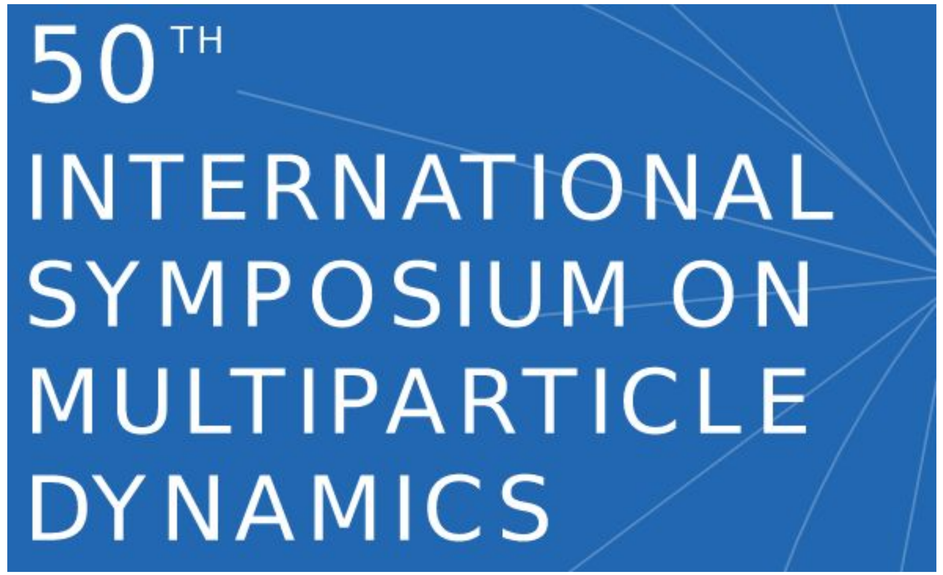
Measurements of jet quenching via hadron+jet correlations in Pb-Pb and high-particle multiplicity pp collisions with ALICE

Kotliarov Artem, NPI CAS

for the ALICE Collaboration

50th International Symposium on Multiparticle Dynamics

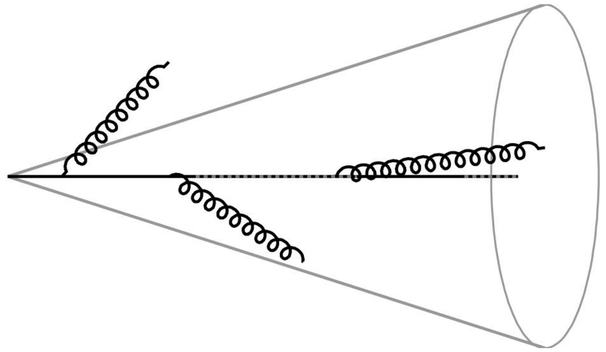


Introduction

Jet shower in vacuum

Evolution of highly virtual parton via gluon radiation

- Precise understanding in pQCD
- Reference process for nucleus collisions



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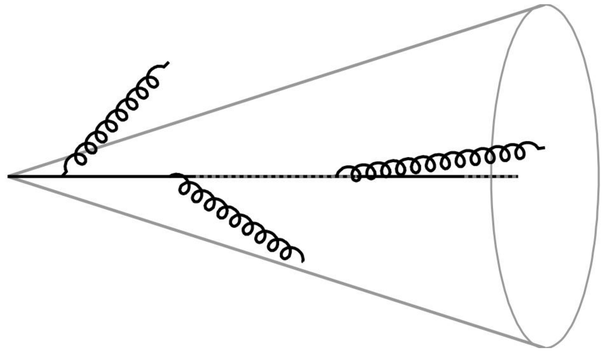
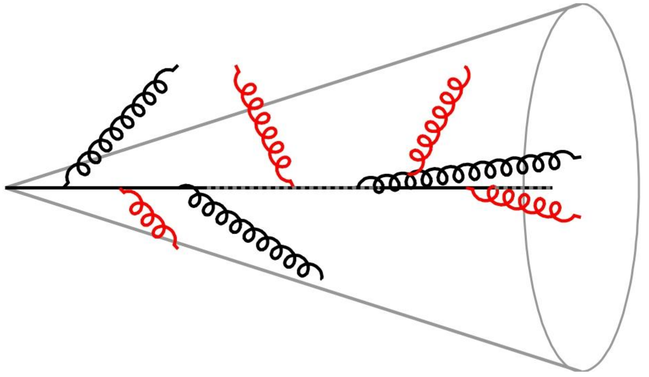


Jet shower in-medium

- Parton energy loss via medium-induced gluon radiation and elastic collisions → **jet quenching**
- Consequences of jet quenching:
  1. Yield suppression of high-p_T hadrons and jets
  2. Modification of jet substructure
  3. **Medium-induced acoplanarity** → semi-inclusive measurements of **trigger-jet acoplanarity** (trigger: **high-p_T hadron,** γ or Z)

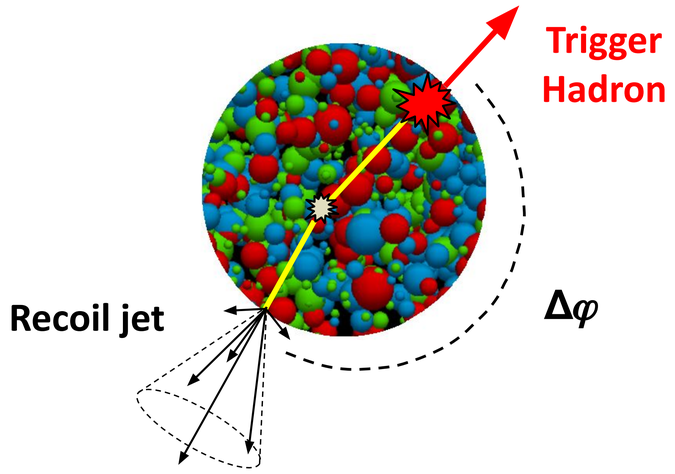


Hadron-jet acoplanarity

Regions of interest

1. Small $|\Delta\varphi - \pi|$

- Hadron-jet acoplanarity broadening: **vacuum (Sudakov) radiation and multiple scatterings in medium** (L. Chen et al, Phys. Lett. B773 (2017) 672)
- Direct estimation of **jet transport coefficient *q***
- Negative radiative correction ⟶ **reduction of broadening** (B. G. Zakharov, arxiv:2003.10182)



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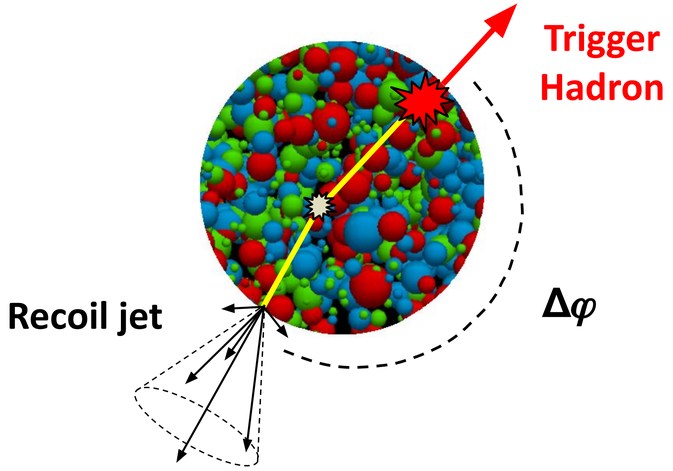
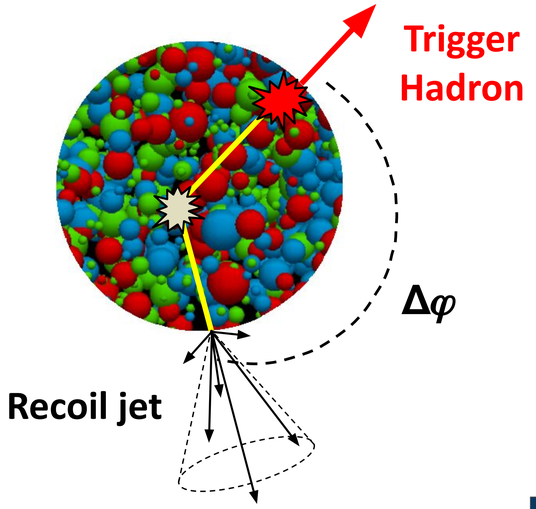


2. Large $|\Delta\varphi - \pi|$

- **Single hard scattering** ⟶ large angle scattering of parton on QGP quasi-particles
- Probe short distance quasi-particle structure of QGP (F. D'Eramo, Rajagopal, Y. Yin, JHEP 01 (2019) 172)



Pb-Pb data $\sqrt{s_{NN}}$ = 5.02 TeV

2018 Pb-Pb data sample

- 133M most central events (0-10 %)

V0 arrays

- Centrality determination
- **V0A:** $2.8 < \eta < 5.1$ & **V0C:** $-3.7 < \eta < -1.7$

