Clustering structure effect on Hanbury-Brown–Twiss correlation in ^{12}C+^{197}Au collisions at $\sqrt{s_{NN}} = 200$ GeV

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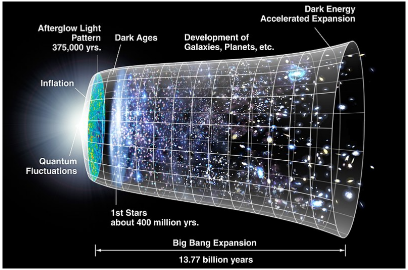
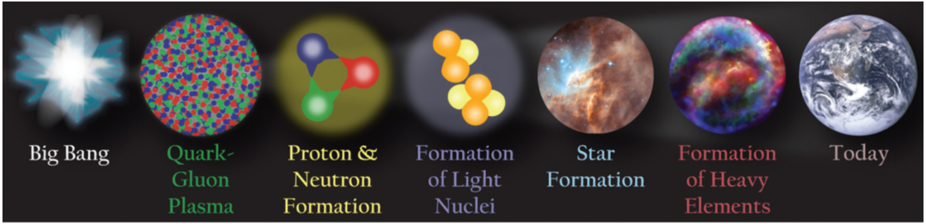
Outline

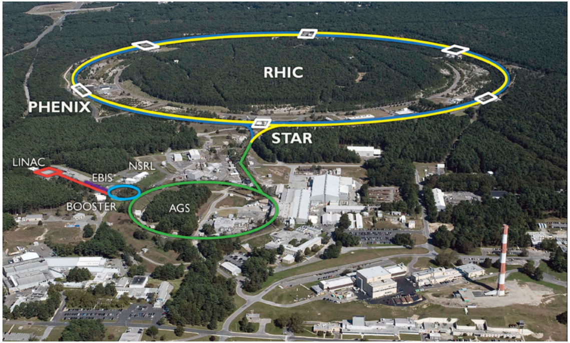
Background

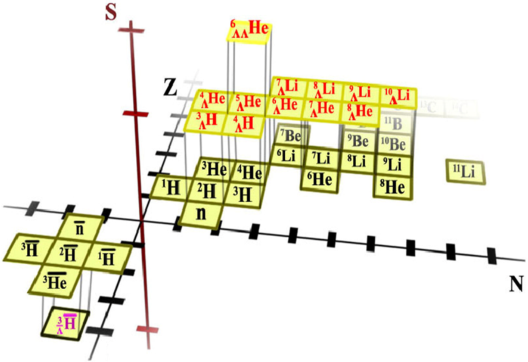
- Quark-Gluon Plasma
- Light Nuclei





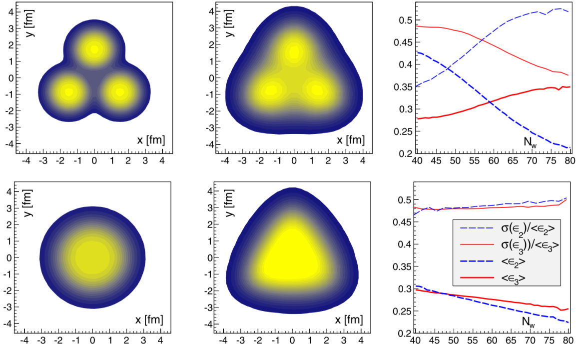
Background





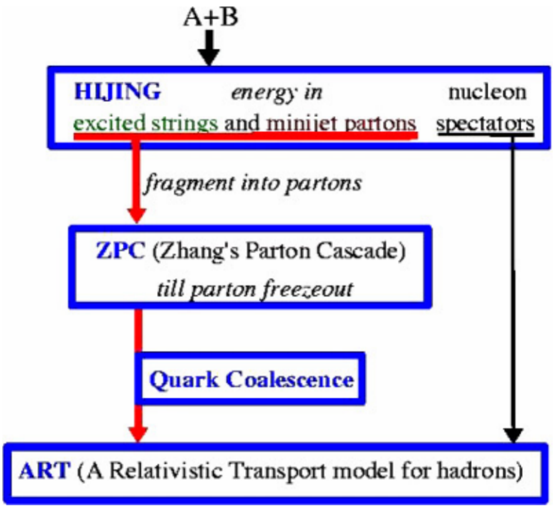
Background

- In 2014, Broniowski, Arriola et al. proposed that through relativistic heavy-ion collision, collective flow can be the signature of α clustering in light nuclei in their ground state

