Impact Parameter Dependence of Isospin Diffusion in Heavy Ion Collisions

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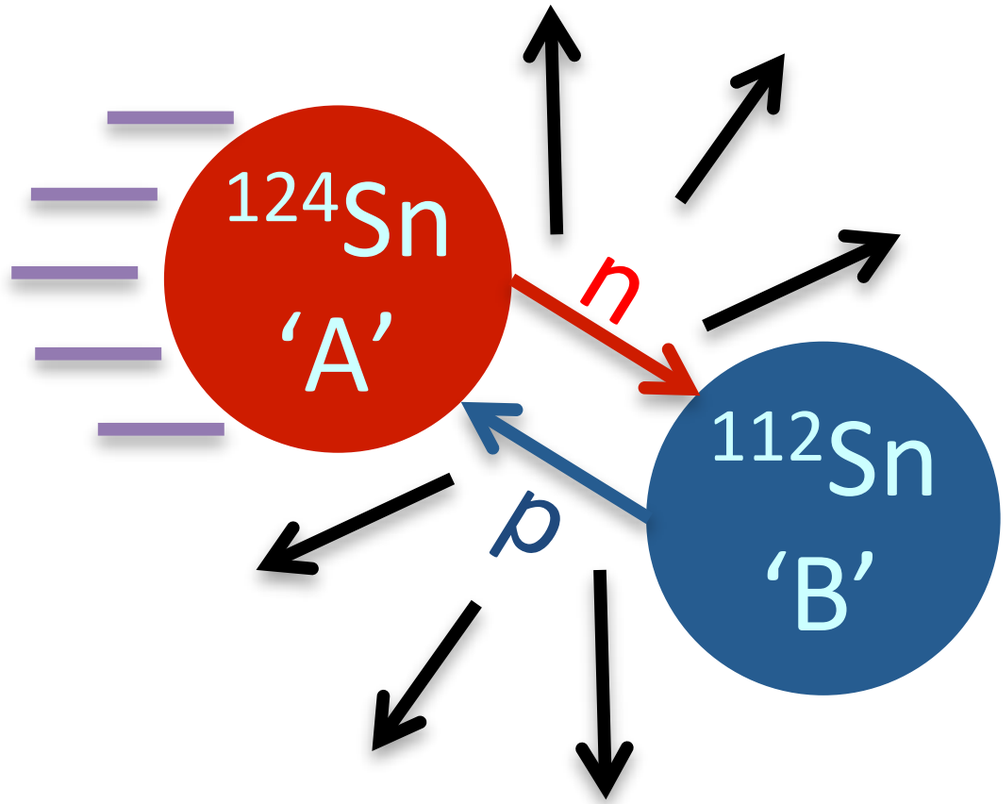
Outline

- **How do we measure Isospin Diffusion?**

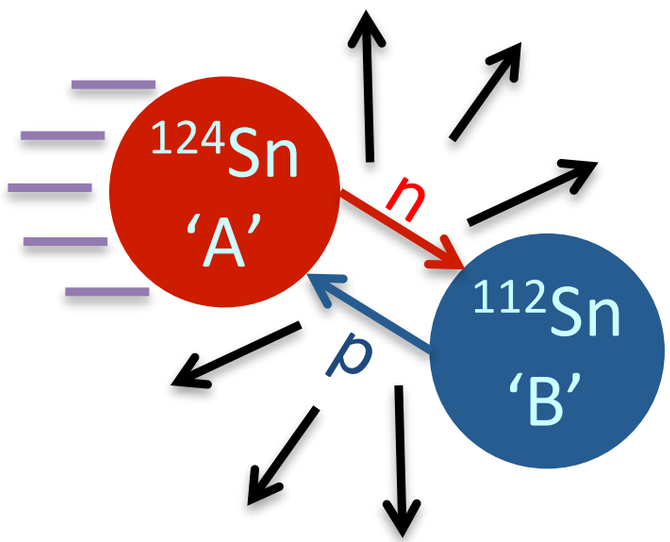
- **What we measured at NSCL?**

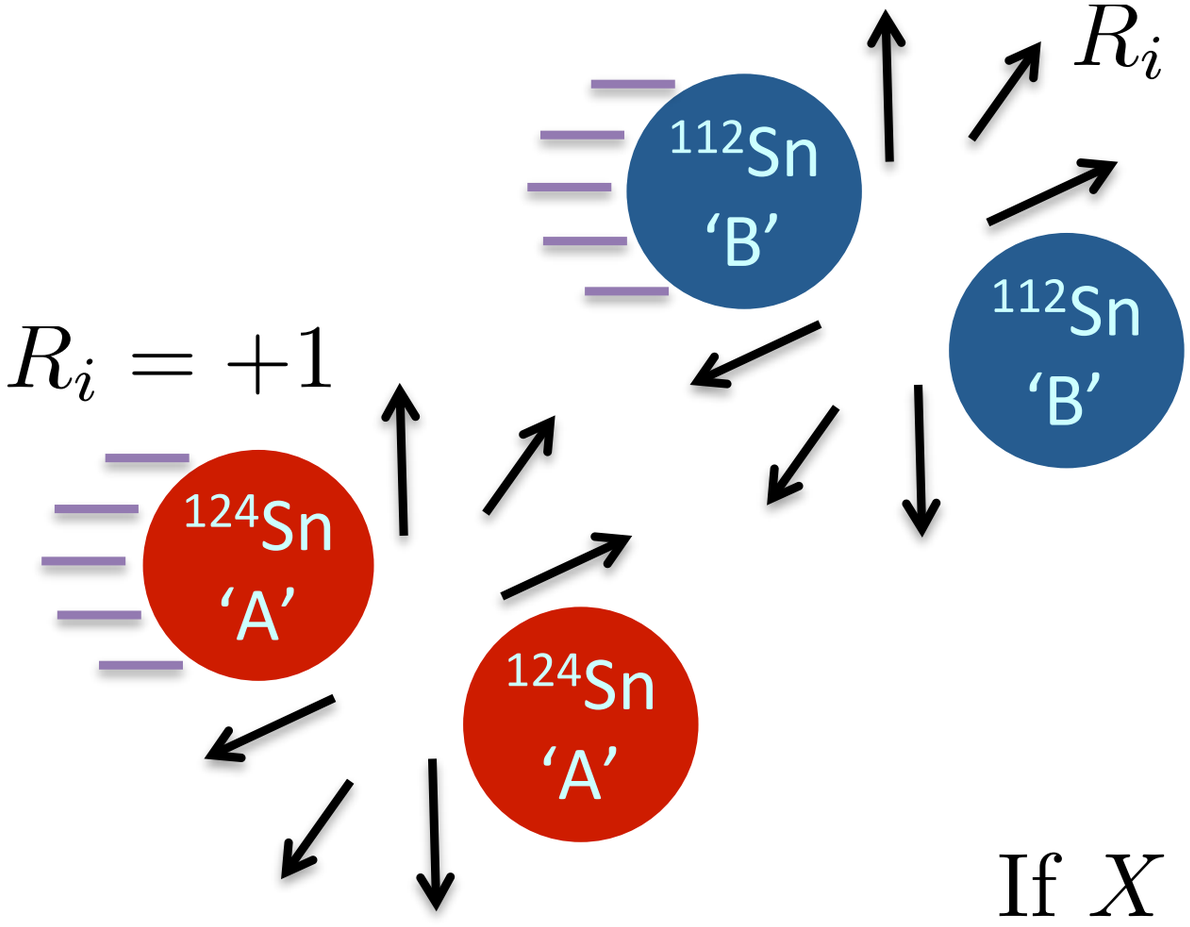
- **How can we compare to transport simulations?**



Isospin Diffusion

- Isospin gradient drives diffusion
- Measure some observable X which is related to δ.





- Diffusion-Free baseline
- Compare using Isospin Transport Ratio

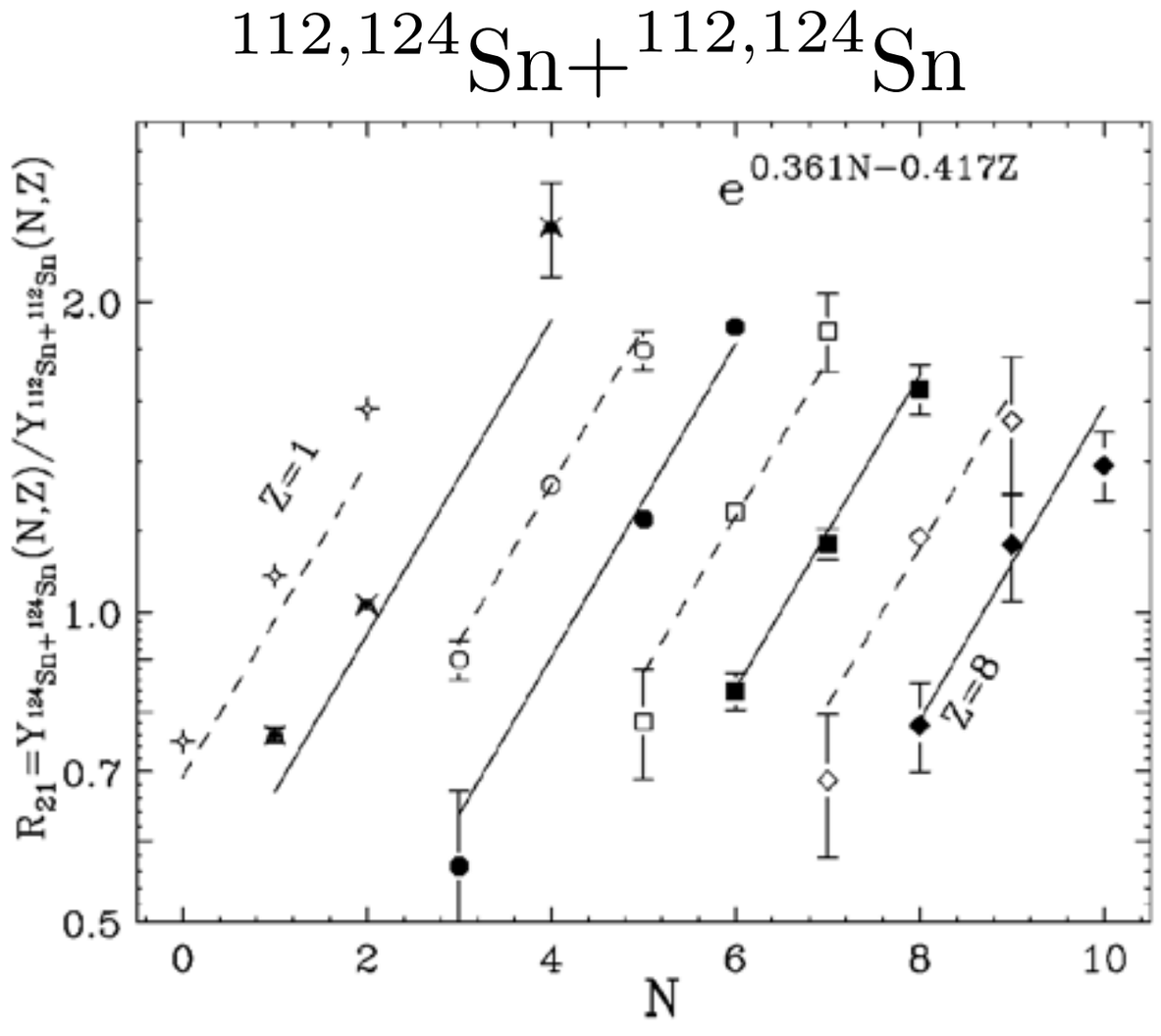
$$R_i = \frac{2X - (X_{A+A} + X_{B+B})}{X_{A+A} - X_{B+B}}$$

$$\text{If } X = a\delta + b, \text{ then } R_i(X) = R_i(\delta)$$

Isoscaling from Multifragmentation

- Isotopic scaling ("isoscaling") in central collisions of Sn+Sn

$$R_{21} = \frac{Y_2(N,Z)}{Y_1(N,Z)} = Ce^{\alpha N + \beta Z}$$

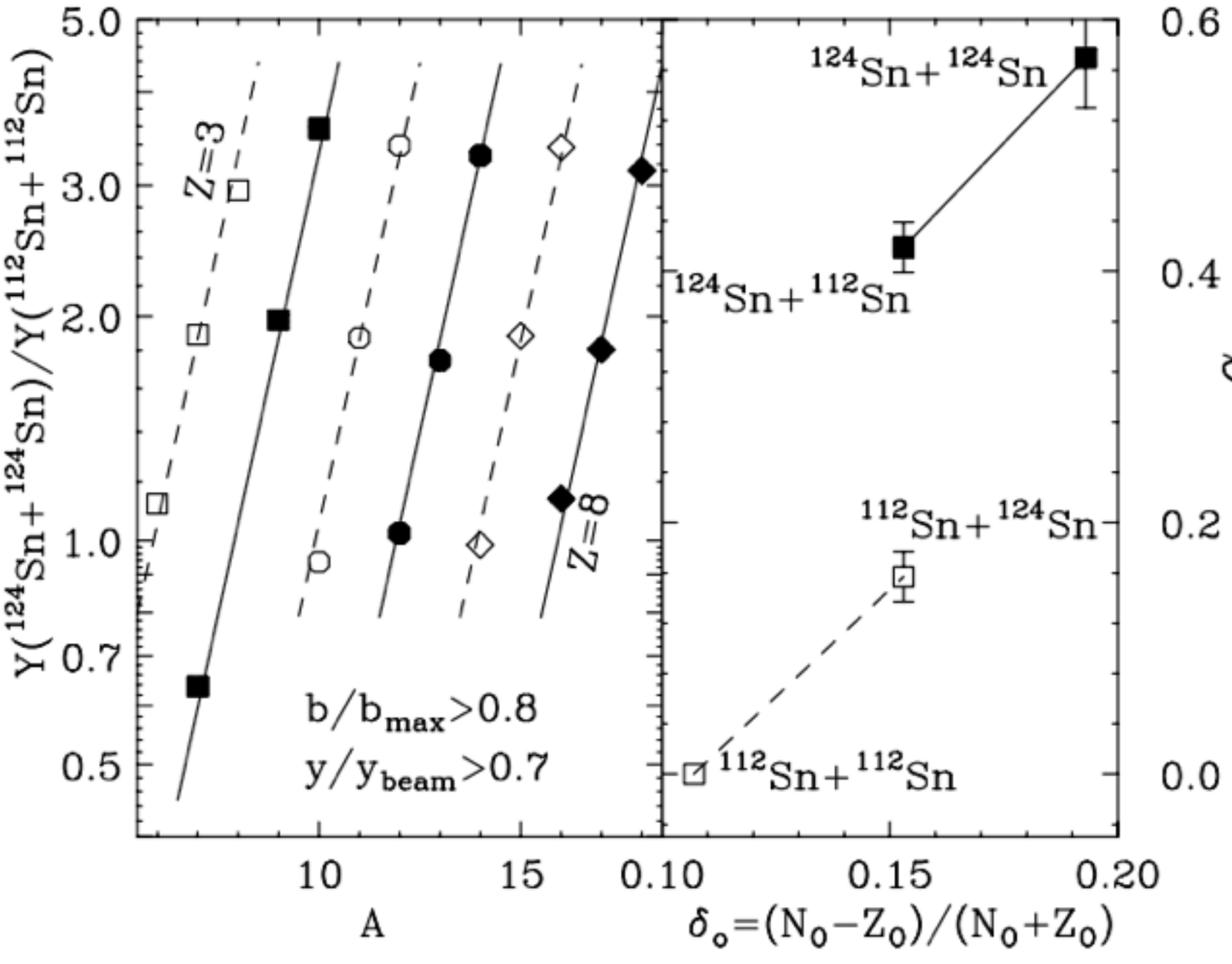


Xu et al., PRL **85**, 716 (2000)

