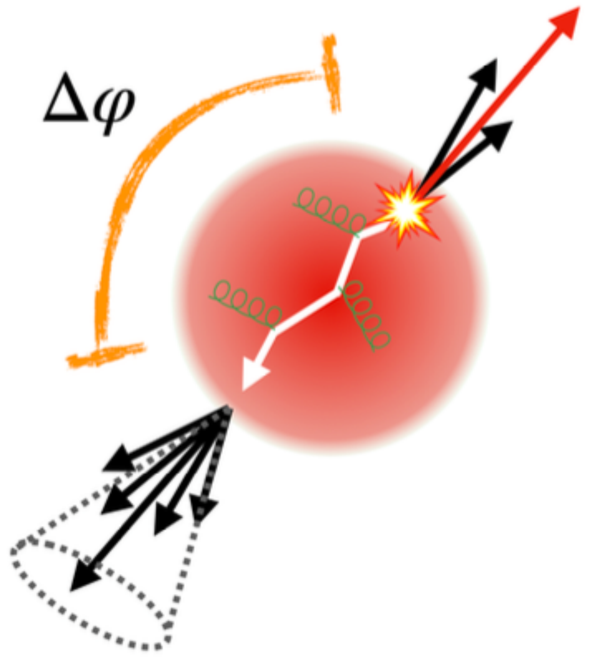
Jet correlation measurements with ALICE



Yongzhen Hou

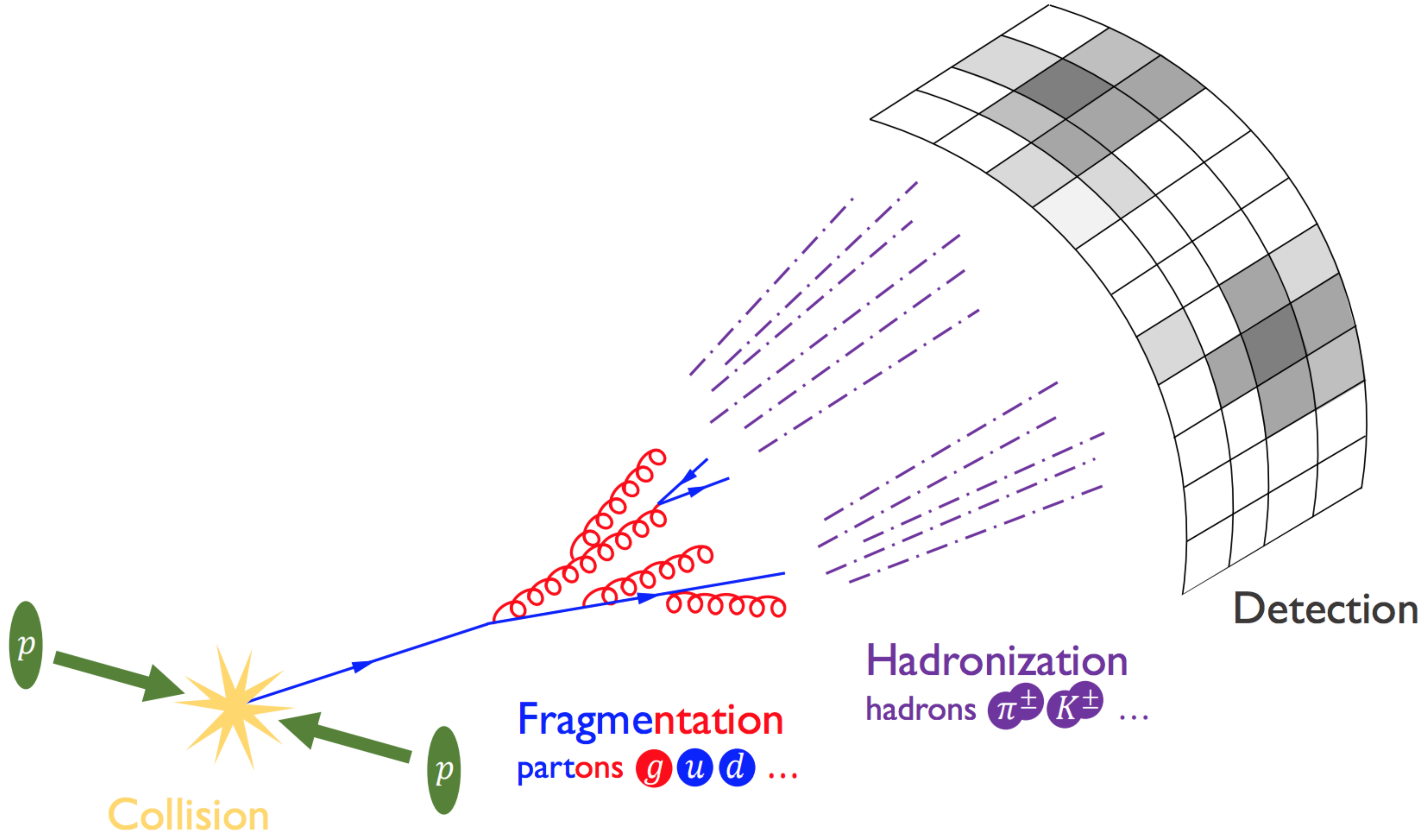
30 June 2026

China University of Geosciences (CUG)

What are jets

- Quarks and gluons are produced in hard scatterings at hadron colliders
- Due to color confinement, free quarks and gluons cannot be observed directly

→ only **color-singlet particles** are detected in nature



Credit: Eric M. Metodiev

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  → *proxy for the original hard-scattered parton*

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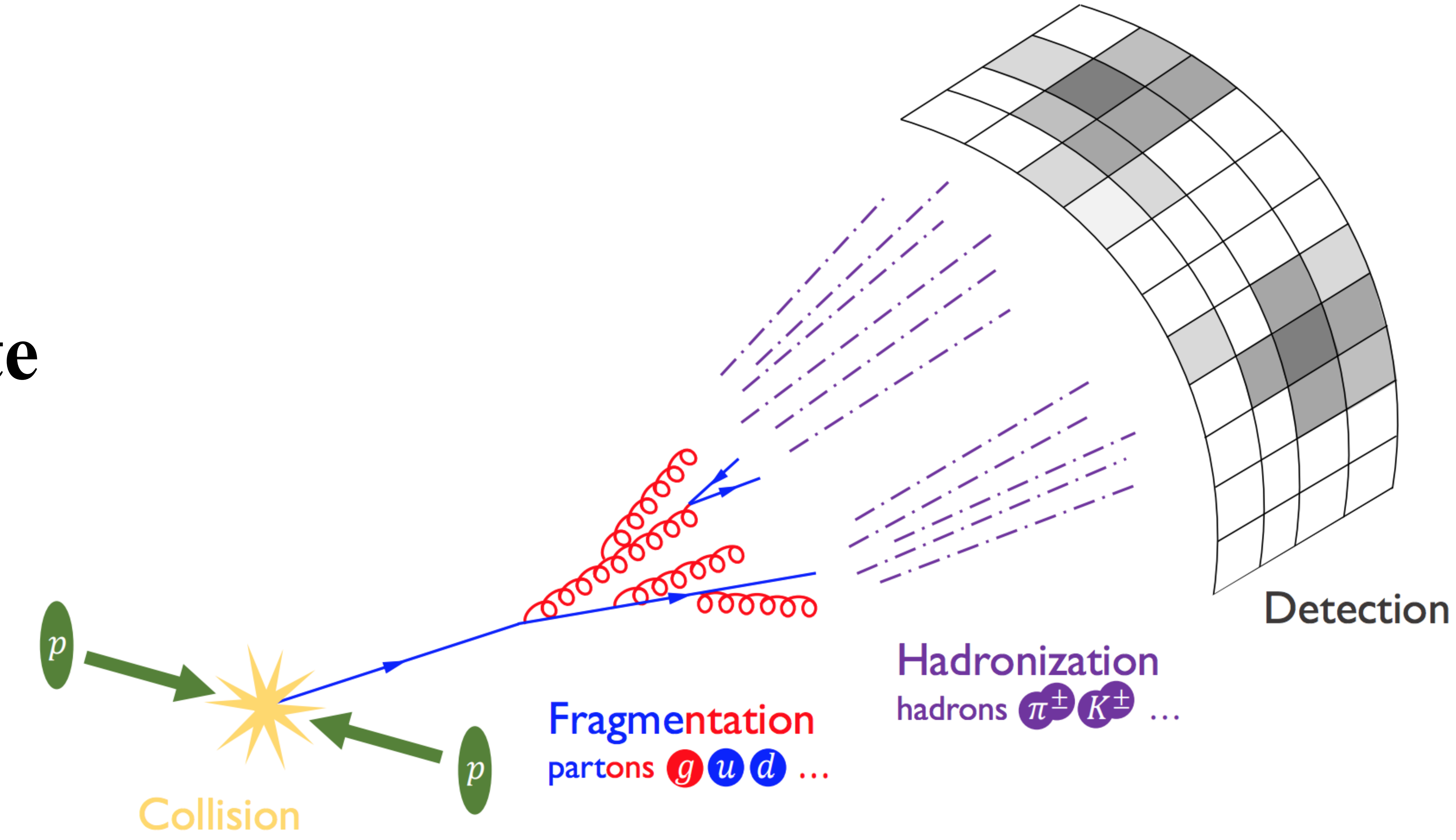
  - ***In reality:*** only observe final state particles produced from hard partons



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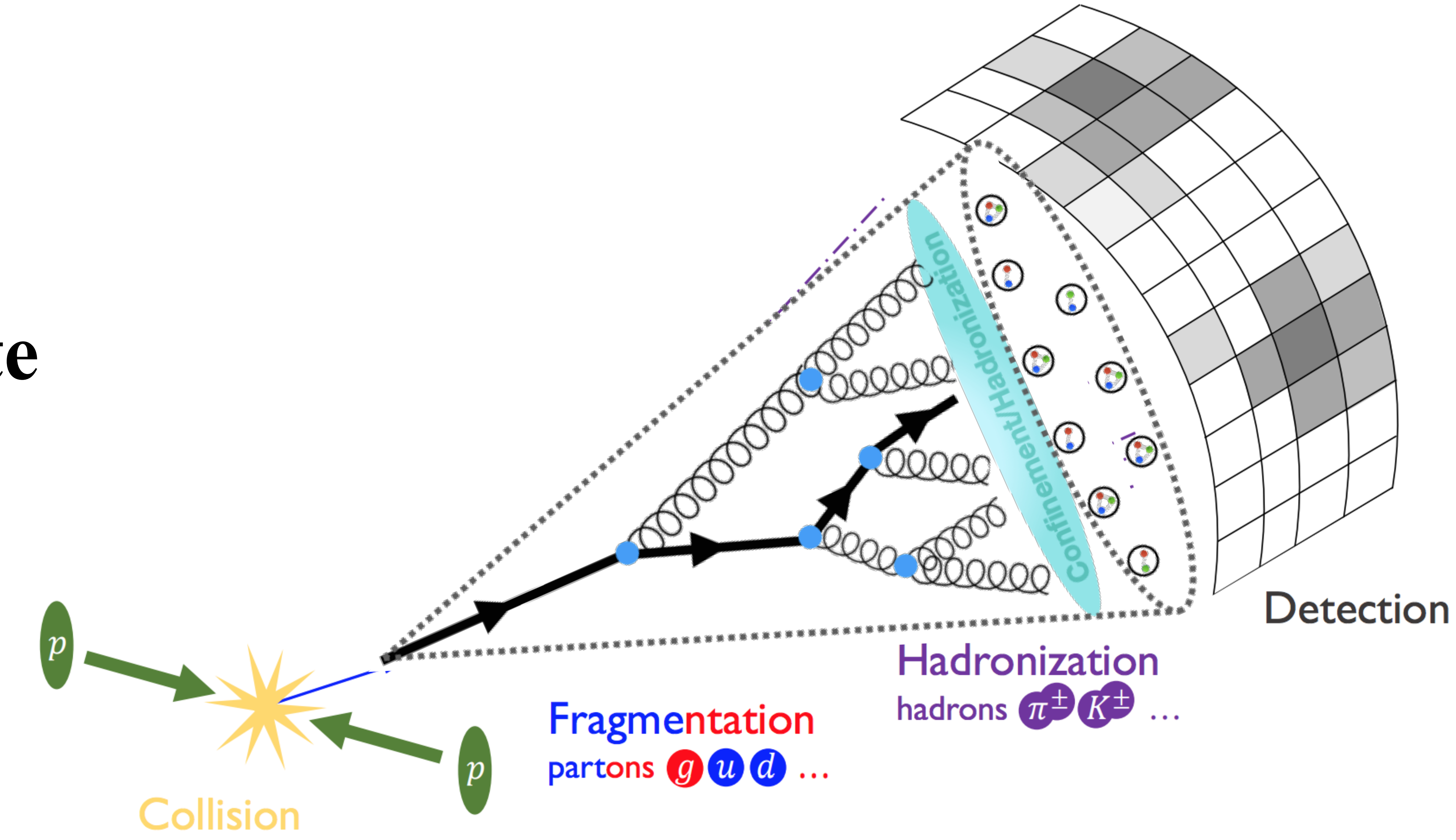


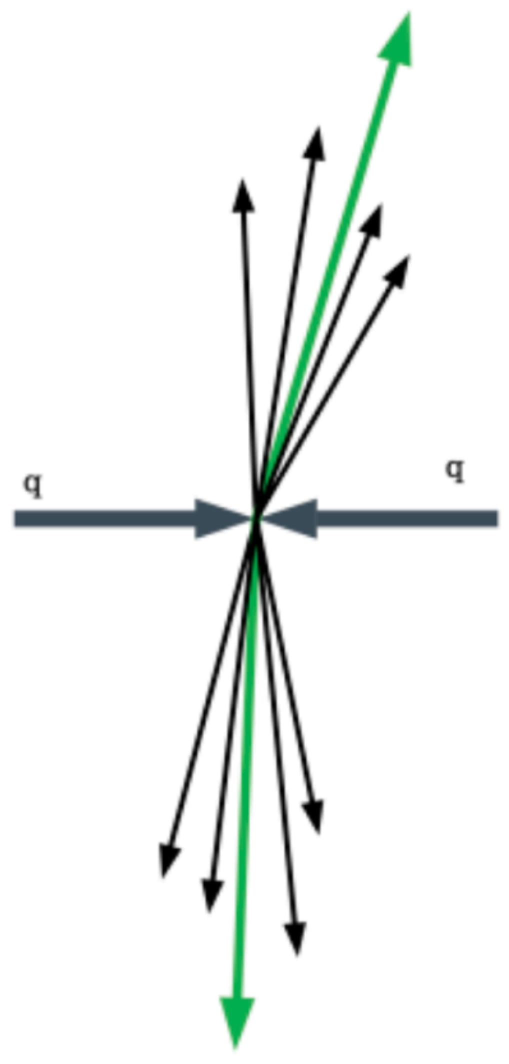
Credit: Eric M. Metodiev

Jets connect unobservable partons to measurable final-state particles

Why study jets

Jets in small collision systems (pp, p-Pb)

- **Well described by pQCD calculations**
- Investigate the parton splitting functions
- Test the Cold Nuclear Matter (CNM) effects in p-Pb collisions
- Provide the baseline for jet-quenching measurements in heavy-ion collisions
- Search for possible **QGP droplet formation** in small collision systems



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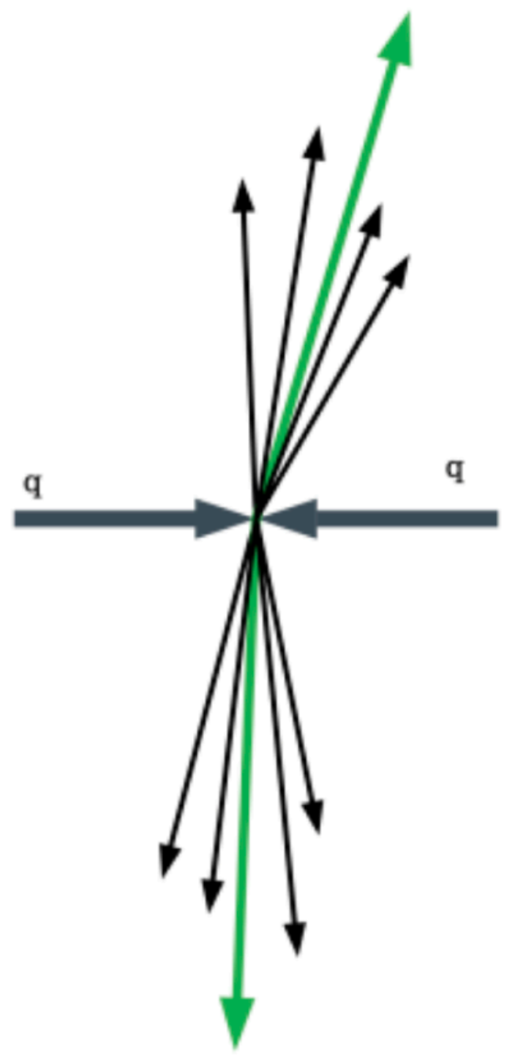
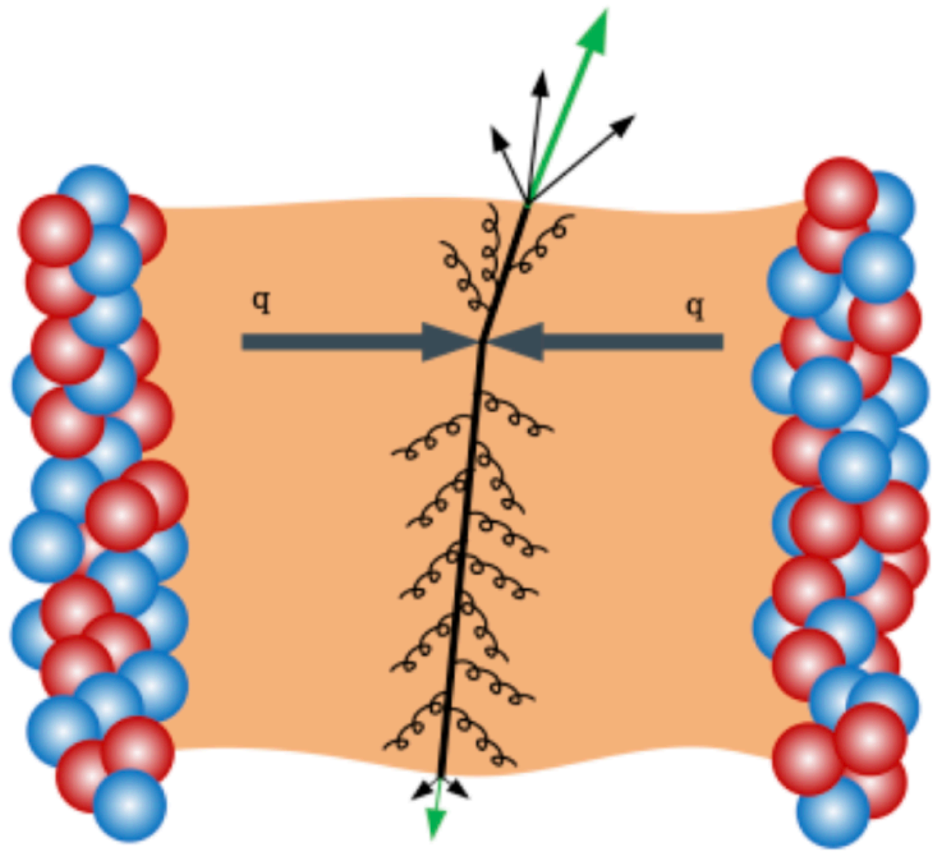


p+p

Jets in heavy-ion collisions → study the transport properties of the QGP

- Partons interact with QGP and lose energy through medium-induced gluon radiation (inelastic) and elastic scatterings with medium constituents
  - $\text{Jet}(E) \rightarrow \text{Jet}(E' - \Delta E) + \text{soft particles}(\Delta \text{E})$



A+A

How does the QGP modify jets

- **Jet quenching:** modification of jets in heavy-ion collisions relative to the pp baseline

- Observable consequences:

→ jet yield suppression

→ modification of jet structure and fragmentation

→ jet angular deflection

→ Medium response / energy redistribution

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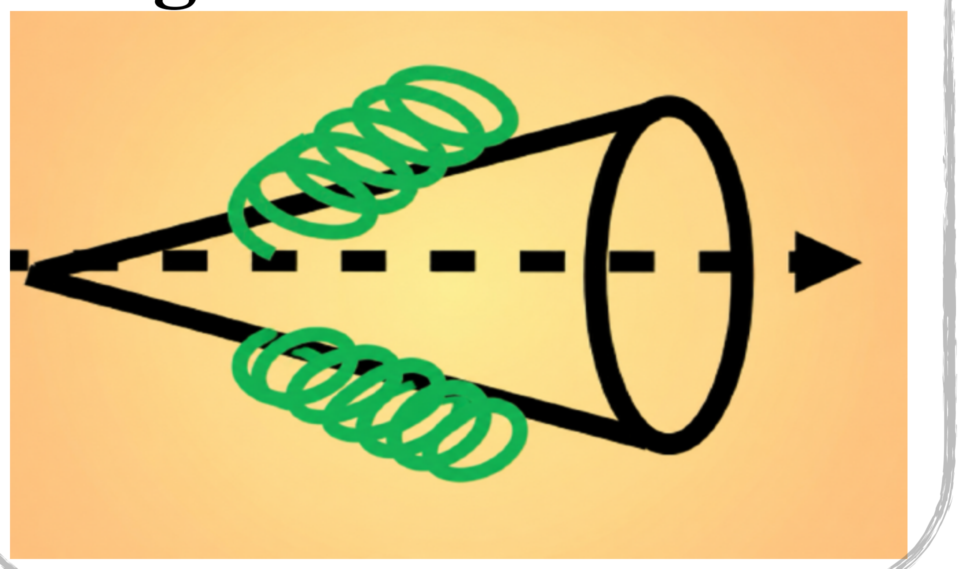
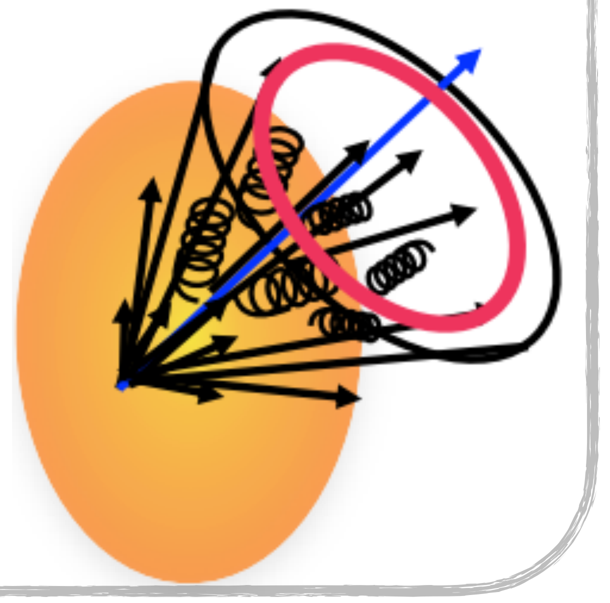
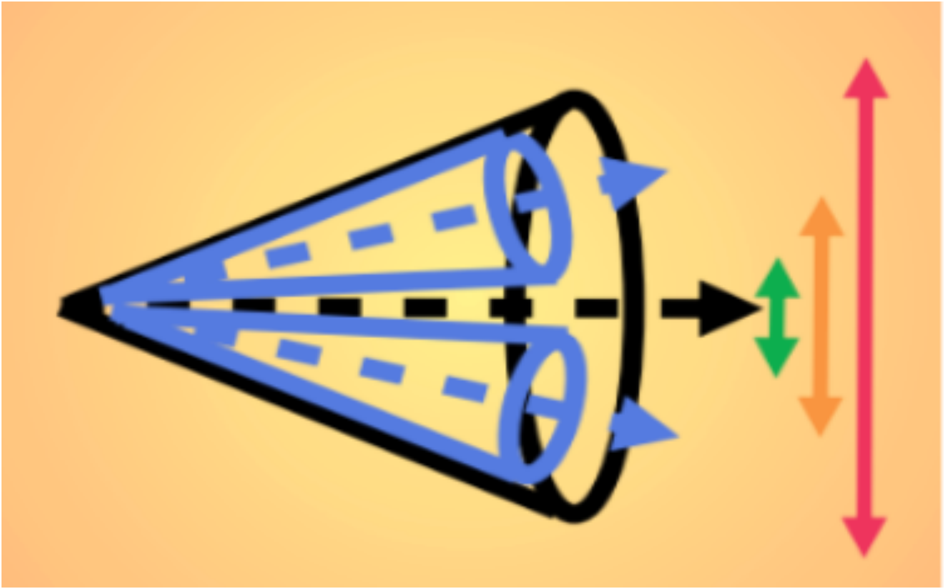
Medium-induced gluon radiation



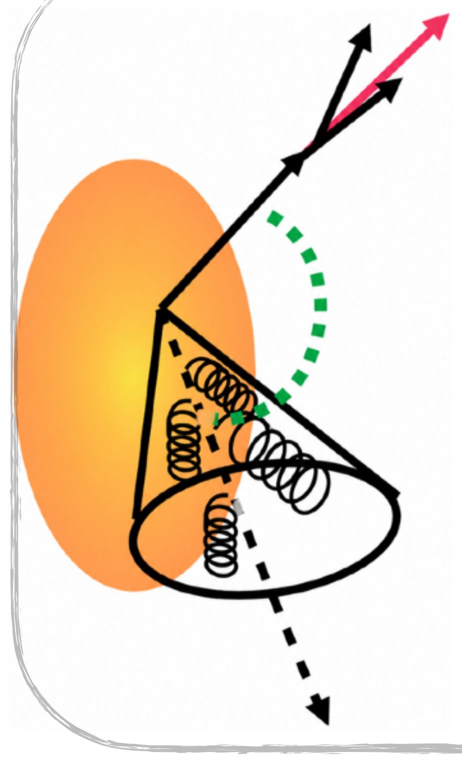
Momentum broadening: soft gluon emissions widen jet



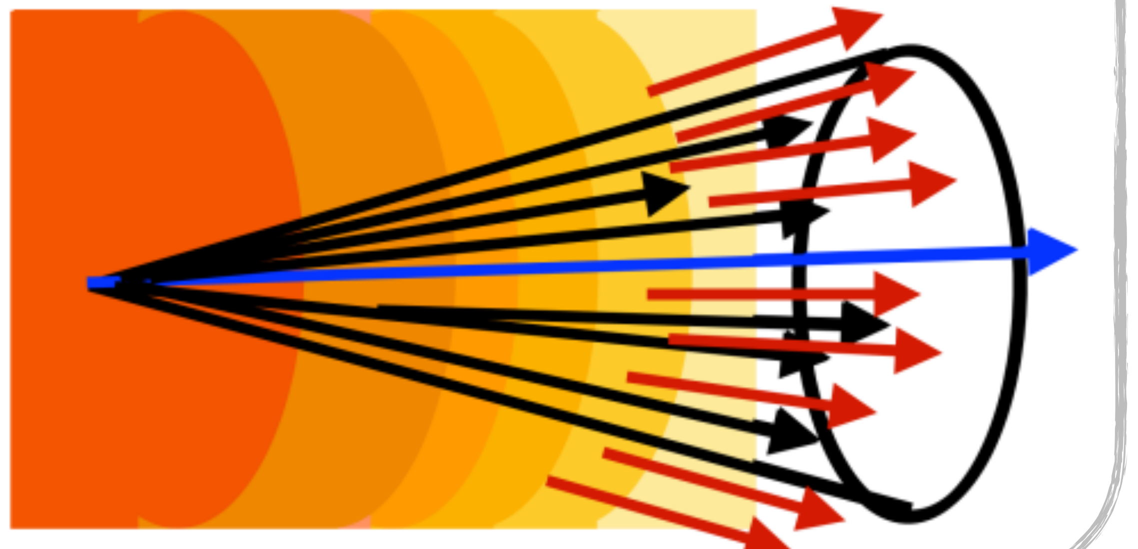
Resolving power of medium for partons in jets



Large angle deflection from Molière scattering off quasi-particles

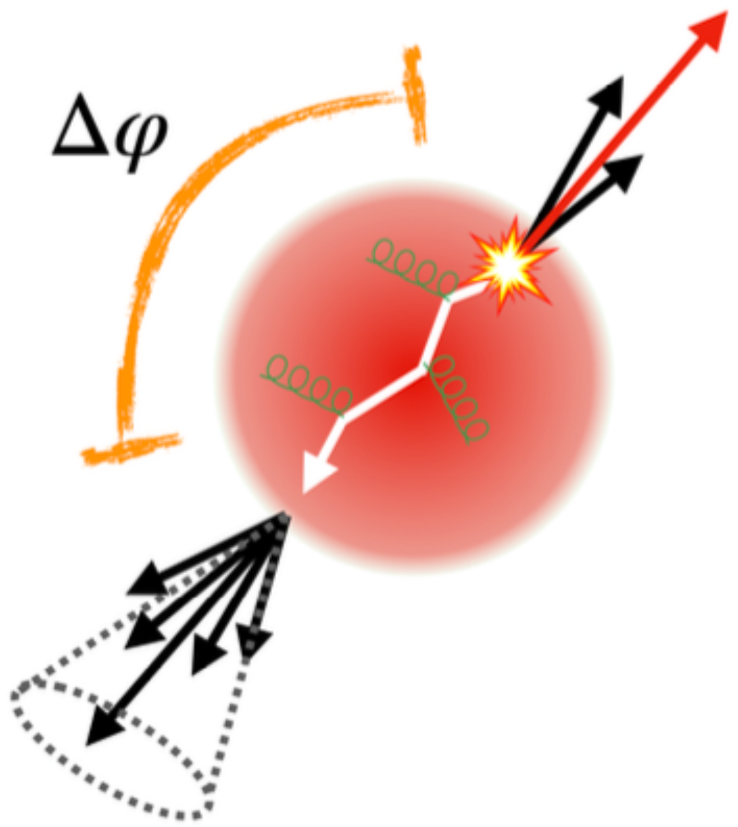


Medium response: causing a wake effect of soft particles



Why hadron+jet correlations

- Measure yield of charged jets recoiling from a high p_T trigger hadron as function of:
  - transverse momentum ($p_{T,jet}$) of recoil jet
  - opening angle ($\Delta\varphi$) of jet relative to trigger axis



