Isolated photon measurements with the ALICE electromagnetic calorimeter at the LHC Run 1 and 2 pp, p–Pb & Pb–Pb collisions

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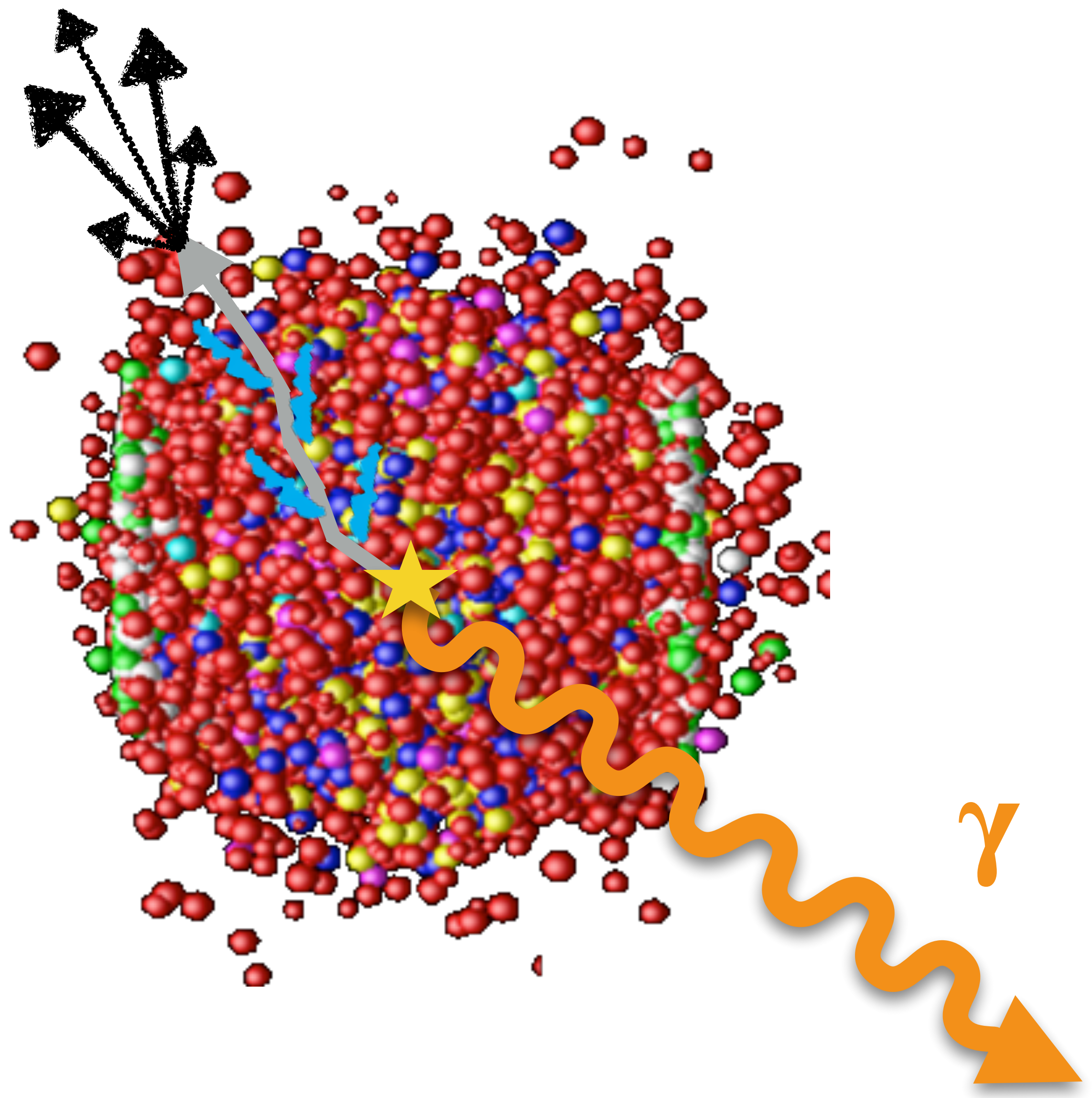

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Les deux infinis

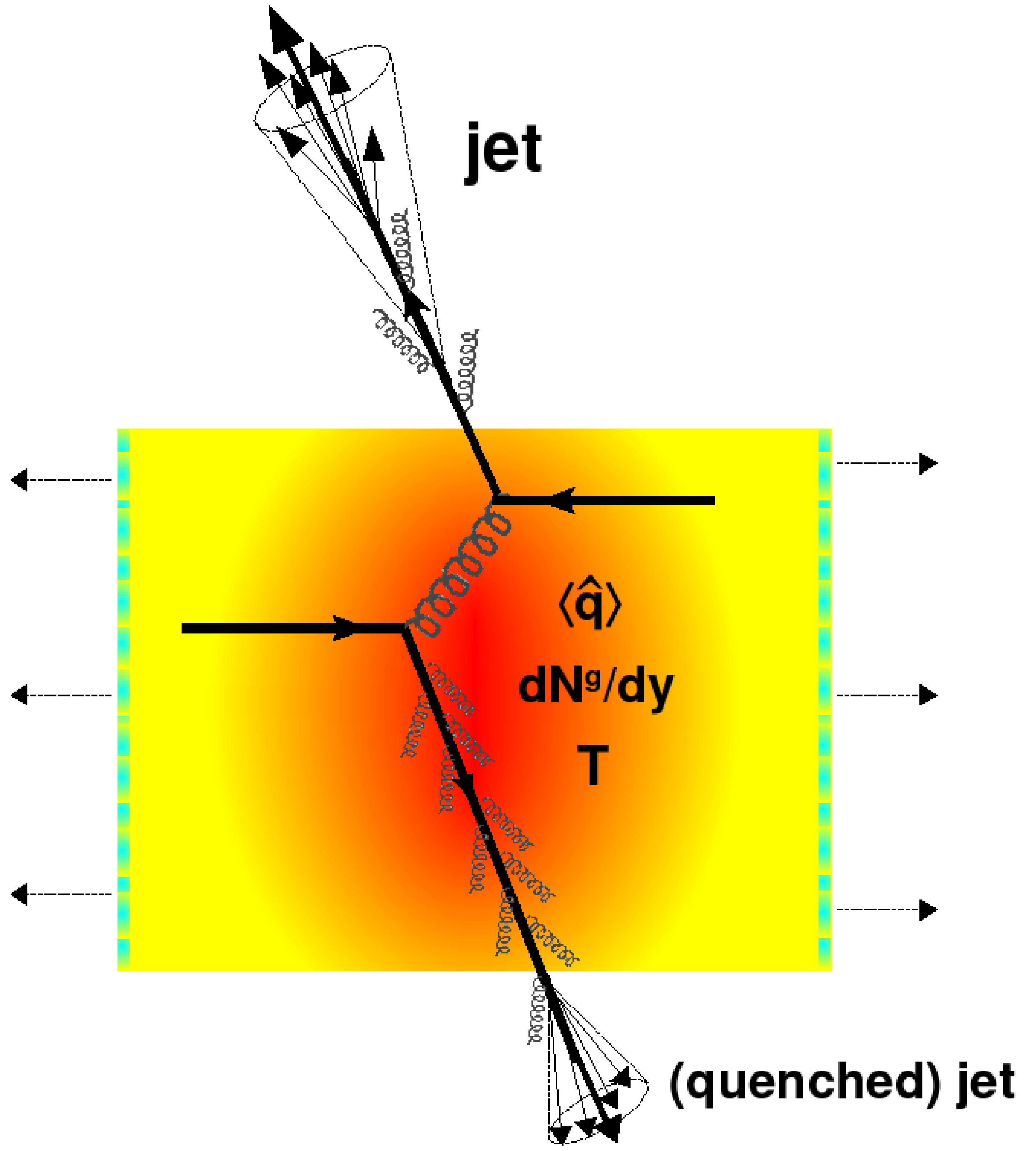
INFN LNF Seminar | 18/06/2025

Probing the QGP in heavy-ion collisions

- In heavy-ion collisions at the LHC, a dense, hot and strongly interacting coloured QCD medium is produced
  → the *"**quark-gluon plasma**"* (***QGP***)

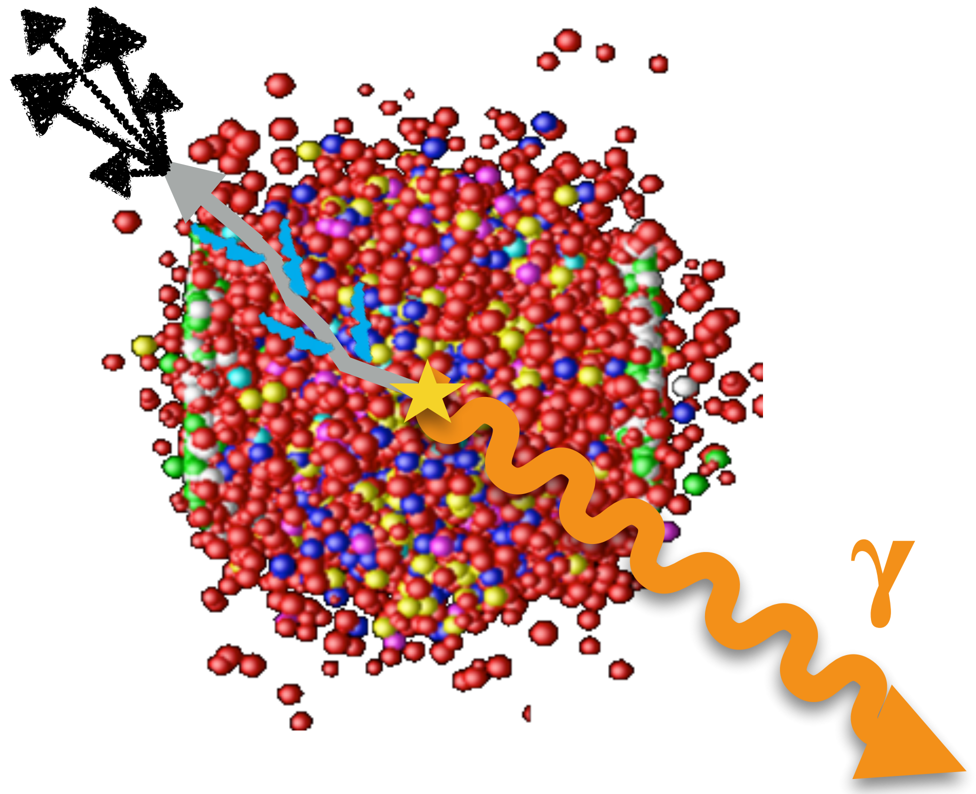
- The ALICE experiment aims at the characterisation of the QGP (temperature, energy density, etc., the equation of state) via the measurements of different types of probes

- **Hard probes**: *high-E partons* (quarks and gluons) and *electroweak particles* *(γ, Z^0 & $W^\pm$)* emitted in the first stages of the collision:
  → *"bullets"* passing through the QGP



  - **Partons lose energy** via radiational (gluonstrahlung) or collisional processes
    → **"jet quenching"**

  - γ, Z^0 & $W^\pm$ are **colourless: not affected** by the *QGP*
    → **Candle particles**
    → **Associated with a back-to-back parton**



Observation of QGP effects: The nuclear modification factor

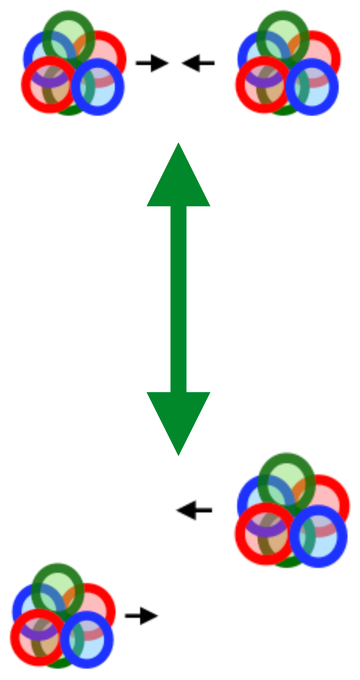
- Consequence of jet-quenching: modification of jets and high p_T particle production cross sections with respect to pp collisions

- Observation via the nuclear modification factor

$$R_{AA} = \frac{1}{\langle N_{coll} \rangle} \frac{d^2\sigma_{AA} / (dp_T\, d\eta)}{d^2\sigma_{pp} / (dp_T\, d\eta)}$$

$R_{AA} > 1$	Generation in the medium: Thermal γ
$R_{AA} = 1$	Transparent to the medium: Prompt γ
$R_{AA} < 1$	"Suppressed" by the medium: Coloured partons

If no QGP, a Pb–Pb collision is roughly $N_{coll} \times$ pp collisions



Centrality	$<N_{coll}>$
0–10%	1572 ± 17
10–30%	783 ± 7
30–50%	265 ± 3
50–70%	65.9 ± 1.2
70–90%	10.9 ± 0.2

$\sqrt{s_{NN}}$ = 5.02 TeV

- Collision centrality (impact parameter b) variation: Change of the QGP volume → change of R_{AA}
  - Higher centrality (larger b) implies smaller modification of the hadronic cross section

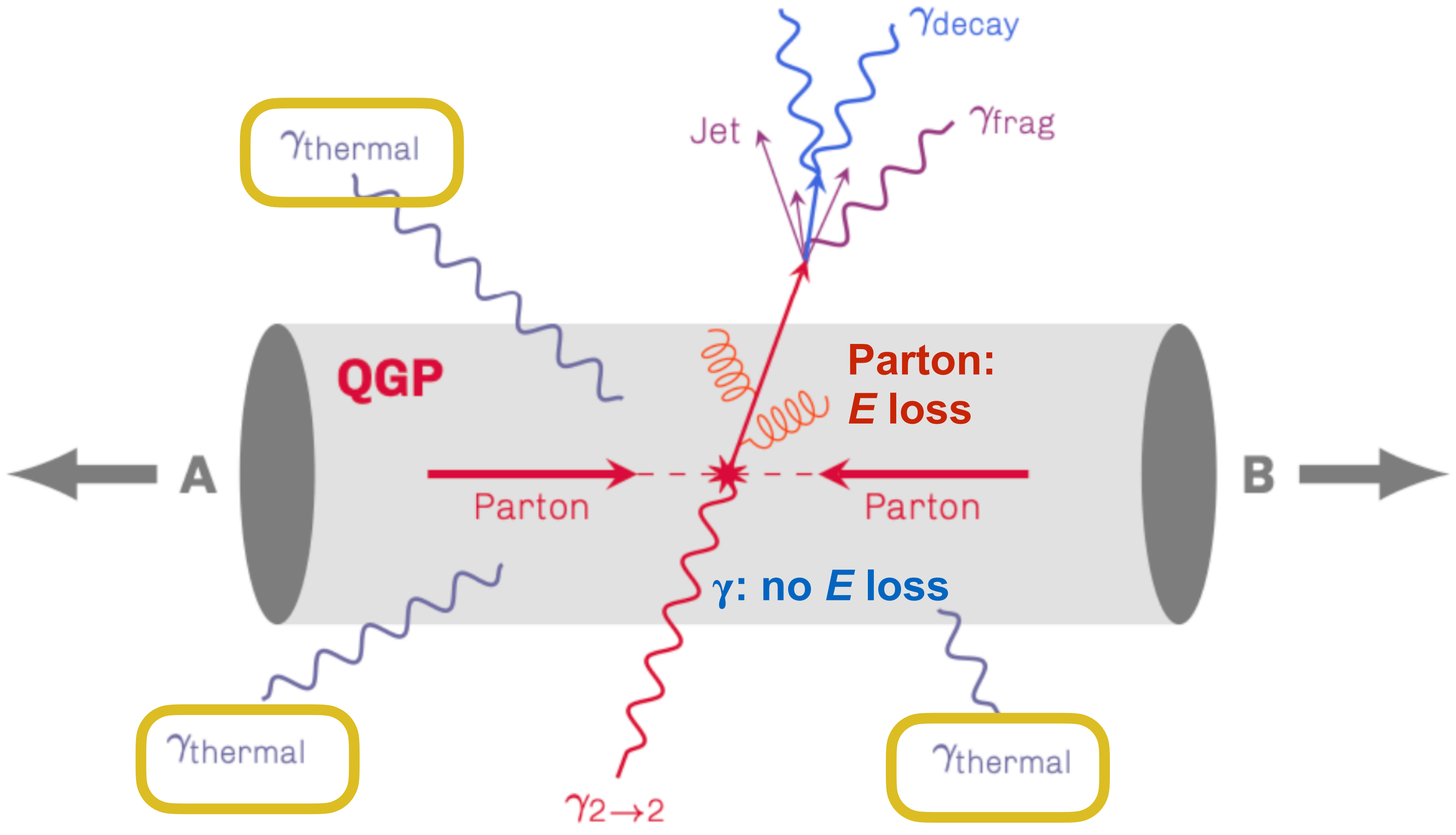
Photon sources probing the QGP

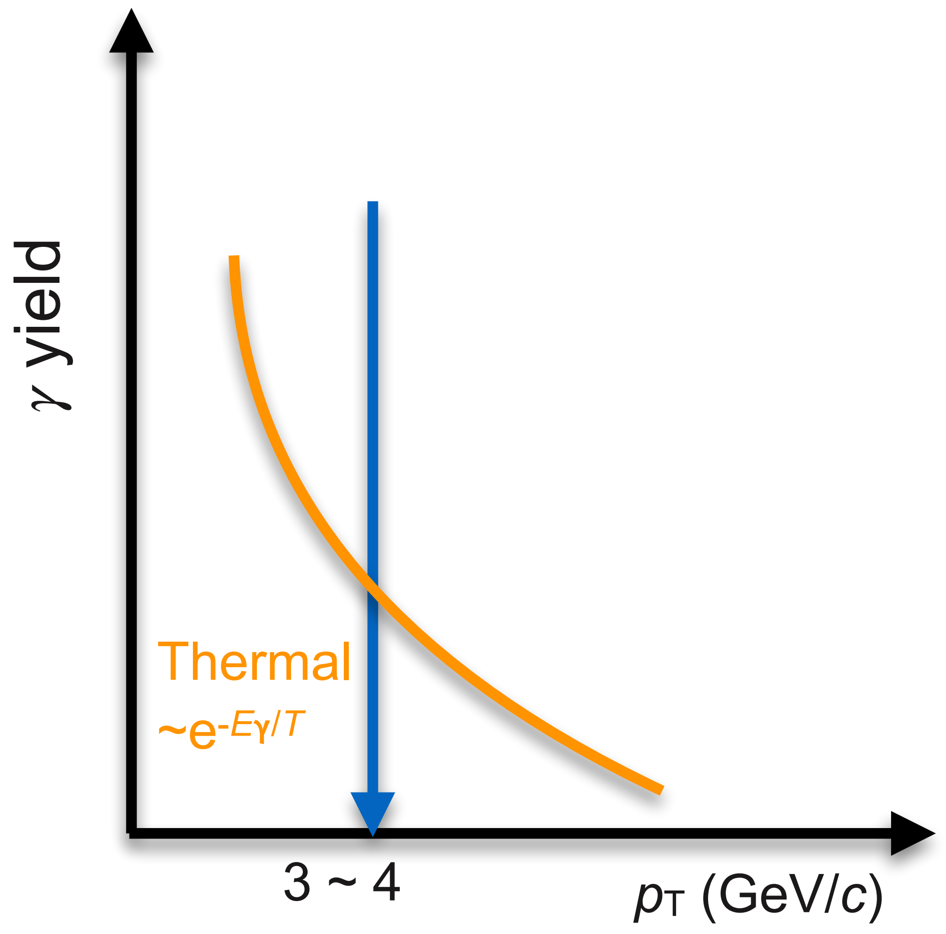
- Direct γ, <u>*not originating from hadronic decays*</u>

➡ **Direct thermal γ**: R_{AA} >> 1

– QGP thermal radiation

– Measure ***T* & time/size evolution**





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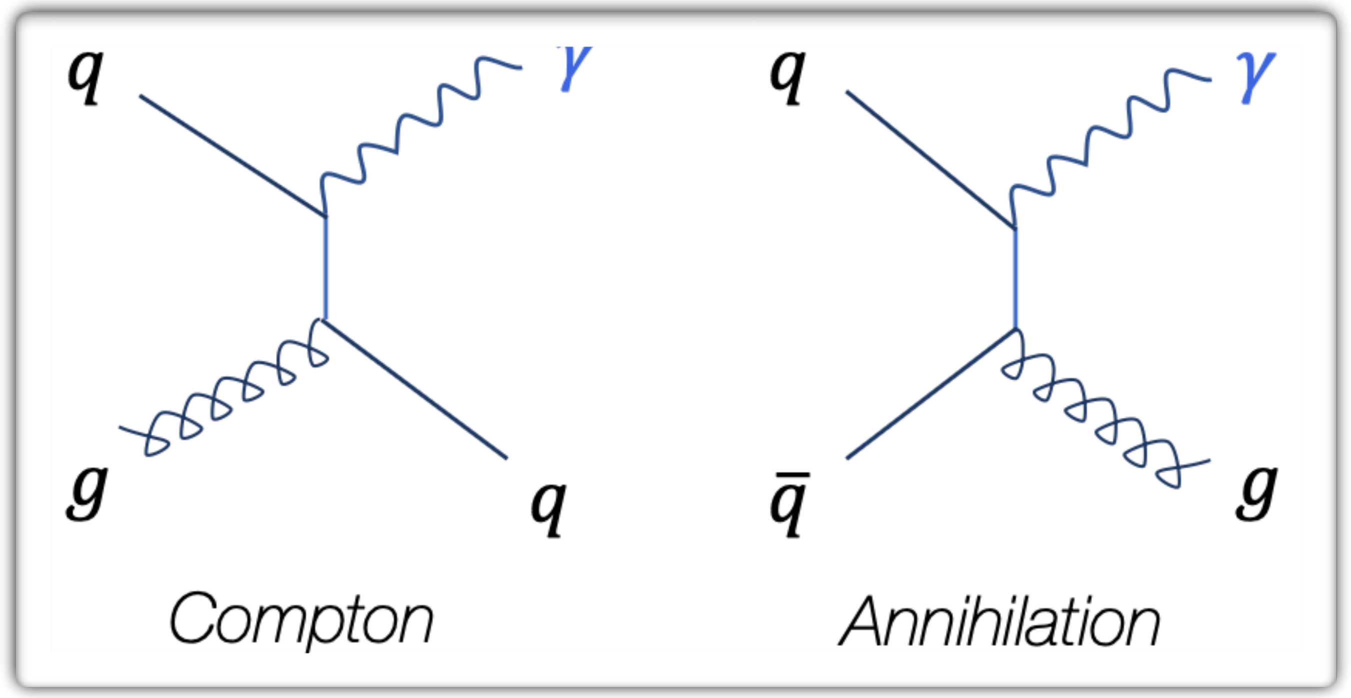
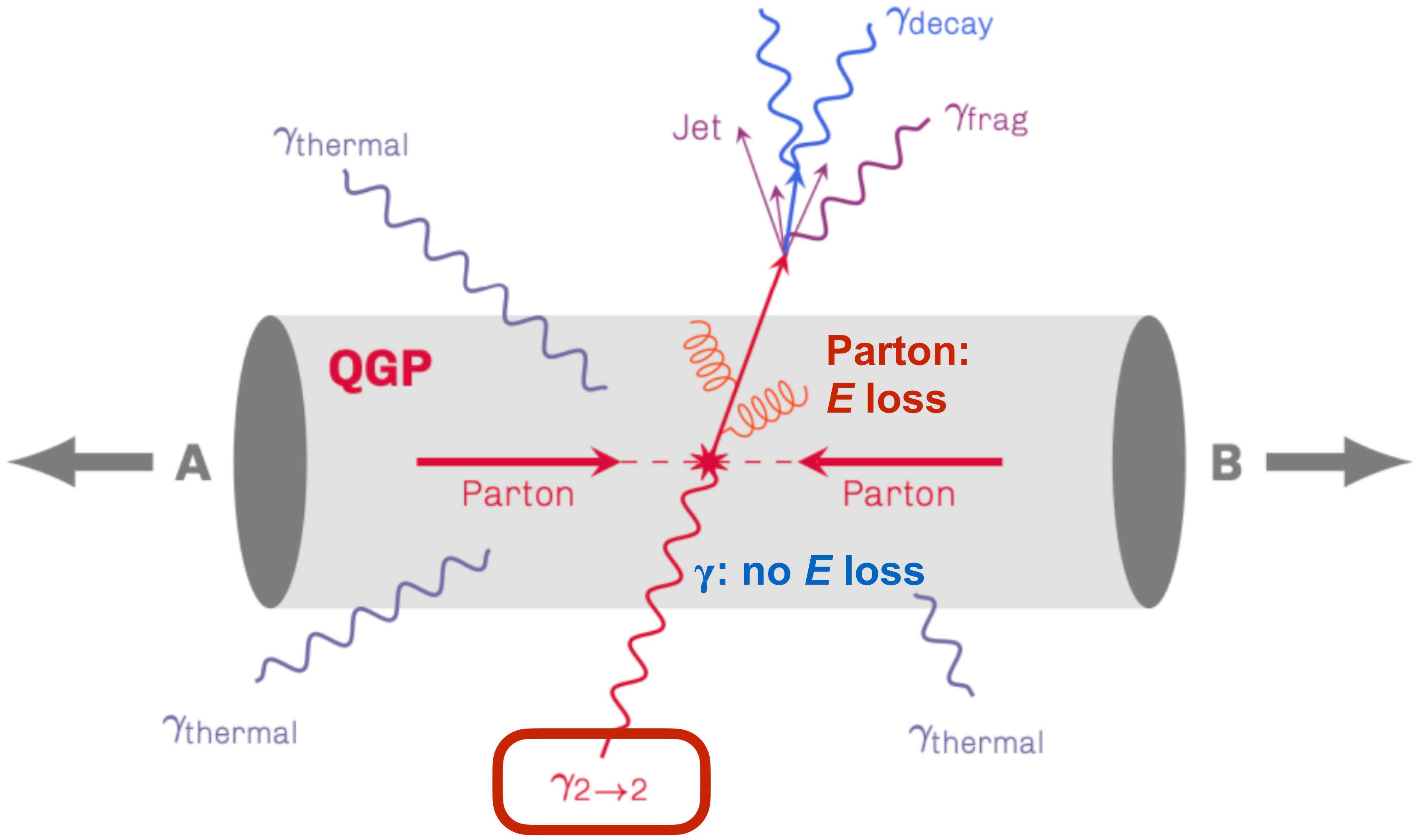
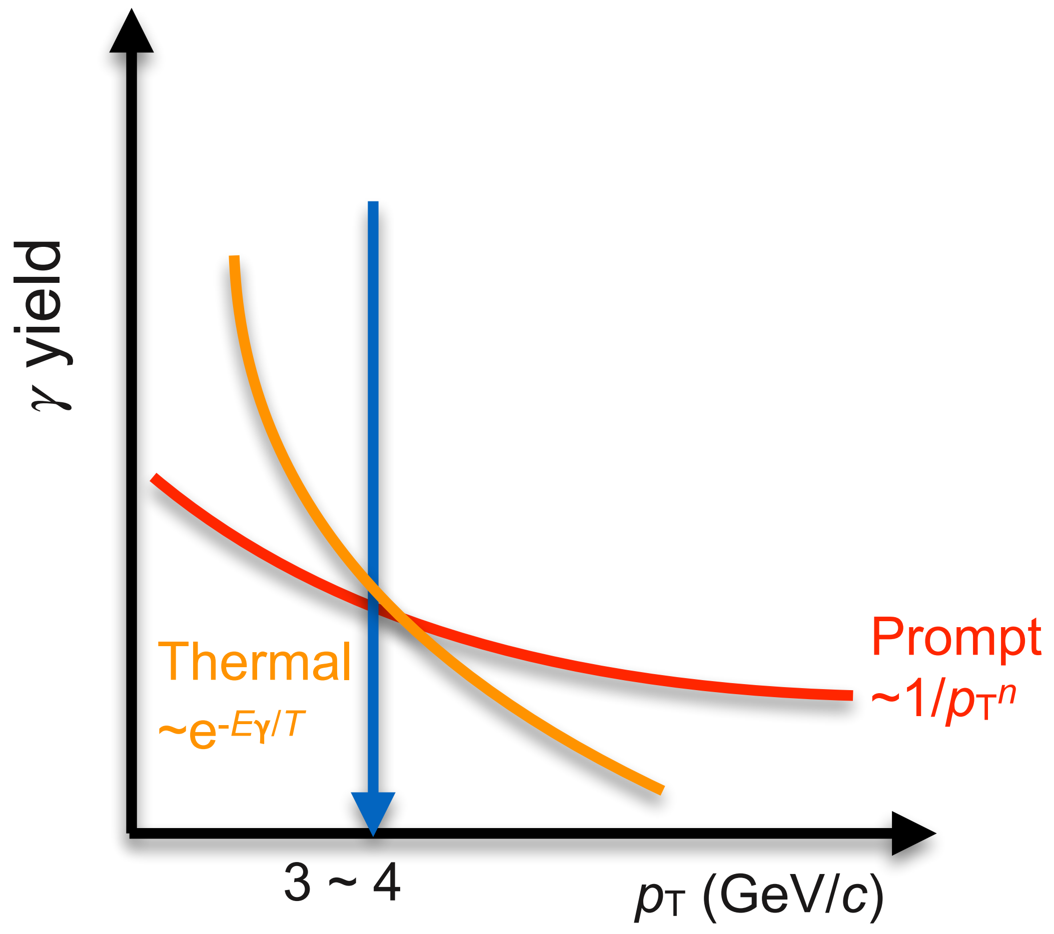
  ➡ **Direct prompt γ**: $R_{AA} \approx 1$
  - Initial hard scattering, processes at LO:







  - **Test pQCD** predictions, **constrain (n)PDFs & FF**
    - Cold nuclear matter (nPDF) effects can lead to $R_{AA} \neq 1$
  - $p_T^{\gamma} \simeq p_T^{\text{parton}}$, before parton loses Δ*E* in QGP
  - Measure **FF modifications**, where is the Δ*E* radiated?

$$d\sigma^{hard}_{AB\to h} = \underbrace{\boxed{f_{a/A}(x_1, Q^2)} \otimes \boxed{f_{b/B}(x_2, Q^2)}}_{\text{PDFs}} \otimes \underbrace{\boxed{d\sigma^{hard}_{ab\to c}(x_1, x_2, Q^2)}}_{\text{Hard scattering (pQCD)}} \otimes \underbrace{\boxed{D_{c\to h}(z, Q^2)}}_{\text{Fragmentation function (FF)}}$$

Main focus of today's presentation!

Photon sources probing the QGP

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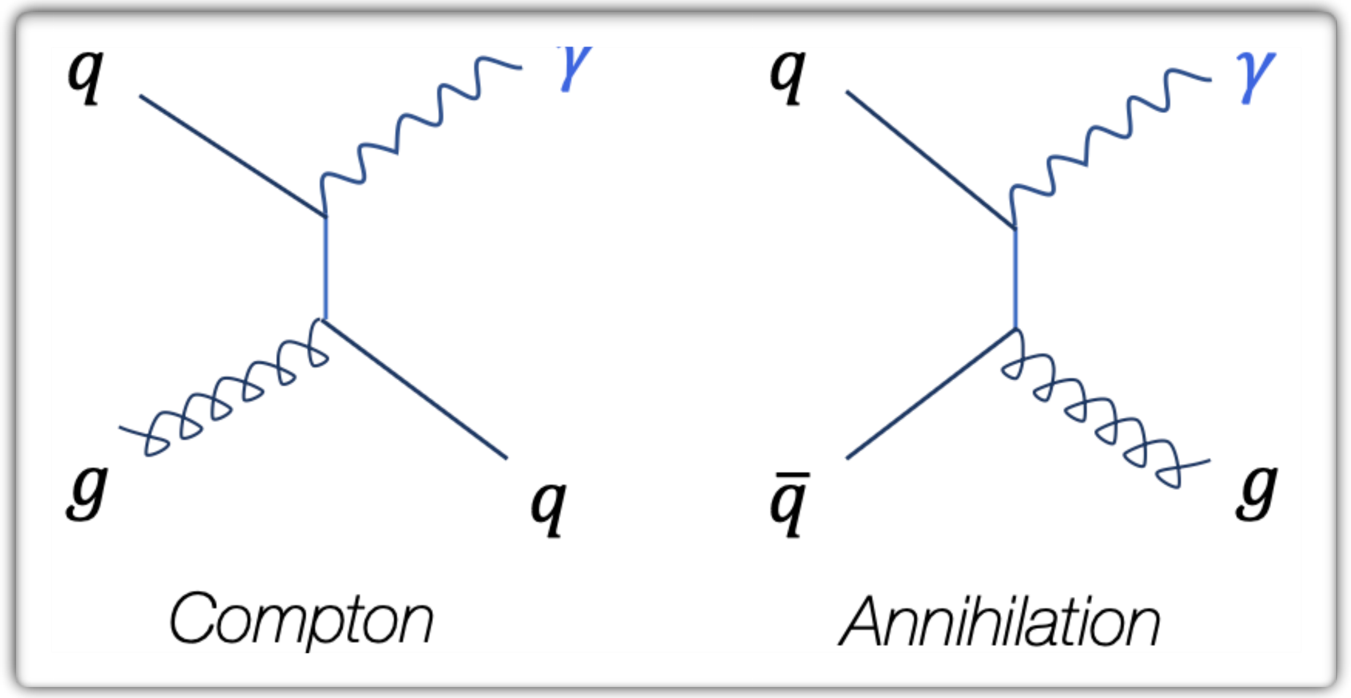

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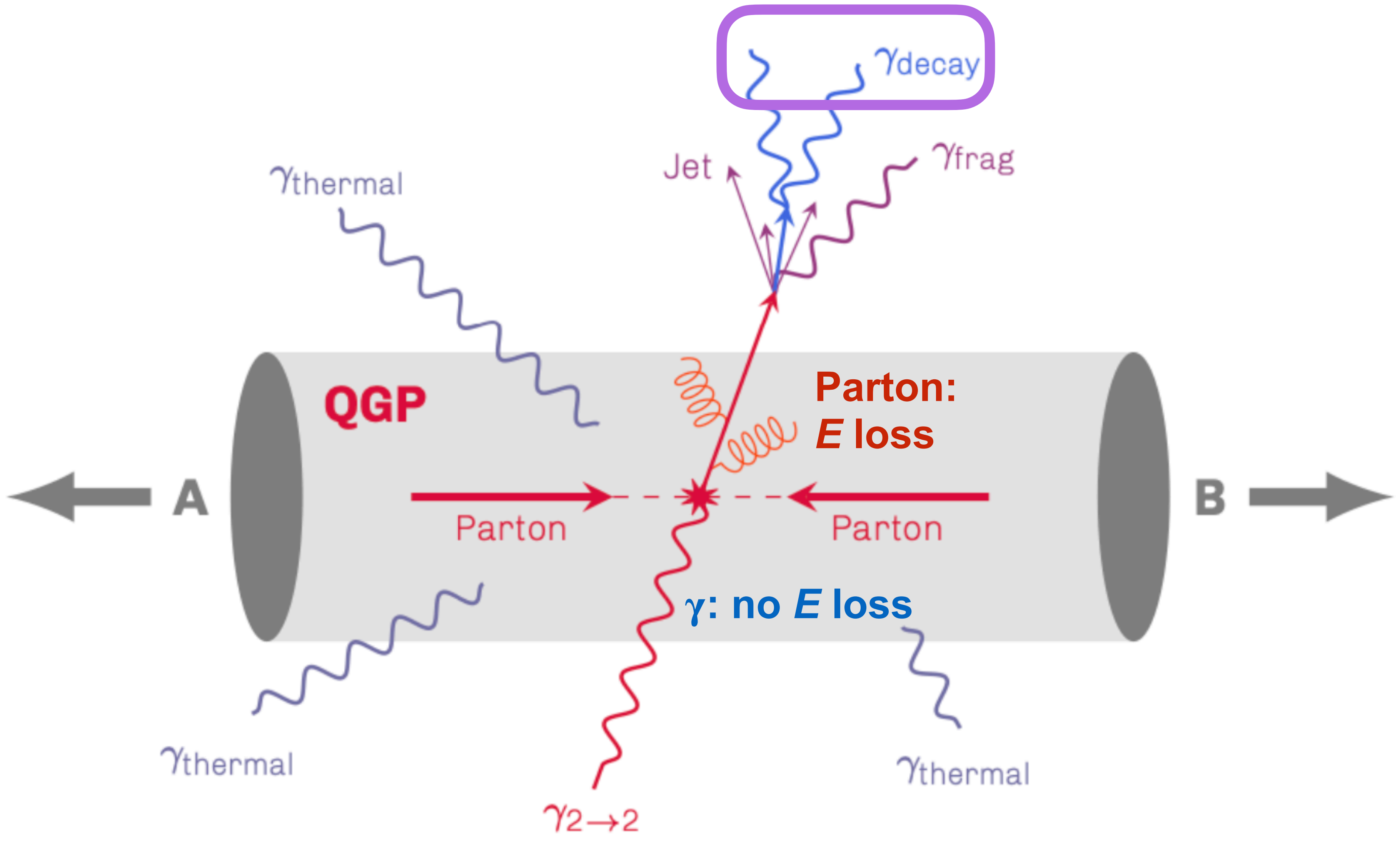

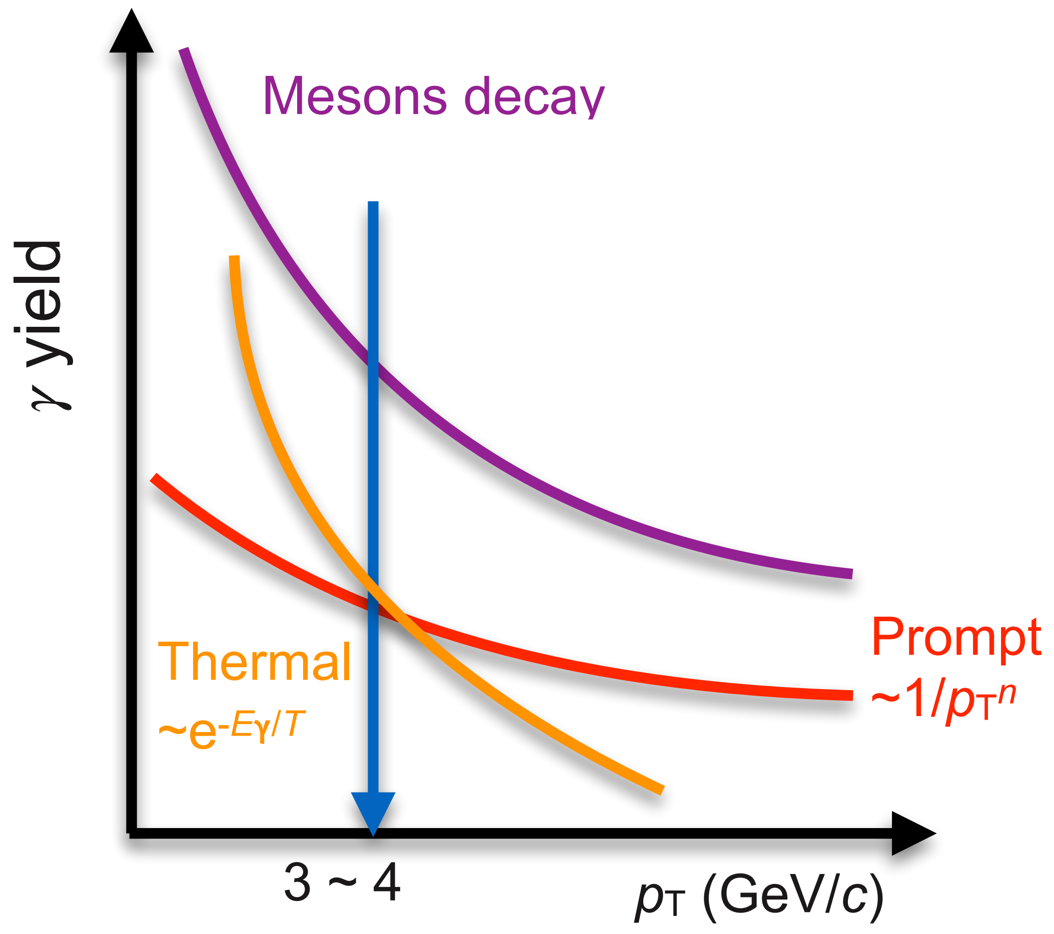

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PDFs *Hard scattering (pQCD)* *Fragmentation function* (FF)

- **Decay γ (π^0 & η)**: R_{AA} << 1
  - Main background for direct γ measurements
    - ***N***

Photon sources probing the QGP

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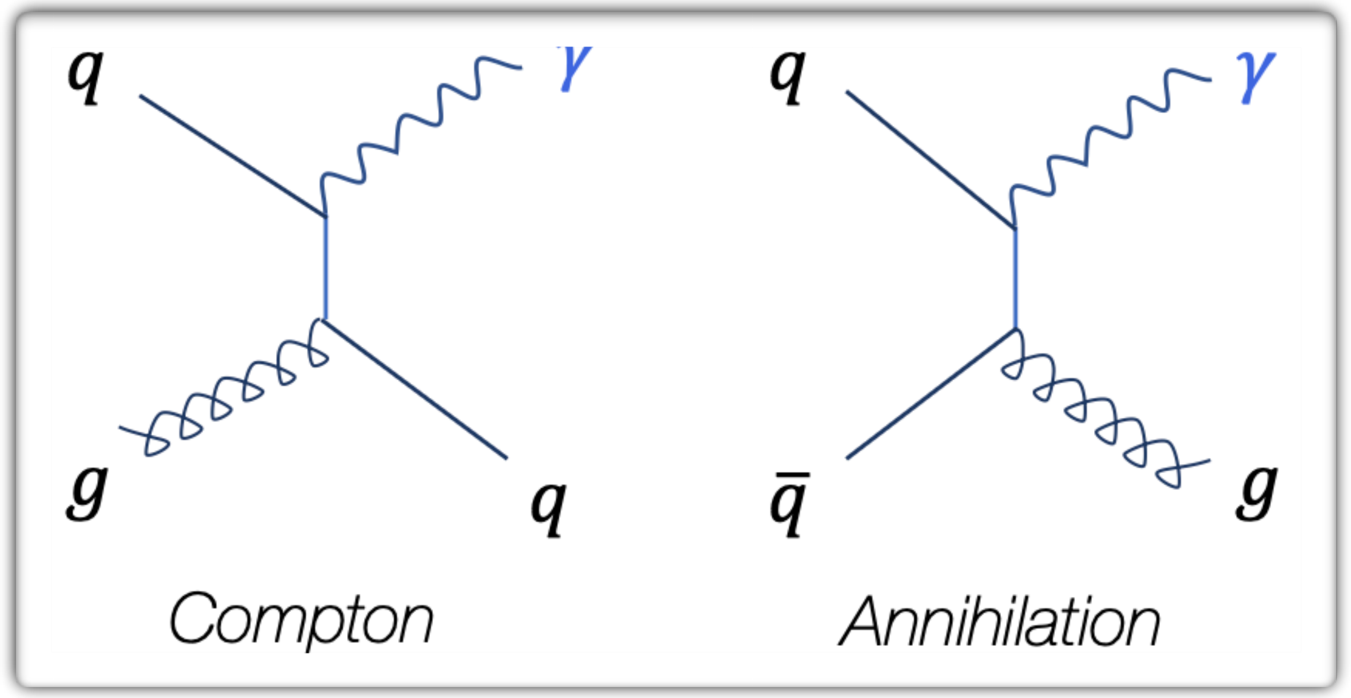

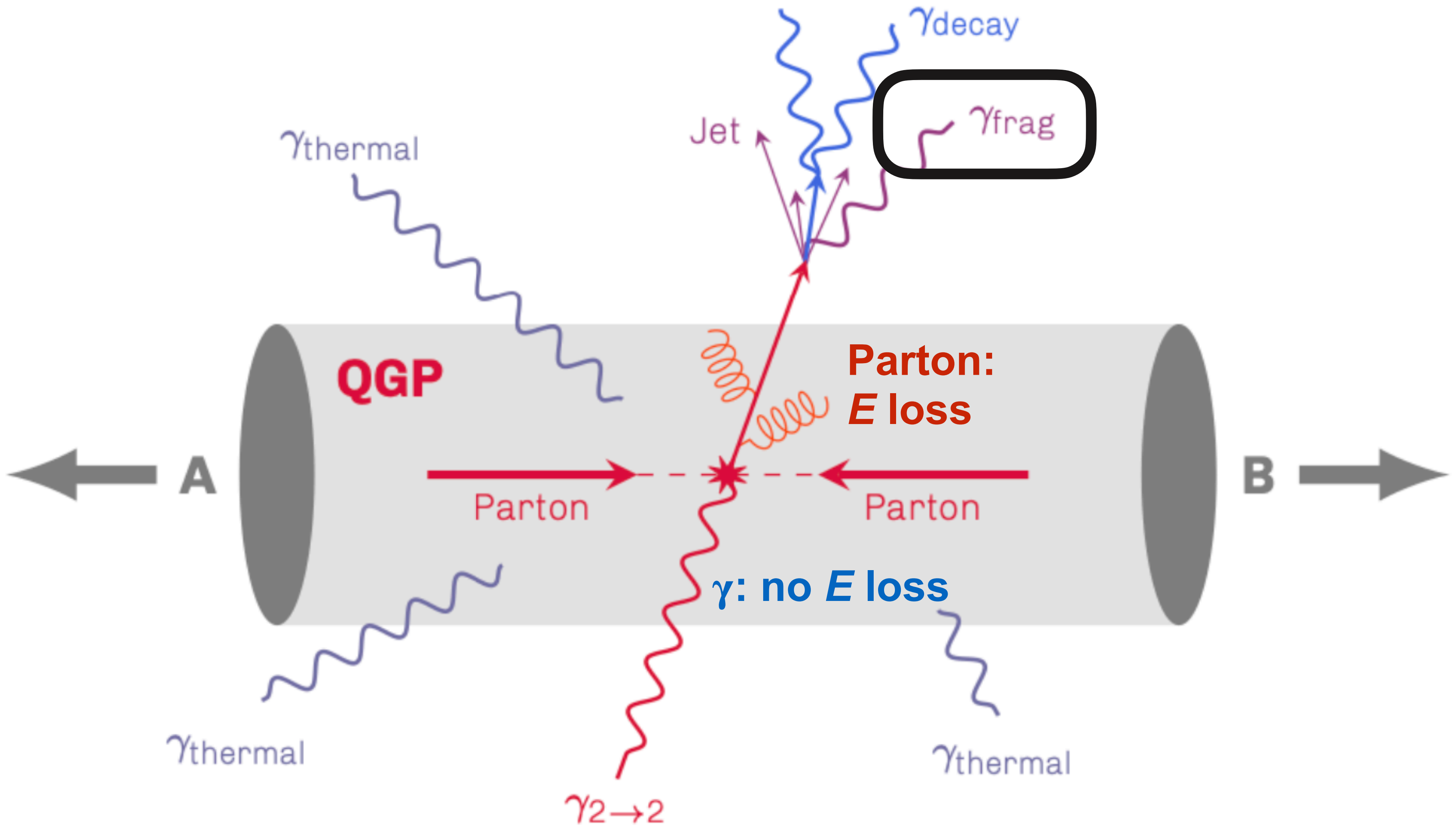

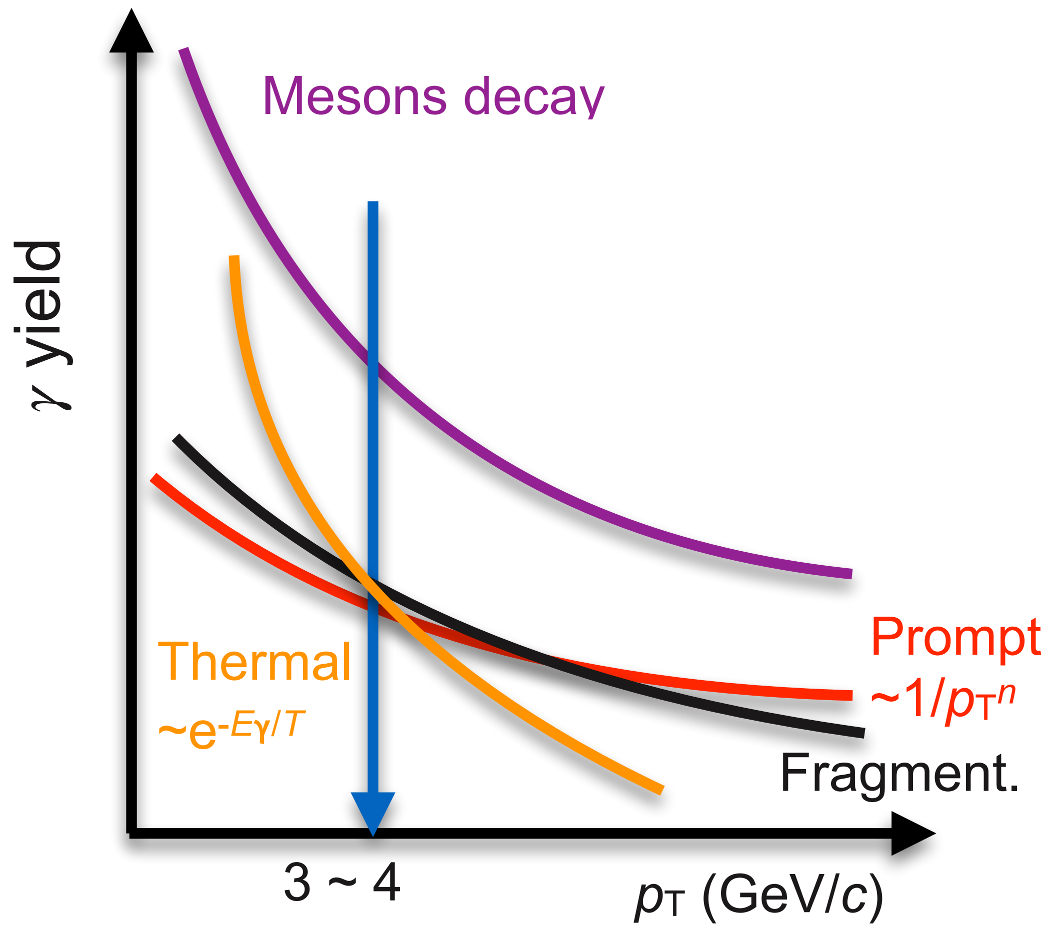

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PDFs — *Hard scattering (pQCD)* — *Fragmentation function (FF)*

    - **Test pQCD** predictions, **constrain (n)PDFs & FF**
      - Cold nuclear matter (nPDF) effects can lead to $R_{AA} \neq 1$
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- **Decay** γ (π^0 & η): R_{AA} << 1
  - Main background for direct γ measurements
    - $N_{\text{prompt}} / N_{\text{decay}}$ ~ 0.01 (pp)

➡ **Other direct γ sources:**

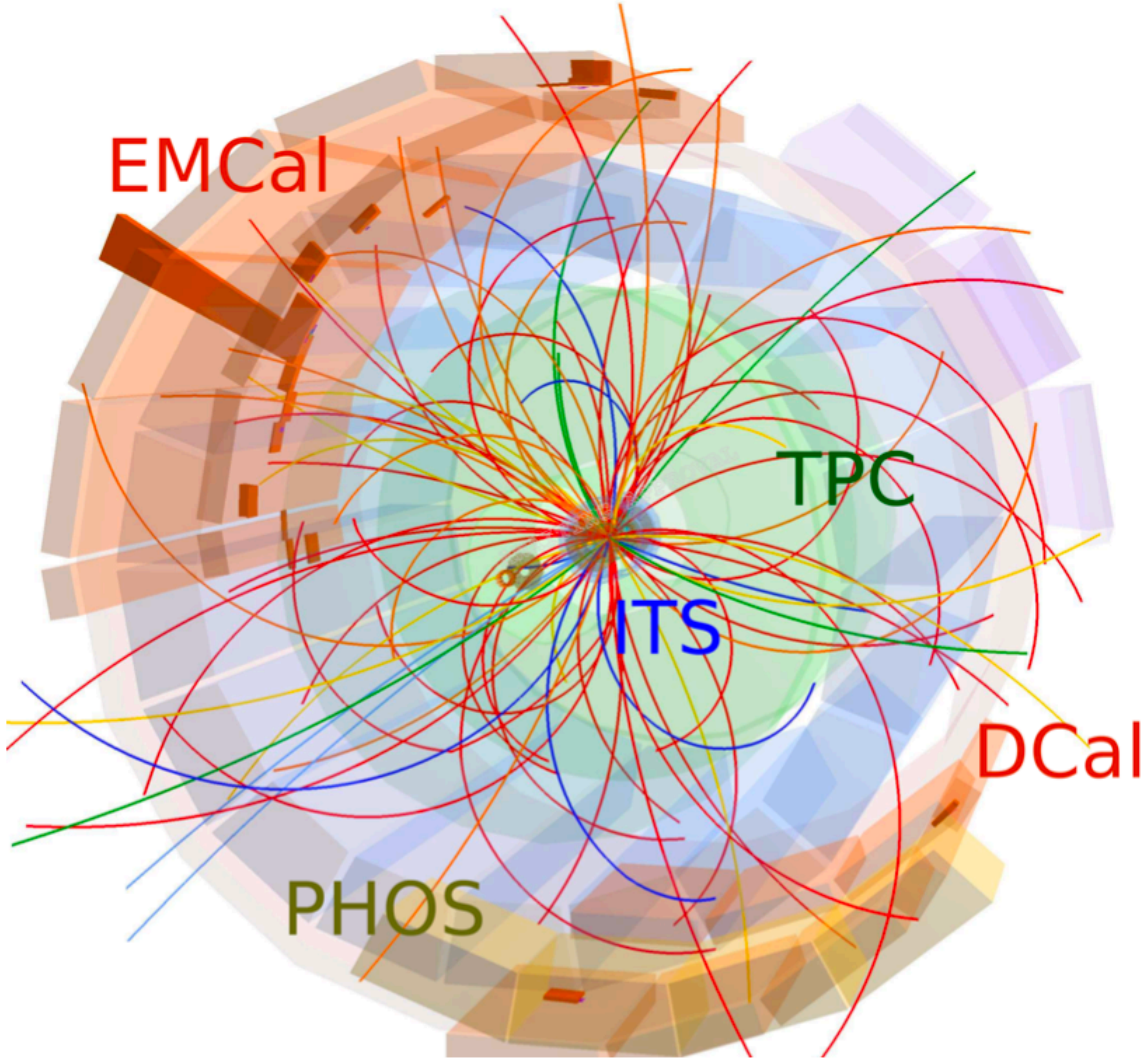
- **Fragmentation** γ: $R_{AA} < 1$? comparable yield to direct prompt γ
- QGP pre-equilibrium γ? $R_{AA} >> 1$ (glasma phase)
- Jet-QGP interaction γ? $R_{AA} >> 1$ (hard partons scattering)

How to measure and identify prompt γ in ALICE?

- For the measurements presented here:

➡ Calorimeter, EMCal/DCal:
- Pb/scintillator towers (6×6 cm)
- 4.4 m from the interaction point
- $|\eta| < 0.67$ for $\Delta\varphi = 107^\circ$,
  $0.22 < |\eta| < 0.67$ for $\Delta\varphi = 60^\circ$ (DCal);
- Identification: EM shower dispersion
- E_γ > 700 MeV
- Photon and jet trigger
- **LNF and LPSC contributed to this project**

➡ Tracking, TPC & ITS
- $|\eta| < 0.9$ for $\Delta\varphi = 360^\circ$
- E_γ > 100 MeV



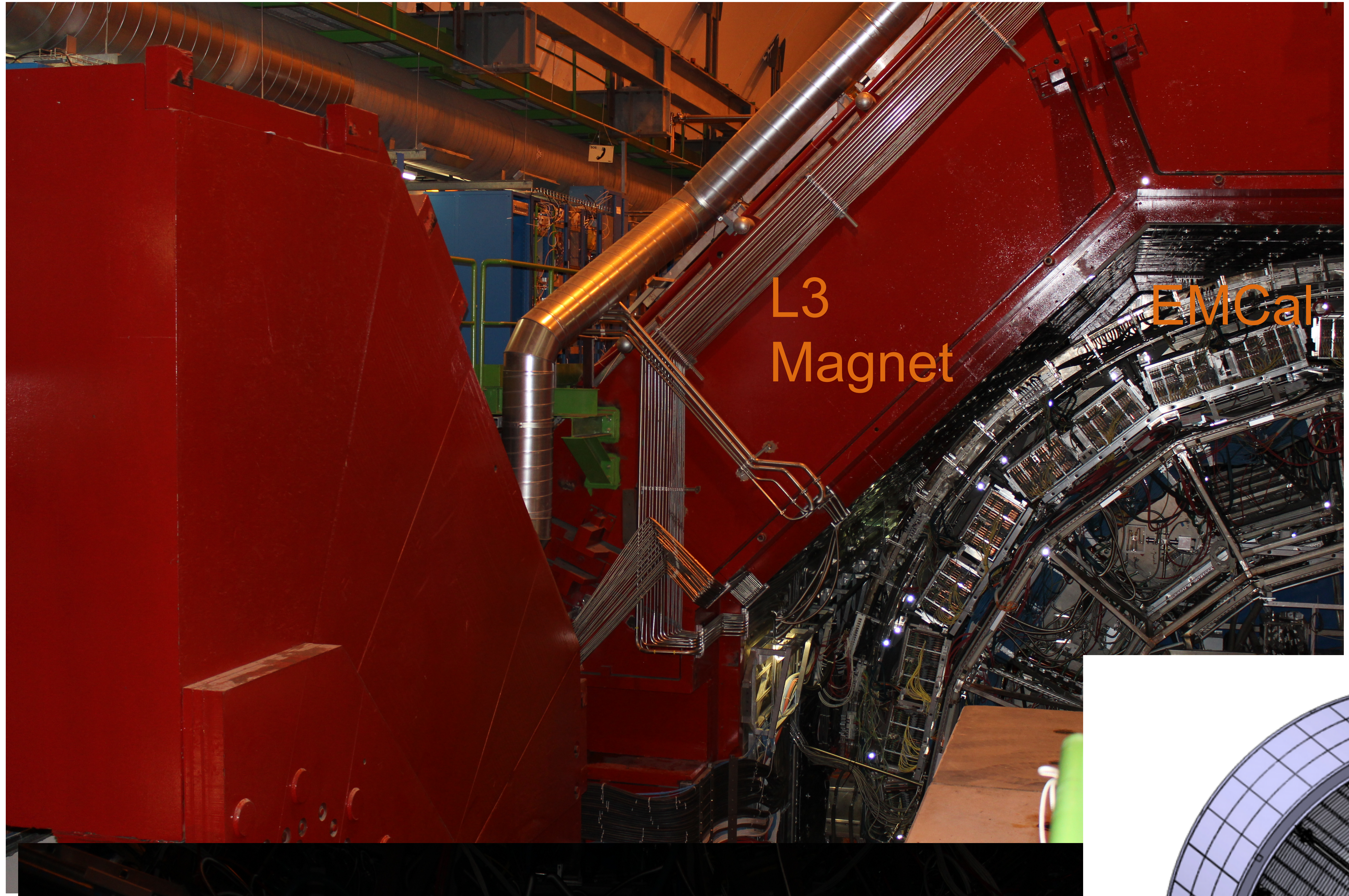
- γ identification combining tracking+calorimeter

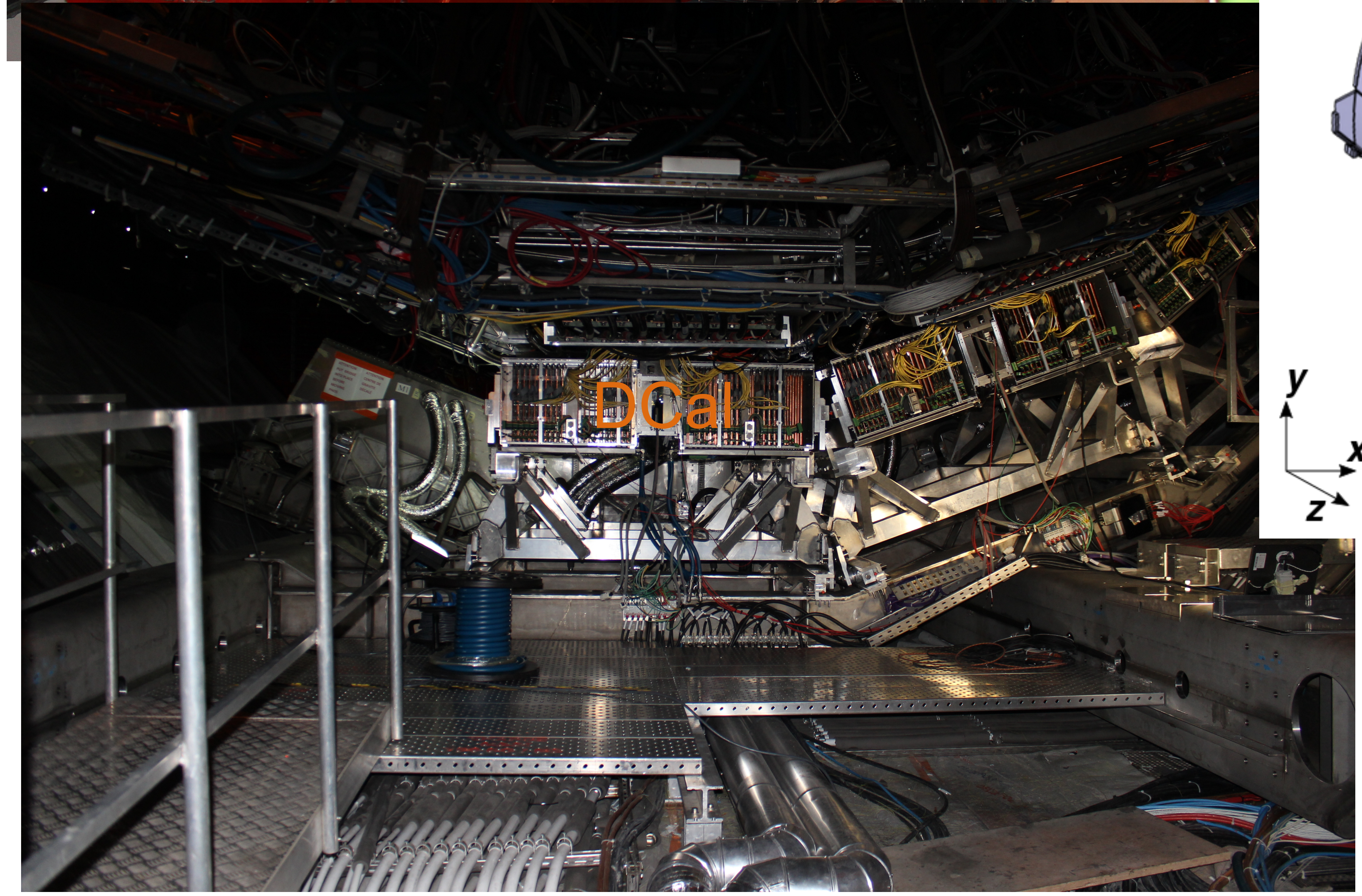
➡ Inclusive γ: Charged particle veto

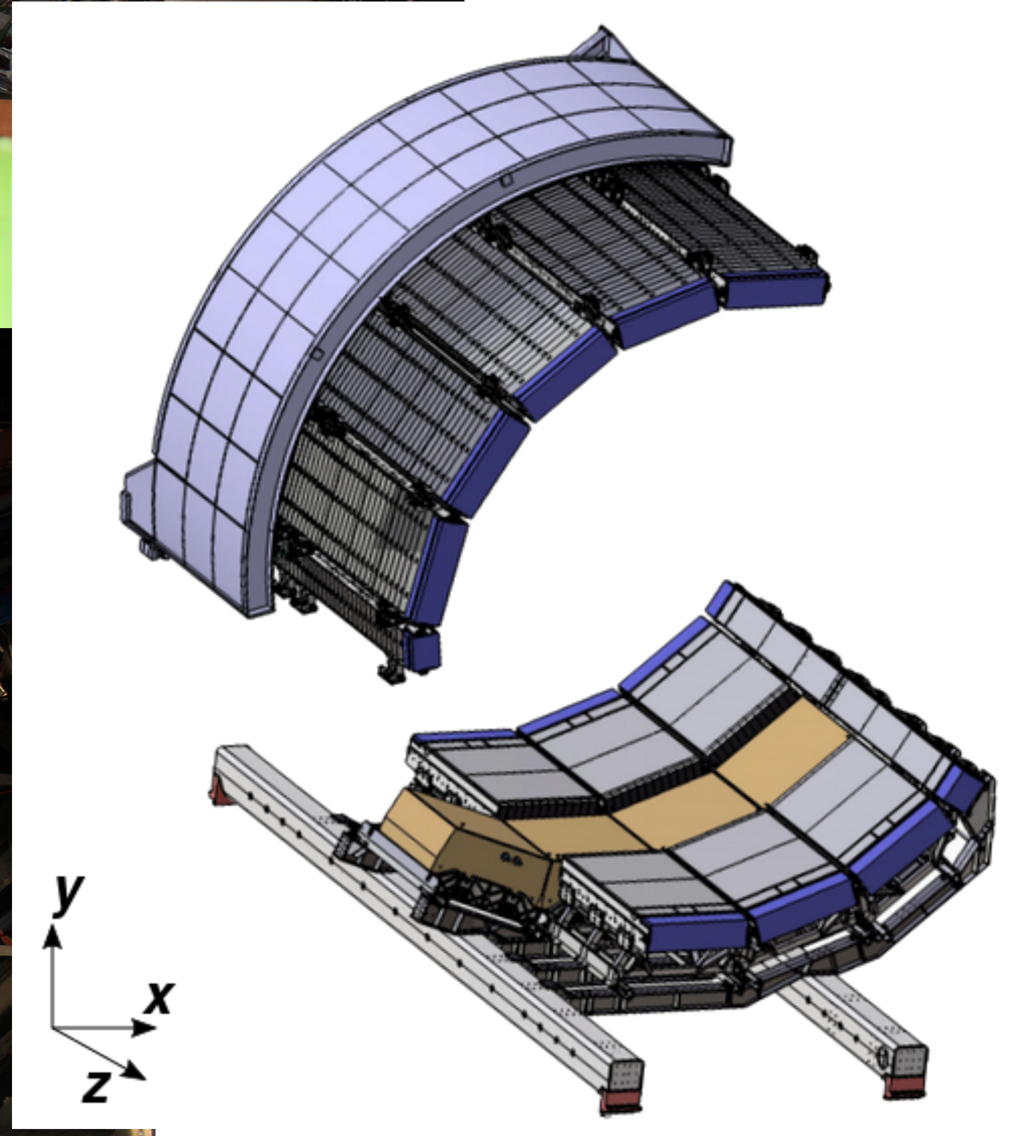
➡ Prompt γ: **Isolation** (next slides)


Tower module
2x2 cells
LNF lab ~ 2008


Supermodule
LHCB
SMUS#4


L3
Magnet
EMCal


DCal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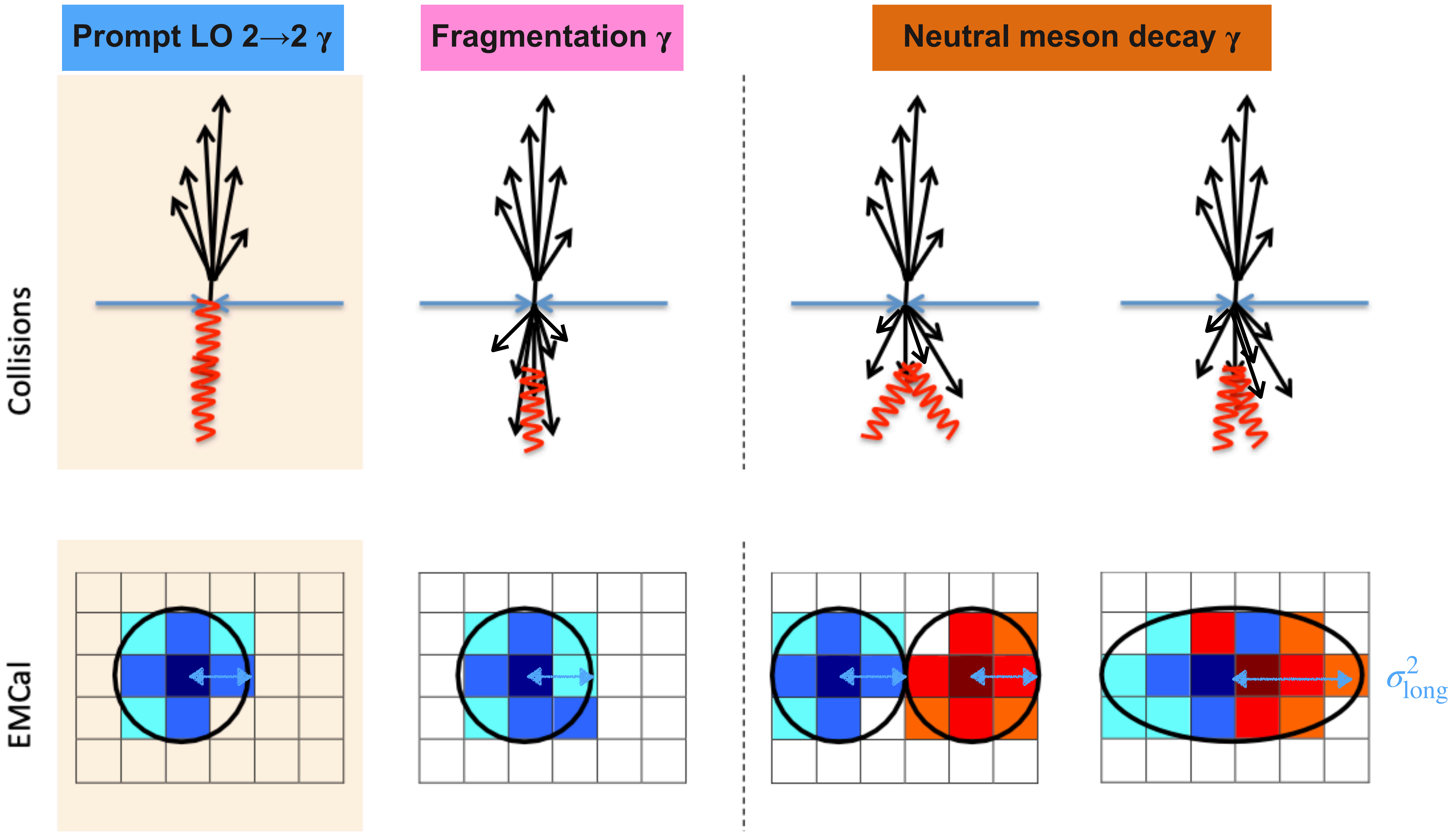
ALICE

Prompt γ identification in ALICE: EM shower spread shape



EM shower discrimination

γ single vs merged decays

- ➡ **EMCal**
- ➡ Shower elongation $\sigma^2_{\rm long}$: longest ellipse axis size

➡ **circular "narrow" cluster**

➡ circular narrow clusters, potentially wider due to jet particles nearby merging

➡ decay γ merge, E_{π^0} > 6 GeV **elliptical "wide" cluster**

Prompt γ identification in ALICE: EM shower spread shape & isolation with tracks

Prompt γ at LO 2→2: *isolated*

- **TPC+ITS charged tracks**
- Select γ with low hadronic activity in R, small $p_{\mathrm{T}}^{\mathrm{iso,\,ch}}$

$$\sqrt{(\eta_{\mathrm{track}} - \eta_{\gamma})^2 + (\varphi_{\mathrm{track}} - \varphi_{\gamma})^2} < R = 0.4 \text{ or } 0.2$$

$$p_{\mathrm{T}}^{\mathrm{iso,\,ch}} = \sum p_{\mathrm{T}}^{\mathrm{tracks\ in\ cone}} - \rho_{\mathrm{UE}} \cdot \pi \cdot R^2 < 1.5\ \mathrm{GeV}/c$$

- Underlying event (UE) subtracted event-by-event, ρ_{UE} density estimation

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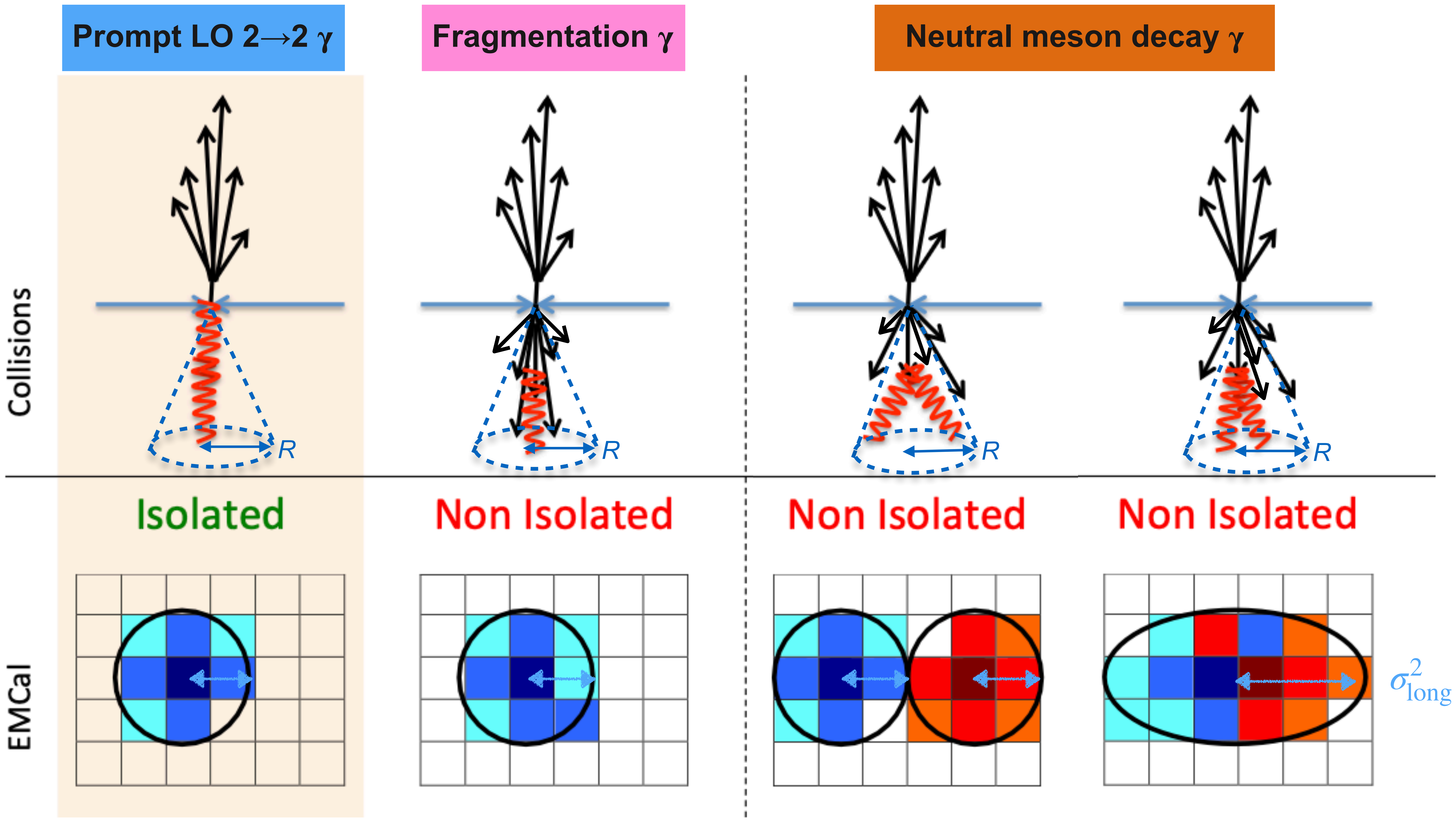

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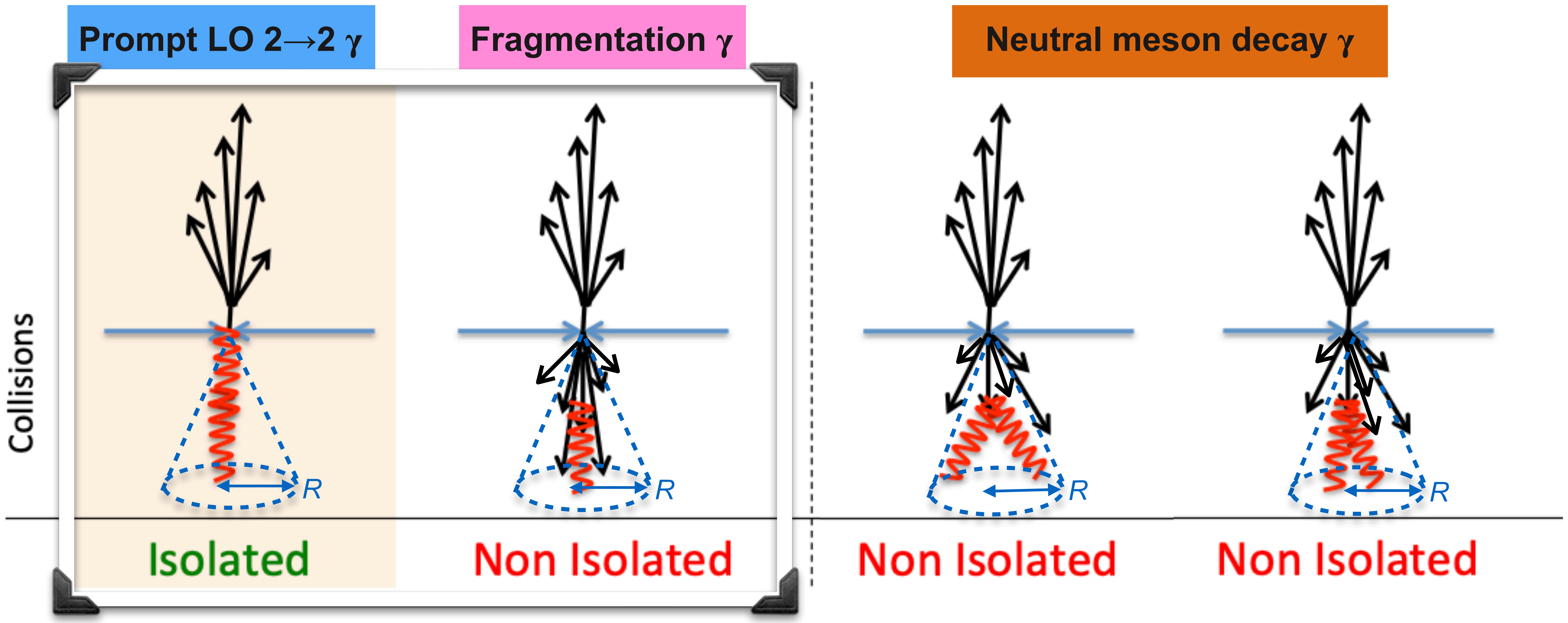
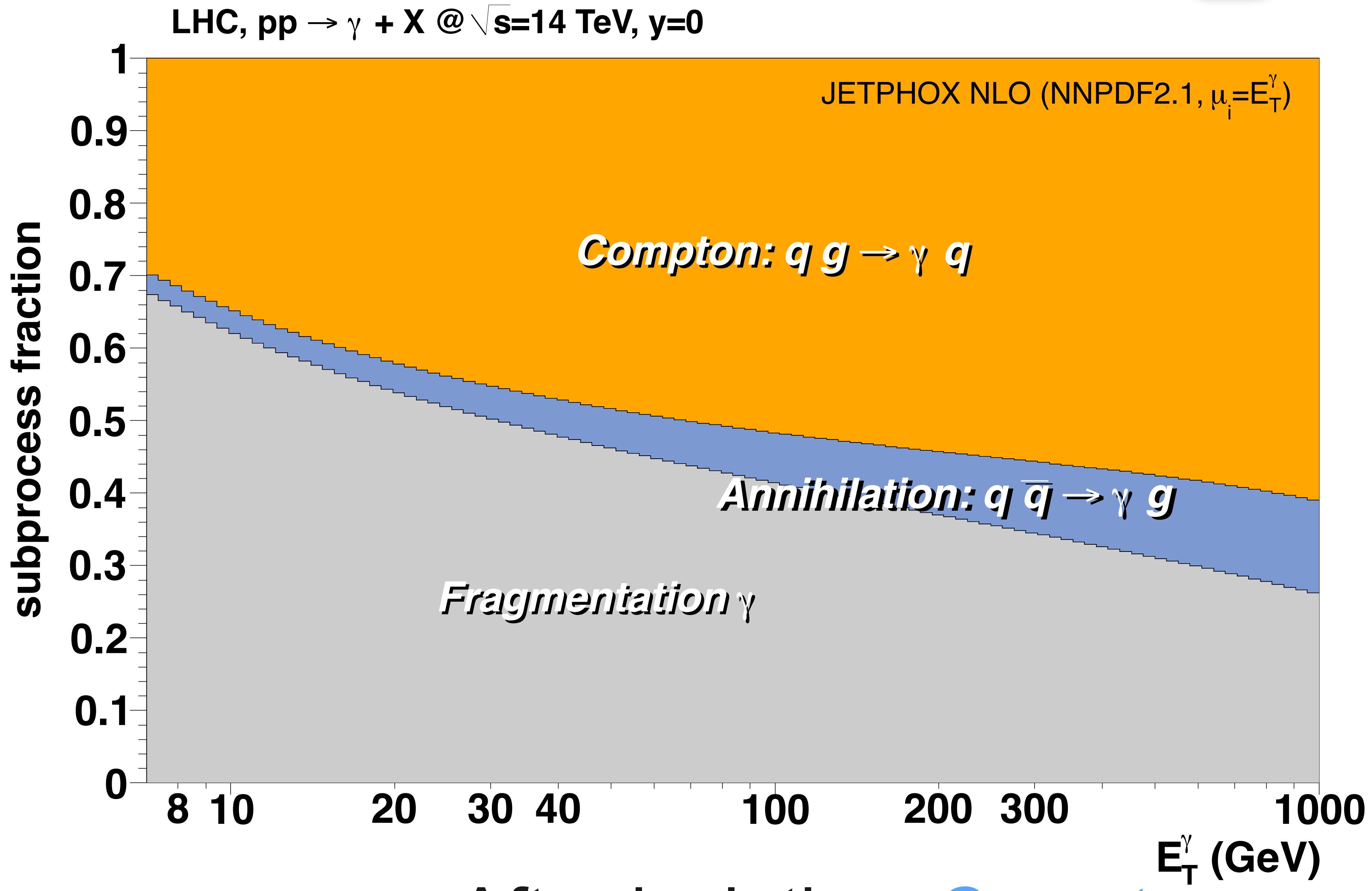


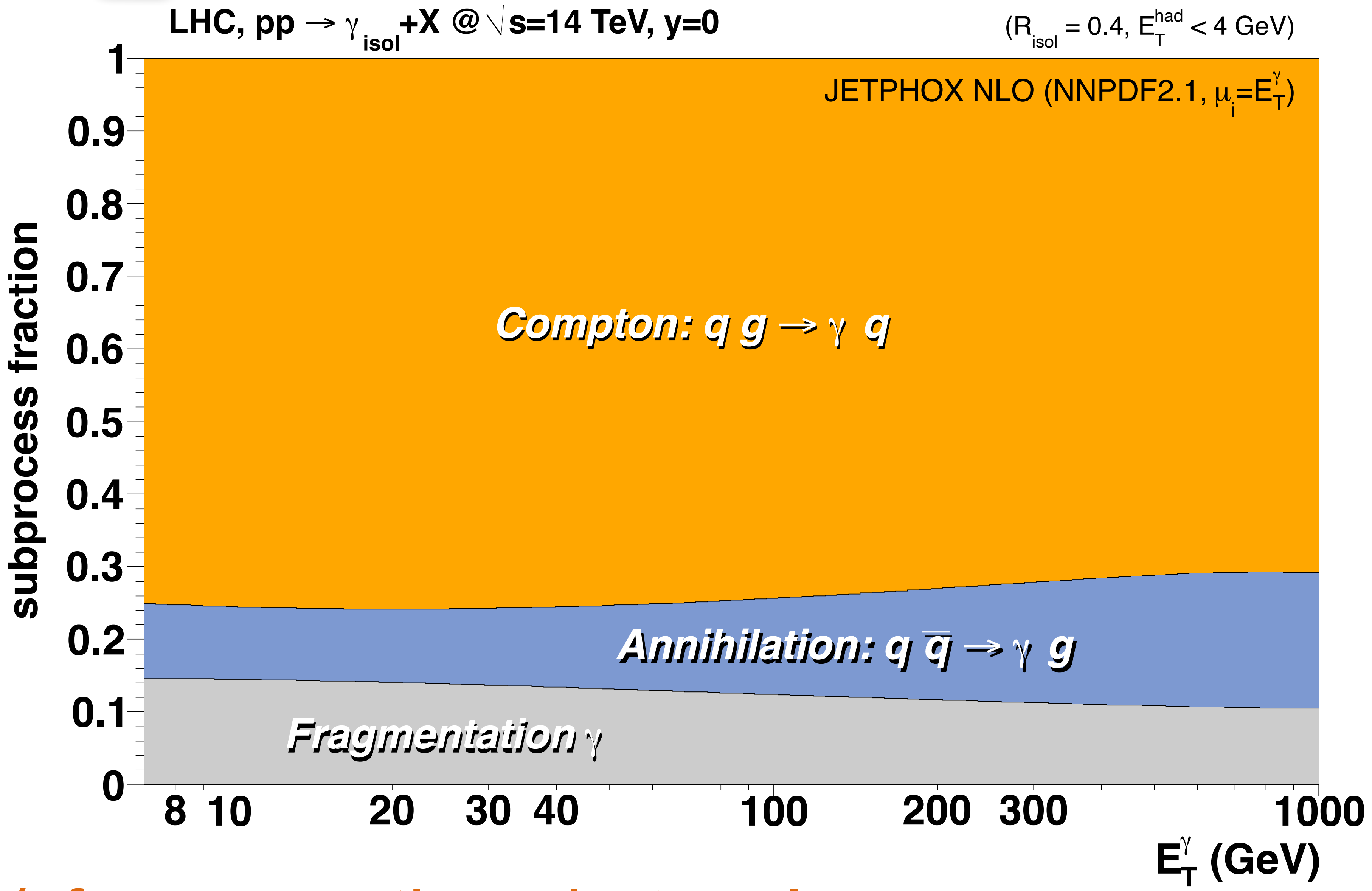


pp, $\sqrt{s}$ = 14 TeV

Isolation

R = 0.4, $E_{\mathrm{T}}^{\text{had}} < 4$ GeV

D. D'Enterria & J. Rojo
Nucl. Phys. B 860 (2012),
arXiv:1202.1762 [hep-ph]



After isolation: Compton process dominance, 10-15% fragmentation photons!

