Influence of initial state fluctuations on the production of thermal photons

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Plan of the talk:

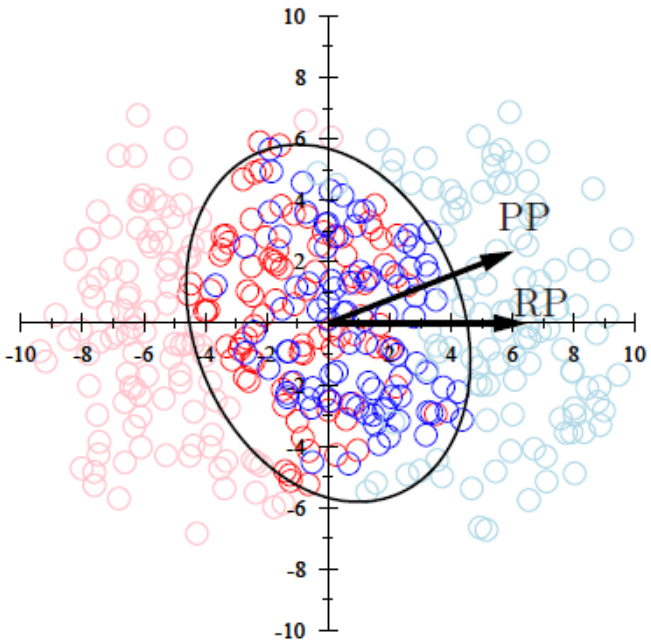
- Motivation
- Thermal photons from event-by-event fluctuating initial conditions
- Collision centrality dependence at RHIC and LHC
- Initial formation time (τ_0) dependence
- Results from centrality dependent τ_0 values
- Central to peripheral ratio (R^{γ}_{cp}) of thermal photon yield
- Elliptic flow of thermal photons from fluctuating initial conditions
- Summary and conclusions

Event-by-event hydrodynamics and initial density profile

- Event-by-event hydrodynamics from Hannu Holopainen et al., Phys. Rev. C 83, 034901 (2011).

- Monte Carlo Glauber Model: two nucleons i and j from different nuclei collide when

$$(x_i - x_j)^2 + (y_i - y_j)^2 \leq \frac{\sigma_{NN}}{\pi}$$



- Entropy density s is distributed in the (x,y) plane around the wounded nucleons using a 2D Gaussian:

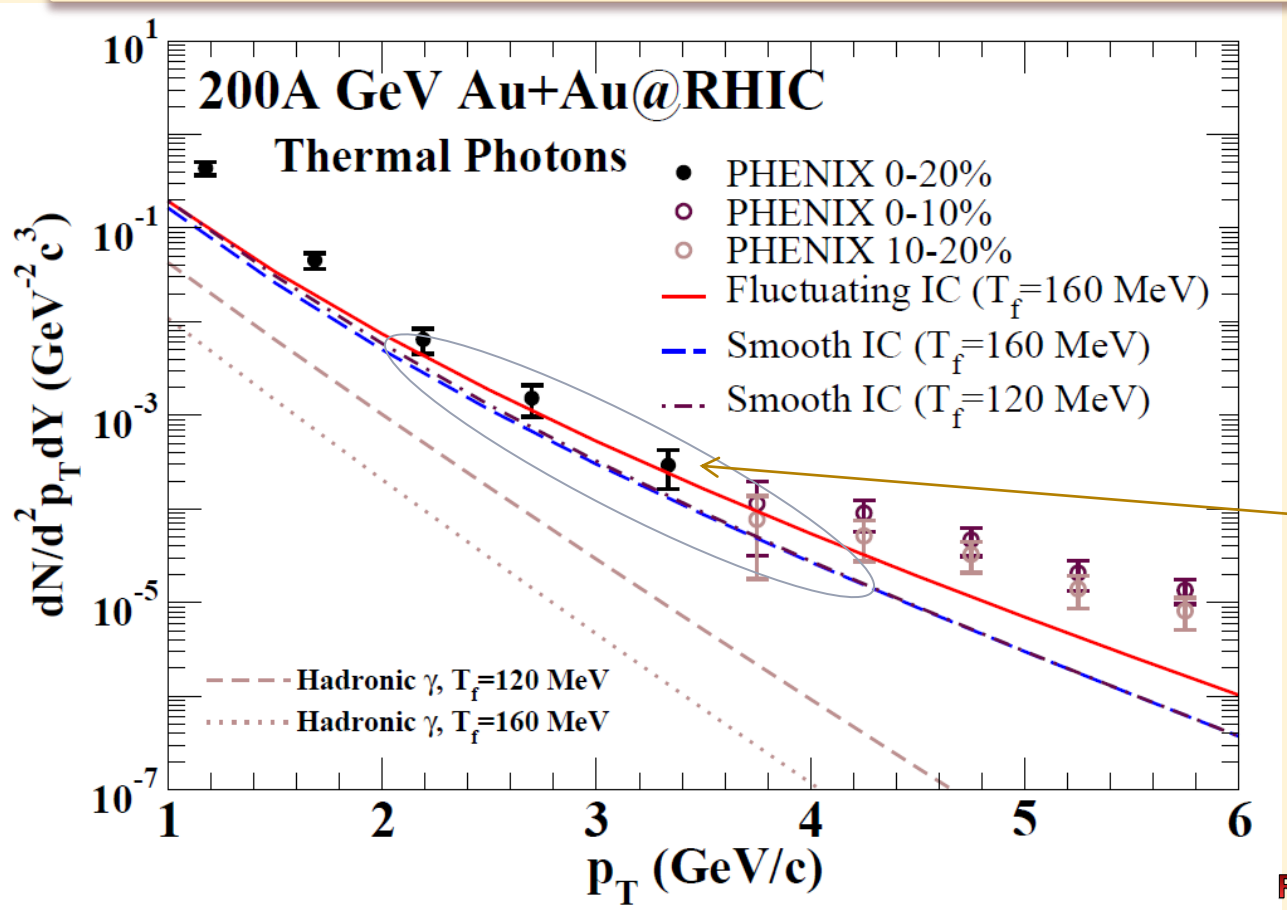
$$s(x,y) = \frac{K}{2\pi\sigma^2} \sum_{i=1}^{N_{WN}} \exp\left(-\frac{(x - x_i)^2 + (y - y_i)^2}{2\sigma^2} \right)$$

- σ is a free parameter determining the size of the fluctuation.

- Successfully reproduces both the measured centrality dependence and the p_T shape of charged particle elliptic flow upto p_T ~ 2 GeV.

Photons are especially suitable for probing fluctuations in the initial conditions

Thermal photons from smooth and fluctuating initial density profiles



τ_0=0.17 fm/c
σ=0.4 fm

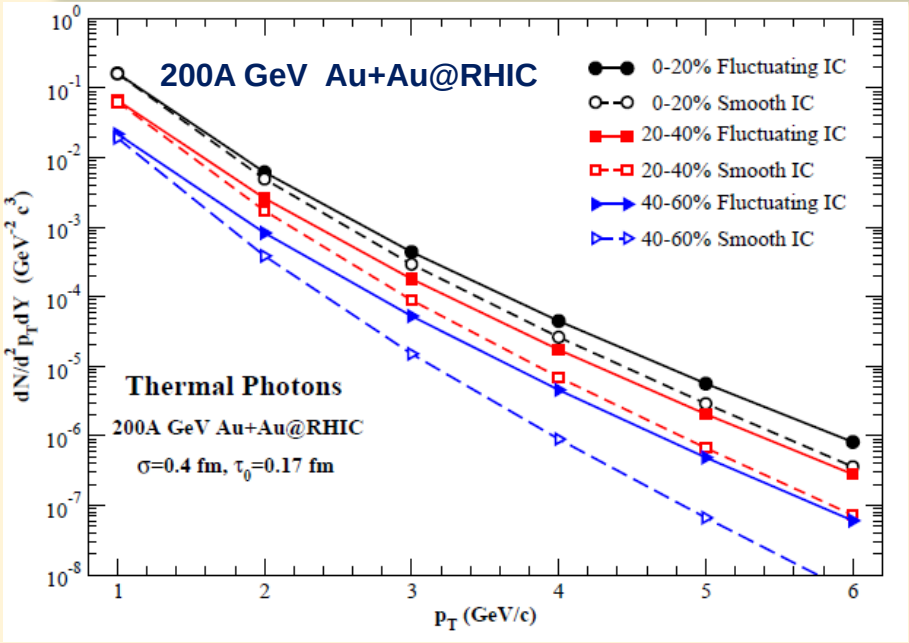
Spectrum from fluctuating initial conditions (IC) is flatter than the spectrum from smooth IC.

