第八届中国LHC物理研讨会 The 8th China LHC Physics Workshop (CLHCP2022)

Jet acoplanarity measurements via hadron-jet correlations in pp and Pb-Pb collisions with ALICE

Yongzhen HOU for the ALICE collaboration

Central China Normal University

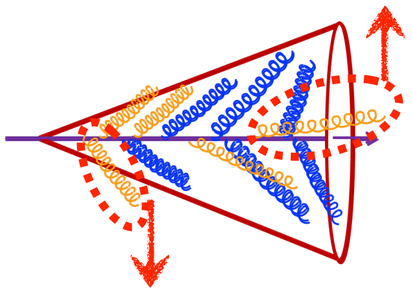
University of Strasbourg

CLHCP 2022 (23-27 Nov 2022)

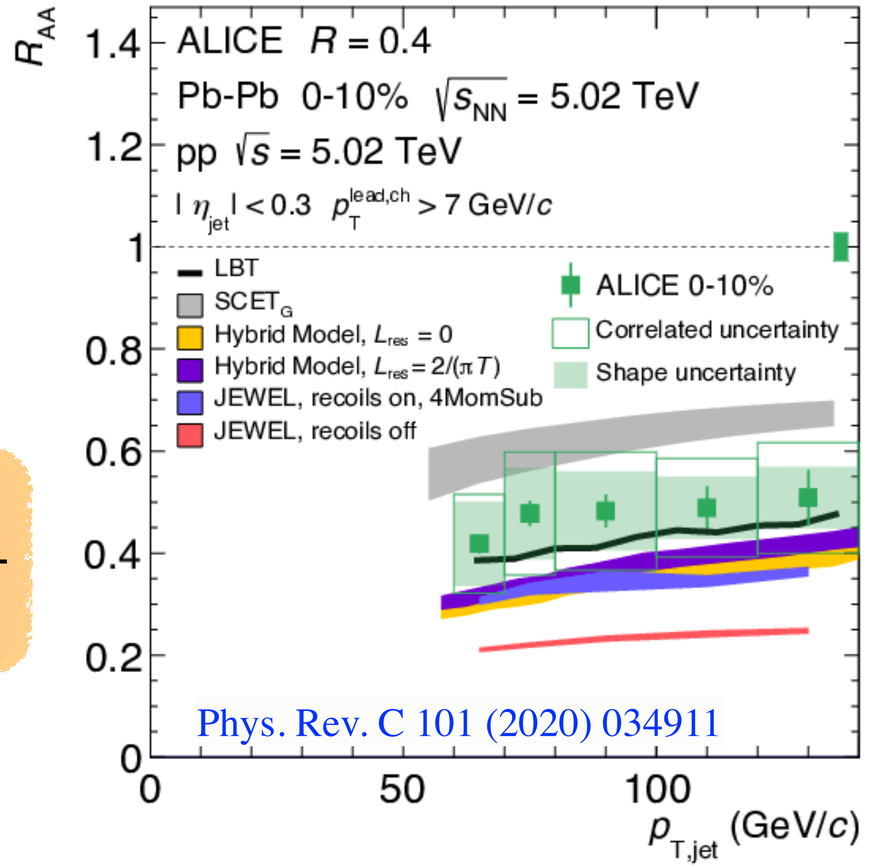
Online

Why study jets?

- Jet production in vacuum
  - Provides constraints to pQCD calculation via the jet yield and jet structure
  - Serves as a reference for measurements in heavy-ion collisions
- Jet modification in heavy-ion collisions
  - **Jet energy redistribution** in nucleus-nucleus collisions (energy loss)
  - **Jet angular deflection** (jet acoplanarity)
  - Modification of jet substructure



$$R_{\mathrm{AA}} = \frac{\mathrm{d}N^{\mathrm{AA}}_{\mathrm{jts}}/\mathrm{d}p_{\mathrm{T}}\mathrm{d}\eta}{\langle T_{\mathrm{AA}}\rangle\, \mathrm{d}\sigma^{\mathrm{pp}}_{\mathrm{jets}}/\mathrm{d}p_{\mathrm{T}}\mathrm{d}\eta}$$



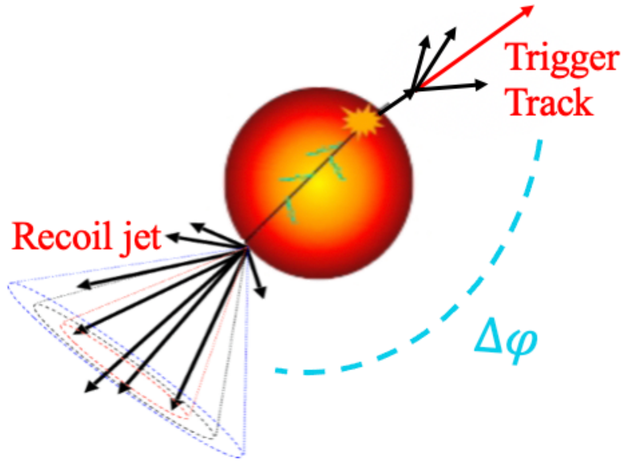
hadron-jet measurements

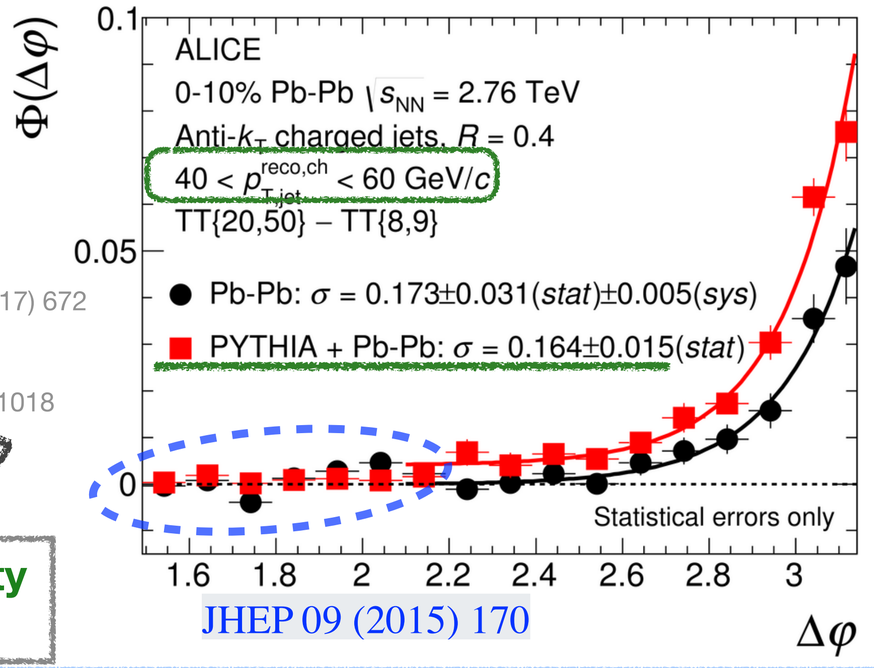
- Trigger track (TT) close to the surface, but no bias on recoil jets
- Provide a good handle of combinatorial background by varying the trigger track intervals → access low p_T, large R jets
- **Opening angle** ($\Delta\varphi$) of the recoil jet relative to trigger axis
- Azimuthal distributions provide additional insight into quark-gluon plasma(QGP) properties
- Hadron-jet acoplanarity broadening: vacuum (Sudakov) radiation
- Multiple soft scattering in the QGP may further broaden $\Delta\varphi$
  - Related to transport coefficient $\hat{q} \sim \langle p_\perp^2 \rangle / L \sim \langle \Delta\varphi^2 \rangle / L$

