Direct photon production in p–Pb collisions measured with ALICE/PHOS

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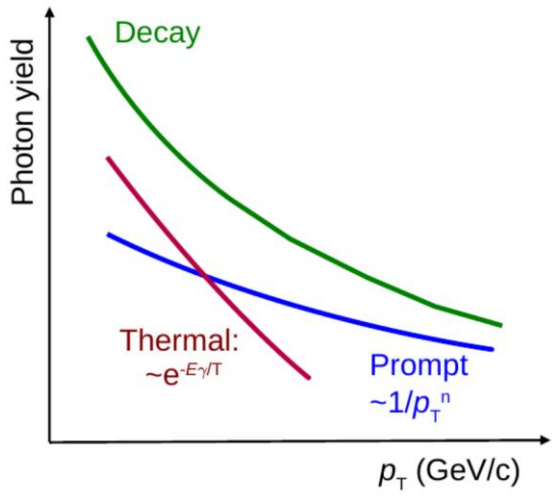
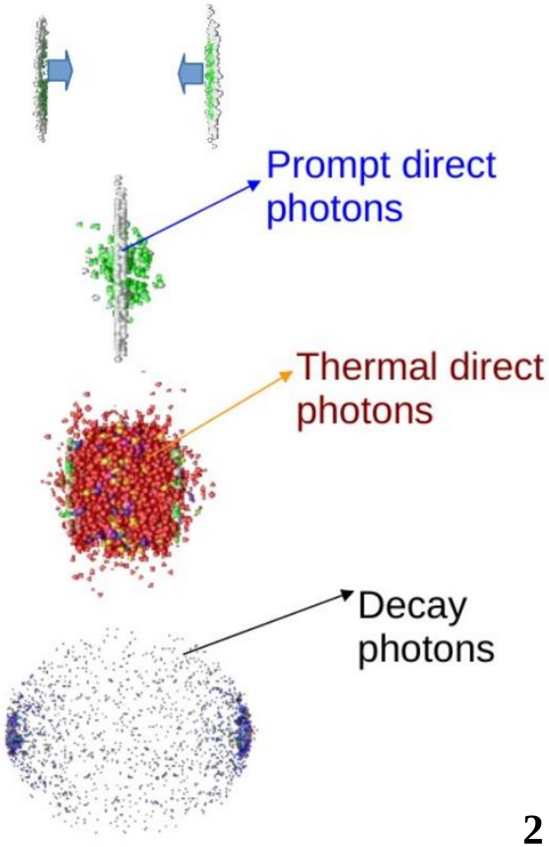
Direct photons

- **Direct photons** – photons not originating from hadronic decays (unlike **decay photons**).

- No strong final-state interactions → information about all stages of the collision

- Experimentally, only the total photon spectrum can be measured





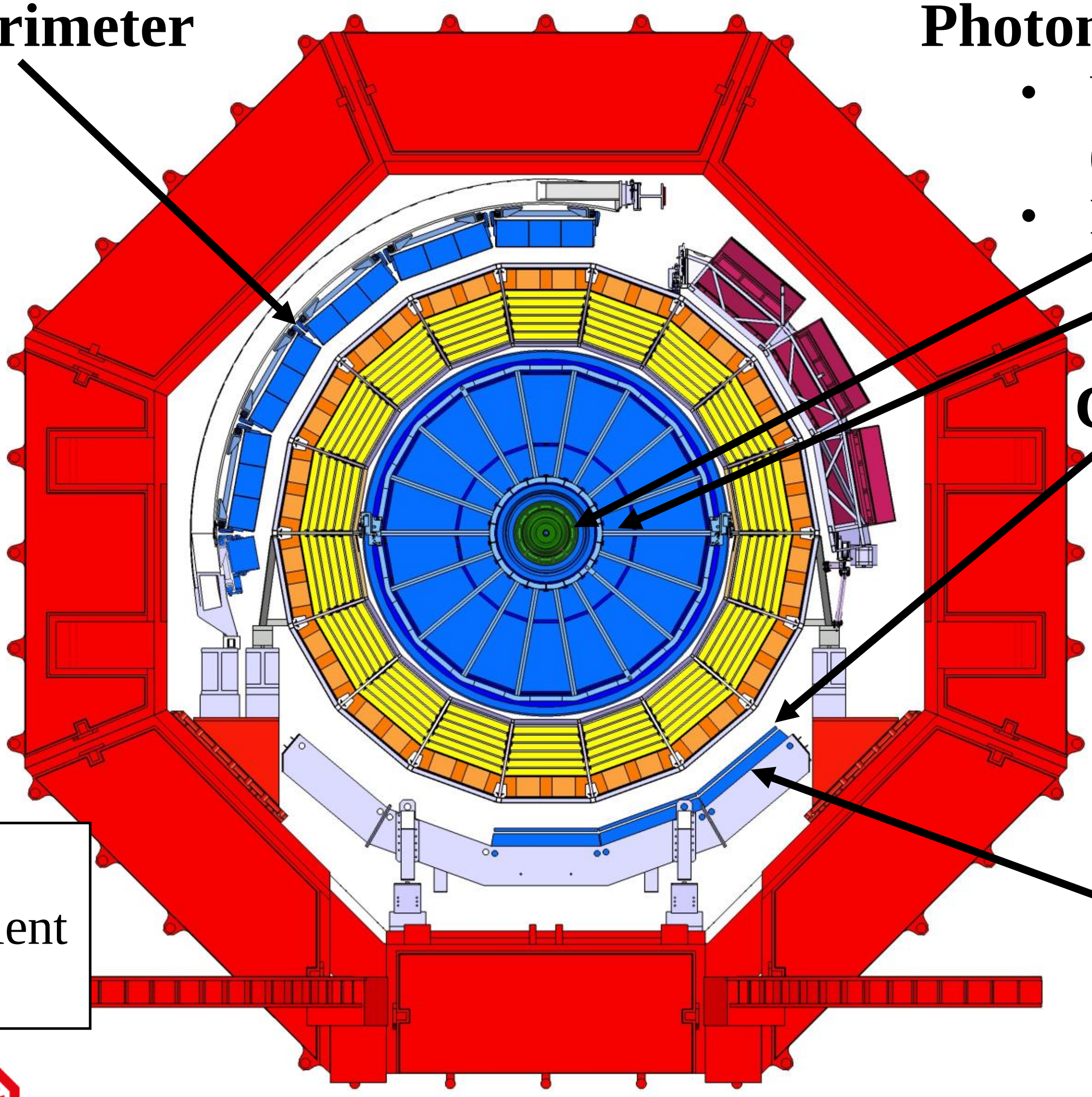
- High p_T = **prompt direct photons** (from initial hard scatterings between partons) – test of initial conditions:
  - N_{coll} **scaling** and **PDF modification**

- Low p_T = **thermal direct photons** (from hot matter thermal radiation) – test of hot matter evolution:
  - Spectrum → **temperature** and **Collective flow**

ALICE detector setup

Electromagnetic calorimeter (EMCal) + DCal

- Pb-scintillator sampling calorimeter
- Cell size – 6×6 cm^2
- $|\eta| < 0.7$, $80° < \varphi < 187°$ (large acceptance)



Photon conversion method (PCM)

- Using photon conversion probability (~ 8%) in detector material
- ITS + TPC: $|\eta| < 0.9$, $0° < \varphi < 360°$

Charged-Particle Veto (CPV)

- Used for photon identification
- 2 additional CPV modules were installed prior to Run 3

PHOS calorimeter

- $PbWO_4$ crystals
- High granularity (2.2×2.2 cm^2 cell size)
- $|\eta| < 0.12$, $260° < \varphi < 320°$

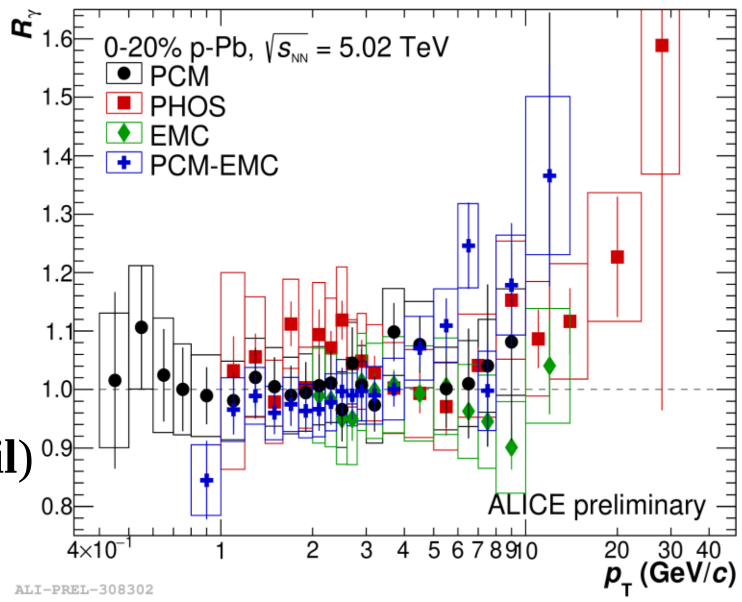
Different techniques are combined to achieve excellent precision and p_T range.

