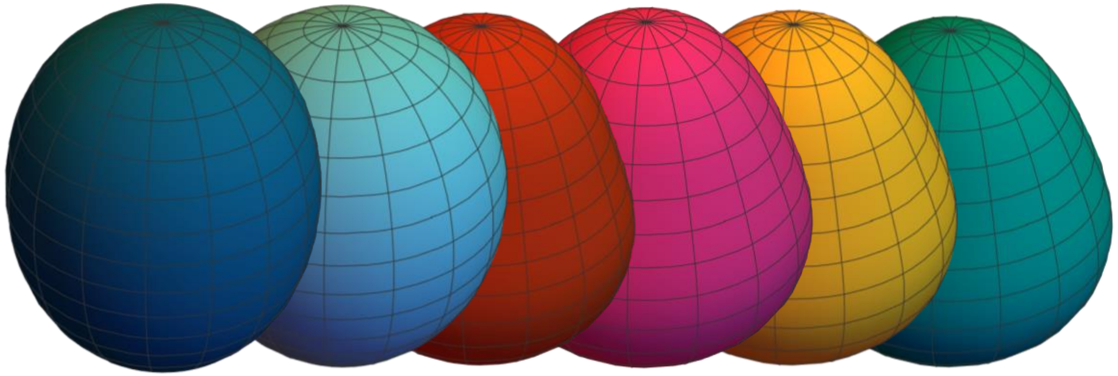


INITIAL CONDITION IN ISOBAR COLLISIONS

W. M. SERENONE[1,2], A. GIANNINI[3], F. GARDIM[4], F. GRASSI[1], K. PALA[1]

[1]UNIVERSIDADE DE SAO PAULO, SP/BRAZIL

[2]UNIVERISTY OF ILLINOIS AT URBANA-CHAMPAIGN, IL/USA

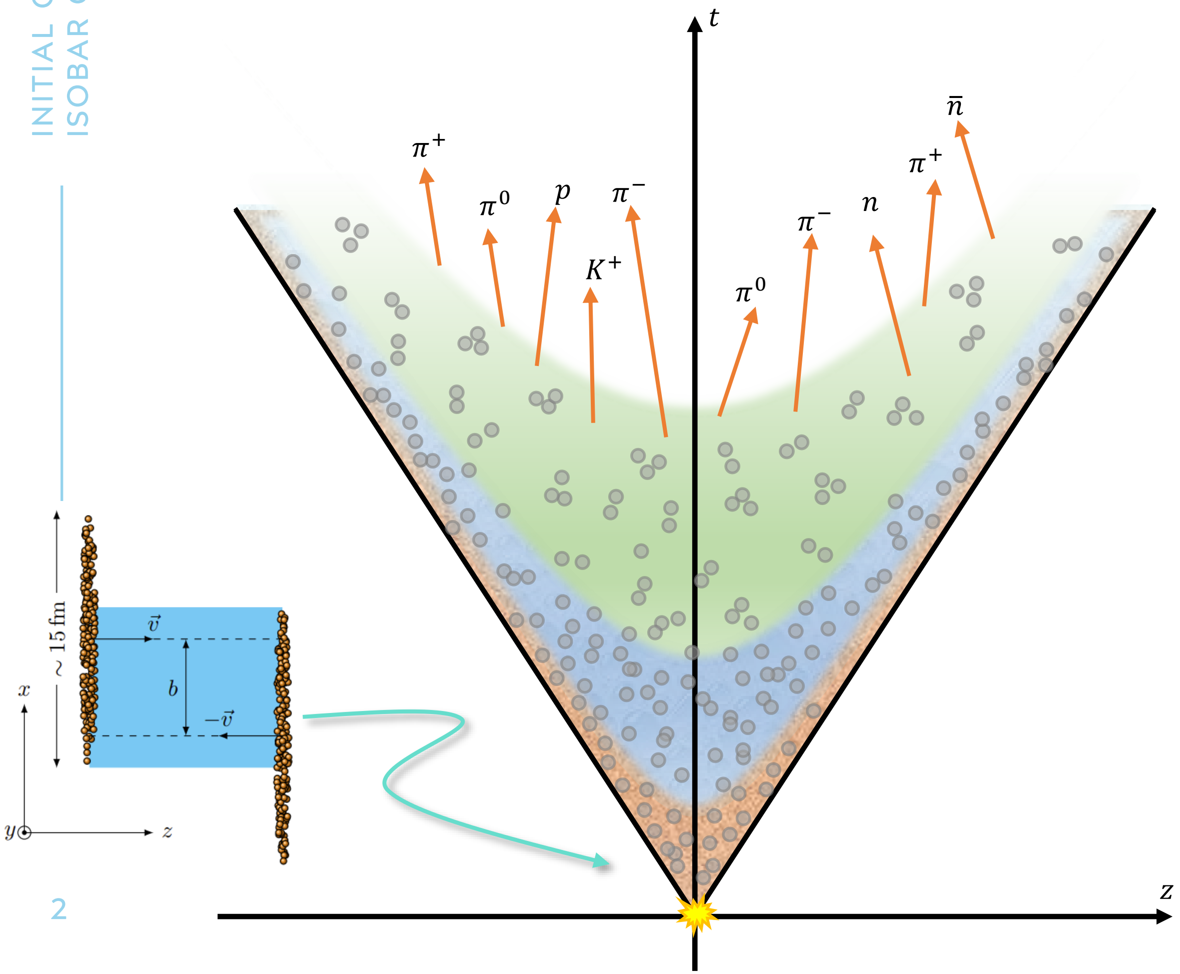
[3]UNIVERSIDADE FEDERAL DE GRANDE DOURADOS MS/BRAZIL

[4]UNIVERSIDADE FEDERAL DE ALFENAS, MG/BRAZIL

USPHYDRO

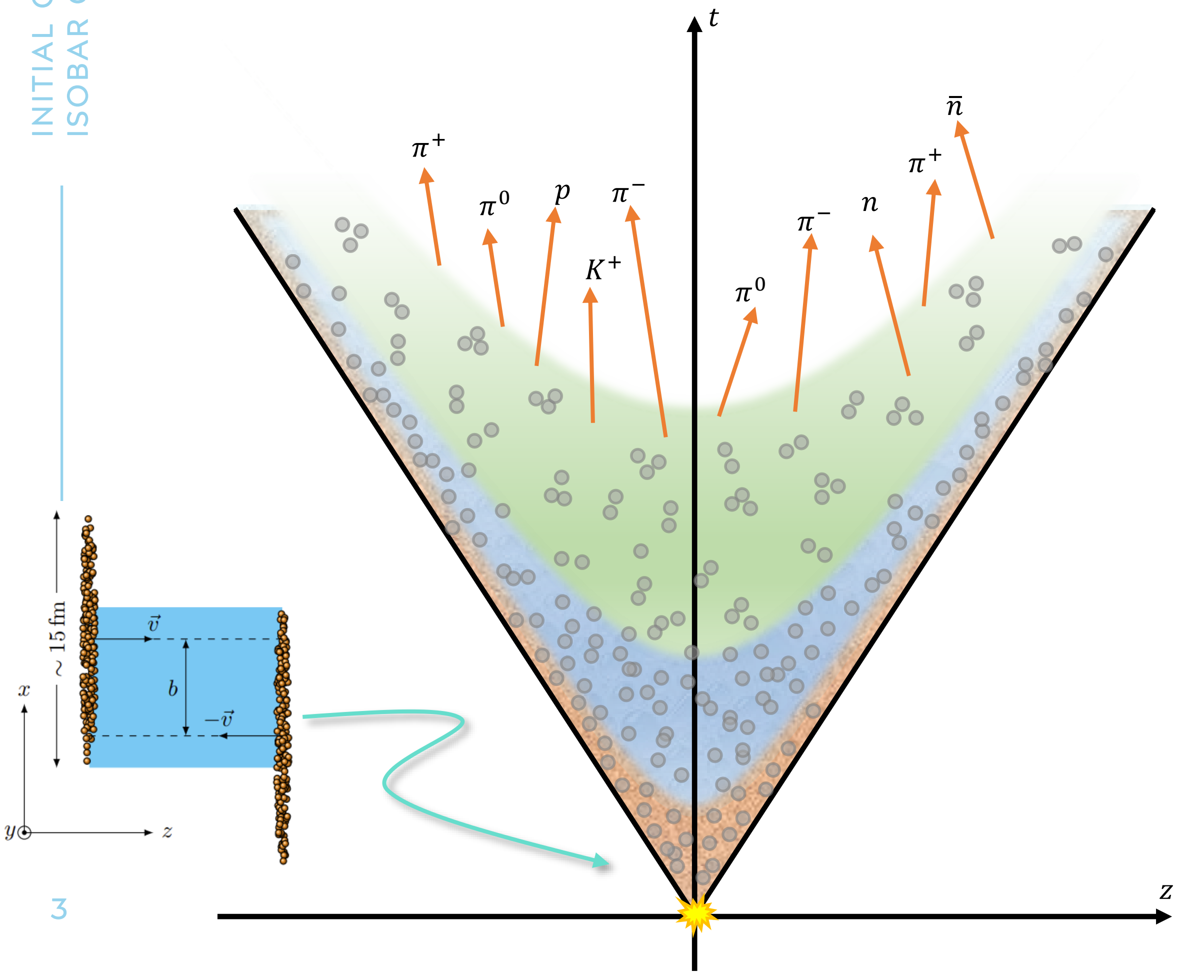
IFUSP
Instituto de Física da USP

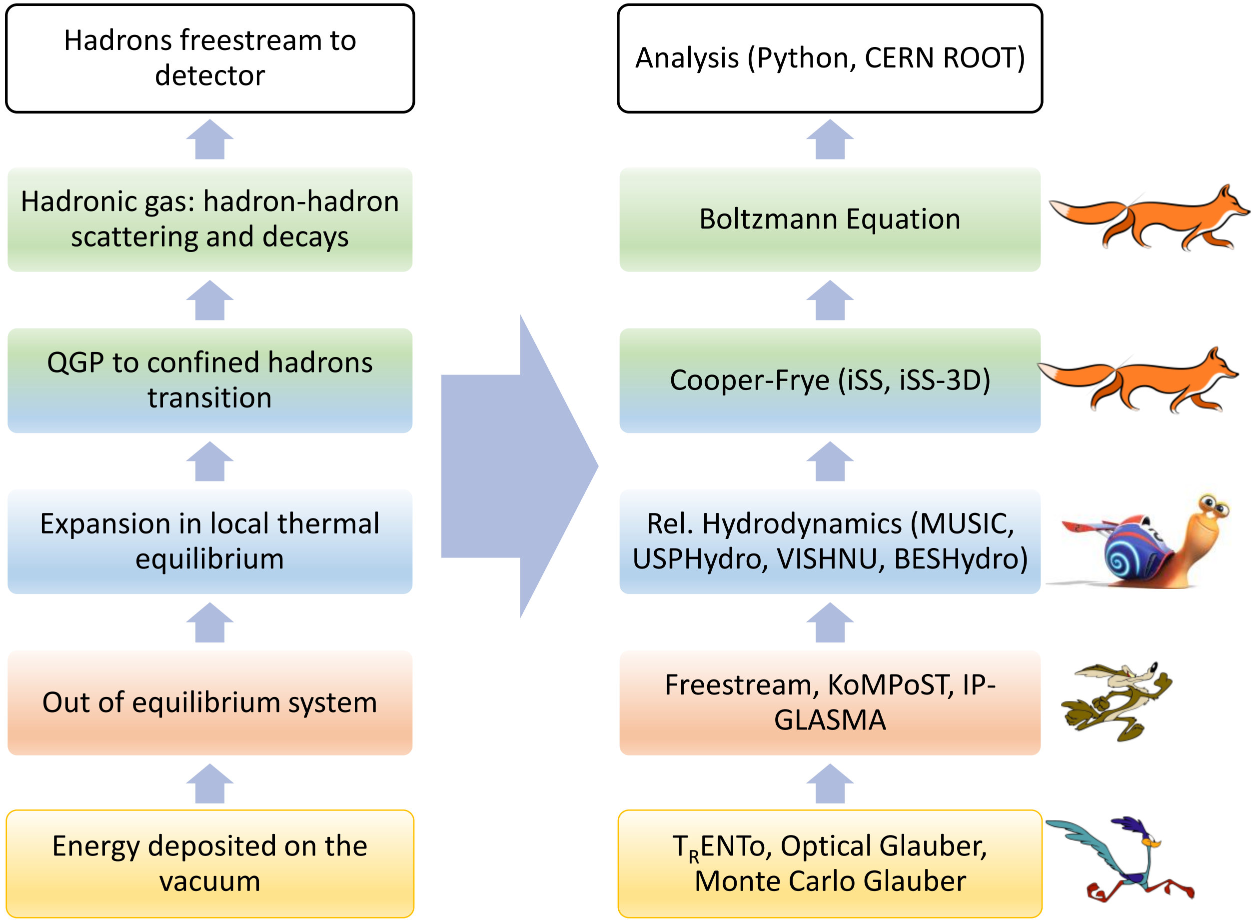
MOTIVATION



Hadrons freestream to detector	Analysis (Python, CERN ROOT)
Hadronic gas: hadron-hadron scattering and decays	Boltzmann Equation
QGP to confined hadrons transition	Cooper-Frye (iSS, iSS-3D)
Expansion in local thermal equilibrium	Rel. Hydrodynamics (MUSIC, USPHydro, VISHNU, BESHydro)
Out of equilibrium system	Freestream, KoMPoST, IP-GLASMA
Energy deposited on the vacuum	T$_R$ENTo, Optical Glauber, Monte Carlo Glauber

