Holographic Photon Production and Flow in Heavy Ion Collisions

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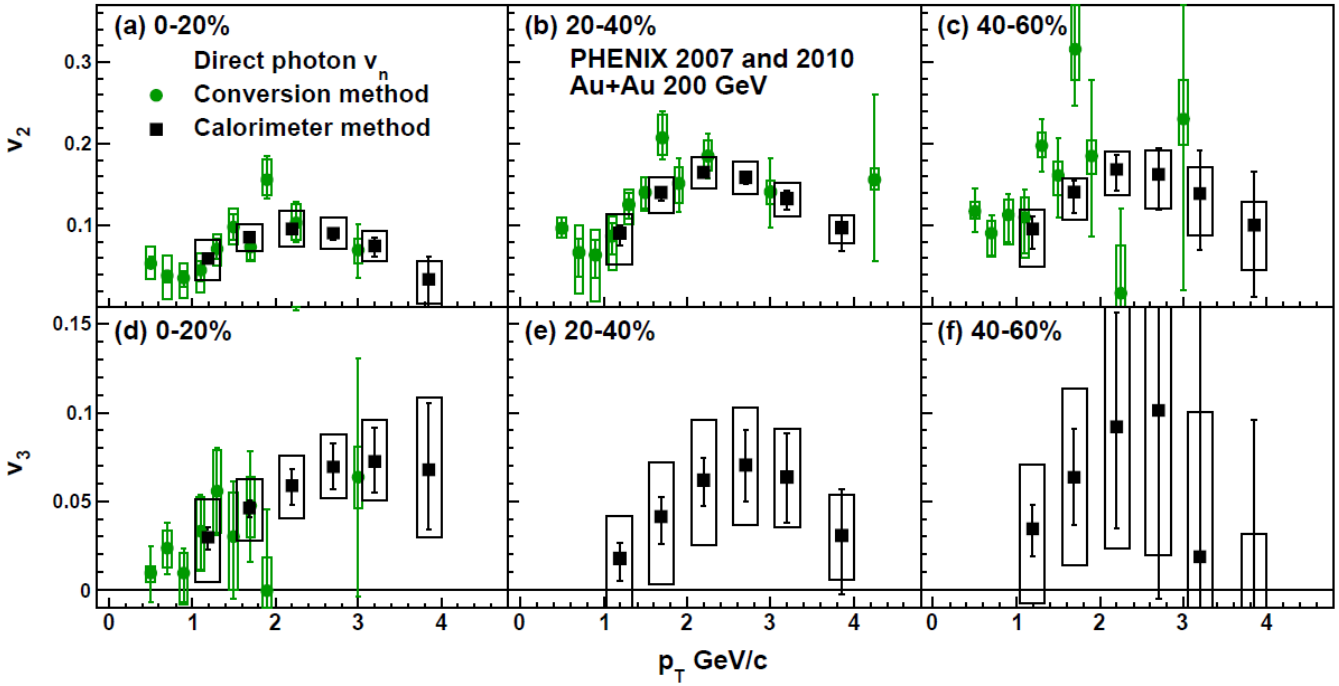
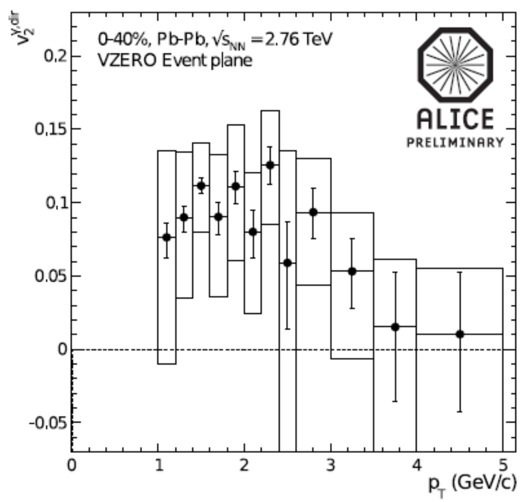
arXiv:1609.XXXX

Motivations

- The direct-photon flow puzzle : $$E\frac{d^3N}{d^3p} = \frac{1}{2\pi}\frac{dN}{p_T dp_T dy}\left[1 + 2\sum_{n=1}^{\infty} v_n \cos n\left(\phi - \Psi_n\right)\right]$$



arXiv:1509.07758



arXiv:1212.3995

- It is difficult to fit both the spectra & flow simultaneously.
- Many theoretical attempts :

B-field enhancement, Polyakov-loop corrections, slow quark chemical equilibration, transport models, etc.

- In general, all approaches underestimate either spectra or flow.
- Thermal photon production in holography:
  - Starting from the N=4 SYM plasma Caron-Huot et al., JHEP 0612, 015 (2006)
  - In various backgrounds :

D3/D7, SS model, bottom-up models, inclusion of B fields and pressure anisotropy, etc.

- Although the gravity dual of QCD is unknown, we could still learn something from holographic "models".
- Without the convolution with hydro and the inclusion of other contributions, it is hard to compare with experimental data.
- We perform the state-of-the-art computations of holographic photon production in heavy ion collisions.

