Measurement of isolated photon production cross section in pp collisions at 13 TeV with ALICE

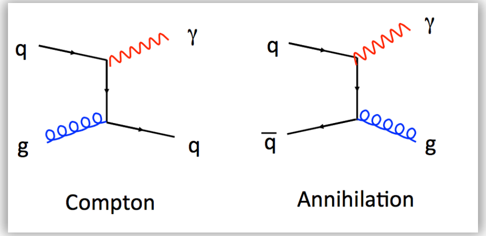
Ran XU (徐冉)
(for the ALICE collaboration)

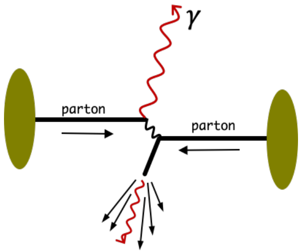
Central China Normal University
Université-Grenoble Alpes

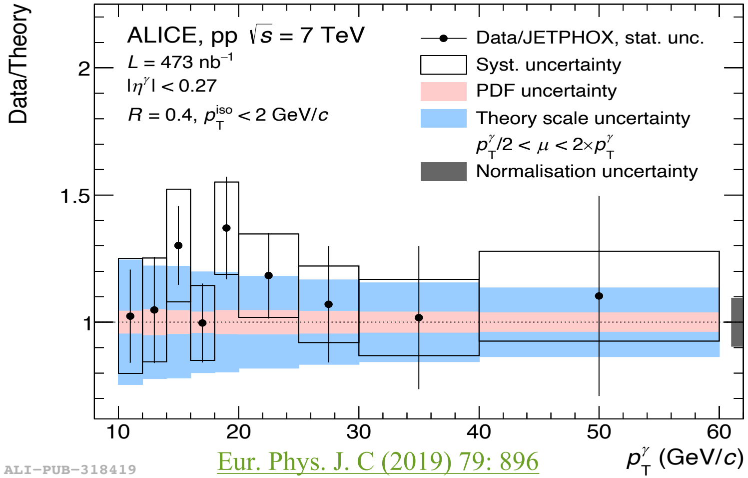
24 November 2022

Why direct photons ?

- Test pQCD predictions and constrain PDF, in particular for gluons PDF
- Reference for measurements in heavy-ion collisions
- Measurement already published in pp collisions at $\sqrt{s} = 7$ TeV with ALICE.
  - → Measurement at $\sqrt{s} = 13$ TeV shown here profits from a significantly larger sample: extend the p_{T} above 60 GeV/c and below 10 GeV/c.





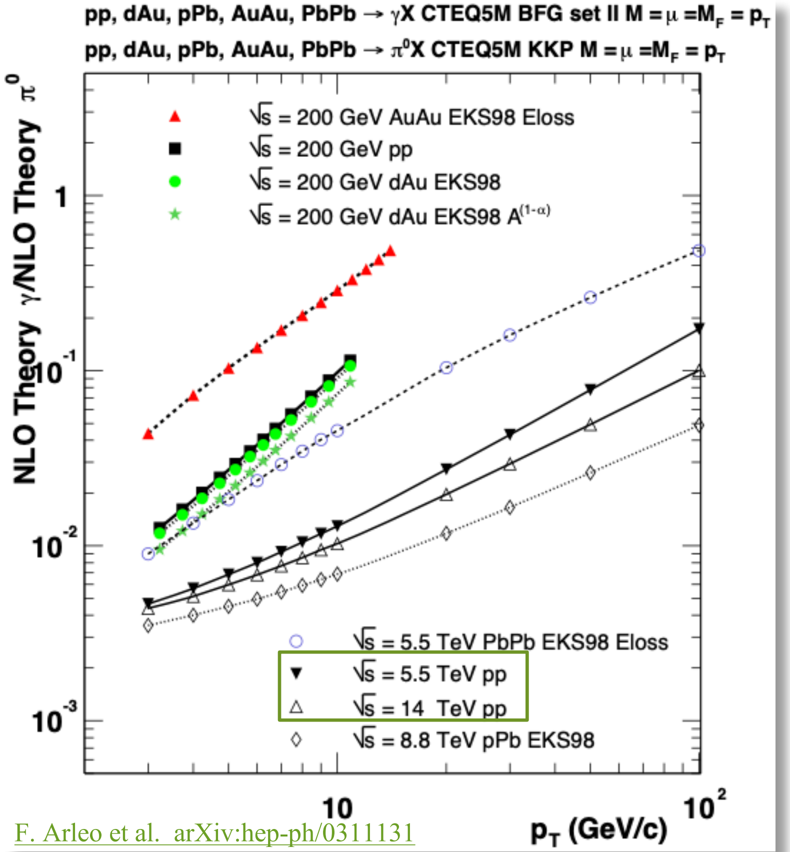


Eur. Phys. J. C (2019) 79: 896

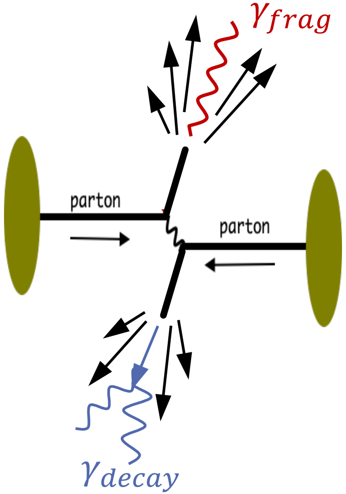
🌟 LO not the main photon source

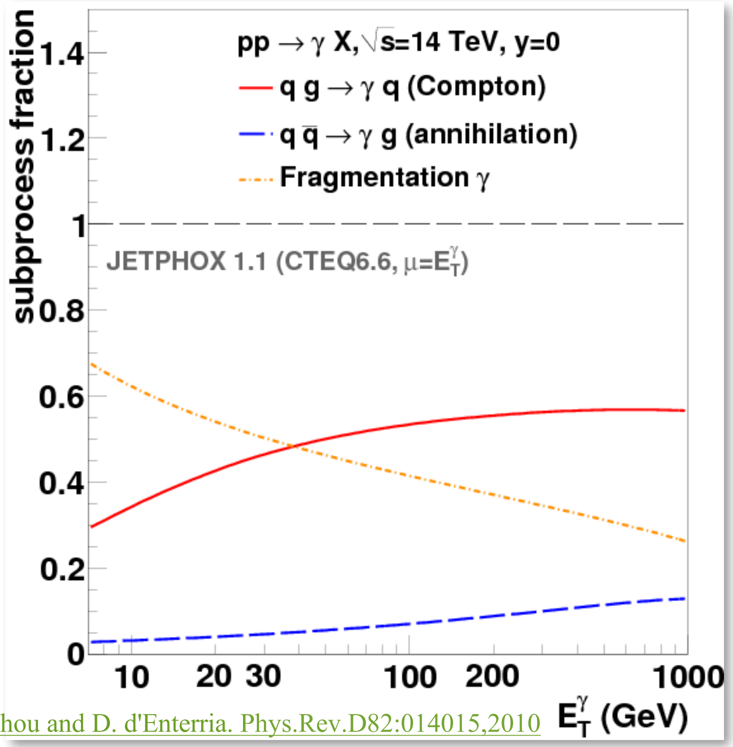
$$\gamma_{inclusive} = \underbrace{\gamma_{LO} + \gamma_{fragmentation}}_{\gamma_{direct}} + \underbrace{\gamma_{decay}}_{\text{from } \pi^0, \eta \text{ ... decay}}$$

Photon sources



F. Arleo et al. arXiv:hep-ph/0311131





R. Ichou and D. d'Enterria. Phys.Rev.D82:014015,2010

The main photon source are π^0, especially at low p_T.

Fragmentation photons are comparable to LO photons.

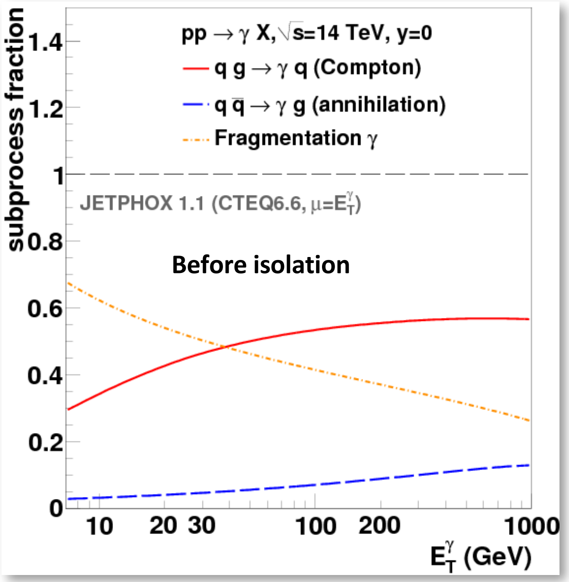
Isolation method

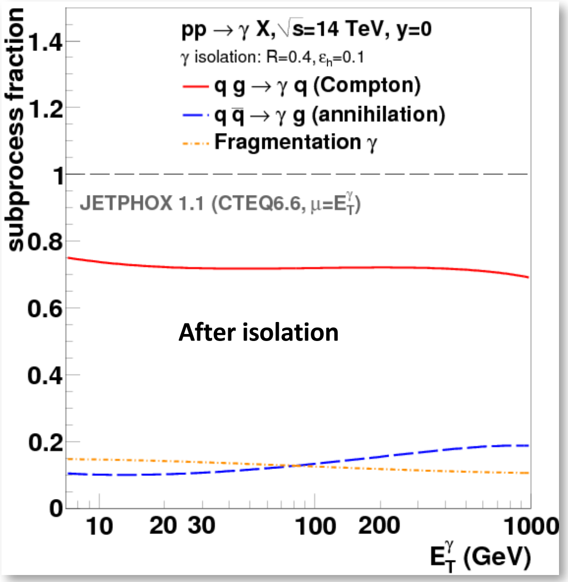
Direct photon from Compton and annihilation hard processes

