Neutral meson measurements with the ALICE experiment

Vladislav Kuskov for the ALICE collaboration
vladislav.kuskov@cern.ch

NRC «Kurchatov Institute»,
National Research Nuclear University MEPhI

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Motivation

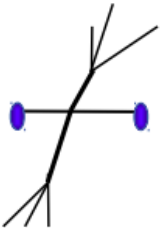
π^0 and η mesons provide strong constraints to:

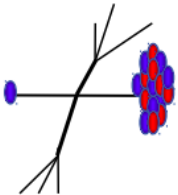
- Measurements of high-p_T identified hadrons (up to 200 GeV/c)
- Parton Distribution Functions (PDFs)
- Fragmentation Functions (FFs)

which are essential for **pQDC** calculations:

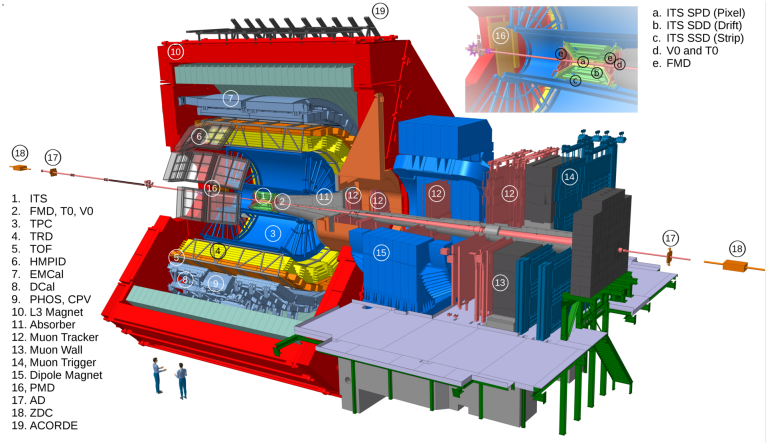
$$E\frac{d^3\sigma}{dp^3} = \sum_{i,j,k} f_i(x_i, Q^2) \otimes f_j(x_j, Q^2) \otimes D_k(z_k, Q^2) \otimes d\sigma_{ij\to kX}(x_i, x_j, Q^2)$$

- Background for direct photon and dielectron analyses
- Modification of the PDFs to the nuclear PDFs (nPDFs)
- Multiplicity dependencies: modification of particles production.





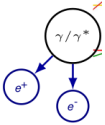
Detector setup



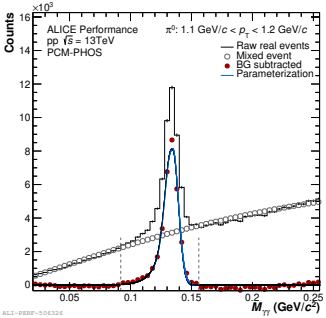
For the π^0 and η measurements the following detectors are used:

- Inner Tracking System (ITS)
- Time-Projection Chamber (TPC)
- Calorimeters EMCal/DCal and PHOS.

ITS and TPC are used to implement the Photon Conversion Method (PCM): reconstruction of photon by its conversion in the detector material

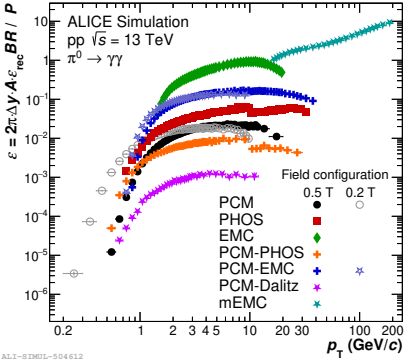


Neutral meson measurement techniques



Diphoton invariant mass method:

- Combinations of photons reconstructed via PCM and via calorimeters
- Background described by mixed-events or rotation technique
- Raw yields are extracted by integration around estimated masses

