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Direct photon elliptic flow in Pb-Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV

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Netherlands Organisation for Scientific Research

Universiteit Utrecht

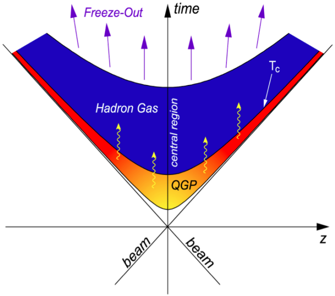
ALICE A JOURNEY OF DISCOVERY

Nikhef

Direct Photon production mechanisms

Three classes of photons:

- **Inclusive photons:** photons from any source
- **Decay photons:** photons from hadronic decays $(\pi^0, \eta, ...)$
- **Direct photons:** photons *not* coming from hadronic decays



Direct photons...

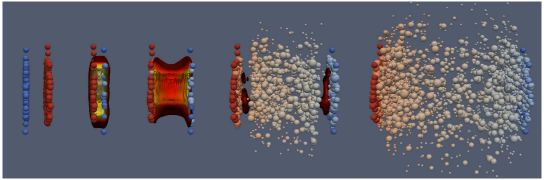
In pp, pA, and AA collisions:

- **prompt photons**
  - dominant at $p_{\mathrm{T}} > 5$ GeV/c
  - calculable within NLO pQCD

Additional sources in AA collisions:

- **Thermal photons**
  - dominant at $p_{\mathrm{T}} < 4$ GeV/c
  - scattering of particles in the hot matter
  - susceptible to flow evolution
- **Jet-Medium interactions**
  - Scattering of hard partons with partons of the QGP
  - In-medium (photon) bremsstrahlung emitted by quarks

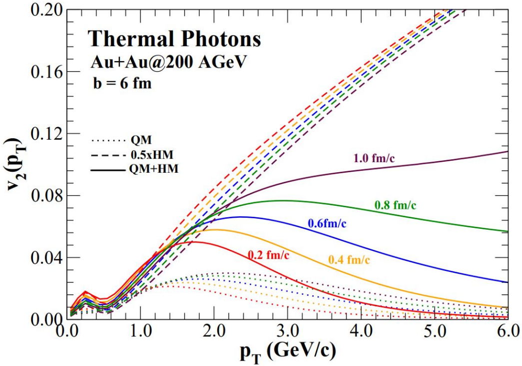
Why measure the flow of direct photons?



Direct photon measurements give access to the temperature and space-time evolution of the produced medium!

- Early emission of photons: high yield ↔ low v_2
- Late emission of photons: low yield ↔ high v_2

PRC 79 (2009) 021901



Extracting the direct photon yield:

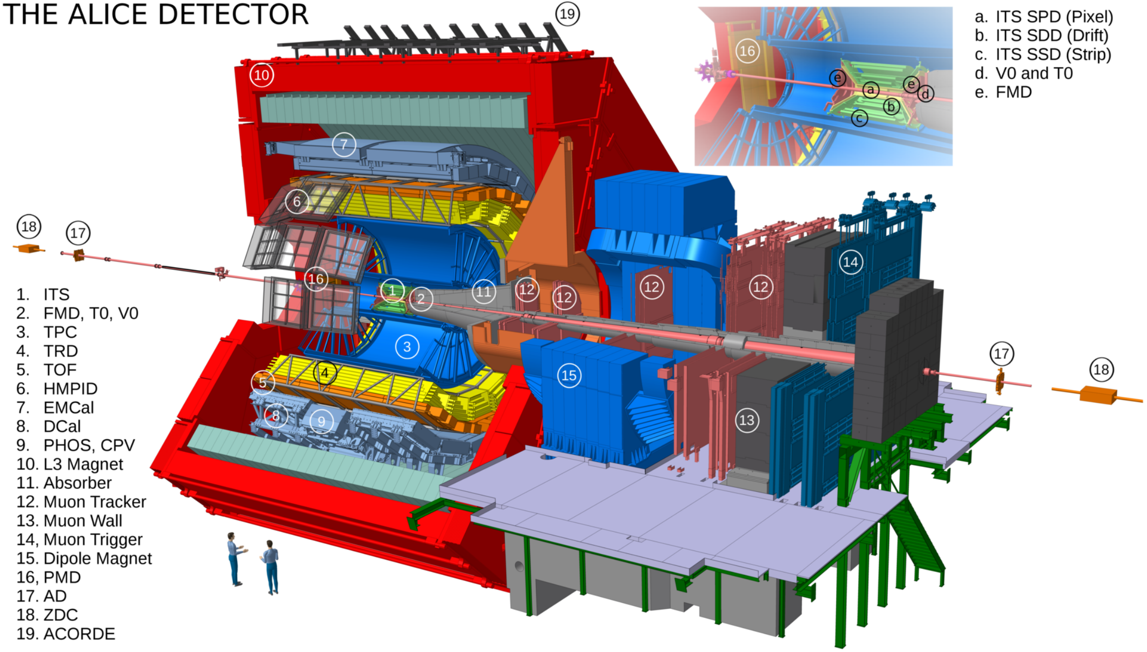
$$\gamma_{direct} = \gamma_{incl} - \gamma_{decay} = \left(1 - \frac{1}{R_\gamma}\right) \cdot \gamma_{incl}$$

