Simulations of direct photon yield at NICA energies

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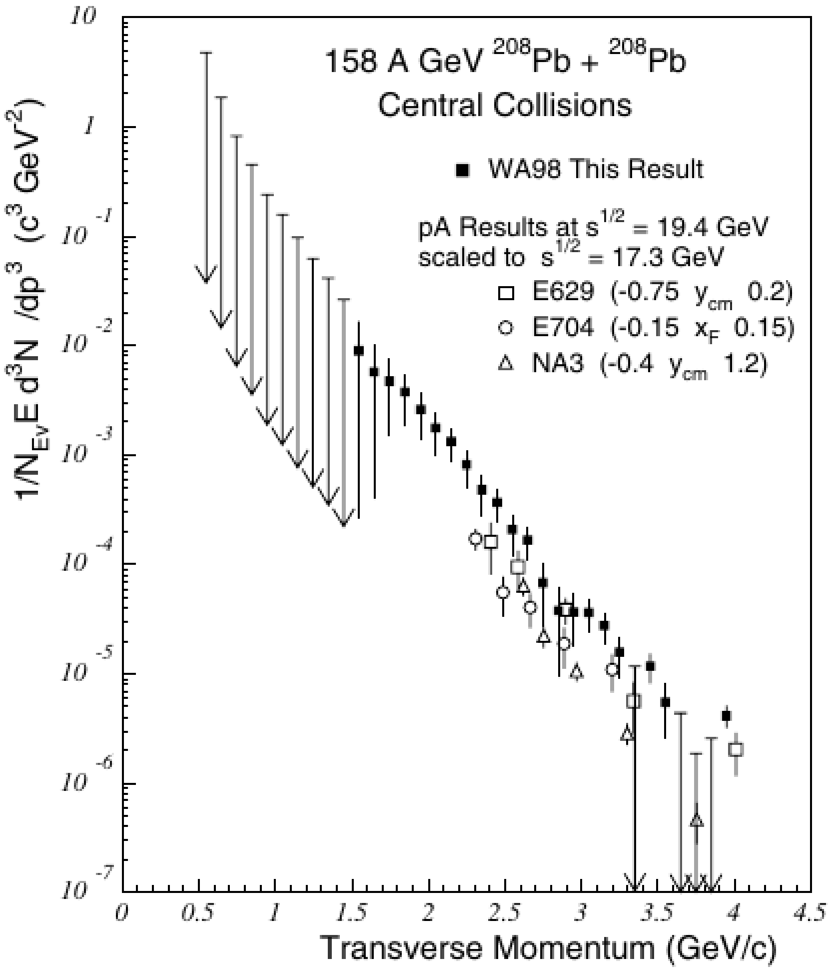
Motivation

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

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

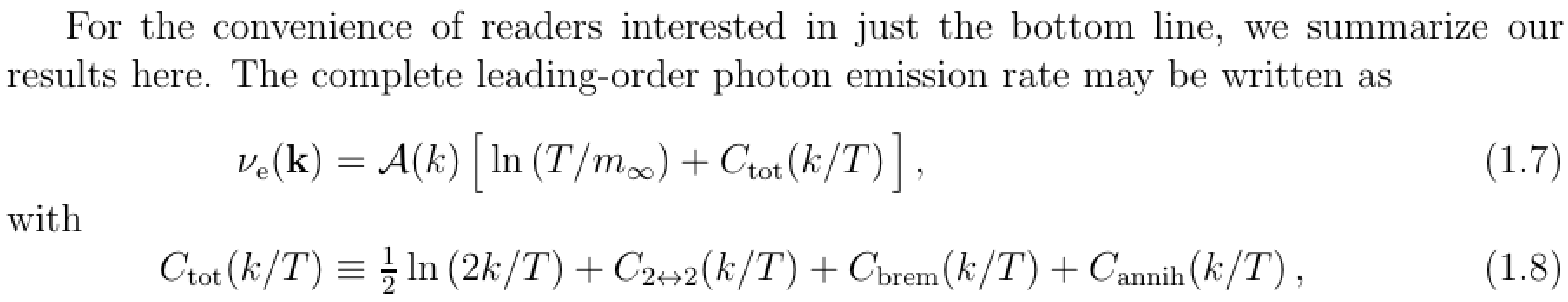
- M M Aggarwal et al, (WA98 Collaboration), Phys. Rev. Lett. 85, 3595 (2000)
- B. Bäuchle and M. Bleicher, PhysRevC 81 (2010) 044904 – UrQMD simulations with hybrid approach

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)



