



Direct photon spectrum and flow in pp and Pb-Pb collisions at $\sqrt{s}_{NN}=2.76$ TeV



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Direct photons are the photons created in course of pp, p-A or A-A collision and not in decay of final hadrons. In the case of pp collision direct photons appear in collisions of partons of incoming protons. In the case of A-A collision direct photons are produced in all stages of its evolution and are sensitive to details of the expansion of the produced medium. The soft part of the direct photon spectrum in A-A collisions is expected to be dominated by thermal direct photons - thermal radiation of hot matter, quark-gluon plasma and hadron gas. The transverse momentum spectrum of thermal photons is defined by the temperature of the emitting matter, but also distorted by considerable radial flow. Typical hydrodynamic description of the evolution of nucleus-nucleus collisions predicts that a considerable part of the thermal photons are emitted at the early hot stage of the collision, when collective flows are not developed yet. As a result, such models predict smaller values of elliptic (v_2) and triangular (v_3) flow for direct photons compared to hadrons. However, the PHENIX experiment observed v_2 values of direct-photons similar to the pion v_2 .

Direct photons contribute only few percent of the total photon yield, so their extraction is very challenging task. Presently two basic methods are used:

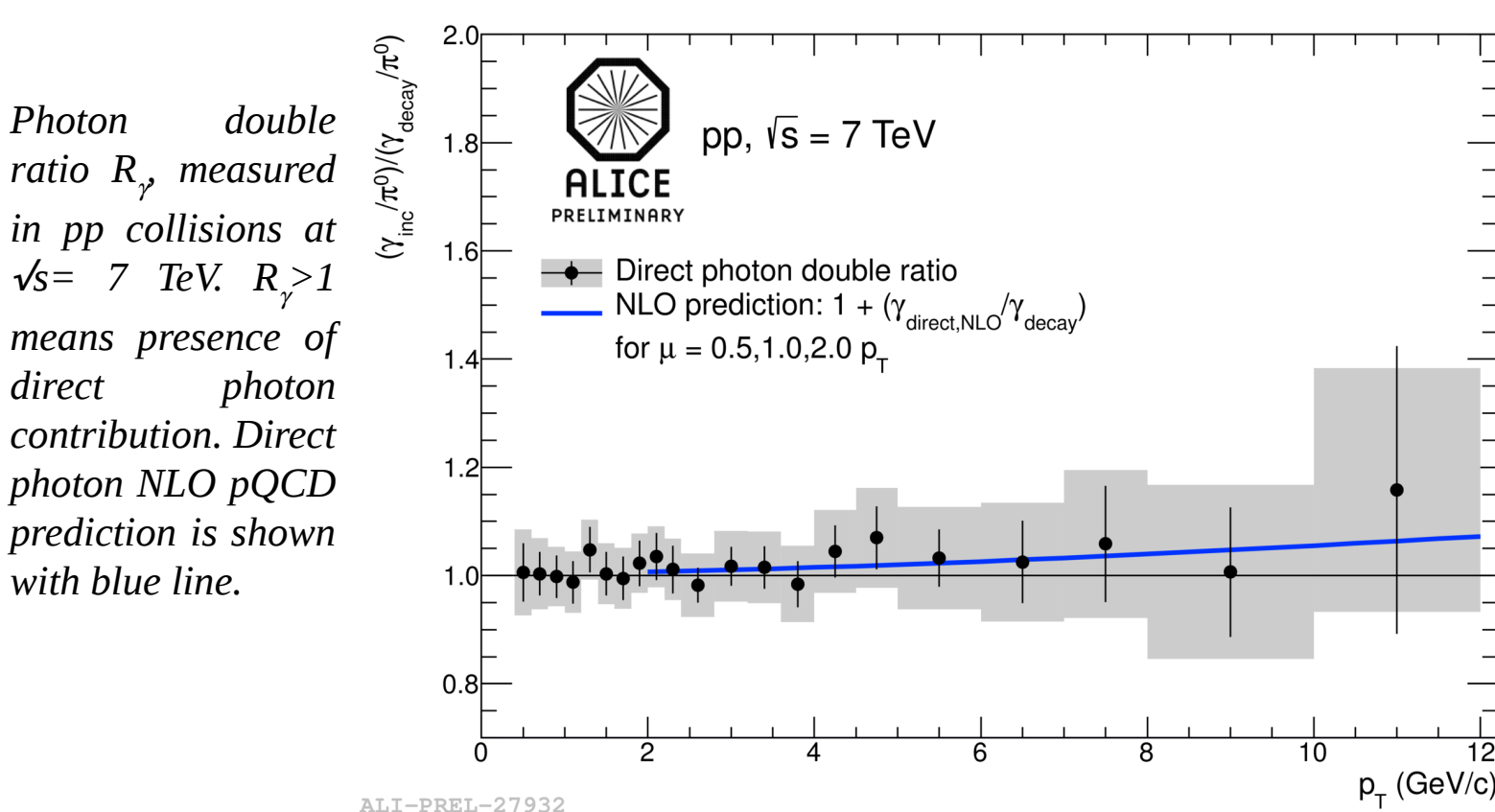
Real photons

Experimentally, direct photon spectrum is calculated as a difference of the inclusive spectrum and an expected spectrum of decay photons from final hadron (mainly π^0 and η) decays:

$$Y_{direct} = Y_{incl} - Y_{decay}$$

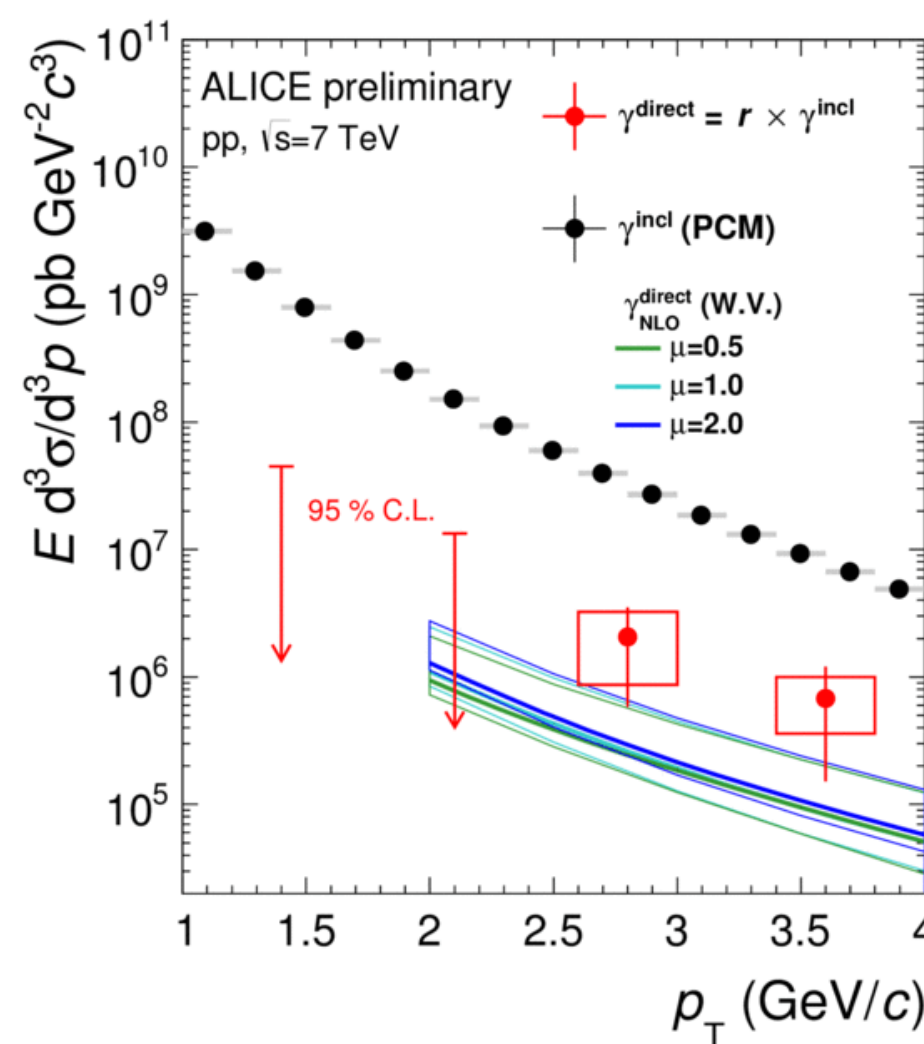
It is convenient to first construct the “double ratio”, where few main uncertainties cancel:

$$R_\gamma = \frac{Y_{incl}/\pi_{meas}^0}{Y_{decay}/\pi_{cocktail}^0} \approx \frac{Y_{incl}}{Y_{decay}}$$



Having double ratio and inclusive photon spectrum, one can calculate direct photon spectrum as

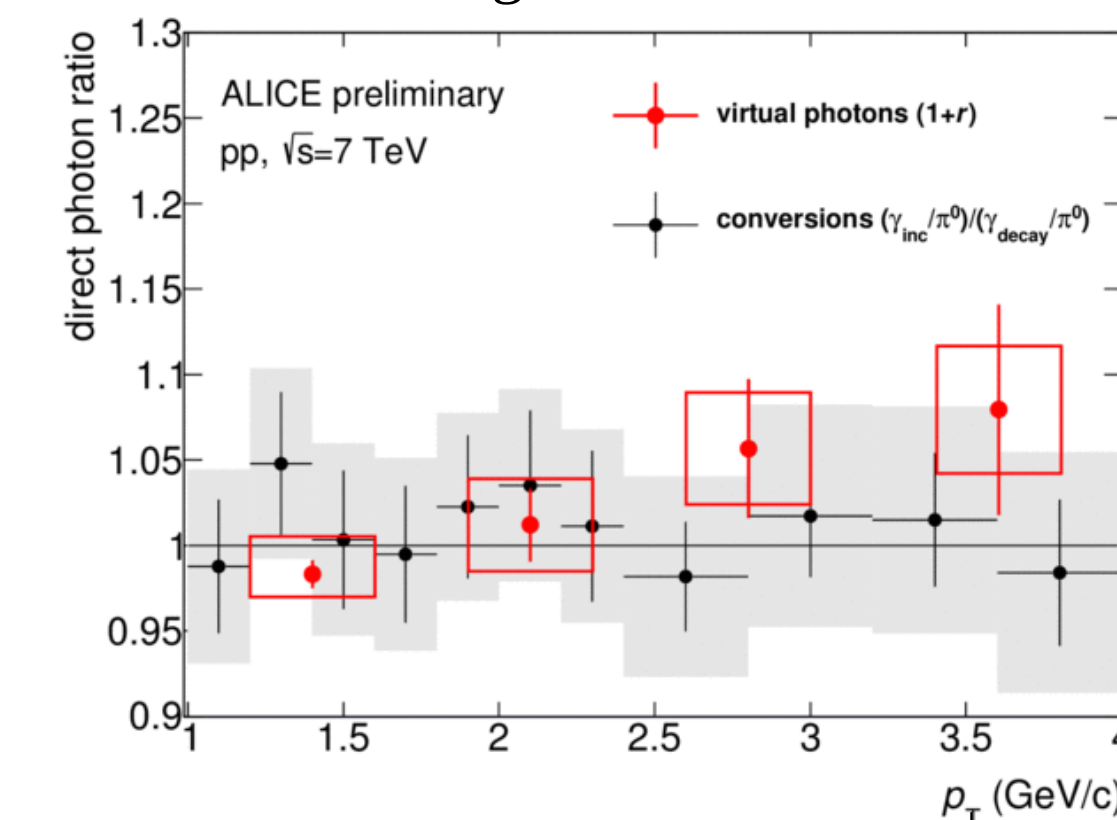
$$Y_{direct} = Y_{incl} - Y_{decay} = \left(1 - \frac{1}{R_\gamma}\right) Y_{incl}$$



