Betty Tsang

Subal Das Gupta Festschrift
McGill University, Montreal
Dec 4, 2004

The National Superconducting
Cyclotron Laboratory
Michigan State University

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Isoscaling in Nuclear Reactions

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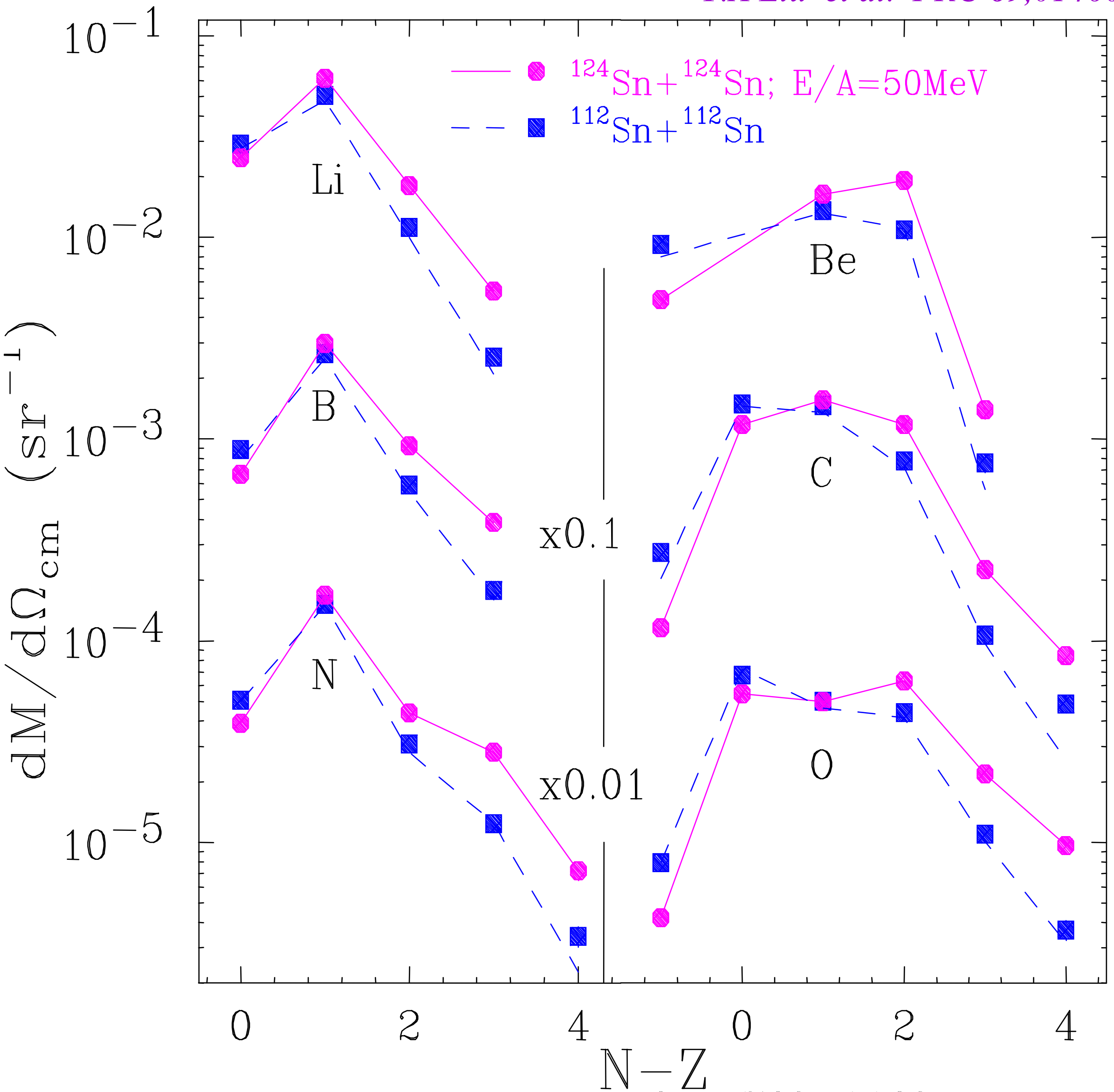
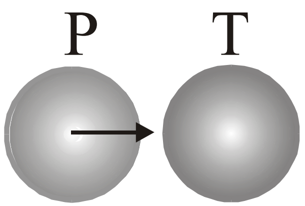
Outline

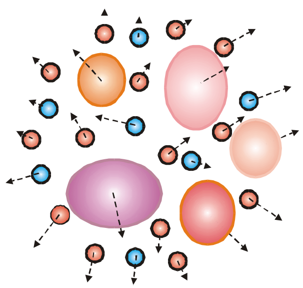
- What is isoscaling?
- Where is it observed?
  - From multifragmentation to binary reactions
- What is the physics of isoscaling? – Subal D.
- What can we learn from it?
  - Density dependence of symmetry energy.