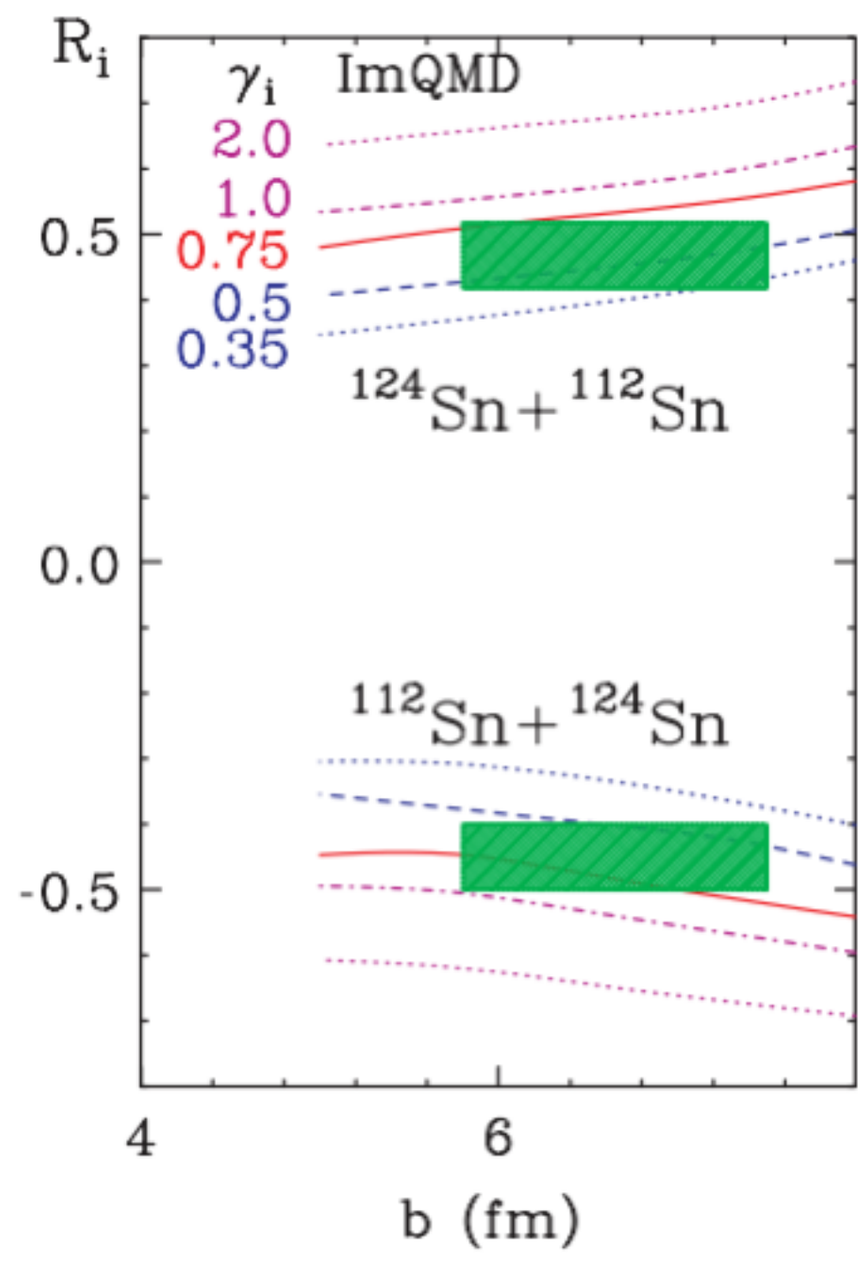
- Statistical Models:

$$\alpha = \frac{\mu_{n,2} - \mu_{n,1}}{T} \approx \frac{4C_{sym}}{T}\left(\left(\frac{Z_1}{N_1}\right)^2 - \left(\frac{Z_2}{N_2}\right)^2\right)$$

Isospin Diffusion: Isoscaling of Intermediate Mass Fragments



Tsang et al., PRL **92**, 62701 (2004)



Tsang et al., PRL102, 122701 (2009)

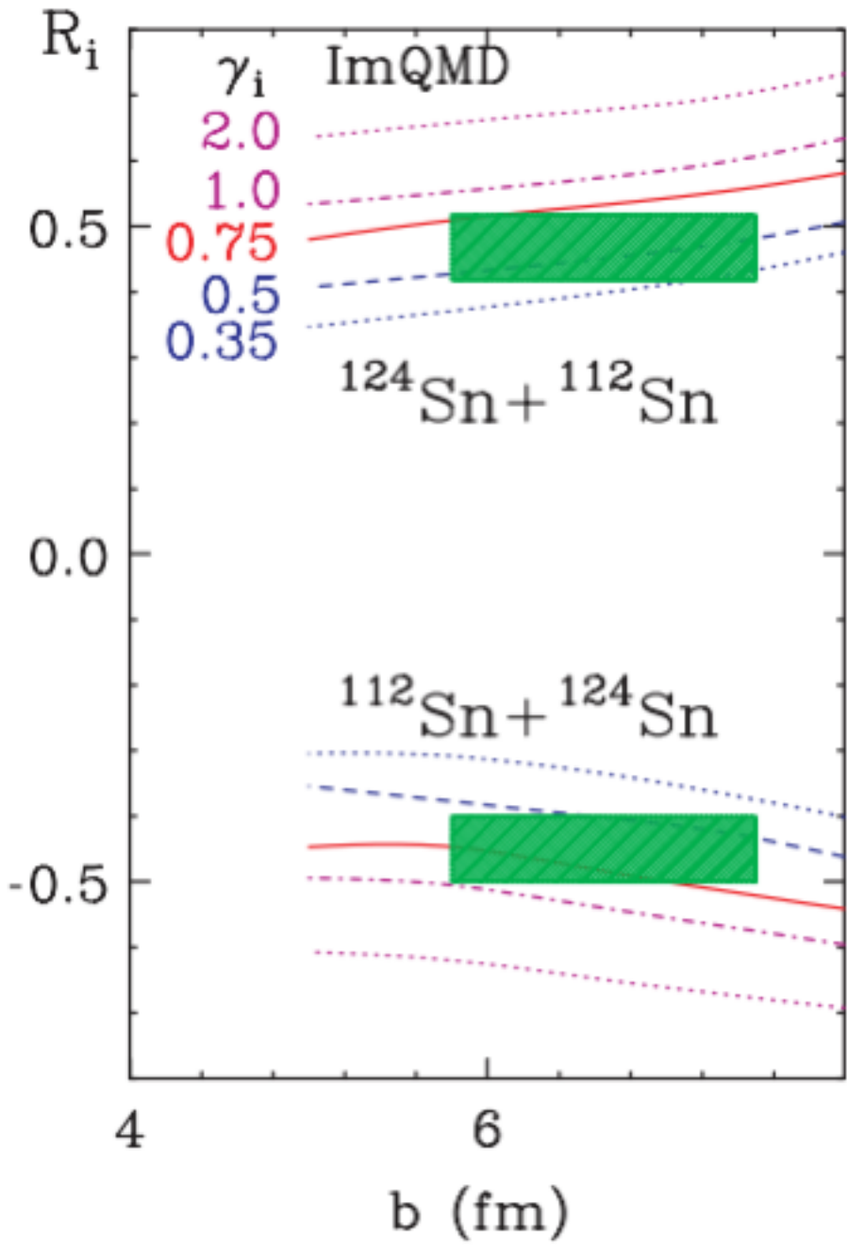
Isospin Diffusion: Isoscaling of Intermediate Mass Fragments

- Need to improve the precision of the Ri measurement

- Need to improve extraction of impact parameter

- Need to check:

$$\text{If } X = a\delta + b, \text{ then } R_i(X) = R_i(\delta)$$

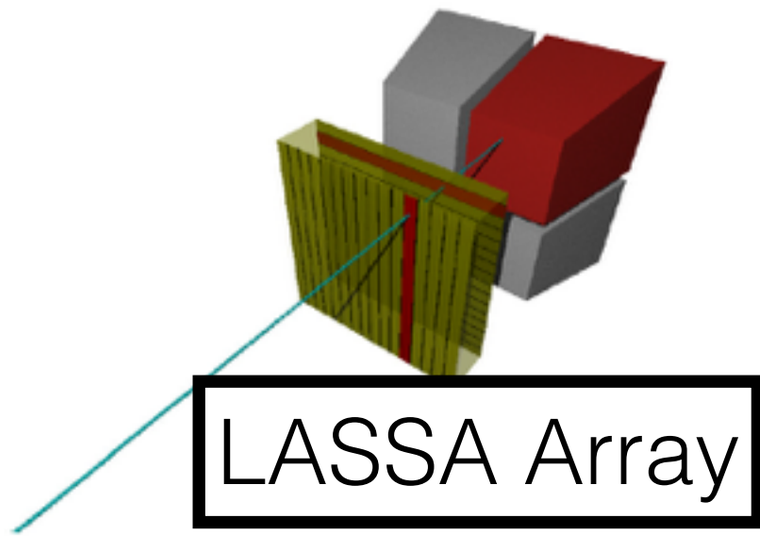


Tsang et al., PRL102, 122701 (2009)

NSCL Experiment e07038: “Precision Measurement of Isospin Diffusion”

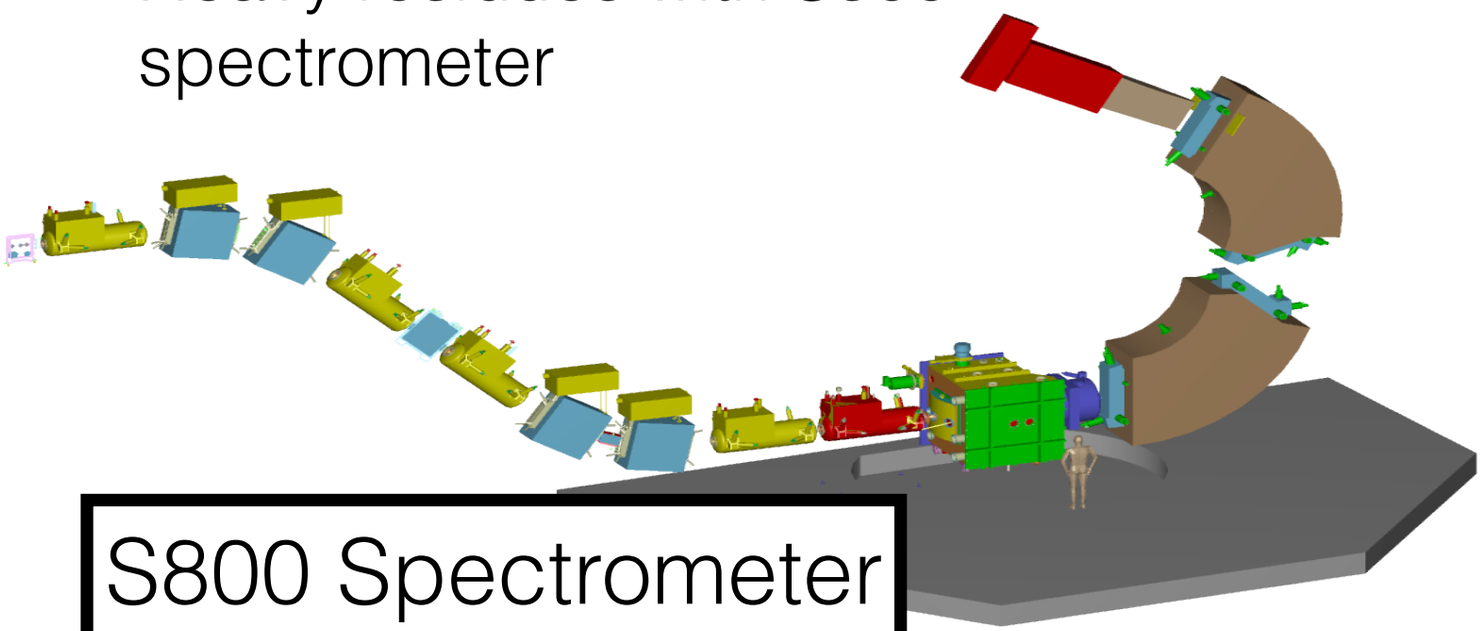
- $^{112,118,124}Sn + ^{112,118,124}Sn$ Collisions, 70 MeV/u

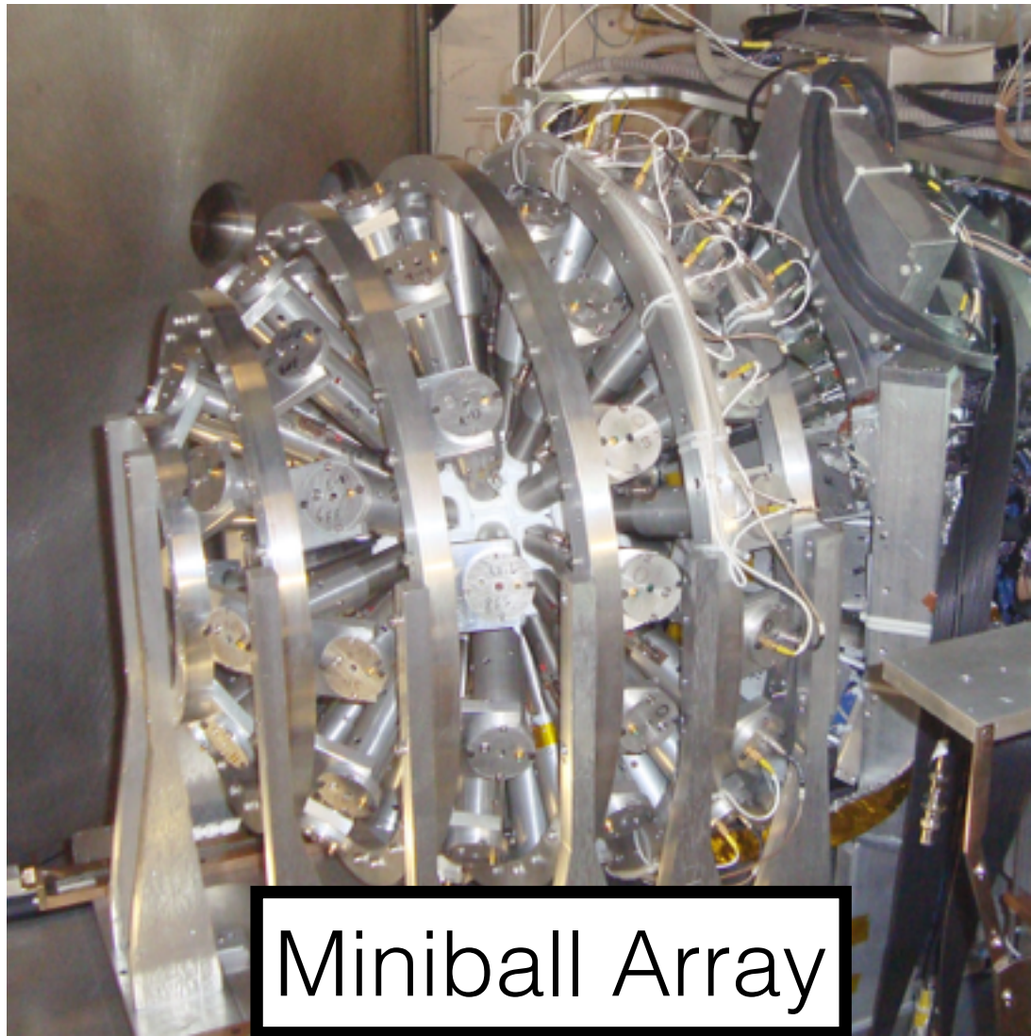
- Intermediate mass fragments with LASSA array



