Update on simulations of direct photon yield at NICA energies

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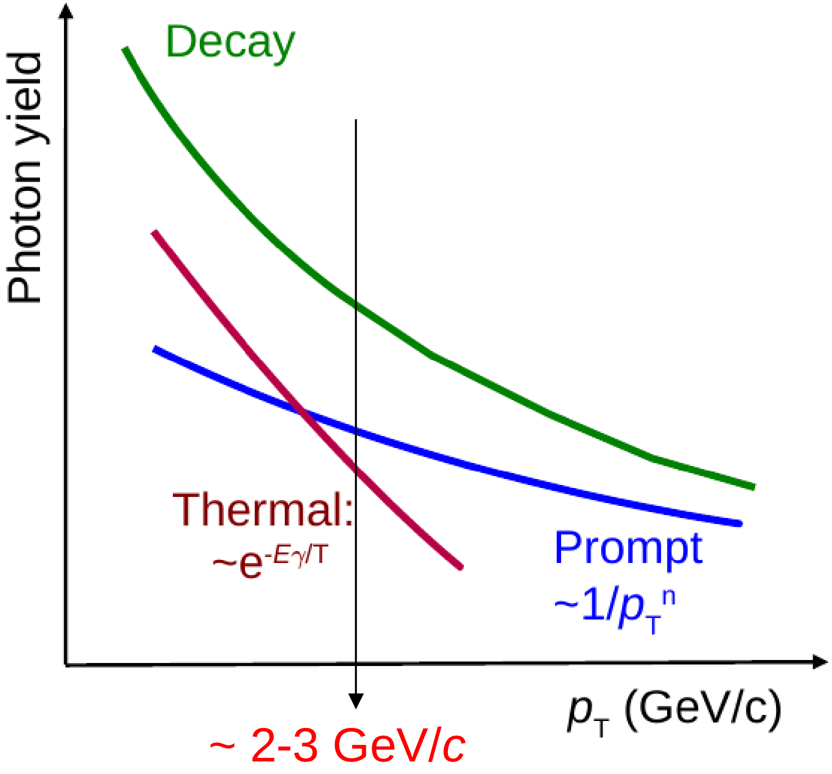
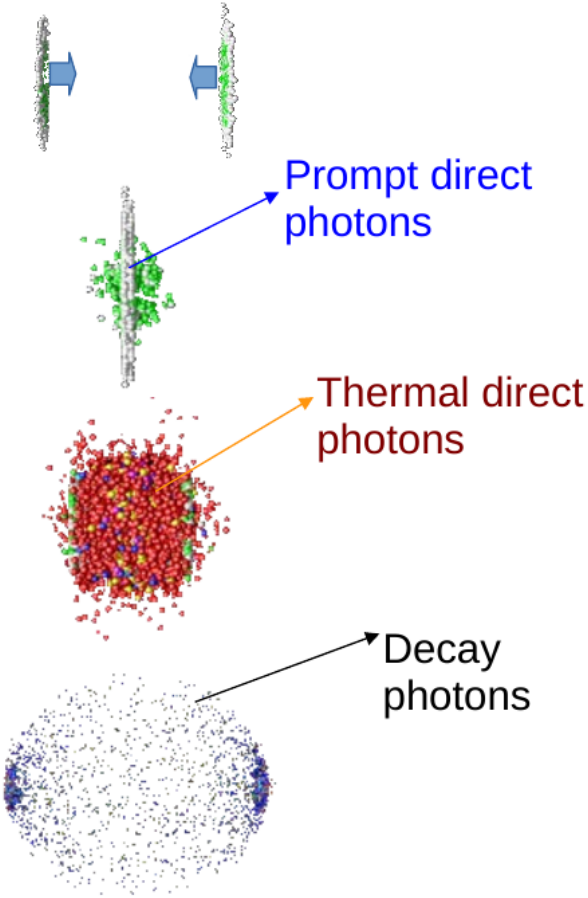
Motivation

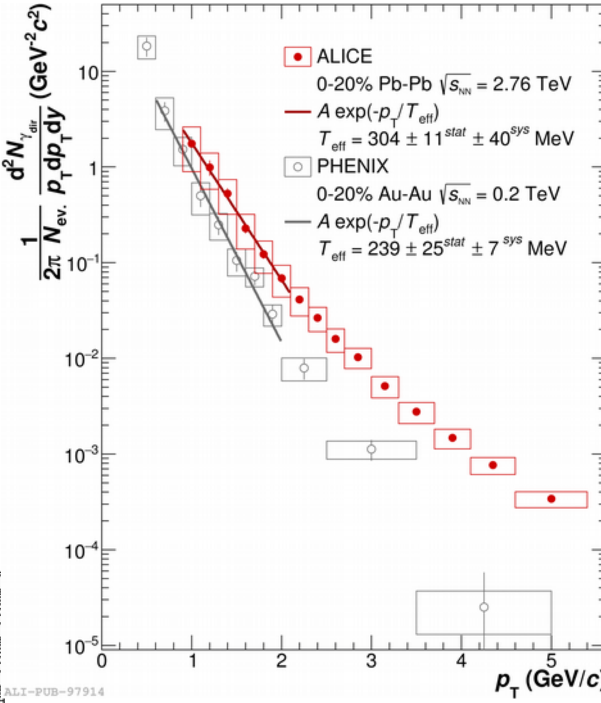
- Direct photons – photons not originating from hadronic decays but produced in electromagnetic interactions in course of collision
- Photons are produced at different collision times
- Photons don’t interact strongly and carry out information about collision, even the earliest stage

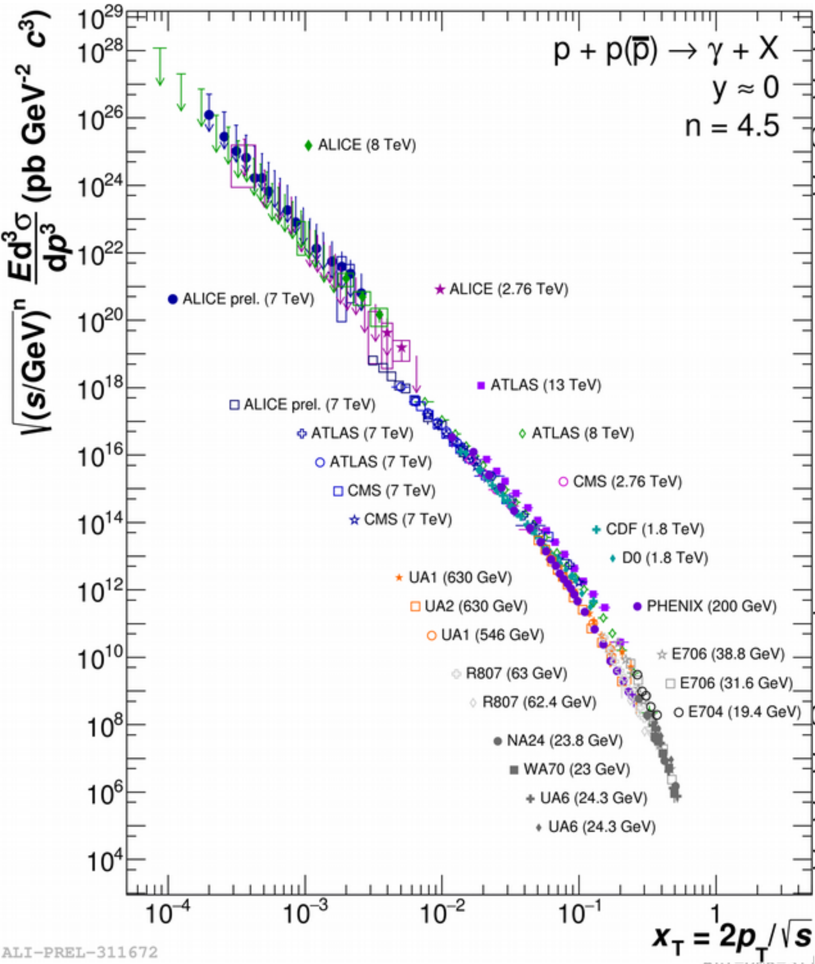


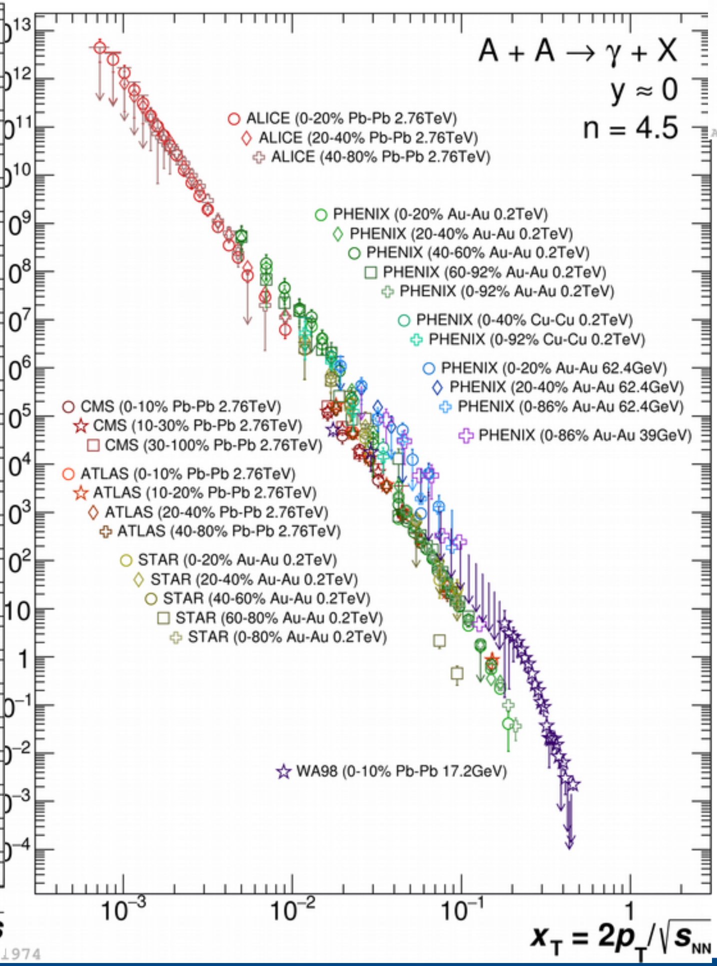


Motivation

Via direct photons we can study properties of QGP (i.e. Temperature) and test QCD.
Interesting also is xT scaling properties at large xT.