Isoscaling constructed from Measured Isotopic yields

*T.X Liu et al. PRC **69**,014603*

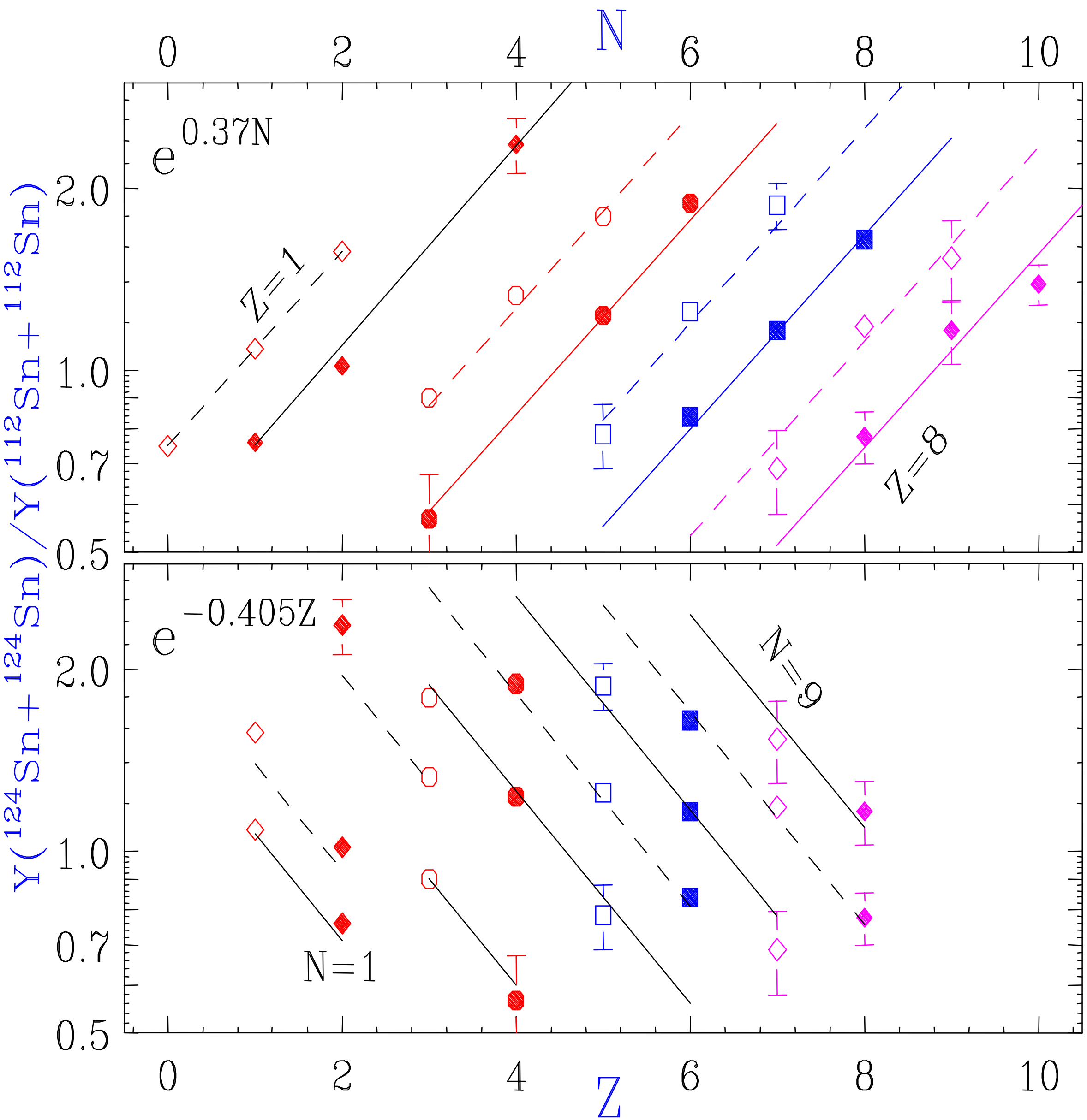






Multifragmentation

Isoscaling from Relative Isotope Ratios

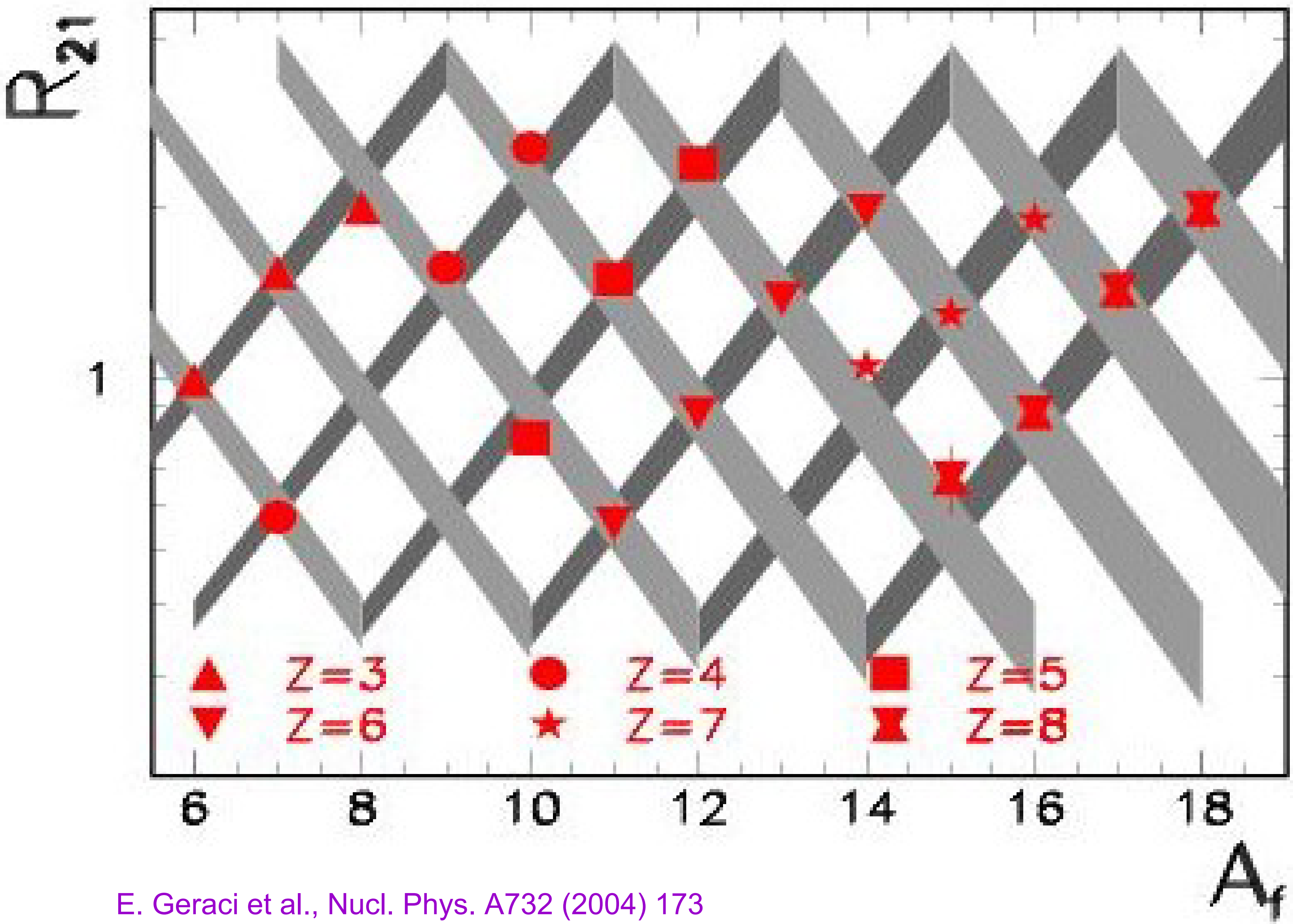


$$R_{21} = Y_2 / Y_1$$

$$\propto e^{N\Delta\mu_n/T + Z\Delta\mu_p/T}$$

*MB Tsang et al. PRC **64**,054615*

$^{112}Sn+^{58}Ni$ and $^{124}Sn+^{64}Ni$ at 35 AMeV; Central collisions, CHIMERA-REVERSE experiment



E. Geraci et al., Nucl. Phys. A732 (2004) 173

Simple derivation of the isoscaling law

- Basic trends from Grand Canonical ensemble:
  - Yields $\propto$ term with exponential dependence on the chemical potentials.