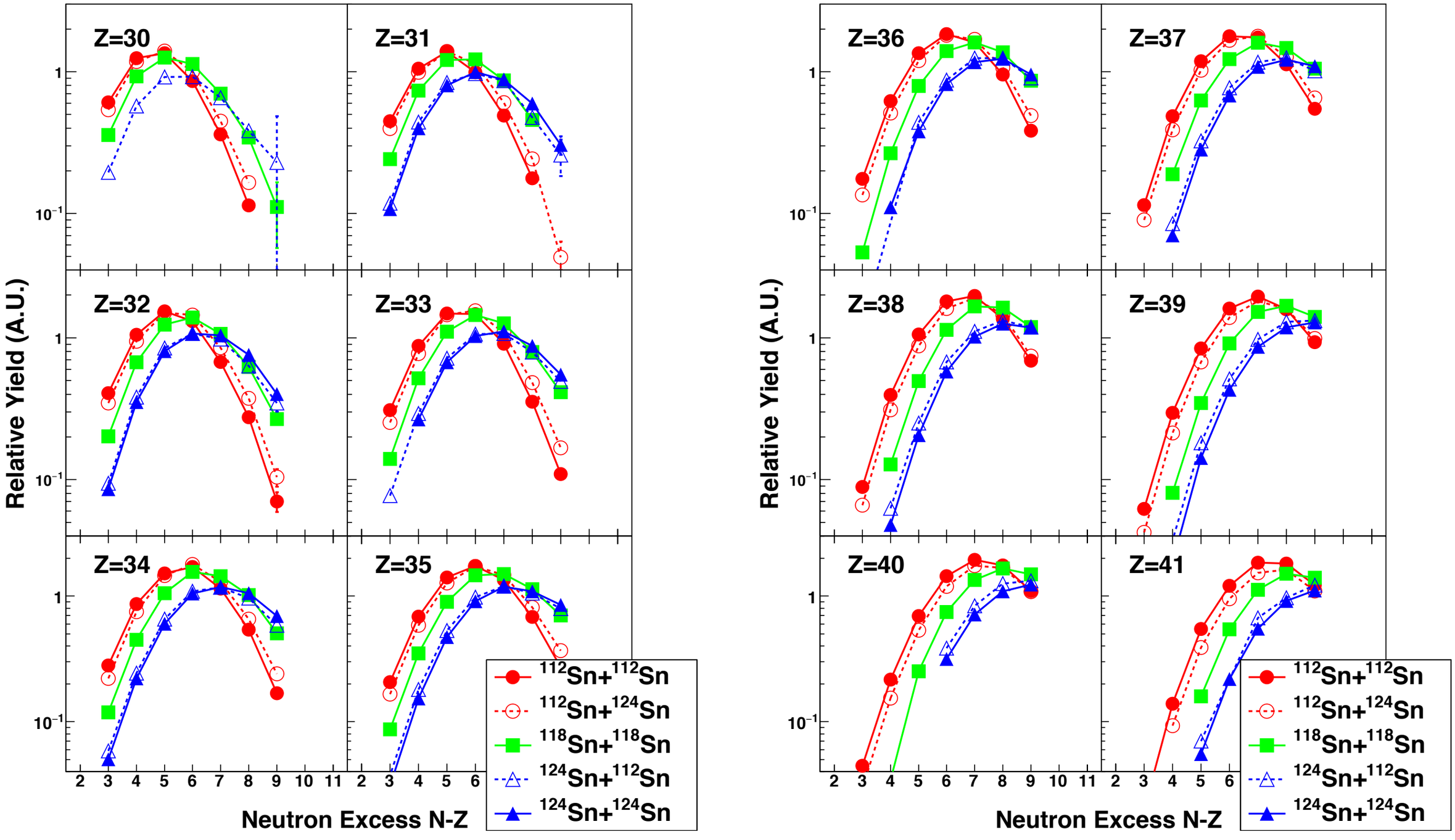
- Impact Parameter with MSU Miniball

- Heavy residues with S800 spectrometer





Isotopic Distributions

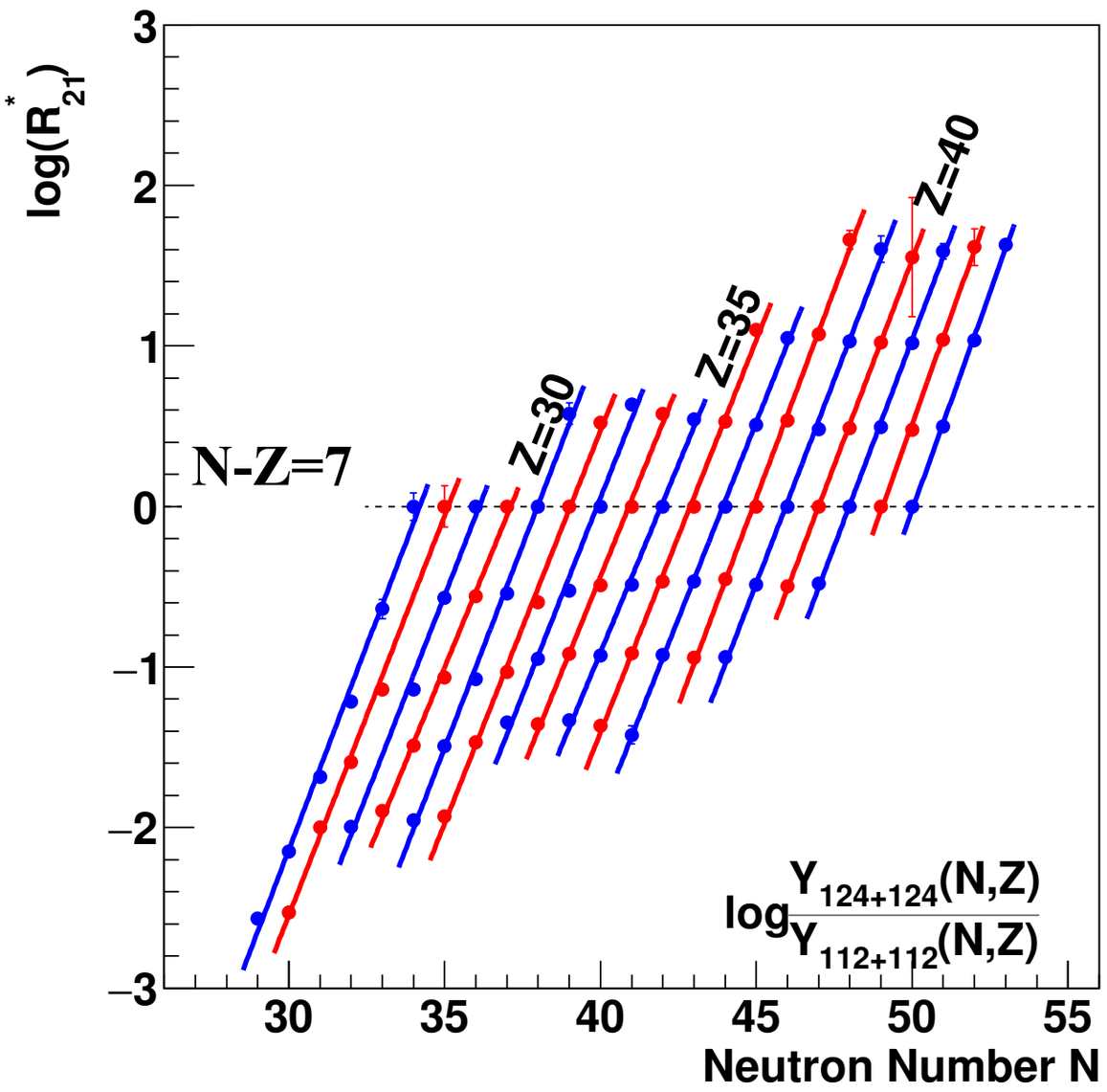


Relative yields; not corrected for detection efficiency

Isoscaling of Heavy Residues

$$R_{21} = \frac{Y_2(N,Z)}{Y_1(N,Z)} = Ce^{\alpha N + \beta Z}$$

- Slope related to change in asymmetry of source
- Largest signal between $^{112}Sn+^{112}Sn$ and $^{124}Sn+^{124}Sn$

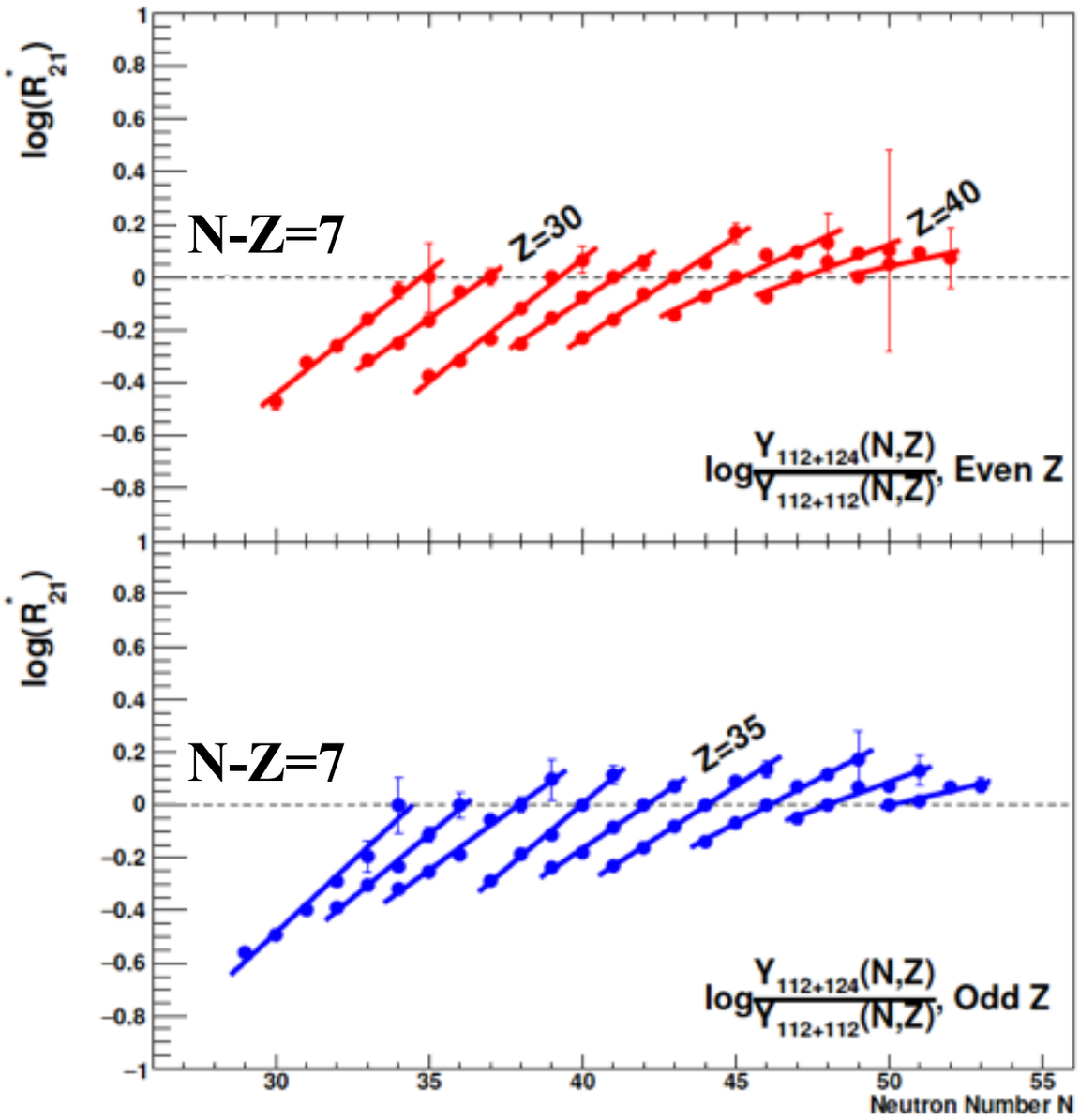


Each Z normalized to N-Z=7

Isoscaling of Heavy Residues-Mixed System

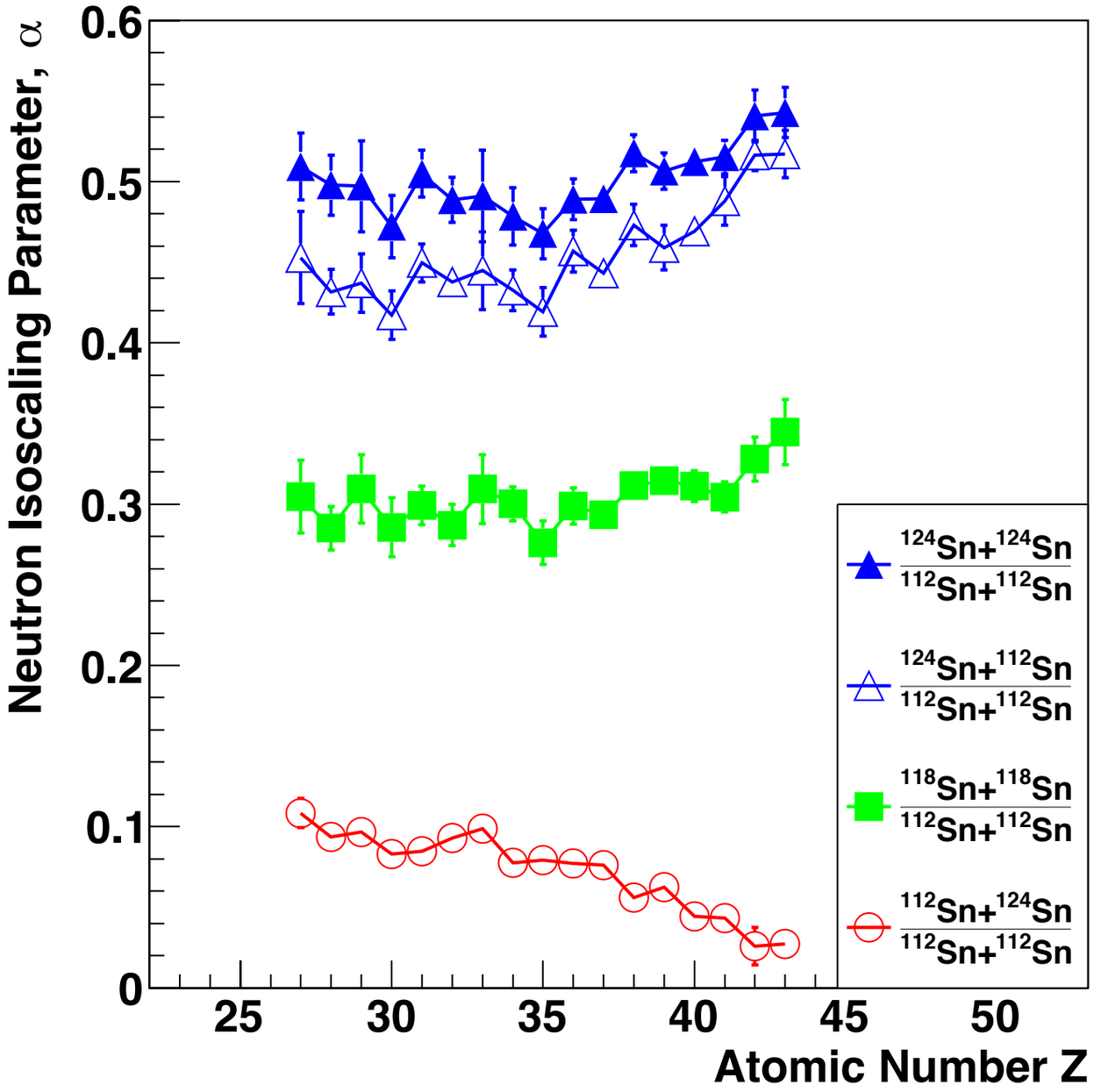
$$R_{21} = \frac{Y_2(N,Z)}{Y_1(N,Z)} = Ce^{\alpha N + \beta Z}$$

