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

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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 $q = p_1 - p_2$:

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

The Basics (contd.)

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)]

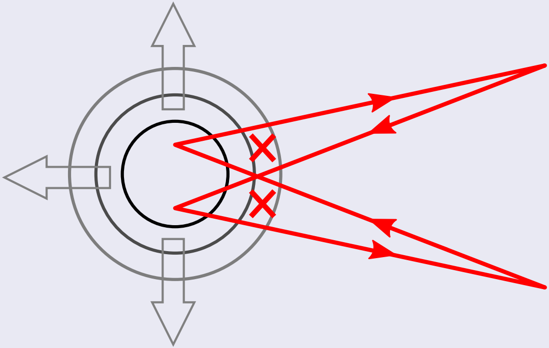
- $\kappa_3 = (\lambda_3 - 3\lambda_2)/2\lambda_2^{3/2} = (1 - p_c - 2p_c^2)/\left[(1+p_c)\sqrt{1-p_c^2}\right]$
  (independent of f_c)
- λ_2, λ_3 & $\kappa_3 \rightarrow$ probes for partial coherence

The Basics (contd..)

Coulomb-interaction effects

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

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



- Background is the internal field $\rightarrow$ causes the phase-shift

The Basics (contd...)

Random phase

- Correlation functions modified by randomly picked up phases
- Two-particles, pure core, w/o random phase:

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

- With random phase:

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

- $C_2(q) = 1 + \cos(qR) \quad \rightarrow \quad C_2(q) = 1 + \cos(qR + \phi)$
- Phase distribution is Gaussian $e^{-\phi^2/\left(2\sigma_\phi^2\right)}$
- Averaging over ϕ values: $C_2(q) - 1 = \cos(qR) e^{-\frac{\sigma_\phi^2}{2}}$
- Two- and three-particle correlation strengths reduced:

$$\lambda_2 = C_2(0) - 1 = e^{-\sigma_\phi^2/2} \;\&\; \lambda_3 = C_3(0) - 1 = 3e^{-\frac{\sigma_\phi^2}{2}} + 2e^{-\frac{2\sigma_\phi^2}{9}}$$

The Model

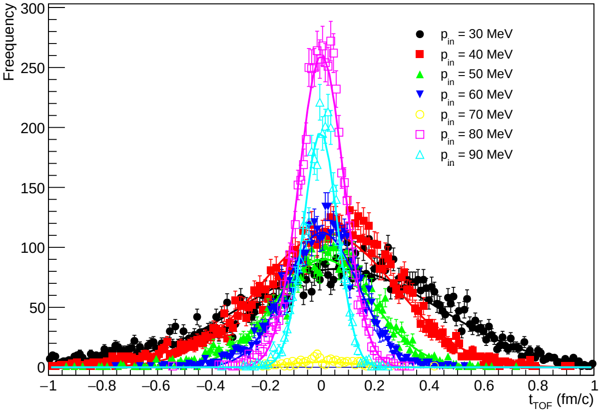
From phase-shift to time delay

- 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 $t_{\mathrm{ToF}}(d)$, calculate $\Delta t = t_{\mathrm{ToF}}(d) - t_{\mathrm{ToF}}^{(N_c=0)}(d)$
- Δt distribution is Gaussian, with width σ_t
- Δt related to phase-shift:
  $\phi = k\Delta x = \Delta t \cdot v\frac{p}{\hbar} = \Delta t \frac{p^2}{\hbar\sqrt{m^2+p^2}} \implies \sigma_\phi = \frac{\sigma_t p^2}{\hbar\sqrt{m^2+p^2}}$
- $\sigma_t = \sigma_t(p)$ close to power-law
- More charges: larger phase shift possible
- Important parameters: charge density N_c, path-length d & fireball size R