Run:266438
Timestamp:2016-11-26 17:56:16(UTC)
System: Pb-p
Energy: 8.16 TeV
EMCal L1 gamma and jet triggered event

Direct photon subtraction method

- **Subtraction method**: $N_{\gamma_{\text{direct}}} = N_{\gamma}^{\text{incl}} - N_{\gamma}^{\text{decay}} = \left(1 - \frac{1}{R_{\gamma}}\right) N_{\gamma}^{\text{incl}}$

$$R_{\gamma} = \frac{N_{\gamma}^{\text{incl}}}{N_{\gamma}^{\text{decay}}} \approx \left(\frac{N_{\gamma}^{\text{incl}}}{N_{\gamma_{\pi^0}}}\right)_{\text{measured}} \Bigg/ \left(\frac{N_{\gamma}^{\text{decay}}}{N_{\gamma_{\pi^0}}}\right)_{\text{simulated}}$$

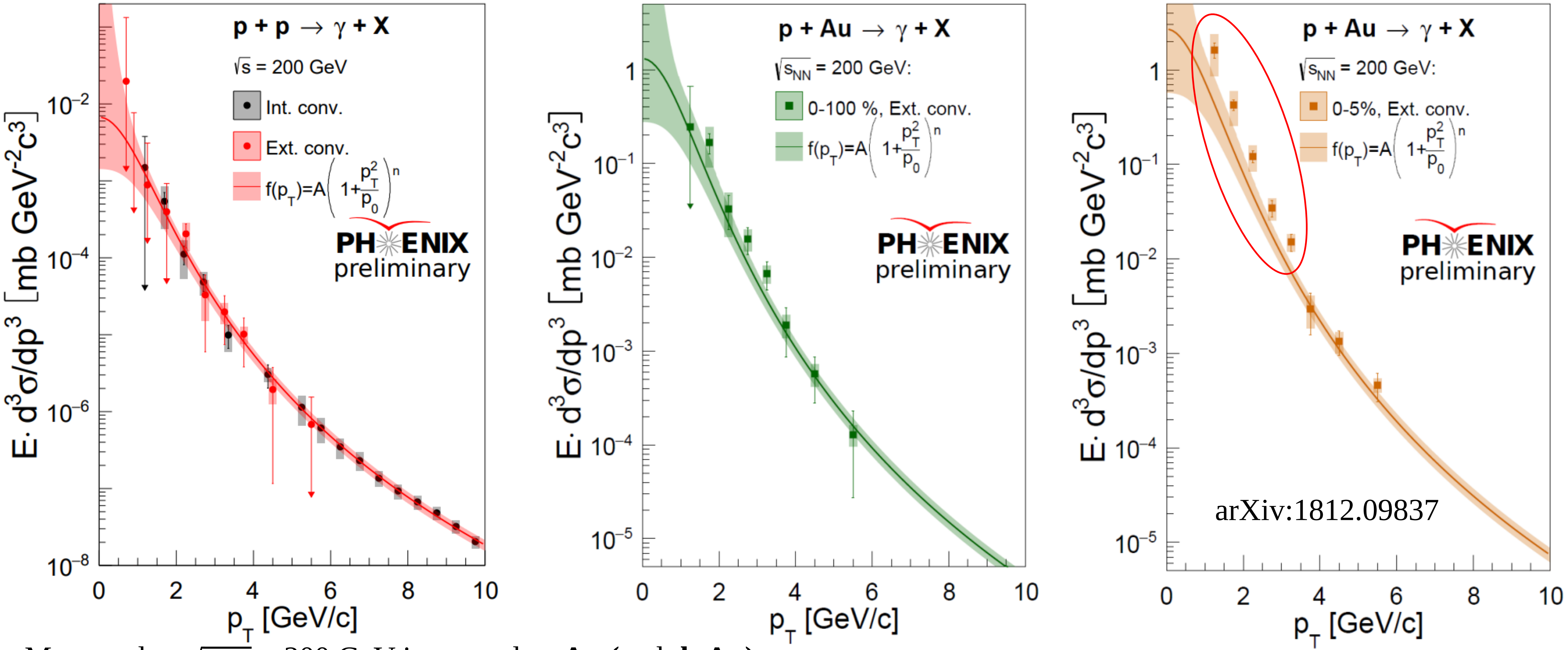


- **Inclusive photons** = all photons produced (decay + direct)
- Decay photons = decay simulation from measured/m_T-scaled hadron spectra (**cocktail**)
- Double ratio (**R_γ**) → cancel some large systematic uncertainties

- Different methods (PCM, PHOS, EMC) – statistically and systematically **uncorrelated** and produce **consistent results**.

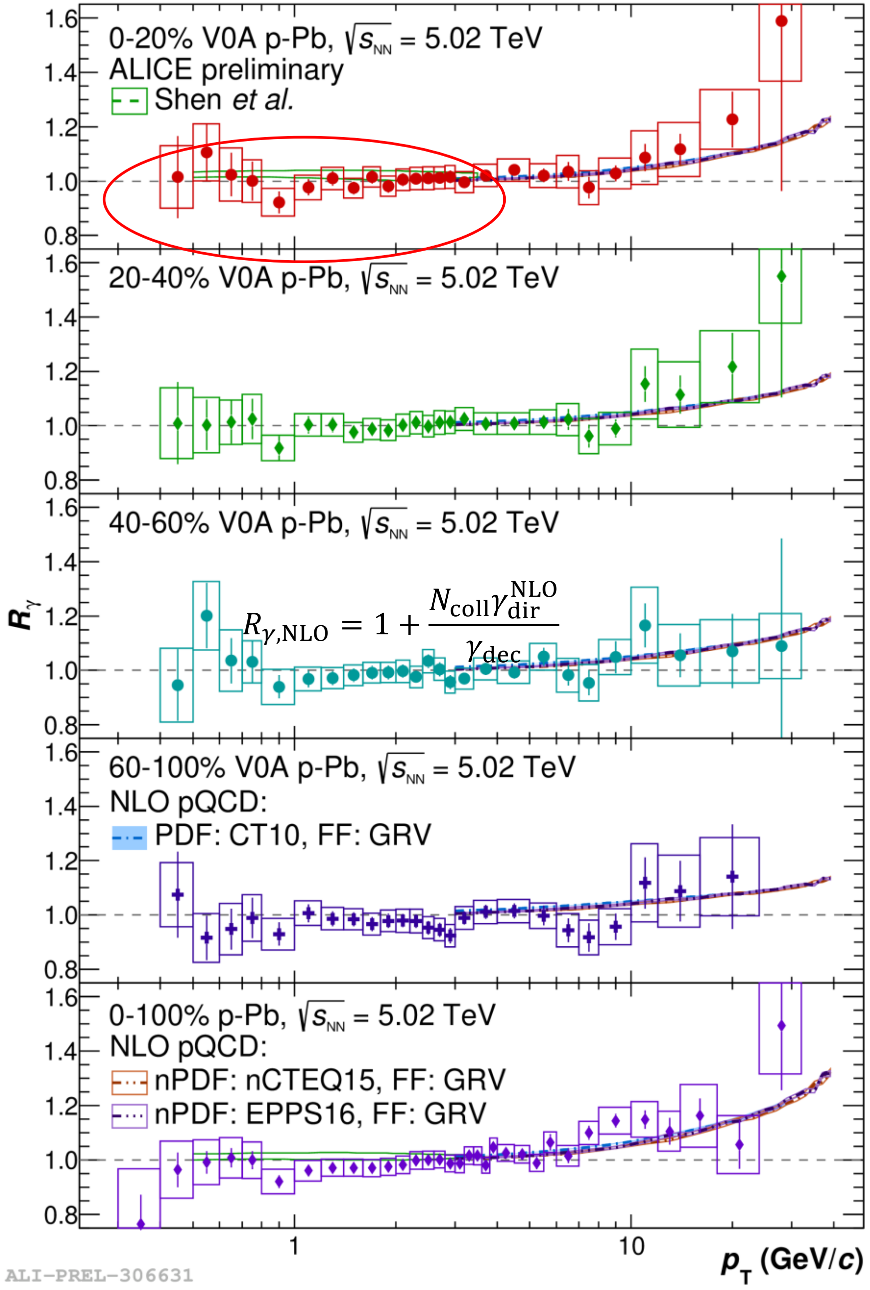
- Systematic uncertainties of individual measurements are mostly ***p_T*-independent**.

