Direct photon production and correlations at low p_T in Pb-Pb collisions in ALICE

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for the ALICE Collaboration

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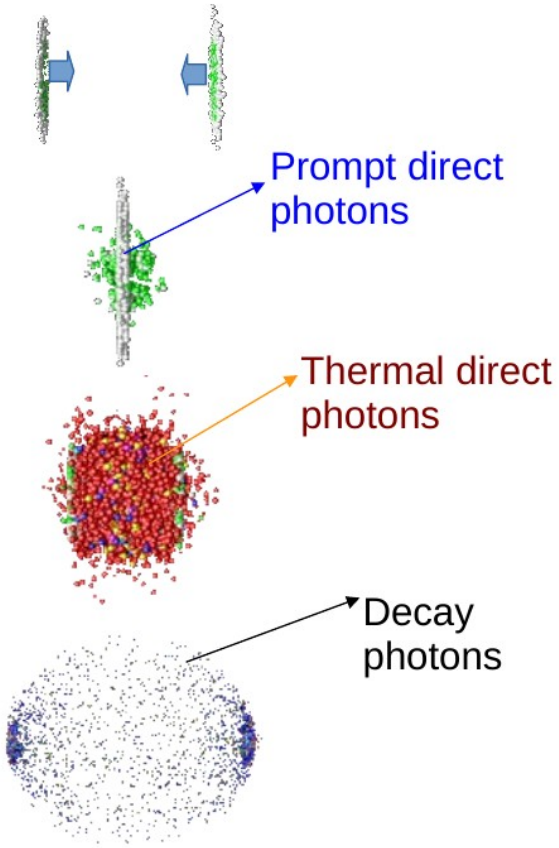
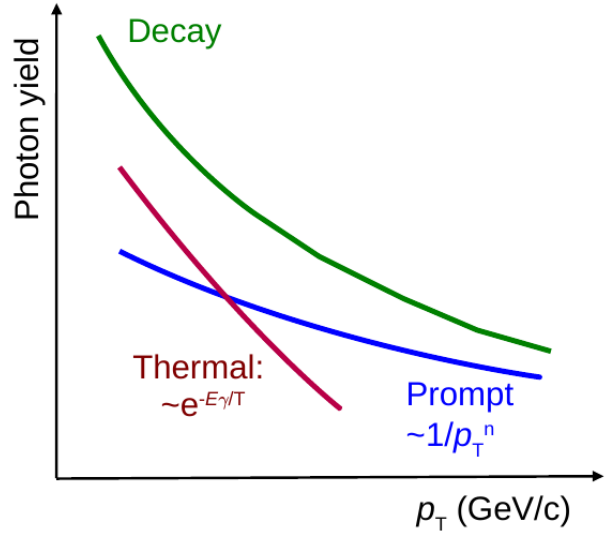
NAGASAKI

Direct photons



Direct photons – photons not originating from final-state hadron decays but produced in electromagnetic interactions in course of collision

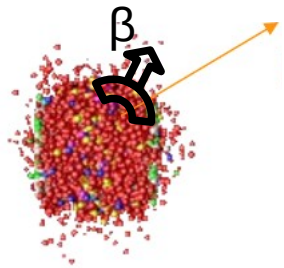
- **Prompt** direct photons: those resulting from the interaction of incoming nucleons
  - Control of initial state, number of binary collisions, structure functions modification etc.
- **Thermal** direct photons: thermal radiation of hot matter
  - Test temperature, collective flow development, space-time dimensions of hot fireball
- **Decay** photons: photons from decays of final-state hadrons



Real vs virtual direct photons

$$E_\gamma \frac{d^3 N_\gamma}{d^3 p_\gamma} \propto e^{-E_\gamma / T_{\text{eff}}}$$

$$T_{\text{eff}} = \sqrt{\frac{1+\beta_{\text{flow}}}{1-\beta_{\text{flow}}}} \times T$$