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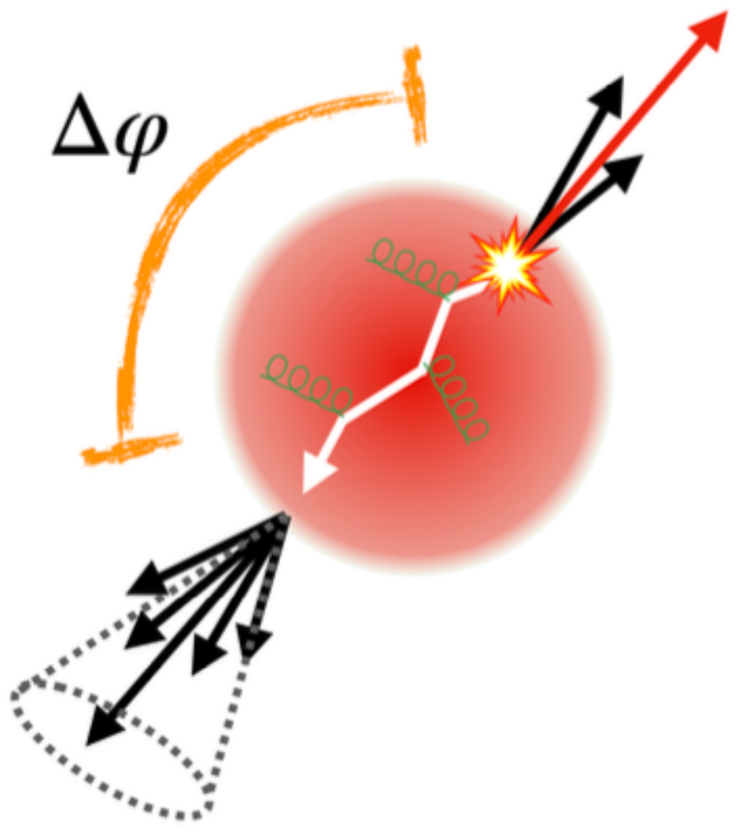
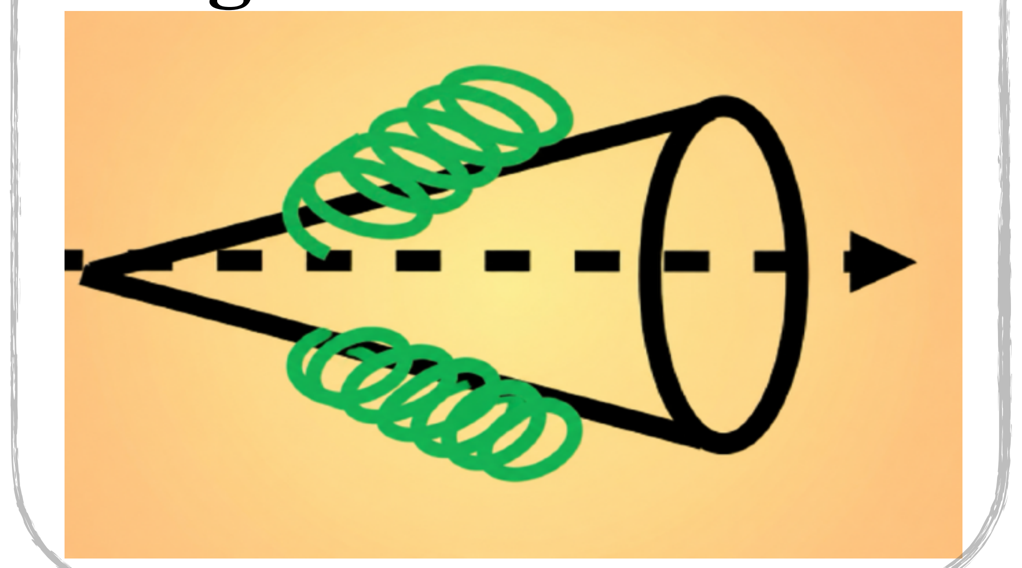
    → acoplanarity broadening



Medium-induced gluon radiation



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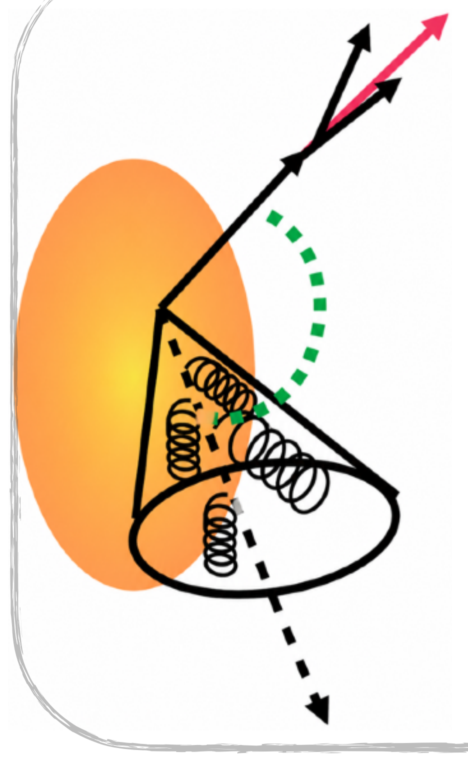

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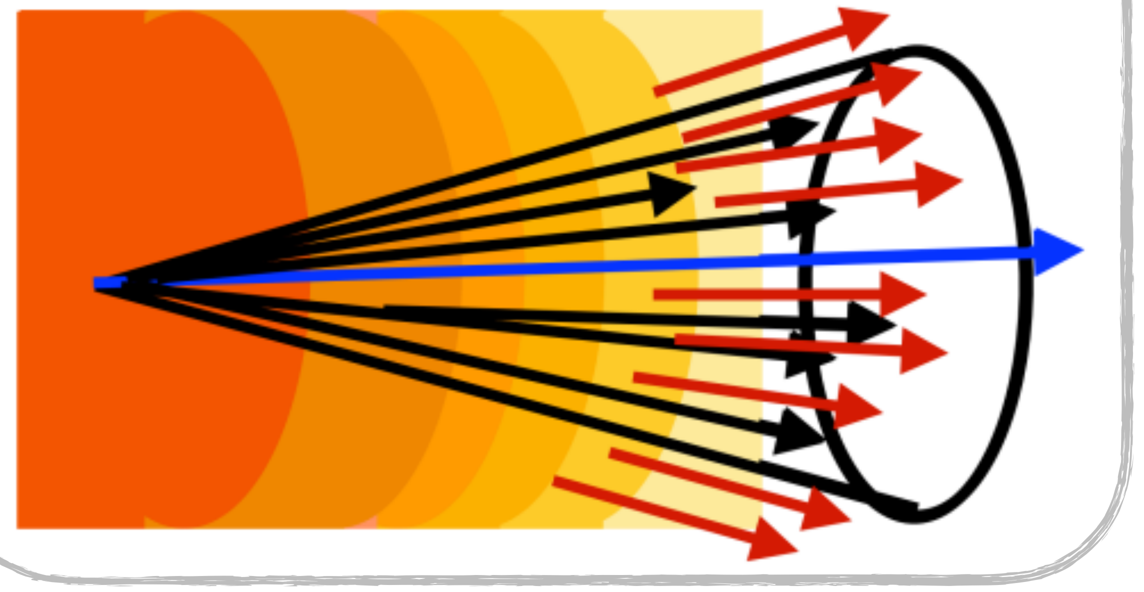
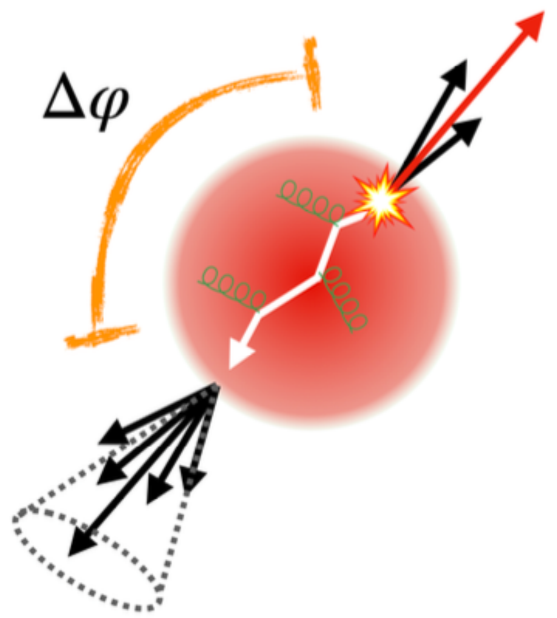


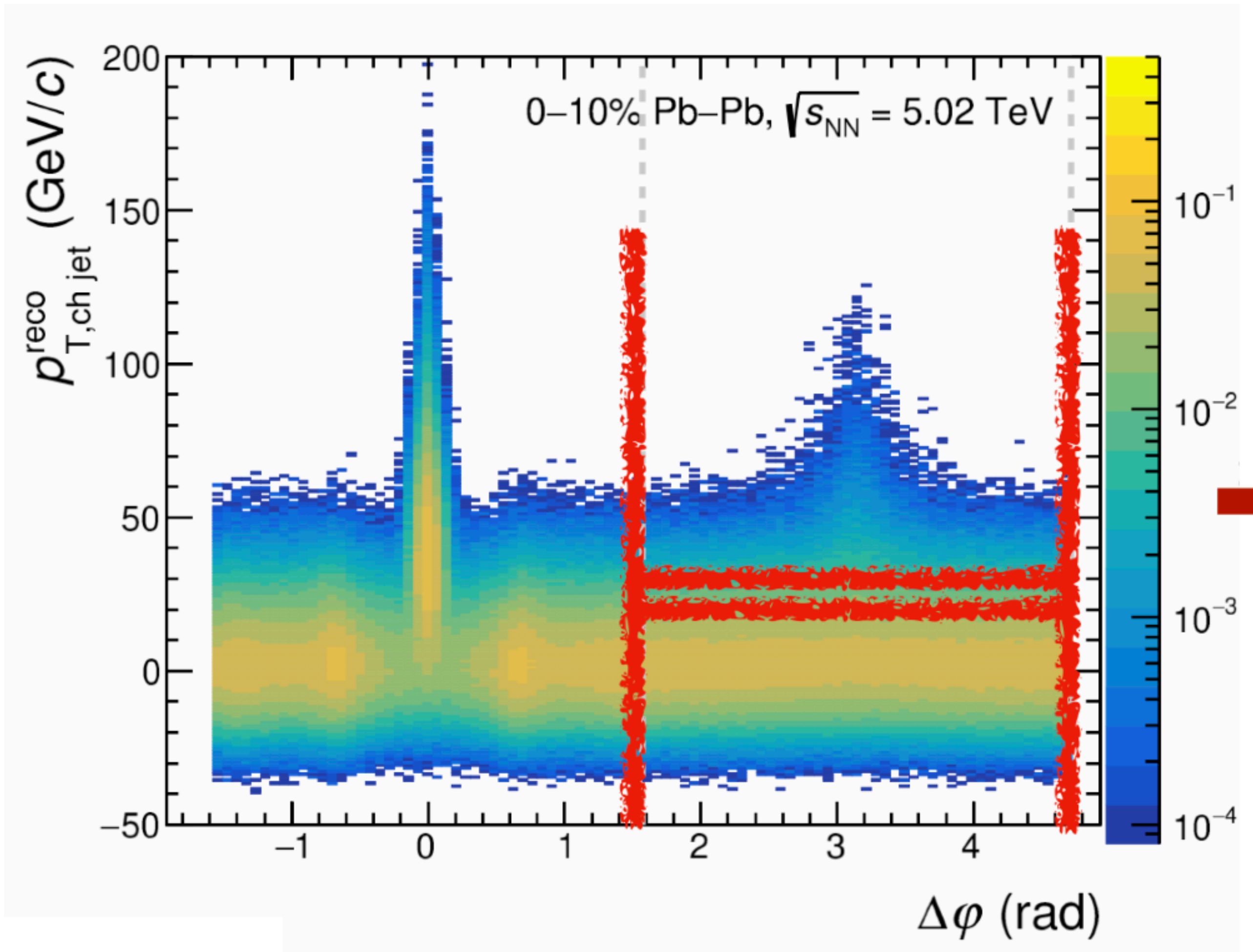
Hadron+jet correlations

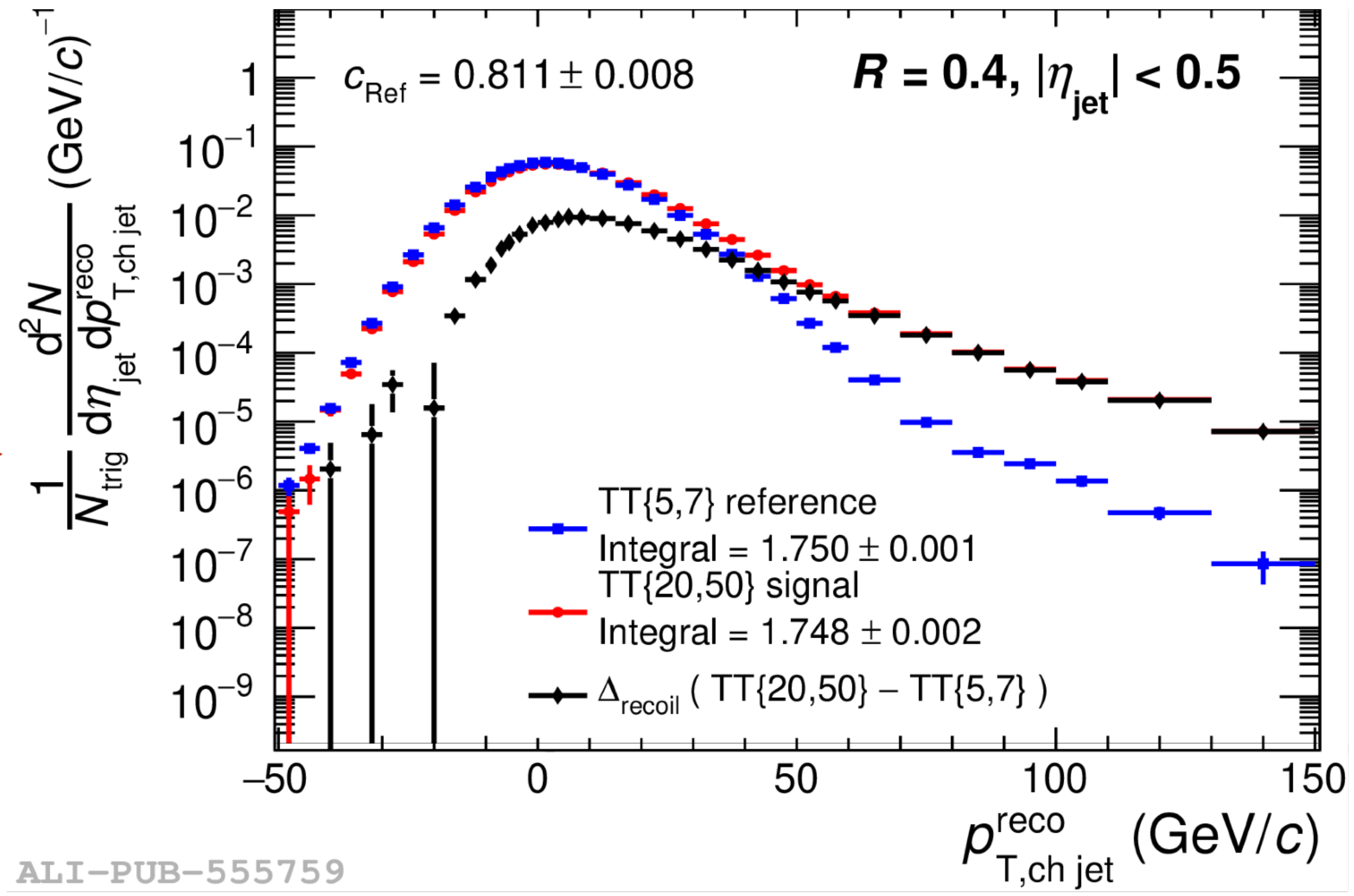
- **Subtract uncorrelated background**: yield difference between exclusive trigger-hadron classes: **'signal'** and **'reference'**:

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



- provides data-driven suppression of combinatorial background → **access low p_{T}, large R jets**





PRL 133 (2024) 022301
PRC 110 (2024) 014906

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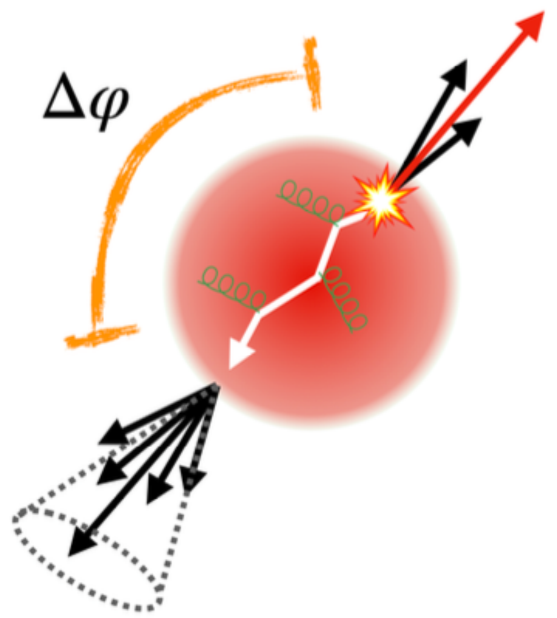

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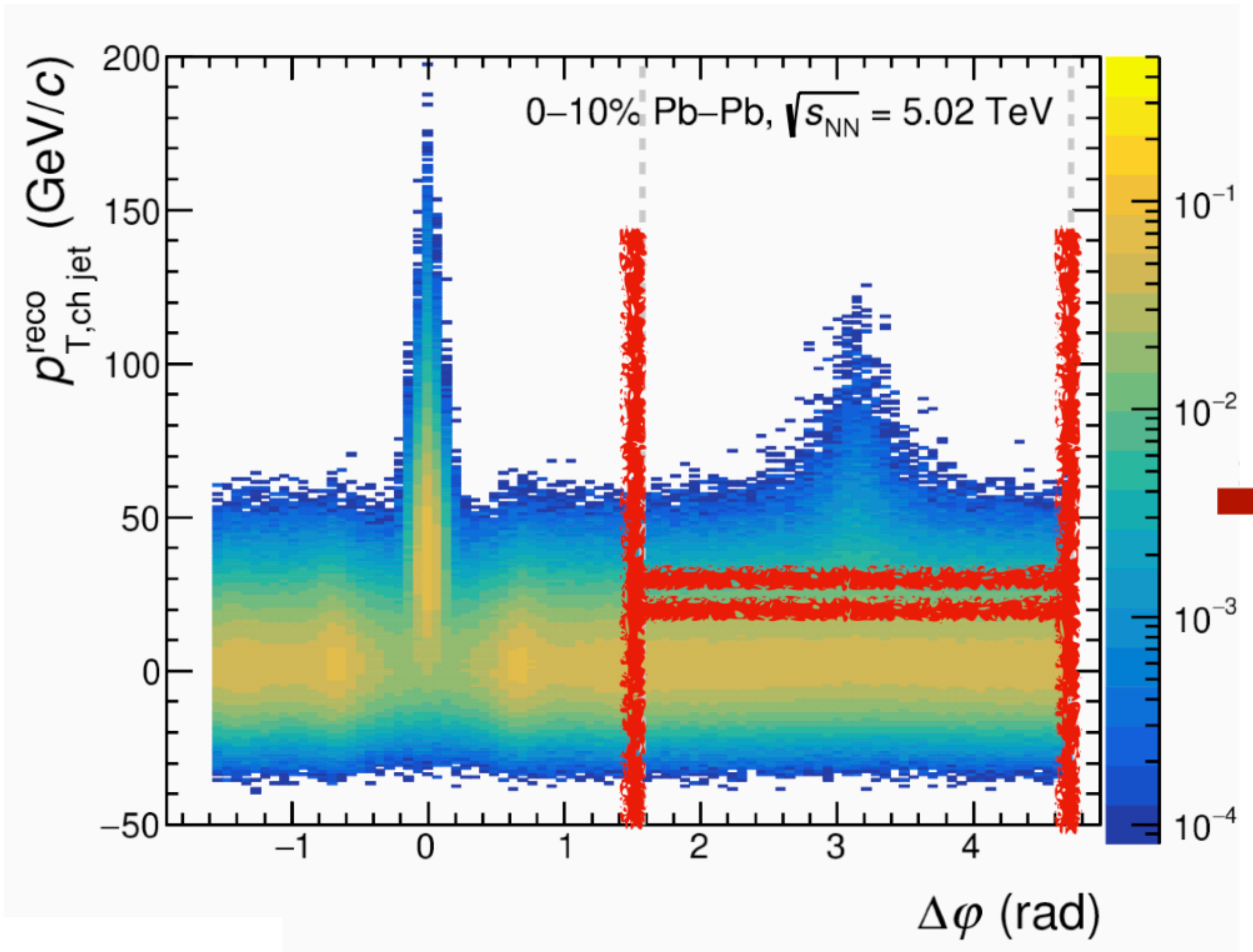

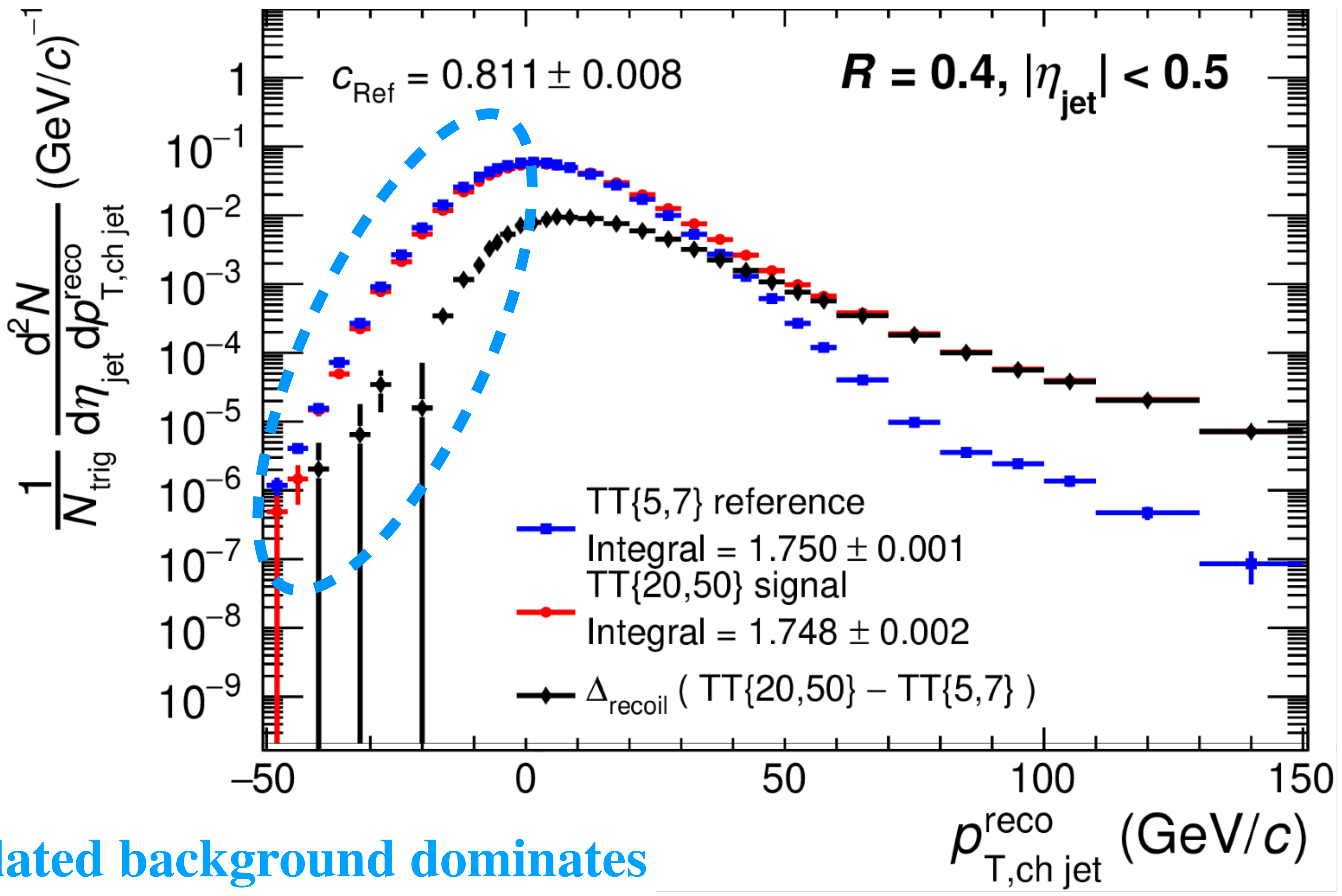

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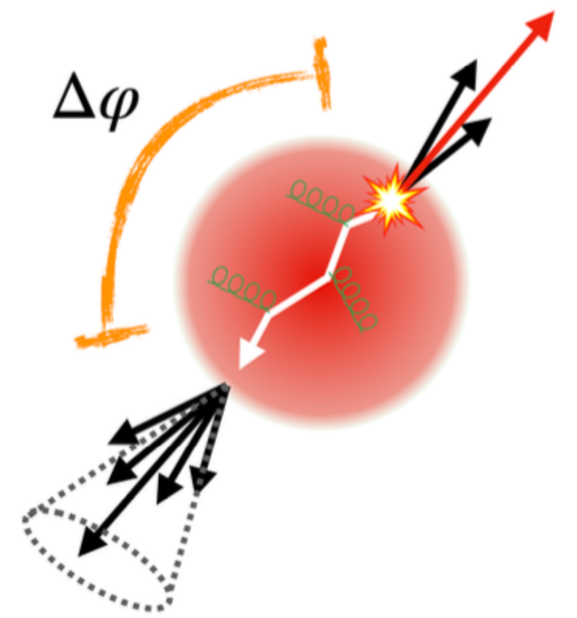

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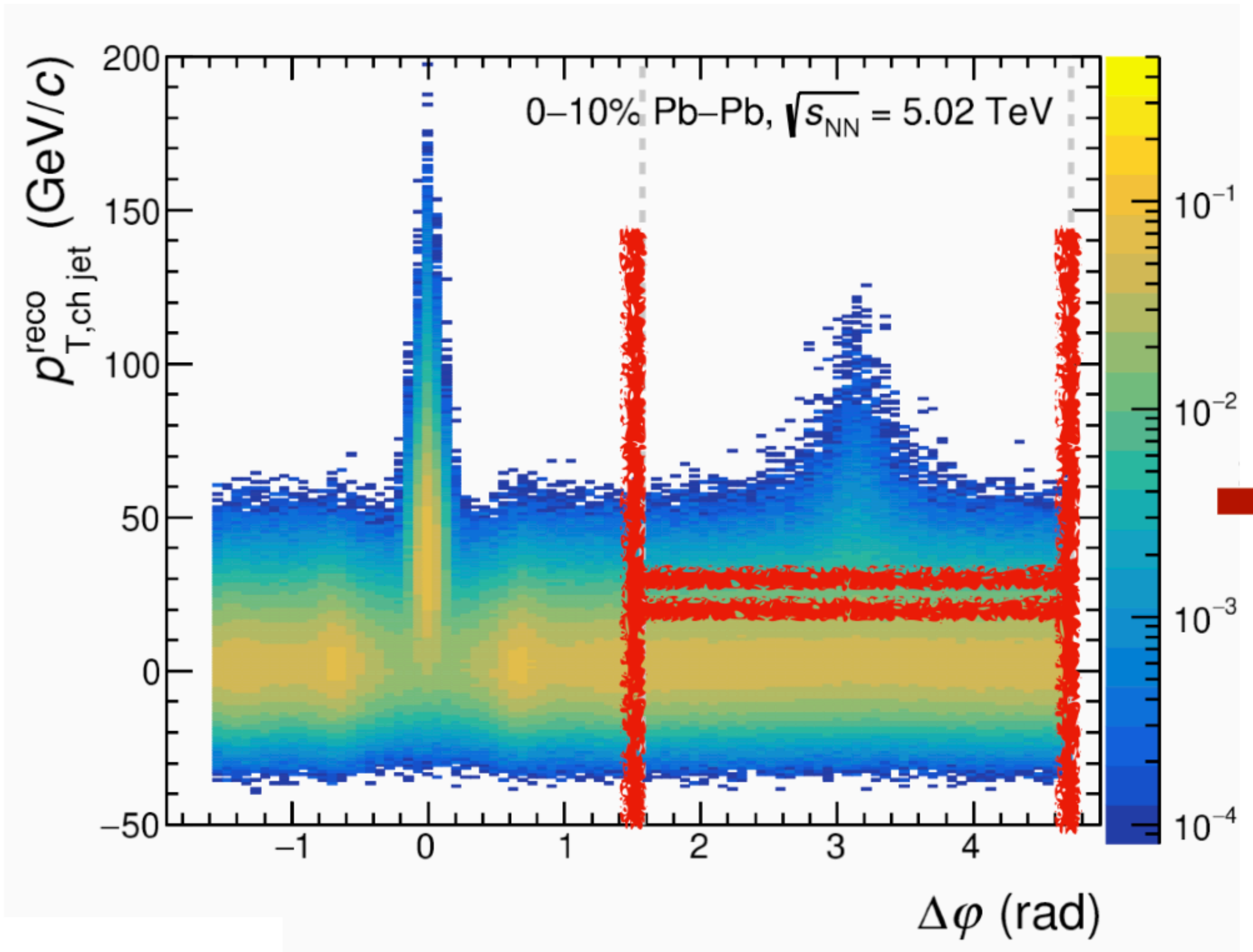