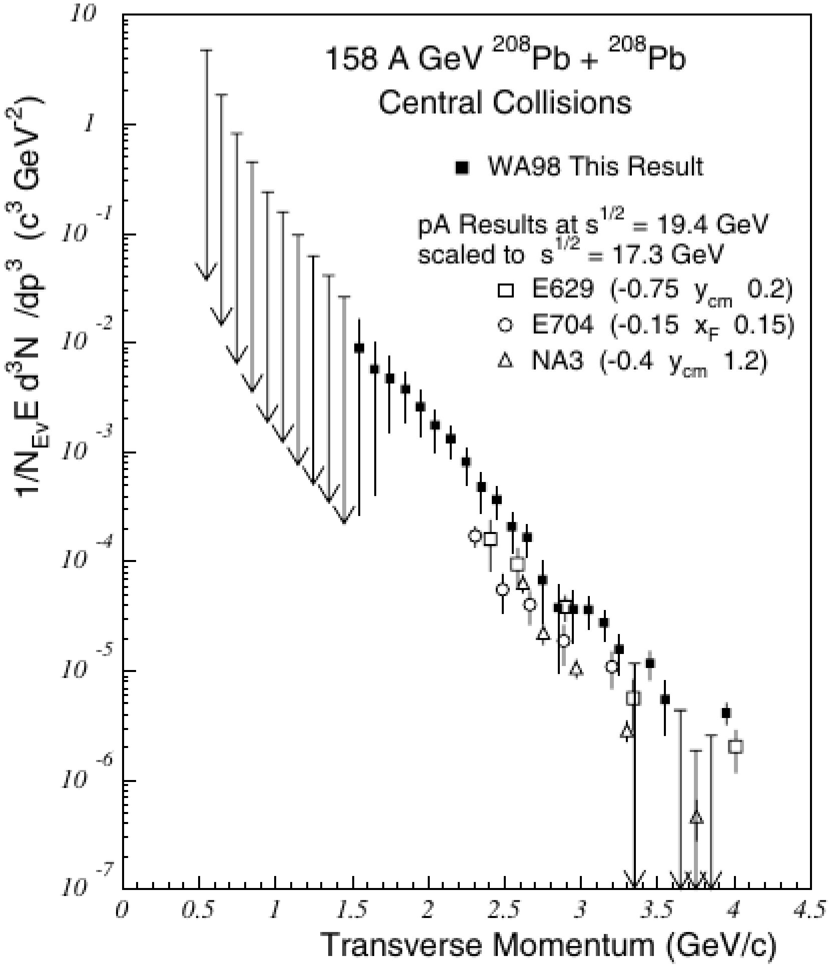
Motivation

Thanks to large electromagnetic calorimeter of MPD, it is possible to measure neutral mesons and photons in previously not-well-discovered region of $\sqrt{s_{NN}}$: 4-11 GeV.

Previous studies of AA collisions at low energies mainly concern WA98 experimental results ($\sqrt{s_{NN}}$ = 17.2 GeV) which served as a reference for simulations, see:

- M M Aggarwal et al, (WA98 Collaboration), Phys. Rev. Lett. 85, 3595 (2000)
- B. Bäuchle and M. Bleicher, PhysRevC 81 (2010) 044904 – UrQMD simulations with hybrid approach

See also nice review by T. Peitzmann: “Direct photon production in heavy-ion reactions at SPS and RHIC” Pramana – J. Phys. V. 60 Issue 4 pp 651-661 (2003)



Calculation of direct photon yield

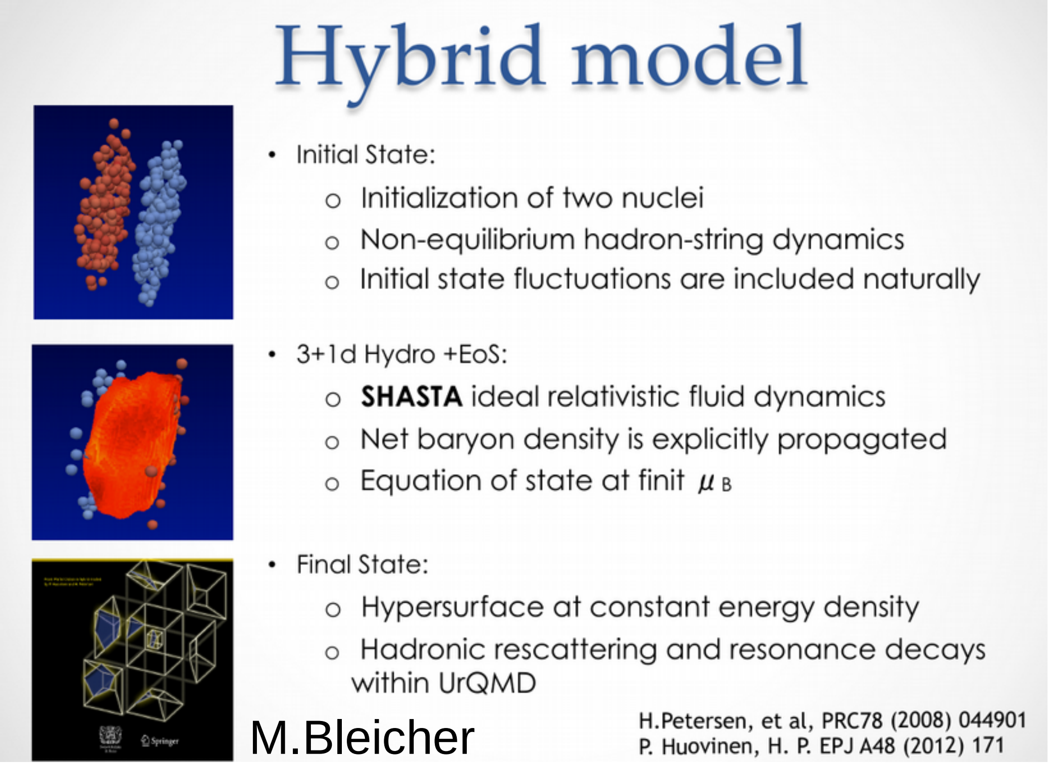
We use UrQMD with hydro evolution ("hybrid approach") in order to calculate direct photon yields. Each cell have T_i, E_i, μb_i. If T is high it is in QGP, if low – in HG, intermediate – mixed phase. For QGP calculate emission rate from QGPRate(E_i,T_i,μb_i) Peter Arnold, Guy D. Moore, Laurence G. Yaffe JHEP 0112:009 2001

For HG from HadronRate(E_i,T_i,μb_i) Simon Turbide, Ralf Rapp, Charles Gale Phys.Rev.C69:014903,2004

Mixed phase (1-QGP_fraction) * HadronRate(E_i,T_i,μb_i) + QGP_fraction * QGPRate(E_i,T_i,μb_i)

Integrate over all cells and all timesteps

UrQMD model version 3.4: http://uqrdm.org Prog. Part. Nucl. Phys. 41 (1998) 225-370
Hybrid approach: Phys. Rev. C 78 (2008) 044901
Options to choose EOS (cto 47): HG, Chiral or BM. At the moment we use Bag model option