$$Y(N,Z)_{HOT} \propto \exp\left(\left[\mu_n N + \mu_p Z + B(N,Z)\right]/T\right) \bullet Z_{\text{int}}(N,Z)$$

$$where\ Z_{\text{int}} = \sum_i \left(2J_i + 1\right)\exp(-E_i^* / T)$$

$$Y(N,Z)_{COLD} = Y(N,Z)_{HOT} * f(N,Z)$$

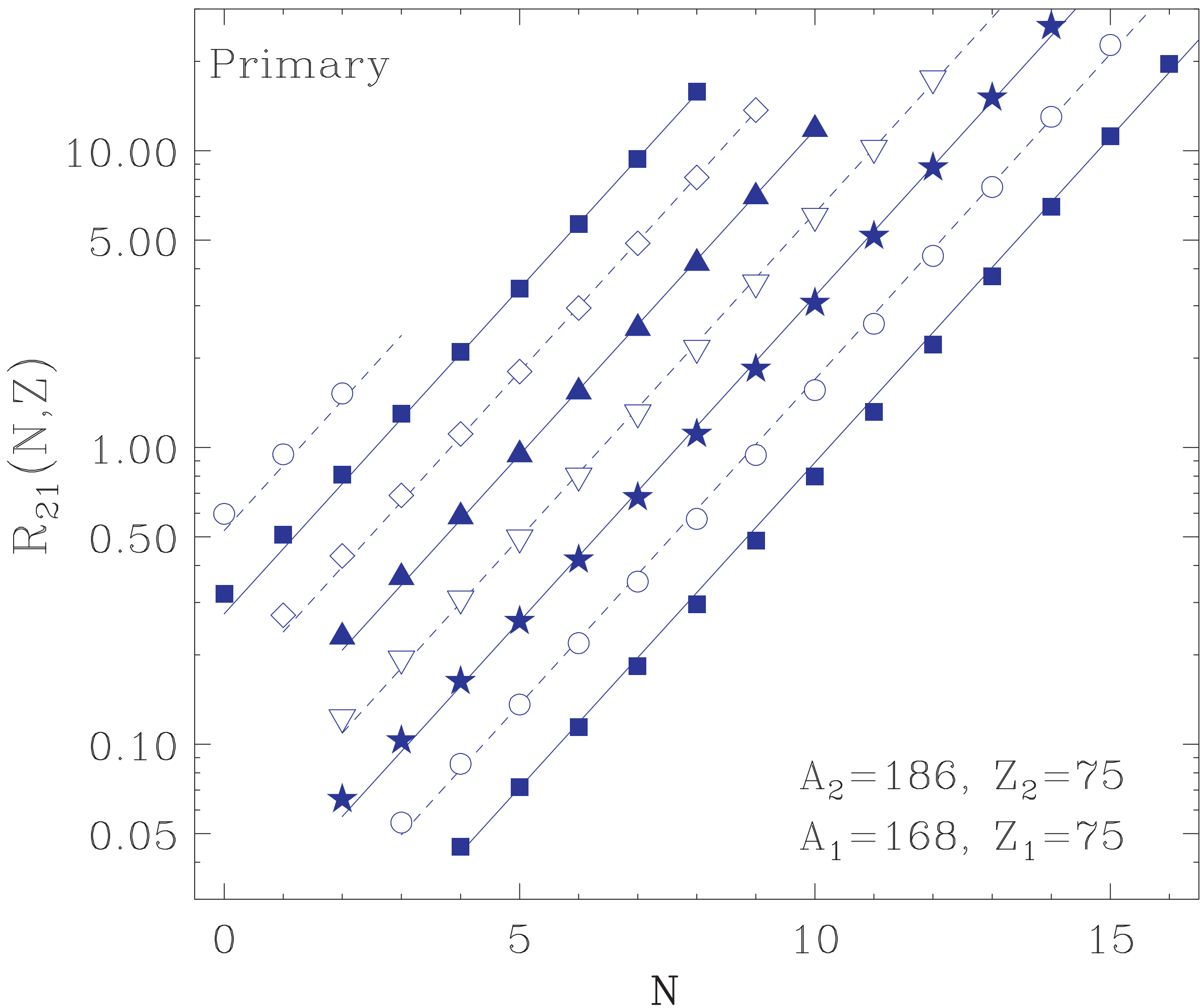
feeding correction

- Ratios to reduce sensitivity to secondary decays:

$$R_{21}(N,Z) = \frac{Y_2(N,Z)}{Y_1(N,Z)} \approx C \cdot \mathrm{e}^{N\Delta\mu_\mathrm{n}/T + Z\Delta\mu_\mathrm{p}/T}$$

- Scaling parameters *C*, $\alpha = \Delta\mu_n / T, \beta = \Delta\mu_p / T$

Isoscaling in statistical models : PRC **64**, 054615 (2001)



