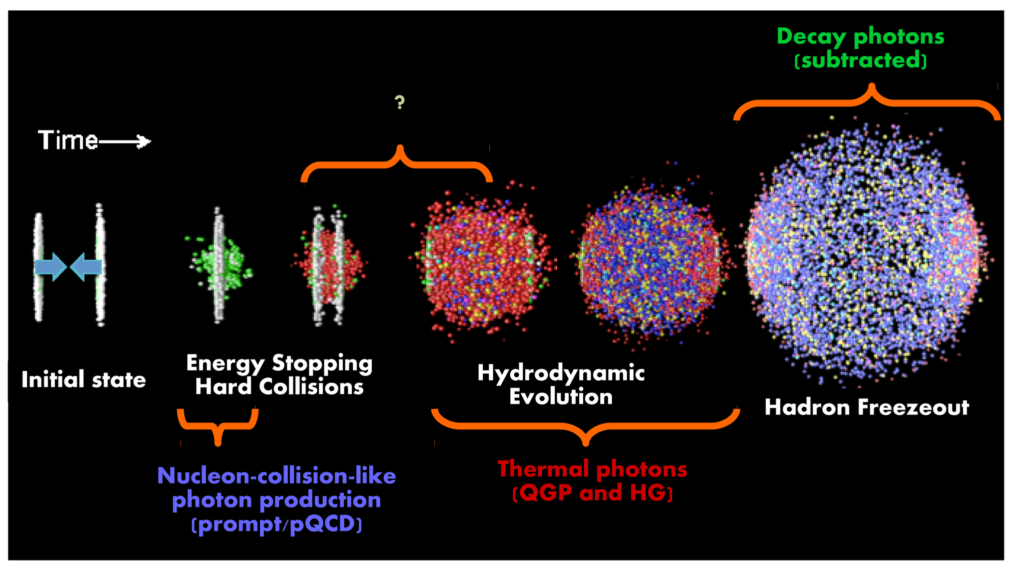
The electromagnetic signature of IP-Glasma

Jean-François Paquet, McGill, Montréal, *jfpaquet@physics.mcgill.ca*

Co-authors: Chun Shen, Gojko Vujanovic, Gabriel Denicol, Björn Schenke, Matthew Luzum, Ulrich Heinz, Sangyong Jeon, Charles Gale

Inclusive and direct photon production in heavy-ion collisions



(Adapted from *Nayak. Pramana 79, 719-735*)

Photon source	How we compute it
Prompt	Next-to-leading order **perturbative QCD** with nuclear p.d.f. and isospin effect, **scaled by the number of binary collisions** (Glauber)
Thermal	Quasi-thermal **QGP and meson gas** photon production **rates** [2], along with thermal **baryonic** photon rate [3], **folded with hydrodynamics**
Hadronic decays	Hadrons computed from hydro through **Cooper-Frye** and decayed into photons through measured **decay channels**: $\pi^0 \to \gamma\gamma$, $\eta \to \gamma\gamma$, $\omega \to \pi^0\gamma, \ldots$
Thermalisation, jet-medium, . . .	Currently not included

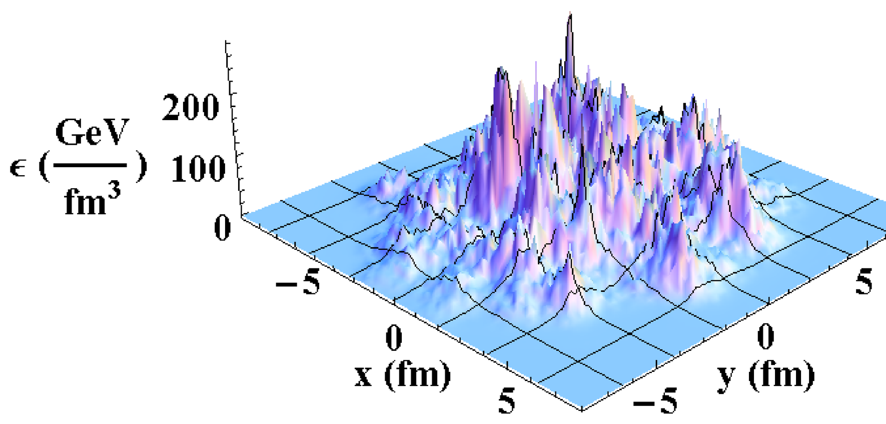
Direct photons are obtained experimentally by **subtracting** a **simulation of hadronic decay photons** (cocktail) from the **measured inclusive photons** [4]

