



Search for jet quenching effects in high multiplicity pp collisions at $\sqrt{s} = 13$ TeV

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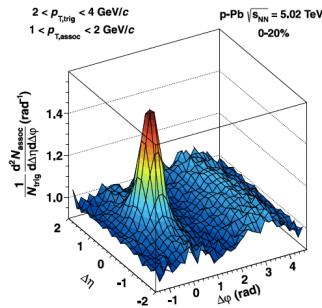
Quark-Gluon Plasma in small systems?



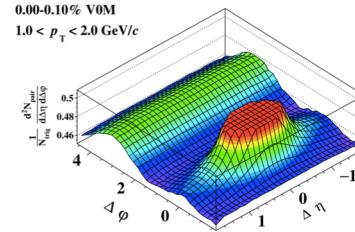
Focus on events with high Event Activity (EA)

Evidence of collective effects

Phys.Lett. B719 (2013) 29

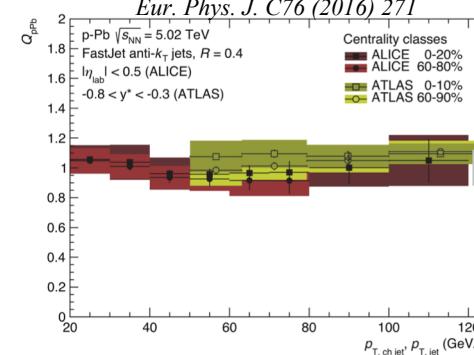


ALICE Preliminary, pp $\sqrt{s} = 13$ TeV
0.00-0.10% V0M
 $1.0 < p_T < 2.0$ GeV/c



No significant evidence of jet quenching

Eur. Phys. J. C76 (2016) 271



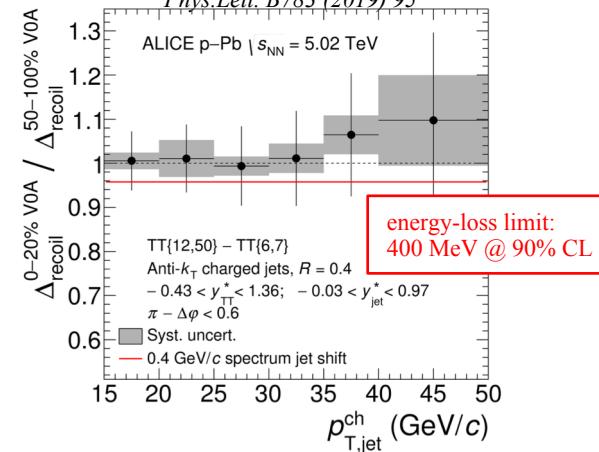
QGP generates both collective effects and jet quenching: cannot have one without the other

Next steps for jet quenching searches:

- improve precision
- other observables
- other small systems

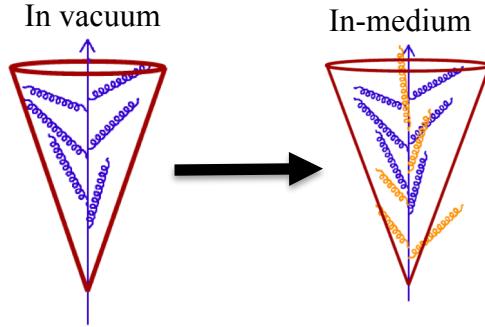
} this talk

Phys.Lett. B783 (2019) 95





Jet quenching observables



Signatures of in-medium interactions

1. Energy transport out-of-cone
→ yield suppression (R_{AA} , I_{AA})
2. Jet substructure modification
3. Jet deflection → acoplanarity

All must occur

Different sets of observables probe different aspects of jet quenching

- explore all three, require consistent picture

Jet quenching in high-EA pp collisions

Inclusive R_{AA}

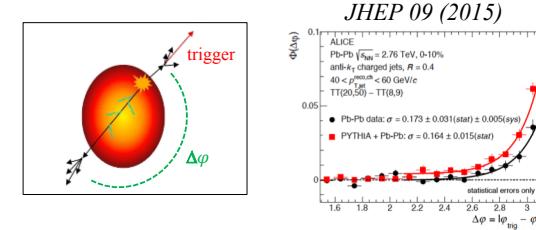
- Glauber scaling undefined, measurement not possible

Acoplanarity

D. A. Appel, PRD 33, 717 (1986)

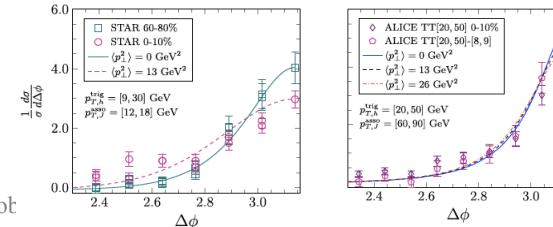
J.P. Blaizot and L. McLerran, PRD 34, 2739 (1986)

