The Intrinsic Shape of ^{238}U at the Relativistic Heavy Ion Collider

Giuliano Giacalone

Institut für Theoretische Physik (ITP)
Universität Heidelberg

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UNIVERSITÄT
HEIDELBERG
ZUKUNFT
SEIT 1386

IsoQuant
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INSTITUTE for NUCLEAR THEORY

INT PROGRAM INT-23-1A

Intersection of nuclear structure and high-energy nuclear collisions

January 23, 2023 - February 24, 2023

OUTLINE

1 – Collective flow and nuclear structure in high-energy nuclear physics.

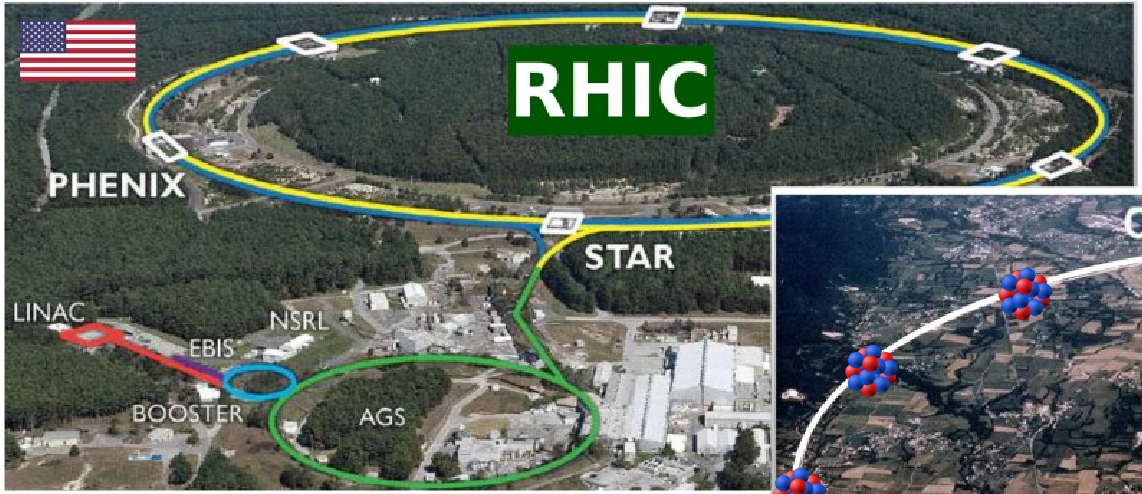
2 – The intrinsic shape of ^{238}U in ultrarelativistic collisions.

3 – Prospects.

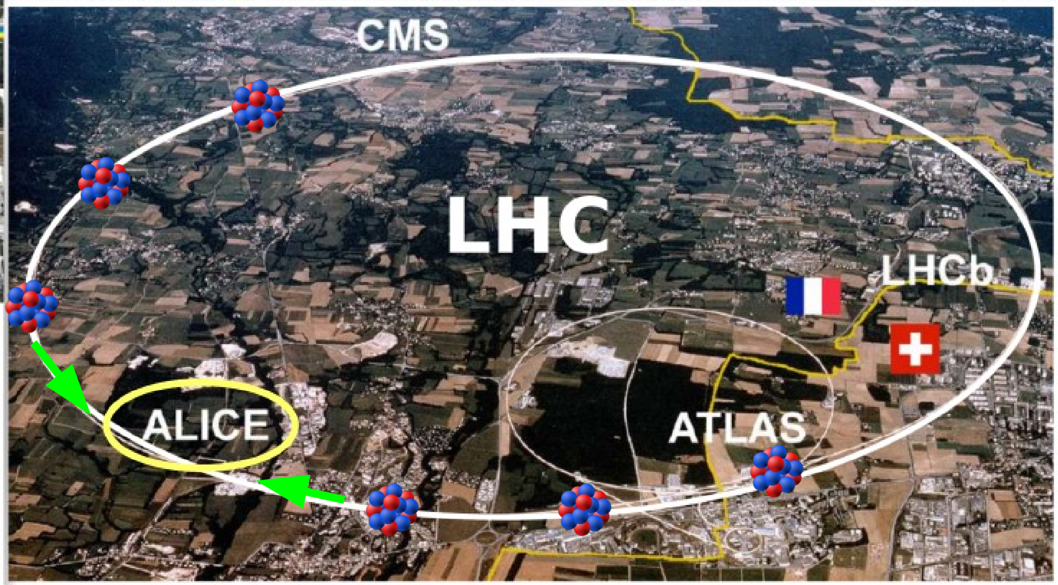
1 – Collective flow and nuclear structure in high-energy nuclear physics.

HIGH ENERGY NUCLEAR PHYSICS

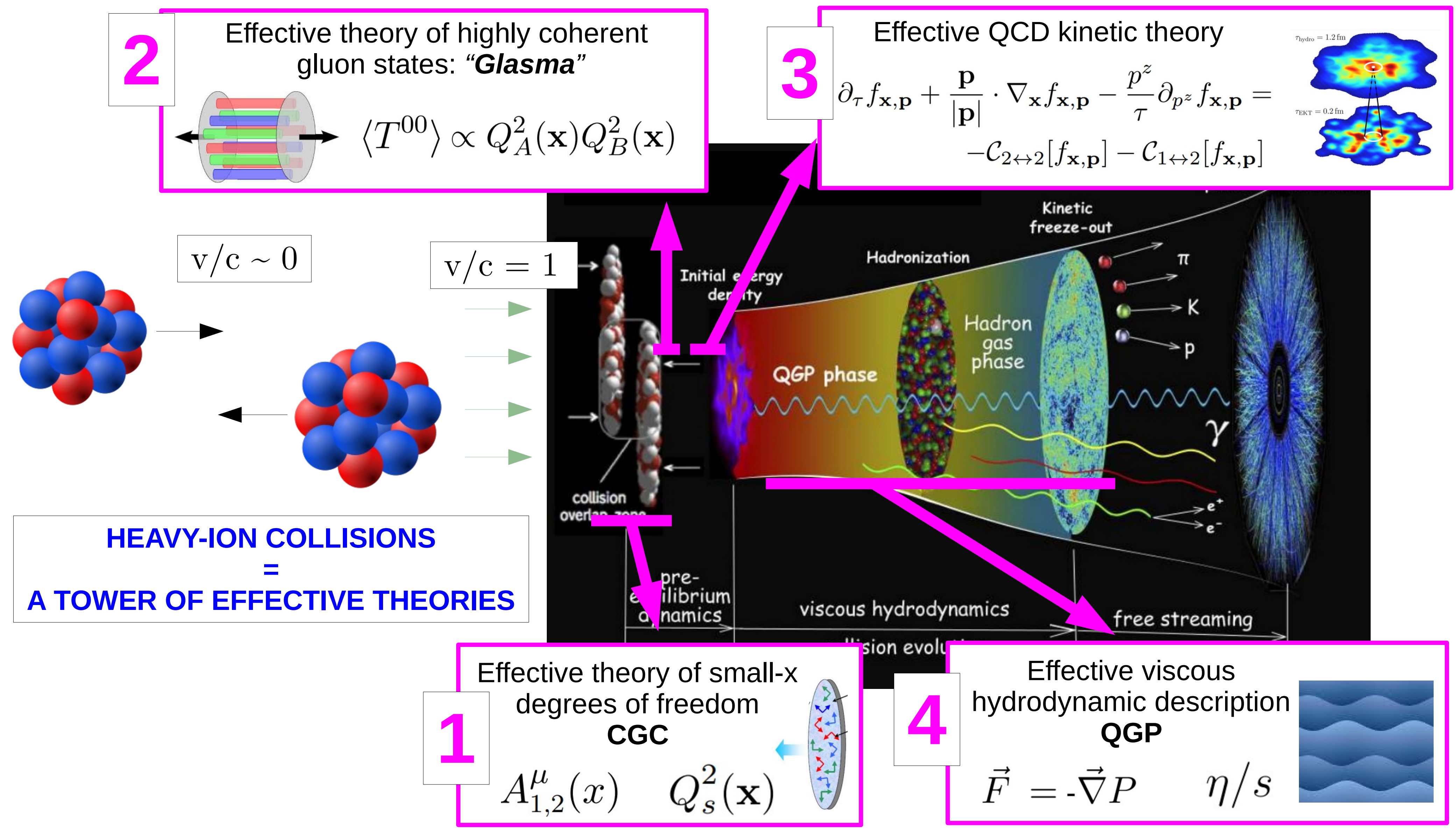
Long Island (NY)



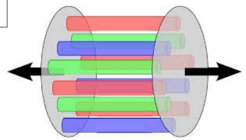
Geneva (CH)



Huge program to explore emergent phenomena in strong-interaction matter.


2
Effective theory of highly coherent gluon states: “*Glasma*”
$\langle T^{00}\rangle \propto Q_A^2(\mathbf{x})Q_B^2(\mathbf{x})$
3
Effective QCD kinetic theory
$\partial_\tau f_{\mathbf{x},\mathbf{p}} + \frac{\mathbf{p}}{|\mathbf{p}|}\cdot\nabla_{\mathbf{x}} f_{\mathbf{x},\mathbf{p}} - \frac{p^z}{\tau}\partial_{p^z} f_{\mathbf{x},\mathbf{p}} = -\mathcal{C}_{2\leftrightarrow2}[f_{\mathbf{x},\mathbf{p}}] - \mathcal{C}_{1\leftrightarrow2}[f_{\mathbf{x},\mathbf{p}}]$
$\tau_{\rm hydro} = 1.2\,{\rm fm}$
$\tau_{\rm EKT} = 0.2\,{\rm fm}$
v/c ~ 0
v/c = 1
Initial energy density
Kinetic freeze-out
Hadronization
π
K
p
Hadron gas phase
QGP phase
γ
e^+
e^-
collision overlap zone
pre-equilibrium dynamics
viscous hydrodynamics
free streaming
collision evolution
HEAVY-ION COLLISIONS
=
A TOWER OF EFFECTIVE THEORIES
1
Effective theory of small-x degrees of freedom
CGC
$A^\mu_{1,2}(x)$ $Q_s^2(\mathbf{x})$
4
Effective viscous hydrodynamic description
QGP
$\vec{F} = -\vec{\nabla}P$ η/s

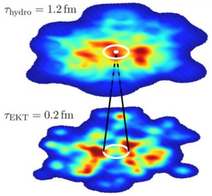
2 Effective theory of highly coherent gluon states: “***Glasma***”



$$\langle T^{00}\rangle \propto Q_A^2(\mathbf{x})Q_B^2(\mathbf{x})$$

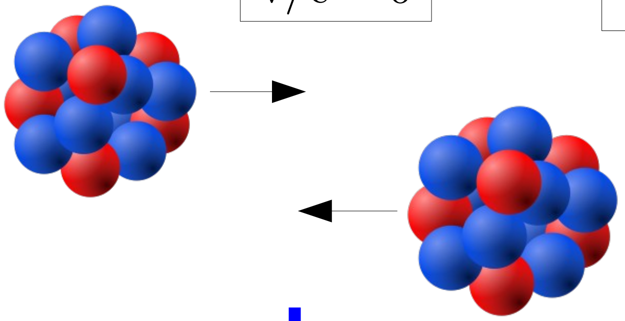
3 Effective QCD kinetic theory

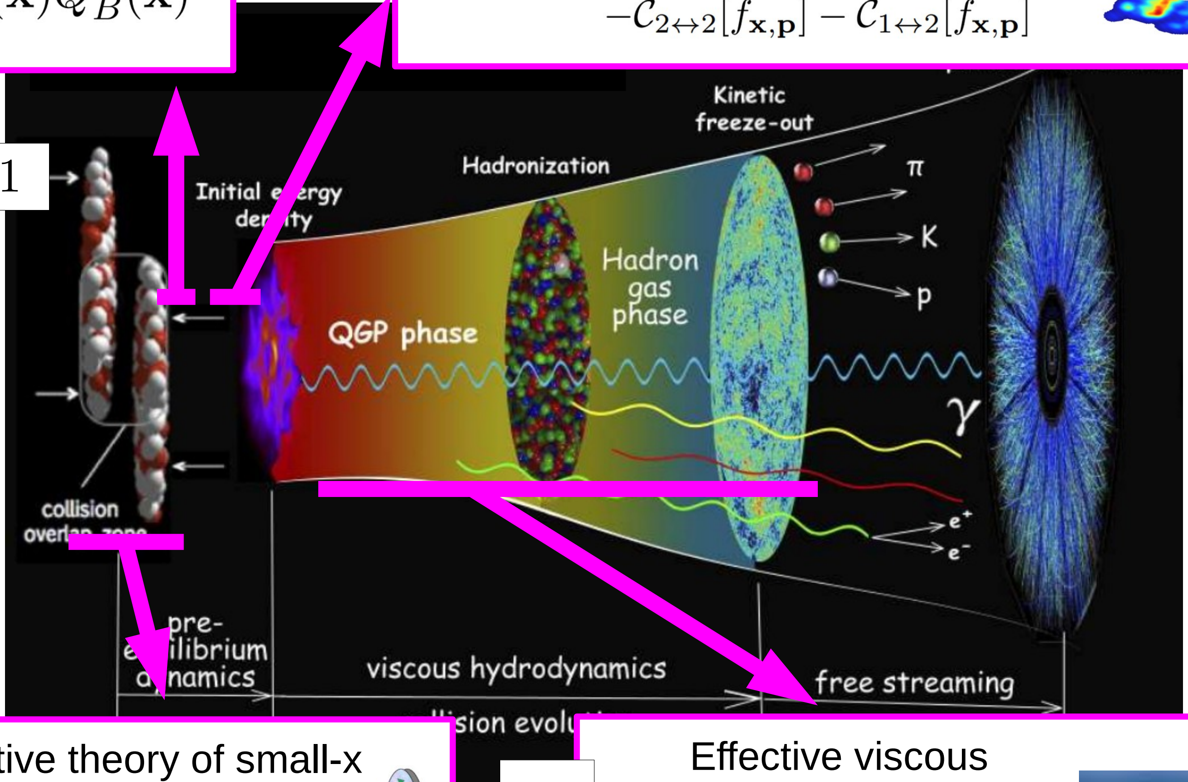
$$\partial_\tau f_{\mathbf{x},\mathbf{p}} + \frac{\mathbf{p}}{|\mathbf{p}|}\cdot\nabla_{\mathbf{x}} f_{\mathbf{x},\mathbf{p}} - \frac{p^z}{\tau}\partial_{p^z} f_{\mathbf{x},\mathbf{p}} = -\mathcal{C}_{2\leftrightarrow 2}[f_{\mathbf{x},\mathbf{p}}] - \mathcal{C}_{1\leftrightarrow 2}[f_{\mathbf{x},\mathbf{p}}]$$