$$v_n^{\gamma,dir} = \frac{R^\gamma v_n^{\gamma,incl} - v_n^{\gamma,cocktail}}{R^\gamma - 1} \quad (1)$$

$$R^\gamma = \frac{dN^{\gamma,incl}}{dN^{\gamma,cocktail}}$$

Simulating heavy-ion collisions with MUSIC and IP-Glasma

IP-Glasma



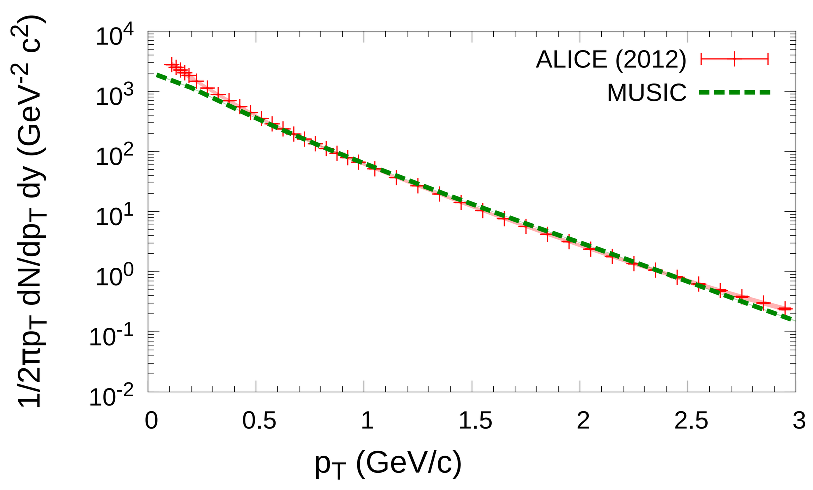
Initial energy density $\epsilon(\tau_0)$ and **flow** $u^\mu(\tau_0)$ of hydro matched to IP-Glasma [1] at τ_0**=0.4 fm/c**

MUSIC and parameters

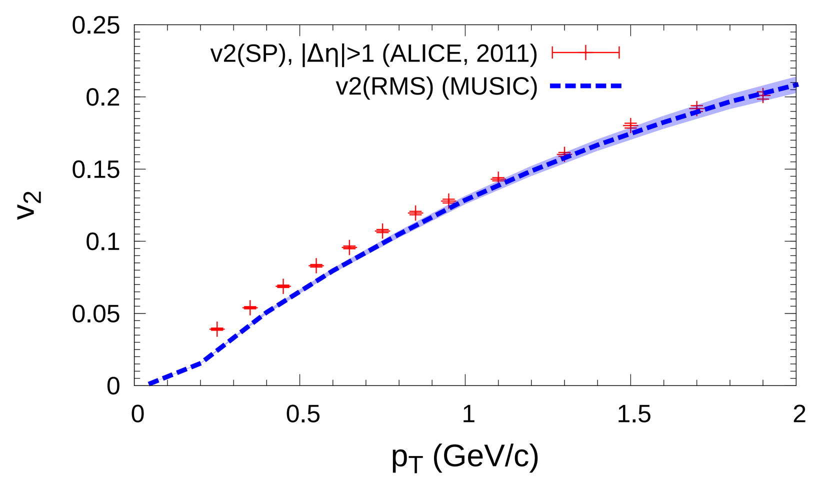
- **Event-by-event**, second order (**Israel-Stewart**) relativistic hydrodynamics
- Lattice + PCE hadron resonance gas **equation of state** with chemical freeze-out at $T_{chem} = 150$ MeV
- Hadron production through **Cooper-Frye** on constant temperature hypersurface at $T_{FO} = 103$ MeV
- Transport coefficients: **shear viscosity to entropy** $\eta/s = 0.22$ and **shear relaxation time** $\tau_\pi = 5\eta/(\epsilon + P)$
- No initial shear stress tensor: $\pi^{\mu\nu}(\tau_0) = 0$

