Untangling the evolution of heavy ion collisions using direct photon interferometry

Oscar Garcia-Montero[1], Nicole Löher[2], A. Mazeliauskas[3], K. Reygers[2] and J. Berges[4].

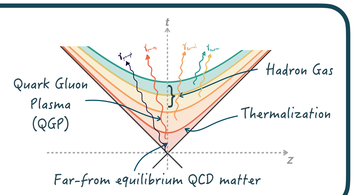
[1] Institute for Theoretical Physics, Goethe University, Max-von-Laue-Strasse 1, 60438 Frankfurt am Main, Germany
[2] Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany
[3] Theoretical Physics Department, CERN, CH-1211 Genève 23, Switzerland.
[4] Institut für Theoretische Physik, Universität Heidelberg, Philosophenweg 16, 69120 Heidelberg, Germany.

GARCIA@FIAS.UNI-FRANKFURT.DE

Motivation

- Direct photons are clean probes created throughout the collision and free of final state effects.
- Current mismatch with data ("Direct Photon Puzzle") may be fixable via inclusion extra sources
- Many proposed sources to solve the mismatch. Question is then:

How to disentangle such a long exposure picture?



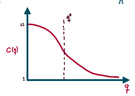
Hanbury-Brown-Twiss Correlations (Particle Interferometry)

Learn about spatio-temporal details of particle production using particle Interferometry [2].

Fundamental object, the HBT correlator.

$$C(p_1,p_2)=\frac{E_{p_1}E_{p_2}\frac{dN}{d^3p_1 d^3p_2}}{\frac{dN}{d^3p_1}E_{p_2}\frac{dN}{d^3p_2}}$$

Correlation length: $q^* = \frac{\pi\hbar}{R}$



Important caveat

HBT is normally used to understand the physical size of the sources. Since photons are created along a set of diverse hypersurfaces, this is not useful, but understanding the changes to the correlation lengths can help discriminate between different models

Variables: average (K) and relative (q).

$$K=(p_1+p_2)/2 \qquad q=(p_1-p_2)$$

Projection along the pair momentum

$$K^\mu=(K^0,K_\perp,0,K^z)$$
$$q^\mu=(q^0,q_o,q_s,q_l),$$

Correlation is computed:

$$C(p_1,p_2)=1+\frac{1}{d}\frac{|S(q,K)|^2}{S(0,p_1)S(0,p_2)} \qquad S(x,K) \rightarrow \text{Emission Function (rate)}$$

$$\sim 1+\frac{1}{2}\exp\left[-q_i R^{ij} q_j\right], \qquad R_{ij}(K) \rightarrow \text{HBT Radii}$$

Radii are computed using

$$\langle\langle q_i q_j\rangle\rangle=\int d^3q\, q_i q_j\, g(q;K)\equiv\frac{1}{2}(R^{-1})_{ij} \quad \text{with} \quad g(q;K)\equiv\frac{C(q,K)-1}{\int d^3q\,[C(q,K)-1]}$$

Showcase photon HBT: Two models

We want to test test photon HBT and its sensitivity using two models, which both give results compatible with experimental data [3].

Enhance "base" hydrodynamical evolution with two extra sources.

"Base" Calculation

- We use VISH (2+1) to compute hydrodynamical evolution for the QGP and Hadronic stages.
- MC-Glauber initial conditions
- Rates at LO (AMY [4]) to compute the thermal photons.

Far-from-equilibrium Photons

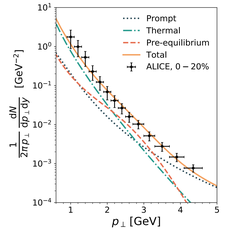
- High energies densities [5] at pre-thermalization stages can produce a sizeable amount of photons [6].
- Pre-equilibrium photons are computed using a BMSS-like evolution [7] and kinetic rates,