Prompt γ identification in ALICE: isolation with tracks

Prompt γ at LO 2→2: *isolated*

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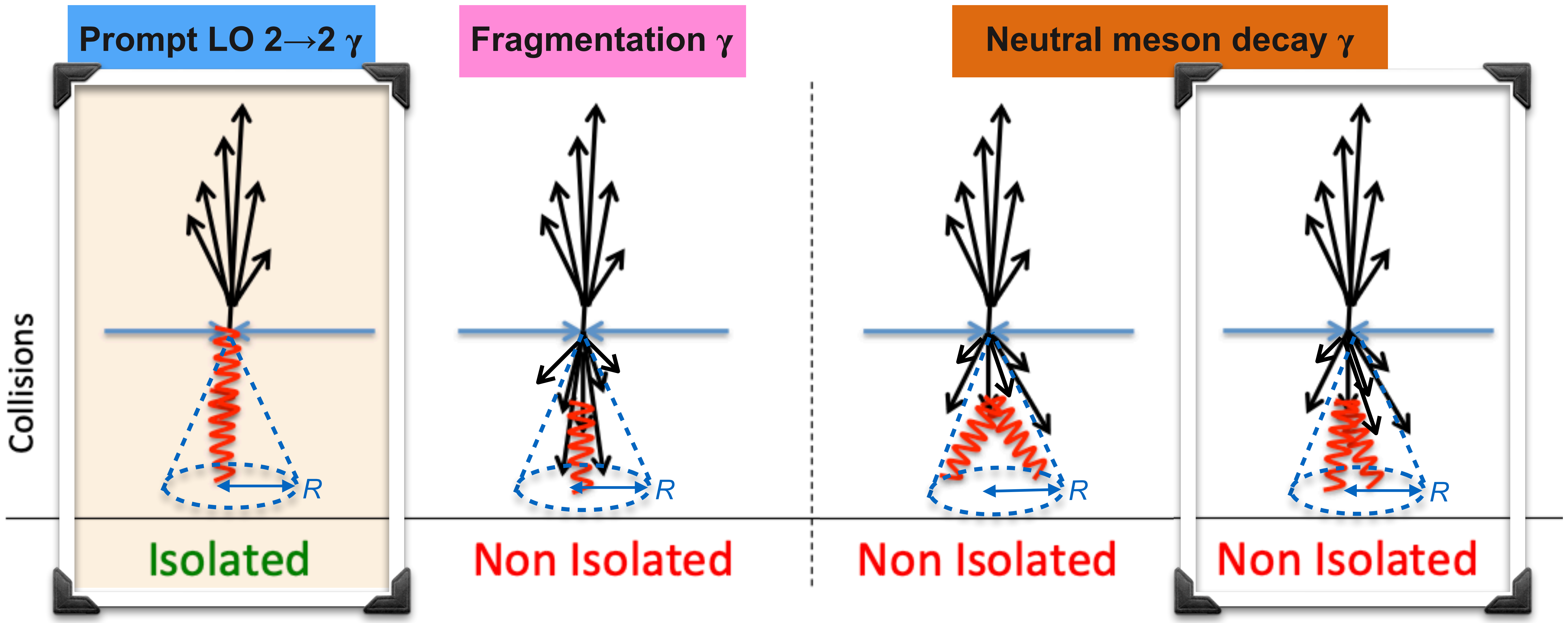
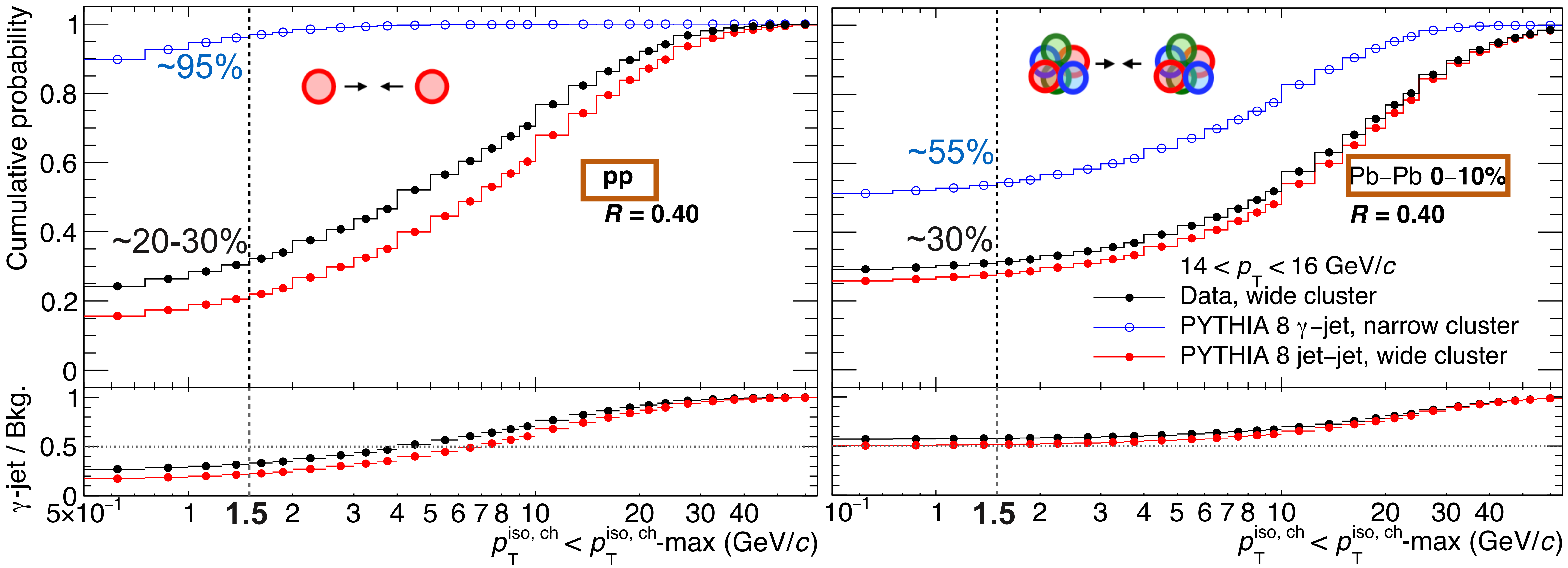


➡ Strong neutral meson background rejection
◉ Remaining cases: parton fragments into meson plus few low p_{T} particles → low $p_{\mathrm{T}}^{\mathrm{iso,\,ch}}$

➡ Strong effect in central Pb–Pb in signal rejection due to UE fluctuations

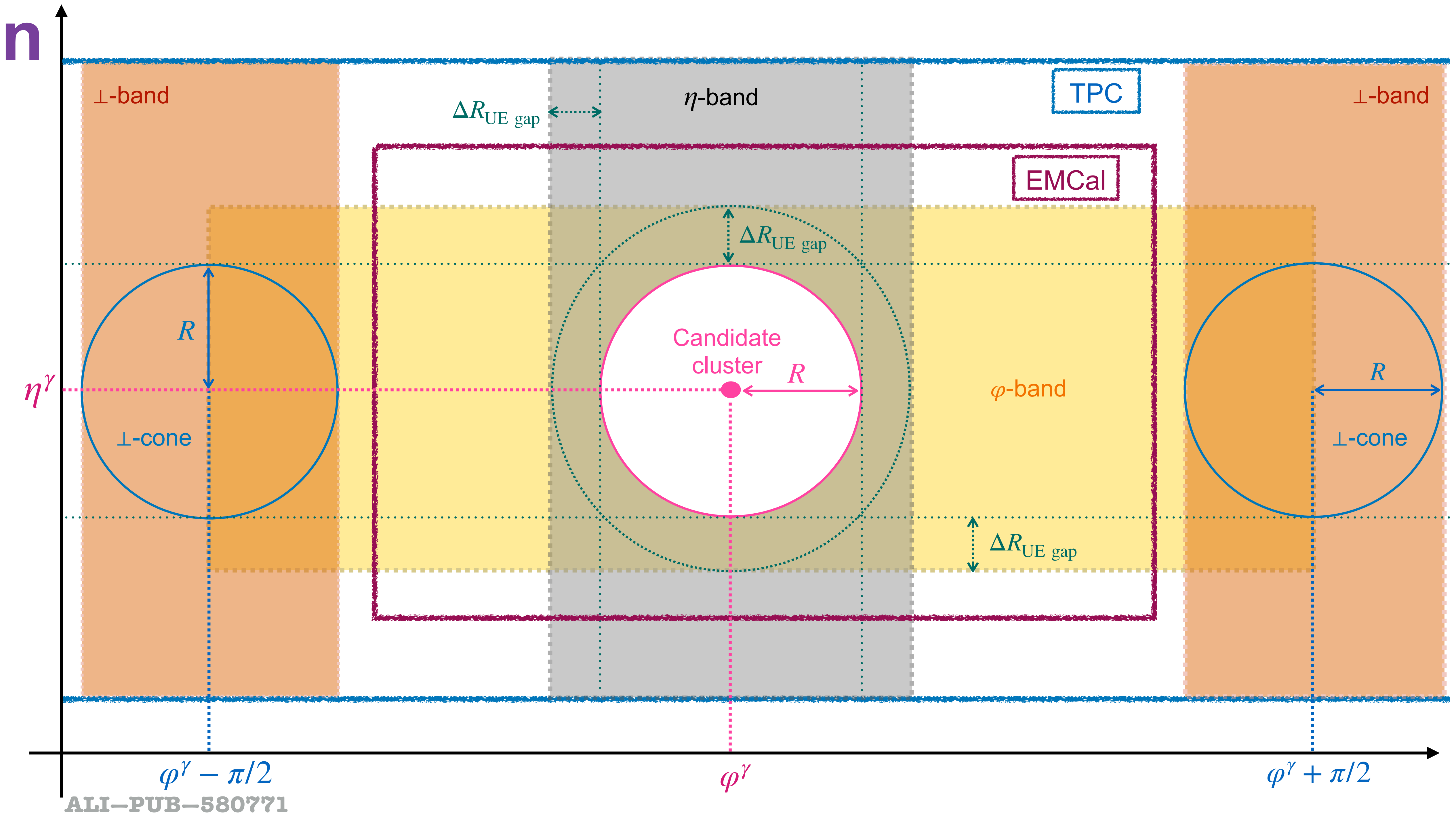
ALICE-PUBLIC-2024-003

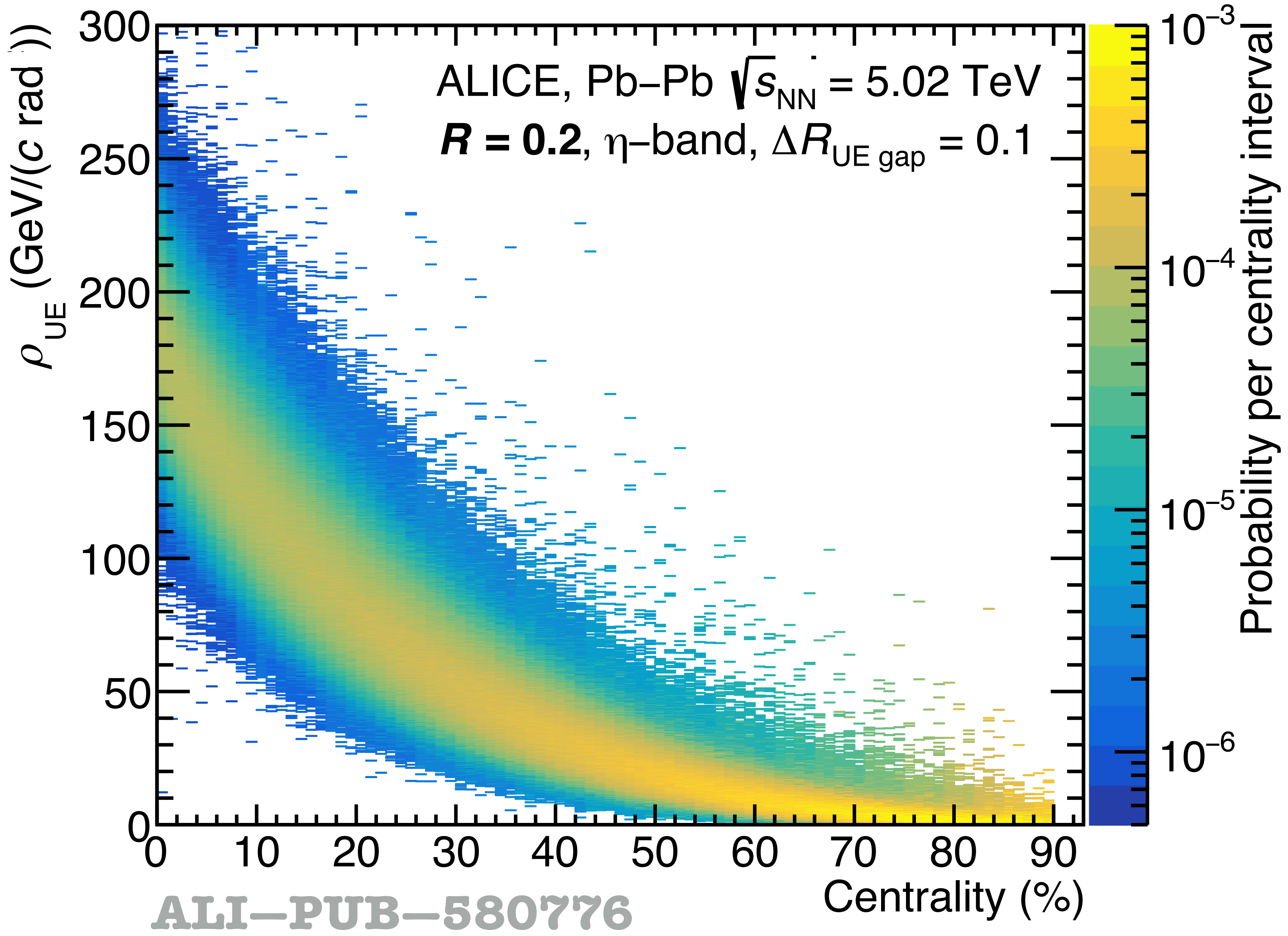


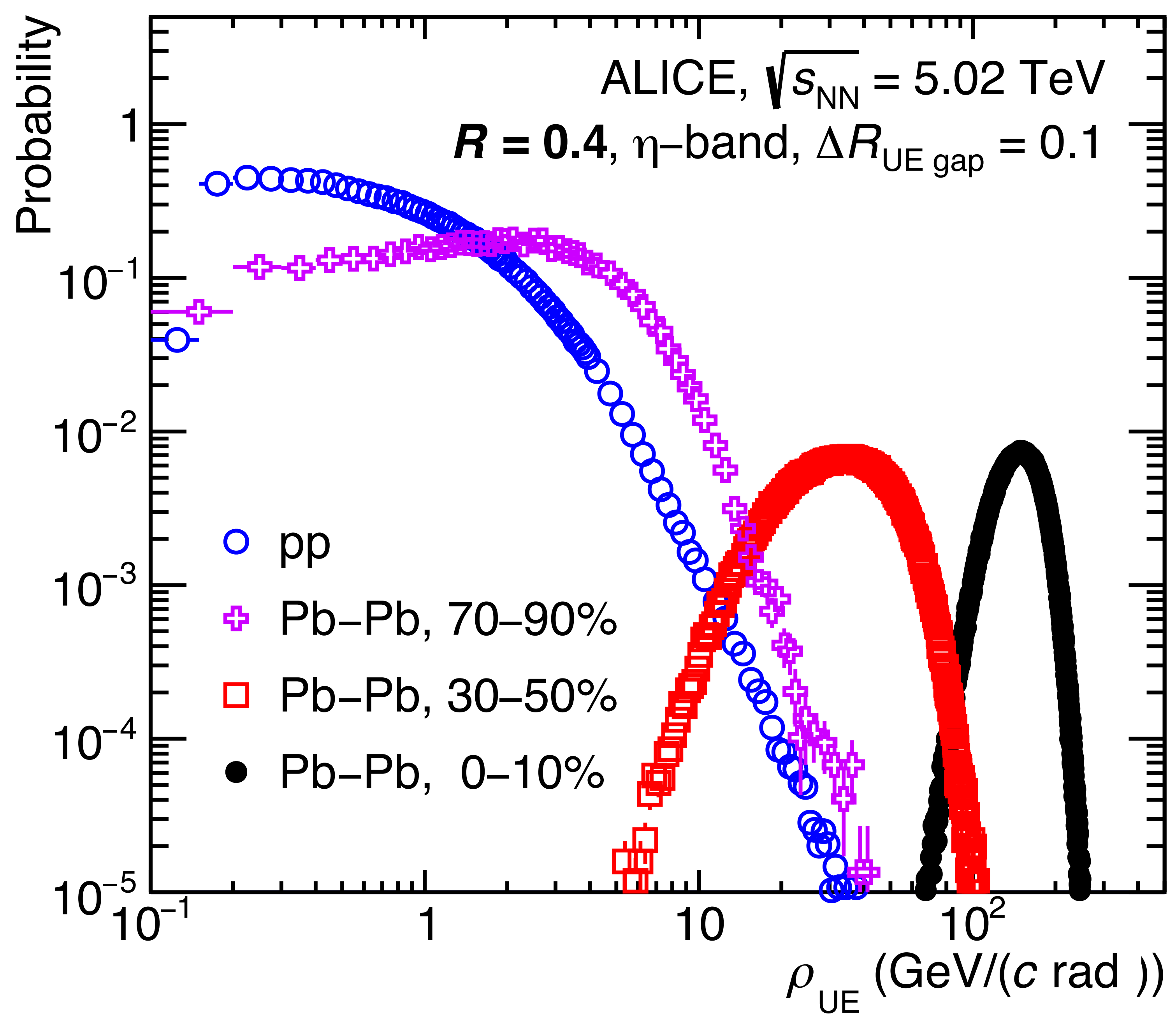
Underlying event estimation

Track p_T UE density estimated on Pb–Pb & pp collisions at $\sqrt{s_{NN}}$ = 5.02 TeV:

- ➡ Sum of tracks p_T normalised by ***η*-band** area
  → *Avoid flow effects*
- ➡ Gap between cone and band of $\Delta R_{\mathrm{UE\ gap}}$= 0.1
  → *Avoid jet remnants*

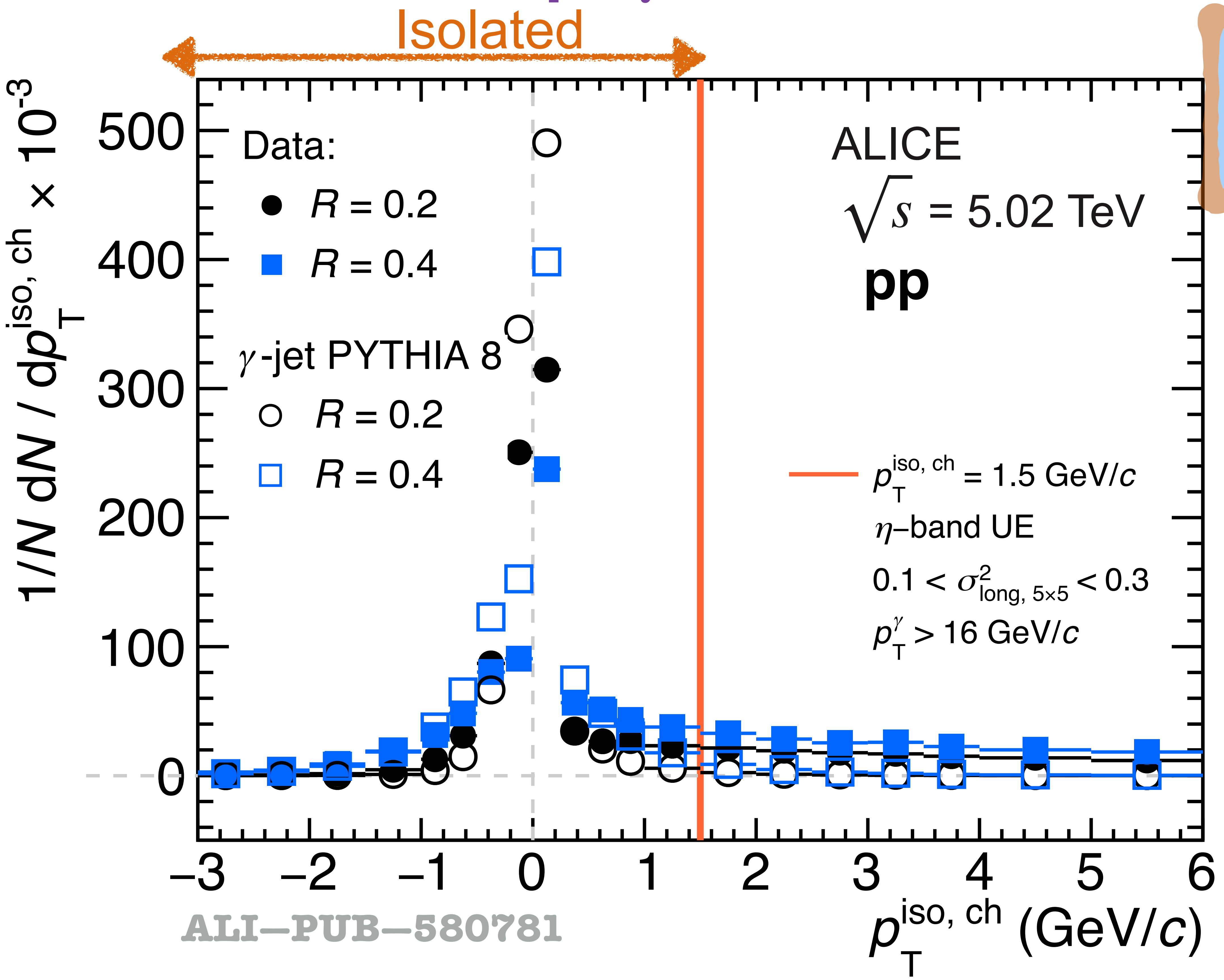


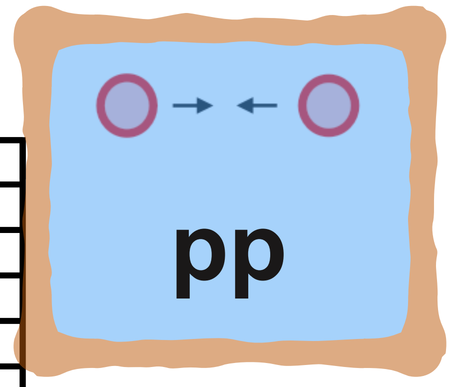


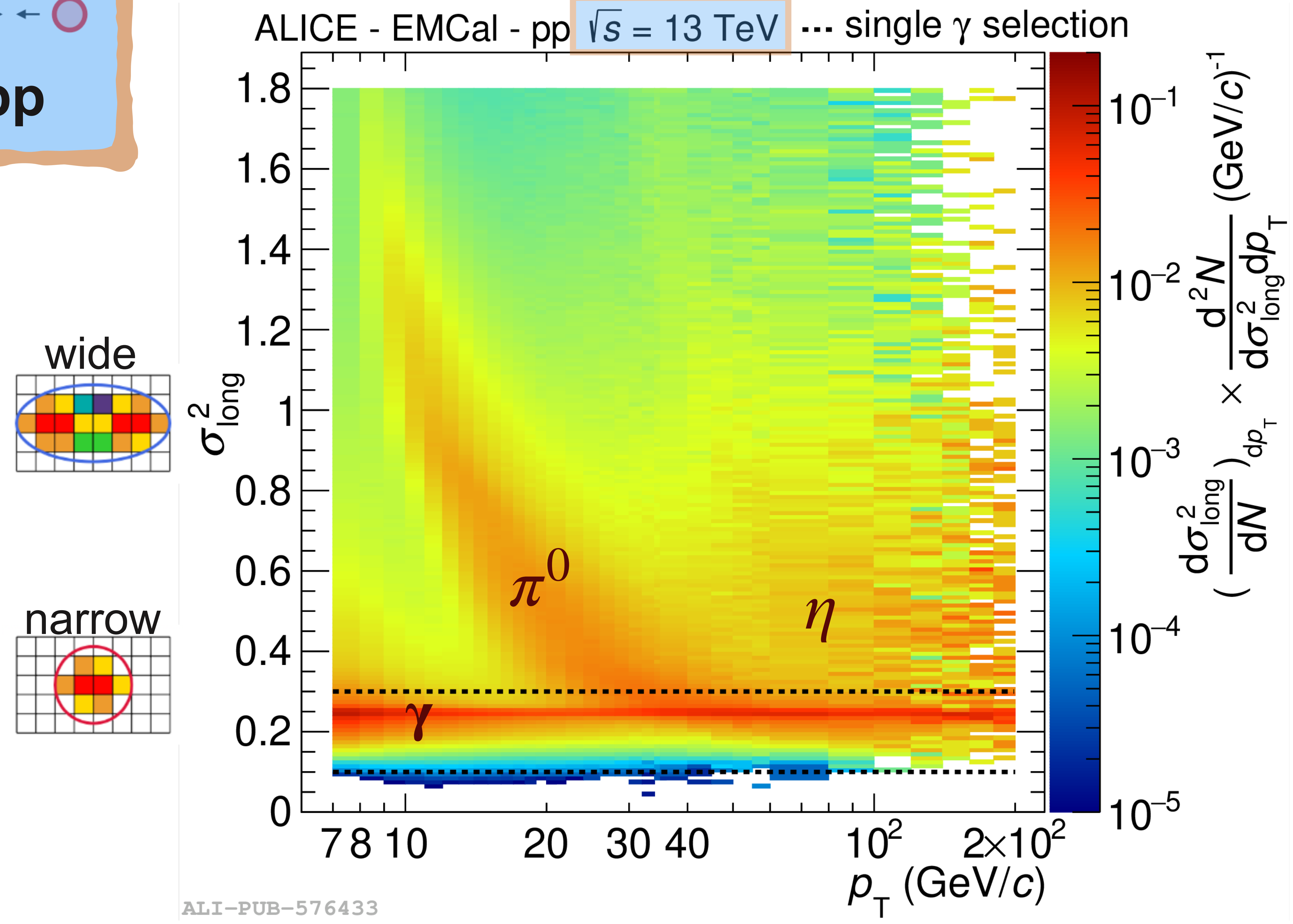


Remark: UE was not subtracted in pp $\sqrt{s}$ = 7 & 13 TeV measurements, UE small

Prompt γ identification in ALICE: EM shape & isolation



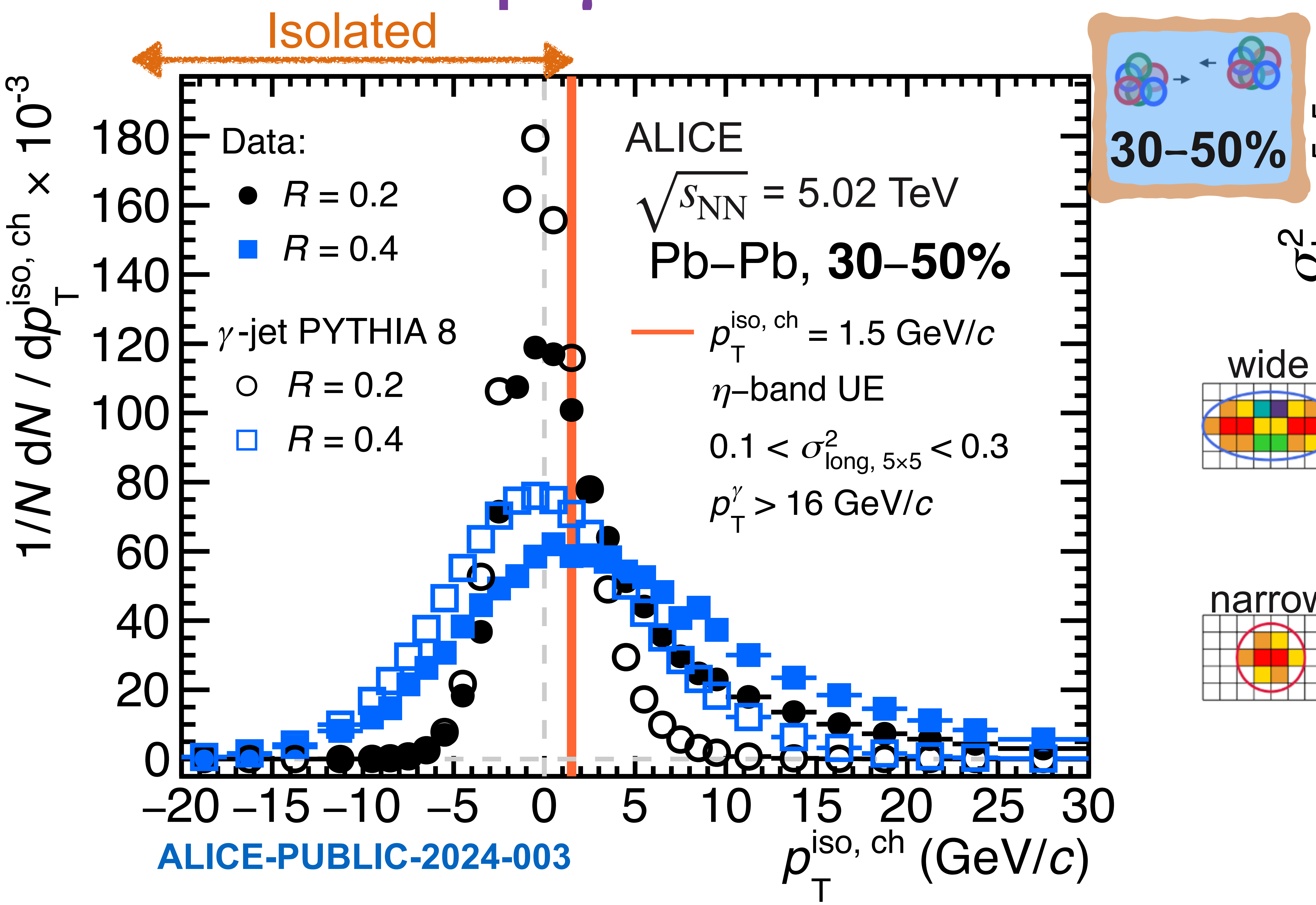


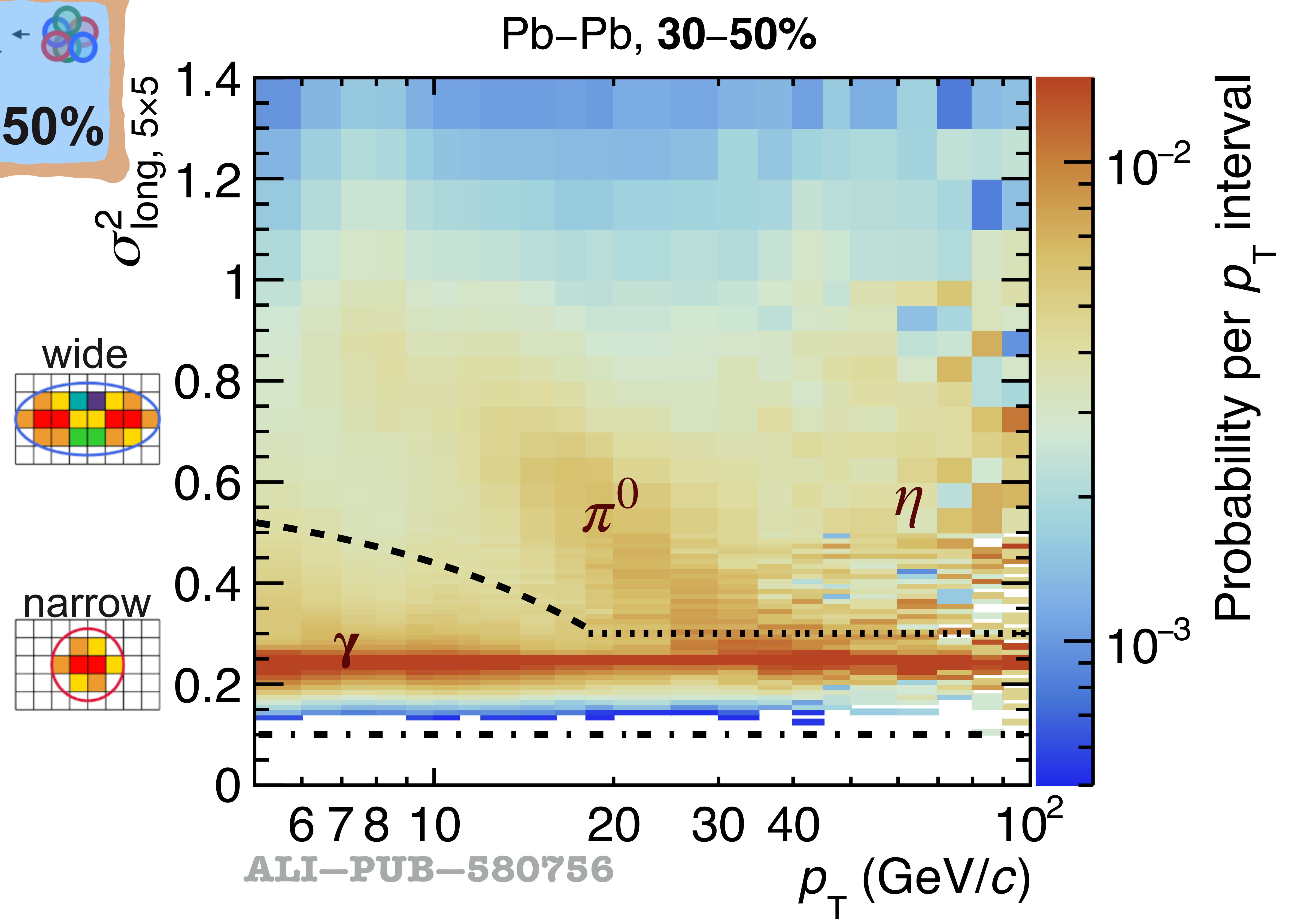


- Isolated if $p_{\mathrm{T}}^{\text{iso, ch}} < 1.5$ GeV/c with R = 0.4 or 0.2
- Symmetric in PYTHIA 8 **γ**-jet process simulation
- In data, more asymmetric and less peaked distribution due to jet contribution
- Wider for R = 0.4 due to UE fluctuations

- Visible bands for **γ** (narrow clusters) & π^0 (wide clusters)
- Select as **γ** clusters with $0.1 < \sigma^2_{\text{long, }5\times5} < 0.3$

Prompt γ identification in ALICE: EM shape & isolation

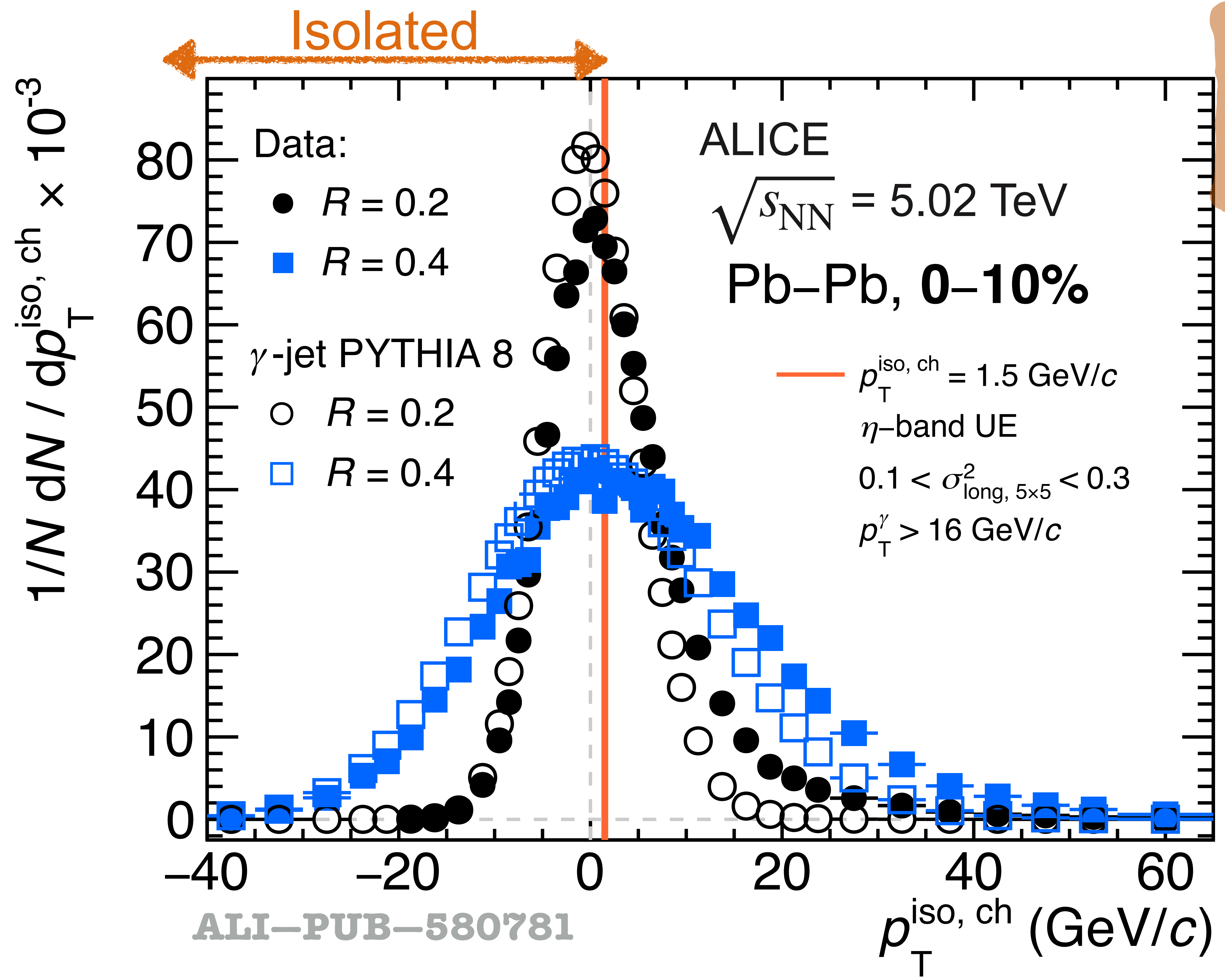


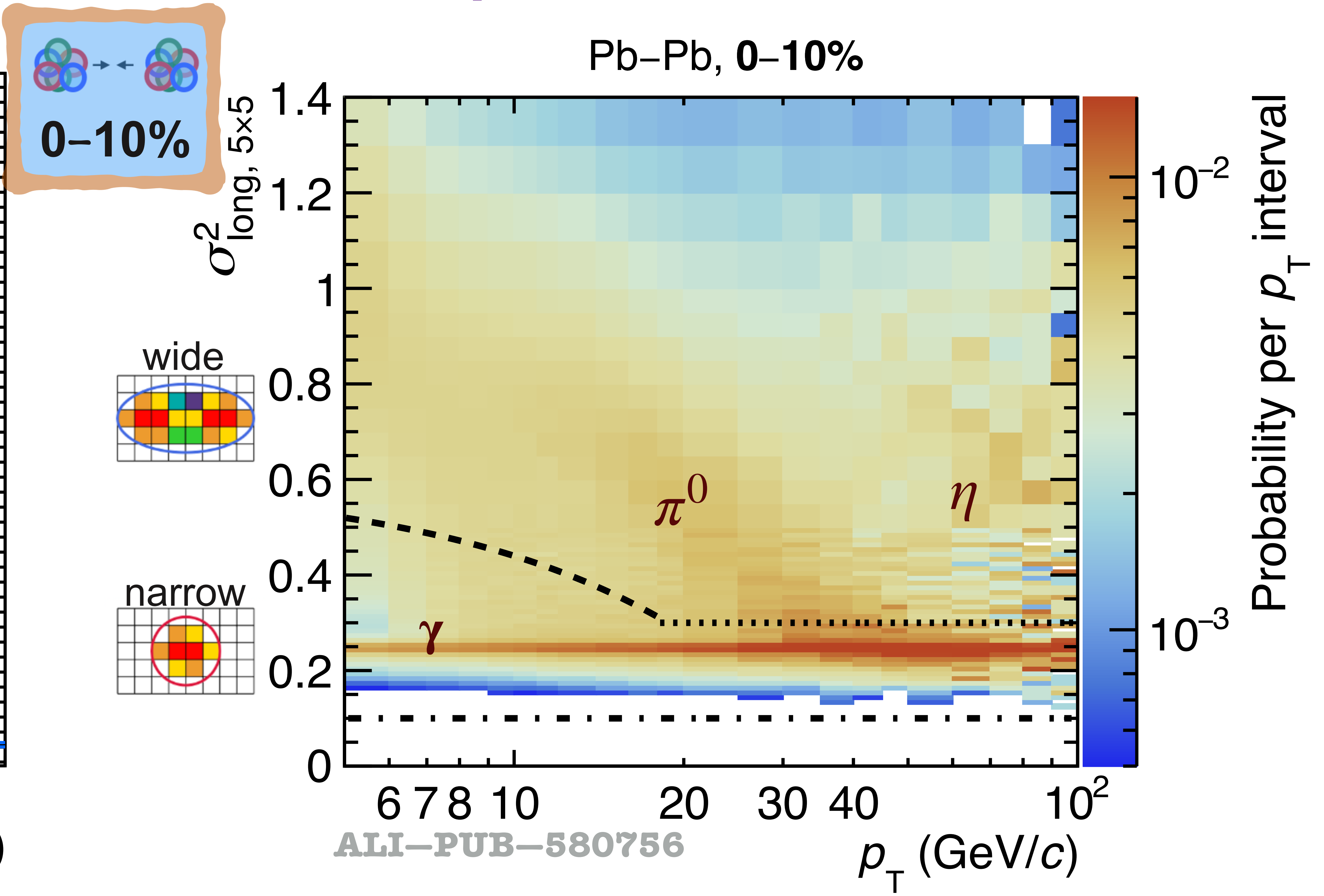


- Isolated if $p_T^{iso, ch} < 1.5$ GeV/c with R = 0.4 or 0.2
- Embedded pp PYTHIA 8 γ-jet process simulation into MB data, symmetric distribution
- In data, more asymmetric distribution due to jet contribution
- Significantly wider distributions for R = 0.4 due to UE fluctuations

- Visible bands for γ (narrow clusters) & π^0 (wide clusters)
- Select as γ clusters with
  - Pb–Pb:
    - $p_T < 18$ GeV/c: $0.1 < \sigma^2_{long, 5\times5} < 0.6 - 0.016 \cdot p_T$
    - $p_T > 18$ GeV/c: $0.1 < \sigma^2_{long, 5\times5} < 0.3$
  - pp:
    - $0.1 < \sigma^2_{long, 5\times5} < 0.3$

Prompt γ identification in ALICE: EM shape & isolation





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    - $p_{\mathrm{T}} > 18$ GeV/c: $0.1 < \sigma^2_{\mathrm{long,\,5\times5}} < 0.3$
  - pp:
    - $0.1 < \sigma^2_{\mathrm{long,\,5\times5}} < 0.3$

γ increase their $\sigma^2_{\mathrm{long,\,5\times5}}$ due to the UE

Purity

- Purity, ABCD method: Phase space of calorimeter clusters divided in 4 regions: $\mathbb{A}$, signal dominated & $\mathbb{B}$-$\mathbb{C}$-$\mathbb{D}$, background dominated

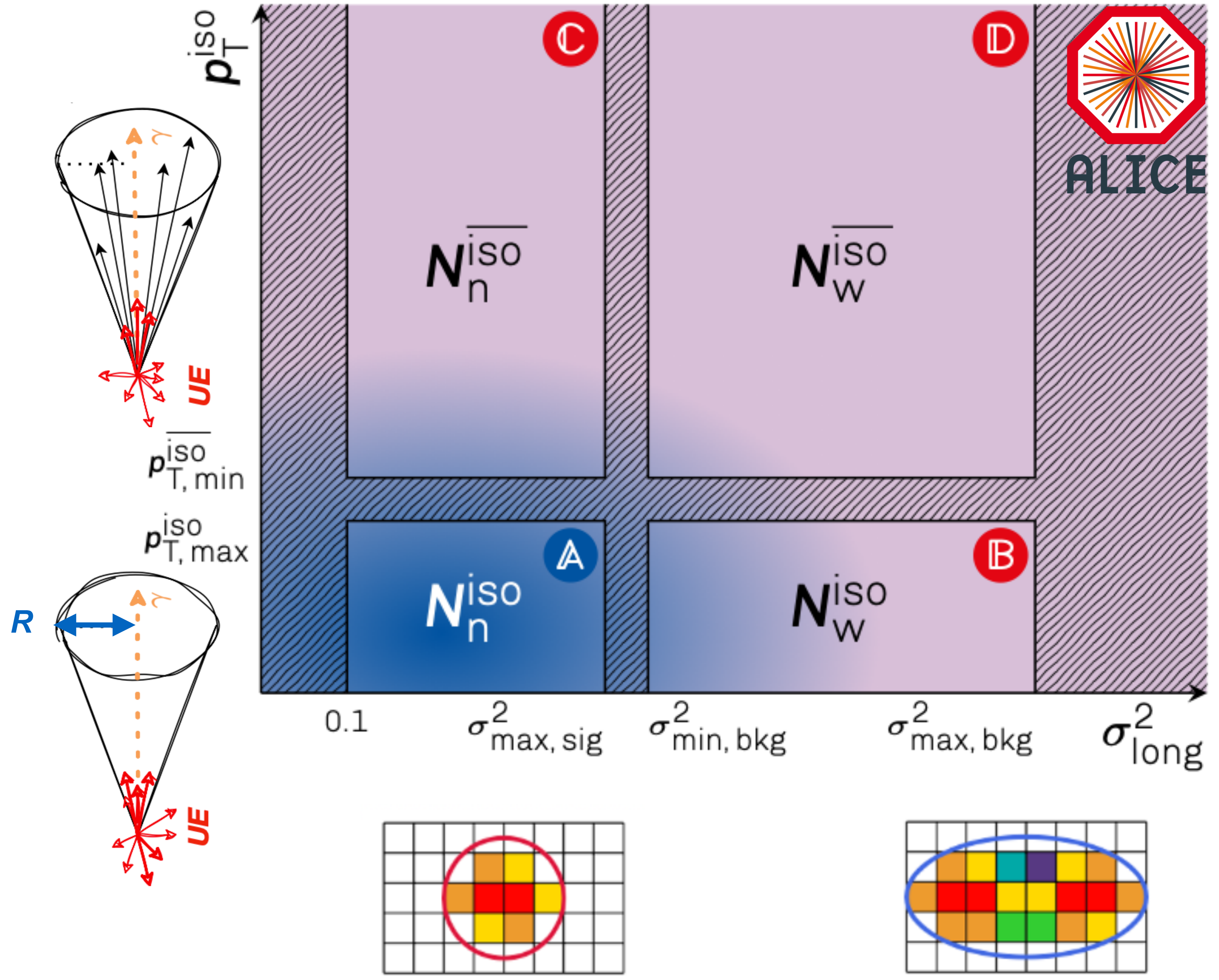
Data driven | PYTHIA

$$P = 1 - \boxed{\left(\frac{N_{\rm n}^{\overline{\rm iso}}/N_{\rm n}^{\rm iso}}{N_{\rm w}^{\overline{\rm iso}}/N_{\rm w}^{\rm iso}}\right)_{\rm data}} \times \boxed{\left(\frac{B_{\rm n}^{\rm iso}/N_{\rm n}^{\overline{\rm iso}}}{N_{\rm w}^{\rm iso}/N_{\rm w}^{\overline{\rm iso}}}\right)_{\rm MC}}$$

$N_{\rm n,w}^{\rm iso,\overline{iso}}$ = jet-jet ($B_{\rm n,w}^{\rm iso,\overline{iso}}$) + γ-jet ($S_{\rm n,w}^{\rm iso,\overline{iso}}$)

($\sigma^2_{\rm long}$ cluster n: narrow, w: wide)

➡ Semi data-driven approach, simulation used to correct correlations between $p_{\rm T}^{\rm iso,\,ch}$ and $\sigma^2_{\rm long}$



Purity, pp $\sqrt{s}$ = 13 TeV

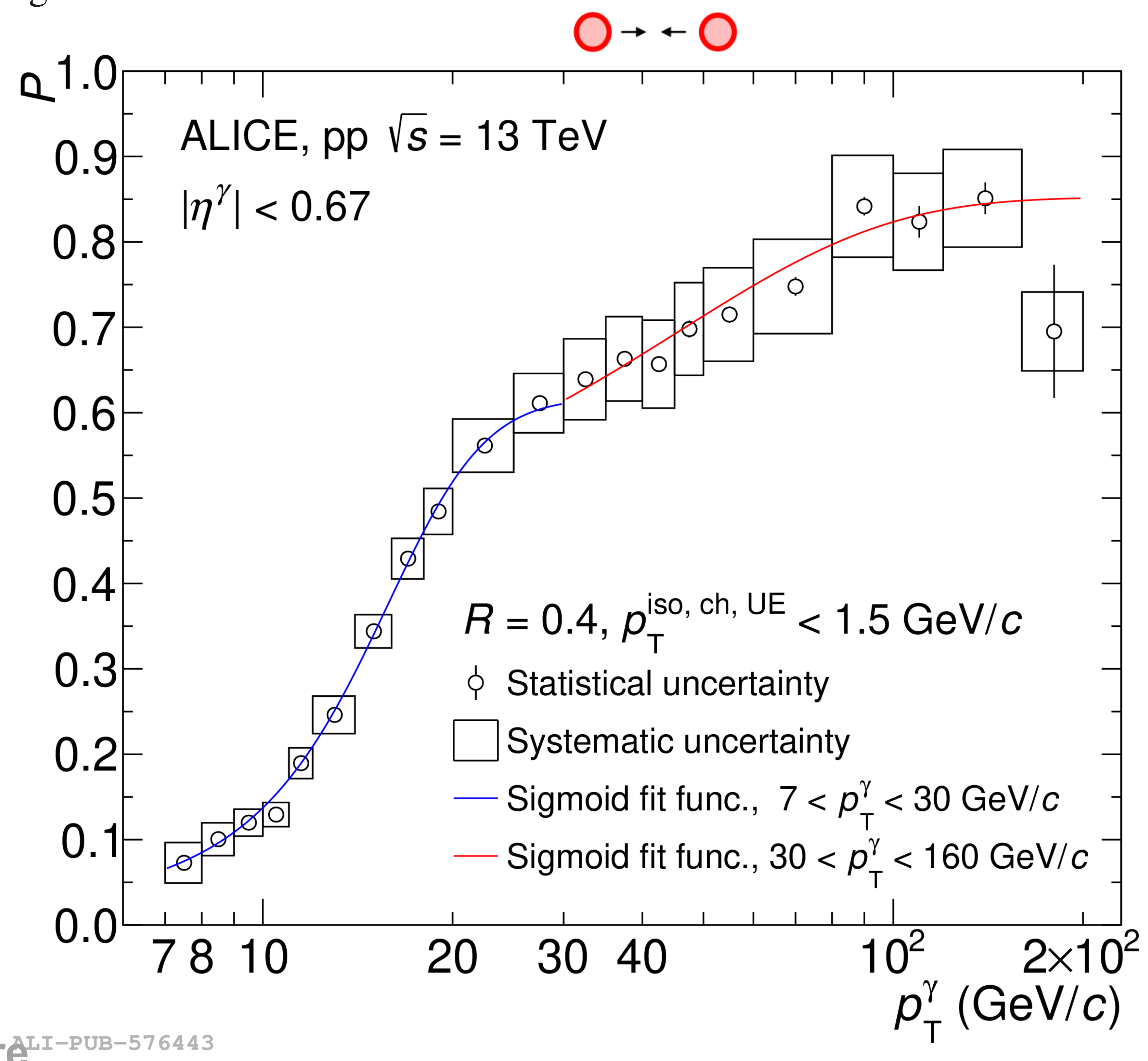
- Purity, ABCD method: Phase space of calorimeter clusters divided in 4 regions: $\mathbb{A}$, signal dominated & $\mathbb{B}$-$\mathbb{C}$-$\mathbb{D}$, background dominated

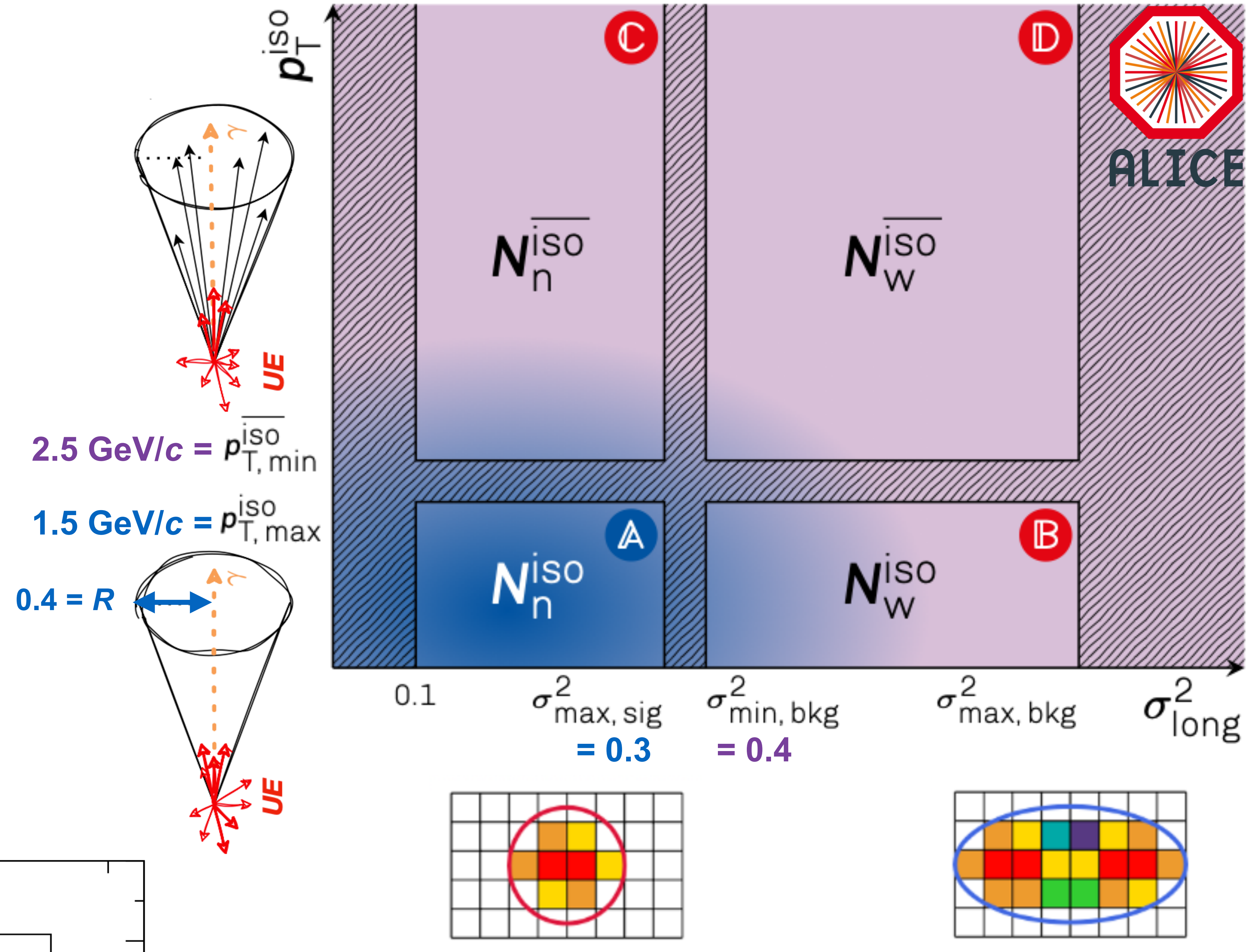
$$P = 1 - \underbrace{\left(\frac{N_{\mathrm{n}}^{\overline{\mathrm{iso}}}/N_{\mathrm{n}}^{\mathrm{iso}}}{N_{\mathrm{w}}^{\overline{\mathrm{iso}}}/N_{\mathrm{w}}^{\mathrm{iso}}}\right)_{\mathrm{data}}}_{\text{Data driven}} \times \underbrace{\left(\frac{B_{\mathrm{n}}^{\mathrm{iso}}/N_{\mathrm{n}}^{\overline{\mathrm{iso}}}}{N_{\mathrm{w}}^{\mathrm{iso}}/N_{\mathrm{w}}^{\overline{\mathrm{iso}}}}\right)_{\mathrm{MC}}}_{\text{PYTHIA}}$$

$N_{\mathrm{n,w}}^{\mathrm{iso},\overline{\mathrm{iso}}}$= jet-jet ($B_{\mathrm{n,w}}^{\mathrm{iso},\overline{\mathrm{iso}}}$) + γ-jet ($S_{\mathrm{n,w}}^{\mathrm{iso},\overline{\mathrm{iso}}}$)

(σ^2_{long} cluster n: narrow, w: wide)

➡ Semi data-driven approach, simulation used to correct correlations between $p_{\mathrm{T}}^{\mathrm{iso,\,ch}}$ and σ^2_{long}





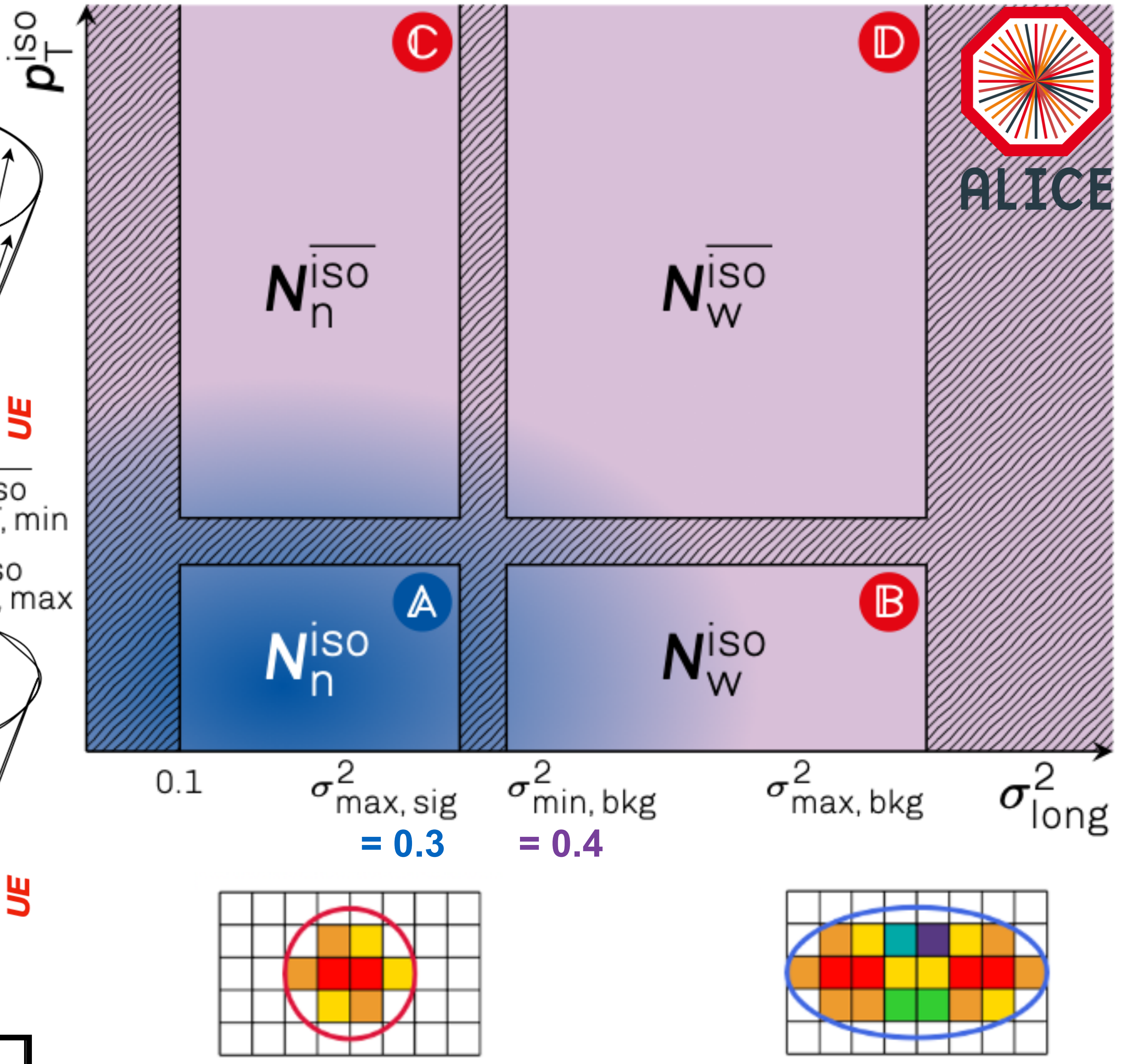
- Reduce the influence of statistical fluctuations with sigmoid function fits

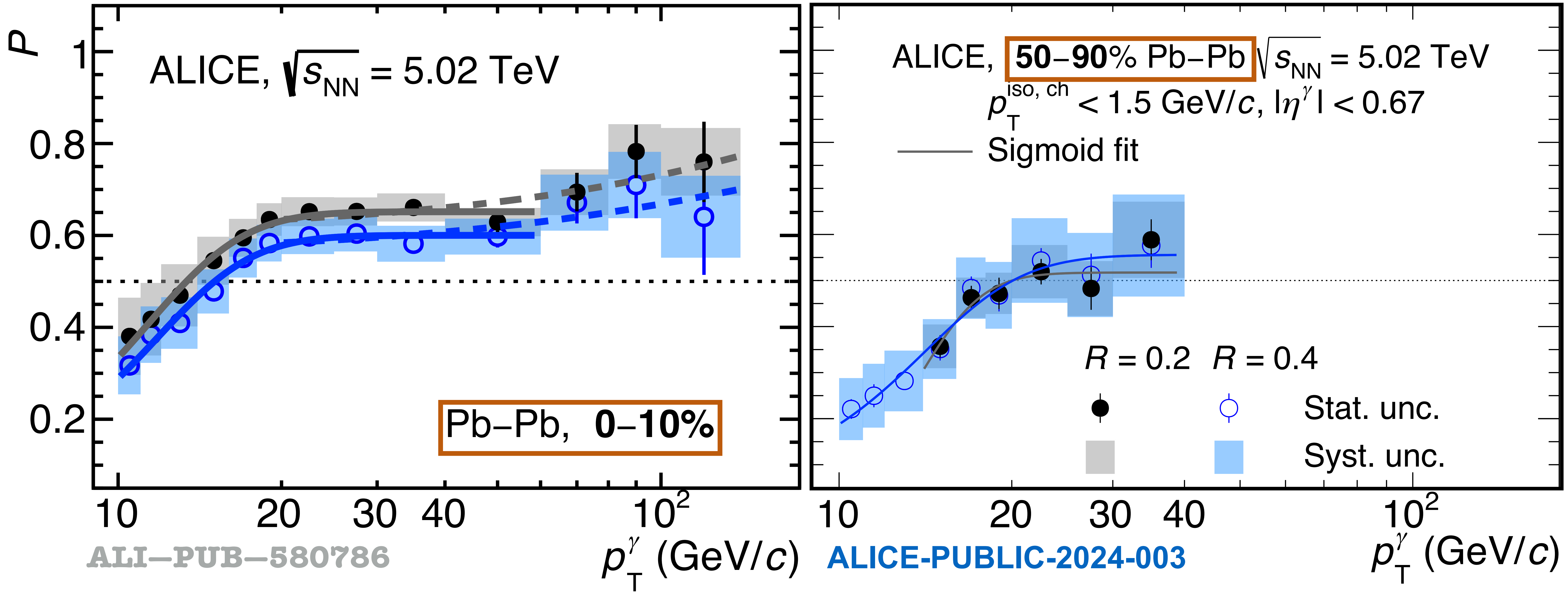
Purity, Pb–Pb $\sqrt{s_{NN}}$ = 5.02 TeV

- Purity, ABCD method: Phase space of calorimeter clusters divided in 4 regions: $\mathbb{A}$, signal dominated & $\mathbb{B}$-$\mathbb{C}$-$\mathbb{D}$, background dominated

$$P = 1 - \underbrace{\left(\frac{N_{\rm n}^{\overline{\rm iso}}/N_{\rm n}^{\rm iso}}{N_{\rm w}^{\overline{\rm iso}}/N_{\rm w}^{\rm iso}}\right)_{\rm data}}_{\text{Data driven}} \times \underbrace{\left(\frac{B_{\rm n}^{\rm iso}/N_{\rm n}^{\overline{\rm iso}}}{N_{\rm w}^{\rm iso}/N_{\rm w}^{\overline{\rm iso}}}\right)_{\rm MC}}_{\text{PYTHIA}}$$

$N_{\rm n,w}^{\rm iso,\overline{iso}}$= jet-jet ($B_{\rm n,w}^{\rm iso,\overline{iso}}$) + γ-jet ($S_{\rm n,w}^{\rm iso,\overline{iso}}$)
($\sigma^2_{\rm long}$ cluster n: narrow, w: wide)



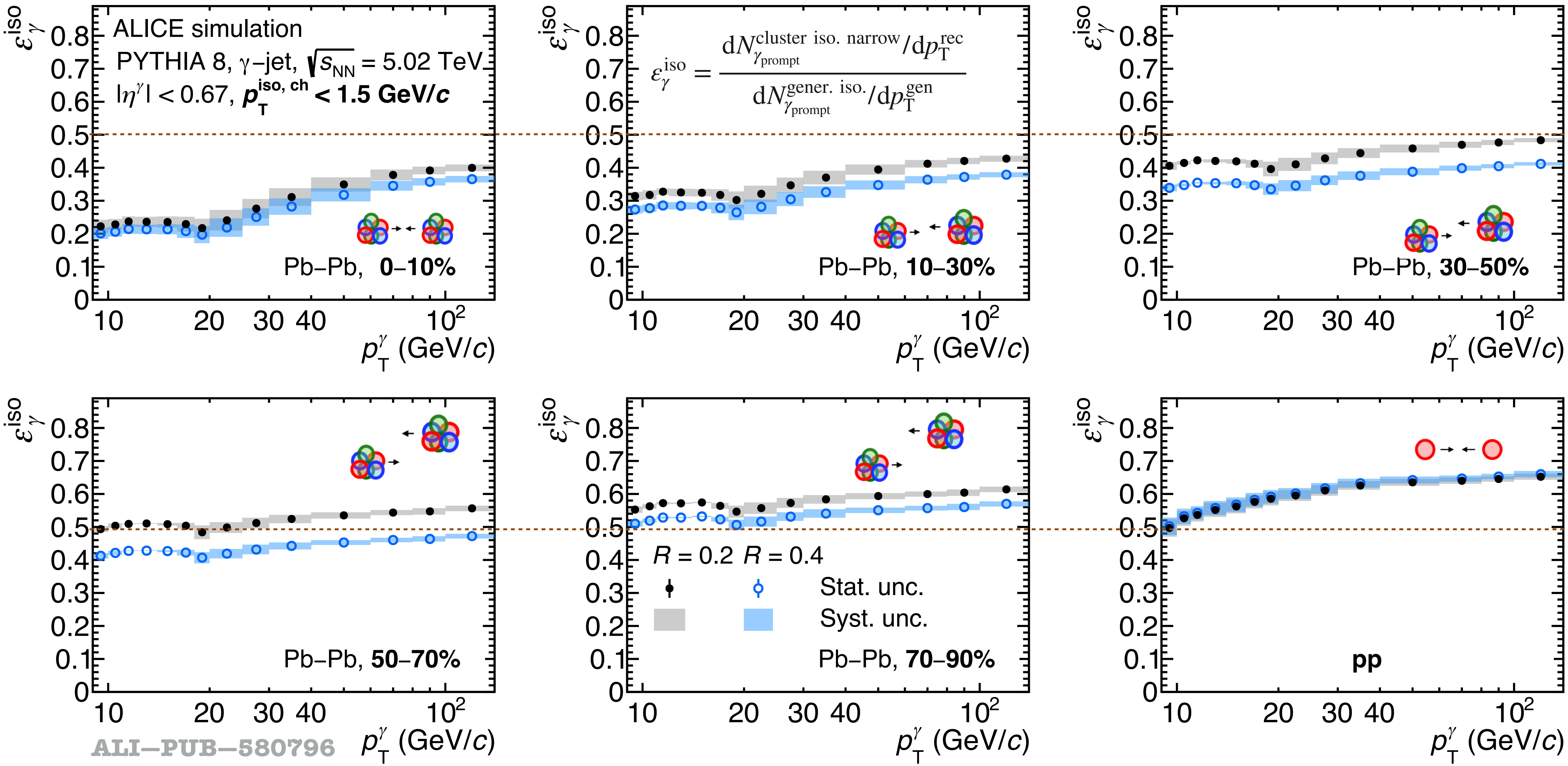


ALI–PUB–580786

ALICE-PUBLIC-2024-003

- Reduce the influence of statistical fluctuations with sigmoid function fits
- Higher purity in central vs peripheral collisions due to neutral meson background suppression due to QGP
- Higher purity in central collisions for R = 0.2 vs R = 0.4 due to lower UE fluctuations in $p_{\rm T}^{\rm iso,\,ch}$

