Recent neutral meson and direct photon measurements with ALICE

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Motivation

π^0 and η mesons:

- Constrains to pQCD calculations: (nuclear) Parton Distribution Functions ((n)PDFs) and Fragmentation Functions (FFs)

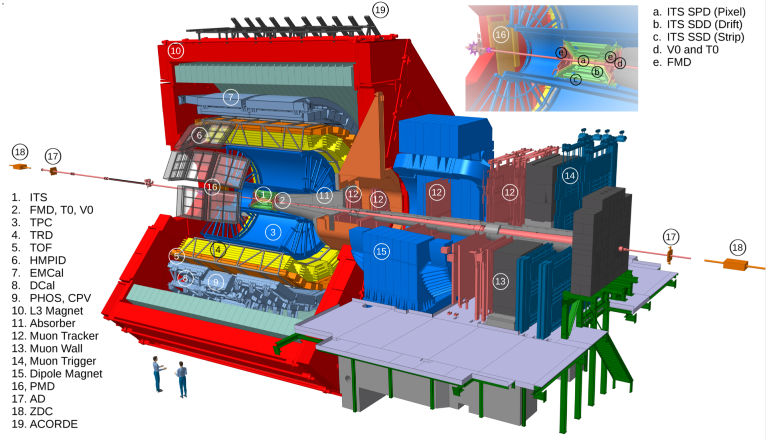
$$E\frac{d^3\sigma}{dp^3} = \sum_{i,j,k} f_i(x_i, Q^2) \otimes f_j(x_j, Q^2) \otimes D_k(z_k, Q^2) \otimes d\sigma_{ij\to kX}(x_i, x_j, Q^2)$$

- Background for direct photon and dielectron analyses
- Testing scaling properties on x_T or m_T distributions

Direct photons:

- Studies on the space-time evolution of Quark-Gluon Plasma (QGP) with correlations of thermal direct photons
- Prompt direct photons (from Compton and annihilation processes) allow to test (n)PDFs and FFs
- Studies on the jet-photon correlations

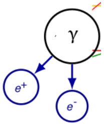
Experimental setup



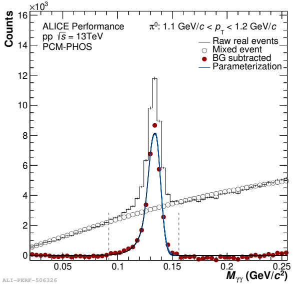
For the photon measurements, the following detectors are used:

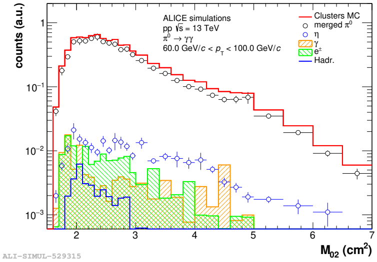
- Inner Tracking System (ITS)
- Time Projection Chamber (TPC)
- Calorimeters EMCal/DCal and PHOS.

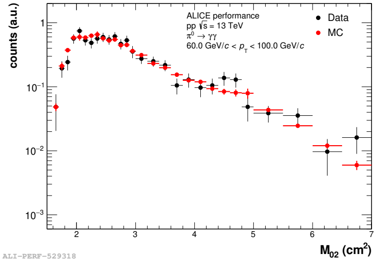
ITS and TPC are used to implement the Photon Conversion Method (PCM): reconstruction of photon by its conversion in the detector material



Neutral meson measurement techniques







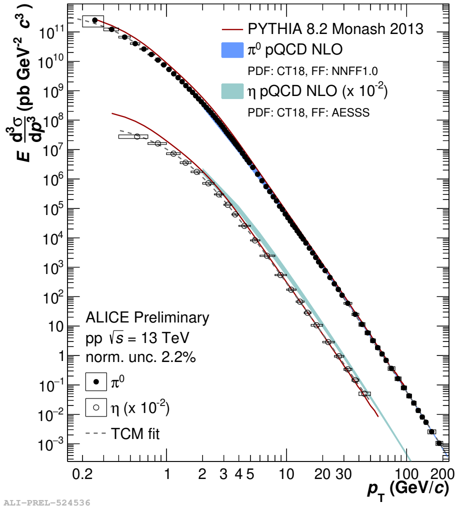
Diphoton invariant mass method:

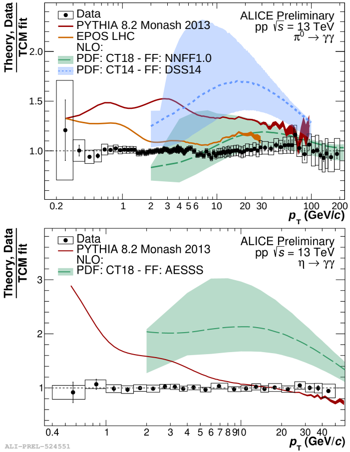
- Combinations of photons reconstructed via PCM and via calorimeters
- Background described by mixed-events or rotation technique
- Raw yields are extracted by integration around estimated masses

Merged clusters approach (only for π^0):

