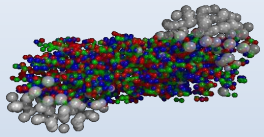
H-QM | Helmholtz Research School Quark Matter Studies



GOETHE UNIVERSITÄT FRANKFURT AM MAIN

Direct Photons in Heavy-Ion Collisions from Microscopic Transport Theory and Fluid Dynamics

Bjørn Bäuchle, Marcus Bleicher

The UrQMD-Group
Based on [arXiv:0810.0488 (nucl-th)]

DPG Spring Meeting
March 17^{th}, 2009

Collaborators

The UrQMD-Group

Marcus Bleicher, Horst Stöcker, Gerhard Burau, Michael Mitrovski, **Elvira Santini (HK 33.6)**, Bjørn Bäuchle, **Marlene Nahrgang (HK 55.7)**, Hannah Petersen, Tim Schuster, **Jan Steinheimer-Froschauer (HK 45.4)**, **Sascha Vogel (HK 45.2)**, **Gunnar Gräf (HK 79.1)**, Katharina Schmidt, Timo Spielmann

Sponsors

Deutsche Telekom Stiftung

HIC for FAIR

H-QM | Helmholtz Research School Quark Matter Studies

FIAS Frankfurt Institute for Advanced Studies

Interactions with photons

Photons are the gauge bosons of electromagnetic interactions.

- Photons do **not** interact strongly
- Small production cross-section, but small rescattering rate
- Photons from hadronic decays make ~ 97 % of all photons

Interactions with photons

Photons are the gauge bosons of electromagnetic interactions.

- Photons do **not** interact strongly
- Small production cross-section, but small rescattering rate
- Photons from hadronic decays make ~ 97 % of all photons

Direct Photons

All the photons that do **do not** come from hadronic decays are called **direct photons**.

Previous works

Measurements

- Helios, WA 80, CERES (SPS) — upper limits
- WA 93 (SPS) and STAR (RHIC) — no results (yet)
- WA 98 — first measurements at SPS
- PHENIX (RHIC) — various results

Previous works

Measurements

- Helios, WA 80, CERES (SPS) — upper limits
- WA 93 (SPS) and STAR (RHIC) — no results (yet)
- WA 98 — first measurements at SPS
- PHENIX (RHIC) — various results

Theory

- High $p_\perp$: yields calculated by NLO-pQCD. Important at RHIC- and LHC-energies!
- Hydrodynamics: naturally implement phase transition (QGP $\leftrightarrow$ HG): e.g. Turbide, Liu , Vitev, Haglin
- Transport: Study non-equilibrium effects and effects from dilute system: e.g. Dumitru, Huovinen, Li, Bratkovskaya

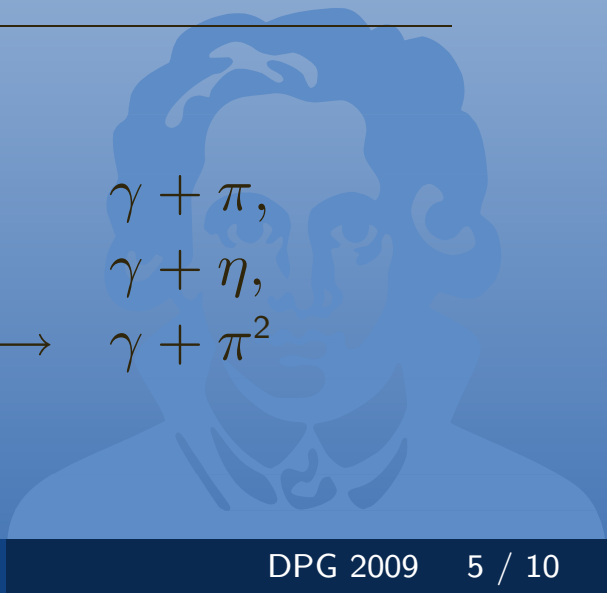
UrQMD

UrQMD: **U**ltra-**R**elativistic **Q**uantum **M**olecular **D**ynamics

- Non-equilibrium transport model
- Hadrons and resonances up to $m = 2.2$ GeV
- String excitation and fragmentation
- Cross sections are parametrized via AQM or calculated by detailed balance
- pQCD hard scattering at high energies
- Generates full space-time dynamics of hadrons and strings

Currently implemented channels[1]:

$$\begin{array}{llll} \pi + \pi \to \gamma + \rho, & \pi + \rho \to \gamma + \pi, \\ \pi + \eta \to \gamma + \pi, & \pi + \pi \to \gamma + \eta, \\ \pi + \pi \to \gamma + \gamma, & \pi + \rho \to a_1 \to \gamma + \pi^2 \end{array}$$



