Recent measurement of isolated γ with ALICE

- Cross section in pp and Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV
  - Also pp and p-Pb at different energies
- Isolated γ-hadron correlation in Pb-Pb at $\sqrt{s_{NN}}$ = 5.02 TeV
- Run 2 measurements at mid-rapidity |η|<0.67

Preliminary results shown at HEP-EPS 23 (G. Conesa), QM 23 and GDR-QCD (C. Arata)

LPSC Grenoble
Laboratoire de Physique Subatomique et de Cosmologie

Gustavo CONESA BALBASTRE
LPSC Grenoble — IN2P3-CNRS-UGA

FCCPN/L | Bordeaux | 13/06/2024

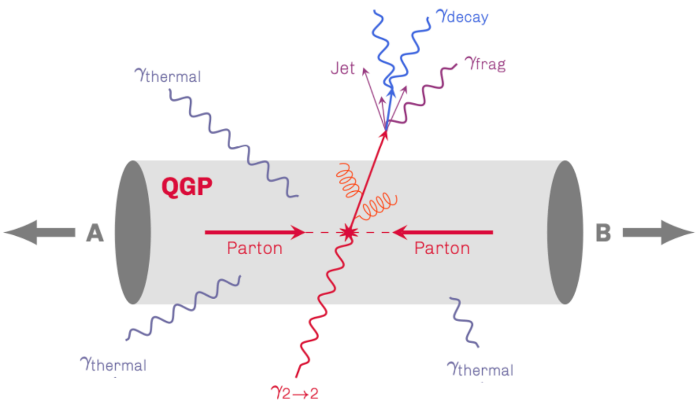
cnrs IN2P3 Les deux infinis

Motivation

- γ are **color neutral: not affected** by *"quark-gluon plasma" (QGP)* presence in *heavy-ion collisions* unlike **partons** that **lose energy**
- Direct γ, *not originated by hadronic decays*

Nuclear modification factor:
p_T yield modification from AA to pp coll. due to QGP and other effects

$$R_{AA} = \frac{1}{N_{\text{coll}}} \frac{\mathrm{d}^2\sigma_{\text{AA}} / (\mathrm{d}p_T \, \mathrm{d}\eta)}{\mathrm{d}^2\sigma_{\text{pp}} / (\mathrm{d}p_T \, \mathrm{d}\eta)}$$



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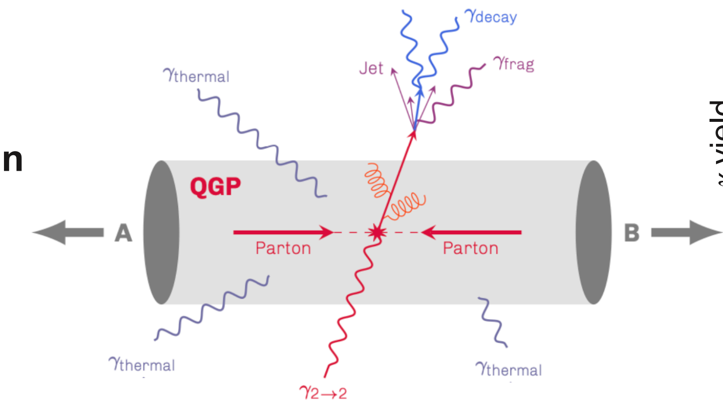
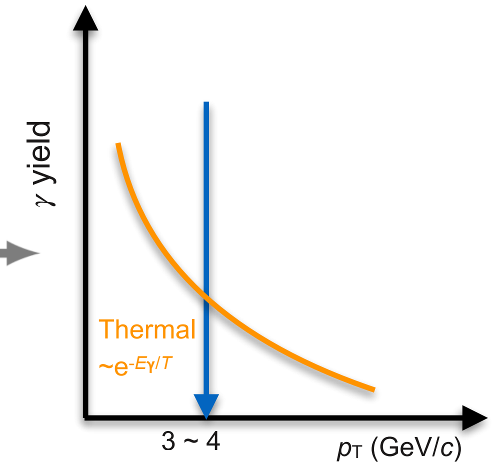
➡ **Direct thermal γ: R_{AA} >> 1**
- QGP thermal radiation
- Measure ***T* & time/size evolution**





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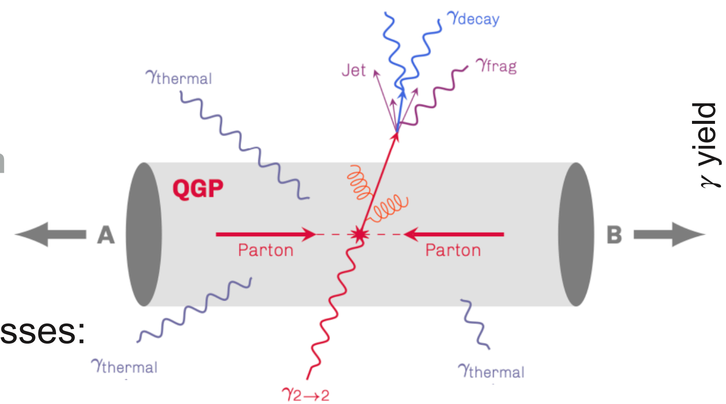
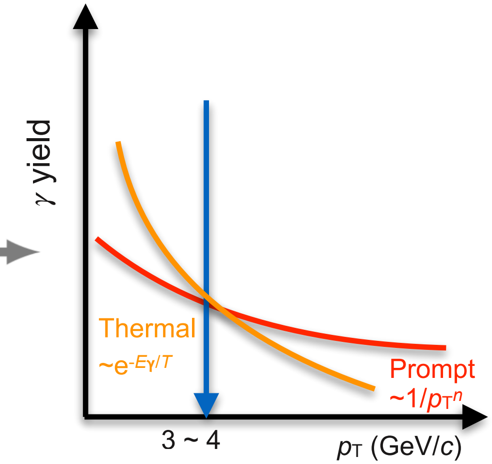
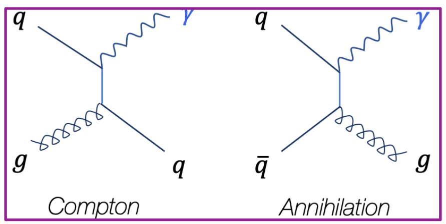




➡ **Direct prompt γ: $R_{AA} \approx 1$**
- – Initial hard scattering, 2→2 processes:



$$d\sigma^{hard}_{AB\to h} = f_{a/A}(x_1, Q^2) \otimes f_{b/B}(x_2, Q^2) \otimes d\sigma^{hard}_{ab\to c}(x_1, x_2, Q^2) \otimes D_{c\to h}(z, Q^2)$$

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

- – **Test pQCD** predictions, **constrain (n)PDFs & FF**
- – $p_T^{\gamma} \simeq p_T^{parton}$, before parton loses Δ*E* in QGP
- – Measure **FF modifications**, <u>where is the Δ*E* radiated?</u>

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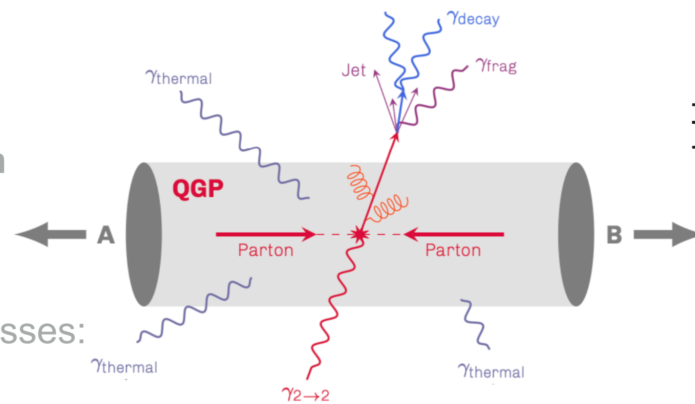

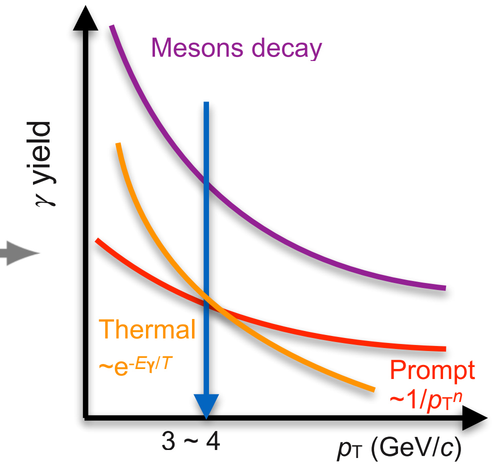

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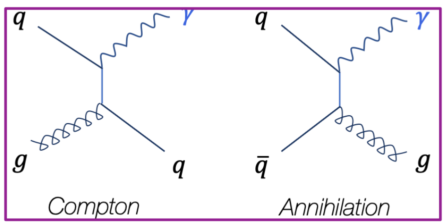

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- **Decay γ (π^0 & η):** R_{AA} << 1
  - **Main background for direct γ measurements**

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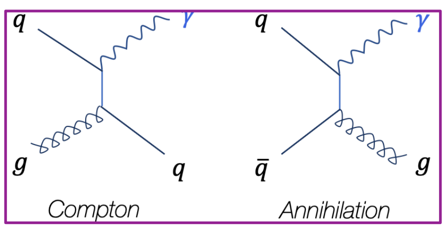

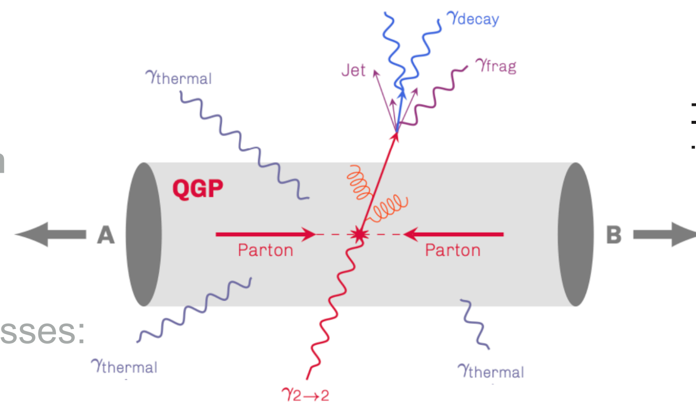

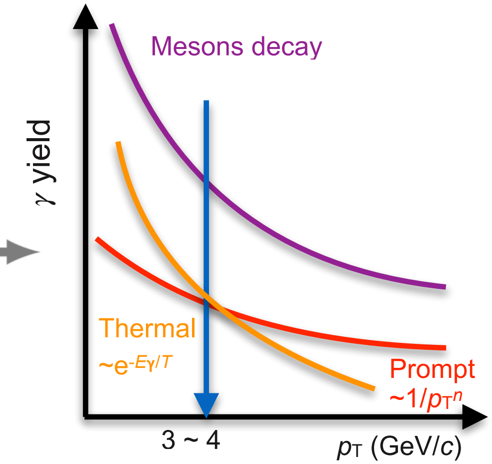

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  - **Main background for direct γ measurements**

- **Other 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)

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

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

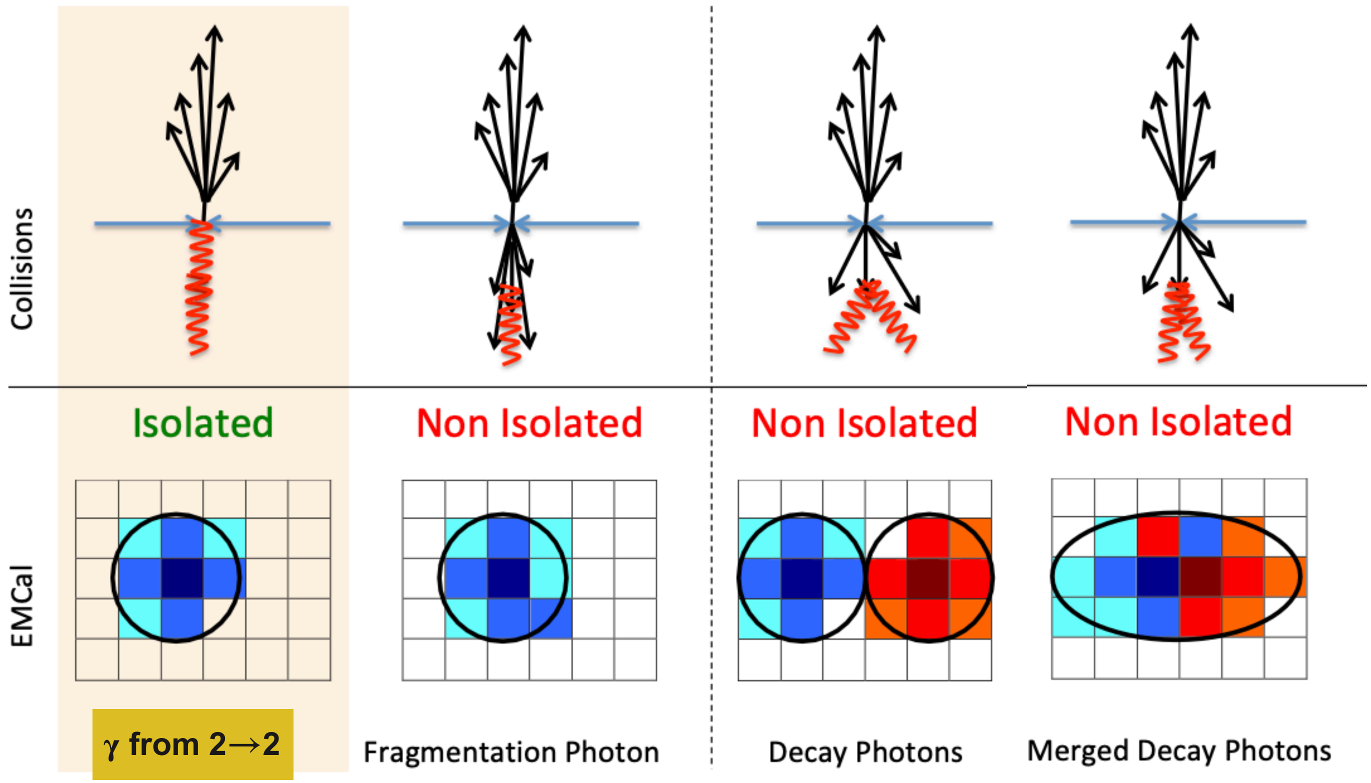
$$p_{\rm T}^{\rm iso,\, ch} = \sum p_{\rm T}^{\rm tracks\ in\ cone} - \rho_{\rm UE} \cdot \pi \cdot R^2 < \mathbf{1.5\ GeV/c}$$

γ from 2→2: isolated

- TPC+ITS charged tracks
- Select γ with low hadronic activity in *R*, small $p_{\rm T}^{\rm iso,\, ch}$
  - Underlying event (UE) subtracted event-by-event, $\rho_{\rm UE}$ density estimated in η-band

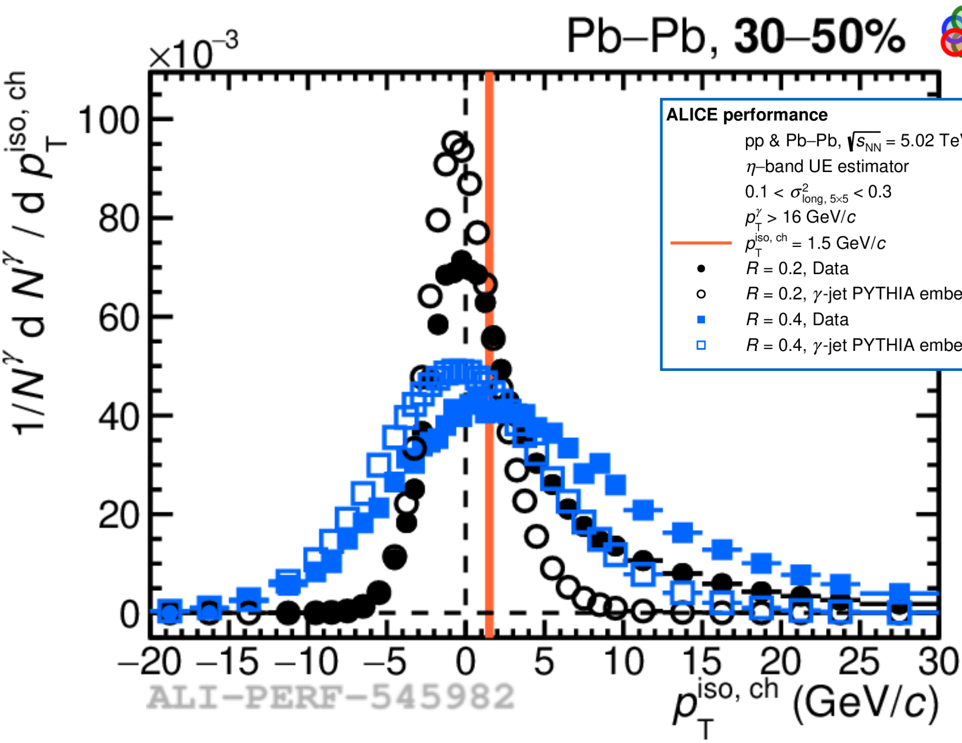
EM shower discrimination

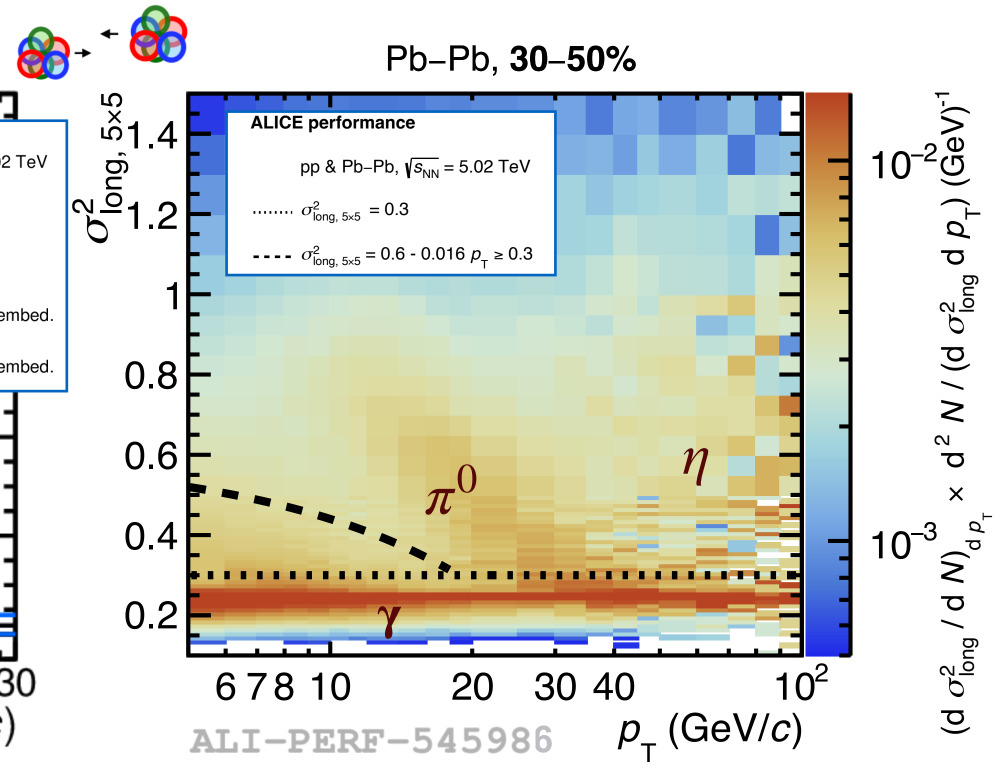
- EMCal
- lateral dispersion $\sigma^2_{\rm long,\, 5\times5}$ calculated in 5×5 cells around the highest energy cell



- prompt γ **circular "narrow" cluster**
- circular narrow clusters but potentially wider due to jet particles nearby merging
- decay γ merge *E* > 6 GeV **elliptical "wide" cluster**

Prompt γ identification in ALICE: EM shape & isolation





- Embedded pp PYTHIA simulation into MB data, symmetric distribution
- In data, more asymmetric distribution due to jet contribution
- Significantly wider distributions for $R = 0.4$
- Isolated if $p_{\mathrm{T}}^{\mathrm{iso,\,ch}} < 1.5$ GeV/c (orange line)

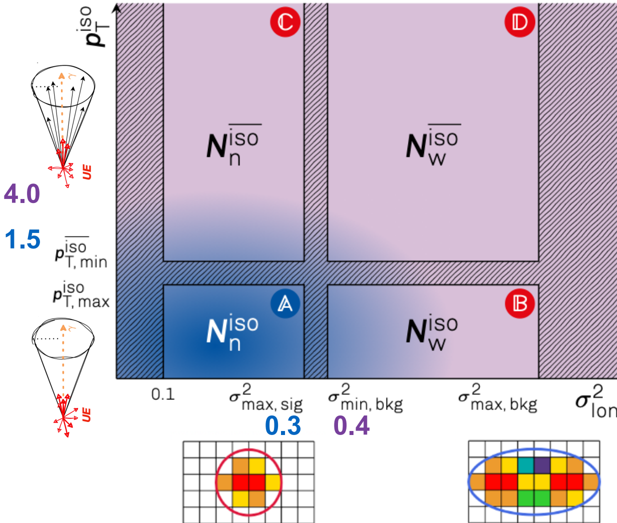
- Bands for γ (narrow clusters) & π^0 (wide clusters) visible from pp to Pb–Pb
- Select as γ clusters with
  - $0.1 < \sigma^2_{\mathrm{long,\,5\times5}} < 0.6 - 0.016 \cdot p_{\mathrm{T}}$ for Pb-Pb $p_{\mathrm{T}} < 18$ GeV/c
  - $0.1 < \sigma^2_{\mathrm{long,\,5\times5}} < 0.3$ for pp & Pb-Pb, $p_{\mathrm{T}} > 18$ GeV/c

Purity, R = 0.2 & 0.4

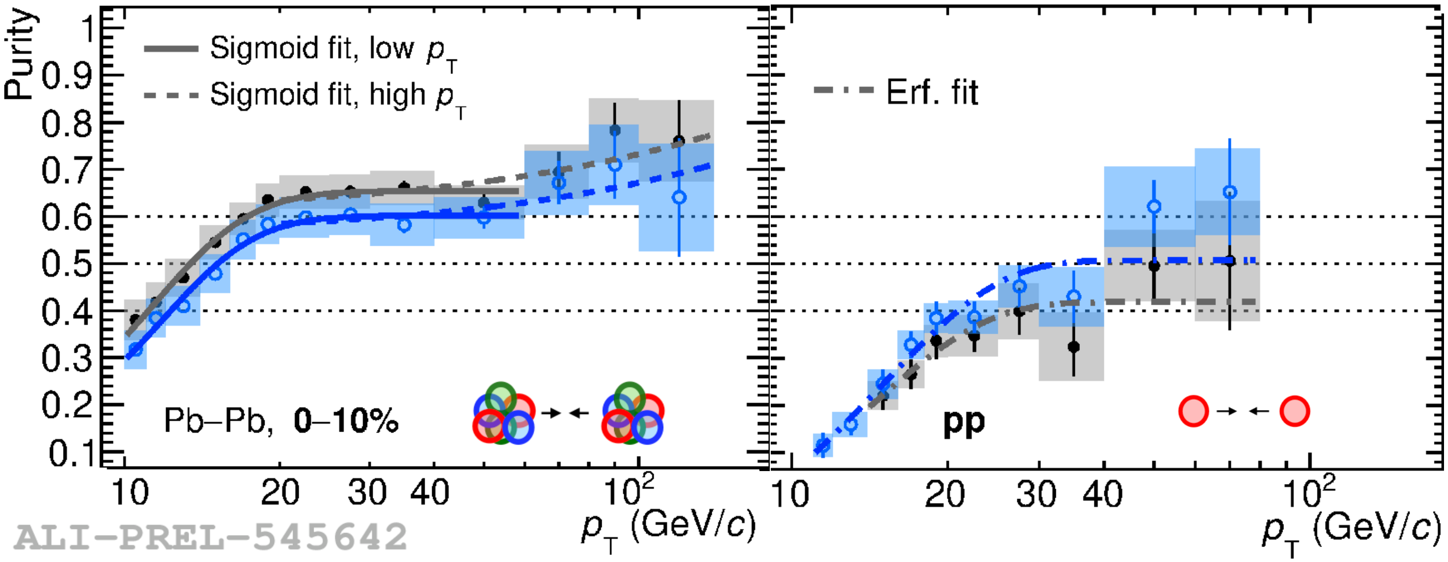
- Phase space of calorimeter clusters divided in 4 regions:
  𝔸, signal dominated & 𝔹-ℂ-𝔻, background dominated

$$P = 1 - \underbrace{\left(\frac{N_n^{\overline{\text{iso}}}/N_n^{\text{iso}}}{N_w^{\overline{\text{iso}}}/N_w^{\text{iso}}}\right)_{\text{data}}}_{\text{data-driven}} \times \underbrace{\left(\frac{B_n^{\text{iso}}/N_n^{\overline{\text{iso}}}}{N_w^{\overline{\text{iso}}}/N_w^{\text{iso}}}\right)_{\text{MC}}}_{\text{PYTHIA}}$$

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



➡ Semi data-driven approach, simulation used to correct correlations between $p_{\mathrm{T}}^{\mathrm{iso,\,ch}}$ and $\sigma^2_{\mathrm{long},\,5\times5}$

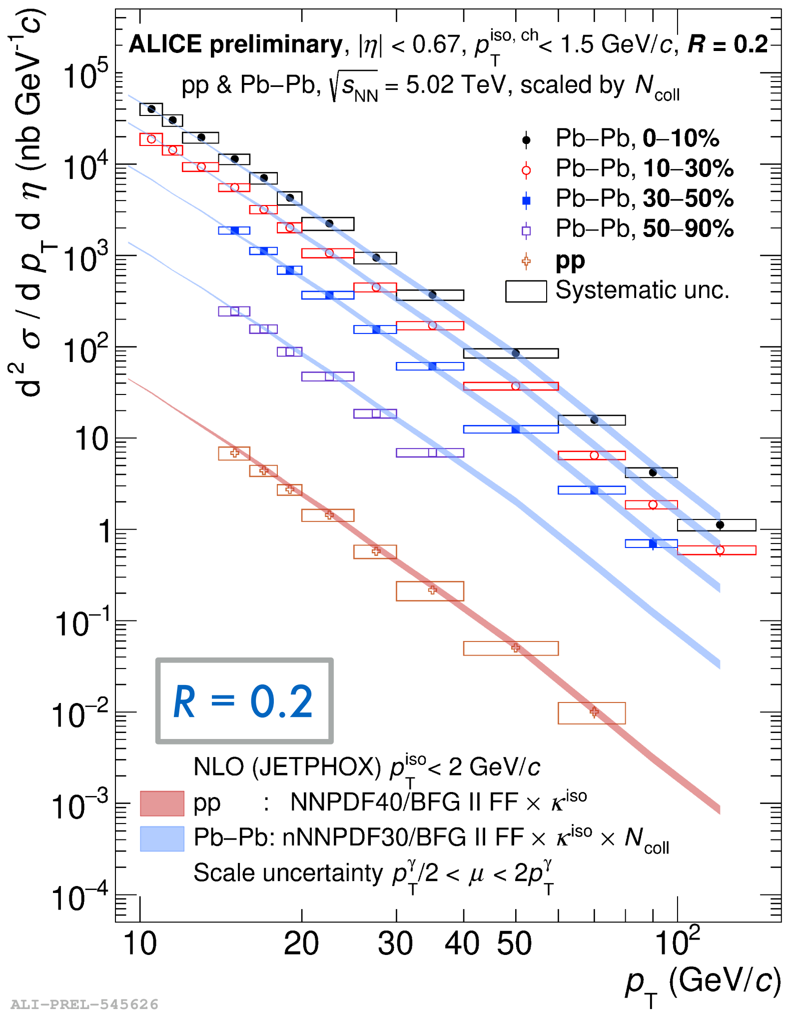


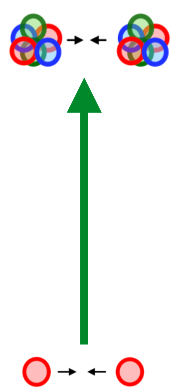
- Reduce influence of statistical fluctuations with Sigmoid or Erf functions fits
  → used in spectra

