Direct Photon Production and Correlations in Pb-Pb Collisions at $\sqrt{s_{NN}}$ = 5.02 TeV

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Vladislav Kuskov
National Research Center “Kurchatov Institute”
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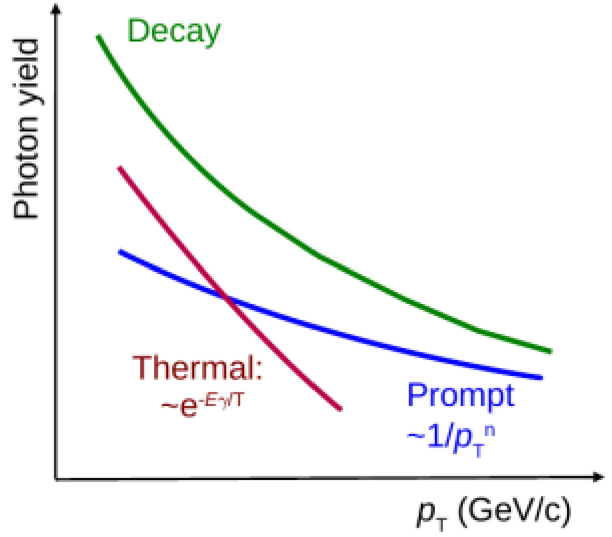
vladislav.kuskov@cern.ch

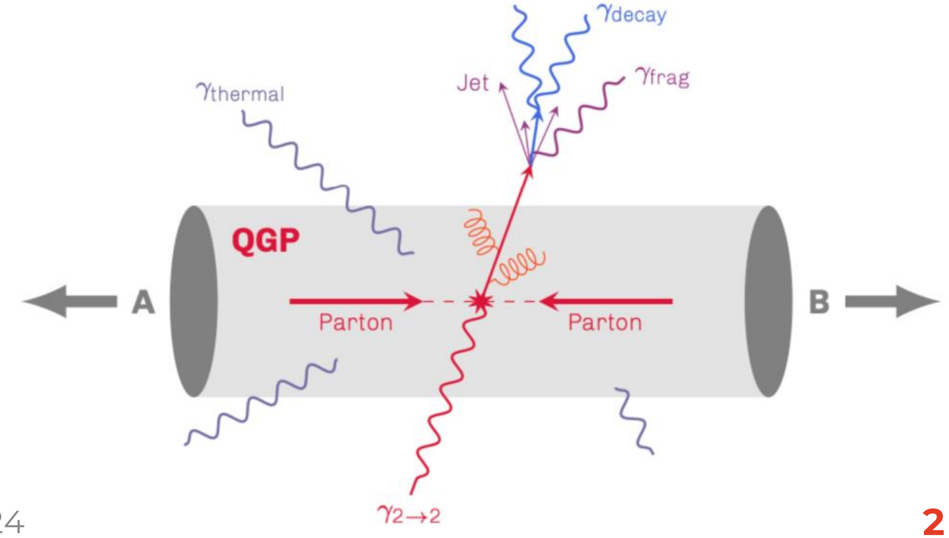
Introduction

- **Direct photons** – photons not originating from hadron decays:
  - **thermal photons** ($\sim e^{-E_\gamma T}$), thermal radiation of QGP, space-time evolution of QGP
  - **prompt photons** ($\sim 1/p_T^n$), initial hard scattering, testing pQCD, PDF (+nPDF modification) and FF constrains:

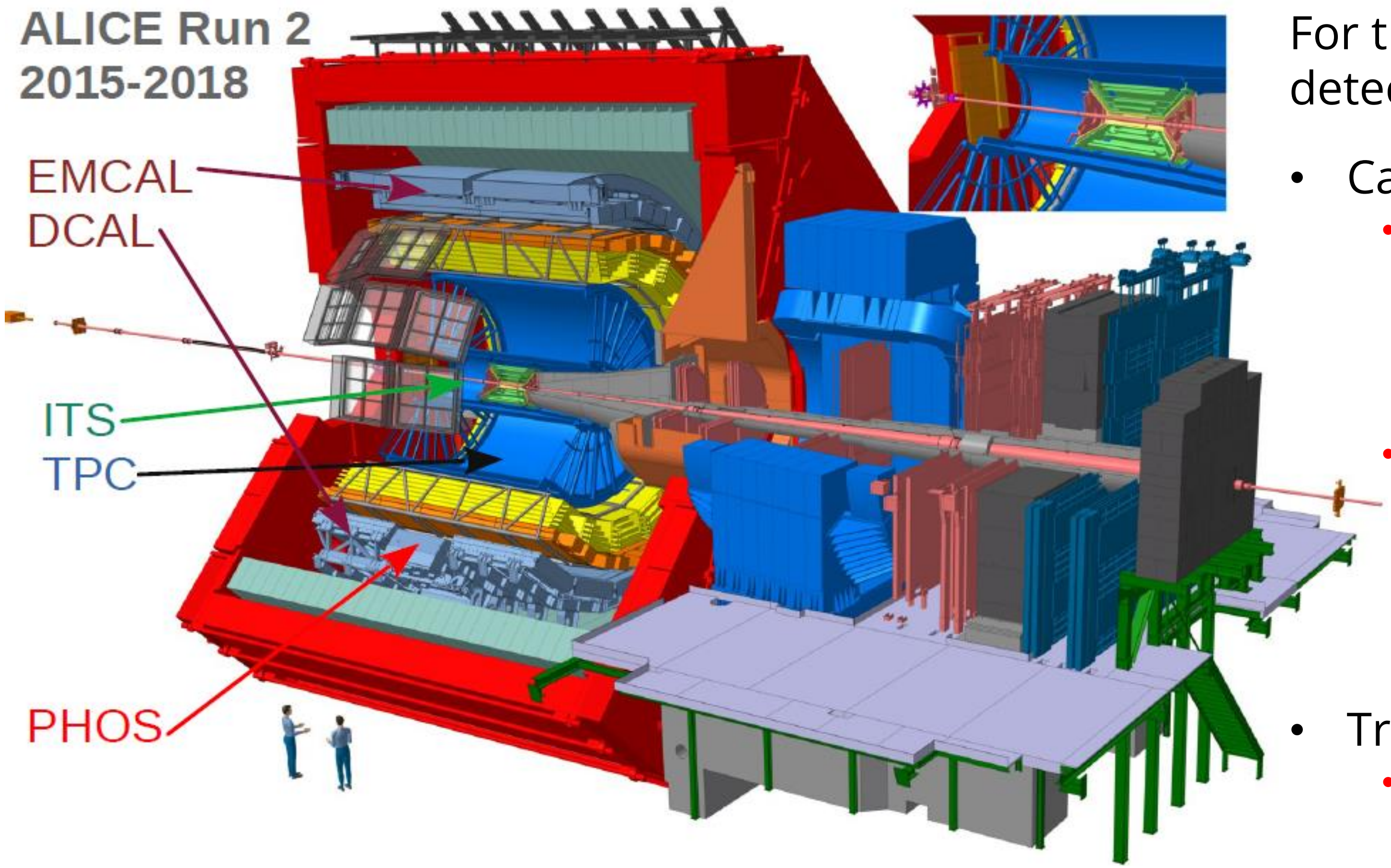
$$E\frac{\mathrm{d}^3\sigma}{\mathrm{d}p^3} = \sum_{i,j,k} f_i(x_i, Q^2) \otimes f_j(x_j, Q^2) \otimes D_k(z_k, Q^2)$$