MOTIVATION





Hadrons freestream to detector

Hadronic gas: hadron-hadron scattering and decays

QGP to confined hadrons transition

Expansion in local thermal equilibrium

Out of equilibrium system

Energy deposited on the vacuum

Analysis (Python, CERN ROOT)

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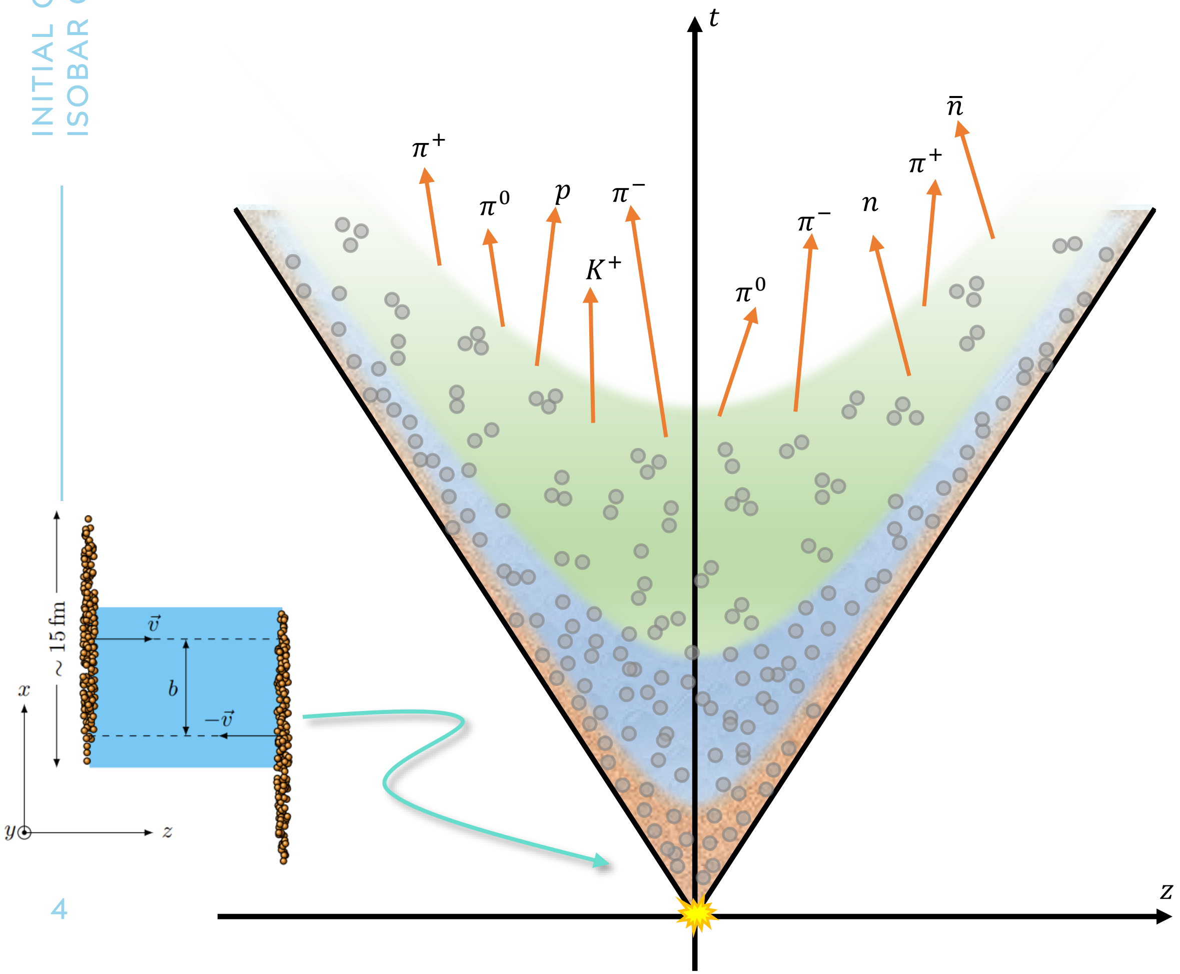
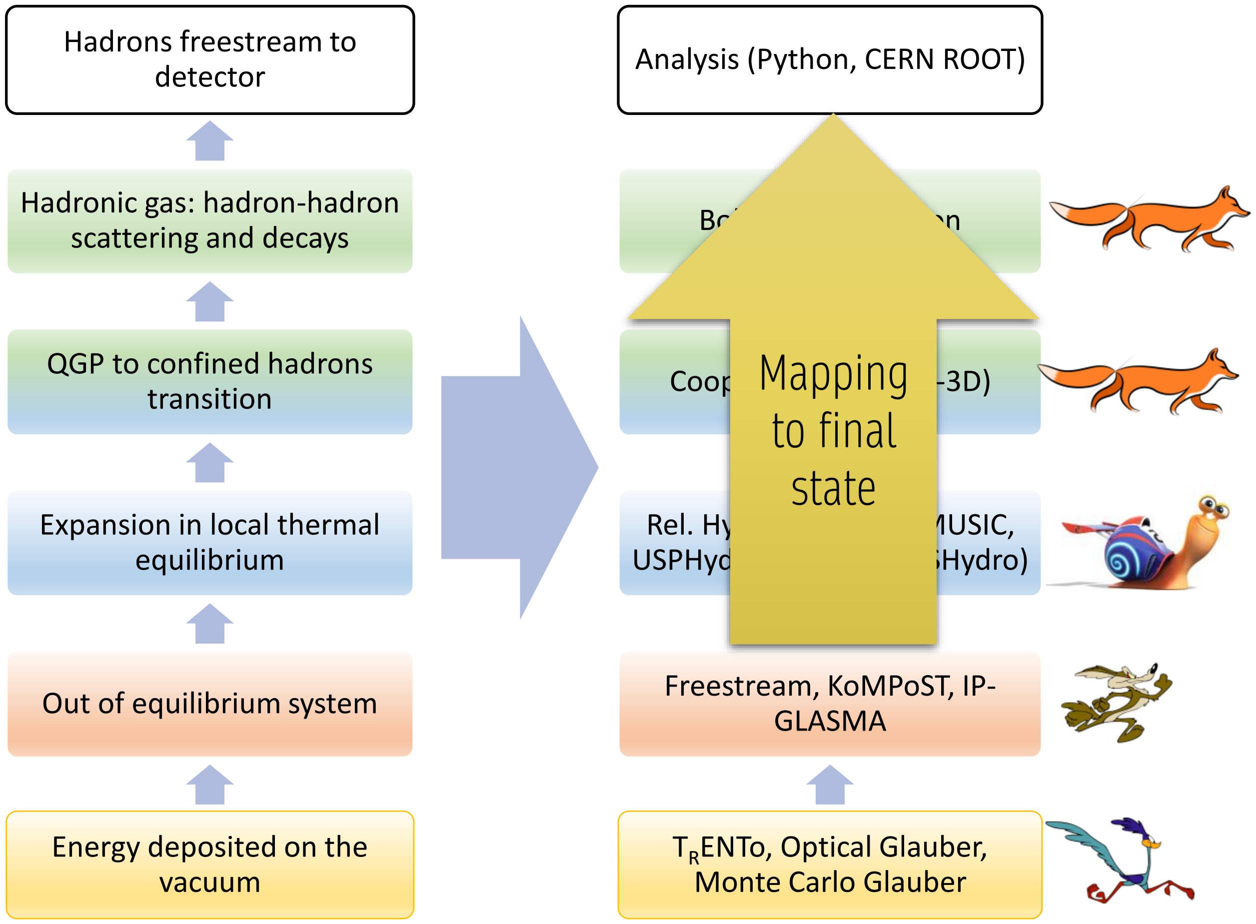
Freestream, KoMPoST, IP-GLASMA

