Probing the initial state with isolated photon production and dijet invariant mass distributions in small collision systems with ALICE

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On behalf of the ALICE Collaboration

Motivation

- **Use isolated photons & dijet invariant mass in pp and p–Pb collisions to:**
  - Test pQCD predictions and constrain PDFs (& nPDFs)
  - Constrain the kinematics of hard scattered partons
  - Explore cold nuclear matter effects
- Baseline reference for measurements in Pb–Pb collisions.

The ALICE detector

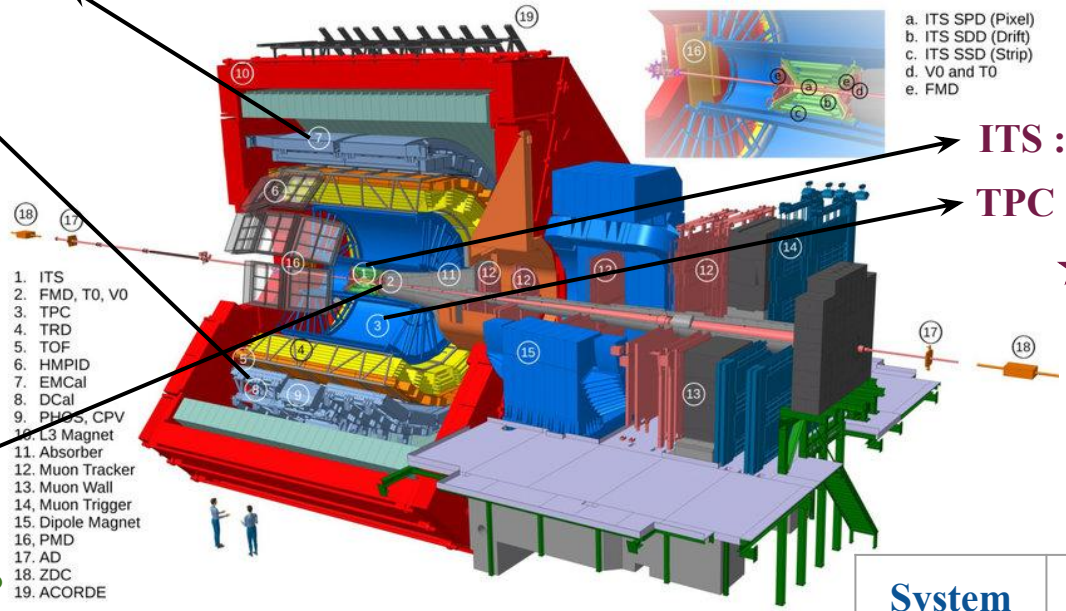
EMCal : $|\eta| < 0.7$; $80° < \varphi < 187°$

DCal : $0.22 < |\eta| < 0.7$;
$260° < \varphi < 320°$

$|\eta| < 0.7$;
$320° < \varphi < 327°$

★ Used for photon reconstruction

★ Used as trigger detector (photons/jets)



ITS : $|\eta| < 0.9$; $\Delta\varphi = 360°$

TPC : $|\eta| < 0.9$; $\Delta\varphi = 360°$

★ Used for track reconstruction

V0A : $2.8 < \eta < 5.1$; $\Delta\varphi = 360°$

V0C : $-1.7 < \eta < -3.7$; $\Delta\varphi = 360°$

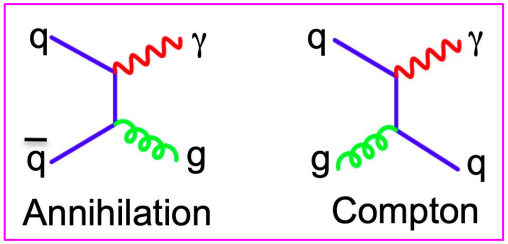
★ Used as MB trigger detector

System	$\sqrt{s}$, $\sqrt{s_{NN}}$ (TeV)
pp	5.02, 8, 13
p–Pb	5.02

Photons in hadronic collisions

$$\gamma_{\text{inclusive}} = \underbrace{\gamma_{\text{LO}} + \gamma_{\text{fragmentation}}}_{\gamma_{\text{prompt}}} + \underbrace{\gamma_{\text{thermal}}}_{\text{in Pb–Pb}} + \underbrace{\gamma_{\text{decay}}}_{\pi^0,\ \eta\ldots}$$

- Signal: Leading Order (LO) direct photons - Emitted in hard QCD processes at the early stage of hadron collisions (p_{T}^{γ} > a few GeV/c)
  - Quark-gluon Compton scattering
  - Quark-antiquark annihilation
- Background: Fragmentation and decay photons.
- **Isolation** is a tool to access: LO direct photons
- **Isolation** techniques: Strongly suppress fragmentation and decay components.



Photon identification

Cluster shower shape

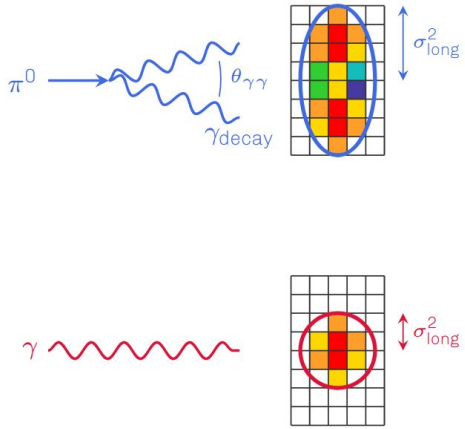
$$\sigma^2_{\text{long}} = (\sigma^2_{\varphi\varphi} + \sigma^2_{\eta\eta})/2 + \sqrt{(\sigma^2_{\varphi\varphi} - \sigma^2_{\eta\eta})^2/4 + \sigma^4_{\eta\varphi}}$$

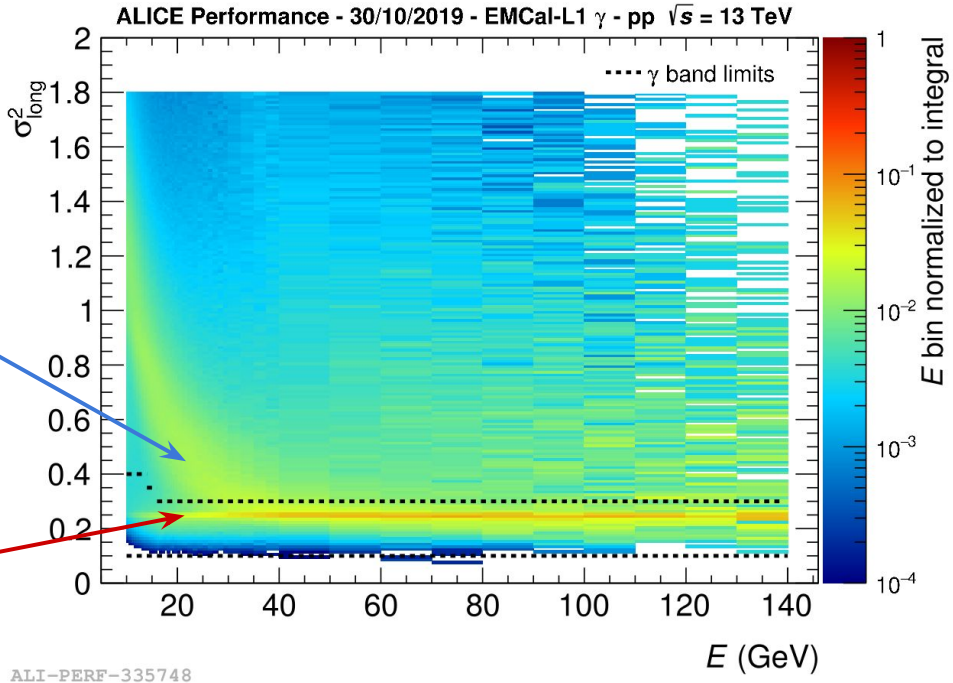
$$\sigma^2_{xz} = \langle xz \rangle - \langle x \rangle \langle z \rangle \qquad \langle x \rangle = (1/w_{\text{tot}}) \sum w_i x_i$$