  - Other sources: fragmentation photons, pre-equilibrium photons
- Photons are color neutral: not affected by QGP ⟶ perfect probe for studying QGP properties
- **Two-photon Bose-Einstein correlations** could be used for measurements of direct photon yields and correlations radii
- In this talk we present recent results on direct photon production and correlations measured with ALICE in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV





Experimental setup

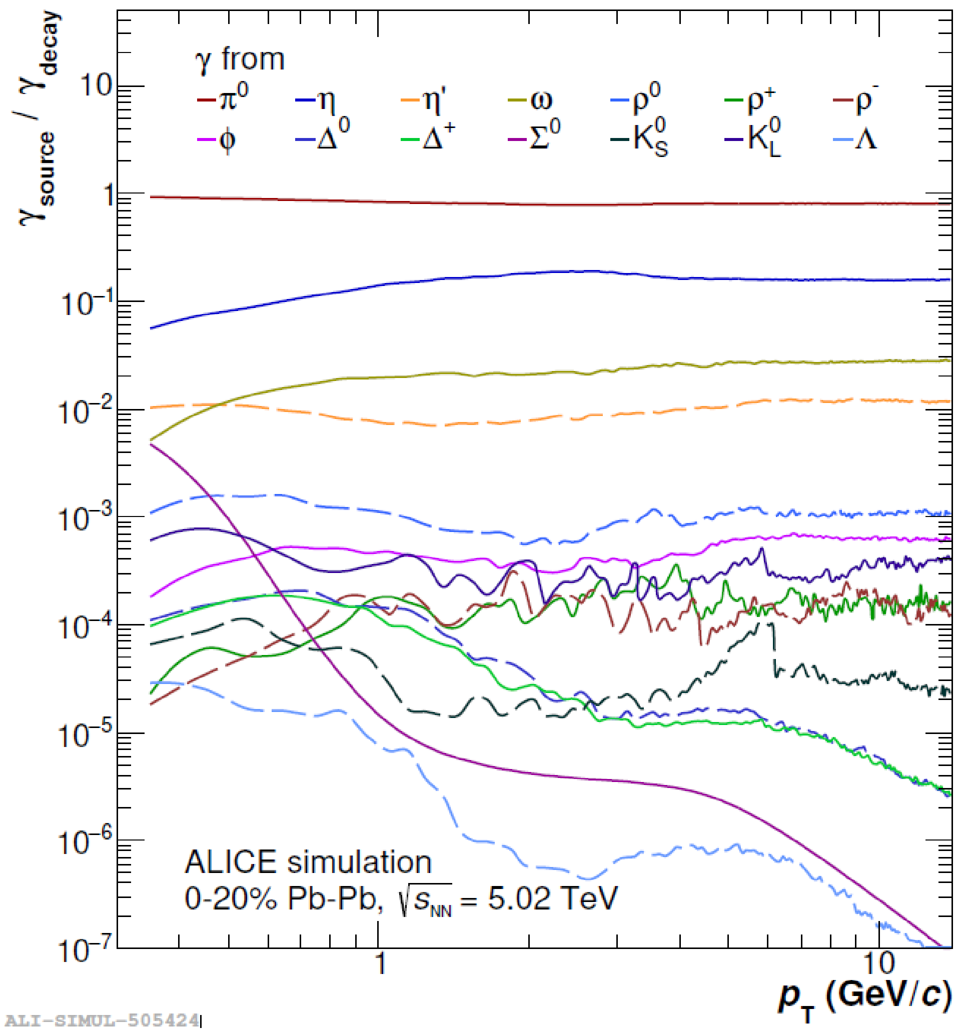


For the photon measurements the following detectors are used:

- Calorimeters:
  - **PHOS**:
    $PbWO_4$ crystals 22×22 cm^2
    4.6 m away from Interaction Point
    acceptance: $|\eta| < 0.13$ for $\Delta\phi = 70^o$
  - **EMCal/DCal:**
    Pb absorber + scintillator, 60× 60 cm^2
    4.4 m away from Interaction Point
    EMCal acc.: $|\eta| < 0.67$ for $\Delta\phi = 107^o$
    DCal acc.: $0.22 < |\eta| < 0.67$ for $\Delta\phi = 60^o$
- Tracking ITS + TPC:
  - **Photon Conversion Method (PCM):**
    $R_{conv} < 180$ cm
    8% conversion probability
    acceptance: $|\eta| < 0.9$ for $\Delta\phi = 360^o$

Direct photon subtraction

Decay photon contamination:



- Subtraction method:

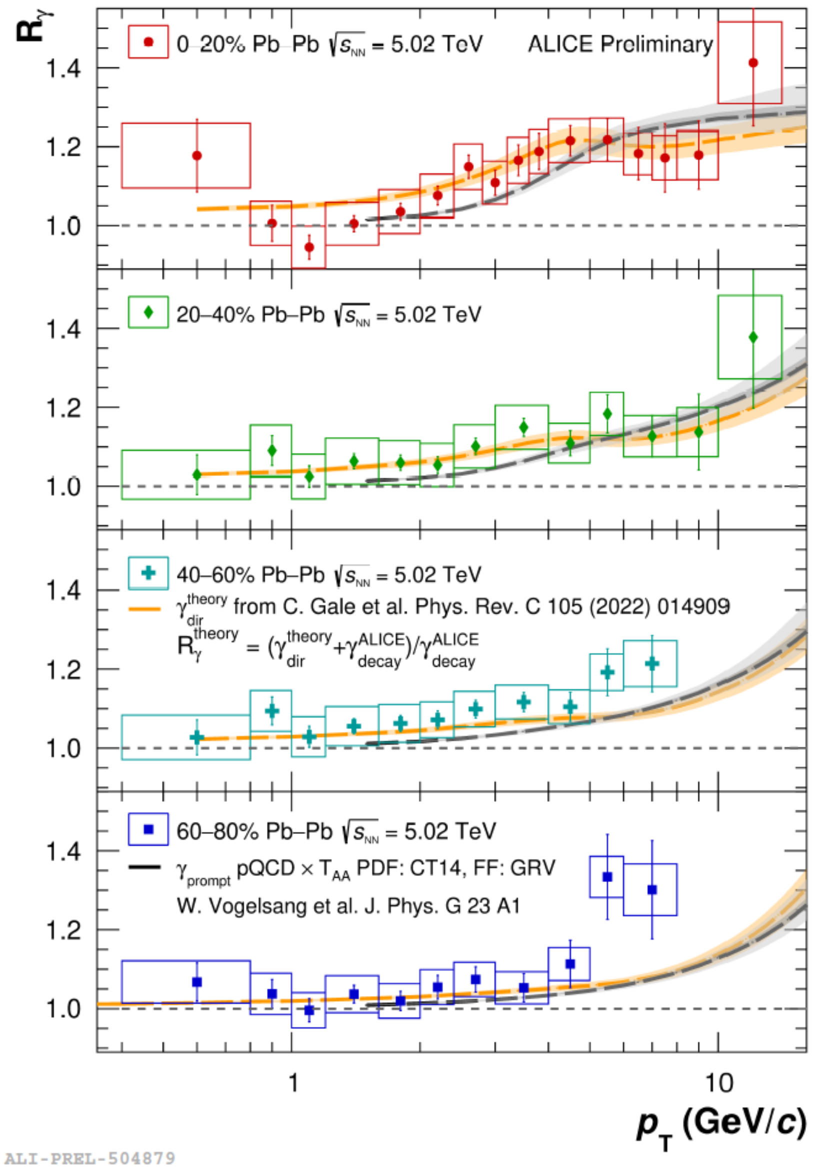
$$\gamma_{\mathrm{dir}} = \gamma_{\mathrm{inc}} - \gamma_{\mathrm{decay}} = \left(1 - \frac{\gamma_{\mathrm{decay}}}{\gamma_{\mathrm{inc}}}\right)\gamma_{\mathrm{inc}}$$

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

- **Inclusive photons:** all photons produced in the event
- **Decay photons:** photons calculated by decay simulation of measured or m_T-scaled hadron spectra
- **Double ratio:**

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

Double ratios in Pb-Pb at $\sqrt{s_{NN}}$ = 5.02 TeV



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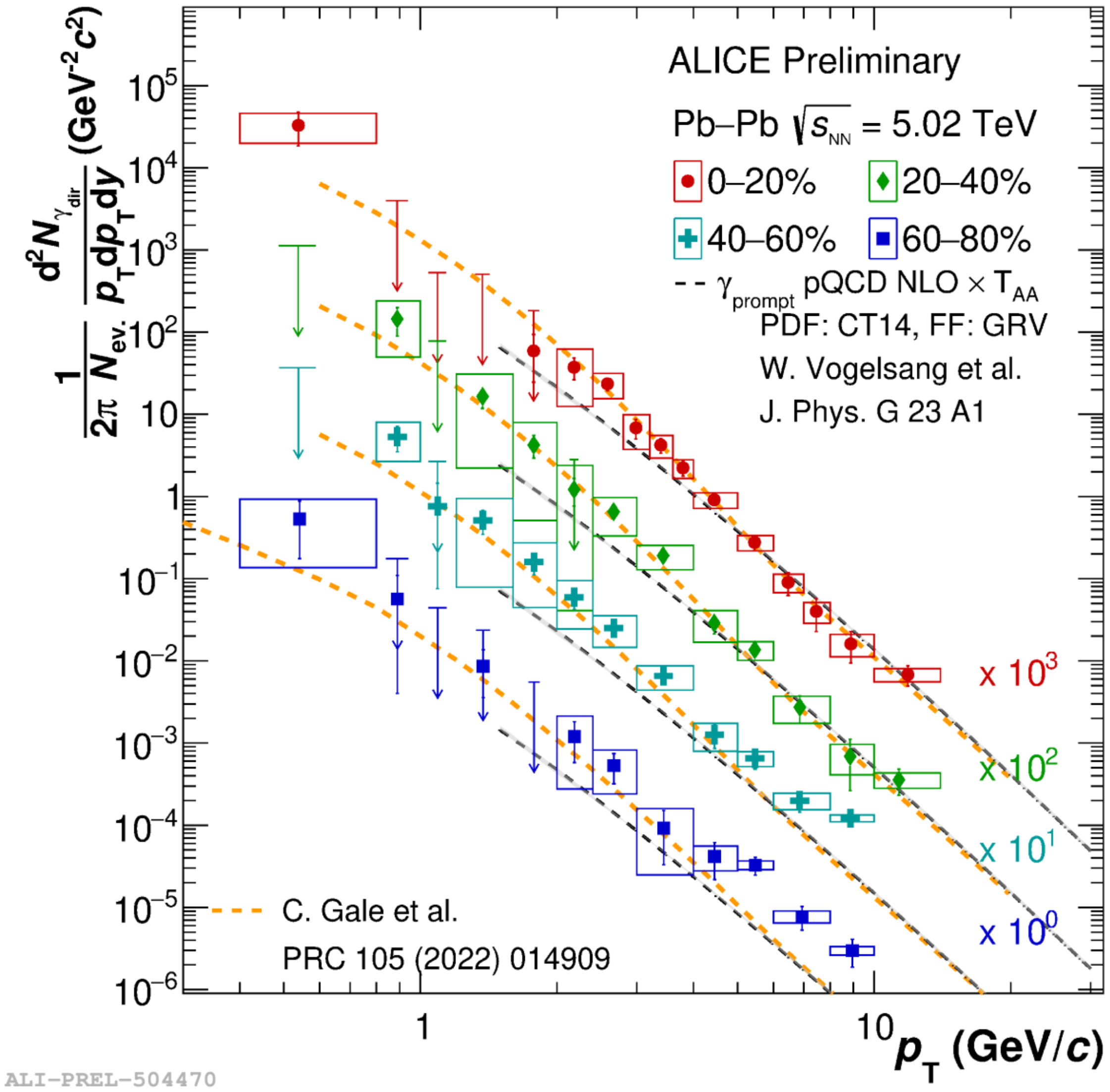
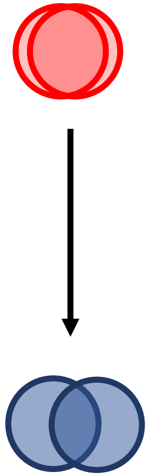
- At low p_T R_γ compatible with 1 – no additional thermal photons excess in this region could be extracted with this method (in Pb-Pb@2.76TeV it was extracted)
- p_T > 3 GeV/c – excess of prompt photons
- Scaled NLO pQCD calculations in pp collisions using **PDF:CT14** and **FF:GRV** describe data within uncertainties
- Hydrodynamic model including prompt and thermal photons consistent with data down to low p_T