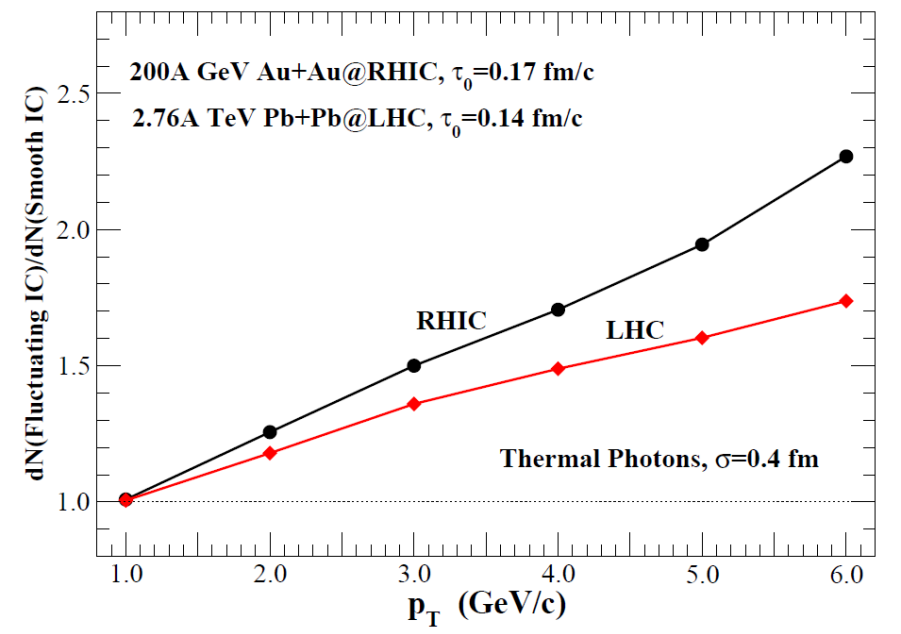
RC, Holopainen, Renk, Eskola, Phys. Rev. C 83, 054908 (2011)

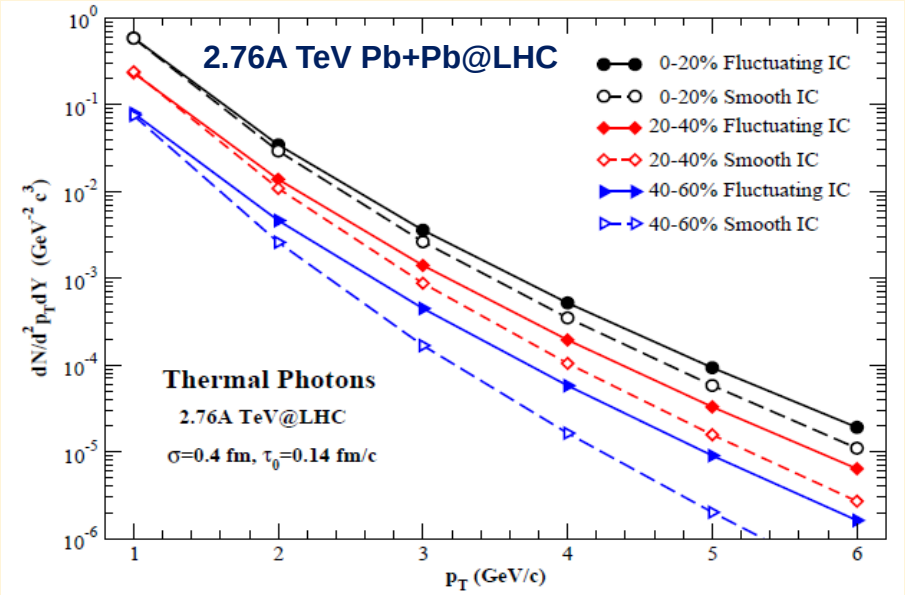
- The hotspots in the fluctuating events produce more high p_T photons compared to the smooth profile.

- Note: Hardening of hadron spectra from fluctuating IC is due to larger radial flow.

Thermal photons from smooth and fluctuating initial conditions: collision centrality and beam energy dependence





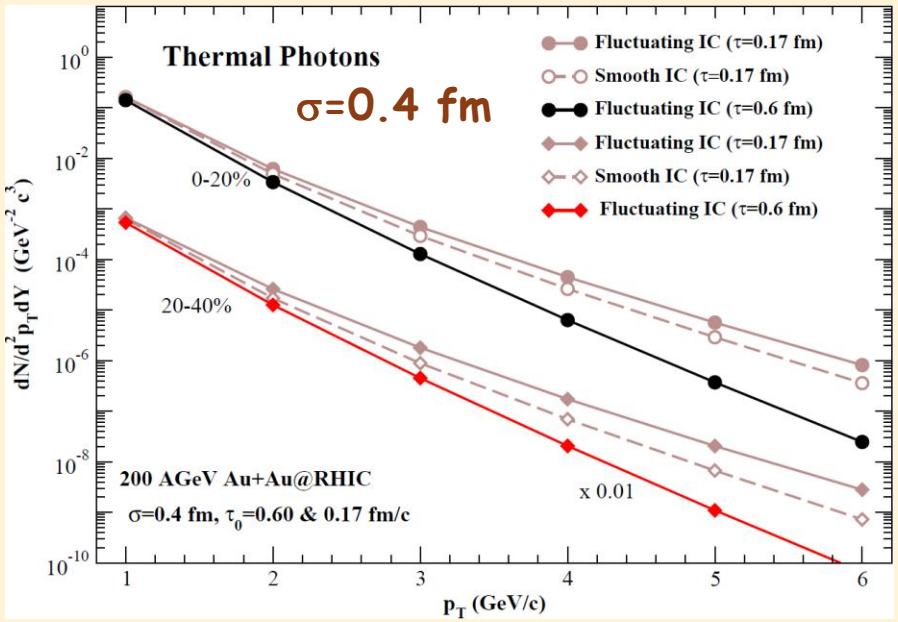


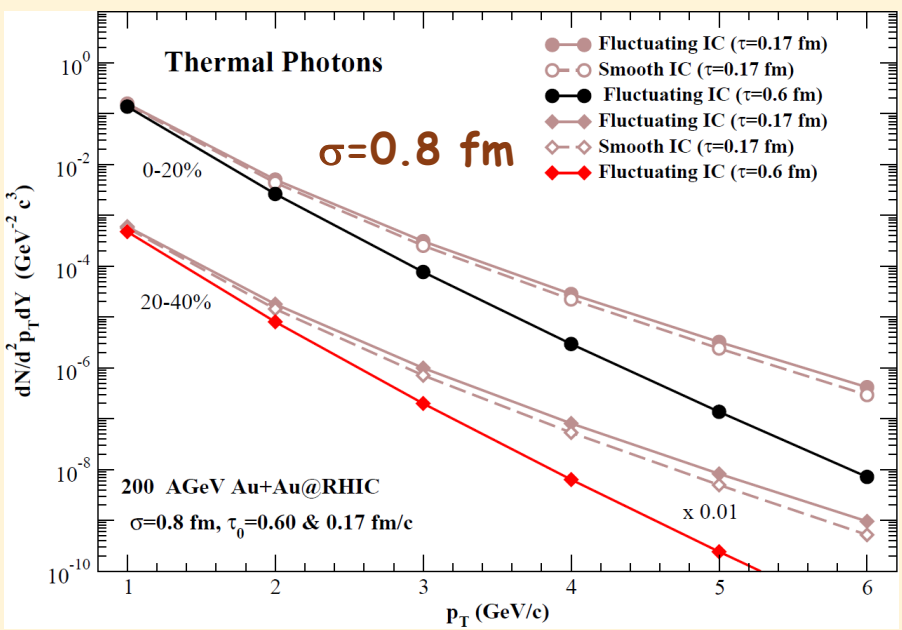
RC, Holopainen, Renk, Eskola, Phys. Rev. C 85, 064910 (2012)

<u>The effect of fluctuations in the initial conditions is more pronounced:</u>

- for peripheral collisions than for central collisions.
- at RHIC than at LHC.

Results are sensitive to the initial formation time and size parameter





Initial formation time of the plasma τ_0 is not known unambiguously.

The range of τ_0 mostly used is 0.17-0.6 fm/c.

p_T spectra are compared for τ_0 values 0.17 and 0.60 fm/c.