L Chen, Phys. Lett. B 773 (2017) 672

B. G. Zakharov, arxiv:2003.1018

- Negative radiative correction → reduction of broadening

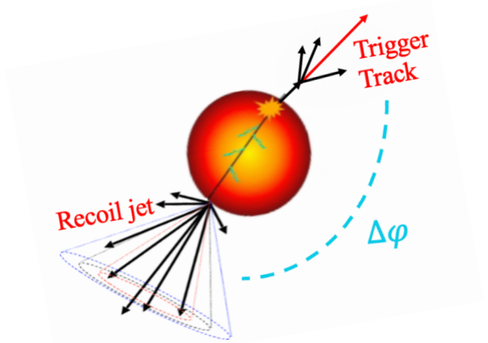




JHEP 09 (2015) 170

No medium-induced acoplanarity observed within uncertainties

Jet measurements in ALICE

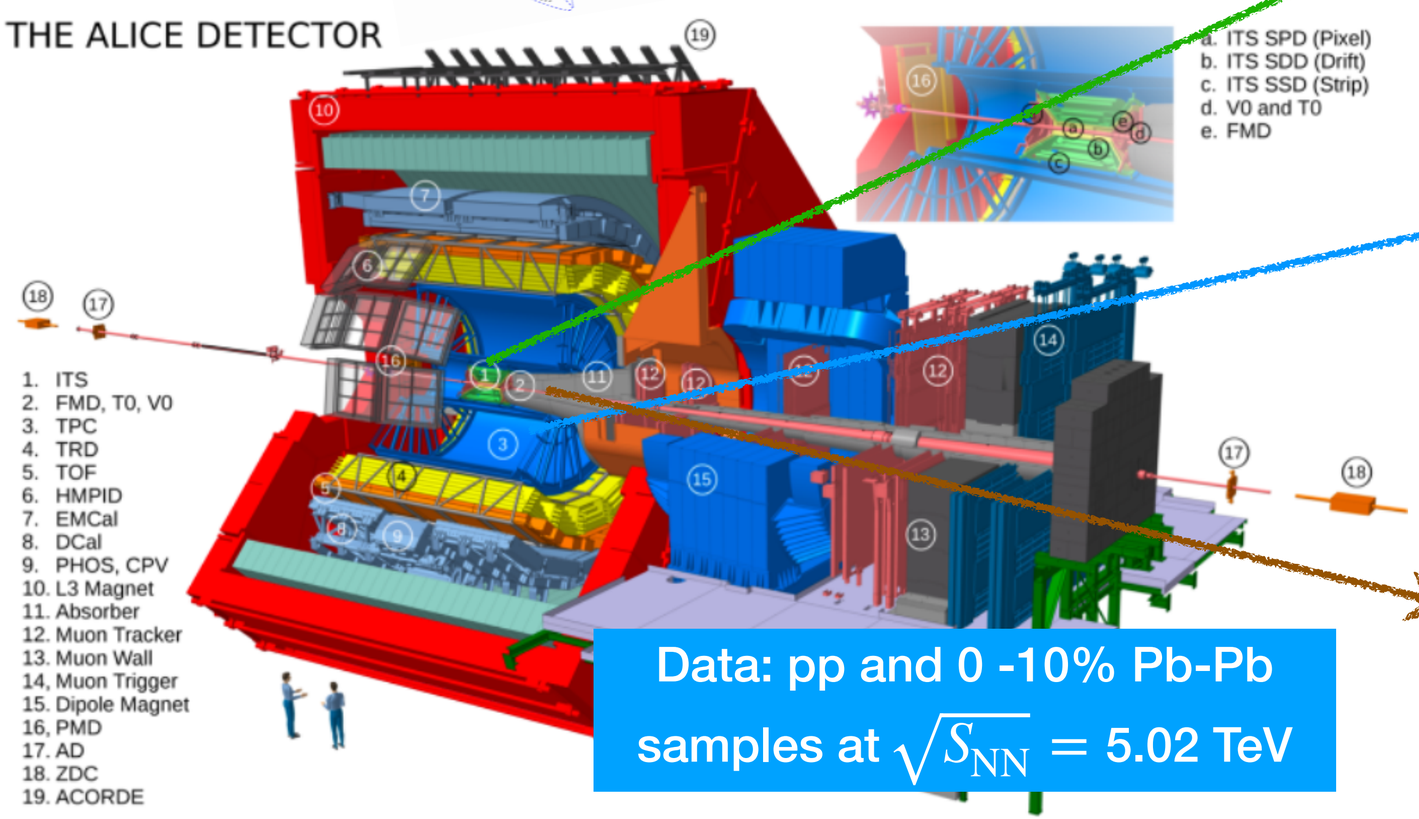


Charged particle tracks

$p_{\mathrm{T,track}}^{\mathrm{ch}} > 0.15$ GeV/c

anti-k_{T} algorithm

Charged-particle jets



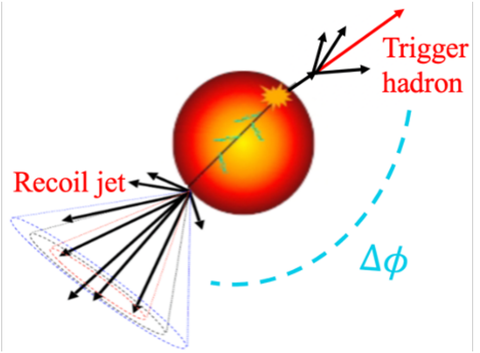
Data: pp and 0 -10% Pb-Pb samples at $\sqrt{S_{\mathrm{NN}}} = 5.02$ TeV

- **ITS** (Inner Tracking System)
  - $|\eta| < 0.9,\ 0 < \varphi < 2\pi$
  - Primary vertex reconstruction
  - Charged particle tracking
- **TPC** (Time Projection Chamber)
  - $|\eta| < 0.9,\ 0 < \varphi < 2\pi$
  - Charged particle tracking
  - Particle identification
- **V0** (V0C + V0A)
  - $-3.7 < \eta < -1.7,\ 2.8 < \eta < 5.1$
  - Event multiplicity, centrality determination
  - Event trigger

Observables

- Measure **trigger-normalised yield** of jets recoiling from a trigger hadron

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

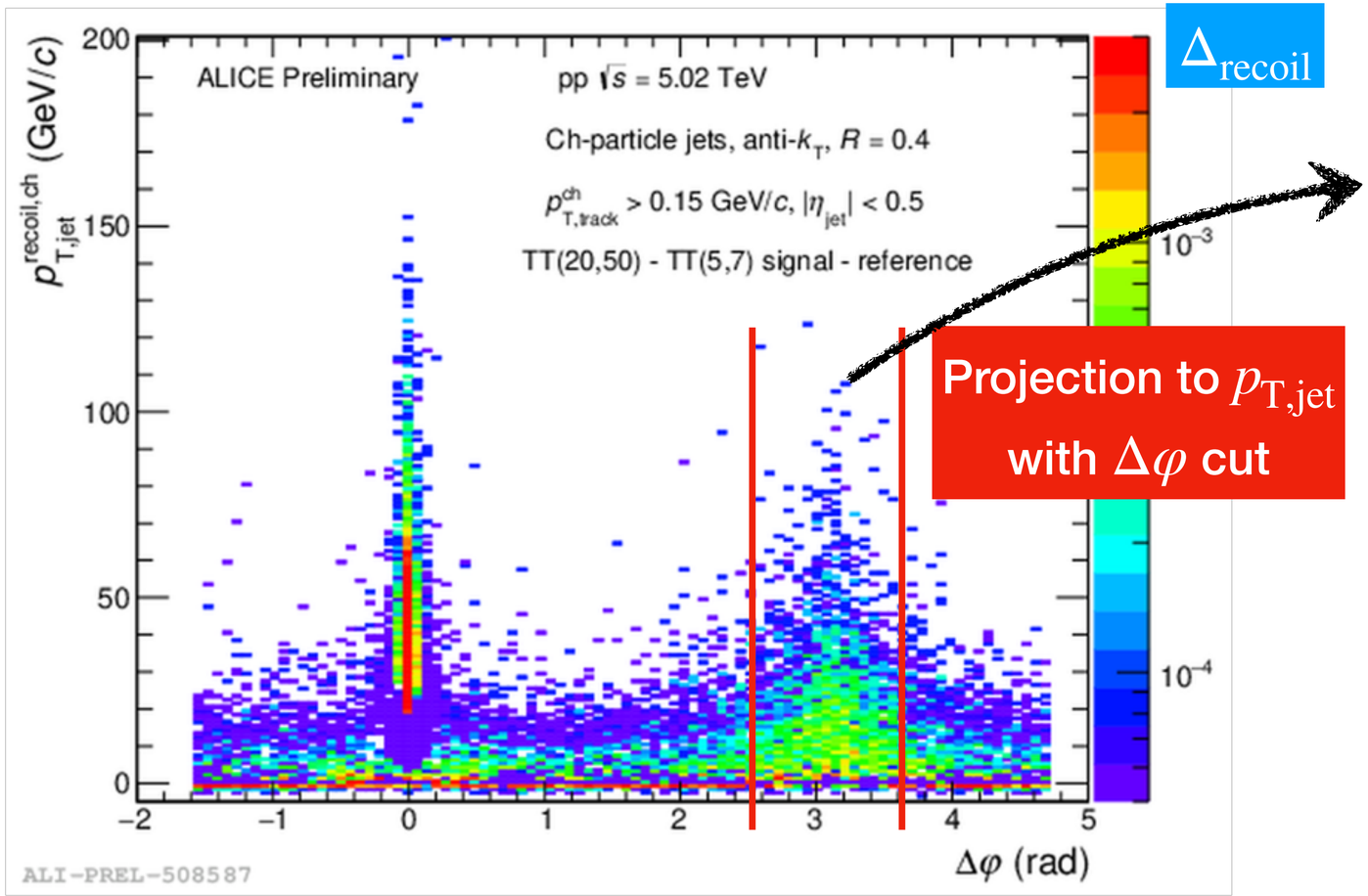


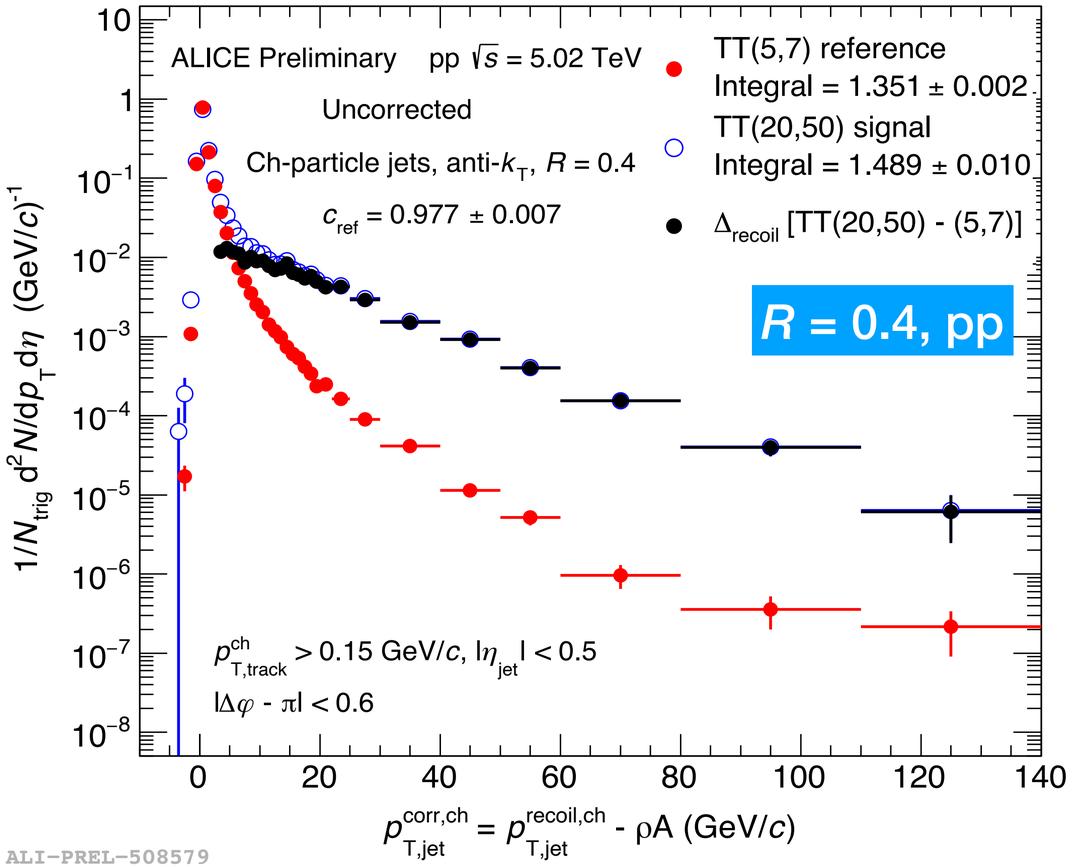
- Observables defined as **the difference** between trigger-normalised recoil jet yields in **two trigger track intervals** in order to **subtract all uncorrelated background jets**