Experimental techniques in place



Background: initial-state (Sudakov) radiation

L. Chen et al., Phys.Lett. B773 (2017) 617





pp collisions at $\sqrt{s}=13$ TeV



Dataset: pp, $\sqrt{s}=13$ TeV (2016-18)

Online triggers (see also backup slide):

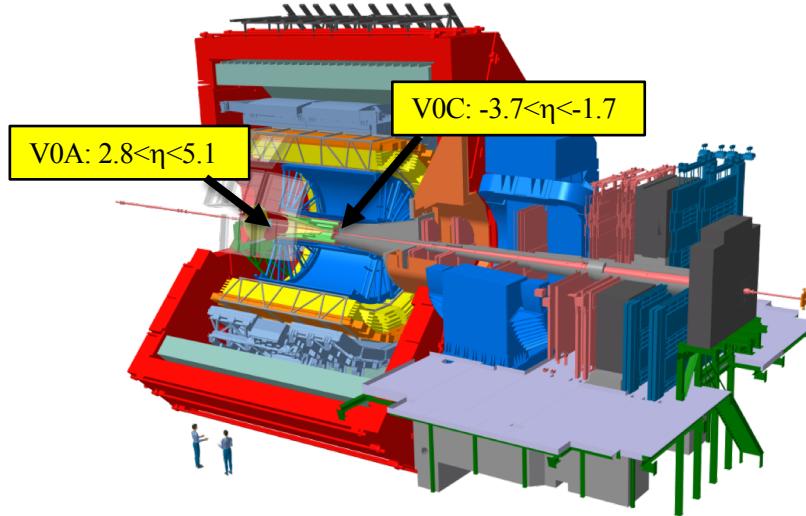
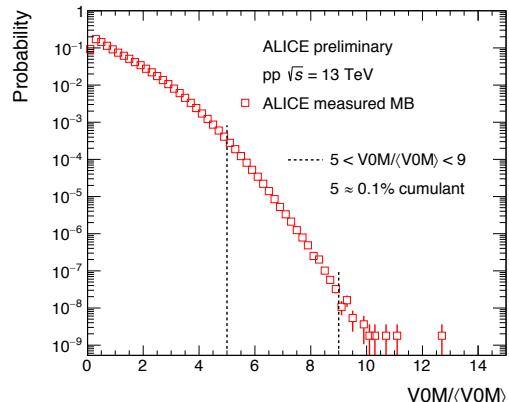
- MB: 0.098 pb^{-1} (3.2B evts)
- High Multiplicity: 13 pb^{-1}

Offline Event Activity (EA)

- $V0M = V0A + V0C$

Scaled multiplicity $V0M/\langle V0M \rangle$

- $\langle V0M \rangle$ = mean of MB distribution
- Enables comparison of runs with differing V0 gain, and with theory



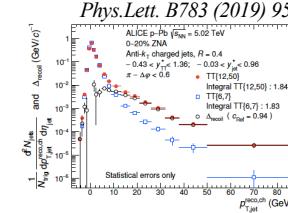
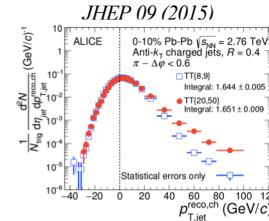
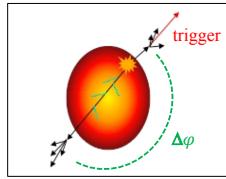
Offline: High Multiplicity (HM) selection

- $5 < (V0M/\langle V0M \rangle) < 9$
- 0.1% of MB cross section



Semi-inclusive recoil jet analysis

Semi-incl. distribution of recoil jets relative to a high- p_T hadron trigger



$$\Delta_{recoil}(p_T^{jet}, \Delta\varphi) = \left[\frac{1}{N_{trig}} \frac{dN_{Jet}}{dp_T^{jet} d\Delta\varphi} \right]_{Signal} - c_{Ref} \cdot \left[\frac{1}{N_{trig}} \frac{dN_{Jet}}{dp_T^{jet} d\Delta\varphi} \right]_{Reference}$$

Trigger: charged hadron

- Signal: TT{20,30}
- Reference: TT{6,7}

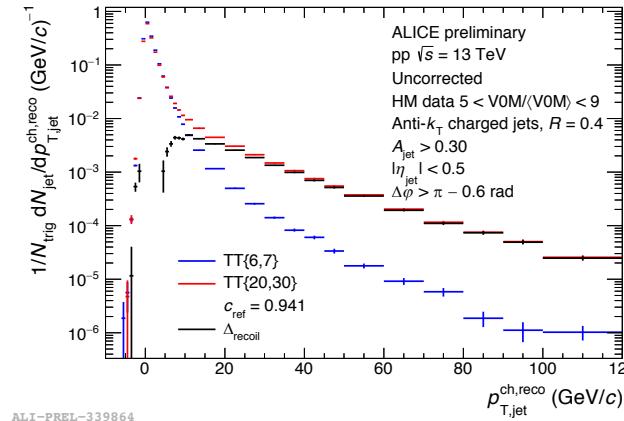
Recoil jets: Charged jets, anti- k_T ,
R=0.4