- Small difference between ^{112}Sn +^{112}Sn and ^{112}Sn+^{124}Sn



Each Z normalized to N-Z=7

Isoscaling of Heavy Residues

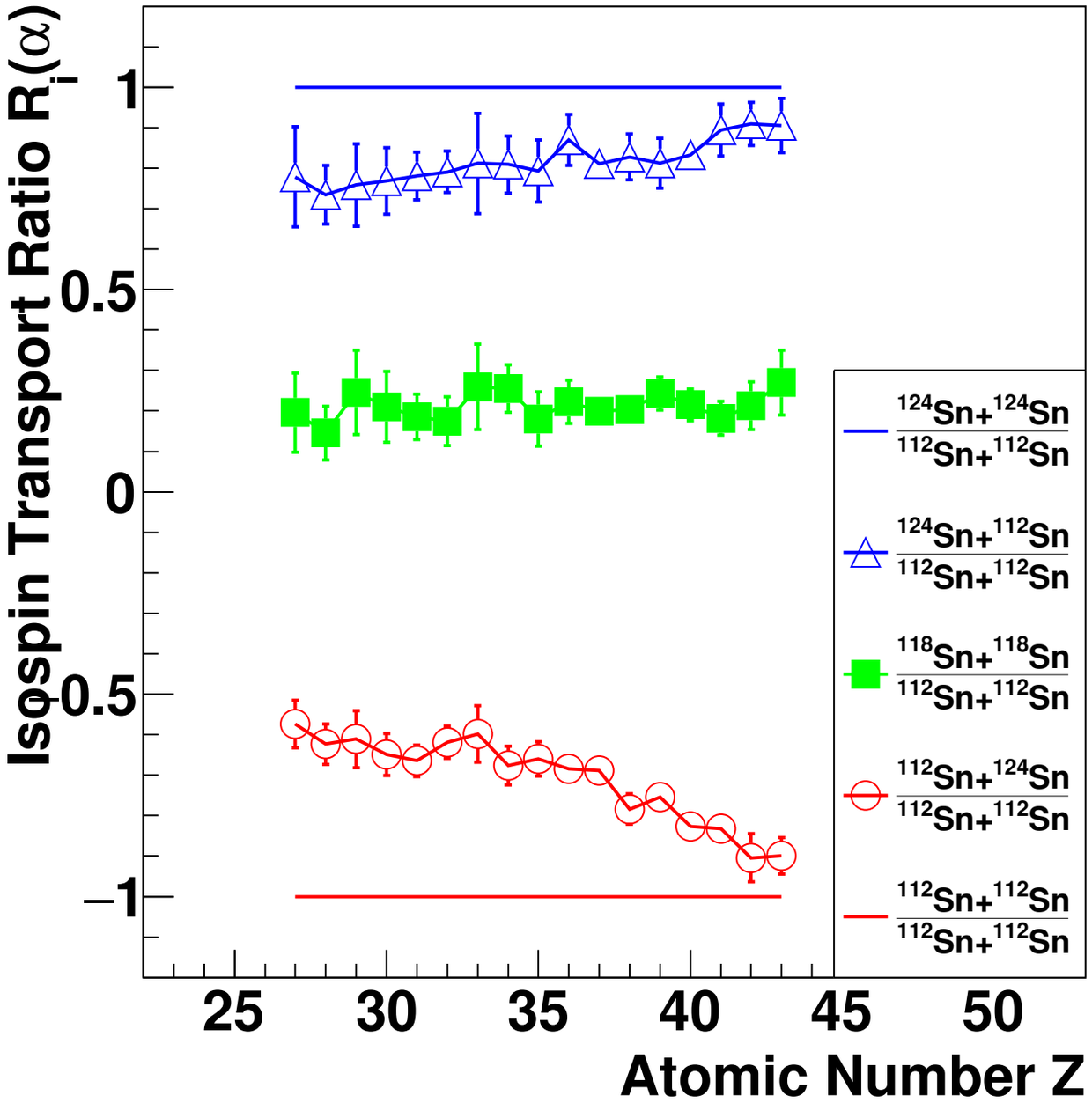


$$\alpha \approx \frac{4C_{sym}}{T}\left(\left(\frac{Z_1}{N_1}\right)^2 - \left(\frac{Z_2}{N_2}\right)^2\right)$$

- All systems compared to $^{112}Sn+^{112}Sn$

$$X_{118+118} \neq \frac{(X_{112+112} + X_{124+124})}{2}$$

Isospin Transport Ratio



$$R_i = \frac{2X - (X_{A+A} + X_{B+B})}{X_{A+A} - X_{B+B}}$$

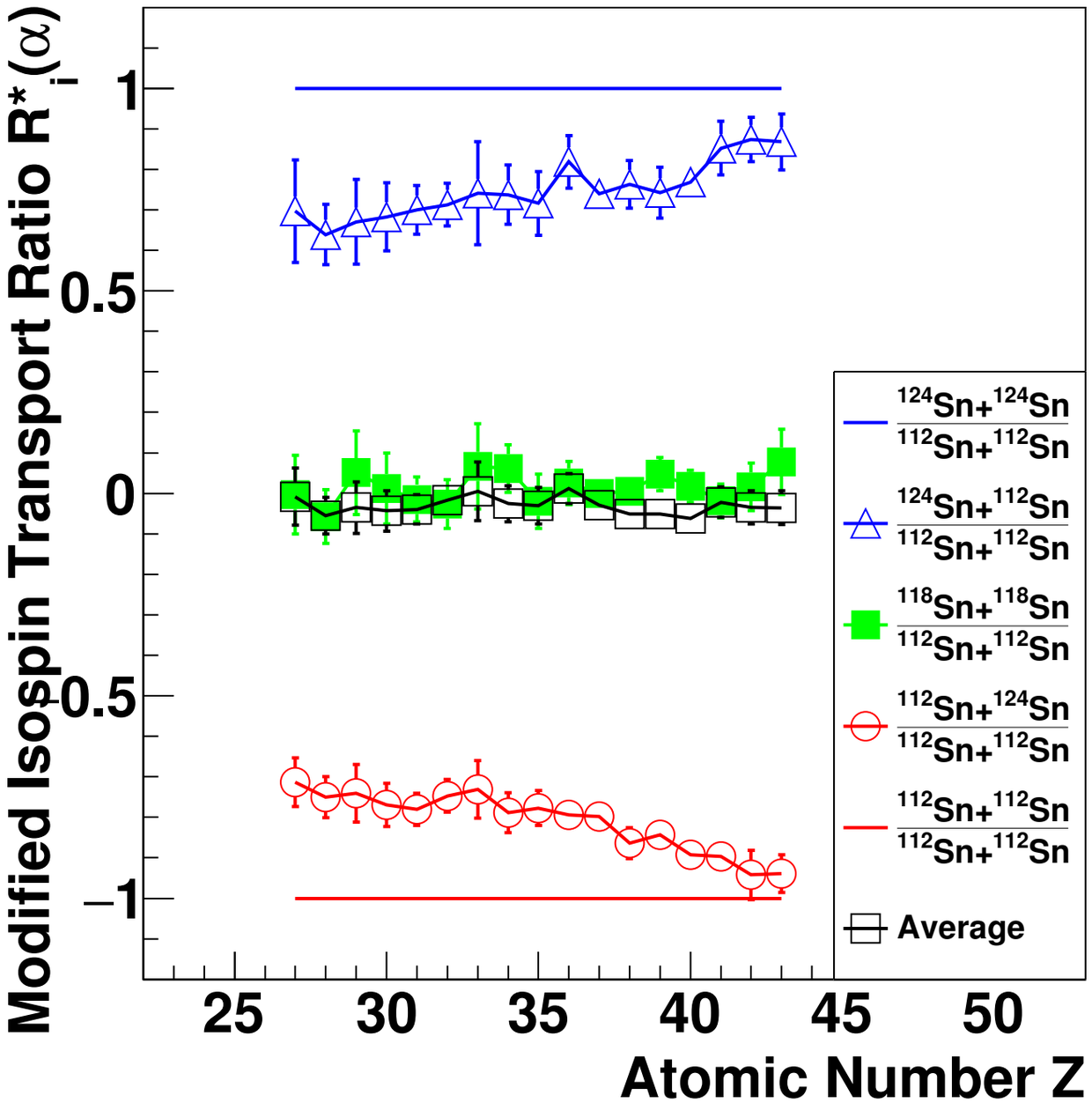
- Clear evidence of isospin diffusion
- Asymmetric between reactions

$$\alpha \neq a\delta + b$$

$$R_i^*(X) = R_i(X) + R_i(X_{eq})\left(R_i(X)^2 - 1\right)$$

Modified Isospin Transport Ratio

$$R_i^*(X) = R_i(X) + R_i(X_{eq})\left(R_i(X)^2 - 1\right)$$



- Restores symmetry
- Allows model comparison

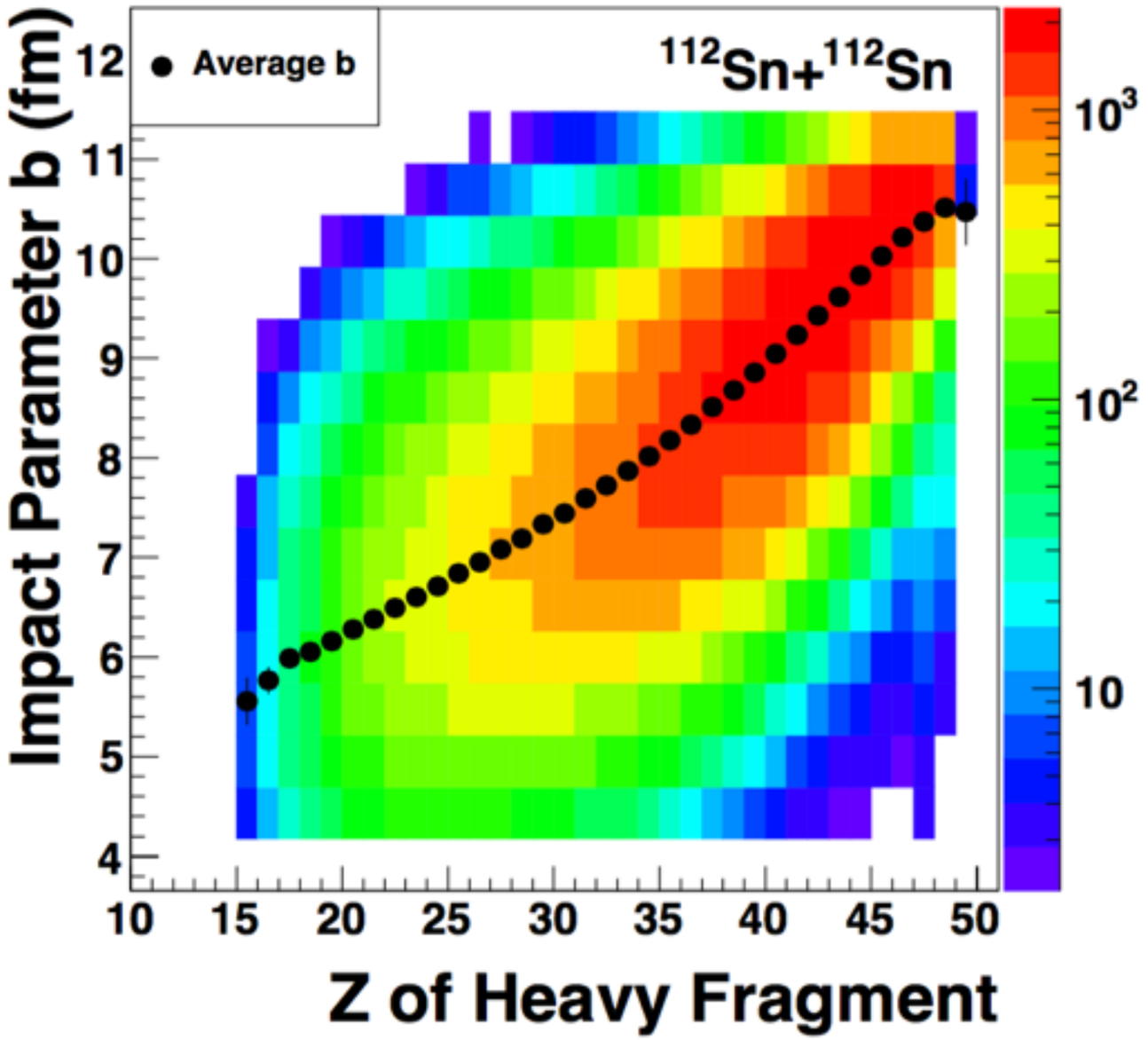
Impact Parameter Selection from the Miniball-Miniwall

- 188 CsI+PMT
- 75% of 4π detection
- N_c - charged particle multiplicity

$$\pi b^2 = \int_0^b \sigma(b')db'$$

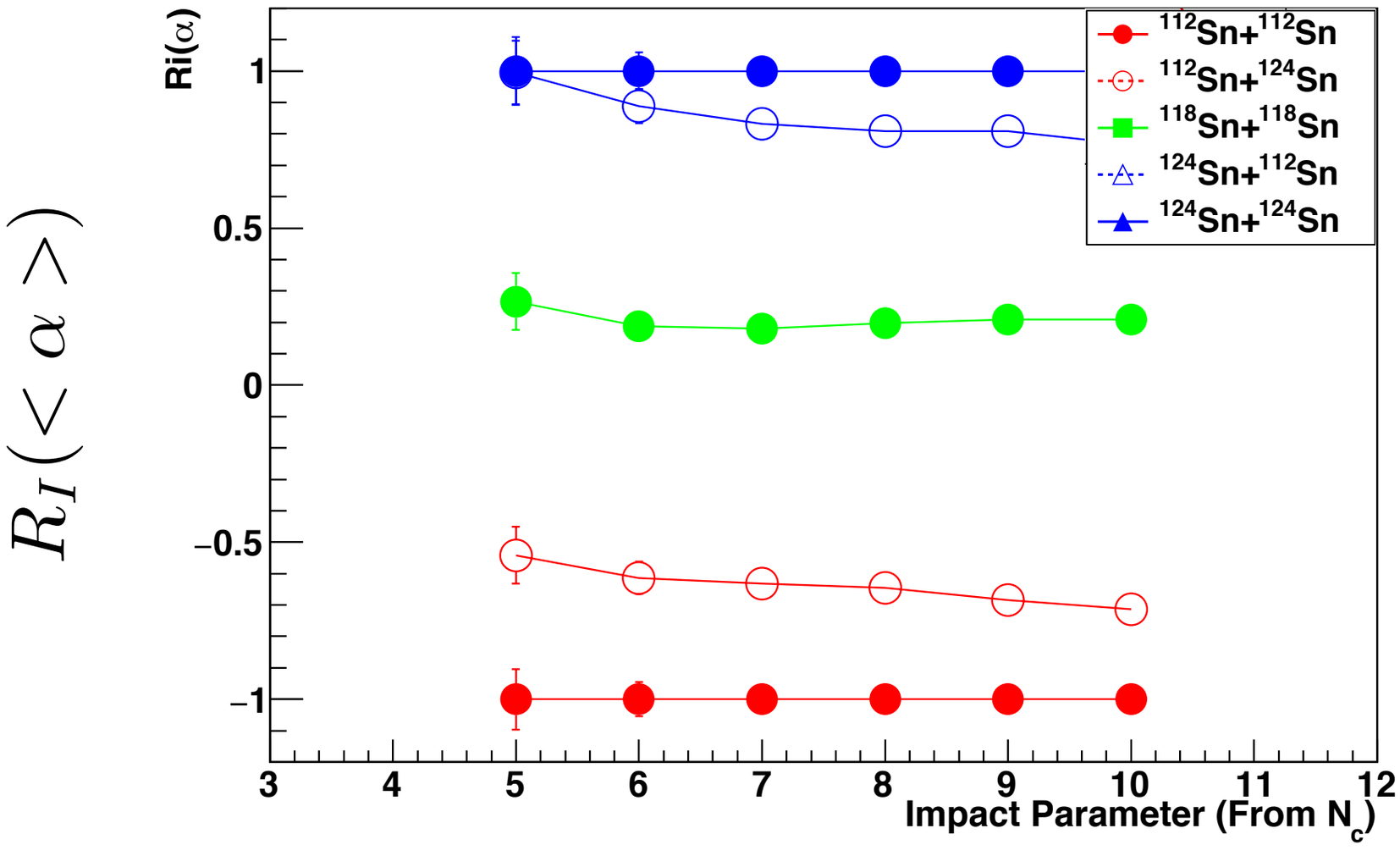
$$\int_0^b \sigma(b')db' = \int_{N_c}^{\infty} \sigma(N_c')dN_c'$$

Impact Parameter Selection



- Each Z contains 5-10 fm
- Decreases statistics significantly
- Different cuts to different systems