$v/c \sim 0$

$v/c = 1$





0 **THIS PROGRAM**

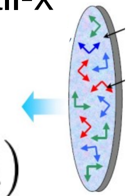
Effective theories of QCD for spatial distribution of large-x degrees of freedom

→ nuclear structure

1 Effective theory of small-x degrees of freedom

CGC

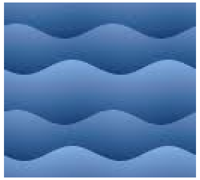
$$A^\mu_{1,2}(x) \qquad Q_s^2(\mathbf{x})$$



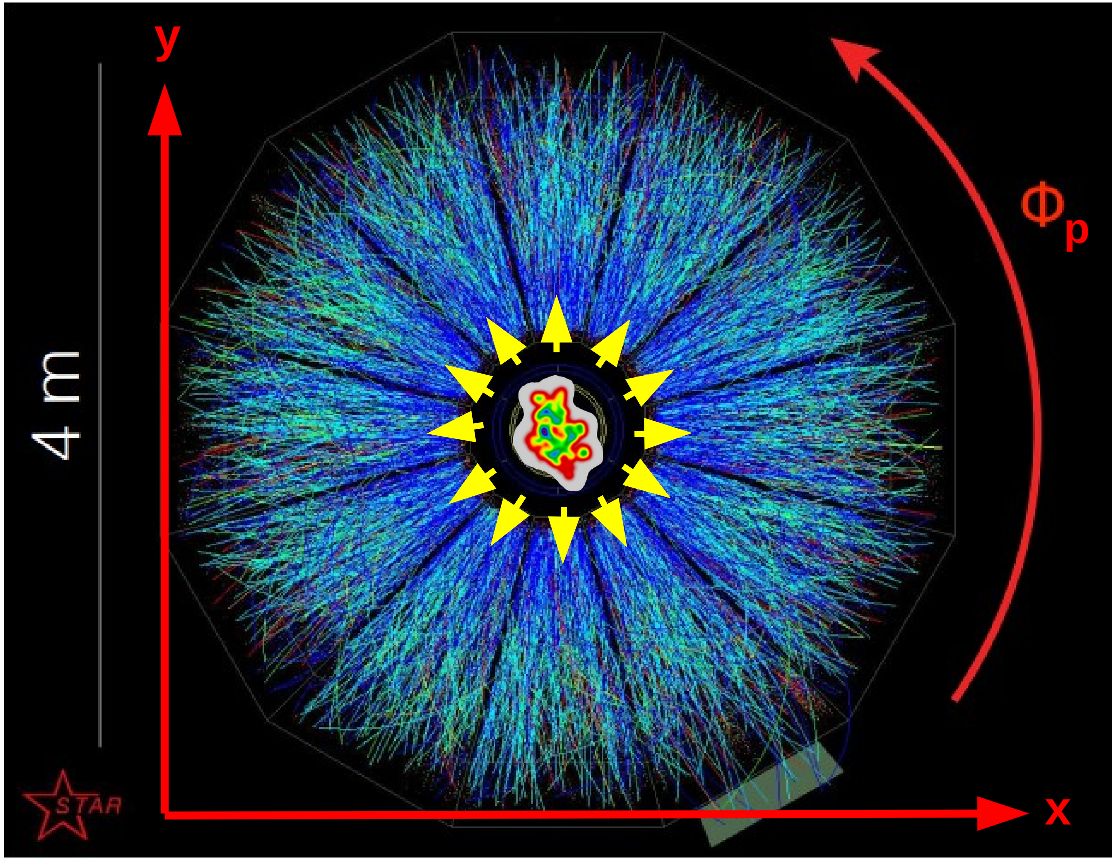
4 Effective viscous hydrodynamic description

QGP

$$\vec{F} = -\vec{\nabla}P \qquad \eta/s$$



How do we reconstruct the initial condition of the QGP?



Low-momentum particles follow the hydrodynamic expansion.

$$\frac{d^2N}{dp_T d\phi} = \frac{dN}{2\pi dp_T}\left(1 + 2\sum_{n=1}^{\infty} v_n \cos n(\phi - \Phi_n)\right)$$

EXPLOSIVENESS OF THE EXPANSION

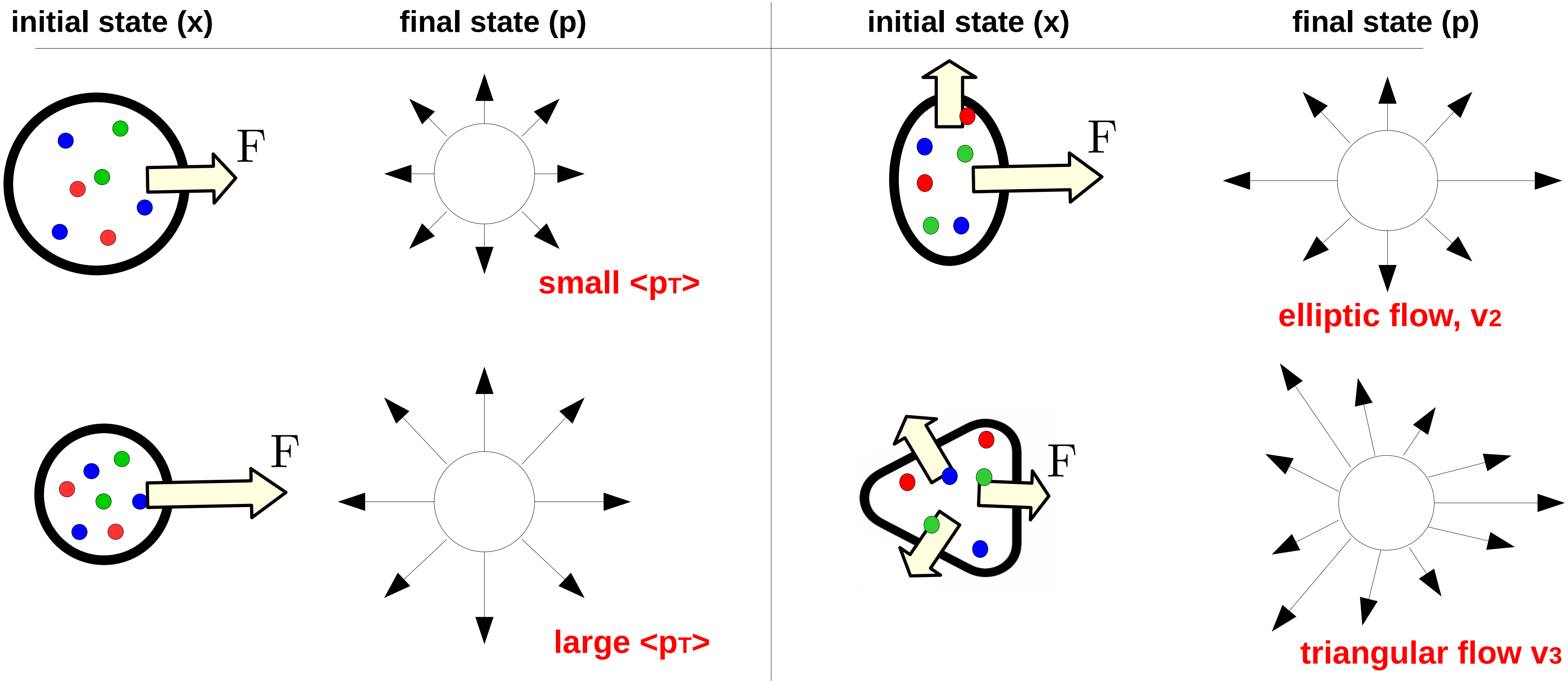
ANISOTROPY OF AZIMUTHAL DISTRIBUTION

[SEMINAR BY J-Y OLLITRAULT, WEEK 1]

Mapping initial-state geometry to final-state observables via pressure-gradient force.

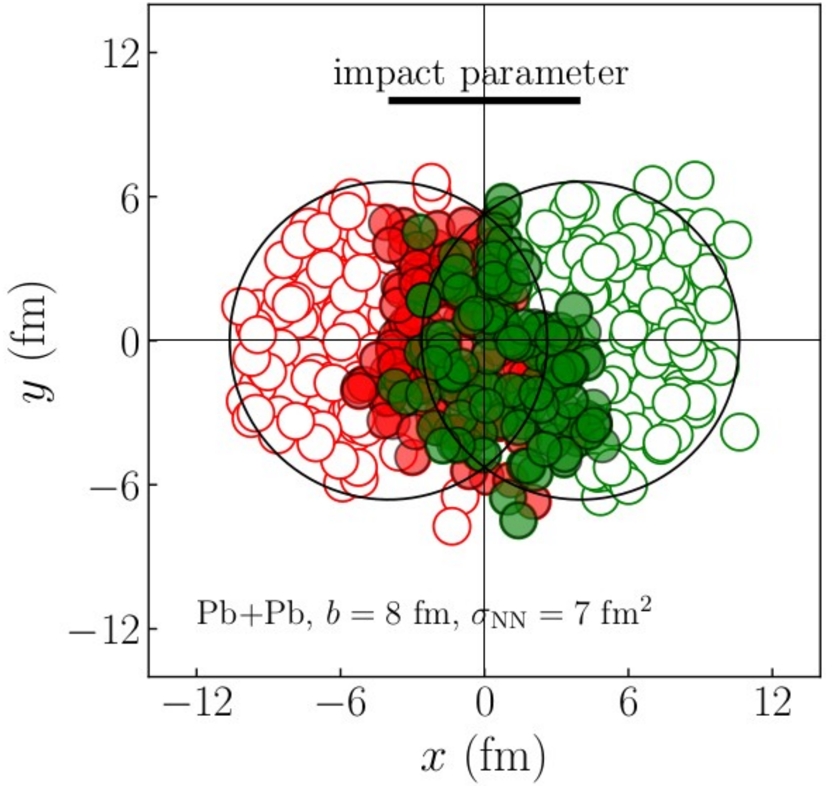
$$F = -\nabla P$$

[SEMINAR BY J-Y OLLITRAULT, WEEK 1]



Shape and size of the QGP can be reconstructed from data!

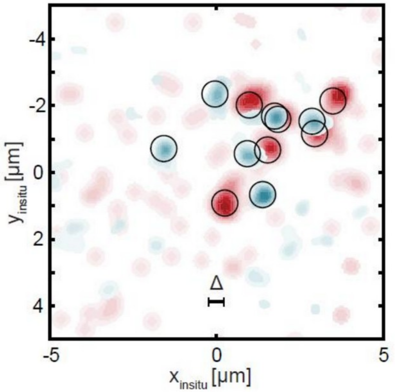
Formation of QGP starts with an input from nuclear structure.



High-energy model

Scattering occurs mainly within nucleons.

"quantum measurement" of the nucleon positions.



[from Sandra Brandstetter (PI Heidelberg), Collapsed wave function of a gas of 10 ^{6}Li atoms]

Origin of nucleon positions: for "spherical" systems like 208Pb, independent sampling in common potential (mean field) is appropriate.

FULL PROBLEM

$$H|\psi\rangle = E|\psi\rangle$$

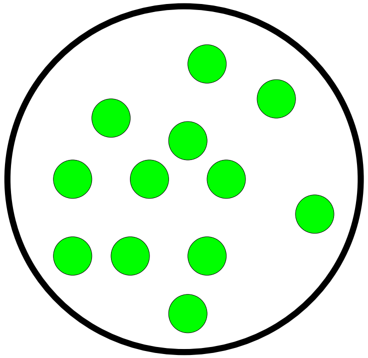
INDEPENDENT PARTICLE PROBLEM

$$h_i|\phi_k^i\rangle = \varepsilon_k^i|\phi_k^i\rangle$$

$$h_i = \frac{p_i^2}{2m} + V(r_i)$$

$$V(r_i) = -\frac{V_0}{1+\exp\left(\frac{r_i - R}{a}\right)}$$

Woods-Saxon



More realistic: Potential generated by effective nucleon-nucleon interaction (Gogny force, Skyrme force, etc.), in "Energy Density Functional" theory.

[SEMINAR BY B BALLY, WEEK 1] [SEMINAR BY A AFANASJEV, WEEK 1]

Goodness of mean field description justifies the Glauber Monte Carlo approach.

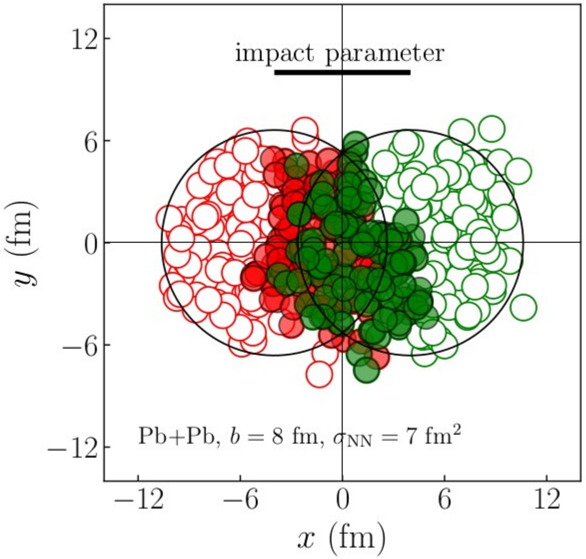
$$\rho(r) = \frac{\rho_0}{1 + \exp\left(\frac{r-R}{a}\right)}$$

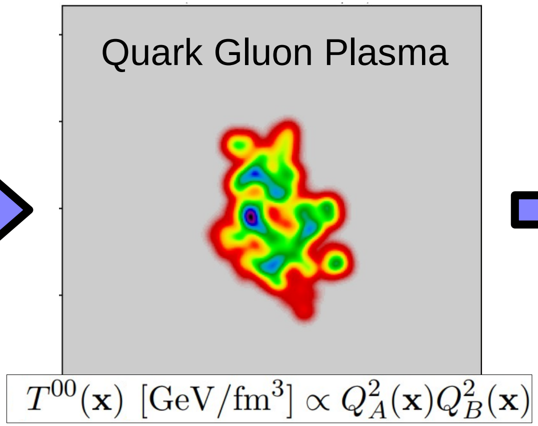
Interaction does not modify the global geometry of the overlap area.

