Measurement of isolated photon cross section in pp collisions at $\sqrt{s} = 13$ TeV with ALICE at the LHC

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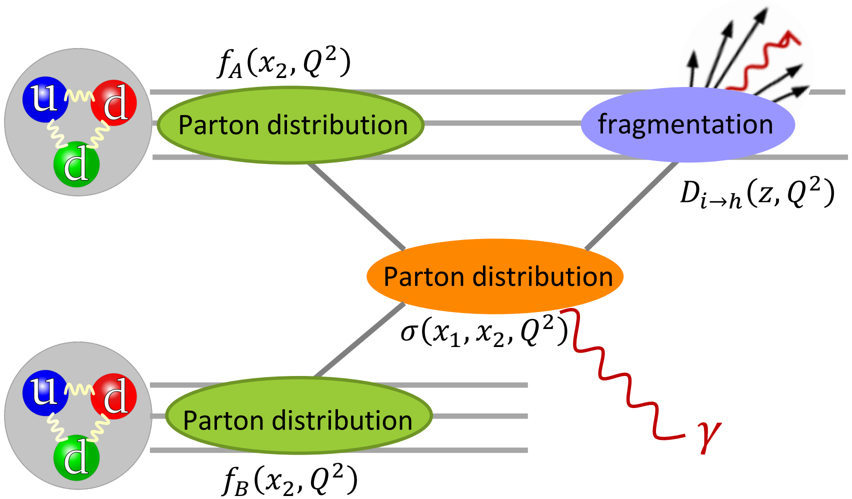
QCD factorisation theorem

QCD is the theory that describes the interaction between quarks and gluons (partons)

Proton-proton (pp) collisions at the LHC:

high energy parton interactions

- High Q^2
- Production of direct photons, $W^{\pm}$, Z and jets



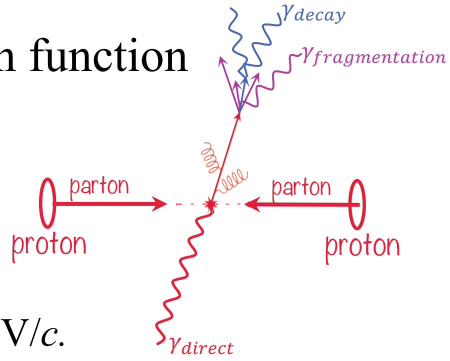
Perturbative QCD is applicable:

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

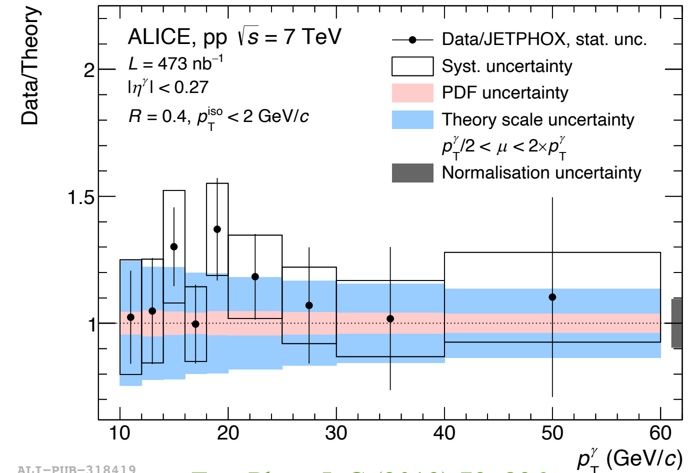
Parton Distribution Function (PDF) — QCD — Fragmentation Function

Motivation

- Test perturbative QCD predictions and constrain parton distribution function (PDF), in particular for gluons.



- Reference for measurements in heavy-ion collisions.
  - → Nuclear modification factor, photon hadron correlation as low as 10 -- 20 GeV/c.
- 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.



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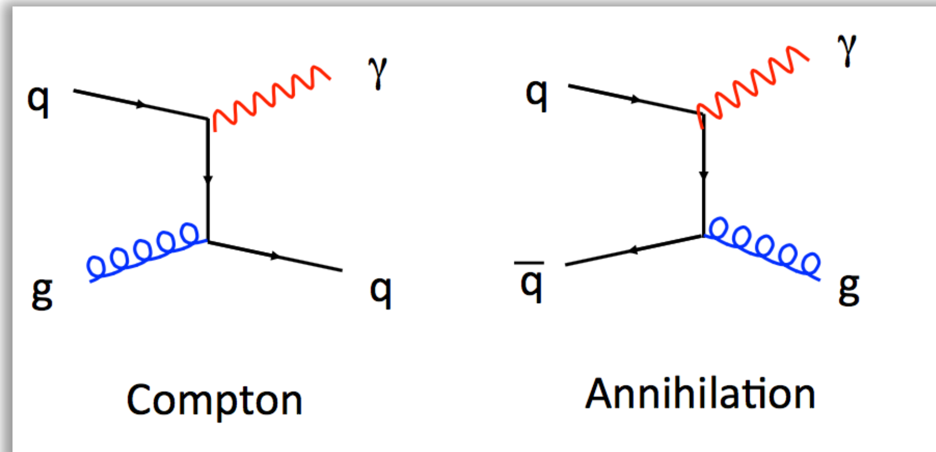
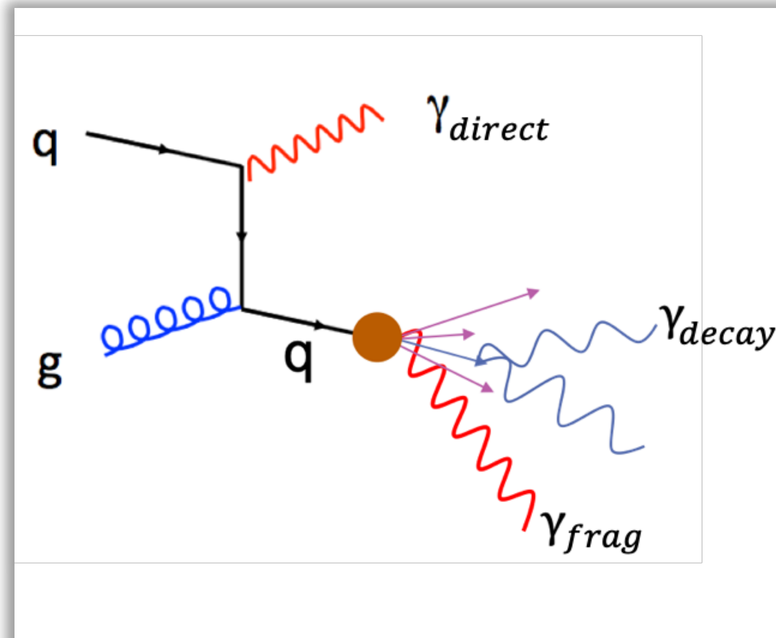
Photon sources in pp collisions

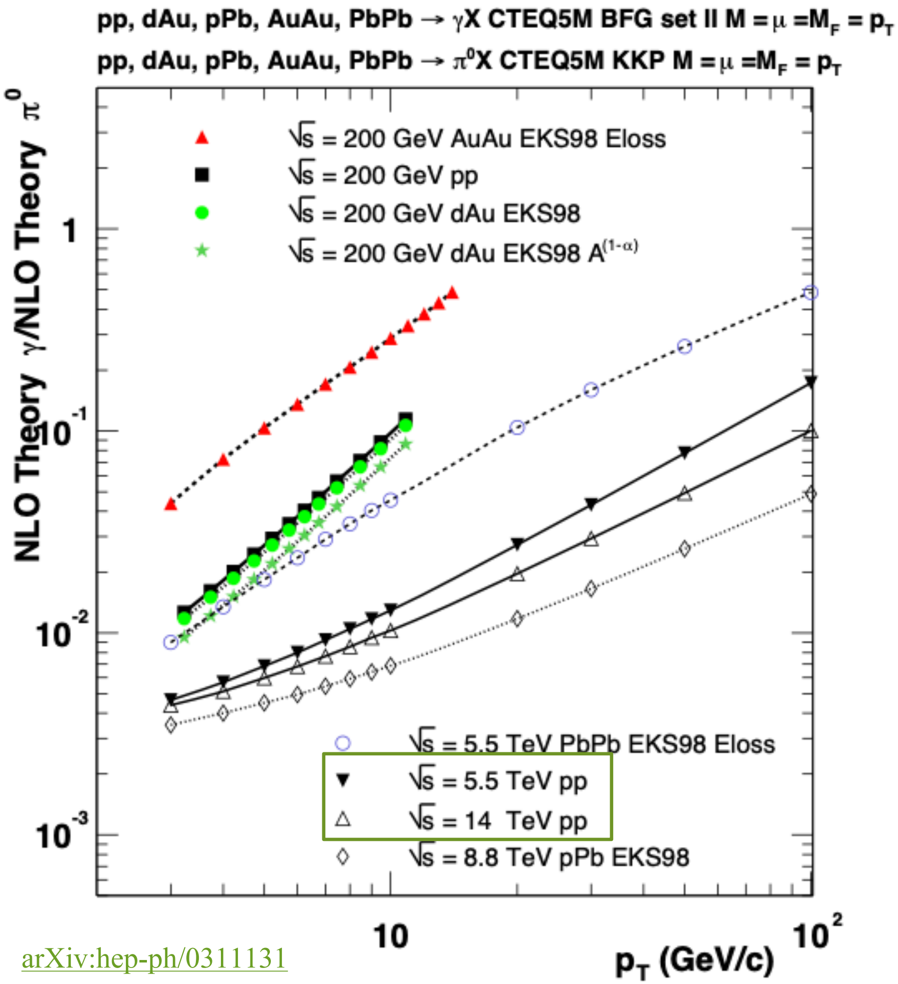
$$\gamma_{inclusive} = \underbrace{\gamma_{LO} + \gamma_{frag}}_{\gamma_{direct}} + \underbrace{\gamma_{decay}}_{\text{from } \pi^0, \eta \text{ ... decay}}$$