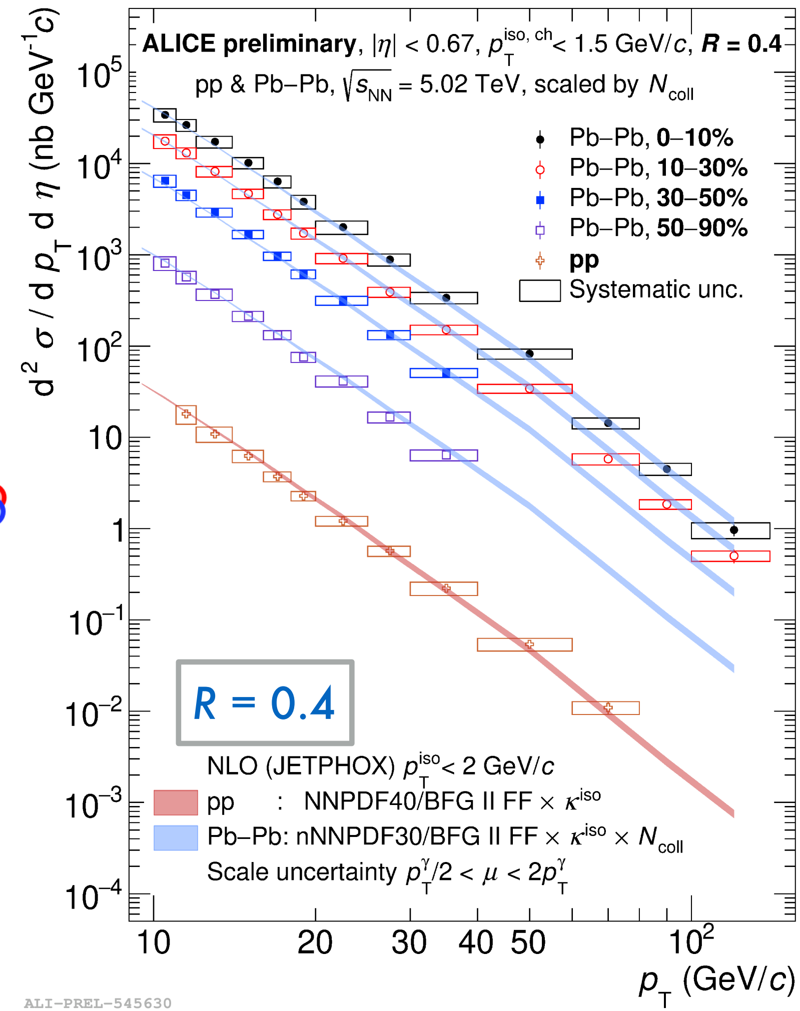
- P (R = 0.4) > P (R = 0.2) in pp coll., more jet particles in cone, but
  P (R = 0.2) > P (R = 0.4) in 0-10% Pb–Pb coll., due to UE fluctuations, but not significantly different
- P (Pb–Pb) > P (pp), better tracking & higher $N(\gamma)/N(\pi^0)$ ratio

Cross section, *R* = 0.2 & 0.4

$$\frac{d^2\sigma}{d\,p_T\,d\,\eta} = \frac{\sigma_{MB}}{N_{events} \times RF_{\varepsilon_{trig}}} \times \frac{d^2N}{dp_T\,d\eta} \times \frac{P}{Acc \times \varepsilon_\gamma^{iso} \times \varepsilon_{trig}}$$

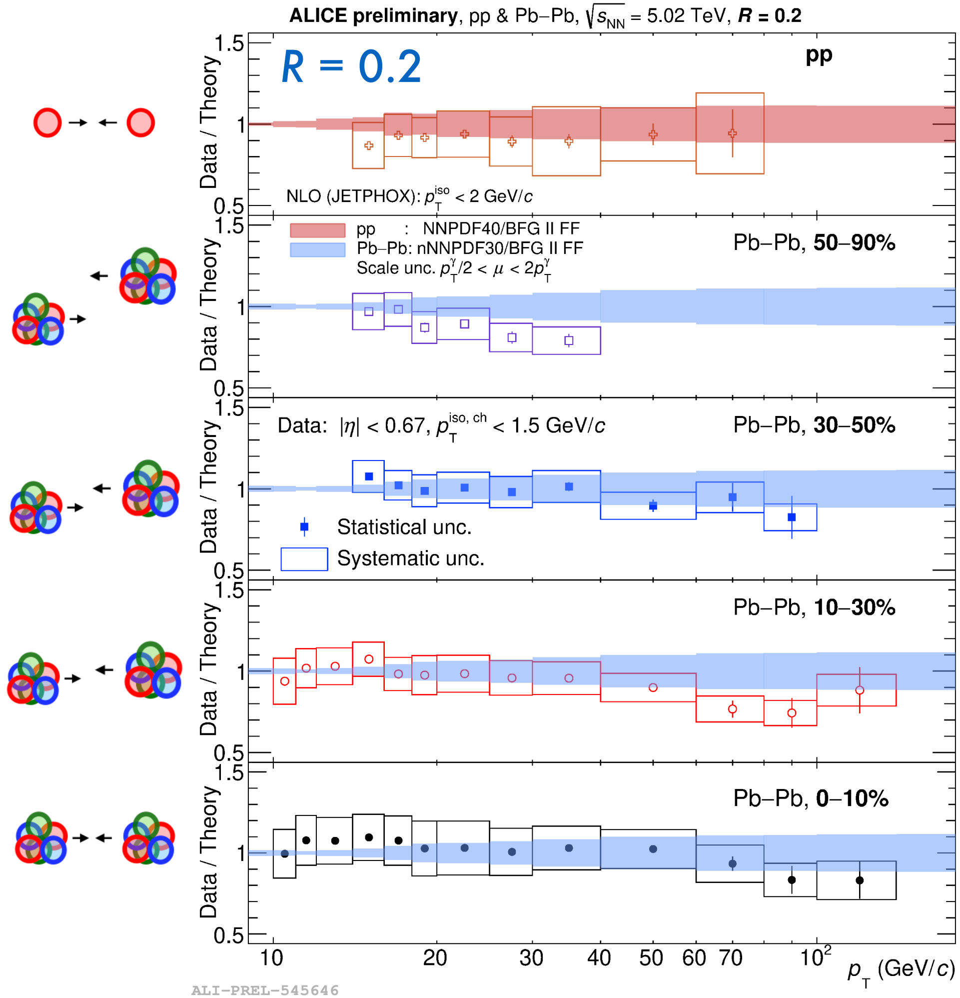


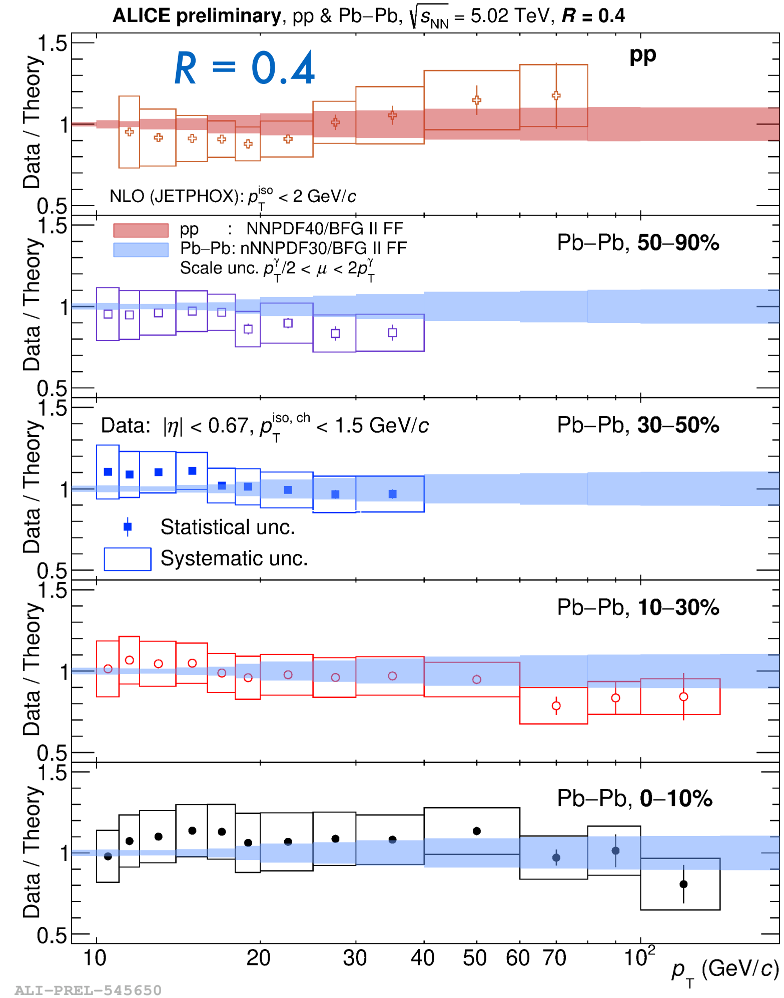




- Wide range: 10 < p_T < 140 GeV/c in Pb–Pb 0-30% coll. & 11-14 < p_T < 60 GeV/c in pp coll.
- NLO pQCD predictions (JETPHOX)
  - ➡ Note: **<u>Theory is centrality independent!</u>** only difference is PDF (pp) vs nPDF × N_{coll} (Pb–Pb)

Cross section Data/Theory, R = 0.2 & 0.4





- NLO pQCD predictions (JETPHOX)
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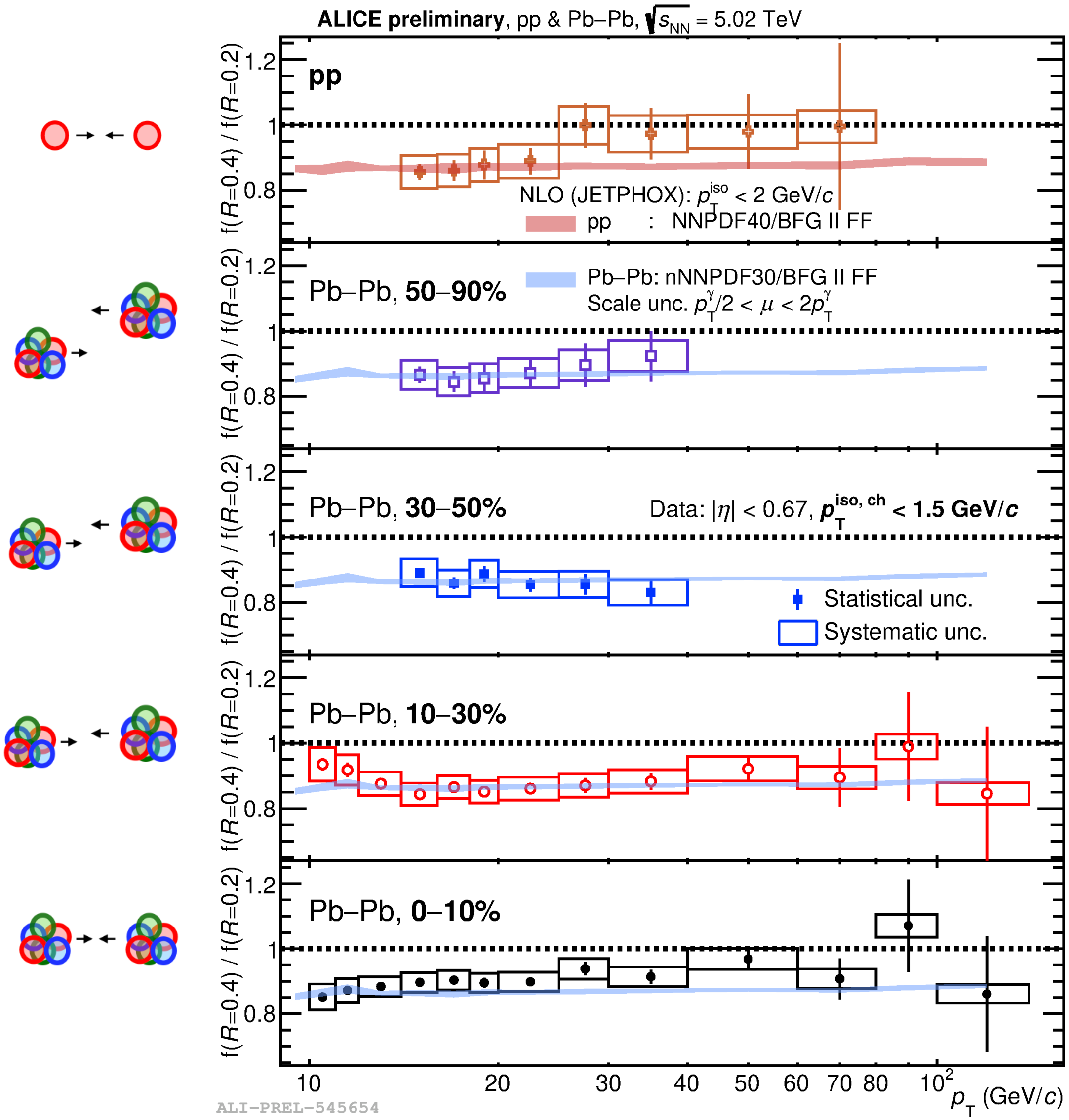
- Theory & data agreement for both *R* and coll. system within uncertainties

Cross sections R ratios

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



- Ratio sensitive to fraction of fragmentation **γ** surviving the isolation selection
  - ➡ Interesting for theory models
- Quite good agreement with theory on all collision systems
  - Theory (NLO) seems to control the isolation mechanism in 2→2 processes and the direct fragmentation & prompt **γ** production even in Pb–Pb
  - Same measurement done by ATLAS in pp collisions at 13 TeV for p_T > 250 GeV/c shows a good agreement with pQCD with even smaller uncertainties than theory: JHEP 2023 (2023) 86 arXiv:2302.00510 (back-up)

Nuclear modification factor R_{AA}, R = 0.2 & 0.4

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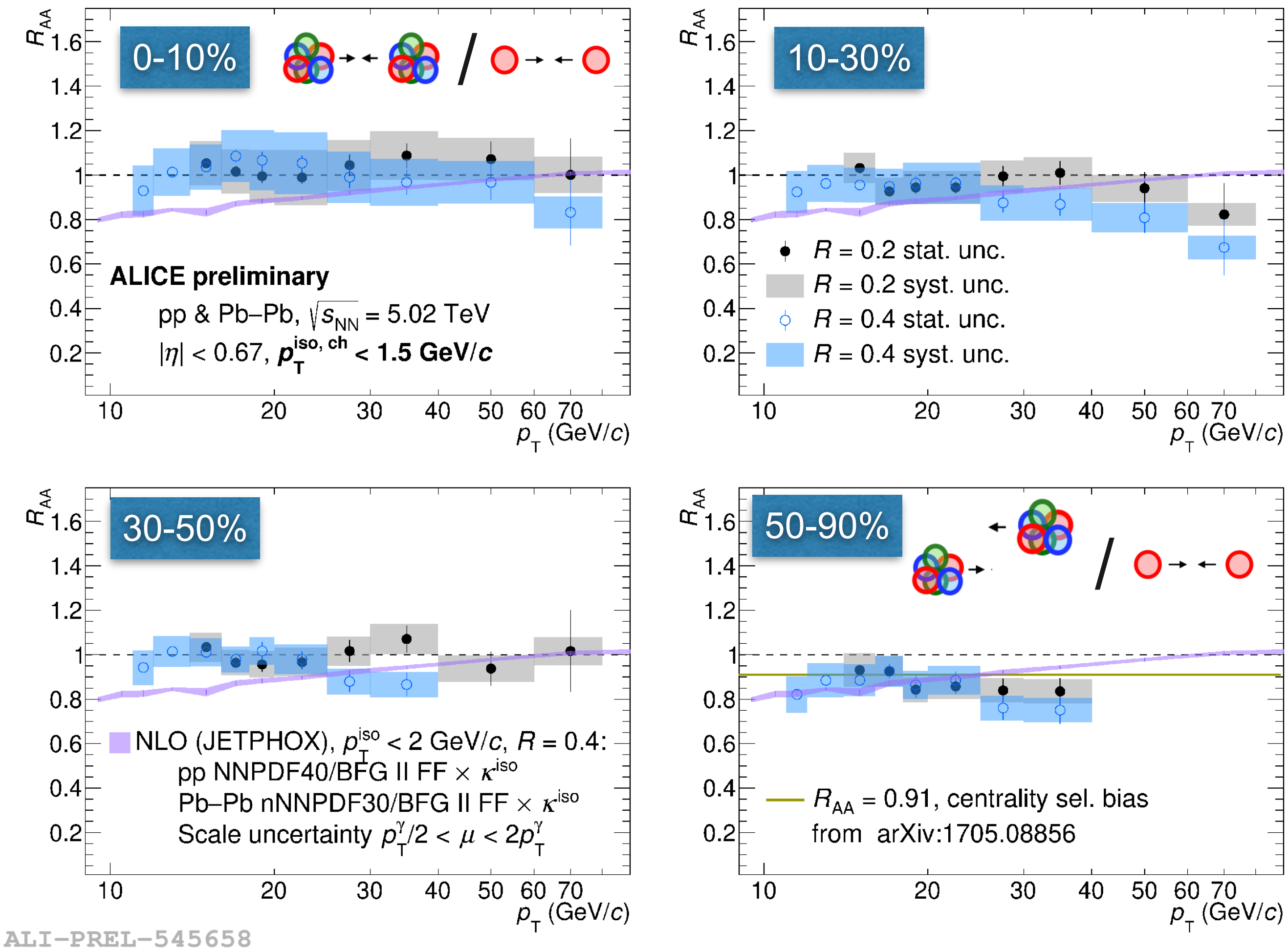

- **0-50%:**
  - Consistent with unity within the unc. for both R
    - No modification of the prompt photon yield due to the QGP as expected
  - Agreement with NLO pQCD ratio above 20 GeV/c, a decrease is expected below due to PDF vs nPD
- **50-90%:**
  - Closer to 0.9 than 1 for both R likely due to centrality selection bias of Glauber model
  - Model by C. Loizides & A. Morsch expects a value of 0.91 (arXiv:1705.08856)
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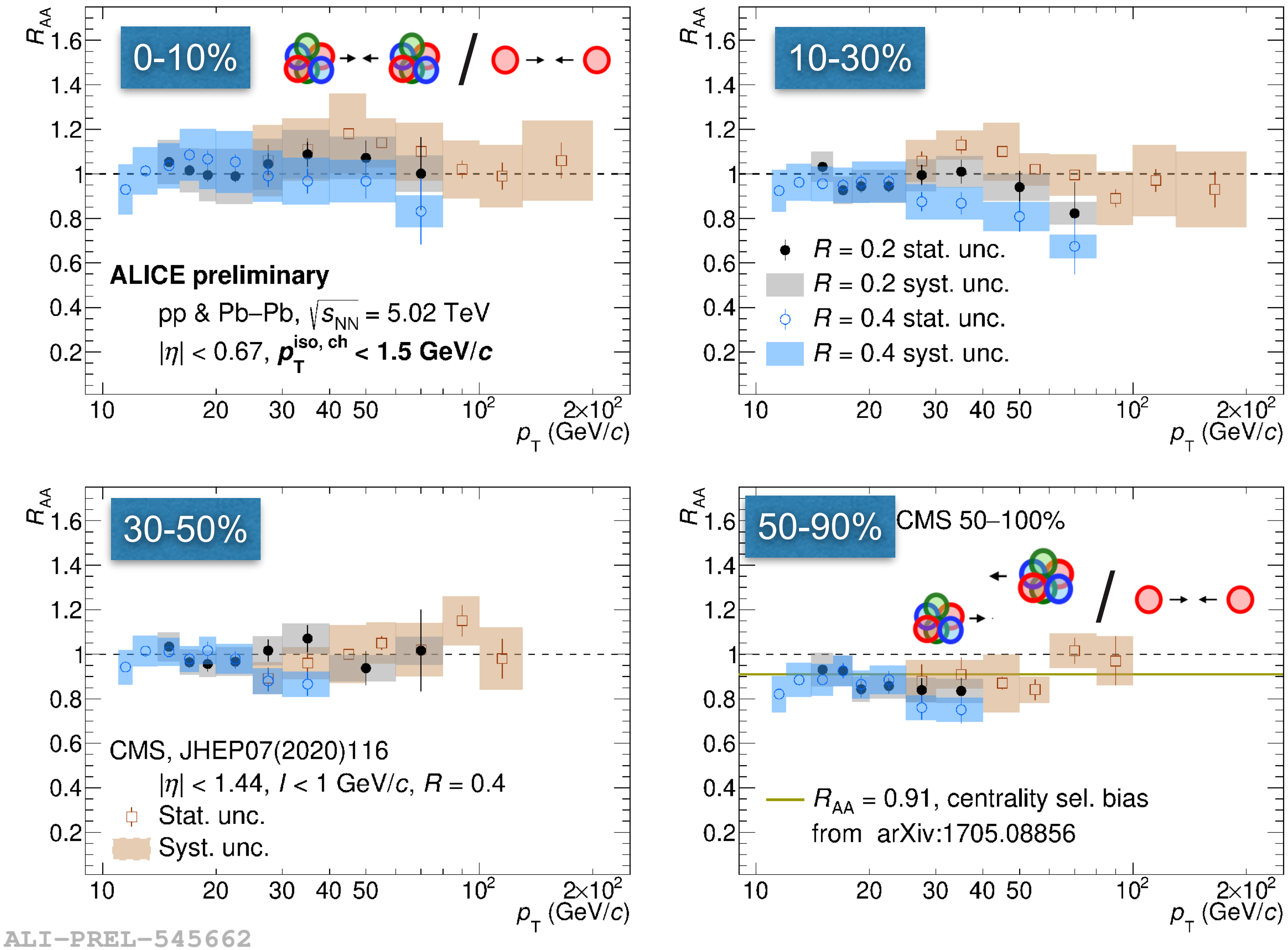

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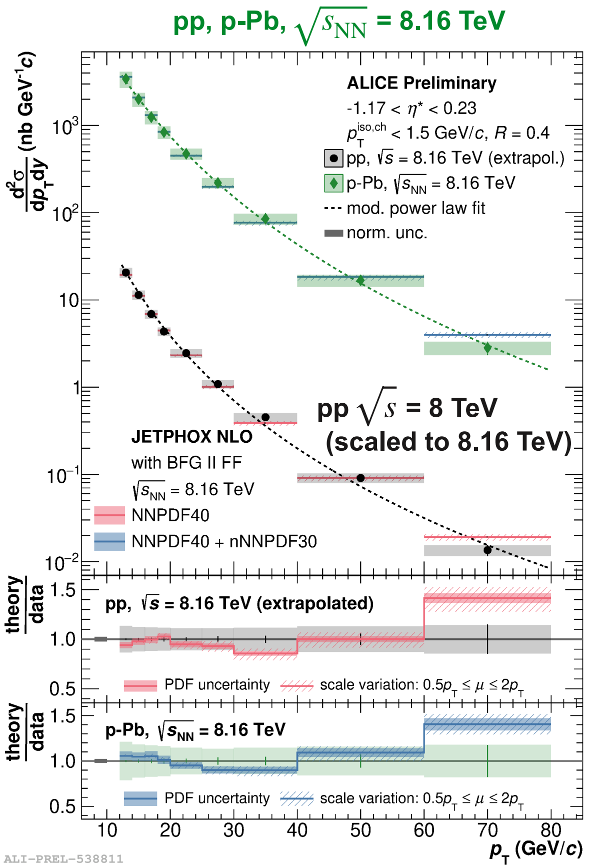
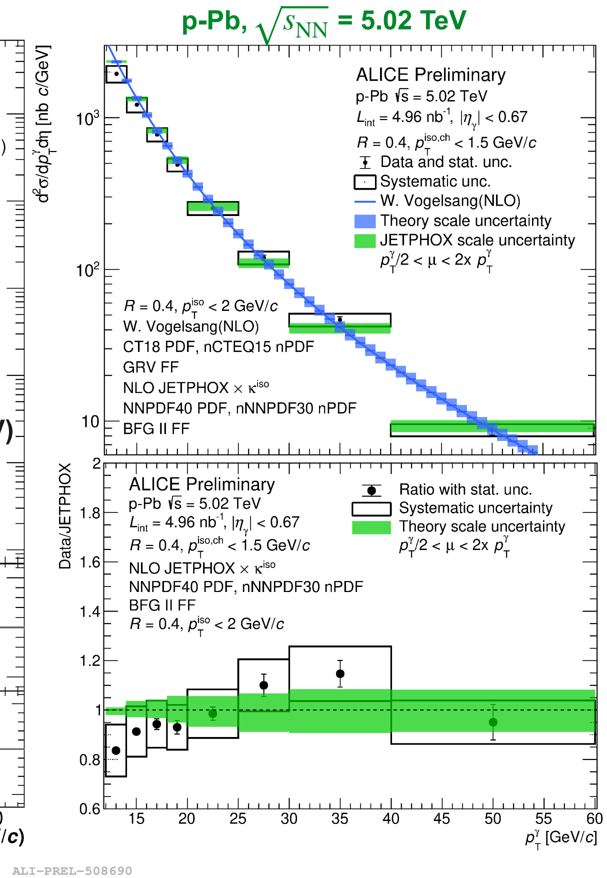
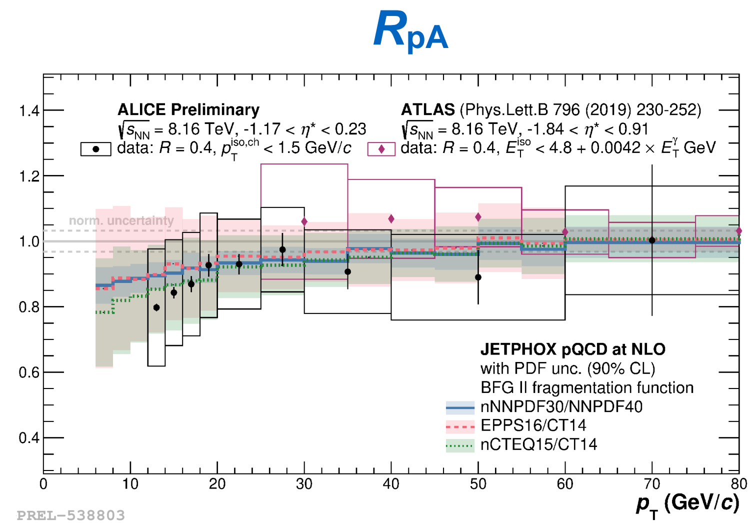
- Agreement within the uncertainties with CMS in the overlapping region 25 < p_T < 60 GeV/c

