Precision Measurement of Isospin Diffusion and Odd-Even Staggering in Fragment Yields

Jack Winkelbauer

NSCL, MSU

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Outline

- Isospin Diffusion Experiment
  - Motivation
  - Experimental Setup
  - Current Progress (Analysis is ongoing)
- Fragment Production (Staggering in fragment yields)
  - Motivation
  - Preliminary Results
- Future

Isospin Diffusion → Isospin Transport Ratio

Isospin diffusion occurs only in asymmetric systems A+B

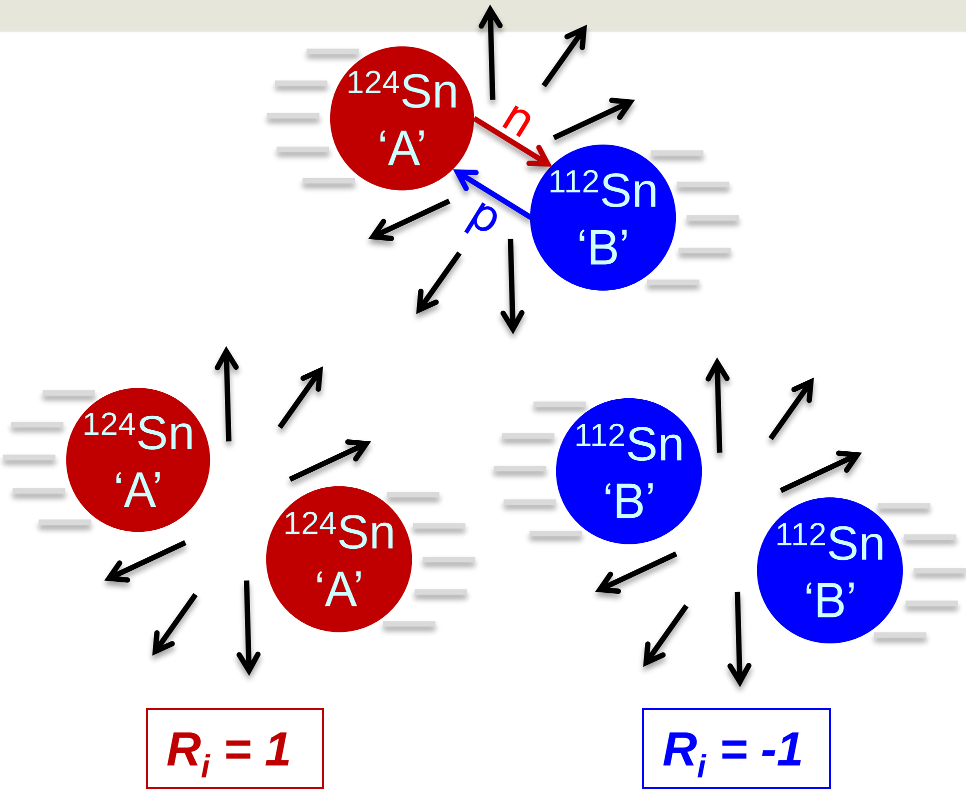
No isospin diffusion between symmetric systems A+A , B+B

Non-isospin diffusion effects:

- same for A in A+B & A+A;
- same for B in B+A & B+B

$$R_i = 2\frac{x_{AB} - (x_{AA} + x_{BB})/2}{x_{AA} - x_{BB}}$$

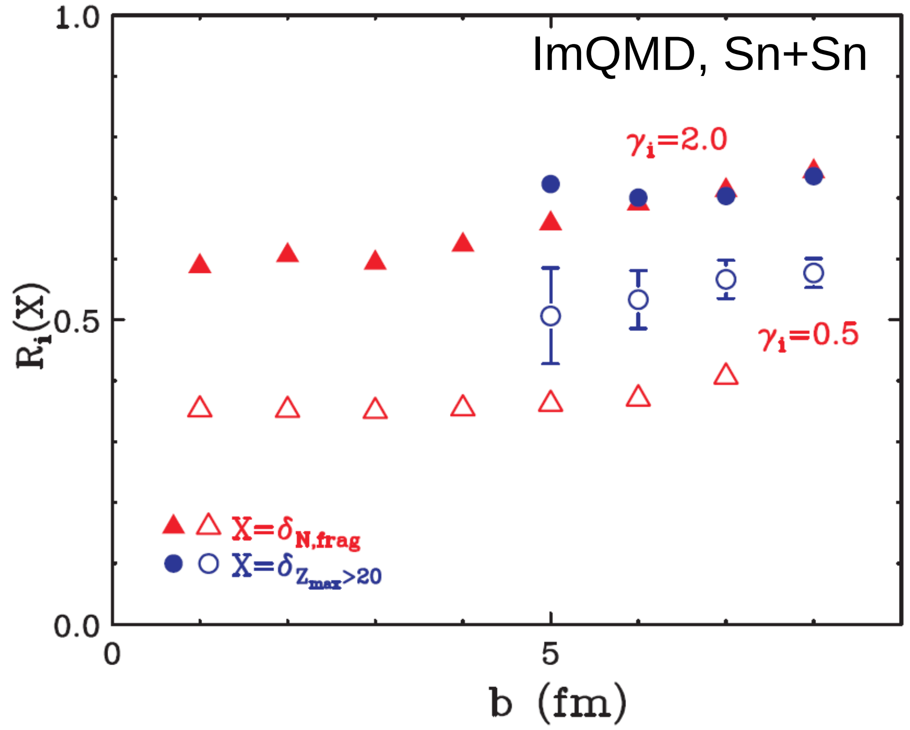
δ - Residue asymmetry (from theory)
α - (isoscaling parameter, Exp. Obs.)
$R_i(\alpha)=R_i(\delta)$ *assuming* $\delta=m\alpha+b$



Non-isospin transport effects are "cancelled"!

Main Goal: Isospin Transport in Residues

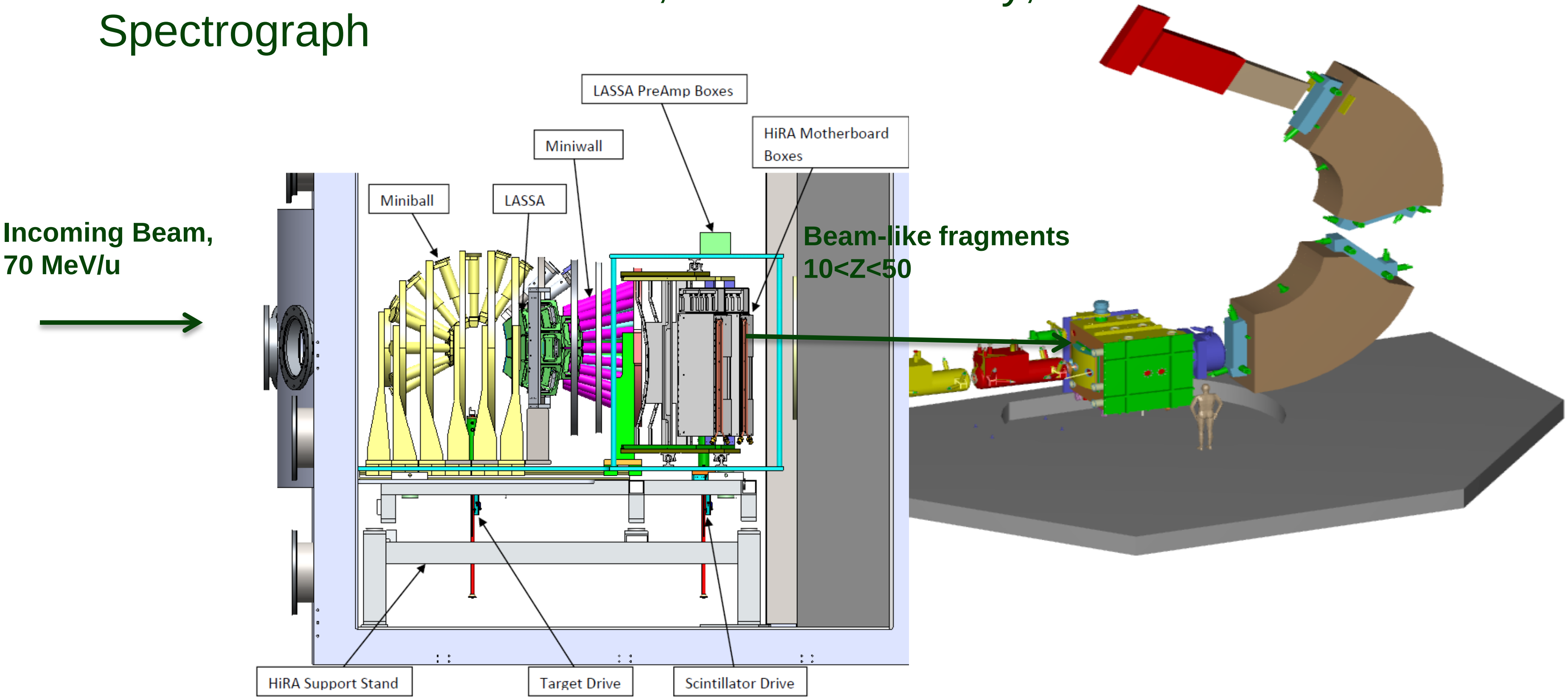
- Different amount of isospin diffusion for heavy residues.
- We will measure the isospin transport for the residue using the S800 spectrograph in addition to measuring the fragment distributions.



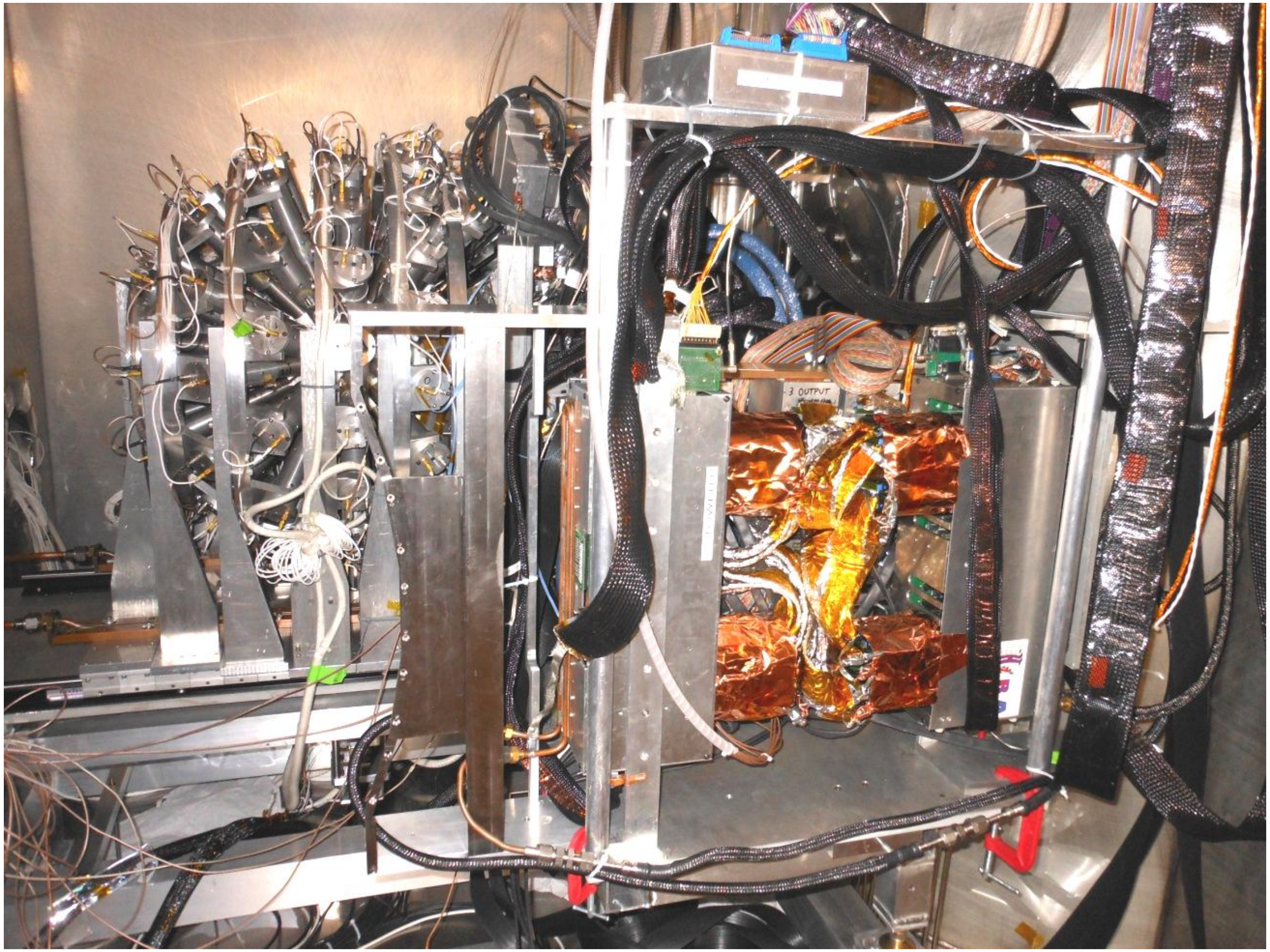
$$E_{sym}(\rho) = S_k\left(\frac{\rho}{\rho_0}\right)^{2/3} + S_i\left(\frac{\rho}{\rho_0}\right)^{\gamma_i}$$