Weighted over all cells associated with the cluster in η, φ plane.

$$w_i = \max(0, 4.5 + \ln(E_i/E_{\text{cluster}}))$$

$$w_{\text{tot}} = \sum w_i$$





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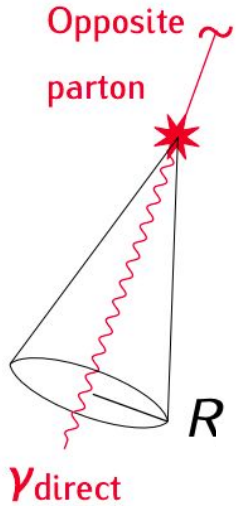
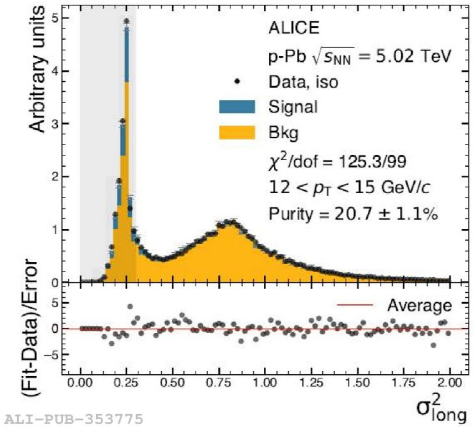
Photon isolation

- **"Isolated photons" - no hadronic activity surrounding the photons from hard processes.**
- Sum the p_T of particles i, inside a cone of radius $R = \sqrt{(\eta_i - \eta_\gamma)^2 + (\varphi_i - \varphi_\gamma)^2}$
- Set an isolation threshold (according to the following conventions):
  - $p_T^{\text{iso, UE}} = \Sigma p_T^{\text{cluster}} + \Sigma p_T^{\text{track}} < 2$ GeV/c
  - $p_T^{\text{iso, ch, UE}} = \Sigma p_T^{\text{track}} < 1.5$ GeV/c
  - $p_T^{\text{iso, ch}} = \Sigma p_T^{\text{track}} - \text{UE}\ (\rho_{\text{UE}}\, \pi\, R^2) < 1.5$ GeV/c
- Underlying event (UE) estimation:
  - Using **perpendicular cone** method
  - For a given cluster with position (η,φ), rotate cone by ± 90° in φ
  - Calculate sum of all charged track p_T
  - Divide by both cone area.



Purity estimation for isolated photons

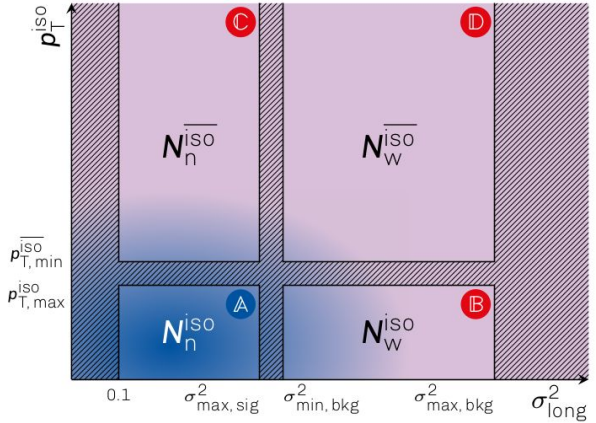
The Template Fit



$$N = S + B$$

$$P = 1 - (B/N)$$

The ABCD Method



The shower shape distribution of isolated clusters is fitted with a 2 component linear combination of background and signal templates.

The three background dominated regions (BCD) are used to estimate the background contribution in the signal region (A).

$$N^{observed}\left(\sigma^2_{long}\right) = N_{sig} \times S\left(\sigma^2_{long}\right) + \left(N - N_{sig}\right) \times B\left(\sigma^2_{long}\right)$$

PRC 102, 044908 (2020)

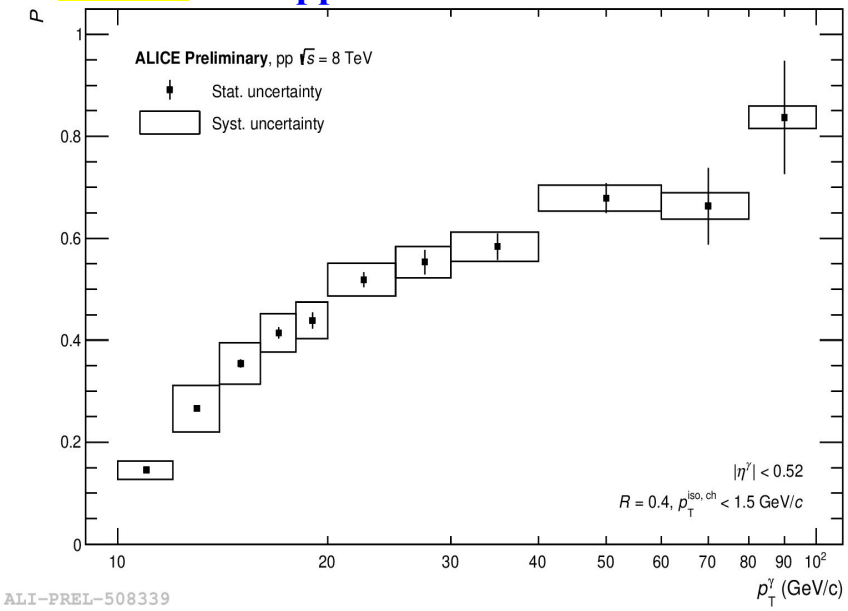
$$P = 1 - \left(\frac{N_n^{\overline{iso}}/N_n^{iso}}{N_w^{\overline{iso}}/N_w^{iso}}\right)_{data} \times \left(\frac{B_n^{iso}/N_n^{\overline{iso}}}{N_w^{iso}/N_w^{\overline{iso}}}\right)_{MC}$$

Eur. Phys. J. C 79: 896 (2019)