$c_{Ref} \sim 0.95-1.0$ (extracted from data)

JES: area-based ρA adjustment

Full unfolding not yet done

→ data labelled “uncorrected”



Δ_{recoil} removes all uncorrelated background yield including multiple partonic interactions (MPI) → essential for precise acoplanarity measurement



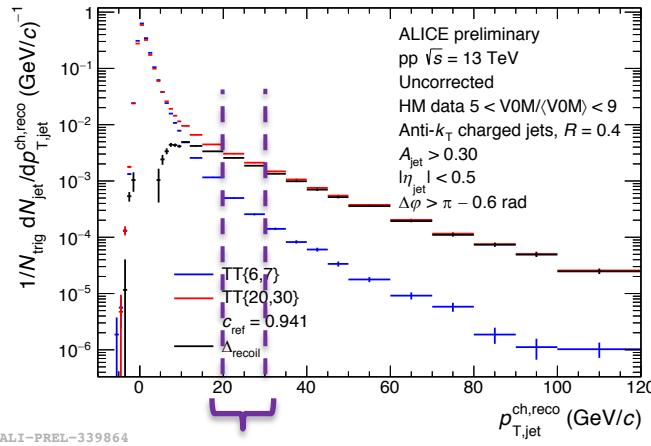
Acoplanarity via Δ_{recoil}



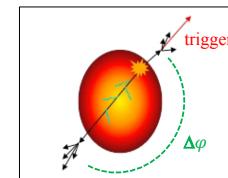
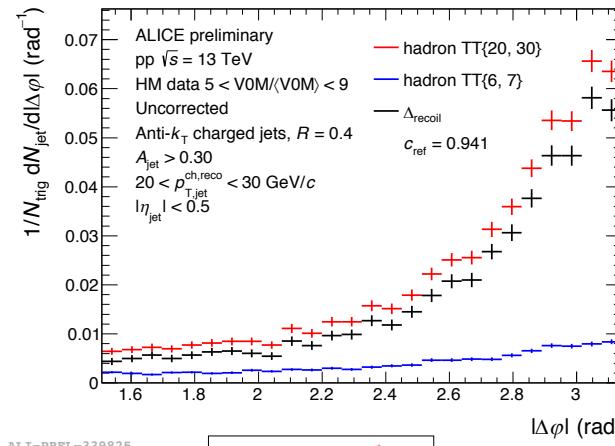
$$\Delta_{\text{Recoil}}(p_T^{\text{jet}}, \Delta\varphi) = \left[\frac{1}{N_{\text{trig}}} \frac{dN_{\text{Jet}}}{dp_T^{\text{jet}} d\Delta\varphi} \right]_{\text{Signal}} - c_{\text{Ref}} \cdot \left[\frac{1}{N_{\text{trig}}} \frac{dN_{\text{Jet}}}{dp_T^{\text{jet}} d\Delta\varphi} \right]_{\text{Reference}}$$

