Alpha clusters from ultrarelativistic nuclear collisions

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[based on WB& E. Ruiz Arriola, **arXiv:1312.0289**]

Instead of outline

Two phenomena are related:

α clustering in light nuclei

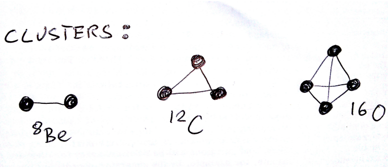
$\updownarrow$

harmonic flow in ultra-relativistic A+B collisions

low-energy structure $\longleftrightarrow$ highest energy mini bangs (!)

History

David Brink: After Gamow's theory of α-decay it was natural to investigate a model in which nuclei are composed of α-particles. Gamow developed a rather detailed theory of properties in his book "Constitution of Nuclei" published in 1931 before the discovery of the neutron in 1932. He supposed that 4n-nuclei like ^{8}Be, ^{12}C, ^{16}O ... were composed of α-particles



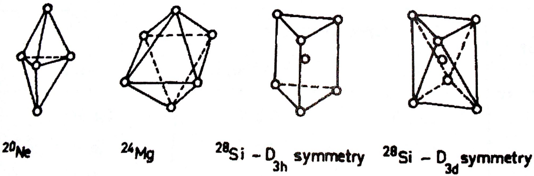
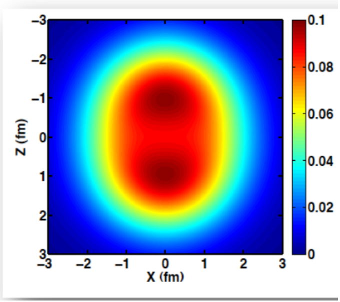
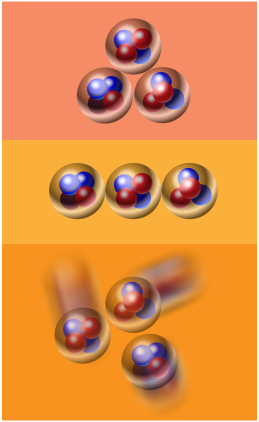


Fig. 1. Alpha-particle configuration for some 4*N* nuclei.

Status





ground

Hoyle 2^+

other excited

^{9}Be

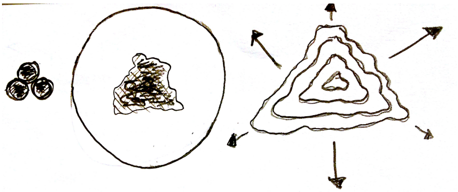
^{12}C

[M. Freer, WPCF2013, H. Fynbo+Freer, Physics 4 (2011) 94]

ab initio calculations up to $^{16}O \longleftrightarrow$ strong α clusterization

From α clusters to flow in relativistic collisions

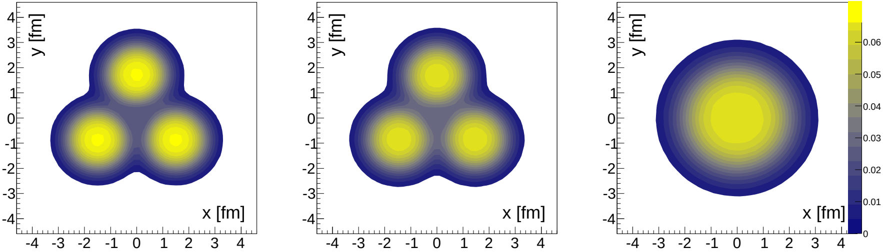
α clusters $\rightarrow$ asymmetry of shape $\rightarrow$ asymmetry of initial fireball $\rightarrow$
$\rightarrow$ hydro or transport $\rightarrow$ collective harmonic flow



What are the chances of detection?

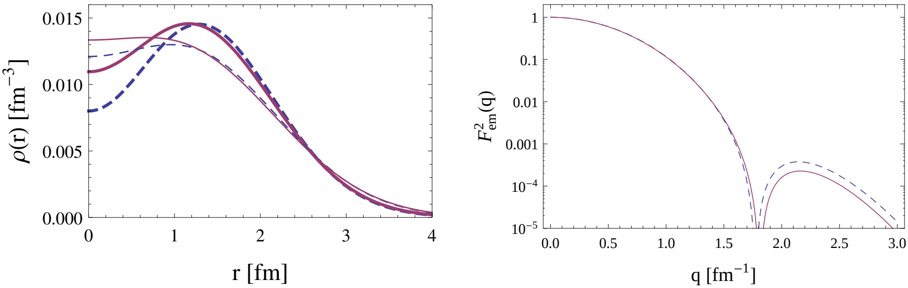
Related idea: triton/^{3}He–Au at RHIC in 2015 [Sickles (PHENIX) 2013]
The case of light nuclei is more promising, as it leads to abundant fireballs