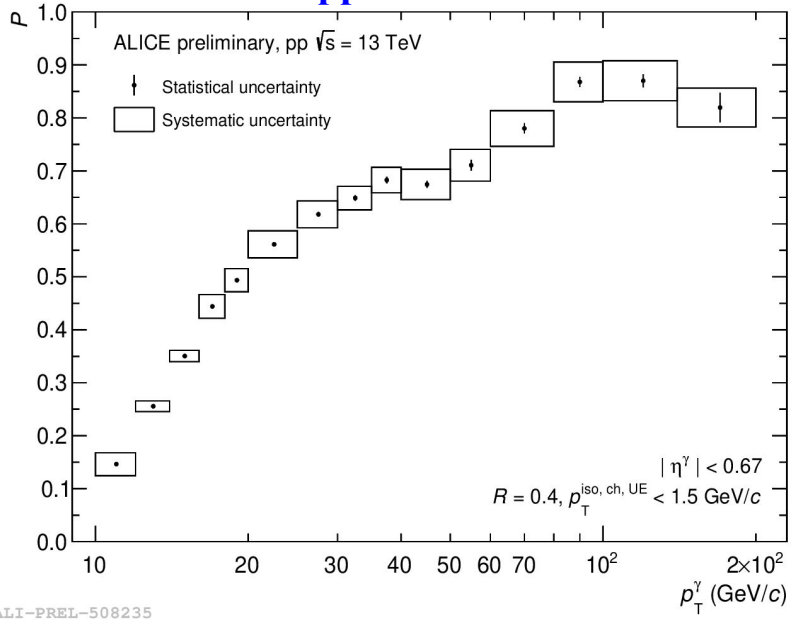
Isolated photons purity

Purity is similar in different systems

NEW **pp $\sqrt{s}$ = 8 TeV**



NEW **pp $\sqrt{s}$ = 13 TeV**



Charged isolation using ITS+TPC tracks, UE subtracted.

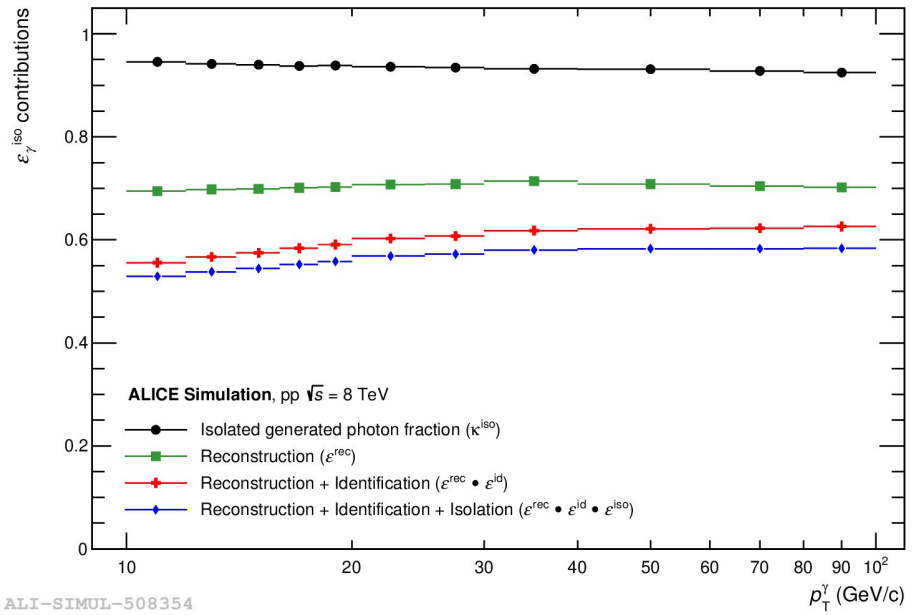
$R = 0.4, p_T^{\text{iso, ch}} < 1.5$ GeV/c

Charged isolation using ITS+TPC tracks, UE not subtracted.

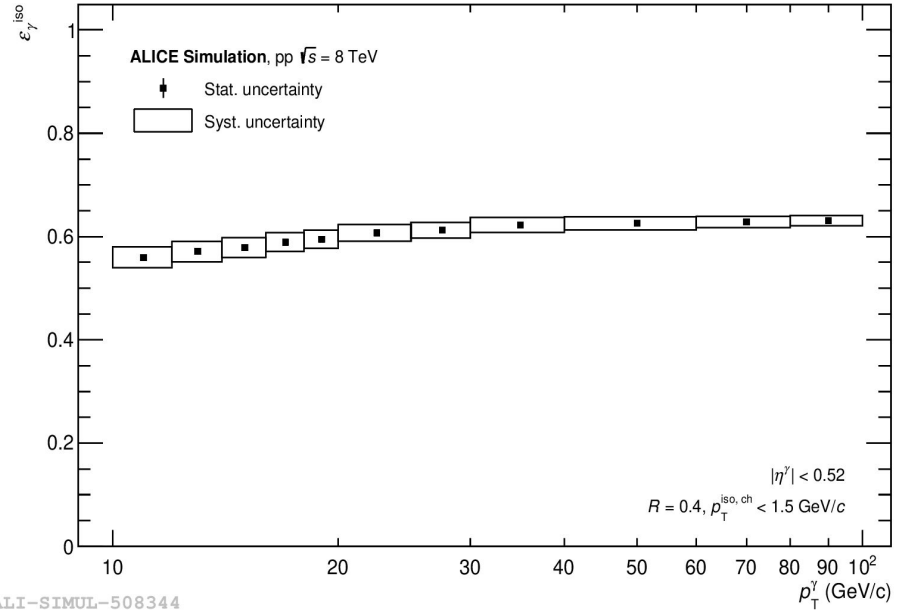
$R = 0.4, p_T^{\text{iso, ch, UE}} < 1.5$ GeV/c

Efficiency estimation for isolated photons

NEW



NEW **pp $\sqrt{s}$ = 8 TeV**



$$\varepsilon_\gamma^{iso} = \frac{\varepsilon^{rec} \bullet \varepsilon^{id} \bullet \varepsilon^{iso}}{\kappa^{iso}}$$

κ^{iso} – Fraction of generated photons which are isolated

Identification – Shower shape cut ($0.1 < \sigma^2_{long} < 0.3$)

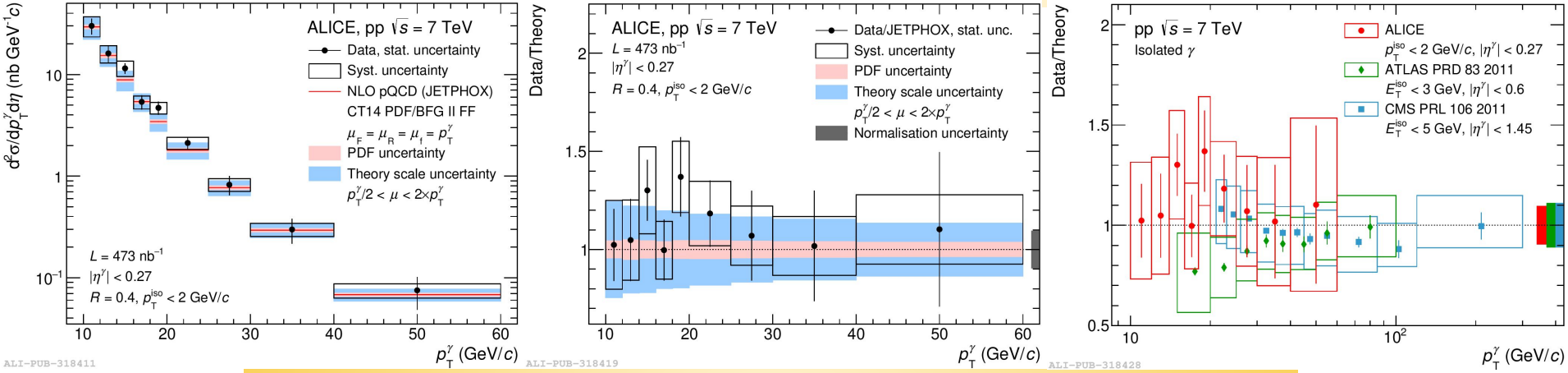
Isolation – $R = 0.4$, $p_T^{iso,ch} < 1.5$ GeV/c

Isolated photon cross section in pp $\sqrt{s}$ = 7 TeV

Eur. Phys. J. C 79: 896 (2019)
JETPHOX 1.3.1 (JHEP 0205 (2002) 028,
Phys. Rev. D 73 (2006) 094007)
PDF, CT14 (Phys. Rev. D 93 (2016), 033006)

Charged+Neutral isolation using ITS+TPC tracks and EMCal clusters, UE not subtracted.