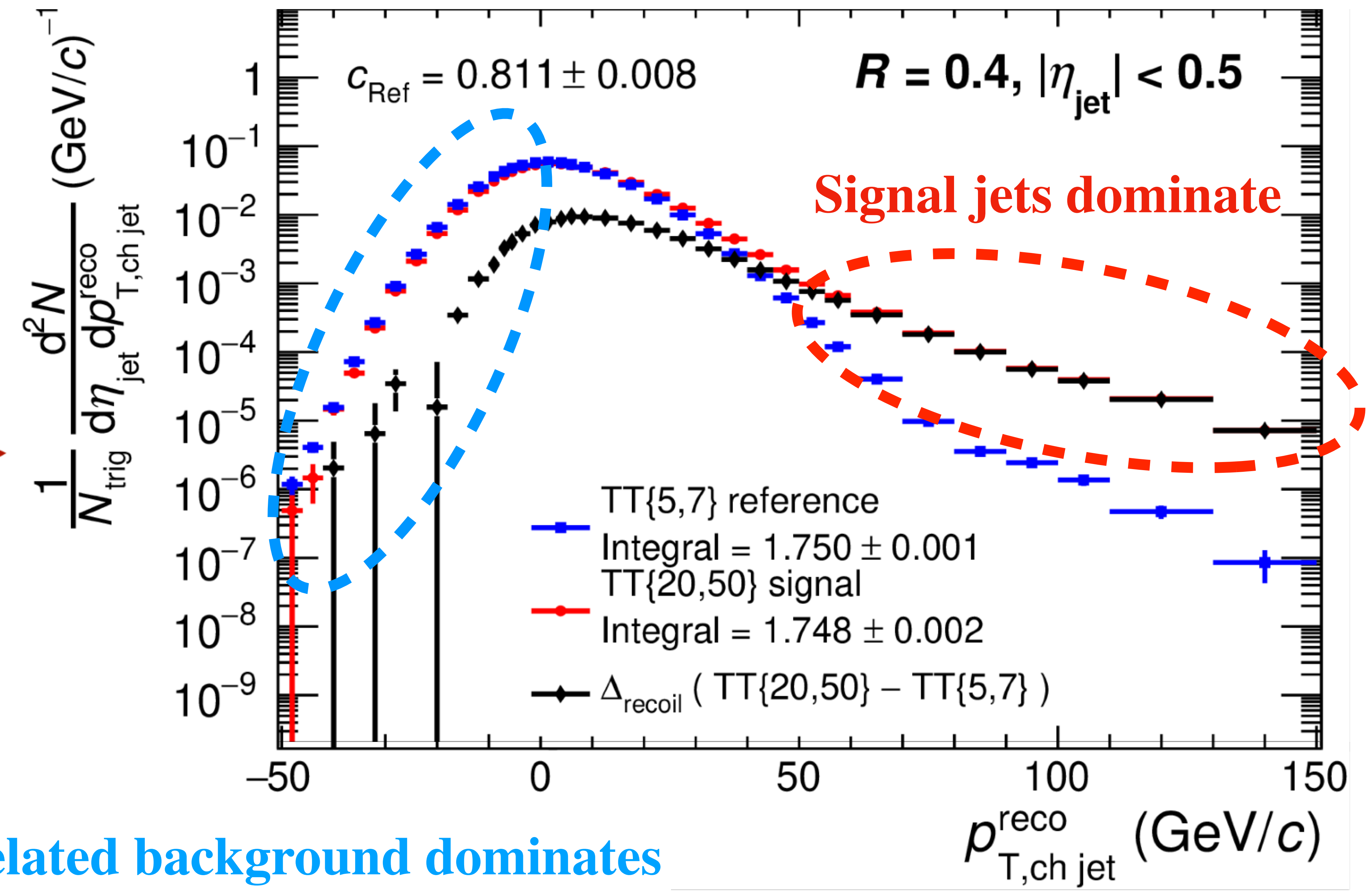

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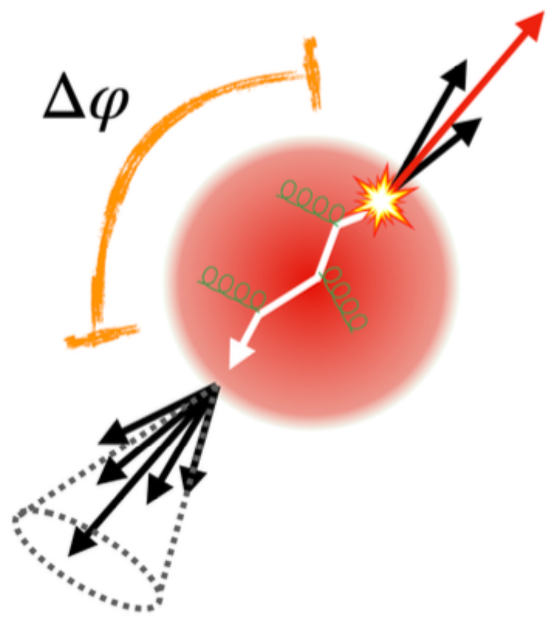

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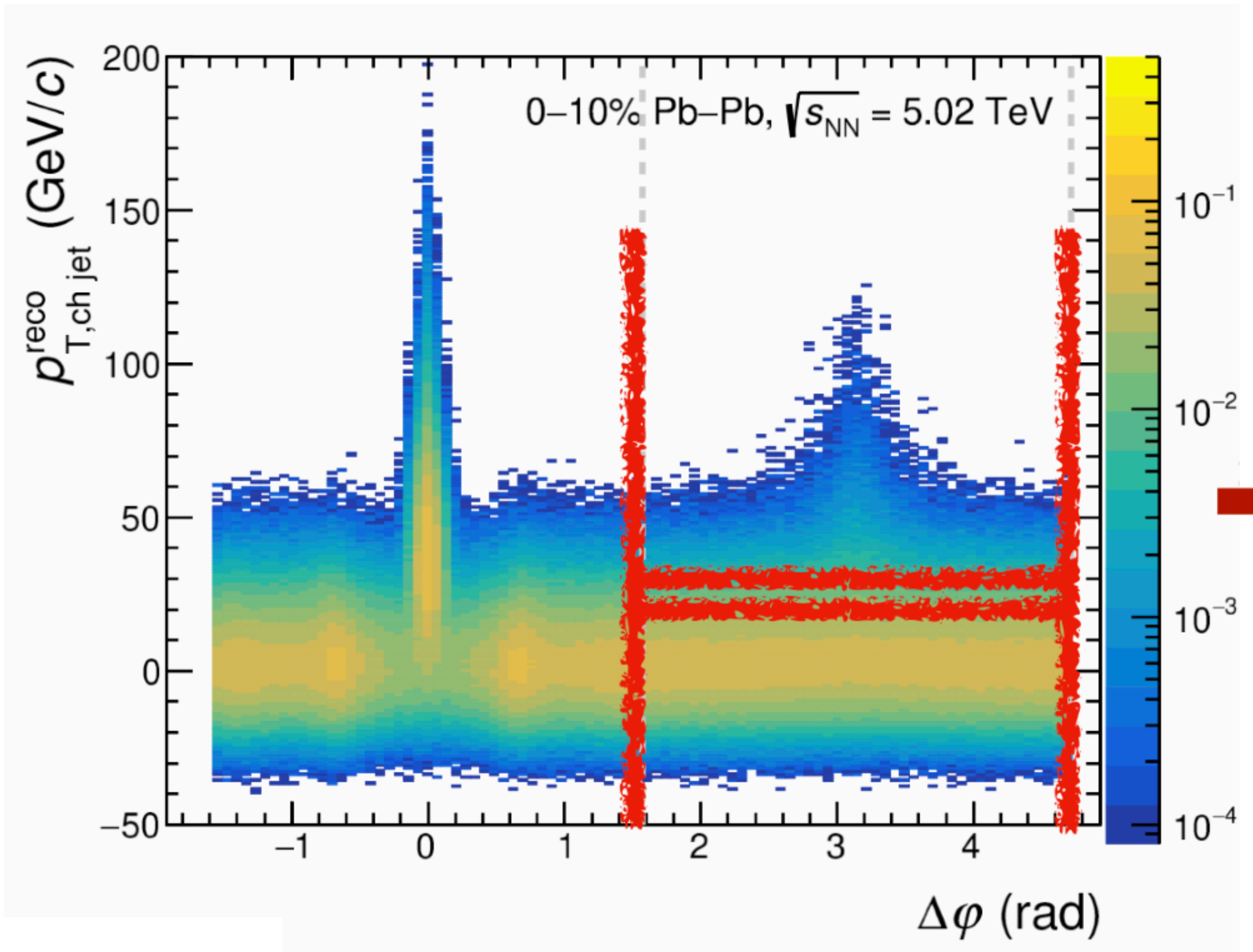

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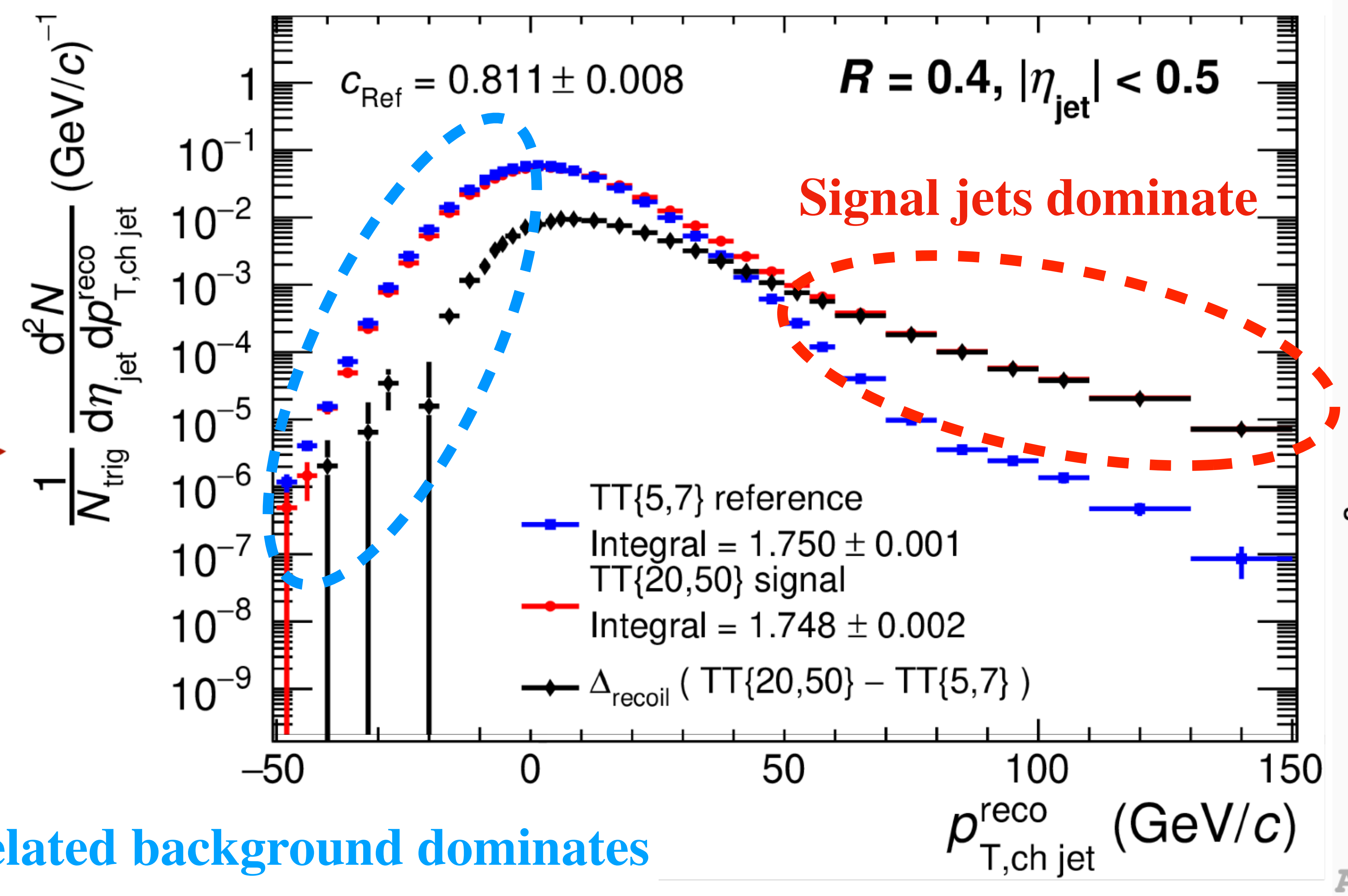
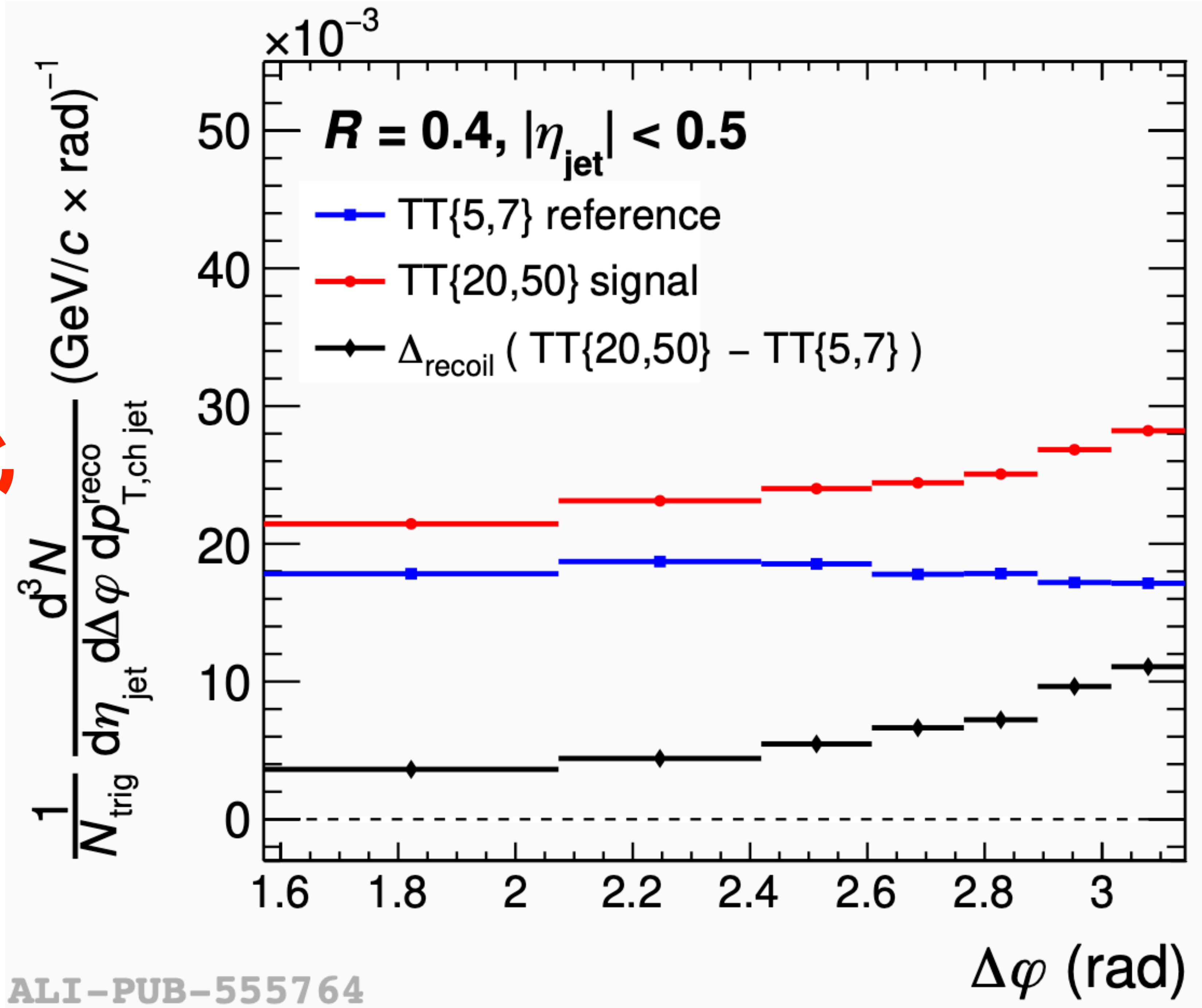
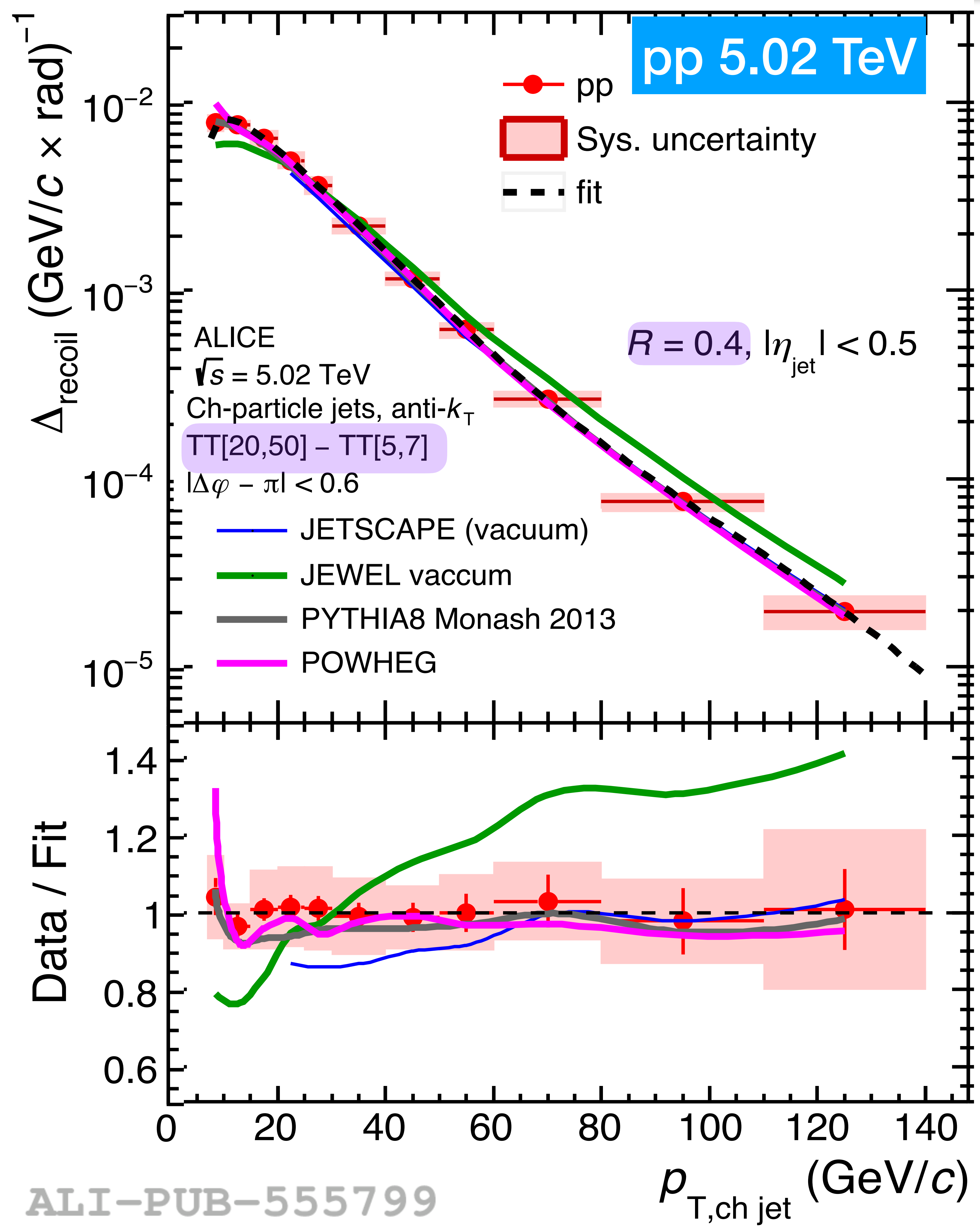
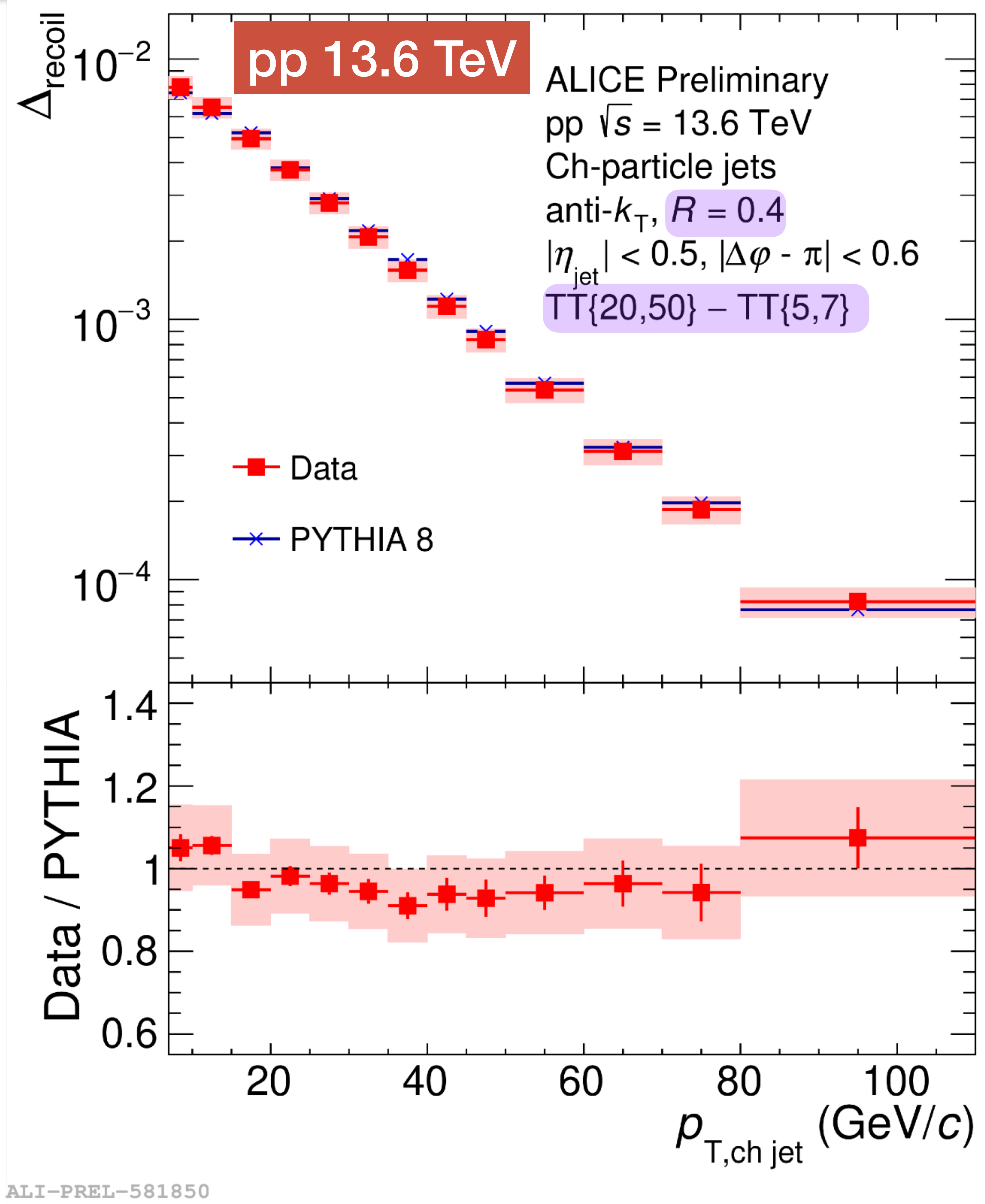
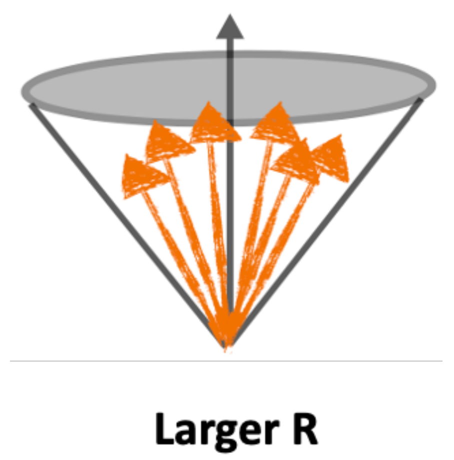




Fully-corrected $\Delta_{recoil}\,(p_T)$ distributions in small systems







- Fully-corrected $\Delta_{recoil}(p_T)$ distributions for $R = 0.4$ in pp collisions at 5.02, 13.6 TeV
- Most model calculations, except JEWEL, reproduce the ALICE data within uncertainties

Fully-corrected $\Delta_{\text{recoil}}(p_T)$ distributions in small systems

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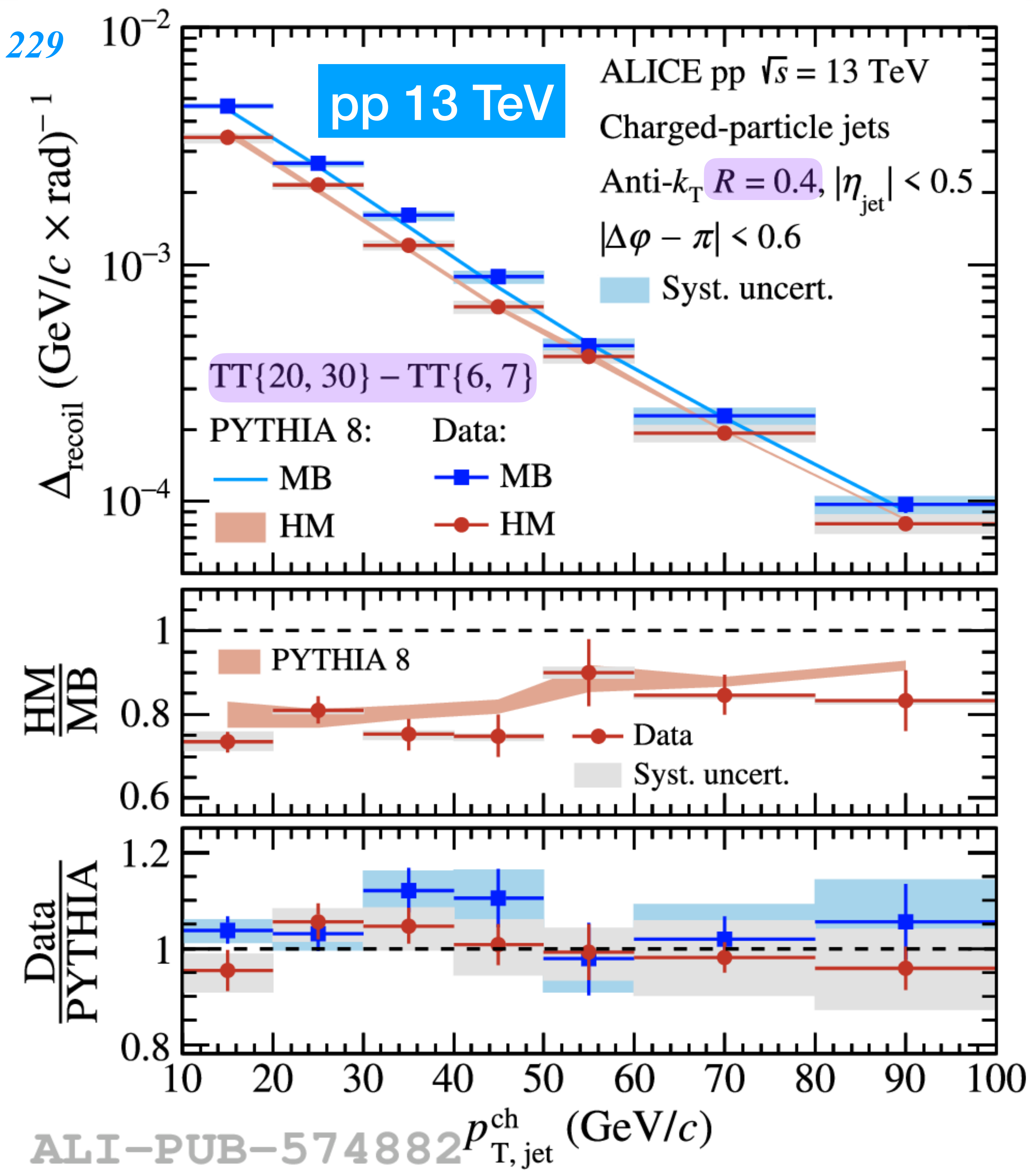
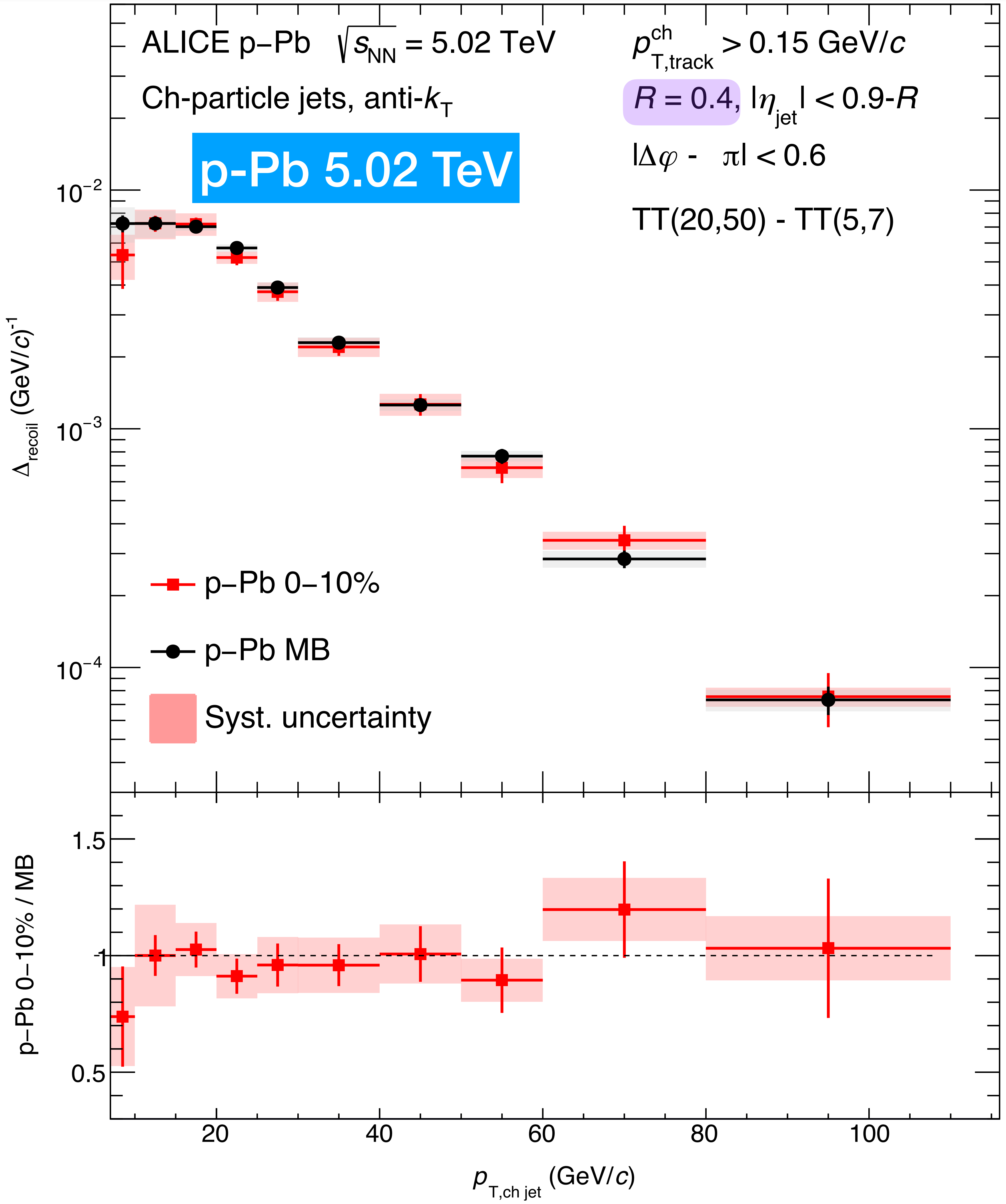
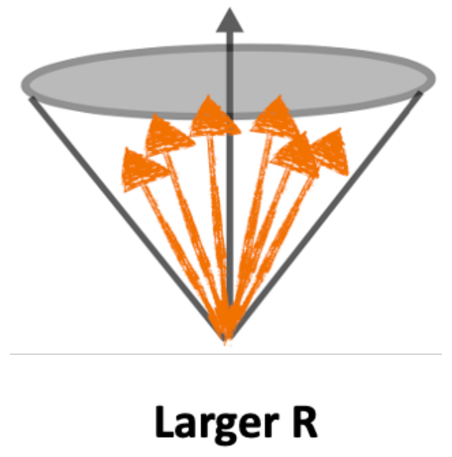
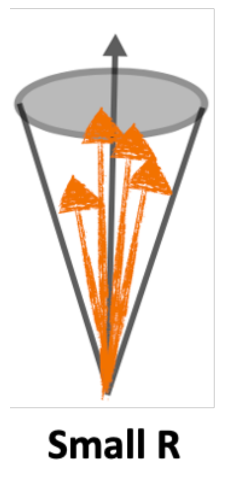