Hadronic observables

Pions, 0-10% centrality

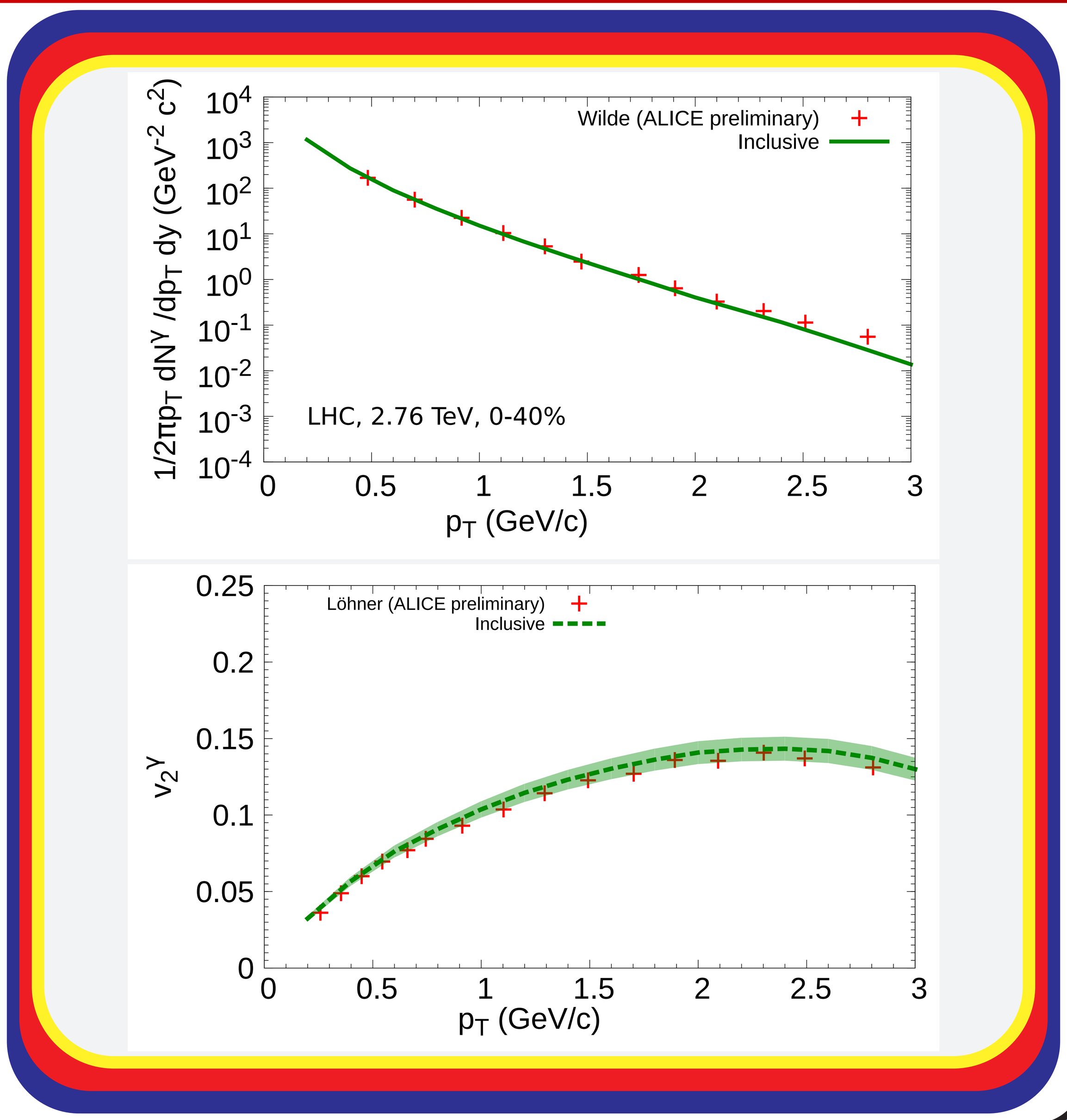


LHC, Pb+Pb, $\sqrt{s} = 2.76$ TeV



Charged hadrons, 30-40% centrality

Inclusive photons



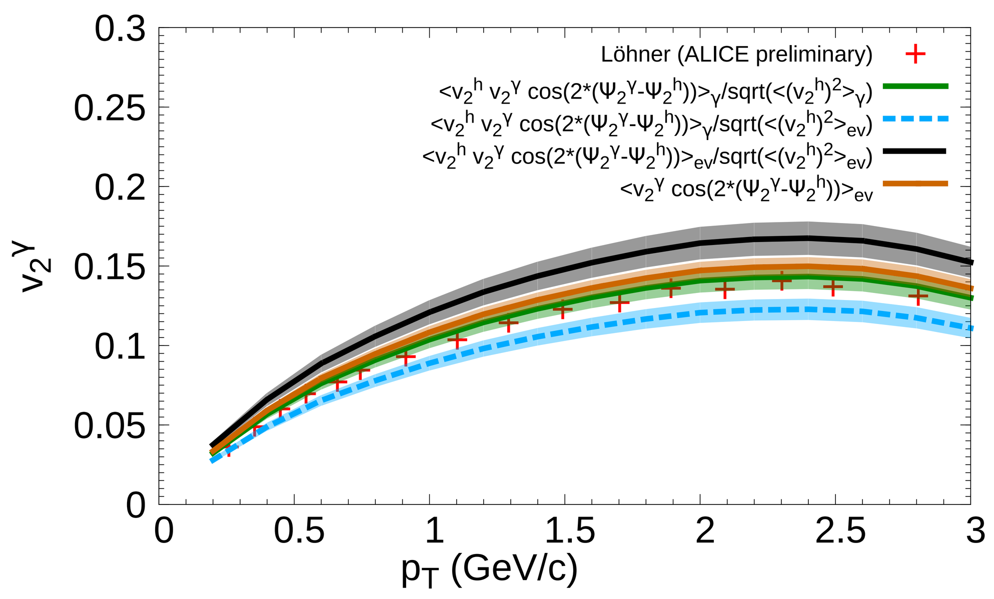
Computing the photon v_2

The **photon** v_2 is measured with the **event-plane method**, which reduces to the **scalar