Efficiency, R = 0.2 & 0.4, pp & Pb–Pb $\sqrt{s_{\rm NN}}$ = 5.02 TeV



- $\varepsilon_{\gamma}^{\rm iso}$ (0-10%) < $\varepsilon_{\gamma}^{\rm iso}$ (70-90%): UE fluctuations ($p_{\rm T}^{\rm iso,\,ch}$) and cluster size increase ($\sigma^2_{\rm long}$) (see backup)
- In Pb–Pb, $\varepsilon_{\gamma}^{\rm iso}$ (R = 0.2) > $\varepsilon_{\gamma}^{\rm iso}$ (R = 0.4) a factor ~0.9 due to lower UE fluctuations ($p_{\rm T}^{\rm iso,\,ch}$)
- In pp, $\varepsilon_{\gamma}^{\rm iso}$ (R = 0.2) ≈ $\varepsilon_{\gamma}^{\rm iso}$ (R = 0.4), due to the less performing ITS-only tracks (TPC+ITS in Pb–Pb)

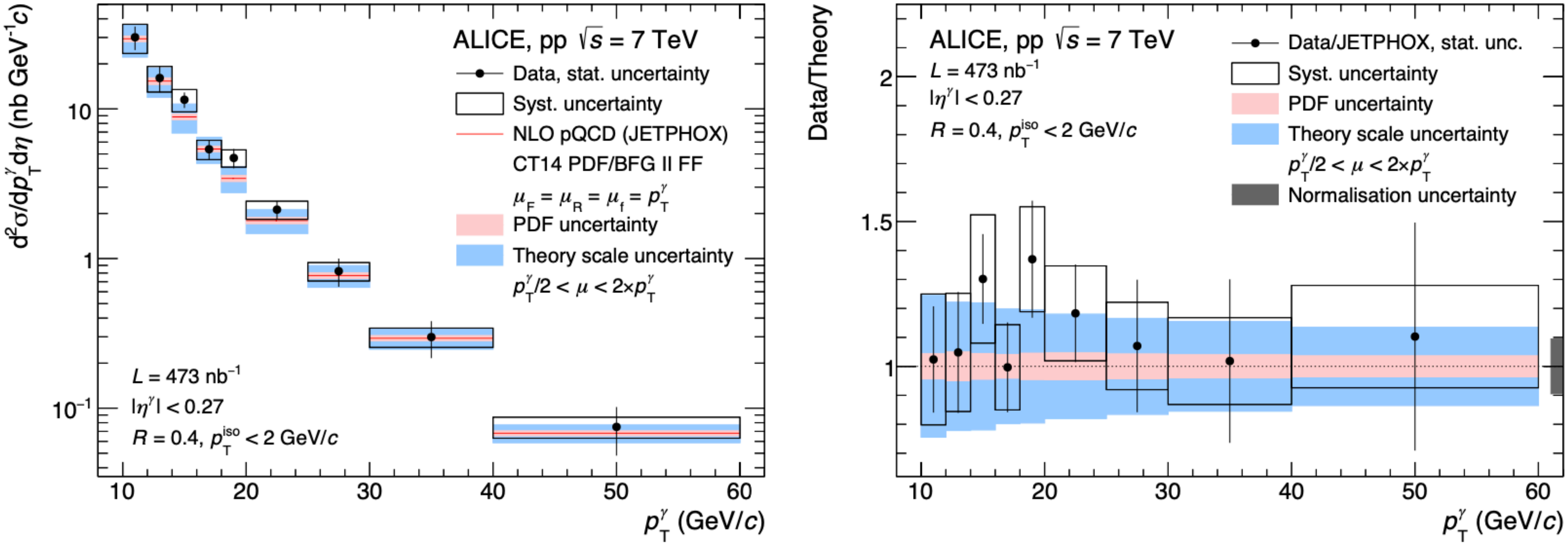
Inclusive isolated-γ production cross section in pp collisions

13 TeV: Eur. Phys. J. C 85 (2025) 98, arXiv:2407.01165

7 TeV: Eur. Phys. J. C 79 (2019) 896, arXiv:1906.01371

Cross section, pp $\sqrt{s}$ = 7 TeV

Eur. Phys. J. C 79 (2019) 896, arXiv:1906.01371

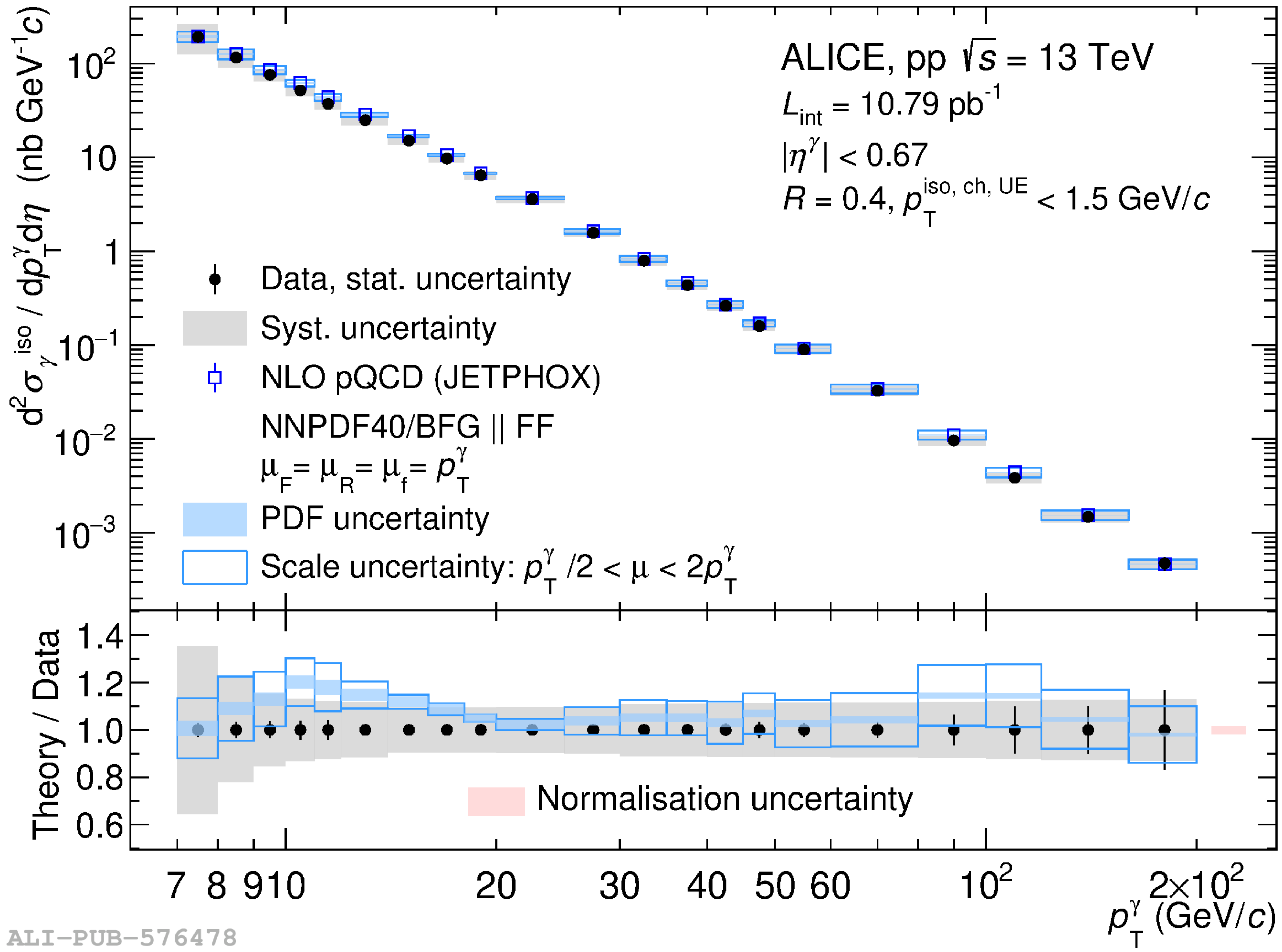


➡ First isolated photon measurement in ALICE

➡ NLO pQCD predictions (JETPHOX) and data agree

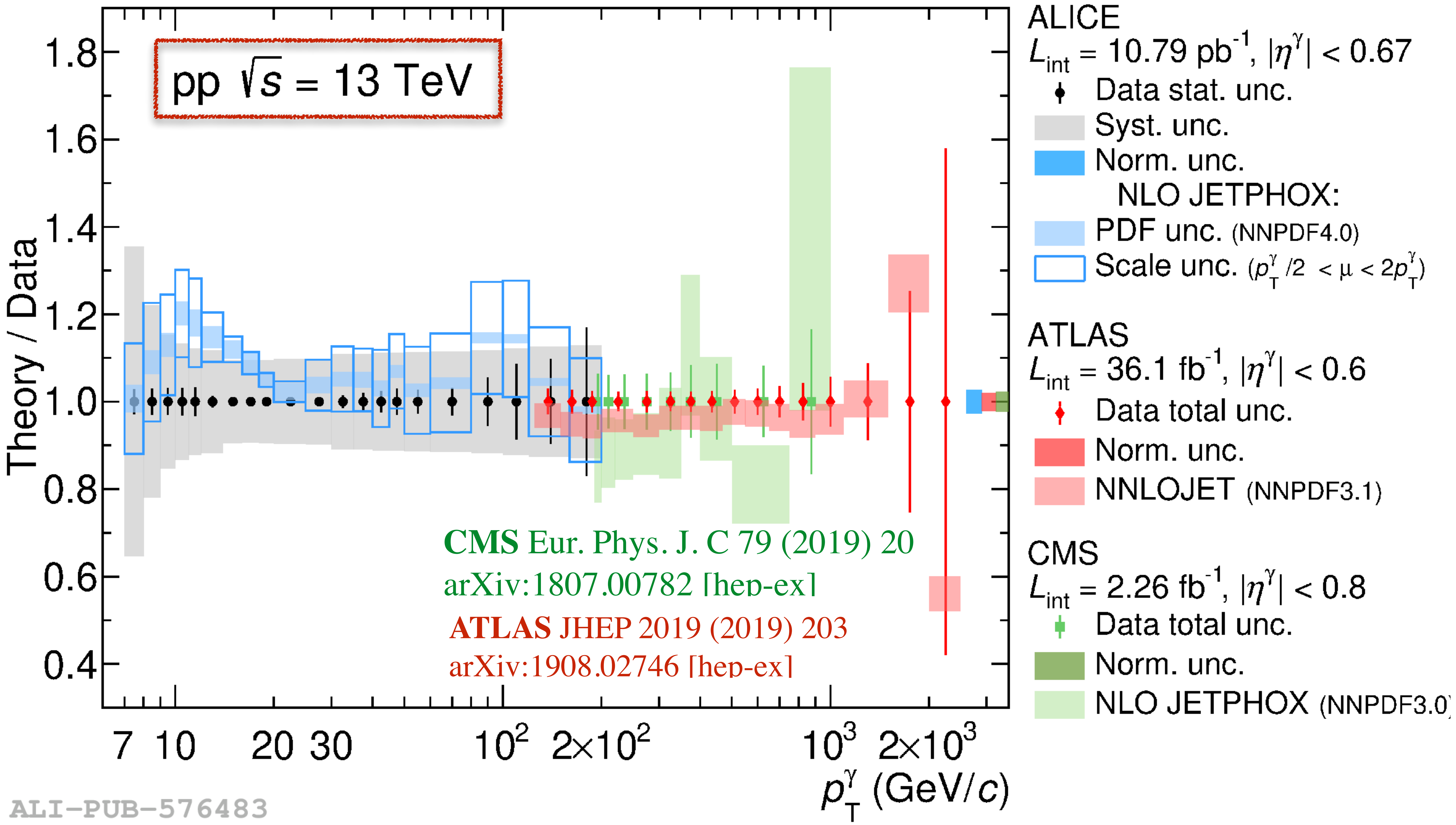
Cross section, pp $\sqrt{s}$ = 13 TeV

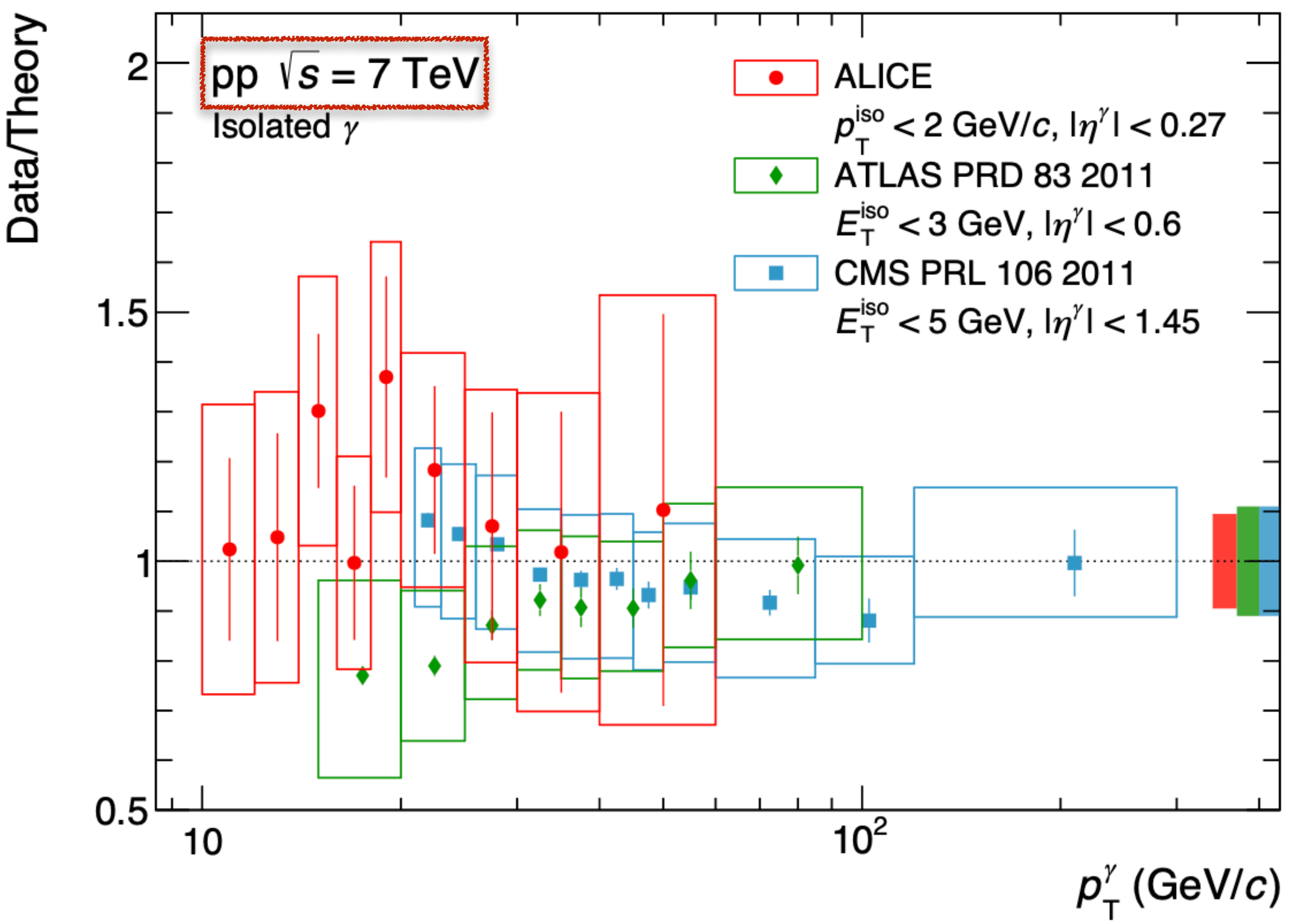
Eur. Phys. J. C 85 (2025) 98, arXiv:2407.01165



➡ NLO pQCD predictions (JETPHOX) and data agree

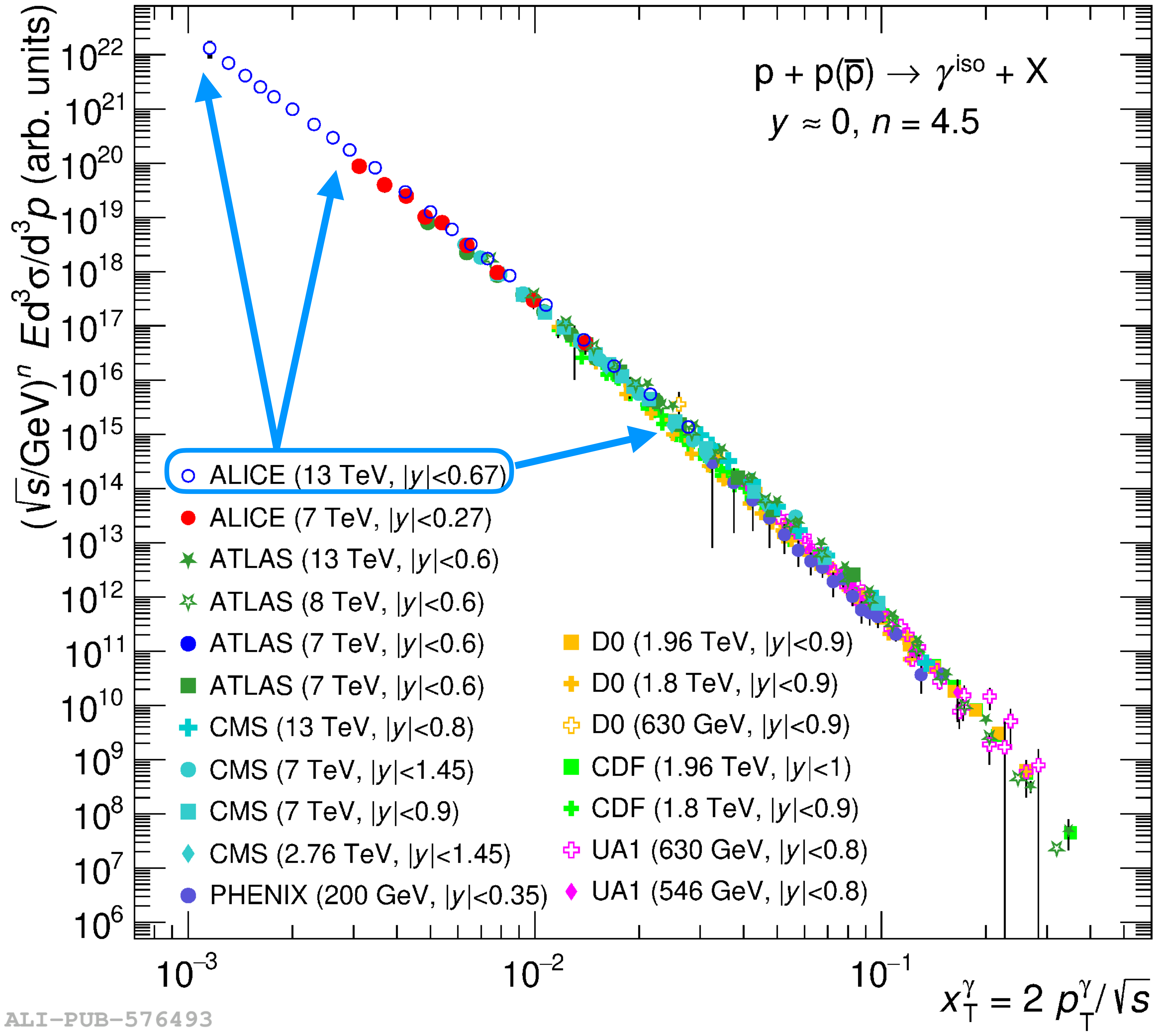
Cross section, pp $\sqrt{s}$ = 7 &13 TeV, at the LHC





- Different isolation parameters in LHC measurements:
  - The only way to compare experiments is via the ratio to the theory using the same isolation condition
- NLO pQCD predictions (JETPHOX) and data agree in the three experiments
- Agreement between LHC experiments
  - ALICE measures significantly lower p_T than CMS and ATLAS at $\sqrt{s}$ = 13 TeV, small overlap
  - ALICE measures lower p_T than CMS and ATLAS at $\sqrt{s}$ = 7 TeV, but more overlap

Cross section, pp, different $\sqrt{s}$



- NLO pQCD predictions (JETPHOX) and data agree
- Significantly lower p_T than CMS and ATLAS at $\sqrt{s}$ = 13 TeV
- Lowest x_T at mid-rapidity $\left(\sqrt{s}\right)^{4.5}$ scale from x_T ~10^{-3} to 10^{-1}
- Additional constrains to the gluon PDF at low Bjorken-x

Full list of older results compiled in D. D'Enterria & J. Rojo Nucl. Phys. B 860 (2012), arXiv:1202.1762 [hep-ph]

CERN courier story for the Jan/Feb 2025 issue!

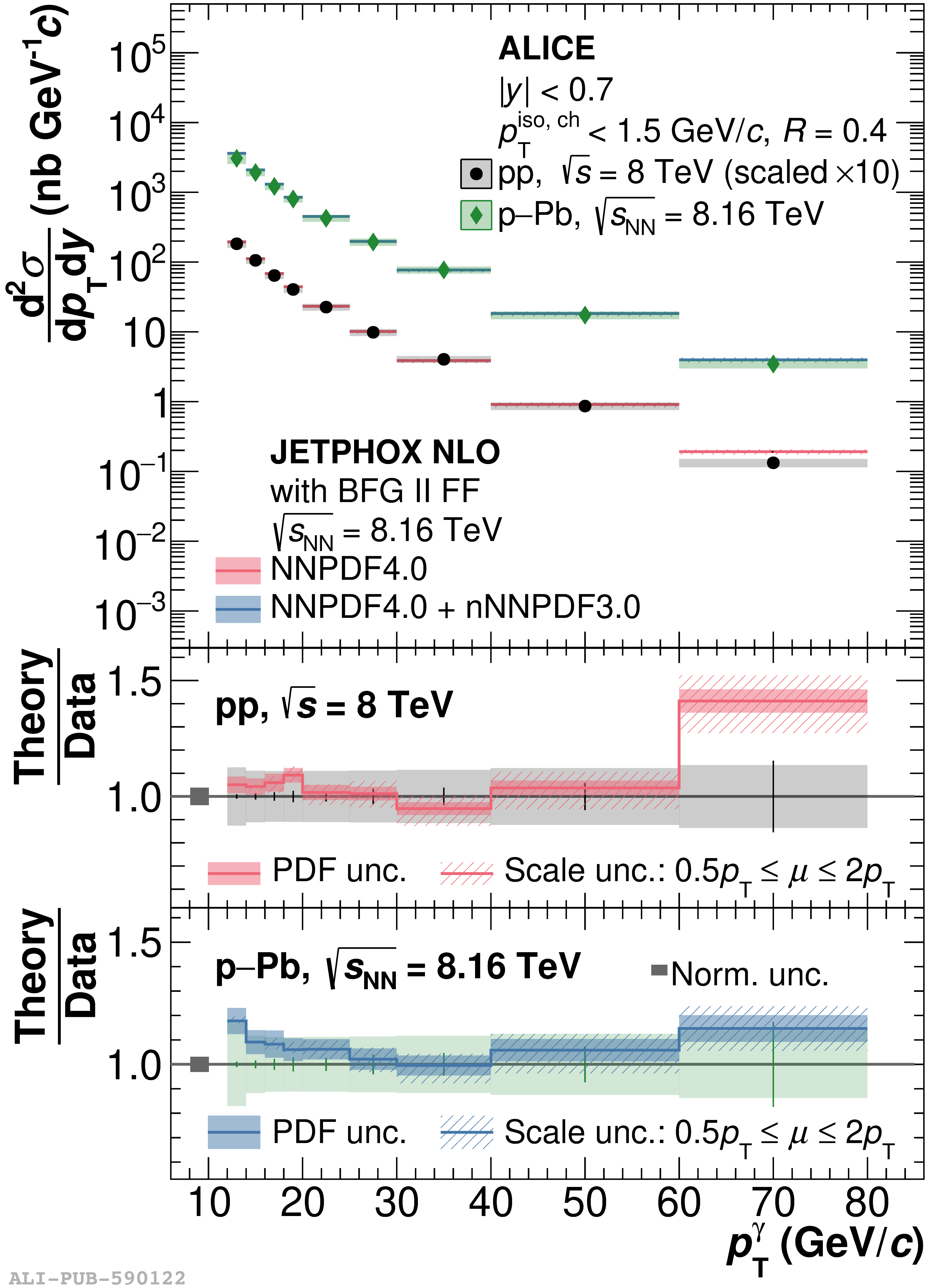
Inclusive isolated-γ production cross section in pp collisions at pp $\sqrt{s}$ = 8 TeV & p–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 & 8.16 TeV

arXiv:2502.18054

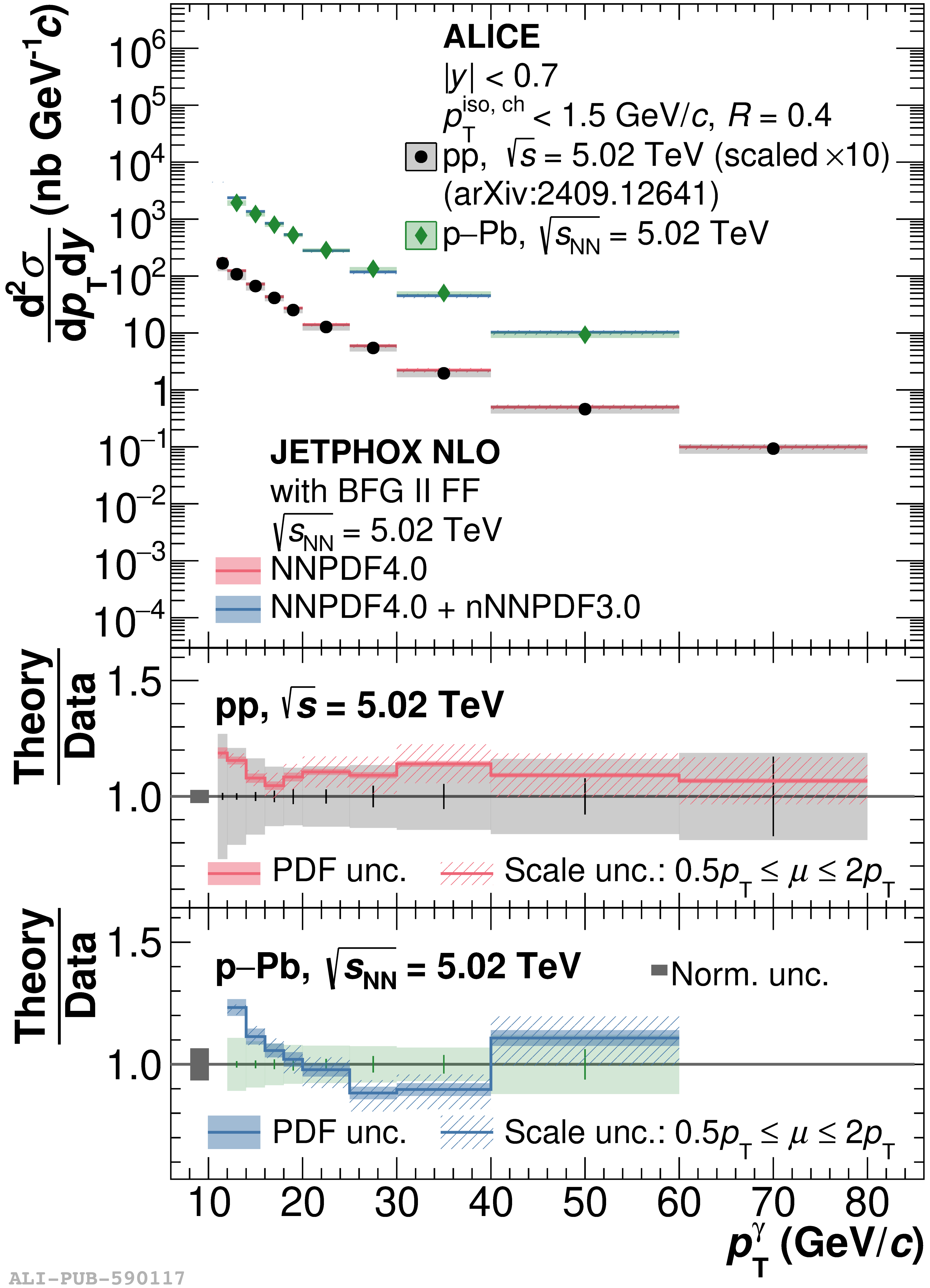
Submitted to EPJ C

Cross section, p–Pb

pp, p-Pb, $\sqrt{s_{NN}}$ = 8.16 TeV



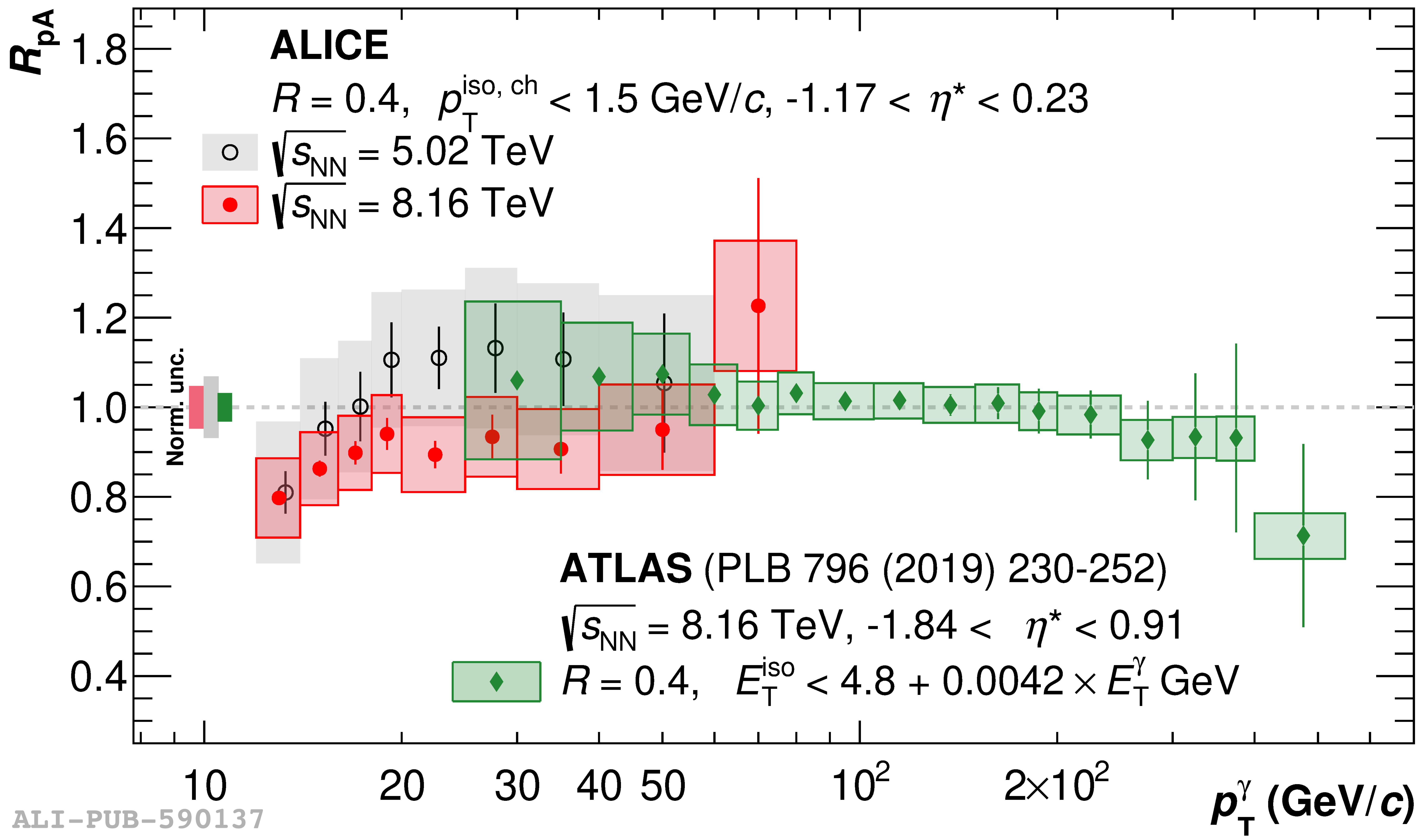
p-Pb, $\sqrt{s_{NN}}$ = 5.02 TeV



➡ NLO pQCD predictions (JETPHOX) and data agree

Nuclear modification factor R_{pA}

$$R_{pA} = \frac{d^2\sigma^{\gamma}_{pA}/dp_T dy^*}{A_{Pb} \times d^2\sigma^{\gamma}_{pp}/dp_T dy^*}$$



- R_{pA} in agreement with unity
  - No suppression at high p_T, agreement with ATLAS

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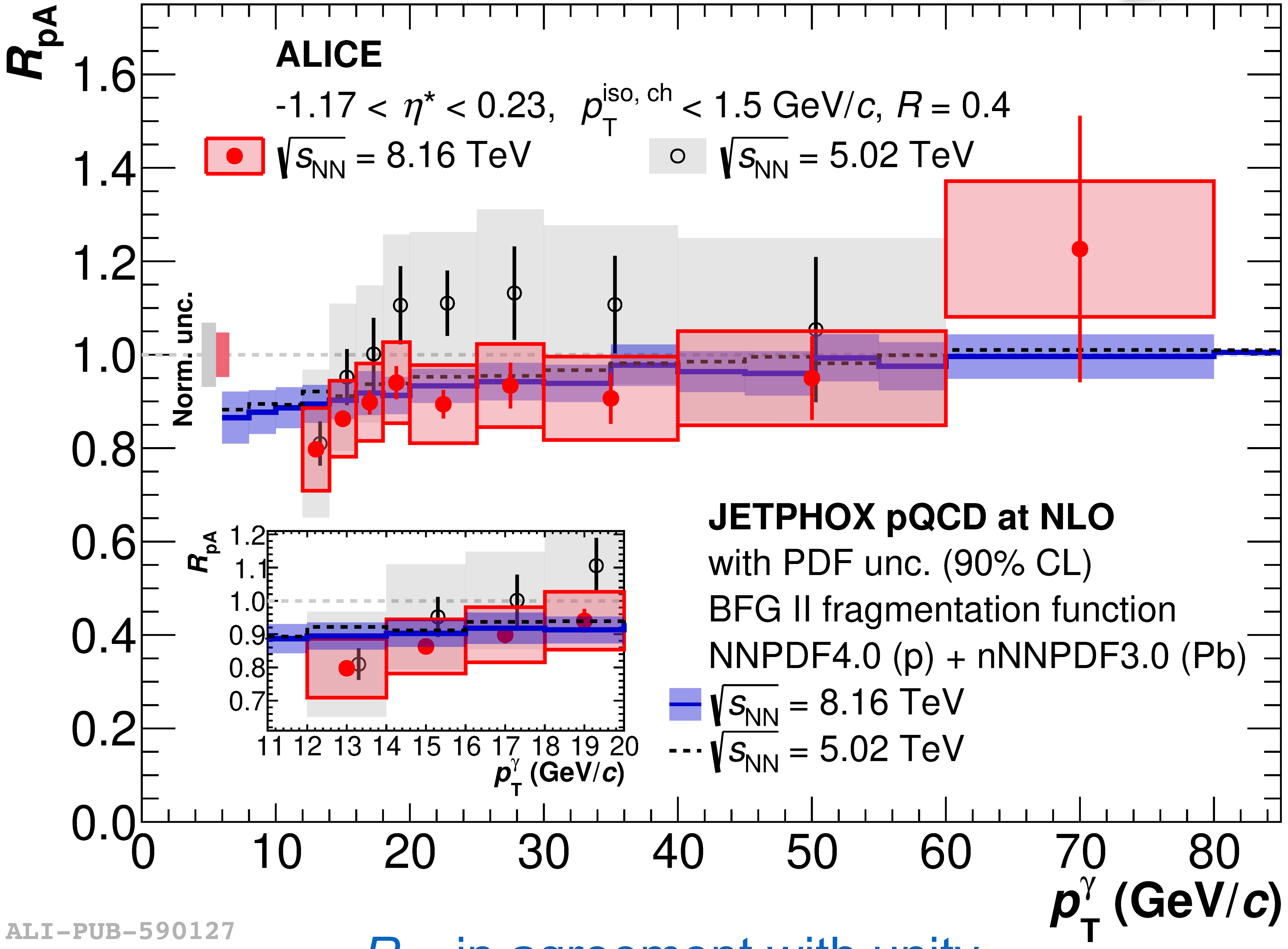
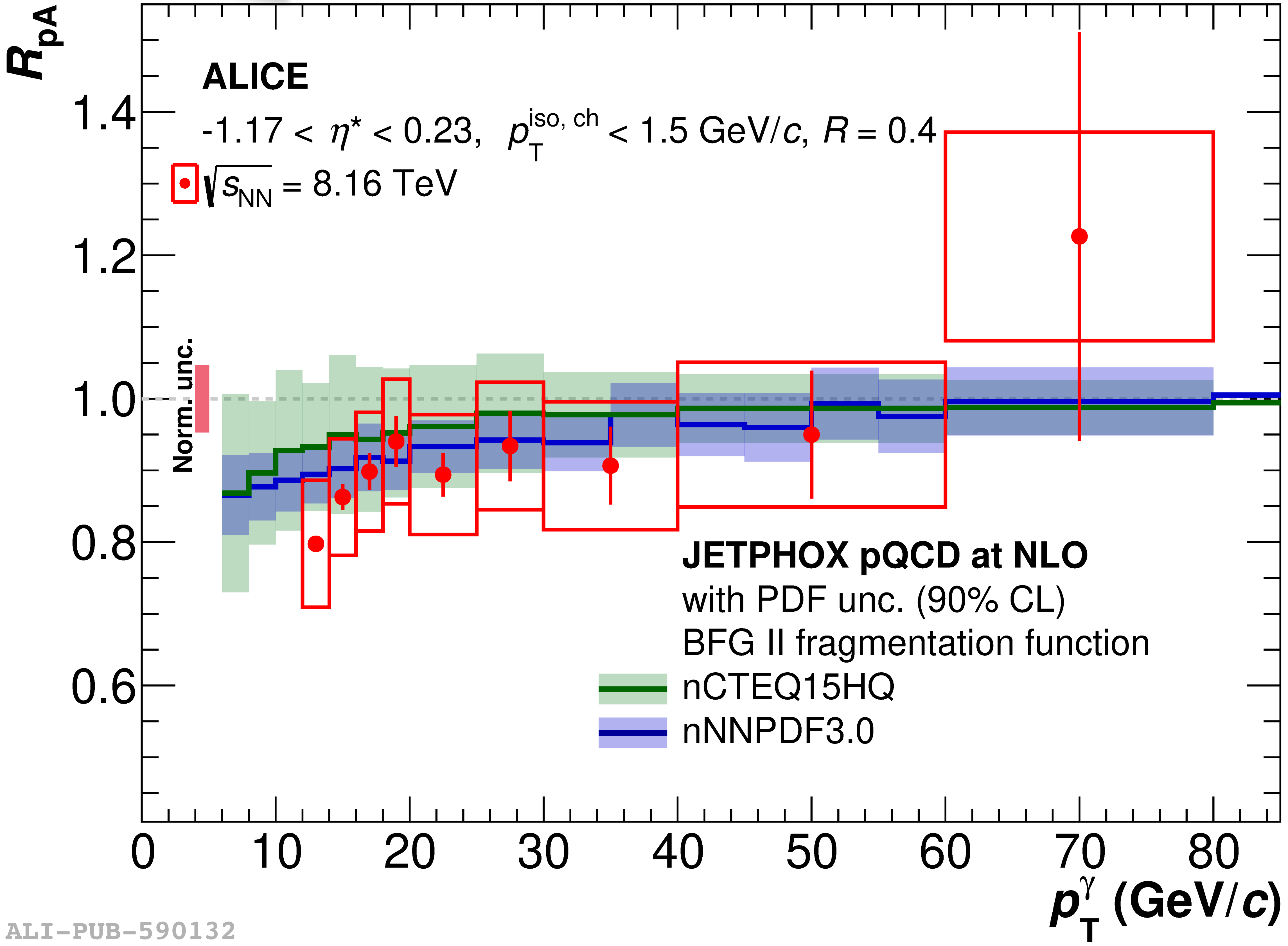




- R_{pA} in agreement with unity
  - No suppression at high p_T, agreement with ATLAS
  - Hints of lower than unity for $p_T < 20$ GeV/c, expected in theory, cold nuclear matter effects, shadowing

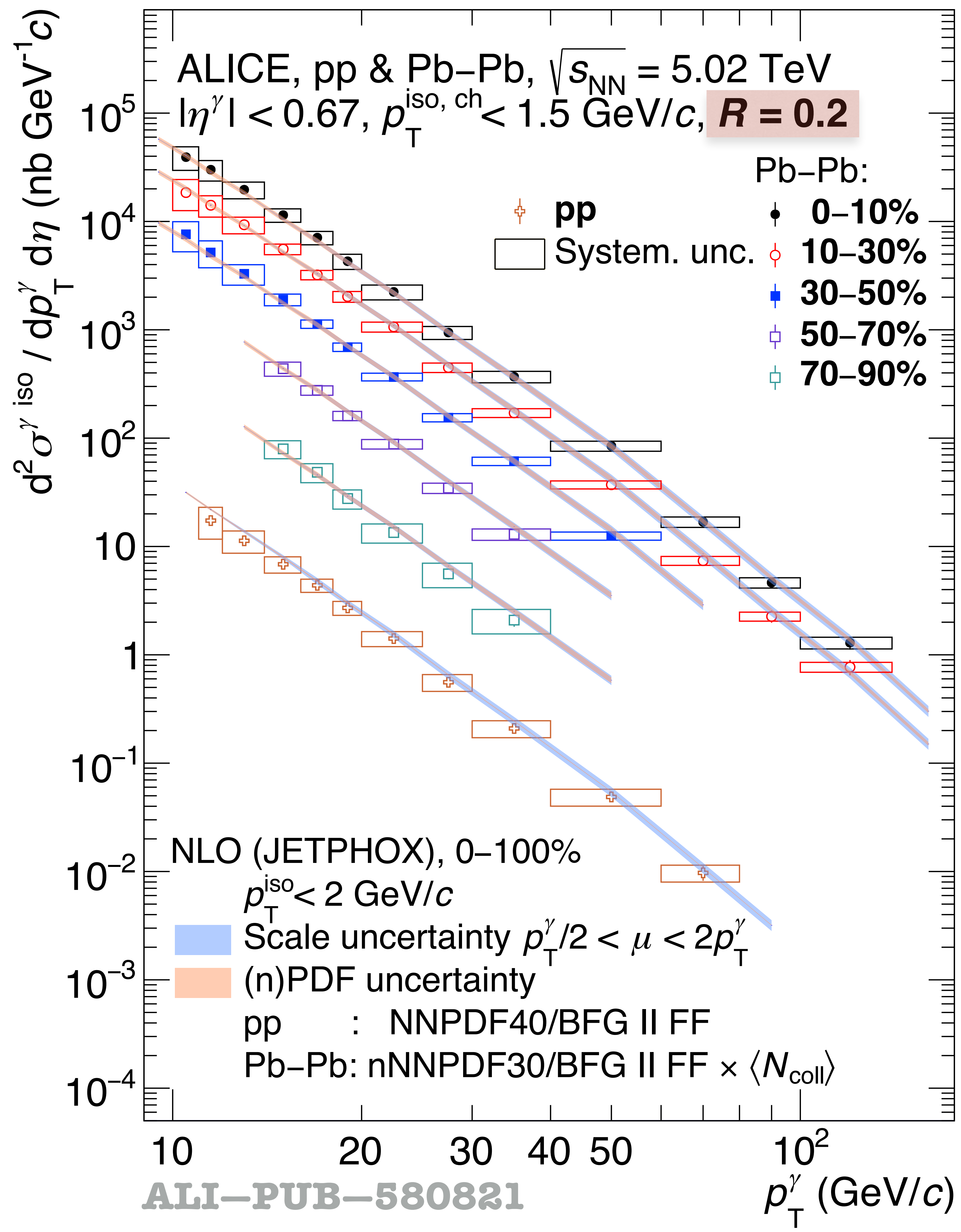
Inclusive isolated-γ production cross section in pp & Pb–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV

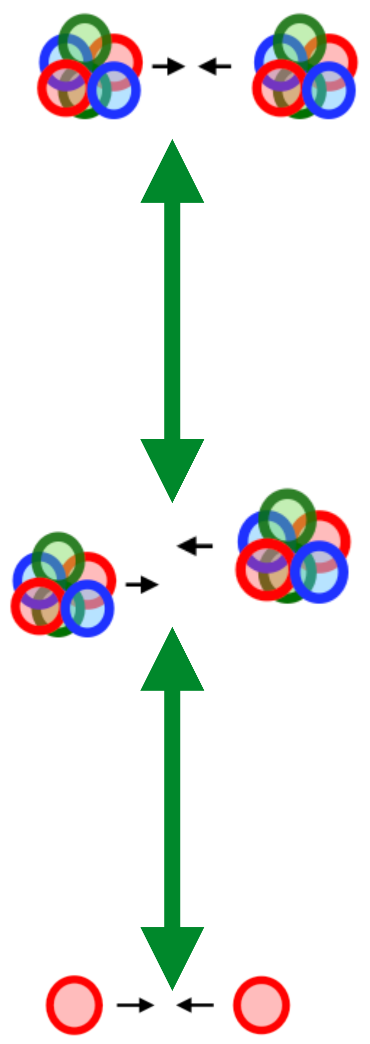
Eur. Phys. J. C 85, 553 (2025), arXiv:2409.12641, Supplementary note ALICE-PUBLIC-2024-003

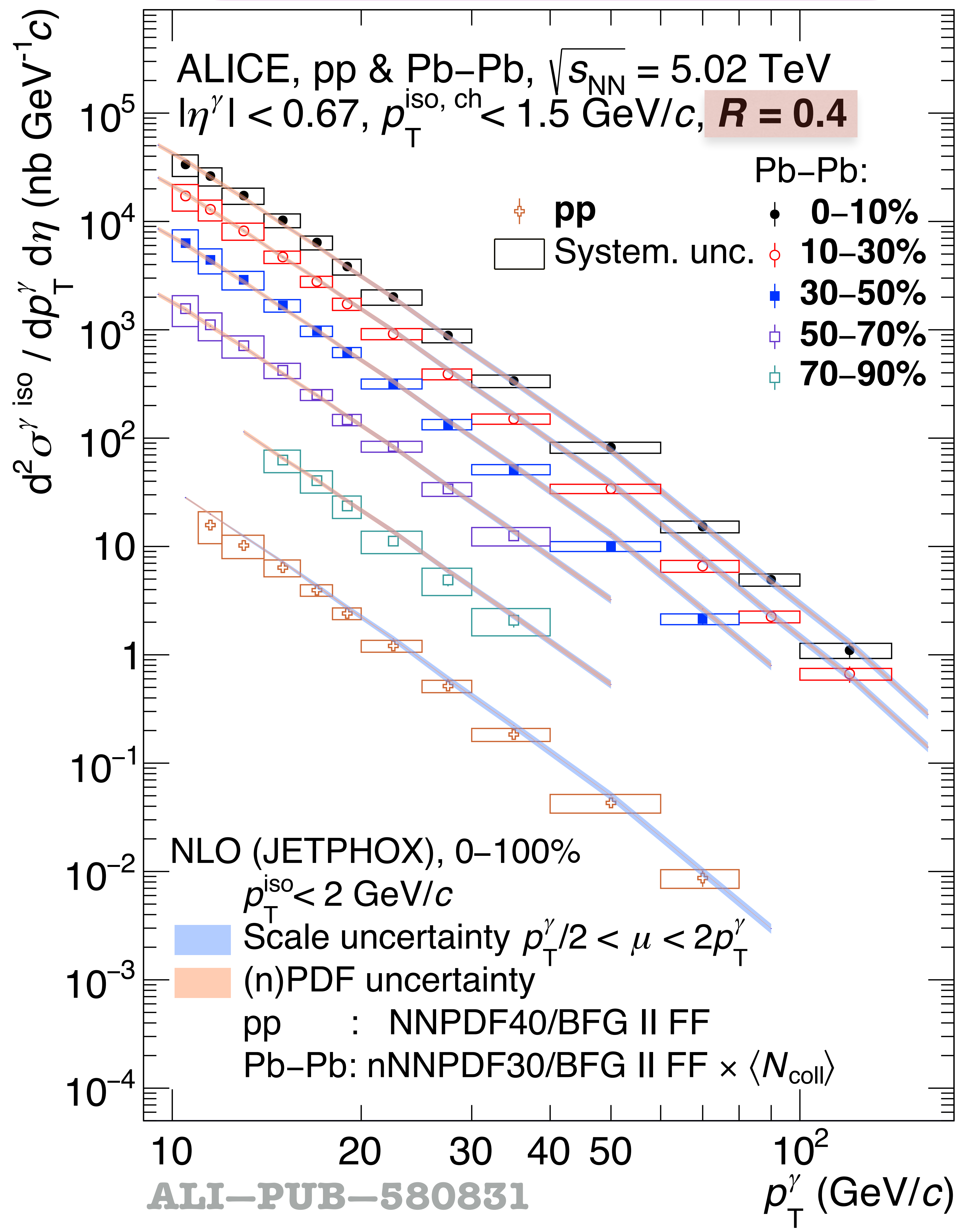
Published last month!

Cross section, pp & Pb–Pb at $\sqrt{s_{\rm NN}}$ = 5.02 TeV

$$\frac{d^2\sigma^{\gamma\ \rm iso}}{dp_{\rm T}\ d\eta} = \frac{\sigma_{\rm NN}^{\rm INEL}}{N_{\rm events} \times {\rm RF}_{\varepsilon_{\rm trig}}} \times \frac{d^2N}{dp_{\rm T}\ d\eta} \times \frac{P}{{\rm Acc} \times \varepsilon_\gamma^{\rm iso} \times \varepsilon_{\rm trig}}$$

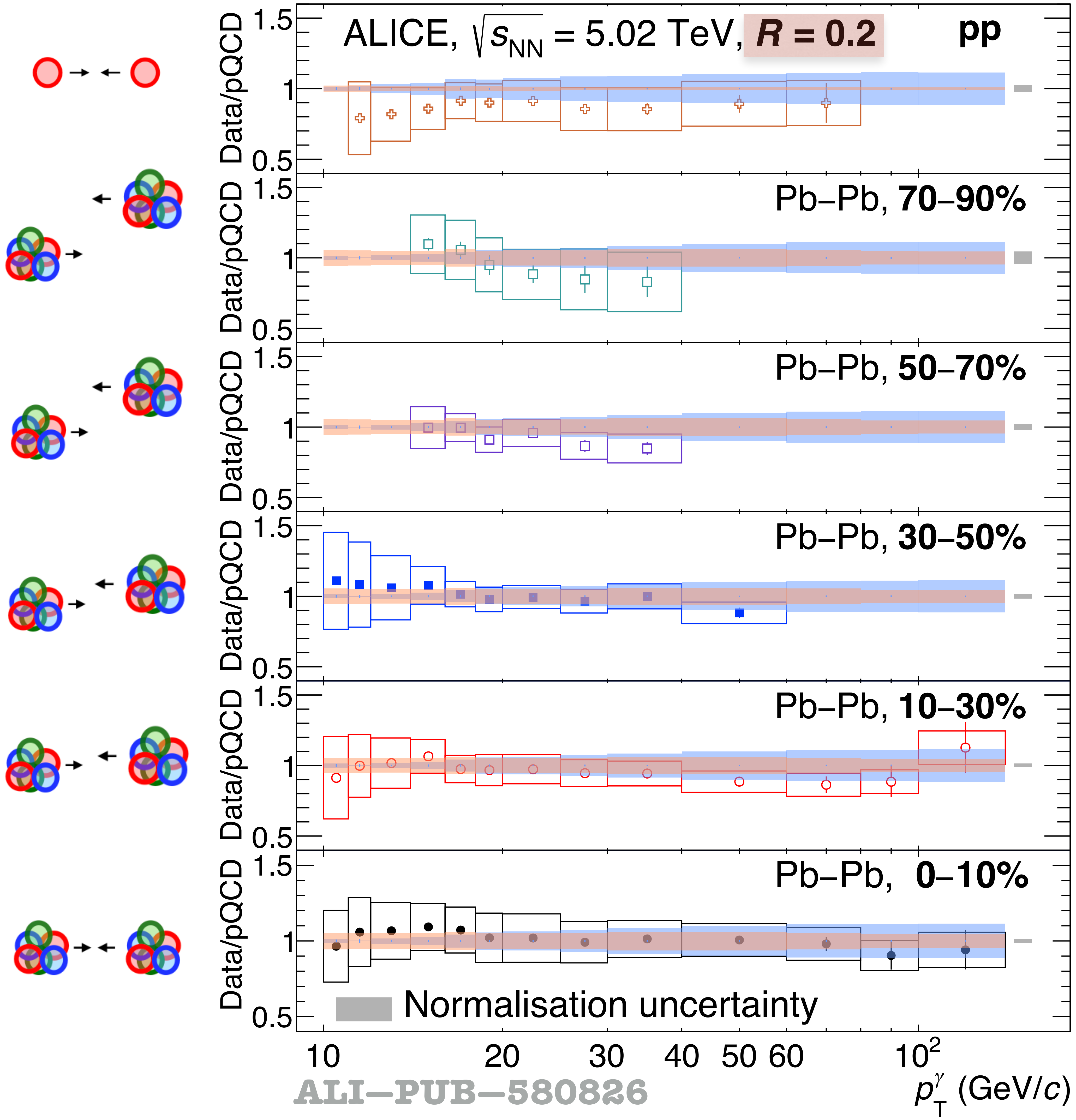


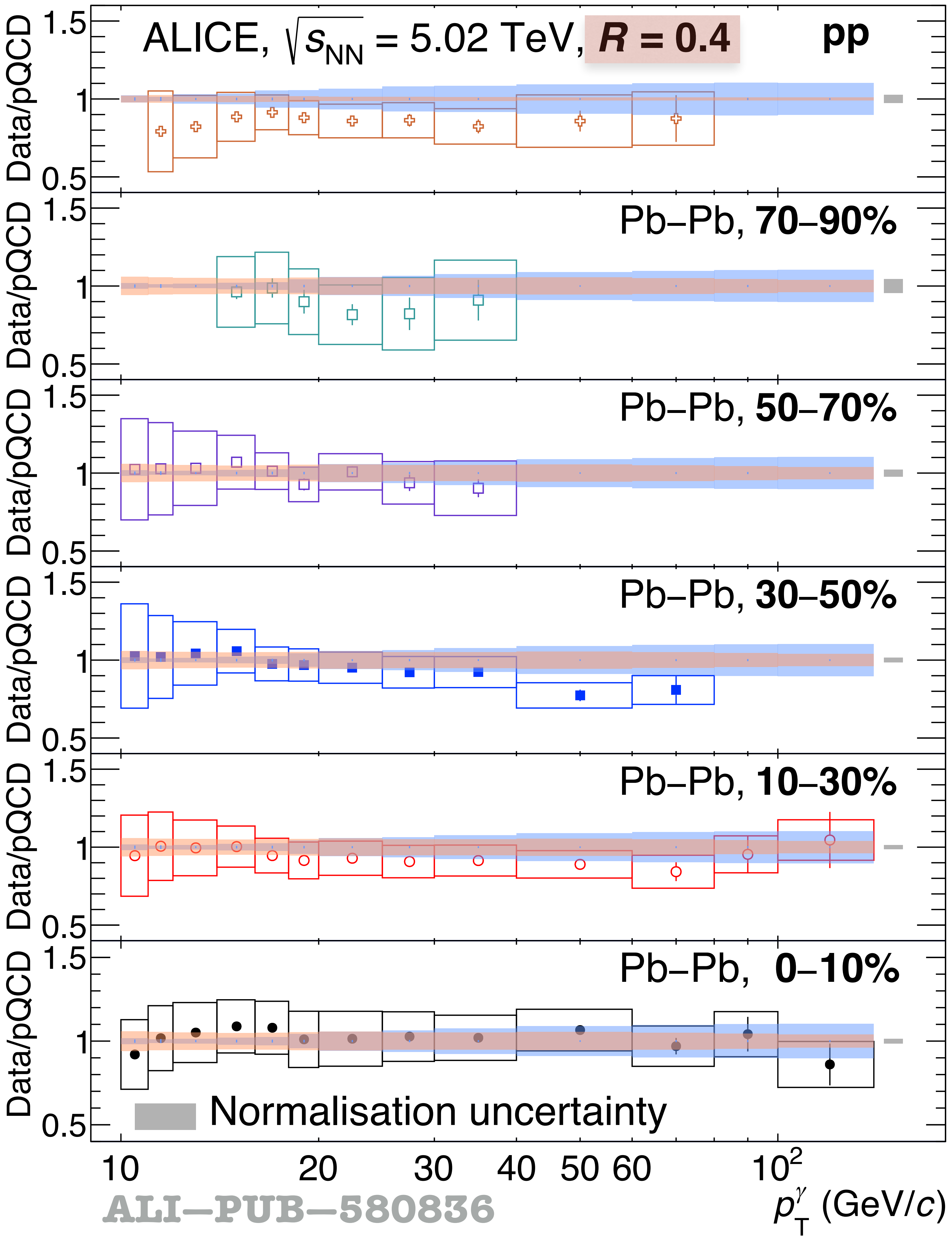




- Wide range: 10 < $p_{\rm T}$ < 140 GeV/c in Pb–Pb 0-30% & 11 < $p_{\rm T}$ < 80 GeV/c in pp
- NLO pQCD predictions (JETPHOX)
  - ➡ Note: Theory calculated for 0–100%, **PDF (pp) & nPDF** $\times N_{\rm coll}$ **(Pb–Pb)**

Cross section, pp & Pb–Pb at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV

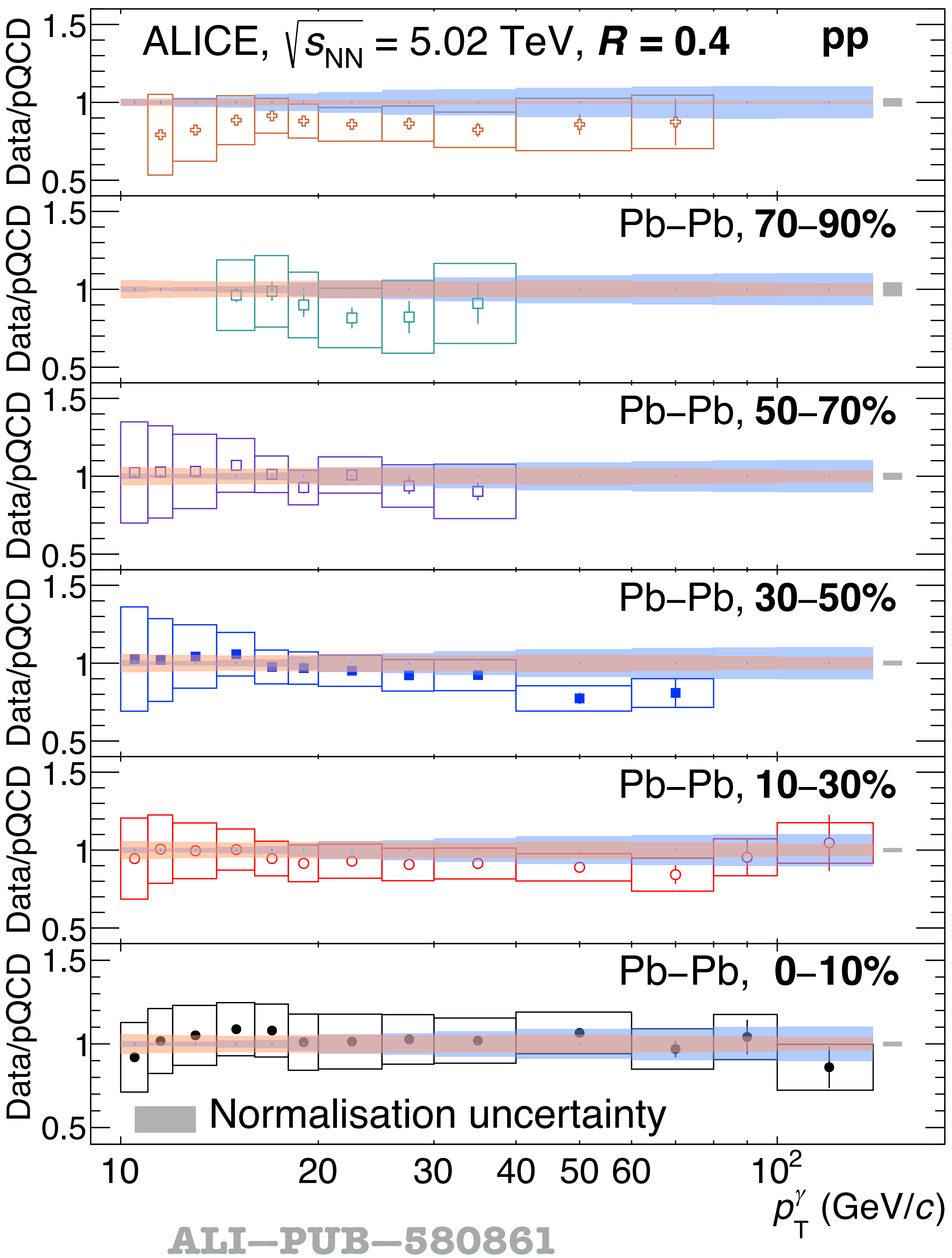




- NLO pQCD predictions (JETPHOX)
  - ➡ Note: Theory calculated for 0–100%, **PDF (pp) & nPDF** $\times N_{\mathrm{coll}}$ **(Pb–Pb)**
- Theory & data agreement for both R and collision system

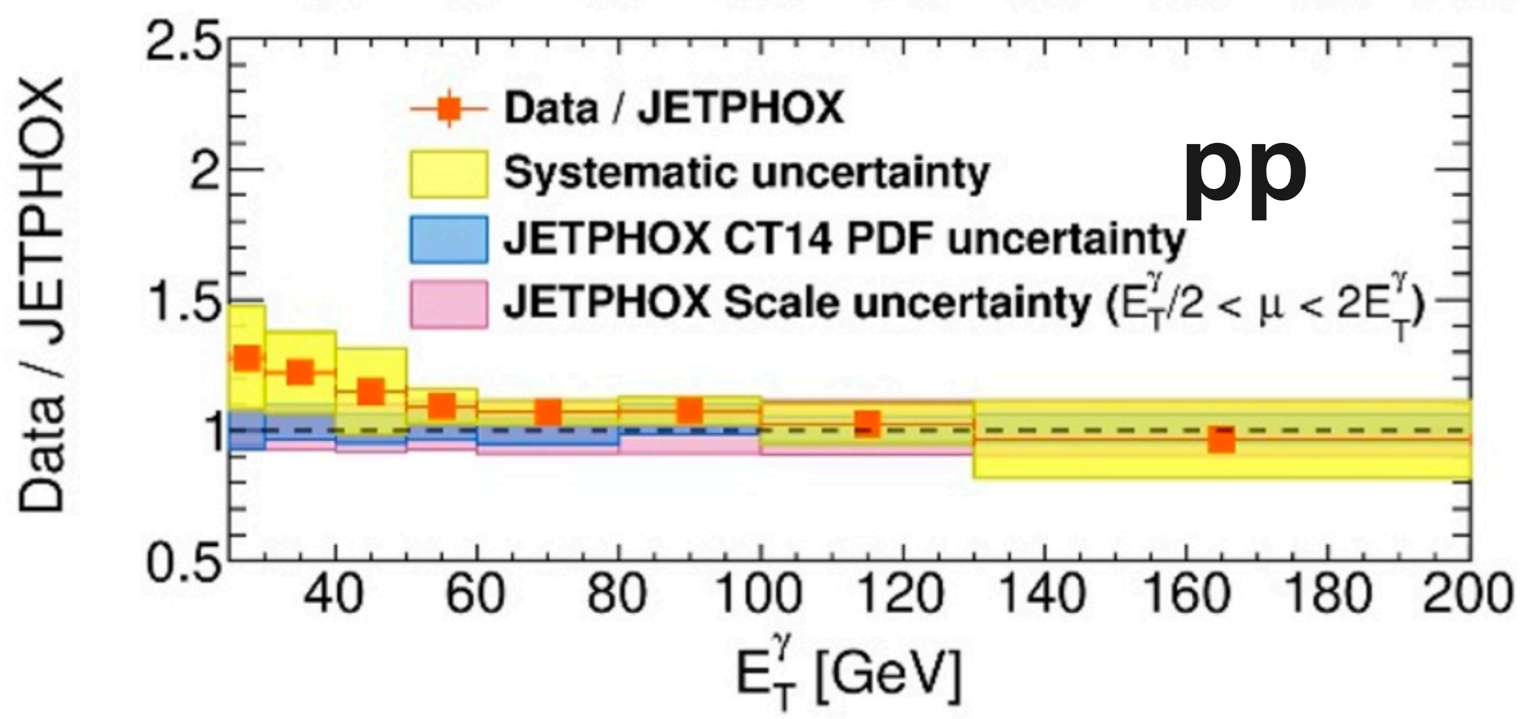
Data over theory, R = 0.4, pp & Pb–Pb at $\sqrt{s_{NN}}$ = 5.02 TeV

ALICE

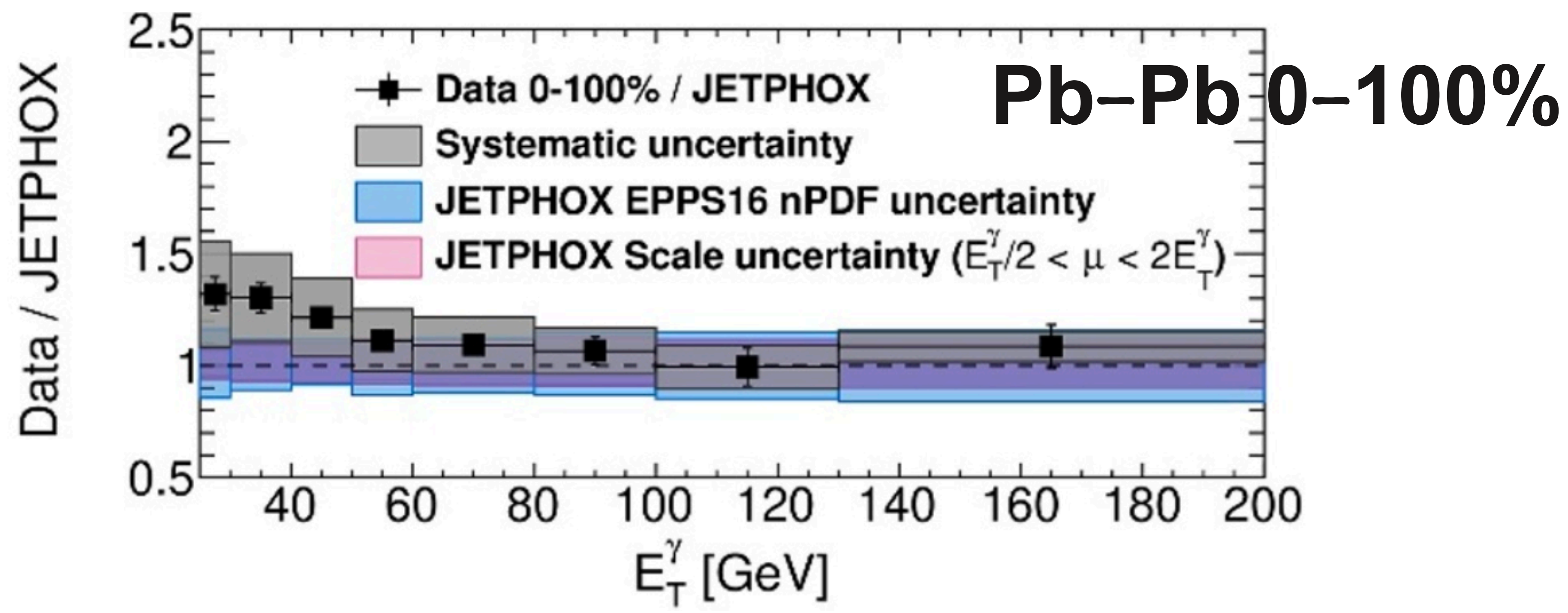


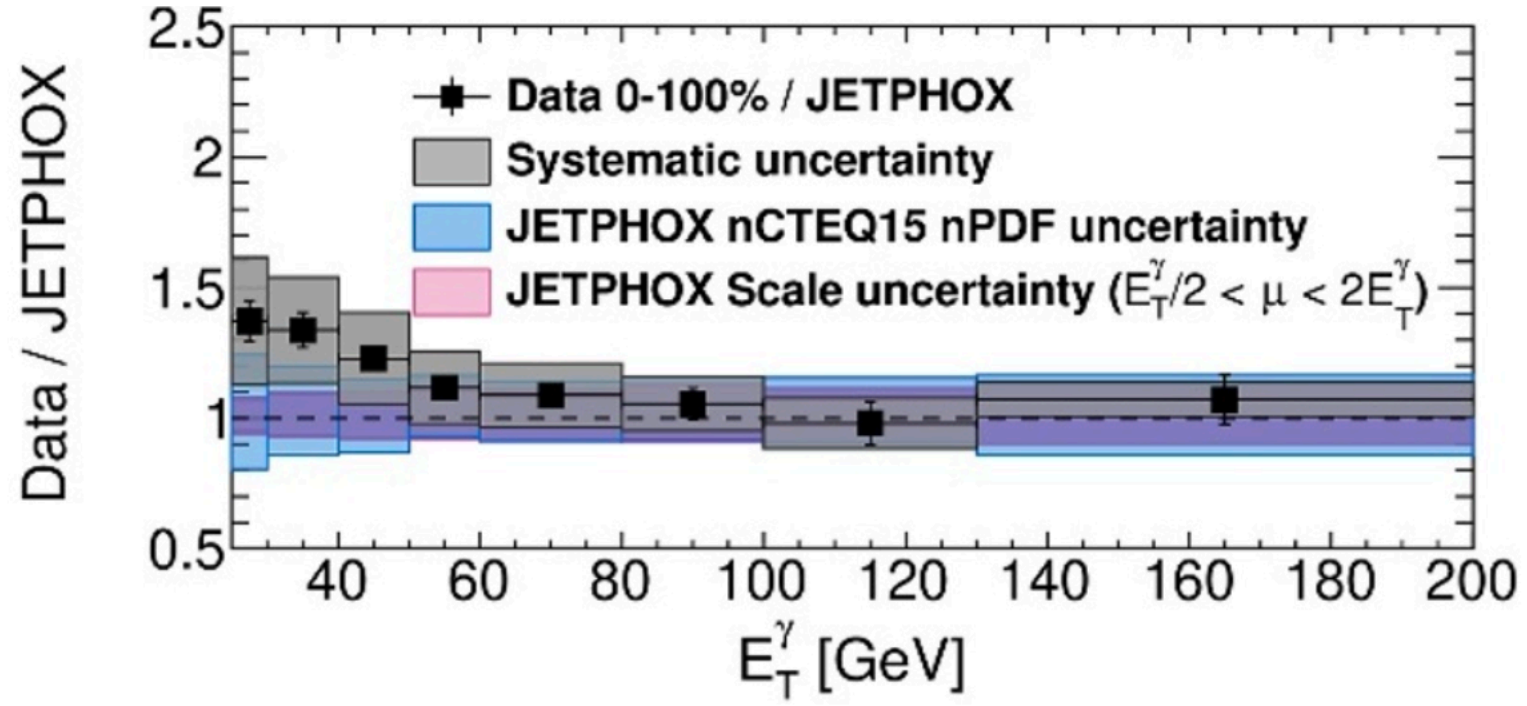
- NLO pQCD predictions (JETPHOX) and data agree in the two experiments
- Agreement between LHC experiments

CMS



CMS JHEP 07 (2020) 116
arXiv:2003.12797 [hep-ex]

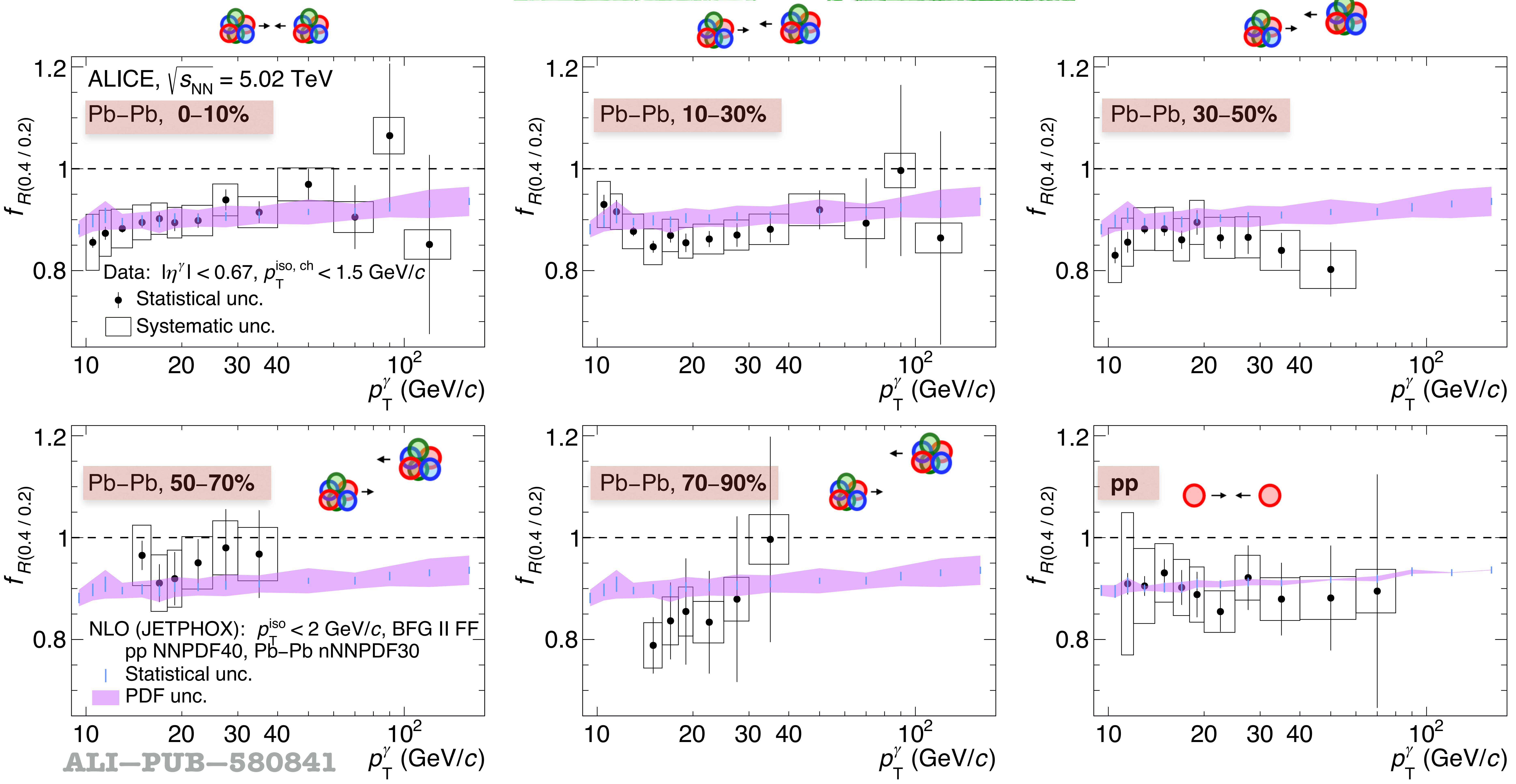




Cross section R ratio, pp & Pb–Pb at $\sqrt{s_{NN}}$ = 5.02 TeV

$$f_{R(0.4/0.2)} = \left.\frac{d^2\sigma}{dp_T\, d\eta}\right|_{(R=0.4)} \Big/ \left.\frac{d^2\sigma}{dp_T\, d\eta}\right|_{(R=0.2)}$$

- Sensitive to fraction of fragmentation γ surviving the isolation selection
  ➡ Interesting for theory models
- Agreement with theory and between collision systems
  ➡ Theory (NLO): controls the isolation mechanism, fragmentation γ & prompt γ production even in Pb–Pb

