INSTITUTE for NUCLEAR THEORY

ABOUT PEOPLE PUBLICATIONS EVENTS

Stony Brook University

Event Schedule

Intersection of nuclear structure and high-energy nuclear collisions

Towards Bayesian constraints on nuclear structure via isobar collisions

Shuzhe Shi (Stony Brook University)

reference:

Yi-Lin Cheng, *SS*, Y.-G. Ma, H Stoecker, K. Zhou, 2301.03910

The isobar program was designed to detect the Chiral Magnetic Effect(CME)

expectation before the isobar collisions:

Correlator[Ru] **>** *Correlator*[Zr] $\Rightarrow$ **CME**

Correlator[Ru] **=** *Correlator*[Zr] $\Rightarrow$ **no CME**

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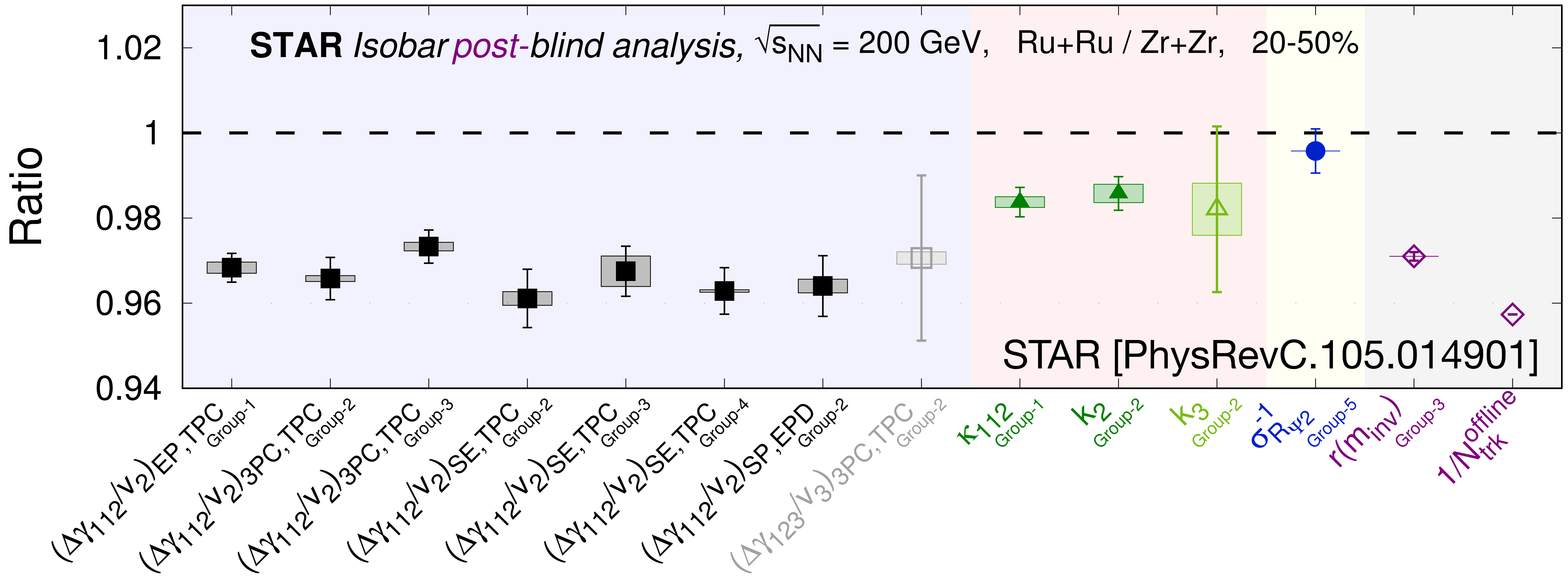
measurement in the isobar collisions:

Correlator[Ru] **<** *Correlator*[Zr]



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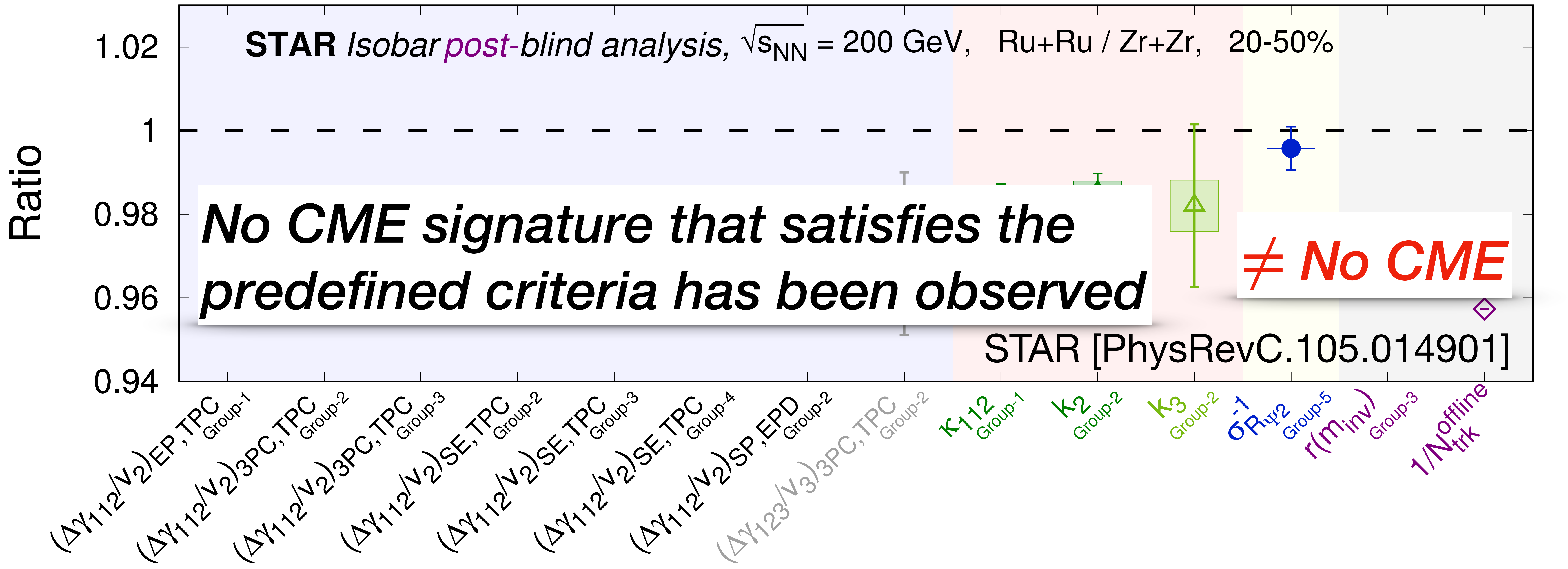
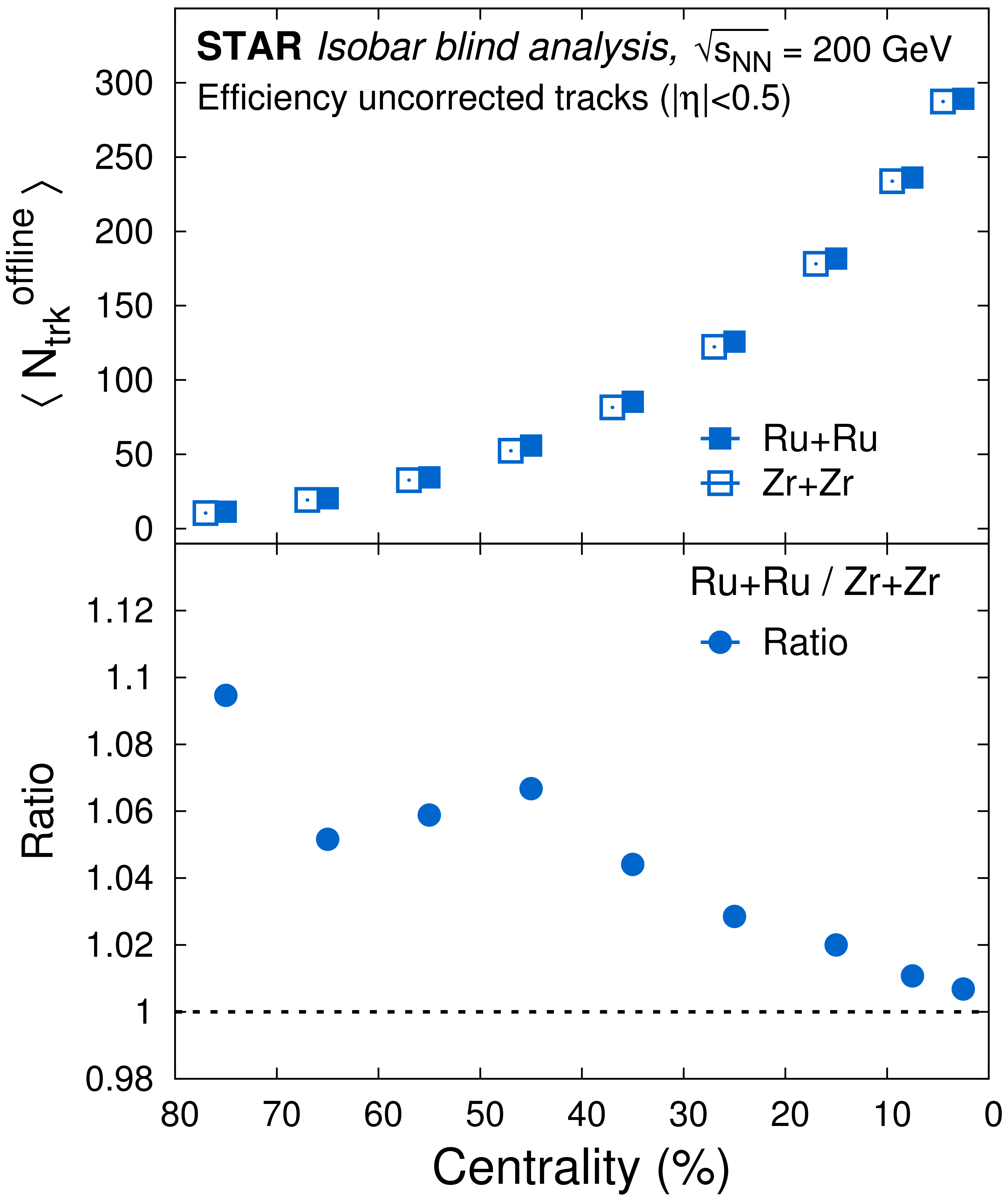
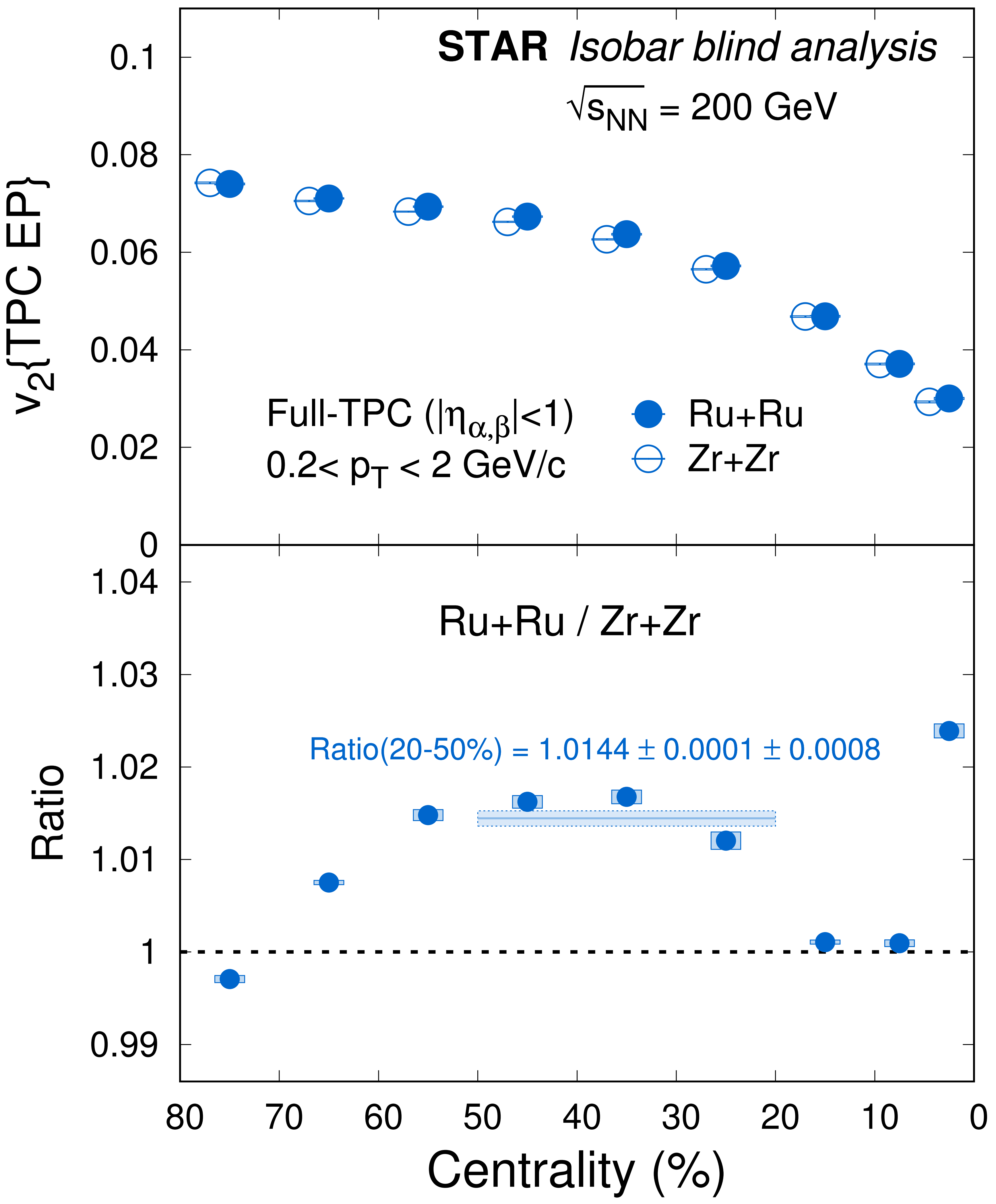