$$\frac{dN}{dM_{ee}} \propto (M_{ee} T)^{3/2} e^{-M_{ee}/T}$$

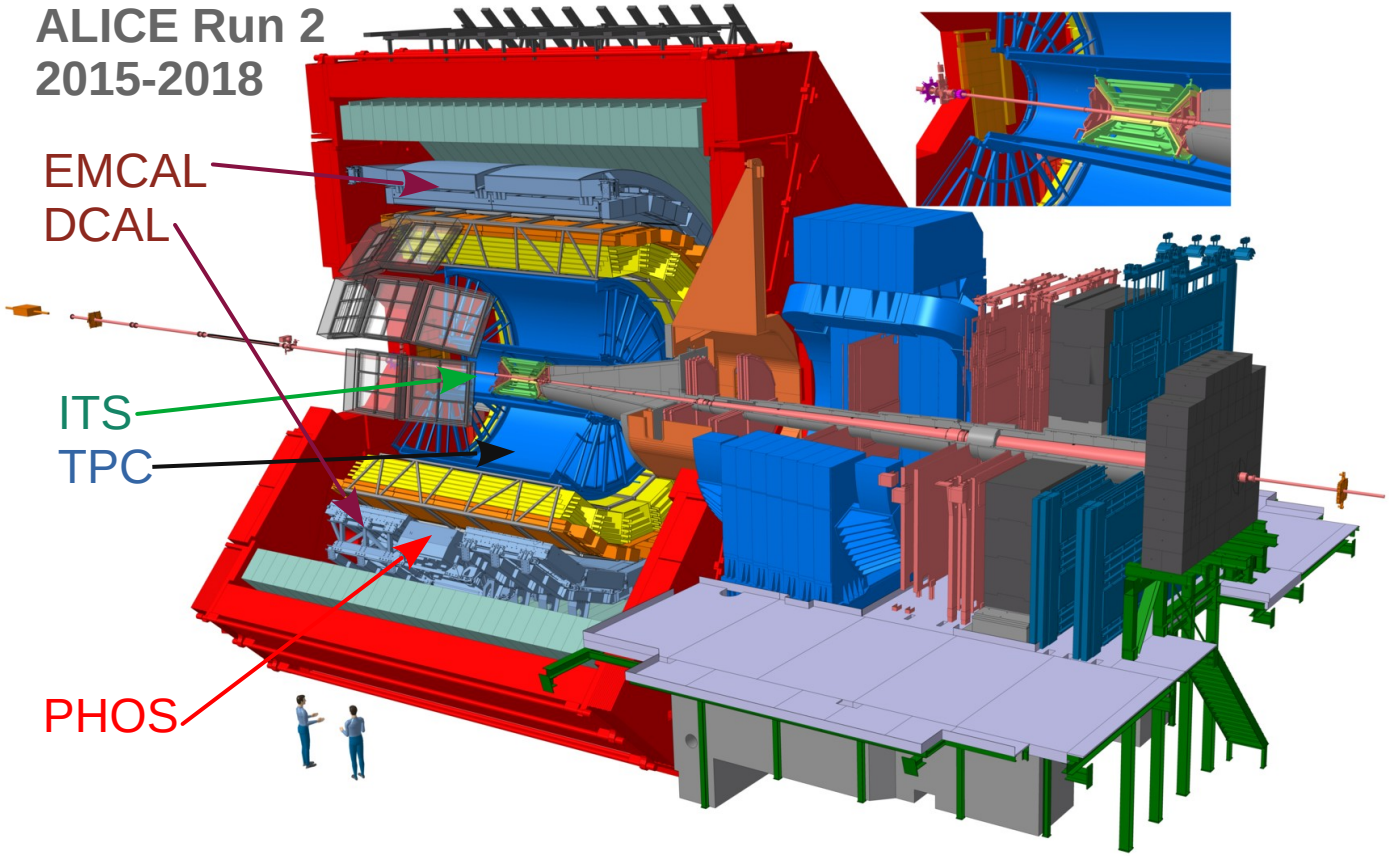
Real photons:

- Integrate contributions from pre-equilibrium phase till hadronic gas freeze-out
- Thermal contribution significant at p_T<3 GeV/c
- Slope strongly affected by collective flow

Virtual photons:

- Low-mass dielectron pairs: relate to real photon yield with Kroll-Wada formula
- Intermediate mass region: test true temperature without blueshift
  - May contain pre-equlibrium contribution

Possibilities to measure direct photons in ALICE



Statistical subtraction:

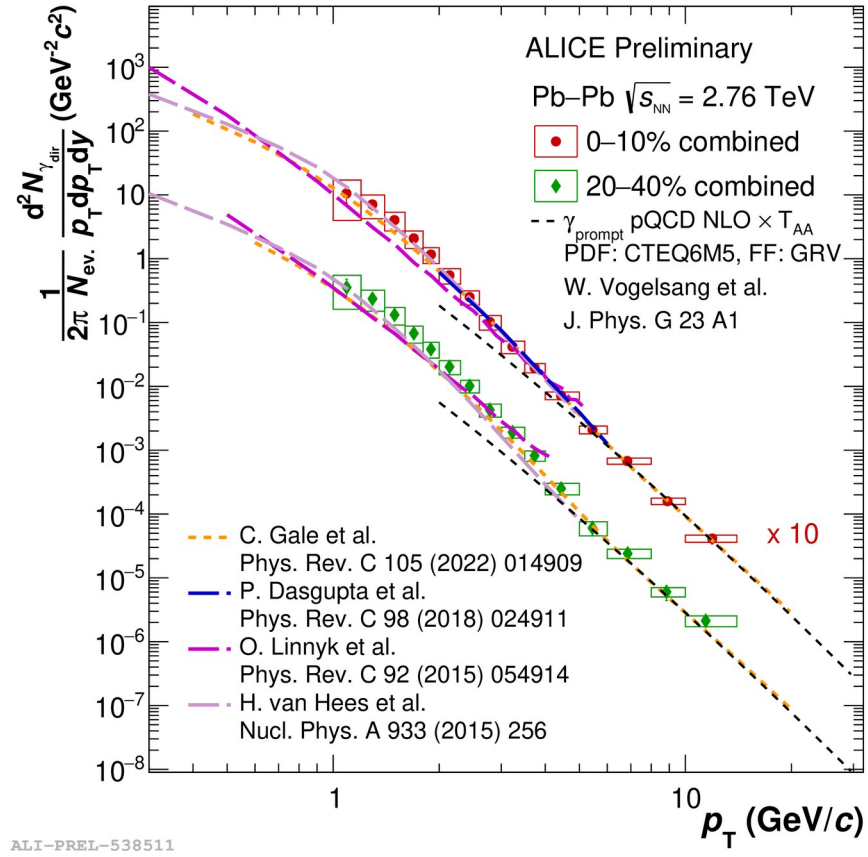
- Measure inclusive photon spectrum in large acceptance calorimeters EMCAL, DCAL or precise calorimeter PHOS or via Photon Conversion Method (PCM)
- Measure neutral meson spectra (π^0,η, ω, ...)
- Subtract estimated decay photon yield from the inclusive one