[1] Cross-sections taken from Kapusta, Lichard and Seibert, PRD **44** (1991) 2774

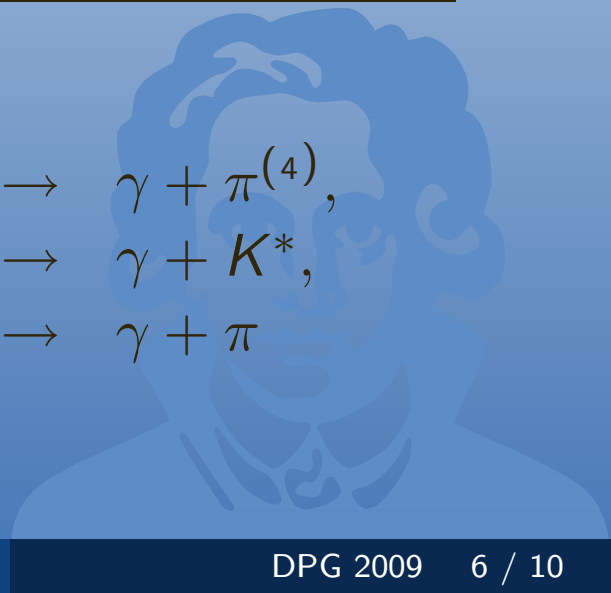
[2] This cross-section from Xiong, Shuryak and Brown, PRD **46**, 3798 (1992)

UrQMD+Hydro

- Non-equilibrium initial conditions from UrQMD
- Hydro evolution with hadronic Equation of State that includes all particles from UrQMD; **no phase transition**
- Isochronous freeze-out
- Rescatterings and decays with hadronic cascade (UrQMD)
- See also **Phys. Rev. C 78 (2008) 044901** and talk from Marlene Nahrgang: **Wednesday, 18:30**, Session **HK 55.7**

Currently implemented rates[3]:

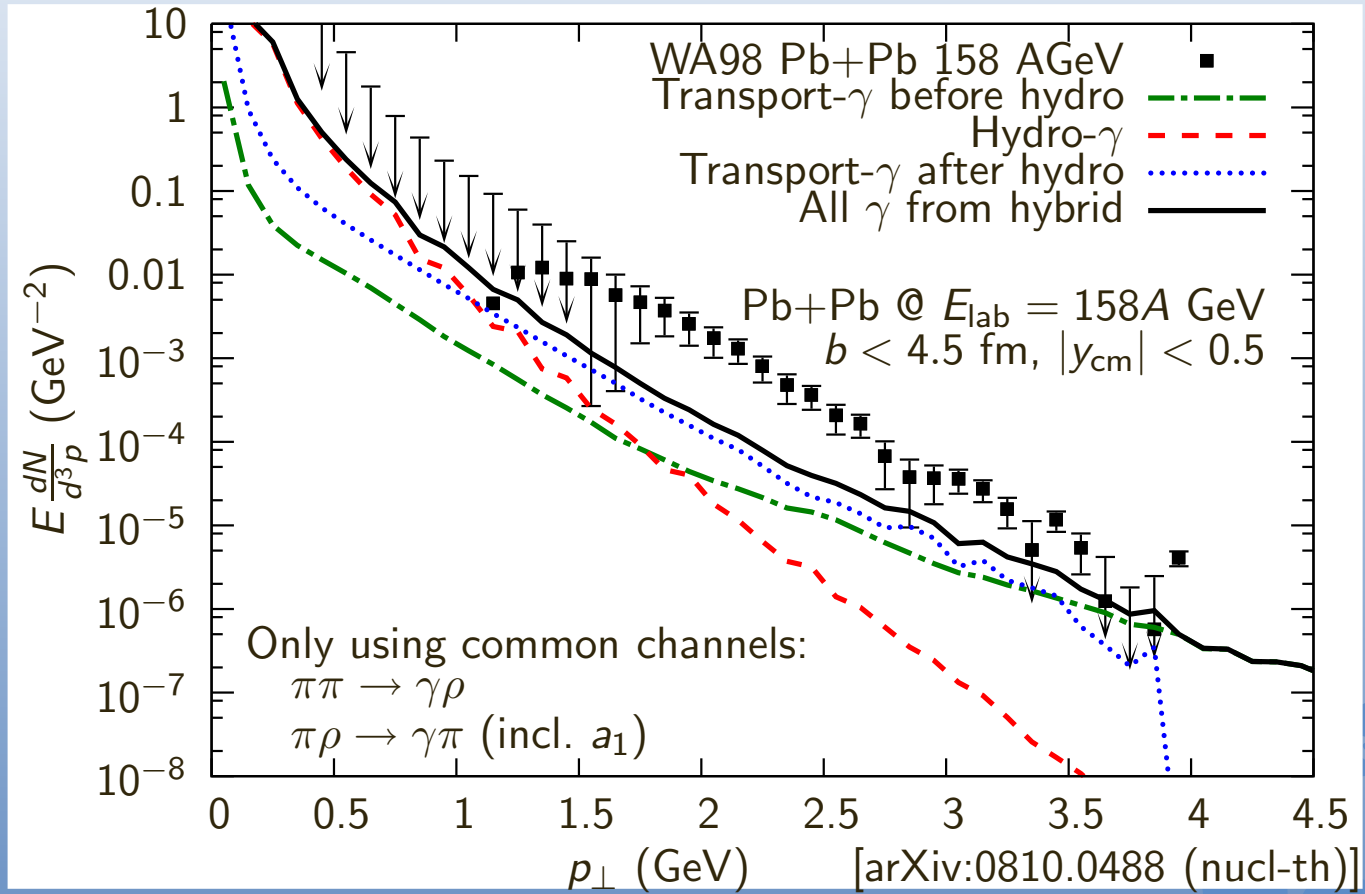
$$\pi + \pi \longrightarrow \gamma + \rho, \qquad \pi + \rho \longrightarrow \gamma + \pi^{(4)},$$
$$\pi + K^* \longrightarrow \gamma + K, \qquad \pi + K \longrightarrow \gamma + K^*,$$
$$\rho + K \longrightarrow \gamma + K, \qquad K + K^* \longrightarrow \gamma + \pi$$