Experiment 07038: Precision Measurement of Isospin Diffusion

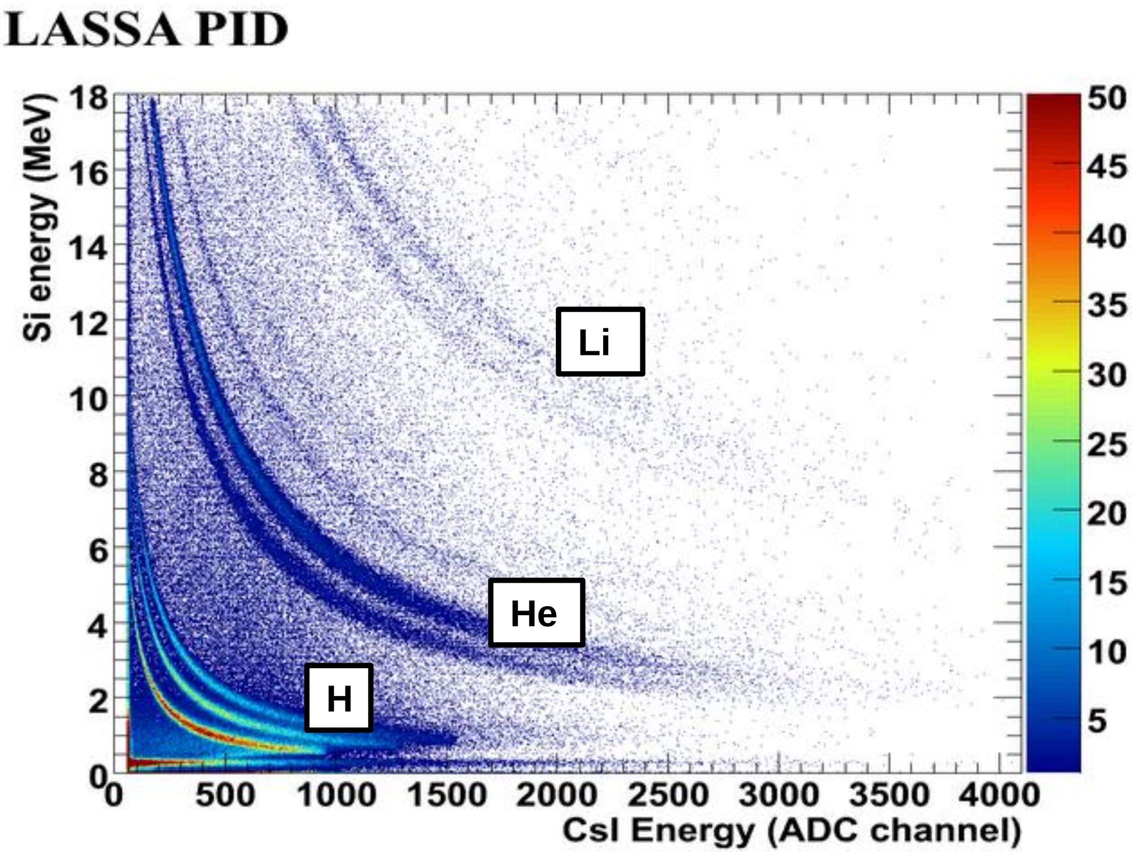
- Investigates the density-dependence of the nuclear symmetry energy
- $^{112,118,124}Sn + {}^{112,118,124}Sn$ Collisions
- Combines the MSU Miniball, the LASSA Array, and the S800 Spectrograph

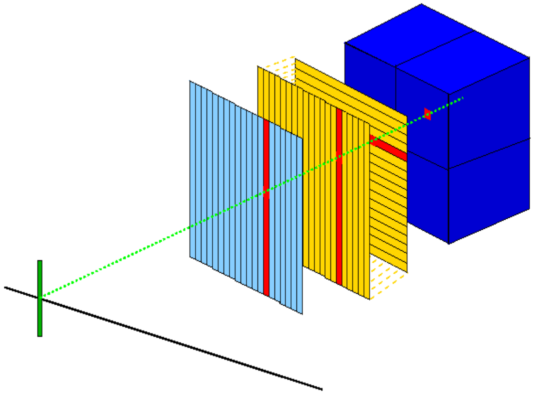


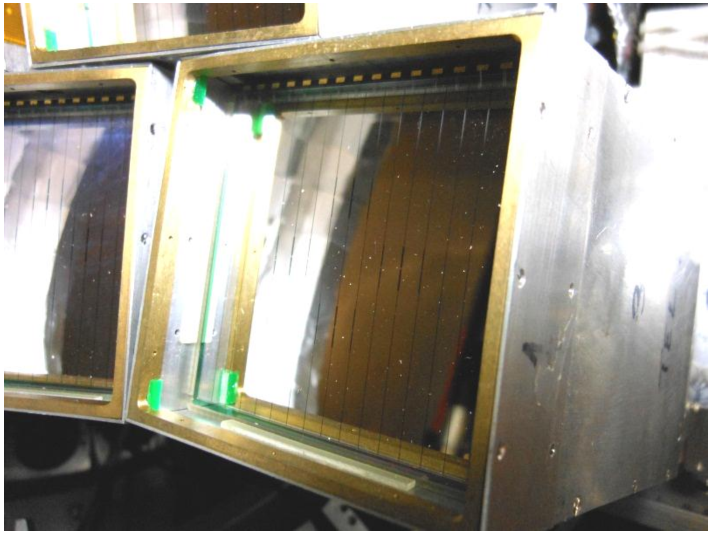
Experiment 07038: Precision Measurement of Isospin Diffusion



The LASSA Array

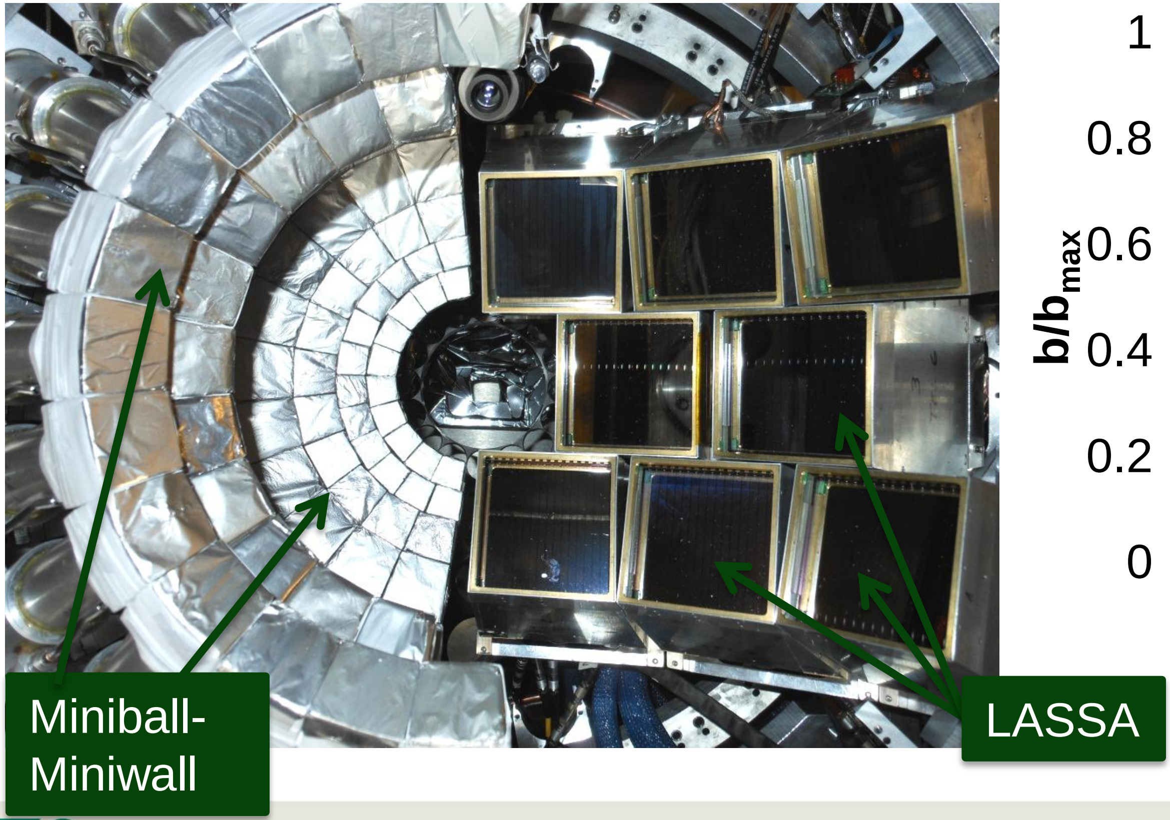






The MSU Miniball/WU Miniwall

- Total charged particle multiplicity is related to impact parameter



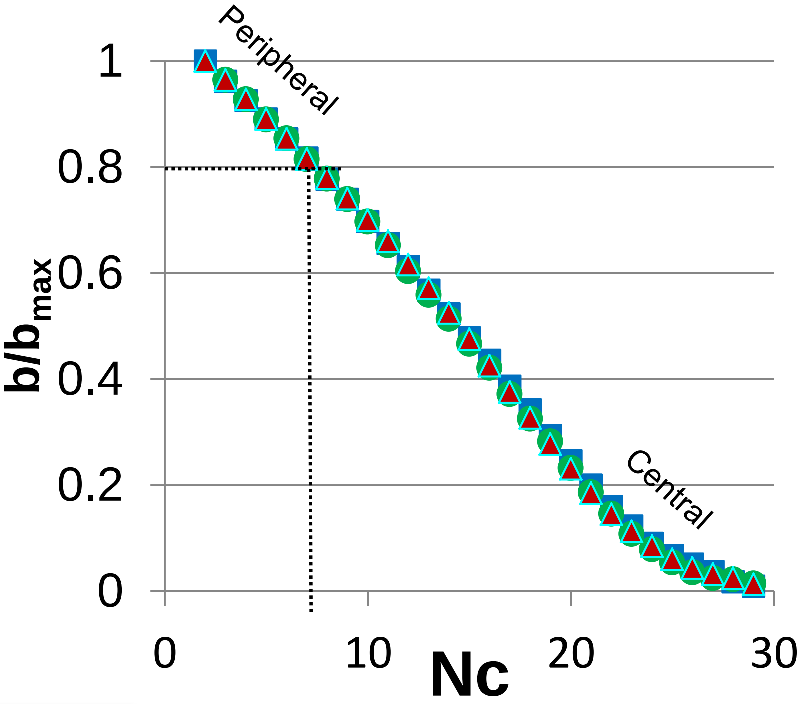


Figure: Andira Ramos (CEU Poster)