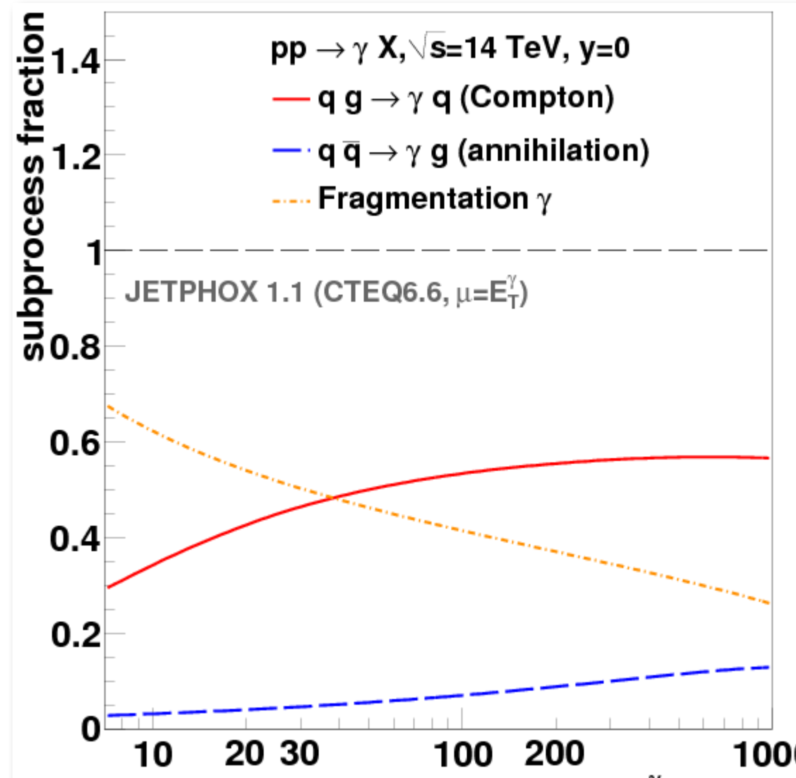
main object of my analysis



Comparison of direct photon yield to other photon sources



arXiv:hep-ph/0311131



arXiv:1005.4529

Main photon source comes from π^0, especially at low p_T. Fragmentation photons are comparable.

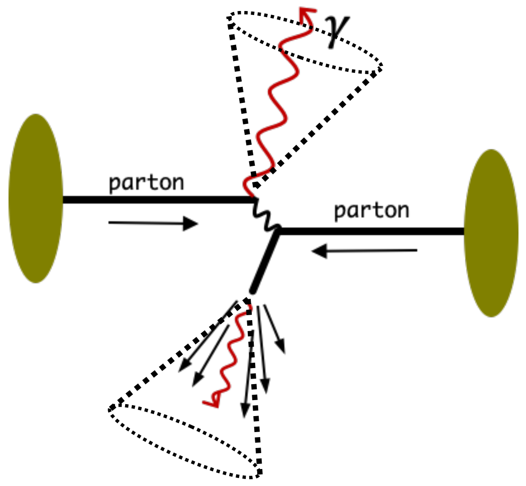
Direct photons at LO: isolated

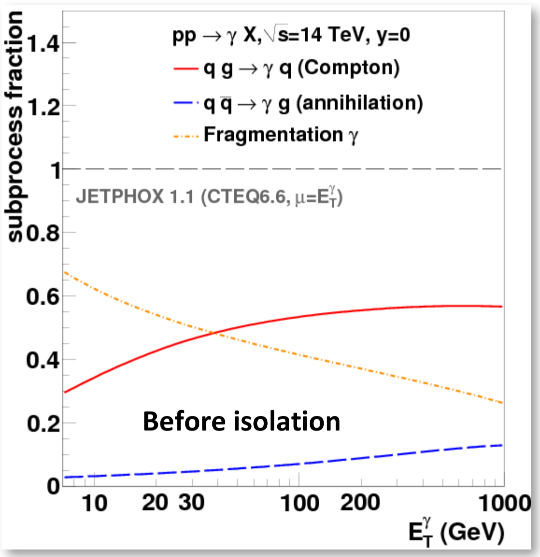
Direct photon from compton and annihilation hard processes

- no hadronic activity around

Decay and fragmentation photons from parton fragmentation

- accompanied by many other hadrons





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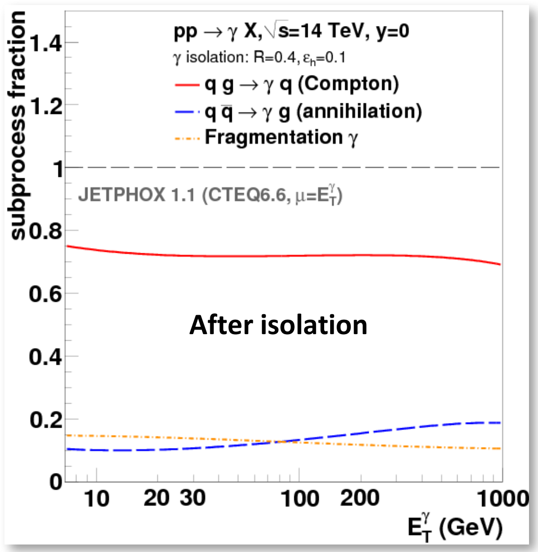


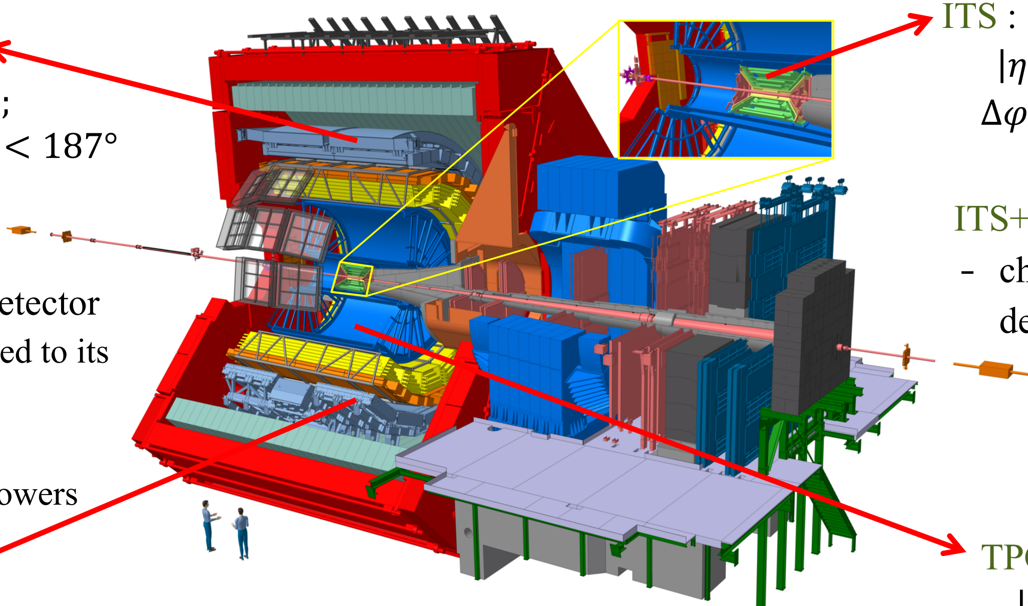
arXiv:1005.4529

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

How to measure direct photons in ALICE

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

EMCal/DCal:
- γ/jet triggers detector
- LPSC contributed to its construction
- Composed of Pb/scintillator towers



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

- High p_{T} photons used in the analysis are measured with the EMCal and DCal.
- Isolation method use information on the ITS and TPC trackers

