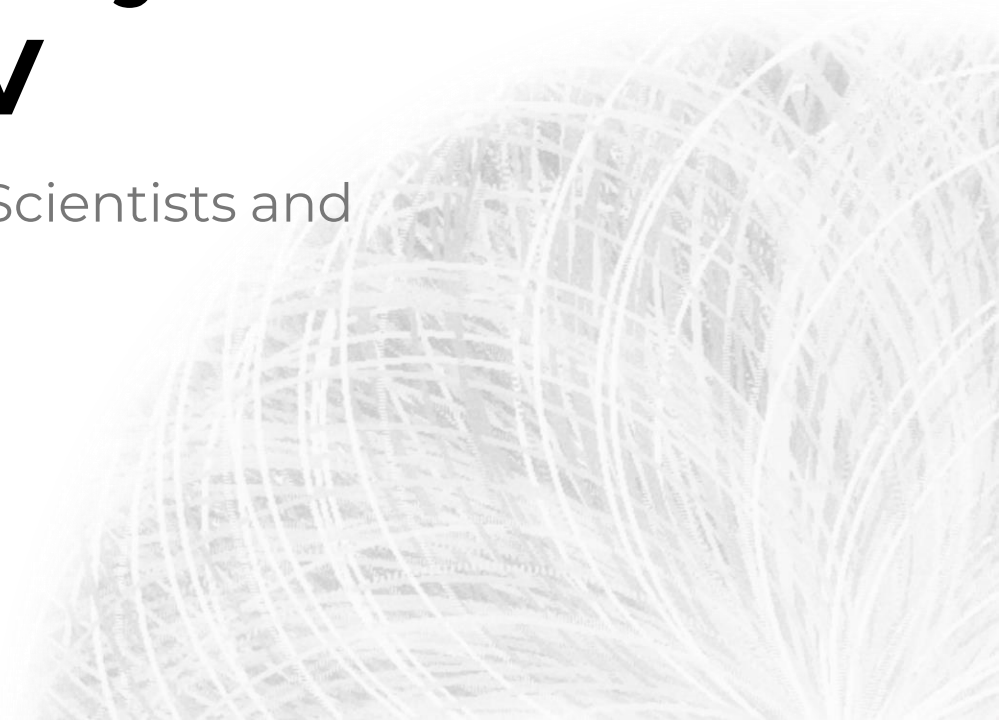


Direct Photon Interferometry in Bi-Bi Collisions at $\sqrt{s_{NN}} = 9.2$ GeV

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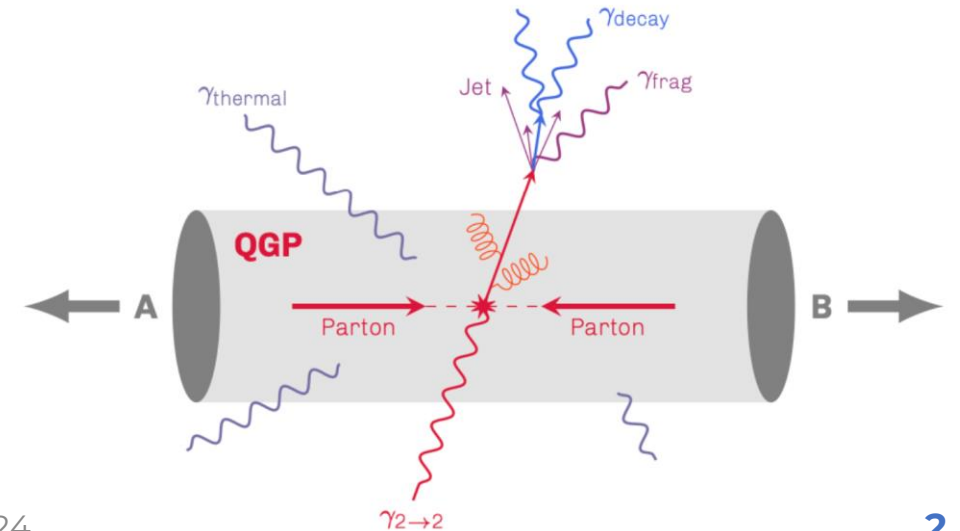
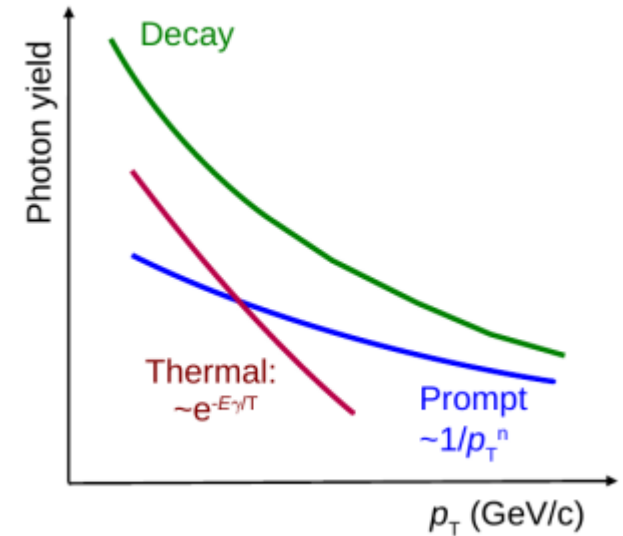


