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

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Sponsors

Deutsche Telekom Stiftung

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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 $\sim 97\%$ of all photons
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**Direct Photons**

All the photons that 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
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### Theory
- High $p_{\perp}$: yields calculated by NLO-pQCD. Important at RHIC- and LHC-energies!
- Hydrodynamics: naturally implement phase transition (QGP ↔ 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: Ultra-Relativistic Quantum Molecular Dynamics
- 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 channels¹:

\[
\begin{align*}
\pi + \pi & \rightarrow \gamma + \rho, \\
\pi + \eta & \rightarrow \gamma + \pi, \\
\pi + \pi & \rightarrow \gamma + \gamma, \\
\pi + \rho & \rightarrow \pi + \rho 
\end{align*}
\]

¹Cross-sections taken from Kapusta, Lichard and Seibert, PRD 44 (1991) 2774
²This cross-section from Xiong, Shuryak and Brown, PRD 46, 3798 (1992)
Why photons

UrQMD + photons

Results

Conclusions

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\(^3\):

\[
\begin{align*}
\pi + \pi &\rightarrow \gamma + \rho, \\
\pi + K^* &\rightarrow \gamma + K, \\
\rho + K &\rightarrow \gamma + K, \\
K + K^* &\rightarrow \gamma + \pi \\
\end{align*}
\]

\(^3\)Parametrizations taken from Turbide, Rapp and Gale, PRC 69, 014903 (2004)

\(^4\)Includes \(\pi + \rho \rightarrow a_1 \rightarrow \gamma + \pi\)
Comparison of $p_{\perp}$-spectra

Only using common channels:

$\pi \pi \rightarrow \gamma \rho$

$\pi \rho \rightarrow \gamma \pi$ (incl. $a_1$)

Transports-$\gamma$ before hydro

Hydro-$\gamma$

Transports-$\gamma$ after hydro

All $\gamma$ from hybrid

Pb+Pb @ $E_{\text{lab}} = 158$ A GeV

$b < 4.5$ fm, $|y_{\text{cm}}| < 0.5$

[arXiv:0810.0488 (nucl-th)]
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

![Graph showing the distribution of $dN/d\sqrt{s}$ and $E_{T}/d^{3}\rho_{T}$ for all photons and pure UrQMD.](image)

- $dN/d\sqrt{s}$ for all photons decreases with increasing $\sqrt{s_{\text{coll}}}$.
- $E_{T}/d^{3}\rho_{T}$ for pure UrQMD decreases with increasing $p_{\perp}$.

**Results**

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

- Most photons at high $p_\perp$ come from high-$\sqrt{s}$-collisions
- Hadronic treatment questionable
Taking $\rho$ off its pole

In channels that produce $\rho$-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
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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 $\pi^\pm \rho^0 \rightarrow \gamma \pi^\pm$: \(^{(5)}\)

\[
\frac{d\sigma}{dt} = \frac{\alpha g^2}{12s p^2}_{\text{c.m.}} \left[ 2 - s \frac{m^2_{\rho} - 4m^2_{\pi}}{(s-m^2_{\pi})^2} - (m^2_{\rho} - 4m^2_{\pi}) \left( \frac{s-m^2_{\rho}+m^2_{\pi}}{(s-m^2_{\pi})(t-m^2_{\pi})} + \frac{m^2_{\pi}}{(t-m^2_{\pi})^2} \right) \right]
\]

Hydro: Photons are produced at a given temperature acc. to thermal rates. E.g. for $\pi \rho \rightarrow \gamma \pi$: \(^{(6,7)}\)

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

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

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\(^{(5)}\) 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 appropriate weight

$$N = \frac{d\sigma^\gamma}{dt} \Delta t / \sigma_{\text{tot}} \Rightarrow \text{less events calculated, better statistics}$$

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 $N = \int \frac{d^3p}{E} \Delta V \Delta t E \frac{dR}{d^3p}$) 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 ⇔ transport) and different physics (QGP ⇔ 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 $\pi\pi \rightarrow \gamma\rho$ I

![Graph showing cross-sections for $\pi\pi \rightarrow \gamma\rho$]
Cross-sections for $\pi\pi \rightarrow \gamma\rho$ II

Mass integrated

Mass fixed at $m_\rho = 770$ MeV

$\pi^\pm\pi^\mp \rightarrow \gamma\rho^0$

$\pi^\pm\pi^0 \rightarrow \gamma\rho^\pm$