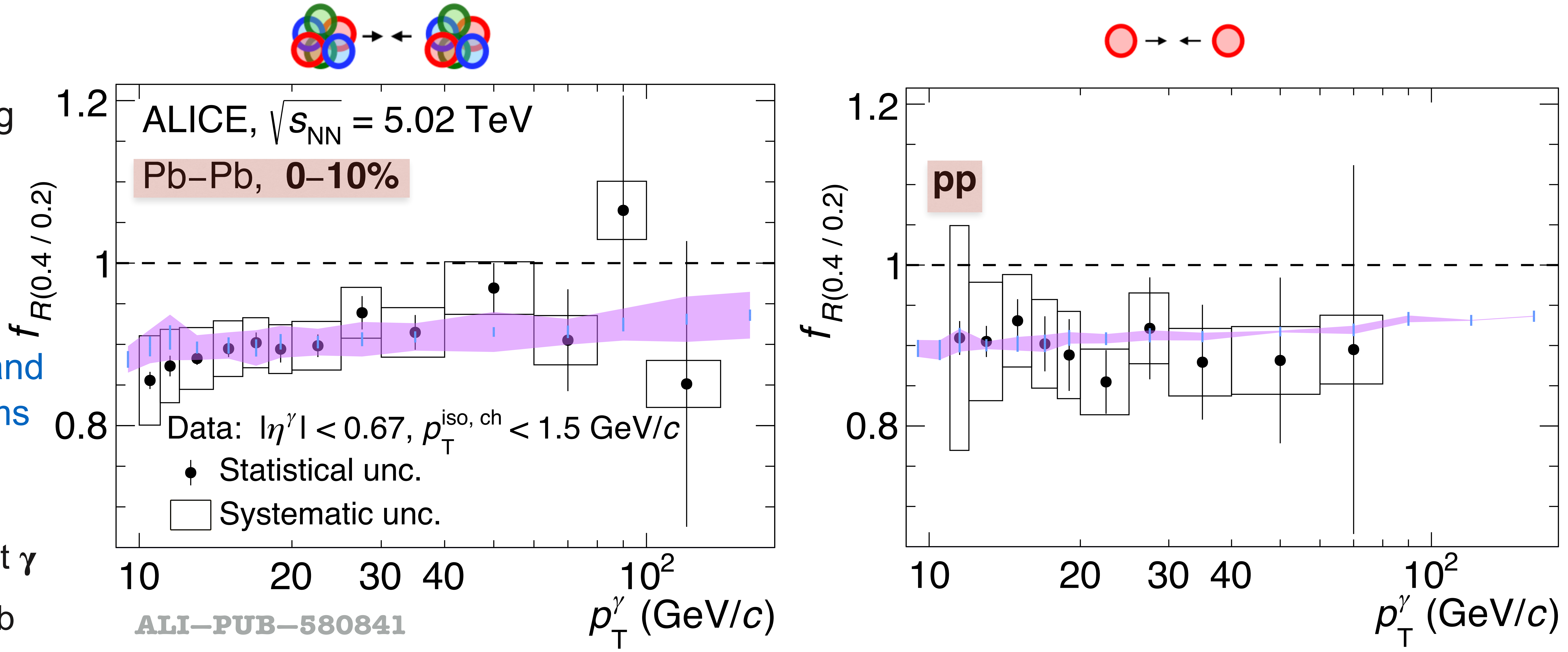


✳ Not shown (backup): ATLAS pp $\sqrt{s}$ =13 TeV, for p_T > 250 GeV/c
JHEP 07 (2023) 86 arXiv:2302.00510

Cross section R ratio, pp & Pb–Pb at $\sqrt{s_{NN}}$ = 5.02 TeV

$$f_{R(0.4/0.2)} = \left.\frac{d^2\sigma}{dp_T\, d\eta}\right|_{(R=0.4)} \Big/ \left.\frac{d^2\sigma}{dp_T\, d\eta}\right|_{(R=0.2)}$$

- Sensitive to fraction of fragmentation γ surviving the isolation selection
  - ➡ Interesting for theory models
- Agreement with theory and between collision systems
  - ➡ Theory (NLO): controls the isolation mechanism, fragmentation γ & prompt γ production even in Pb–Pb
  - ➡ Intriguing: No modification from central Pb–Pb to pp collisions in data

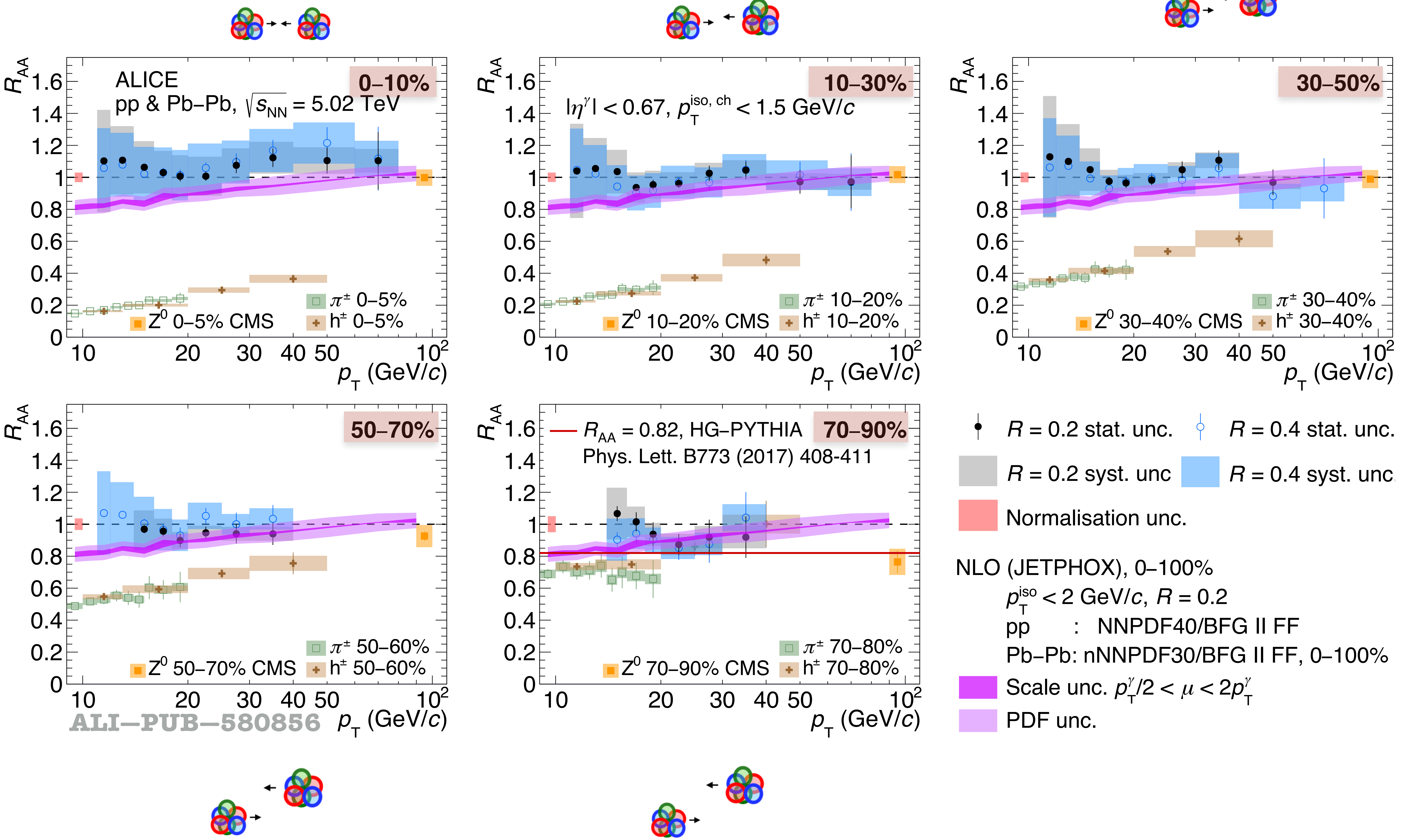


✳ Not shown (backup): ATLAS pp $\sqrt{s}$ =13 TeV, for p_T > 250 GeV/c JHEP 07 (2023) 86 arXiv:2302.00510

Nuclear modification factor R_{AA}, pp & Pb–Pb at $\sqrt{s_{NN}}$ = 5.02 TeV

$$R_{AA} = \frac{1}{\langle N_{coll} \rangle} \frac{d^2\sigma_{AA} / (dp_T\, d\eta)}{d^2\sigma_{pp} / (dp_T\, d\eta)}$$

- 0-70%
  - ➡ Consistent with unity within the unc. for both R
    - ✤ No modification of the prompt γ yield due to the QGP as expected
  - ➡ Agreement with NLO pQCD incorporating cold nuclear matter effects: PDF vs nPDF

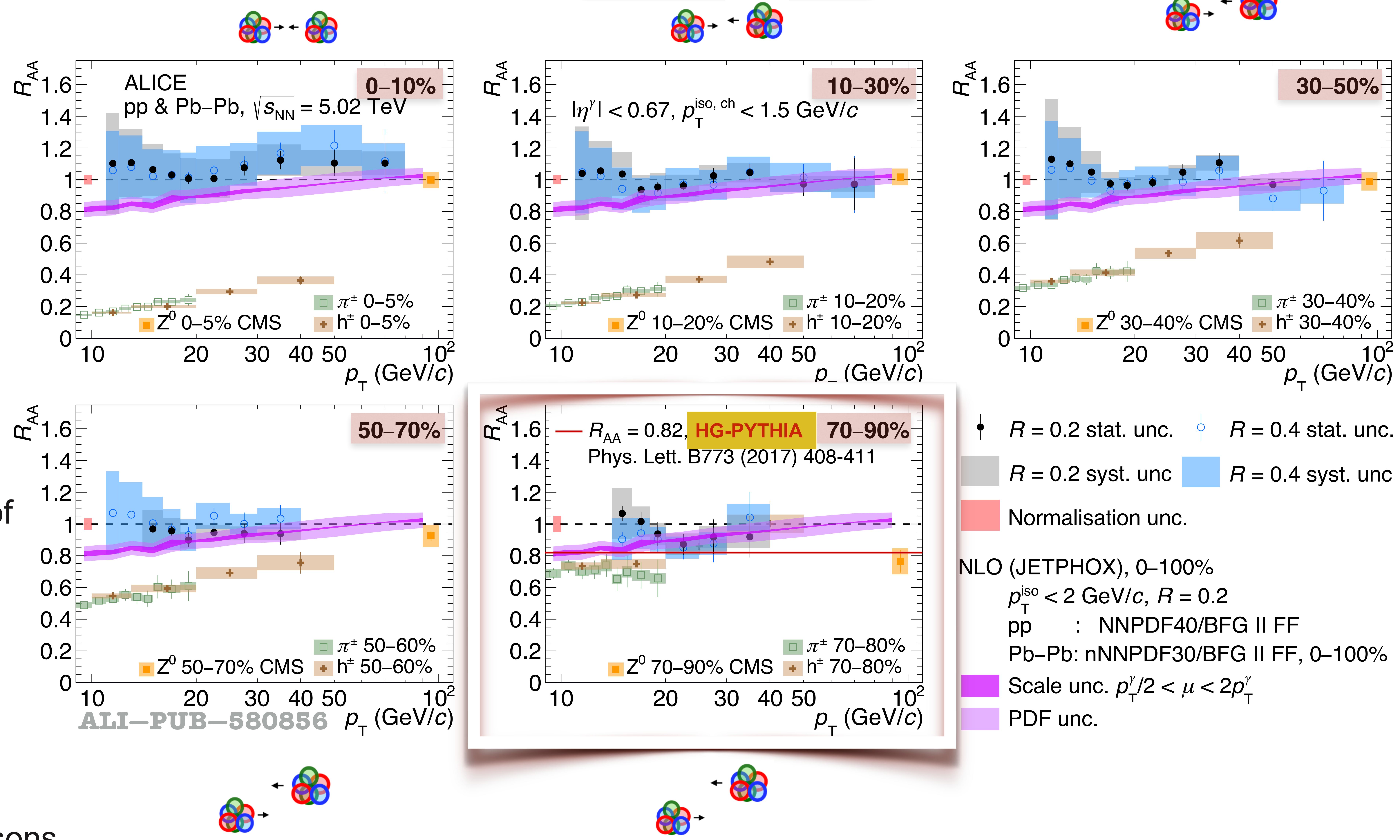


ALICE

Nuclear modification factor R_{AA}, pp & Pb–Pb at $\sqrt{s_{NN}}$ = 5.02 TeV

$$R_{AA} = \frac{1}{\langle N_{coll} \rangle} \frac{d^2\sigma_{AA} / (dp_T\, d\eta)}{d^2\sigma_{pp} / (dp_T\, d\eta)}$$

- 0-70%
  - ➡ Consistent with unity within the unc. for both R
    - ✤ No modification of the prompt γ yield due to the QGP as expected
  - ➡ Agreement with NLO pQCD incorporating cold nuclear matter effects: PDF vs nPDF
- 70-90%
  - ➡ Closer to 0.9 than 1 for both R likely due to centrality selection bias of Glauber model
  - ➡ Model by C. Loizides & A. Morsch (Phys. Lett. B773 (2017) 408-411) yields a value at 0.82
    - ✤ In agreement within the uncertainties
  - ➡ Seen by CMS with Z⁰ bosons



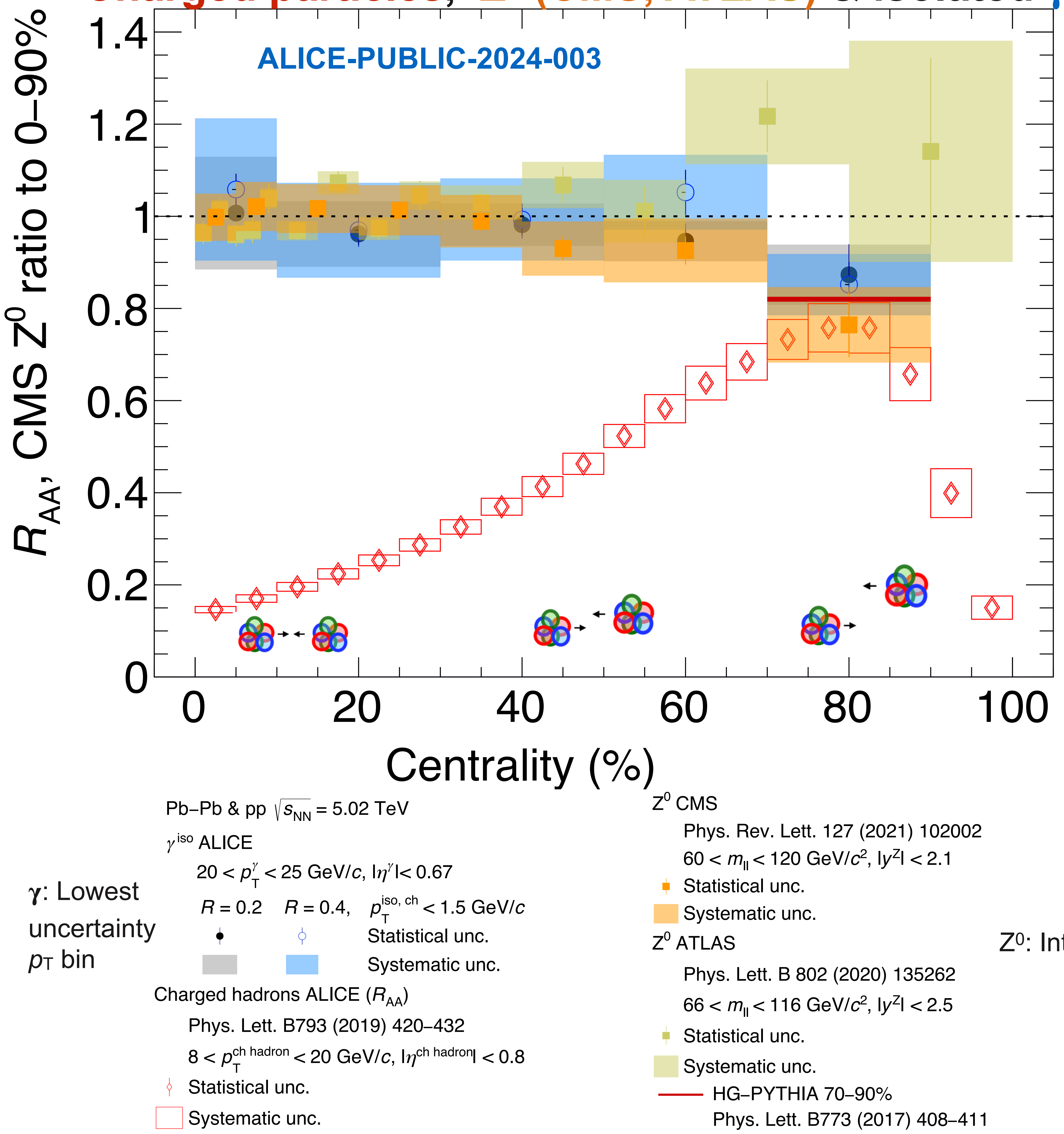
Nuclear modification factor R_{AA} in peripheral Pb–Pb at $\sqrt{s_{NN}}$ = 5.02 TeV: Centrality election bias

- Centrality calculation in data based typically in the event particle multiplicity and the Glauber model
- Early unexpected observation of rather suppressed hadron cross section in peripheral collision
- Glauber model breaks in peripheral collisions (above ~70%), effects not considered:
  - Colliding ions fluctuating geometry
  - Presence of jets, multi-parton interactions, in the event affects the particle multiplicity

- **HG-PYTHIA** model includes those effects and reproduces observations for charged hadrons and for Z^0 bosons and photons

- ATLAS Z^0 disagreement in peripheral, possible explanation in **Phys. Rev. C 104 (2021) 4, 044905**

Charged particles, Z^0 (CMS, ATLAS) & isolated γ



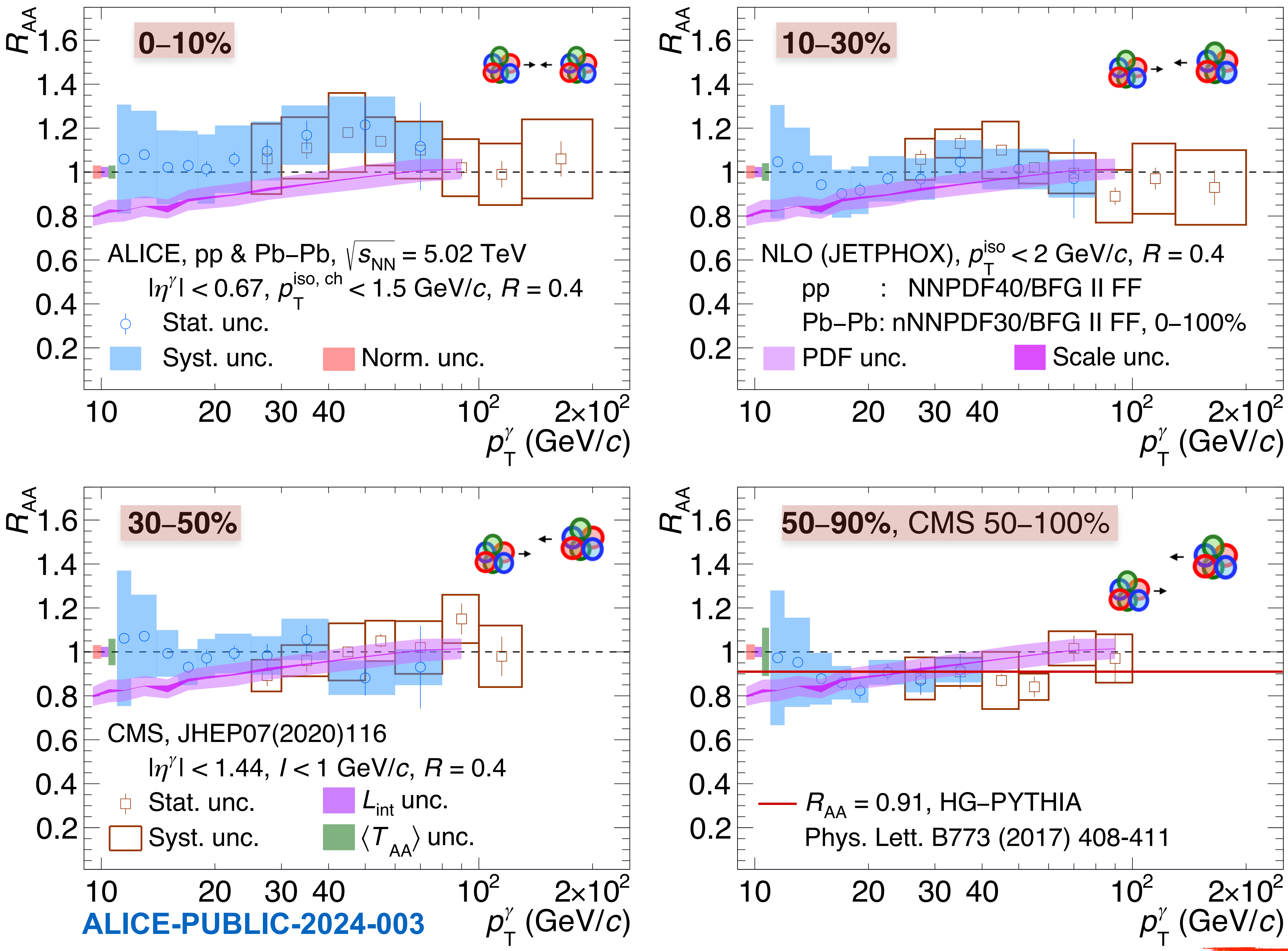
γ: Lowest uncertainty p_T bin

Z^0: Integrated p_T

Nuclear modification factor R_{AA}, pp & Pb–Pb at $\sqrt{s_{NN}}$ = 5.02 TeV

$$R_{AA} = \frac{1}{\langle N_{coll} \rangle} \frac{d^2\sigma_{AA} / (dp_T \, d\eta)}{d^2\sigma_{pp} / (dp_T \, d\eta)}$$

- **ALICE** & **CMS**: good agreement in the overlapping region 25 < p_T < 40–80 GeV/c

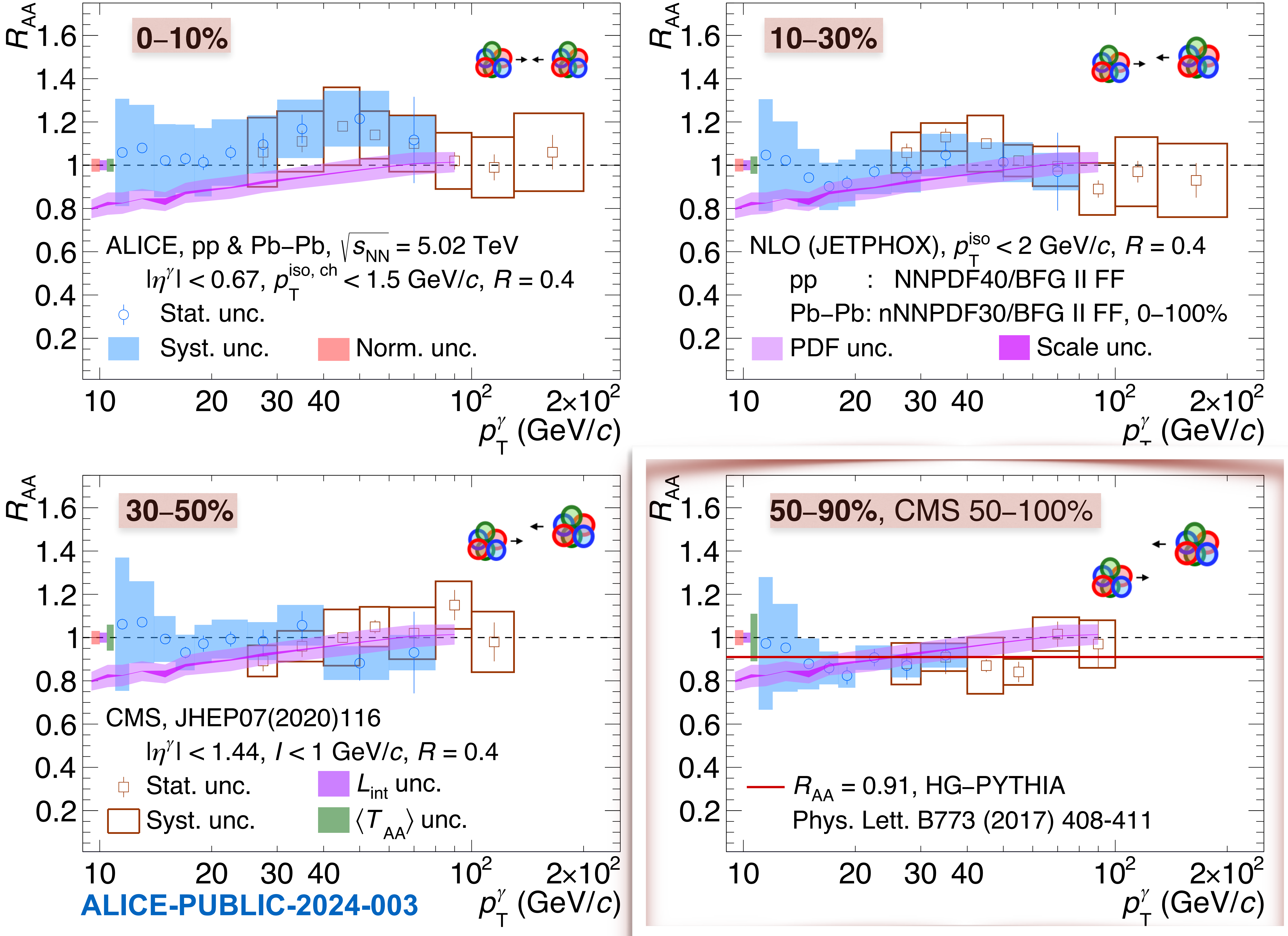


Nuclear modification factor R_{AA}, pp & Pb–Pb at $\sqrt{s_{NN}}$ = 5.02 TeV

$$R_{AA} = \frac{1}{\langle N_{coll} \rangle} \frac{d^2\sigma_{AA} / (dp_T\, d\eta)}{d^2\sigma_{pp} / (dp_T\, d\eta)}$$

- **ALICE & CMS**: good agreement in the overlapping region 25 < p_T < 40–80 GeV/c

- 50-90%
  - ➡ Closer to 0.9 than 1 for both R likely due to centrality selection bias of Glauber model
  - ➡ Model by C. Loizides & A. Morsch (Phys. Lett. B773 (2017) 408-411) yields a value at 0.91
    - ✤ In agreement within the uncertainties



ALICE-PUBLIC-2024-003

Nuclear modification factor R_{AA}, pp & Pb–Pb at $\sqrt{s_{NN}}$ = 5.02 TeV

$$R_{AA} = \frac{1}{\langle N_{coll} \rangle} \frac{d^2\sigma_{AA} / (dp_T\, d\eta)}{d^2\sigma_{pp} / (dp_T\, d\eta)}$$

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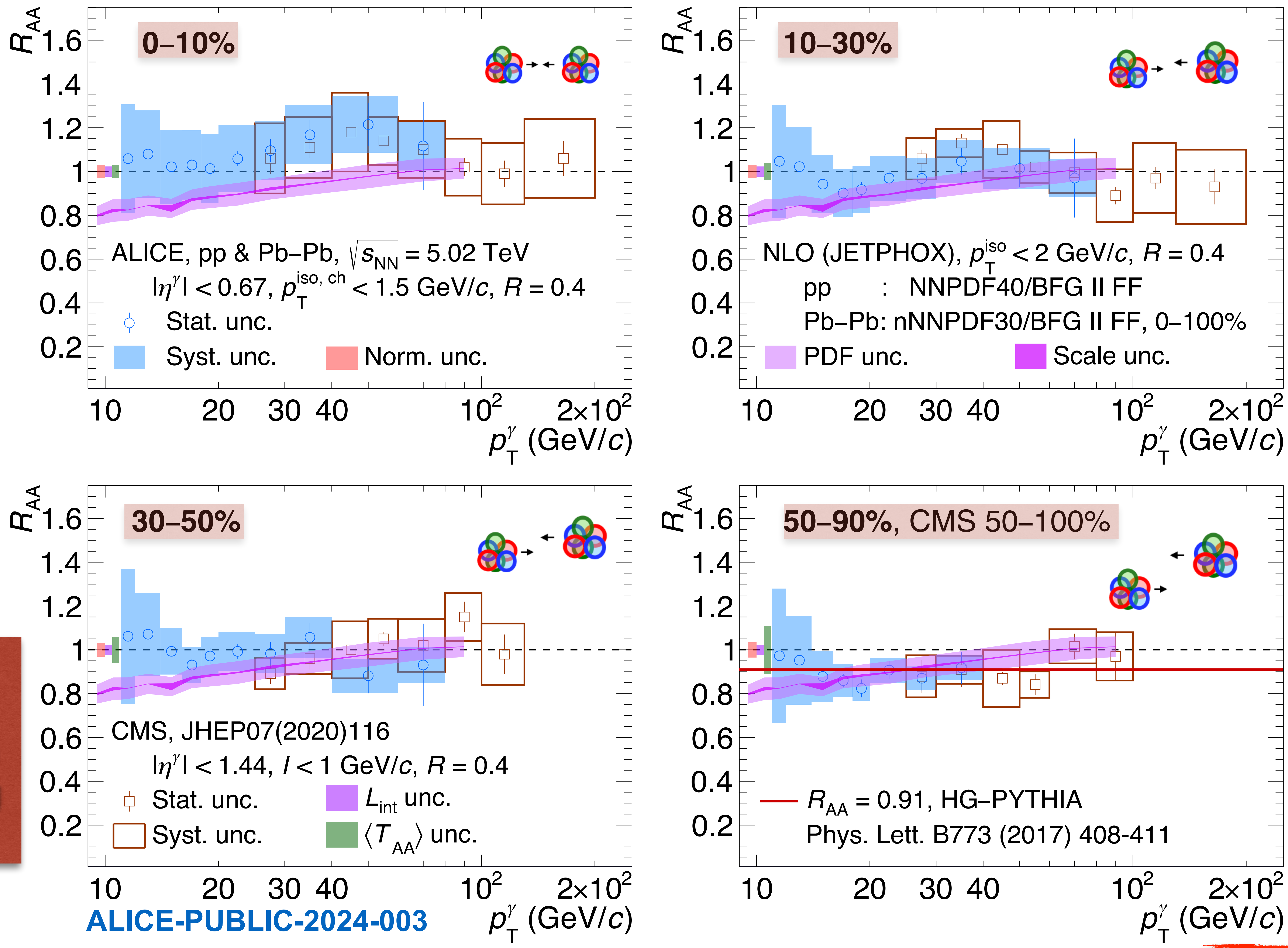
  - ➡ Model by C. Loizides & A. Morsch (Phys. Lett. B773 (2017) 408-411) yields a value at 0.91
    - ✤ In agreement within the uncertainties

Isolated photons are not modified by the QGP from central to peripheral collisions and are candle/calibrated probes to test the interpretation of other particles R_{AA} and study the jet-quenching of the back-to-back correlated partons



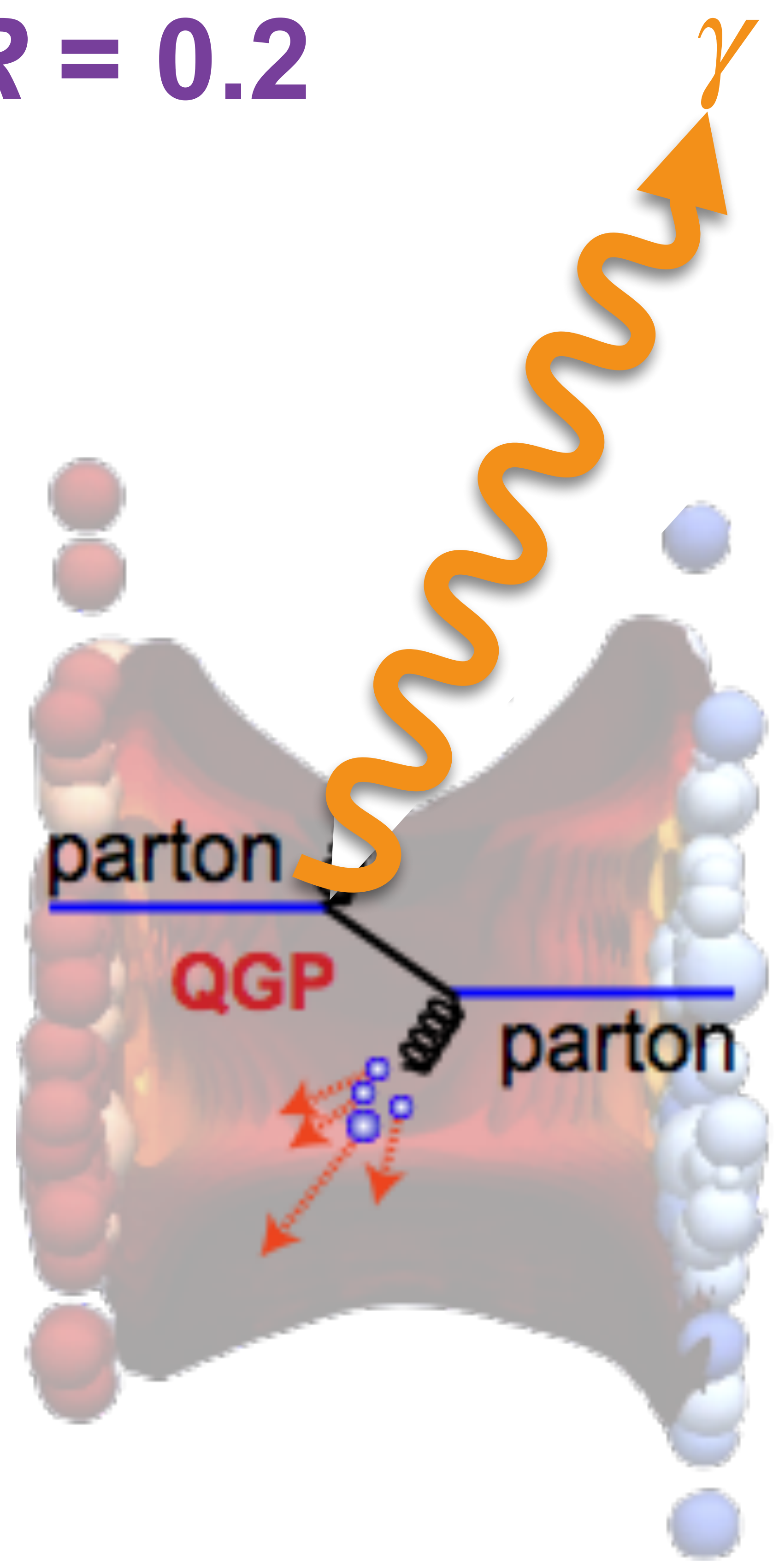
ALICE-PUBLIC-2024-003

Isolated-γ hadron correlation Pb–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV

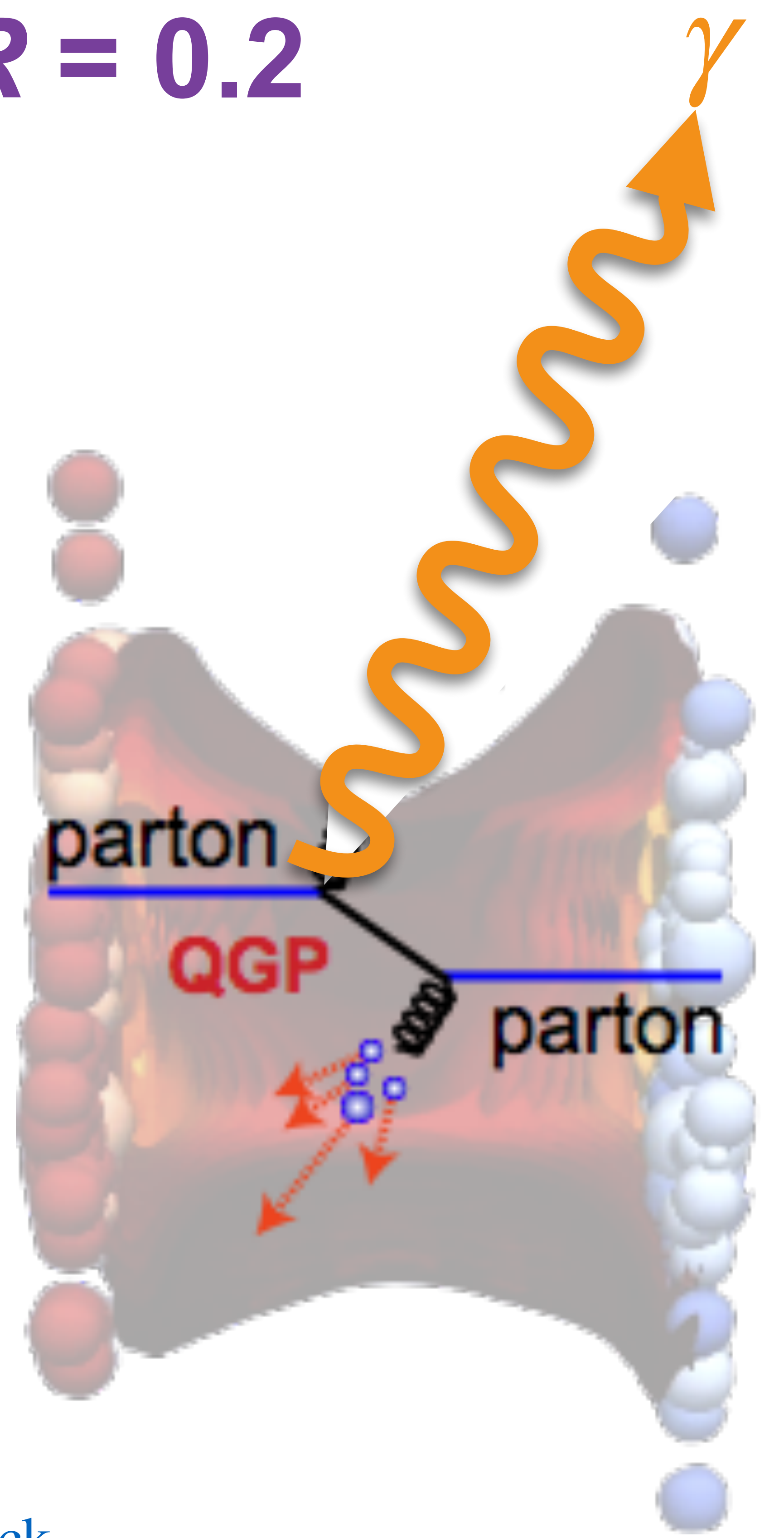
Preliminary results

Isolated γ-hadron correlations in Pb–Pb at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV, R = 0.2

- Prompt γ associated to a parton emitted in opposite side
- **Tags the parton initial energy** $p_{\mathrm{T}}^{\gamma} \simeq p_{\mathrm{T}}^{\mathrm{parton}}$, before losing ΔE in QGP
  - ➡ Aim: Measure jet fragmentation function modifications**,** *where is the ΔE radiated?*

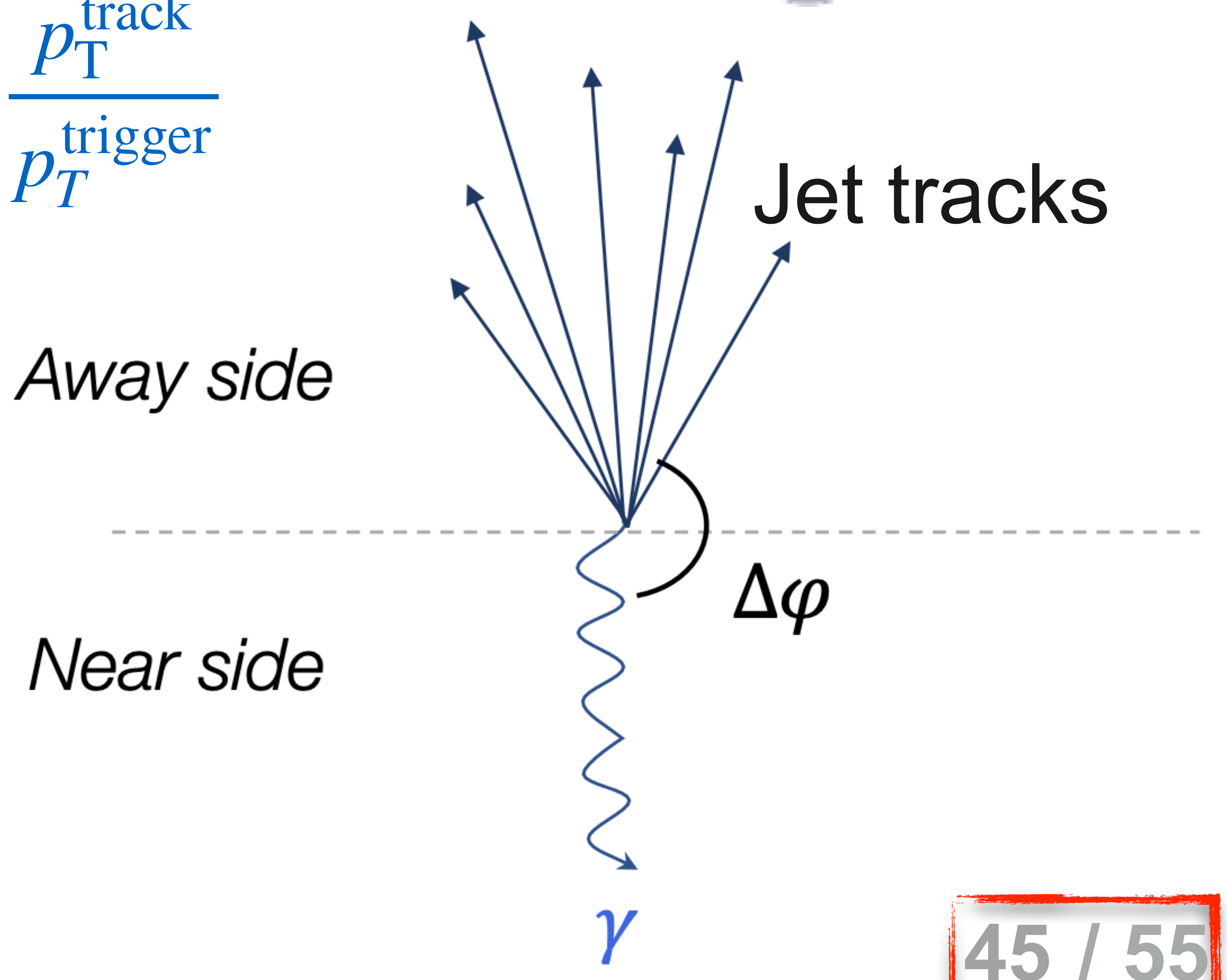


Isolated γ-hadron correlations in Pb–Pb at $\sqrt{s_{\rm NN}}$ = 5.02 TeV, R = 0.2



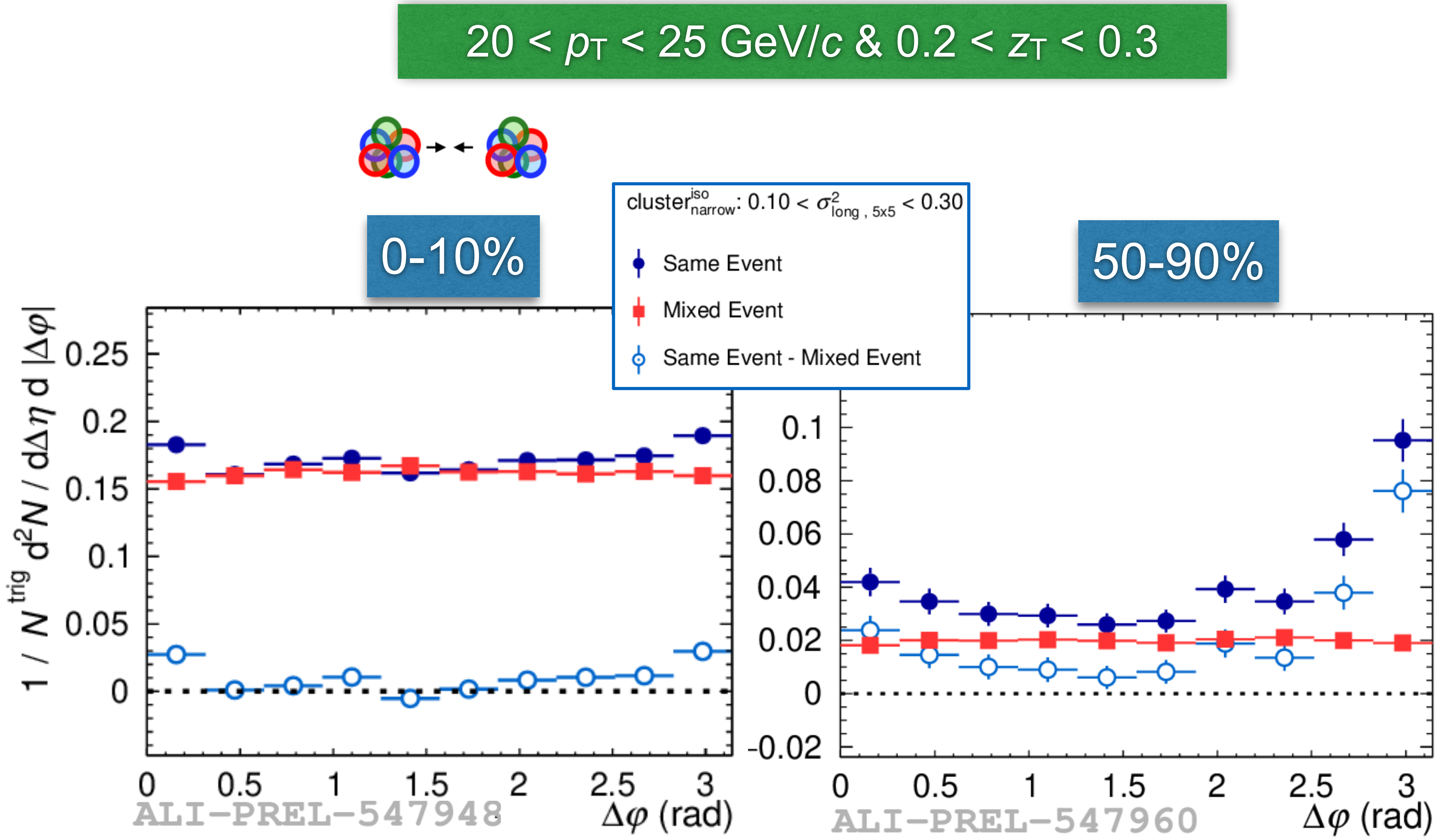
- Prompt **γ** associated to a parton emitted in opposite side
- **Tags the parton initial energy** $p_{\rm T}^{\gamma} \simeq p_{\rm T}^{\rm parton}$, before losing Δ*E* in QGP
  - ➡ Aim: Measure jet fragmentation function modifications, *where is the ΔE radiated?*
- Observables:
  - ➡ Trigger: isolated narrow or wide clusters, 18 < $p_T^{\rm trigger}$< 40 GeV/*c*
    - ◉ *R* = 0.2 & $p_{\rm T}^{\rm iso\ ch}$ < 1.5 GeV/*c:* Higher isolation purity and efficiency in central collisions
  - ➡ Azimuthal correlation: $\Delta\varphi = \varphi^{\rm trigger} - \varphi^{\rm track}$, $p_T^{\rm track}$ > 0.5 GeV/*c*
  - ➡ Per trigger yield $\mathrm{D}(z_{\rm T}) = \frac{1}{N^{\rm trigger}}\frac{{\rm d}\ N^{\rm track}}{{\rm d}\ z_{\rm T}}$ for tracks in $|\Delta\varphi| > 3/5\pi$ rad (mirrored) with $z_{\rm T} = \frac{p_{\rm T}^{\rm track}}{p_T^{\rm trigger}}$
    - ◉ When trigger = prompt **γ**, $\mathrm{D}(z_{\rm T})$ is a proxy for the jet fragmentation function
  - ➡ Study $\mathrm{D}(z_{\rm T})$ modification due to jet-quenching via $I_{\rm AA} = \frac{D(z_{\rm T})_{\ \rm Pb-Pb}}{D(z_{\rm T})_{\ \rm pp}} \approx \frac{D(z_{\rm T})_{\ \rm Pb-Pb}}{D(z_{\rm T})_{\ \rm NLO\ pQCD}}$

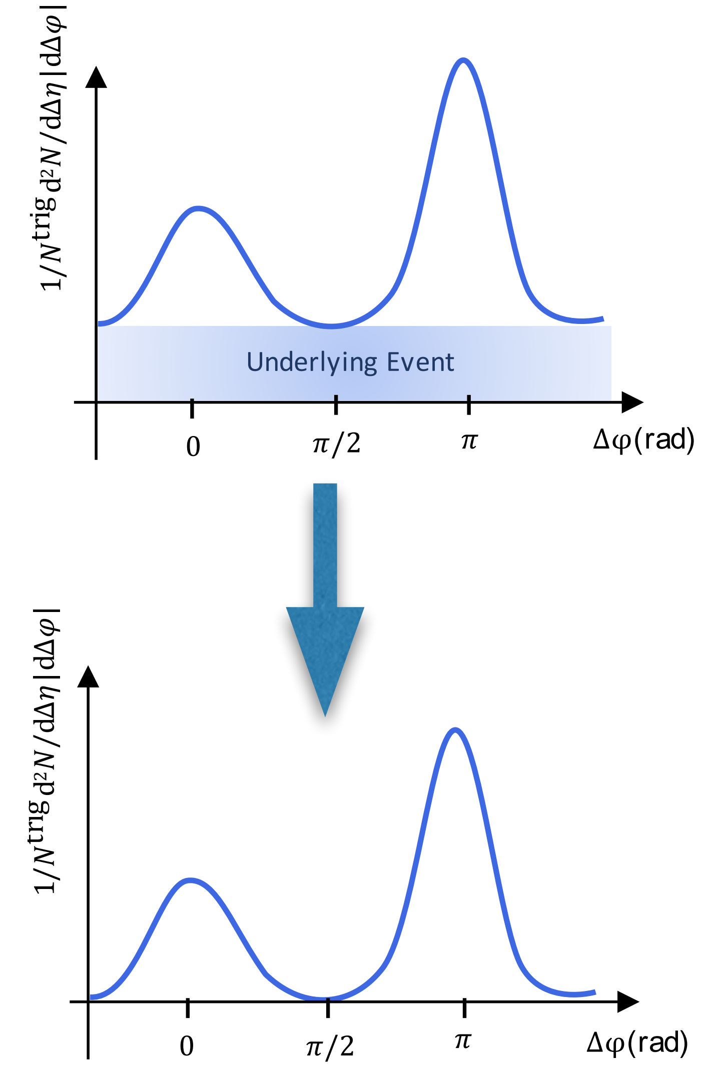
(similar to $R_{\rm AA}$ but no need of $N_{\rm col}$, per trigger yields)



Isolated γ-hadron correlations in Pb–Pb: Azimuthal distribution

- UE in $\Delta\varphi$: uncorrelated tracks shift up the distribution
- *<u>UE subtraction with mixed event</u>*: artificial dataset created combining the trigger cluster with tracks on different collisions





Isolated γ-hadron correlations in Pb–Pb: Azimuthal distribution

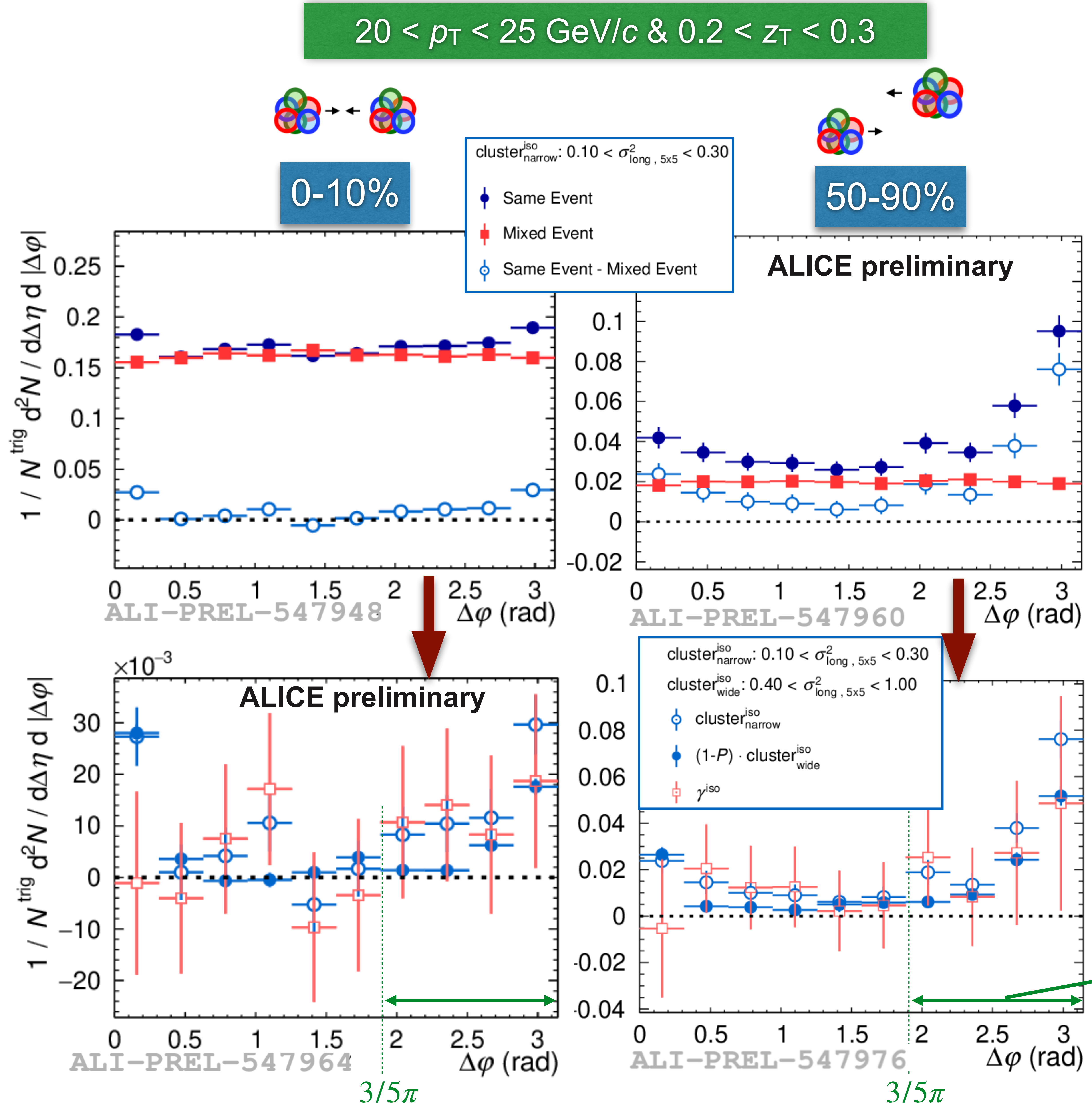
- UE in $\Delta\varphi$: uncorrelated tracks shift up the distribution
- *UE subtraction with mixed event*: artificial dataset created combining the trigger cluster with tracks on different collisions

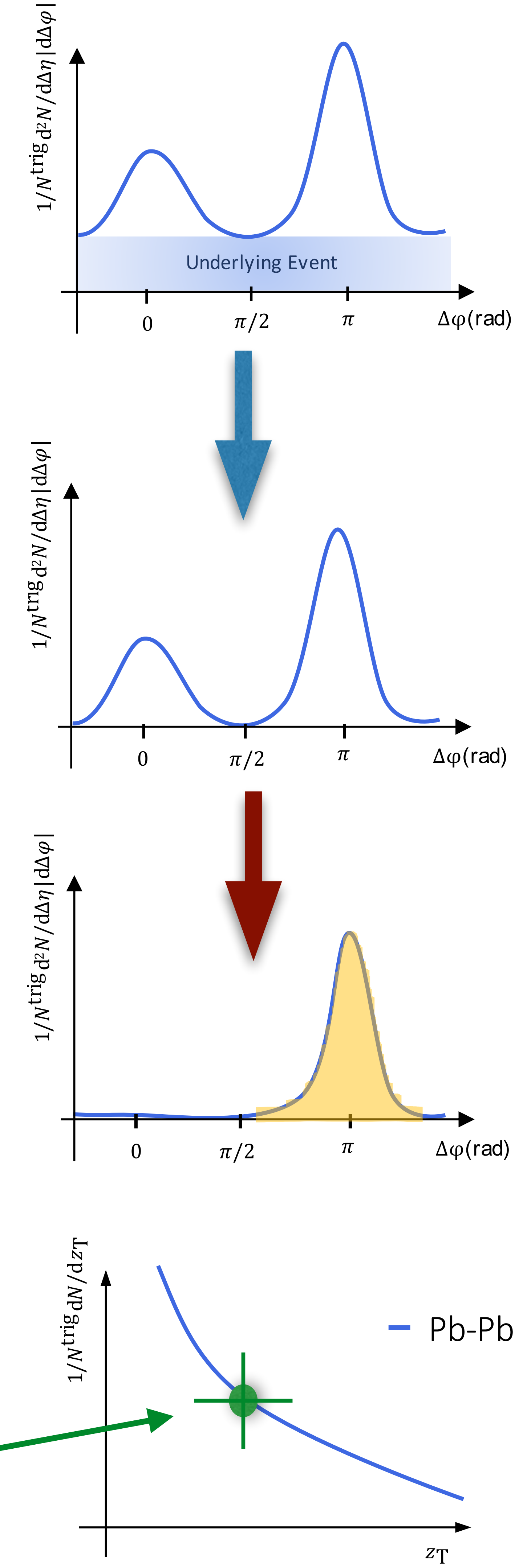
- Purity < 1, considering
  $f(\Delta\varphi^{\mathrm{cls}^{\mathrm{iso}}_{\mathrm{narrow}}})$ bkg $= f(\Delta\varphi^{\mathrm{cls}^{\mathrm{iso}}_{\mathrm{wide}}})$:

$$f(\Delta\varphi^{\gamma^{\mathrm{iso}}}) = \frac{f(\Delta\varphi^{\mathrm{cls}^{\mathrm{iso}}_{\mathrm{narrow}}}) - (1-P)\cdot f(\Delta\varphi^{\mathrm{cls}^{\mathrm{iso}}_{\mathrm{wide}}})}{P}$$

➡ Subtraction of two close distributions → large statistical uncertainty

➡ $D(z_T)$: Integrate $f(\Delta\varphi^{\gamma^{\mathrm{iso}}})$ in $3/5\pi < |\Delta\varphi| < \pi$ rad





Isolated γ-hadron correlations in p–Pb & pp, $R = 0.4$: $D(z_T)$

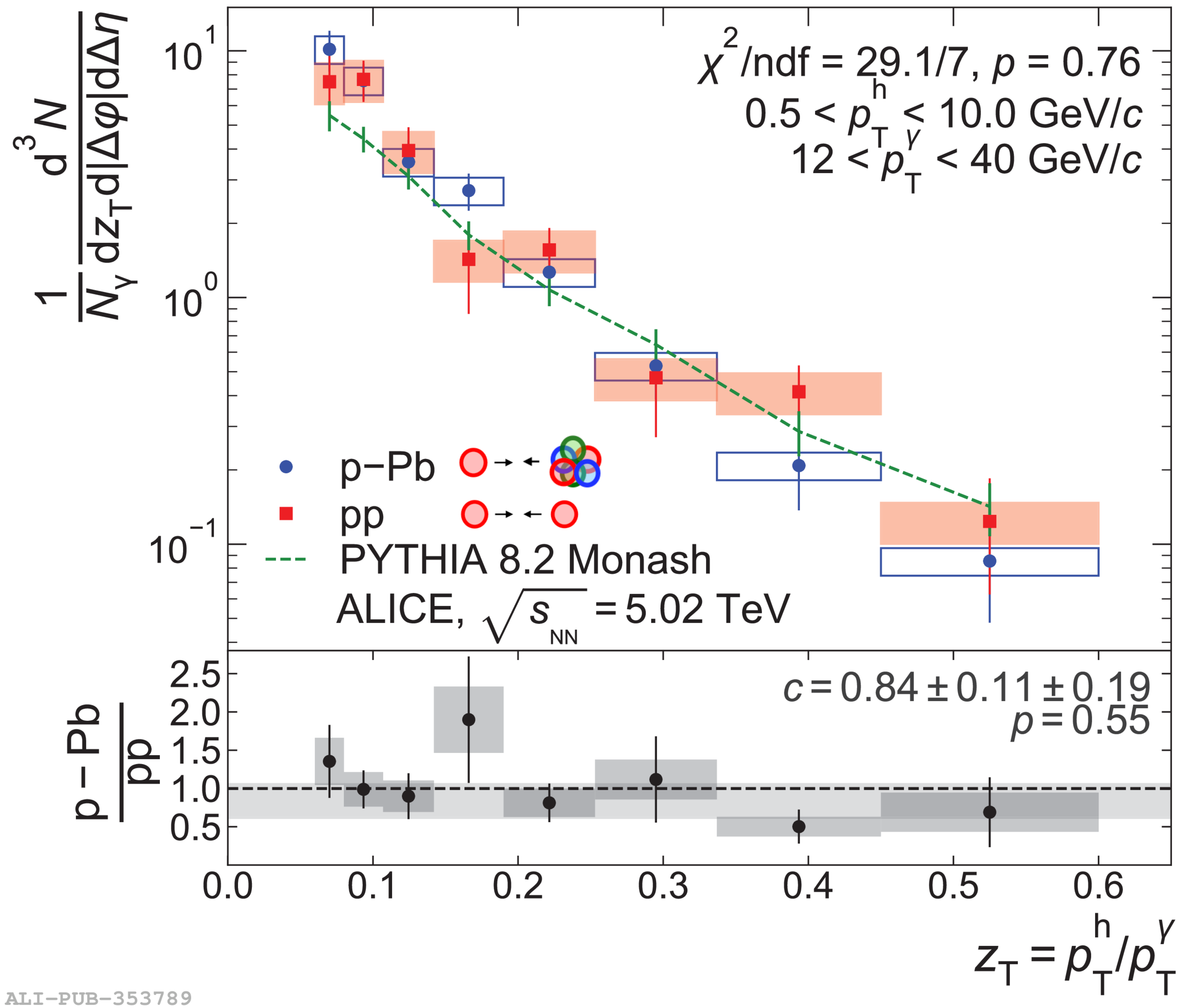
Phys Rev C 102 (2020) 044908

Previous published results in p–Pb and pp collisions

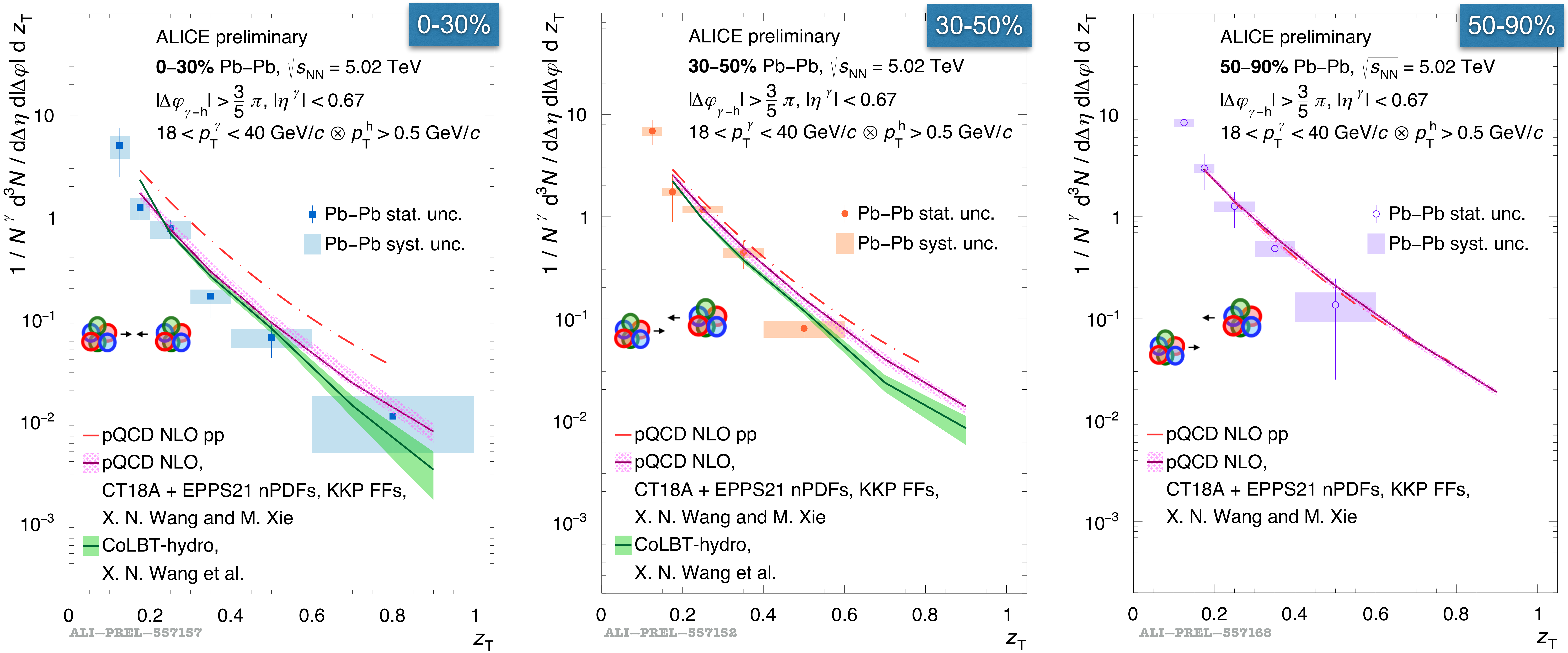
➡ Agreement between systems and with PYTHIA

➡ Note: Pb–Pb collisions measurement (next slides)

done in different p_T ranges and is compared directly to pQCD predictions



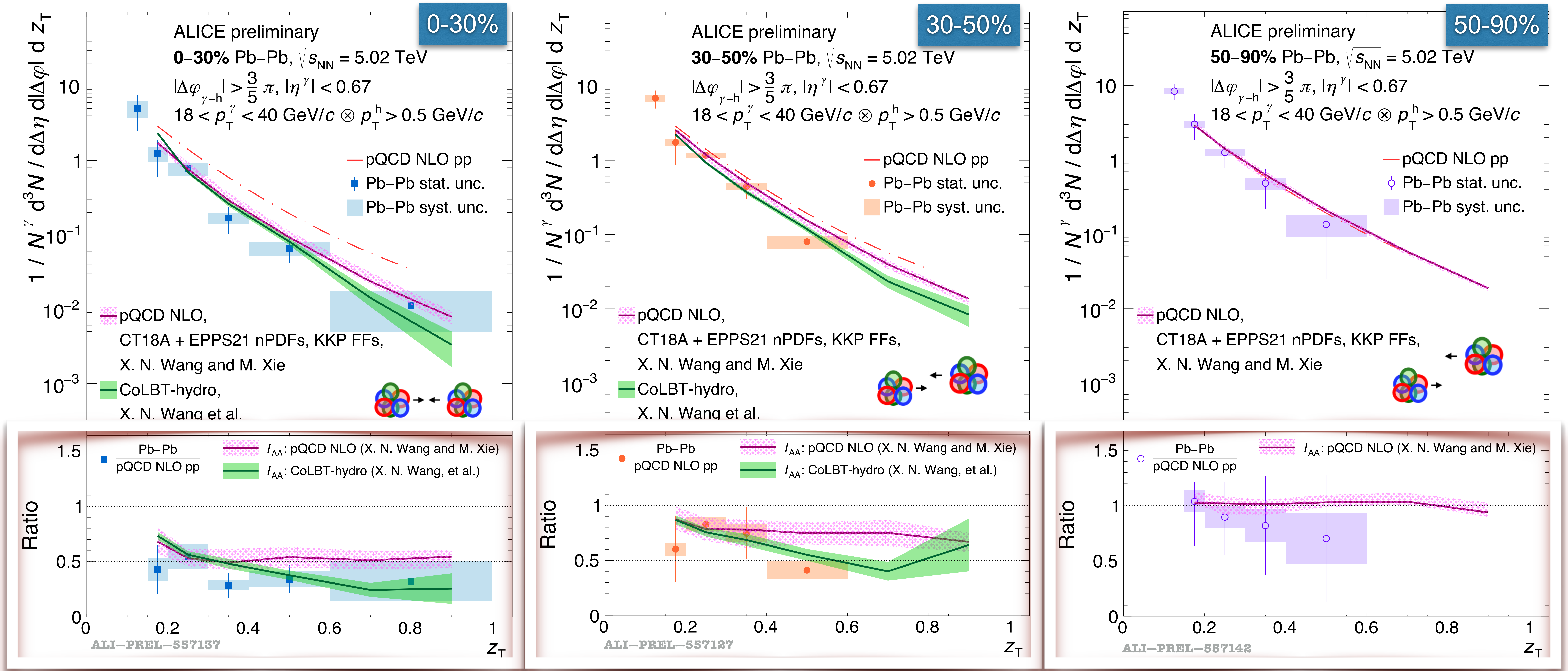
Isolated γ-hadron correlations in Pb–Pb: $D(z_T)$



- Pb–Pb data compared with theory: *NLO pQCD* and *CoLBT* (0-50% only)
  - ➡ In agreement with both models
  - ➡ Discrimination not possible yet

- *Phys. Rev. C 103, 034911, Xie, Wang and Zhang,*
- *Phys. Rev. Lett. 103, 032302, Xie, Wang and Zhang*
- *Phys.Lett.B 777 (2018) 86-90 , Chen et al.*

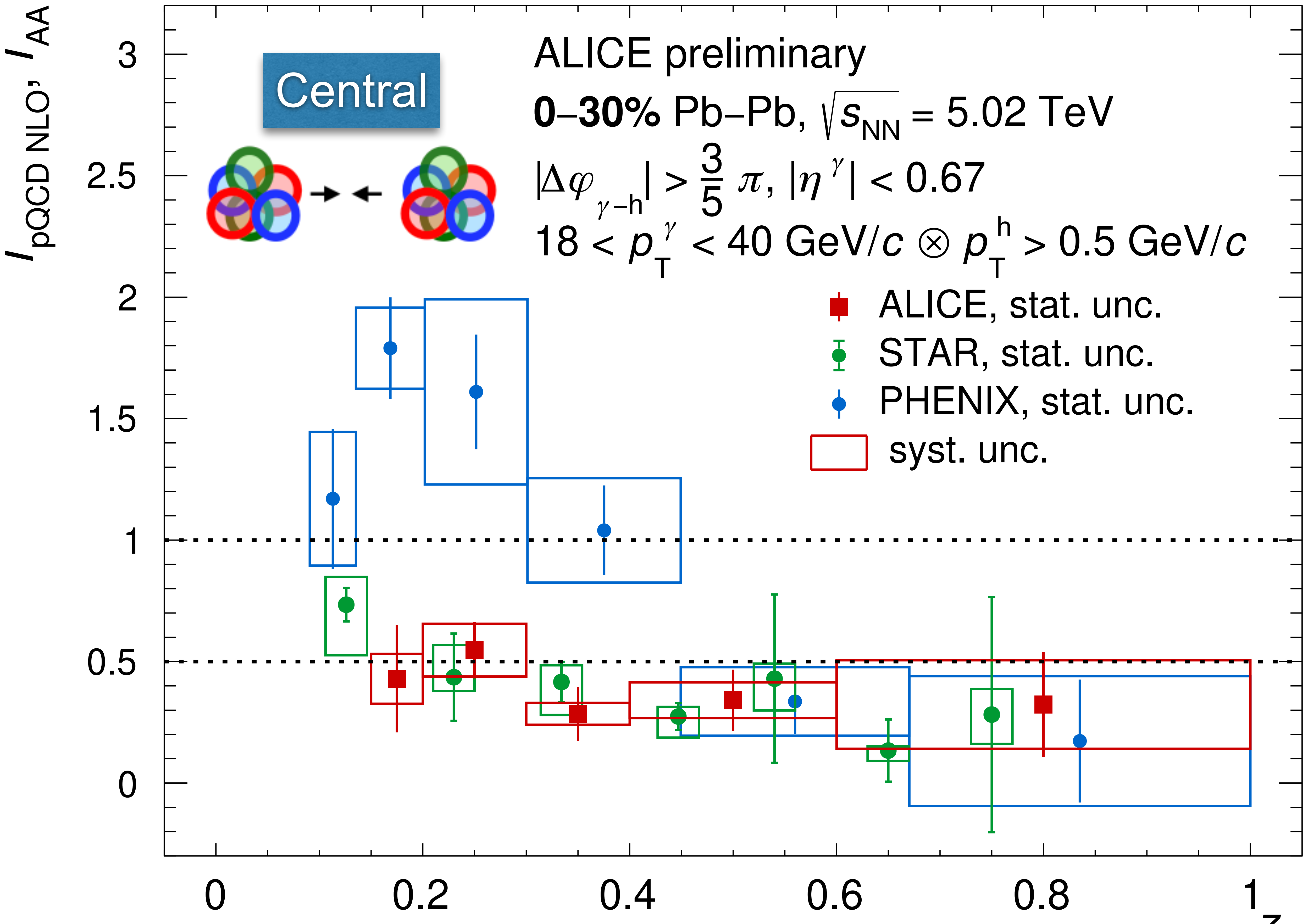
Isolated γ-hadron correlations in Pb–Pb: $D(z_T)$



- Ratio with respect to NLO pQCD pp collision simulation → A proxy for $I_{AA} = \frac{D(z_T)_{\text{Pb–Pb}}}{D(z_T)_{\text{pp}}}$
- Clear modifications in data with respect to NLO pQCD pp simulation
- Comparison with I_{AA} from NLO pQCD and CoLBT models → agreement

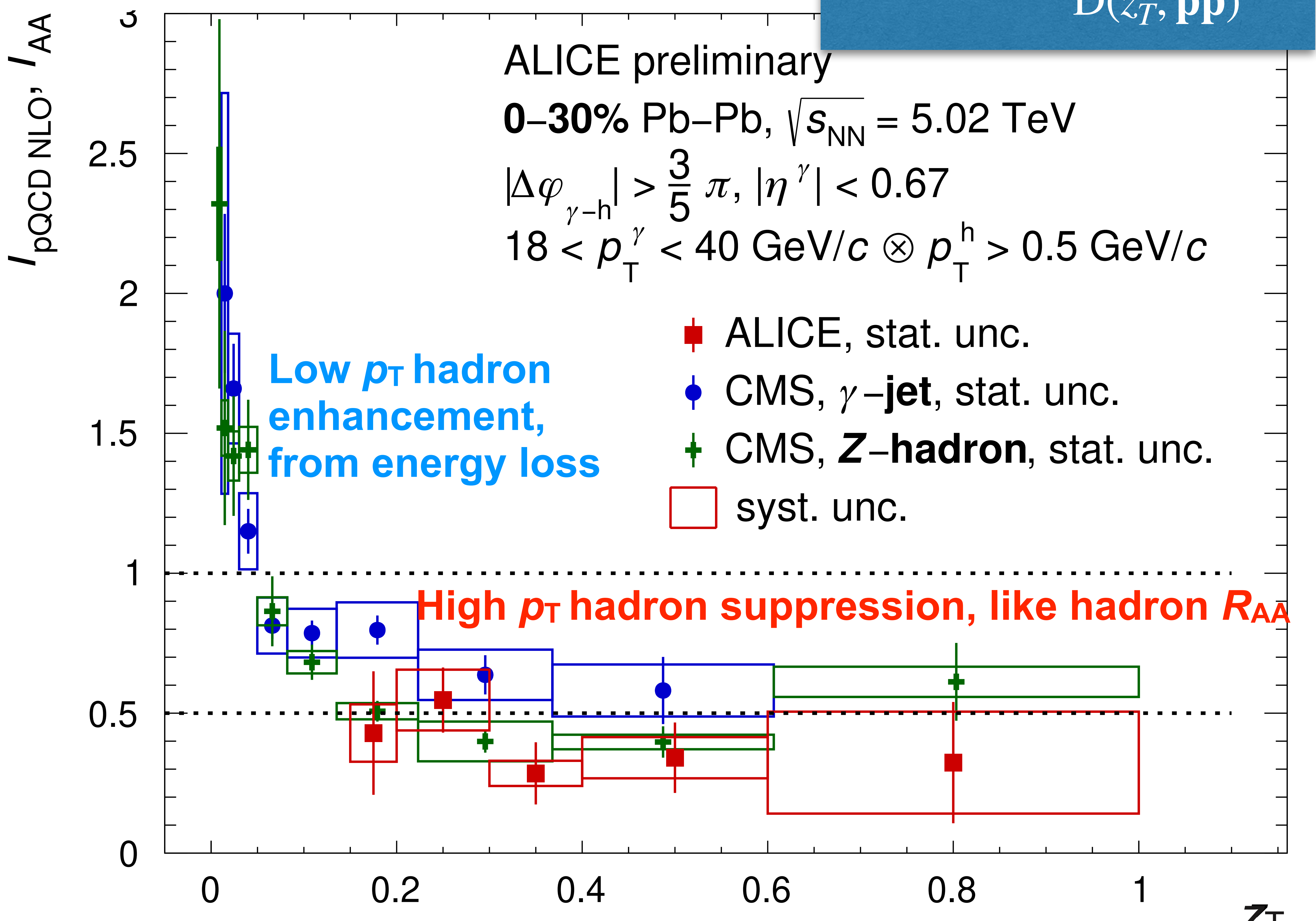
Isolated γ-hadron correlations I_{AA} in *central* Pb–Pb: LHC & RHIC

$$I_{AA}(z_T) = \frac{D(z_T, \mathrm{Pb-Pb})}{D(z_T, \mathrm{pp})}$$



STAR, Phys.Lett.B 760 (2016) 689-696

PHENIX, PRL 111, 032301 (2013)