Introduction

- **Direct photons** – photons not originating from hadron decays:
 - **thermal photons** ($\sim e^{-E_\gamma T}$), thermal radiation of QGP, space-time evolution of QGP
 - **prompt photons** ($\sim 1/p_T^n$), initial hard scattering, testing pQCD, PDF (+nPDF modification) and FF constrains:

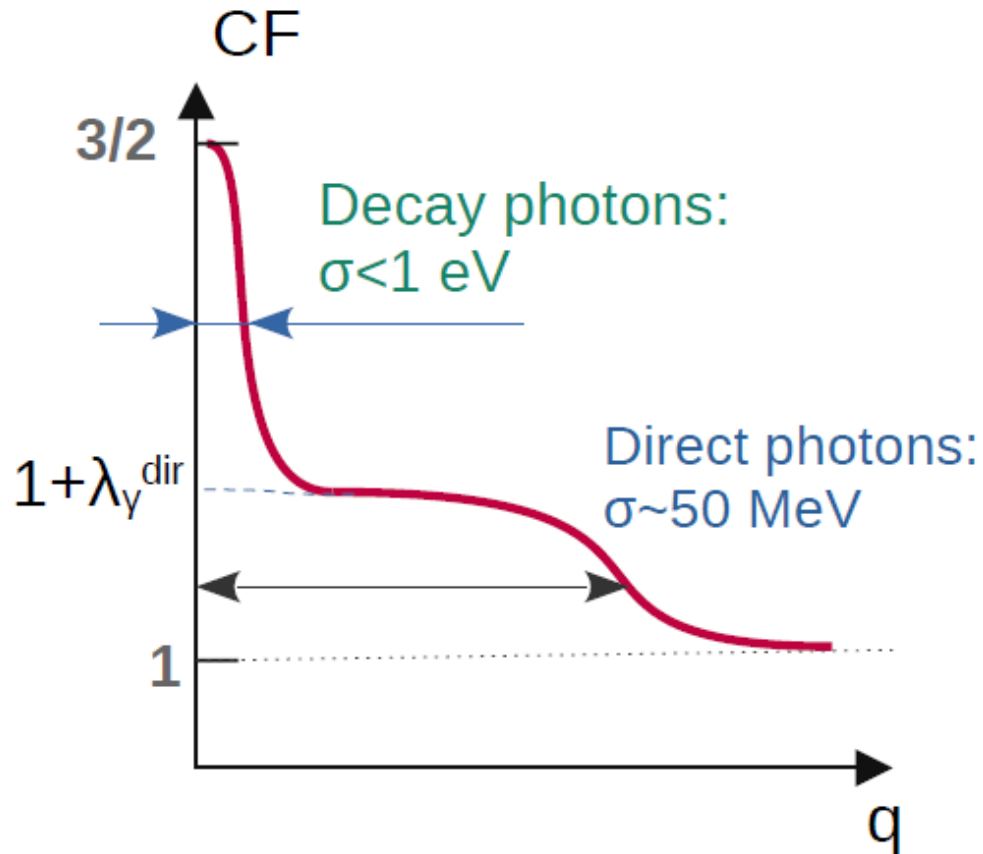
$$E \frac{d^3 \sigma}{dp^3} = \sum_{i,j,k} f_i(x_i, Q^2) \otimes f_j(x_j, Q^2) \otimes D_k(z_k, Q^2)$$

- Other sources: fragmentation photons, pre-equilibrium photons
- Photons are color neutral: not affected by QGP \rightarrow perfect probe for studying QGP properties
- **Two-photon Bose-Einstein correlations** could be used for measurements of direct photon yields and correlations radii
- In this talk we present results on hydrodynamic calculations of direct photon correlations (interferometry) in Bi-Bi collisions at $\sqrt{s_{NN}} = 9.2$ GeV



Direct photon Bose-Einstein correlations

Correlation function:



- Interferometry in heavy-ion collisions is based on the symmetrization of the wave-functions of two identical particles
 → for bosons: **Bose-Einstein (BE) Correlation**
- Increased probability of finding particles with low **relative momentum of the pair (q)** → estimation of the size of the emitting source
- The observable for the interferometry is **correlation function (C_2)** – ratio of correlated two-photon distribution to noncorrelated distribution