Virtual photons:

- Measure dilepton invariant mass spectra
- Subtract combinatorial background
- Decompose into meson and direct photon contributions

Direct photon yield in Pb-Pb at $\sqrt{s_{NN}}$=2.76 TeV

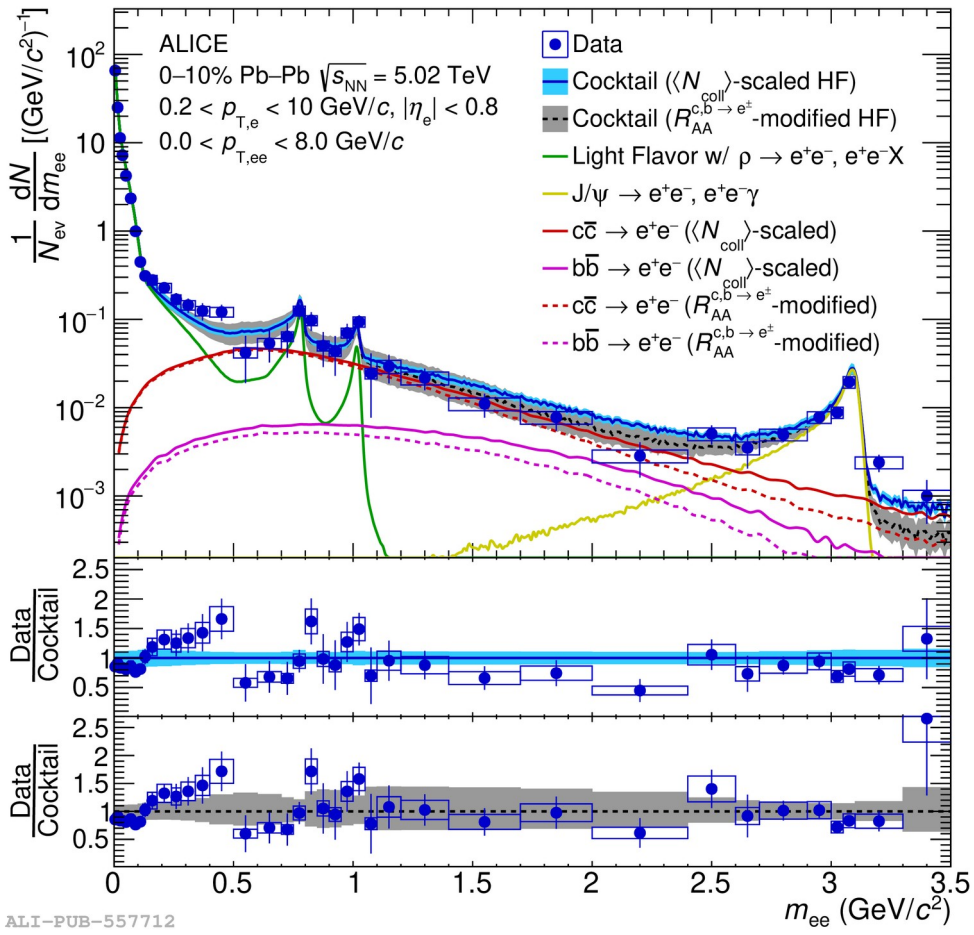
- Improved results from the previous publication (PLB 754 (2016) 235-248)
  - Larger statistics : 20M events in 0-10%
  - Data-driven material budget correction (JINST 18 (2023) 11, P11032)
- Agree with NLO calculations scaled with T_{AA} at high p_T>4 GeV/c
- Excess of direct photon production beyond pQCD
- In general measured yield is higher than predictions (thermal + pre-eq. photons) though agree within uncertainties