1. Temperature dependence
2. Density dependence
3. Size and charge dependence
4. $\alpha \propto \delta_1 - \delta_2$

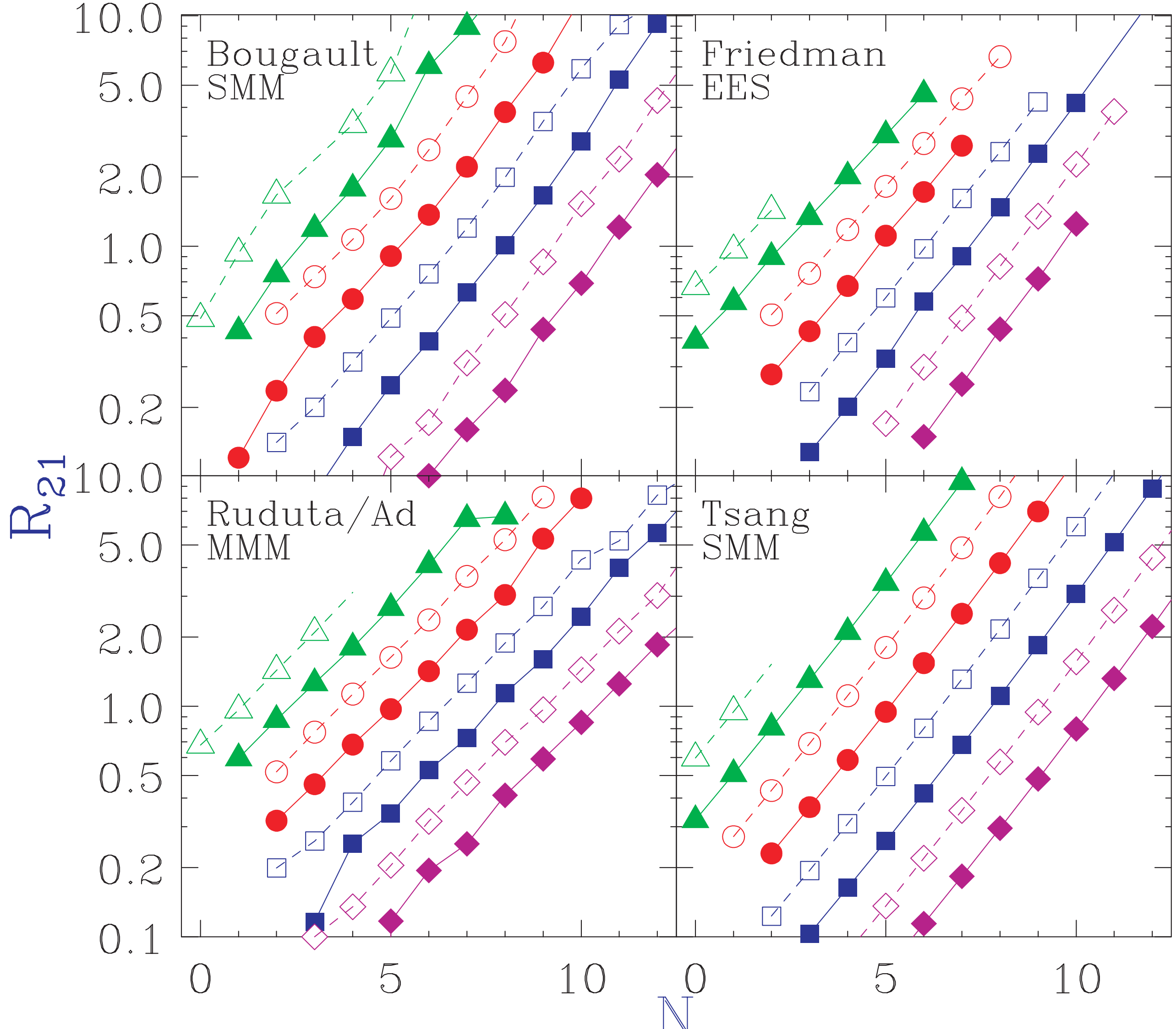
$\delta = (N-Z)/(N+Z)$

Aspects of statistical model for multifragmentation
P. Bhattacharyya, S. Das Gupta, and A. Z. Mekjian
PRC 60, 064625 (1999)

Isoscaling in statistical models

Primary distributions show good isoscaling

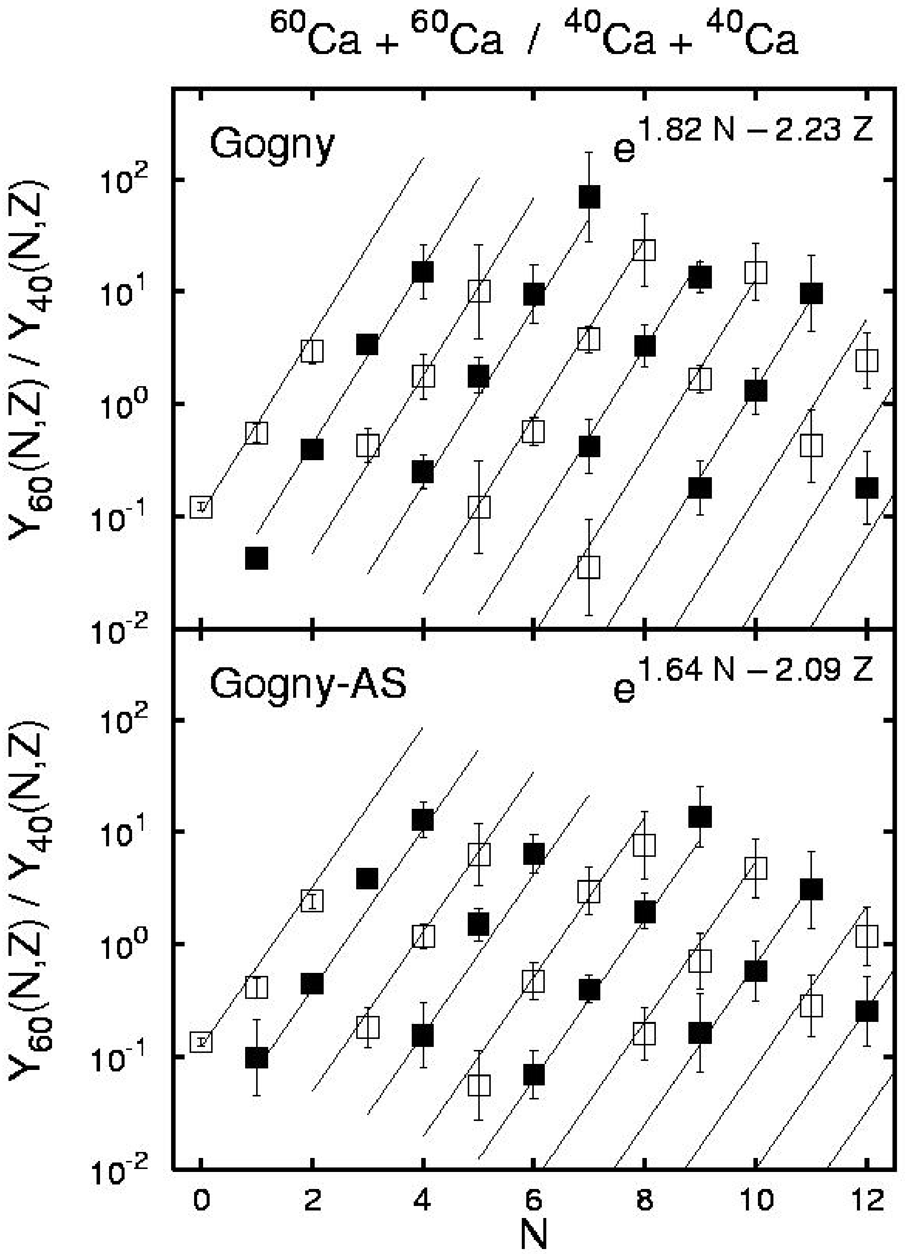
A_2=186, Z_2=75; A_1=168, Z_1=75



WCI statistical model working group (2004)

