Flow in collisions of light nuclei

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Outline

Attempt of outlook to the future:

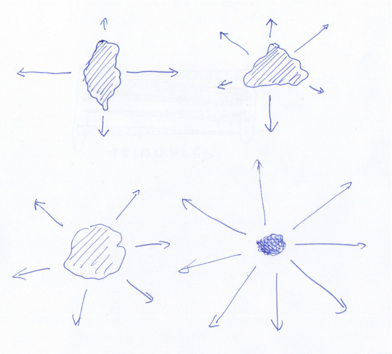
Collisions with

- Polarized light targets (deuteron)
- ^{16}O
- Light clustered nuclei

Introduction

Shape – flow transmutation

[Ollitrault 1992 ... Miller, Snellings 2003 ... Alver, Roland 2010 ...]

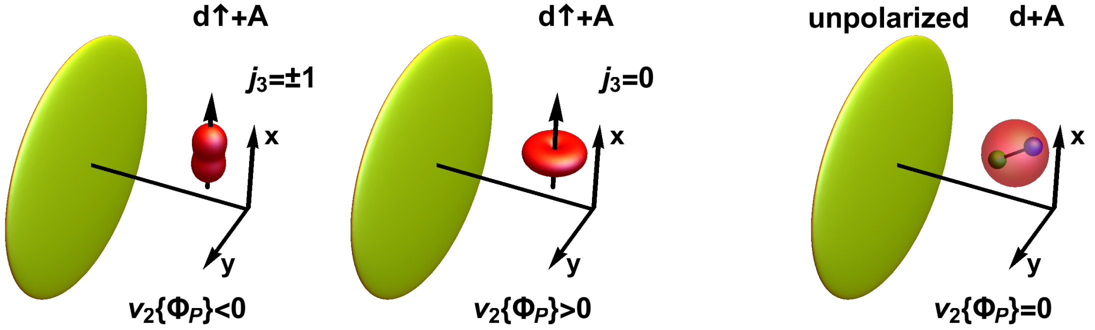


smaller → faster

- Any (copious) rescattering will do (hydro, transport)
- Challenge: reaction plane not known → obtaining flow coefficients from correlation methods
- How small can the system be?

Controlling the geometry: collisions on polarized deuteron

A + ↑d collisions



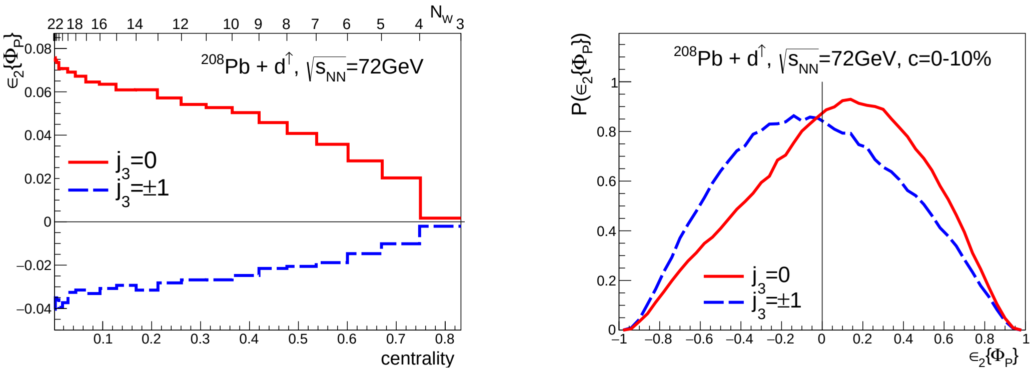
Admixture of the D-wave $\rightarrow$ control the geometry via polarization
Small but clearly measurable effect

[PB, WB, PRL 121 (2018) 202301 and 1906.09045]

NEW aspects

Ellipticity of the fireball relative to polarization axis

GLISSANDO:



[GLISSANDO 3 – see poster by G. Stefanek]

Predictions from hydrodynamics ($c = 0 - 5\%$)

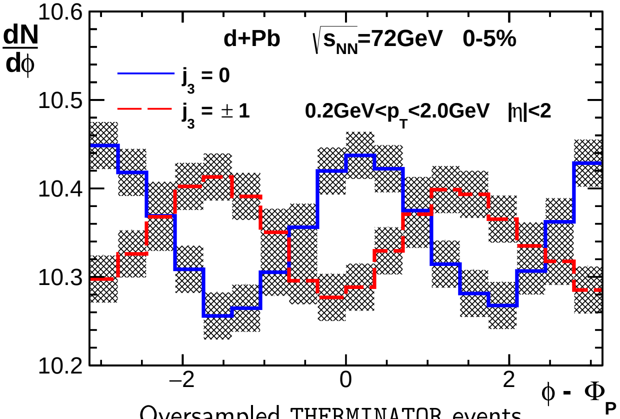
One-body measurement (!)