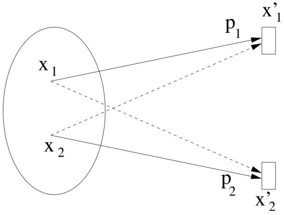


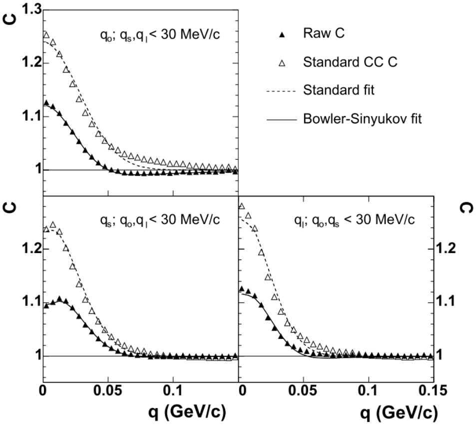
PhysRevLett.112.112501

AMPT


A+B
HIJING energy in nucleon
excited strings and minijet partons spectators
fragment into partons
ZPC (Zhang's Parton Cascade)
till parton freezeout
Quark Coalescence
ART (A Relativistic Transport model for hadrons)

- 1956 Hanbury Brown and Twiss
- 1960 Goldhaber-Goldhaber-Lee-Pais effect





STAR: PhysRevC.71.044906

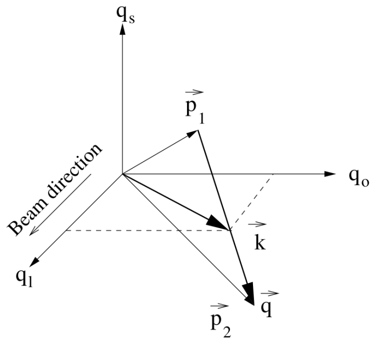
$$C(\vec{q},\vec{K}) = \frac{\int d^4x_1 d^4x_2 S(x_1,p_1)S(x_2,p_2)|\phi(\vec{q'},\vec{r'})|^2}{\int d^4x_1 S(x_1,p_1)\int d^4x_2 S(x_2,p_2)} \quad (1)$$

$$C(\vec{q},\vec{K}) = 1 \pm \left|\frac{\int d^4x e^{i\vec{q}\cdot(\vec{x}-\vec{\beta}t)} S(x,K)}{\int d^4x S(x,K)}\right|^2 \quad (2)$$

$$C(\vec{q},\vec{K}) = 1 \pm e^{-\sum_{i,j=o,s,l} R^2_{ij}(\vec{K})q_i q_j} \quad (3)$$

$$R_s^2(K_T,\Phi,Y) = \langle(y\cos\Phi - x\sin\Phi)^2\rangle - \langle y\cos\Phi - x\sin\Phi\rangle^2 \quad (4)$$

$$R_o^2(K_T,\Phi,Y) = \langle(x\cos\Phi + y\sin\Phi - \beta_\perp t)^2\rangle - \langle x\cos\Phi + y\sin\Phi - \beta_\perp t\rangle^2 \quad (5)$$



Coulomb Interaction

From Schrödinger Equation with Coulomb potential,

$$\phi_{\text{coulomb}}(\vec{q},\vec{r}) = \Gamma(1+i\eta)e^{-\frac{1}{2}\pi\eta}e^{\frac{i}{2}\vec{q}\cdot\vec{r}}F(-i\eta;1;iz_-) \tag{6}$$

where $\eta = \frac{Z_1 Z_2 \alpha c}{v_{rel}} = \frac{2 Z_1 Z_2 \alpha \mu}{q} = \frac{2}{a_0 q}$, $G(\eta) \equiv e^{-\pi\eta}|\Gamma(1+i\eta)|^2 = 2\pi\eta/(e^{2\pi\eta}-1)$ and $z_\pm = \frac{1}{2}(qr \pm \vec{q}\cdot\vec{r})$.