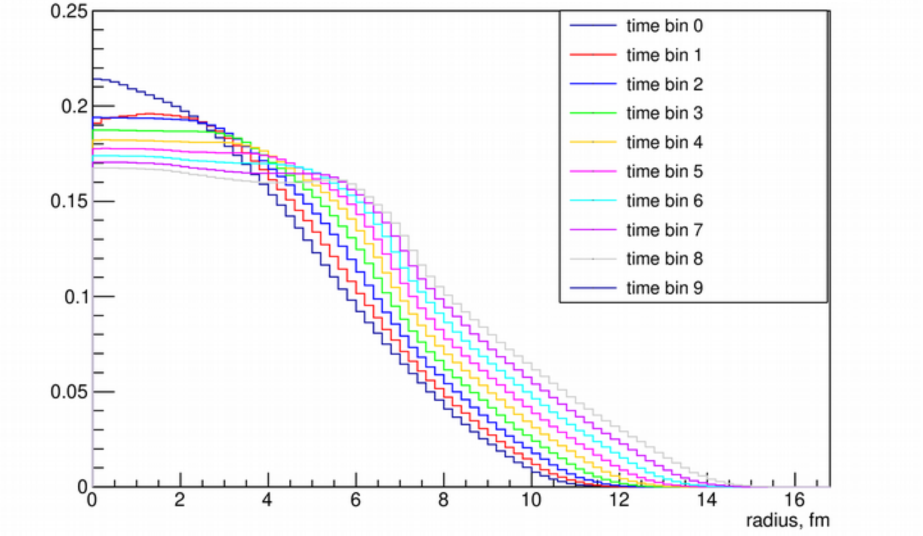
Hybrid model

- Initial State:
  - Initialization of two nuclei
  - Non-equilibrium hadron-string dynamics
  - Initial state fluctuations are included naturally
- 3+1d Hydro +EoS:
  - **SHASTA** ideal relativistic fluid dynamics
  - Net baryon density is explicitly propagated
  - Equation of state at finit μ_B
- Final State:
  - Hypersurface at constant energy density
  - Hadronic rescattering and resonance decays within UrQMD

M.Bleicher

H.Petersen, et al, PRC78 (2008) 044901
P. Huovinen, H. P. EPJ A48 (2012) 171

Temperature vs radius for different timesteps for √sNN = 11 GeV



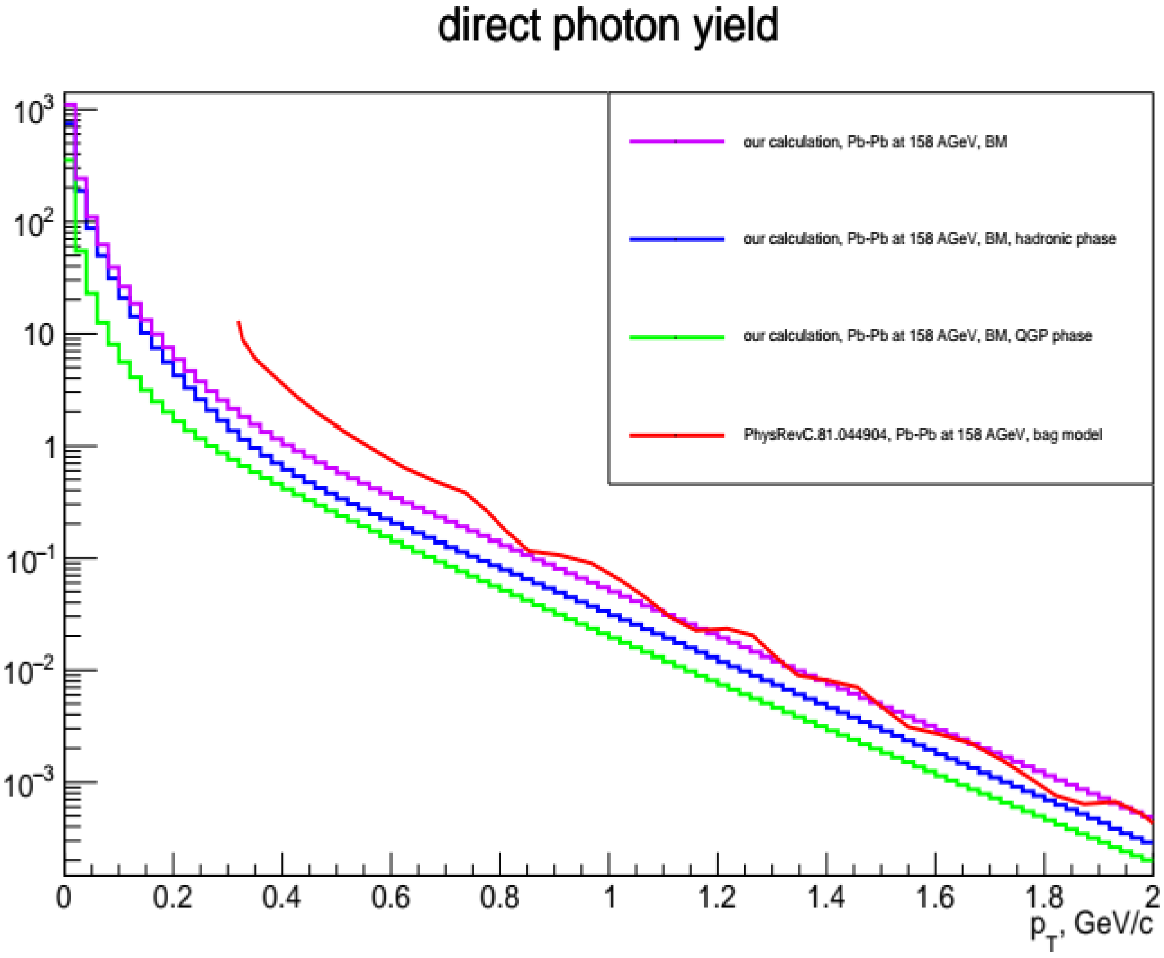
Calculation of pi0 yield

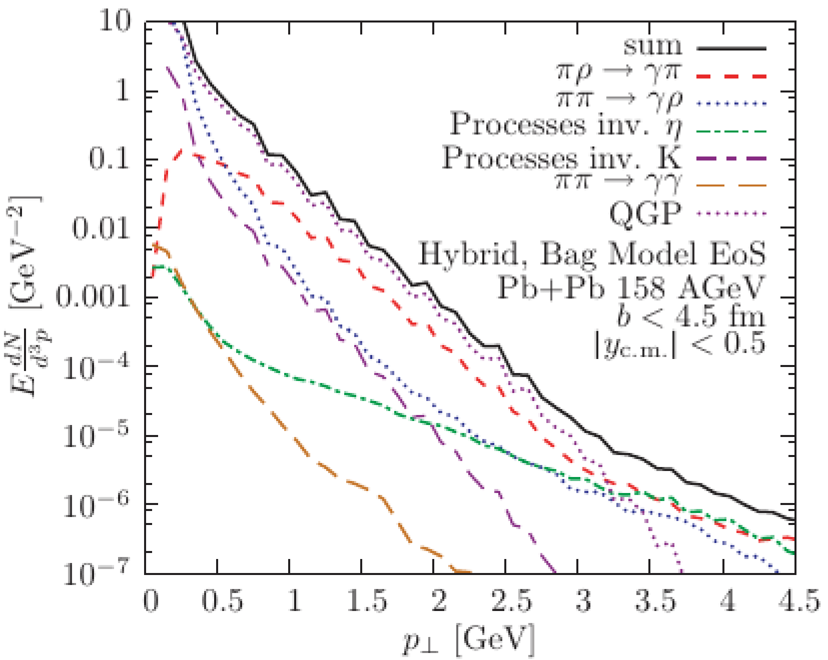
- Calculate π^0 yield from UrQMD with hydro mode off (cto 45 0). Cut on unit rapidity: |y|<0.5
- Calculate decay photon spectrum. Cut on unit rapidity: |y|<0.5

Comparisons at 158 AGeV

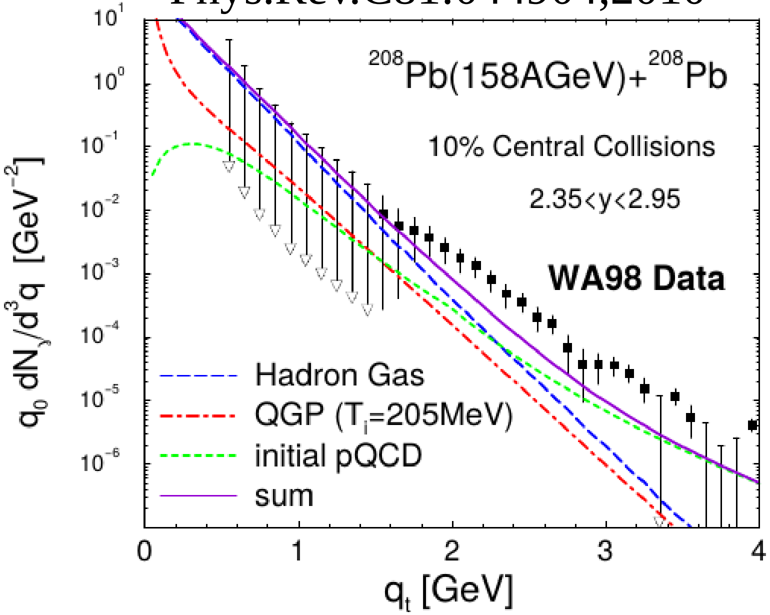
Compare yields from hadronic and QGP phases and overall yield with previous calculation from S. Turbide et al and M. Bleicher at al. Note: we have b<4.5, y=0.