T_RENTo, Optical Glauber, Monte Carlo Glauber

MOTIVATION





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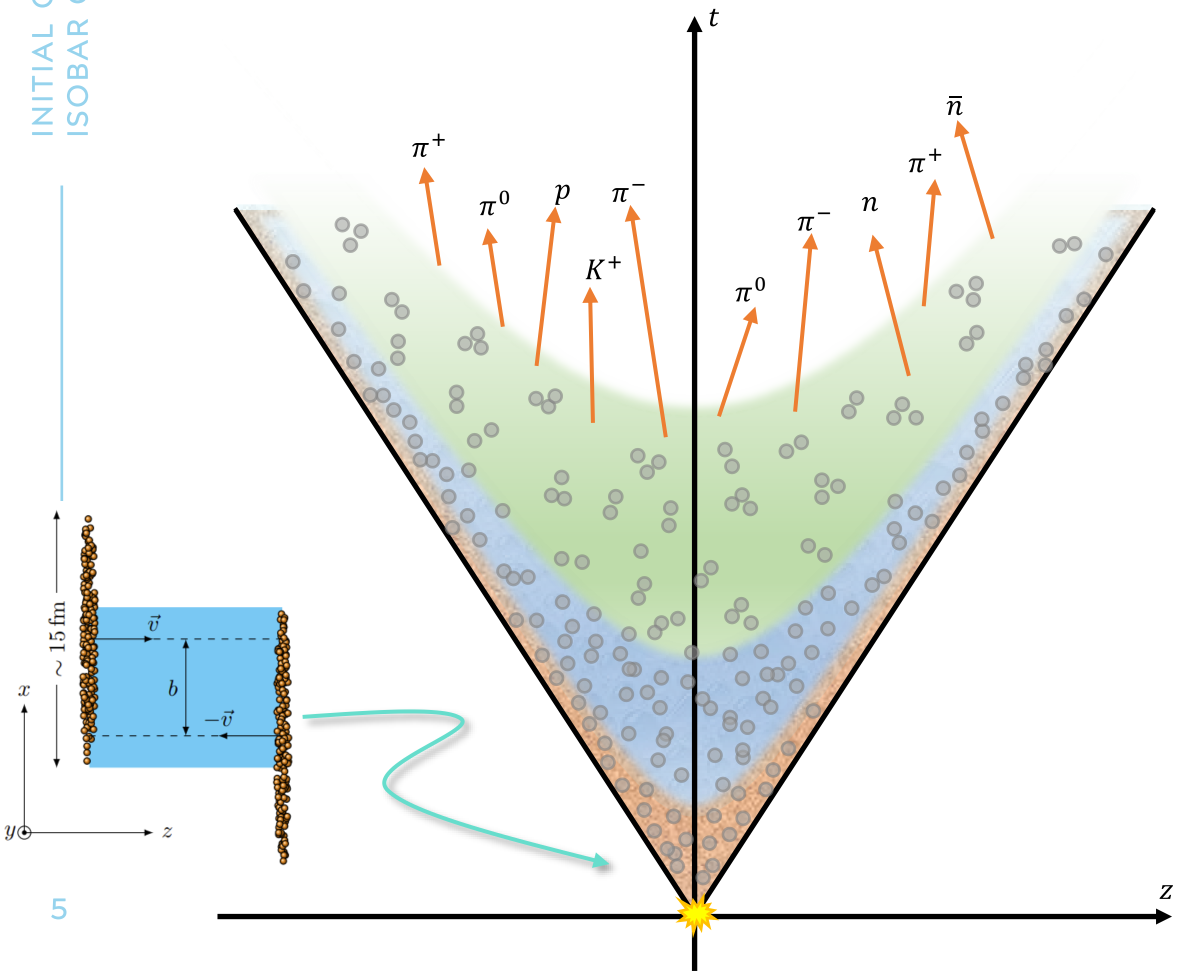
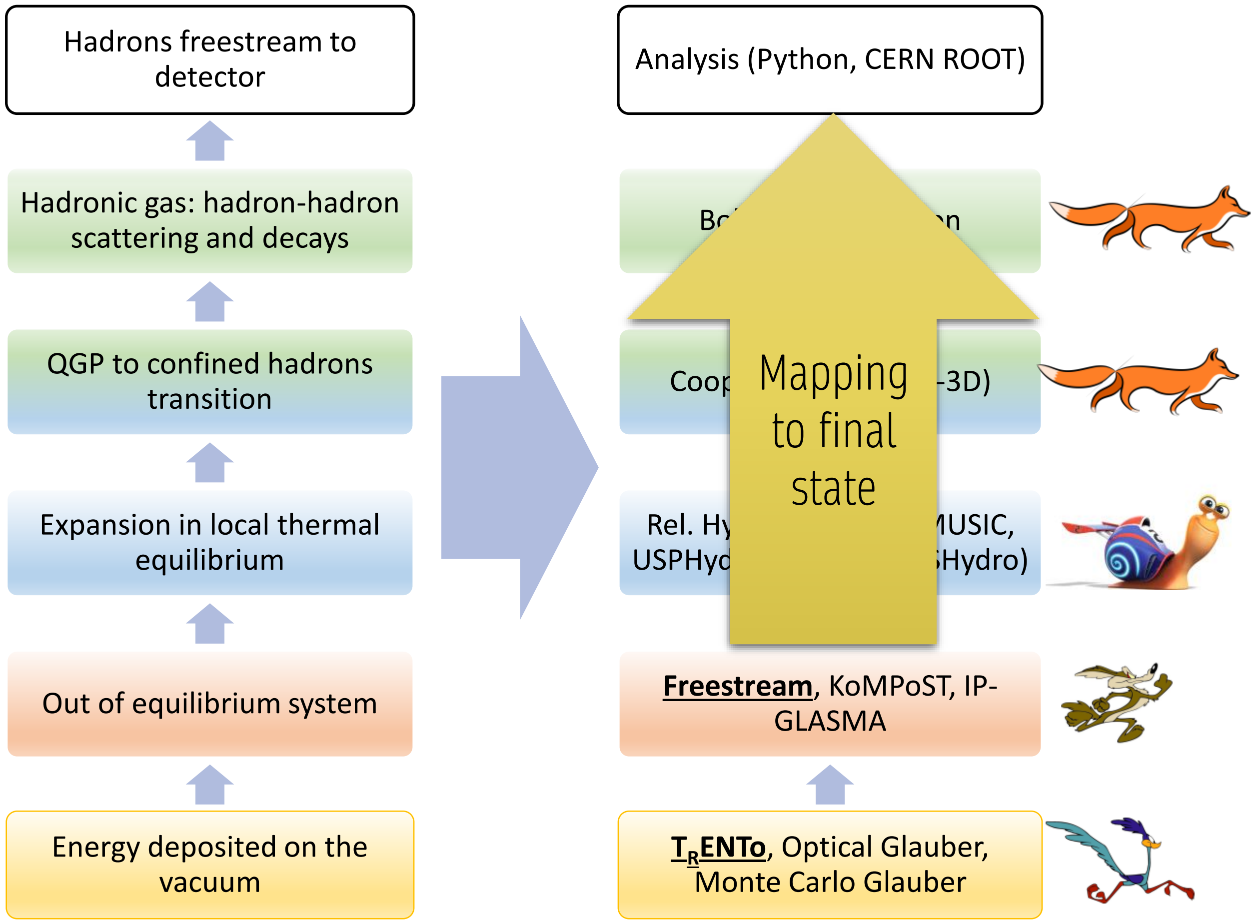
Mapping to final state

MOTIVATION





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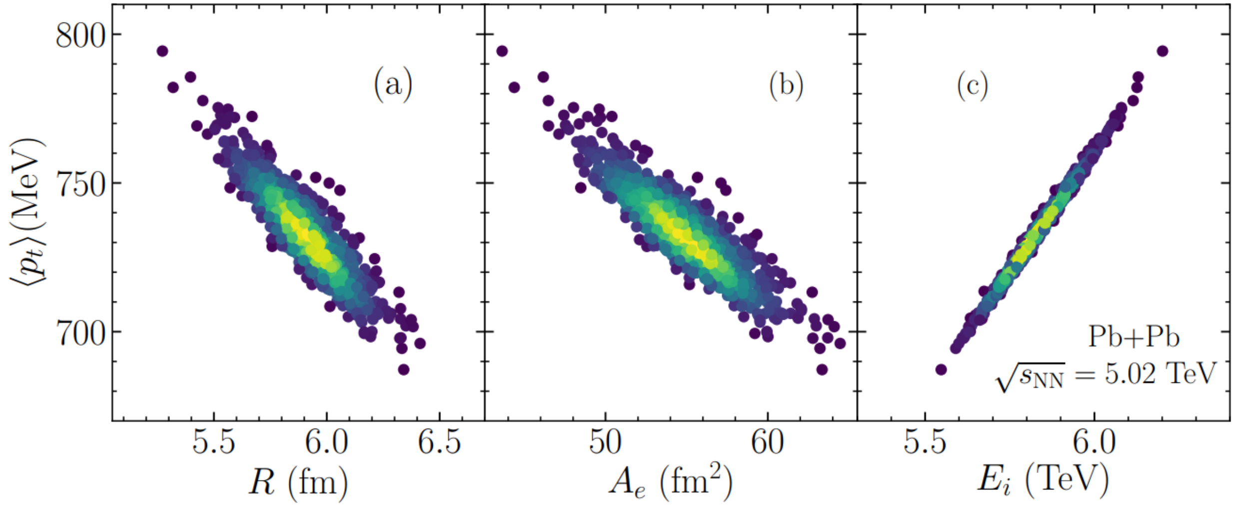
Freestream, KoMPoST, IP-GLASMA

$\mathrm{T_R}$ENTo, Optical Glauber, Monte Carlo Glauber

Mapping to final state

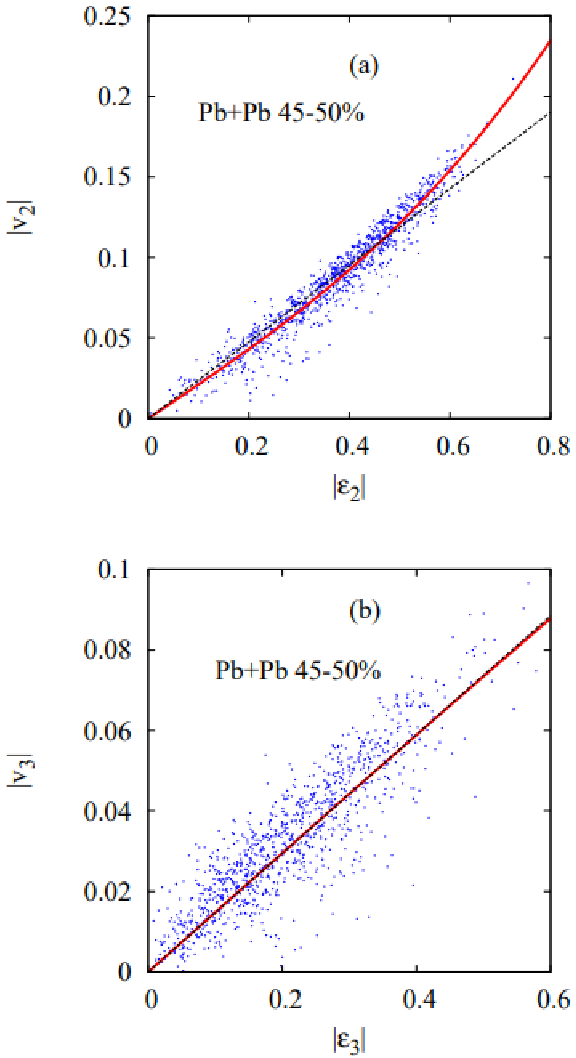
MOTIVATION

- Mapping between initial hydrodynamic state and final state well tested
- Less tested: what are the effects of pre-equilibrium on final-state estimators?



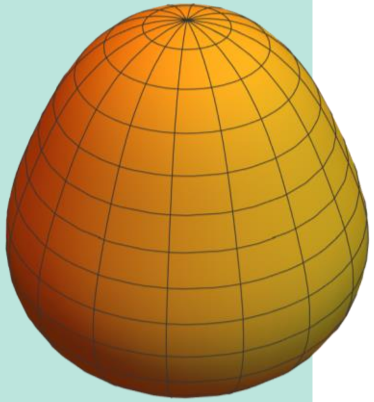
G. Giacalone, F. Gardim, J. Noronha-Hostler, J-Y. Ollitrault, PRC **103**, 024909 (2021)

G. Giacalone, L. Yan, J. Noronha-Hostler,
J-Y. Ollitrault PRC **95**, 014913 (2017)



$$\varepsilon_n = \frac{\int \epsilon(x,y) r^n e^{in\varphi} d^2x}{\int \epsilon(x,y) r^n d^2x}$$

NUCLEUS MODEL



- Random sample nucleon positions according to deformed Wood-Saxon

$$\rho(r,\theta,\phi) = \frac{\rho_0}{1+\exp\frac{[r-R(\theta,\varphi)]}{a}}$$

$$R(\theta,\varphi) = \mathrm{R}_0\left\{1+\beta_2\left[\mathrm{Y}_2^0(\theta,\varphi)\cos\gamma + \frac{2}{\sqrt{2}}\Re\,\mathrm{Y}_2^0(\theta,\varphi)\sin\gamma\right]\right\}$$

$$+\beta_3\,\mathrm{Y}_3^0(\theta,\varphi)$$

- If the distance d between the sorted position and any other nucleon is smaller than a parameter d_{min}, the value is discarded and a new point sorted

INITIAL CONDITION IN ISOBAR COLLISIONS

NUCLEUS MODEL

	R_0 (fm)	a (fm)	β_2	β_3	γ
Case 1	5.09	0.46	0.16	0	$\pi/6$
Case 2	5.09	0.46	0.16	0	0
Case 3	5.09	0.46	0.16	0.2	0
Case 4	5.09	0.46	0.06	0.2	0
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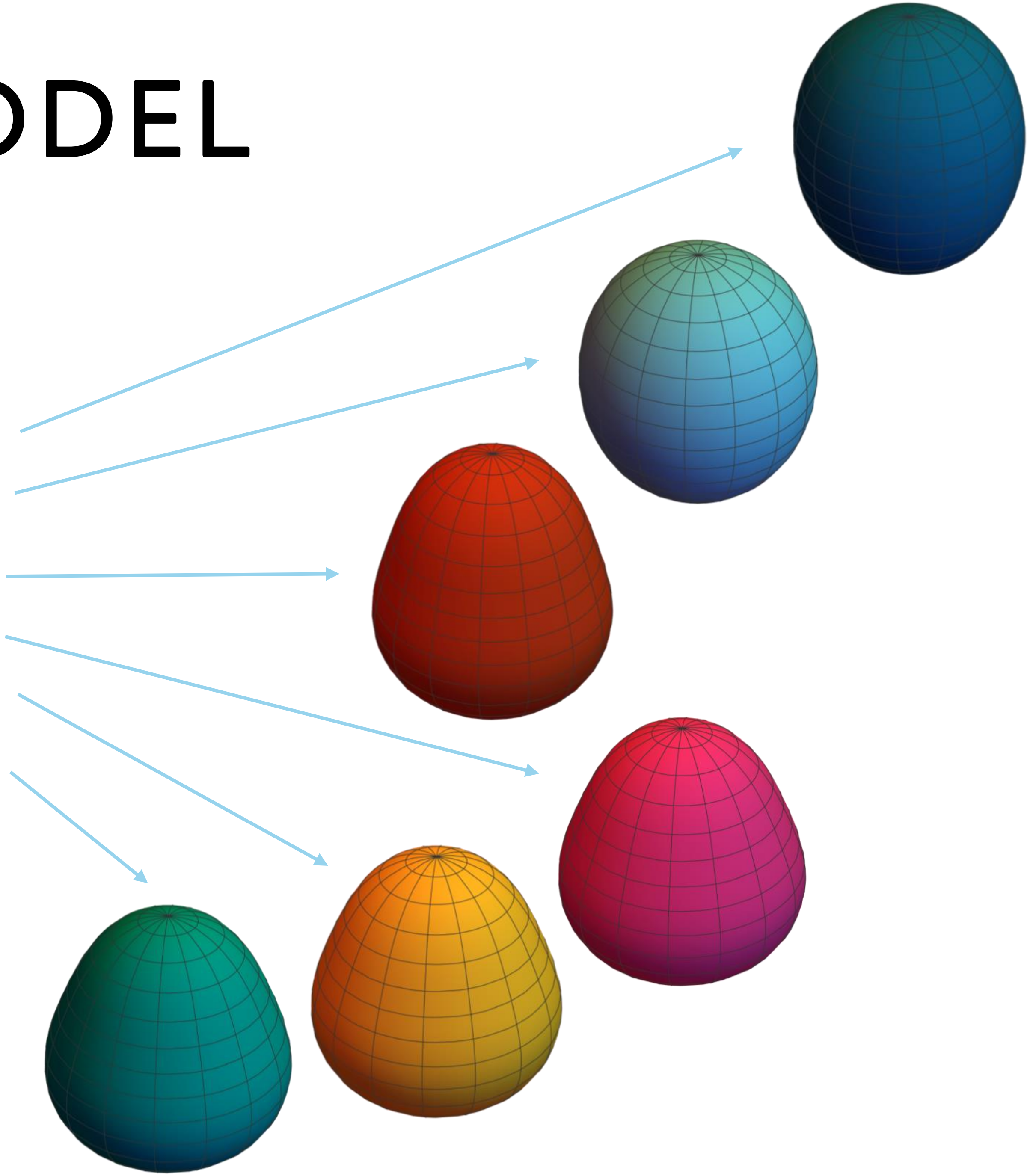