Measurement via dileptons

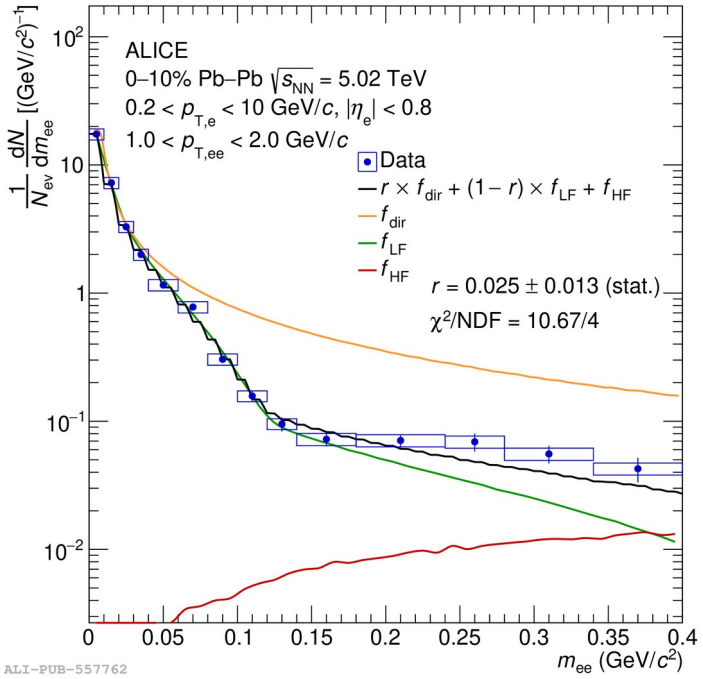
arxiv:2308.16704

- Hint for an excess at low m_{ee}
  - Consistent with additional thermal radiation from the medium
- Need to control heavy-flavour background
  - DCA_{ee} studies in Pb-Pb
- No significant excess at intermediate mass range $1.1<m_{ee}<2.5$ GeV/c^2
- Extract fraction of direct photons by fitting the m_{ee} spectra (m_{ee} < 0.4 GeV/c^2)



Direct photons in pp collisions at $\sqrt{s}$=13 TeV

arxiv:2308.16704



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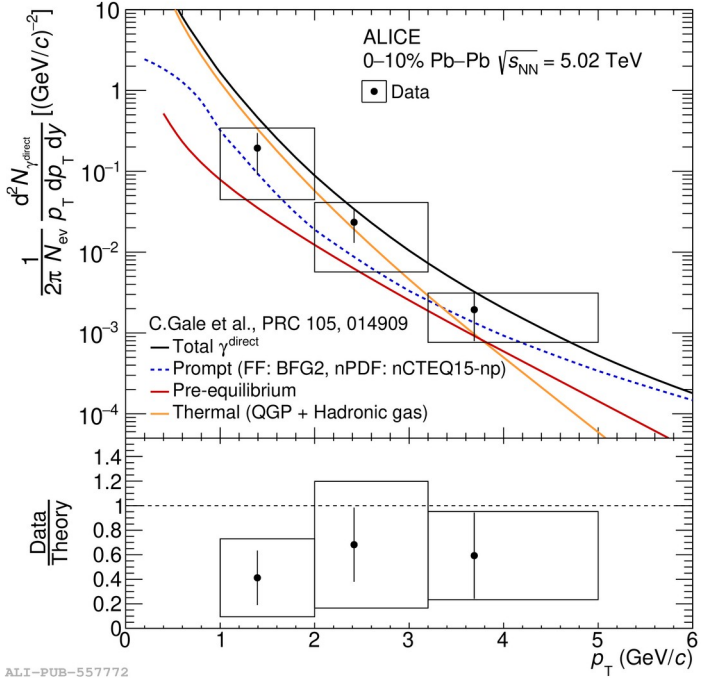
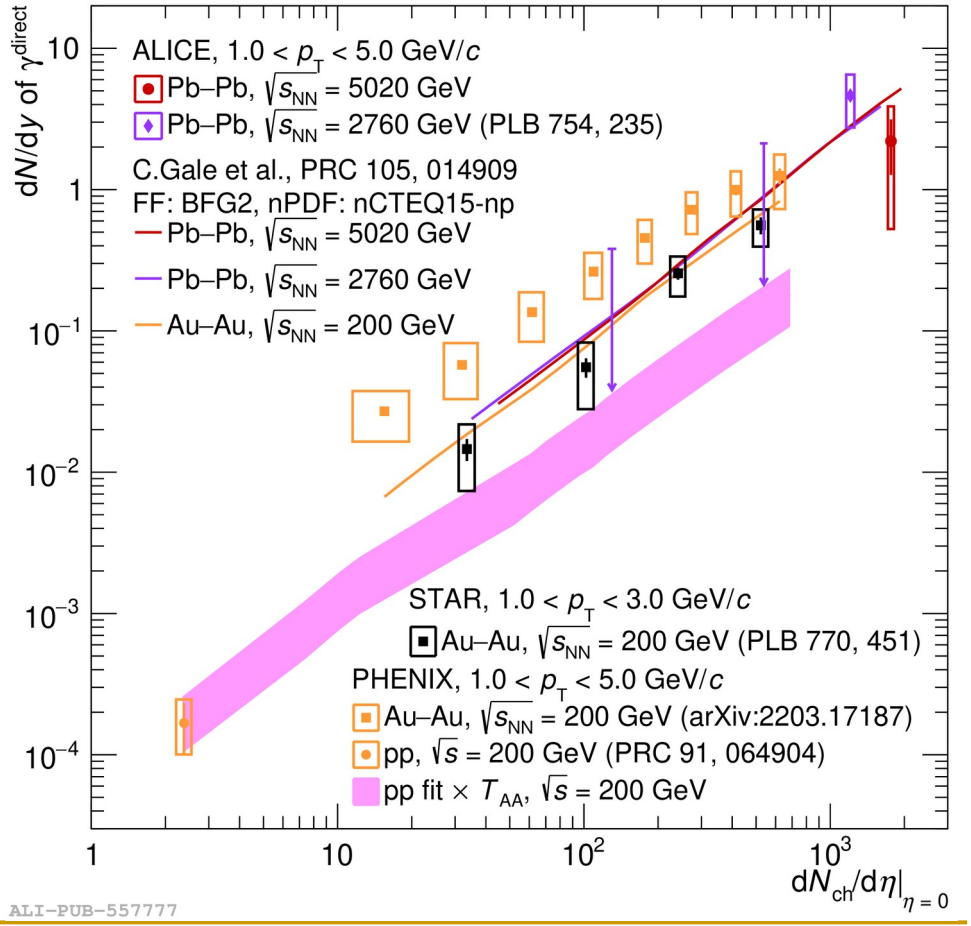


