Search for jet quenching effects in high-multiplicity proton-proton collisions at √s = 13 TeV

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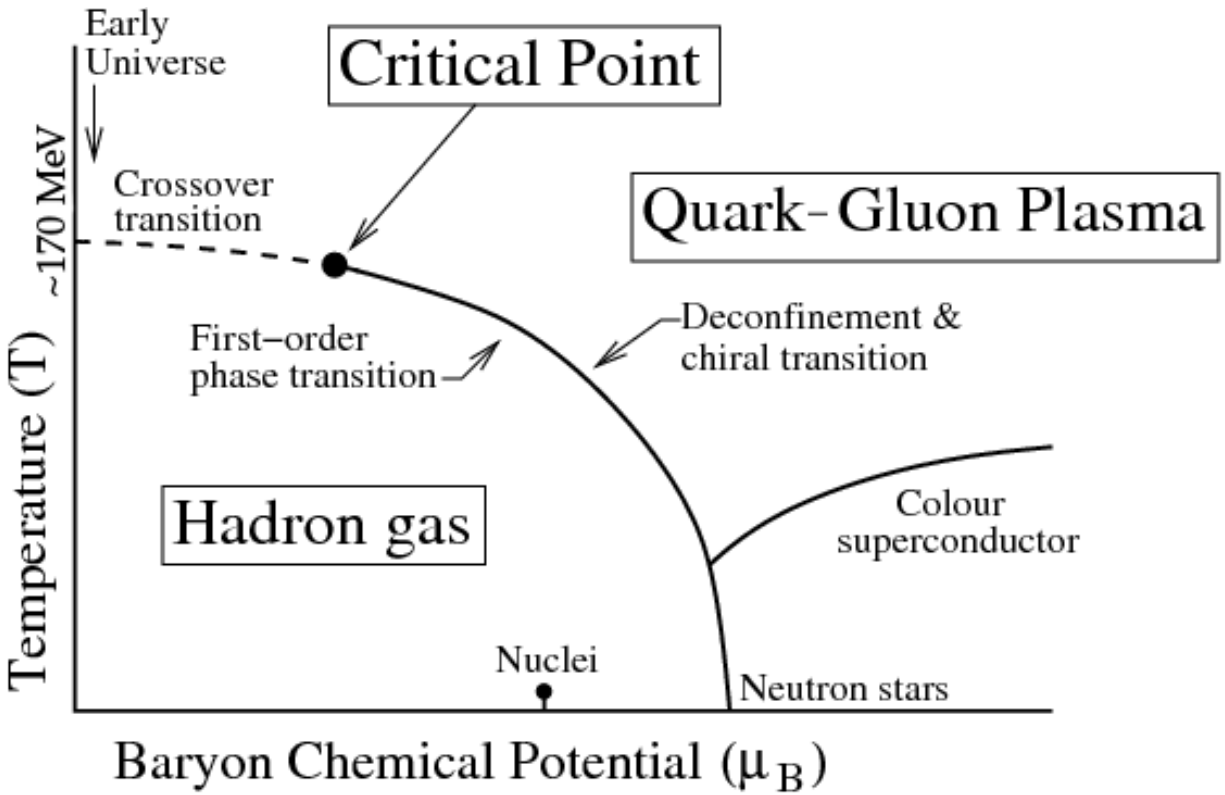
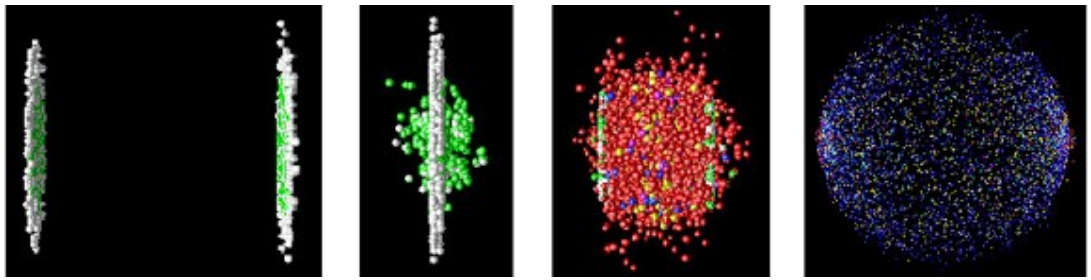
20th Conference of Czech and Slovak physicists

Phase diagram of strongly interacting matter

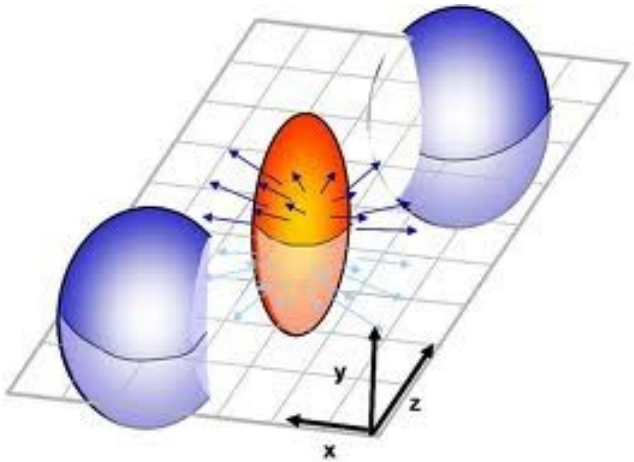


Collisions of ultra-relativistic heavy-ions probe high-energy-density and high-*T* corner of the phase diagram, where quark-gluon plasma is expected to exist

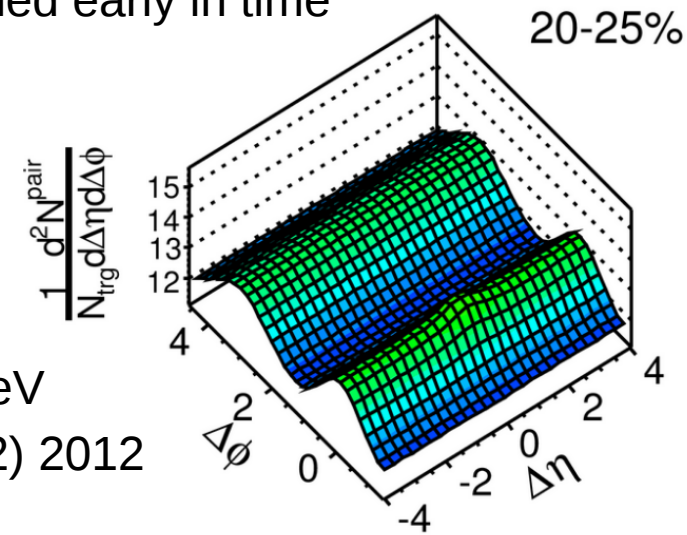


Probing quark-gluon plasma

- Collective flow of final state particles indicate perfect fluidity of QGP

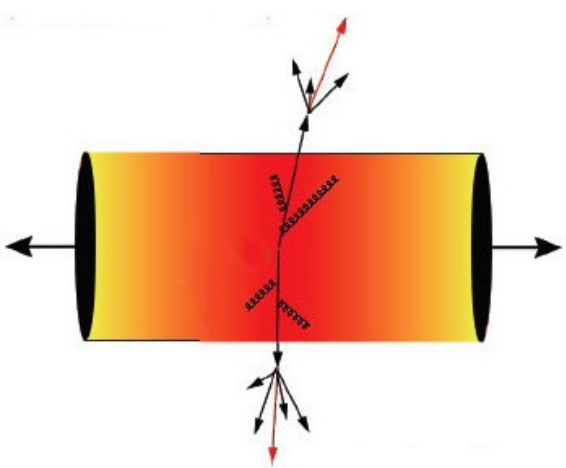


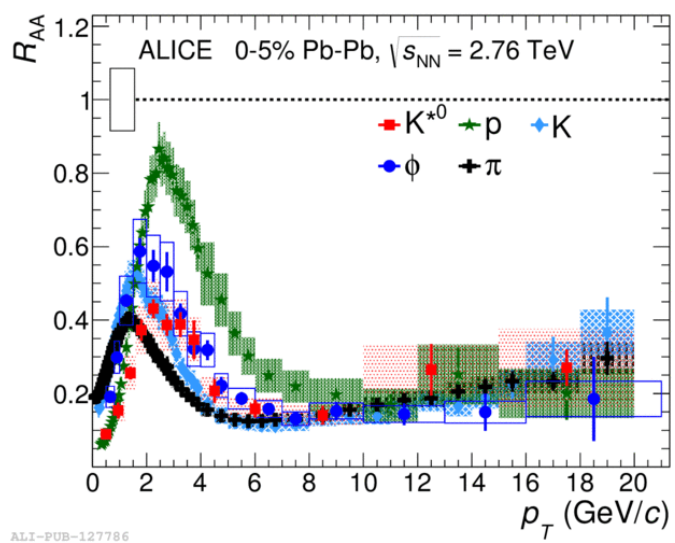
Azimuthal correlation between two particles across wide separation in pseudorapidity → established early in time



Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV
CMS EPJ C72 (2012) 2012

- Jet quenching : interaction of hard quarks and gluons with the medium → suppression of high p_T hadrons and jets, jet substructure modification, medium induced jet deflection



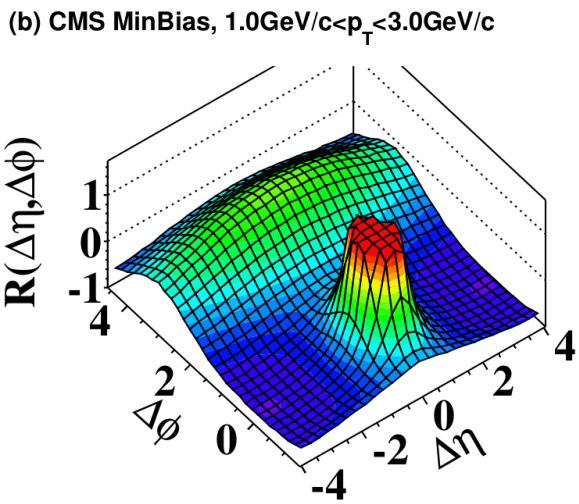


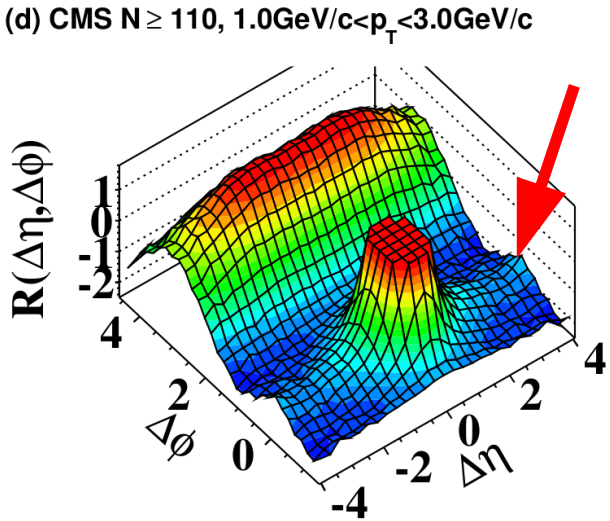
Nuclear modification factor:

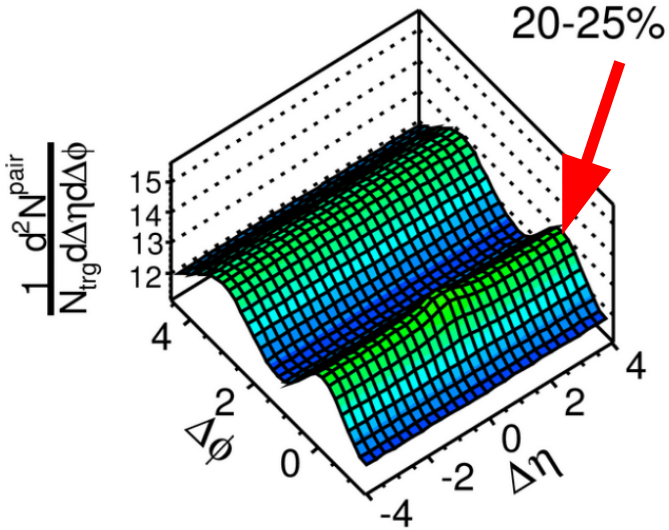
$$R_{AA} = \frac{Y_{AA}}{\langle N_{coll} \rangle \, Y_{pp}}$$

ALICE, PRC 95 (2017) 064606

QGP in small systems?







pp minimum bias

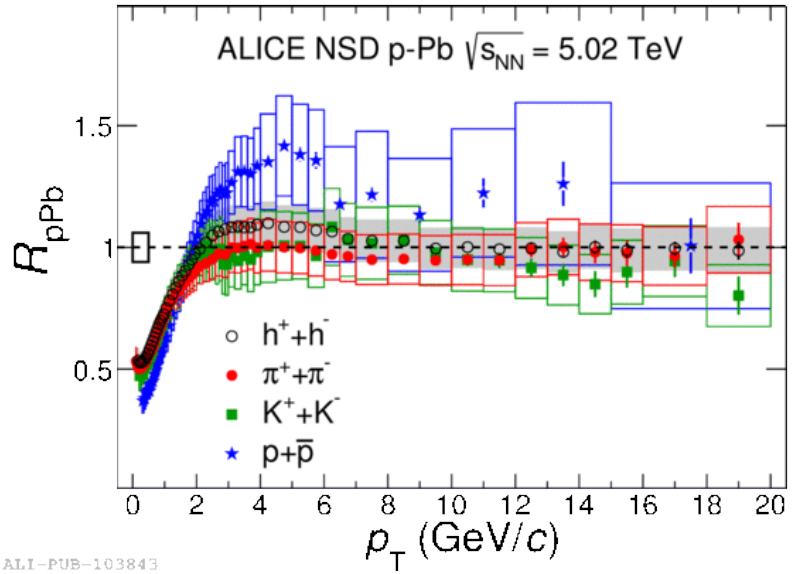
pp high multiplicity

CMS, JHEP 09 (2010) 091

Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV

CMS EPJ C72 (2012) 2012

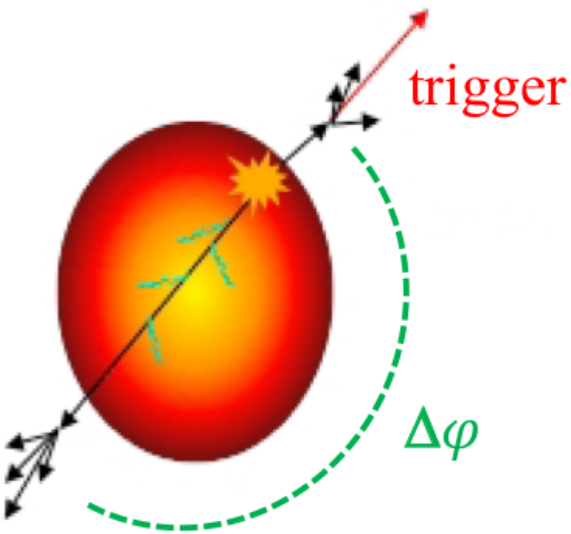
HM pp and p-Pb collisions exhibit collectivity but without a visible sign of jet quenching.