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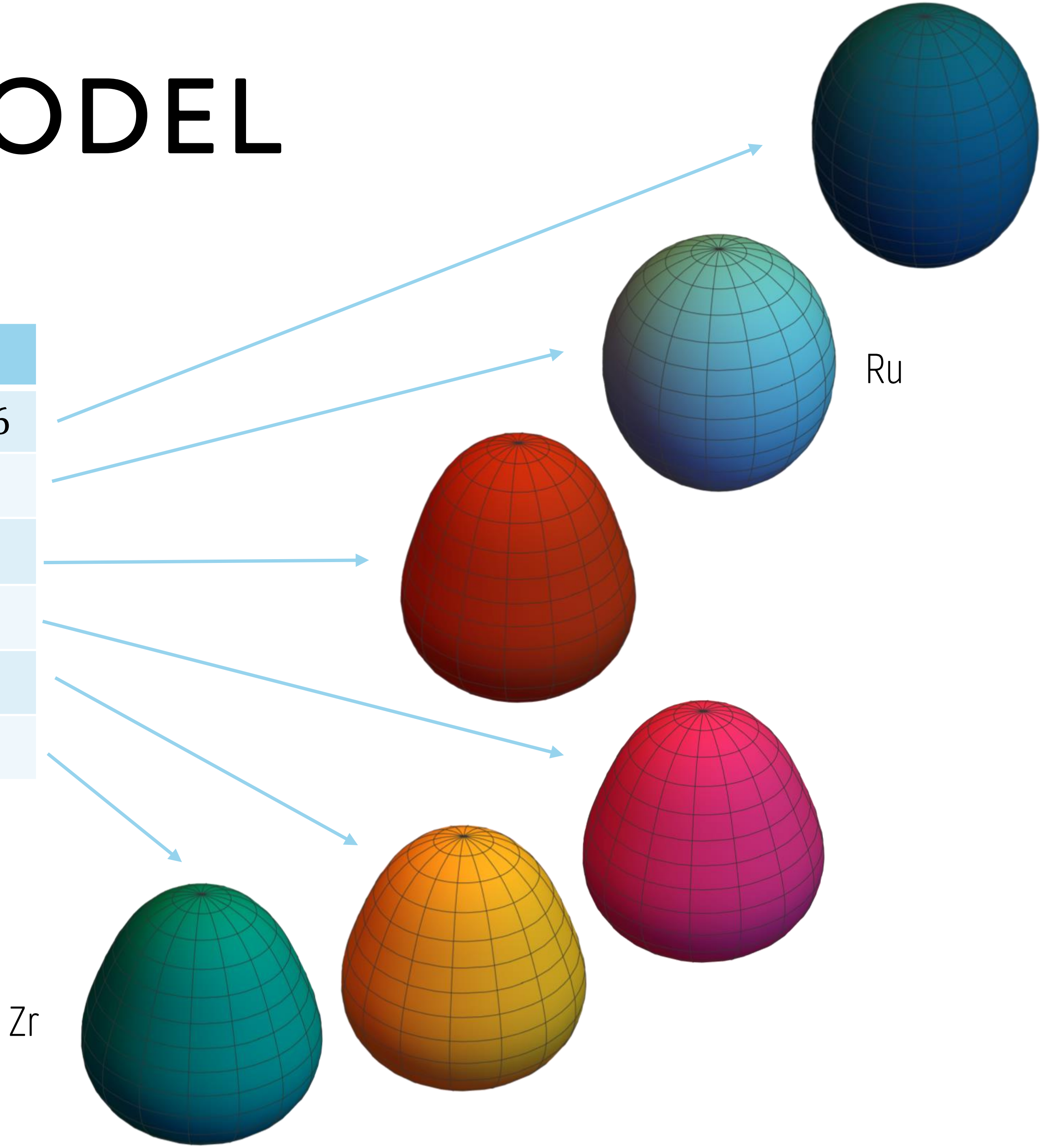
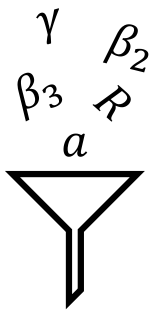
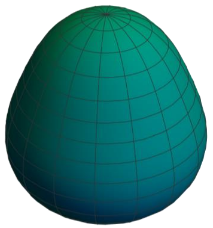
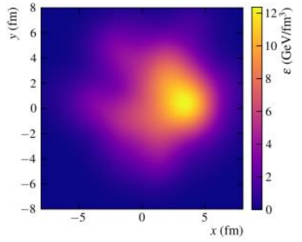


SIMULATION



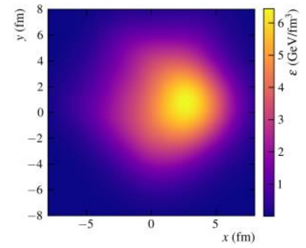




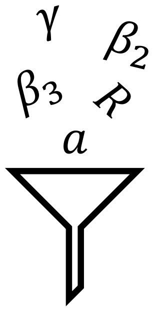
Values from Bayesian estimation
from JETSCAPE Collab., PRC **103**, 054904 (2021)

$$\tau_{FS} = 1.46\left(\frac{\langle\varepsilon\rangle}{\varepsilon_0}\right)^{0.031}$$

Nuclear Config Generator → case_n.hdf → T_RENTo → Energy Density Profile → Free-Stream



SIMULATION



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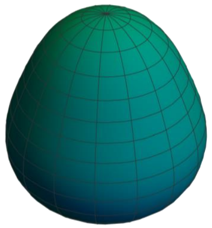

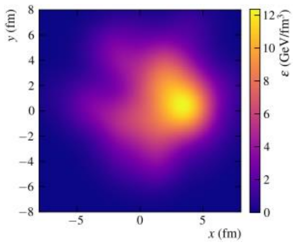

$\varepsilon_n, \rho_n, E/S$

Values from Bayesian estimation
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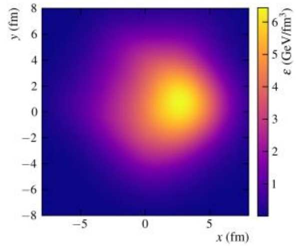

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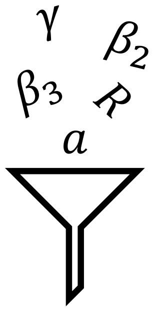
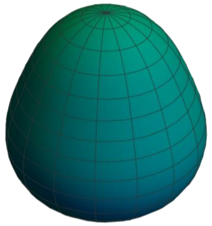
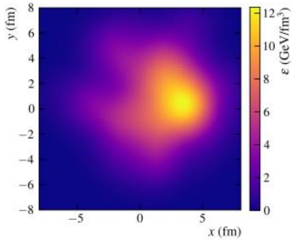
SIMULATION

$\varepsilon_n, \rho_n, E/S$

V… Bayesian estimation
from … PE Collab., PRC **103**, 054904 (2021)







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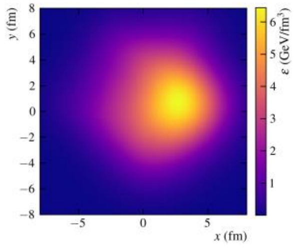
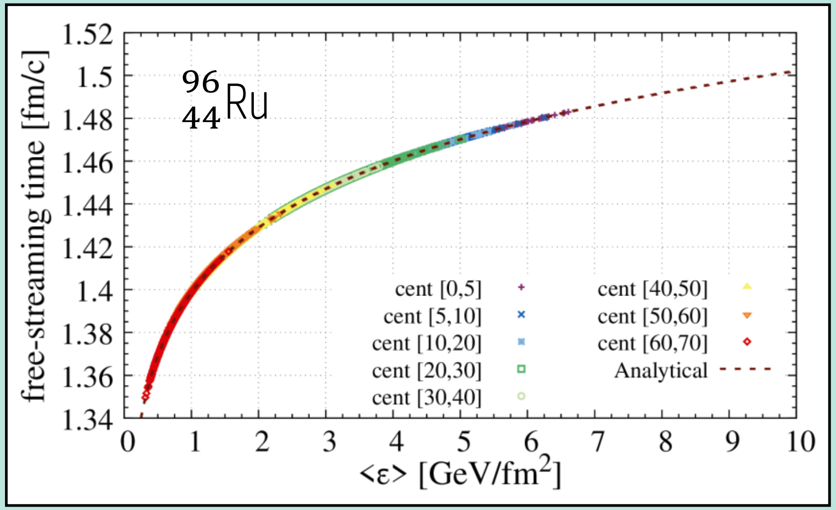


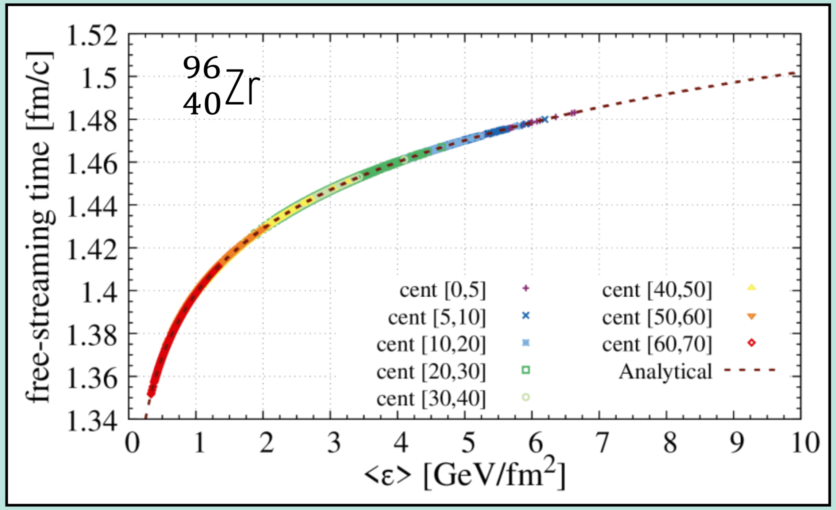
$\varepsilon_n, \rho_n, E/S$

$$\tau_{FS} = 0.4, 1.0 \text{ and } 1.46\left(\frac{\langle\varepsilon\rangle}{\varepsilon_0}\right)^{0.031} \quad \text{fm/c}$$

