



ALICE



Probing the initial state with isolated photon production in small collision systems with ALICE

Ran XU

On behalf of the ALICE collaboration



ICHEP 2022
BOLOGNA

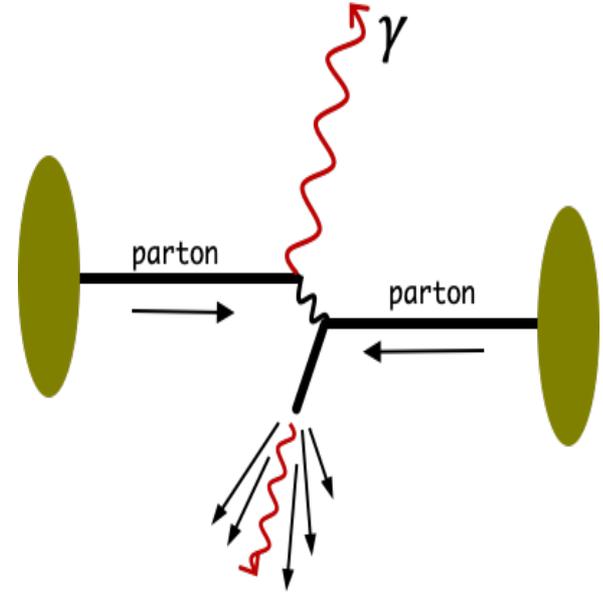
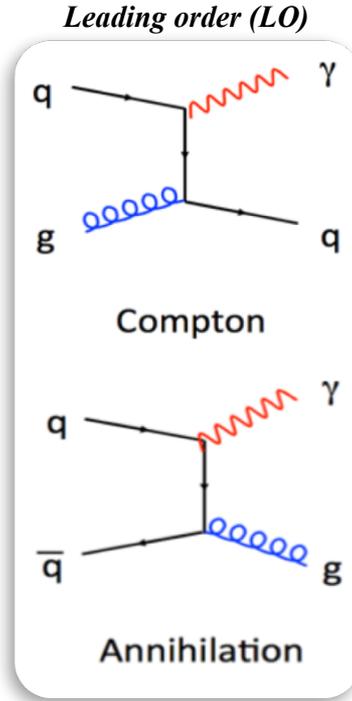
ICHEP 2022
XLI
International Conference
on High Energy Physics
Bologna (Italy)

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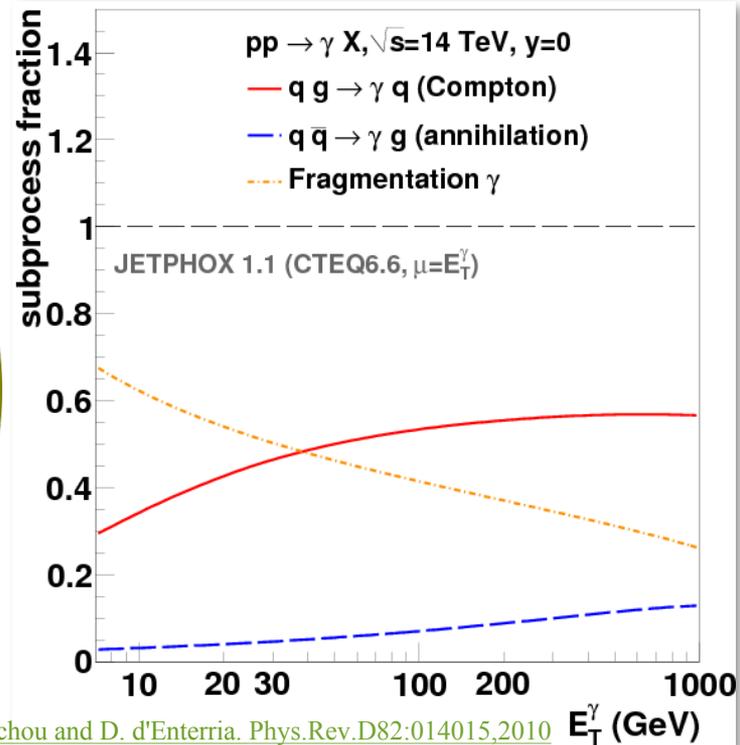
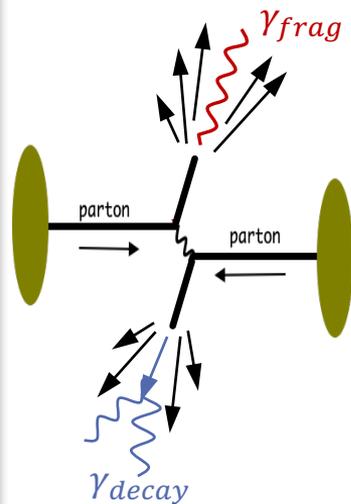
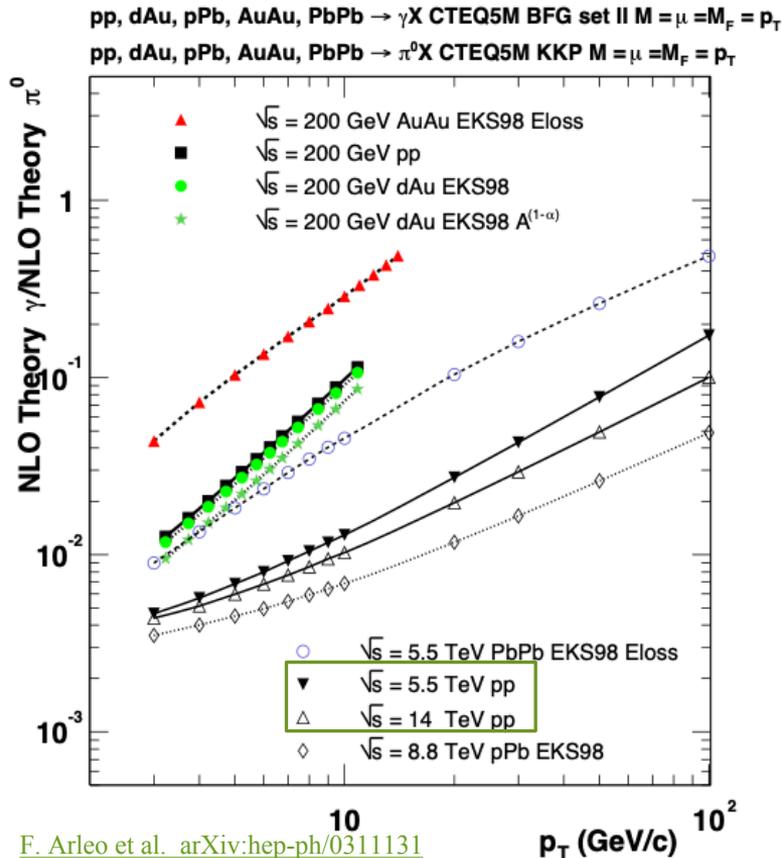
Why direct photons ?

- Test pQCD predictions and constrain the parton distribution function (PDF, nPDFs)
- Constrain the kinematics of hard scattered partons
- Explore cold nuclear matter effects
- Reference for Pb-Pb collisions measurements



→ LO not the main photon source

$$\gamma_{inclusive} = \underbrace{\gamma_{LO}}_{\gamma_{direct}} + \underbrace{\gamma_{fragmentation} + \gamma_{decay}}_{\text{from } \pi^0, \eta \dots \text{ decay}}$$



The main photon source are π^0 , especially at low p_T .
 Fragmentation photons are comparable to LO photons.

Isolation method

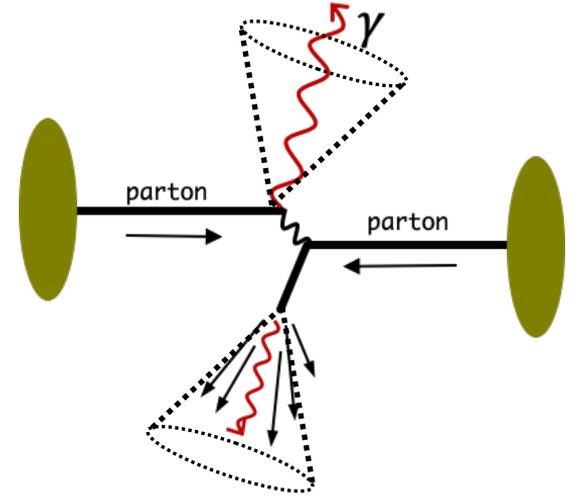
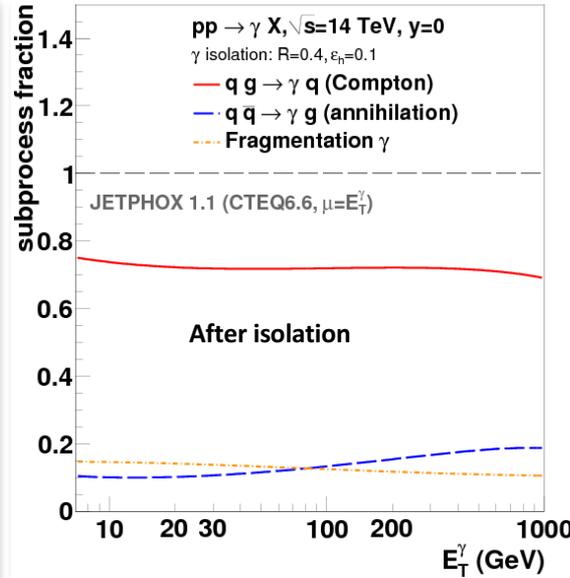
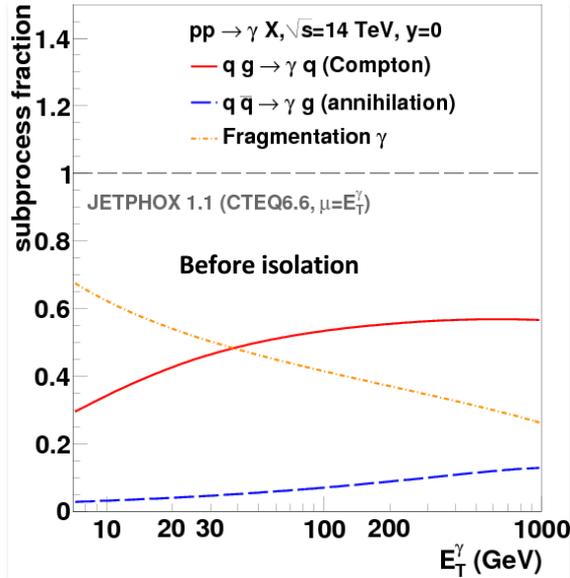


Direct photon from Compton and annihilation hard processes

📌 no hadronic activity around

Decay and fragmentation photons from parton fragmentation

📌 accompanied by many other hadrons



- In this calculation direct photons are selected if total energy in the cone is less than 10% of the photon energy.

