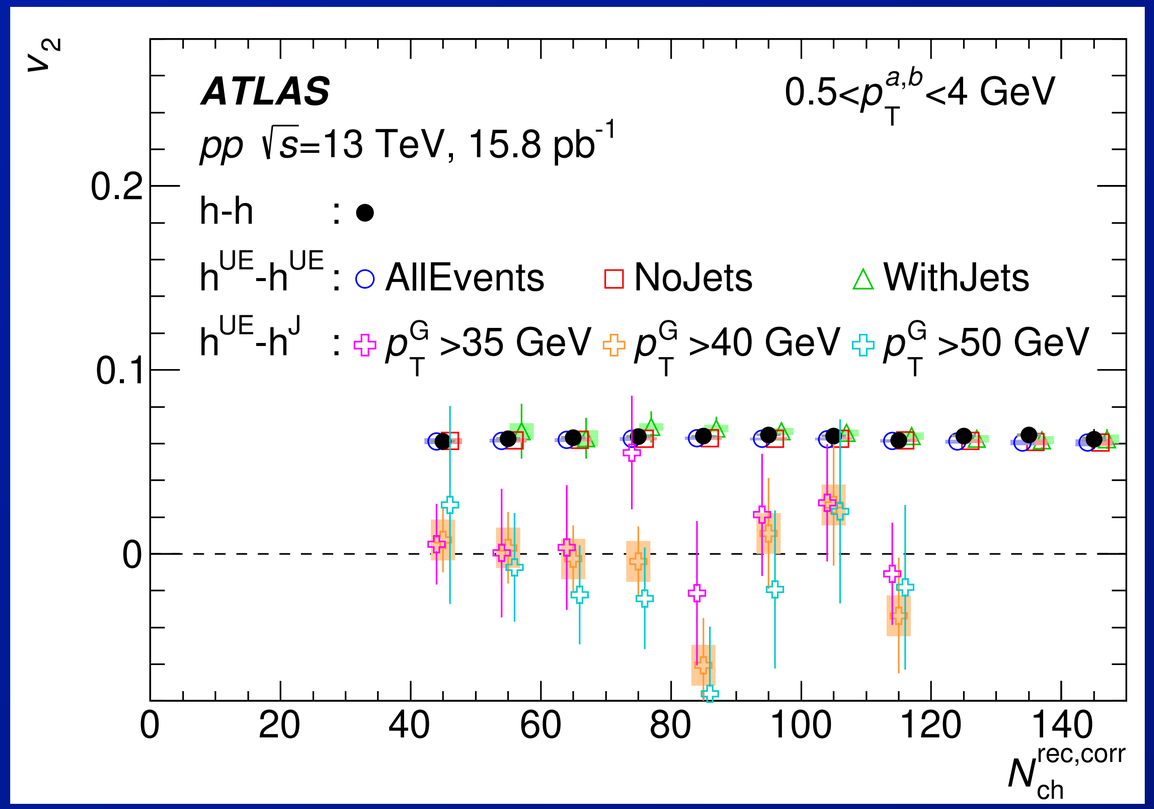
2PC functions in bins of p_T

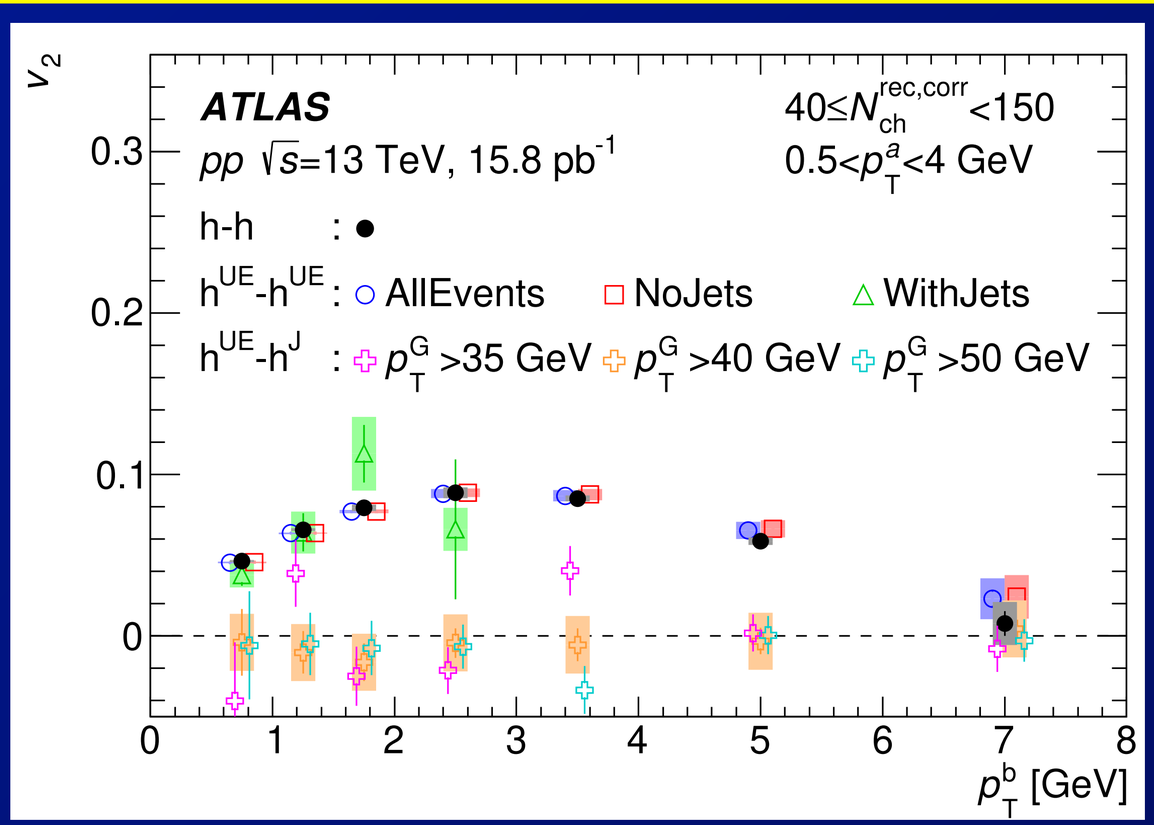


Top: jet-triggered, multiplicity-integrated

Bottom: all events, multiplicity-integrated

Dependence of jet-triggered 2PC on jet threshold



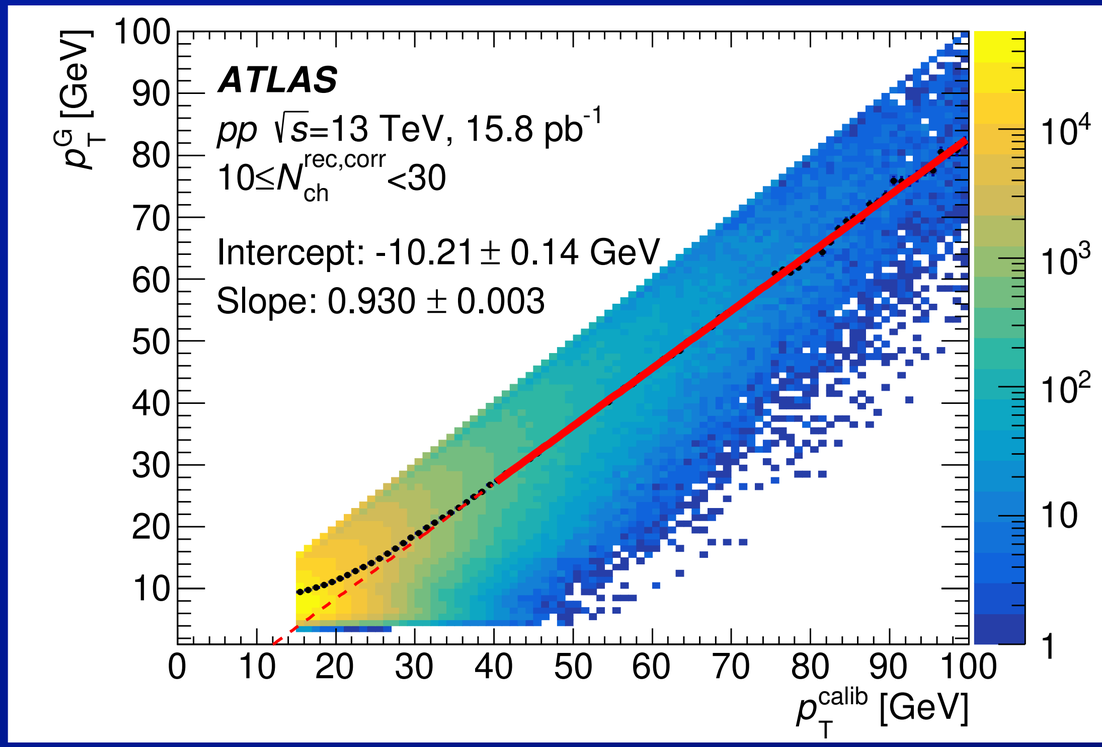


- **Results obtained w/ different requirements on trigger jet p_T^G**