$$\Delta_{\mathrm{recoil}}\,(p_{\mathrm{T,jet}},\,\Delta\varphi) = \frac{1}{N_{\mathrm{trig}}}\frac{\mathrm{d}^3 N_{\mathrm{jet}}}{\mathrm{d}\eta_{\mathrm{jet}}\,\mathrm{d}p_{\mathrm{T,jet}}\,\mathrm{d}\Delta\varphi}\Bigg|_{p_{\mathrm{T}}^{\mathrm{trig}}\in\mathrm{TT_{Sig}}} - c_{\mathrm{Ref}}\cdot\frac{1}{N_{\mathrm{trig}}}\frac{\mathrm{d}^3 N_{\mathrm{jet}}}{\mathrm{d}\eta_{\mathrm{jet}}\,\mathrm{d}p_{\mathrm{T,jet}}\,\mathrm{d}\Delta\varphi}\Bigg|_{p_{\mathrm{T}}^{\mathrm{trig}}\in\mathrm{TT_{Ref}}}$$

  - TT signal: $p_{\mathrm{T}} \in (20,\,50)$ GeV/c, TT reference: $p_{\mathrm{T}} \in (5,\,7)$ GeV/c, jet R: 0.2, 0.4
  - c_{ref}: “alignment” constant extracted from data; precise subtraction of uncorrelated jet yield

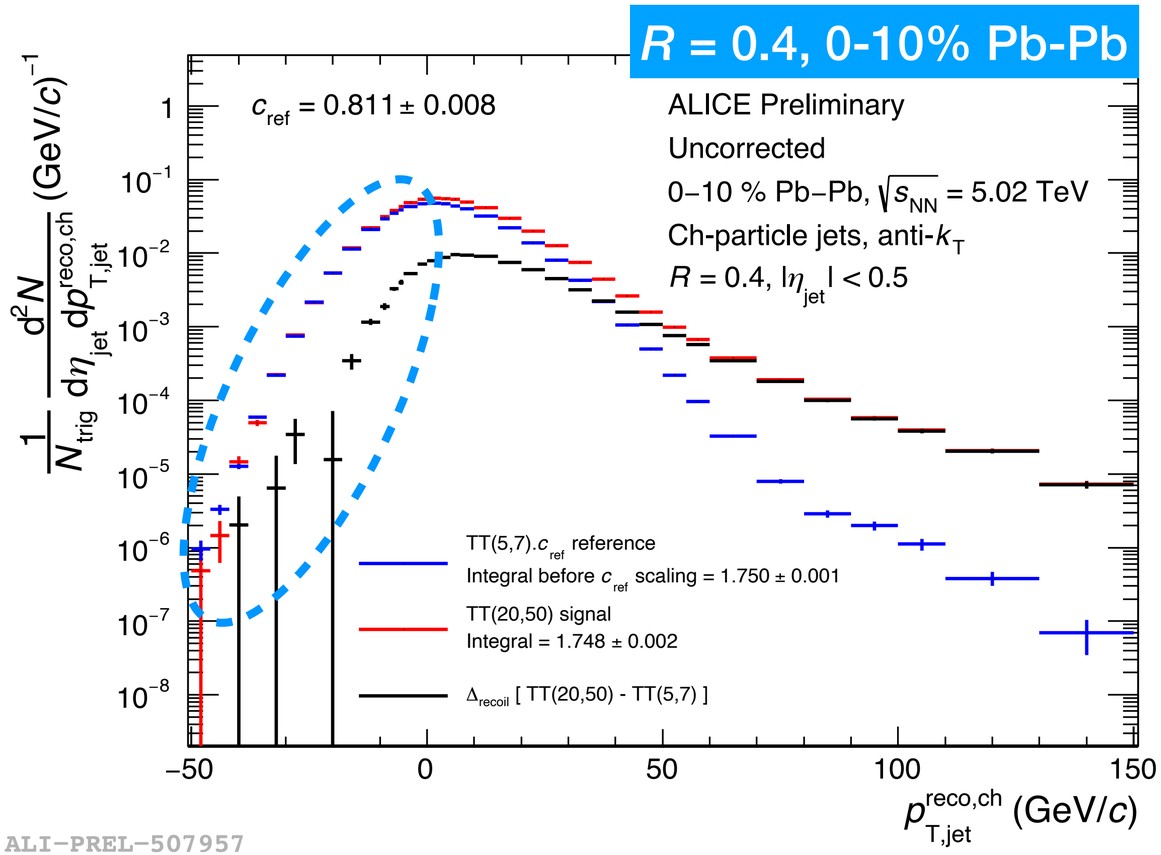
Analysis details



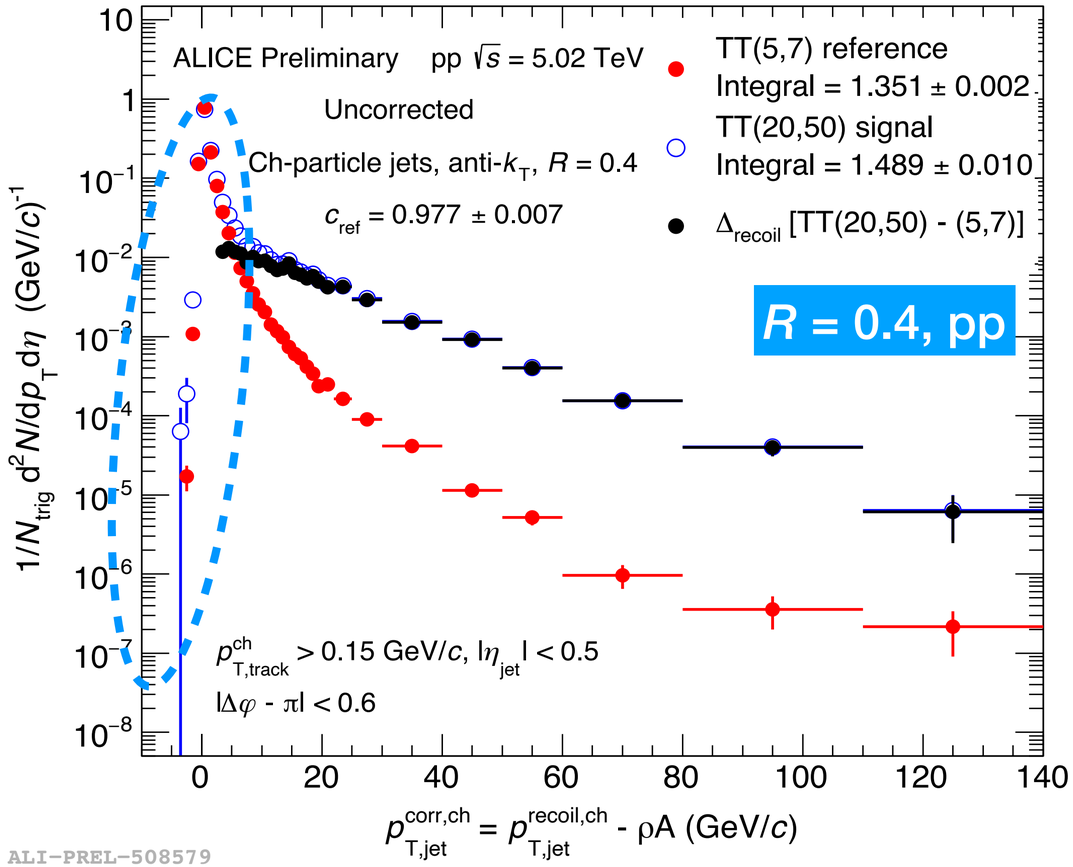


- Get **the raw p_T vs $\Delta\varphi$ 2-dimensional** distributions for two trigger track p_T intervals and Δ_{recoil}
- **Recoil jet p_T distributions** measured for two p_T trigger track classes using 2d projection