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

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

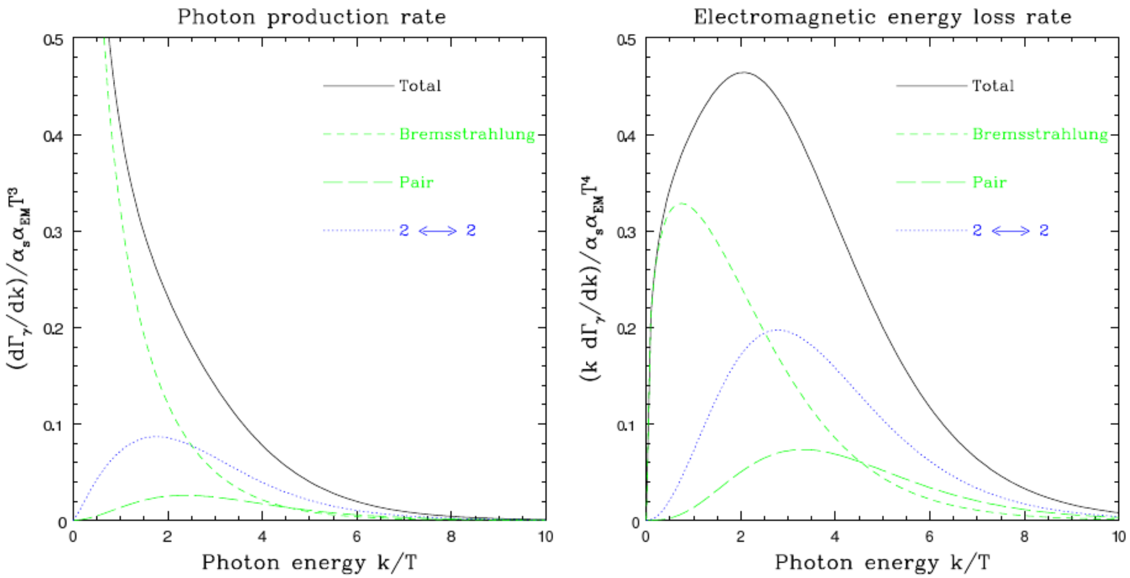
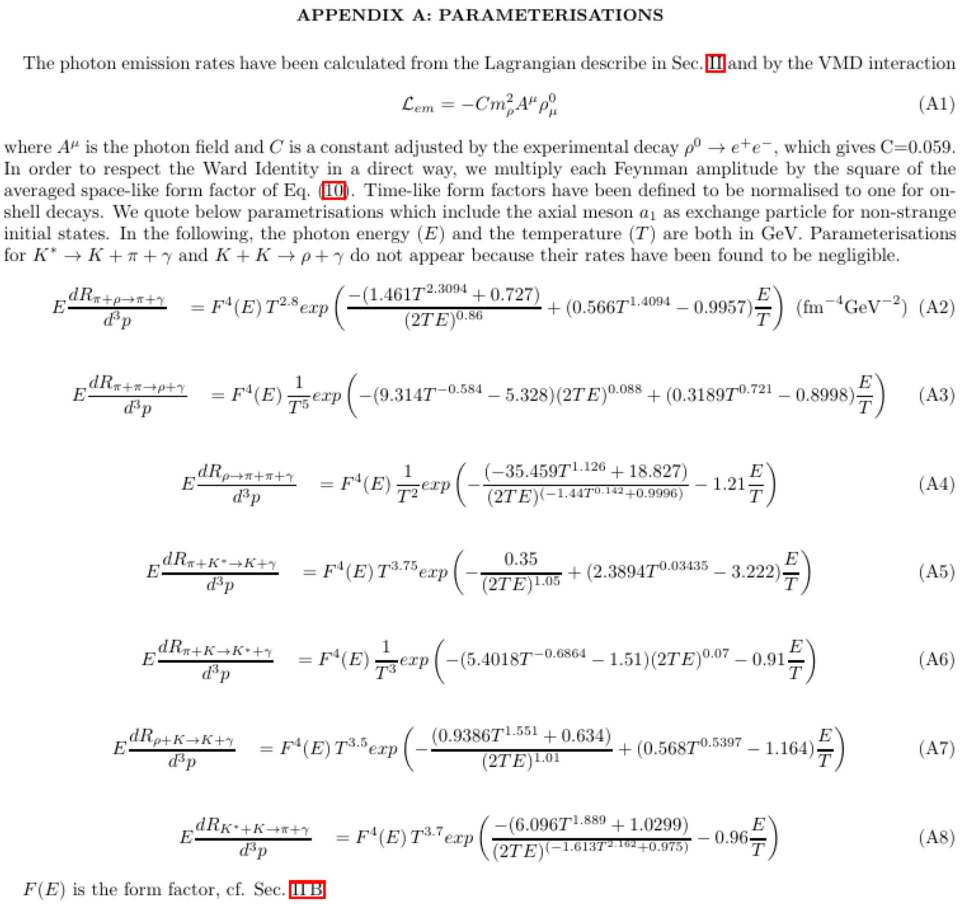


FIG. 9. Total photon emission rate, together with the bremsstrahlung, inelastic pair annihilation and $2 \leftrightarrow 2$ contributions, for two-flavor QCD with $\alpha_s = 0.2$. The left panel shows $d\Gamma_\gamma/dk$, divided by $\alpha_s\,\alpha_{\rm EM}\,T^3$, while the right panel shows rates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

