

# Direct photon flow in ALICE

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# Direct photon elliptic flow in Pb-Pb collisions

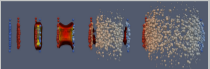
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## Introduction

Direct photons, which are photons not coming from decaying hadrons, provide information of the evolution of the Quark-Gluon Plasma created in heavy-ion collisions. They are produced at all stages of the collision and can be classified in thermal and prompt (direct) photons. These photons have a mean free path much larger than the system size (pseudorapidity), carrying information about the conditions at the time of their production.



## Thermal photons



Thermal (direct) photons are emitted from the hot strongly interacting medium throughout the system evolution and their spectrum depends on the medium properties, such as temperature and flow velocity, of all phases of the collision. They dominate direct photon yields at low transverse momenta. Next to the spectra, also azimuthal anisotropies  $v_n$  of direct photons are measured, which can provide additional constraints to theoretical models.

## Definitions:

- **Inclusive photons:** photons from any source
- **Decay photons:** photons from hadronic decays
- **Direct photons:** photons not coming from decaying particles

## The direct photon puzzle

Theoretical calculations, employing hydrodynamics, struggle to explain both the measured direct photon spectra and  $v_2$  [ALICE, STAR, PHOS].

## Detection method: Photons in ALICE Run 1

### Calorimetric

- Photons hitting the surface of the calorimeter (EMCal or PHOS) produce an electromagnetic shower and deposit their total energy.



### Photon Conversion Method

- Photons converting into  $e^+e^-$  by interacting with the detector material are reconstructed using the ITS and TPC.

## Analysis method: Direct photon yield and flow

The direct photon spectrum is extracted by subtracting the decay photon spectrum from the inclusive photon spectrum:

$$Y_{\text{direct}} = Y_{\text{incl}} - Y_{\text{decay}} = \left(1 - \frac{1}{R_c}\right) \cdot Y_{\text{incl}} \quad (1)$$

where

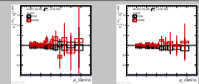
$$R_c \equiv \frac{Y_{\text{incl}}}{Y_{\text{decay}}} \quad (2)$$

The azimuthal anisotropy  $v_2$  of direct photons is measured using:

$$v_2^{\text{direct}} = \frac{R_c v_2^{\text{incl}} - v_2^{\text{decay}}}{R_c - 1} \quad (3)$$

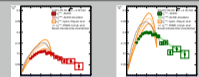
where the inclusive photon flow is measured using the Scalar Product method, using a rapidity gap of  $|\Delta\eta| > 0.9$  between the photons and the reference flow particles.

## Results: Inclusive photon flow with PCM and PHOS



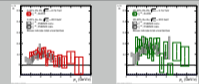
The individual measurements are consistent for both centrality classes.

## Results: Inclusive and decay photon flow



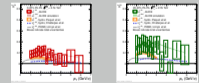
The theoretical predictions, based on hydrodynamics, are overestimating the elliptic flow of inclusive photons for both centrality classes.

## Results: Direct photon flow



The significance of the deviation from the hypothesis  $v_2^{\text{direct}} = 0$  is 1.0 $\sigma$  and 1.4 $\sigma$ , assuming full correlation of systematic uncertainties in  $p_T$ . Furthermore, the direct photon flow is consistent with the results obtained at RHIC.

## Results: Direct photon flow



The direct photon flow is generally under-predicted by theoretical calculations. In addition, it is consistent with the flow of decay photons.

## Conclusion and Outlook

The flow of inclusive photon has been measured in Pb-Pb collisions at  $\sqrt{s_{NN}} = 2.76$  TeV for two centrality classes and is obtained by combining the PCM and PHOS measurements. The measured inclusive photon flow is over-predicted by about 40% by the theoretical models and the direct photon elliptic flow is not inconsistent with the expectation from theory.

References:  
[1] M. Sas, ALICE Collaboration, Phys. Rev. Lett. 120, 152301 (2018).  
[2] ALICE Collaboration, Phys. Rev. Lett. 110, 232301 (2013).  
[3] ALICE Collaboration, Phys. Rev. Lett. 110, 232301 (2013).  
[4] ALICE Collaboration, Phys. Rev. Lett. 110, 232301 (2013).