Bulk properties are not identical!





STAR [PhysRevC.105.014901]

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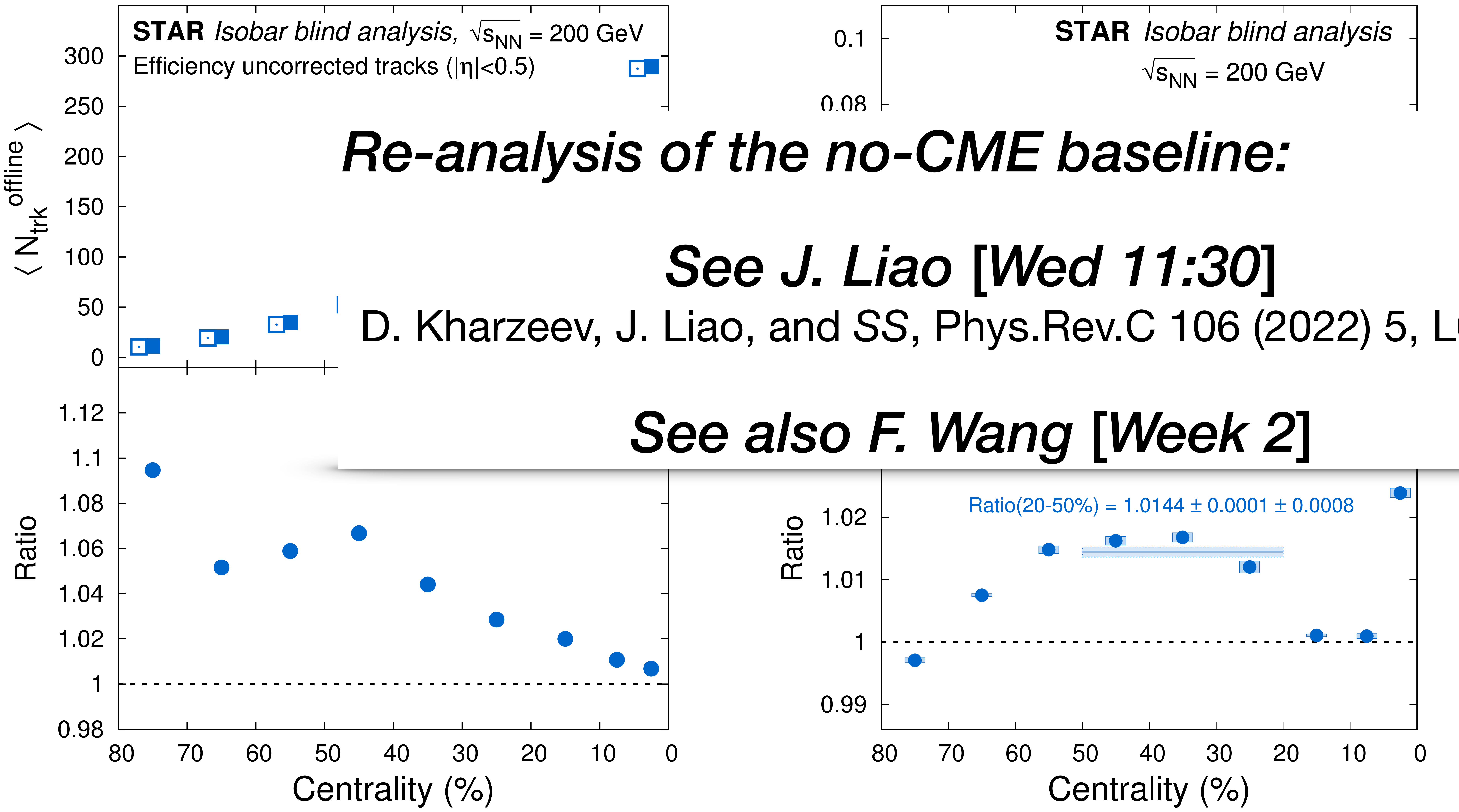


Re-analysis of the no-CME baseline:

See J. Liao [Wed 11:30]

