Isolated photons measurement in pp and p–Pb collisions at LHC with ALICE

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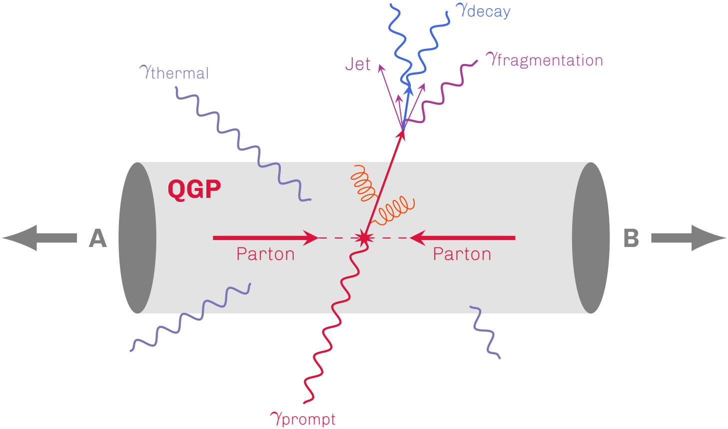
Isolated photons measurement in pp and p–Pb collisions

- Physics motivation
- Experimental context
- Analysis details
- Status

  $\rightarrow$ pp at $\sqrt{s} = 7$ TeV

  $\rightarrow$ p–Pb at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV
- Conclusions and outlook

Photons in hadron collisions



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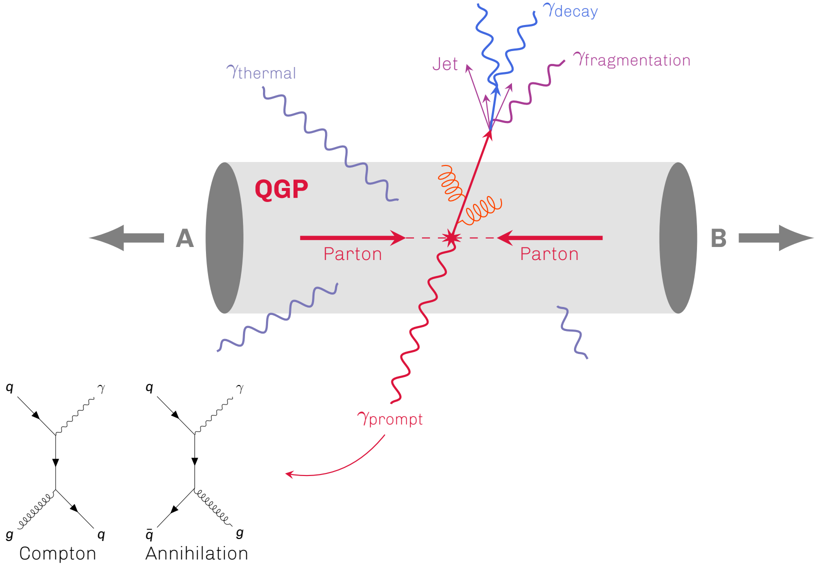

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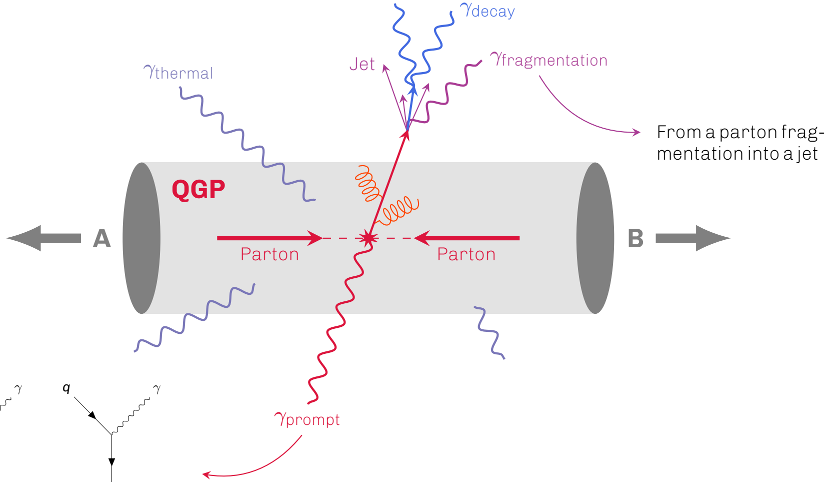

