ATHIC2012

Study QCD matter with Direct Photons from Pb+Pb at LHC

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Outline

- Motivation:
  1) What's the matter above Tc in QCD phase ?
  2) Is thermalization a condition for collective expansion?
  3) What will direct photons from Pb+Pb at 2.76TeV tell?

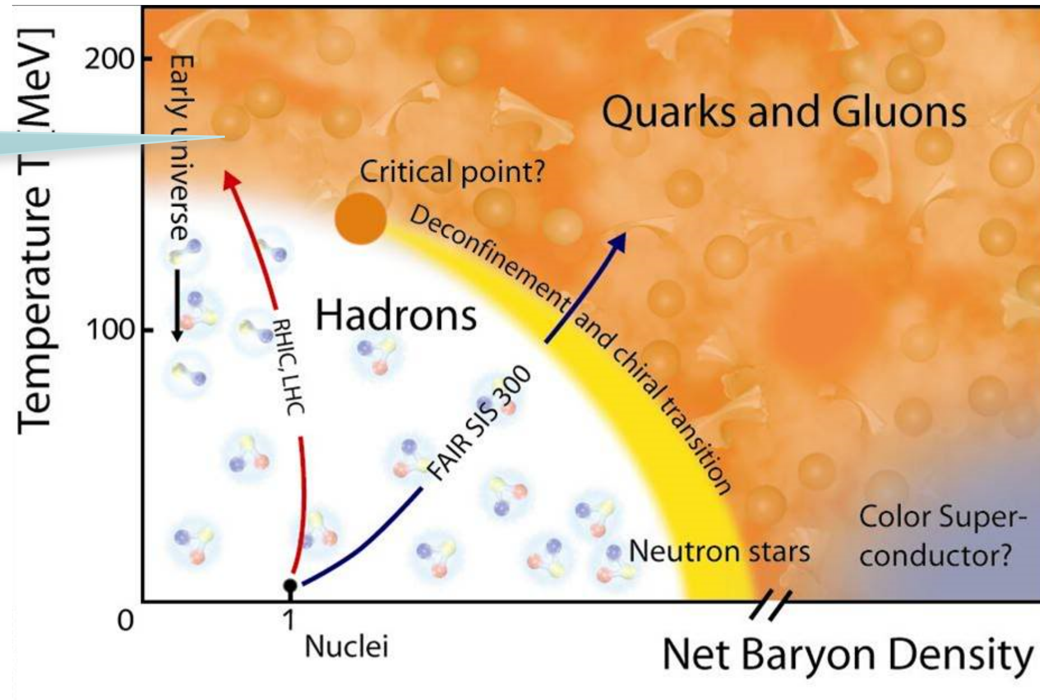
- Calculations and comparison.
  1) Thermal photon rates from different phases;
  2) Calculate photon emission from Pb+Pb collisions with two modes of phase transitions;
  3) Comparison with experimental data;
  4) Reflection to RHIC Au+Au, and pp at 7TeV.

- Conclusions

- Discussion on initial time and thermalization time

QCD phase diagram

What's the matter ?



A mixture of QGP and
hadron gas?
Quasi particles?
Purely QGP?

Cross-over or 1^{st} -order phase transition ?

Hadron data can hardly tell. Photon data may help.

Thermal photon emission rates

$$\frac{dN^{\text{thermal}}}{dy\,d^2p_t} = \int d^4x\,\Gamma_{\text{thermal}}(E^*,T), \quad E^* = p^\mu u_\mu$$

$q\bar{q} \to g\gamma$

$qg \to \gamma q$

$$\Gamma^{\text{QGP}\to\gamma}(E^*,T) = \frac{6}{9}\frac{\alpha\alpha_s(T)}{2\pi^2}T^2\frac{1}{e^{E^*/T}+1}C_{\text{AMY}}$$