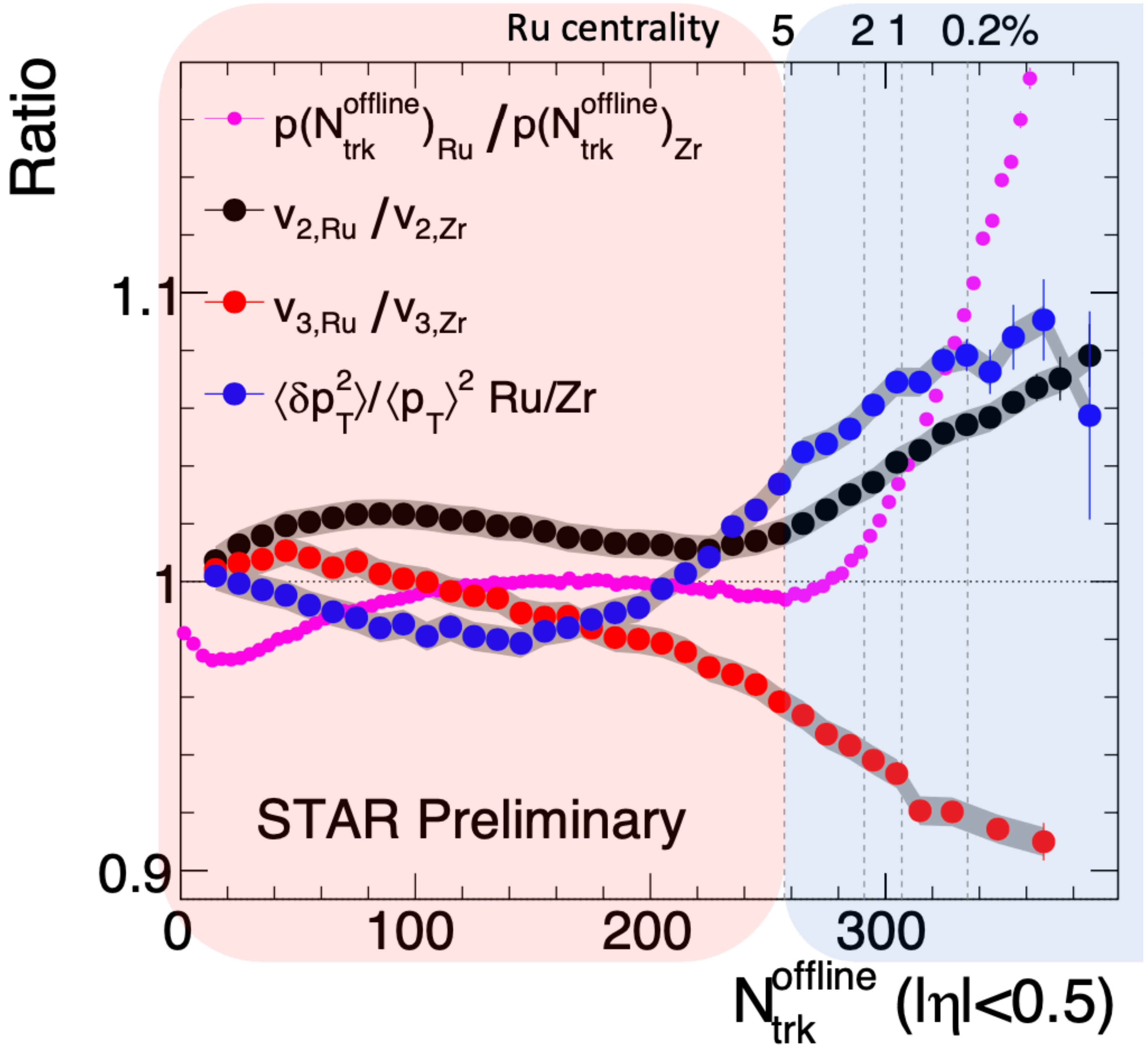
D. Kharzeev, J. Liao, and *SS*, Phys.Rev.C 106 (2022) 5, L051903

See also F. Wang [Week 2]

STAR [PhysRevC.105.014901]

New opportunity!

Giuliano Giacalone, Jiangyong Jia, Chunjian Zhang, et al.



Plot from Chunjian Zhang's talk

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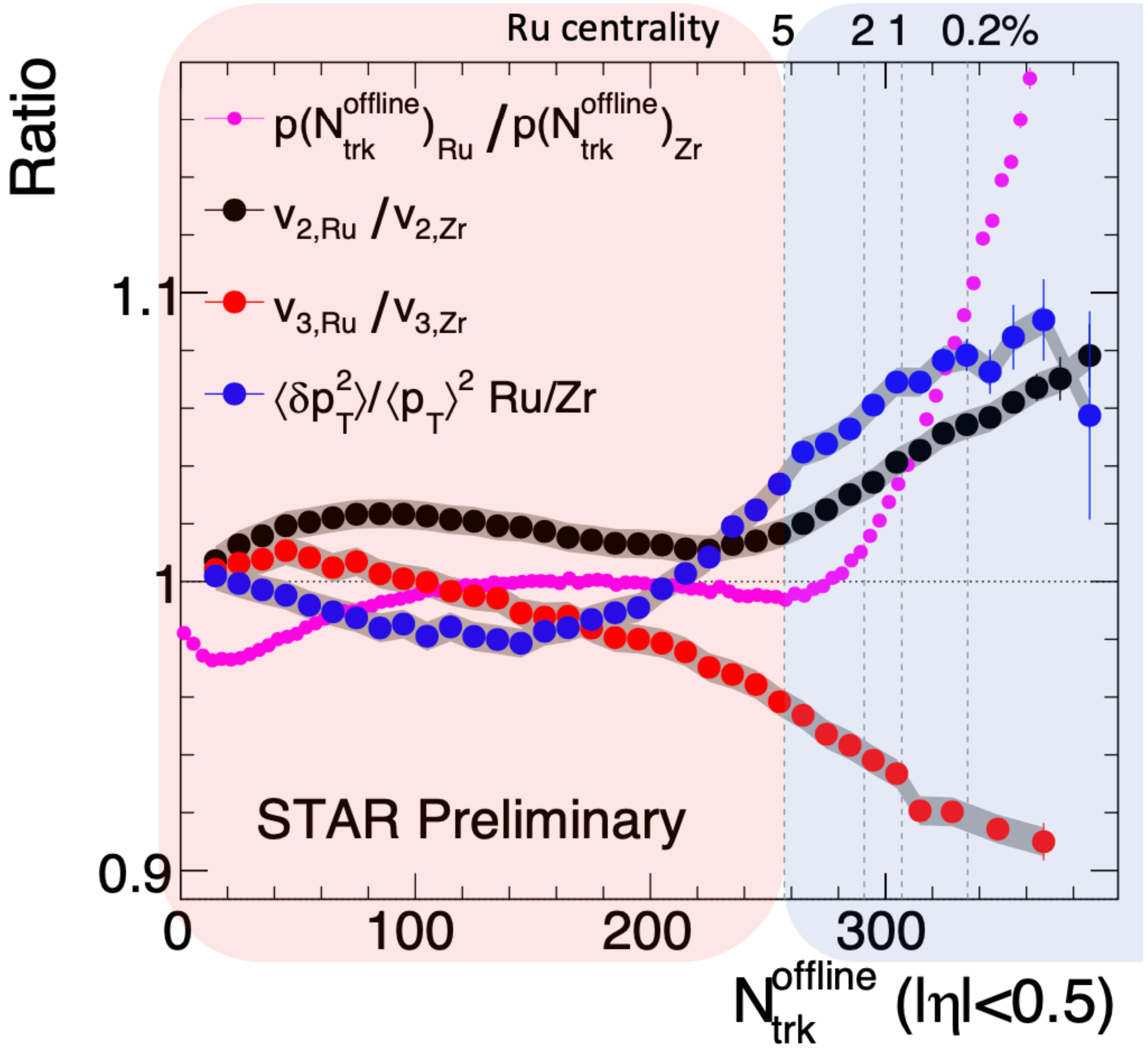

Plot from Chunjian Zhang's talk

*Key argument: **ratios** of observable are **insensitive** to transport details.*

