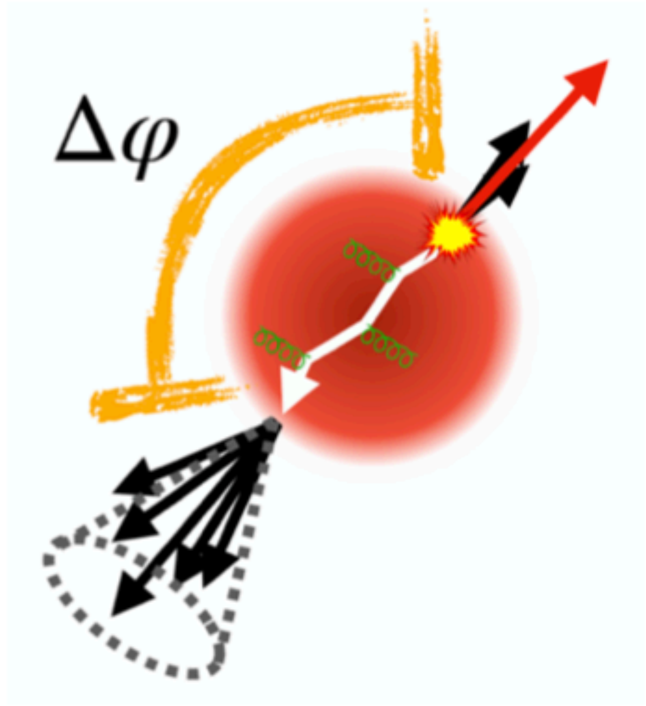
HP2024
NAGASAKI



Measurements of jet quenching using hadron-jet observables at ALICE

Daniel Jones
24th September 2024
University of Liverpool
Hard Probes 2024
On behalf of ALICE

UNIVERSITY OF LIVERPOOL

ALICE

Motivation

- **We want to explore jet quenching across the full LHC phase space**
  - Specifically low-p_T and large R - probe medium response effects
- **Uncorrelated background is huge in these regions**
  - We cannot discriminate between signal and uncorrelated background on a per event basis
- **Apply statistical, data driven-approach for background yield suppression: semi-inclusive approach**
  - Cleanly select events based on a high-p_T trigger
  - Count recoil jets

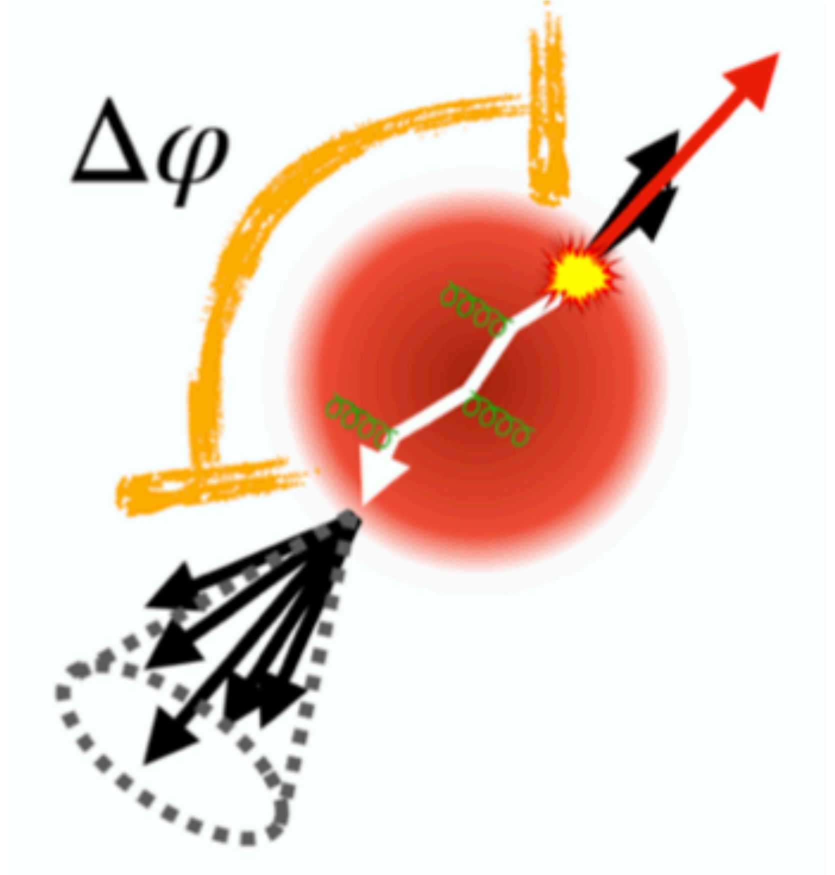
ALICE Run 1: JHEP 09 (2015) 170
STAR: Phys.Rev.C 96 (2017) 2, 024905

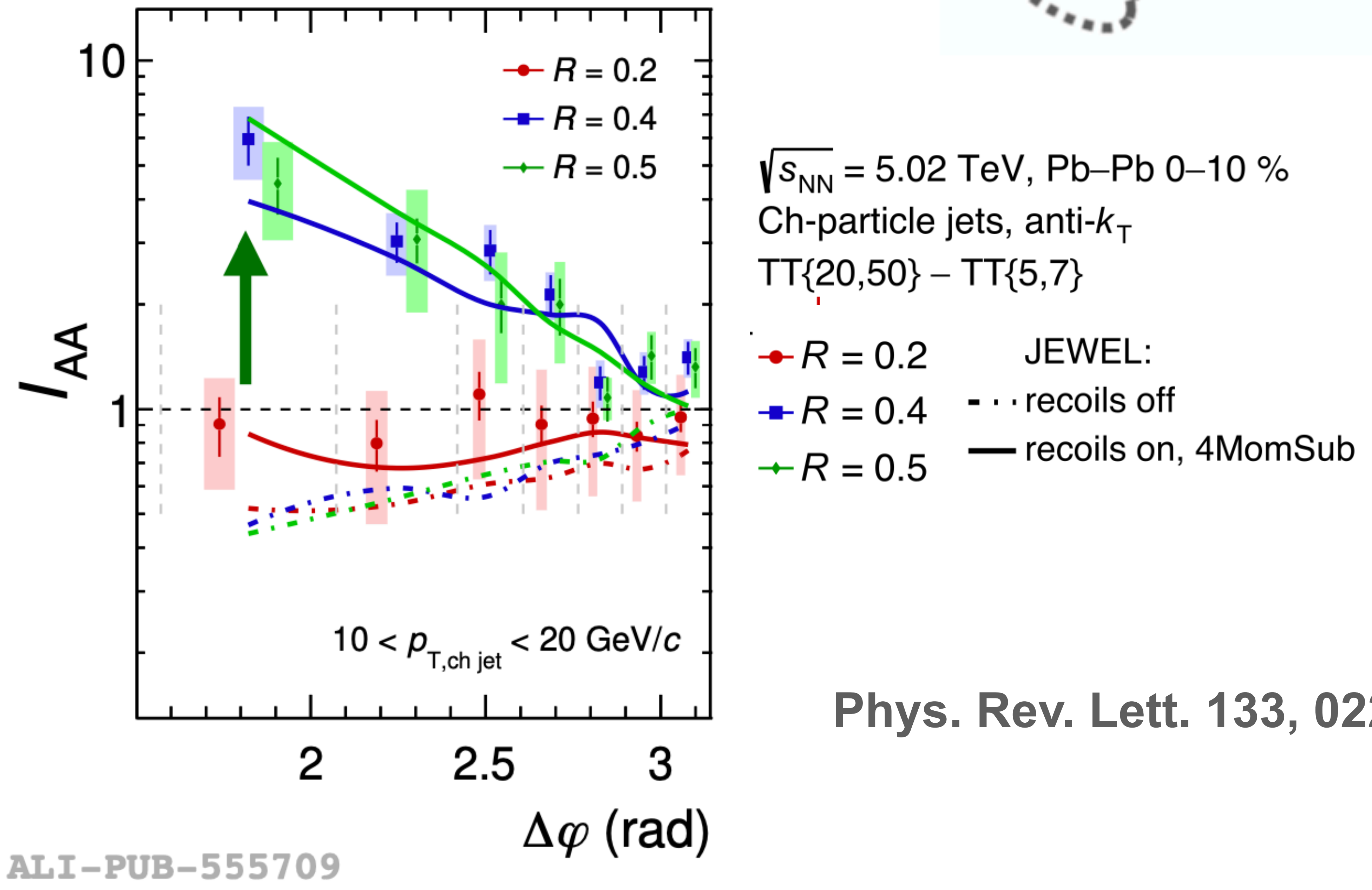
See Aimeric's talk (24/09, 15:00): statistical approach for inclusive jets!

Semi-inclusive hadron-jet measurements

- **Measure the yield of charged particle jets recoiling from a high-p_{T} hadron as a function of:**
  - The jet transverse momentum ($p_{\mathrm{T,jet}}$) Energy loss
  - The trigger-jet opening angle ($\Delta\phi$) Azimuthal broadening
- **In pp:**
  - Test pQCD predictions
  - Investigate the limits of QGP formation
  - Reference for Pb-Pb
- **This talk:**
  - **Run 2, 13 TeV pp High Multiplicity (HM)**
  - **Run 3, 13.6 TeV pp (Preliminary)**

Pb-Pb!





Phys. Rev. Lett. 133, 022301

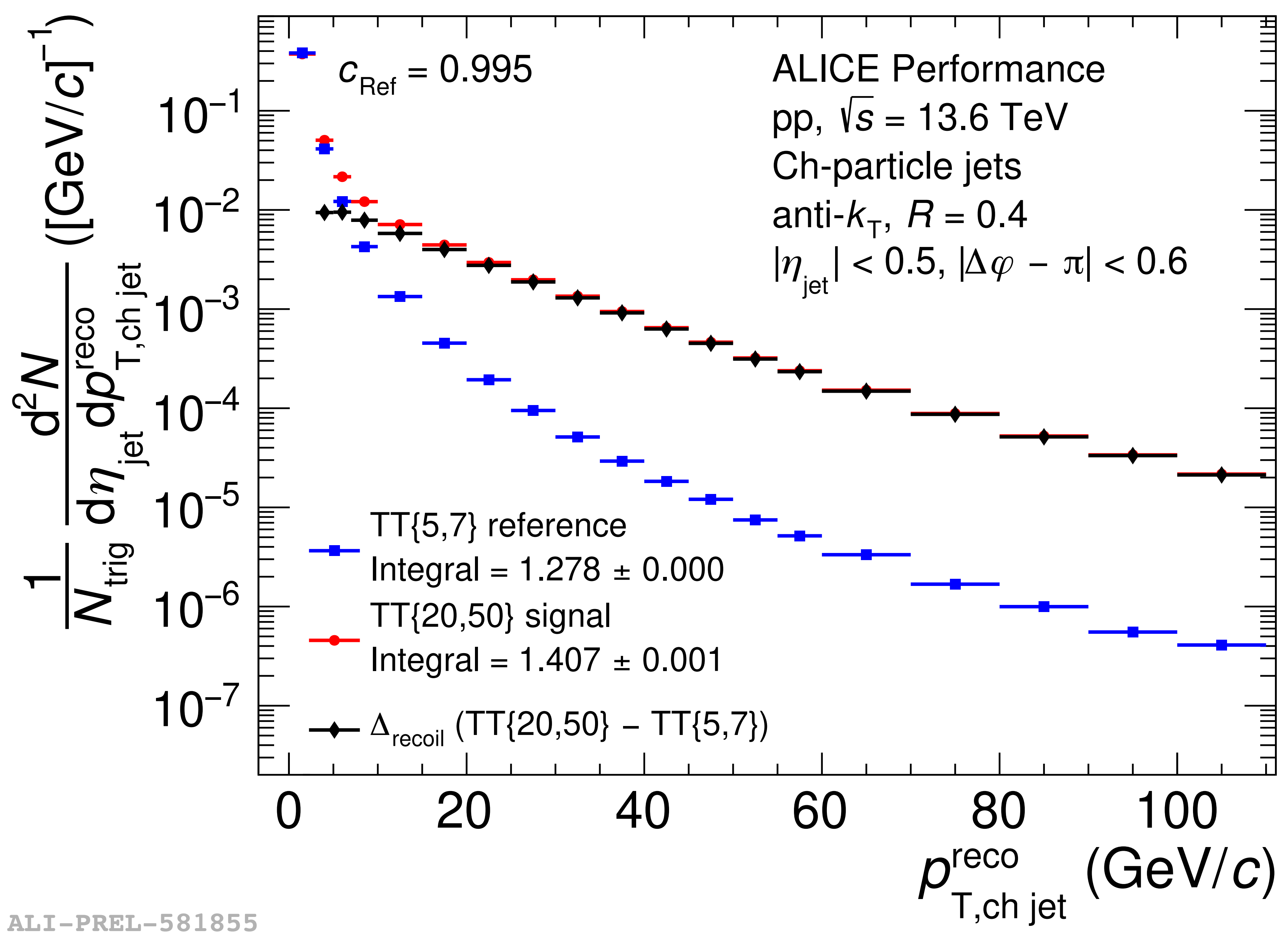
Δ_{recoil} - approach to uncorrelated background yield subtraction

