Isolated photon measurement in pp and p–Pb collisions at LHC with the ALICE Experiment

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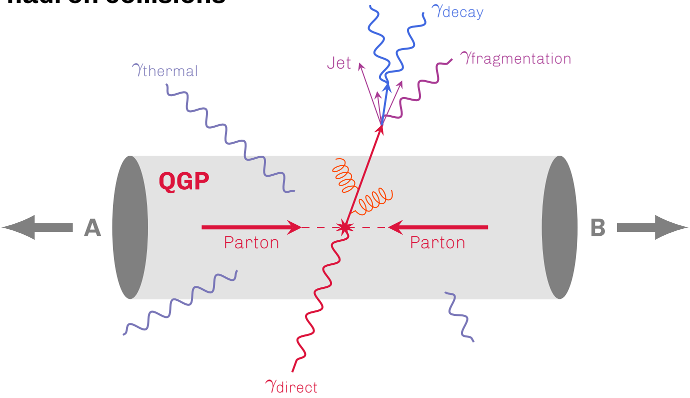
Rencontres QGP France 2018

Photons in hadron collisions



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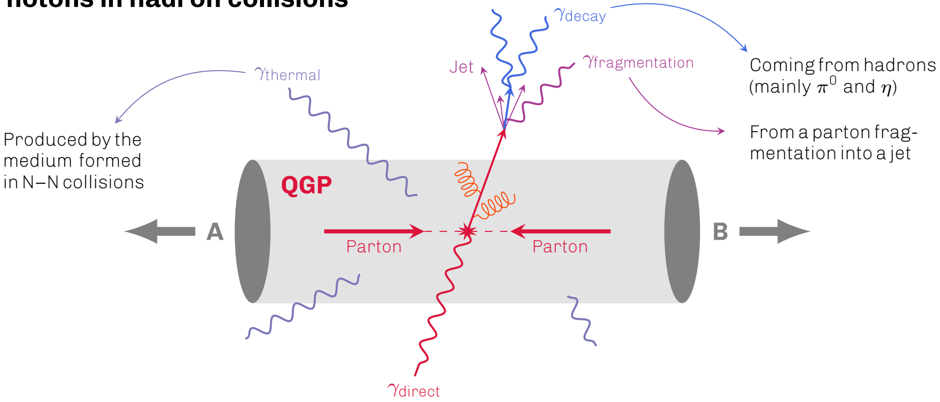

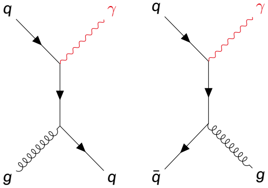

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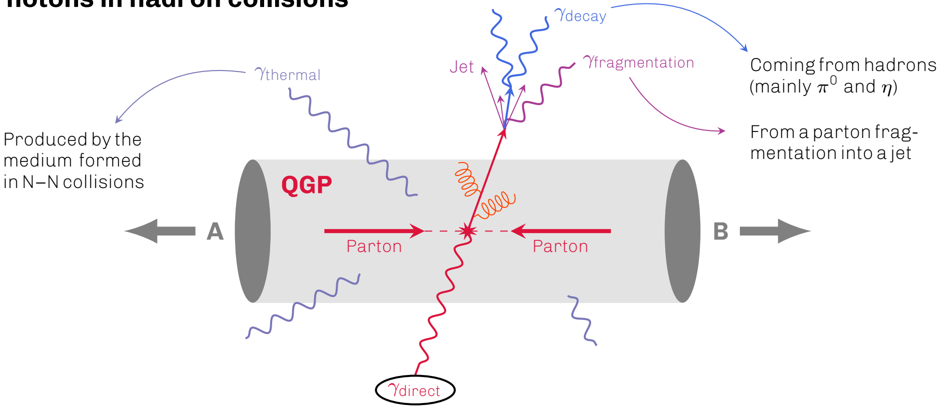

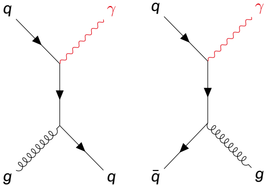

Main interests

- Calibrated energy **reference for parton energy loss studies** through γ_{direct}-hadron correlations
- Key observable to **test pQCD** and put new **constraints on theory**
- Measurement in p–Pb collisions → address **cold nuclear effects** by comparing with pp results and have a **reference for Pb–Pb** measurement and studying the QGP

Photon isolation

- γ_{direct} emitted back to the other hard products → selection using an **isolation method**