$q \to q\gamma$

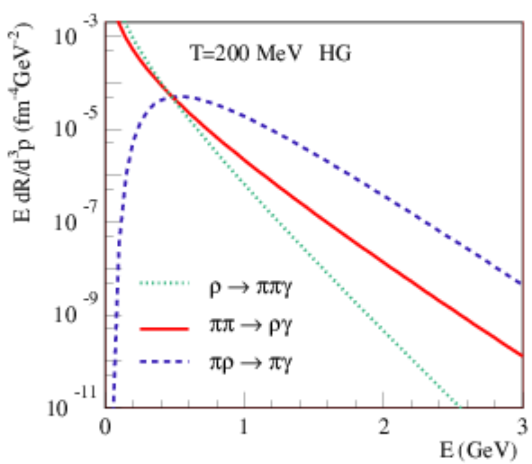
$g \to q\bar{q}$

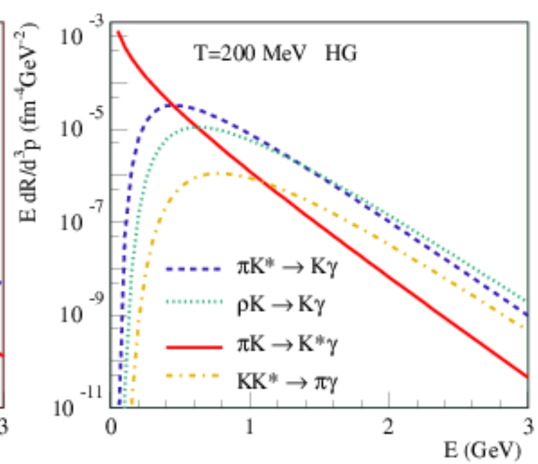
LPM effect ...

$\Gamma^{\text{HG}\to\gamma}(E^*,T)$: Kapusta et al, 1991

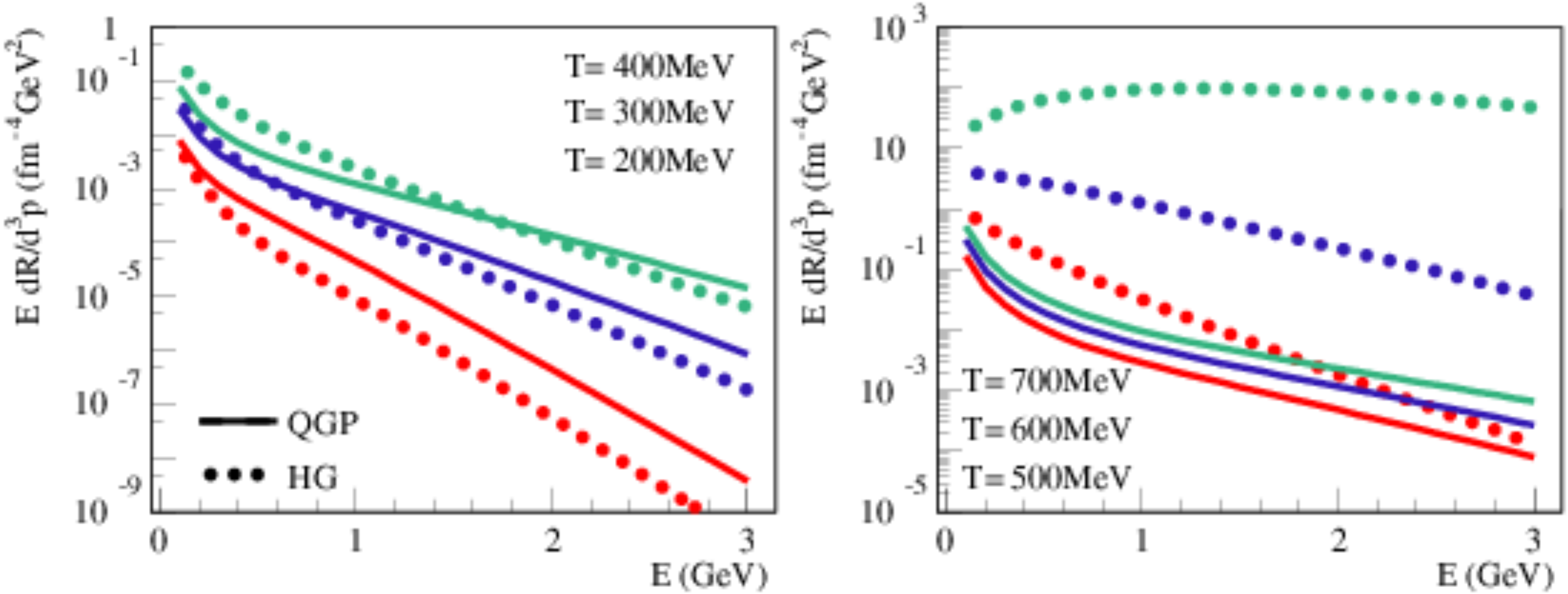
R. Rapp et al, 2004

Quasi-particle mode?





Photon Emission Rates



Big difference between emission rates at high *T* !

Show up in central PbPb collisions at 2.76TeV?