product** v_2 due to the low hadron multiplicity used to determine the event-plane:

$$v_2^\gamma\{\mathrm{SP}\} = \frac{\langle \bar{v}_2^h v_2^\gamma \cos(2(\Psi_2^\gamma - \bar{\Psi}_2^h))\rangle}{\sqrt{\langle(\bar{v}_2^h)^2\rangle}} \quad (2)$$

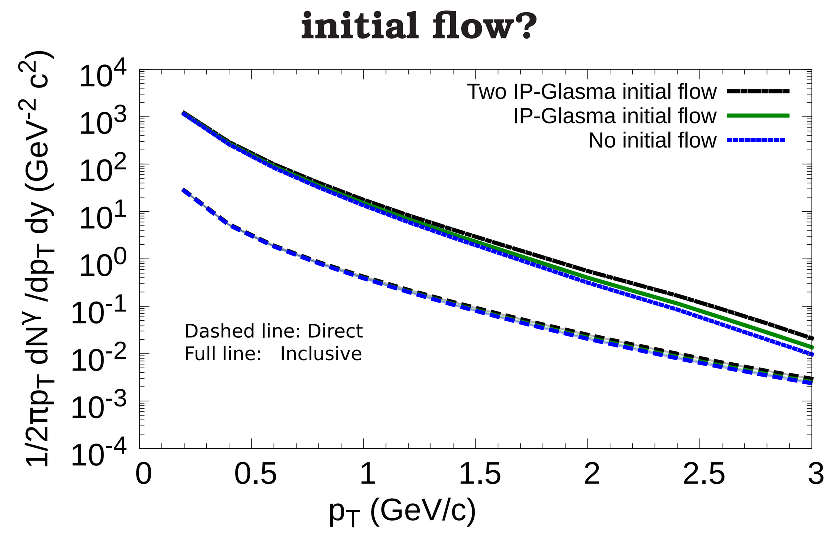
. . . but how the event averaging is done matters:

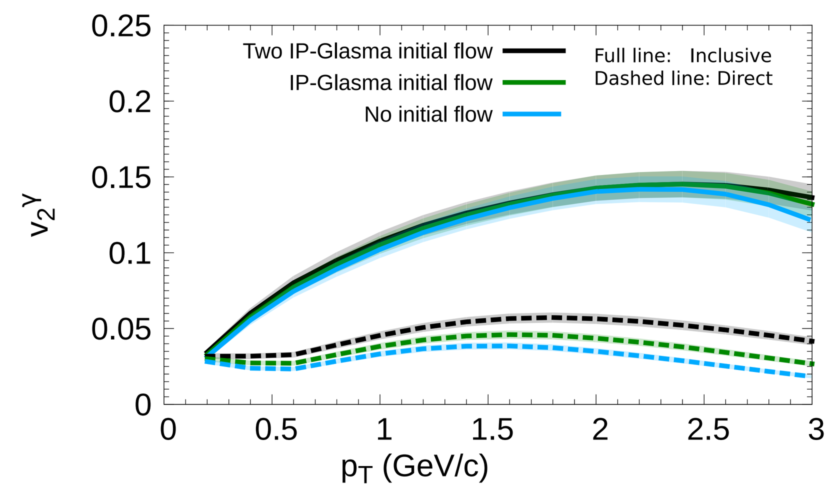
$$\langle X\rangle_\gamma = \frac{\sum_{j\in\text{events}} \left(\frac{1}{2\pi p_T}\frac{d^2N_j^\gamma}{dp_T dy}\right) X_j}{\sum_{j\in\text{events}} \left(\frac{1}{2\pi p_T}\frac{d^2N_j^\gamma}{dp_T dy}\right)} \text{ or } \langle X\rangle_{ev} = \frac{1}{N}\sum_{j\in\text{events}} X_j$$