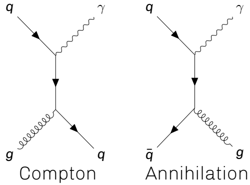

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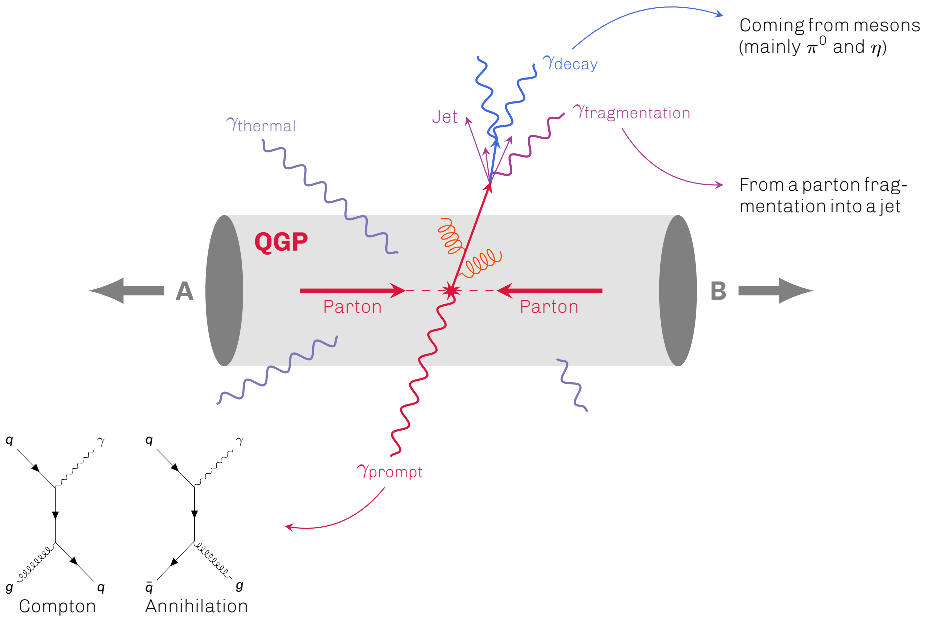

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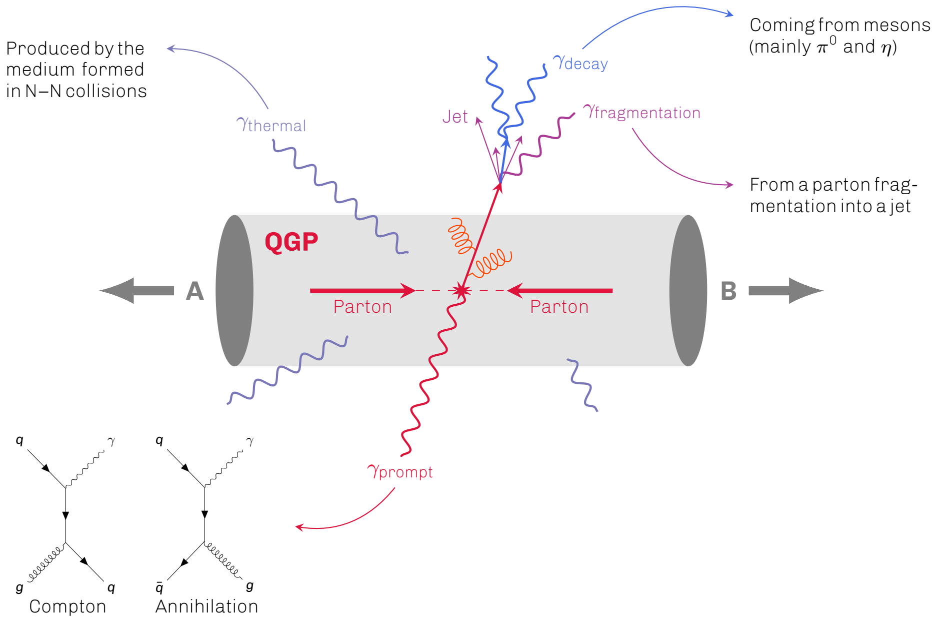

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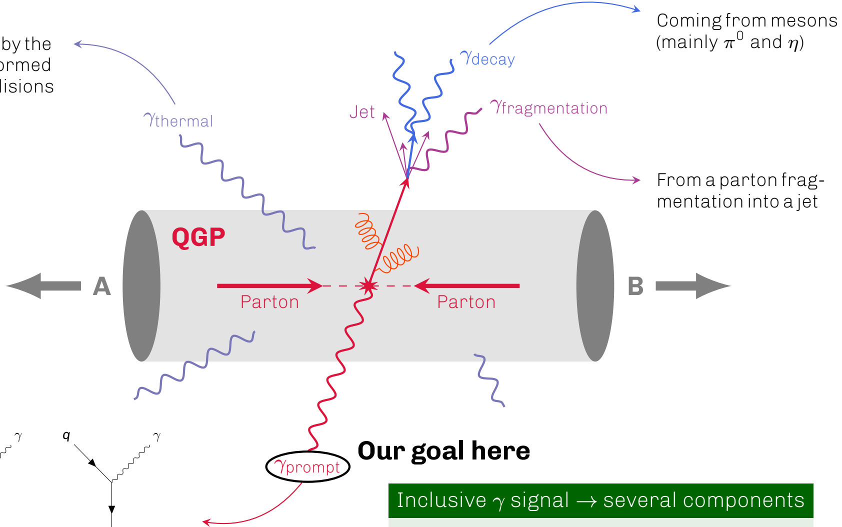
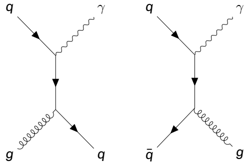




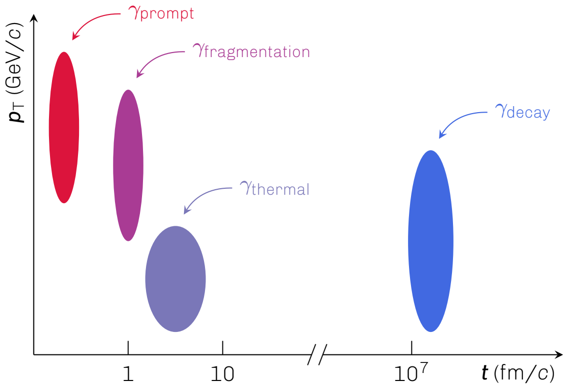
Compton Annihilation

Inclusive γ signal $\rightarrow$ several components

$$\gamma_{\text{incl}} = \underbrace{\gamma_{\text{prompt}} + \gamma_{\text{frag}}}_{\gamma_{\text{direct}}} + \gamma_{\text{decay}} \; (+\,\gamma_{\text{thermal}})$$

Why study the γ_{prompt} component?