Inner tracking system $|\eta| < 0.9$

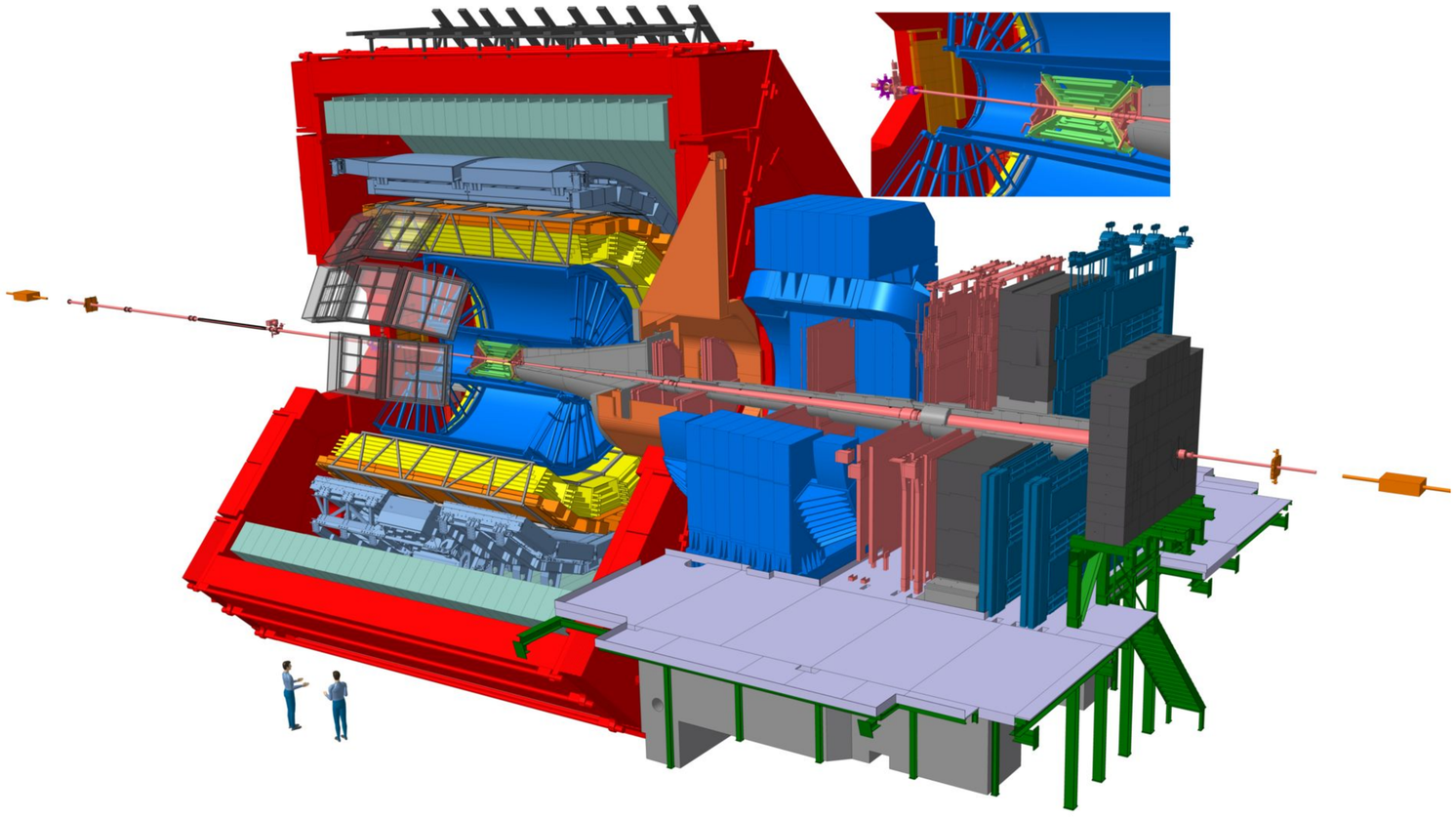
- Tracking and vertexing

Time projection chamber $|\eta| < 0.9$

- Tracking

Jet reconstruction

- Track $p_T > 150$ MeV/c
- Anti-k_T $R = 0.2$ charged-particle jets
- Fiducial cut $|\eta_{Jet}| < 0.7$



Hadron-jet acoplanarity via semi-inclusive measurements

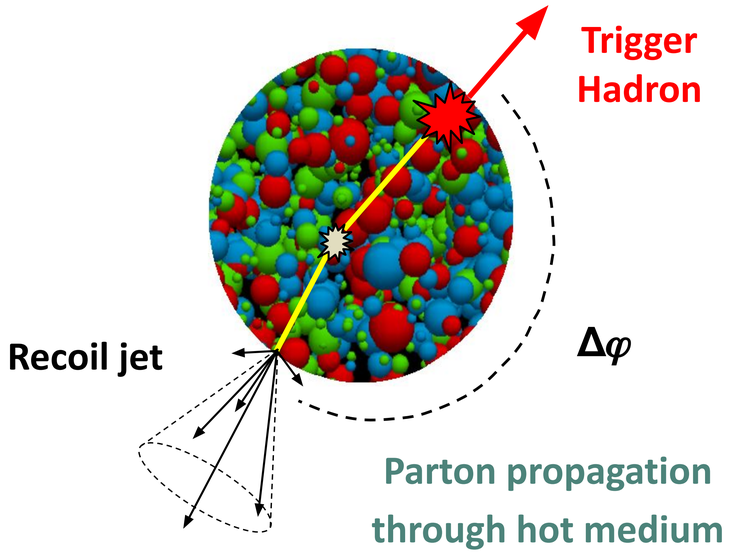
Per trigger normalized yield of jets recoiling from high-p_T hadron

$$\left.\frac{1}{N_{trig}^{AA}}\frac{d^2N_{jet}^{AA}}{dp_{T,jet}^{ch}d\eta_{jet}}\right|_{p_{T,trig}\in TT} = \left(\frac{1}{\sigma^{AA\to h+X}}\cdot\frac{d^2\sigma^{AA\to h+jet+X}}{dp_{T,jet}^{ch}d\eta_{jet}}\right)\Bigg|_{p_{T,h}\in TT}$$

→ Calculable in pQCD

Cross section for trigger hadron production

Differential cross section for coincidence production of trigger hadron and recoil jet



Semi-inclusive measurements provide:

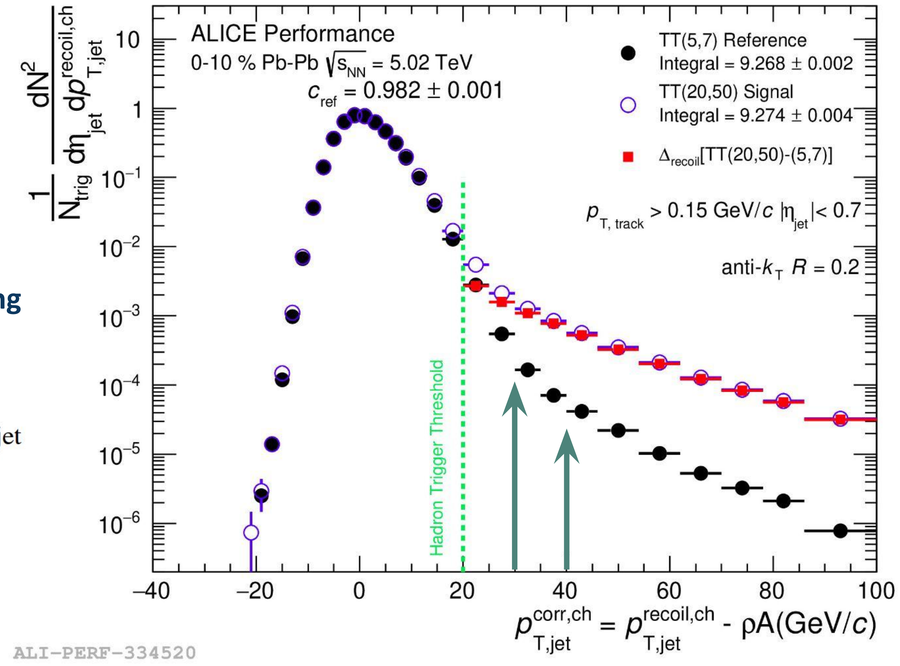
- Unbiased jet population
- Access to **low p_T jets → more sensitive to medium-induced broadening**
- **Data driven approach for removal of uncorrelated background yield**

  → essential for precise acoplanarity measurements

Hadron-jet acoplanarity: Δ_{recoil} observable

TT_{Sig}: $20 < p_T < 50$ GeV/c

TT_{Ref}: $5 < p_T < 7$ GeV/c



Jet p_T corrected for **underlying event density ρ**

$$p_{\mathrm{T,jet}}^{\mathrm{recoil,ch}} = p_{\mathrm{T,jet}}^{\mathrm{raw,ch}} - \rho A_{\mathrm{jet}}$$