- Direct photon spectrum measured at low p_T
- Data can be reproduced by the model with thermal contribution

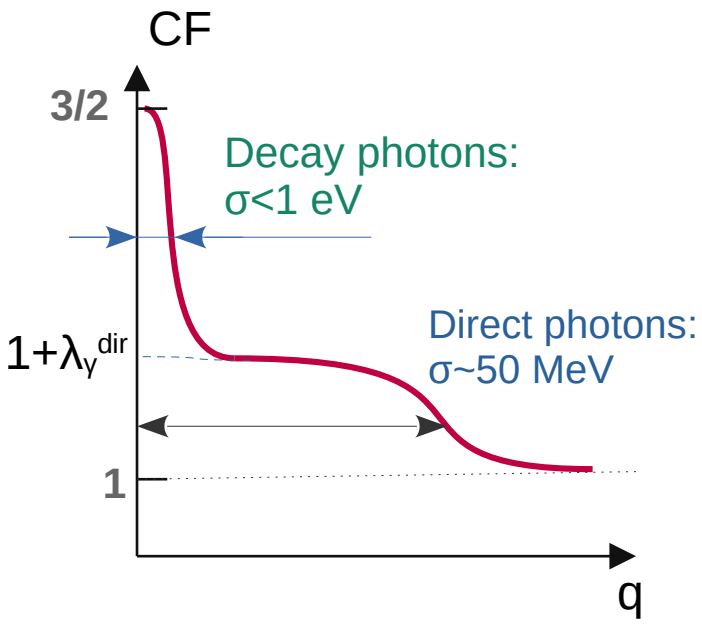
Direct photons in Pb-Pb

arxiv:2308.16704

- Improved results in Pb-Pb collisions at $\sqrt{s_{NN}}$= 2.76 and 5.02 TeV
- Agree with both STAR and PHENIX



Direct photon Bose–Einstein correlations



- No need to select direct photons:
  - Decay-decay, decay-direct correlations have tiny width (~1 eV) and not visible
  - Correlation stength reflects proportion of direct photons