- Produced early in hard processes, colourless (**not affected by the traversed medium**) $\rightarrow$ calibrated energy reference for studying **jet energy loss** via γ-jet and γ-hadron correlations



- Described by **perturbative QCD (pQCD)** at the **Next-To-Leading Order (NLO)** $\rightarrow$ measuring γ_{prompt} better constrains models

Measuring prompt photons

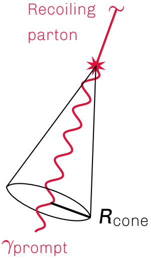
- γ_{prompt} emitted back to the other hard-produced particles → selection using an **isolation method**

Isolated photons

- An **isolation cone** of radius R_{cone} is defined **around a candidate photon** at $(\eta_\gamma, \varphi_\gamma)$ → it is **isolated** if the energy inside this cone is below a set threshold $E_{\text{T}}^{\text{max}}$

$$R_{\text{cone}} = \sqrt{(\eta - \eta_\gamma)^2 + (\varphi - \varphi_\gamma)^2} \text{ and } \sum_{\text{cone}} E_{\text{T}} < E_{\text{T}}^{\text{max}}$$

- Common values → $R_{\text{cone}} = 0.4$ and $E_{\text{T}}^{\text{max}} = 2\,\text{GeV}$



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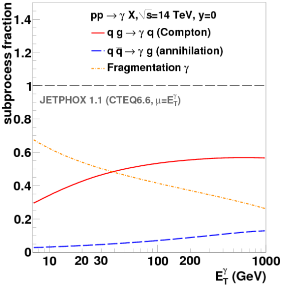

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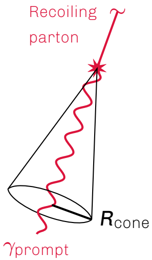

R. Ichou et al., Phys. Rev. D 82, 014015 (2010)

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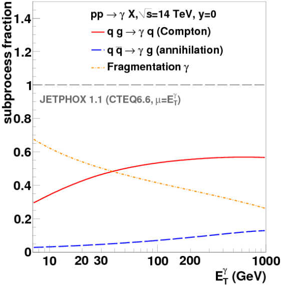

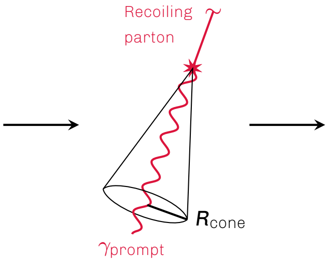

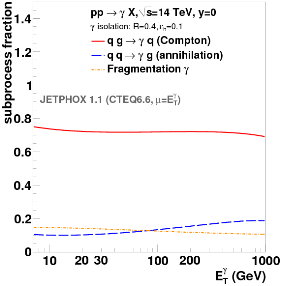

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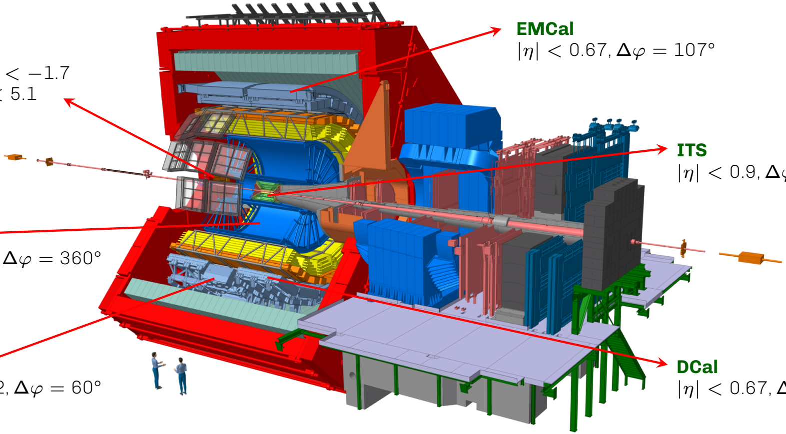
The ALICE experiment (Run II configuration)

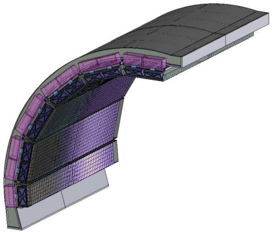


- V0 $\rightarrow$ minimum bias **trigger** (“raw” events)
- ITS/TPC $\rightarrow$ **primary vertex** determination + charged particle **tracking and identification**
- EMCal/DCal $\rightarrow$ **electromagnetic particles** measurement (especially γ and mesons) + **γ/jet trigger**