Analysis flow

photon identification

↓

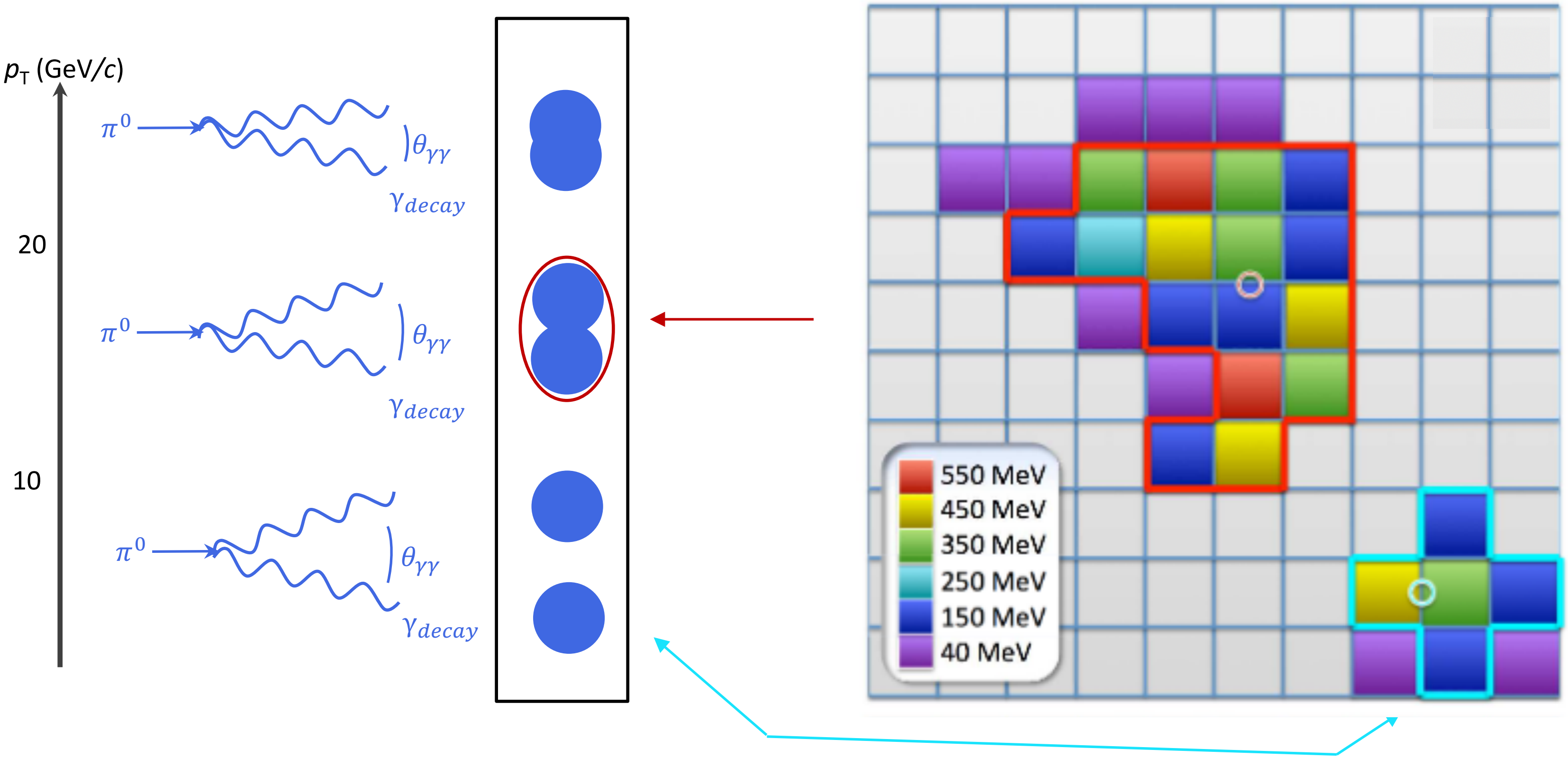
photon isolation

↓

cross section

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 identification

Raw EMCal clusters

→ Track match veto: reject electron and charge hadrons via angular correlation with TPC tracks

Neutral EMCal clusters

→ Shower shape selection

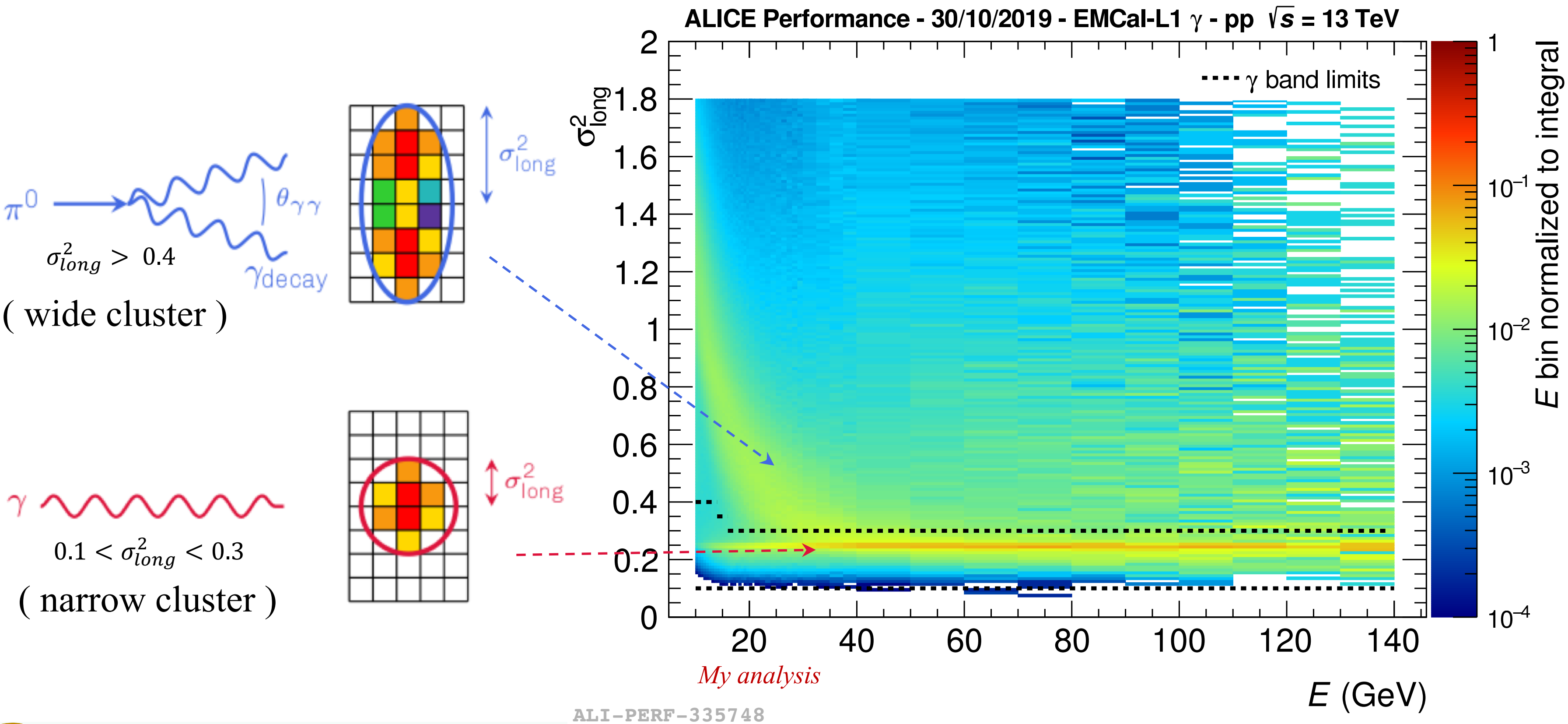
Photon candidates

γ/π^0 separation in calorimeter

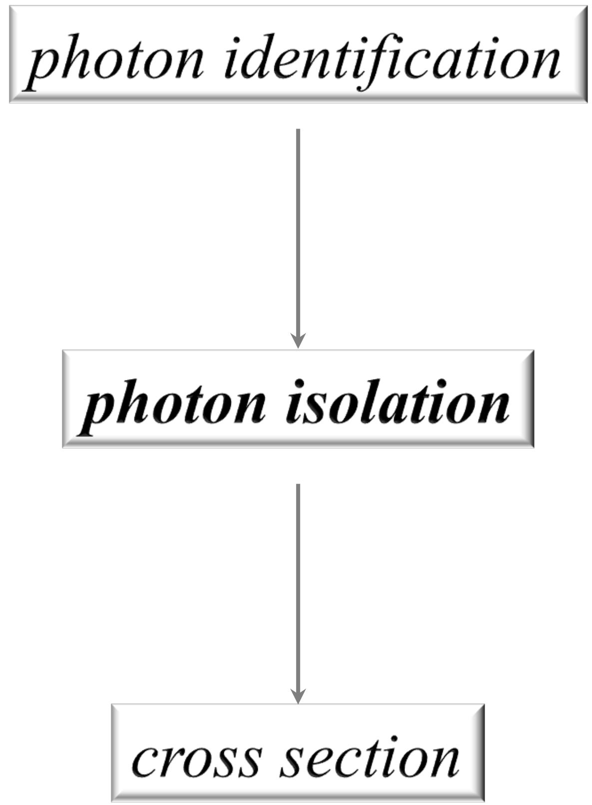
Cluster elongation described by $\sigma^2_{\rm long}$:

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

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



Analysis flow

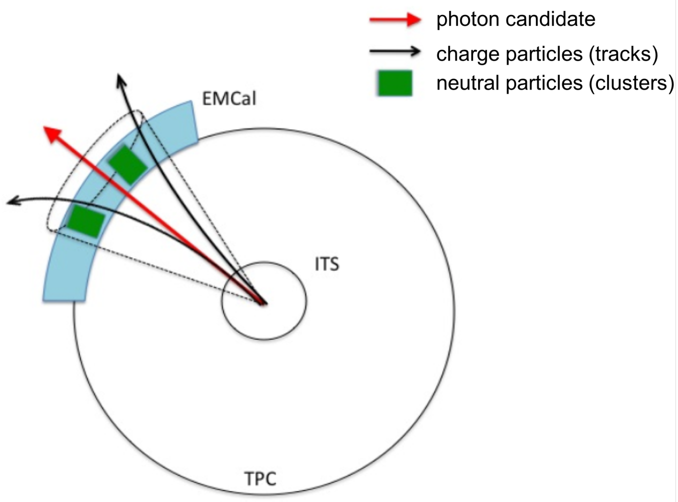


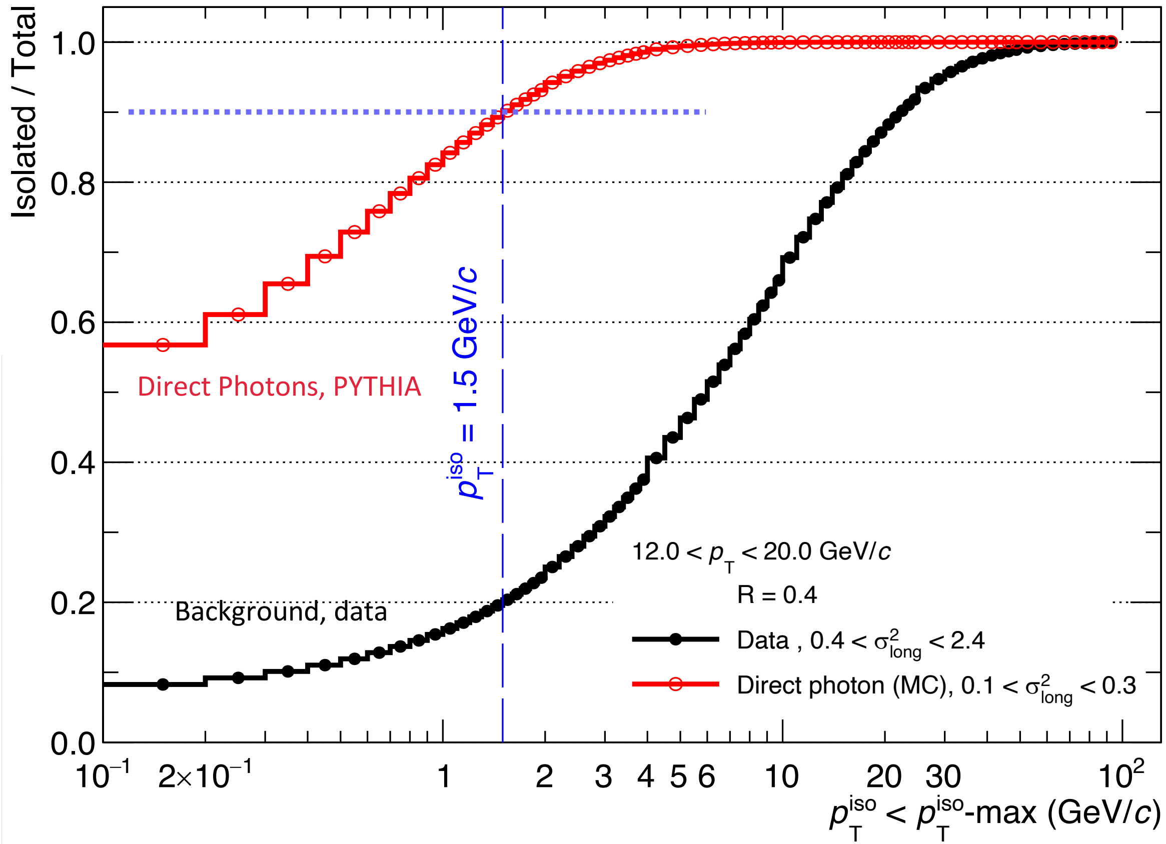
Photon isolation

- 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)**

Analysis flow

photon identification

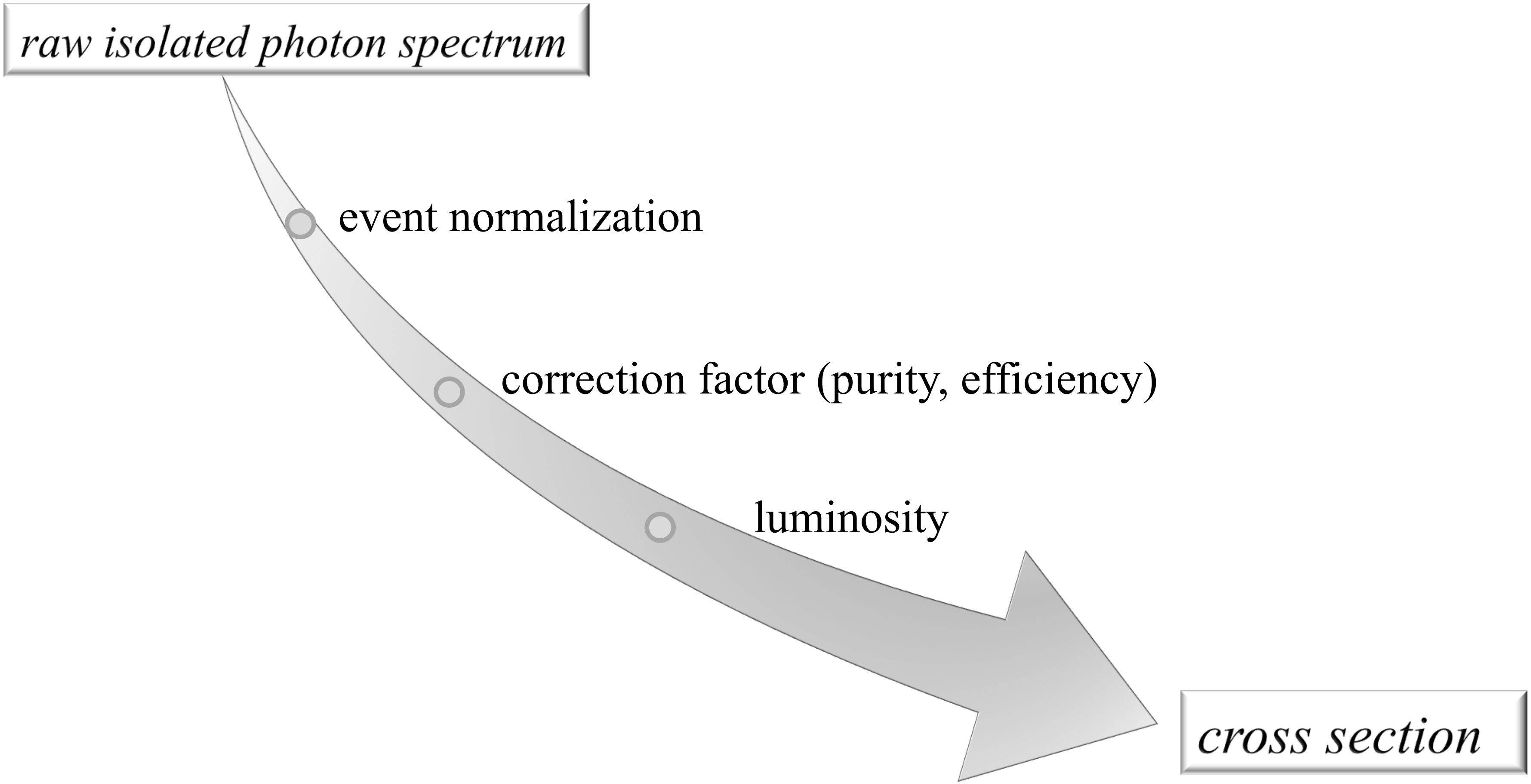
↓

photon isolation

↓

cross section

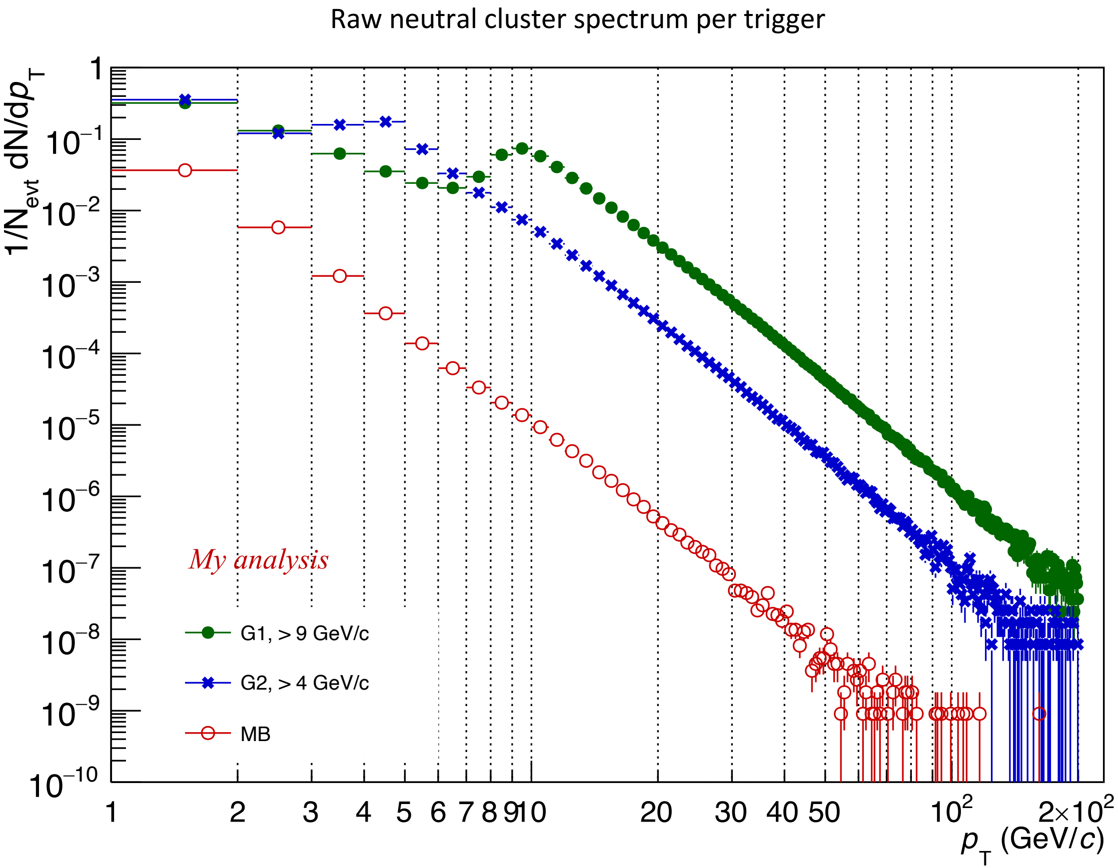
Analysis flow



Calorimeter trigger

- Minimum bias (MB): reach ~60 GeV/c
- Hardware trigger in EMCal
  - G1: E > 9 GeV/c
  - G2: E > 4 GeV/c

More info, here (O. Bourrion ect, arXiv:1210.8078v2)
LPSC involvement on L1 trigger development



