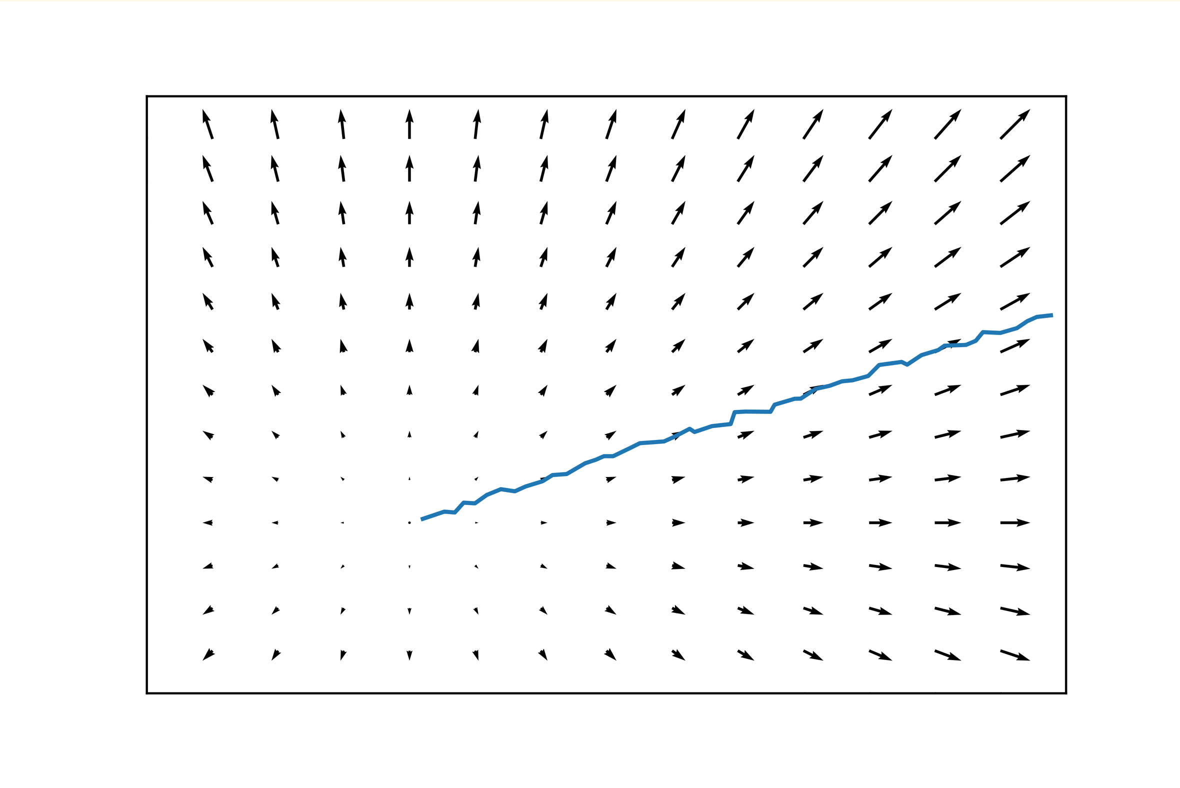
Multi-particle BE-HBT correlations

in a Hubble-expanding random field

Ayon Mukherjee
with M. Csanád, A. Jakovac, S. Lokos & S. K. Tripathy
Eötvös Loránd University, Budapest, Hungary

IS2021
The VI[th] International Conference on the INITIAL STAGES OF HIGH-ENERGY NUCLEAR COLLISIONS

Introduction



- Quantum-statistical BE-HBT correlations as the main source of momentum correlation for identical bosons (with symmetric pair WF's) in HIC's
- A toy model simulation, to quantify the effects of an expanding cloud of charged gas on the 2- and 3-particle correlation-functions of correlated pions, is presented

Basics I: Core-Halo model

- Probes for space-time geometry of emitter
- Phase-space density of emitter:

$$S(x,p) = S_{\text{core}}(x,p) + S_{\text{halo}}(x,p)$$

- "core" → primordial hadrons & "halo" → hadrons from decays
- Two-particle correlation fn., with $q = p_1 - p_2$:

