Thermal photons from a modern hydrodynamical model: status of the direct photon puzzle

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In collaboration with:

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(arXiv:1509.06738)

Quark Matter 2015

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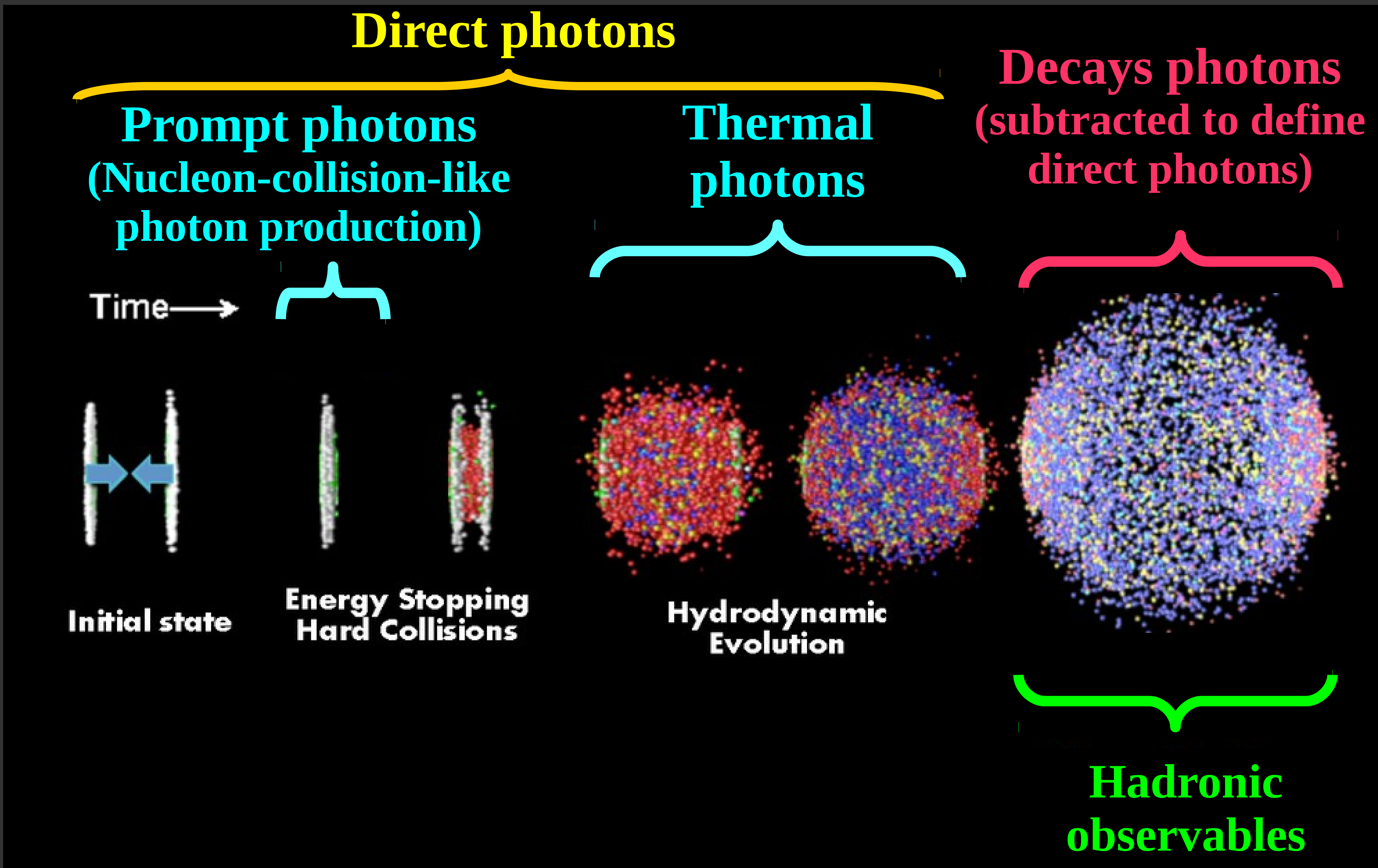
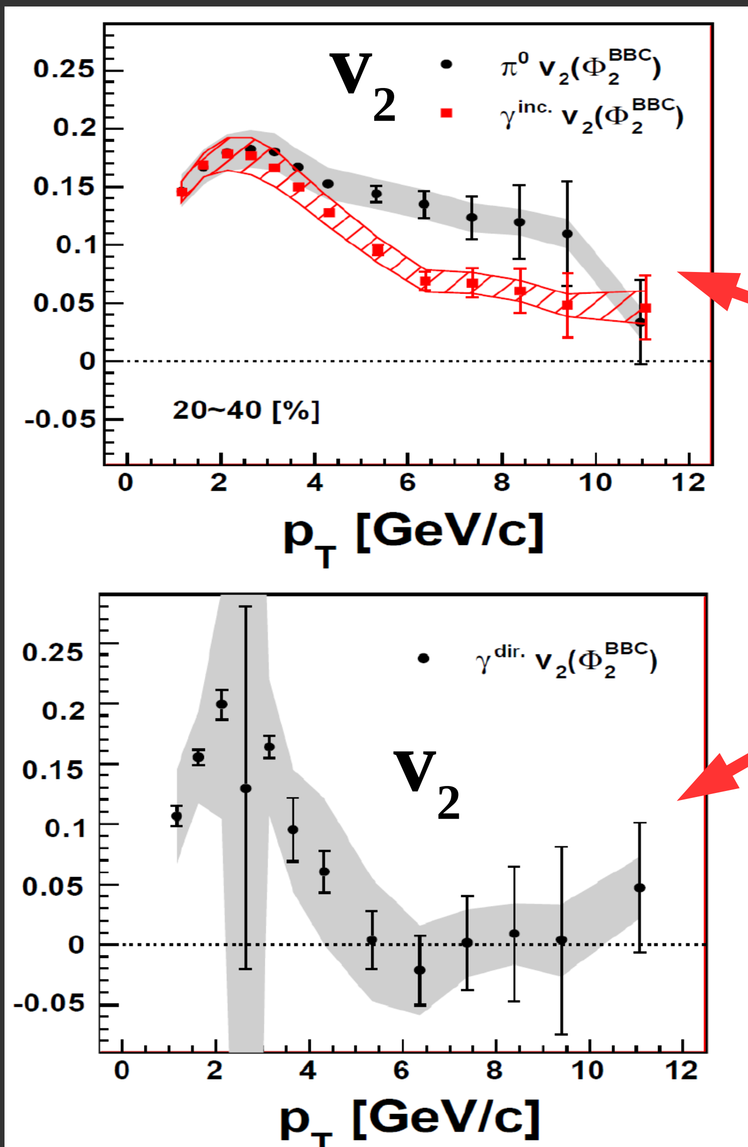
Photon and hadron sources in HIC



A puzzlingly large photon v_2 (and spectra)



Hadrons/
hadronic
decay photons

Unexpectedly
large direct
photon v_2

Direct
photons

Also: large
direct photon
spectra

Outline

- Hydrodynamical model & hadrons
- Evaluating thermal photons
- Comparison with measurements & discussion
- Status of the direct photon puzzle

Hydrodynamical model

- Event-by-event IP-Glasma (τ**<0.4 fm/c**)
- Hydrodynamics - MUSIC (τ**>0.4 fm/c**)

(Schenke, Tribedy, Venugopalan. 2012)

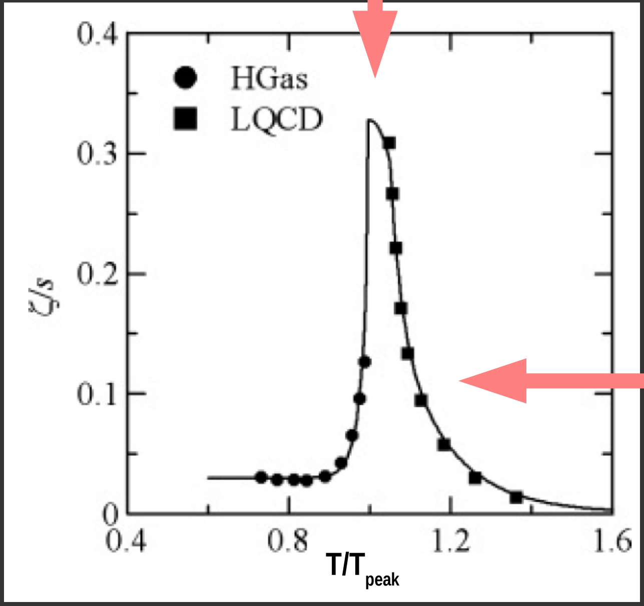
2+1D second-order (viscous) relativistic hydrodynamics

Shear EOM

$$\tau_\pi \Delta^{\mu\nu}_{\alpha\beta} \pi^{\alpha\beta} + \pi^{\mu\nu} = 2\eta\sigma^{\mu\nu} - \delta_{\pi\pi}\pi^{\mu\nu}\theta - \tau_{\pi\pi}\Delta^{\mu\nu}_{\alpha\beta}\pi^{\lambda\alpha}\sigma^{\beta}_{\lambda} + \lambda_{\pi\Pi}\Pi\sigma^{\mu\nu} + \varphi_7 \Delta^{\mu\nu}_{\alpha\beta}\pi^{\lambda\alpha}\pi^{\beta}_{\lambda}$$

$$\tau_\Pi \dot{\Pi} + \Pi = -\zeta\theta - \delta_{\Pi\Pi}\Pi\theta + \lambda_{\Pi\pi}\pi^{\mu\nu}\sigma_{\mu\nu}$$

Bulk EOM



Shear viscosity: $\eta/s = 0.095(LHC); 0.06(RHIC)$

Bulk viscosity: Peak at T=180 MeV

Inspired from:
HRG: Noronha-Hostler, Noronha and Greiner. 2009
(Lattice: Karsch, Kharzeev and Tuchin. 2008)

(from Denicol, Kodama, Koide, Mota. 2009)

Hydrodynamical model

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- Afterburner UrQMD (**$T<T_{sw}$**)

At RHIC: T_{sw}=165 MeV

At the LHC: T_{sw}=145 MeV

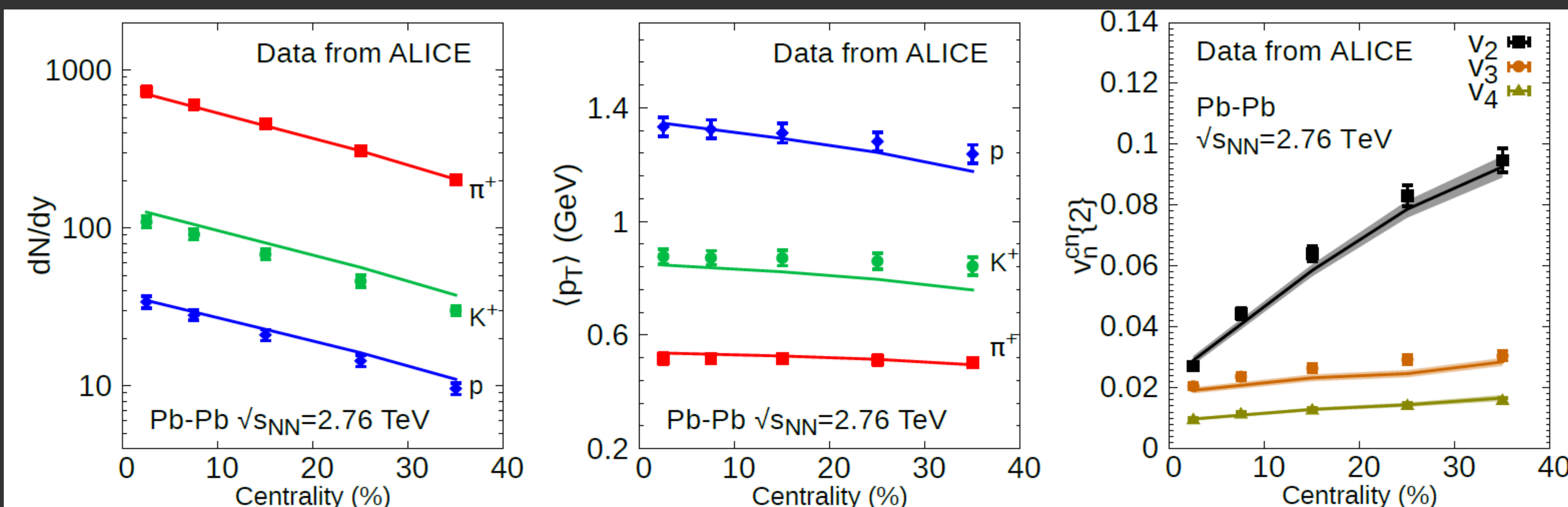
LHC $\sqrt{s_{NN}}$=2760 GeV

(Sangwook Ryu's poster)

Multiplicity of π^+, K^+ & p

Mean transverse momentum of π^+, K^+ & p

$V_{2/3/4}$ of charged hadrons



Hydro with bulk = good description of hadrons

(not possible here without bulk)

(see Ryu et al, PRL 115, 132301)

Direct photons

How are they computed?