- **Take the difference between two semi inclusive, trigger normalised jet yields: signal and reference**

$$\Delta_{\text{recoil}}(p_{\text{T,jet}}, \Delta\varphi) = \frac{1}{N_{\text{trig}}} \frac{\mathrm{d}^2 N_{\text{jet}}}{\mathrm{d}p_{\text{T,jet}}\mathrm{d}\Delta\varphi}\bigg|_{p_{\text{T}}^{\text{trig}} \in \text{TT}_{\text{sig}}} - c_{\text{Ref}} \times \frac{1}{N_{\text{trig}}} \frac{\mathrm{d}^2 N_{\text{jet}}}{\mathrm{d}p_{\text{T,jet}}\mathrm{d}\Delta\varphi}\bigg|_{p_{\text{T}}^{\text{trig}} \in \text{TT}_{\text{ref}}}$$

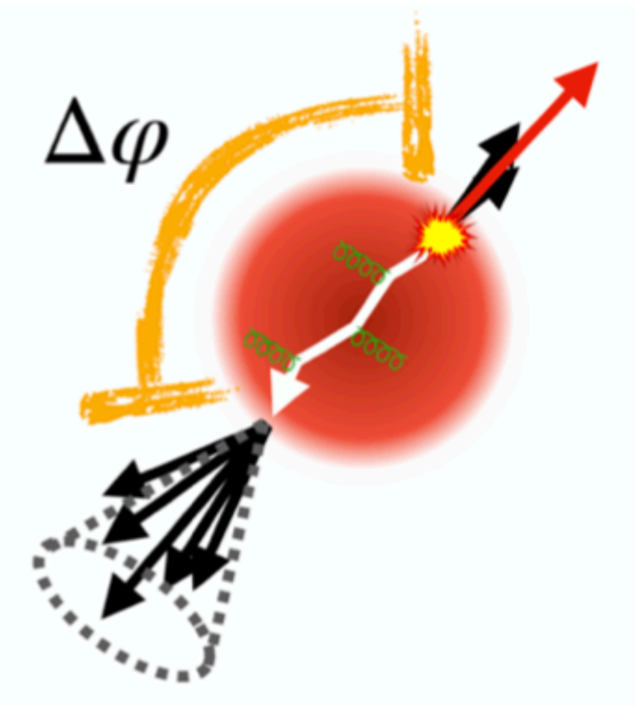
- **Advantages:**
  - Data-driven subtraction of uncorrelated background yield
  - Perturbatively calculable

c_{ref}: normalisation factor - derived from data

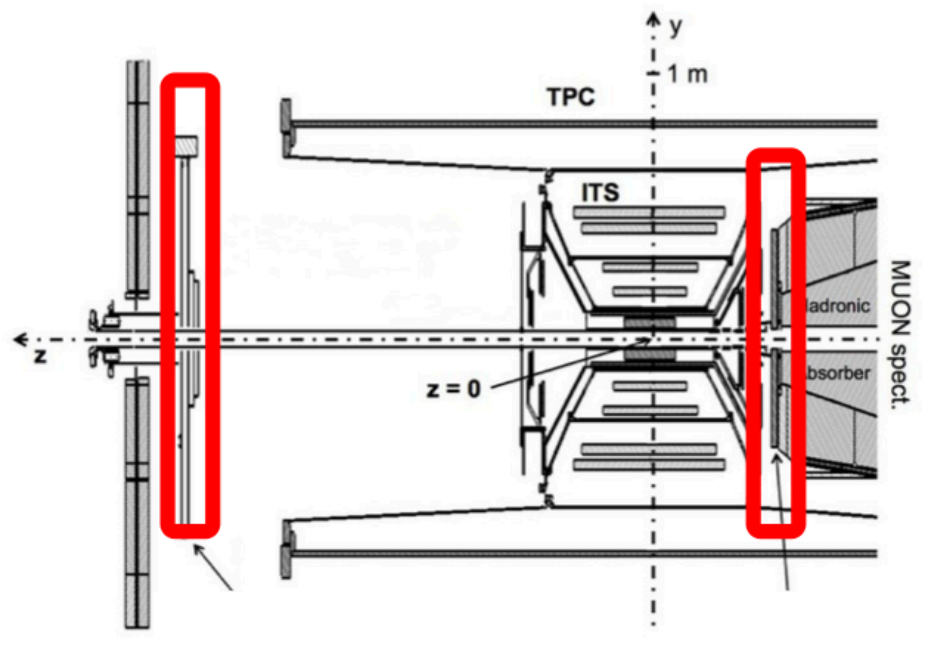


What is the limit of QGP formation?

- **We know a QGP forms in heavy-ion collisions. What about small collision systems?**
  - p-Pb?
  - High multiplicity pp? ← QGP like effects seen in HM small systems
- **Look for the key signatures of QGP formation:**
  - Strangeness enhancement
  - Collective flow (Biao Zhang 23/09, Yiping Wang 24/09)
  - Jet quenching ←
    - Suppression of back to back correlations
    - Enhancement at large acoplanarity



Event selection



2.8 < η < 5.1

-3.7 < η < -1.7

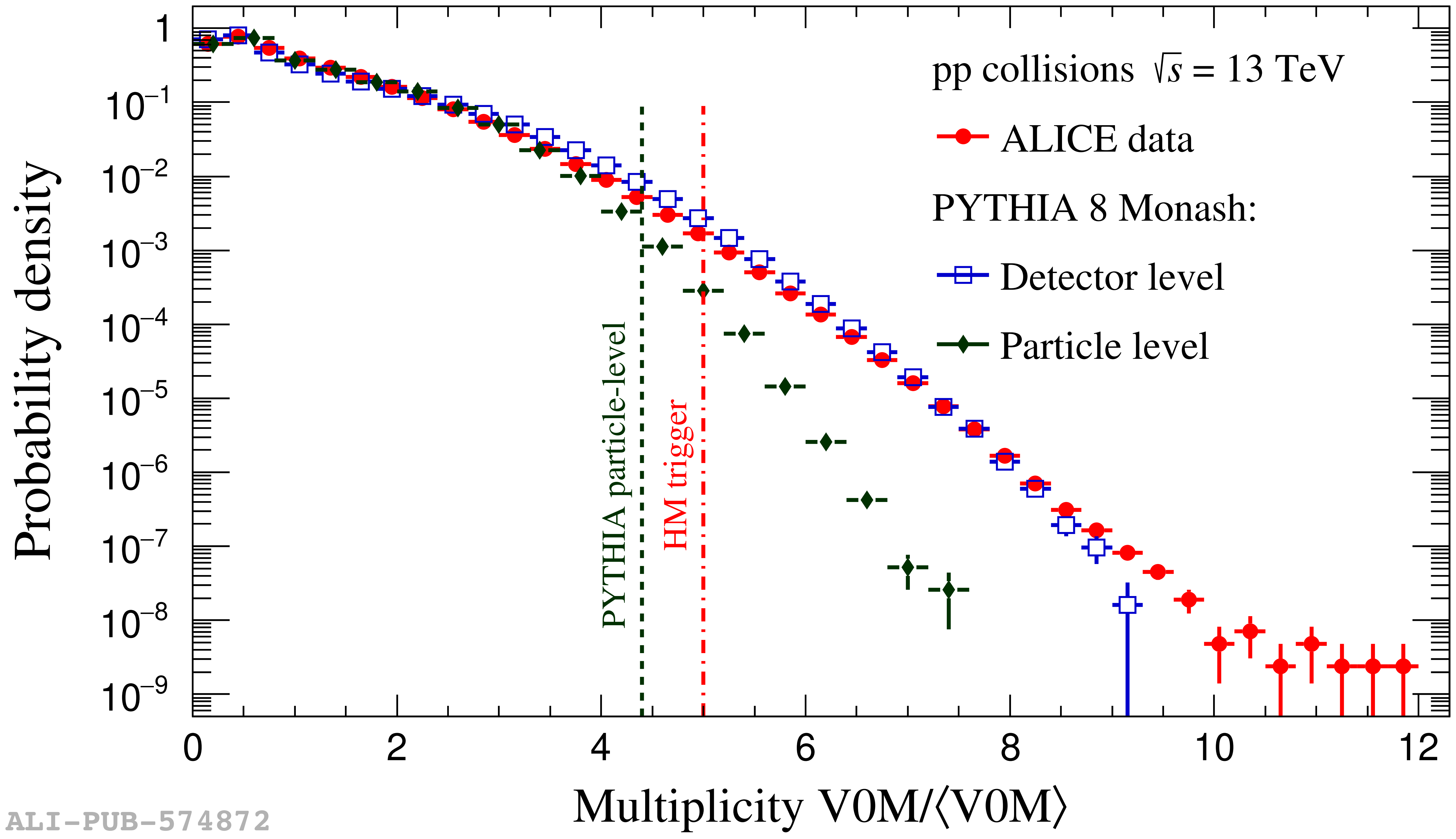
New paper!

JHEP 05 (2024) 229

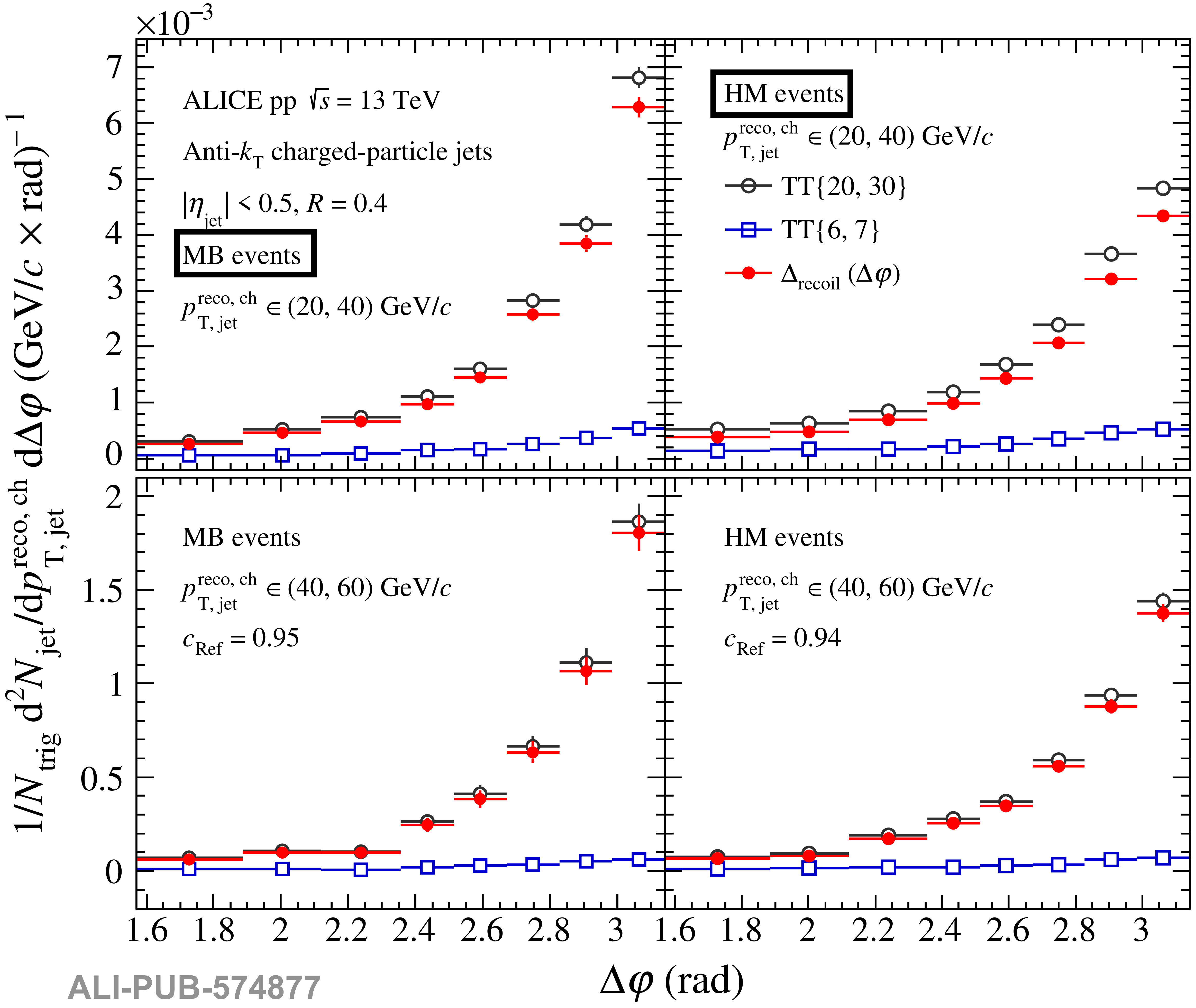
- **Event selections:**
  - **MB**: in-time coincidence of V0A and V0C
  - **HM**: $V0M/\langle V0M\rangle > 5$

$V0M = V0A + V0C$

$\langle V0M\rangle$ = Mean MB multiplicity



Raw distributions



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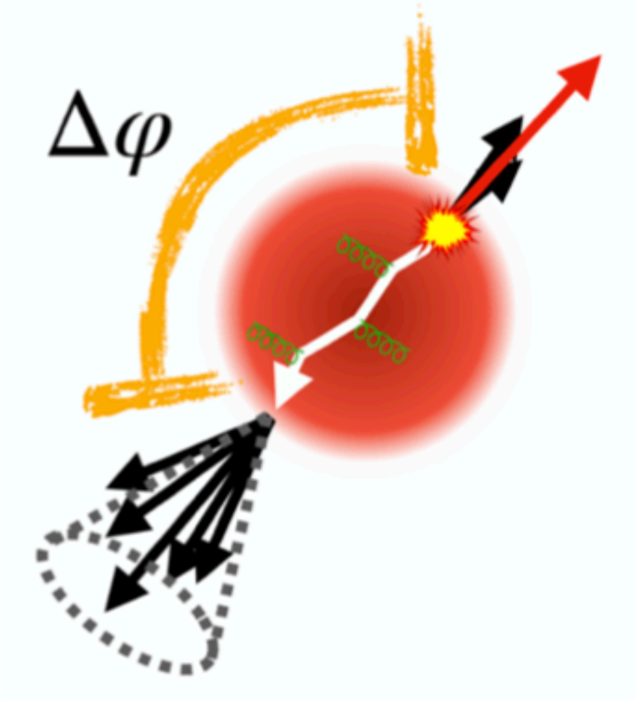