Hydro evolution of collision systems

$$\boldsymbol{\varepsilon}, \boldsymbol{p}, \boldsymbol{u}^{\mu}, \boldsymbol{s}, \boldsymbol{B}, \ldots (\boldsymbol{\tau}, \boldsymbol{x}, \boldsymbol{y}, \boldsymbol{z}) \qquad T^{\mu\nu} = (e + P) u^{\mu} u^{\nu} - P g^{\mu\nu} + \cdots$$

Initial condition $\boldsymbol{\tau}_0$ EPOS event generator

Evolution $\partial_{\mu} \boldsymbol{T}^{\mu\nu} = 0$

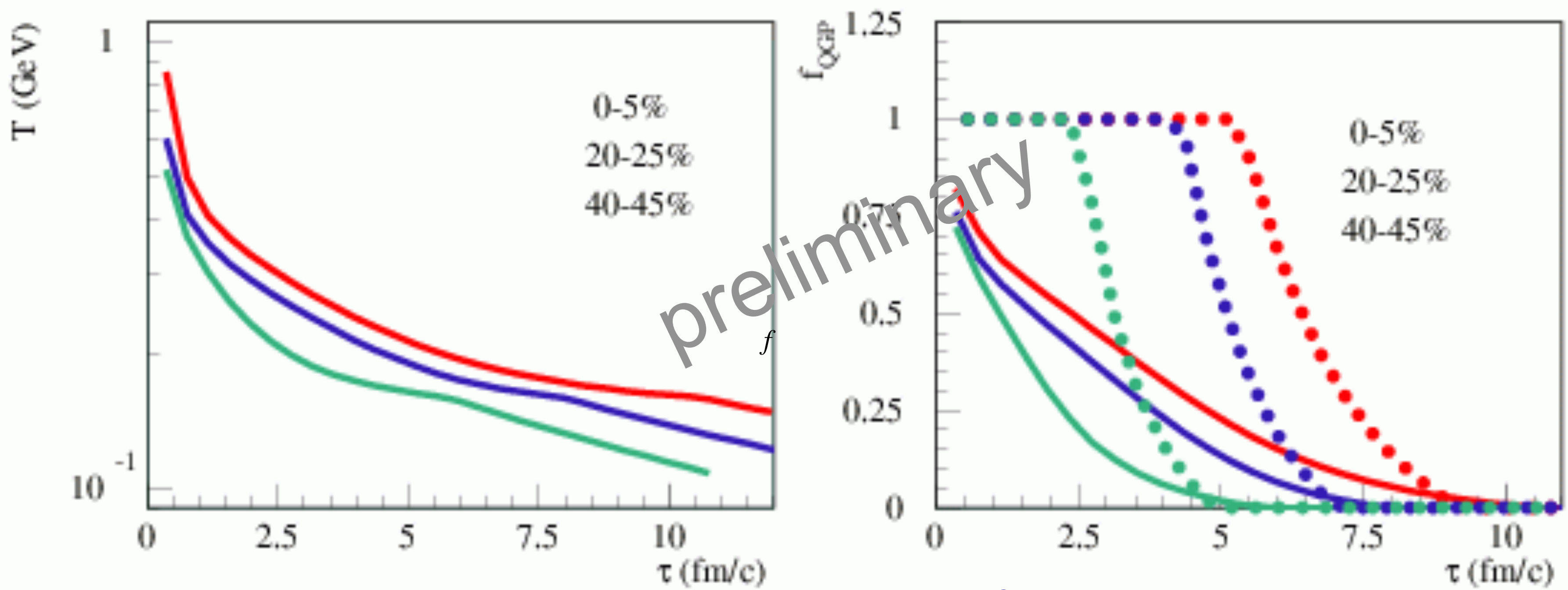
EoS: Lattice QCD, S. Borsanyi et al, arXiv:1007:2580

Freeze-out: $e^{th} = 0.08 \mathrm{GeV} / \mathrm{fm}^3$ or $T^{th} \sim 100 \mathrm{MeV}$

Constrained with Hadron data:
Werner, Karpenko, Bleicher, Pierog, Phys. Rev. C85, (2012), 024907.