Holographic Models

- Two bottom-up models :
  - GN model Gubser & Nellore, Phys.Rev. D78, 086007 (2008)
  - VQCD (Veneziano limit large N_c& N_f with finite $x = N_f/N_c$=1) Kiritsis et al. 07
- The glue sectors are constructed to reproduce thermal properties of the QGP from lattice QCD.
- In the flavor sectors, we fix the gauge-field-gravity couplings by fitting the electric conductivity from lattice QCD.
- The Wightman function and emission rate :

$$C^{<}_{\mu\nu}(K) = \int d^4X\, e^{-iK\cdot X}\, \langle J^{\rm EM}_{\mu}(0) J^{\rm EM}_{\nu}(X)\rangle \longrightarrow d\Gamma_{\gamma} = \frac{d^3k}{(2\pi)^3}\frac{e^2}{2|\boldsymbol{k}|}\,\eta^{\mu\nu}C^{<}_{\mu\nu}(K)\Big|_{k^0=|\boldsymbol{k}|}$$

- Computing spectral density from holography :

$$C^{<}_{\mu\nu}(K) = n_{\rm b}(k^0)\,\chi_{\mu\nu}(K)$$

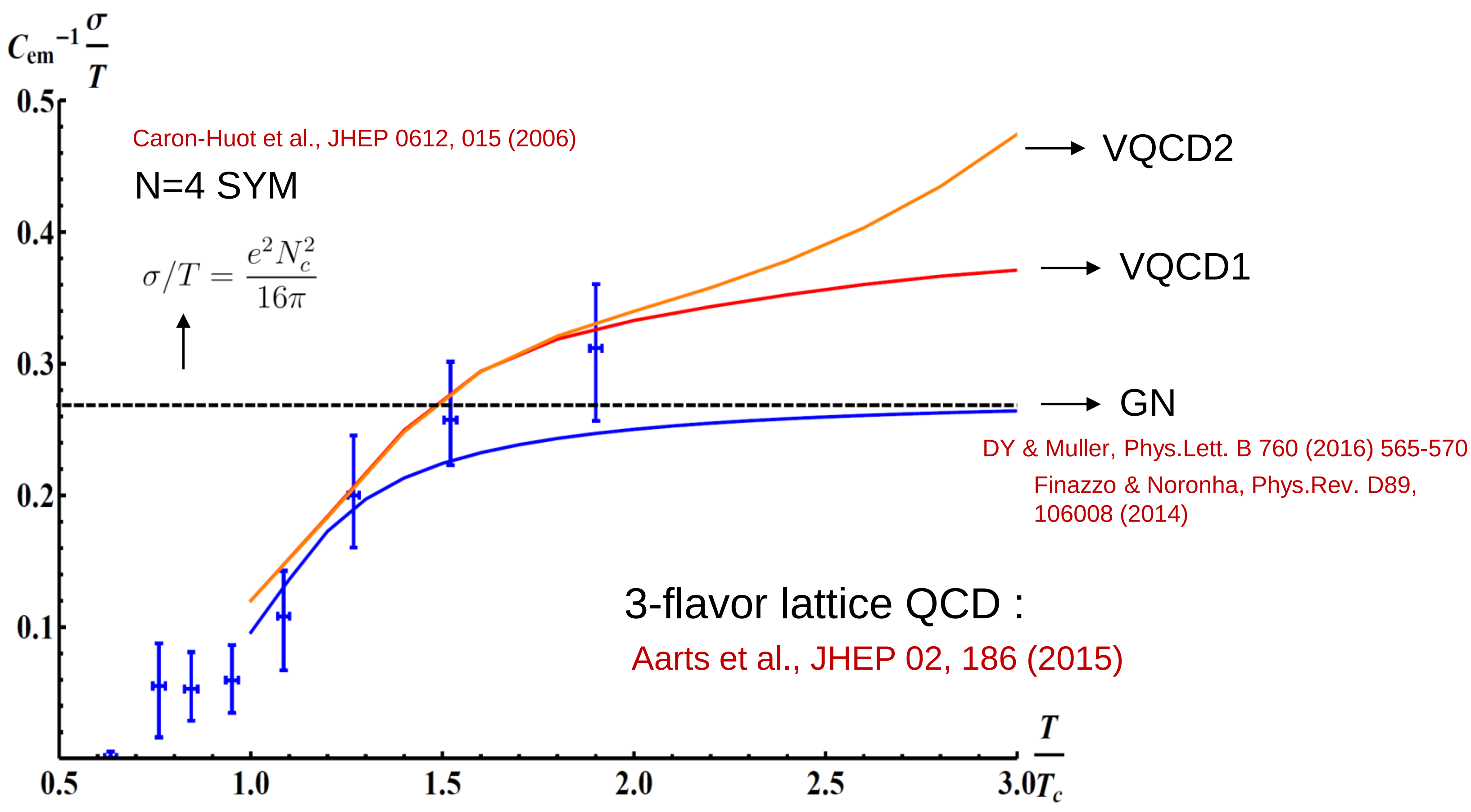
$$\chi_{\mu\nu}(K) = -2\,{\rm Im}\,C^{\rm ret}_{\mu\nu}(K)$$

- Electric conductivity : $\sigma = \lim_{k^0\to 0}\frac{e^2}{4T}\,\eta^{\mu\nu}C^{<}_{\mu\nu}(K)\Big|_{|\boldsymbol{k}|=k^0}$