Semi-inclusive recoil jet p_{T} distributions



ALI-PREL-507957

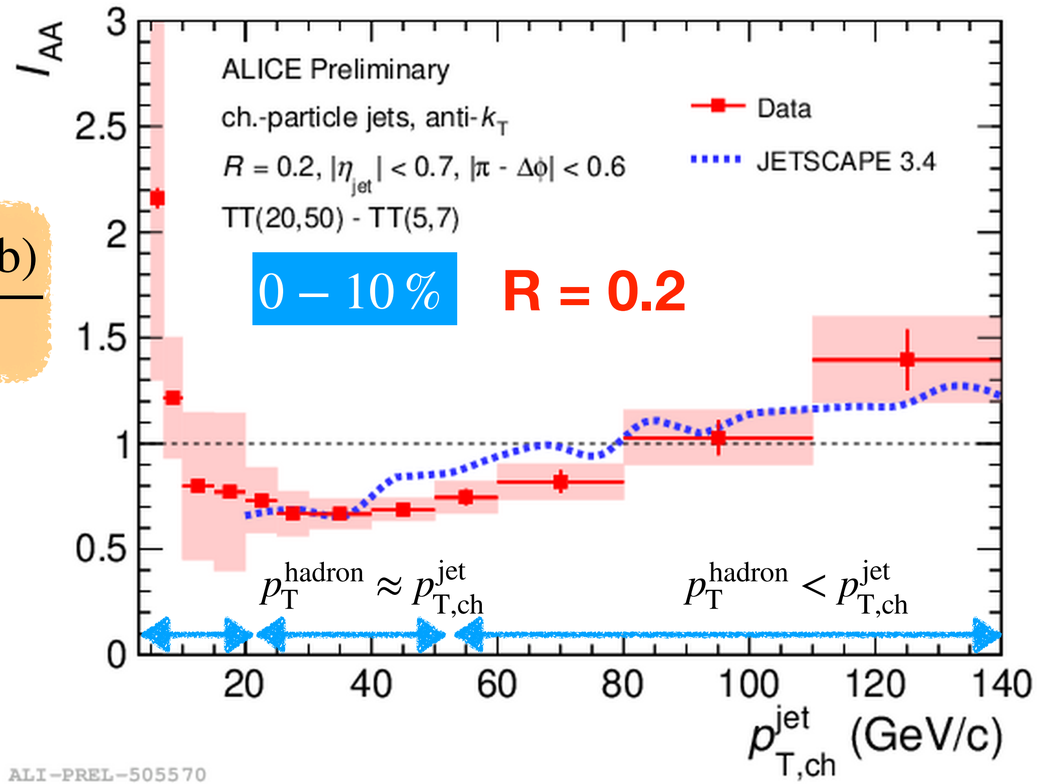


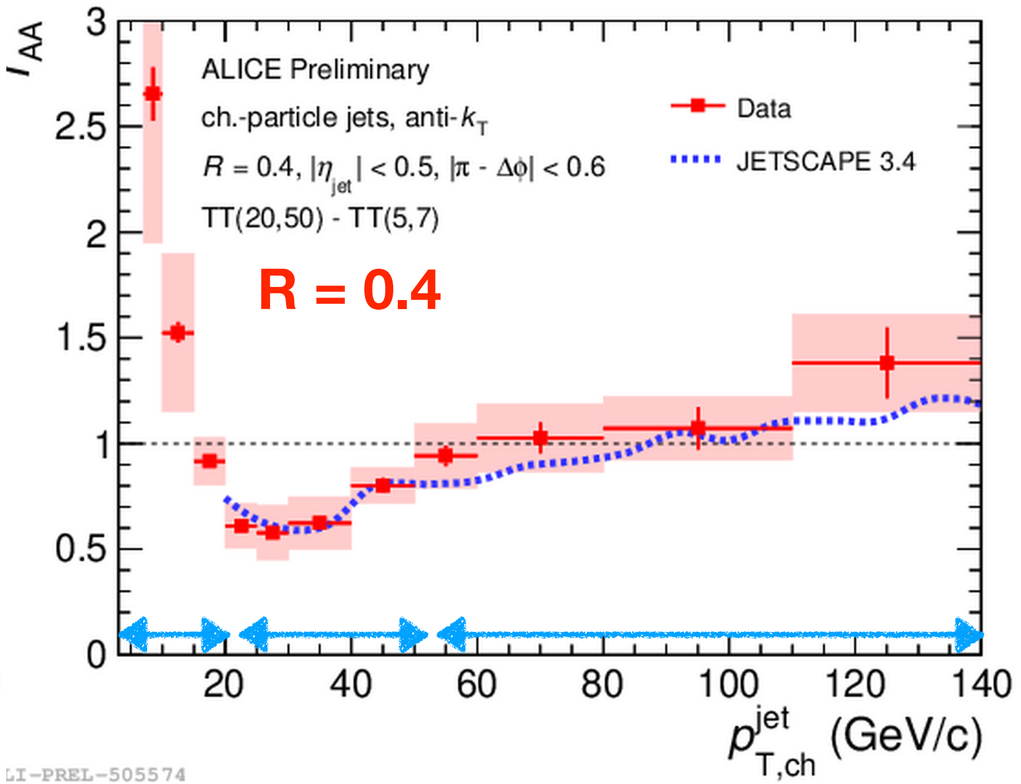
ALI-PREL-508579

- **Combinational background** uncorrelated with the trigger
  - Small background contribution in pp, much larger in Pb-Pb
  - Combinatorial background can be removed by taking the difference of the recoil jet distributions in two TT intervals

Recoil jet energy redistribution

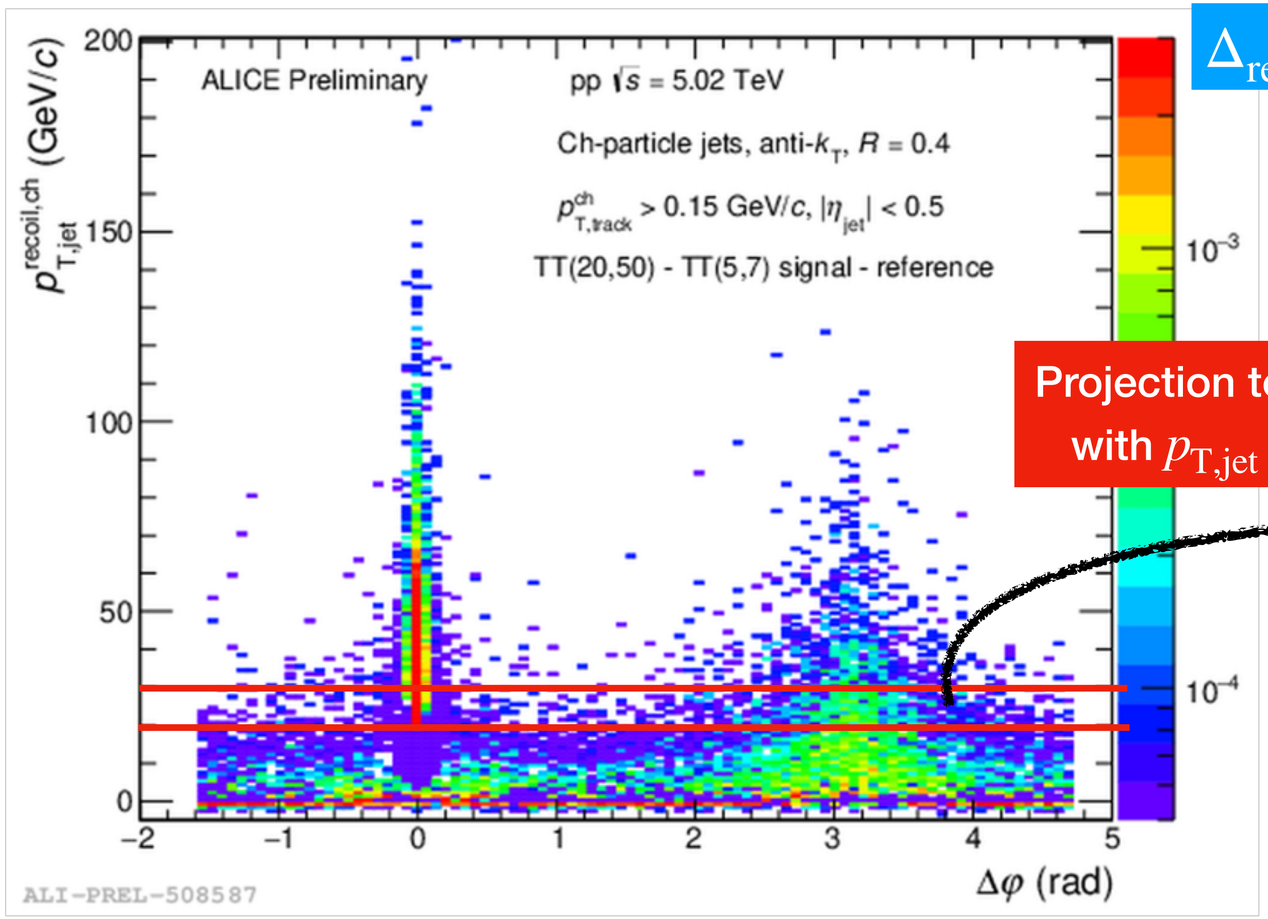
$$I_{AA} \equiv \frac{\Delta_{recoil}\ (\mathrm{Pb}-\mathrm{Pb})}{\Delta_{recoil}\ (\mathrm{pp})}$$