- (anti)symmetrization for identical particles
- Coulomb weight is only valid for $qr/\hbar < 1$

Gaussian Fitting Function

- Quantum Statistics:

$$C(\vec{q},\vec{K}) = 1 \pm \lambda(\vec{K}) e^{-\sum_{i,j=o,s,l} R_{ij}^2(\vec{K}) q_i q_j} \tag{7}$$

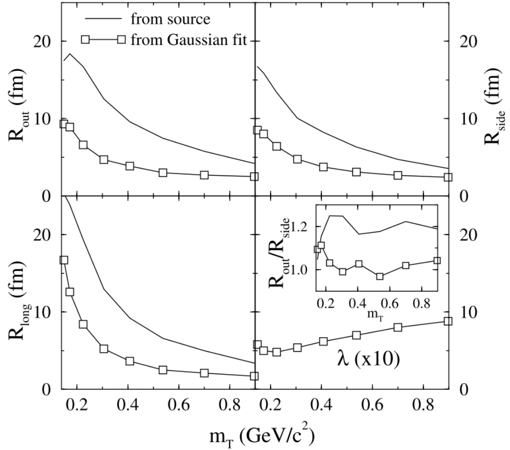
$$\Rightarrow C(q_i) = 1 \pm \lambda e^{-R_i^2 q_i^2} \quad (i = o, s, l, inv) \tag{8}$$

- Coulomb Interaction: (Bowler-Sinyukov procedure)

$$C(\vec{q},\vec{K}) = (1-\lambda) + \lambda K_{coul}(q_{inv})(1 \pm e^{-\sum_{i,j=o,s,l} R_{ij}^2(\vec{K}) q_i q_j}) \tag{9}$$

$$\Rightarrow C(q_i) = (1-\lambda) + \lambda K_{coul}(q_{inv})(1 \pm e^{-R_i^2 q_i^2}) \quad (i = o, s, l, inv) \tag{10}$$

Source radii vs. Gaussian fit



PhysRevLett.89.152301

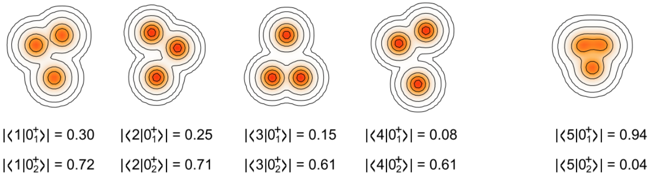
Q moments and Kurtosis

$$\left\langle\left\langle q_i^2\right\rangle\right\rangle(\vec{K}) = \frac{\int dq_i q_i^2 [C(\vec{K}, q_i) - 1]}{\int dq_i [C(\vec{K}, q_i) - 1]} \tag{11}$$

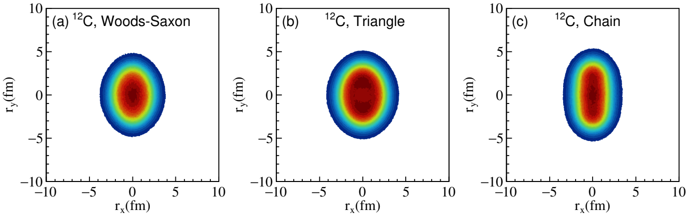
$$R_i^2(\vec{K}) = \frac{1}{2\left\langle\left\langle q_i^2\right\rangle\right\rangle} \tag{12}$$

$$\Delta_i(\vec{K}) = \frac{\left\langle\left\langle q_i^4\right\rangle\right\rangle(\vec{K})}{3\left\langle\left\langle q_i^2\right\rangle\right\rangle^2(\vec{K})} - 1 \quad i = o, s, l \tag{13}$$