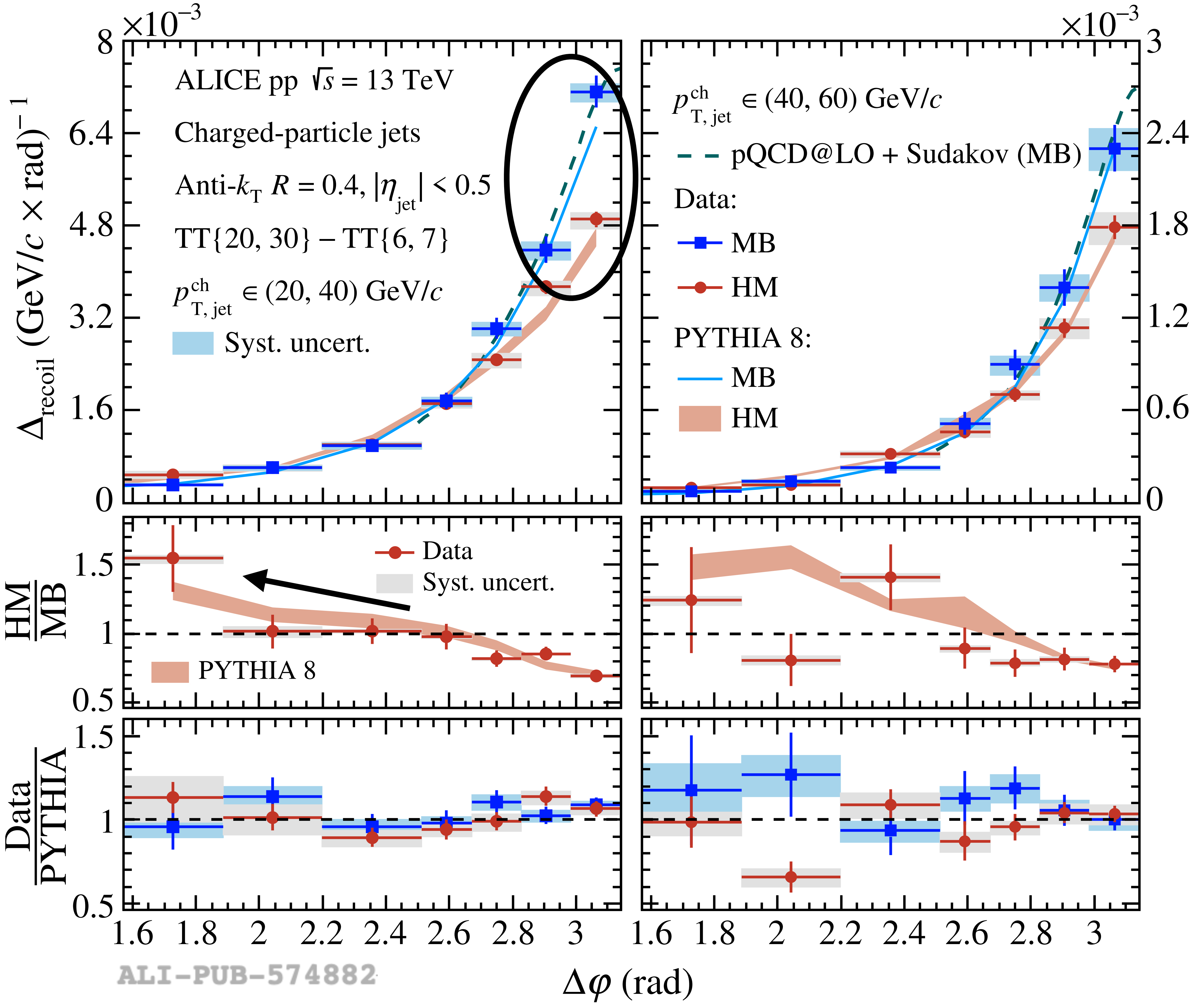
New paper!

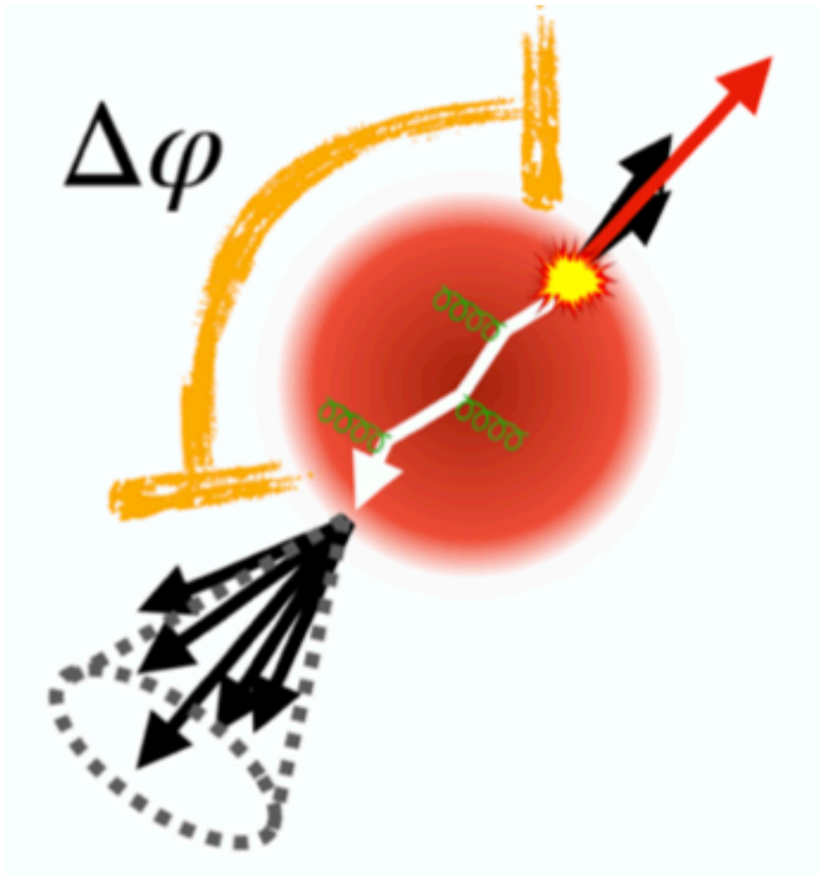
$$\Delta_{\mathrm{recoil}}(p_{\mathrm{T,jet}},\Delta\varphi) = \frac{1}{N_{\mathrm{trig}}}\frac{\mathrm{d}^2N_{\mathrm{jet}}}{\mathrm{d}p_{\mathrm{T,jet}}\mathrm{d}\Delta\varphi}\bigg|_{p_{\mathrm{T}}^{\mathrm{trig}}\in\mathrm{TT_{sig}}} - c_{\mathrm{Ref}} \times \frac{1}{N_{\mathrm{trig}}}\frac{\mathrm{d}^2N_{\mathrm{jet}}}{\mathrm{d}p_{\mathrm{T,jet}}\mathrm{d}\Delta\varphi}\bigg|_{p_{\mathrm{T}}^{\mathrm{trig}}\in\mathrm{TT_{ref}}}$$

- **Δ_{recoil} corrects uncorrelated background yield**
- **Distribution then corrected for p_{T} smearing due to detector effects and residual background (unfolding)**

Fully corrected HM/MB Δ_{recoil} ratio

New paper!





- **Possible azimuthal broadening in HM w.r.t MB**
  - Suppression of back to back correlations
  - Jet quenching like signal?
- **Results reproduced by PYTHIA**

PYTHIA does **NOT** model Jet Quenching!

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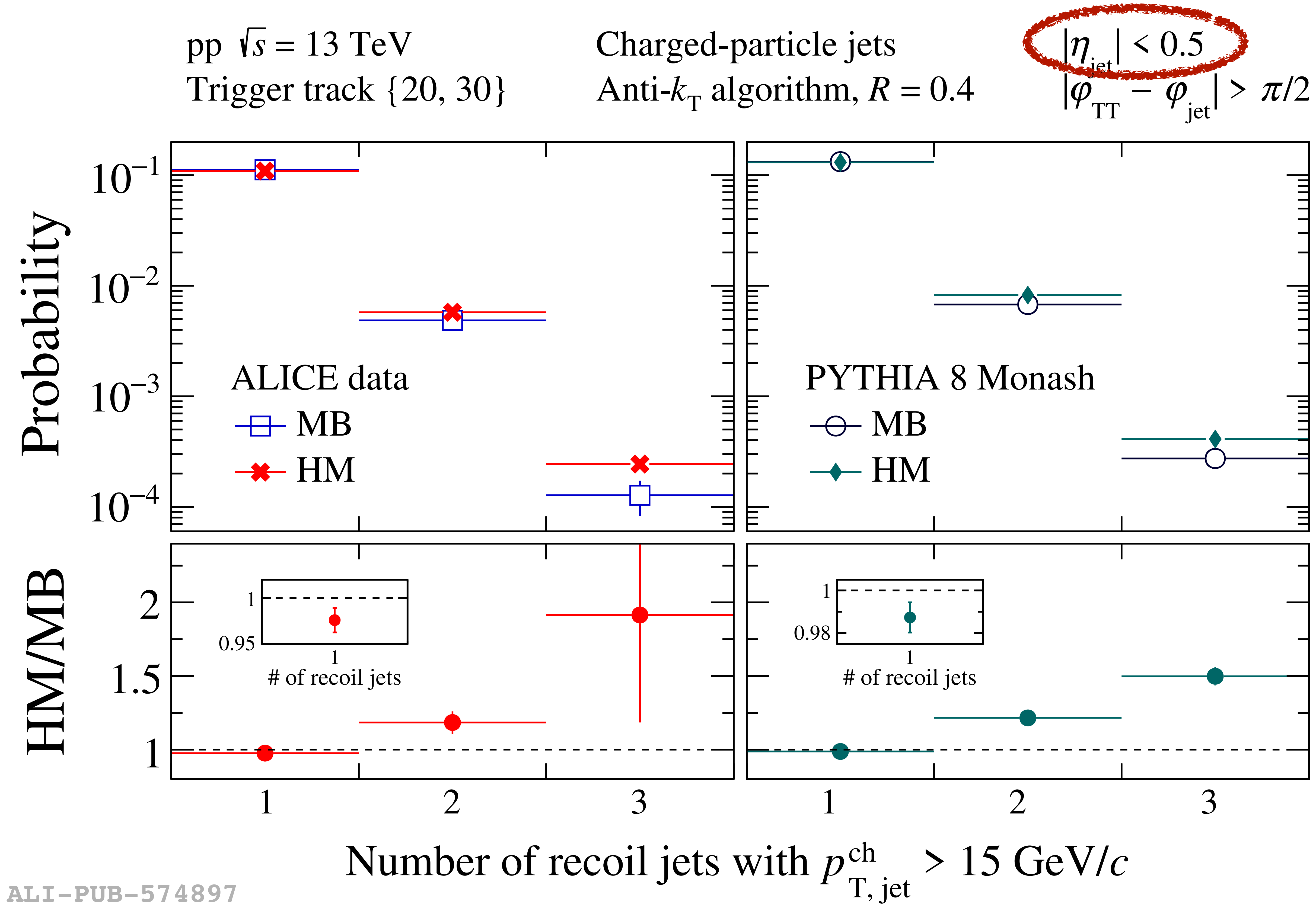
Event selections - bias

New paper!

