Direct photon and neutral pion production in pp and Pb-Pb collisions measured with the ALICE experiment at the LHC

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Initial conditions (Parton Distribution Functions)

- Different sensitivity to aluon PDF

Cross-section of hard process

- Similar techniques

Fragmentation

- Fragmentation is not dominant source of photons at not too small $x_T=2p_T/\sqrt{s}$

- One can vary fragmentation contribution imposing isolation cut



Initial conditions (nPDF)

Photons provide tool to control

Parton energy loss

- Modification of initial conditions or final state effect?

Fragmentation

- In matter or in vacuum?

Thermal photons

-Temperature, evolution of hot matter

Direct γ and π^0 in pp and Pb-Pb collisions





Photon measurements in ALICE





π^0 yield in Pb-Pb collisions measured with different approaches





π^0 spectra in Pb-Pb and pp collisions

pp: Clear power-law dependence at high $\ensuremath{p_{\text{T}}}\xspace$.

√s (TeV)	n
0.2	8.22 ± 0.1
2.76	6.0 ± 0.1

Pb-Pb: π^0 invariant yield measured from central to peripheral collisions Clear modification on the spectrum in central collisions







Quantitative comparison: R_{AA}

$$R_{AA}(p_T) = \frac{(1/N_{\text{evt}}^{AA}) d^2 N_{\text{ch}}^{AA}/d\eta \, dp_T}{\langle N_{\text{coll}} \rangle (1/N_{\text{evt}}^{pp}) d^2 N_{\text{ch}}^{pp}/d\eta \, dp_T}$$

Variable with clear meaning:

- unity in case of independent NN collisions
- below unity in case of suppression
- Output Depends not only on energy loss, but also on the steepness of the spectrum
- Bepends on initial conditions (PDF modifications in nuclei, isospin effects in case of (γ,Z)...)



GLV: Phys. Rev. C80, 54902 (2009), Phys. Lett.B704, 590 (2011)

final-state radiative energy loss, "nuclear broadening", initial dN_g/dy constrained by LHC dN_{ch}/dη. R_{AA} centrality and p_T dependence reproduced

WHDG: Int.J.Mod.Phys.E16, 2193 (2007) collisional and radiative parton energy loss, geometrical path length fluctuations. 0-5%: R_{AA} reproduced > 10%: Suppression overestimated



Comparison to theory (2)

EPOS: Phys. Rev. C85, 064907 (2012)

Low p_T: Hydrodynamic flow High p_{T} : Energy loss of string segments

0-5%, 20-40%: π⁰ reproduced well 60-80%: discrepancy: underestimation of the hydrodynamic flow contribution $(1 < p_T < 5 \text{ GeV/c})$?

Nemchik: Phys. Rev. C86, 054904 (2012), Arxiv 1310.3455

Low p_{T} : Hydrodynamic description High p_{T} : Color dipole absorption

0-5%: Approximately described (except intermediate p_{T}) region. **20-40%**: overpredicted up to $p_T = 2 \text{ GeV/c}$







Direct photon measurement

ALICE measures direct photon spectrum using subtraction

$$\gamma^{direct} = \gamma^{inclusive} - \gamma^{decay}$$



R_{γ} =1 means absence of direct photons



Direct photon double ratio in pp



No excess of direct photons within systematic errors seen in pp collisions Data, however, consistent with expectation of pQCD.



Direct photon double ratio in Pb-Pb collisions

In **central** collisions double ratio shows excess of 20% ± 5%stat ± 10%syst for $p_T < 4 \text{ GeV/c}$

In peripheral events double ratio shows no excess at any value of p_{T}

Consistency of Pb-Pb measurements with N_{coll}-scaled pQCD predictions in pp at high p_{T} >5-6 GeV/c justifies that initial conditions are not modified in Pb-Pb collisions.

In central collisions at low $p_T < 4 \text{ GeV/c}$ excess with respect to N_{coll}-scaled pQCD predictions - the region where thermal photons are expected.





Direct photon spectrum



Systematic uncertainties on the double ratio are partially correlated in p_T . Significance of direct photon signal depends on degree of correlation. Easiest example for fully correlated uncertainties: Material budget uncertainty (absolute 4.5% of double ratio)



Collective flow



Initial spatial anisotropy, defined by target and projectile, transformed into anisotropy in momentum space of final particles.