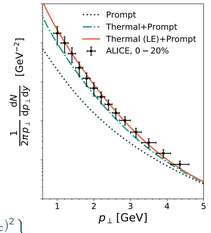
$$E\frac{d\mathcal{N}}{d^4X\,d^3p}=\frac{40}{9\pi^2}\,\alpha\,\alpha_S\,\underbrace{\mathcal{L}}_{a}\,\underbrace{f_q(\mathbf{p})}_{b}\,\underbrace{(l_g+l_q)}_{c}$$

a) Regulator
b) Quark distribution
c) Related to screening masses

Pseudo-Critical Enhancement

- Phenomenological model [8] inspired by the fact that at hadronization, partonic cross-sections will see a rise which cannot be accounted for by perturbative physics
- AMY rates enhanced with $E\frac{dN_{\rm enh}}{d^4x\,d^3p}\equiv h(T)\,E\frac{dN_{\rm thermal}}{d^4x\,d^3p}$ and $h(T)=1+h_0\exp\left\{-\frac{(T-T_{pc})^2}{d^2}\right\}$

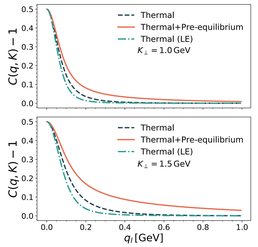




- Even when the discrepancies of the ***Direct Photon Puzzle*** are solved, we need to differentiate between the different sources of emission.
- Photon HBT can be the tool we use to cross-compare different models of photon production
- With the new LHC run, HBT measurements are possible.

Interested? Read the paper here!

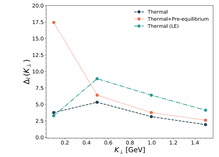
Results



The HBT correlators

- Longitudinal direction affected the most by the inclusion of the sources.
- Non-gaussianities are strong at early times, thanks to Bjorken expansion
- Early-times production reduces effective radii, while late times increase them.

Bonus: Normalized Excess Kurtosis

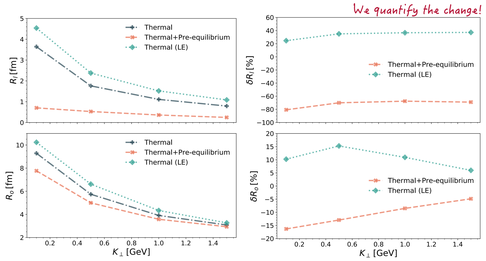


- Quantifies deviations from Gaussianity. Strong at small pair momenta.
- Very interesting observable, but hard to measure.

The HBT Radii

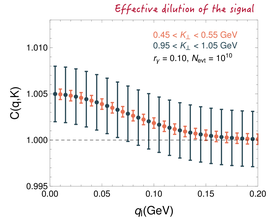
- Longitudinal direction affected the most by the inclusion of the sources.
- Early-times production reduces effective radii, while late times increase it.
- Are these differences enough to measure it?

We quantify the change!



Modelling of the Signal

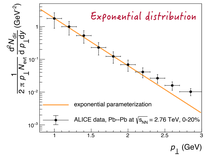
Effective dilution of the signal



Study the feasibility of measuring a direct photon HBT signal in the upcoming high-luminosity LHC runs.

With statistical uncertainties, and 10^{10} events, HBT correlations for $K_\perp < 1$ GeV are statistically significant.

- Exponential-like source used as test model.
- Included effective dilution of the signal thanks to decay photons
- Error depends strongly on the average momentum of the pair.
- Low momentum pairs statistically significant.



References

[1] Garcia-Montero *et al* , **arXiv:1909.12246**
[2] E. Frodermann and U. Heinz, **Phys. Rev. C80, 0449 (2009)**
[3] Adam *et al.* Phys.Lett. B754 (2016) 235-248
[4] Arnold, P.B., Moore, G.D. and Yaffe, L.G., **JHEP 0112 (2001) 009.**
[5] R. Baier, A. H. Mueller, D. Schiff, and D. T. Son, **Phys. Lett. B502, 51 (2001)**
[6] Berges, J., Reygers, K., Tanji, N., Venugopalan, R., **Phys.Rev. C95 (2017) no.5, 054904**
[7] Garcia-Montero, **arXiv:1909.12294**
[8] H. van Hees, M. He, and R. Rapp, **Nucl. Phys. A933, 256 (2015)**