C. Gale et al. Multimessenger heavy-ion collision physics, Phys.Rev.C 105 (2022) 1, 014909

Direct photon yields in Pb-Pb at $\sqrt{s_{NN}}$ = 5.02 TeV





- Direct photon invariant yield estimated as

$$\frac{1}{2\pi N_{ev}}\frac{d^2 N_{\gamma dir}}{p_T\, dp_T\, dy} = \frac{1}{2\pi N_{ev}}\frac{d^2 N_{\gamma inc}}{p_T\, dp_T\, dy}\times\left(1-\frac{1}{R_\gamma}\right)$$

- $p_T > 3$ GeV/c – excess of prompt photons
- Scaled NLO pQCD calculations in pp collisions using **PDF:CT14** and **FF:GRV** describe data within uncertainties
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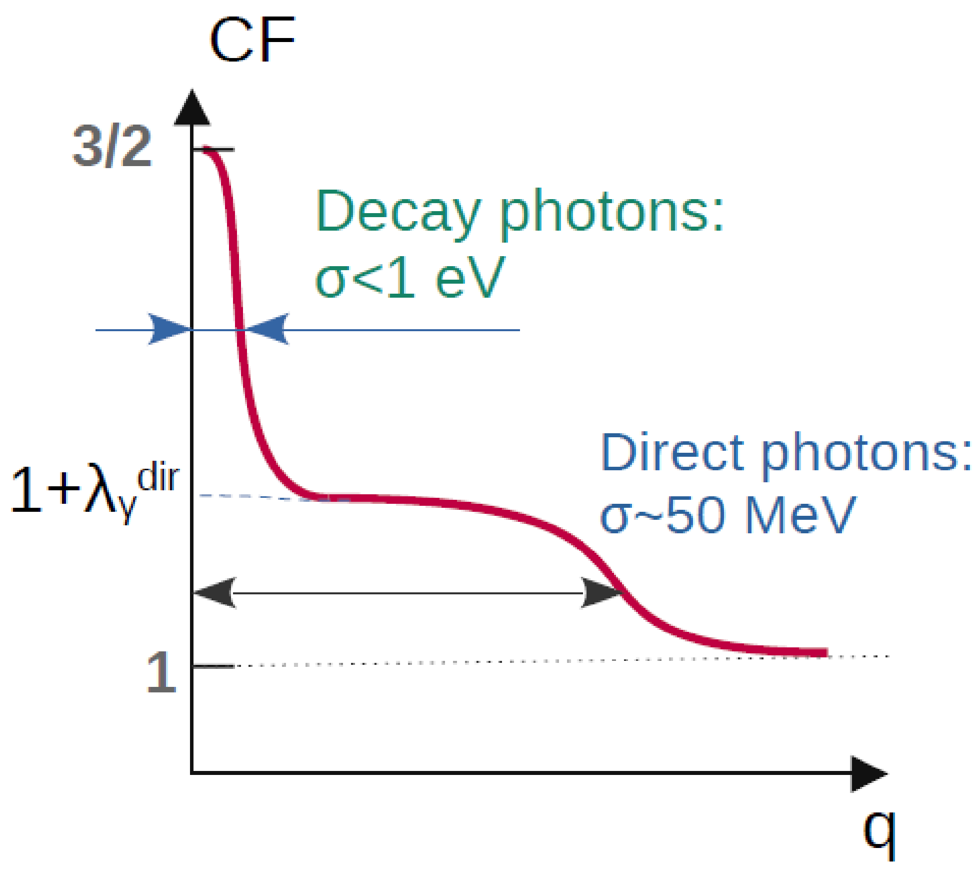
Direct photon Bose-Einstein correlations

Correlation function:



- Interferometry in heavy-ion collisions is based on the symmetrization of the wave-functions of two identical particles
  → for bosons: **Bose-Einstein (BE) Correlation**

- Increased probability of finding particles with low **relative momentum of the pair (*q*)** → estimation of the size of the emitting source

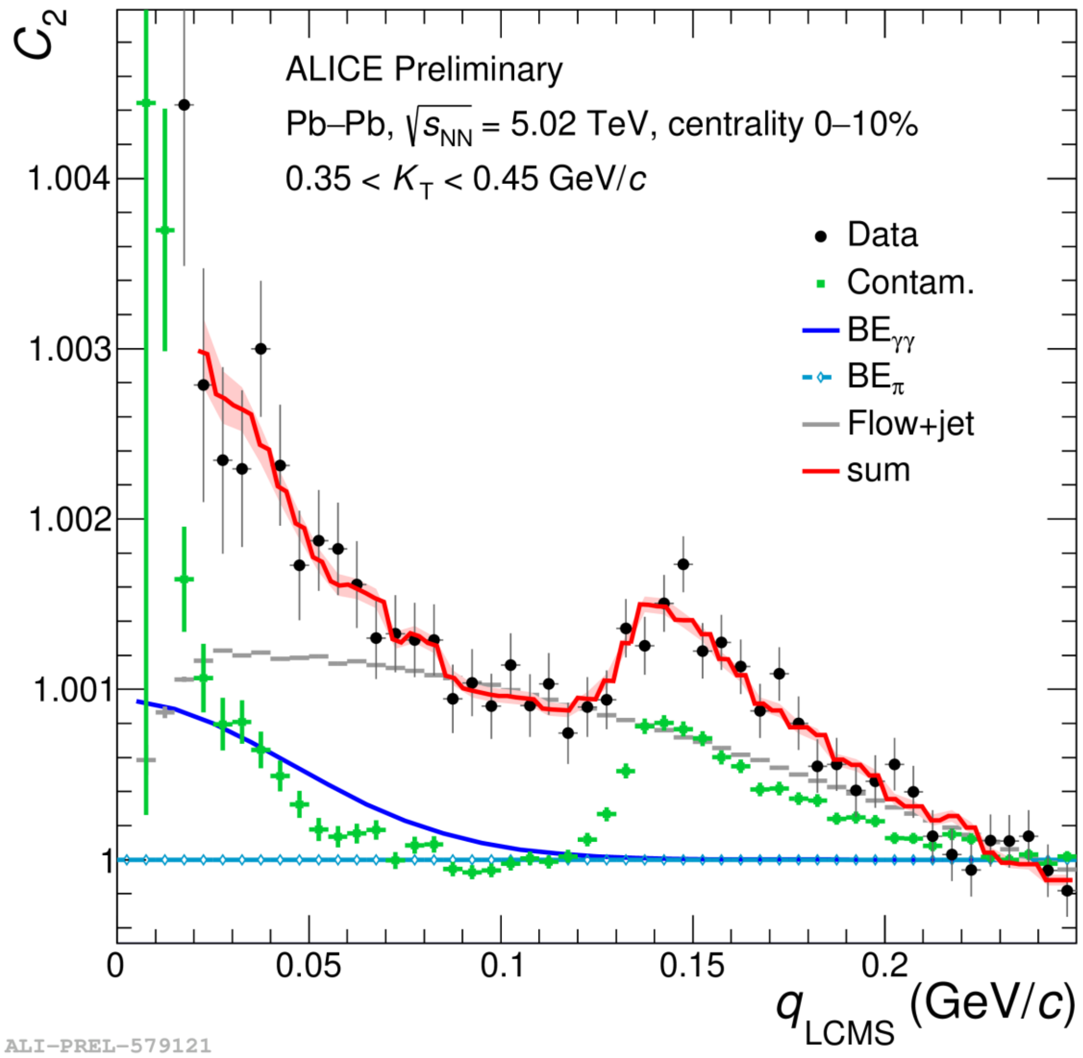
- Photons are color neutral → access to the initial stage of QGP, to its hottest regions with thermal photons at low K_T (see next slides)

