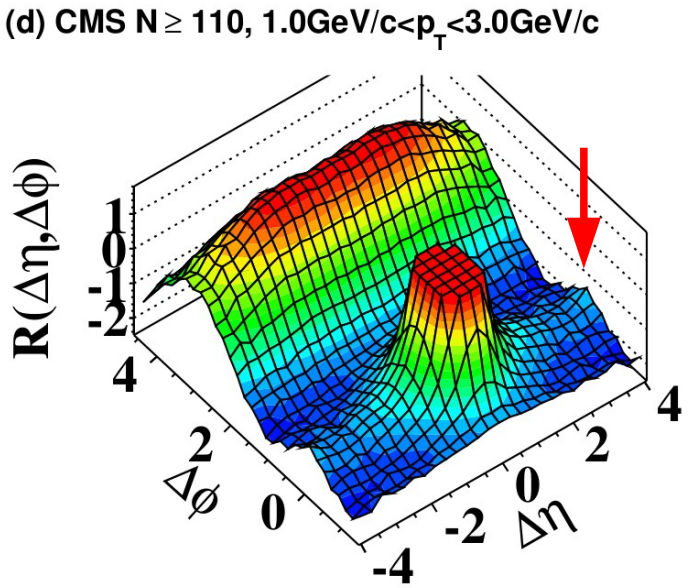
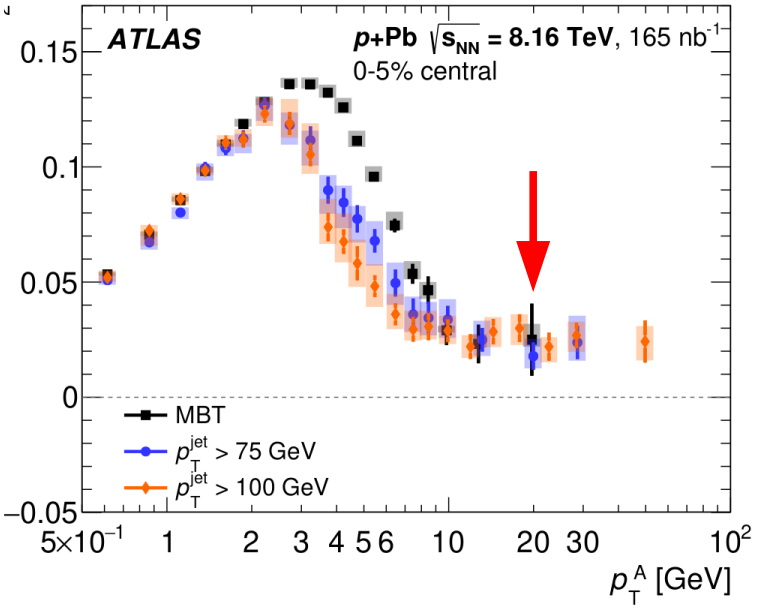
Search for jet quenching in high-multiplicity pp collisions using inclusive and semi-inclusive jet production in ALICE

Filip Krizek
for the ALICE Collaboration
Nuclear Physics Institute of the Czech Academy of Sciences

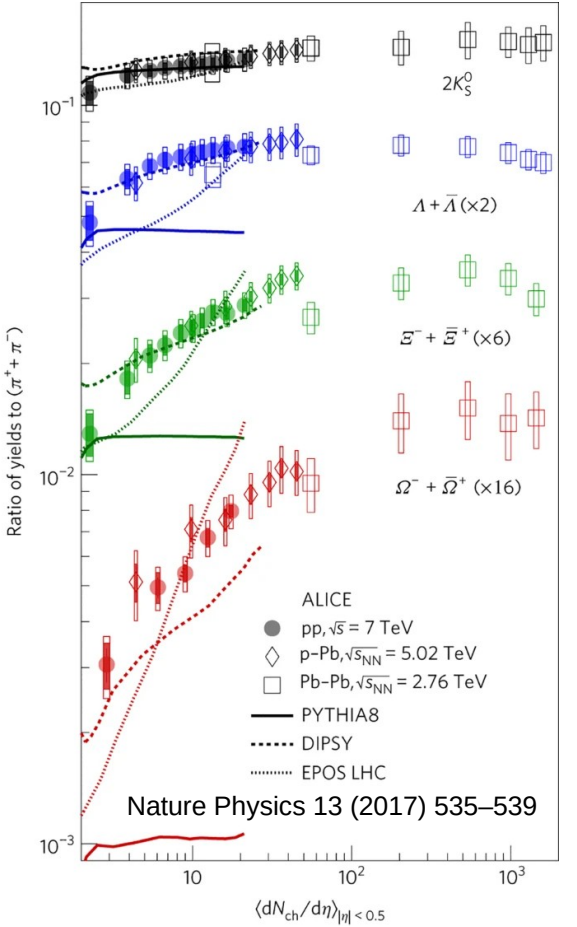
QGP in small collision systems?



CMS, JHEP 09 (2010) 091



ATLAS, Eur. Phys. J. C 80 (2020) 73



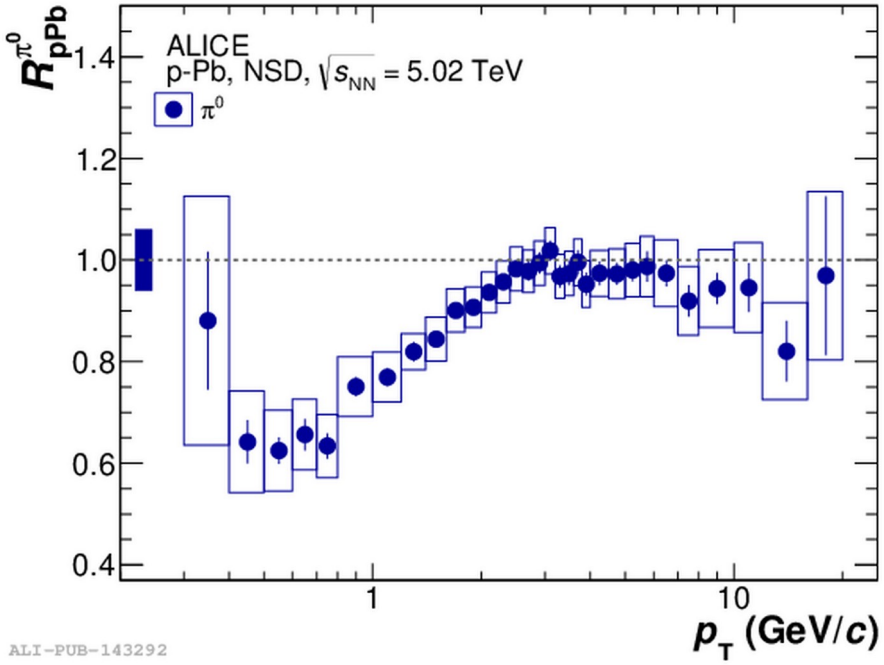
Nature Physics 13 (2017) 535–539

QGP-like signatures in high-multiplicity pp and pA:

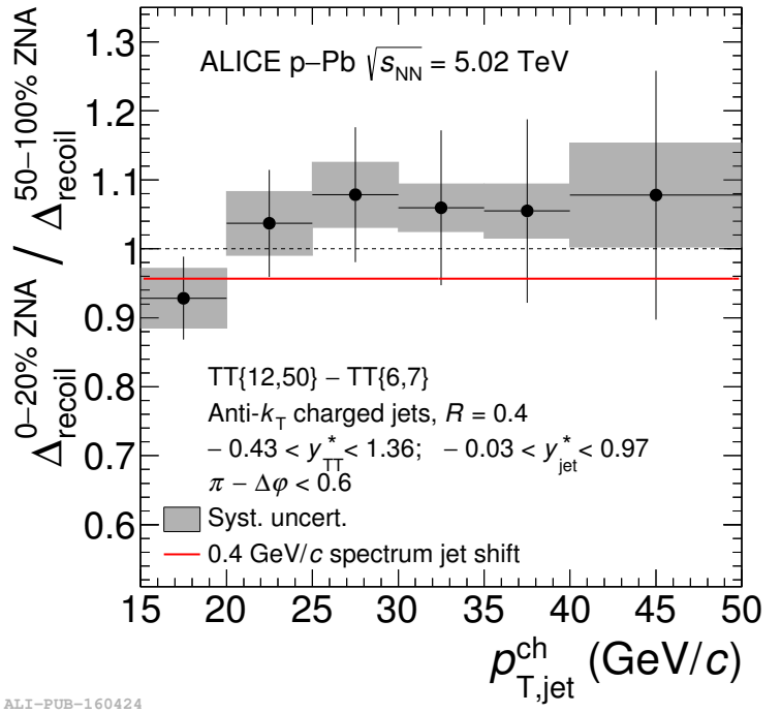
- Collective phenomena (ridge, v_2)
- Strangeness enhancement

Jet quenching in small collision systems?

ALICE, Eur. Phys. J. C 78 (2018) 624



ALICE, Phys. Lett. B 783 (2018) 95

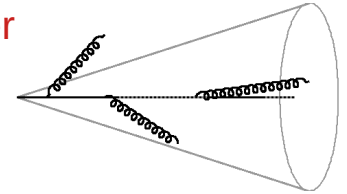


Energy-loss limit
400 MeV @ 90%CL

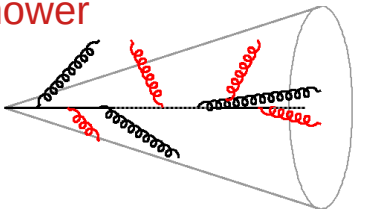
But at the same time jet quenching signal is below current sensitivity

Jet quenching observables

in-vacuum shower



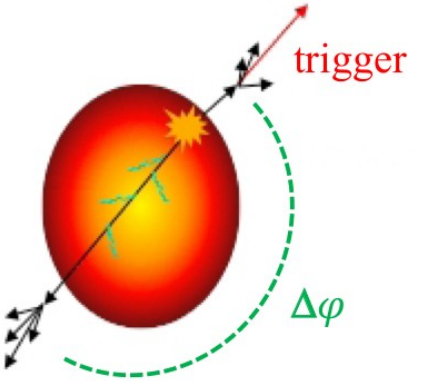
in-medium shower



- yield suppression relative to min. bias pp → energy transport out-of-cone

  - measurement of inclusive suppression (R_{AA}) requires Glauber scaling → ill defined in high-multiplicity pp collisions

- Jet substructure modification
- Jet deflection → dijet acoplanarity



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

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

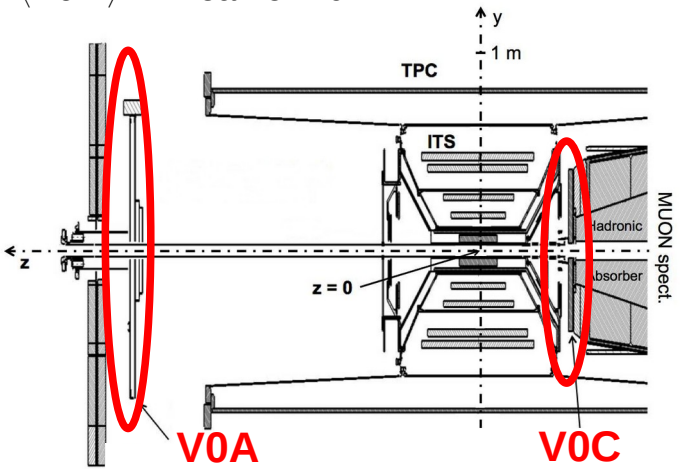
Event activity selection in pp at √s = 13 TeV

- Trigger:
  - Minimum bias (MB) $L_{int} \approx 32\ nb^{-1}$
  - High multiplicity (HM) $L_{int} \approx 10\ pb^{-1}$
- Event activity (EA) selection:

  V0M = V0A + V0C
- **HM is 0.1% of MB cross section**

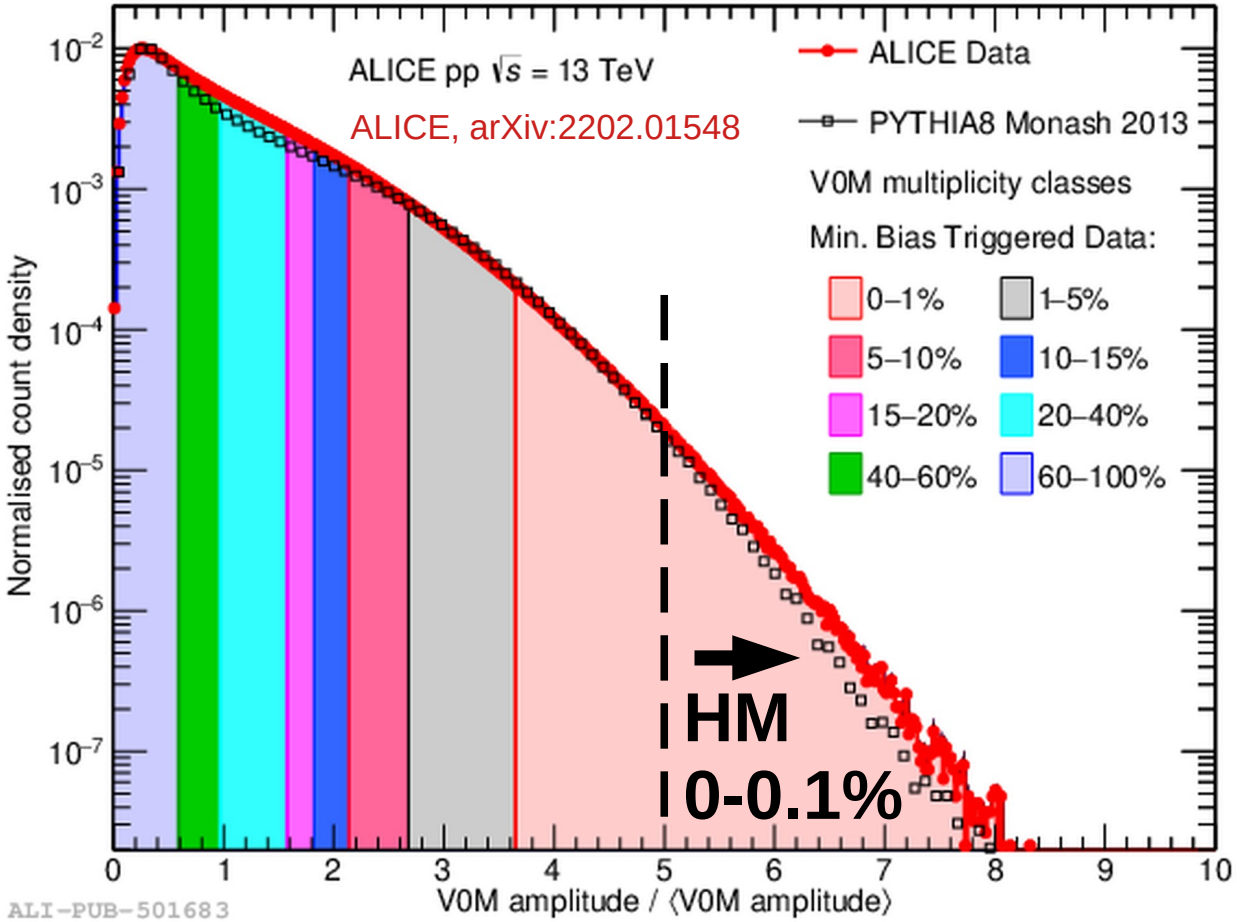
  $5 < V0M / \langle V0M \rangle < 9$

  $\langle V0M \rangle$ = mean of V0M in MB



2.8 < η < 5.1

-3.7 < η < -1.7



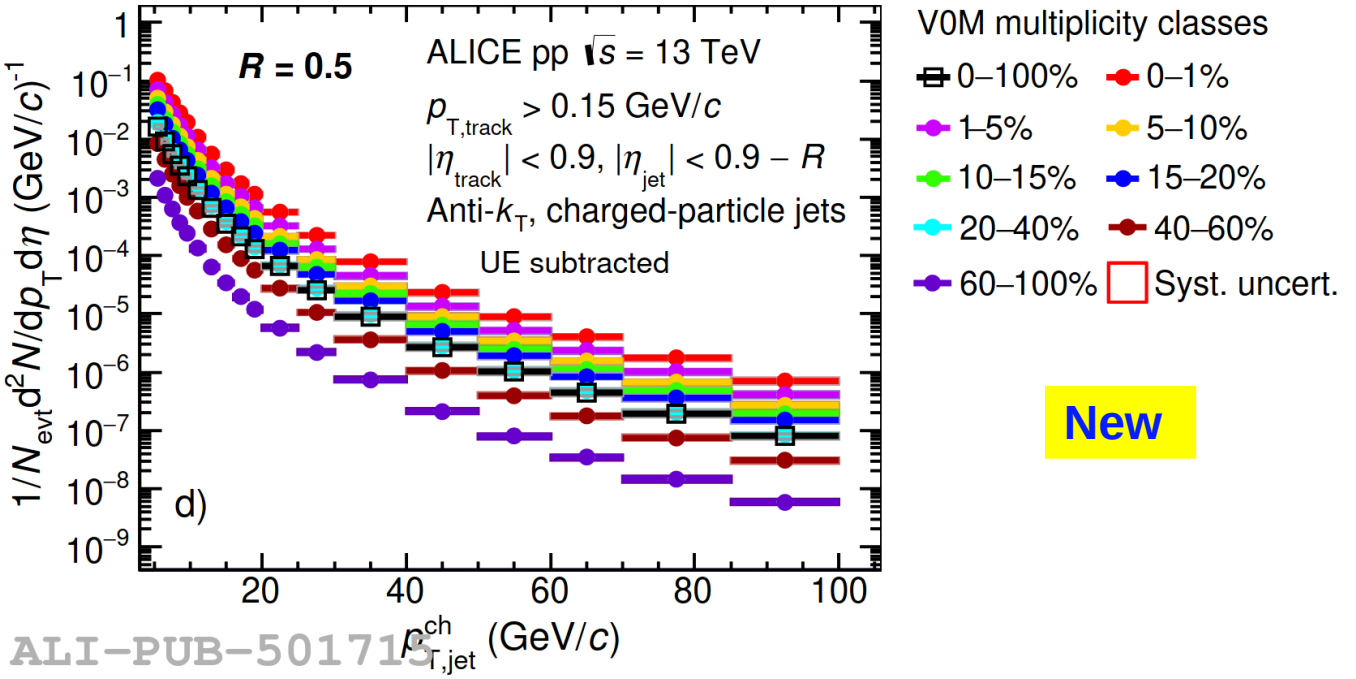
Charged-particle jets in MB and event activity biased pp collisions at √s = 13 TeV

arXiv:2202.01548

- Tracks
  $|\eta_{track}| < 0.9$
  $0 < \varphi_{track} < 2\pi$
  $p_{T,track} > 150$ MeV/c

- Charged-particle jets
  Anti-k_T algorithm
  $|\eta_{jet}| < 0.9 - R$
  $R = 0.2 – 0.7$

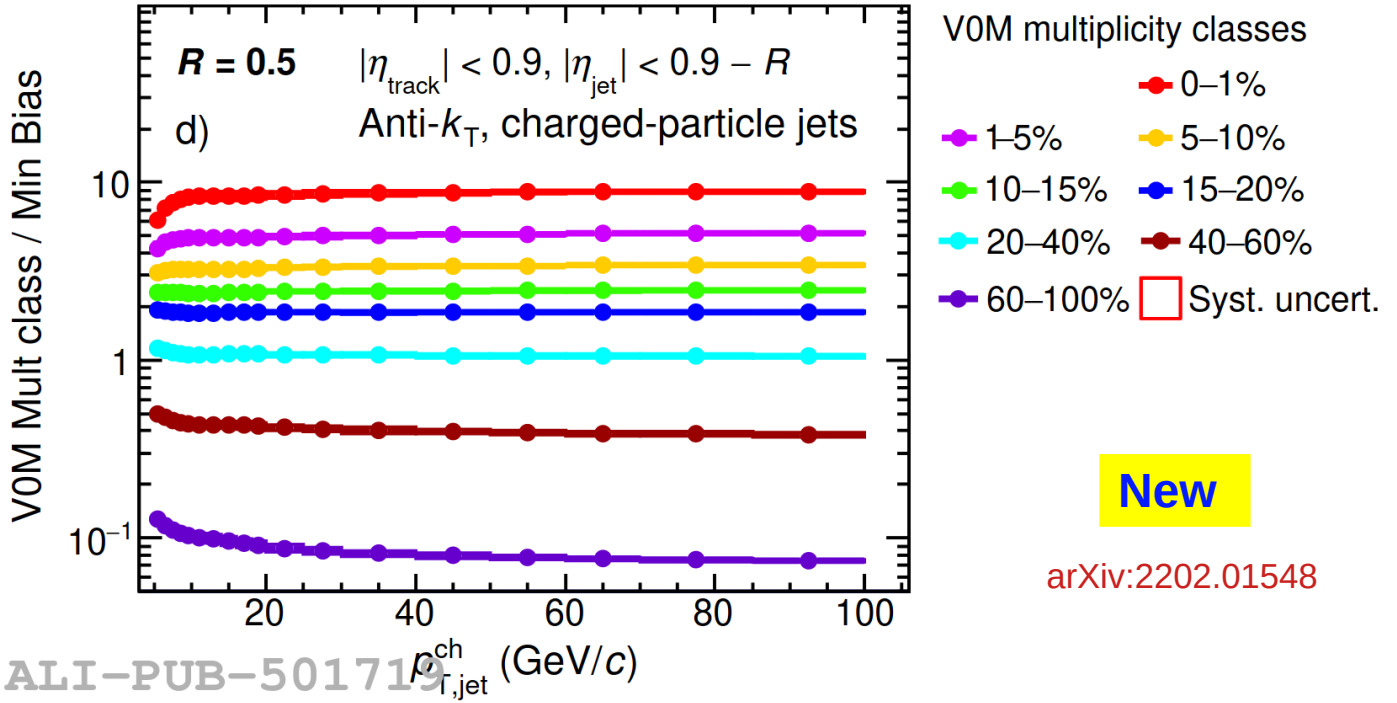
- $p_{T,ch\ jet} = p^{raw}_{T,ch\ jet} - \rho A_{jet}$



New

How does the imposed event activity selection bias the spectrum shape?