- Jets recoiling from a high-p_T trigger hadron
- Data-driven approach to **remove uncorrelated background yield**

$$\Delta_{\mathrm{recoil}} = \frac{1}{N_{\mathrm{trig}}^{\mathrm{AA}}} \frac{\mathrm{d}^2 N_{\mathrm{jet}}^{\mathrm{AA}}}{\mathrm{d}p_{\mathrm{T,jet}}^{\mathrm{ch}} \mathrm{d}\eta_{\mathrm{jet}}}\Bigg|_{p_{\mathrm{T,trig}} \in \mathrm{TT_{Sig}}} - c_{\mathrm{Ref}} \cdot \frac{1}{N_{\mathrm{trig}}^{\mathrm{AA}}} \frac{\mathrm{d}^2 N_{\mathrm{jet}}^{\mathrm{AA}}}{\mathrm{d}p_{\mathrm{T,jet}}^{\mathrm{ch}} \mathrm{d}\eta_{\mathrm{jet}}}\Bigg|_{p_{\mathrm{T,trig}} \in \mathrm{TT_{Ref}}}$$

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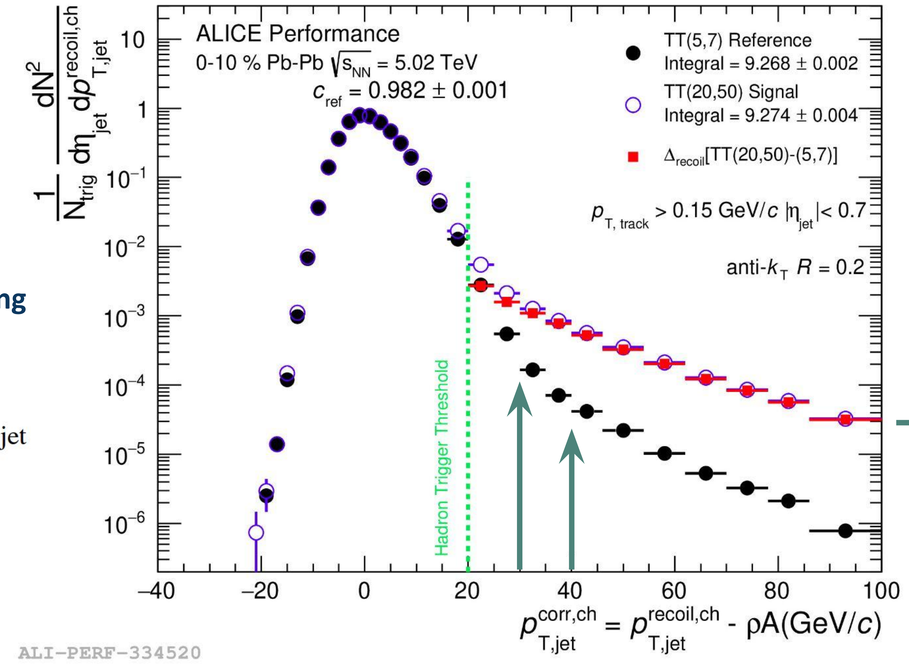
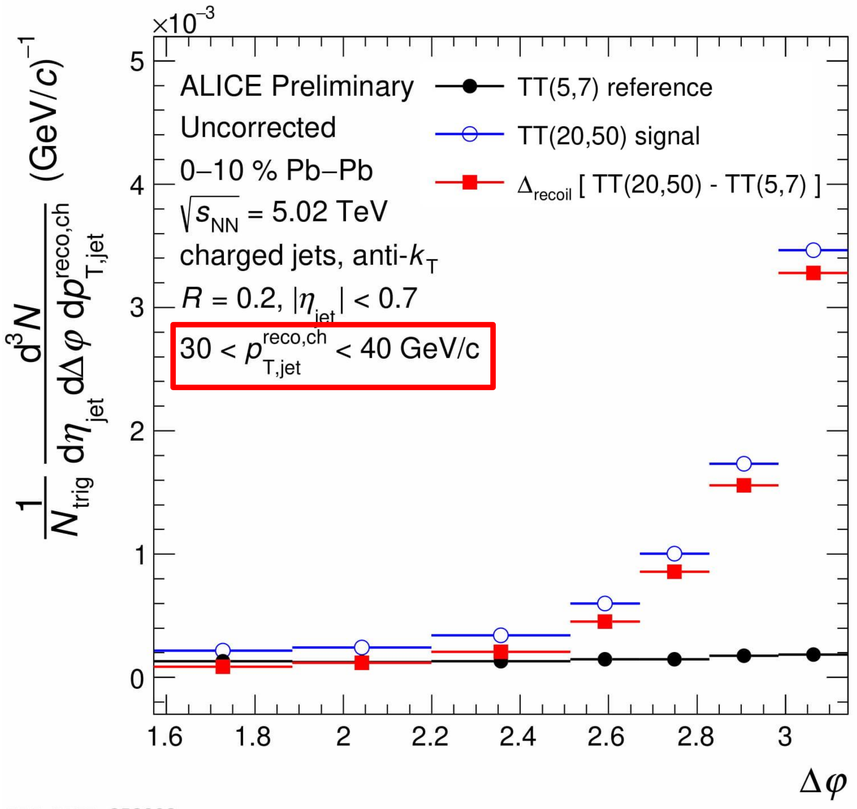


Δ_{recoil} as function of TT-jet opening angle



- Jets recoiling from a high-p_T trigger hadron
- Data-driven approach to **remove uncorrelated background yield**

$$\Delta_{recoil} = \frac{1}{N_{trig}^{AA}} \frac{d^2N_{jet}^{AA}}{dp_{T,jet}^{ch} d\eta_{jet}}\bigg|_{p_{T,trig} \in TT_{Sig}} - c_{Ref} \cdot \frac{1}{N_{trig}^{AA}} \frac{d^2N_{jet}^{AA}}{dp_{T,jet}^{ch} d\eta_{jet}}\bigg|_{p_{T,trig} \in TT_{Ref}}$$

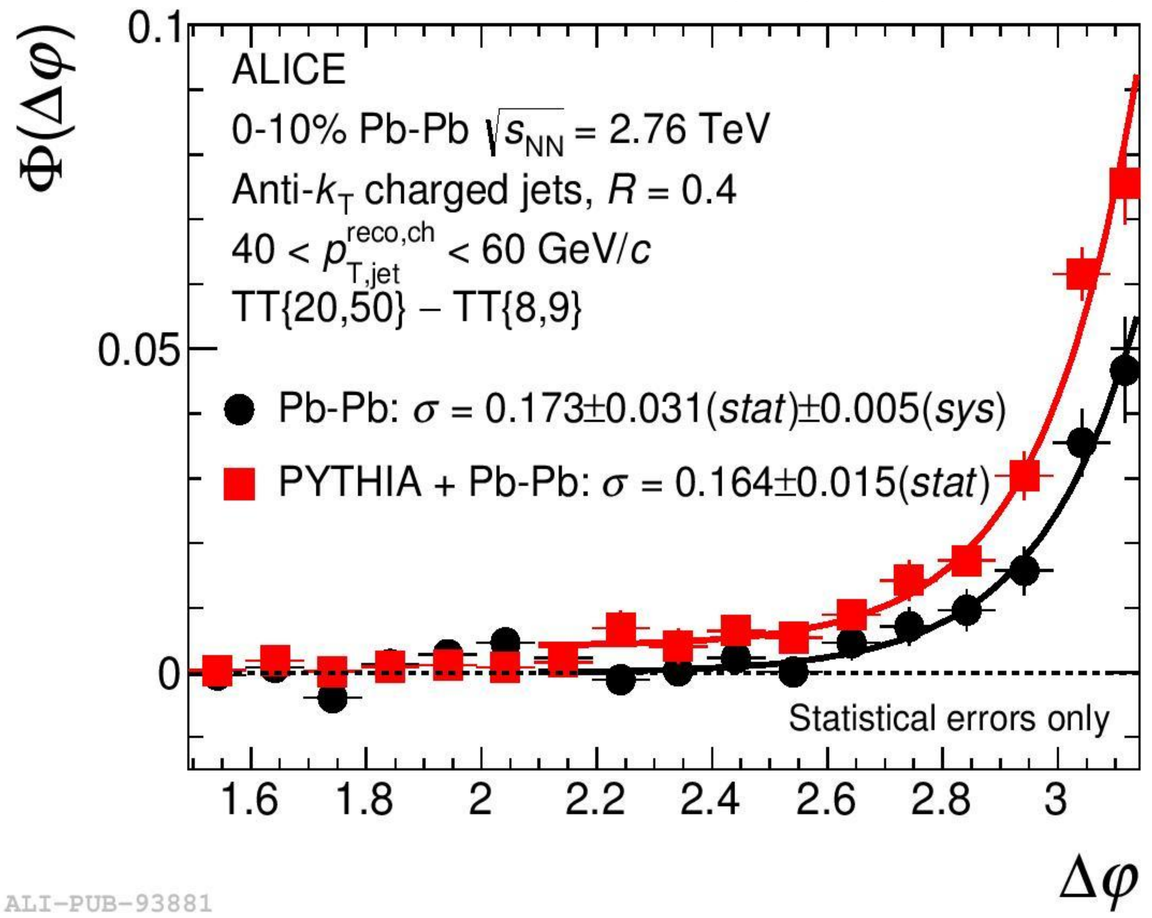
Results: Run 1 Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV

- Limited statistics
- **Uncorrected for p_T and angular smearing**
- Anti-k_T charged-particle jets R = 0.4 with $p_T \in$ (40, 60) GeV/c
- Fit function:

$$f(\Delta\varphi) = p_0 \times e^{(\Delta\varphi-\pi)/\sigma} + p_1$$

  - Suppression of Pb-Pb data comparing to PYTHIA pp
  - **No evidence for medium-induced acoplanarity within uncertainties**

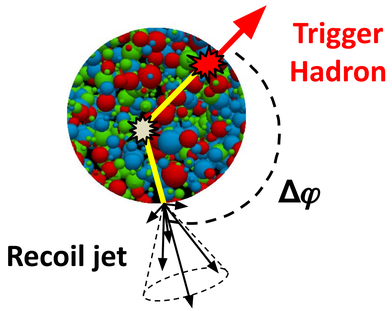
JHEP 09 (2015) 170 (arxiv:1506.03984)

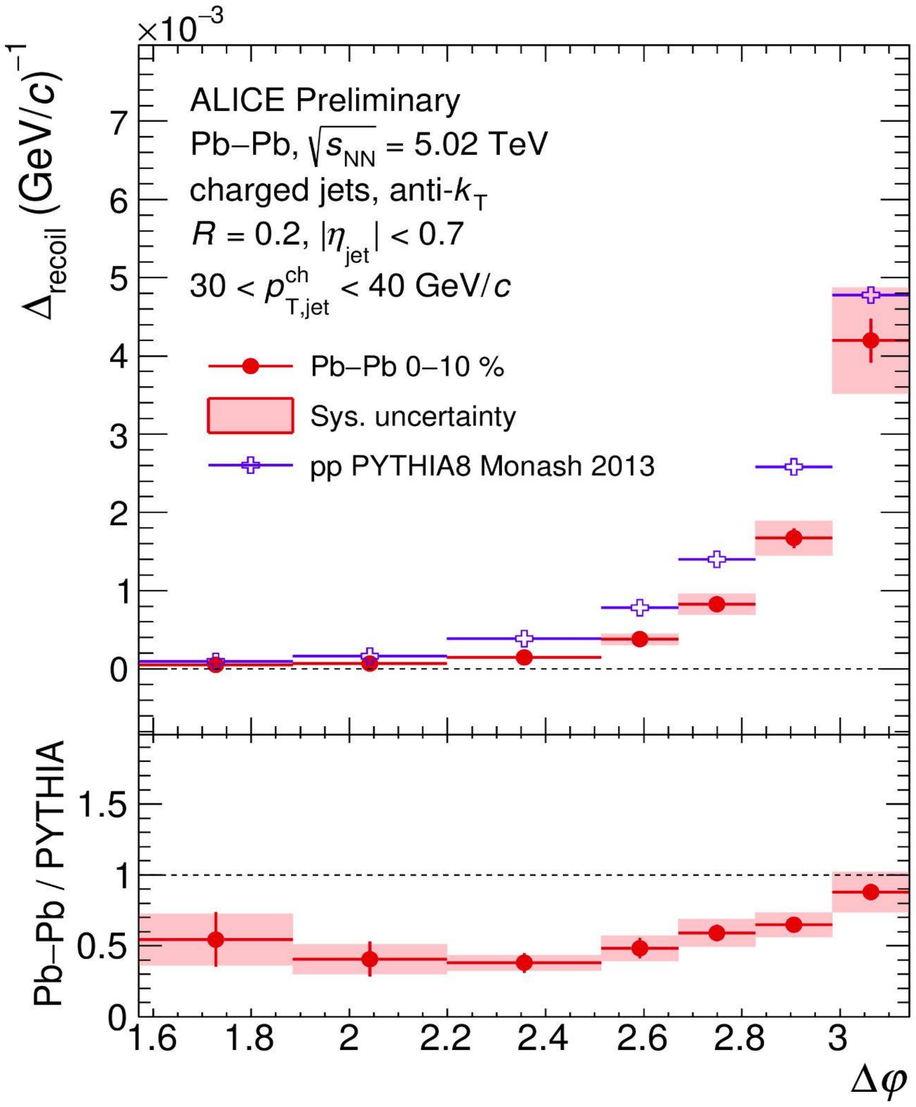


ALI-PUB-93881

Results: Run 2 Pb-Pb $\sqrt{s_{NN}}$ = 5.02 TeV

- **$\Delta\varphi \sim \pi$:** multiple soft momentum exchanges
- **$\Delta\varphi \ll \pi$:** Rutherford-like scattering off QGP quasi-particles





ALI-PREL-353019

- **x9 larger statistics** with respect to Run 1 data
- Anti-k_T charged-particle jets R = 0.2 with $p_T \in$ (30, 40) GeV/c
- Fully corrected hadron-jet $\Delta\varphi$ distribution

- Recoil jet yield suppressed compared to pp PYTHIA data
- **Indication of narrowing of acoplanarity distribution in $30 < p_{T,jet}^{ch} < 40$ GeV/c**

Radiative corrections?

B. G. Zakharov, arxiv:2003.10182

Pb-Pb collisions $\sqrt{s_{NN}}$ = 5.02 TeV: Summary

- **Fully corrected hadron-jet $\Delta\varphi$ distribution for R = 0.2 jets in 30 < $p_{T,\,jet}^{ch}$ < 40 GeV/c**
- Suppression with respect to PYTHIA pp data
- Observation of narrowing of $\Delta\varphi$ distribution with respect to pp $\longrightarrow$ signs of radiative corrections?

Next steps

- pp reference: large-statistics 2017 pp data sample at $\sqrt{s}$ = 5.02 TeV (~ 1B events)
- Measurements towards lower jet p_T and larger R

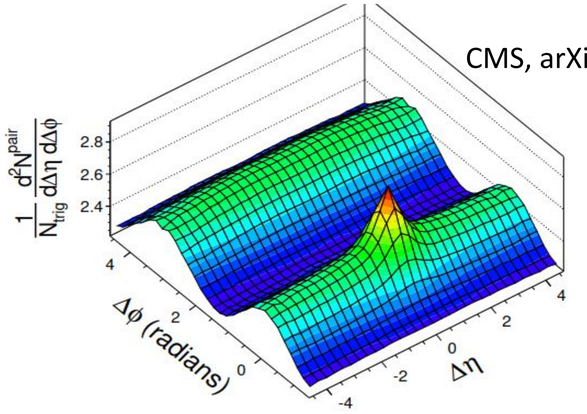
High-particle multiplicity pp collisions

Quark-gluon plasma formation in small collision systems?

Collective flow

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

CMS, arXiv:1305.0609v3

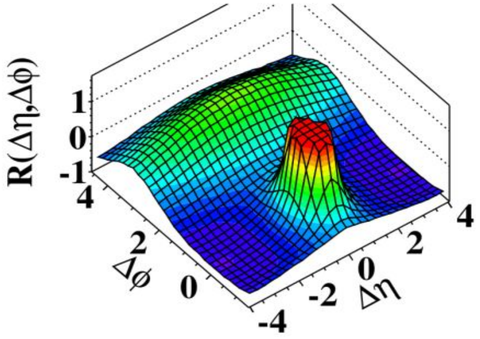


Quark-gluon plasma formation in small collision systems?

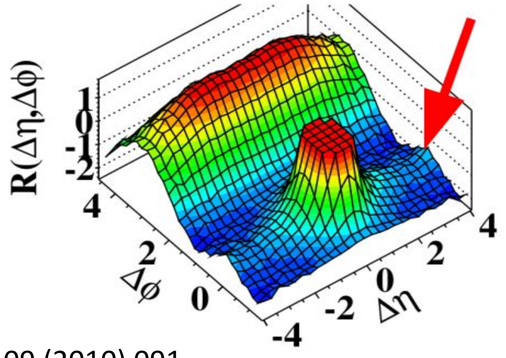
Collective flow

Azimuthal correlation between two particles pp 7 TeV

Minimum bias events



High-multiplicity events



CMS, JHEP 09 (2010) 091

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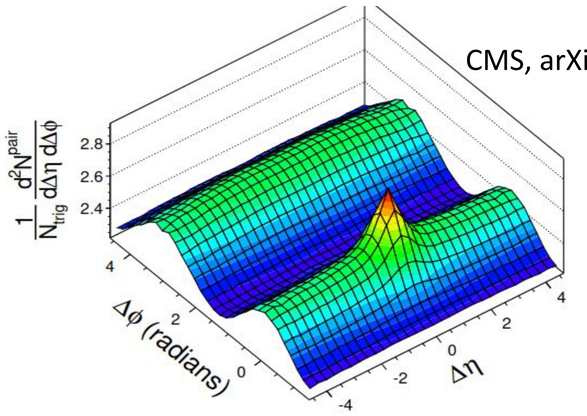