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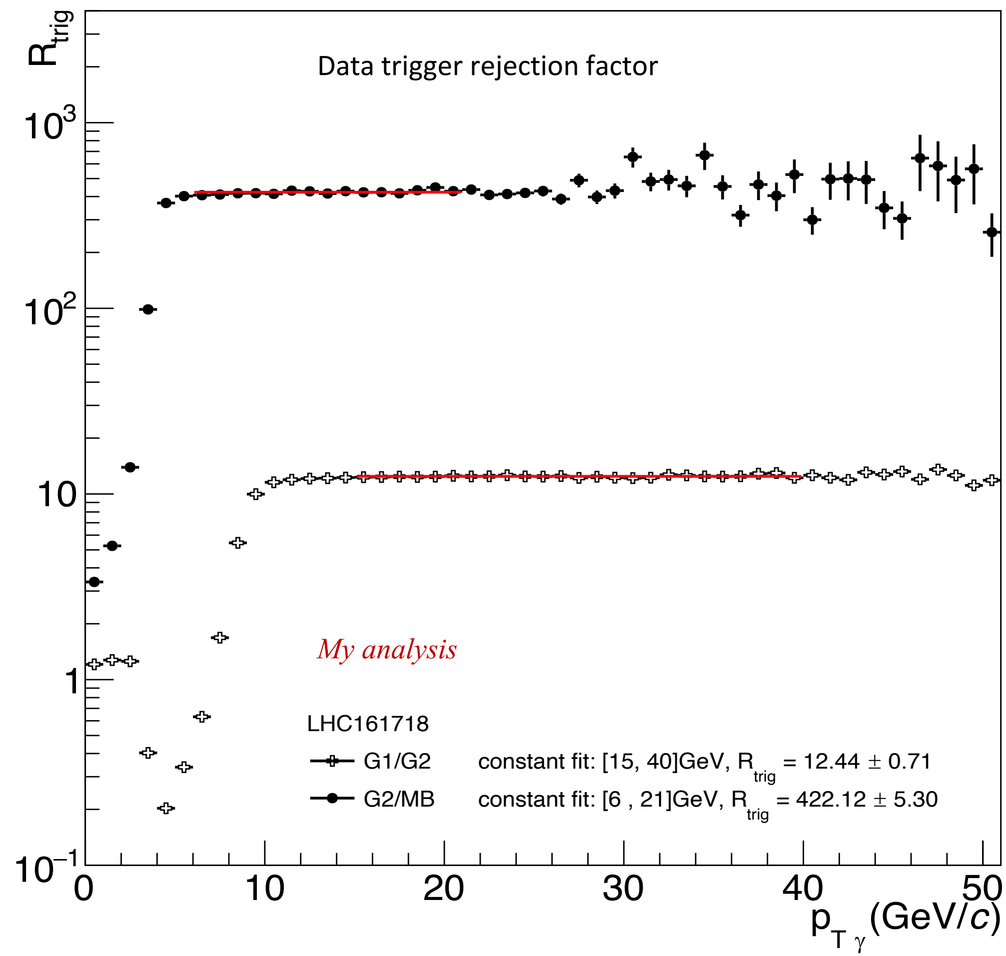
LPSC involvement on L1 trigger development

- Trigger enhancement factor:

$$RF = \left(\frac{1}{N_{evt}}\frac{dN}{dp_{\mathrm{T}}}\right)_{trigger} \Big/ \left(\frac{1}{N_{evt}}\frac{dN}{dp_{\mathrm{T}}}\right)_{MB}$$

$\Rightarrow$ 1 event in triggered = RF events in MB

trigger	G1	G2	MB
NO. of event	81.4M	115.6M	1103.8M
luminosity	7382 nb^{-1}	843 nb^{-1}	19 nb^{-1}
Enhancement factor	**5251**	**422.12**	**1**



Uncorrected isolated photon spectrum normalization and combination

- Combined raw spectrum calculated as:

$$\frac{1}{N_{evt}}\frac{d^2N}{dp_T d\eta} = \frac{1}{\sum(N_{evt,i} \times RF_i)}\sum\frac{dN}{dp_T}$$

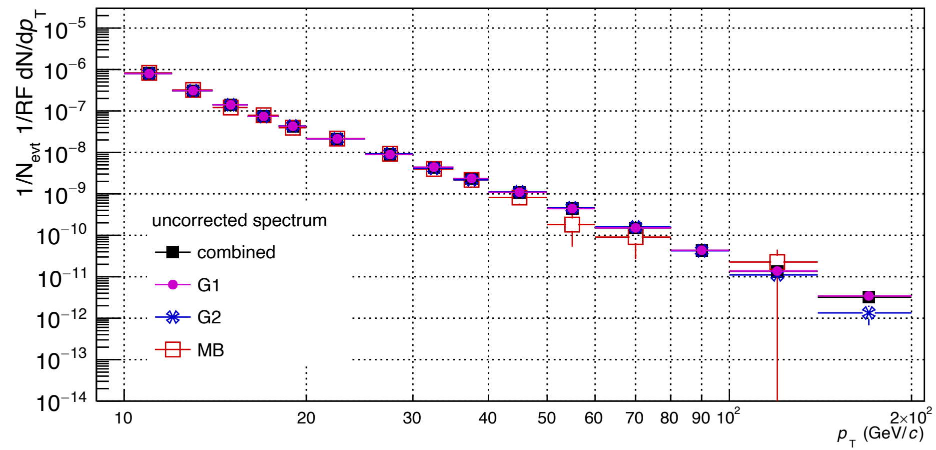
- To avoid trigger edge effect, a limit energy cut for trigger sample before combine:

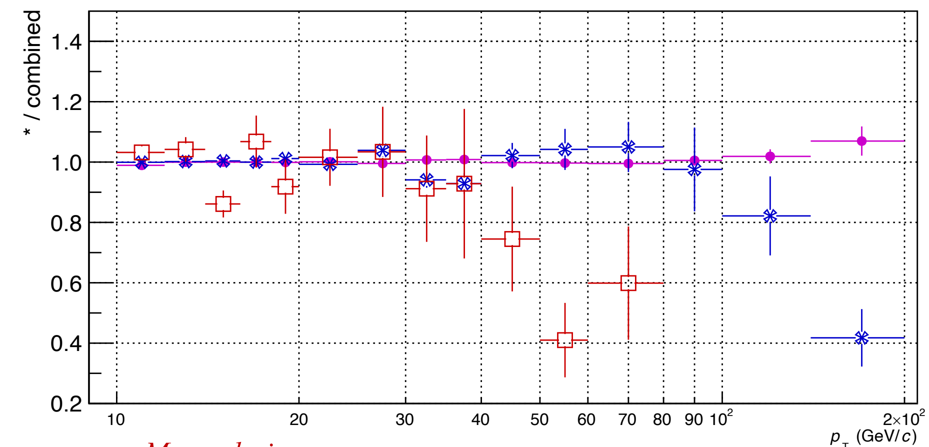
  MB: [0, 200]

  G2(> 4GeV/c): [6, 200]

  G1(> 9GeV/c): [12, 200]

- Each EMCal trigger sample has a compatible distribution with the MB sample.





My analysis

Purity: the ABCD method

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

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

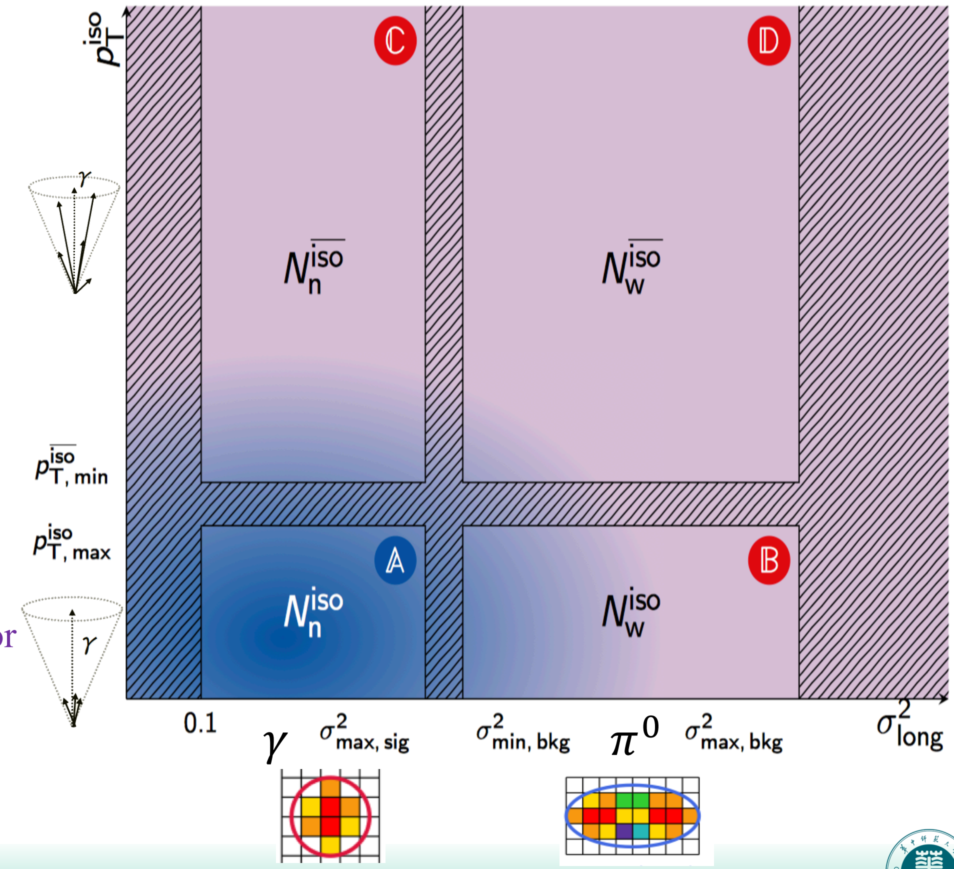
data-driven purity   MC correction factor

Assume:

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

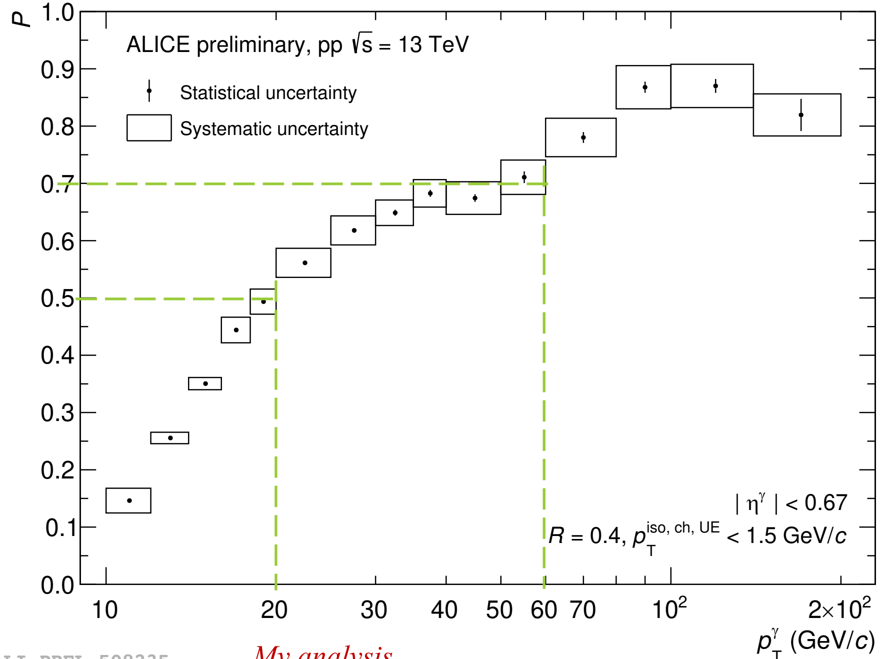
$B_A/B_C = B_B/B_D$

Unfortunately assumption not completely true



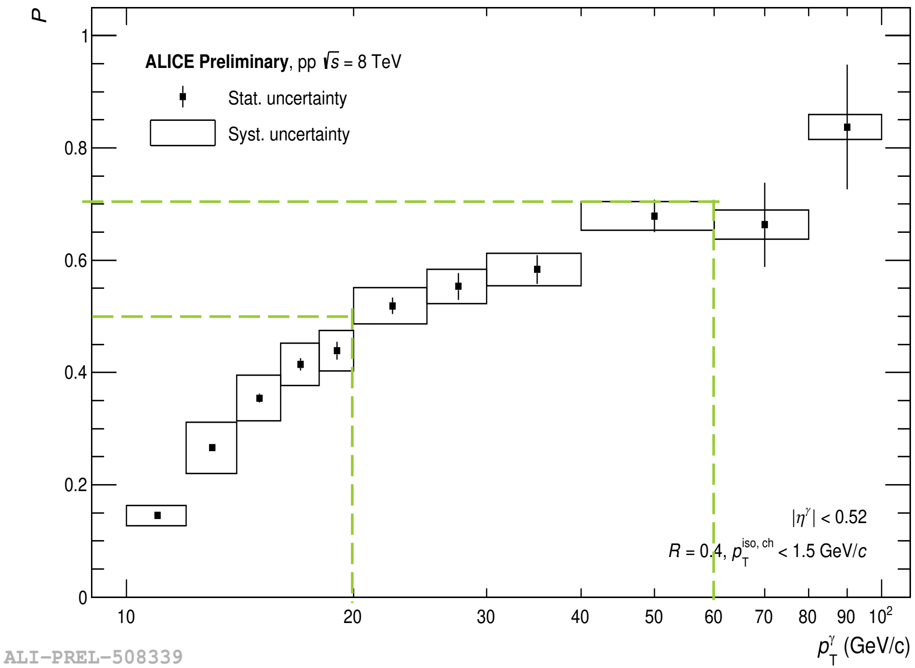
Purity

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



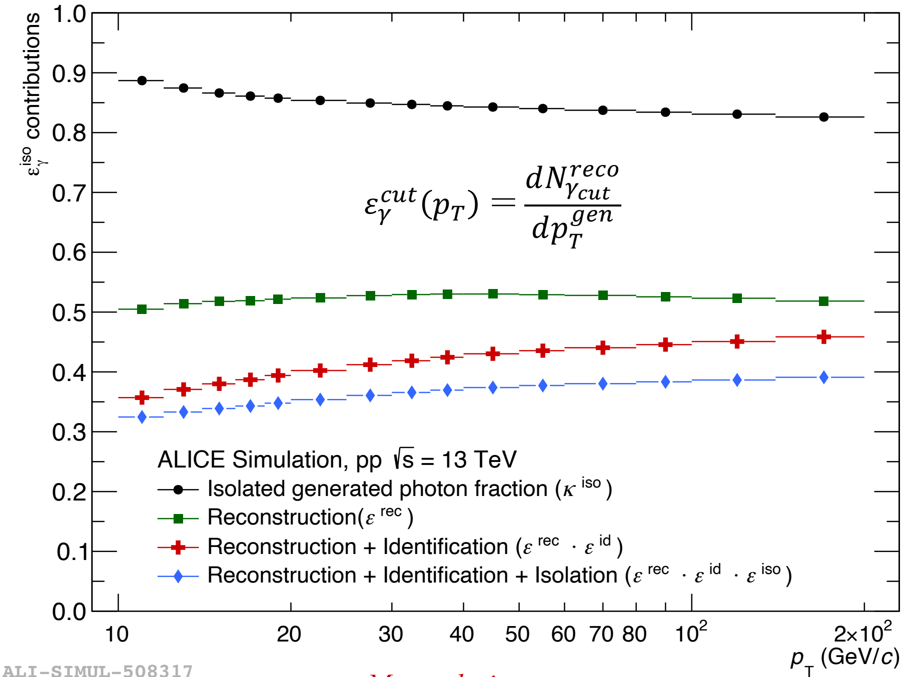
My analysis

pp, $\sqrt{s}$ = 8 TeV

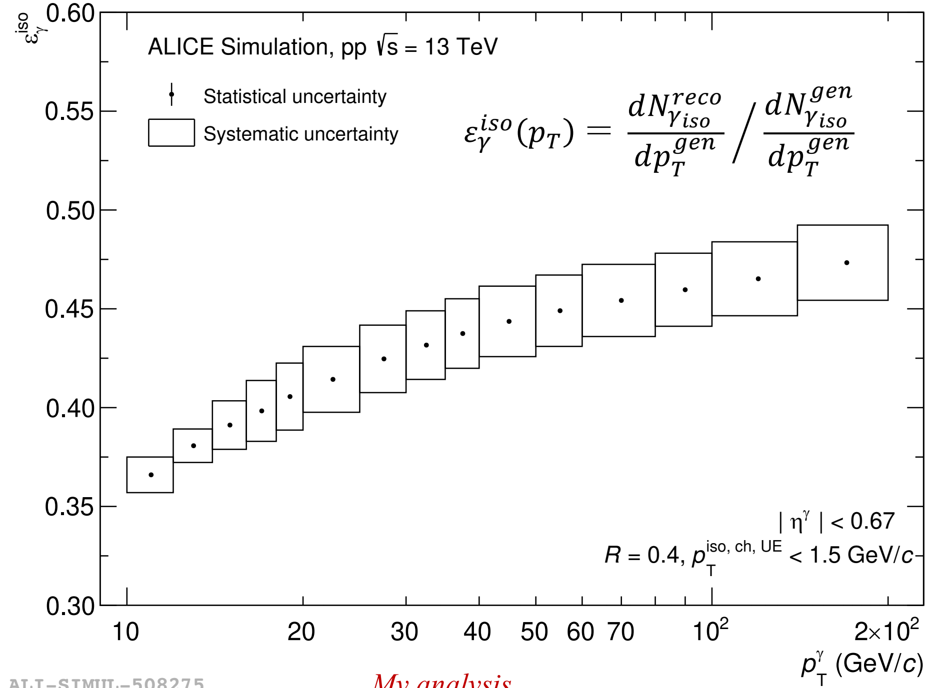


🌟 purity is similar in different $\sqrt{s}$

Efficiency



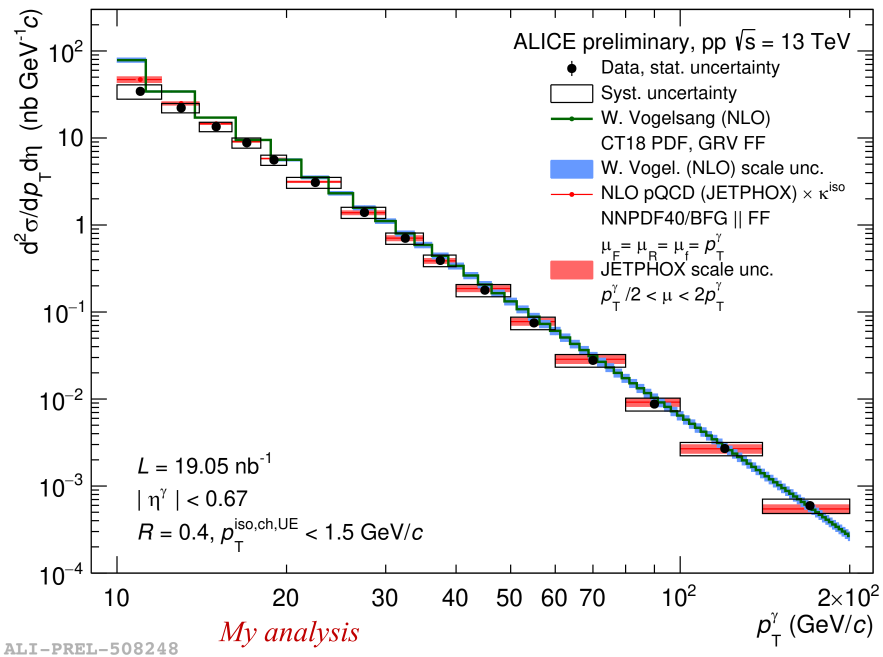
My analysis



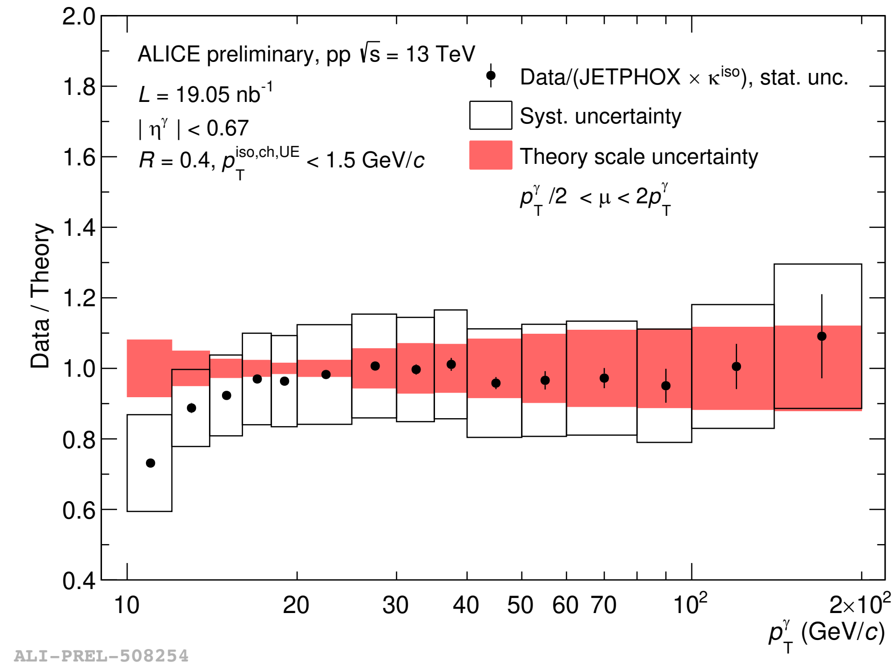
My analysis

- Simulation using PYTHIA gamma-jet event
- Fraction of photons surviving analysis cuts: reconstruction, shower shape and isolation
- Efficiency includes detector effects corrections: resolution, material absorption/conversions, masked regions, false non isolation, etc.