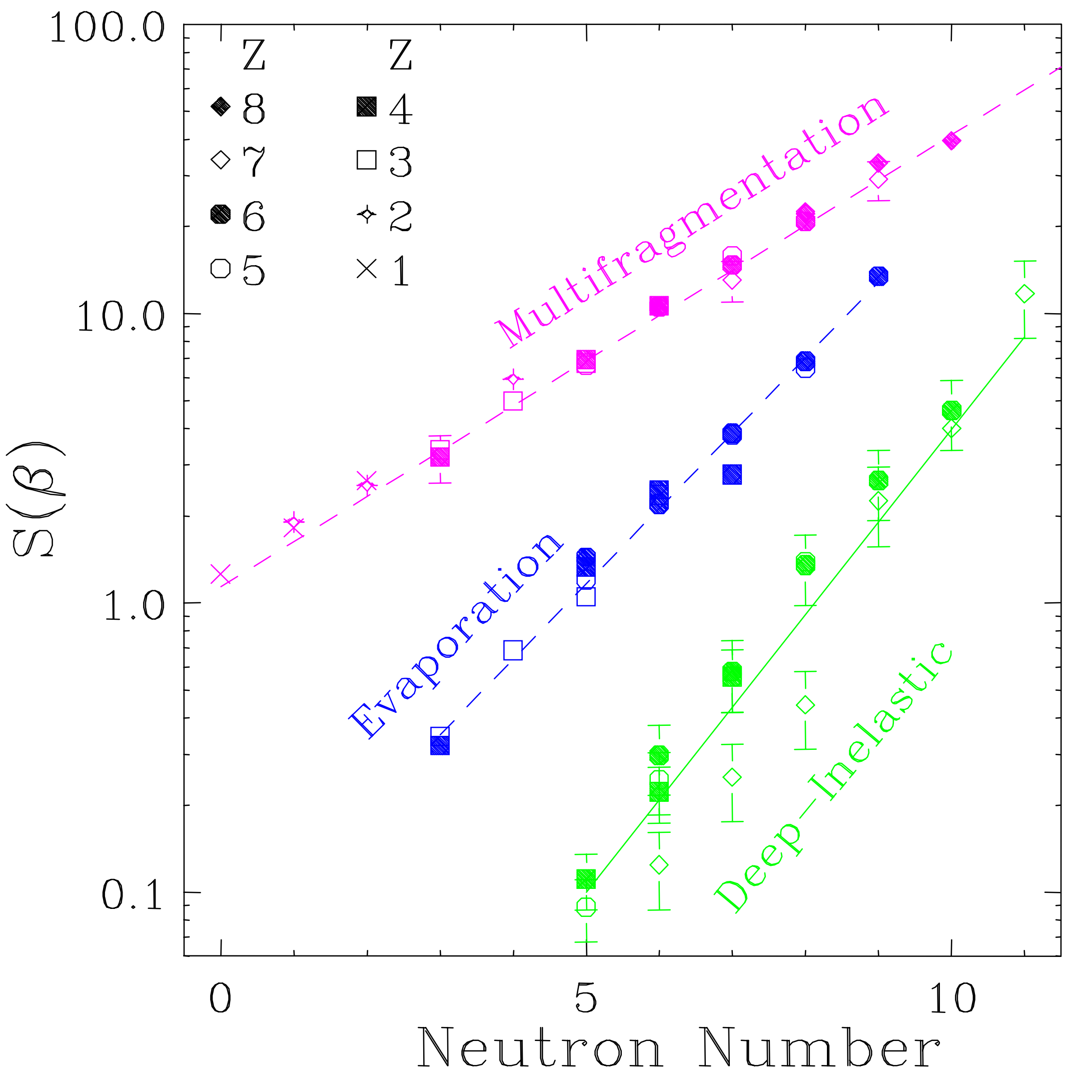
Isoscaling in Antisymmetrized Molecular Dynamical model

*A. Ono et al. PRC **68**,051601 (2003)*



Isoscaling observed in many reactions

$$Y_2/Y_1 \propto e^{(N\Delta\mu_n + Z\Delta\mu_p)/T}$$



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

$^{4}He+^{116}Sn$
$^{4}He+^{112}Sn$
E/A=50 MeV
$\theta=160°$

$^{16}O+^{232}Th$
$^{16}O+^{197}Au$
E/A=8.6 MeV

PRL, 86, 5023 (2001)

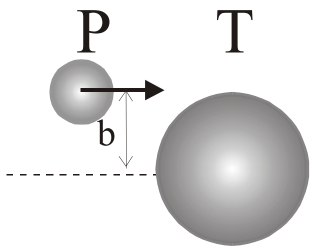
More Data

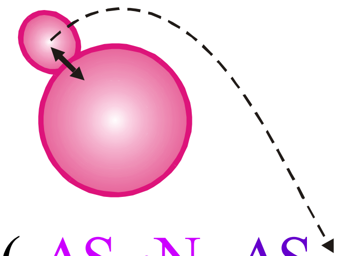
$^{58}Ni+^{58}Ni$
$^{58}Fe+^{58}Fe$
E/A=30,40,47
Shetty et al (2003)

p,$^{4}He+^{116}Sn$
p,$^{4}He+^{124}Sn$
E/A>1 GeV
Botvina,Trautmann (2002)

$^{86}Kr+^{116}Sn,^{124}Sn$
$^{86}Kr+^{58}Ni,^{64}Ni$
E/A=35 MeV
Souliotis et al(2003)

DIC



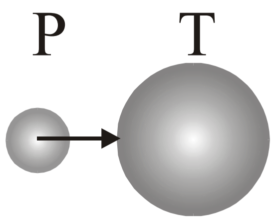


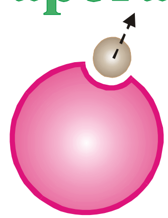
Q Value, Sep. E

E_{Coul} E_{sym}

$$R_{21} \propto \exp[(-\Delta S_n \cdot N - \Delta S_p \cdot Z)/T]$$

Evaporation



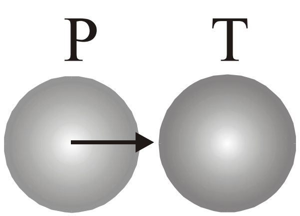


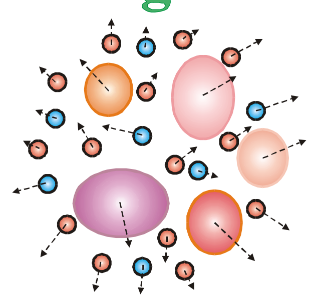
Separation Energy

E_{Coul} E_{sym}

$$R_{21} \propto \exp[((-\Delta S_n + \Delta f_n^{*}) \cdot N + (-\Delta S_p + \Delta f_p^{*} + \Delta\Phi) \cdot Z)/T]$$