1-d projections of the 2-d distribution

Integrated over $\Delta\varphi > \pi - 0.6$



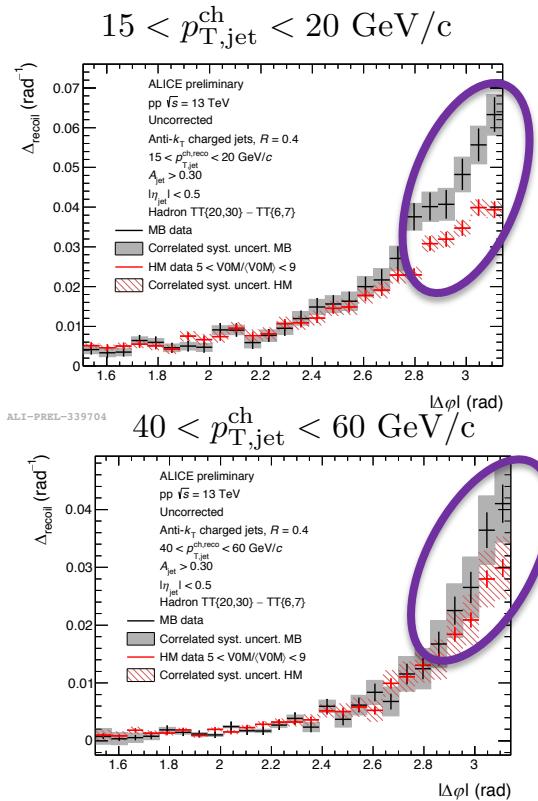
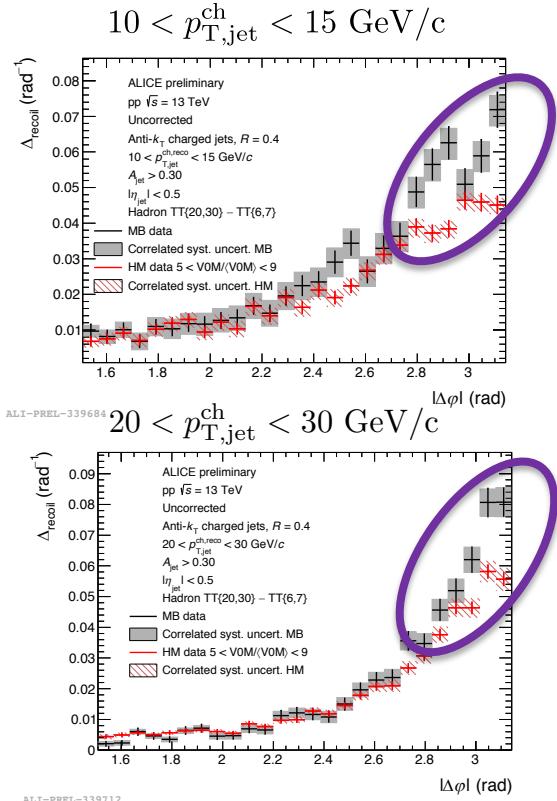
$20 < p_{T,\text{jet}}^{\text{ch},\text{reco}} < 30 \text{ GeV}/c$





EA dependence of acoplanarity

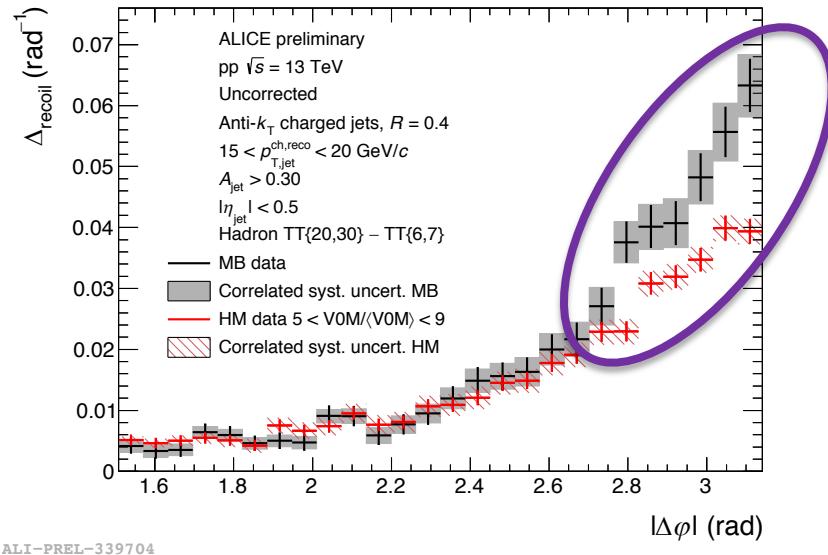
Data not unfolded; estimated systematic uncertainty from track eff



- Significant suppression and broadening of HM wrt MB distribution
- Strongest effects at lowest $p_{T,\text{jet}}^{\text{ch}}$



$15 < p_{T,\text{jet}}^{\text{ch}} < 20 \text{ GeV}/c$



The observed effect is characteristic of enhanced jet quenching in high EA collisions.

However, before concluding that its origin is indeed jet quenching, all other potential sources must be eliminated.



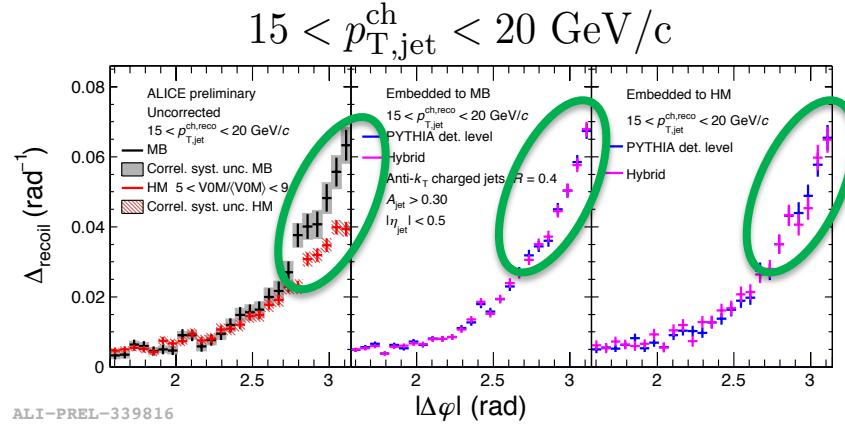
Systematic check:

Broadening due to track density?