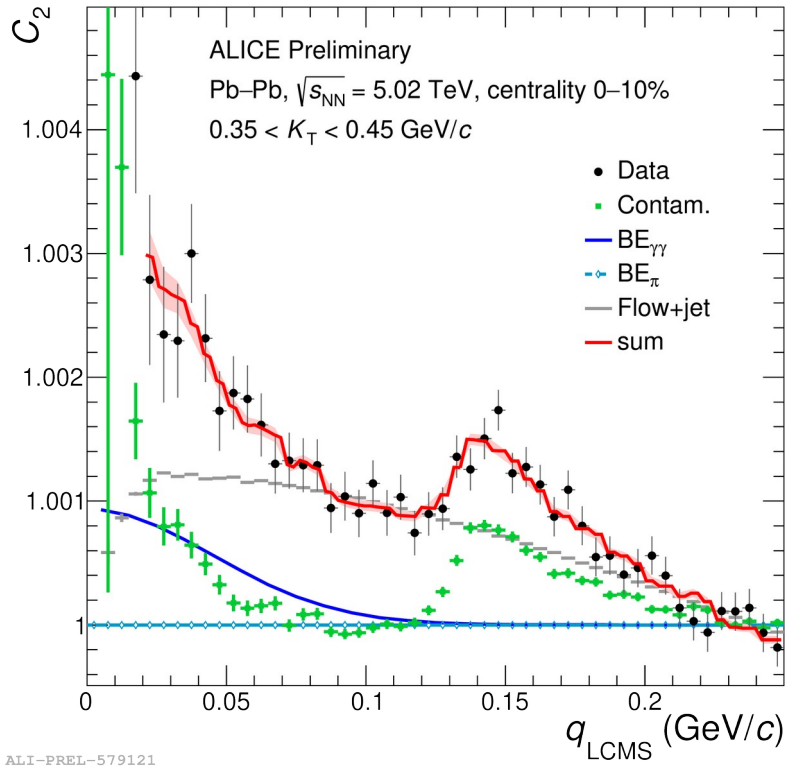
$$\lambda_{\gamma}^{dir} \approx \frac{1}{2}\left(\frac{N_{\gamma}^{dir}}{N_{\gamma}^{incl}}\right)^2 \sim 10^{-3}$$

Variables: $K_T = \frac{1}{2}(\vec{p}_1 + \vec{p}_2)_T$ $q_{LCMS} = |\vec{p}_1 - \vec{p}_2|$ in Longitudinally Co-Moving System

Direct photon correlation function

$$A\left(1+\lambda\exp\left(-q^2R^2\right)+a_{contam}Cont+a_{BE\,\pi\pi}\left(C_2^{BE\,\pi\pi}-1\right)+a_{Flow}\left(C_2^{Flow}-1\right)\right)$$

- Template fit
  - **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



$$K_T=\frac{1}{2}(\vec{p}_1+\vec{p}_2)_T \qquad q_{LCMS}=|\vec{p}_1-\vec{p}_2|$$

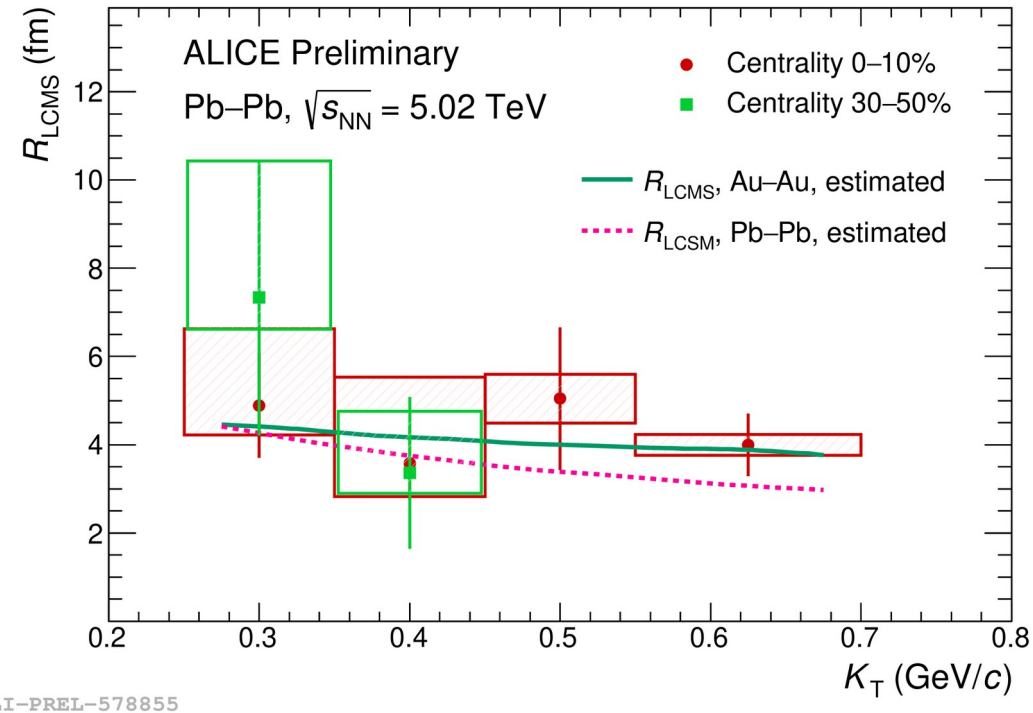
Correlation radius

- Correlation radius R_{LCMS} is an average of all 3 source radii
- Correlation radius shows minor K_T dependence
  - No significant radial flow or interplay of early and later contributions?
- Agrees with estimated radii from hydro predictions
  - Theoretical curves were stimated by averagind of published R_{out}, R_{side}, R_{long} radi