FREESTREAM VARIABLE TIME

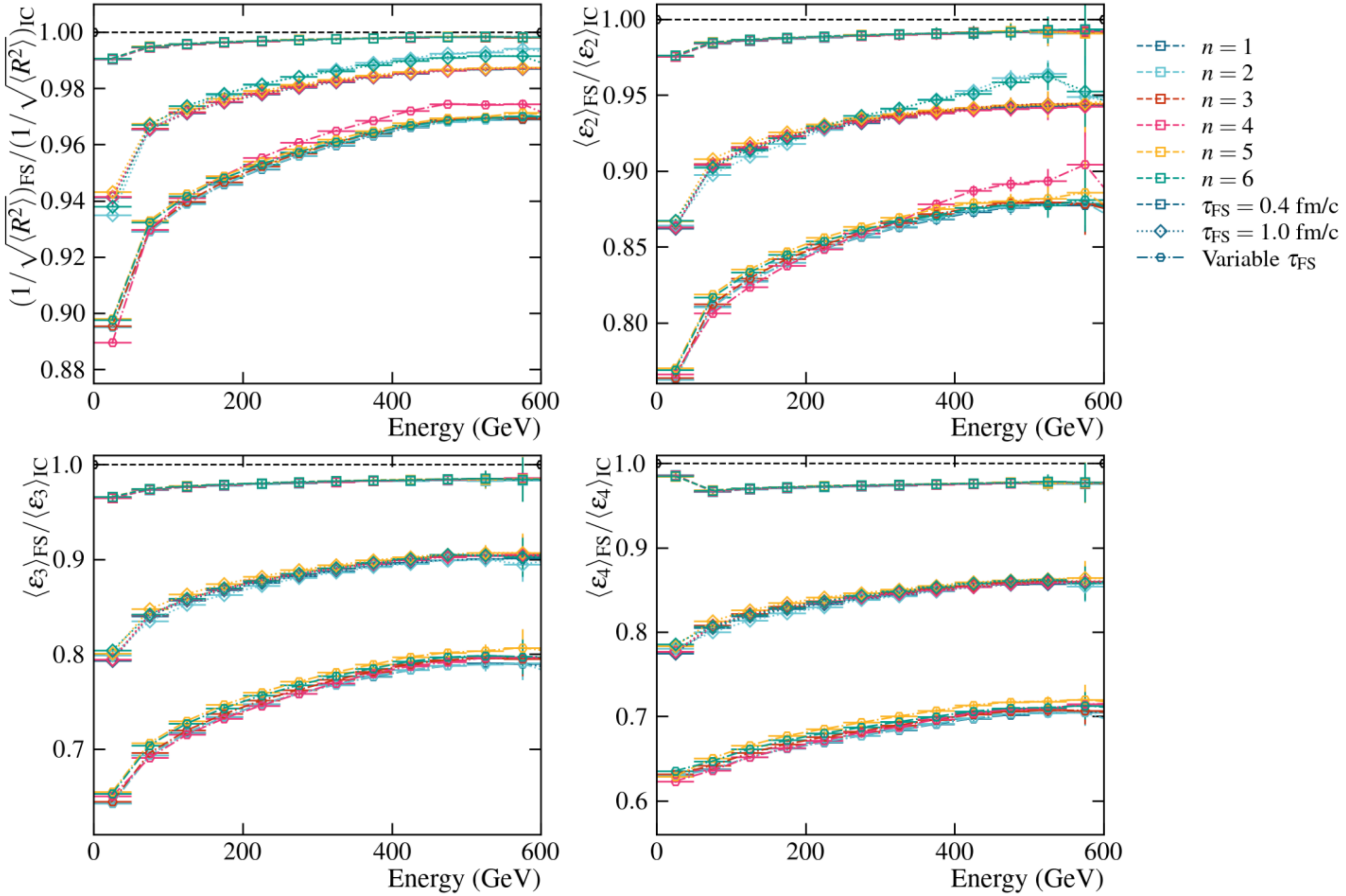
Variable freestream time with is $\tau_{FS}\sim 1.35-1.5\ \mathrm{fm/c}$





FS EFFECTS

- SMALL DIFFERENCE BETWEEN SYSTEMS
- EXPECTED BEHAVIOR
  - Increase in mean radius
  - Decrease in eccentricities

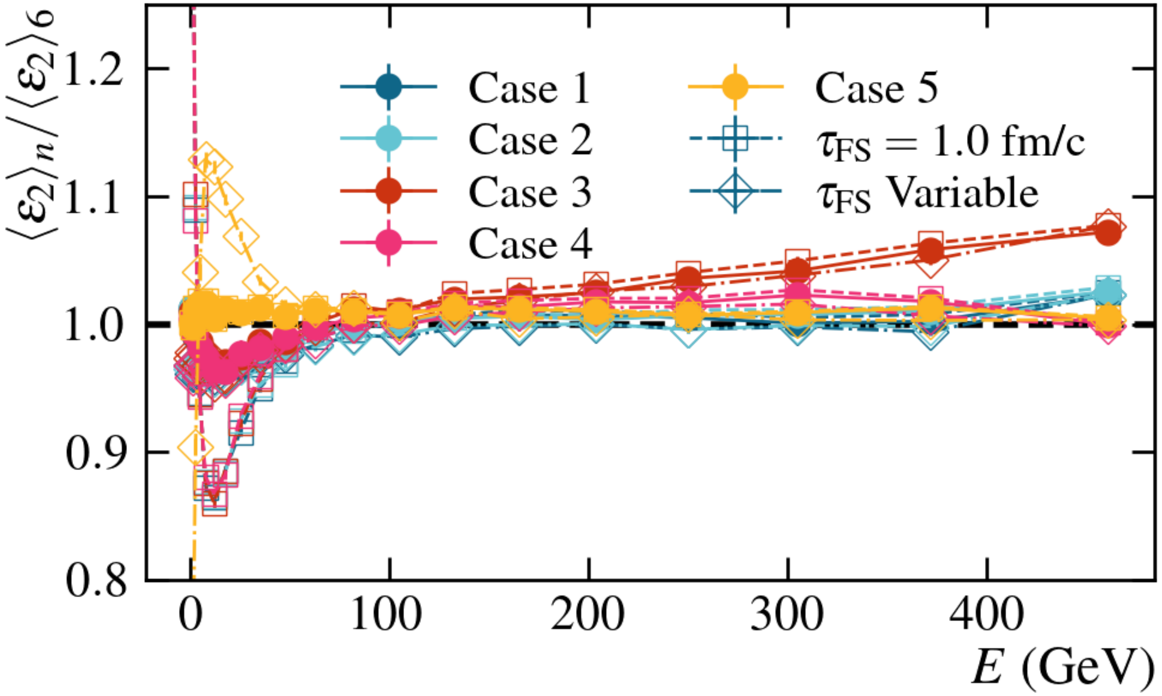


THE DEVIL IS IN THE DETAILS

ECCENTRICITIES-ε_2

$$\varepsilon_n = \frac{\int \epsilon(x,y) r^n e^{in\varphi} d^2x}{\int \epsilon(x,y) r^n d^2x}$$

- REMOVAL OF β_2 DECREASES ε_2
- β_3 ADDITION ENHANCES ε_2
  - See J. Jia, Phys. Rev. C **105**, 014905
- MINIMAL EFFECTS DUE FREESTREAMING



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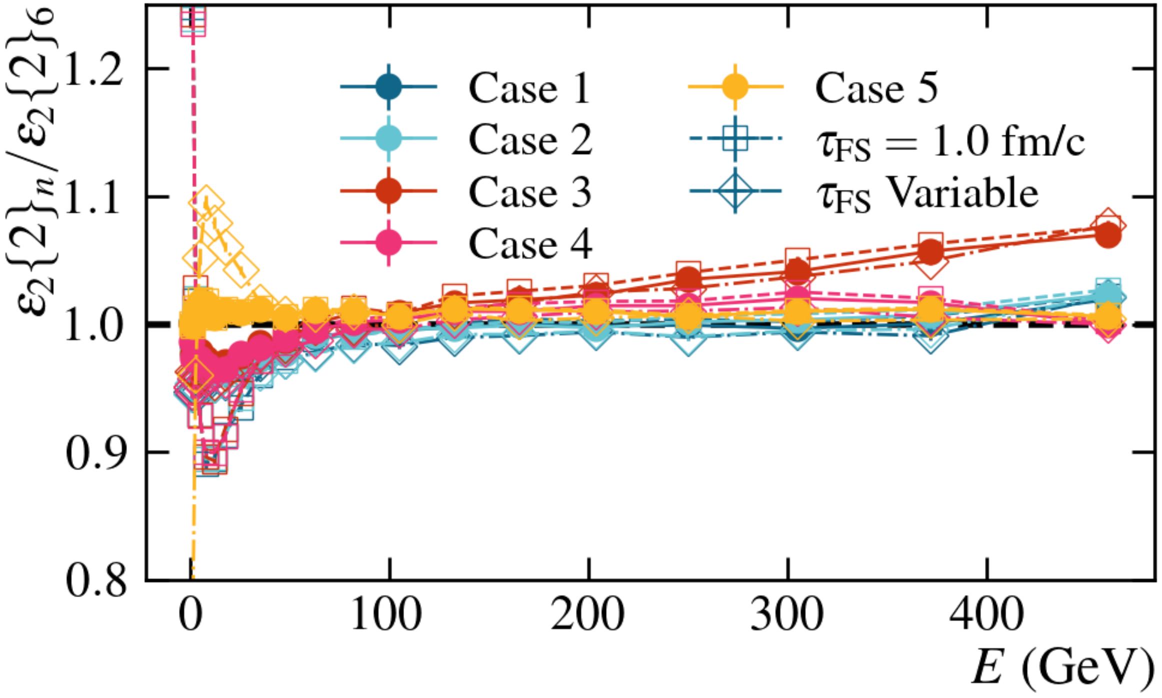
- LARGELY UNSENSITIVE TO FLUCTUATIONS



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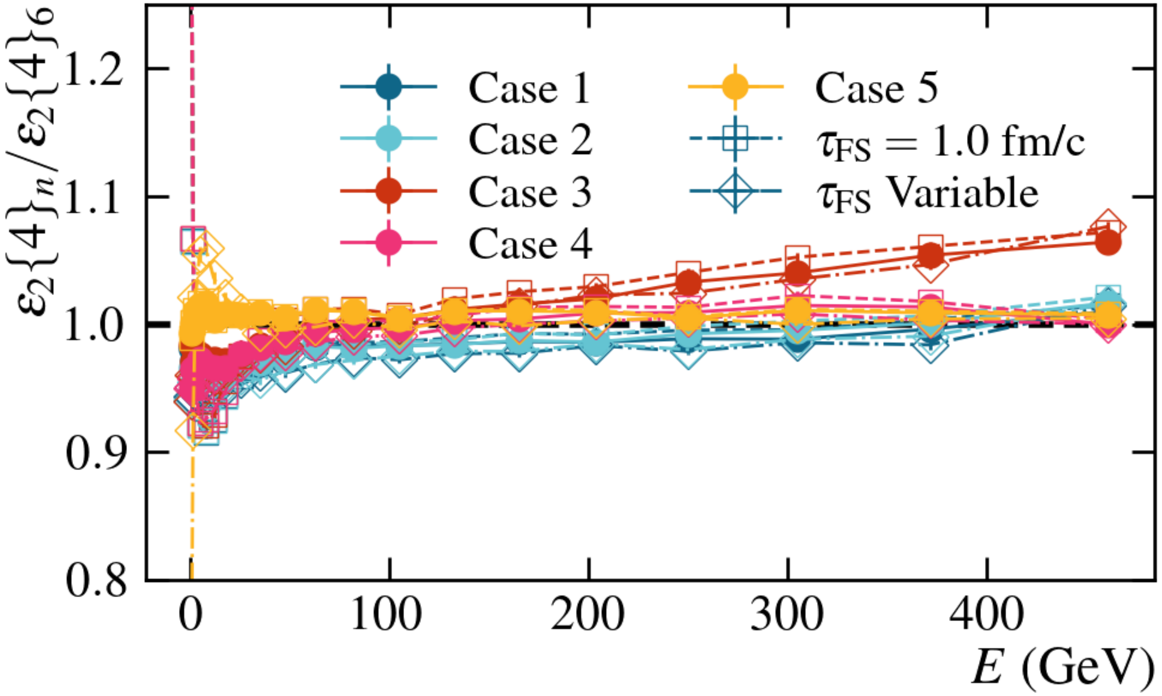
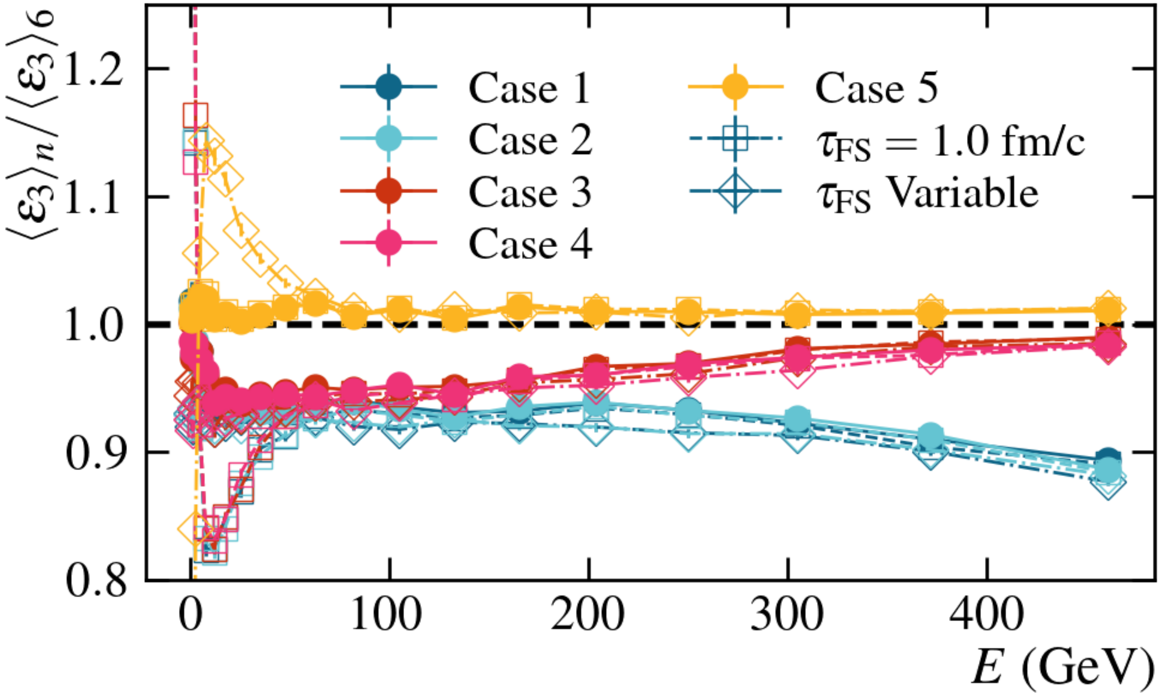