Cross section in p-Pb col. with R = 0.4



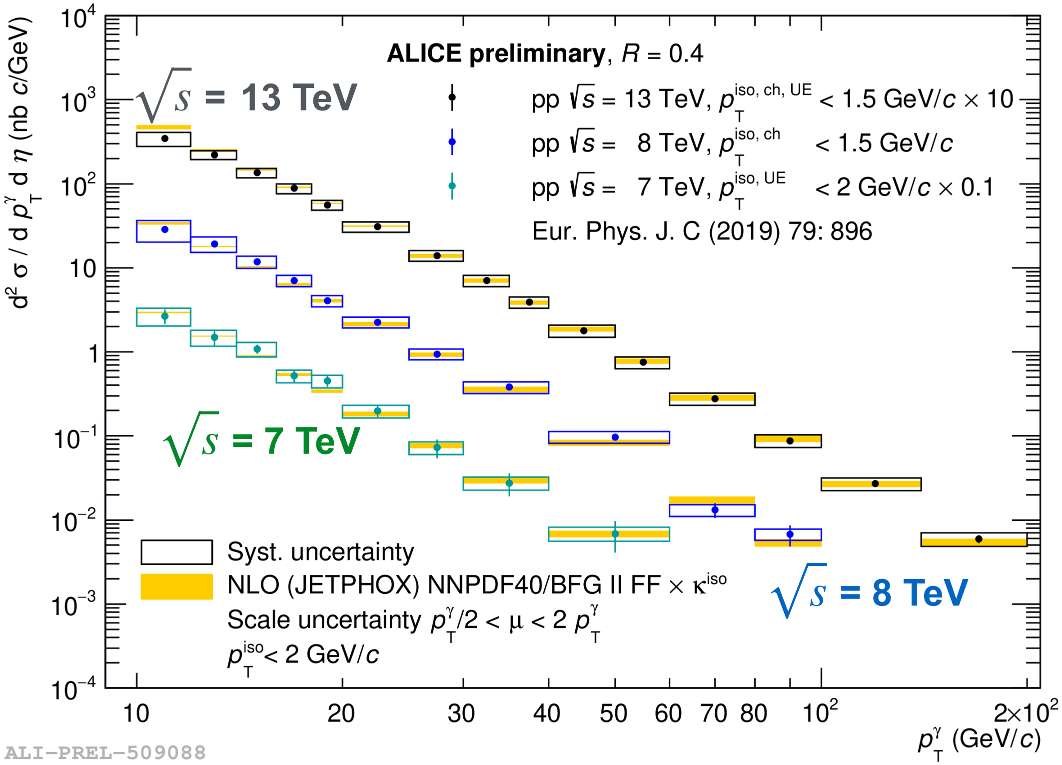


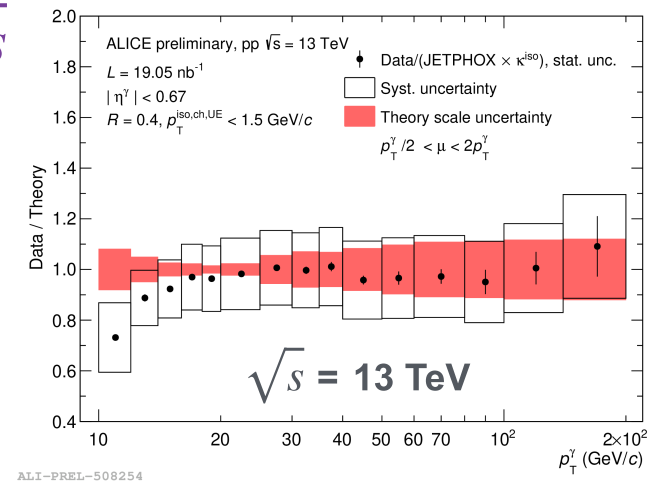


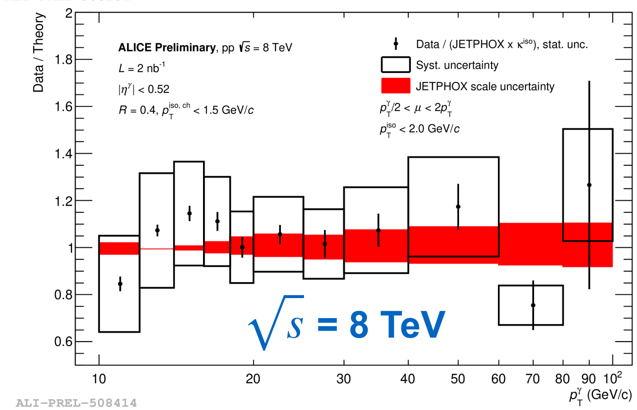
Shown at HP 2023

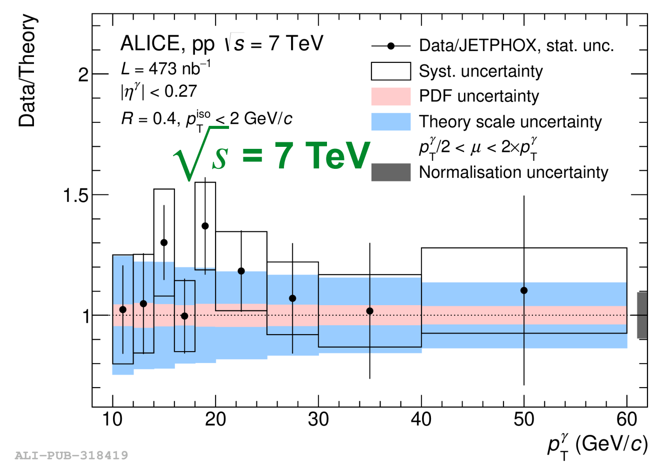
- NLO pQCD predictions (JETPHOX) and data agree
- $R_{\text{p-Pb}}$ in agreement with unity
  - Hints of lower than unity for p_T < 20 GeV/c, expected in theory

Cross section in pp col. and other $\sqrt{s}$ with R = 0.4



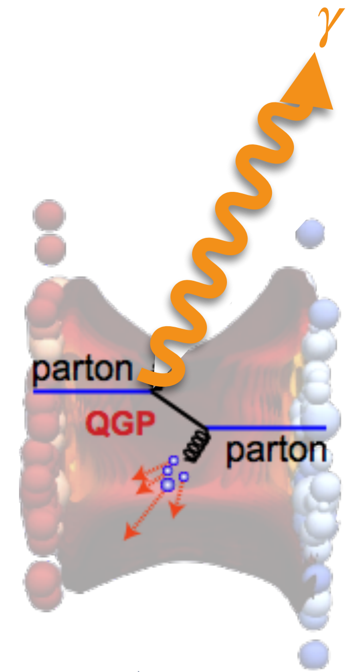




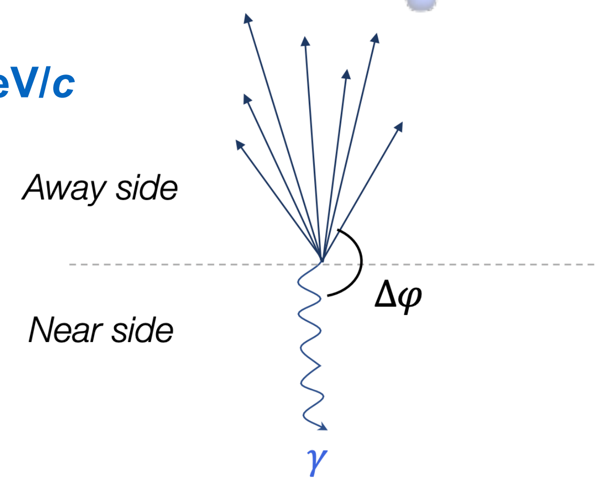


- NLO pQCD predictions (JETPHOX) and data agree measurement by Ran Xu @ LPSC & CCNU
  - **$\sqrt{s}$ = 13 TeV measurement by Ran Xu @ LPSC & CCNU, on arXiv in ~ a week!**
    - **Lower p_T & x_T than in preliminary**
    - **Lowest x_T LHC measurement at mid-rapidity**
  - **Strong involvement of LPSC on all ALICE isolated-photon measurements**

Isolated γ-hadron correlations in Pb–Pb



- Prompt γ associated to a parton emitted in opposite side
- Prompt γ measurement allow to **tag the parton initial energy** $p_{\mathrm{T}}^{\gamma} \simeq p_{\mathrm{T}}^{\mathrm{parton}}$, before losing Δ*E* in QGP
  - ➡ Aim: Measure FF modifications, where is the Δ*E* radiated?
- Observables:
  - ➡ Azimuthal correlation: $\Delta\varphi = \varphi^{\mathrm{trigger}} - \varphi^{\mathrm{track}}$ with trigger isolated narrow or wide clusters, ***R*** **= 0.2 &** $p_{\mathrm{T}}^{\mathrm{iso\ ch}}$ **< 1.5 GeV/*c***
  - ➡ $z_{\mathrm{T}} = \frac{p_{\mathrm{T}}^{\mathrm{track}}}{p_{T}^{\mathrm{trigger}}}$ and $\mathrm{D}(z_{\mathrm{T}}) = \frac{1}{N^{\mathrm{trigger}}} \frac{\mathrm{d}\ N^{\mathrm{track}}}{\mathrm{d}\ z_{\mathrm{T}}}$ for tracks in $|\Delta\varphi| > 3/5\pi$ rad (mirrored)
  - ➡ **When trigger = prompt γ,** $\mathrm{D}(z_{\mathrm{T}})$ **is a proxy for FF**
  - ➡ Measurement: 18 < p_{T}^{trigger}< 40 GeV/*c* & p_{T}^{track} > 0.5 GeV/*c*



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

C. Arata thesis

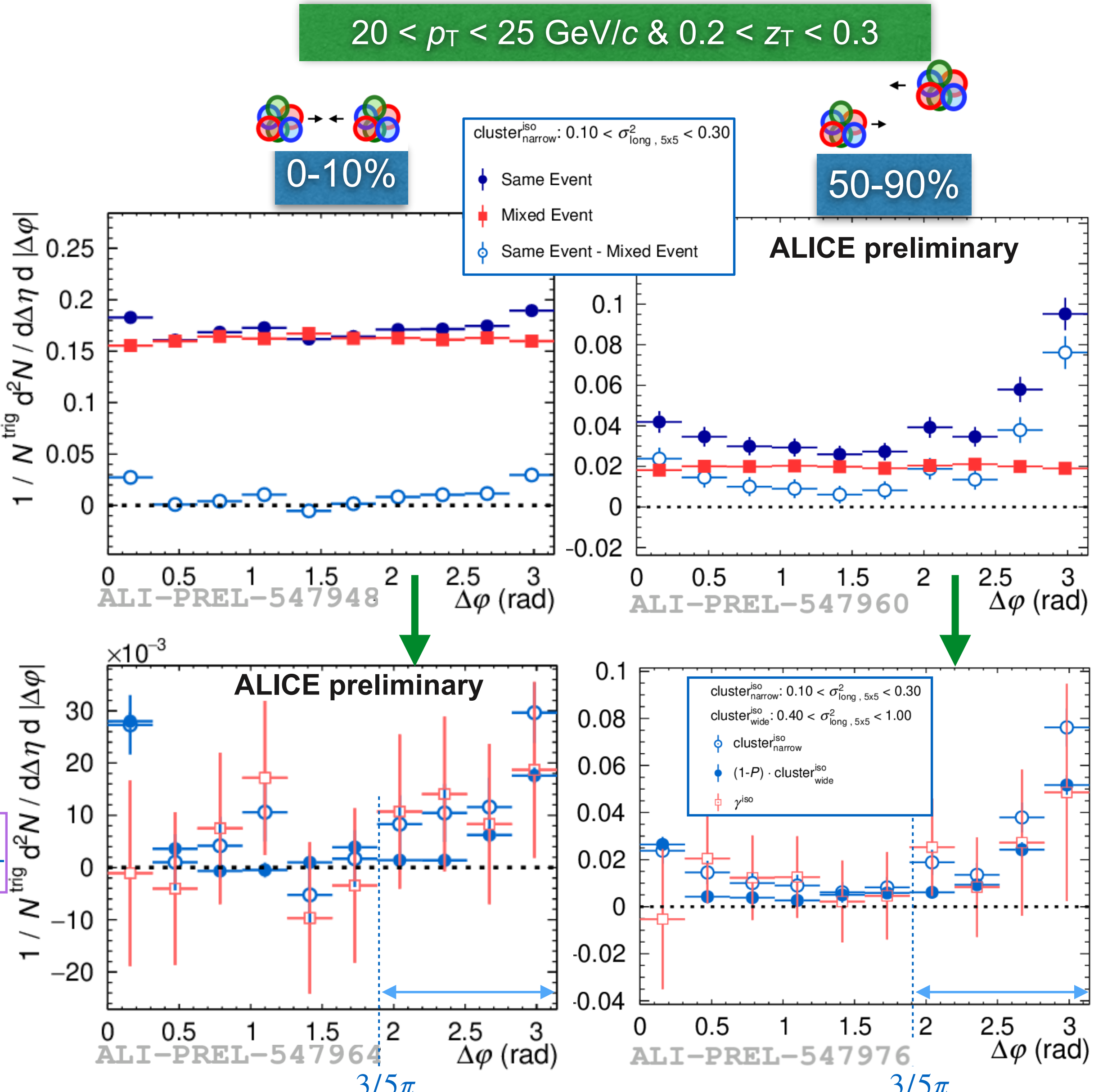
- UE in $\Delta\varphi$: uncorrelated tracks shifting up the distribution

- *UE subtraction with mixed event*: artificial dataset created combining the trigger cluster with tracks on different MB collisions

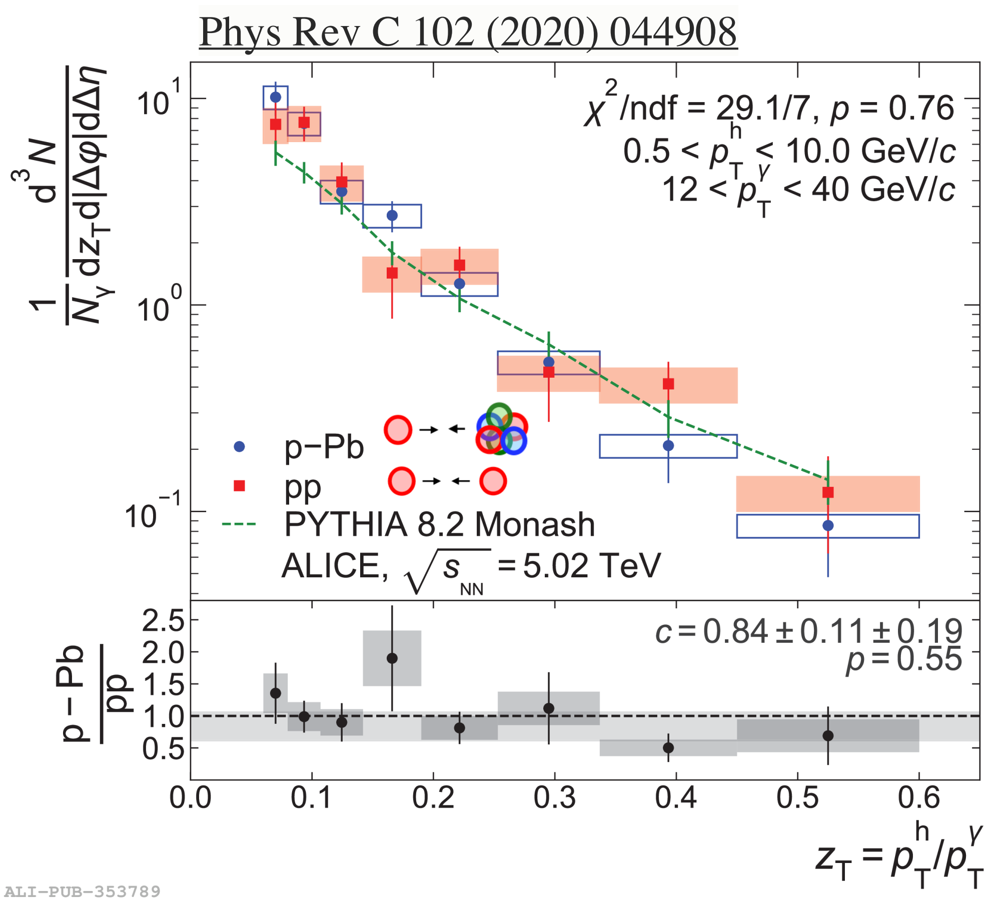
- Purity < 1, considering $f(\Delta\varphi^{\mathrm{cls}^{\mathrm{iso}}_{\mathrm{narrow}}})$ bkg $= f(\Delta\varphi^{\mathrm{cls}^{\mathrm{iso}}_{\mathrm{wide}}})$:

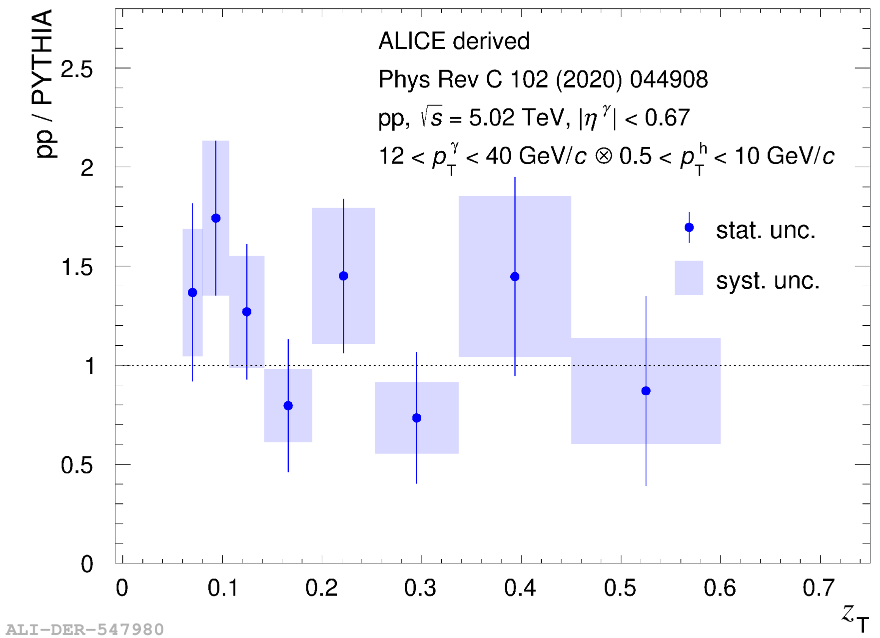
$$f(\Delta\varphi^{\gamma^{\mathrm{iso}}}) = \frac{f(\Delta\varphi^{\mathrm{cls}^{\mathrm{iso}}_{\mathrm{narrow}}}) - (1-P)\cdot f(\Delta\varphi^{\mathrm{cls}^{\mathrm{iso}}_{\mathrm{wide}}})}{P}$$

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



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

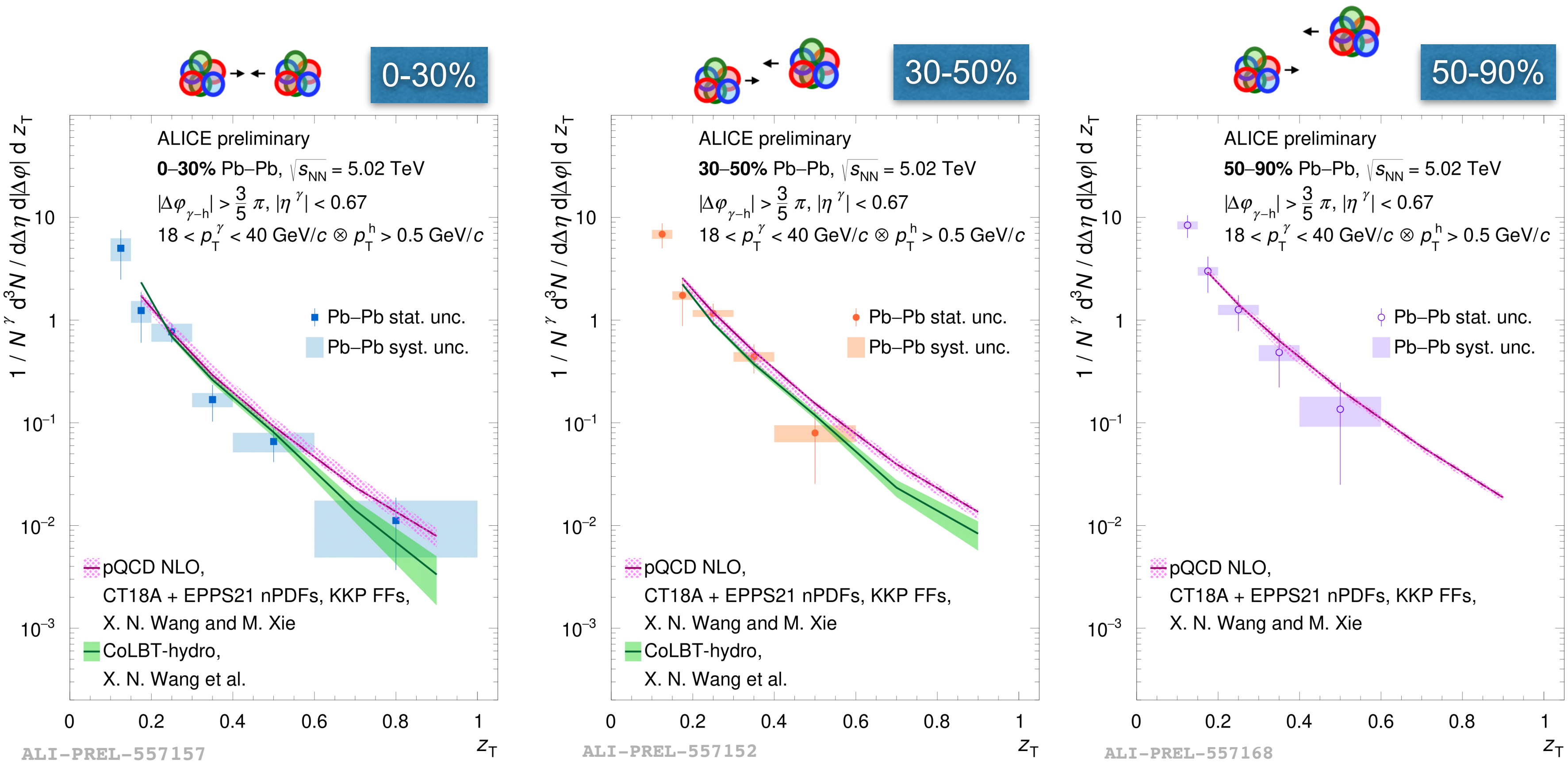




- Previous published results in p–Pb and pp collisions
  - ➡ Agreement between systems and with PYTHIA
- Note: Pb–Pb collisions measurement done in <u>different p_T ranges</u> and is compared directly to pQCD predictions

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

C. Arata thesis

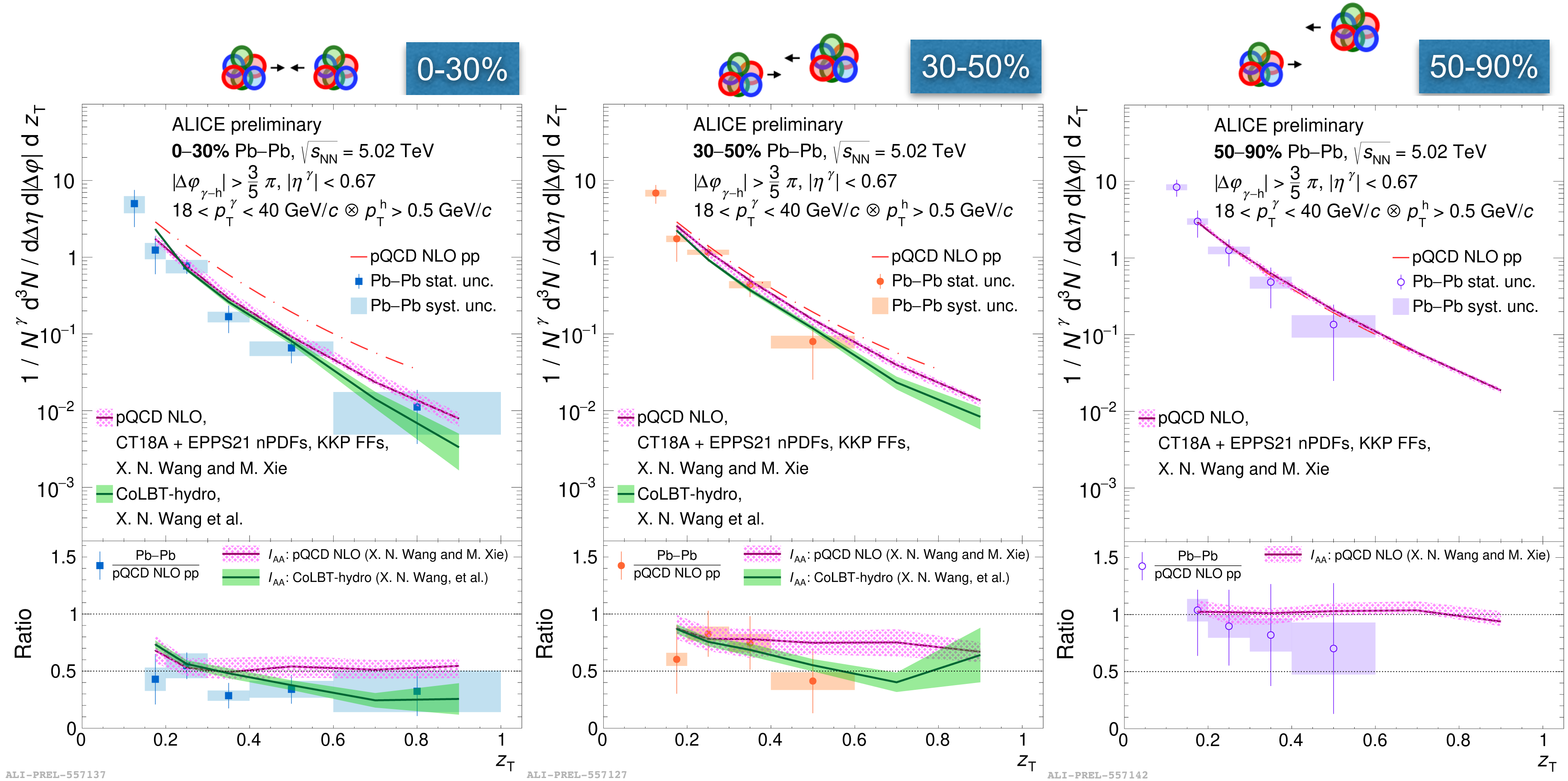


- Pb–Pb data compared with theory: *NLO pQCD* and *CoLBT* (0-50% only)
  - ➡ There seems to be an agreement with both models
  - ➡ Discrimination not possible yet

- *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: $D(z_T)$

C. Arata thesis



- Ratio with respect to NLO pQCD pp collision simulation → sort of $I_{AA} = \frac{D(z_T)_{\text{Pb–Pb}}}{D(z_T)_{\text{pp}}}$
- 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 in Pb–Pb: $D(z_T)$

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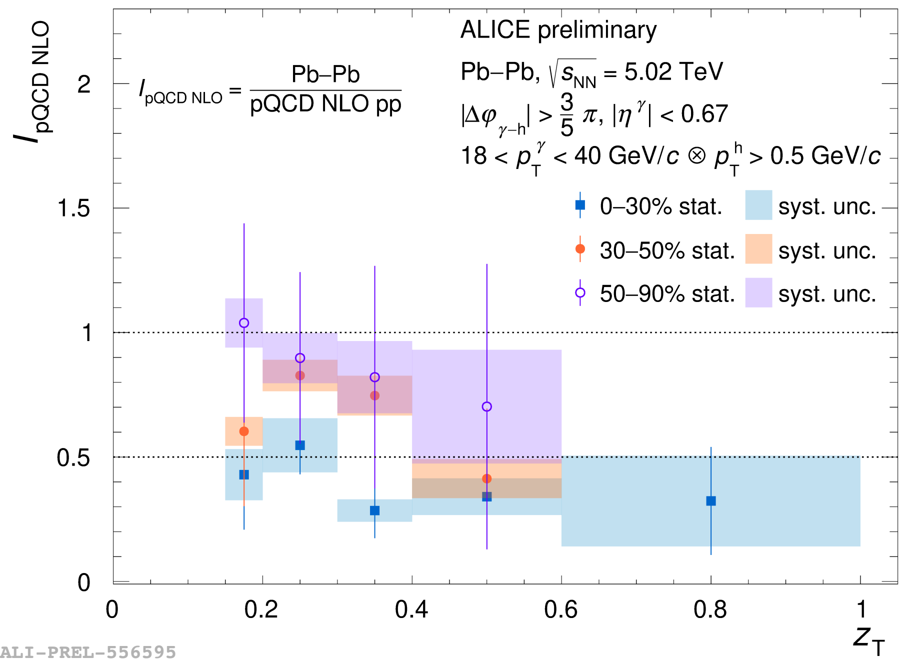
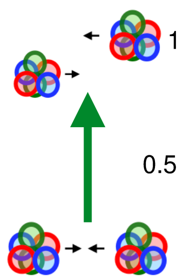
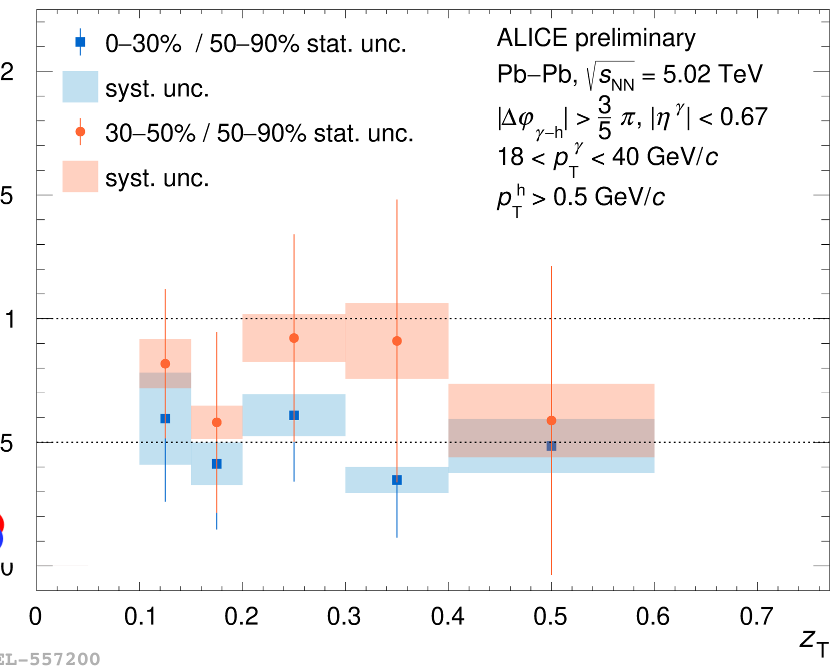
I_{pQCD} = Pb–Pb Data / pp pQCD