Impact Parameter Selection



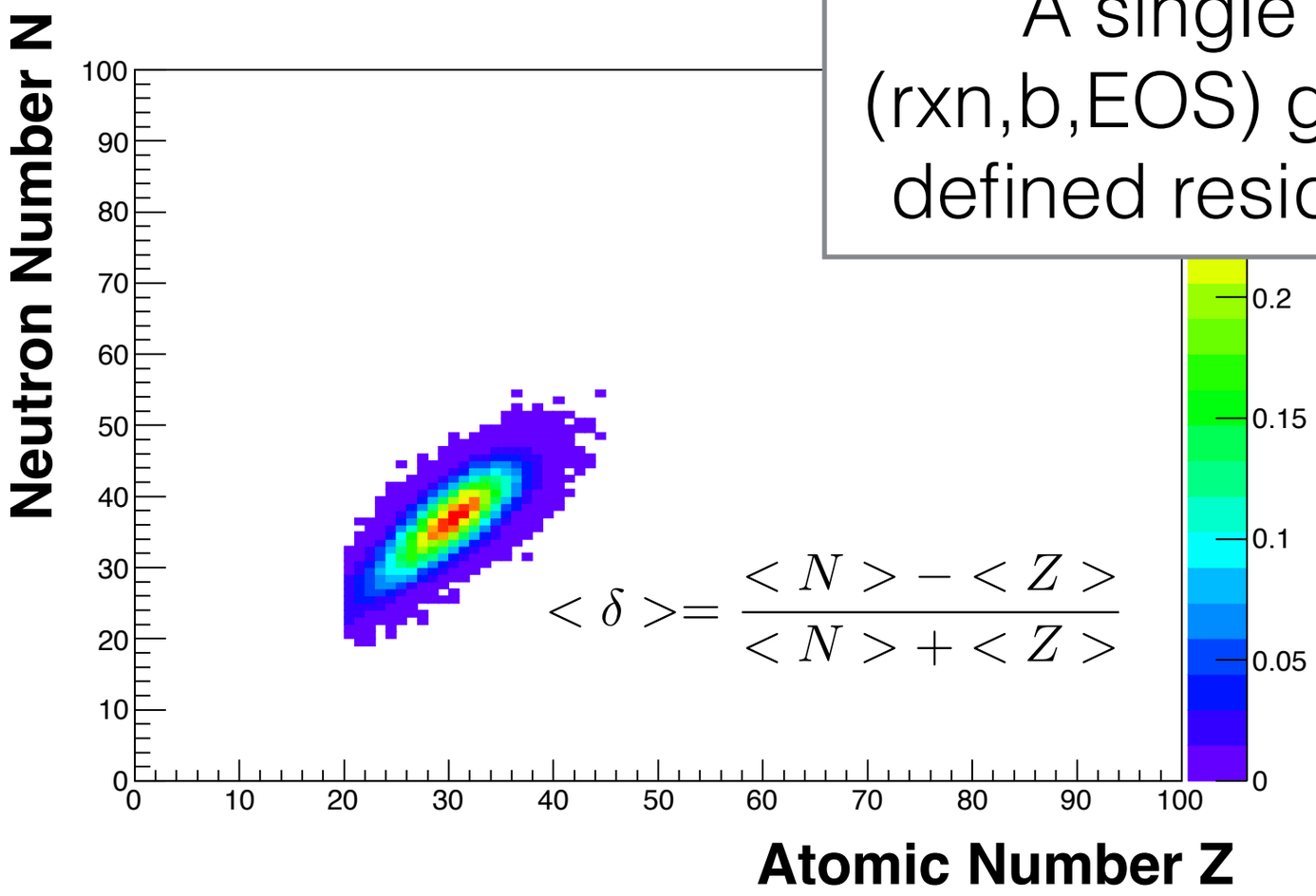
But what “observables” can we get from ImQMD…

ImQMD05

Calculations for
b=7,8,9,10,11,12
γ=0.5,0.75,1.0,1.5,2.0

$$S(\rho) = S_k \left(\frac{\rho}{\rho_0}\right)^{\frac{2}{3}} + S_i \left(\frac{\rho}{\rho_0}\right)^{\gamma}$$

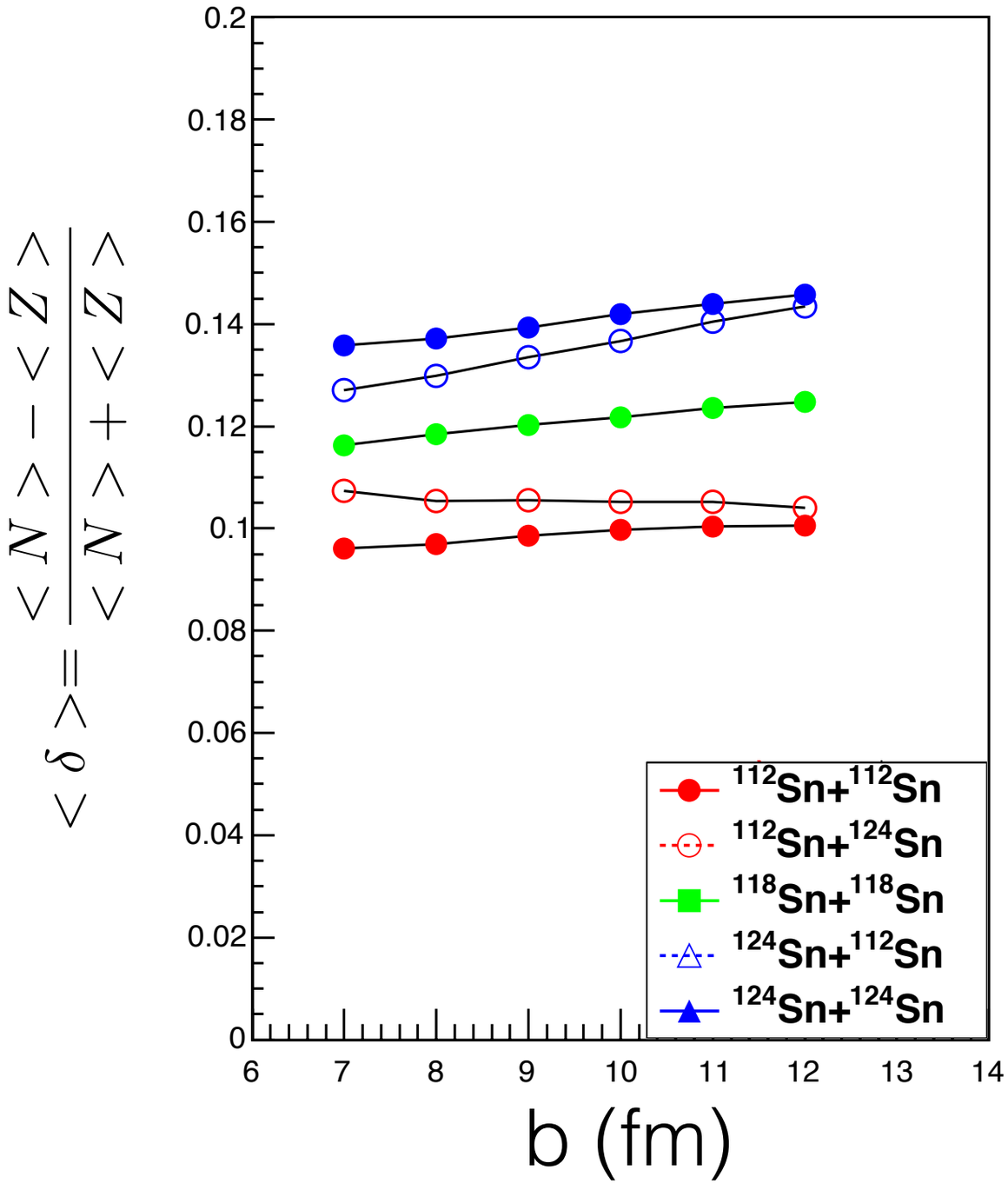
A single calculation (rxn,b,EOS) generates a well defined residue asymmetry

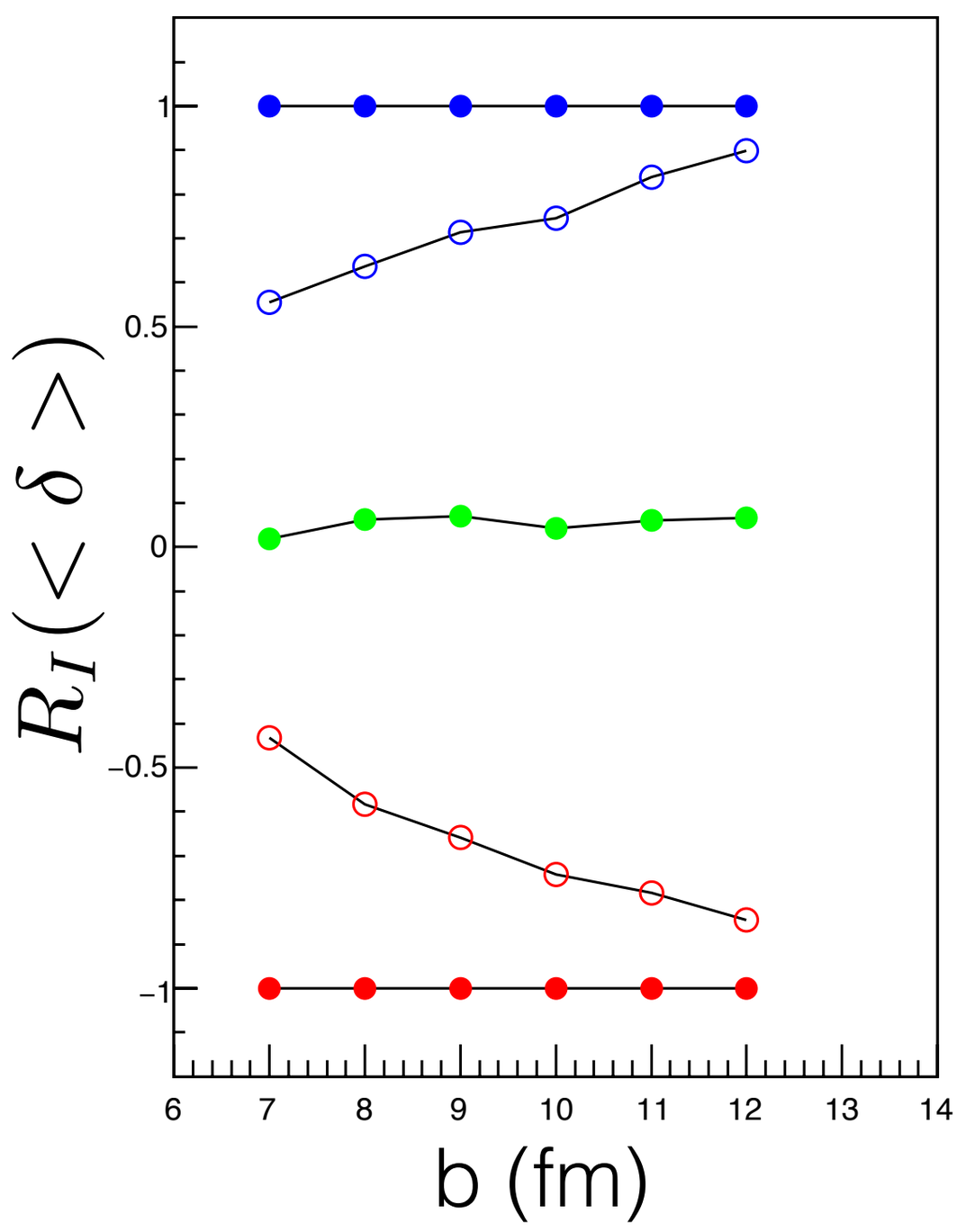


Zhang et al., PRC **71**, 24604 (2005)