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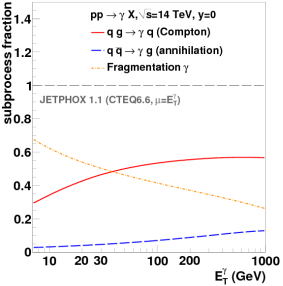
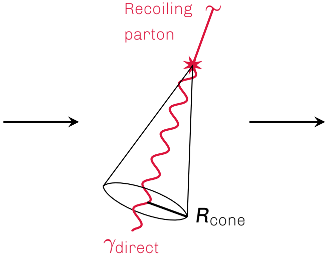
Isolated photons

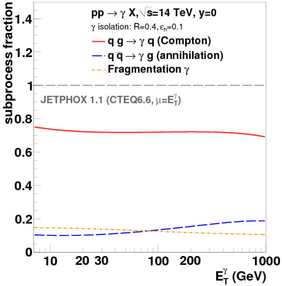
- **Isolation cone** of radius R_{cone} defined **around a candidate photon** at $(\eta_\gamma, \varphi_\gamma)$

$$R_{\text{cone}} = \sqrt{(\eta - \eta_\gamma)^2 + (\varphi - \varphi_\gamma)^2}$$

- Photon declared **isolated** if $p_T^{\text{iso}} < p_T^{\text{max}}$ (typical values → $R_{\text{cone}} = 0.4$, $p_T^{\text{max}} = 2\,\text{GeV}/c$)

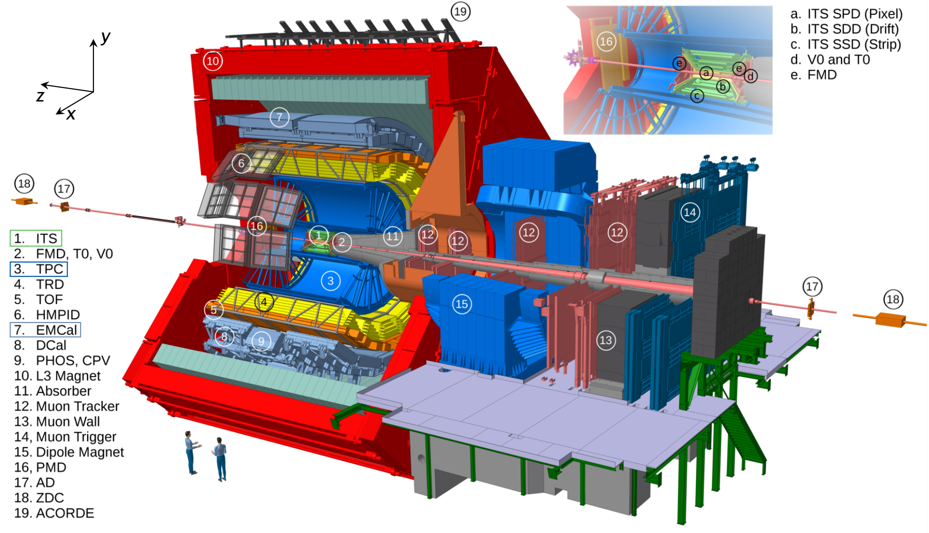






R. Ichou et al., Phys. Rev. D 82, 014015 (2010)

The ALICE experiment

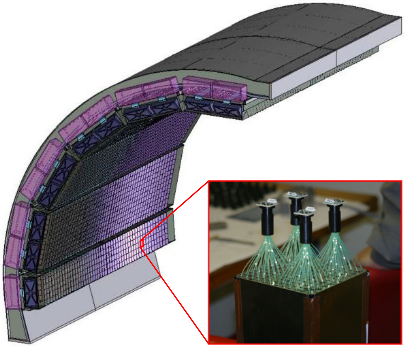


- ITS/TPC → **primary vertex** determination + charged particle **tracking and identification**
- EMCal → **electromagnetic particle** measurement (e.g. γ and electrons) + **γ/jet trigger**

EMCal, the ALICE ElectroMagnetic Calorimeter

Specifications

- 12 supermodules $\rightarrow$ 3072 modules $\rightarrow$ **12288 cells** with a $6 \times 6\,\mathrm{cm}^2$ area
- Each cell $\rightarrow$ **153 lead/scintillator** alternating layers (24.6 cm thick in total)
- Energy/position resolutions $\rightarrow$ $4.8\,\%/E \oplus 11.3\,\%/\sqrt{E} \oplus 1.7\,\%$ and $5.3\,\mathrm{mm}/\sqrt{E} \oplus 1.5\,\mathrm{mm}$
- Covers $|\eta_\gamma| < $ **0.67** and **107°** in azimuth (φ)
- Used as **trigger detector** (γ/jets)