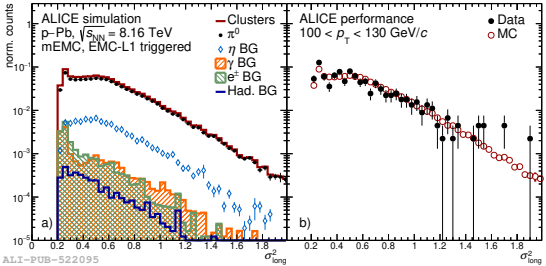


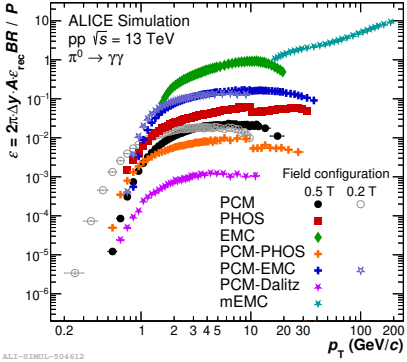
Invariant cross section from the raw yield ($N^{\pi^0(\eta)}$) as

$$E\frac{\mathrm{d}^3\sigma}{\mathrm{d}p^3} = \frac{1}{\varepsilon}\frac{1}{L_{int}}\frac{N^{\pi^0(\eta)} - N^{\pi^0}_{\mathrm{sec}}}{\mathrm{TR}\, p_{\mathrm{T}}\, \Delta p_{\mathrm{T}}}$$

L_{int} — integrated luminosity, TR — trigger rejection, $N^{\pi^0}_{\mathrm{sec}}$ secondary π^0

Neutral meson measurement techniques





Merged clusters approach:

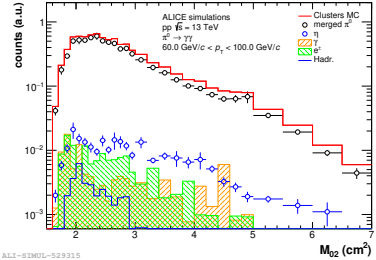
- Merged clusters in EMCal/DCal → separation from single clusters by shower shape
- High purity (>70%) of selected merged clusters
- Merged clusters approach provides ability to extend π^0 spectra range up to unprecedentedly high p_T

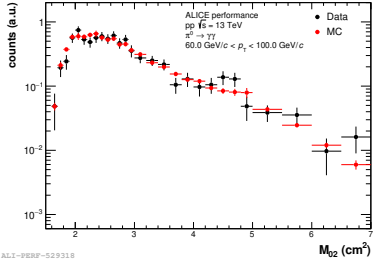
Invariant cross section from the raw yield ($N^{\pi^0(\eta)}$) as

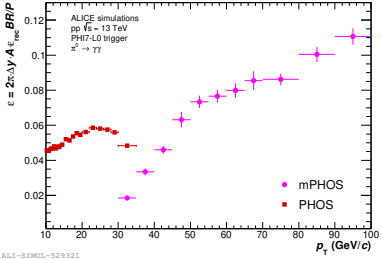
$$E\frac{d^3\sigma}{dp^3} = \frac{1}{\varepsilon}\frac{1}{L_{int}}\frac{N^{\pi^0(\eta)} - N^{\pi^0}_{sec}}{TR\, p_T\, \Delta p_T}$$

L_{int} — integrated luminosity, TR — trigger rejection, $N^{\pi^0}_{sec}$ secondary π^0

Merged clusters approach for PHOS

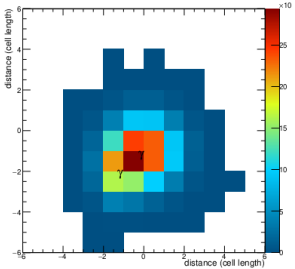






- Noticeable cluster merging for PHOS is shifted to ≈ 40 GeV/c compared with EMCal/DCal due to its high granularity
- p_T-dependent shower-shape cut is used to select merged clusters
- mPHOS method is limited to $p_T = 100$ GeV/c due to the limited dynamic range of the PHOS cells
- π^0 merged clusters in PHOS are selected with high purity $> 70\%$