The Results I

Time-delay distribution

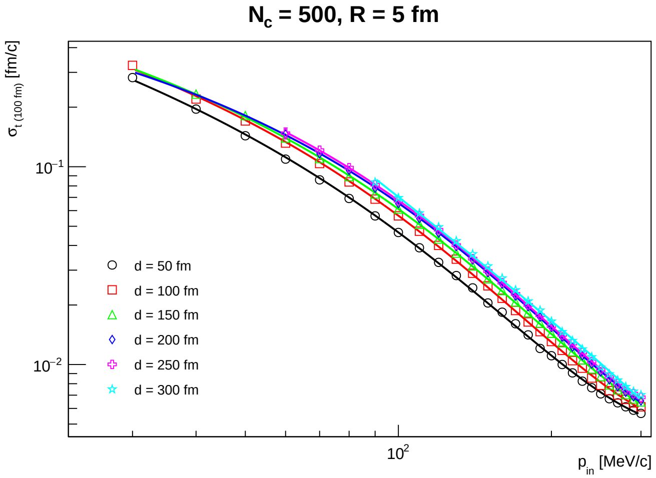
Δt distribution is slightly off-centre and also not perfectly Gaussian: needs detailed investigation



The Results II

σ_t & path-length

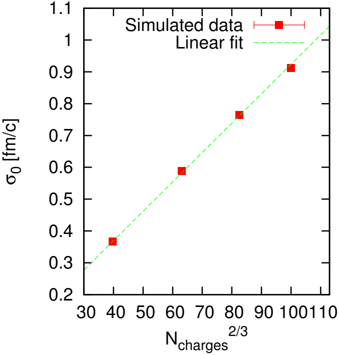
Convergence of $\sigma_t(p)$ with path-length d to be investigated

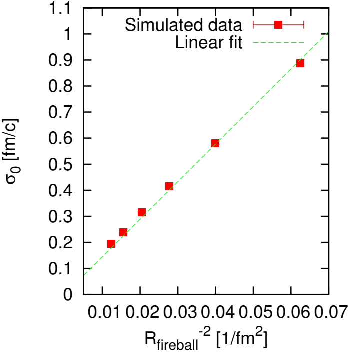


The Results III

σ_t vs. N_c & R

- Phase shift seems to scale with $\left(N_c^{1/3}/R\right)^2$
- Probably due to linear density squared?

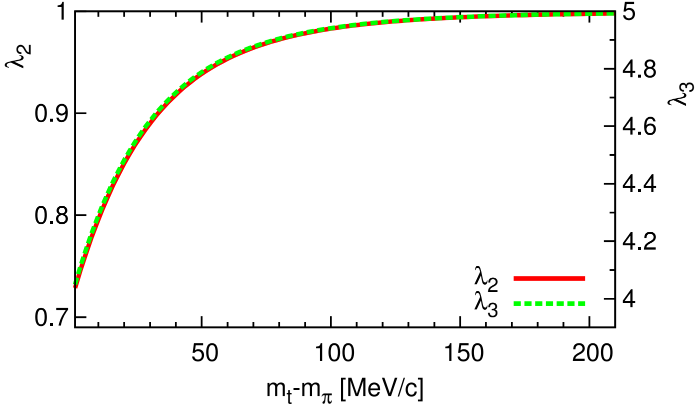




The Results IV

Correlation strength modification I

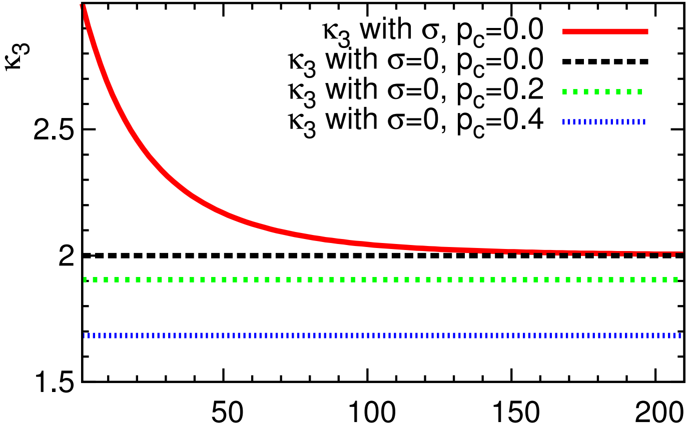
- Low-m_t decrease of $\lambda_{2,3}$
- Small magnitude, depends on charge density



The Results V

Correlation strength modification II

- $\kappa_3(p_c)$ [independent of f_c] is increased by this effect
- $p_c > 0$ decreases it



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
- $\kappa_3(m_t)$ can distinguish partial coherence and AB-like effect
- Still need to explore many details ...

The End

Thank you for your attention!