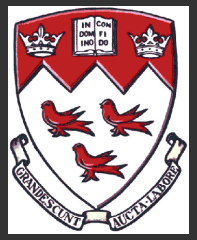
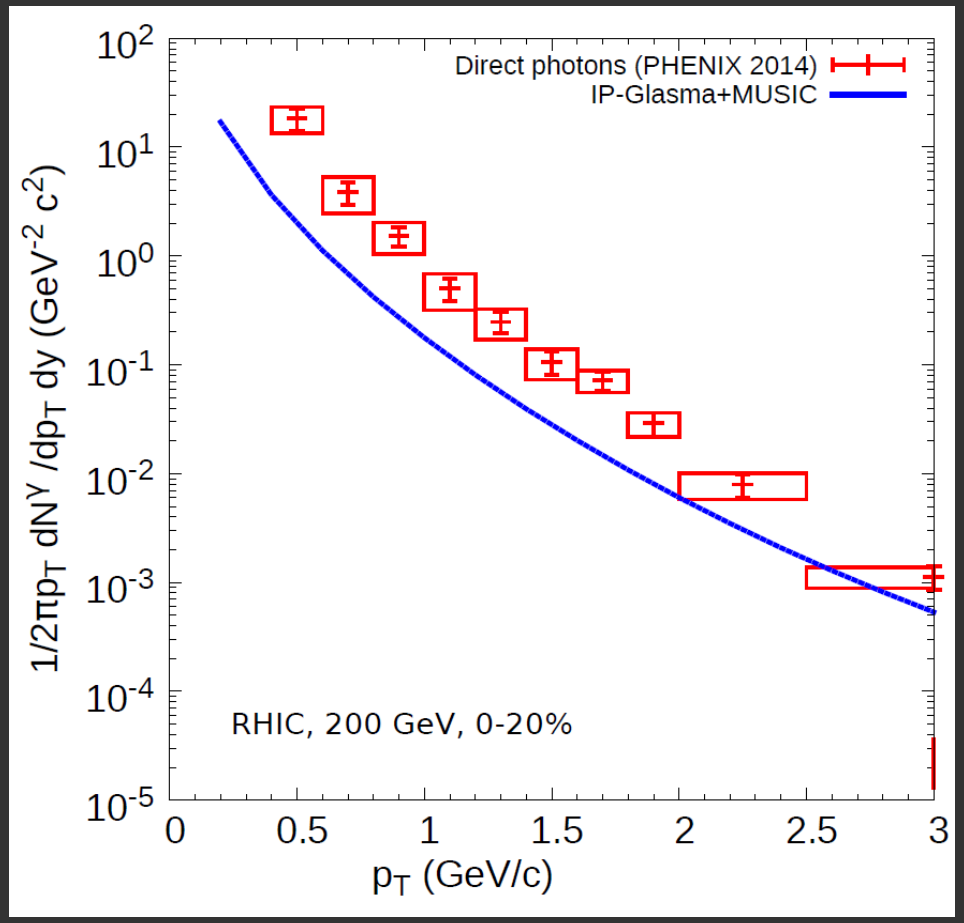
Photons in heavy-ion collisions: inclusive and peripheral

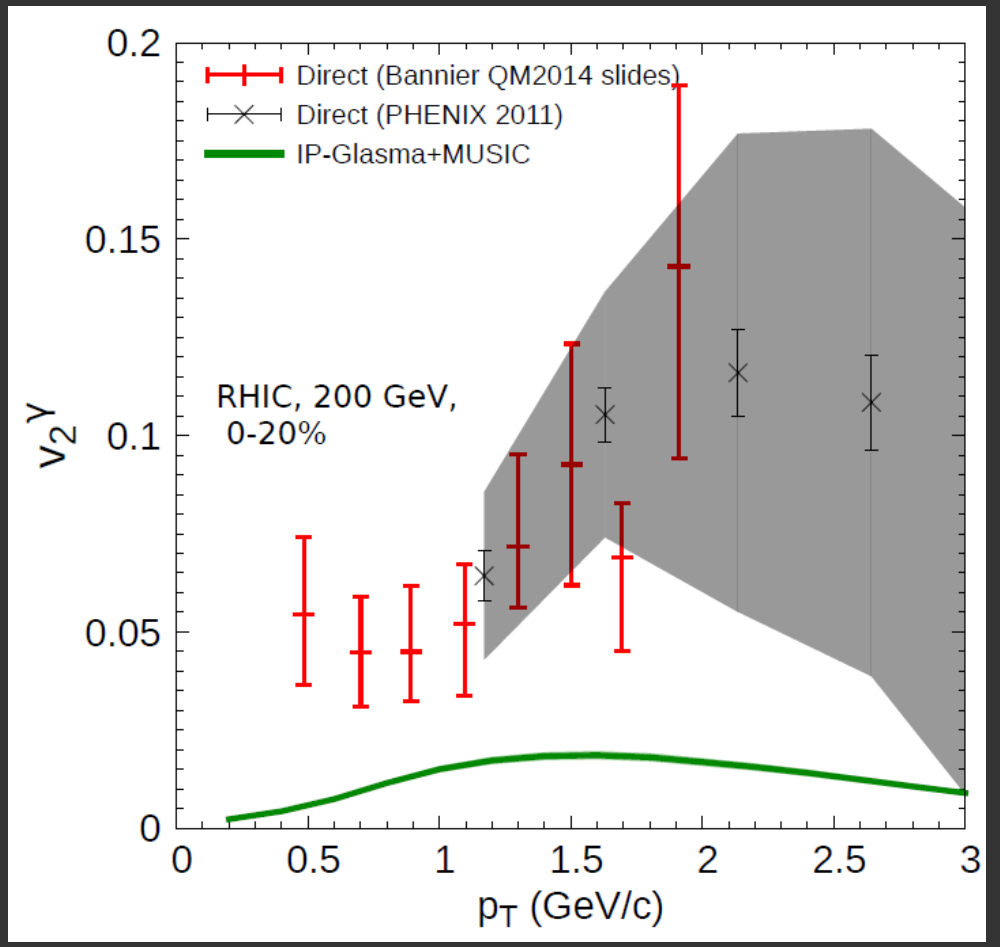


Jean-François Paquet
(McGill University)