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

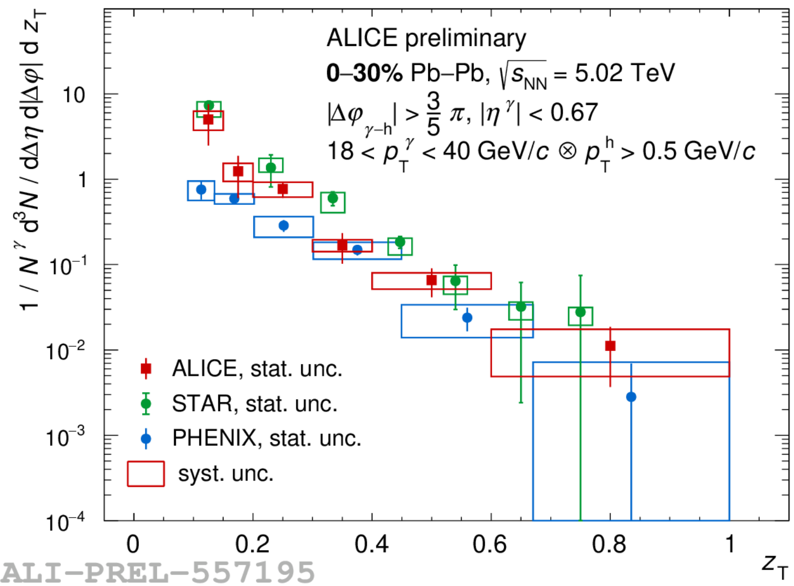




- Ordering between centralities, central more suppressed than peripheral
- Hints of less suppression at lower z_T in I_{pQCD}

Isolated γ-hadron correlations in Pb–Pb: RHIC & LHC

C. Arata thesis



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

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

PHENIX, PRL 111, 032301 (2013)

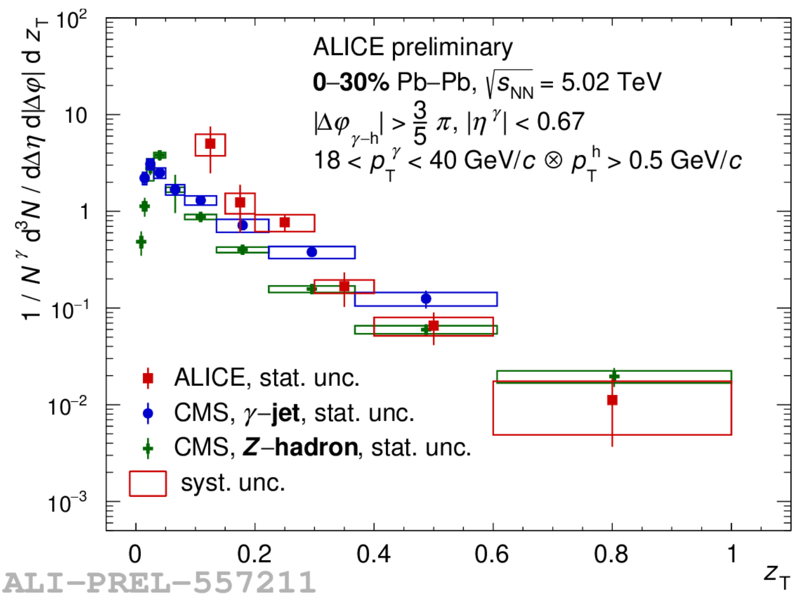
0–40% Au–Au, $\sqrt{s_{NN}}$ = 200 GeV

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

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

Central

- Similar behaviour as observed at RHIC and LHC experiments
  - ➡ Note: <u>not completely apples-to-apples comparisons!</u>



CMS, Phys.Rev.Lett. 121 (2018) 24, 242301, 2018

***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

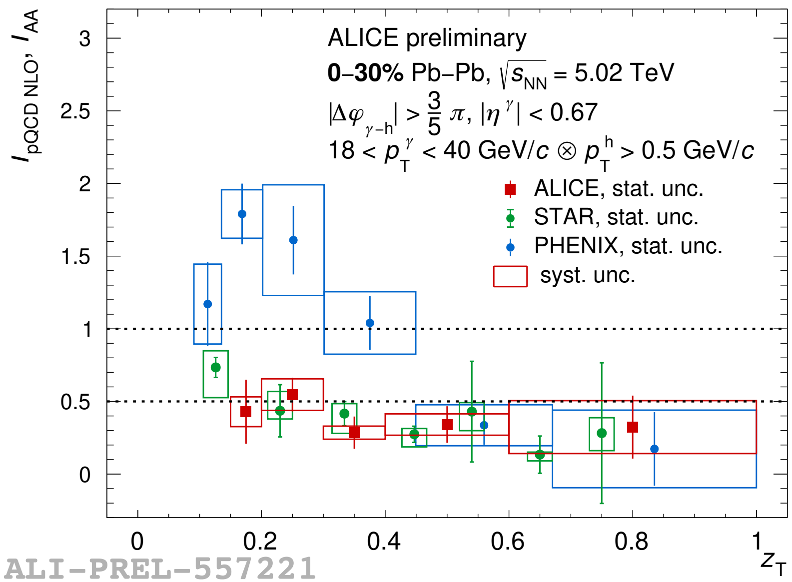
CMS, Phys.Rev.Lett. 128 (2022) 12, 122301, 2022

***Z*–hadron, 0–30%**

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

Isolated γ-hadron correlations in Pb–Pb: RHIC & LHC

C. Arata thesis



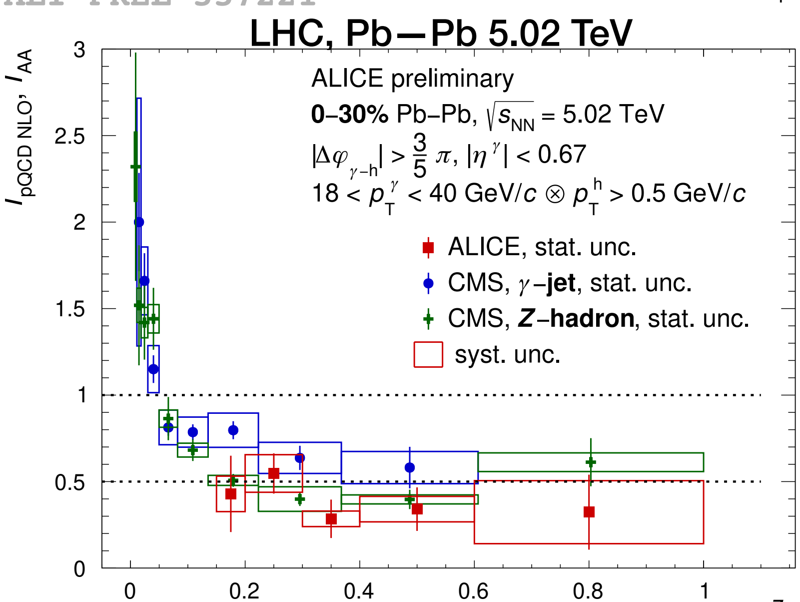
ALI-PREL-557221

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

- **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

PHENIX, PRL 111, 032301 (2013)

- **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



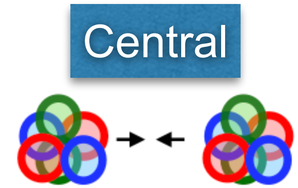
ALI-PREL-557216

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

- **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

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



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

- Similar behaviour as observed at RHIC and LHC experiments
  - ➡ Note: <u>not completely apples-to-apples comparisons!</u>

Summary

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

Various analyses on isolated photon in pp and p-Pb have been released or published during the last years:

- *the results in Pb—Pb were the last missing step*

➡ **Cross section,** with *R* = 0.4 (std) & 0.2 (new)

- Spectra & *R* ratio agreement with pQCD
- 0-50% col.: $R_{AA} \simeq 1$, no γ suppression
- 50-90% col.: $R_{AA} \simeq 0.9$, expected bias of Glauber model in centrality selection
- $R_{\rm AA}$: agreement with CMS, tension with pQCD nPDF / PDF (0-100%) at low $p_{\rm T}$

➡ **γ—hadron correlations, Pb–Pb $\sqrt{s_{\rm NN}} = 5.02$ TeV** → C. Arata thesis

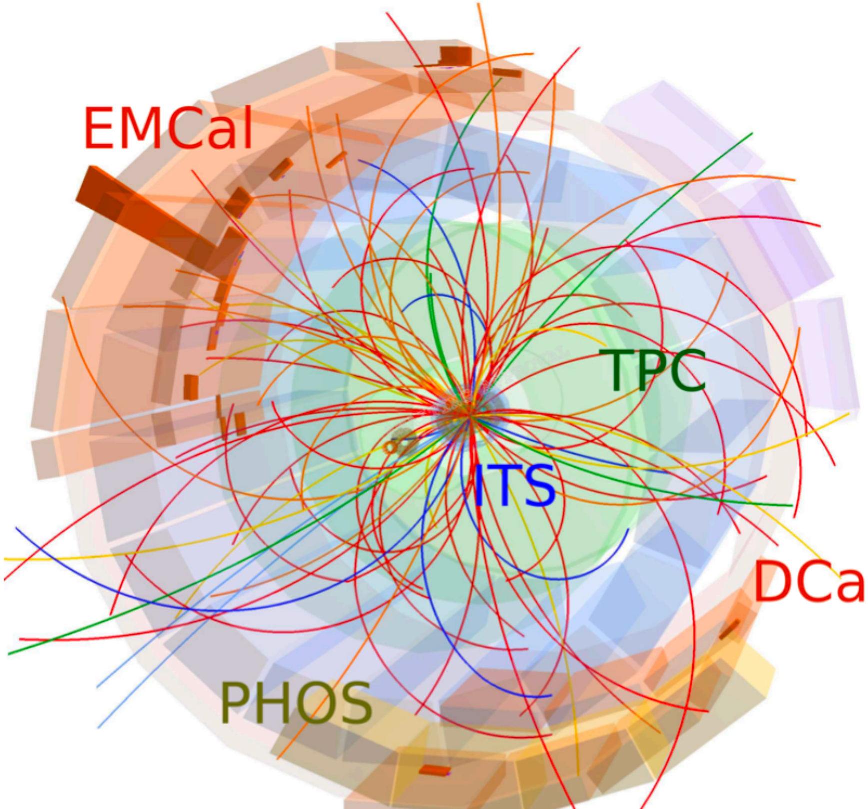
- Very statistically limited, challenging!
- FF modification stronger for central compared to peripheral collisions
- Results described by models, but discrimination not possible yet

Stay tuned for the final publications in the coming weeks (pp at $\sqrt{s_{\rm NN}}$ = 13 TeV) and months (Pb–Pb and p–Pb)!

BACK-UP

γ measurement in ALICE

- γ measurement
  - ➡ Calorimeters
    - EMCal: Pb/scintillator towers (6 × 6 cm)
      - 4.4 m from interaction point (IP)
      - $|\eta| < 0.67$ for $\Delta\varphi = 107^\circ$, $0.22 < |\eta| < 0.67$ for $\Delta\varphi = 60^\circ$ (DCal);
      - Identification via EM shower dispersion selection
      - $E_\gamma > 700$ MeV
    - PHOS: PWO_4 crystals (2.2 × 2.2 cm)
      - 4.6 m from IP
      - $|\eta| < 0.13$ for $\Delta\varphi = 70^\circ$
      - Identification via EM shower dispersion selection
      - $E_\gamma > 200$ MeV
  - ➡ Tracking, TPC & ITS
    - γ conversion method (PCM)
      - $R < 180$ cm
      - 8% conversion probability
      - $|\eta| < 0.9$ for $\Delta\varphi = 360^\circ$
      - $E_\gamma > 100$ MeV

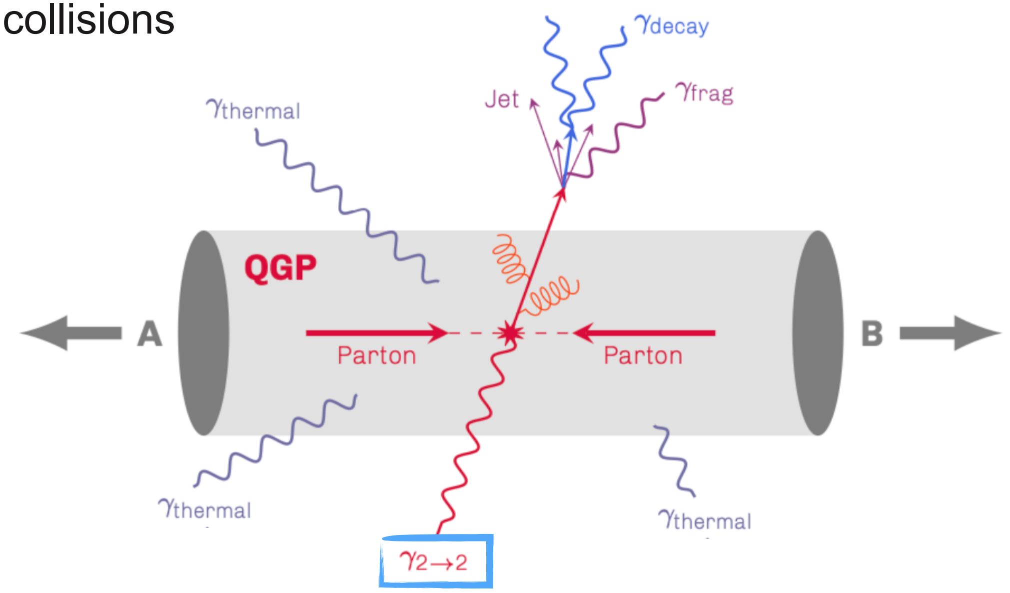


- γ identification combining tracking+calorimeter
  - ➡ Inclusive γ: Charged particle veto
  - ➡ Prompt γ: Isolation (next slides)

Direct prompt γ measurement with EMCal: Isolated γ

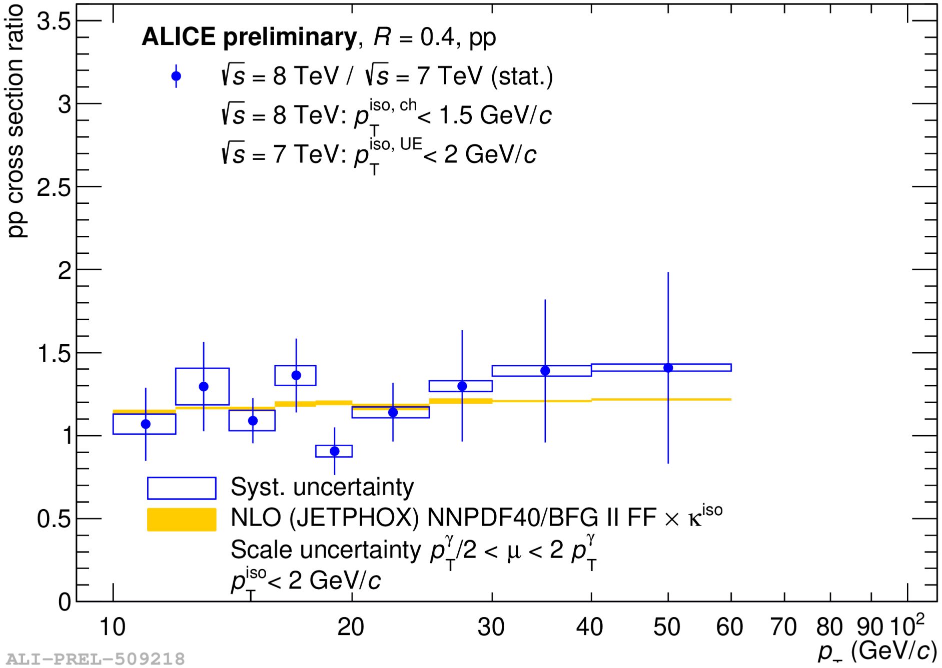
New ALICE results shown today for the first time, LHC Run 2 at $\sqrt{s_{NN}} = 5.02$ TeV:

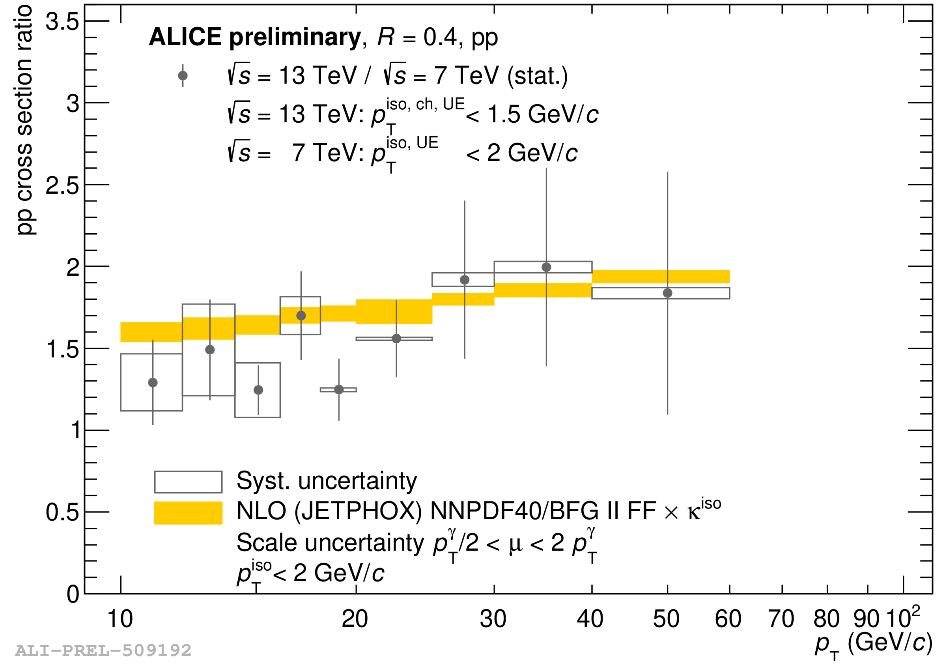
- Isolated γ cross section in pp & Pb–Pb collisions
- Isolated γ-hadron correlations in Pb–Pb collisions

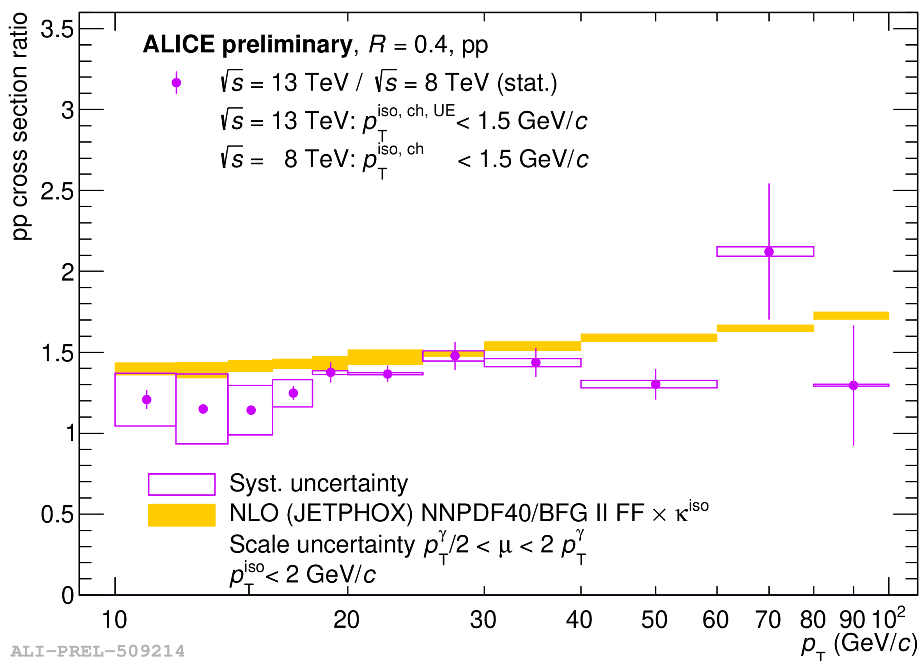


- Calorimeter: EMCal
- Tracking:
  - Pb–Pb, TPC+ITS tracks
  - pp, ITS-only tracks
- Simulation: PYTHIA pp events randomly embedded in Pb–Pb Minimum bias (MB) data
- Triggers: MB & EMCal L1-γ trigger at $E_{threshold}$ = 12 (Pb–Pb) and 4 (pp) GeV
  - Pb–Pb, L_{int} = 18 nb^{-1} ; pp L_{int} = 245 nb^{-1}
  - Pb–Pb centrality bins: **0-10%, 10-30%, 30-50%, 50-90%**

