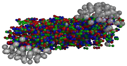
HIC for FAIR
Helmholtz International Center



FIAS Frankfurt Institute for Advanced Studies

Soft Photons from transport and hydrodynamics

Bjørn Bäuchle
The UrQMD Group (http://urqmd.org)
(in preparation)

FIAS Frankfurt

FAIRNESS 2012, Χερσόνησος, Ελλάδα
2012/09/04

The UrQMD-Group

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Yurii Karpenko, Thomas Lang, Gunnar Gräf, Jochen Gerhard,
Stephan Endres, Andreas Grimm

Outline

Three Ways to learn about bulk QCD

(According to the Nahrgang classification, curtesy of Marlene Nahrgang)

1. Be brave and solve…

$$\dots Z(T, \mu_B) = \int \mathcal{D}(A, q, q^\dagger) \mathrm{e}^{-S^E_{\mathrm{QCD}}}$$


ab initio and nonperturbatively,

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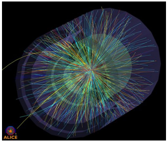
2. Be strong and collide…



…heavy ions at ultrarelativistic energies,

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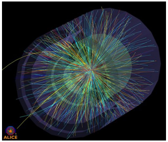


…heavy ions at ultrarelativistic energies,

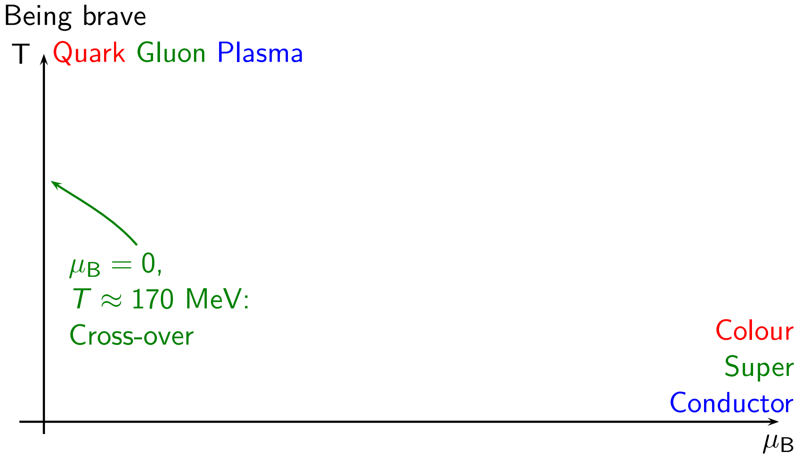
3. Be creative and study…

…effective models of QCD.

$$\mathcal{L}_{\mathrm{eff}}$$

What we have learned about bulk QCD

(According to the Nahrgang classification, courtesy of Marlene Nahrgang)



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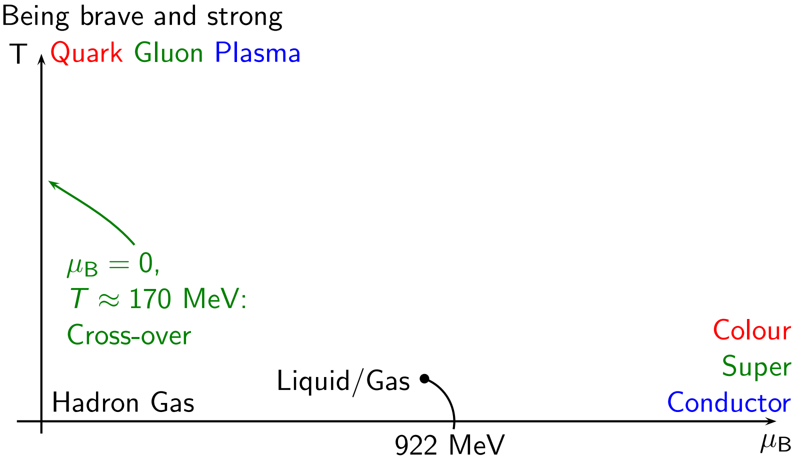