- **Bias towards multi-jet final states**
  - Seen in both data and PYTHIA
  - Explains the jet quenching like effects
- **Bias is generic - must be considered in all Jet Quenching searches in small systems**



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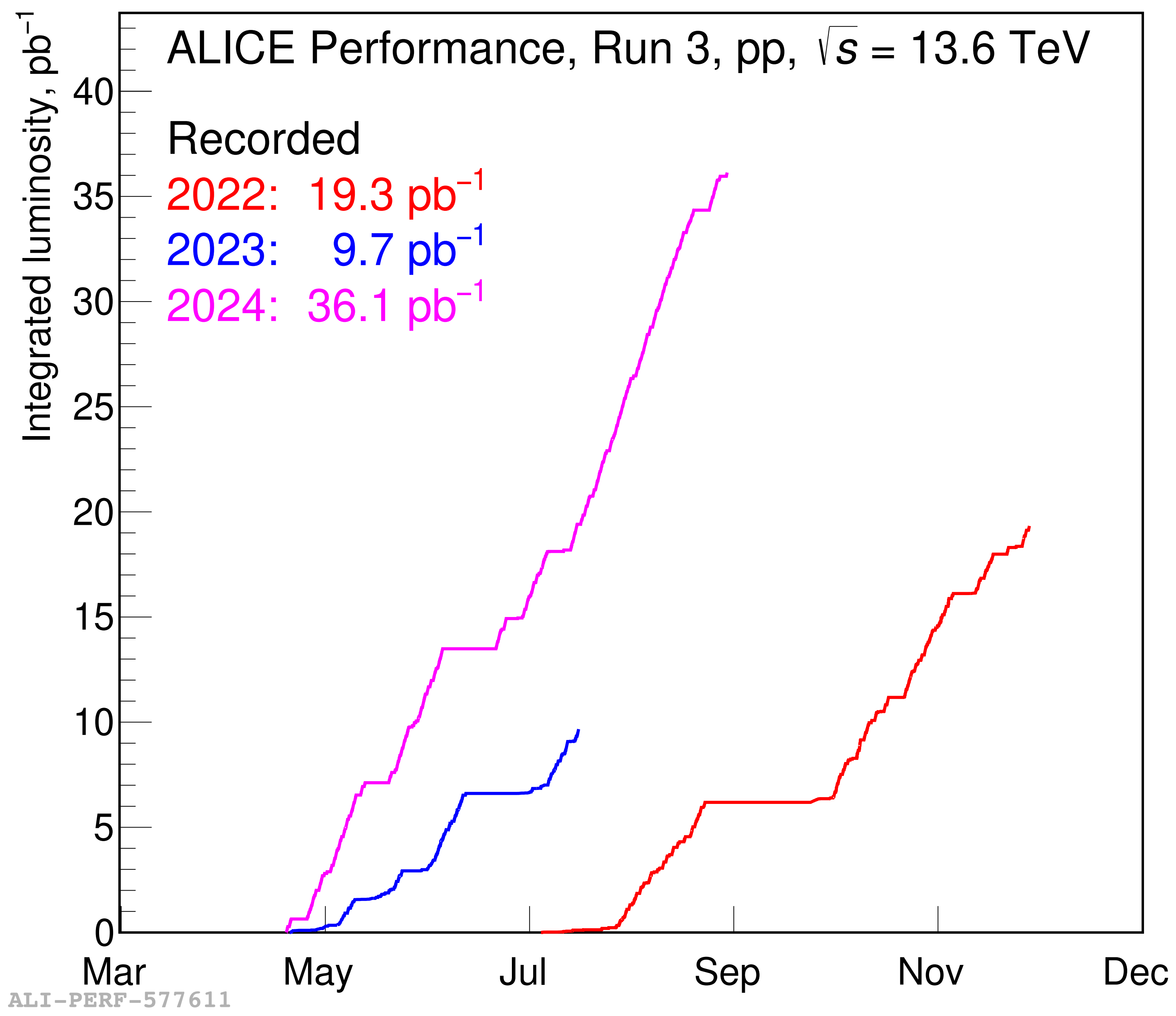
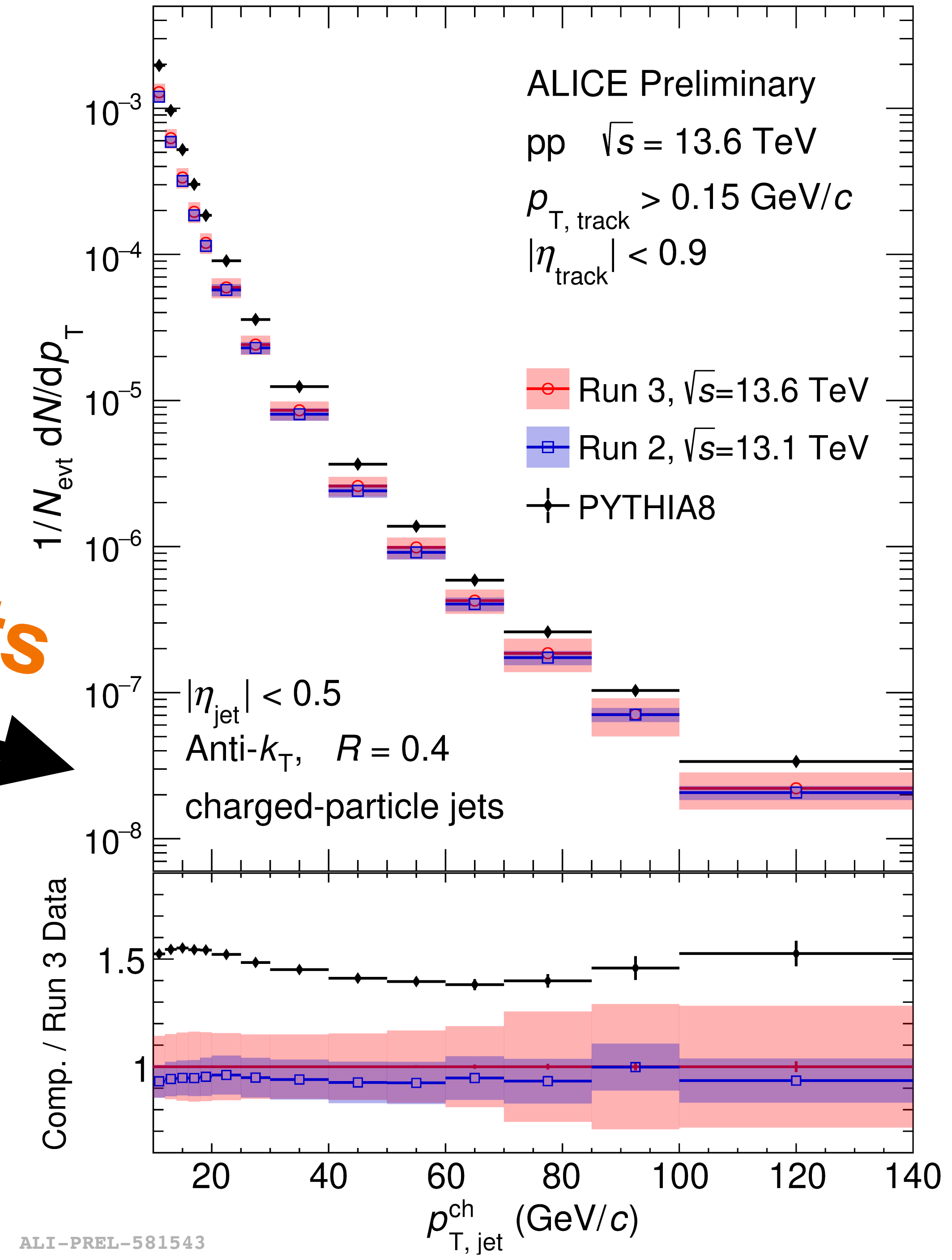
Run 3: Whats new?

- **Run 3 of the LHC began in July 2022:**
  - Increased collision energy - 13.6 TeV
  - Improved luminosity - already surpassed Run 2 luminosity in first few weeks in Run 3!
- **First Run 3 jet based preliminary results shown at Hard Probes 2024**
- **We analyse 2022 pp data:**
  - 49.2B events (1.04B in 5.02 TeV Run 2)!