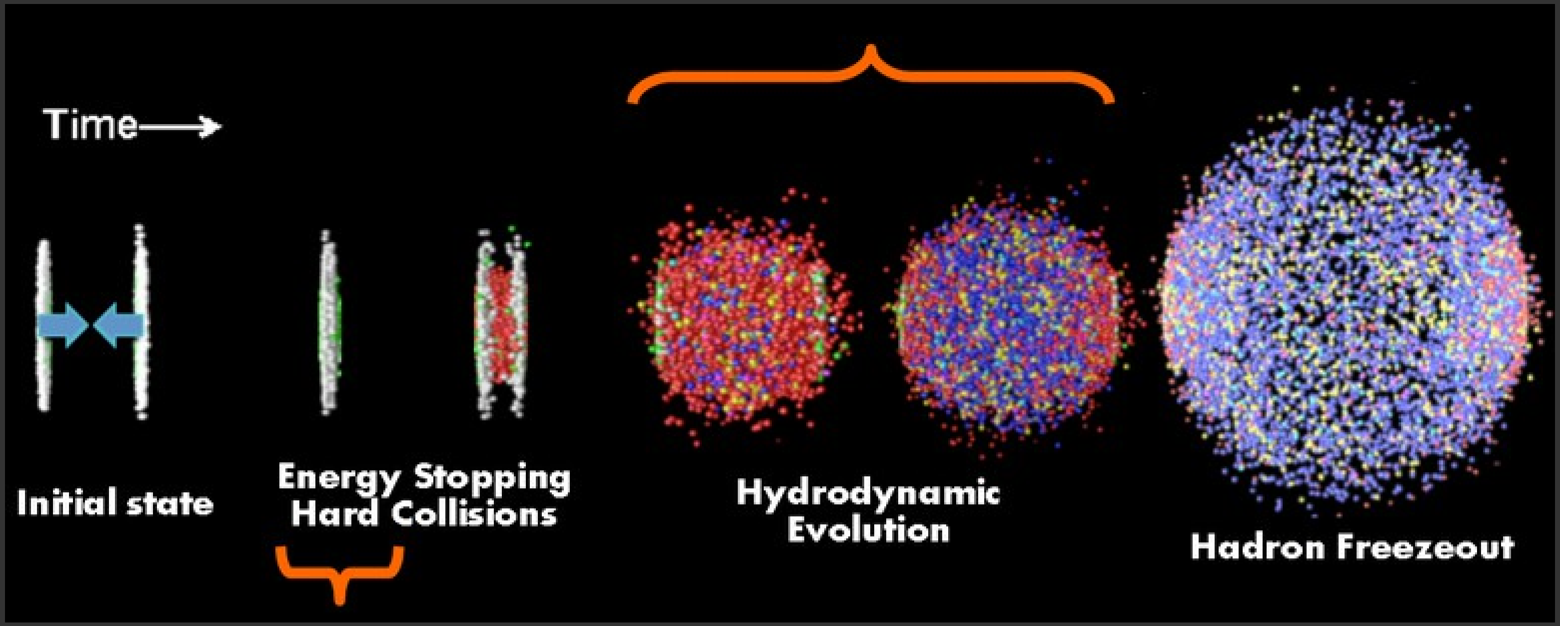
Photon production

Thermal photons:

$$E\frac{d^3N}{d\mathbf{k}} = \int d^4X\, E\frac{d^3\Gamma}{d\mathbf{k}}(K^\mu, u^\mu(X), T(X), \pi^{\mu\nu}(X), \Pi(X))$$

"Thermal" photon production rate

Spacetime profile of medium



Prompt photons: NLO perturbative QCD + nuclear p.d.f.'s + isospin effect, scaled by the number of binary collisions

Thermal photon emission rate

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- Photon production rate

less hot (hadronic D.O.F.) — **Temperature** — *very hot (QGP)*

Effective Lagrangian

(Switch at 180 MeV)

Perturbative expansion in α_s

Include corrections due to viscosity

Texas A&M/McGill (Turbide, Rapp, Gale et al)

(Meson gas
+ photons from ρ spct fct
+ pion brem. + π–ρ–ω channels)

QGP LO (Arnold, Moore, Yaffe. 2002)

(Compton scattering &
quark-antiquark annihilation
+ bremsstrahlung)

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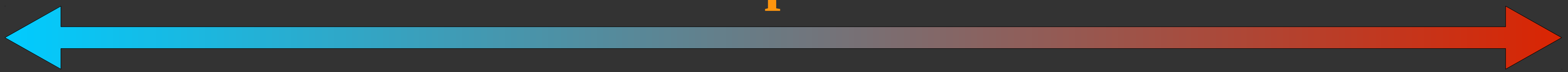

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(Compton scattering &
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Post-hydrodynamics photons

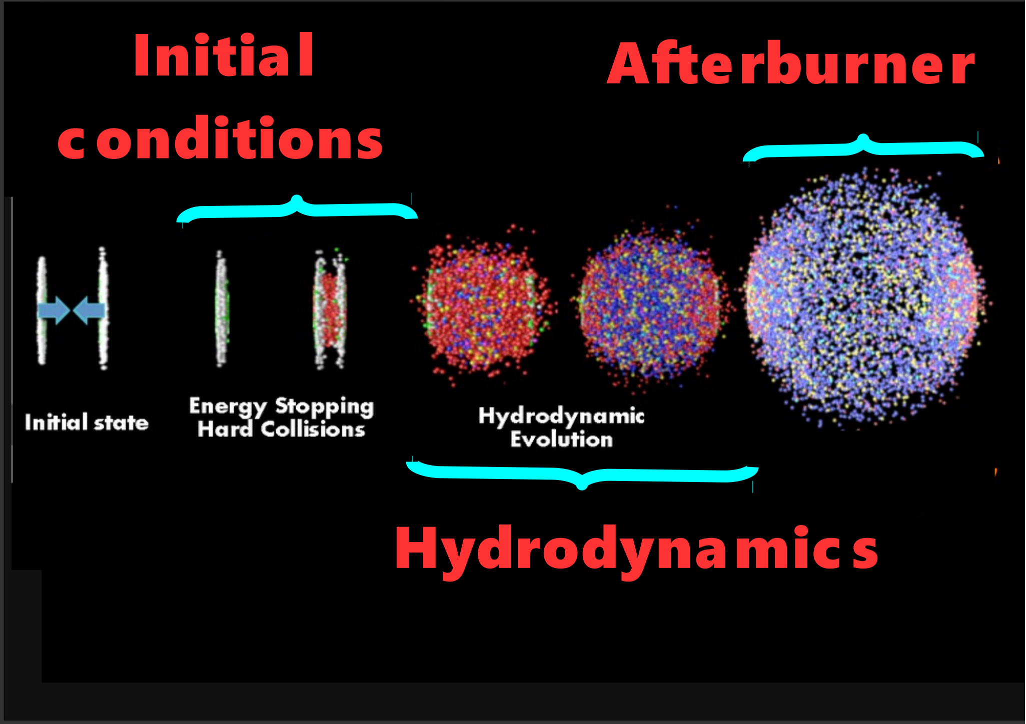
Photons after hydro phase?

Hadrons: UrQMD

Photons:

Not yet calculated from transport model

▶ Run hydro to lower temperature (105 MeV) instead



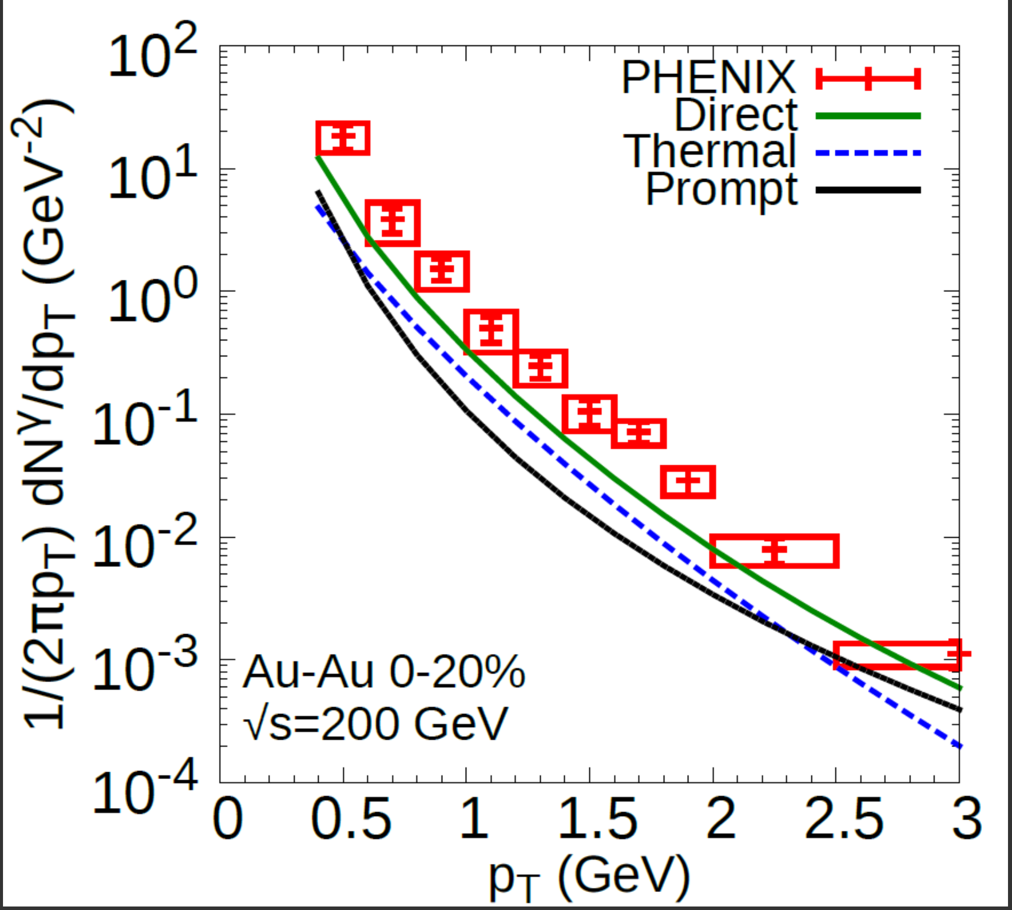
Coarse-grained UrQMD vs hydro: Huovinen et al. 2002