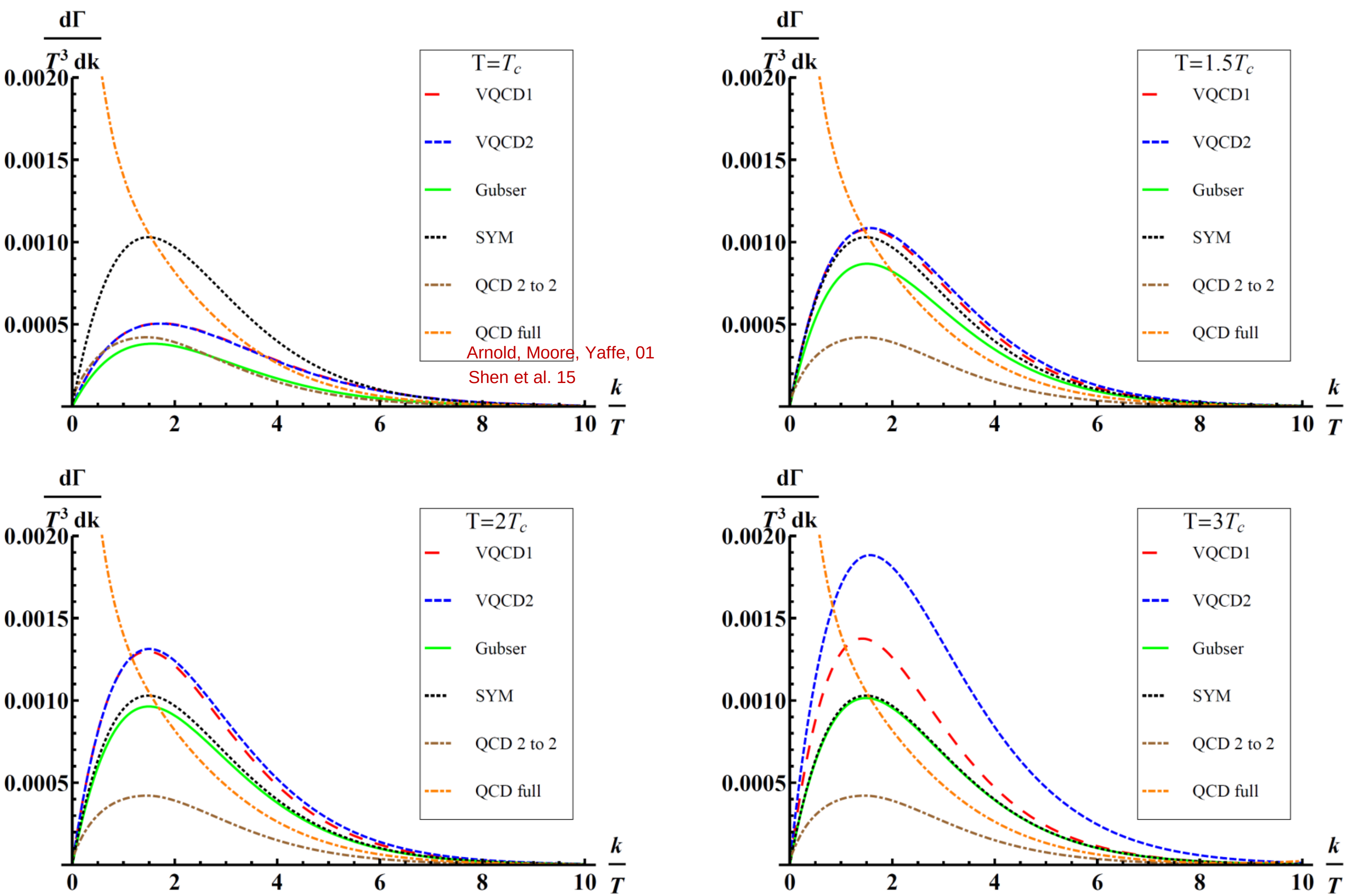
Electric Conductivity

- Fitting the conductivity :

$C_{em} = 2e^2/3$



Emission Rates



Setup for Simulations

- Convolution with the medium evolution : $$q\frac{dN^{\gamma}}{d^3q} = \int d^4x q\frac{dR^{\gamma}}{d^3q}(T(x), E_q)\Big|_{E_q=q\cdot u(x)}$$

- CGC initial states+ viscous hydro

Ryu et al., Phys. Rev. Lett. 115, 132301 (2015) Paquet et al., Phys.Rev. C93, 044906 (2016)

- Direct-photon production :

prompt photons : pQCD

Aurenche et al., Phys. Rev. D73, 094007 (2006)
Paquet et al., Phys. Rev. C93, 044906 (2016)

thermal photons :

Rate
QGP — $2 \to 2$
QGP — Bremsstrahlung
Hadronic — Meson gas (π, K, ρ, K^*, a_1)
Hadronic — ρ spectral function (incl. baryons)
Hadronic — $\pi + \pi$ bremsstrahlung
Hadronic — π-ρ-ω system