- no hadronic activity around

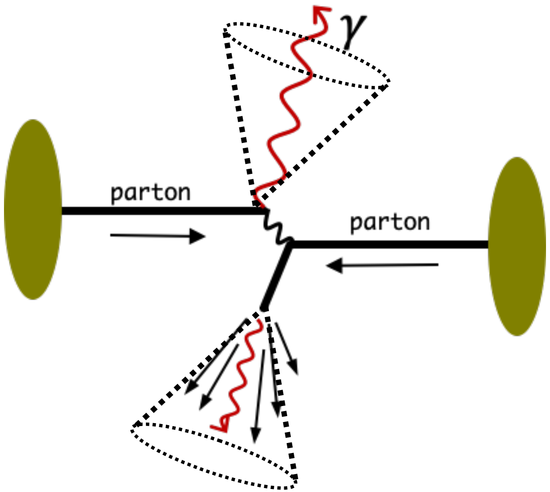
Decay and fragmentation photons from parton fragmentation

- accompanied by many other hadrons





R. Ichou and D. d'Enterria. Phys.Rev.D82:014015,2010



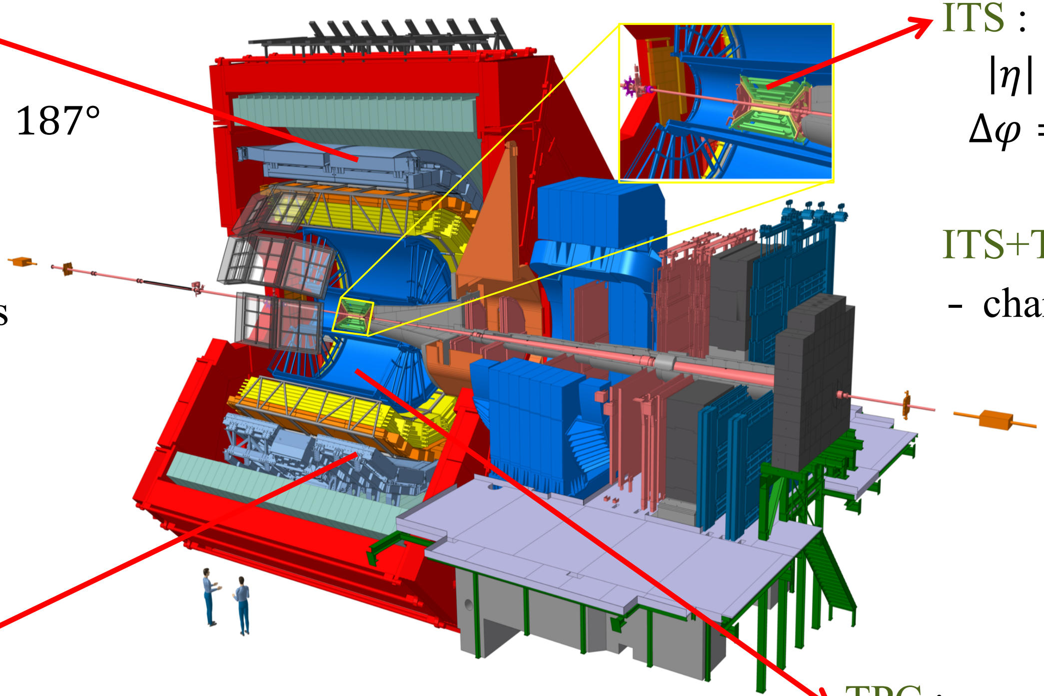
- In this calculation direct photons are selected if total energy in the cone is less than 10% of the photon energy.

Measuring direct photons in ALICE

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

EMCal/DCal:
- γ/jet triggers detector

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



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

ITS+TPC:
- charged particle detector

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

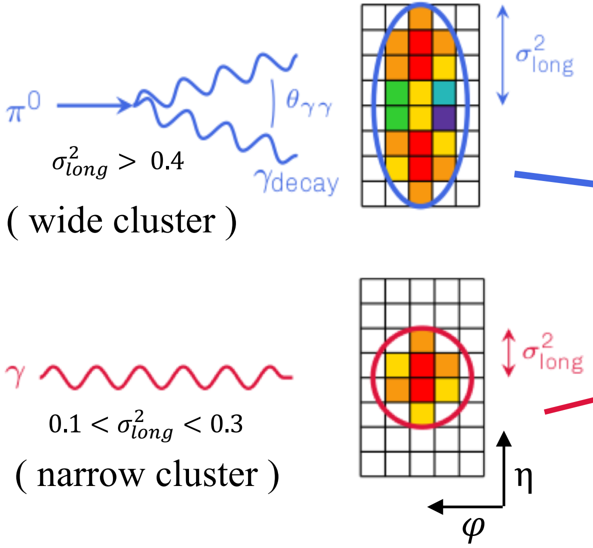
collision	$\sqrt{s_{NN}}$ (TeV)
pp	2.76, 5.02
	7, 8, **13**
p-Pb	5.02, 8.16
Pb-Pb	2.76, 5.02

Photon identification: shower shape

Cluster shower shape :

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

$$\sigma^2_{xz} = \langle xz\rangle - \langle x\rangle\langle z\rangle\, ;\, \langle x\rangle = (1/w_{tot})\Sigma w_i x_i$$

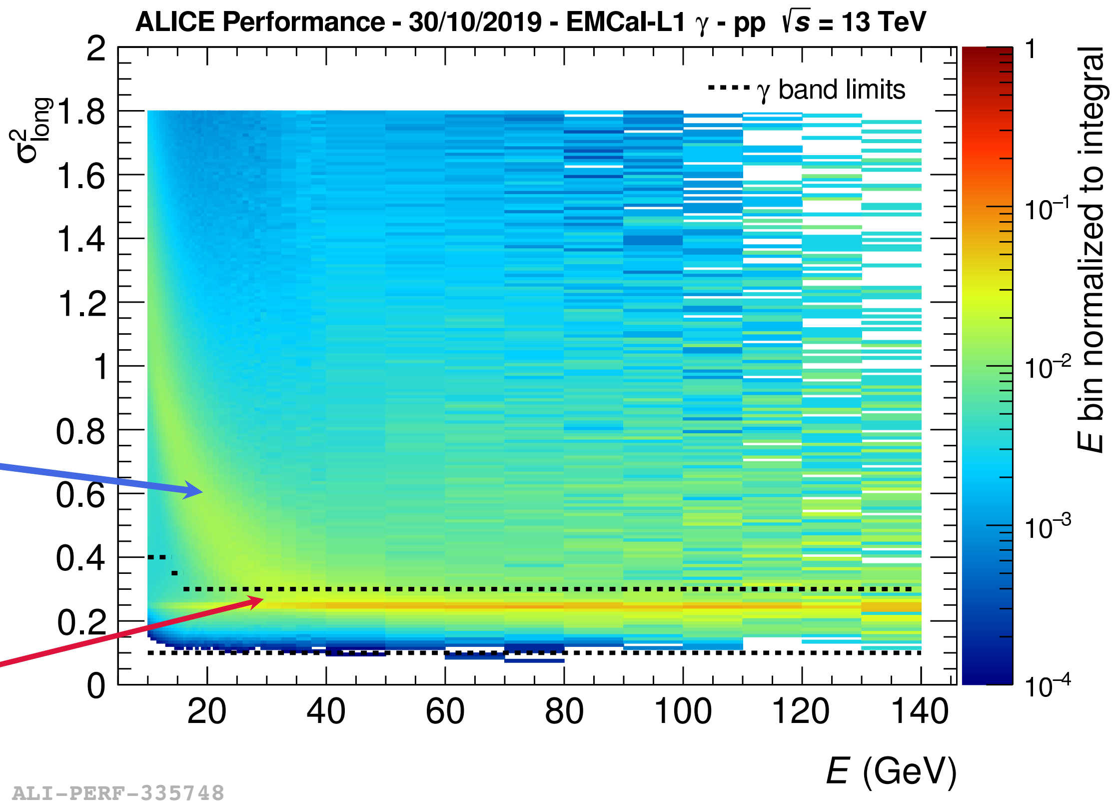


$\sigma^2_{long} > 0.4$

(wide cluster)

$0.1 < \sigma^2_{long} < 0.3$

(narrow cluster)