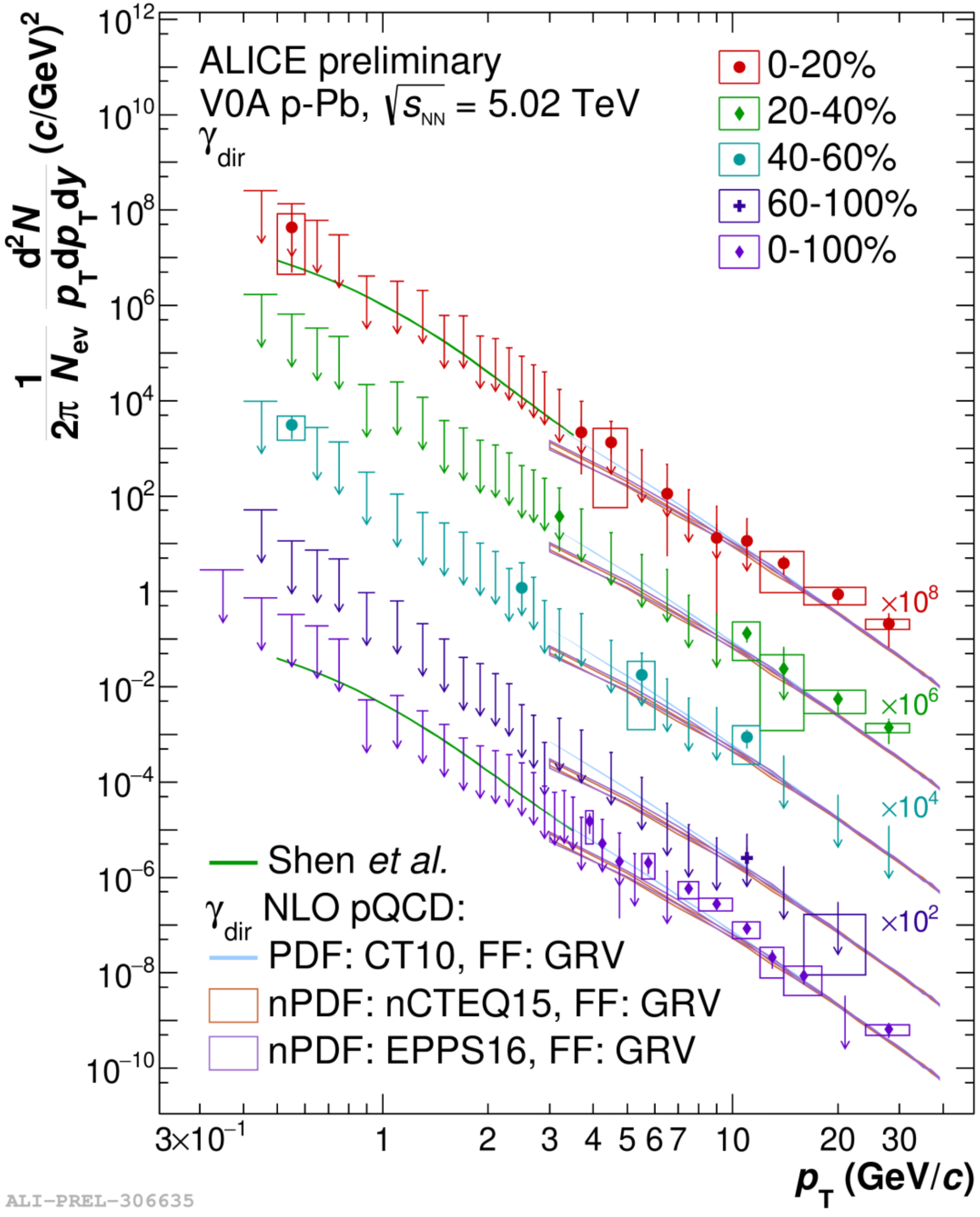
Direct photon measurements in pp and p–Au with PHENIX



- Measured at $\sqrt{s_{NN}}$ = 200 GeV in **pp** and **p+Au (**and **d+Au)**
- In pp and 0-100% p+Au collisions there is **no visible excess** of thermal photons at **low p_T**
- However in 0–5% p+Au with the highest multiplicity there is **a hint for excess** of direct photons at **low p_T < 4 GeV/c**.

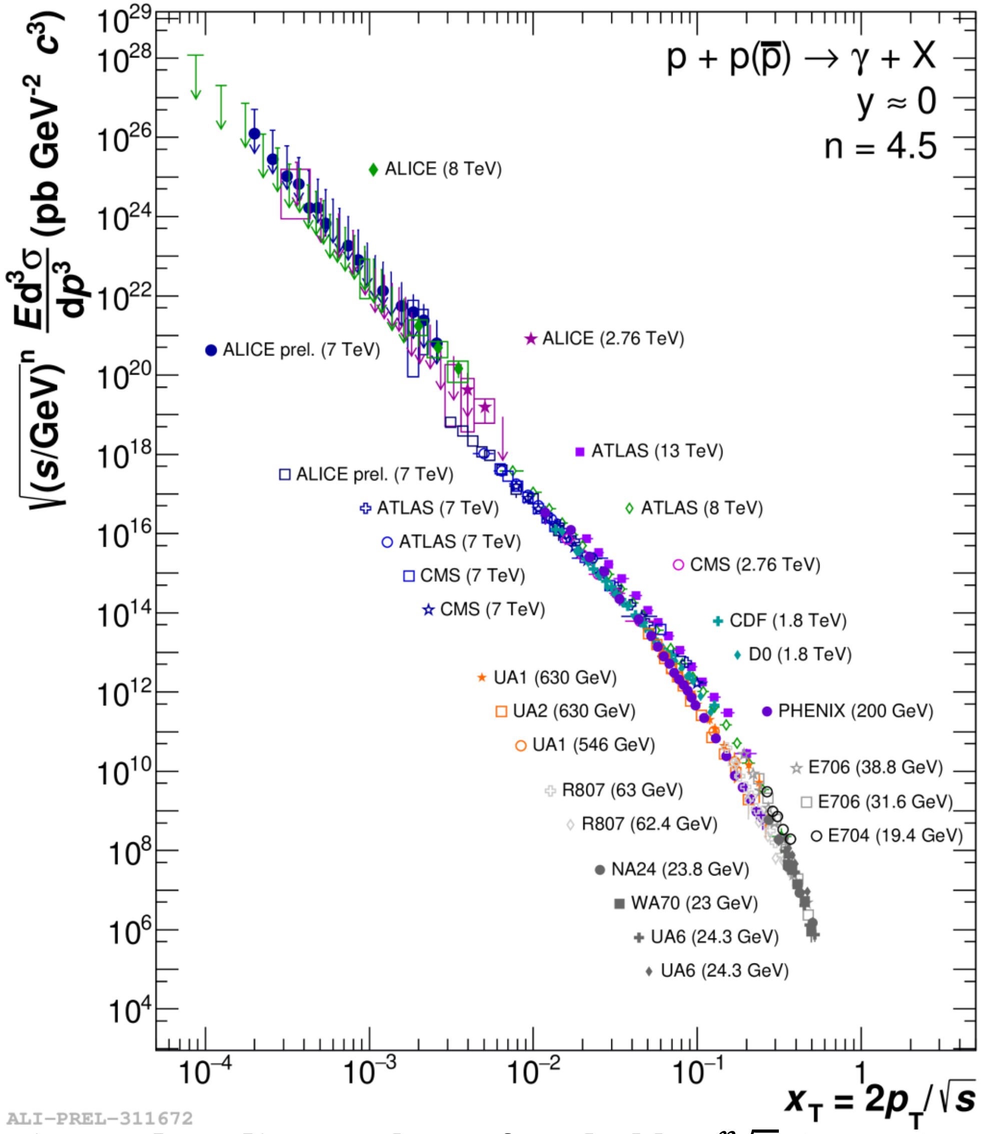
Direct photon measurements in p–Pb with ALICE