EMCal design and principle

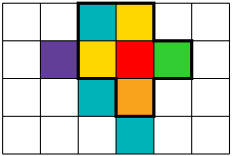
Global properties

- 12 supermodules → **12288 cells** with $\Delta\eta \times \Delta\varphi = 0.0143 \times 0.0143$
- Each cell → **76 lead and 77 scintillator** alternating layers (24.6 cm thick in total)
- Energy/position resolutions → $4.8\,\%/E \oplus 11.3\,\%/\sqrt{E} \oplus 1.7\,\%$ and $5.3\,\text{mm}/\sqrt{E} \oplus 1.5\,\text{mm}$
- Used as **trigger detector** → Level-0 and Level-1 on γ **and jets**
- 2011-2013 → 10 supermodules in data taking
  DCal → active since 2015 (8 supermodules)



Detection principle and reconstruction

- Electromagnetic-interacting particles induce **electromagnetic showers** in the EMCal layers
- **Adjacent cells** with energy deposited in here → grouped in **clusters**
- Candidate photon selection based on **several criteria on clusters**



Data selection

Common to pp and p–Pb analyses

Events

- High-level EMCal γ triggers
- Interaction **primary vertex** $\rightarrow |v_z| < 10\,\mathrm{cm}$
- $\sim$ **10 %** of events rejected

vertex_z.pdf

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Clusters

- Cluster **total energy** $> 300\,\text{MeV}$
- Cluster **time** $\in (-30\,\text{ns}, 30\,\text{ns})$
- Rejection of exotic clusters
- Number of **cells per cluster** ≥ 2
- Number of cells from **EMCal border and bad cells** ≥ 2
- Number of **local maxima per cluster** ≤ 2

time.pdf

Photon selection

Neutral clusters (charged particle veto)

- Candidate clusters must not match a track
  $\rightarrow$ only **neutral clusters** are kept

$$\Delta\eta = |\eta_{\text{clus}} - \eta_{\text{track}}| > 0.02$$

$$\Delta\varphi = |\varphi_{\text{clus}} - \varphi_{\text{track}}| > 0.03$$

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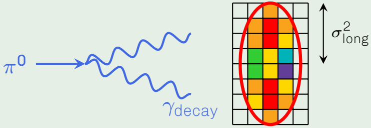
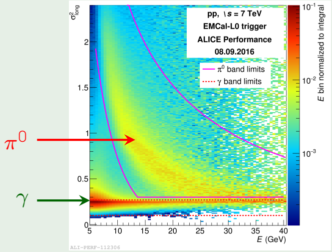
Candidate photons (shower shape cuts)

- Clusters **shower shape** σ^2_{long} is used to reject the γ_{decay} component

$$0.1 < \sigma^2_{\mathrm{long}} < \left(\sigma^2_{\mathrm{long}}\right)_{\mathrm{max}}$$





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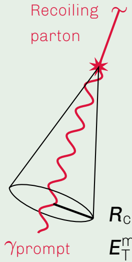
Candidate γ_{prompt} (isolation)



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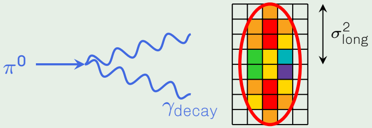
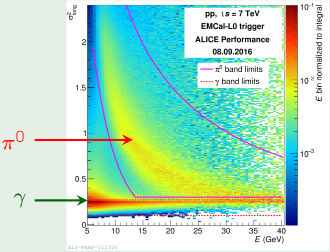
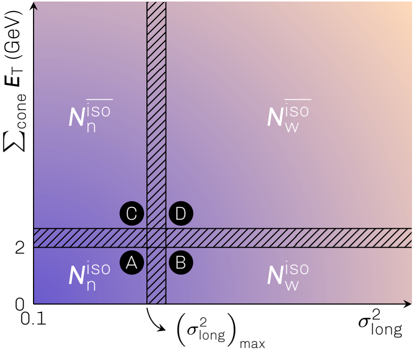




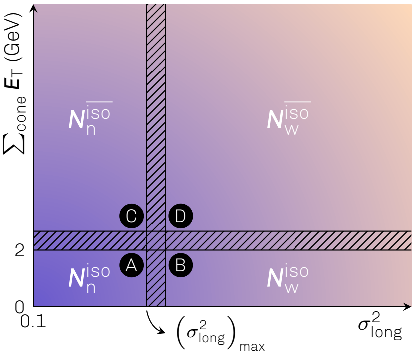
Signal extraction and background estimation



The ABCD method

- A = isolated narrow clusters
  → mainly **signal**
- B = isolated wide clusters
- C = non-isolated narrow clusters
- D = non-isolated wide clusters
  → mainly **background**

Signal extraction and background estimation



Quantities

- S_i^j = $\gamma_{\mathbf{prompt}}$ **signal** in region (i, j)
- B_i^j = background in region (i, j)
- N_i^j = total population in region (i, j)

  $\rightarrow N_i^j = S_i^j + B_i^j$, **what we measure**

  i $\in$ (n, w), i.e. (narrow, wide)

  j $\in$ (iso, $\overline{\text{iso}}$), i.e. (isolated, non-isolated)

