Alpha clustering from relativistic collisions

Wojciech Broniowski

UJK Kielce & IFJ PAN Cracow

STAR Regional Meeting:
Heavy Quark Production, Jets and Correlations
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[based on WB& E. Ruiz Arriola, **arXiv:1312.0289**]

Instead of outline

(WPCF 2013 $\to \alpha$)

Two phenomena are related:

α clustering in light nuclei

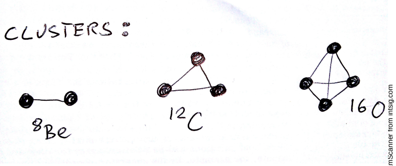
$\updownarrow$

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



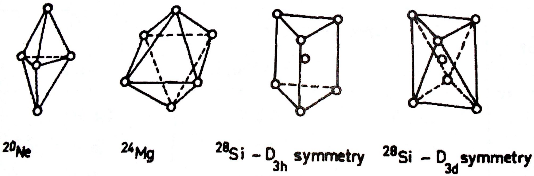
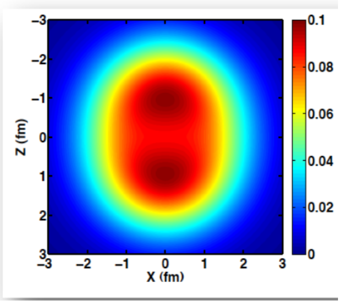
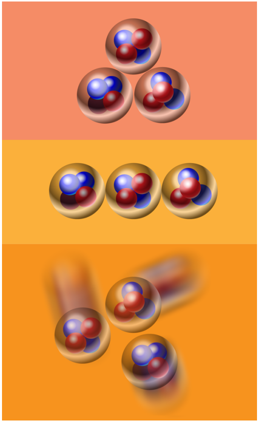


Fig. 1. Alpha-particle configuration for some 4N nuclei.

Present status



^{9}Be



ground

Hoyle 2^+

other excited

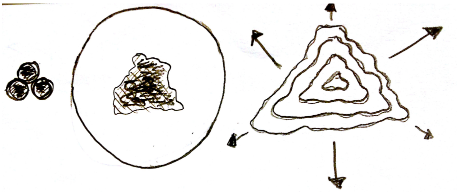
^{12}C

[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

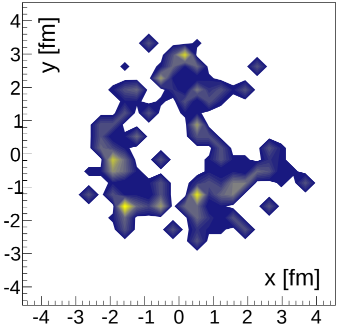
α clusters $\rightarrow$ asymmetry of shape $\rightarrow$ asymmetry of initial fireball $\rightarrow$
$\rightarrow$ hydro or transport $\rightarrow$ collective harmonic flow



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

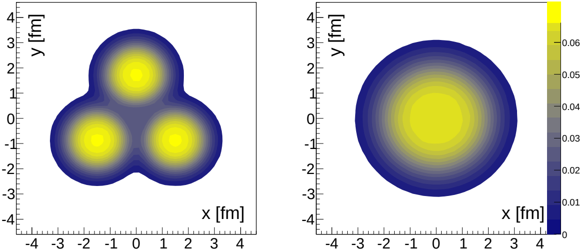
^{12}C-^{208}Pb – single event



Imprints of the α clusters clearly visible

^{12}C-^{208}Pb – intrinsic average over events

Intrinsic distributions: 3 α's in a triangular arrangement



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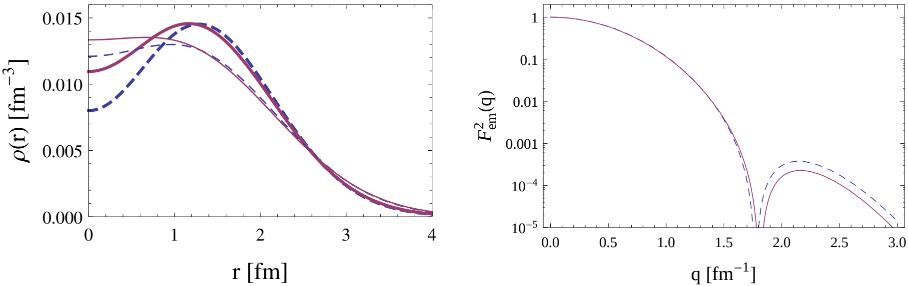
Constraints from EM form factor

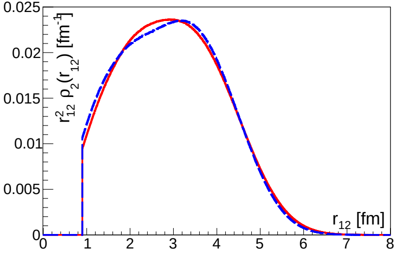


Electric charge density (thin lines) and the corresponding distribution of the centers of nucleons (thick lines) in ^{12}C for the data and BEC calculations (dashed lines), and for the FMD calculations (solid lines), plotted against the radius.