- Merged clusters in EMCal/DCal and PHOS → 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 of π^0 and η in pp collisions at 13 TeV



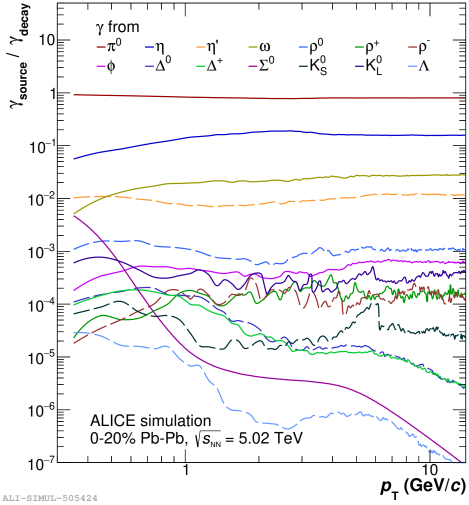


- PDF:CT14 – FF:NNFF1.0 fails to describe data;
- PDF CT18 for π^0 consistent with obtained cross section;
- However, PDF:CT18 – FF:AESSS does not describe data for η mesons $\rightarrow$ **updated FF is necessary** (NNFF1.0 applicable only for pions, kaons and protons);
- PYTHIA 8 shows different p_T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

NLO calculation provided by W. Vogelsang.

Direct photon production in Pb–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV

Photons contamination:



- Subtraction method:

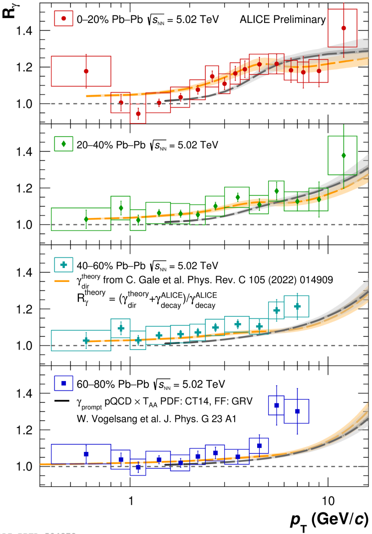
$$\gamma_{dir} = \gamma_{inc} - \gamma_{decay} = \left(1 - \frac{\gamma_{decay}}{\gamma_{inc}}\right)\gamma_{inc}$$

$$\gamma_{dir} = \left(1 - \frac{1}{R_\gamma}\right)\gamma_{inc}$$

- Inclusive photons: all photons produced in the event
- Decay photons: photons calculated by decay simulation of measured mesons (π^0 and η) or m_T scaled hadron spectra
- Double ratio:

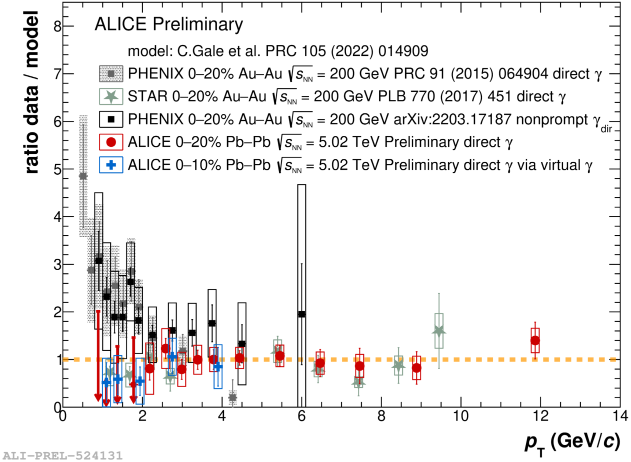
$$R_\gamma = \frac{\gamma_{inc}}{\gamma_{decay}} \approx \frac{\gamma_{inc}/\pi^0_{meas}}{\gamma_{decay}/\pi^0_{sim}}$$

Direct photon production in Pb–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV



- At low p_T $R_\gamma \approx 1$ — no additional thermal or pre-equilibrium photons excess
- $p_T > 3$ GeV/c — excess of prompt photons
- Scaled NLO pQDC calculations in pp collisions using PDF:CT14, FF:GRV describe data within uncertainties
- Hydrodynamic model including prompt, thermal and pre-equilibrium consistent with data down to low p_T
  C. Gale et al. Multimessenger heavy-ion collision physics, Phys.Rev.C 105 (2022) 1, 014909

Contribution to direct photon puzzle



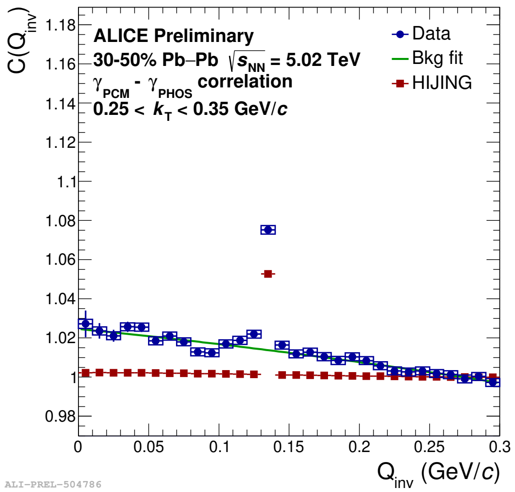
Direct photon puzzle: unexpectedly large elliptic flow v_2 and yield of direct photons measured by PHENIX