Hydro for Pb+Pb at 2.76TeV

For the central point: $x=y=z=0$

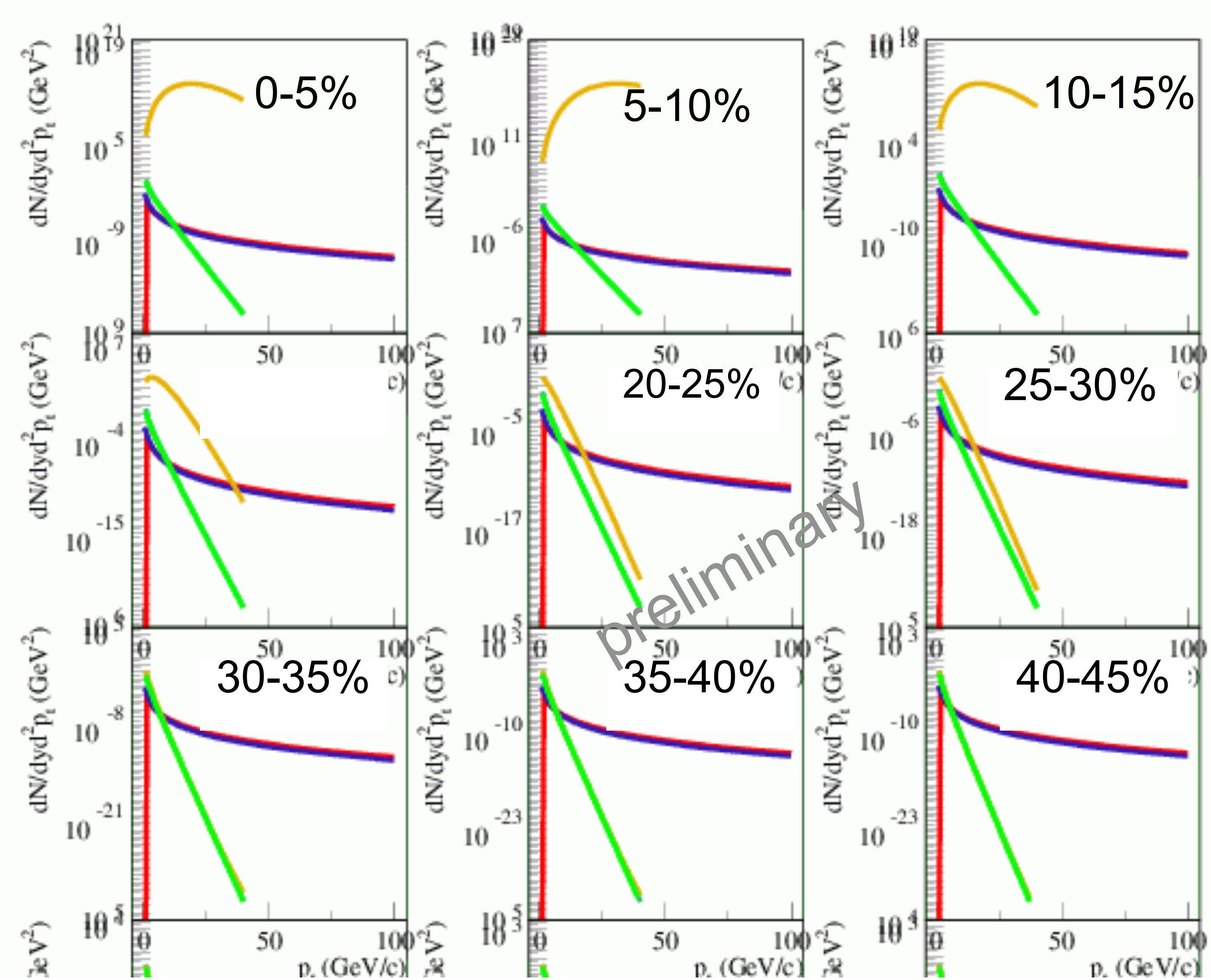


f_{QGP} : fraction of QGP.