- Experimental observable for the interferometry is **correlation function (C_2)** – ratio of correlated two-photon distribution to noncorrelated distribution

$$C_2(q, K) = \frac{P_2^{\mathrm{corr}}(q, K)}{P_2^{\mathrm{noncorr}}(q, K)}$$

Direct photon correlation function

C_2 measured with PHOS:



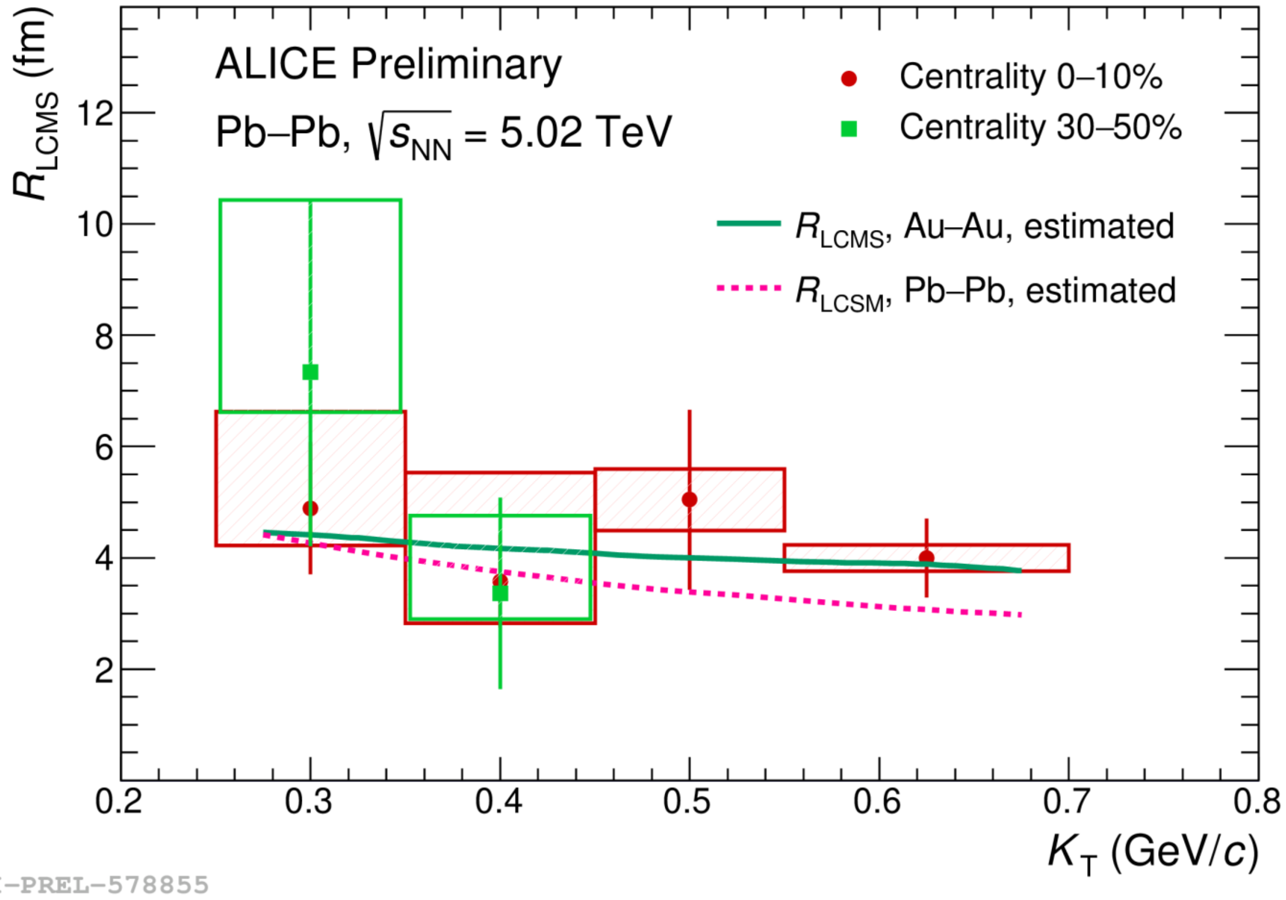
C_2 is decomposed into the contributions:

- **Contamination**: photon conversion, hadron bremsstrahlung, residual correlations in resonance decays
- **Direct photon BE** correlations
- Residual correlation in decays of BE correlated π^0 (negligible in this K_T bin)
- **Long-range** (flow and jet) correlations
- **Summary** of all contributions

Kinematics variables:

- 3D relative momentum of the pair in Longitudinally Co-Moving System: $q_{\rm LCMS} = |\vec{p_1} - \vec{p_2}|$
- Mean pair transverse momentum: $K_{\rm T} = \frac{1}{2}(p_{1_{\rm T}} + p_{2_{\rm T}})$