Direct photon cross section measured via virtual photon method compared with NLO pQCD calculations of W. Vogelsang. Inclusive photon spectrum is shown with black points.

We compare photon double ratio measured in pp collisions at $\sqrt{s}=7$ TeV with different methods. Two methods agree within uncertainties.

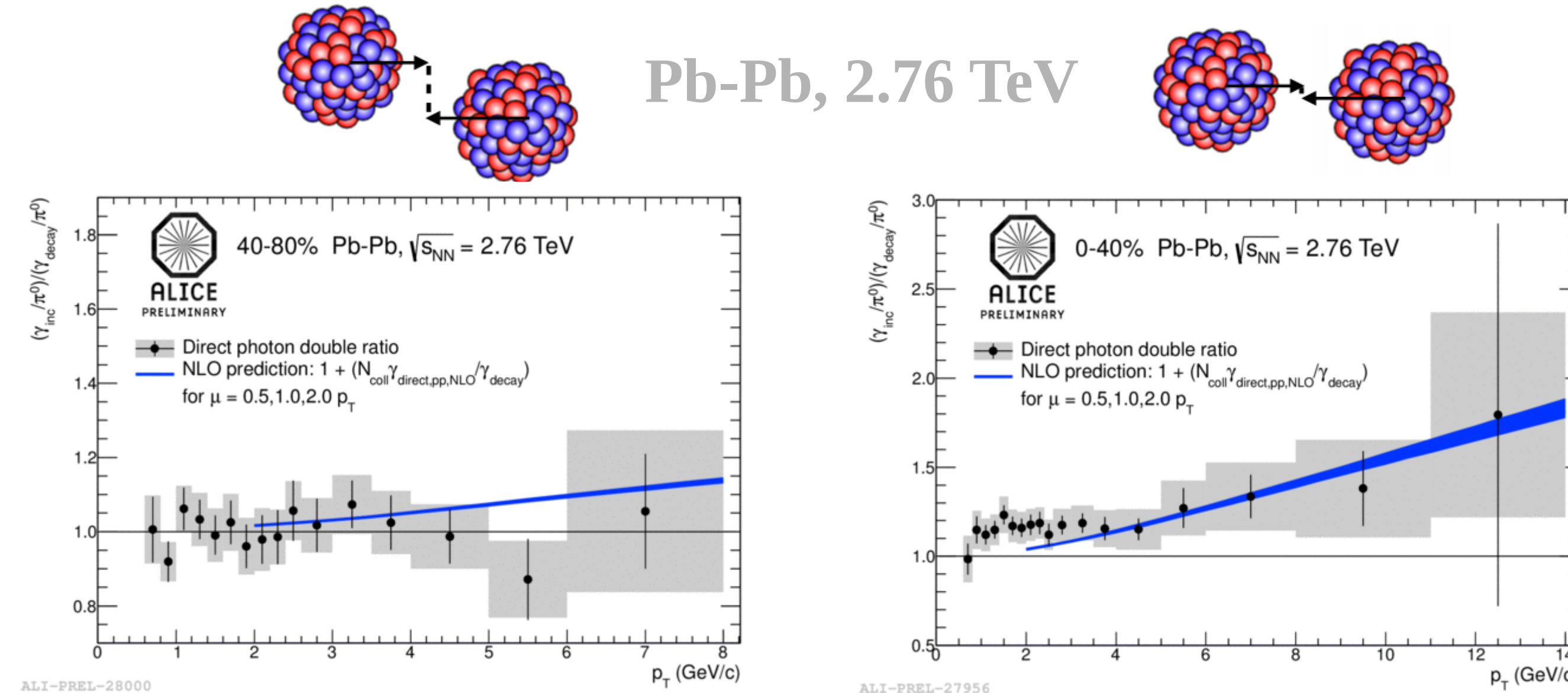
Comparison of direct photon double ratio measured via virtual and real photons in pp collisions at $\sqrt{s}=7$ TeV.



Example of decomposition of the dilepton mass distribution after combinatorial background subtraction onto decay and direct photon contributions.