Phys.Rev.C 94 (2016) 6, 064901

- ALICE measurements are in agreement with model calculations

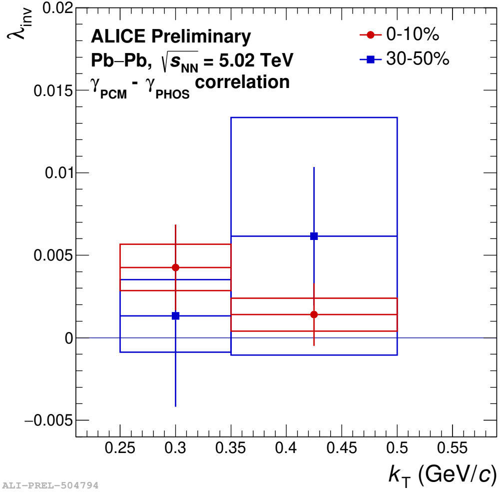
model: C. Gale et al. Phys. Rev. C 105 (2022)

Bose-Einstein correlations of direct photons in Pb–Pb collisions



- Correlation function $C(Q_{\rm inv})$ is sensitive to the size of the emitting source $\rightarrow$ peak at low $Q_{\rm inv}$ indicates $\gamma\gamma$ correlations
- $C(Q_{\rm inv}) = \dfrac{A(Q_{\rm inv})}{B(Q_{\rm inv})}$, where:
  $A(Q_{\rm inv})$ stands for the invariant mass distribution $M_{\gamma\gamma}$ $(Q_{\rm inv})$ in the same event
  $B(Q_{\rm inv})$ stands for $M_{\gamma\gamma}$ from mixed events $\rightarrow$ corresponds to combinatorial background
- The fit function:
  $C(Q_{\rm inv}) = 1 + \lambda_{\rm inv} \exp(-R^2_{\rm inv} Q^2_{\rm inv})$
  $R^2_{\rm inv}$ — source size

Bose-Einstein correlations of direct photons in Pb–Pb collisions



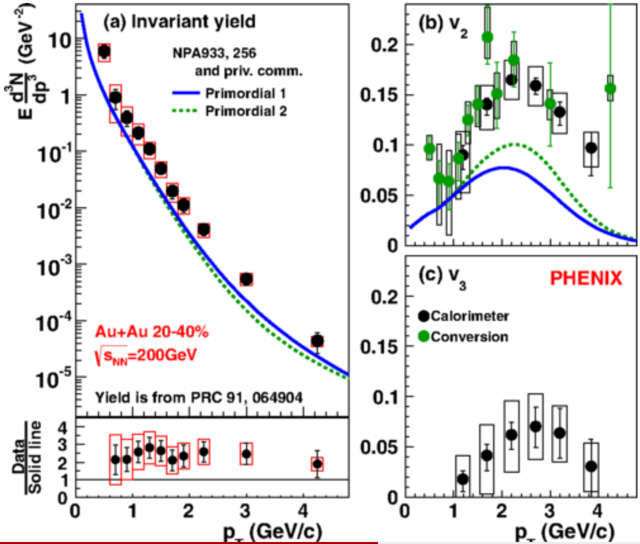
- Correlation function $C(Q_{\mathrm{inv}})$ is sensitive to the size of the emitting source
- The fit function: $C(Q_{\mathrm{inv}}) = 1 + \lambda_{\mathrm{inv}} \exp(-R^2_{\mathrm{inv}} Q^2_{\mathrm{inv}})$ $\rightarrow$ extraction of correlation strength λ_{inv} from the fit
- λ_{inv} is consistent with 0 within uncertainties $\rightarrow$ no significant information on the source size yet

Summary and outlook

- Spectra of neutral mesons in pp collisions at $\sqrt{s} = 13$ TeV measured in 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 $p_{\mathrm{T}} \geq 30$ GeV/c
- Direct photon production in Pb–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV measured up to $p_{\mathrm{T}} = 14$ GeV/c. At low p_{T} R_{γ} is showing no discrepancy from 1 within uncertainties $\rightarrow$ there is no significant additional direct photon source of thermal photons or pre-equilibrium photons
- Direct photon puzzle is not currently observed in ALICE within experimental uncertainties
- Bose-Einstein correlations of direct photons could be used to estimate the size of the Quark-Gluon Plasma at the earliest stages of its evolution and could also provide complementary method for R_{γ} measuring down to $p_{\mathrm{T}} \approx 0.25$ GeV/c

THANK YOU FOR YOUR ATTENTION!

Backup. Direct phtoton puzzle



Direct photon puzzle: unexpectedly large elliptic flow v_2 and yield of direct photons measured by PHENIX

- Large direct photon yield and elliptic flow coefficient cannot be described simultaneously

See the following paper for details:

Phys.Rev.C 94 (2016) 6, 064901