Central depletion

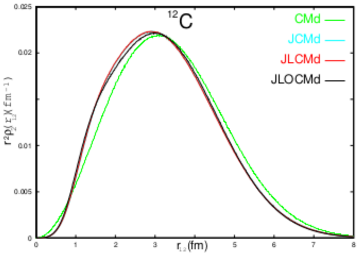
Distribution of pairs

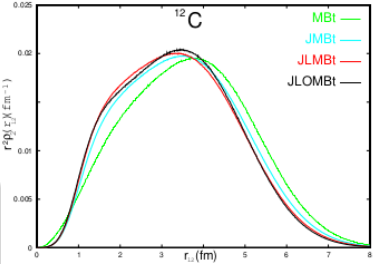
Radial density in the relative NN distance r_{12}



Our Monte Carlo

The α cluster structure is modeled sufficiently accurately



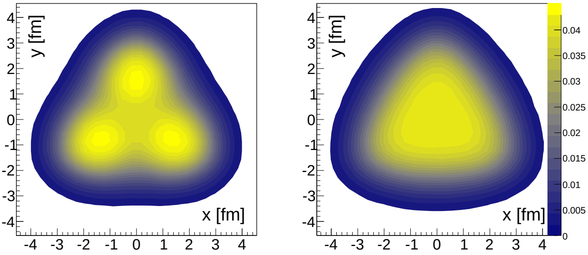


[Buendia et al. 2004]

^{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



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Eccentricity parameters

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

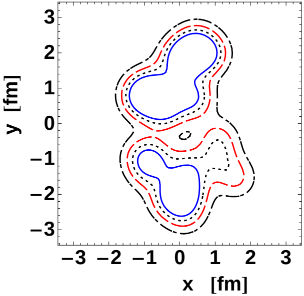
describe the shape (j labels the sources in the event, n=rank)

Two components:

- intrinsic (from existent mean deformation of the fireball)
- from fluctuations

Digression: d-Pb

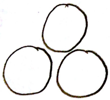
Initial entropy density in a d-Pb collision with $N_{\text{part}} = 24$ [Bozek 2012]



Fluctuations around the intrinsic ellipticity

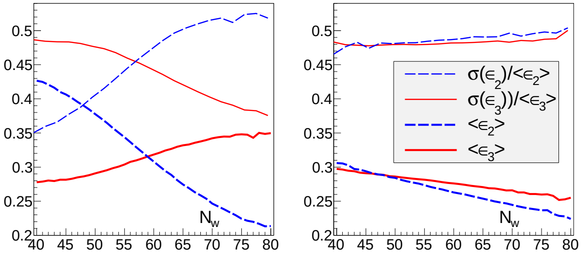
Geometry vs multiplicity in ^{12}C-Pb

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



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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 $\sqrt{4/\pi - 1} \sim 0.52$

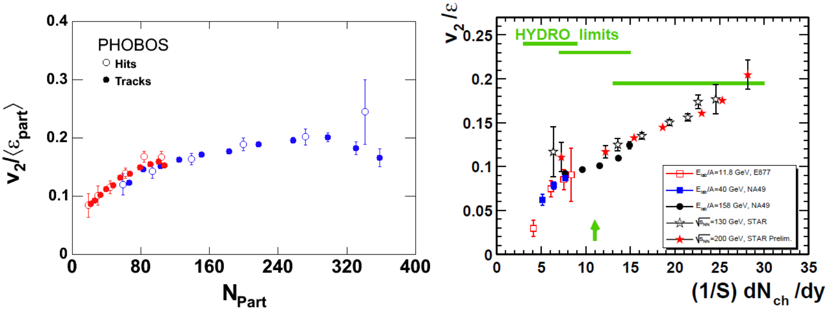
No clusters:

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

Shape-flow transmutation

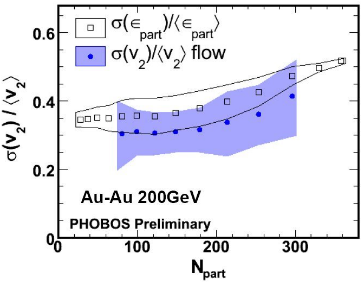
The eccentricity parameters are transformed (in all models based on collective dynamics) into asymmetry of the transverse-momentum flow. It has been found that

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



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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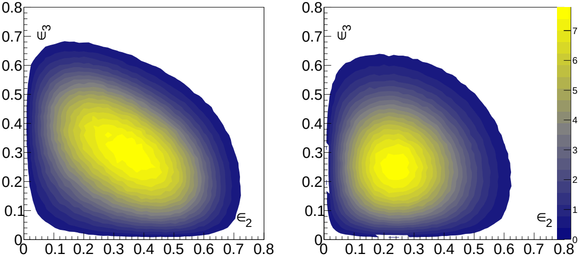
Measured flow coefficients reflect the initial shape eccentricities

Triangularity vs ellipticity



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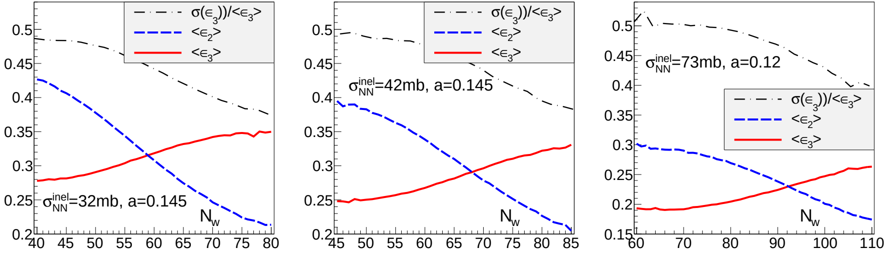
Clusters:

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

Dependence on the collision energy



32mb (SPS) 42mb (RHIC) 72mb (LHC)

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

Possible future data (NA61?) in conjunction with a detailed knowledge of the dynamics of the evolution of the fireball would 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