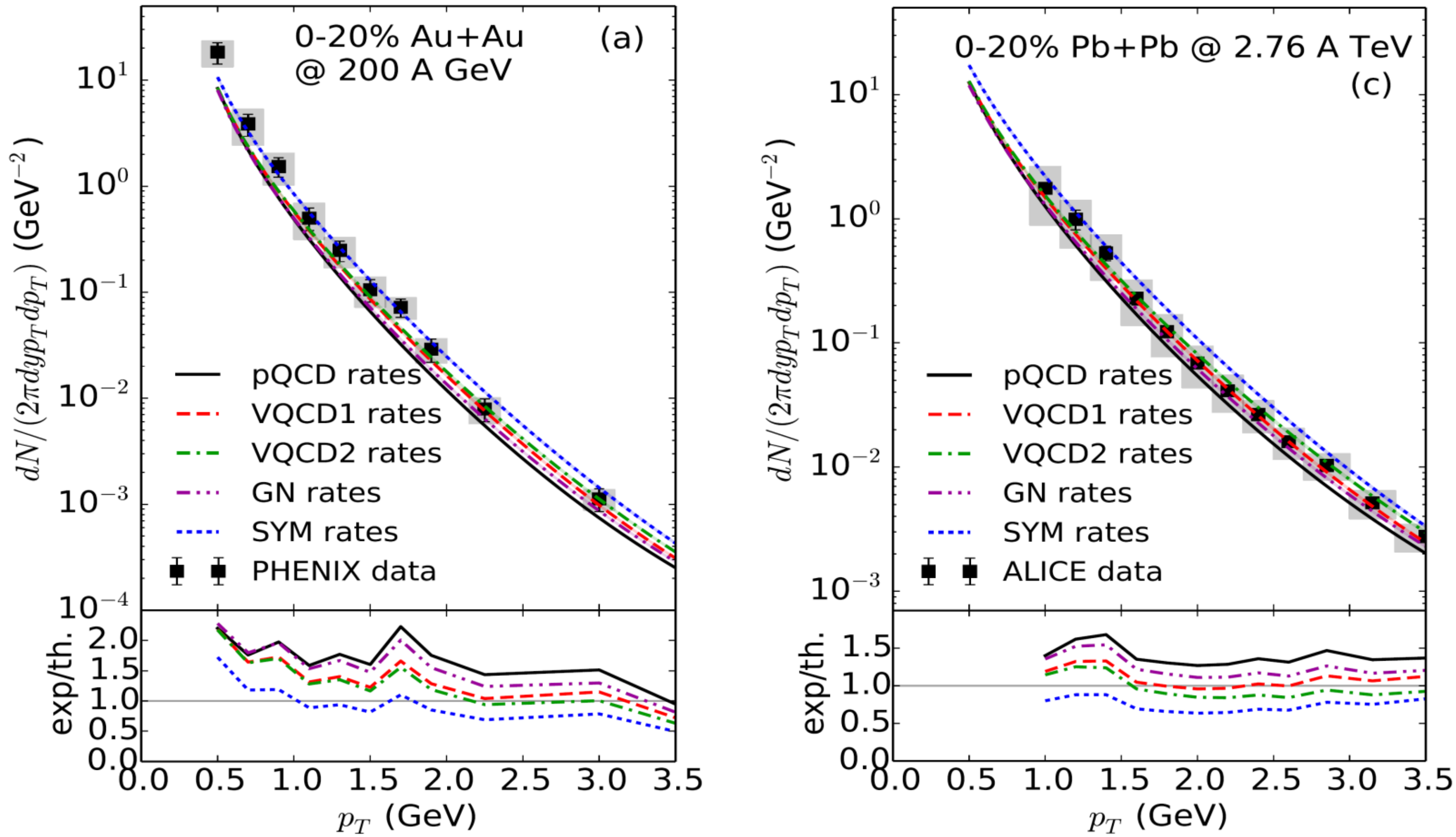
QGP rows: Arnold, Moore, Yaffe, JHEP 0112 (2001) 009; Shen et al., Phys. Rev. C91, 014908 (2015) — HTL or holographic models — QGP

Hadronic rows: R. Rapp et al. — hadron gas

Paquet et al.,
Phys.Rev. C93 (2016) no.4, 044906

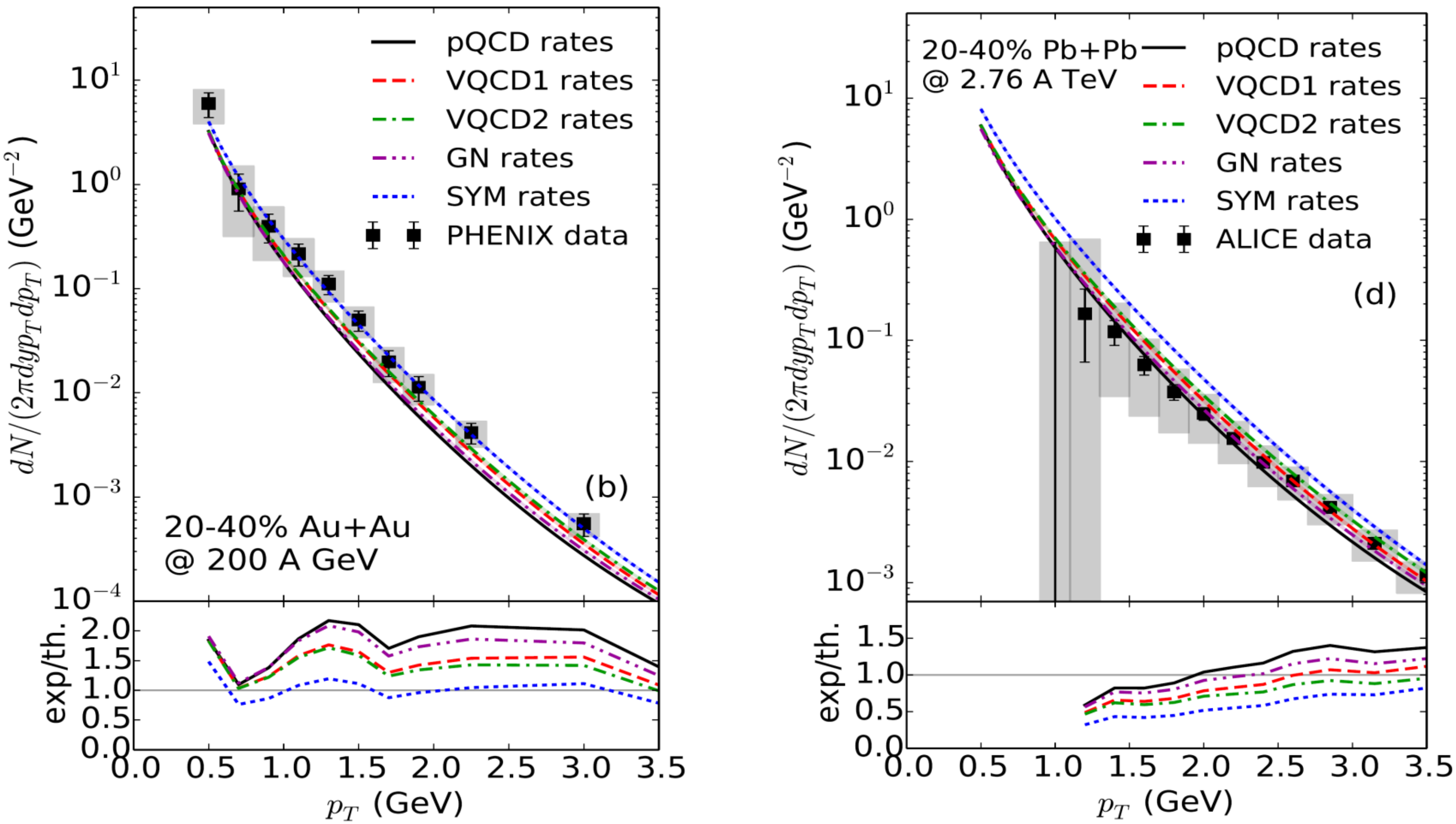
Direct-Photon Spectra (0-20%)