Brookhaven National Laboratory
August 22nd, 2014

The (double) direct photon puzzle



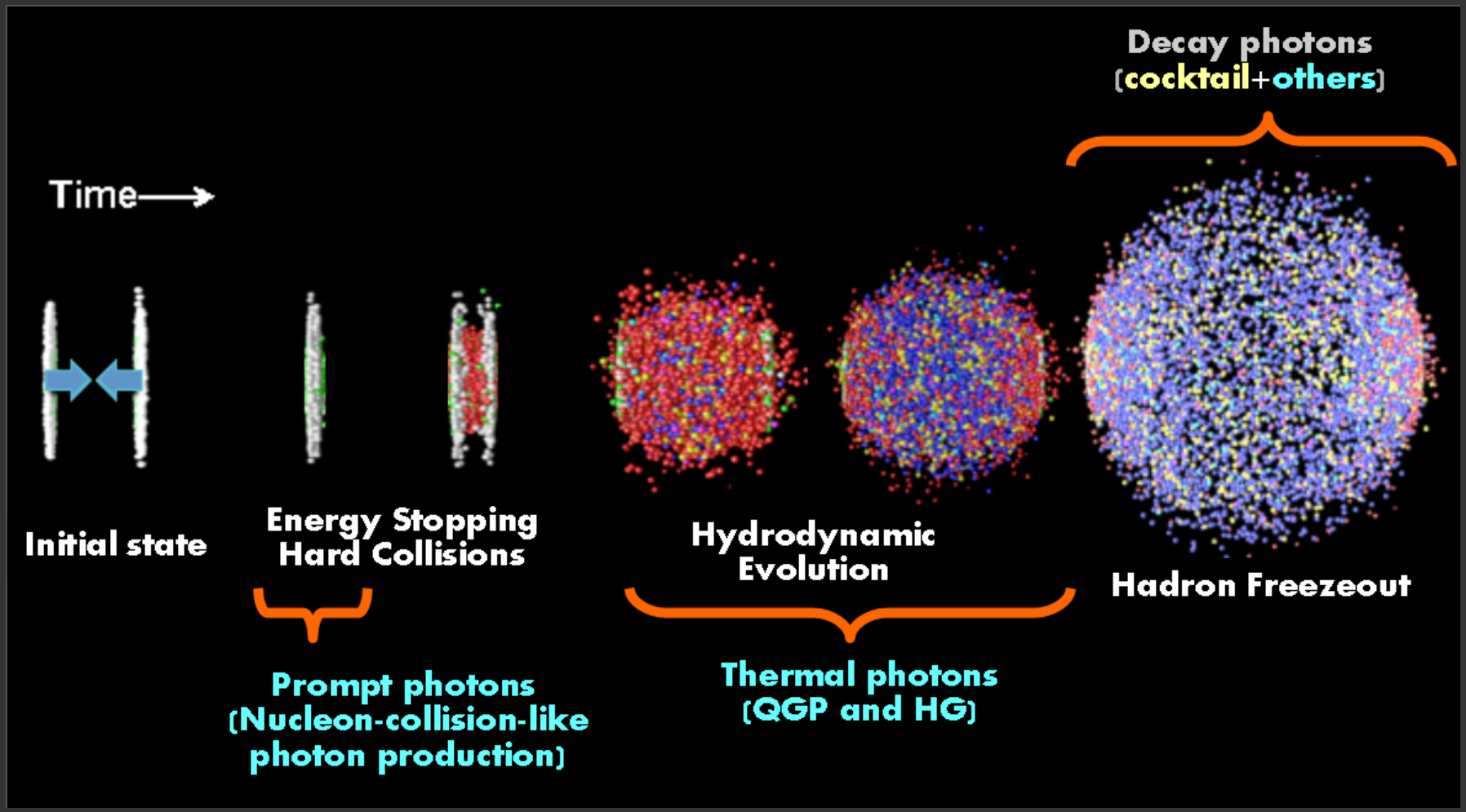


Spectra and v_2, direct photons, RHIC 0-20%

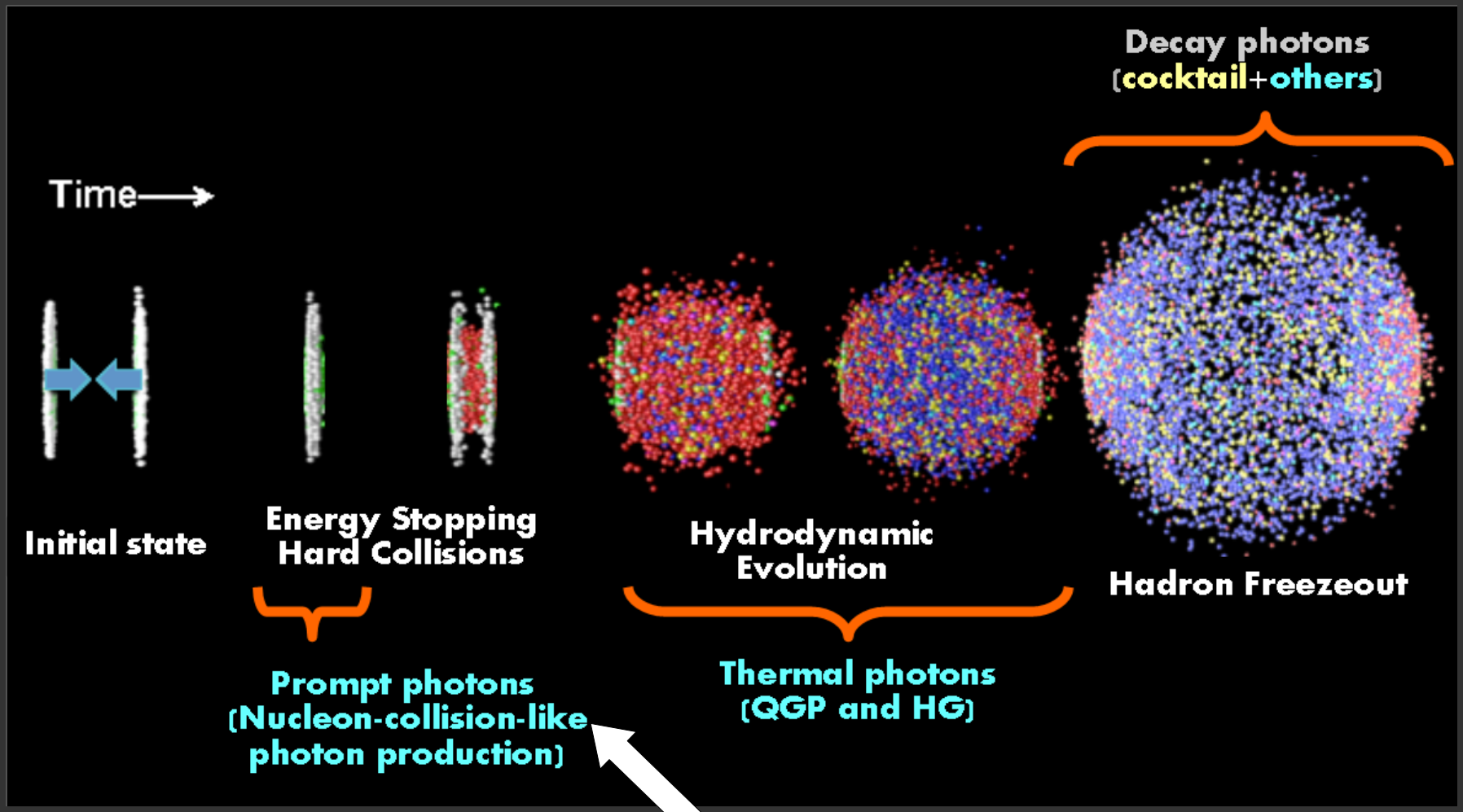
Outline

- Inclusive photons
  - How well can inclusive photons be described?
  - Opportunities?
  - Photon v_n definitions
- Centrality dependence of direct photons

Photon sources



Prompt photons



Binary-scaled NLO pQCD (with isospin effect and nuclear pdf)

More information on model

IP-Glasma (τ<0.4 fm/c)+MUSIC (τ>0.4 fm/c)

- MUSIC:
  - Event-by-event 2+1D viscous (Israel-Stewart, conformal) hydrodynamics with fluctuating initial conditions
  - Shear viscosity/entropy 0.13 (0.21 at LHC)
  - Lattice + hadron resonance gas equation of state with chemical freeze-out at 150 MeV
  - Cooper-Frye freeze-out at 150 MeV (103 MeV for LHC), + resonance decays 1.4 GeV

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  - **Shear viscosity/entropy** 0.13 (0.21 at LHC)
  - Lattice + hadron resonance gas equation of state with **chemical freeze-out** at 150 MeV
  - Cooper-Frye **freeze-out at temperature** 150 MeV (103 MeV for LHC), + resonance decays 1.4 GeV

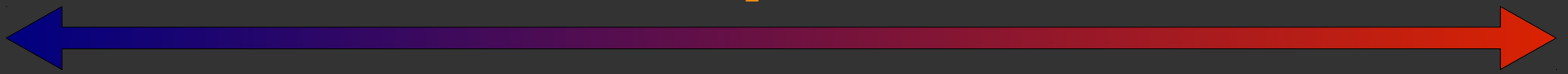
Parameters fitted to the π^0 spectra and charged hadron v_2

Thermal photons

$$E\frac{d^3N^{\gamma,th}}{dp^3} = \int d^4x \left[E\frac{d^3R^{\gamma}}{dp^3}(T(x), u(x), \pi^{\mu\nu}(x))\right]$$

- Photon production rate

less hot (hadron gas) **Temperature** ***very hot (QGP)***



Effective Lagrangian

Linear interpolation (between 184 and 220 MeV)

Perturbative expansion in α_s

- Mesons (Turbide, Gale, Rapp. 2004)
- Baryons (Rapp, private comm.)

- AMY LO (Arnold, Moore, Yaffe. 2002)

Thermal photons

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Effective Lagrangian

- Mesons (Turbide, Gale, Rapp. 2004)
- Baryons (Rapp, private comm.)

Linear interpolation (between 184 and 220 MeV)

Corrected* for anisotropy of momentum distribution

Perturbative expansion in α_s

- AMY LO (Arnold, Moore, Yaffe. 2002)

(Shen, Paquet, Heinz, Gale, to be published soon)

(*only non-bremsstrahlung part is corrected for AMY)

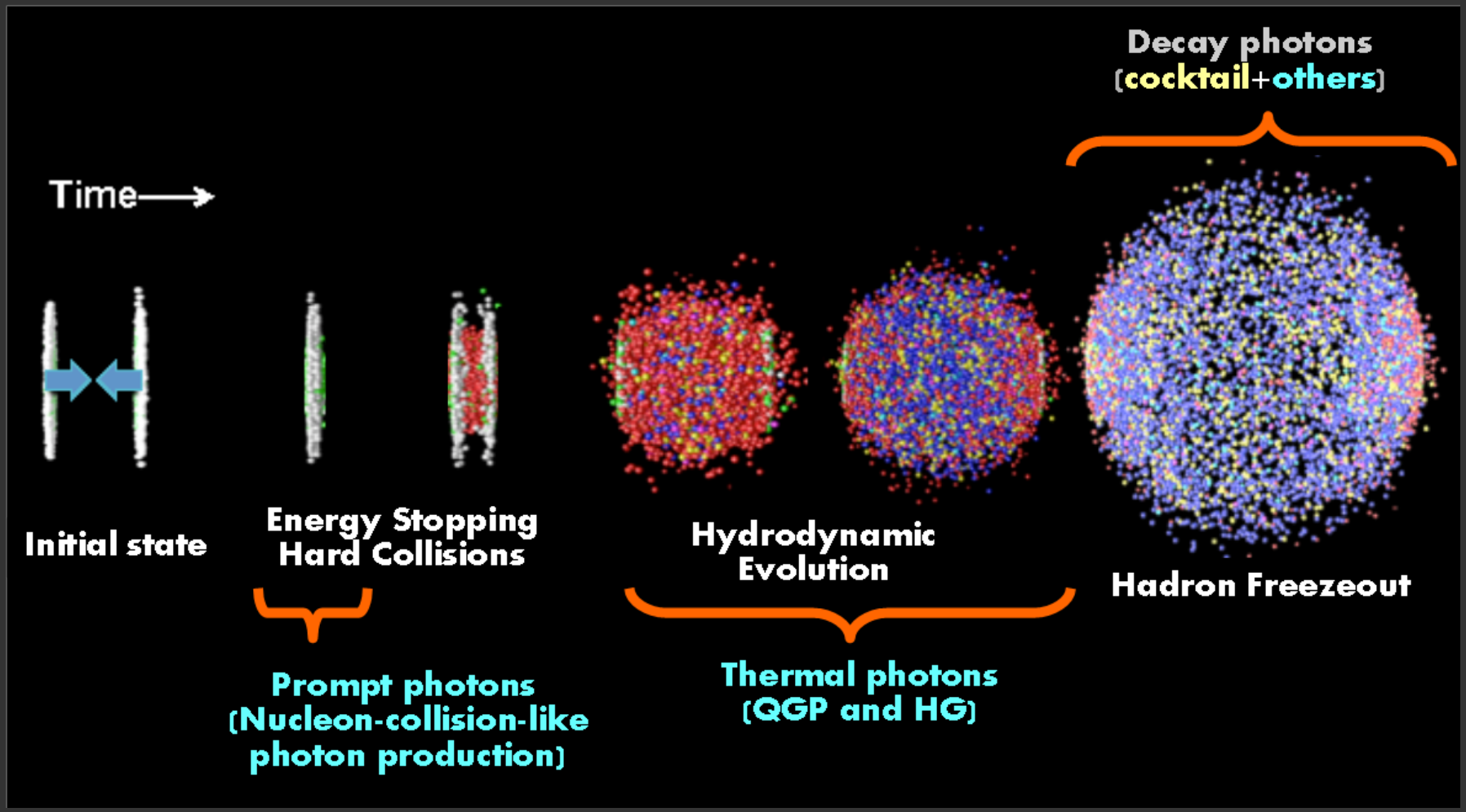
Decay photons

- Decay photons from hadronic spectra computed after Cooper-Frye and resonances decays

$\pi^0 \to \gamma\gamma$	98.82×10^{-2}
$\to e^+e^-\gamma$	1.17×10^{-2}
$\eta \to \gamma\gamma$	39.41×10^{-2}
$\to \pi^+\pi^-\gamma$	4.22×10^{-2}
$\to e^+e^-\gamma$	6.9×10^{-3}
$\to \pi^0\gamma\gamma$	2.7×10^{-4}
$\rho^0 \to \pi^+\pi^-\gamma$	9.9×10^{-3}
$\to \pi^0\gamma$	6×10^{-4}
$\to \eta\gamma$	3×10^{-4}

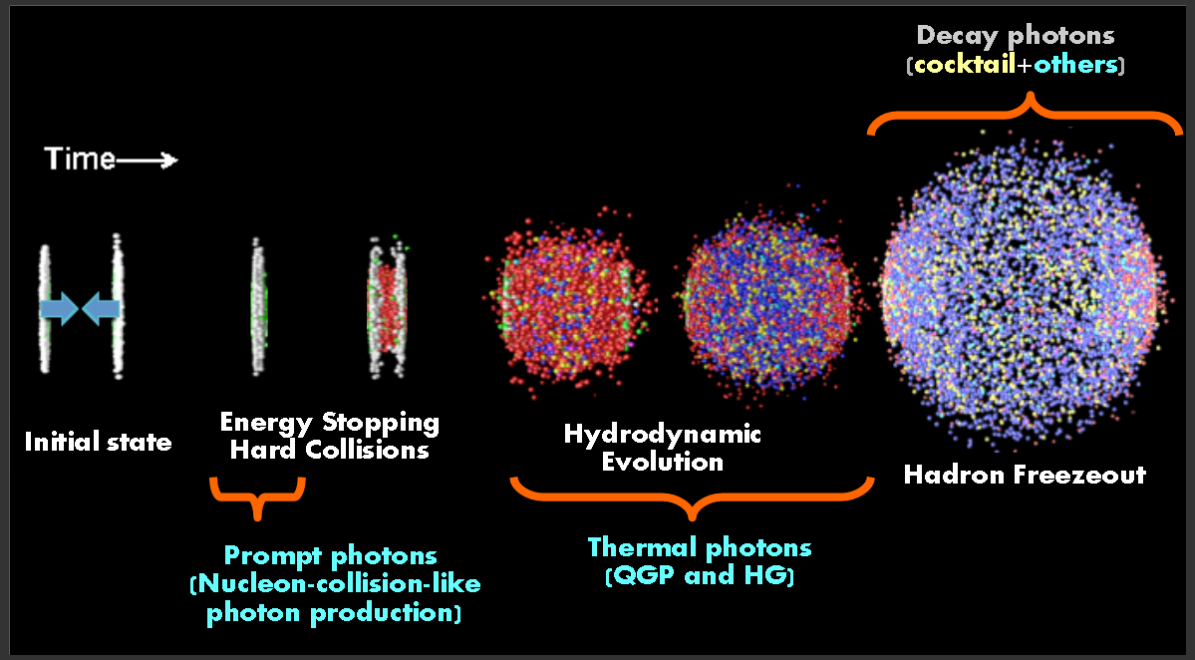
$\rho^\pm \to \pi^\pm\gamma$	4.5×10^{-4}
$\omega \to \pi^0\gamma$	8.28×10^{-2}
$\eta' \to \rho_0\gamma$	29.1×10^{-2}
$\to \omega\gamma$	2.75×10^{-2}
$\to \gamma\gamma$	2.2×10^{-2}
$\phi \to \eta\gamma$	1.3×10^{-2}
$\Sigma^0 \to \Lambda\gamma$	1