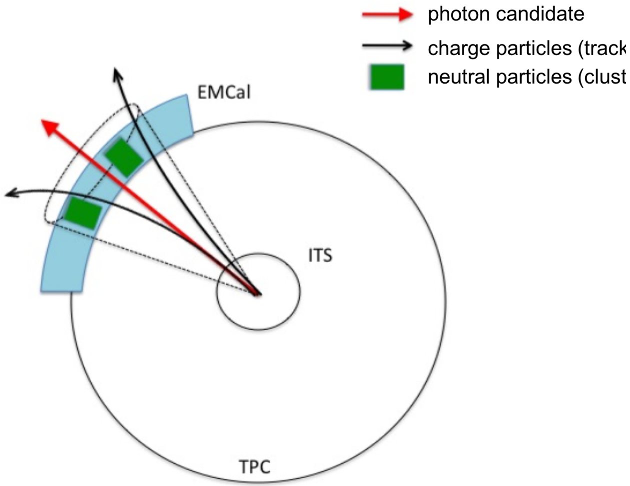


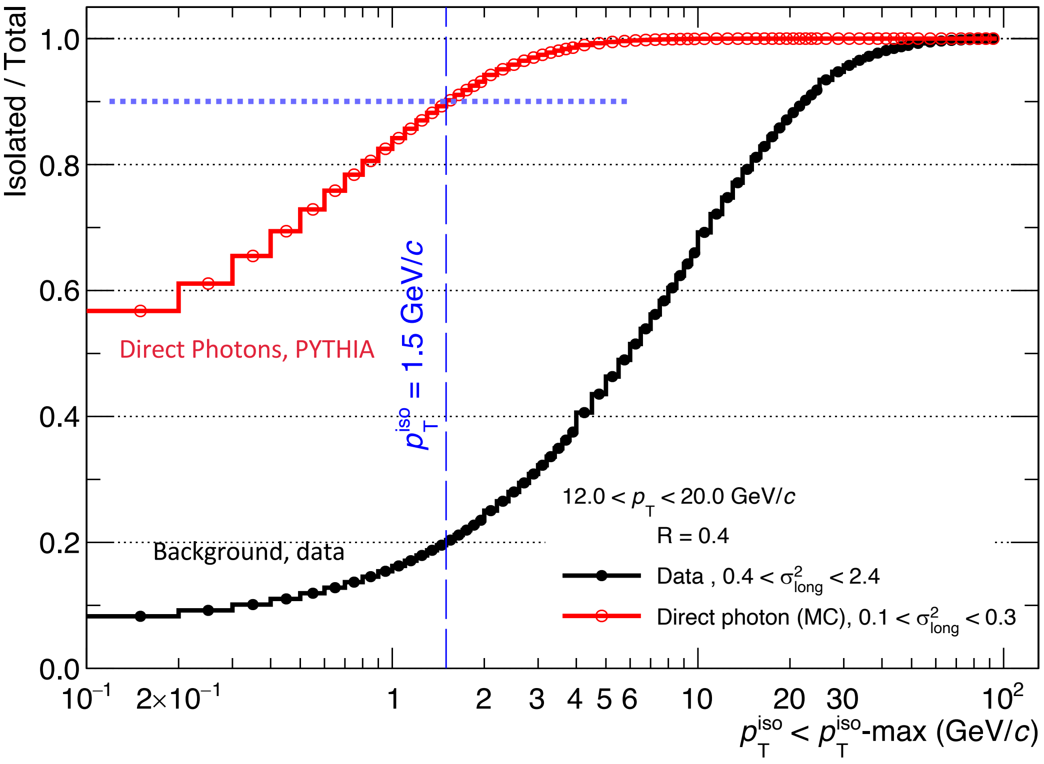
Photon isolation

- particle in cone: charged only
- isolation criteria:

$$\text{cone size } R = \sqrt{(\eta_i - \eta_\gamma)^2 + (\varphi_i - \varphi_\gamma)^2} = 0.4$$

$$p_T^{iso} \equiv \Sigma p_{T,track} < E_T^{th} = 1.5 \text{ GeV}/c$$





- π^0 are highly suppressed but yield still important
- **Purity needs to be estimated (more detail later)**

Isolated photons: purity estimation

Idea: divide clusters σ^2_{long} - isolation energy plane into 4 regions

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

Define N(total) = S(signal) + B(background)

- purity = S/N in A region

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

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

data-driven purity

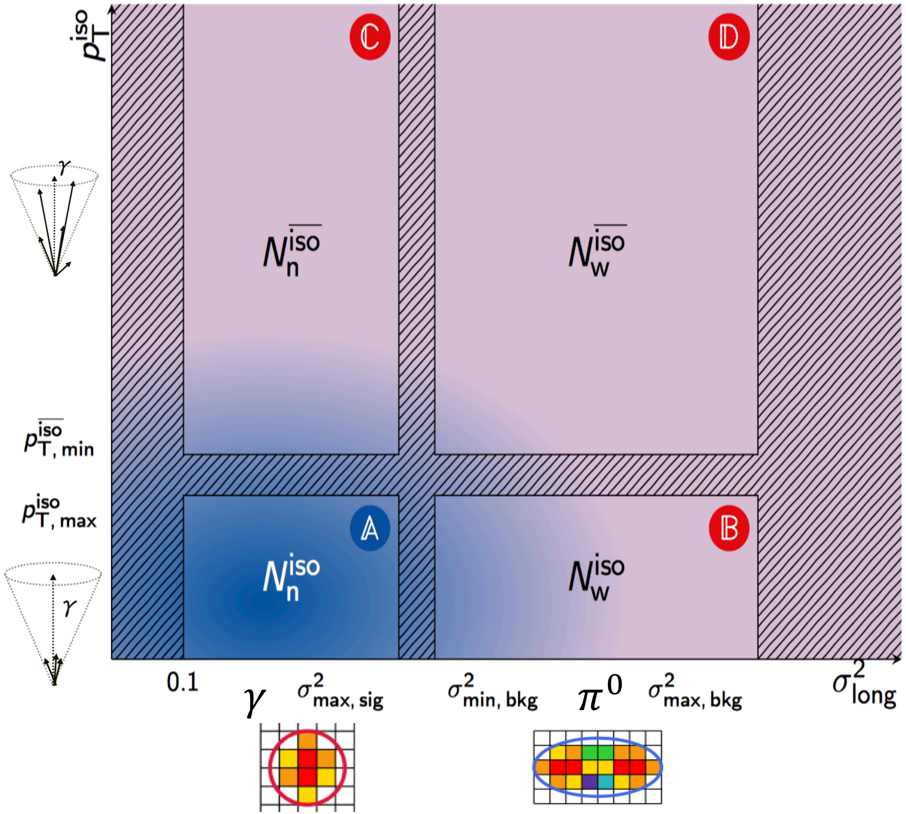
MC correction factor

Assume:

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

$B_A/B_C = B_B/B_D$

Unfortunately assumption not completely true



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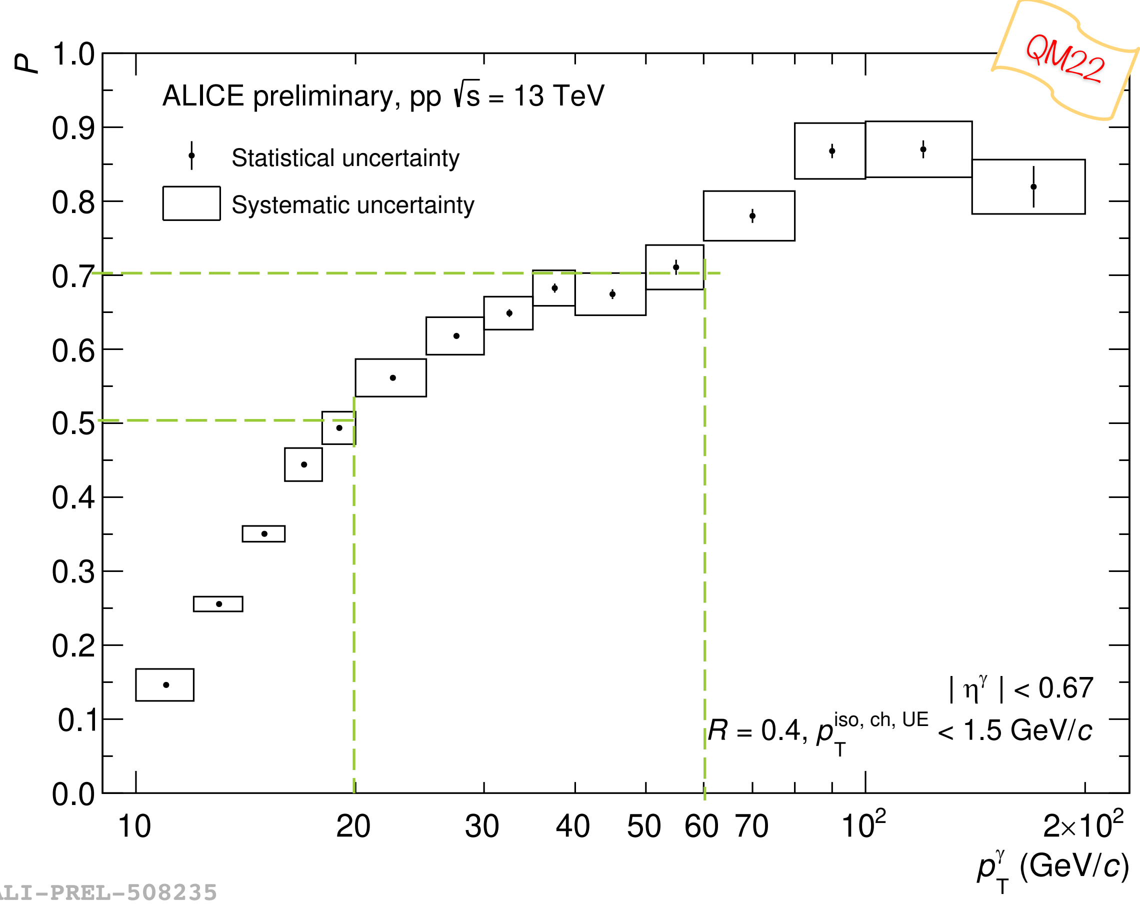
Isolated photons: purity