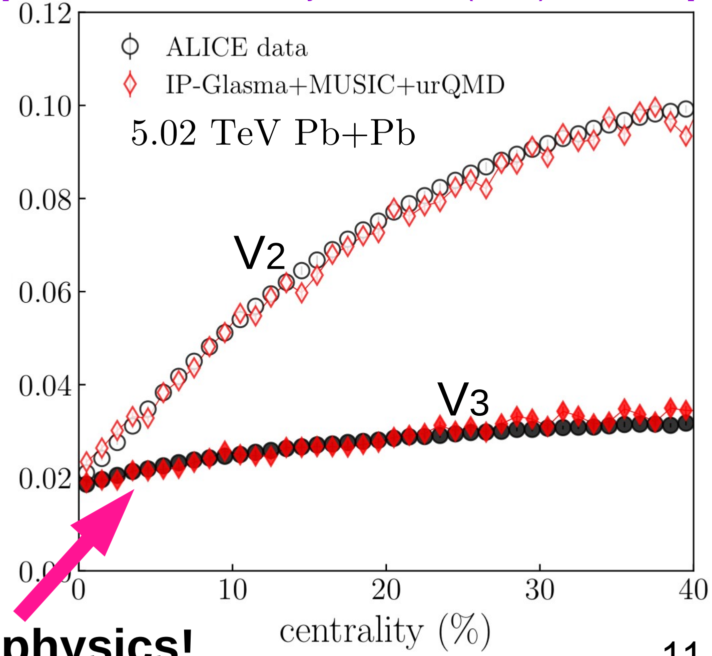
$$\mathcal{T}_{A/B} = \sum_{i \in \text{wounded } A/B} \gamma \exp(-|\mathbf{x} - \mathbf{x}_i|^2 / 2w^2) \longrightarrow \mathrm{d}E/\mathrm{d}y \propto \left(\frac{\mathcal{T}_A^p + \mathcal{T}_B^p}{2} \right)^{q/p}$$

[SEMINAR BY G NIJS, WEEK 1]

[Schenke, Shen, Tribedy, PRC **102** (2020) 4, 044905]





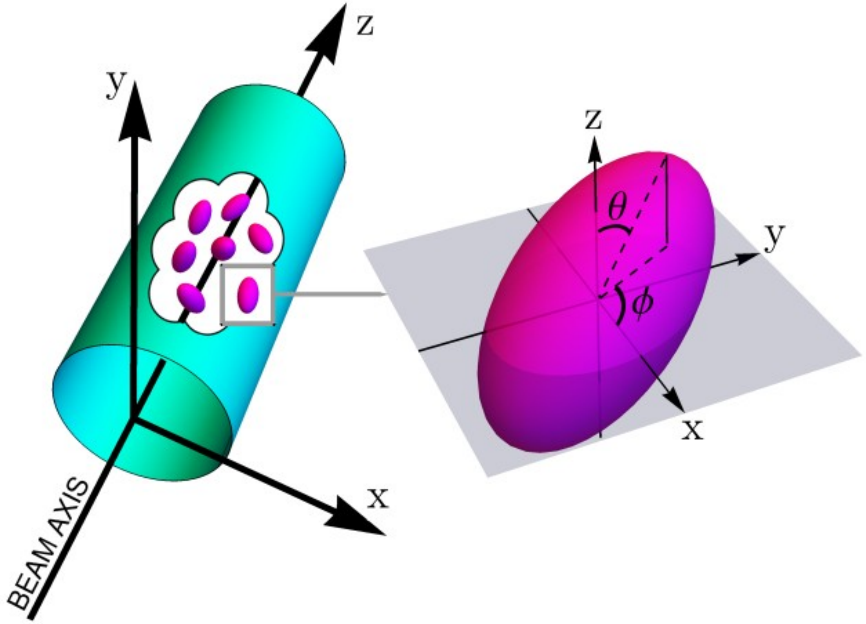


precision physics!

Beyond ^{208}Pb? Heavy-ion collisions require *a priori* knowledge of **all spatial correlations**.

Help from low-energy nuclear physics:
Spatial correlations encapsulated in “intrinsic shapes”.
Instead of A-body correlation functions, use 1-body density with a deformed shape.

[SEMINAR BY W NAZAREWICZ, WEEK 1]



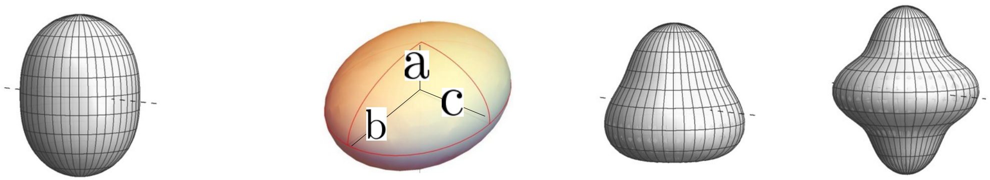
The bag of nucleons is now deformed and with a random orientation.

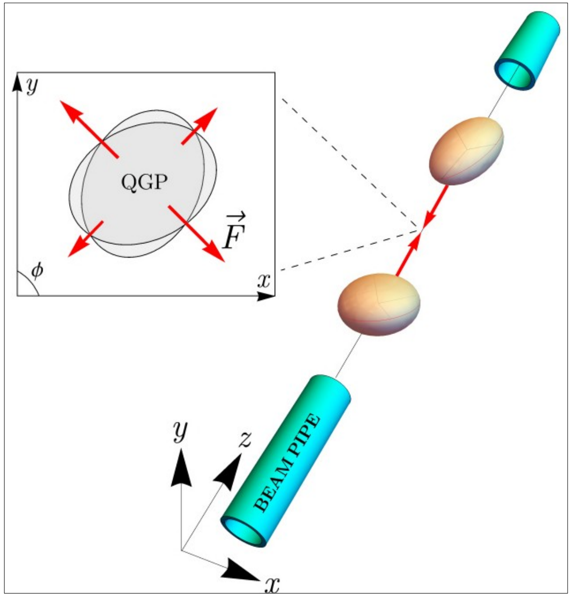
The collision selects one such orientation.

Intrinsic shapes are non-observable for direct measurements, but they leave their fingerprint on virtually all nuclear observables and phenomena

Michael Bender – RBRC Workshop Jan 2022

$$\rho(r,\Theta,\Phi) \propto \frac{1}{1+\exp\left([r-R(\Theta,\Phi)]/a\right)}\ ,\quad R(\Theta,\Phi) = R_0\left[1+\underline{\beta_2}\left(\cos\underline{\gamma} Y_{20}(\Theta)+\sin\gamma Y_{22}(\Theta,\Phi)\right)+\underline{\beta_3}Y_{30}(\Theta)+\underline{\beta_4}Y_{40}(\Theta)\right]$$





Can we consistently understand the signatures of the intrinsic shape at high energy?

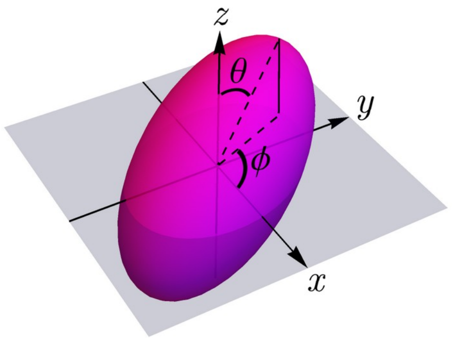
2 – The intrinsic shape of ^{238}U in ultrarelativistic collisions.

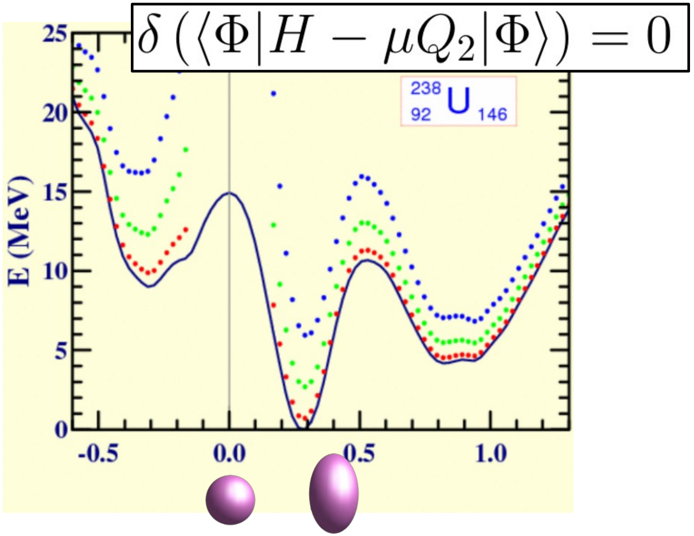
Uranium-238 is the archetype of a well-deformed nucleus. β_2 = 0.29 from B(E2).

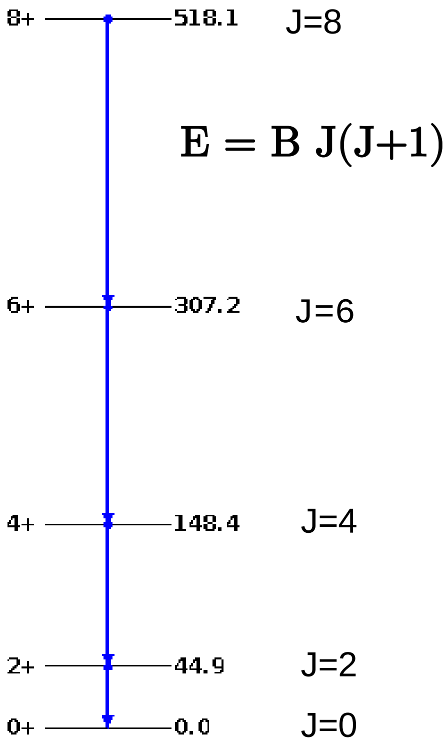
[Pritychenko *et al.*, Atom.Data Nucl.Data Tabl. 107 (2016) 1-139]

Ideal to study shape effects. U+U collisions are available at RHIC.

How far can we go?







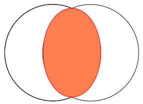
[AMEDEE database, link]

[SEMINAR BY K WIMMER, WEEK 1]

From https://www.nndc.bnl.gov/nudat3/

First evidence of nuclear deformation in high-energy nuclear collisions.

$$\langle v_2^2 \rangle = \sigma^2 + v_{\mathrm{RP}}^2$$

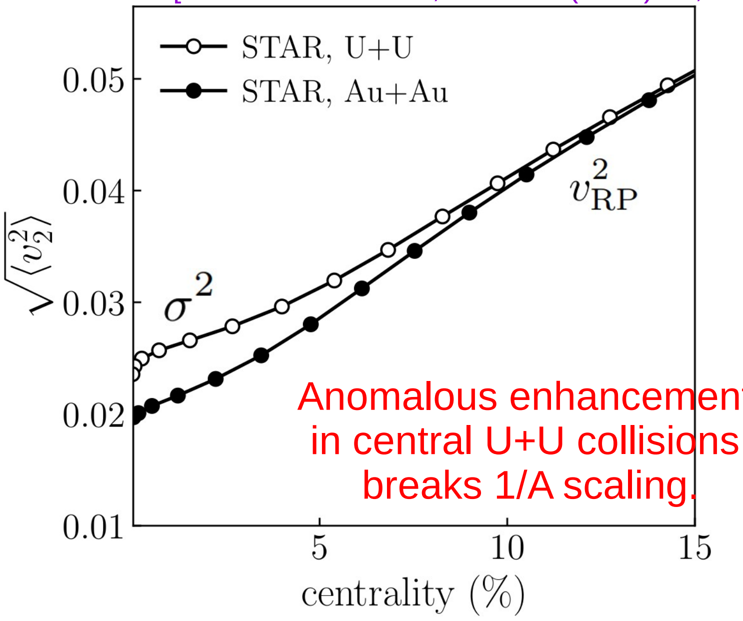


Fluctuation.
Scales like 1/A.

Reaction plane flow.
Dominates in off-central collisions.

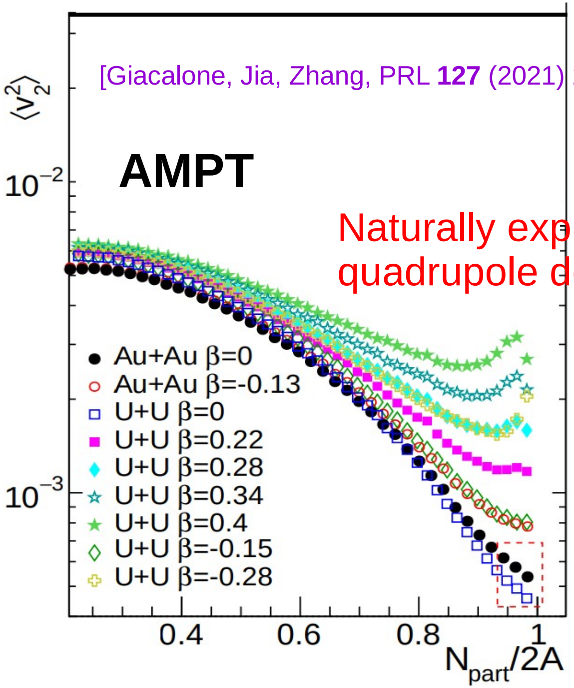
[PHOBOS collaboration, PRL **98** (2007) 242302]

[STAR collaboration, PRL **115** (2015) 22, 222301]



Anomalous enhancement
in central U+U collisions
breaks 1/A scaling.

[Giacalone, Jia, Zhang, PRL **127** (2021) 24, 242301]



Naturally explained by
quadrupole deformation.

How is elliptic flow enhanced? Simple model for collisions at b=0.

[Giacalone, Mehrabpour, in preparation]
[see also Jia, PRC **105** (2022) 1, 014905]

Gaussian nuclei: $$N_{A,B}(x,y,z) = e^{\frac{-(x^2+y^2+z^2)}{R^2_{A,B}}}\left(1+\beta_{A,B}\left[\cos\gamma Y_2^0(x,y,z) + \frac{\sin\gamma}{\sqrt{2}} Re\{Y_2^2(x,y,z)\}\right]\right)$$

Thickness: $$T_{A,B}(r,\phi,\Omega_{A,B}) = \int dz\, N_{A,B}\left(R_{zxz}(\Omega_{A,B})\vec{X}\right) \longrightarrow T_{A,B}(r,\phi) = \mathcal{F}_{A,B}(r) + \beta_{A,B}\,\mathcal{G}_{A,B}(r,\phi)$$

Euler angles

Eccentricity: $$\epsilon(r,\phi,\Omega_A,\Omega_B) \propto \left(T_A(r,\phi,\Omega_A)T_B(r,\phi,\Omega_B)\right)^q \longrightarrow V_n \propto \mathcal{E}_n = -\frac{\int rdrd\phi\; r^n e^{in\phi}\epsilon(r,\phi,\Omega_A,\Omega_B)}{\int rdrd\phi\; r^n \epsilon(r,\phi,\Omega_A,\Omega_B)}$$

Mean squared anisotropy in many events (average over Euler angles and $\beta_A=\beta_B$):

$$\langle v_2^2\rangle \propto \langle \mathcal{E}_2\mathcal{E}_2^*\rangle = c(R_A,R_B,q)\beta_2^2$$

positive coefficient

Mean squared ellipticity receives a correction proportional to β^2.