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

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

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

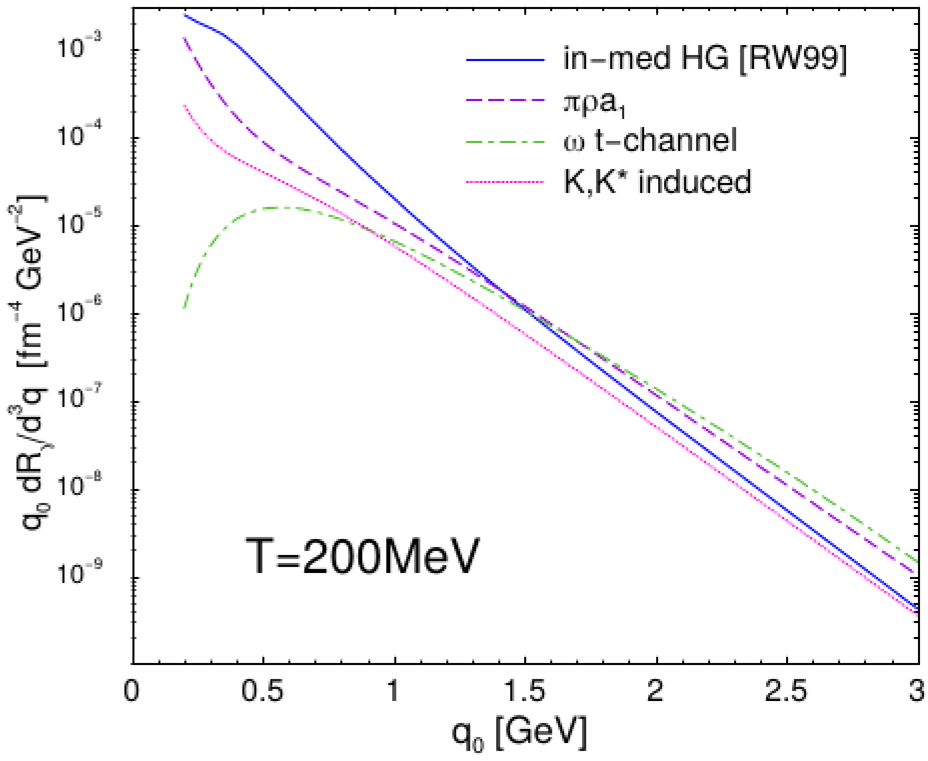
$$E\frac{dR_{\pi+K^*\to K+\gamma}}{d^3p} = F^4(E)\, T^{3.75} exp\left(-\frac{0.35}{(2TE)^{1.05}} + (2.3894T^{0.03435}-3.222)\frac{E}{T}\right) \tag{A5}$$

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

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

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

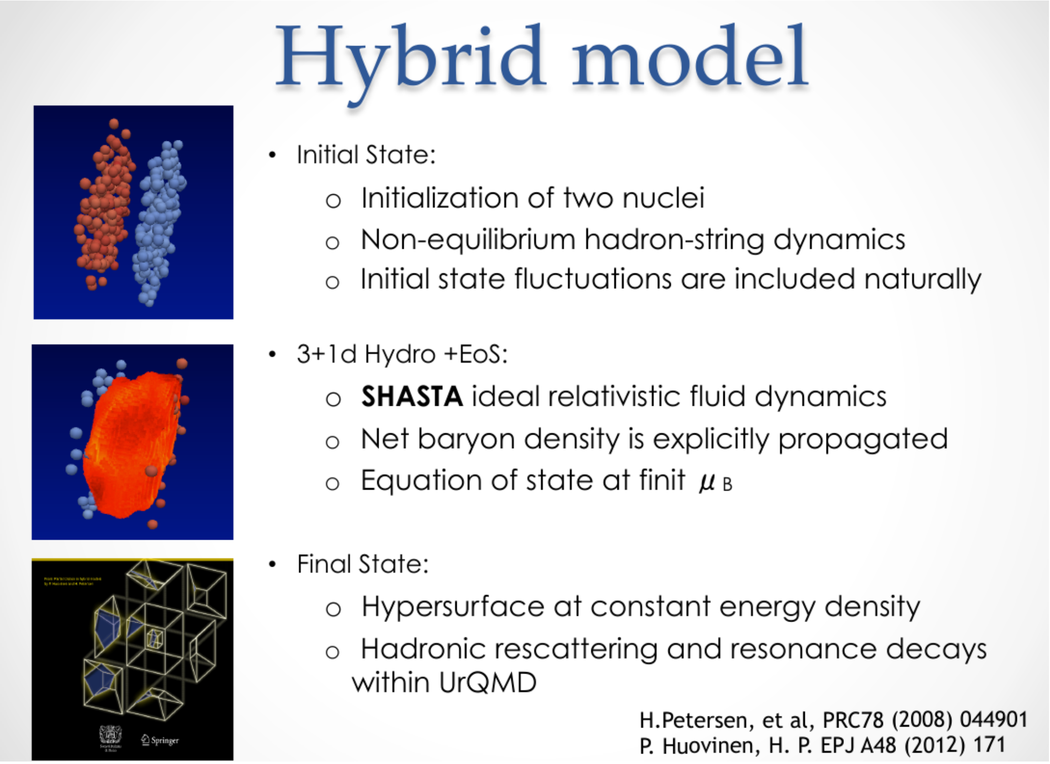
$F(E)$ is the form factor, cf. Sec. II B



Ingredients: UrQMD model

UrQMD model version 3.4: http://uqrdm.org Prog. Part. Nucl. Phys. 41 (1998) 225-370
Hybrid approach: Phys. Rev. C 78 (2008) 044901