The MSU Miniball/WU Miniwall

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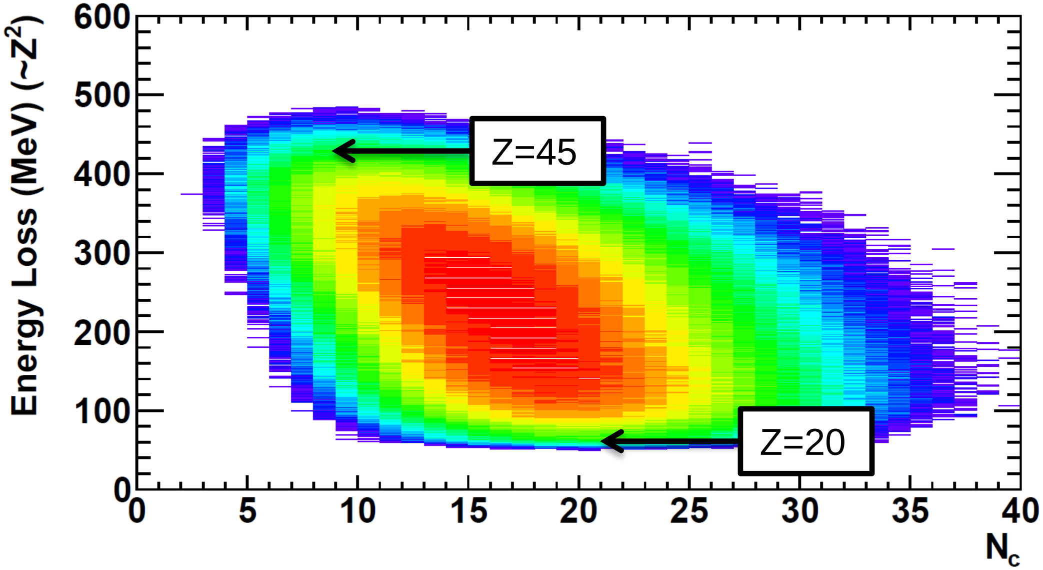
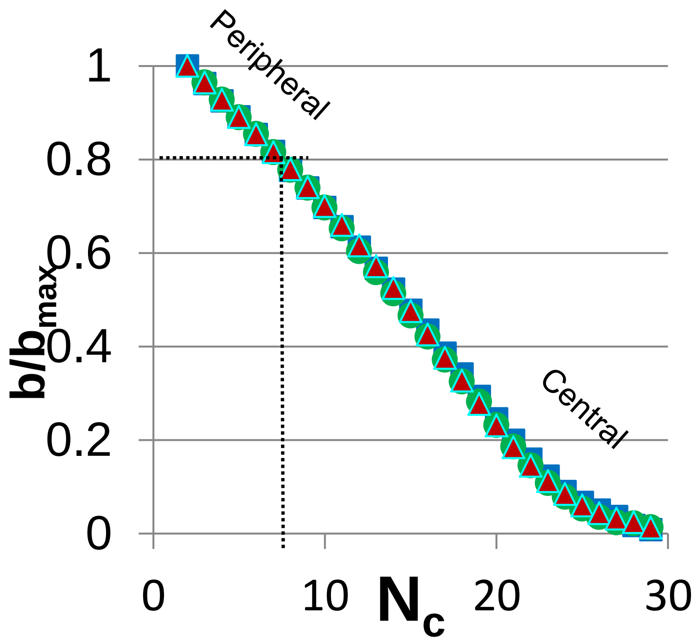
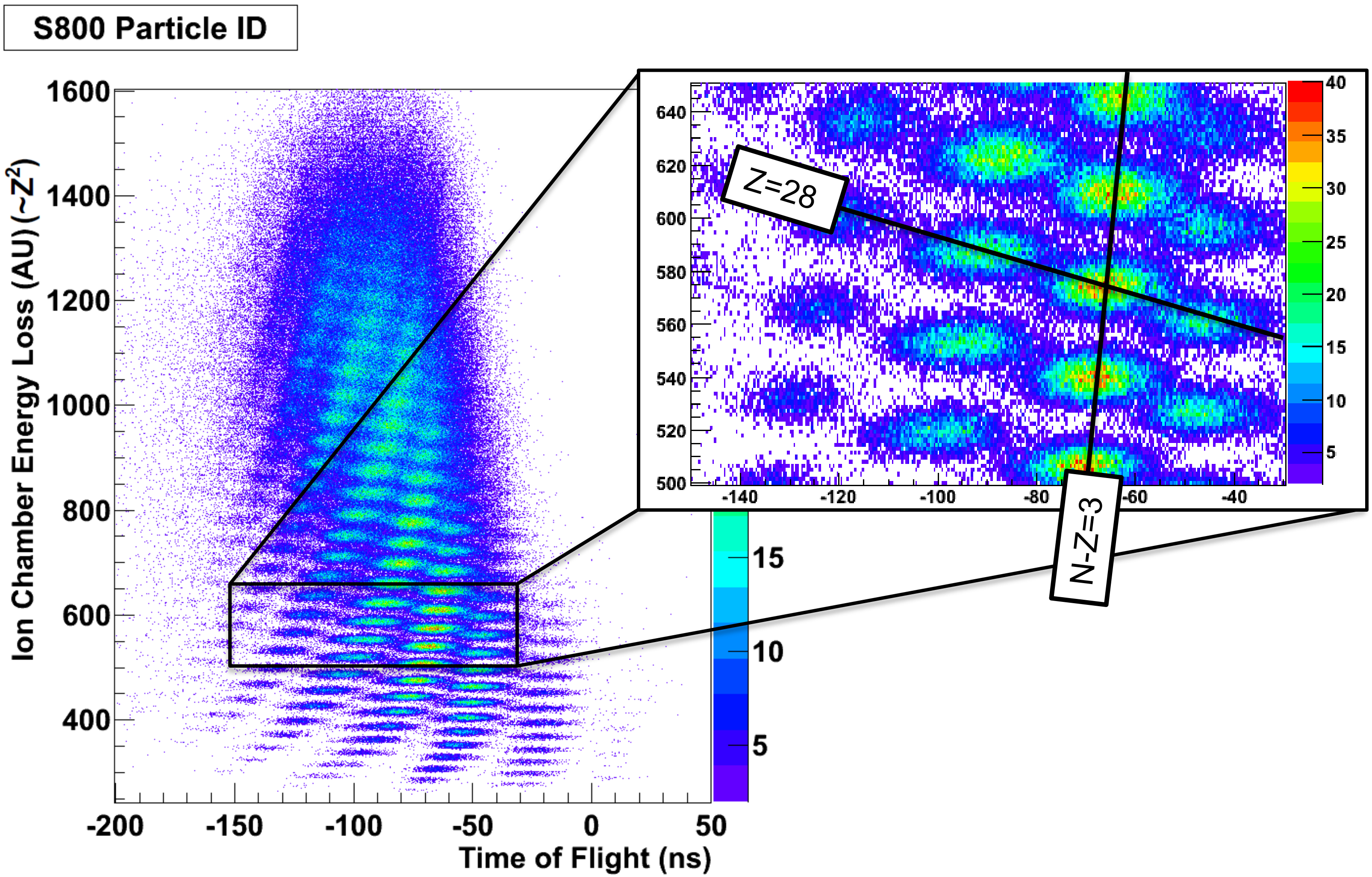




The S800 Spectrometer

Separates isotopes (Z≈20-50) by comparing ΔE, TOF, and Bρ



Progress Towards Isospin Diffusion

- Impact parameter Selection using MB (Rachel Showalter, GS NSCL)
- Analysis of LASSA data is underway
- S800
  - Detector calibrations are done
  - Working on implementing TKE CsI Hodoscope for q-state identification
  - Working on producing/fitting momentum distributions for heavy fragments

- Meanwhile, we are looking at the structure in heavy fragment yields
  - Hot excited system -> stable heavy fragment

Odd-Even Z Staggering

112Sn+58Ni 35 MeV/u, Catania

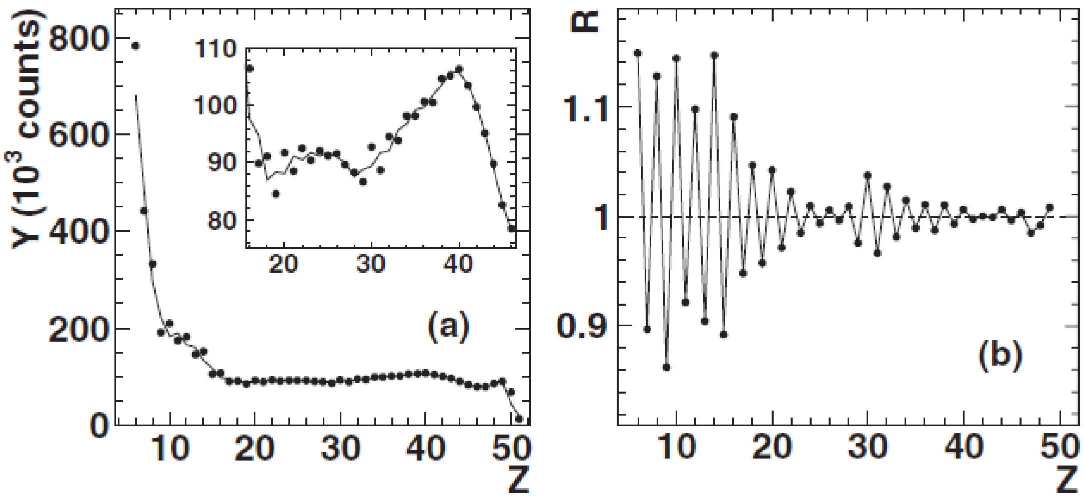


Figure: Casini et al., PRC 86 011602 2012

- 112Sn+112Sn 70 MeV/u, NSCL
  - See odd-even staggering, but analysis is incomplete
- Staggering is complex, need A identification
- 58Ni+Be, 140 MeV/u, NSCL
  - Complete Analysis
  - Michal Mocko, PRC 74, 054612 2006

$$R = \frac{Y(Z)}{Y_{smooth}(Z)} \longrightarrow R = \frac{Y(Z, N-Z)}{Y_{smooth}(Z, N-Z)}$$

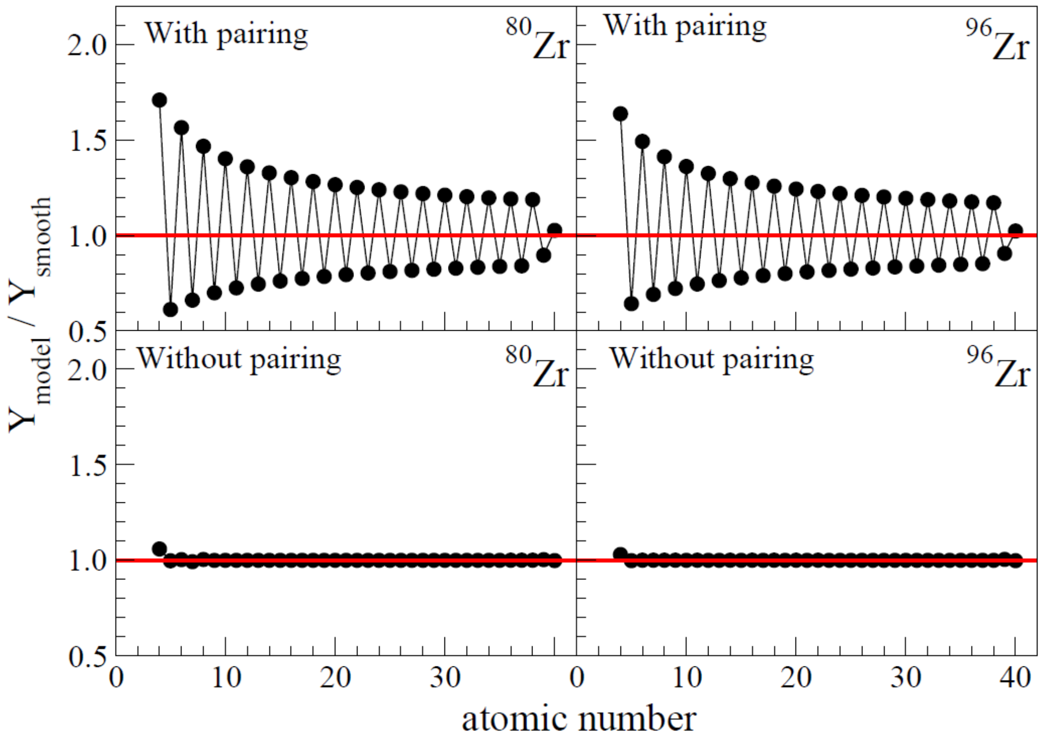
Pairing Energy in the SMM

$$E_B = a_V A - a_S A^{2/3} - a_A \frac{(A-2Z)^2}{A^{1/3}} - a_C \frac{Z(Z-1)}{A^{1/3}} + \delta(A,Z)$$