Solid lines: Lattice QCD cross-over

Dotted lines: 1st-order phase transition

Pb+Pb→γ 2.76TeV



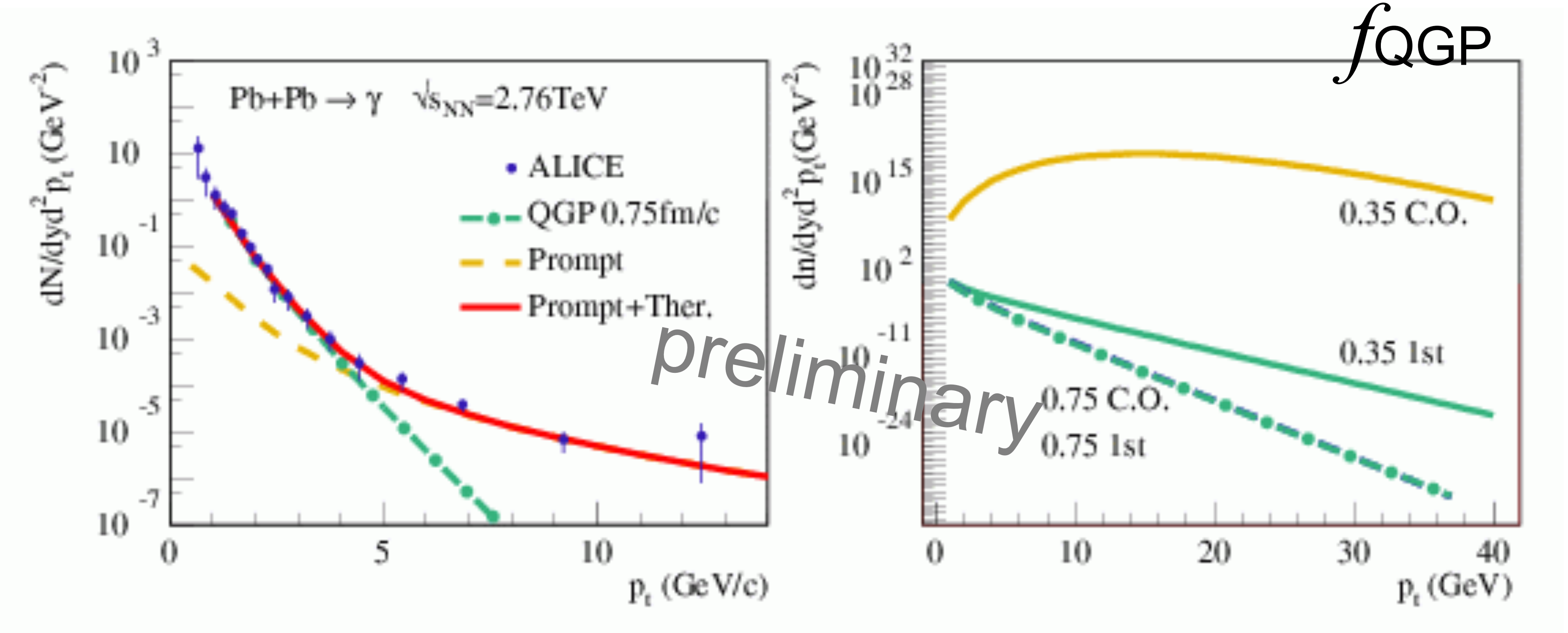
prompt photon
R: LO
B: NLO

Ther. photons
Y: LQCD
G: 1[st]-order

τ0=0.35 fm/c

Can photon data from central collisions distinguish Y or G is right?

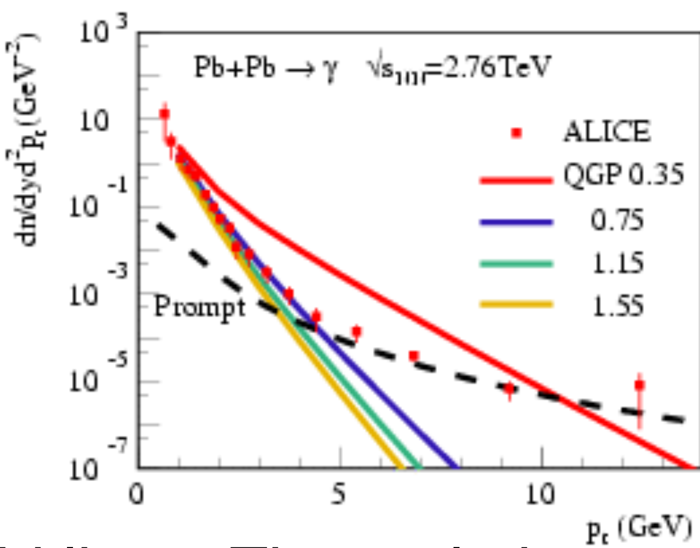
Exp. Data Vs. Theo. Results

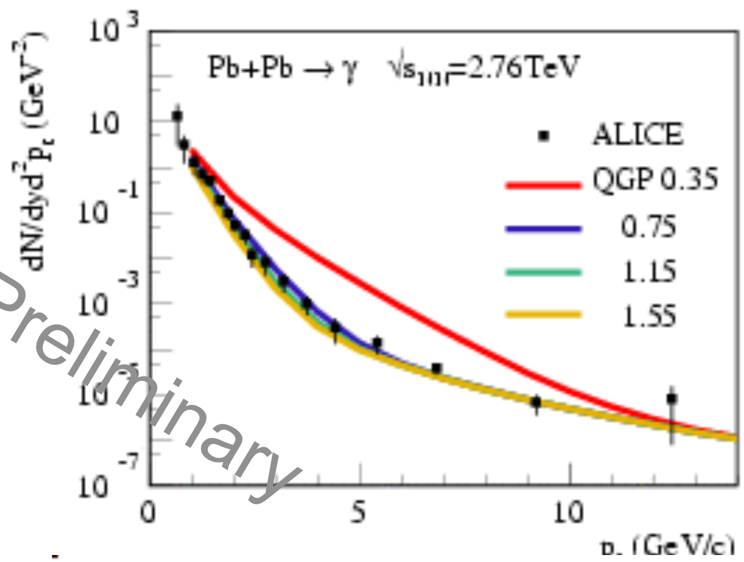


1) The system starts to expanding collectively at 0.35fm/c.
2) But photon data favor QGP formation later.
3) Photon data at 2.76TeV can not tell yet what is matter.

Higher collision energy may be helpful.