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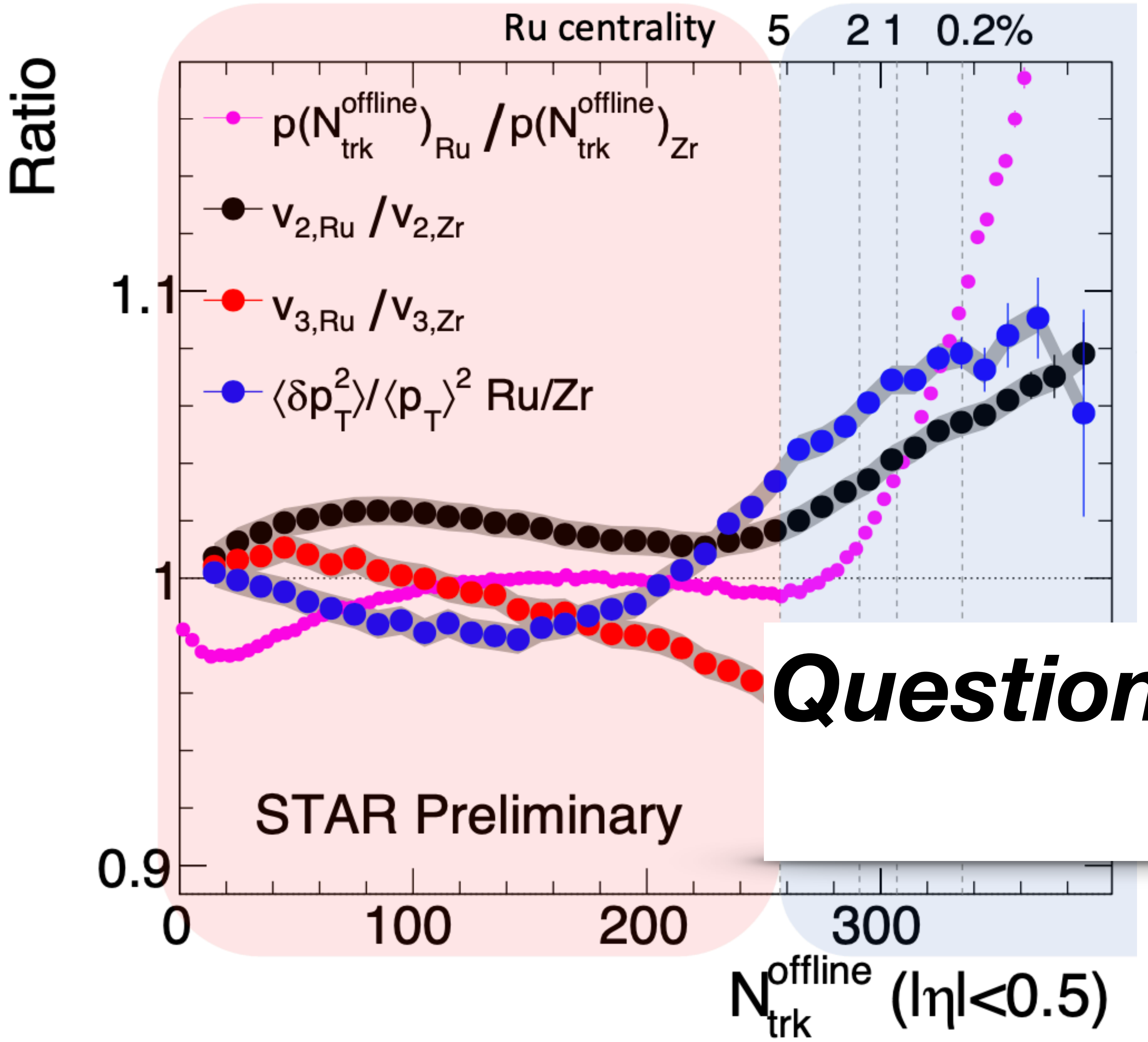

Plot from Chunjian Zhang's talk

*Key argument: **ratios** of observable are **insensitive** to transport details.*

***Question**: can we recover the **nuclear structures** from only the **ratios** of observable?*

- Background: isobar collision ✓

- Proof of concept study:
  - *reconstruct nuclear structures of **both nuclei***

    *from observables and/or **ratios***

Outline

- Background: isobar collision ✓
- Bayesian Inference
- Proof of concept study:
  - *reconstruct nuclear structures of* ***both nuclei***

    from observables and/or ***ratios***
- Summary and outlook

Bayesian Inference

$$L(\text{parameter} \mid \text{data}) \propto P(\text{data} \mid \text{parameter}) \times \text{Prior}(\text{parameter})$$

Bayesian Inference

nuclear structure

heavy-ion collision observables

$$L(\text{parameter}\,|\,\text{data}) \propto P(\text{data}\,|\,\text{parameter}) \times \text{Prior}(\text{parameter})$$

$L(\text{parameter}\,|\,\text{data})$: likelihood of structure parameter given HIC data

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$P(\text{data}\,|\,\text{parameter})$: probability HIC data given ***model***

$$P(\text{data}\,|\,\text{parameter}) \propto \exp\left(-\frac{\Sigma_{a,b}^{-1}}{2}(y_a^{\text{model}} - y_a^{\text{exp}})(y_b^{\text{model}} - y_b^{\text{exp}}) \right)$$

Bayesian Inference

nuclear structure

heavy-ion collision observables

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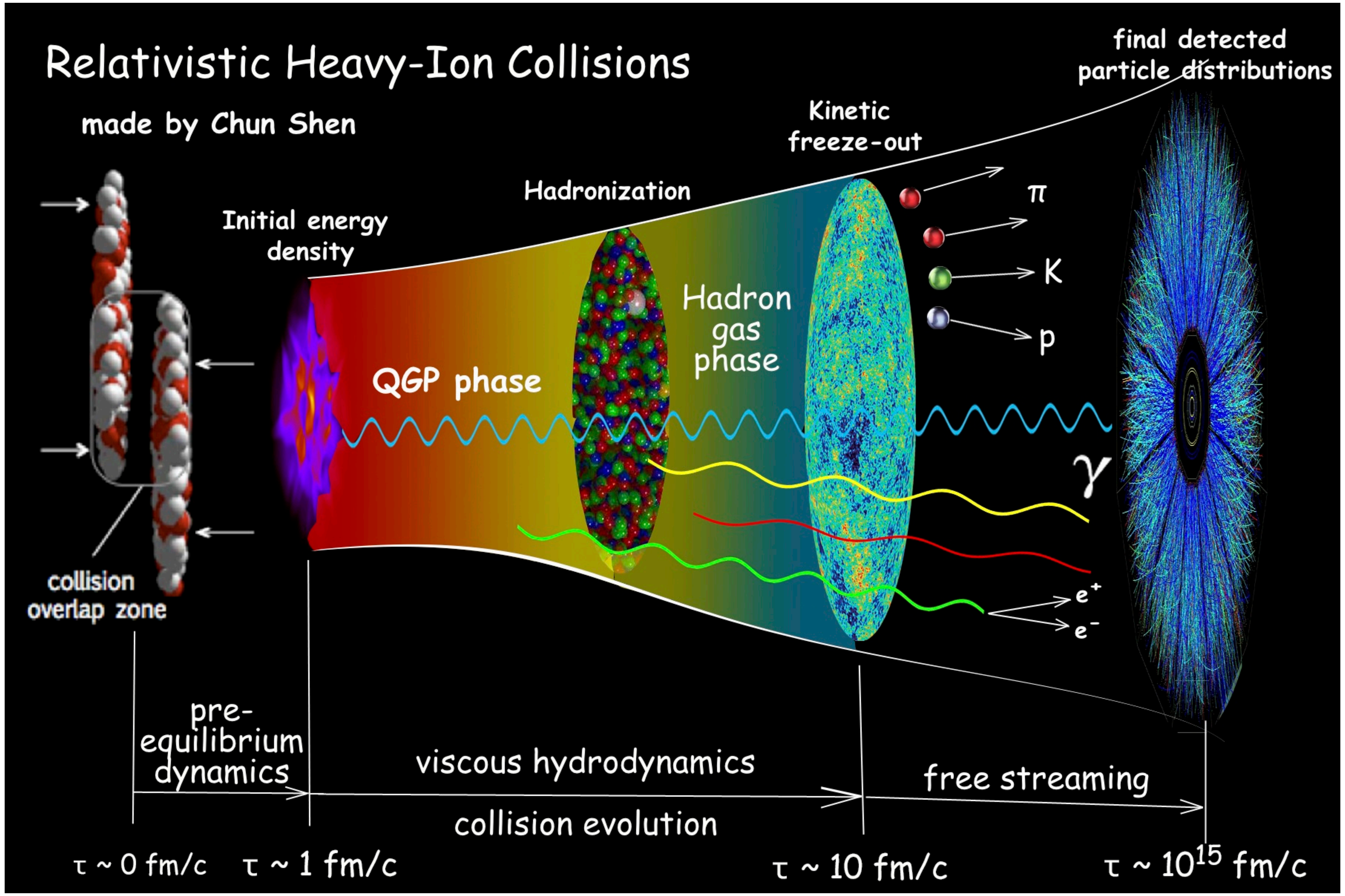
Model needed to map the nuclear structure to final state observables



Model needed to map the nuclear structure to final state observables

initial		final
E	$\Rightarrow$	N_{ch}
ε_2	$\Rightarrow$	v_2
ε_3	$\Rightarrow$	v_3
$d_\perp$	$\Rightarrow$	$\langle p_T \rangle$

Monte-Carlo Glauber as Estimator

As a *proof of concept* study, assumed "perfect" Monte-Carlo Glauber modeling:

initial		final
E	$\Rightarrow$	$N_{ch} = \lambda_N E$
ε_2	$\Rightarrow$	$v_2 = \lambda_2 \varepsilon_2$
ε_3	$\Rightarrow$	$v_3 = \lambda_3 \varepsilon_3$
$d_\perp$	$\Rightarrow$	$\langle p_T \rangle = f(d_\perp)$

"perfect mappings"

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MC Glauber

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fill histograms

nuclear structure

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fill histograms

nuclear structure

"observables"

$$\rho(r,\theta,\phi) = \frac{\rho_0}{1 + \exp[r - R(\theta,\phi)]/a}, \qquad R(\theta,\phi) = R \times (1 + \beta_2 Y_2^0 + \beta_3 Y_3^0 + \cdots),$$