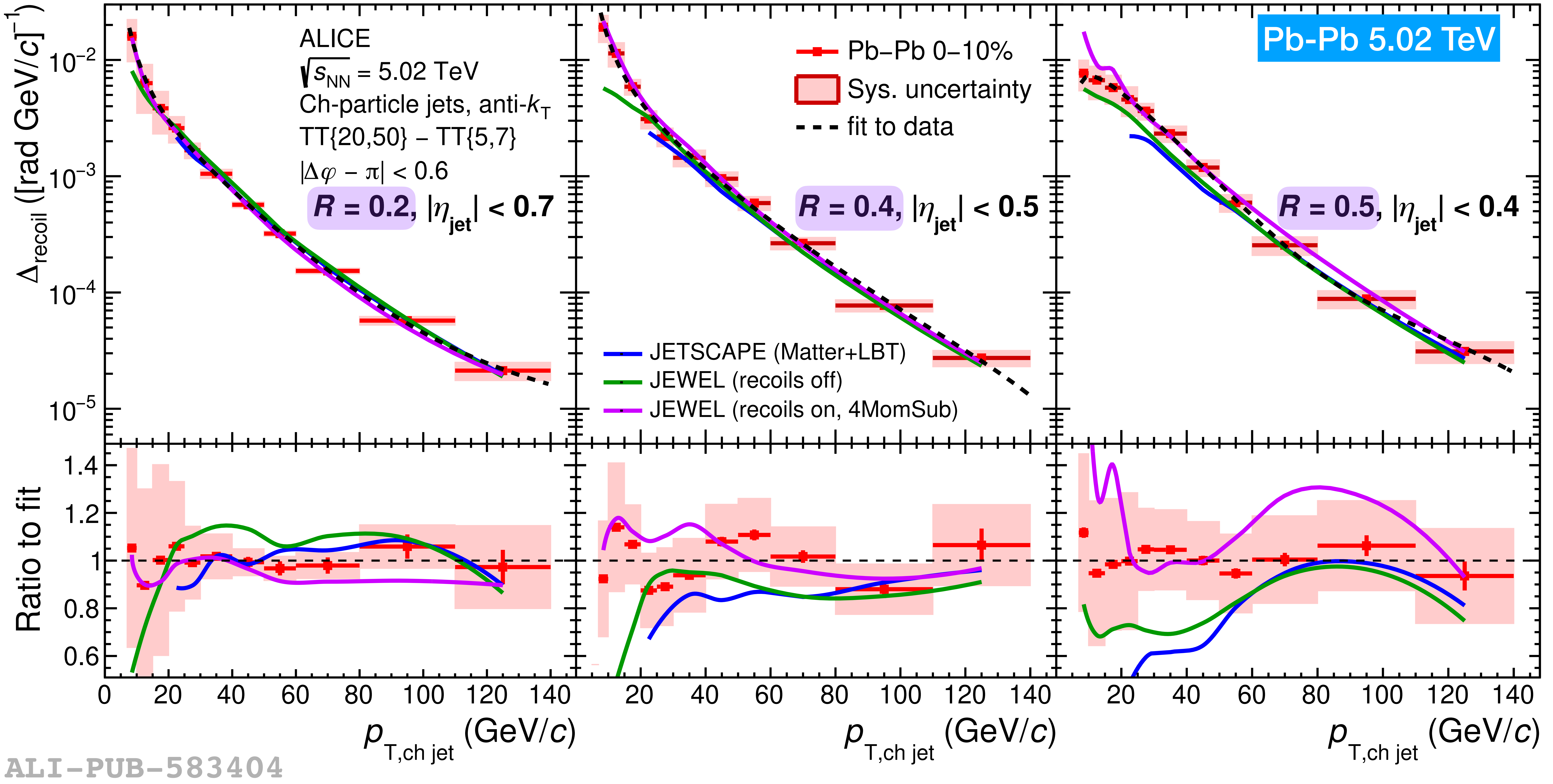


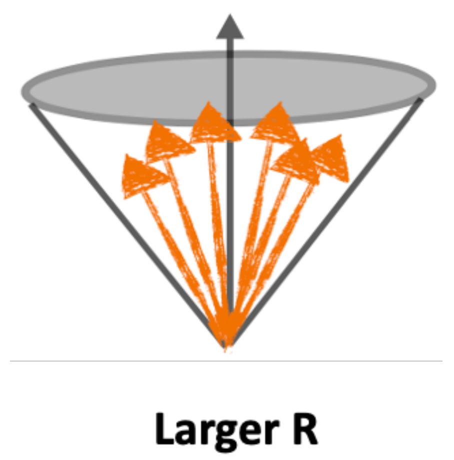


- In HM pp, recoil-jet yields are **suppressed** relative to MB with **weak p_T dependent**
- In HM p-Pb collisions, recoil jet yield shows **no significant dependence** on event activity

Fully-corrected $\Delta_{recoil}(p_T)$ distributions in Pb-Pb



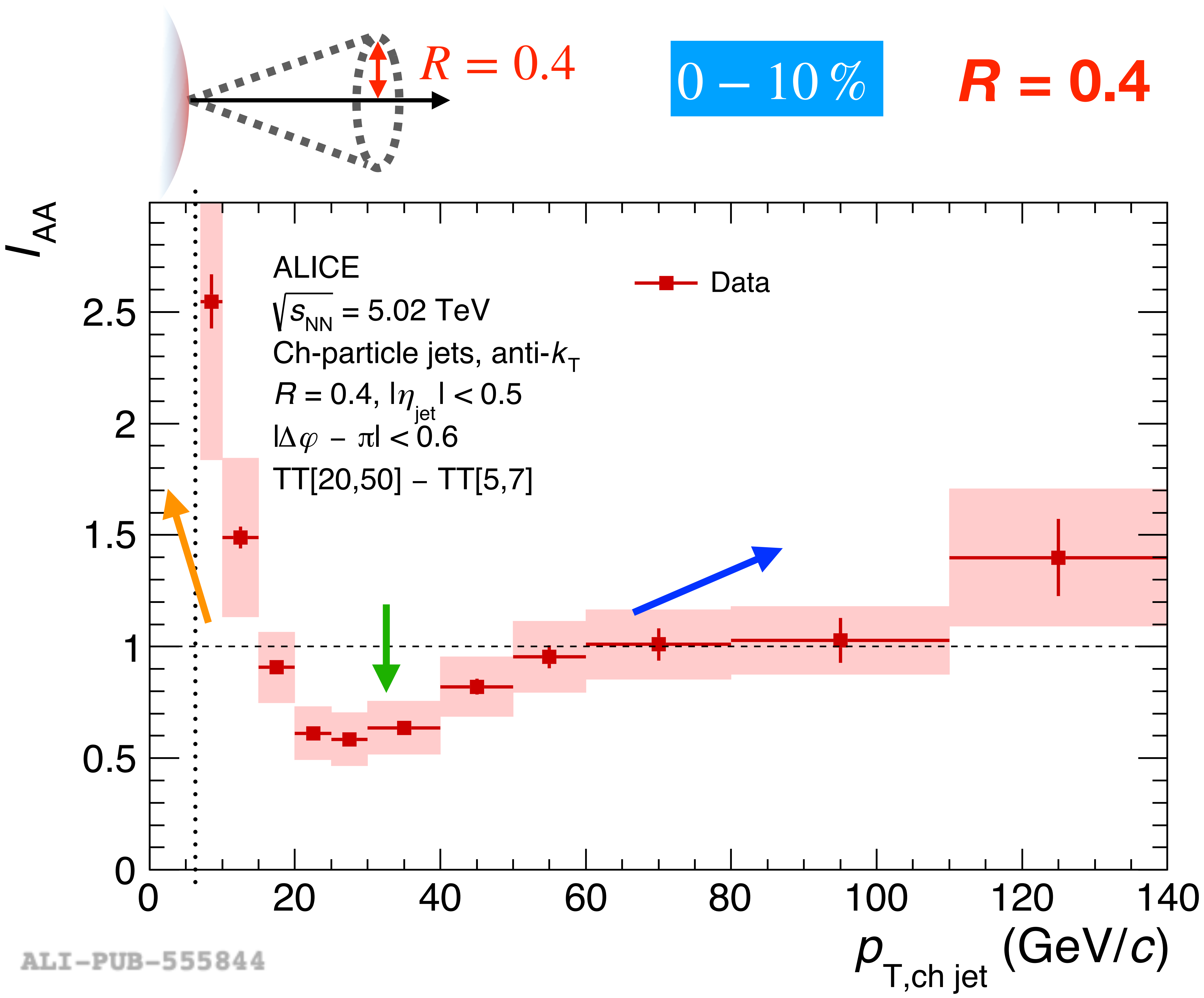




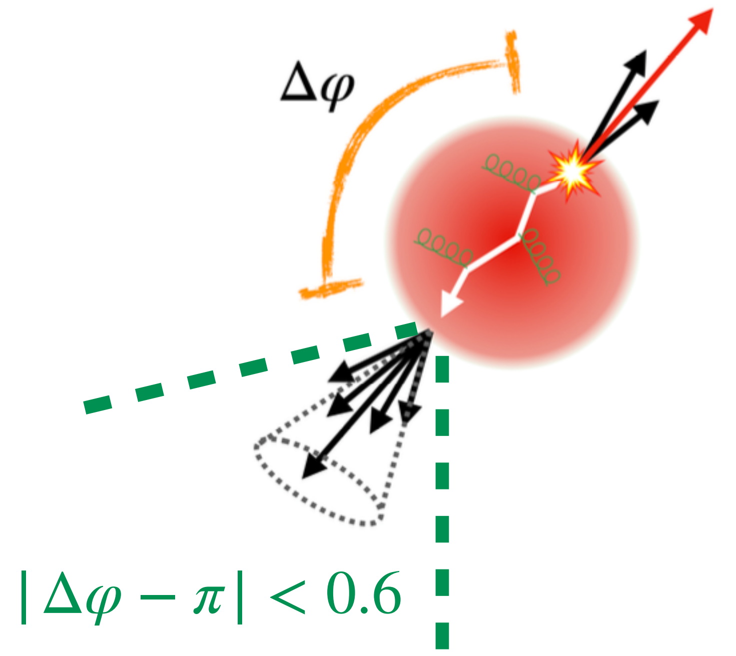
- $\Delta_{recoil}(p_T)$ distributions measured **down to $p_T \sim 7$ GeV/c** in Pb-Pb collisions

→**Among the lowest jet measurement in Pb-Pb collisions with ALICE at the LHC!**

$I_{AA}(p_T)$: recoil-jet yield modification in Pb-Pb



$$I_{AA} \equiv \frac{\Delta_{recoil}\ (p_T)_{AA}}{\Delta_{recoil}\ (p_T)_{pp}}$$



- Low p_T **jet yield enhancement**

  → possible recovery of redistributed energy

- **Suppression** at $20 < p_{T,jet} < 60$ GeV/c

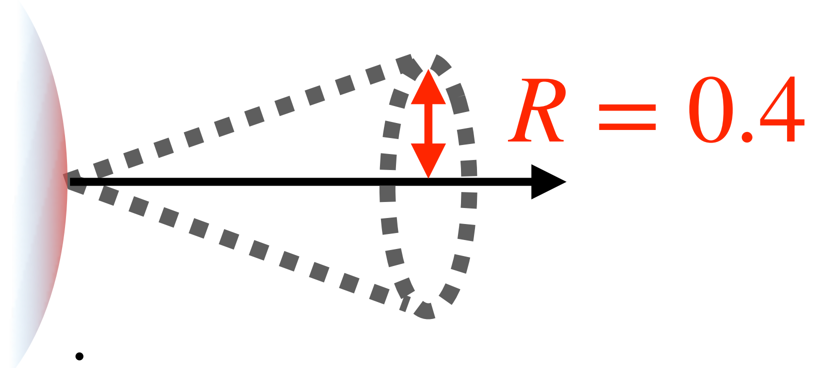
  → jet energy loss

- **Rising trend** with increasing jet p_T

  → Interplay of jet quenching and jet production or hadron energy loss

Phys.Lett.B 854 (2024) 138739

$I_{AA}(p_T)$ compared to models



0 – 10 %

***R* = 0.4**

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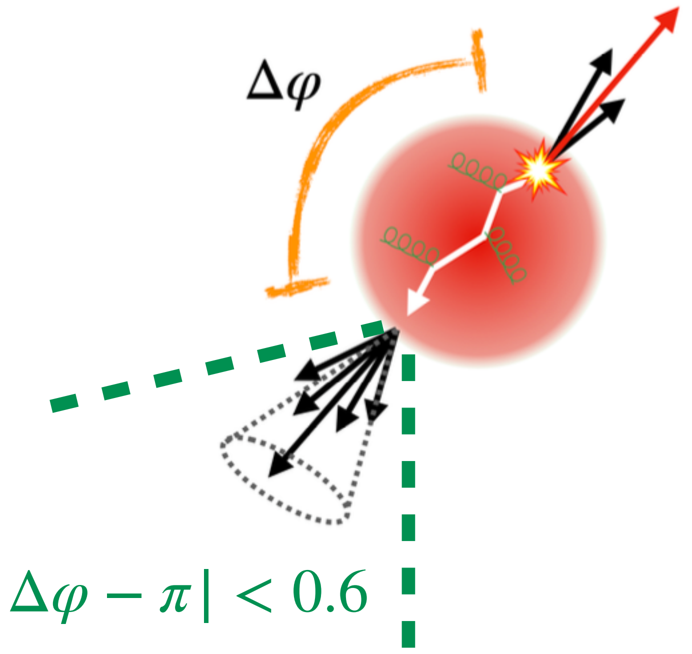
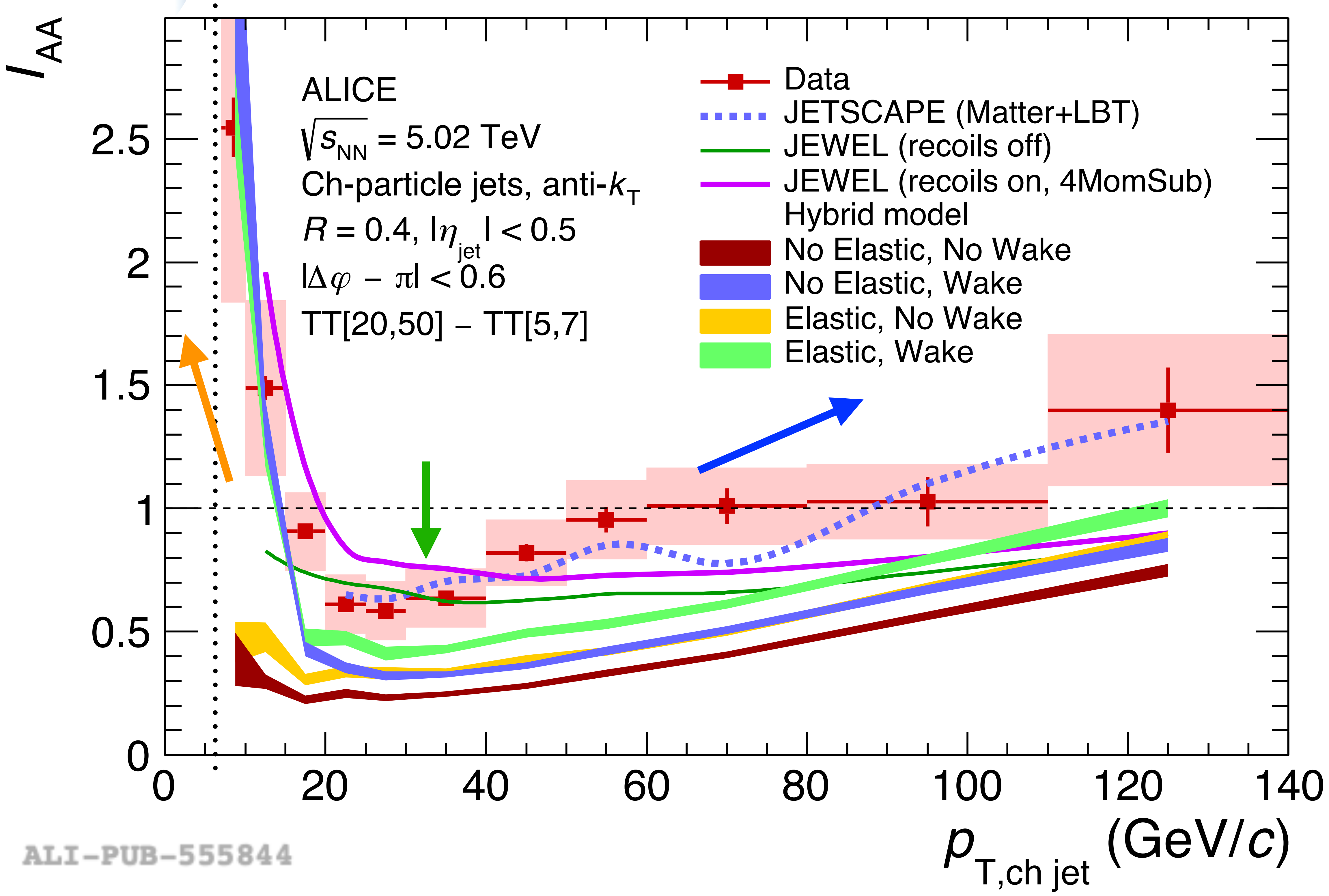
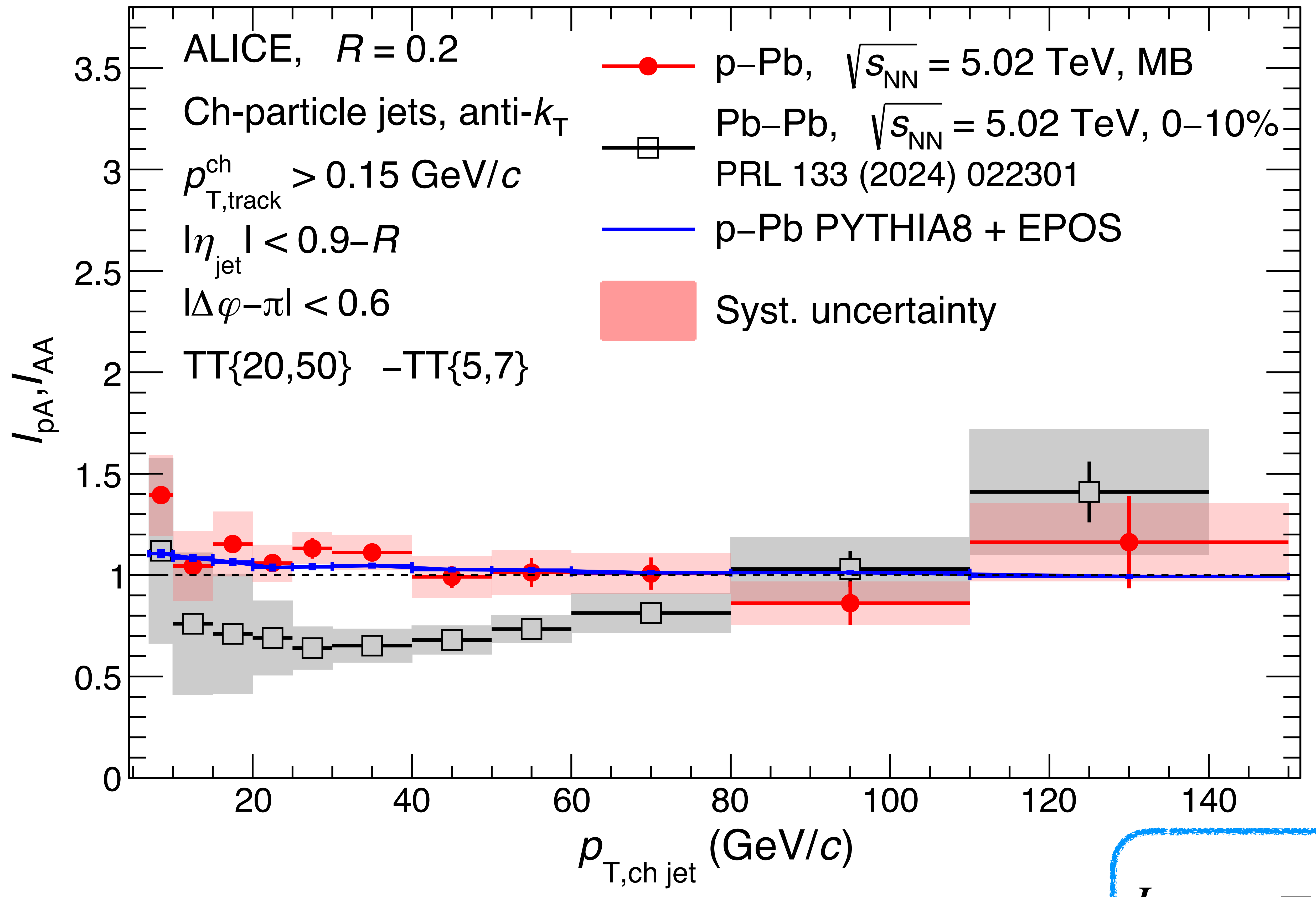
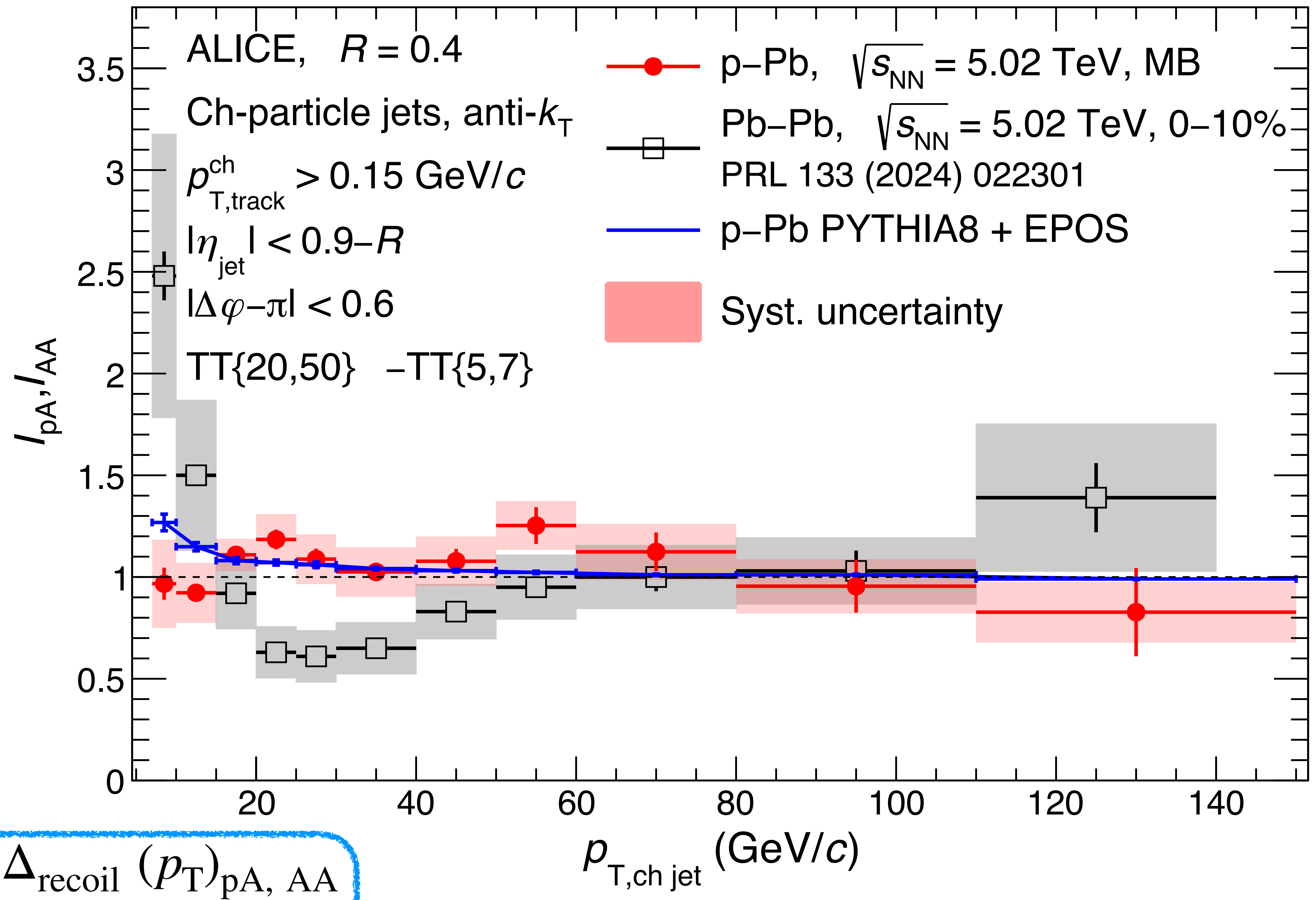




- **JETSCAPE broadly describes** the I_{AA} distributions
- **Hybrid Model** and **JEWEL** predictions tend to **overestimate** the **suppression** at high p_T
- **Hybrid Models** with wake effect and **JEWEL** with recoils on partially catch the low p_T yield enhancement
  - **Medium response** is favored as a possible origin of the low-p_T yield **enhancement**

Comparison of $I_{AA}(p_T)$ and $I_{pA}(p_T)$





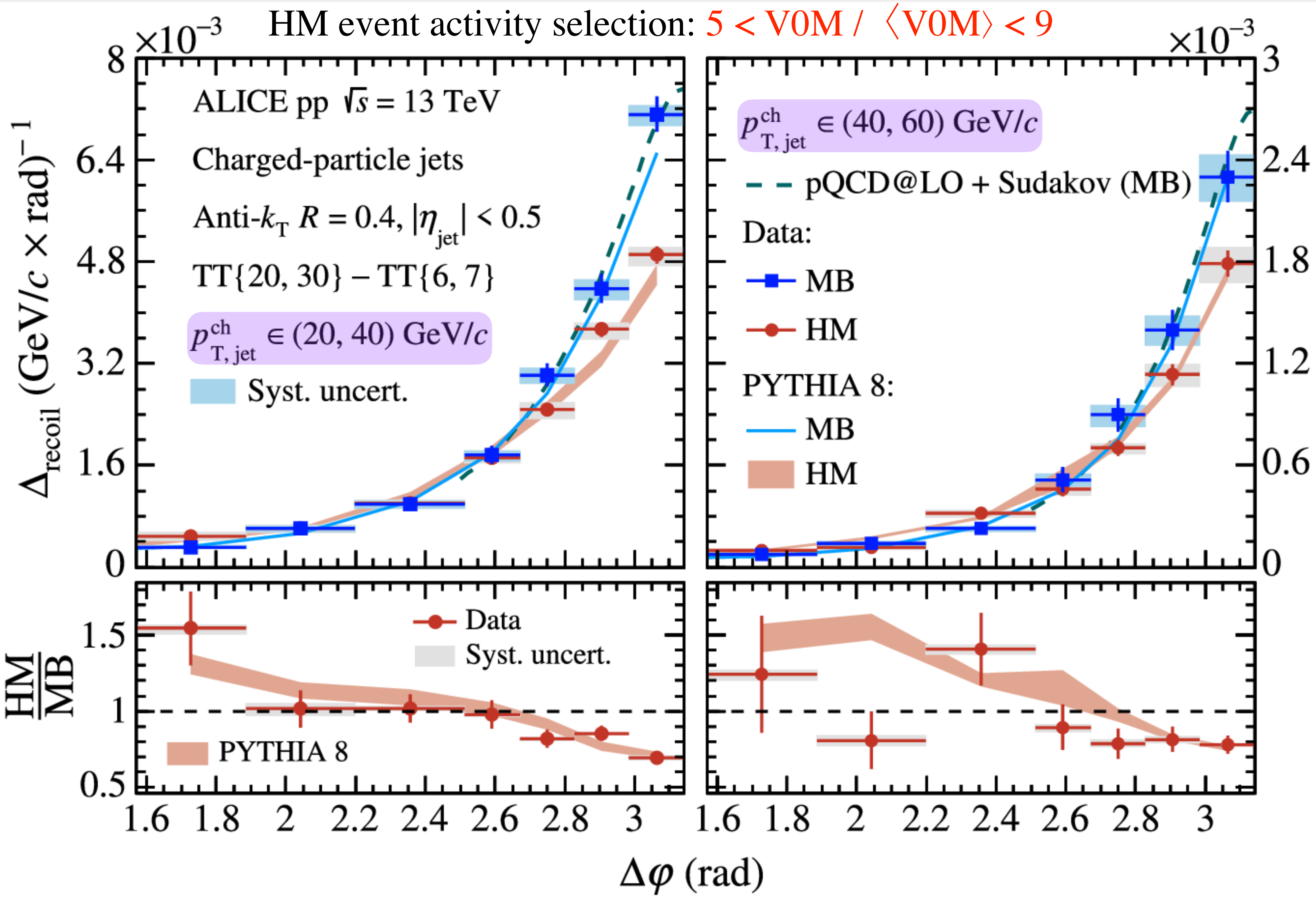
$$I_{\mathrm{pA,\ AA}} \equiv \frac{\Delta_{\mathrm{recoil}}\ (p_{\mathrm{T}})_{\mathrm{pA,\ AA}}}{\Delta_{\mathrm{recoil}}\ (p_{\mathrm{T}})_{\mathrm{pp}}}$$

- For the I_{pA} (p–Pb/pp ratios), the uncertainties in pp and p–Pb collisions are treated as uncorrelated and are added in quadrature.
- **No significant modification** is observed with uncertainties in p-Pb collisions

Δ_{recoil} ($\Delta\varphi$) distributions in pp at 5.02 TeV: R = 0.4

- Corrected $\Delta_{\mathrm{recoil}}(\Delta\varphi)$ distributions for R = 0.4 in **pp collisions** with different jet p_{T} bins
- Vacuum calculations **describe the pp acoplanarity distributions** within uncertainties

Δ_{recoil} ($\Delta\varphi$) distributions in pp at 13 TeV: $R = 0.4$



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- **Broadening** of HM acoplanarity distribution with respect to MB
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  - At first sight: jet-quenching-like broadening?