In this poster, we present results of direct photon spectra measurements in pp collisions at $\sqrt{s} = 7$ TeV and in Pb-Pb collisions at $\sqrt{s}_{NN} = 2.76$ TeV. The results were obtained by measuring e^+e^- pairs from conversions of photons in the detector material. The measured direct-photon spectra are compared with predictions from state-of-the-art hydrodynamic models. We also present the inclusive photon elliptic (v_2) and triangular (v_3) flow in Pb-Pb collisions at $\sqrt{s}_{NN} = 2.76$ TeV in the range $1 < p_T < 5$ GeV/c and discuss implications for the v_2 and v_3 of direct photons.

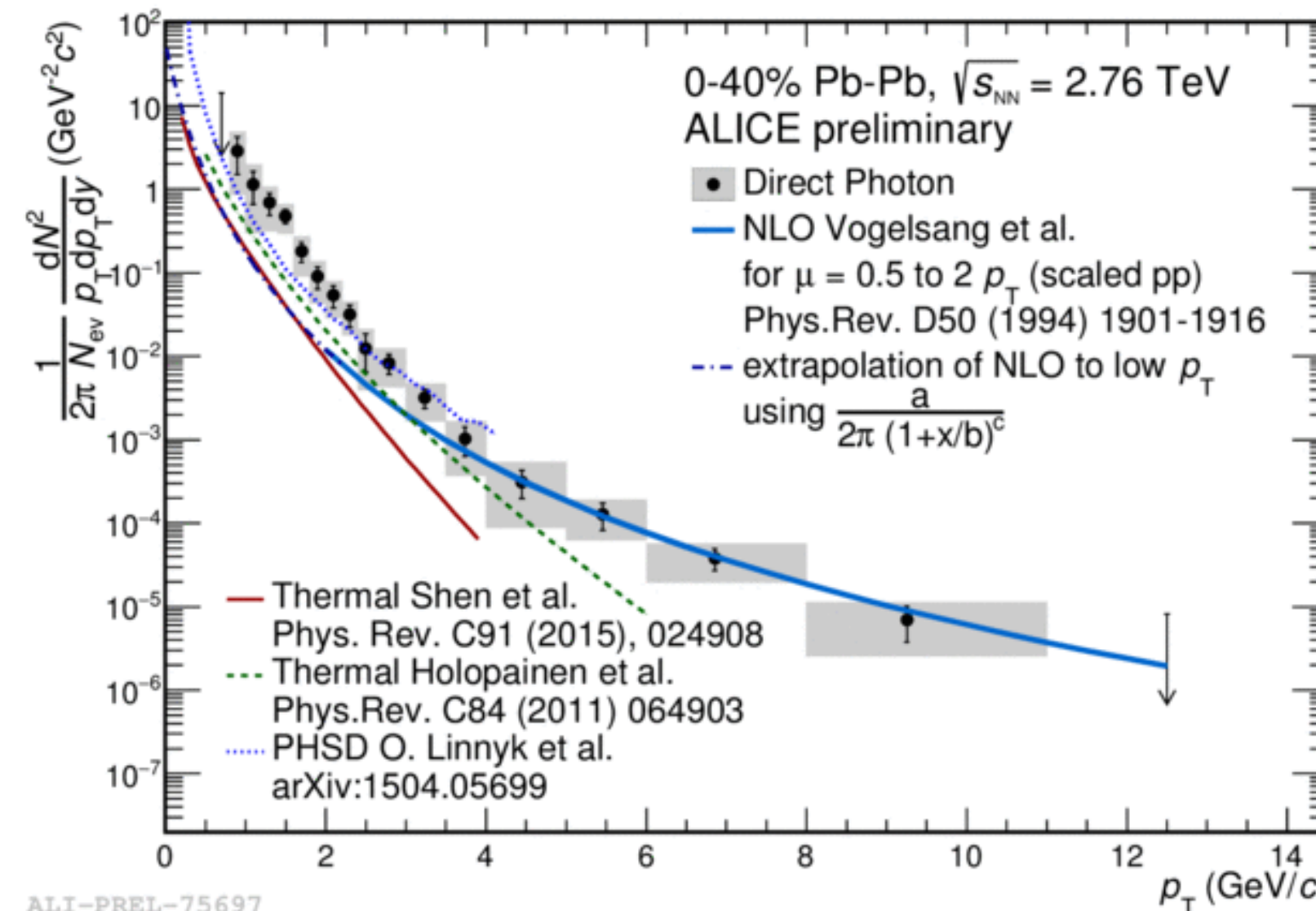
ALICE also measured direct photon spectrum in peripheral (left plot below) and central (right plot below) Pb-Pb collisions at $\sqrt{s}_{NN} = 2.76$ TeV. Peripheral means large impact parameters and small number of participants, while central is head-on collisions as illustrated below:



Photon double ratio measured in peripheral (left) and central (right) Pb-Pb collisions at $\sqrt{s}_{NN} = 2.76$ TeV. Excess over the unit means presence of direct photon contribution. For comparison, NLO pQCD predictions of prompt direct photons in pp collisions at same energy and scaled according the number of binary nucleon-nucleon collisions in Pb-Pb event in given centrality class are shown with blue band.