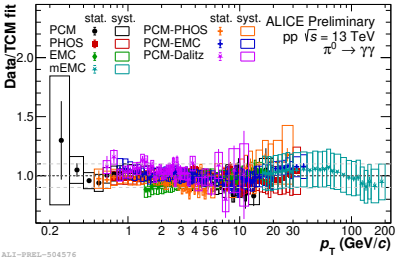
Example of a merged cluster:



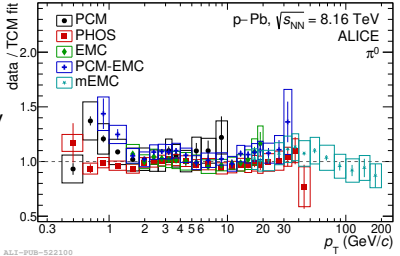
Combination of different techniques

π^0

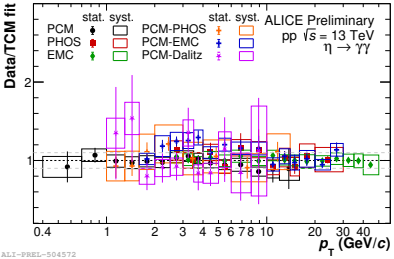
pp @ 13TeV



pPb @ 8TeV



η

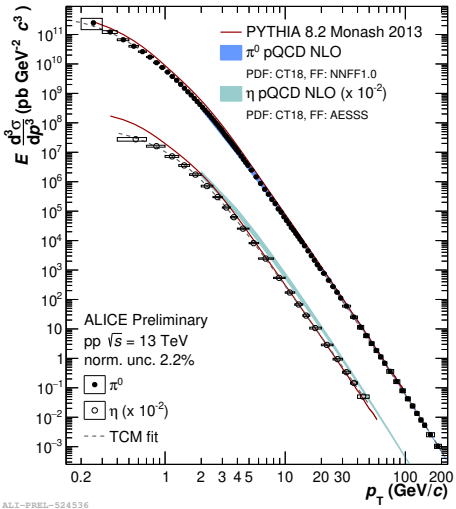


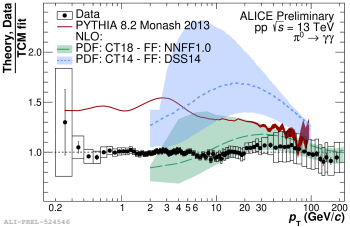
Spectra parameterized by two-component model (TCM):

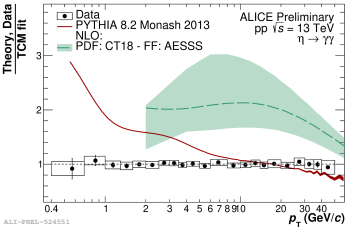
$$E\frac{\mathrm{d}^3\sigma}{\mathrm{d}p^3} = A_1 \exp\left(\frac{-E_\mathrm{T}^\mathrm{kin}}{T_\mathrm{e}}\right) + A_2\left(1+\frac{p_\mathrm{T}^2}{T^2 n}\right)^{-n}$$

Eur. Phys. J. C 75 no. 4, (2015) 166, arXiv:1501.05235 [hep-ph]