[R. Ichou and D. d'Enterria. Phys.Rev.D82:014015,2010](#)

Measuring direct photons in ALICE



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

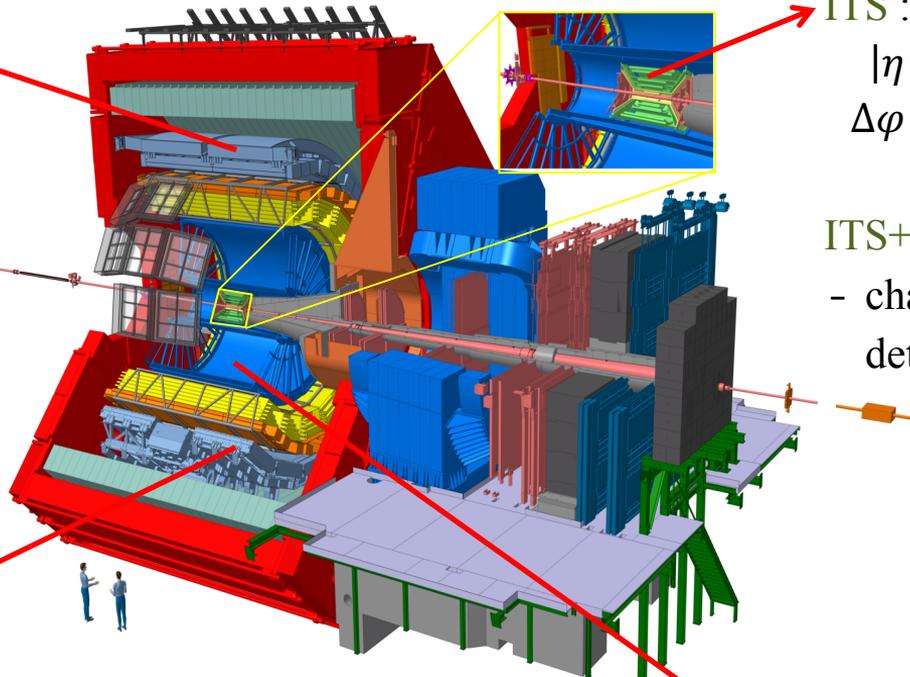
EMCal/DCal:
- γ /jet triggers
detector

DCal:
 $0.22 < |\eta| < 0.7$; $260^\circ < \varphi < 320^\circ$
 $|\eta| < 0.7$; $320^\circ < \varphi < 327^\circ$

ITS :
 $|\eta| < 0.9$
 $\Delta\varphi = 360^\circ$

ITS+TPC:
- charged particle
detector

TPC :
 $|\eta| < 0.9$
 $\Delta\varphi = 360^\circ$



System	$\sqrt{s_{NN}}$ (TeV)
pp	7, 8, 13
p-Pb	5.02

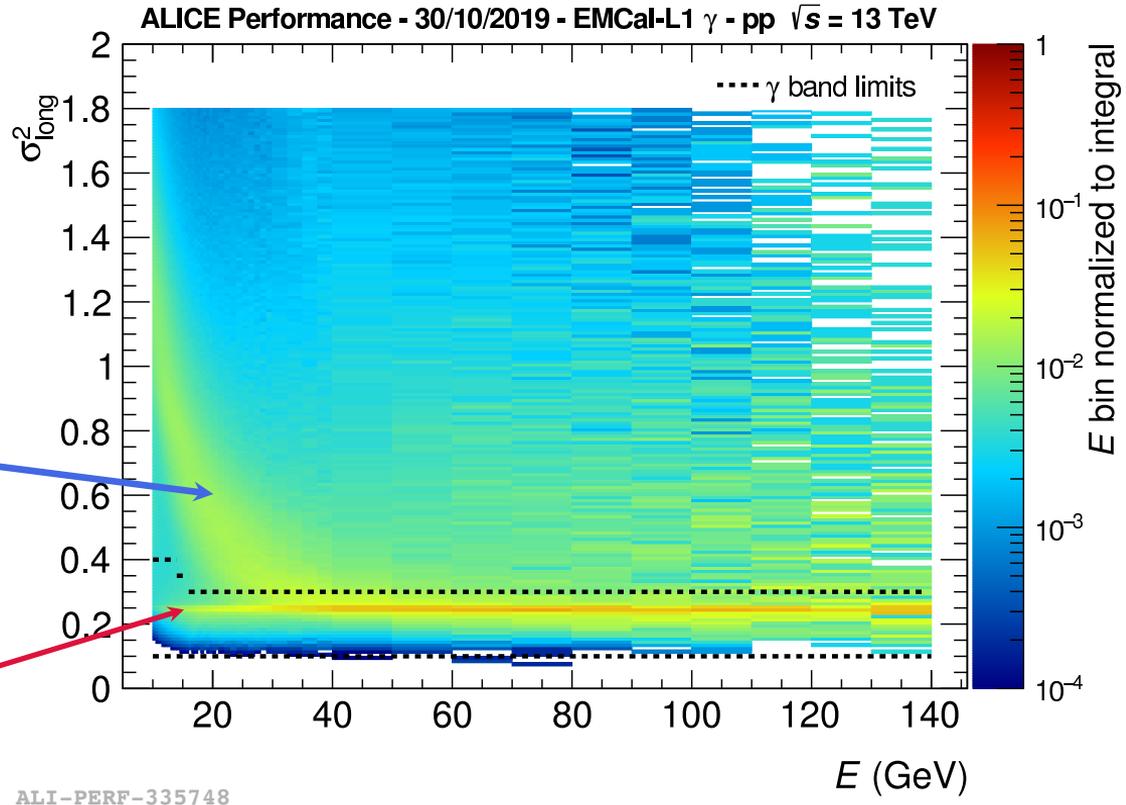
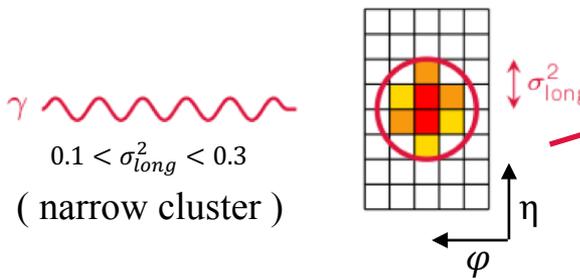
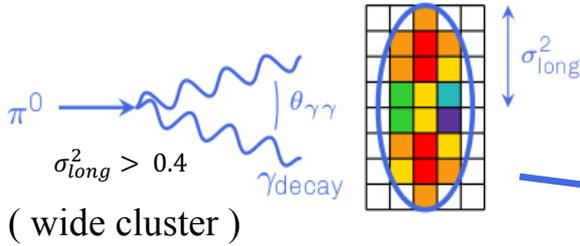
Photon identification: shower shape



Cluster shower shape :

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

$$\sigma_{xz}^2 = \langle xz \rangle - \langle x \rangle \langle z \rangle ; \langle x \rangle = (1/w_{tot}) \sum w_i x_i$$



ALI-PERF-335748



- Sum the p_T of particles (i) inside a cone of radius: $R = \sqrt{(\eta_i - \eta_\gamma)^2 + (\varphi_i - \varphi_\gamma)^2} = 0.4$
- Set an isolation threshold (conventions used in different measurements):

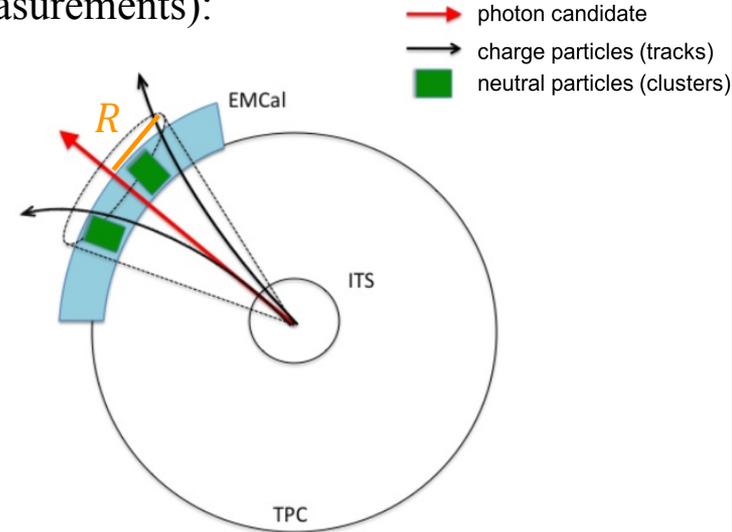
$$\text{➤ } p_T^{iso,UE} = \Sigma p_T^{cluster} + \Sigma p_T^{track} < 2 \text{ GeV}/c$$

$$\text{➤ } p_T^{iso,ch,UE} = \Sigma p_T^{track} < 1.5 \text{ GeV}/c$$

$$\text{➤ } p_T^{iso,ch} = \Sigma p_T^{track} - UE(\rho_{UE} \pi R^2) < 1.5 \text{ GeV}/c$$

✦ Underlying event (UE) density (ρ_{UE}) estimation:

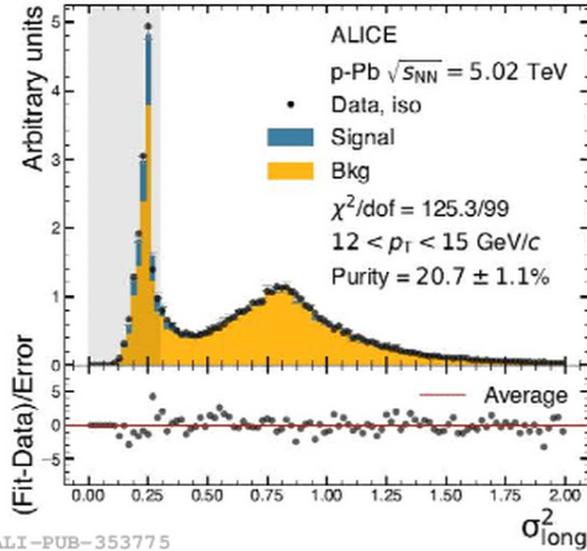
- Using perpendicular cone method in pp at $\sqrt{s} = 8 \text{ TeV}$
 - For a given cluster with position (η, φ) , rotate cone by $\pm 90^\circ$ in φ
 - UE is the sum of all charge track p_T in perpendicular cone
- Using FASTJET jet area/median method (Voronoi area) in p-Pb at $\sqrt{s_{NN}} = 5.02 \text{ TeV}$