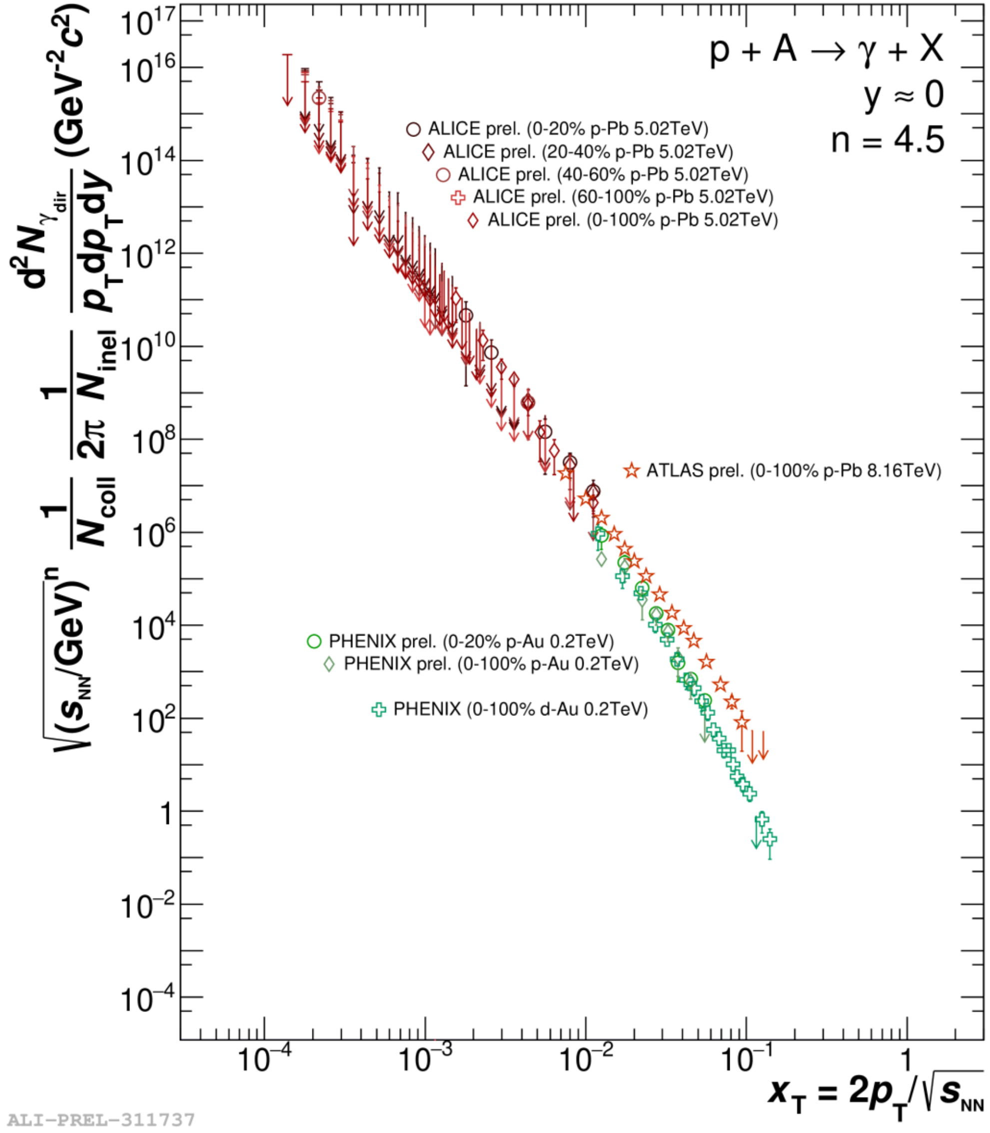




- Measured at $\sqrt{s_{NN}}$ = 5.02 TeV in **4 multiplicity classes**
- At **high** $\boldsymbol{p_T}$ – **excess** of prompt photons, in agreement with the NLO pQCD calculations.
- Even in the class 0–20% with the highest multiplicity there is **no visible excess** of direct photons at **low** $\boldsymbol{p_T}$.
- Need to carry out **more precise measurements** to confirm or exclude thermal radiation in p–Pb collisions.

Compilation of direct photon measurements



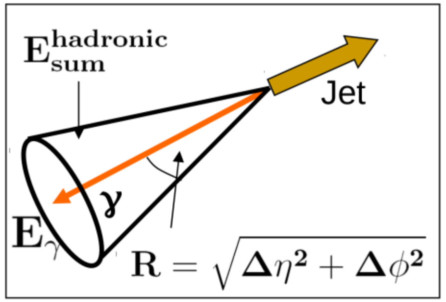


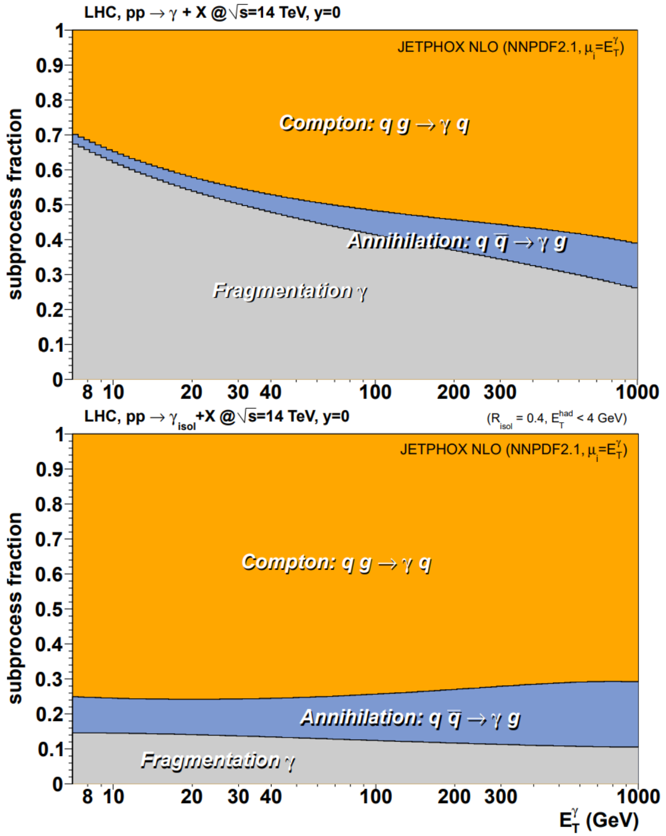
Dmitry Blau, Dmitri Peresunko // Particles 2023, 6(1), 173-187

- **Universal scaling** with x_T if scaled by $\sqrt[n]{s}$ ($\sqrt[n]{s_{NN}}$) with n = 4.5
- **Direct photon** results from different experiments are included (both published and preliminary)
- In **p–Pb** collisions data are aligned on a **common x_T curve, however, not as clear scaling** as in pp collisions

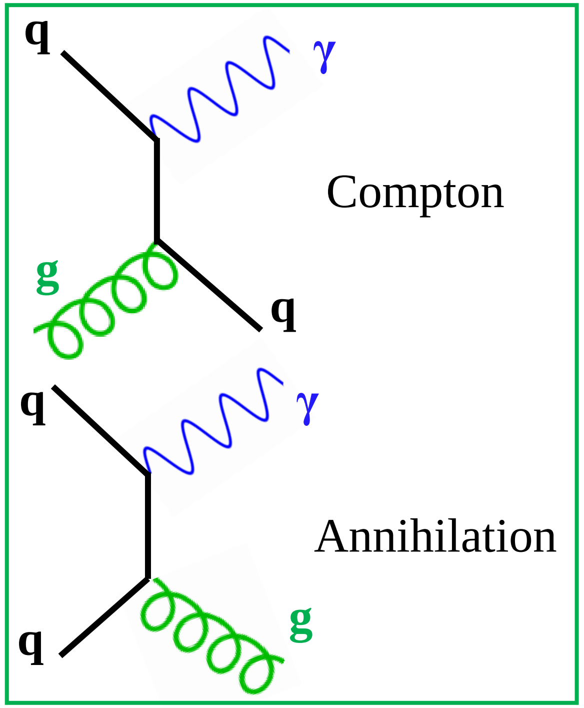
Isolated photons

- **Isolated photons** – photons with no hadron activity in cone with radius R ~ 0.4
- Can be measured in event-by event basis
- Cannot be measured at low p_T due to rapid purity decrease (< 5 GeV/c in PHENIX and < 10-20 GeV/c in ALICE)
- Almost no difference between direct and isolated photons at high p_T