Isolated γ in pp collisions

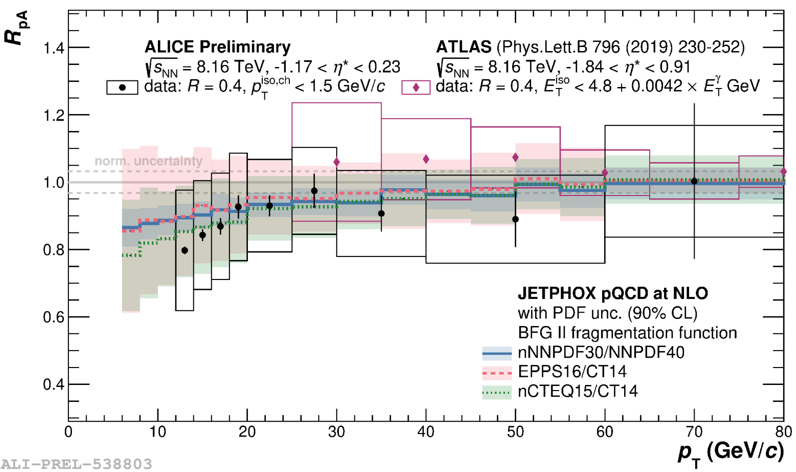




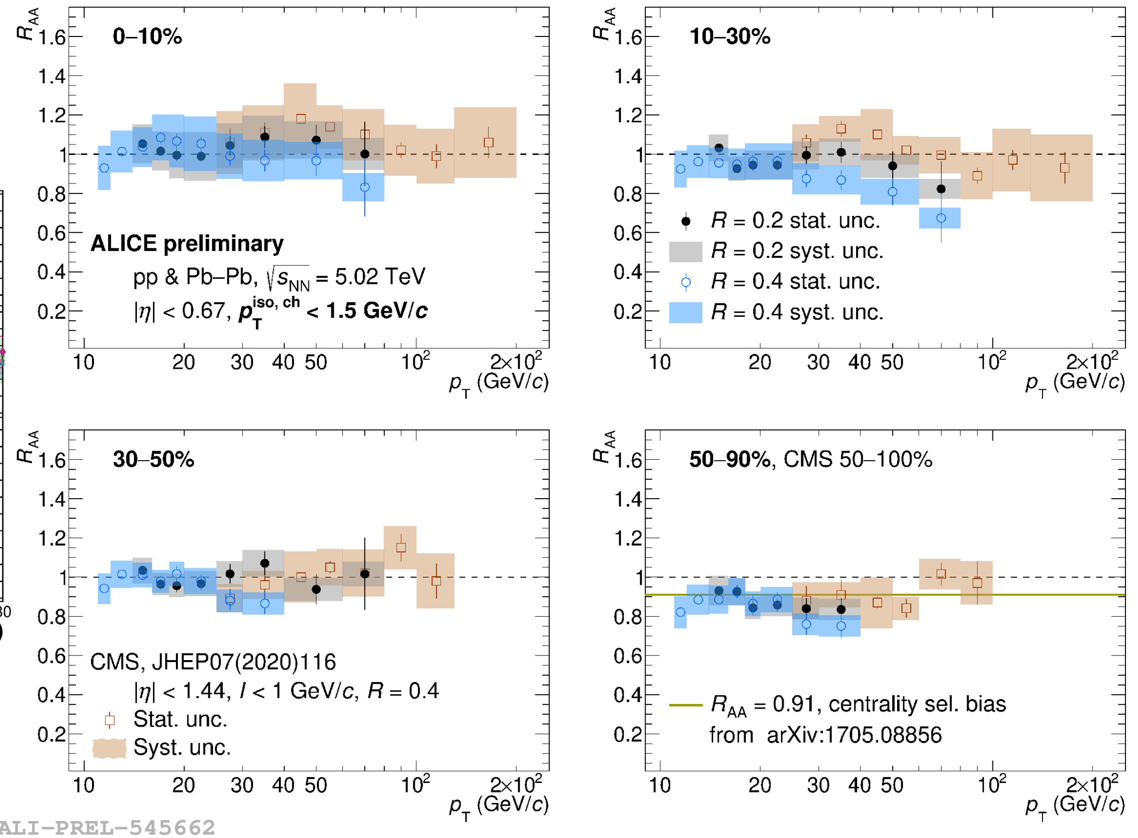


Isolated γ R_{AA} & R_{pA}

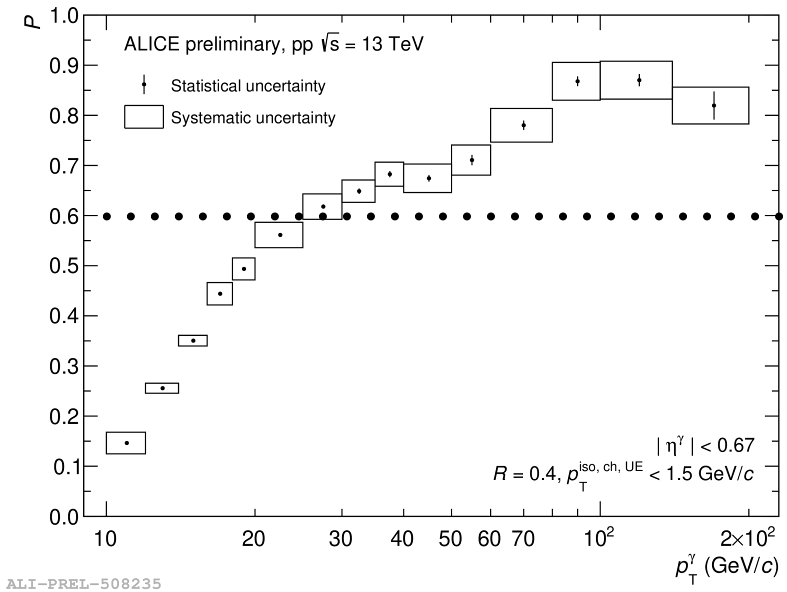
p-Pb / pp

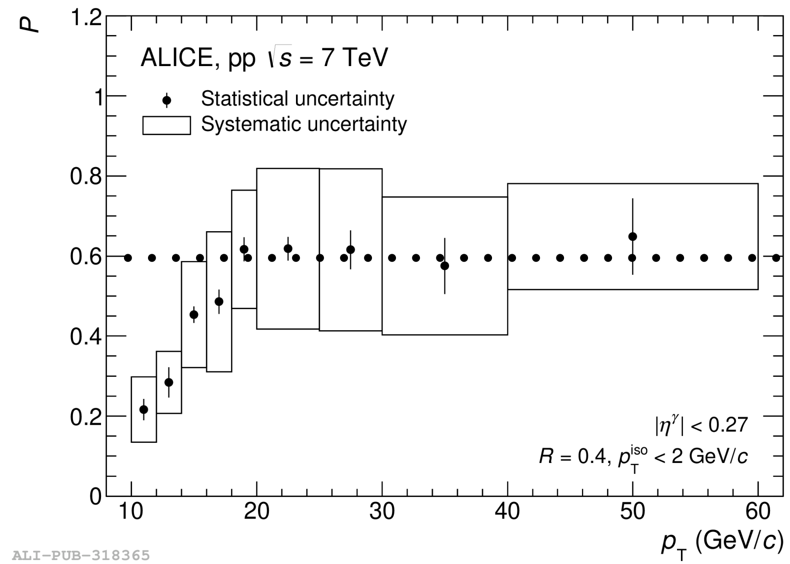


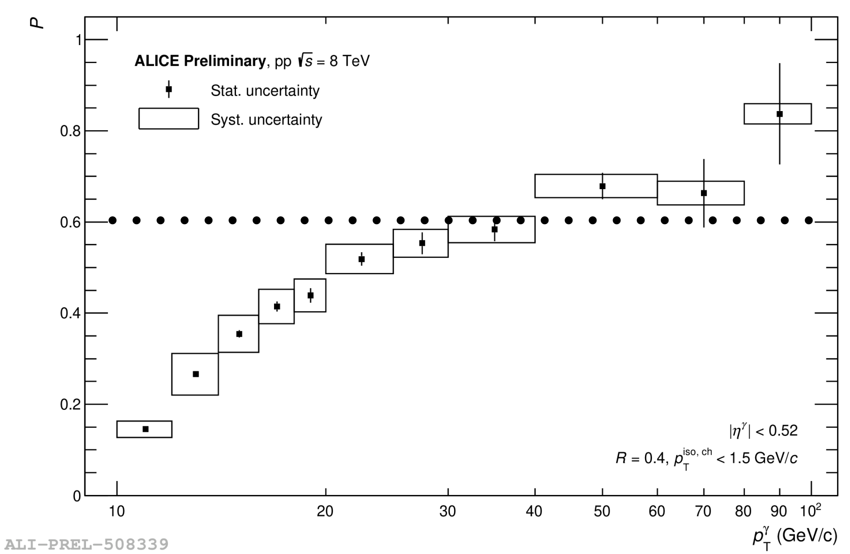
Pb-Pb / pp

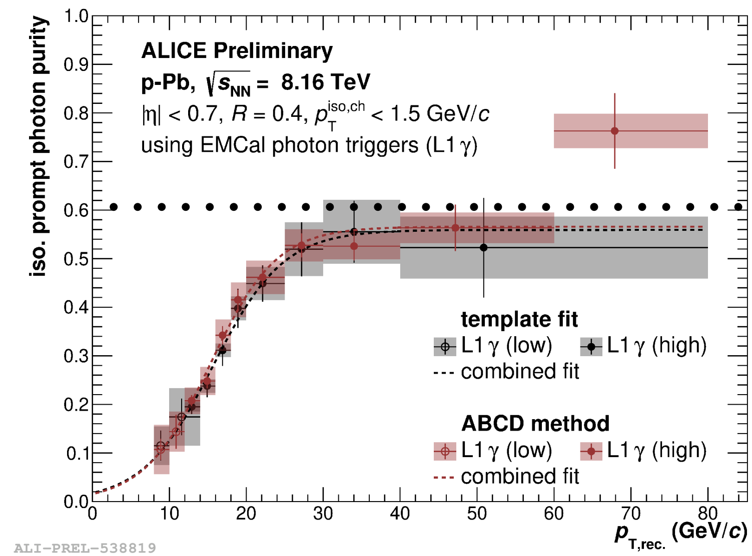


Isolated γ purity in pp & p–Pb collisions

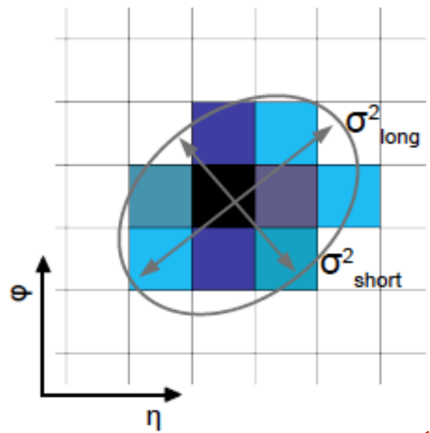








EMCal cluster shower lateral dispersion parameter



- 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

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

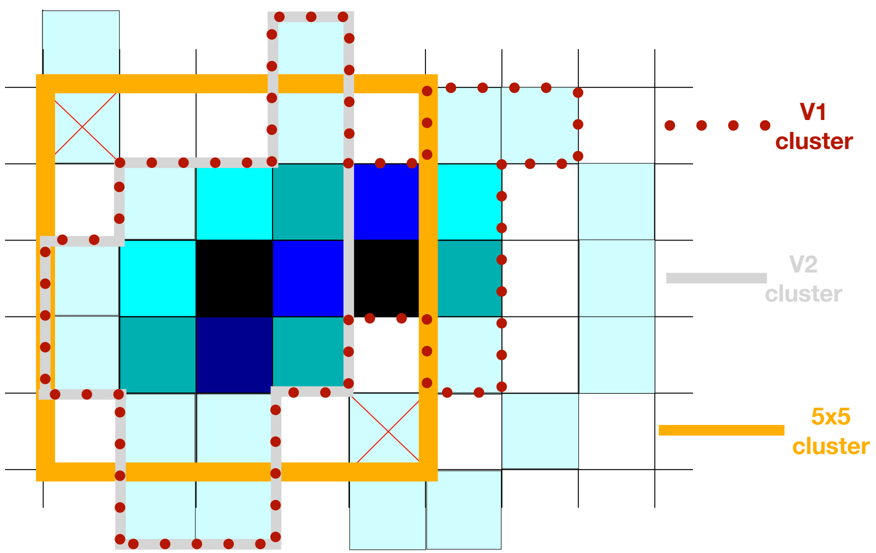
$$\sigma^2_{\alpha\beta} = \sum_i \frac{w_i \alpha_i \beta_i}{w_{\text{tot}}} - \sum_i \frac{w_i \alpha_i}{w_{\text{tot}}} \sum_i \frac{w_i \beta_i}{w_{\text{tot}}}$$

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

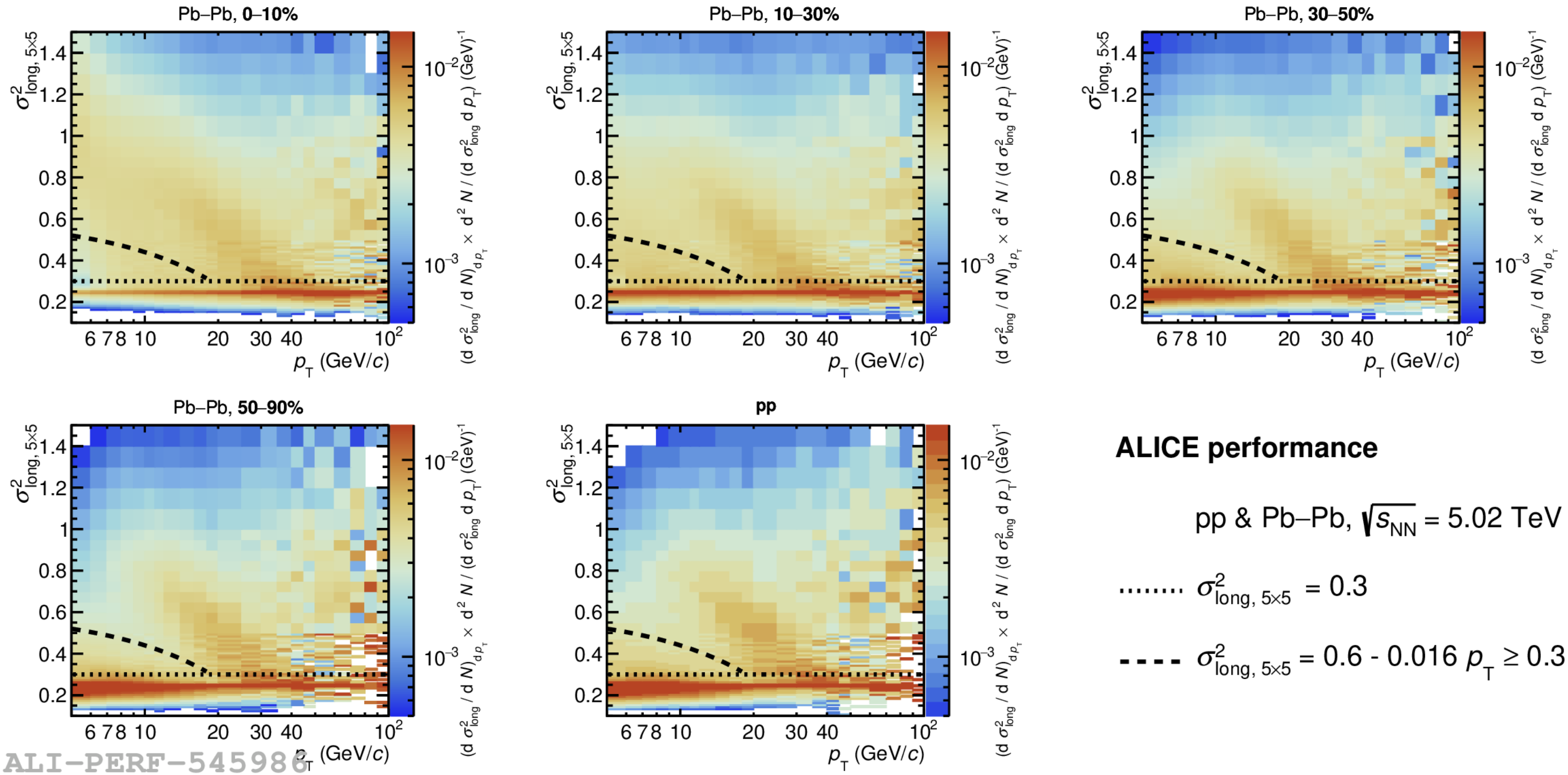
$$\sigma^2_{\text{long}} = 0.5(\sigma^2_{\varphi\varphi} + \sigma^2_{\eta\eta}) + \sqrt{0.25(\sigma^2_{\varphi\varphi} - \sigma^2_{\eta\eta})^2 + \sigma^2_{\eta\varphi}},$$

$$\sigma^2_{\text{short}} = 0.5(\sigma^2_{\varphi\varphi} + \sigma^2_{\eta\eta}) - \sqrt{0.25(\sigma^2_{\varphi\varphi} - \sigma^2_{\eta\eta})^2 + \sigma^2_{\eta\varphi}},$$

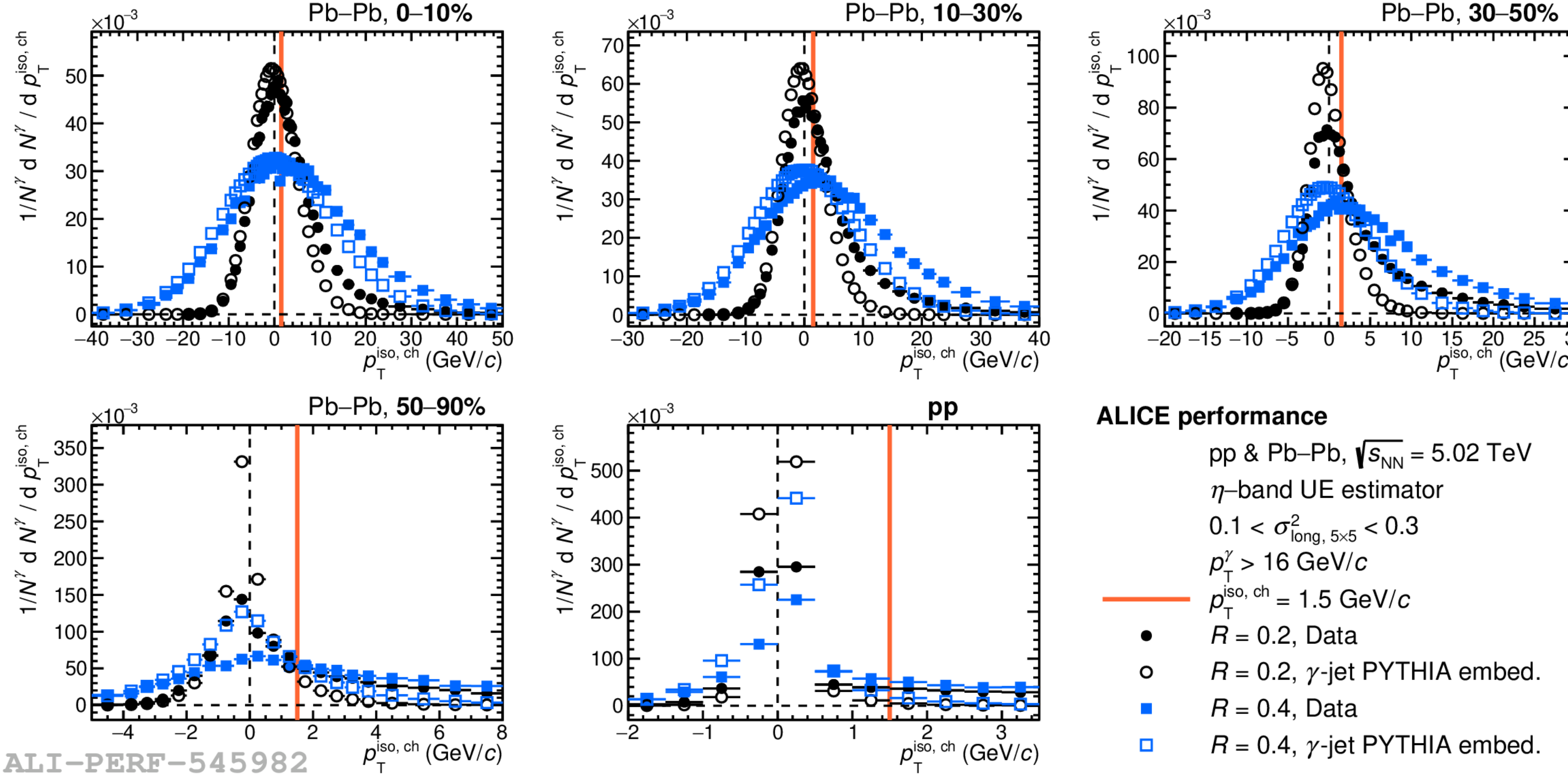
- For Pb–Pb, let's just consider the cells around the highest energy cell in a 5x5 fixed window in the σ^2_{long} calculation, independently if cells were assigned to the V3 cluster
  - Those cells must be all neighbours
- **The cluster energy and position remains the same as the V3 cluster**
- **Use same definition in pp and Pb–Pb collisions**

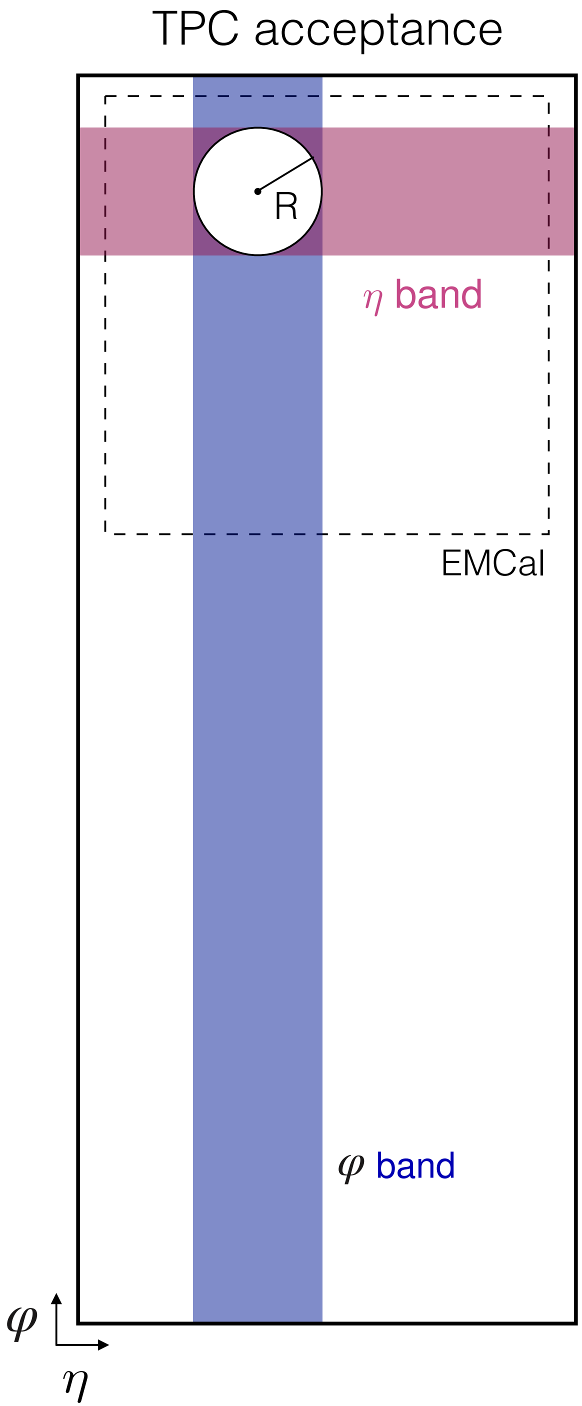


EMCal cluster shower shape



Isolation energy in cone for R = 0.2 & 0.4





TPC acceptance
R
η band
EMCal
φ band
φ
η

ISOLATED CROSS SECTION CALCULATION

$$\frac{d^2\sigma}{d\,p_T\,d\,\eta} = \frac{\sigma_{MB}}{N_{col} \times \sum^{n\ \text{periods}}_{\&\ \text{triggers}} (N_{events} \times RF_{\varepsilon_{trig}})} \times \sum^{n\ \text{triggers \& periods}} \left(\frac{d^2N}{dp_T\,d\eta}\right) \times \frac{Purity}{Acc. \times \varepsilon_\gamma^{iso} \times \varepsilon_{trig}}$$

Ingredients:

- Trigger efficiency: ε_{trig}
- Rejection factor: RF_{trig}
- EMCal acceptance correction Acc: 0.527
- Minimum bias cross section: σ_{MB}
- N_{coll}
- Purity
- Efficiency:

	σ_{MB} (mb)	N_{col}
pp	50.87 (2.1%)	1
Pb–Pb	67.6 (0.88%)	
0-10%		1572 ± 17.4 (1.1%)
10-30%		783.05 ± 7.0 (0.9%)
30-50%		264.75 ± 3.3(1.2%)
50-90%		38.42 ± 0.6 (1.6%)

Efficiency per selection cut:

$$\varepsilon^{sel} = \frac{dN^{\text{cluster sel.}}_{\gamma_{prompt}} / dp_T^{rec}}{dN^{\text{gener.}}_{\gamma_{prompt}} / dp_T^{gen}}$$

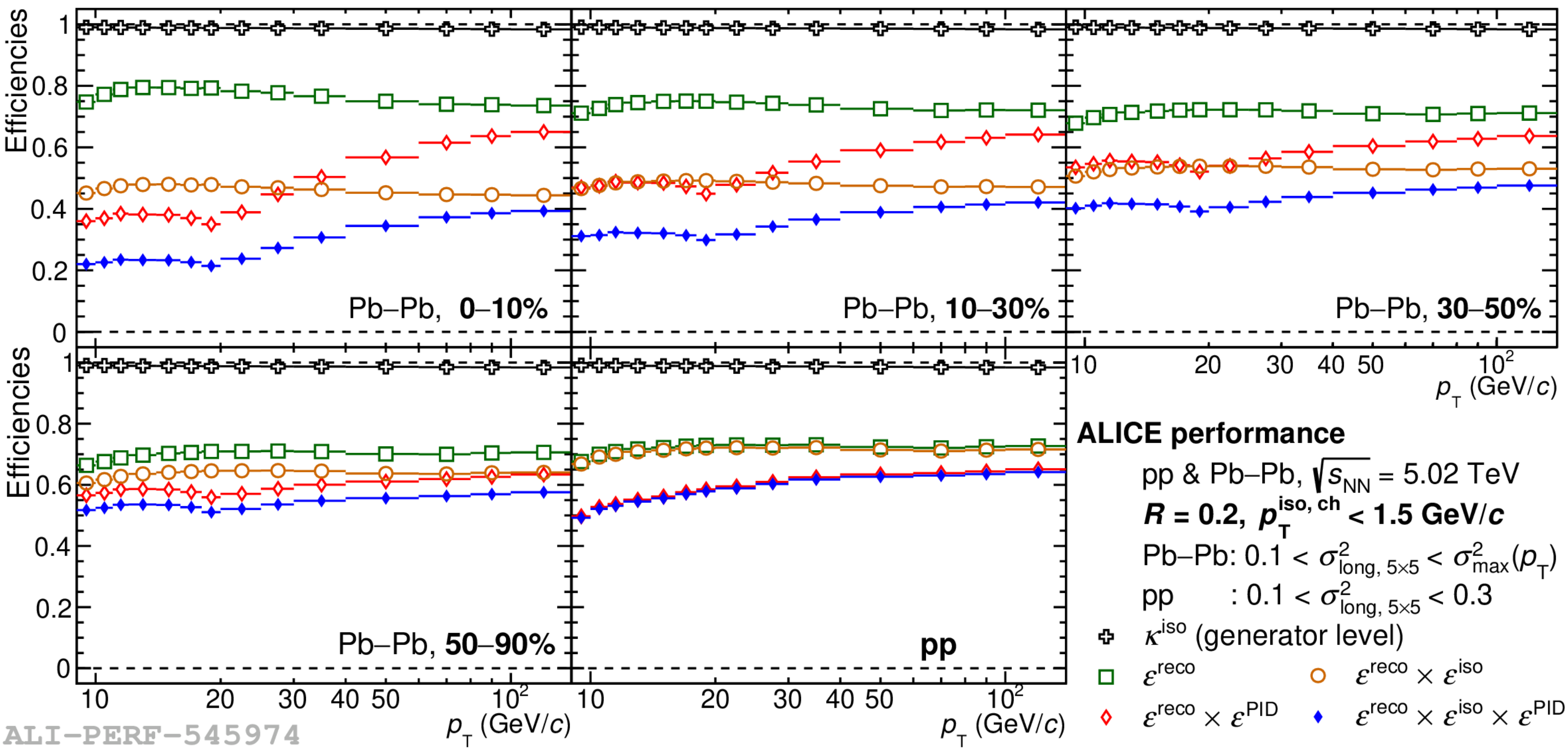
- Reconstruction
- PID (shower shape)
- Isolation

Final efficiency:

$$\varepsilon_\gamma^{iso} = \frac{dN^{\text{cluster iso. narrow}}_{\gamma_{prompt}} / dp_T^{rec}}{dN^{\text{gener. iso.}}_{\gamma_{prompt}} / dp_T^{gen}}$$

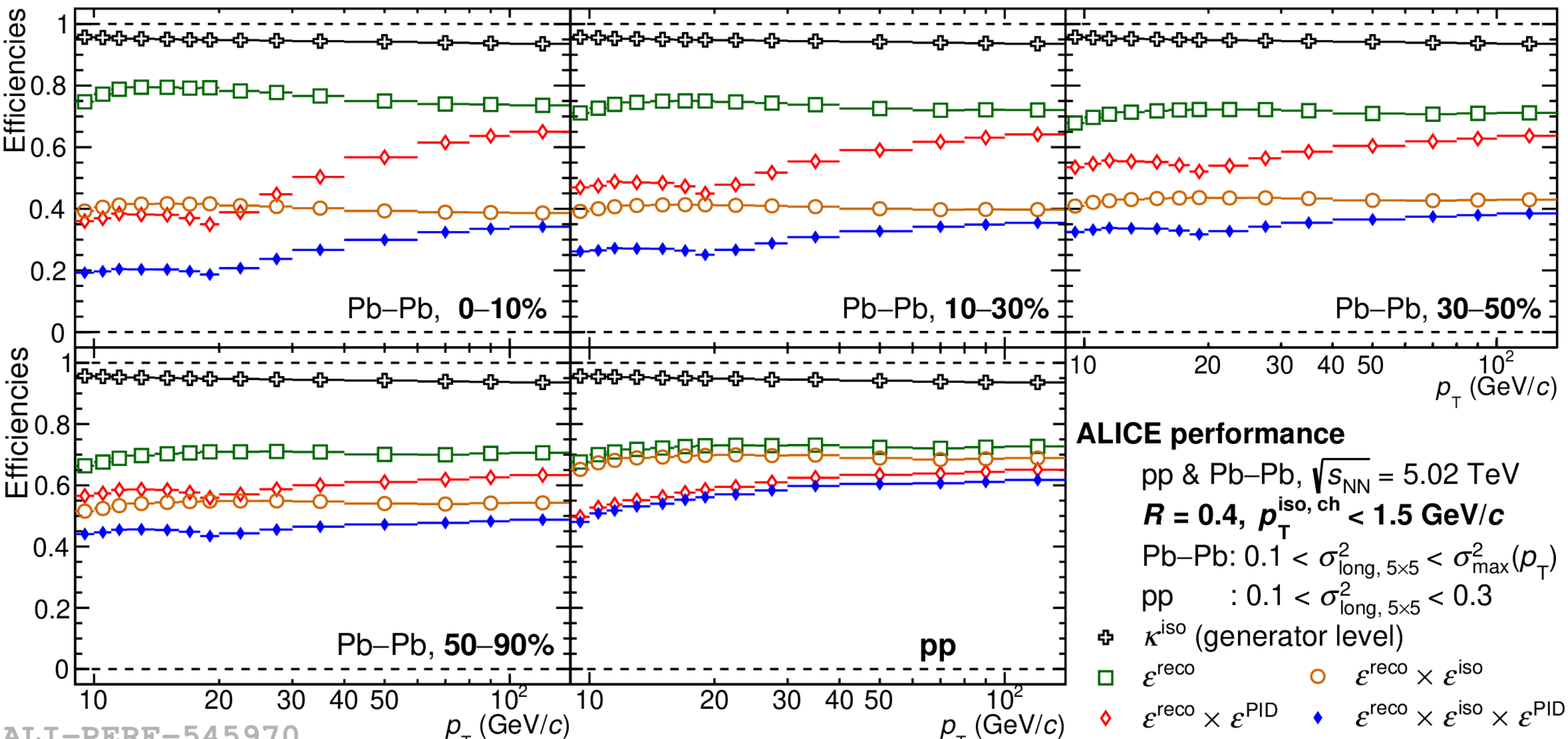
Isolated γ efficiency components, $R = 0.2$