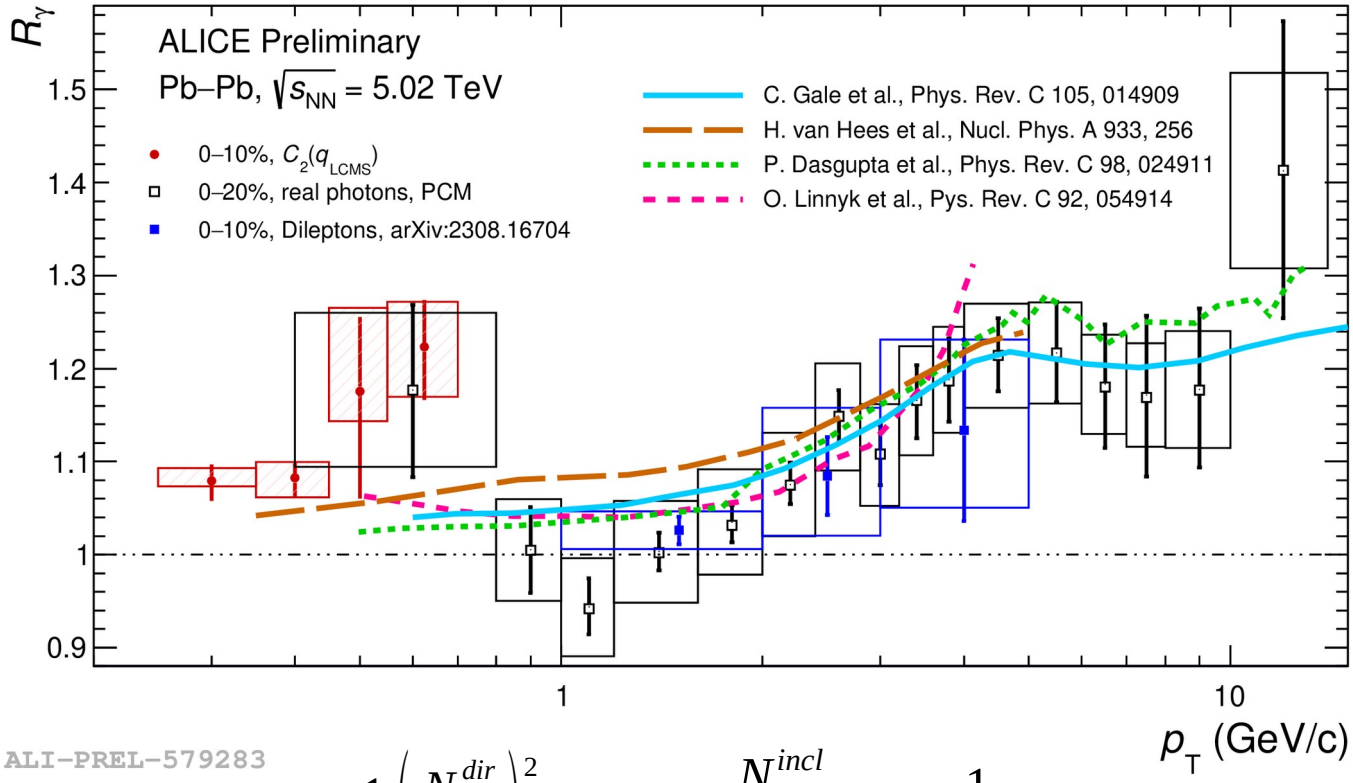
Hydrodynamic calculations:

Pb-Pb: O. Garcia-Montero et al., Phys.Rev.C 102 (2020) 2, 024915

Au-Au: D. Peressounko, Phys.Rev.C 67



Direct photon excess

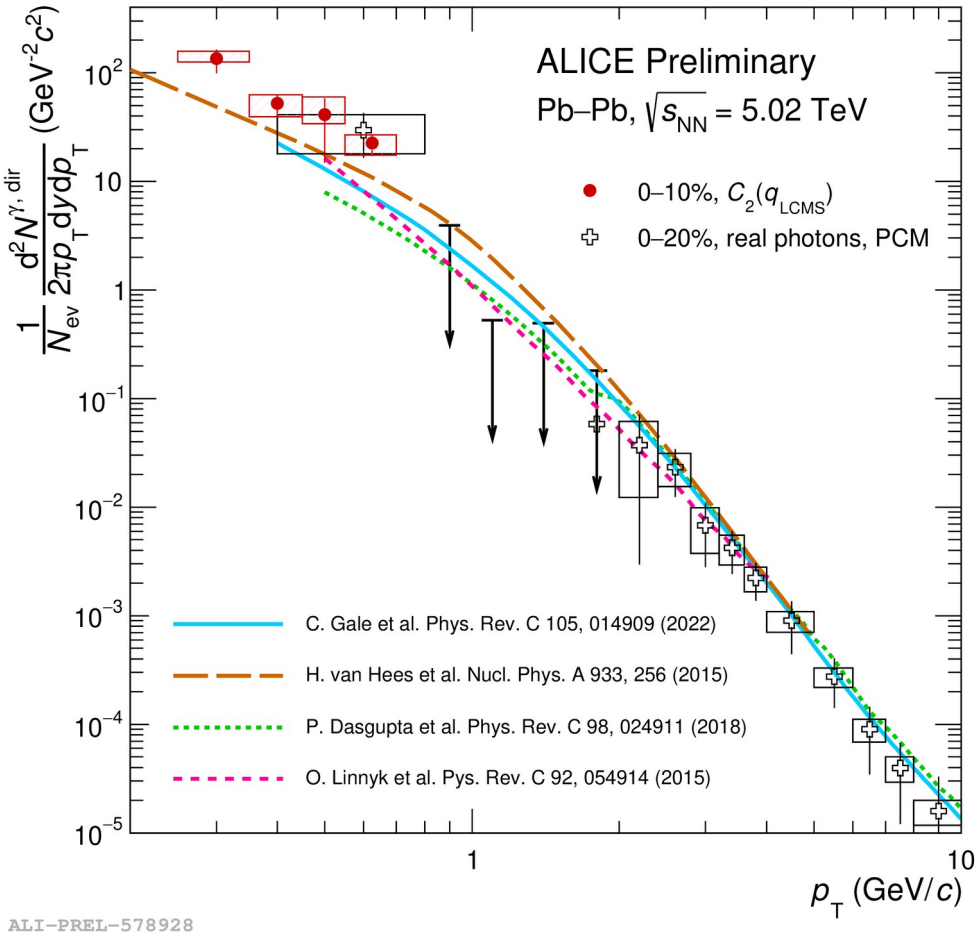


$$\lambda = \frac{1}{2}\left(\frac{N_\gamma^{dir}}{N_\gamma^{incl}}\right)^2 \qquad R_\gamma = \frac{N_\gamma^{incl}}{N_\gamma^{decay}} = \frac{1}{1-\sqrt{2\lambda}}$$

- BE correlations provide possibility to measure direct photon yield with unprecedented accuracy
- In the overlap region measurements are consistent with measured with PCM subtraction method
- At low p_T measured direct photon yield is larger than predictions by factor ~2

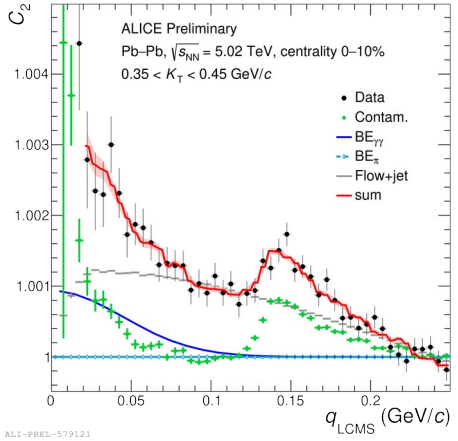
Direct photon spectrum

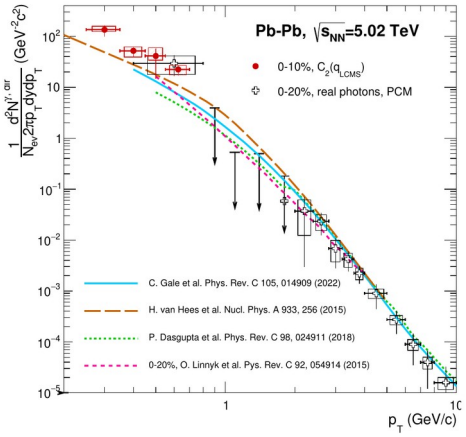
- Extended measurements down to 250 MeV
- Methods provide consistent results in the overlap region
- Measured spectrum exceeds predictions at low p_T by factor ~2



Conclusions

- ALICE provides measurement of direct photon spectra with several independent approaches
- Direct photon spectra were measured in Pb-Pb collisions with two available energies
- Consistent scaling with N_{ch} at high p_T was observed for all collisions
- 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





Talks and Posters to have a look

- Jerome Jung, «Direct photon measurement in small systems and thermal radiation from QGP with ALICE»,

  talk in session 16, 12:10
- Gustavo Conesa Balbastre, «Measuring isolated prompt photon production in small and large collision systems with ALICE»

  talk in session 28, 9:00
- Emma Charlotte Ege, «Performance of the dielectron analysis in Pb-Pb collisions in Run 3 with ALICE»

  poster #74
- Florian Eisenhut, «Dielectron production and topological separation of dielectron sources with ALICE in Run 3»

  poster #44

Backup slides