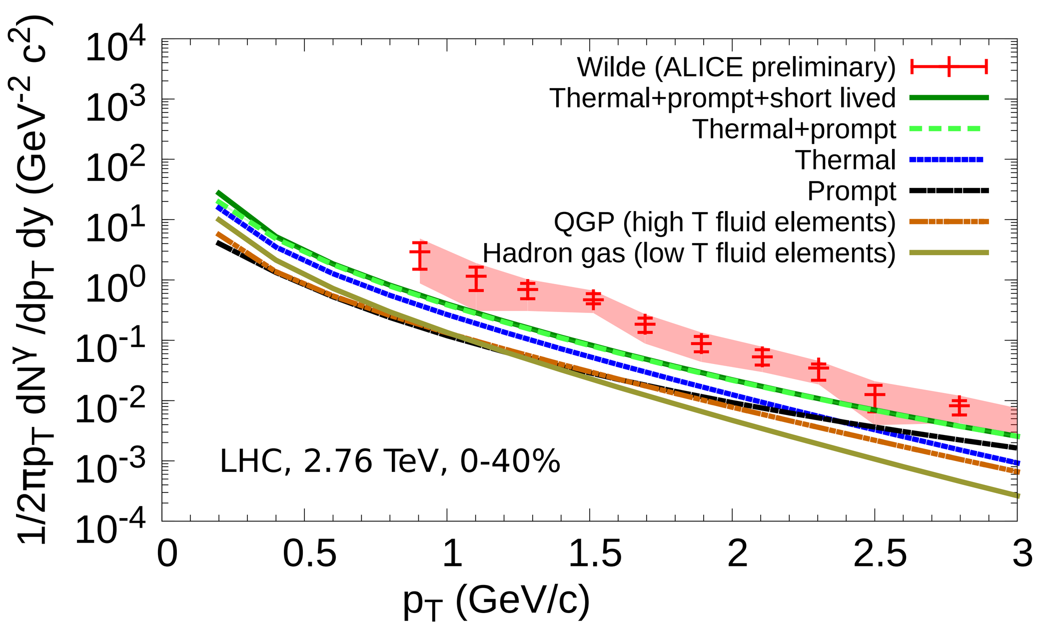
Photons and initial flow

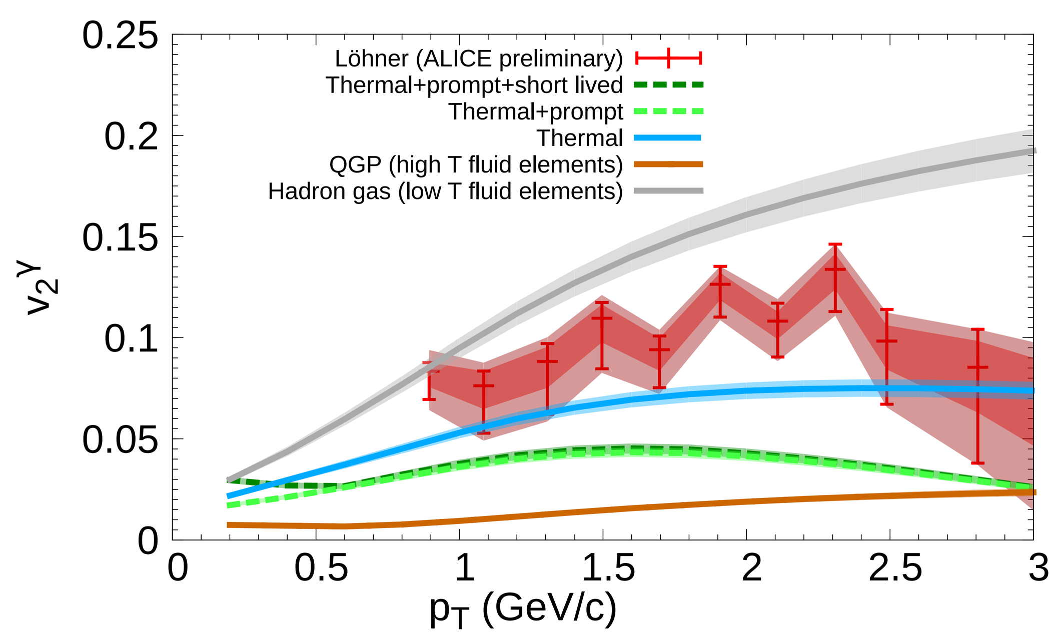
What is the effect on photons of the IP-Glasma intrinsic initial flow?





