Direct virtual photon production in minimum-bias and high-multiplicity pp collisions at \( \sqrt{s}=13 \text{ TeV} \) at the LHC with ALICE

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What do we call “direct photons” in hadronic collisions?

- All photons arising from processes during the collision rather than from decays of hadrons.

Direct photons in Heavy Ion Collisions (HIC):

- Prompt direct photons (high \( p_T \) range): from the initial hard scattering of quarks and gluons. Provide information on parton distributions in nuclei.
- Thermal photons (low \( p_T \) range): carry information about the temperature (approximate exponential spectrum), collective flow, and space-time evolution of the medium.
- From partonic interactions in the QGP.
- From hadron annihilation in the hadronic phase.
- Other medium related mechanisms
  - Interaction of hard scattered photons with the medium
  - Jet-photon conversion, jet bremsstrahlung.

Why to study direct photons in pp collisions?

- Baseline for thermal photons in HIC: crucial reference to establish the presence of thermal radiation from the hot and dense medium created in heavy-ion collisions.
- Calculable via pQCD NLO (at high \( p_T \)) QCD calculations for direct photon production are considerably easier to perform than for other processes, direct photons are used to test predictions made by perturbative QCD.
- At low \( p_T \), pQCD is not applicable: an experimental measurement is the only reliable reference.

Direct photon studies with ALICE:

- Performed by detecting real photons using the two electromagnetic calorimeters (PHOS, EMCal) and its conversion into dielectron pairs in the detector materials.

Dielectrons

- Provide a complementary and independent approach to that of real direct photons:
  - All sources of real photons have an analogous process where virtual photons (\( \gamma^* \)) are produced (with much lower yield, reduced by \( m_{\gamma^*} \)).
  - If the mass of the \( \gamma^* \) is ~ 2 GeV, it will decay into a dielectron pair (internal conversion).
  - Like photons, virtual photons in the shape of dielectrons are produced at all stages of the collision and the electrons arrive to the detector practically unaffected by any final-state interaction.
  - Advantage of this method: thanks to the mass degree of freedom of virtual photons the main background originating from the \( m_{\gamma^*} \) decays (90% of the hadron decay background) can be suppressed.

Virtual direct photon measurements with ALICE:

- In this analysis, inelastic (INEL) and High-Multiplicity (HM) pp collisions at \( \sqrt{s}=13 \text{ TeV} \) are studied by using \( \Delta T_{\text{ee}} = 2.87 \pm 0.40 \text{ nb}^{-1} \) and \( \Delta T_{\text{INEL}} = 2.79 \pm 0.15 \text{ pb}^{-1} \) of ALICE data, with \( \text{d}N_{\text{ch}}/\text{d}y(\text{INEL})/\text{d}N_{\text{ch}}/\text{d}y(\text{INEL}) = 6.27 \pm 0.62 \) at midrapidity.
- In ALICE, electrons are tracked by the central barrel detectors (ITS, TPC, TOF) with \( p_T > 0.2 \text{ GeV} \) and \( |\eta| < 0.8 \). The dielectron signal is obtained with the like-sign subtraction method.

For the extraction of the fraction of real direct photons / inclusive photons, assuming the equivalence in this ratio for real and virtual photons, the data are fitted in bins of \( p_T \) with:

\[
\frac{dN_{\text{el}}}{dM_{\text{ee}}} = \frac{dN_{\text{dir}}}{dM_{\text{ee}}(m_{\gamma^*})} + \left(1 - \frac{1}{1 - \tau}\right) f_{\text{dir}}(m_{\text{ee}}) + f_{\text{ch}}(m_{\text{ee}})
\]

- \( \tau \) = Light flavour “cocktail” of measured hadronic sources contributing to the dielectron signal.
- \( f_{\text{ch}} \) = A small contribution from dielectrons from open heavy flavour decays (via PYTHIA 6 [4]).
- \( f_{\text{dir}} \) = Virtual direct photon component. Shape described by the Kroll-Wada equation [3] in the quasi-real virtual photon regime \( (m_{\gamma^*} < p_T) \).

\[
\frac{dN_{\text{dir}}}{dM_{\text{ee}}} = \frac{2N_{\gamma^*}}{3\pi M_{\gamma^*}}\int_{4M_{\gamma^*}^2}^{M_{\gamma^*}^2} \frac{1}{M_{\gamma^*}^2} F_{\text{dir}}(M_{\gamma^*}) M_{\gamma^*}^2 dM_{\gamma^*} \quad \text{with } S=1
\]

- \( \tau \) = Fraction of real direct photons / inclusive photons. Only free parameter of the fit.

Fit method:

- Normalize both \( f_{\text{dir}} \) and \( f_{\text{ch}} \) to data at \( m_{\gamma^*} < 0.04 \text{ GeV}^2 / c^2 \), i.e. in a mass window in which both \( m_{\gamma^*} \) Dalitz decays and direct photons have the same \( 1/m_{\gamma^*} \) dependence.
- Heavy flavour components (open charm and beauty) are fixed to measured values (poster 879 by A. Dash).
- Fit the data in the mass interval 0.14 < \( m_{\gamma^*} < 0.32 \text{ GeV}^2 / c^2 \).

Results

- No significant direct photon contribution is observed in MB or HM events.
- Upper limits at 90% confidence level (CL) are extracted with the Feldman–Cousins method [5].
- Results compared to pQCD NLO calculations [6].

References