Is the broadening due smearing of the jet direction due to uncorrelated background?

- Generate PYTHIA 8 Monash events that satisfy the TT cuts
- Detector effects via fast simulation
- Embed in MB or HM events
- Do the full Δ_{recoil} analysis
- Compare embedded and Truth distributions



Embedded distributions: no significant broadening
→ broadening not due to higher track density

Additional checks (backup slide):

broadening seen in raw distributions → not introduced by subtraction in Δ_{recoil}

Broadening not due to instrumental effects or analysis procedure
→ effect is physical



Comparison to PYTHIA



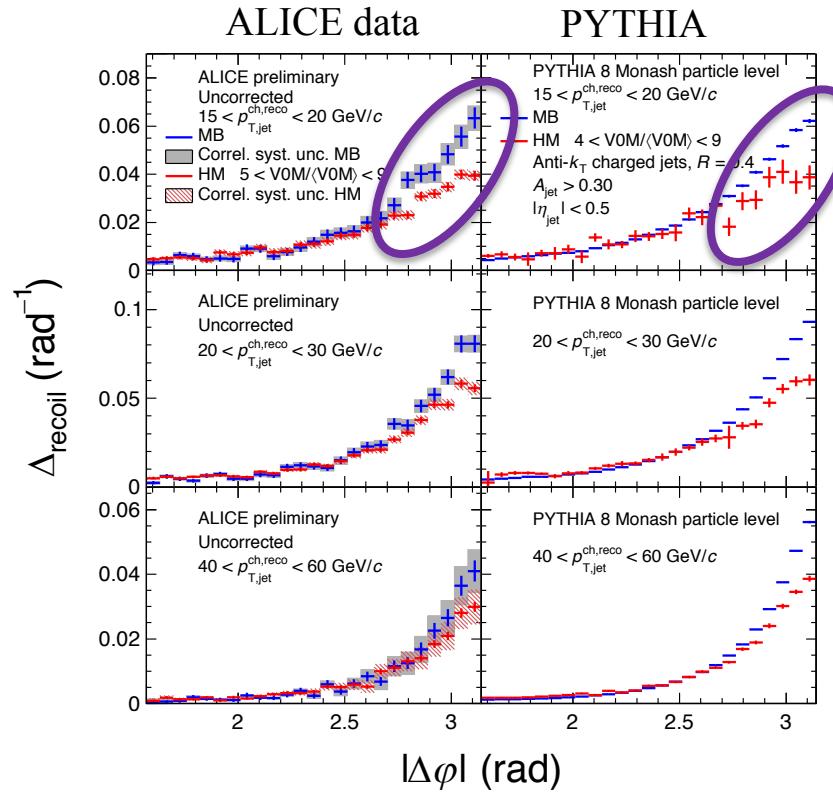
PYTHIA 8 Monash

Qualitative comparison

Particle-level

No effects of B-field or interactions in material
→ V0M = Charged particles in V0A/C
 η -acceptance

HM: $4 < (\text{V0M}/\langle \text{V0M} \rangle) < 9$

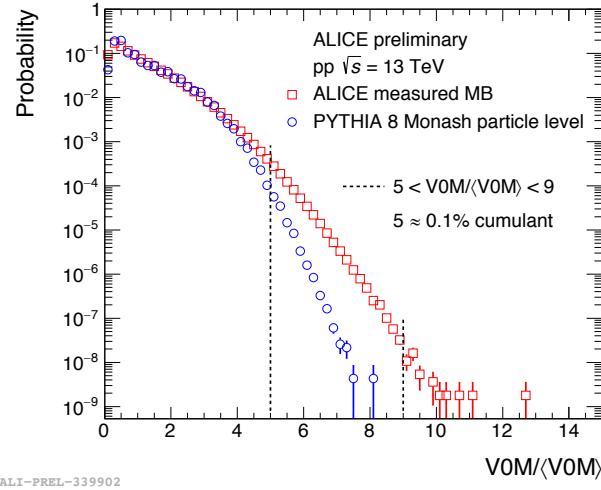


ALI-PREL-339740

PYTHIA exhibits qualitatively similar broadening as data for HM vs MB



What are high multiplicity pp collisions? I



PYTHIA particle-level undershoots high-multiplicity tail

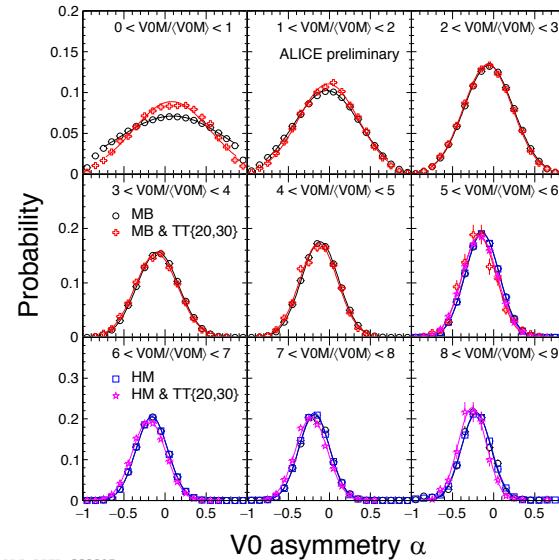
- Additional physics mechanisms
- Detector fluctuations (det-level simulations in progress)