- Holographic models lead to enhancements in high pT (blue-shift).
- The spectra at low pT are underestimated.

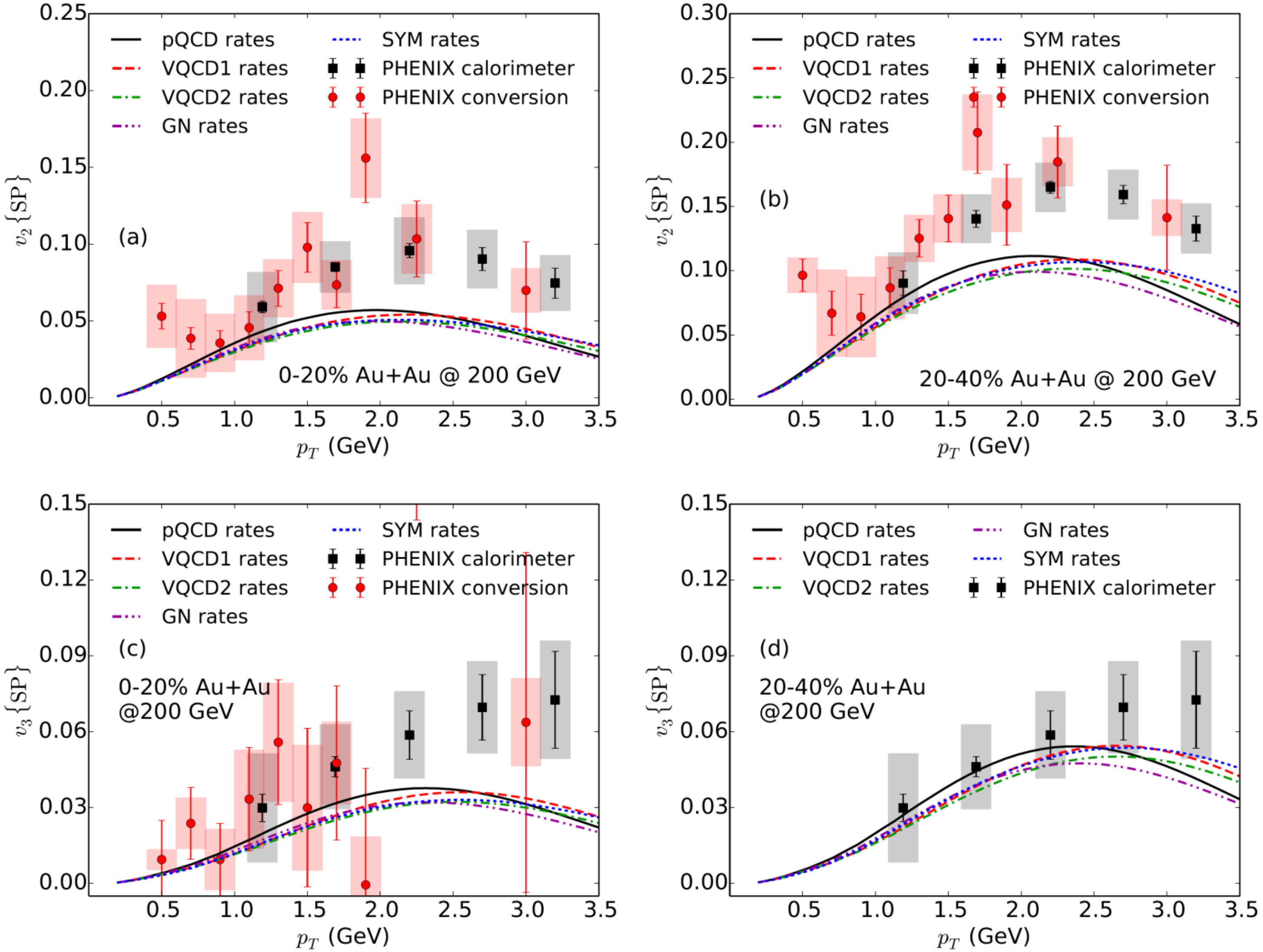


Direct-Photon Spectra (20-40%)

- The deviations from experiments increase for more non-central collisions particularly at low pT for LHC.