Volume term | Surface term | Asymmetry term | Coulomb term | Pairing term

For pairing term:

$$\delta(A,Z) = \begin{cases} +\delta_o & \text{A, Z even} \\ 0 & \text{A odd} \\ -\delta_o & \text{A, Z odd} \end{cases}$$

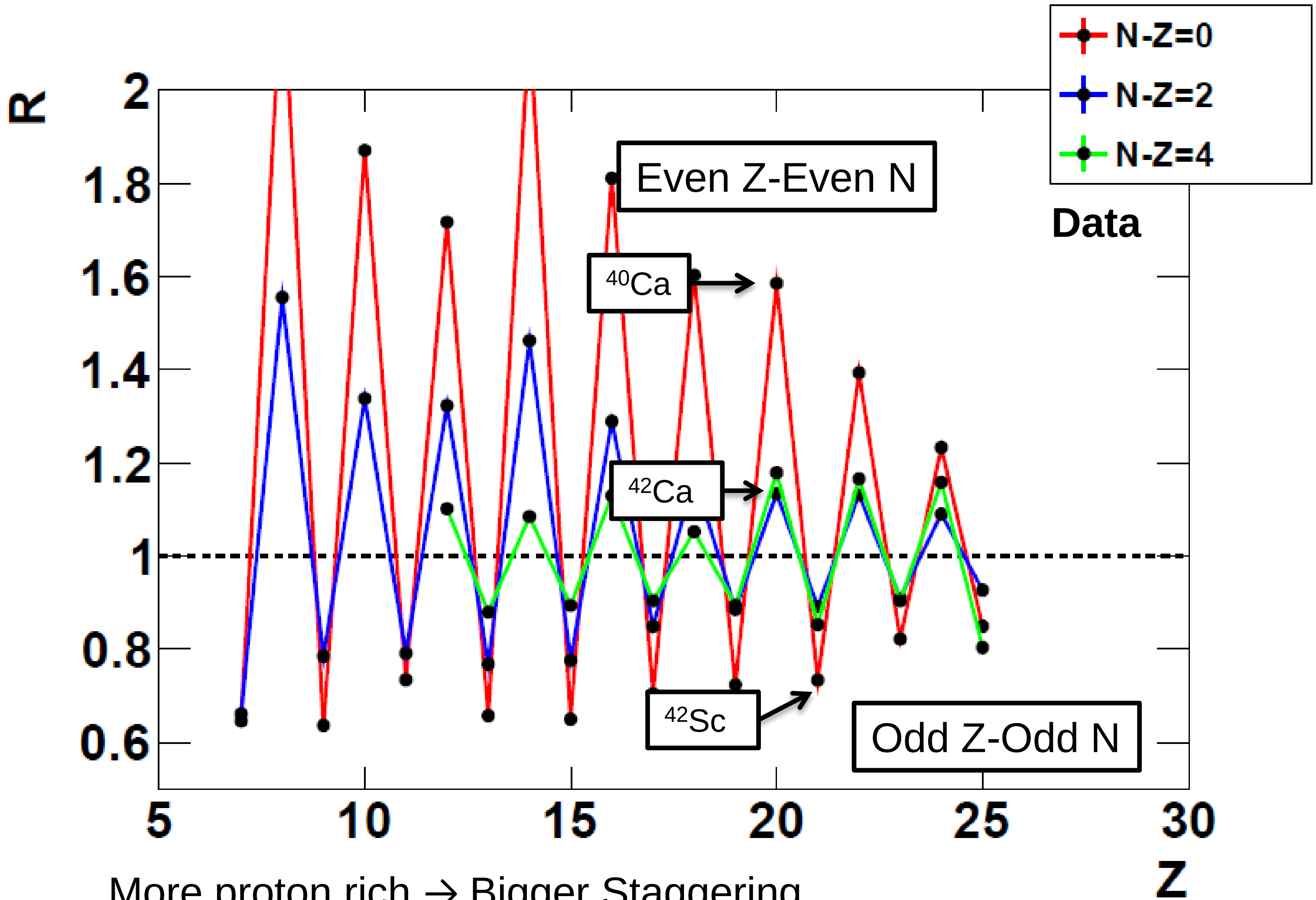


Odd mass → No Pairing

No Pairing → No Staggering

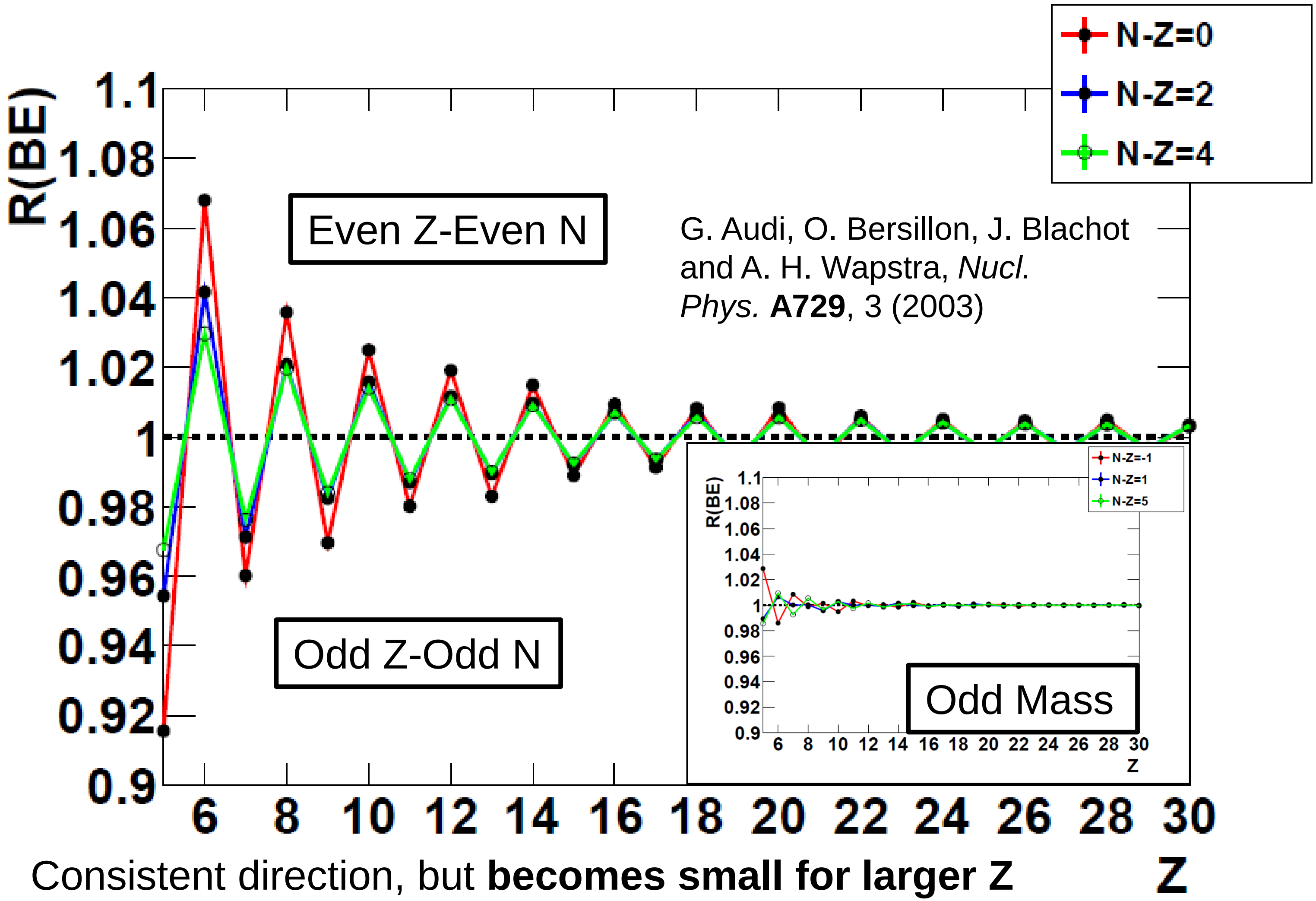
Figure: Sergio Souza, SMM Calc.