Multifragmentation



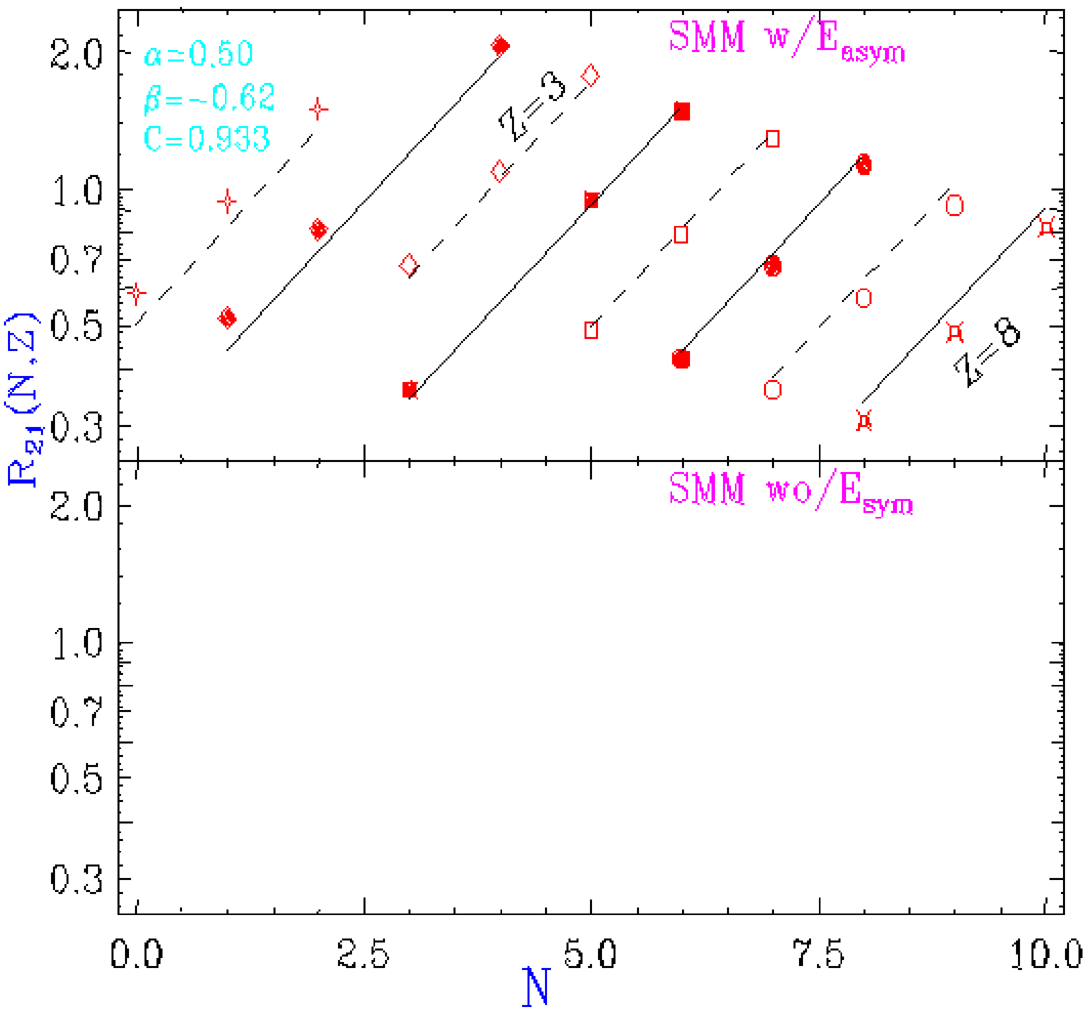


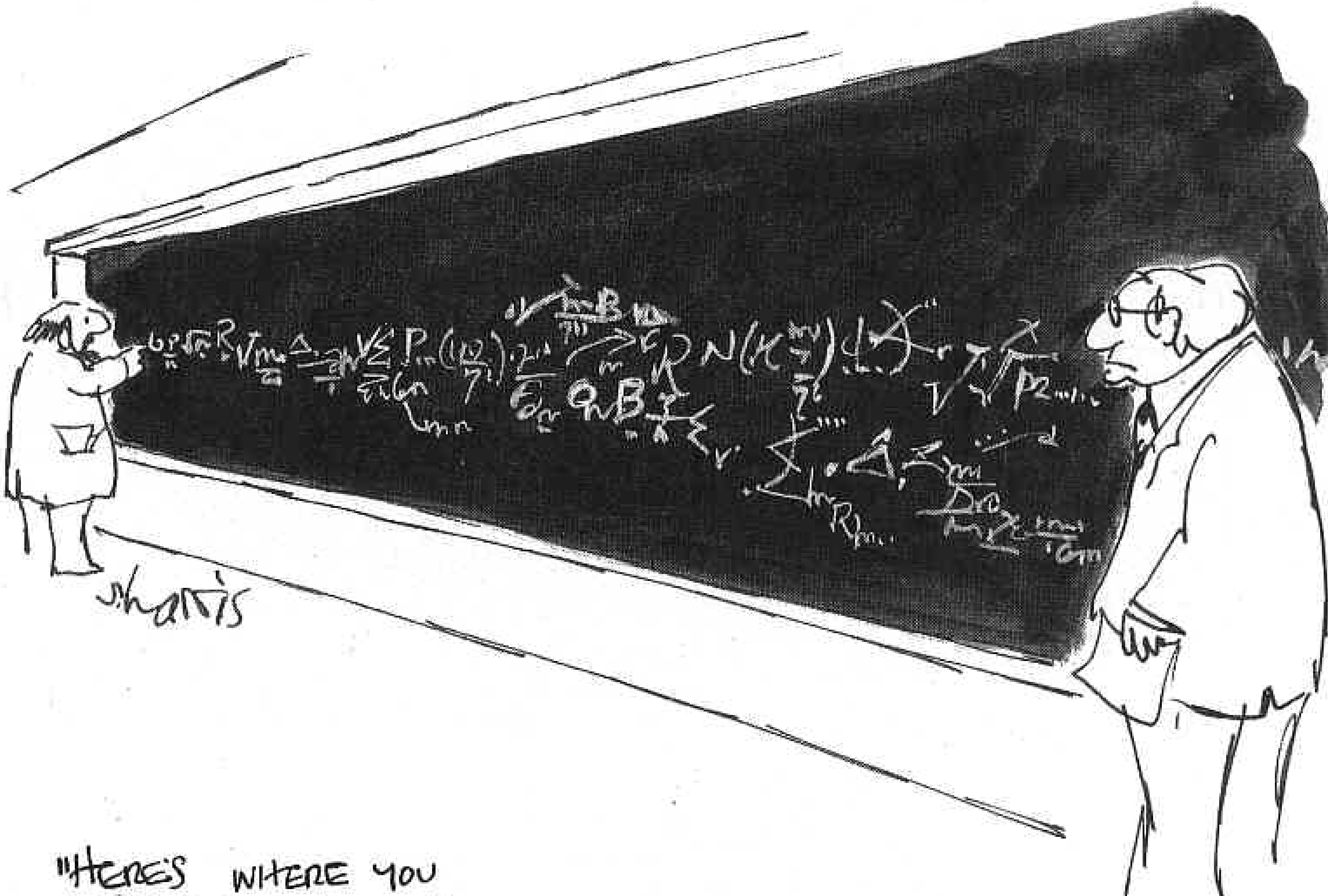
Chemical Potentials

E_{Coul} E_{sym} ρ_p ρ_n