In peripheral collisions the photon double ratio is consistent within uncertainties both with unit (no direct photons) and with expected yield of prompt direct photons. In central collisions we clearly see excess. At high p_T it is consistent with expected contribution of prompt direct photons, but at low p_T < 2-3 GeV/c we see excess over the prompt photons which can be interpreted as thermal photon contribution. Although higher multiplicity introduces additional difficulties in direct photon measurement in central collisions, it is still easier than peripheral because of suppression of π^0 and η yields in central collisions due to parton energy loss in hot matter.

We calculated direct photon spectrum in central Pb-Pb collisions at $\sqrt{s}_{NN} = 2.76$ TeV, as shown in the right figure. For comparison with blue line we present prompt photon NLO pQCD predictions from W. Vogelsang scaled with number of binary nucleon-nucleon collisions. We find good agreement at $p_T > 4$ GeV/c, while at lower p_T there is additional contribution of thermal direct photons. We compare several theoretical predictions of thermal direct photon spectra, shown with lines, but all of them underpredict yield of direct photons. This situation is similar to one at RHIC energy, where most of theoretical calculations underpredict direct photon yield.



Direct photon spectrum measured in central Pb-Pb collisions at $\sqrt{s}_{NN} = 2.76$ TeV, compared to NLO pQCD predictions of prompt direct photons in pp collisions at same energy and scaled with the number of binary nucleon-nucleon collisions in Pb-Pb event in given centrality class (blue line) and some thermal photon predictions.

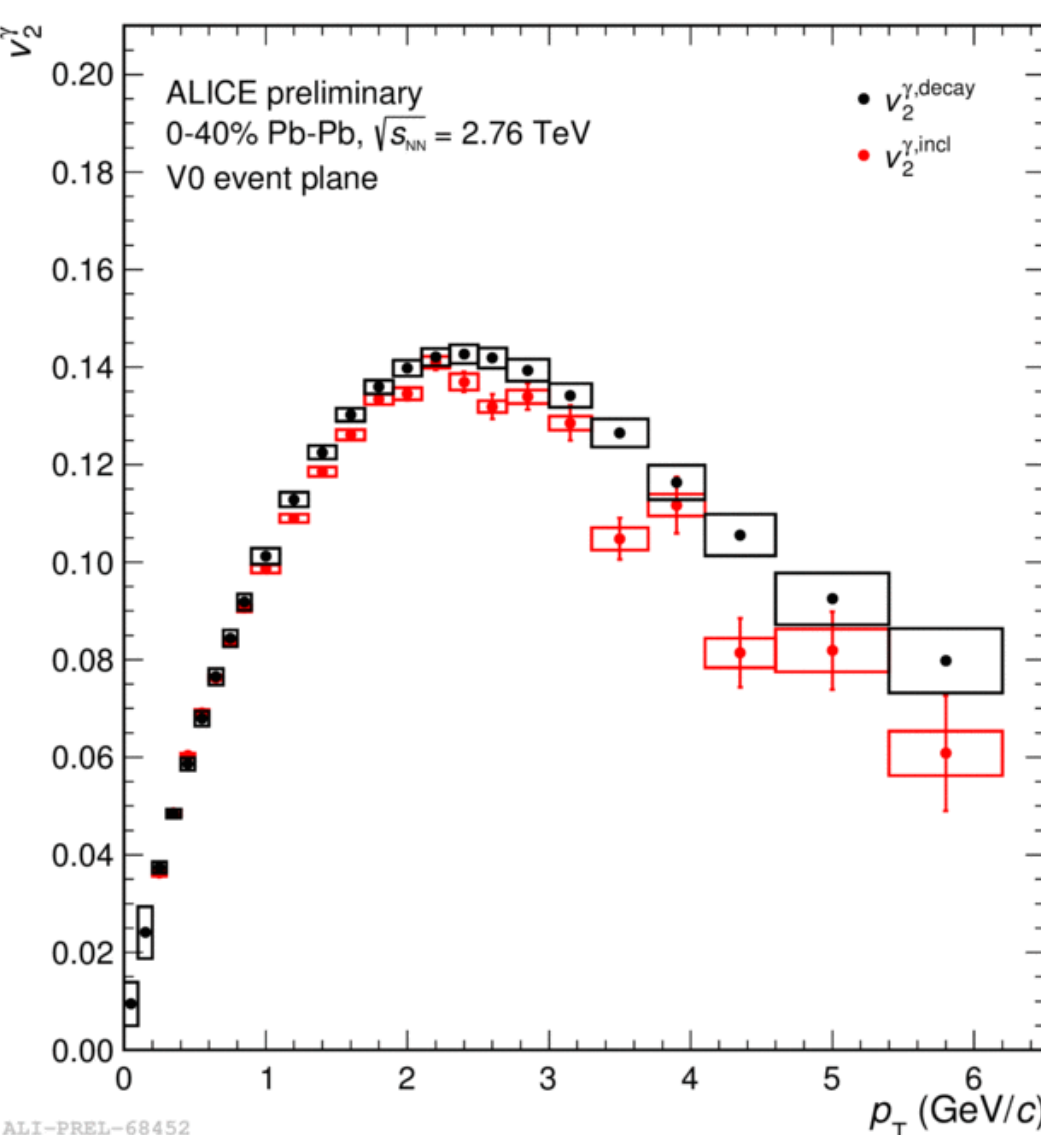
Collective flow in heavy-ion collisions manifests itself as an asymmetry of particle emission in azimuthal direction with respect to some “event plane”, common for all particle species in the event and all rapidity ranges. It is interpreted as a consequence of hydrodynamic-like expansion of initially asymmetric almond-like overlap region of colliding nuclei. Usually azimuthal asymmetry is decomposed as following

$$\frac{dN}{d\phi} \propto \frac{1}{2\pi} \left(1 + \sum 2v_n \cos(n(\phi - \Psi_{RP}))\right)$$

where parameters v_2, v_3, \dots are called elliptic, triangular, ... flow parameters. In the case of photons, all contributions: direct and decay photons contribute to the total inclusive photon flow:

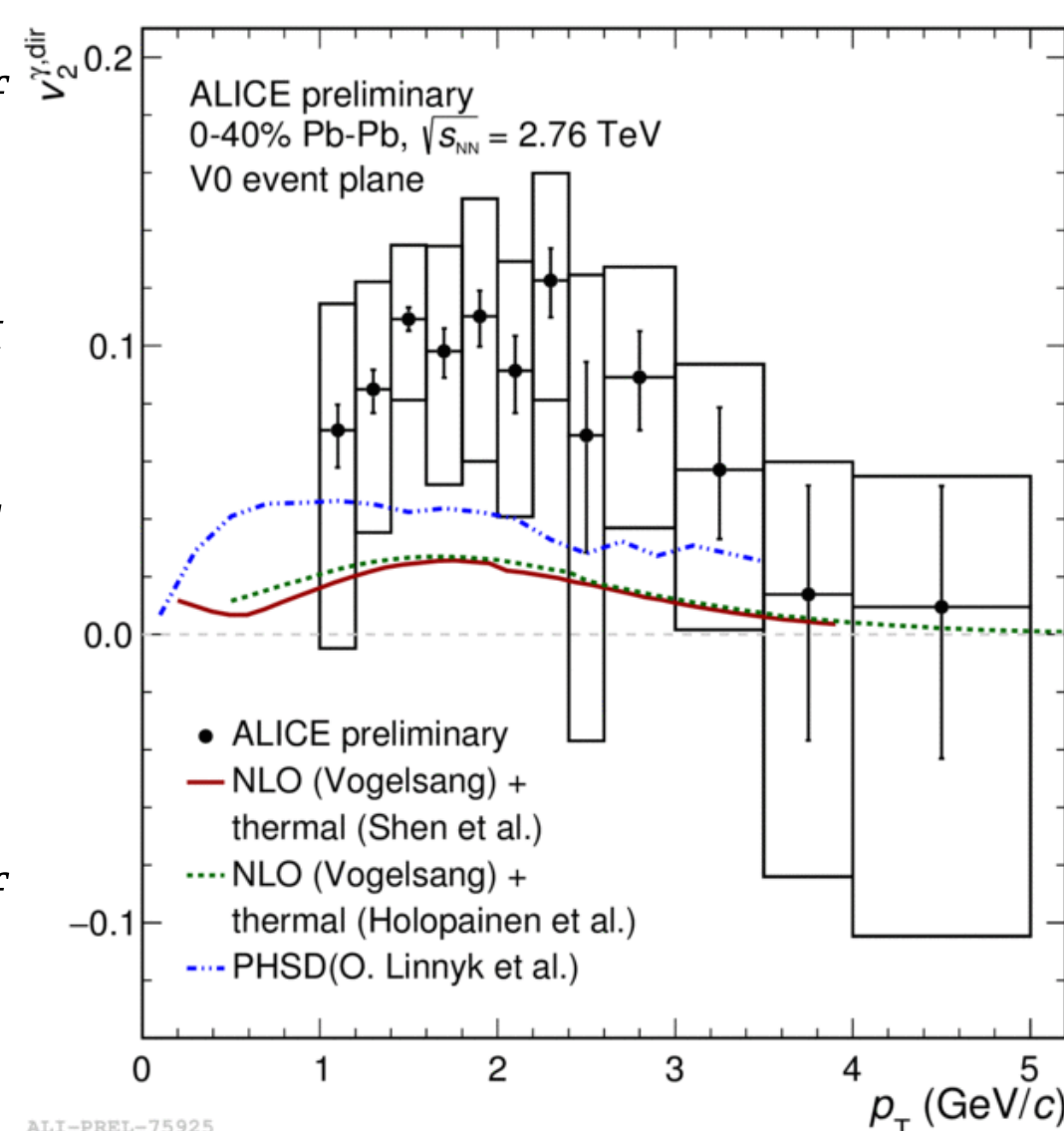
$$v_n^{incl} = \frac{N_y^{dir}}{N_y^{incl}} v_n^{dir} + \frac{N_y^{decay}}{N_y^{incl}} v_n^{decay} \Rightarrow v_n^{y,dir} = \frac{R_Y v_n^{incl} - v_n^{y,decay}}{R - 1}$$

That is to calculate direct photon flow one need photon double ratio R .



Left plot: comparison of inclusive and decay photon elliptic flow in central Pb-Pb collisions, $\sqrt{s}_{NN} = 2.76$ TeV. At $p_T > 3$ GeV/c inclusive photon flow is significantly smaller than decay photon one.