Good agreement 0.8 < pT < 2 GeV/c





B. Bauhle, M. Bleicher
Phys.Rev.C81:044904,2010



S.Turbide, R. Rapp, C. Gale
Phys.Rev.C69:014903,2004

A few additional notes

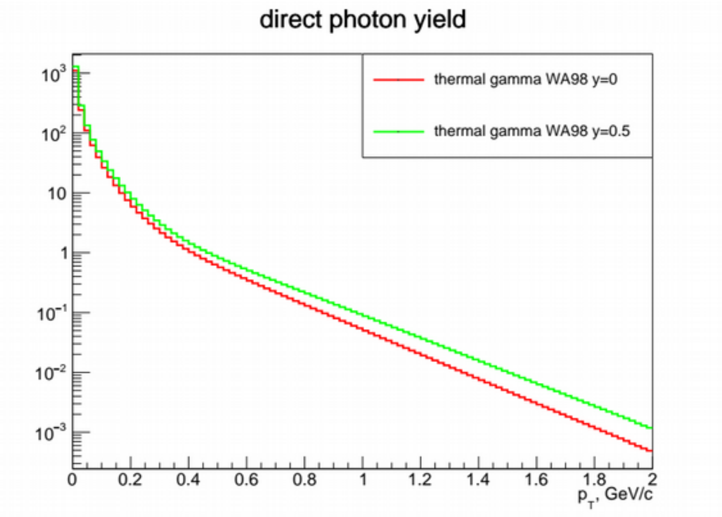
- QGPRate depends on alpha_s which can be constant or temperature dependent. Now we use temperature dependent one $\alpha_S(T) = \frac{6\pi}{(33 - 2N_f)\ln\left(\frac{8T}{T_C}\right)}$,

- QGPRate depends on Nf. We use 2 currently instead of 3 that was used by B. Bauhle, M. Bleicher Phys.Rev.C81:044904,2010
- We integrate over phi for rapidity 0

- gamma2 = $\sqrt{1/_{1-v^2}}$
- Ei = Pt*gamma2*(1.-cosφ*vx(i,j,k) - sinφ*vy(i,j,k)) !product of 4-vectors: p*u

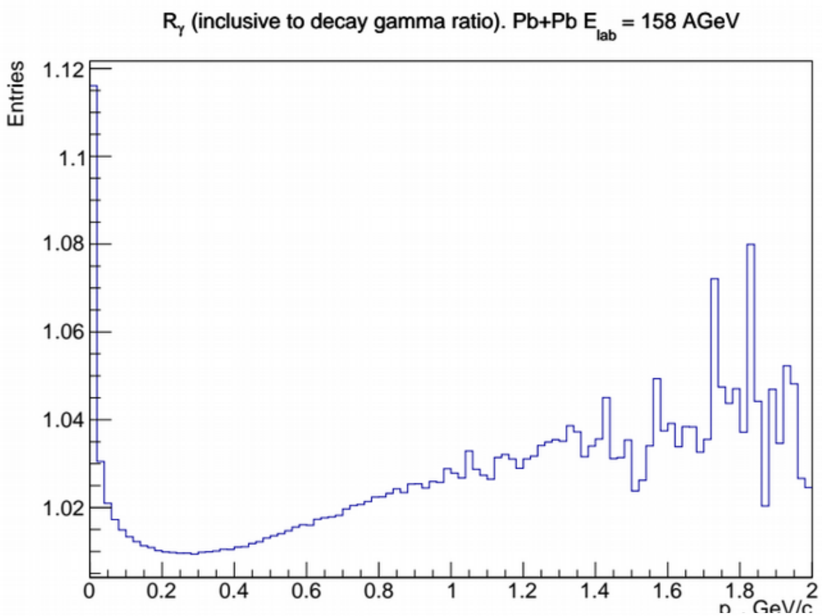
- New option: calculate at fixed rapidity:
- Ei = Pt*gamma2*(1.-cosφ*vx(i,j,k)*sinθ - sinφ*vy(i,j,k)*sinθ - vz(i,j,k)*cosθ) / sinθ

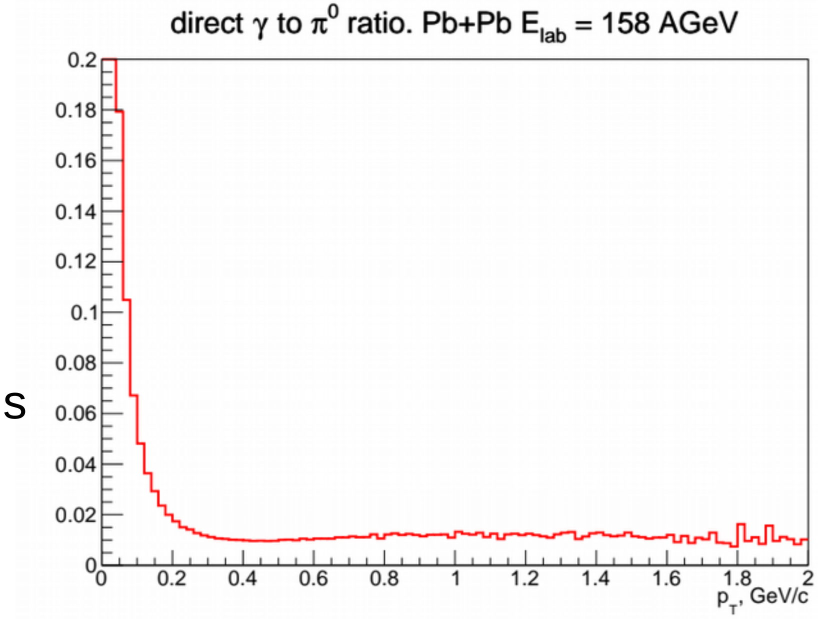
- Can higher yield at y=0.5 compared to y=0 be explained?



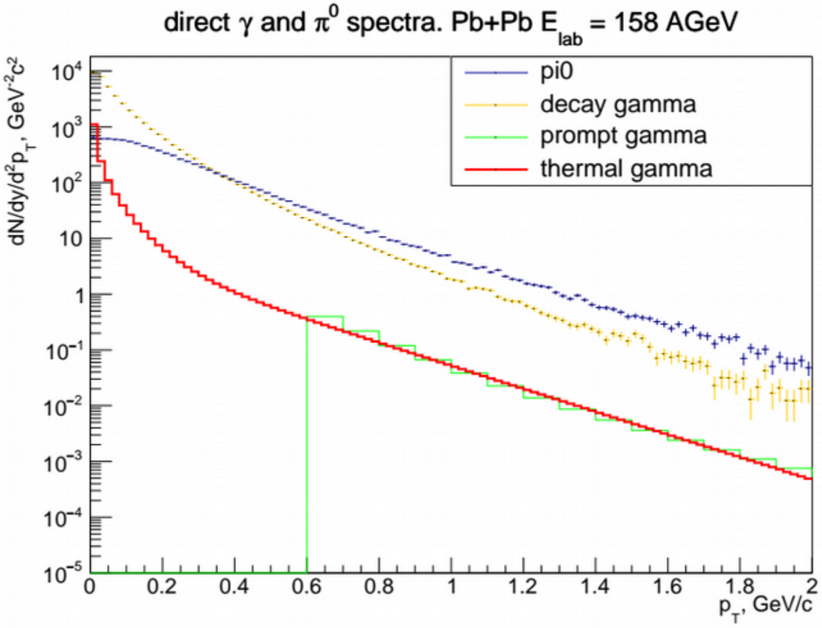
Comparisons at 158 AGeV

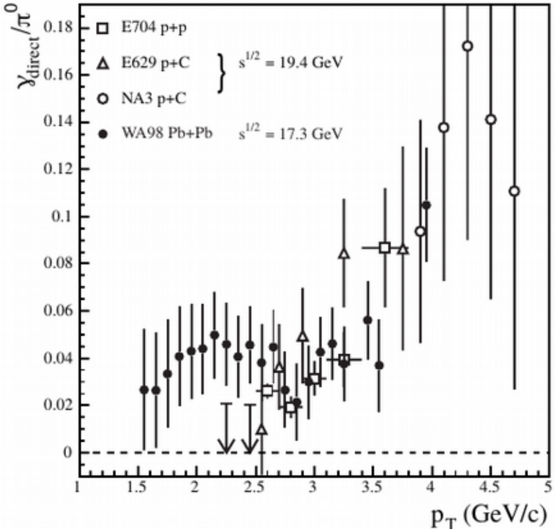
Compare direct γ to π^0 ratio to WA98 results. Note: prompt photons (pQCD) not included yet in the ratio.
Note: b<4.5, y=0