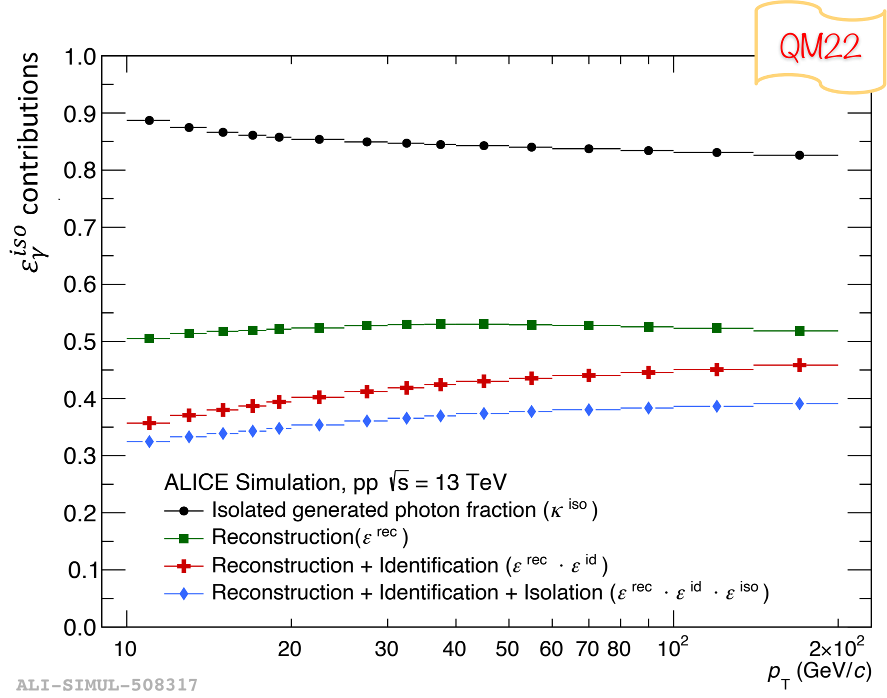
Charged isolation using ITS+TPC tracks

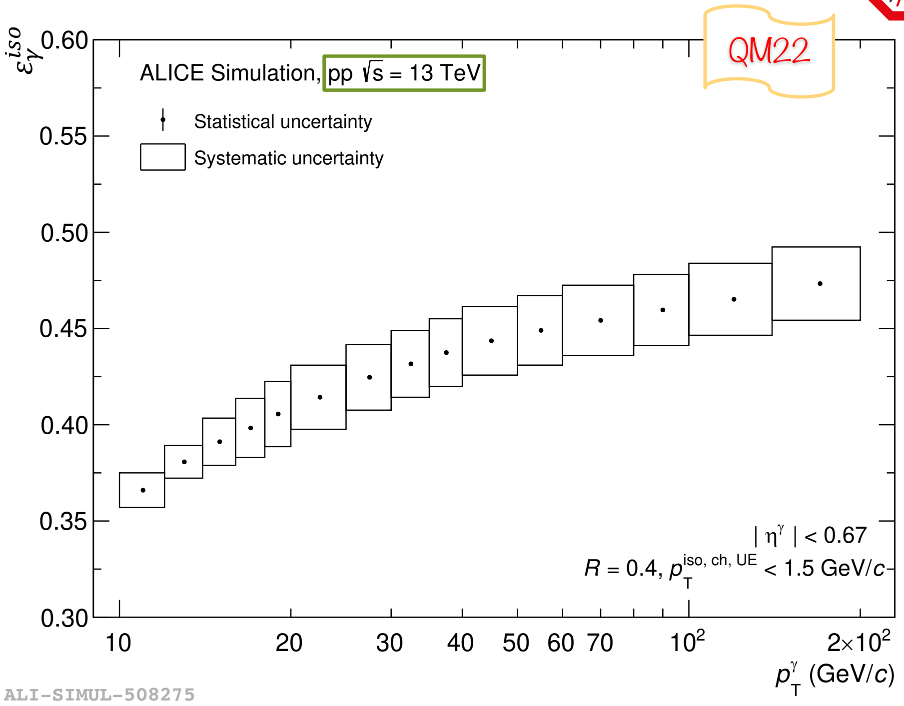
$R = 0.4$

$p_{T}^{iso,ch,UE} < 1.5\ \text{GeV}/c$

Purity up to 0.7 – 0.8

Isolated photons: efficiency





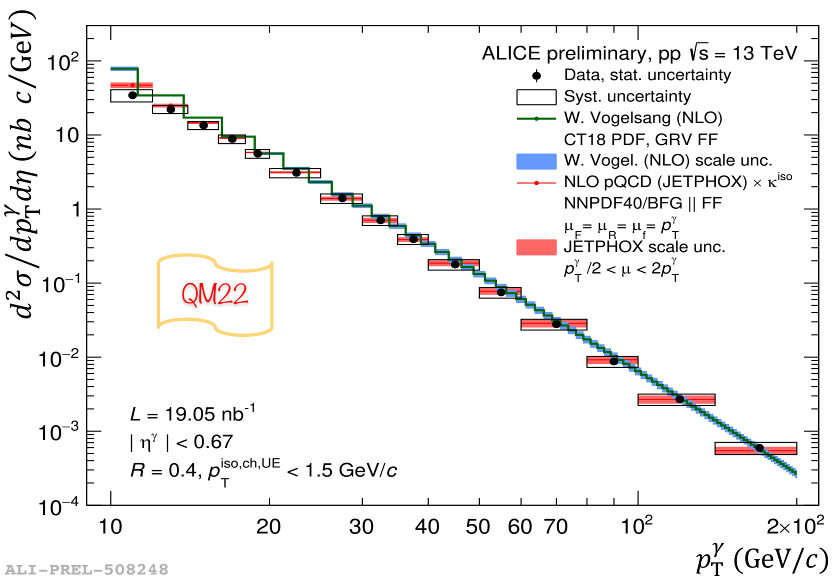
$$\varepsilon_{\gamma}^{iso}(p_T) = \frac{\varepsilon^{rec} \cdot \varepsilon^{id} \cdot \varepsilon^{iso}}{\kappa^{iso}}$$

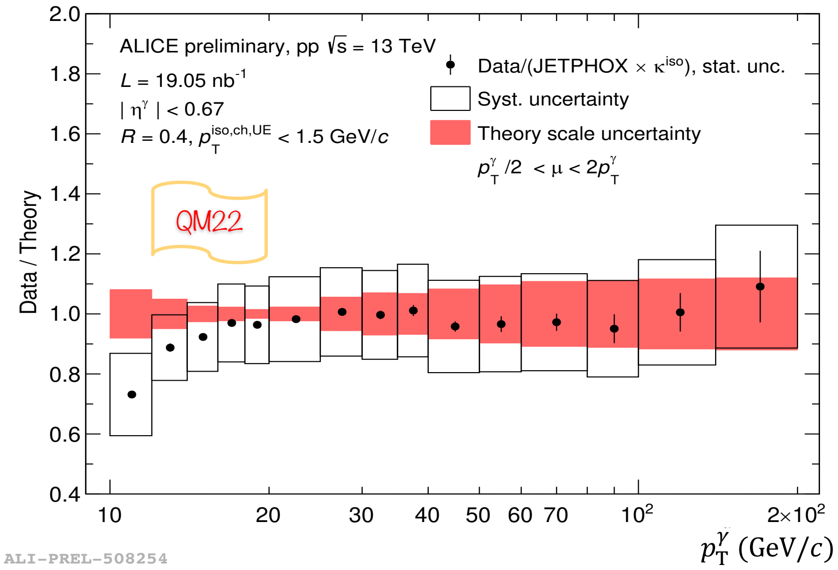
Identification – Shower shape cut ($0.1 < \sigma_{long}^2 < 0.3$)

Isolation – $R = 0.4$, $p_{\mathrm{T}}^{\mathrm{iso,ch,UE}} < 1.5$ GeV/c

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

Isolated photon cross section: measured compared to theory





Charged isolation using ITS+TPC tracks

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

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

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

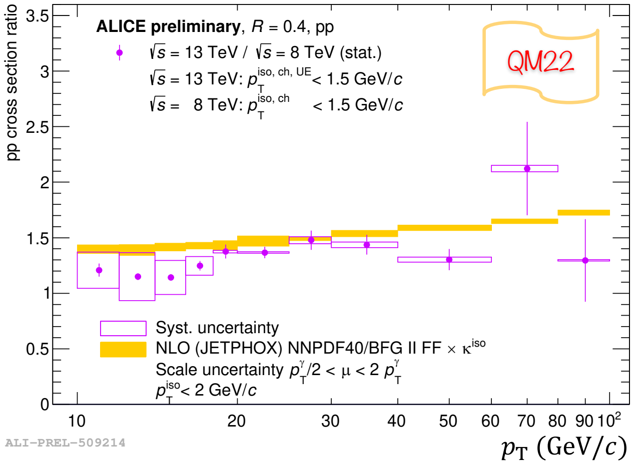
[3] JHEP10(2019)203
[4] Eur. Phys. J. C 79 (2019) 20

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

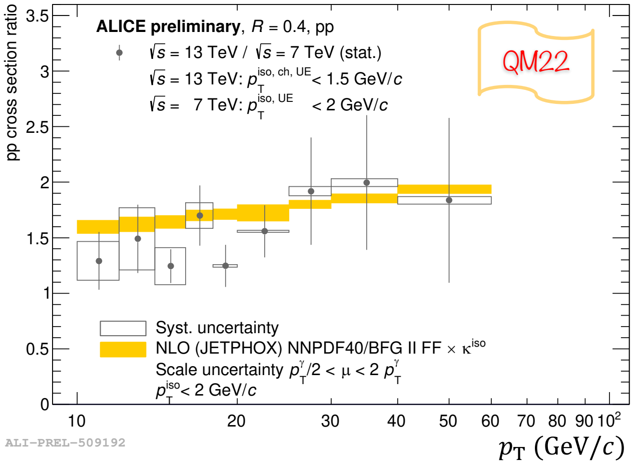
Isolated photon comparisons

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

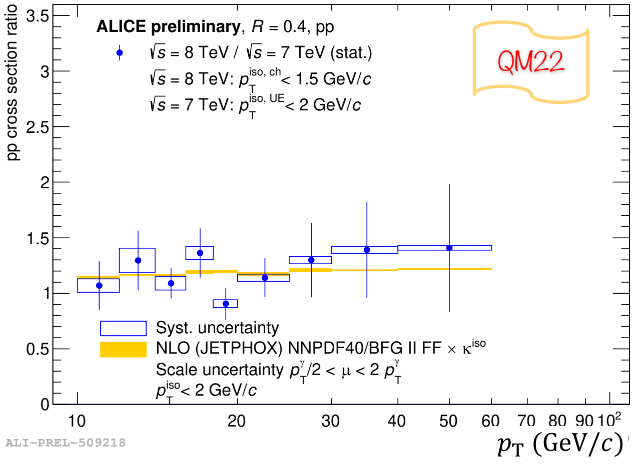
$\sqrt{s}$ = 13 TeV / $\sqrt{s}$ = 8 TeV