Inclusive photons

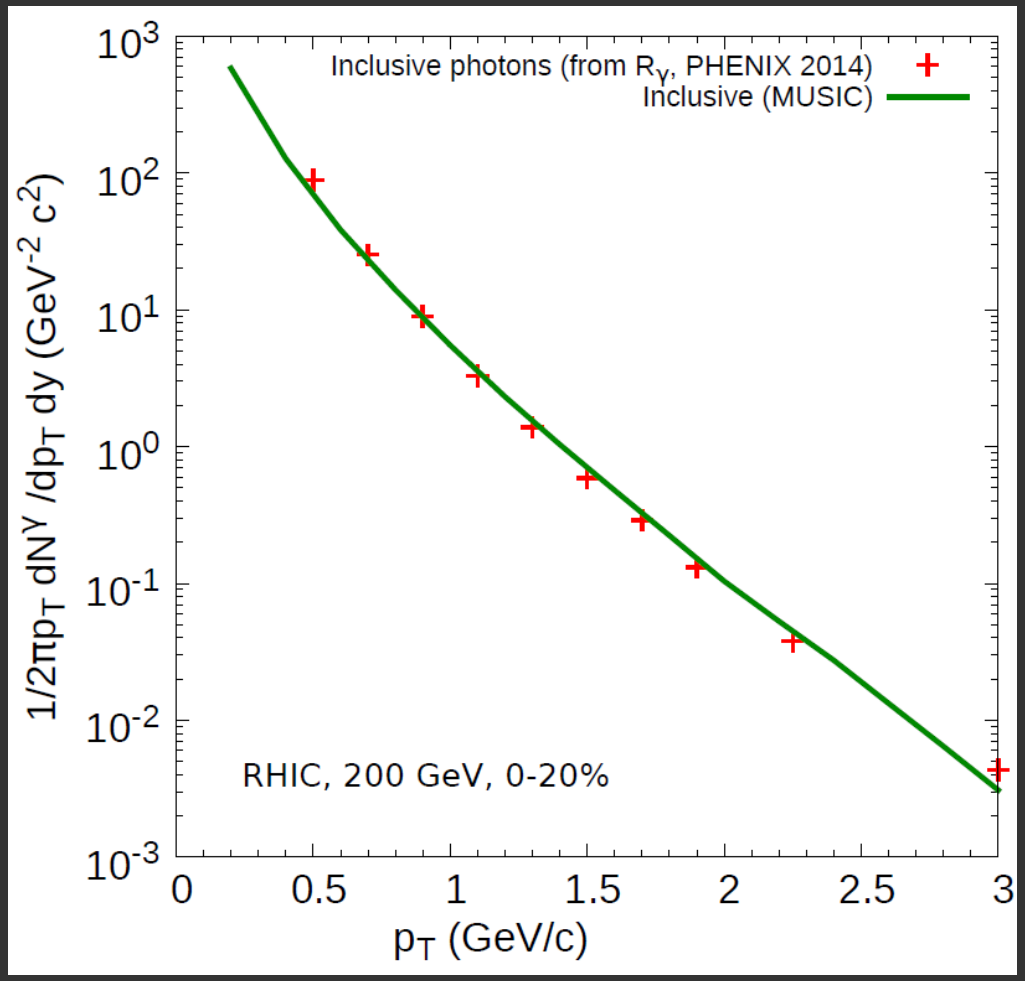


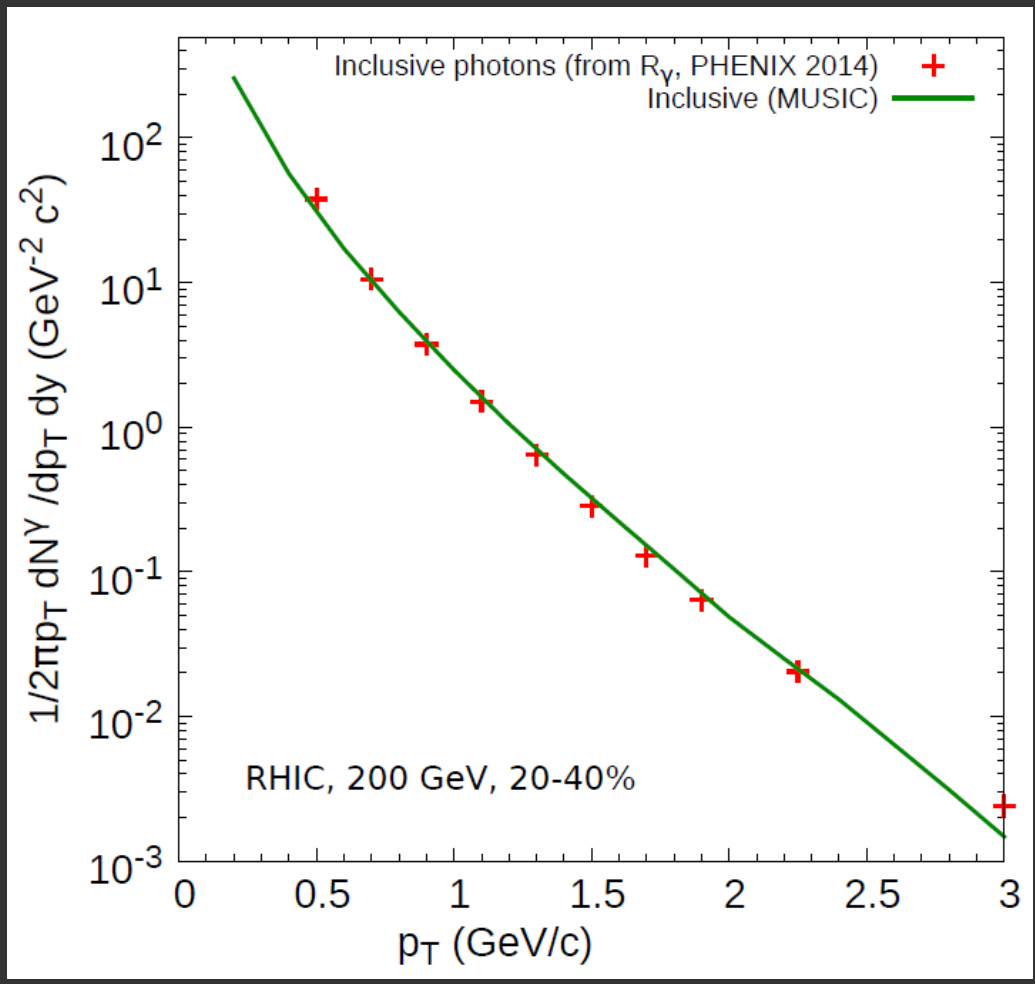
Inclusive photons

	Inclusive	Cocktail	Direct
Experiment	Measurement	Simulation based on available hadronic data	Subtraction of inclusive and cocktail
Theory	Addition of cocktail and direct	Computed from hydrodynamics	Computed from hydrodynamics + prompt photons