Monte-Carlo Glauber as Estimator

As a *proof of concept* study, assumed "perfect" Monte-Carlo Glauber modeling:

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nuclear structure

R, a, β_2, β_3

"observables"

"experiments"

Markov Chain Monte Carlo (MCMC)

each parameter set

"scan" R, a, β_2, β_3 space

compute χ^2

$L(R, a, \beta_2, \beta_3) \propto \exp(-\chi^2/2)$

Markov Chain Monte Carlo (MCMC)

each parameter set

Emulator +
Markov Chain MC

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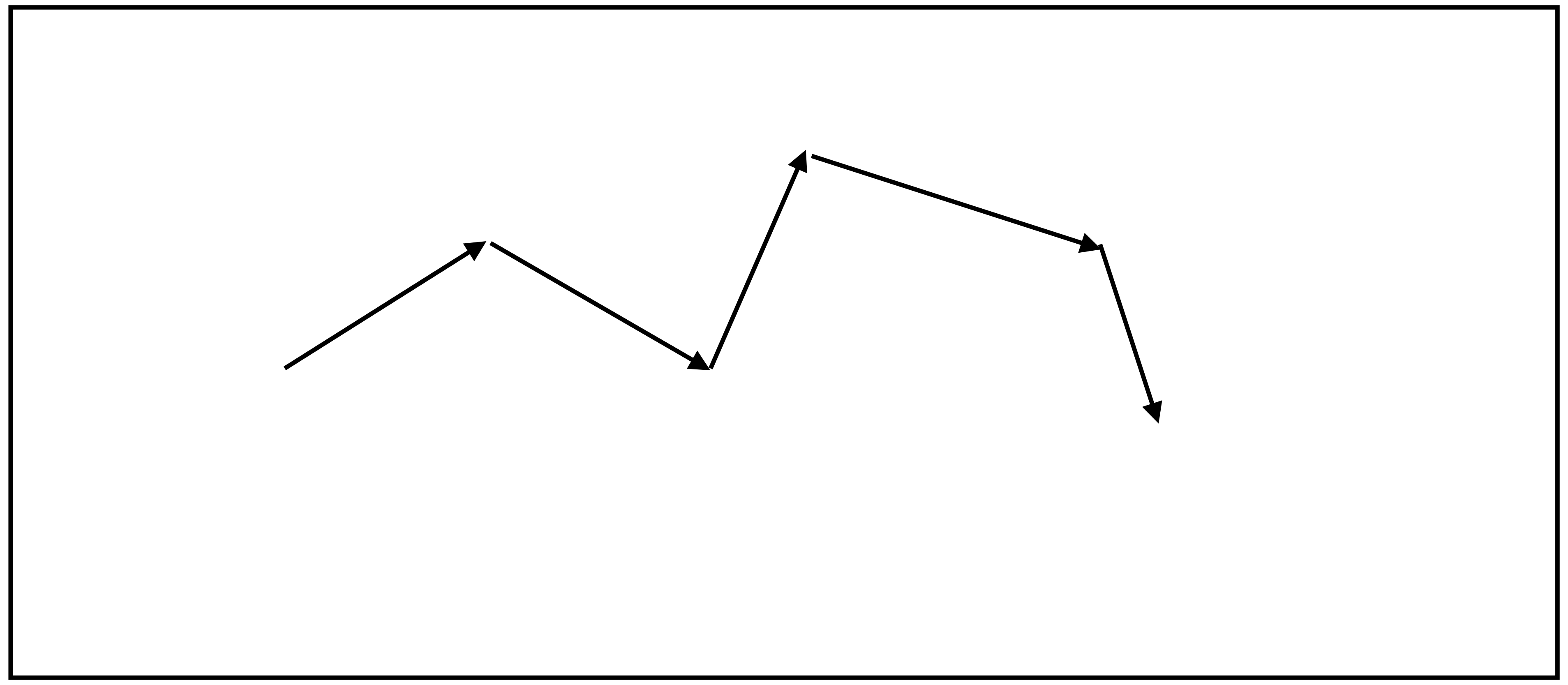
parameter space



$$P_{\mathrm{keep}} = \min\left[1, \frac{\exp(-\chi^2_{\mathrm{next}}/2)}{\exp(-\chi^2_{\mathrm{prev}}/2)}\right]$$

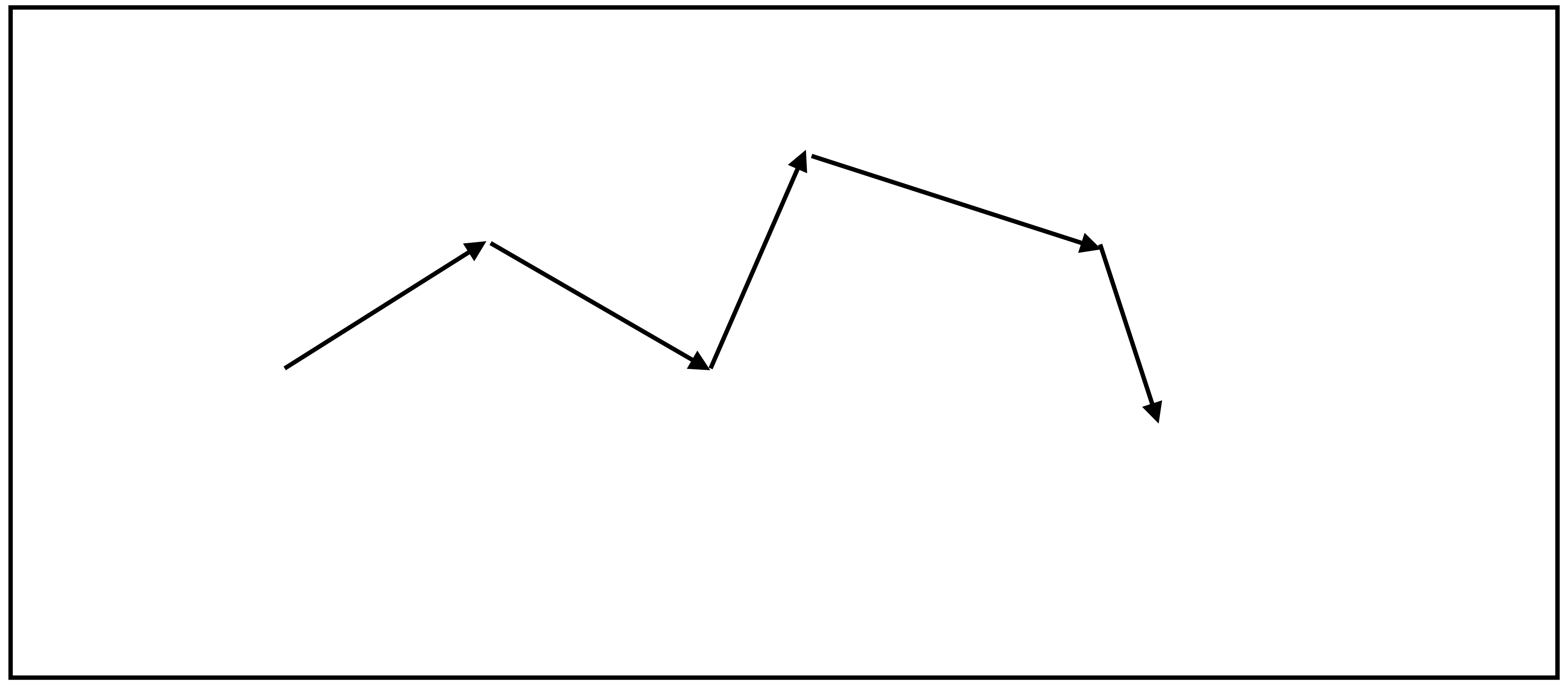
Markov Chain Monte Carlo (MCMC)

Emulator + Markov Chain MC

"scan" R, a, β_2, β_3 space

$$L(R, a, \beta_2, \beta_3) \propto \exp(-\chi^2/2)$$

parameter space



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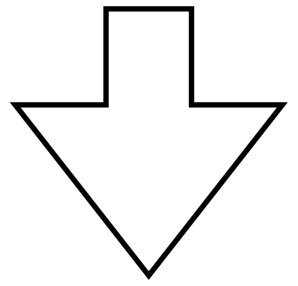

ensemble of parameter sets that follows the likelihood distribution

single system test

1. start from ***known*** parameters;

2. run ***high-stat MCGlauber*** sim. and use it as ***mock data***;

3. run MCMC and reconstruct WS parameters from ***mock data***.