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



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

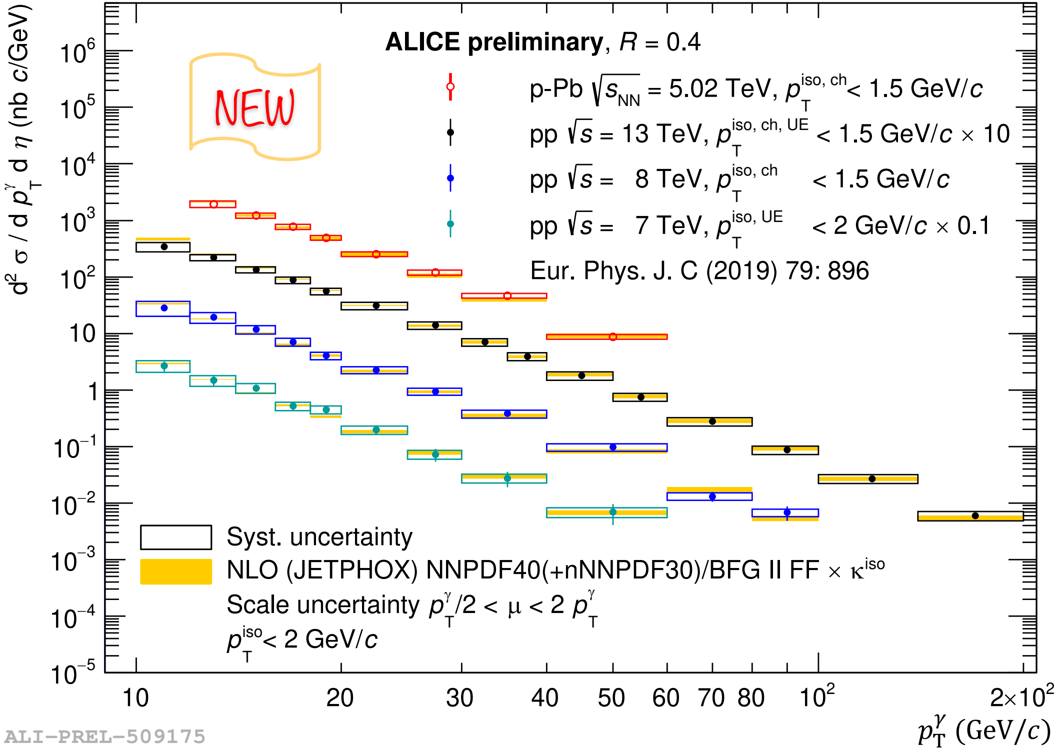


The data ratios are compared to NLO JETPHOX (NNPDF40/BFG II FF) calculations.

Reasonable agreement within uncertainties

Summary

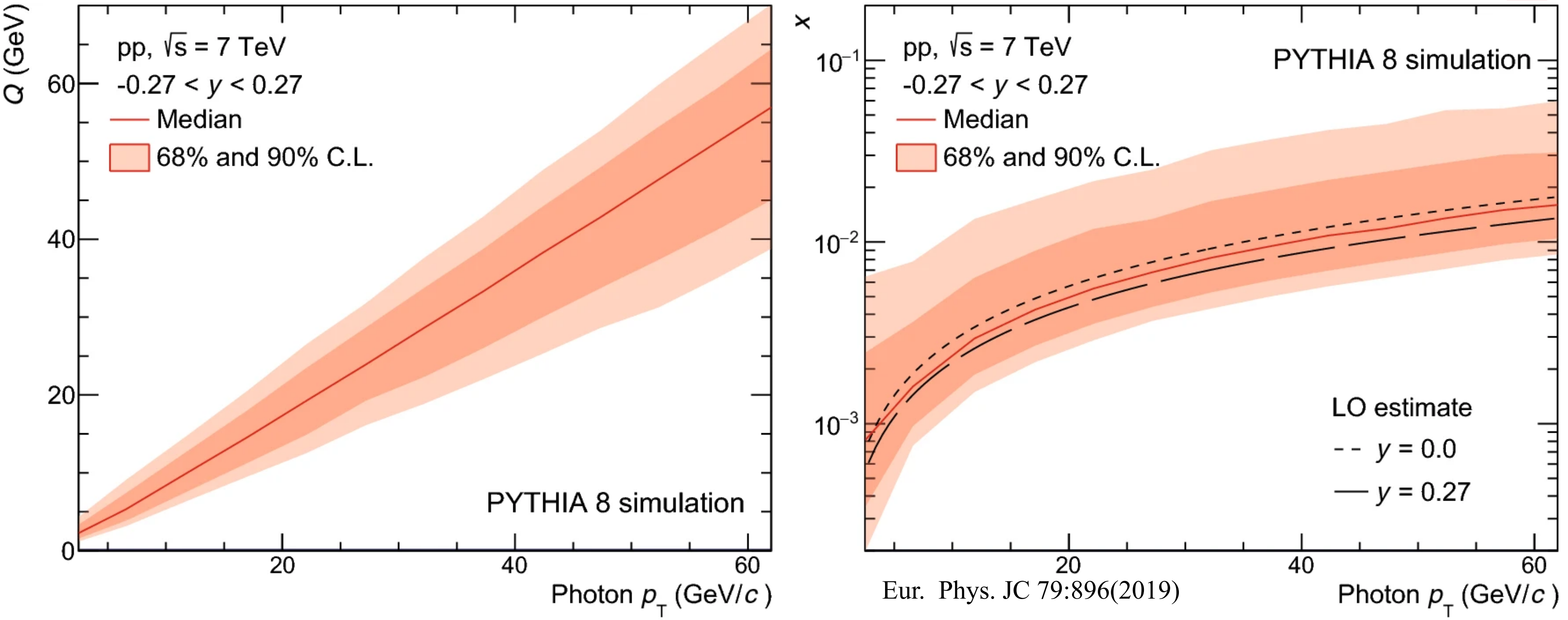
- Results are compatible with pQCD calculations.
- The analysis extends the p_T range to higher values compared to other ALICE measurements at lower $\sqrt{s}$
- ALICE extends the LHC measurements towards lower p_T^{γ} (10 – 12 GeV/c)
  $\rightarrow$ lower x_T



Thank you !!!

BACK UP

Scale Q and fraction x



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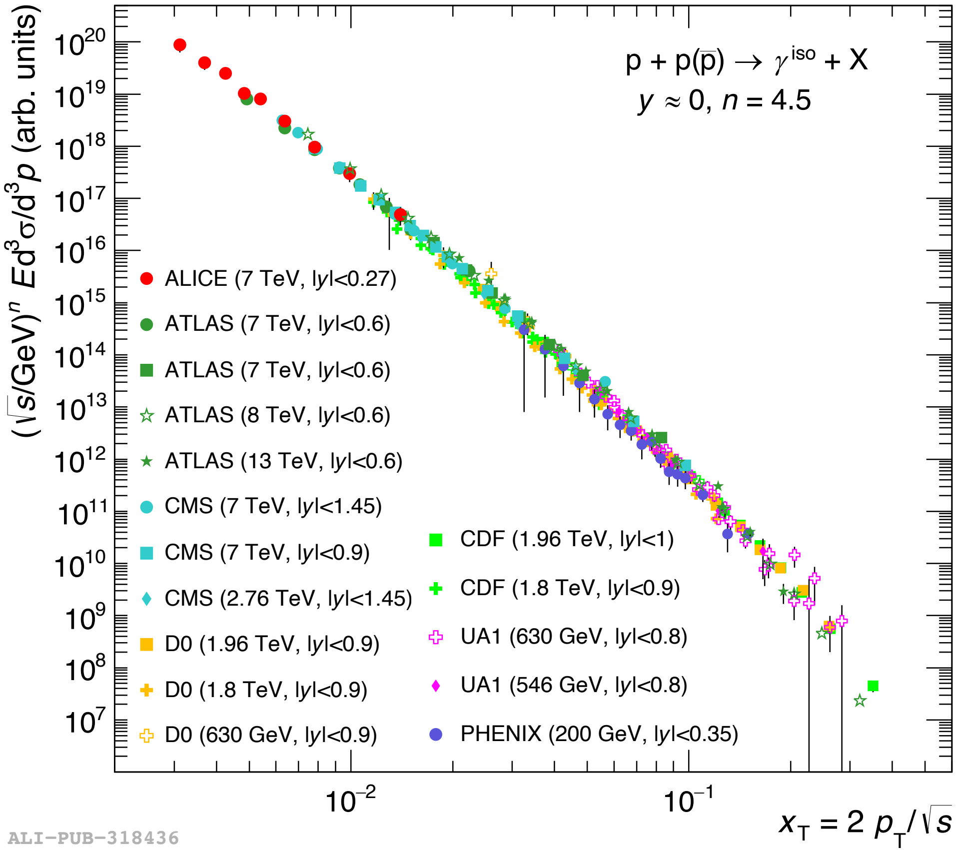
The scale Q (left), and the fraction x (right) of longitudinal momentum of the initial state partons of the hard process for photon production at mid-rapidity versus photon p_{T} for pp collisions at $\sqrt{s}$ =7 TeV