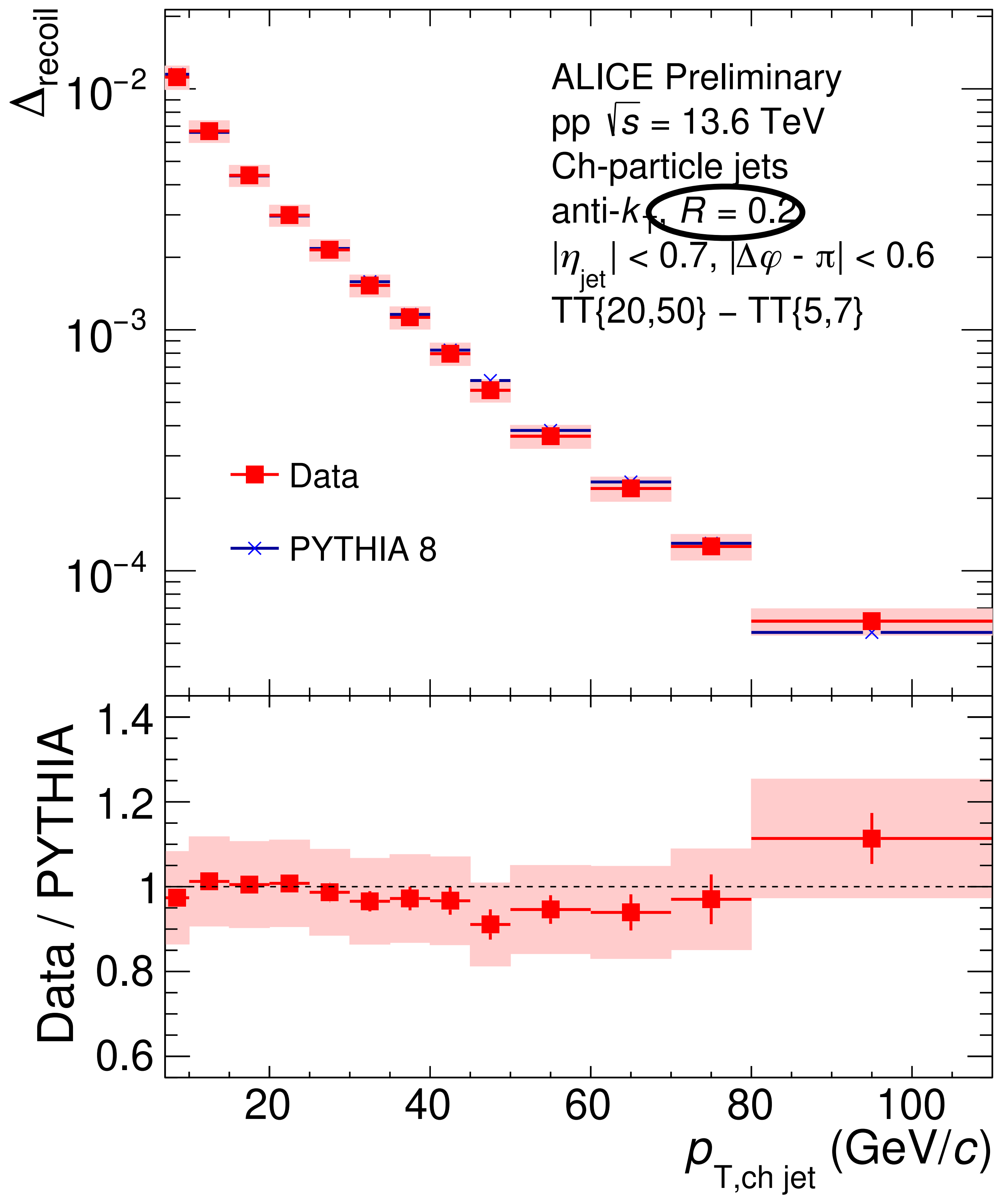


Inclusive jets



See poster by Joonsuk Bae

Fully corrected semi-inclusive hadron+jet yield



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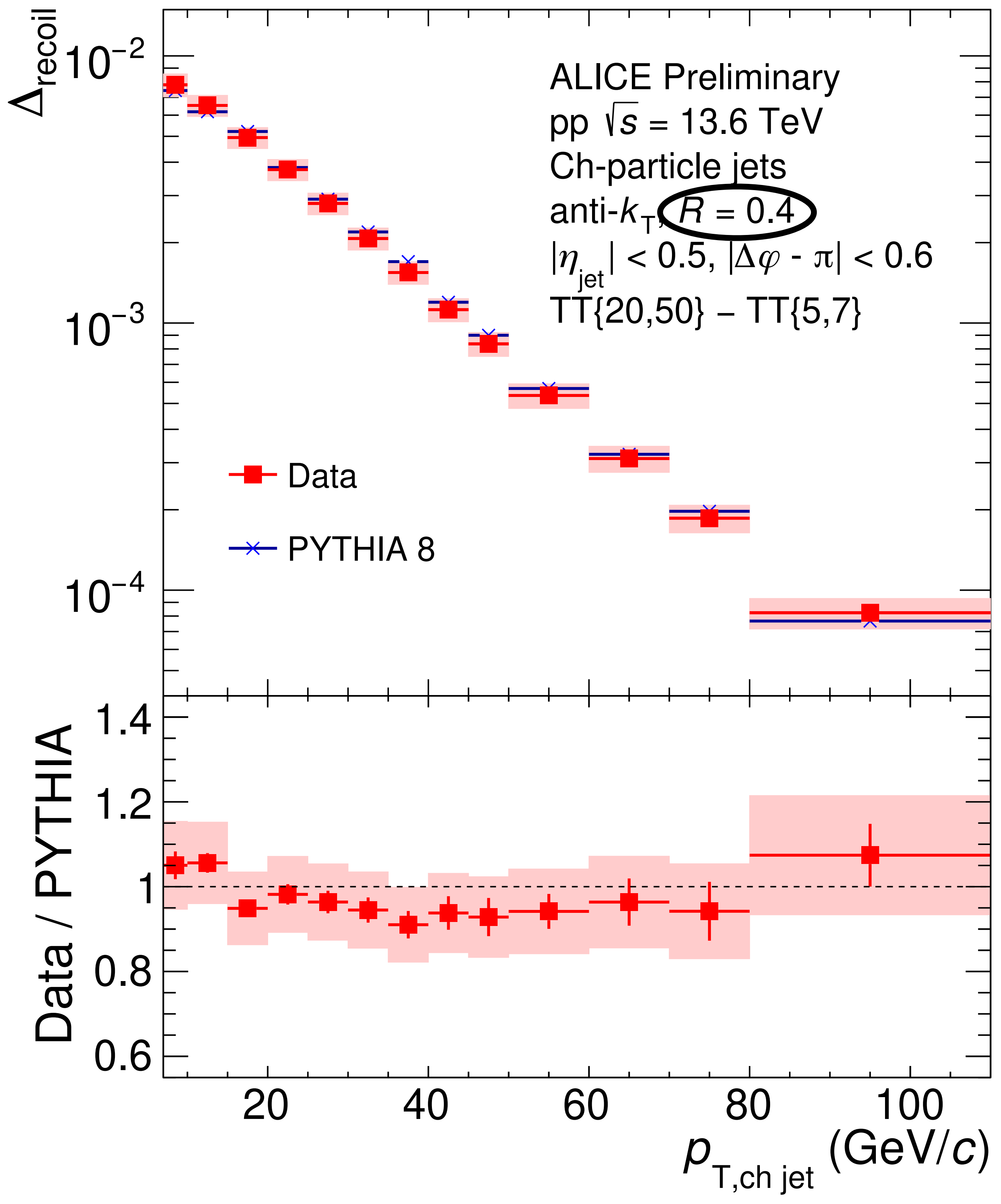
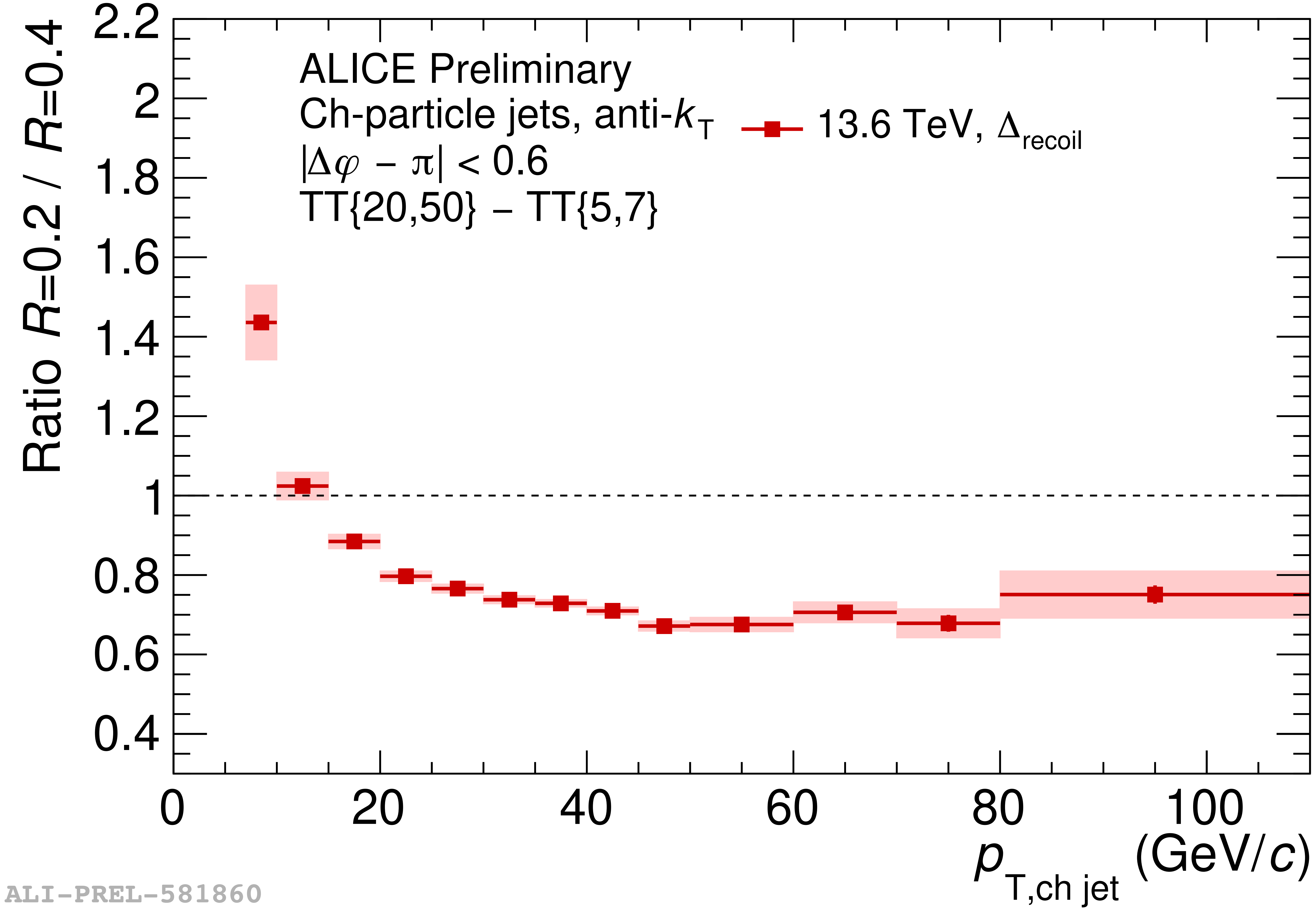


ALI-PREL-581850

- Measure $\Delta_{\text{recoil}}(p_{\text{T}})$ from 7 GeV/c to 110 GeV/c for $R = 0.2$ and $R = 0.4$
  → **PYTHIA describes the data well within uncertainties**

Fully corrected yield ratio, $(R = 0.2)/(R = 0.4)$

Run 3 prelim.



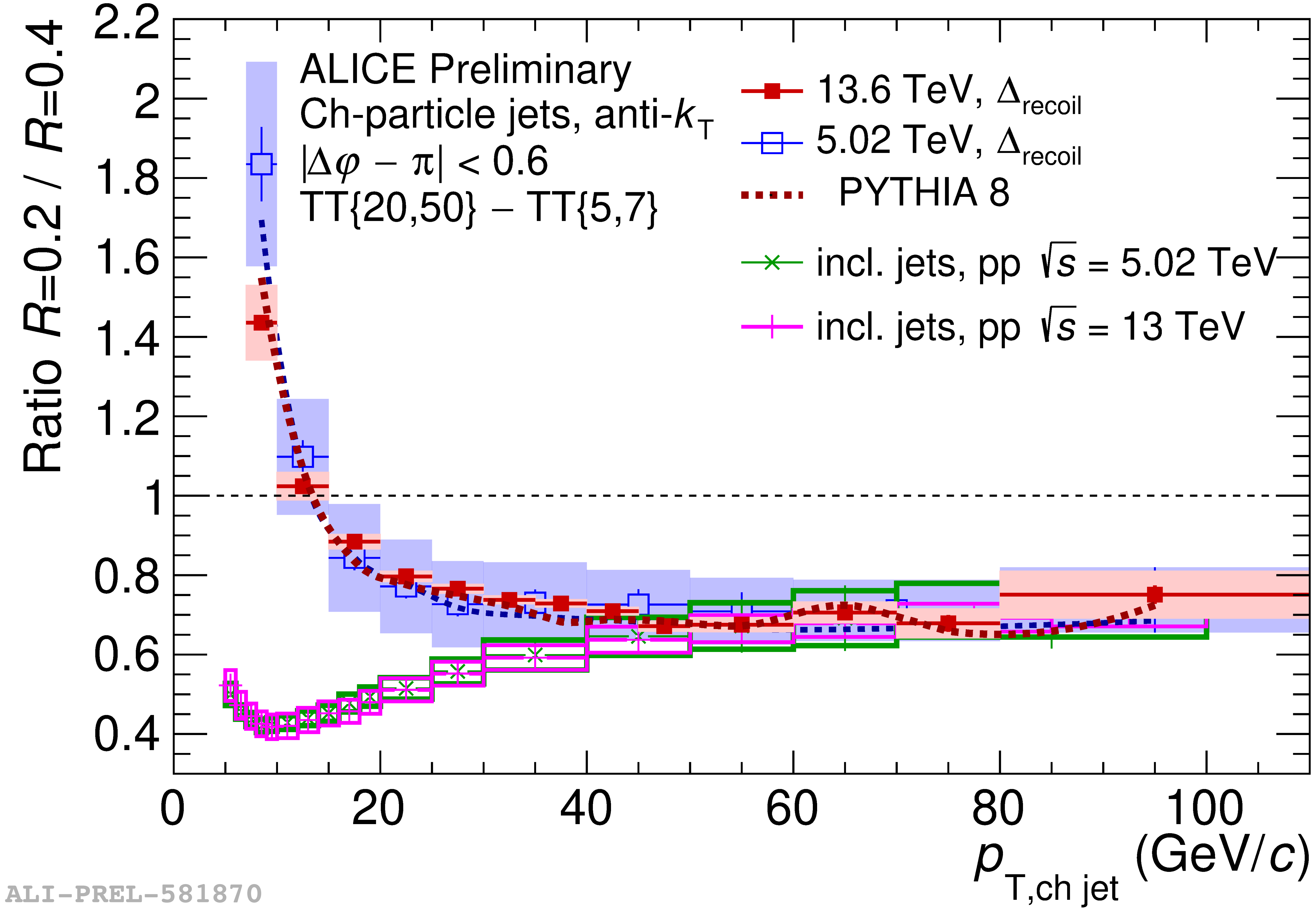
Far smaller systematics in Run 3!

Fully corrected yield ratio, $(R = 0.2)/(R = 0.4)$

Run 3 prelim.

Robust jet shape observable - precise theory and experiment

pQCD: JHEP 04 (2015) 039



Phys.Rev.C 110 (2024) 1, 014906

- **Good agreement with Run 2 result**

Fully corrected yield ratio, $(R = 0.2)/(R = 0.4)$

Run 3 prelim.

Robust jet shape observable - precise theory and experiment

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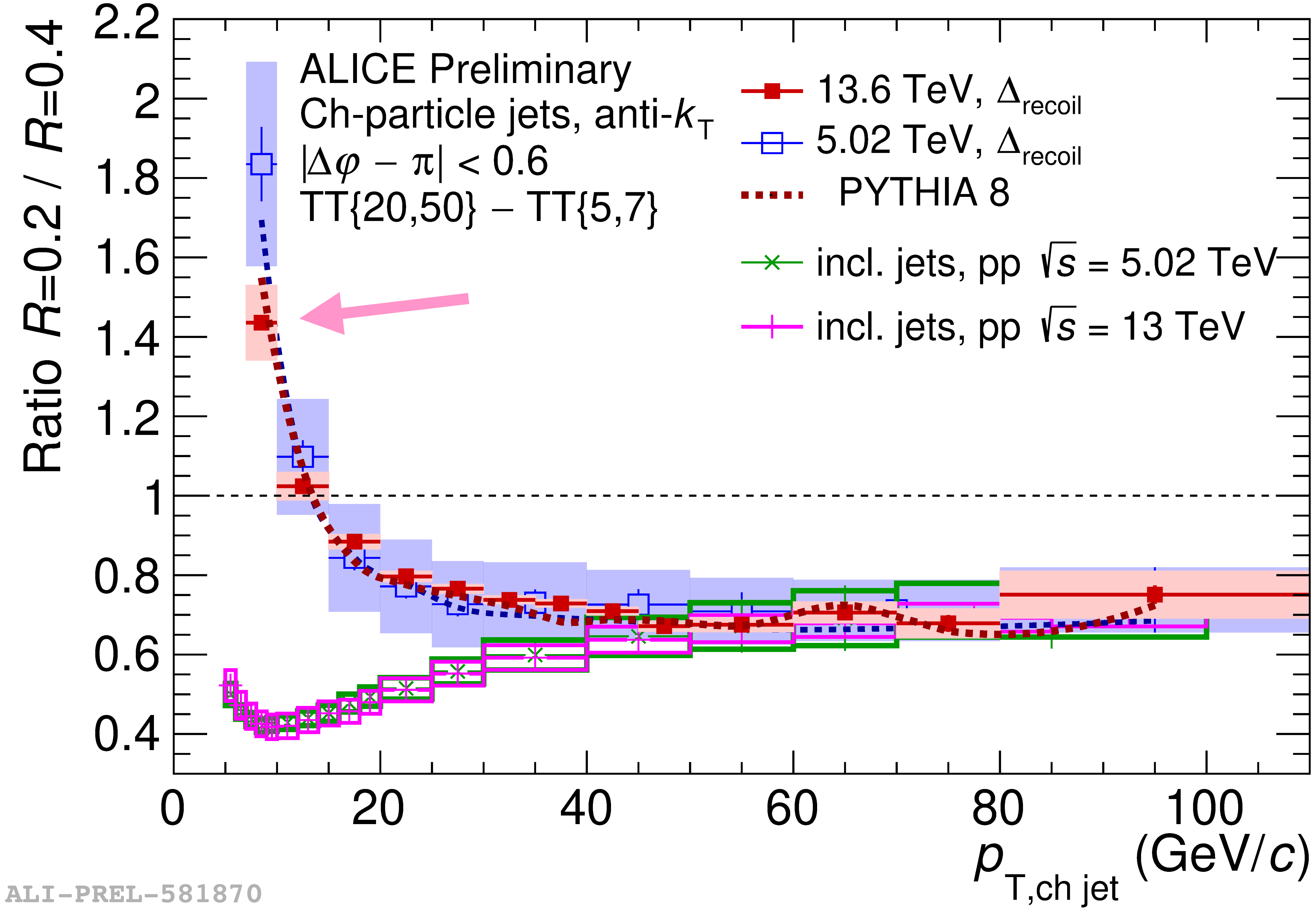

- **Good agreement with Run 2 result**
  - Possible collision energy dependence at low-p_T?