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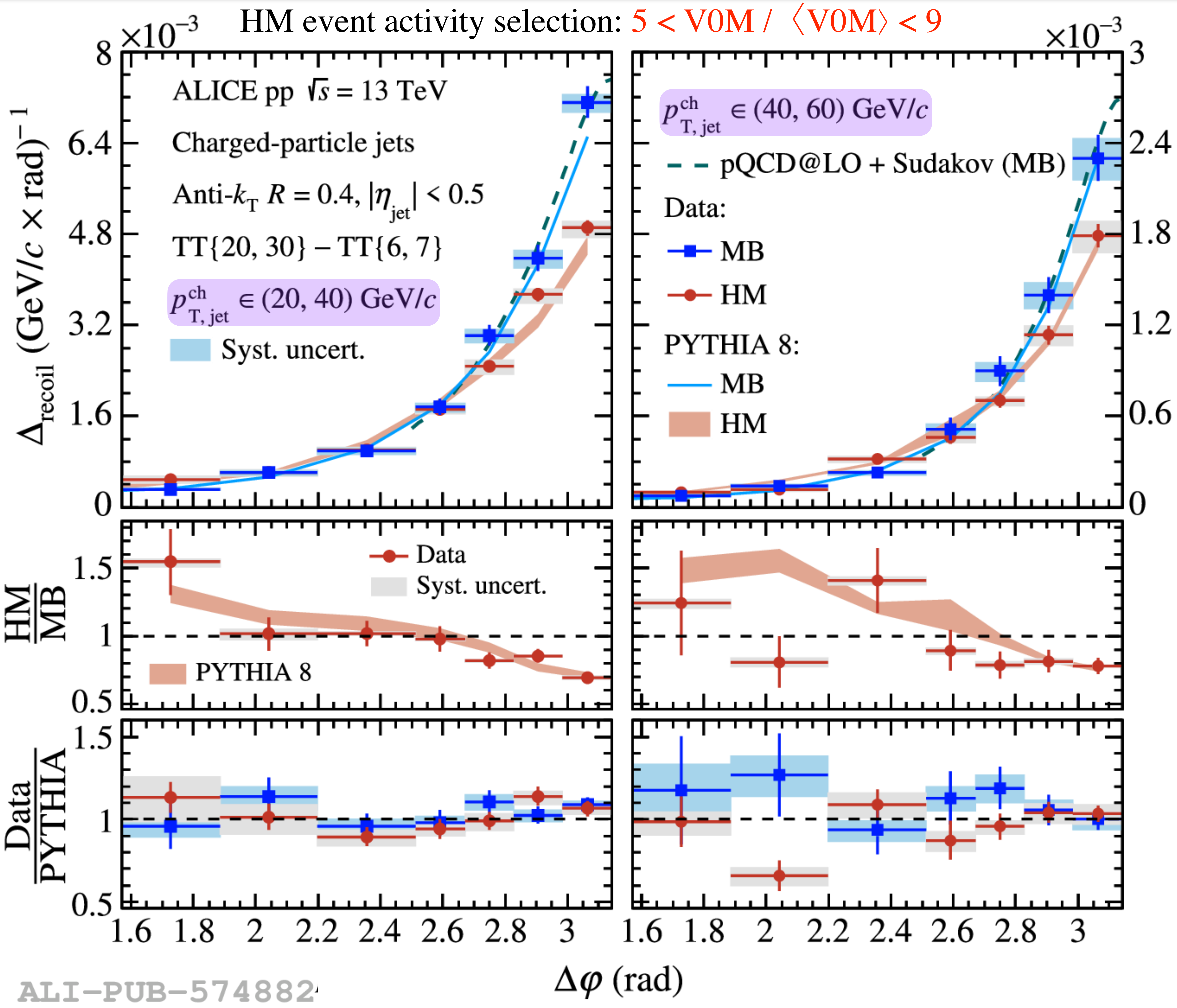

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  - The effect is stronger for low p_T jets
  - At first sight: jet-quenching-like broadening?

- Quantitative comparison to PYTHIA8 Monash (does not account for jet quenching effects) shows similar trend

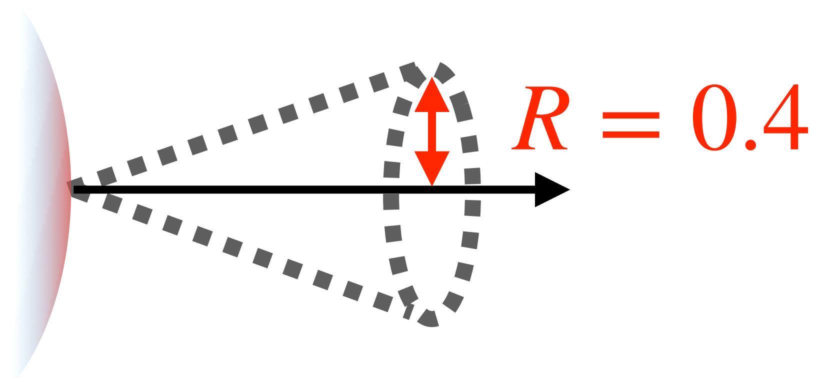
→ indicate the effect is not from the jet-medium interaction

→ broadening driven by **HM event selection**

Δ_{recoil} $(\Delta\varphi)$ distributions in p-Pb at 5.02 TeV: $R = 0.4$

- Corrected $\Delta_{\mathrm{recoil}}(\Delta\varphi)$ distributions for $R = 0.4$ across jet p_{T} intervals for 0-10% p-Pb collisions
- The 0–10% / MB ratios show **no significant dependence on event activity**

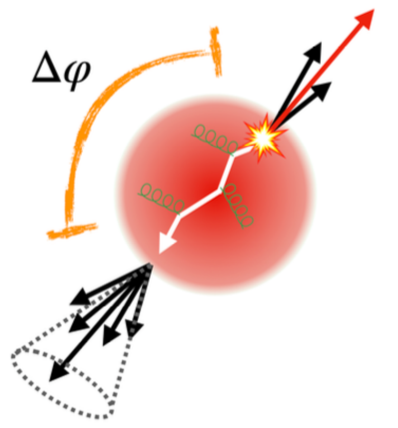
$I_{AA}(\Delta\varphi)$ - recoil jet angular modification in Pb-Pb

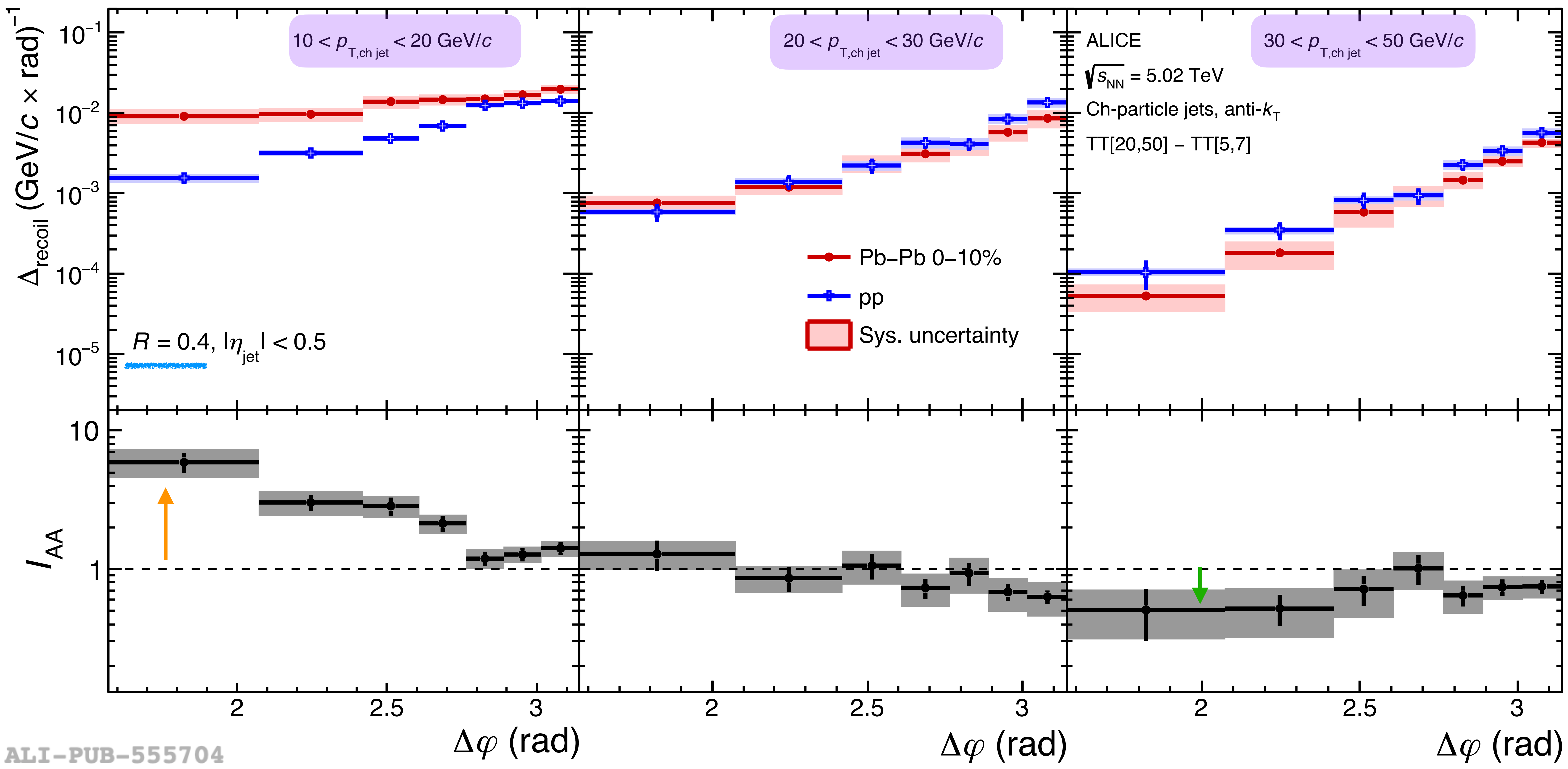


$0-10\,\%$

R = 0.4

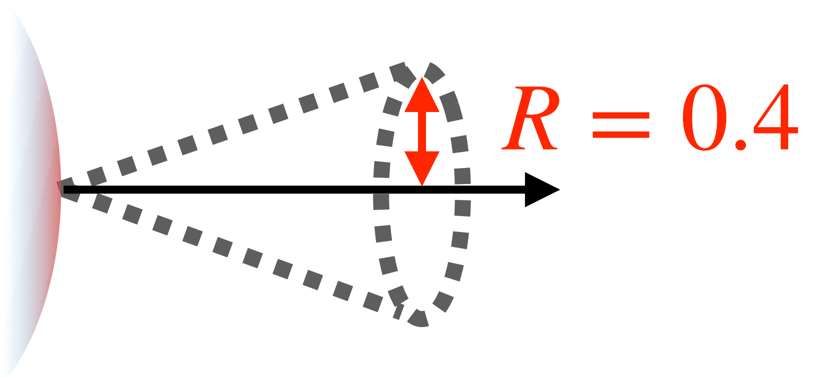
$$I_{AA} \equiv \frac{\Delta_{\mathrm{recoil}}\,(\Delta\varphi)_{AA}}{\Delta_{\mathrm{recoil}}\,(\Delta\varphi)_{pp}}$$





- $p_T \in [10,20]$ GeV/c: **significant acoplanarity broadening**
- $p_T \in [20,30]$ GeV/c: **no broadening or suppression**
- $p_T \in [30,50]$ GeV/c: **recoil-jet yield suppression**

$I_{AA}(\Delta\varphi)$ compared to models



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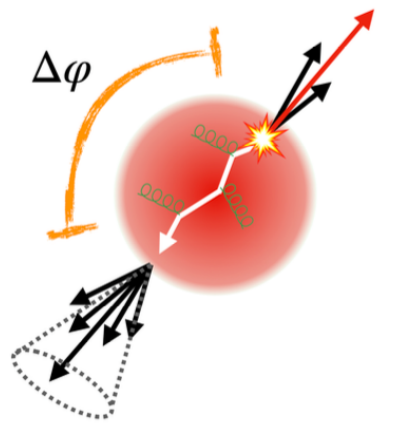
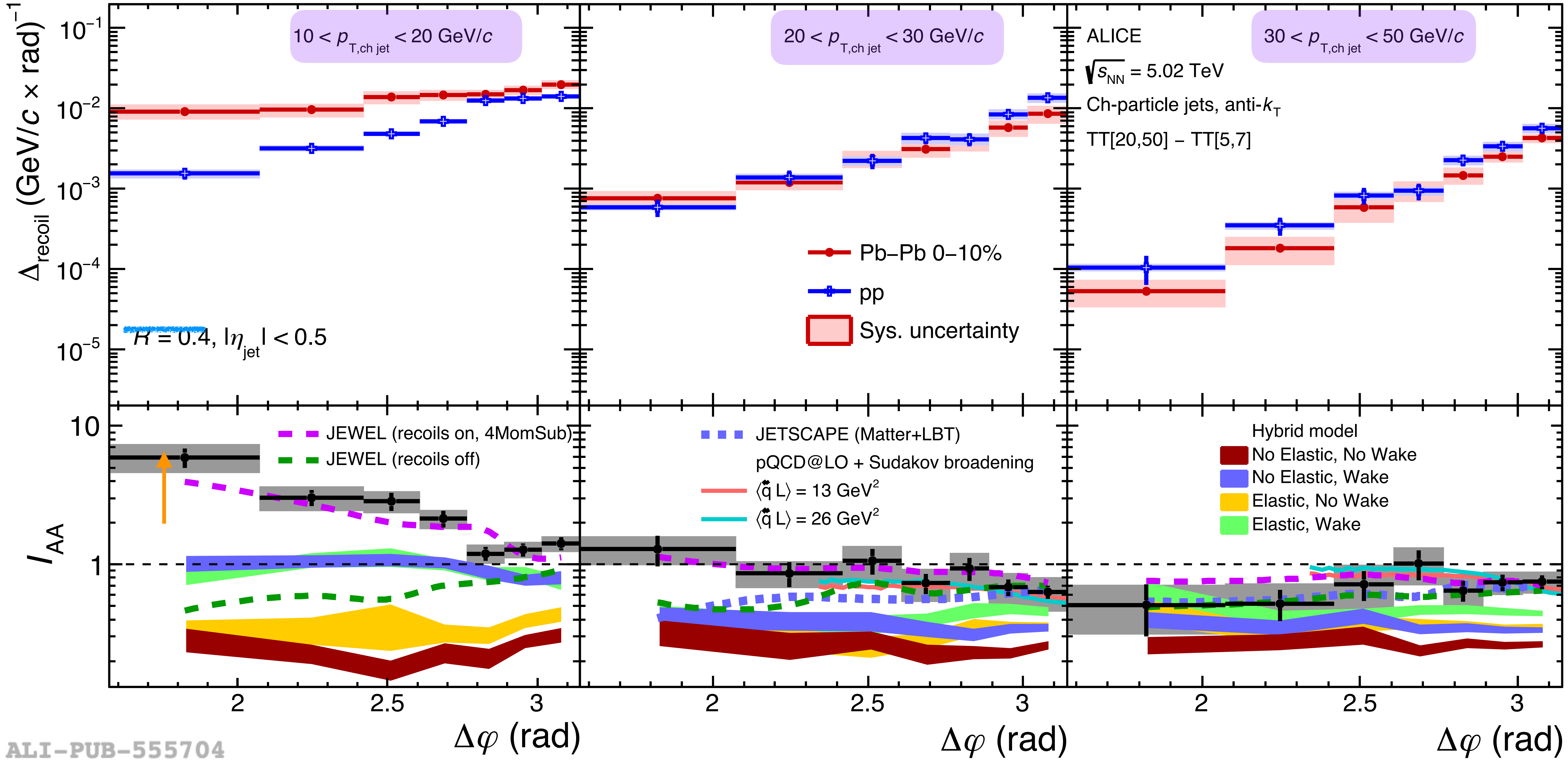
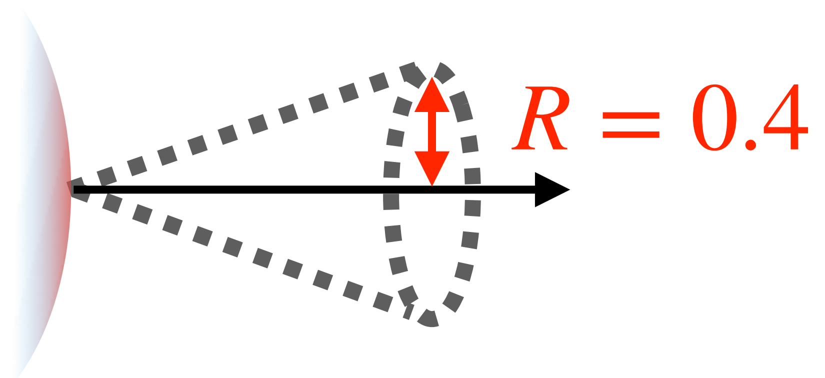




- **JETSCAPE** and **pQCD w/ broadening reasonably describe** I_{AA} for $p_T \in [20,50]$ GeV/c
- **JEWEL** with recoils-on **describes** well the I_{AA} distributions across jet p_T intervals
- **Hybrid model** captures the yield enhancement, but does not reproduce the observed broadening when elastic and wake components are included

$I_{AA}(\Delta\varphi)$ compared to models



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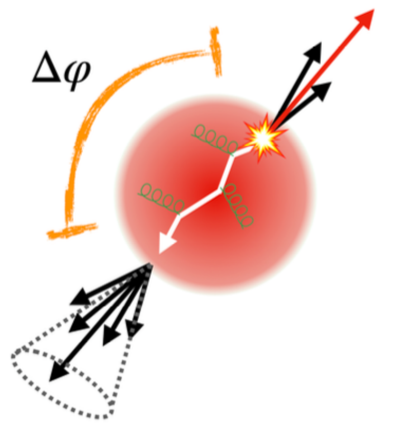

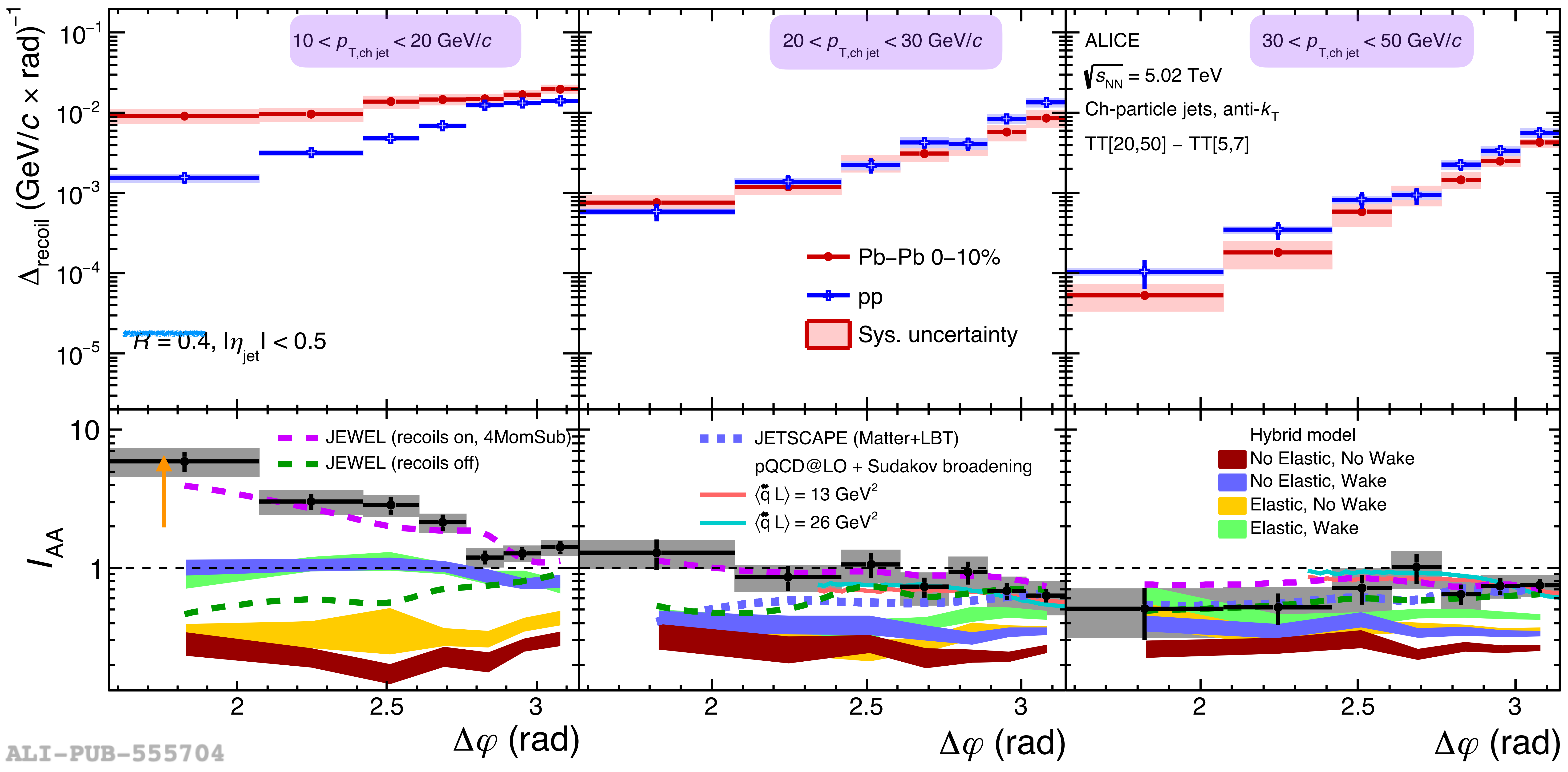

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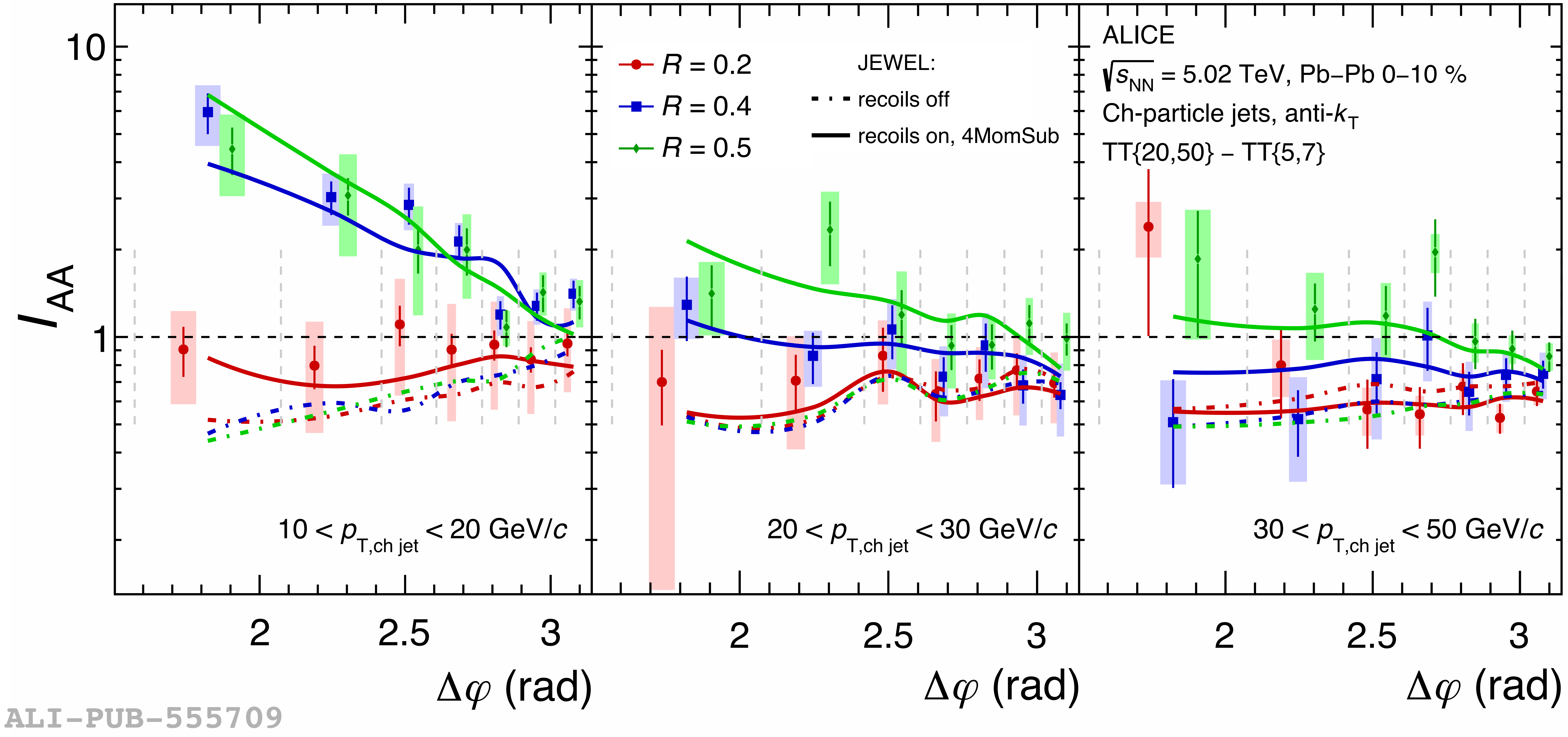
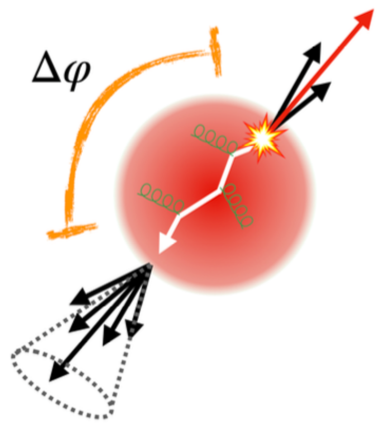
$I_{AA}(\Delta\varphi)$ vs R