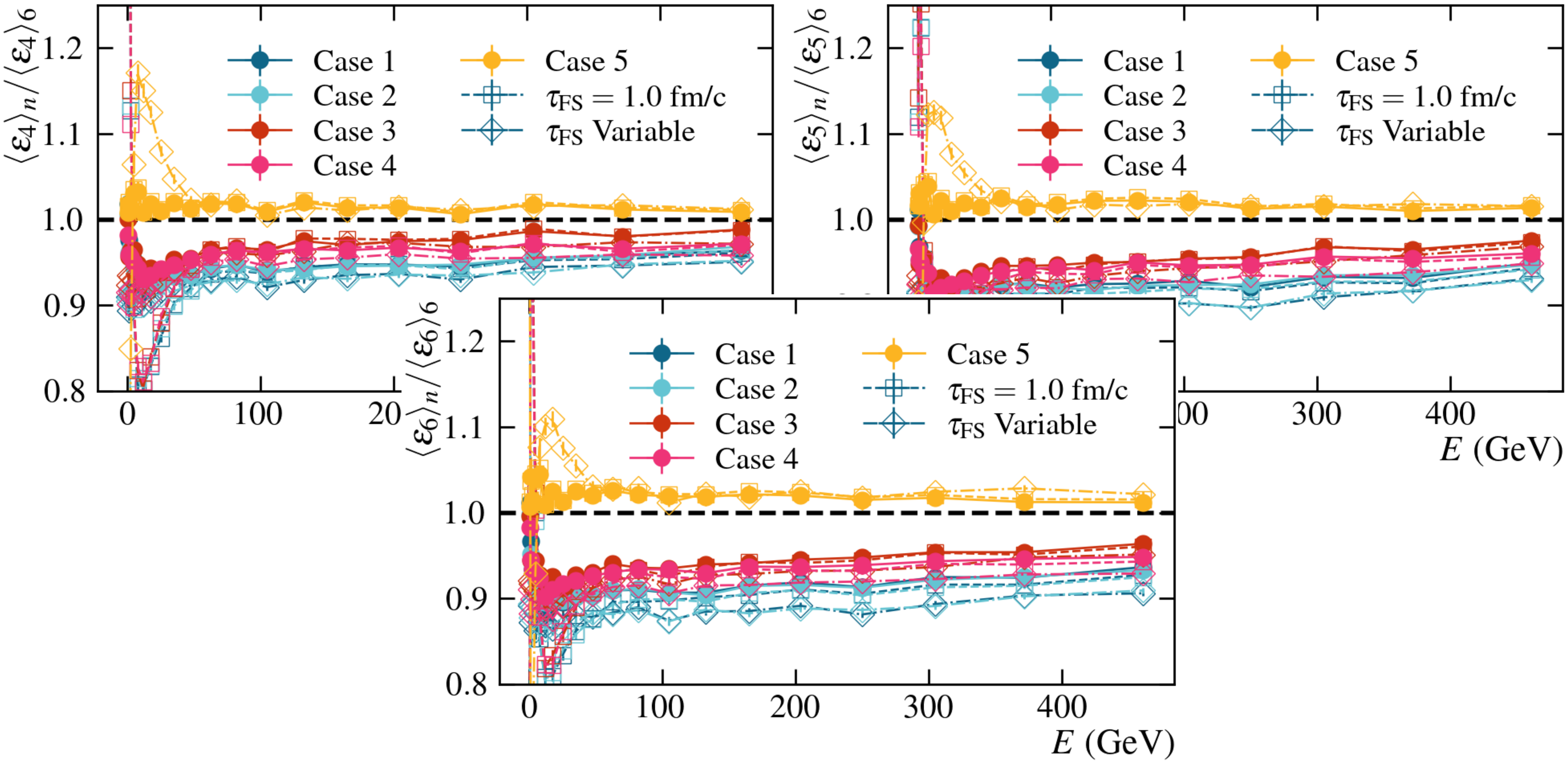
ECCENTRICITIES-ε_3

$$\varepsilon_n = \frac{\int \epsilon(x,y) r^n e^{in\varphi} d^2x}{\int \epsilon(x,y) r^n d^2x}$$

- NOT SENSITIVE TO β_2
- LARGE EFFECTS FROM DIFFUSIVENESS

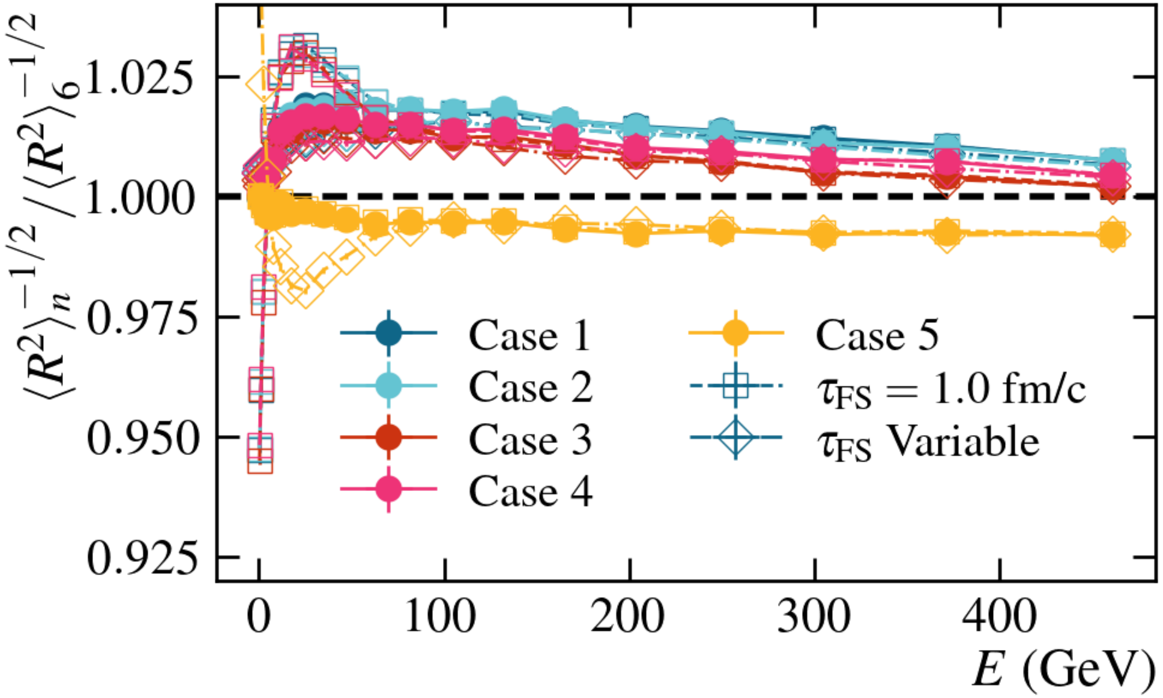


ECCENTRICITIES-$\varepsilon_4, \varepsilon_5$ AND ε_6



MEAN RADIUS

- ONLY SMALL SIZE DIFFERENCES IN SIZES
- MOST SENSITIVE TO DIFFUSIVENESS



MOMENTUM ANISOTROPY

FREESTREAM INPUT: $T^{tt} = \epsilon$, $T^{ij} = P(\epsilon)\delta^{ij}$, $T^{0i} = 0$

FREESTREAM OUTPUT: $T^{\mu\nu}\left(\tau_{Hydro}, x, y\right) \neq 0$

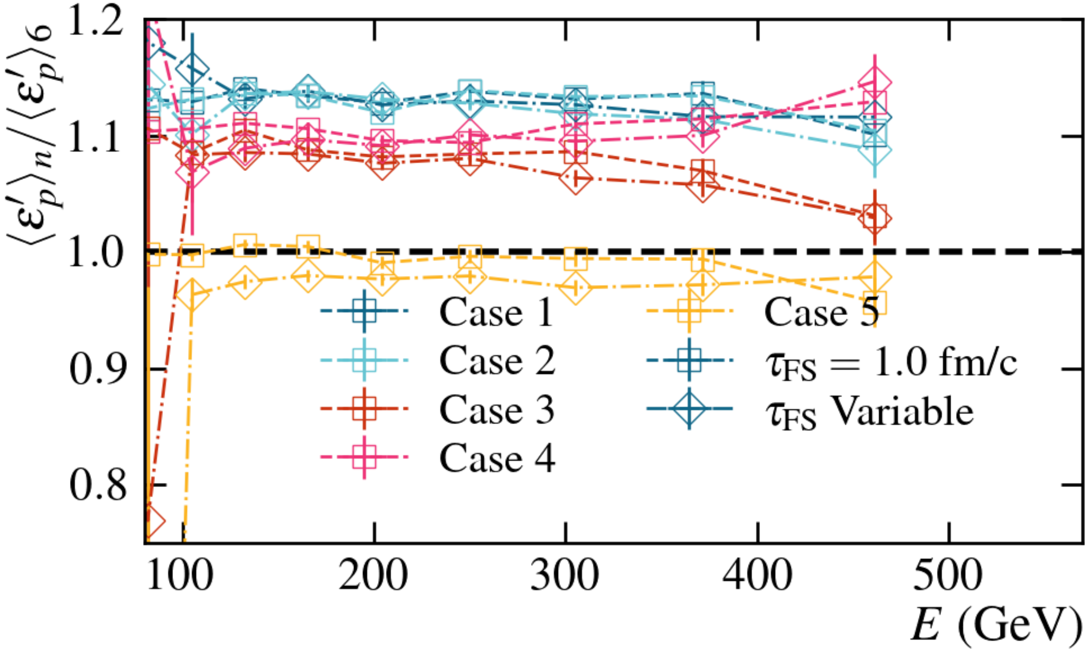
POSSIBILITY FOR A MOMENTUM ANISOTROPY: $\varepsilon'_p = \frac{\int d^2x \, T^{xx} - T^{yy}}{\int d^2x \, T^{xx} + T^{yy}}$

J. Liu, C. Shen, U. Heinz, PRC **91** (2015), 064906

IT WILL PRESENT ADDITIONAL CONTRIBUTION TO FINAL STATE ON TOP OF THE GEOMETRY INDUCED CONTRIBUTIONS.