Even Mass Staggering for ^{58}Ni+Be



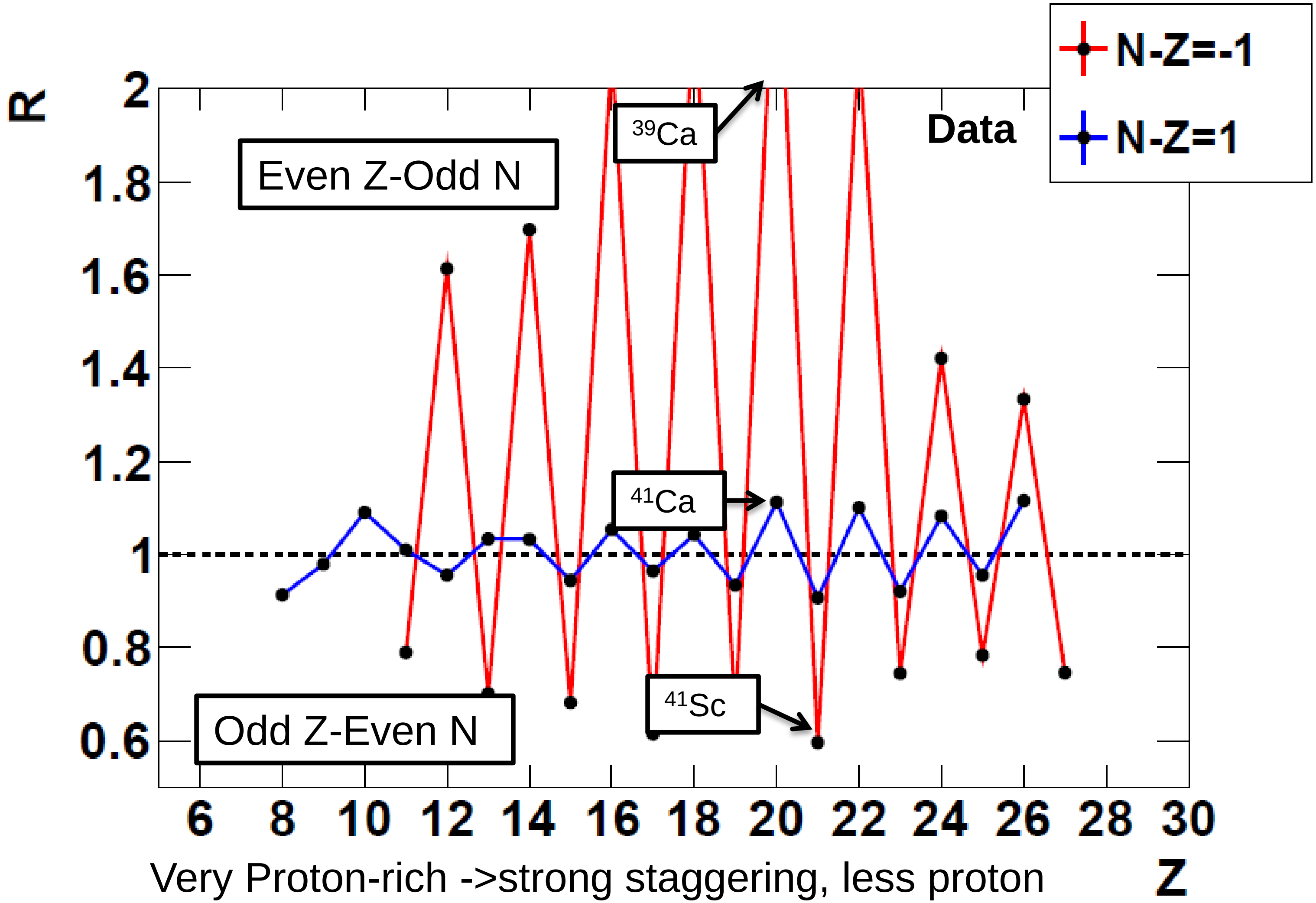
More proton rich → Bigger Staggering

Even Mass Staggering in Exp. BE



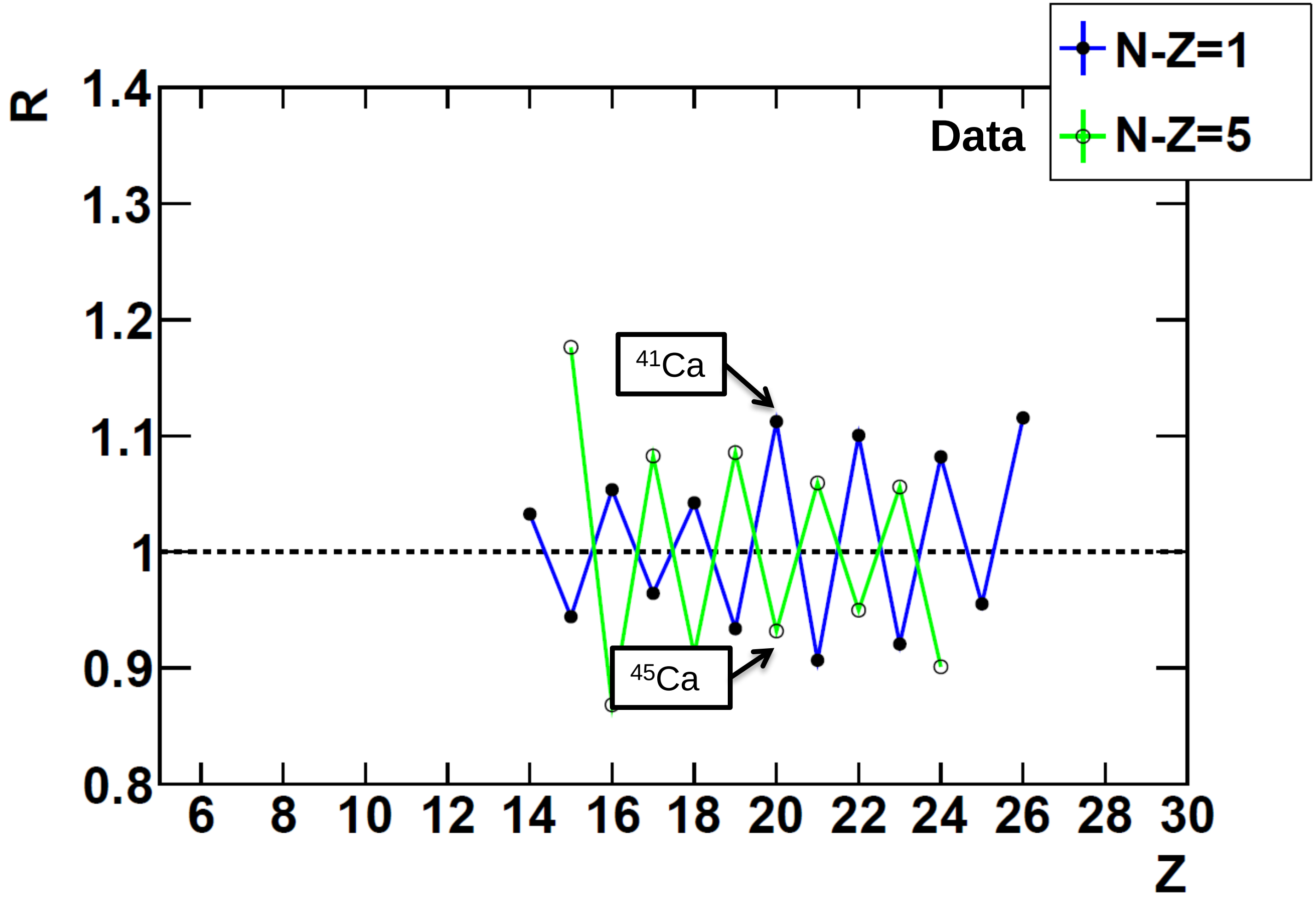
Consistent direction, but **becomes small for larger Z**

Odd Mass Staggering for ^{58}Ni+Be



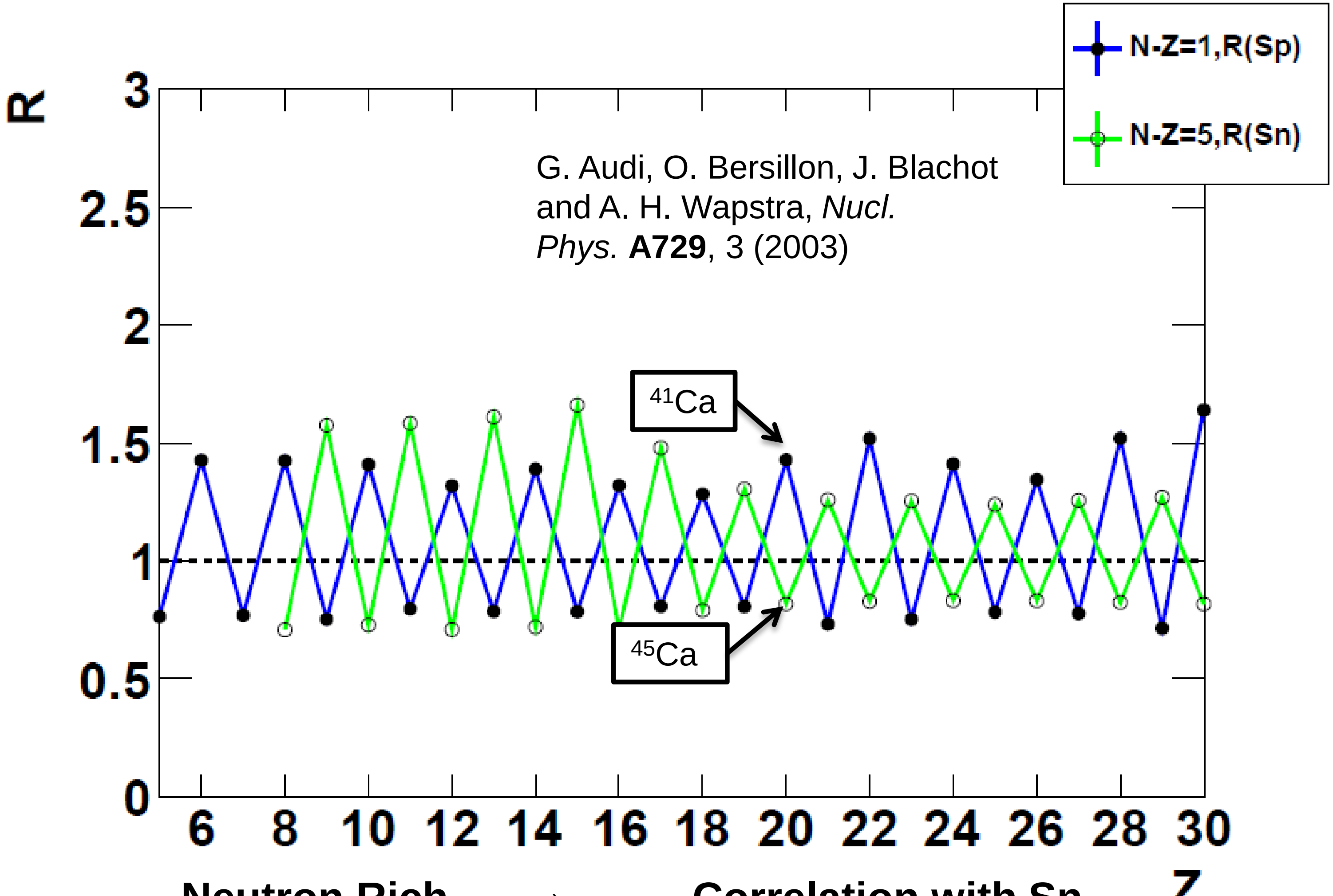
Very Proton-rich ->strong staggering, less proton rich-> less staggering

Odd Even Staggering for ^{58}Ni+Be



Very Neutron Rich → Staggering Flips

Odd Even Staggering in Sn and Sp



Neutron Rich → Correlation with Sn

Proton Rich → Correlation with Sp

Influence of Secondary Decay

- Neutron Rich (N-Z=5)
  - Over producing for odd Z, under producing for even Z
  - Sn<Sp, likely to excite to a neutron unbound level.
  - Odd Z, Even N emitting a neutron decays to odd-odd nucleus, which is unfavorable, because of pairing term.
- Proton Rich (N-Z=1)
  - Over producing for even Z, under producing for odd Z
  - Sn>Sp, likely to excite to a proton unbound level.
  - Even Z, Odd N emitting a proton decays to odd-odd nucleus, which is unfavorable, because of pairing term.

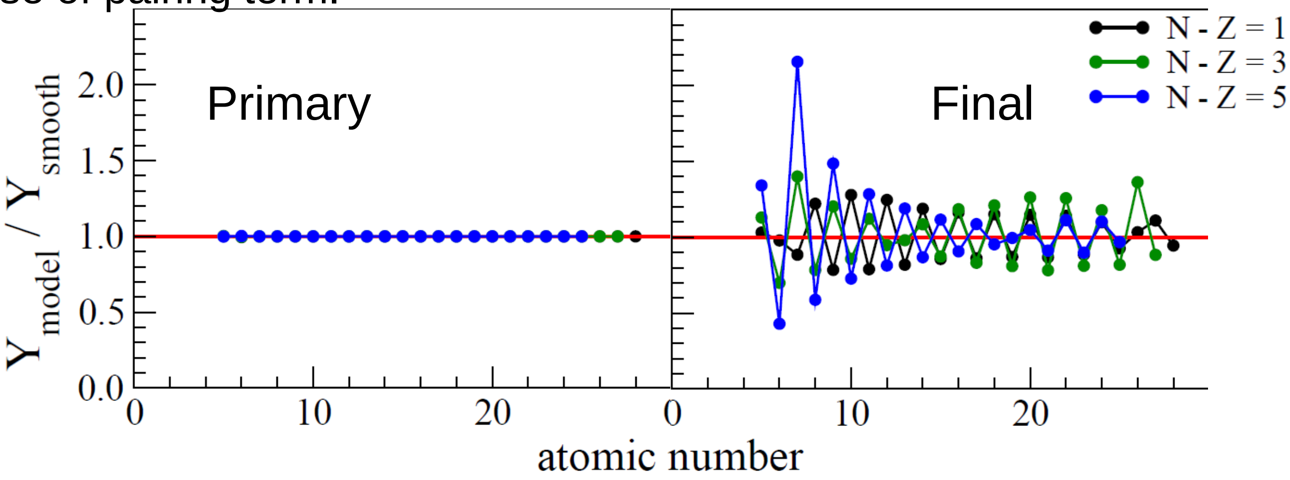


Figure: Sergio Souza, SMM Calc.