$R = 0.4$, $p_T^{\text{iso, UE}} < 2$ GeV/c



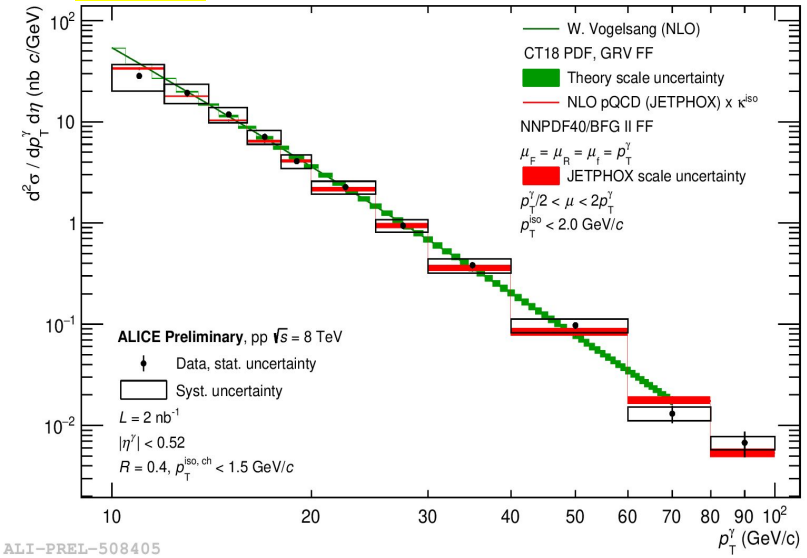
ALICE data – compared to pQCD calculations with JETPHOX. Good agreement is observed between data and theory within uncertainties.

ALICE measurements: extends other LHC experiments toward lower p_T.

Isolated photon cross section in pp $\sqrt{s}$ = 8 TeV

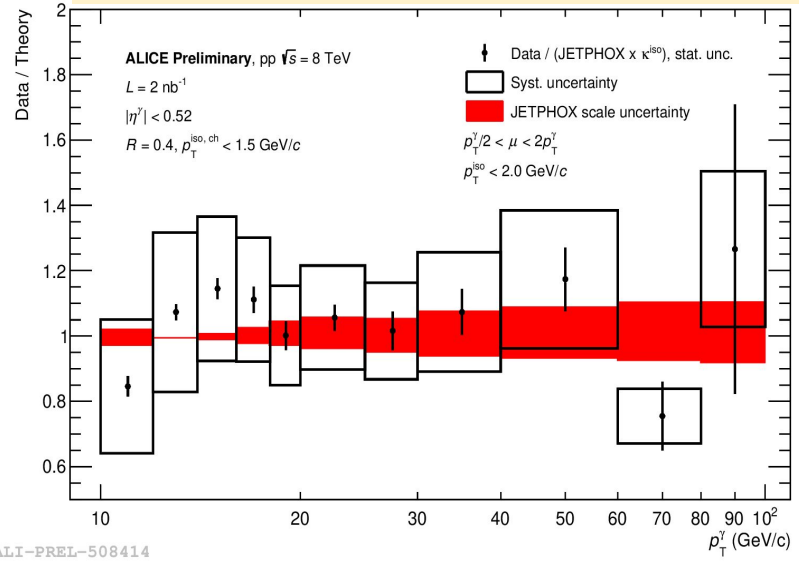
JETPHOX NLO calculations scaled by the PYTHIA isolation fraction at generator level, κ^{iso} to consider the parton to hadron fragmentation.

NEW



Charged isolation using ITS+TPC tracks, UE subtracted.

NEW $R = 0.4, p_T^{iso, ch} < 1.5$ GeV/c



JETPHOX model calc. – NNPDF40, BFG II FF

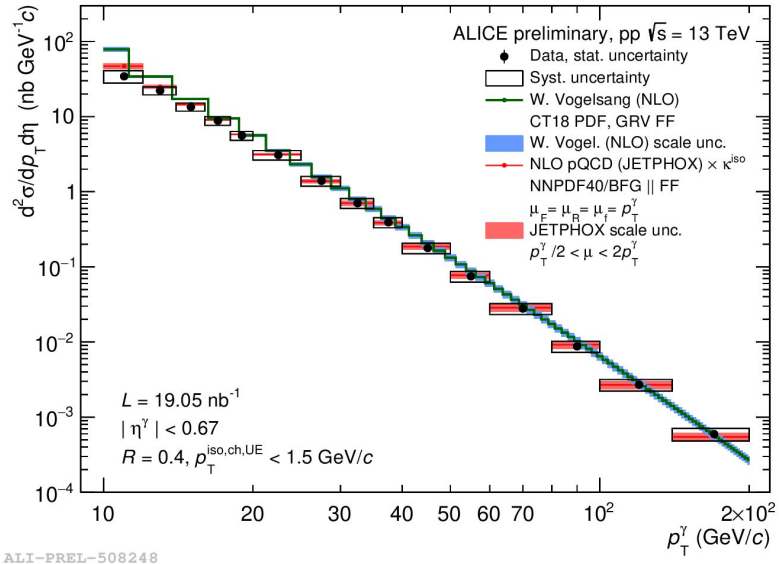
NLO calc. Werner Volgelsang – CT18 PDF, GRV FF

NNPDF Collaboration: arXiv.2109.02653

Isolated photon cross section in pp $\sqrt{s}$ = 13 TeV

JETPHOX NLO calculations scaled by the PYTHIA isolation fraction at generator level, κ^{iso} to consider the parton to hadron fragmentation.

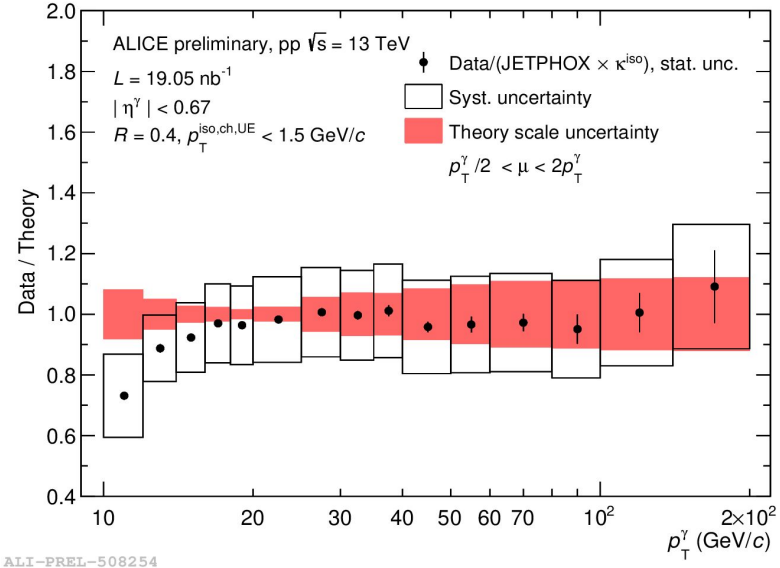
NEW



ALI-PREL-508248

Charged isolation using ITS+TPC tracks, UE not subtracted.