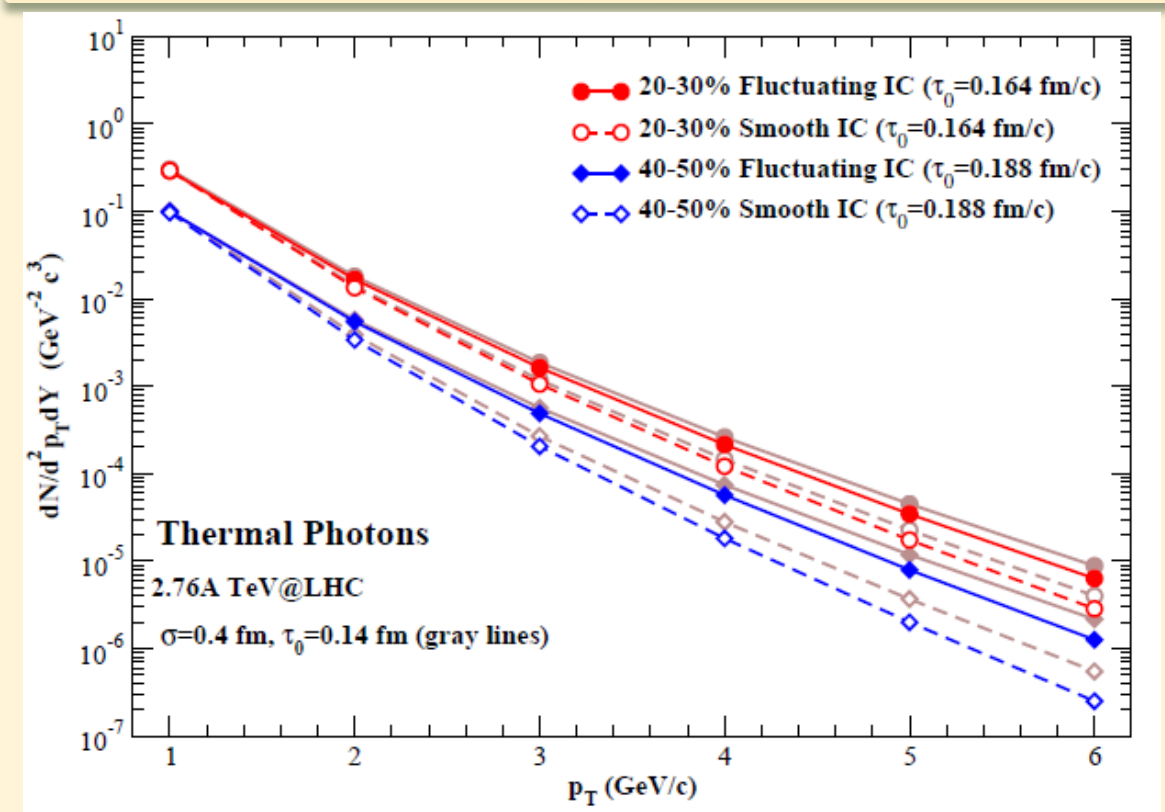
Spectra fall sharply for larger values of τ_0.

Difficult to differentiate between enhancement due to :

- IC fluctuations
- a relatively smaller value of τ_0.

RC, Holopainen, Renk, Eskola, Phys. Rev. C 85, 064910 (2012)

Effect of centrality dependent formation time and fluctuating IC



The p_T spectra alone are found to be insufficient to quantify the fluctuations in the IC due to uncertainties in the initial conditions.

Centrality bin (%)	p_0 (GeV)	A_{eff}	τ_0 (fm)
0 – 5	1.3945	193	0.140
20 – 30	1.2070	90	0.164
40 – 50	1.0507	40	0.188

Table from Risto Paatelainen

Centrality dependent formation time is estimated from EKRT model.

RC, Holopainen, Renk, Eskola, Phys. Rev. C 85, 064910 (2012)

A suitably normalized ratio of central to peripheral yield of thermal photons (R^{γ}_{cp}) can be a useful measure of the fluctuation size scale by reducing the uncertainties in the model calculation.

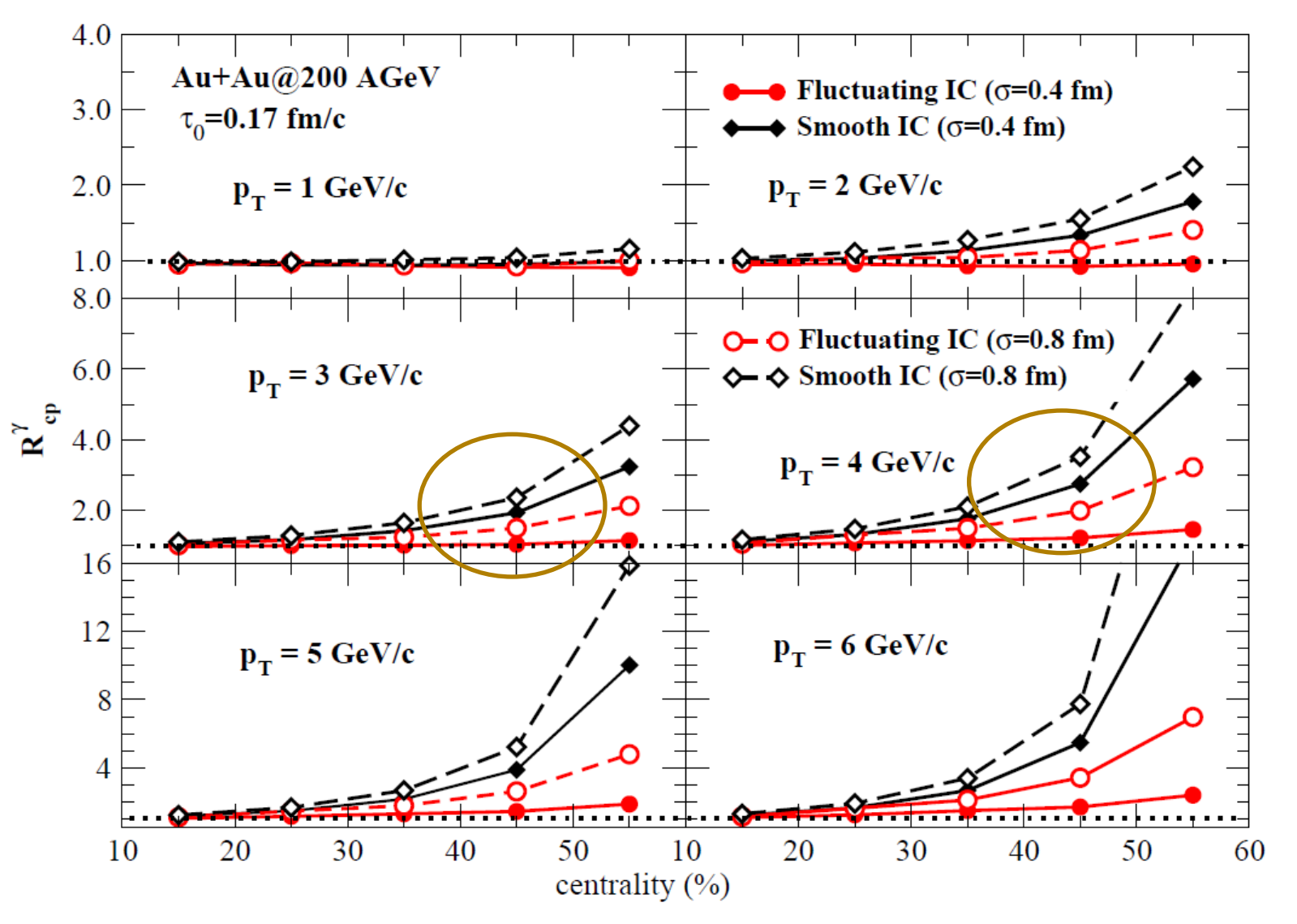
R^{γ}_{cp}, is defined as:

$$R_{cp}{}^{\gamma}\,|_i = \frac{dN/d^2p_T dY\,|_{0-10\%}}{dN/d^2p_T dY\,|_{i-j\%}} \times \frac{N_{bin}\,|_{i-j\%}}{N_{bin}\,|_{0-10\%}}$$

R^{γ}_{cp} is calculated as a function of collision centrality for different values of p_T and σ.

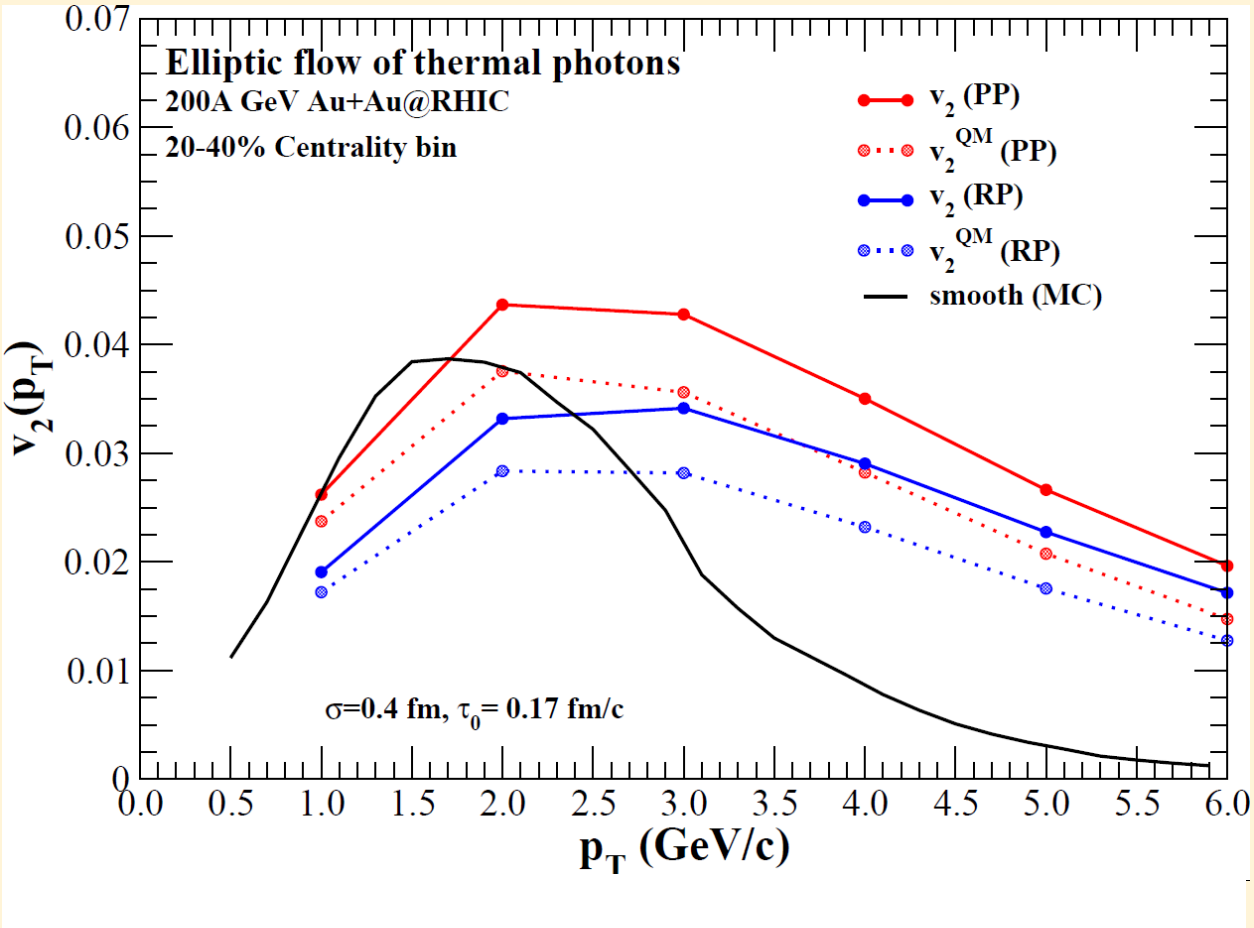
Note: we choose a different definition of R^{γ}_{cp} rather than the conventional definition. The numerator is kept fixed in our case as hydrodynamics is known to work better for central collisions.