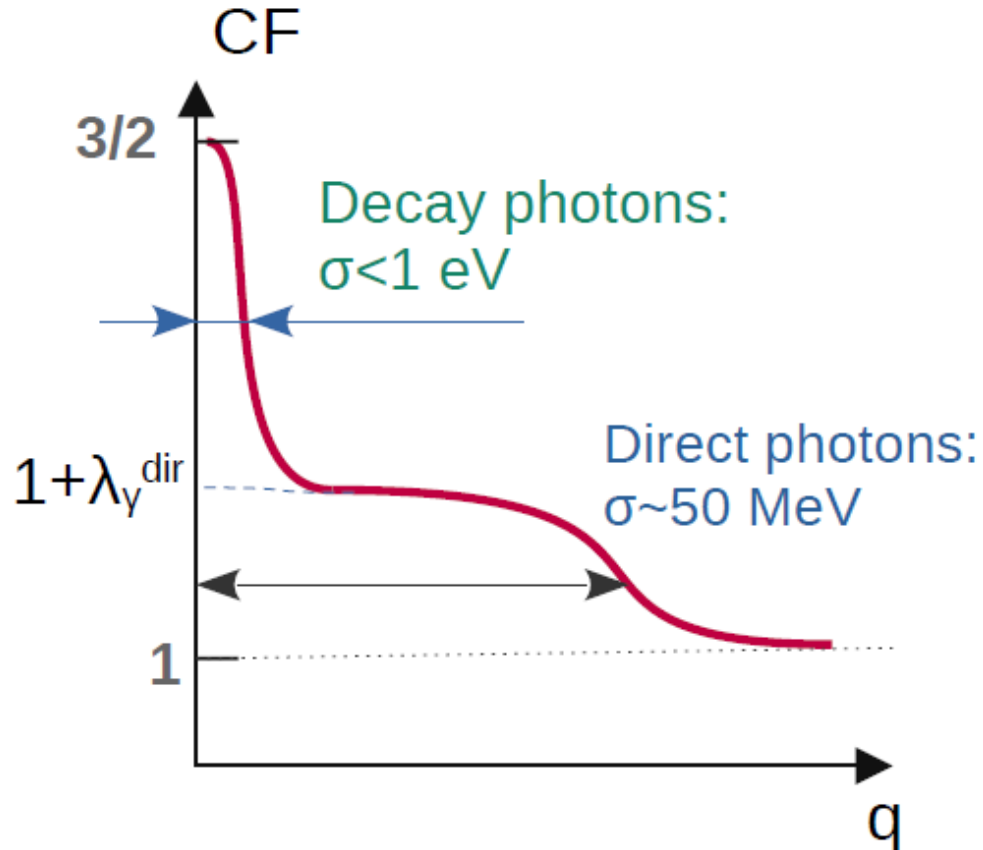
$$C_2(\mathbf{p}_1, \mathbf{p}_2) = \frac{E_1 E_2 dN / (d^3 p_1 d^3 p_2)}{(E_1 dN / d^3 p_1)(E_2 dN / d^3 p_2)}$$

Kinematics variables:

- Relative momentum of the pair: $\mathbf{q} = \mathbf{p}_1 - \mathbf{p}_2$
- Mean pair momentum: $\mathbf{K} = \frac{1}{2}(\mathbf{p}_1 + \mathbf{p}_2)$

Direct photon Bose-Einstein correlations

Correlation function:



- General definition:

$$C_2(\mathbf{p}_1, \mathbf{p}_2) = \frac{E_1 E_2 dN / (d^3 p_1 d^3 p_2)}{(E_1 dN / d^3 p_1)(E_2 dN / d^3 p_2)}$$

- This expression could be written as

$$C_2(\mathbf{q}, \mathbf{K}) = 1 \pm \frac{|\int d^4 x S(x, K) e^{iq \cdot x}|^2}{\int d^4 x_1 S(x_1, K + 1/2 \cdot q) \int d^4 x_2 S(x_2, K + 1/2 \cdot q)}$$

where \mathbf{S} is emitting function, (-) for fermions, and (+) for bosons

- It was shown that the **smoothness approximation** is valid for calculations in heavy-ion collisions Pratt S. *Phys. Rev. C* 56:1095 (1997)

$$C_2(\mathbf{q}, \mathbf{K}) \approx 1 + \left| \frac{\int d^4 x S(x, K) e^{iq \cdot x}}{\int d^4 x S(x, K)} \right|^2$$

Kinematics variables:

- Relative momentum of the pair: $\mathbf{q} = \mathbf{p}_1 - \mathbf{p}_2$
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Thermal photon emitting functions

QGP emission: JHEP 0112:009,2001

$$S(K) = A(K) \cdot (\ln(T/m) + C_{\text{tot}})$$

$$C_{\text{tot}} = \frac{1}{2} \ln(2K/T) + C_{\text{brems}}(K/T) + C_{\text{annih}}(K/T) + C_{2 \rightarrow 2}(K/T)$$

Combination of photons produced in bremsstrahlung, quark annihilation and scattering processes in QGP