Isolated photons: purity estimation

The template Fit



ALI-PUB-353775

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

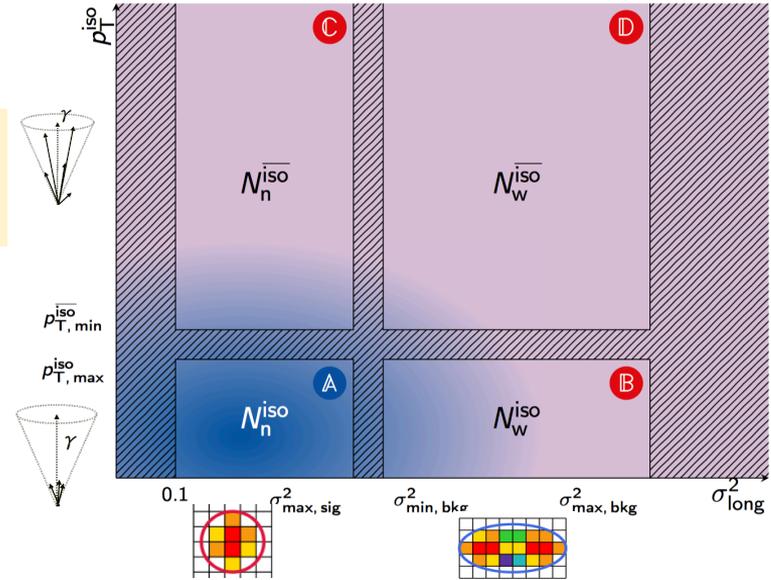
$$N^{observed}(\sigma_{long}^2) = N_{sig} \times S(\sigma_{long}^2) + (N - N_{sig}) \times B(\sigma_{long}^2)$$

PRC 102, 044908(2020)

$$N = S + B$$

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

The ABCD method

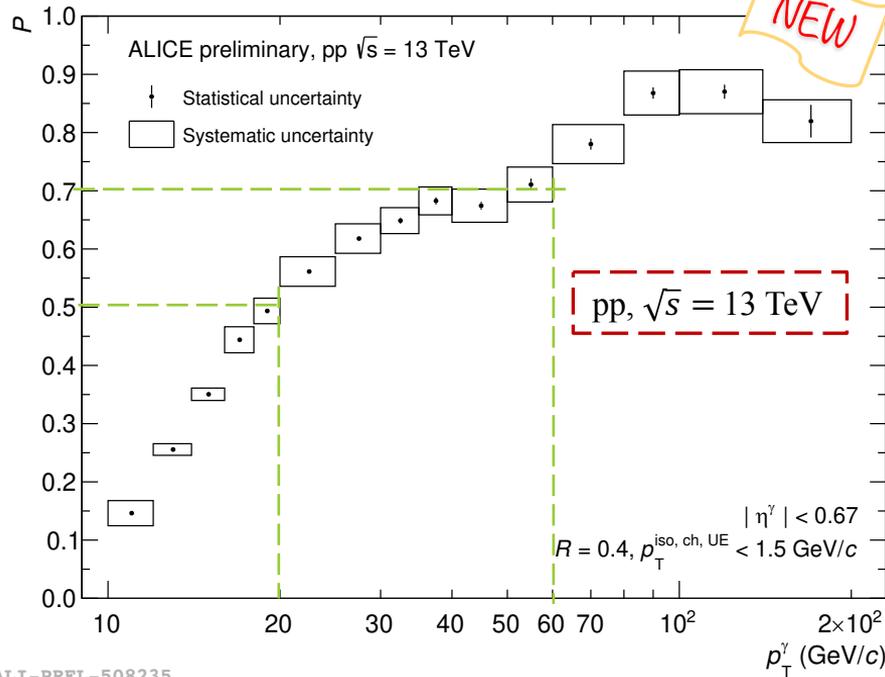


The three background denominated regions (BCD) are used to estimate the background contribution in the signal region (A)

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

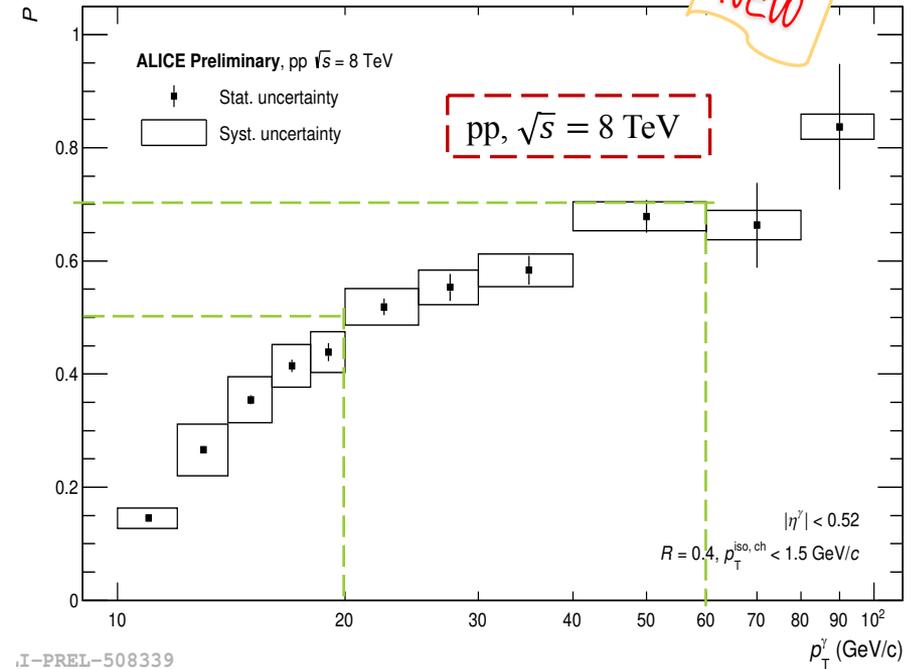
Eur. Phys. J. C 79:896 (2019)

Isolated photons: purity



ALI-PREL-508235

Charged isolation using ITS+TPC tracks,
UE not subtracted
 $R = 0.4, p_T^{iso, ch, UE} < 1.5$ GeV/c

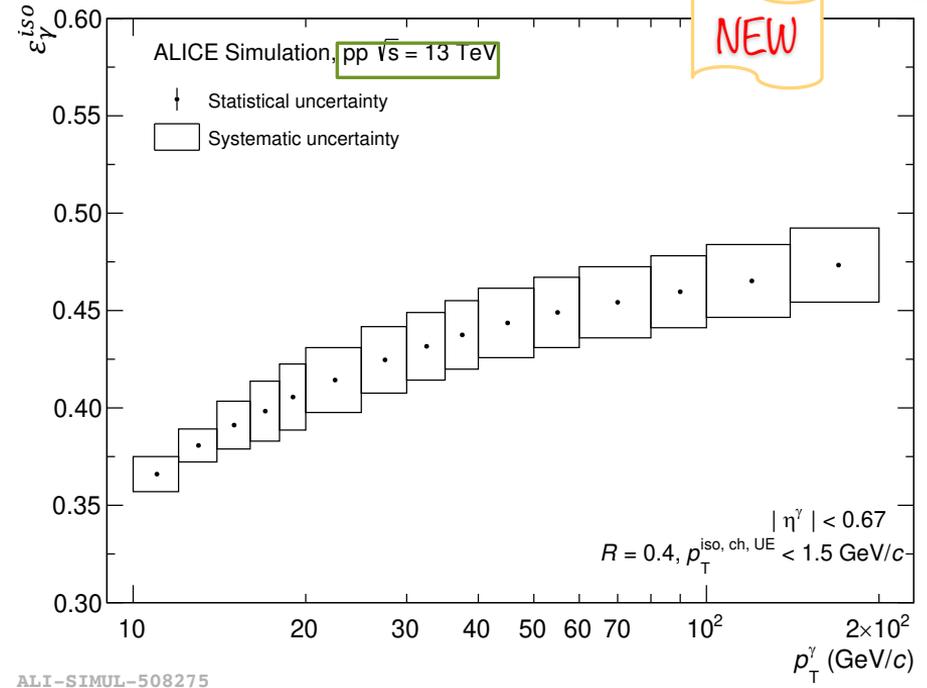
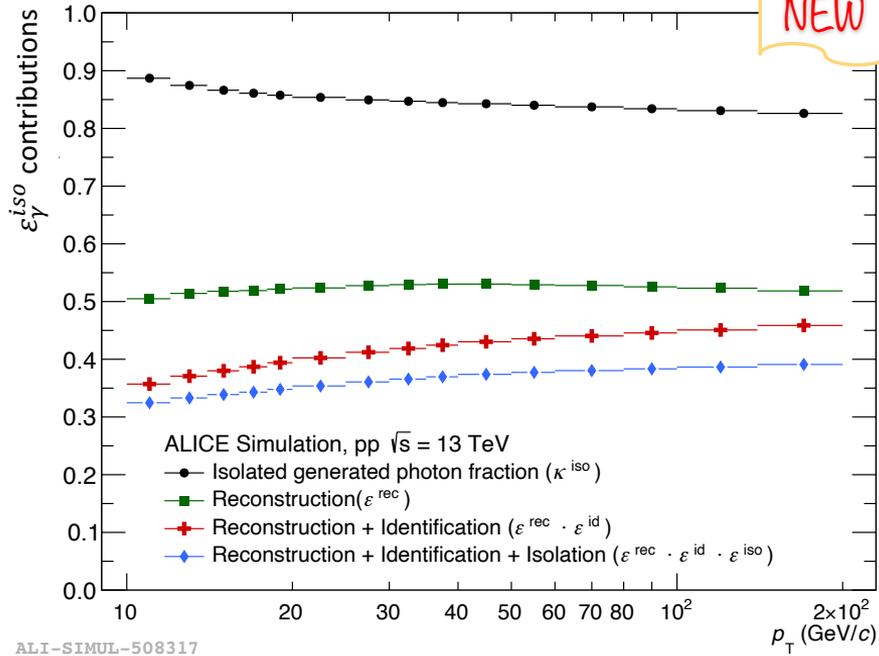


LI-PREL-508339

Charged isolation using ITS+TPC tracks,
UE subtracted
 $R = 0.4, p_T^{iso, ch} < 1.5$ GeV/c