Thermal photons R^{γ}_{cp} at RHIC for σ values 0.4 & 0.8 fm



RC, Holopainen, Renk, Eskola, Phys. Rev. C 85, 064910 (2012)

$v_2(p_T)$ of thermal photons from 200A GeV Au+Au@RHIC & 20-40% centarlity bin



RP: reaction plane
PP: participant plane

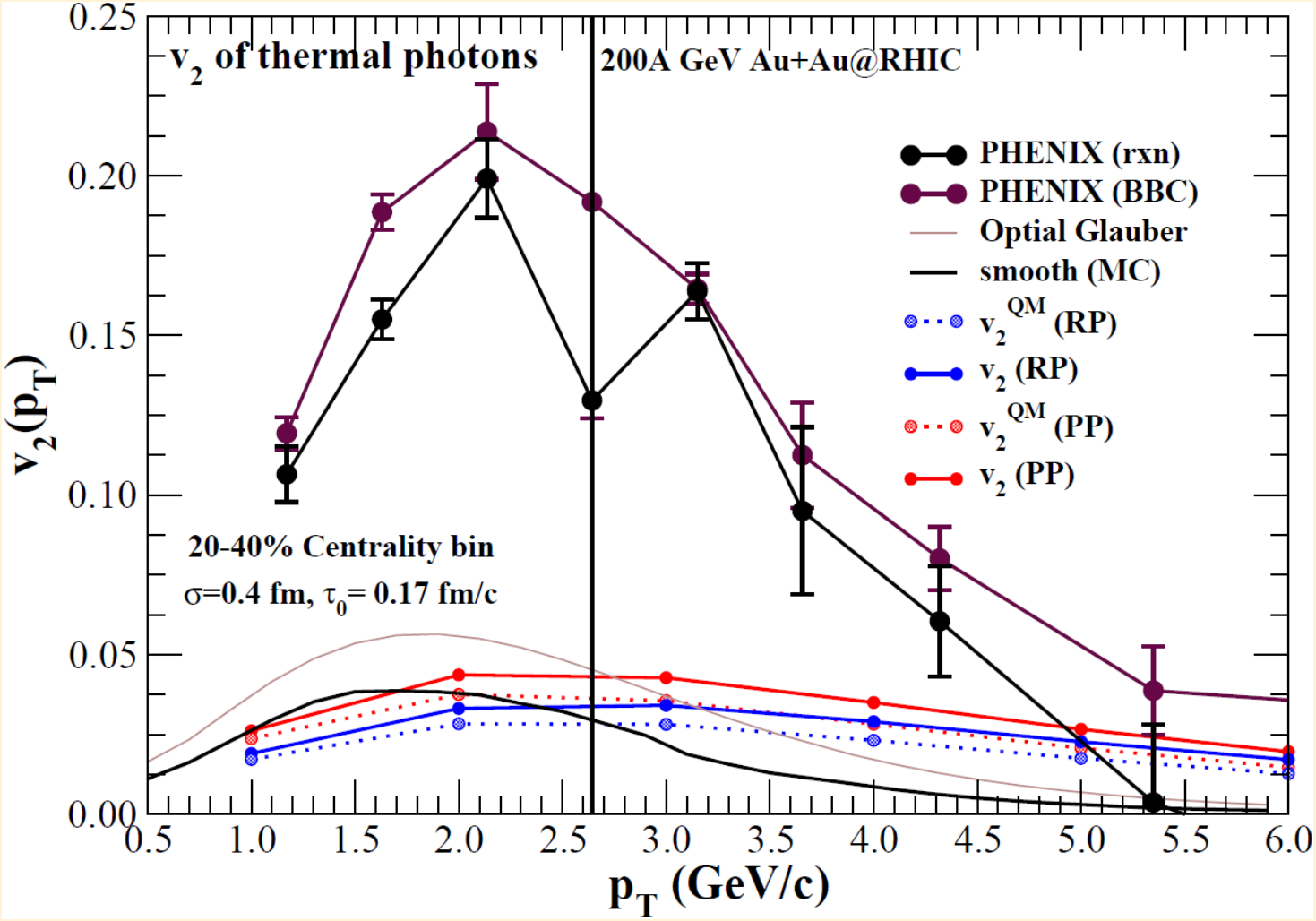
Larger v_2 from fluctuating IC for $p_T > 2$ GeV/c compared to smooth IC.

Low p_T part (< 2 GeV/c) is not affected significantly.

RC, Holopainen, Renk, Eskola, in preparation

$v_2(PP) = \langle\cos(2(\varphi - \psi_{PP}))\rangle_{events}$ $\qquad$ $v_2(RP) = \langle\cos(2\varphi)\rangle_{events}$

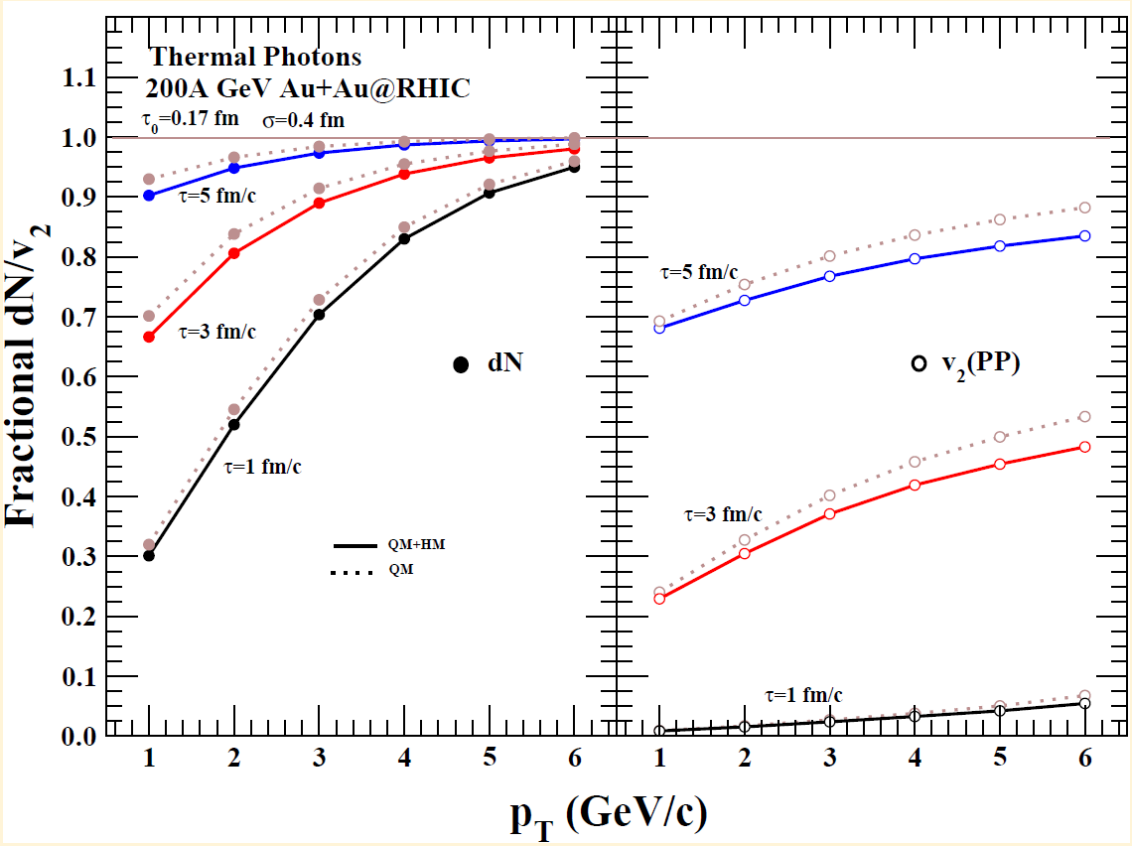
Comparison with the direct photon v_2 data from PHENIX