Only thermal direct photons now



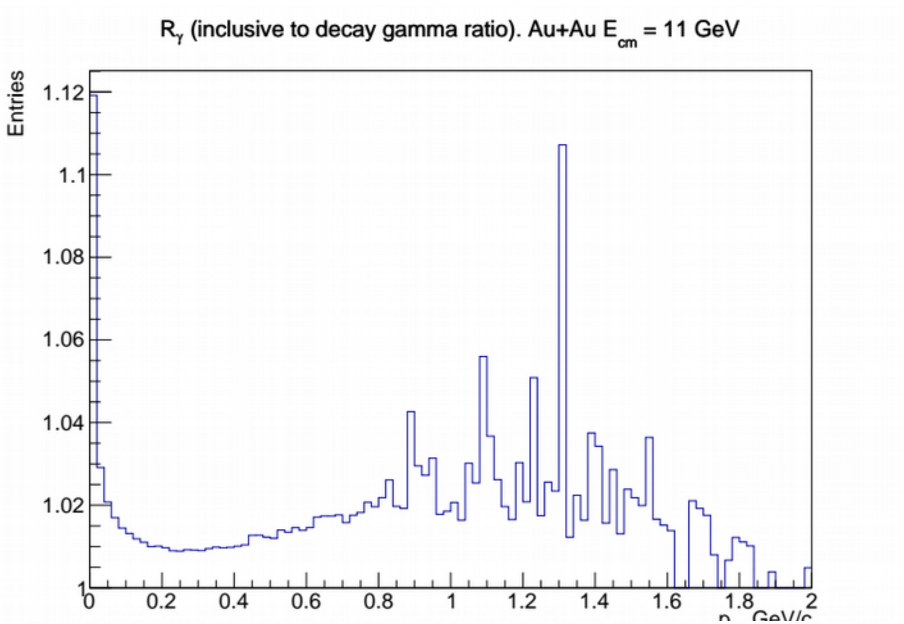


Green: D. Peresunko pQCD calculations with GRV94 structure functions

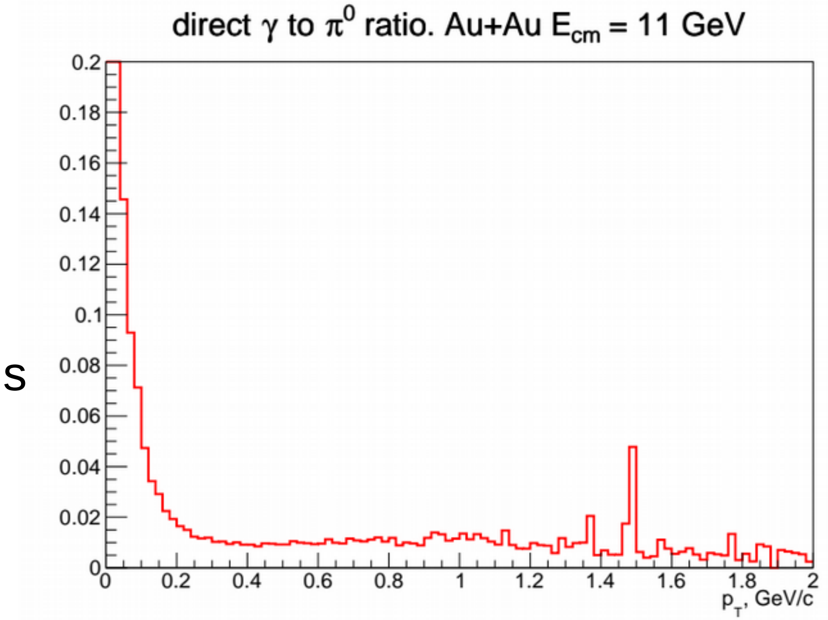
T. Peitzmann Pramana – J. Phys. V. 60 Issue 4 pp 651-661 (2003)

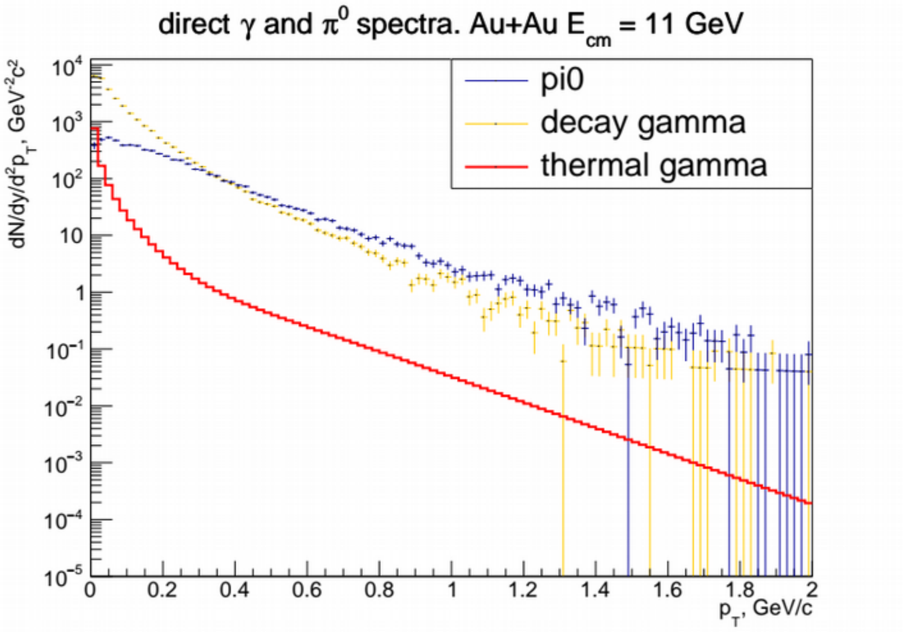
Calculations at $\sqrt{s_{NN}}$ = 11 GeV

Calculate the same dependences at the top NICA energy. Note: b=0 and y=0 here

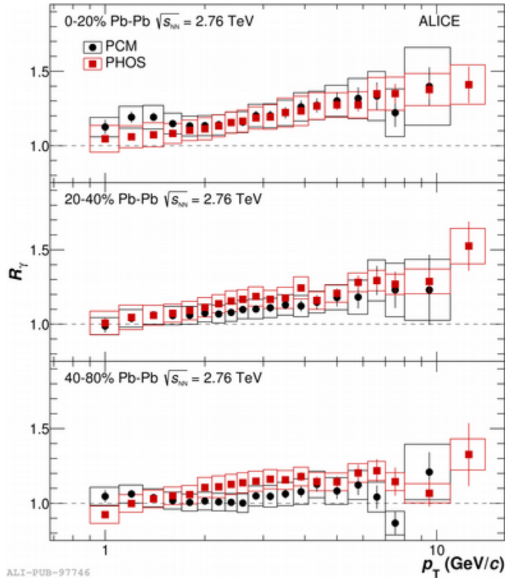


Only thermal direct photons now



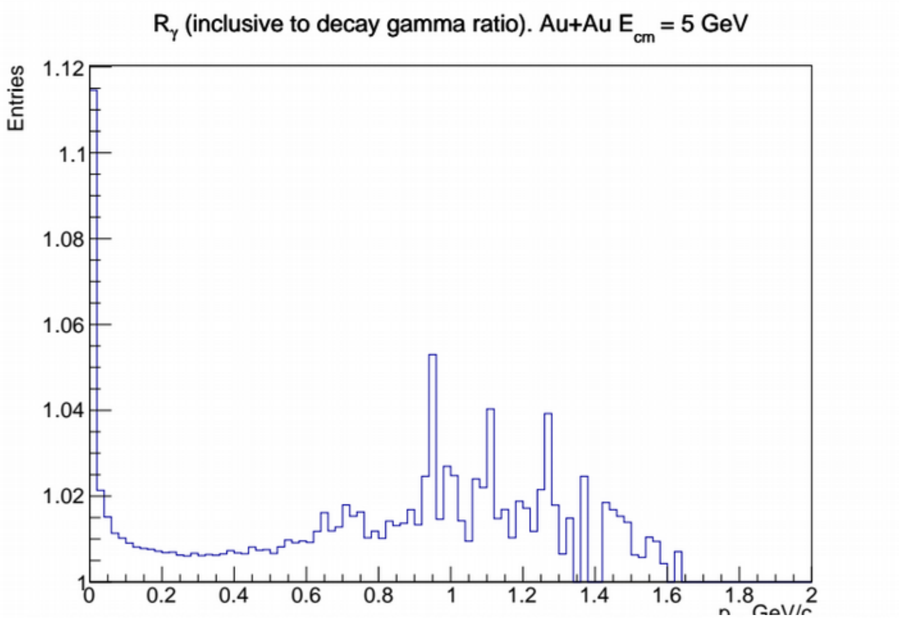


R_gamma in ALICE Pb-Pb (note that above 3 GeV/c main contribution is from prompt photons)