QGP formation time

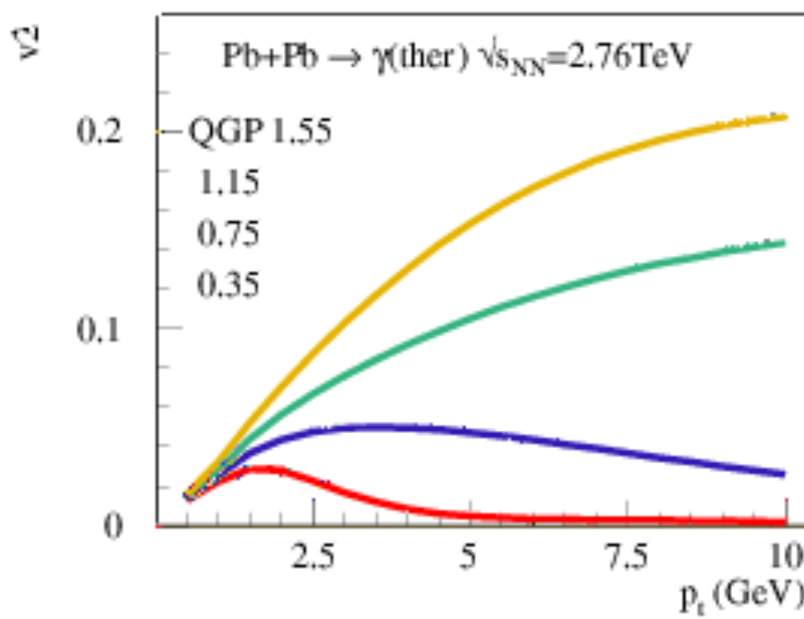




solid lines: Thermal photons

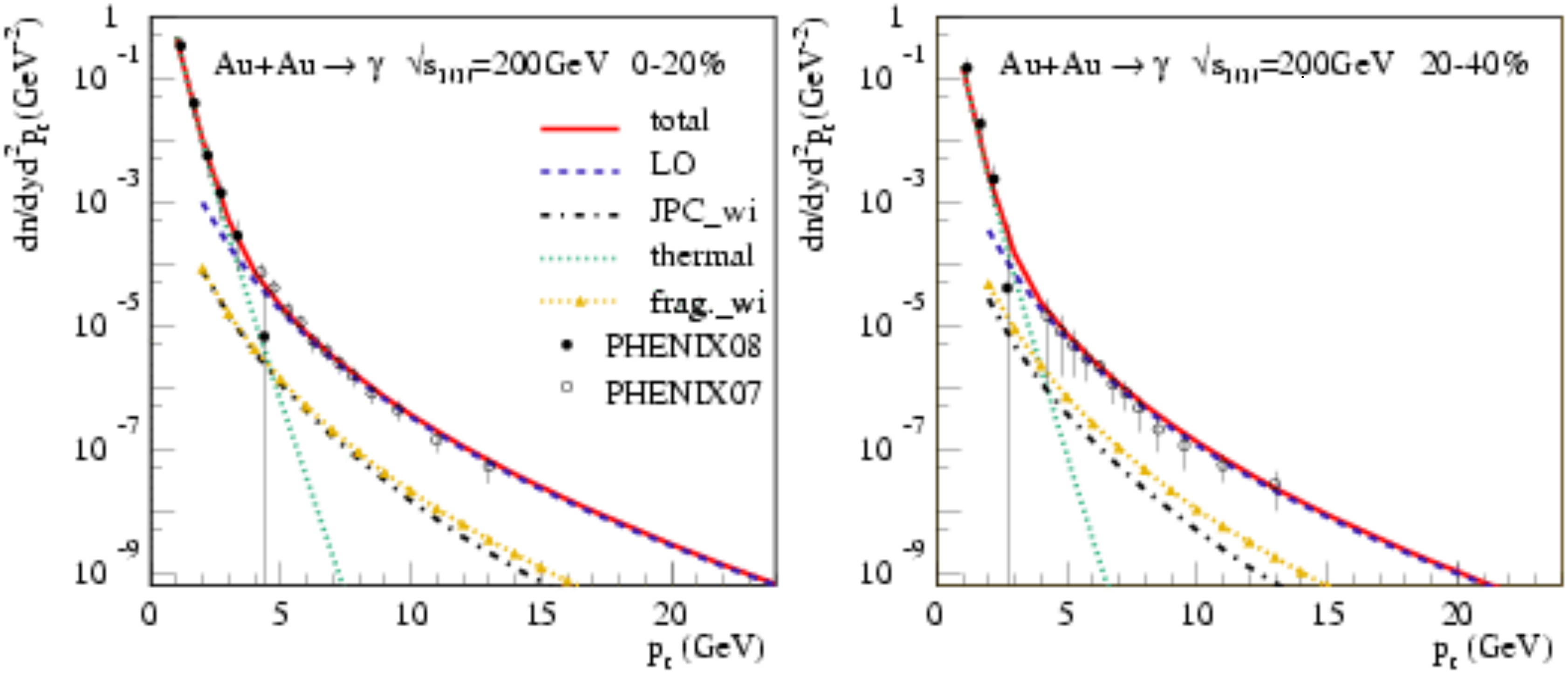
Pt spectrum can not tell QGP formation time.