MOMENTUM ANISOTROPY

- ONLY SMALL SENSITIVENESS TO DIFFERENT FREESTREAM PARAMETERS
- ALSO SENSITIVE TO β_2, β_3 AND a



FREESTREAM HAS NEGLIGIBLE EFFECTS ON BASIC QUANTITIES

- Only affects momentum anisotropy
- No observable shown so far is sensitive to triaxiality
- Pearson correlator should be sensitive

$$\rho_2 = \frac{\langle \varepsilon_2^2 E/S \rangle - \langle \varepsilon_2^2 \rangle \langle E/S \rangle}{\sigma_{\varepsilon_2^2} \sigma_{E/S}}$$

- G. Giacalone, F. Gardim, J. Noronha-Hostler, J.-Y. Ollitrault, PRC **103**, 024909 (2021)
- B. Bally, M. Bender, G. Giacalone, V. Somà, PRL **128**, no.8, 082301 (2022)

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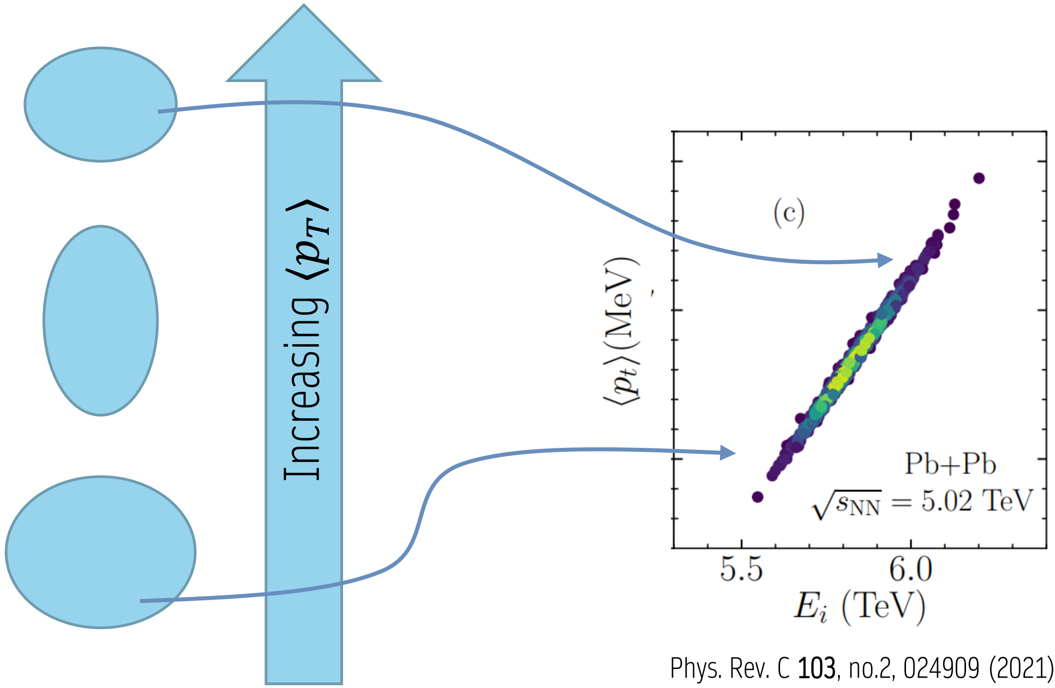
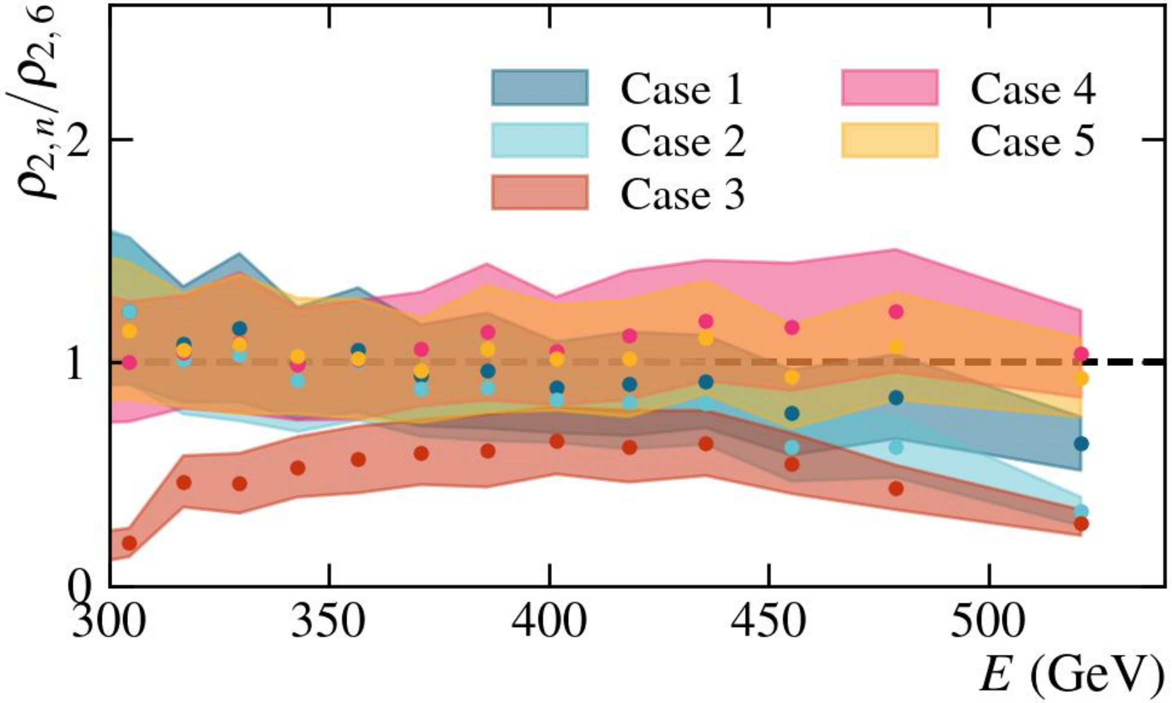


Phys. Rev. C **103**, no.2, 024909 (2021))

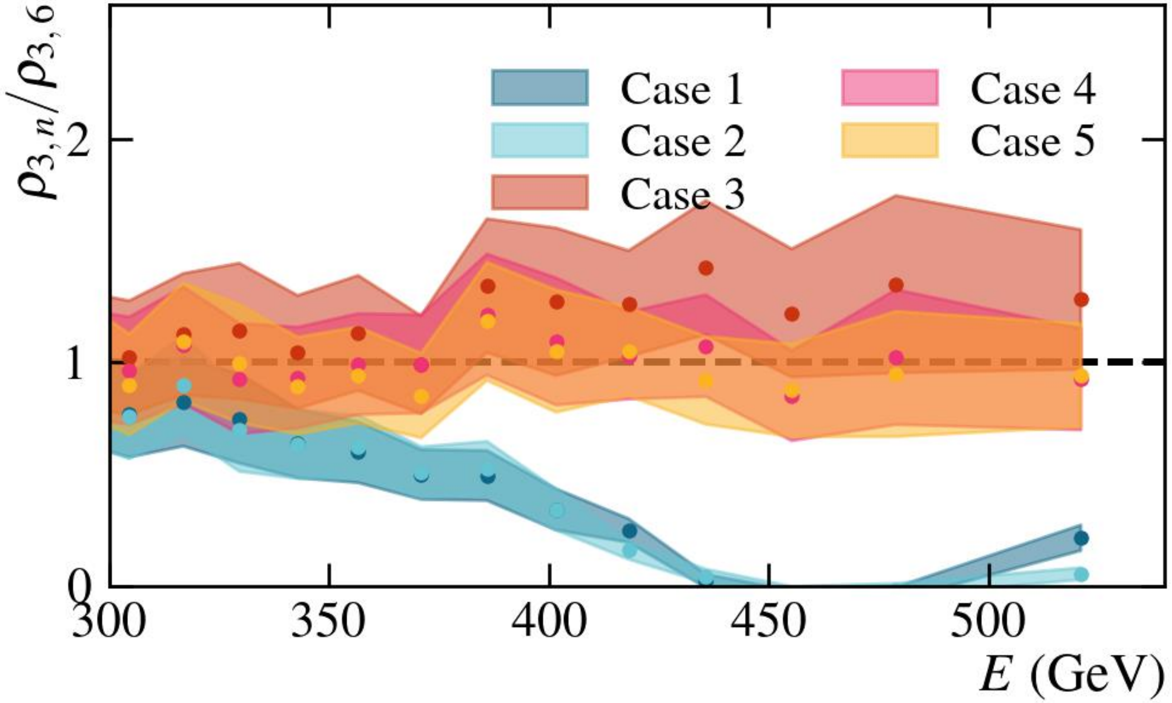
PEARSON CORRELATOR

- AS EXPECTED, IS SENSITIVE TO γ
- ALSO β_2
- LARGE STATISTICS: 10-20M EVENTS
  - Enlarging statistics for free-streaming



PEARSON CORRELATOR

- AS EXPECTED, IS SENSITIVE TO γ
- ALSO β_2
- LARGE STATISTICS: 10-20M EVENTS
  - Enlarging statistics for free-streaming
- ρ_3 IS MOSTLY SENSITIVE TO β_3



PREDICTING RATIOS (WIP)

$$\frac{O_{Ru}}{O_{Zr}} \approx 1 + c_1\Delta\beta_2^2 + c_2\Delta\beta_3^2 + c_3\Delta R + c_4\Delta a + \boxed{c_5\,\Delta\gamma}$$

First Guess

- Each observable will have its own set of coefficients c_n
- We can easily obtain one of these coefficients by computing the ratio between two systems where only one parameter was changed
- Case 3/Case 4 → c_1
- Case 2/Case 3 → c_2
- Case 5/Case 6 → c_3
- Case 4/Case 5 → c_4
- Case 1/Case 2 → c_5