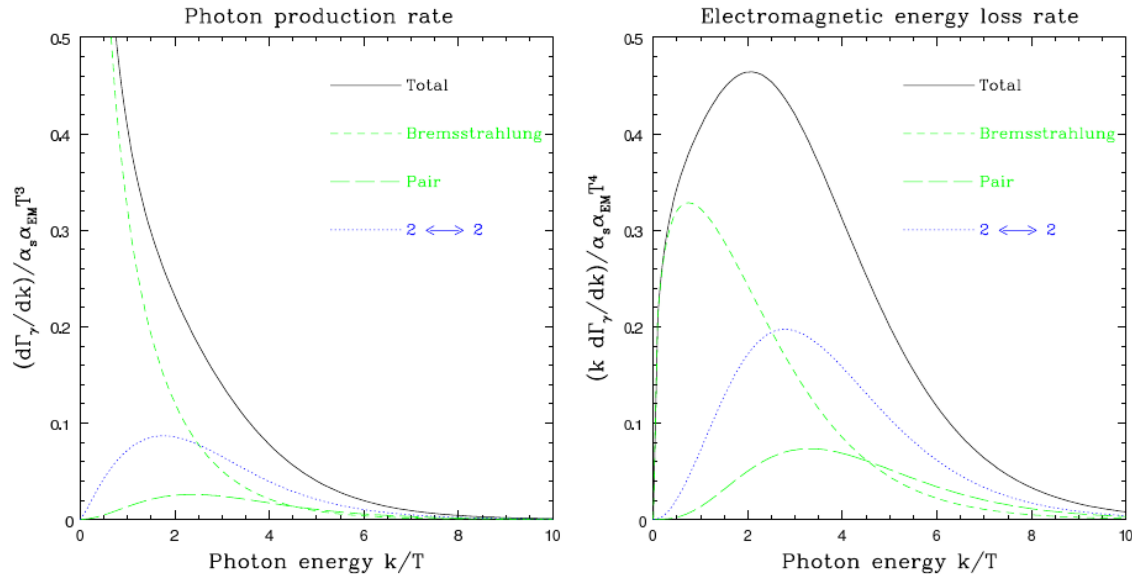
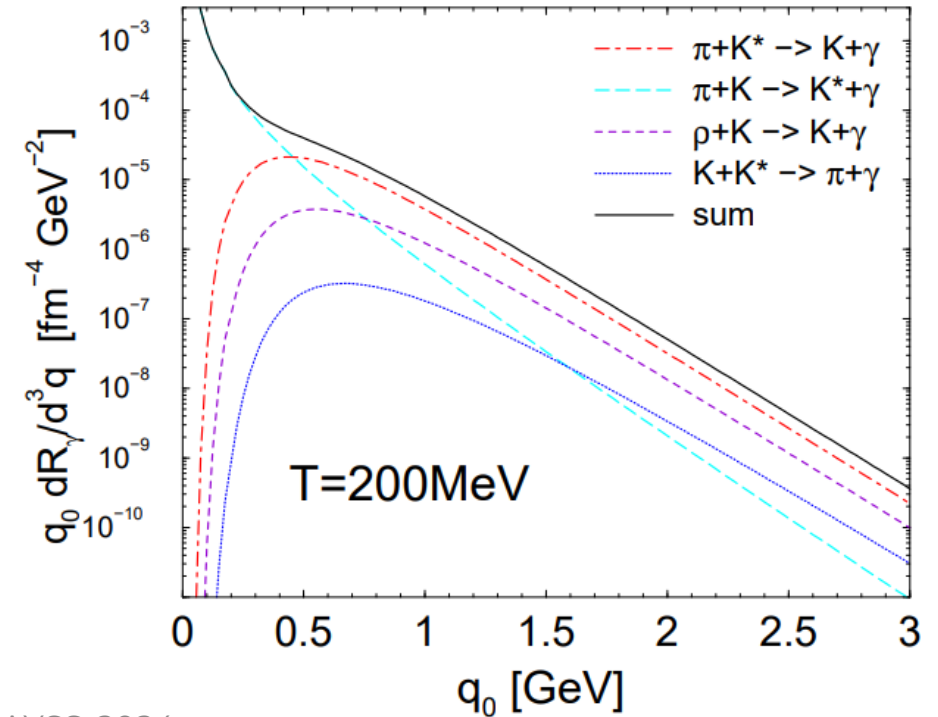
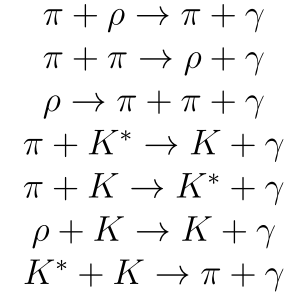


FIG. 9. Total photon emission rate, together with the bremsstrahlung, inelastic pair annihilation and $2 \leftrightarrow 2$ contributions, for two-flavor QCD with $\alpha_s = 0.2$. The left panel shows $d\Gamma_\gamma/dk$, divided by $\alpha_s \alpha_{EM} T^3$, while the right panel shows rates weighted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