Very robust relation, works even away from central collisions.

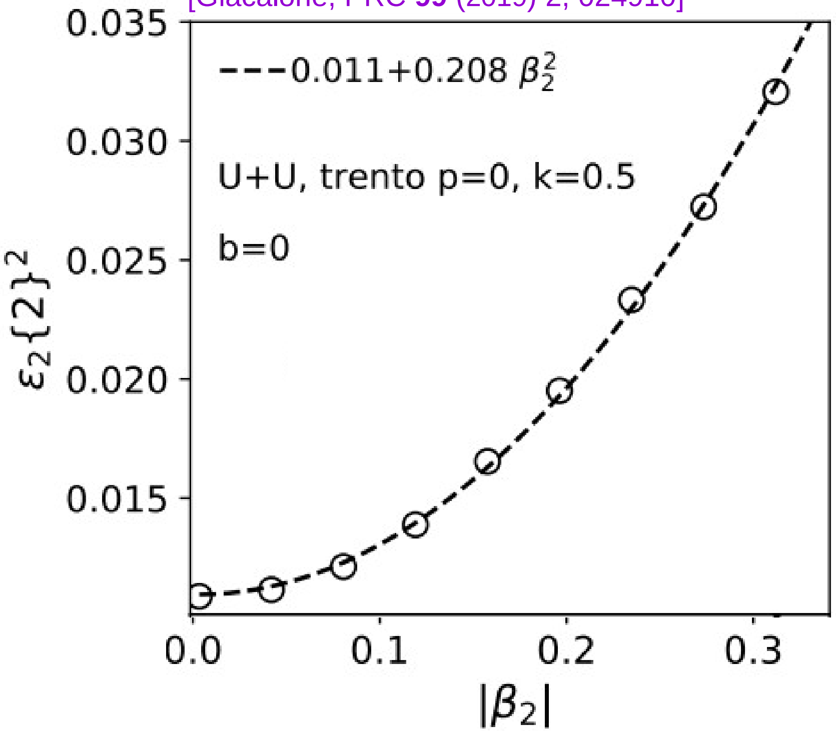
$$\langle v_2^2 \rangle = \sigma_0^2 + c\beta_2^2 + v_{\rm RP}^2$$

Scales like 1/A

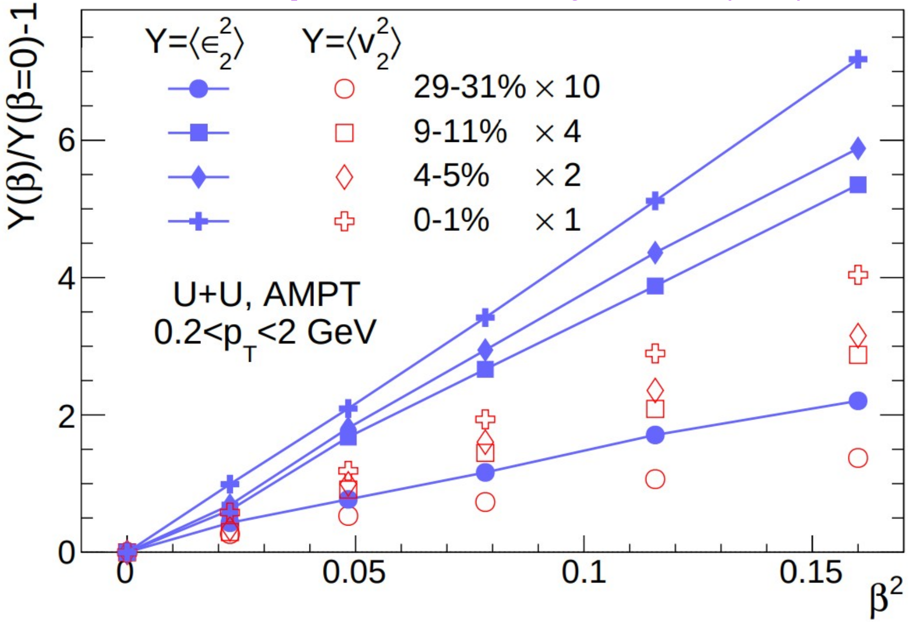
Positive number (depends little on A)

Reaction plane flow.

[Giacalone, PRC **99** (2019) 2, 024910]



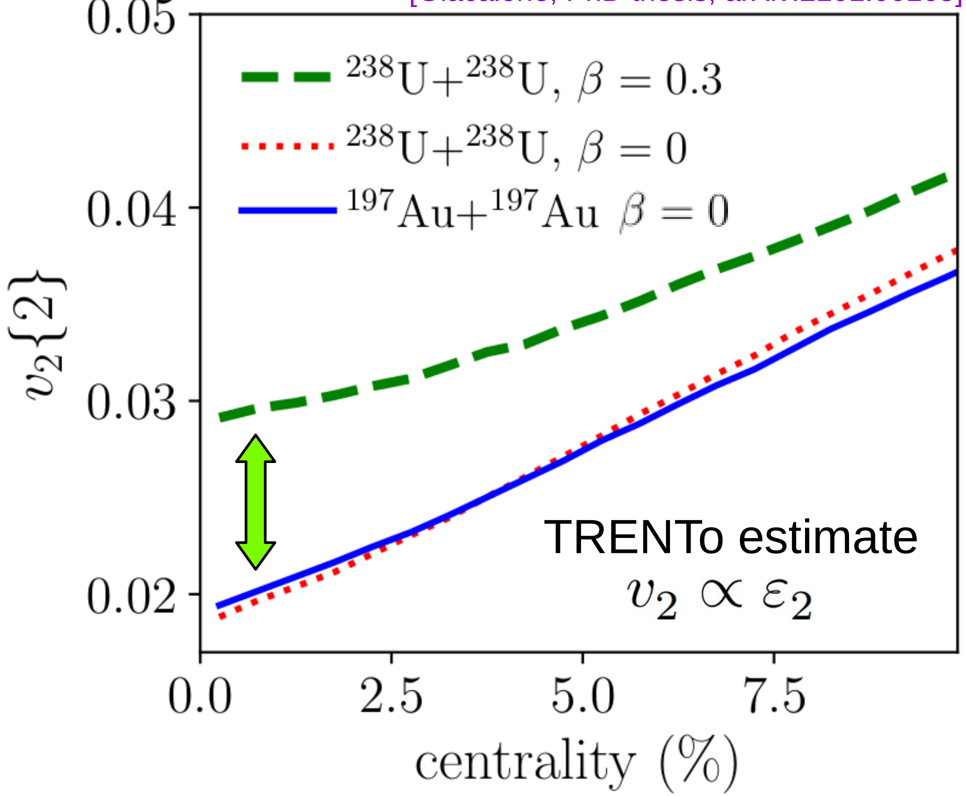
[Giacalone, Jia, Zhang, PRL **127** (2021) 24, 242301]



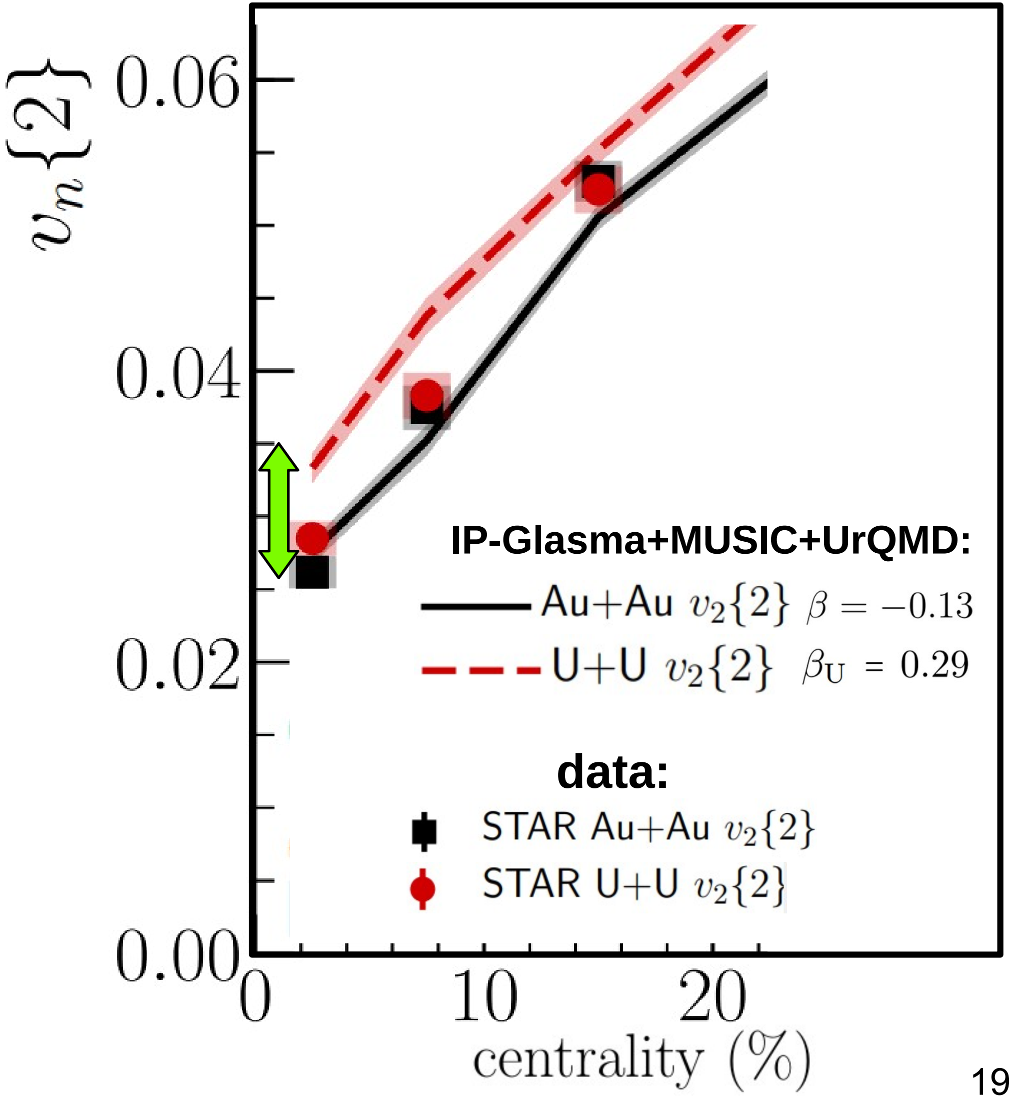
Do we understand RHIC data?

Too large v_2 in U+U.

[Giacalone, PhD thesis, arXiv:2101.00168]



[Schenke, Shen, Tribedy, PRC **102** (2020) 4, 044905]



Improper implementation of deformation in heavy-ion literature. Parameters of Woods-Saxon do not correspond to measured multipole moments.

[SEMINAR BY W NAZAREWICZ, WEEK 1]

SHAPE IN INTRINSIC BODY FRAME

$$\rho^{\mathrm{WS}}(\mathbf{r}) = \frac{\rho_0}{1+\exp\left([r - R(\theta,\phi)]/a\right)}$$

$$R(\theta,\phi) = R_d\left[1 + \sum_{\ell=2}^{\ell_{\max}} \sum_{m=-\ell}^{\ell} \beta_{\ell m}^{\mathrm{WS}} Y_{\ell m}(\theta,\phi)\right]$$

not the same thing!

MEASURED MULTIPOLE MOMENT

$$\beta_\ell = \frac{4\pi}{(2\ell+1)ZR_0^\ell}\sqrt{\frac{B(E\ell)\uparrow}{e^2}}$$

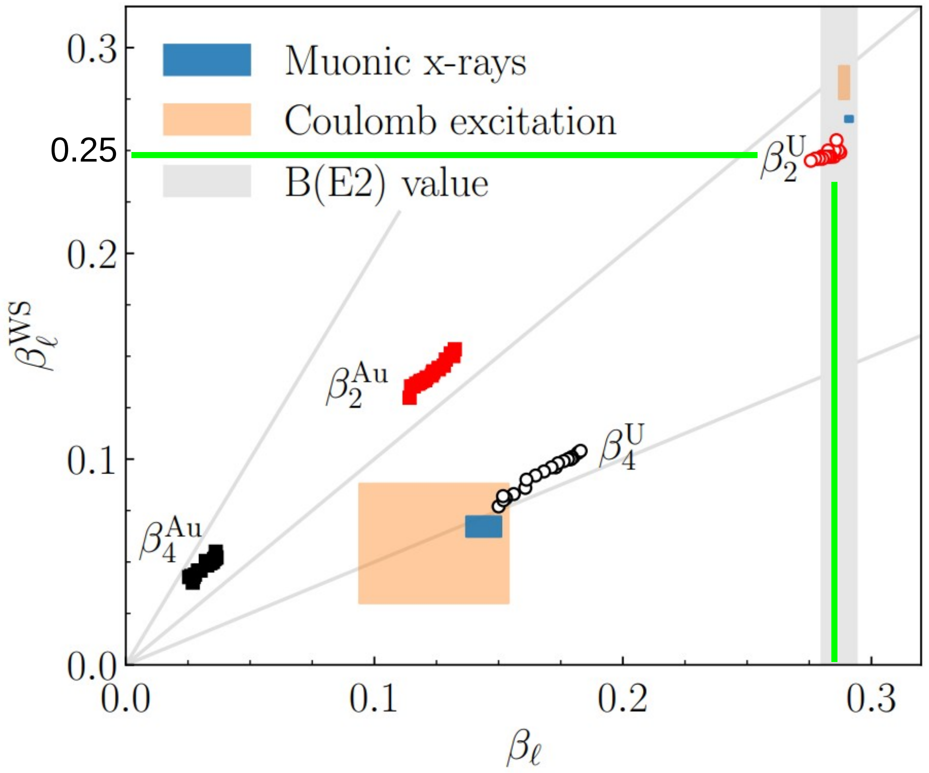
[Ryssens, Giacalone, Schenke, Shen, in preparation]