Forward/backward asymmetry

- does F/B correlation change with multiplicity, e.g. due to changing jet contribution?

$$\boxed{\begin{array}{l} \text{V0A: } 2.8 < \eta < 5.1 \\ \text{V0C: } -3.7 < \eta < -1.7 \end{array}}$$

$$\alpha = \frac{V0A / \langle V0A \rangle - V0C / \langle V0C \rangle}{V0A / \langle V0A \rangle + V0C / \langle V0C \rangle}$$

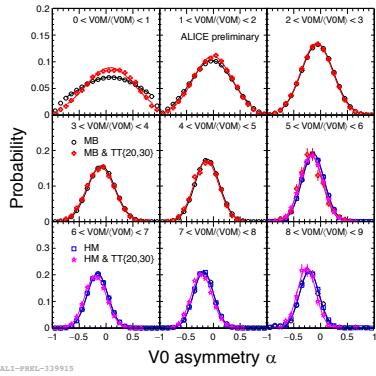




What are high multiplicity pp collisions? II



$$\alpha = \frac{V0A/\langle V0A \rangle - V0C/\langle V0C \rangle}{V0A/\langle V0A \rangle + V0C/\langle V0C \rangle}$$

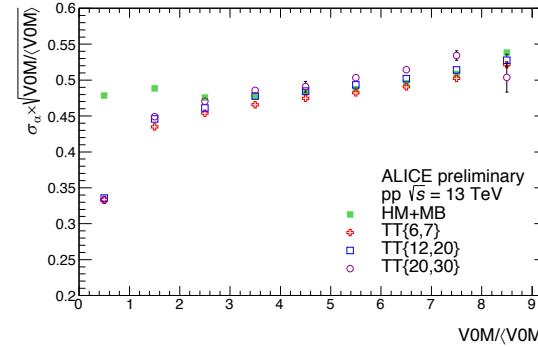
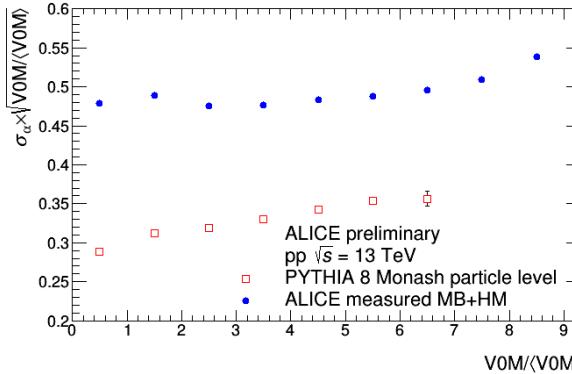


Width of α narrower for larger $V0M/\langle V0M \rangle$

- good fits by a Gaussian fn

If width of α due to counting statistics:

$$\sigma_\alpha \times \sqrt{V0M/\langle V0M \rangle} \sim \text{const}$$



- Scaled width vs scaled multiplicity: minor evolution, small TT{} bias at large mult
- Character of events does not change significantly up to $9 \times \langle V0M \rangle$



Summary and outlook



Novel techniques developed to search for jet quenching in High Multiplicity (HM) pp collisions at $\sqrt{s}=13$ TeV

Δ_{recoil} measurement of acoplanarity:

- significant broadening observed for $p_{T,\text{jet}}^{\text{ch}} < 40$ GeV/c
- Coincident with yield suppression
- Broadening seen in raw (unsubtracted) data; not due to track density

V0 asymmetry α :