What we have learned about bulk QCD

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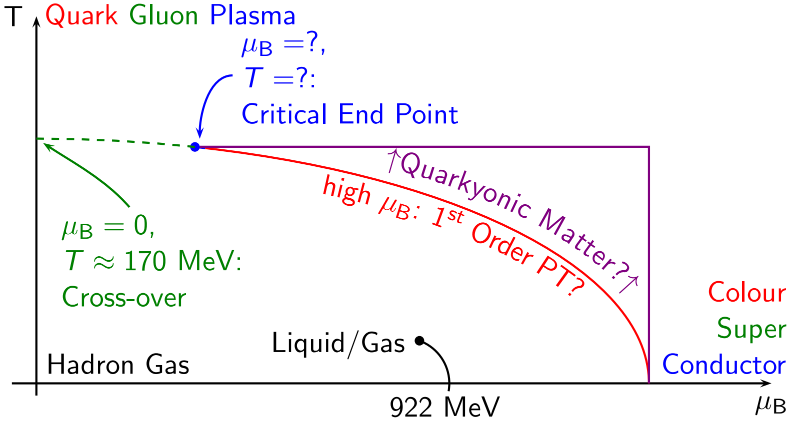
Being brave, strong and creative



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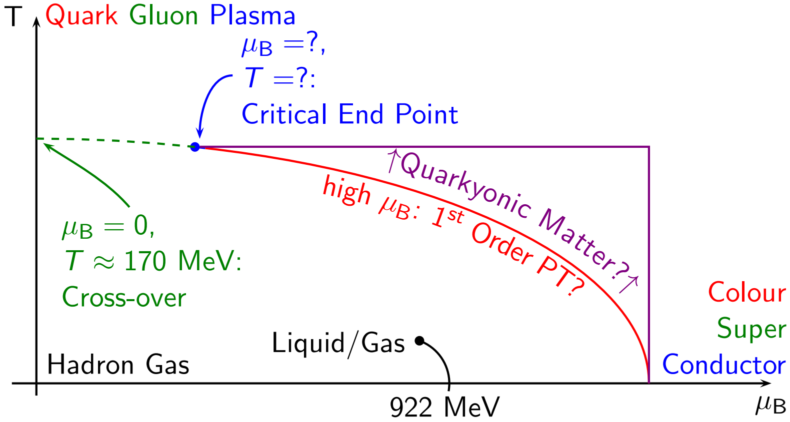
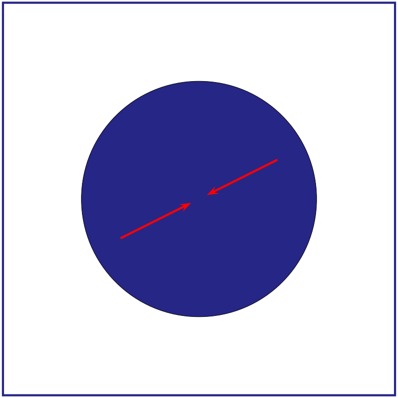


Need to connect creativity and bravery with strength by dynamic models

What Are Direct Photons

And why are they interesting?



✓ Interesting scattering in fireball

Direct Photons. . .

. . . all photons which do not come from hadronic decays

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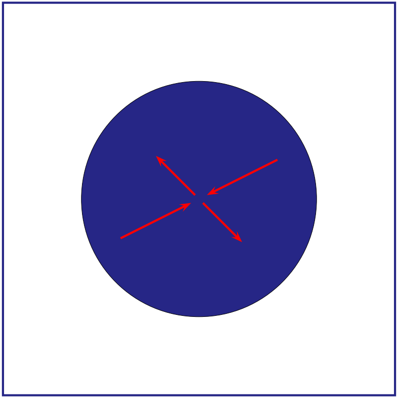
And why are they interesting?