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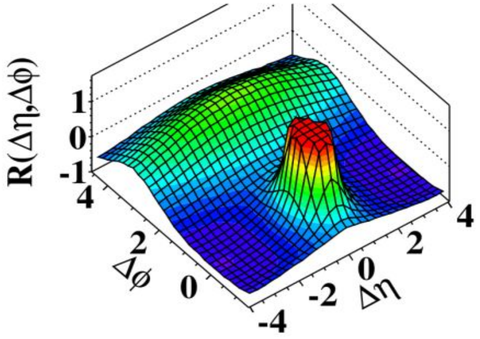

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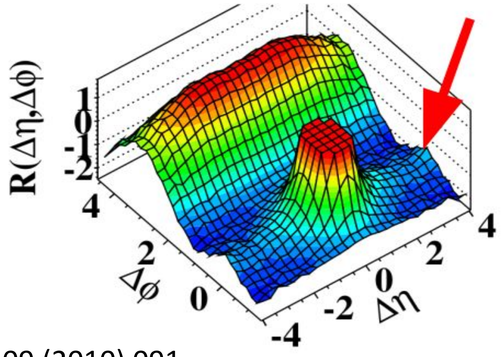

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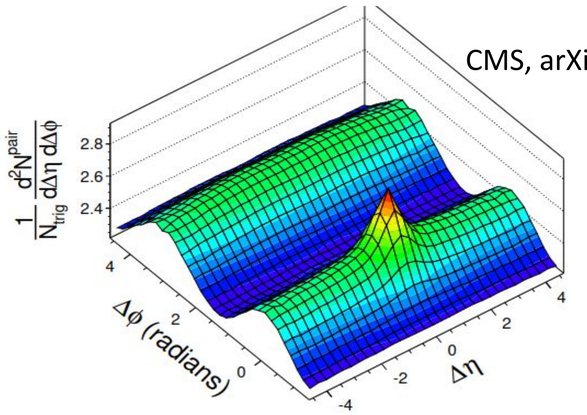

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Jet quenching in high particle multiplicity pp collisions

R_{AA} nuclear modification factor measurements

$$R_{\mathrm{AA}} = \frac{\mathrm{d}^2 N_{\mathrm{AA}}/\mathrm{d}y\mathrm{d}p_{\mathrm{T}}}{\langle T_{\mathrm{AA}} \rangle \mathrm{d}^2\sigma_{\mathrm{pp}}^{\mathrm{INEL}}/\mathrm{d}y\mathrm{d}p_{\mathrm{T}}}$$

undefined Glauber scaling factor for high particle multiplicity pp

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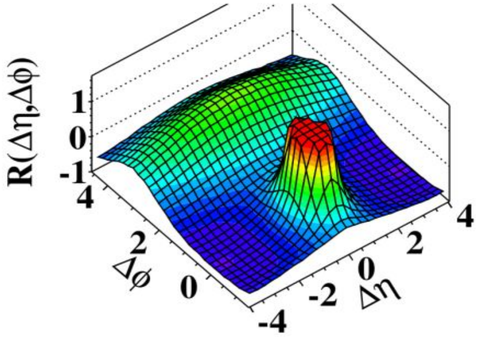

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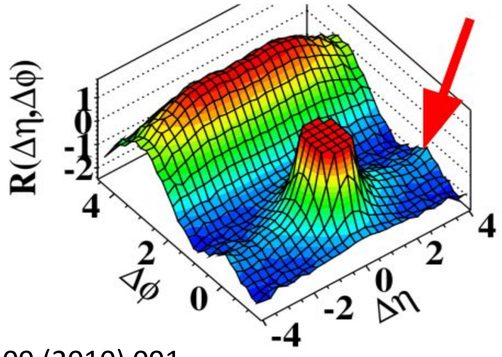

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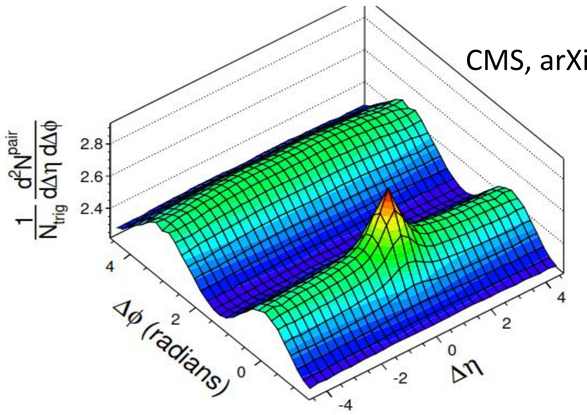

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undefined Glauber scaling factor for high particle multiplicity pp

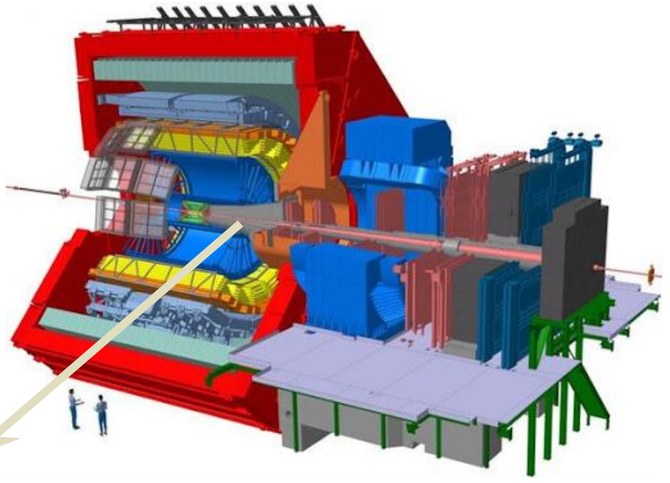
Semi-inclusive measurements

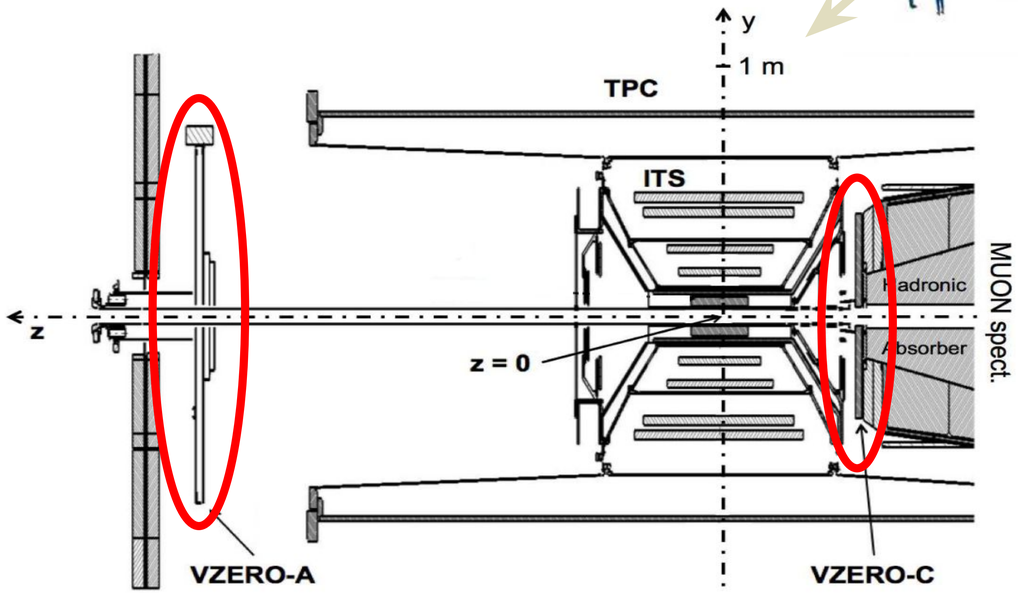
$$\left.\frac{1}{\sigma^{\mathrm{AA}\to\mathrm{h+X}}}\frac{\mathrm{d}^2\sigma^{\mathrm{AA}\to\mathrm{h+jet+X}}}{\mathrm{d}p_{\mathrm{T,\,jet}}^{\mathrm{ch}}\mathrm{d}\eta_{\mathrm{jet}}}\right|_{\mathrm{h}\,\in\,\mathrm{TT}} = \frac{1}{\sigma^{\mathrm{pp}\to\mathrm{h+X}}}\frac{\mathrm{d}^2\sigma^{\mathrm{pp}\to\mathrm{h+jet+X}}}{\mathrm{d}p_{\mathrm{T,\,jet}}^{\mathrm{ch}}\mathrm{d}\eta_{\mathrm{jet}}} \times \left.\frac{\langle T_{\mathrm{AA}}\rangle}{\langle T_{\mathrm{AA}}\rangle}\right|_{\mathrm{h}\,\in\,\mathrm{TT}}$$

Glauber scaling factors $\langle T_{AA}\rangle$ cancel identically

pp data $\sqrt{s}$ = 13 TeV

- Data from 2016 - 2018
- Online triggers based on V0 arrays:
  - **Minimum bias** (MB): 0.098 pb^{-1}
  - **High-multiplicity** (HM): 13 pb^{-1}