But v2 will help.



Results at RHIC

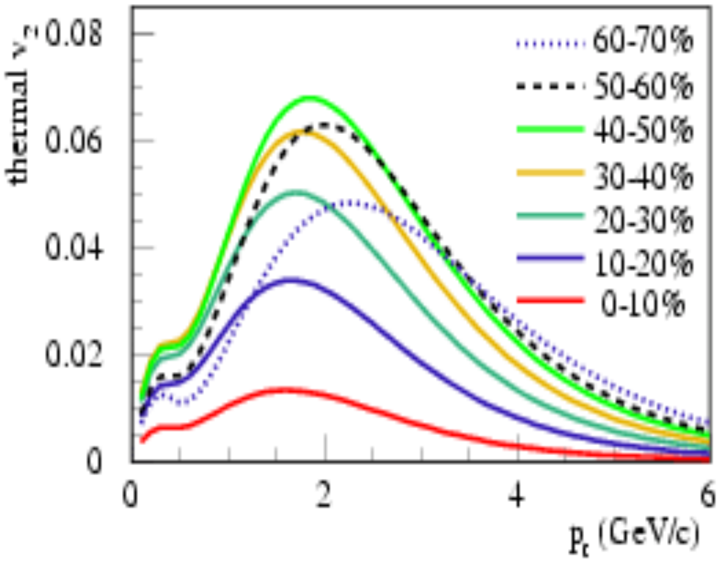
F.M. Liu, T.Hirano, K.Werner, Y. Zhu, Phys.Rev.C79:014905,(2009)



1) Tau0=0.6fm/c, local thermalization realized at this time.
Maybe the same time interval is needed for LHC.

2) JPC contribution compensates the E-loss reduced contribution.
Simply count prompt photons without medium => Raa=1 and v2=0.

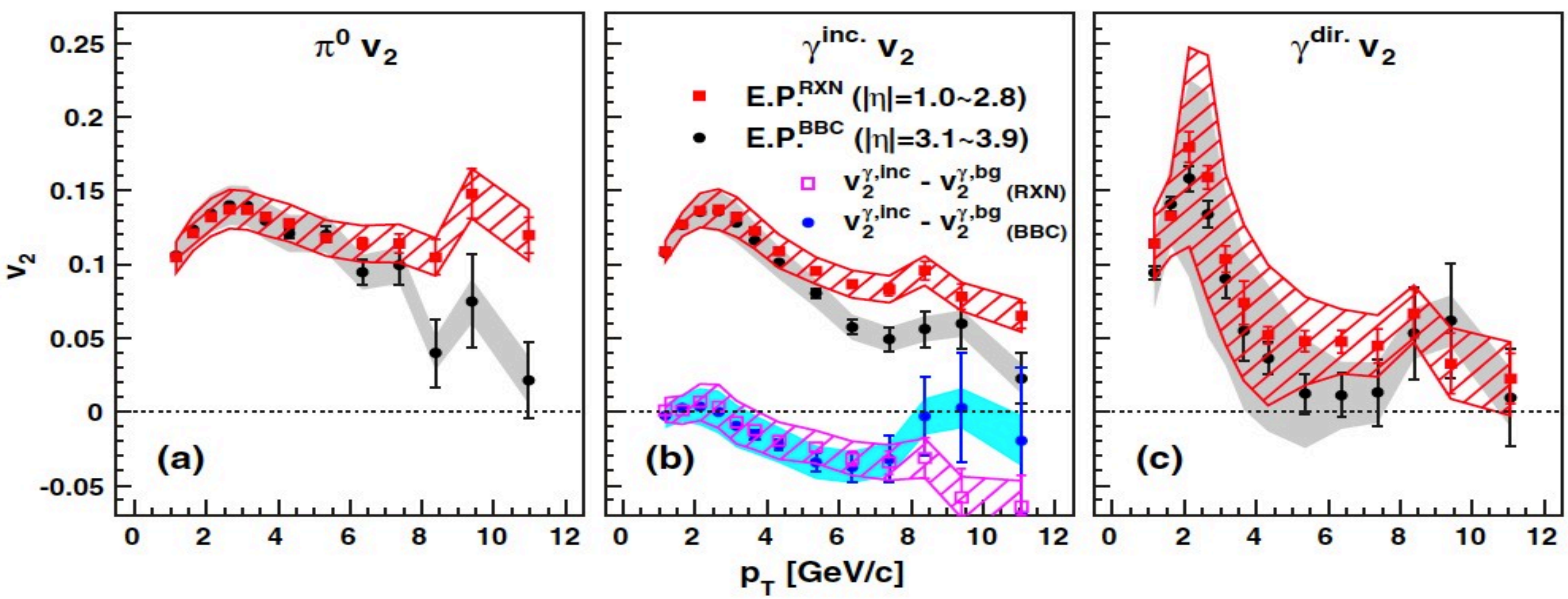
Direct photon v2 at RHIC



F.M. Liu, T.Hirano, K.Werner, Y. Zhu, Phys. Rev. C80,034905 (2009).