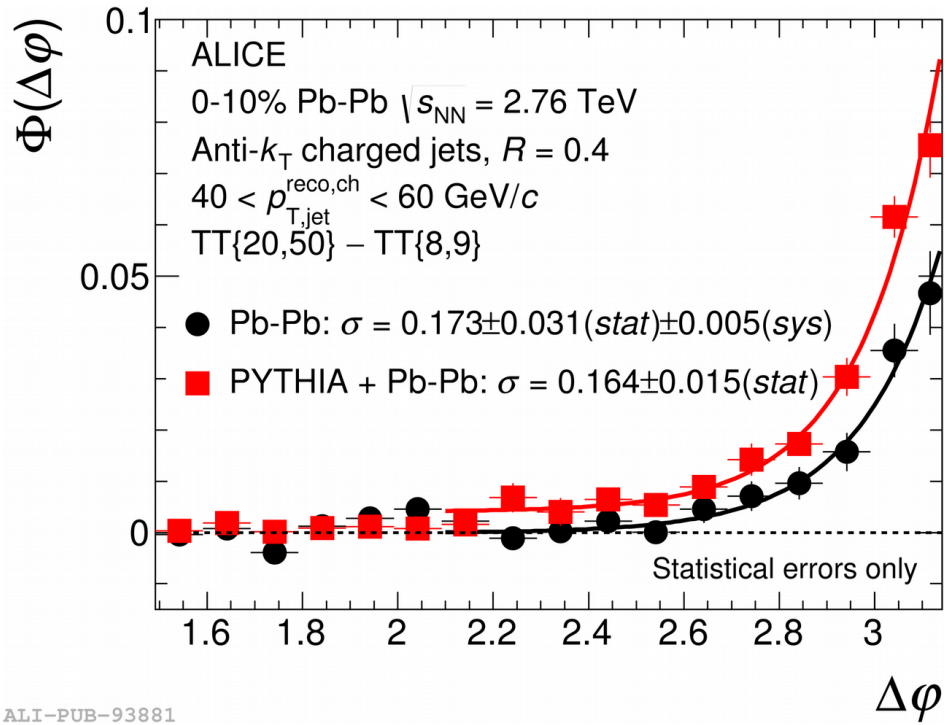


Jet quenching in high-multiplicity pp

- Measurement of nuclear modification factor in pp:

  binary collision scaling undefined → measurement impossible
- Medium induced deflection → increase of dijet acoplanarity





ALICE, JHEP 09 (2015) 1

pp collisions at √s = 13 TeV

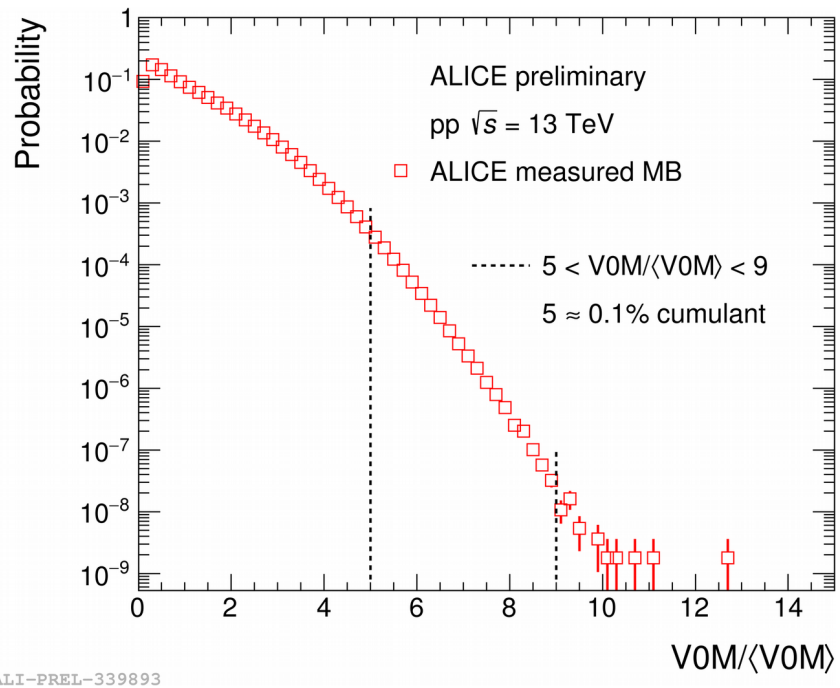
- Data from 2016-2018
- Online triggers:
  - Minimum bias (MB) 0.098 pb^{-1} (3.2G events)
  - High multiplicity (HM): 13 pb^{-1}
- Offline event activity (EA) selection:

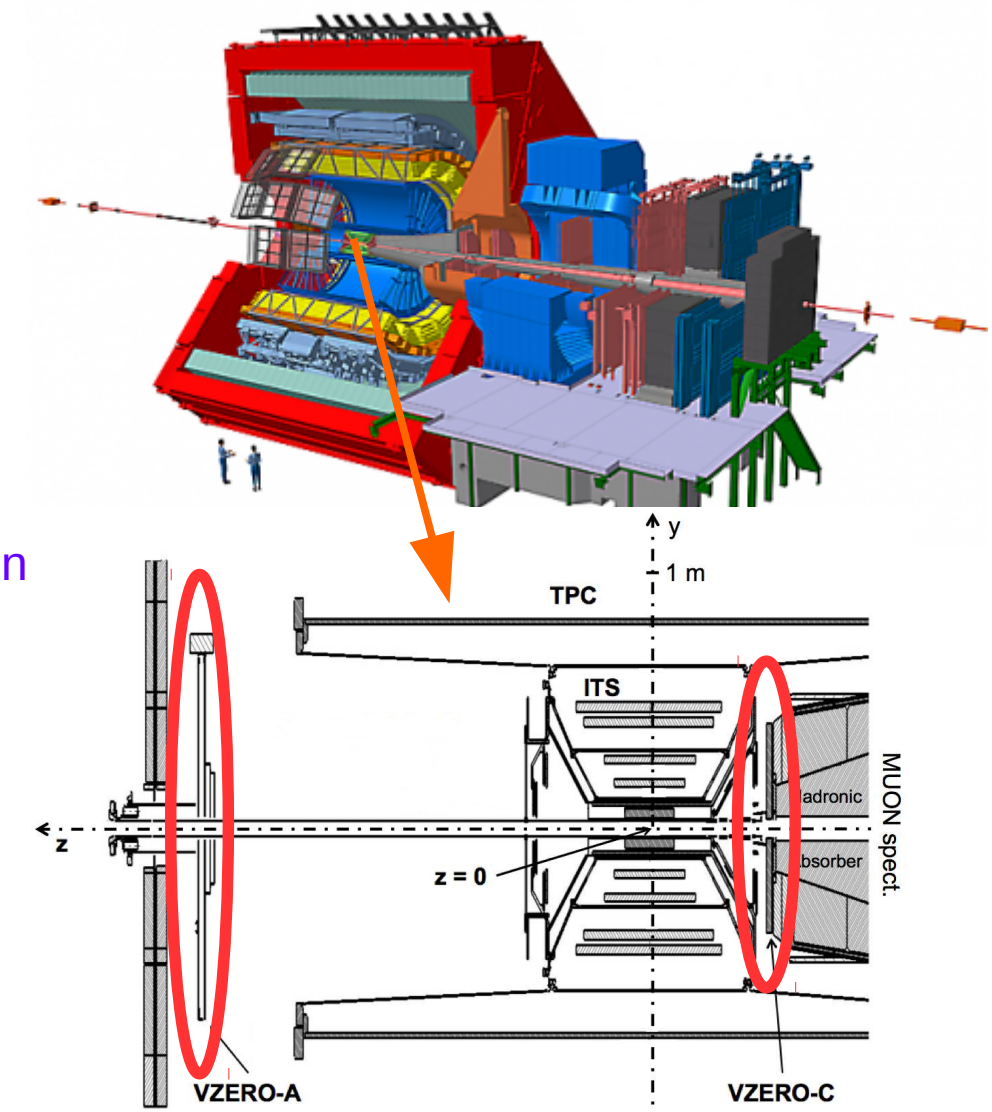
  V0M = V0A + V0C

  Scaled multiplicity V0M/⟨V0M⟩

  ⟨V0M⟩ = mean of MB distribution

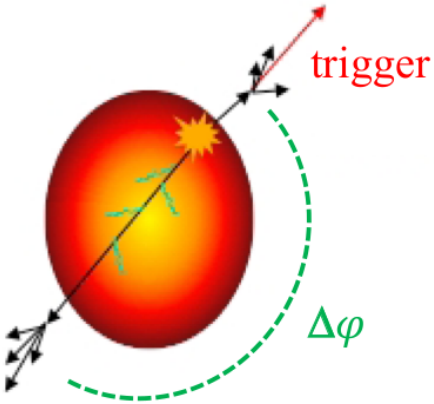
  Enables comparison of runs with differing V0 gain, and with theory
- 5 < V0M/⟨V0M⟩ < 9 ≈ 0.1% of MB cross section