- Signal in region A

$$S_n^{iso} = N_n^{iso} - B_n^{iso}$$

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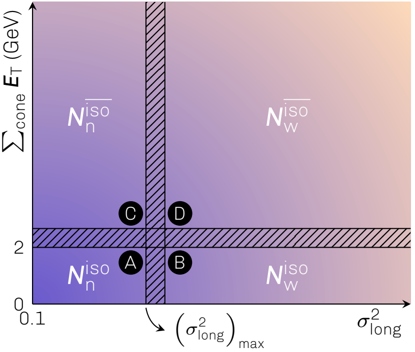

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  $\rightarrow$ mainly **signal**
- B = isolated wide clusters
- C = non-isolated narrow clusters
- D = non-isolated wide clusters

  $\rightarrow$ mainly **background**

Assumptions

- Only **background clusters** in B, C and D

  $\rightarrow (N_w^{\text{iso}}, N_n^{\overline{\text{iso}}}, N_w^{\overline{\text{iso}}}) \equiv (B_w^{\text{iso}}, B_n^{\overline{\text{iso}}}, B_w^{\overline{\text{iso}}})$
- Background isolation fraction **equal in signal (A, C)** and **background (B, D)** regions

Purity estimation

- Background **estimation** in region A

$$B_{\mathrm{n}}^{\mathrm{iso}} = N_{\mathrm{w}}^{\mathrm{iso}} \times N_{\mathrm{n}}^{\overline{\mathrm{iso}}} / N_{\mathrm{w}}^{\overline{\mathrm{iso}}}$$

Purity estimation

- Background **estimation** in region Ⓐ

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- Introduction of a **contamination** $\mathbb{C}$ and a **purity** $\mathbb{P}$ in region Ⓐ

$$\mathbb{C} = \frac{B_{\mathrm{n}}^{\mathrm{iso}}}{N_{\mathrm{n}}^{\mathrm{iso}}} = \frac{N_{\mathrm{w}}^{\mathrm{iso}} \times N_{\mathrm{n}}^{\overline{\mathrm{iso}}}}{N_{\mathrm{w}}^{\overline{\mathrm{iso}}} \times N_{\mathrm{n}}^{\mathrm{iso}}} \Rightarrow \mathbb{P} = 1 - \frac{B_{\mathrm{n}}^{\mathrm{iso}}}{N_{\mathrm{n}}^{\mathrm{iso}}} = 1 - \frac{N_{\mathrm{w}}^{\mathrm{iso}} \times N_{\mathrm{n}}^{\overline{\mathrm{iso}}}}{N_{\mathrm{w}}^{\overline{\mathrm{iso}}} \times N_{\mathrm{n}}^{\mathrm{iso}}}$$

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- Assumptions not valid, there may be **signal in B, C and D** and **asymmetric $\gamma_{\mathbf{decay}}$ in A** $\rightarrow$ $\mathbb{P}$ **biased**, to be corrected using Monte-Carlo (MC) simulations

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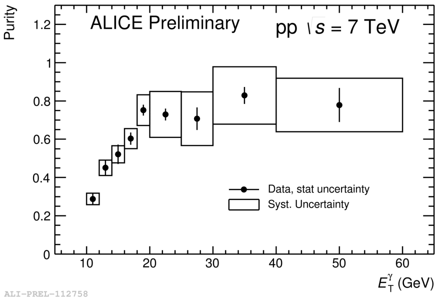
- Two MC samples $\rightarrow$ jet-jet (JJ, **background**) + γ-jet (GJ, **signal**), both mixed and used to compute a contamination **correction factor** α

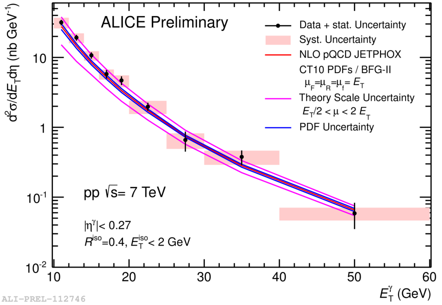
$$\alpha = \frac{\left(B_{\mathrm{n}}^{\mathrm{iso}}\right)_{\mathrm{JJ}}}{\left(B_{\mathrm{n}}^{\mathrm{iso}}\right)_{\mathrm{JJ+GJ}}} = \left(B_{\mathrm{n}}^{\mathrm{iso}}\right)_{\mathrm{JJ}} \times \left(\frac{N_{\mathrm{w}}^{\overline{\mathrm{iso}}}}{N_{\mathrm{w}}^{\mathrm{iso}} \times N_{\mathrm{n}}^{\overline{\mathrm{iso}}}}\right)_{\mathrm{JJ+GJ}} \Rightarrow \mathbb{P}_{\mathrm{corr}} = 1 - \alpha \times \left(\frac{N_{\mathrm{w}}^{\mathrm{iso}} \times N_{\mathrm{n}}^{\overline{\mathrm{iso}}}}{N_{\mathrm{w}}^{\overline{\mathrm{iso}}} \times N_{\mathrm{n}}^{\mathrm{iso}}}\right)_{\mathrm{data}}$$