$$R_{21} \propto \exp[(-\Delta\mu_n \cdot N - \Delta\mu_p \cdot Z)/T]$$

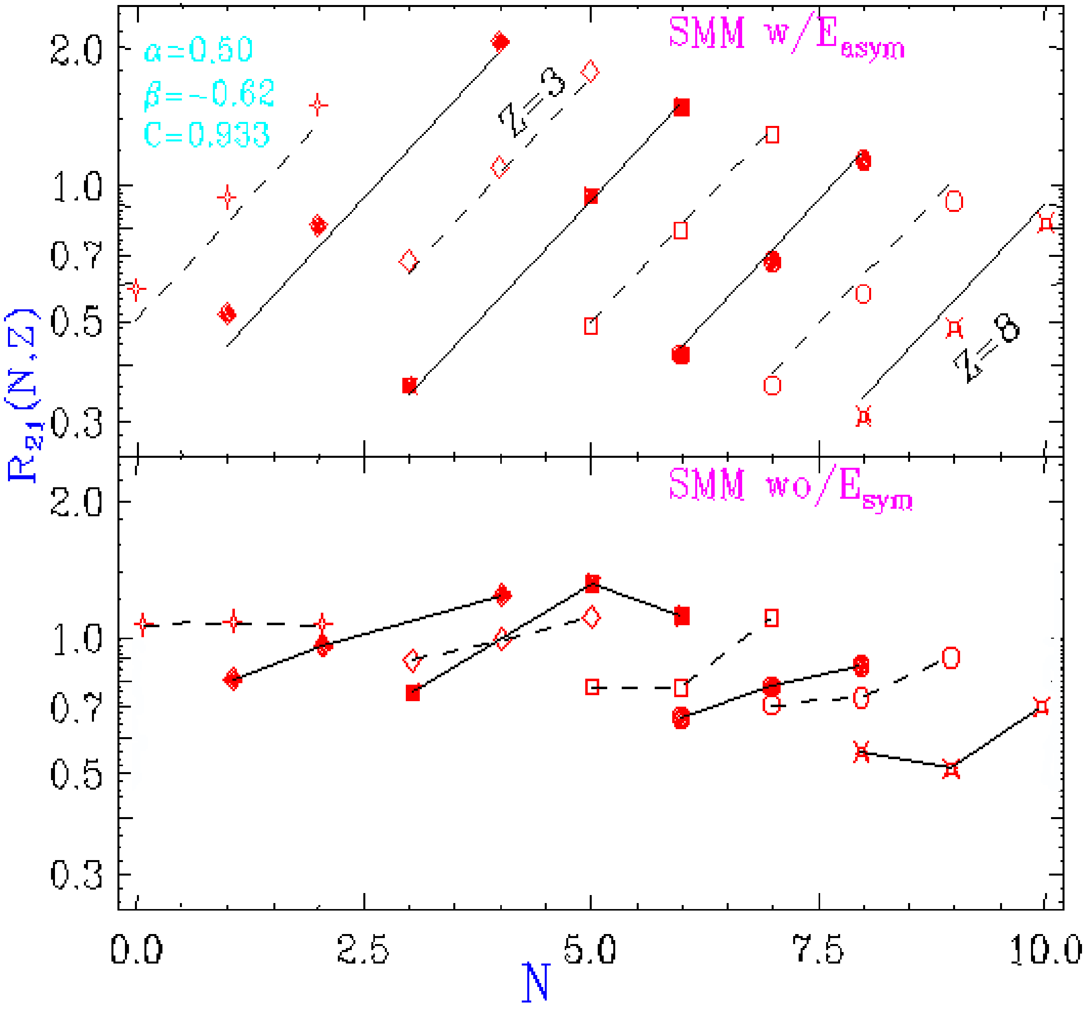
Origin of isoscaling





"*Here's* where you made your mistake."