Ratios of EA-biased jet p_T spectra to MB



New

arXiv:2202.01548

- Event activity (EA) bias affects the shape mostly for $p_{T,ch\ jet} < 20$ GeV/c
- Bias on high-EA causes increase of jet yield per event

  May arise from increase in average number of hard scatterings per event

Self-normalized jet yield versus self-normalized multiplicity

- Jets with $p_{T,\,jet}^{ch}$>9 GeV/*c* follow non-linear trend similar to J/ψ in midrapidity

  Phys. Lett. B 810 (2020) 135758

  and heavy-flavor electrons and prompt D

  Luigi Dello Stritto, talk on 7 Apr at 4 pm

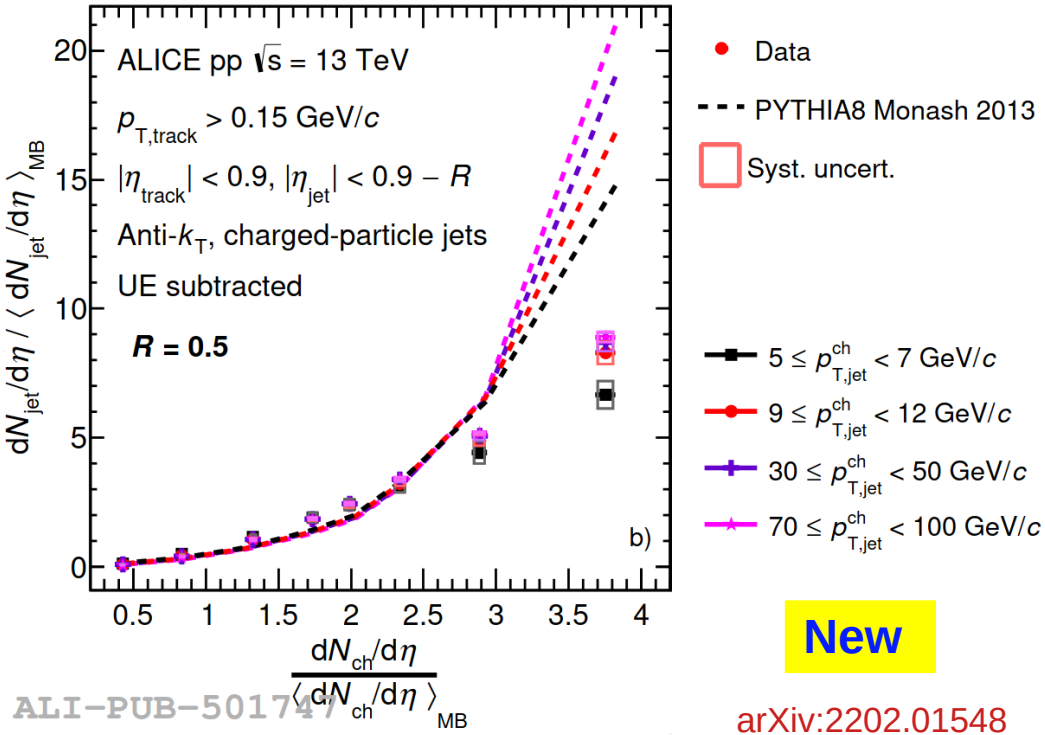
  Parallel Session T14: Hadron prod. and col. dyn. I

- Electrons from W decay follow linear trend

  Shingo Sakai, talk on 7 Apr at 5 pm

  Parallel Session T13: Electroweak probes II

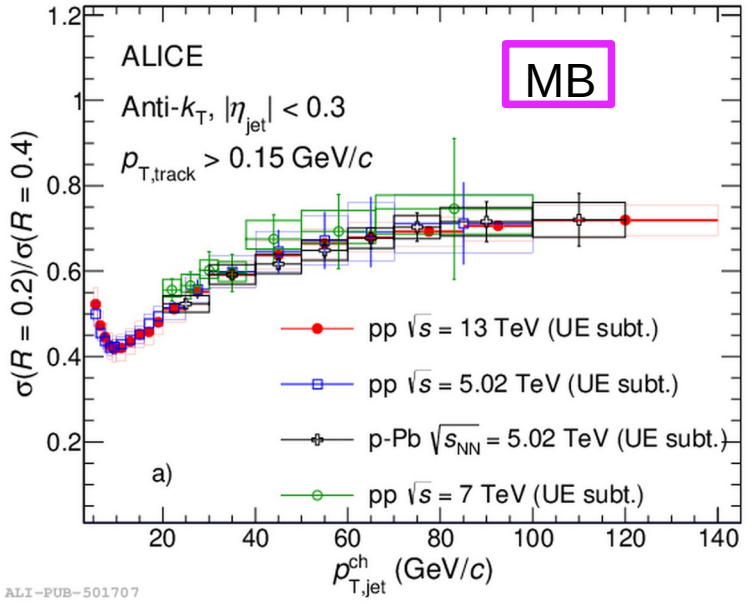
- Overshoot of the trend by PYTHIA at high charged-particle multiplicities