CMS, Phys.Rev.Lett. 121 (2018) 242301, 2018

0–12% Au–Au, $\sqrt{s_{NN}}$ = 200 GeV

$|\Delta\varphi_{\gamma-h} - \pi| \leq 1.4$

$12 < p_T^{\gamma} < 20$ GeV/c ⊗ $p_T^{h} > 1.2$ GeV/c

0–40% Au–Au, $\sqrt{s_{NN}}$ = 200 GeV

$|\Delta\varphi_{\gamma-h} - \pi| < \pi/2$, $|y| < 0.35$

$5 < p_T^{\gamma} < 9$ GeV/c ⊗ $0.5 < p_T^{h} < 7$ GeV/c

CMS, Phys.Rev.Lett. 128 (2022) 122301, 2022

***Z*–hadron, 0–30%**

$|\Delta\varphi_{Z-h}| > \frac{7}{8}\pi$, $p_T^{Z} > 30$ GeV/c ⊗ $p_T^{h} > 1$ GeV/c

γ–jet, 0–10%

anti-k$_T$ jet R = 0.3, $p_T^{jet} > 30$ GeV/c, $|\eta^{jet}| < 1.6$

$|\Delta\varphi_{\gamma-jet}| > \frac{7}{8}\pi$, $|\eta^{\gamma}| < 1.44$ $p_T^{\gamma} > 60$ GeV/c ⊗ $p_T^{h} > 1$ GeV/c

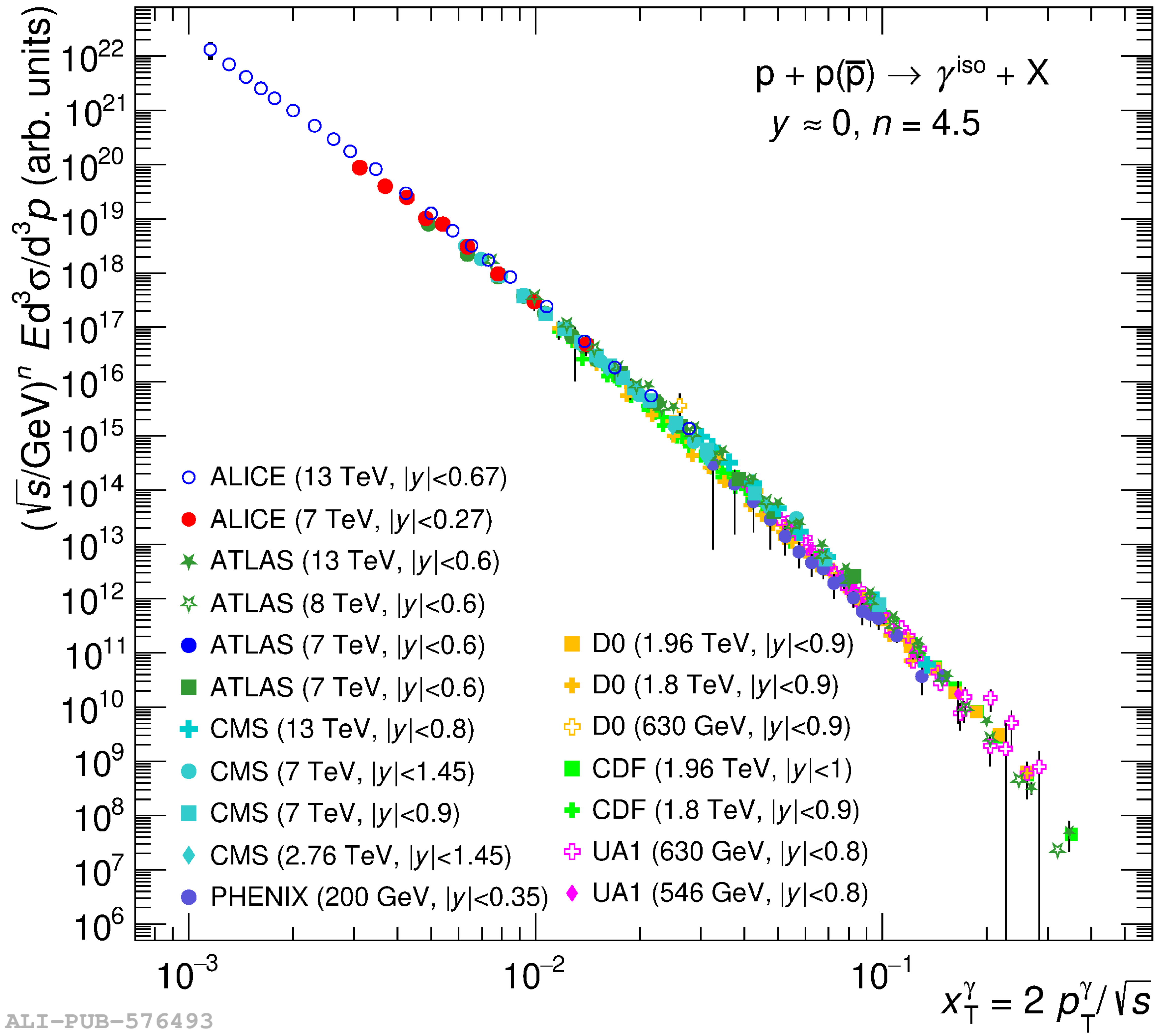
Similar behaviour observed at RHIC and LHC experiments

- ➡ Note: not completely apple-to-apple comparisons!
- ➡ ALICE results closer to STAR and CMS Z-hadron that have closer kinematic and/or centrality selections

Summary

➡ **Cross section**

- Data in agreement with NLO pQCD in multiple collision systems & $\sqrt{s_{\mathrm{NN}}}$
- Lowest measured x_{T} at mid-rapidity in pp collisions at $\sqrt{s}$ = 13 TeV
- Ratio of cross sections for different R in agreement with theory and within the different collision systems



Summary

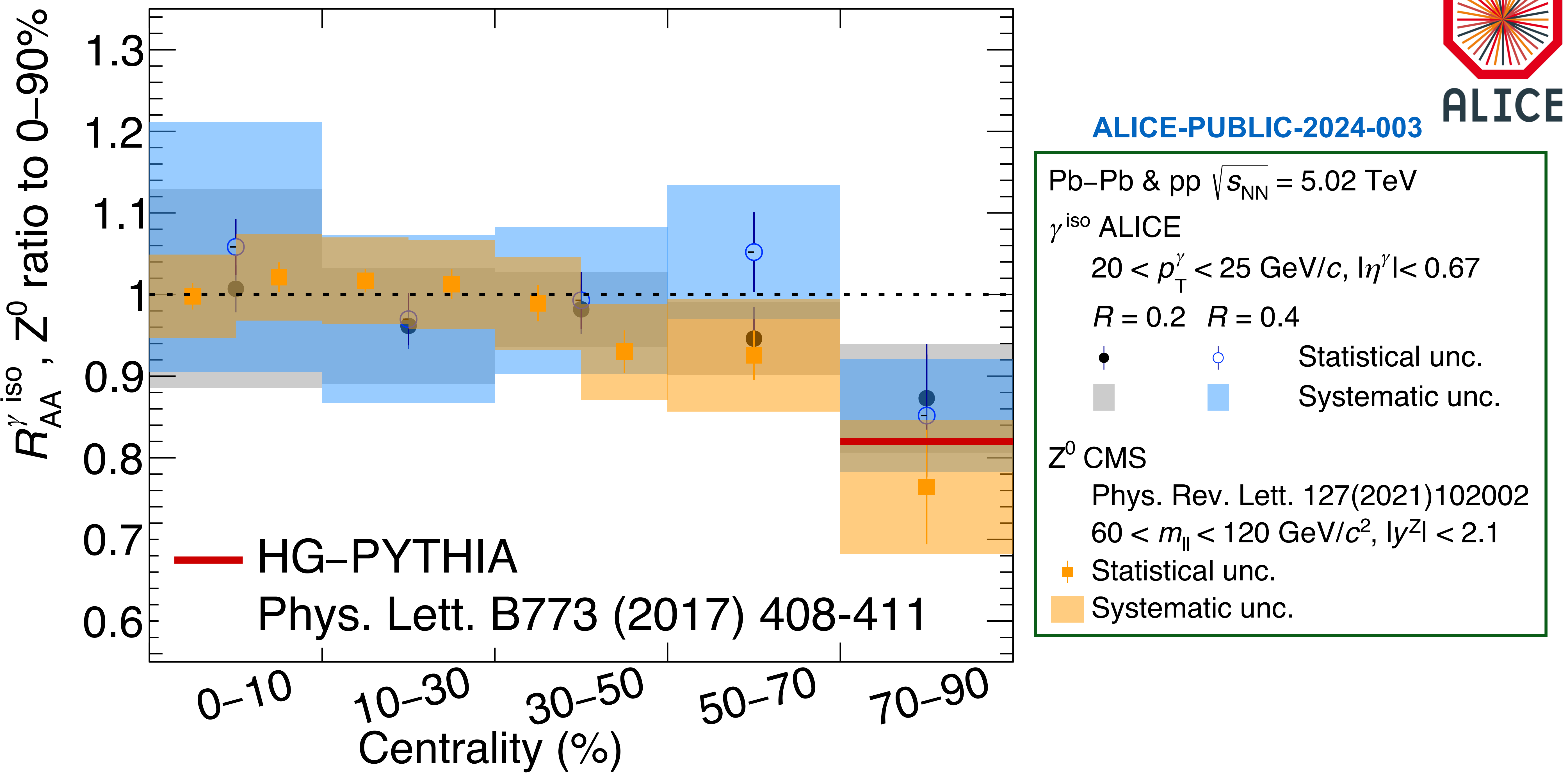
➡ **Cross section**

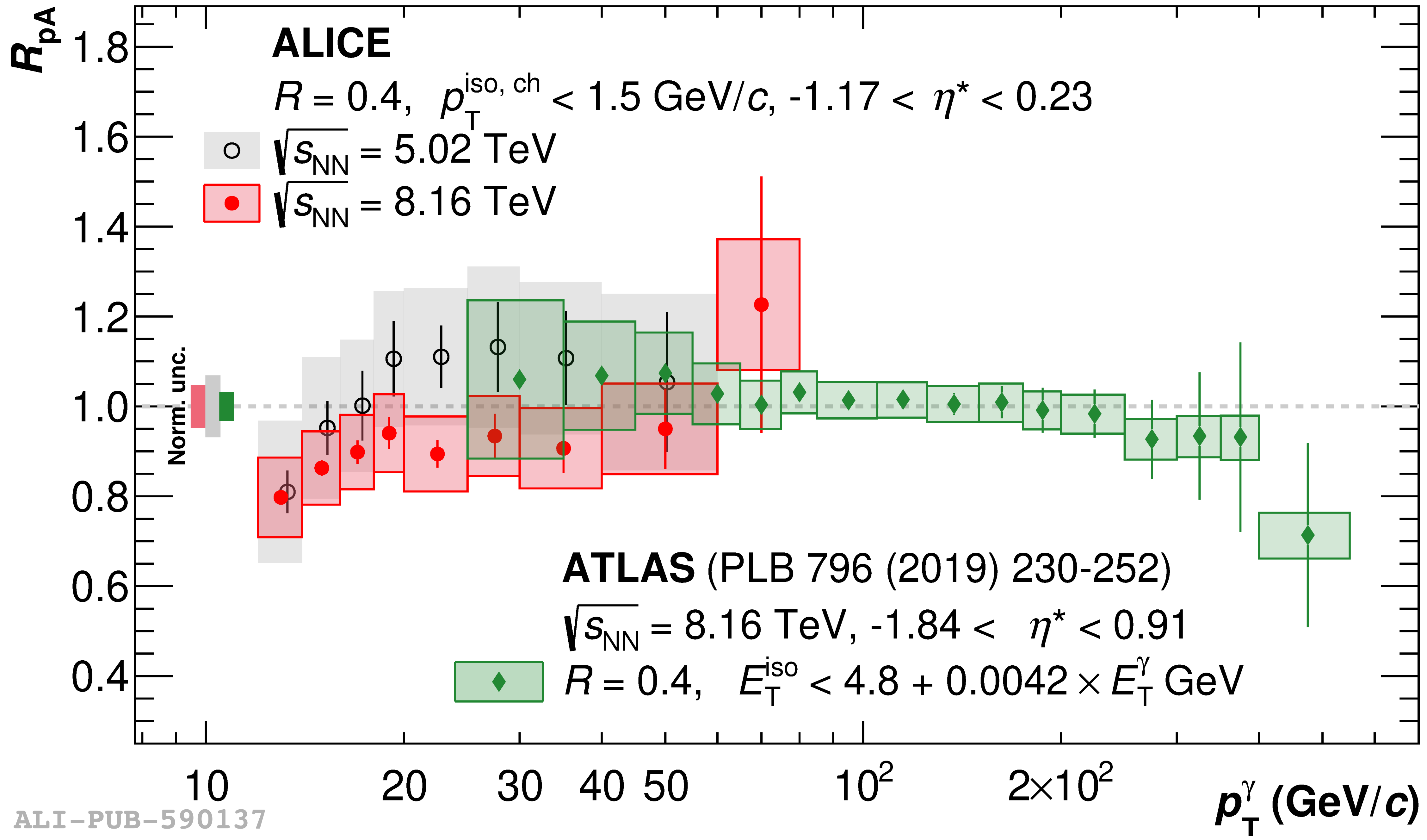
✱ $R_{AA} \simeq 1$, no $\boldsymbol{\gamma}$ production modification by QGP

– but for 50–90% & 70–90%: $R_{AA} \simeq 0.9$, agreement ($1\boldsymbol{\sigma}$) with HG-PYTHIA, model of the centrality selection bias

– Pb-Pb col. agree with nPDF prediction

✱ $R_{pA} \simeq 1$ but hints decrease below 20 GeV/c as expected by nPDF

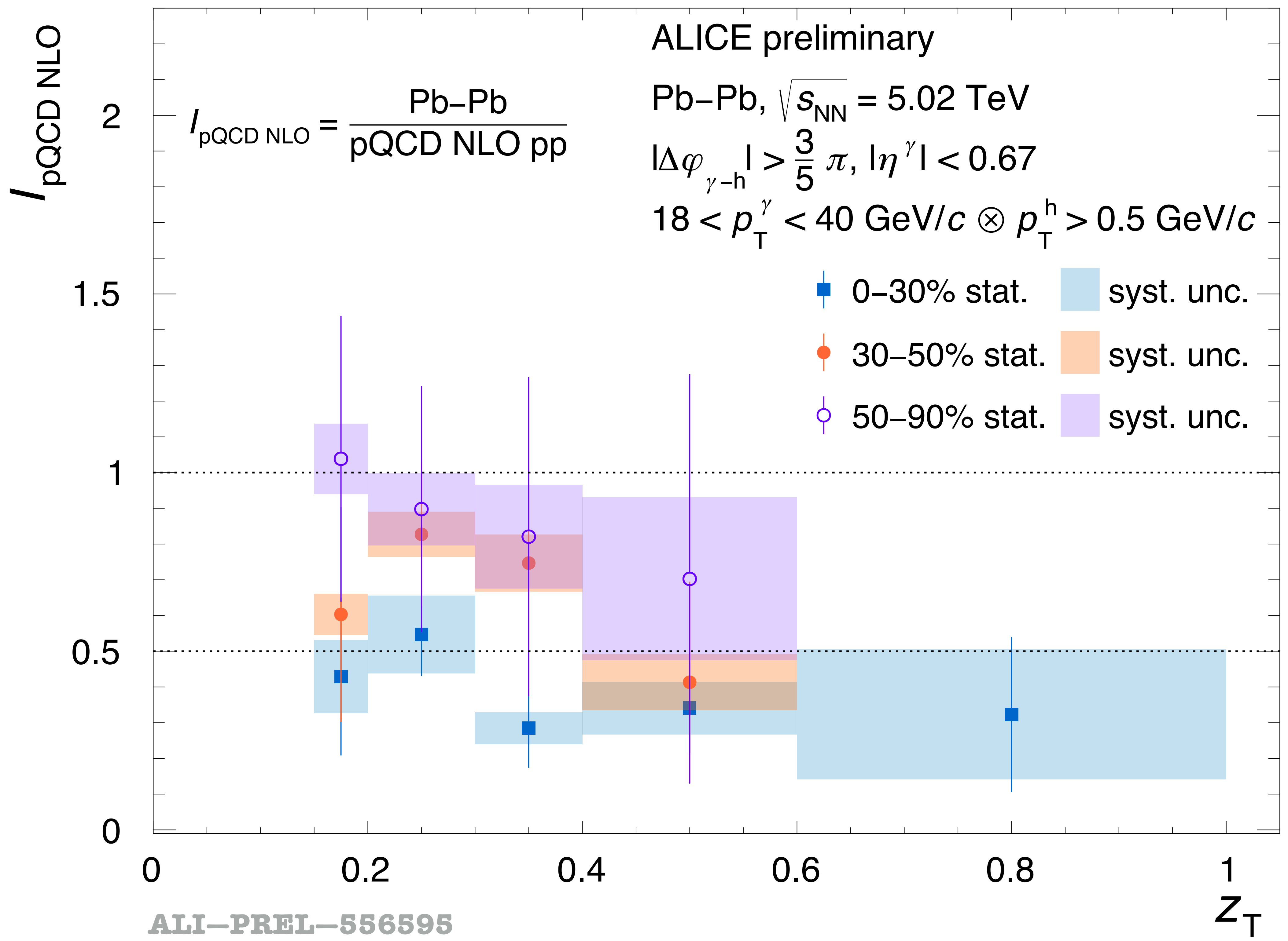




Summary

➡ **γ–hadron corr. in Pb–Pb at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV**

- **Very statistically limited, challenging!**
- z_{T} distribution significantly lower than pp NLO pQCD in central
  - FF modification: stronger for central compared to peripheral
- Results described by two models, model discrimination not possible yet



Expected improvement with Run 3 + Run 4 data samples, in particular γ-hadron correlations

Thank you for your attention and your invitation!

- Differential p_T cross section
  - pp & Pb–Pb at $\sqrt{s_{NN}}$ = 5.02 TeV Eur. Phys. J. C 85, 553 (2025), arXiv:2409.12641, ALICE-PUBLIC-2024-003
  - pp at $\sqrt{s}$ = 8 TeV & p–Pb at $\sqrt{s_{NN}}$ = 5.02 & 8.16 TeV arXiv:2502.18054, submitted to EPJC
  - pp at $\sqrt{s}$ = 13 TeV Eur. Phys. J. C 85 (2025) 98, arXiv:2407.01165
  - pp at $\sqrt{s}$ = 7 TeV Eur. Phys. J. C 79 (2019) 896, arXiv:1906.01371
- Isolated γ-hadron correlation
  - Pb–Pb at $\sqrt{s_{NN}}$ = 5.02 TeV, preliminary

BACK-UP

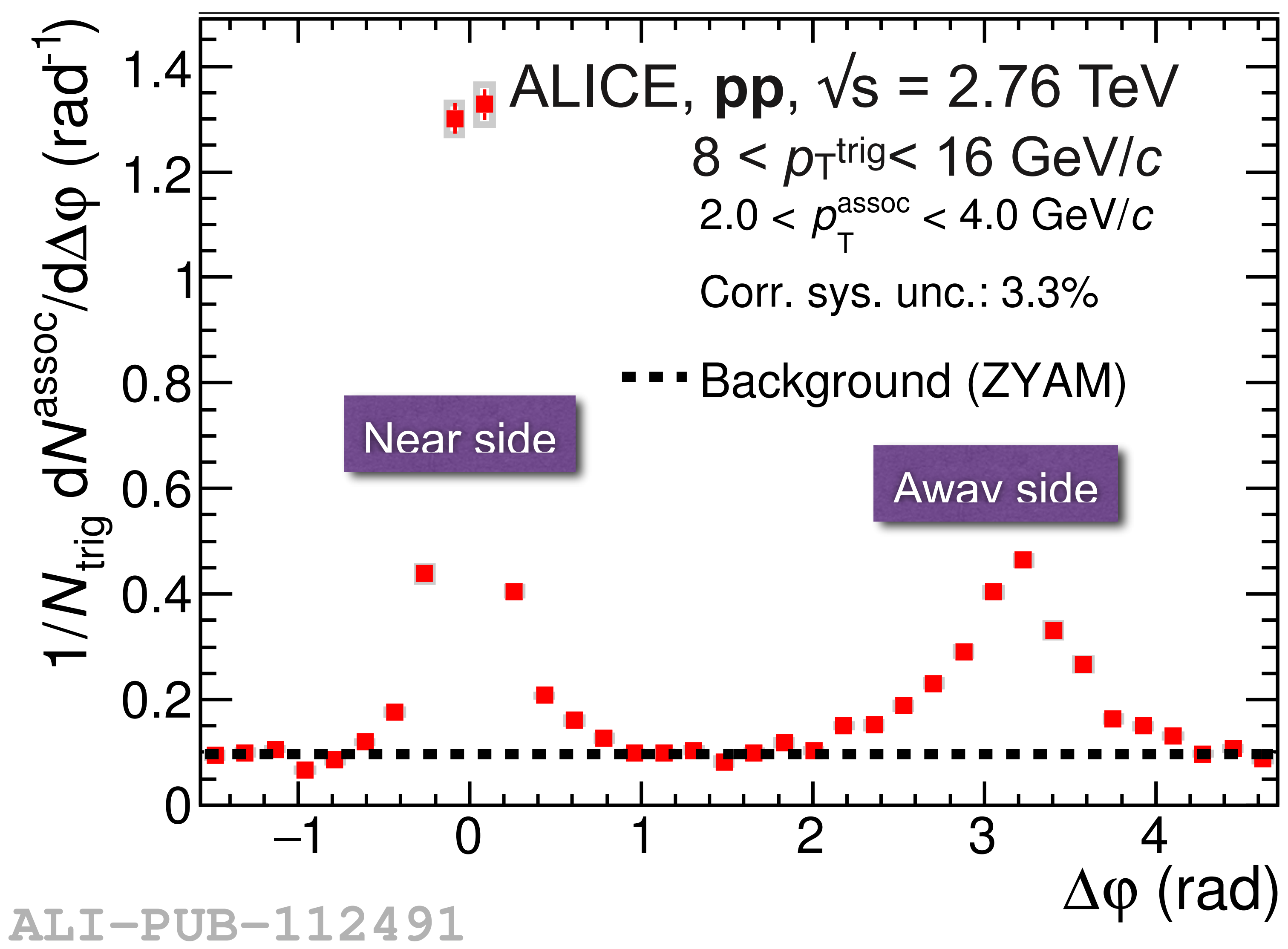
PI0-HADRON CORRELATION

Y: Yield of particles in region (jet) near trigger particle or opposite

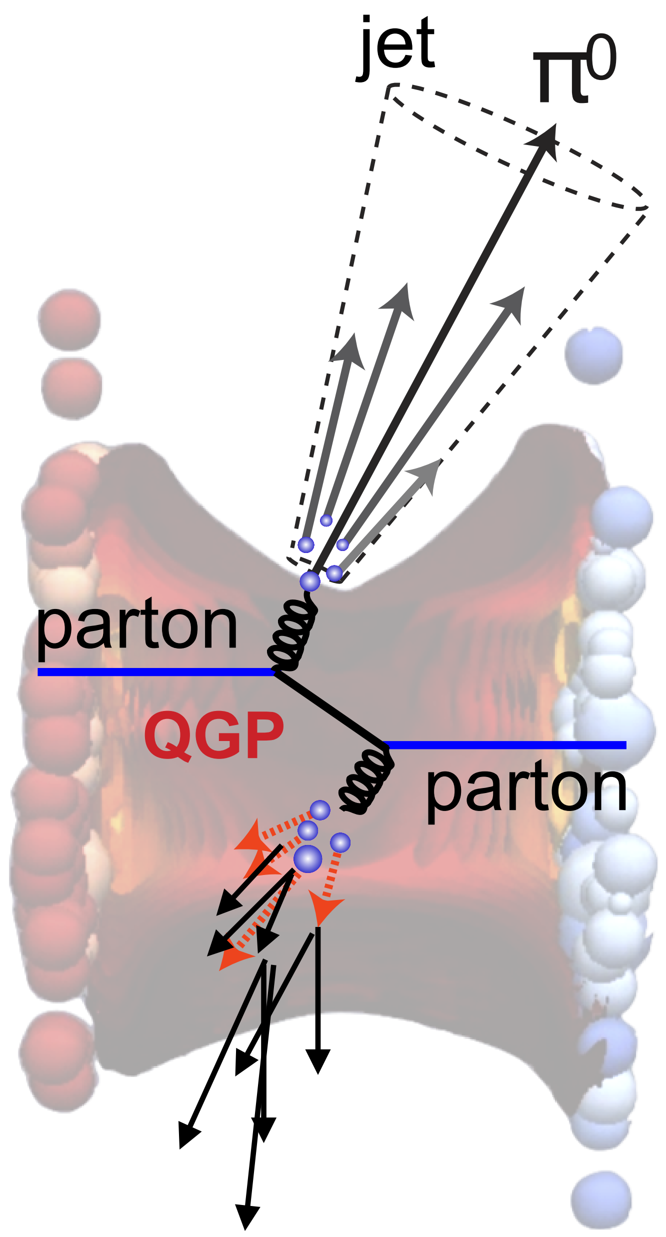
$I_{AA} = Y(AA) \,/\, Y(pp)$

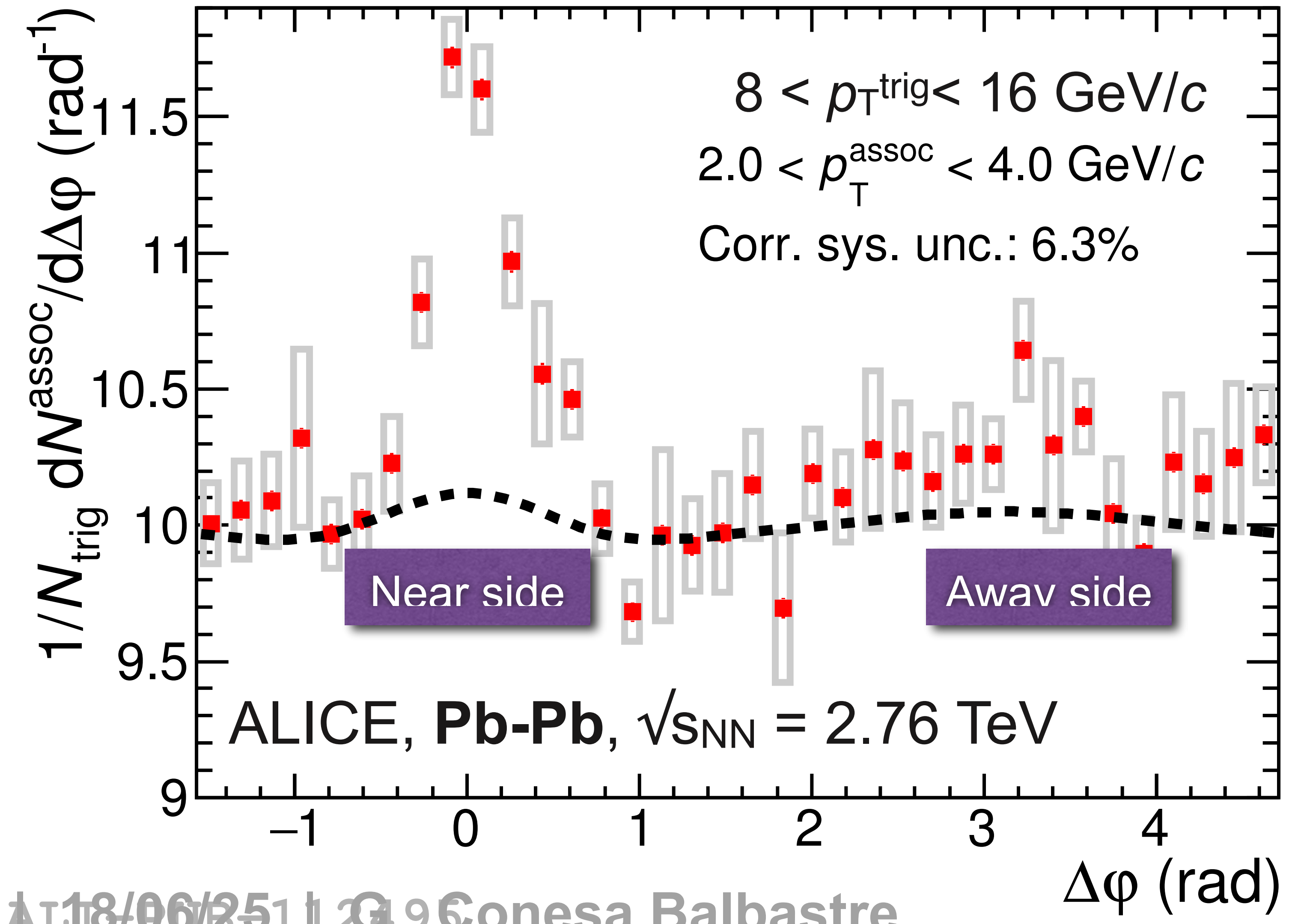
Where is the lost jets energy? With high-p_T hadron (π^0) trigger - associated hadron correlations

- At high p_T^{assoc}, hadrons moderate Enhancement for Near side and large Suppression for Away side trigger
- At low p_T^{assoc}, both for Near and Away side~2-5 Enhancement!



ALICE, PLB 763 (2016) 238-250



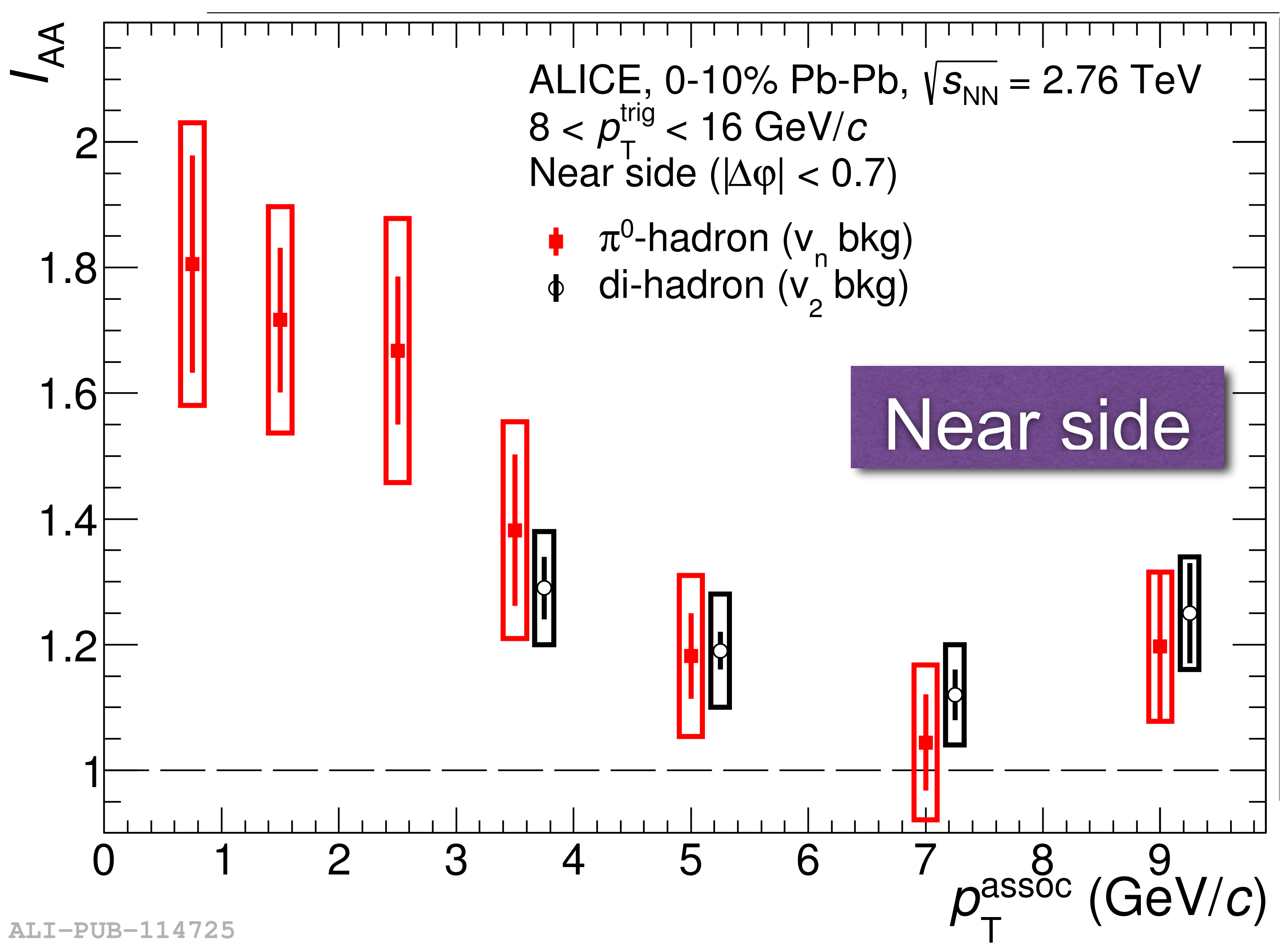


Hard partons can lose most of their energy (jet and away side suppression) in the medium which can go to very low p_T particles over all the event (away side and near side enhancements)

PI0-HADRON CORRELATION

Y: Yield of particles in region (jet) near trigger particle or opposite

$I_{AA} = Y(AA) / Y(pp)$



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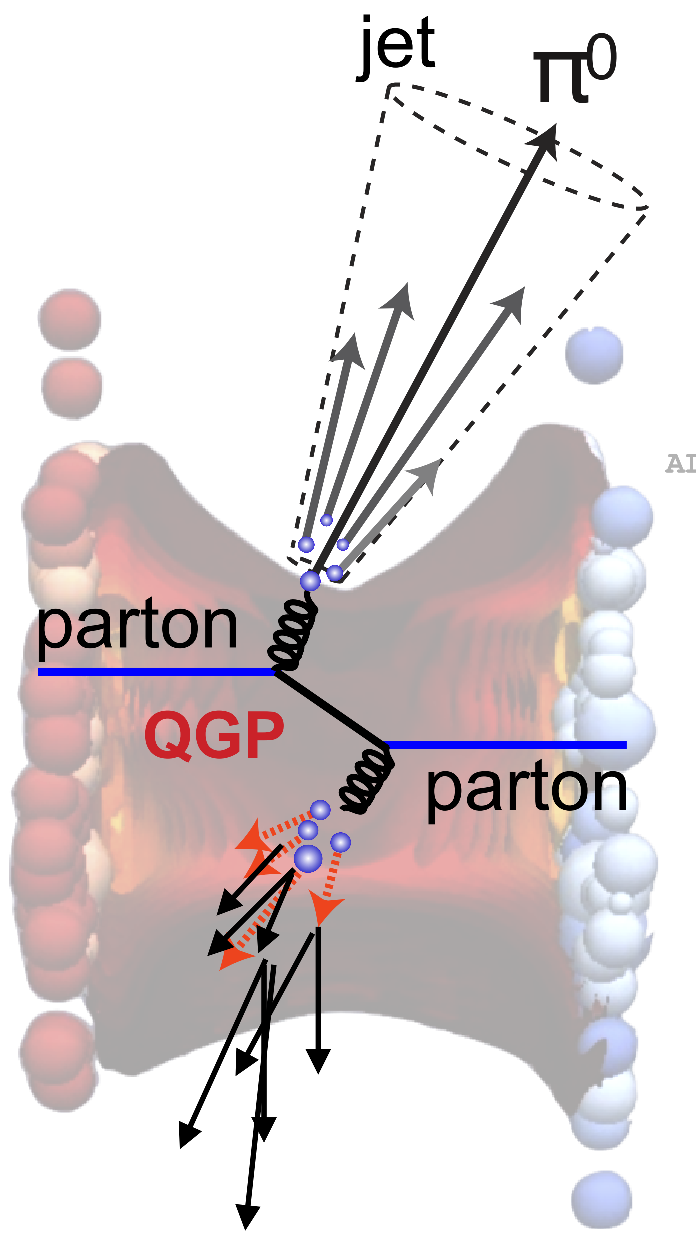
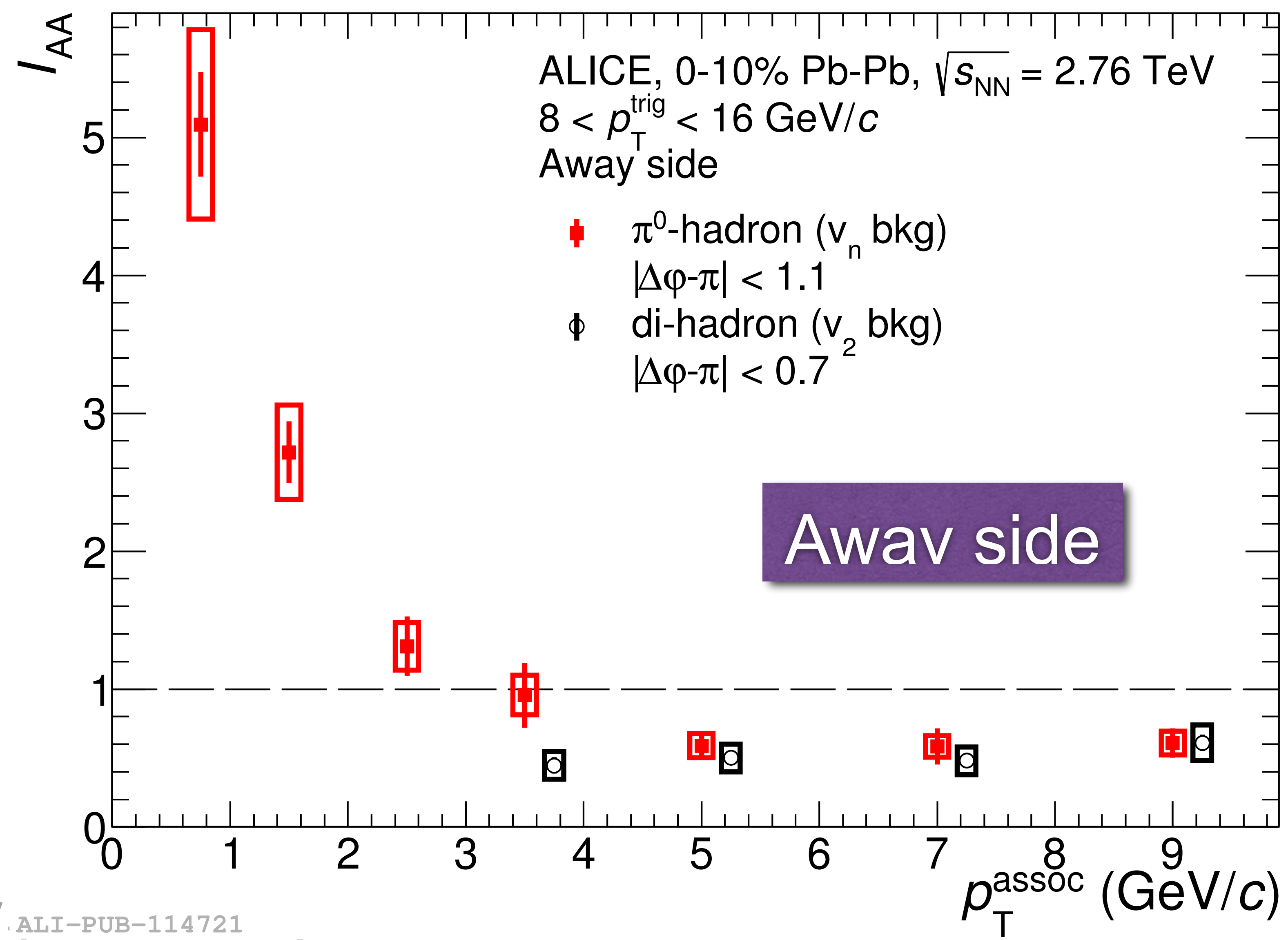
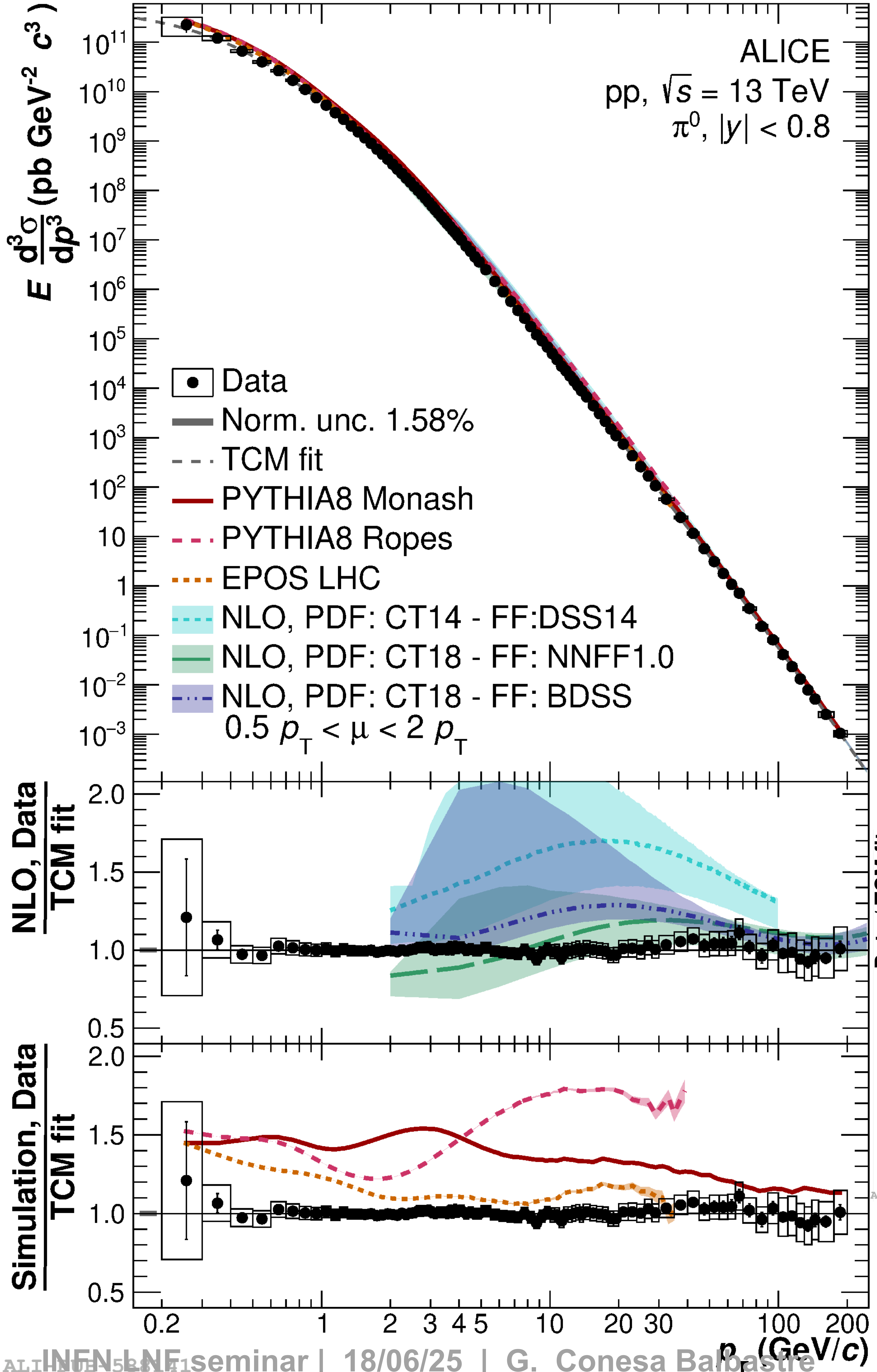


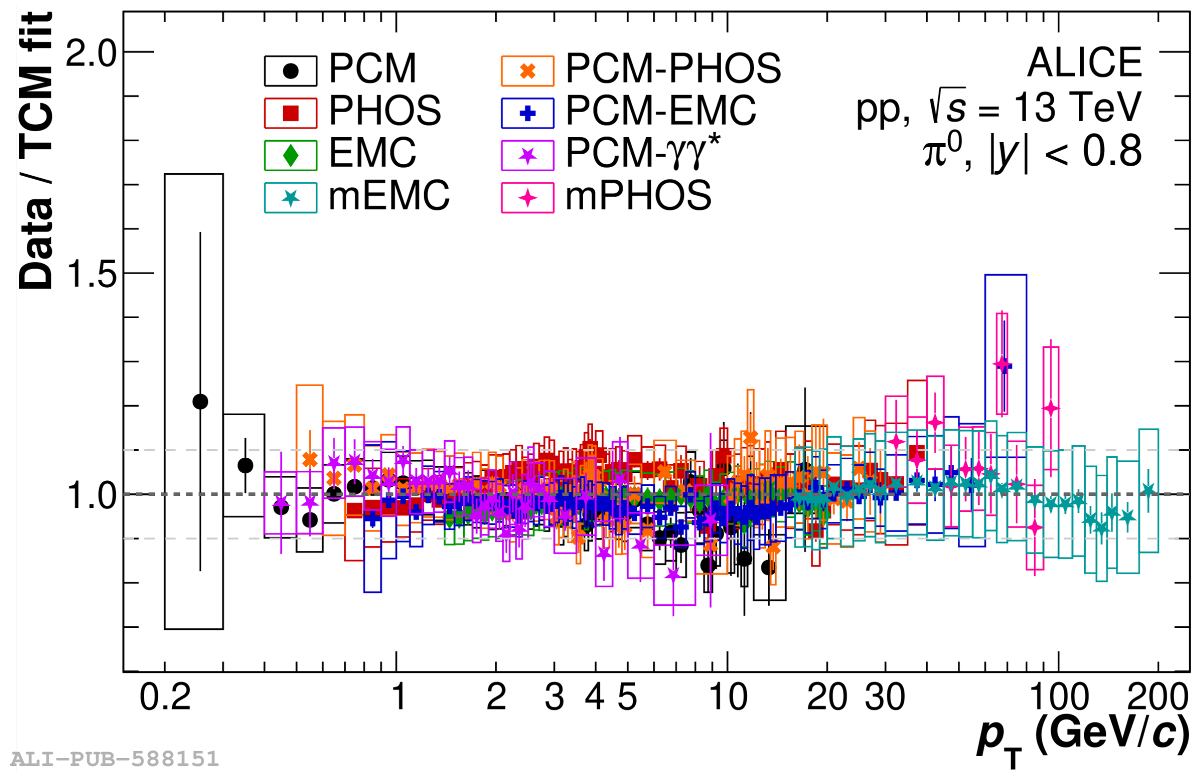
ALICE, PLB 763 (2016) 238-250

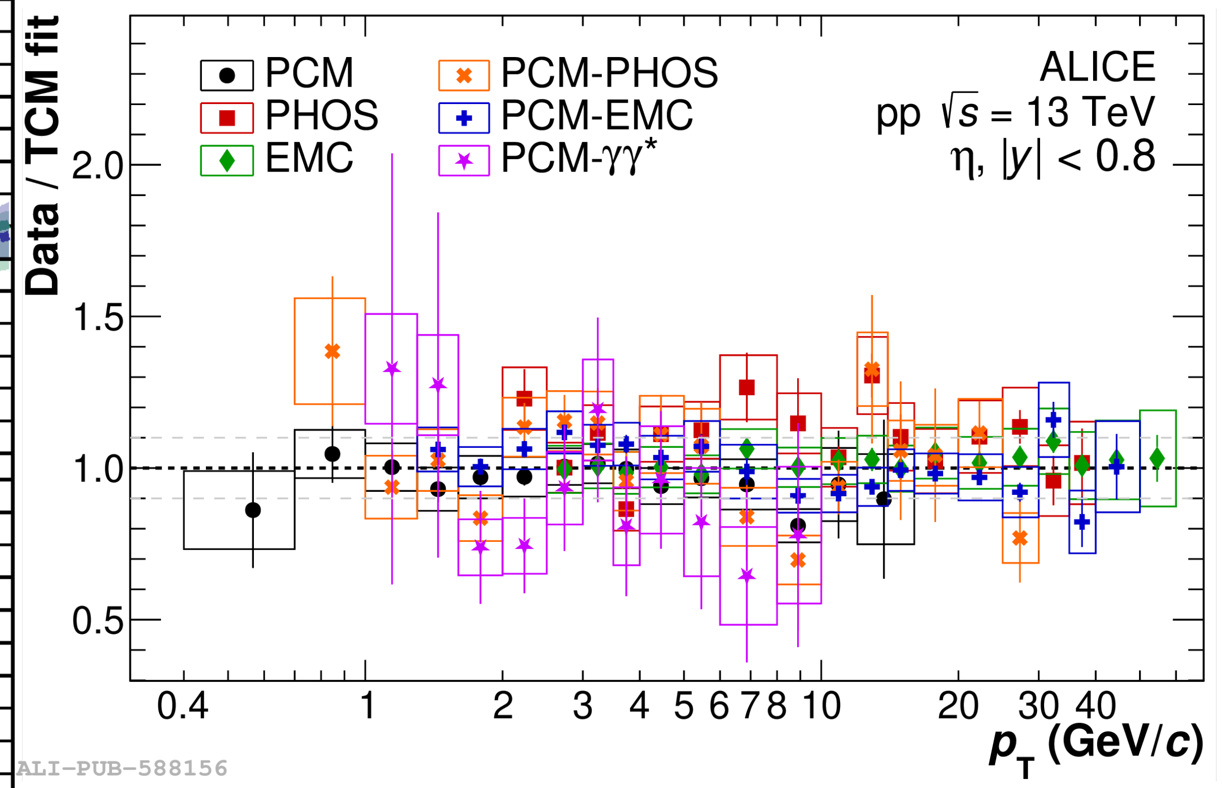


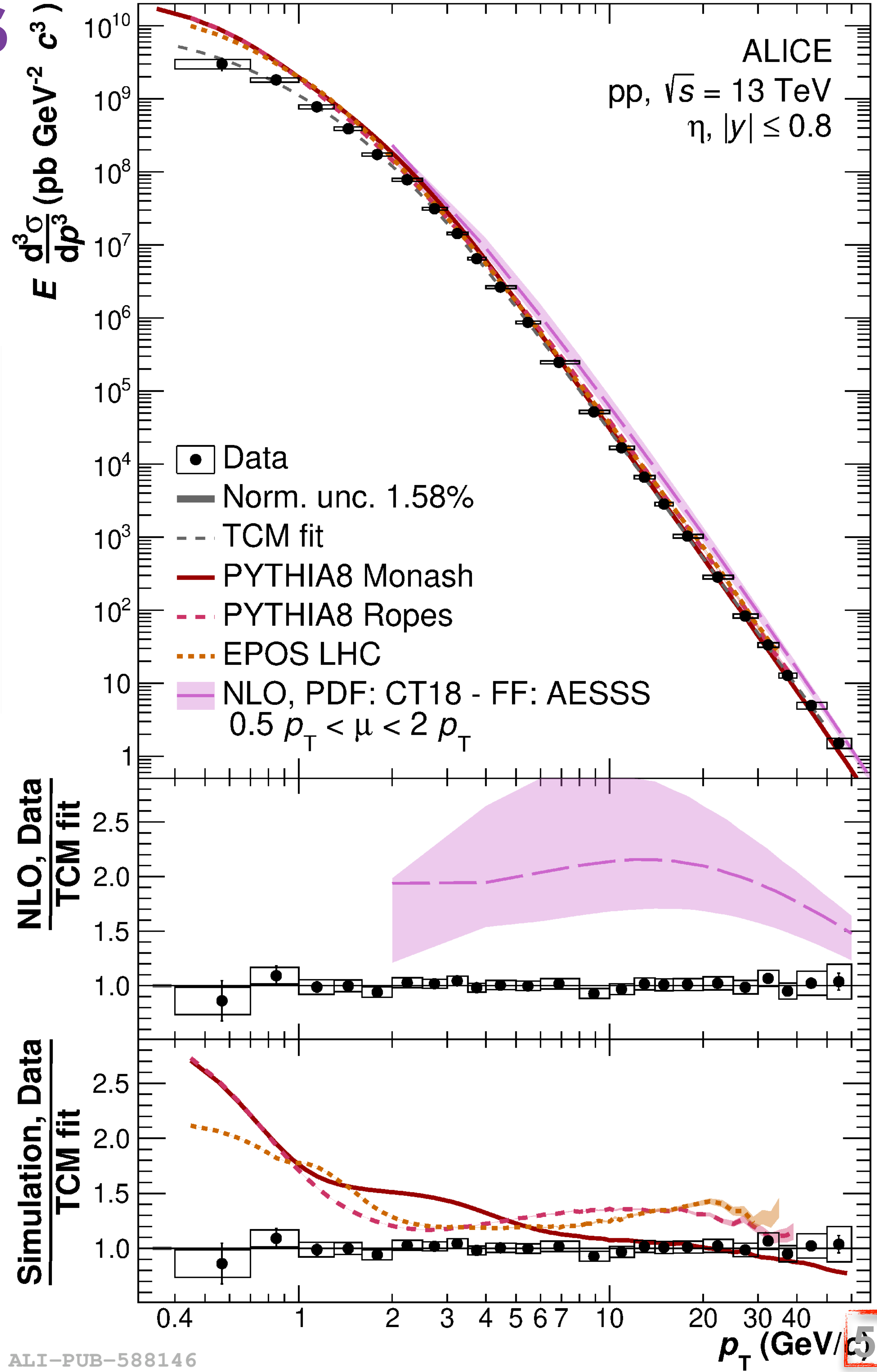
Hard partons can lose most of their energy (jet and away side suppression) in the medium which can go to very low p_T particles over all the event (away side and near side enhancements)

NEUTRAL MESONS SPECTRA IN PP

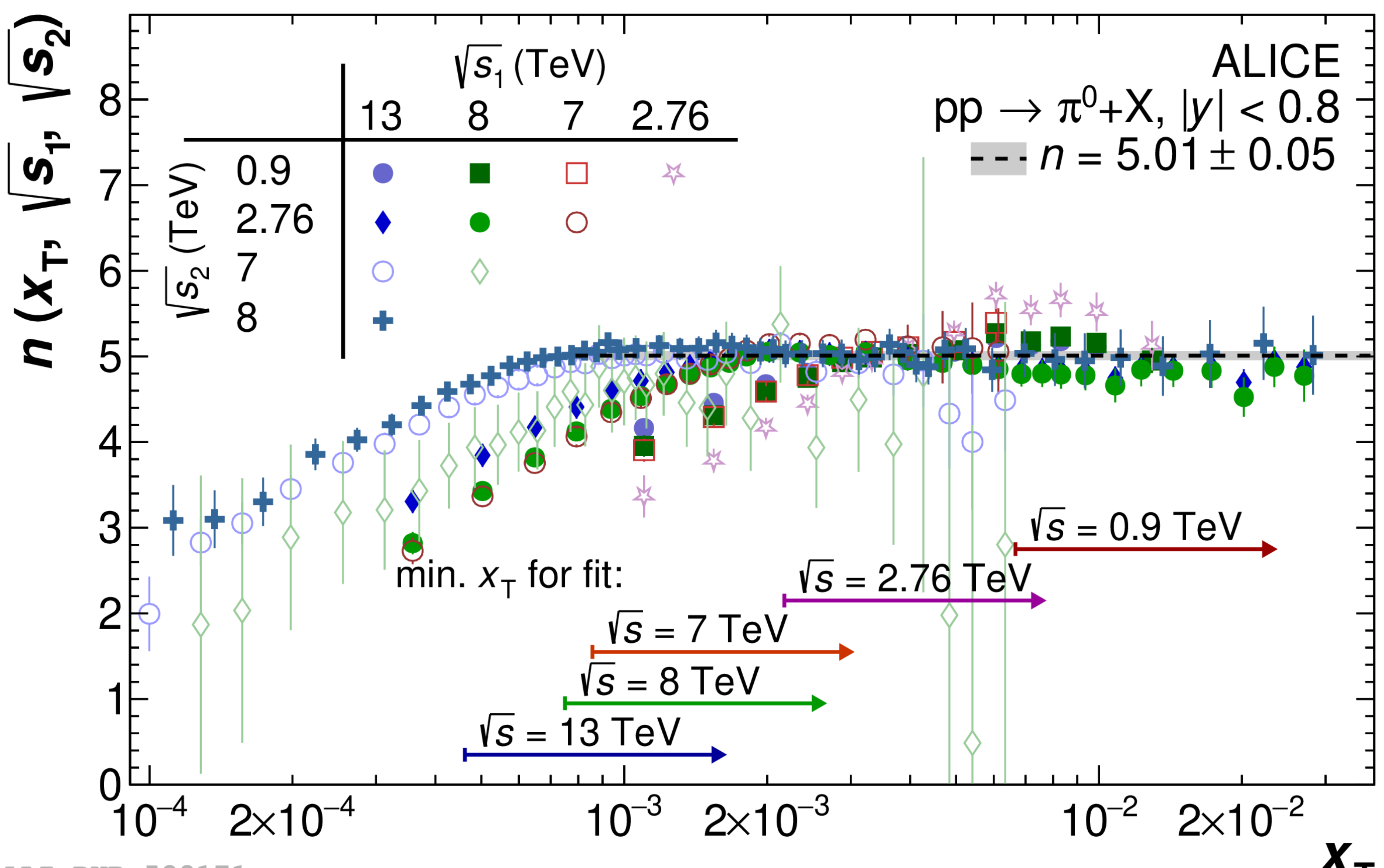




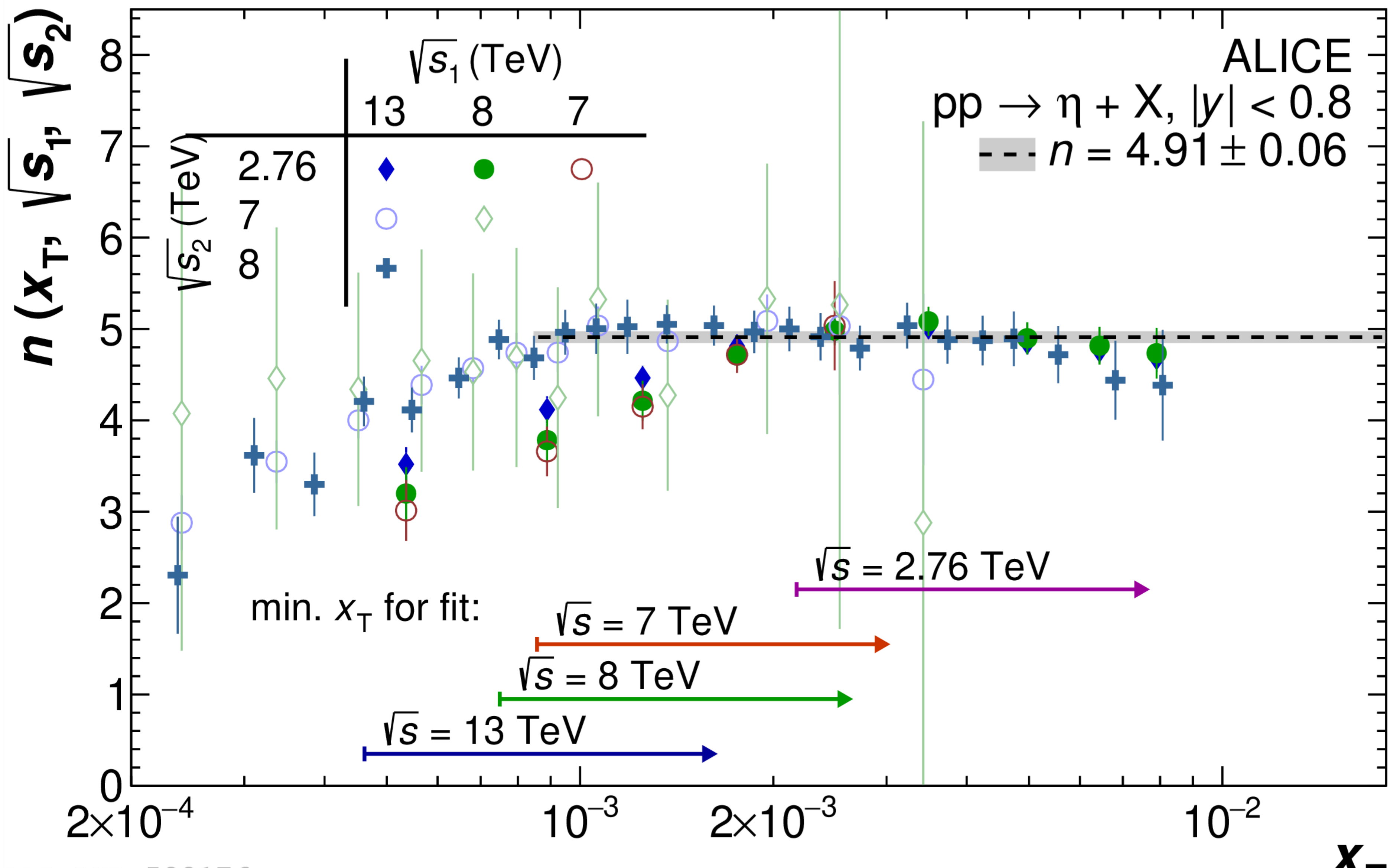




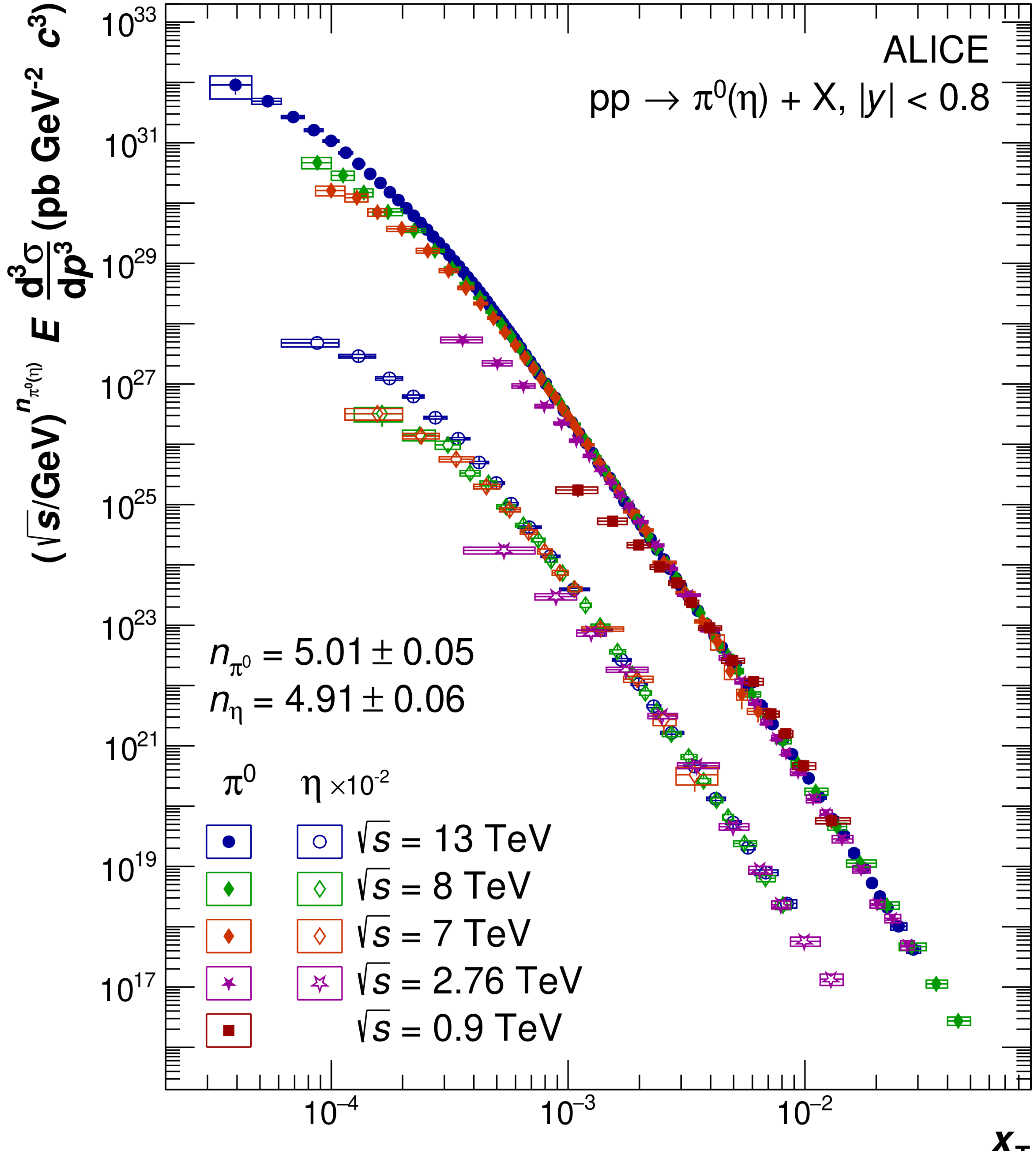
NEUTRAL MESONS SPECTRA IN PP



ALI-PUB-588171



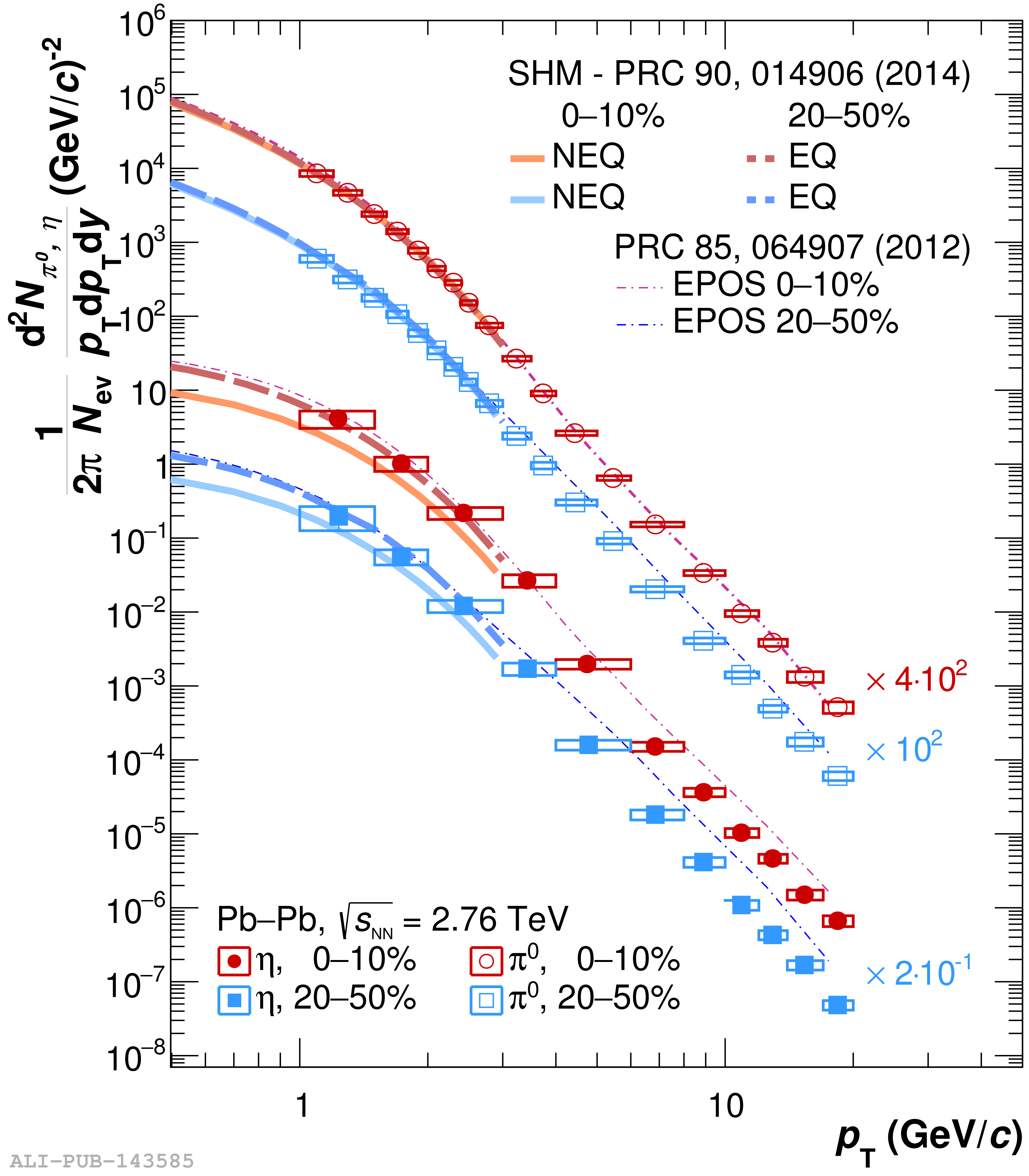
ALI-PUB-588176

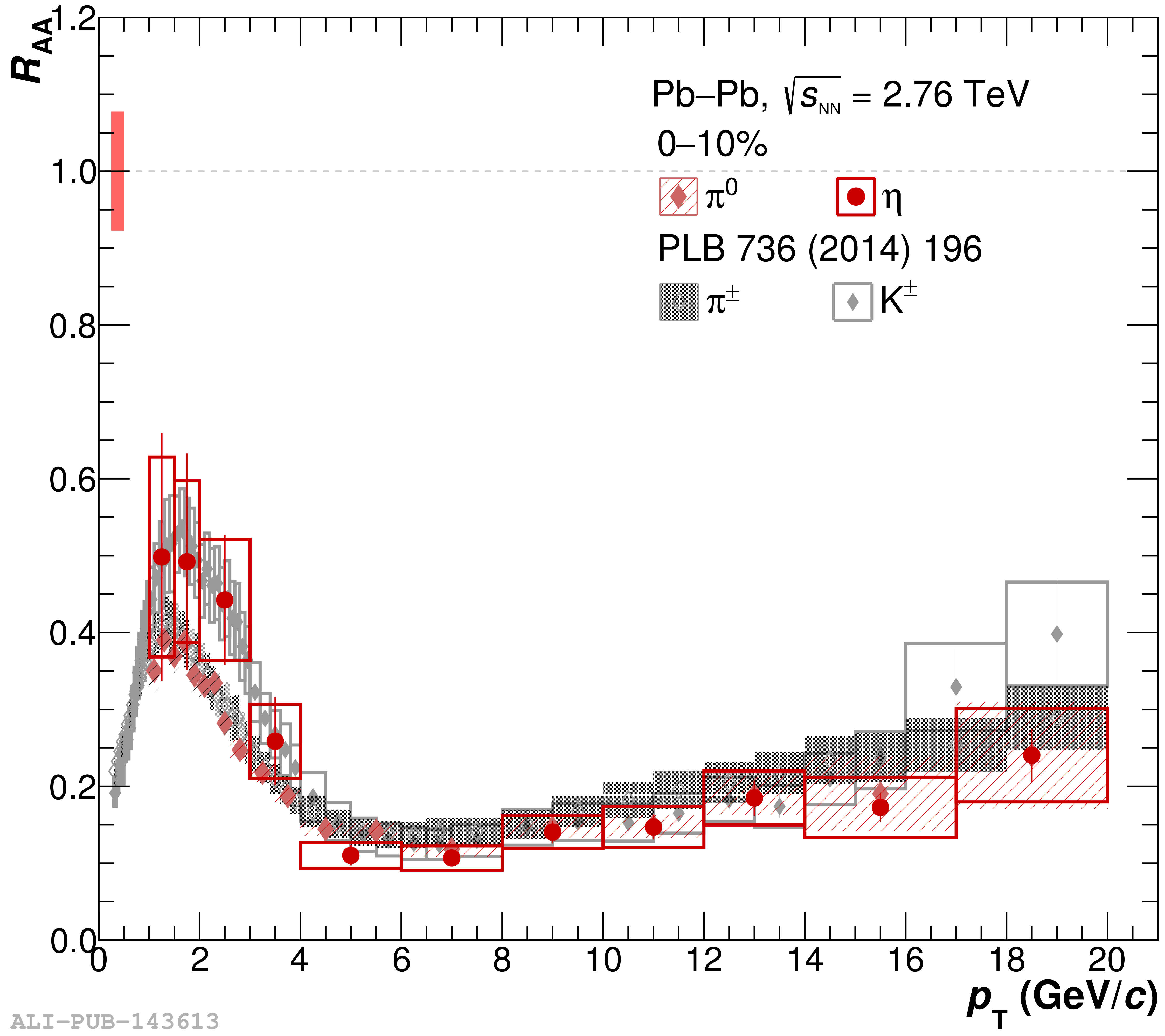


ALI-PUB-588181

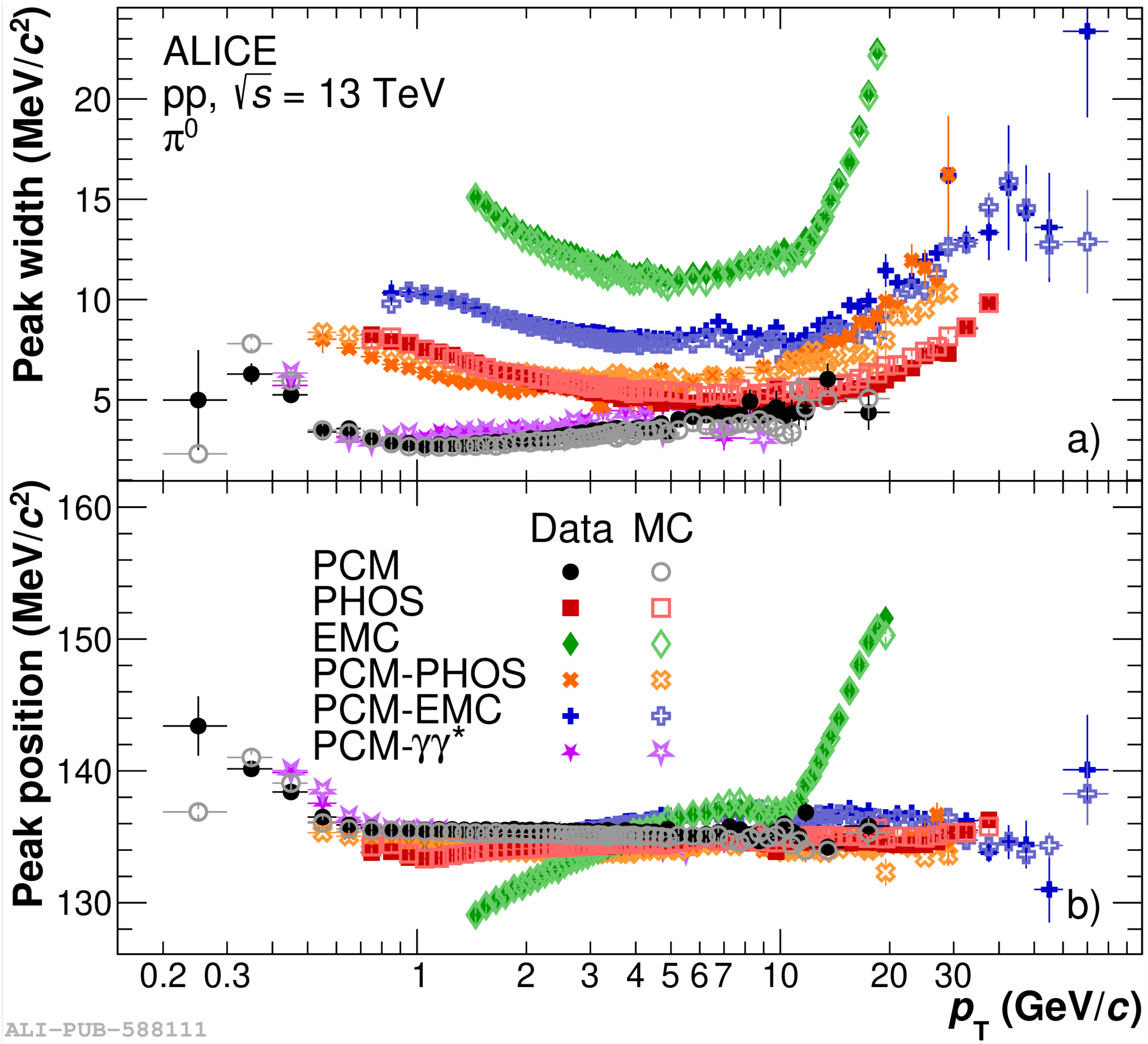
NEUTRAL MESONS IN PB-PB

Pb-Pb, $\sqrt{s_{NN}}$ = 2.76 TeV,
0-10%, 20-50%, η & π⁰





NEUTRAL MESONS SPECTRA IN PP



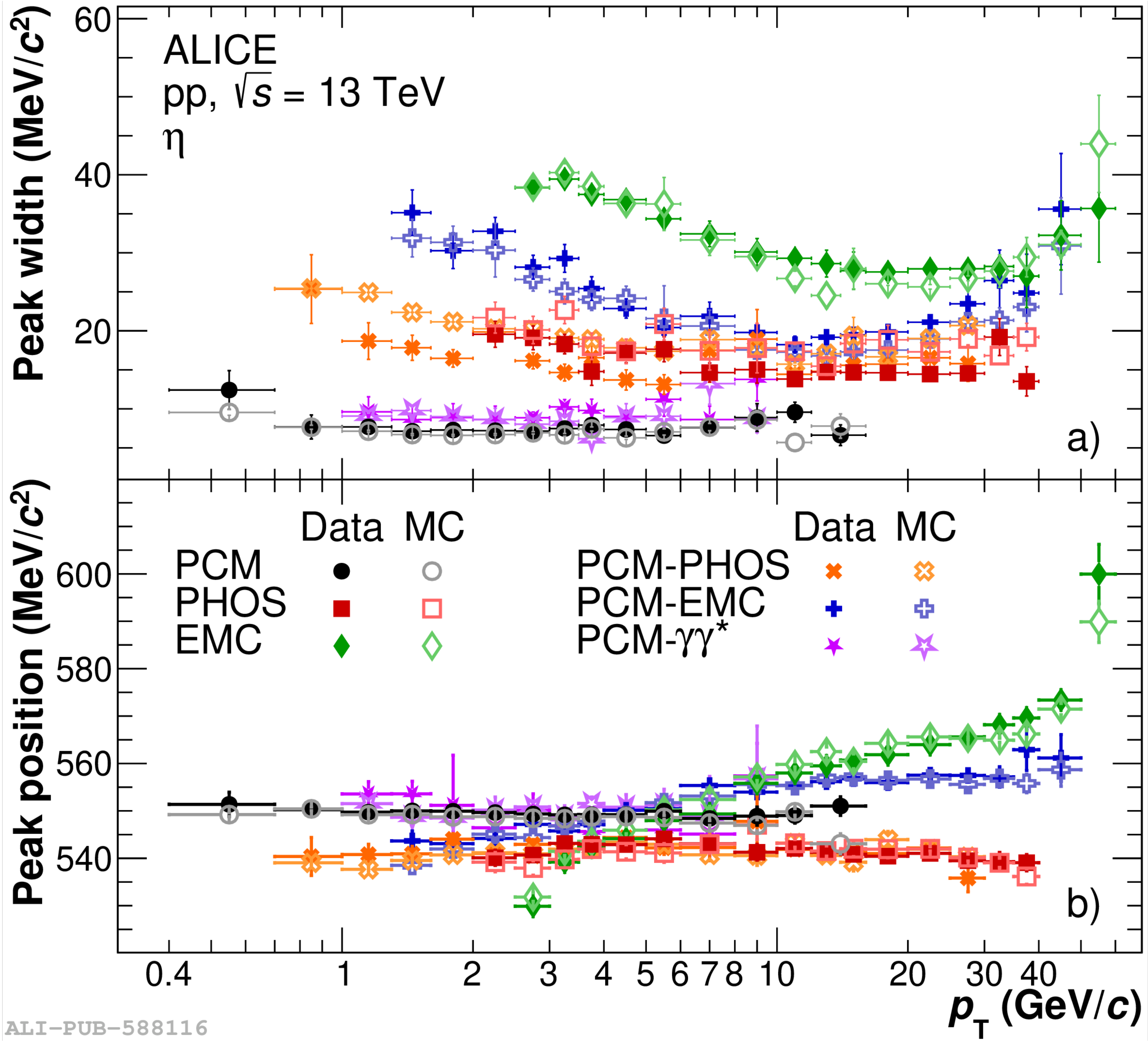


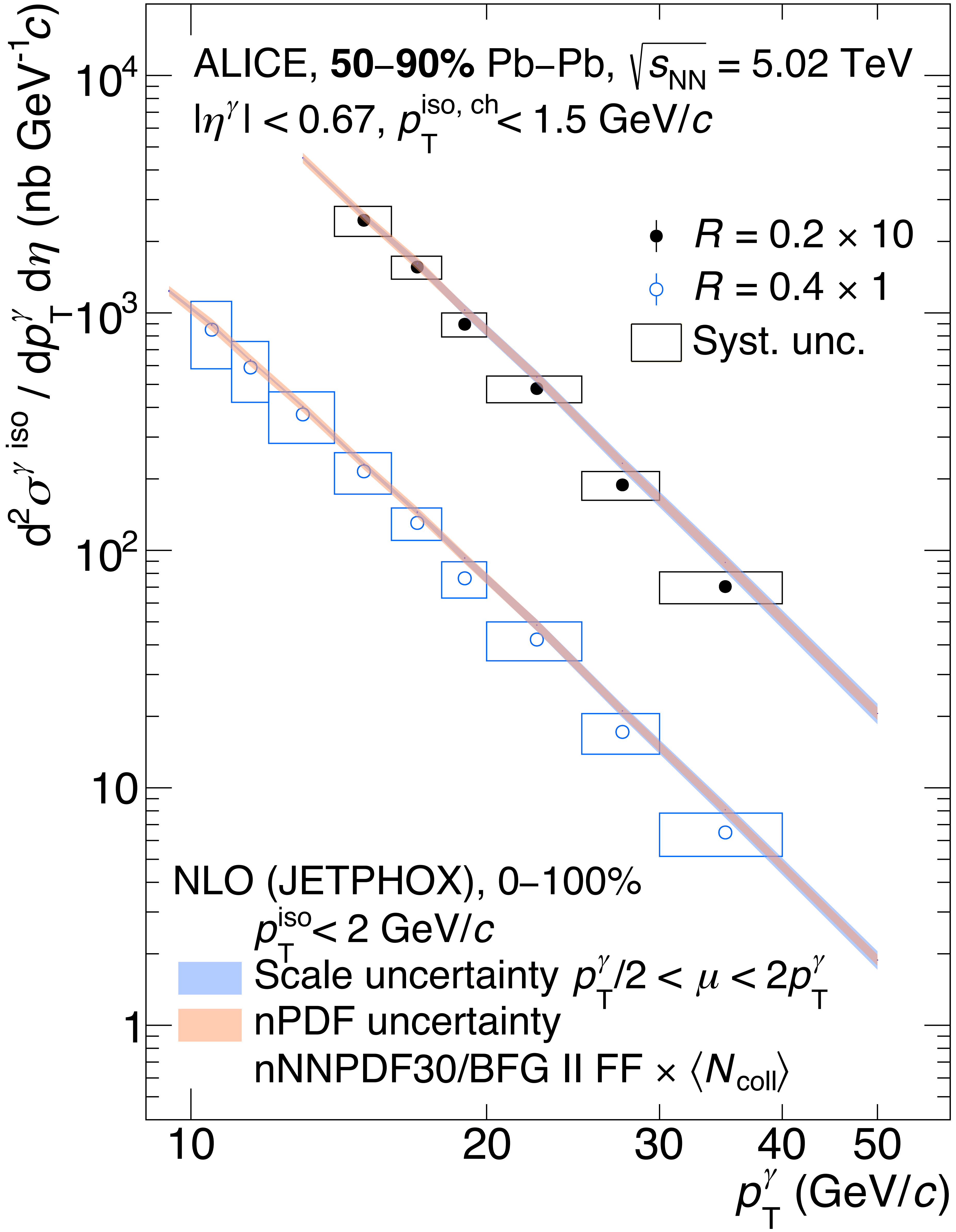
Table 1: Cluster reconstruction and selection criteria. Description and discussion can be found in Ref. [80].