Correlation radius



Hydrodynamic calculations:
Pb-Pb: O. Garcia-Montero et al., Phys.Rev.C 102 (2020) 2, 024915
Au-Au: D. Peressounko, Phys.Rev.C 67

- Assuming gaussian spherically symmetric source with radius R, C_2 might be described as

$$C_2 = 1 + \lambda \exp(-q^2_{\mathrm{LCMS}} R^2)$$

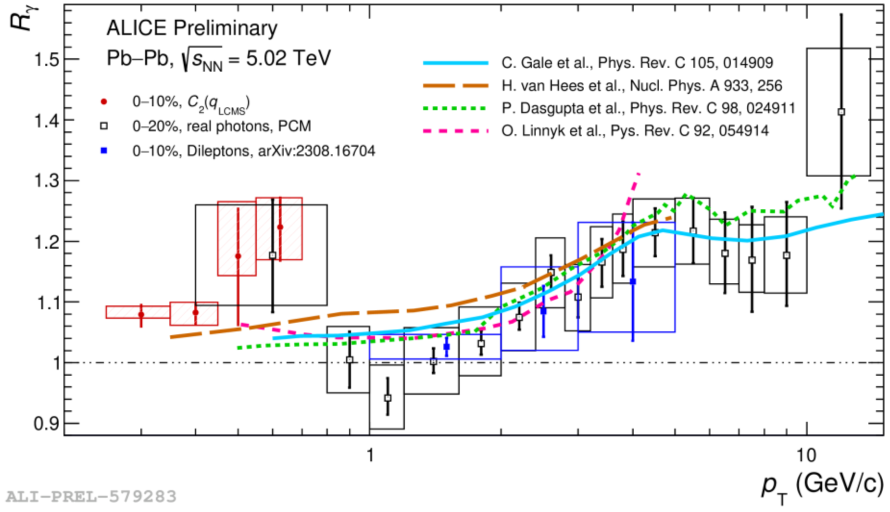
where λ is correlation

→ radius of source size could be estimated with measured C_2

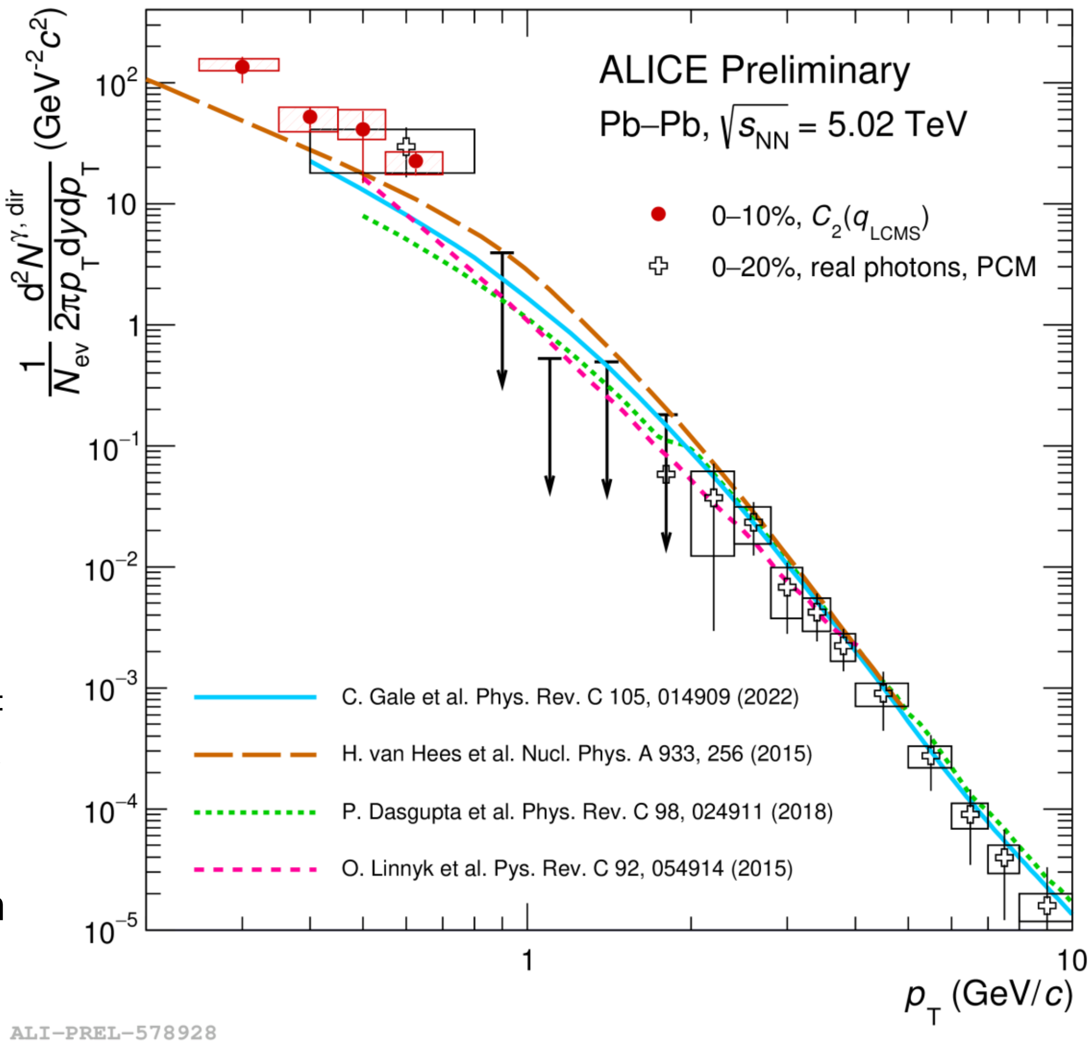
- Results are consistent with estimated radii from hydro predictions

Direct photon yields with BE correlations

Double ratio estimated with C_2:



Direct photon yield:



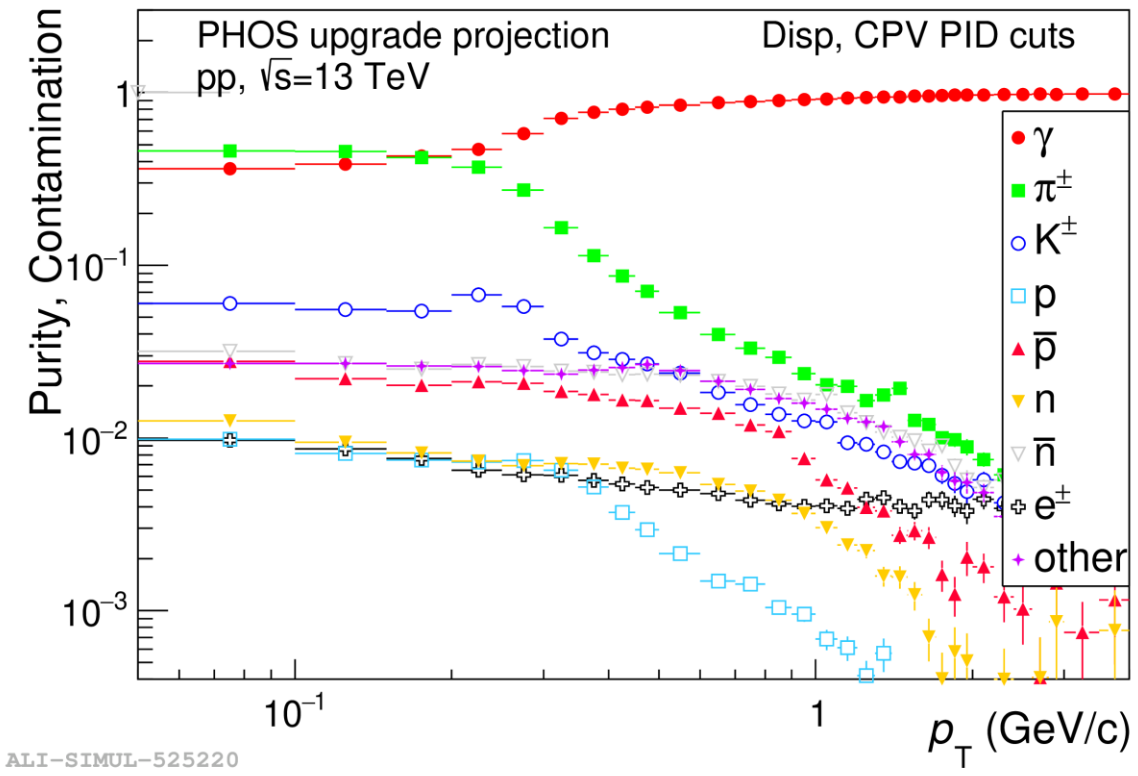
Correlation strength (**λ**) of C_2 ⟶ ***R_γ***:

$$\lambda = \frac{1}{2}\left(\frac{N_\gamma^{\text{dir}}}{N_\gamma^{\text{inc}}}\right)^2 \rightarrow R_\gamma = \frac{N_\gamma^{\text{inc}}}{N_\gamma^{\text{decay}}} = \frac{1}{1-\sqrt{2\lambda}}$$

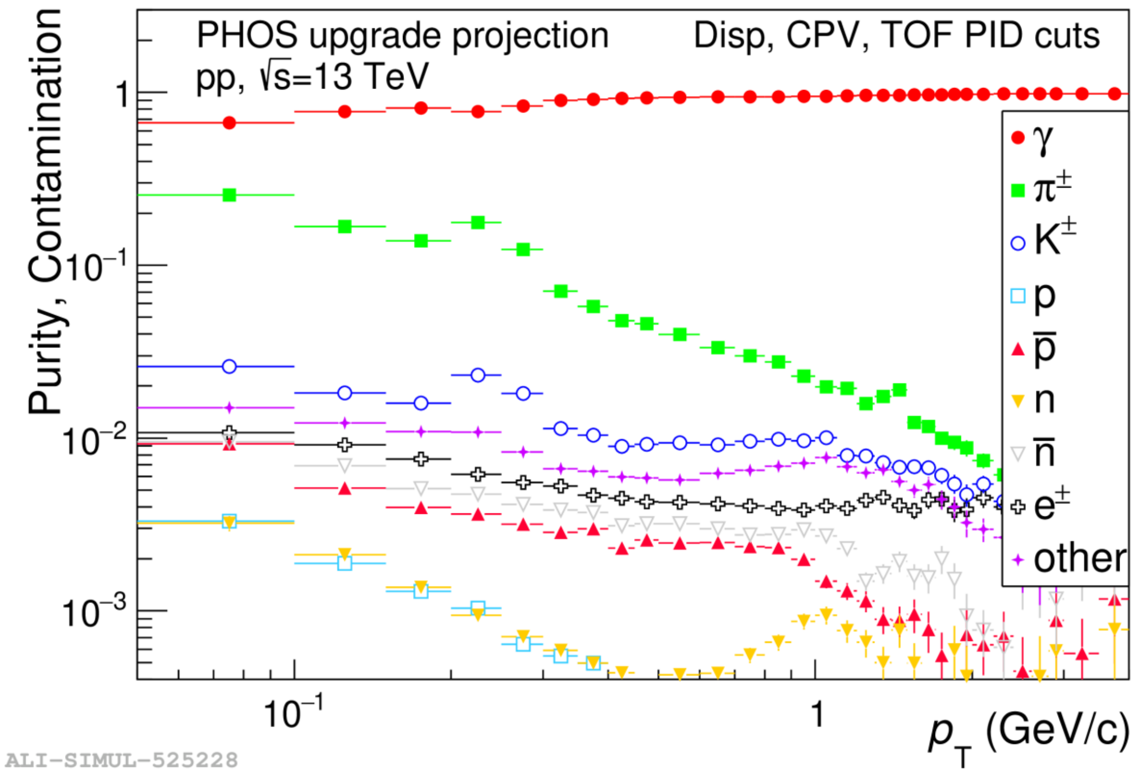
- Extended measurements down to **250 MeV/c**
- Method provide consistent results in the overlap region
- Measured spectrum exceeds predictions at low p_T **by factor ≈ 2**

Further improvements

- Photon identification in calorimetry might be improved by implementing time cut on a signal:
  - That requires good time resolution might be achieved using SiPM as read-out electronics
  - For example, simulation for PHOS shows that time resolution σ_t ~ 0.1 ns could significantly improve purity of photons at low p_T (< 200 MeV/c)



+ time cut



Summary

- ALICE provides measurement of direct photon spectra with several independent approaches
- Direct photon spectra were measured in Pb-Pb at $\sqrt{s_{NN}}$ = 5.02 TeV
- Consistent scaling with N_{ch} at high p_T was observed according to predictions of scaled NLO pQCD calculations in pp
- Direct photon Bose-Einstein correlations were measured:
  - Correlation radius is consistent with hydrodynamic model predictions
  - Direct photon yield was estimated with correlation analysis, consistent with other measurements