	R_0 (fm)	a (fm)	β_2	β_3	γ
Case 1	5.09	0.46	0.16	0	$\pi/6$
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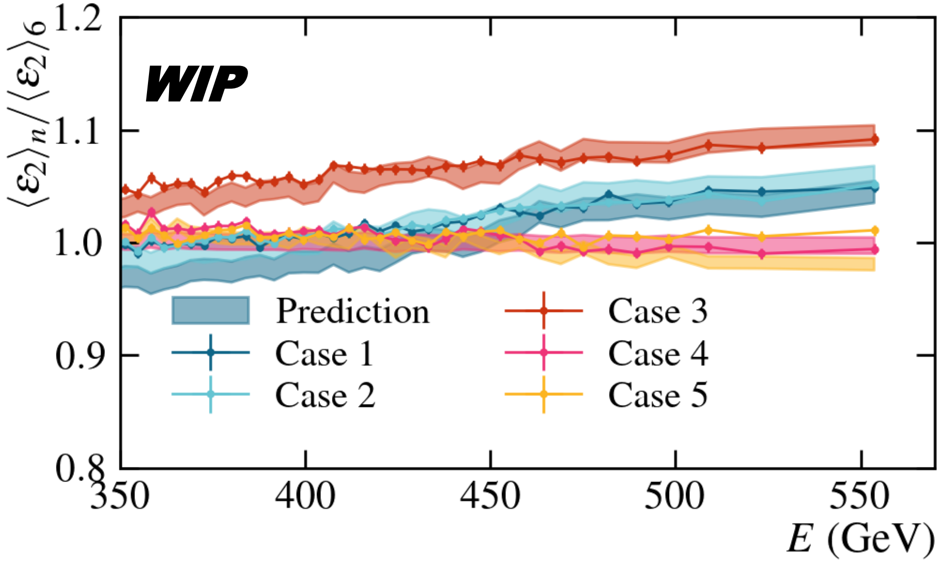
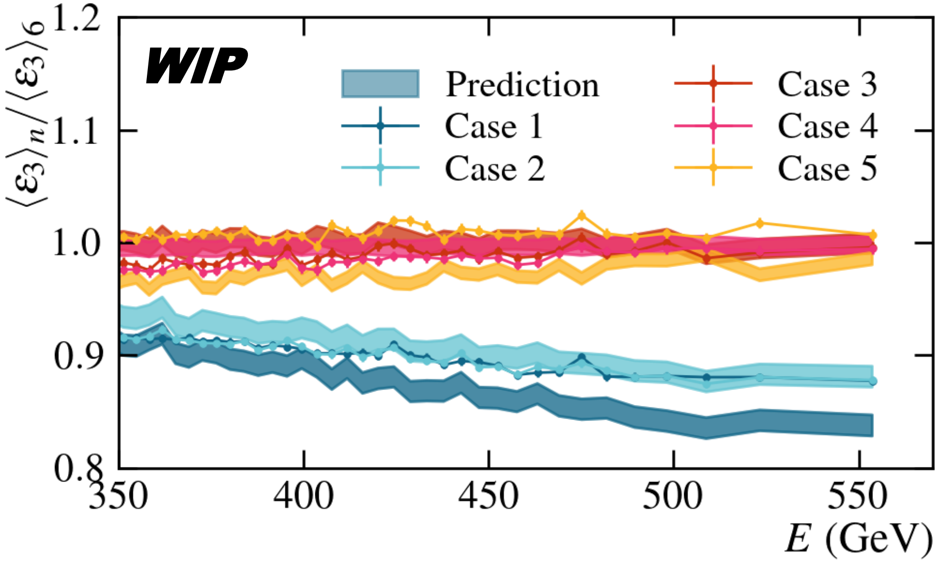
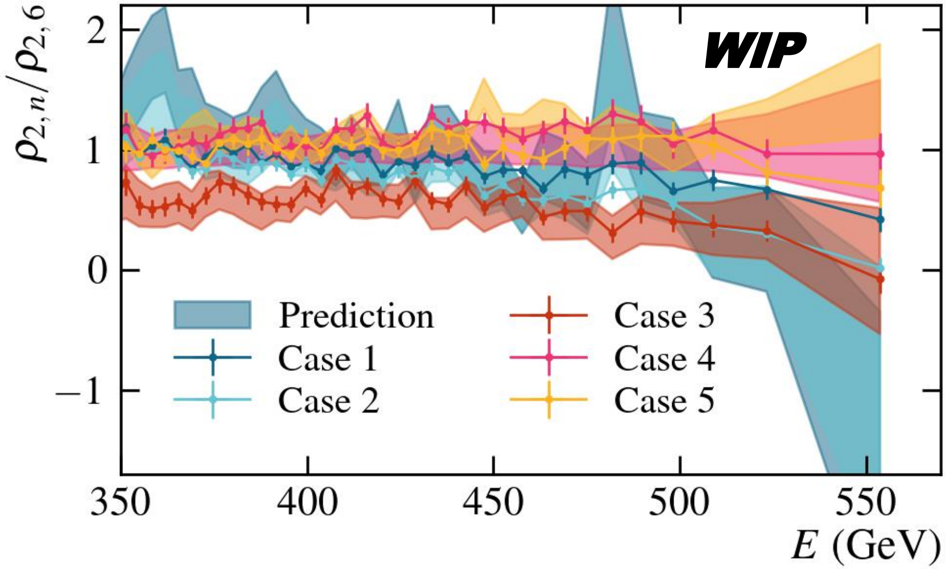
PREDICTING RATIOS



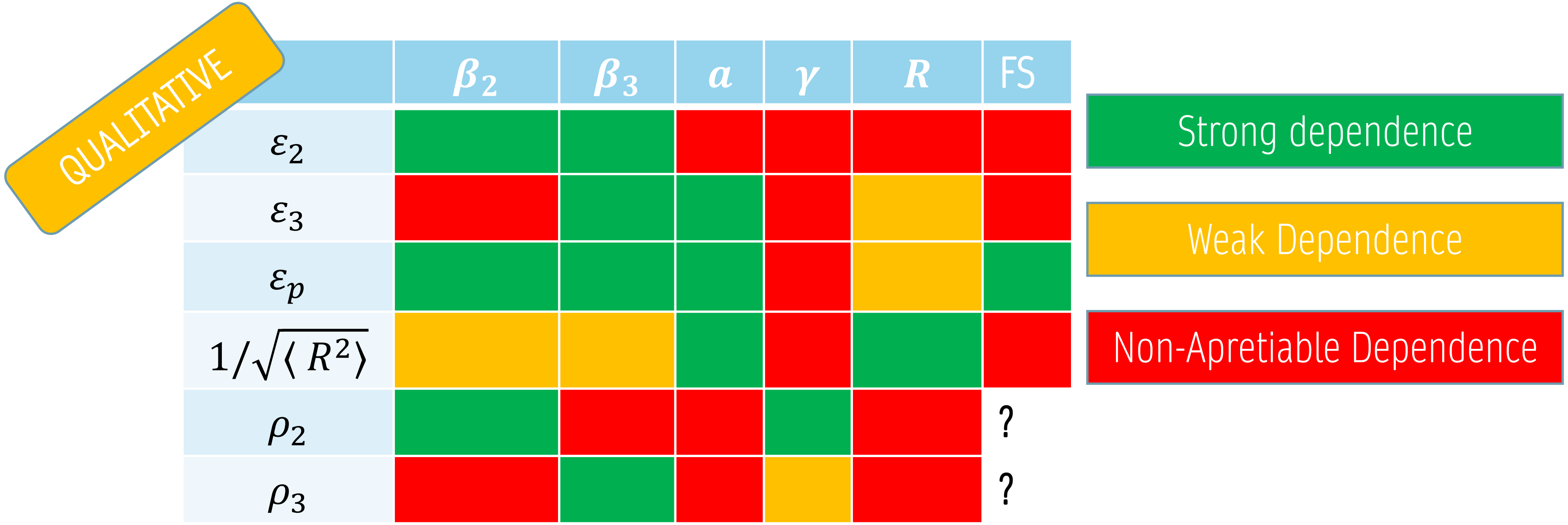




- Overall good descriptions for cases 2, 3 and 4
- Investigating why it does not work for cases 1 and 5
- Once these parameters are determined, could be used for constraining Woods-Saxon parameters deltas in isobar or close-to-isobar systems

SUMMARY

- We showed the effects of freestreaming on several initial State estimators
  - Freestream effects are small on most (but not all cases, e.g. ε_p)



QUALITATIVE

	β_2	β_3	a	γ	R	FS
ε_2	🟩	🟩	🟥	🟥	🟥	🟥
ε_3	🟥	🟩	🟩	🟥	🟨	🟥
ε_p	🟩	🟩	🟩	🟥	🟨	🟩
$1/\sqrt{\langle R^2 \rangle}$	🟨	🟨	🟩	🟥	🟩	🟥
ρ_2	🟩	🟥	🟥	🟩	🟥	?
ρ_3	🟥	🟩	🟥	🟨	🟥	?

🟩 Strong dependence

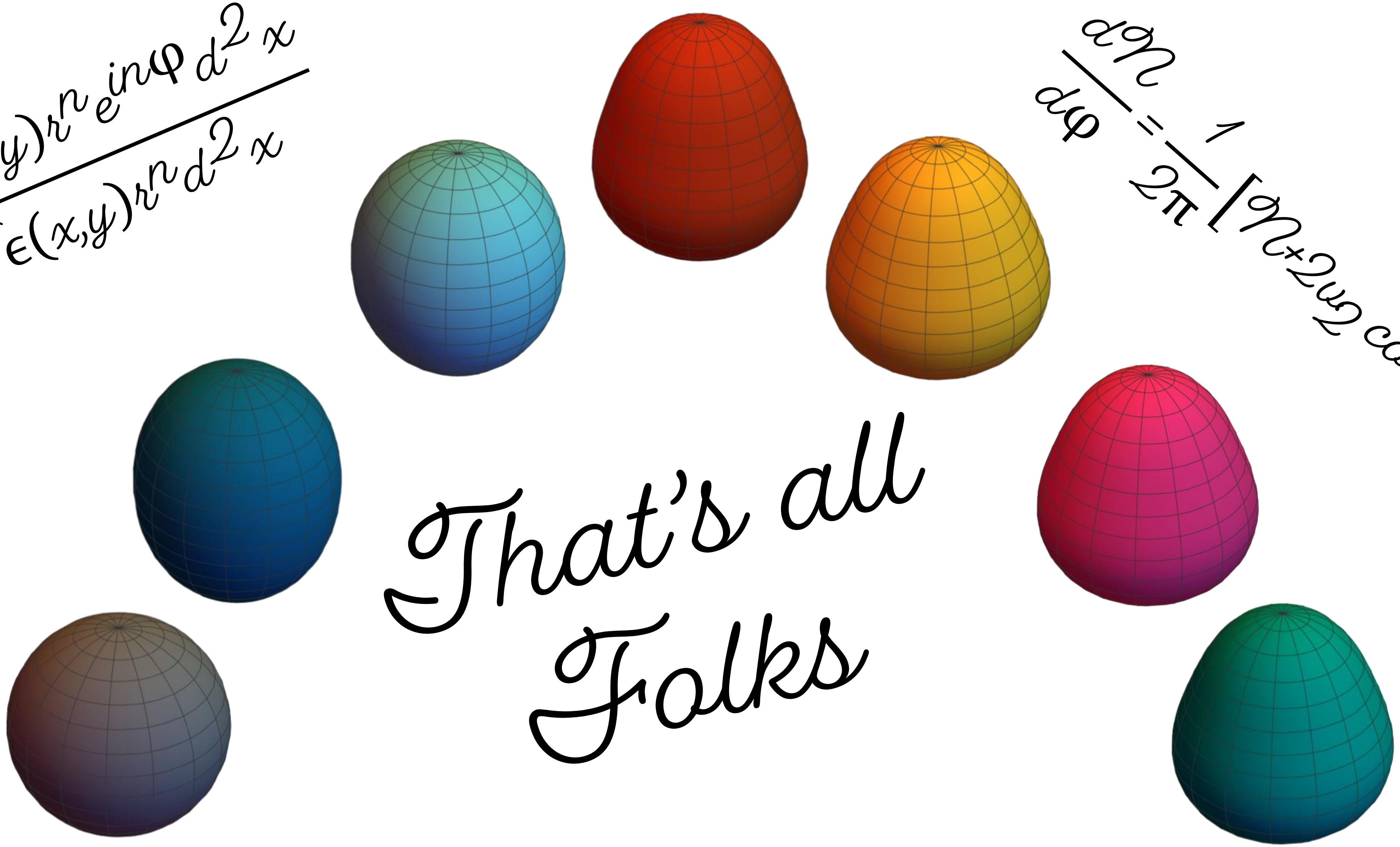
🟨 Weak Dependence

🟥 Non-Apretiable Dependence

  - Similar results should also be applicable for other models such as IP-Glasma and KoMPoST
- Provided estimator used are good predictors, c_n could be used to constraint values Woods-Saxon parameters deltas (See also B. Bally et al. arXiv:2209.11042)

$$\varepsilon_n = \frac{\int \epsilon(x,y) r^n e^{in\varphi} d^2 x}{\int \epsilon(x,y) r^n d^2 x}$$

$$\frac{dN}{d\varphi} = \frac{1}{2\pi}\left[N + 2v_2 \cos 2\varphi + \cdots\right]$$



That's all Folks

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WHAT WE HAVE LEARNED

	β_2	β_3	a	γ	R	FS
ε_2	🟩	🟩	🟥	🟥	🟥	🟥
ε_3	🟥	🟩	🟩	🟥	🟨	🟥
ε_p	🟩	🟩	🟩	🟥	🟨	🟩
$1/\sqrt{\langle R^2 \rangle}$	🟨	🟨	🟩	🟥	🟩	🟥
ρ_2	🟩	🟥	🟥	🟩	🟥	?
ρ_3	🟥	🟩	🟥	🟨	🟥	?

🟩 Strong dependence

🟨 Weak Dependence

🟥 Non-Apretiable Dependence

WHAT WE HAVE LEARNED (CENT ~< 40%)

	β_2	β_3	a	γ	R	FS
ε_2	🟩	🟩	🟥	🟥	🟥	🟥
ε_3	🟥	🟩	🟨	🟥	🟥	🟥
ε_p	🟩	🟩	🟩	🟥	🟨	🟩
$1/\sqrt{\langle R^2\rangle}$	🟩	🟩	🟩	🟥	🟩	🟥

🟩 Strong dependence

🟨 Weak Dependence

🟥 Non-Apretiable Dependence

EFFECTS OF VISCOUS COMPONENTS IN MOMENT ANISOTROPY