Direct virtual photon production in minimum-bias and high-multiplicity pp collisions at $\sqrt{s}$=13 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.

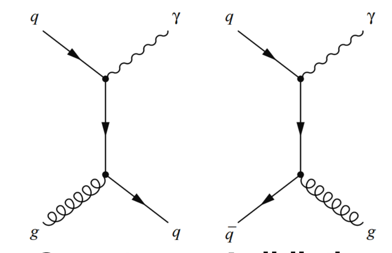
Direct photons in Heavy Ion Collisions (HIC):

- **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.

thermal photons ~ $\exp(-E_\gamma/T_{eff})$

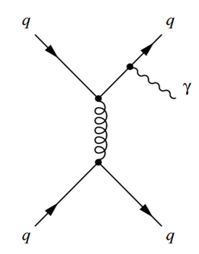
- **Other medium related mechanisms** Interaction of hard scattered protons with the medium
  - Jet-photon conversion, Jet bremsstrahlung.

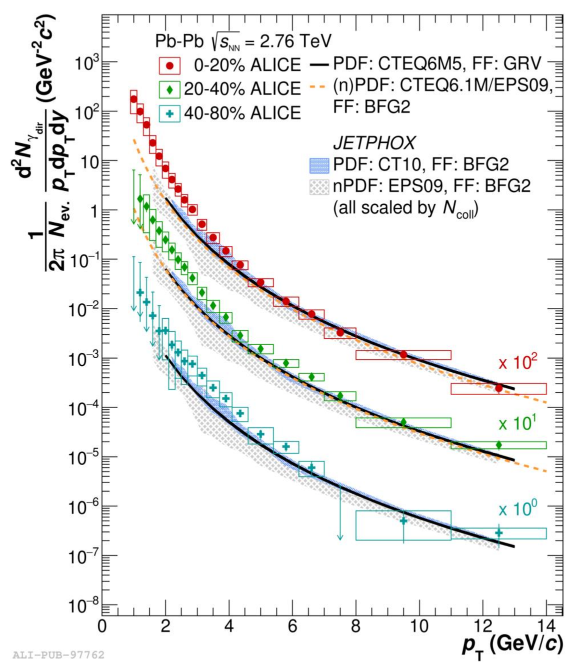
Prompt photons:



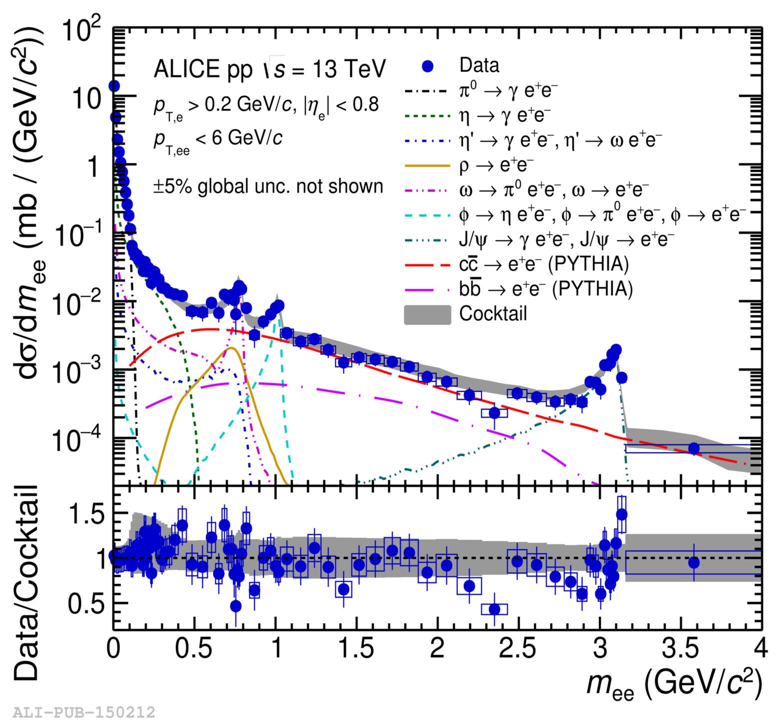
Compton Anihilation

Medium induced Bremsstrahlung:





Direct real photons measured by ALICE in Pb-Pb collisions at 2.76TeV [1]



Dielectron signal measured by ALICE in pp collisions at 13 TeV [2]

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 collisionsQCD.
- **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 [1].