Inclusive photons: spectra

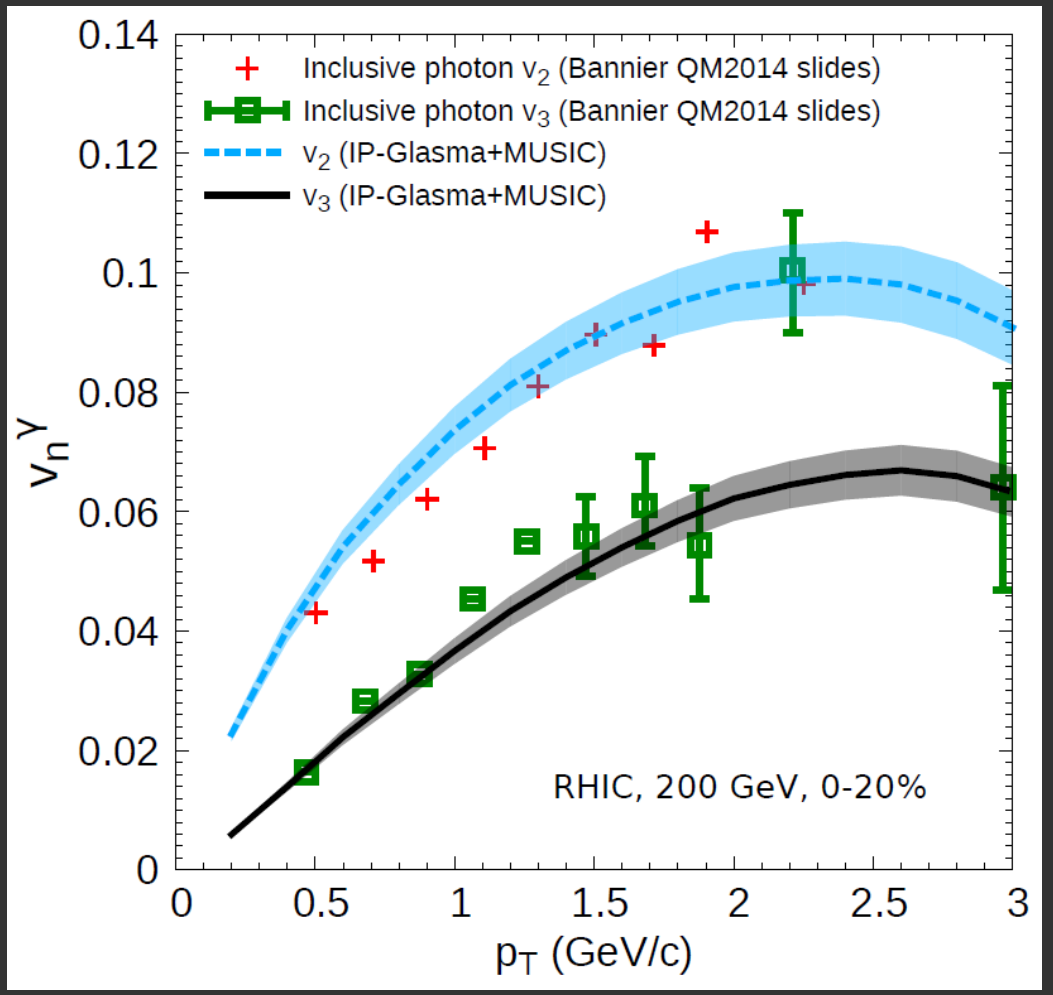


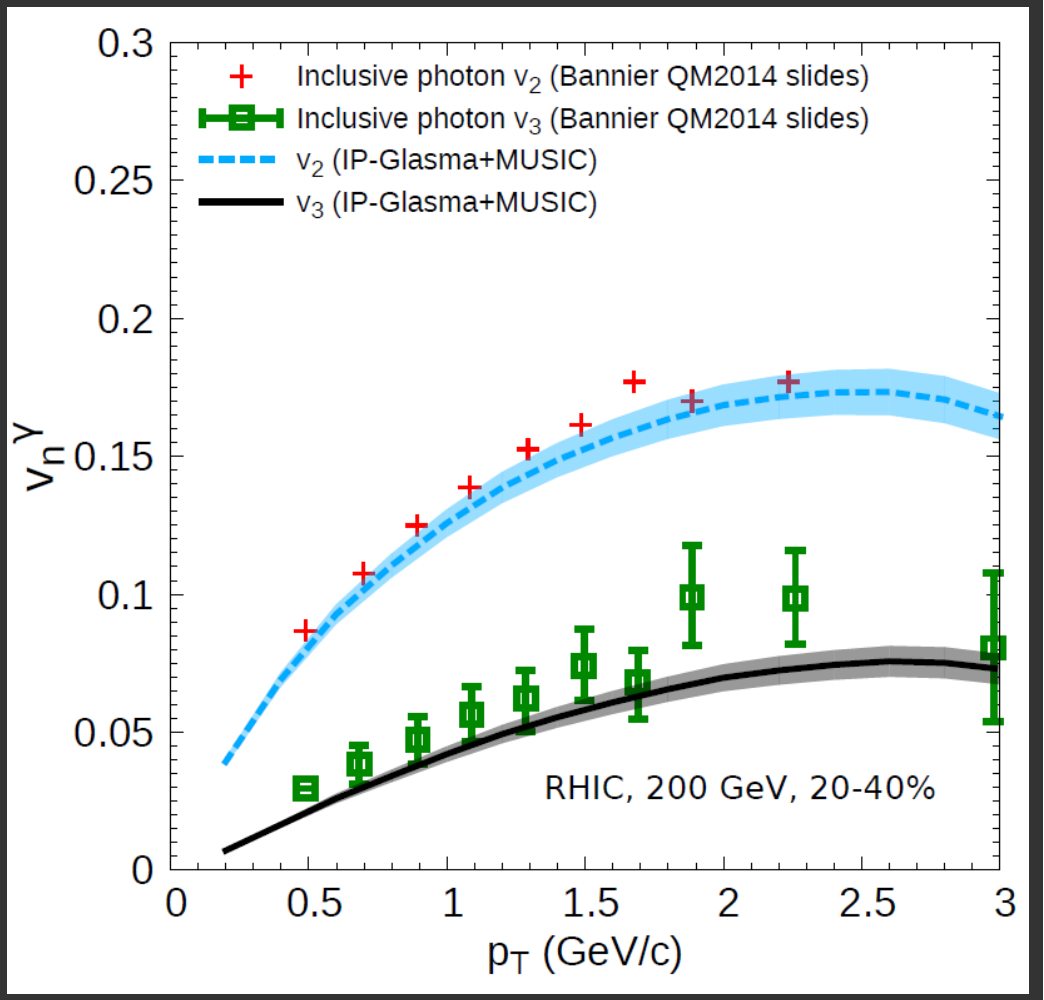


RHIC, 0-20% and 20-40% centrality

(Many thanks to Profs Axel Drees and Takao Sakaguchi for clarifying how to get the inclusive photon spectra from the available PHENIX data)

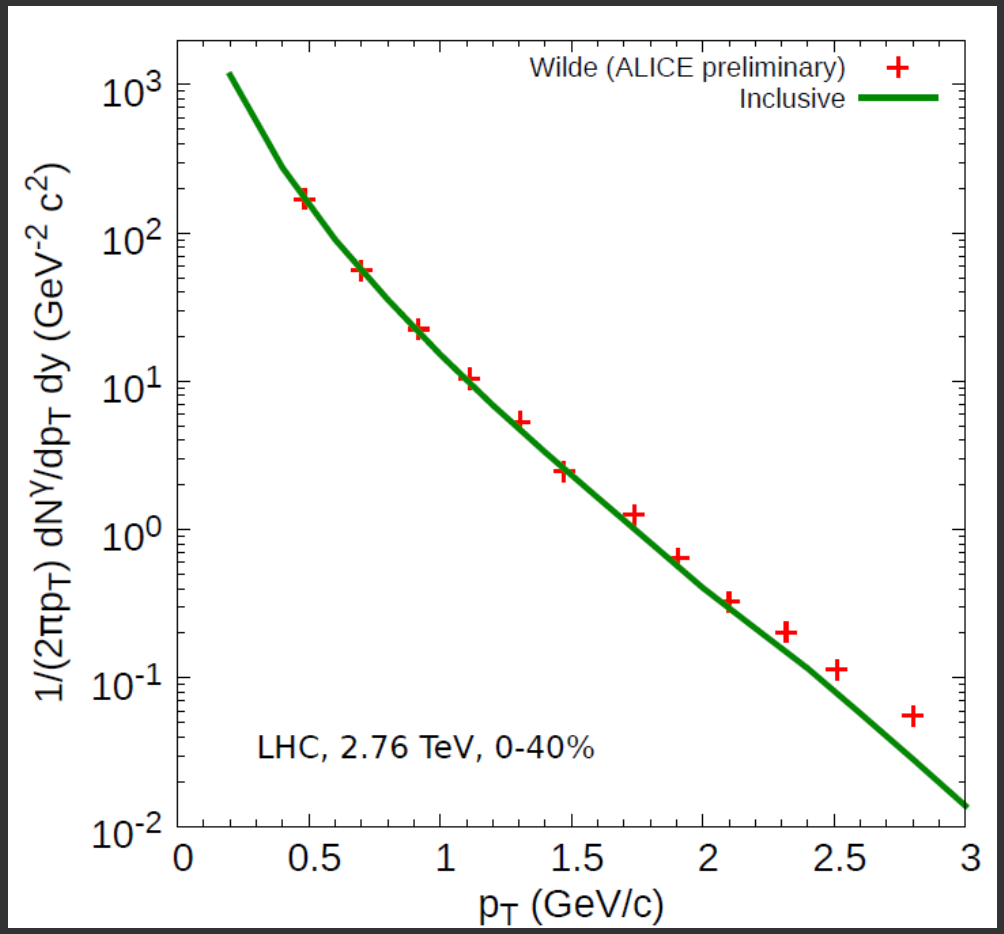
Inclusive photons: v_n

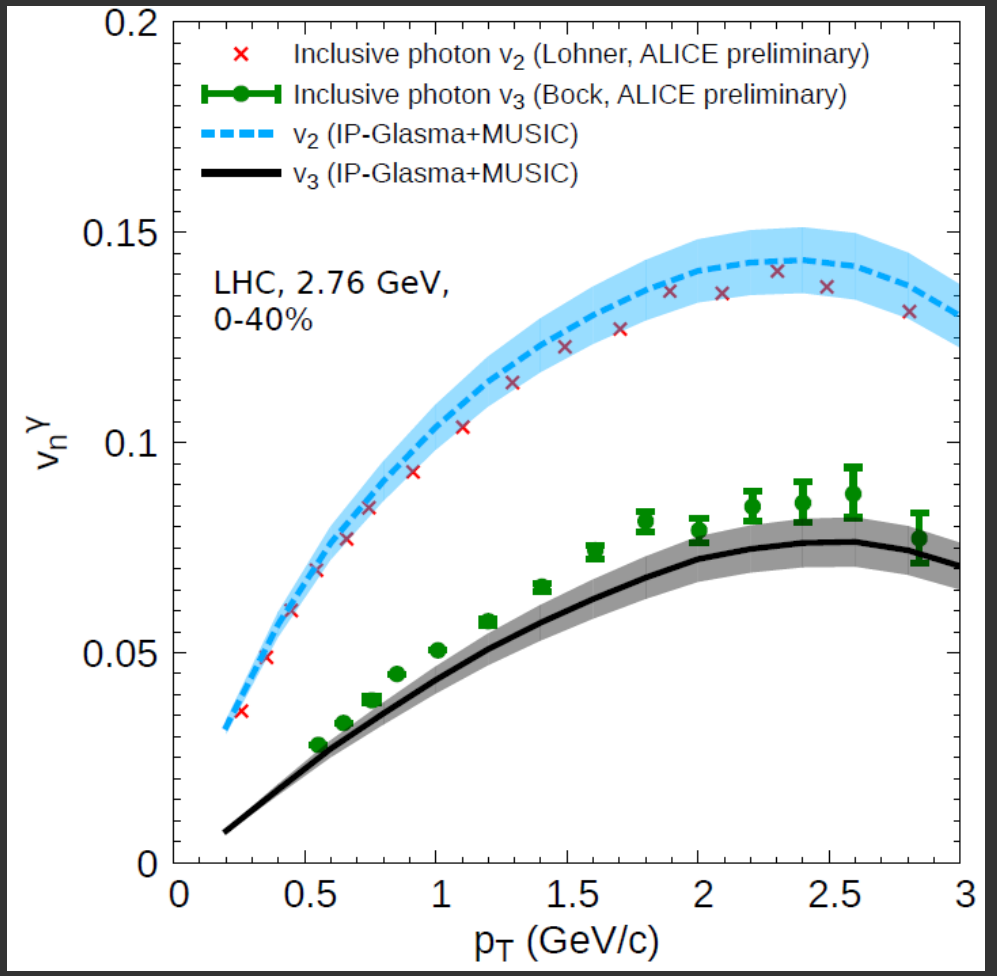




RHIC, 0-20% and 20-40% centrality

Inclusive at LHC





Last comment: how to compute v_n?

$$v_n e^{in\Psi_n}(p_T,\eta) \equiv \frac{\int_0^{2\pi} d\phi \frac{dN}{d\phi dp_T d\eta} e^{in\phi}}{\int_0^{2\pi} d\phi \frac{dN}{d\phi dp_T d\eta}}$$

- Photon v_n computed from event-plane method: the photon anisotropy is measured with respect to the hadronic event plane

$$v_n\{\mathrm{EP}\} \equiv \frac{\left\langle \cos n(\phi_i - \Psi_n^A) \right\rangle_{\mathrm{particles,events}}}{\sqrt{\left\langle \cos n(\Psi_n^A - \Psi_n^B) \right\rangle}},$$

(From Luzum and Petersen, 2013)

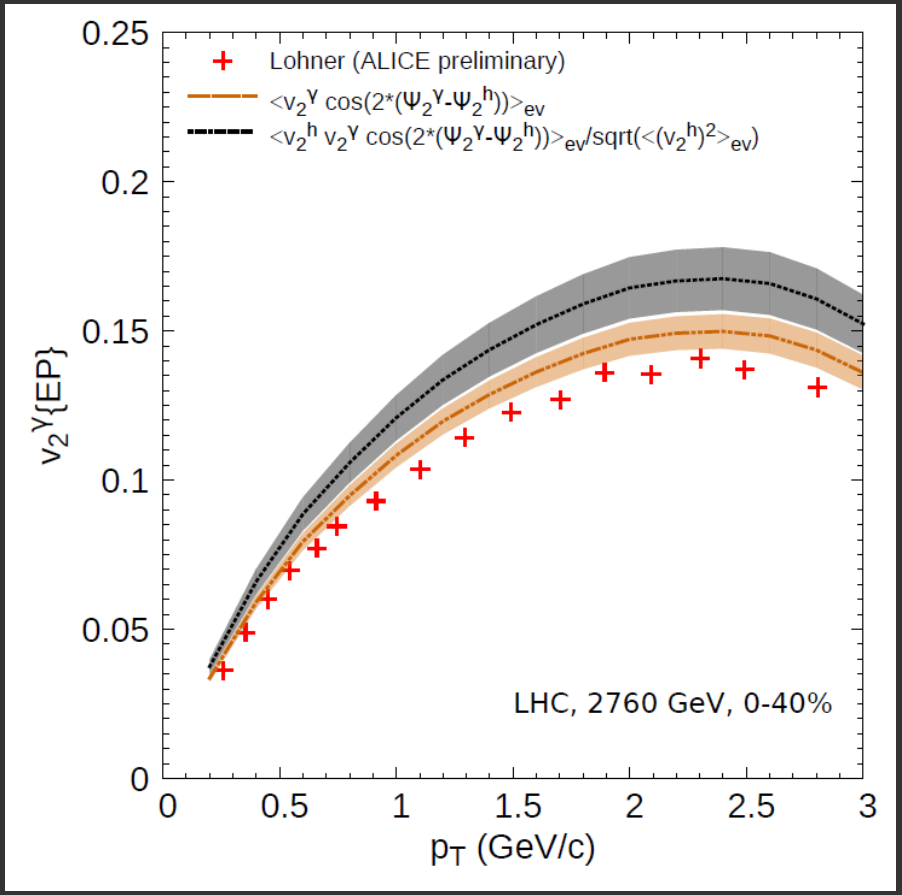
(Brackets mean averaging over events)

$$v_n\{EP\} \simeq \frac{\left\langle v_n^\gamma v_n^h \cos\left[n(\Psi_n^\gamma - \Psi_n^h)\right]\right\rangle}{\sqrt{\left\langle (v_n^h)^2 \right\rangle}}$$

v_n definitions: why does it matter

- Hadron v_n fluctuations:

$$v_n\{EP\} \simeq \frac{\langle v_n^{\gamma} v_n^{h} \cos[n(\Psi_n^{\gamma} - \Psi_n^{h})]\rangle}{\sqrt{\langle (v_n^{h})^2 \rangle}}$$



v_n definitions: why does it matter

- Photon multiplicity weights in the event-averaging

$$v_n\{EP\} \simeq \frac{\left\langle v_n^{\gamma} v_n^{h} \cos\left[n\left(\Psi_n^{\gamma} - \Psi_n^{h}\right)\right]\right\rangle}{\sqrt{\left\langle \left(v_n^{h}\right)^2 \right\rangle}}$$