Conclusions and Future

- Odd Even Staggering
  - Z-Staggering is more complicated, isotopic resolution is necessary
  - Staggering effect increases as you go to more proton rich isotopes (N-Z=-1, N-Z=-2)
  - Staggering trend flips as you go to more neutron rich isotopes (N-Z=5, N-Z=7)
  - Working on quantifying effect with model calculations

- Isospin Diffusion
  - Analysis is ongoing, look for results soon

Collaborators

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

Western Michigan University

Michael Famiano, Steven Dye , Steven Nielsen, Mohamed el Houssieny

Washington University at St. Louis

Robert Charity, Lee Sobotka, Jon Elson

Indiana University

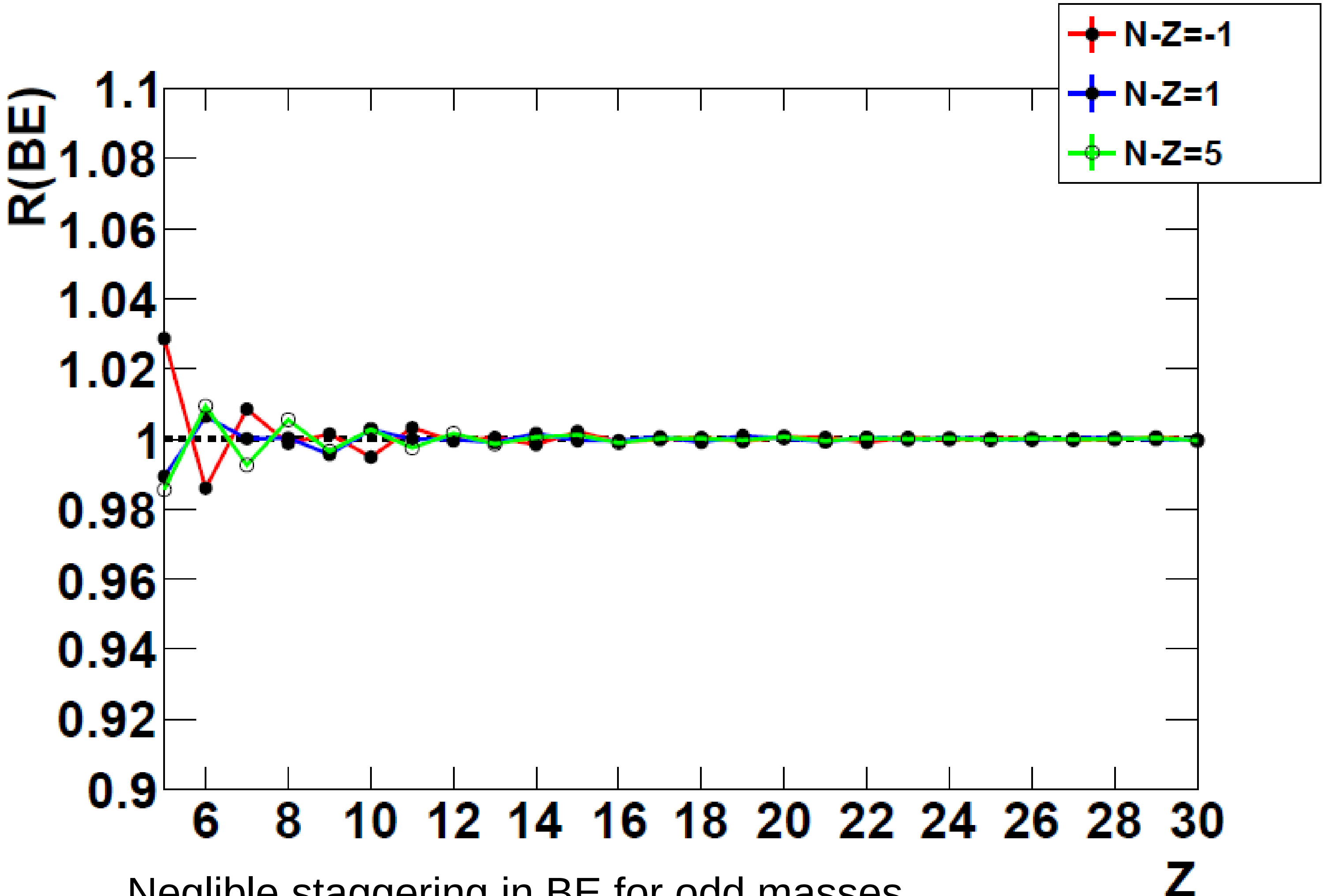
Romualdo de Souza

Variable Energy Cyclotron Centre

Tilak Ghosh, Tapan Rana

Universidade Federal do Rio Grande do Sul

Sergio R. Souza



Neglible staggering in BE for odd masses

Measured Systems

- Data taken (Millions of events):

Beam	Target		
	^{112}Sn	^{118}Sn	^{124}Sn
^{112}Sn	11.4	x	8.7
^{118}Sn	3.8	10.7	x
^{124}Sn	12.3	10.1	15.2

What is the Symmetry Energy?

$$\frac{E}{A}(\rho,\delta) = \frac{E}{A}(\rho,0) + E_{sym}(\rho)\delta^2$$

$$\delta = \frac{\rho_n - \rho_p}{\rho_n + \rho_p}$$

$$E_{sym}(\rho) = S_k\left(\frac{\rho}{\rho_0}\right)^{2/3} + S_i\left(\frac{\rho}{\rho_0}\right)^{\gamma_i}$$

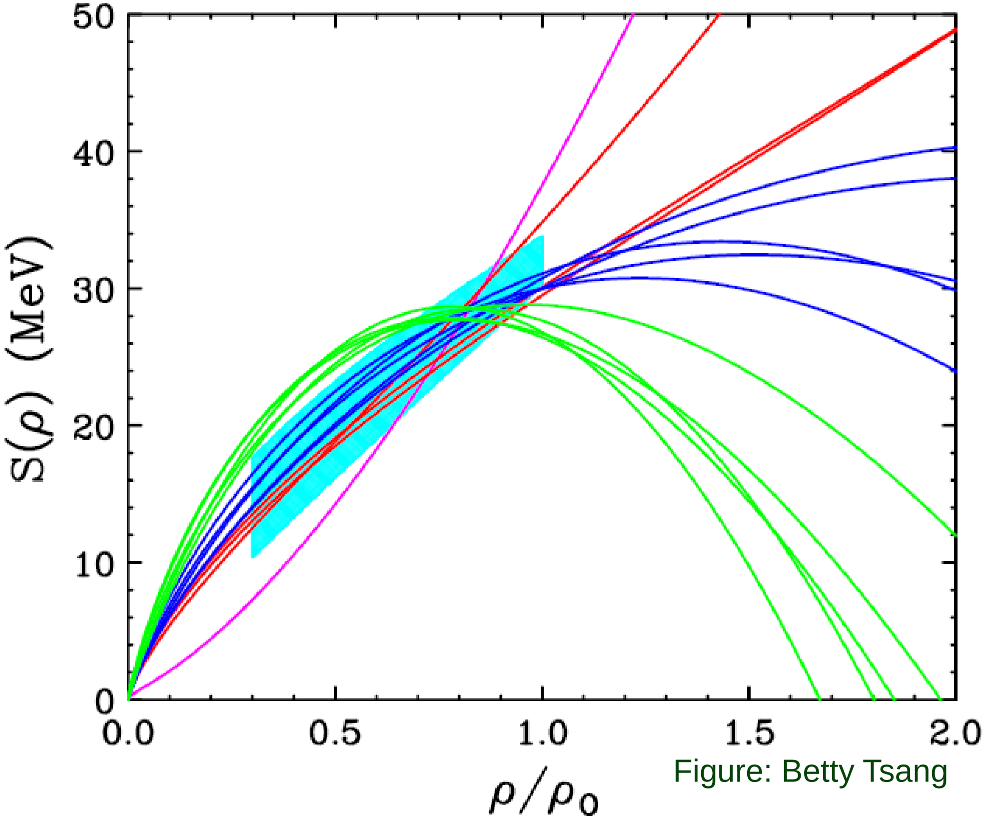
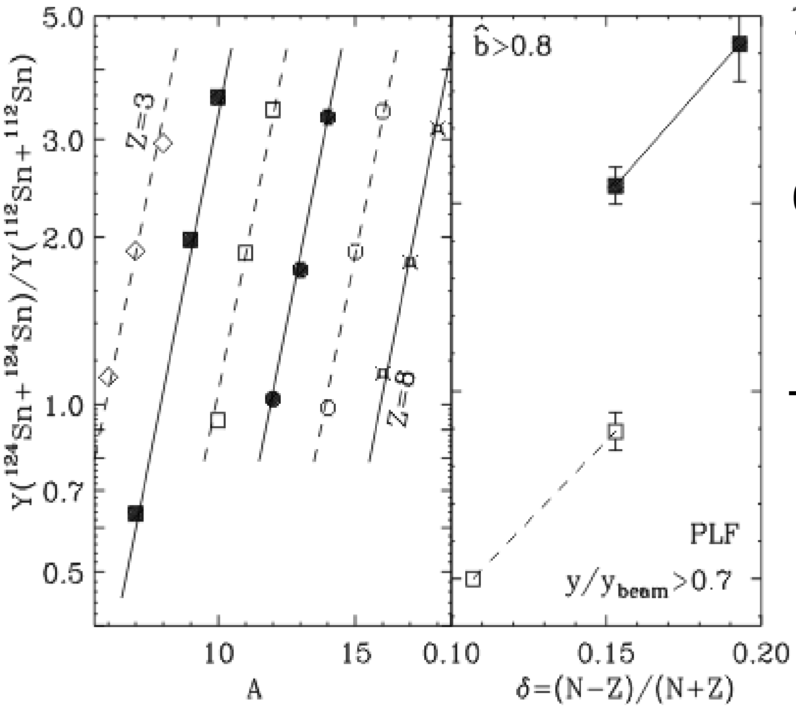


Figure: Betty Tsang

This constraint mainly comes from "isospin diffusion" measured in HIC's.

Isoscaling

Tsang et. al.,PRL 92, 062701 (2004)



1.0

0.33

$R_i(\delta)$

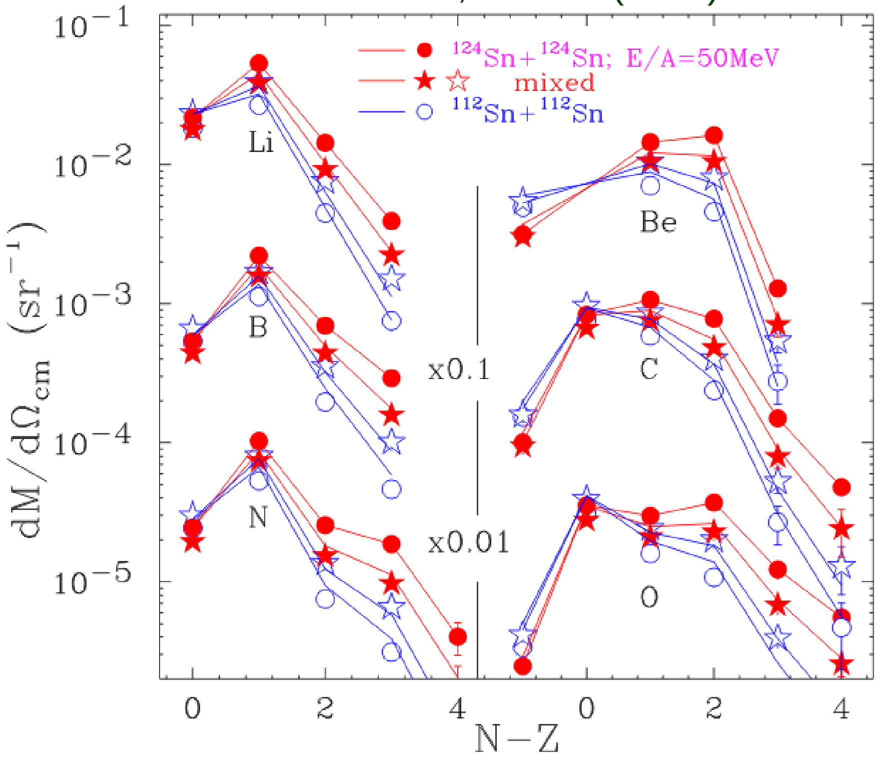
-0.33

-1.0

Probing the Asymmetry of the Spectators

The main effect of changing the asymmetry of the projectile spectator remnant is to shift the isotopic distributions of the products of its decay.

Liu et al.PRC 76, 034603 (2007).