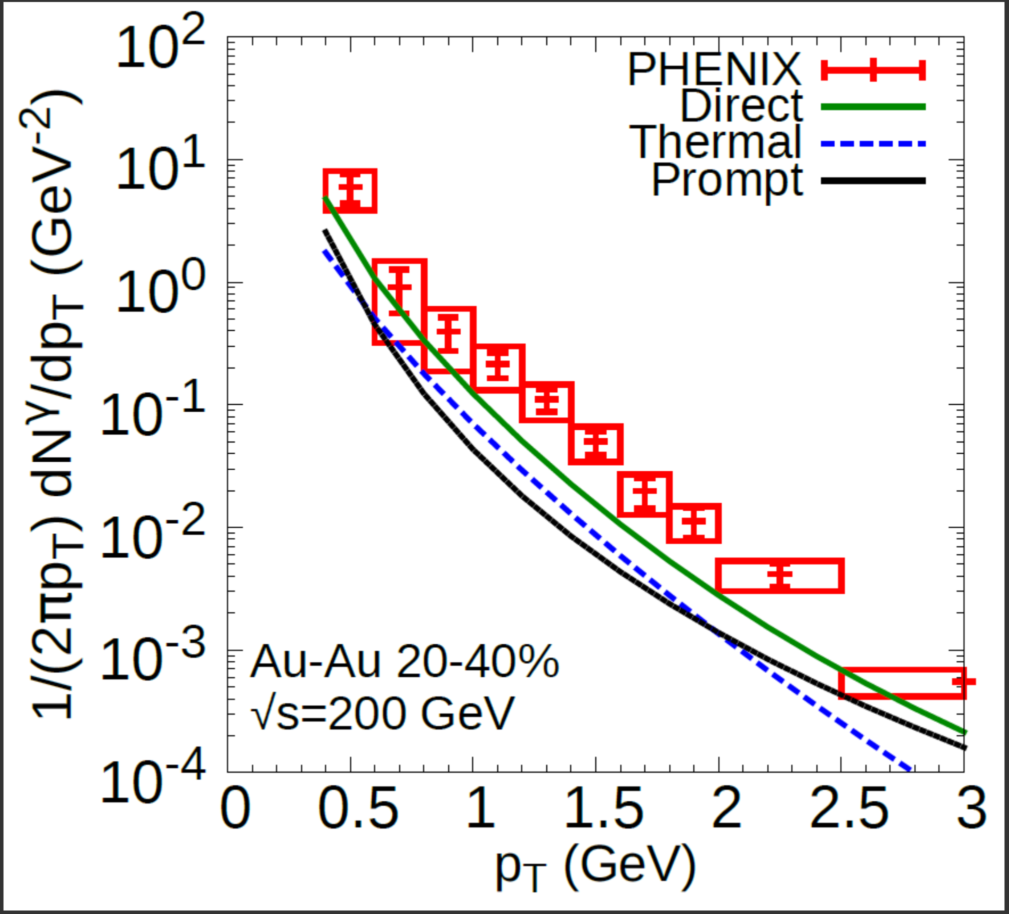
Direct photons

Comparison with data from RHIC and the LHC

RHIC $\sqrt{s}_{NN}$=200 GeV: spectra

Direct photon spectra

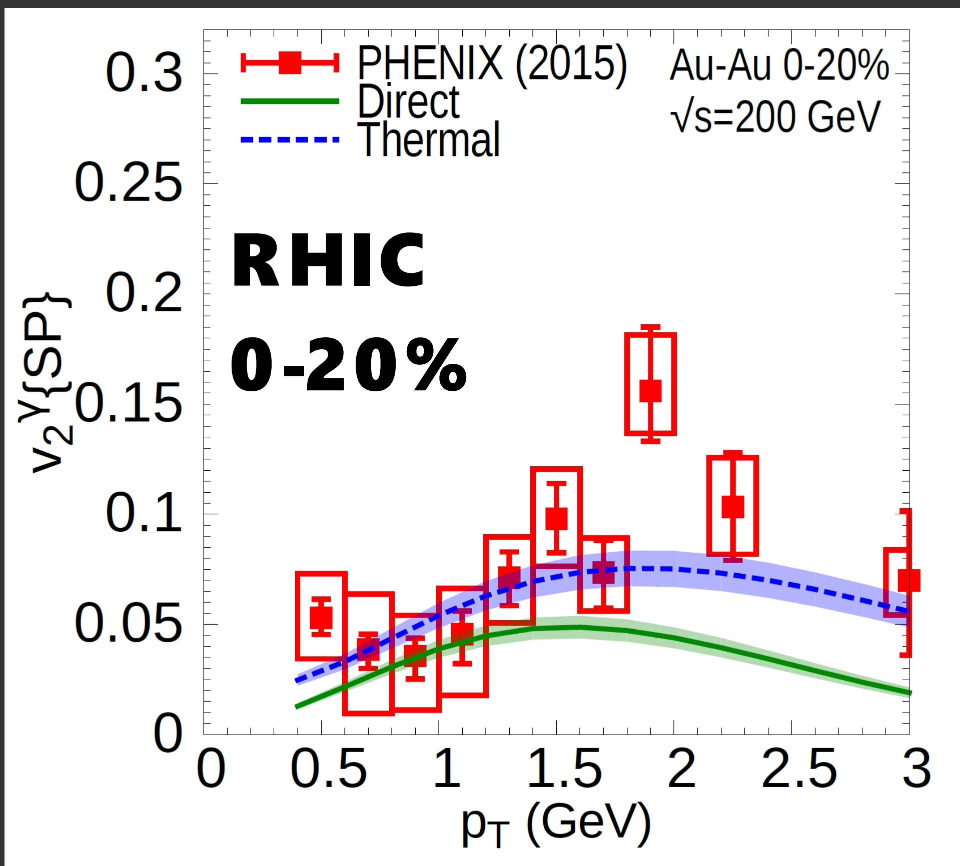


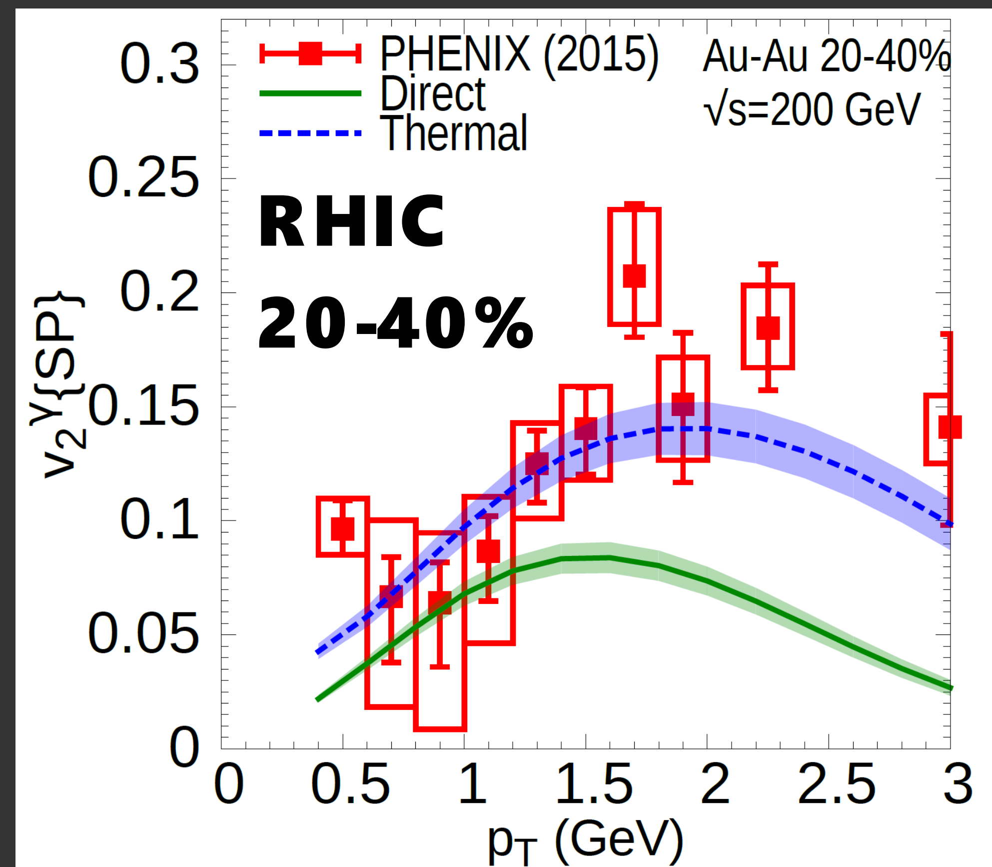


0-20% **RHIC** **20-40%**

RHIC $\sqrt{s_{NN}}$=200 GeV: v_2

Direct photon v_2



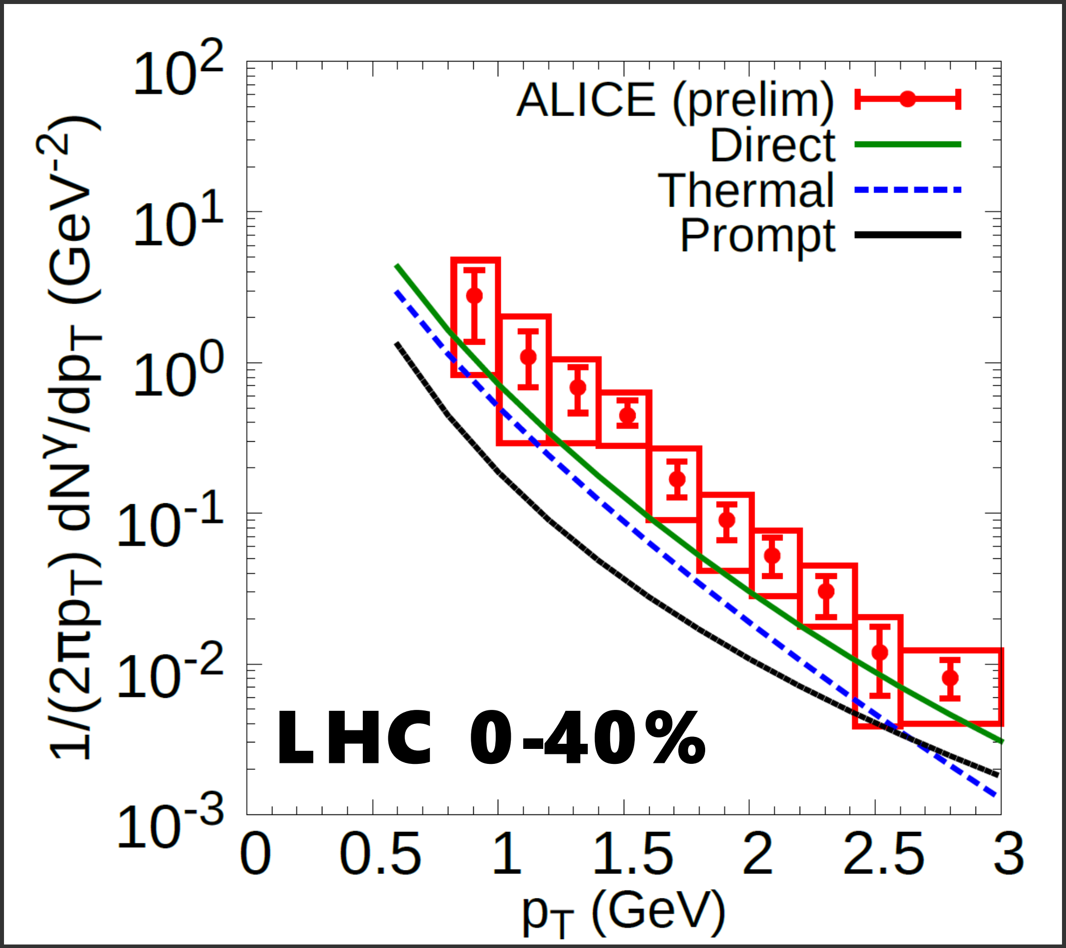


