Direct photons and neutral mesons in pp, p-Pb and Pb-Pb collisions measured with the ALICE experiment

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Photon detection in ALICE

Photon Conversion Method (PCM)
- Good resolution at low $p_T$
- Small conversion probability (~8.5%),
- Full azimuthal angle coverage, $|\eta|<0.9$
- Small contamination of the photon sample

PHOS
- Excellent resolution at high $p_T$
- High efficiency of the photon detection
- Limited acceptance ($60^\circ$) $|\eta|<0.135$

EMCAL
- Large acceptance ($100^\circ$) $|\eta|<0.9$
- Limited energy resolution
Neutral pion production in pp

Updated DSS: “Global extraction of the parton-to-pion fragmentation functions at NLO accuracy in QCD”, R.J. Hernández-Pinto, M. Epele, D. de Florian, R. Sassot, M. Stratmann, arXiv:1609.02455:

Agreement with ALICE pp 7 TeV data: $\chi^2/\text{NDF} = 32.1/11$
Neutral pion production in $p$-$Pb$

Preliminary data do not show cold nuclear effects in pion $R_{p-Pb}$.
Neutral pions in Pb-Pb

Neutral pions show suppression at large $p_T$, which corresponds to the energy loss by hard parton. Not all models are able to reproduce centrality and $p_T$ dependence of the suppression.

\[
R_{AA}(p_T) = \frac{(1/N_{\text{evt}}^{AA}) \frac{d^2N_{\text{ch}}^{AA}}{d\eta dp_T}}{(N_{\text{coll}})(1/N_{\text{evt}}^{pp}) \frac{d^2N_{\text{ch}}^{pp}}{d\eta dp_T}}
\]

Photon sources in AA collisions

Prompt direct photons dominate at high $p_T$.

$\Rightarrow$ measure prompt direct photons in pp collisions, normalize to the number of binary collisions and subtract: produce thermal direct photon spectrum.

One can separate direct and decay photons experimentally, but thermal and prompt direct photons are indistinguishable.

$pQCD \sim 1/P_t^n$

$Decay \sim 1/P_t (e^{-p_T/T} + 1/P_t^n)$

$Thermal \sim e^{-p_T/T}$
Collective flow of photons can be decomposed into contributions of decay and direct photons:

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

\[
v_n \equiv \langle \cos[n(\phi - \Psi_{RP})] \rangle
\]

Intermediate result in direct photon spectrum extraction:

\[
R = \frac{N_y^{incl}}{N_y^{decay}}
\]

\[
v_{n,dir} = \frac{v_{n,incl} R - v_{n,decay}}{R - 1}
\]
Direct photon spectrum and flow at RHIC


Amount of direct photon flow is comparable with flow of pions

Direct photon puzzle at RHIC:
- Theory underestimates direct photon yield
- Strongly underestimates amount of direct photon flow.
Inclusive photon spectra in PHOS and PCM

Systematic uncertainties are $p_T$ correlated to large extend.

Detailed analysis shows that measurements are statistically consistent.
Direct photon double ratios in PHOS and PCM show better agreement with each other than inclusive photon spectra because some systematic uncertainties cancel.

$$R_\gamma \equiv \frac{\gamma_{\text{incl}}}{\pi^0_{\text{param}}} \left/ \frac{\gamma_{\text{decay}}}{\pi^0_{\text{param}}} \right. = \frac{\gamma_{\text{incl}}}{\gamma_{\text{decay}}}$$

Double ratios in PHOS and PCM show better agreement with each other than inclusive photon spectra because some systematic uncertainties cancel.
Direct photon spectra in Pb-Pb collisions

Measured direct photon spectra agree with NLO QCD predictions scaled with $N_{\text{coll}}$, and exceed them at $p_T < 4$ GeV/c.

Full theoretical predictions, including thermal direct photon predictions predict somewhat smaller yield, though touching systematic uncertainties.
Similar to RHIC energy direct photon flow is underestimated by theoretical calculations especially at $p_T < 2$ GeV/c approximately by factor 2-10.

Difference between data and theory predictions ~1-2 standard deviations: not very significant.

One should carefully treat all uncertainties
Conclusions

- Neutral meson spectra in pp collisions provide possibility to test QCD predictions and restrict PDF and FF for identified hadrons in wide kinematic region.
- Neutral meson spectra in p-Pb and Pb-Pb collisions provide possibility to test energy loss by hard partons in hot quark-gluon matter.
- Direct photon spectrum and flow provide possibility to study initial state of the AA collision and evolution of the hot matter at the very beginning of the collision.
- ALICE has collected a large amount of high quality data in Run2, so one can expect many new results.

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Prompt direct photon spectrum at pp collisions is well reproduced by QCD calculations.

There is agreement with $N_{\text{col}}$ scaled pp spectrum at high $p_T > 4$ GeV/c and clear excess over the expected prompt photon yield at $p_T < 3$ GeV/c.
Double ratio in pp collisions at 7 TeV

$$R_{NLO} = 1 + \frac{\gamma_{direct, NLO}}{\gamma_{decay}}$$

3.8 \times 10^8 event were analyzed

Some uncertainties: normalization, $\pi^0$ spectrum, Efficiency partially cancel

Measurement agree with no direct photon signal and with NLO QCD predictions