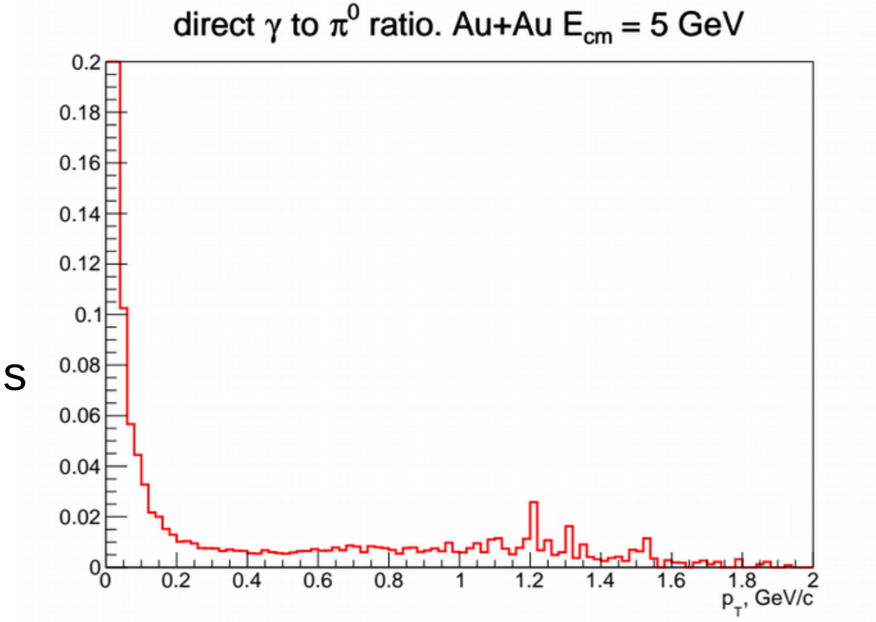


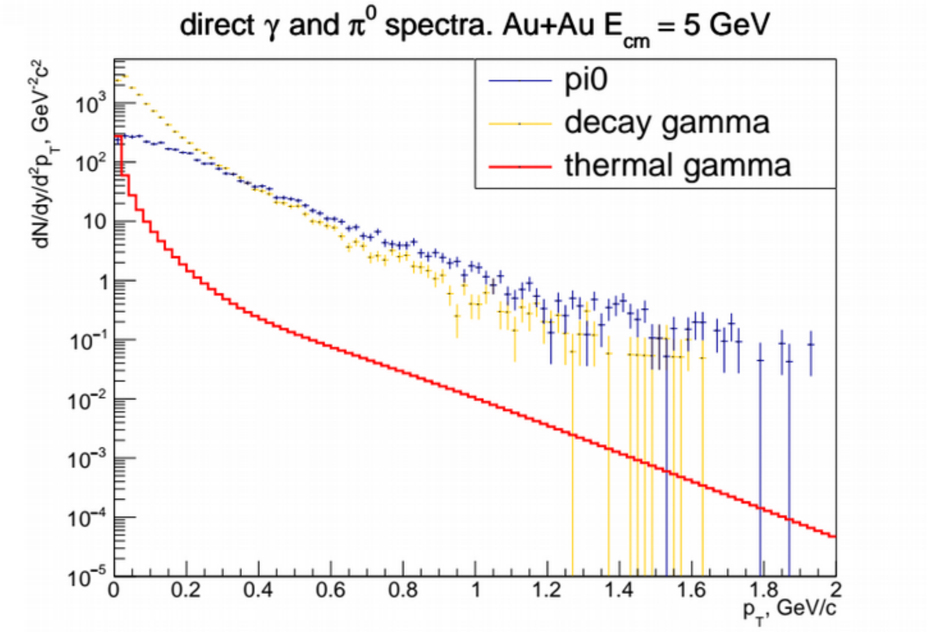
Calculations at $\sqrt{s_{NN}}$ = 5 GeV

Calculate the same dependences at the low NICA energy


R_γ (inclusive to decay gamma ratio). Au+Au E_{cm} = 5 GeV

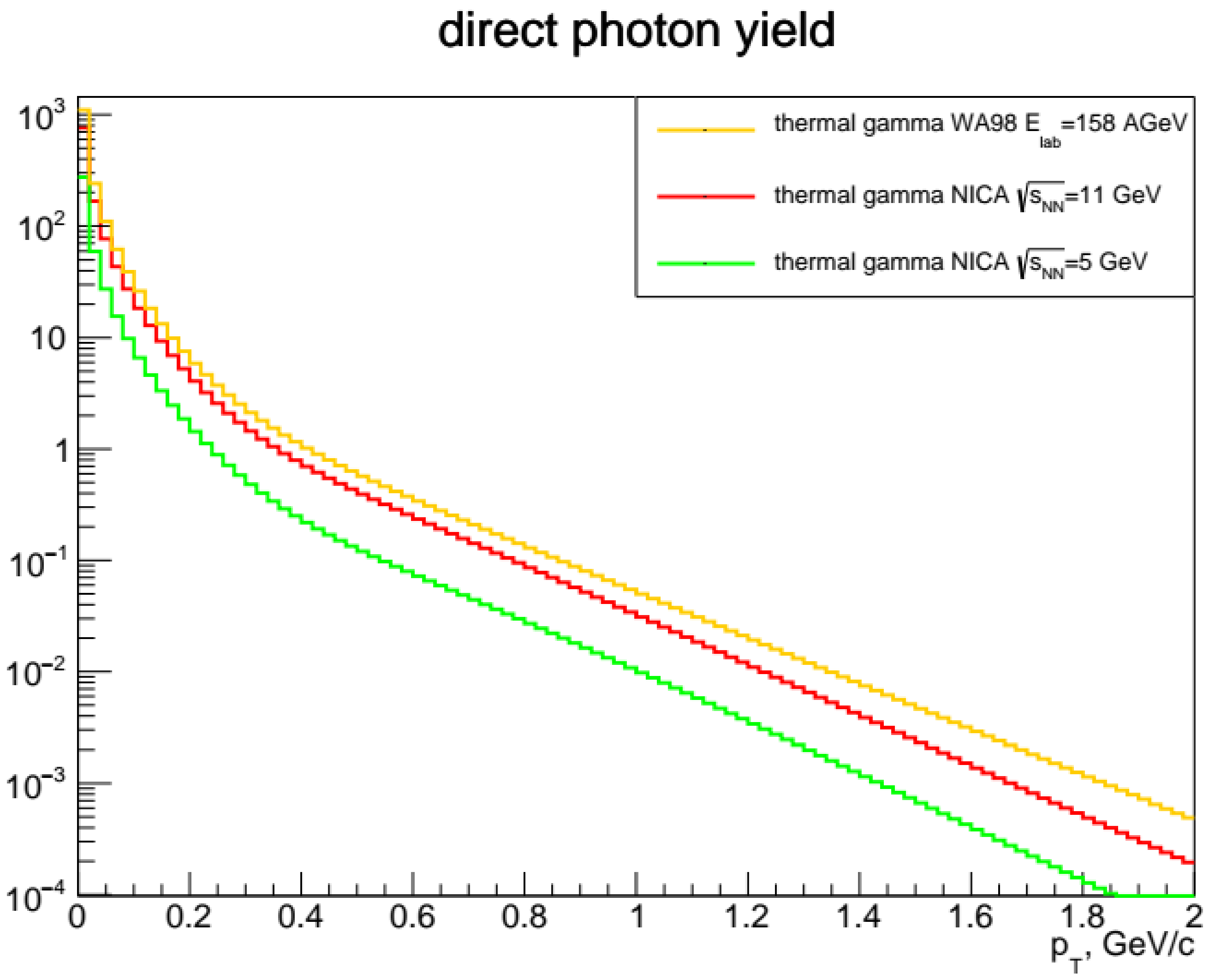
Only thermal direct photons now


direct γ to π^0 ratio. Au+Au E_{cm} = 5 GeV


direct γ and π^0 spectra. Au+Au E_{cm} = 5 GeV

Comparison

Yields for all three energies



Only thermal direct photons now

Conclusions

- Direct photon simulations using UrQMD are performed and tested for SPS energy 158 AGeV, compared to WA98 results.

First results of direct gamma spectrum predictions at MPD top energy ($\sqrt{s_{NN}}$ = 11 GeV) and low energy ($\sqrt{s_{NN}}$ = 5 GeV) regimes were obtained. Direct gamma to π^0 and R_γ ratios are calculated.

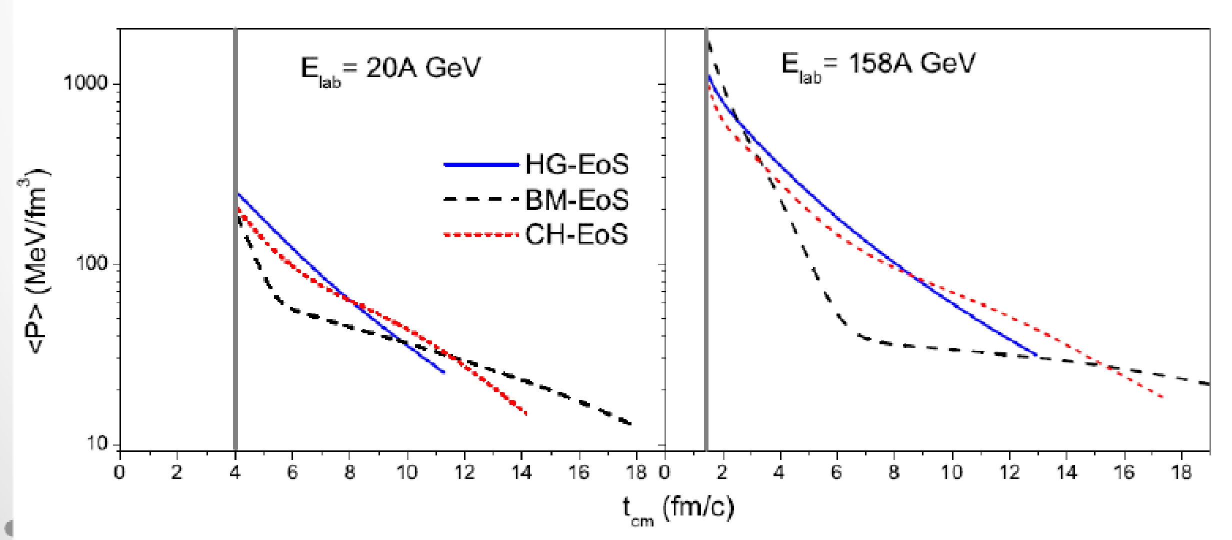
Backup

Hybrid model details: Equations of State

Ideal relativistic one fluid dynamics:

$$\partial_\mu T^{\mu\nu} = 0 \quad \text{and} \quad \partial_\mu \left(n u^\mu \right) = 0$$