V0A: 2.8 < η < 5.1

V0C: -3.7 < η < -1.7

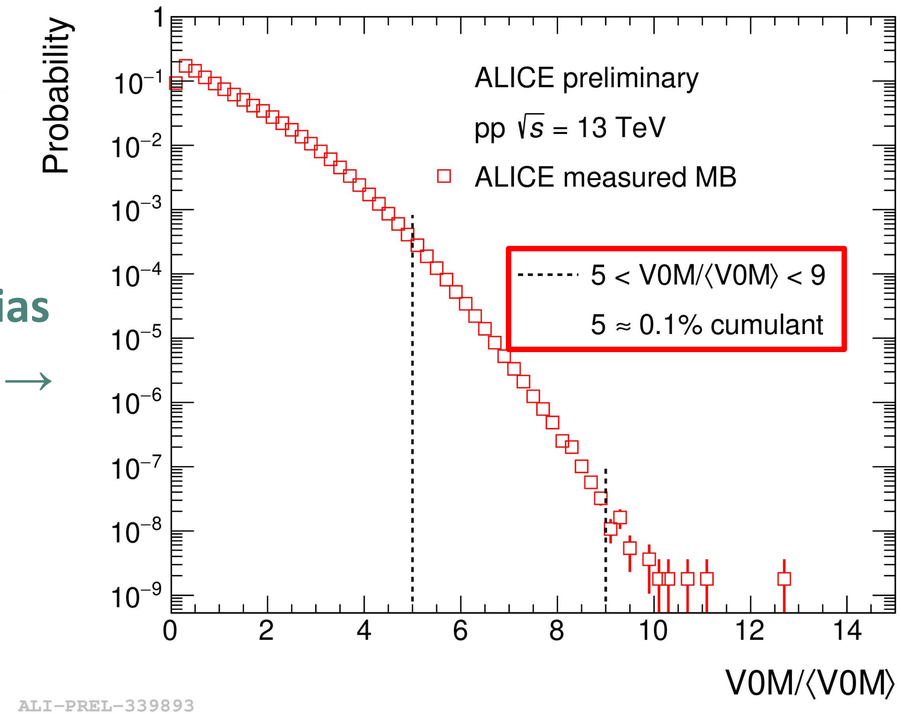
- **Offline event activity (EA) selection:**

  V0M = V0A + V0C ⟶ sum of signals

- **Scaled multiplicity V0M/⟨V0M⟩**

  ⟨V0M⟩ - mean of MB distribution

Minimum bias distribution ⟶



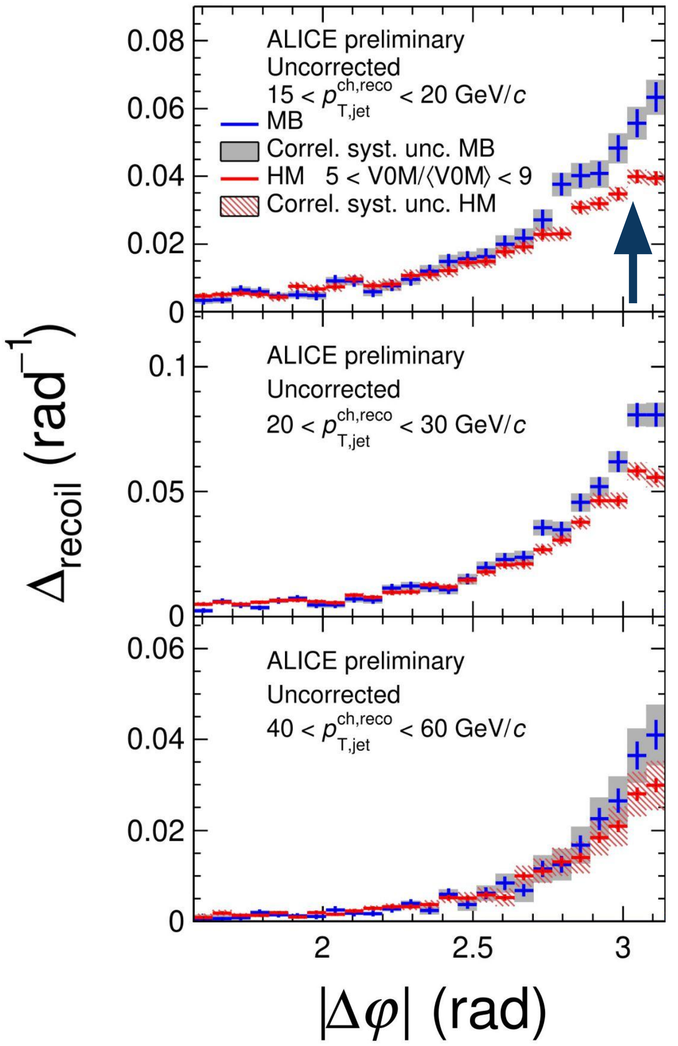
Acoplanarity versus event activity: uncorrected data and PYTHIA 8

- Anti-k_T R = 0.4 charged-particle recoil jets

Uncorrected data

- Estimated uncertainty from tracking efficiency
- **Significant suppression and broadening of HM data when compared to MB**

Uncorrected data



ALI-PREL-339740

Acoplanarity versus event activity: uncorrected data and PYTHIA 8

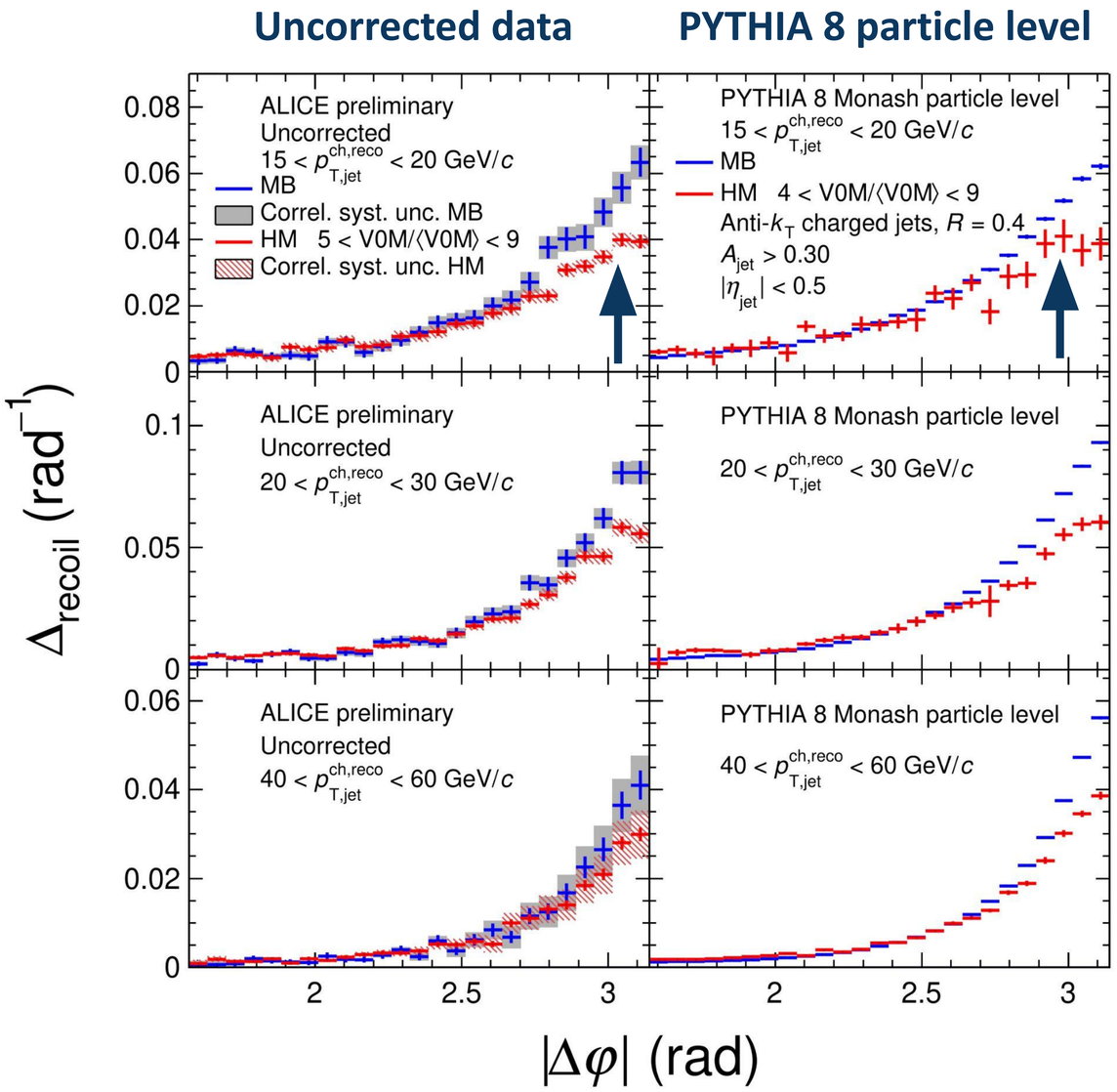
- Anti-k_T R = 0.4 charged-particle recoil jets

Uncorrected data

- Estimated uncertainty from tracking efficiency
- **Significant suppression and broadening of HM data when compared to MB**