Purity up to 0.7 – 0.8 reached in both systems and quite similar

Isolated photons: efficiency



$$\epsilon_Y^{iso}(p_T) = \frac{\epsilon^{rec} \cdot \epsilon^{id} \cdot \epsilon^{iso}}{\kappa^{iso}}$$

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

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

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

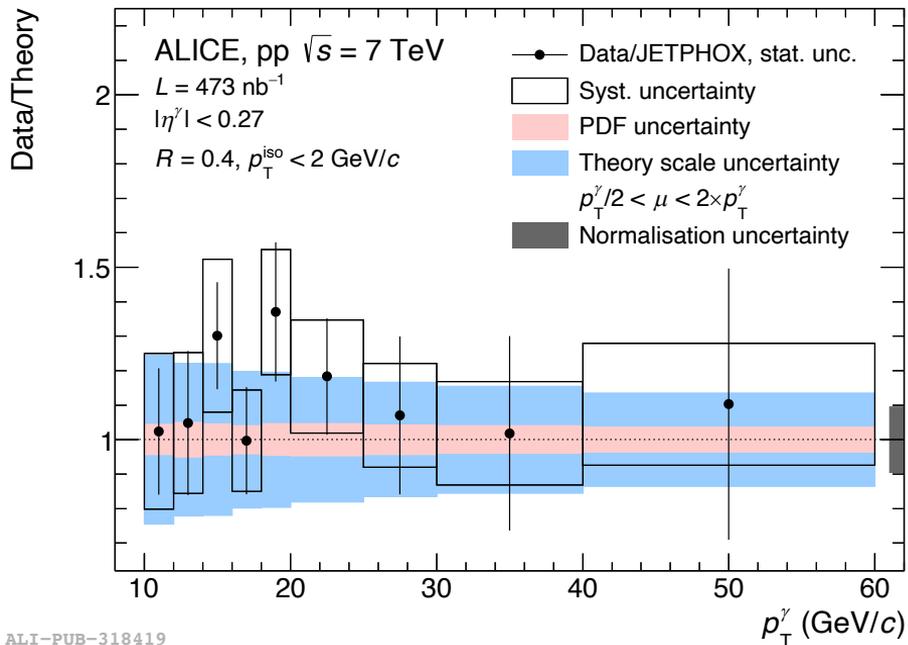
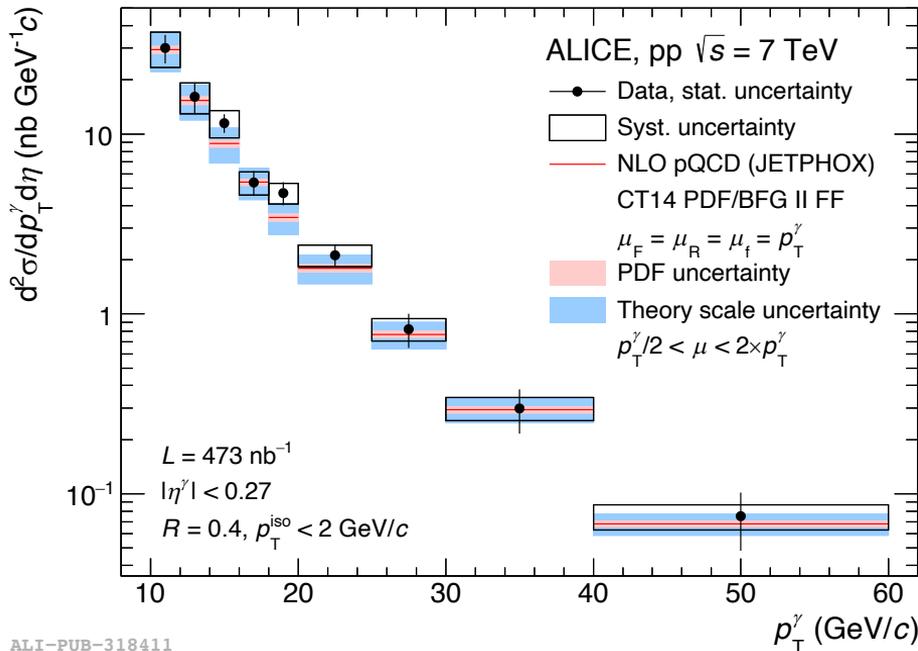
Isolated photons in pp: cross section at $\sqrt{s} = 7 \text{ TeV}$



ALICE Collaboration: Eur. Phys. JC 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)

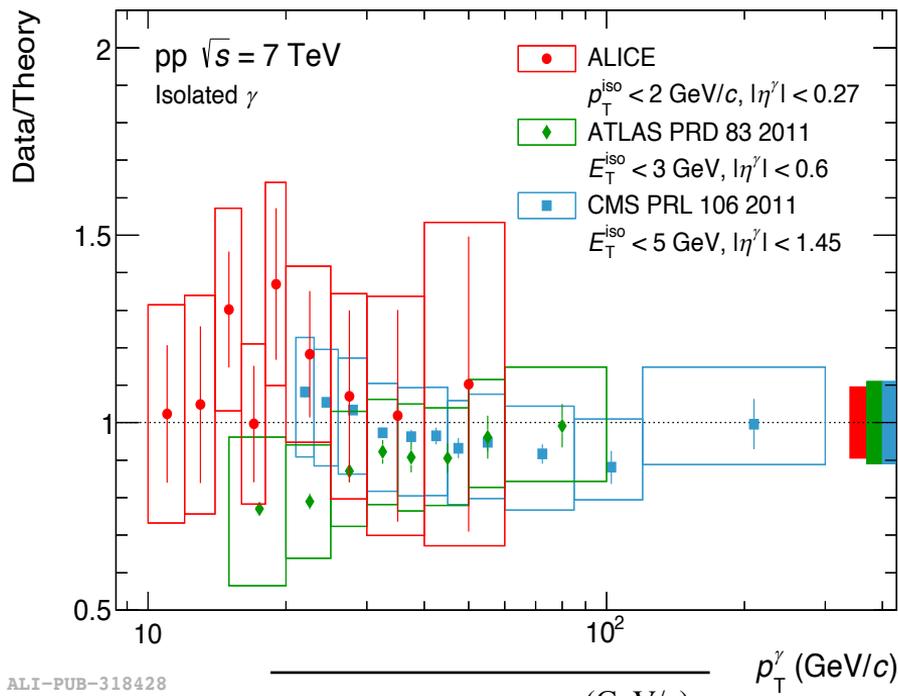
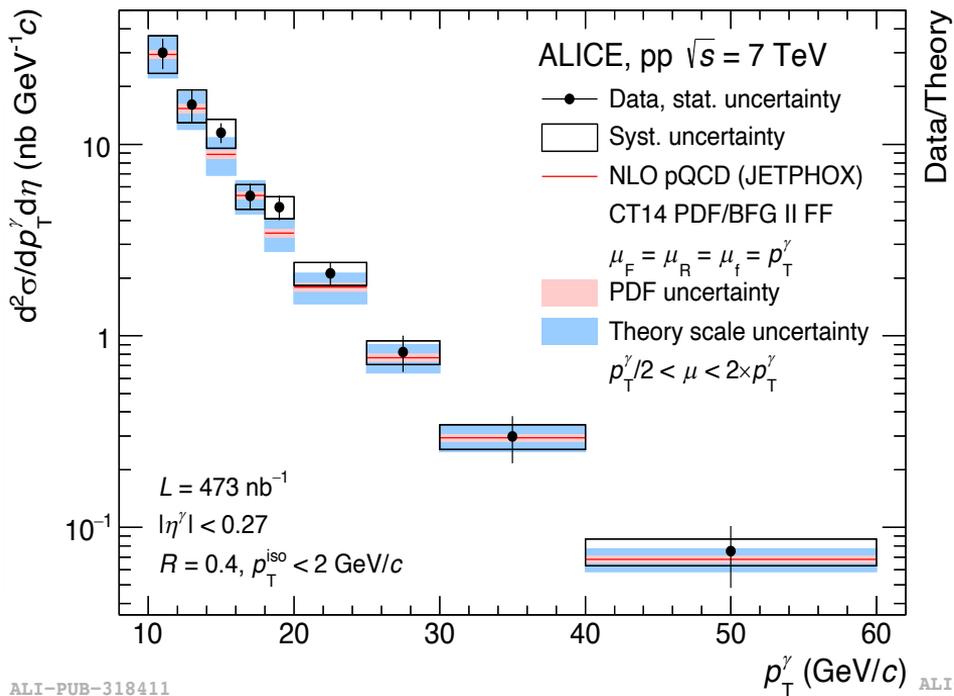
Charge+Neutral isolation using ITS+TPC tracks and
 EMCal cluster, UE not subtracted

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



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

Isolated photons in pp: cross section at $\sqrt{s} = 7 \text{ TeV}$



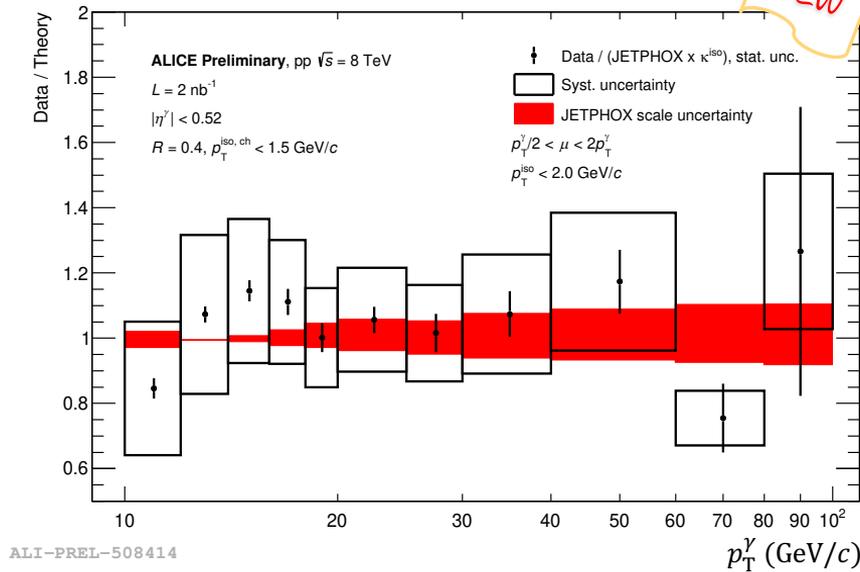
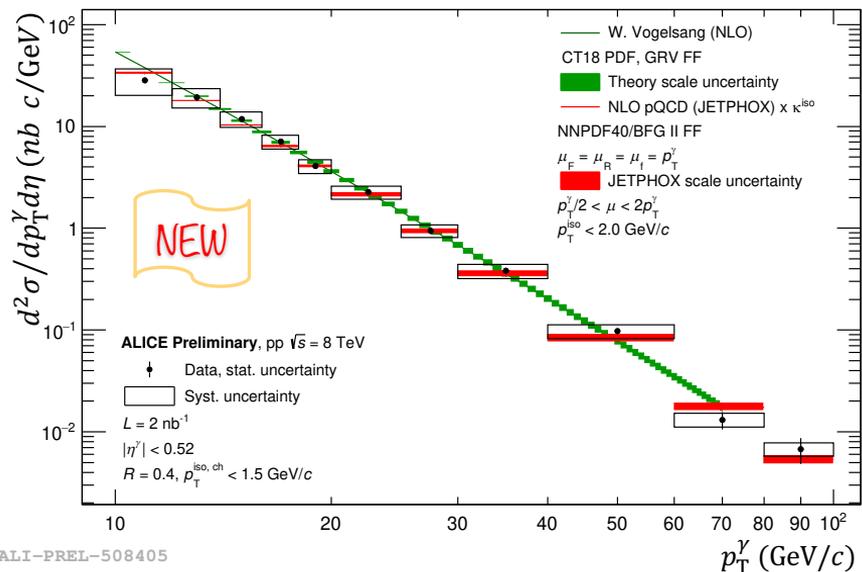
ALICE measurements: extends other LHC experiments
 towards lower p_T and $x_T = 2p_T/\sqrt{s}$

	p_T range (GeV/c)
ALICE	$10 < p_T < 60$
ATLAS	$15 < p_T < 100$
CMS	$21 < p_T < 140$