Dielectrons [2]

See Posters by A. Dashi (879), C. Klein (222), S. Scheid (340), J. Jung (428), I. Vorobyev (239) and S. Lehner (104)

Provide a complementary and independent approach to that of real direct photons:

- all sources of real photons have an analogous process where virtual photons (γ*) are produced (with much lower yield, reduced by $\propto\alpha_{em}$).
- If the mass of the γ* is > $2m_e$, 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 π^0 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 TeV are studied by using $\mathcal{L}_{int}^{MB}$ = 7.87 ± 0.40 nb^{-1} and $\mathcal{L}_{int}^{HM}$ = 2.79 ± 0.15 pb^{-1} of ALICE data, with $dN_{ch}/d\eta$(HM) / $\langle dN_{ch}/d\eta$(INEL)$\rangle$ = 6.27 ± 0.22 at midrapidity.
- In ALICE, electrons are tracked by the central barrel detectors (ITS, TPC, TOF) with p_T > 0.2 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 $p_{T,ee}$ with:

$$d\sigma/dm_{ee} = r\, f_{dir}\,(m_{ee}) + (1-r) f_{LF}(m_{ee}) + \; f_{HF}(m_{ee})$$

- f_{LF} = **Light flavour "cocktail"** of measured hadronic sources contributing to the dielectron signal.
- f_{HF} = A small contribution from dielectrons from **open heavy-flavour** decays (via PYTHIA 6 [4])
- f_{dir} = **Virtual direct photon component.** Shape described by the Kroll-Wada equation [3] in the quasi-real virtual photon regime ($m_{ee} << p_{T,ee}$)

$$\frac{d^2N_{ee}}{dM} = \frac{2\alpha_{em}}{3\pi}\frac{1}{M}\sqrt{1-\frac{4m_e^2}{M^2}}\left(1+\frac{2m_e^2}{M^2}\right)S\,dN_\gamma \qquad \text{with } S\text{=1.}$$

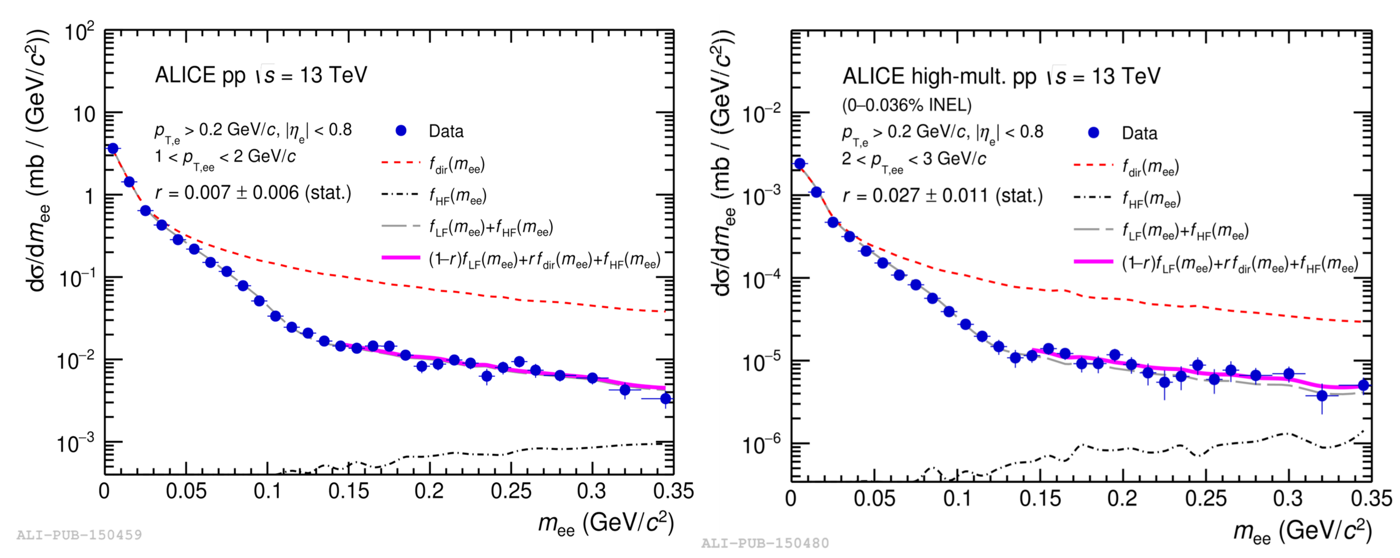
- r = fraction of real direct photons / inclusive photons. Only free parameter of the fit.

Fit method:

- Normalize both f_{LF} and f_{dir} to data at m_{ee} < 0.04 GeV/c^2, i. e. in a mass window in which both π^0 Dalitz decays and direct photons have the same $1/m_{ee}$ dependence.
- Heavy flavour components (open charm and beauty) are fixed to measured values (poster 879 by A. Dashi).
- Fit the data in the mass interval 0.14 < m_{ee} < 0.32 GeV/c^2.