IMPACT OF QUADRUPOLE-HEXADECAPOLE COUPLING

$$\beta_2 = \frac{R_d^2}{R_0^2}\left[\beta_{20}^{\mathrm{WS}} + \frac{2}{7}\sqrt{\frac{5}{\pi}}(\beta_{20}^{\mathrm{WS}})^2 + \frac{12}{7\sqrt{\pi}}\beta_{20}^{\mathrm{WS}}\beta_{40}^{\mathrm{WS}}\right]$$

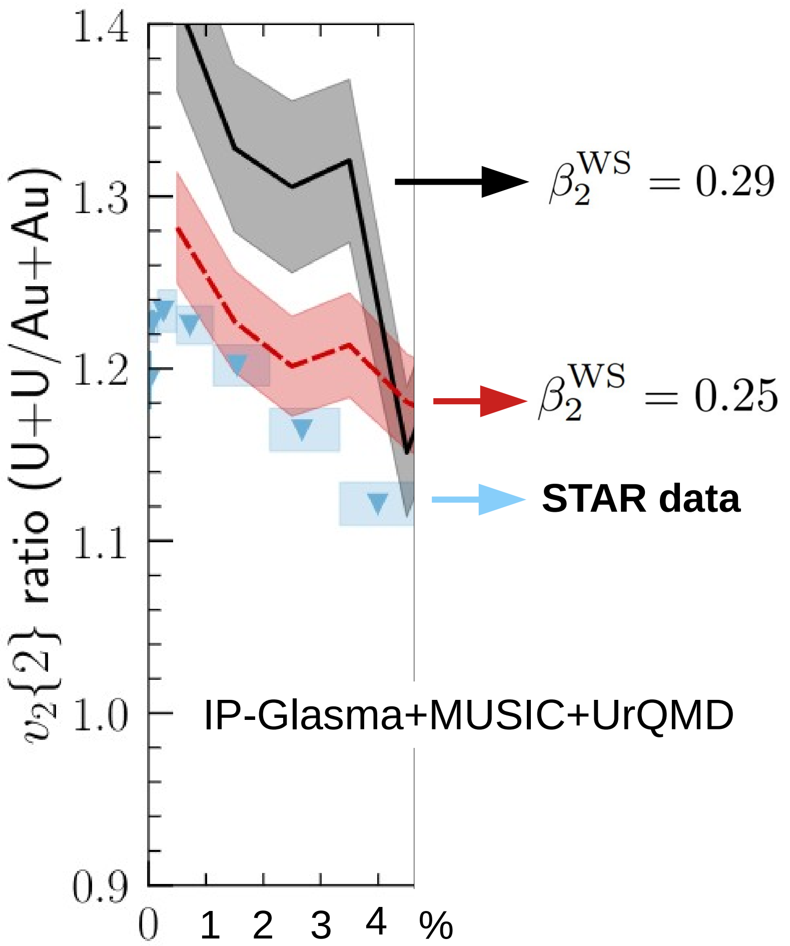
Uranium-238 has both a large β_2 and a sizable β_4. Interplay plays a major role.

Fitting Woods-Saxon profiles to one-body HFB density with 21 different Skyrme functionals.



We conclude: $\beta_{2,U}^{WS} \in [0.24, 0.25]$

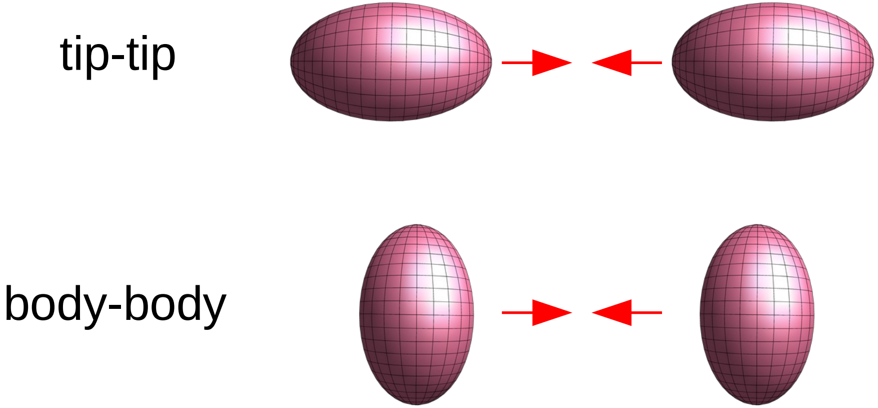
Impact of hexadecapole deformation on high-energy data!



[Ryssens, Giacalone, Schenke, Shen, in preparation]

MORE EXCLUSIVE OBSERVABLES

CAN WE DISCERN THE DIFFERENT ORIENTATIONS?



Old idea: Multiplicity should be higher in tip-tip collisions (larger N_{coll}). Not supported by data.

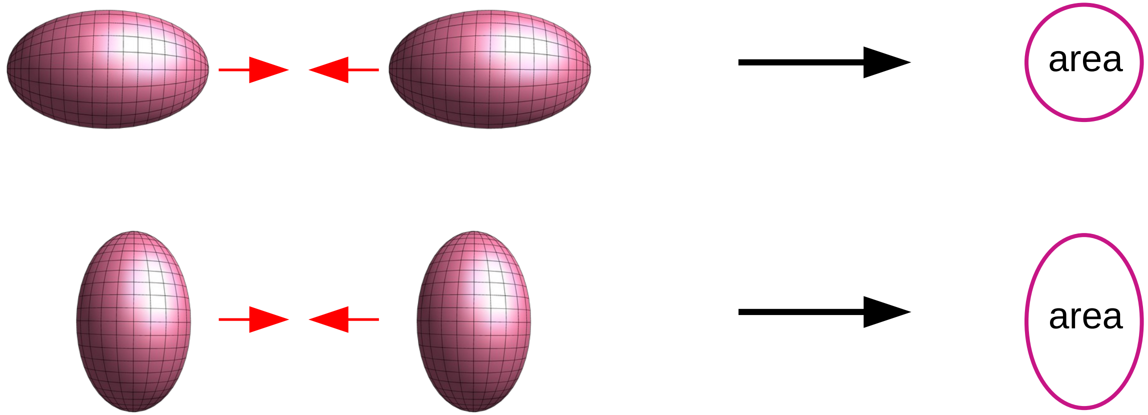
[see e.g. Goldschmidt *et al.*, PRC **92** (2015) 4, 044903]

HOW TO DO THAT? SHAPE-SIZE CORRELATION.

[Giacalone, PRL **124** (2020) 20, 202301]

tip-tip

body-body



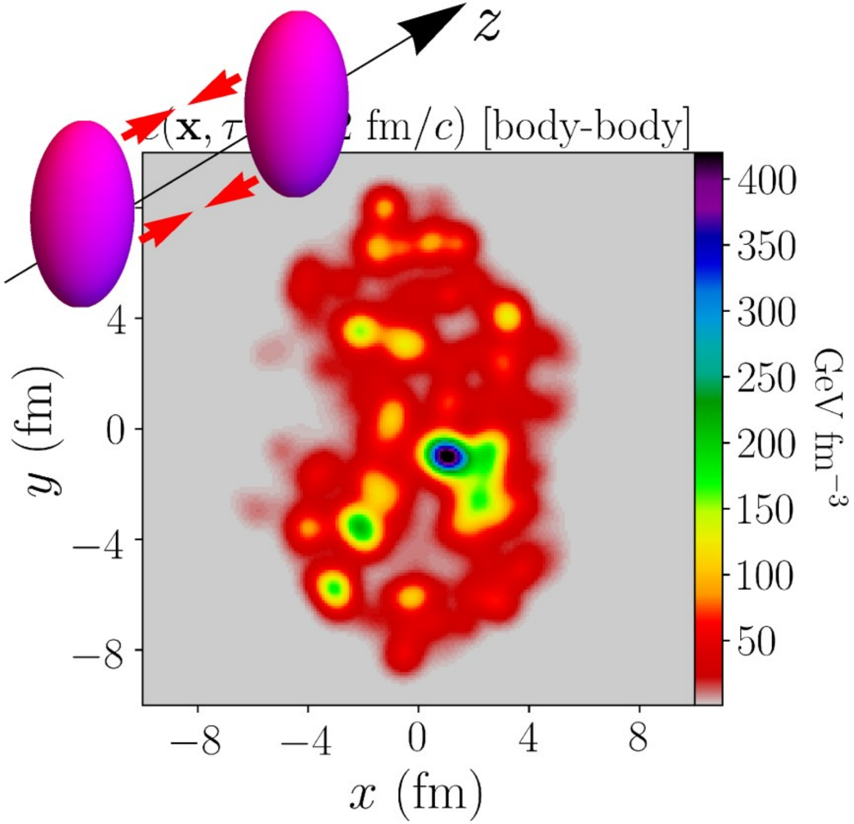
small v_2
small area
large $\langle p_t \rangle$

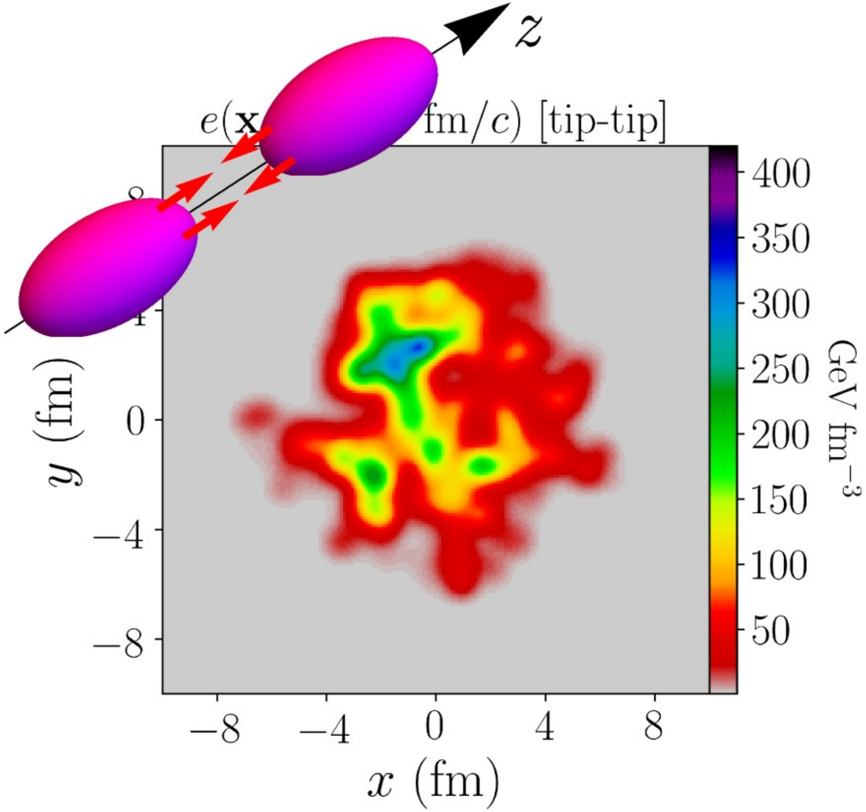
large v_2
large area
small $\langle p_t \rangle$

CENTRAL COLLISIONS OF (PROLATE) DEFORMED IONS

The ellipticity of the quark-gluon plasma is positively correlated with its area.

Deformation yields a negative correlation between v_2 and the $\langle p_t \rangle$.



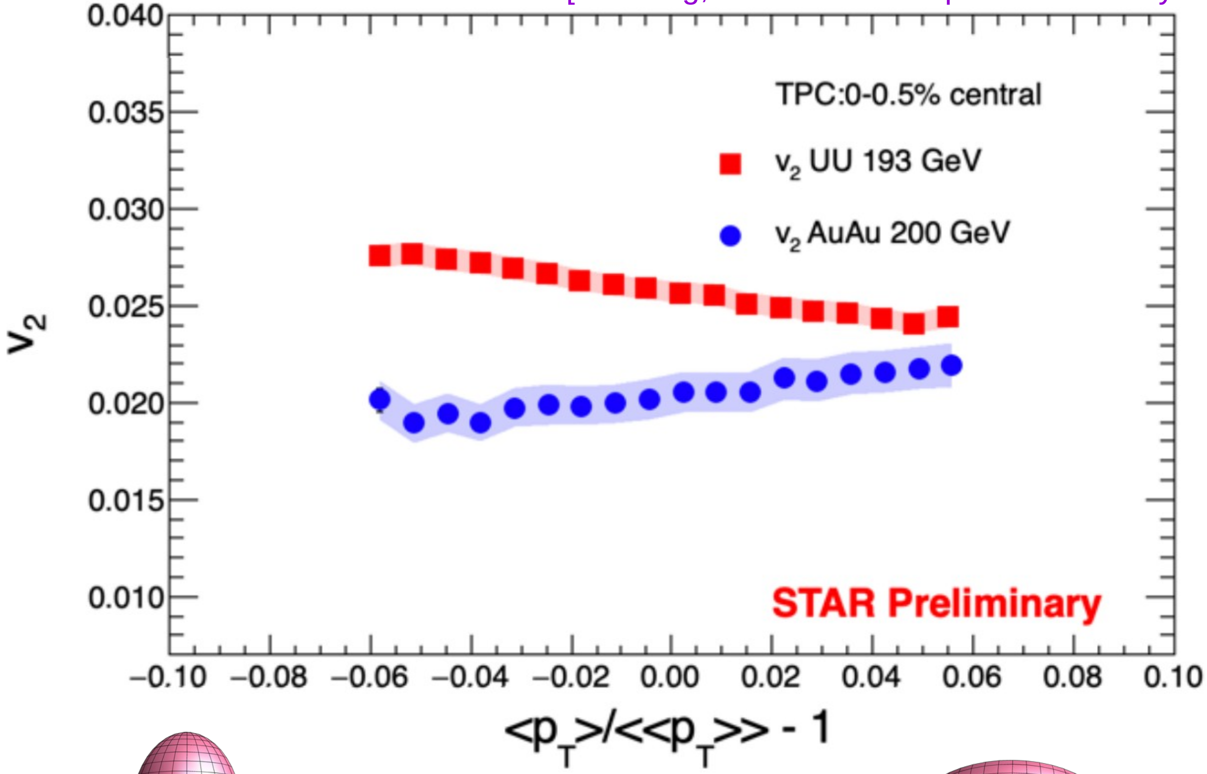


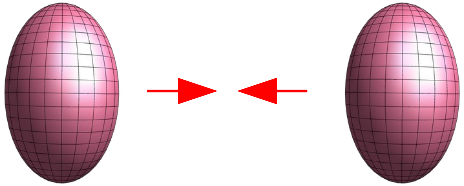
$\langle p_t \rangle$: 0.578 GeV	$\ll$	$\langle p_t \rangle$: 0.651 GeV
v_2: 0.083	$\gg$	v_2: 0.027

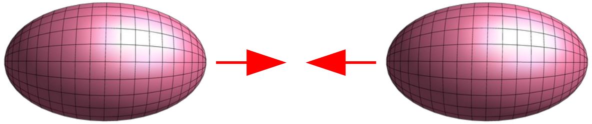
[Giacalone, PRC **102** (2020) 2, 024901]

SEEING BODY-BODY COLLISIONS "BY EYE"

[S Huang, Winter Workshop on Nuclear Dynamics 2020]







Interplay of ellipticity and mean transverse momentum. Simple model for collisions at b=0.