New data: **Stay tuned for Richard Petti's (PHENIX) talk at 9h40**

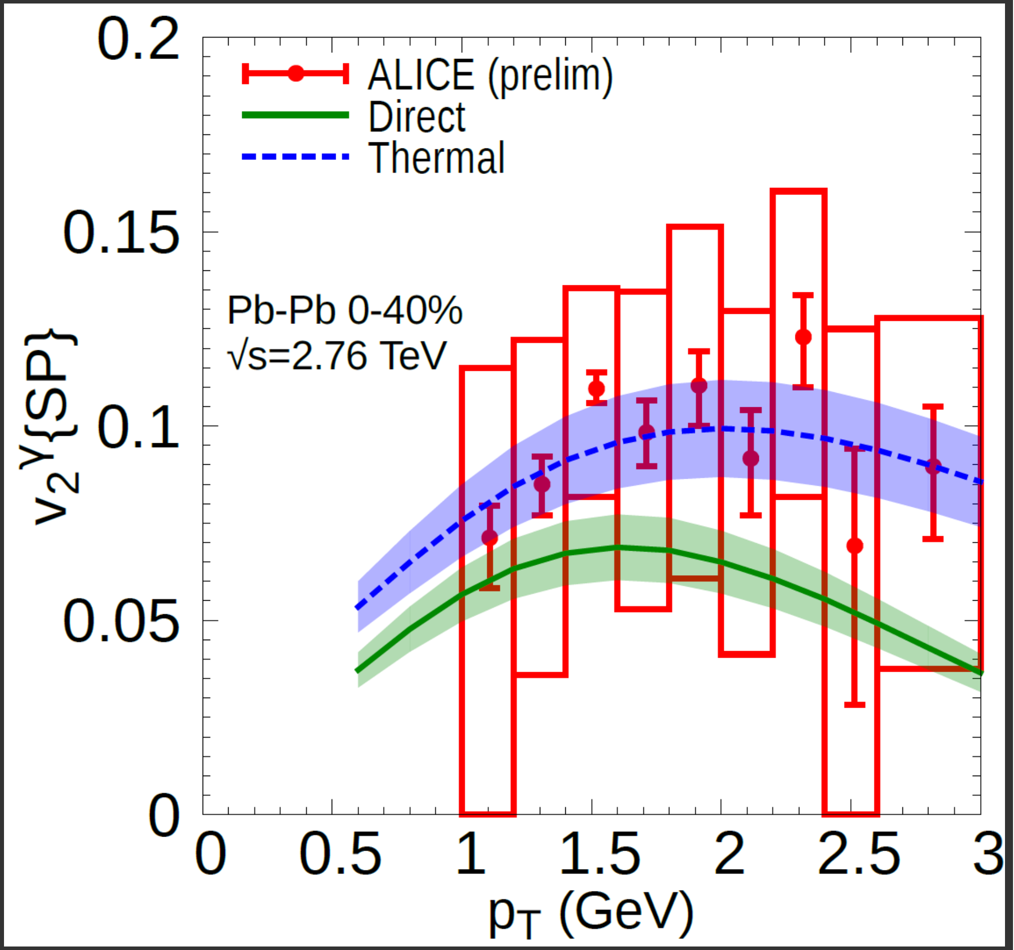
LHC $\sqrt{s}_{NN}$=2760 GeV:

Prompt, thermal & direct

Direct photon spectra



Direct photon v_2

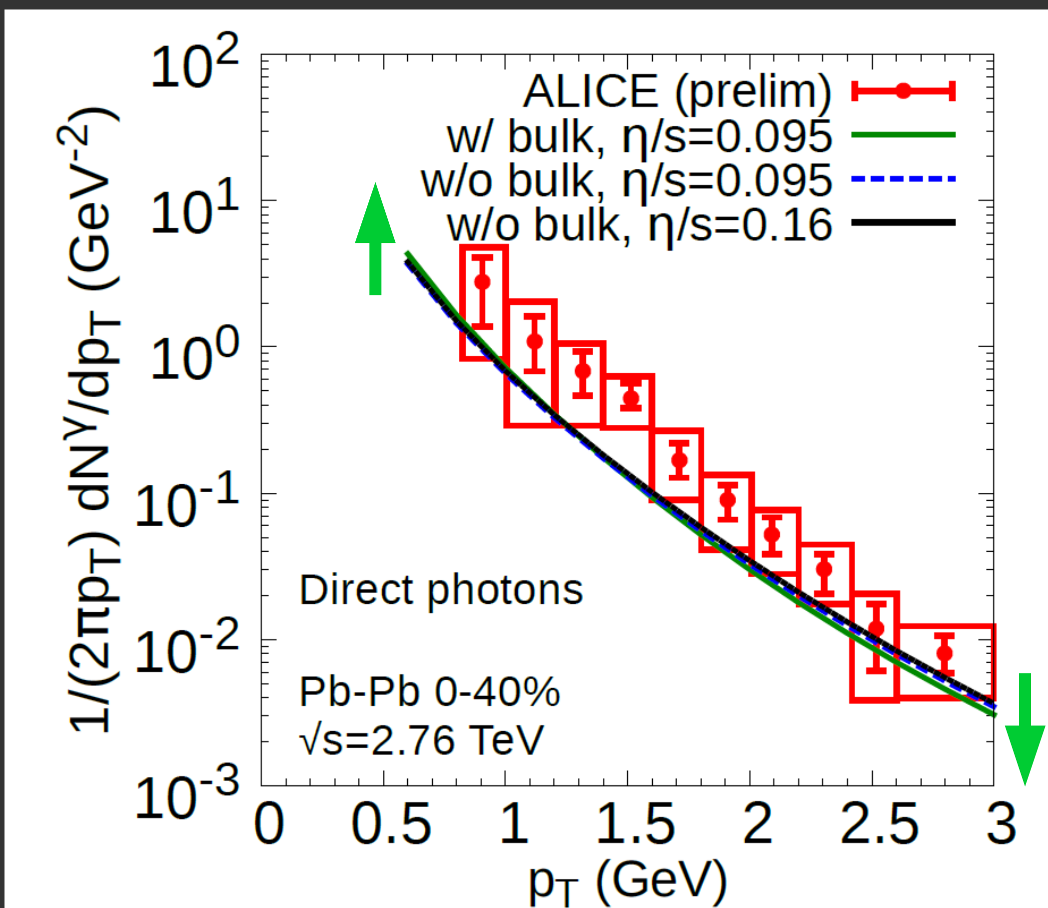


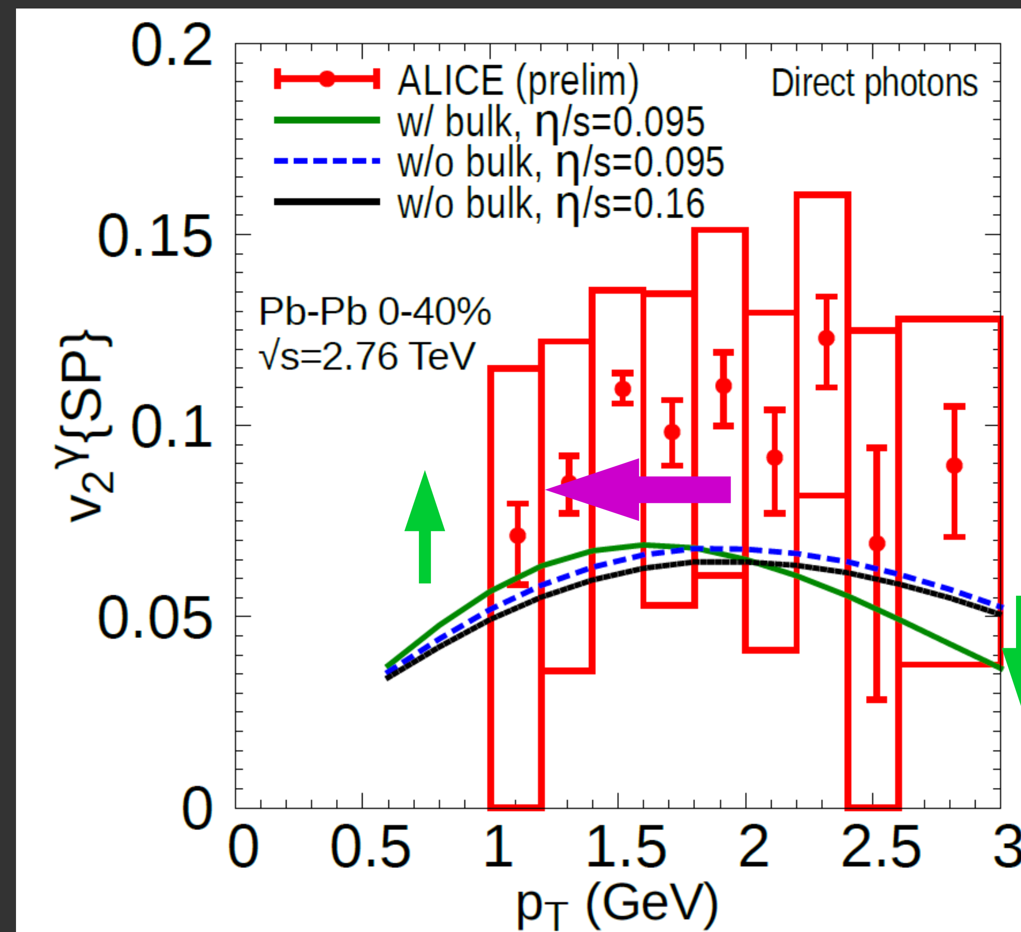
New data just published: see ALICE talk at 10h