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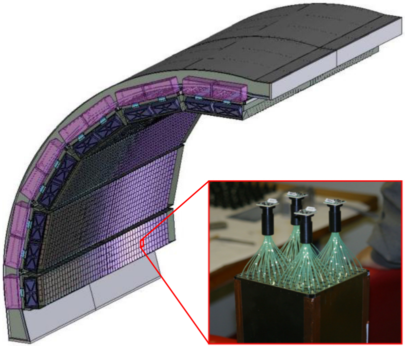


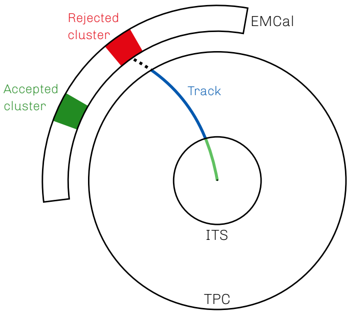
Photon selection

Neutral clusters (charged particle veto)

- Candidate clusters **must not** match a track spatially

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

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



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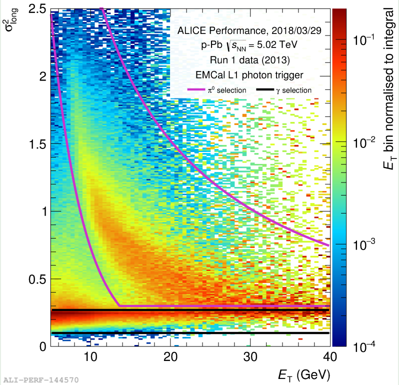
Candidate photons (shower shape cuts)

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

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



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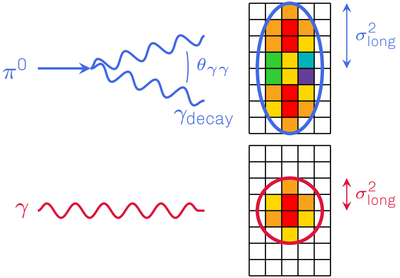

⚠ Not discriminant at high energy

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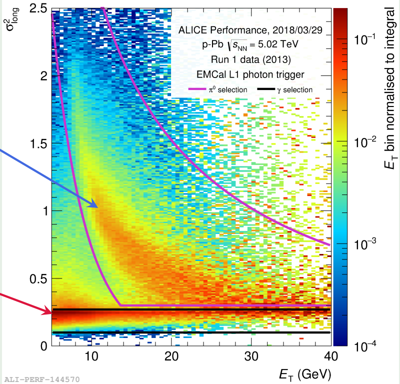
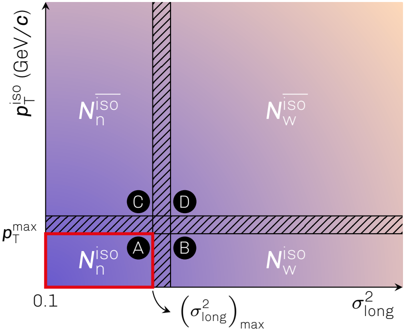


Signal extraction



The ABCD method: two strong assumptions
(ATLAS Coll., Phys. Rev. D 83, 052005 (2011))

- $N = S + B = \gamma_{direct}$ signal + background

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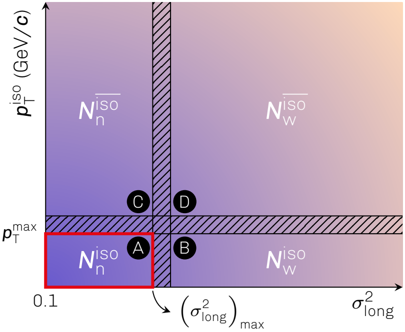

The ABCD method: two strong assumptions
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- $N = S + B = \gamma_{\mathrm{direct}}$ signal $+$ background
- Only **background clusters** in B, C and D

$$\left(N_{\mathrm{w}}^{\mathrm{iso}}, N_{\mathrm{n}}^{\overline{\mathrm{iso}}}, N_{\mathrm{w}}^{\overline{\mathrm{iso}}}\right) \equiv \left(B_{\mathrm{w}}^{\mathrm{iso}}, B_{\mathrm{n}}^{\overline{\mathrm{iso}}}, B_{\mathrm{w}}^{\overline{\mathrm{iso}}}\right)$$

- Background isolation fraction **equal in narrow (A, C)** and **wide (B, D)** σ^2_{long} regions

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

- Part of **signal region A** clusters induced by $\gamma_{\mathrm{direct}} \rightarrow$ **purity** of the $N_{\mathrm{n}}^{\mathrm{iso}}$ sample

$$\mathbb{P} = S_{\mathrm{n}}^{\mathrm{iso}} / N_{\mathrm{n}}^{\mathrm{iso}} = 1 - \frac{B_{\mathrm{n}}^{\mathrm{iso}}}{N_{\mathrm{n}}^{\mathrm{iso}}}$$