Intrinsic distributions: 3 α's in a triangular arrangement



Case I | Case II | unclustered

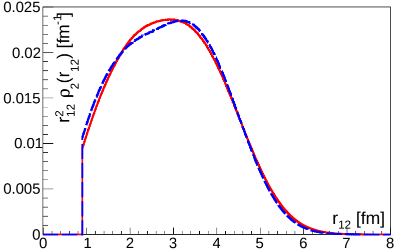
Constraints from EM form factor



Electric charge density (thin lines) and the corresponding distribution of the centers of nucleons (thick lines) in ^{12}C for the data and BEC calculations (dashed lines), and for the FMD calculations (solid lines), plotted against the radius.

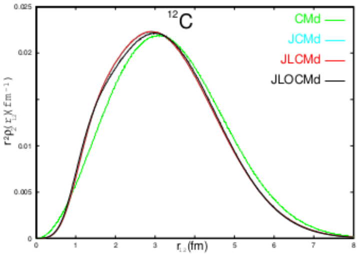
Central depletion

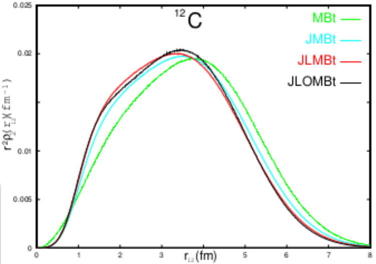
Radial density in the relative NN distance r_{12}



Our Monte Carlo

The α cluster structure is modeled sufficiently accurately



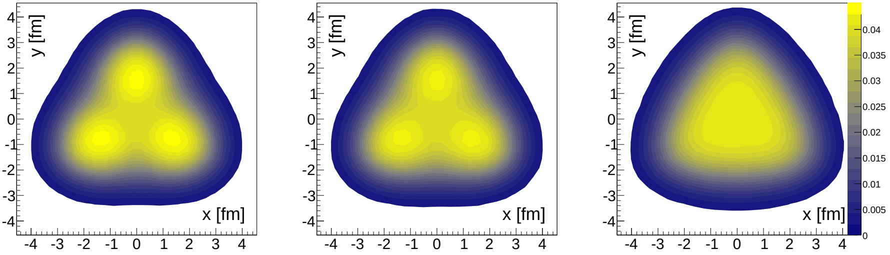


[Buendia et al. 2004]

^{12}C–^{208}Pb collision

Mixed Glauber model at SPS conditions: $n \sim \frac{1-a}{2} N_{\rm w} + a N_{\rm bin}, \quad a = 0.12$

Intrinsic distributions in the transverse plane in the fireball, $N_w > 70$ – large multiplicity



Case I | Case II | unclustered

Geometry vs multiplicity

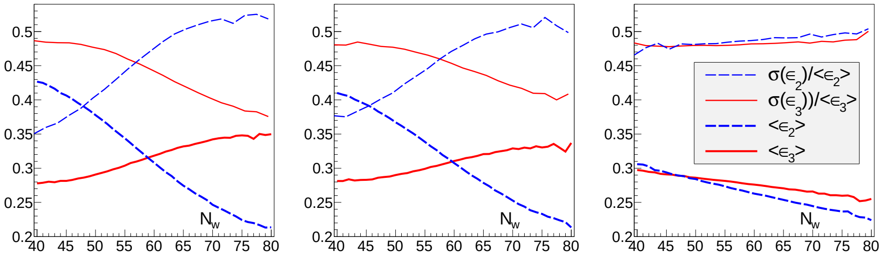
Eccentricity parameters
$$\epsilon_n e^{in\Phi_n} = \frac{\sum_j \rho_j^n e^{in\phi_j}}{\sum_j \rho_j^n}$$

describe the shape (j labels the sources in the event, n=rank)

The triangle plane parallel or perpendicular to the transverse plane:

higher multiplicity	lower multiplicity
higher triangularity	lower triangularity
lower ellipticity	higher ellipticity

Ellipticity and triangularity vs multiplicity



Case I | Case II | unclustered

Clusters:

When $N_w \nearrow$ then $\langle\epsilon_3\rangle \nearrow$ and $\langle\epsilon_2\rangle \searrow$

and $\langle\sigma(\epsilon_3)/\epsilon_3\rangle \searrow$, $\langle\sigma(\epsilon_2)/\epsilon_2\rangle \nearrow$ tending to $\sqrt{4/\pi - 1} \sim 0.52$