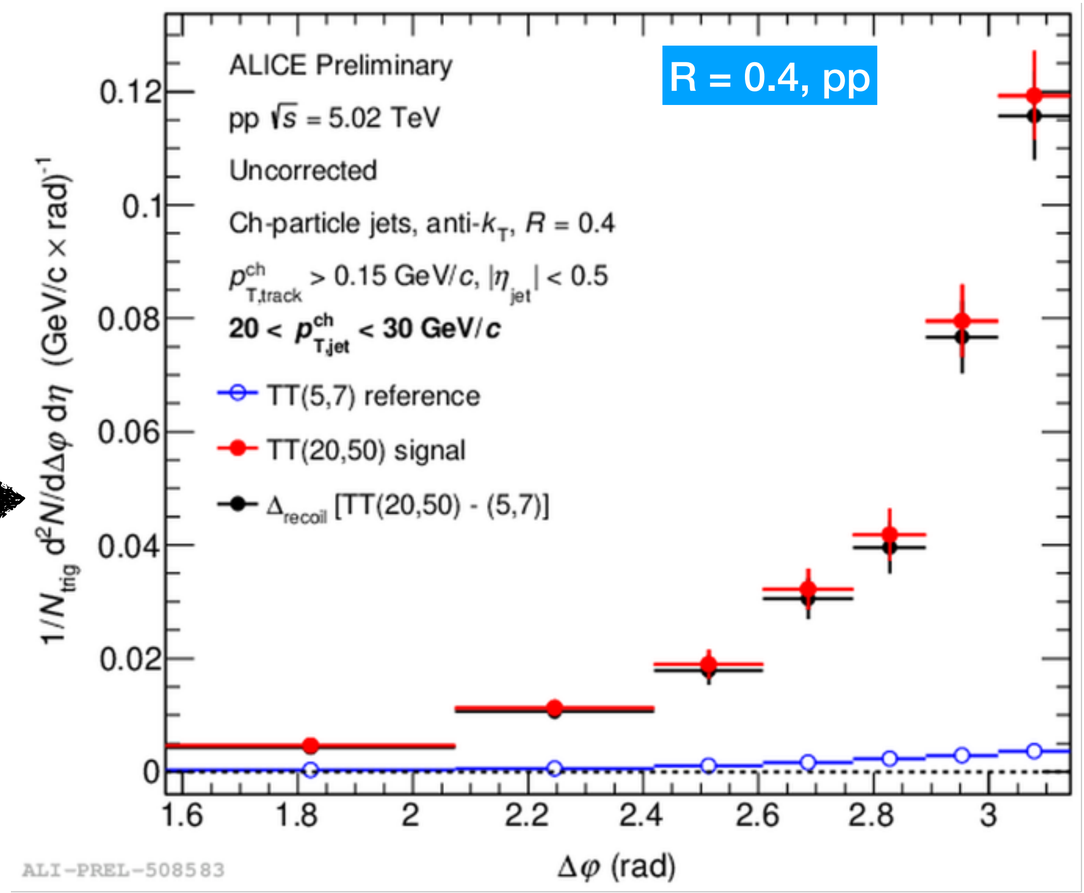


- Push the measurements of semi-inclusive recoil jet yields to very **low p_T and large R**
  - Connection to low p_T jet quenching and intra-jet broadening
- Increase of low p_T yields → hint of energy recovery in low p_T jets
- Rising trend: interplay of jet quenching effects on hadron and jet production?

Recoil jet angular distributions

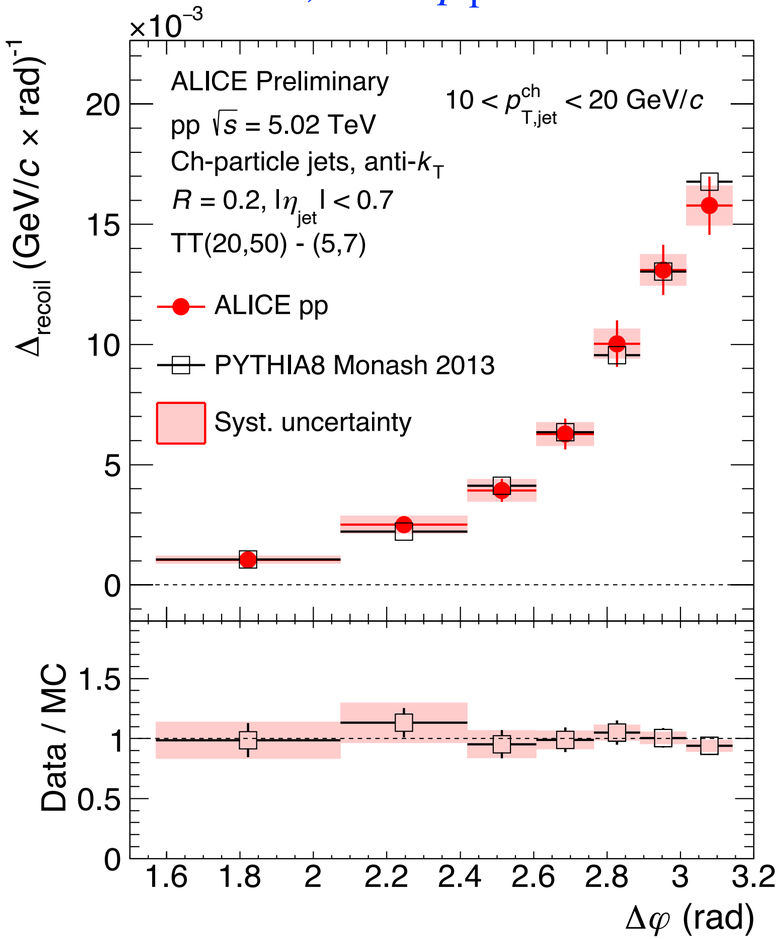


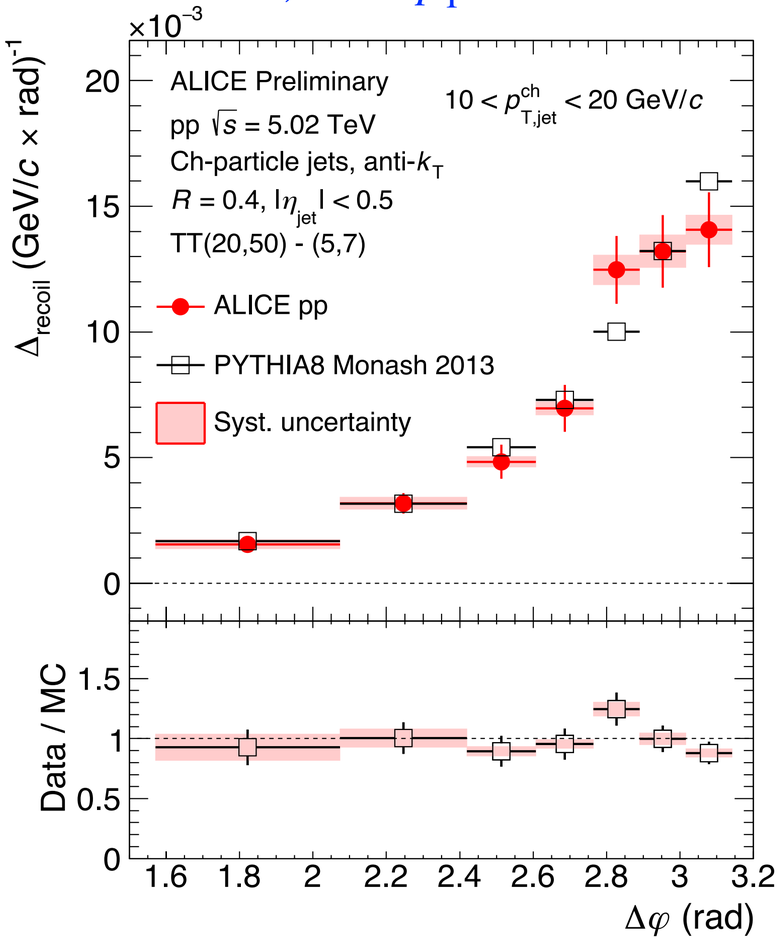
Projection to $\Delta\varphi$ with $p_{T,jet}$ cut

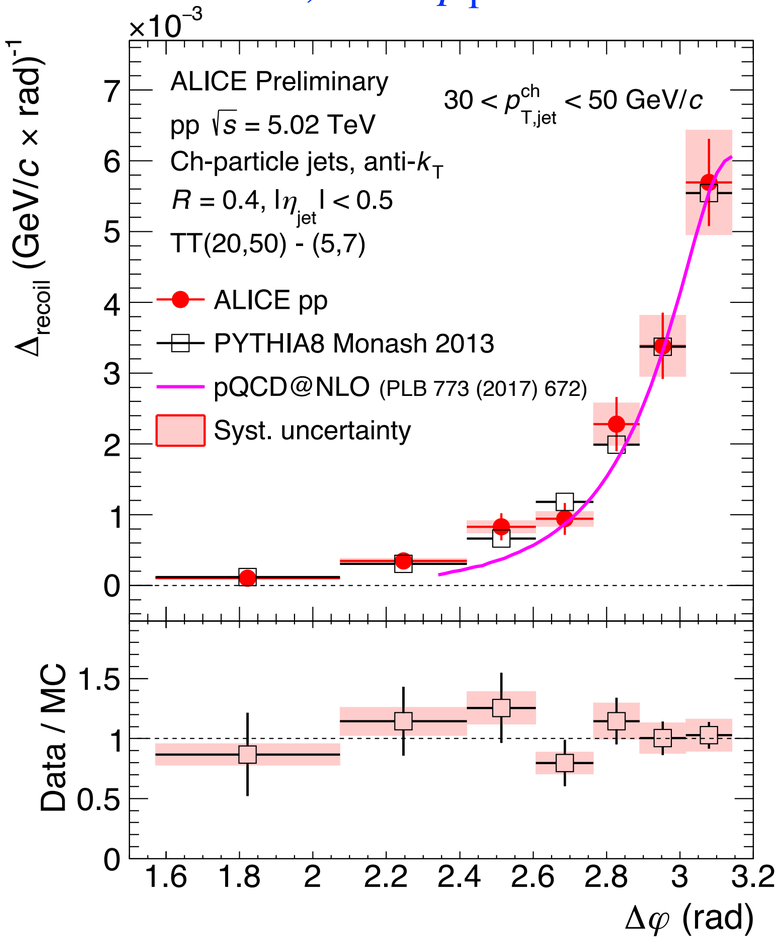


$$\Delta_{recoil}\,(\Delta\varphi) = \frac{1}{N_{trig}}\frac{d^3N_{jet}}{d\eta_{jet}\,dp_{T,jet}\,d\Delta\varphi}\bigg|_{p_T^{trig}\in TT_{Sig}} - c_{Ref}\cdot\frac{1}{N_{trig}}\frac{d^3N_{jet}}{d\eta_{jet}\,dp_{T,jet}\,d\Delta\varphi}\bigg|_{p_T^{trig}\in TT_{Ref}}$$