Gaussian nuclei:

$$N_{A,B}(x,y,z) = e^{\frac{-(x^2+y^2+z^2)}{R^2_{A,B}}} \left(1 + \beta_{A,B}\left[\cos\gamma Y_2^0(x,y,z) + \frac{\sin\gamma}{\sqrt{2}} Re\{Y_2^2(x,y,z)\}\right]\right)$$

Thickness:

$$T_{A,B}(r,\phi,\Omega_{A,B}) = \int dz\, N_{A,B}\left(R_{zxz}(\Omega_{A,B})\vec{X}\right) \longrightarrow T_{A,B}(r,\phi) = \mathcal{F}_{A,B}(r) + \beta_{A,B}\, \mathcal{G}_{A,B}(r,\phi)$$

Euler angles

Eccentricity and total energy:

$$\epsilon(r,\phi,\Omega_A,\Omega_B) \propto \left(T_A(r,\phi,\Omega_A)T_B(r,\phi,\Omega_B)\right)^q \longrightarrow V_n \propto \mathcal{E}_n = -\frac{\int r dr d\phi\, r^n e^{in\phi}\epsilon(r,\phi,\Omega_A,\Omega_B)}{\int r dr d\phi\, r^n \epsilon(r,\phi,\Omega_A,\Omega_B)}$$

$$[p_t] \propto E = \int r dr d\phi\, \epsilon(r,\phi,\Omega_A,\Omega_B)$$

Covariance of two quantities (average over Euler angles):

<v_2^2> <p_T>

$$\langle \mathcal{E}_2\mathcal{E}_2^* E\rangle - \langle \mathcal{E}_2\mathcal{E}_2^*\rangle\langle E\rangle = -c(R_A,R_B,q)\beta_2^3\cos(3\gamma)$$

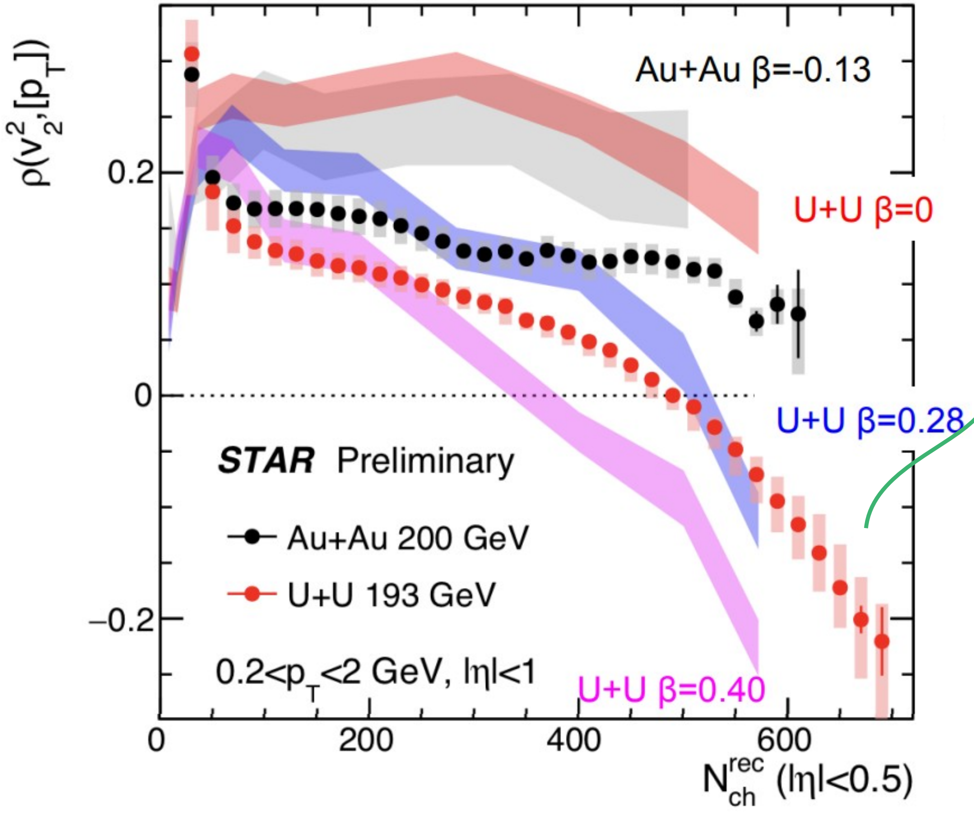
positive coefficient

[Giacalone, Mehrabpour, in preparation]
[see also Jia, PRC **105** (2022) 4, 044905]

Covariance measured via Bozek's correlator:

[Bozek, PRC **93** (2016) 4, 044908]

$$\rho(v_2^2, \langle p_t \rangle) = \frac{\langle \delta v_2^2 \delta \langle p_t \rangle \rangle}{\sqrt{\langle (\delta v_2^2)^2 \rangle \langle (\delta \langle p_t \rangle)^2 \rangle}}$$



$\langle v_2^2 \rangle$ $\langle p_T \rangle$

$$\langle \mathcal{E}_2 \mathcal{E}_2^* E \rangle - \langle \mathcal{E}_2 \mathcal{E}_2^* \rangle \langle E \rangle = -c(R_A, R_B, q)\beta_2^3 \cos(3\gamma)$$

negative sign

positive coefficient

Hydro: IP-Glasma+MUSIC+UrQMD.
Effect of deformation is clear.

Bad description of data.
Bayesian analysis?

Wrapping up: what have we learned from $^{238}U+^{238}U$ collisions?

1. Elliptic flow is enhanced by fluctuations in nuclear orientations.

$$\langle v_2^2 \rangle = \sigma_0^2 + c\beta_2^2 + v_{\mathrm{RP}}^2$$

2. In ^{238}U, interplay of quadrupole and hexadecapole deformations is crucial.

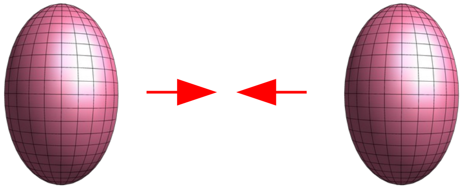
$$\beta_{20} = \frac{R_d^2}{R_0^2}\left[\beta_{20}^{\mathrm{WS}} + \frac{2}{7}\sqrt{\frac{5}{\pi}}(\beta_{20}^{\mathrm{WS}})^2 + \frac{12}{7\sqrt{\pi}}\beta_{20}^{\mathrm{WS}}\beta_{40}^{\mathrm{WS}}\right]$$

Optimal input from nuclear structure:

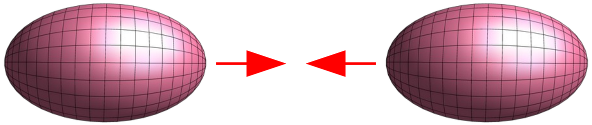
- Nuclear structure input: $\langle\Phi(\bar{\beta},\bar{\gamma})|a_r^\dagger a_r|\Phi(\bar{\beta},\bar{\gamma})\rangle \rightarrow$ WS fit

Bally *et al.*, PRL 128, 082301 (2022) **[SEMINAR BY B BALLY, WEEK 1]**

3. We can use $<p_T>$ in conjunction with v_2 to discern body-body and tip-tip collisions.



small $<p_T>$

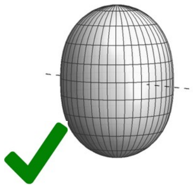


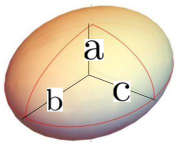
large $<p_T>$

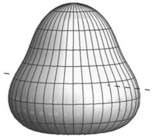
3 – Prospects.

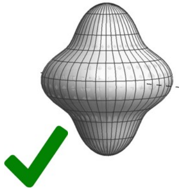
More features of the intrinsic shape?

$$\rho(r,\Theta,\Phi) \propto \frac{1}{1+\exp\left(\left[r-R(\Theta,\Phi)\right]/a\right)}\ , \quad R(\Theta,\Phi) = R_0\left[1+\beta_2\left(\cos\gamma Y_{20}(\Theta)+\sin\gamma Y_{22}(\Theta,\Phi)\right)+\beta_3 Y_{30}(\Theta)+\beta_4 Y_{40}(\Theta)\right]$$









?

?

?

BEYOND THE QUADRUPOLE

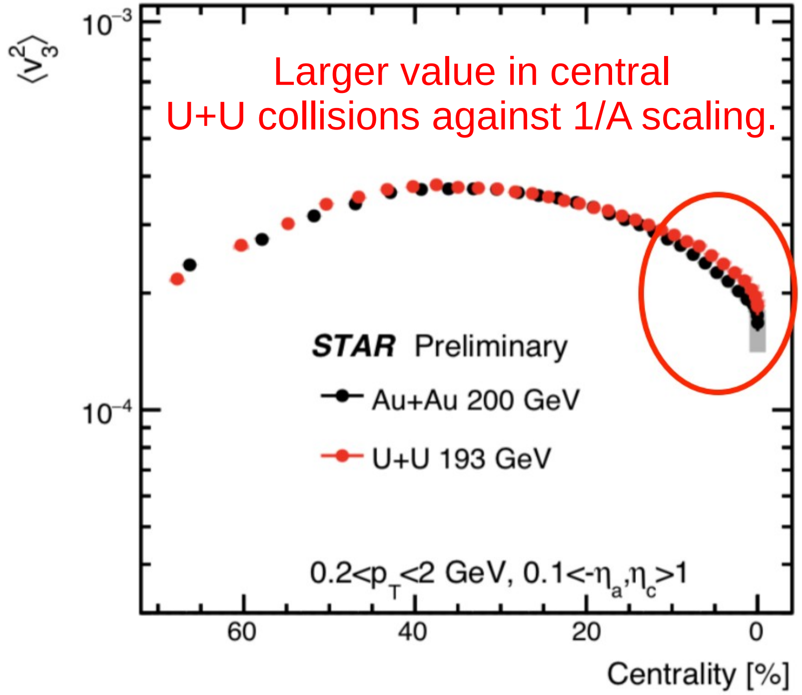
[Alver, Roland, PRC **81** (2010) 054905]

$$\langle v_3^2 \rangle = \sigma^2$$

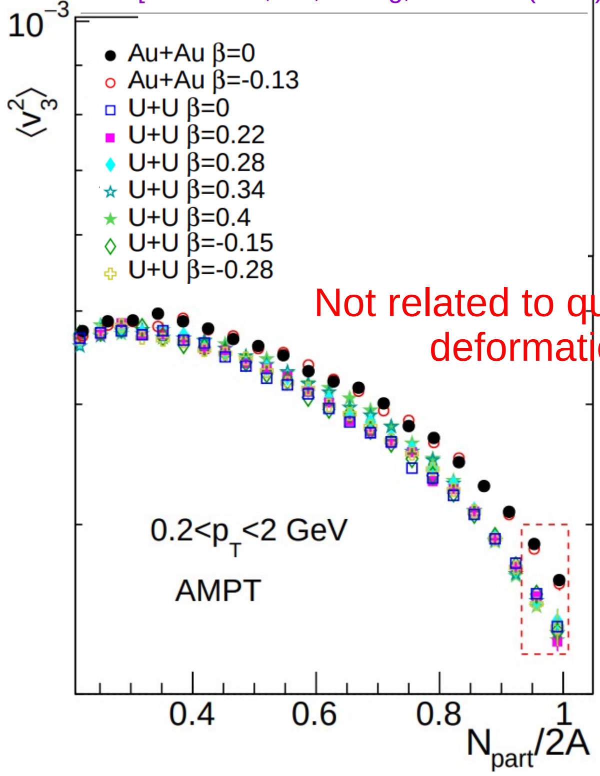
Scales like 1/A

[J Jia, Initial Stages 2021]

Larger value in central U+U collisions against 1/A scaling.



[Giacalone, Jia, Zhang, PRL **127** (2021) 24, 242301]



Not related to quadrupole deformation.

BEYOND THE MEAN FIELD? OCTUPOLE DEFORMATION

EDF CALCULATIONS WITH THE GOGNY FUNCTIONAL

[SEMINAR BY T RODRIGUEZ, WEEK 2]

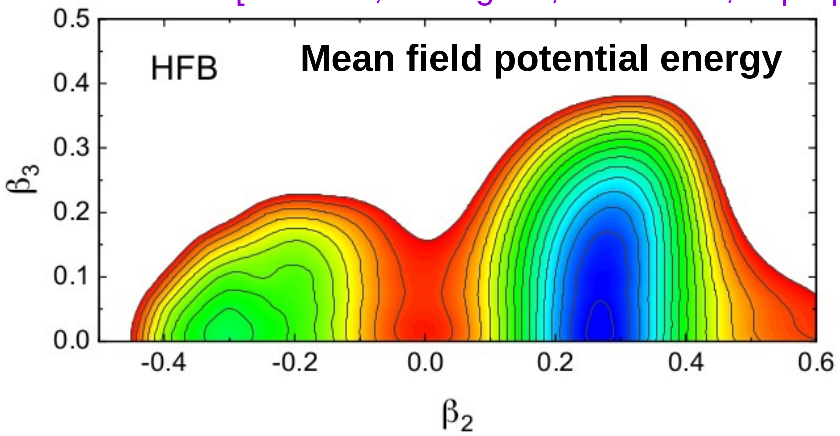
Nuclear wave functions: Generator Coordinate Method (GCM) ansatz

$$|\Psi_\sigma^{JMNZ\pi}\rangle = \sum_{qK} f_{\sigma;qK}^{JMNZ\pi} P_{MK}^J P^N P^Z P^\pi |\Phi(q)\rangle$$

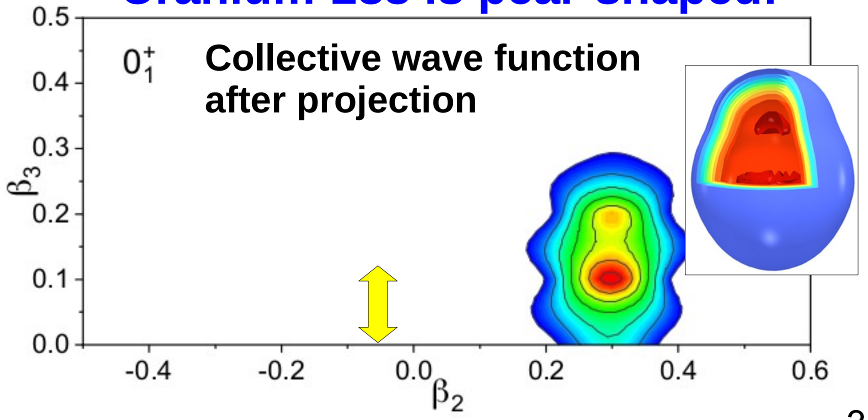
$\Gamma \equiv (JMNZ\pi)$

linear combination — coefficients of the linear combination — "basis" states

[Robledo, Rodriguez, Giacalone, in preparation]



Uranium-238 is pear-shaped!