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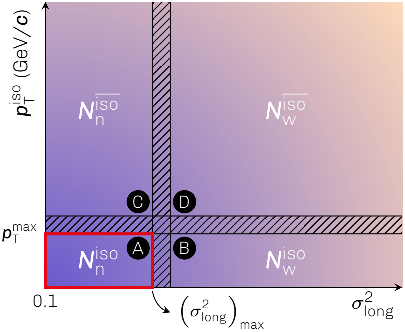

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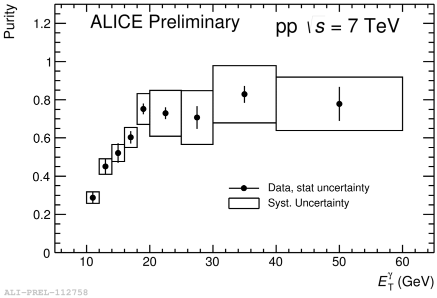
- Background $B_{\mathrm{n}}^{\mathrm{iso}}$ **estimated with data** and **corrected with simulation**

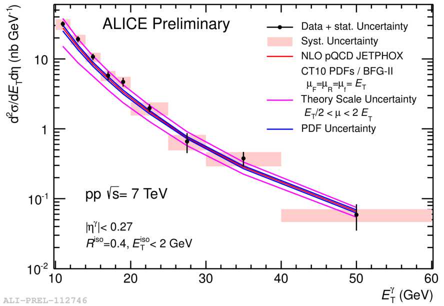
$$\mathbb{P}_{\mathrm{corr}} = 1 - \left(\frac{B_{\mathrm{n}}^{\mathrm{iso}} \times N_{\mathrm{w}}^{\overline{\mathrm{iso}}}}{N_{\mathrm{w}}^{\mathrm{iso}} \times N_{\mathrm{n}}^{\overline{\mathrm{iso}}}}\right)_{\mathrm{simu}} \times \left(\frac{N_{\mathrm{w}}^{\mathrm{iso}} \times N_{\mathrm{n}}^{\overline{\mathrm{iso}}}}{N_{\mathrm{w}}^{\overline{\mathrm{iso}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

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

Specifications

- 2011 datasets, EMCal Level-0 trigger at **5.5 GeV** → **8.6 × 10^6 events**
- Integrated luminosity → $\mathcal{L}_{int} = 473 \pm 22\,(stat) \pm 17\,(syst)\,nb^{-1}$





- Good agreement between **measurement and NLO** predictions (Jetphox – PDF CT10, FF BFG2)

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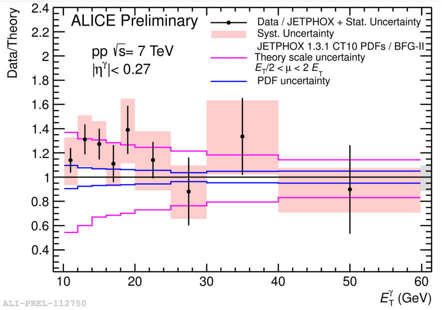
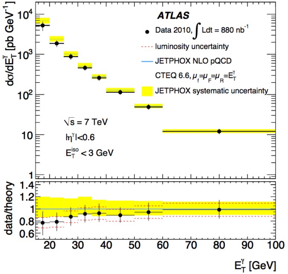


- ► Consistent with the **ATLAS and CMS** measurements in the overlapping E_T region (within uncertainties)
- ► Access to **lower E_T** isolated photons



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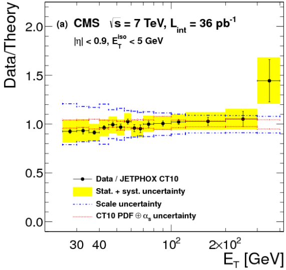

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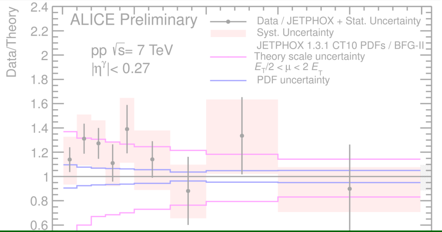

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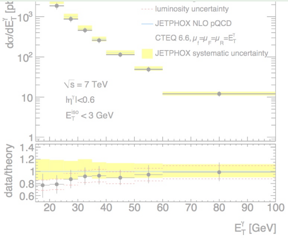
Ongoing improvements

- Correction for a **crosstalk between EMCal cells** (extensive studies by G. Conesa Balbastre)
- Re-evaluation of all systematic uncertainties