Phys.Rev.C 110 (2024) 1, 014906

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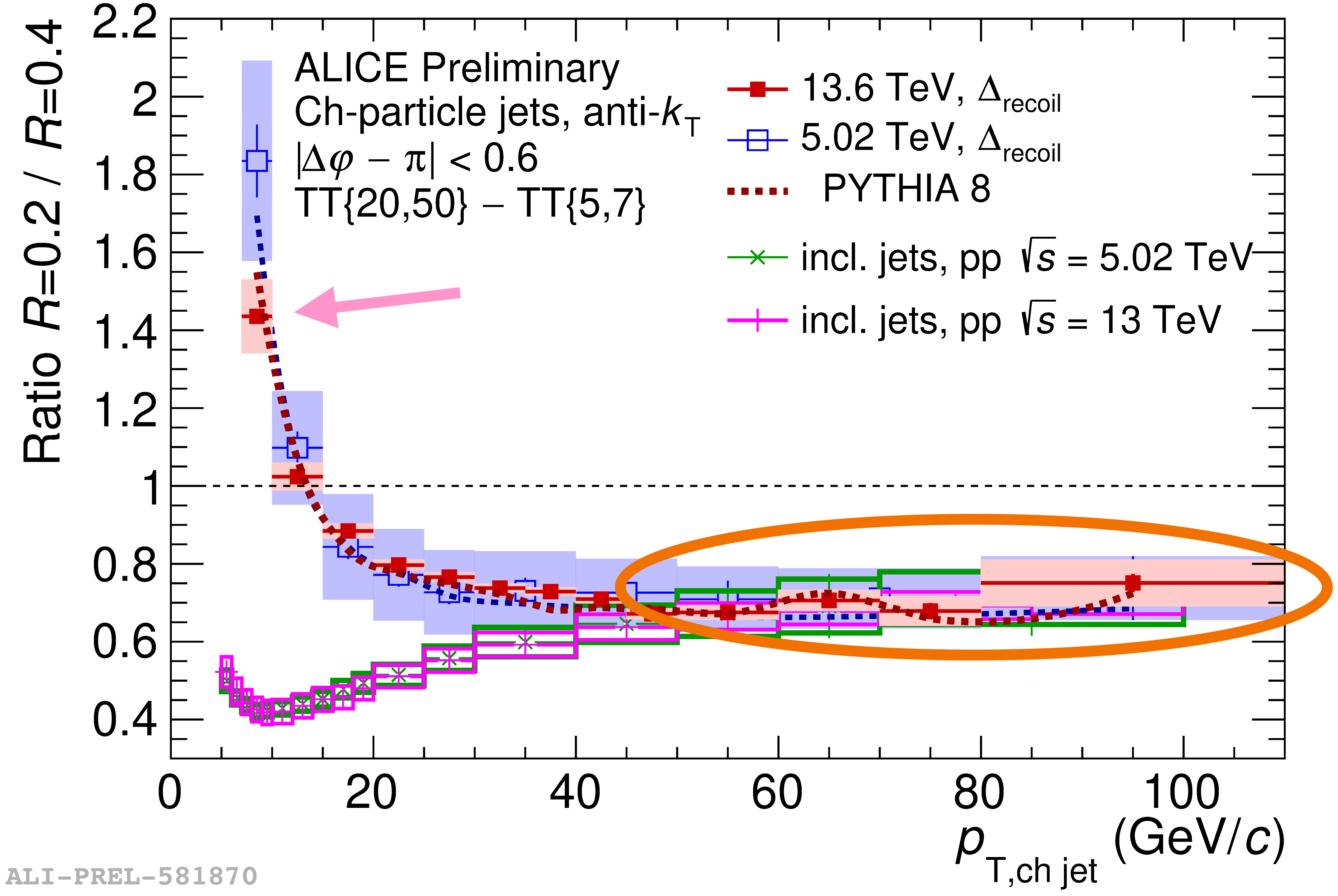

- **Good agreement with Run 2 result**
  - Possible collision energy dependence at low-p_T?
- **Agreement between inclusive jets and semi-inclusive at high p_T**

Phys.Rev.C 110 (2024) 1, 014906

Fully corrected yield ratio, $(R = 0.2)/(R = 0.4)$

Run 3 prelim.

Robust jet shape observable - precise theory and experiment

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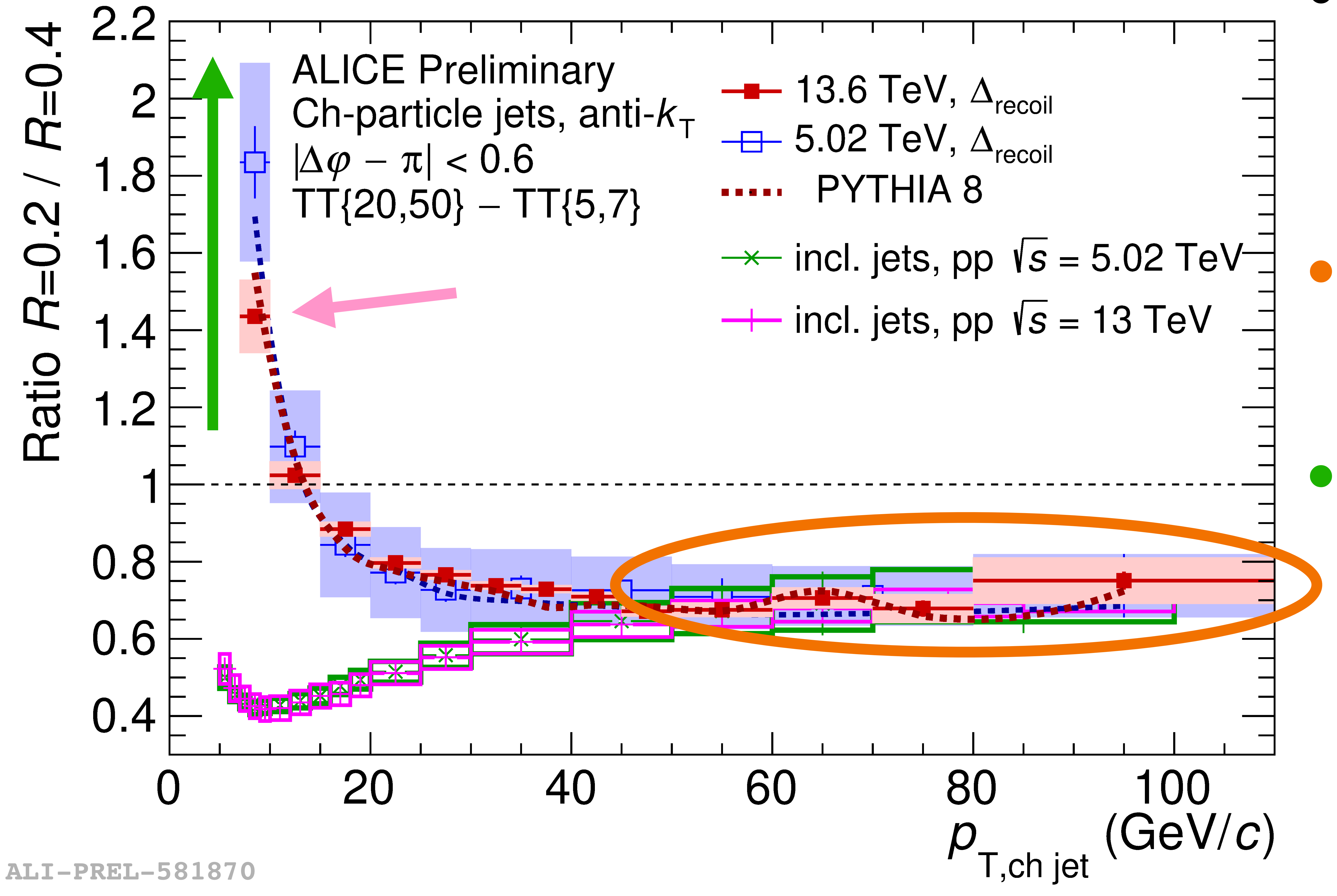

Phys.Rev.C 110 (2024) 1, 014906

- **Good agreement with Run 2 result**
  - Possible collision energy dependence at low-p_T?
- **Agreement between inclusive jets and semi-inclusive at high p_T**
- **Enhancement in $R = 0.2$ recoil jet yield at low p_T**
  - Bias towards NLO effects when $p_{T,jet} < p_{T,trig}$?
  - Jet splitting?

Looking ahead…

- **Investigate the origin of the low p_T R-ratio shape**
- **Introduce an observable to look at recoil jet substructure: ΔR_{axis}**
    - Utilise the statistical approach - the first application to jet substructure
- **Begin Pb-Pb analysis!**
    - What is the origin of the acoplanarity broadening?