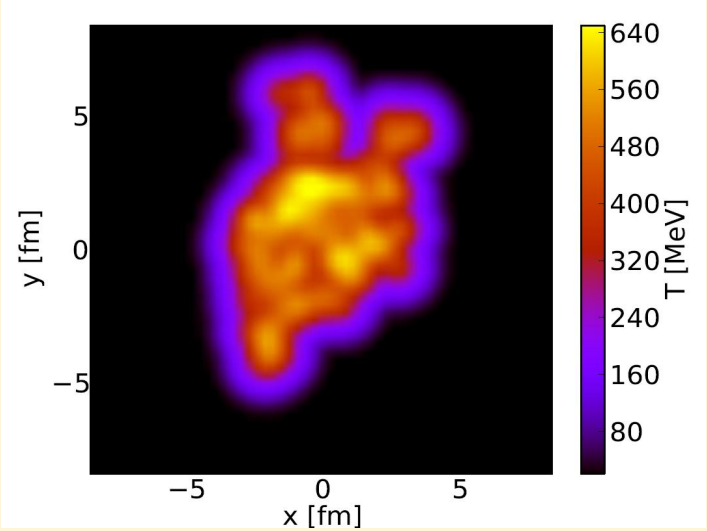


- Our results are still well below the experimental data points.

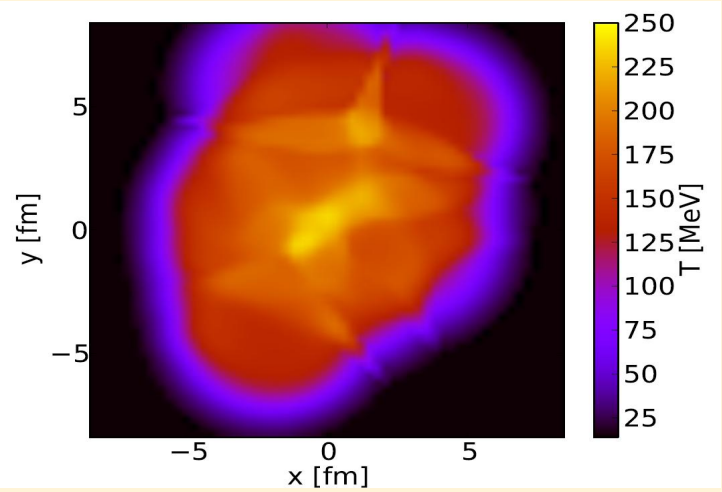
- Larger τ_0 and smaller freezeout temperature increase the v_2 significantly, however no enough to match the data points.

Time evolution of p_T spectra & $v_2(p_T)$ of thermal photons





τ=0.17 fm/c, σ=0.4 fm



τ=3.0 fm/c, σ=0.4 fm

RC, Holopainen, Renk, Eskola, in preparation

Summary and conclusions

- Fluctuations in the initial QCD matter density distribution lead to a significant enhancement in the production of thermal photons compared to a smooth initial state averaged profile.

- The enhancement is found to be more pronounced for peripheral collisions than for central collisions. The relative enhancement is found to be comparatively less at LHC than at RHIC for the same centrality bin.

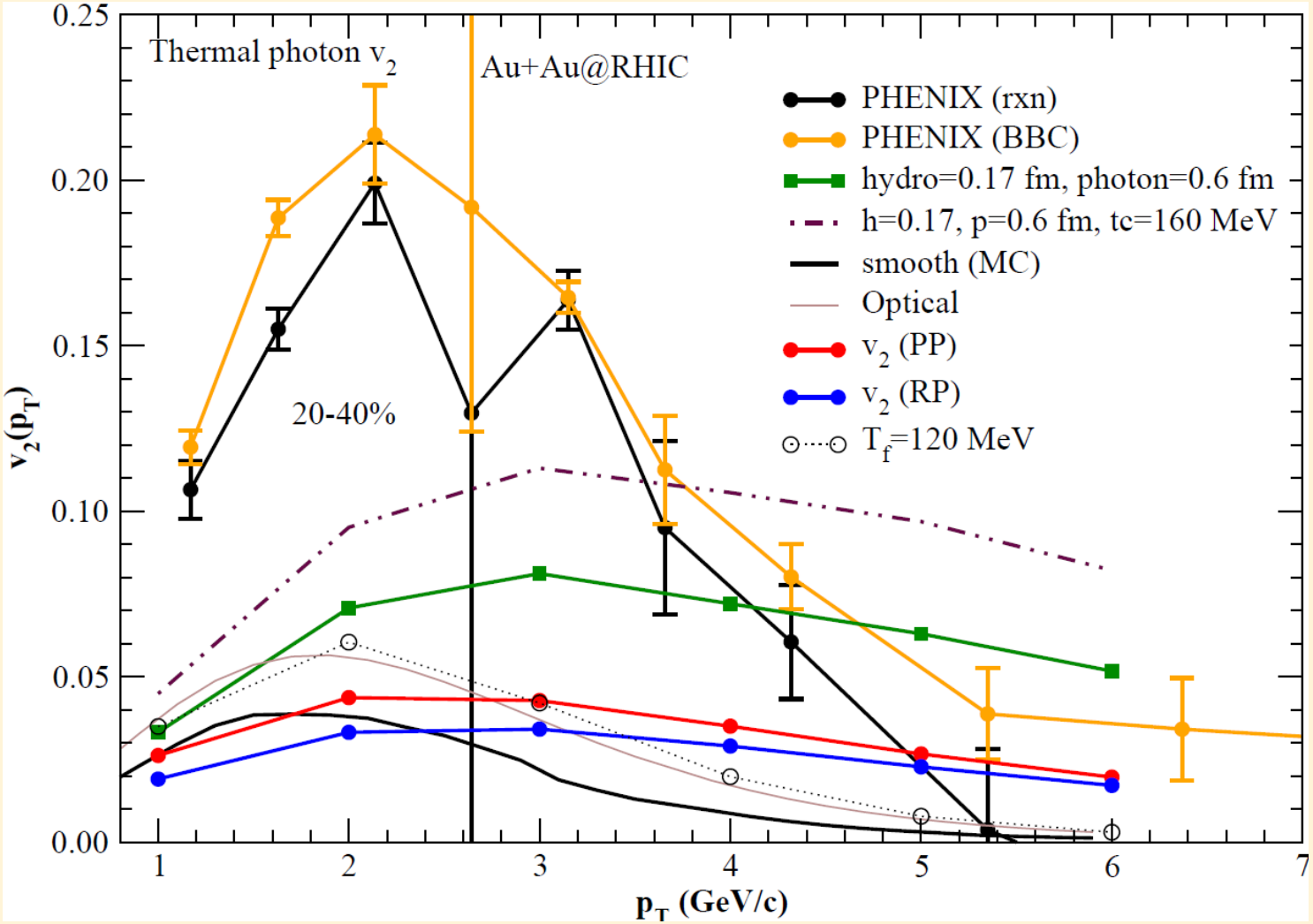
- The p_T spectra at RHIC and LHC are found to be quite sensitive to the value of the initial formation time which may also vary with collision centralities.

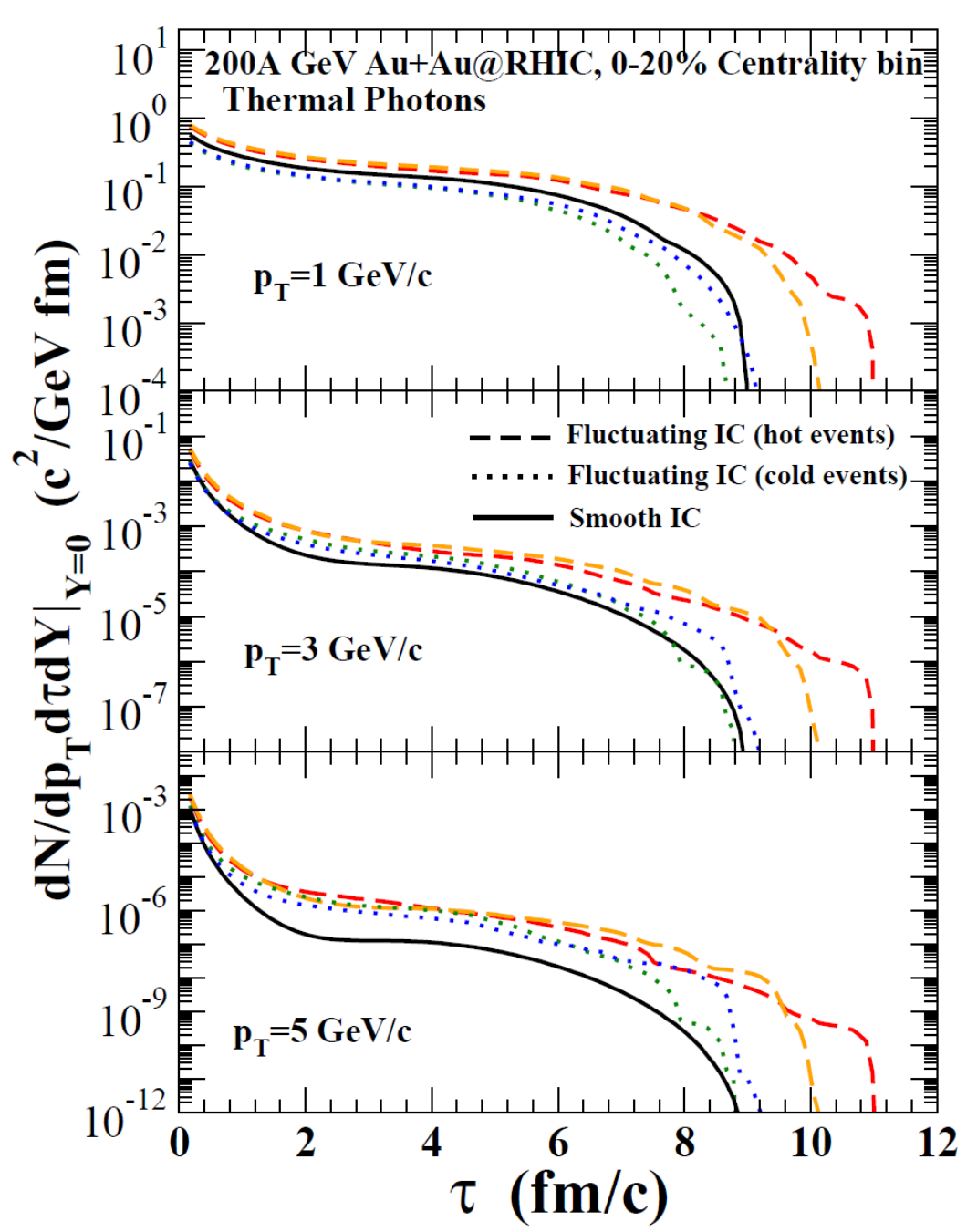
- The p_T spectra alone are found to be insufficient to quantify the fluctuations in the initial density distribution due to the uncertainties in the initial conditions.