A Simple Picture

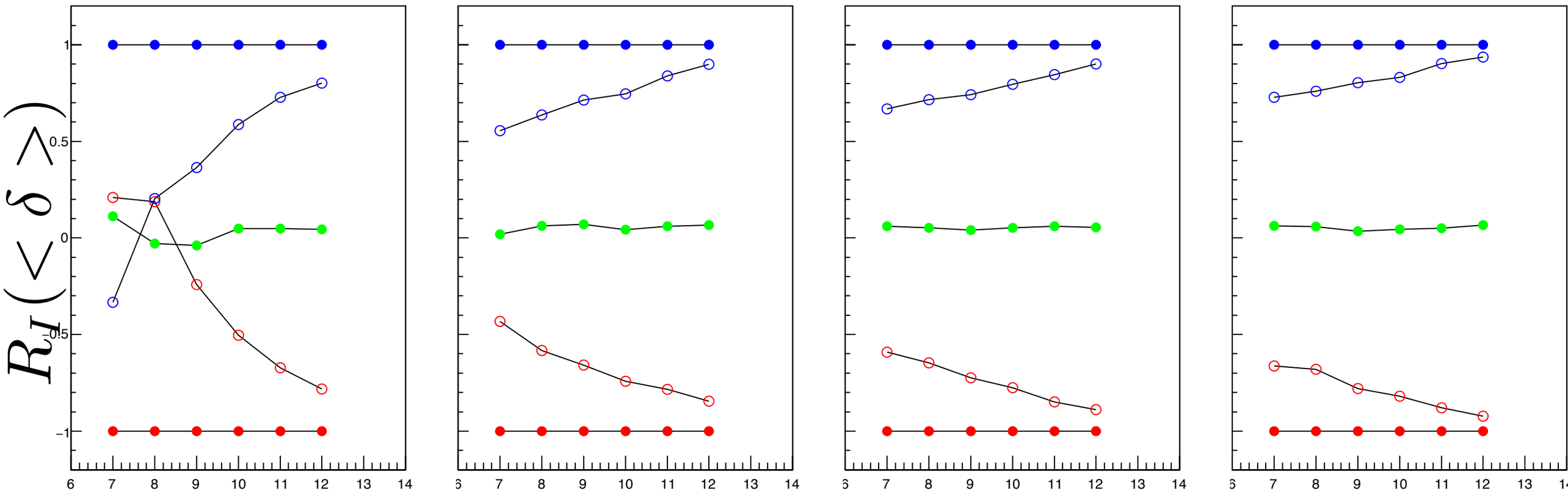
γ=0.75





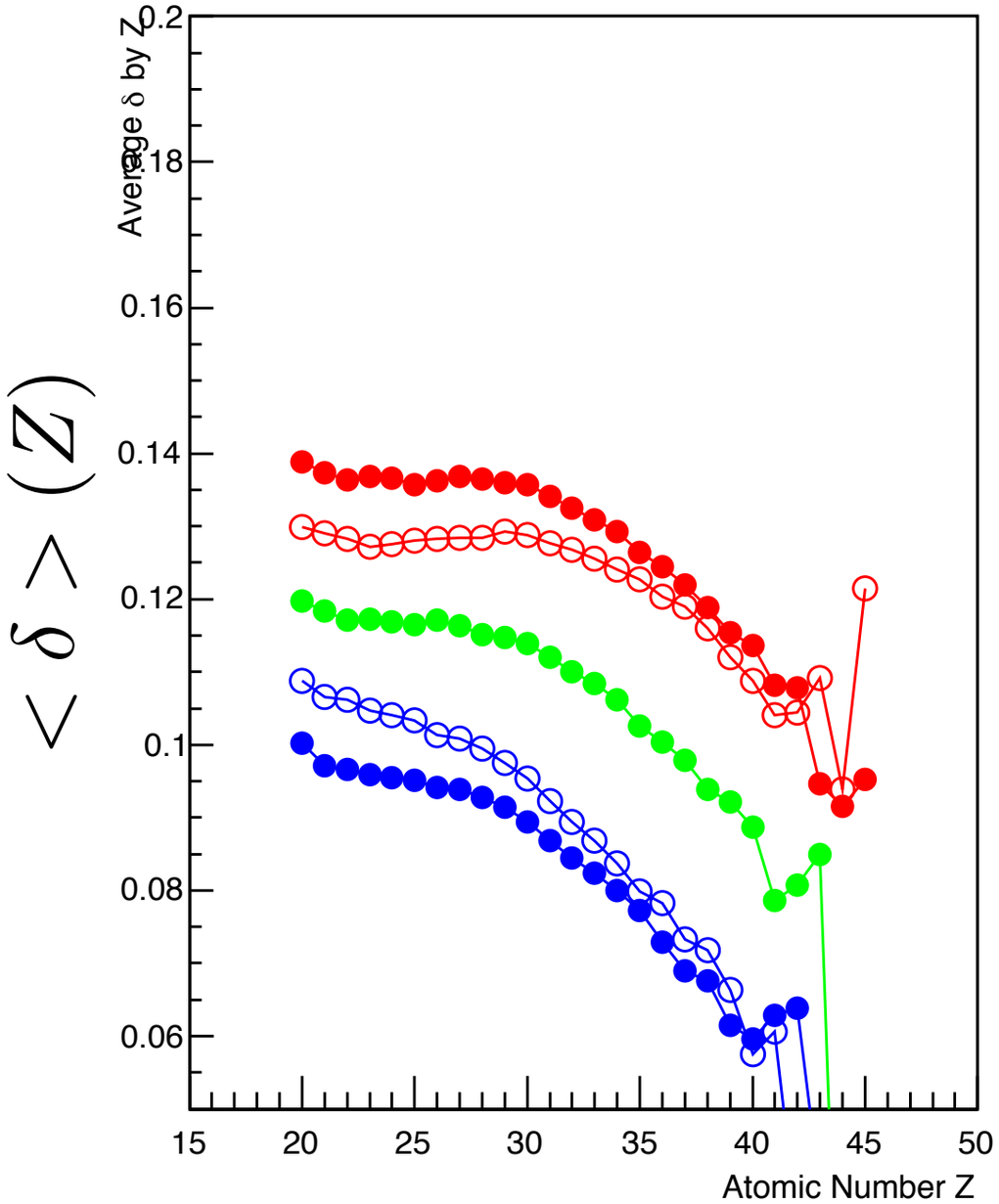
A Simple Picture

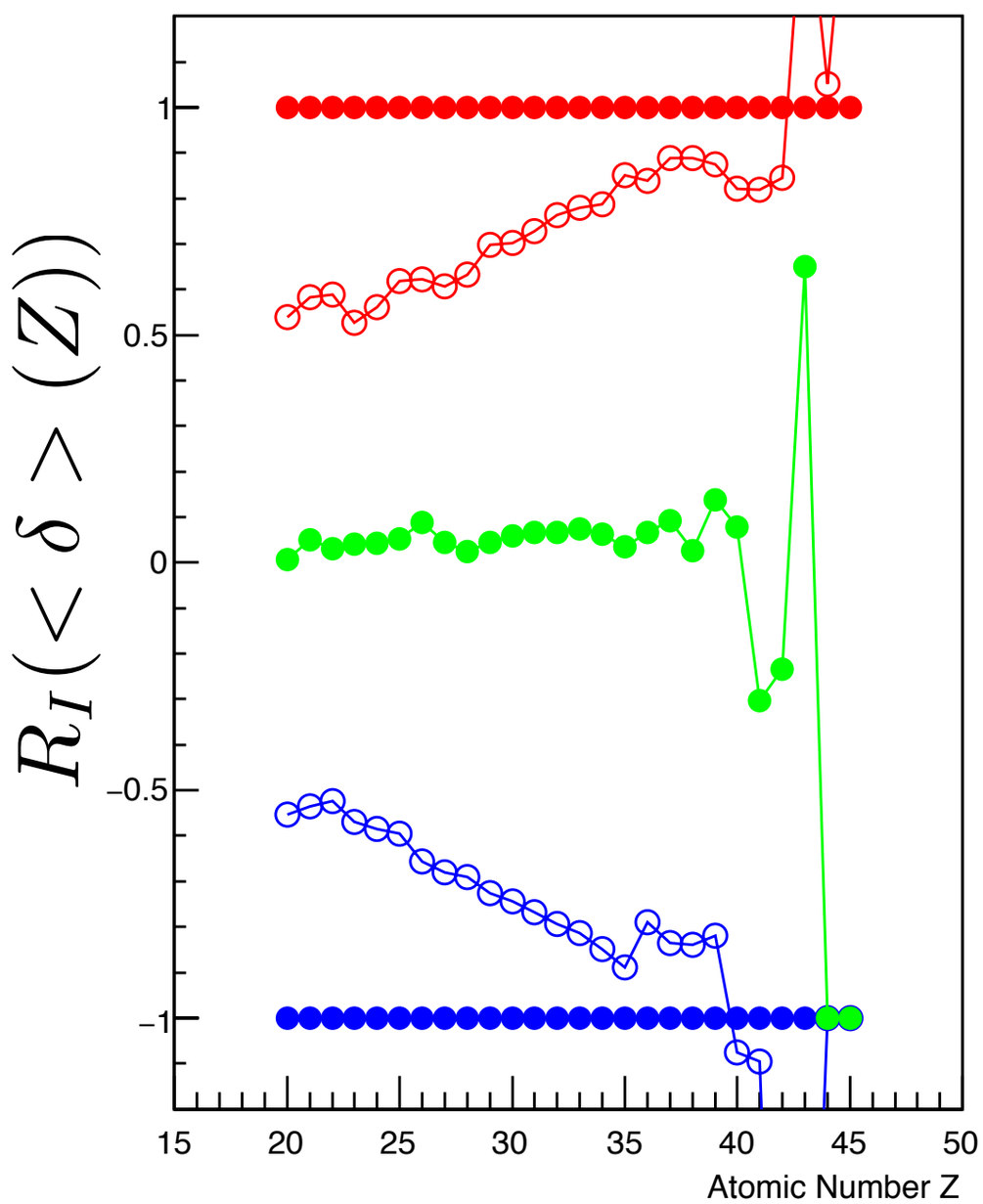
γ=0.5 γ=0.75 γ=1.0 γ=1.5



But what do we measure with Isoscaling?
More like asymmetry as a function of Z, integrated over a region of b…