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



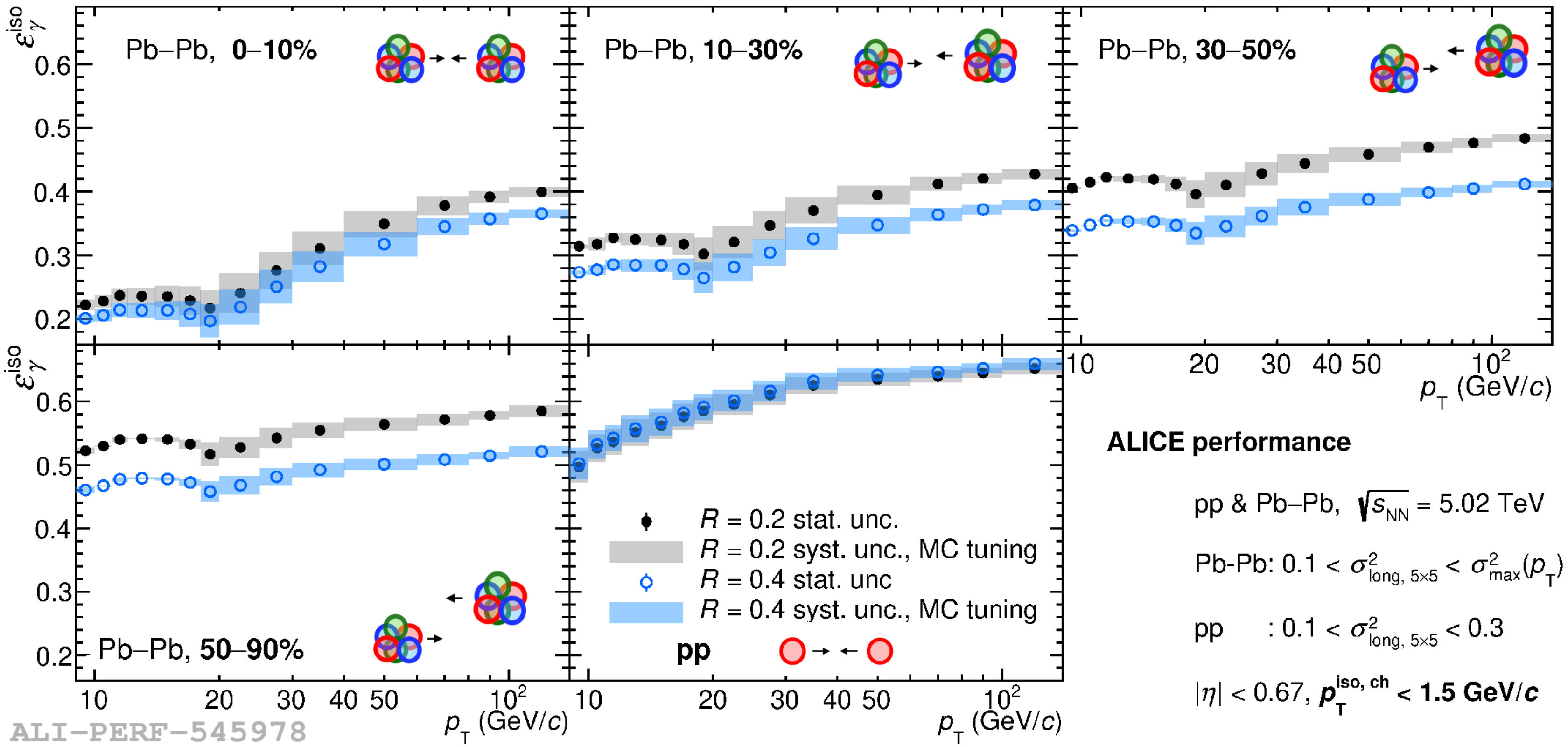
Isolated γ efficiency components, R = 0.4

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



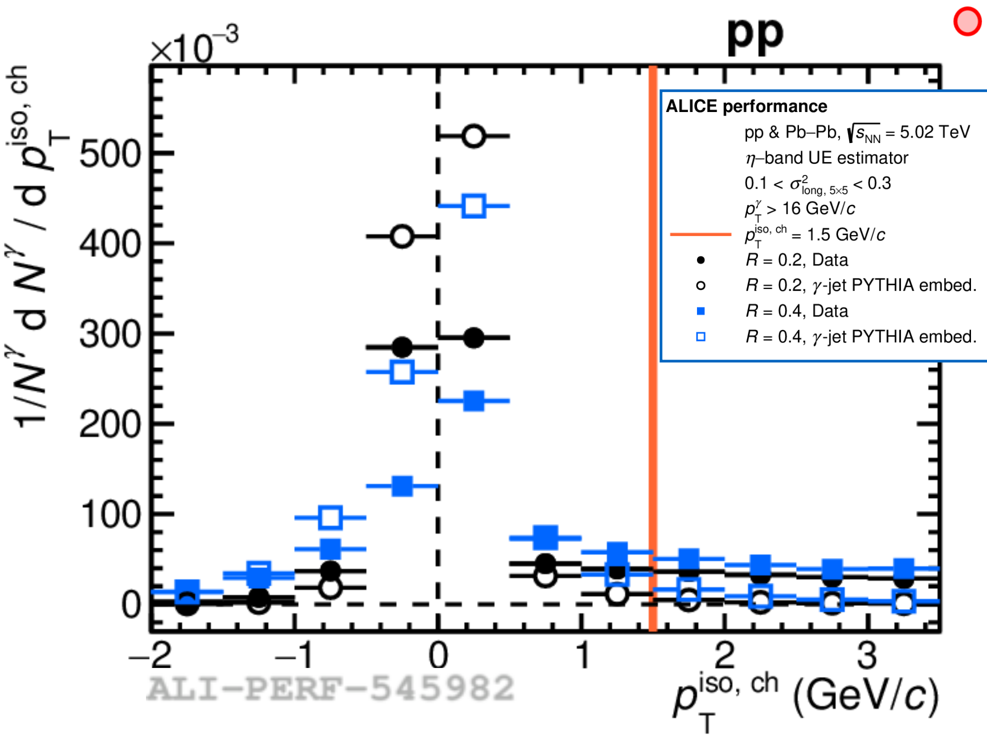
Efficiency, R = 0.2 & 0.4

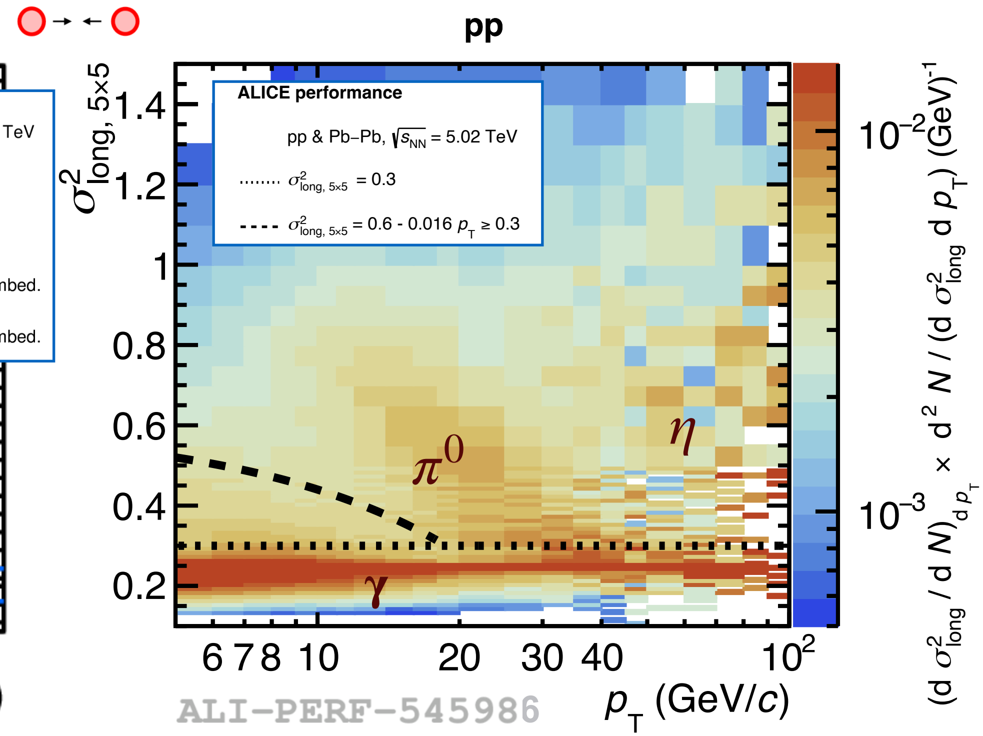
$$\varepsilon_{\gamma}^{\mathrm{iso}} = \frac{\mathrm{d}N_{\gamma_{\mathrm{prompt}}}^{\mathrm{cluster\ iso.\ narrow}}/\mathrm{d}p_{\mathrm{T}}^{\mathrm{rec}}}{\mathrm{d}N_{\gamma_{\mathrm{prompt}}}^{\mathrm{gener.\ iso.}}/\mathrm{d}p_{\mathrm{T}}^{\mathrm{gen}}}$$



- $\varepsilon_{\gamma}^{\mathrm{iso}}$ *(0-10%)* < $\varepsilon_{\gamma}^{\mathrm{iso}}$ (50-90%*)*: UE increases cluster size in more central collisions
- In Pb–Pb, $\varepsilon_{\gamma}^{\mathrm{iso}}$ (R = 0.2) > $\varepsilon_{\gamma}^{\mathrm{iso}}$ (R = 0.4) a factor ~0.9 due to lower UE fluctuations
- In pp, $\varepsilon_{\gamma}^{\mathrm{iso}}$ (R = 0.2) ≈ $\varepsilon_{\gamma}^{\mathrm{iso}}$ (R = 0.4), due to the less performing ITS-only tracks

Prompt γ identification: EMCal EM shape & isolation

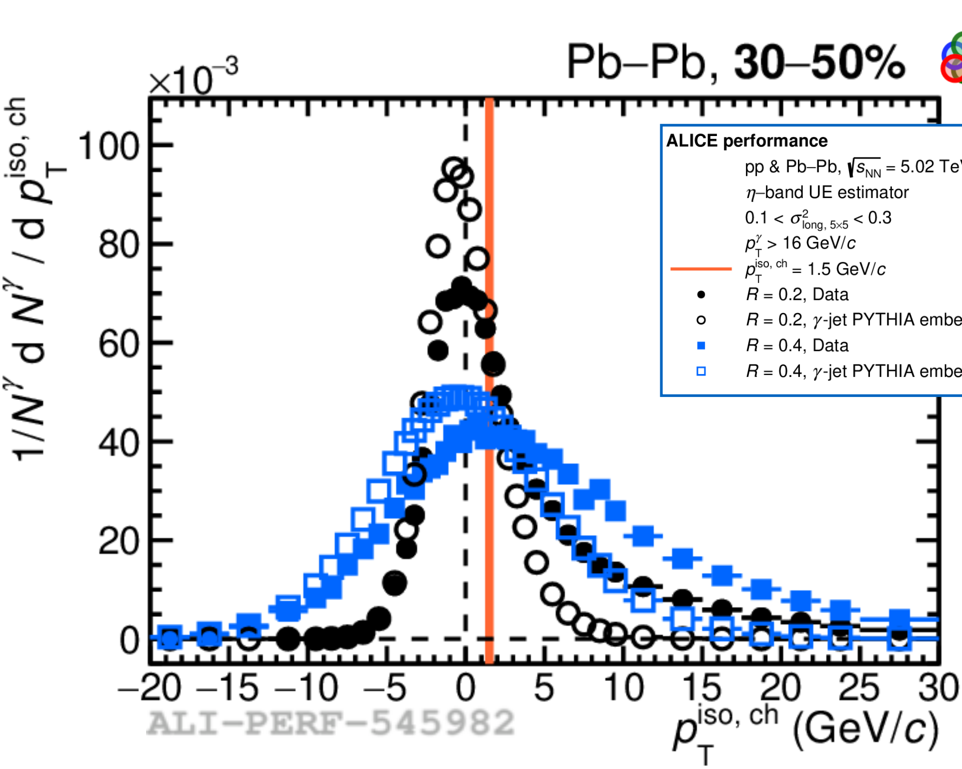


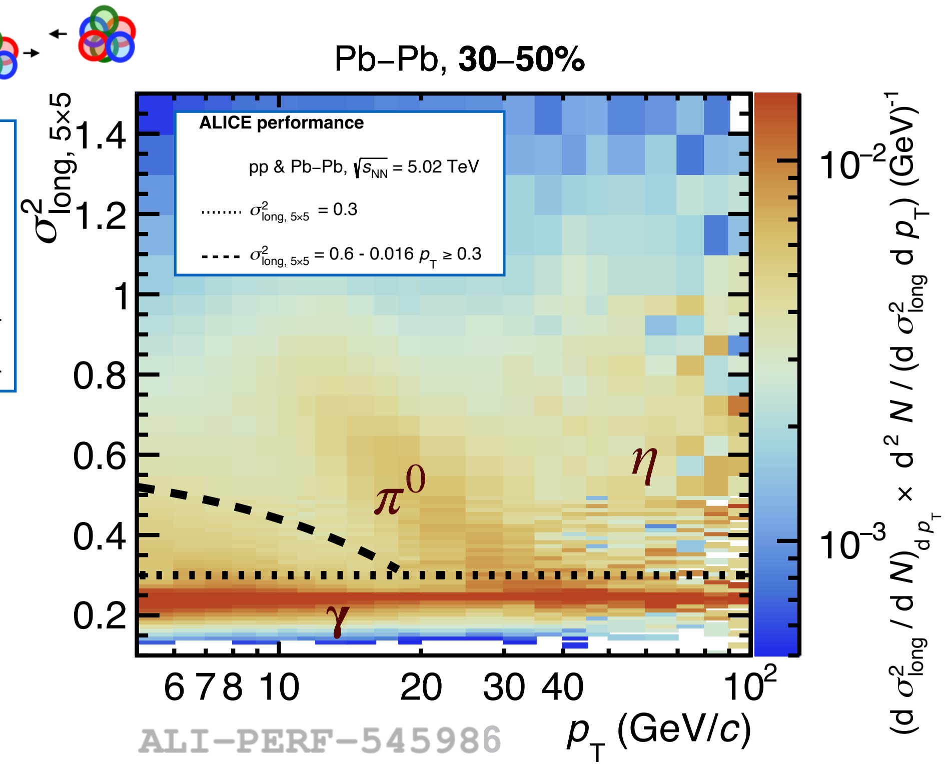


- Similar narrow peaked distribution for both *R*, more peaked for *R* = 0.2
- In data, more jet contribution to the right tail for *R* = 0.4

- Select as γ clusters with $0.1 < \sigma^2_{long, 5\times5} < 0.3$
- γ & π^0 bands well separated for $p_T < 20$ GeV/*c*, then overlap

Prompt γ identification: EMCal EM shape & isolation

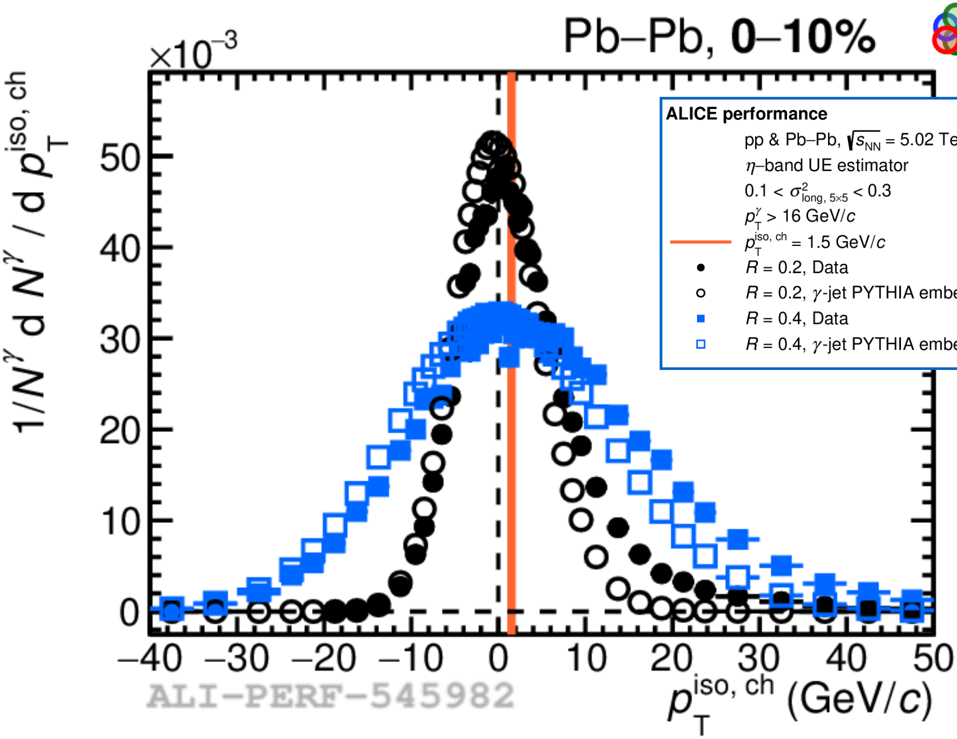


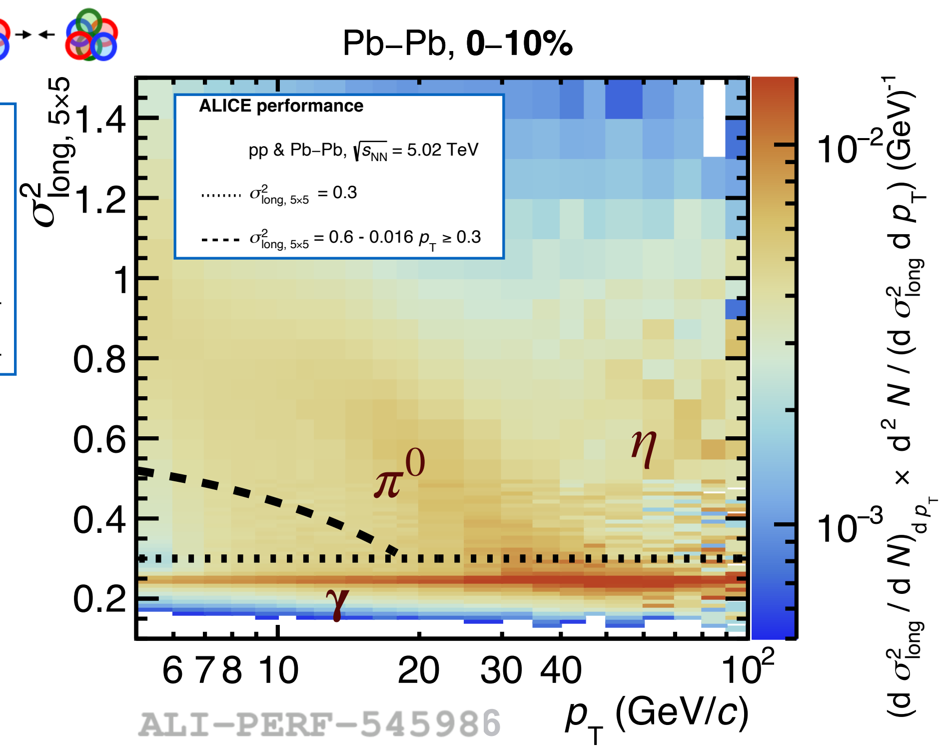


- Significantly wider for R = 0.4
- Embedded pp PYTHIA simulation into MB data, symmetric distribution
- In data, more asymmetric distribution due to jet contribution

- Select as **γ** clusters with
  $0.1 < \sigma^2_{\text{long, }5\times5} < 0.6 - 0.016 \cdot p_{\text{T}} \geq 0.3$
- **γ** & π^0 bands visible from pp to Pb–Pb semi-central collisions

Prompt γ identification: EMCal EM shape & isolation





- Significantly <u>much</u> wider for $R = 0.4$
- Embedded pp PYTHIA simulation into MB data, symmetric distribution
- In data, more asymmetric distribution due to jet contribution

- Select as **γ** clusters with
  $0.1 < \sigma^2_{\text{long, }5\times5} < 0.6 - 0.016 \cdot p_T \geq 0.3$
- **γ** & π^0 bands visible from pp to Pb–Pb central collisions
  - ➡ but many **γ** increase their $\sigma^2_{\text{long, }5\times5}$ due to the UE contribution to the cluster

Purity

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

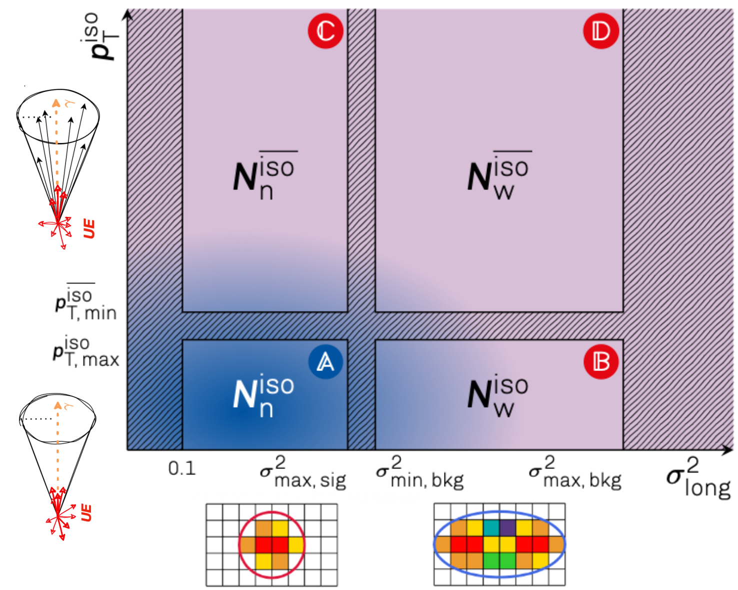
➡ $\mathbb{A}$: $0.1 < \sigma^2_{\mathrm{long,\ 5\times5}} < \sigma^2_{\mathrm{max}}(p_{\mathrm{T}})$, $p_{\mathrm{T}}^{\mathrm{iso,\ ch}} < 1.5$ GeV/c

➡ $\mathbb{B}$: $0.1+\sigma^2_{\mathrm{max}}(p_{\mathrm{T}}) < \sigma^2_{\mathrm{long,\ 5\times5}} < 2.0$, $p_{\mathrm{T}}^{\mathrm{iso,\ ch}} < 1.5$ GeV/c

➡ $\mathbb{C}$: $0.1 < \sigma^2_{\mathrm{long,\ 5\times5}} < \sigma^2_{\mathrm{max}}(p_{\mathrm{T}})$, $4 < p_{\mathrm{T}}^{\mathrm{iso,\ ch}} < 25$ GeV/c

➡ $\mathbb{D}$: $0.1+\sigma^2_{\mathrm{max}}(p_{\mathrm{T}}) < \sigma^2_{\mathrm{long,\ 5\times5}} < 2.0$, $4 < p_{\mathrm{T}}^{\mathrm{iso,\ ch}} < 25$ GeV/c

with $\sigma^2_{\mathrm{max}} = 0.6 - 0.016 \cdot p_{\mathrm{T}} \geq 0.3$ (Pb–Pb) or $\sigma^2_{\mathrm{max}} = 0.3$ (pp)



- Purity in $\mathbb{A}$ region extracted as:

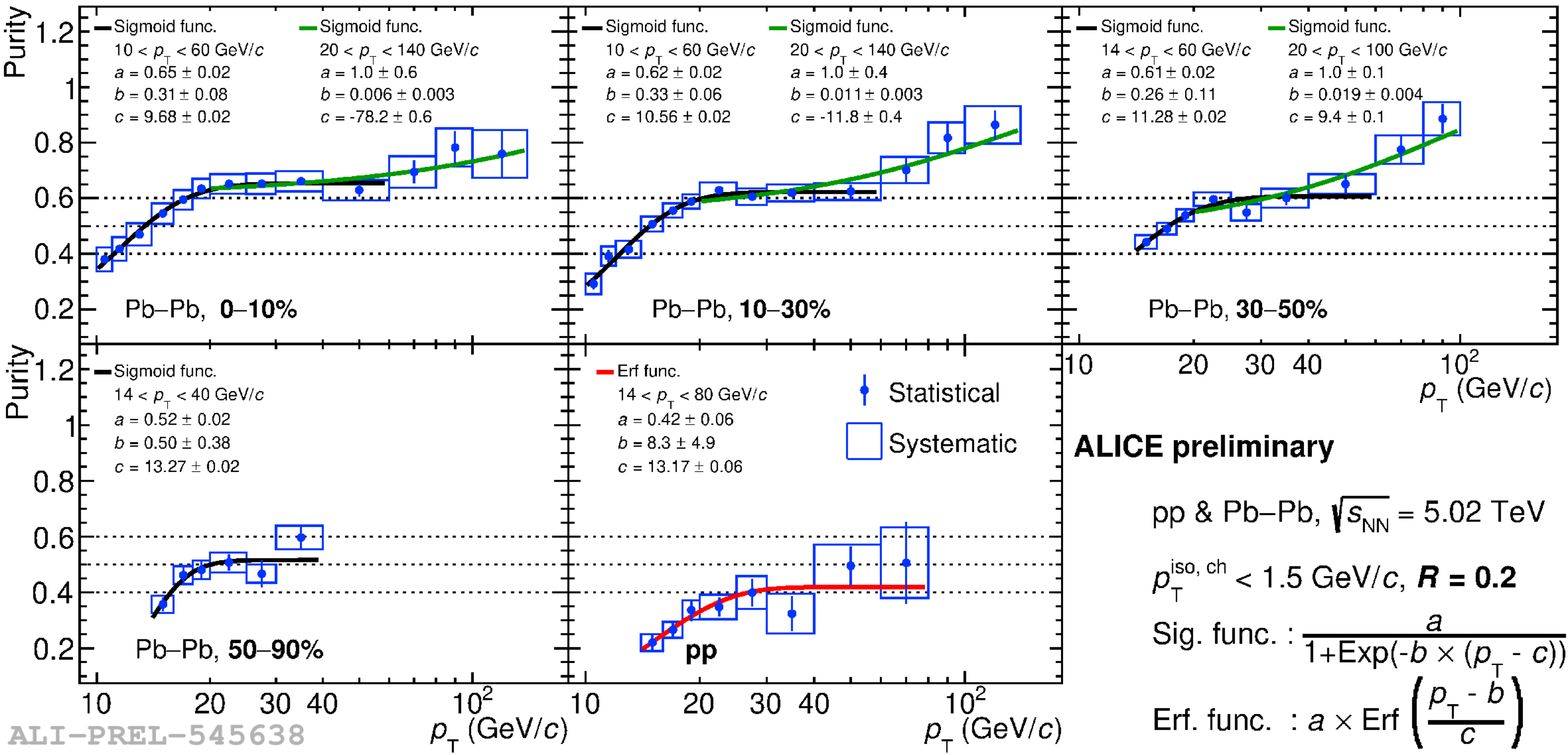
$$P = 1 - \left(\frac{N_n^{\overline{\mathrm{iso}}}/N_n^{\mathrm{iso}}}{N_w^{\overline{\mathrm{iso}}}/N_w^{\mathrm{iso}}}\right)_{\mathrm{data}} \times \left(\frac{B_n^{\mathrm{iso}}/N_n^{\overline{\mathrm{iso}}}}{N_w^{\mathrm{iso}}/N_w^{\overline{\mathrm{iso}}}}\right)_{MC}$$

data-driven

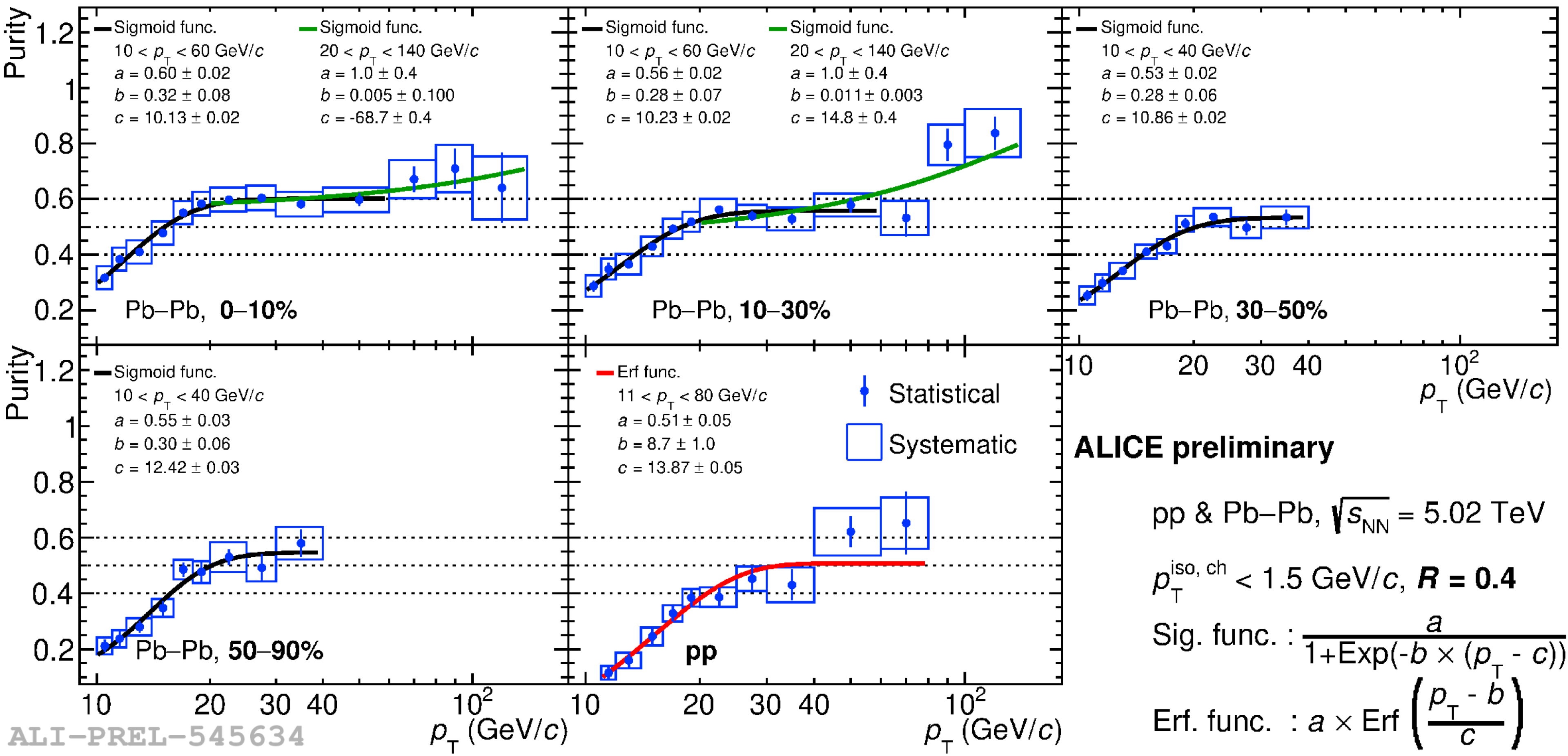
PYTHIA:
$N_{n,w}^{\mathrm{iso},\overline{\mathrm{iso}}}$= jet-jet ($B_{n,w}^{\mathrm{iso},\overline{\mathrm{iso}}}$) + γ-jet ($S_{n,w}^{\mathrm{iso},\overline{\mathrm{iso}}}$)