- A suitably normalized ratio of central-to-peripheral yield as a function of collision centrality and p_T can be a useful measure of the fluctuation size scale.

- Fluctuations in the IC enhance the $v_2(p_T)$ significantly for $p_T > 2$ GeV/c, however not enough to explain the experimental data points.

THANK YOU


Thermal photon v_2
Au+Au@RHIC
20-40%
PHENIX (rxn)
PHENIX (BBC)
hydro=0.17 fm, photon=0.6 fm
h=0.17, p=0.6 fm, tc=160 MeV
smooth (MC)
Optical
v_2 (PP)
v_2 (RP)
T_f=120 MeV
$v_2(p_T)$
p_T (GeV/c)
0.00
0.05
0.10
0.15
0.20
0.25
1
2
3
4
5
6
7



Time evolution

- Results from smooth and fluctuating initial conditions.

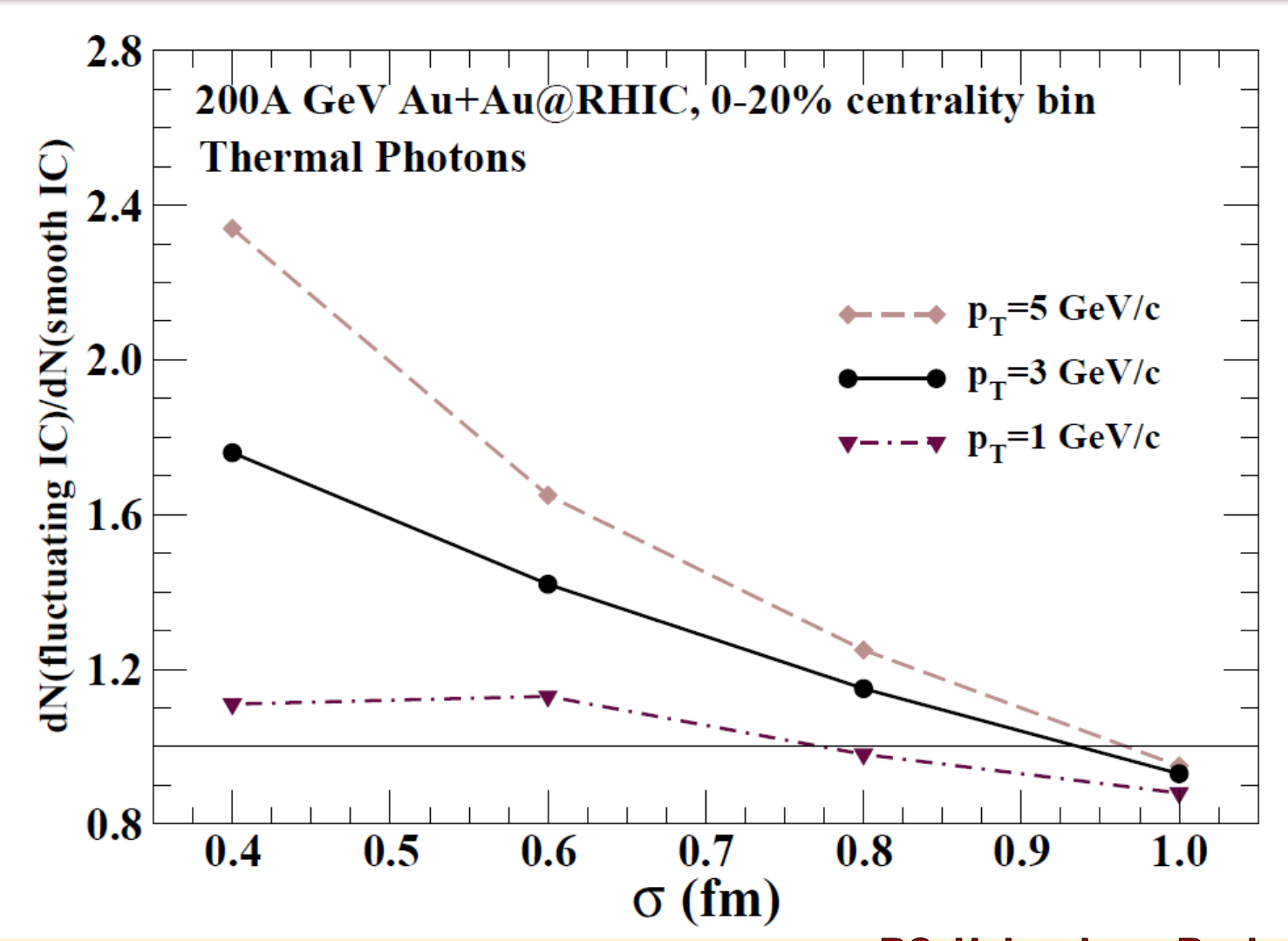
- Two very hot events and two relatively cold events are chosen for the fluctuating IC.

Hot events: entropy larger than average entropy.
Cold events: entropy smaller than average entropy.

- The cold events produce more photons compared to the smooth IC for $p_T \geq 3$ GeV/c due to the presence of hotspots.

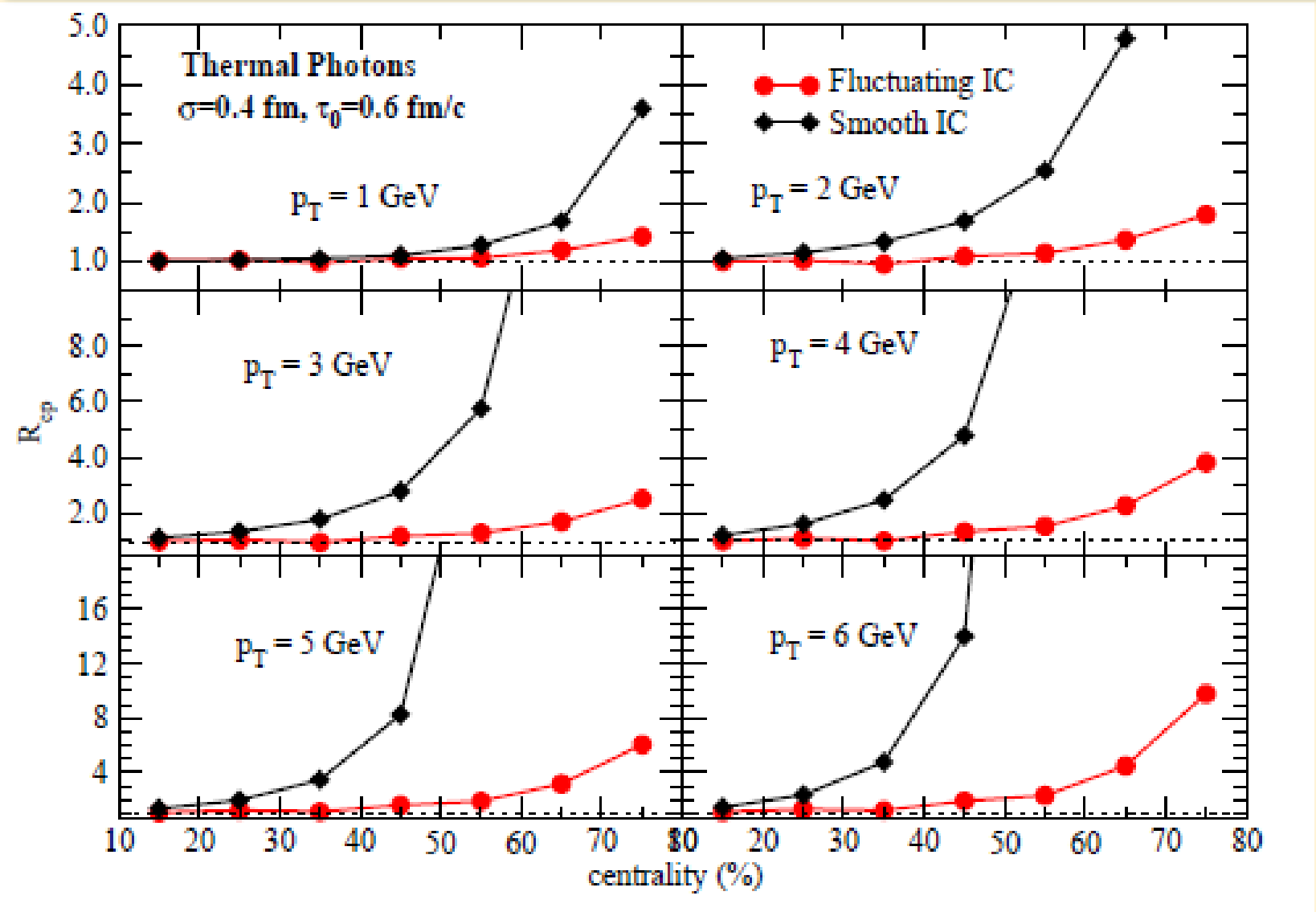
RC, Holopainen, Renk, Eskola, Phys. Rev. C 83, 054908 (2011)