Direct photons

Effect of bulk viscosity

Bulk: change shape of v_2

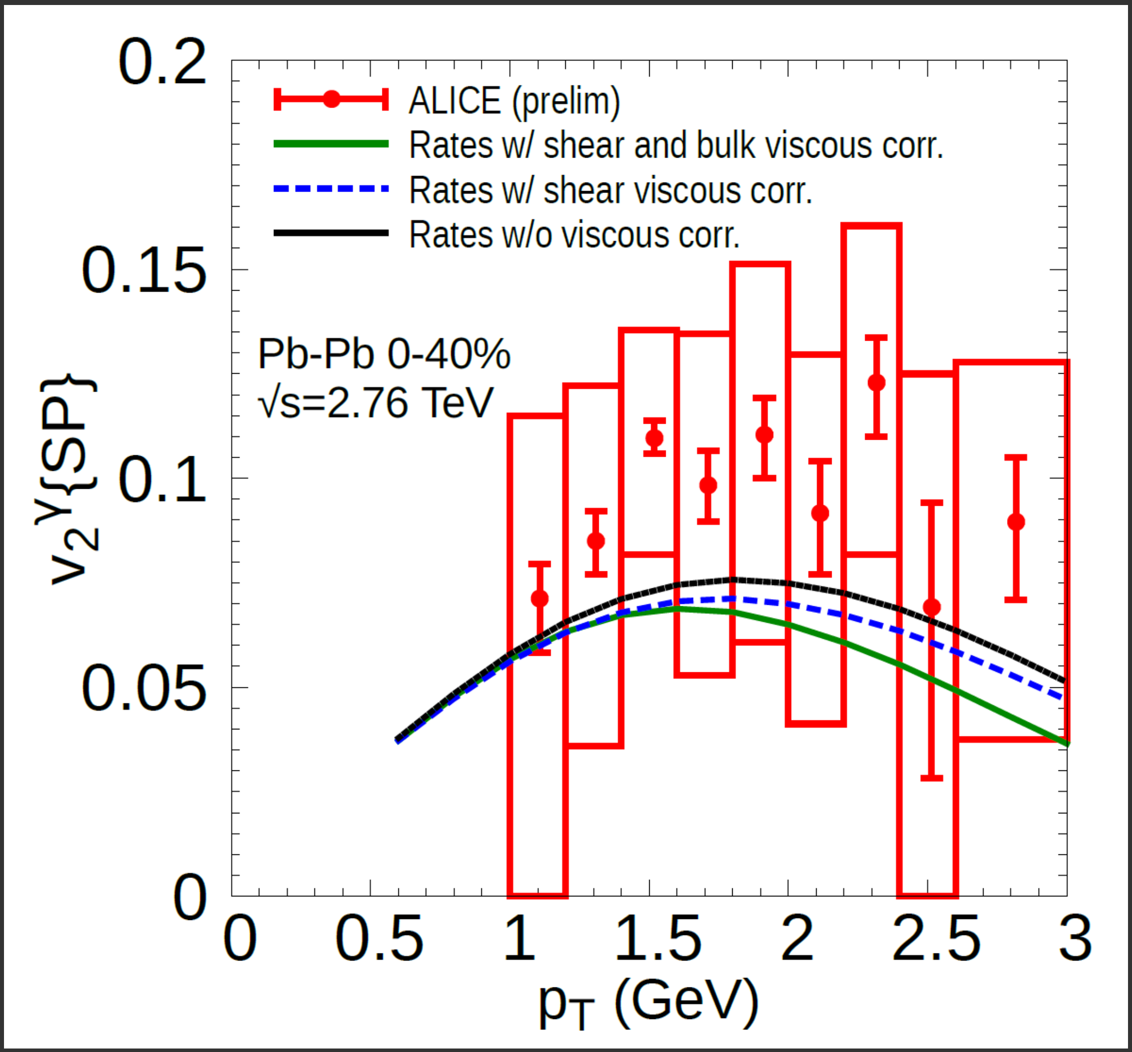




Medium expands for longer with a reduced transverse flow

► More photons, softer photons ◄

Effect of viscosity on the rates



Viscous corrections to rate suppress the v_2 at high p_T

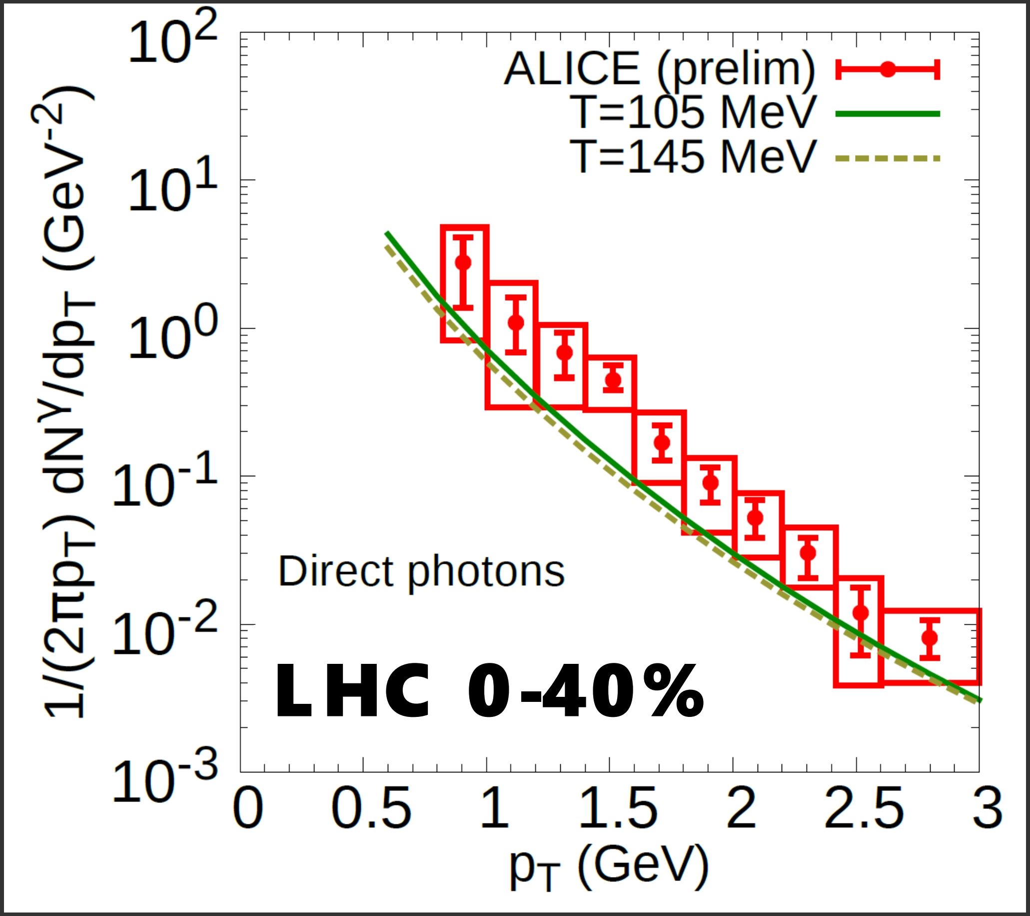
(And only part of the rates are corrected)

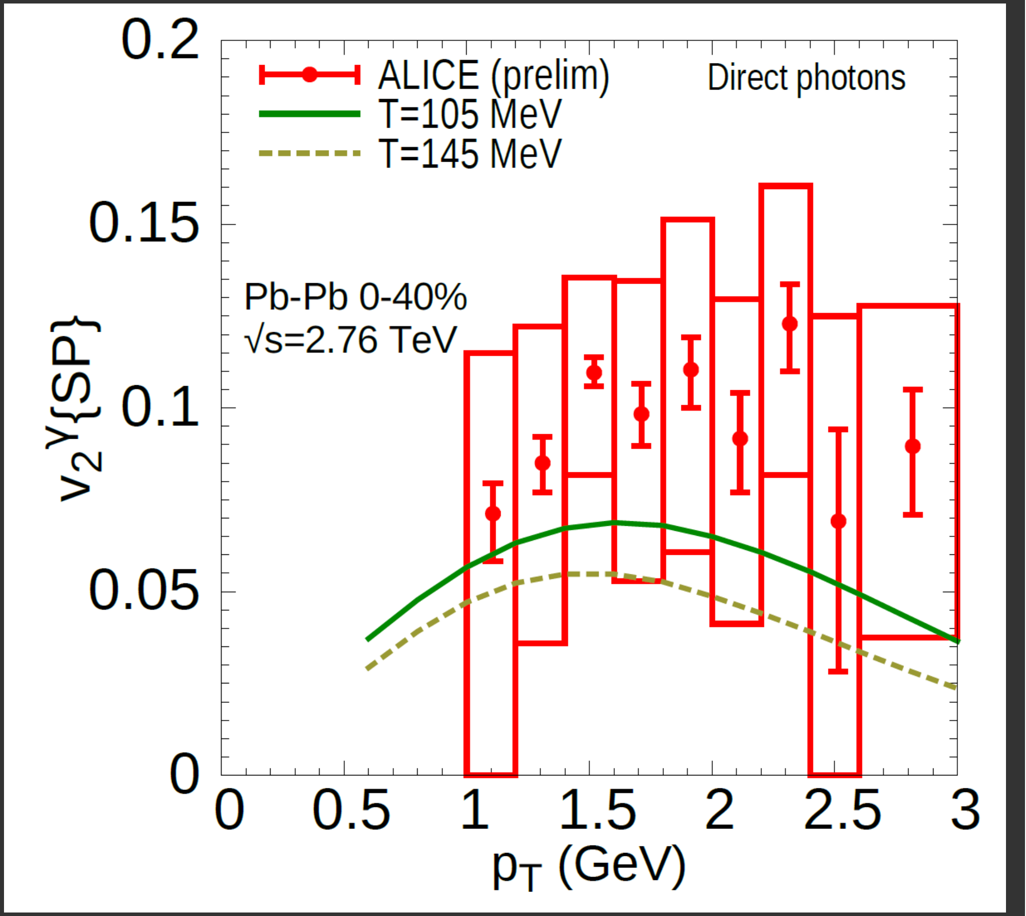
Direct photon v_2 LHC 0-40%

Direct photons

Late stage photons and hadronic rates

Late stage photons

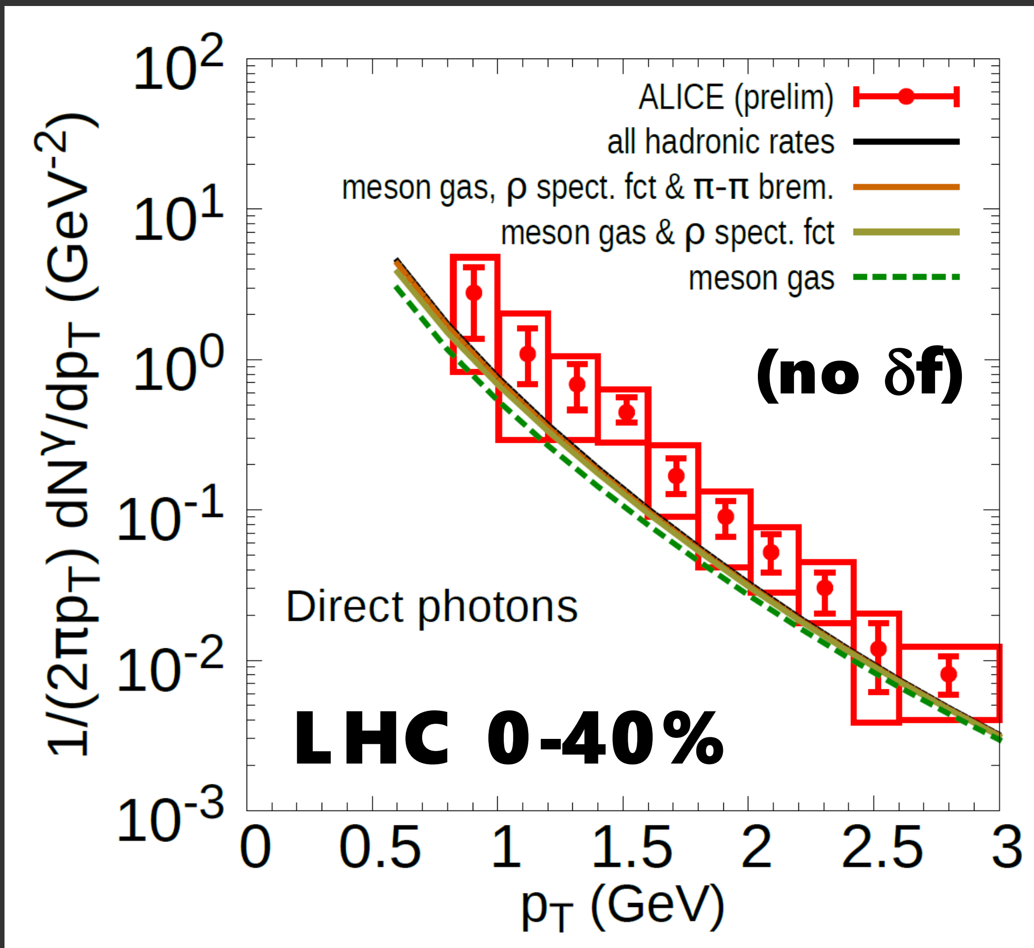


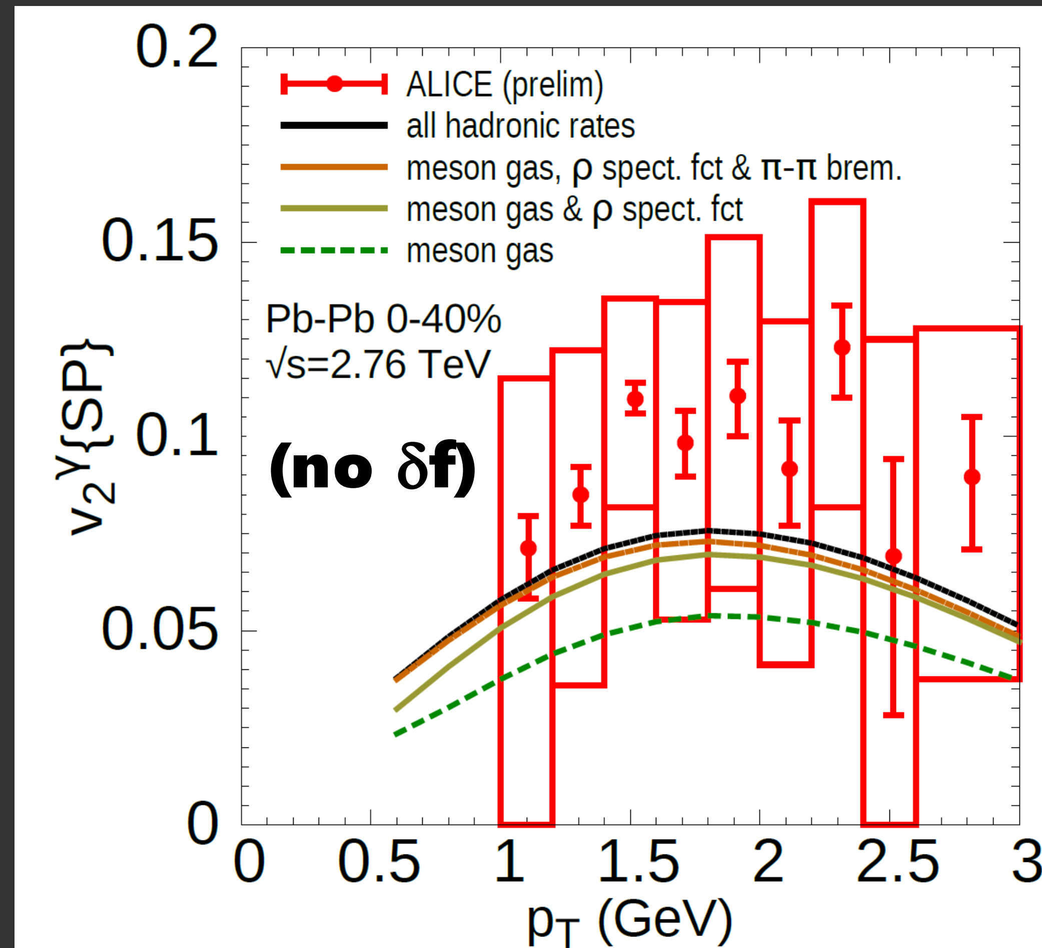


Significant contribution of late stage photons to v_2

► Need afterburner calculation? ◄

Hadronic rate channels





► **Using latest hadronic rates is important** ◄

(many emission channels contribute)

Verdict: puzzle or not?