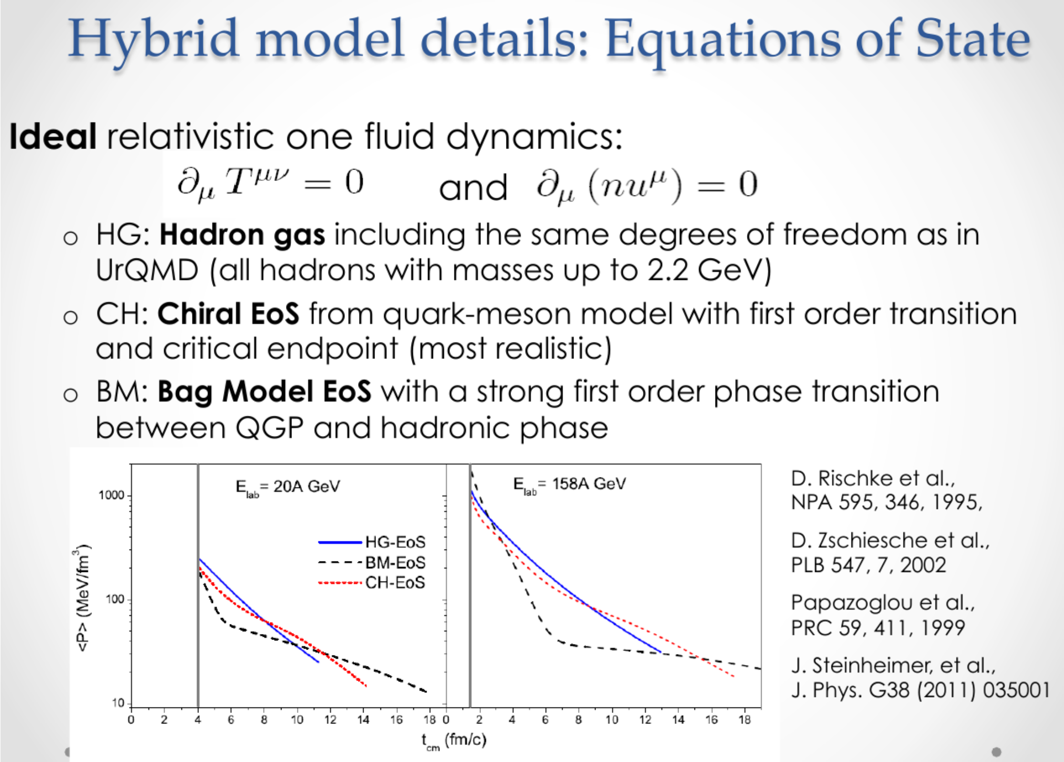
Options to choose EOS (cto 47): HG, Chiral or BM
At the moment we use Bag model option



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

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



Hybrid model details: Equations of State

Ideal relativistic one fluid dynamics:

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

- 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

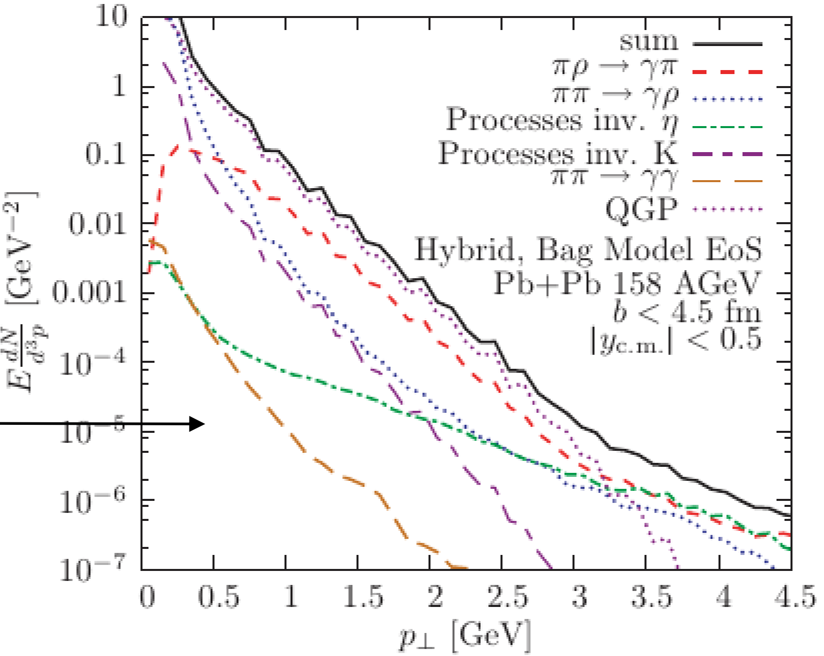
Strategy

- 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: $|y|<0.5$
- Calculate photon yield from UrQMD with hydro mode on (cto 45 1).
    - At each timestep calculate QGP and HG rates as integral over volume based on energy density, temperature and baryon mu and QGP fraction values from hydro (oschydro_event function in 1fluid.f).
    - Sum all timesteps.
    - To get overall direct photon yield one should sum thermal photons (QGP and HG calculated at previous step) and prompt photons (need pQCD calculation).