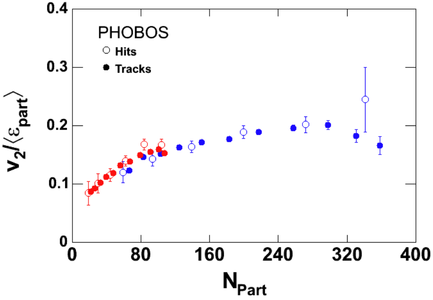
No clusters:

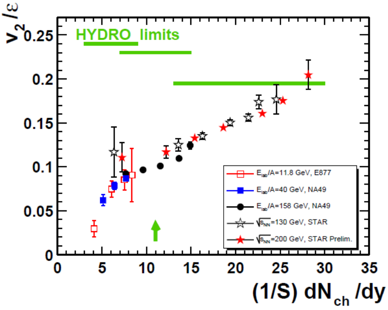
similar behavior for $n = 2$ and $n = 3$

Shape-flow transmutation

The eccentricity parameters are transformed (in all models based on collective dynamics) into asymmetry of the transverse-momentum flow. It has been found that

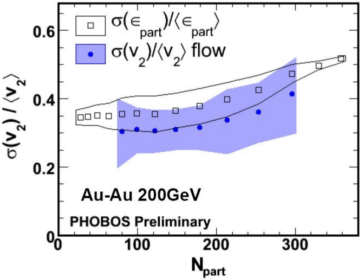
$$\langle v_n \rangle \simeq A \langle \epsilon_n \rangle$$





E-by-e fluctuations

$$\frac{\sigma(v_n)}{\langle v_n \rangle} \simeq \frac{\sigma(\epsilon_n)}{\langle \epsilon_n \rangle}$$



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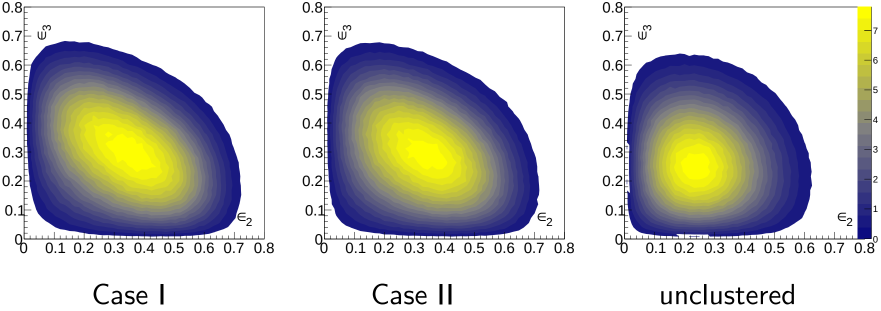
Measured flow coefficients reflect the initial shape eccentricities

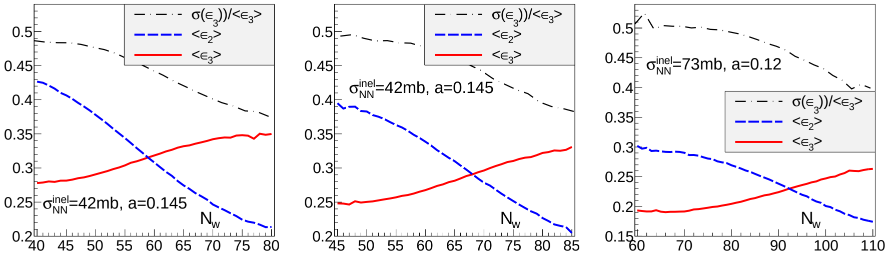
Triangularity vs ellipticity



Clusters:

Anticorrelation: $\rho(\epsilon_2, \epsilon_3) \simeq -0.3$

Dependence on the collision energy



Qualitative conclusions remain from SPS to the LHC

Conclusions

Signatures of clustered ^{12}C-^{208}Pb collisions $\rightarrow$

- Increase of ϵ_3 and v_3 with multiplicity for the highest multiplicity events
- Decrease of scaled variance ϵ_3 and v_3 with multiplicity for the highest multiplicity events
- Anticorrelation of ϵ_2 and ϵ_3, or v_2 and v_3

Extensions:

- Other systems
- More detailed modeling

Future data in conjunction with a detailed knowledge of the dynamics of the evolution of the fireball will allow to place constrains on the α-cluster structure of the colliding nuclei. Conversely, the knowledge of the clustered nuclear distributions may help to verify the fireball evolution models