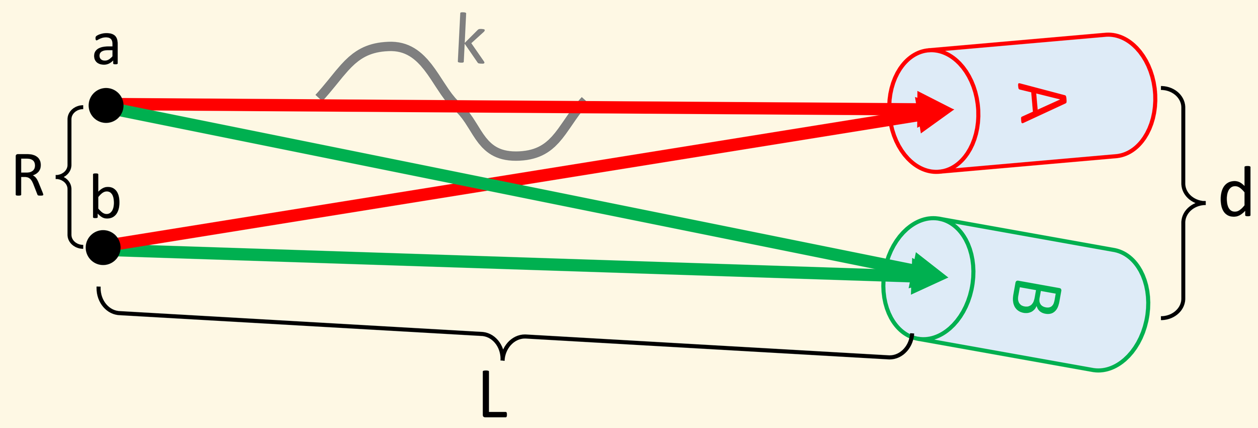
$$C_2(q,K) = 1 + \frac{\left|\tilde{S}(q,K)\right|^2}{\left|\tilde{S}(0,K)\right|^2} \approx 1 + \lambda_2 \frac{\left|\tilde{S}_{\text{core}}(q,K)\right|^2}{\left|\tilde{S}_{\text{core}}(0,K)\right|^2}$$

- Two-particle correlation strength:
  $\lambda_2 = C_2(0) - 1 = f_c^2 = \left(\frac{N_{\text{core}}}{N_{\text{core}}+N_{\text{halo}}}\right)^2$
- Three-particle correlation strength: $\lambda_3 = C_3(0) - 1$
- λ_2 & λ_3 → probes for partial coherence

Basics II: Particles' paths and background

- Particles' paths modified by surrounding charges → phase shift
- Bose-Einstein correlations contain symmetrised wave functions
- Path of pair: closed loop → Aharonov-Bohm effect with random field
- Background is the internal field → causes the phase-shift

Set-up I: Illustration



- Illustration of 2-particle correlation measurement set-up
- a and b as sources, A and B as detectors
- R and d as distance between the sources and detectors, respectively
- k as the phase difference and L as the path length

Set-up II: Correlation functions

- CF's modified by randomly picked up phases
- 2-particles, pure core, w/o random phase:

$$C_{AB} = \frac{\langle|\Psi(r_A,r_B)|^2\rangle}{\langle|\Phi(r_A)|^2\rangle\langle|\Phi(r_B)|^2\rangle} = 1 + \cos(qR)$$

$$\implies C_{AB}\big|_{q=0} - 1 = 1$$

Summary

- 2- & 3-particle correlations may reveal coherence
- The charge-cloud around a given pair → a random background around correlated particles
- Interpreted as an Aharonov-Bohm-like effect
- The $\lambda_2(m_t)$ & $\lambda_3(m_t)$ are modified at lower m_t
- There may be cases where this effect has to be taken into account, esp. at low pair transverse masses