x_T



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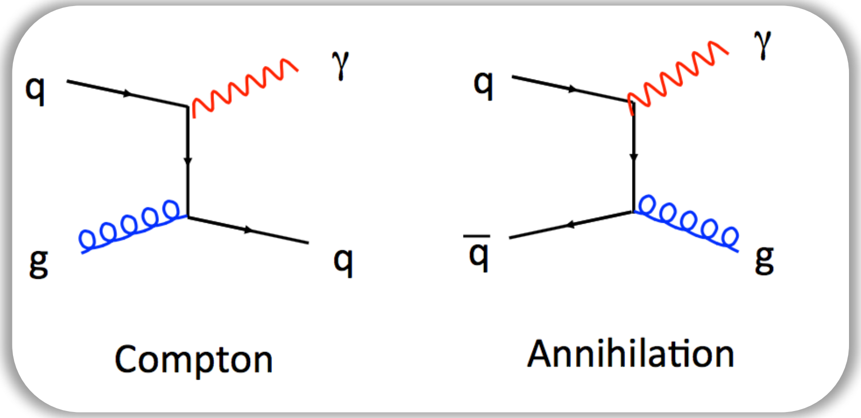
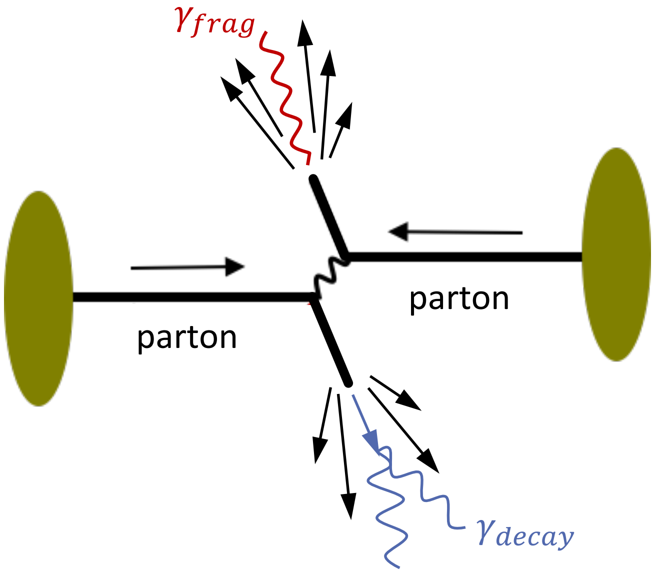
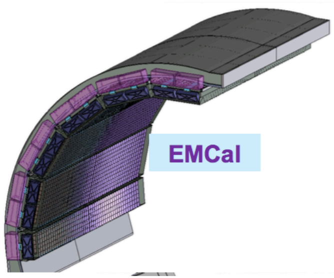
Photon sources in hadronic collisions

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

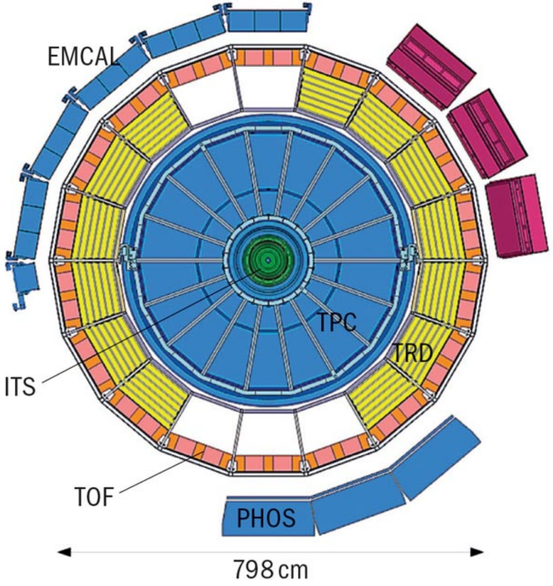


main objective

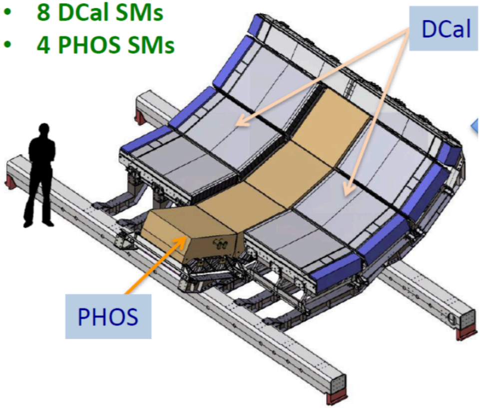




12 EMCal superr
8 DCal superm
4 PHOS module
1 CPV module

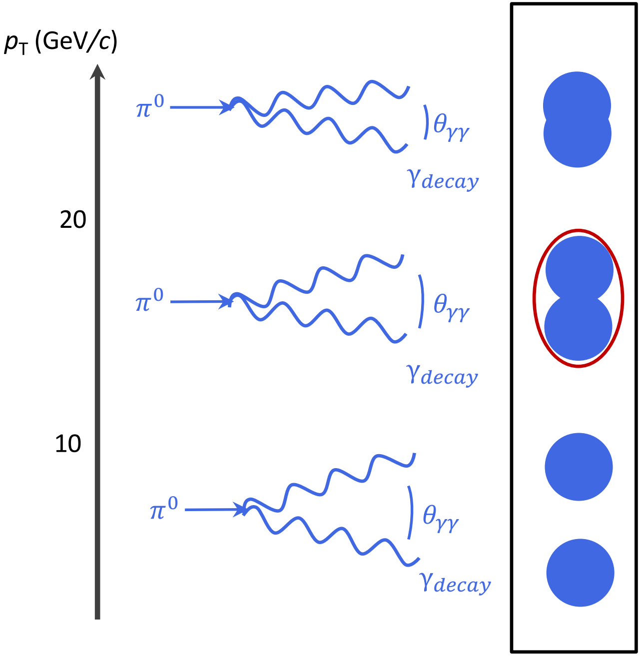


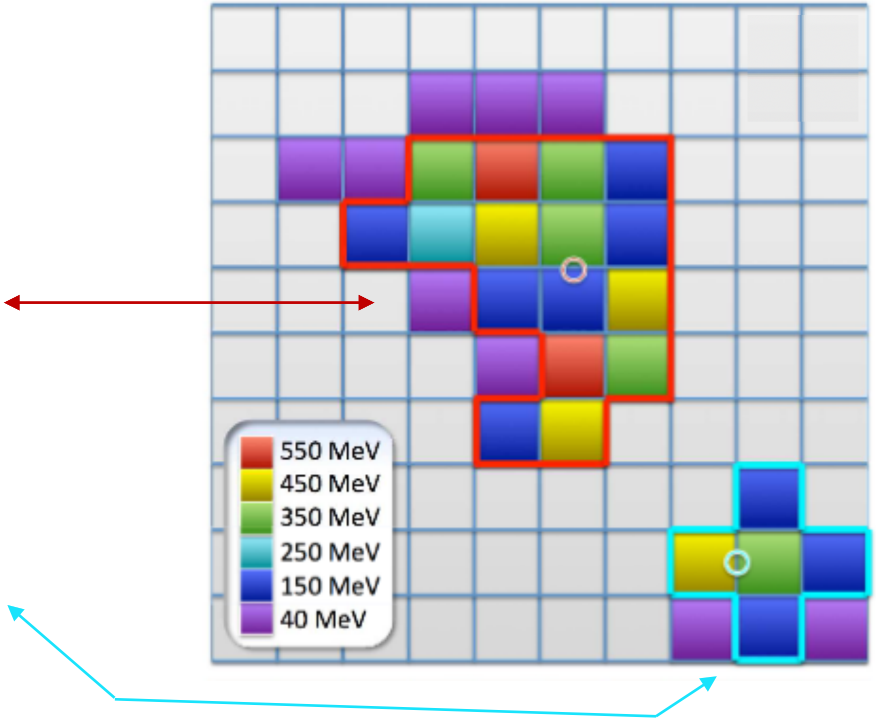
- 8 DCal SMs
- 4 PHOS SMs



Particle energy measurement in the calorimeter

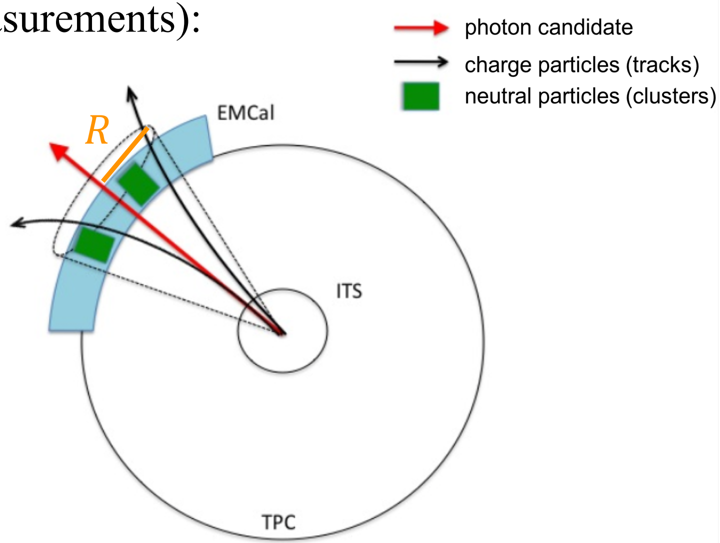
- EMCal measures photon energy deposited in several cells, a cluster.
- Energy spreads in a clusters differently for single γ and high energy π^0.