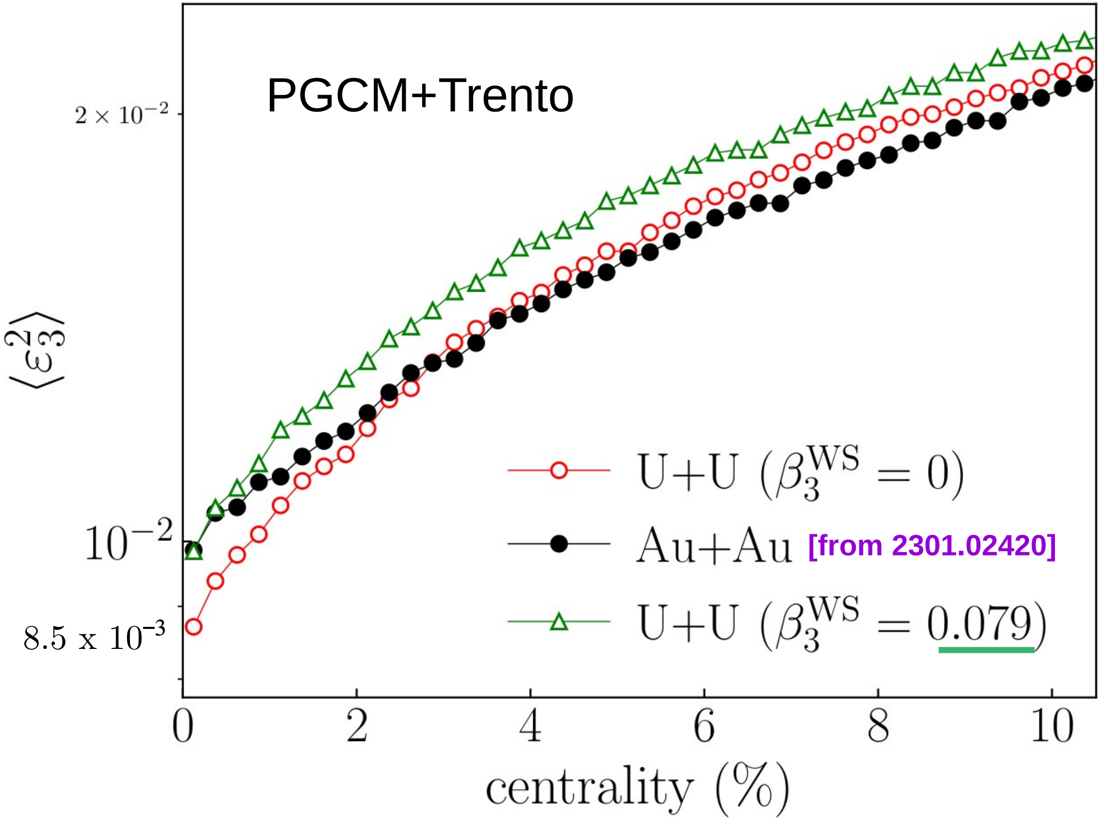


ENHANCEMENT OF TRIANGULAR FLOW?

$$\langle v_3^2 \rangle = \sigma^2 + c\beta_3^2$$

Scales like 1/A

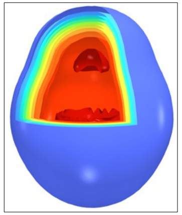
[Robledo, Rodriguez, Giacalone, in preparation]



From this model setup and assuming:

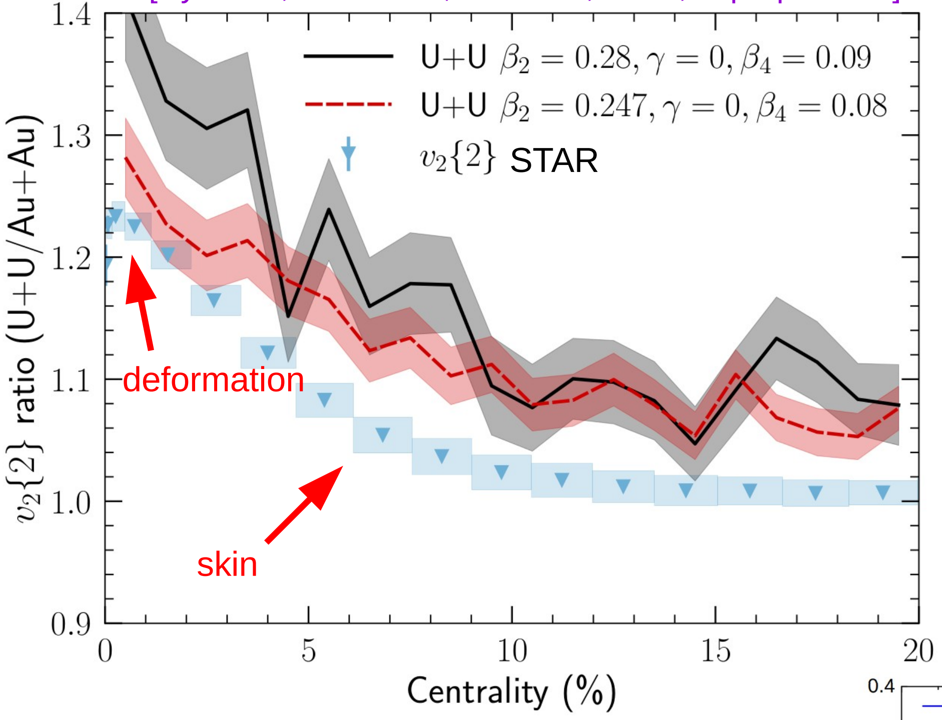
$$\frac{\langle v_3^2 \rangle}{\langle \varepsilon_3^2 \rangle}_{\mathrm{Au+Au}} = \frac{\langle v_3^2 \rangle}{\langle \varepsilon_3^2 \rangle}_{\mathrm{U+U}}$$

RHIC has observed pear-shaped ^{238}U!

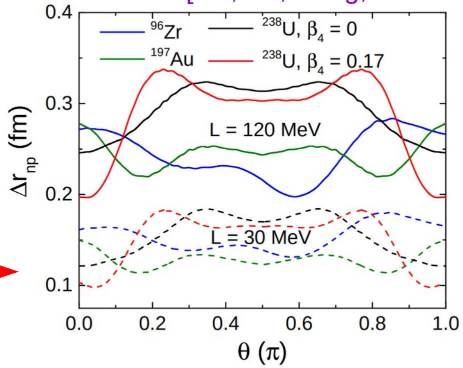


Off-central collisions: Centrality dependence of v_2 in U+U is not captured.

[Ryssens, Giacalone, Schenke, Shen, in preparation]



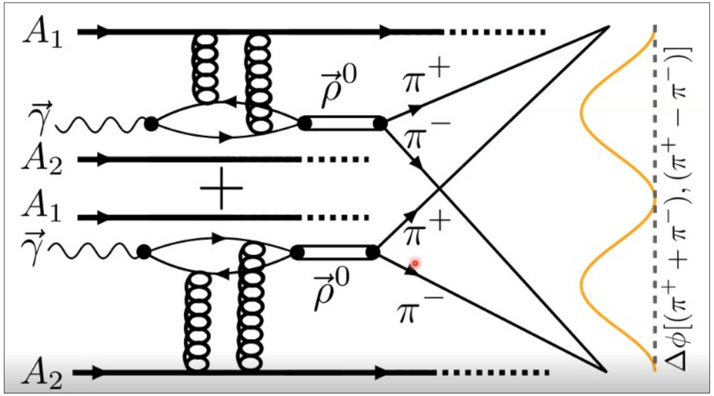
[Liu, Xu, Peng, arXiv:2301:08251]
[Liu, Xu, Peng, PLB **838** (2023) 137701]



Issue with the Ansatz for the energy deposition?

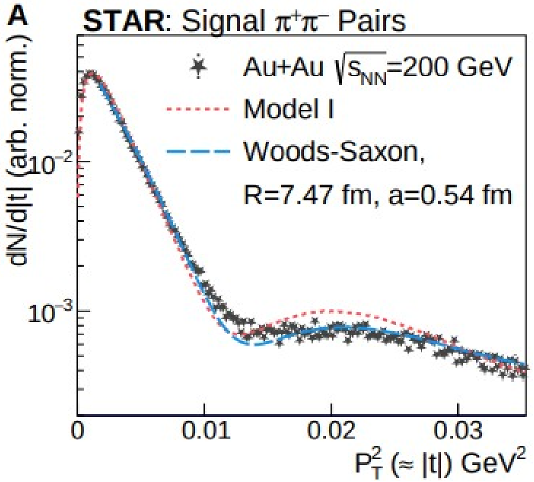
Problem with ^{238}U skin? Surface polarization?

INDEPENDENT PROBES (AND ISSUES!) OF THE SKIN



$$f(t) = A_c|\mathcal{F}[\rho_A(r;R,a)](|t|)|^2 + \frac{A_i/Q_0^2}{(1+|t|/Q_0^2)^2}$$

FT of gluon density
(Woods-Saxon)



[STAR Collaboration, Sci.Adv. 9 (2023) 1, eabq3903]

[SEMINAR BY D BRANDENBURG, WEEK 5]

Measured skin of gold-197:

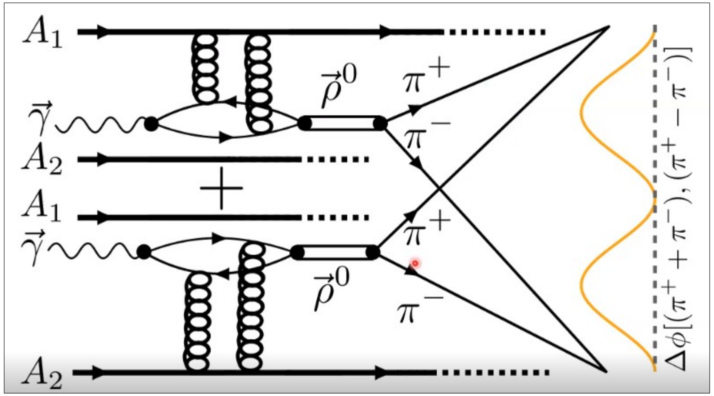
$$\Delta r_{np}[\mathrm{STAR}] = 0.17 \pm 0.03\ (\mathrm{stat.}) \pm 0.08\ (\mathrm{syst.})\ \mathrm{fm}$$

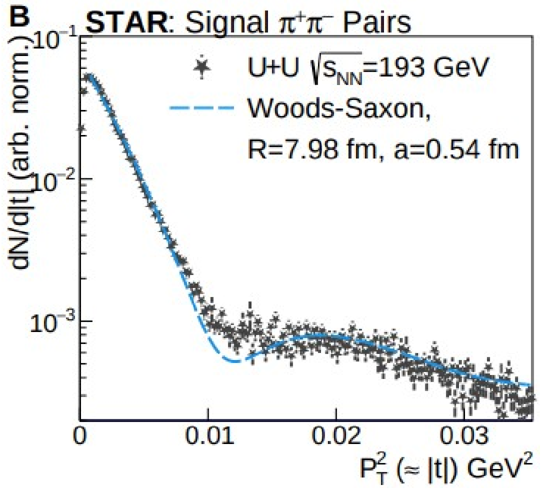
Fully consistent with state-of-the-art density functional results:

$$\Delta r_{np}[\mathrm{MREDF}] = 0.17\ \mathrm{fm}$$

[Bally, Giacalone, Bender, arXiv:2301.02420]

INDEPENDENT PROBES (AND ISSUES!) OF THE SKIN





$$f(t) = A_c |\mathcal{F}[\rho_A(r; R, a)](|t|)|^2 + \frac{A_i/Q_0^2}{(1+|t|/Q_0^2)^2}$$

FT of gluon density
(Woods-Saxon)

[STAR Collaboration, Sci.Adv. 9 (2023) 1, eabq3903]

[SEMINAR BY D BRANDENBURG, WEEK 5]

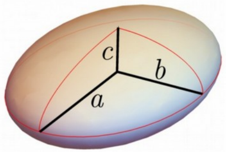
Measured skin of uranium-238:

$$\Delta r_{np}\ [\text{STAR}] = 0.44 \pm 0.05\ (\text{stat.}) \pm 0.08\ (\text{syst.})$$

Inconsistent with low-energy physics.
Why?

MORE THOUGHTS …

Triaxiality

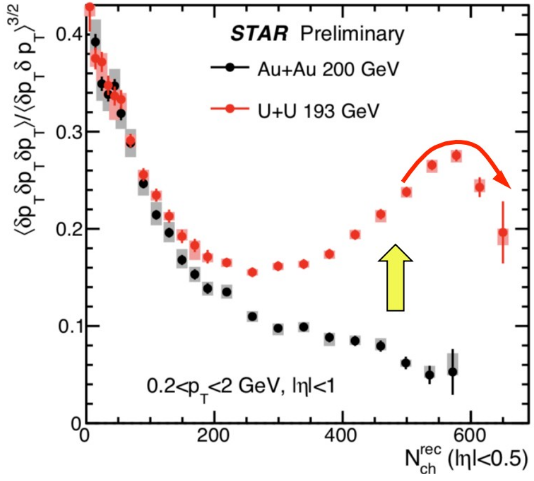


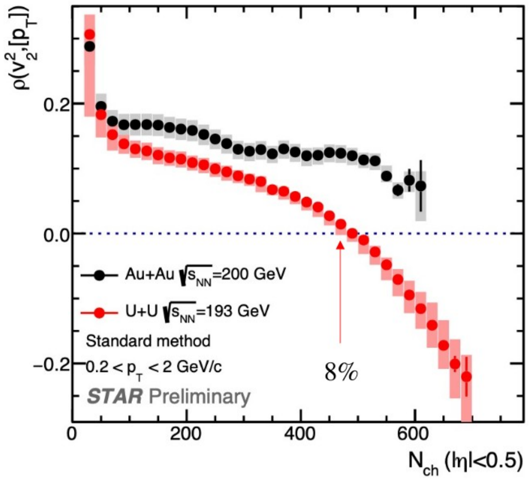
Beyond mean field calculations predict $\gamma \approx$ 5-10°.