  - **For 3 selections, 35, 40, 50 GeV, obtain v_2 consistent w/ zero**

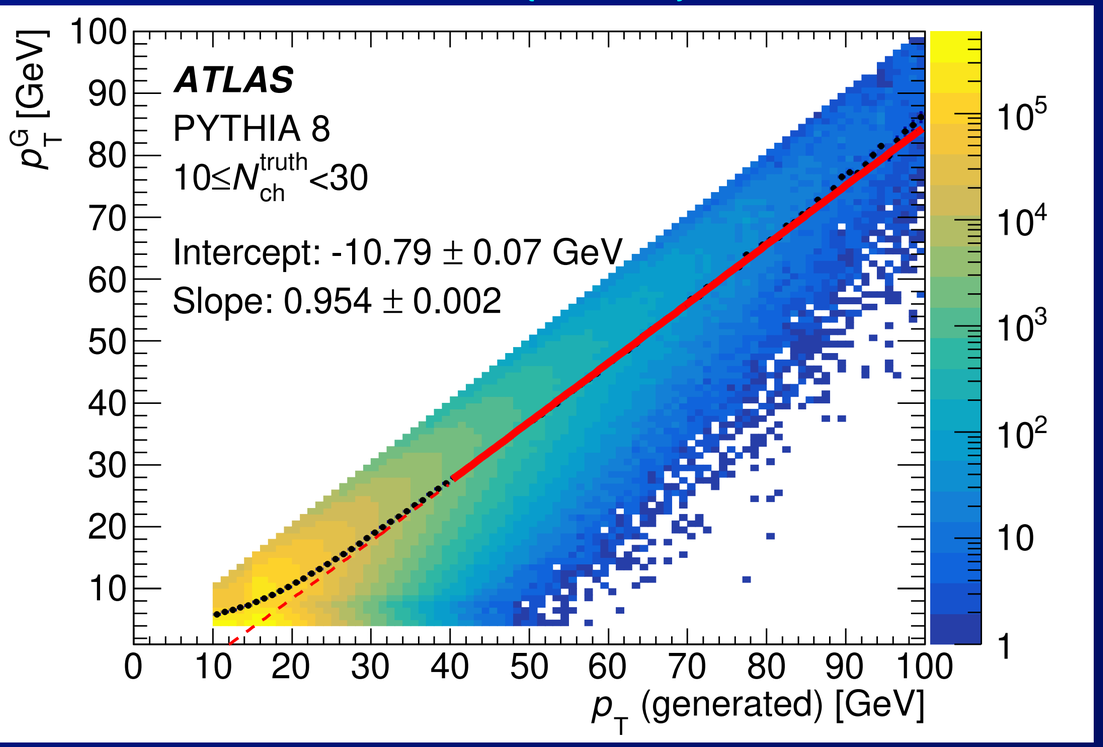
⇒Beware correlated uncertainty due to low-statistics peripheral reference, especially for 50 GeV selection.

Impact of constituent threshold on jet p_T

Data



MC (truth)



- Assess impact of the constituent threshold requirement in low-multiplicity (10 — 30) pp collisions where UE bias is negligible
  - Compare p_T^G to original calibrated PFlow jet p_T
  - Data (left) AND Pythia8 truth (right)

⇒ consistent ⇒ theoretical comparisons using p_T^G reasonable

pp event plane resolution

- Calculated using the sub-event method with particle-flow objects having $|\Delta\eta| > 1$ from any $p_T^G > 15$ GeV jet.