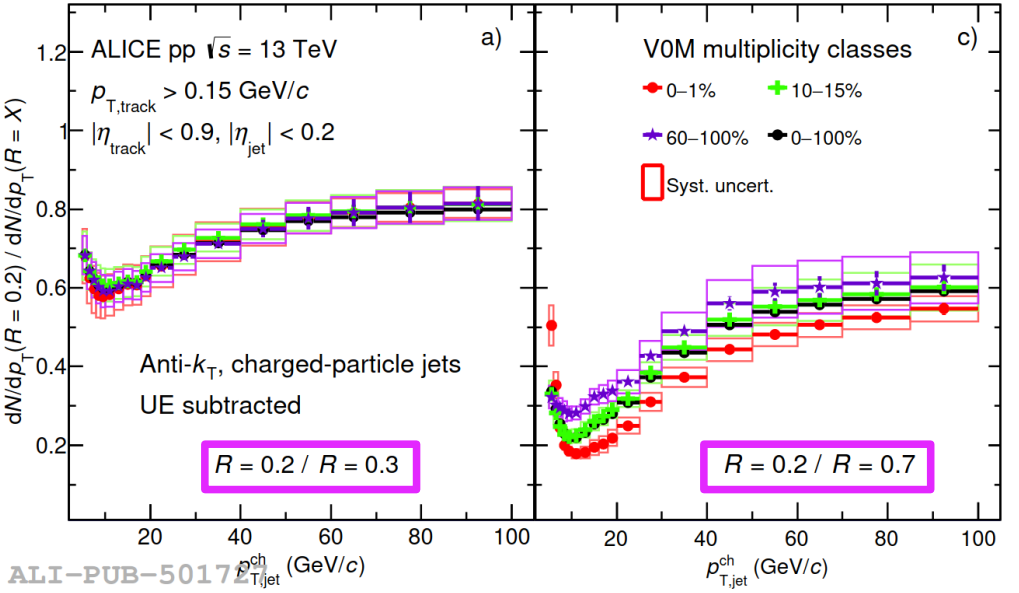


New

arXiv:2202.01548

Ratios of jet p_T spectra with different R





New

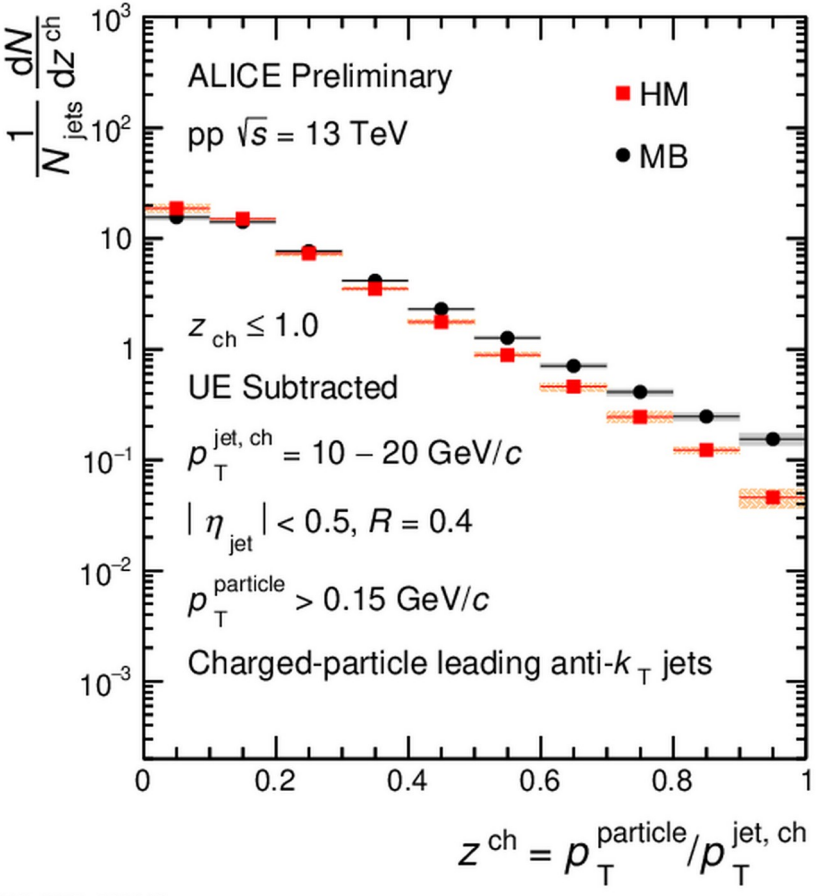
arXiv:2202.01548

MB ratio of p_T-differential cross section spectra:

independent of $\sqrt{s}$

EA-selected ratio of spectra:
- small R : independent of EA
- large R : hint of EA dependence

Impact of high-EA bias on jet logitudinal fragmentation



New

Poster by Debjani Banerjee

Poster Session 1 T05_1 on 6 Apr

HM event selection → softer jet fragmentation

This is consistent with larger portion of jets comming from NLO processes

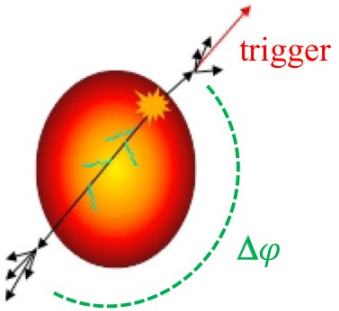
HM event activity selection:

5 < V0M / ⟨V0M⟩ < 9

0.1% of MB cross section

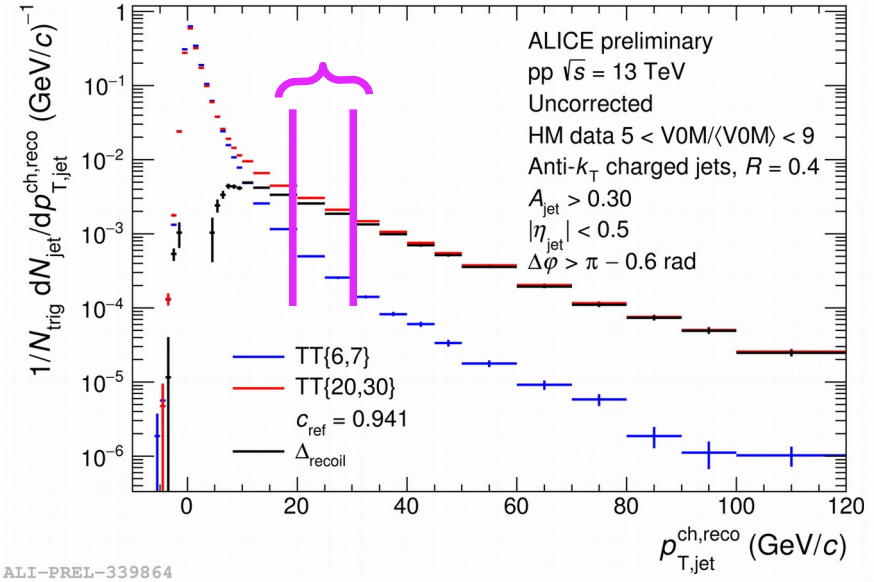
Hadron-jet acoplanarity

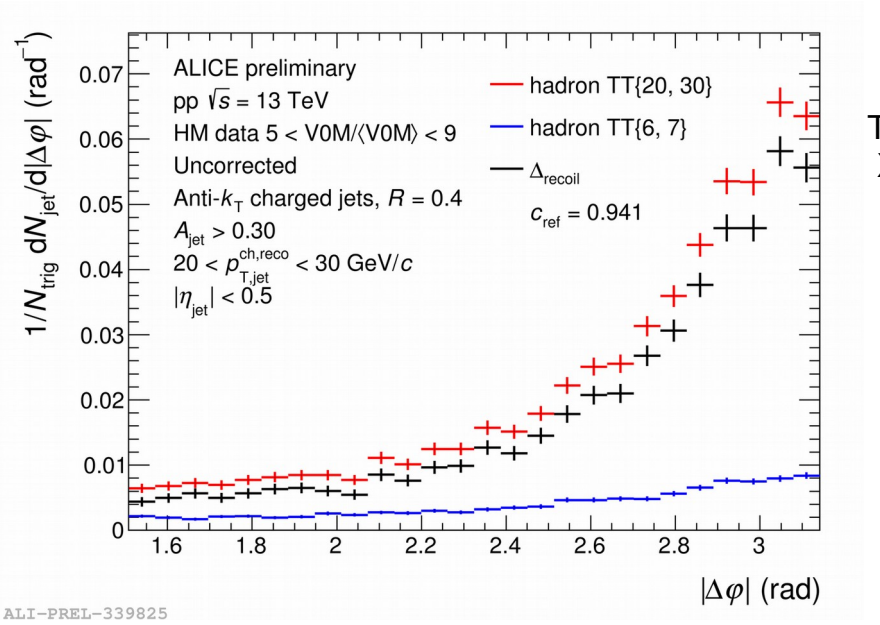
Poster by Artem Kotliarov *Poster Session 1 T05_1 on Apr 6*



- Jets recoiling from high-p_T trigger hadron (TT)
- Data-driven statistical approach to remove recoil-jet yield uncorrelated to TT