- ✓ Interesting scattering in fireball
- ✓ Hadronic daughter particles…

Direct Photons…

…all photons which do not come from hadronic decays

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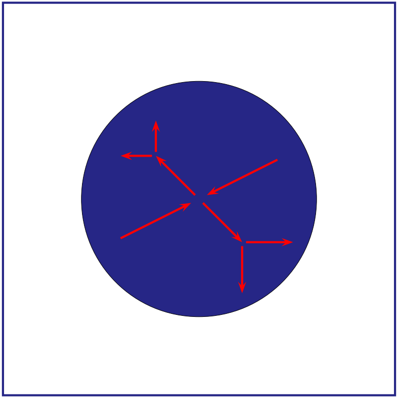

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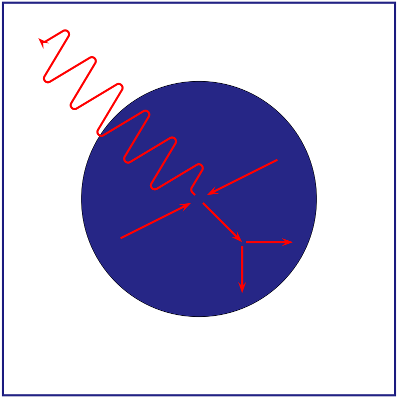

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- ✓ Photons do not rescatter $\rightarrow$ keep information!

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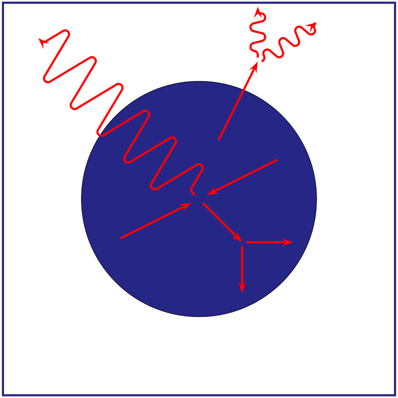
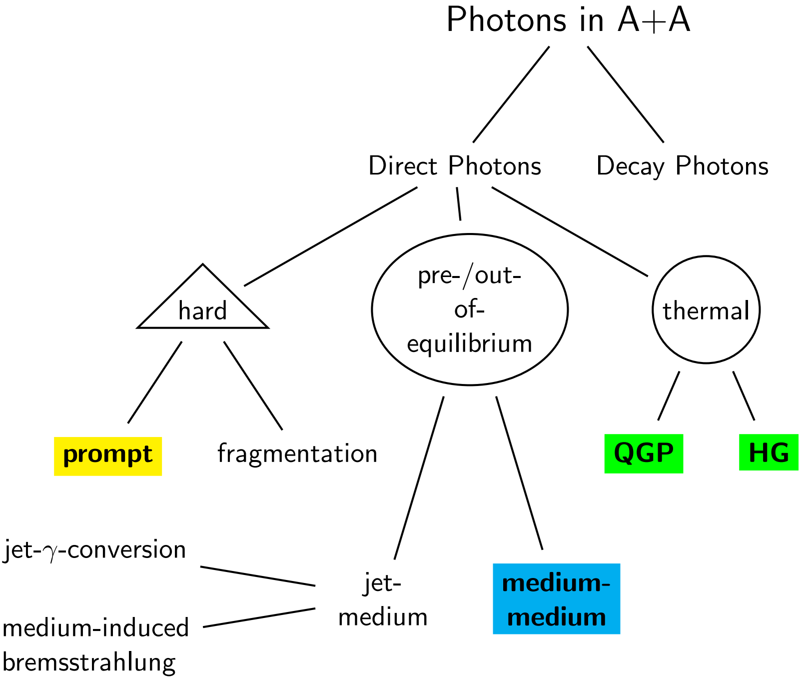


- ✓ Interesting scattering in fireball
- ✓ Hadronic daughter particles…
- ϟ …rescatter. Information lost.
- ✓ Photons do not rescatter → keep information!
- ! Plenty uninteresting photon sources

Direct Photons…

…all photons which do not come from hadronic decays


Photons in A+A
Direct Photons
Decay Photons
hard
pre-/out-of-equilibrium
thermal
prompt
fragmentation
QGP
HG
jet-γ-conversion
medium-induced bremsstrahlung
jet-medium
medium-medium

Direct Photon Experiments

- ! Helios, WA 80, CERES (SPS) [1] — upper limits
- ↯ WA 93 (SPS) and STAR (RHIC) — no results (yet)
- ✓ WA 98[2] — first measurements at SPS
- ✓ PHENIX[3] (RHIC) — various results
- ? ALICE, ATLAS, CMS (LHC) — data for hard γ available ($p_\perp > 5$ GeV)
- ? CBM (FAIR) — coming in ≈ 1 decade (hopefully)