Isolated photons in pp collisions at $\sqrt{s} = 7$ TeV

Specifications

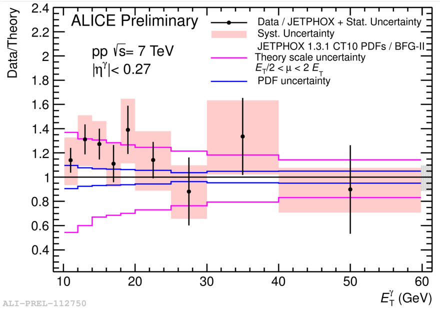
- 2011 datasets (LHC11c/d, 88 runs)
- EMCal Level-0 γ trigger at **5.5 GeV** $\rightarrow$ **8.6 $\times$ 10^6 events**
- Integrated luminosity $\rightarrow \mathcal{L}_{\text{int}} = 473 \pm 22\,(\text{stat}) \pm 17\,(\text{syst})\,\text{nb}^{-1}$



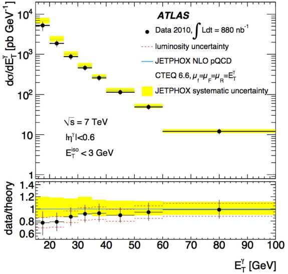


- Good agreement between **measurement and NLO** predictions

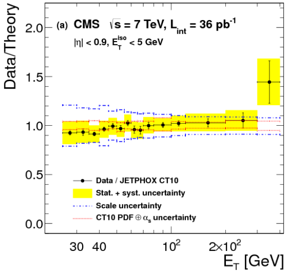
Isolated photons in pp collisions at $\sqrt{s} = 7$ TeV



- ► Consistent with the **ATLAS and CMS** measurements in the overlapping E_T region (within uncertainties)
- ► Access to **lower E_T** isolated photons



G. Aad et al., Phys. Rev. D 83, 052005 (2011)



S. Chatrchyan et al., Phys. Rev. D 84, 052011 (2011)

Isolated photons in p–Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02\,\mathrm{TeV}$

Specifications

- 2013 datasets (79 runs) $\rightarrow$ p–Pb (LHC13d/e) and Pb–p (LHC13f)
- EMCal Level-1 γ triggers $\rightarrow$ 11 GeV and 7 GeV $\rightarrow$ **1.2×10^{6}** and **580×10^{3}** events
- Same E_{T} range than in pp analysis, easy comparison

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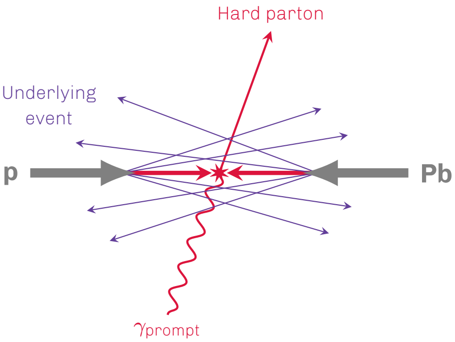
⚠ Larger contribution from the **underlying event (UE)** in p–Pb than in pp collisions



Underlying event estimation

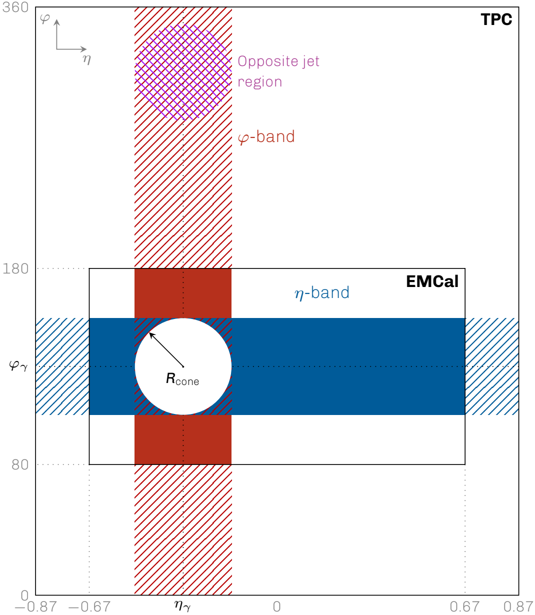
- Needed to **estimate and subtract the UE contribution** to the isolation cone energy → various methods based on the isolation cone, mainly **φ-band** and **η-band**

- UE area **density**

$$\rho_{\mathrm{UE}} = \frac{1}{A_{\mathrm{UE}}}\left(\sum_{\mathrm{UE}} E_{\mathrm{T}}^{\mathrm{cluster}} + \sum_{\mathrm{UE}} p_{\mathrm{T}}^{\mathrm{track}}\right)$$

$$\sum_{\mathrm{cone}} E_{\mathrm{T}} \longmapsto \sum_{\mathrm{cone}} E_{\mathrm{T}} - \rho_{\mathrm{UE}} \times A_{\mathrm{cone}}$$

- Isolation criteria applied **after UE subtraction** (event by event)



Underlying event estimation

134_SumEtUEPerBin_13de_EtaBand_NtrChg.pdf

η-band (EMCal acc.)

136_SumEtUEPerBin_13de_PhiBand_Chg.pdf

φ-band (TPC acc.)