$$R_\gamma = \frac{\gamma_{incl}}{\gamma_{decay}}$$

Direct photon flow calculation:

$$v_2^{\gamma,\mathrm{dir}} = \frac{R_\gamma \; v_2^{\gamma,\mathrm{inc}} - v_2^{\gamma,\mathrm{dec}}}{R_\gamma - 1}$$

THE ALICE DETECTOR



a. ITS SPD (Pixel)
b. ITS SDD (Drift)
c. ITS SSD (Strip)
d. V0 and T0
e. FMD

1. ITS
2. FMD, T0, V0
3. TPC
4. TRD
5. TOF
6. HMPID
7. EMCal
8. DCal
9. PHOS, CPV
10. L3 Magnet
11. Absorber
12. Muon Tracker
13. Muon Wall
14, Muon Trigger
15. Dipole Magnet
16, PMD
17. AD
18. ZDC
19. ACORDE

Photons in ALICE

Photon Conversion Method(PCM)

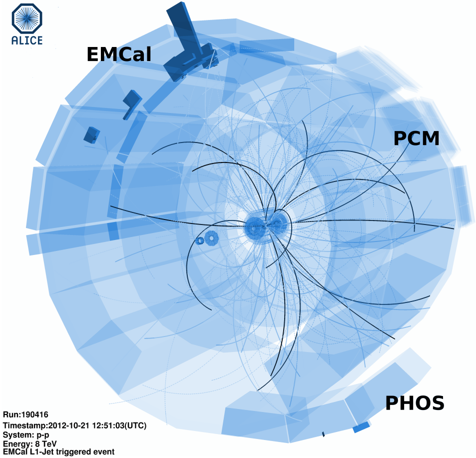
- $\gamma_{\text{conversion}} \rightarrow e^{+}e^{-}$
- ITS and TPC
- $|\eta| < 0.9$ and $0^{\circ} < \varphi < 360^{\circ}$
- Conversion probability $\sim 8\%$
- Signal selection based on the decay topology

PHOS calorimeter

- $PbWO_4$ crystals
- $|\eta| < 0.12$ and $260^{\circ} < \varphi < 320^{\circ}$

Trigger and event plane orientation detectors

- V0A $(2.8 < \eta < 5.1)$
- V0C $(-3.7 < \eta < -1.7)$



Results

Inclusive photon elliptic flow calculated with the Scalar Product method:

$$v_2 = \sqrt{\frac{\left\langle\left\langle \vec{\mathrm{u}}_2 \cdot \frac{\vec{Q}_2^{\mathrm{A}*}}{M_{\mathrm{A}}} \right\rangle\right\rangle \left\langle\left\langle \vec{\mathrm{u}}_2 \cdot \frac{\vec{Q}_2^{\mathrm{C}*}}{M_{\mathrm{C}}} \right\rangle\right\rangle}{\left\langle \frac{\vec{Q}_2^{\mathrm{A}}}{M_{\mathrm{A}}} \cdot \frac{\vec{Q}_2^{\mathrm{C}*}}{M_{\mathrm{C}}} \right\rangle}},$$

where

$$\vec{\mathrm{u}}_2 = e^{i2\varphi},$$

are the unit flow vectors build from the inclusive photons. And

$$\vec{Q}_n = \sum_{i \in \mathrm{RFP}} w_i e^{in\varphi_i},$$

where φ_i is the azimuthal angle of the i-th reference particle (V0A/V0C), n is the order of the harmonic, and w_i is the applied weight.