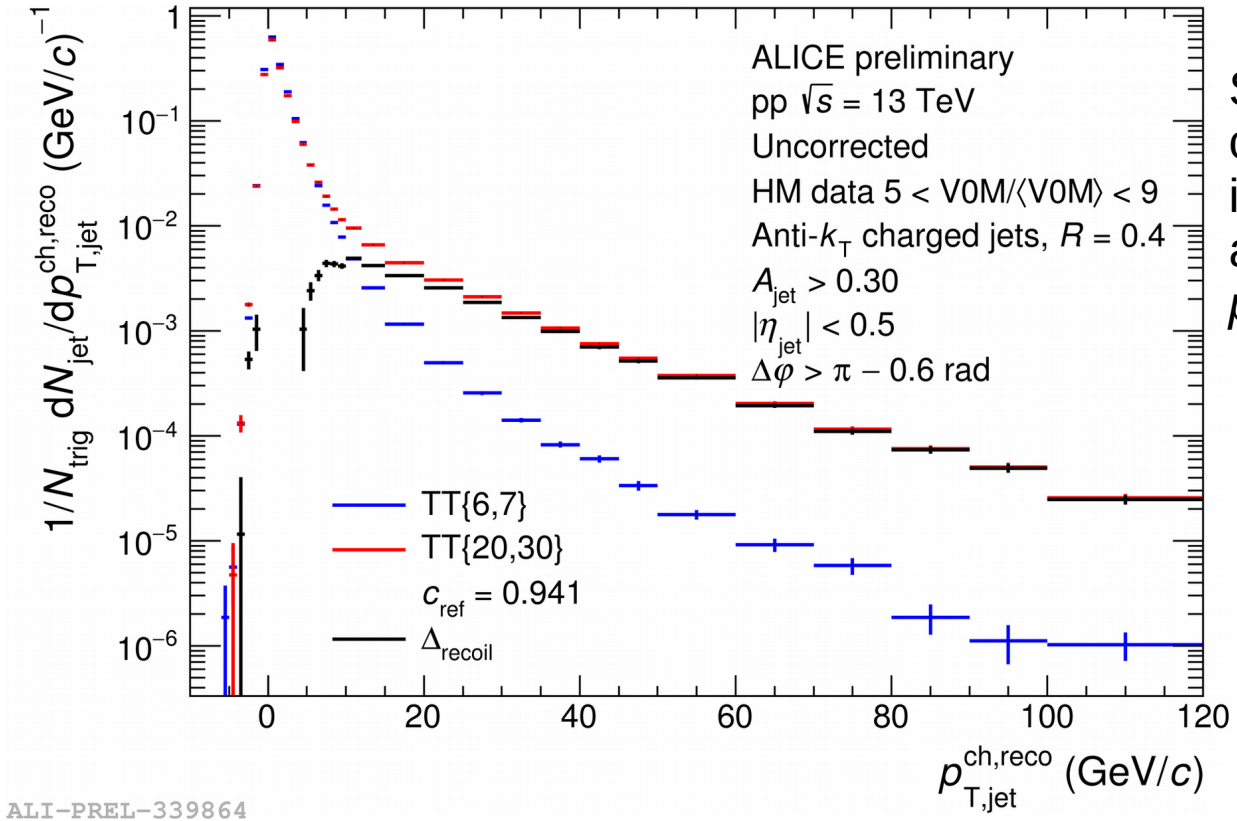




V0A : 2.8 < η < 5.1 **V0C : -3.7 < η < -1.7**

Semi-inclusive recoil jet analysis





Spectra are not corrected for instrumental effects and background p_T-smearing

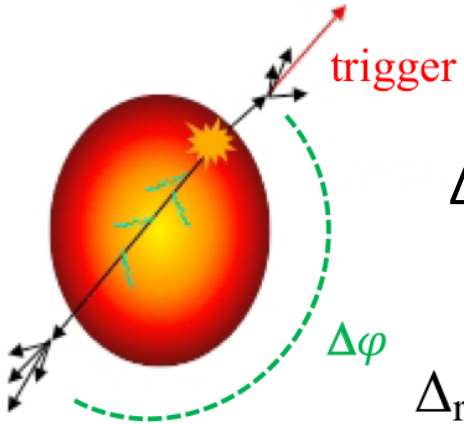
TT{X,Y} means $X < p_{T,trig} < Y$ GeV/c

A_{jet} = jet area

- Charged-particle jets recoiling from a high-p_T hadron (Trigger Track, TT)
- Jet-wise correction for estimated event density ρ: $p_{T,jet}^{ch,reco} = p_{T,jet}^{ch,raw} - \rho A_{jet}$
- Ensemble-level: correct for uncorrelated jet yield

$$\Delta_{recoil}\left(p_{T,jet}^{ch}\right) = \frac{1}{N_{trig}} \frac{dN_{jet}}{dp_{T,jet}^{ch}}\bigg|_{TT\{20,30\}} - \frac{1}{N_{trig}} \frac{dN_{jet}}{dp_{T,jet}^{ch}}\bigg|_{TT\{6,7\}}$$

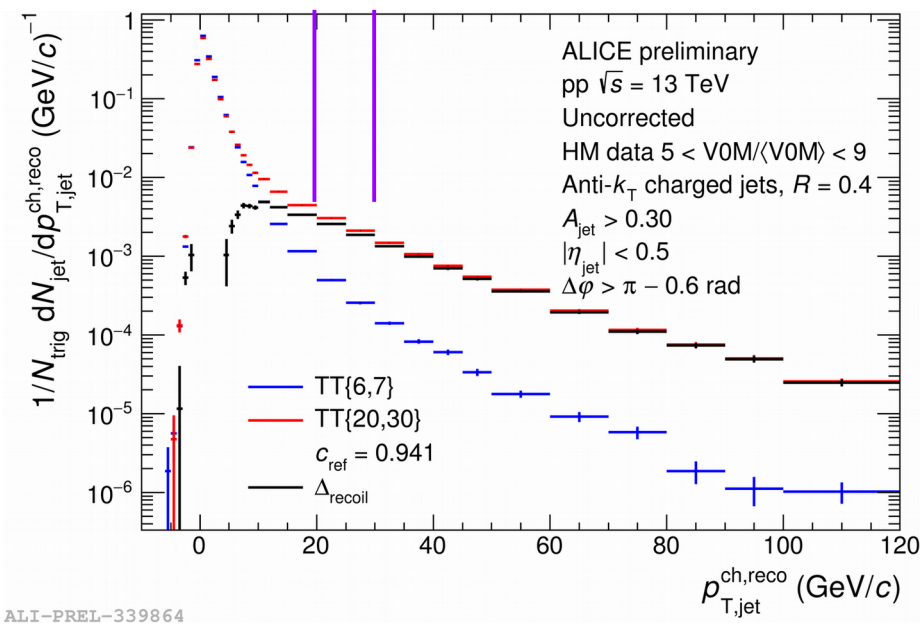
Acoplanarity measured with Δ_{recoil}

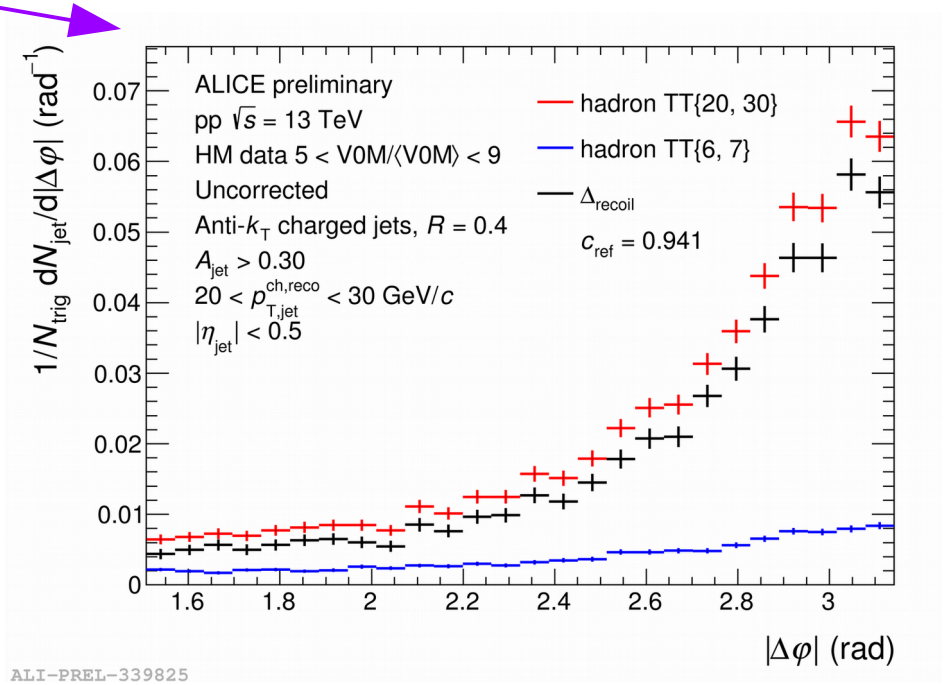


Δ_{recoil} as a function of TT-jet opening angle $\Delta\varphi$ for a fixed jet p_T:

$$\Delta_{recoil}(\Delta\varphi) = \frac{1}{N_{trig}} \frac{dN_{jet}}{d\Delta\varphi}\Big|_{TT\{20,30\}\ \&\ p_{T,jet}^{ch}} - \frac{1}{N_{trig}} \frac{dN_{jet}}{d\Delta\varphi}\Big|_{TT\{6,7\}\ \&\ p_{T,jet}^{ch}}$$