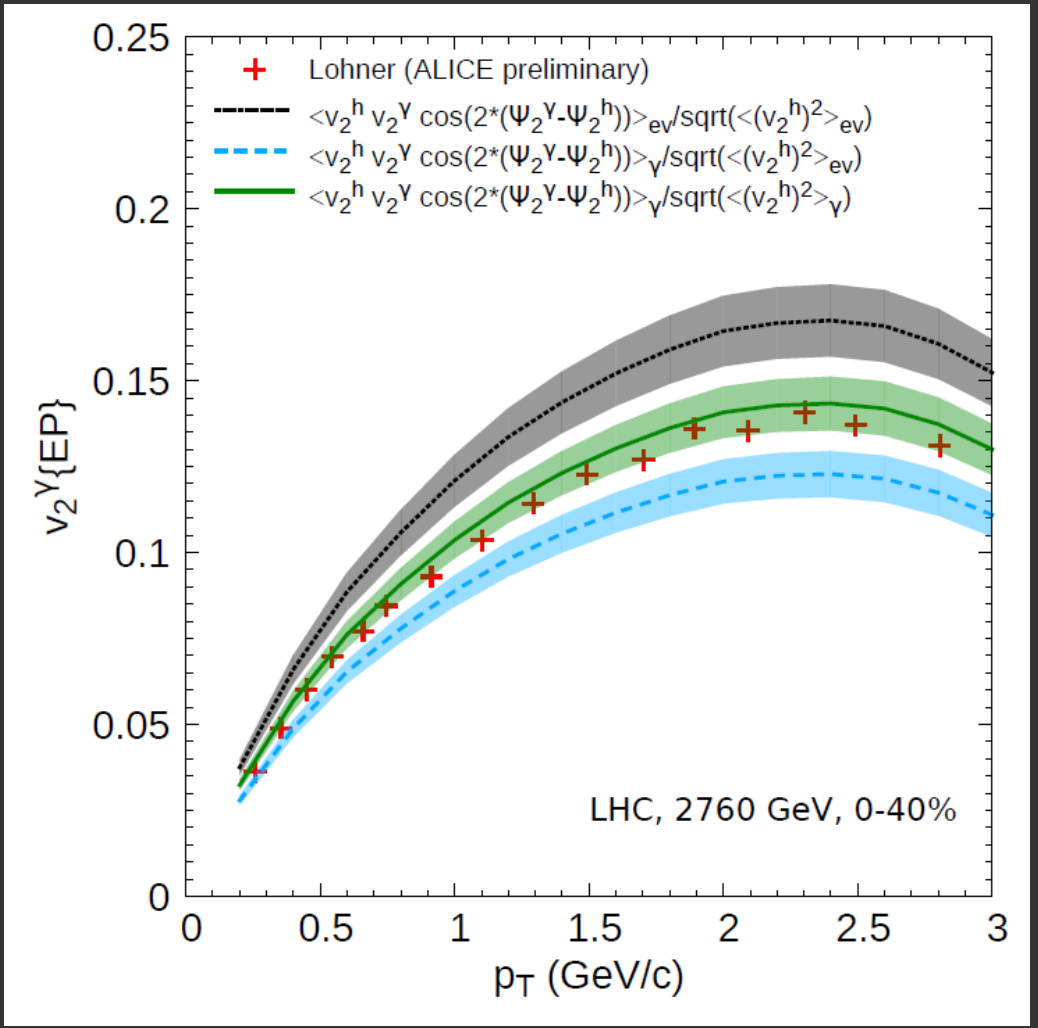
More weight on high photon multiplicity events

All events treated equally

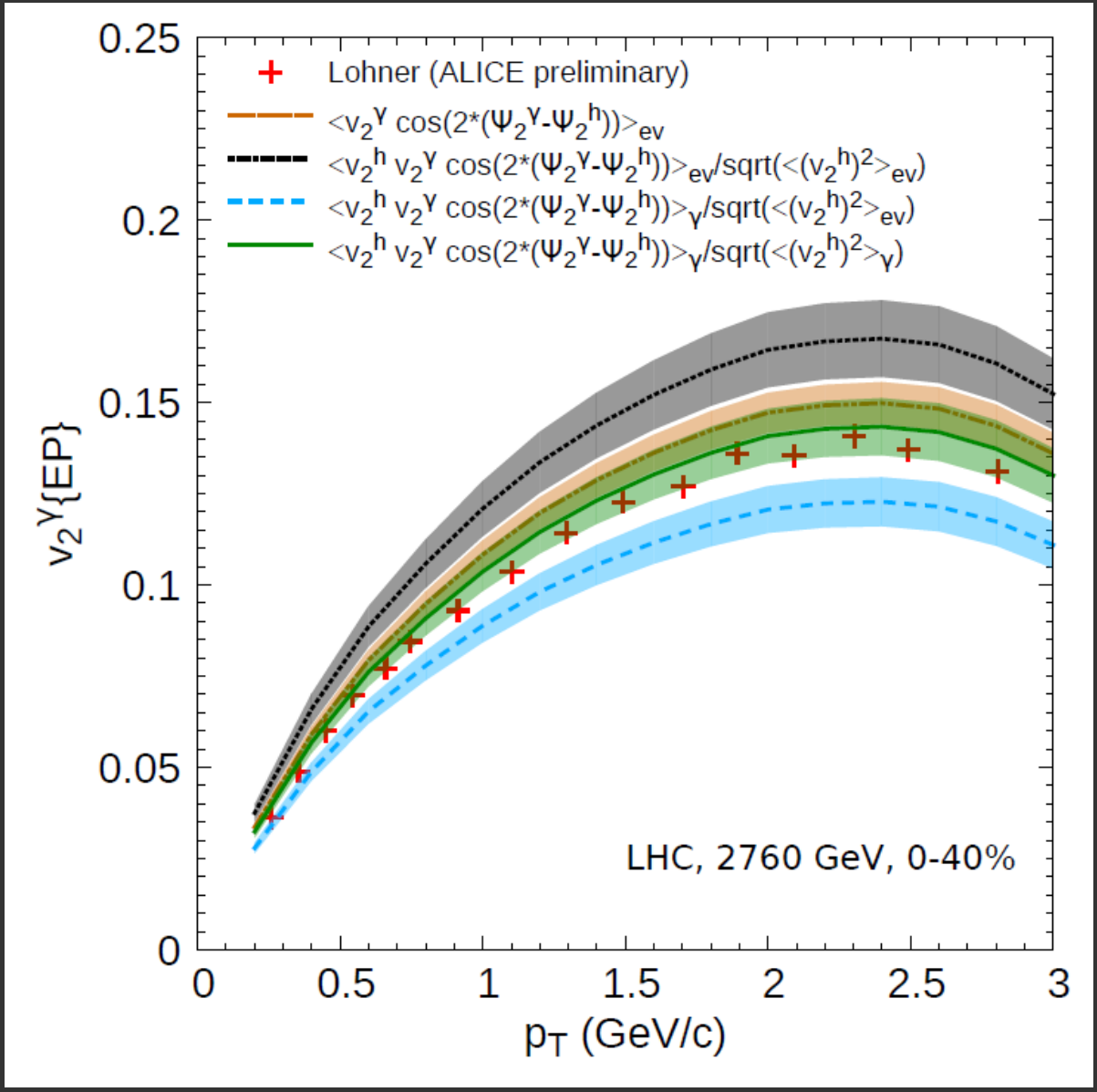
$$\langle X \rangle_{\gamma} = \frac{\sum_{j \in \text{events}} \left(\frac{1}{2\pi p_T} \frac{d^2 N_j^{\gamma}}{dp_T dy} \right) X_j}{\sum_{j \in \text{events}} \left(\frac{1}{2\pi p_T} \frac{d^2 N_j^{\gamma}}{dp_T dy} \right)} \text{ or } \langle X \rangle_{ev} = \frac{1}{N} \sum_{j \in \text{events}}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

v_n definitions: why does it matter

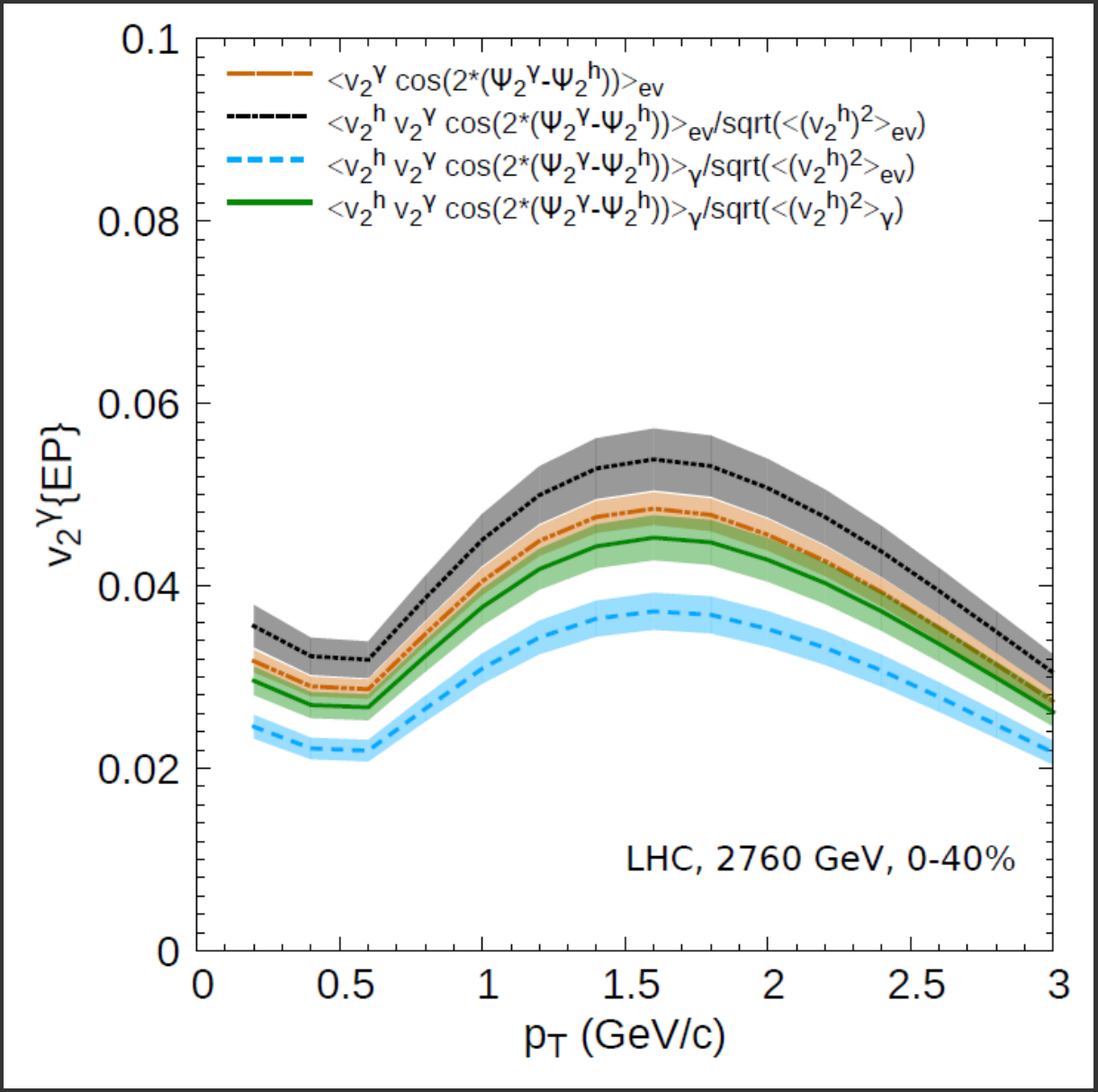
- Photon multiplicity weights in the event-averaging