Recoil jet angular distributions in pp



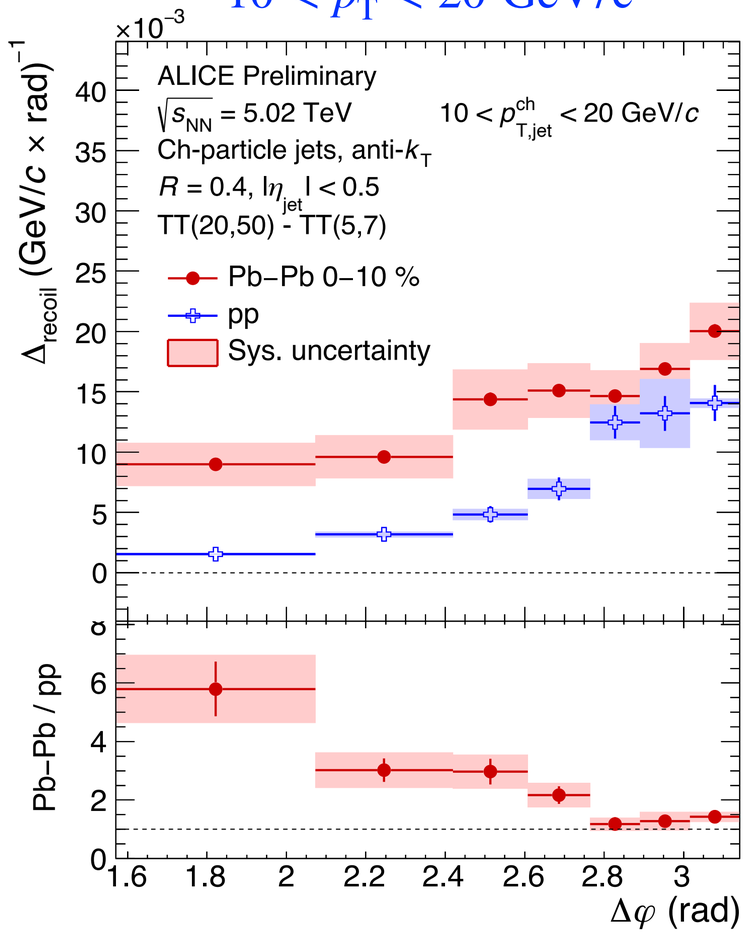


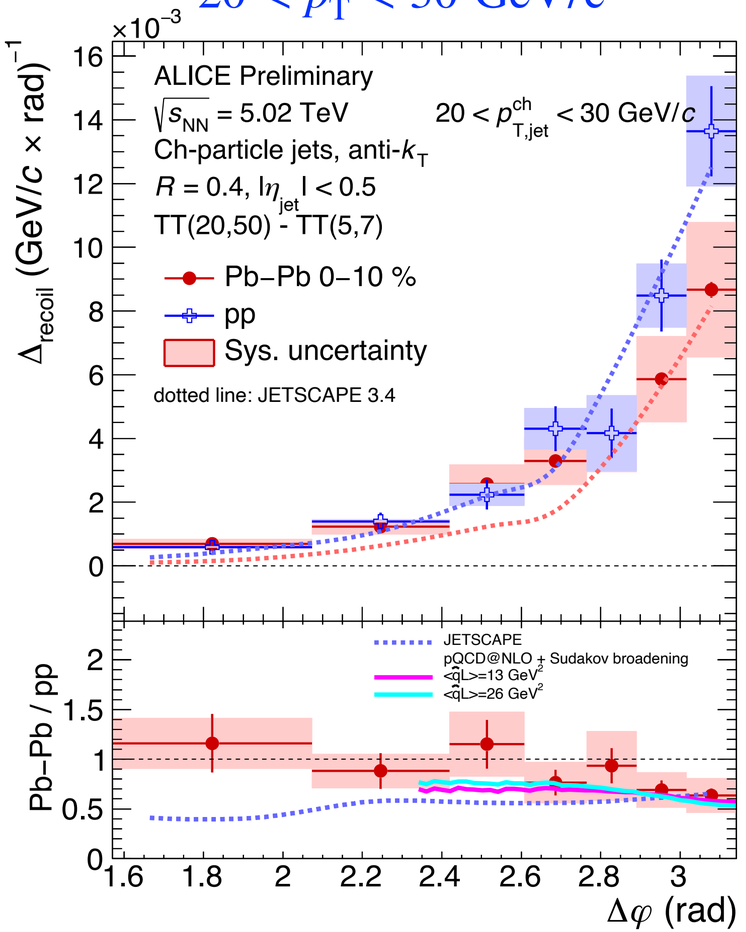


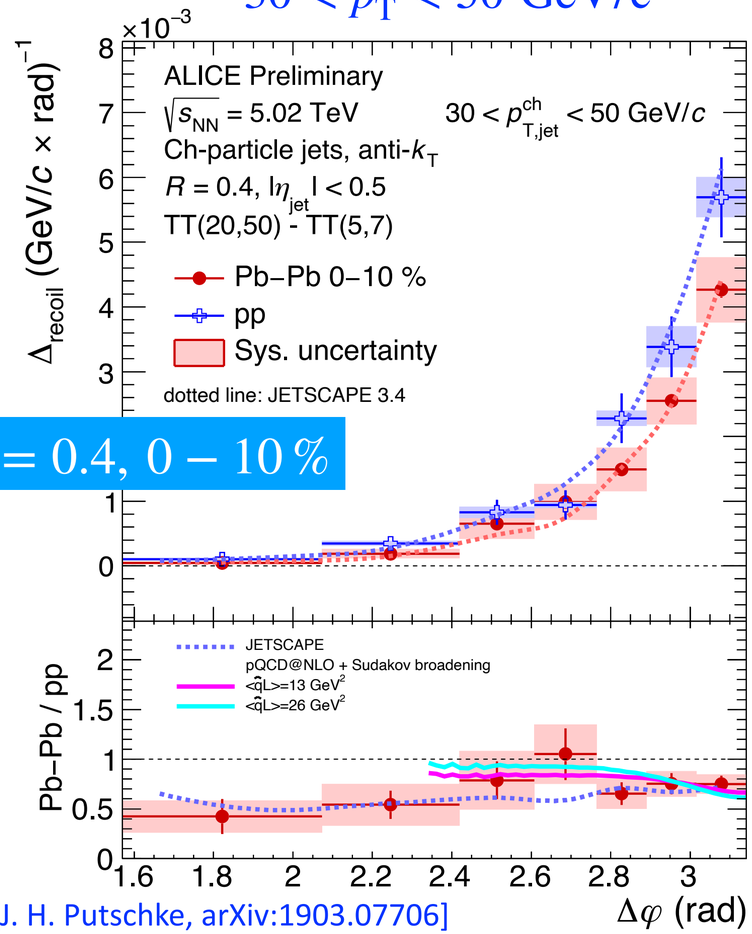
1. [L Chen, Phys. Lett. B 773 (2017) 672]

- First **measurement of the fully-corrected** hadron-jet $\Delta\varphi$ distribution in pp collisions at $\sqrt{s} = 5.02$ TeV
- Good **agreement of $\Delta\varphi$ distributions** between data and different predictions (PYTHIA 8 and pQCD prediction[1])

Recoil jet angular distributions in Pb-Pb





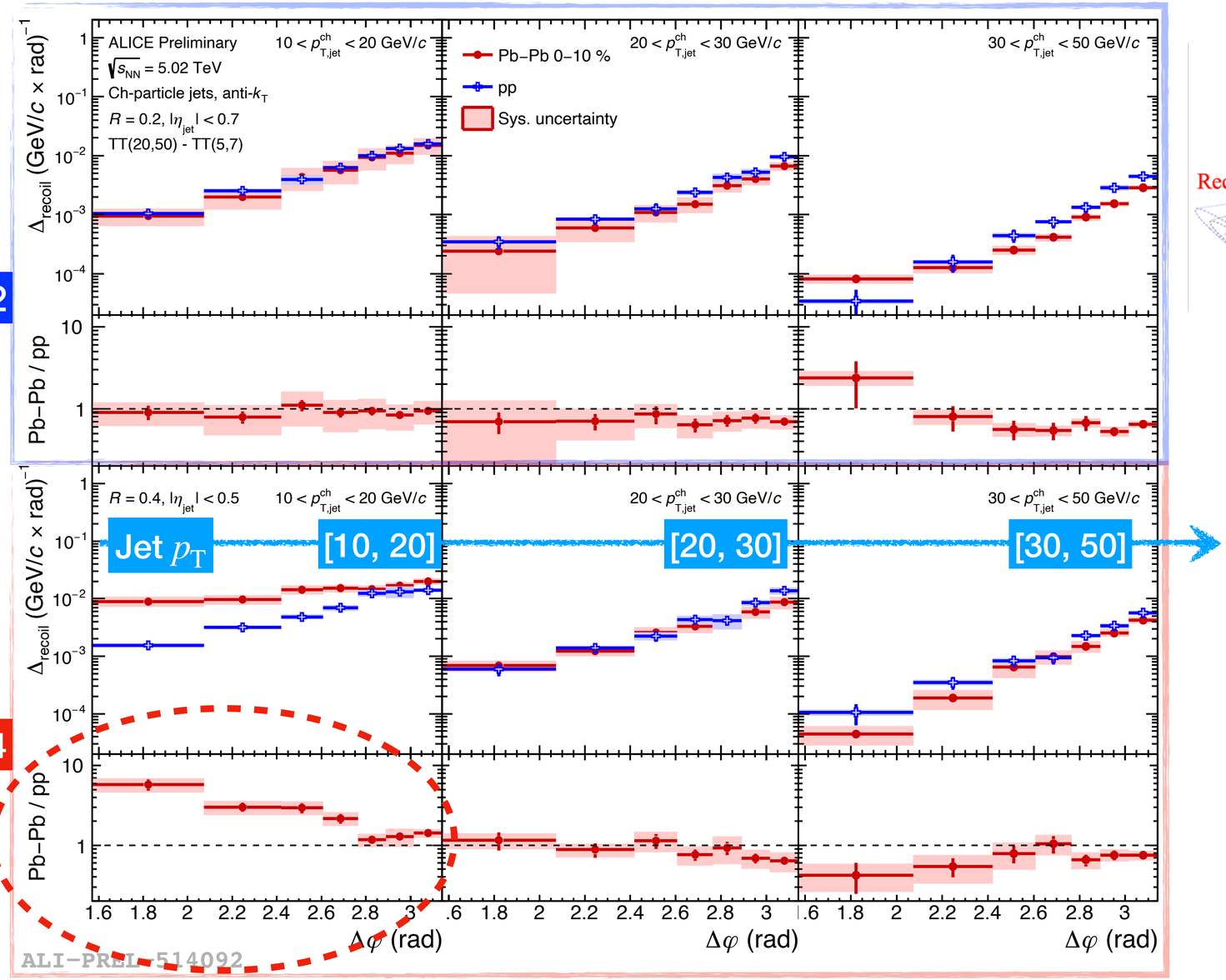


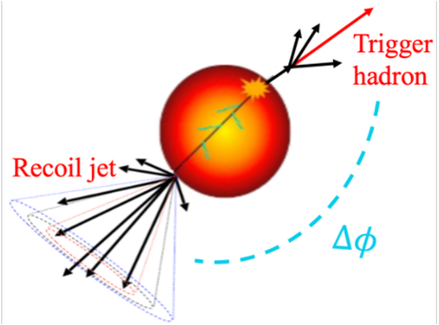
2. [J. H. Putschke, arXiv:1903.07706]