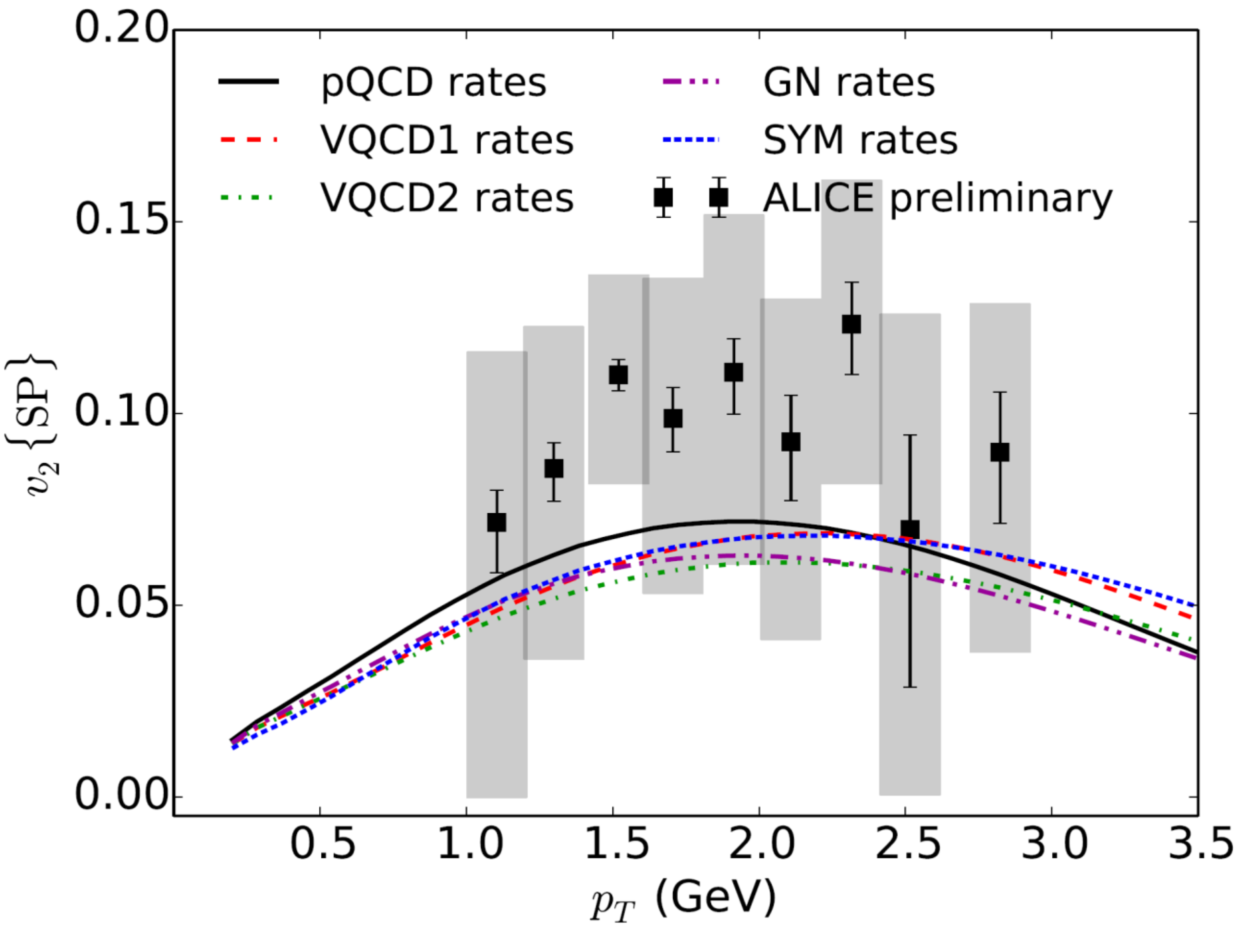


Direct-Photon Flow in RHIC

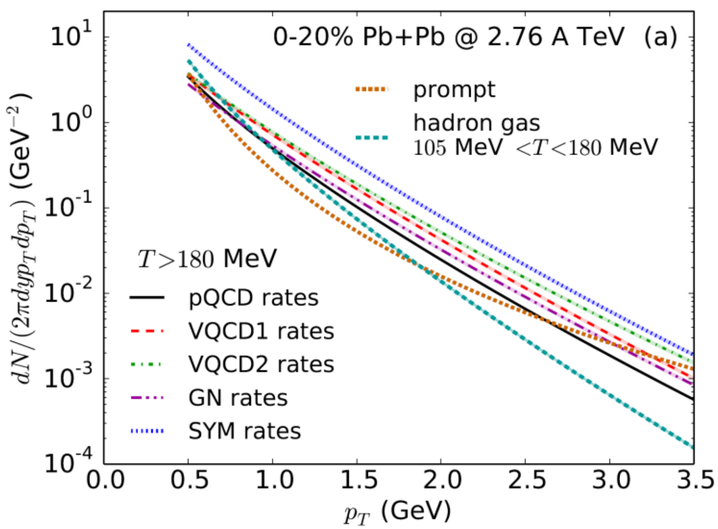


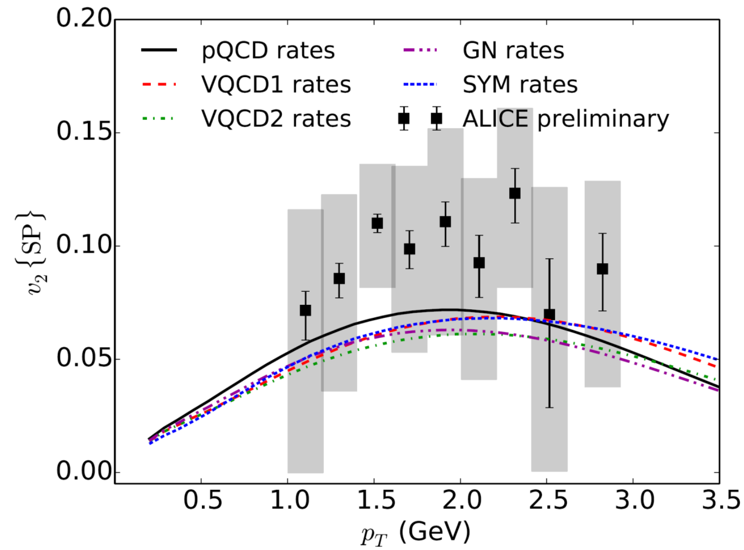
Direct-Photon Flow in LHC

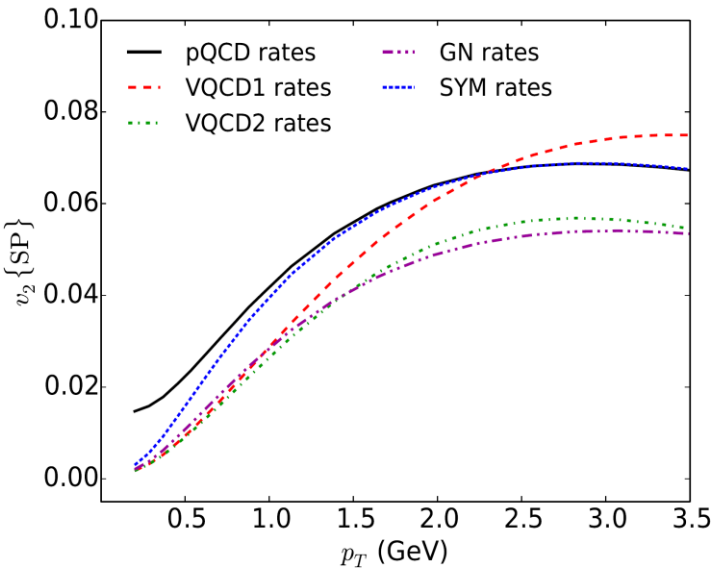
- Similar to the case in RHIC, the flow from holographic models is increased in high pT but reduced at low pT.