[1] Helios: Z. Phys. C **46**, 369 (1990); WA 80: Z. Phys. C **51**, 1 (1991); PRL **76**, 3506 (1996); CERES: Z. Phys. C **71**, 571 (1996)

[2] PRL **85**, 3595 (2000)

[3] e.g. PRL **94**, 232301 (2005)

Theory: Underlying Models

pQCD Good for high $p_\perp$, plays no role at FAIR

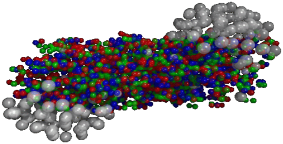
Hydro Good for thermalized systems, phase transitions.
Input: Parametrized Rates $E\frac{dN}{d^3pd4x}(p, T, \mu)$
Application: numerical challenge[4]!

Transport Good for not-too-dense systems.
Input: Cross-sections $\frac{d\sigma}{dt}(s, t, \rho)$
Application: straight-forward[5]

[4] Turbide *et al.*, PRC **69**, 014903 (2004); Turbide *et al.*, PRC **72**, 014906 (2005); Liu *et al.*, arXiv:0712.3612 [hep-ph]; Vitev *et al.* arXiv:0804.3805 [hep-ph]; Haglin, PRC **50**, 1688 (1994); Haglin, JPG **30**, L27 (2004); Duisling *et al.*, PRC **82**, 054909 (2010)

[5] Dumitru *et al.*, PRC **57**, 3271 (1998); Huovinen *et al.*, PRC **66**, 014903 (2002); Li *et al.* arXiv:nucl-th/9712048

UrQMD



UrQMD
Ultra-Relativistic Quantum
Molecular Dynamics

- Classical propagation of hadrons & strings
- QM scattering cross-sections
- Cross-sections fitted to data or
  calculated via detailed balance or
  parametrized via additive quark model
- All hadrons from PDG up to $m = 2.2$ GeV

✓ Full microscopic collision history availavble

✓ Version 3.3 out now! Go to http://urqmd.org/

UrQMD+Hydro (new in u3.3)

- ✓ High-density part of evolution optionally substituted by ideal hydrodynamics
- ✓ Macroscopic description
- Microscopic initial state from transport (UrQMD) mapped to densities and flow velocities (fluidization)
- Hydro propagation with variable Equation of State
- Back to transport when $\epsilon < 5\epsilon_0$ in all cells at same longitudinal position (particlization)
- Rescatterings and decays with UrQMD
- See also Petersen *et al.* Phys. Rev. C **78** (2008) 044901

Equations of State

Hadron Gas

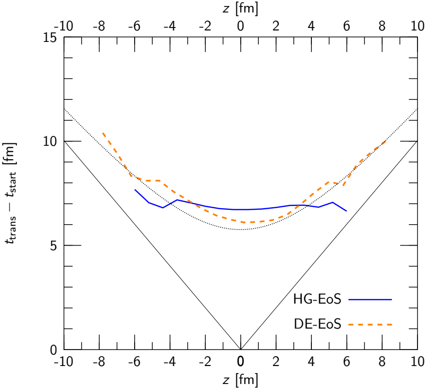
- Includes all particles from UrQMD
- no phase transition

Deconfinement

- Chirally restored and deconfined phase
- First Order PT, Cross-over and CEP

Particlization positions

Particlization times at different z-positions



- One event, Pb+Pb @ $E_{\mathrm{lab}} = 35$ AGeV
- HG/DE-EoS
- dotted line: constant τ
- fast cells survive longer in DEconfinement scenario

BB, PhD thesis

Coordinate considerations

- ! Hydro Code: SHASTA (Rischke, 1995)
- ! Code in cartesian coordinates (xyzt)
- ! Stability requires $\Delta x = \Delta y = \Delta z$
- ↯ Hard to fit A+A at high lorentz contraction to grid
- ✓ No Problem at FAIR!
- ✓ (At energies $>$ SPS, only particles with $|y| \leq 2$ put into hydro)