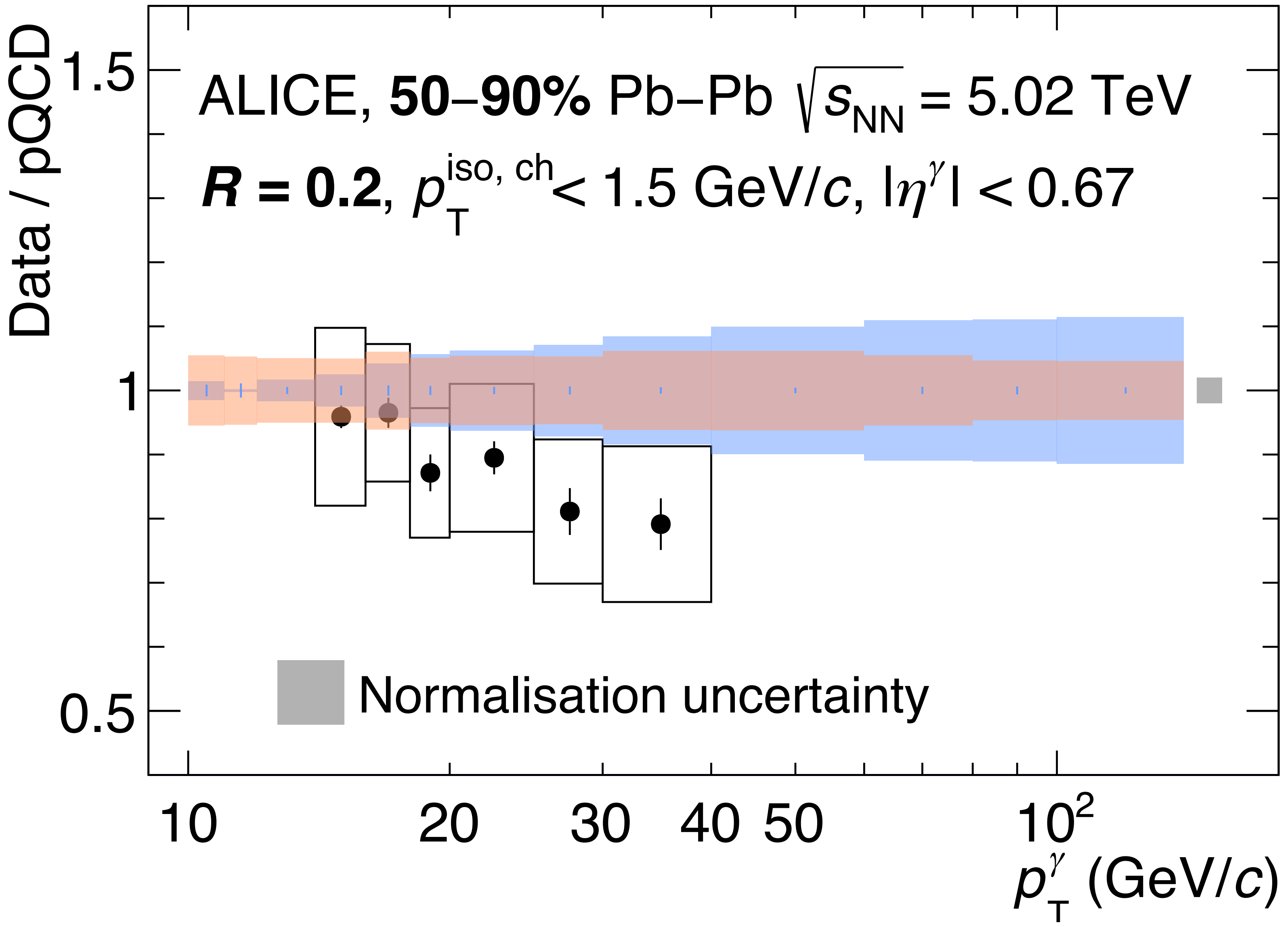
Cluster seed threshold	$E_{\mathrm{seed}} > 500$ MeV
Cluster aggregation threshold	$E_{\mathrm{agg}} > 100$ MeV
Number of cells	$N_{\mathrm{cell}} > 1$
N cells from highest E cell to SM border	$N_{\mathrm{border}} > 1$
Cluster time - bunch crossing time	$\lvert\Delta t_{\mathrm{cluster}}\rvert < 20$ ns
Abnormal signal removal	$F_{+} = 1 - \frac{\sum_{\mathrm{cell}} E_{\mathrm{adjacent\ to\ highest\ }E}}{E_{\mathrm{highest\ }E\ \mathrm{cell}}} < 0.95$
Charged particle veto (Pb–Pb only):	
when	$E_{\mathrm{cluster}}/p^{\mathrm{track}} < 1/7$
track–cluster η residual	$\Delta\eta^{\mathrm{residual}} > 0.010 + (p_{\mathrm{T}}^{\mathrm{track}} + 4.07)^{-2.5}$
track–cluster φ residual	$\Delta\varphi^{\mathrm{residual}} > 0.015 + (p_{\mathrm{T}}^{\mathrm{track}} + 3.65)^{-2}$ rad
Acceptance:	
Top section	$81.2^\circ < \varphi < 185.8^\circ$ $\lvert\eta\rvert < 0.67$
Bottom section	$261.2^\circ < \varphi < 318.8^\circ$ $0.25 < \lvert\eta\rvert < 0.67$

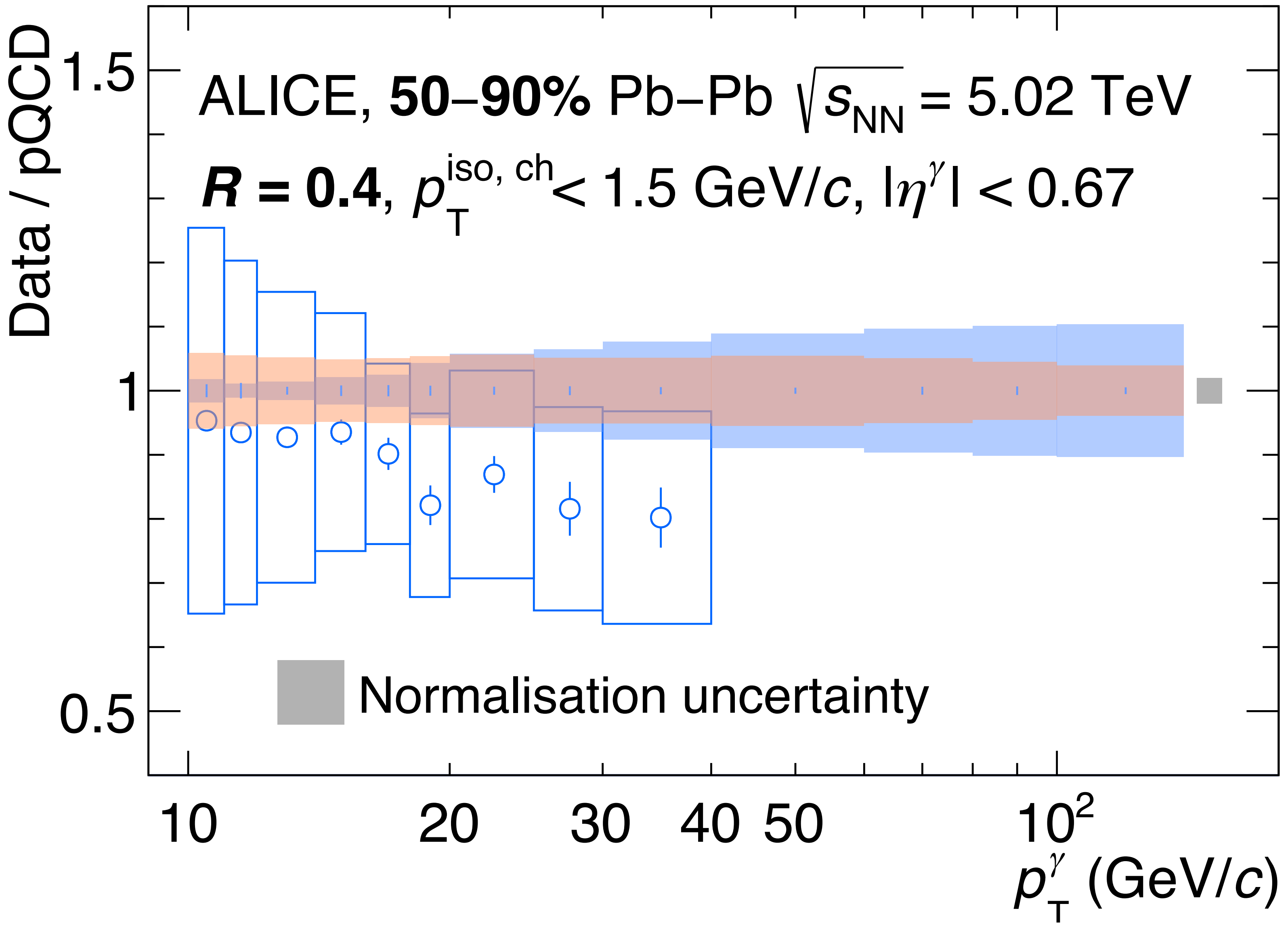
Table 2: Trigger $RF^{\mathrm{trig}}_{\varepsilon_{\mathrm{trig}}}$ (Eq. (8)) fits to a constant in Fig. 9-right, $\mathscr{L}^{\mathrm{trig}}_{\mathrm{NN}}$, and $\mathscr{L}^{\mathrm{trig}}_{\mathrm{int}}$ (Eq. (9)), for pp and Pb–Pb collisions per centrality class and per trigger inclusive cluster p_{T} range. The $\mathscr{L}^{\mathrm{trig}}_{\mathrm{NN}}$ uncertainty contains both the $\sigma^{\mathrm{col.\ system}}_{\mathrm{NN}}$ and rejection factor uncertainties. The integrated luminosity uncertainty includes in addition the $\langle N_{\mathrm{coll}}\rangle$ uncertainty.

Trigger	System	p_{T} (GeV/c)	$RF^{\mathrm{trig}}_{\varepsilon_{\mathrm{trig}}}$	$\mathscr{L}^{\mathrm{trig}}_{\mathrm{NN}}$ (nb^{-1})	$\mathscr{L}^{\mathrm{trig}}_{\mathrm{int}}$ (nb^{-1})
L1-γ	pp	$p_{\mathrm{T}} > 11$	997 ± 10	265 ± 7	265 ± 7
	Pb–Pb:				
MB	0–10%	$p_{\mathrm{T}} < 12$		1.189 ± 0.011	1869 ± 26
MB	10–30%	$p_{\mathrm{T}} < 12$		0.522 ± 0.005	409 ± 5
MB	30–50%	$p_{\mathrm{T}} < 12$		1.163 ± 0.010	308 ± 5
MB+L1-γ-high	0–10%	$p_{\mathrm{T}} > 12$	45.0 ± 0.2	2.50 ± 0.02	3936 ± 55
MB+L1-γ-high	10–30%	$p_{\mathrm{T}} > 12$	79.2 ± 0.4	4.90 ± 0.05	3834 ± 51
MB+L1-γ-high	30–50%	$p_{\mathrm{T}} > 12$	179.3 ± 1.5	5.01 ± 0.05	1325 ± 21
MB+L1-γ-low	50–70%	$p_{\mathrm{T}} < 12$	72.2 ± 1.2	3.5 ± 0.5	230 ± 5
MB+L1-γ-low	70–90%	$p_{\mathrm{T}} < 12$	315 ± 13	3.62 ± 0.11	39.5 ± 1.3
MB+L1-γ-high+low	50–70%	$p_{\mathrm{T}} > 12$	98.2 ± 1.2	4.88 ± 0.07	322 ± 7
MB+L1-γ-high+low	70–90%	$p_{\mathrm{T}} > 12$	410 ± 20	5.1 ± 0.2	55 ± 2

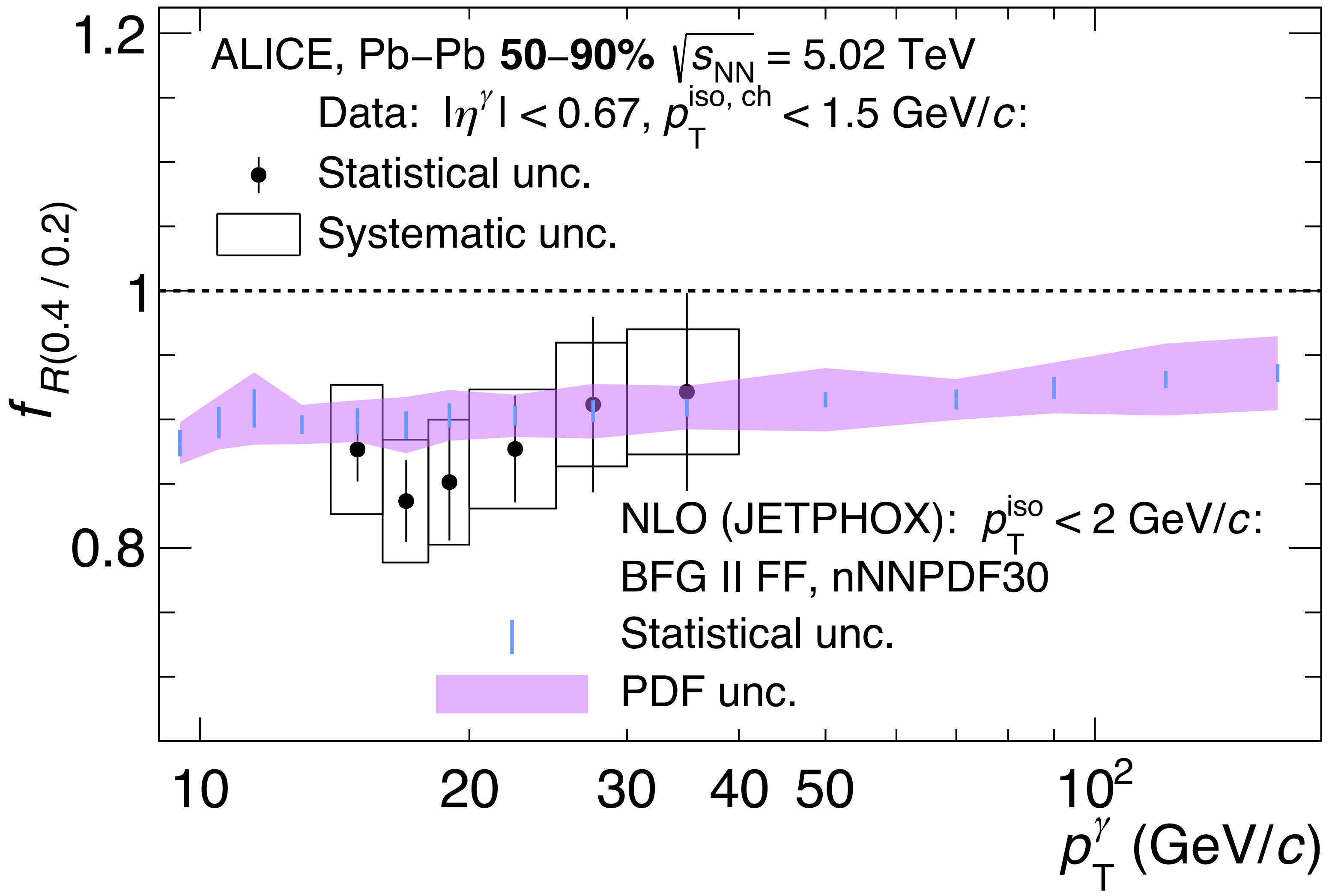
Pb–Pb 50-90%: cross section and ratios







ALICE-PUBLIC-2024-003

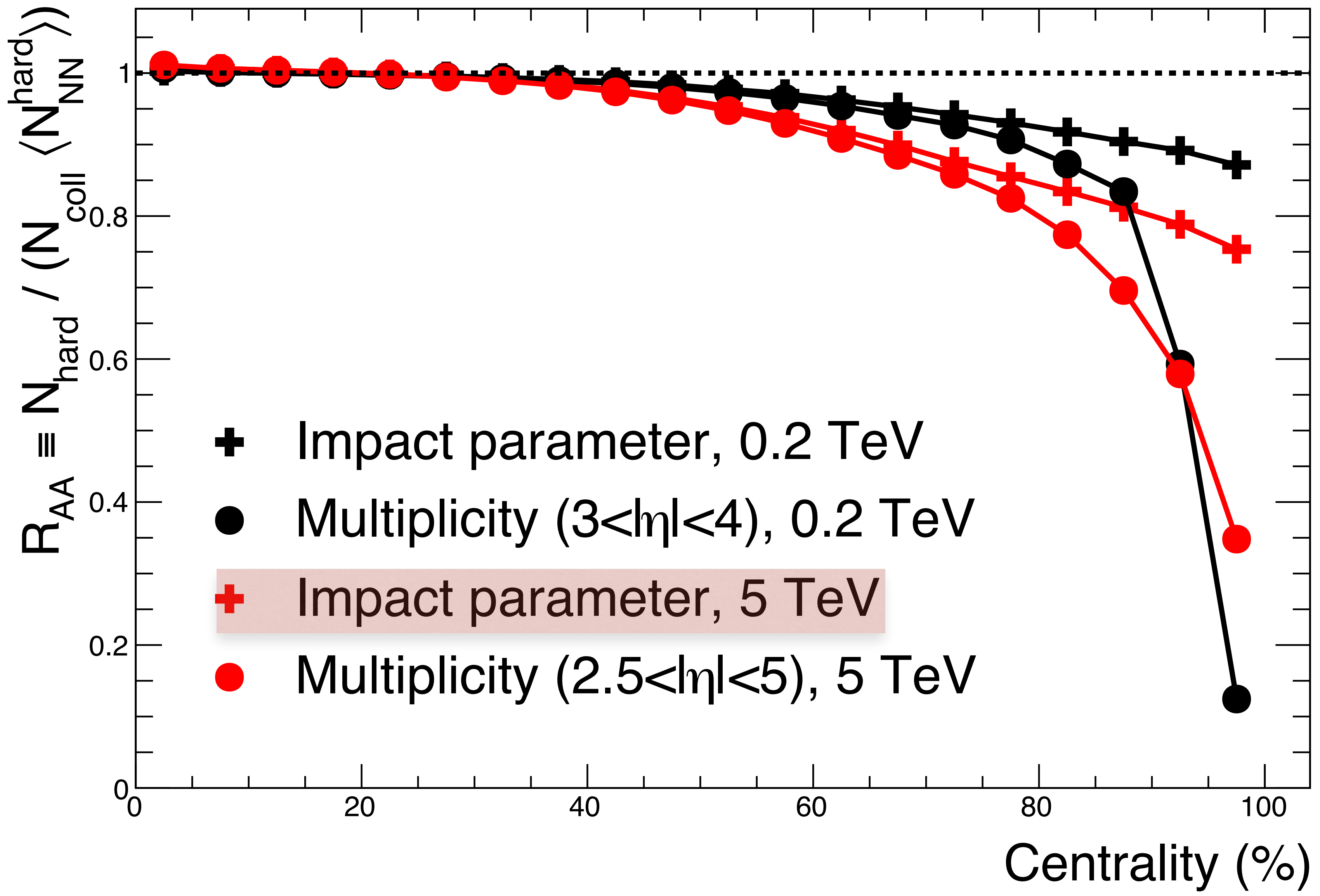


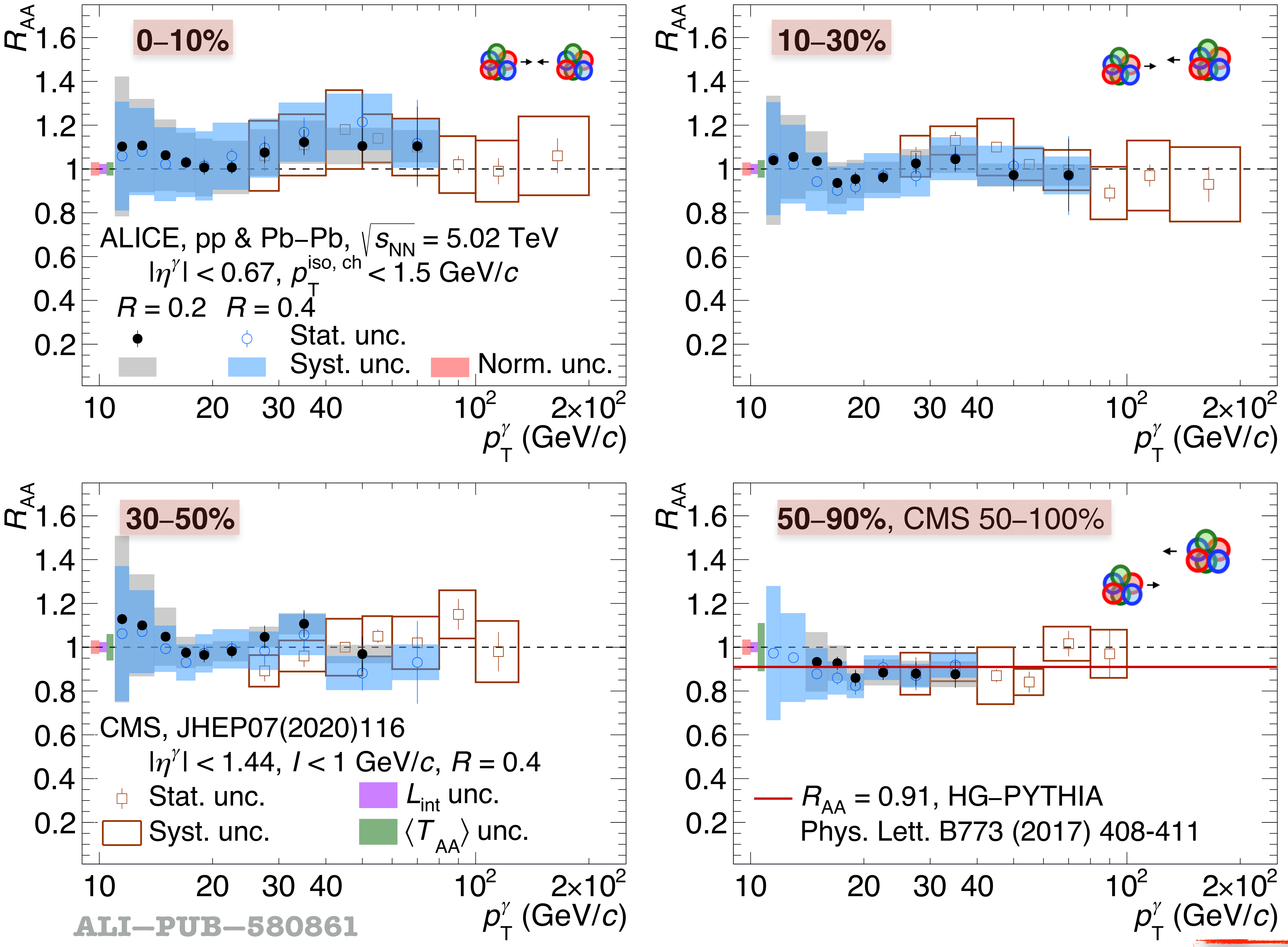
Nuclear modification factor R_{AA}, pp & Pb–Pb at $\sqrt{s_{NN}}$ = 5.02 TeV

$$R_{AA} = \frac{1}{\langle N_{coll} \rangle} \frac{d^2\sigma_{AA} / (dp_T\, d\eta)}{d^2\sigma_{pp} / (dp_T\, d\eta)}$$

- **ALICE** & **CMS**: good agreement in the overlapping region 25 < p_T < 40–80 GeV/c

- 50-90%
  - ➡ Closer to 0.9 than 1 for both *R* likely due to centrality selection bias of Glauber model
  - ➡ Model by C. Loizides & A. Morsch (Phys. Lett. B773 (2017) 408-411) yields a value at 0.91
    - ✤ In agreement within the uncertainties





Nuclear modification factor
pp data denominator replaced by pp NLO pQCD

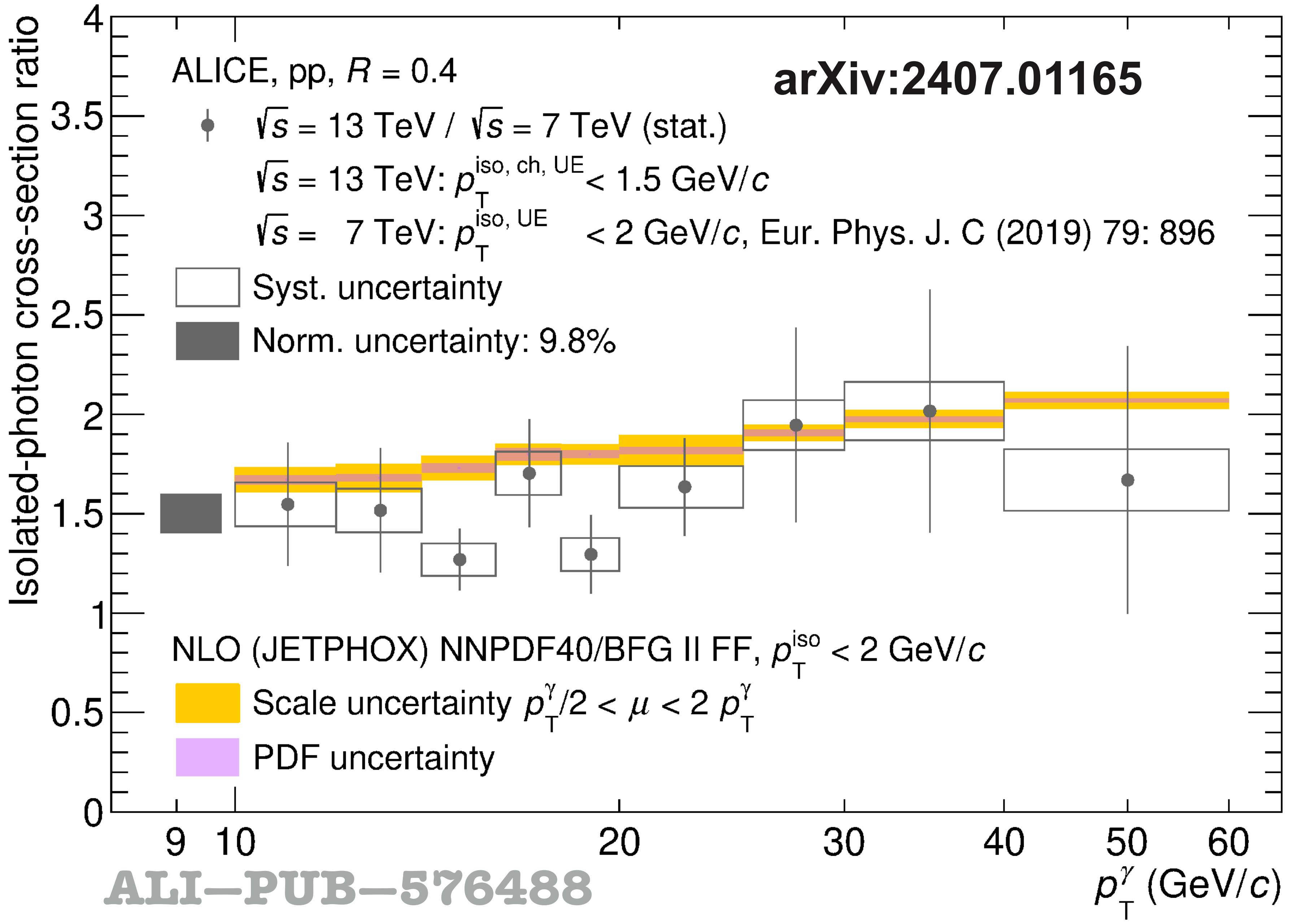
ALICE-PUBLIC-2024-003

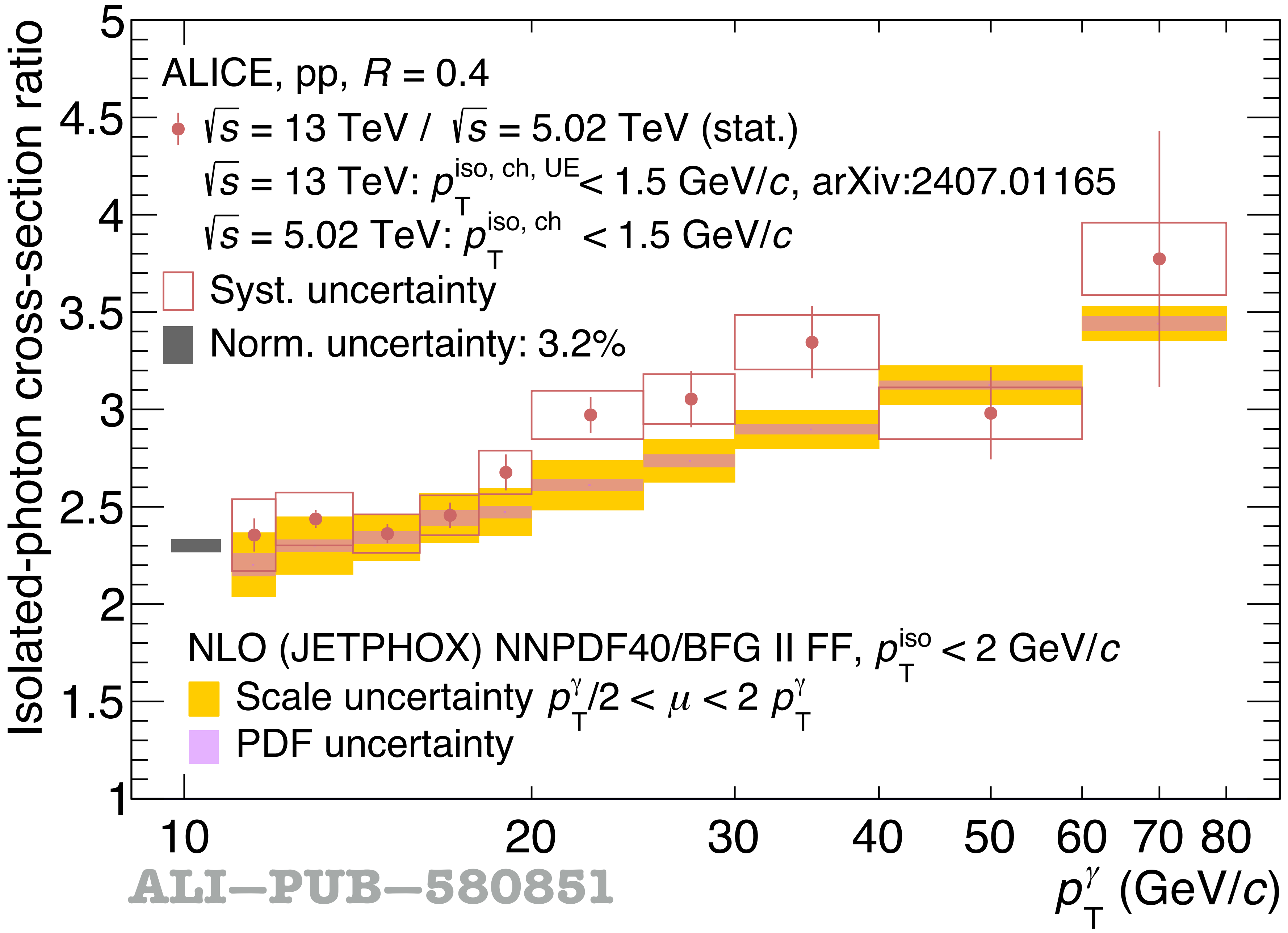
Pb–Pb cross section ratios

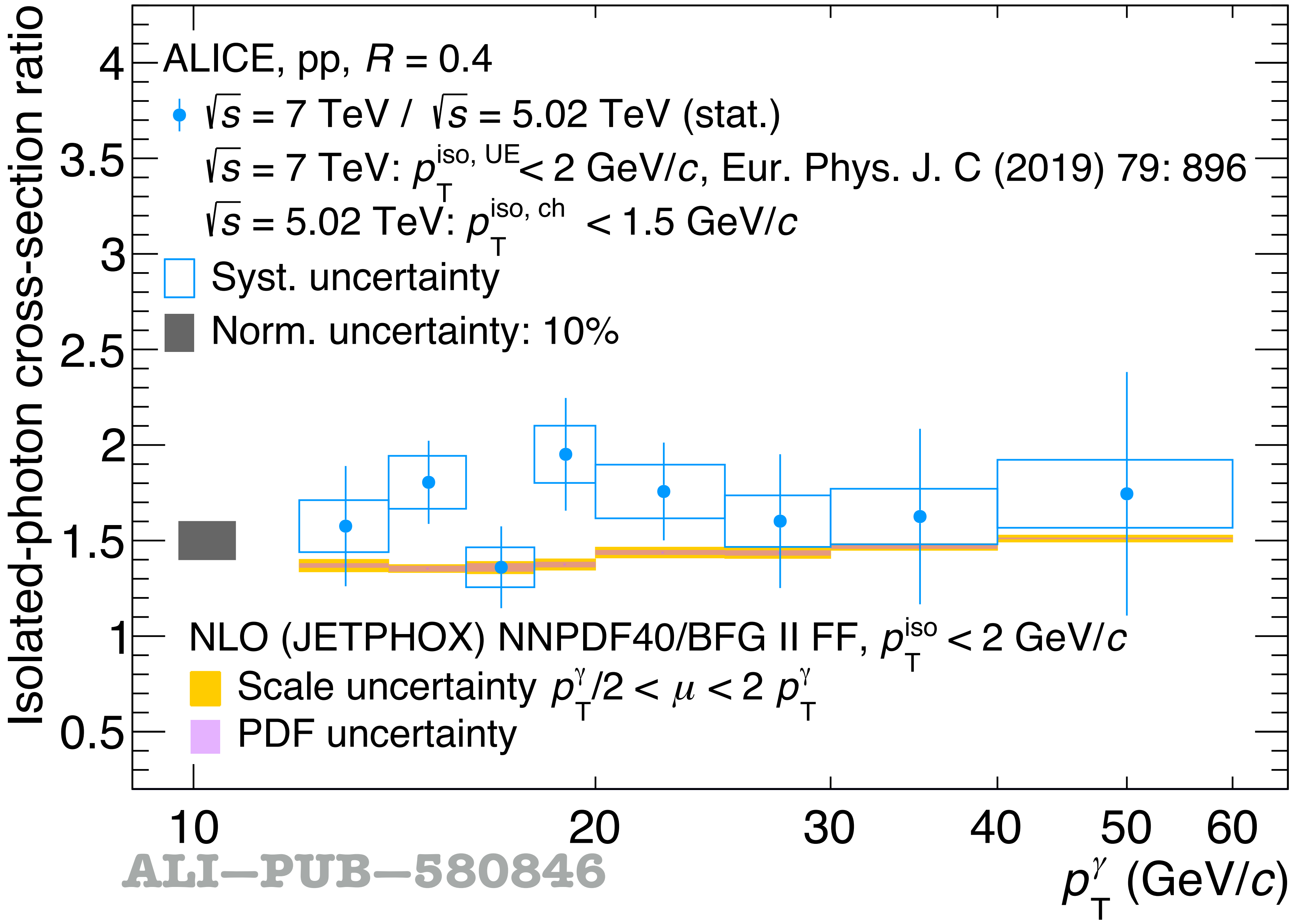
$$R_{\mathrm{CSP}} = \frac{\langle N_{\mathrm{coll}}\rangle^{50-70\%}}{\langle N_{\mathrm{coll}}\rangle^{k}} \frac{\mathrm{d}^2\sigma^{\gamma\,\mathrm{iso}}_{\mathrm{Pb-Pb}}/(\mathrm{d}p_{\mathrm{T}}\,\mathrm{d}\eta)|_k}{\mathrm{d}^2\sigma^{\gamma\,\mathrm{iso}}_{\mathrm{Pb-Pb}}/(\mathrm{d}p_{\mathrm{T}}\,\mathrm{d}\eta)|_{50-70\%}}, \qquad R_{\mathrm{CSC}} = \frac{\langle N_{\mathrm{coll}}\rangle^{30-50\%}}{\langle N_{\mathrm{coll}}\rangle^{k}} \frac{\mathrm{d}^2\sigma^{\gamma\,\mathrm{iso}}_{\mathrm{Pb-Pb}}/(\mathrm{d}p_{\mathrm{T}}\,\mathrm{d}\eta)|_k}{\mathrm{d}^2\sigma^{\gamma\,\mathrm{iso}}_{\mathrm{Pb-Pb}}/(\mathrm{d}p_{\mathrm{T}}\,\mathrm{d}\eta)|_{30-50\%}}$$

ALICE-PUBLIC-2024-003

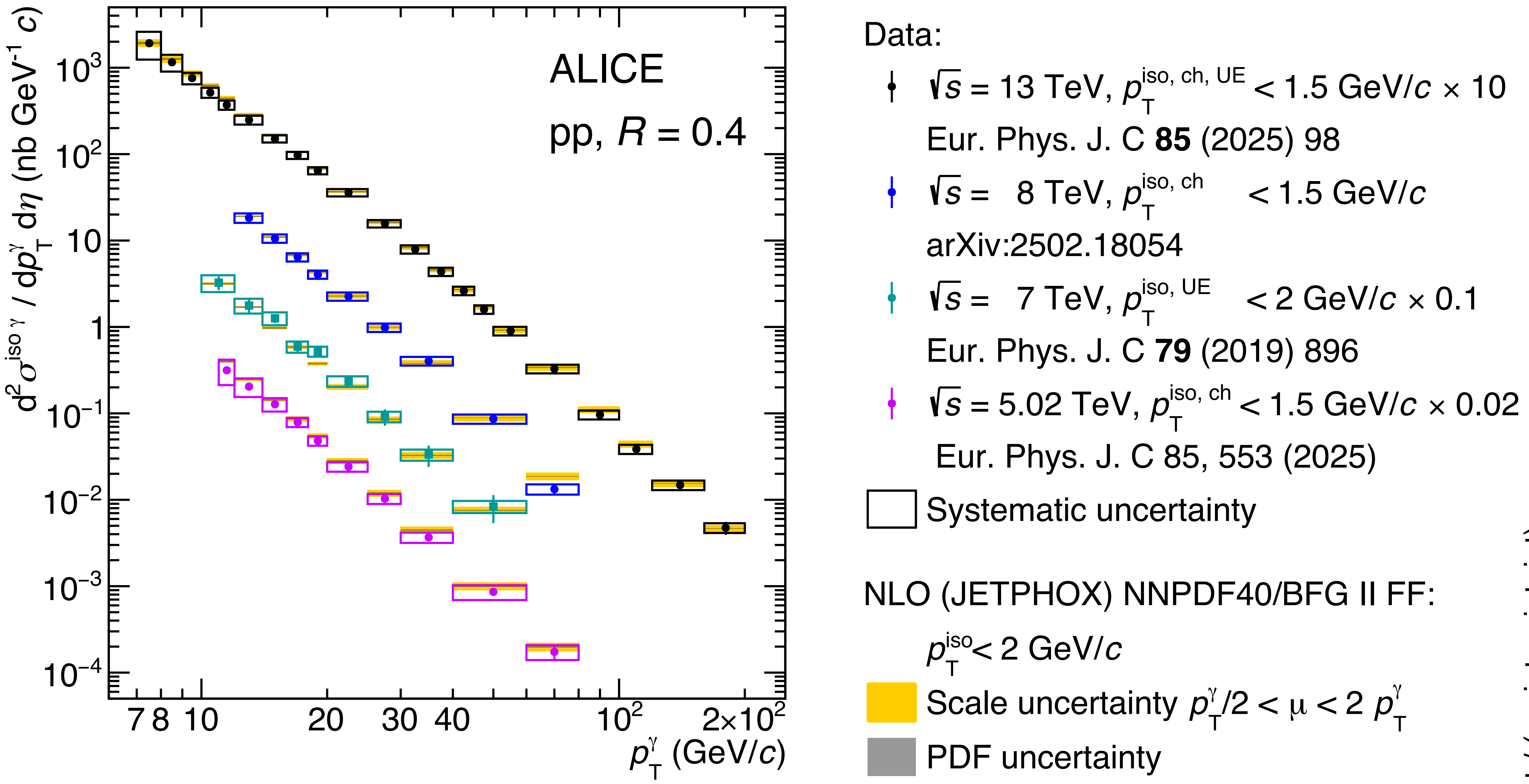
Cross section ratios in pp collisions

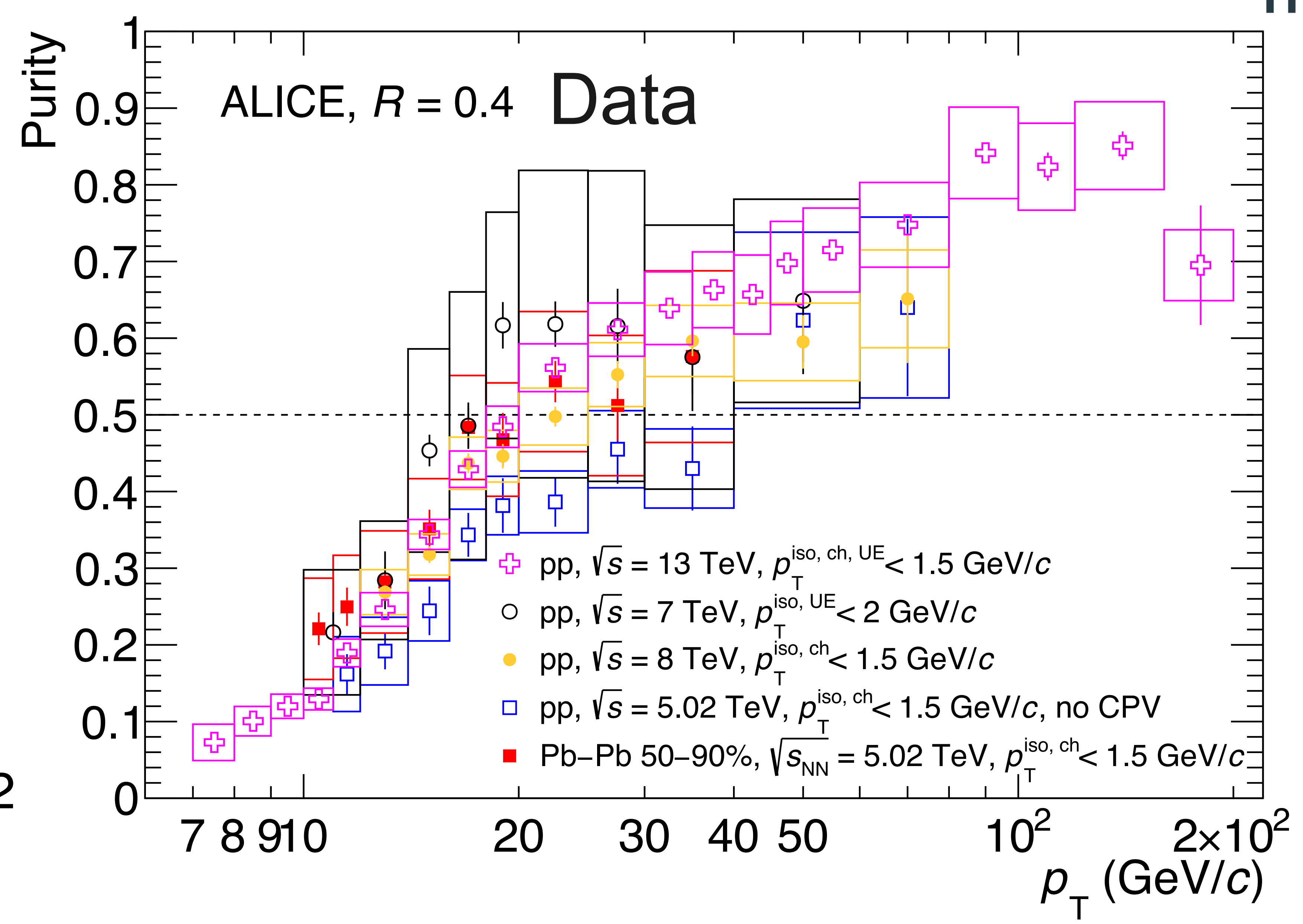


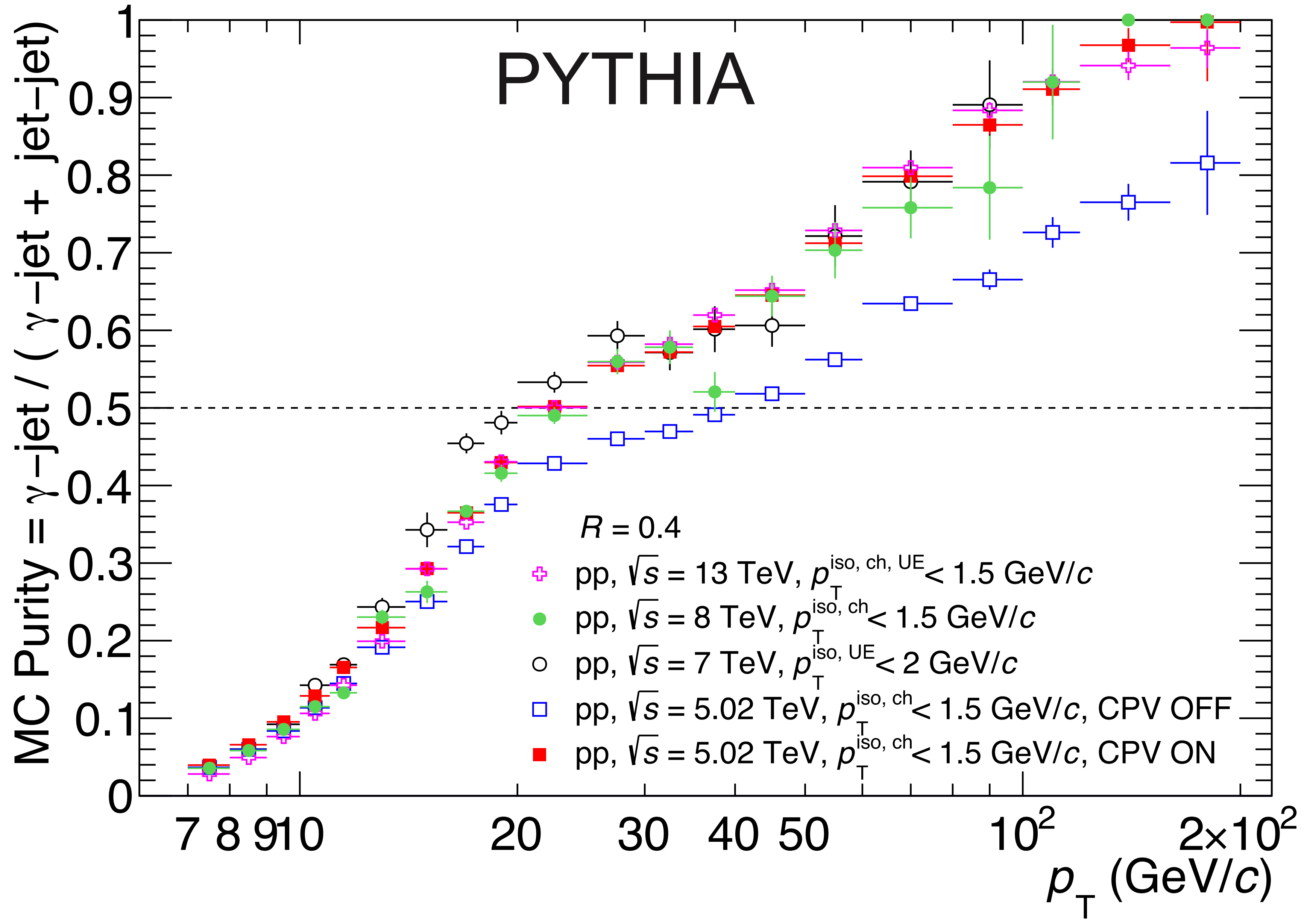




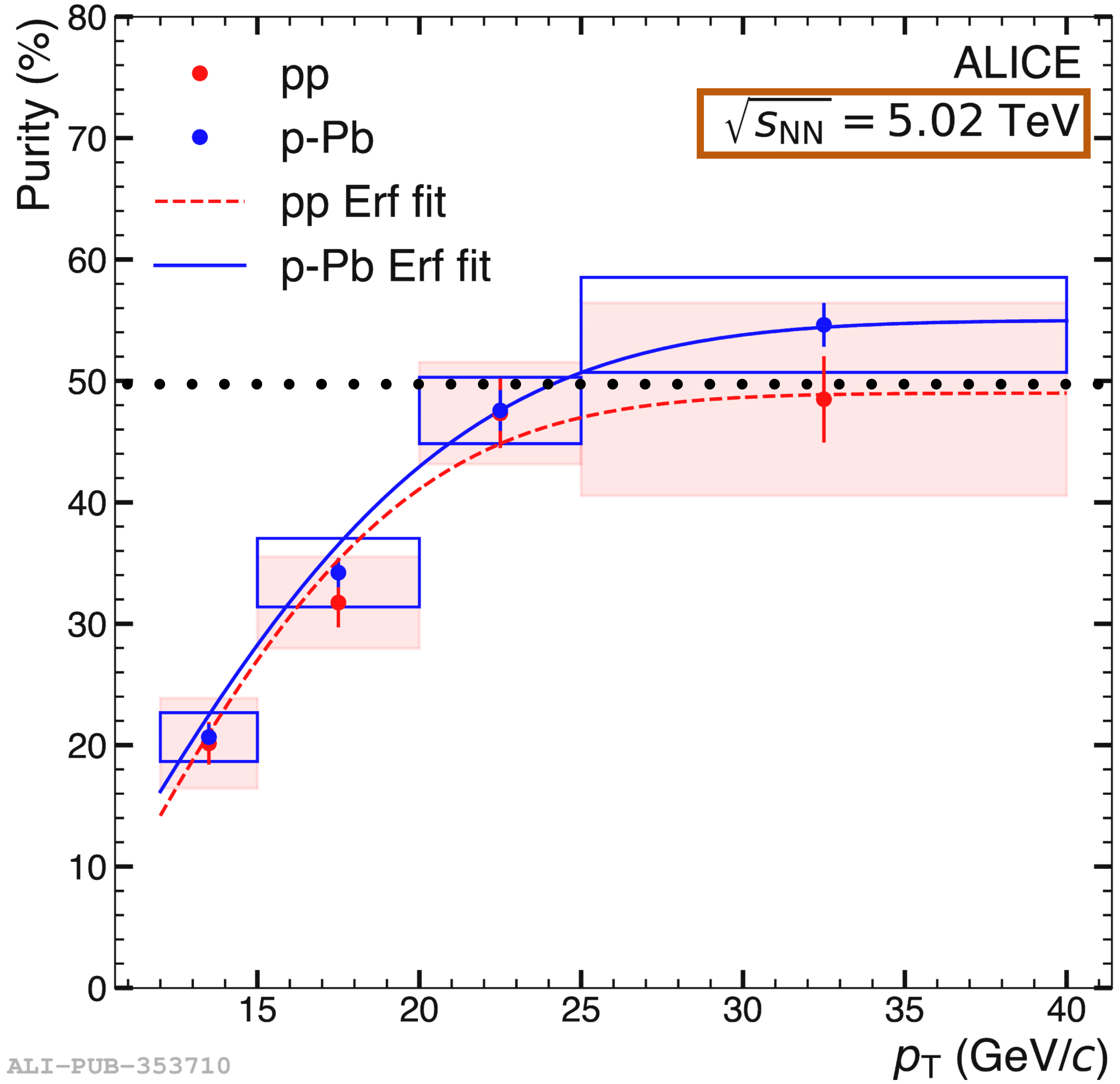
Cross section and purity at different $\sqrt{s}$

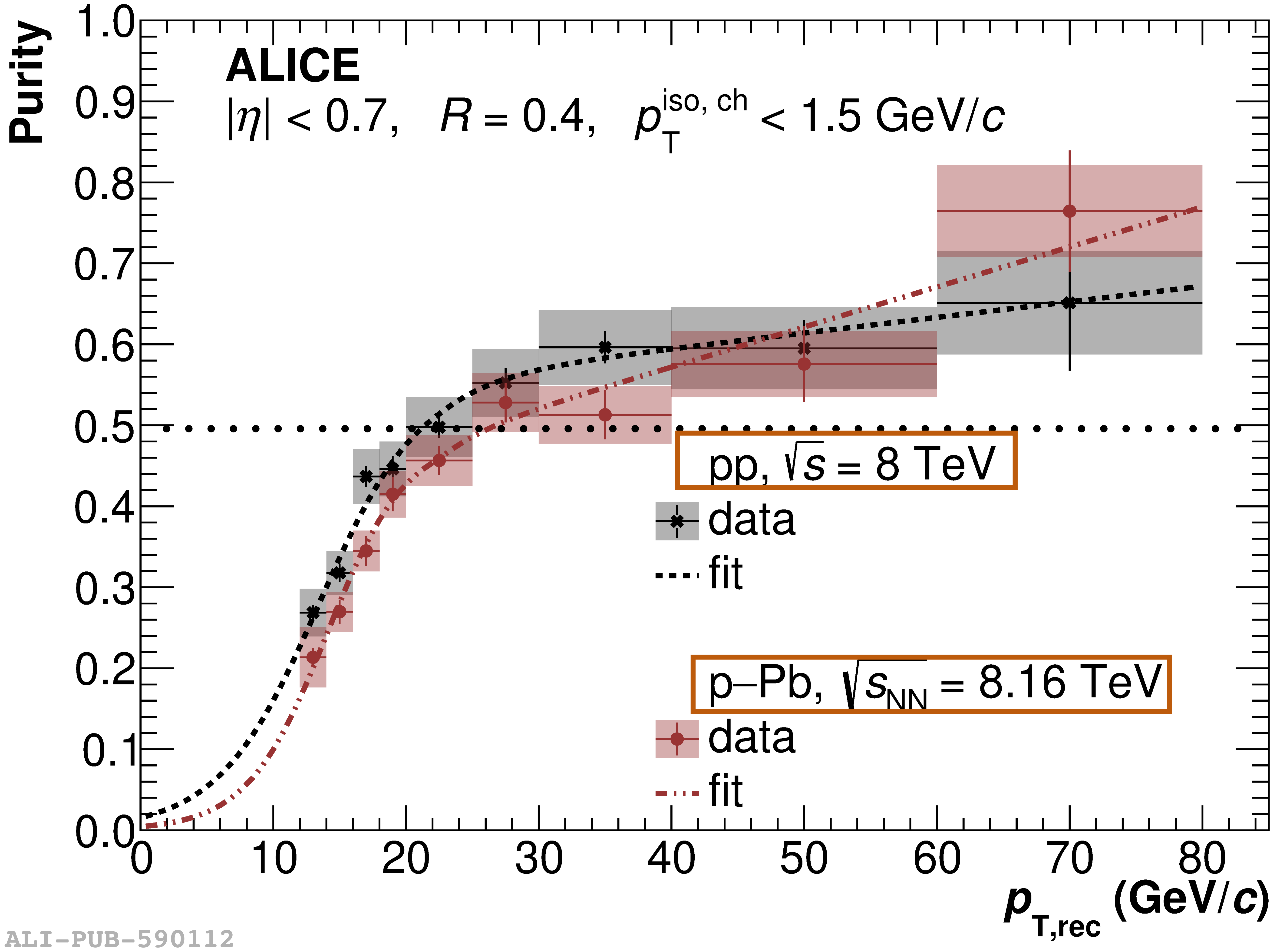




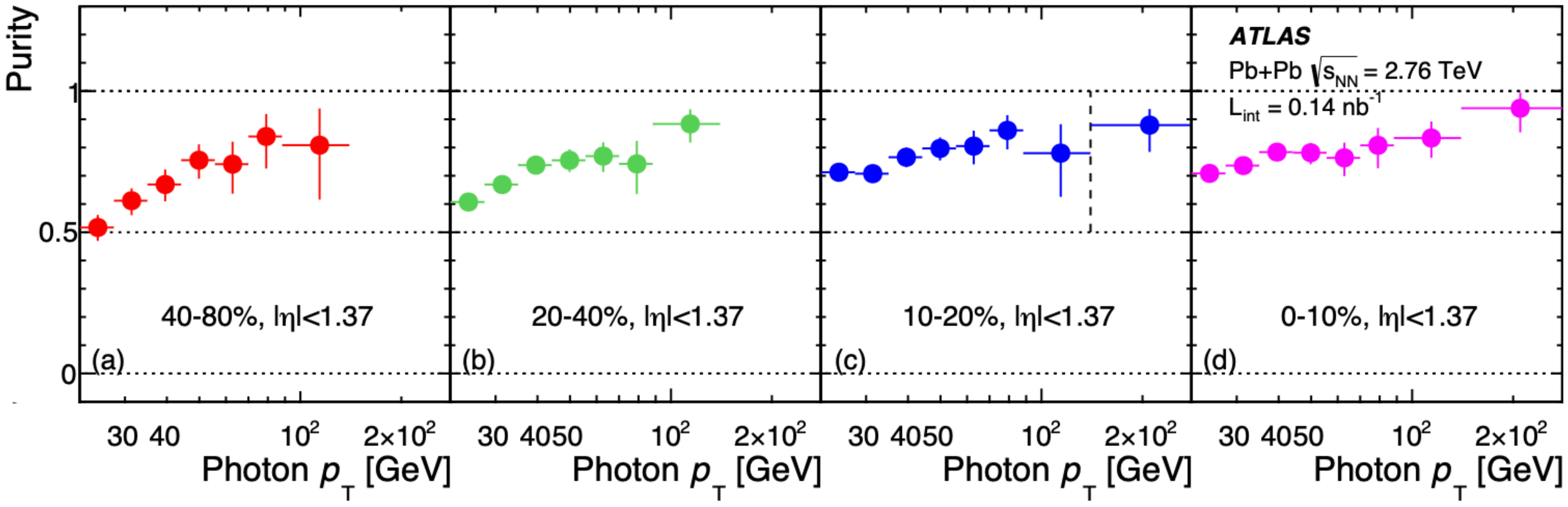


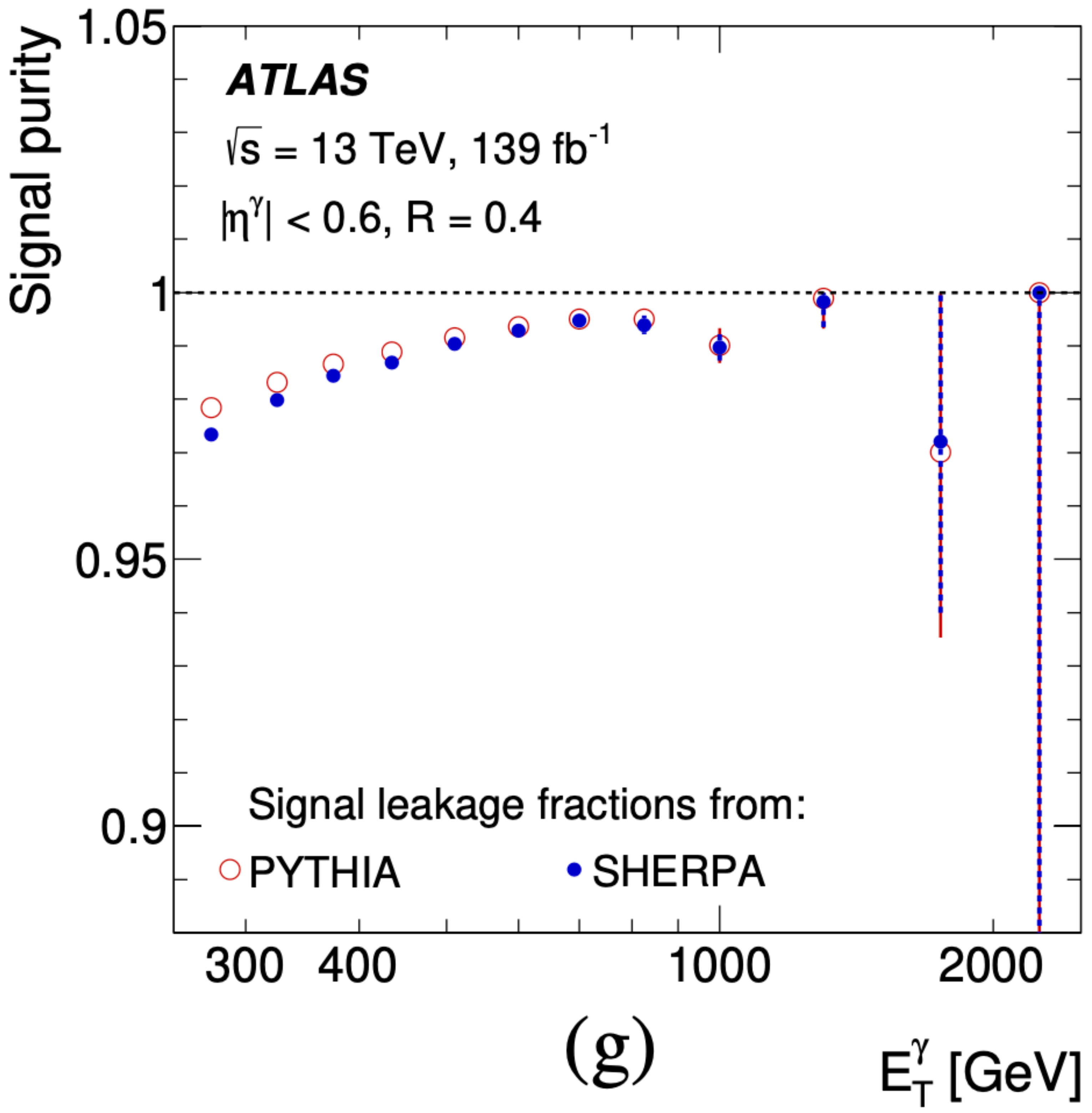
Isolated γ purity in p–Pb collisions, R = 0.4



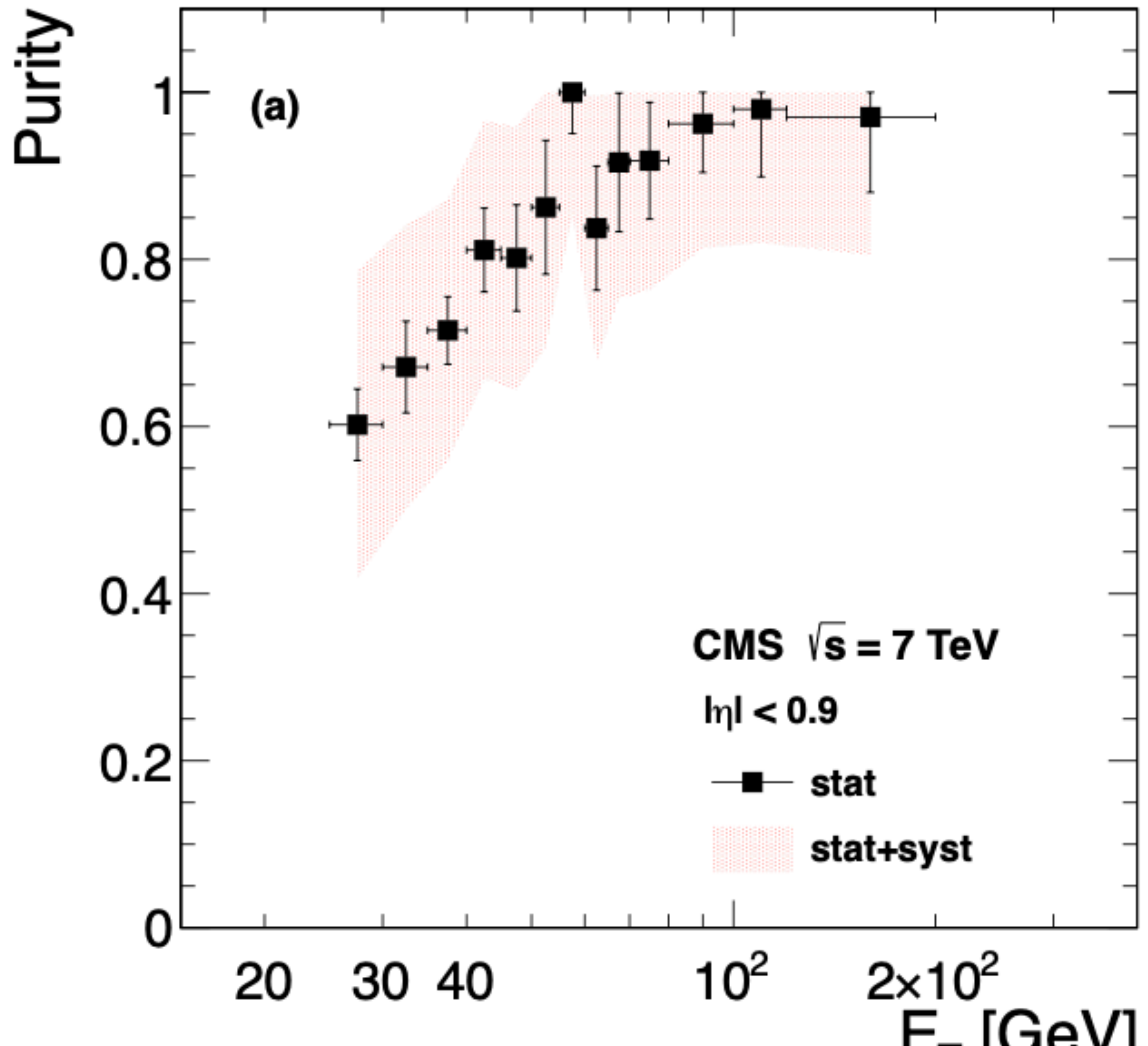


Isolated γ purity in other experiments, $R = 0.4$





(g)



ISOLATED IN PP COLLISIONS
Cross section, p-Pb, ATLAS

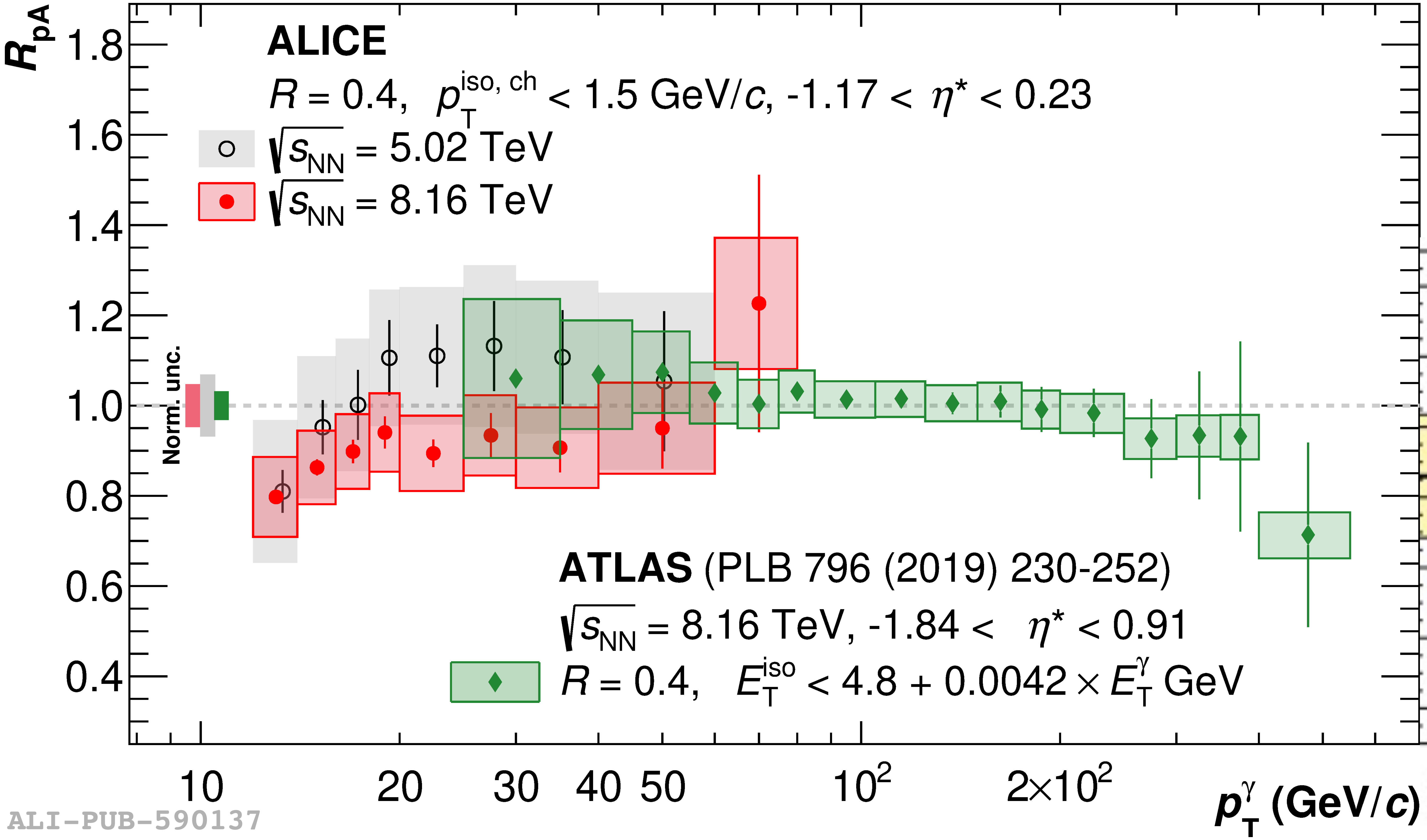
Phys. Lett. B 796 (2019) 230–252

➡ NLO pQCD predictions with nPDFs (JETPHOX) and data have some tension in certain p_T ranges

ISOLATED IN PP COLLISIONS

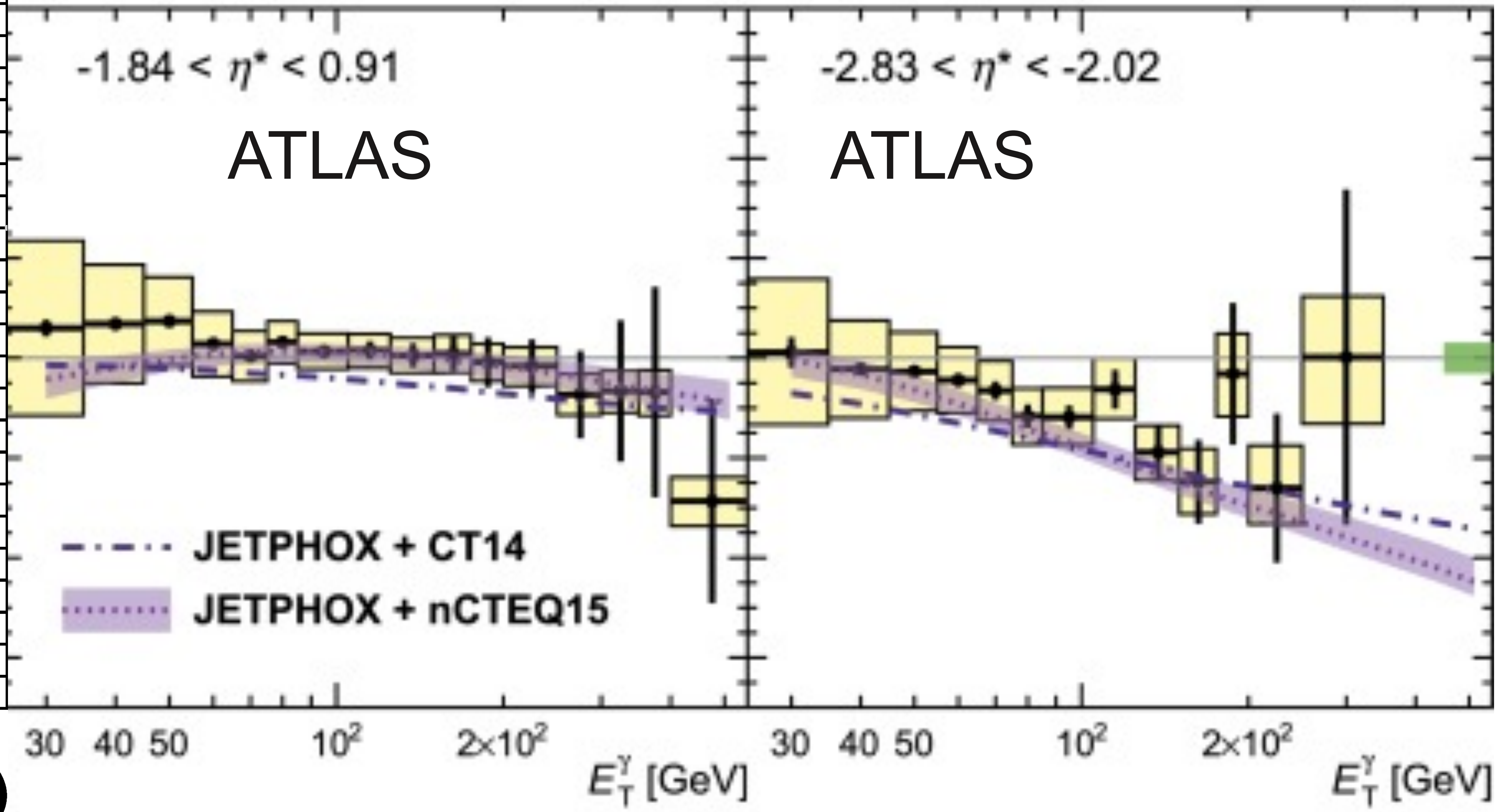
Nuclear modification factor R_{pA}

$$R_{\mathrm{pA}} = \frac{\mathrm{d}^2\sigma^{\gamma}_{\mathrm{pA}}/\mathrm{d}p_{\mathrm{T}}\,\mathrm{d}y^*}{A_{\mathrm{Pb}} \times \mathrm{d}^2\sigma^{\gamma}_{\mathrm{pp}}/\mathrm{d}p_{\mathrm{T}}\,\mathrm{d}y^*}$$