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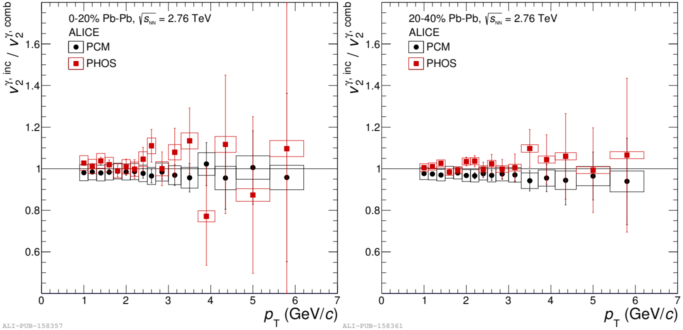
Individual inclusive photon flow measurements:



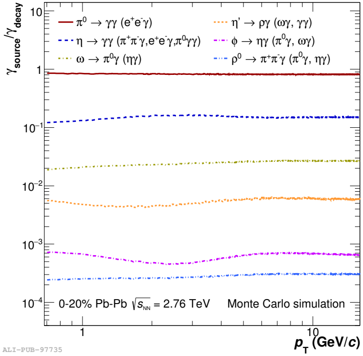
arXiv:1805.04403

Observations:

- Agreement: $p-$values of 0.93 and 0.43 for centrality classes 0–20% and 20–40%, respectively
- Statistical uncertainty starts to be dominant at $p_T > 2$GeV/c

Results – Decay photon cocktail: spectrum and flow

Relative contributions to the decay photons



arXiv:1509.07324, Phys. Lett. B 754 (2016) 235-248

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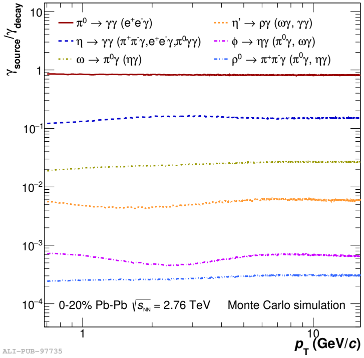

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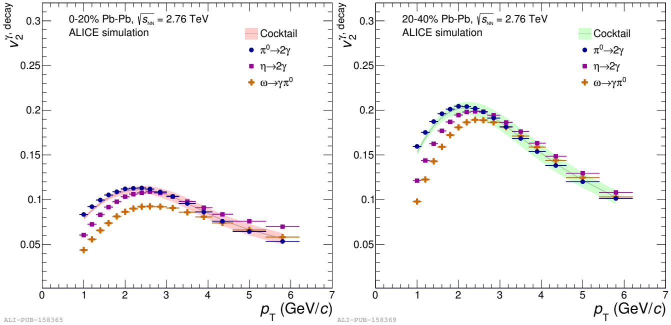
Decay photon cocktail:



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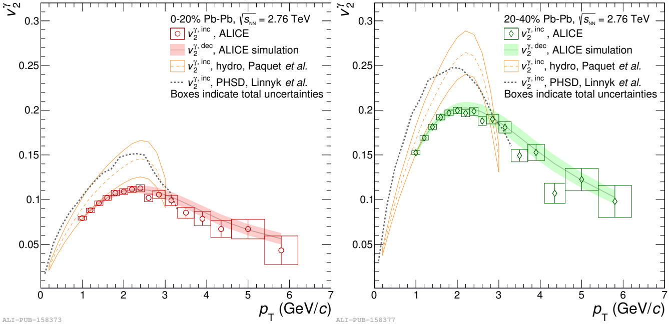
- Simulated the decay of most dominant hadronic decays to photons
- Parametrized the yield and elliptic flow of $\pi^{\pm}$, $K^{\pm,0}$
- Apply m_T and KE_T scaling for η and ω

Results

Observations:

- Significant elliptic flow develops for inclusive and decay photons; dominated by the elliptic flow of $\pi^0 \rightarrow \gamma\gamma$
- $v_2^{\gamma,\mathrm{inc}} \sim v_2^{\gamma,\mathrm{dec}}$
- Prediction from theory overshoots the data by $\sim 40\%$

Combined Inclusive photon flow & decay photon cocktail:



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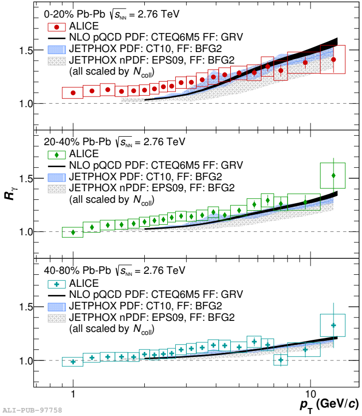
Using covariance matrices to combine the measurements:

$$\vec{v}_2^{\gamma,\mathrm{inc}} = (V^{-1}_{v_2,\mathrm{PCM}} + V^{-1}_{v_2,\mathrm{PHOS}})^{-1}(V^{-1}_{v_2,\mathrm{PCM}}\vec{v}_2^{\gamma,\mathrm{inc,PCM}} + V^{-1}_{v_2,\mathrm{PHOS}}\vec{v}_2^{\gamma,\mathrm{inc,PHOS}})$$

Results

Direct photon excess R_γ



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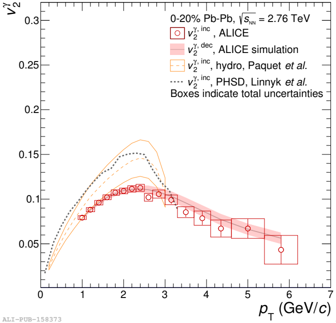

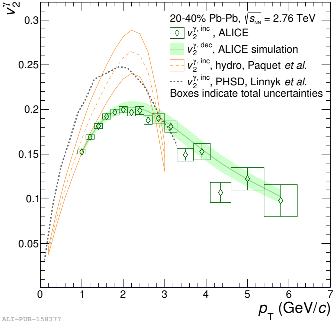

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Direct photon flow calculation:

$$v_2^{\gamma,\mathrm{dir}} = \frac{R_\gamma \, v_2^{\gamma,\mathrm{inc}} - v_2^{\gamma,\mathrm{dec}}}{R_\gamma - 1}$$

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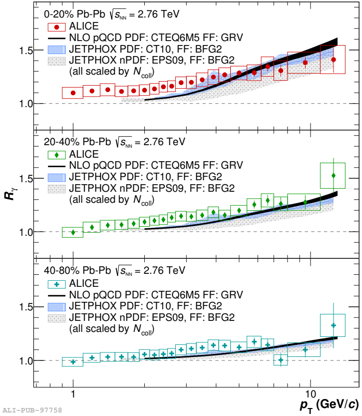

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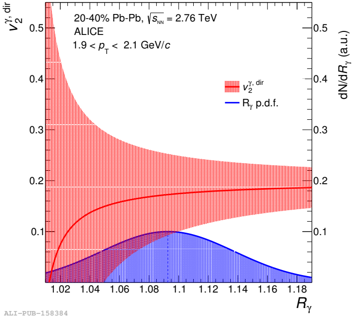
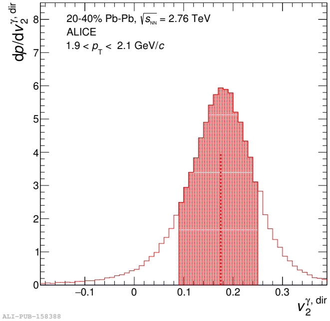
Difficulty of the direct photon v_2 extraction:





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Direct photon flow calculation:

$$v_2^{\gamma,\text{dir}} = \frac{R_\gamma \; v_2^{\gamma,\text{inc}} - v_2^{\gamma,\text{dec}}}{R_\gamma - 1}$$

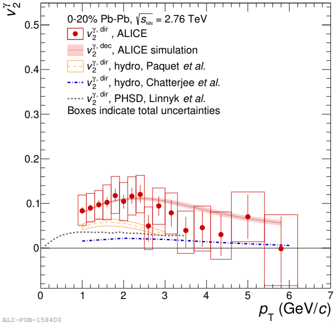
Results – Direct photon elliptic flow

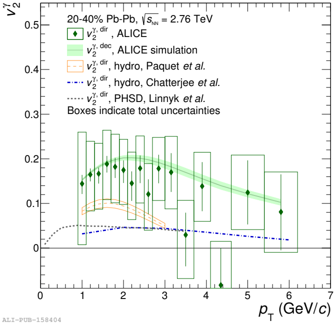
Final results obtained by employing a Bayesian approach ($R_{\gamma,true} > 1$).