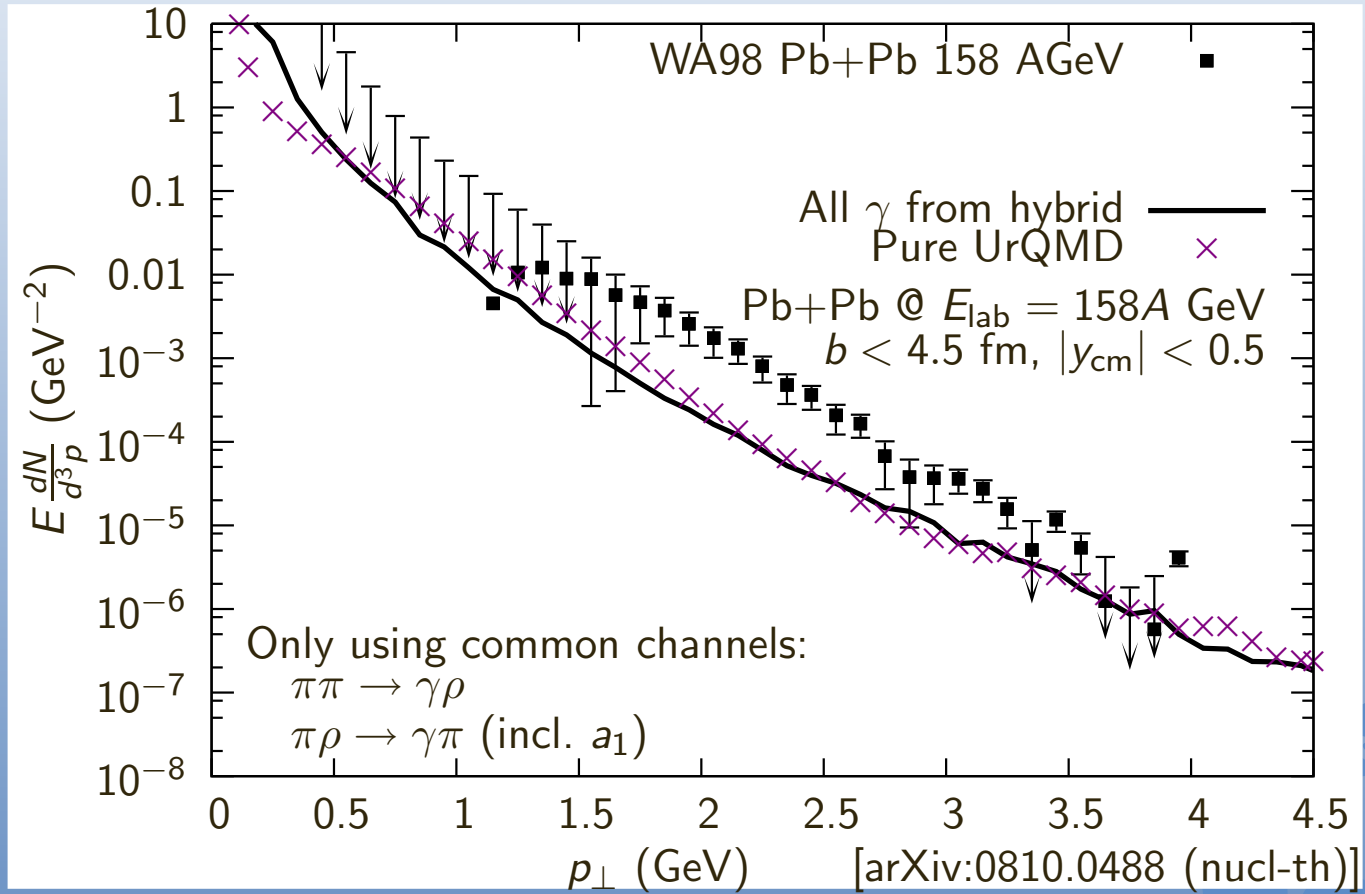
[3] Parametrizations taken from Turbide, Rapp and Gale, PRC **69**, 014903 (2004)

