Effects of random phase shifts from multi-particle Coulomb-interactions on Bose-Einstein correlations

Ayon Mukherjee
with
Srikanta Kumar Tripathy, Sándor Lökös, Antal Jakovác & Máté Csanád

Department of Atomic Physics
Eötvös Loránd Tudományegyetem
Budapest, Hungary

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The Basics: Bose-Einstein correlations

- Quantum-statistical BE-HBT correlations: main source of momentum correlation for identical bosons (with symmetric pair WF's) in HIC's
- Probes for space-time geometry of emitter
- Phase-space density of emitter:

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

- "core" $\rightarrow$ primordial hadrons & "halo" $\rightarrow$ hadrons from decays

  [T.Csörgő, B.Lörstadand, J.Zimányi; Z.Phys.C71,491 (1996)]

- Two-particle correlation fn., with $q = p_1 - p_2$:

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

Correlation strengths

- Two-particle correlation strength:
  $\lambda_2 = C_2(0) - 1 = f_c^2 = \left(\frac{N_{\rm core}}{N_{\rm core}+N_{\rm halo}}\right)^2$
- Three-particle correlation strength: $\lambda_3 = C_3(0) - 1$
- Partially coherent hadron production distorts λ_2 & λ_3 :

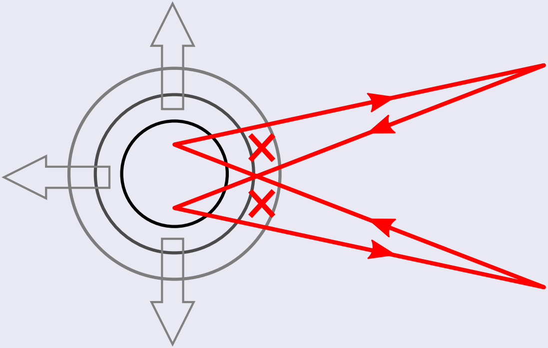
$$\lambda_2 = f_c^2((1-p_c)^2 + 2p_c(1-p_c))$$
$$\lambda_3 = 2f_c^3((1-p_c)^3 + 3p_c(1-p_c)^2) + 3f_c^2((1-p_c)^2 + 2p_c(1-p_c)) \;;$$

- p_c: partially coherent fraction of the fireball
  [T.Csörgő; HeavyIonPhys.15:1-80 (2002)]
- λ_2 & λ_3 $\rightarrow$ probes for partial coherence

Coulomb-interaction effects

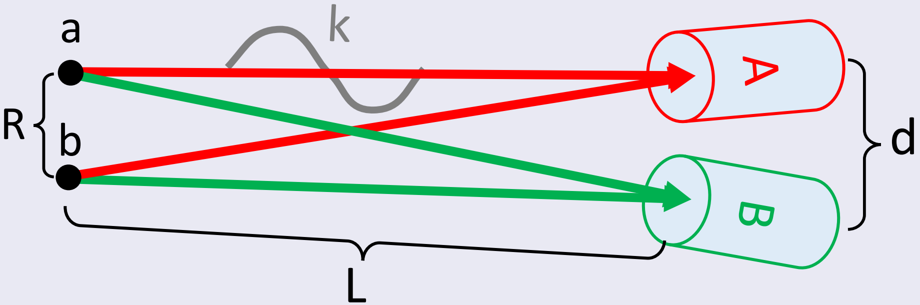
- Particles' paths modified by surrounding charges → phase shift
- Bose-Einstein correlations contain symmetrised wave functions
- Path of pair: closed loop → Aharonov-Bohm effect with random field:

[Y.Aharonov & D.Bohm; Phys.Rev.115,485 (1959)]



- Background is the internal field → causes the phase-shift

Set-up



- 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
- Two-particles, pure core, w/o random phase:

$$C_{AB} = \frac{\langle|\Psi(r_A, r_B)|^2\rangle}{\langle|\Phi(r_A)|^2\rangle\langle|\Phi(r_B)|^2\rangle} = 1 + \cos(qRd/L) \implies C_{AB}\Big|_{q=0} - 1 = 1$$

Random phase

- Correlation functions modified by randomly picked up phases
- With random phase:

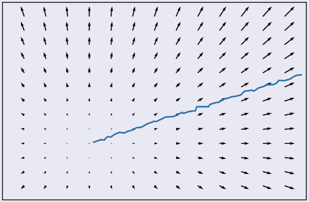
$$\langle|\Psi(r_A, r_B)|^2\rangle \sim 1 + \cos\left(qRd/L + \phi\right) \implies C_{AB} - 1 = \cos(\phi),$$

$$\phi = k\left(\sqrt{L^2 + R^2} - L\right) = k\Delta x$$

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

From time delay to phase shift

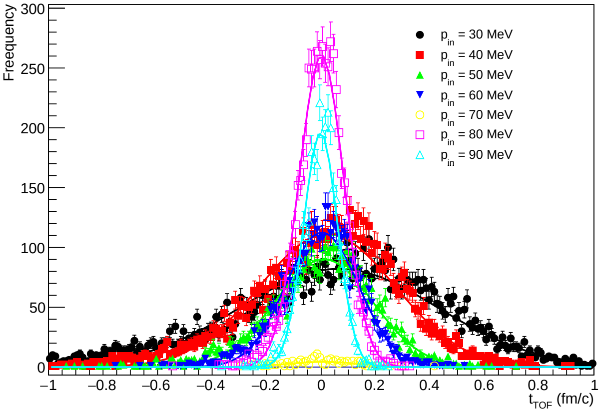
- ϕ results in a change in the "time-of-flight" Δt
- Charge cloud has N_{charges} (N_c) in a 3-D Hubble flow
- Test particle with initial momentum p_{in} in random direction



- 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:
  $\phi = k\Delta x = \Delta t \cdot v\frac{p}{\hbar} = \Delta t\frac{p^2}{\hbar\sqrt{m^2+p^2}} \implies \sigma_\phi = \frac{\sigma_t p^2}{\hbar\sqrt{m^2+p^2}}$
- Imp. parameters: charge density N_c, path-length d & fireball size R

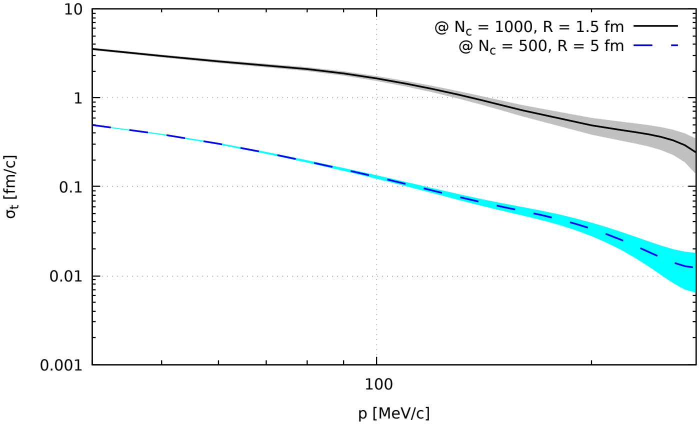
Time-delay distribution

- Normalised Δt distr. is slightly off-centre and not perfectly Gaussian
- Δt distr. becomes narrower with increasing p



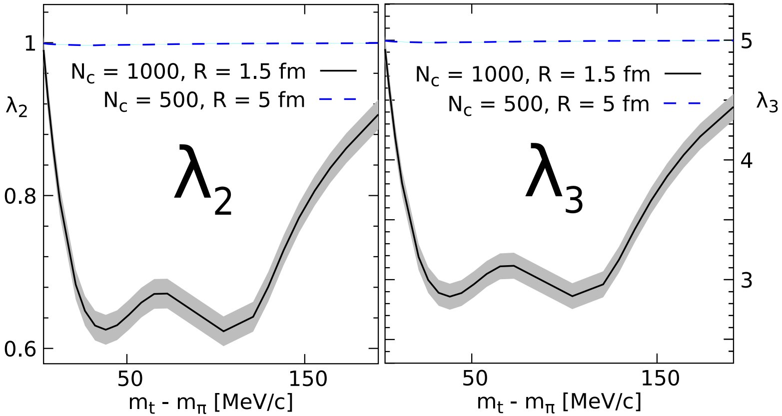
σ_t & momentum

- $\sigma_t \equiv \sigma_t(p)$ close to power-law
- Larger charge density: larger phase shift possible



Correlation strength modification

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



The Conclusions

- Two- & three-particle correlations may reveal coherence
- The charge-cloud around a given pair $\rightarrow$ a random background
- Can be interpreted as an Aharonov-Bohm-like effect
- The $\lambda_2(m_t)$ & $\lambda_3(m_t)$ are modified at lower m_t
- At very small momenta, the effect disappears due to σ_ϕ being proportional to $p^2 \cdot \sigma_t$, and σ_t not increasing fast enough for $p \rightarrow 0$
- At large momenta, the effect disappears as $\sigma_\phi \rightarrow 0$
- The results indicate that there may be cases where this effect has to be taken into account, especially at low pair transverse masses

The End

Thank you for your attention!