- HG: **Hadron gas** including the same degrees of freedom as in UrQMD (all hadrons with masses up to 2.2 GeV)
- CH: **Chiral EoS** from quark-meson model with first order transition and critical endpoint (most realistic)
- BM: **Bag Model EoS** with a strong first order phase transition between QGP and hadronic phase



D. Rischke et al.,
NPA 595, 346, 1995,

D. Zschiesche et al.,
PLB 547, 7, 2002

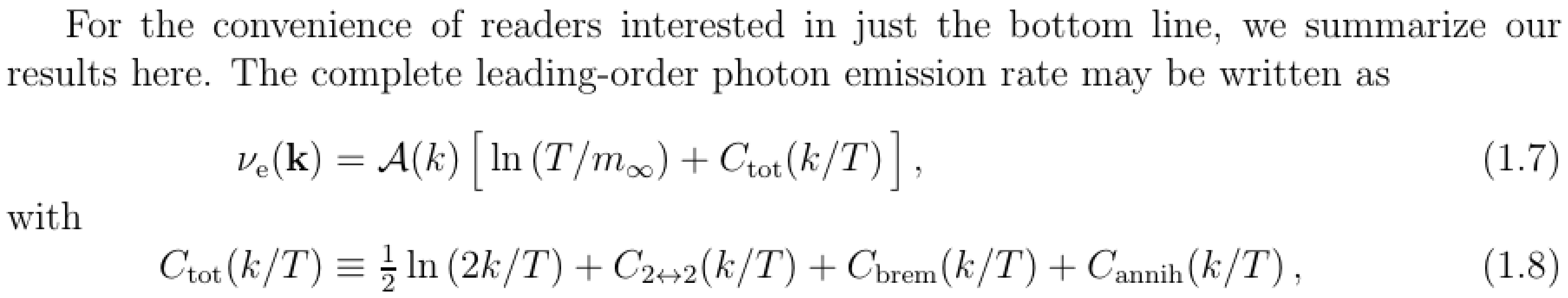
Papazoglou et al.,
PRC 59, 411, 1999

J. Steinheimer, et al.,
J. Phys. G38 (2011) 035001

M.Bleicher

Ingredients: QGP rate

“Photon Emission from Quark-Gluon Plasma: Complete Leading Order Results”
Peter Arnold, Guy D. Moore, Laurence G. Yaffe JHEP 0112:009,2001



For the convenience of readers interested in just the bottom line, we summarize our results here. The complete leading-order photon emission rate may be written as

$$\nu_{\rm e}(\mathbf{k}) = \mathcal{A}(k)\left[\ln\left(T/m_\infty\right) + C_{\rm tot}(k/T)\right], \tag{1.7}$$

with

$$C_{\rm tot}(k/T) \equiv \tfrac{1}{2}\ln\left(2k/T\right) + C_{2\leftrightarrow2}(k/T) + C_{\rm brem}(k/T) + C_{\rm annih}(k/T)\,, \tag{1.8}$$

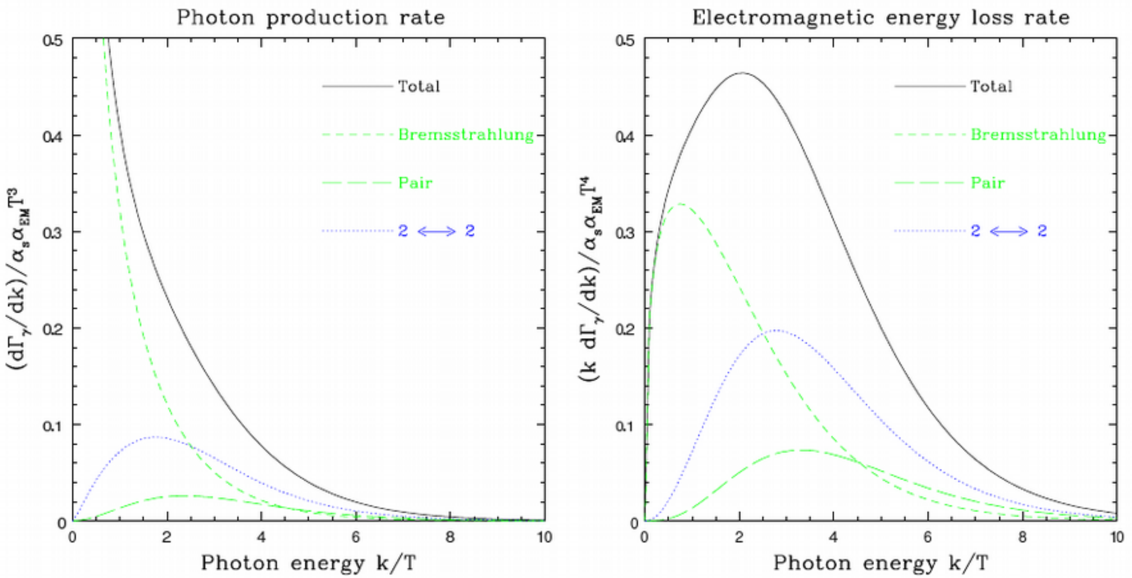
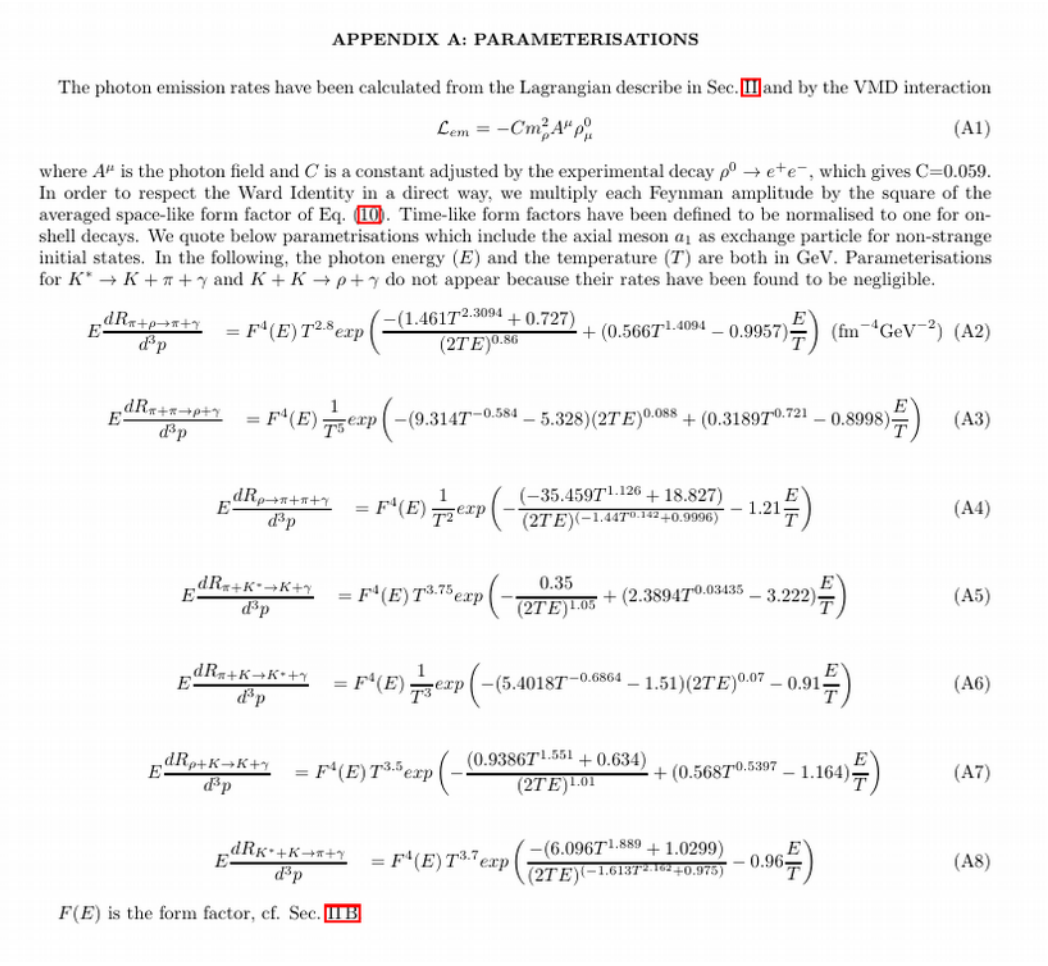


FIG. 9. Total photon emission rate, together with the bremsstrahlung, inelastic pair annihilation and $2 \leftrightarrow 2$ contributions, for two-flavor QCD with $\alpha_s = 0.2$. The left panel shows $d\Gamma_\gamma/dk$, divided by $\alpha_s\,\alpha_{\rm EM}\,T^3$, while the right panel shows rates weighted by photon energy.