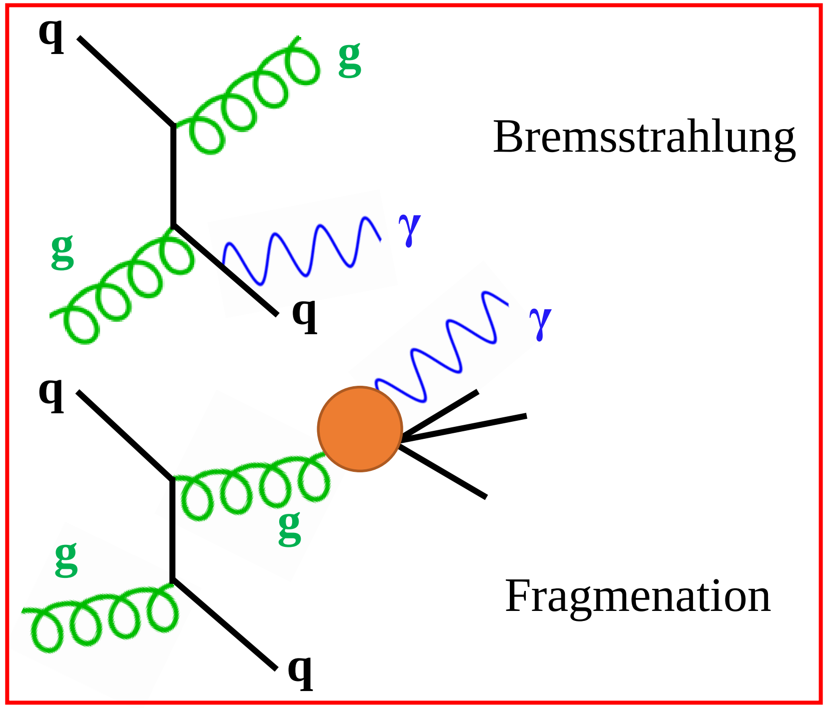


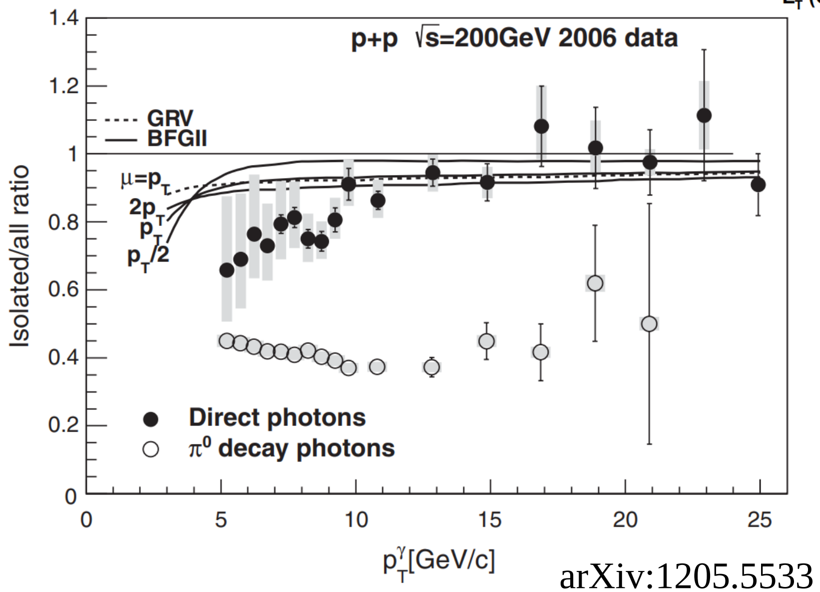


Isolated



Non-isolated





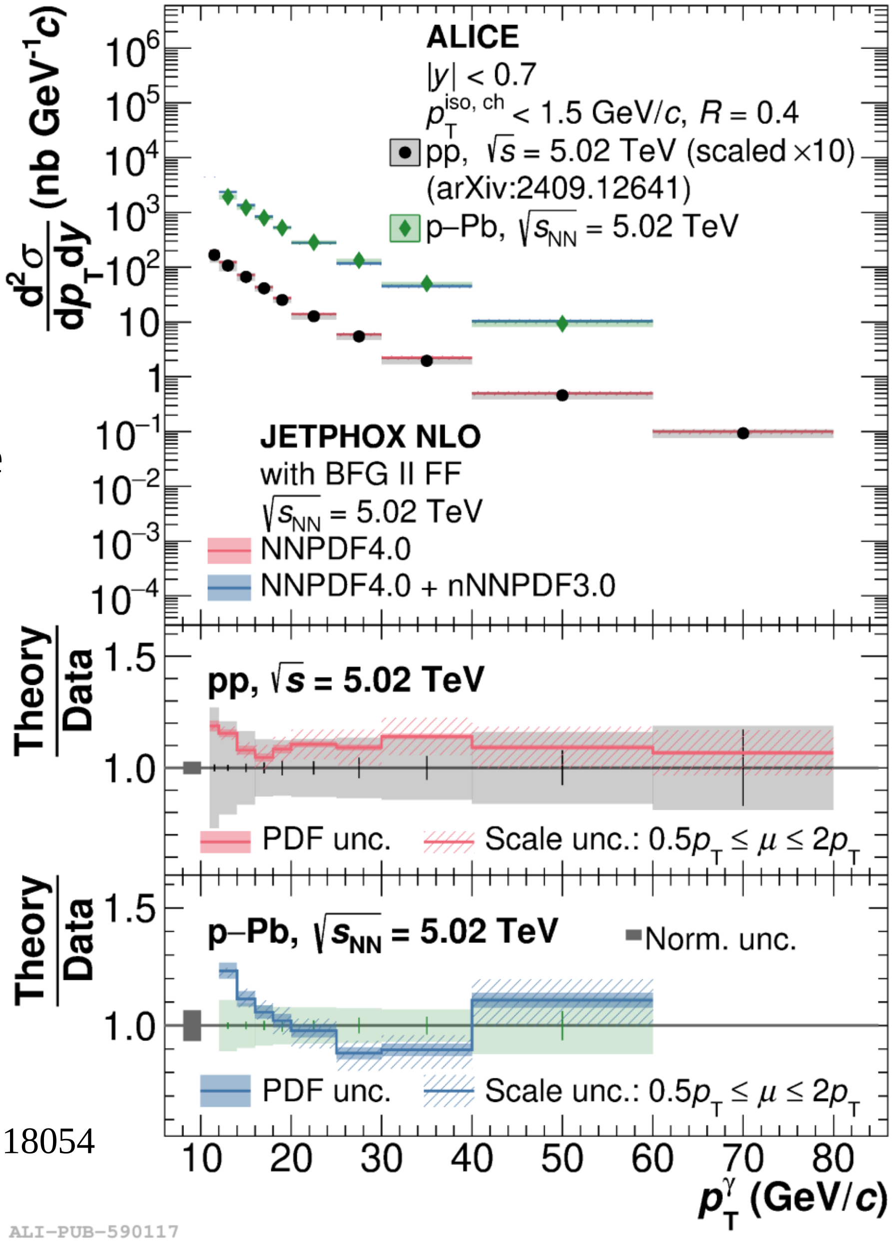
arXiv:1205.5533

Isolated photon measurements in p–Pb with ALICE

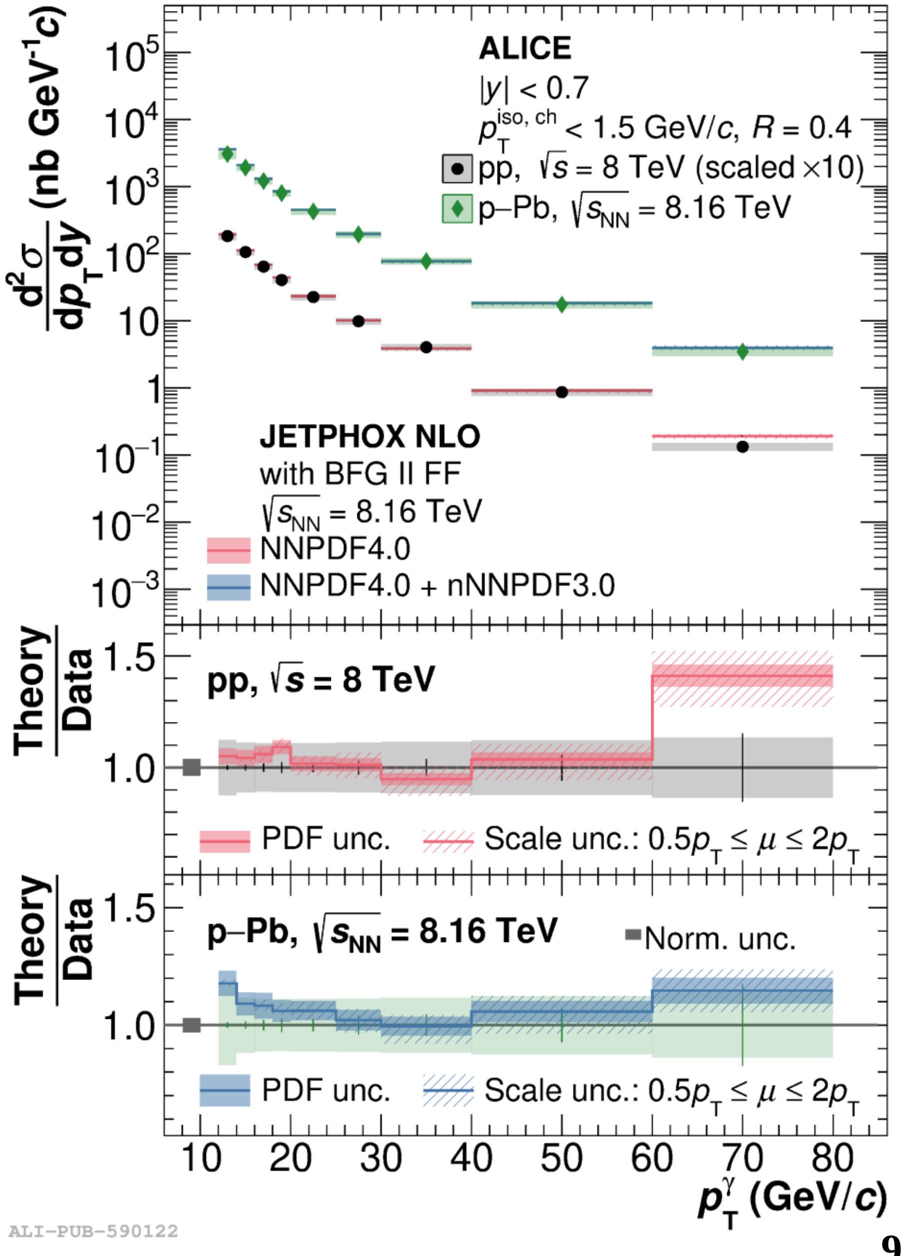
- Isolated photons were measured in ALICE in **p–Pb** collisions at **5.02** and **8.16 TeV**

- ALICE measurements **extend the p_T range** to lower values in comparison with previous CMS and ATLAS measurements

- The measurements are consistent with NLO pQCD predictions



arXiv:2502.18054



Direct photon tagging method

- In this approach photons having a pair with the π^0 mass are excluded from the spectrum **in each event** (unlike in the subtraction method) leaving the spectrum of photons not having a partner in the calorimeter acceptance from π^0 decays. After such a procedure **additional corrections (δ, α, β)** are introduced.