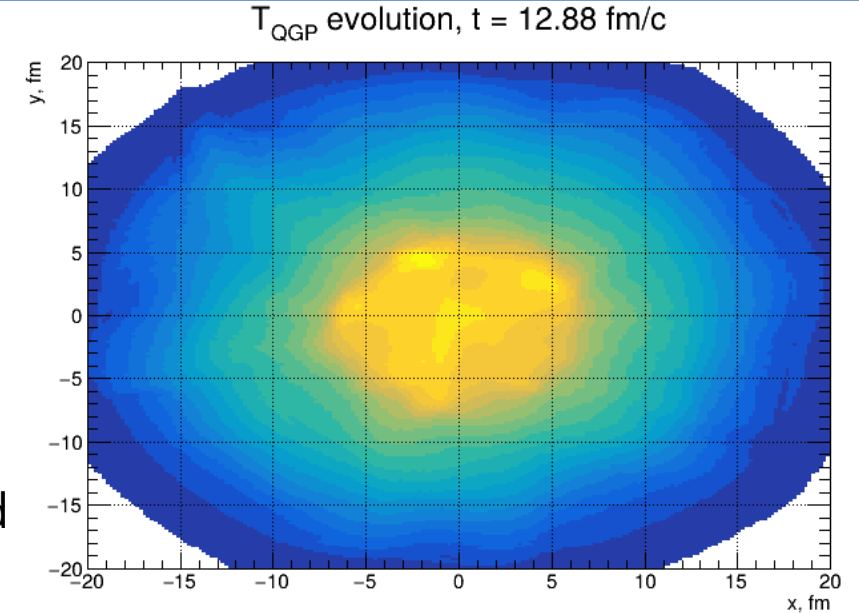
Hadron gas emission: Phys. Rev. C 69, 014903 (2004)

includes such reactions as:



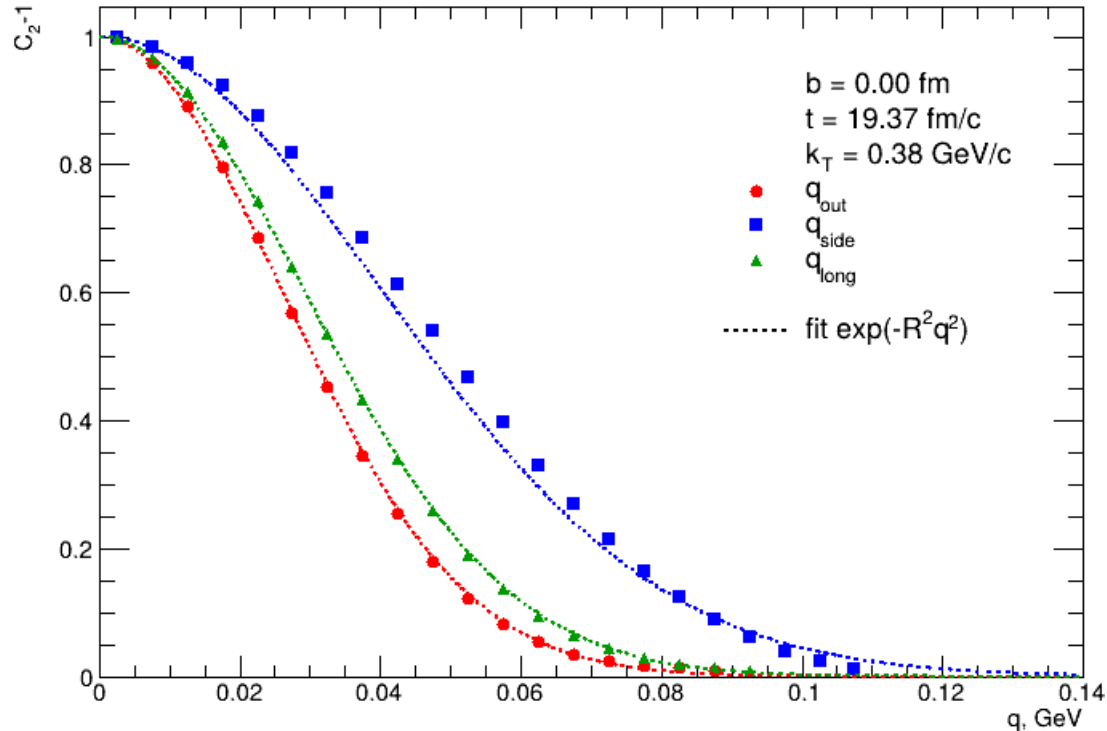
Hydrodynamic model

- Calculations were done using UrQMD hydro model
- We consider two scenarios of hydrodynamic evolution:
 - Thermalized hot dense nuclear matter with a first-order phase transition from QGP to hadronic phase (Bag model EoS)
 - Hadron gas including the same degrees of freedom as UrQMD (hadrons with masses up to 2.2 GeV)
- We used **out-side-long parametrization** of relative momentum (and corresponding observables):
 - out – direction along the transverse momentum
 - long – along the longitudinal momentum
 - side – perpendicular to previous directions
- For each cell in hydro calculations emission rates of thermal photons are calculate according to functions from previous slide:
 - estimation of thermal photon yields for given p_T (K_T) and φ in lab system \rightarrow **integration** over all cells and evolution time
 - this study was conducted for midrapidity region (**$y = 0$**)