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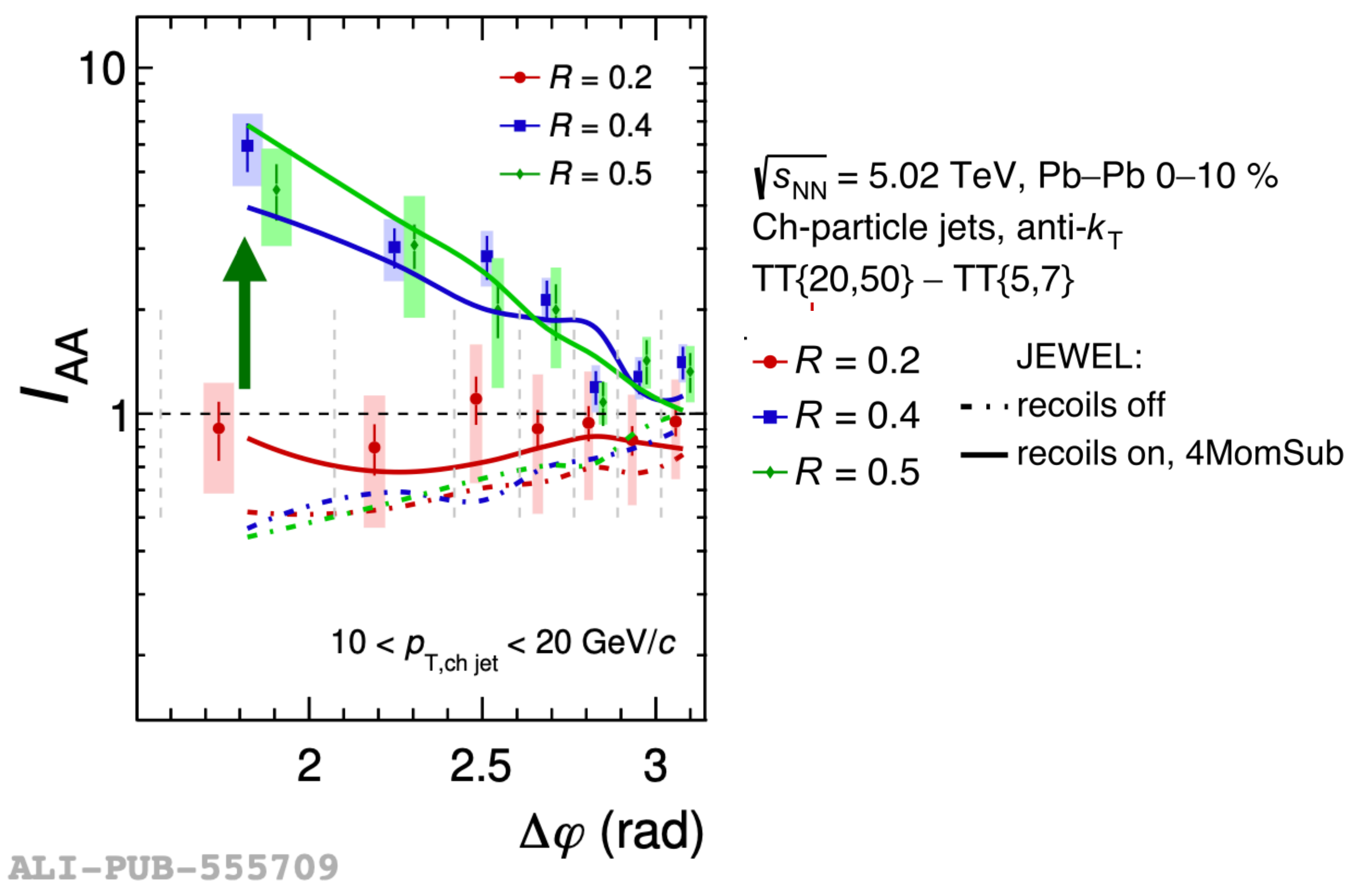
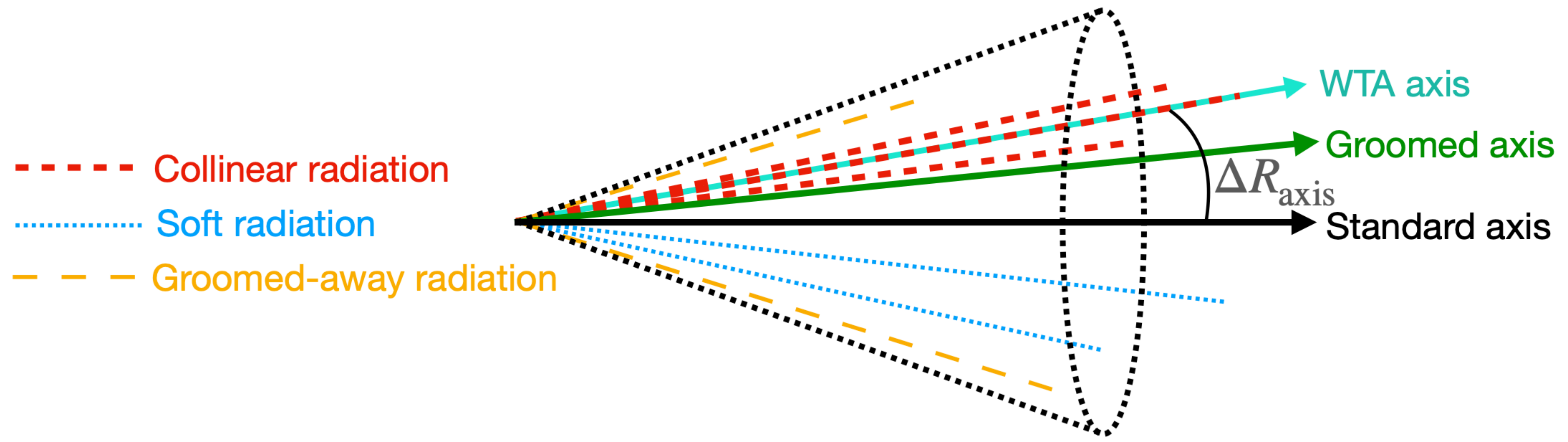
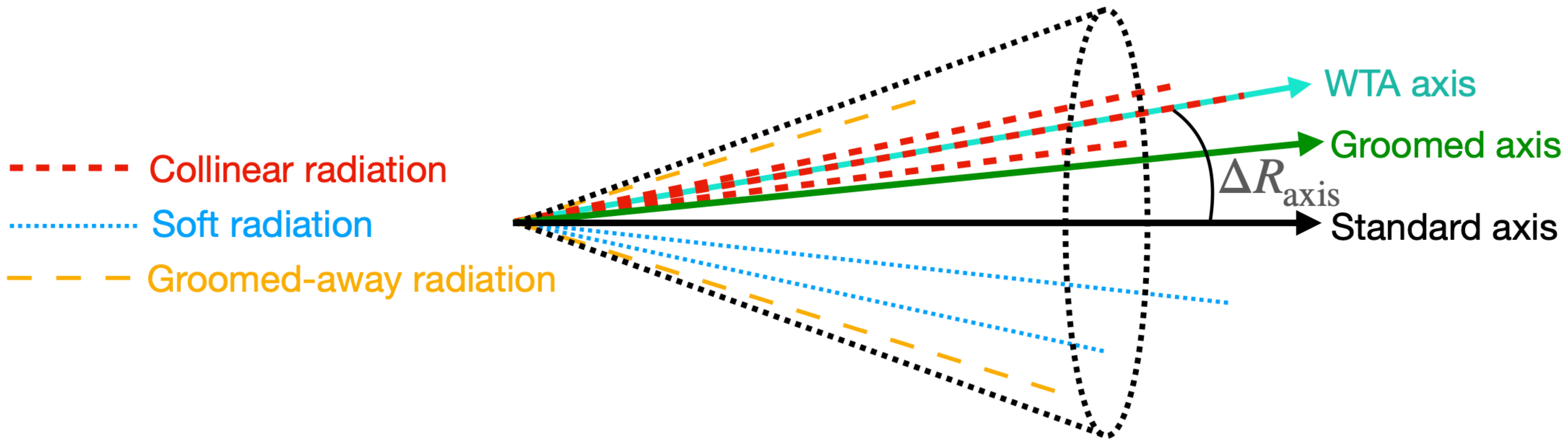
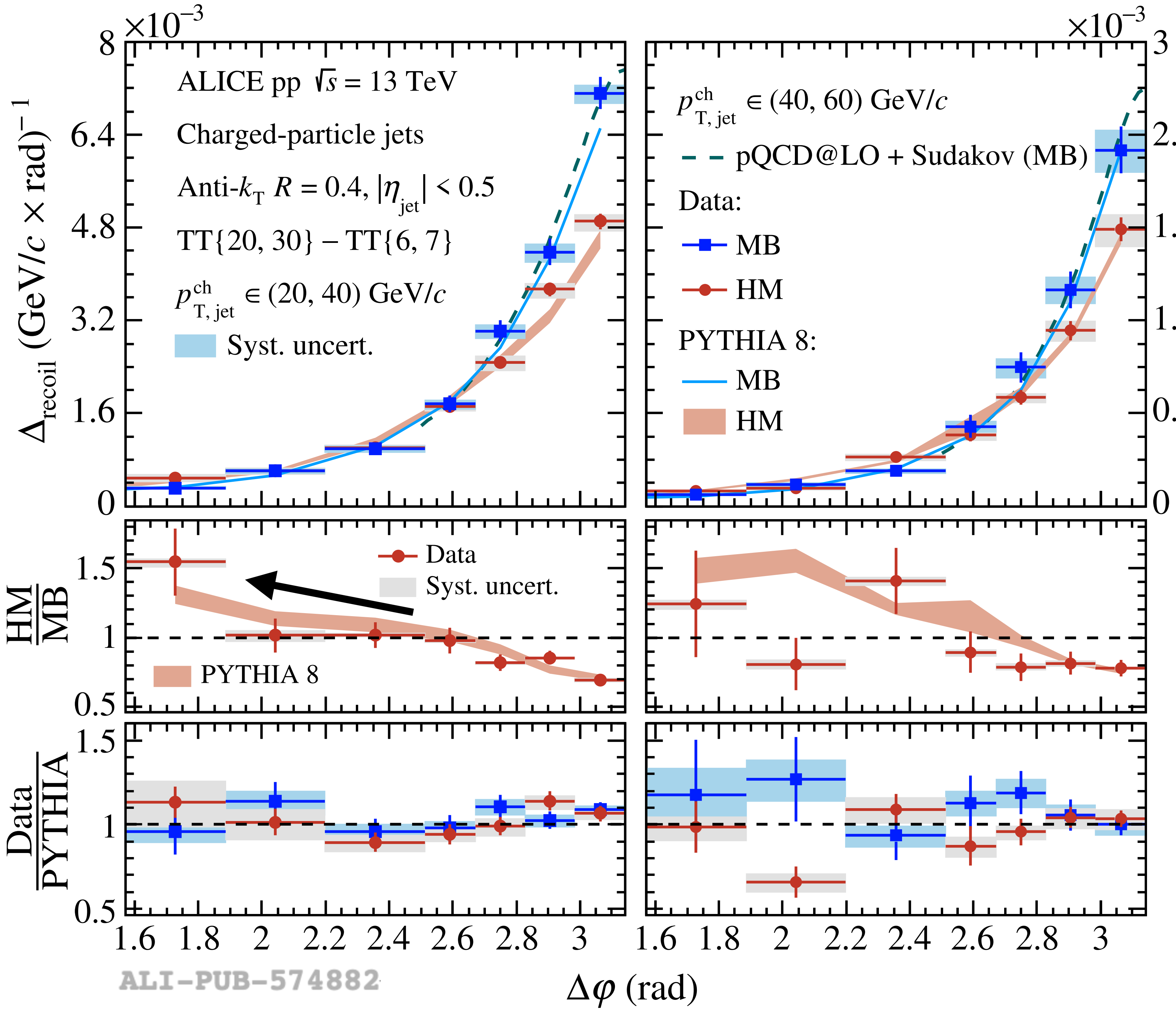




Summary and outlook





- **Search for QGP signatures in high multiplicity pp collisions**
  - Jet quenching like effects masked by generic event selection bias
- **First look at recoil jet spectra in Run 3**
  - Results in good agreement with PYTHIA and Run 2
  - Probe of pQCD with the additional scale from hadron trigger
- **Next steps: investigate recoil jet substructure including in Pb-Pb**

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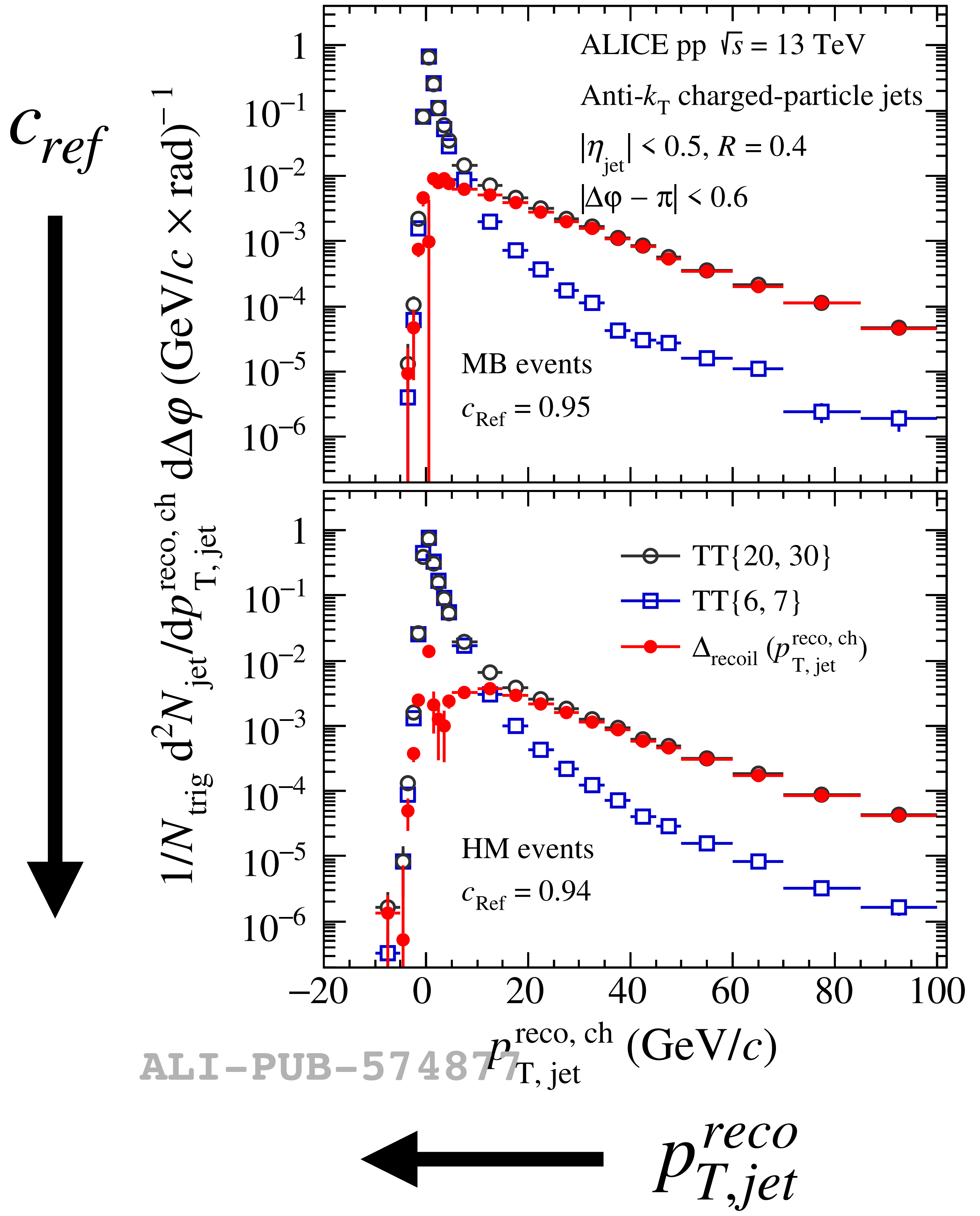
Backup

Corrections

- **Raw spectrum calibrations:**



- **The raw distributions are unfolded to remove detector effects**
- **Closure test for validation:** Take embedded PYTHIA, unfold and compare to truth-level
  - Small non closure (7-10%) in Run 3 → added as a systematic

$$\Delta_{recoil}(p_{T,jet}, \Delta\varphi) = \frac{1}{N_{trig}} \frac{d^2N_{jet}}{dp_{T,jet}d\Delta\varphi}\bigg|_{p_T^{trig}\in TT_{sig}} - c_{Ref} \times \frac{1}{N_{trig}} \frac{d^2N_{jet}}{dp_{T,jet}d\Delta\varphi}\bigg|_{p_T^{trig}\in TT_{ref}}$$