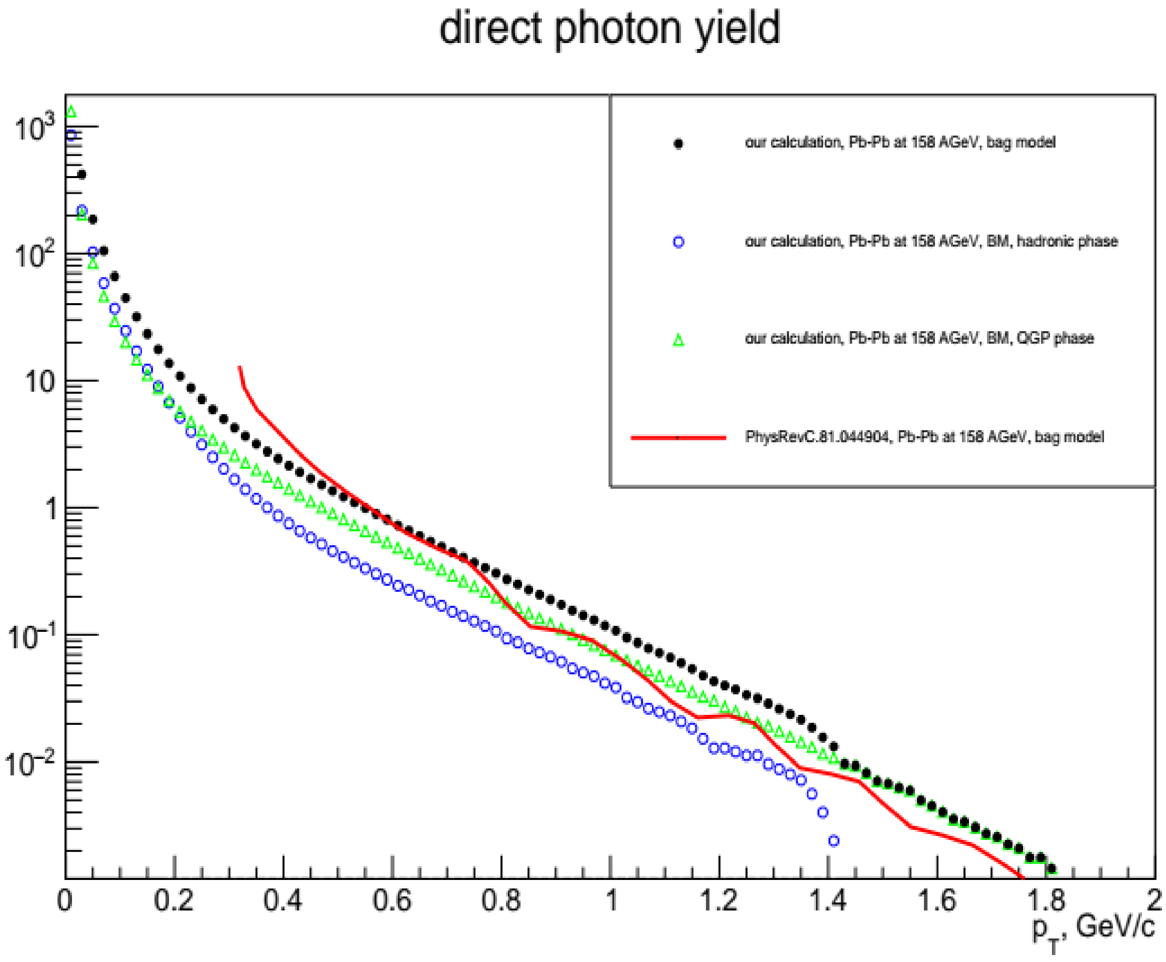
Comparisons at 158 AGeV

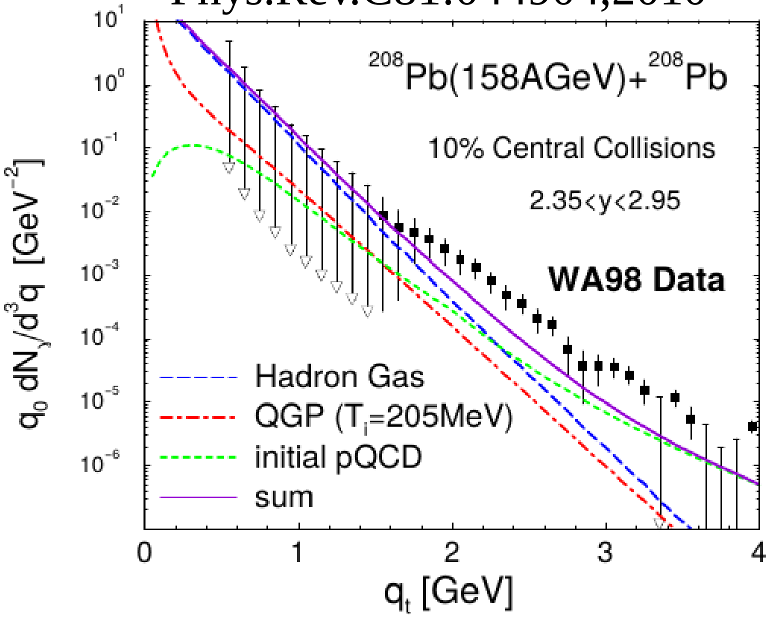
Compare yields from hadronic and QGP phases and overall yield with previous calculation from S. Turbide et al and M. Bleicher at al. Note: we have b=0.