➡ Semi data-driven approach, simulation to correct correlations between $p_{\mathrm{T}}^{\mathrm{iso,\ ch}}$ and $\sigma^2_{\mathrm{long,\ 5\times5}}$

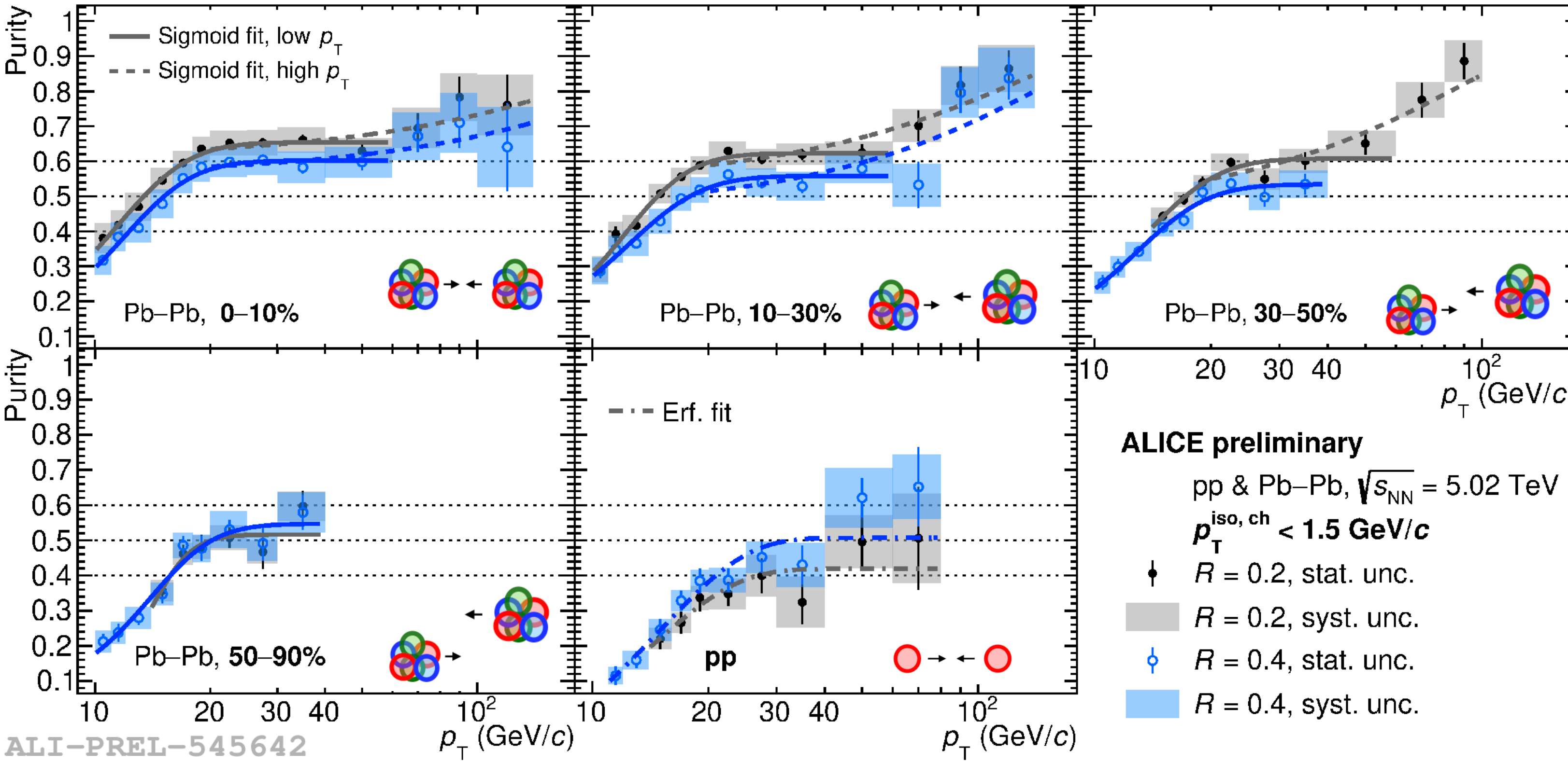
Isolated γ purity, R = 0.2



Isolated γ purity, R = 0.4

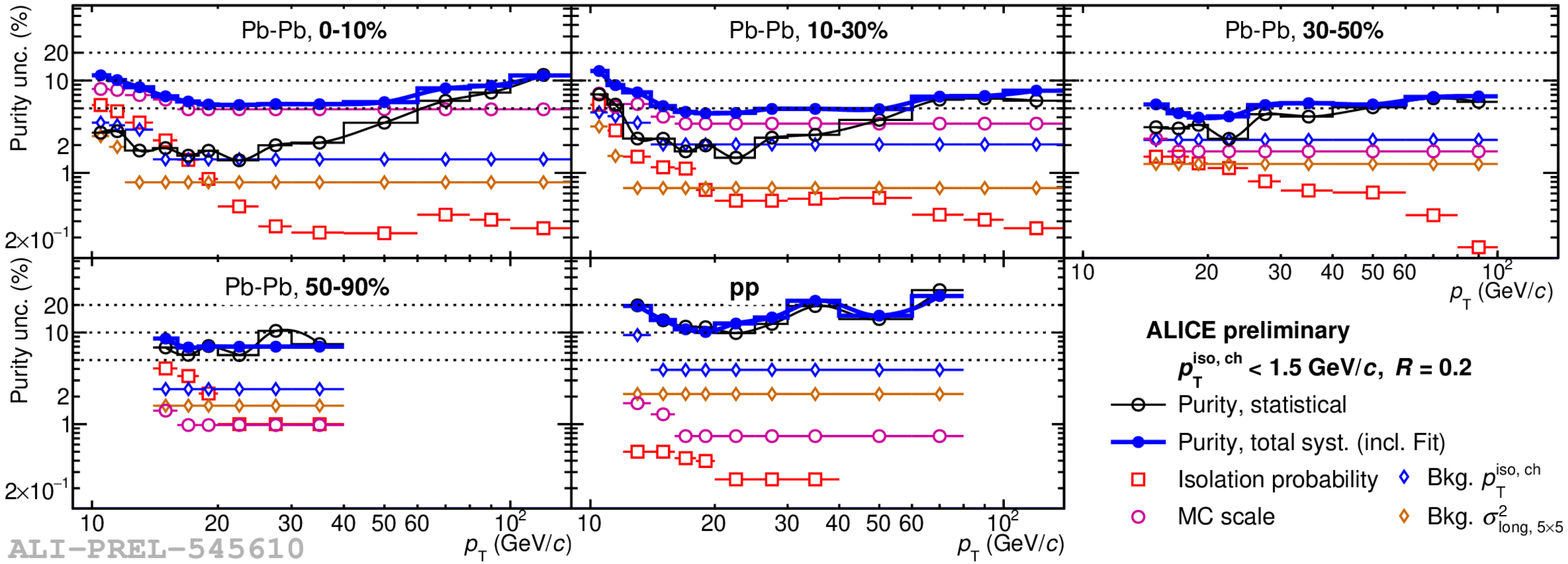


Purity for R = 0.2 & 0.4

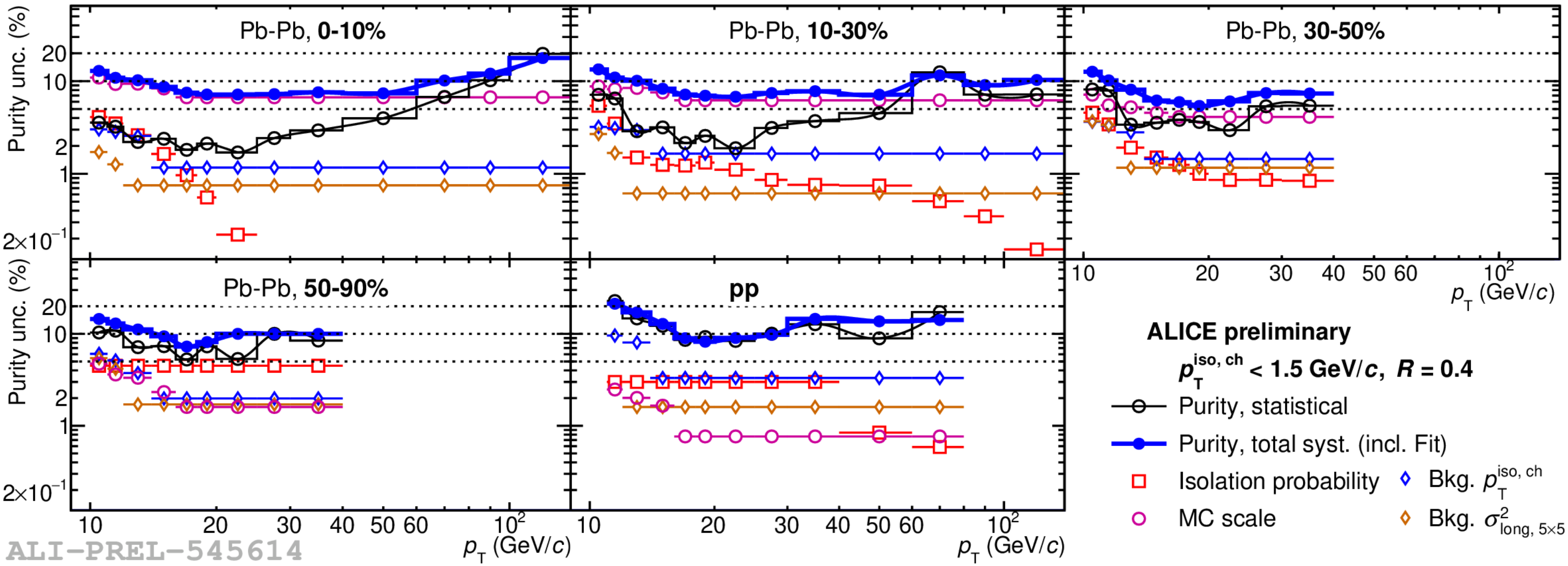


- Distributions fitted to Sigmoid or Erf functions to reduce influence of fluctuations, fits used to correct the spectra
- P (R = 0.4) > P (R = 0.2) in pp collisions, more jet particles in cone, but decreasing centrality P (R = 0.2) > P (R = 0.4), due to UE fluctuations, although not significantly different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

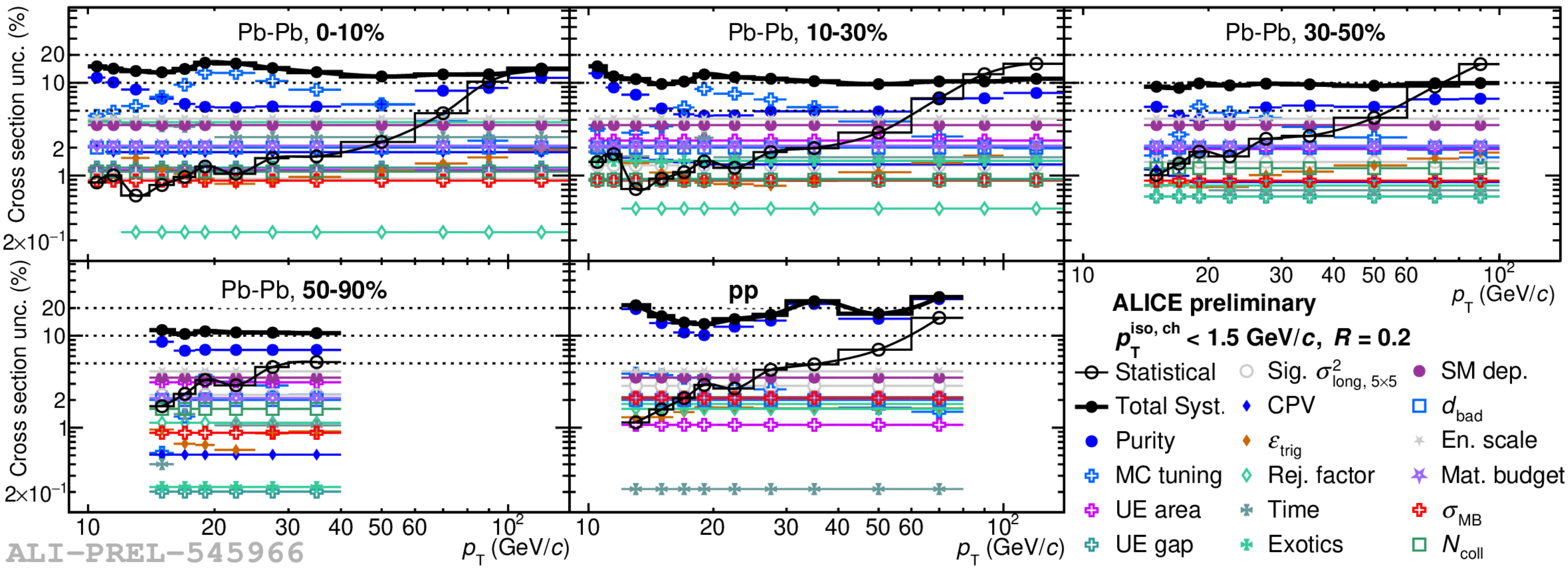
Isolated γ purity uncertainty, R = 0.2



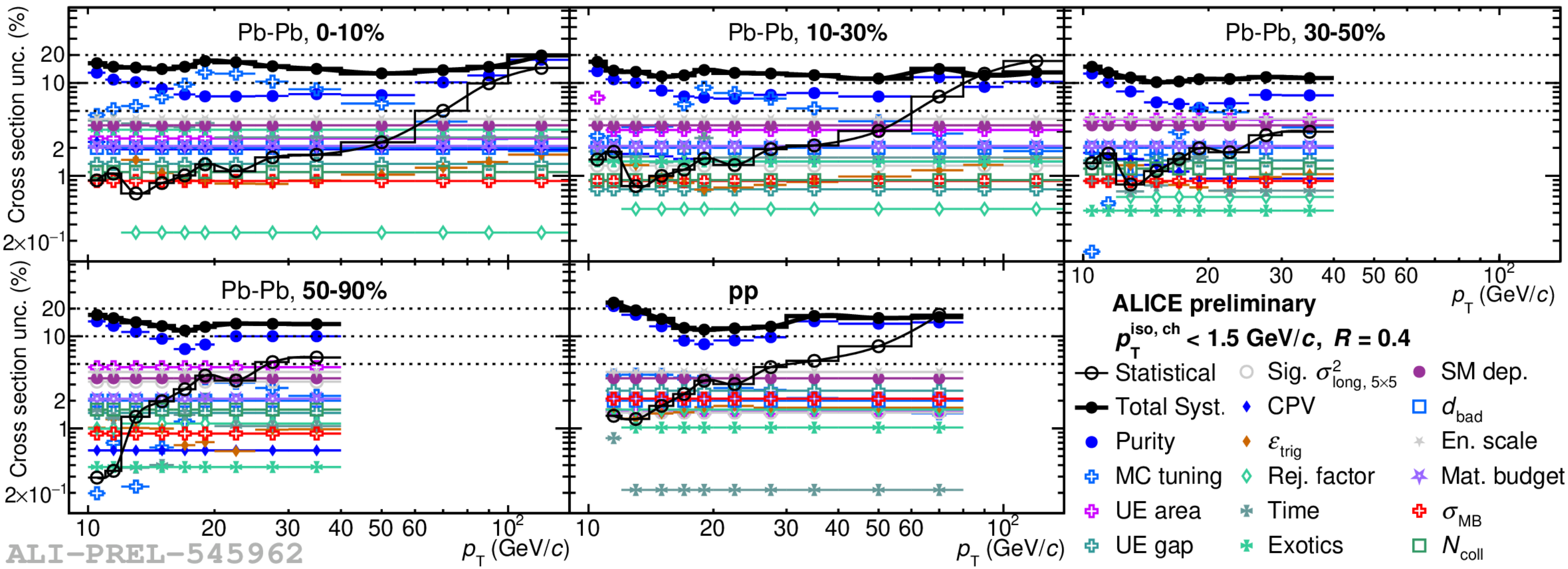
Isolated γ purity uncertainty, R = 0.4



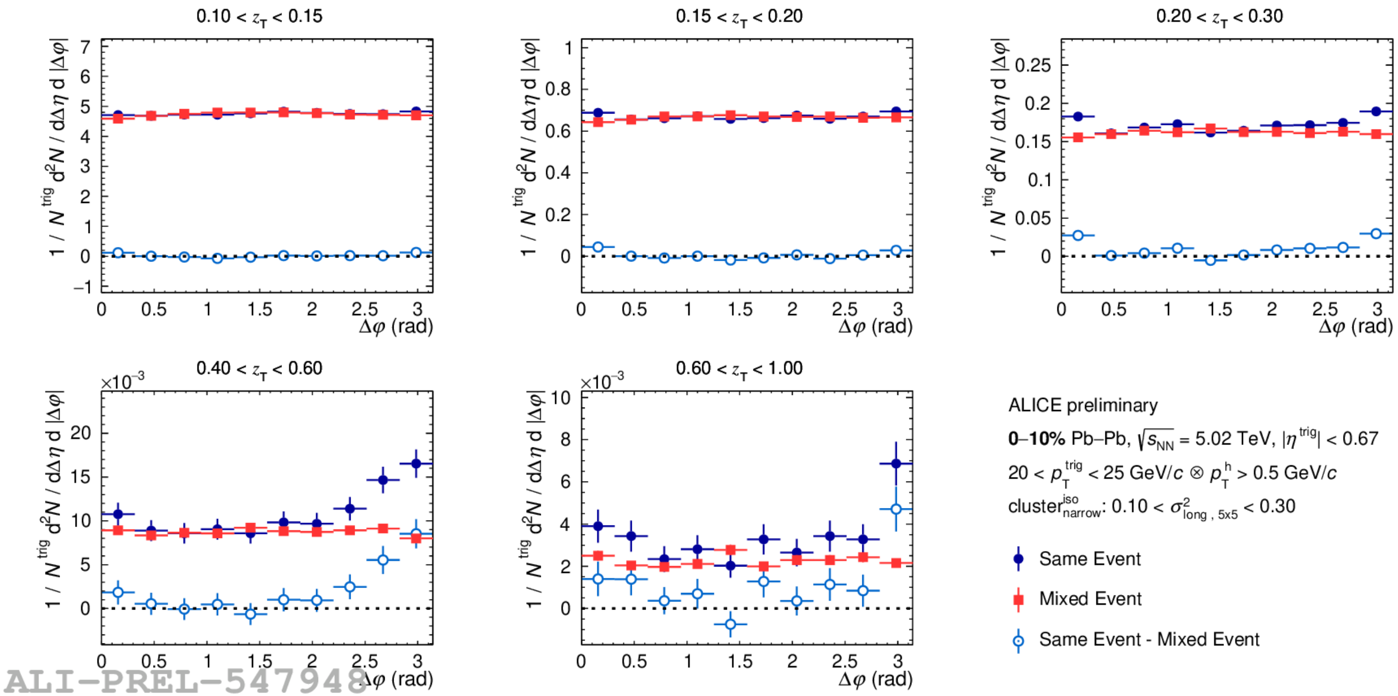
Isolated γ cross section uncertainty, R = 0.2



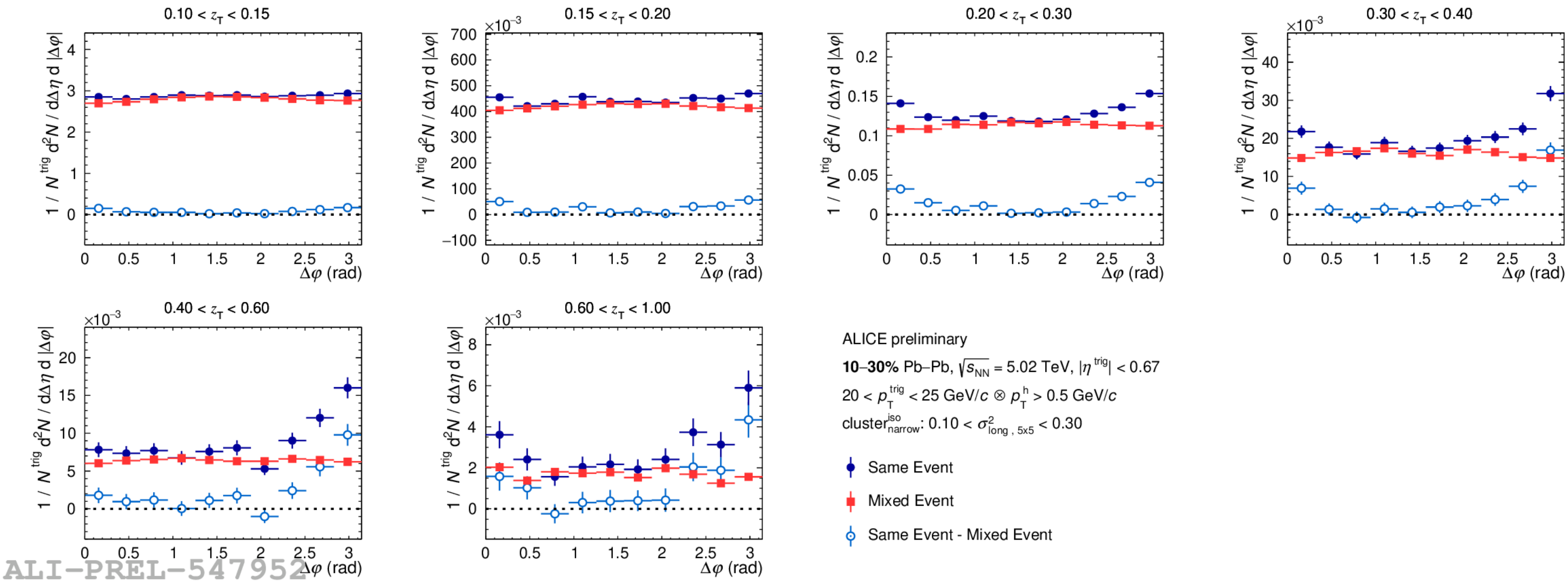
Isolated γ cross section uncertainty, R = 0.4



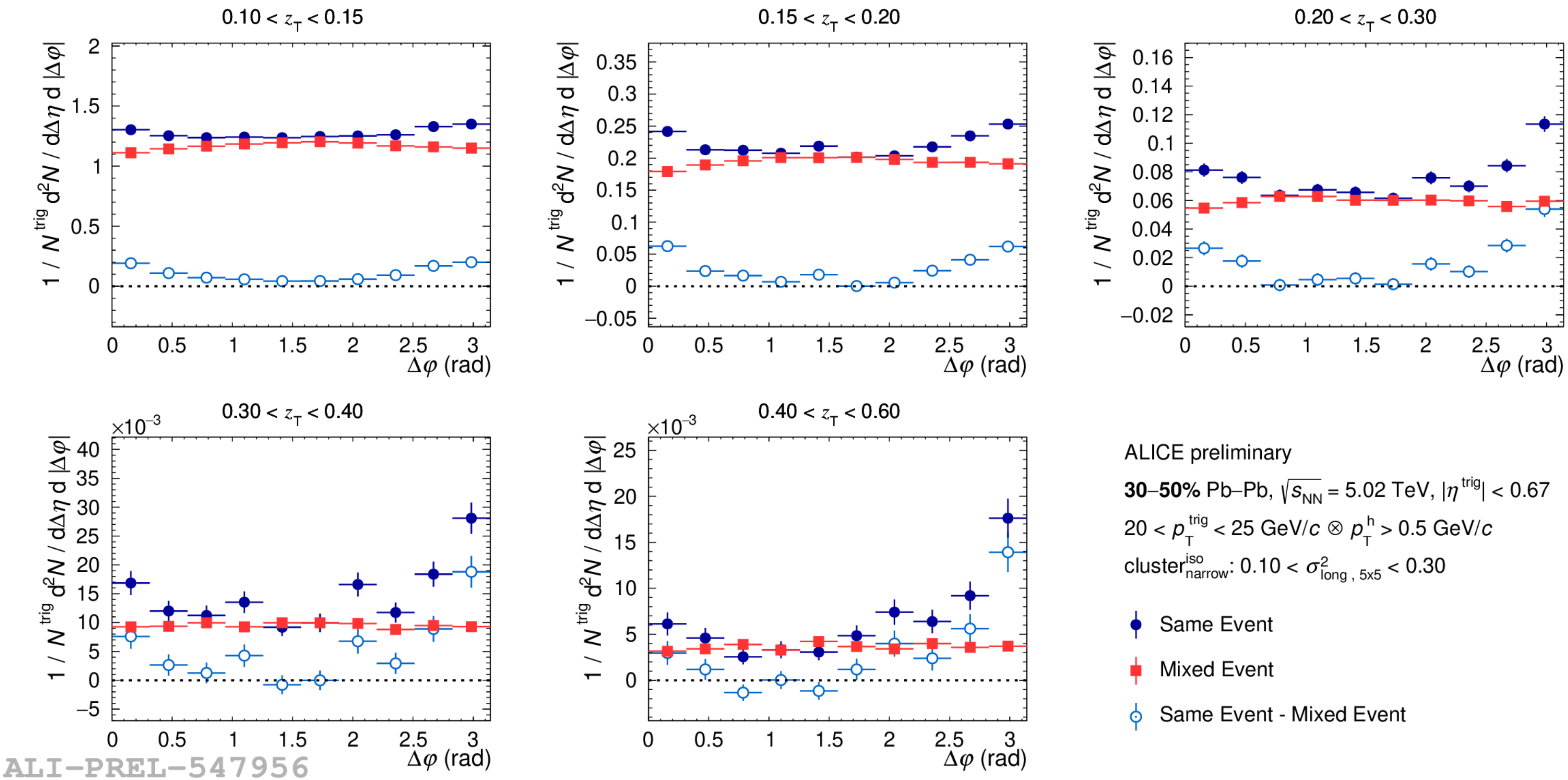
Isolated γ-hadron correlations in Pb–Pb: $D(z_T)$