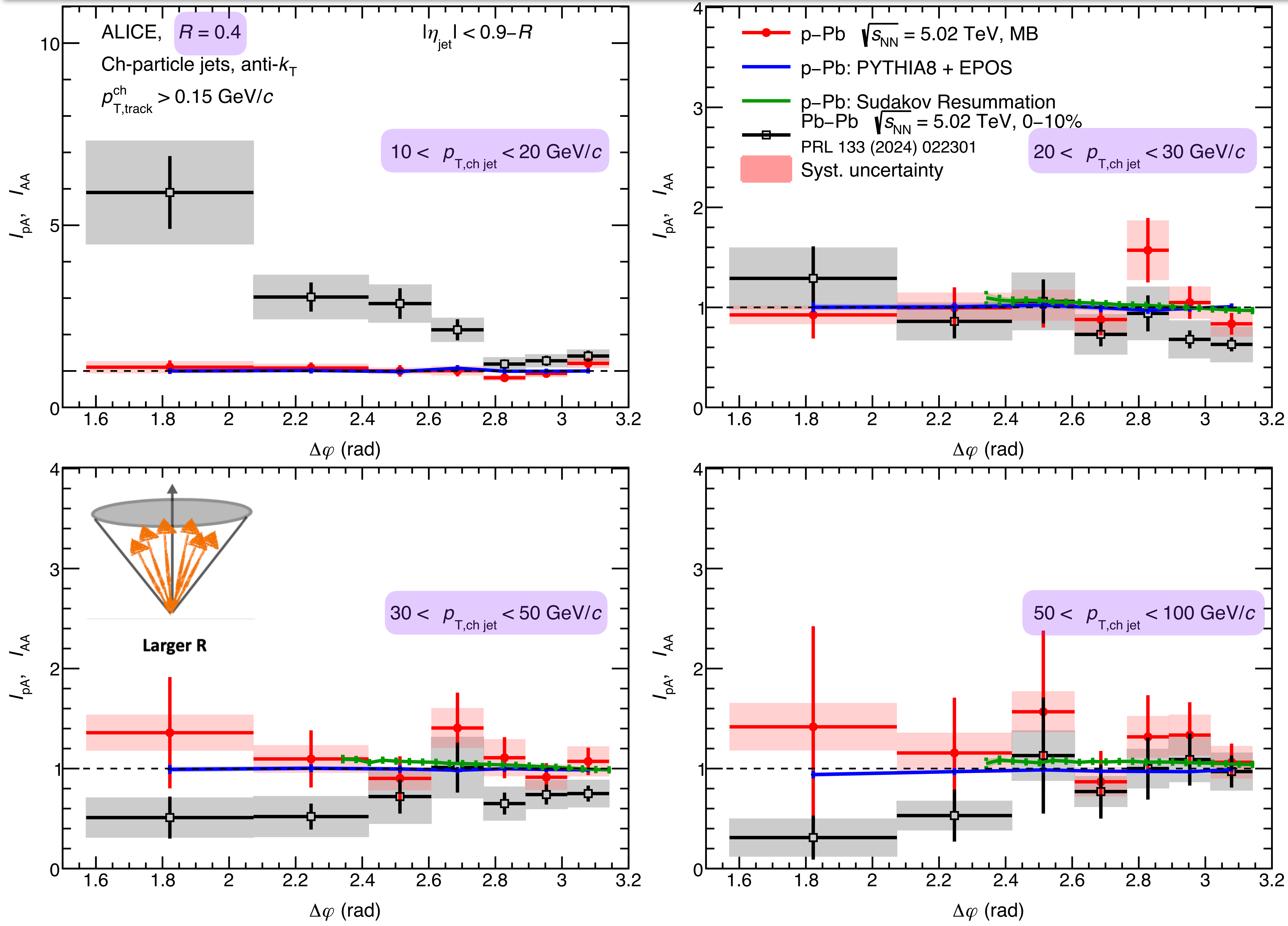


$$I_{AA} \equiv \frac{\Delta_{recoil}(\Delta\varphi)_{AA}}{\Delta_{recoil}(\Delta\varphi)_{pp}}$$

- Transition to broadening from $R = 0.2$ to $R = 0.4$ for $p_T \in [10,20]$ GeV/c

  → soft particles from the **medium response** are increasingly clustered into the jet as R increases
- All features of distribution **reproduced by JEWEL** with recoils on → observed broadening consistent with **medium response** rather than Molière scattering

$I_{AA}(\Delta\varphi)$ vs $I_{pA}(\Delta\varphi)$



$$I_{pA,\ AA} \equiv \frac{\Delta_{recoil}\ (\Delta\varphi)_{pA,\ AA}}{\Delta_{recoil}\ (\Delta\varphi)_{pp}}$$

- In p-Pb collisions: no modification is observed across all $\Delta\varphi$ and jet p_T bins within uncertainties

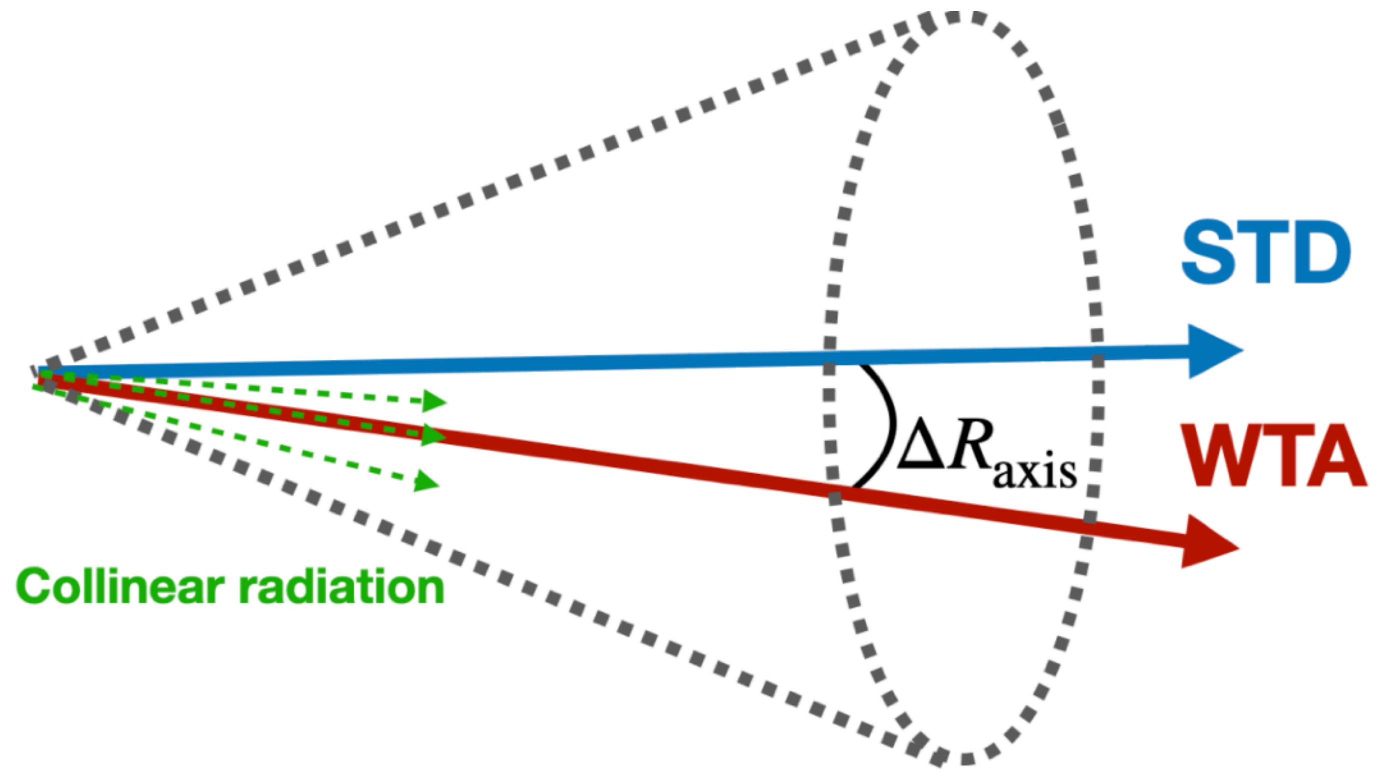
Outlook 1: differential h-jet measurements in Run3

- Different jet-axis definitions have different sensitivity to soft radiation
- **Standard (STD)** = Jet constituents combined with the E-scheme
- **Winner-Take-All (WTA)** = Jet recombined with the WTA scheme

  → axis follows the hardest branch

- Opening angle between different axes: $\Delta R_{\text{axis}} = \sqrt{(\Delta\eta)^2 + (\Delta\varphi)^2}$

  → differential probe of jet broadening and medium response



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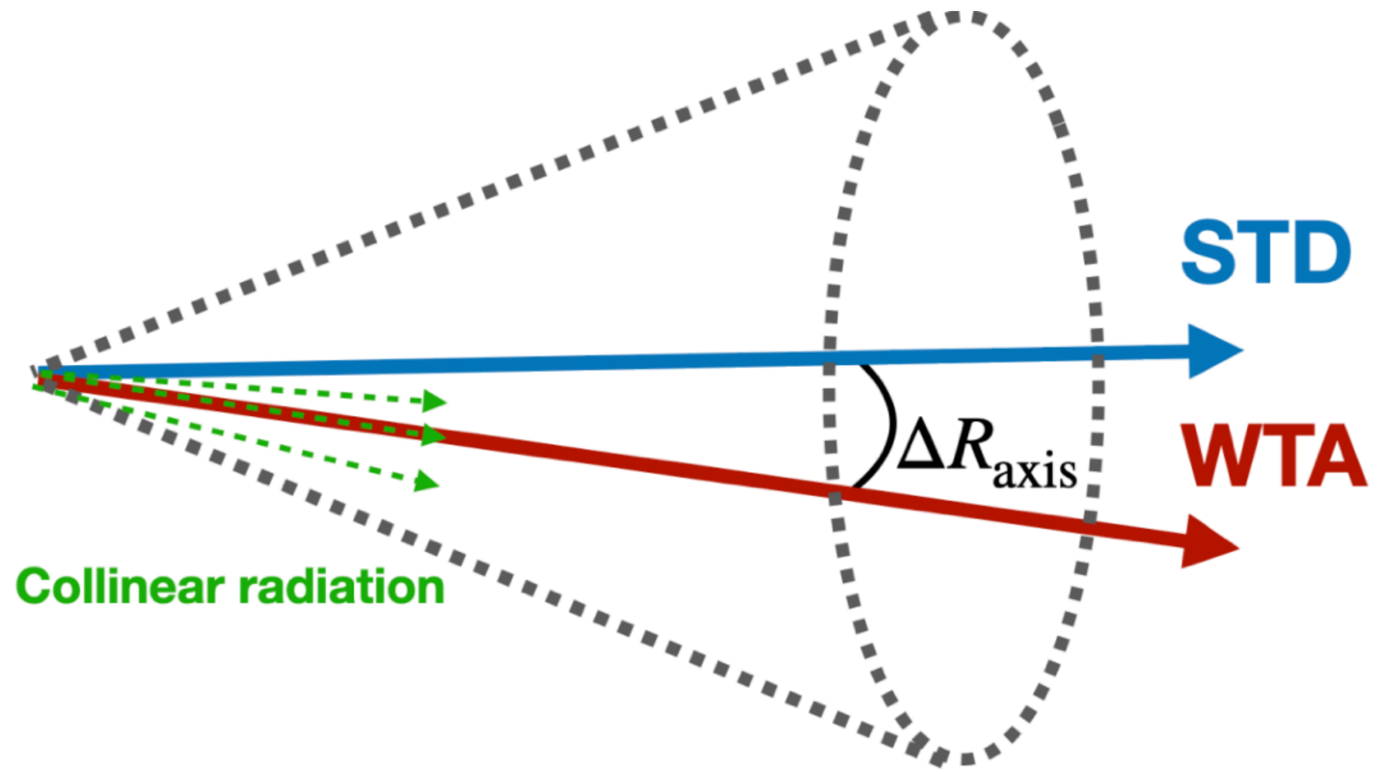

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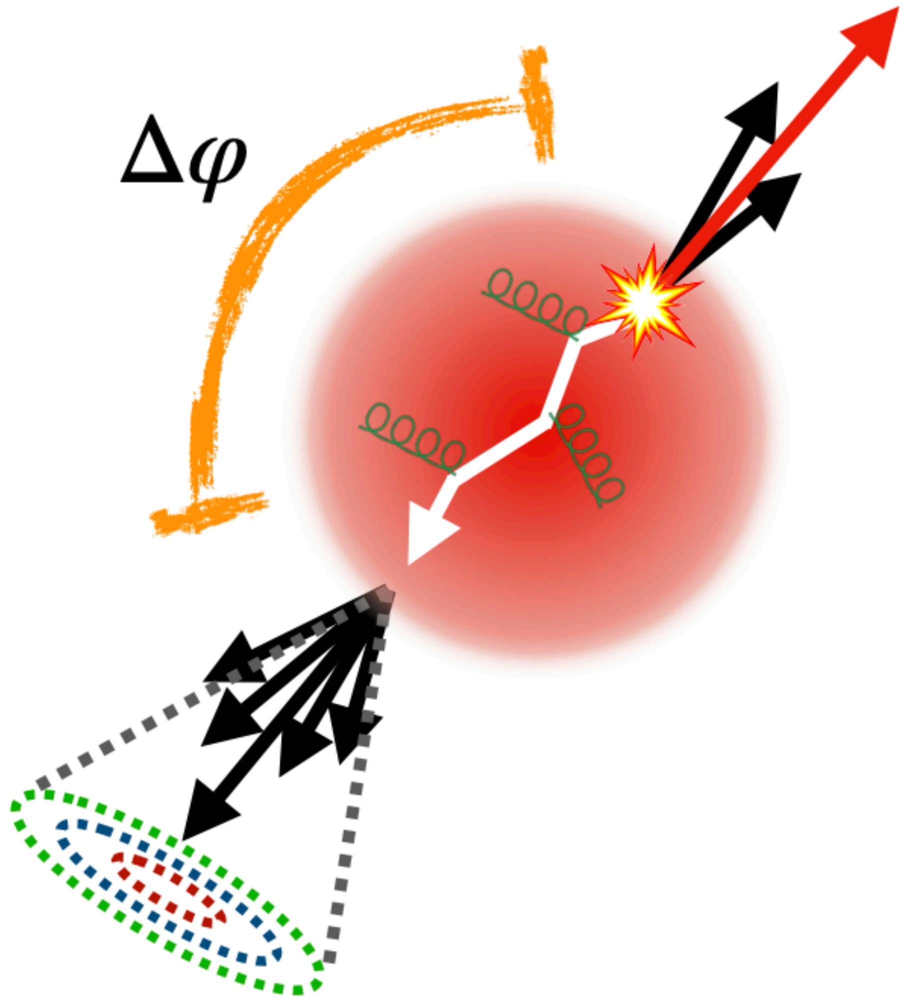
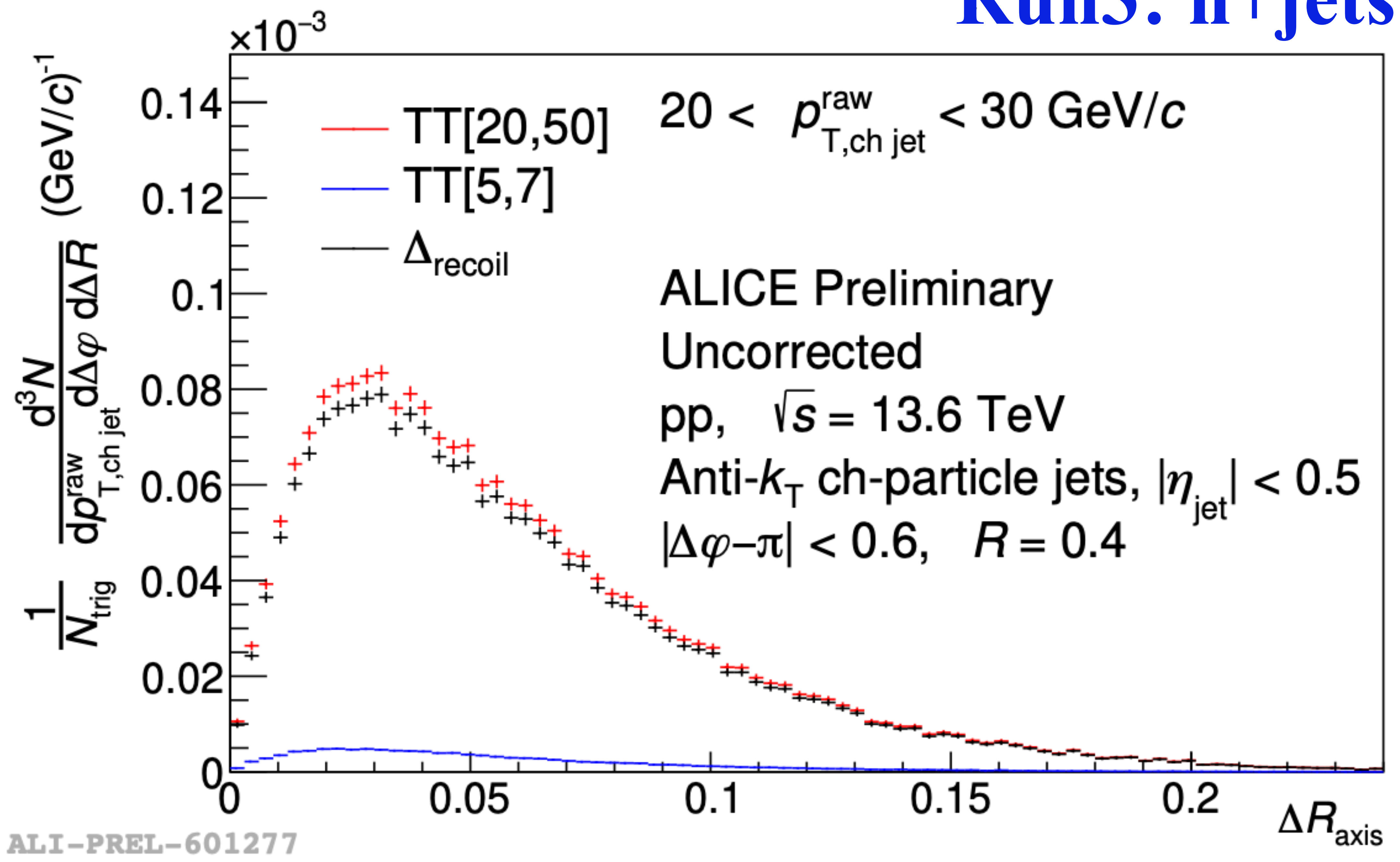
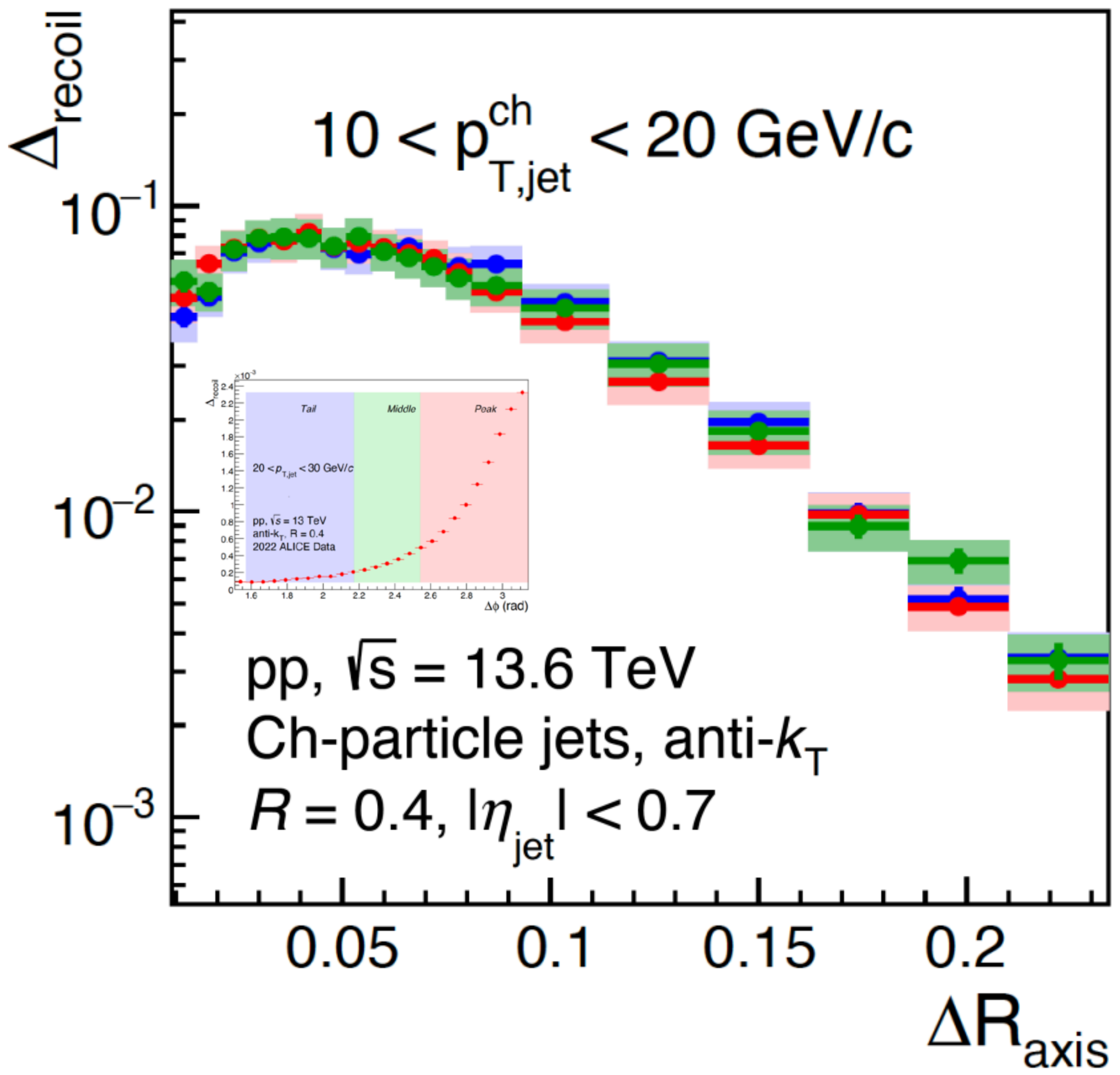
Run3: h+jets

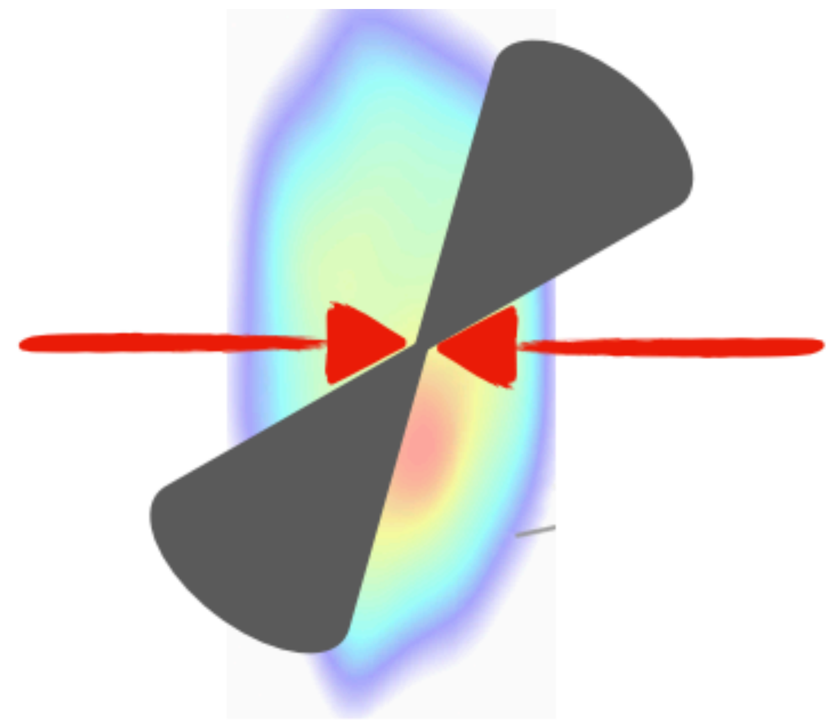




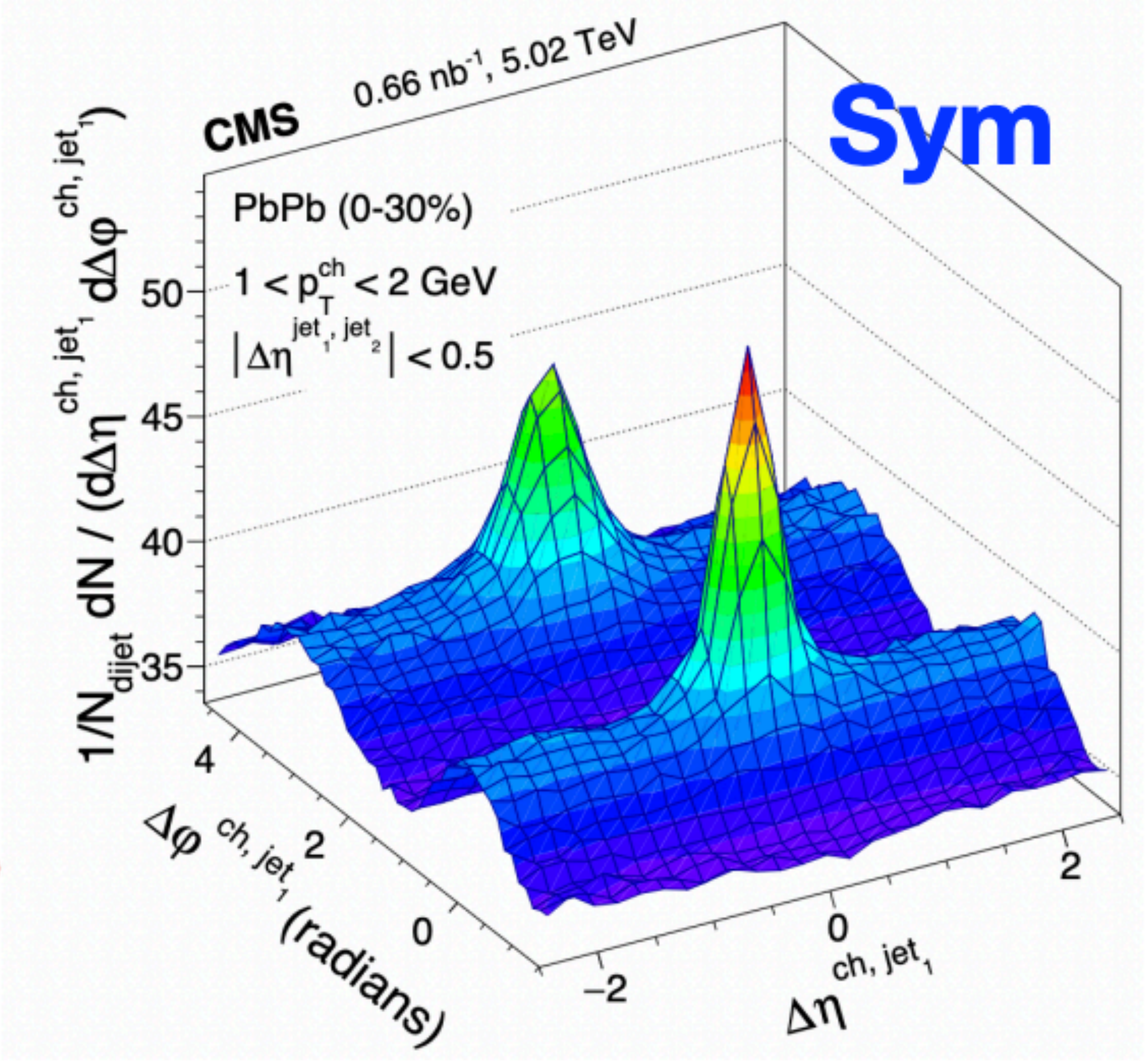


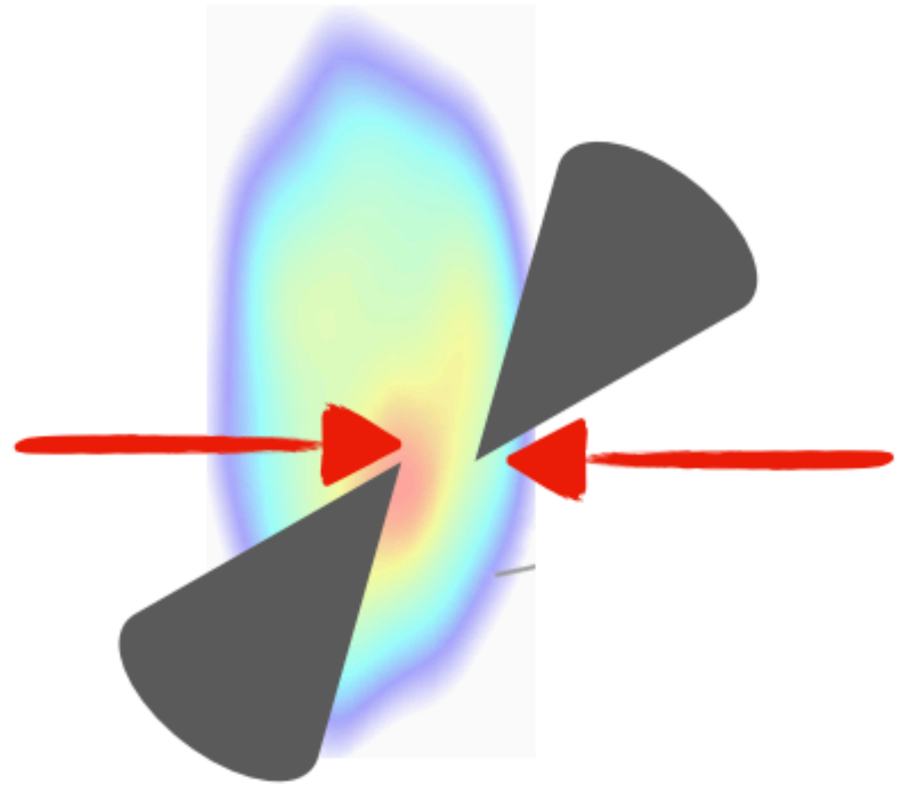
Outlook 2: searching for medium response in dijets