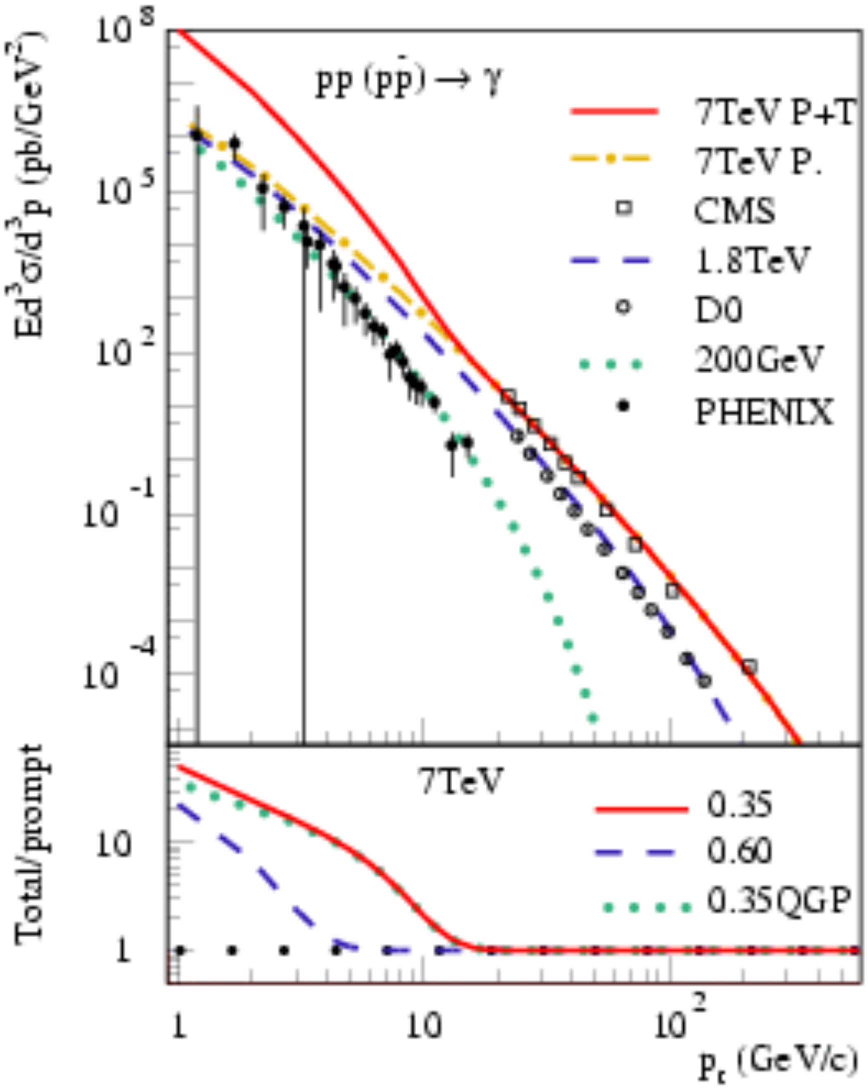
Calculated v2 is lower than data.
Reasons:
1) initial fluctuation,
2) later thermalization.

PHENIX: PRL 109, 122302 (2012)



Direct photons from pp at 7TeV

FML, K.Werner,**Phys.Rev.Lett.106:**242301,(2011)



Thermal photons dominate low pt region, up to 10GeV/c. As a sensitive QGP signal.

Is it really so sensitive?

If QGP formed later than 0.35fm/c, then not so sensitive.

Conclusion

1. Thermal photons may be a useful tool to detect the matter above Tc in QCD phase, 2.76TeV is not high enough yet.

2. ALICE direct photons shows, QGP formation time may be later than the hydro initial time. Direct photon’s v2 may help to determine it more precisely.

3. PHENIX direct photon v2 may be explained with later QGP formation time, or fluctuating initial condition. Work to do.

4. If it is true that QGP formation time is later than hydro initial time, then thermal photons can not be so sensitive to detect QGP formation in pp at 7TeV.

Initial time and thermalization

- At hydro tau0, the collective expansion of the systems starts, due to the gradient of energy density.

Bjorken's tau0 (1984), Laudau's tau0 (1953), ArXiv:1210.2833......

- The motion of each single particle is a superposition of the collective motion (flow velocity) and the individual motion in the comoving frame.

- In the comoving frame, the energy distribution of particles may follow thermal distribution (F.D., B.E. Or M.B.), then the system is locally thermalized. But at tau0, it may not be this case.

Thermalization takes time. QGP formation takes time, whose individual particles are partons.