Isolated photons in pp: cross section at $\sqrt{s} = 8 \text{ TeV}$



NEW



Charged isolation using ITS+TPC tracks,
 UE subtracted
 $R = 0.4, p_T^{\text{iso, ch}} < 1.5 \text{ GeV}/c$

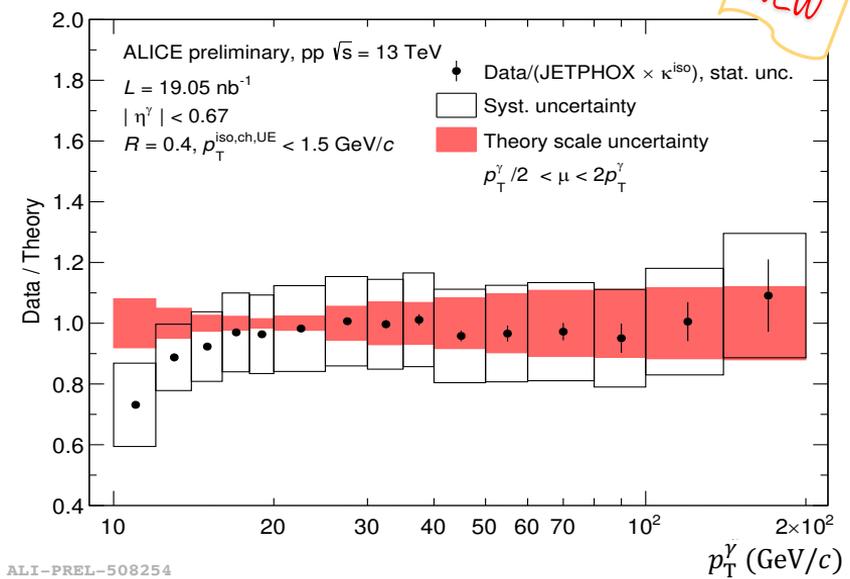
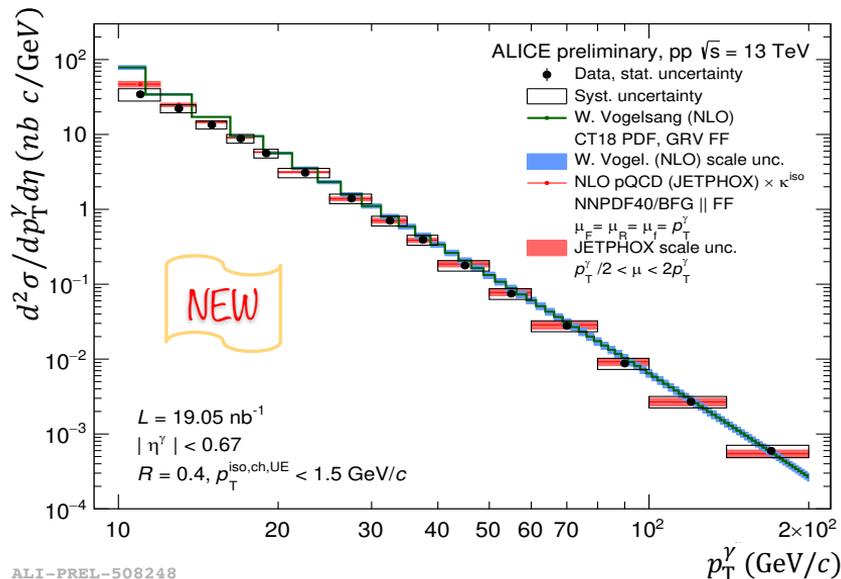
JETPHOX mode calc. – NNPDF40, BFG II FF
 NLO calc. Werner Vogelsang – CT18 PDF, GRV FF
 NNPDF Collaboration: arXiv.2019.02653

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

	p_T range (GeV/c)
ALICE	$10 < p_T < 100$
ATLAS	$25 < p_T < 1500$ [1]
CMS	$40 < p_T < 1000$ [2]

[1] JHEP 06 (2016) 005
 [2] Eur. Phys. J. C (2019) 79:969

Isolated photons in pp: cross section at $\sqrt{s} = 13 \text{ TeV}$



Charged isolation using ITS+TPC tracks,
 UE not subtracted
 $R = 0.4, p_T^{iso, ch, UE} < 1.5 \text{ GeV}/c$

JETPHOX mode calc. – NNP40, BFG II FF
 NLO calc. Werner Vogelsang – CT18 PDF, GRV FF
 NNPDF Collaboration: arXiv.2019.02653

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

	p_T range (GeV/c)
ALICE	$10 < p_T < 200$
ATLAS	$125 < p_T < 2000$ [3]
CMS	$190 < p_T < 1000$ [4]

[3] [JHEP10\(2019\)203](#)
 [4] [Eur. Phys. J. C 79 \(2019\) 20](#)



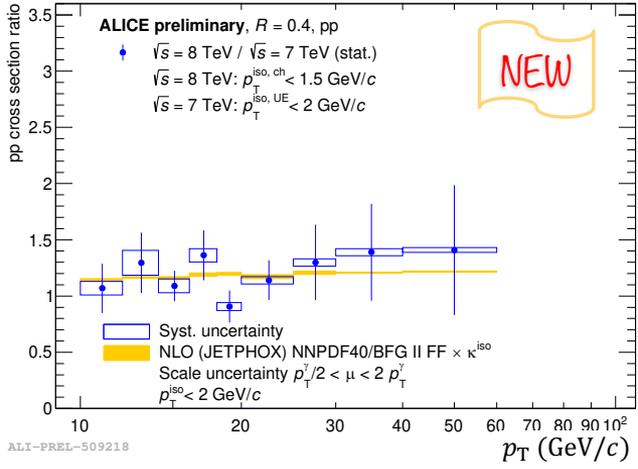
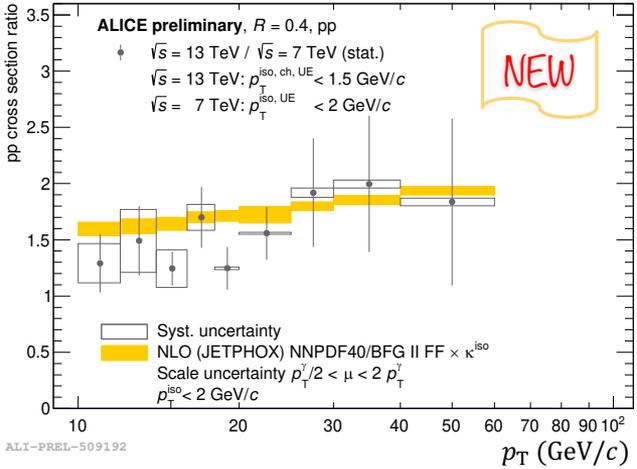
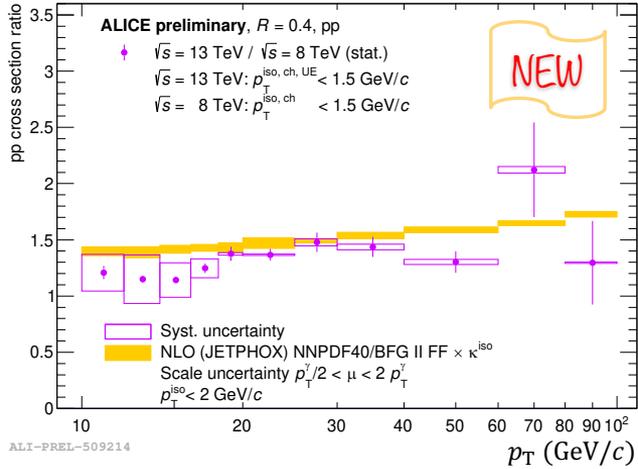
Isolated photon comparisons