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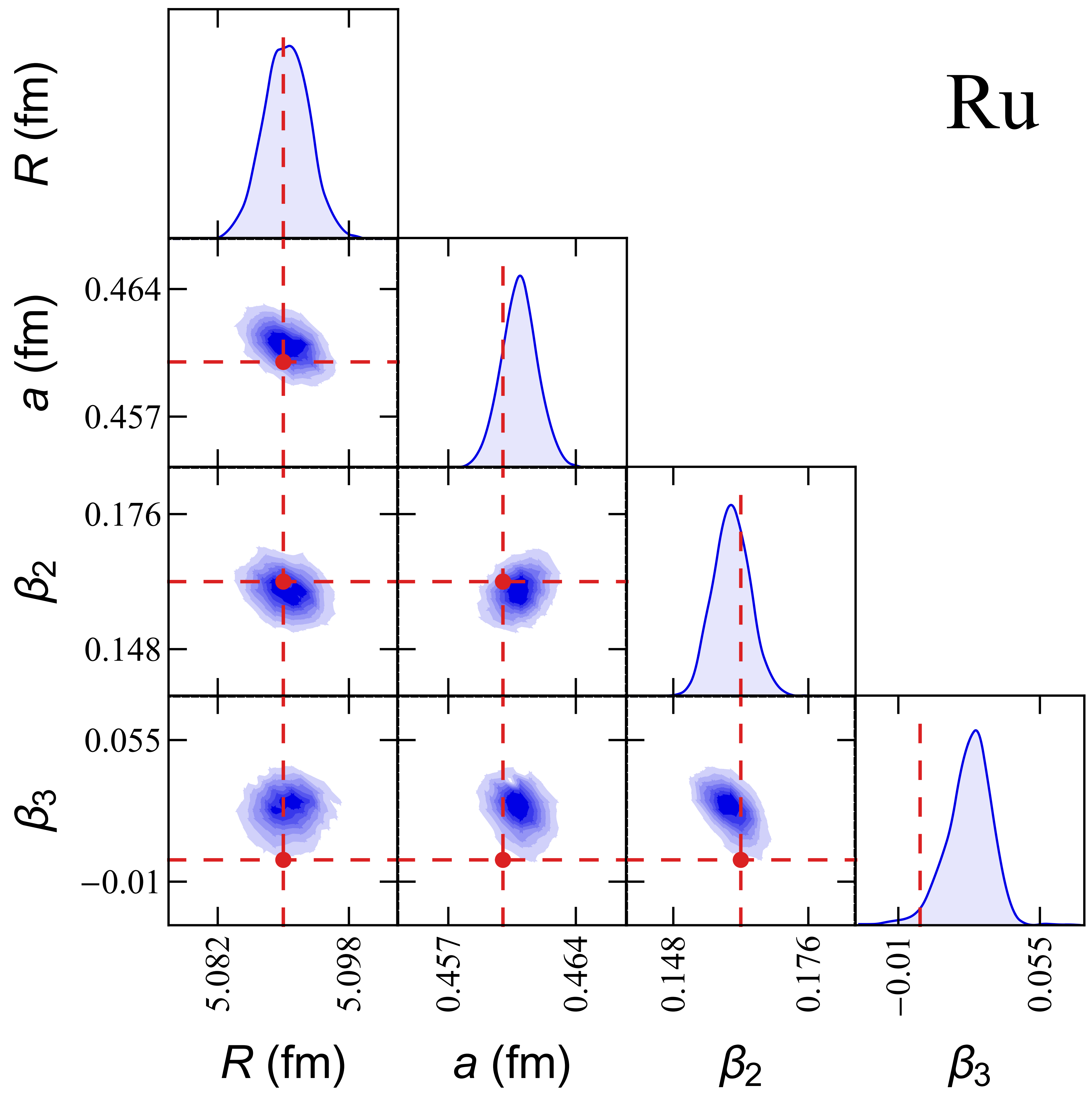
1d and 2d marginal distribution



red dots/lines: ground truth

single system test

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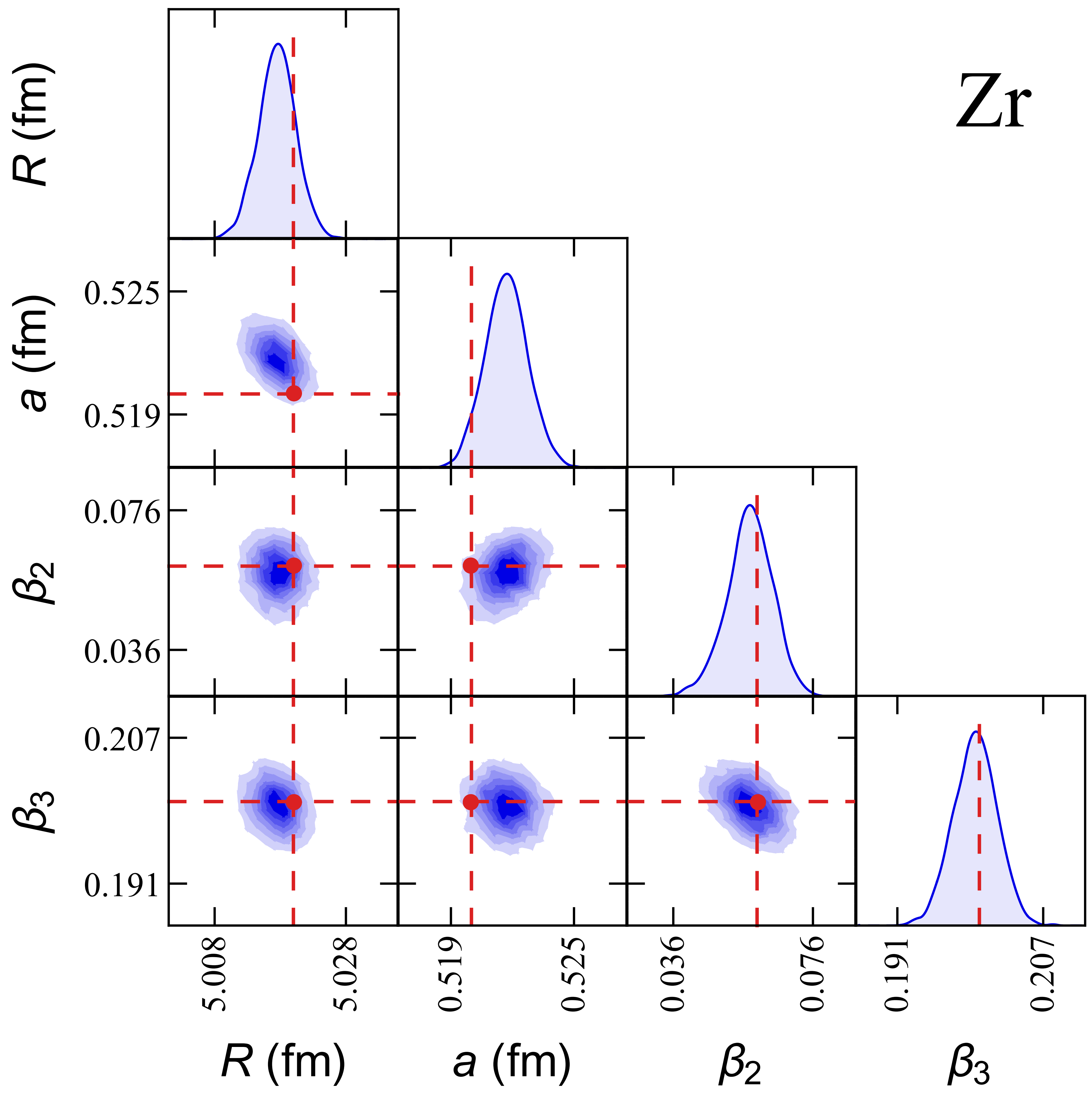


red dots/lines: ground truth

isobar pair?

single system

1. start from ***known*** parameters;

2. run ***high-stat MCGlauber*** sim. and use it as ***mock data***;

3. run MCMC and reconstruct WS parameters from ***mock data***.

isobar system

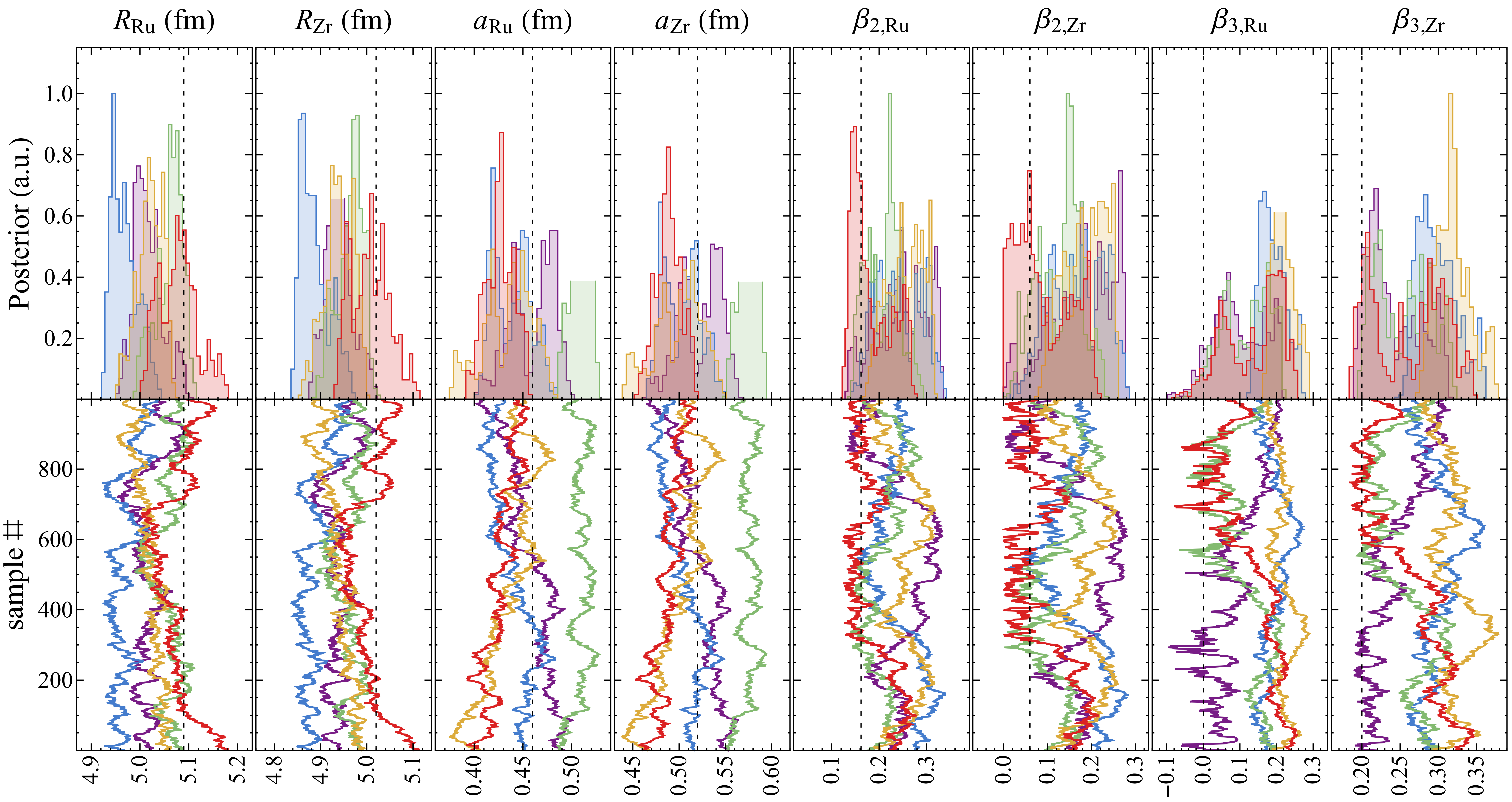
1. start from ***two*** parameter sets;