Correlation functions

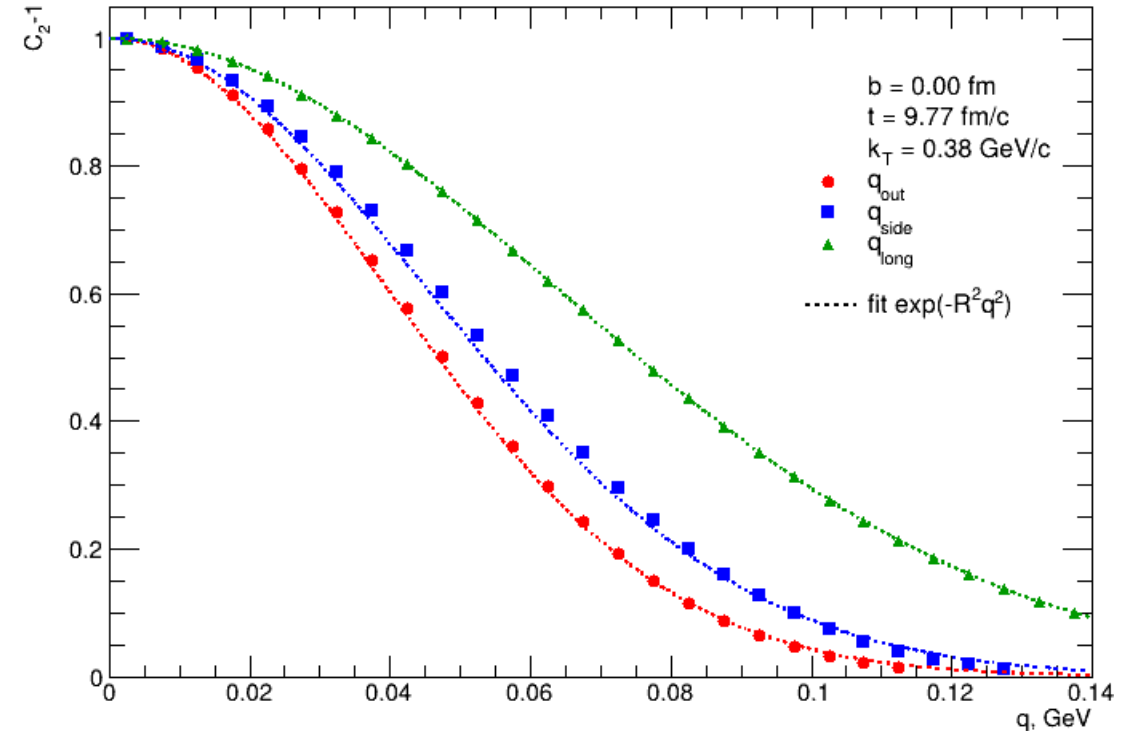
Hydro calculations including QGP phase transition:



- Assuming gaussian source with radius R , C_2 might be described as

$$C_2(q) = \lambda \exp(-q^2 R^2)$$

Hydro calculations including pure hadron gas:

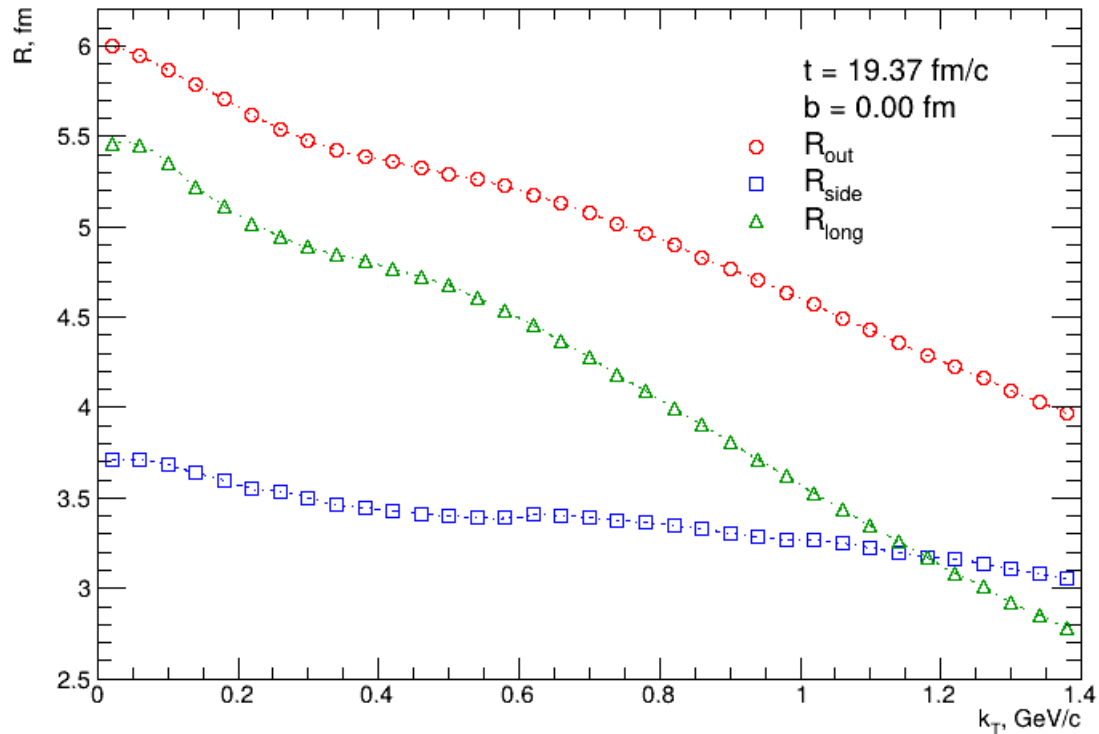


- C_2 are taken at a given mean transverse momentum of a pair

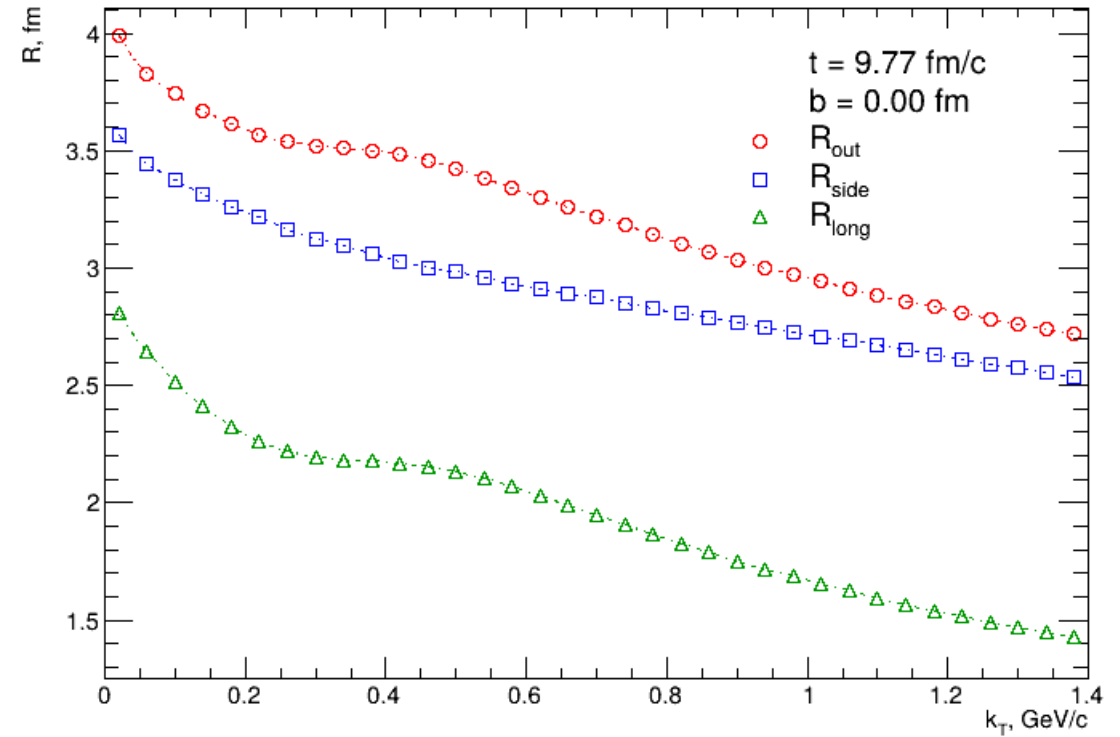
$$K_T = \frac{1}{2}(p_{1T} + p_{2T})$$

Correlation radius

Hydro calculations including QGP phase transition:



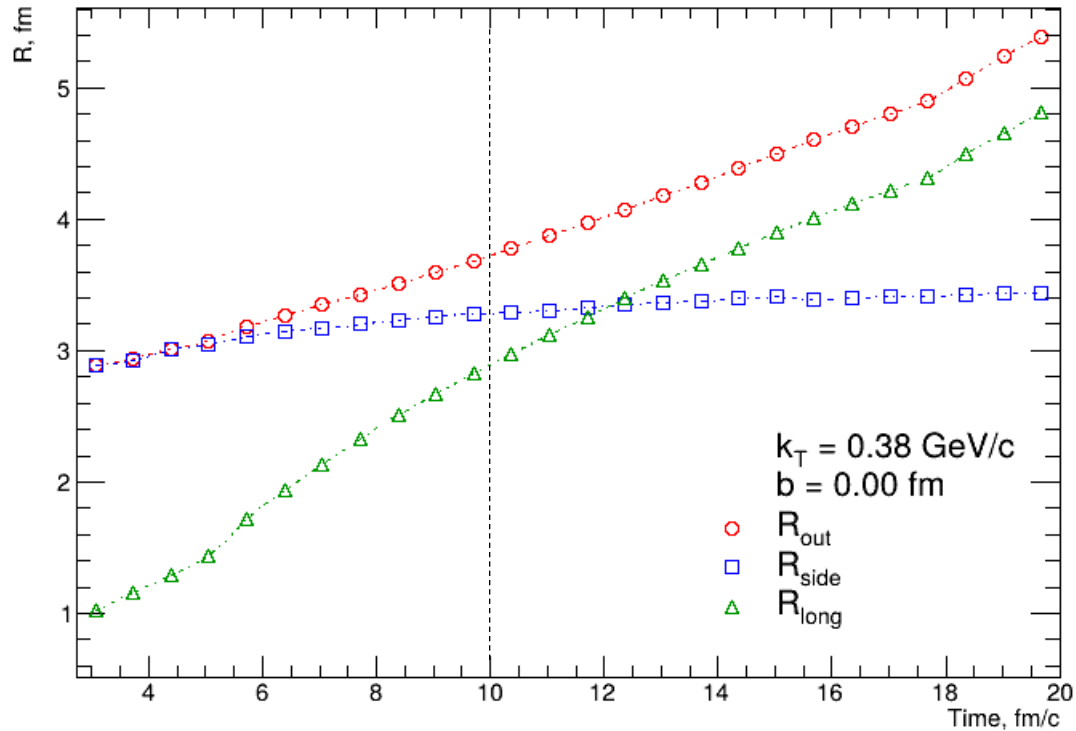
Hydro calculations including pure hadron gas:



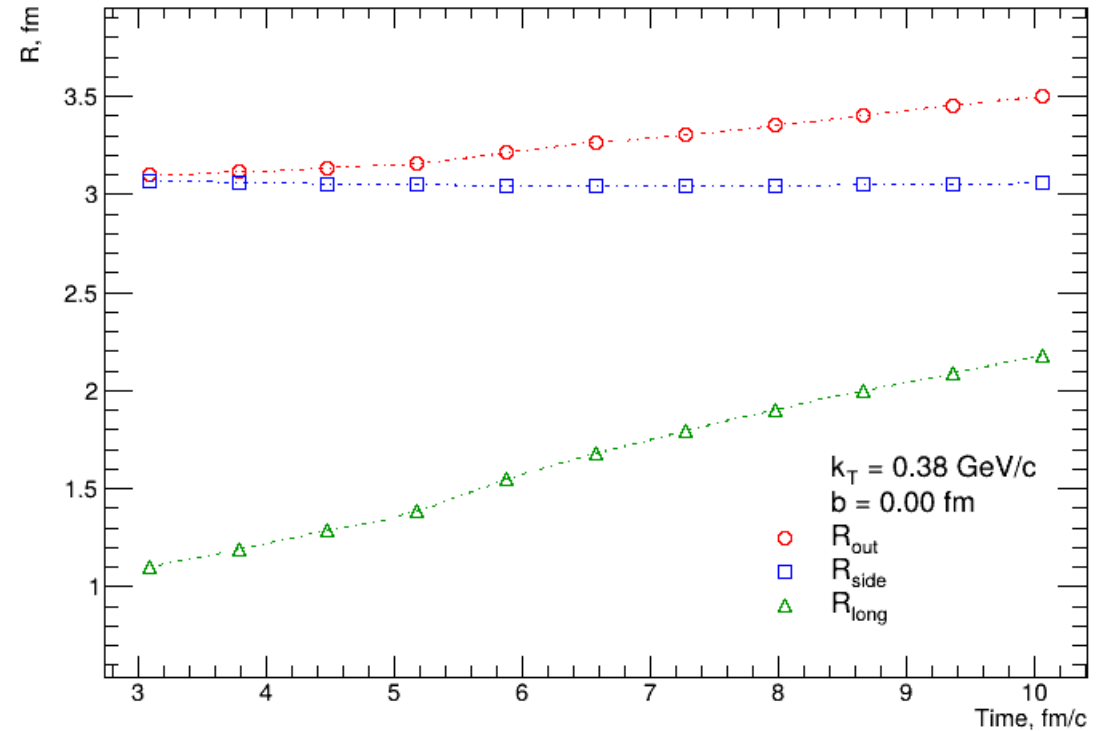
Despite significantly larger evolution time for QGP, model with the phase transition shows larger scales of a system and more rapid evolution, especially in long direction

Correlation radius vs evolution time

Hydro calculations including QGP phase transition:



Hydro calculations including pure hadron gas:



Despite significantly larger evolution time for QGP, model with the phase transition shows larger scales of a system and more rapid evolution, especially in long direction

Summary and outlook

- Calculation of two-photon correlation in Bi-Bi collisions at $\sqrt{s_{NN}} = 9.2$ GeV was performed in hydrodynamic approach for two model with and w/o phase-transition to QGP
- Work in progress:
 - From the experimental point of view, considered out-side-long parametrization is not applicable – it is more convenient to use averaged $q_{inv} = -\sqrt{q^2}$ or parametrization in **longitudinal co-moving system** (LCMS)
 - With this approach it is also possible to extract **yields of direct photons** at low p_T region:

$$\lambda = \frac{1}{2} \left(\frac{N_{\gamma}^{\text{dir}}}{N_{\gamma}^{\text{inc}}} \right)^2 \rightarrow R_{\gamma} = \frac{N_{\gamma}^{\text{inc}}}{N_{\gamma}^{\text{decay}}} = \frac{1}{1 - \sqrt{2\lambda}} \quad \frac{1}{2\pi N_{\text{ev}}} \frac{d^2 N_{\gamma}^{\text{dir}}}{p_T dp_T dy} = \frac{1}{2\pi N_{\text{ev}}} \frac{d^2 N_{\gamma}^{\text{inc}}}{p_T dp_T dy} \times \left(1 - \frac{1}{R_{\gamma}} \right)$$

- Fraction of direct photons as well might be estimated with UrQMD \rightarrow more realistic C_2 (suppressed down to $\sim 10^{-3}$)

THANK YOU FOR THE ATTENTION!

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29 October 2024

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