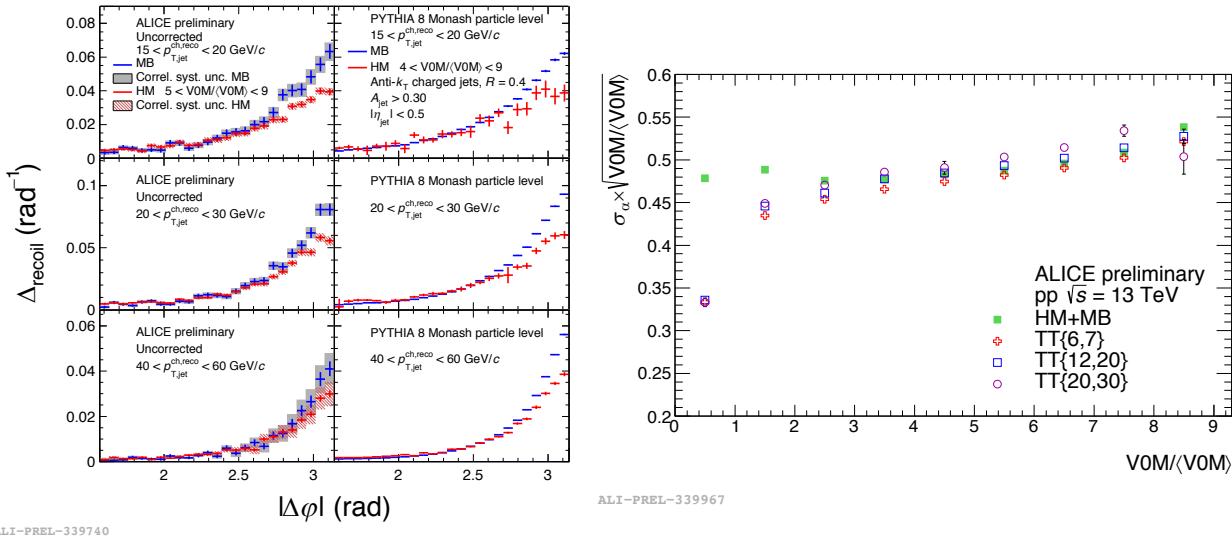
- event characteristics evolve little up to 9 times the mean MB multiplicity

PYTHIA shows qualitatively similar broadening

Broadening may be consistent with enhanced multi-jet contribution in HM events

Next steps:

- Understand broadening/suppression mechanisms in PYTHIA
- Additional observables sensitive to multi-jet final states



This analysis raises a question for all measurements at high multiplicity in small systems:

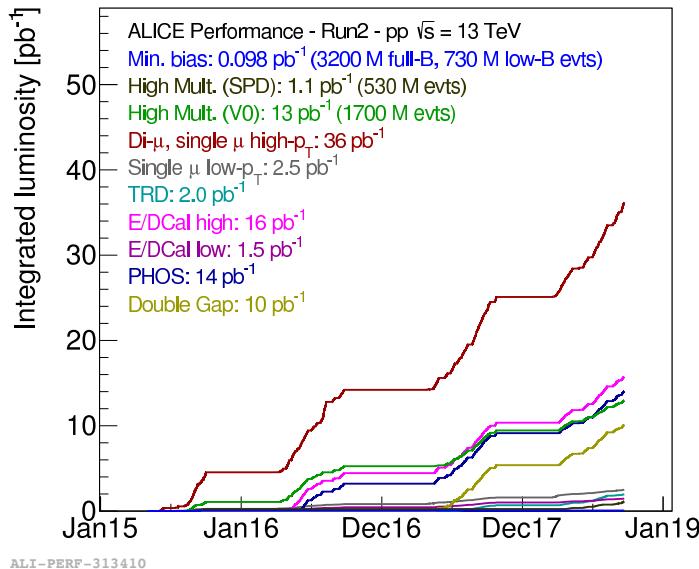
When we ask for high multiplicity, what is QCD giving us?



Backup slides

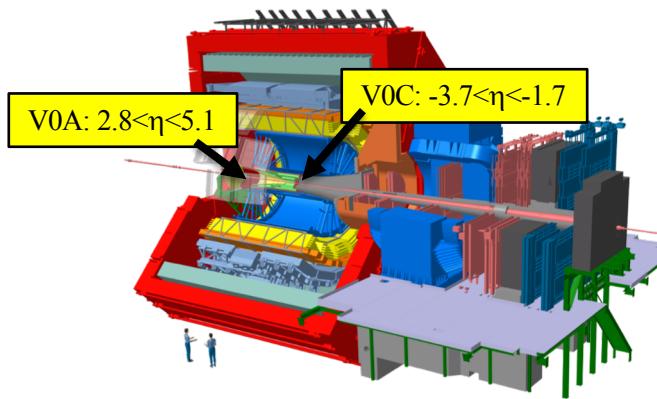


ALICE datasets for pp collision at $\sqrt{s}=13$ TeV



High Multiplicity (V0) Online Trigger

- Sum > threshold of V0 signals (excluding innermost V0A ring) within 25 ns of bunch crossing
- #channels with timing compatible with beam-beam interaction > threshold
- #channels with timing compatible with beam-gas interaction < threshold
- CTP: past-future protection within 7 bunch-crossings around the trigger.