Invariant cross section of π^0 and η in pp collisions at 13 TeV



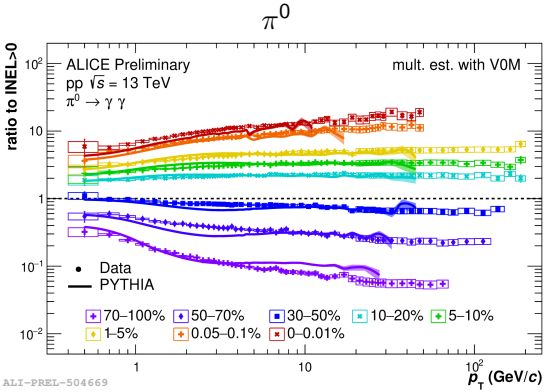


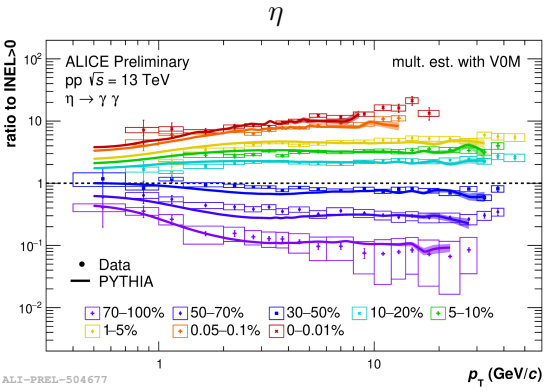


- PDF:CT14 – FF:NNFF1.0 fails to describe data;
- PDF CT18 for π^0 consistent with obtained cross section;
- However, PDF:CT18 – FF:AESSS does not describe data for η mesons $\rightarrow$ **updated FF is necessary** (NNFF1.0 applicable only for pions, kaons and protons);
- PYTHIA 8 shows different p_T dependence.

NLO calculation provided by W. Vogelsang.

Multiplicity dependencies in pp collisions

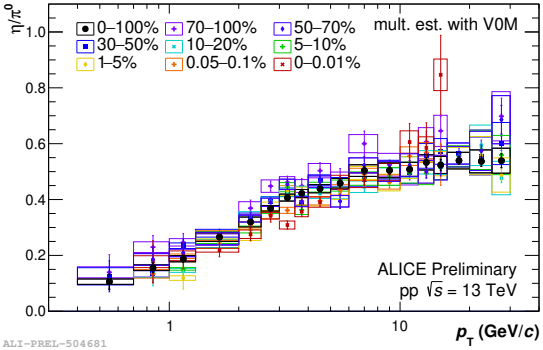




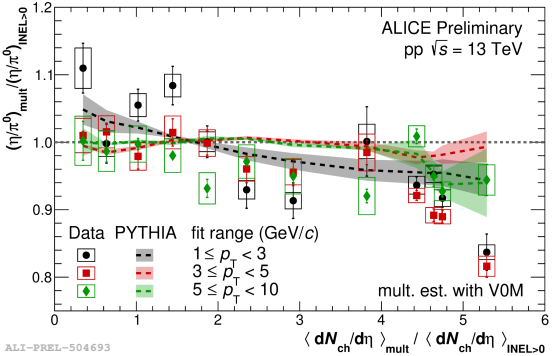
- INEL>0 means MB trigger + one track within $|\eta| < 1$
- PYTHIA 8 describes the magnitude and ordering of ratios (with slightly different p_T dependencies)
- Approach to unity at low p_T and hardening of p_T spectra with rising multiplicity