[Bertsch *et al.*, PRL **99** (2007) 032502]
[Delaroche *et al.*, PRC **81** (2010) 014303]

Visible?

Observables sensitive to $(\beta_2)^3 \cos(3\gamma)$.



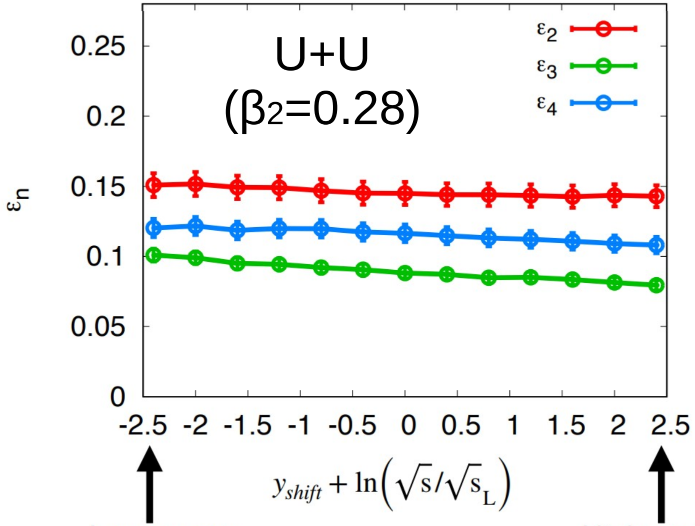


Same analysis at different energy?

- Nuclear deformation with full 3+1D dynamics, @sqrt(s)~1 GeV. Role of shapes has to be addressed.

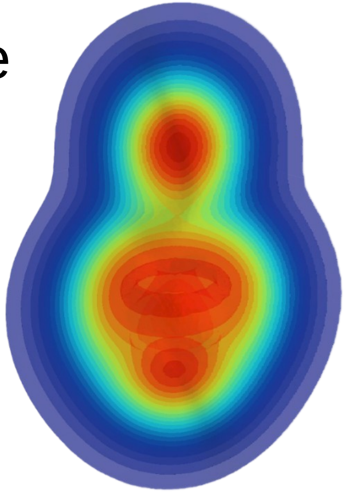
- Impact of small-x evolution?

[SEMINAR BY P SINGH, WEEK 2]

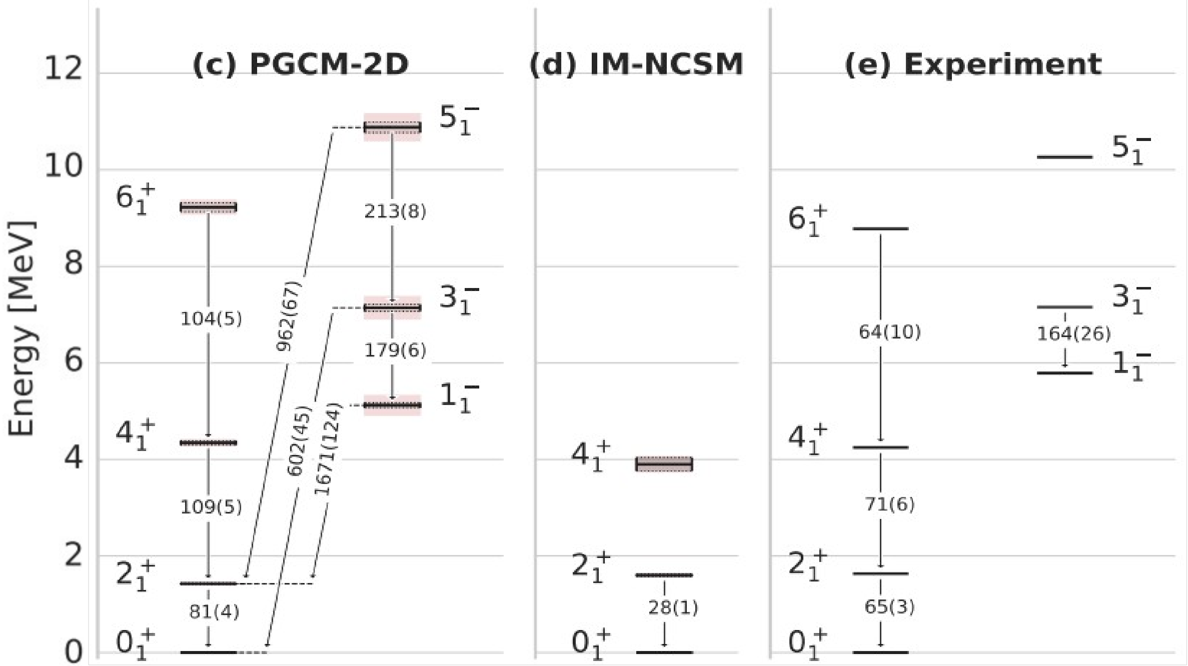


Ceterum autem censeo …

^{20}Ne



[Frosini *et al.*, EPJA **58** (2022) 4, 63]



[SEMINAR BY J-P EBRAN, WEEK 4]

[SEMINAR BY W VAN DER SCHEE, WEEK 4]

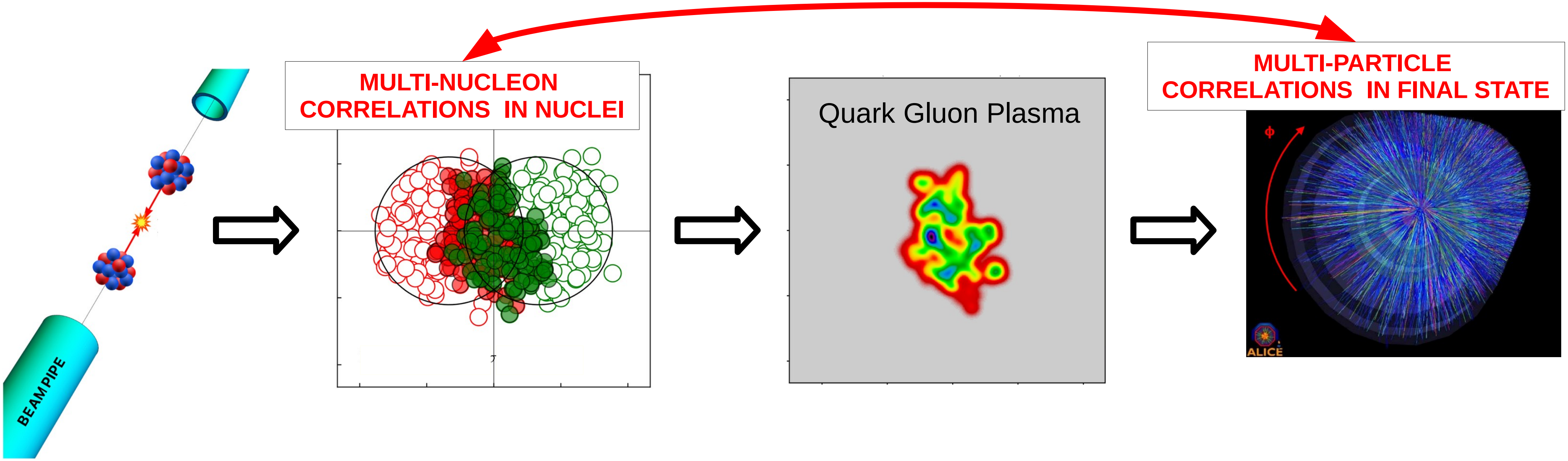
PRECISE INPUTS FROM AB INITIO NUCLEAR THEORY [WEEK 4]

Play same games in a small system, comparing to "spherical baseline" of O+O collisions

Unique insights on origin of collectivity and the response to the initial geometry.

[*ab initio* PGCM + Trajectum frameworks, in preparation]

SUMMARY



- The initial geometry and the collective flow of high-energy nuclear collisions are strongly impacted by nuclear deformations.
- Understanding the effect of the ellipsoidal shape of ^{238}U boosts confidence in understanding of the collision process. Much progress made.
- Prospects: more detailed features (octupole, skin…). Impact of collision runs at lower energies and with smaller systems?

THANK YOU

Intersection of nuclear structure and high-energy nuclear collisions: a new research direction.

ExtreMe Matter Institute EMMI
EMMI Rapid Reaction Task Force
Nuclear Physics Confronts Relativistic Collisions of Isobars
Heidelberg University, Germany, May 30 – June 3 & October 12-14 2022

Organizers:
Giuliano Giacalone
Jiangyong Jia
Vittorio Somà
You Zhou

Deciphering nuclear phenomenology across energy scales
https://esnt.cea.fr/Phocea/Page/index.php?id=107 **Sep 20th - Sep 23rd 2022**

Organizers:
Giuliano Giacalone (ITP Heidelberg)
Jean-Yves Ollitrault (IPhT Saclay)
You Zhou (Niels Bohr Institute)

Intersection of nuclear structure and high-energy nuclear collisions

Organizers:
Jiangyong Jia (Stony Brook & BNL)
Giuliano Giacalone (ITP Heidelberg)
Jacquelyn Noronha-Hostler (Urbana-Champaign)
Dean Lee (Michigan State & FRIB)
Matt Luzum (São Paulo)
Fuqiang Wang (Purdue)

Jan 23rd - Feb 24th 2023

→ Next Initial Stages conference (Copenhagen, 2023) will have a track related to nuclear structure.

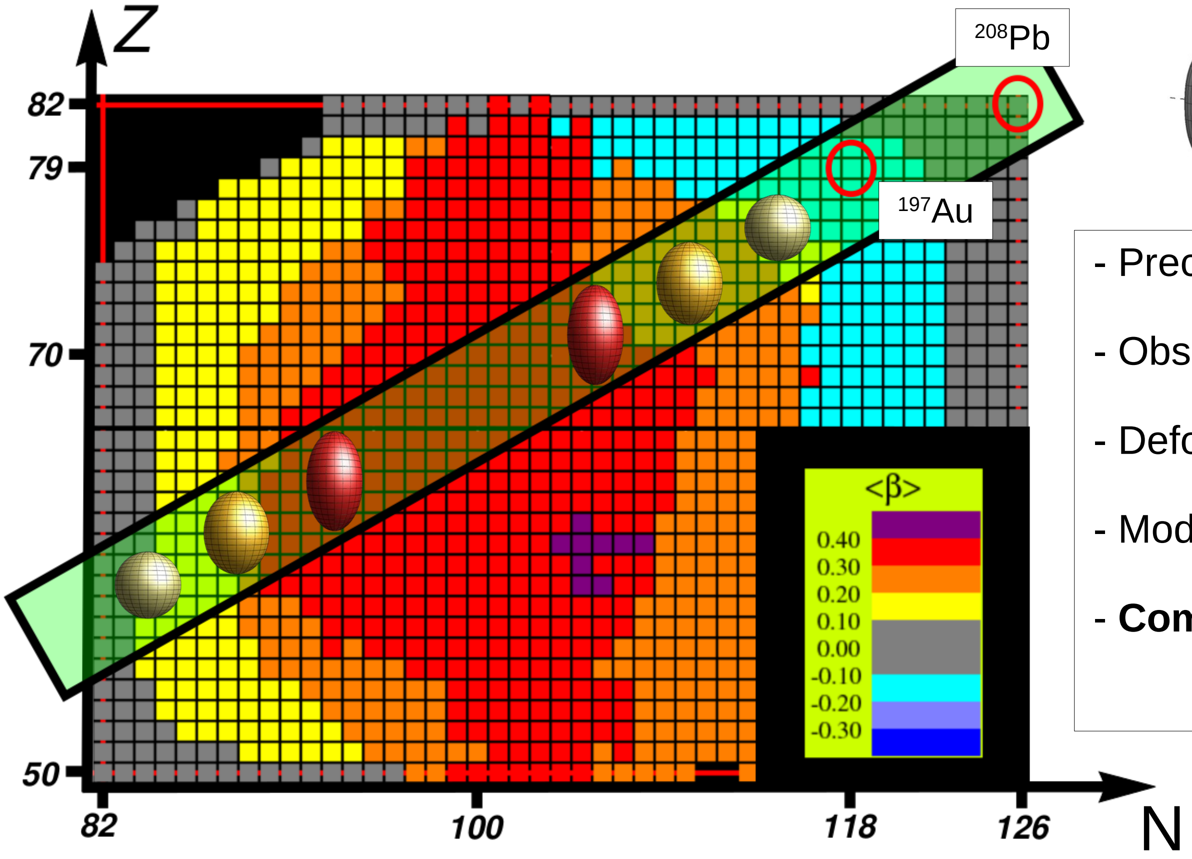
→ Input to Nuclear Physics LRP in the US, both hot QCD (e.g. arXiv link) and nuclear theory.

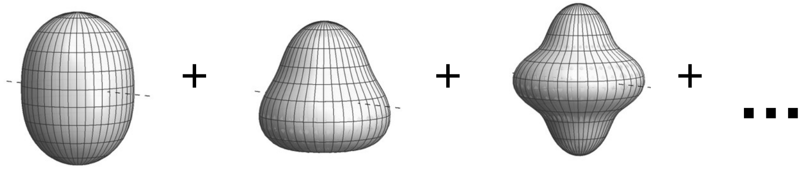
→ Contributed input to NUPECC LRP 2024 [with Y. Zhou (NBI Copenhagen)] (link)

→ Just started a Topical Issue on EPJA on the intersection of the two areas (~20 papers in 2023) [T. Duguet, G. Giacalone, V. Somà, Y. Zhou]

IN CONCLUSION – NEW METHOD TO IMAGE NUCLEI

The ultimate nuclear shape experiment? Exploration of rare earth nuclei.





- Precise determination of relative deformations.
- Observation of small triaxial deformations.
- Deformations beyond hexadecapole (β_4).
- Model-independent constraints for *ab-initio* theory.
- **Complementary knowledge about nuclei.**