 $\frac{dN}{d\phi} = 1 + 2v_1 \cos(\phi - \Psi_{RP}) + 2v_2 \cos[2(\phi - \Psi_{RP})] + 2v_3 \cos[3(\phi - \Psi_{RP})] + \dots$





Elliptic flow of inclusive and decay photons

Above 3 GeV/c v_2 of inclusive photons significantly smaller than v_2 of decay photons \rightarrow Direct photon v_2 contribution with $v_2^{\text{direct}} < v_2^{\text{decay}}$

Below 3 GeV/c v_2 of inclusive photons is consistent with v_2 of decay photons within uncertainties \rightarrow Either contribution of direct photons with similar v_2 or no

direct photons





Direct photon v2



Close to pole $1/(1-R_{\gamma})$ =>Error propagation highly non-trivial

Large direct photon v_2 for $p_T < 3$ GeV/c measured

Magnitude of v_2 comparable to v_2 of hadrons points to late production times of direct photons after flow is established – in contrast to most theoretical calculations, where thermal photons are emitted from hot early stage (QGP), where flow is not developed yet.

> Central points for direct photon yield and v_2 underestimated by most theoretical calculations by factors of 2-10 ALL-P No significant deviation beyond 2σ





Alternative representation

Comparison of $v_2^{\gamma, \text{ incl}}$ to various models:

 $\begin{array}{l} V_{2}{}^{\gamma,\,\text{decay}} + V_{2}{}^{\gamma,\,\text{NLO}} \\ V_{2}{}^{\gamma,\,\text{decay}} + V_{2}{}^{\gamma,\,\text{NLO}} + V_{2}{}^{\gamma,\,\text{thermal}} \end{array}$

 v_{γ}^{decay} based on measured π^0 data

Allows decoupling of measured R_{γ} from comparison





Quantitative comparison to models

Deviations from 0 for data, mainly explained by contribution from prompt photons

Region of interest for thermal sources: 1-3 GeV/c

Large systematic uncertainties

No statement on the existence of direct photon puzzle can be made by ALICE at this stage







Triangular flow of direct photons

First measurement of inclusive photon v_3 at LHC

Above 3 GeV/c inclusive photons consistently smaller than decay photons, with large statistical uncertainties \rightarrow Direct photon v₃ contribution with V₃^{γ ,direct} < V₃^{γ ,decay} as expected for prompt photons

Below 3 GeV/c mostly consistent within uncertainties

 \rightarrow Either contribution of direct photons with similar v_3 or no direct photons





Triangular flow: comparison to theory



Very small contribution from thermal v_3 No significant deviation from zero in region of interest between 1-3 GeV/c







Conclusions

- NLO pQCD calculations overestimate π^0 production in pp at \sqrt{s} = 2.76 and 7 TeV
- $\pi^0 R_{AA}$ measured in different centrality classes. $R_{AA} \sim 0.1$ for 0-5% centrality. Comparison to theoretical models (GLV and WHDG) is shown.
- The measured suppression is stronger than at lower $\sqrt{s_{NN}}$. The shapes of $R_{AA}(p_T)$ at $\sqrt{s_{NN}}$. = 2.76 TeV and at $\sqrt{s_{NN}}$ = 200 GeV are similar.
- Photon double ratio R_γ ≈ 1.2 ± 0.05^{stat} ± 0.1^{syst} has been measured by ALICE in 0-40% Pb-Pb collisions, indicating presence of direct photons
- Direct photon yield extracted with an exponential slope of $T = 304 \pm 51^{\text{stat+syst}} \text{ MeV}$
- Direct photon v₂ which is of similar size as the charged hadron flow has been measured in 0-40% Pb–Pb collisions
- First measurement of inclusive photon v_3 at the LHC in 0-40% Pb-Pb collisions v_3^{vincl} ~ v_3^{\gamma decay}
- Current uncertainties on R_γ, v_n^{γ, incl} & v_n^{γ, decay} do not allow statement on the existence of a direct photon puzzle at LHC energies





Backup slides



Contributions of different hadrons into decay photon spectrum





Material thickness to the middle of TPC is $X/X_0=11.4\pm0.5^{sys}$ %. ALICE material thickness agrees within ±4.5% with its implementation in GEANT simulations











Evolution of R_{AA}