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

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

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

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



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

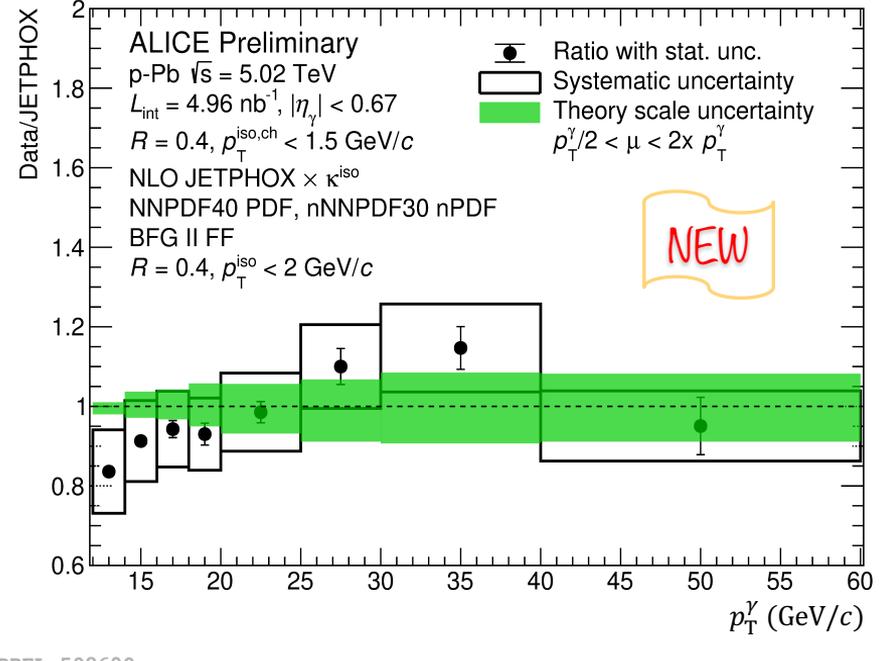
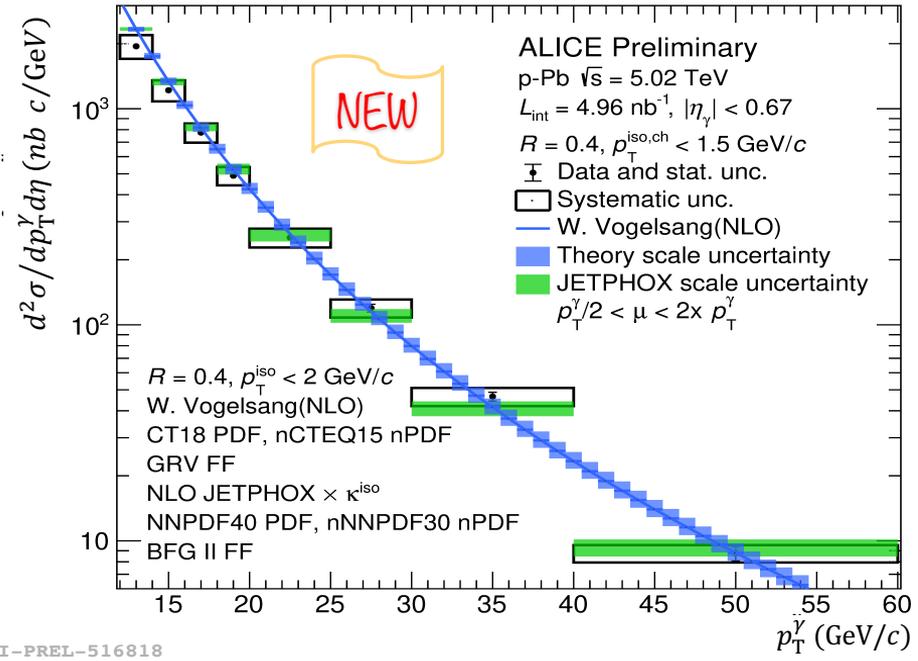
Reasonable agreement within uncertainties

Isolated photons in p -Pb: cross section at $\sqrt{s_{NN}} = 5.02$ TeV



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

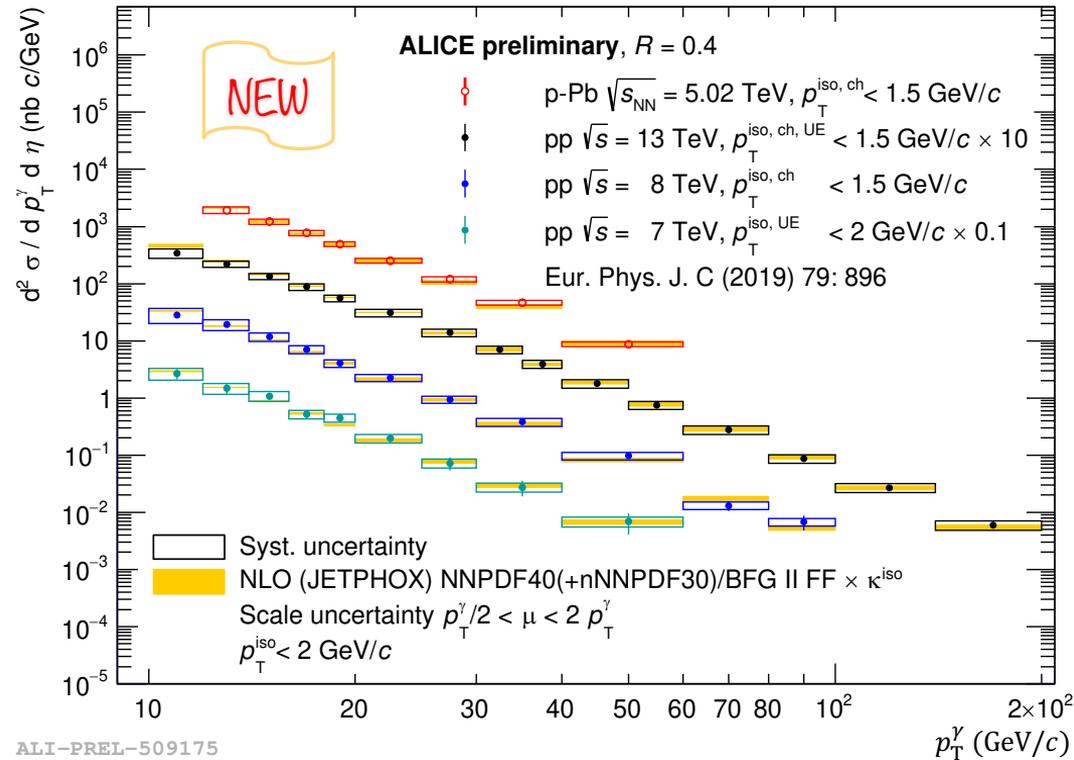
Charged isolation using ITS tracks, UE subtracted
 $R = 0.4, p_T^{iso, ch} < 1.5$ GeV/c



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

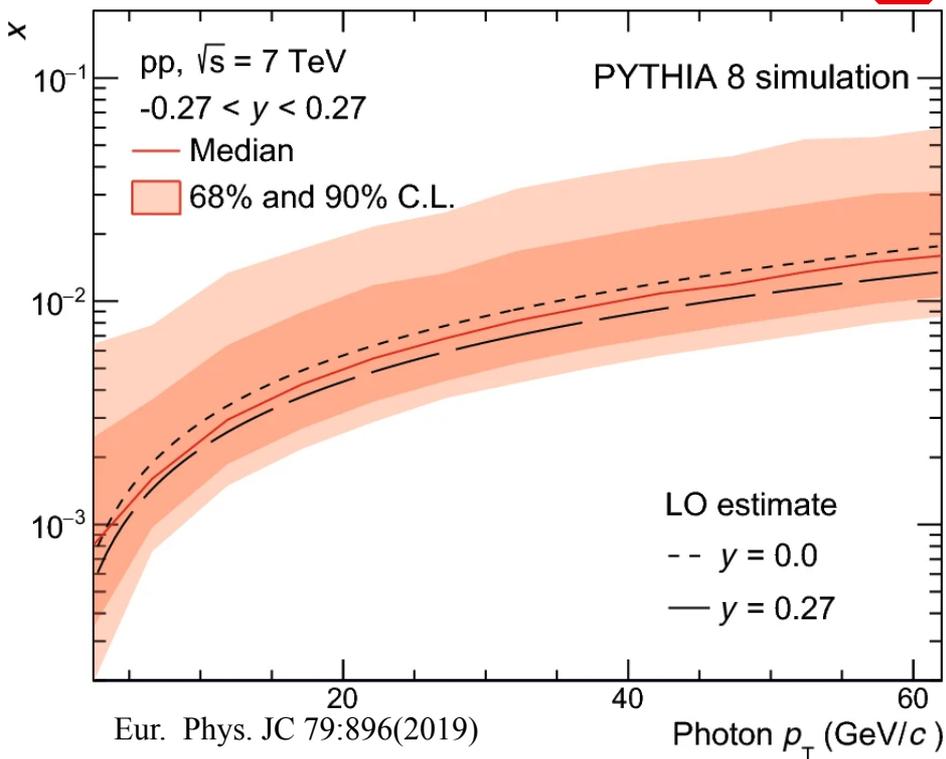
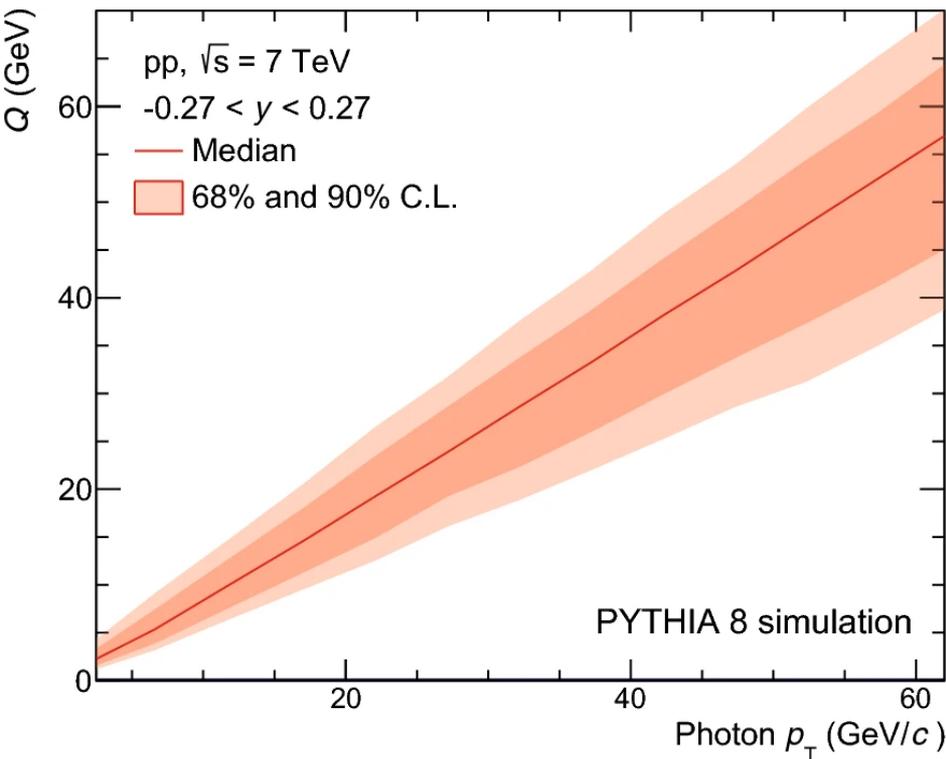


- Measurement of isolated photons cross sections in pp and p-Pb collisions.
- ALICE extends the LHC measurements towards lower p_T^γ (10 – 12 GeV/c)
→ lower x_T
- Results are compatible with pQCD calculations.
- Establishes a benchmark for these measurements in Pb-Pb collisions.