NEW $R = 0.4, p_T^{iso, ch, UE} < 1.5$ GeV/c



ALI-PREL-508254

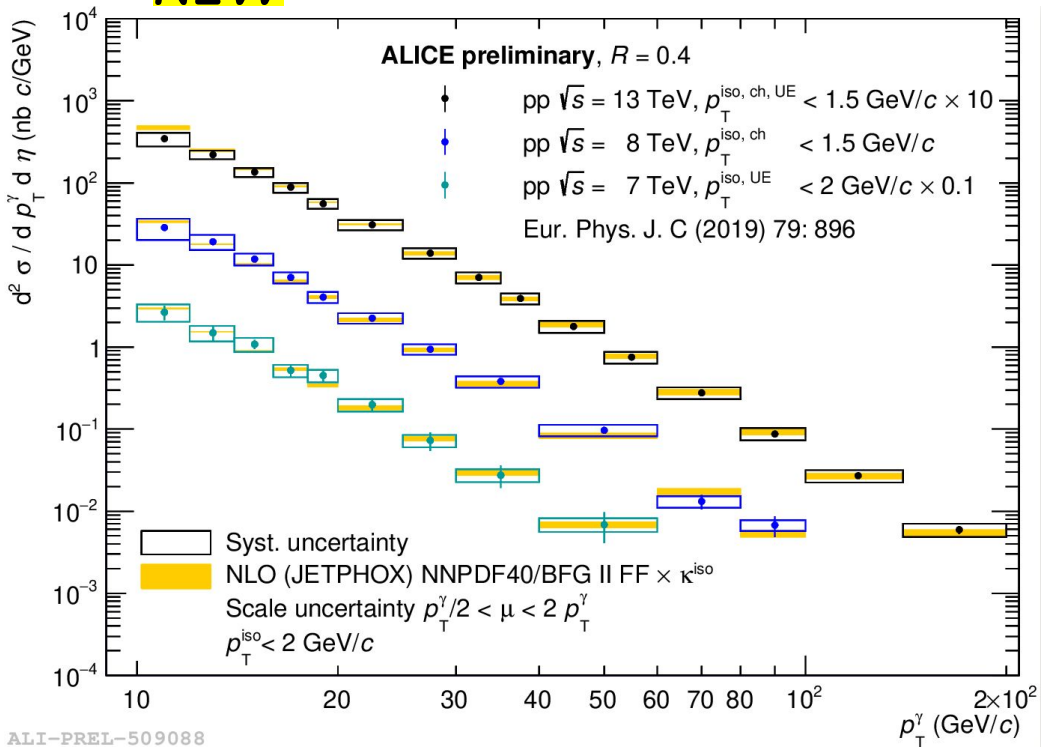
JETPHOX model calc. – NNPDF40, BFG II FF

NLO calc. Werner Volgelsang – CT18 PDF, GRV FF

NNPDF Collaboration: arXiv.2109.02653

Comparison of isolated photon cross section in pp collisions

NEW



pp $\sqrt{s}$ = 7 TeV:
$R = 0.4$, $p_T^{iso, UE} < 2$ GeV/c
JETPHOX 1.3.1.4 NNPDF40 / BFG II FF

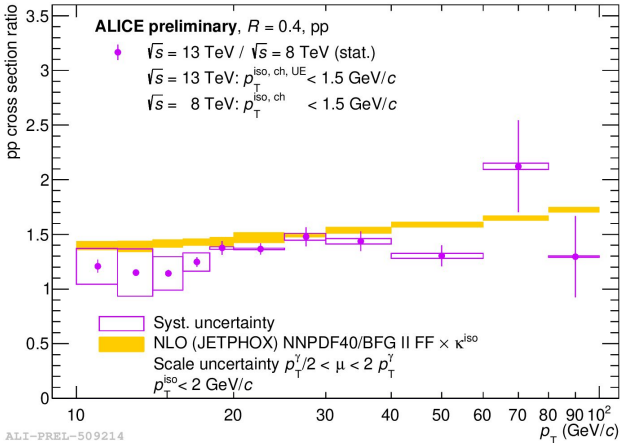
pp $\sqrt{s}$ = 8 TeV:
$R = 0.4$, $p_T^{iso, ch} < 1.5$ GeV/c
JETPHOX 1.3.1.4 NNPDF40 / BFG II FF

pp $\sqrt{s}$ = 13 TeV:
$R = 0.4$, $p_T^{iso, ch, UE} < 1.5$ GeV/c
JETPHOX 1.3.1.4 NNPDF40 / BFG II FF

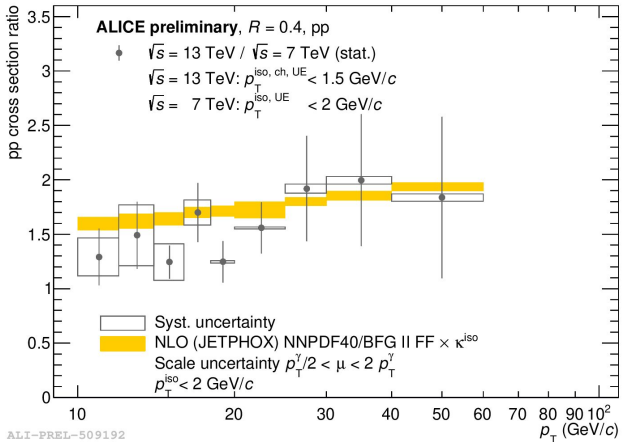
All NLO calculations scaled by the PYTHIA isolation fraction at generator level, κ^{iso} to consider the parton to hadron fragmentation

Isolated photon cross section ratios in pp collisions

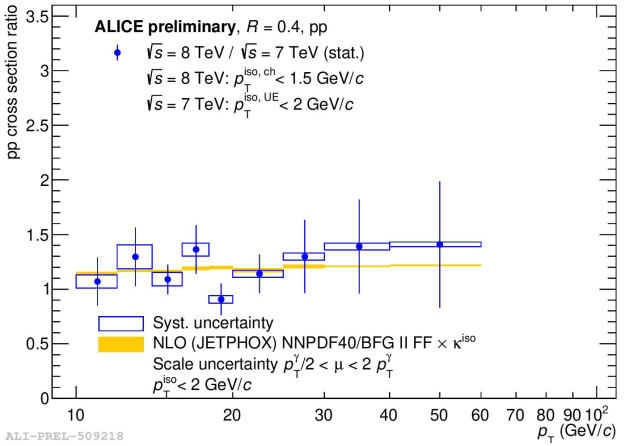
NEW $\sqrt{s}$ = 13 TeV / $\sqrt{s}$ = 8 TeV



NEW $\sqrt{s}$ = 13 TeV / $\sqrt{s}$ = 7 TeV



NEW $\sqrt{s}$ = 8TeV / $\sqrt{s}$ = 7 TeV



All NLO calculations scaled by the PYTHIA isolation fraction at generator level, κ^{iso} to consider the parton to hadron fragmentation.