[4] Includes $\pi + \rho \longrightarrow a_1 \longrightarrow \gamma + \pi$

Comparison of $p_\perp$-spectra

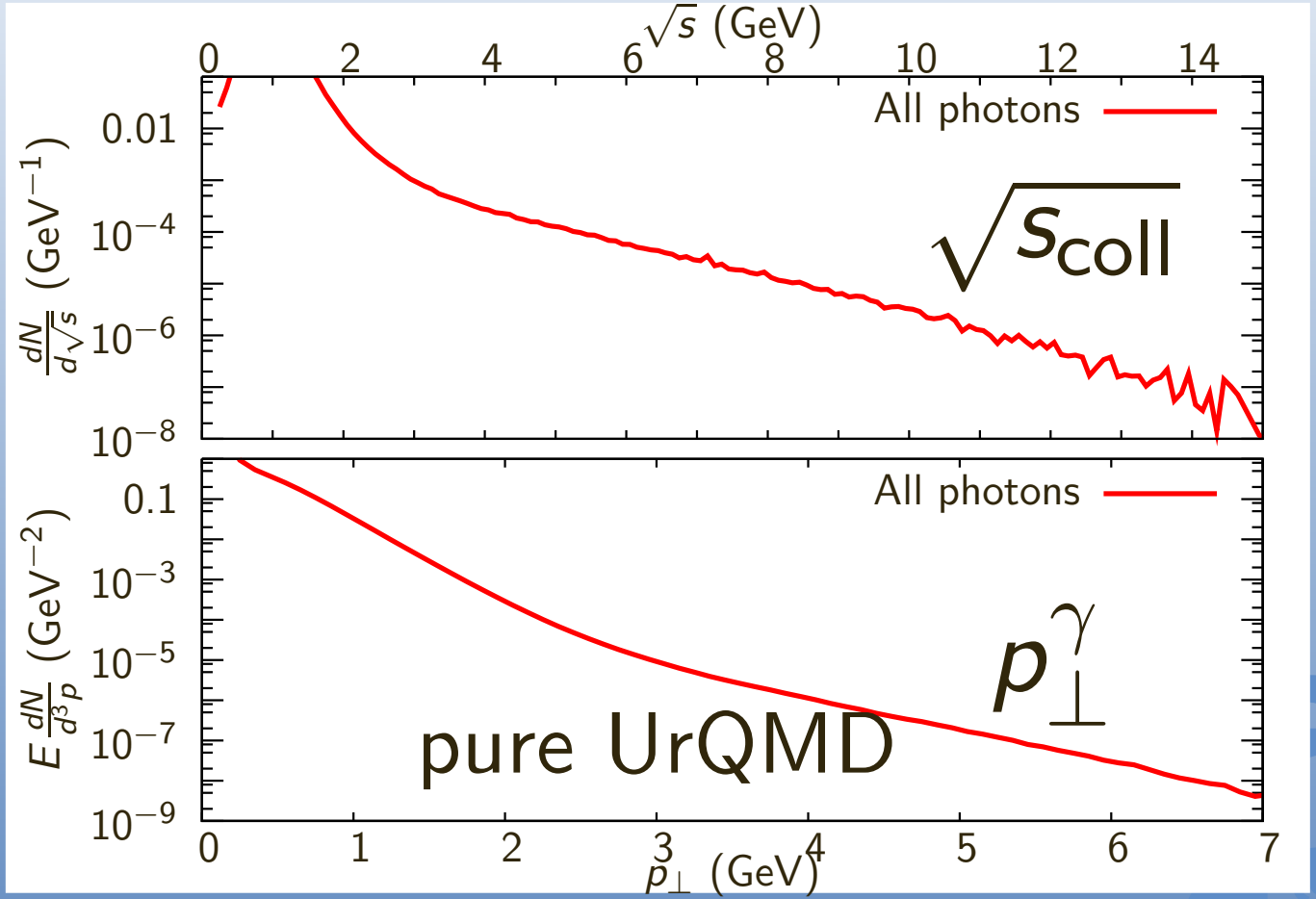


Comparison of $p_\perp$-spectra