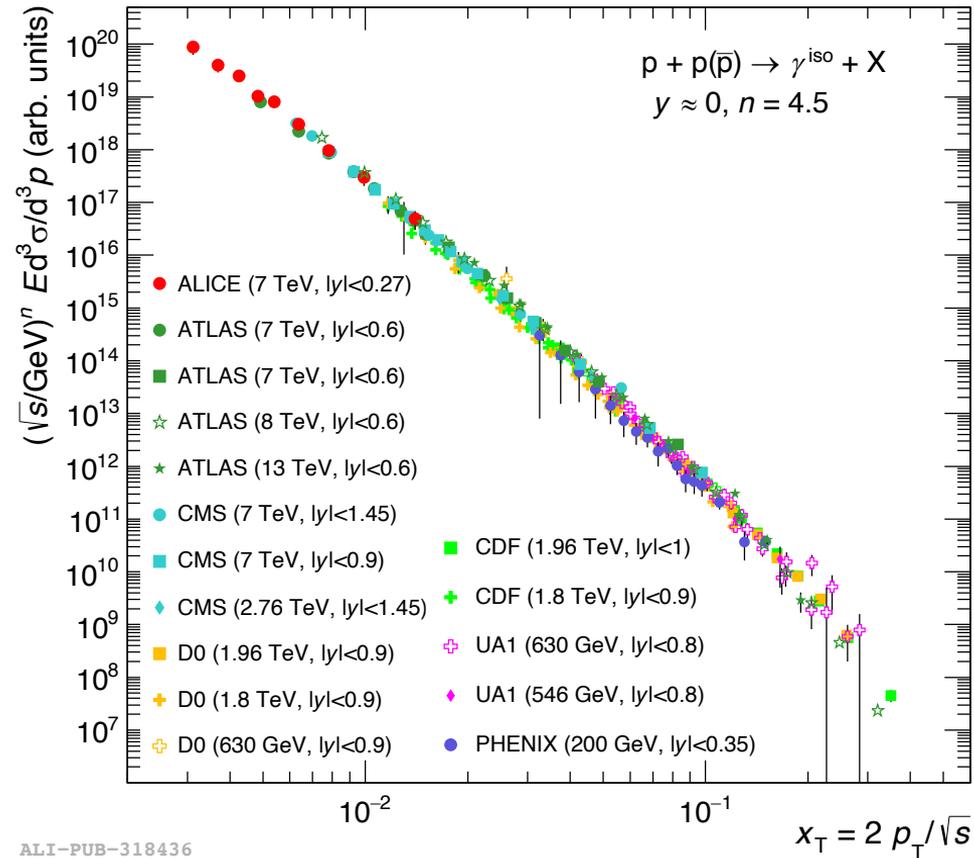


Thank you !!!

BACK UP



The scale Q (left), and the fraction x (right) of longitudinal momentum of the initial state partons of the hard process for photon production at mid-rapidity versus photon p_T for pp collisions at $\sqrt{s} = 7$ TeV

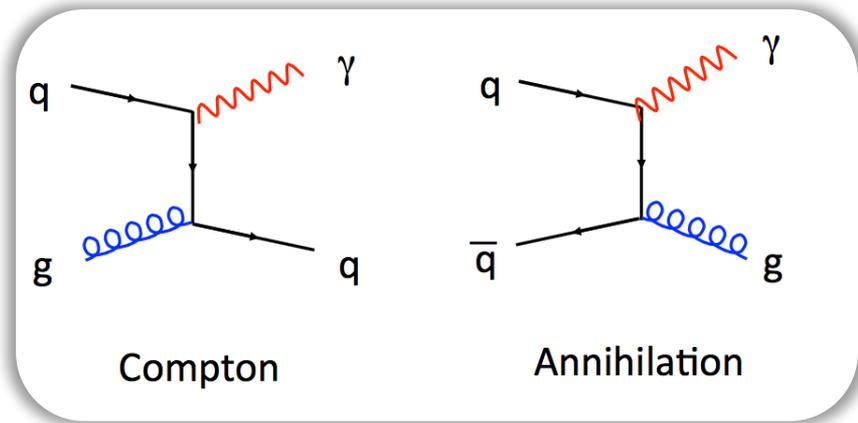


ALI-PUB-318436

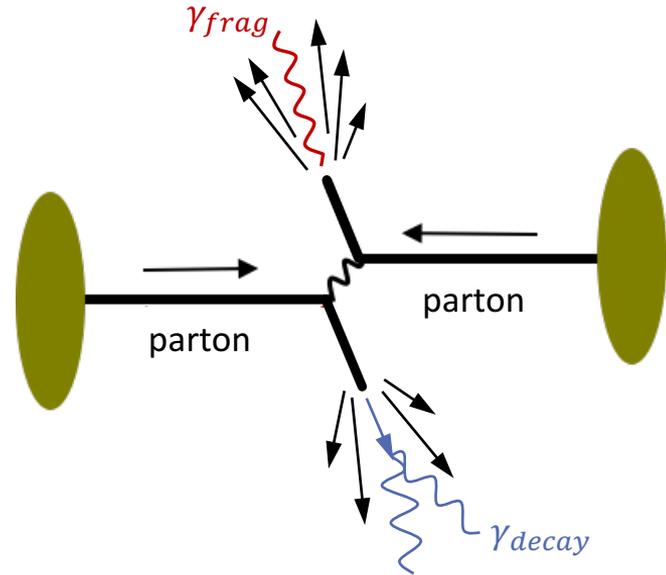
Eur. Phys. JC 79:896(2019)

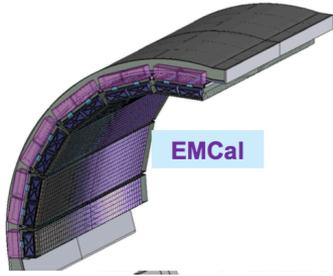


$$\gamma_{inclusive} = \underbrace{\gamma_{LO} + \gamma_{fragmentation}}_{\gamma_{direct}} + \underbrace{\gamma_{thermal}}_{\text{in Pb-Pb}} + \underbrace{\gamma_{decay}}_{\text{from } \pi^0, \eta \dots \text{ decay}}$$



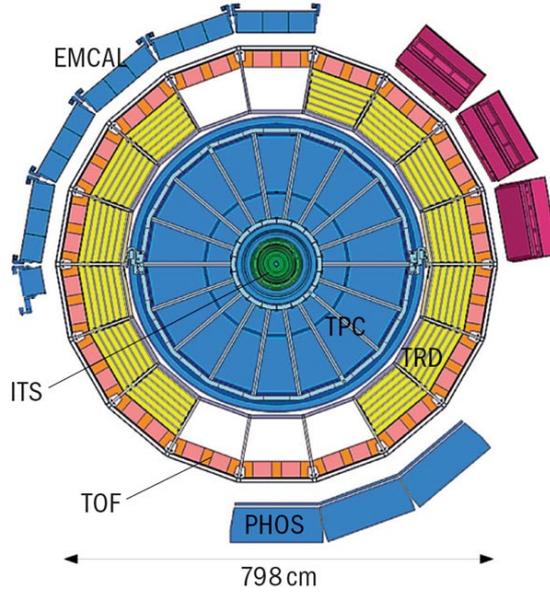
main objective



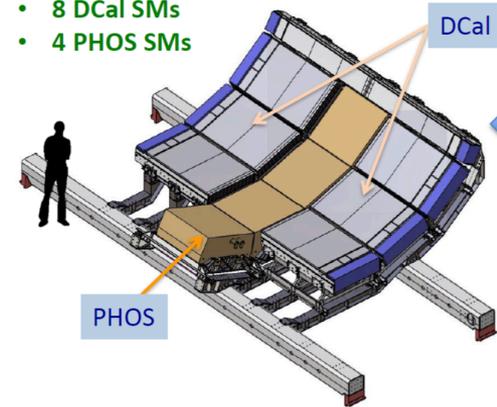


EMCal

- 12 EMCal superm
- 8 DCal superm
- 4 PHOS module
- 1 CPV module



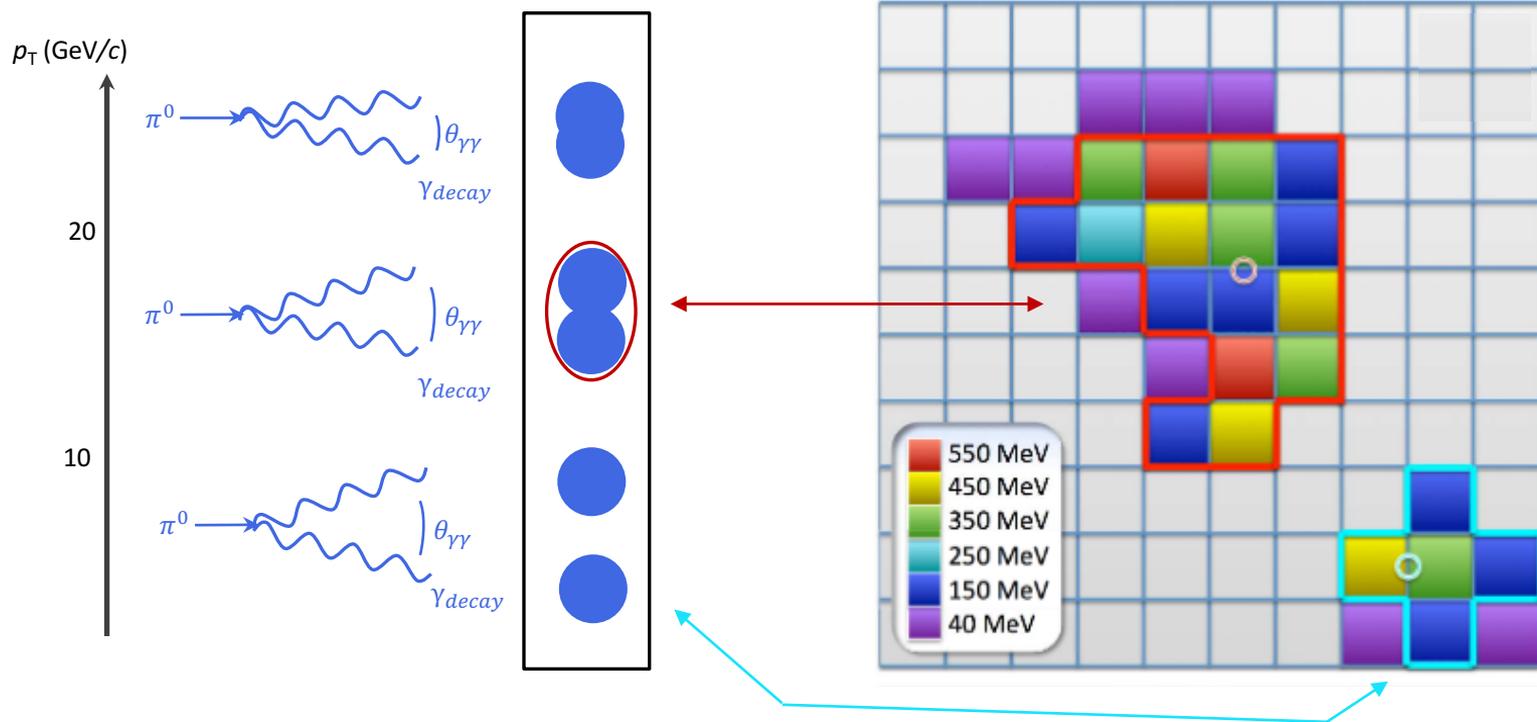
- 8 DCal SMs
- 4 PHOS SMs





Particle energy measurement in the calorimeter

- EMCal measures photon energy deposited in several cells, a cluster.
- Energy spreads in a clusters differently for single γ and high energy π^0 .