The data ratios are compared with corresponding ratios in NLO JETPHOX (NNPDF40/BFG II FF) calculations.

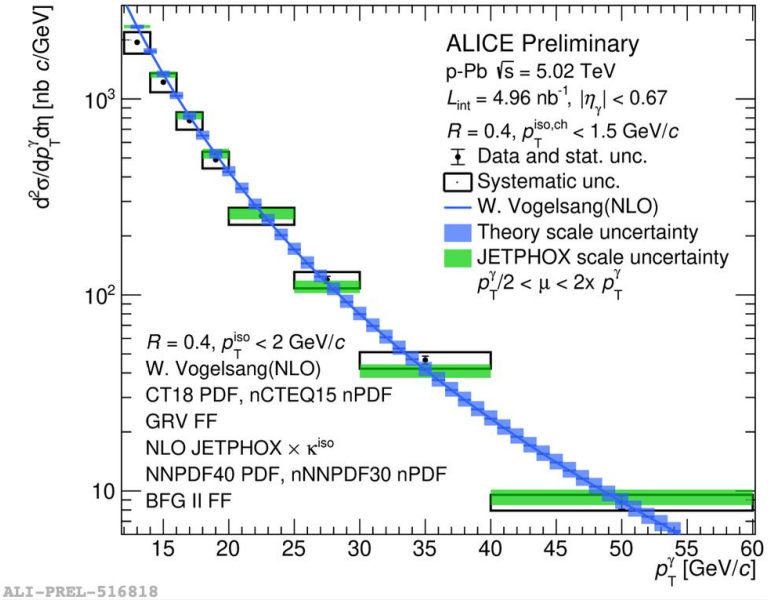
Good agreement is seen between them within uncertainties.

Isolated photon cross section in p–Pb $\sqrt{s_{NN}}$ = 5.02 TeV

JETPHOX NLO calculations scaled by the PYTHIA isolation fraction at generator level, κ^{iso} to consider the parton to hadron fragmentation.

Charged isolation using ITS tracks, UE subtracted.

NEW $R = 0.4, p_T^{iso, ch} < 1.5$ GeV/c



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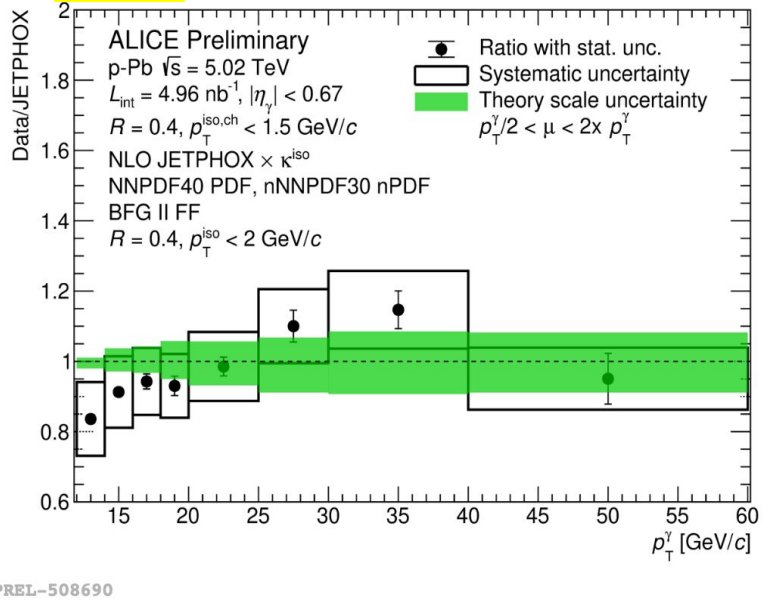


JETPHOX model calc. – NNPDF40 (nNNPDF30), BFG II FF, NLO calc. Werner Volgelsang – CT18 PDF, GRV FF

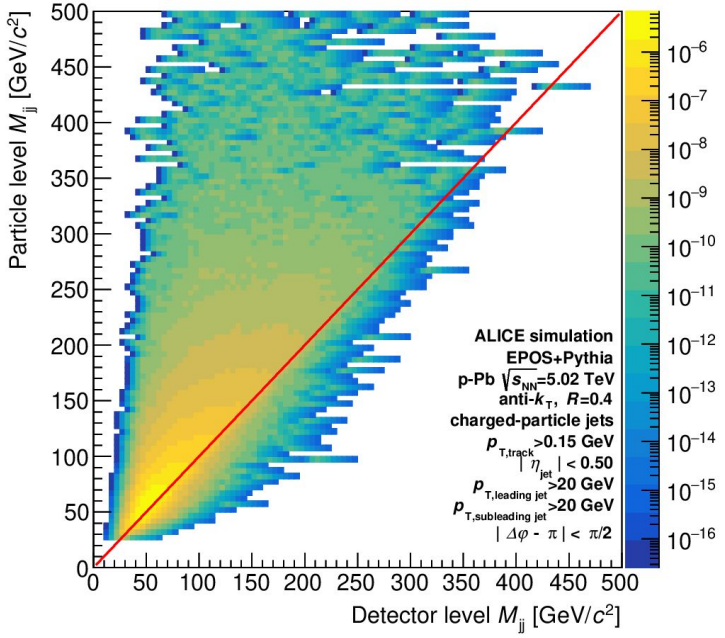
Dijet invariant mass analysis technique

- Dijet mass is defined as
  - $M_{jj}^2 = (p_1 + p_2)^2 \approx 2\, p_{T,1}\, p_{T,2}\, (\cosh(\Delta\eta) - \cos(\Delta\varphi))$
- Only charged particles are used

  (full azimuthal acceptance is required)
- Tracks selected with $|\eta| < 0.9$

  and $p_T > 0.15$ GeV/c
- For jets $|\eta_{jet}| < 0.9 - R = 0.5$, $R = 0.4$
- Anti-k_T algorithm
- $p_{T,\text{ leading jet}} > 20$ GeV/c
- $p_{T,\text{ subleading jet}} > 20$ GeV/c
- Background fluctuations: Estimated with rotated cones