- Modern hydro + latest hadronic photon rates = reasonable agreement with measurements, mild tension at worst
- Large thermal photon v_2
- Late stage photons & hadronic rates are important for photon v_2

Thermal photons can explain most low p_T direct photon excess and v_2

Where do we go from here?

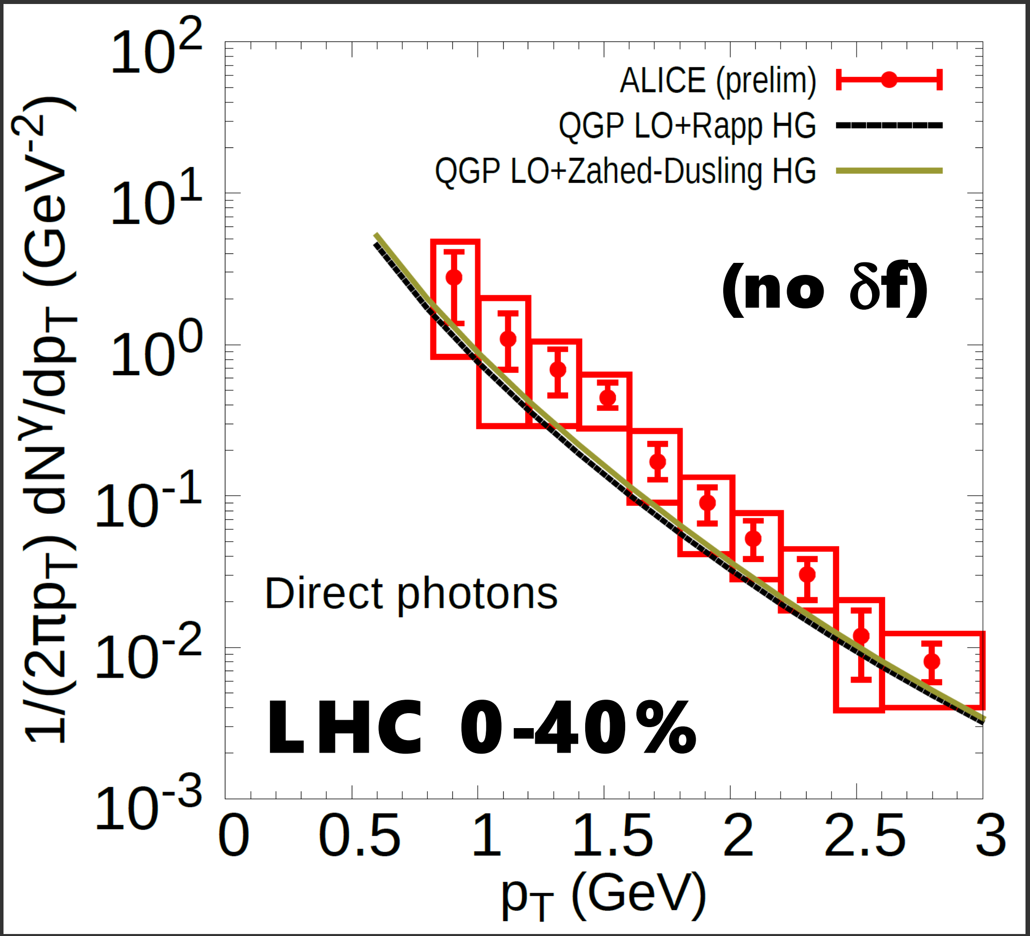
- Late stage photons: transport model?
- Photon emission rates: QGP/cross-over/hadronic thermal rates & effect of viscosity
- Prompt photons: Parton energy loss vs fragmentation photons; jet-QGP photons
- Include other proposed sources of photons?

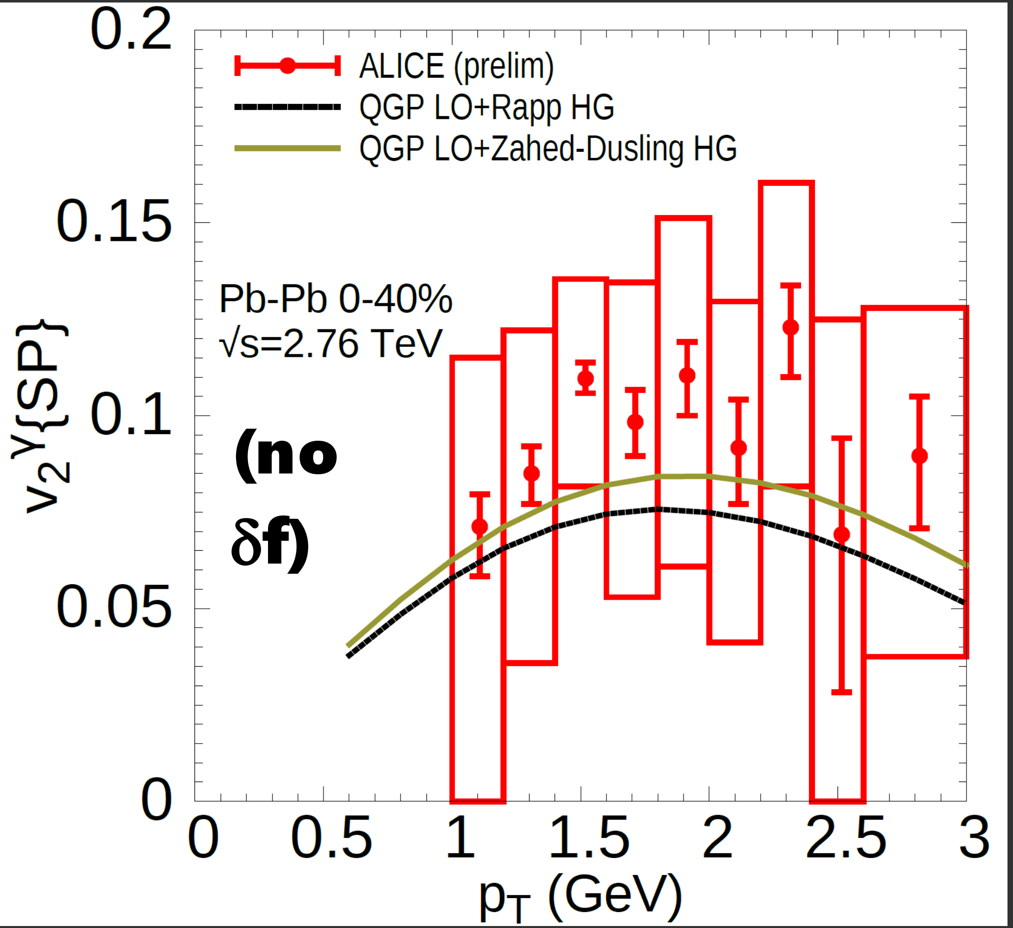
Backup

Hadronic rates comparison

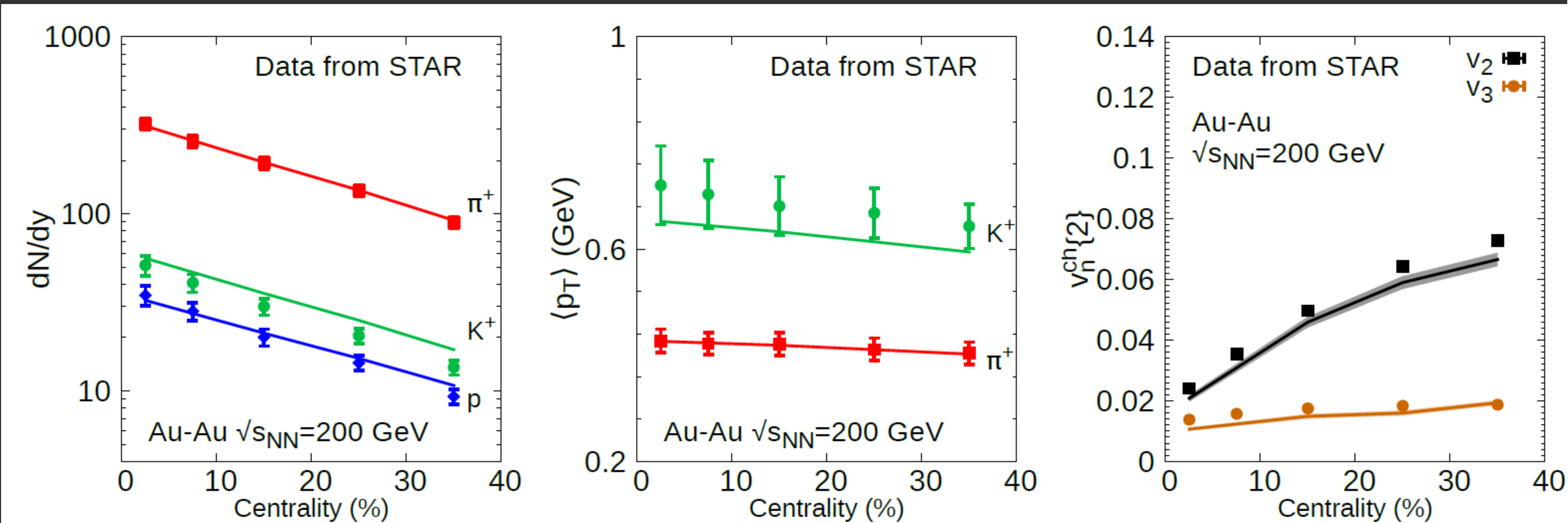
Two different hadronic rates calculations:

Texas-A&M/McGill and Stony Brook (Zahed-Dusling)





RHIC $\sqrt{s_{NN}}$=200 GeV



<u>Multiplicity</u> of π^+, K^+ & p

<u>Mean transverse momentum</u> of π^+ & K^+

v_2 and v_3 of <u>charged hadrons</u>

Dual effect of viscosity

Thermal photons:

$$E\frac{d^3N}{d^3k}=\int d^4X\left[E\frac{\Gamma^{ideal}}{d^3k}(K^\mu,u^\mu(X),T(X))+E\frac{\Gamma^{viscous}}{d^3k}(K^\mu,u^\mu(X),T(X),\pi^{\mu\nu}(X),\Pi(X))\right]$$

- Viscosity modifies:
  - The photon emission rate
  - Spacetime profile of the temperature, flow, volume, ...