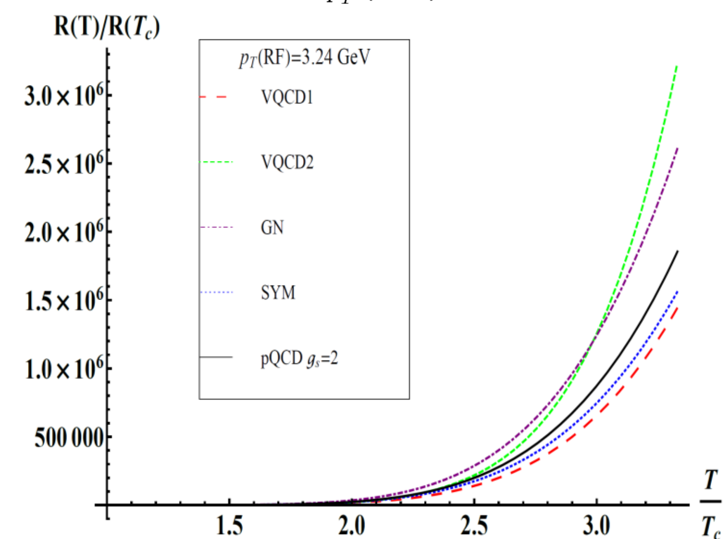


Qualitative analysis at high energy



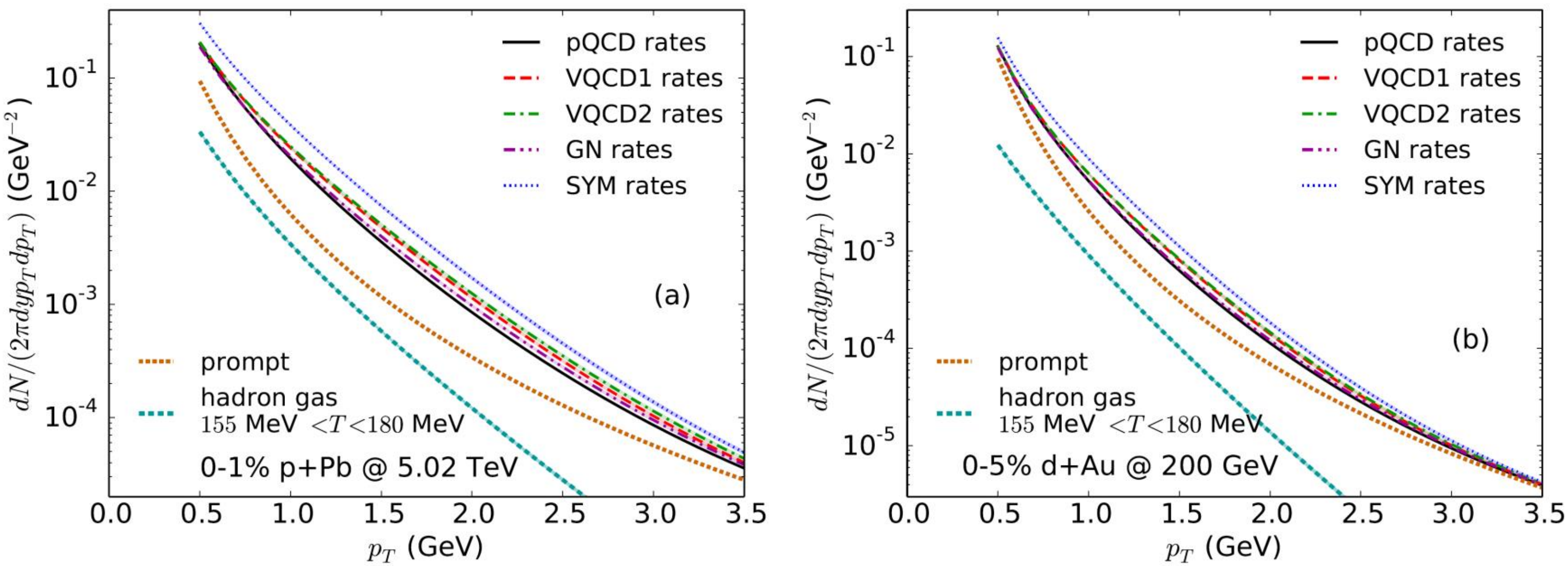




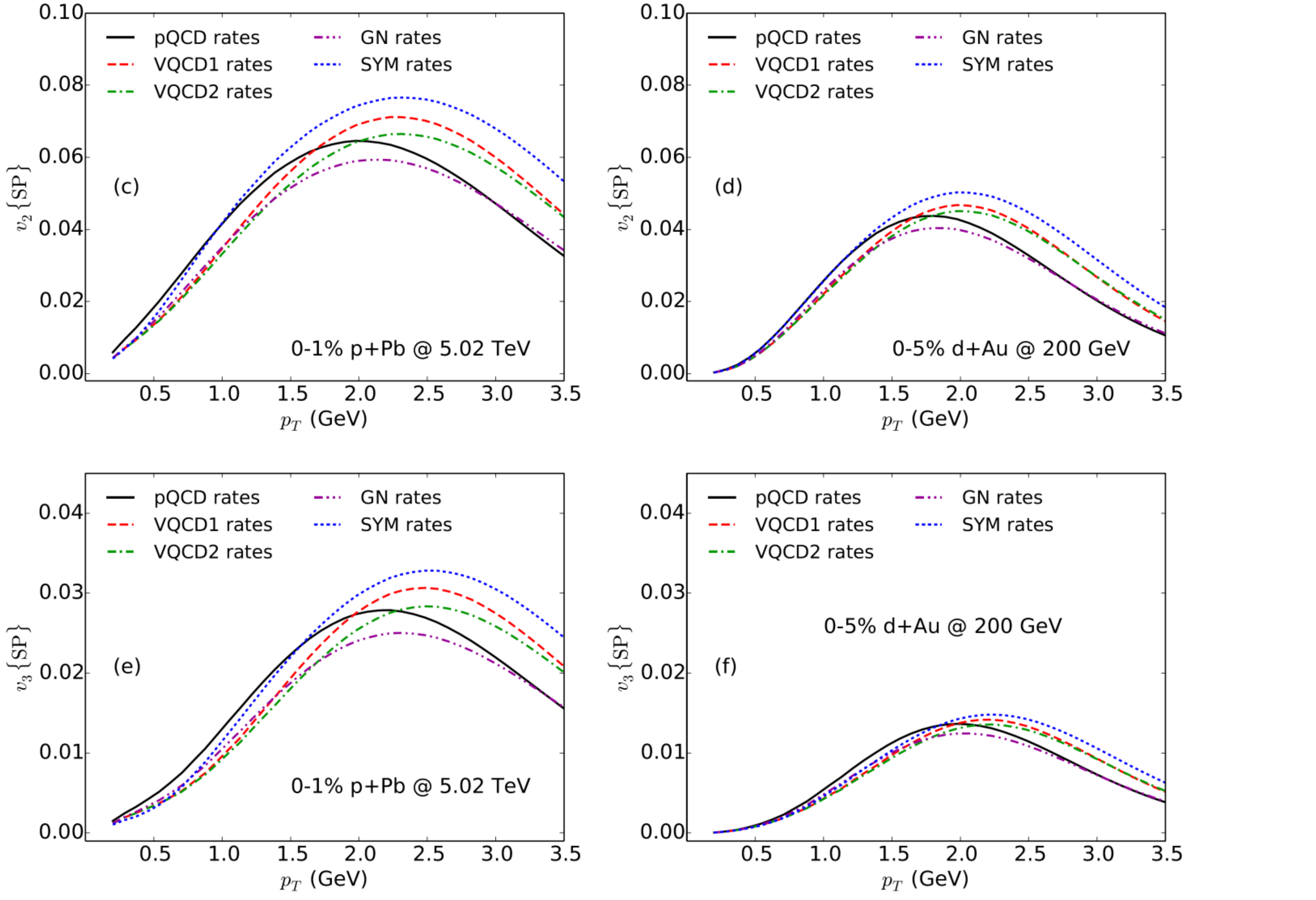


Direct photons in small collision systems

- The caveat : it is still controversial that the QGP can be formed in small collision systems.
- In small collision systems, thermal photons from the QGP phases become more dominant.



Direct-photon flow in small collision systems



Conclusions

- Holographic models lead to enhancements for both spectra and flow at high pT (blue-shift), whereas the models still underestimate the flow.
  - In low pT, the flow is mostly generated by hadronic contributions.
  - In high pT, the flow is mainly contributed by thermal photons from the QGP phase.

- The magnitude of flow in high pT is associated with the ratios of emission rates at high temperature and dilution from prompt photons.

- Future comparisons with experimental data in small collision systems may justify the importance of QGP photons for flow (if QGP phases exist).

- The emission rate for sQGP is crucial to resolve the direct-photon puzzle in high pT.