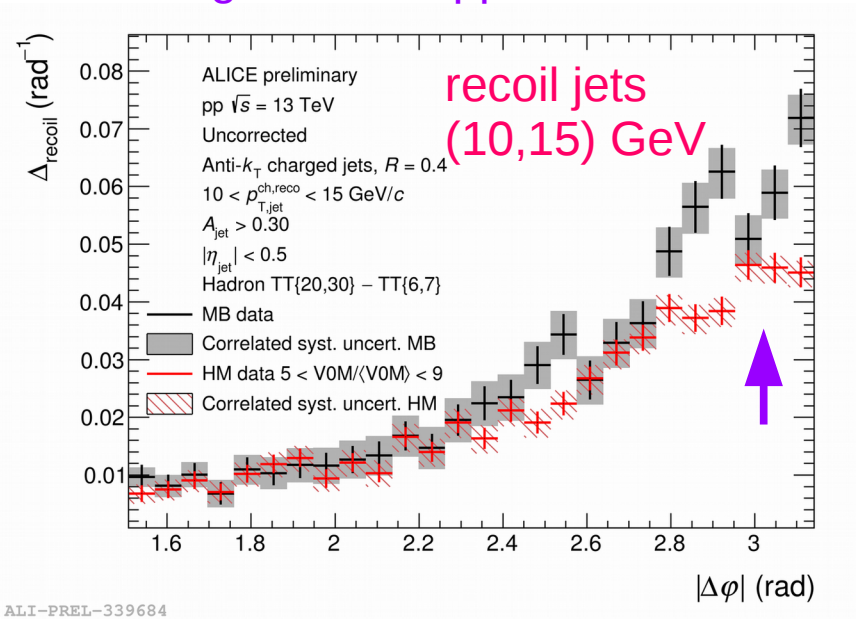
$20 < p_{T,jet}^{ch} < 30\ \mathrm{GeV}/c$