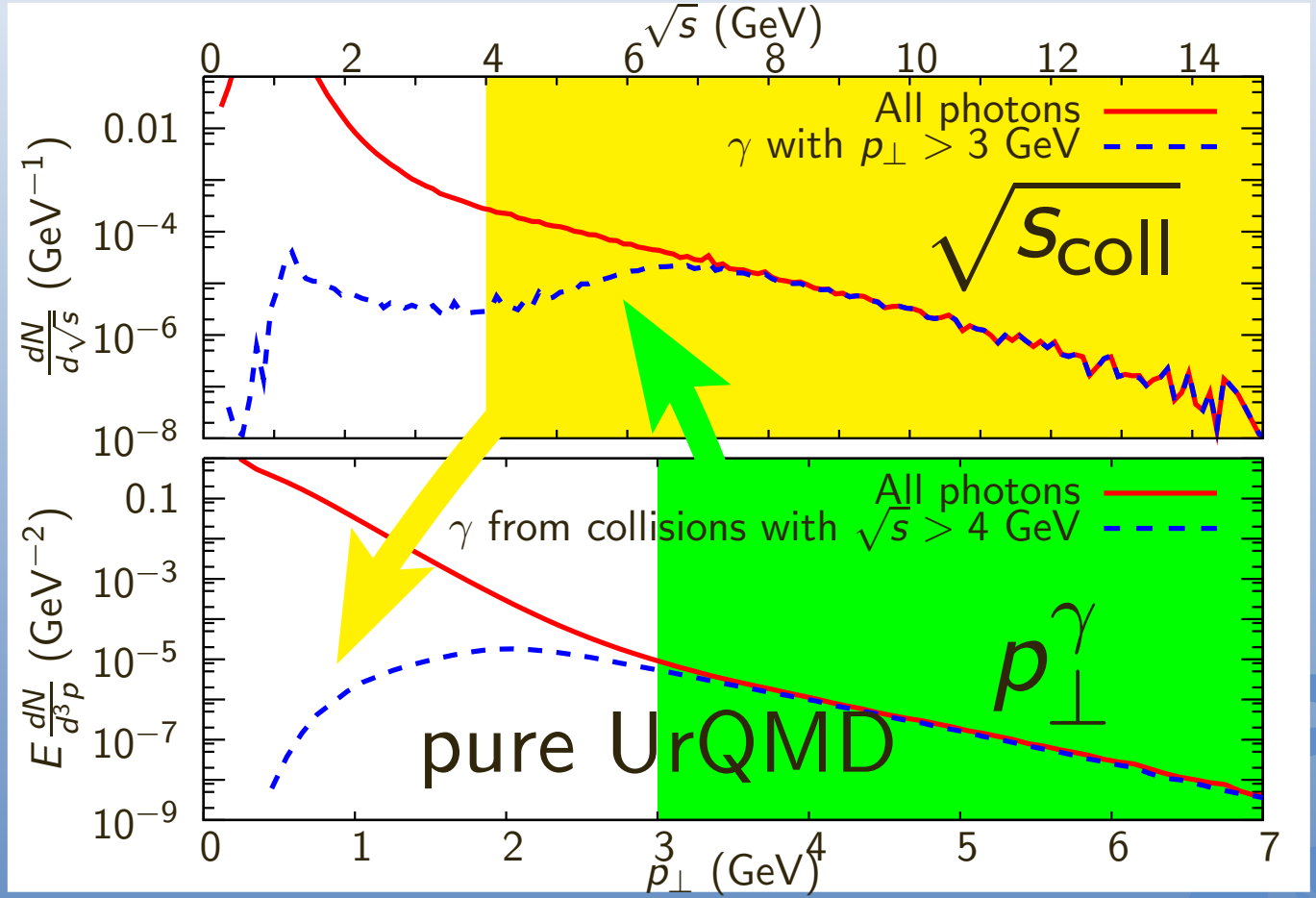


- Hybrid and pure cascade model produce similar spectra
- Spectra too low
- Photons show non-thermal spectra at high $p_\perp$

