Effect of an Expanding Charged Cloud on two-particle Bose-Einstein Correlations

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Outline

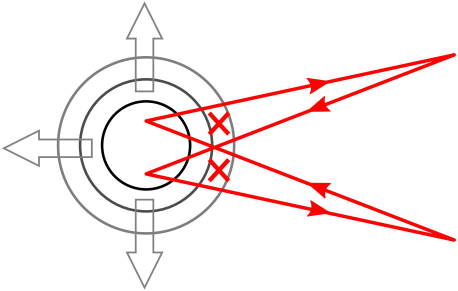
Motoviation

- Understanding the space-time structure of particle emitting source using quantum-statistical BE-HBT correlations.

- Investigate modifications in BEC strength by considering AB-like effect and Coloubm interaction with HICs.

Main Idea

- The space-time geometry of the particle emitting source may be explored by measuring BE or HBT correlation functions, which is main source of momentum correlation for identical bosons.
- In quantum mechanics, identical particles are genuinely indistinguishable due to Heisenberg uncertainty principle.



Bose-Einstein Correlations

- Momentum correlation function of two identical particles, generally is:

$$C_2(p_1, p_2) \equiv \frac{N_2(p_1, p_2)}{N_1(p_1)N_1(p_2)}, \tag{1}$$

- Using phase-space density to describe the correlation function of the emitter $S(x, p)$ as:

$$C_2(p_1, p_2) = 1 + Re\frac{\widetilde{S}(q, p_1)\widetilde{S}^*(q, p_2)}{\widetilde{S}(0, p_1)\widetilde{S}^*(0, p_2)} \tag{2}$$

where $\widetilde{S}(q, p)$ denotes as Fourier transform of the source

- with $q \equiv p_1 - p_2$, the two particle correlation func becomes:

$$C_2(q, K) = 1 + \frac{|\widetilde{S}(q, K)|^2}{|\widetilde{S}(0, K)|^2} \approx 1 + \lambda_2\frac{|\widetilde{S}(q, K)|^2}{|\widetilde{S}(0, K)|^2} \tag{3}$$

Two- and Three-particle strengths

- The correlation strength is defined by the fraction of the pions that come from the core to contribute to the visible correlation function:

$$\lambda_2 = f_c^2, \quad f_c = \frac{N_{core}}{N_{core} + N_{halo}} \tag{4}$$

- The presence of partially coherent pion production distorts $\lambda_2 \& \lambda_3$, however two- and three-particle BEC func. at zero relative momentum are in simple connection to the partially coherent fraction (pc) of the fireball:

$$\lambda_2 = f_c^2((1 - p_c)^2 + 2p_c(1 - p_c)) \tag{5}$$

$$\lambda_3 = 2f_c^3((1-p_c)^3 + 3p_c(1-p_c)^2) + 3f_c^2((1-p_c)^2 + 2p_c(1-p_c)) \tag{6}$$

Model Setup

- The produced hadron gas flow can be described by the dynamical system of equations as:

$$\frac{d\boldsymbol{p}}{dt} = \hbar c\alpha \sum_{j=1}^{N_{ch}} \frac{q(\boldsymbol{r}_j - \boldsymbol{X})}{r^3} \tag{7}$$

$$\frac{d\boldsymbol{X}}{dt} = \boldsymbol{V} = \frac{\boldsymbol{p}}{m\gamma} \tag{8}$$

- Where $r = \sqrt{(\boldsymbol{r_j} - \boldsymbol{X})^2}$ & $\gamma = \sqrt{1 - \frac{\boldsymbol{p}^2}{m^2}}$
- This model was solved numerically using Euler Method with time iteration for pion mass $=139.57$, charge $q = \pm 1$,and using the natural units ($\hbar = c = 1$).