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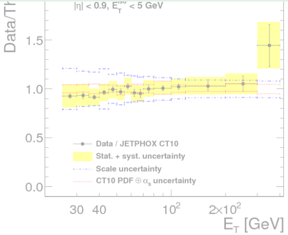

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Isolated photons in p–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV

Specifications

- 2013 datasets, EMCal Level-1 γ triggers at 11 GeV and 7 GeV $\rightarrow$ **1.9×10^6** events
- Integrated luminosity $\rightarrow \mathcal{L}_{int} = 4.64 \pm 0.41\,\mathrm{nb}^{-1}$

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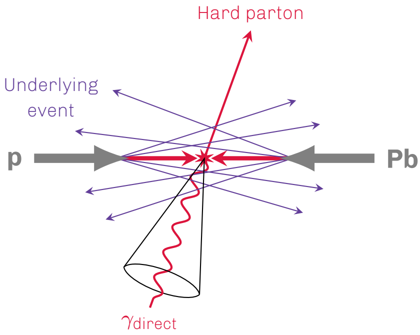
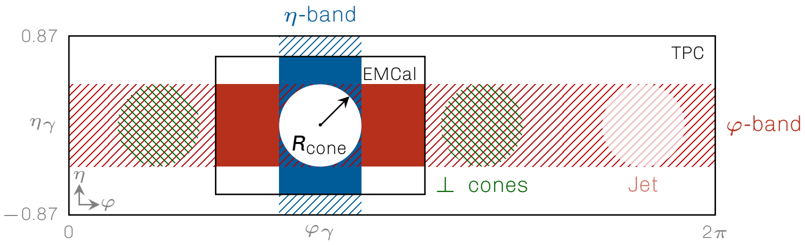
⚠ Larger contribution from the **underlying event (UE)** in p–Pb than in pp collisions



- Underlying event → **all processes but the hardest** LO parton interaction

Underlying event estimation

- UE estimated and **subtracted before** isolation, event-by-event $\rightarrow p_{\mathrm{T}}^{\mathrm{iso}} - \rho_{\mathrm{UE}} \times A_{\mathrm{cone}} < 2\ \mathrm{GeV}/c$



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⊥ cones	– Far from the isolation cone – Can be crosschecked with ALICE PHOS	– Neutral part not measurable

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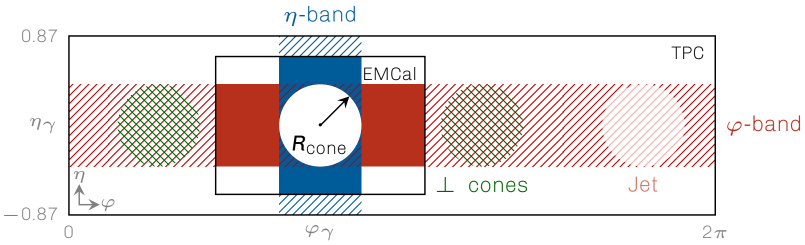

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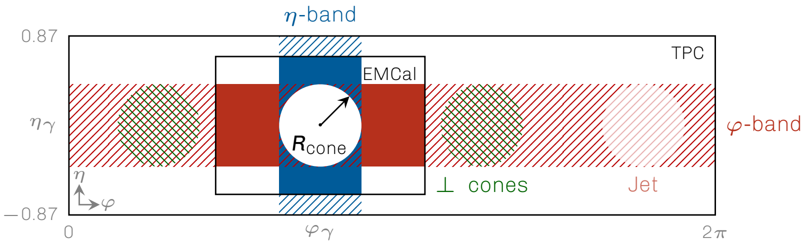

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η-band	– Neutral and charged parts both measurable	– Affected by a hard contribution from cone
φ-band	– Neutral and charged parts both measurable	– Affected by a hard contribution from cone – Possibly sensitive to the opposite jet

- Charged UE measurement in **perpendicular cones** then "neutral + charged" extrapolation → isolation using neutral + charged particles

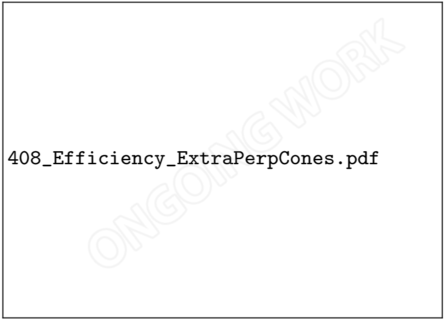
Isolated photon purity

406_SignalBackground_EMCNtrChg_ExtraPerpCone.pdf

407_CorrectedPurity_EMCNtrChg_ExtraPerpC

- Purity from $\sim$ 30 % to $\sim$ 70 % over the probed photon energy range $\rightarrow$ as expected, **lower contamination** (i.e. better purity) at high energy
- Three times more isolated photons thanks to the **fiducial cut enlargement** (implemented since my last talk at QGP France)