A closer look at high $p_\perp$-photons

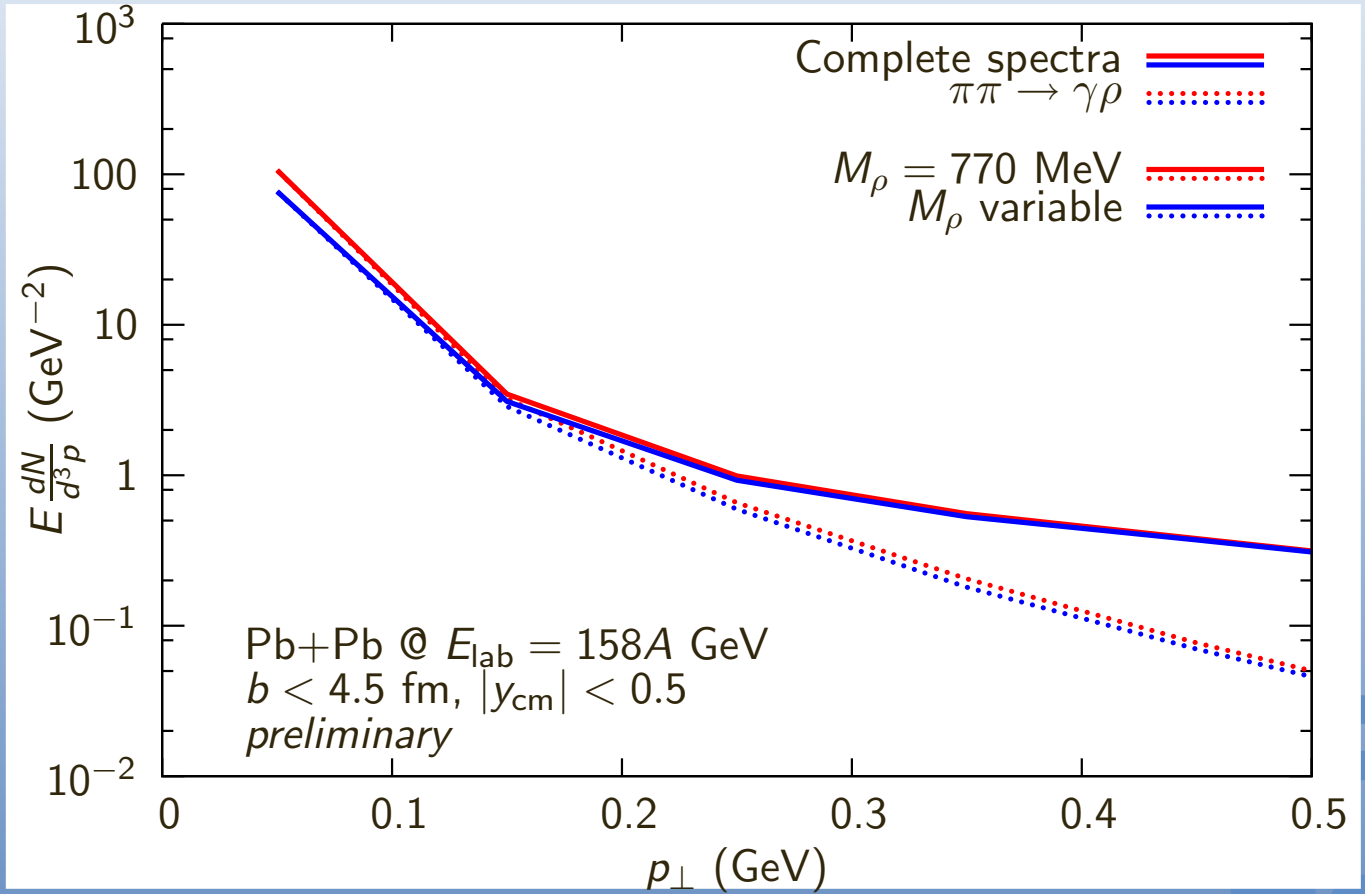


A closer look at high $p_\perp$-photons



- Most photons at high $p_\perp$ come from high-$\sqrt{s}$-collisions
- Hadronic treatment questionable