Purity: the ABCD method

Idea: divide clusters σ_{long}^2 - isolation plane into 4 regions

- A : signal dominated region
- B, C and D : background dominated regions

Define $N(\text{total}) = S(\text{signal}) + B(\text{background})$

✂️ $\text{purity} = S/N$ in A region

The aim is to estimate the purity with data as much as possible

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

data-driven purity

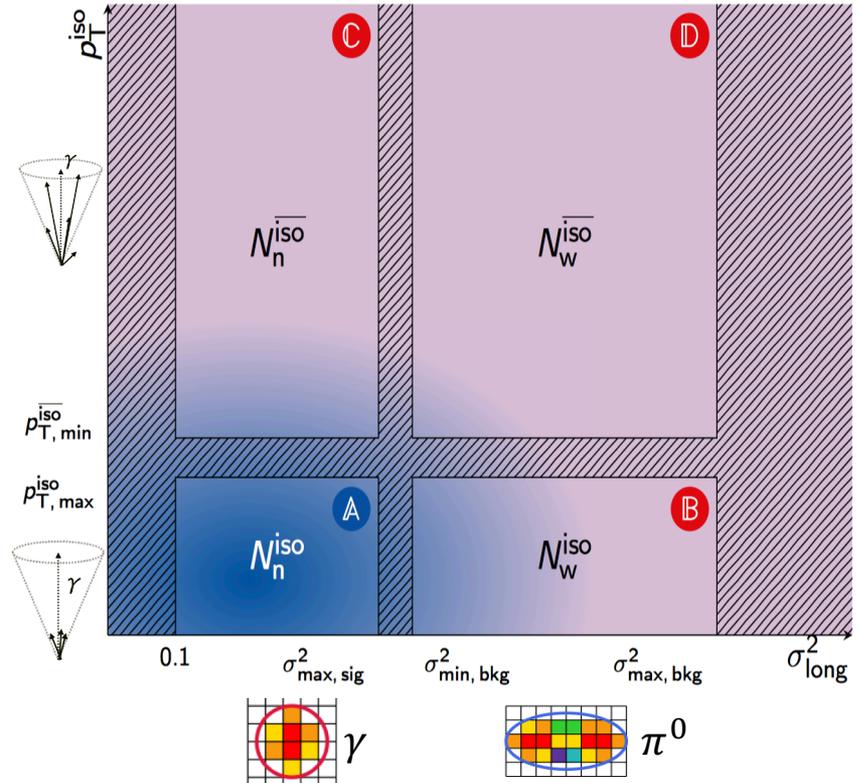
MC correction factor

Assume:

$$B_{B,C,D} = N_{B,C,D}$$

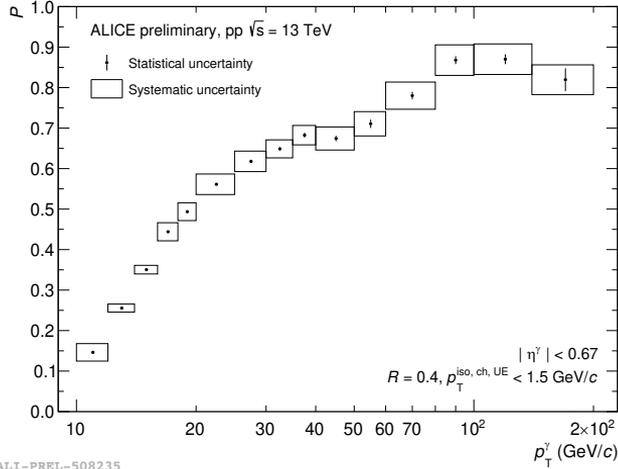
$$B_A/B_C = B_B/B_D$$

Unfortunately assumption not completely true

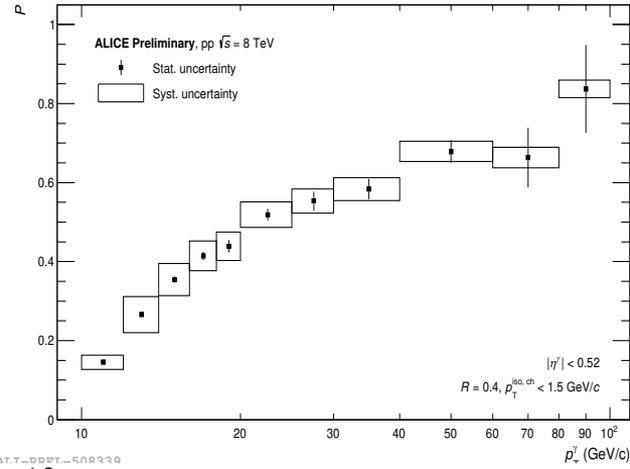




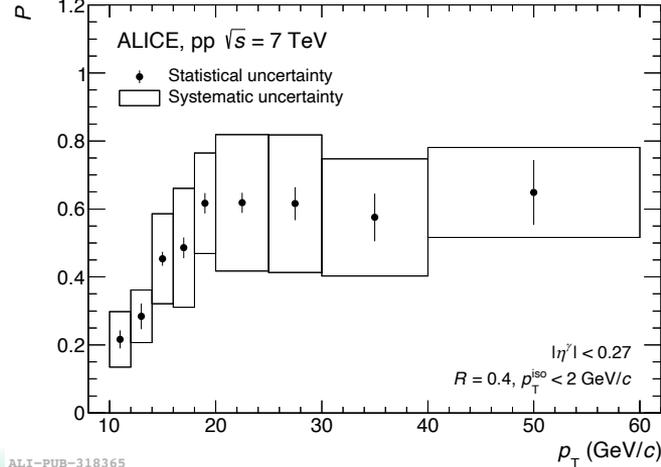
Purity in pp collisions



ALI-PREL-508235



ALICE-PREL-508234

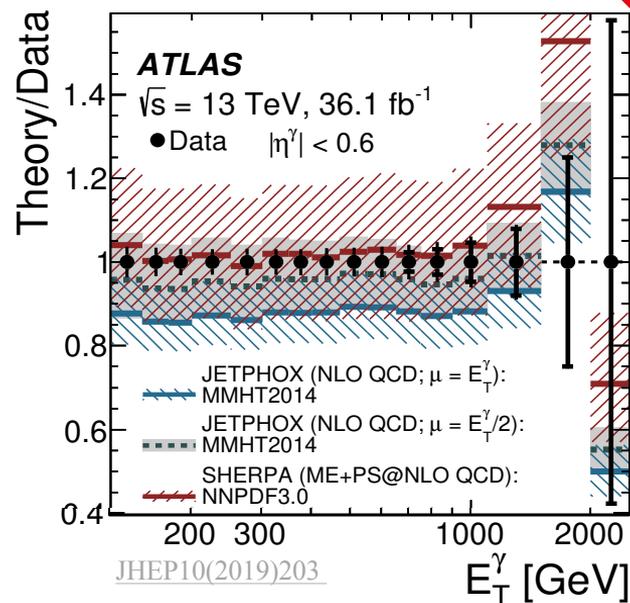
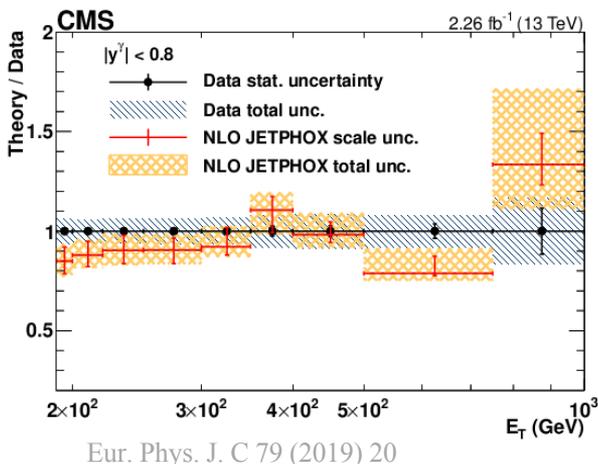
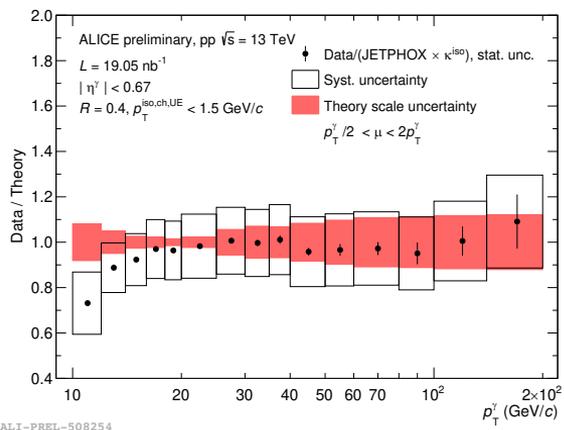


ALI-PUB-318365

\sqrt{s} (TeV)	Particle in cone	p_T^{iso} (GeV/c)
13	Charged only	1.5
8	Charged only	1.5
7	Charge + neutral	2.0

☀️ purity up to 0.7 -- 0.8 reached in both systems and quite similar.

Isolated photon comparison, to other experiments



The ALICE measurement extends to lower p_T range compared to ATLAS and CMS measurements

collaboration	\sqrt{s} (TeV)	p_T range (GeV/c)
ALICE		$10 < p_T < 200$
ATLAS	13	$125 < p_T < 2000$
CMS		$190 < p_T < 1000$