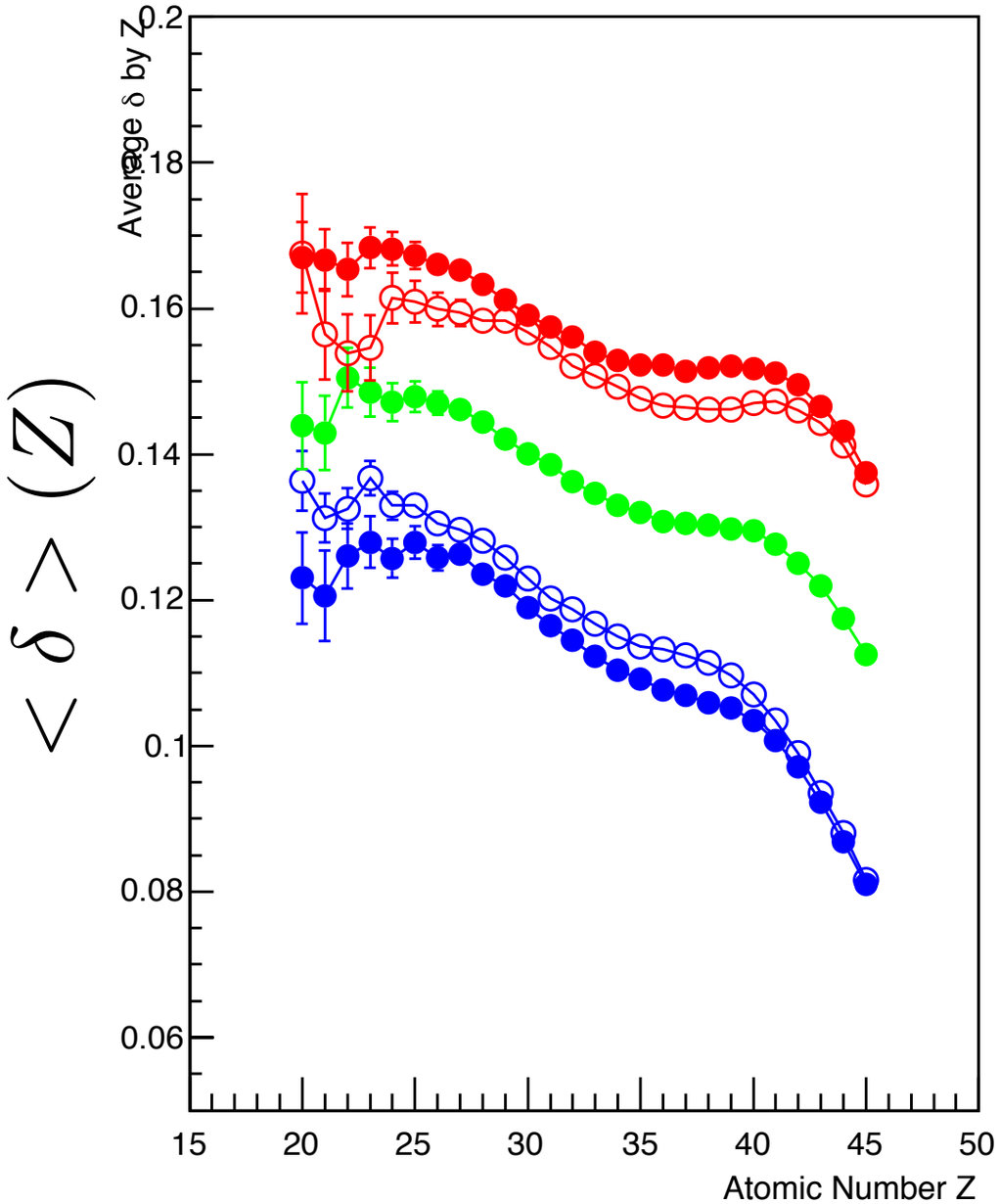
Less Simple Picture: Integrating over b

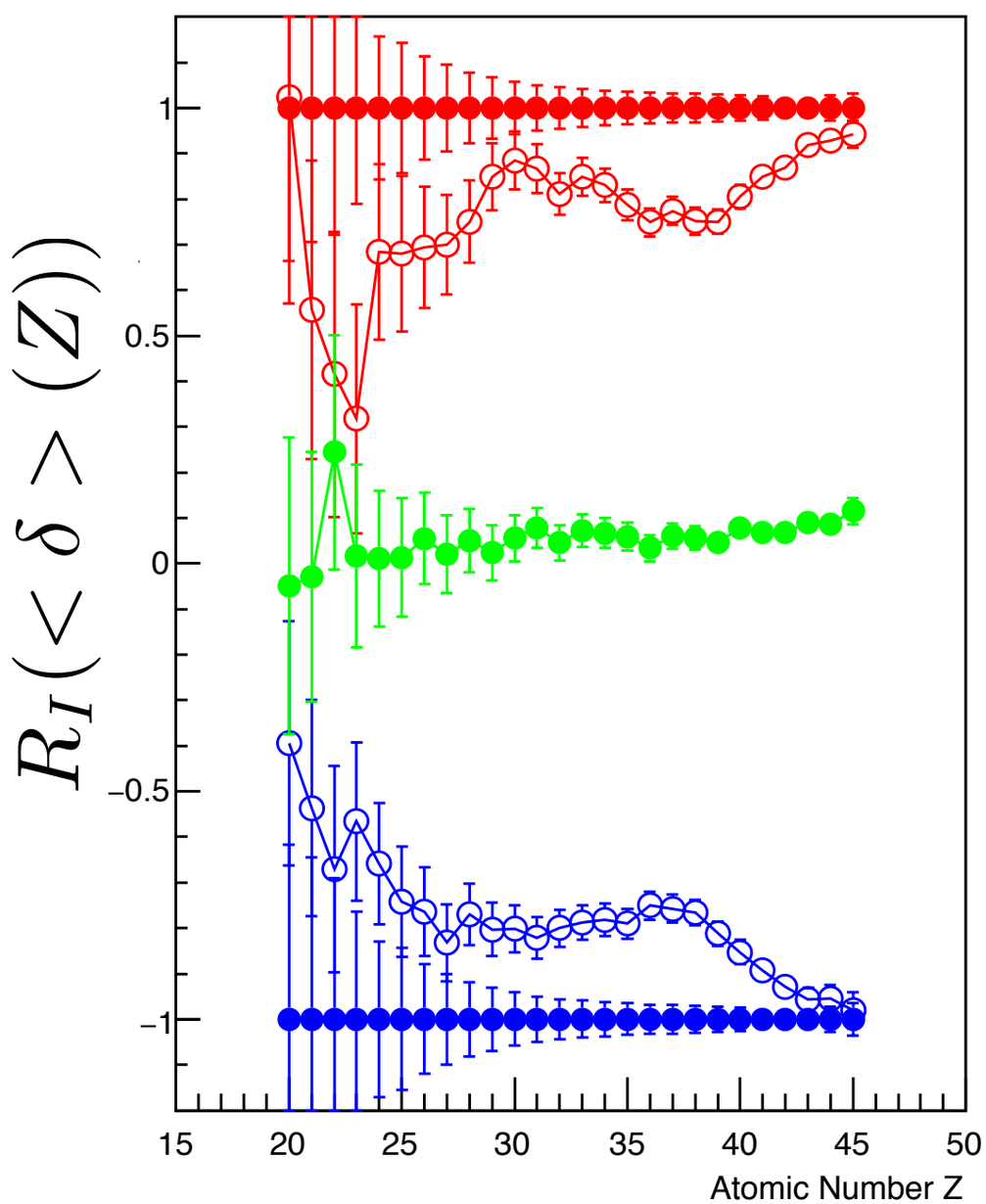




b=[7..12]fm, γ=0.5

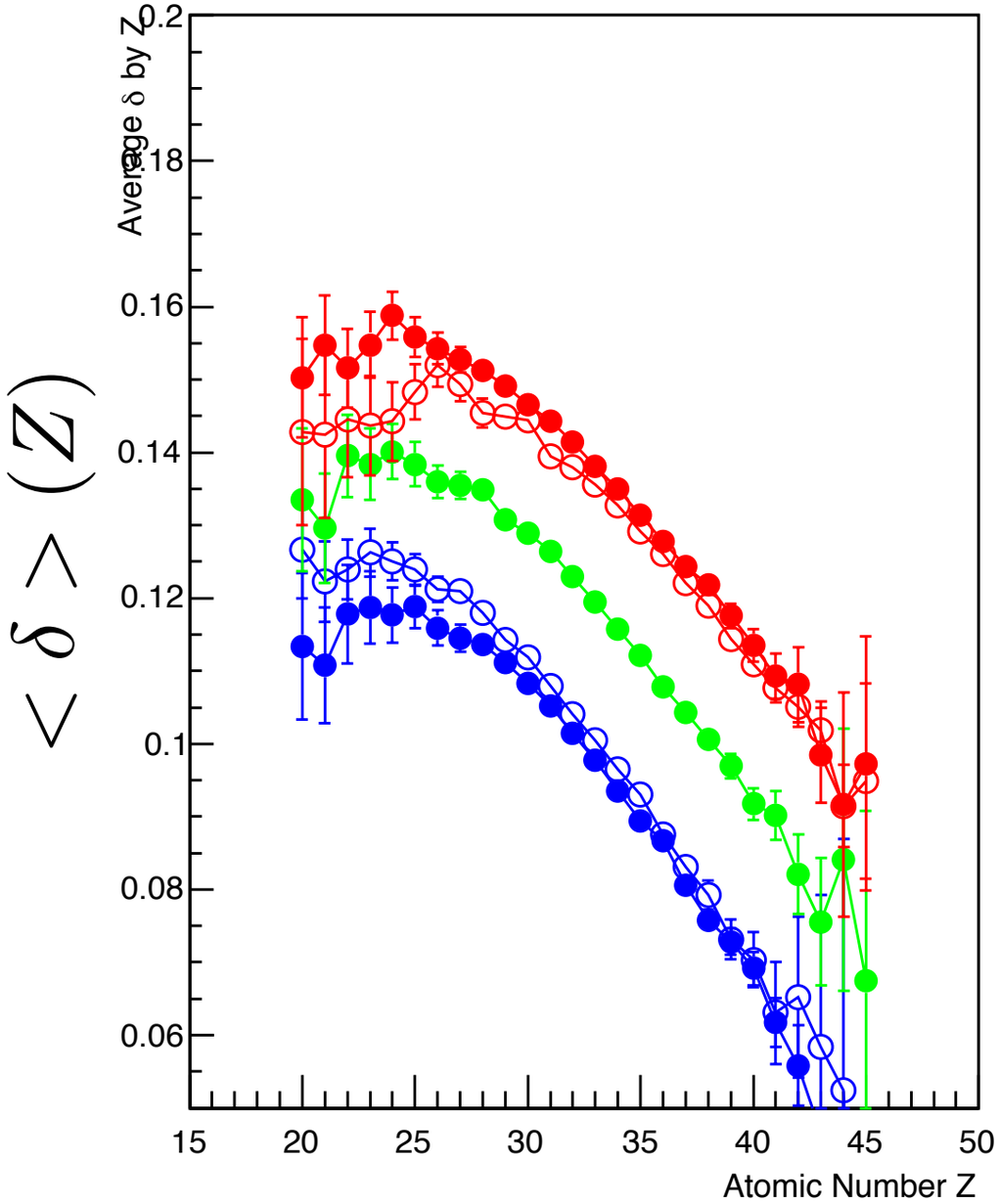
Less Simple Picture: Integrating over b

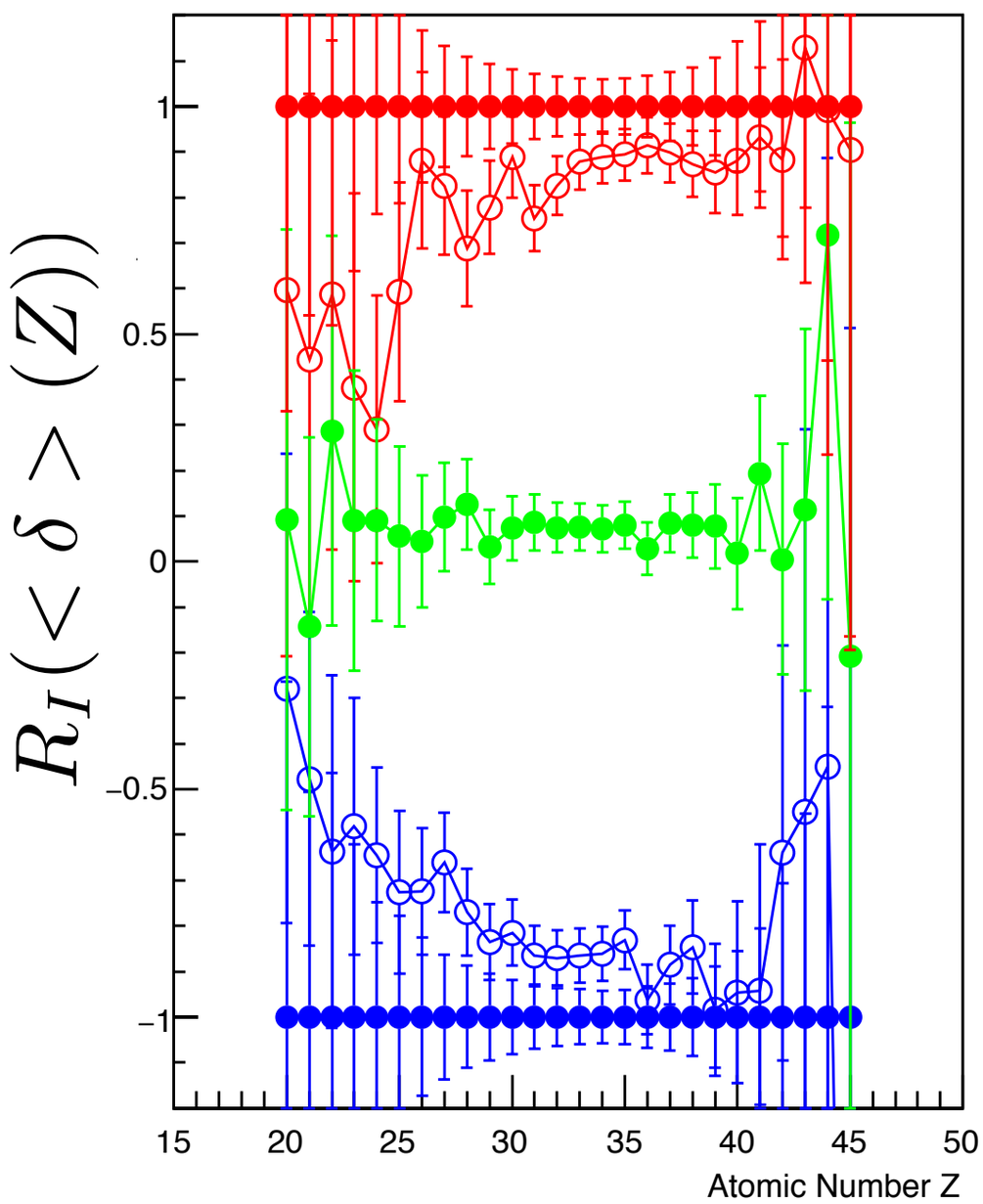




b=[7..12]fm, γ=1.0

Less Simple Picture: Individual b





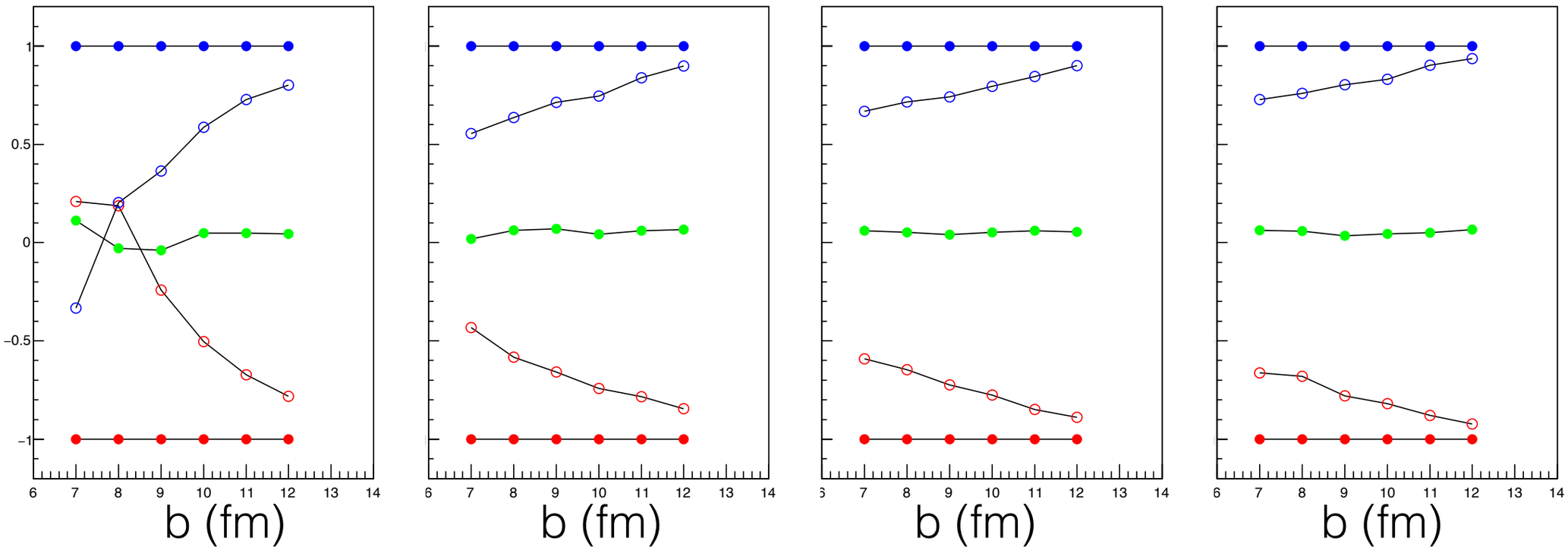
b=8fm, γ=0.75

Important: How you average things matters…

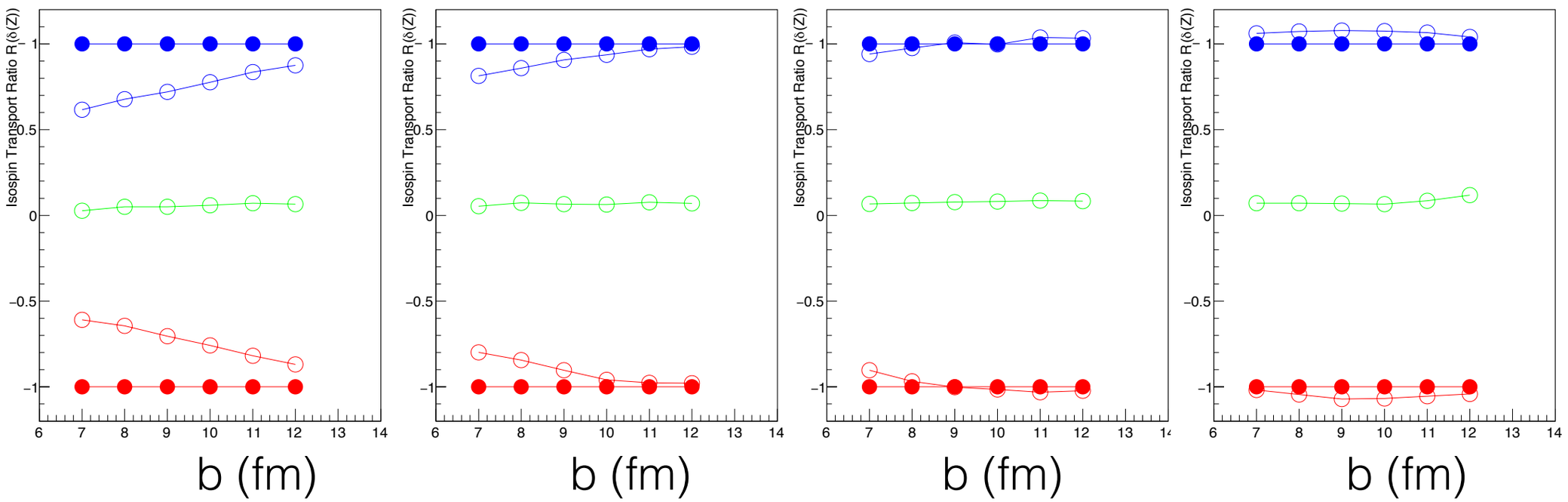
$$R_I(<\delta>_{Z,N}) \neq <R_I(<\delta>_N)>_Z$$

γ=0.5 γ=0.75 γ=1.0 γ=1.5

(Simple) $R_I(<\delta>_{Z,N})$



(New) $<R_I(<\delta>_N)>_Z$

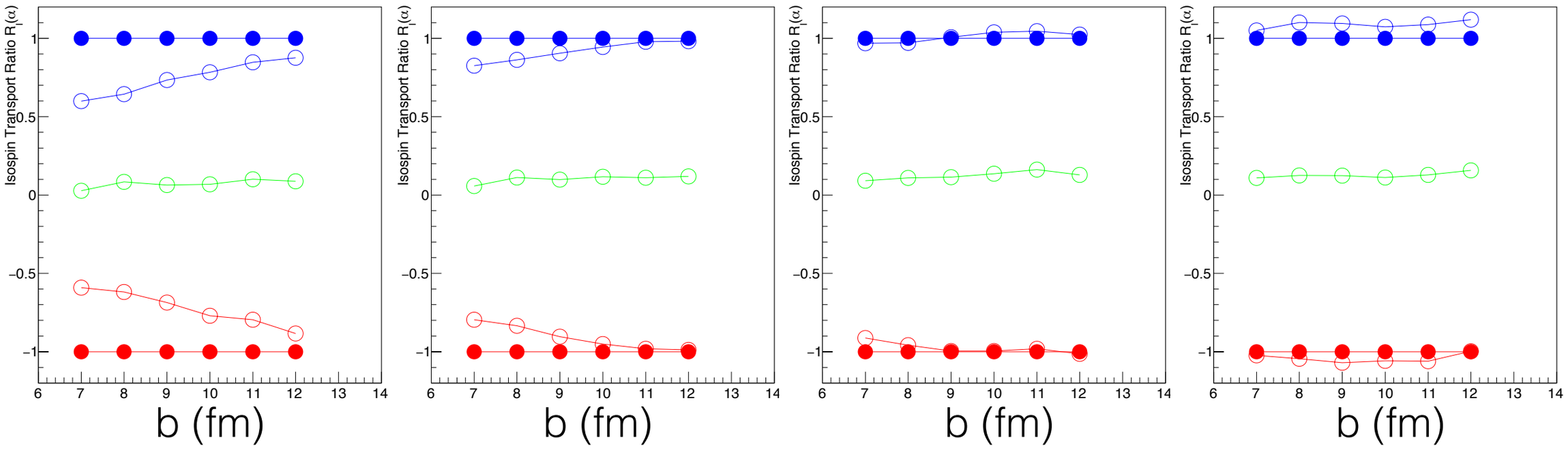


Isoscaling within ImQMD

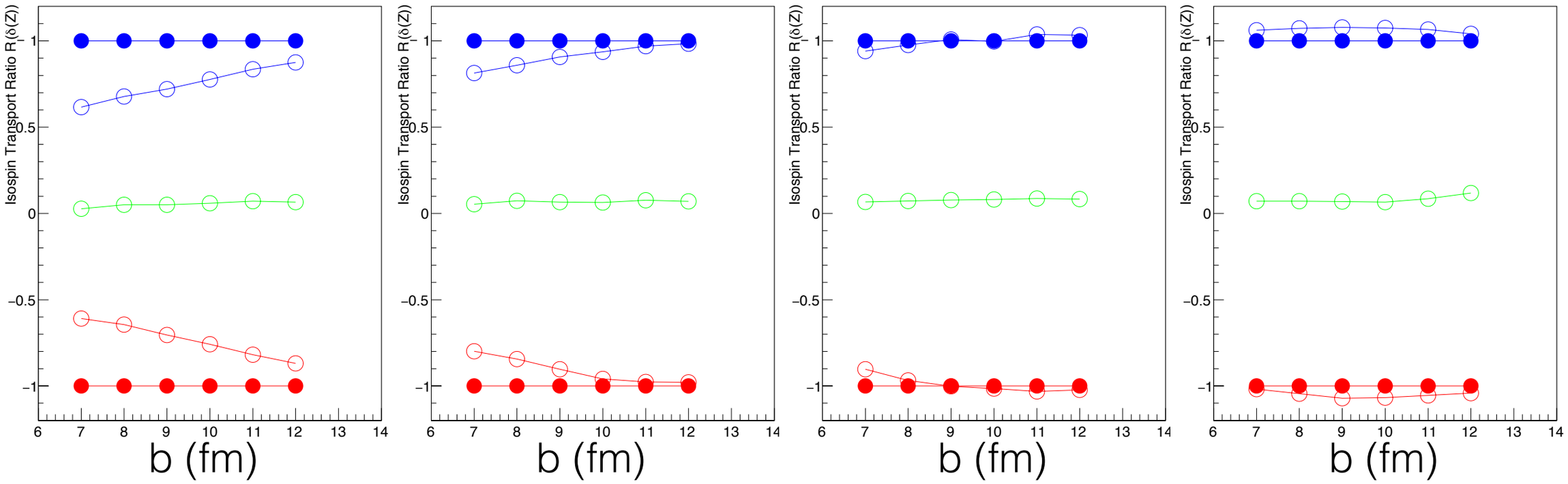
$$< R_I(\alpha_{theory}) >_Z = < R_I(< \delta_{theory} >_N) >_Z$$