Set-up III: Random-phase effects

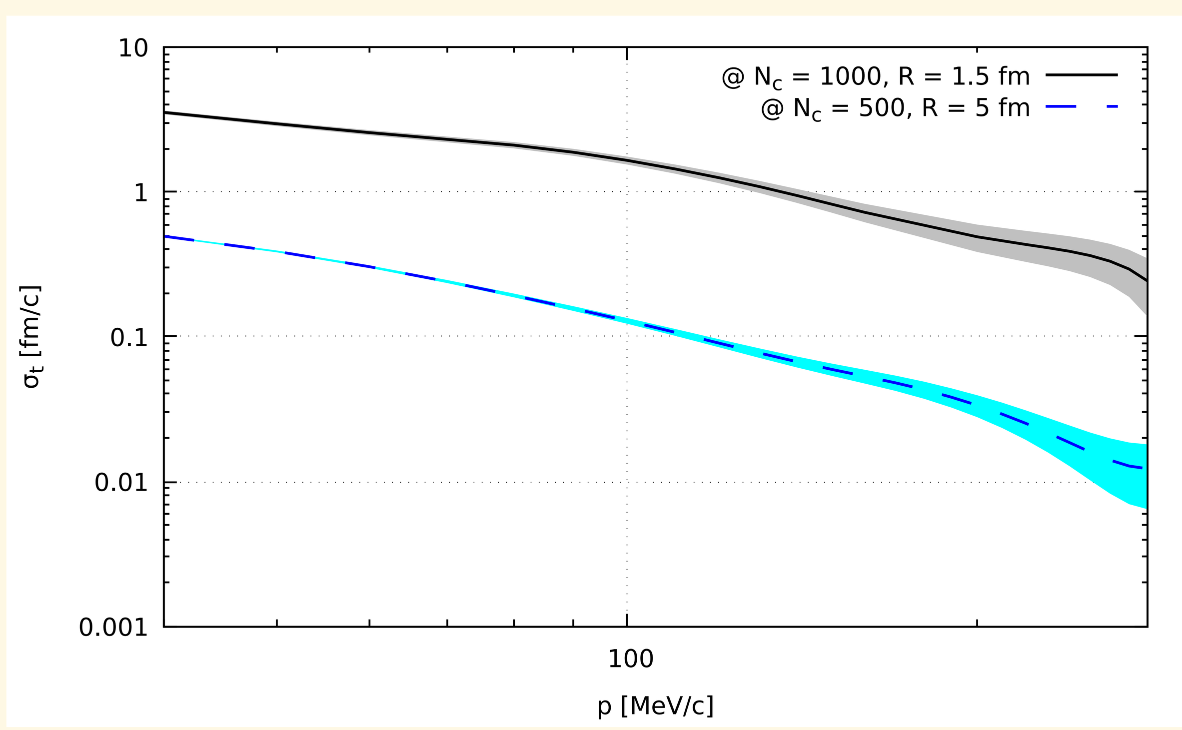
- With random phase:

$$\langle|\Psi(r_A,r_B)|^2\rangle \sim 1 + \cos(qR + \phi)$$

$$\implies C_{AB} - 1 = \cos(\phi)$$

- $C_2(q) = 1 + \cos(qR) \quad \rightarrow \quad C_2(q) = 1 + \cos(qR + \phi)$
- Phase distribution is Gaussian $e^{-\phi^2/(2\sigma_\phi^2)}$
- Averaging over ϕ values: $C_2(q) - 1 = \cos(qR)e^{-2\sigma_\phi^2}$
- 2- and 3-particle correlation strengths reduced: $\lambda_2 = C_2(0) - 1 = e^{-2\sigma_\phi^2}$ & $\lambda_3 = C_3(0) - 1 = 3e^{-2\sigma_\phi^2} + 2e^{3\sigma_\phi^2}$