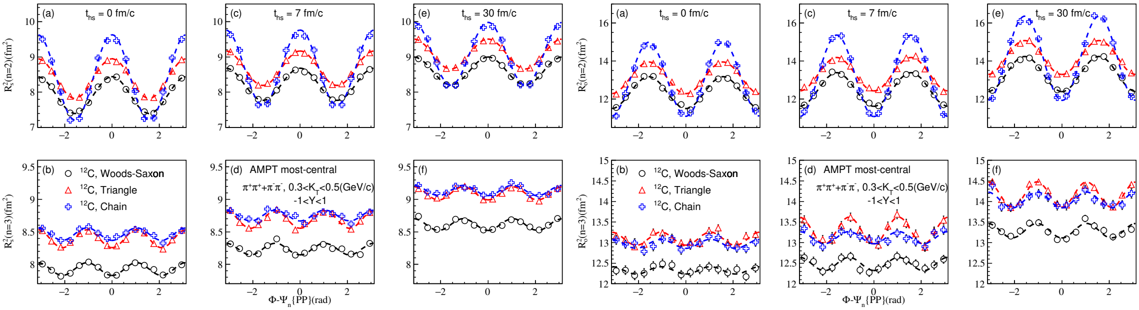
- Chain: Time-dependent Hartree-Fock
- Triangle: Fermionic molecular dynamics, Antisymmetrized molecular dynamics
- *ab initio*



PhysRevLett.98.032501



Azimuthal angle dependence of the HBT radii



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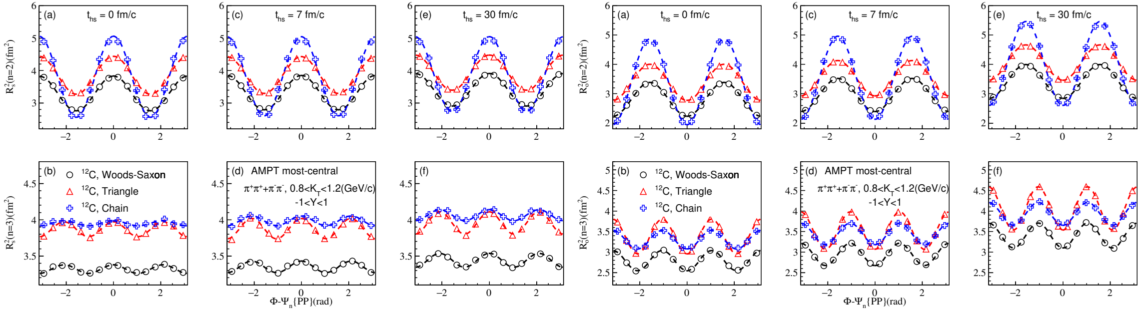
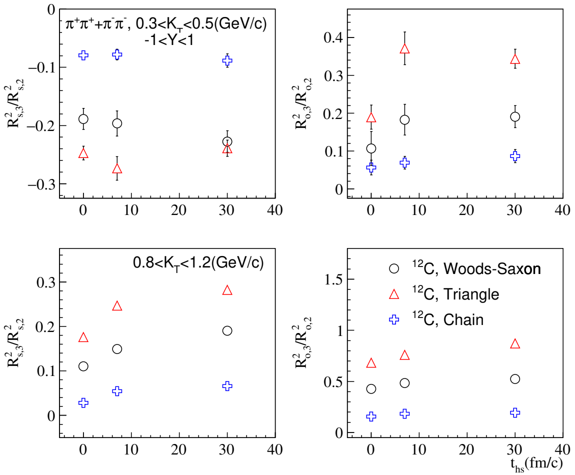


$$
\begin{aligned}
R_s^2(\Phi-\Psi_n) =& R_{s,0}^2 + 2R_{s,n}^2 \cos[n(\Phi-\Psi_n)], \\
R_o^2(\Phi-\Psi_n) =& R_{o,0}^2 + 2R_{o,n}^2 \cos[n(\Phi-\Psi_n)], n=2,3
\end{aligned} \tag{14}
$$

$R^2_{s(o),3}/R^2_{s(o),2}$



π⁺π⁺+π⁻π⁻, 0.3<K_T<0.5(GeV/c)
-1<Y<1
0.8<K_T<1.2(GeV/c)
12C, Woods-Saxon
12C, Triangle
12C, Chain
R²s,3/R²s,2
R²o,3/R²o,2
t_hs(fm/c)

Summary

- HBT method is useful for studying the geometry and dynamics of fireball
- $R^2_{s(o),3}/R^2_{s(o),2}$ is an effective probe to study the clustering structure of light nuclei
- System scan may provide the platform to further study the bulk properties and exotic structures in light nuclei