Towards the isolated photon cross section



- Efficiency $\varepsilon \rightarrow$ correction for photon **reconstruction/identification/isolation**

Towards the isolated photon cross section

408_Efficiency_ExtraPerpCones.pdf

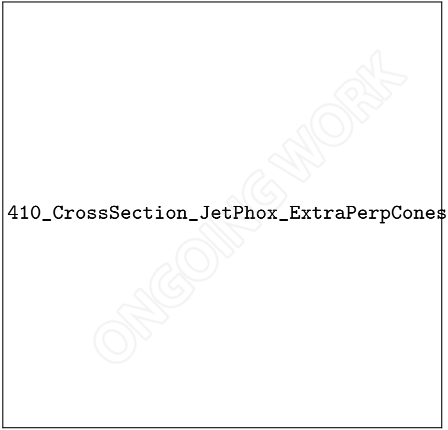
396_CrossSection_TotalSystematicUncertai

- Efficiency $\varepsilon \rightarrow$ correction for photon **reconstruction/identification/isolation**
- Preliminary **systematic uncertainty evaluation** $\rightarrow$ from $\sim 6\,\%$ to $\sim 24\,\%$ on average (ongoing refinement)

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

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

- pp-equivalent differential cross section → p–Pb γ_{iso} yield scaled by the **nuclear overlap factor** $\langle T_{\mathrm{pA}} \rangle$
- Comparison with Jetphox **pQCD calculations**
  - PDF CT10, nPDF EPS09, FF BFG2 (nPDF uncertainty → HKN07, nDS)
  - Scales → $\mu_{\mathrm{R}} = \mu_{\mathrm{f}} = \mu_{\mathrm{F}} = E_{\mathrm{T}}$ (scale uncertainty → half/double)
- **Good agreement** between data and theory



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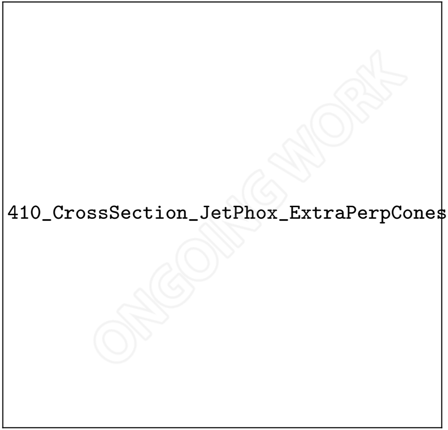

Ongoing improvements

- Final computation of all systematic uncertainties

Conclusions and outlook

Measuring photons in hadron collisions

- Photons **not affected** by the QCD medium → initial information on collision dynamics
- Test pQCD, have an energy reference for **parton energy loss**

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Isolated photons in ALICE, status and outlook

- Cross section measured in pp and p–Pb collisions with ALICE from 10 GeV to 60 GeV → **consistent with ATLAS and CMS (pp)** + access to lower photon energies
- Final corrections and crosschecks before publication
- Results internally documented (ALICE analysis notes) and work **presented in conferences** (Quark Matter 2017 and 2018)
- Further outlook → **compare p–Pb to pp** through a nuclear modification factor (R_{pA}) + with **inclusive direct photon measurements** in ALICE (low energies)

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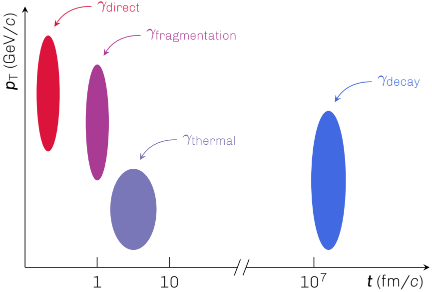
Merci pour votre attention !

Backup

Why study the γ_{direct} component?