$$\frac{dN}{d\phi} \propto 1 + 2v_2\{\Phi_P\}\cos\left[2(\phi - \Phi_P)\right]$$
$$\langle v_2\{\Phi_P\}\rangle \simeq k\langle\epsilon_2\{\Phi_P\}\rangle$$

$k \sim 0.1$ for most central

Clear signal already with 400 hydro* events

$$\langle v_2\{\Phi_P\}_{j3=0}\rangle = 0.0041(13)$$
$$\langle v_2\{\Phi_P\}_{j3=\pm1}\rangle = -0.0029(13)$$



Oversampled THERMINATOR events

* For small systems pioneered by PB, PRC85 (2012) 014911, 3+1D viscous

Can be observed

Main sources of uncertainty:

- Fluctuations of the initial eccentricity

$$\Delta v_2\{\Phi_P\} = \frac{\sigma(v_2\{\Phi_P\})}{\sqrt{N_{\mathrm{ev}}}} \simeq \frac{0.03}{\sqrt{N_{\mathrm{ev}}}}$$

- Sampling with n_h hadrons

$$\delta v_2\{\Phi_P\} \simeq \frac{1}{\sqrt{2N_{\mathrm{ev}}\langle n_h\rangle}}$$

with $\langle n_h\rangle = 80$:

N_{ev}	$\Delta v_2\{\Phi_P\}$	$\delta v_2\{\Phi_P\}$
400	0.0013	0.0040
10^4	0.0003	0.0008
10^5	0.00008	0.00025
10^6	0.00003	0.00008

$$\langle v_2\{\Phi_P\}\rangle \simeq 0.005$$

Can be seen already for 10^4 events with relative uncertainty at the level of 10-20%

For deuteron targets the *tensor polarization* $P_{zz} = n(1) + n(-1) - 2n(0)$ possible to obtain is $-1.5 \leq P_{zz} \leq 0.7$:

$$-0.002 \lesssim v_2\{\Phi_P\} \lesssim 0.004$$

Prospects at fixed target experiments

AFTER@LHC, SMOG2@LHCb after long shutdown 3 (2017 $\rightarrow$)
injecting a polarized gas target into the Pb beam

2.76A TeV Pb beam on a fixed target
$\rightarrow \sqrt{s_{NN}} = 72$ GeV, at LHCb $-2.3 < \eta_{\mathrm{CM}} < 0.7$

[C. Barschel, Ph.D. thesis, (2014), R. Aaij et al. (LHCb), JINST 9, P12005 (2014), arXiv:1410.0149]
P. Di Nezza, private comm.

Other $j \geq 1$ nuclei

Estimates based on the quadrupole moment

	j	j_3	$\langle r^2 \rangle_{\text{ch}}^{1/2}$ [fm]	Q_2 [fm^2]	$-\frac{3Q_2}{4Z\langle r^2\rangle}$
d	1	± 1	2.1421(88)	0.2860(15)	-0.06
(appr.)		0		$\times(-2)$	$\times(-2)$
^{7}Li	$\frac{3}{2}$	$\pm\frac{3}{2}$	2.444(42)	$-4.03(4)$	0.19
		$\pm\frac{1}{2}$		$\times(-1)$	$\times(-1)$
^{9}Be	$\frac{3}{2}$	$\pm\frac{3}{2}$	2.519(12)	5.29(4)	-0.17
		$\pm\frac{1}{2}$		$\times(-1)$	$\times(-1)$
^{10}B	± 3	± 3	2.428(50)	8.47(6)	-0.25

$$v_2\{\Phi_P\}_{\text{cent.}} \simeq -k \frac{3Q_2}{4Z(\langle r^2\rangle + \frac{3}{2}\langle b^2\rangle_{NN})} \frac{3j_3^2 - j(j+1)}{j(2j-1)} P$$

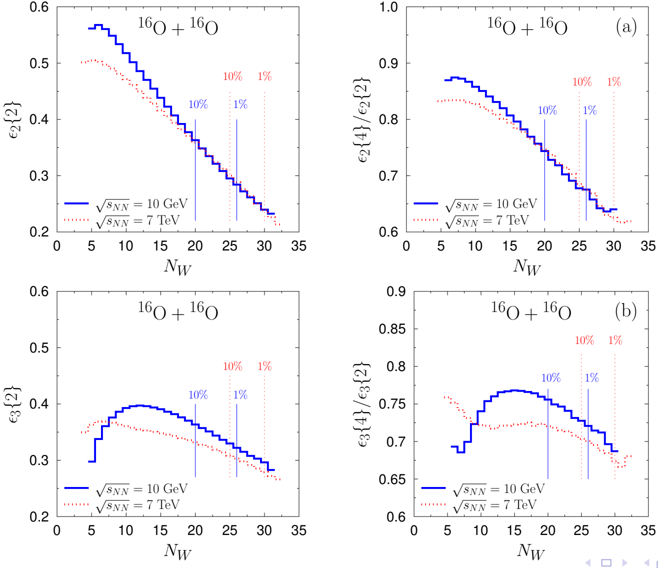
The lowest possible j is 1 (no effect for ^{3}He or ^{3}H, where $j = \frac{1}{2}$)