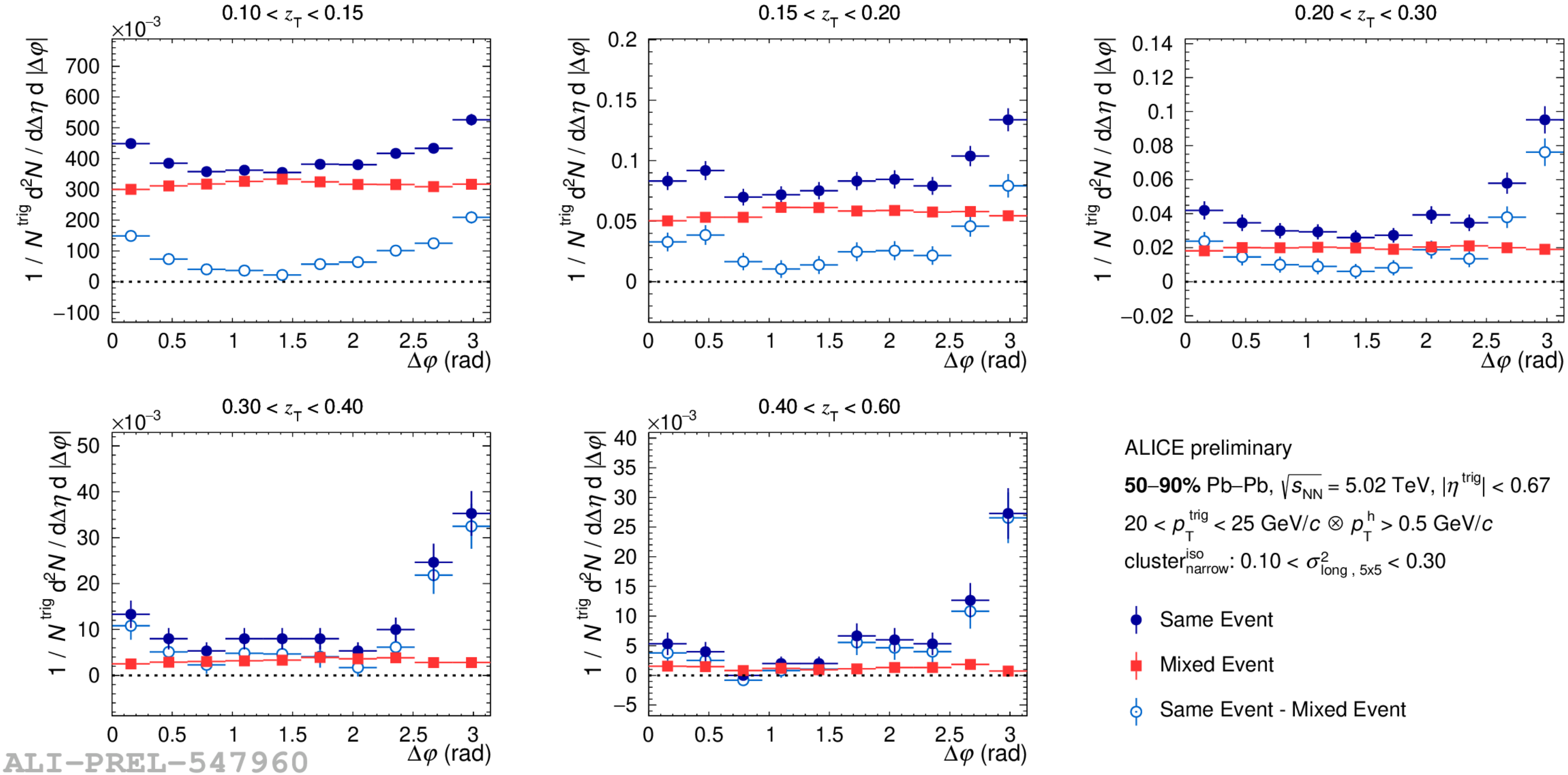
Isolated γ-hadron correlations in Pb–Pb: $\mathrm{D}(z_{\mathrm{T}})$



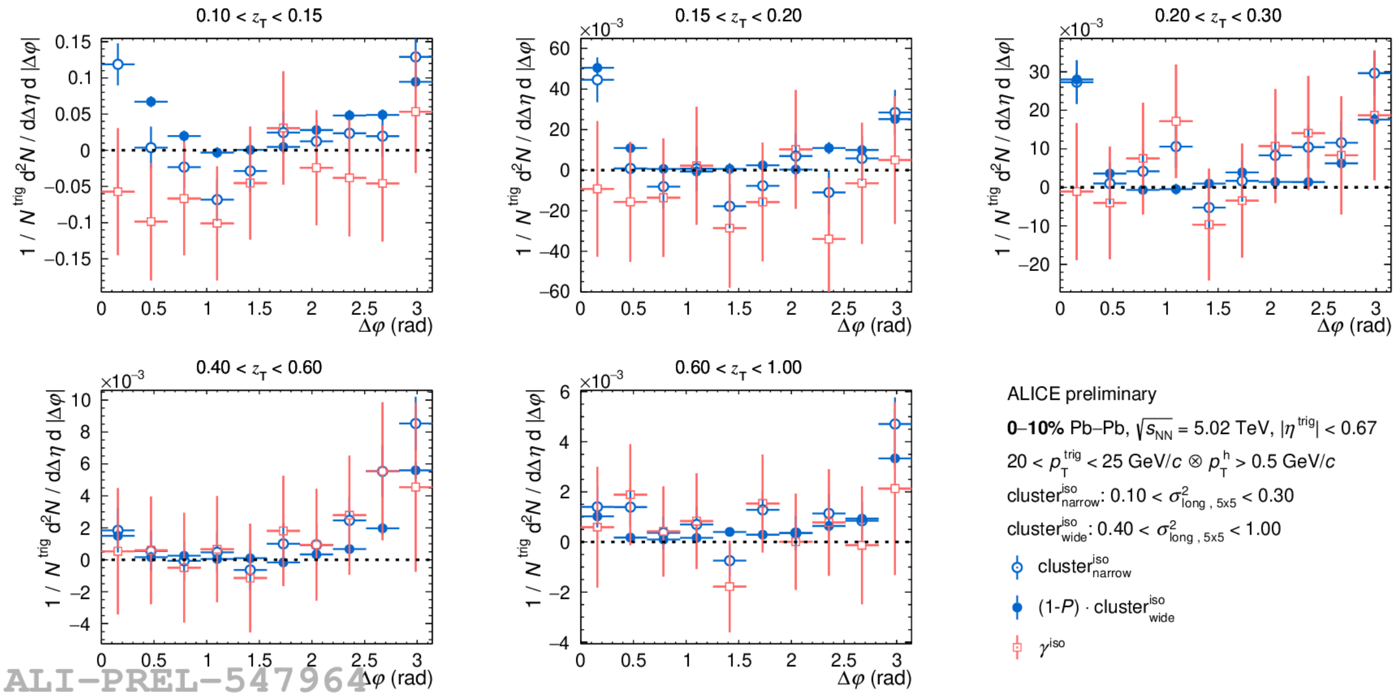
Isolated γ-hadron correlations in Pb–Pb: $D(z_T)$



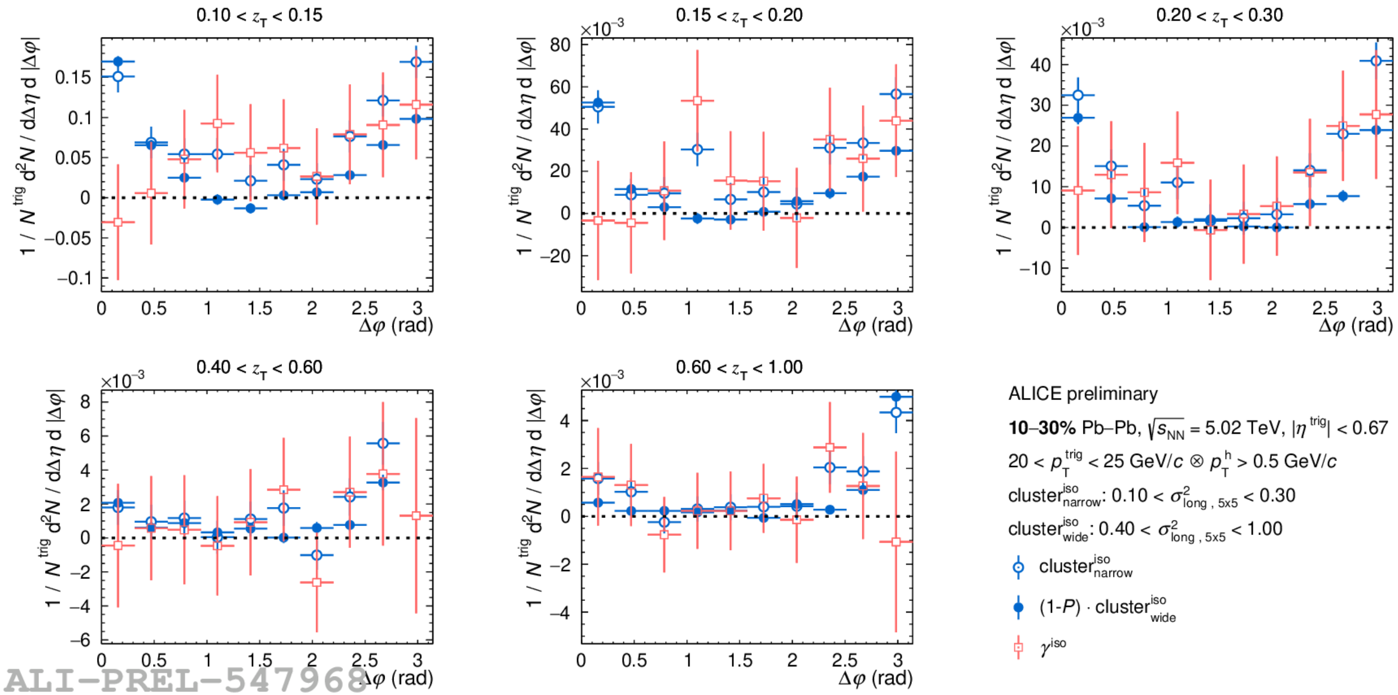
Isolated γ-hadron correlations in Pb–Pb: $D(z_T)$



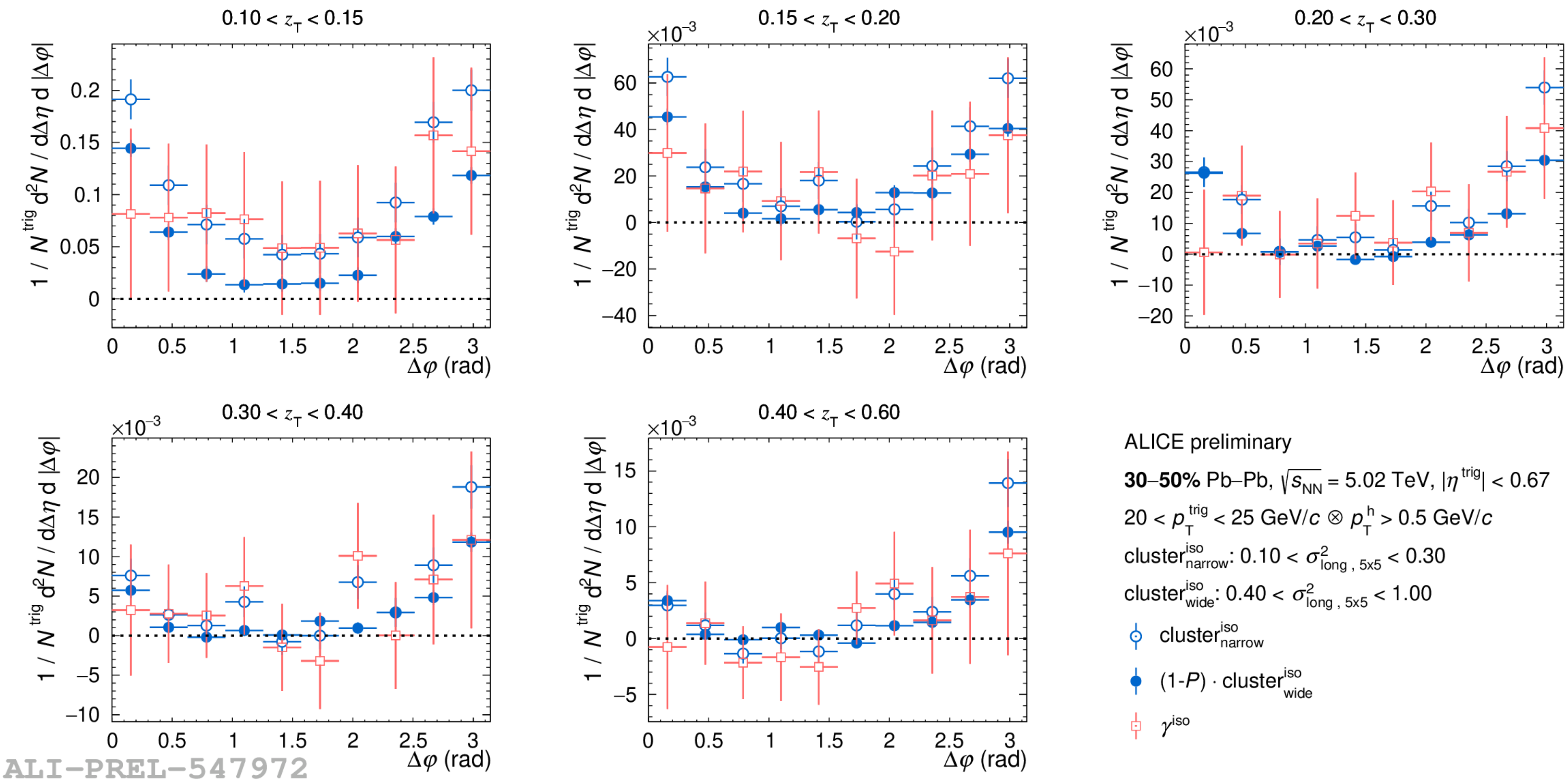
Isolated γ-hadron correlations in Pb–Pb: $D(z_T)$



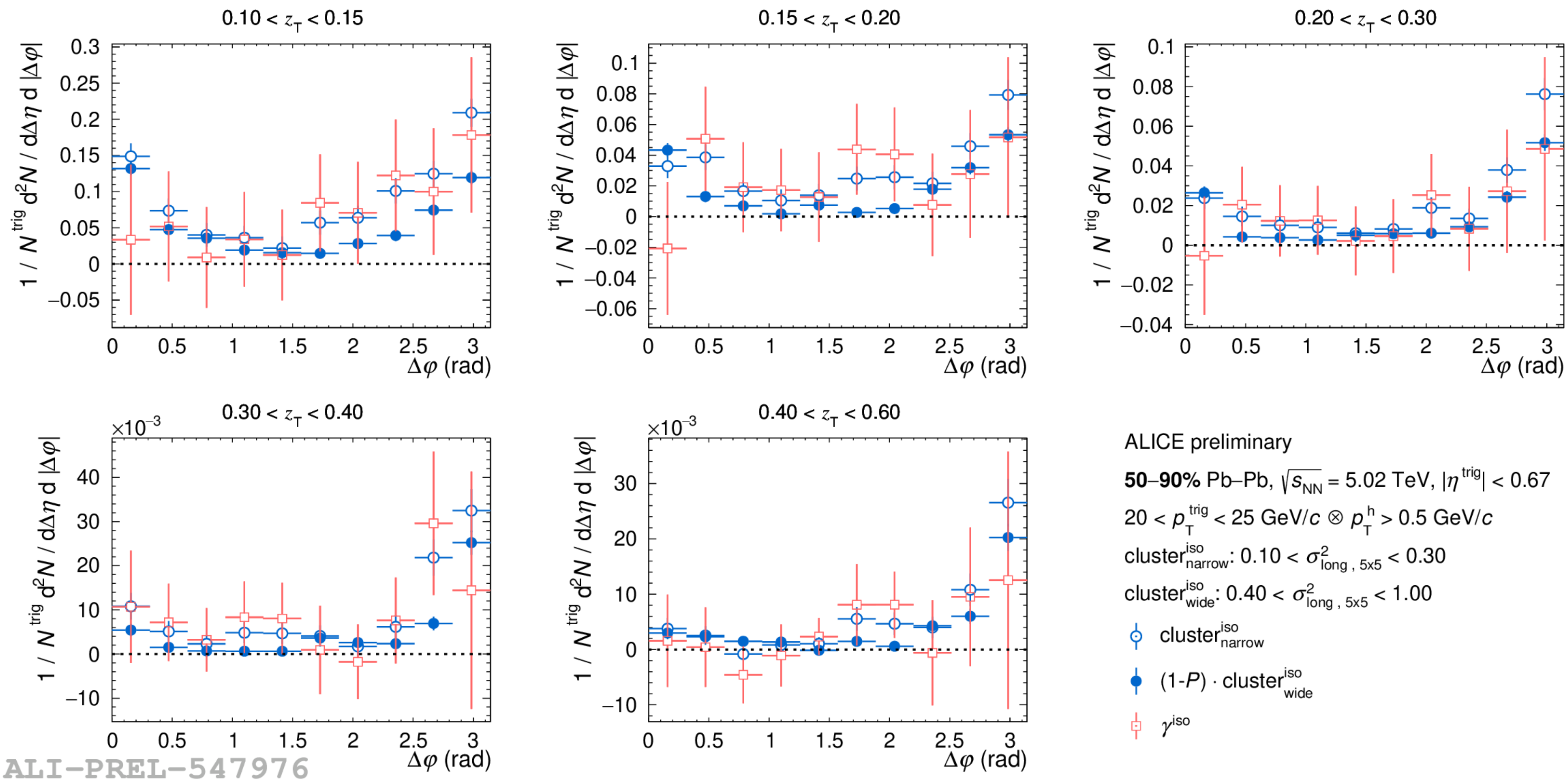
Isolated γ-hadron correlations in Pb–Pb: $\mathrm{D}(z_\mathrm{T})$



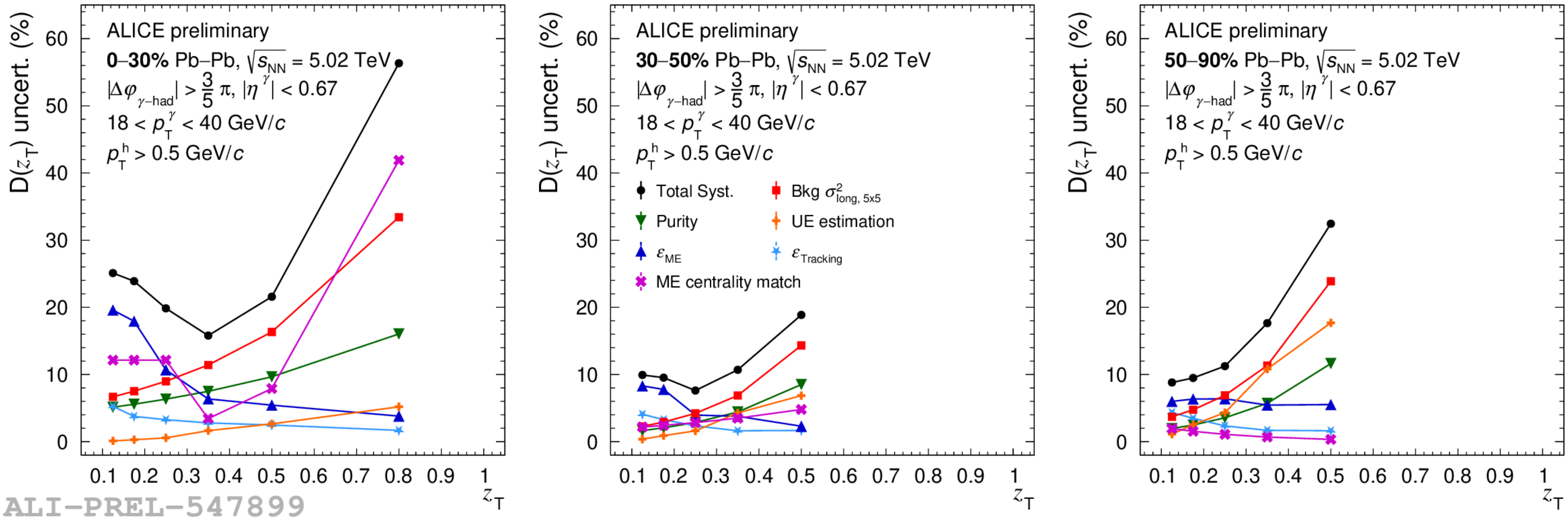
Isolated γ-hadron correlations in Pb–Pb: $\mathrm{D}(z_\mathrm{T})$



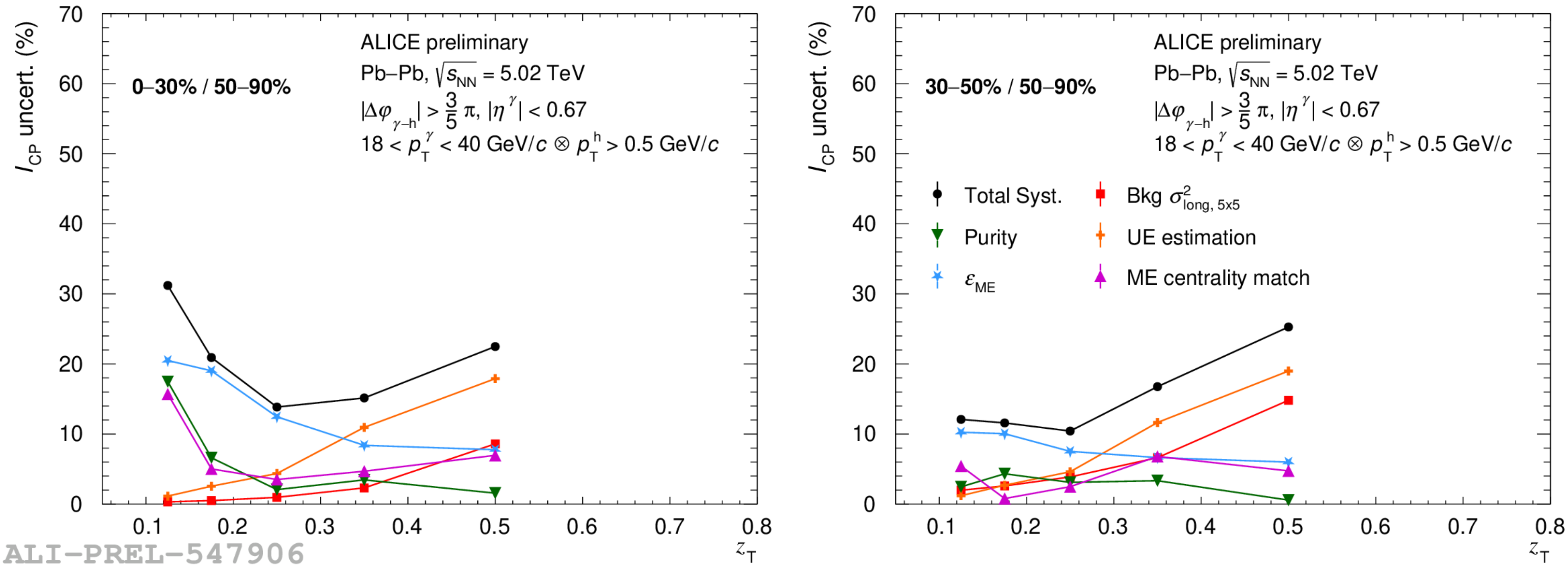
Isolated γ-hadron correlations in Pb–Pb: $D(z_T)$



Isolated γ-hadron correlation uncertainty: $D(z_T)$



Isolated γ-hadron correlation uncertainty: I_{CP}



Isolated γ R ratio in ATLAS pp at 13 TeV

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arXiv:2302.00510

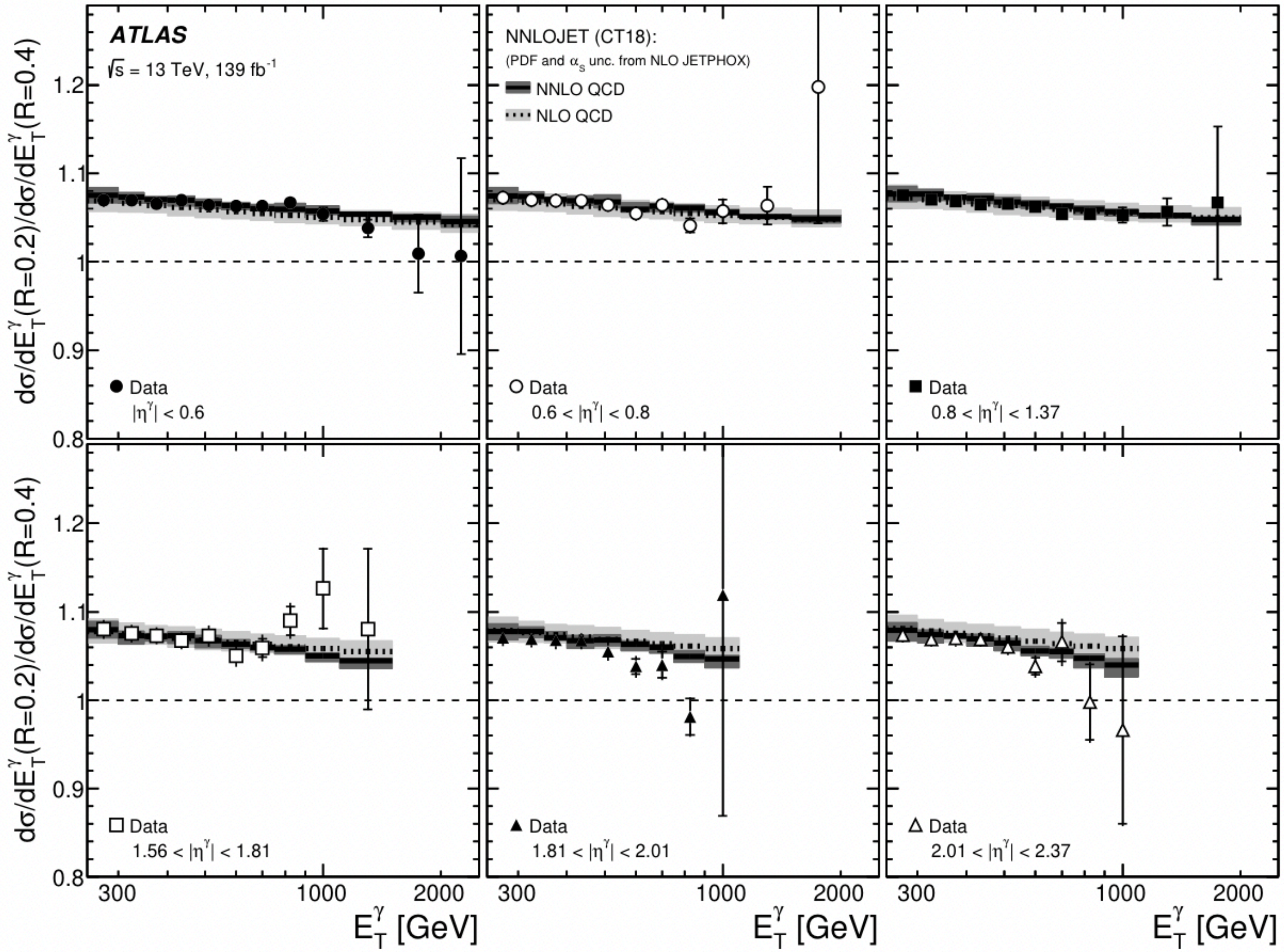

Figure 21: Measured ratios of the differential cross sections for inclusive isolated-photon production for $R = 0.2$ and $R = 0.4$ as functions of E_T^γ in different η^γ regions. The NLO (dotted lines) and NNLO (solid lines) pQCD predictions from NNLOJET based on the CT18 PDF set are also shown. The 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.