Ingredients: hadronic rate

“Hadronic Production of Thermal Photons”
Simon Turbide, Ralf Rapp, Charles Gale Phys.Rev.C69:014903,2004



APPENDIX A: PARAMETERISATIONS

The photon emission rates have been calculated from the Lagrangian describe in Sec. II and by the VMD interaction

$$\mathcal{L}_{em} = -Cm_\rho^2 A^\mu \rho_\mu^0 \tag{A1}$$

where A^μ is the photon field and C is a constant adjusted by the experimental decay $\rho^0 \to e^+e^-$, which gives C=0.059. In order to respect the Ward Identity in a direct way, we multiply each Feynman amplitude by the square of the averaged space-like form factor of Eq. (10). Time-like form factors have been defined to be normalised to one for on-shell decays. We quote below parametrisations which include the axial meson a_1 as exchange particle for non-strange initial states. In the following, the photon energy (E) and the temperature (T) are both in GeV. Parameterisations for $K^* \to K + \pi + \gamma$ and $K + K \to \rho + \gamma$ do not appear because their rates have been found to be negligible.

$$E\frac{dR_{\pi+\rho\to\pi+\gamma}}{d^3p} = F^4(E)\,T^{2.8} exp\left(\frac{-(1.461T^{2.3094}+0.727)}{(2TE)^{0.86}} + (0.566T^{1.4094} - 0.9957)\frac{E}{T}\right)\ (\text{fm}^{-4}\text{GeV}^{-2}) \tag{A2}$$

$$E\frac{dR_{\pi+\pi\to\rho+\gamma}}{d^3p} = F^4(E)\,\frac{1}{T^5} exp\left(-(9.314T^{-0.584} - 5.328)(2TE)^{0.088} + (0.3189T^{0.721} - 0.8998)\frac{E}{T}\right) \tag{A3}$$

$$E\frac{dR_{\rho\to\pi+\pi+\gamma}}{d^3p} = F^4(E)\,\frac{1}{T^2} exp\left(-\frac{(-35.459T^{1.126}+18.827)}{(2TE)^{(-1.44T^{0.142}+0.9996)}} - 1.21\frac{E}{T}\right) \tag{A4}$$

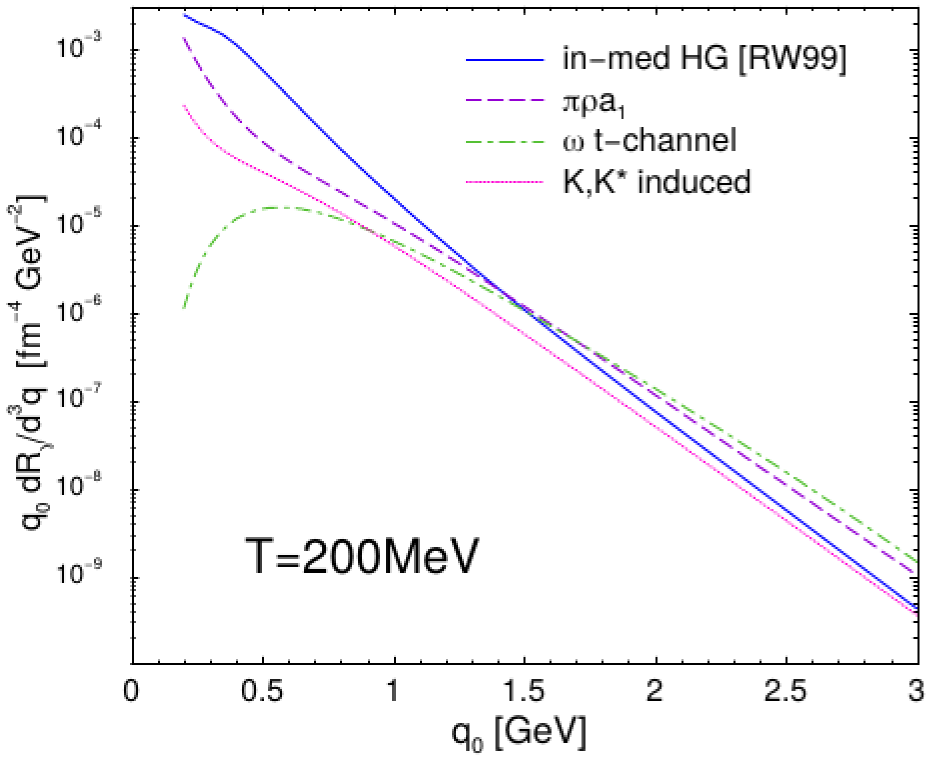
$$E\frac{dR_{\pi+K^*\to K+\gamma}}{d^3p} = F^4(E)\,T^{3.75} exp\left(-\frac{0.35}{(2TE)^{1.05}} + (2.3894T^{0.03435} - 3.222)\frac{E}{T}\right) \tag{A5}$$

$$E\frac{dR_{\pi+K\to K^*+\gamma}}{d^3p} = F^4(E)\,\frac{1}{T^3} exp\left(-(5.4018T^{-0.6864} - 1.51)(2TE)^{0.07} - 0.91\frac{E}{T}\right) \tag{A6}$$

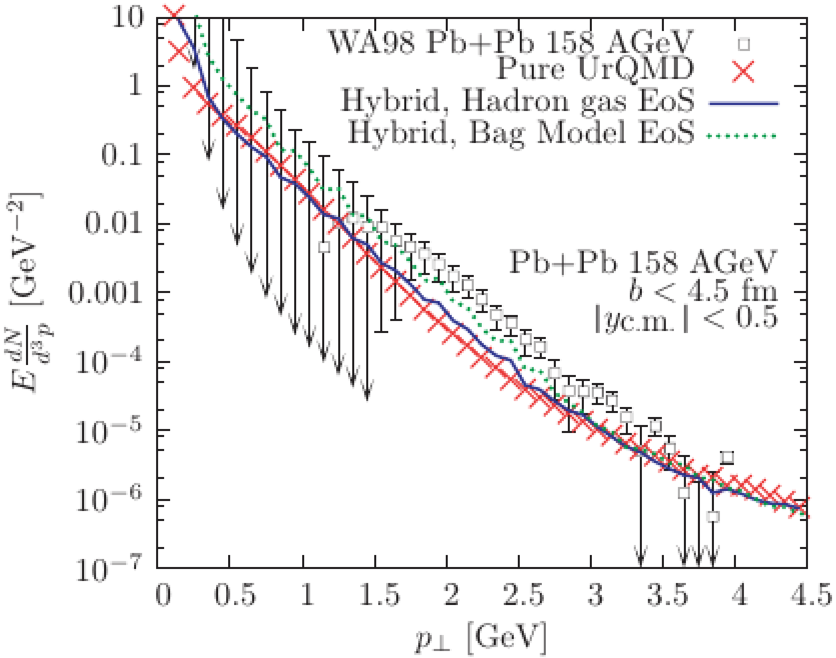
$$E\frac{dR_{\rho+K\to K+\gamma}}{d^3p} = F^4(E)\,T^{3.5} exp\left(-\frac{(0.9386T^{1.551}+0.634)}{(2TE)^{1.01}} + (0.568T^{0.5397} - 1.164)\frac{E}{T}\right) \tag{A7}$$

$$E\frac{dR_{K^*+K\to\pi+\gamma}}{d^3p} = F^4(E)\,T^{3.7} exp\left(\frac{-(6.096T^{1.889}+1.0299)}{(2TE)^{(-1.613T^{2.162}+0.975)}} - 0.96\frac{E}{T}\right) \tag{A8}$$

$F(E)$ is the form factor, cf. Sec. II B



- Different models



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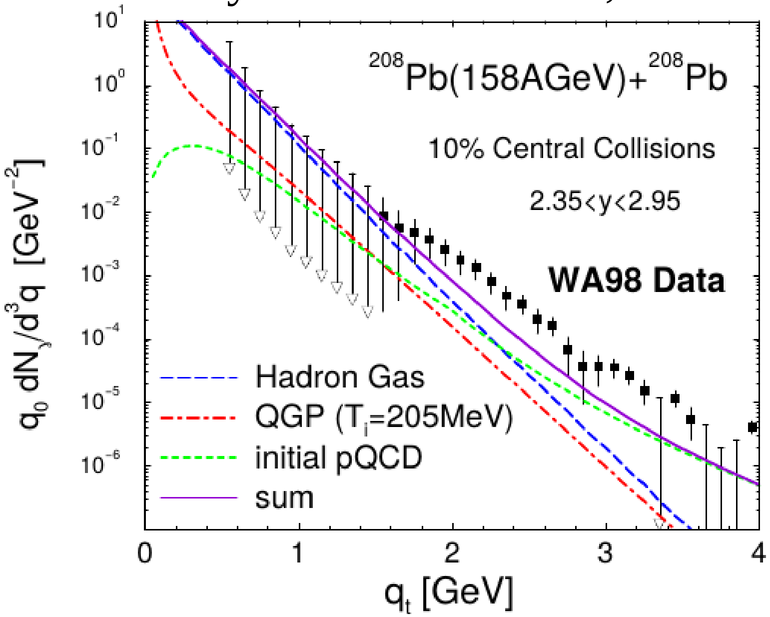

S.Turbide, R. Rapp, C. Gale
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