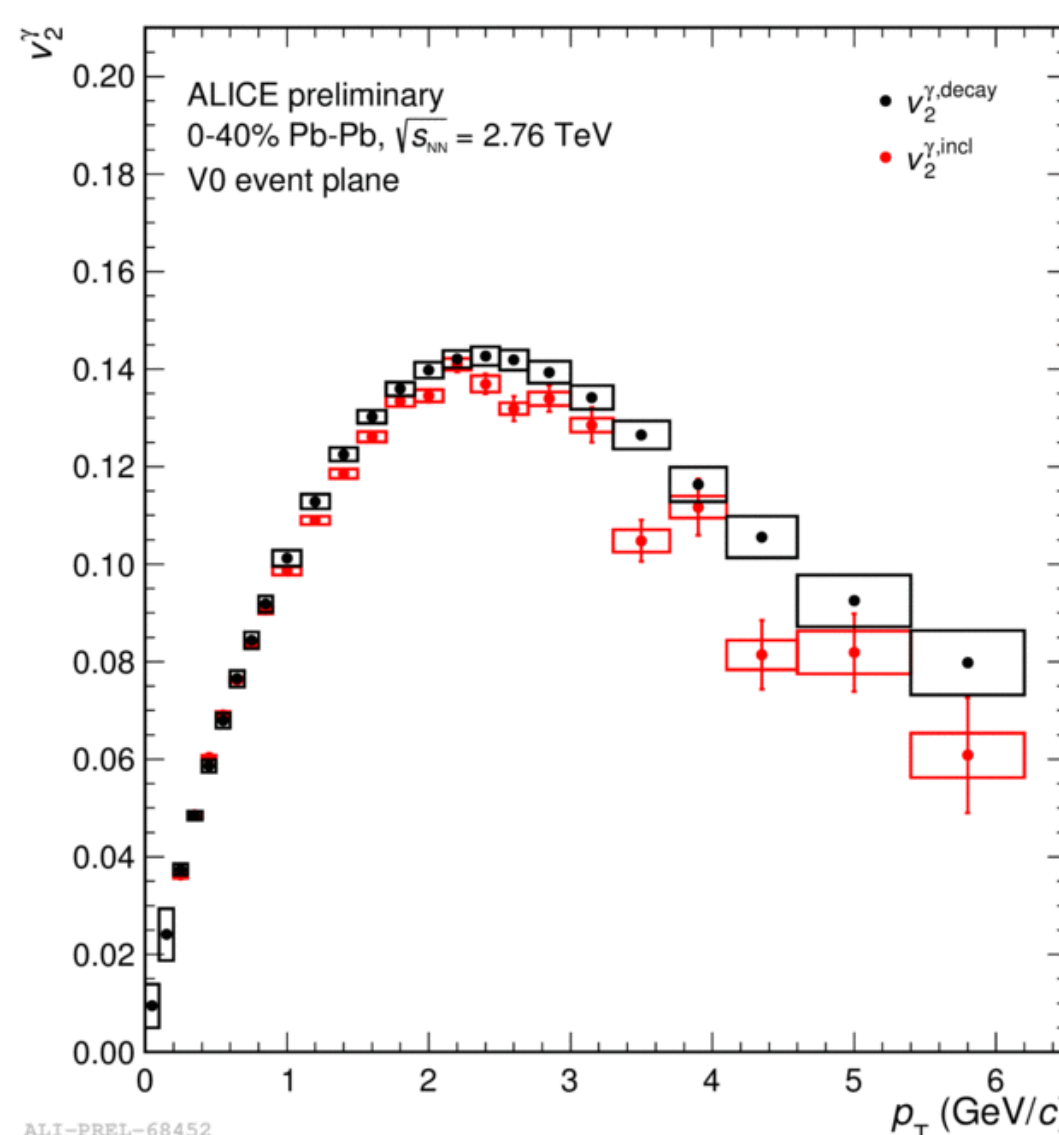
Right plot: Direct photon flow in same collisions compared to predictions of several theoretical models.



Similar to the yield, direct photon flow at low p_T < 2 GeV/c is underestimated by theory calculations by a factor 2-10. However, one should pay attention to uncertainties: difference between data and theory is ~1-2 sigma: not very significant. In addition, presence of pole $1/(1-R)$ in formula for direct photon flow makes uncertainties asymmetric and non-Gaussian. To avoid this, we propose alternative comparison of inclusive photon flow with models, see left plot. In top panel we find clear difference between inclusive and decay photon flow. But if we add contribution of prompt and thermal direct photons (panels below) agreement between data and theory becomes better.