- Charged UE estimation in the TPC acc. $\rightarrow$ φ-band method **sensitive to the opposite jet**
- η-band method $\rightarrow$ **best choice** for evaluating the UE

Underlying event estimation

134_SumEtUEPerBin_13de_EtaBand_NtrChg.pdf

η-band (EMCal acc.)

136_SumEtUEPerBin_13de_PhiBand_Chg.pdf

φ-band (TPC acc.)

- Charged UE estimation in the TPC acc. $\rightarrow$ φ-band method **sensitive to the opposite jet**
- η-band method $\rightarrow$ **best choice** for evaluating the UE

Isolation

- Isolation criteria may be applied then

$$R_{\text{cone}} = 0.4 \quad \text{and} \quad \sum_{\text{cone}} E_{\text{T}} - \rho_{\text{UE}} \times A_{\text{cone}} < 2\,\text{GeV}$$

Raw isolated photon spectrum

p–Pb

138_SignalBackground_13de.pdf

Pb–p

139_SignalBackground_13f.pdf

- Good agreement between p–Pb and Pb–p but **low statistics at high energy** in p–Pb

Corrected purity

130_CorrPurity_13de.pdf

p–Pb

131_CorrPurity_13f.pdf

Pb–p

- Good agreement between p–Pb and Pb–p but **low statistics at high energy** in p–Pb $\rightarrow$ working on how to combine the two datasets

Steps to the isolated photon cross section in p–Pb at $\sqrt{s_{\mathrm{NN}}} = 5.02\,\mathrm{TeV}$

$$\frac{\mathrm{d}^2\sigma}{\mathrm{d}E_{\mathrm{T}}\,\mathrm{d}\eta} = \frac{N_{\mathrm{ev}} \times \mathbb{P}_{\mathrm{corr}}}{\mathcal{L}_{\mathrm{int}} \times \varepsilon} \times \frac{\mathrm{d}^2 N}{N_{\mathrm{ev}}\,\mathrm{d}E_{\mathrm{T}}\,\mathrm{d}\eta}$$

Steps to the isolated photon cross section in p–Pb at $\sqrt{s_{\mathrm{NN}}} = 5.02\,\mathrm{TeV}$

139_SignalBackground_13f.

$$\frac{\mathrm{d}^2\sigma}{\mathrm{d}E_{\mathrm{T}}\,\mathrm{d}\eta} = \frac{N_{\mathrm{ev}} \times \mathbb{P}_{\mathrm{corr}}}{\mathcal{L}_{\mathrm{int}} \times \varepsilon} \times \boxed{\frac{\mathrm{d}^2 N}{N_{\mathrm{ev}}\,\mathrm{d}E_{\mathrm{T}}\,\mathrm{d}\eta}}$$

Steps to the isolated photon cross section in p–Pb at $\sqrt{s_{\mathrm{NN}}} = 5.02\,\mathrm{TeV}$

131_CorrPurity_13f.pdf

139_SignalBackground_13f.

$$\frac{\mathrm{d}^2\sigma}{\mathrm{d}E_{\mathrm{T}}\,\mathrm{d}\eta} = \frac{N_{\mathrm{ev}} \times \mathbb{P}_{\mathrm{corr}}}{\mathcal{L}_{\mathrm{int}} \times \varepsilon} \times \boxed{\frac{\mathrm{d}^2 N}{N_{\mathrm{ev}}\,\mathrm{d}E_{\mathrm{T}}\,\mathrm{d}\eta}}$$

Steps to the isolated photon cross section in p–Pb at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV

131_CorrPurity_13f.pdf

139_SignalBackground_13f.

$$\frac{\mathrm{d}^2\sigma}{\mathrm{d}E_{\mathrm{T}}\,\mathrm{d}\eta} = \frac{N_{\mathrm{ev}} \times \mathbb{P}_{\mathrm{corr}}}{\mathcal{L}_{\mathrm{int}} \times \varepsilon} \times \boxed{\frac{\mathrm{d}^2 N}{N_{\mathrm{ev}}\,\mathrm{d}E_{\mathrm{T}}\,\mathrm{d}\eta}}$$

$$\mathcal{L}_{\mathrm{int}} = \frac{N_{\mathrm{ev}}^{\mathrm{EG1}} \times R_{\mathrm{f}}^{\mathrm{EG1}} + N_{\mathrm{ev}}^{\mathrm{EG2}} \times R_{\mathrm{f}}^{\mathrm{EG2}}}{\sigma_{\mathrm{min\ bias}}}$$

006_TurnonCurves_13de-f.pdf

Steps to the isolated photon cross section in p–Pb at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV

131_CorrPurity_13f.pdf

139_SignalBackground_13f.

$$\frac{\mathrm{d}^2\sigma}{\mathrm{d}E_\mathrm{T}\,\mathrm{d}\eta} = \frac{N_\mathrm{ev} \times \mathbb{P}_\mathrm{corr}}{\mathcal{L}_\mathrm{int} \times \varepsilon} \times \boxed{\frac{\mathrm{d}^2 N}{N_\mathrm{ev}\,\mathrm{d}E_\mathrm{T}\,\mathrm{d}\eta}}$$

$$\mathcal{L}_\mathrm{int} = \frac{N_\mathrm{ev}^\mathrm{EG1} \times R_\mathrm{f}^\mathrm{EG1} + N_\mathrm{ev}^\mathrm{EG2} \times R_\mathrm{f}^\mathrm{EG2}}{\sigma_\mathrm{min\ bias}}$$

$$\varepsilon = \frac{\mathrm{d}N_\mathrm{rec}}{\mathrm{d}E_\mathrm{T}} \Big/ \frac{\mathrm{d}N_\mathrm{gen}}{\mathrm{d}E_\mathrm{T}}$$