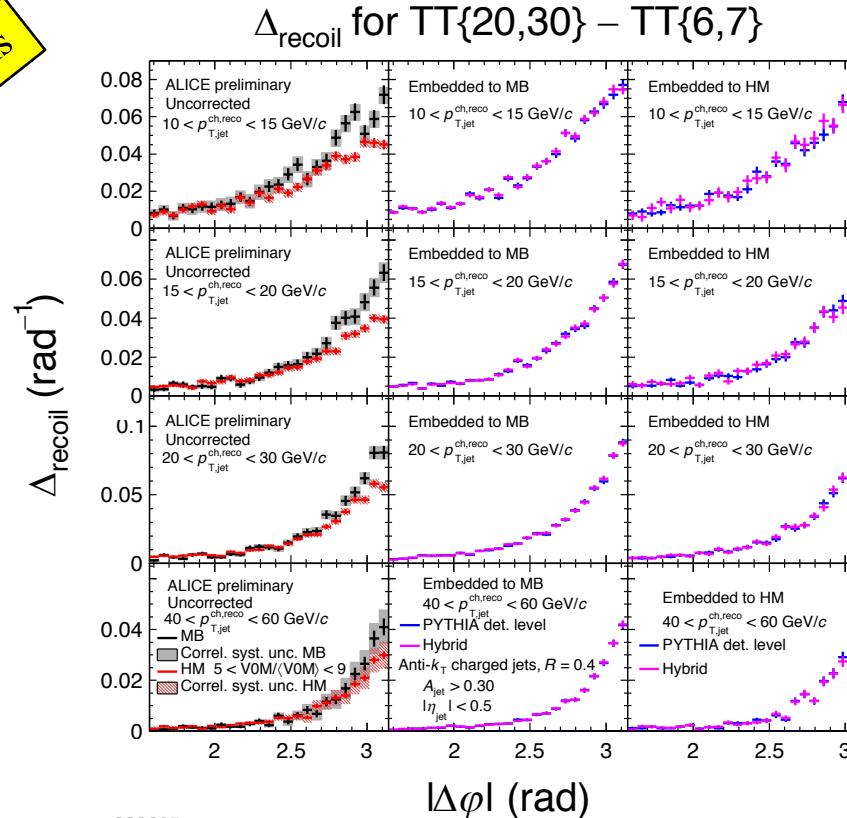




Broadening due to track density?



All $p_{T,\text{jet}}^{\text{ch}}$ bins



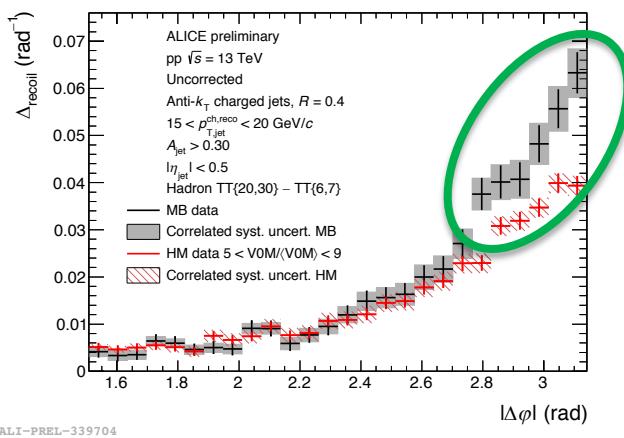


Systematic check: Broadening due to Δ_{recoil} subtraction?

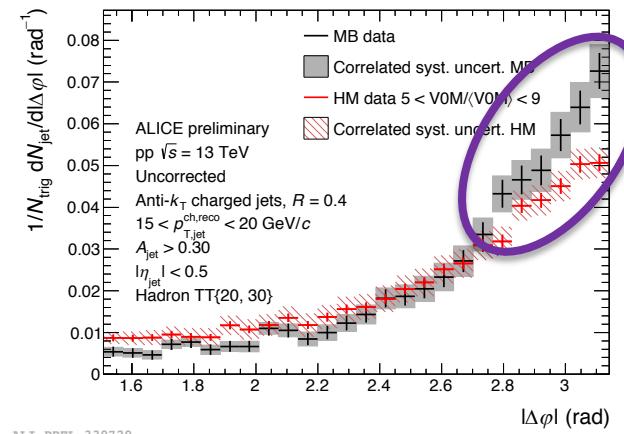


$$\Delta_{\text{Recoil}}(p_T^{\text{jet}}, \Delta\varphi) = \left[\frac{1}{N_{\text{trig}}} \frac{dN_{\text{Jet}}}{dp_T^{\text{jet}} d\Delta\varphi} \right]_{\text{Signal}} - c_{\text{Ref}} \cdot \left[\frac{1}{N_{\text{trig}}} \frac{dN_{\text{Jet}}}{dp_T^{\text{jet}} d\Delta\varphi} \right]_{\text{Reference}}$$

Δ_{recoil} (subtracted)



Signal Only (TT{20,30})



Larger azimuthal broadening in HM seen in Signal Only
Broadening not due to subtraction of Reference distribution in Δ_{recoil}