ALI-PUB-590137

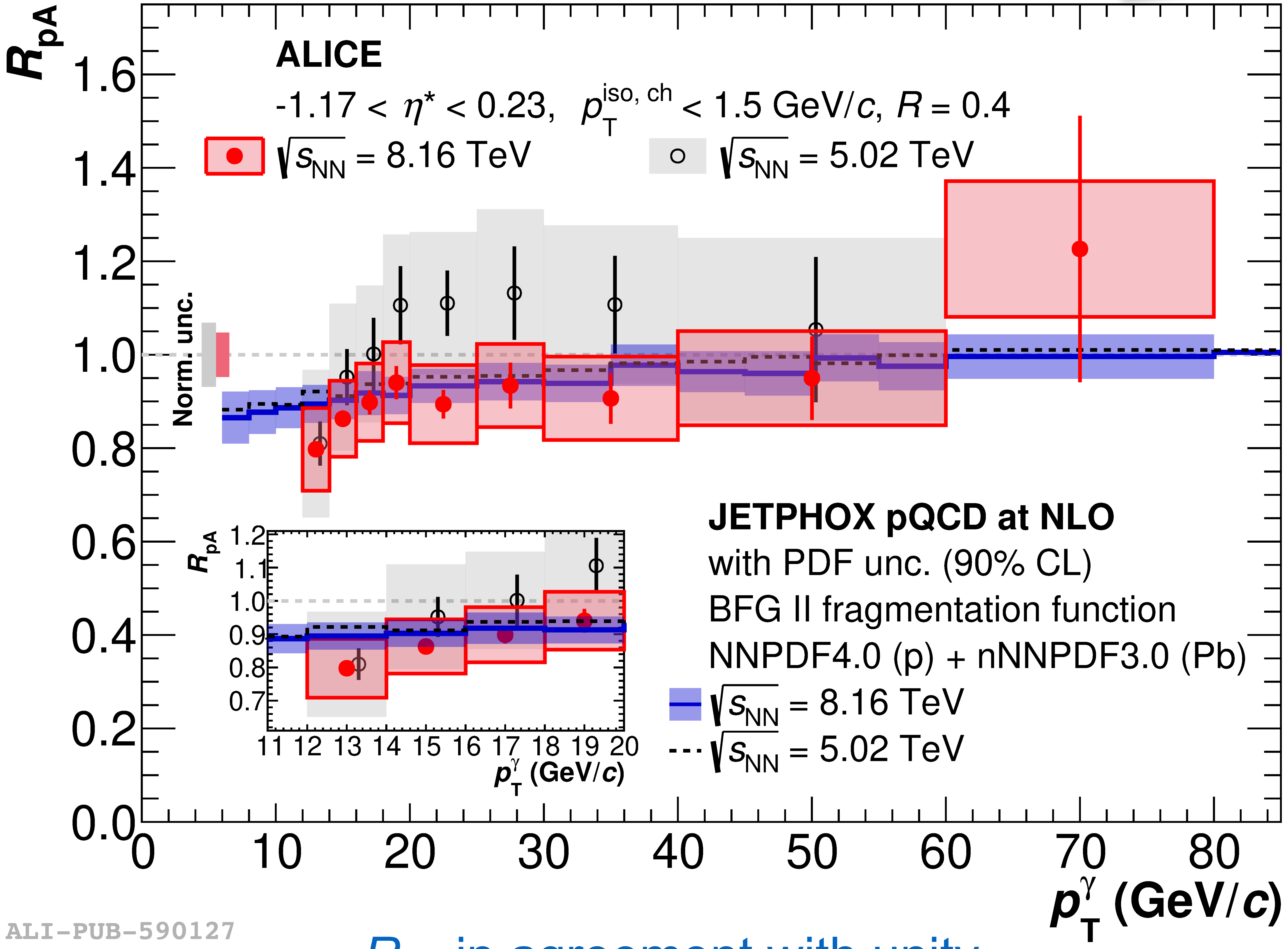
- R_{pA} in agreement with unity
  - No suppression at high p_T,
  - Agreement ALICE and ATLAS at midrapidity
  - ATLAS very forward: decrease with p_T, reproduced by JETPHOX using nPDFs



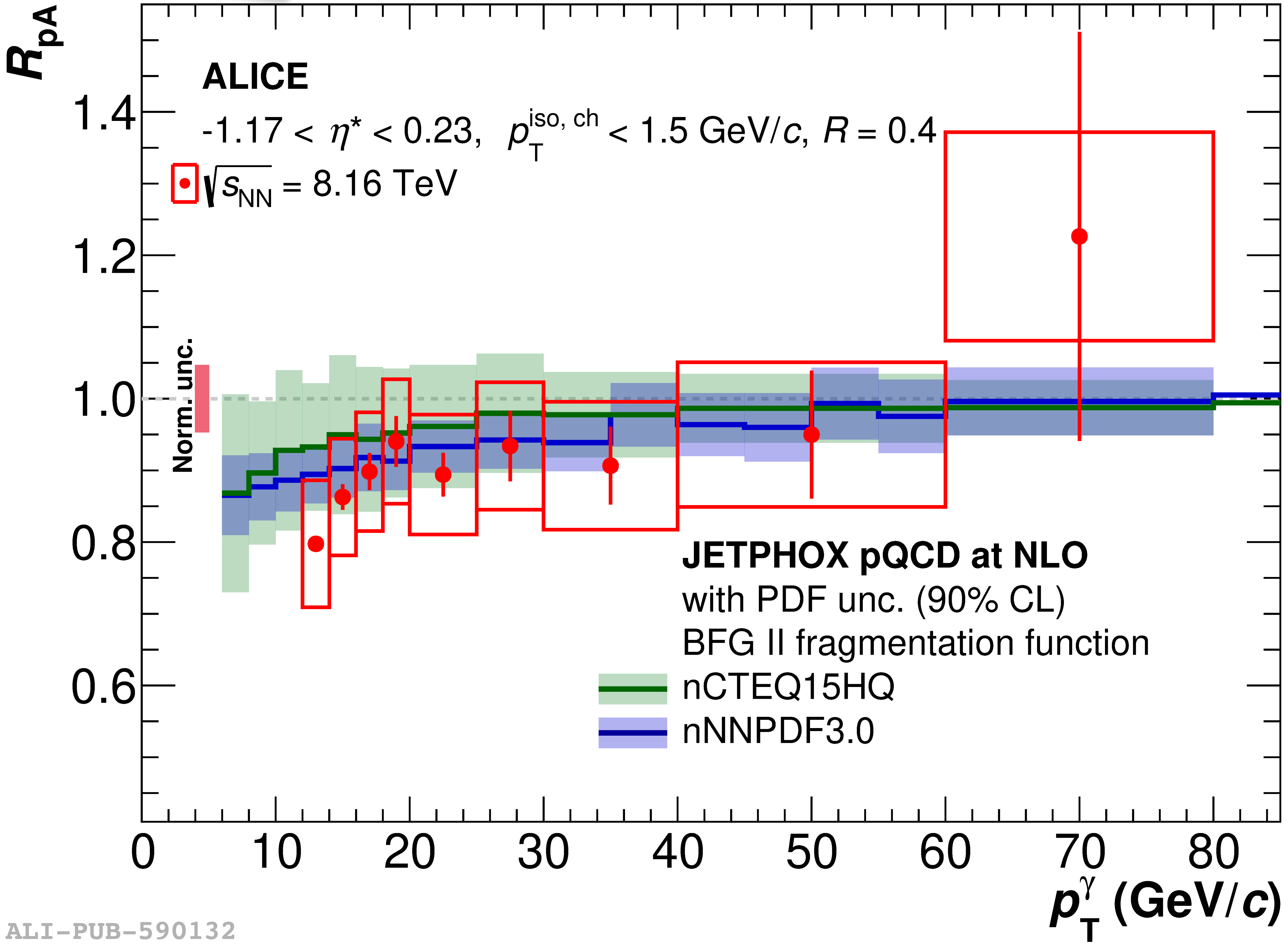
Nuclear modification factor R_{pA}

ISOLATED IN PP COLLISIONS

$$R_{pA} = \frac{d^2\sigma^{\gamma}_{pA}/dp_T\,dy^*}{A_{Pb} \times d^2\sigma^{\gamma}_{pp}/dp_T\,dy^*}$$



ALI-PUB-590127

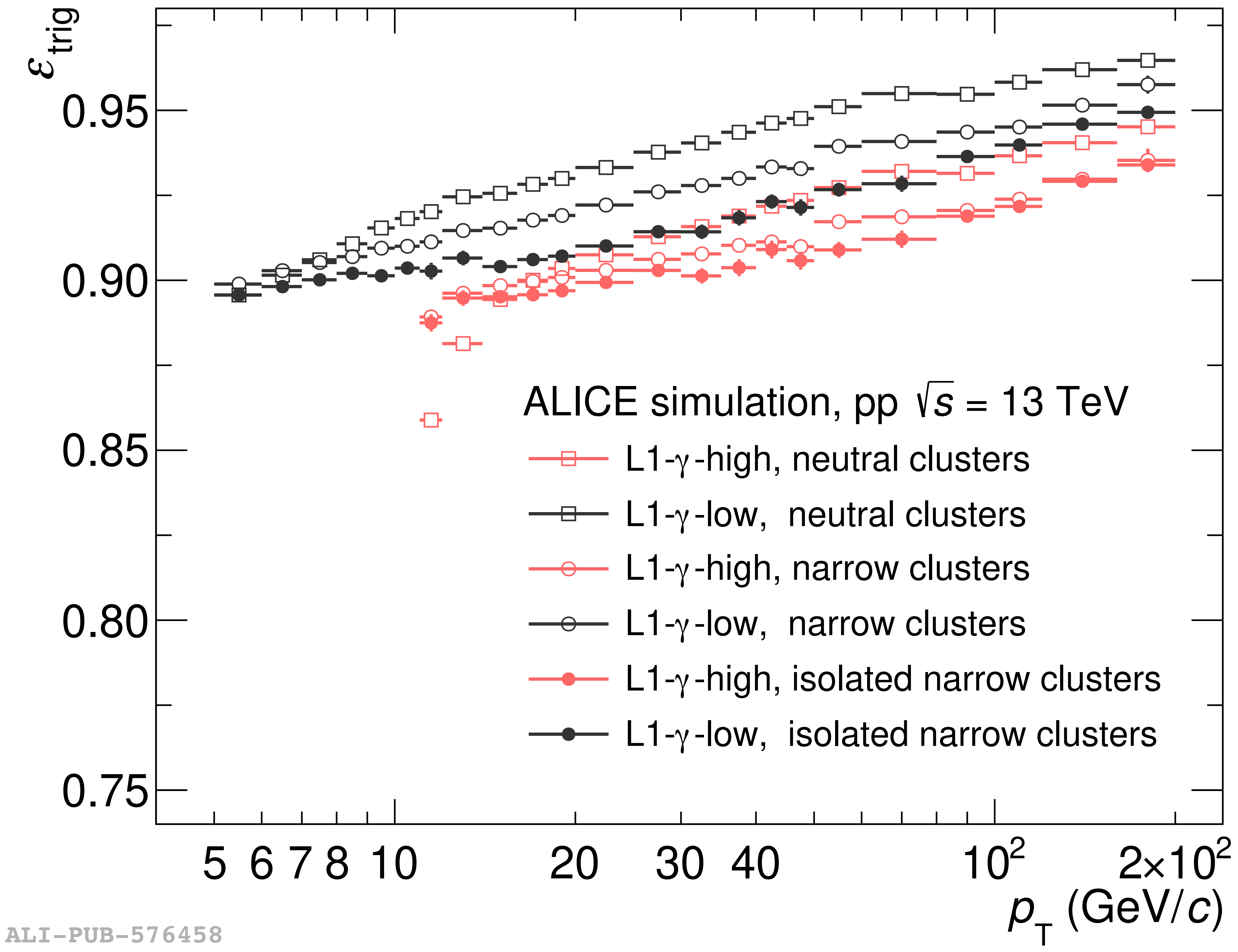


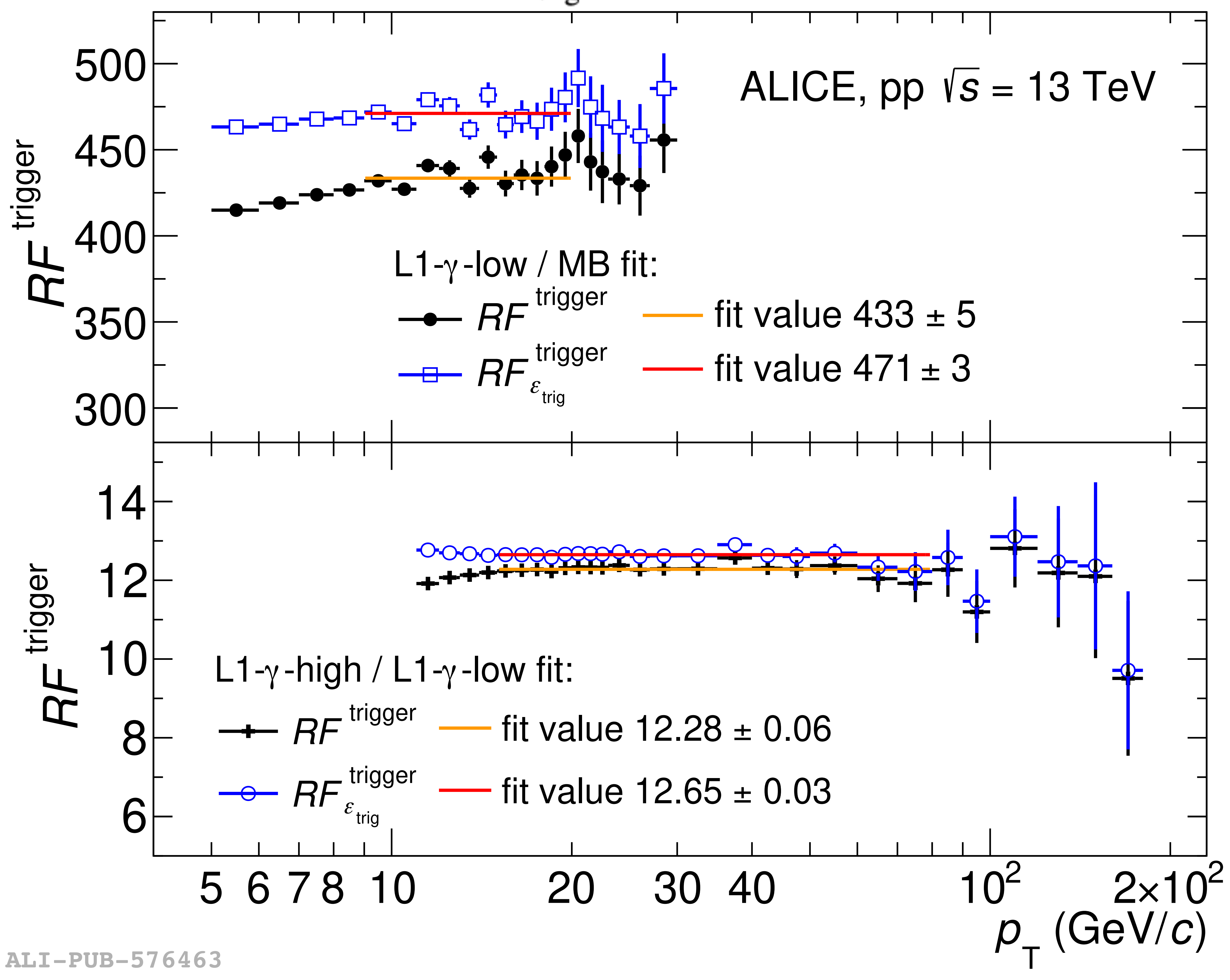
ALI-PUB-590132

- R_{pA} in agreement with unity
  - No suppression at high p_T, agreement between ALICE and ATLAS
  - Hints of lower than unity for $p_T < 20$ GeV/c, expected in theory, cold nuclear matter effects, shadowing

EMCal trigger performance, pp $\sqrt{s}$ = 13 TeV

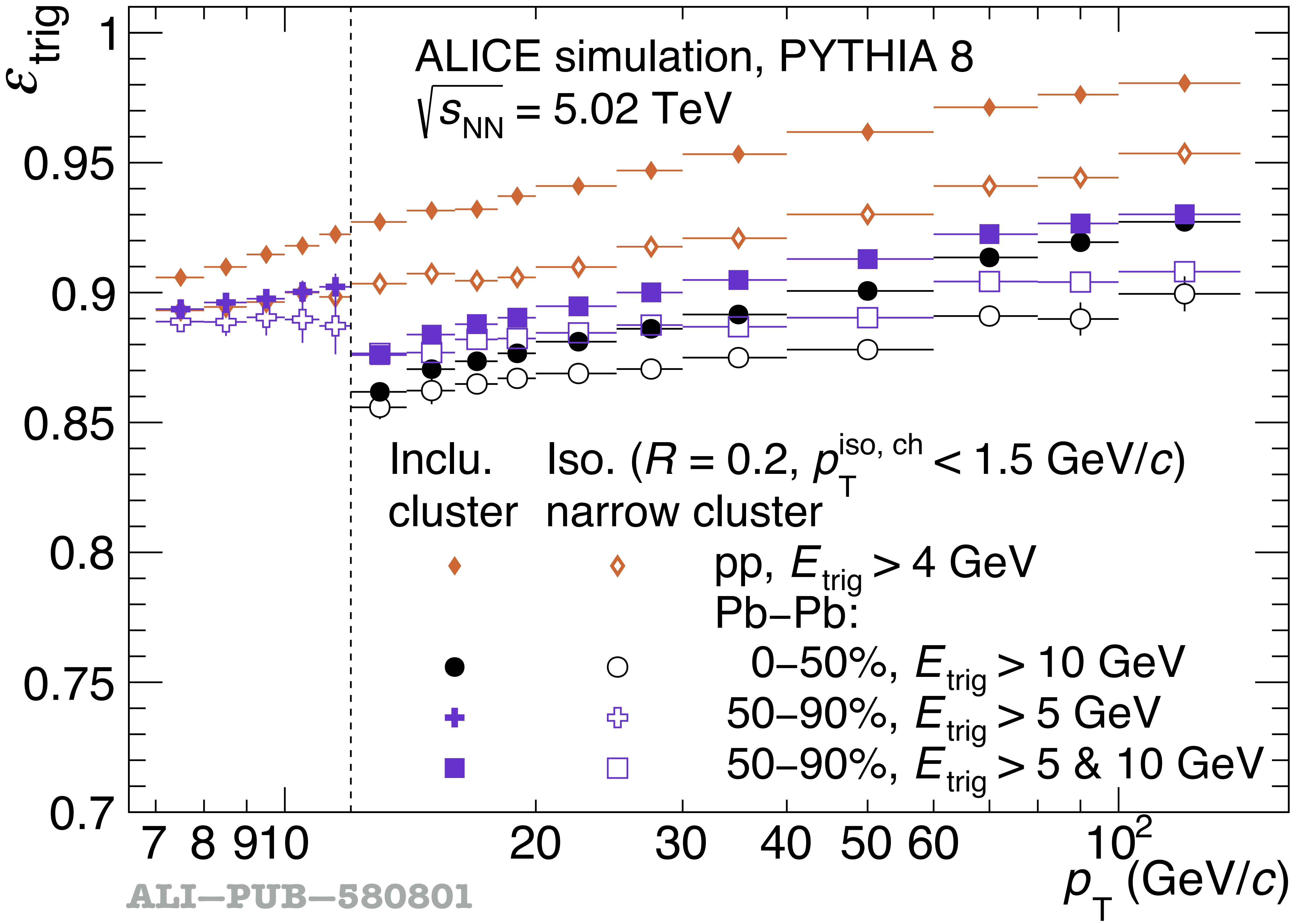
$$RF^{\mathrm{trig}}_{\varepsilon_{\mathrm{trig}}} = \frac{1}{\varepsilon^{\mathrm{clus}}_{\mathrm{trig}}} \frac{1/N^{\mathrm{L1}\text{-}\gamma}_{\mathrm{evt}} \times \mathrm{d}N^{\mathrm{L1}\text{-}\gamma}/\mathrm{d}p_T}{1/N^{\mathrm{MB}}_{\mathrm{evt}} \times \mathrm{d}N^{\mathrm{MB}}/\mathrm{d}p_T}$$

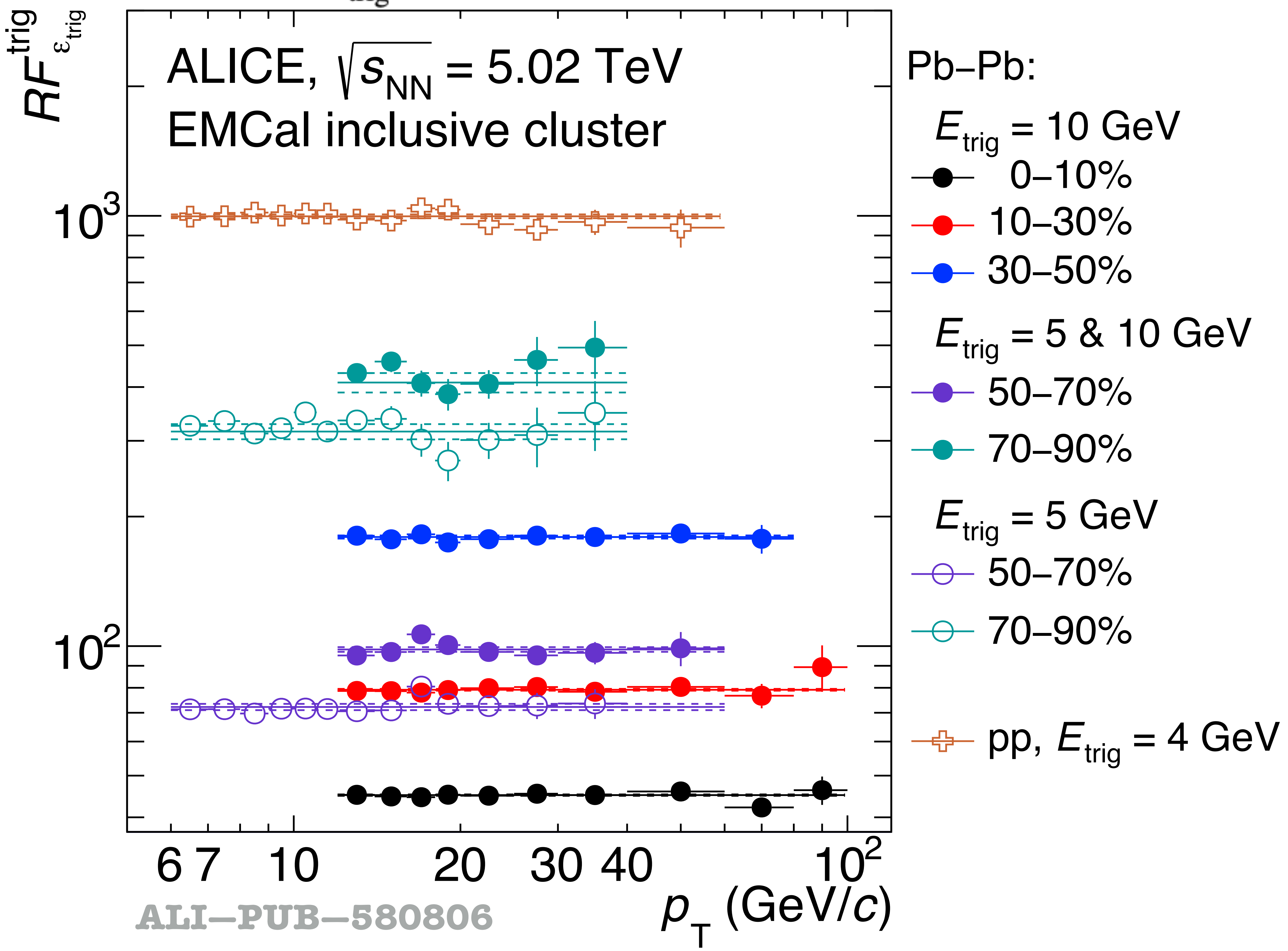




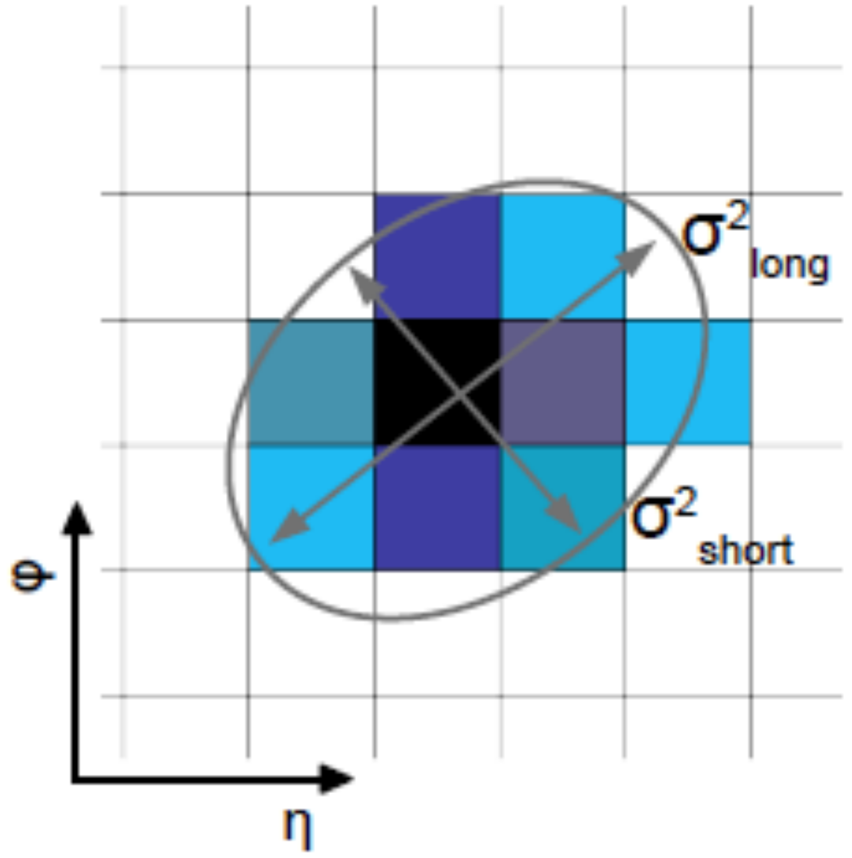
EMCal trigger performance, pp & Pb–Pb $\sqrt{s_{NN}}$ = 5.02 TeV

$$RF^{\rm trig}_{\varepsilon_{\rm trig}} = \frac{1}{\varepsilon^{\rm clus}_{\rm trig}} \frac{1/N^{\rm L1\text{-}\gamma}_{\rm evt} \times {\rm d}N^{\rm L1\text{-}\gamma}/{\rm d}p_T}{1/N^{\rm MB}_{\rm evt} \times {\rm d}N^{\rm MB}/{\rm d}p_T}$$





EMCal cluster shower lateral dispersion parameter



- Shower shape parameter σ^2_{long} is related to the longer axis of the cluster ellipse
- Parameter depends on cluster cells location and its energy

$$w_i = \text{Maximum}(0, w_0 + \ln(E_{\text{cell},\ i}/E))$$

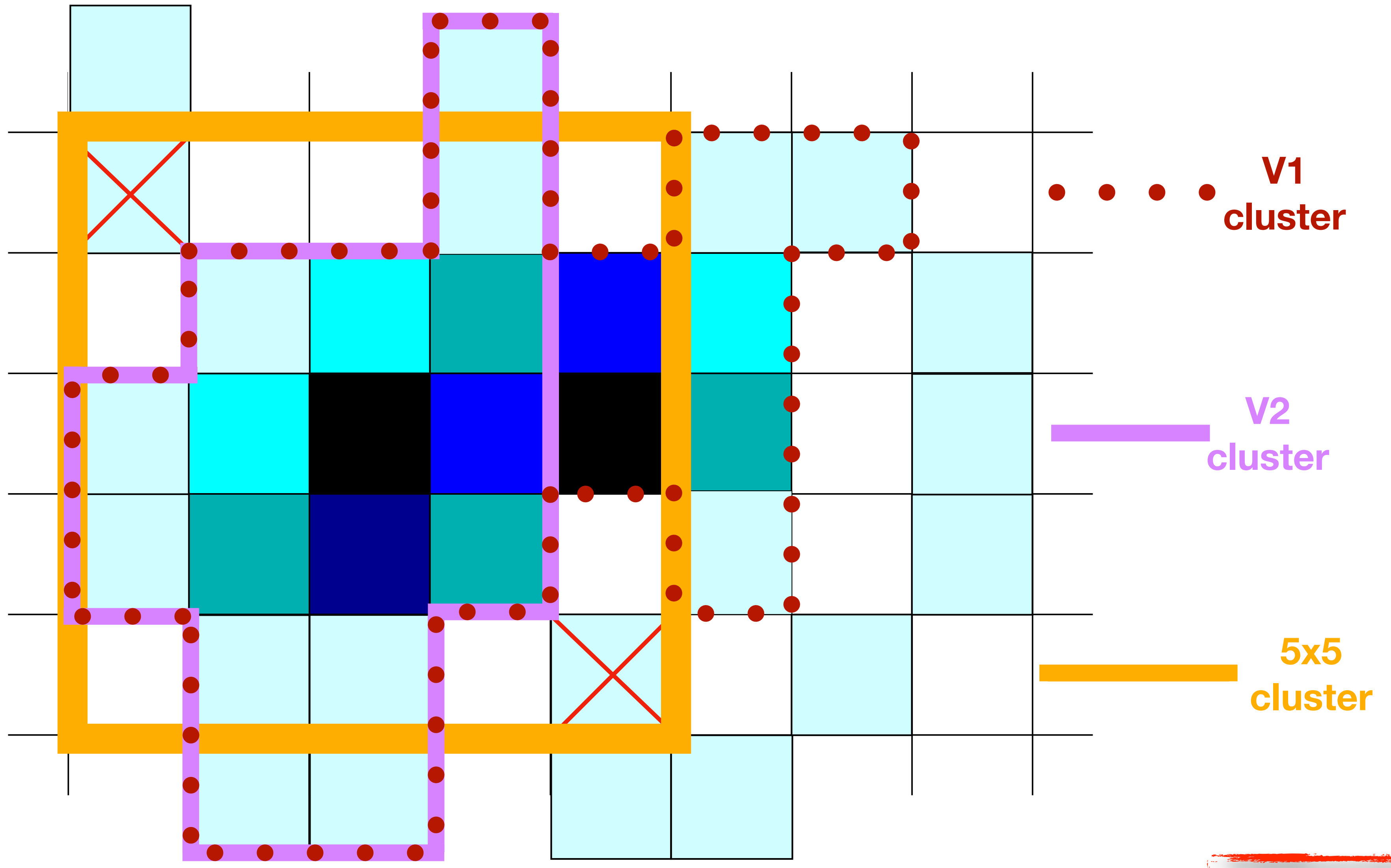
$$\sigma^2_{\alpha\beta} = \sum_i \frac{w_i \alpha_i \beta_i}{w_{\text{tot}}} - \sum_i \frac{w_i \alpha_i}{w_{\text{tot}}} \sum_i \frac{w_i \beta_i}{w_{\text{tot}}}$$

$$w_{\text{tot}} = \sum_i w_i,$$

$$\boxed{\begin{aligned} \sigma^2_{\text{long}} &= 0.5(\sigma^2_{\varphi\varphi} + \sigma^2_{\eta\eta}) + \sqrt{0.25(\sigma^2_{\varphi\varphi} - \sigma^2_{\eta\eta})^2 + \sigma^2_{\eta\varphi}}, \\ \sigma^2_{\text{short}} &= 0.5(\sigma^2_{\varphi\varphi} + \sigma^2_{\eta\eta}) - \sqrt{0.25(\sigma^2_{\varphi\varphi} - \sigma^2_{\eta\eta})^2 + \sigma^2_{\eta\varphi}}, \end{aligned}}$$

- V2 clusters: Used in pp & Pb–Pb at $\sqrt{s_{\text{NN}}}$ = 5.02 TeV to get *E* and position
  - In other pp and p–Pb measurements V1 clusters are used
- For the σ^2_{long} calculation: consider the neighbour cells around the highest energy cell in a 5x5 fixed window
  - Increase meson decay merging but limiting UE merging

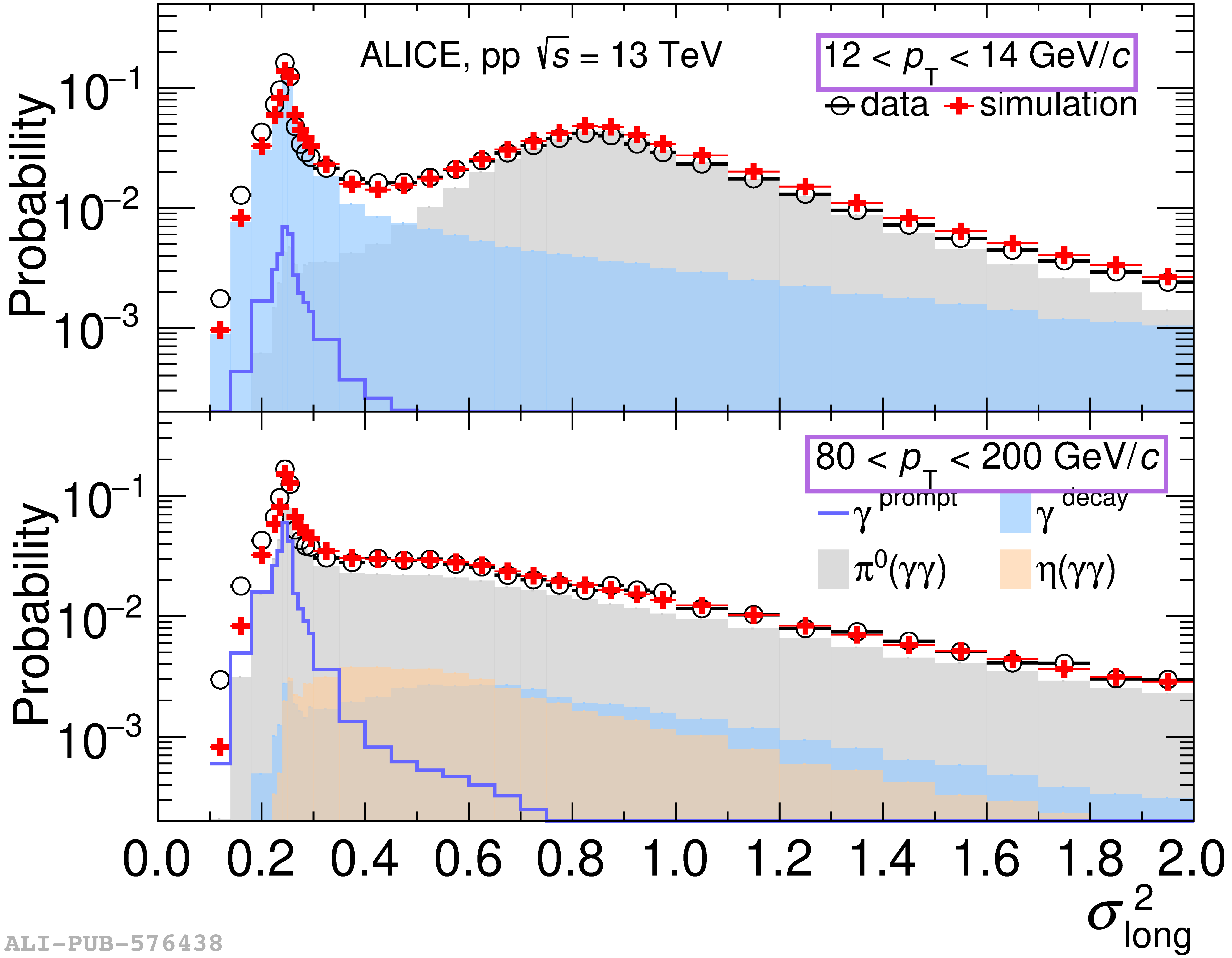
ALICE-PUBLIC-2024-003



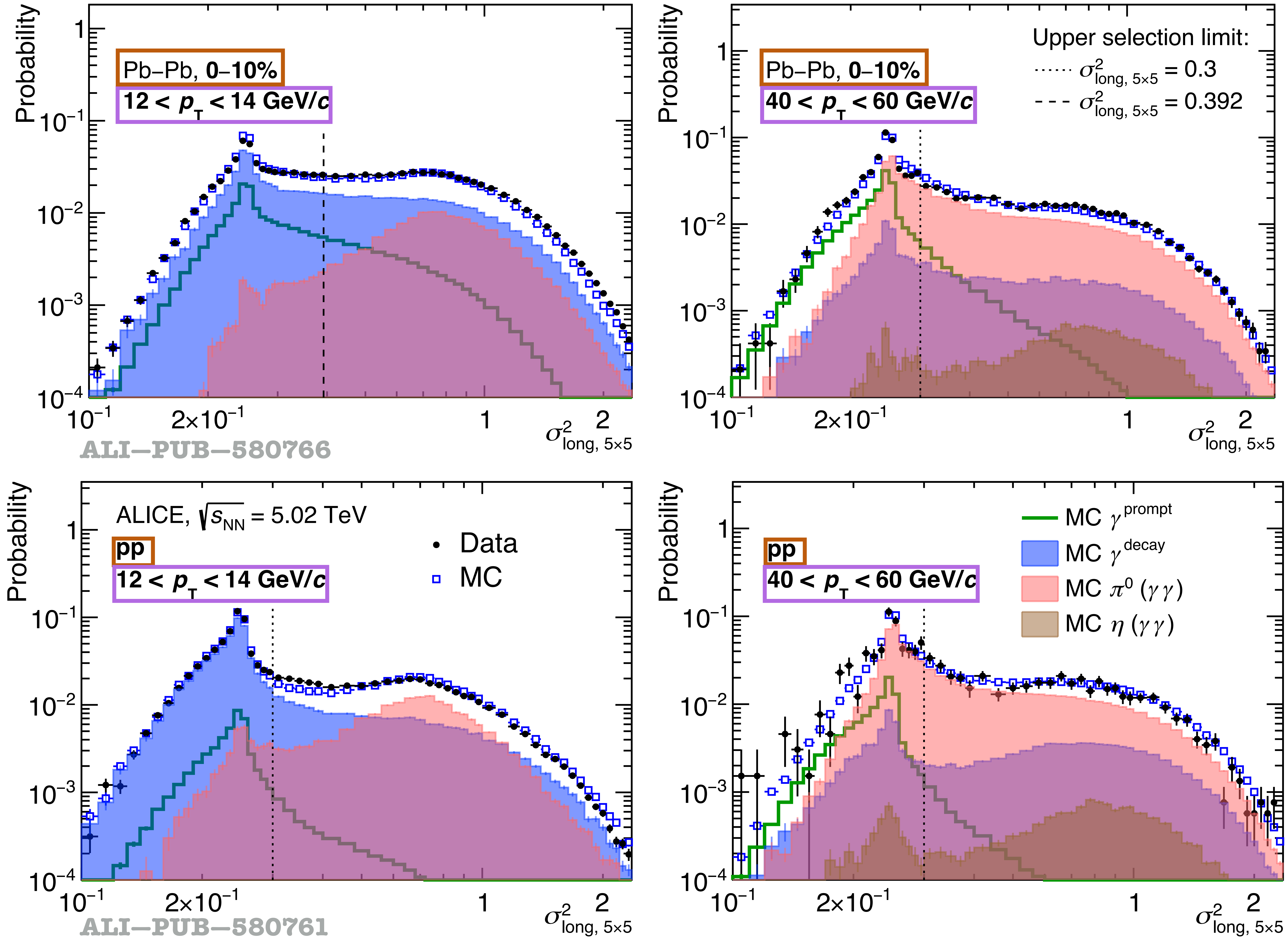
EMCal cluster shower shape, pp & Pb–Pb $\sqrt{s_{NN}}$ = 5.02 TeV

ALICE-PUBLIC-2024-003

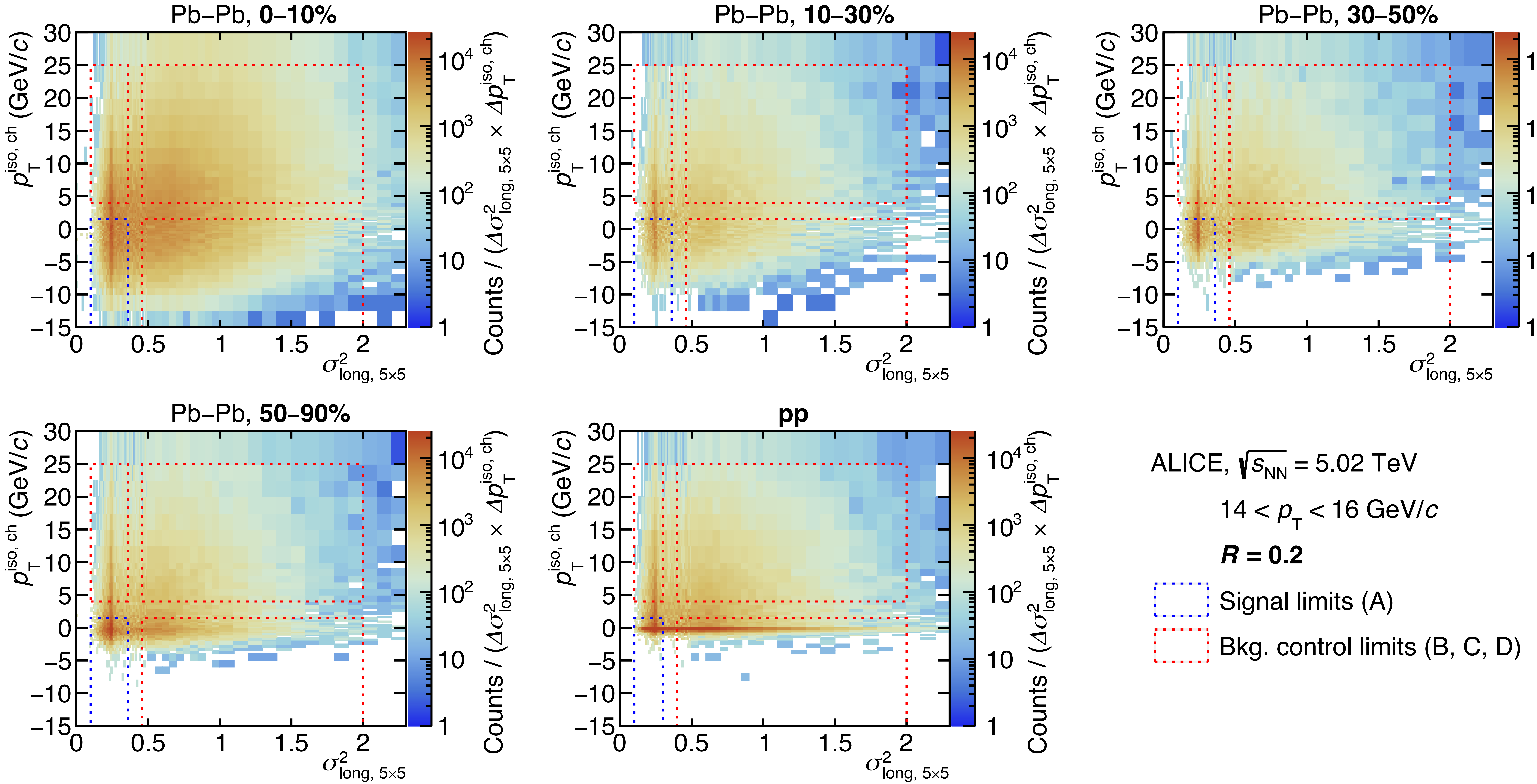
EMCal cluster shower shape, pp $\sqrt{s}$ = 13 TeV



EMCal cluster shower shape, pp & Pb–Pb $\sqrt{s_{NN}}$ = 5.02 TeV

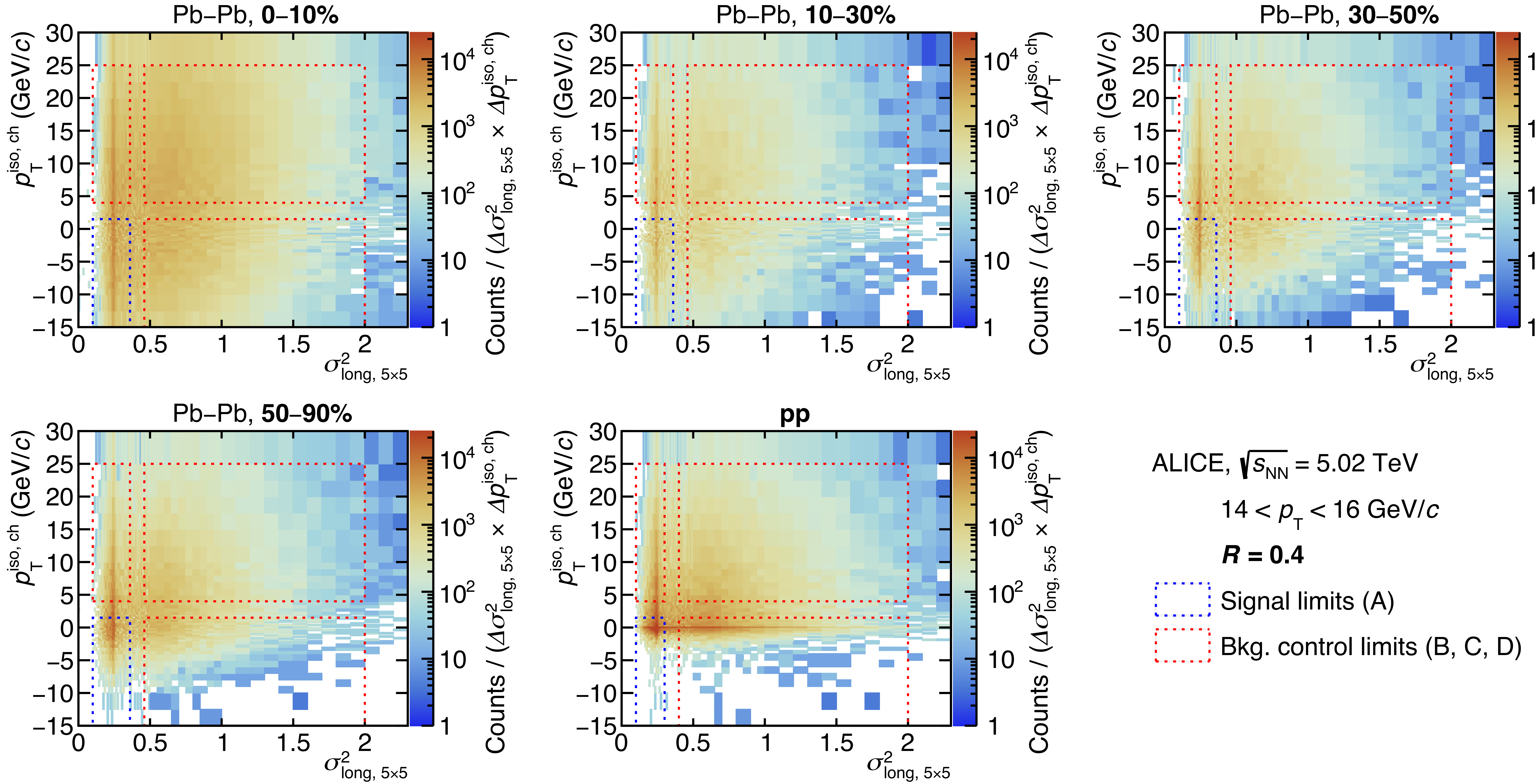


ABCD regions, R = 0.2, pp & Pb–Pb $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV



ALICE-PUBLIC-2024-003

ABCD regions, R = 0.4, pp & Pb–Pb $\sqrt{s_{\rm NN}}$ = 5.02 TeV

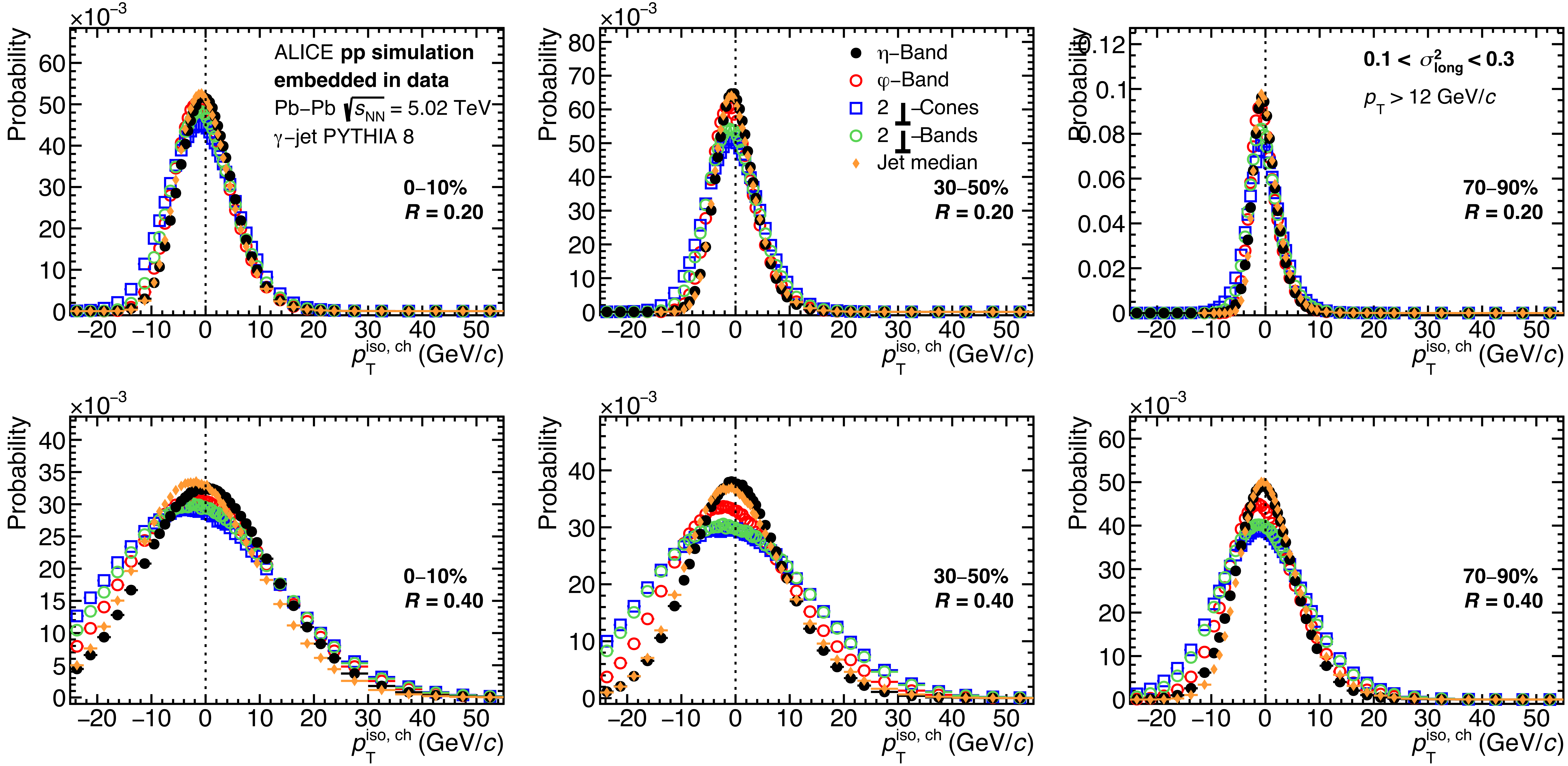


ALICE-PUBLIC-2024-003

Isolation momentum in cone, pp & Pb–Pb $\sqrt{s_{\rm NN}}$ = 5.02 TeV

ALICE-PUBLIC-2024-003

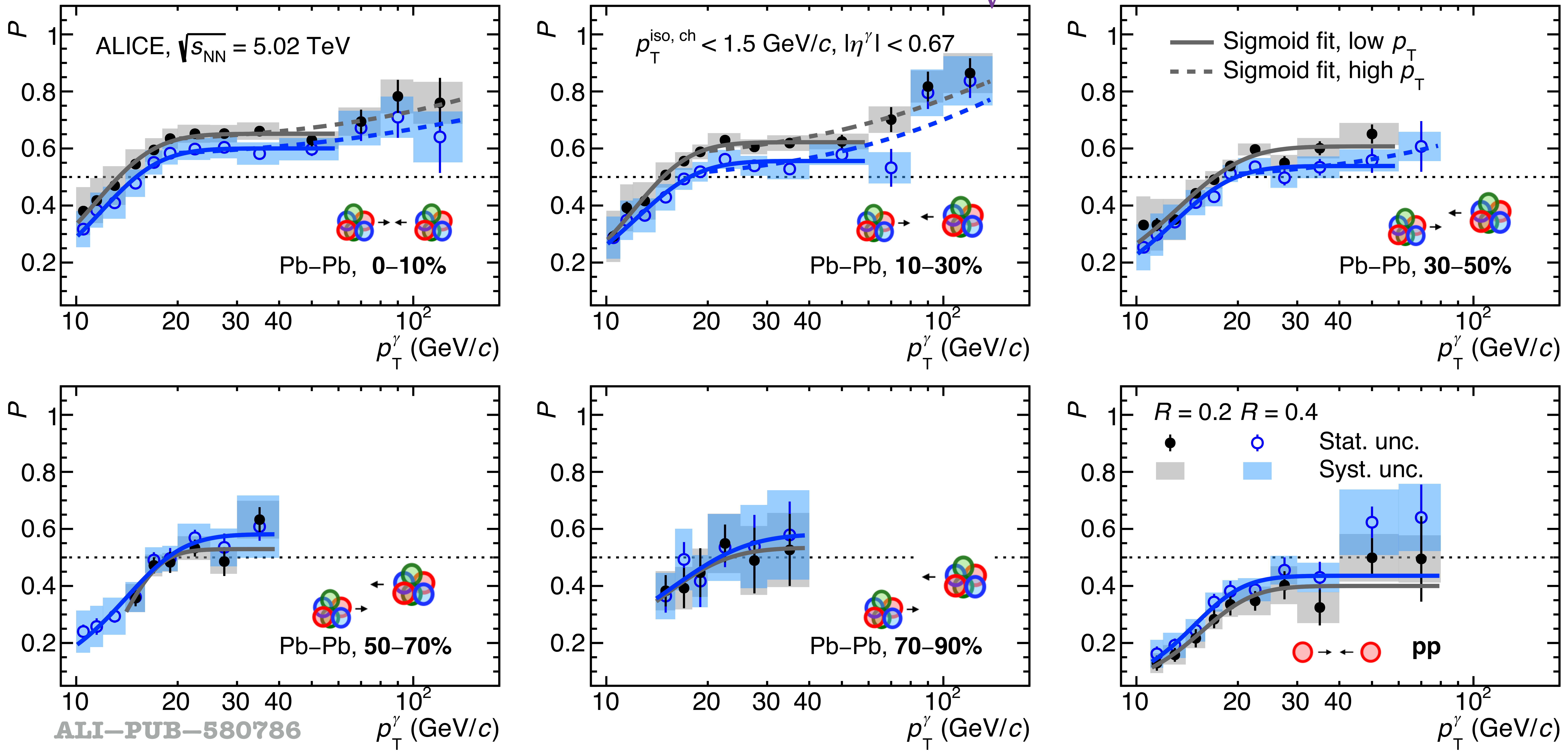
Isolation momentum in cone, different UE areas



pp PYTHIA 8 γ-jet process simulation embedded into data

ALICE-PUBLIC-2024-003

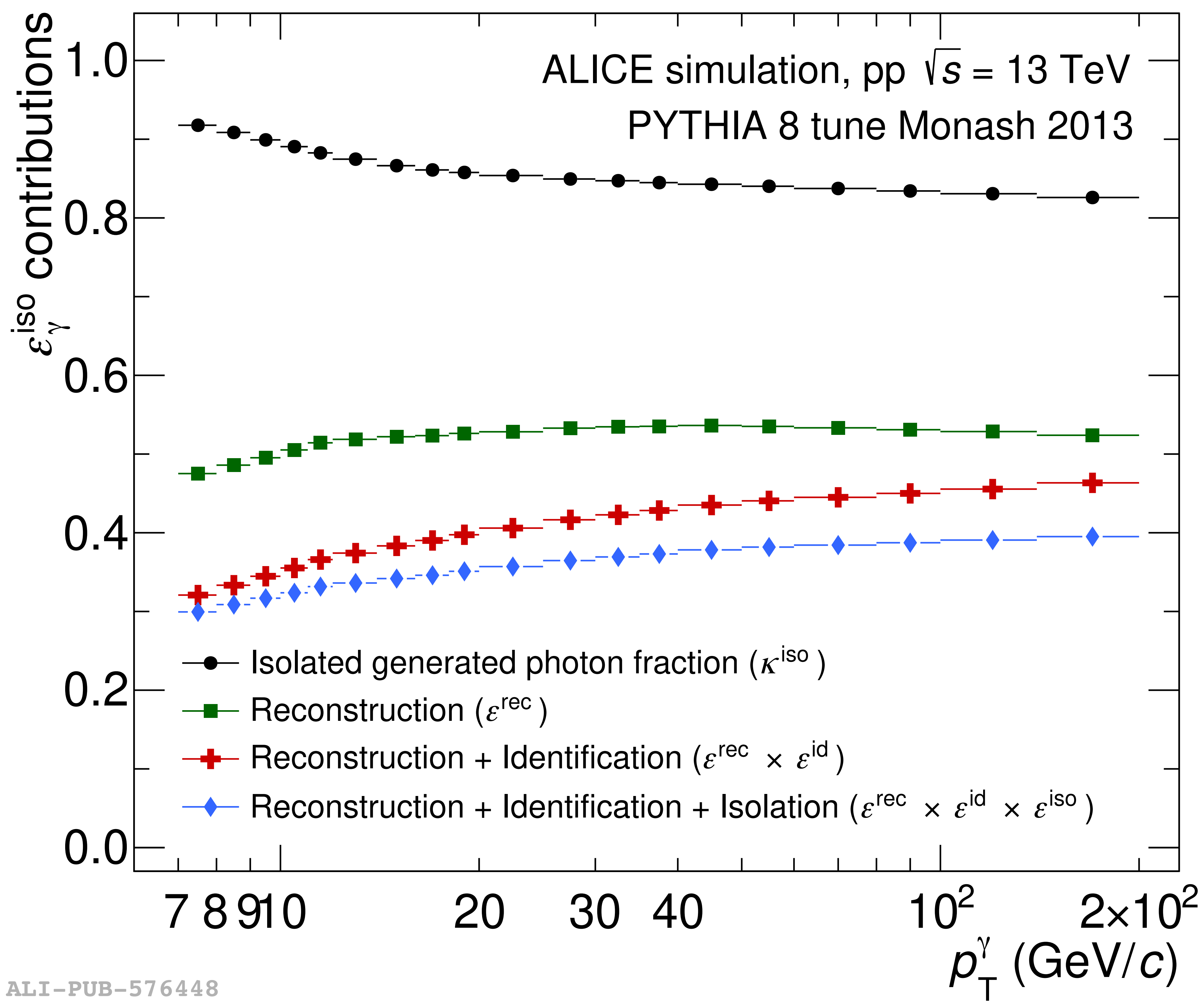
Purity for R = 0.2 & 0.4, pp & Pb–Pb $\sqrt{s_{NN}}$ = 5.02 TeV



- Distributions fitted to sigmoid function to reduce influence of fluctuations, fits used to correct the spectra
- P (R = 0.4) > P (R = 0.2) in pp collisions, more jet particles in cone, but decreasing centrality P (R = 0.2) > P (R = 0.4), due to UE fluctuations, although not significantly different
- P (Pb–Pb) > P (pp) due to better tracking and higher $N(\gamma)$ / $N(\pi^0)$ ratio ($R_{AA}(\pi^0) << 1$)

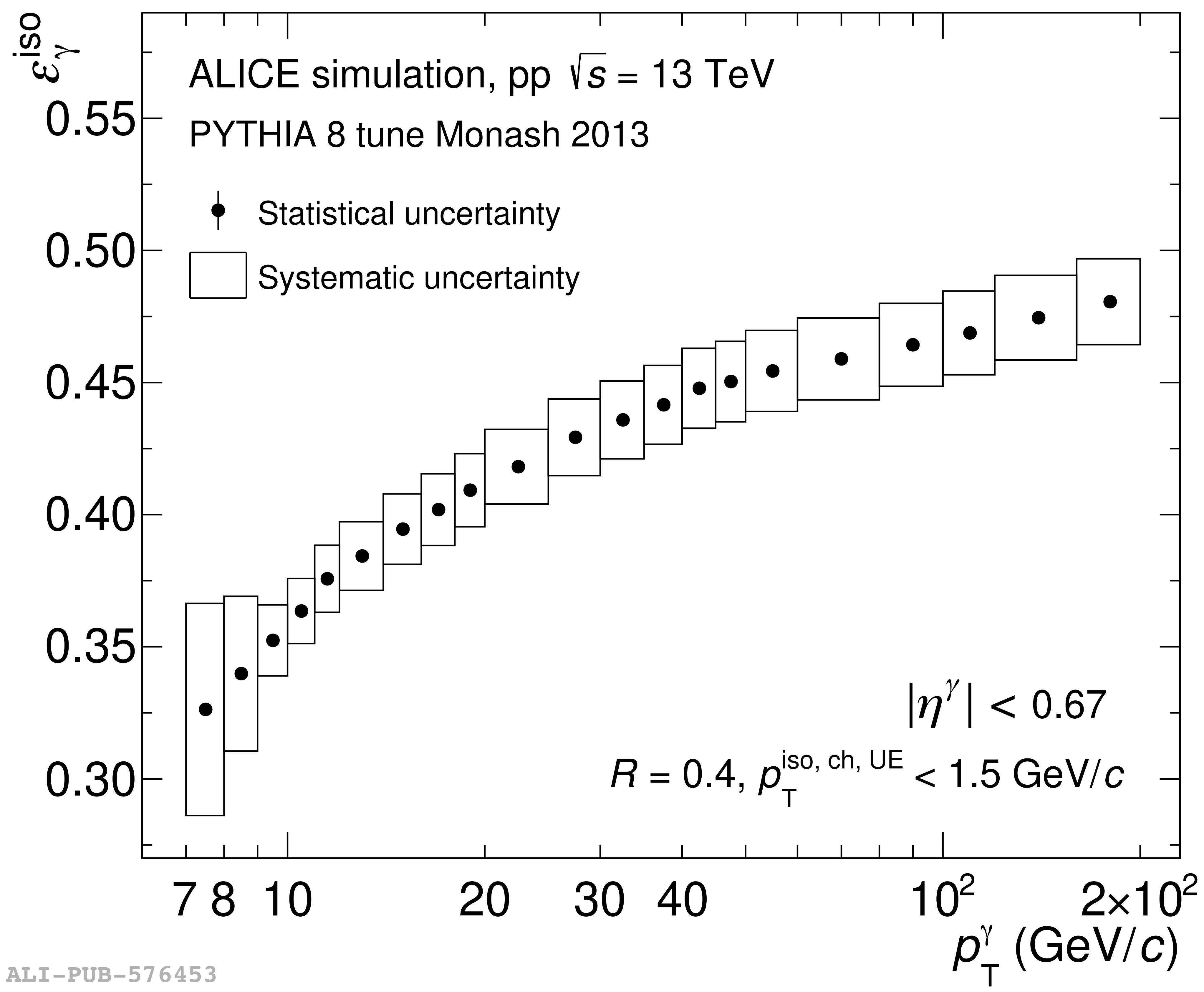
Isolated γ efficiency components, pp $\sqrt{s}$ = 13 TeV

$$\varepsilon^{\rm sel} = \frac{{\rm d}N^{\rm cluster\ sel.}_{\gamma_{\rm prompt}}/{\rm d}p_{\rm T}^{\rm rec}}{{\rm d}N^{\rm gener.}_{\gamma_{\rm prompt}}/{\rm d}p_{\rm T}^{\rm gen}}$$



ALI-PUB-576448

$$\varepsilon^{\rm iso}_{\gamma} = \frac{{\rm d}N^{\rm cluster\ iso.\ narrow}_{\gamma_{\rm prompt}}/{\rm d}p_{\rm T}^{\rm rec}}{{\rm d}N^{\rm gener.\ iso.}_{\gamma_{\rm prompt}}/{\rm d}p_{\rm T}^{\rm gen}}$$



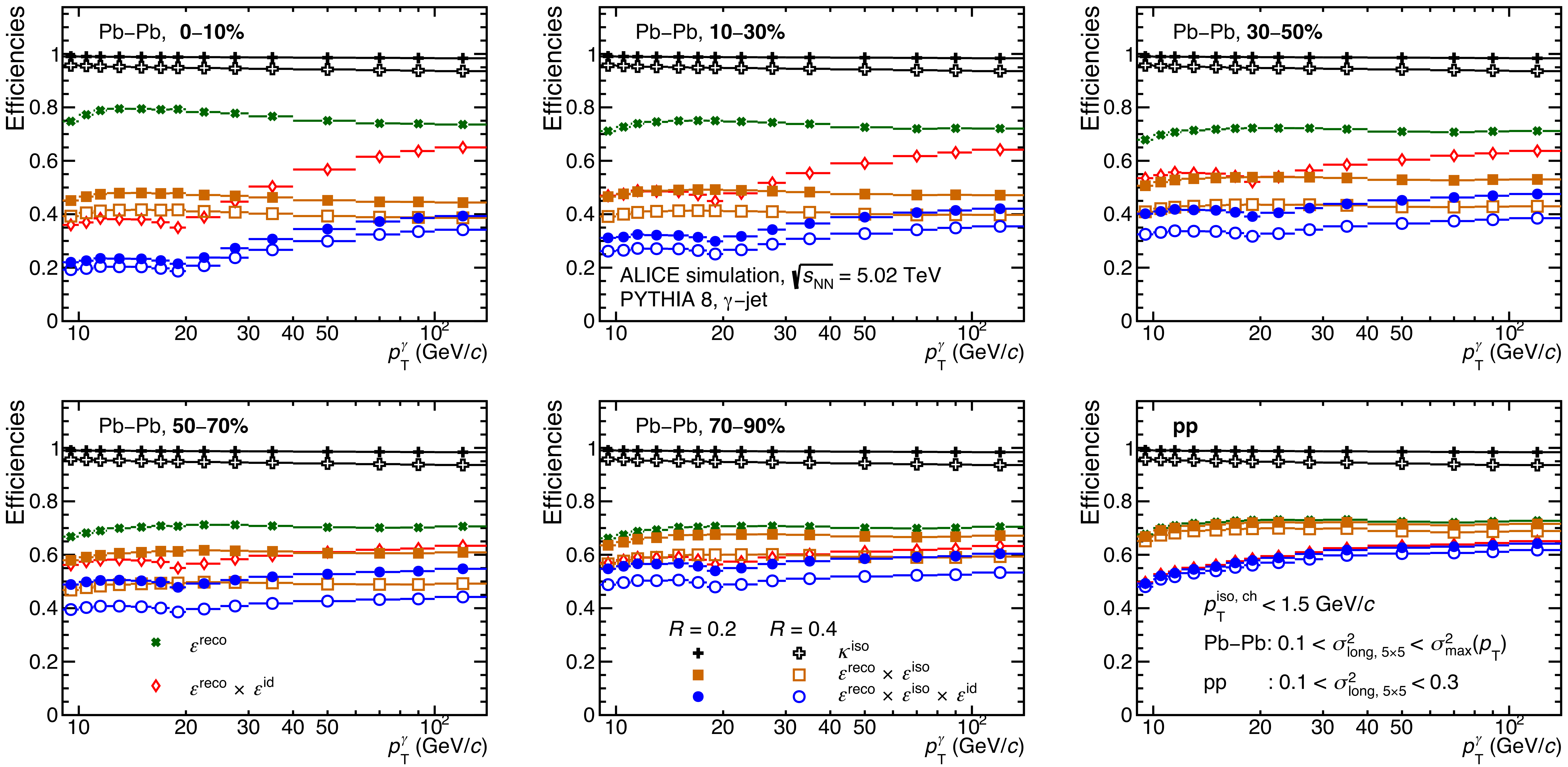
ALI-PUB-576453

Isolated γ efficiency components, pp & Pb–Pb $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV

ALICE

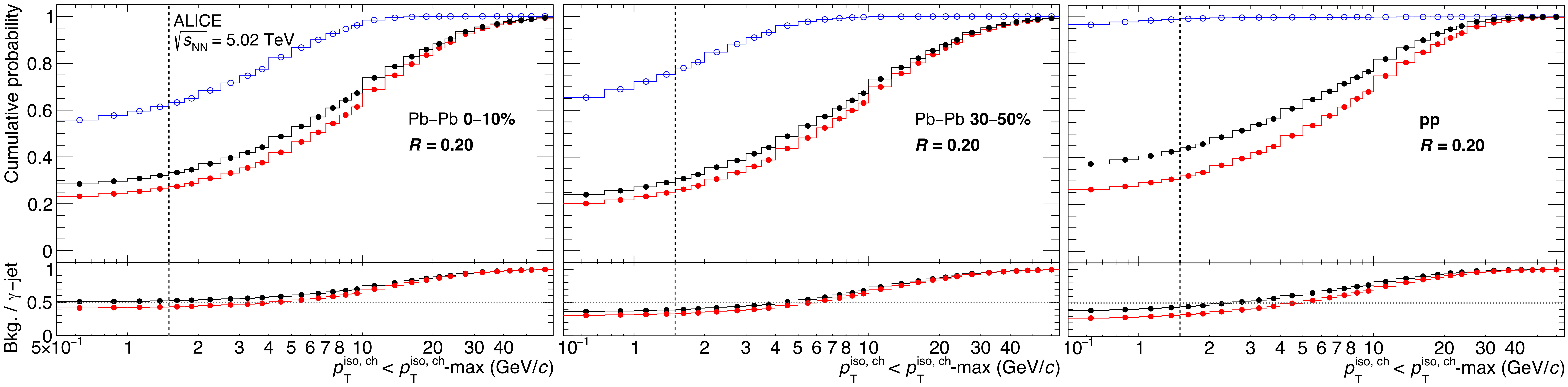
$$\varepsilon^{\mathrm{sel}} = \frac{\mathrm{d}N^{\mathrm{cluster\ sel.}}_{\gamma_{\mathrm{prompt}}}/\mathrm{d}p_{\mathrm{T}}^{\mathrm{rec}}}{\mathrm{d}N^{\mathrm{gener.}}_{\gamma_{\mathrm{prompt}}}/\mathrm{d}p_{\mathrm{T}}^{\mathrm{gen}}}$$

ALICE-PUBLIC-2024-003



Selection probability depending isolation threshold, R = 0.2, pp & Pb–Pb $\sqrt{s_{NN}}$ = 5.02 TeV

ALICE-PUBLIC-2024-003

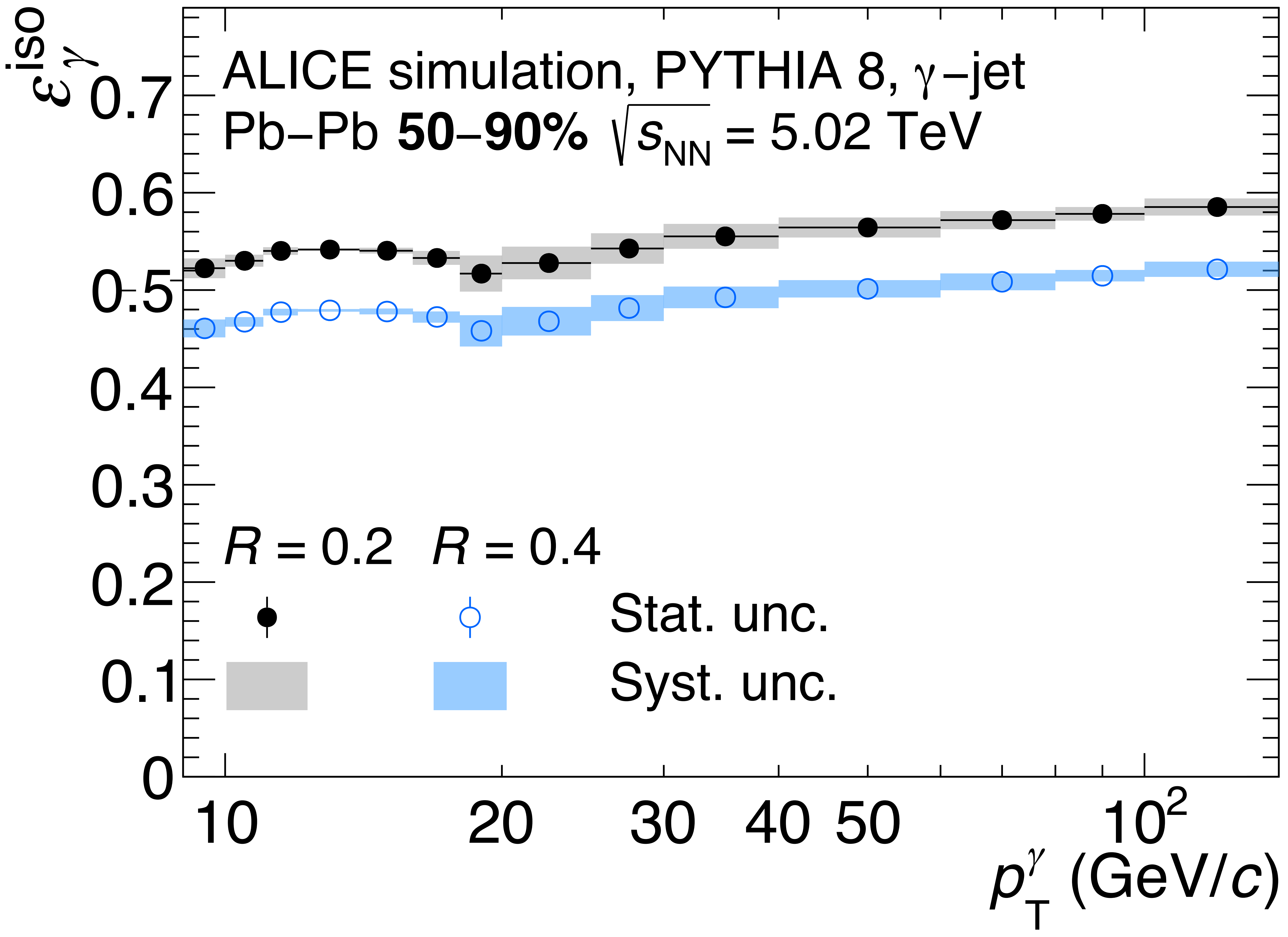


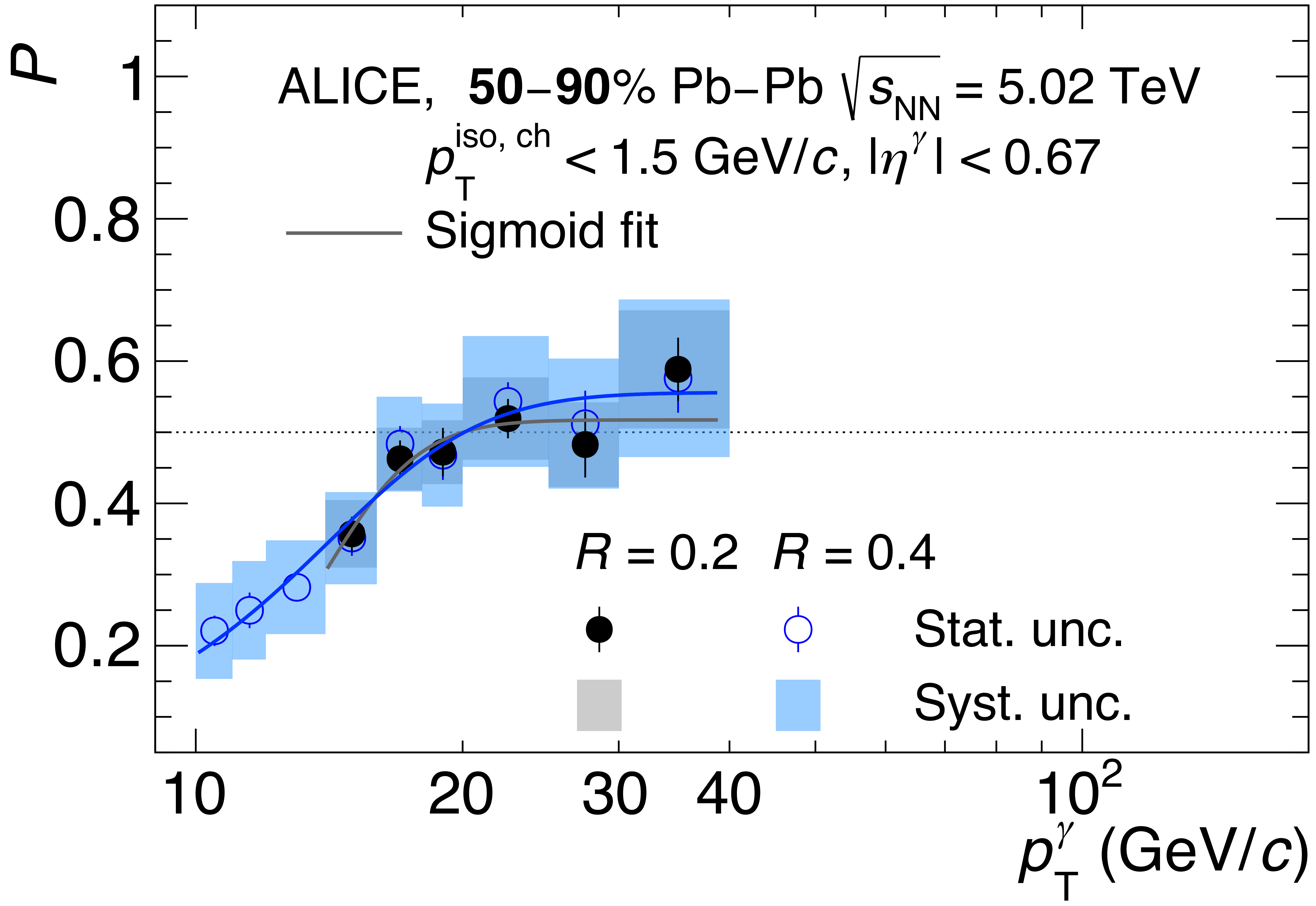
Selection probability depending isolation threshold, R = 0.4, pp & Pb–Pb $\sqrt{s_{NN}}$ = 5.02 TeV