PYTHIA 8 simulation

- Does not account for jet quenching
- **Exhibits qualitatively similar suppression effect as real data**



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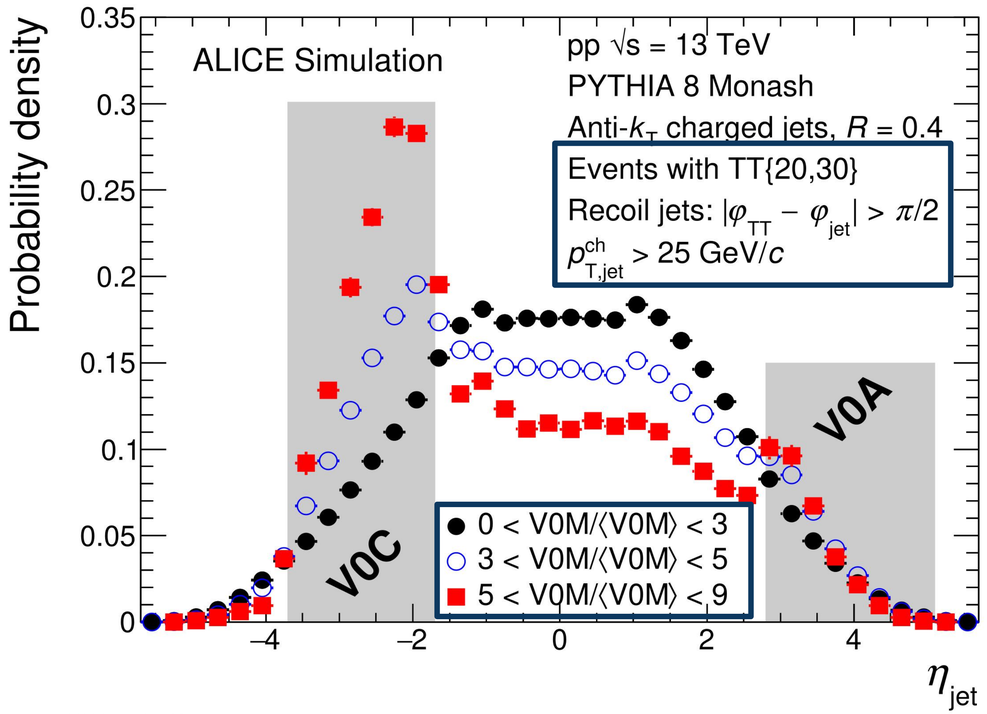
PYTHIA 8 simulation: Recoil jet pseudorapidity vs. event activity



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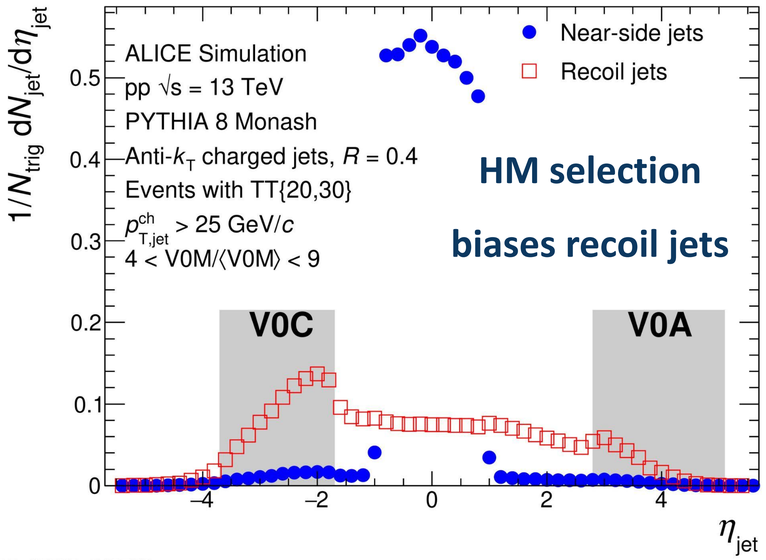
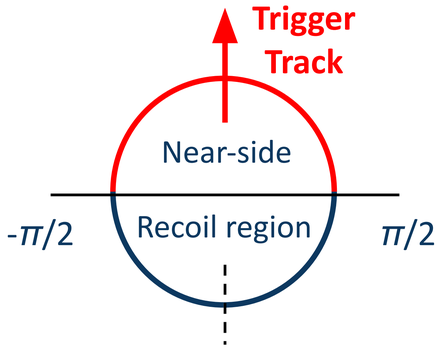
Recoil jets vs. near-side jets



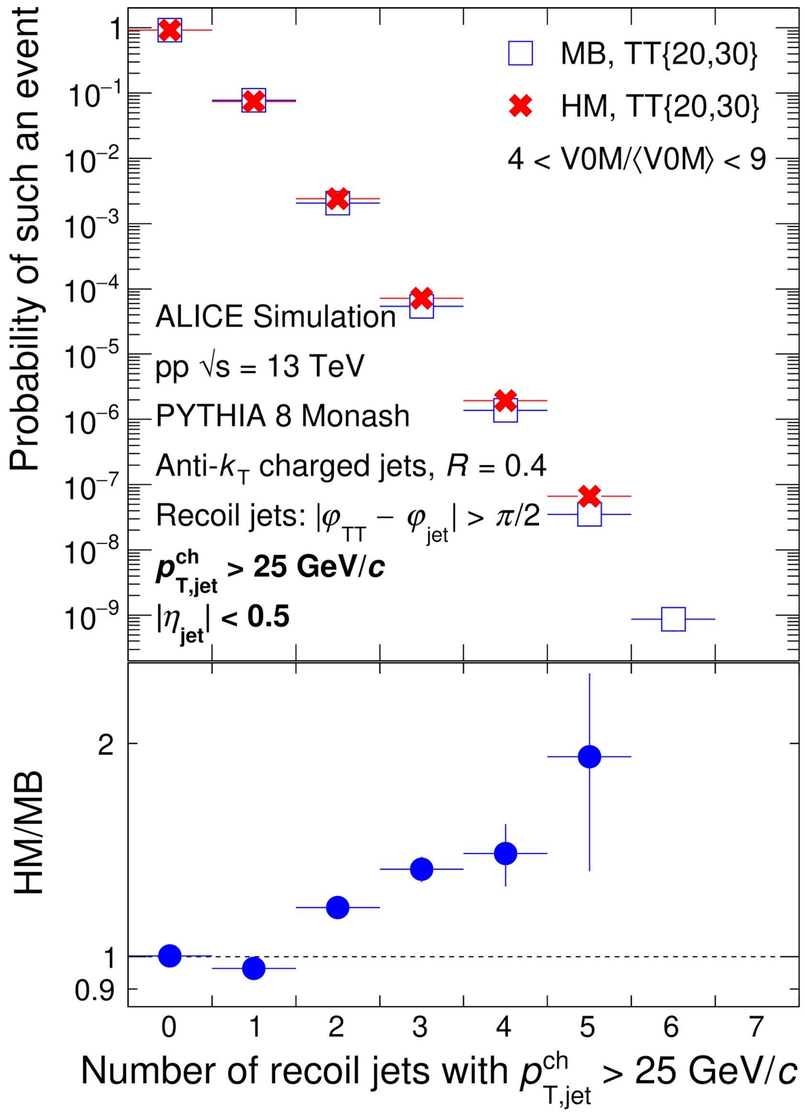
ALI-SIMUL-347701



- HM bias imposed by V0M selection **enhances probability** to find high-p_T recoil jet in V0
- Lower enhancement in V0A is caused by asymmetric coverage of V0 arrays

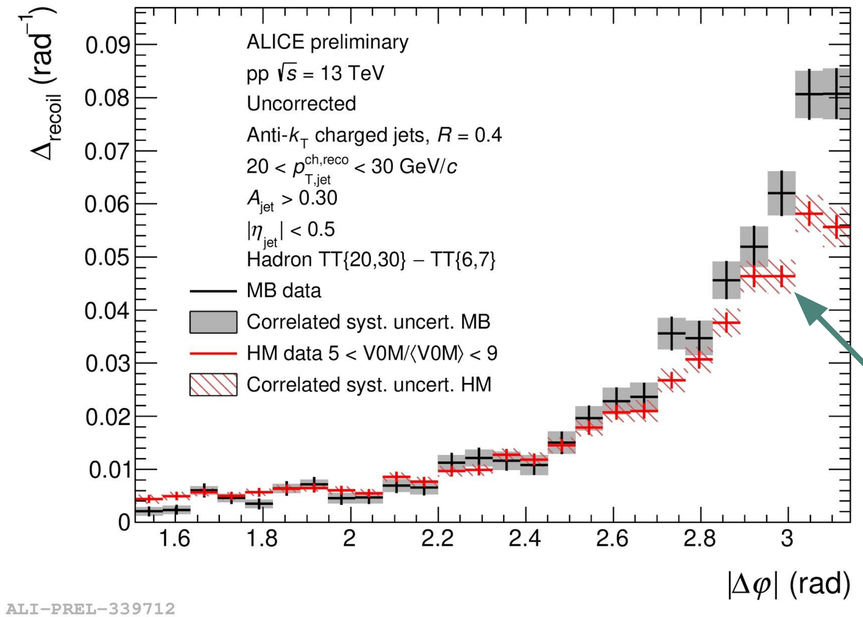
★ V0M is defined as the number of charged, final state particles within V0A & V0C acceptances