2. take ***Ru to Zr ratio*** as ***mock data***;

3. run MCMC and ***simultaneously*** reconstruct Ru and Zr WS parameters.

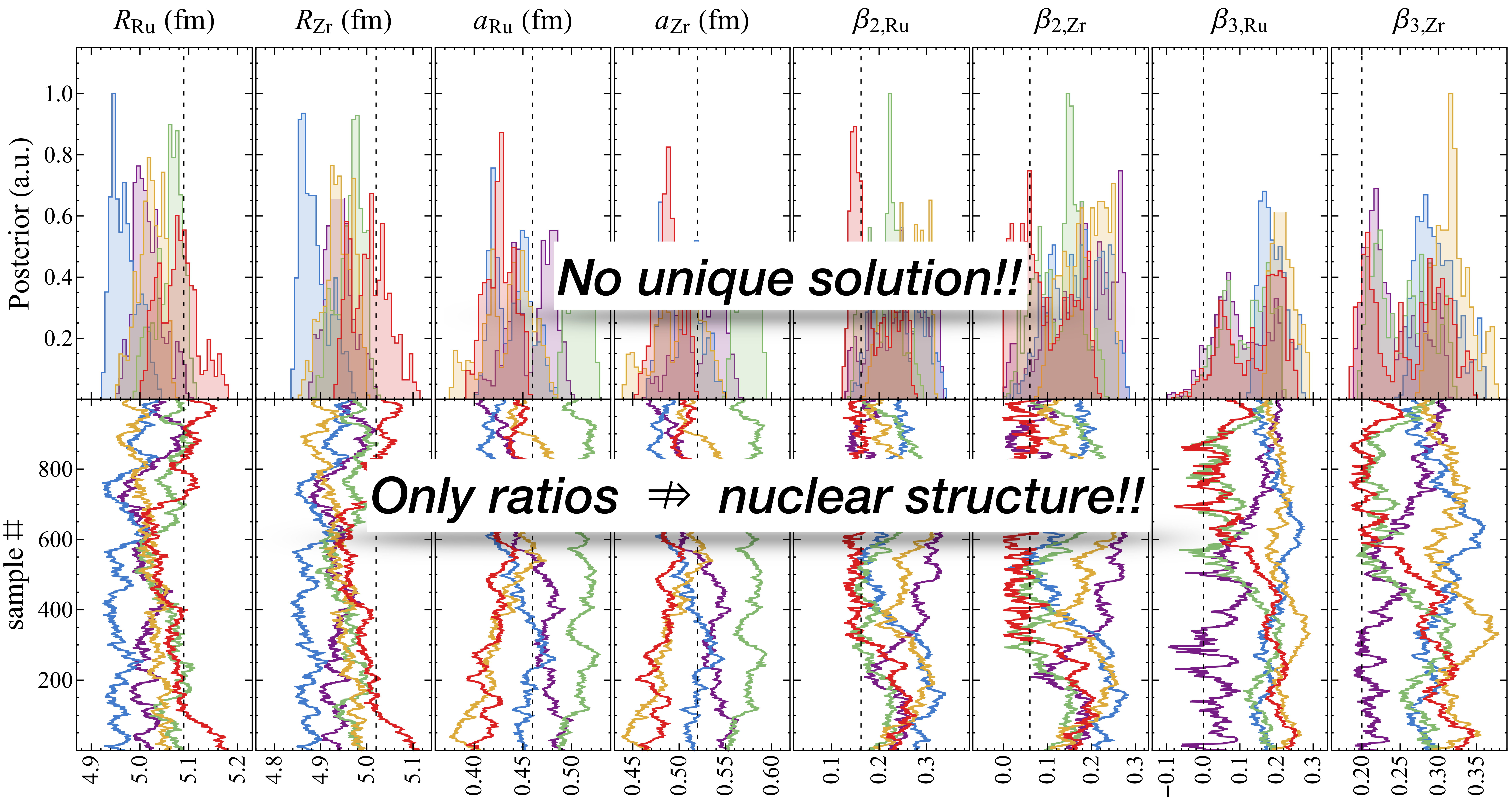
isobar pair

observables: $R[P(N_{ch})], R[v_2], R[v_3], R[\langle p_T \rangle]$



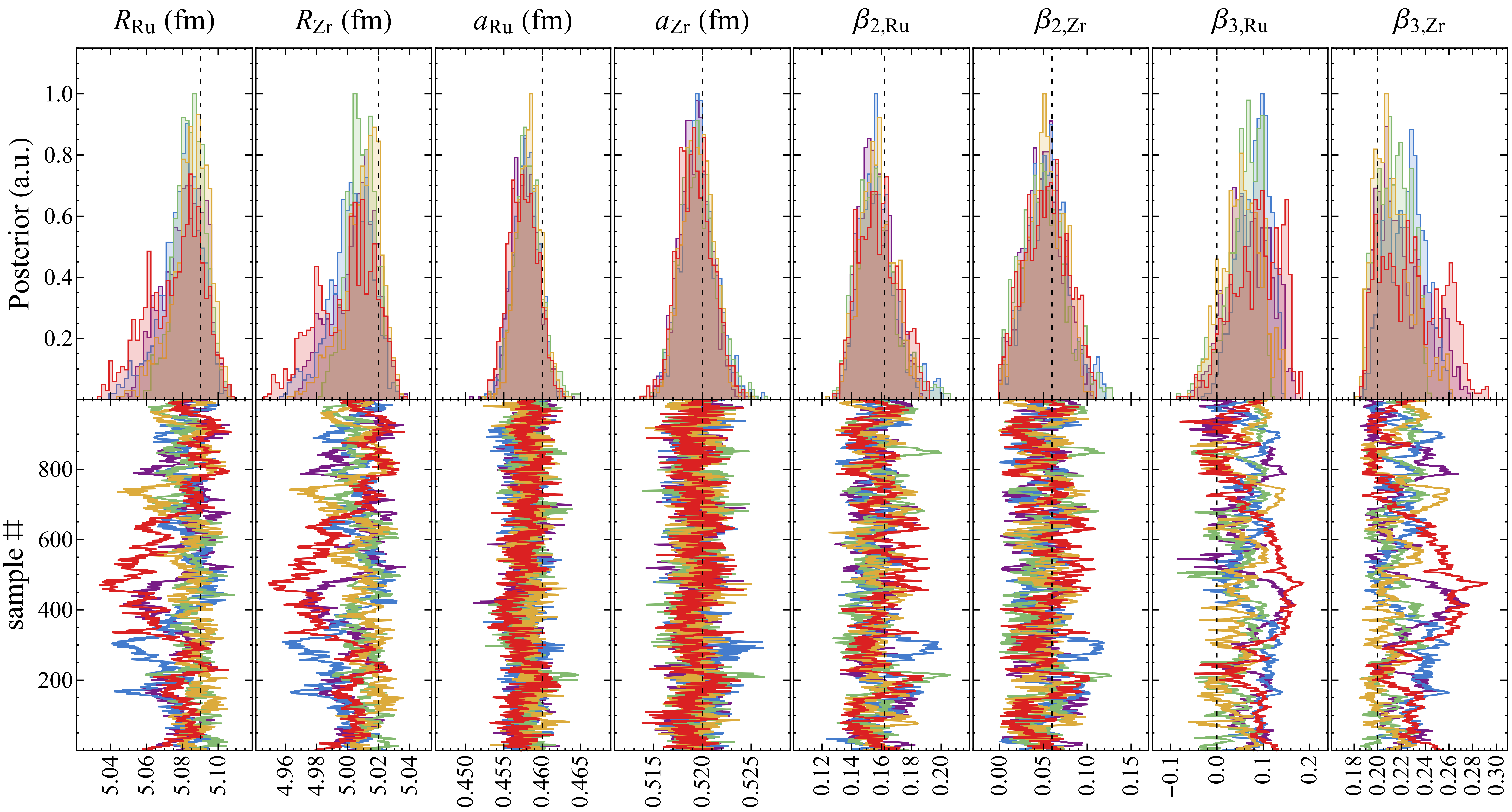
isobar pair

observables: $R[P(N_{ch})], R[v_2], R[v_3], R[\langle p_T \rangle]$



isobar pair

observables: $P^{\mathrm{Ru}}(N_{ch}), P^{\mathrm{Zr}}(N_{ch}), R[v_2], R[v_3], R[\langle p_T \rangle]$