This can be described by the isoscaling parameters α and β:

$$\frac{Y_2(N,Z)}{Y_1(N,Z)} = C\exp(\alpha N + \beta Z)$$

$$R_i = 2\frac{x_{AB} - (x_{AA} + x_{BB})/2}{x_{AA} - x_{BB}}$$

$R_i(\alpha)=R_i(\delta)$ *assuming* $\delta=m\alpha+b$

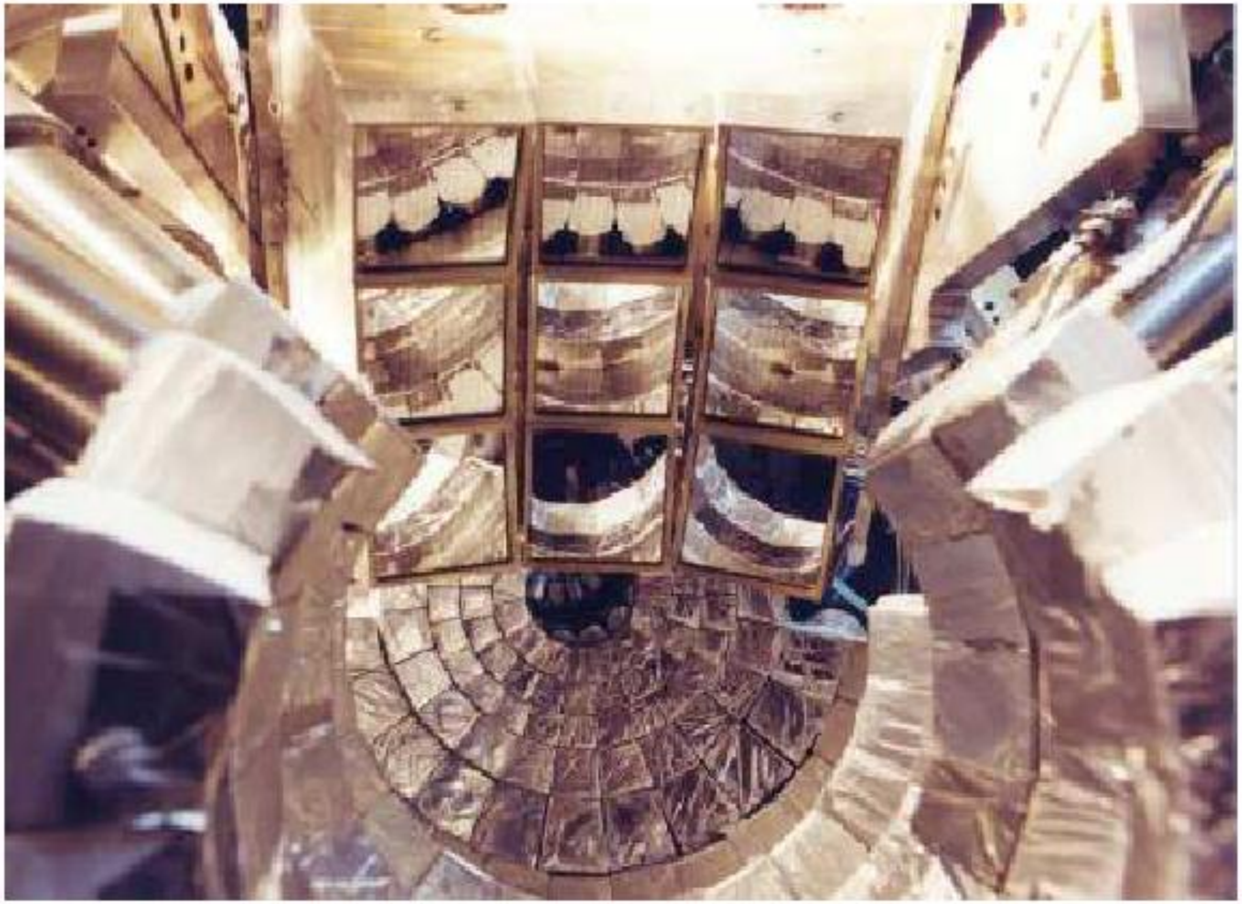
δ *(*residue asymmetry*)*

α *(*isoscaling parameter*)*

Previous Isospin Diffusion Experiment

Collaboration between MSU, IUCF, WU (recall: Rachel Hodges's talk)

$^{112}Sn+^{112}Sn$, $^{112}Sn+^{124}Sn$, $^{124}Sn+^{112}Sn$, $^{124}Sn+^{124}Sn$ at E/A=50 MeV



Miniball/Miniwall

4π multiplicity array

Z resolution for A<4

LASSA

DSSD + CsI(Tl)

Energy, Position,

A,Z Resolution for Z<8

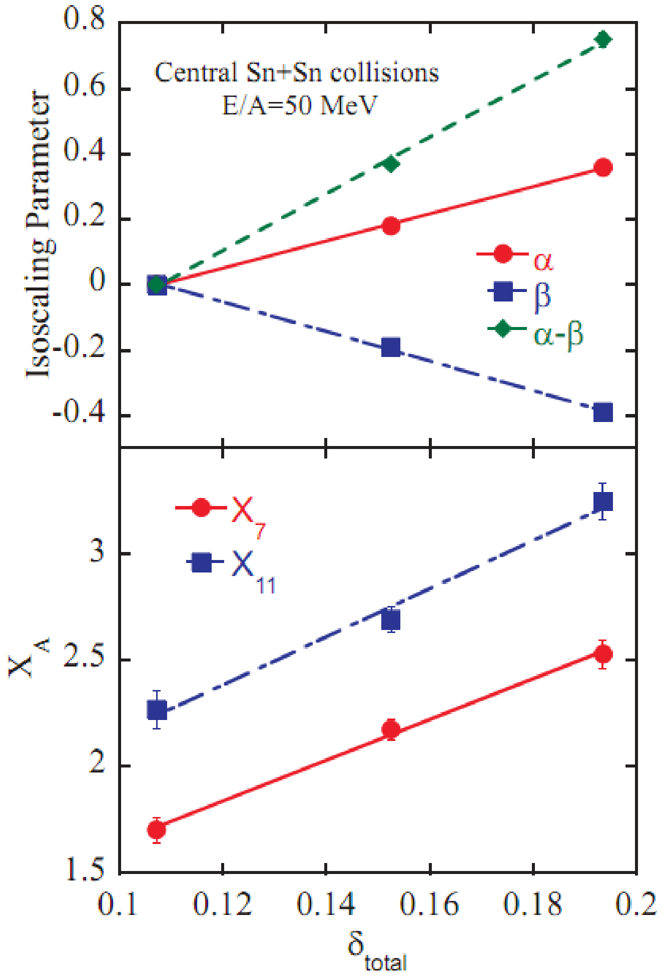
Xu et al, PRL, 85, 716 (2000)

National Science Foundation
Michigan State University

MICHIGAN STATE UNIVERSITY

Confirm Linearity of α on δ

- α depends linearly on the asymmetry according to statistical and dynamic models.
- Experimentally verified in central collisions.
- Measure ^{118}Sn on ^{118}Sn to add a data point to ^{112}Sn + ^{112}Sn and ^{124}Sn + ^{124}Sn.



Establishing A and Z from ΔE, TOF

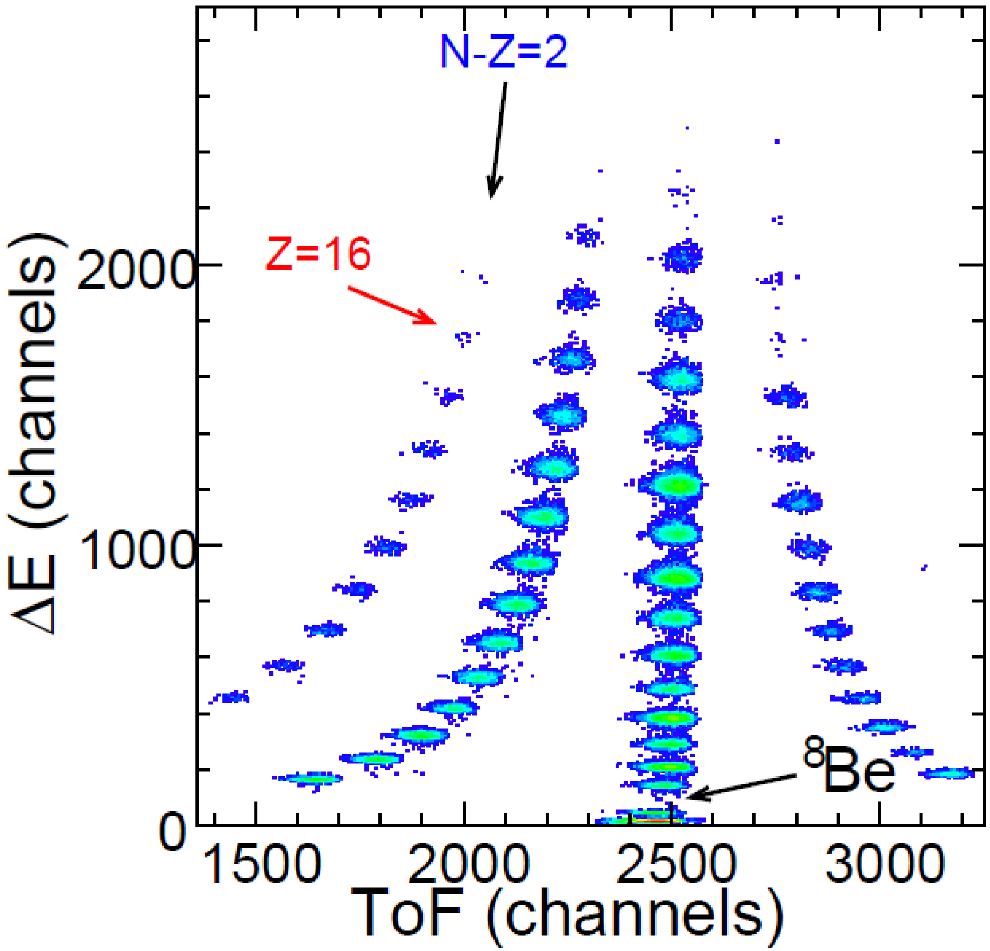
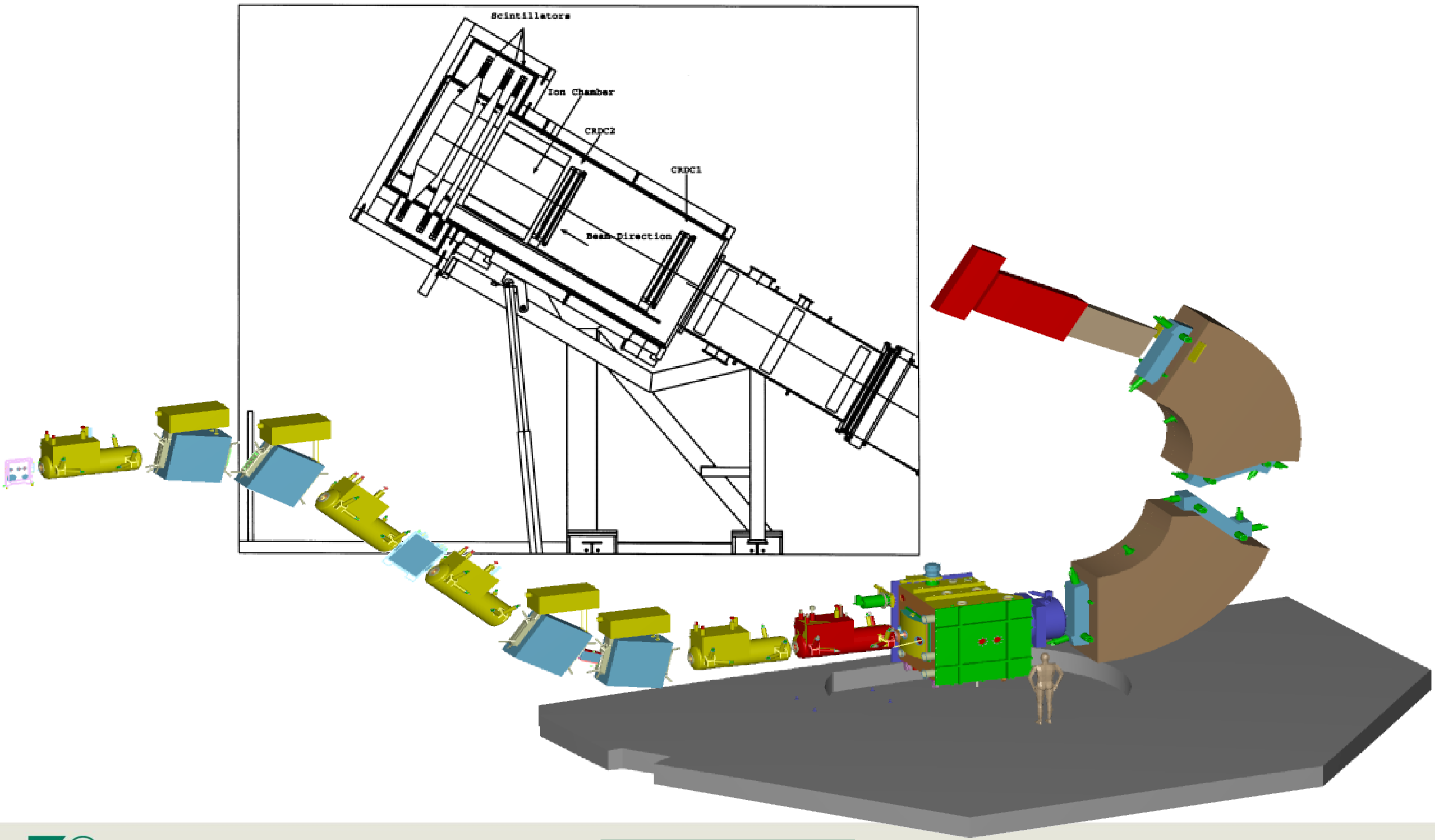