ALI-PREL-524907 ALI-PREL-524899 ALI-PREL-524903

- **Broadening** at low p_T, small medium-induced effects for mid-p_T jets. Recoil jet **yield suppressed** at higher p_T
- For **higher** p_T **jets**: calculations including medium-induced p_T broadening[1] and JETSCAPE[2] describe small-deflection region; large deflection not well-described; For **low** p_T **jets:** calculations not yet available

Recoil jet angular deflection





- Scan of azimuthal deflection study for different jet R and jet p_T
  - broadening of away side jet peak observed for very soft jets with $R = 0.4$

Summary and outlook

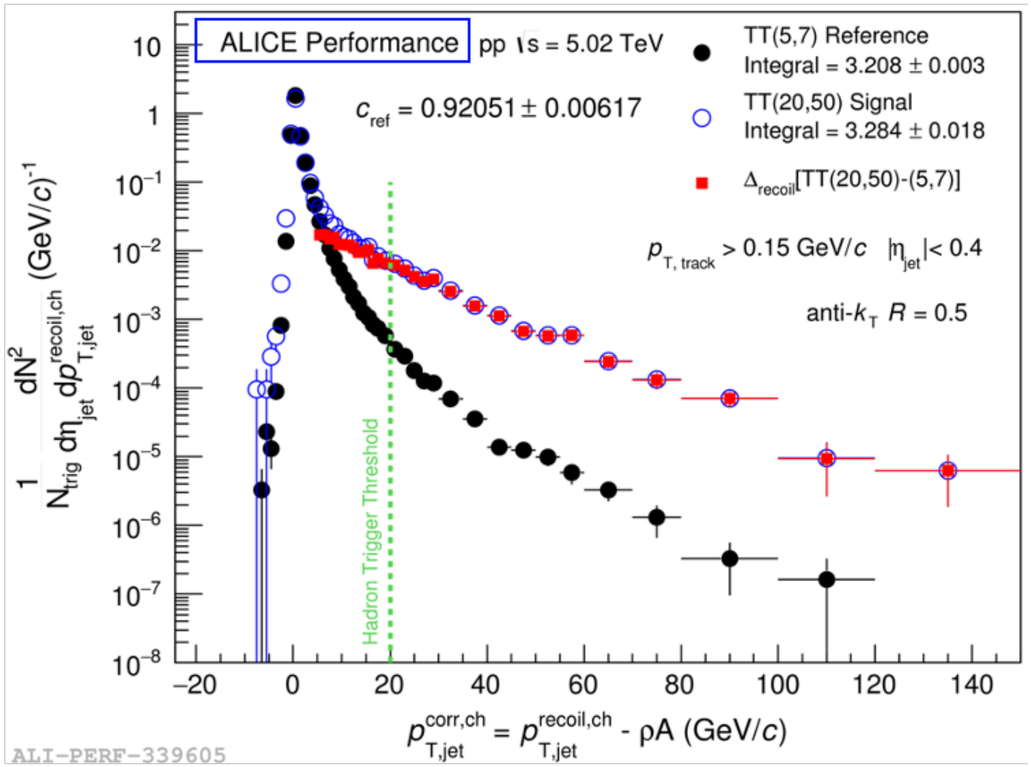
- Semi-inclusive recoil jet measurements in pp and 0 - 10% Pb-Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV
  - **Yield suppression** in high p_{T} jets, jet **energy recovery** at low p_{T}
  - First observation of **jet azimuthal broadening** for large $R = 0.4$ at low p_{T}

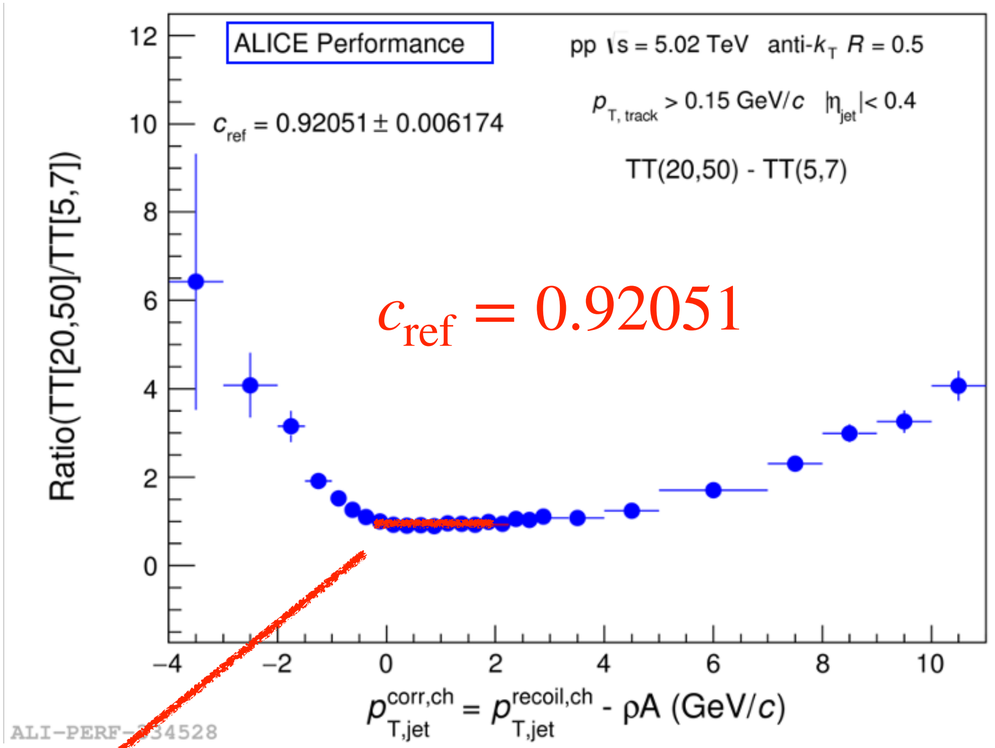
    → Possible origins: in-medium hard scattering, multiple soft scattering, jet fragments, medium response

    Consistent picture between recoil jet $\Delta\varphi$ broadening and energy recovery at low p_{T}
- Outlook
  - Looking at profile and substructure of this population to disentangle the various contributions (in-medium hard scattering, multiple soft scattering, quenched jet fragments, medium response)

Thanks for your attention

Scaling factor calculation

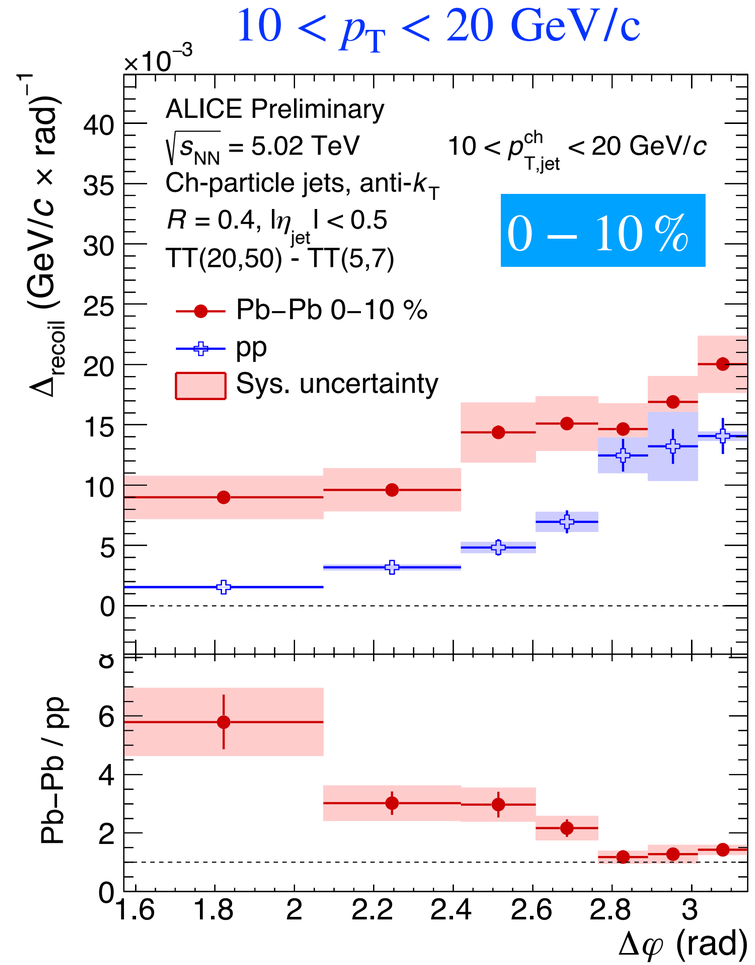


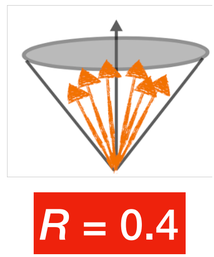


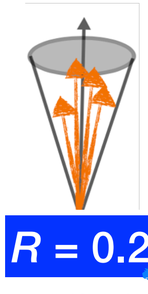
$$\Delta_{\mathrm{recoil}} = \frac{1}{N_{\mathrm{trig}}} \frac{\mathrm{d}^3 N_{\mathrm{jet}}}{\mathrm{d}\eta\, \mathrm{d}p_{\mathrm{T}}^{\mathrm{trig}}\, \mathrm{d}\Delta\varphi}\Bigg|_{p_{\mathrm{T}}^{\mathrm{trig}} \in \mathrm{TT_{Sig}}} - c_{\mathrm{Ref}} \cdot \frac{\mathrm{d}^3 N_{\mathrm{jet}}}{\mathrm{d}\eta\, \mathrm{d}p_{\mathrm{T}}^{\mathrm{trig}}\, \mathrm{d}\Delta\varphi}\Bigg|_{p_{\mathrm{T}}^{\mathrm{trig}} \in \mathrm{TT_{Ref}}}$$