- This method helps to avoid subtracting two close big numbers, which **reduces the systematic uncertainty**.

- To compare results of subtraction and tagging methods R_γ is constructed:

$$R_\gamma = \frac{N_\gamma^{\text{incl}}}{N_\gamma^{\text{decay}}} = \frac{N_\gamma^{\text{incl}}}{N_\gamma^{\text{tag}}} \cdot \frac{\alpha}{\delta} \cdot \frac{P\epsilon}{1+\beta}$$

– where P – purity, ϵ – PID efficiency

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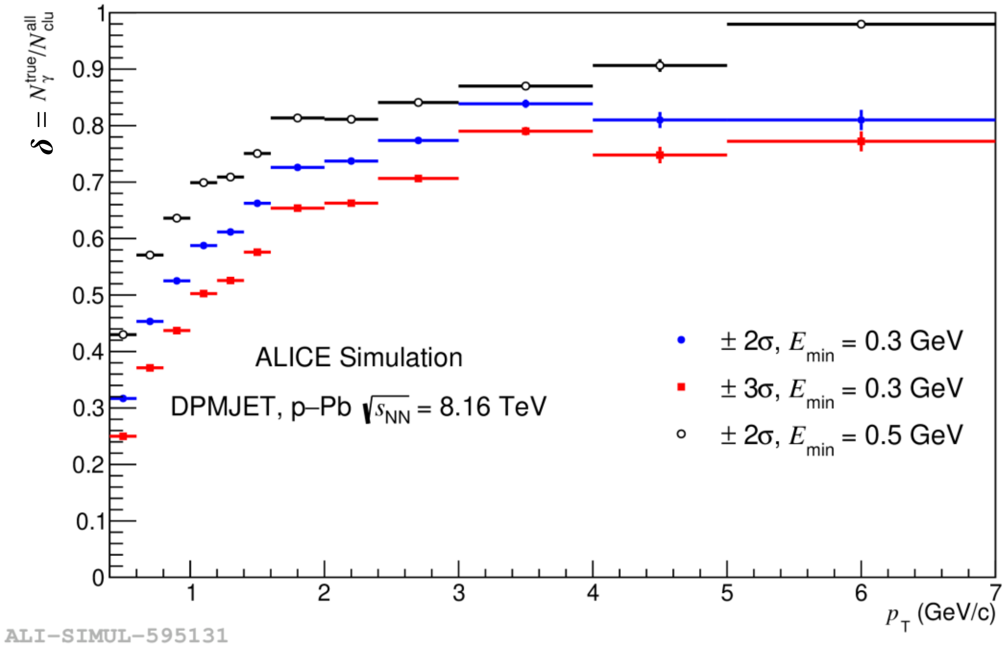
- **<u>Corrections</u>**:
  - $\boldsymbol{\delta}$ – the proportion of “true” tags, i.e. correction for the **fake pairs**



- Tagging method is **effective** when acceptance of the calorimeter is sufficiently large compared to the π^0 decay opening angle and cluster multiplicity is so low that correction for the fake pairs is small, i.e. **in pp and p–Pb collisions**.

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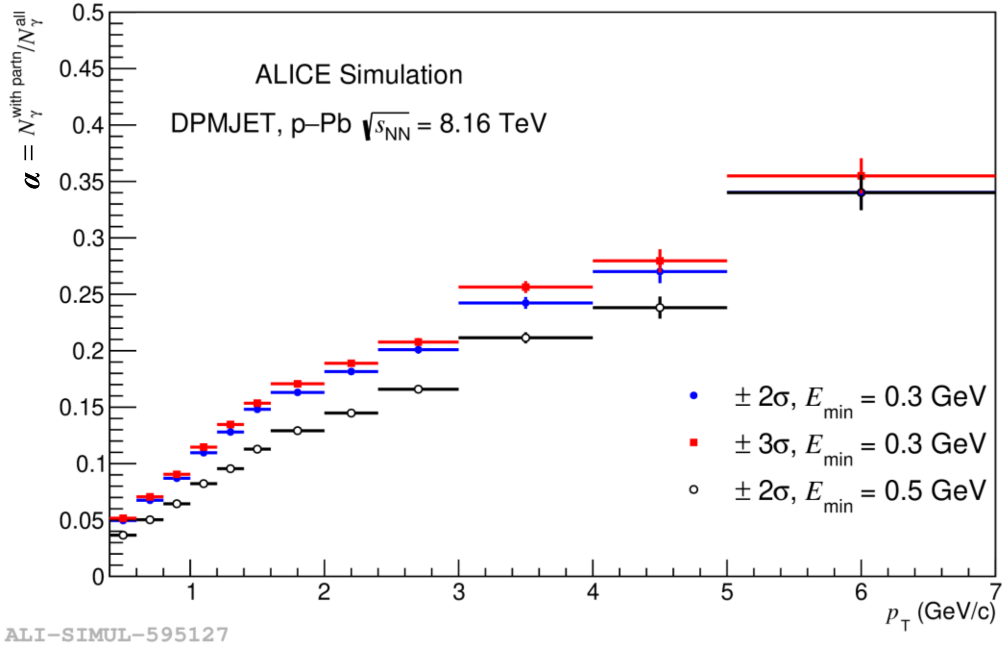
- **Corrections**:

  - **α** – the proportion of photons from π^0 decays having the partner outside the calorimeter acceptance or the partner being too soft or **not being detected** for the other reasons



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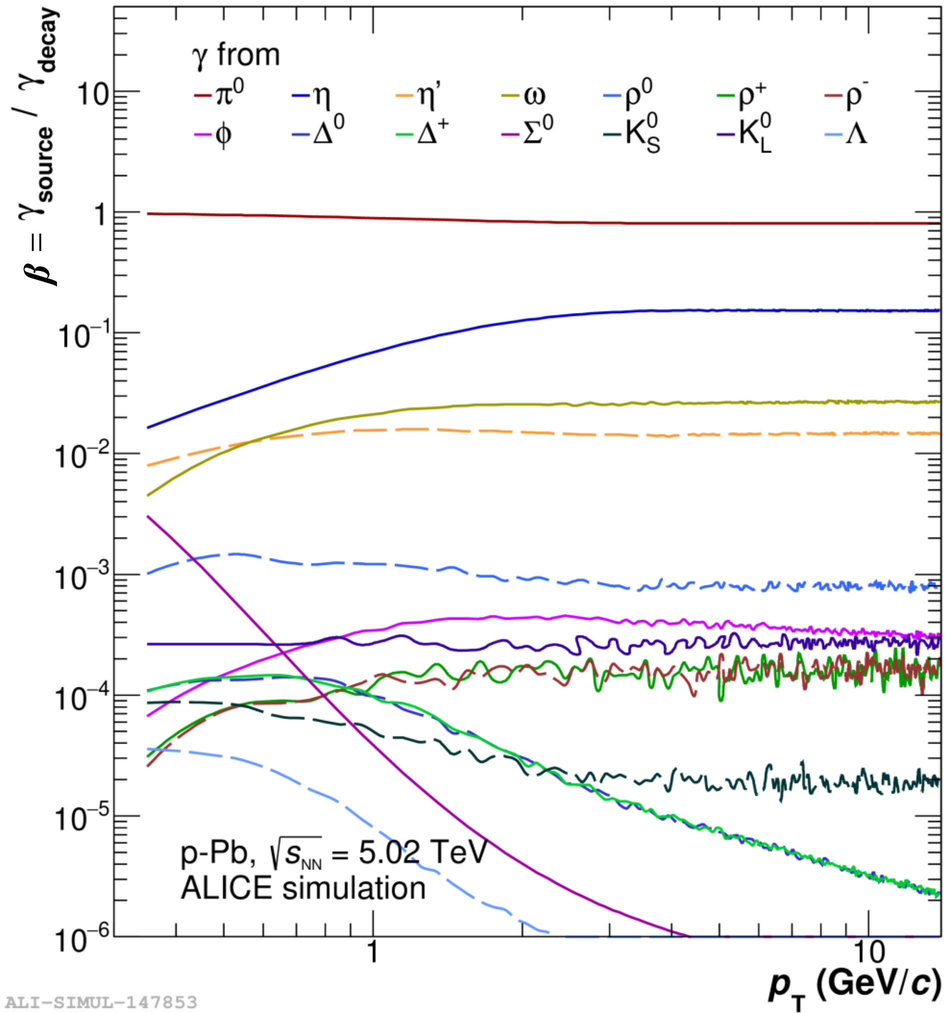
- **<u>Corrections</u>**:
  - ***β*** – correction for η meson and heavier hadron decay contribution (**cocktail**)



Conclusion

- **Direct photon spectra** were measured in **p–Pb** collisions at $\sqrt{s_{\mathrm{NN}}}$ = **5.02 TeV** in ALICE in Run 1+2 in the range 400 MeV < p_{T} < 40 GeV with different methods (real photons via PHOS, EMC, PCM and isolated photons) in various centrality classes and compared to the results obtained at $\sqrt{s_{\mathrm{NN}}}$ = **200 GeV** in PHENIX. However, the measurements via dileptons and via Bose-Einstein correlations are still to be done.

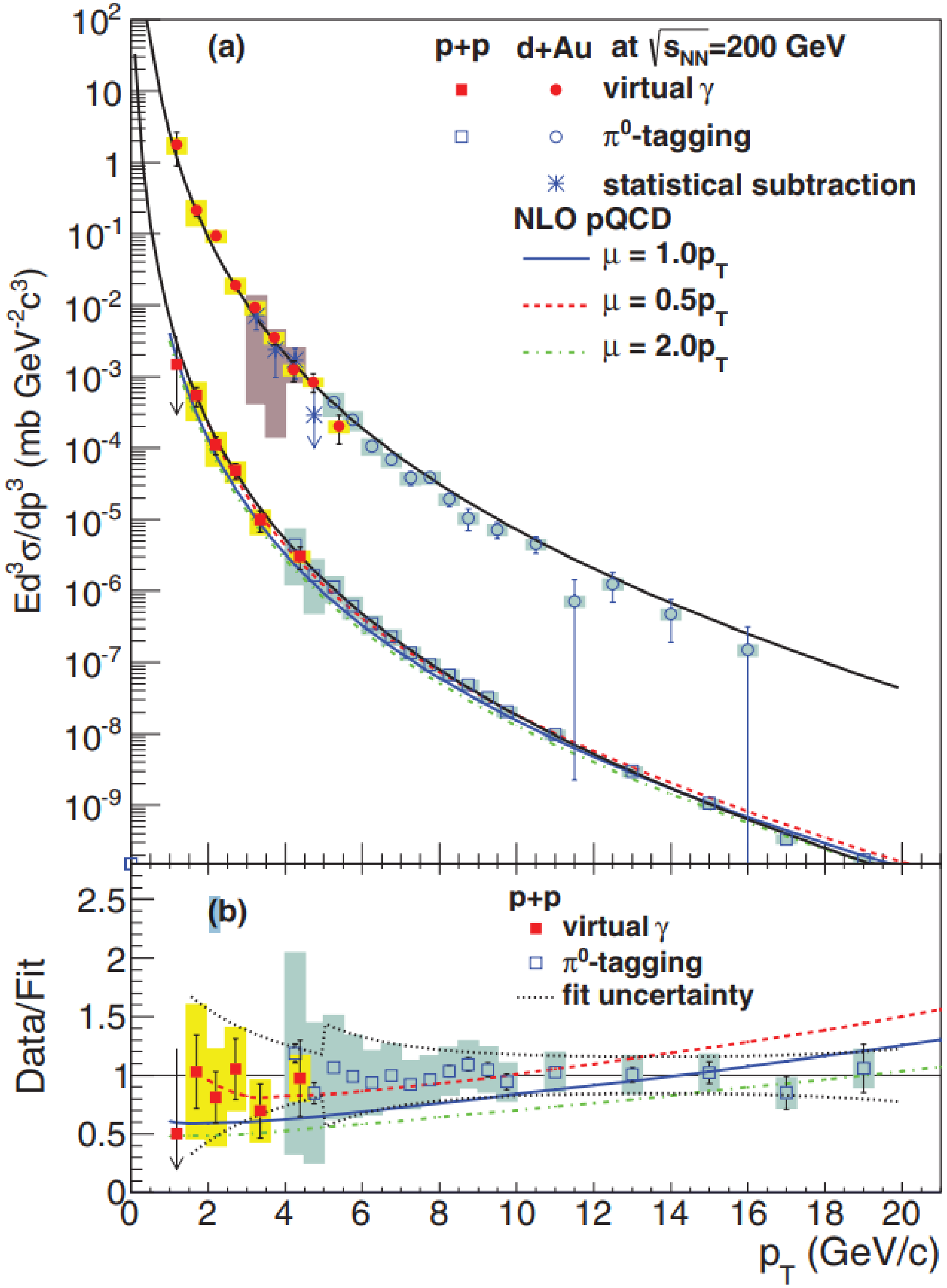
- In **ALICE** in **p–Pb** collisions **no significant thermal photon excess** is observed (p_{T} < 2-3 GeV/c). **The yield of prompt photons** (p_{T} > 7 GeV/c) is in good agreement with the NLO pQCD calculations. In comparison, in **PHENIX**, there is **visible excess** of direct photons at **low p_{T} < 4 GeV/c**.

- The first results from the developed **direct photon tagging method** for p–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = **8.16 TeV** look promising.

Thank you for your attention!