- γ_{direct} **produced early** in hard processes and **not affected** by the traversed medium
  $\rightarrow$ Calibrated energy **reference for parton (q, g) energy loss** studies (correlations)
- Crucial to study their contribution to the total γ population to extract the **thermal component**



spectrum_contrib.png

- γ_{direct} well described by perturbative QCD calculations $\rightarrow$ measuring them helps to **test and constrain theory**

Data selection

Event selection

- Interaction **primary vertex** $\rightarrow |z_{\mathrm{V}}| < 10\,\mathrm{cm}$
- Events must have **at least one track**
- 1.3×10^6 events (EG1) and 0.6×10^6 events (EG2) kept

Cluster selection

- Clusterizer V1 with $(\mathbf{seed}, \mathbf{cell}) = (\mathbf{300}, \mathbf{100})$ **MeV**
- Minimal **number of cells** per cluster $\rightarrow N_{\mathrm{cells/clus}} \geq 2$
- Number of **local maxima** in a cluster $\rightarrow 1 \leq \mathrm{NLM} \leq 2$
- Distance (number of cells) to a **bad channel** $\rightarrow N_{\mathrm{DTBC}} \geq 2$
- Cluster **exoticity** $\rightarrow 1 - E_{\mathrm{cross}}/E_{\mathrm{cell}} > 0.97$
- Cluster **time** $\rightarrow |t_{\mathrm{clus}}| < 30\,\mathrm{ns}$
- Fiducial cut $\rightarrow |\eta| < 0.27$, $\varphi \in (104, 155)°$ (pp) and $|\eta| < 0.52$, $\varphi \in (91, 170)°$ (p–Pb)

Track selection

- Cluster-track matching $\rightarrow$ **TPC-only tracks** (`kTPCOnlyTracks`)
- Isolation $\rightarrow$ **hybrid tracks** (`kHybridTracks`) with $p_{\mathrm{T}} > 0.2\,\mathrm{GeV}/c$

EMCal T-Card crosstalk

- 1 EMCal supermodule $\rightarrow$ 36 FEE-Cards (4×8 cells in (η, φ) each)
- 1 FEE-Card $\rightarrow$ 2 T-Cards (2×8 cells in (η, φ) each)
- It has been observed in the lab a **crosstalk between cells in the same T-Card**, affecting the cell timing and energy distributions $\rightarrow$ likely the cause of the effect on the **shower shape broadening** in data
- Additional energy in the cells neighboring the highest energy cell in cluster might **broaden the photon clusters** and **symmetrize the shape for merged pi0 decay clusters**

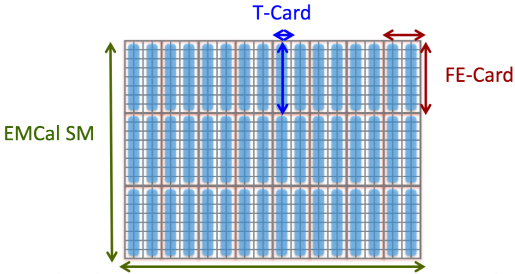
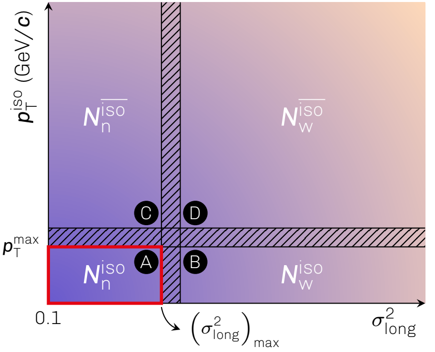


Figure from G. Conesa Balbastre

Signal extraction (p–Pb σ^2_{long} limits)



σ^2_{long} limit	10 – 12	12 – 16	16 – 18	18 – 60
narrow min	0.10	0.10	0.10	0.10
narrow max	0.40	0.35	0.32	0.30
wide min	0.60	0.45	0.35	0.33
wide max	2.10	1.95	1.85	1.83

- Isolation crit. (A, B) → $p_T^{iso} < 2$ GeV/c
- Anti-isolation crit. (C, D) → $p_T^{iso} > 3$ GeV/c

The ABCD method (Phys. Rev. D 83, 052005 (2011))

- Mainly **signal** region
  A = isolated narrow clusters (iso, n)
- Mainly **background** regions
  B = isolated wide clusters (iso, w)
  C = non-isolated narrow clusters ($\overline{\text{iso}}$, n)
  D = non-isolated wide clusters ($\overline{\text{iso}}$, w)

Particle quantities

- $S = \gamma_{direct}$ signal
- B = background (π^0, η, their γ_{decay}, etc.)
- $N = S + B \rightarrow$ **what is measured**