CMS: arXiv:2602.19431



Back to back jets **with no eta gap**
Symmetric





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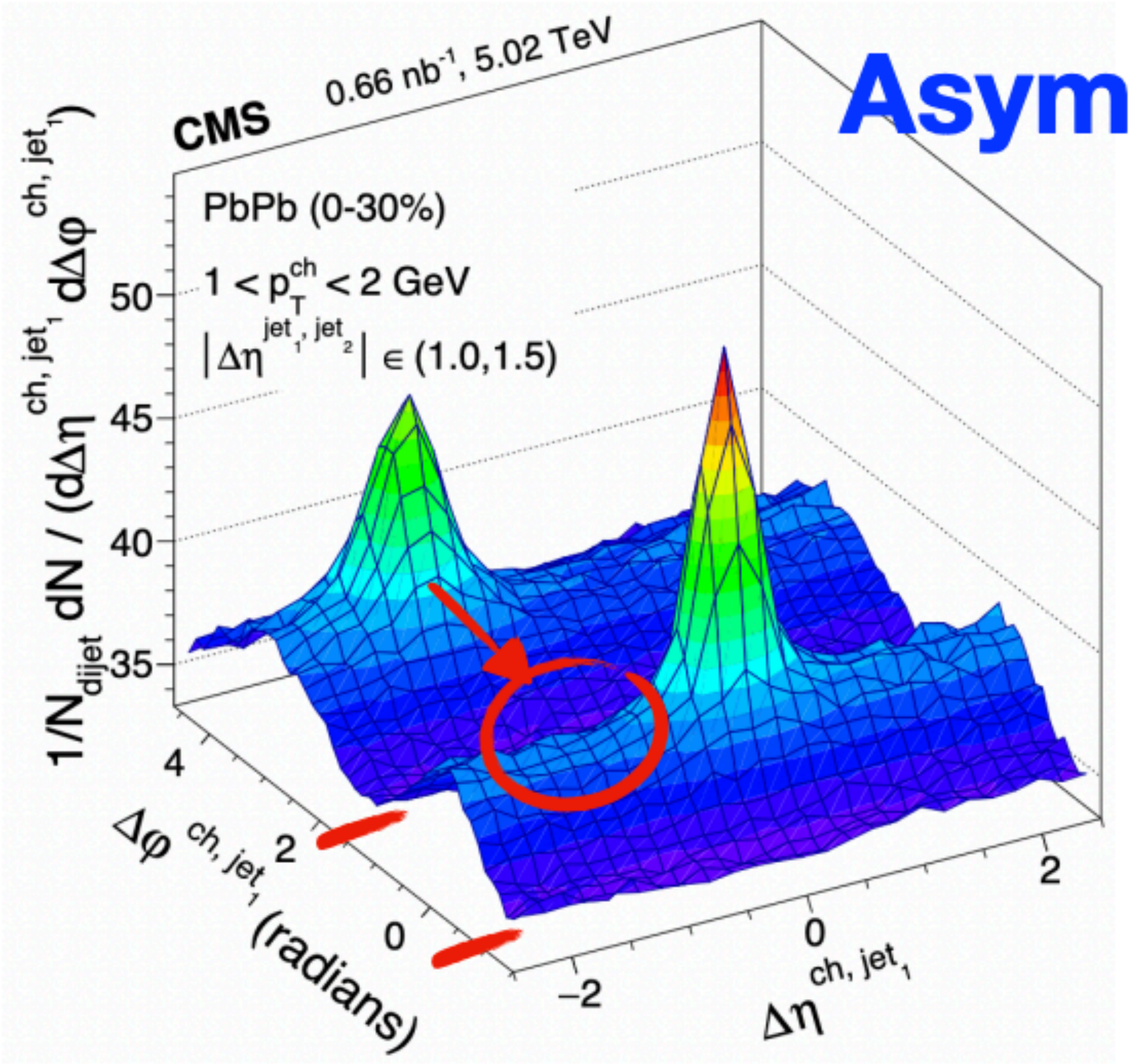

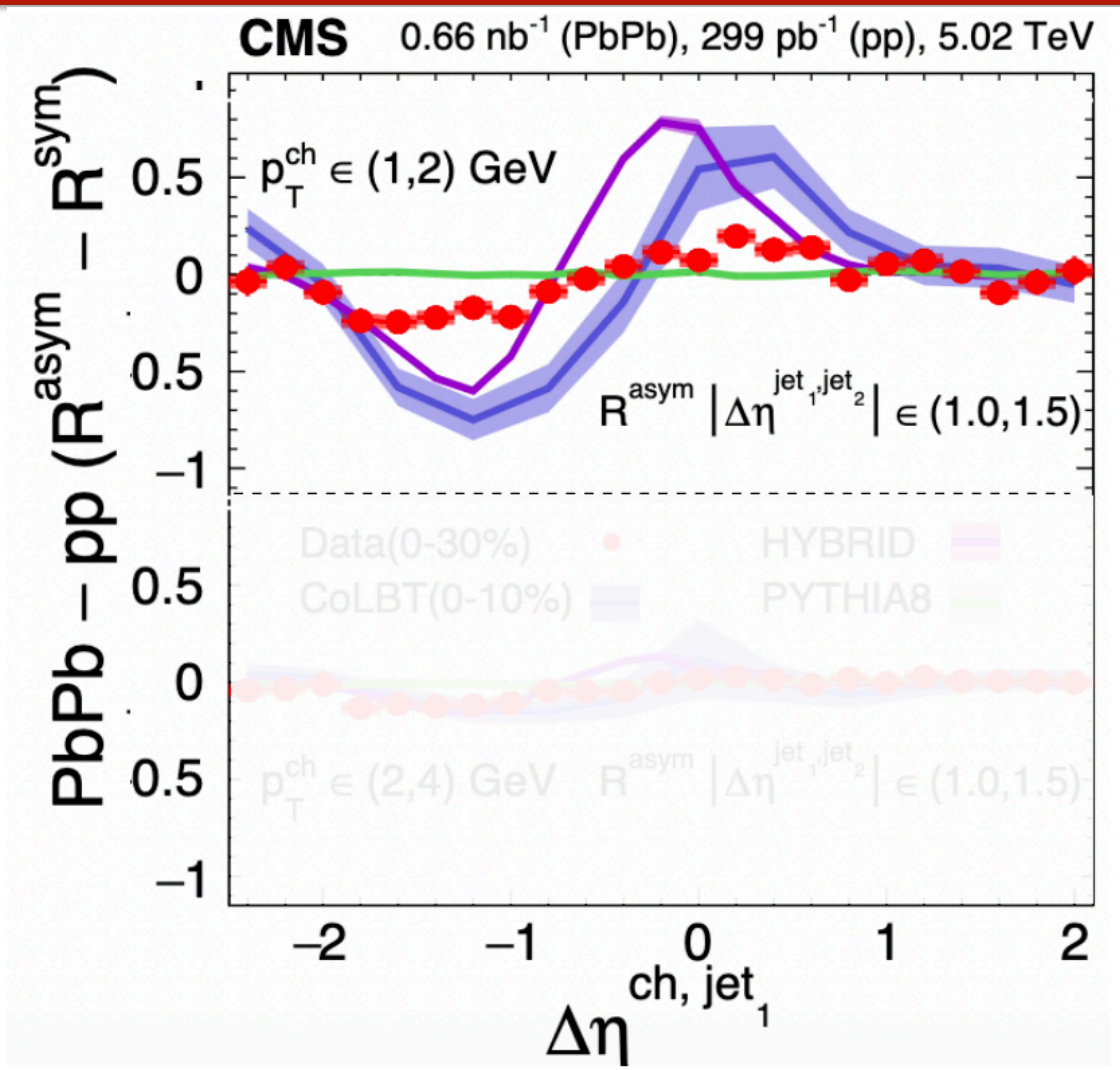

- Diffusion wake hidden in inclusive back-to-back jets

Outlook 2: searching for medium response in dijets

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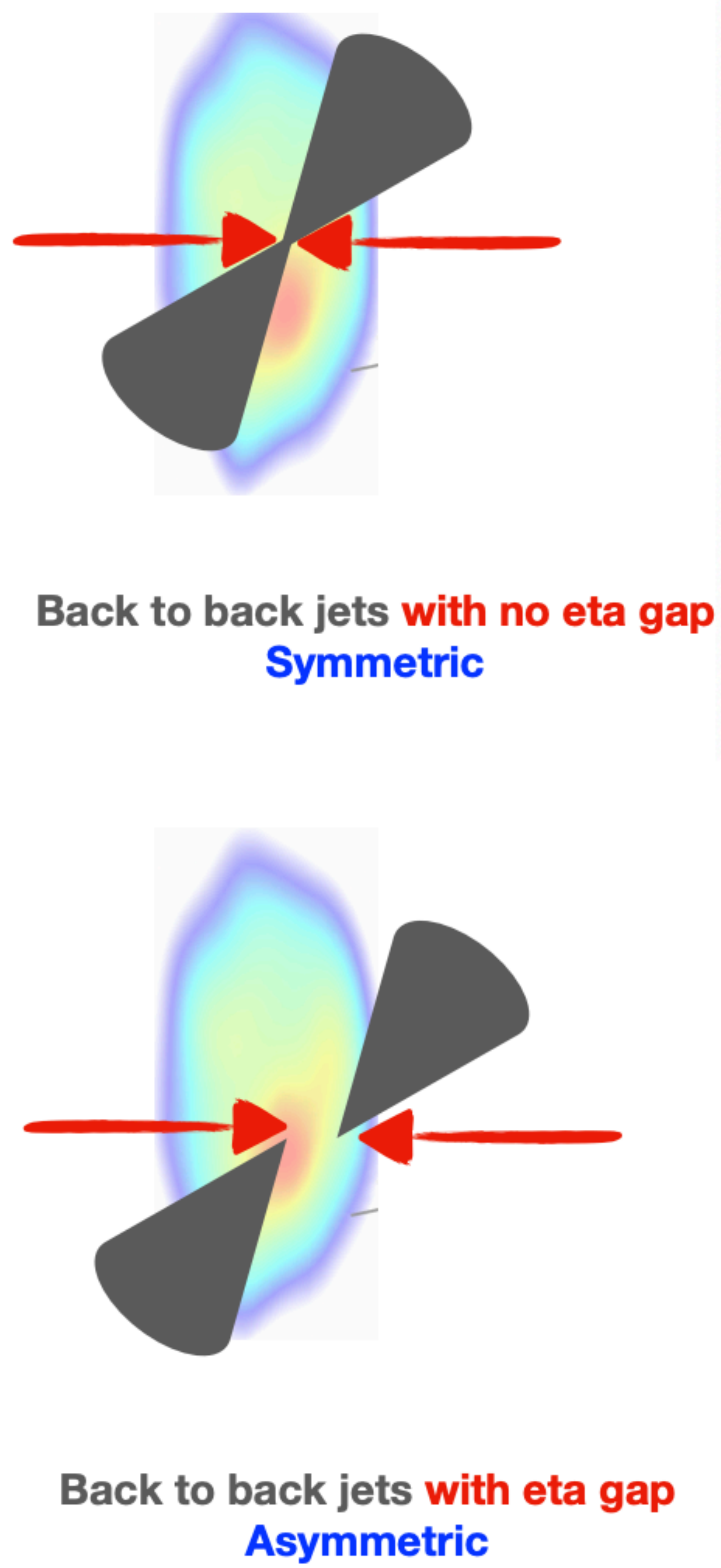

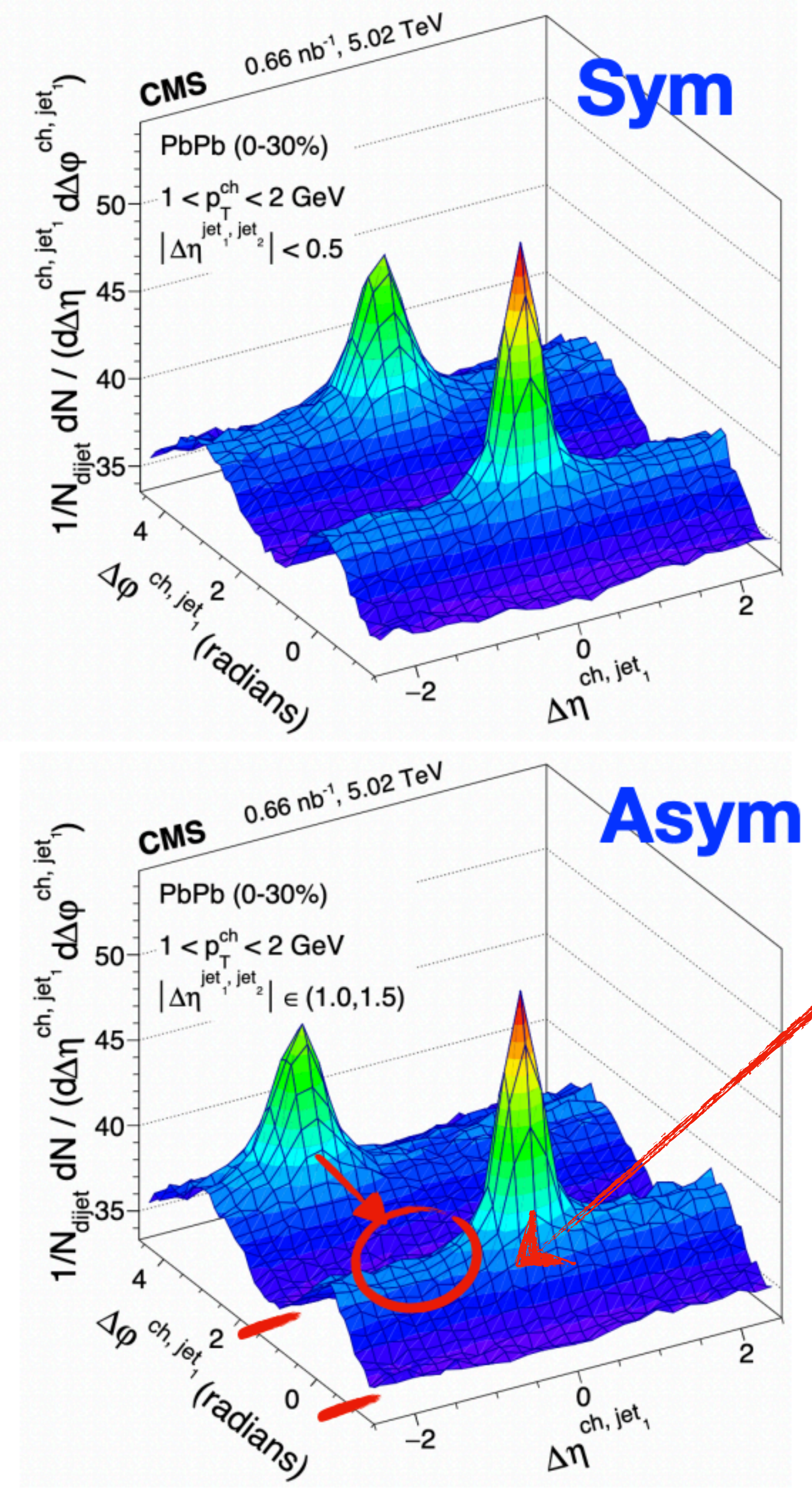

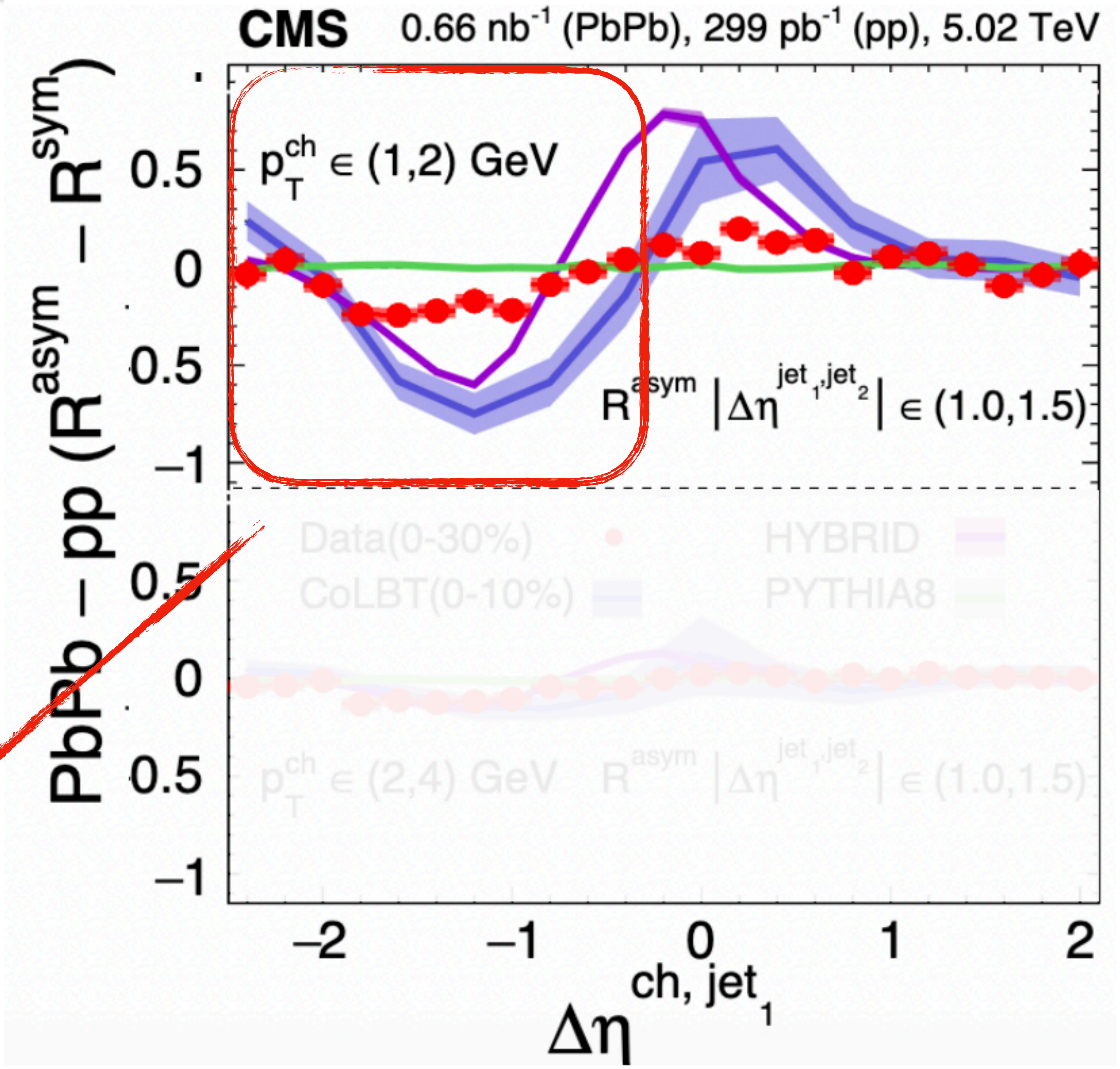

- Diffusion wake hidden in inclusive back-to-back jets
- A rapidity-gap selection enhances sensitivity to the wake signal
- CMS observes a depletion in 0–30% Pb–Pb collisions

Outlook 2: searching for medium response in dijets

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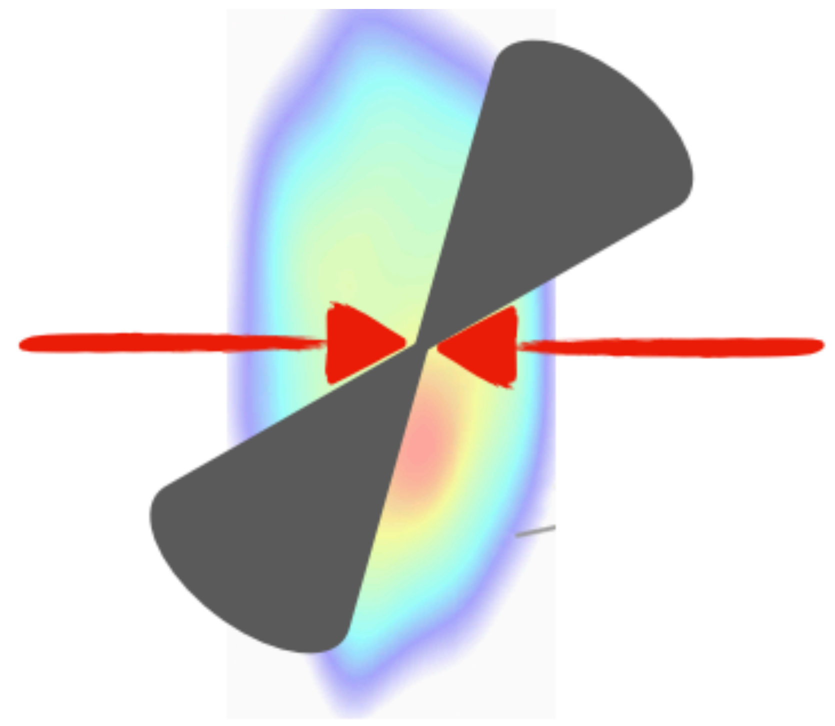
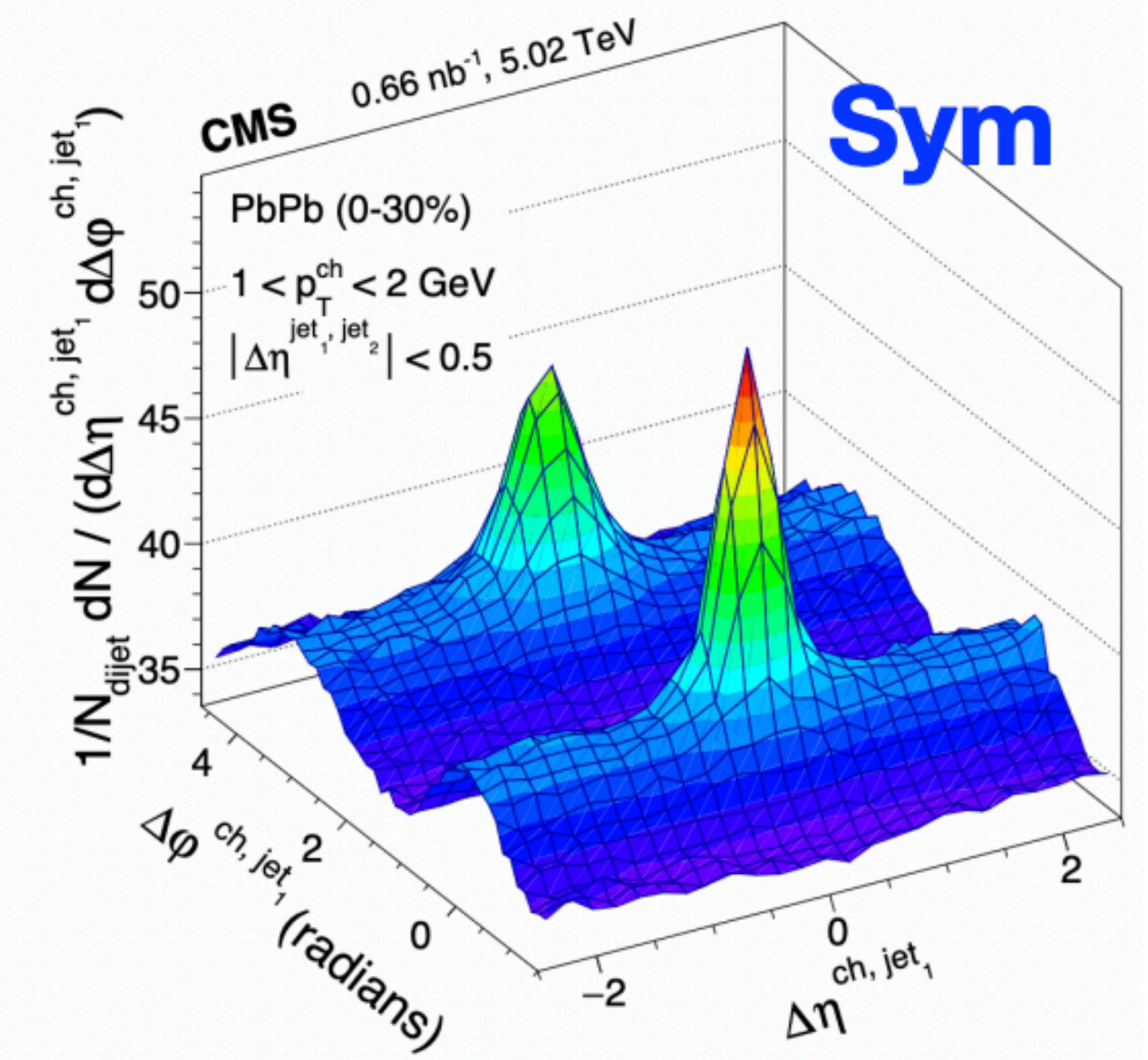
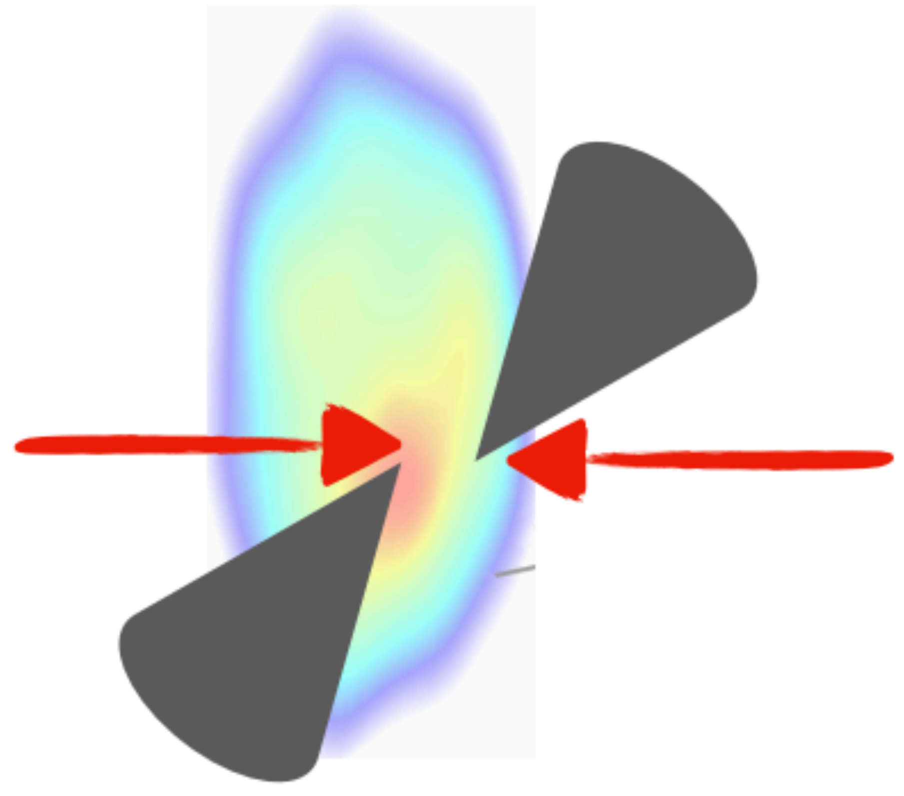