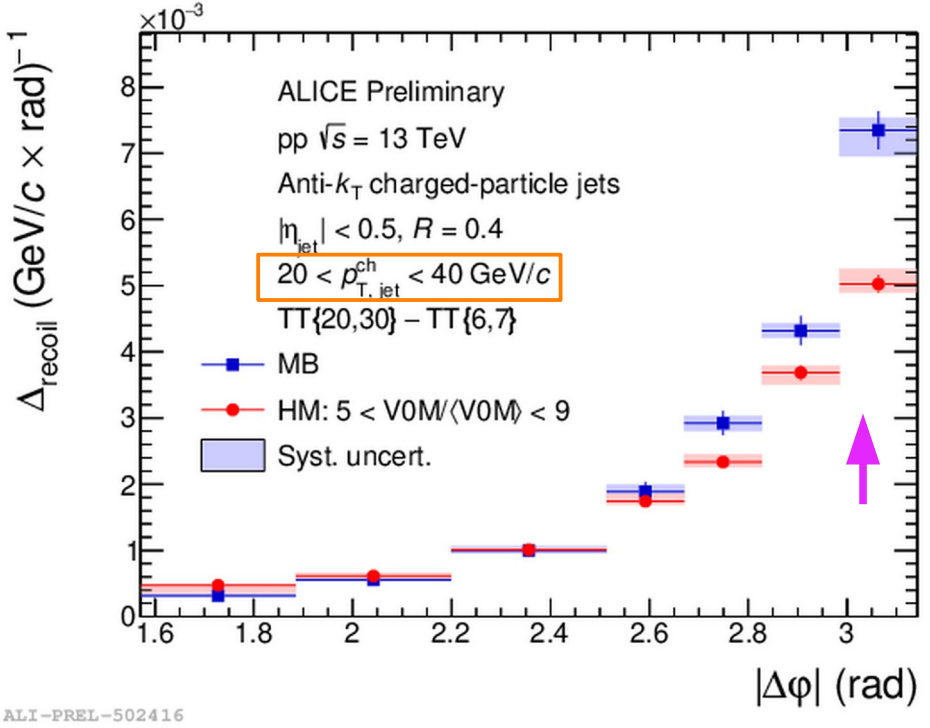
$$\Delta_{\text{recoil}}(\Delta\varphi) = \frac{1}{N_{\text{trig}}}\frac{\mathrm{d}N_{\text{jet}}}{\mathrm{d}\Delta\varphi}\bigg|_{\text{TT}\{20,30\}\,\&\,p_{\text{T,jet}}^{\text{ch}}} - c_{\text{ref}}\cdot\frac{1}{N_{\text{trig}}}\frac{\mathrm{d}N_{\text{jet}}}{\mathrm{d}\Delta\varphi}\bigg|_{\text{TT}\{6,7\}\,\&\,p_{\text{T,jet}}^{\text{ch}}}$$

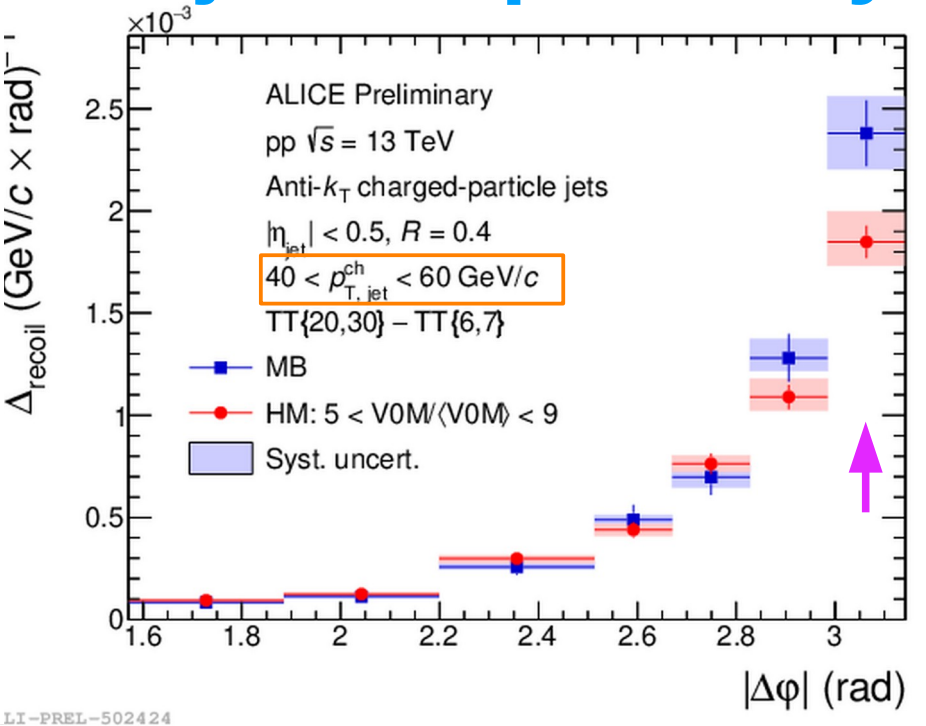




TT{X,Y} means
X< $p_{\text{T,trig}}$ < Y GeV/c

Distributions of hadron-jet acoplanarity

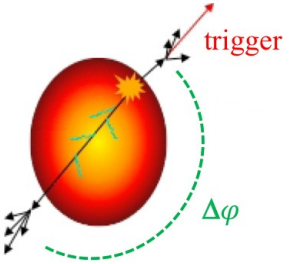




New
Distributions are fully corrected

- HM acoplanarity distributions relative to MB
  - suppressed back-to-back correlation
  - broader

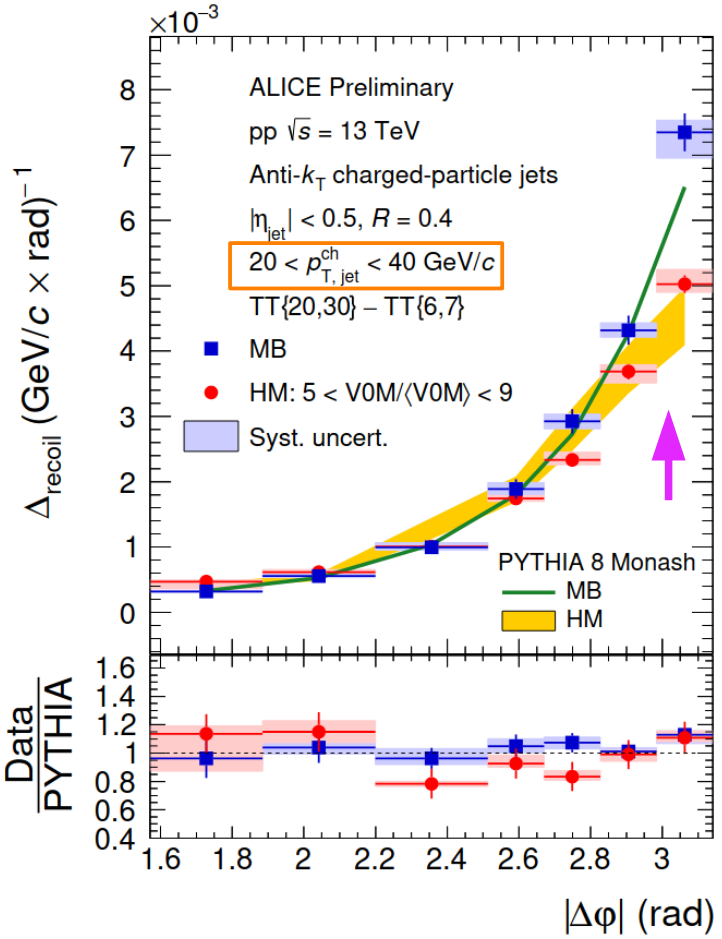
  The effect is stronger for low p_T jets