Soft Photons from the model

Both models

$$\pi + \pi \to \gamma + \rho, \quad \pi + \rho \to \gamma + \pi$$

Trying to extend list to "Only Cascade"-channels (ongoing work)

Only Cascade

$$\pi + \pi \to \gamma + \eta, \quad \pi + \eta \to \gamma + \pi, \quad \pi + \pi \to \gamma + \gamma$$

Only Hydro

$$\pi + K \to \gamma + K^*, \ \pi + K^* \to \gamma + K,$$

$$\rho + K \to \gamma + K, \ K + K^* \to \gamma + \pi$$

$\pi + \pi \to \pi + \pi + \gamma$ (Bremsstrahlung)

QGP-emission (DEconfinement only)

Soft Photons from the model

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$$\rho + K \rightarrow \gamma + K, \ K + K^* \rightarrow \gamma + \pi$$

$\pi + \pi \rightarrow \pi + \pi + \gamma$ (Bremsstrahlung)

QGP-emission (DEconfinement only)

grouping

$\pi/K + \pi/K$; $\pi/K + \rho/K^*/\eta$; Bremsstrahlung; QGP

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 $N = \frac{d\sigma_\gamma}{dt}\Delta t/\sigma_{tot} \Rightarrow$ less events calculated, better statistics
- ✓ Analysis after hadronic run (collision information cheap)

Hydro

Photons from the model

Cascade

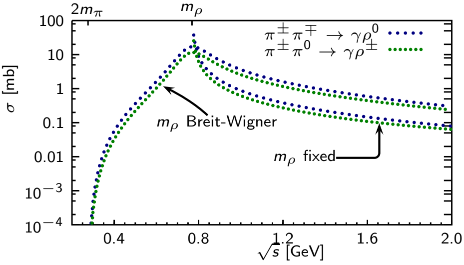
Hydro

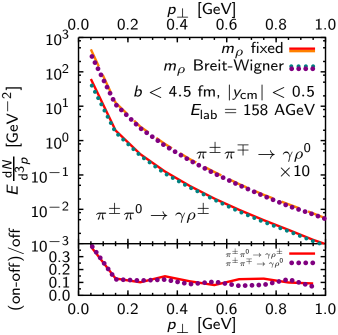
- ! For all cells, every implemented rate
- Rejection method sampling of thermal rate
- One photon-information (with weight $N = \int \frac{\mathrm{d}^3 p}{E} \Delta V \Delta t \, E \frac{\mathrm{d}R}{\mathrm{d}^3 p}$) per cell is created.
- ! Need integral and maximum of distribution (both tabellized)
- ↯ Analysis during hadronic run
  (T for every cell/timestep expensive)

ρ-mass

Producing ρ

- ► ρ is very wide
- ✓ Incoming ρ ($\pi\rho \to \gamma\pi$) has mass from UrQMD ($m = \sqrt{p^\mu p_\mu}$)
  Cross-section calculated with this mass.
- ! Outgoing ρ may be assigned pole mass $m_\rho = 769$ MeV
- ! ...or assigned random mass acc. to Breit-Wigner

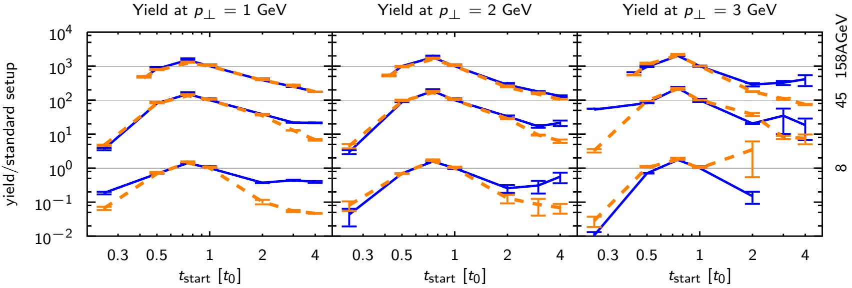




Hydro-parameter I: t_{start}

Time for starting of hydro part

- Starting time varied by factors 0.25...4
  - ! yield changes significantly, largest yield at 0.75× standard
  - ! Early beginning: Energy density not high enough
    ⇒ immediate particlization
  - ! Late beginning: Most parts too dilute ⇒ same effect.