Backup

Direct photon measurements with PHENIX

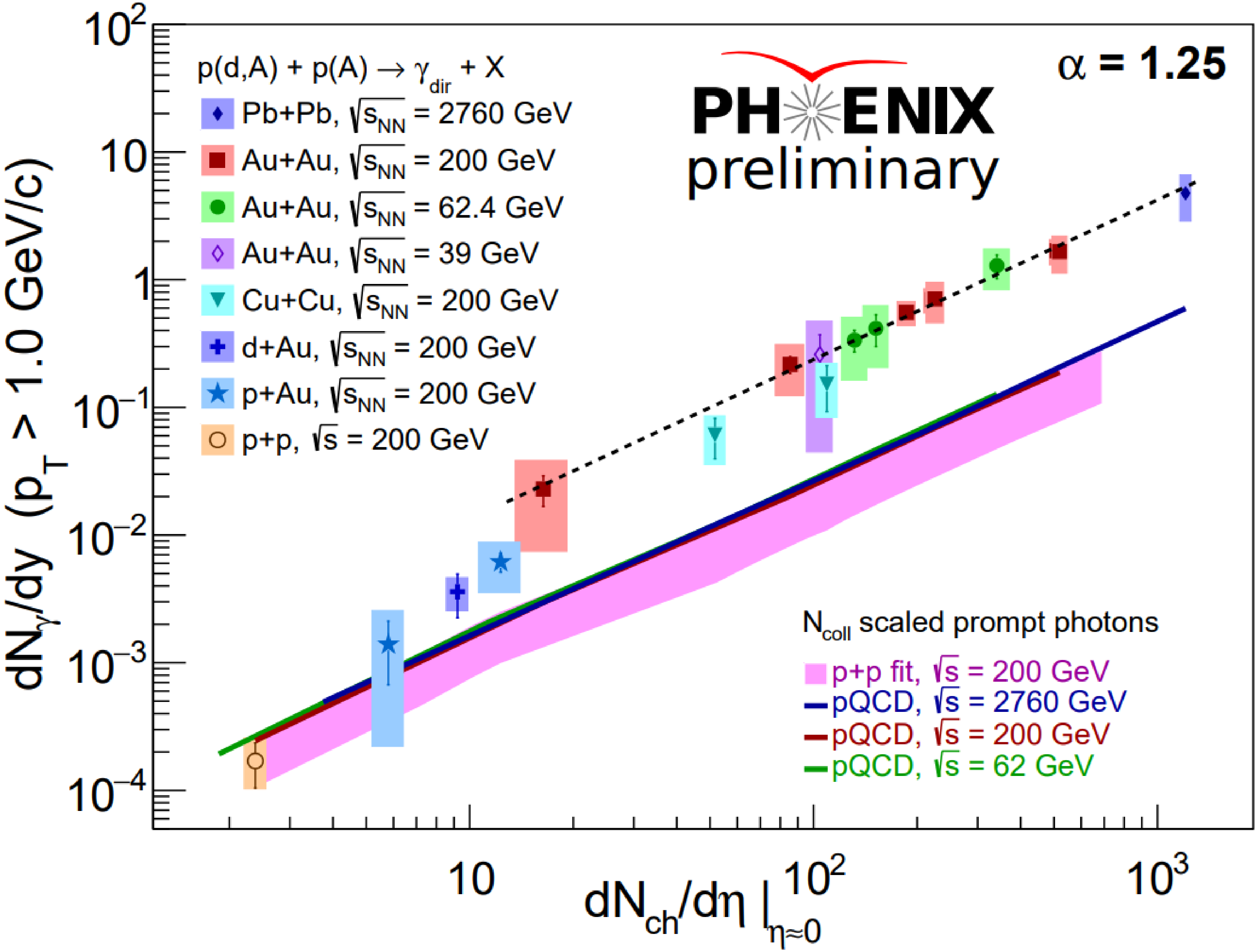


- Measured at **200 GeV** in **pp** and **d+Au** collisions with different methods (the most straightforward **subtraction method**, **tagging method**, via **virtual photons**/dilepton pairs)

- **Consistent results** from different methods

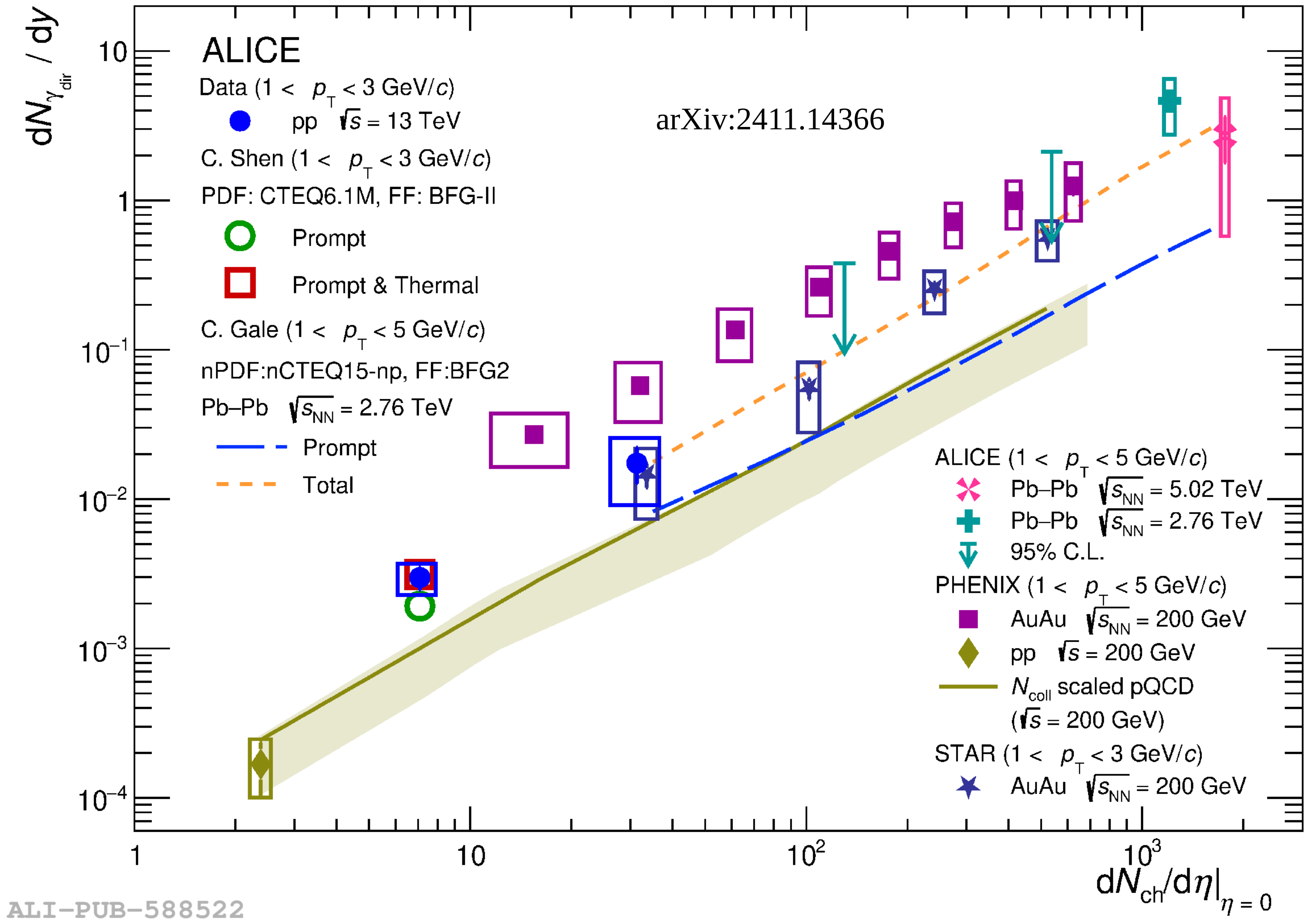
arXiv:1208.1234v1

Direct photon yield scaling in PHENIX



arXiv:1812.09837

Direct photon yield scaling in PHENIX, STAR and ALICE



- **Power-law dependence** of direct photon yield ($dN_{\gamma_{\rm dir}}/dy$) on charged particle multiplicity ($dN_{\rm ch}/d\eta|_{\eta=0}$) suggests production **independent of energy or centrality**

- Improved results in Pb-Pb collisions at $\sqrt{s_{NN}}$ **= 2.76 TeV** (real photons) and **5.02 TeV** (virtual photons)

- Recent results in pp collisions at $\sqrt{s}$ **= 13 TeV** (virtual photons)

- All three ALICE measurements **agree** with both STAR and PHENIX and with model predictions