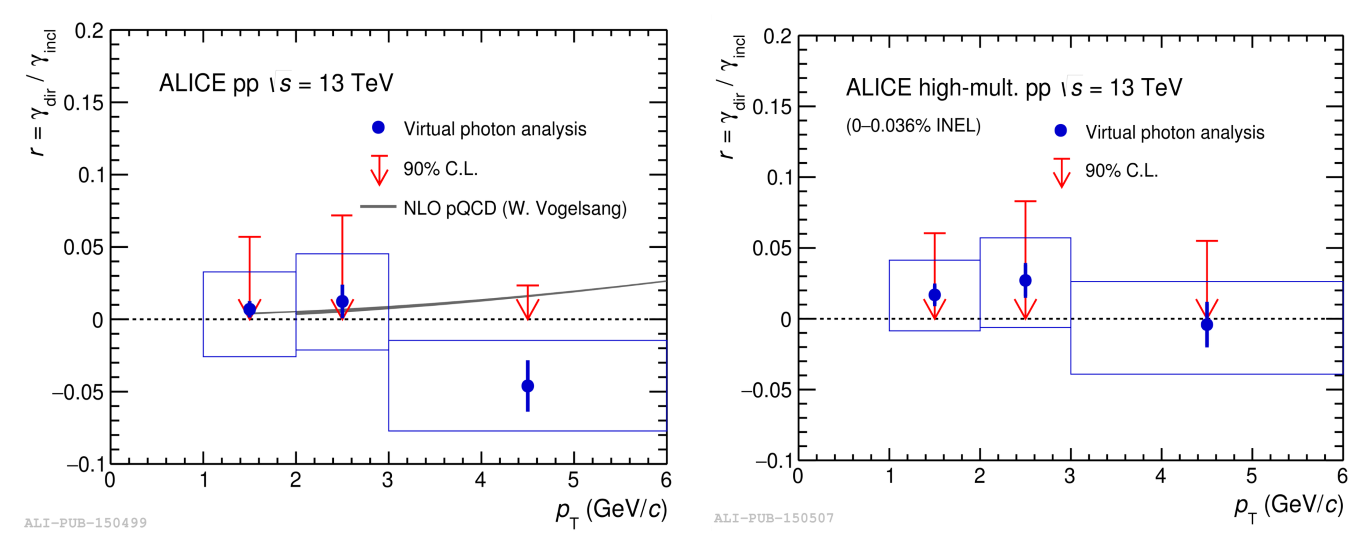
Results

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



Fits to the dielectron spectra in INEL (left) and HM (right) pp collisions at $\sqrt{s}$=13 TeV, for 1 < $p_{T,ee}$ < 2 GeV/c and 1 < $p_{T,ee}$ < 2 GeV/c respectively.

arXiv:1805.04407 (submitted to PLB)



Ratio of direct to inclusive photon cross sections for INEL (left) and HM (right) data, with the respective upper limits. The INEL result is compared to a NLO pQCD calculation [6].

Data sample	$1 < p_{T,ee} < 2$ GeV/c	$2 < p_{T,ee} < 3$ GeV/c	$3 < p_{T,ee} < 6$ GeV/c
Minimum bias	0.057	0.072	0.023
High multiplicity	0.060	0.083	0.055
pQCD	0.003	0.007	0.013

Upper limits at 90% C.L. on the direct-photon fractions in and expectation based on a NLO pQCD calculation for a factorisation and renormalisation scale choice of $\mu=p_T$ [6]

References
[1] ALICE Collaboration, "*Direct photon production in Pb–Pb collisions at sNN=2.76TeV*", Physics Letters B 754, 235–248 (2016) , "*Direct photon production at low transverse momentum in proton-proton collisions at s√ = 2.76 and 8 TeV*", arXiv:1803.09857.
[2] ALICE Collaboration, arXiv:1805.04407, arXiv:1805.04391.
[3] N. Kroll and W. Wada, "*Internal pair production associated with the emission of high-energy gamma rays*", Phys. Rev. 98, 1355 (1955).
[4] T. Sjostrand, S. Mrenna and P. Skands, "*PYTHIA 6.4 physics and manual*", JHEP 05, 026 (2006).
[5] G. Feldman and R. Cousins, "*Unified approach to the classical statistical analysis of small signals*", Phys. Rev. D 57, 3873 (1998).
[6] L. E. Gordon and W. Vogelsang, "Polarized and unpolarized prompt photon production beyond the leading order," Phys. Rev. D 48, 3136 (1993) .