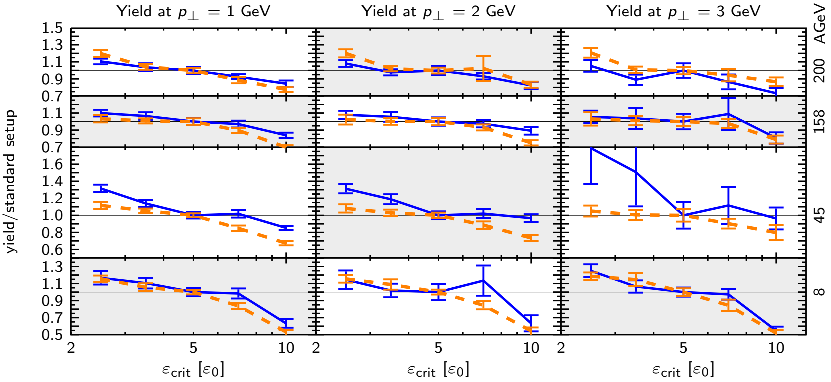


BB, M. Bleicher, JPCS 270 (2011) 012031

Hydro-parameter II: $\varepsilon_{\text{crit}}$

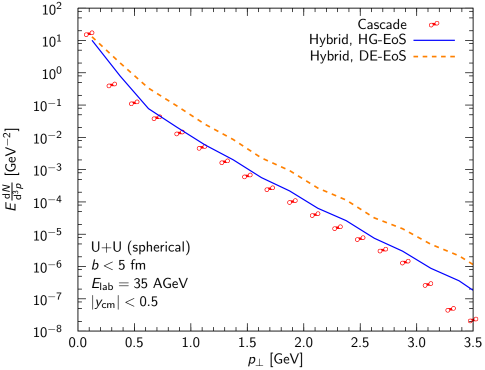
Critical energy density

- ▶ particlization when system drops below $\varepsilon_{\text{crit}}$
- ✓ small changes only
- ! consistent drop with larger threshold (shorter hydro phase)



BB, M. Bleicher, JPCS 270 (2011) 012031

Direct Photon Spectra: FAIR

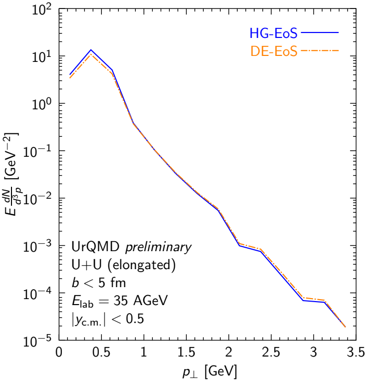


No pQCD present @ FAIR

- ✓ Clear distinction between partonic and purely hadronic scenarios
- ↯ Yield low ⇒ hard to measure
- ↯ Lacks yield from Bremsstrahlung!

BB, M. Bleicher, PLB 695 (2011) 489-494

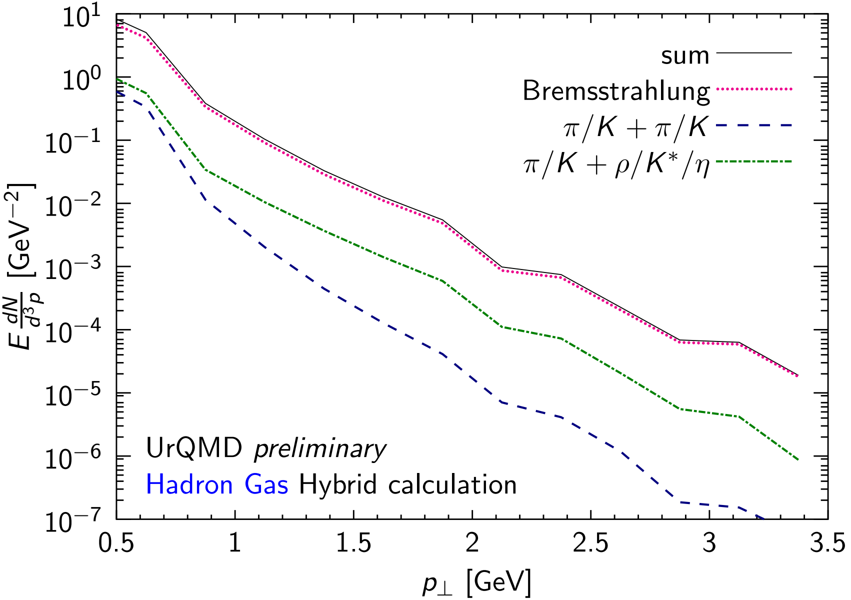
Direct Photon Spectra: add Bremsstrahlung