ALICE-PUBLIC-2024-003

Pb–Pb 50-90%: efficiency and purity

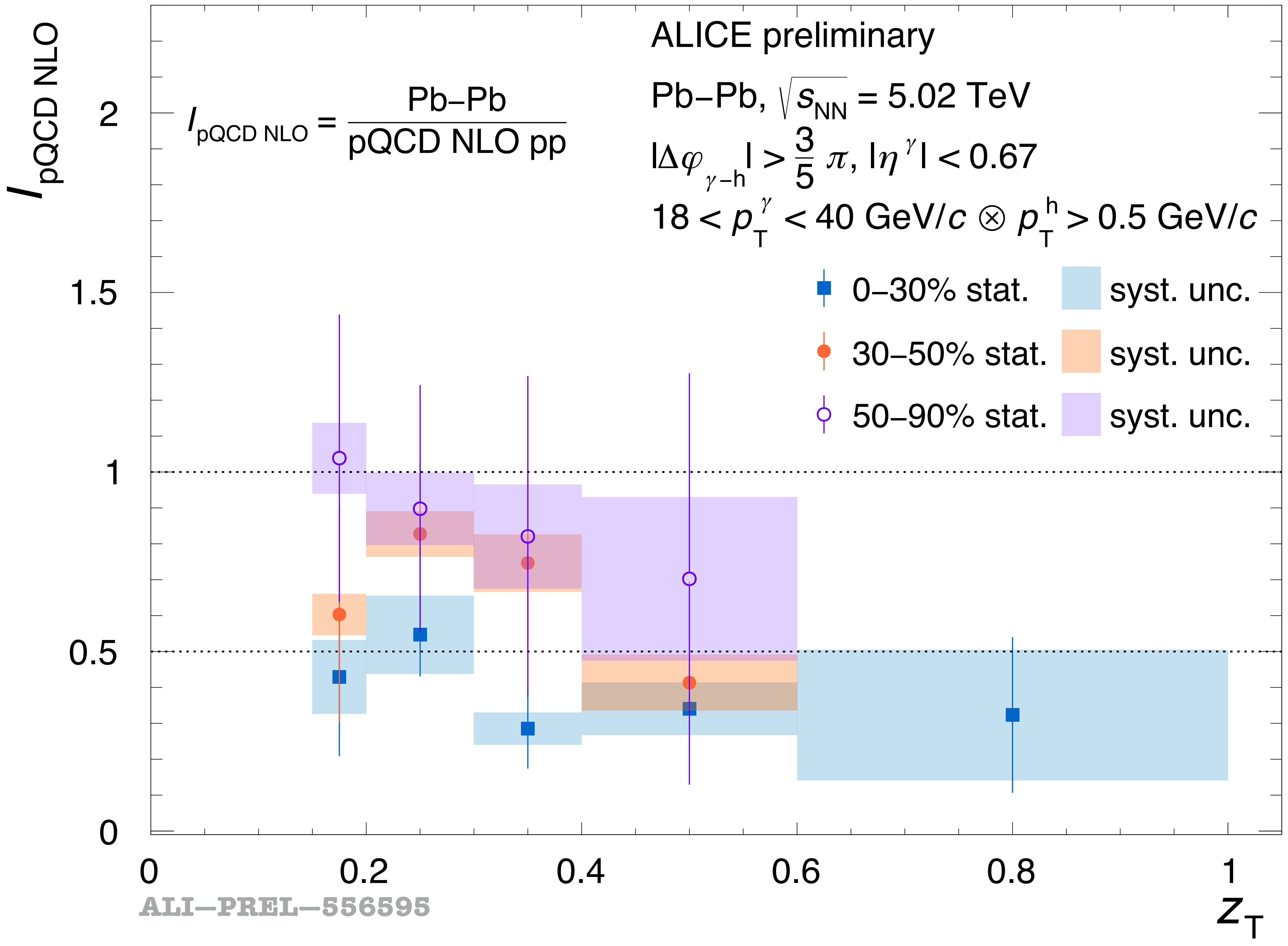
ALICE-PUBLIC-2024-003

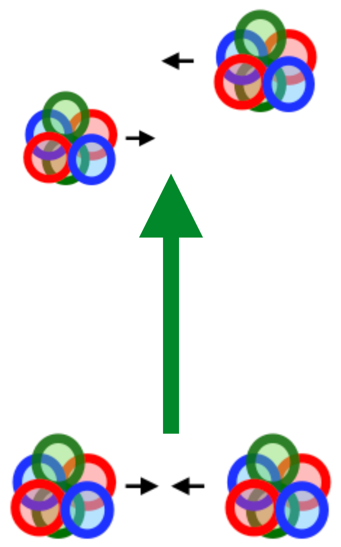




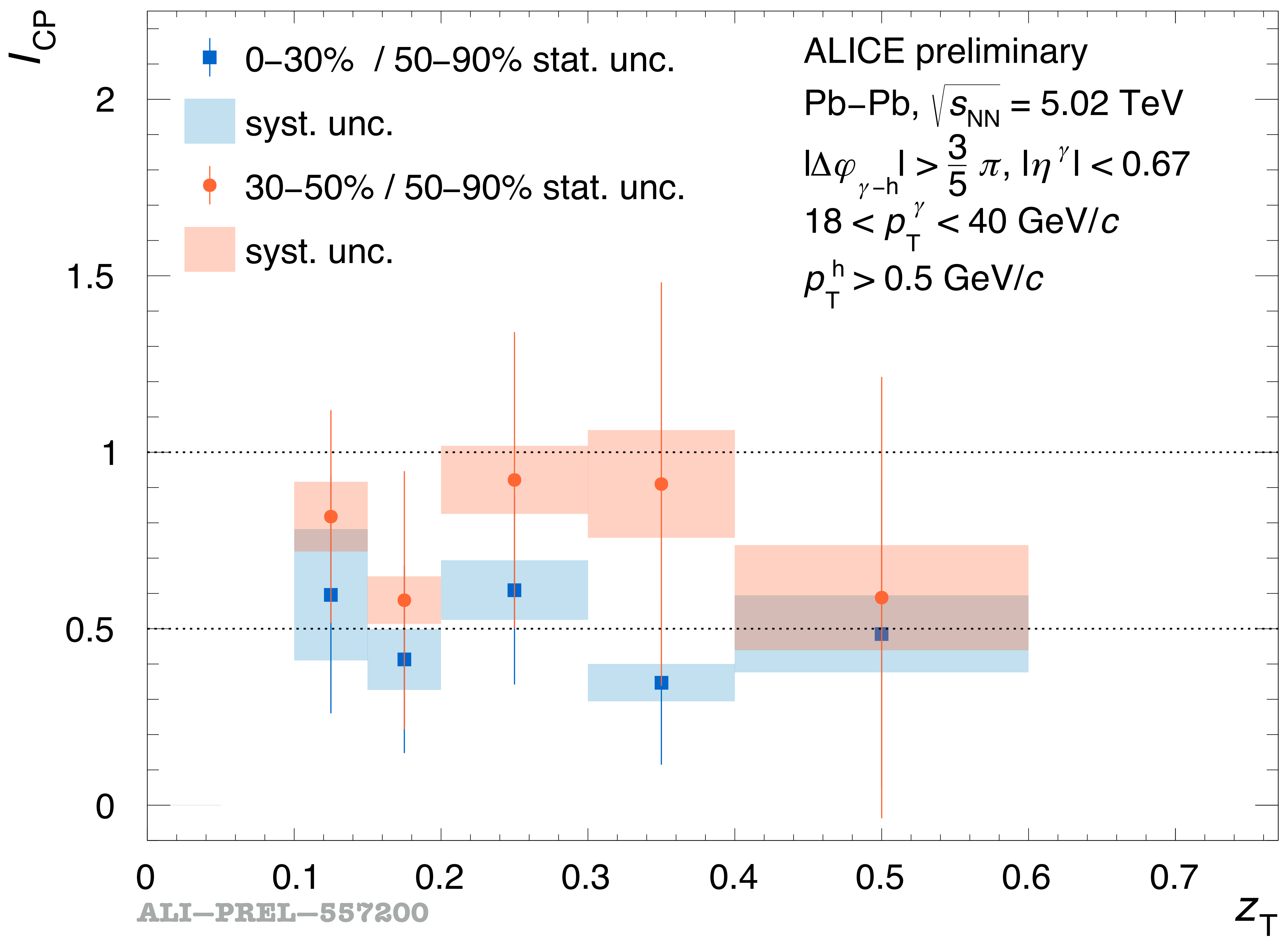
Isolated γ–hadron correlations in Pb–Pb: $D(z_T)$

I_{pQCD} = Pb–Pb Data / pp pQCD



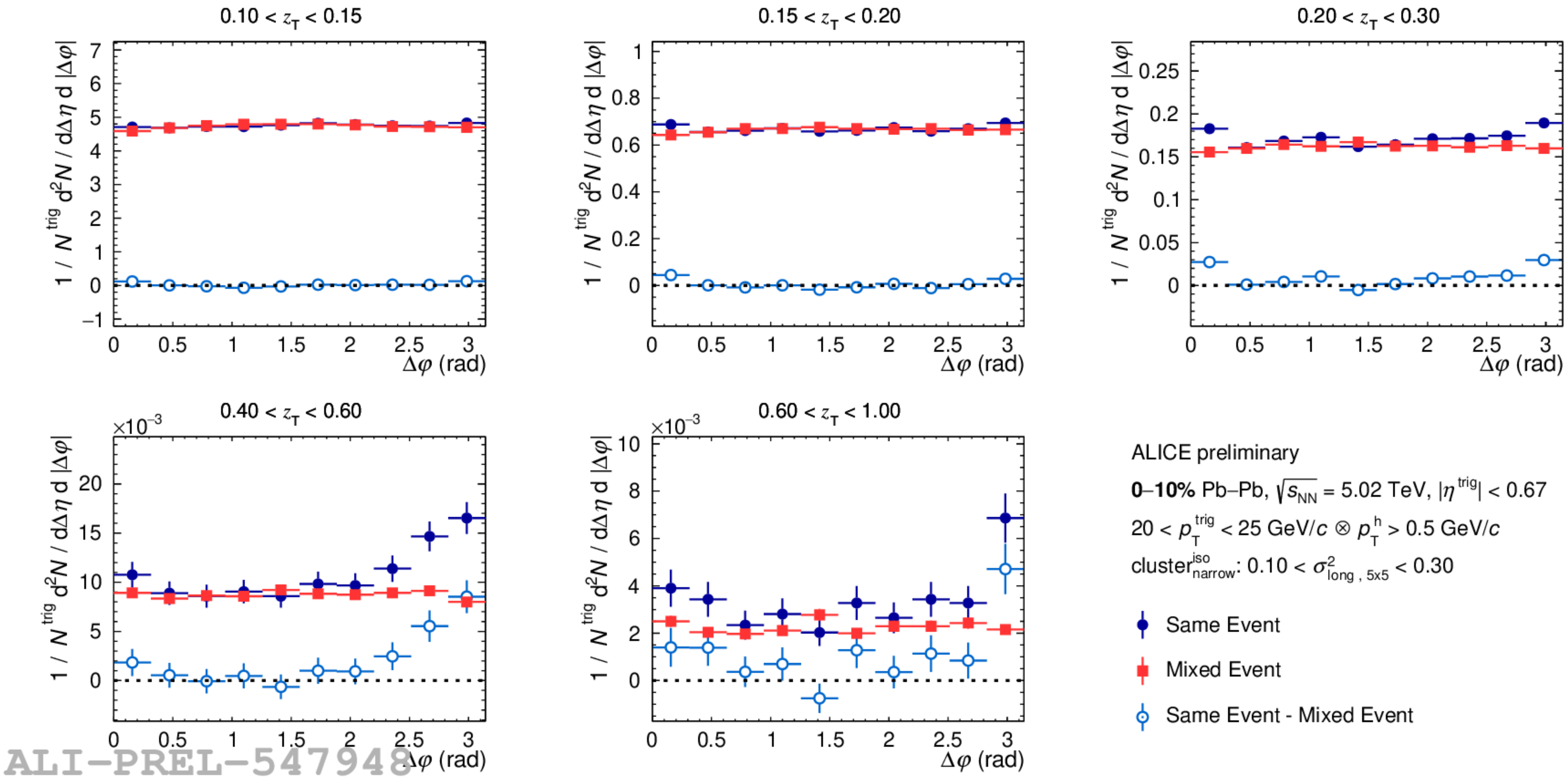


I_{CP} = Pb–Pb (semi) central / peripheral

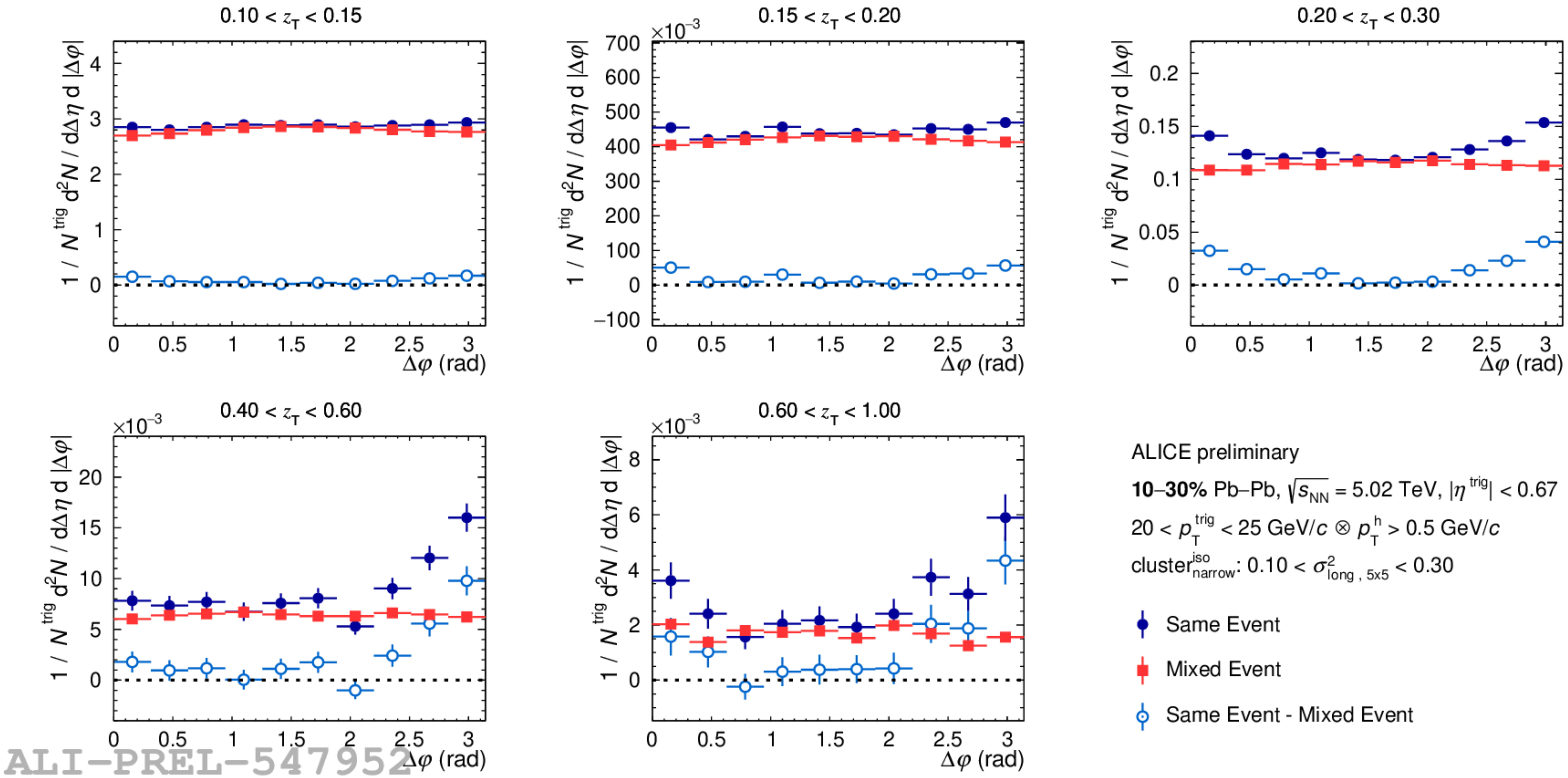


Isolated γ-hadron correlations in Pb–Pb: $D(z_T)$

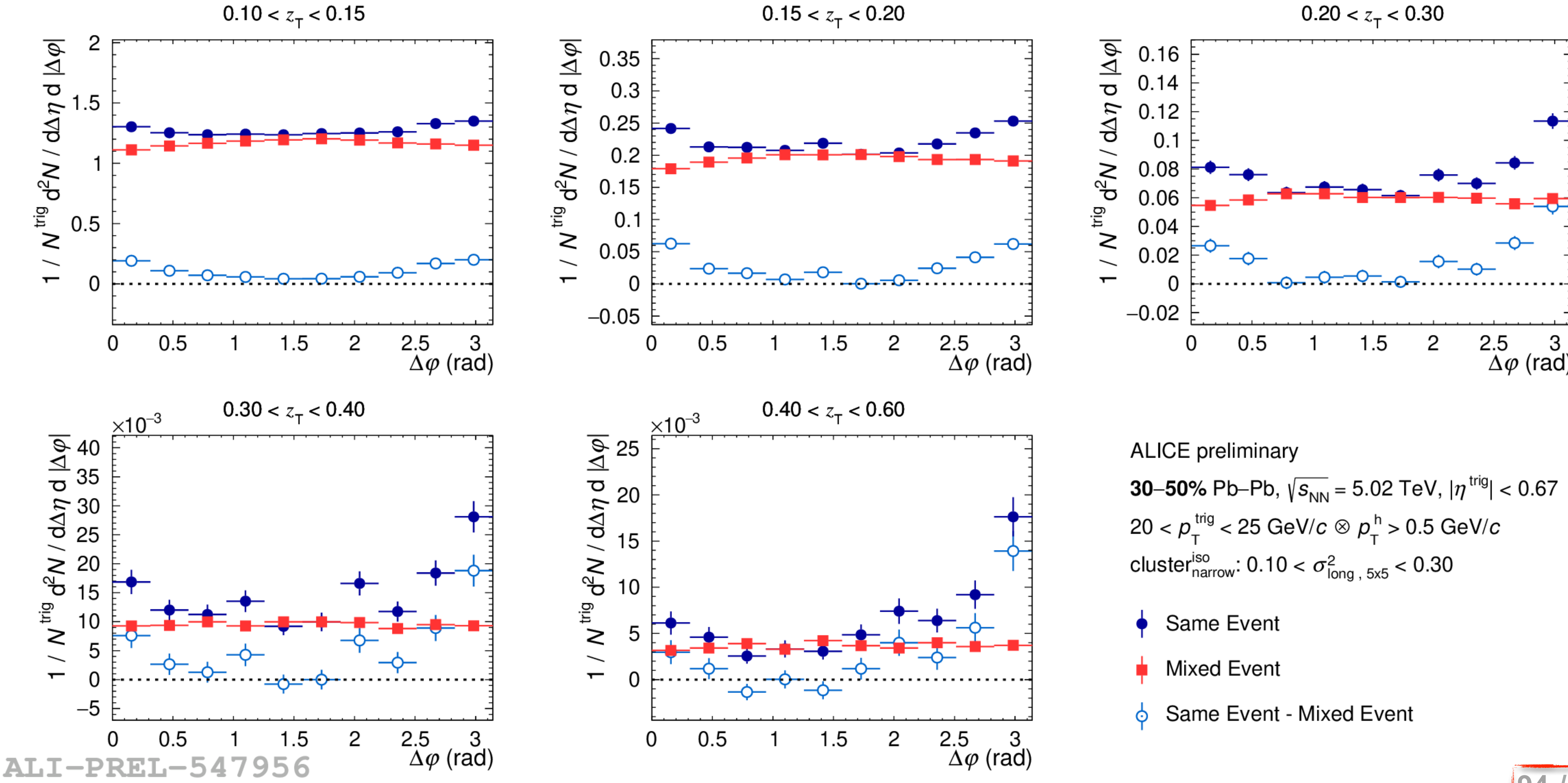
ALICE



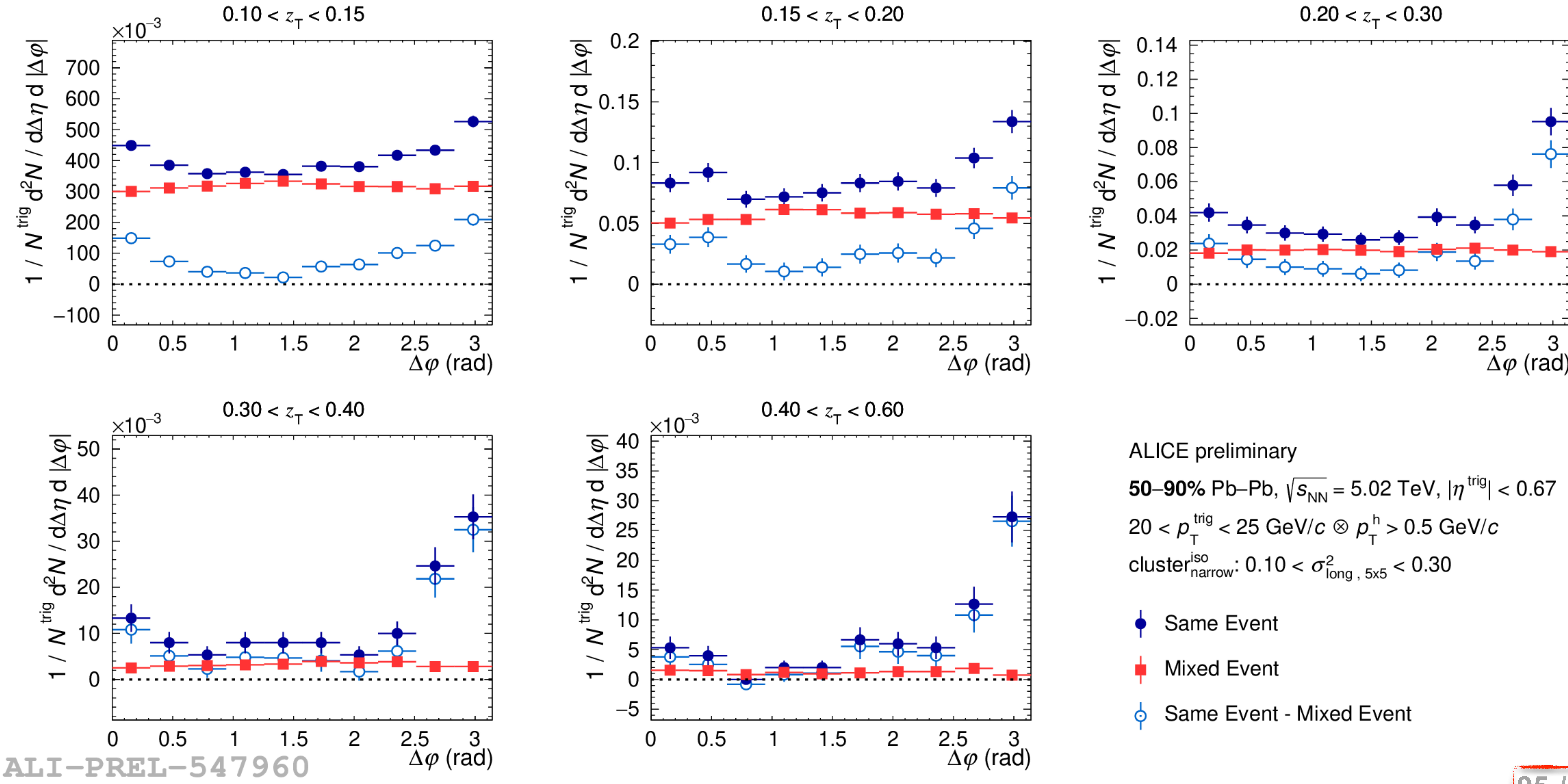
Isolated γ-hadron correlations in Pb–Pb: $D(z_T)$



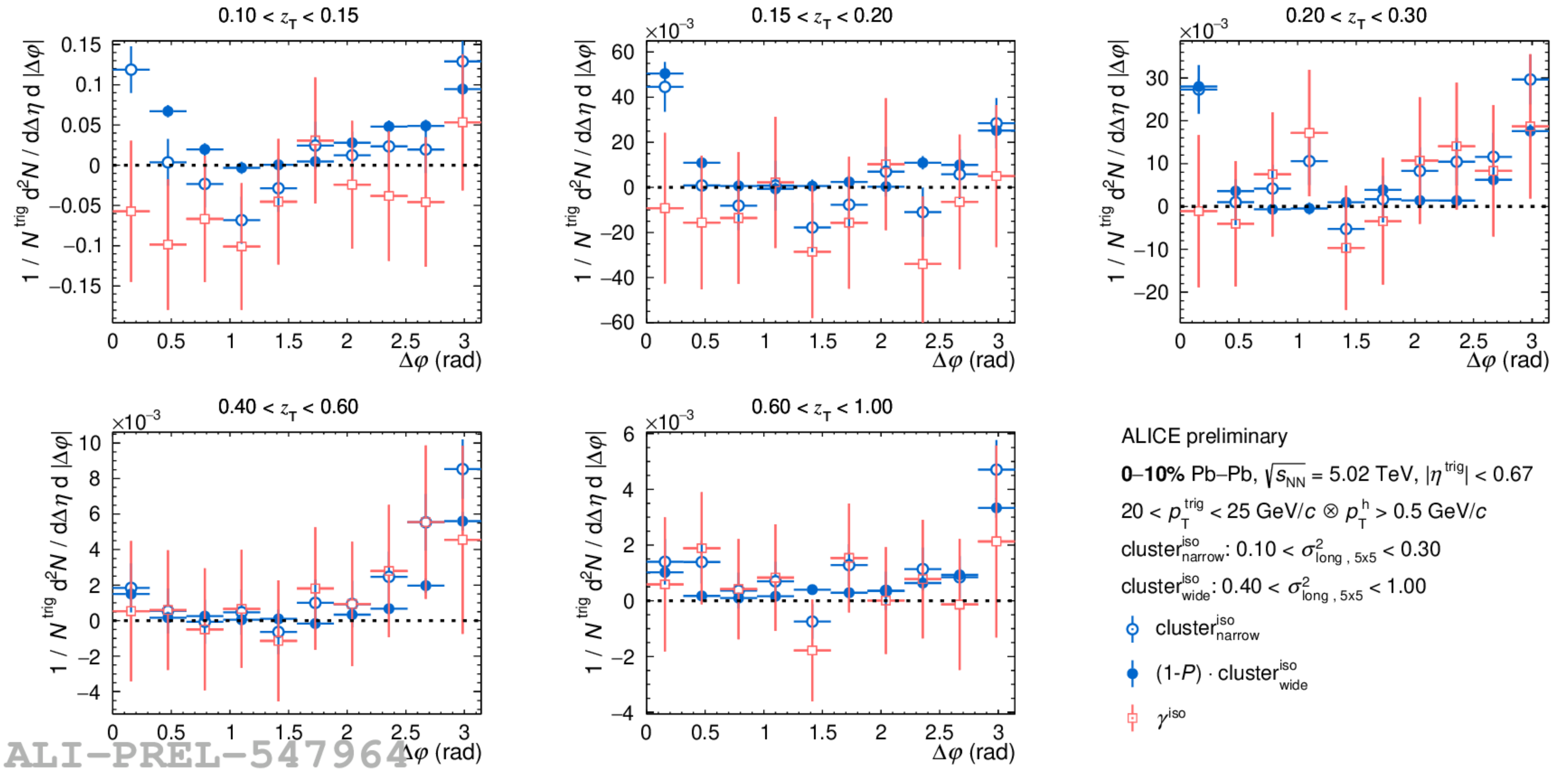
Isolated γ-hadron correlations in Pb–Pb: $D(z_T)$



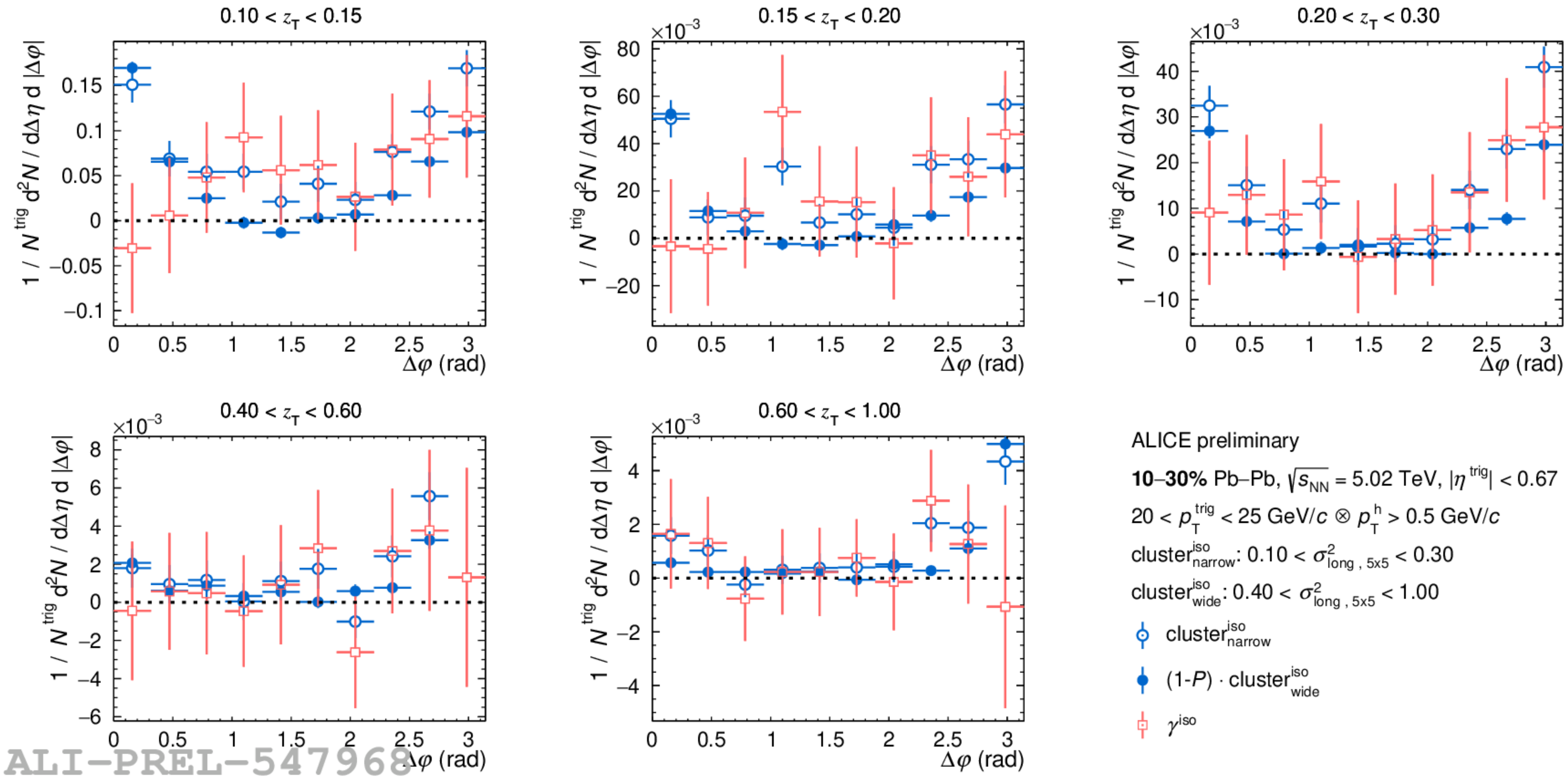
Isolated γ-hadron correlations in Pb–Pb: $D(z_T)$



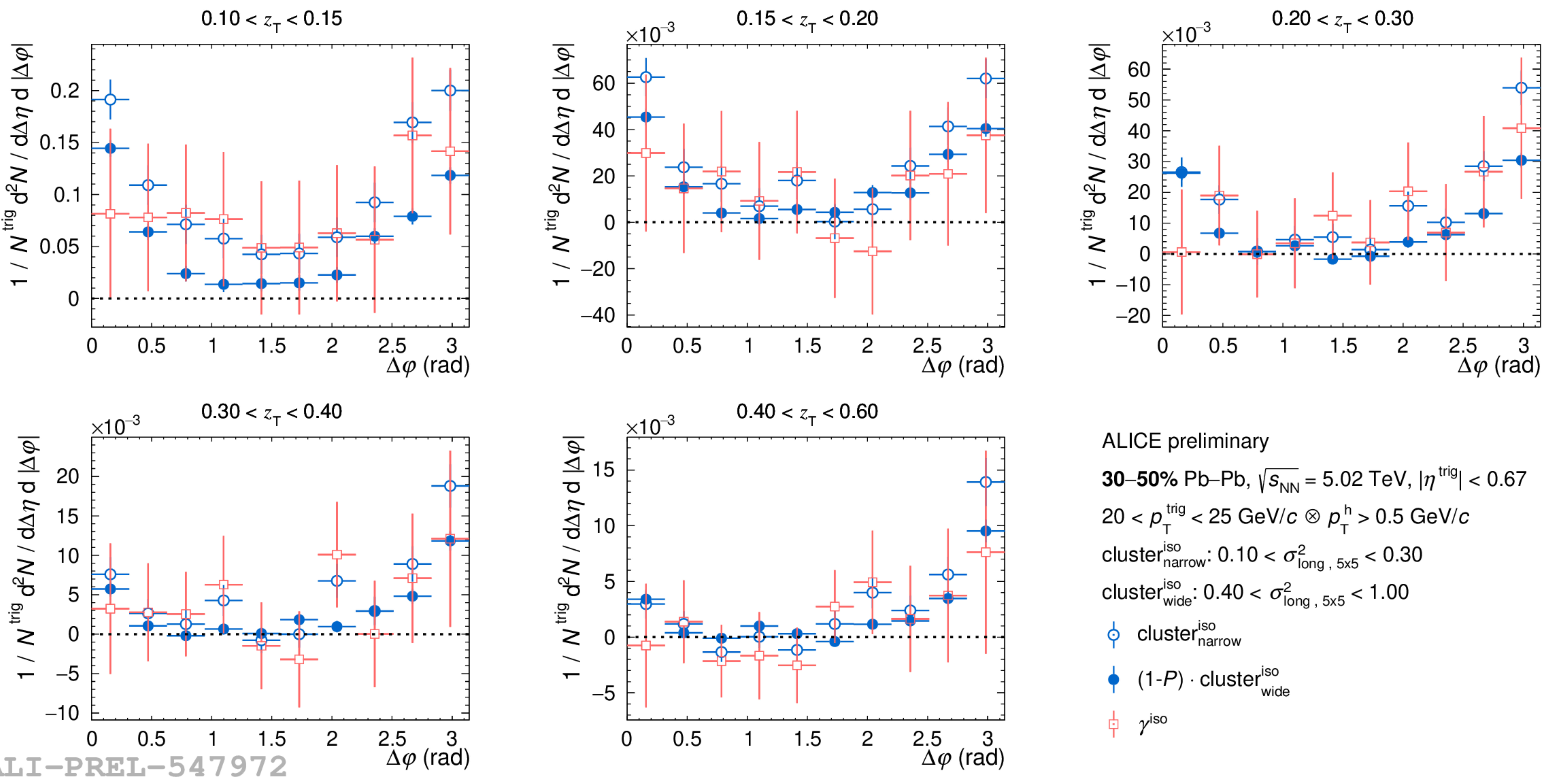
Isolated γ-hadron correlations in Pb–Pb: $D(z_T)$



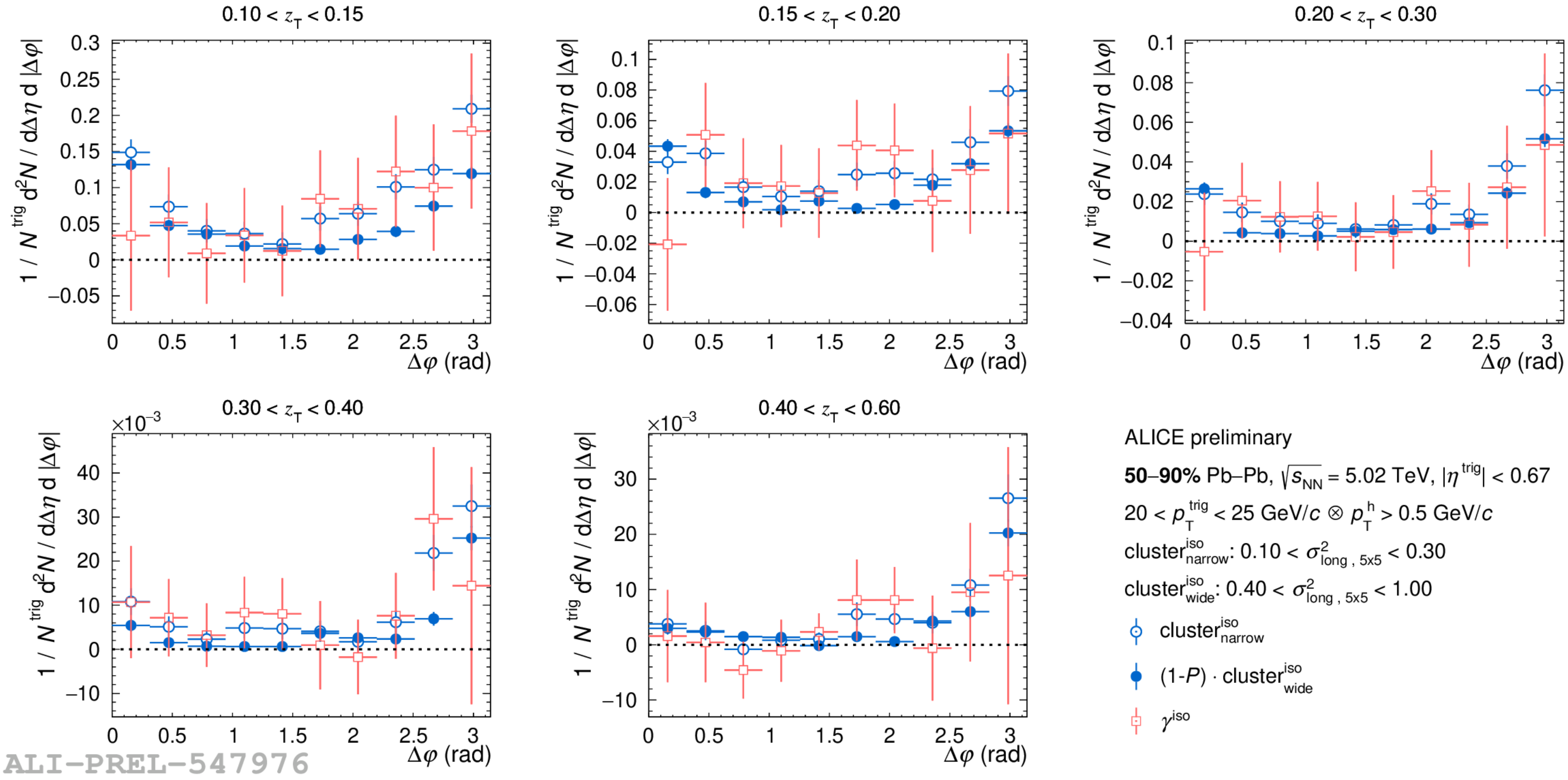
Isolated γ-hadron correlations in Pb–Pb: $D(z_T)$



Isolated γ-hadron correlations in Pb–Pb: $D(z_T)$



Isolated γ-hadron correlations in Pb–Pb: $D(z_T)$



Isolated γ cross section R ratio in ATLAS, pp $\sqrt{s}$ = 13 TeV

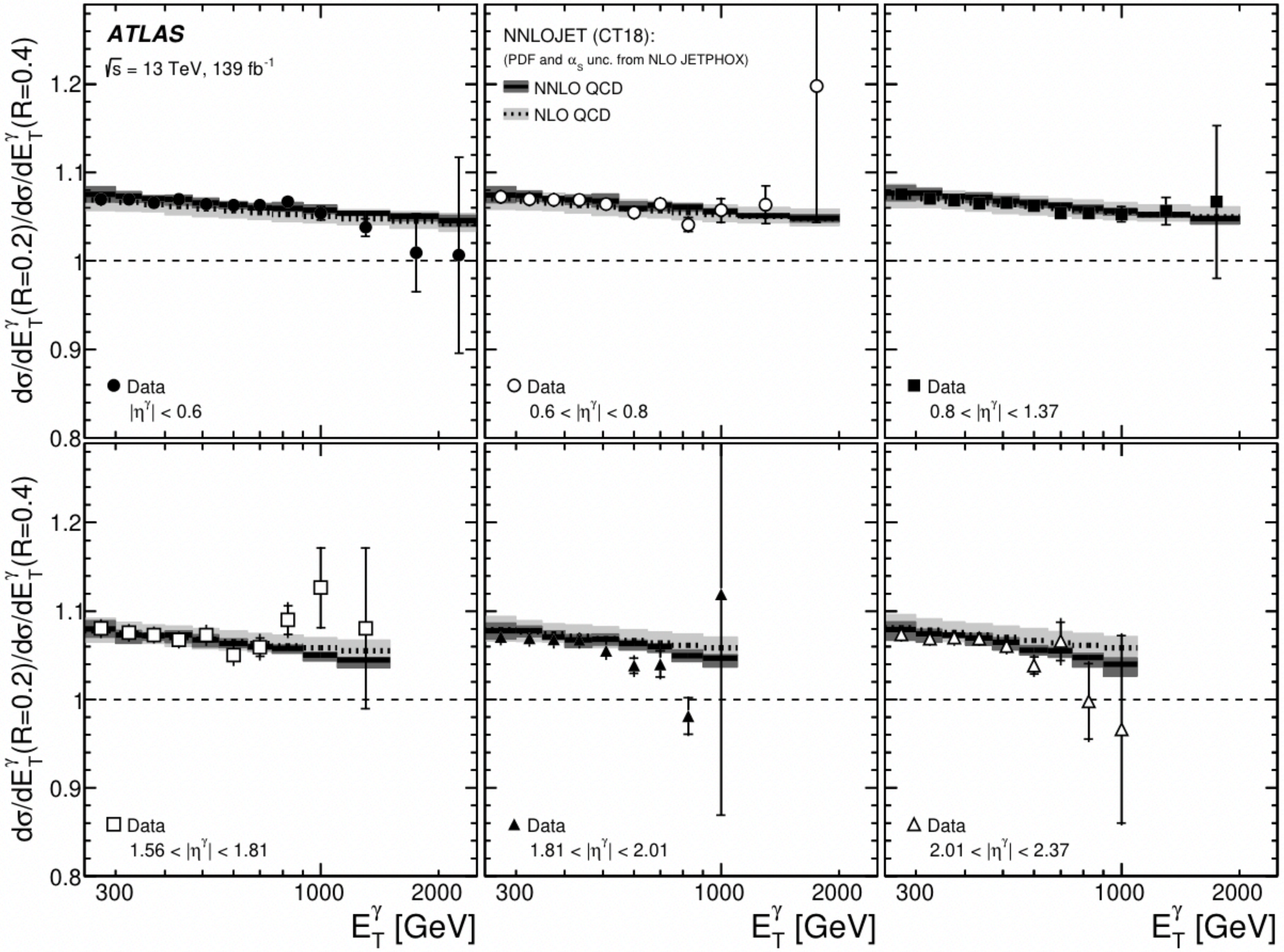


Figure 21: Measured ratios of the differential cross sections for inclusive isolated-photon production for $R = 0.2$ and $R = 0.4$ as functions of E_T^γ in different η^γ regions. The NLO (dotted lines) and NNLO (solid lines) pQCD predictions from NNLOJET based on the CT18 PDF set are also shown. The inner (outer) error bars represent the statistical uncertainties (statistical and systematic uncertainties added in quadrature) and the shaded bands represent the theoretical uncertainties. For some of the points, the inner and outer error bars are smaller than the marker size and, thus, not visible.

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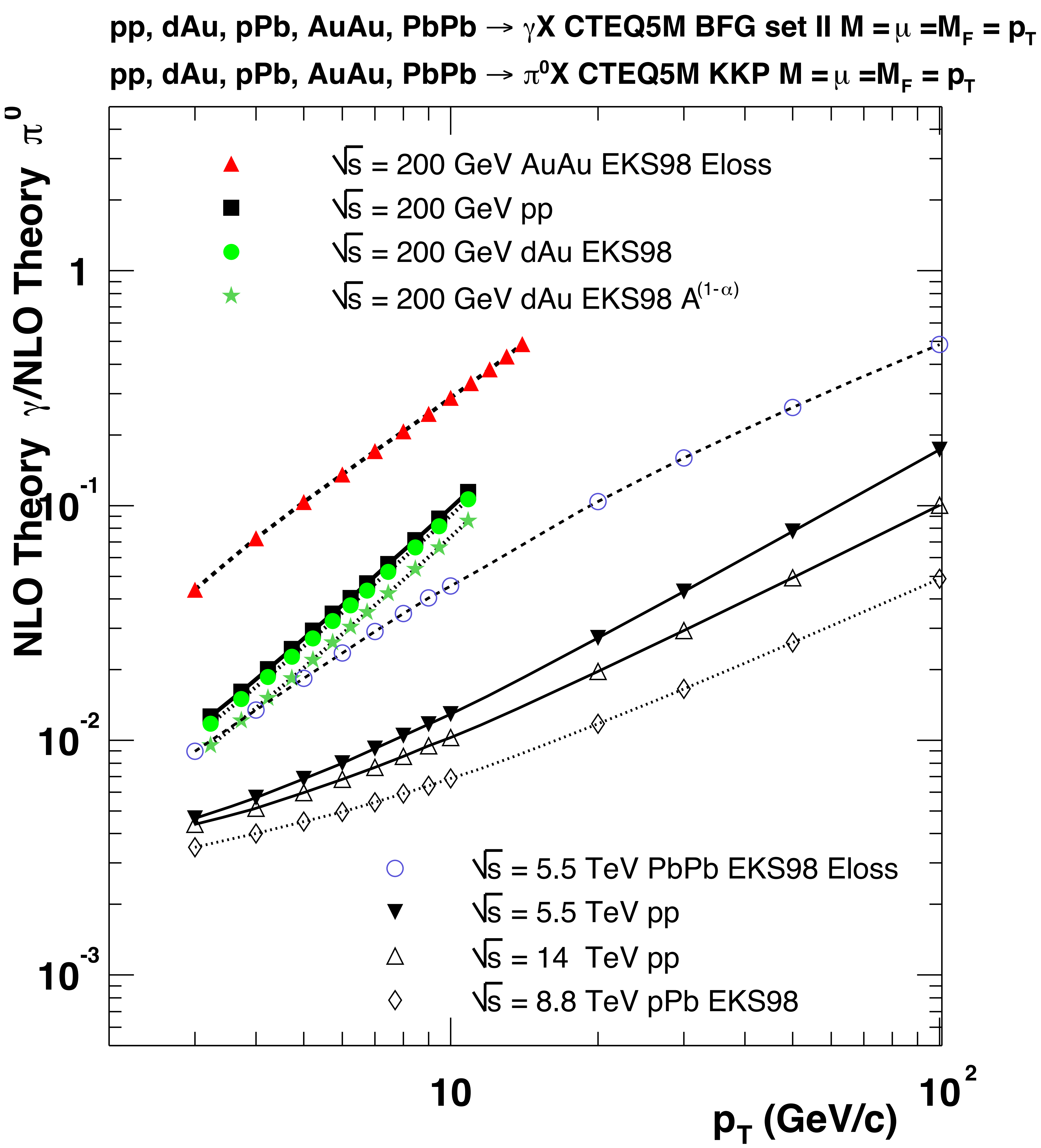
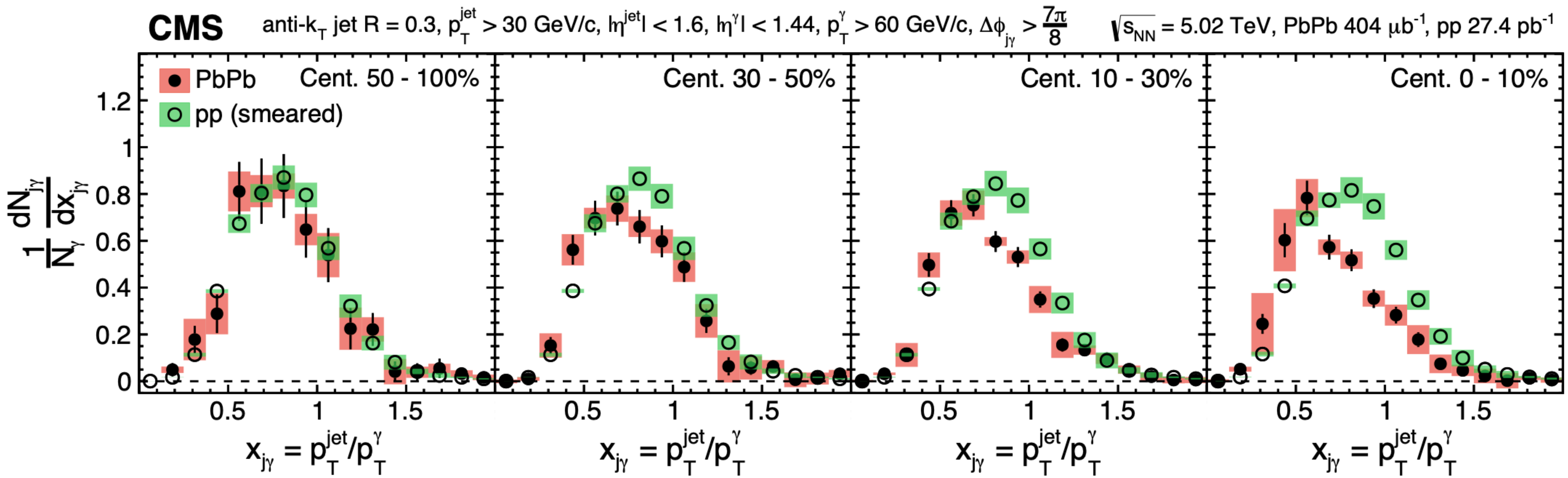
arXiv:2302.00510

Inclusive prompt γ to π^0 ratio



Photon yellow report (2003)
arXiv:hep-ph/031113

Isolated γ-jet correlations in Pb–Pb: $x_{\gamma j} = p_T^{jet}/p_T^{\gamma}$, CMS

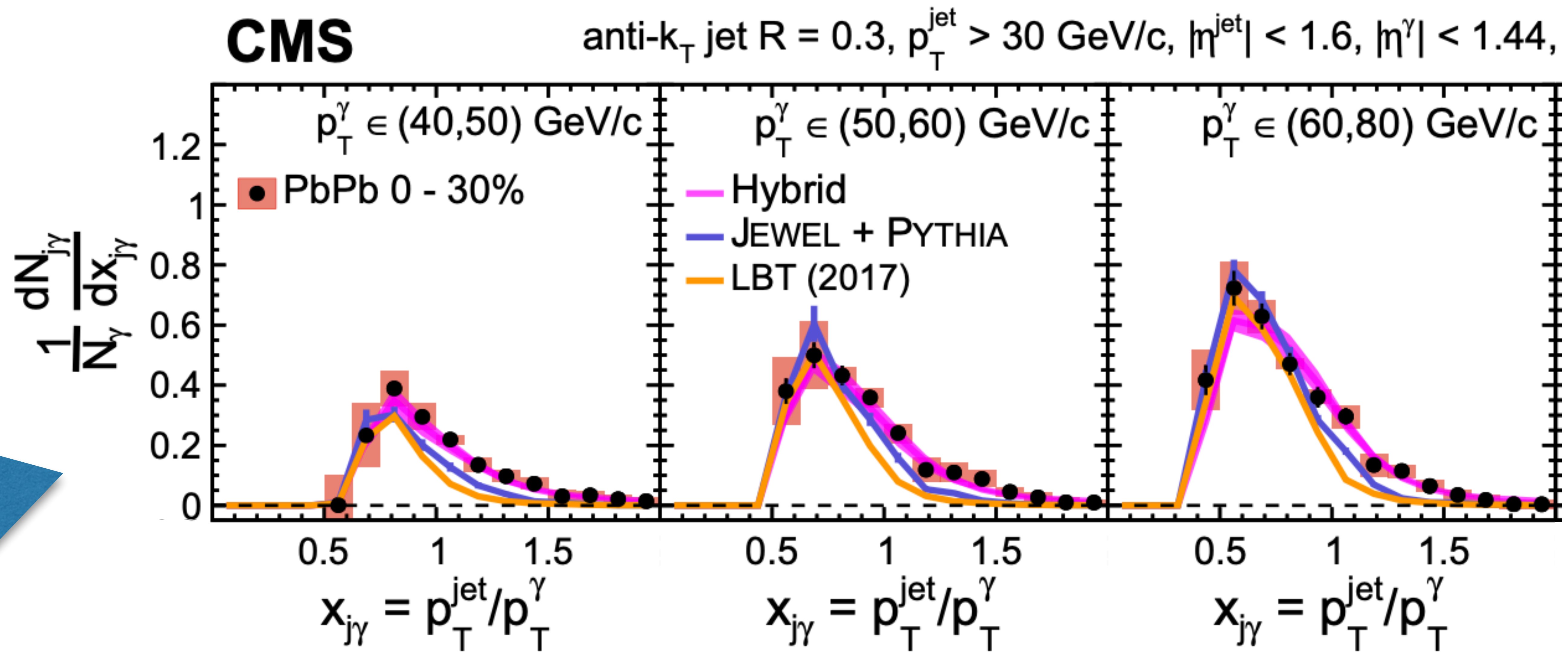


[Phys. Lett. B, 785:14–39, 2018]

➡ **γ**-tagged jets momentum is smaller than the trigger **γ** in central collisions

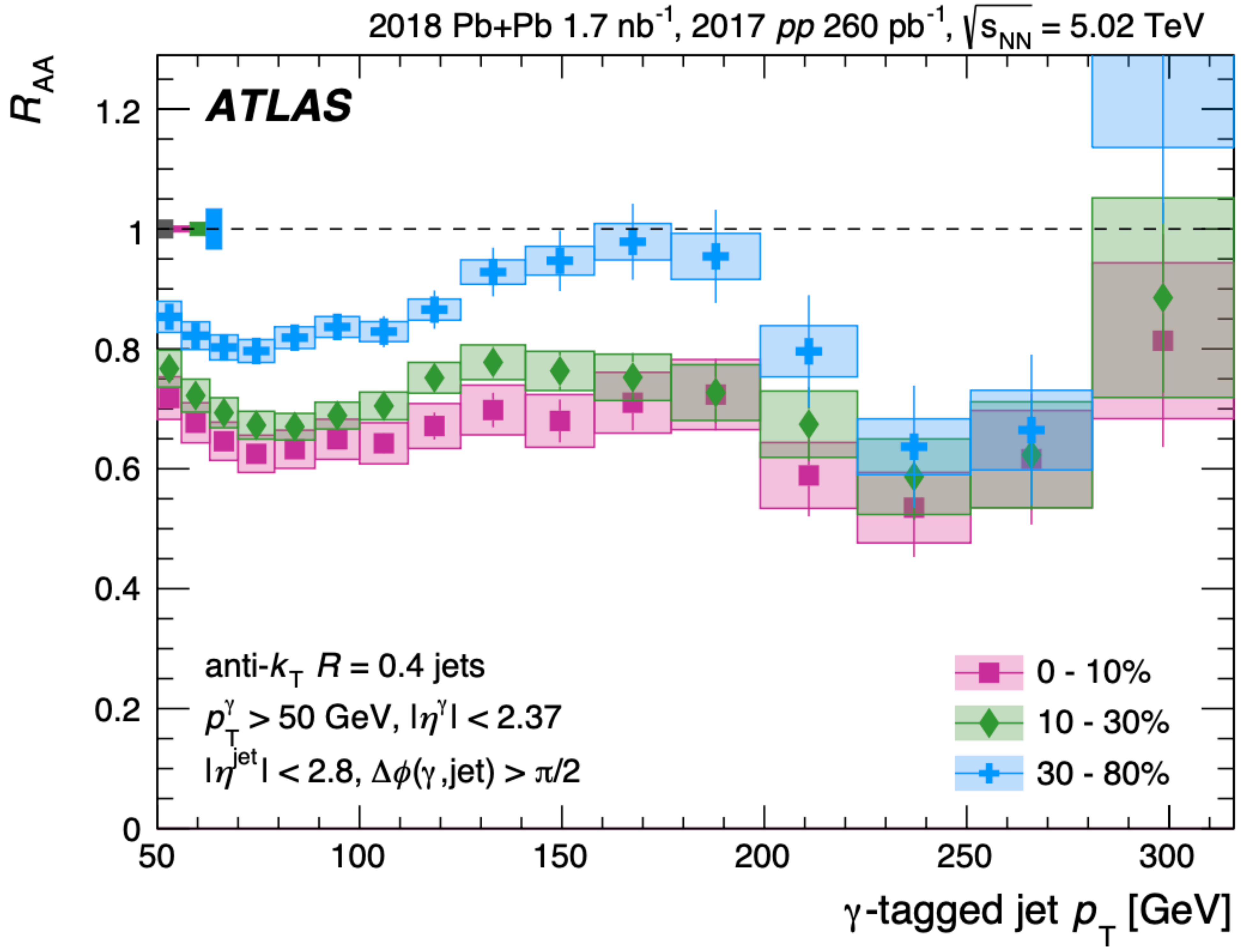
- Jet energy is shifted down
- **Energy loss of quarks in the QGP**

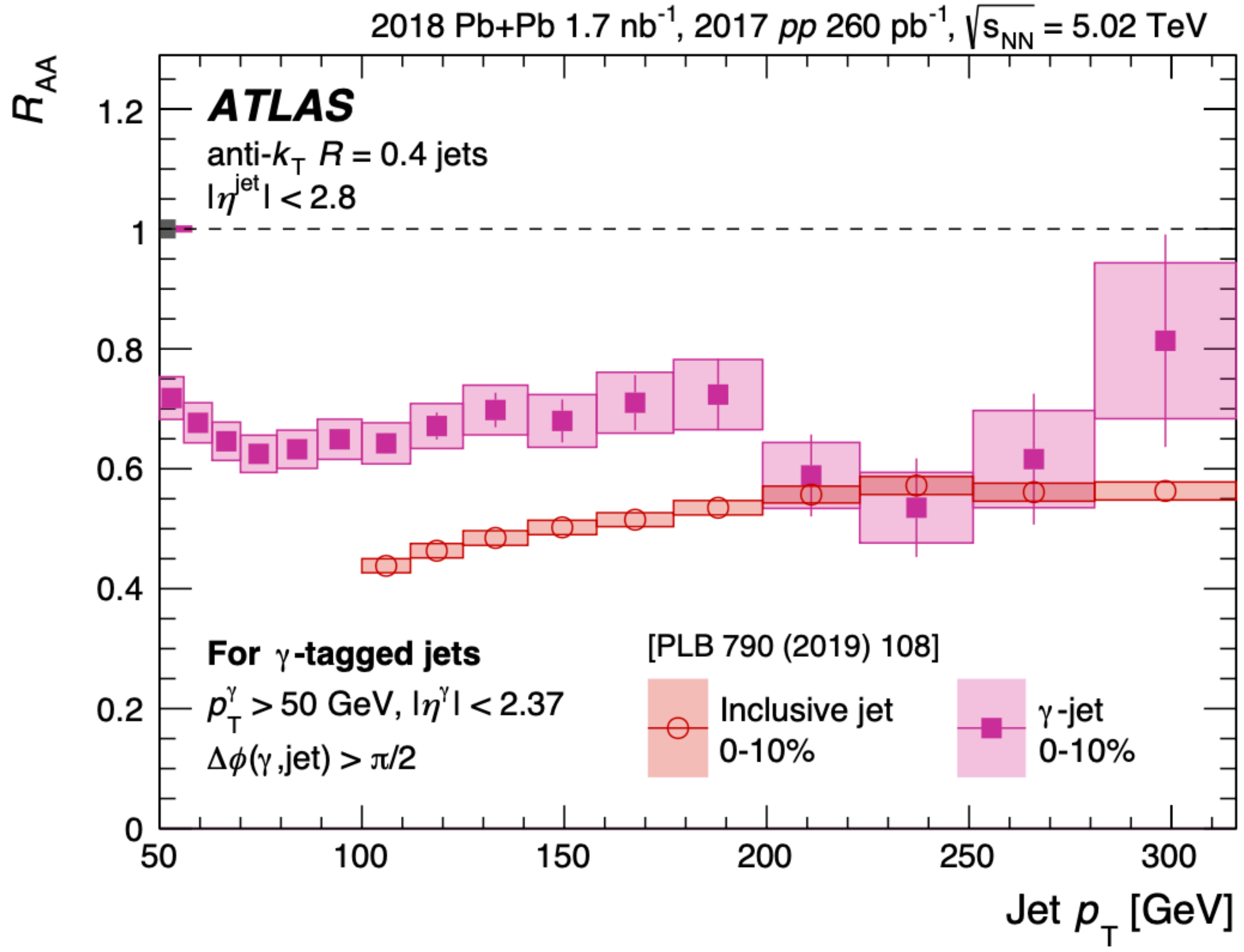
➡ Reproduced by different models, "Hybrid" model seems best in central collisions



Isolated γ-jet correlations in Pb–Pb: R_{AA}, ATLAS

Phys. Lett. B, 846:138154, 2023





At high p_T, inclusive and tagged jets agree.

Expected: quark fraction of inclusive jets increases with p_T

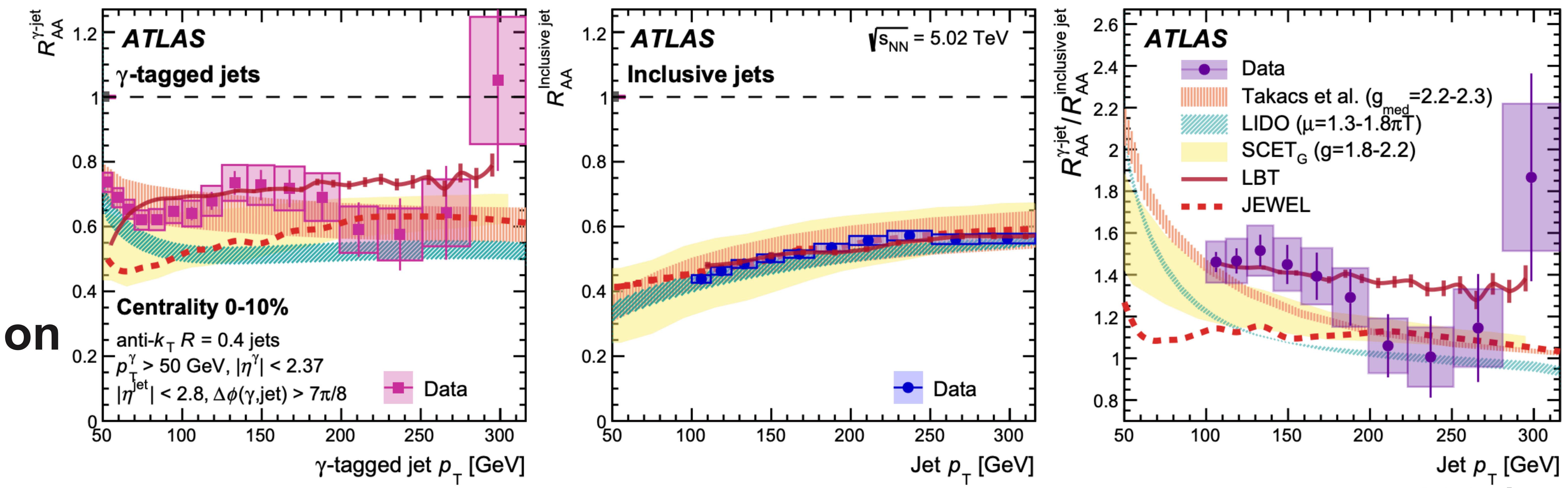
Theory: LBT is the best to reproduce lower p_T, but other models higher p_T

γ-tagged jets are suppressed … but,

γ-tagged jets (quark) are less suppressed than inclusive jets (gluon)!

***ΔE* loss from quark < *ΔE* loss from gluon**

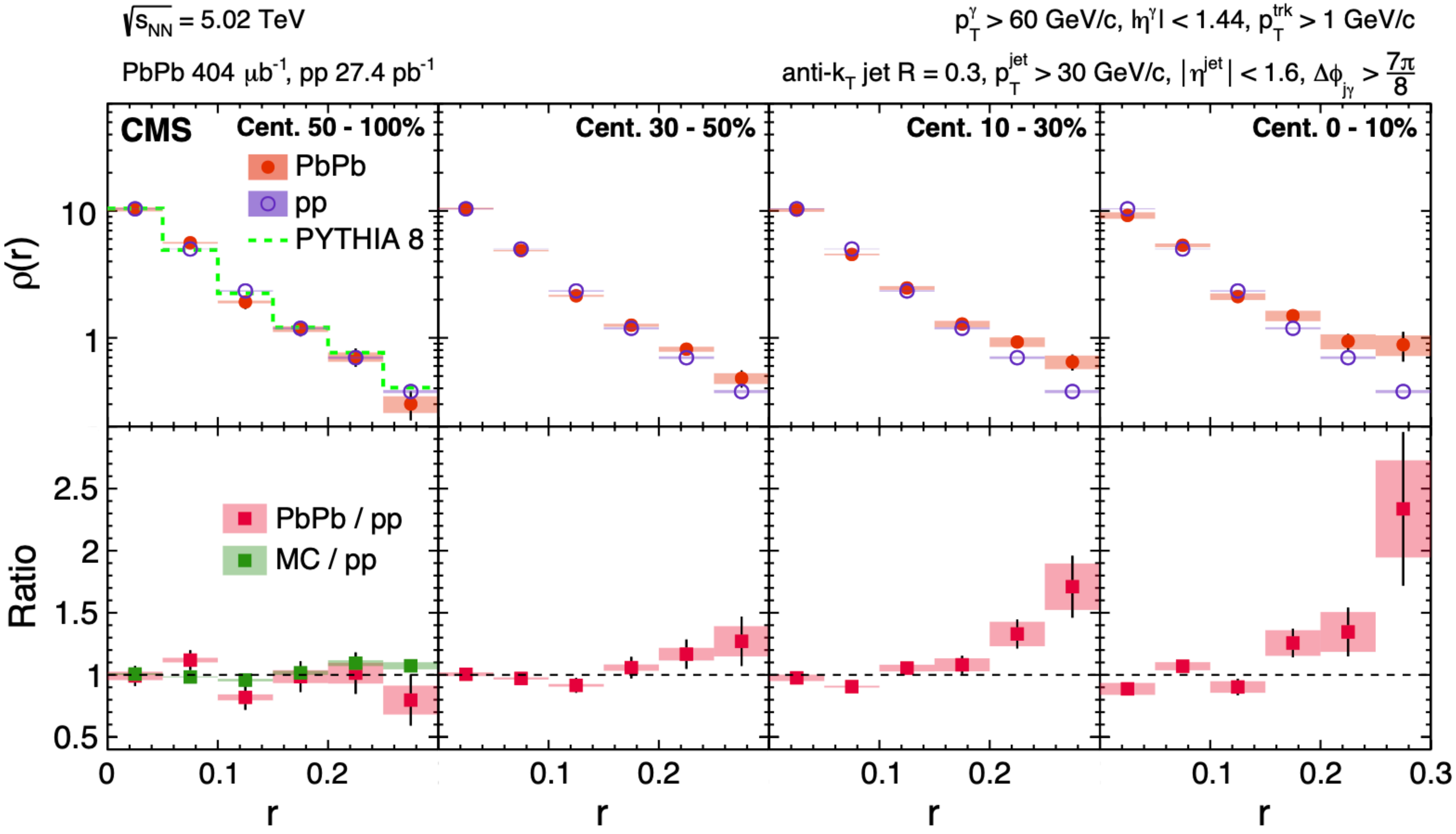
➡ ***where is the ΔE radiated?***

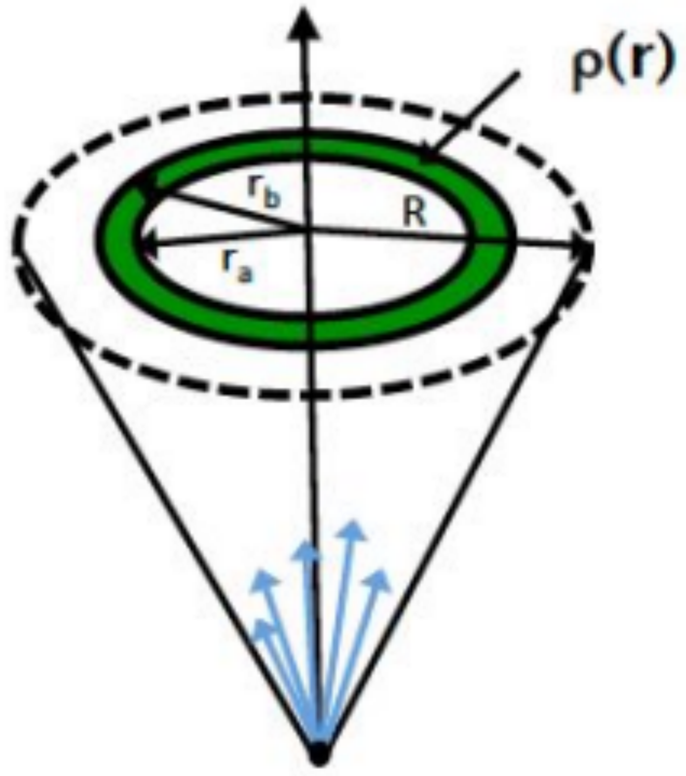


Isolated γ-jet correlations in pp Pb–Pb: ρ(r), CMS

[Phys. Rev. Lett., 122(15):152001, 2019.]

$$\rho(r) = \frac{1}{\delta r}\,\frac{\sum_{\text{jets}}\sum_{r_a<r<r_b}(p_T{}^{\text{trk}}/p_T{}^{\text{jet}})}{\sum_{\text{jets}}\sum_{0<r<r_f}(p_T{}^{\text{trk}}/p_T{}^{\text{jet}})}$$

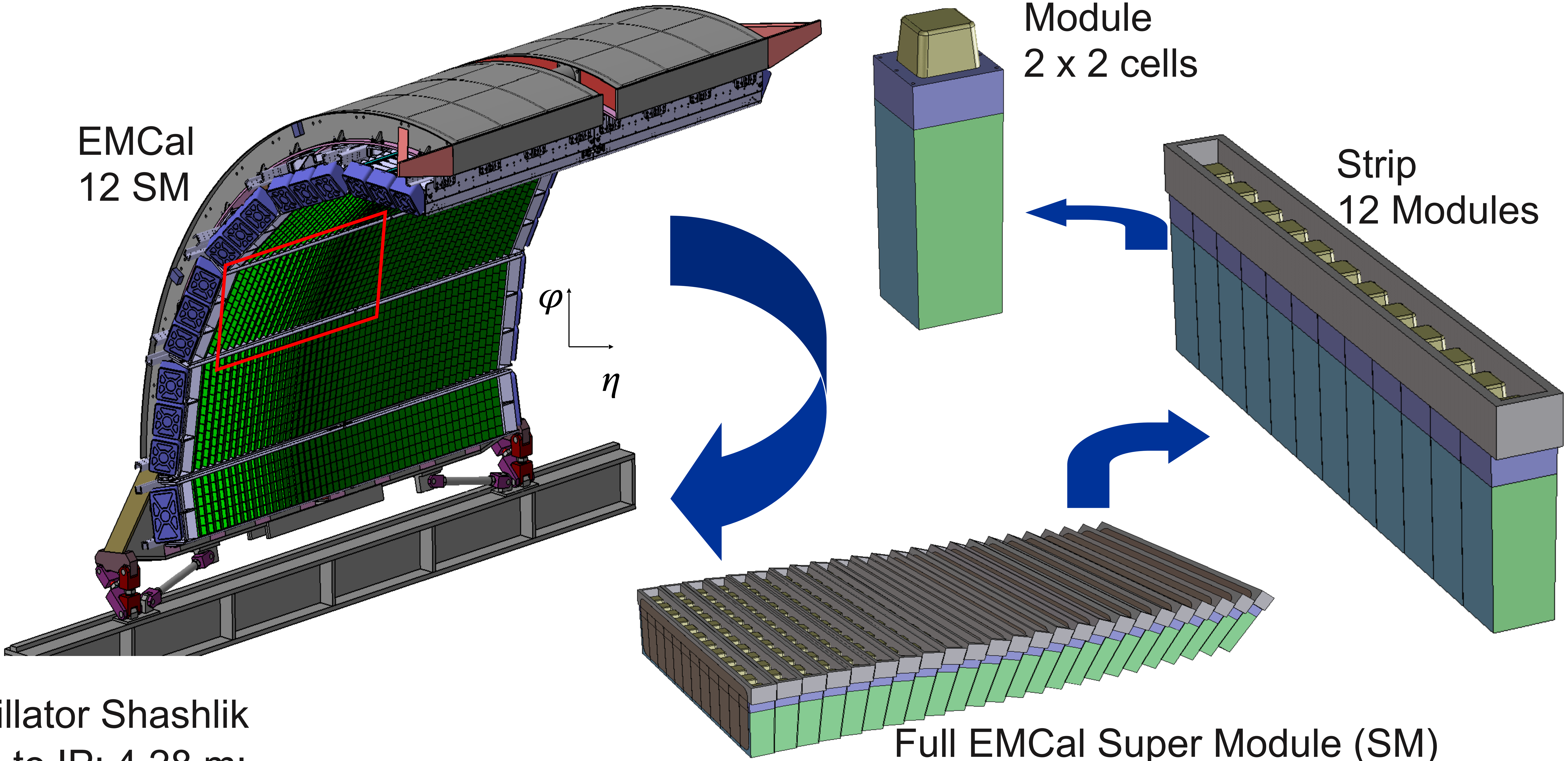




Density of jet tracks depending on the annulus

There are more tracks on the outer annulus in central Pb-Pb than in pp → jet broadening, the radiated energy goes to higher angles

EMCAL & DCAL GEOMETRY



Year	2010	2011-2013	2015-2018
N cells	4k	11k	17k
SM	4	10	20 (12+8)

- Pb/Scintillator Shashlik
- Distance to IP: 4.28 m;
- Granularity $\delta\eta = \delta\varphi = 0.014$ rad
- Variable geometry over the years
- Coverage
  - ➡ EMCal: $\Delta\eta=1.4$, $\Delta\varphi= 40^{o} - 100^{o} - 107^{o}$
  - ➡ DCal: $0.22<|\eta|<0.7$, $\Delta\varphi=60^{o}$; $\Delta\eta=1.4$, $\Delta\varphi=7^{o}$