Phase-shift vs Time-shift

- The time shift of TOF (Δt) is a result of the phase-shift (σ) after scattering of the test particle during the flight towards the detector due to the final state interactions with the cloud of charged particles.
- Charge cloud has N_{ch} in a 3-D Hubble flow with initial momentum p_{in} in random direction for the test particle.
- From the simulation we measured the Δt according to $\Delta t = t_{\mathrm{TOF}}(d) - t_{\mathrm{TOF}}^{(N_{ch}=0)}$ it is a Gaussian distribution with width σ_t.
- From the fitting of Gassian distribution and determining the width we can get the phase-shift as:

$$\phi = k\Delta x = \frac{p}{\hbar} v\Delta t = \frac{p^2}{\hbar\sqrt{m^2+p^2}}\Delta t \Rightarrow \sigma = \frac{p^2}{\hbar\sqrt{m^2+p^2}}\sigma_t. \quad (9)$$

Results

- From the simulation we get an example for particle trajectory of a particle with initial momentum vector:

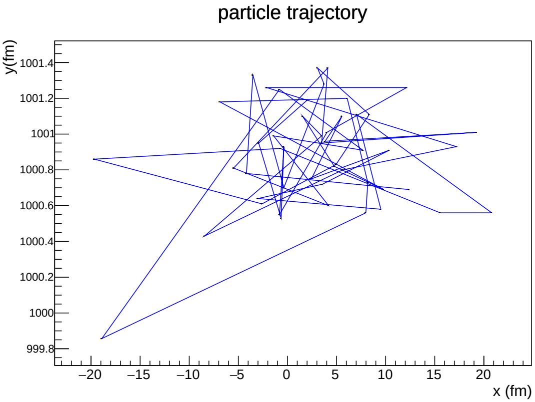


Figure: Example particle trajectory of a particle with initial momentum vector $(0,0,p_z)$ with $p_z = 300$ MeV.

- Time shift distribution

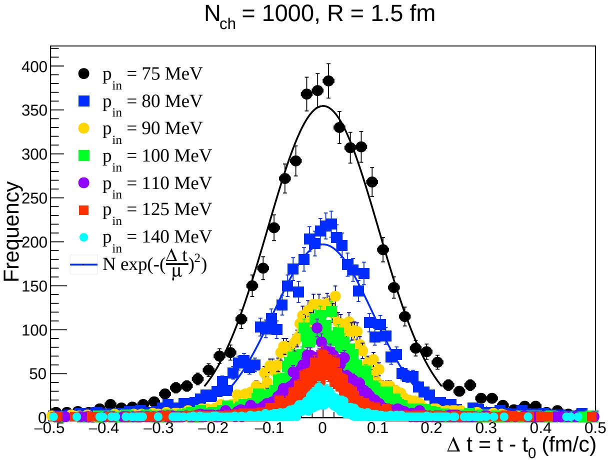


Figure: Time shift distributions from the simulation for different initial momentum values.

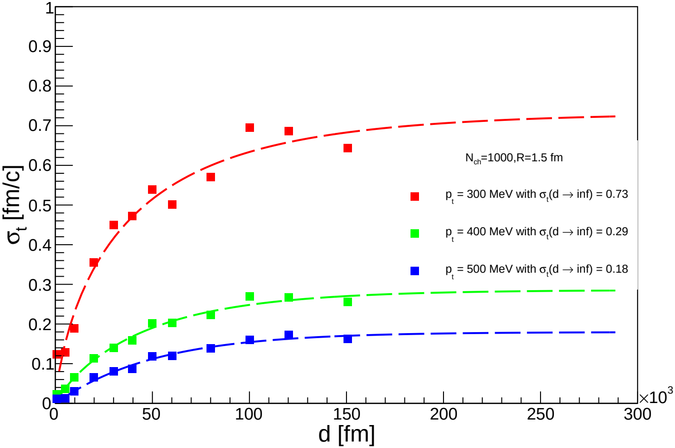


Figure: The traveled distance by the investigated correlated particles with the phase-shift distribution σ_0, for $N_{\mathrm{ch}} = 1000$, $R = 1.5$ fm.

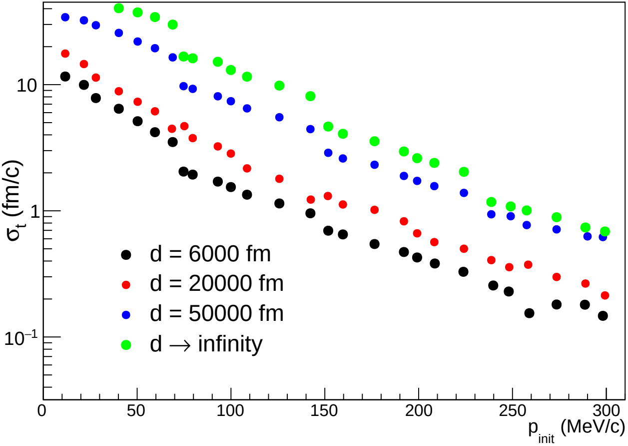


Figure: The dependency of the gaussian width and then the phase shift on the initial momentum of the correlated particles.