Viscosity vs spacetime profile

Thermal photons:

$$E\frac{d^3N}{d^3k}=\int d^4X\left[E\frac{\Gamma^{ideal}}{d^3k}(K^\mu,u^\mu(X),T(X))+E\frac{\Gamma^{viscous}}{d^3k}(K^\mu,u^\mu(X),T(X),\pi^{\mu\nu}(X),\Pi(X))\right]$$

- Viscosity modifies:
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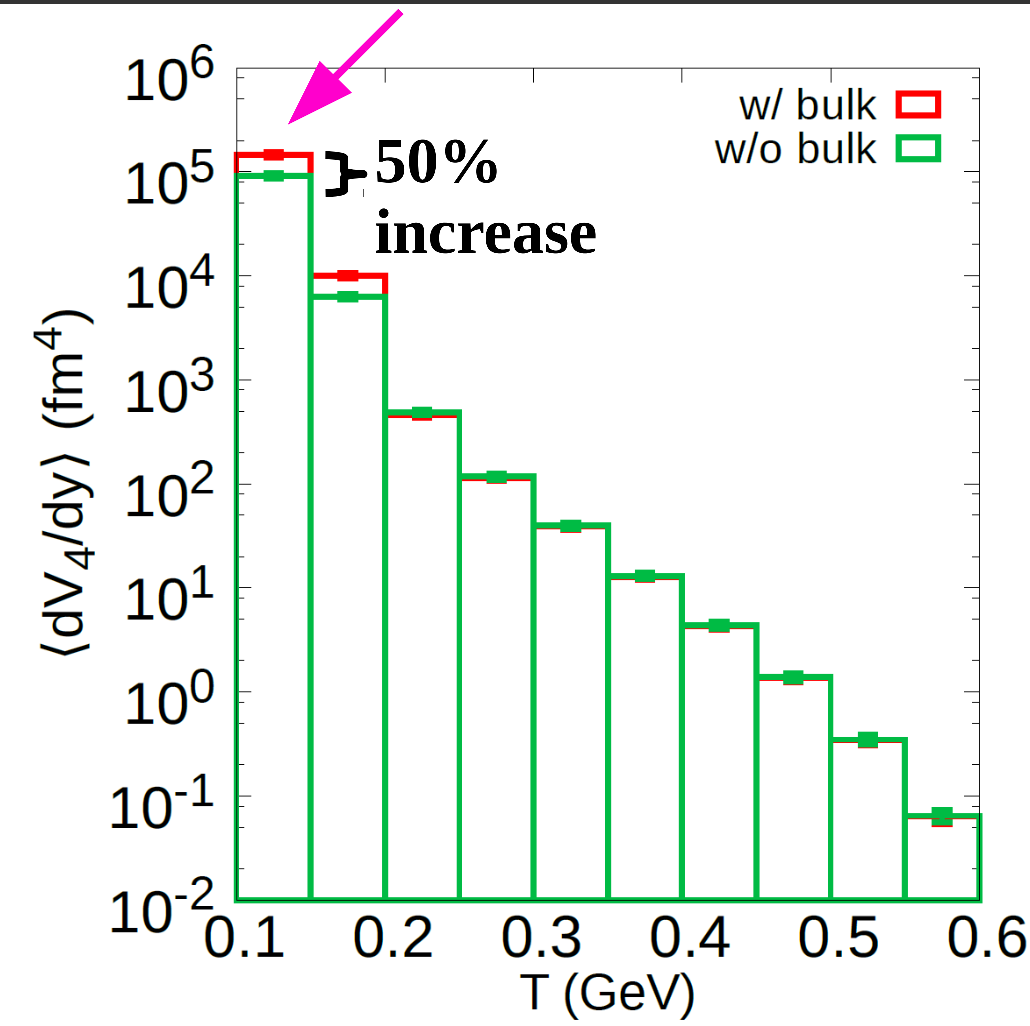
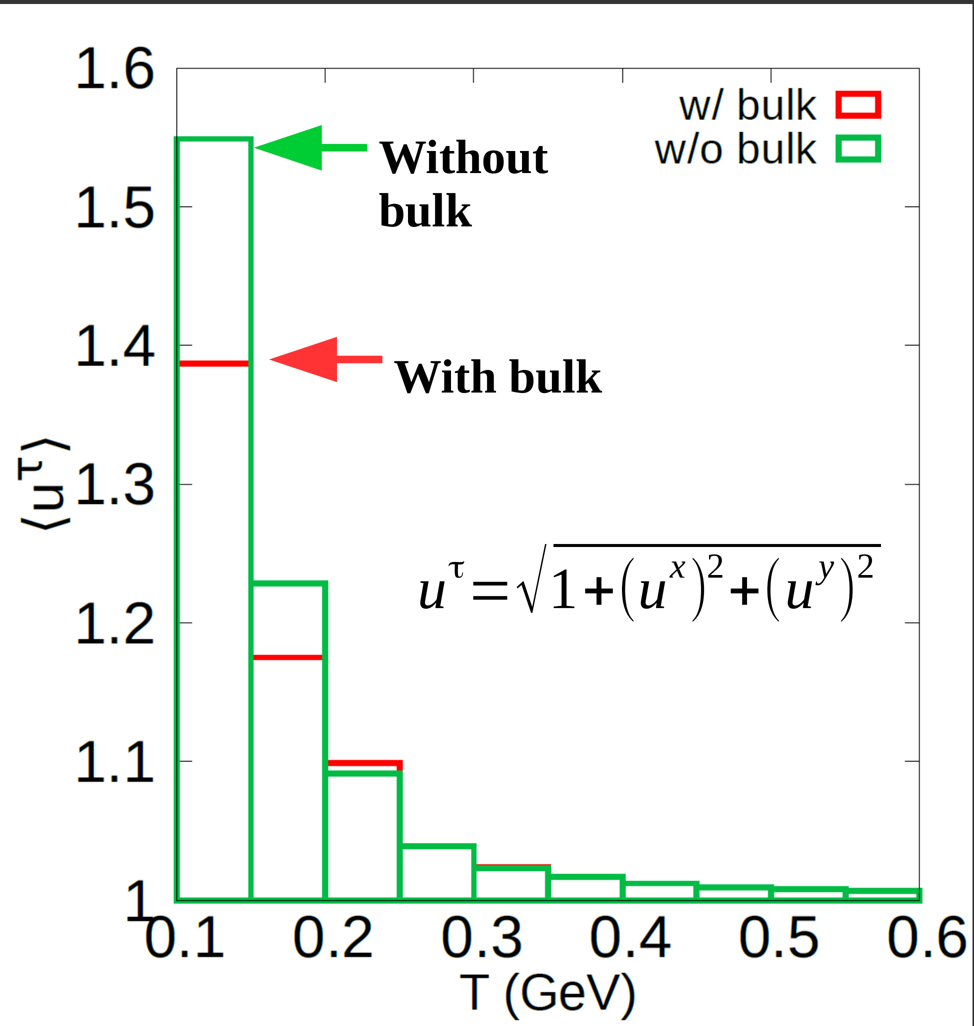
Bulk vs spacetime/flow profiles