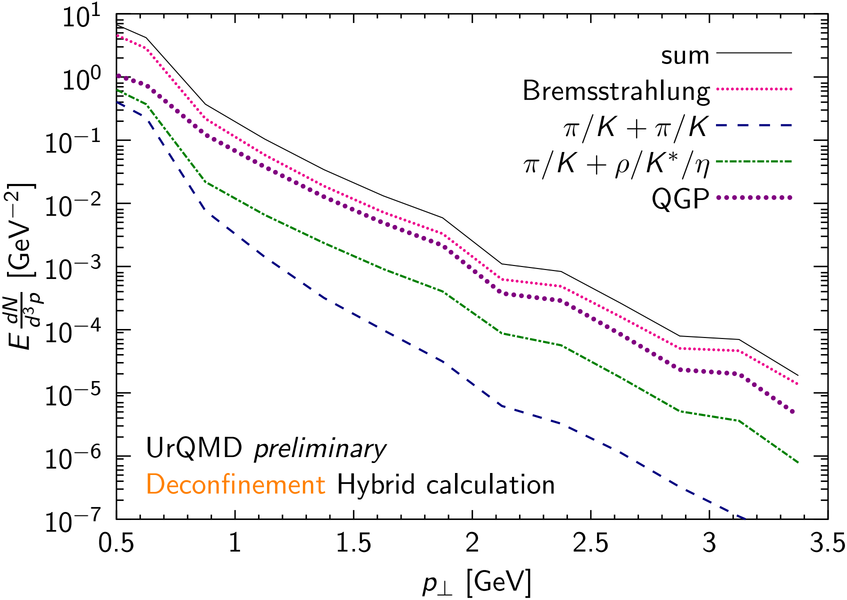
Including Bremsstrahlung

- ! Bremsstrahlung dominates
- ϟ Separation between scenarios gone!
- ! Situation clearly different from higher $\sqrt{s}$