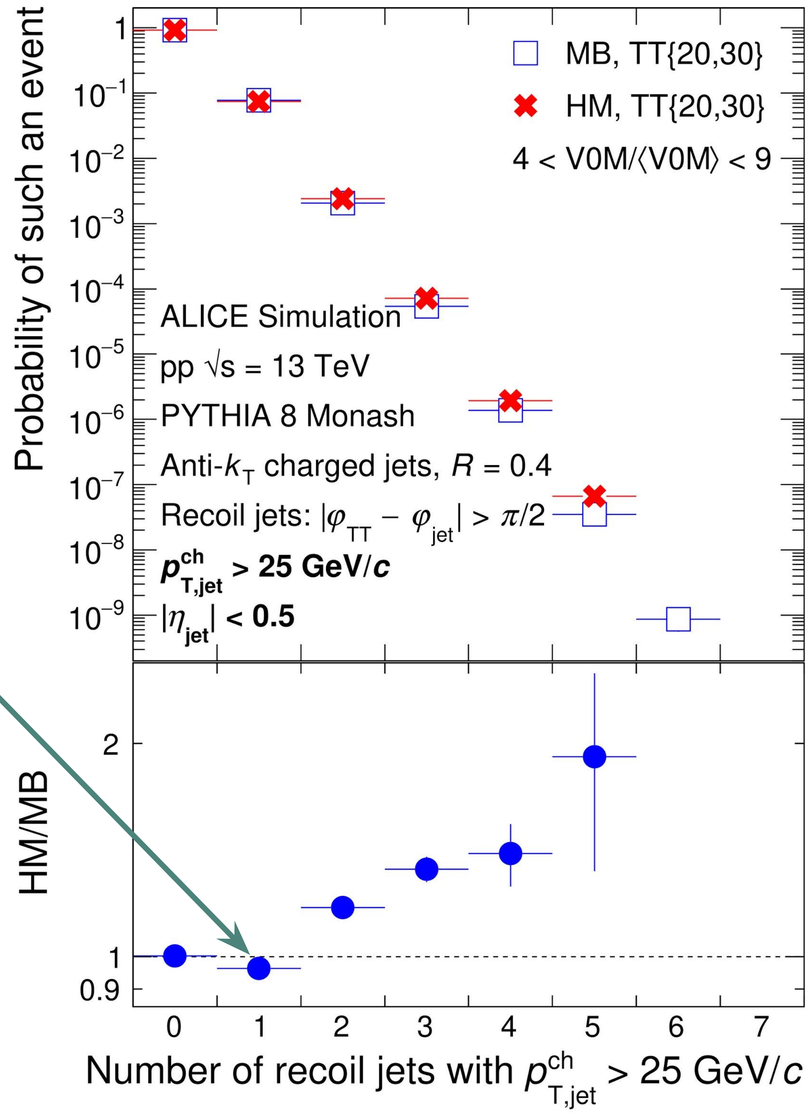
PYTHIA 8 simulation: Number of high-p_T recoil jet vs. event activity



ALI-SIMUL-347715

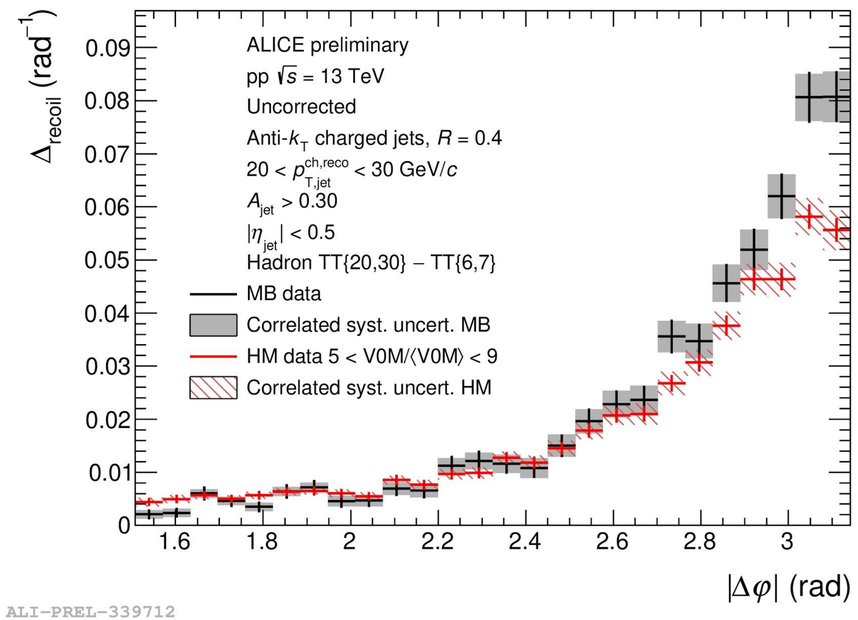
PYTHIA 8 simulation: Number of high-p_T recoil jet vs. event activity

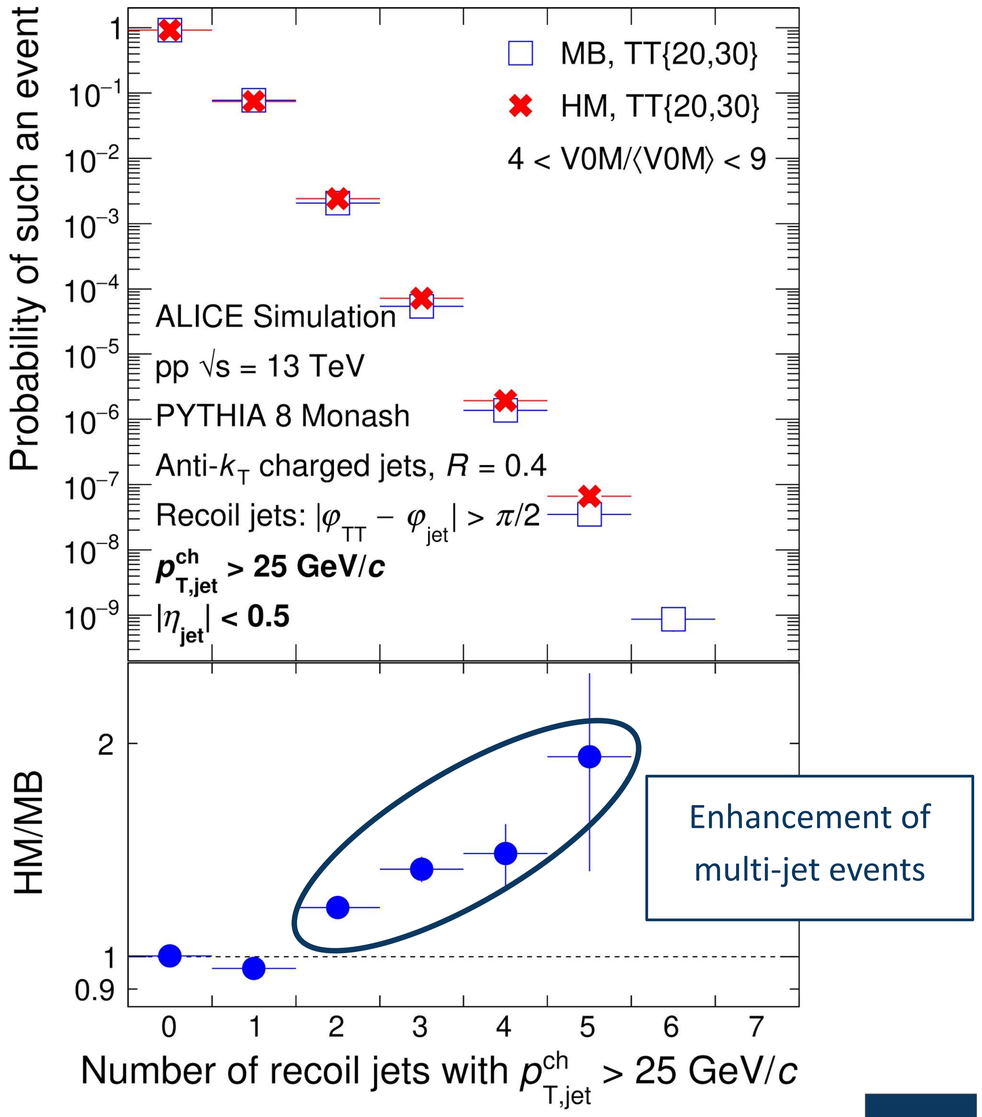




- HM events → **suppressed probability to have 1 hard recoil jet** in ALICE central barrel w.r.t. MB

PYTHIA 8 simulation: Number of high-p_T recoil jet vs. event activity





- HM events ⟶ **suppressed probability to have 1 hard recoil jet** in ALICE central barrel w.r.t. MB
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Thank you for your attention!