Photon isolation

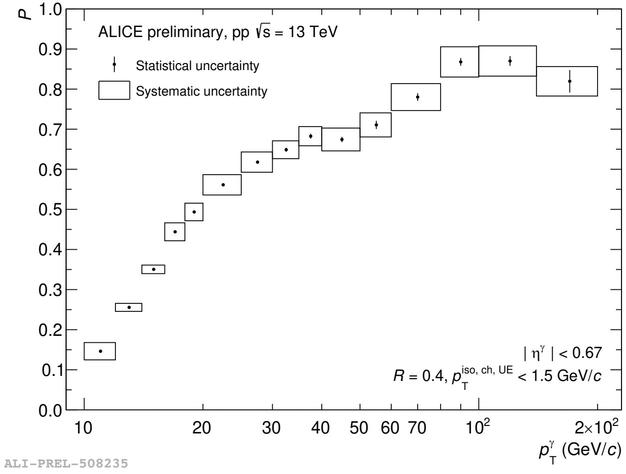
- Sum the p_{T} of particles (i) inside a cone of radius: $R = \sqrt{(\eta_i - \eta_\gamma)^2 + (\varphi_i - \varphi_\gamma)^2} = 0.4$
- Set an isolation threshold (conventions used in different measurements):
  - $p_T^{iso,\mathrm{UE}} = \Sigma p_{\mathrm{T}}^{cluster} + \Sigma p_{\mathrm{T}}^{track} < 2\ \mathrm{GeV}/c$
  - $p_T^{iso,\mathrm{ch,UE}} = \Sigma p_{\mathrm{T}}^{track} < 1.5\ \mathrm{GeV}/c$
  - $p_T^{iso,ch} = \Sigma p_{\mathrm{T}}^{track} - \mathrm{UE}(\rho_{\mathrm{UE}} \pi R^2) < 1.5\ \mathrm{GeV}/c$

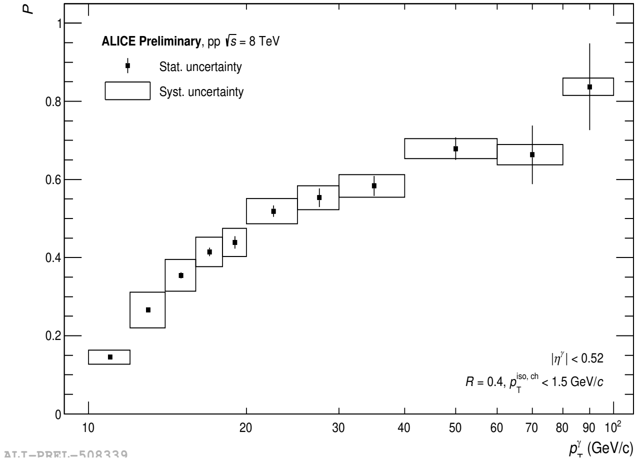


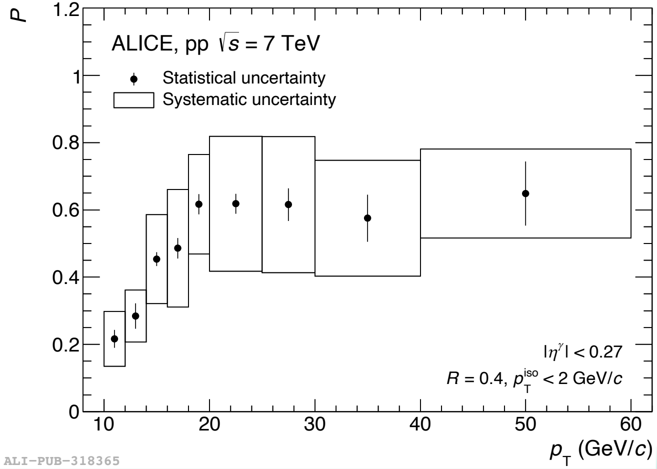
✢ Underlying event (UE) density (ρ_{UE}) estimation:

- Using perpendicular cone method in pp at $\sqrt{s} = 8$ TeV
  - For a given cluster with position (η, φ), rotate cone by $\pm 90°$ 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 $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV

Purity in pp collisions



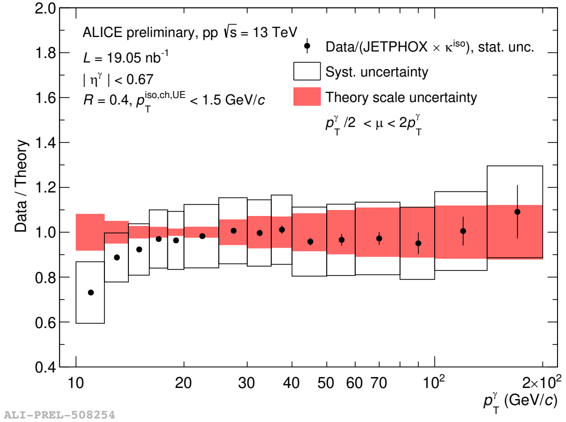


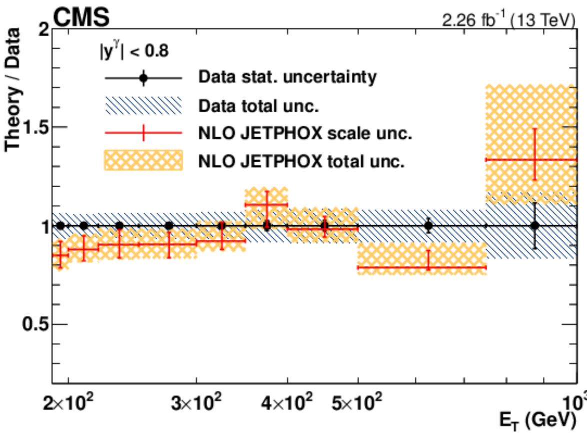


$\sqrt{s}$ (TeV)	Particle in cone	p_{T}^{iso} (GeV/c)
13	Charged only	1.5
8	Charged only	1.5
7	Charge + neutral	2.0

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

Isolated photon comparison, to other experiments





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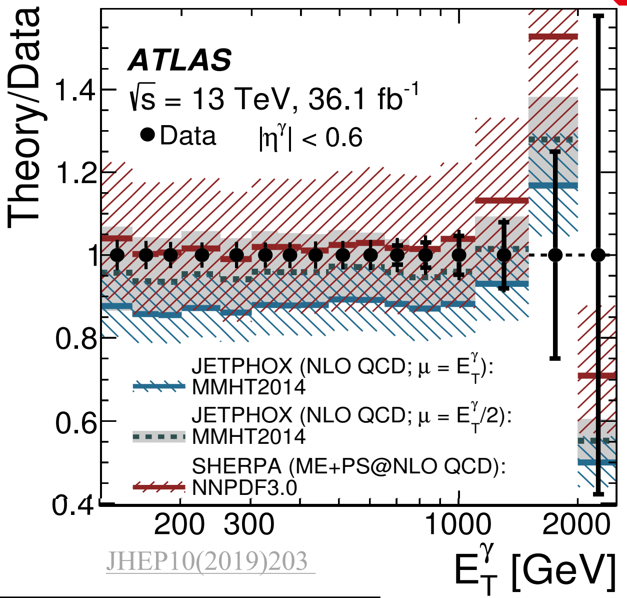


JHEP10(2019)203

The ALICE measurement extends to lower $p_{\rm T}$ range compared to ATLAS and CMS measurements

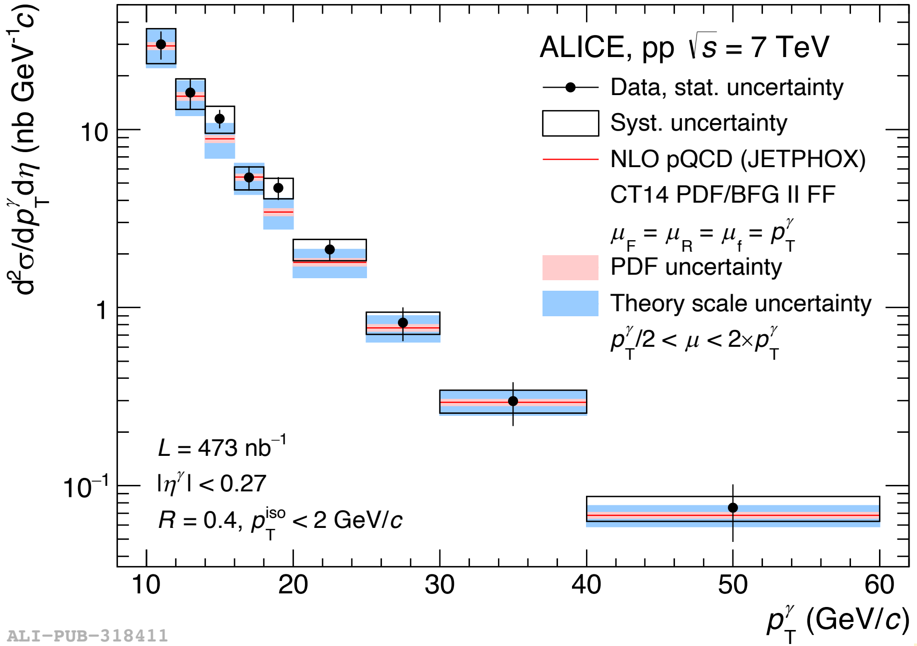
collaboration	$\sqrt{s}$ (TeV)	$p_{\rm T}$ range (GeV/c)
ALICE		**$10 < p_{\rm T} < 200$**
ATLAS	13	$125 < p_{\rm T} < 2000$
CMS		$190 < p_{\rm T} < 1000$