> *"The calculations with the BM-EOS yield a different picture. Here, the dominant contribution comes from the QGP, whose emission magnitude is about two times higher than the combined contribution from all hadronic processes."*



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

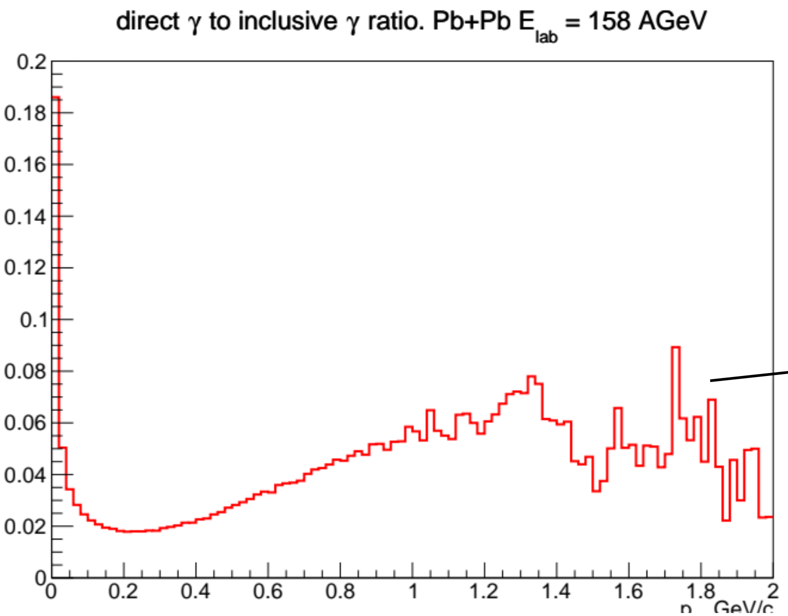




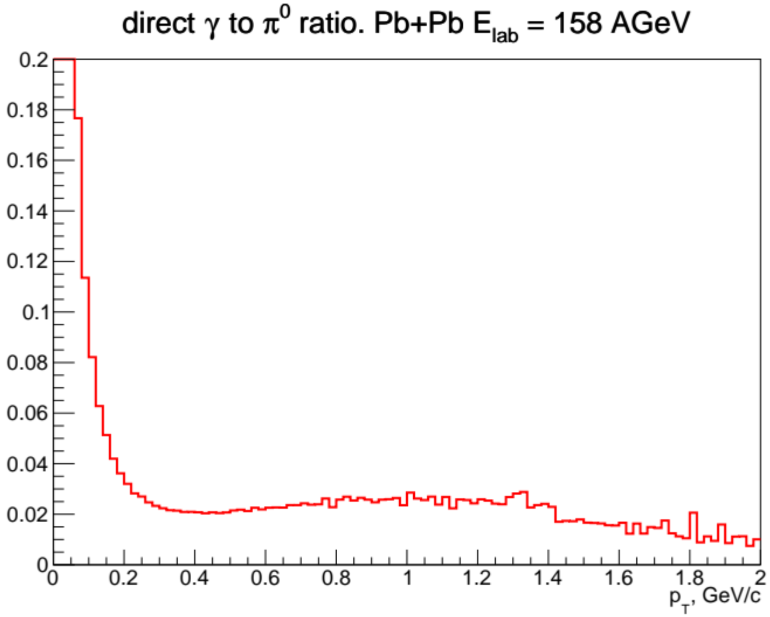
S.Turbide, R. Rapp, C. Gale
Phys.Rev.C69:014903,2004

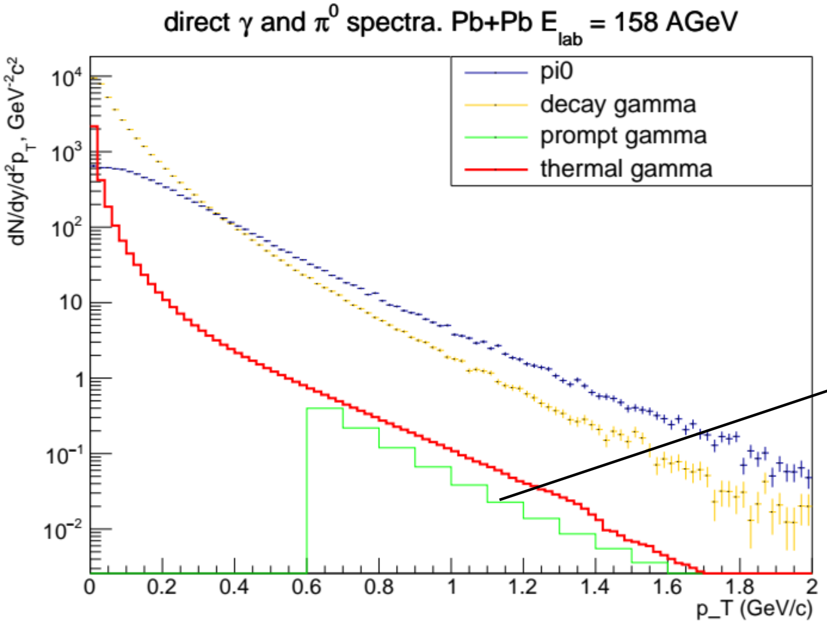
Comparisons at 158 AGeV

Compare direct γ to π^0 ratio to WA98 results. Note: prompt photons (pQCD) not included yet in the ratio.