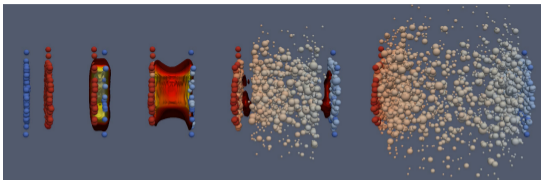
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# Why direct photons?



Extracting the direct photon yield:

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

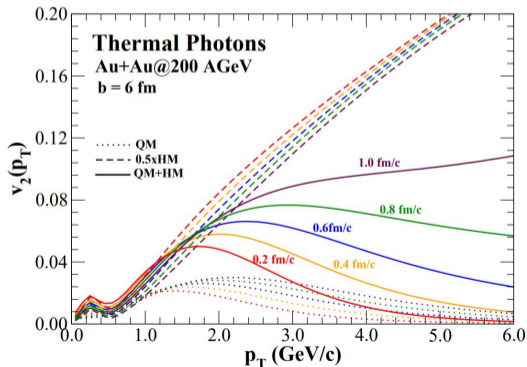
$$R_\gamma = \frac{\gamma_{\text{incl}}}{\gamma_{\text{decay}}}$$

Direct photon flow calculation:

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

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

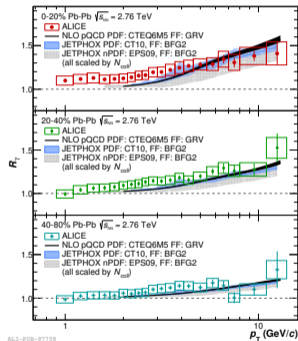
- Early emission of photons: high yield  $\leftrightarrow$  low  $v_2$
- Late emission of photons: low yield  $\leftrightarrow$  high  $v_2$



# Results

Reconstruction methods:

- Photon Conversion Method(PCM)
- PHOS



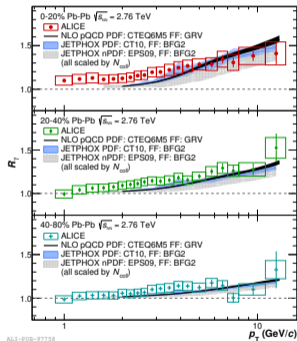
My poster presents the final results  
on the direct photon flow in ALICE

arXiv:1509.07324, arXiv:1805.04403

# Results

Reconstruction methods:

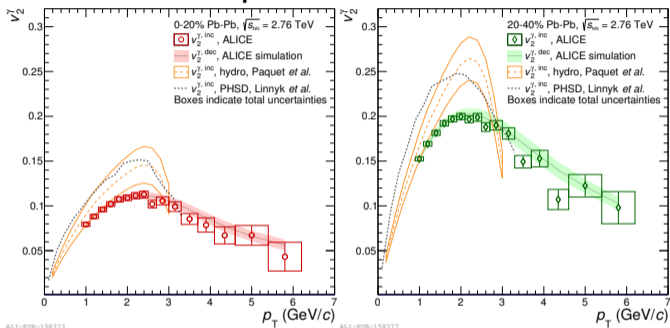
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## Combined Inclusive photon flow:



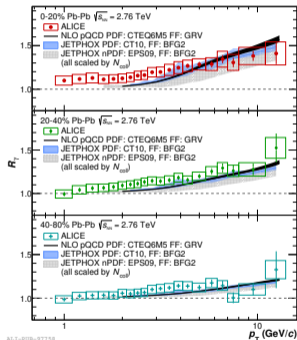
Observations:

- Significant elliptic flow develops for inclusive and decay photons; dominated by the elliptic flow of  $\pi^0 \rightarrow \gamma\gamma$
- $v_2^{\gamma, inc} \sim v_2^{\gamma, dec}$

# Results

Reconstruction methods:

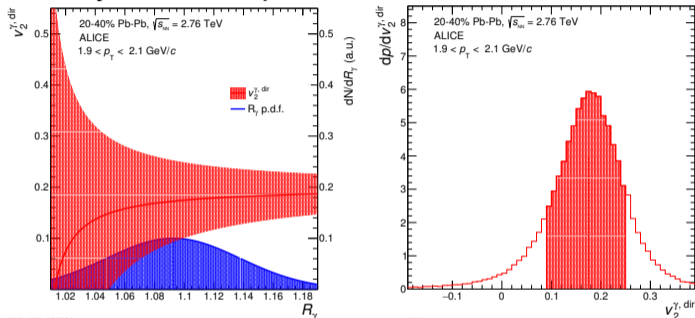
- Photon Conversion Method(PCM)
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## Difficulty of the direct photon $v_2$ extraction



Direct photon flow calculation:

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

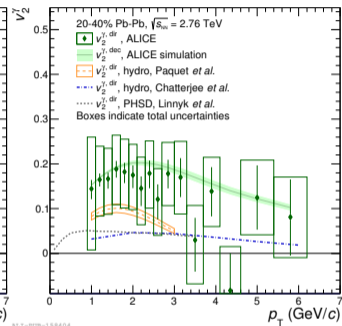
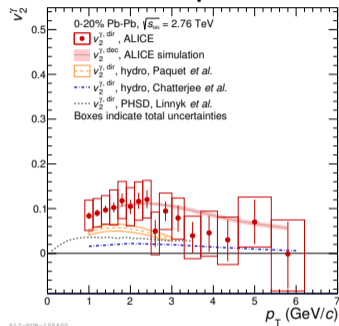
# Results – Direct photon elliptic flow

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

## Observations:

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

## Combined direct photon flow:



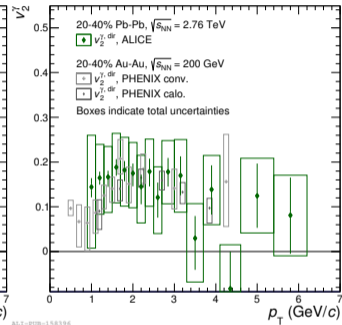
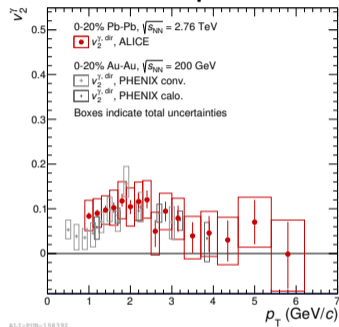
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## Combined direct photon flow:



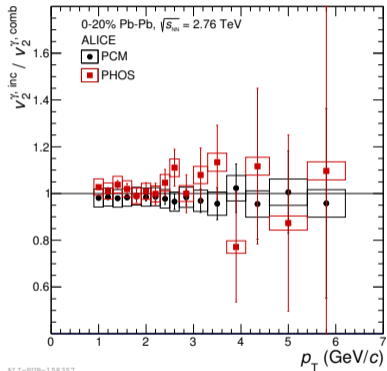
## Outlook:

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

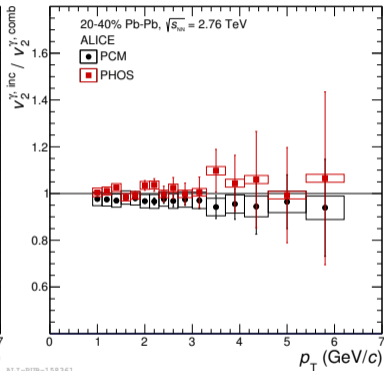
Thanks for the inspiring conference!



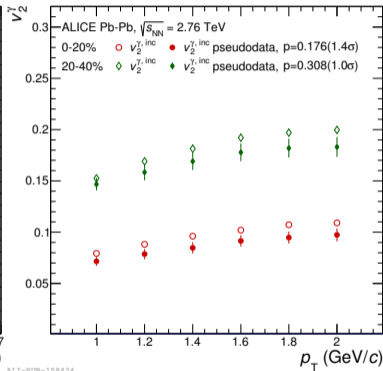
# Backup



ALI-PUB-158357



ALI-PUB-158361



ALI-PUB-158424