Effect on v_n on inclusive photons



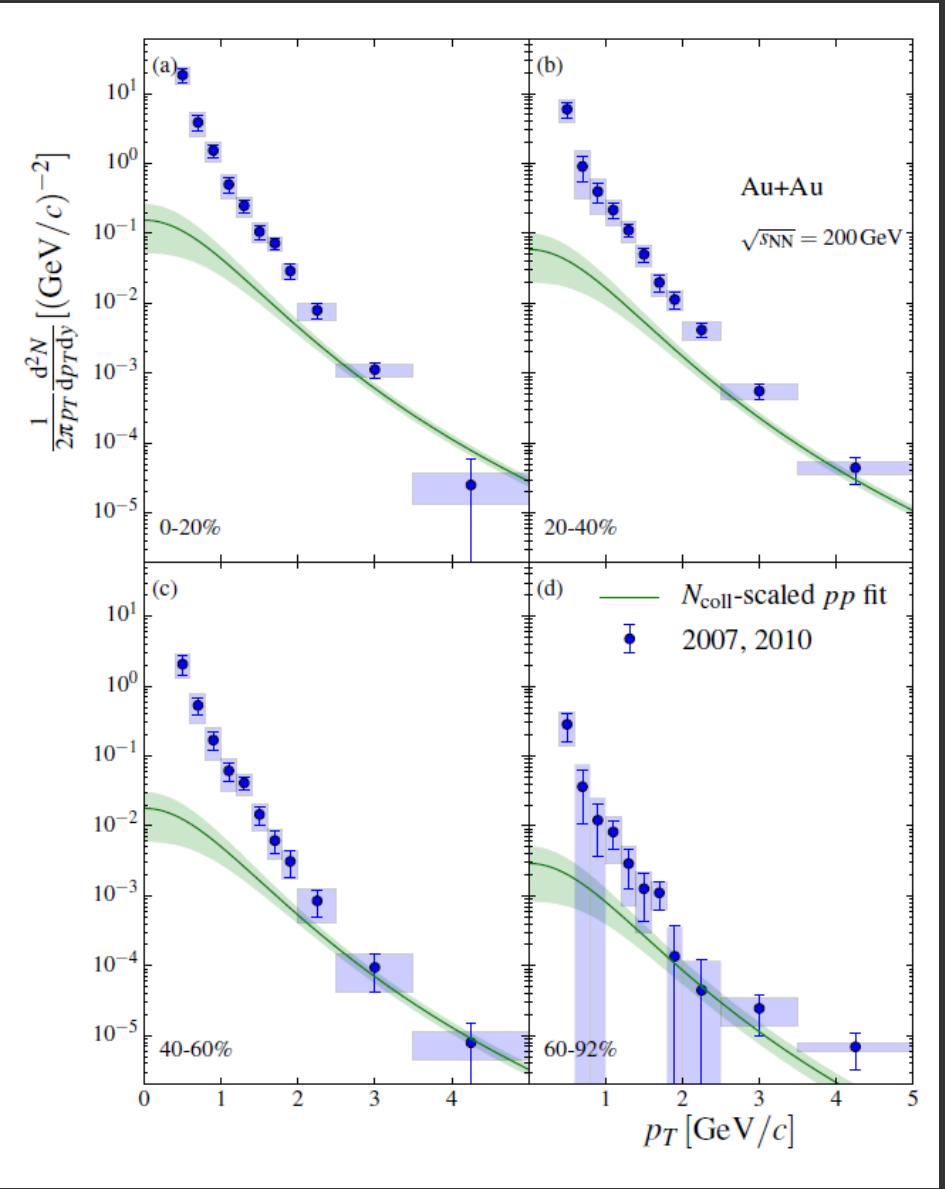
Similar effect on direct photons



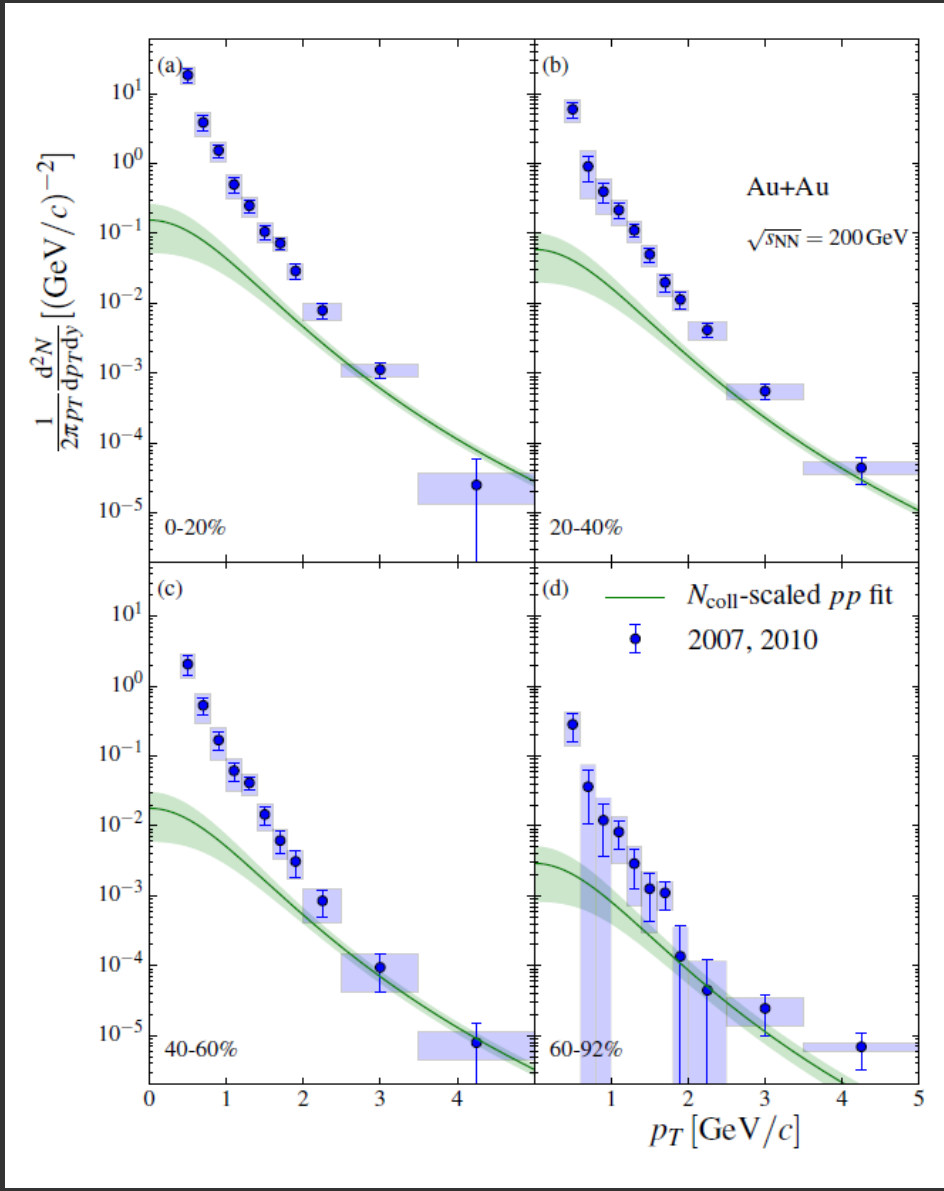
Inclusive?

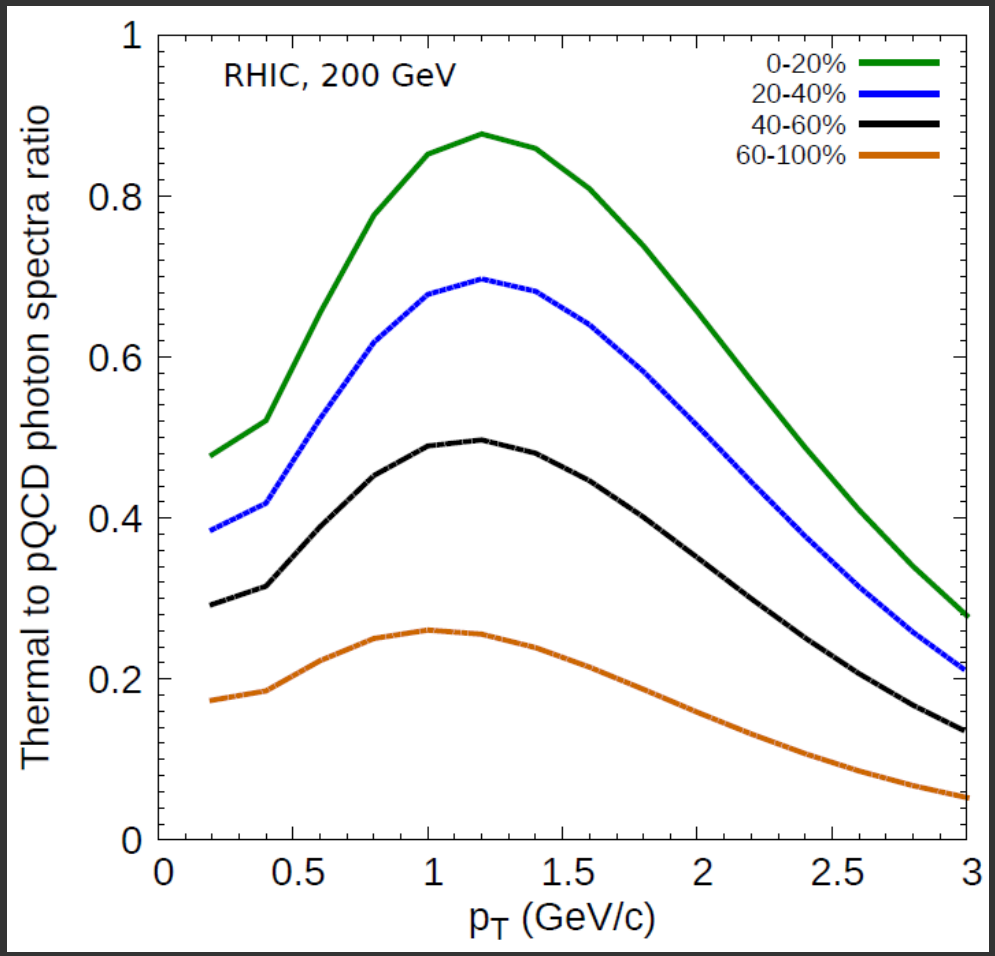
- Inclusive photon spectra agrees with data once hydrodynamics parameters are fitted to hadronic observables
- Using inclusive as an additional constraint on hydrodynamics parameters?
- How the photon v_n is computed is important!

Centrality dependence: closer look



Thermal/pQCD vs centrality





Conclusion

- Inclusive photon:
  - Constraint on hydrodynamics parameters
- Photon v_n definition: event-by-event calculation necessary!
- Very interesting peripheral data
  - Constraint on prompt?