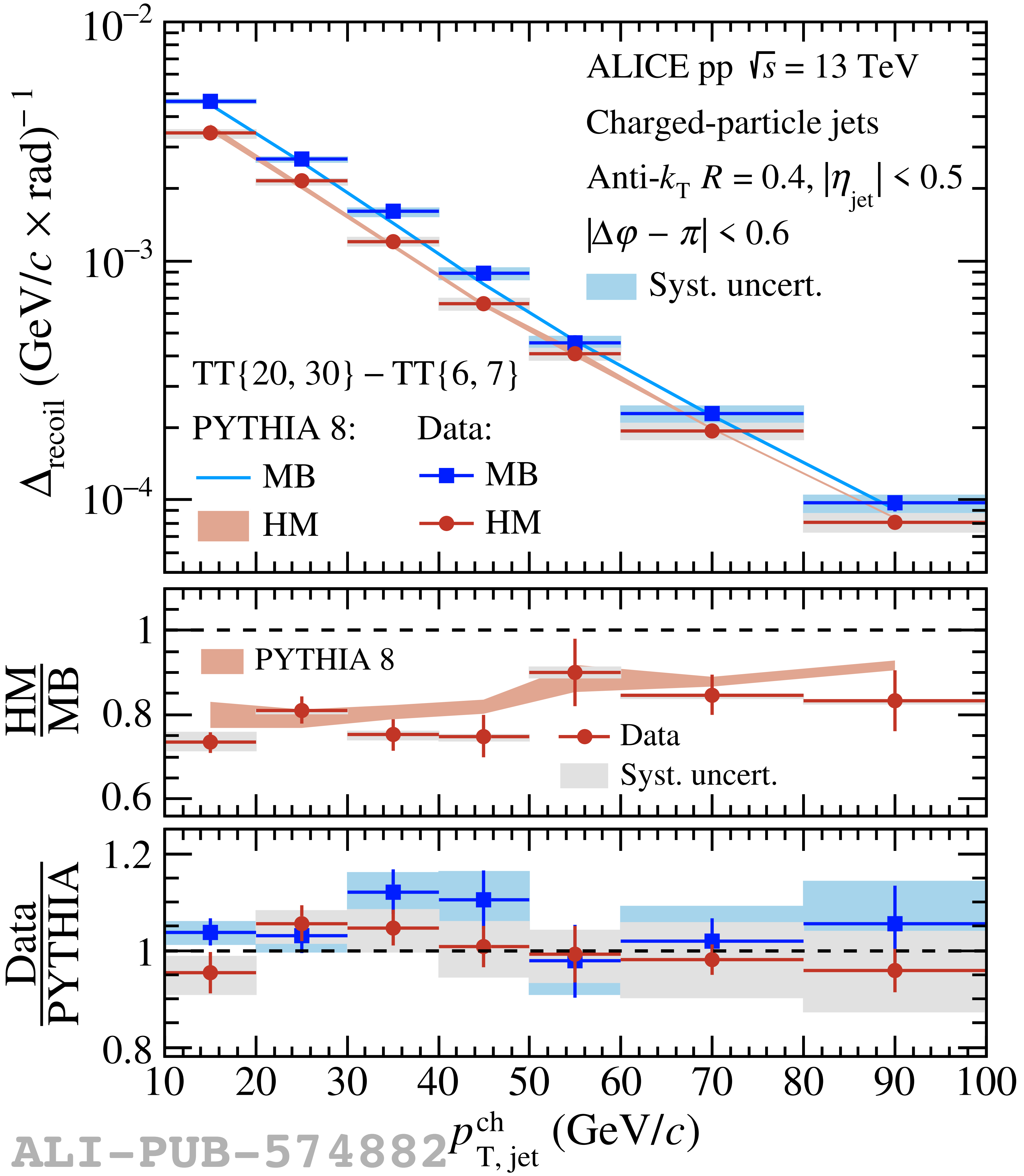
Systematics

- **Run 2:**
  - Tracking efficiency
  - Unfolding procedure
  - Background fluctuations
  - c_{ref} calculation (low-p_T)
- **Run 3:**
  - Tracking efficiency
  - Non-closure
  - c_{ref} calculation (low-p_T)

HM/MB recoil jet yield as a function of p_T

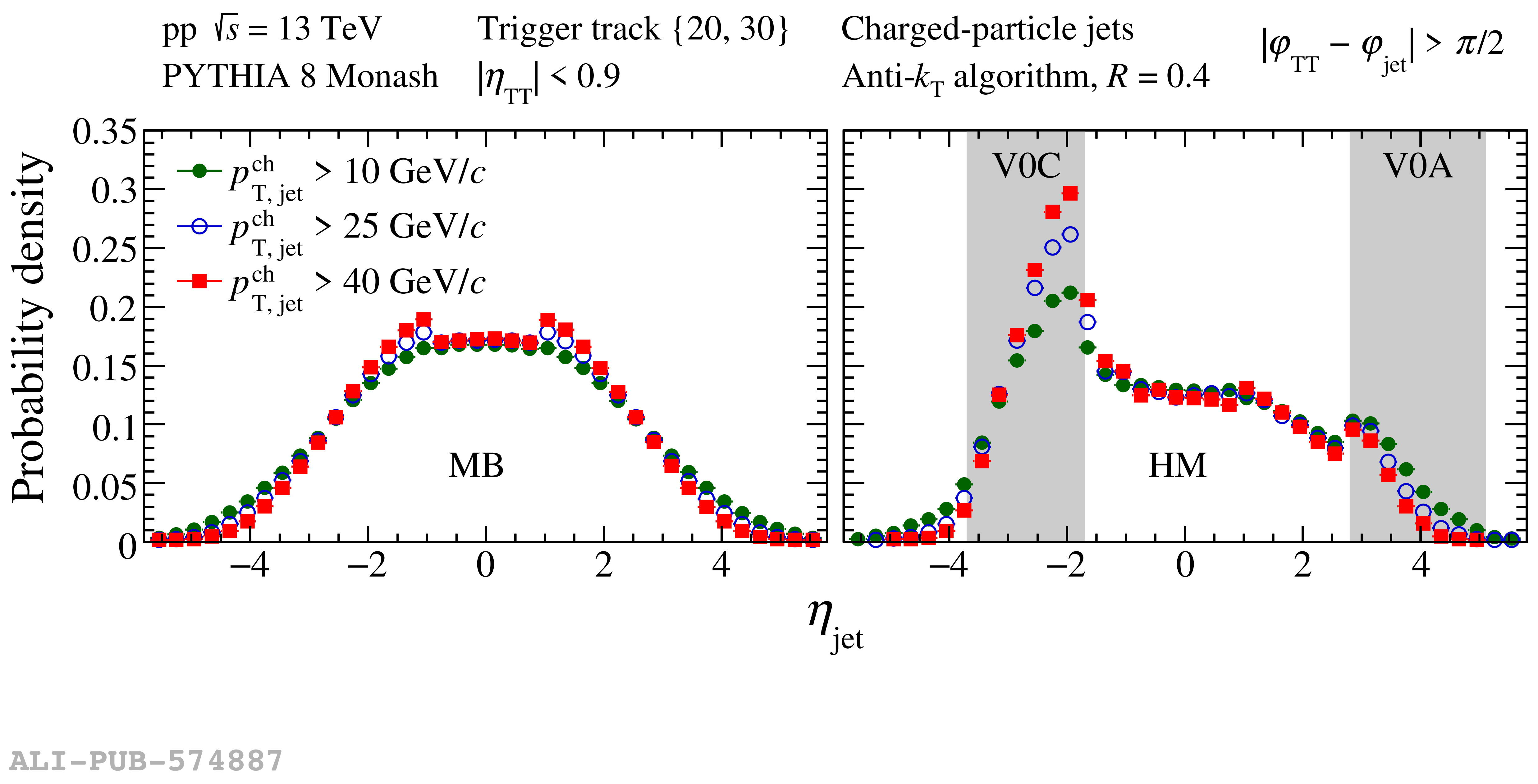
New paper!

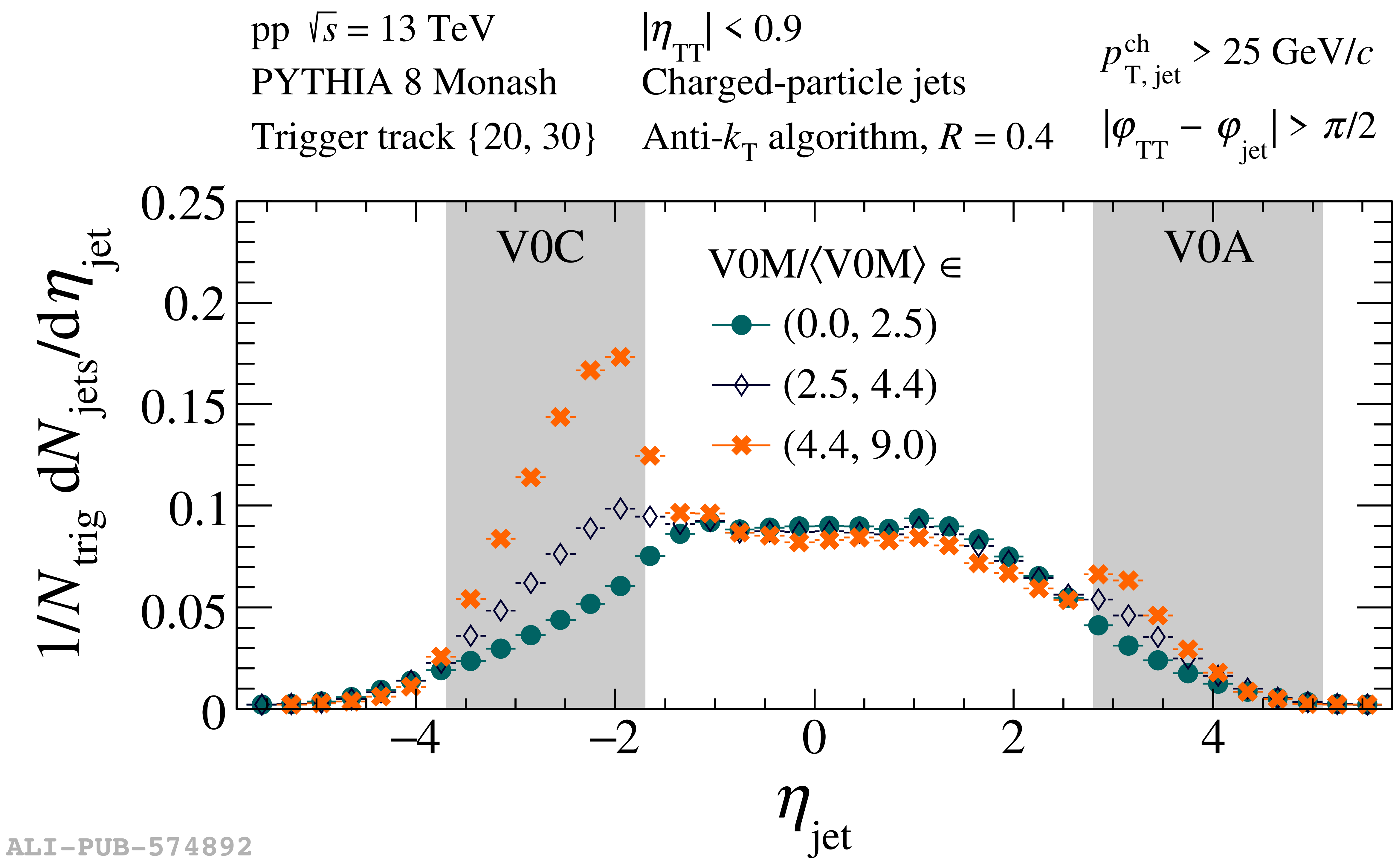
Suppression of HM recoil jet yield across all p_T



η_{jet} spectra in MB and HM events - data and PYTHIA

New paper!

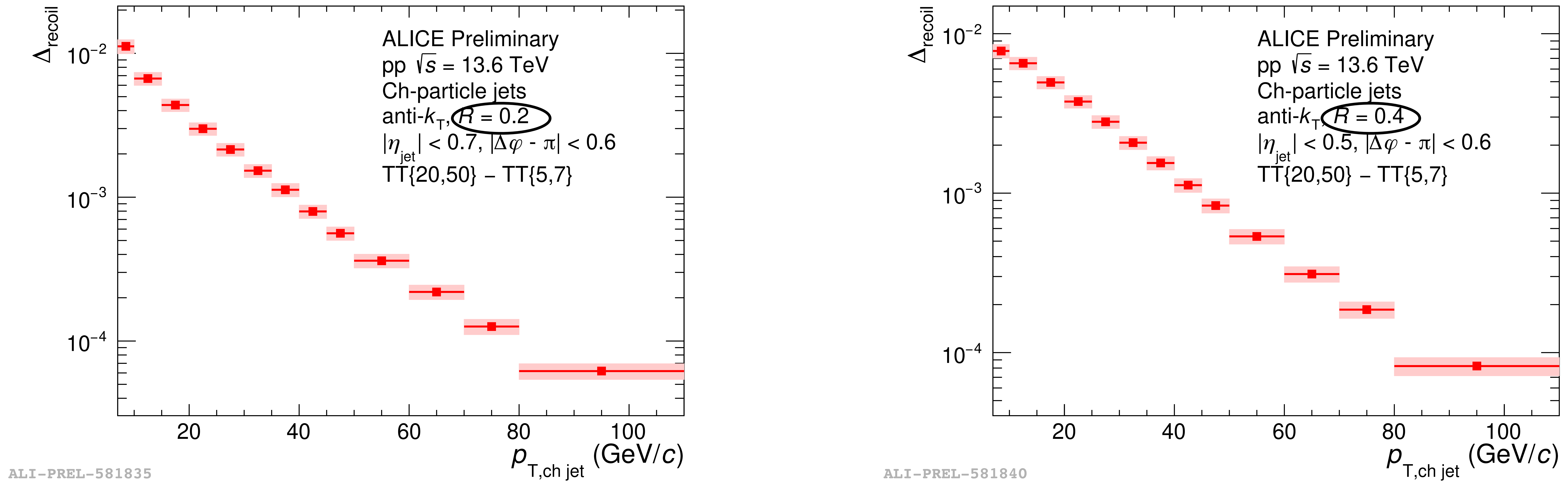




Suppression of jet yield in the central barrel

Fully corrected $\Delta_{\text{recoil}}(p_T)$

Run 3 prelim.



- Measure $\Delta_{\text{recoil}}(p_T)$ from 7 GeV/c to 110 GeV/c for $R = 0.2$ and $R = 0.4$