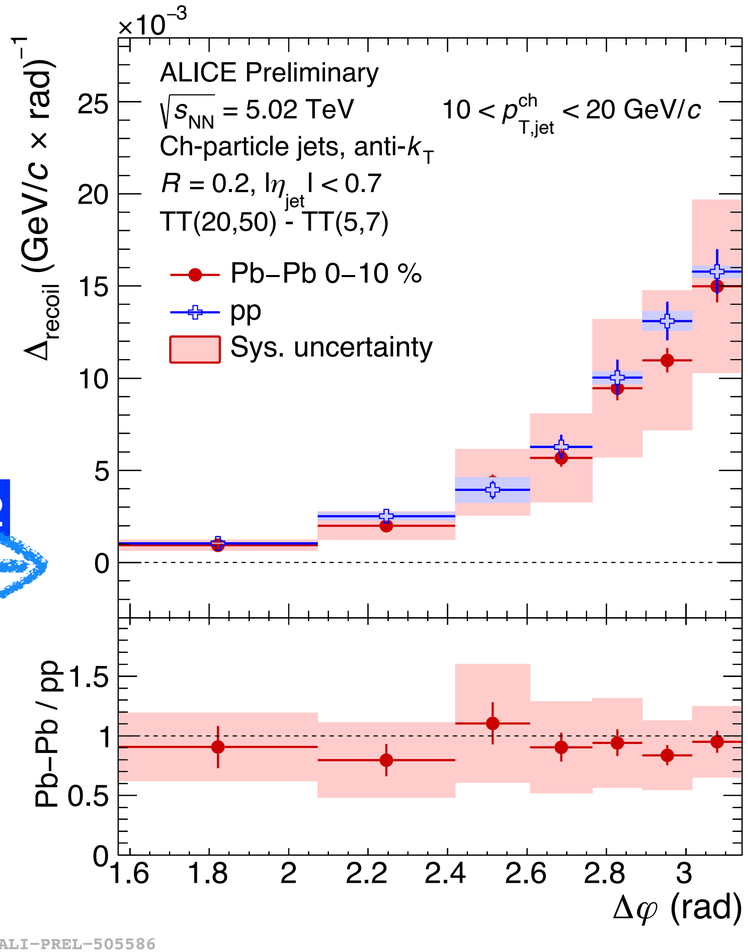
- Fitting by pol0, using the value of the parameter as the scale factor when calculate Δ_{recoil}
- Δ_{recoil} is clean of combinatorial background and corrected for detector effects using unfolding

Recoil jet angular deflection



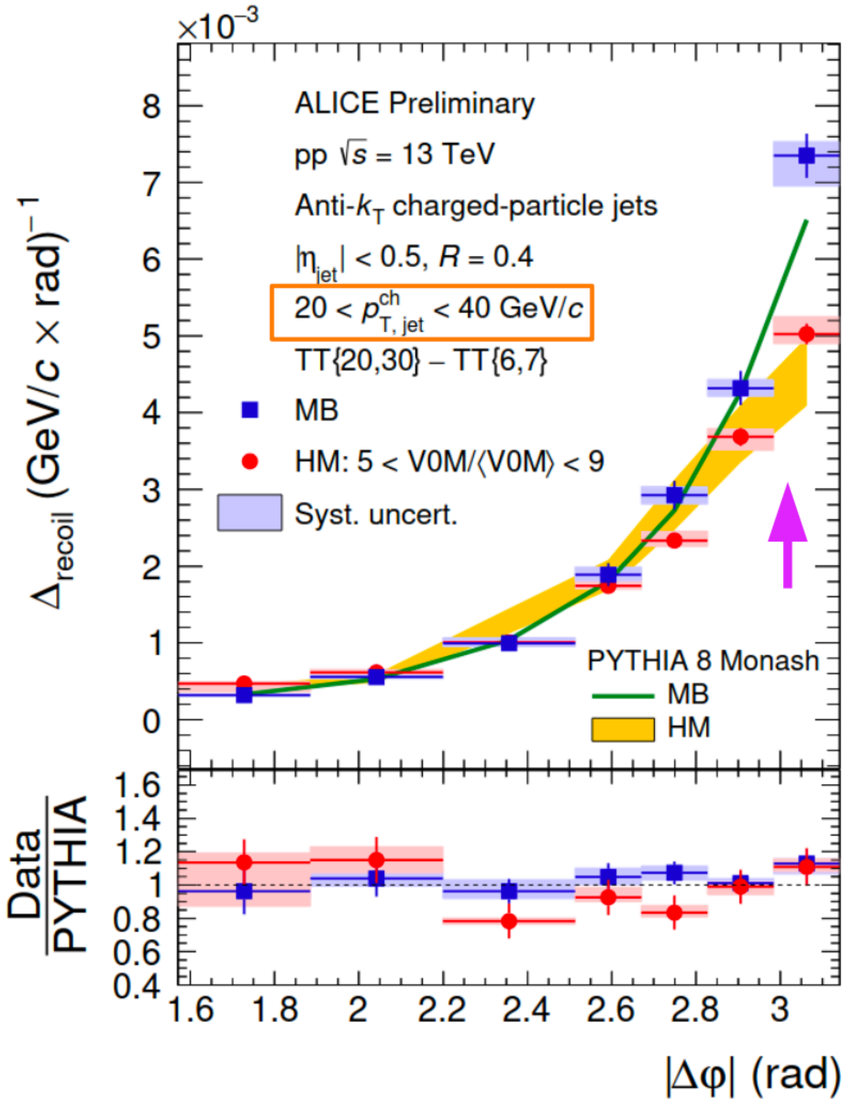


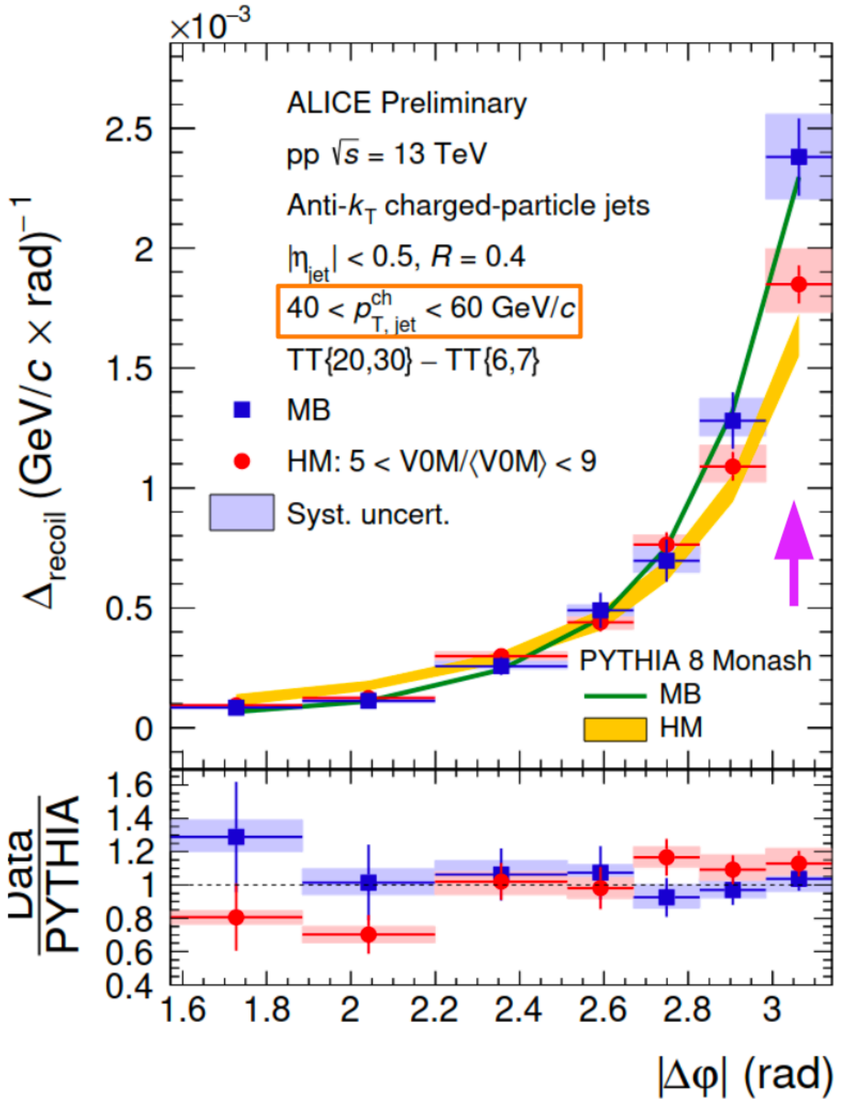




- Clear signature of azimuthal decorrelation of soft jets with large R (= 0.4)
- Negligible for small R (= 0.2) jets

Hadron-jet acoplanarity in High-Mult. pp @13 TeV





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