Correlations strength

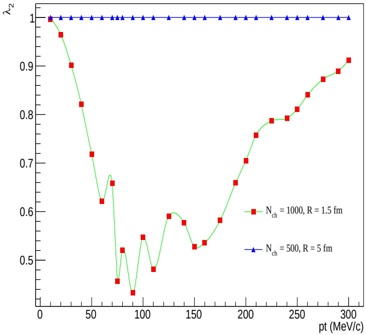


Figure: The intercept parameter λ_2 as a function of the initial transverse momentum of the probe particle, for the two scenarios: $N_{\rm ch} = 500$, $R = 5$ fm and $N_{\rm ch} = 1000$, $R = 1.5$ fm.

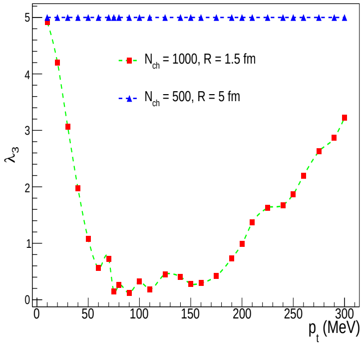


Figure: The intercept parameter λ_3 as a function of the initial transverse momentum of the probe particle, for the two scenarios: $N_{\rm ch} = 500$, $R = 5$ fm and $N_{\rm ch} = 1000$, $R = 1.5$ fm.

Effect of No of charged particle & Fireball radius

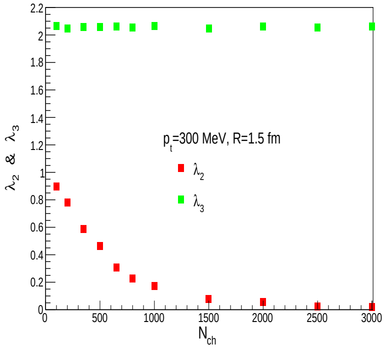


Figure: Correlation strength parameters versus charged particle multiplicity.

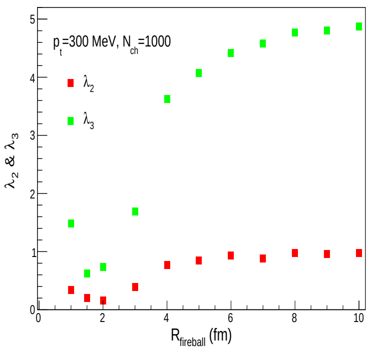


Figure: Correlation strength parameters versus fireball radius.

Charged particle density

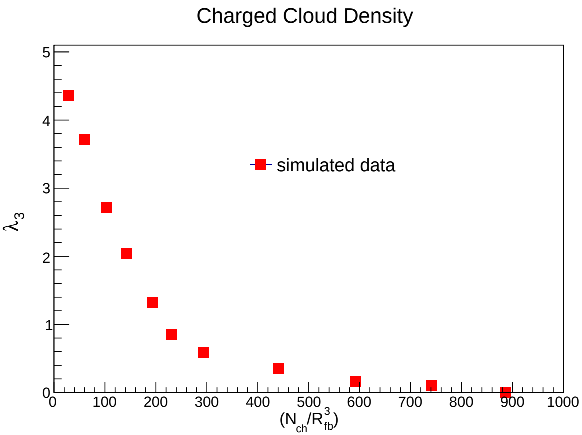


Figure: Intercept parameter λ_3 versus a charged particle density proxy.

Conclusion

- Changes in phases due to the Aharonov-Bohm effect, effectuated via the Coulomb interaction, may cause distortion in quantum-statistical correlations.
- Phase changes are prominent at low particle momenta but diminish at higher momenta.
- The strength of correlation changes is influenced by charged particle density, becoming significant at high densities.
- Challenges and Practical Implications: Incorporating this effect in Monte Carlo simulations is resource-intensive due to the Coulomb interaction's range and the long timescales required. However, it can be accounted for in momentum correlation calculations via an afterburner as proposed.

Thank you!

Questions?