Figure: Michal Mocko

The S800 Spectrometer



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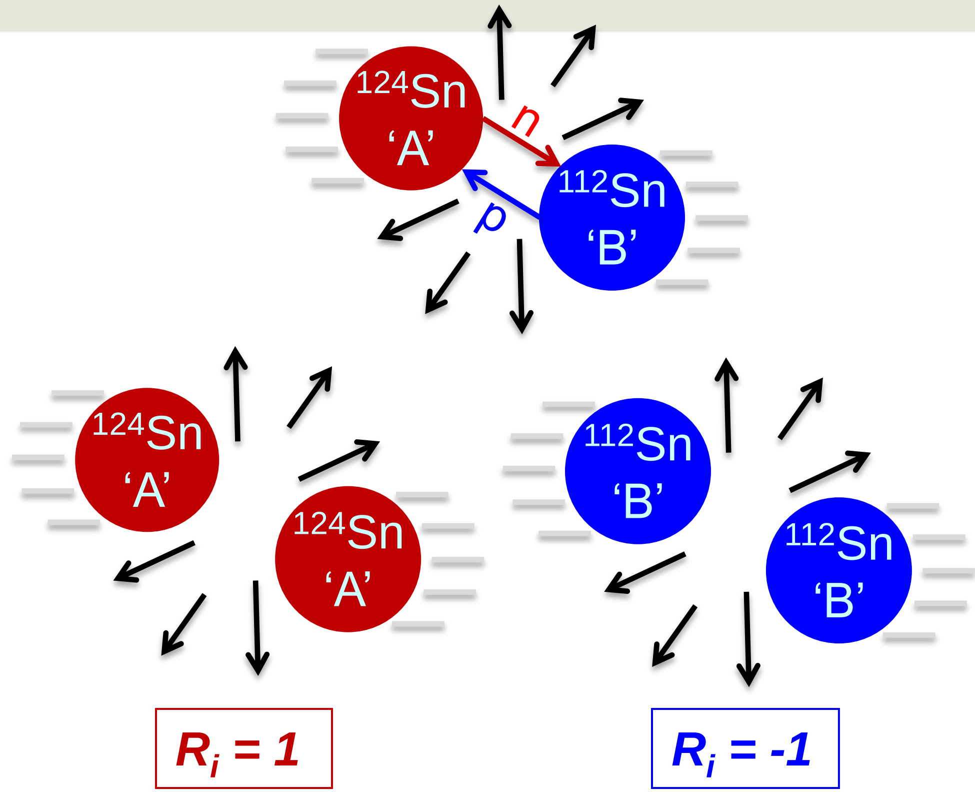
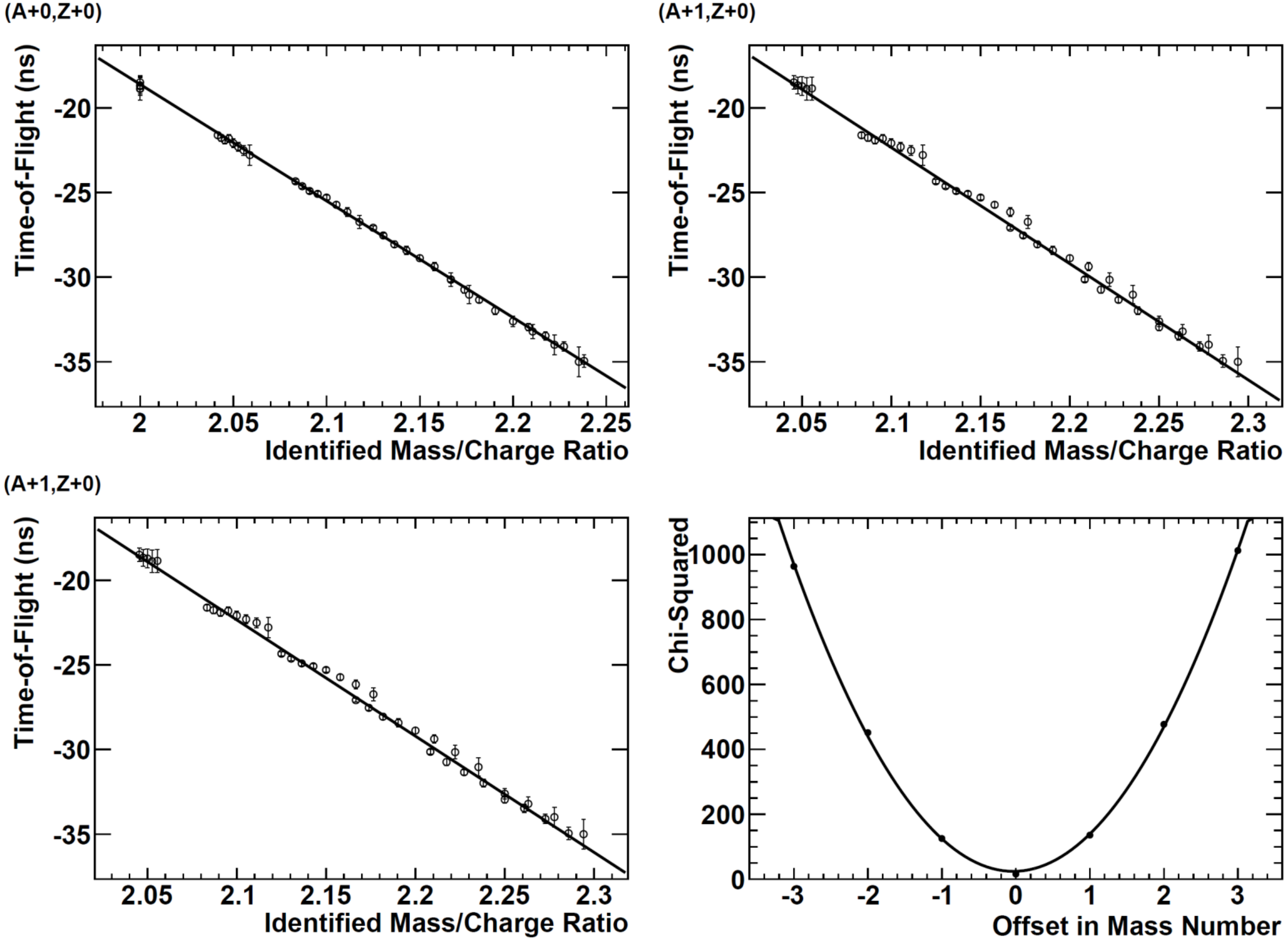
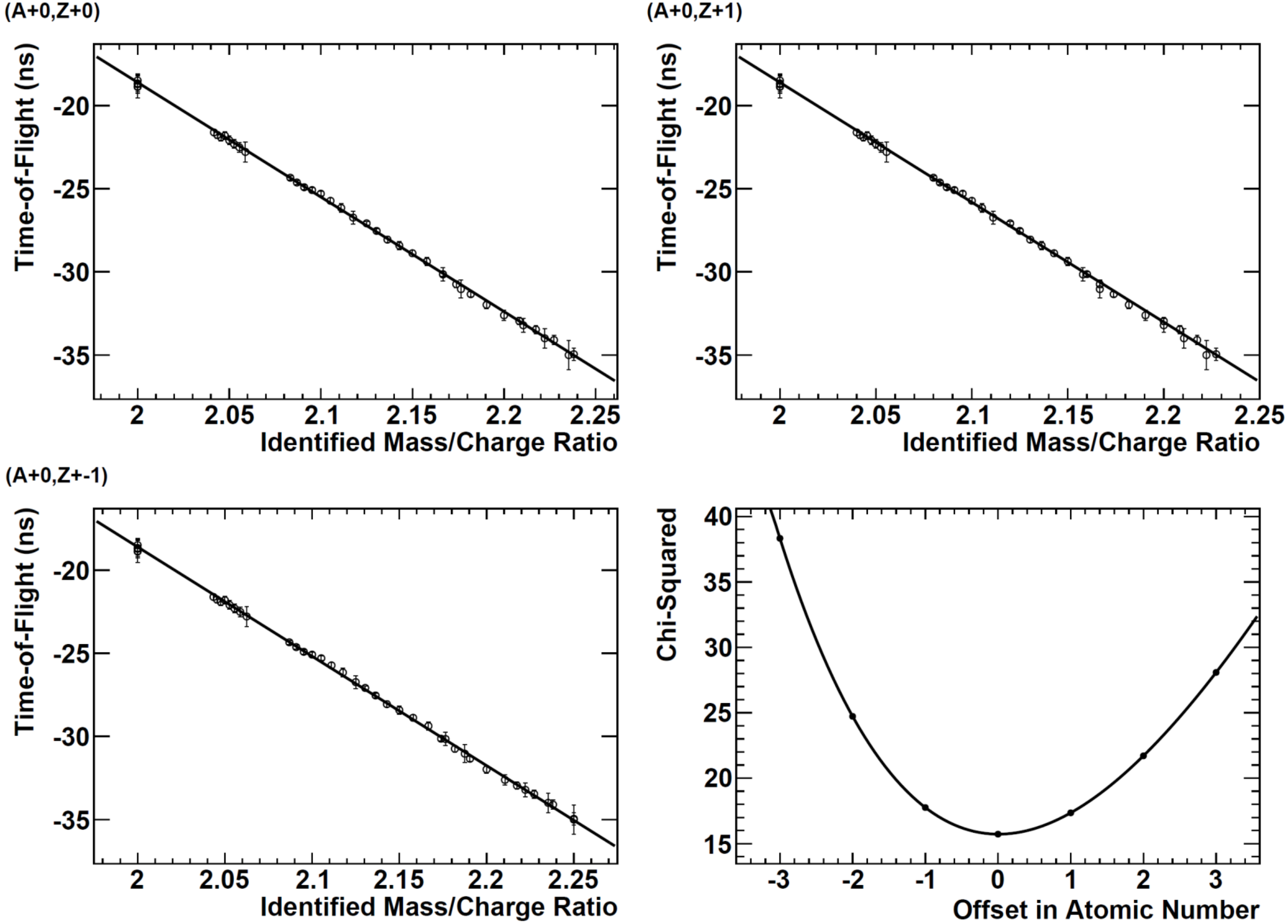


Non-isospin transport effects are "cancelled"!

The S800 Spectrometer
Absolute A-Z Identification



The S800 Spectrometer
Absolute Z Identification



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TOF corrections?

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Odd-Even Staggering for $^{112}Sn+^{112}Sn$