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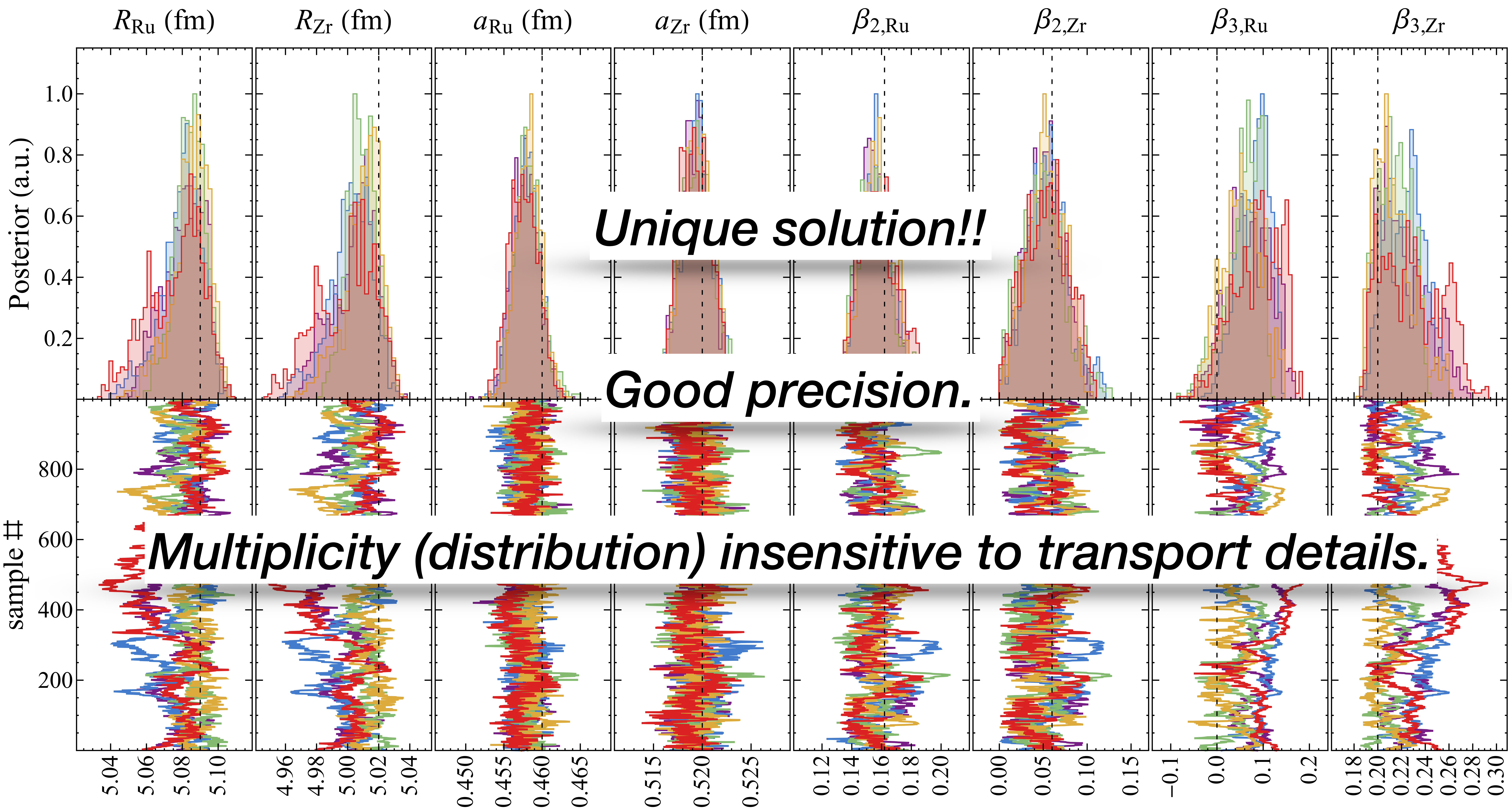

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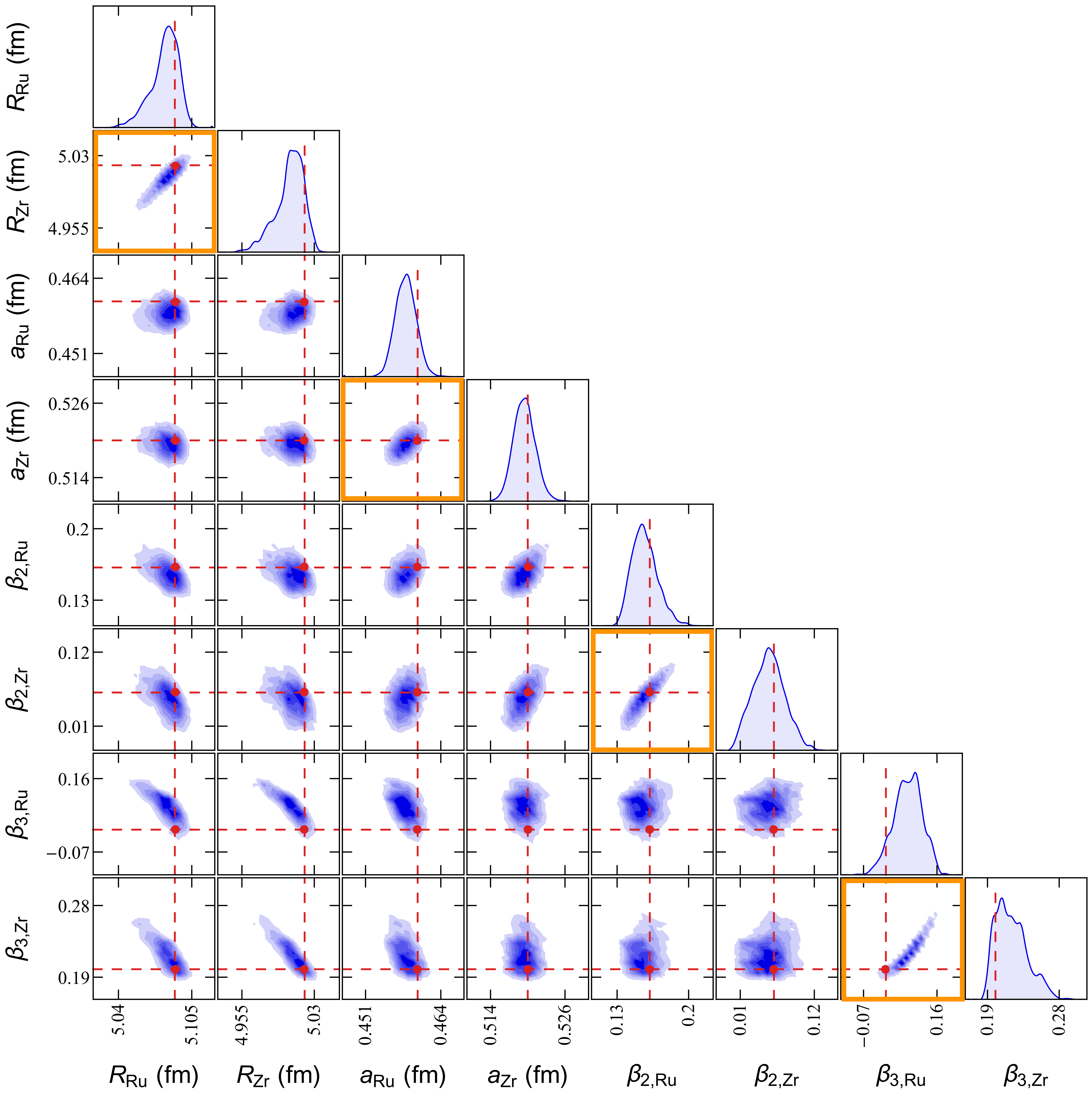

observable ratio =>
same parameter correlation

Summary and Outlook

- proof of concept study: "perfect" initial-final mapping assumed
- single system
    - observable $\Rightarrow$ nuclear structure
- isobar pair
    - only ratio of obs. $\nRightarrow$ nuclear structures
    - multiplicity distribution + ratio of other obs. $\Rightarrow$ nuclear structures
- Outlook: more realistic model needed; AMPT-based in progress.