Direct photons

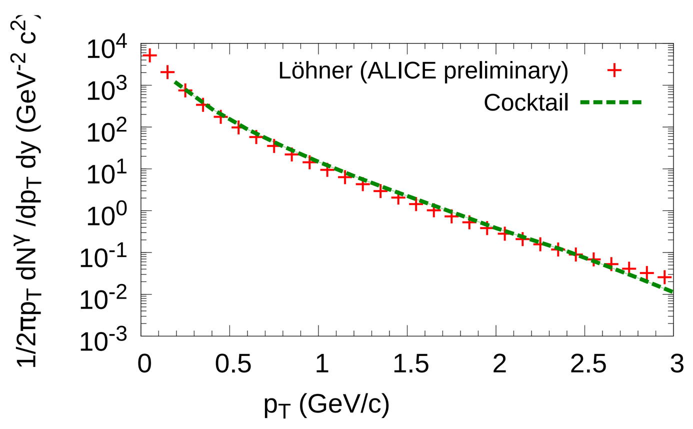


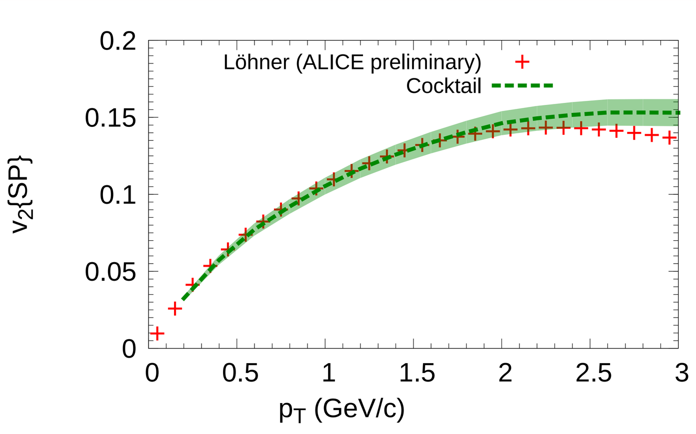


Conclusion

- Our **hydrodynamics model** of heavy-ion collisions **combined** with **IP-Glasma initial conditions** gives a **remarkable description** of the preliminary **inclusive photon** measurement by ALICE at the LHC
- Our calculation also **agrees well** with the $\mathbf{v_2}$ of ALICE's **cocktail simulation** of **hadronic decay photons**, although our calculation gives a **slightly larger spectra**
- The **direct photon** prediction still **underestimates the ALICE preliminary data**, although we hope our work on the **effect of initial flow**, the **definition of** v_2 and the **subtraction process** will help to shed light on the photon puzzle

Cocktail and subtraction

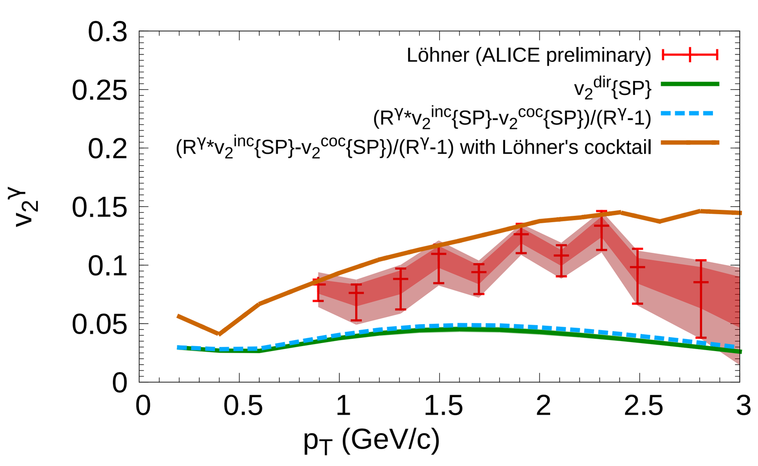




The **hadronic decay photons from hydro** can be **compared** to the **cocktail subtracted experimentally** [4] to get the direct photons

The **photon** v_2 generally gives **different results** when computed **directly (eq. 2)** or by **subtracting** the cocktail from the inclusive **(eq. 1)**

It is also interesting to compute the photon v_2 by **subtracting** the **experimental cocktail** [4] from the **hydro inclusive photon prediction**



References

[1] C. Gale, S. Jeon, B. Schenke, P. Tribedy and R. Venugopalan, Phys. Rev. Lett. **110** (2013) 012302

[2] C. Shen, U. W Heinz, J.-F. Paquet and C. Gale, Phys. Rev. C **89** (2014) 044910

[3] R. Rapp, private communication

[4] D. Lohner, PhD thesis, University of Heidelberg (2013)

[5] M. Wilde [ALICE Collaboration], Nucl. Phys. A **904-905** (2013) 573c