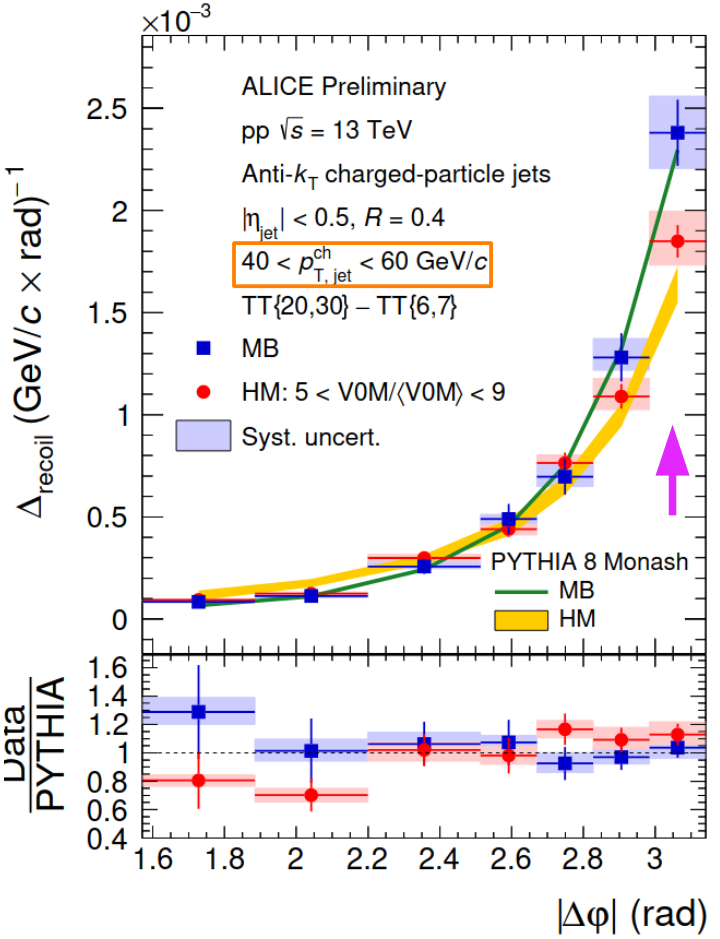


HM event activity selection:
5 < V0M / ⟨V0M⟩ < 9

0.1% of MB cross section

Comparison of hadron-jet acoplanarity with PYTHIA





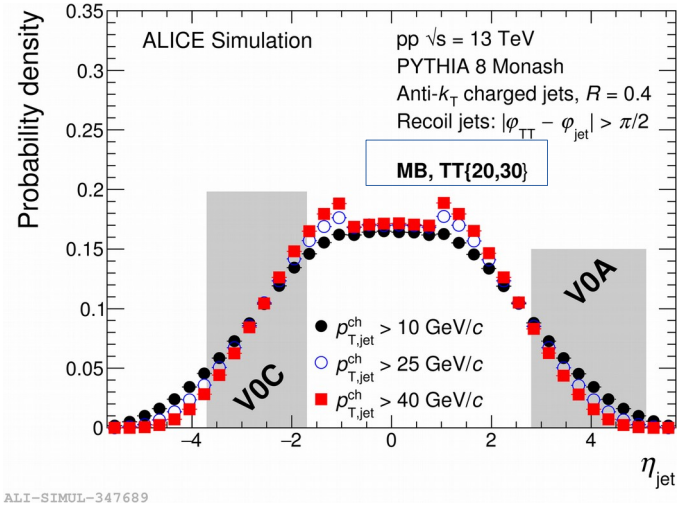
New

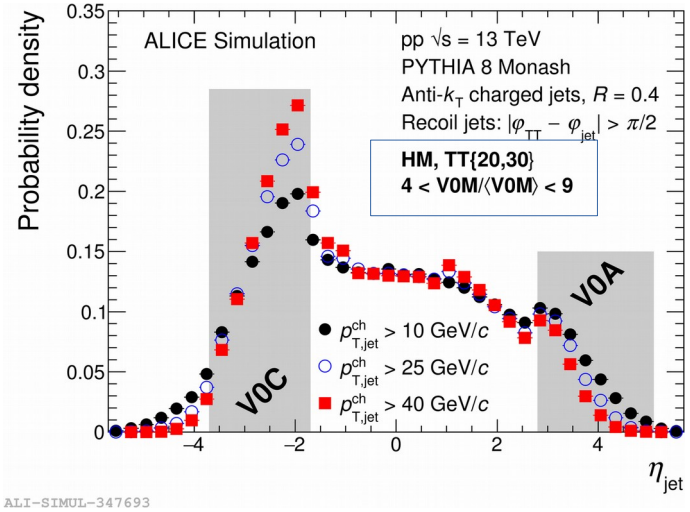
Quantitative comparison to PYTHIA 8 Monash shows similar suppression pattern

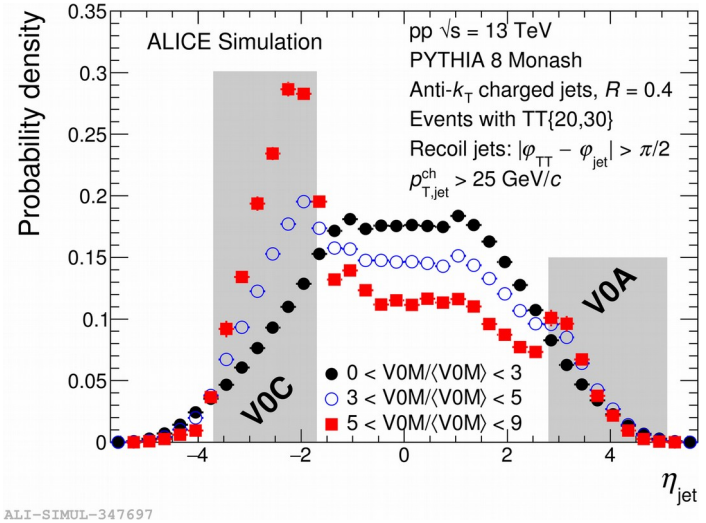
The effect is not due to jet quenching

Use PYTHIA to explore the origin of the effect

PYTHIA : recoil jet η_{jet} versus $p_{T,jet}$







HM events:

- significant bias in distribution of high-p_T recoil jets
- enhancement in forward trigger detector acceptance
- V0A and V0C have asymmetric coverage

Summary

- Event activity bias on inclusive jet production

  - affects largely the yield of high p_T jets

  - has weak impact on the shape of jet p_T spectrum

- Semi-inclusive jet production

  - broadening and suppression of back-to-back hadron-jet correlation in HM pp relative to MB

  - quantitatively reproduced by PYTHIA

- HM event selection

  - biases towards multi-jet final states

  - masks potential jet quenching signatures

- Significant issue for all HM analyses in small collision systems

Backup

Hadron-jet observables and T_{AA}

Calculable at NLO pQCD

$$\underbrace{\frac{1}{N_{\mathrm{trig}}^{\mathrm{AA}}}\frac{\mathrm{d}^2 N_{\mathrm{jet}}^{\mathrm{AA}}}{\mathrm{d}p_{\mathrm{T,jet}}^{\mathrm{ch}}\mathrm{d}\eta_{\mathrm{jet}}}\bigg|_{p_{\mathrm{T,trig}}\in\mathrm{TT}}}_{\text{measured}} = \underbrace{\left(\frac{1}{\sigma^{\mathrm{AA}\to\mathrm{h+X}}}\cdot\frac{\mathrm{d}^2\sigma^{\mathrm{AA}\to\mathrm{h+jet+X}}}{\mathrm{d}p_{\mathrm{T,jet}}^{\mathrm{ch}}\mathrm{d}\eta_{\mathrm{jet}}}\right)\bigg|_{p_{\mathrm{T,h}}\in\mathrm{TT}}}_{\text{from theory}}$$

In case of no nuclear effects

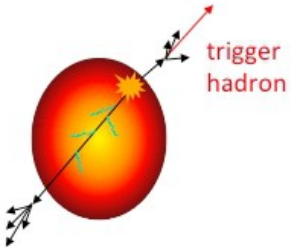
$$\frac{1}{N_{\mathrm{trig}}^{\mathrm{AA}}}\frac{\mathrm{d}^2 N_{\mathrm{jet}}^{\mathrm{AA}}}{\mathrm{d}p_{\mathrm{T,jet}}^{\mathrm{ch}}\mathrm{d}\eta_{\mathrm{jet}}}\bigg|_{p_{\mathrm{T,trig}}\in\mathrm{TT}} = \left(\frac{1}{\sigma^{\mathrm{pp}\to\mathrm{h+X}}}\cdot\frac{\mathrm{d}^2\sigma^{\mathrm{pp}\to\mathrm{h+jet+X}}}{\mathrm{d}p_{\mathrm{T,jet}}^{\mathrm{ch}}\mathrm{d}\eta_{\mathrm{jet}}}\right)\bigg|_{p_{\mathrm{T,h}}\in\mathrm{TT}} \times \cancel{\frac{T_{\mathrm{AA}}}{T_{\mathrm{AA}}}}$$