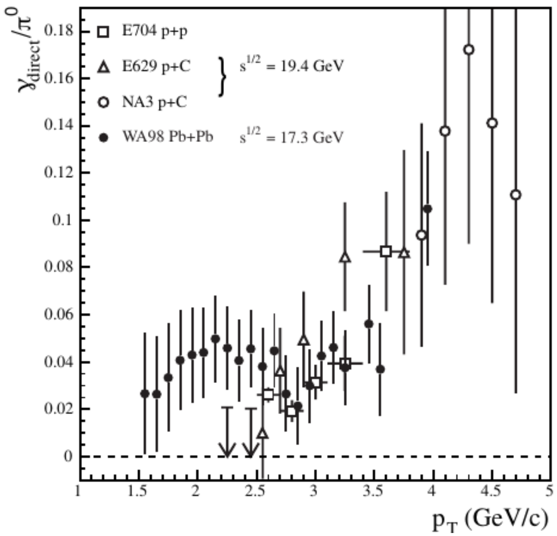


Only thermal direct photons now





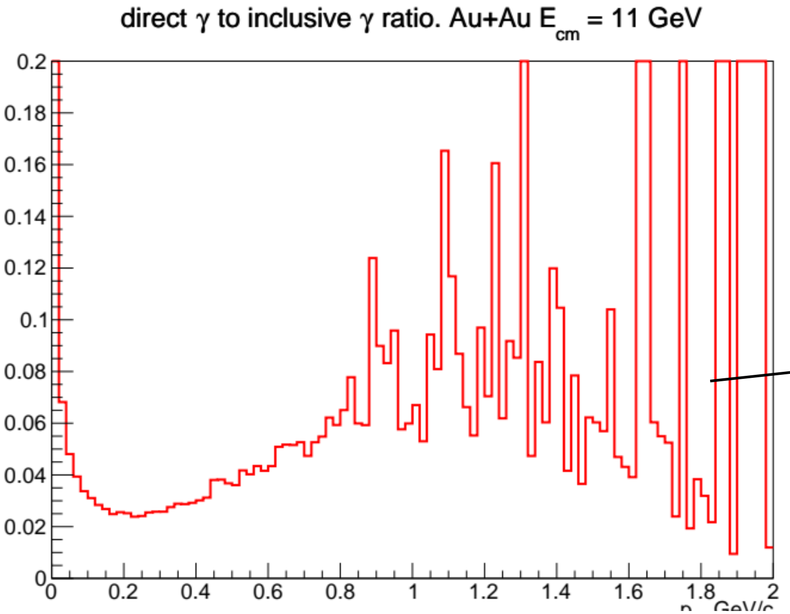
D. Peresunko pQCD calculations with GRV94 structure functions



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

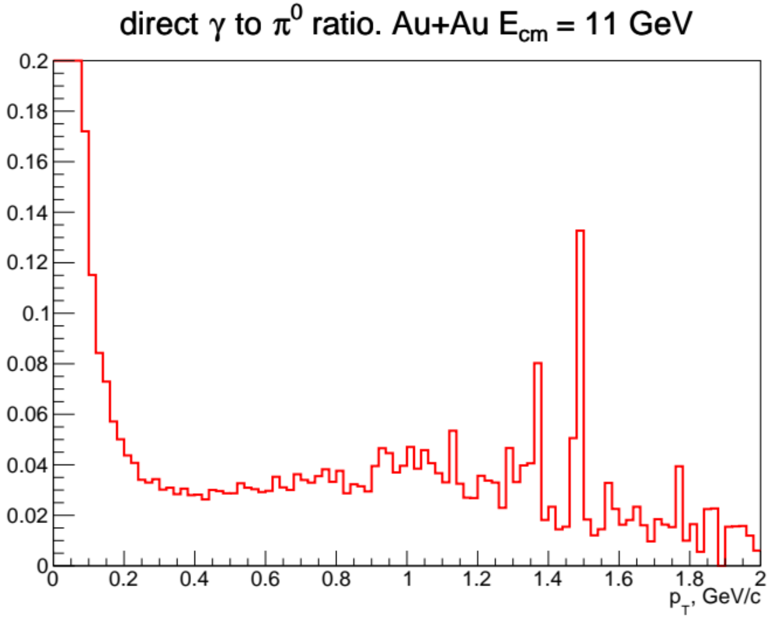
Calculations at $\sqrt{s_{NN}}$ = 11 GeV