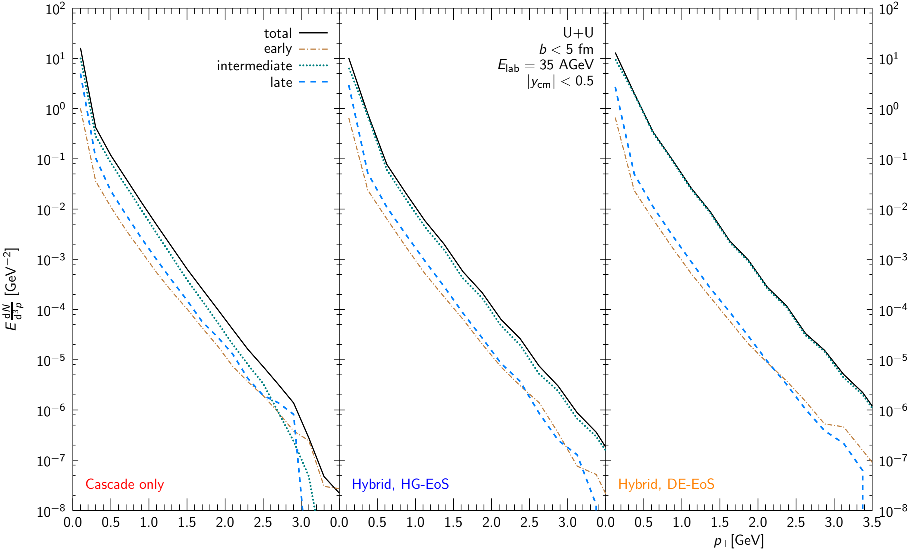
Channel composition Hadron Gas



Channel composition Deconfinement

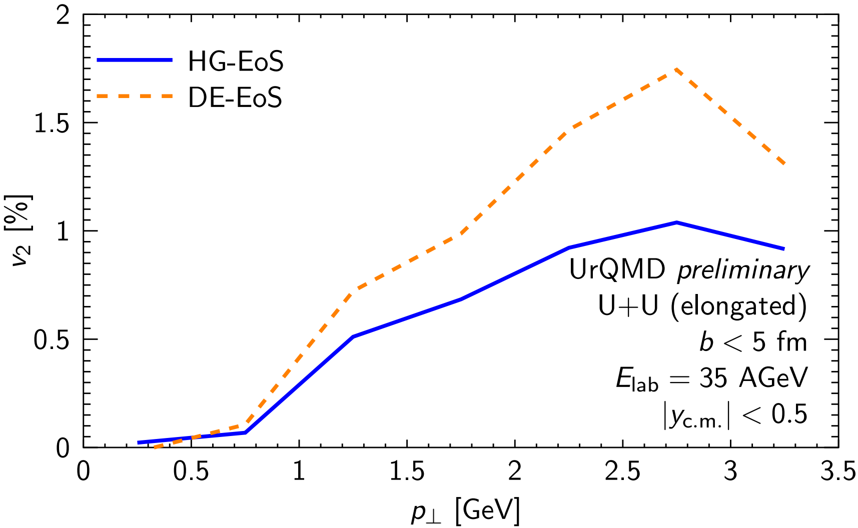


Stages' contributions



- Intermediate stage dominates
- (w/o Bremsstrahlung, dominance would increase even more)

v_2 with Uranium



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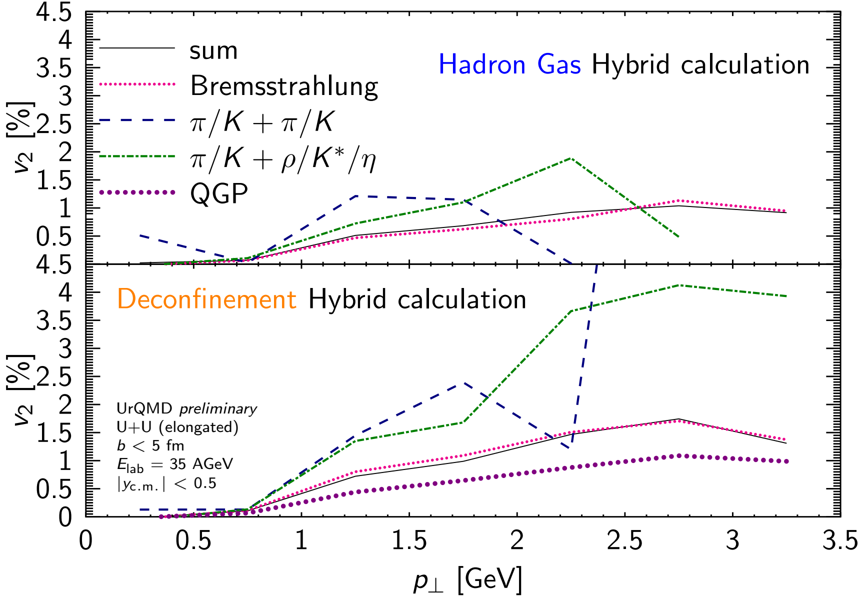
- Elliptic flow larger with partonic phase

Breaking down v_2: different channels



- Bremsstrahlung reduces elliptic flow in both HG and DE!

Summary

Summary

- Successful hadronic model extended to photons
- Systematic error estimation from particlization/fluidization parameters
- ? Bremsstrahlung (seems to) dominate(s) everything at FAIR!
- ? Bremsstrahlung flow lower than other hadronic processes
- (Early) QGP-flow lower than (late) hadronic flow
- Flow might help to distinguish partonic vs. hadronic scenario

To Do

- Examine Bremsstrahlung-dynamics
- (Try to) Add Bremsstrahlung to cascade processes!
- Check results