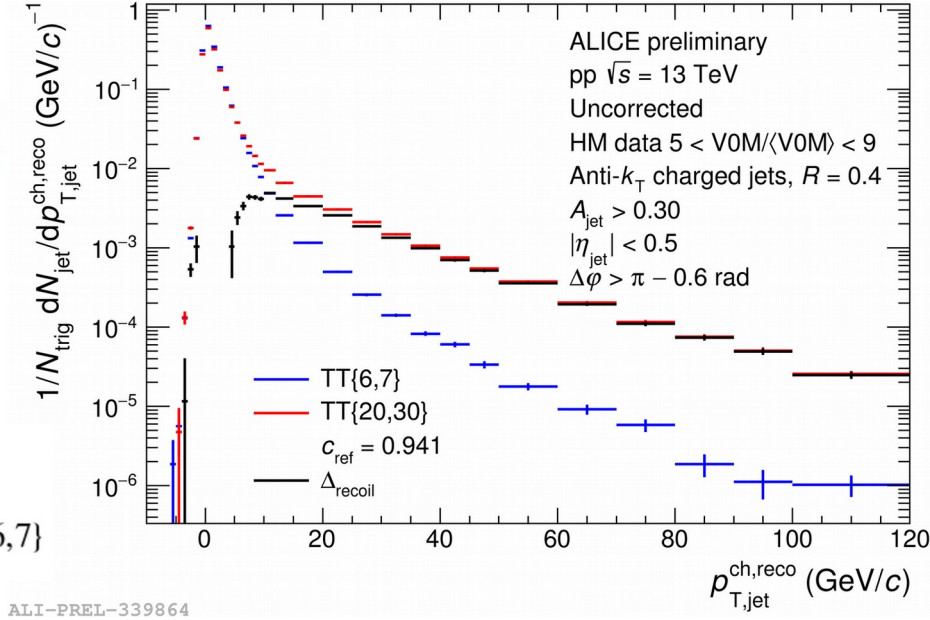
- This coincidence observable is self-normalized, no requirement of T_{AA} scaling
- No requirement to assume correlation between Event Activity and collision geometry

Jet quenching measurements with hadron-jet correlations

Poster by Artem Kotliarov on Wed

- Jets recoiling from high-p_T trigger track (TT)
- Data-driven statistical approach to remove recoil-jet yield uncorrelated to TT (including MPI)
- Does not impose fragmentation bias on the recoil jet





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

Coincidence observable is self-normalized, no requirement of T_{AA} scaling:

$$\frac{1}{N_{\mathrm{trig}}}\frac{\mathrm{d}N_{\mathrm{jet}}}{\mathrm{d}p_{\mathrm{T,jet}}^{\mathrm{ch}}}\bigg|_{\mathrm{TT}} = \left(\frac{1}{\sigma^{\mathrm{pp\to h+jet+X}}}\cdot\frac{\mathrm{d}\sigma^{\mathrm{pp\to h+jet+X}}}{\mathrm{d}p_{\mathrm{T,jet}}^{\mathrm{ch}}}\right)\bigg|_{\mathrm{TT}} \times \cancel{\frac{T_{AA}}{T_{AA}}}$$

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

ALICE, JHEP 09 (2015) 170

PYTHIA simulations

- Charged particles $|\eta| < 6$

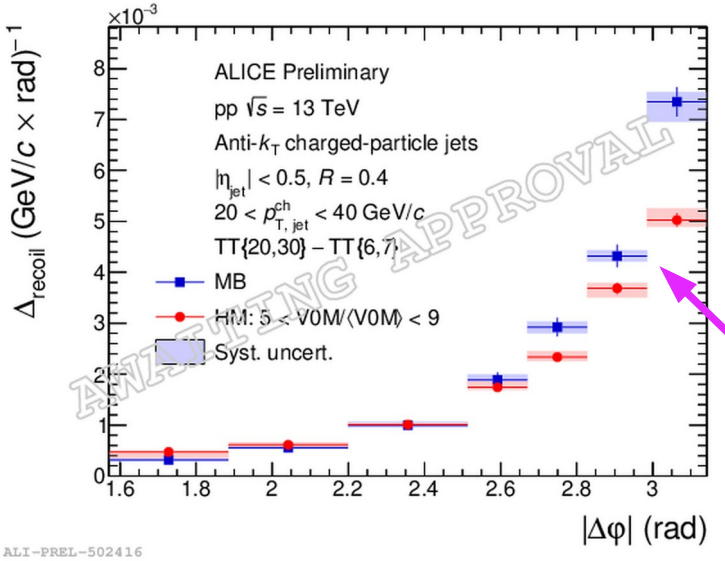
  fully covering V0C and V0A
- Events containing TT{20,30} or TT{6,7} in $|\eta|<0.9$
- Anti-k_T charged particle R=0.4 jets in

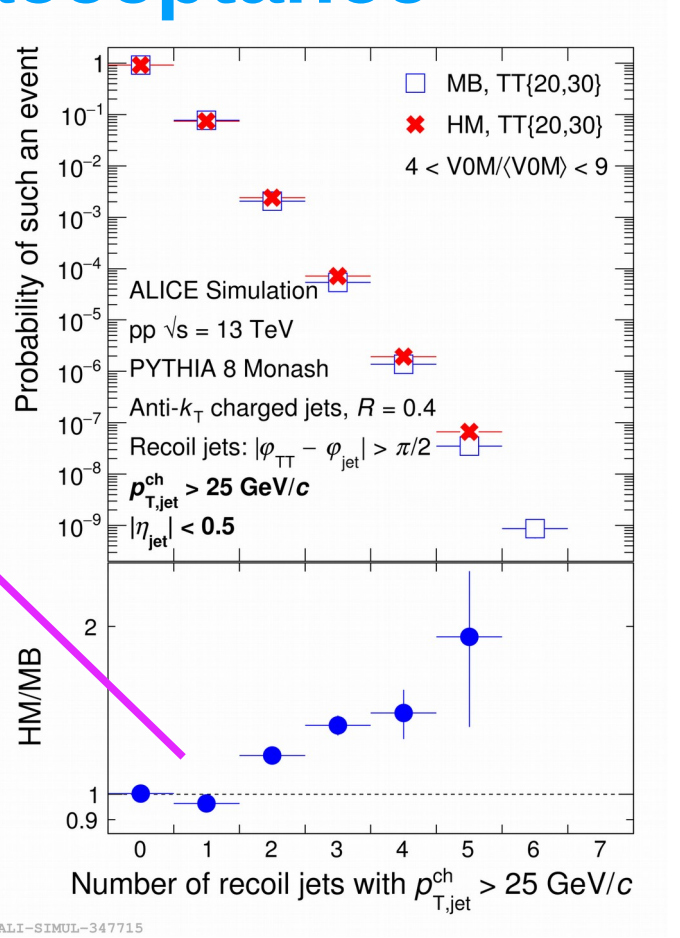
  1) ALICE central barrel $|\eta_{jet}| < 0.5$

  2) broad η range $|\eta_{jet}| < 5.6$

V0M defined by the number of charged, final state particles in V0A & V0C

PYTHIA: Number of recoil jets versus event activity in ALICE acceptance





Distrib. of the number of recoil jets above p_T threshold:

- HM trigger suppresses events with 1 hard recoil jet in the ALICE central barrel
- HM trigger enhances multi-jet events in small systems