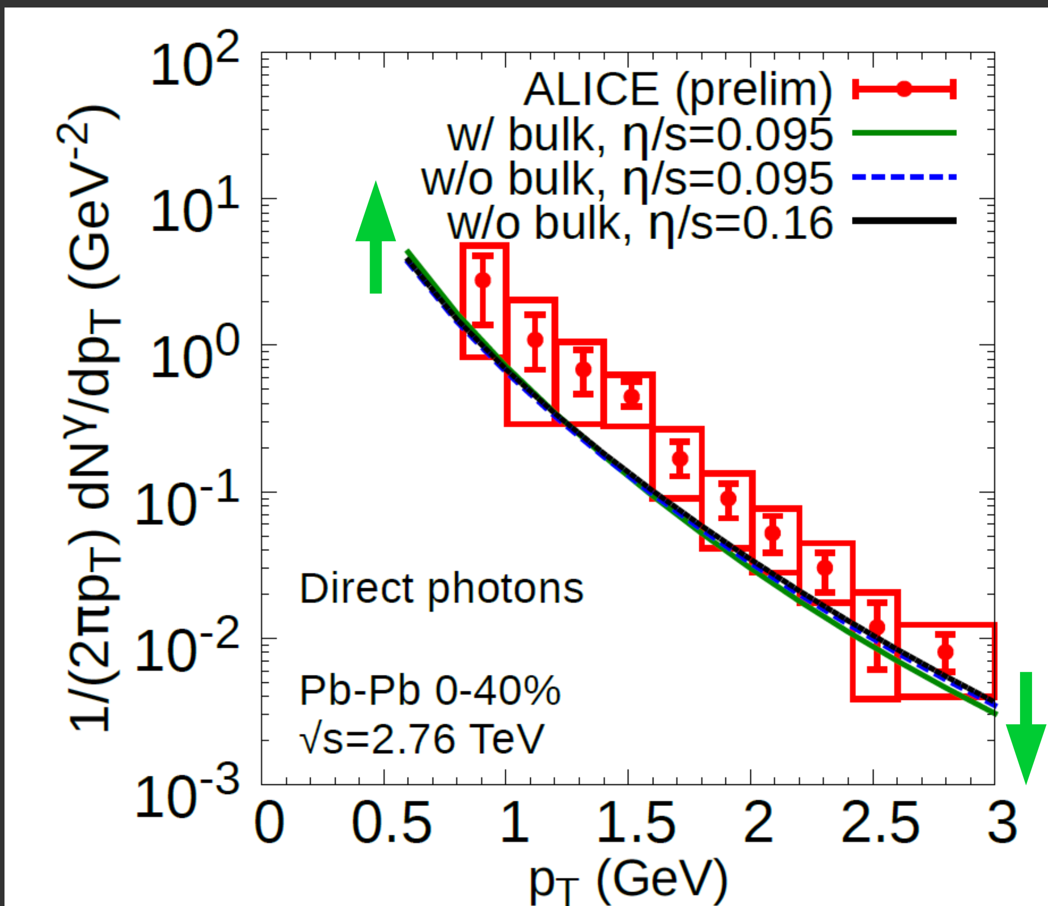
Increased spacetime

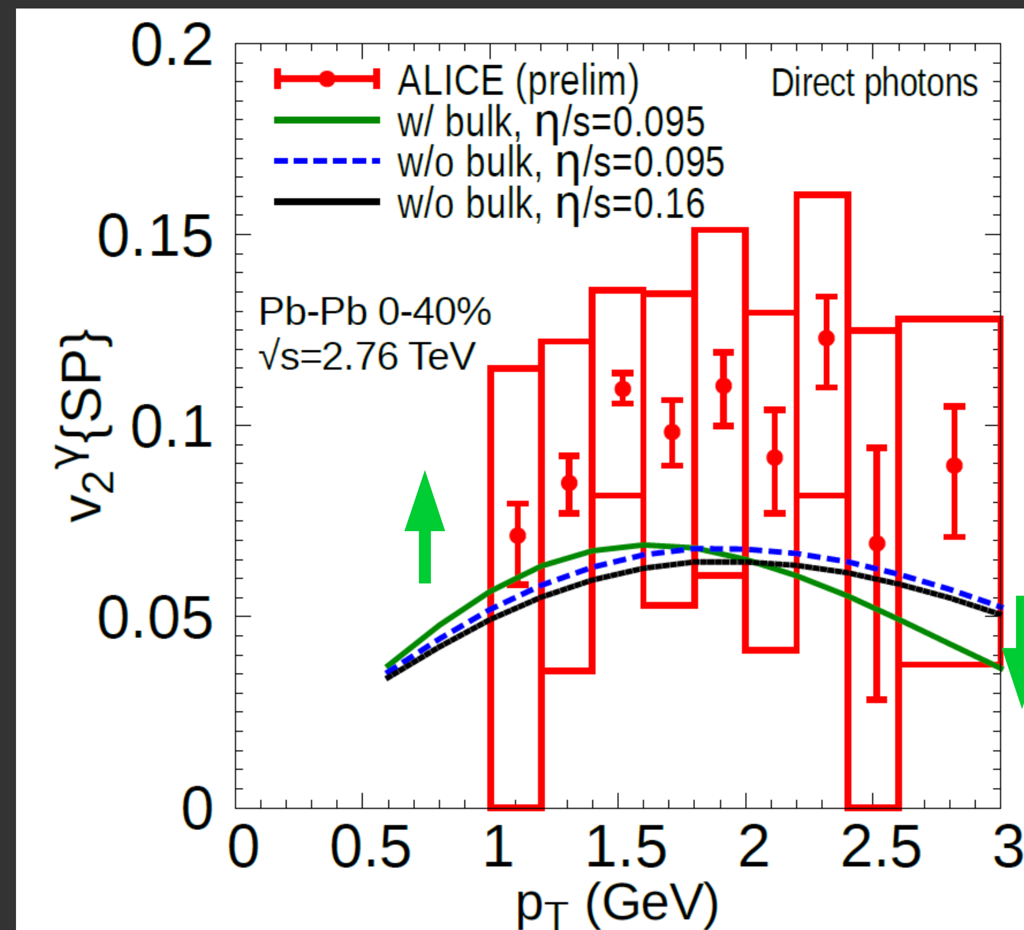


Smaller flow velocity



Bulk: change shape of v_2

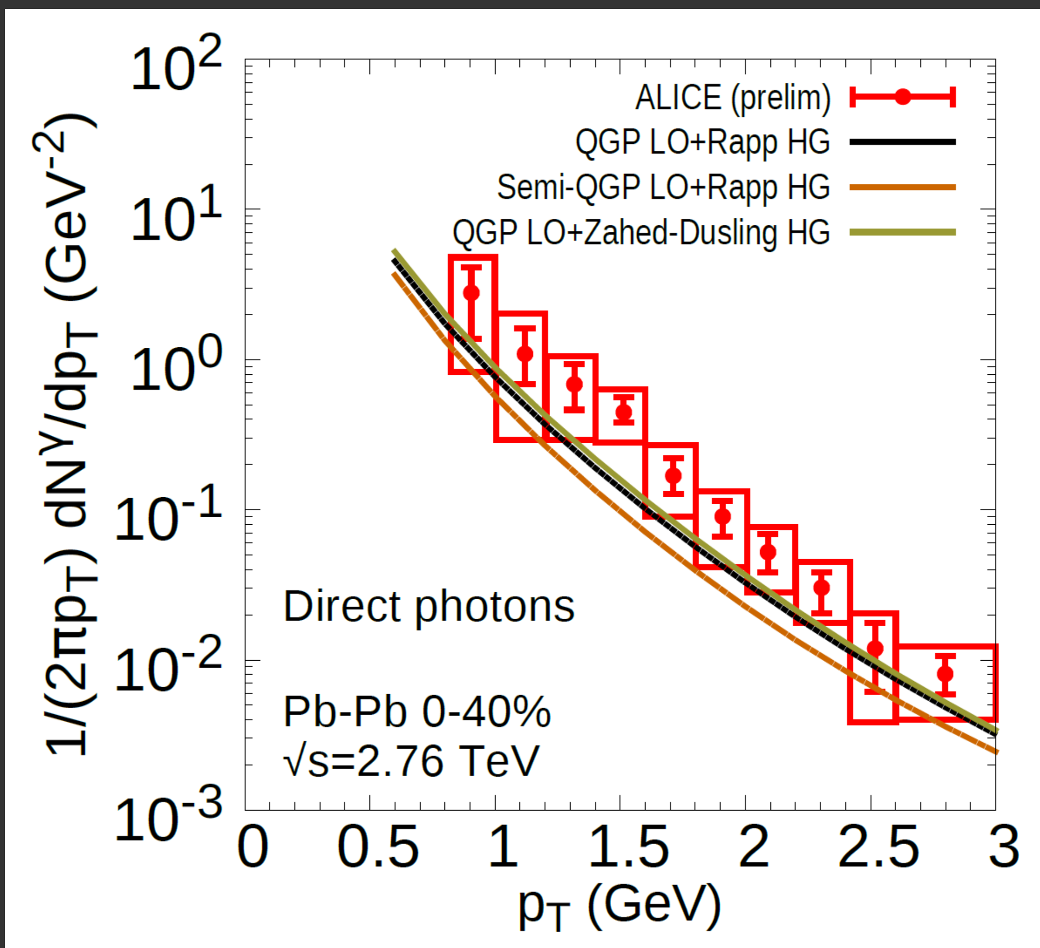




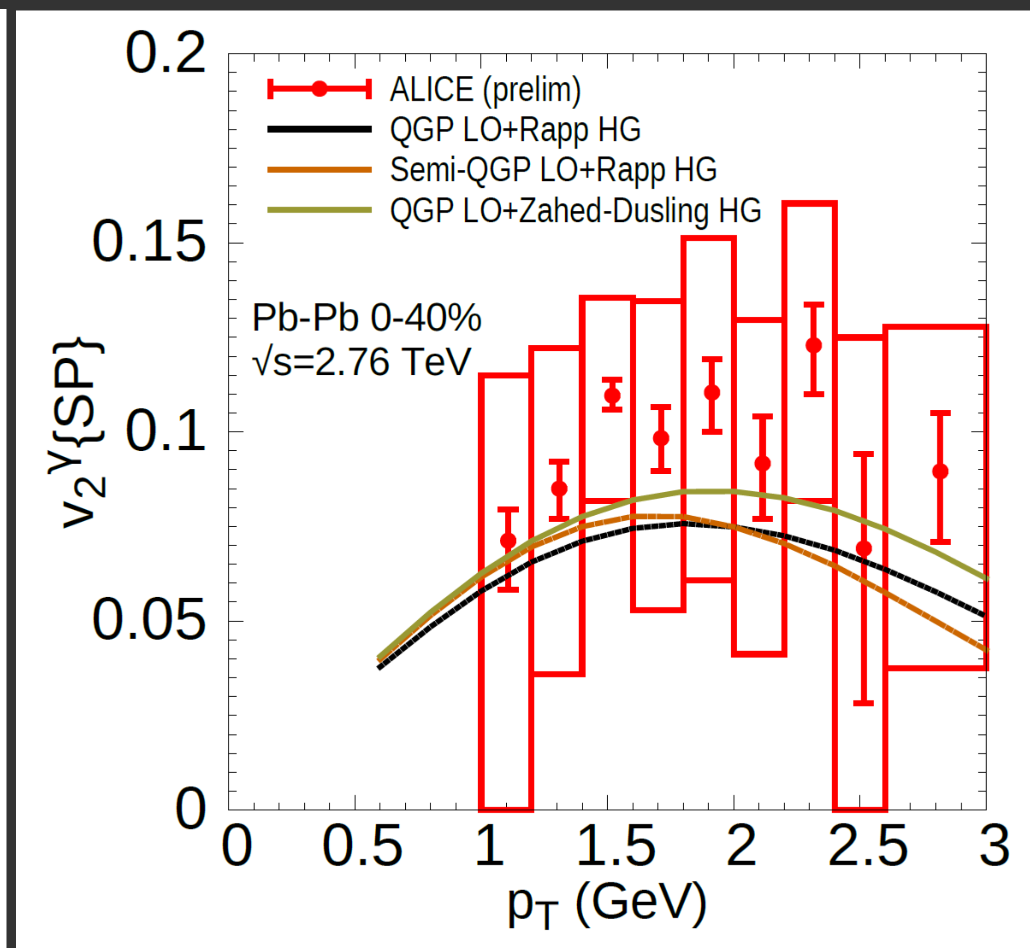
LHC 0-40%

Other thermal rates

Direct photon spectra



Direct photon v_2



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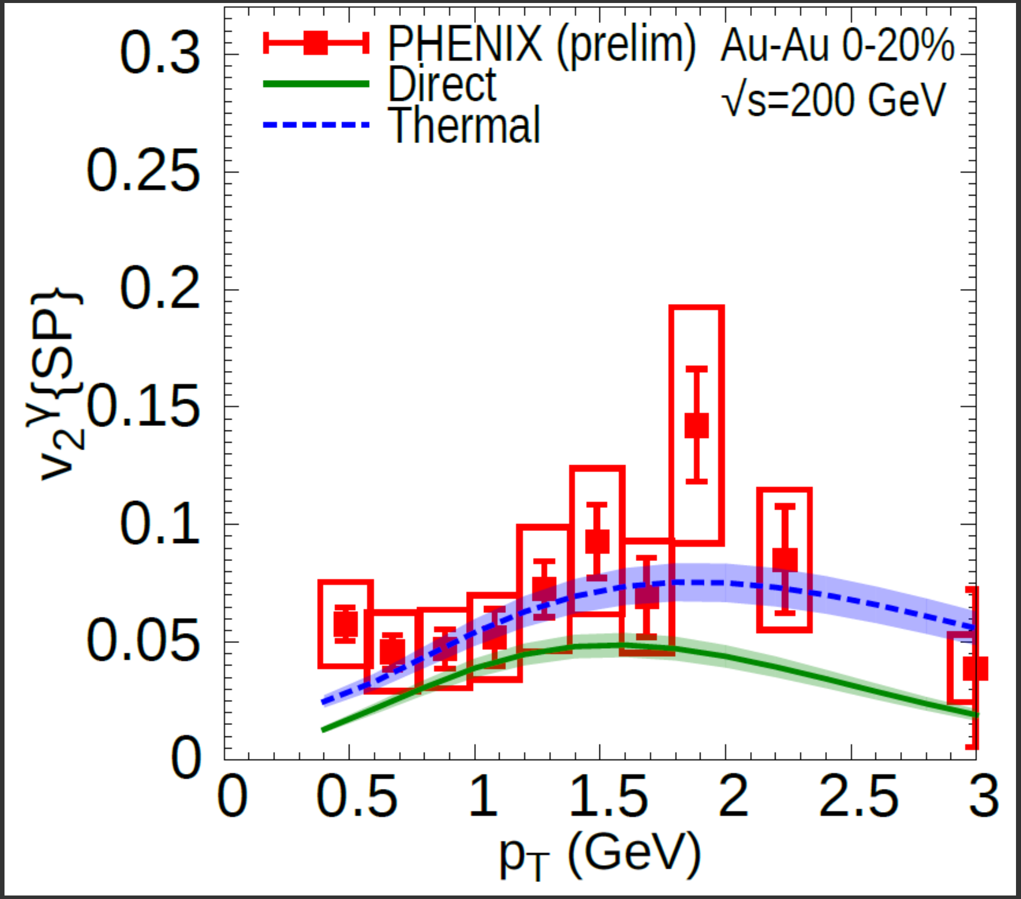
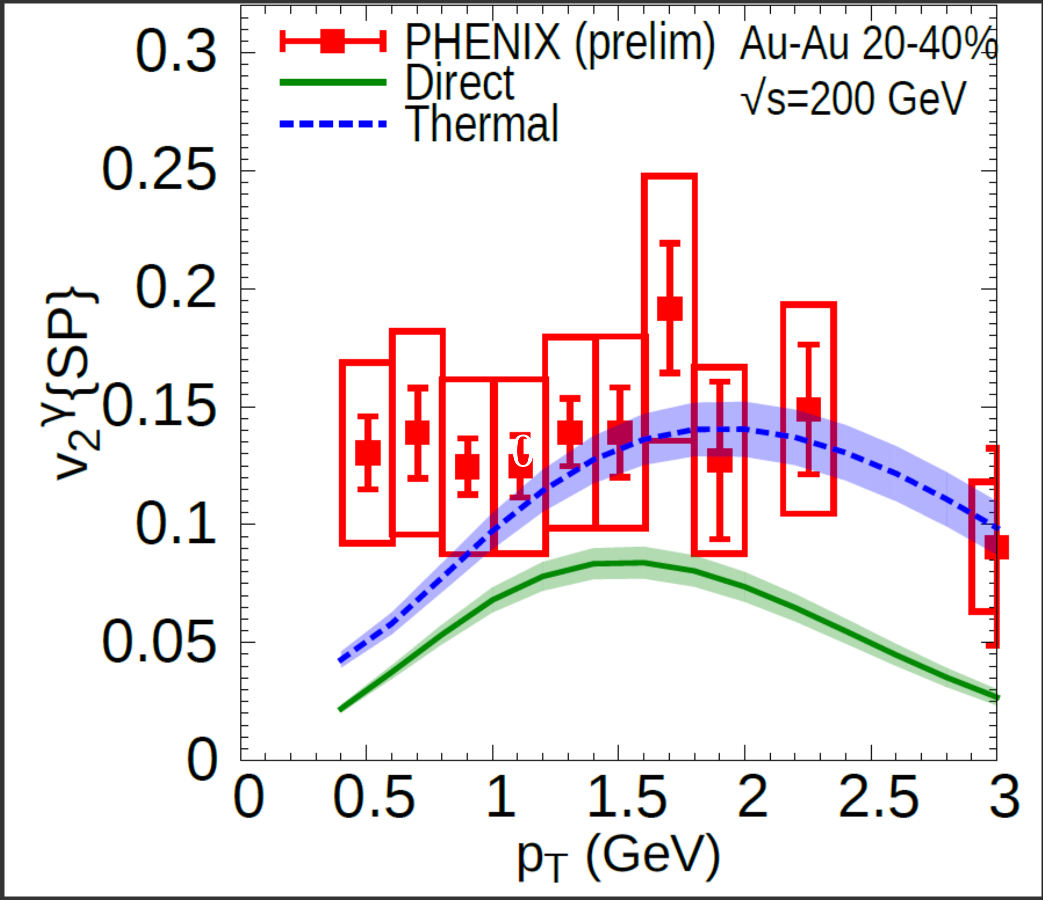
RHIC $\sqrt{s_{NN}}$=200 GeV: v_2

Direct photon v_2





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