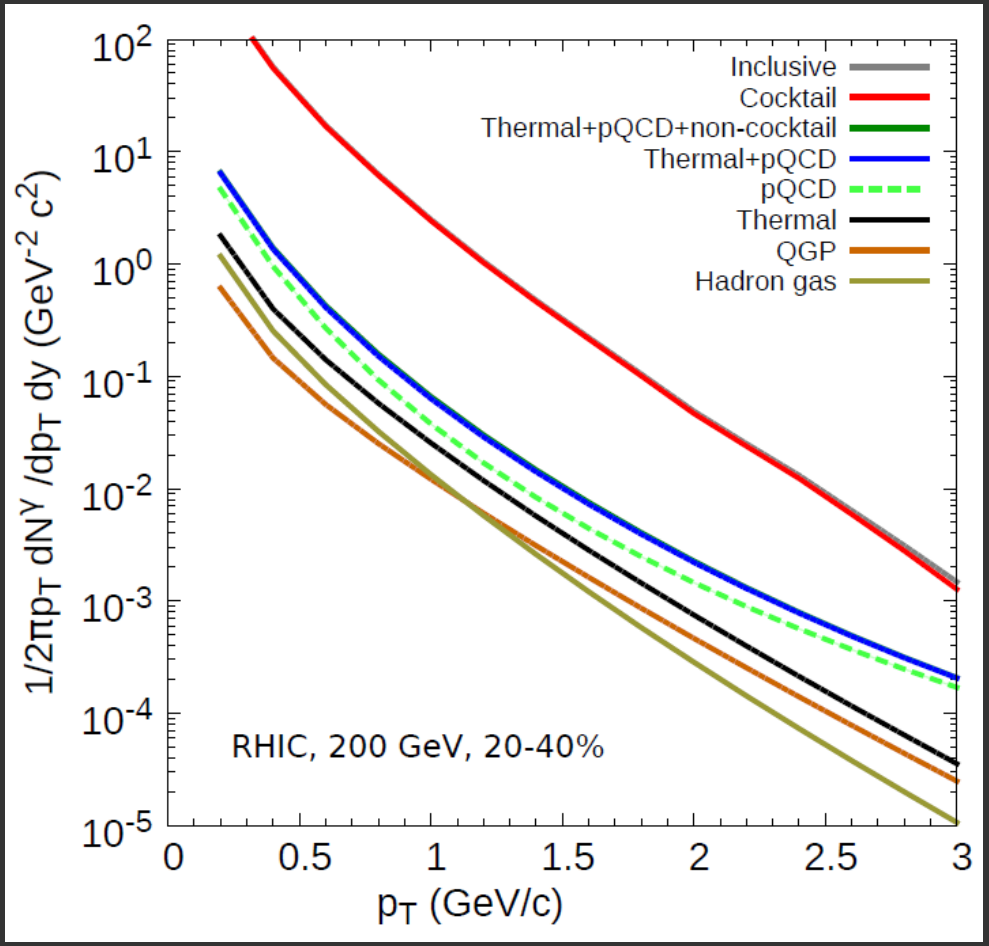
Many thanks to...

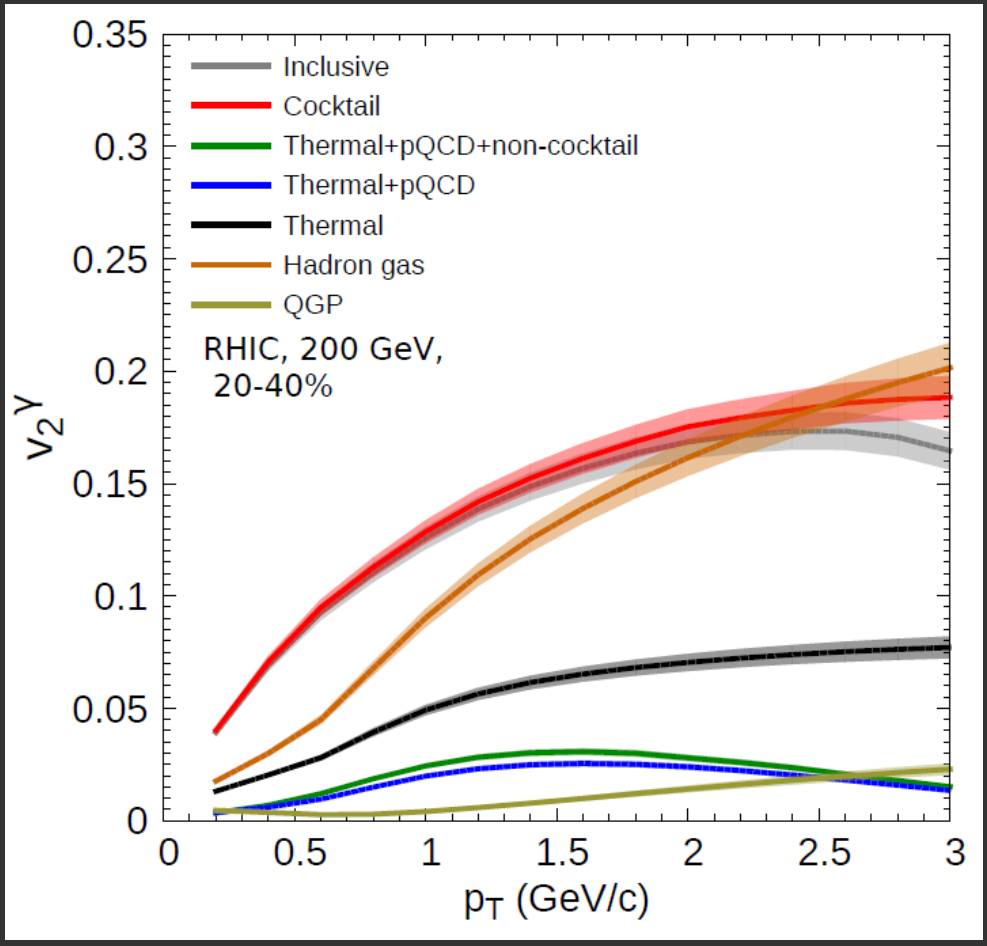
- Charles Gale, Gabriel Denicol, Gojko Vujanovic, Sangyong Jeon, Matt Luzum
- Chun Shen, Ulrich Heinz

without forgetting the participants to this workshop and the earlier “EMMI Rapid Reaction Task Force” for their valuable input before and during these workshops

Backup

Inclusive vs cocktail





Cocktail dominates the inclusive photon signal

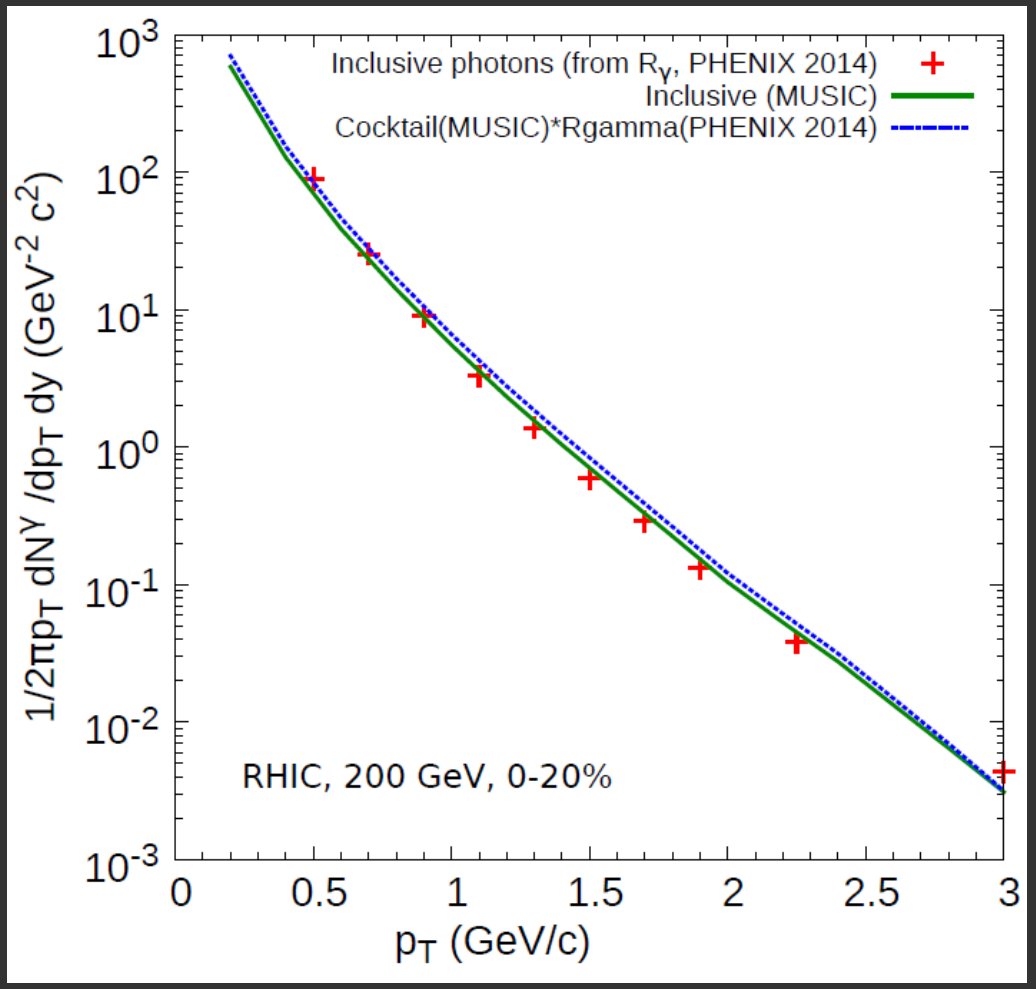
What if there were more direct photons?

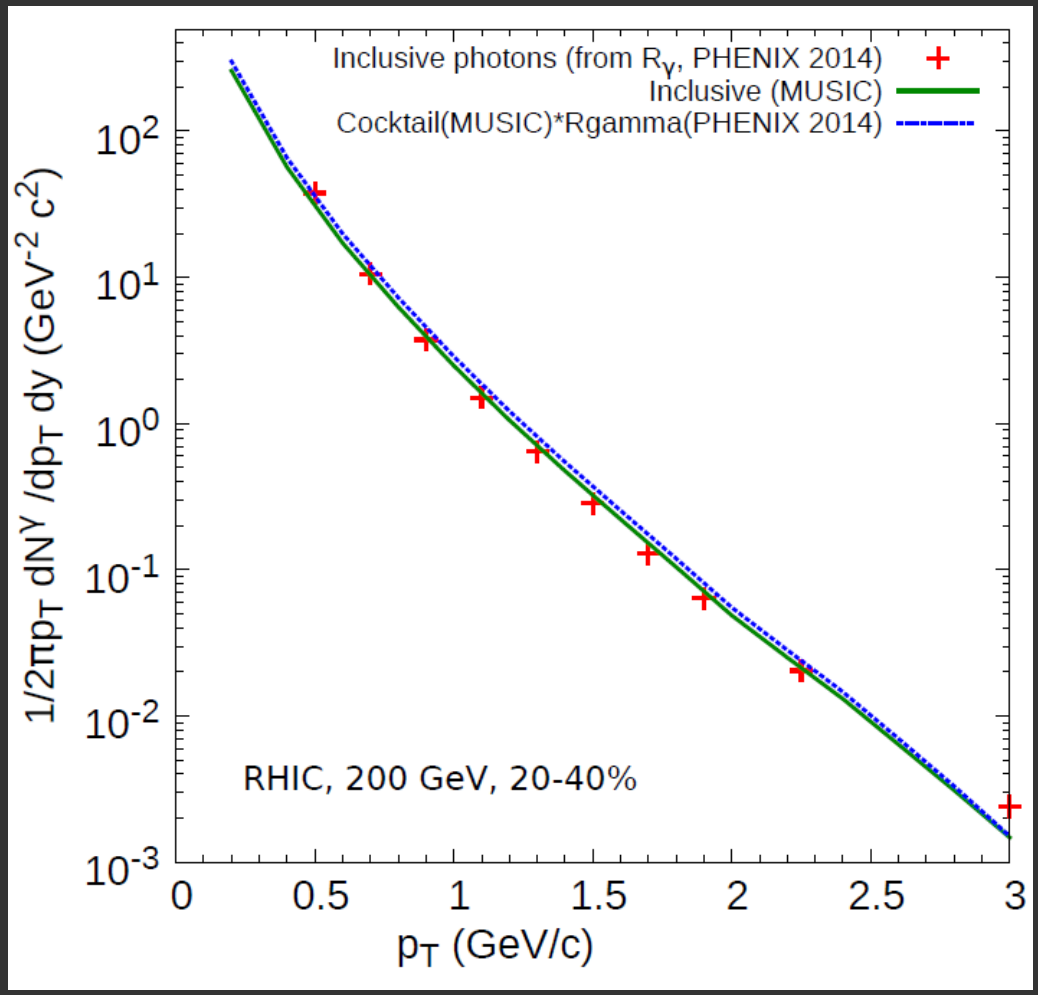
- For the spectra, easy to test:

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

$$d\,N^{\gamma,\,incl.}_{theory\ incl.+\exp\ direct} = d\,N^{\gamma,\,cocktail}\,R^{\gamma}_{experimental}$$

Theoretical cocktail + experimental direct photons

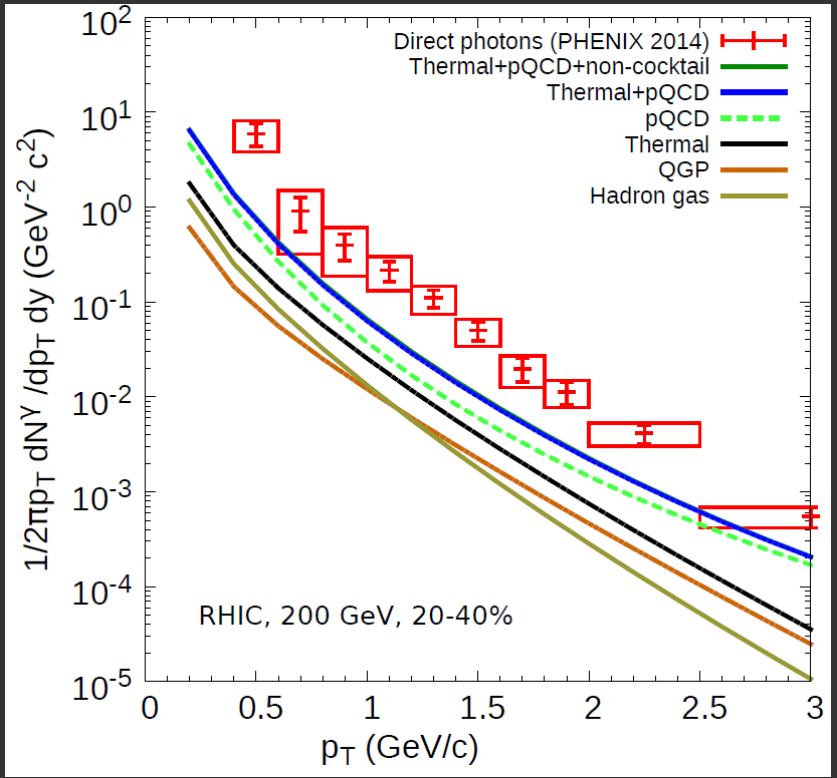


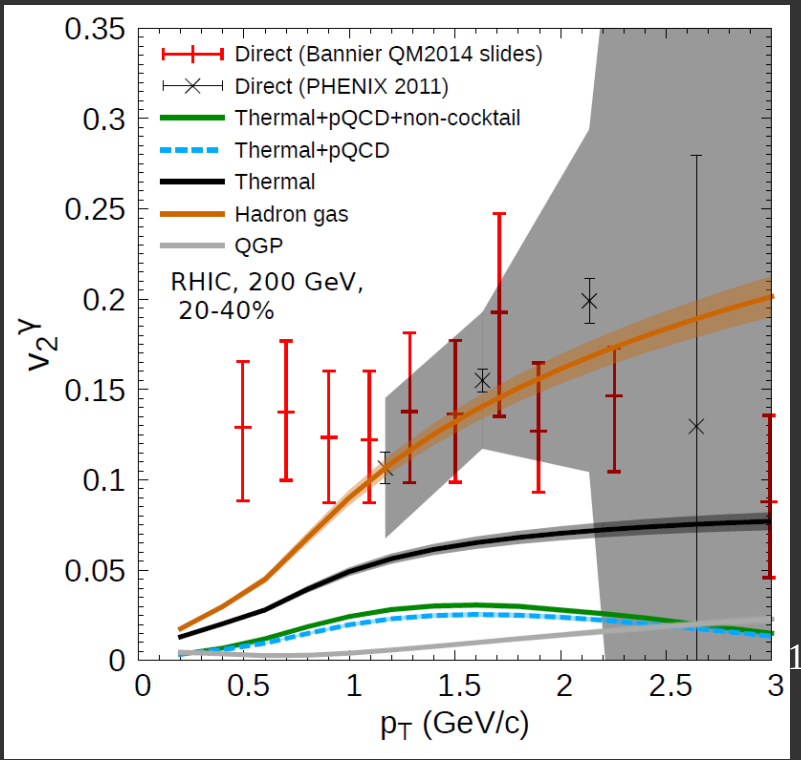


Visible but small effect on spectra

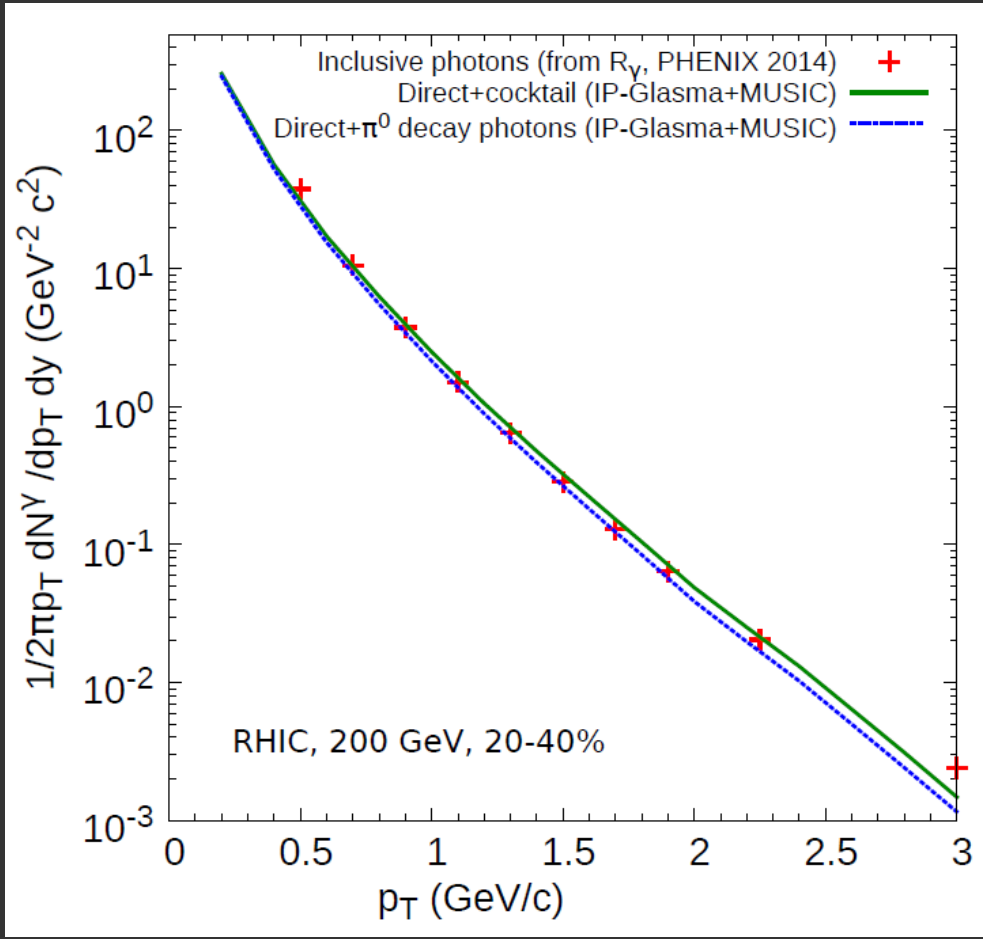
Prompt photons

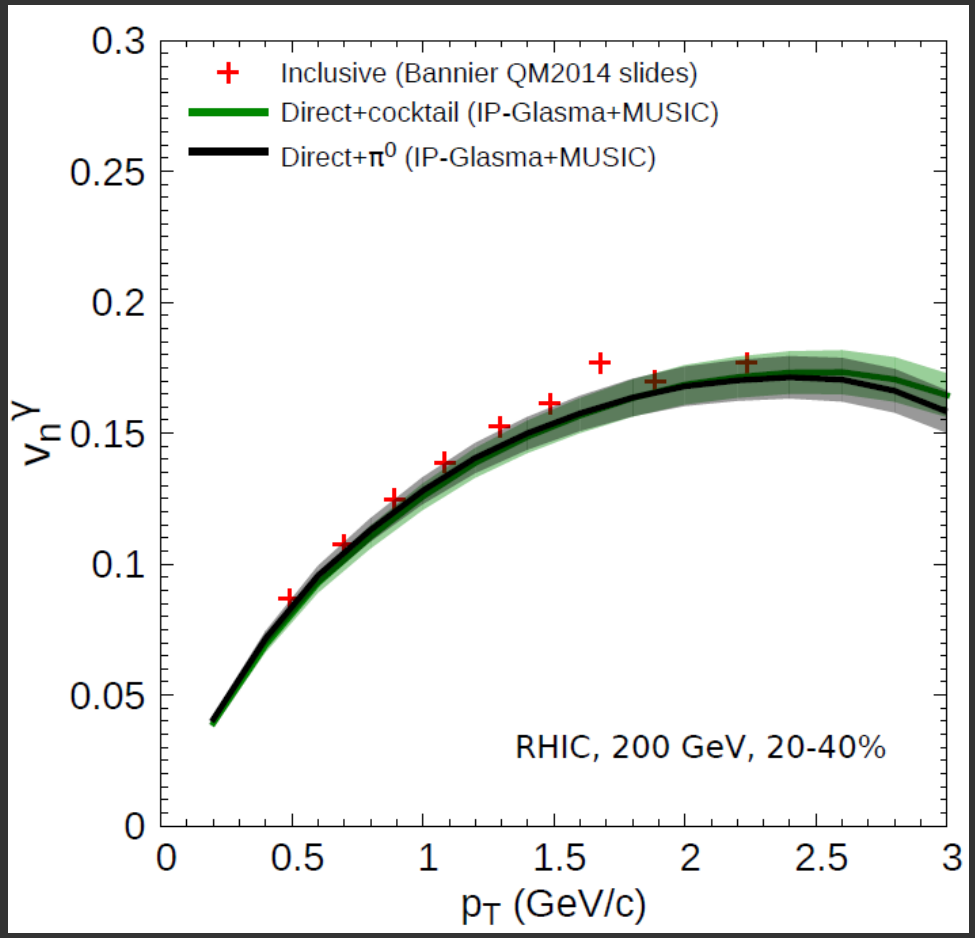
- pQCD calculation or fit to proton-proton data
- Binary scaling is assumed to hold in both cases
- Large contribution to direct photons:





Pion contribution to inclusive





Peripheral photons as “cold” reference?