006_TurnonCurves_13de-f.pdf

Reconstructed isolated photons

Generated isolated photons

Conclusions

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

- Compatible with **NLO calculations**
- Improvement **at low E_T** with respect to ATLAS and CMS

Isolated photons in p–Pb at $\sqrt{s_{NN}} = 5.02$ TeV

- Estimation of the **underlying event** with various methods
- First measurement of the **isolated photon spectrum and purity** with ALICE
- Determination of the isolated photon **reconstruction efficiency** (ongoing)
- Evaluation of **systematic uncertainties** associated to the measurement (ongoing)

Outlook

- Determine the **nuclear modification factor** $R_{\mathrm{p\text{–}A}}$ to compare p–Pb and pp measurements

Outlook

- Determine the **nuclear modification factor $R_{\text{p–A}}$** to compare p–Pb and pp measurements

RpAplot.png

Preliminary studies by Lucile Ronflette
(**many changes** in the analysis framework)
L. Ronflette, PhD thesis, Université de Nantes (2014)

Merci pour votre attention

Isolated photons measurement in pp and p–Pb collisions at LHC with ALICE

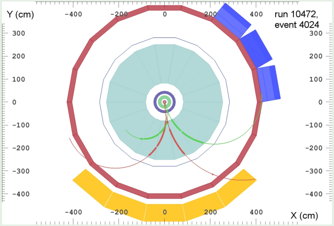
Erwann Masson
Laboratoire Subatech, Nantes

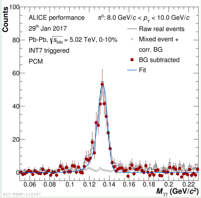
Backup

Several approaches to study photons

Photon Conversion Method (PCM)

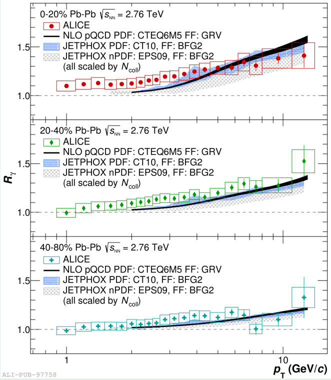
- Uses **electron/positron pair** tracks (ITS/TPC) to reconstruct γ_{decay} and then π^0 with **invariant mass analysis**





PHOS

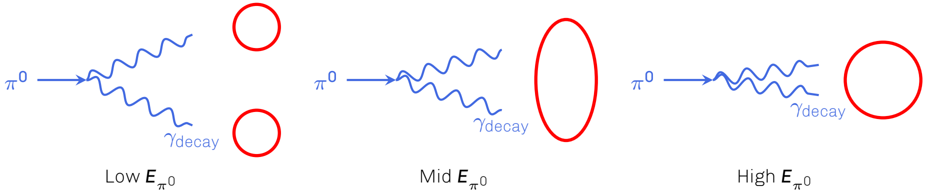
- Uses **energy deposition in crystals** to reconstruct γ
- Combined with PCM for **statistical subtraction** to study γ_{direct} $\rightarrow$ $R_\gamma = (\gamma_{\mathrm{incl}}/\pi^0)/(\gamma_{\mathrm{decay}}/\pi^0)$



Top left fig.: ALICE Collab., Nucl. Phys. A 855 (2011) / Right fig.: ALICE Collab., Phys. Lett. B 754 (2016)

The π^0 background, different cases to consider

- $\pi^0 \to \gamma\gamma$ (BR = 98.8 %), emitted with an **angle $\theta_{\gamma\gamma}$** following $\sin^2 \theta_{\gamma\gamma} = \frac{m^2_{\pi^0}}{E^2_{\pi^0}}$
- $E_{\pi^0} \nearrow \Rightarrow \theta_{\gamma\gamma} \searrow \to$ resulting γ_{decay} clusters are **merged at mid-high E_{π^0}**



- Low E_{π^0} **paired γ_{decay}** clusters possibly **inside the isolation cone** $\to$ one as candidate γ_{prompt}, the other as contributor to $\sum_{\text{cone}} E_{\text{T}}$
- Low E_{π^0} **asymmetric γ_{decay}** clusters possibly considered as **candidate γ_{prompt}** but not as contributor to $\sum_{\text{cone}} E_{\text{T}}$ (one of them inside, the other outside the cone)
- High E_{π^0} **merged γ_{decay}** clusters possibly considered as **candidate γ_{prompt}** but not as contributor to $\sum_{\text{cone}} E_{\text{T}}$

Shower shape cuts

E_T range (GeV)	A, C σ^2_{long} range	B, D σ^2_{long} range
10 – 12	(0.10, 0.45)	(0.55, 1.55)
12 – 16	(0.10, 0.40)	(0.50, 1.50)
16 – 18	(0.10, 0.35)	(0.45, 1.45)
18 – 60	(0.10, 0.30)	(0.40, 1.40)