Taking ρ off its pole



- In channels that produce ρ-mesons: cross-section changes, channels also possible for $\sqrt{s} < m_\rho^0$!
- Affects only very low $p_\perp^\gamma$

Summary & Conclusions

- Hybrid and pure-transport model yield very similar results
- High-$p_\perp$ dominated by high-$\sqrt{s}$
- Onpole-/offpole treatment doesn't change spectra

Summary & Conclusions

- Hybrid and pure-transport model yield very similar results
- High-$p_\perp$ dominated by high-$\sqrt{s}$
- Onpole-/offpole treatment doesn't change spectra

Things to be done:

- Compare rates from cascade and hydro ($\Rightarrow$ Box-Calculation)
- More production channels in both stages
- Different EoS will be compared
- Add photons from initial hard pQCD-Scatterings

Backup-Slides

Cross-Sections and Production Rates

Cascade: Photons are produced in binary collisions acc. to their cross-sections, e.g. for $\pi^{\pm}\rho^0 \longrightarrow \gamma\pi^{\pm}$: [5]

$$\frac{\mathrm{d}\sigma}{\mathrm{d}t} = \frac{\alpha g_\rho^2}{12 s p_{\mathrm{c.m.}}^2}\left[2 - s\frac{m_\rho^2 - 4m_\pi^2}{(s-m_\pi^2)^2} - (m_\rho^2 - 4m_\pi^2)\left(\frac{s - m_\rho^2 + m_\pi^2}{(s-m_\pi^2)(t-m_\pi^2)} + \frac{m_\pi^2}{(t-m_\pi^2)^2}\right)\right]$$

Hydro: Photons are produced at a given temperature acc. to thermal rates. E.g. for $\pi\rho \longrightarrow \gamma\pi$: [6,7]

$$E\frac{\mathrm{d}R}{\mathrm{d}^3 p} = \left(\frac{\Lambda^2}{\Lambda^2 + E m_\pi}\right)^8 T^{2.8} \exp\left(\frac{-(1.461\,T^{2.3094} + 0.727)}{(2TE)^{0.86}} + \left(0.566\,T^{1.4094} - 0.9957\right)\frac{E}{T}\right) fm^{-4}\,GeV^{-2}$$

... and then boosted with the cell's velocity.

[5] See Kapusta, Lichard and Seibert, PRD **44** (1991) 2774

[6] See e.g. Turbide, Rapp and Gale, PRC **69**, 014903 (2004)

[7] All relevant variables given in GeV; $\Lambda = 1$ GeV.

Photons from the model

Cascade

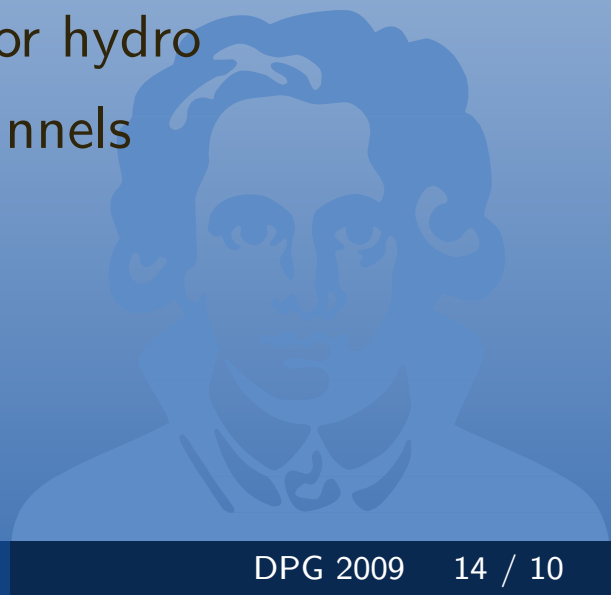
- Emitted photons may be only a fraction of a photon
- Each collision and channel: 100 photons produced with different mandelstam t-values and appropiate weight $N = \frac{\mathrm{d}\sigma_\gamma}{\mathrm{d}t}\Delta t/\sigma_{\mathrm{tot}} \Rightarrow$ less events calculated, better statistics