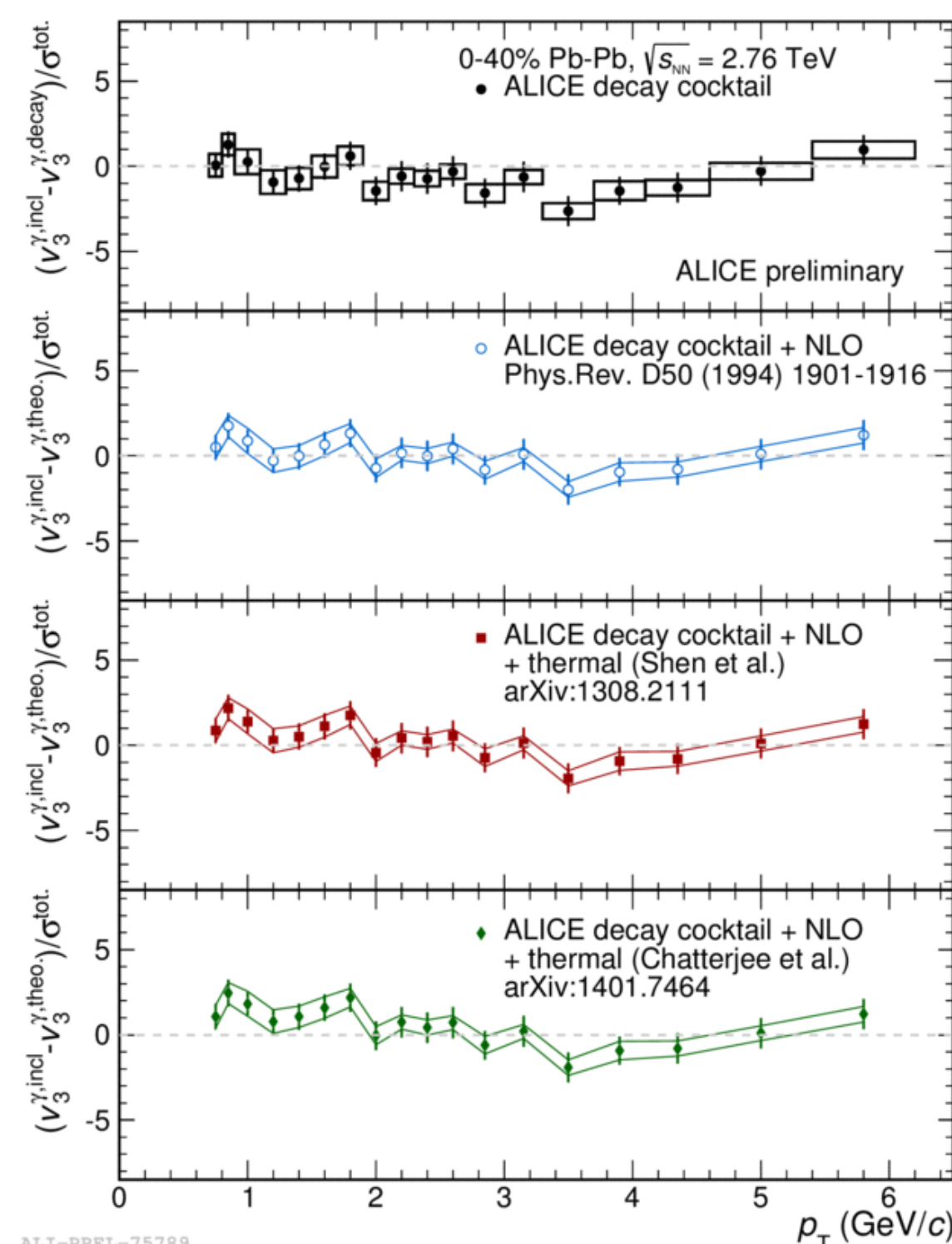
Plot to the left: difference between inclusive photon flow and several model predictions in units of total uncertainty. Top panel: only decay photon flow accounted, then prompt and several estimates of thermal photon flow.

Triangular flow originates due to fluctuations of the initial overlap region, and thus testing its development on early stages of AA collision with direct photons is especially interesting.



Left plot: comparison of inclusive and decay photon triangular flow in central Pb-Pb collisions, $\sqrt{s}_{NN} = 2.76$ TeV. Similar to elliptic flow, at high p_T > 2 GeV/c inclusive photon flow is significantly smaller than decay photon one.

Right plot: difference between inclusive photon triangular flow and several model predictions in units of the total uncertainty. Top panel: only decay photon flow accounted, then prompt and several estimates of thermal photon triangular flow.



Similar to elliptic flow, v_3^{incl} is not reproduced by cocktail $v_3^{y,decay}$. All models failed to reproduce v_3^{incl} at low p_T < 1-2 GeV/c.

Conclusions

ALICE experiment measured direct photon spectrum in pp collisions at $\sqrt{s}=7$ TeV at low p_T with real and virtual photon approaches. Double ratios obtained with two methods agree with each other and with NLO pQCD predictions. Photon double ratios were measured in Pb-Pb collisions at $\sqrt{s}_{NN}=2.76$ TeV with real photon method.

In peripheral 40-80% collisions double ratio R_γ agrees both with no direct photon excess and with scaled NLO pQCD predictions. In central 0-40% collisions R_γ agrees with N_{coll} scaled NLO pQCD predictions at high p_T > 4 GeV/c.

An excess ~20% compared to N_{coll} scaled NLO pQCD predictions in R_γ has been measured in 0-40% central Pb-Pb collisions at p_T < 2 GeV/c, what can be interpreted as direct thermal photon contribution.

A direct photon elliptic v_2 and triangular v_3 flows have been measured in 0-40% Pb-Pb collisions. They appear to be of similar size as the elliptic (triangular) flow of charged pions. An alternative method to compare data and theory for inclusive photon elliptic and triangular flows, avoiding pole $1/(R_\gamma-1)$ was proposed. In all cases available theoretical predictions underestimate direct photon yield and flow.

References for further reading:

Real photon analysis: Nucl.Phys. A904-905 (2013) 573c-576c

Virtual photon analysis: J.Phys.Conf.Ser. 446 (2013) 012049 J.Phys.Conf.Ser. 612 (2015) 1, 012028