Conclusions:

- Non-zero direct photon flow
- Significance of 1.4σ (central) and 1.0σ (semi-central)
- $v_2^{\gamma,\mathrm{dir}} \sim v_2^{\gamma,\mathrm{dec}}$
- Theory underpredicts the data, but no strong tension due to large uncertainties
- $v_2^{\gamma,dir}(\mathrm{ALICE}) \sim v_2^{\gamma,dir}(\mathrm{PHENIX})$

Combined direct photon flow:





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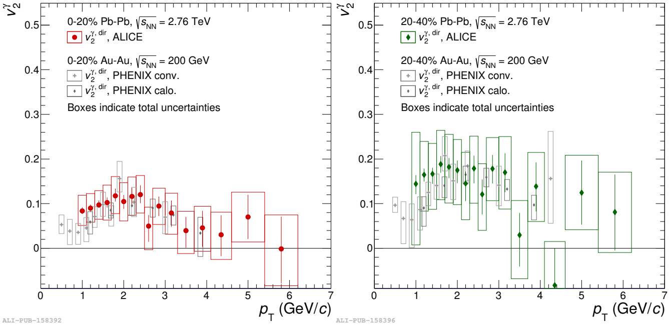

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Outlook:

- Increase precision with new datasets.. $v_3^{\gamma,dir}$..
- Study R_γ and $v_2^{\gamma,\mathrm{dir}}$ in small systems at high multiplicity..

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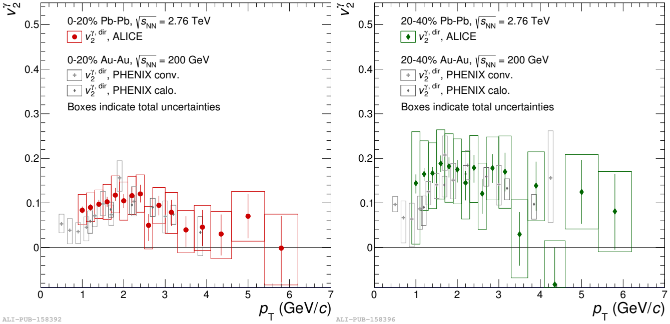

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Thanks for your attention!

BACKUP

Flow method

Collective flow:
Spatial anisotropy of the produced system leads to an anisotropy in momentum space.

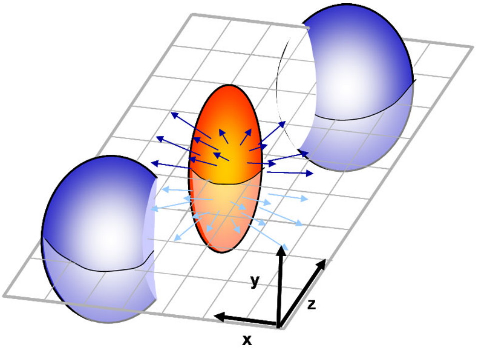
Particle distributions as function of azimuthal angle are described by:

$$E\frac{d^3N}{d^3p} = \frac{1}{2\pi}\frac{d^2N}{p_t dp_t dy}\left(1 + \sum_{n=1}^{\infty} 2v_n cos(n(\varphi - \Psi_R))\right),$$

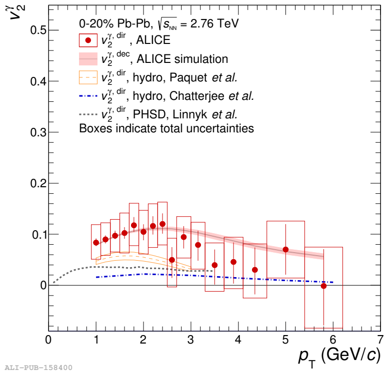
where

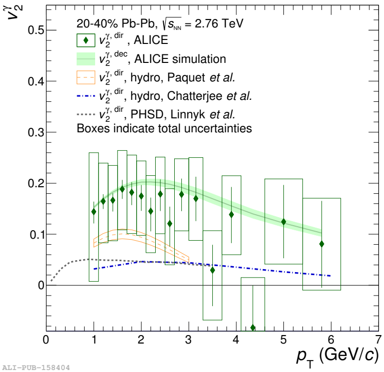
$$v_n = \langle cos(n(\varphi - \Psi_R))\rangle.$$

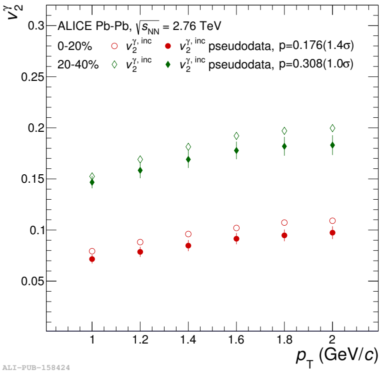
Non-central AA collision



Backup – hypothesis testing







Backup – arXiv:1606.06077