Back to back jets with no eta gap
Symmetric





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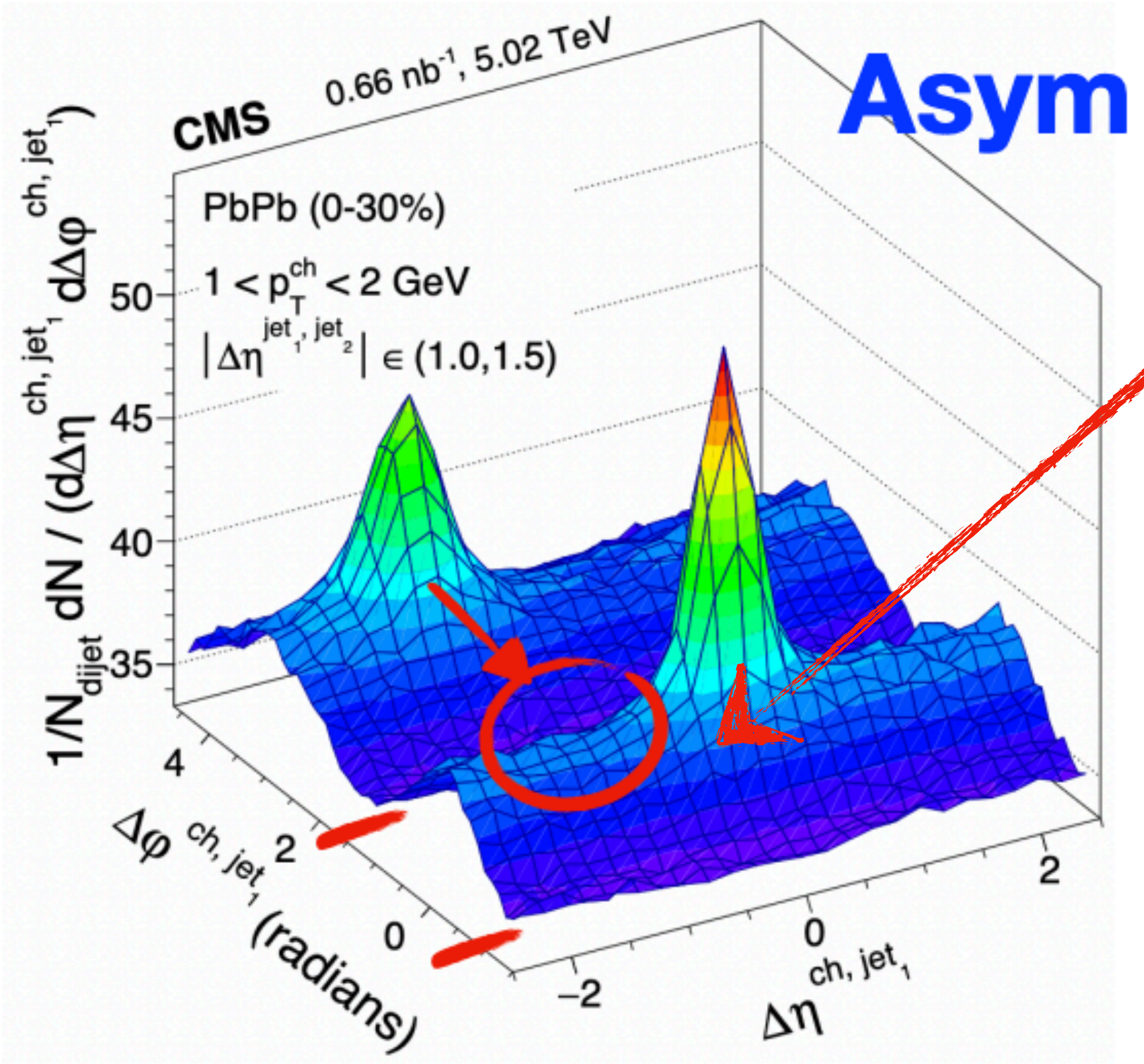
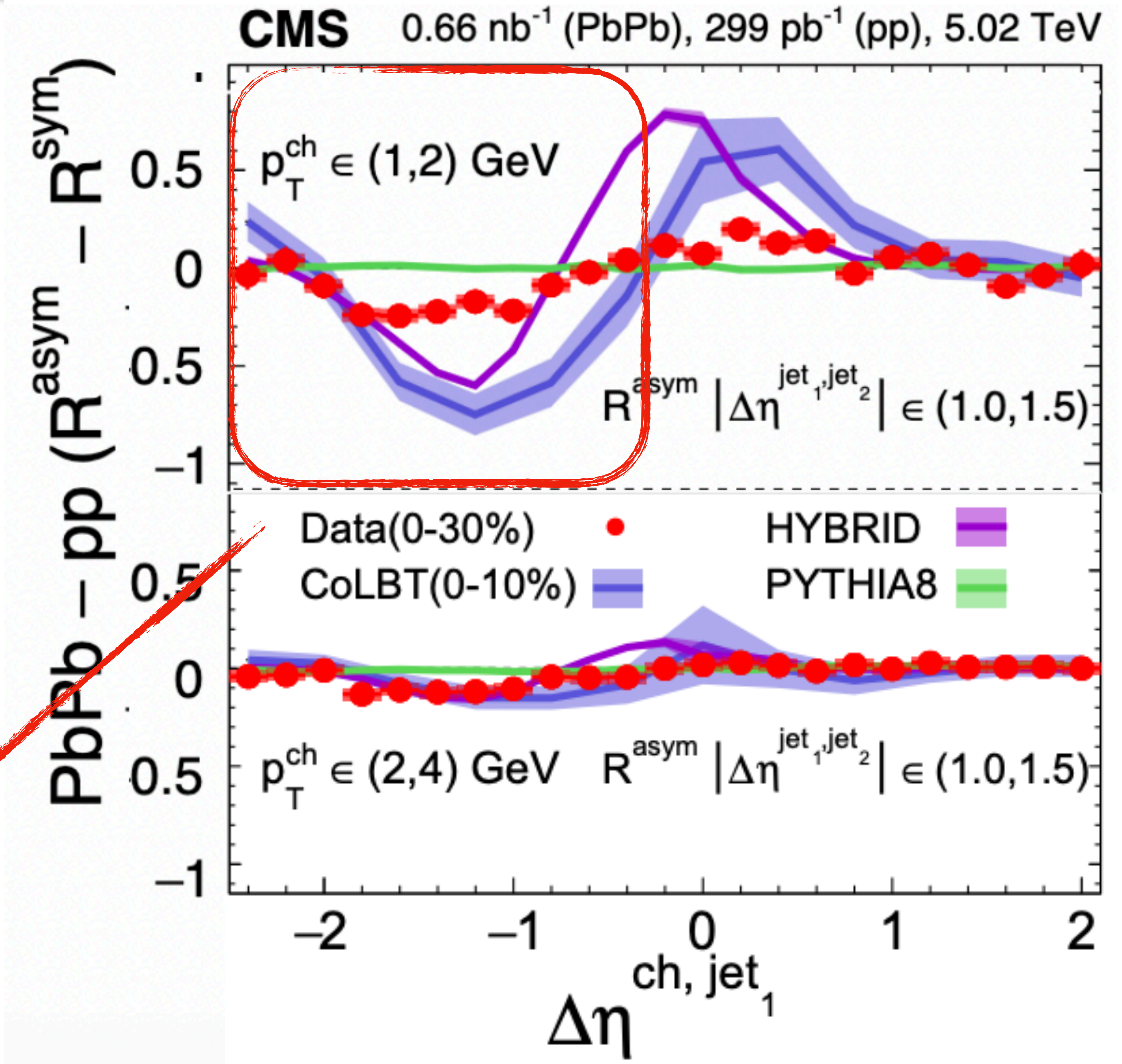
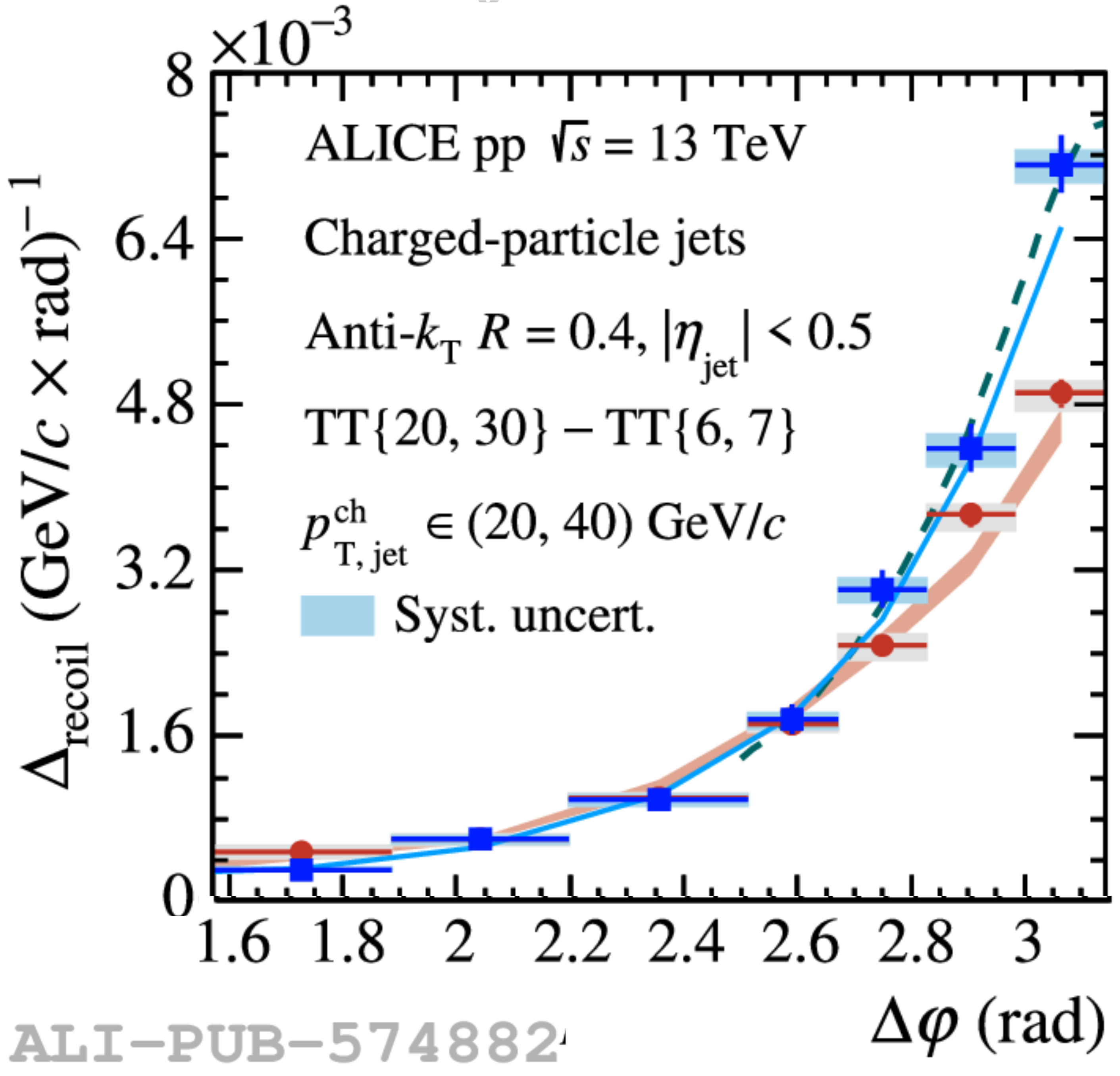


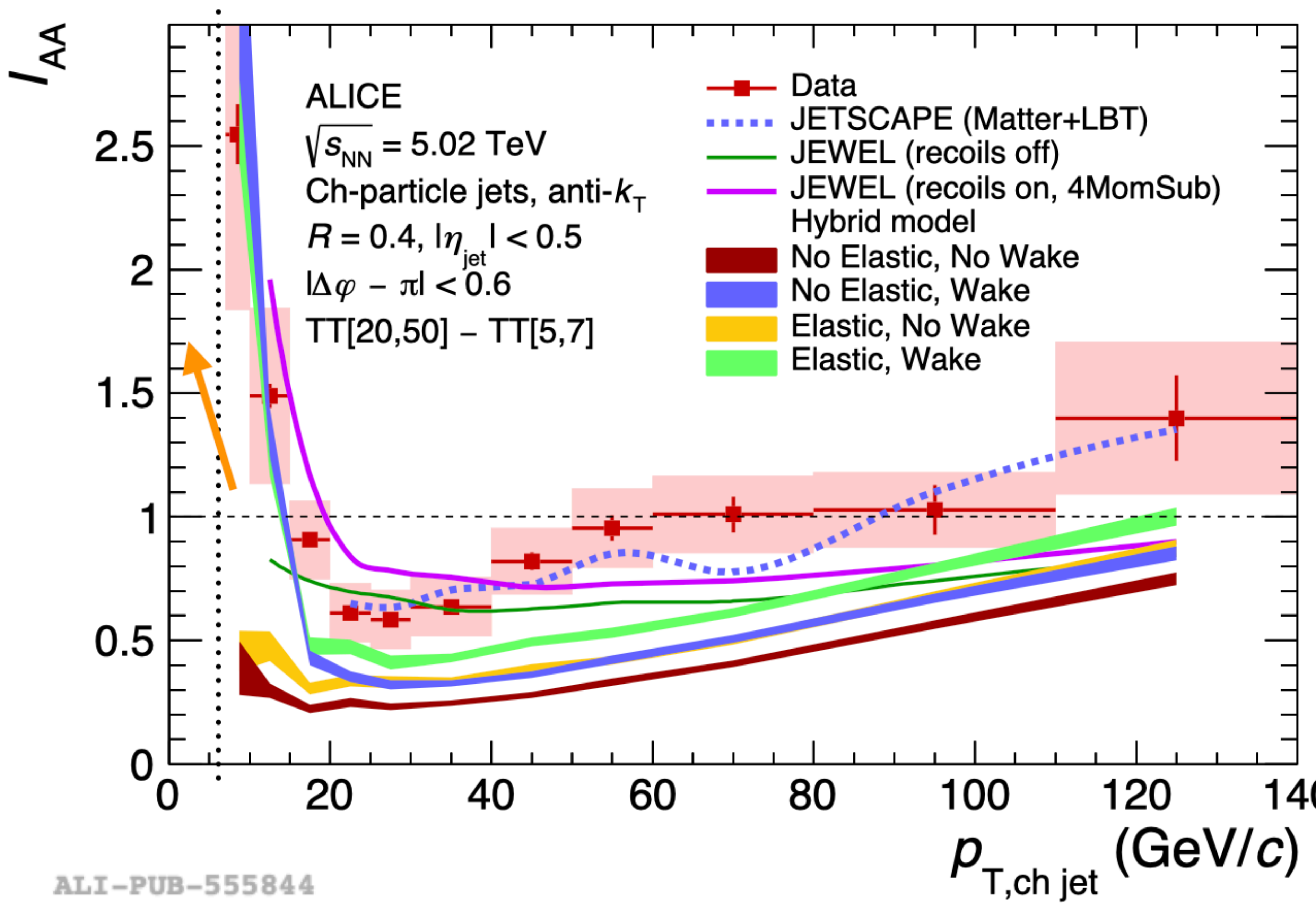


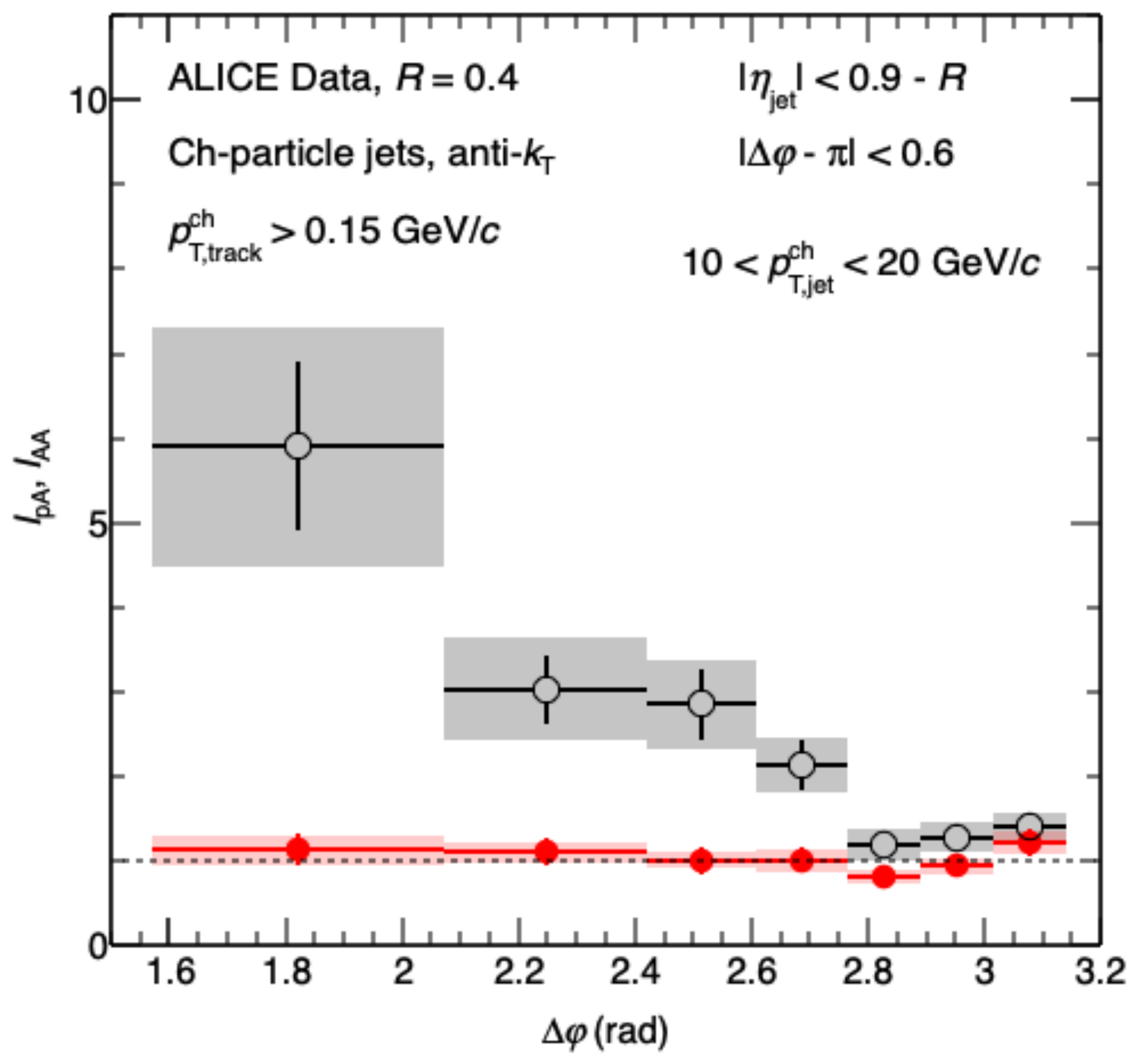
- Diffusion wake hidden in inclusive back-to-back jets
- A rapidity-gap selection enhances sensitivity to the wake signal
- CMS observes a depletion in 0–30% Pb–Pb collisions
- Ongoing work: extend this idea with ALICE dijet correlations

Conclusions

- **Search for QGP signatures in samll collision systems**
  - Jet-quenching-like effects masked by **generic event selection bias** in pp collisions
  - No significant modification in p-Pb relative to pp
- **Observation of significant low-p_T jet yield** and **large-angle enhancement** in Pb-Pb collisions with ALICE!
  - Medium response is favored instead of Molière scattering as the cause for both effects
- **Run 3 recoil-jet measurements** will enable more differential studies of jet quenching and medium response



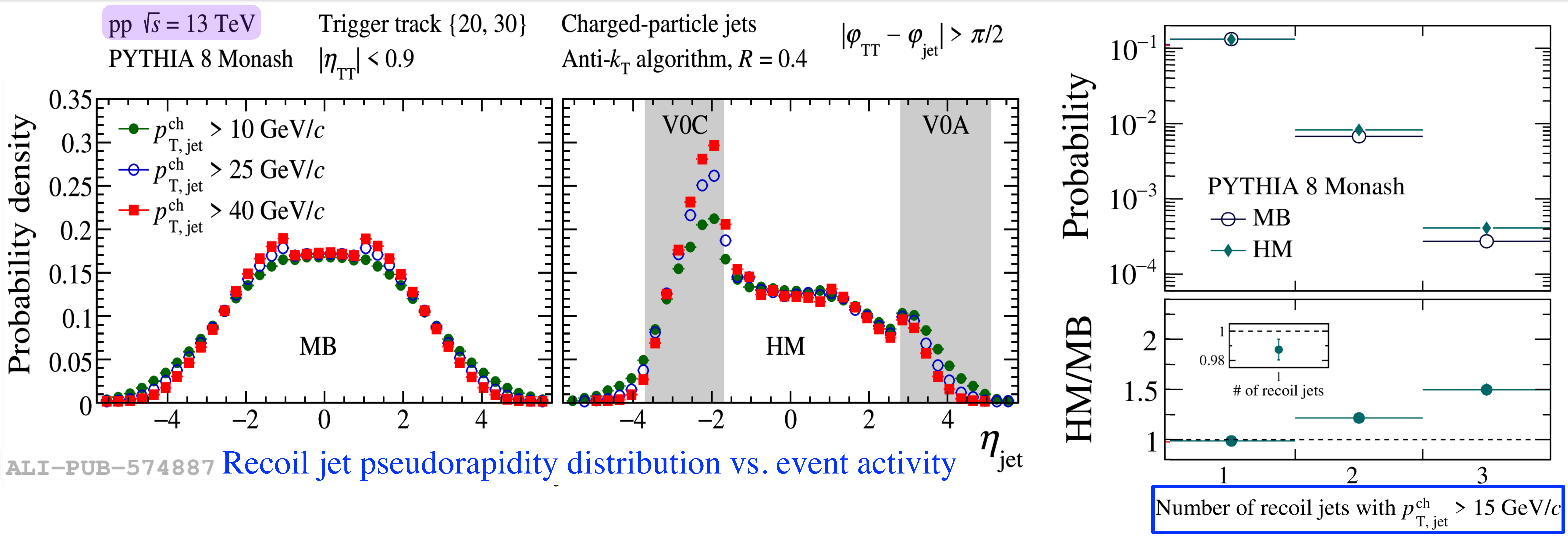




感谢您的聆听

Merci pour votre attention

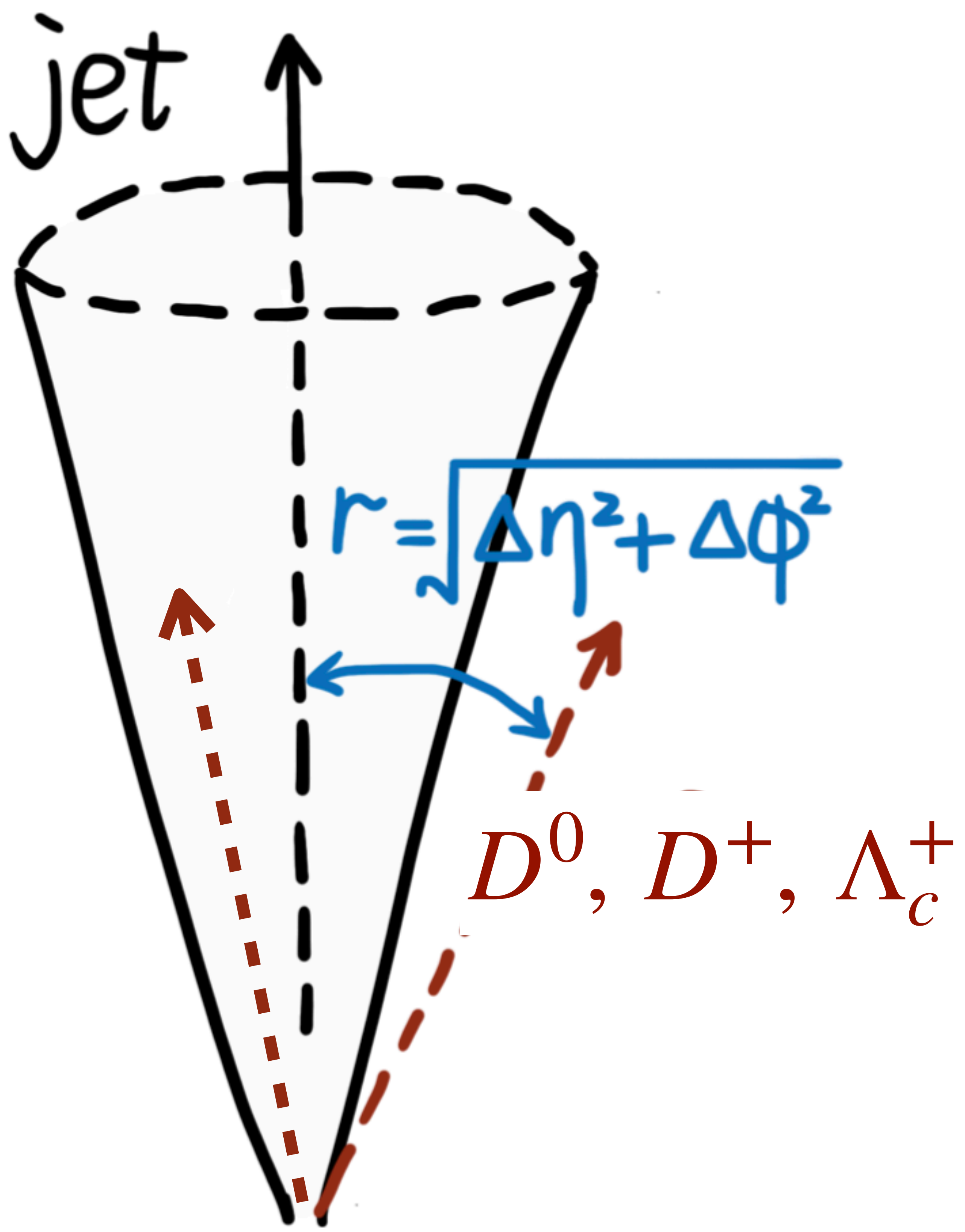
PYTHIA simulations

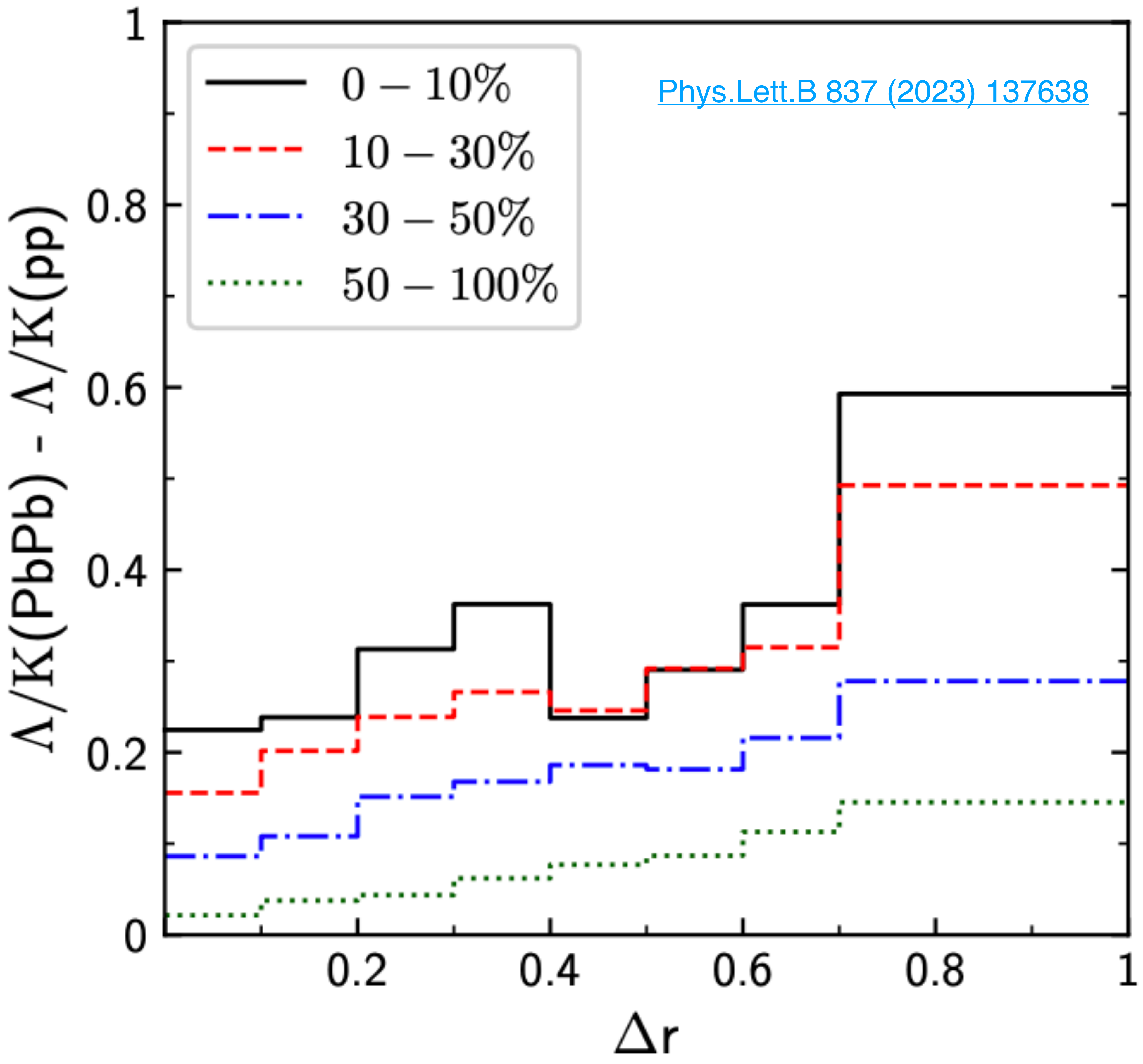


Recoil jet pseudorapidity distribution vs. event activity

- **Larger enhancement in V0C** resulting from the asymmetric pseudorapidity acceptance of V0A and V0C **in HM events**
  → significant bias in the distribution of high-p_T recoil jets
- Broader jets are selected more **in the V0C for HM events** could hide the jet-medium interaction signal
  → Jet quenching signals **can be masked by effects coming from trigger**

Outlook 3: jet heavy-flavor correlations





- Heavy-flavour correlation measurements powerful way to constrain transport properties
- Study jet hadron chemistry with identified particles to understand the hadronization and jet fragmentations

A few measurements I will cover

- **Hadron-jet correlations in pp collisions at 13.6 TeV (Run 3 preliminary)**
- **Hadron-jet correlations in p–Pb collisions at 5.02 TeV (Run 2,** paper under ALICE internal review**)**
- **Hadron-jet correlations in high-multiplicity pp collisions at 13 TeV (Run 2)**

  JHEP 05 (2024) 229
- **Hadron-jet correlations in pp and central Pb–Pb collisions at 5.02 TeV (Run 2)**

  PRL 133 (2024) 022301, PRC 110 (2024) 014906