- Part of region A clusters truly induced by γ_{direct} → **purity** of the N_n^{iso} sample

$$\mathbb{P} = S_n^{iso}/N_n^{iso} = 1 - B_n^{iso}/N_n^{iso}$$

- Background B_n^{iso} **estimated with data** and **corrected with MC**

Signal extraction and purity estimation

- Data-driven background estimation in signal region **A**

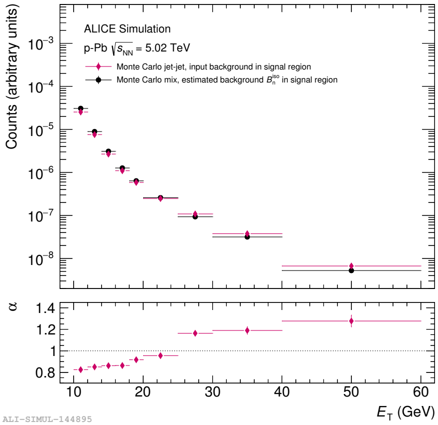
$$B_{\rm n}^{\rm iso} = \frac{N_{\rm w}^{\rm iso} \times N_{\rm n}^{\overline{\rm iso}}}{N_{\rm w}^{\overline{\rm iso}}} \Rightarrow \mathbb{P} = 1 - \frac{B_{\rm n}^{\rm iso}}{N_{\rm n}^{\rm iso}} = 1 - \left(\frac{N_{\rm w}^{\rm iso} \times N_{\rm n}^{\overline{\rm iso}}}{N_{\rm w}^{\overline{\rm iso}} \times N_{\rm n}^{\rm iso}}\right)_{\rm data}$$

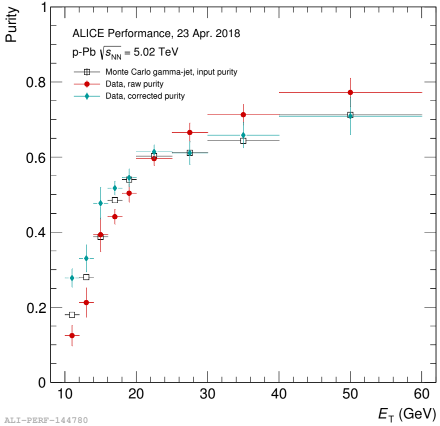
- Possibly **signal contamination** in background regions **B**, **C** and **D** and **non-constant** background isolation probability → purity must be **corrected using MC simulations**

- Jet-jet (JJ, **background**) + γ-jet (GJ, **signal**) → mixed and used to compute a **correction factor** α

$$\alpha = \frac{\overbrace{\left(B_{\rm n}^{\rm iso}\right)_{\rm JJ}}^{\text{real bkg.}}}{\underbrace{\left(B_{\rm n}^{\rm iso}\right)_{\rm MC\ mix}}_{\text{estimated bkg.}}} \Rightarrow \mathbb{P}_{\rm corr} = 1 - \underbrace{\left(\frac{B_{\rm n}^{\rm iso} \times N_{\rm w}^{\overline{\rm iso}}}{N_{\rm w}^{\rm iso} \times N_{\rm n}^{\overline{\rm iso}}}\right)_{\rm MC}}_{\alpha} \times \left(\frac{N_{\rm w}^{\rm iso} \times N_{\rm n}^{\overline{\rm iso}}}{N_{\rm w}^{\overline{\rm iso}} \times N_{\rm n}^{\rm iso}}\right)_{\rm data}$$

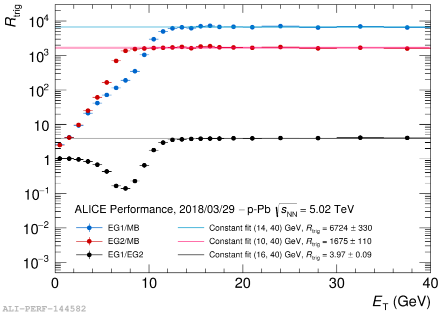
Purity correction (p–Pb)





- α rises from lower to greater than unity → raw purity $\mathbb{P}$ is clearly **underestimated (overestimated) at low (high) photon E_T**
- Corrected estimated purity **closer to “ideal purity”** → mandatory step

Luminosity and global efficiency (p–Pb)



408_Efficiency_ExtraPerpCones.pdf

ONGOING WORK

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

$$\varepsilon = \frac{dN_{\gamma_{iso}}^{rec}}{dE_T^{rec}} \Big/ \frac{dN_{\gamma_{iso}}^{gen}}{dE_T^{gen}}$$

- $\sigma_{min\ bias}$ measured with vdM scans $\sim$ 2.1 b (JINST 9, P11003 (2014))
- Here $\rightarrow$ $\mathcal{L}_{int} = \mathbf{4.64 \pm 0.41\ nb^{-1}}$ (syst. unc. obtained by multi-varying R_{trig} fit ranges)
- Correction for acceptance, reconstruction, identification and isolation $\rightarrow$ **global efficiency**

Systematic uncertainties (p–Pb)

387_CrossSection_SystematicUncertainties_WithTCard.pdf

Systematic uncertainties (p–Pb)

387_CrossSection_SystematicUncertainties_WithTCard_Combined.pdf