Calculate the same dependences at the top NICA energy

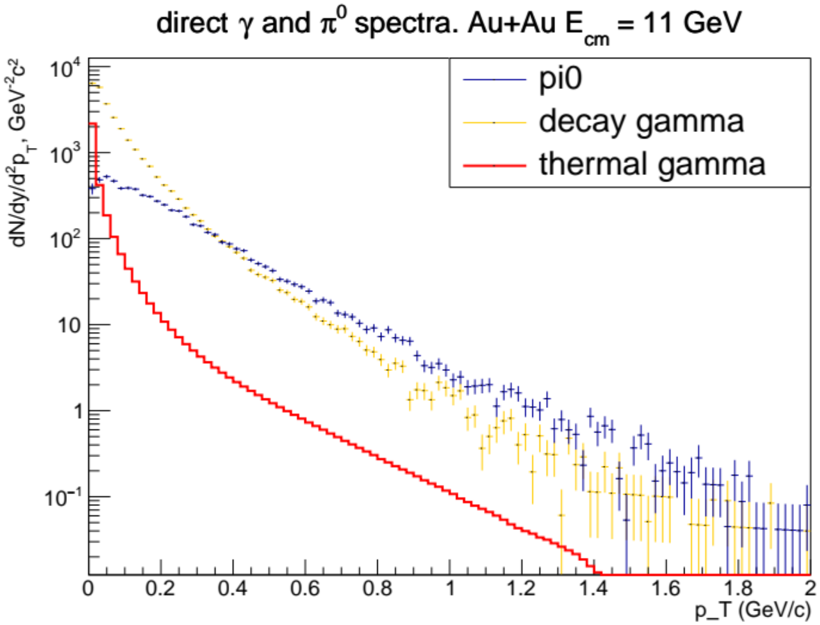


direct γ to inclusive γ ratio. Au+Au E_{cm} = 11 GeV

Only thermal direct photons now



direct γ to π^0 ratio. Au+Au E_{cm} = 11 GeV



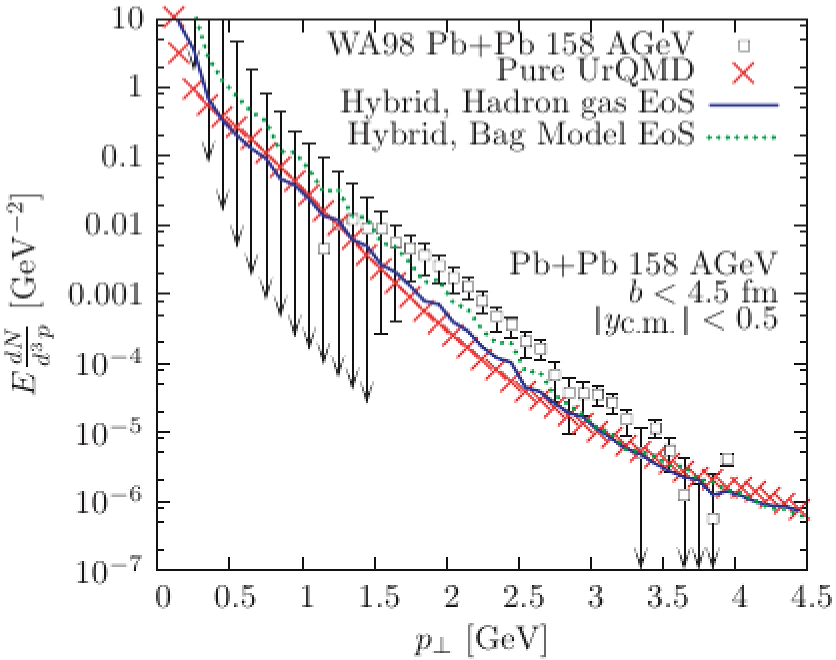
direct γ and π^0 spectra. Au+Au E_{cm} = 11 GeV

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) are obtained. Direct gamma to π^0 and direct gamma to decay gamma ratios are calculated.
- Todo:
  - Calculate pQCD fraction with JetPhox
  - Discuss with UrQMD team (still no contact established…)
  - Compare different EOS (preliminary studies show big difference!)
  - Compare with other models?

Backup

- Different models



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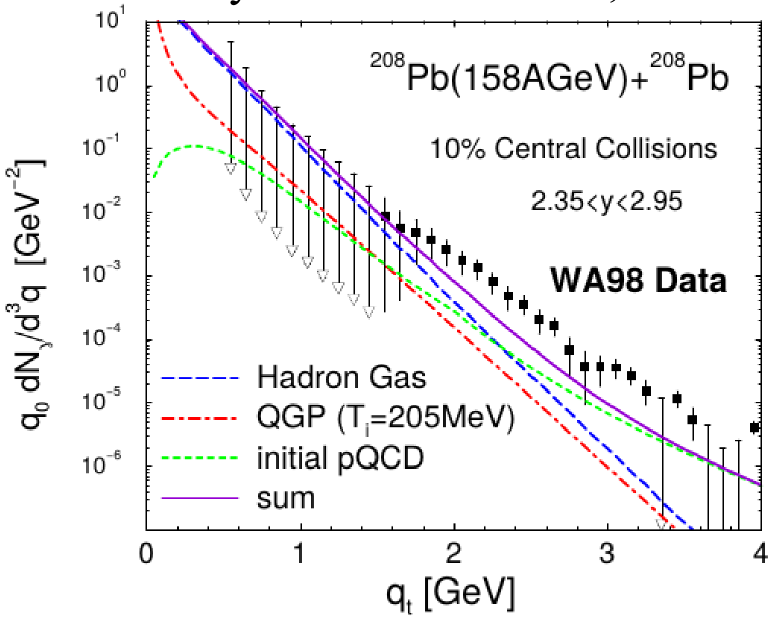

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