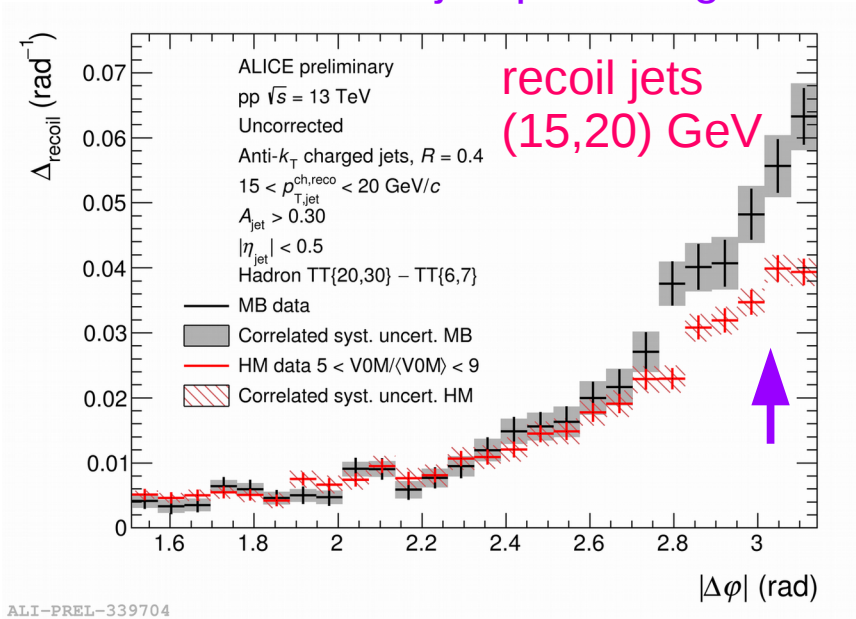


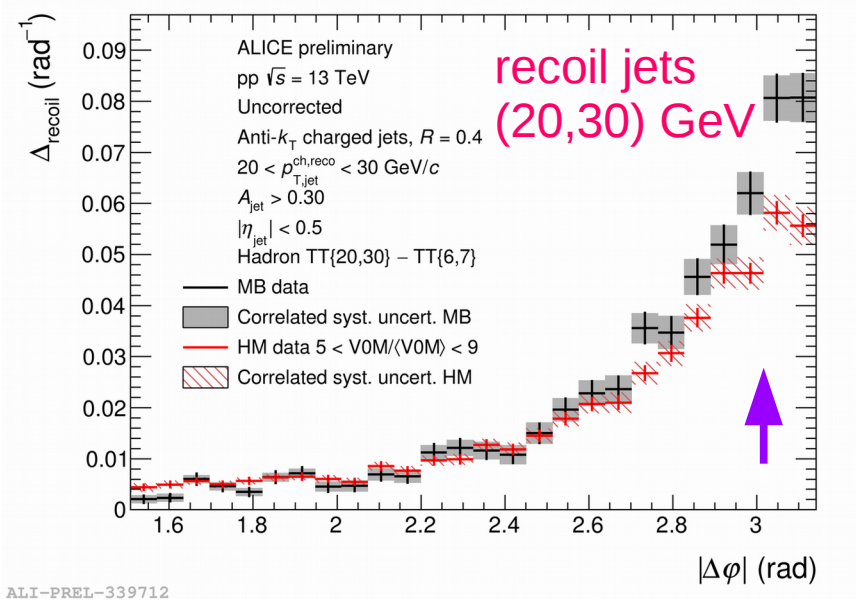


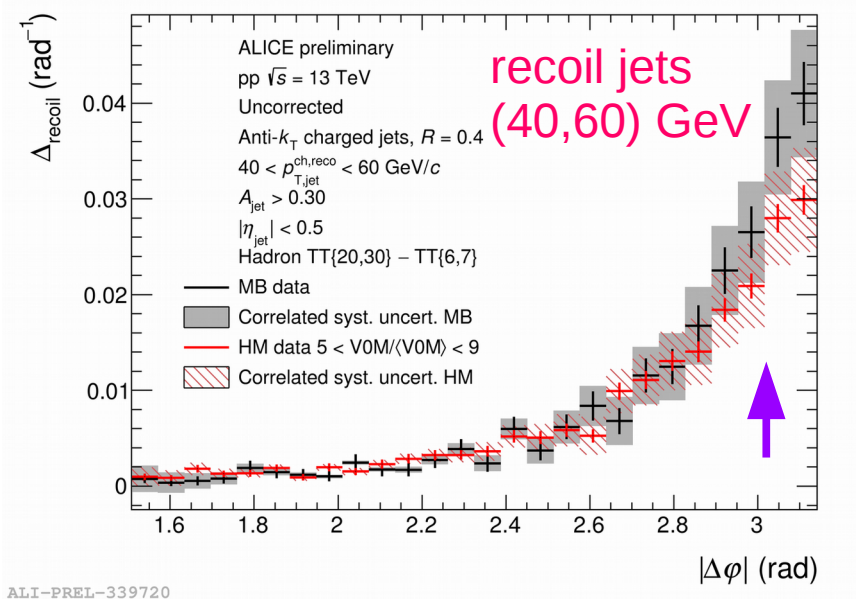
Acoplanarity versus event activity

Significant suppression of **HM** wrt **MB** which resembles jet quenching



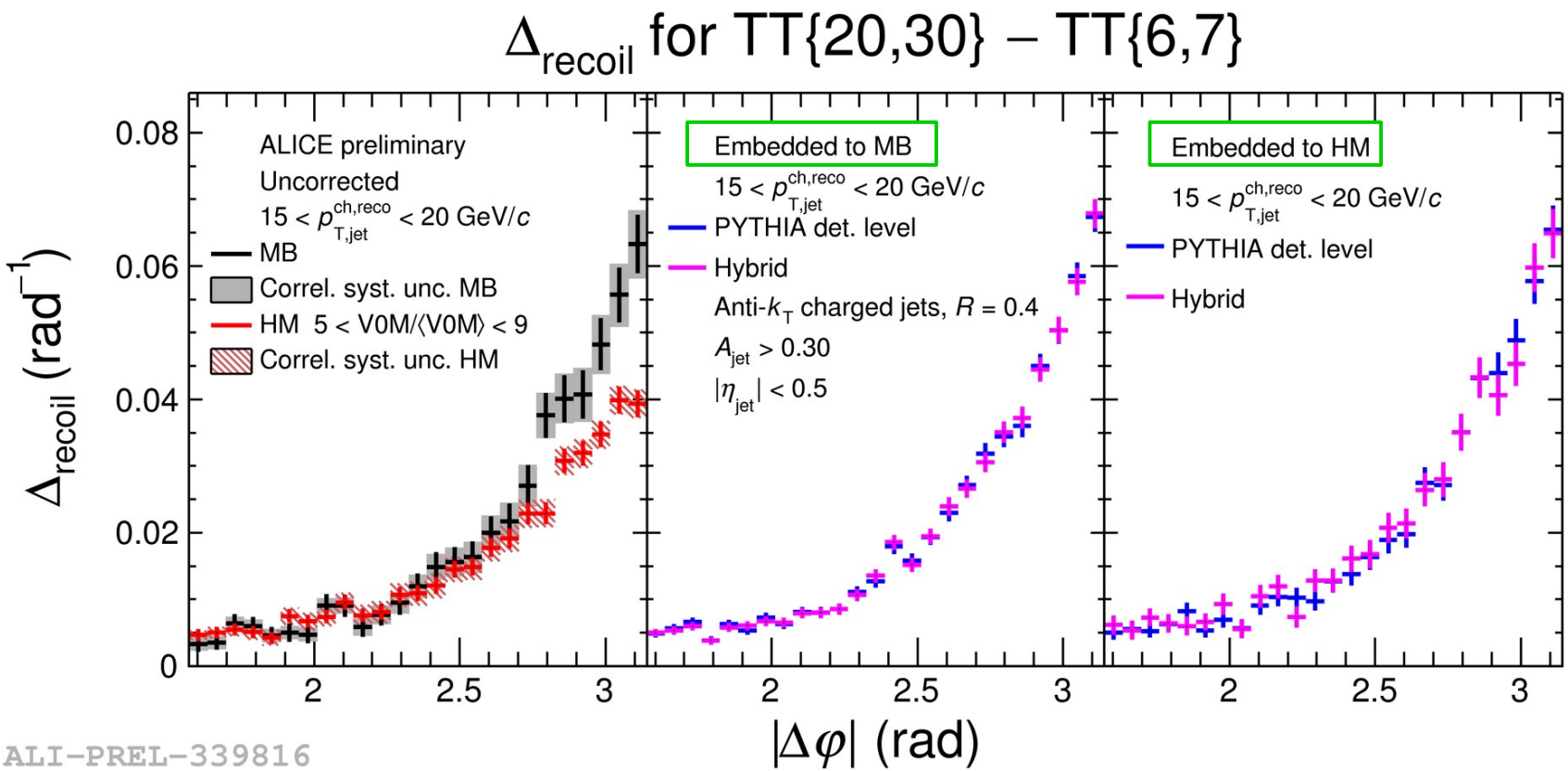






Data not unfolded; estimated uncertainty from tracking efficiency

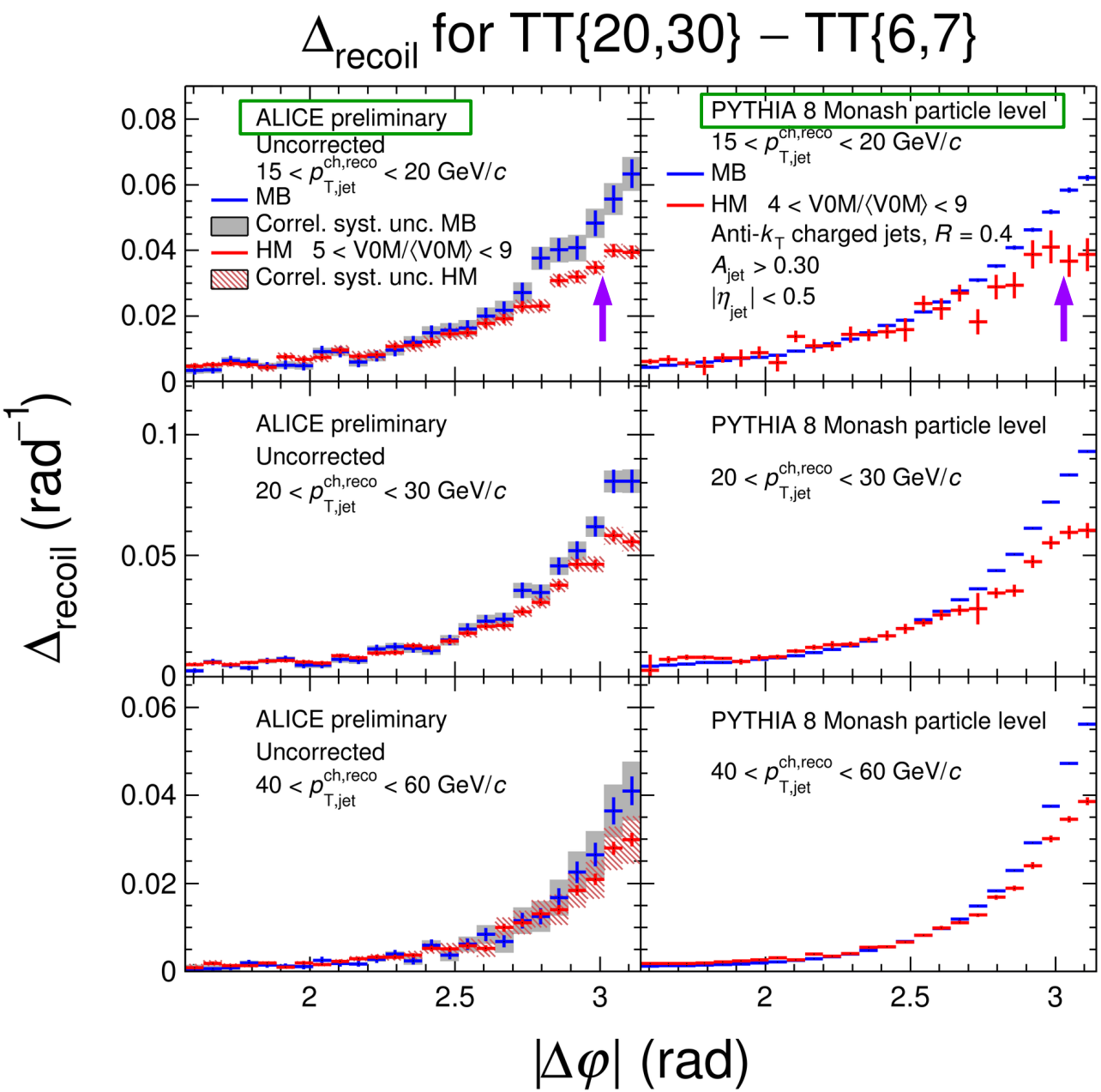
Systematic check:
Is the effect from high track density ?