Hydro

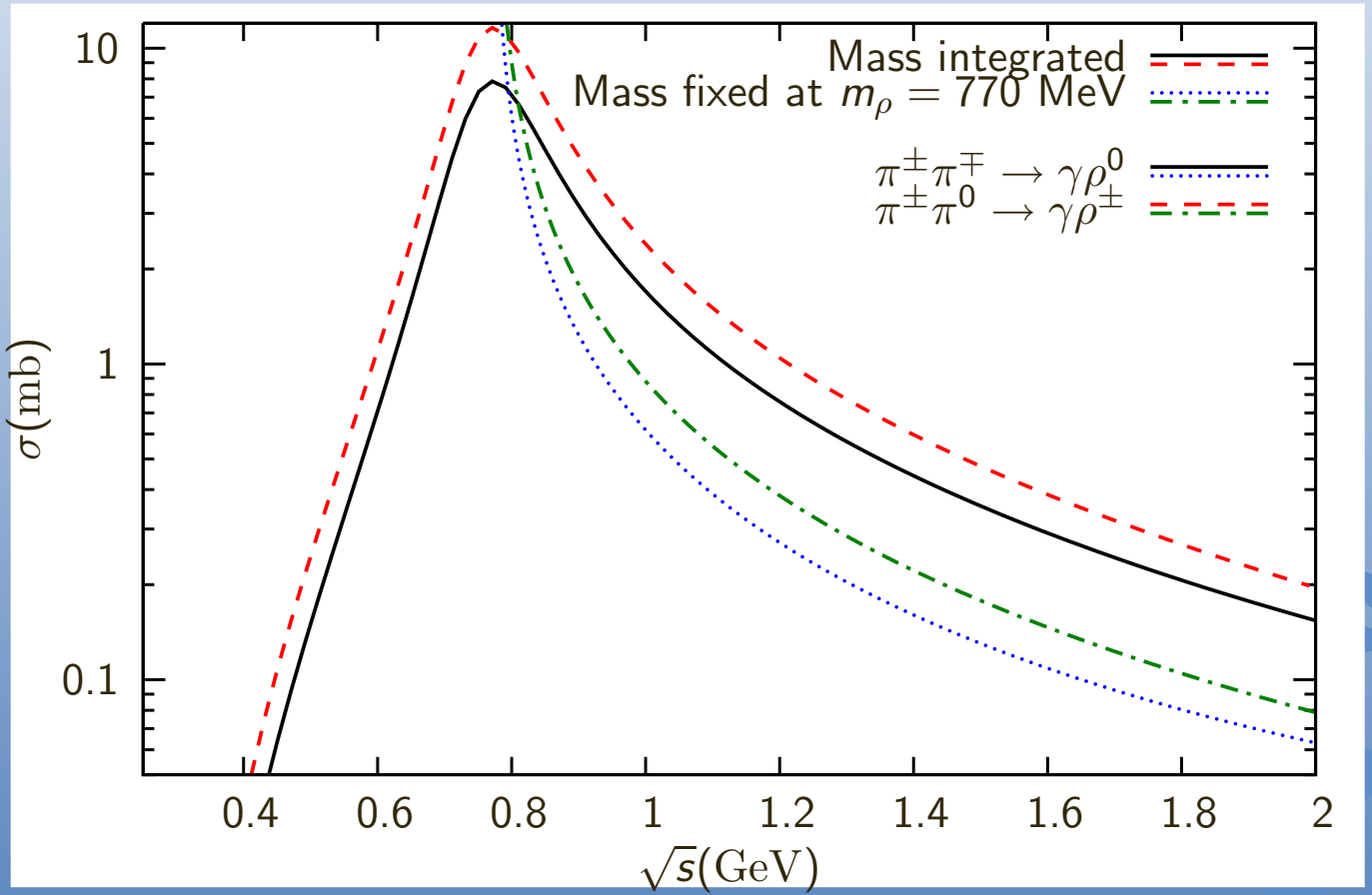
- Take care of proper Lorentz-Transformation (mind Cooper-Frye):
- Generate random $p_\mu u^\mu$ according to thermal rate, then **generate** $\vec{p}$ so that it yields desired $p_\mu u^\mu$.
- For all cells, every implemented rate: one photon-information (with weight $N = \int \frac{\mathrm{d}^3 p}{E}\Delta V \Delta t\, E \frac{\mathrm{d}R}{\mathrm{d}^3 p}$) is created.

Our Model in a nutshell

- Combination of hydrodynamics for high-density part and transport for initial- and final state
- Possibility to study impacts of different dynamics (hydro $\Leftrightarrow$ transport) and different physics (QGP $\Leftrightarrow$ hadron gas) by varying Equation of State in hydro
- No guesswork involved in initial conditions for hydro
- Possibility to clearly distinguish different channels
- Time-resolution of photon emission



Cross-sections for $\pi\pi \longrightarrow \gamma\rho$ I



Cross-sections for $\pi\pi \longrightarrow \gamma\rho$ II