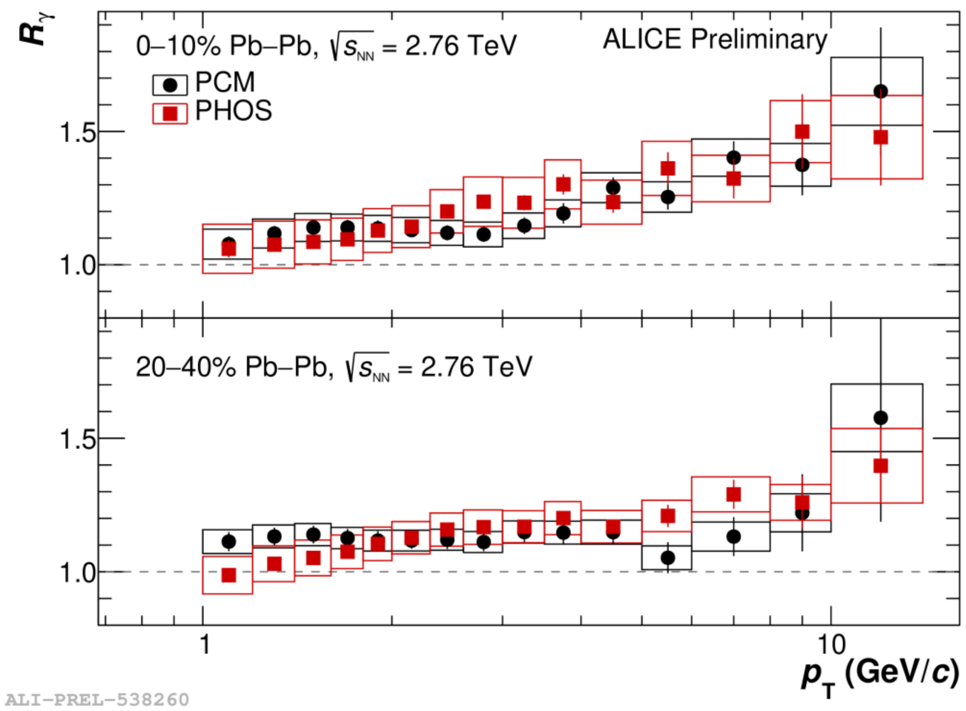
THANK YOU FOR THE ATTENTION!

Vladislav Kuskov
22-25 October 2024

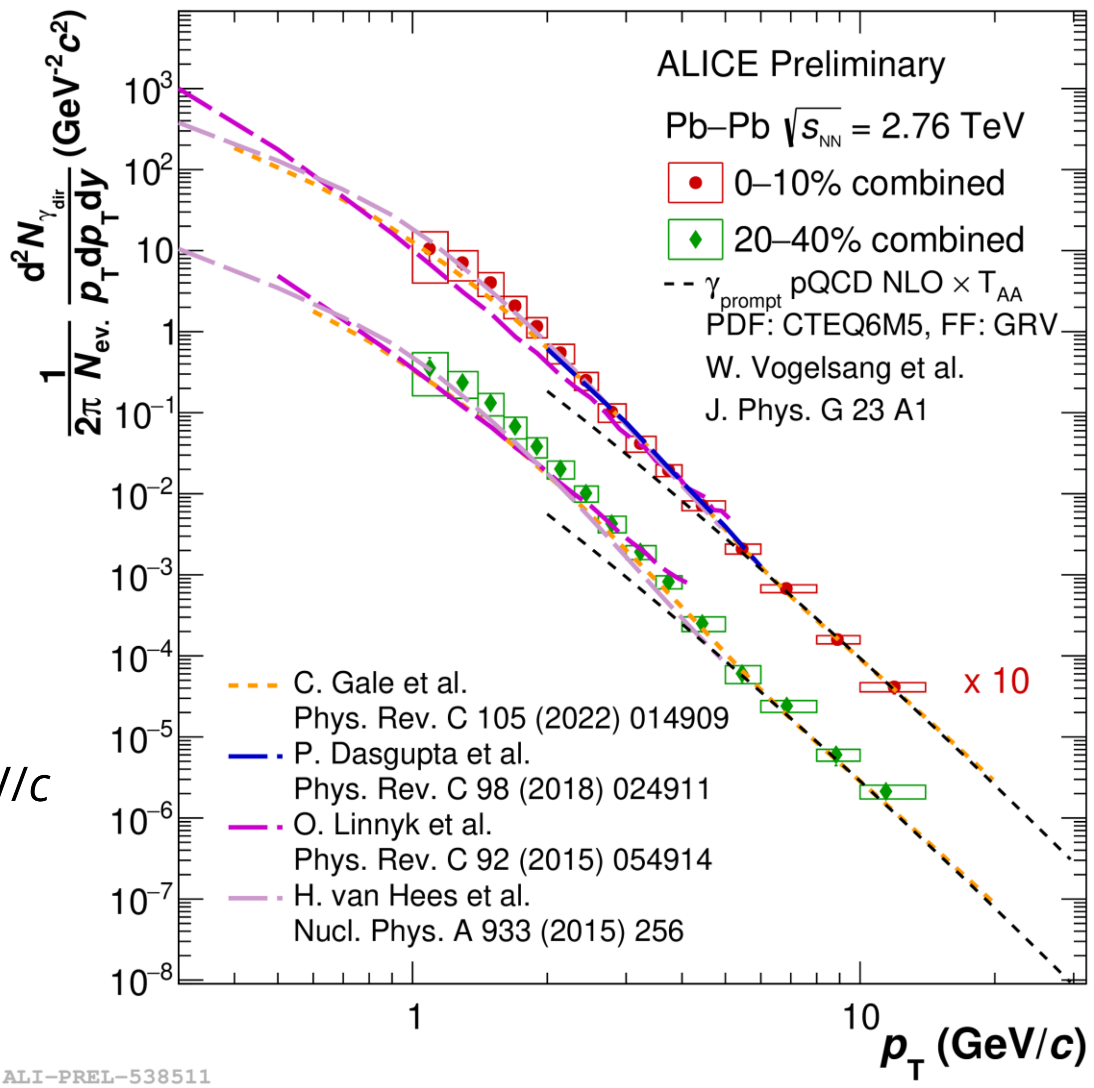
vladislav.kuskov@cern.ch

Backup. Direct photon yields in Pb-Pb@2.76TeV

Double ratio:



Direct photon yield:



- Agree with NLO calculations scaled at high p_T > 4 GeV/c
- Excess of direct photon production beyond pQCD
- In general measured yield is higher than predictions (thermal + pre-eq. photons) at p_T < 4 GeV/c