- Generated PYTHIA detector-level events with TT
- Embeded them into real MB and HM pp events
- Compared Δ_{recoil} distributions from PYTHIA Truth and Embedding (Hybrid)

All distributions agree →
suppression is not due to instrumental effects or analysis procedure

Δ_{recoil} in raw data and PYTHIA



Qualitative comparison to PYTHIA 8 Monash shows similar suppression pattern →

The effect may not be due to jet quenching

Use PYTHIA to explore the origin of the effect

New PYTHIA high statistics simulations

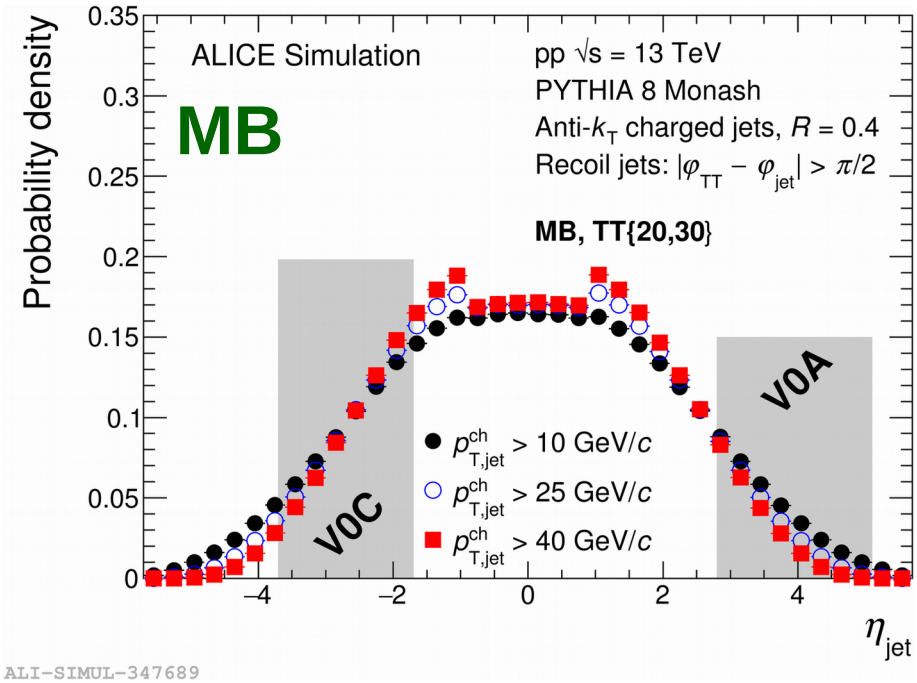
Charged particles $|\eta_{trk}| < 6$

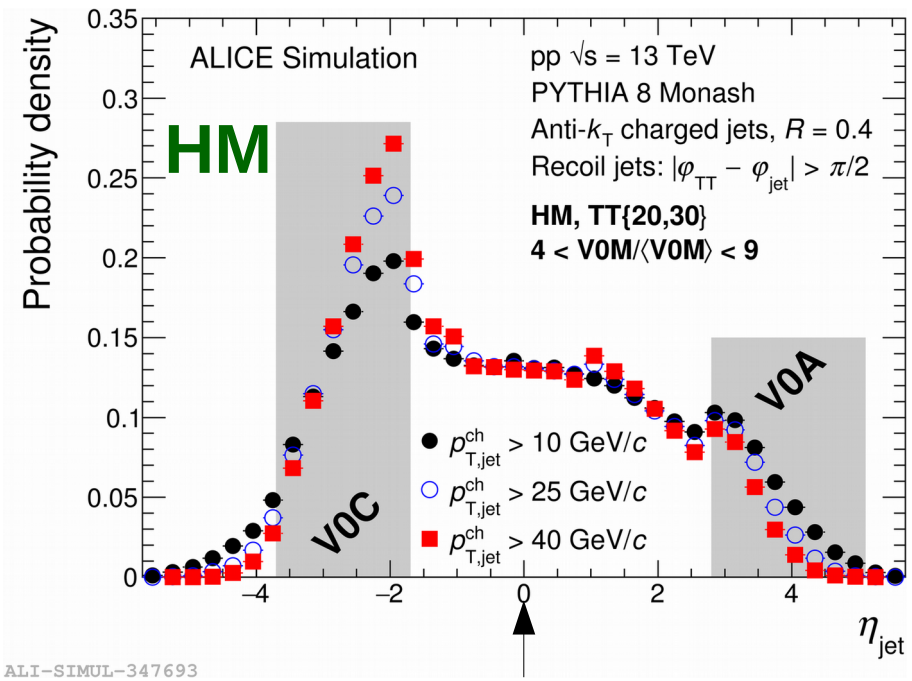
Fully covering V0C : $-3.7 < \eta < -1.7$ and V0A : $2.8 < \eta < 5.1$

- Events containing TT{20,30} or TT{6,7} in $|\eta| < 0.9$
- Anti-k_T track-based jets with $R = 0.4$ in
  1) ALICE central barrel: $|\eta_{jet}| < 0.5$
  2) broad pseudorapidity range: $|\eta_{jet}| < 5.6$

V0M defined by the number of charged, final state particles in V0A & V0C
HM in PYTHIA is $4 < \mathrm{V0M}/\langle \mathrm{V0M} \rangle < 9$; HM in real data is $5 < \mathrm{V0M}/\langle \mathrm{V0M} \rangle < 9$

PYTHIA 8 Monash: recoil jet η distribution vs $p_{T,jet}$

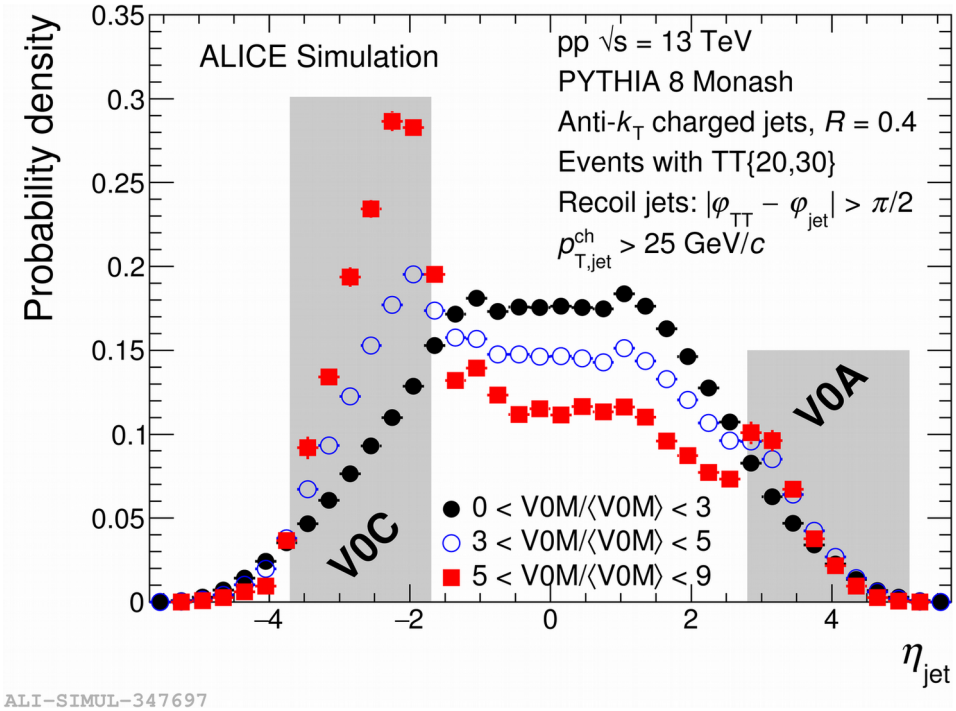


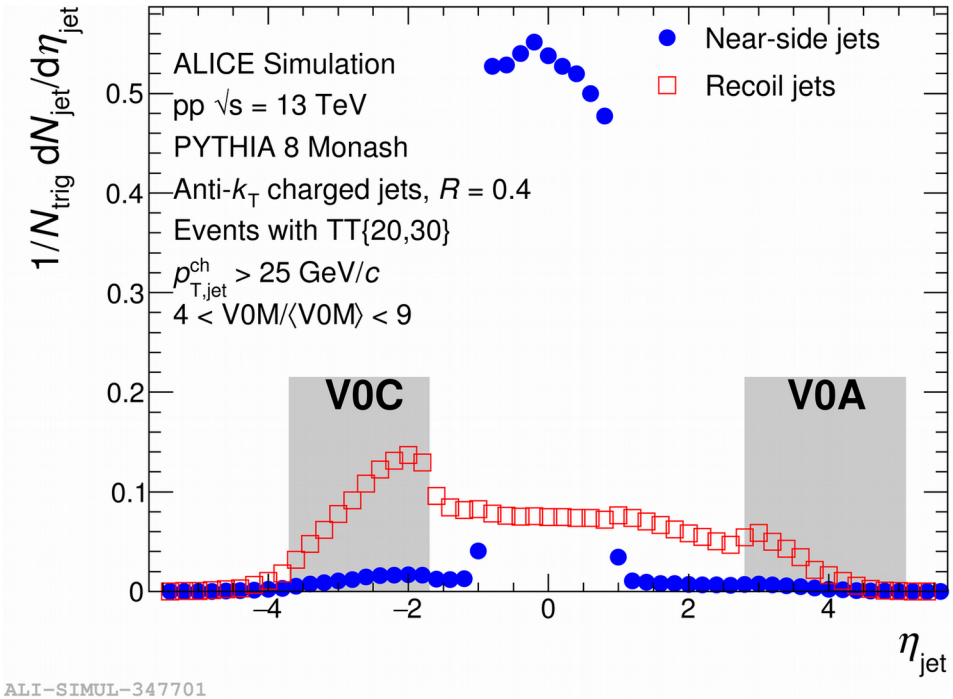


HM events:

- significant bias in distribution of high-p_T recoil jets
- strong enhancement in forward trigger acceptance
- collision system is symmetric but V0s have asymmetric coverage
  → sharply different effects on η-bias

PYTHIA 8 Monash: recoil jet η distribution vs event activity (EA)

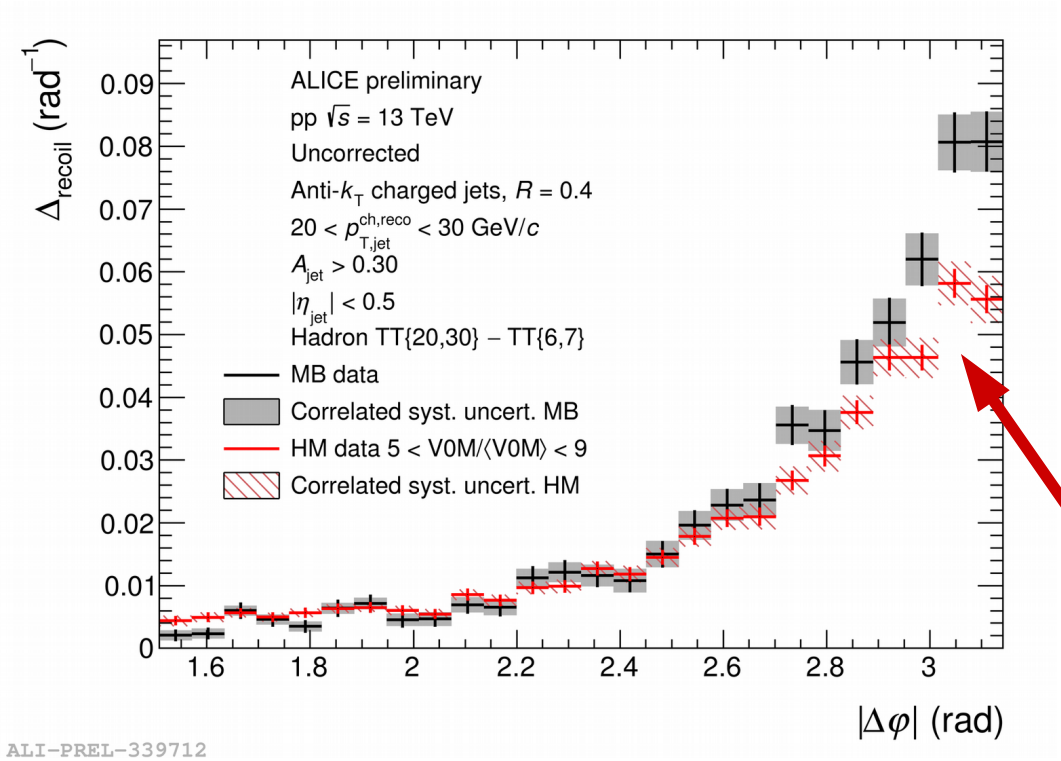


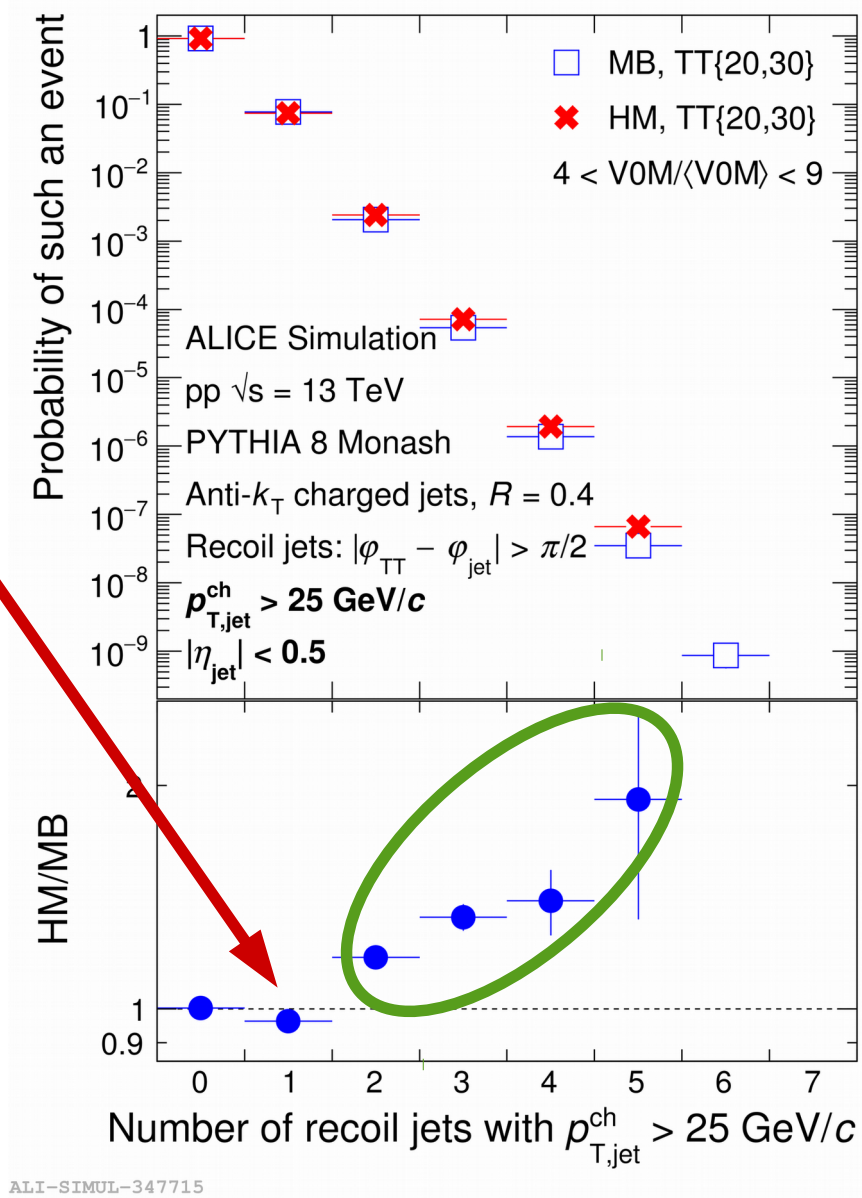


Does high-EA selection enhance:

- recoil jet distribution at large $|\eta|$? → Yes
- near-side jet distribution at large $|\eta|$? → No → HM selection biases recoil jets

PYTHIA 8 Monash: # high-p_T recoil jets vs Event Activity in ALICE acceptance





New observable to characterize the multi-jet distribution vs EA:

Distribution of the number of recoil jets above p_T threshold per triggered event

→ HM trigger suppresses events with 1 hard recoil jet in the ALICE central barrel

→ HM trigger enhances multi-jet events in small systems

Summary

ALICE data: Recoil jet yield suppression and broadening in HM events for $p_{\mathrm{T,ch\ jet}} < 60$ GeV/c

- Similar effect observed in PYTHIA

PYTHIA suggests:

- HM induces bias towards multi-jet events in small systems
- This bias must be taken into account in all studies of small collision systems at high multiplicity