Ratio of photon production from fluctuating and smooth IC at different p_T as a function of the size parameter σ.



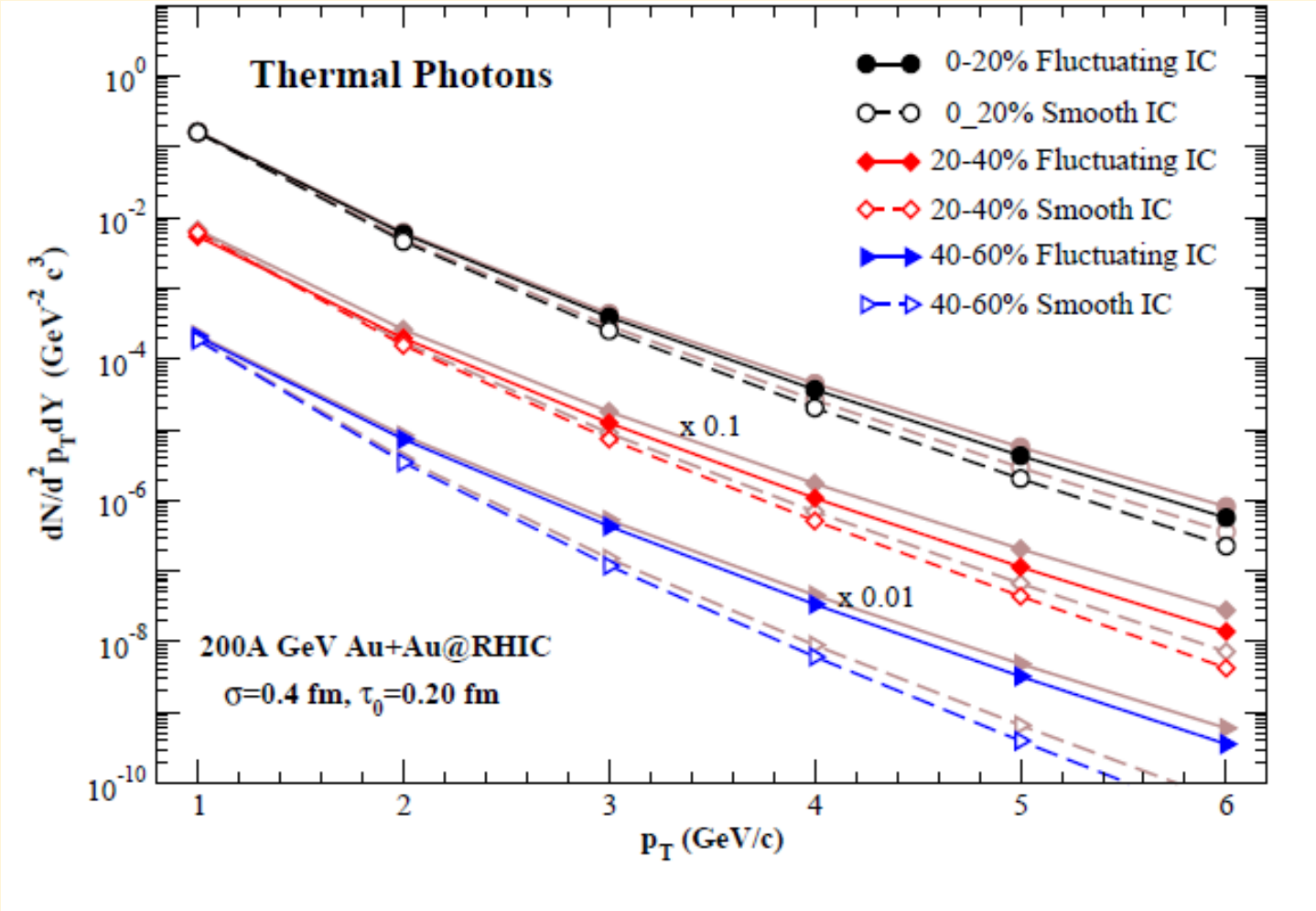
RC, Holopainen, Renk, Eskola, Phys. Rev. C 83, 054908 (2011)

R^{γ}_{cp} for thermal photons at RHIC, size parameter 0.4 fm and τ_o=0.6 fm/c



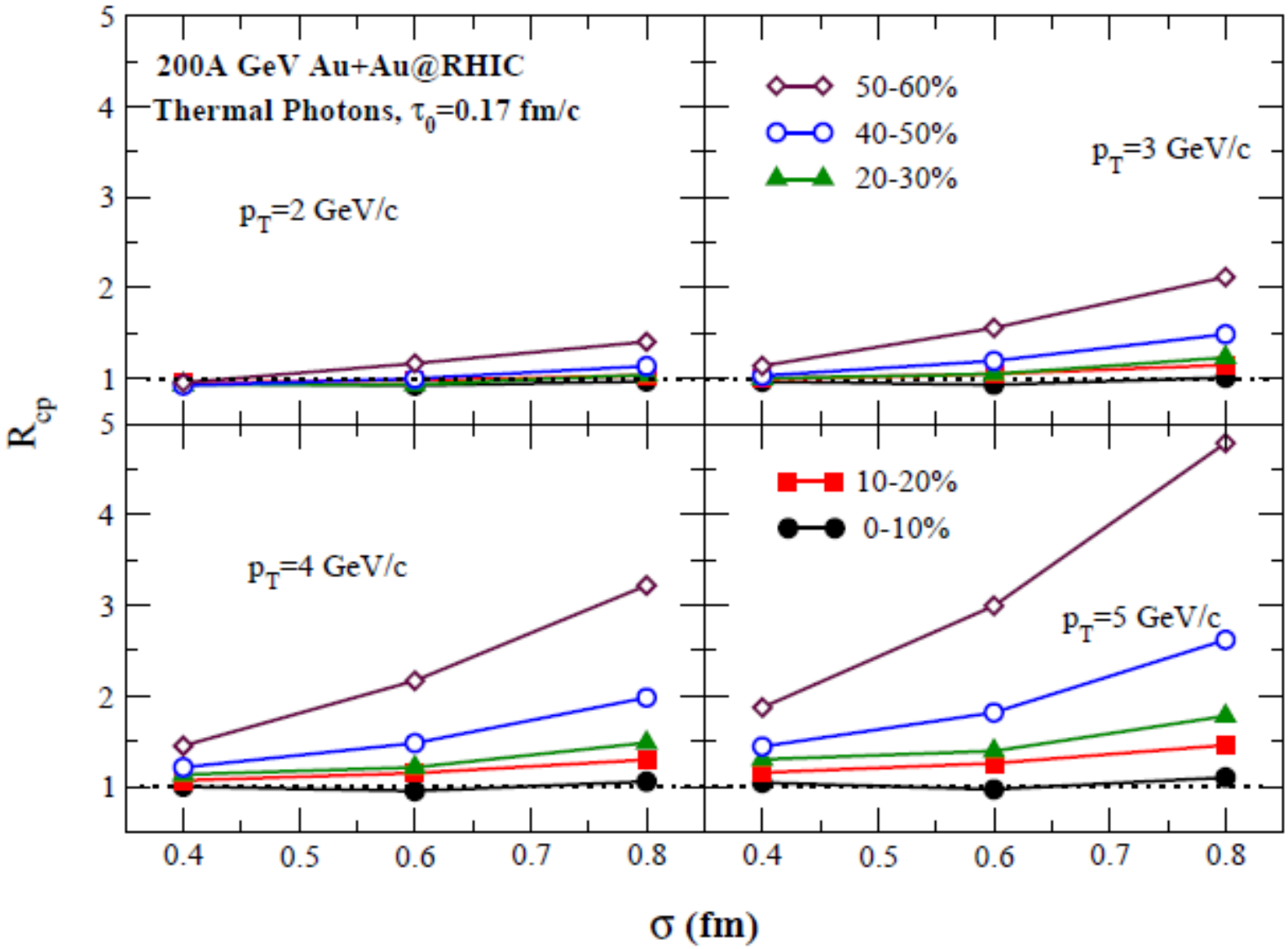
RC, Holopainen, Renk, Eskola, Phys. Rev. C 85, 064910 (2012)