NEW



Unfolding matrix: BG fluctuations and detector effects combined

Dijet invariant mass distribution in pp & p–Pb $\sqrt{s_{NN}}$ = 5.02 TeV

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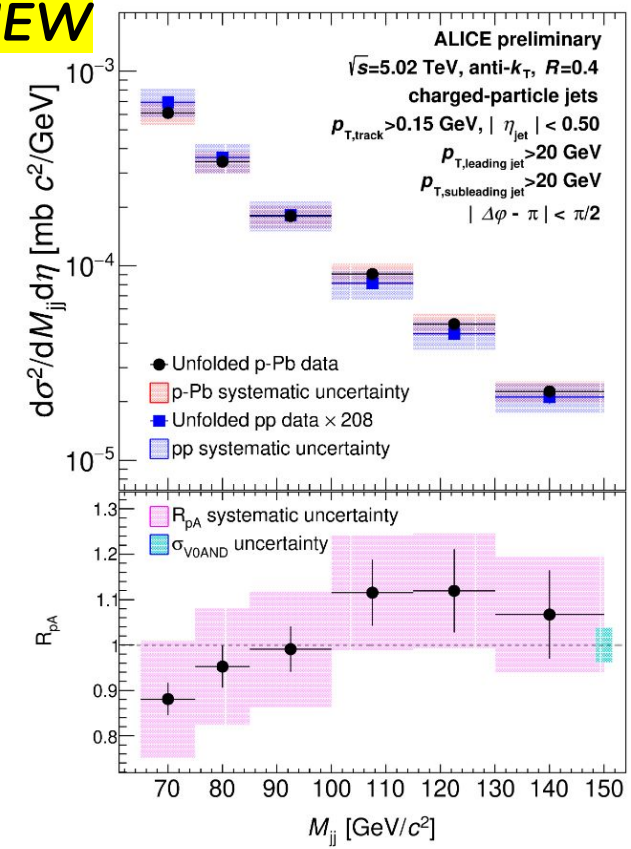

- **This is the first dijet invariant mass measurement from ALICE.**
- **Nuclear modification factor R_{pA} = 1 within uncertainties.**

For more details:

Poster by Oskari A. M. Saarimaki

- T04: (06.04.2022 17:58)

Summary

- Measured isolated photon cross section
  - In pp collisions at $\sqrt{s}$ = 8 TeV and 13 TeV.
  - In p–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV.
- ALICE extends the LHC measurements towards lower p_T^{γ} (10–12 GeV/c) ⟶ lower x_T.
- Results are compatible with pQCD calculations.
- First measurement of dijet invariant mass and nuclear modification factor in pp and p–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV from ALICE.
- Establishes a benchmark for these measurements in Pb–Pb collisions.

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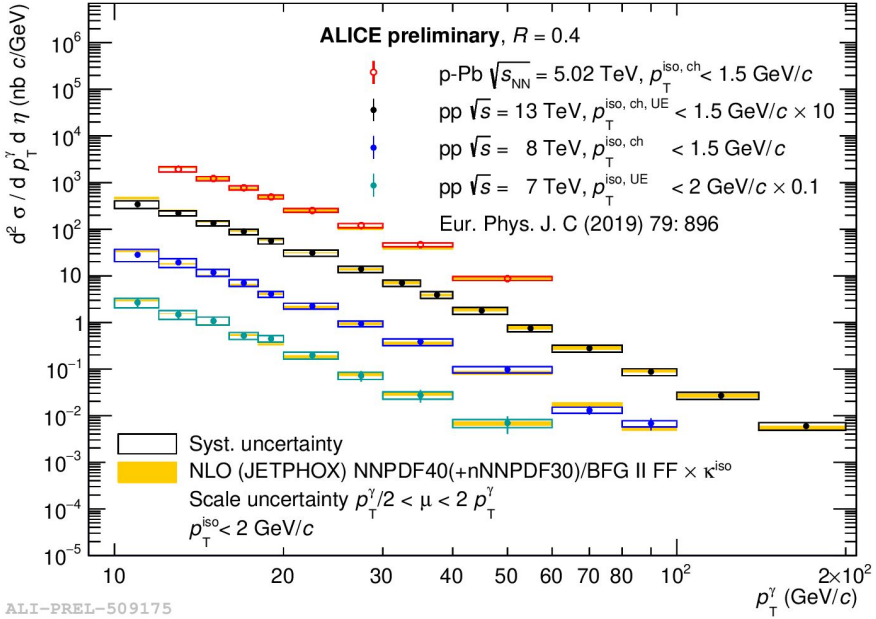


Refer to: Talk by **Alwina Liu** (T04: 05.04.2022 16:30)

Poster by **Haidar Mas'Ud Alfanda** (T05: 06.04.2022 18:18)

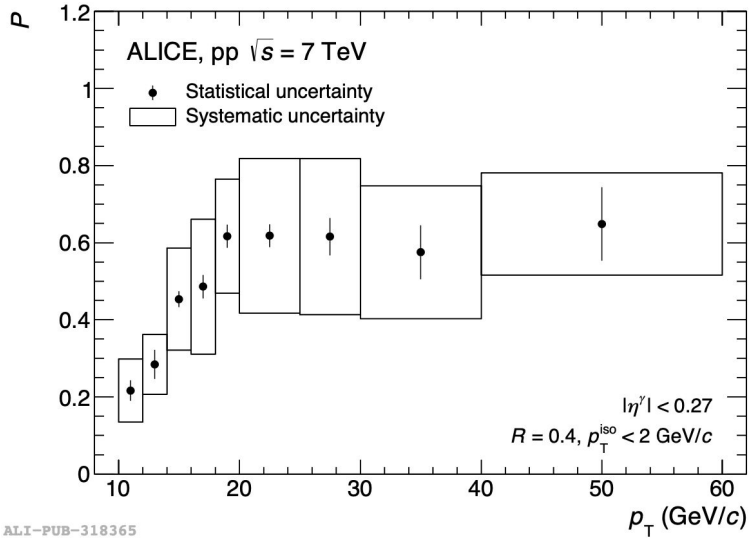
Thank you!

Back up

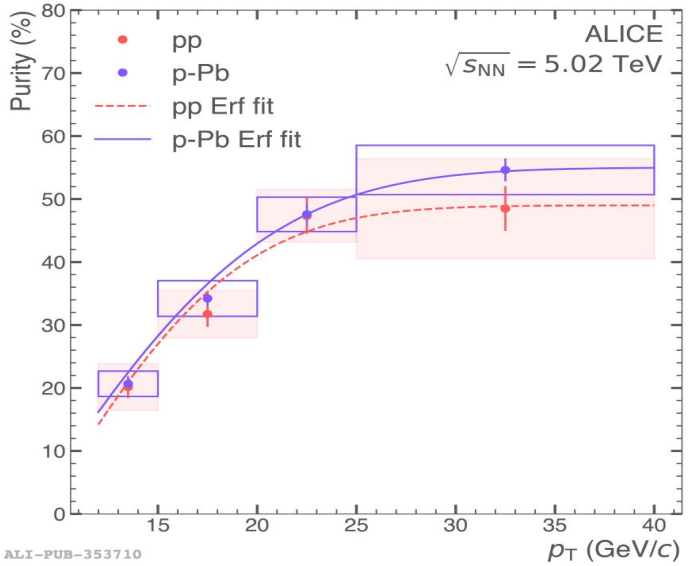
Isolated photons purity

Purity is similar in different systems

pp $\sqrt{s}$ = 7 TeV



p–Pb $\sqrt{s_{NN}}$ = 5.02 TeV



Charged+neutral isolation using ITS+TPC tracks and EMCal clusters, UE not subtracted.