^{16}O

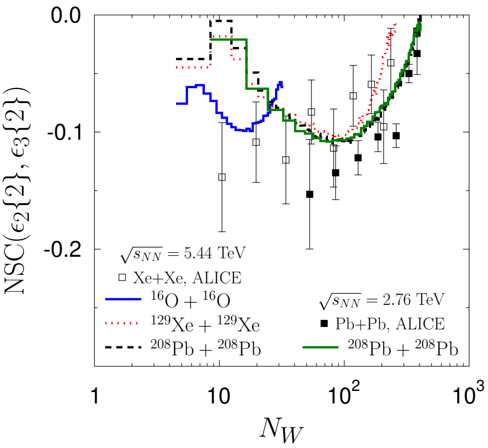
Planned at the LHC [arXiv:1812.06772]
and RHIC ["The STAR beam use request for run-20 and run-21", 2019]

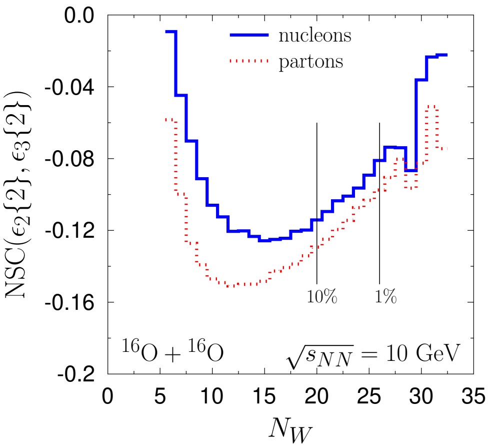
Correlated state-of-the art ^{16}O from cluster Variational Monte Carlo [Lonardoni et al. 2017]

Eccentricities in ^{16}O - ^{16}O, Glauber MC



Flow correlation, normalized symm. cumulant





[MR, WB, 1910.09489]

[see also Sievert, Noronha-Hostler, Phys. Rev. C100 (2019) 024904]

^{16}O-^{16}O compared to p-Pb at the same N_W → more dilute initial condition

Light clustered nuclei

^{12}C-A – role of α clusters

[WB, ERA, PRL 112 (2014) 112501] ...

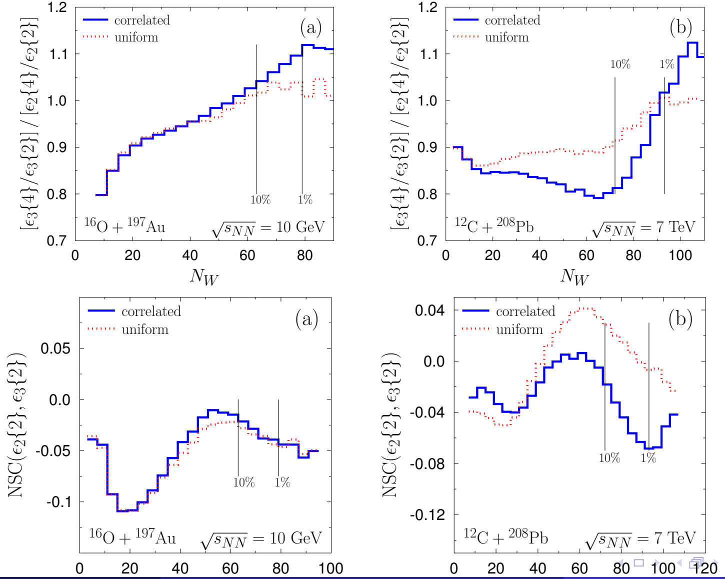
Nuclear structure from ultra-relativistic collisions

Probe to what degree ^{12}C is made of three α's via collisions with a "wall" of Pb or Au:

The cluster plane parallel or perpendicular to the transverse plane:

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

Clusters from “hitting a wall”



Summary

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- Polarized deuteron - unique opportunity to control geometry, one-body measurement possible at low statistics / min. bias data
- For other light $j \geq 1$ nuclei effect even a few times larger
- Glauber MC yields qualitatively similar results for ^{16}O - ^{16}O as for heavy nuclei, but moved to lower multiplicities
- Clustered small nuclei in light-heavy collisions – possible insight into nuclear structure from harmonic flow