Isolated photon cross section: measured compared to theory

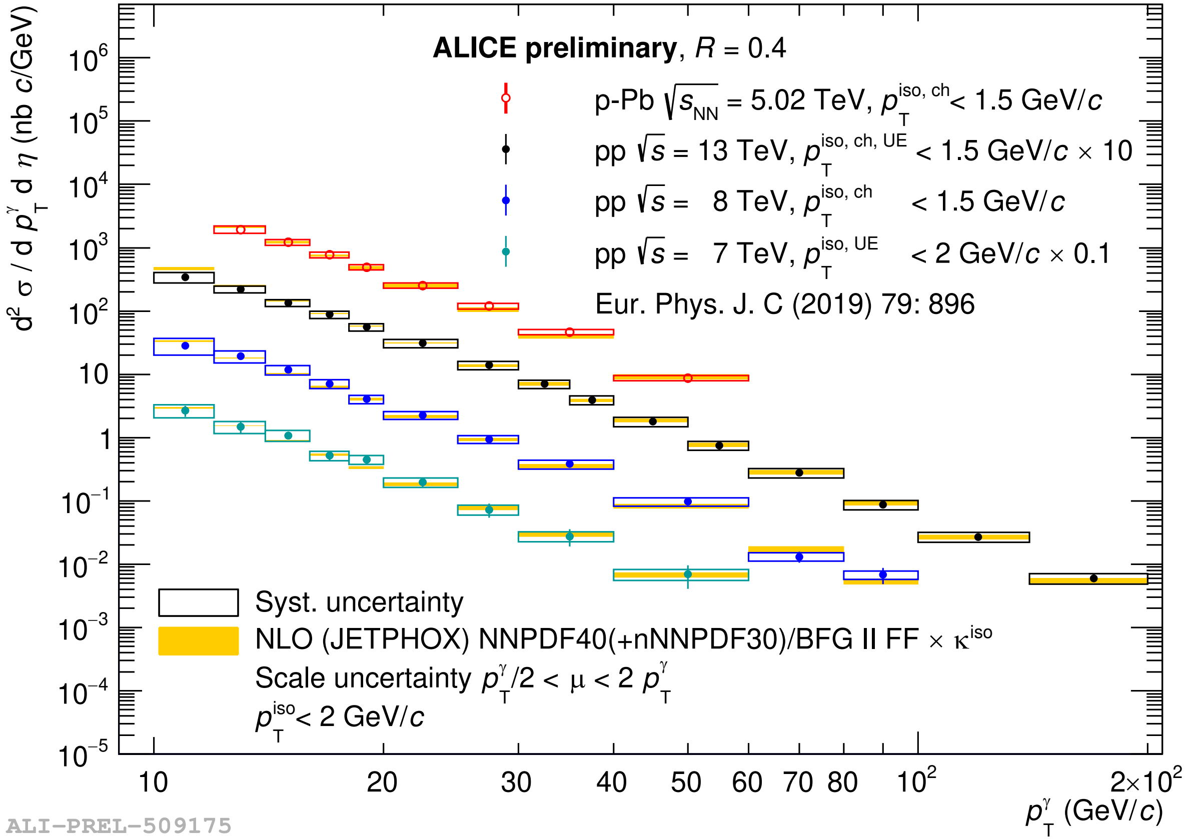


My analysis



- Compared with JETPHOX NLO pQCD calculations → good agreement within uncertainties

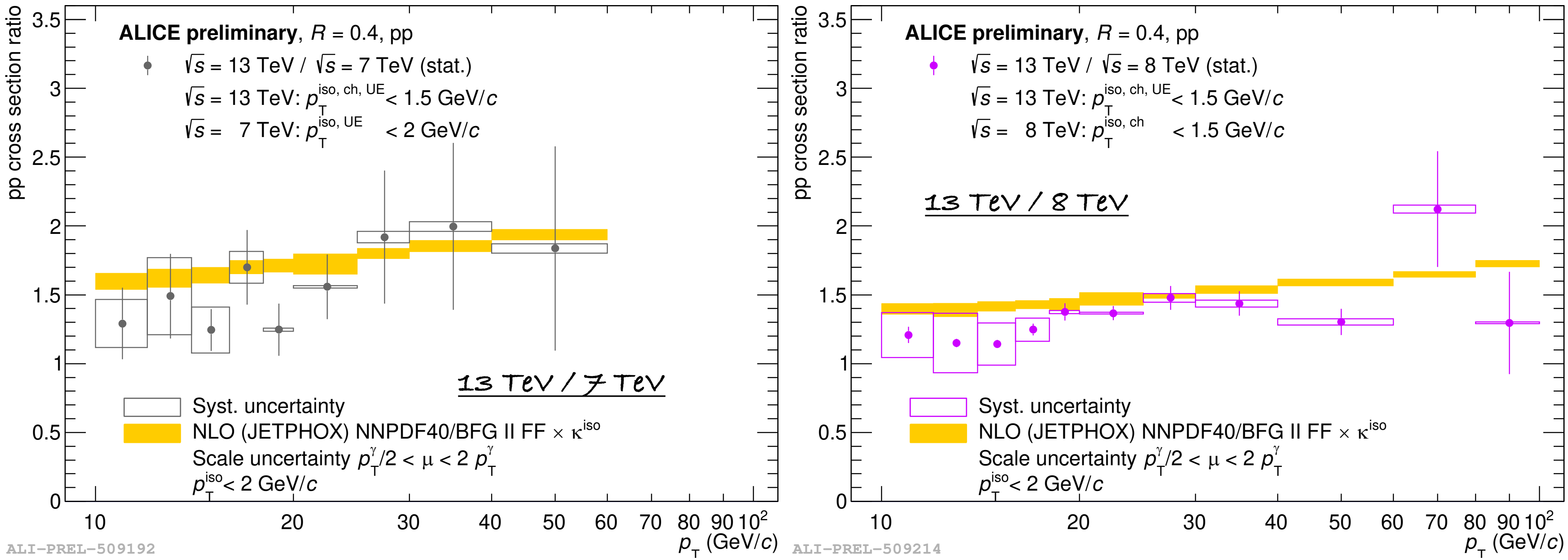
Isolated photon cross section at different $\sqrt{s}$ in ALICE



collision	$\sqrt{s_{NN}}$ (TeV)	p_T range (GeV/c)
pp	**13**	$\mathbf{10 < p_T < 200}$
	8	$10 < p_T < 100$
	7	$10 < p_T < 60$
p-Pb	5.02	$12 < p_T < 60$

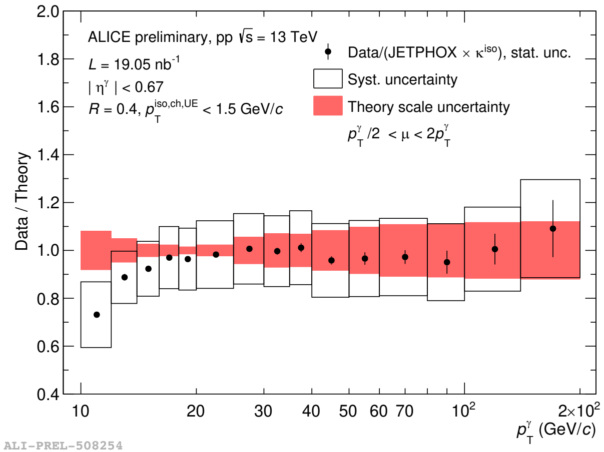
The $\sqrt{s} = 13$ TeV measurement extends the spectrum to higher p_T range compared to the lower collision energies

Results comparison to other collision energies and NLO

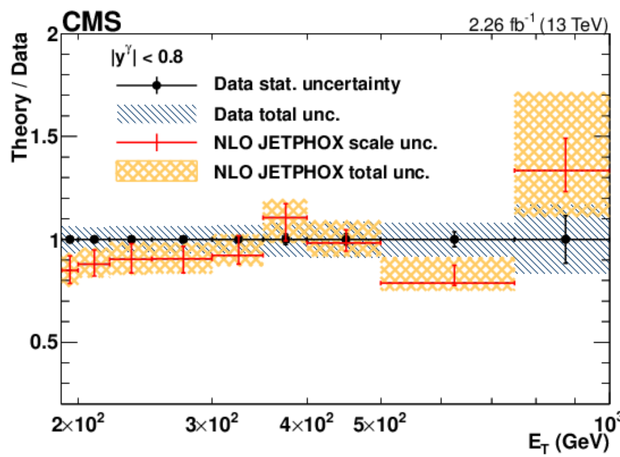


Ratio of measurement is consist with theory within uncertainties.