Thermal photons from smooth and fluctuating IC at RHIC comparison between results from τ_0= 0.17 and 0.20 fm/c

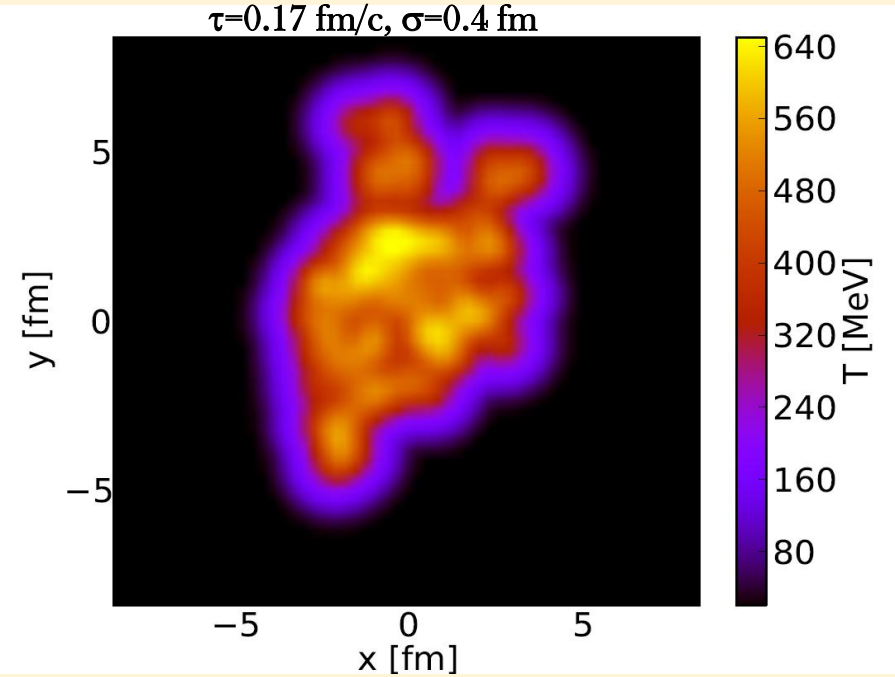


RC, Holopainen, Renk, Eskola, Phys. Rev. C 85, 064910 (2012)

R^{γ}_{cp} as a function of σ for different p_T



RC, Holopainen, Renk, Eskola, Phys. Rev. C 85, 064910 (2012)


τ=0.17 fm/c, σ=0.4 fm
y [fm]
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T [MeV]
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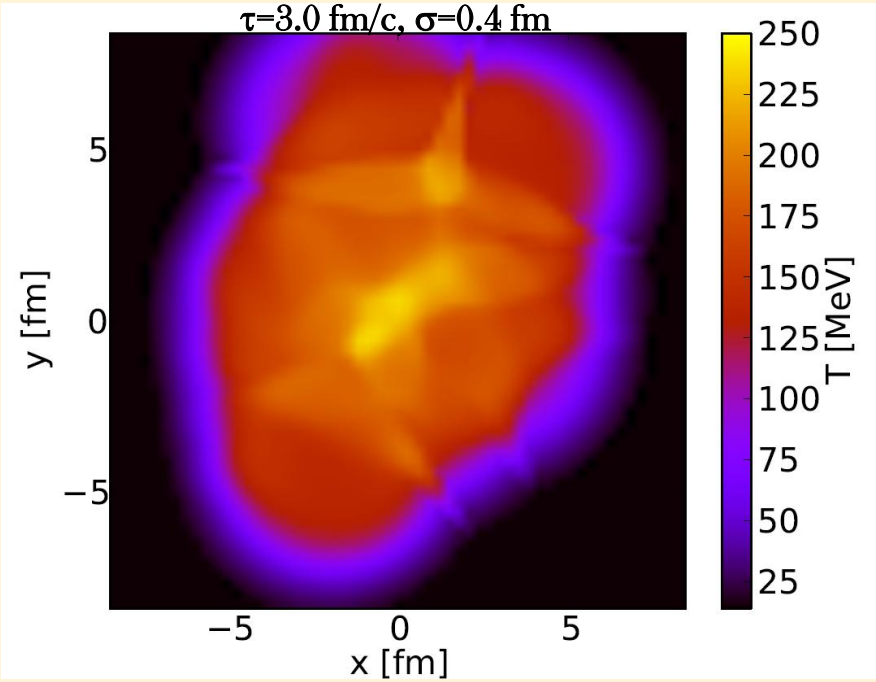
τ=3.0 fm/c, σ=0.4 fm
y [fm]
x [fm]
T [MeV]
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225
200
175
150
125
100
75
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25
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0
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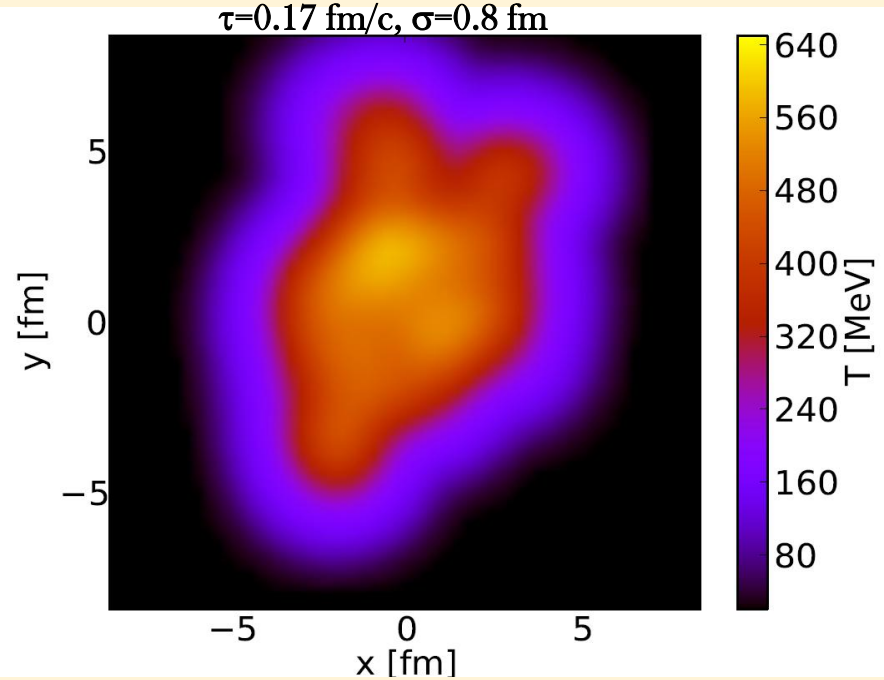
τ=0.17 fm/c, σ=0.8 fm
y [fm]
x [fm]
T [MeV]
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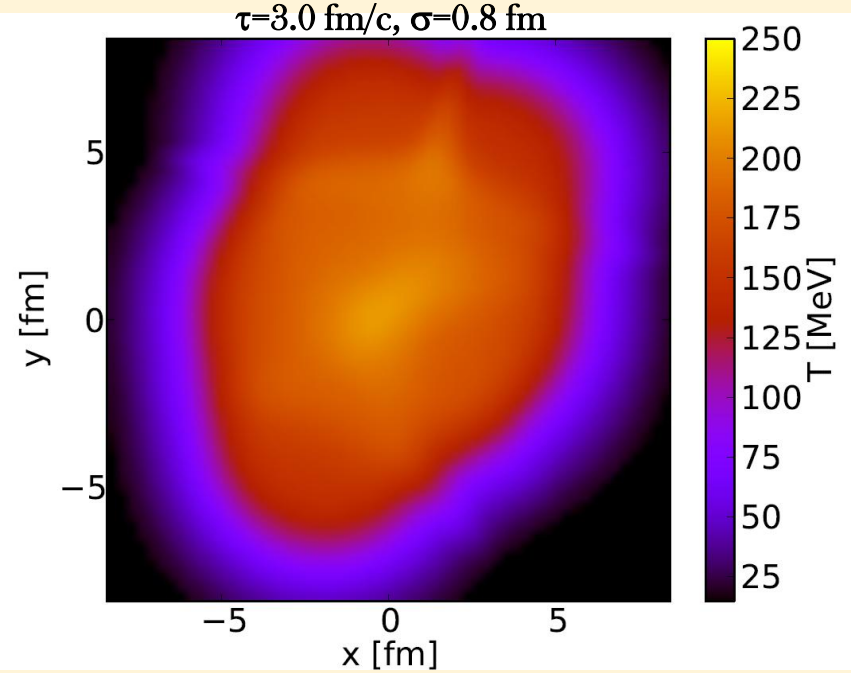
τ=3.0 fm/c, σ=0.8 fm
y [fm]
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T [MeV]
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