$R = 0.4, p_T^{iso, UE} < 2$ GeV/c

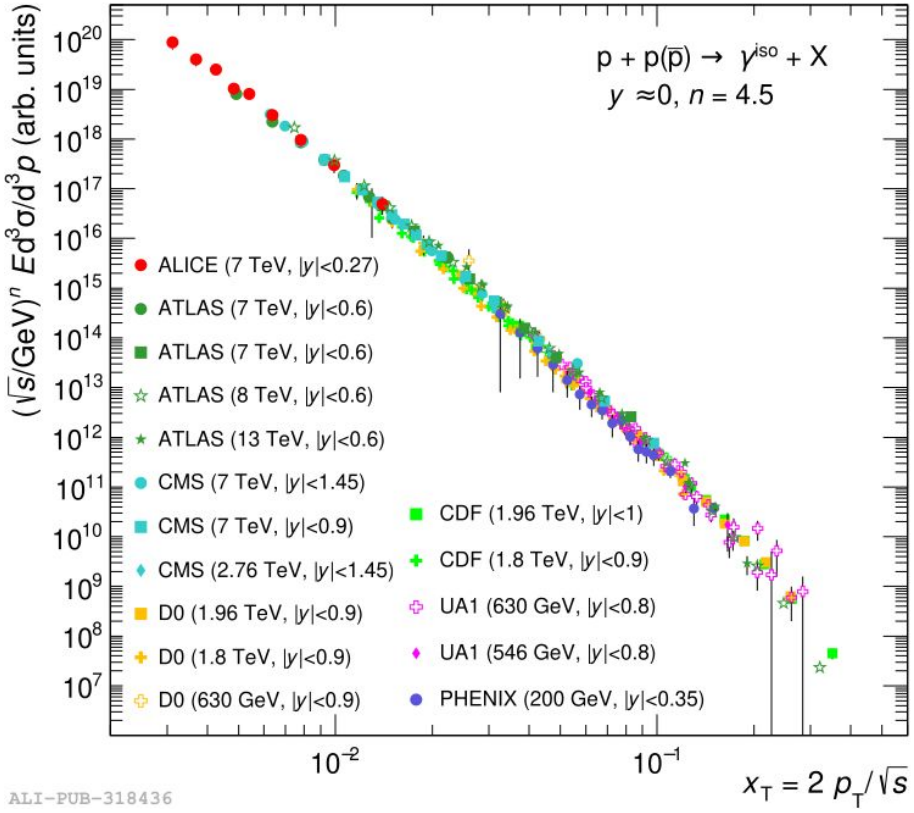
Charged isolation using ITS tracks, UE subtracted.

$R = 0.4, p_T^{iso, ch} < 1.5$ GeV/c

Isolated photons

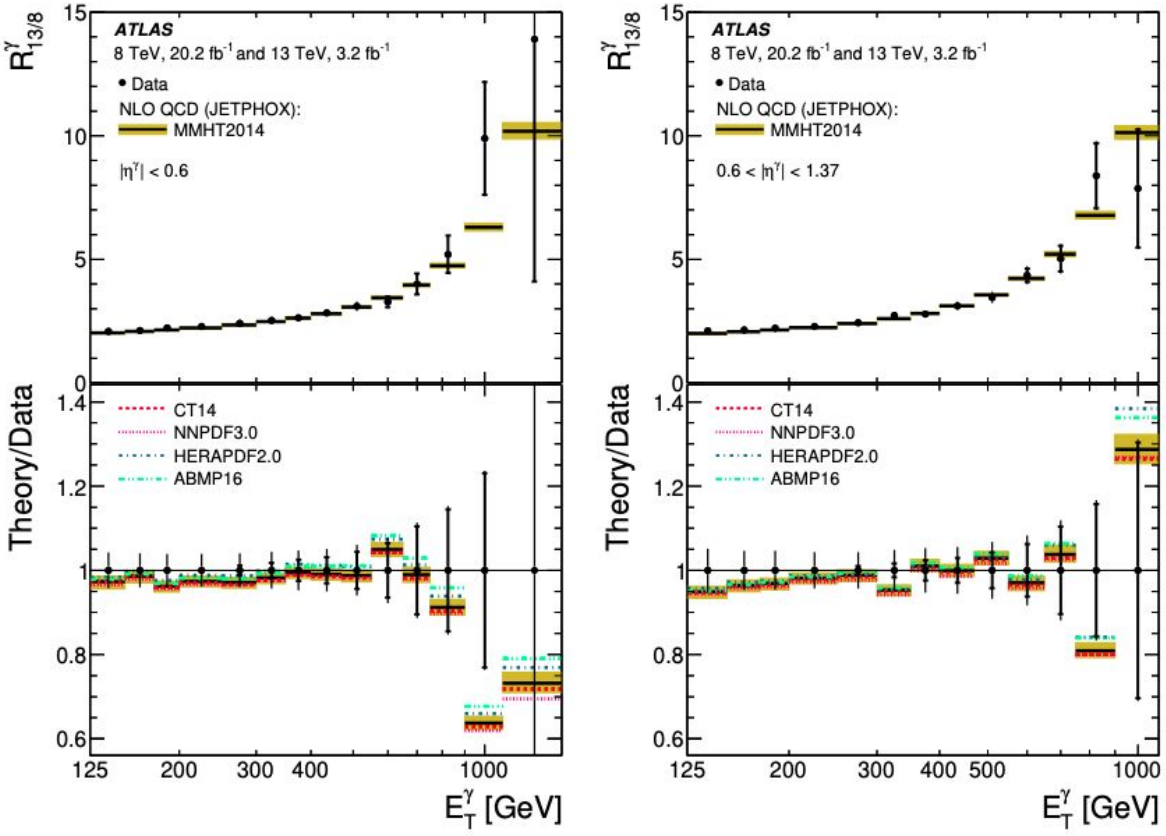
ALICE data compared to the world's data of isolated photon spectra measured in pp and $p\bar{p}$ collisions as a function of x_T. The ALICE measurement allows us to extend the x_T reach to lower values.

https://arxiv.org/pdf/1906.01371.pdf



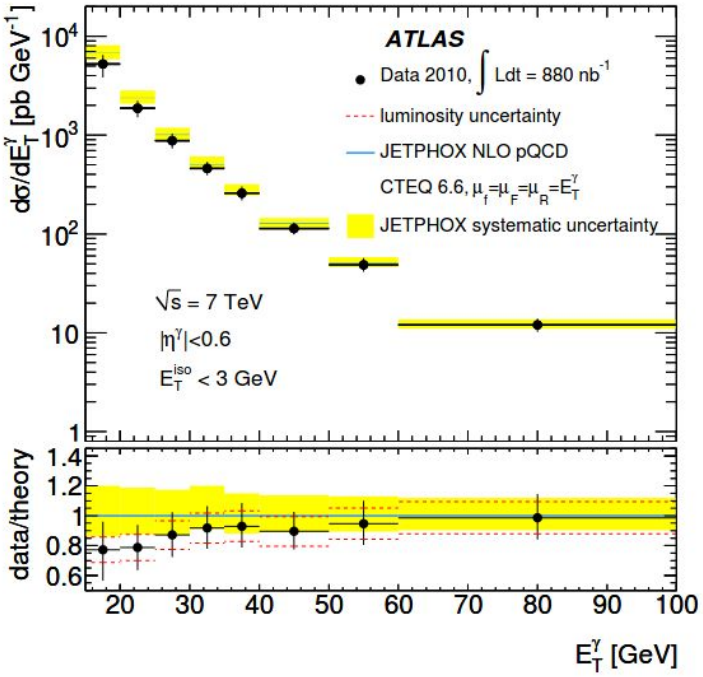
ATLAS results

https://arxiv.org/pdf/1901.10075.pdf



ATLAS & CMS results

ATLAS Collaboration: PRD83(2011)052005



CMS Collaboration: PRL 106(2011)082001