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

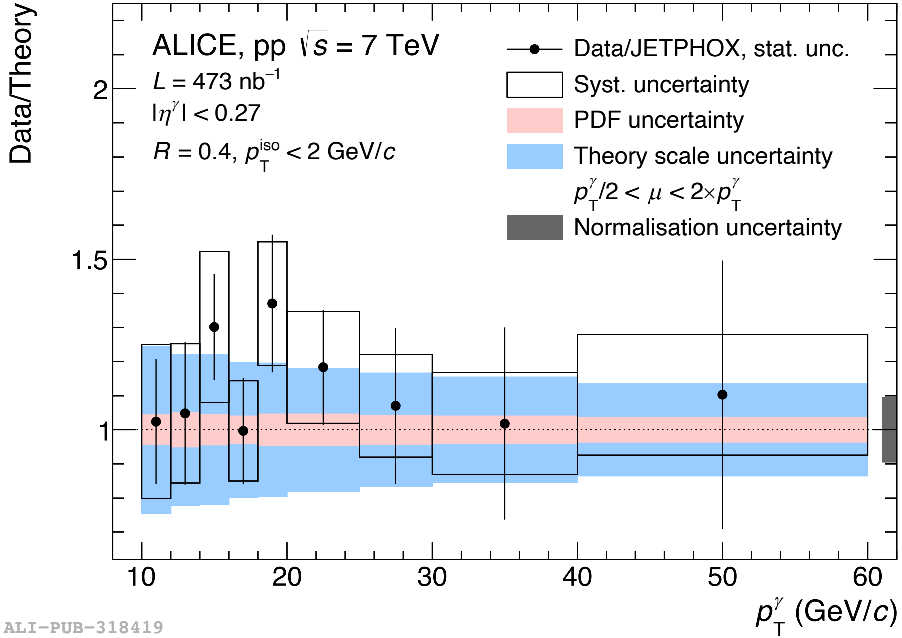
ALICE Collaboration: Eur. Phys. JC 79:896(2019)
JETPHOX 1.3.1 (JHEP 0205. (2002) 028, Phys. Rev.D 73 (2006) 094007)
PDF, CT14 (Phys, Rev. D 93 (2016), 033006)

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

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



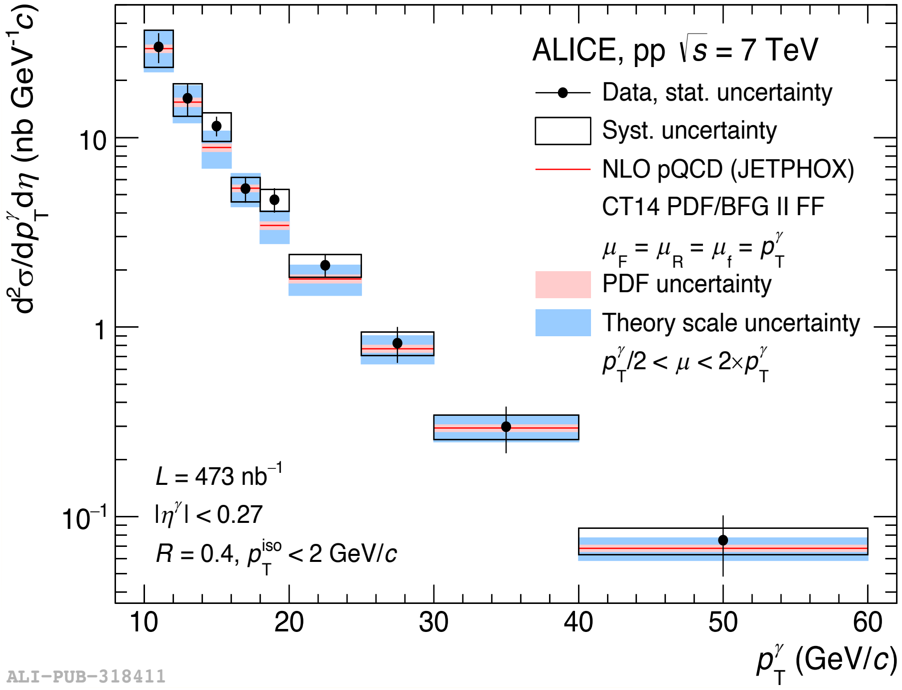
ALI-PUB-318411

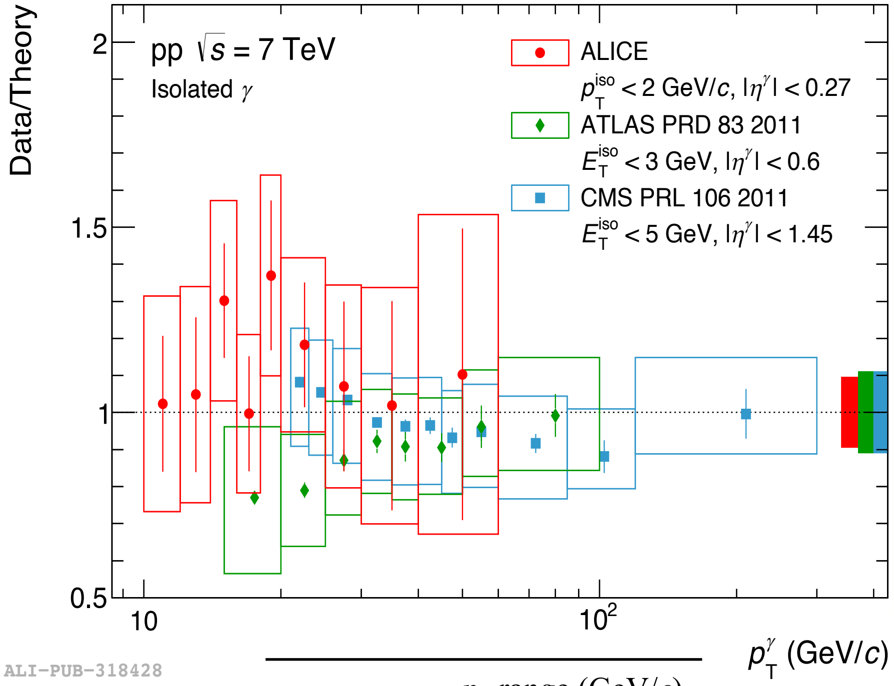


ALI-PUB-318419

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

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

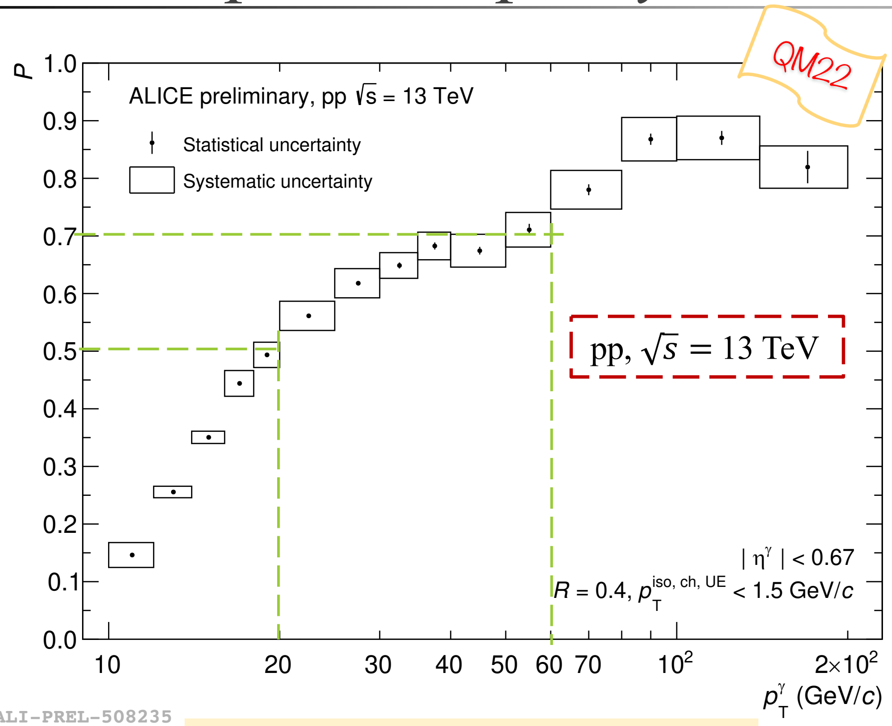


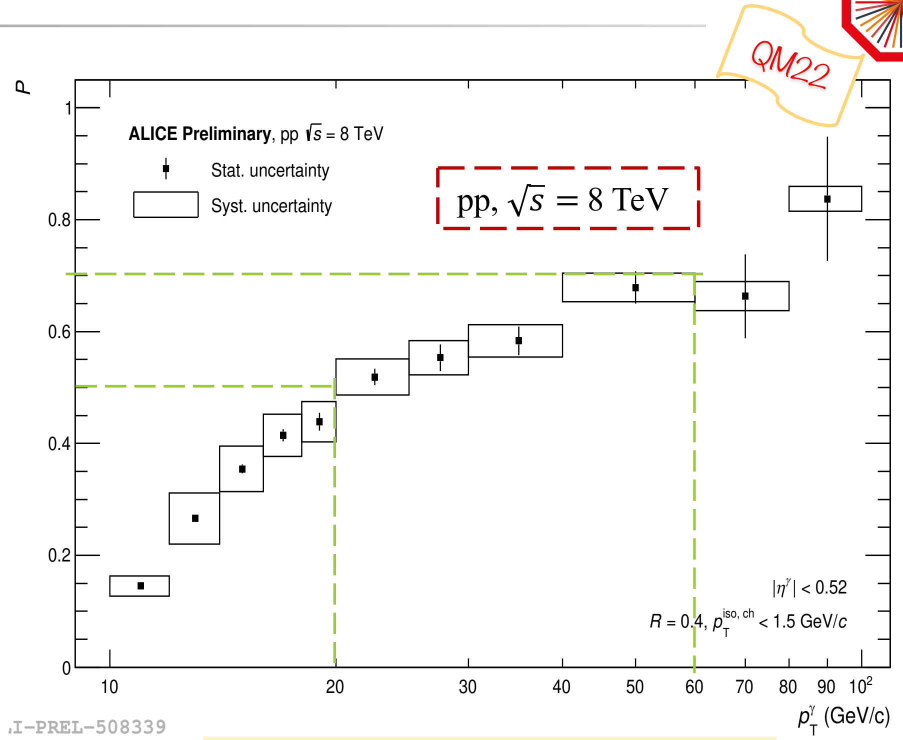


	p_T range (GeV/c)
ALICE	**$10 < p_T < 60$**
ATLAS	$15 < p_T < 100$
CMS	$21 < p_T < 140$

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

Isolated photons: purity





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

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

Purity up to 0.7 – 0.8 reached in both $\sqrt{s}$ and quite similar