Results comparison, to other experiments



My analysis



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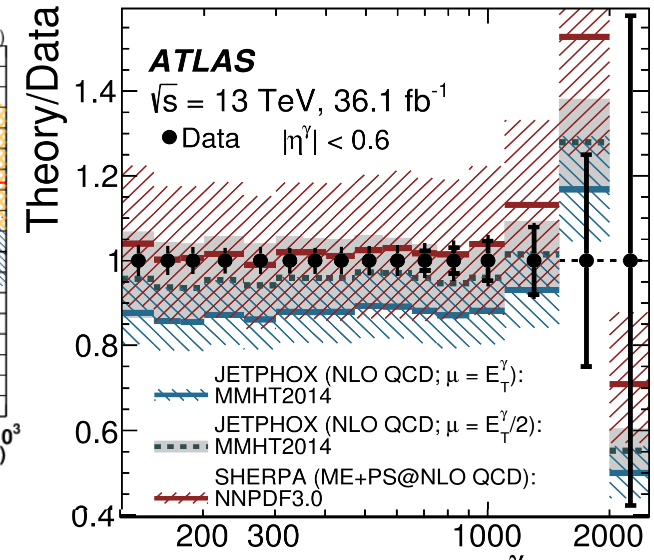


JHEP10(2019)203

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		**$10 < p_{\mathrm{T}} < 200$**
ATLAS	13	$125 < p_{\mathrm{T}} < 2000$
CMS		$190 < p_{\mathrm{T}} < 1000$

Summary and plans

⌘ There is a good agreement between JETPHOX NLO pQCD calculations with pp cross section measurements.

⌘ My analysis extends the p_{T} range to higher values compared to other ALICE measurements at lower $\sqrt{s}$ and cover a lower p_{T} range compared to ATLAS and CMS measurements at the same $\sqrt{s}$

⌘ The results were shown in the Quark Matter conference last month and I will show them on ICHEP in July

Next steps

⌘ Try to lower the p_{T} limit below 10 GeV/c: hard due to the very low purity

⌘ Decrease the systematic uncertainty

⌘ Explore the possibility of measurement with different multiplicity interval

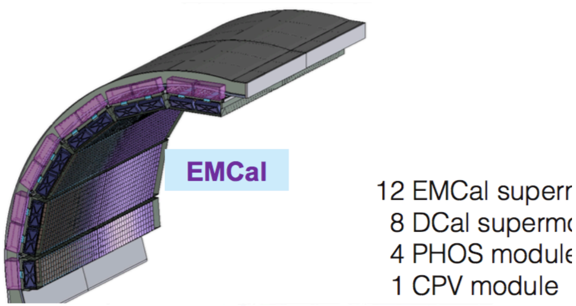
→ check spectra normalization for QGP studies in small collision systems

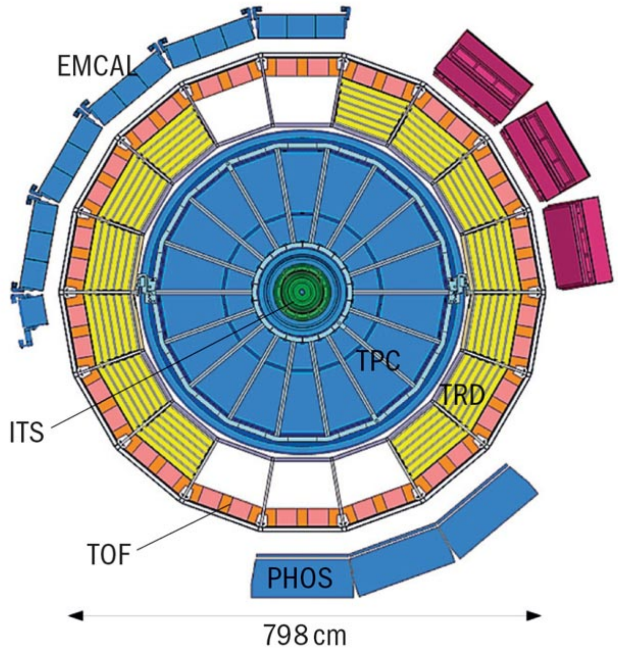
⌘ Write the paper

⌘ Study jet fraction function with photon-hadron correlations

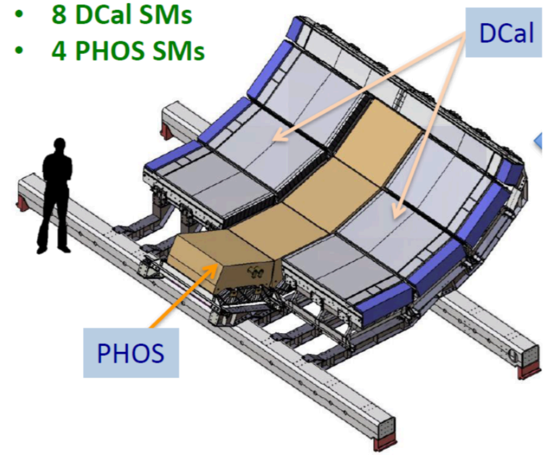
BACK UP

Calorimeter trigger

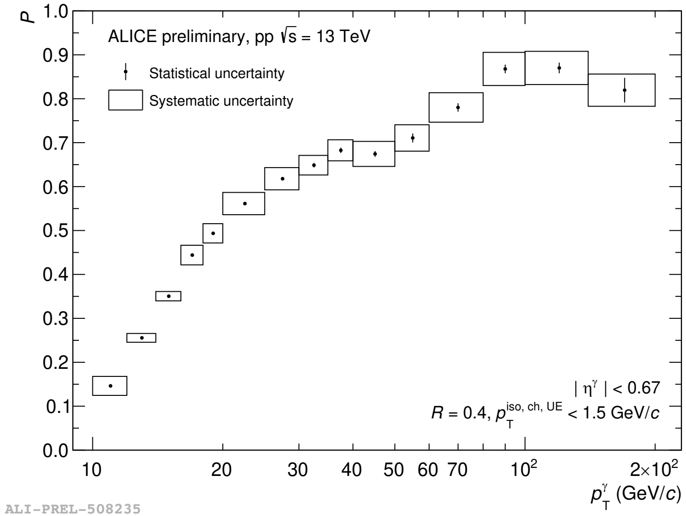


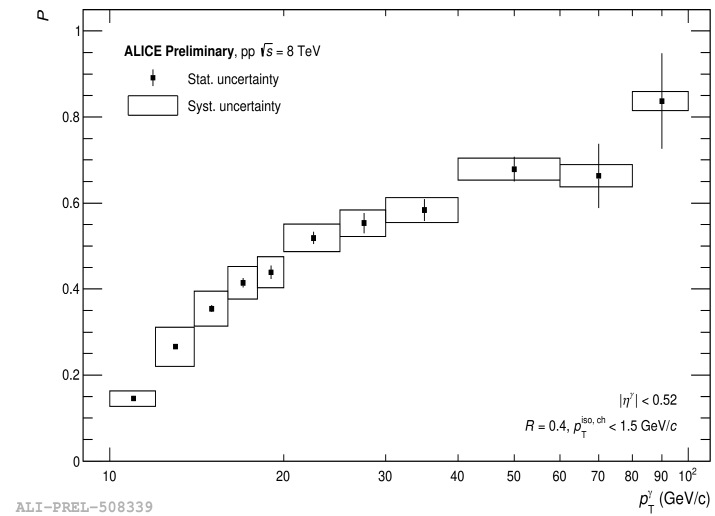


- **8 DCal SMs**
- **4 PHOS SMs**

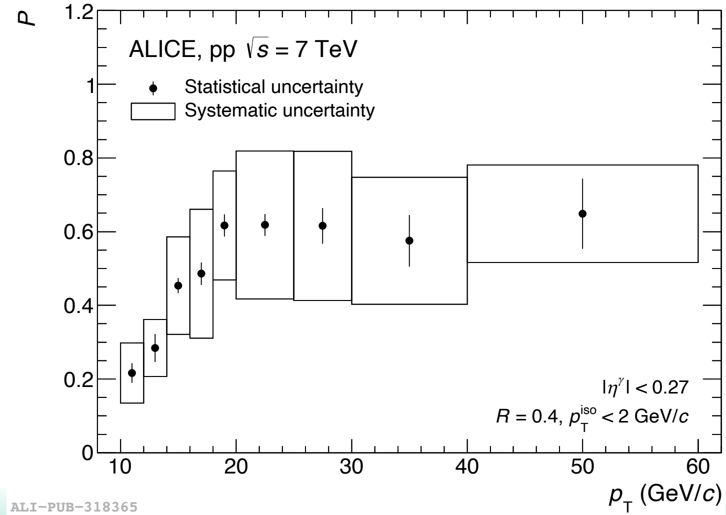


Purity





	Particle in cone	p_{T}^{iso}
pp 13TeV	Charged only	1.5 GeV/c
pp 8TeV	Charged only	1.5 GeV/c
pp 7TeV	Charge + neutral	2.0 GeV/c



- purity is similar in different collision energy

Purity component

$$purity = \left[1 - \left(\frac{N_c/N_A}{N_D/N_B}\right)_{data}\right] \times \left(\frac{B_A/N_C}{N_B/N_D}\right)_{MC}$$

data-driven purity

simulation correction factor