γ=0.5 γ=0.75 γ=1.0 γ=1.5

$< R_I(< \delta >_N) >_Z$

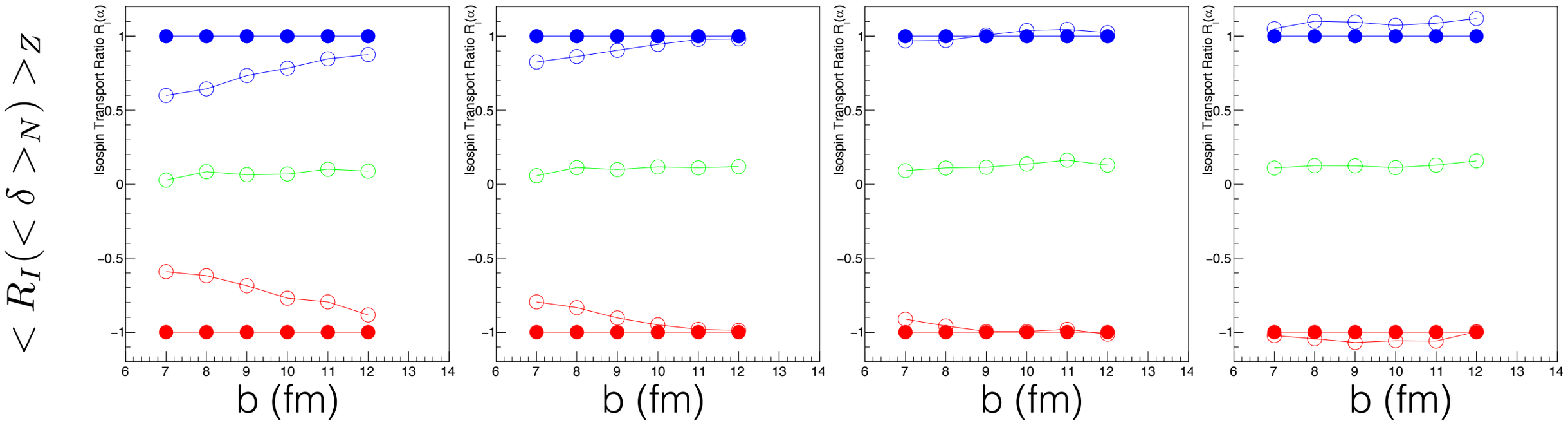


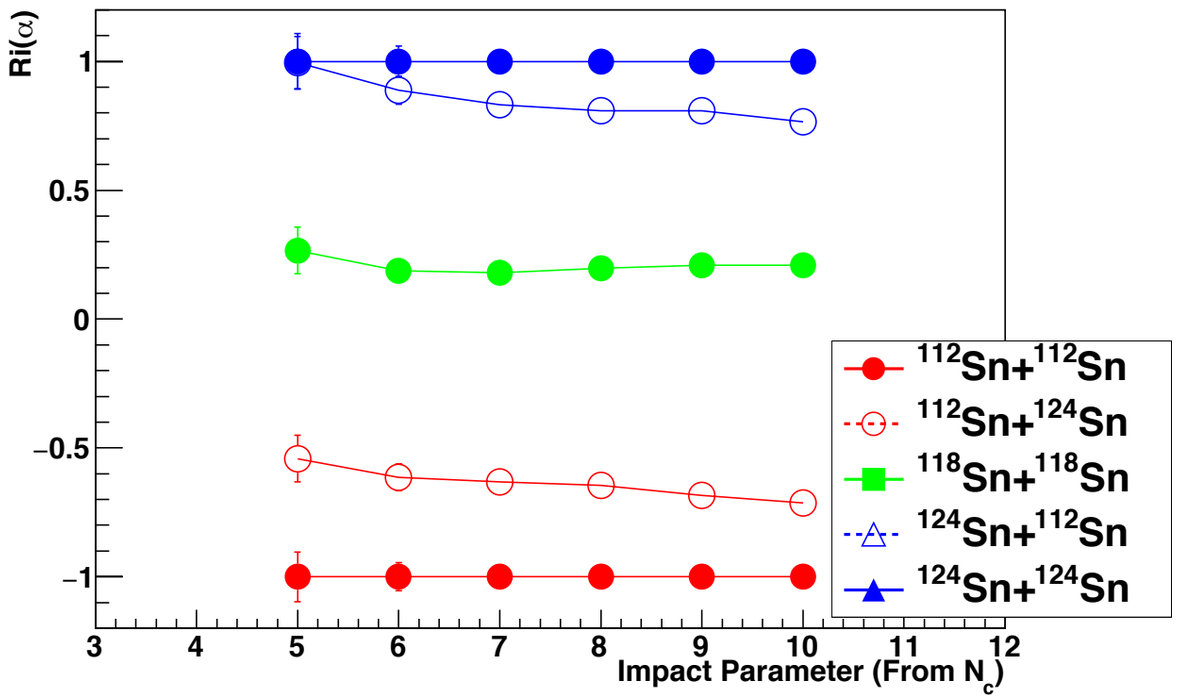
$< R_I(\alpha) >_Z$



Comparison to Isospin Diffusion Data

γ=0.5 γ=0.75 γ=1.0 γ=1.5





- Excludes stiff γ>1.0
- Checking Secondary Decay
- Need to correct with 118Sn+118Sn

Collaboration

NSCL/Michigan State University

Jack Winkelbauer , Rachel Showalter, Betty Tsang , Bill Lynch , Zbigniew Chajecki , Dan Coupland, Jimmy Dunn, Sebastian George, Fei Lu, Andira Ramos, Alisher Sanetullaev , Rebecca Shane , Suwat Tangwancharoen, Mike Youngs

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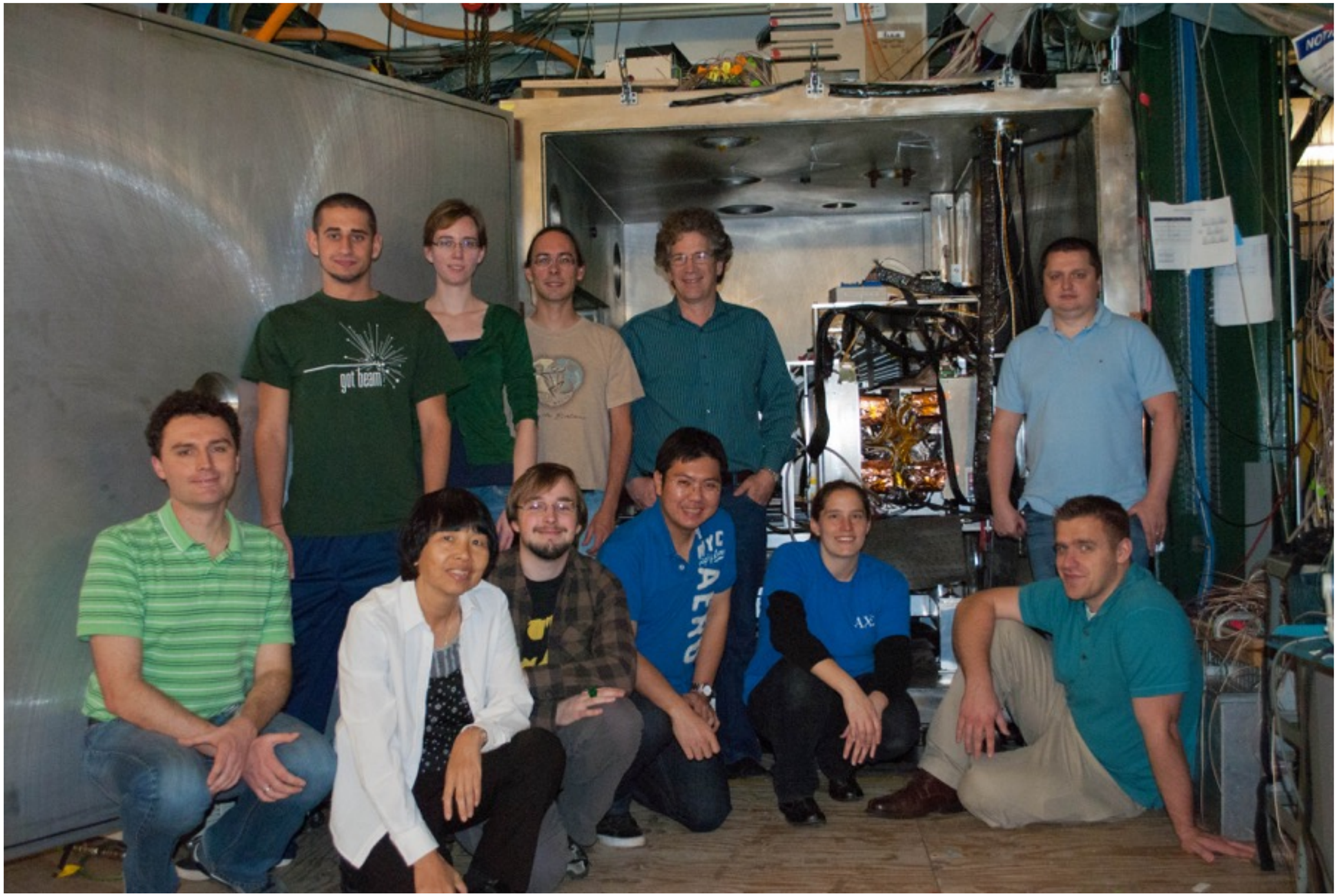
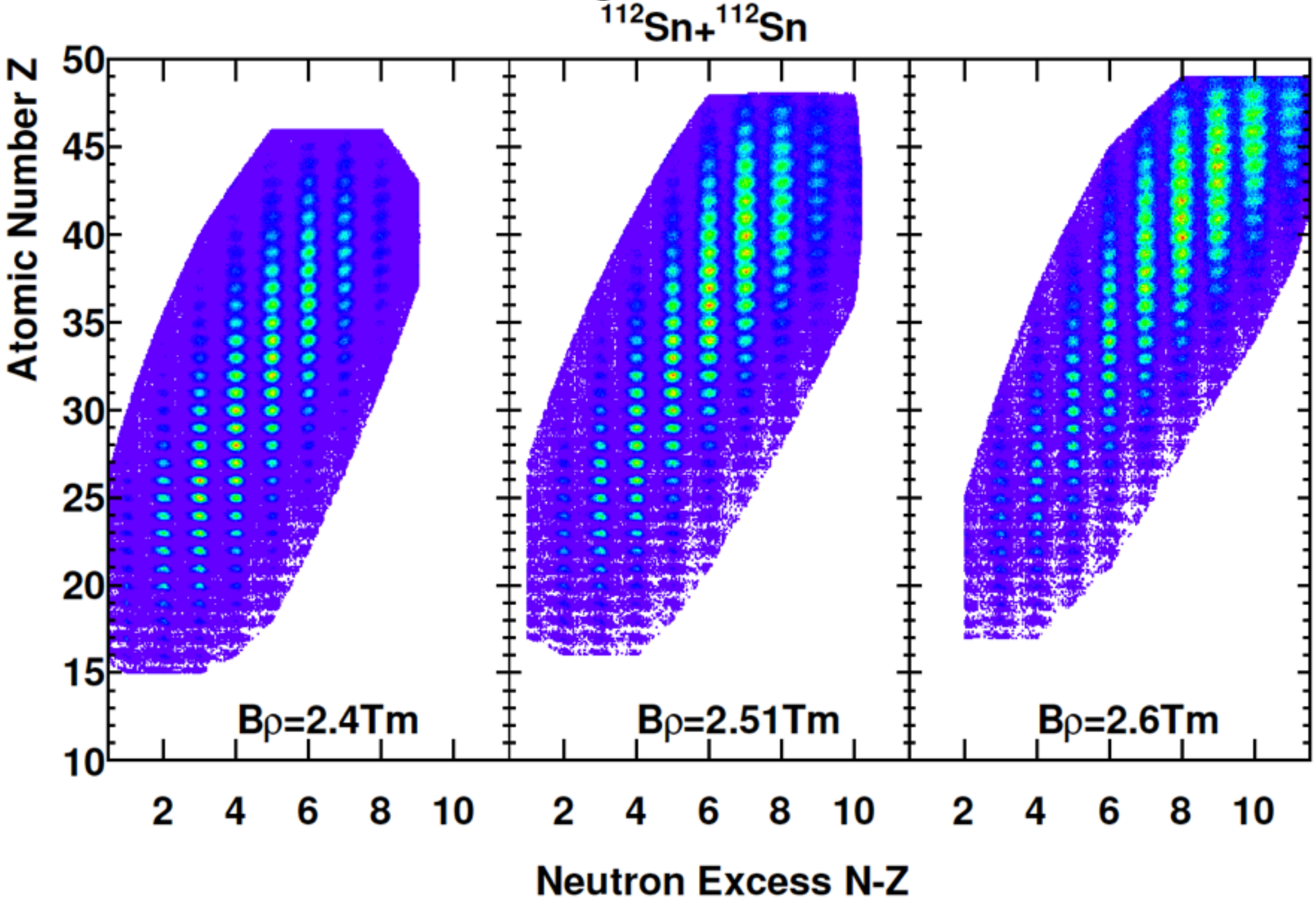
Romualdo de Souza

Variable Energy Cyclotron Centre

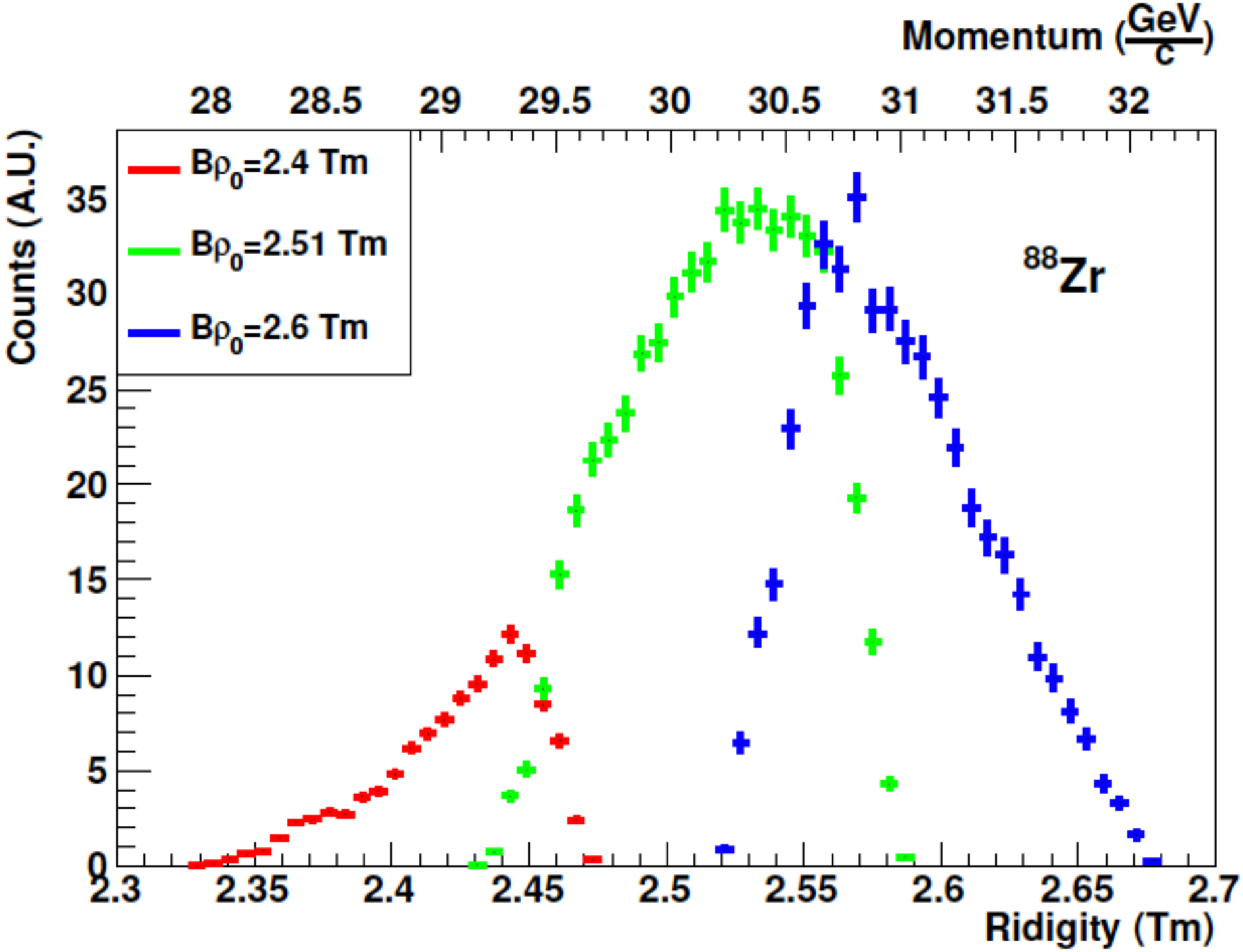
Tilak Ghosh, Tapan Rana


get beam

Identifying Projectile-like Fragments



Combining Momentum Settings



Isoscaling in ImQMD