Multiplicity-driven modification of hadron production in pp collisions

η/π^0 ratios for multiplicity classes

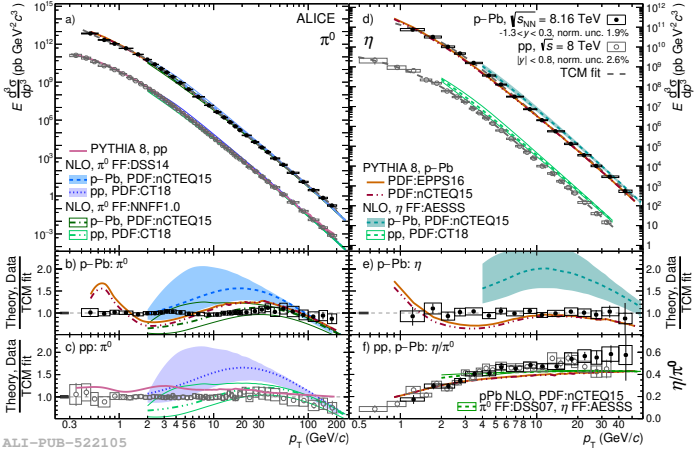


double η/π^0 ratios to INEL>0



- Hint of a multiplicity ordering visible
- No modification for mid and high p_T for low multiplicity
- PYTHIA predicts differences below $p_T \approx$ 2 GeV/c
- Slight suppression at high p_T for high multiplicity→ larger fraction of mesons inside jets ?
- Noticeable suppression at mid p_T for high multiplicity

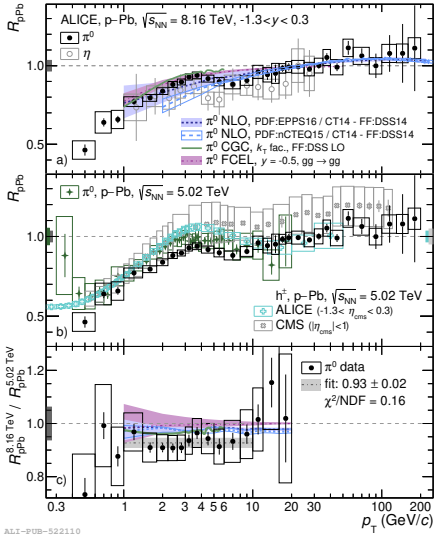
Invariant cross section of π^0 and η in p–Pb collisions at 8.16 TeV



- FF NNFF1.0 shows agreement with π^0 production in pPb collisions as well as in reference pp
- PDF nCTEQ15 consistent with cross section of π^0 production, however it does not describe η production $\rightarrow$ **FF for η is essential**
- NLO and PYTHIA show similar η/π^0 ratio as in the data (discrepancy in p_T shape correlated between π^0 and η), but still underestimate them

Phys. Lett. B 827 (2022) 136943, arXiv:1605.06436 [hep-ex]

Nuclear modification factor for π^0 and η in p–Pb collisions



Nuclear modification factor:

$$R_{\mathrm{pPb}} = \frac{1}{\langle N_{coll} \rangle} \frac{\mathrm{d}^2 N_{\mathrm{pPb}}}{\mathrm{d}\, p_{\mathrm{T}}\, \mathrm{d}\, y} \Big/ \frac{\mathrm{d}^2 N_{\mathrm{pp}}}{\mathrm{d}\, p_{\mathrm{T}}\, \mathrm{d}\, y}$$

- For $p_{\mathrm{T}} > 10$ GeV/c, no deviation from unity is observed within uncertainties for both mesons;
- For $p_{\mathrm{T}} < 10$ GeV/c, a suppression of similar magnitude is observed for both mesons within uncertainties (shadowing effects);
- A stronger suppression for pPb collisions at 5.02 TeV could originate from larger shadowing in the nPDFs, which due to the smaller x probed at 8.16 TeV.

Conclusion

- Clear ordering of π^0 and η mesons in pp collisions at 13 TeV and p–Pb collisions at 8.16 TeV. These spectra provide strong constrains to PDFs and FFs used in models (pQCD calculations and PYTHIA)
- Spectra measured at unprecedentedly high p_{T} range up to 200 GeV/c thanks to merged cluster approach. This approach is extended to PHOS with excellent efficiency and purity for $p_{\mathrm{T}} \geq 40$ GeV/c
- Multiplicity dependence study in pp collisions shows slight suppression of η/π^0 at very high multiplicities, which is underestimated by PYTHIA
- R_{pPb} for π^0 and η in p-Pb collisions at 8.16 TeV are consistent with unity within uncertainties at high p_{T} and show suppression at lower p_{T} which is in agreement with theory predictions

THANK YOU FOR YOUR ATTENTION!