Results I: σ_t and momentum

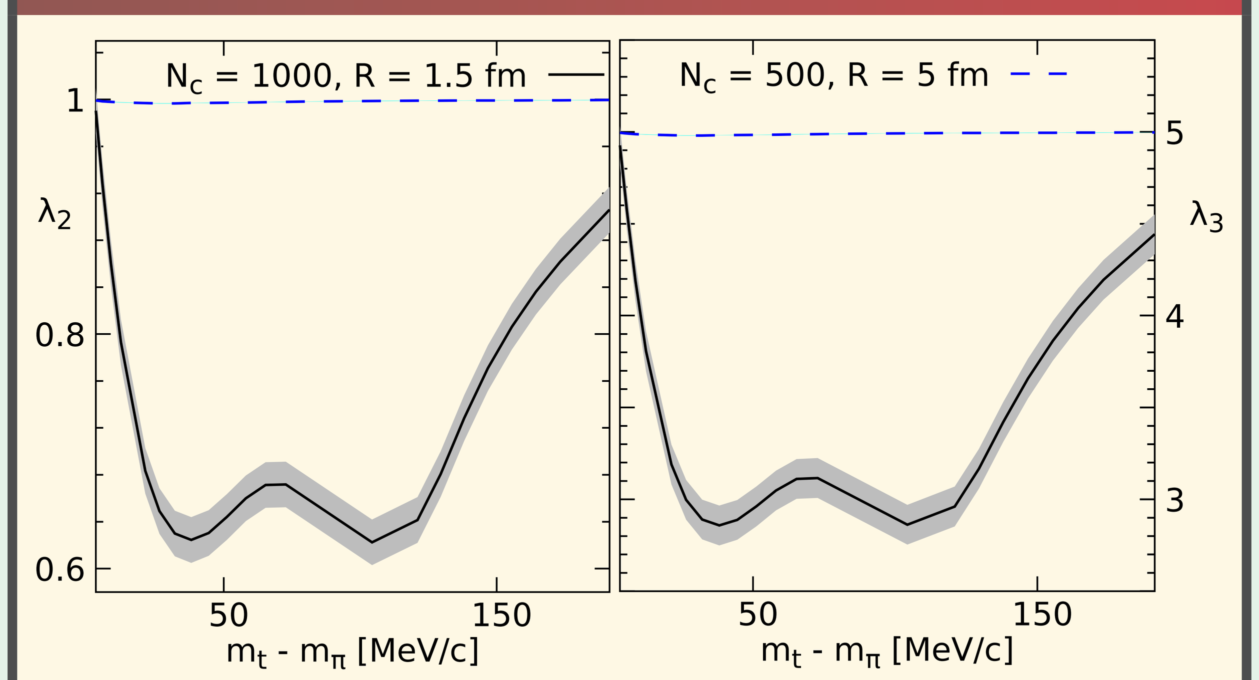


- $\sigma_t = \sigma_t(p)$ close to power-law
- Phase shift: direct dependence on N_{charges} and inverse dependence on fireball-radius observed

Model

- ϕ results in a change in the "time-of-flight" Δt
- Charge cloud has N_{charges} in a 3-D Hubble flow
- Test particle with initial p_{in} in random direction
- Measuring $t_{\text{ToF}}(d)$, calculate $\Delta t = t_{\text{ToF}}(d) - t_{\text{ToF}}^{(N_c=0)}(d)$
- Δt distribution is Gaussian, with width σ_t
- Δt related to phase-shift: $\phi = k\Delta x = \Delta t \cdot v\frac{p}{\hbar} = \Delta t \frac{p^2}{\hbar\sqrt{m^2+p^2}} \implies \sigma_\phi = \frac{\sigma_t p^2}{\hbar\sqrt{m^2+p^2}}$

Results II: λ_2 & λ_3



- Low-m_t decrease of $\lambda_{2,3}$
- Small magnitude, depends on charge density

References

- M. Csanád, A. Jakovac, S. Lokos, A. Mukherjee and S. K. Tripathy. Multi-particle quantum-statistical correlation functions in a Hubble-expanding hadron gas. 7 (2020).
- T. Csörgő, B. Lörstadand and J. Zimányi. Z.Phys.C 71, 491 (1996)
- T. Csörgő. HeavyIonPhys.15: 1-80 (2002)
- Y. Aharonov and D. Bohm. Phys.Rev. 115, 485 (1959)