Origin of isoscaling

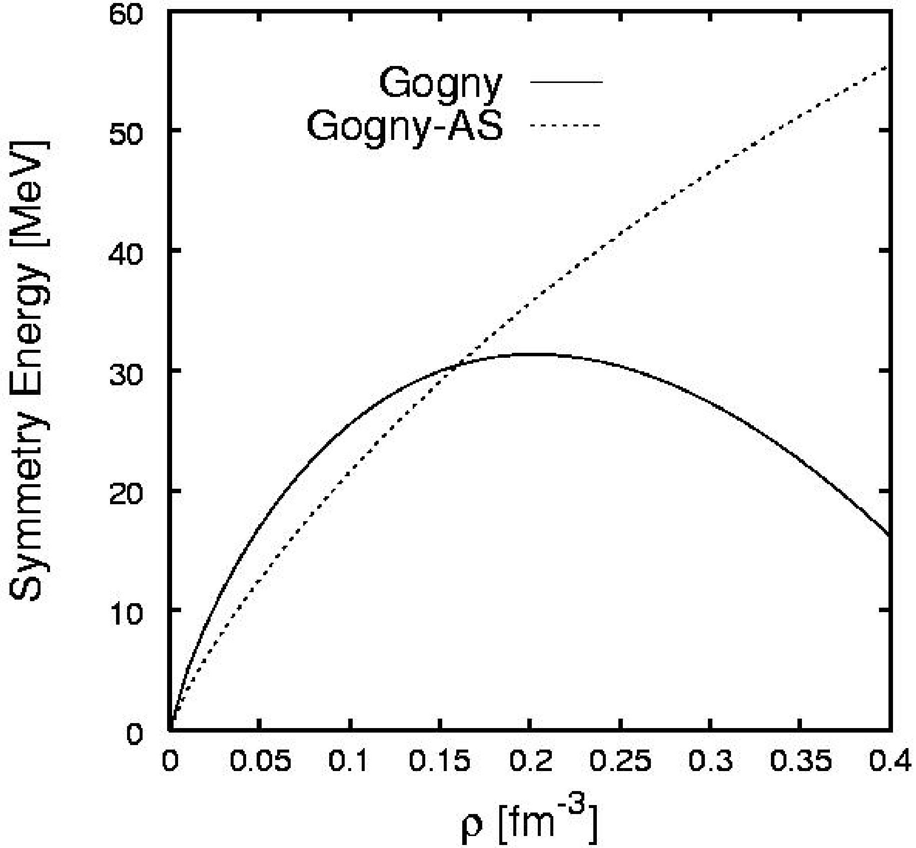


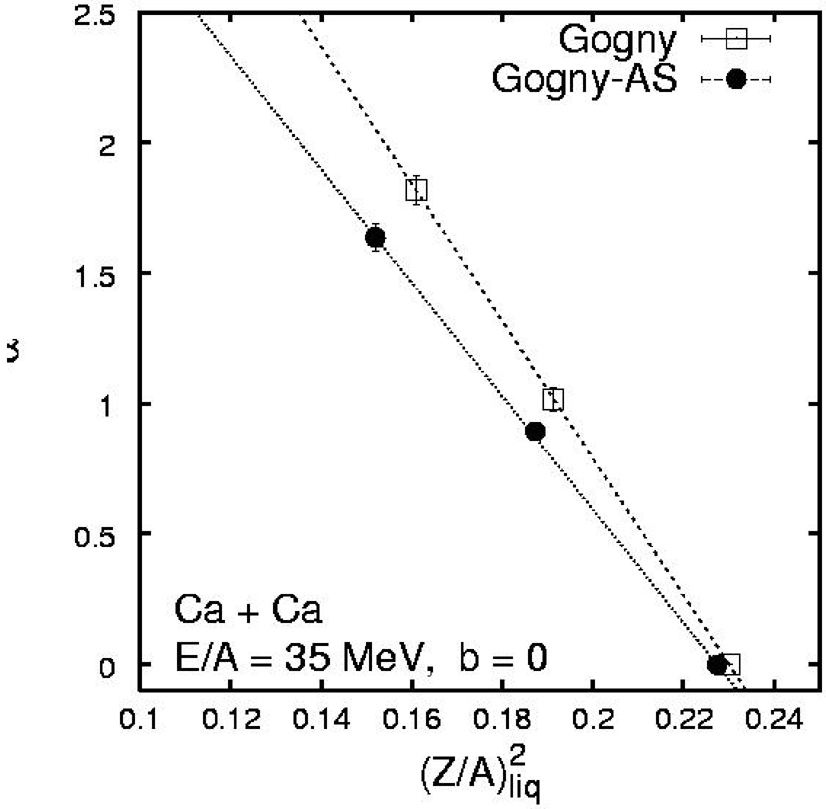
➢ ***Isoscaling disappears when the symmetry energy is set to zero***

➢ ***Provides an observable to study symmetry energy***

Symmetry energy from AMD

*A. Ono et al. PRC **68**,051601 (2003)*





α depends on symmetry term interactions

Boltzmann equation for heavy ion collisions

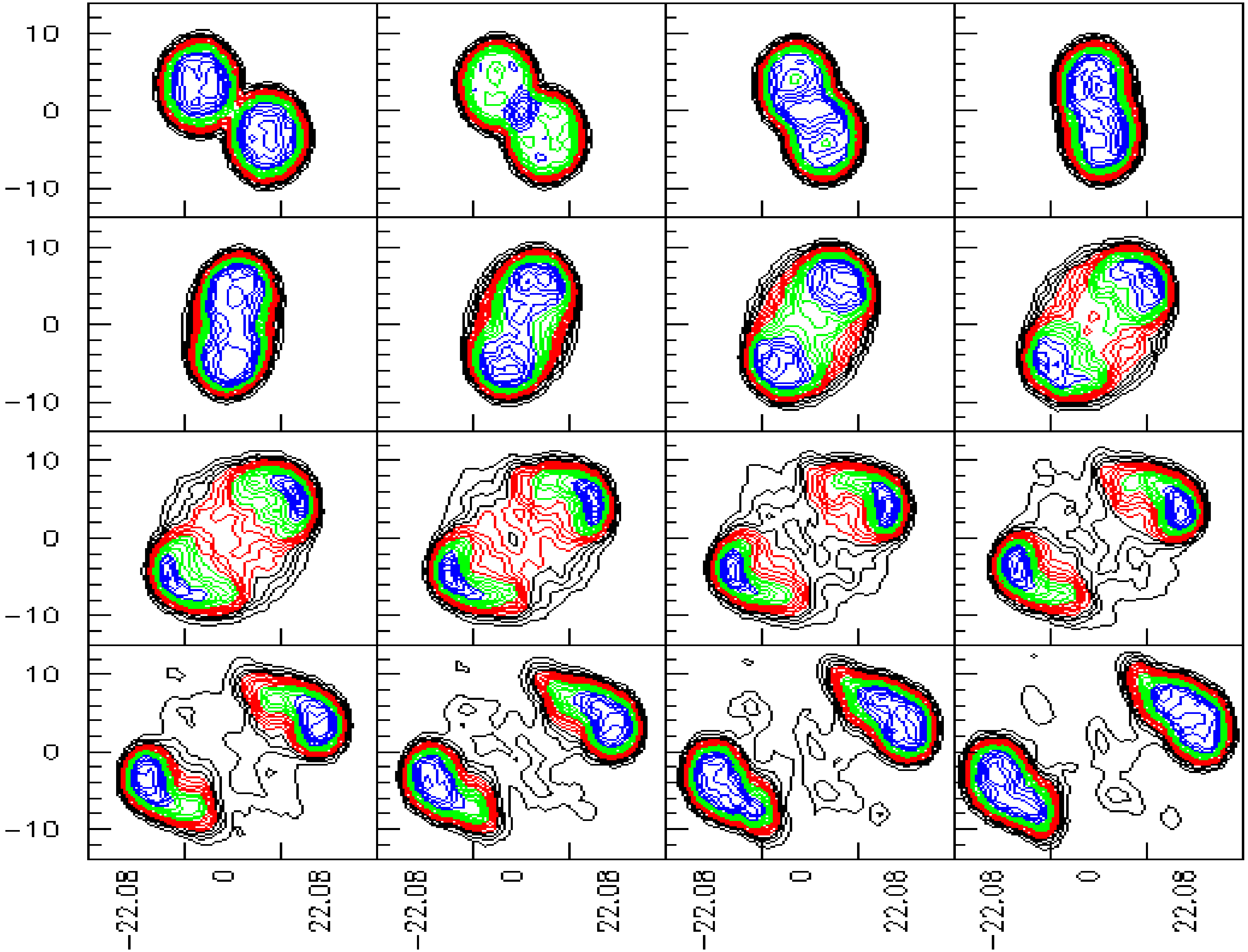
G. F. Bertsch and H. Kruse, S. Das Gupta

PRC 29, 673 (1984)

Sn+Sn; E/A=50 MeV

b=6.6 fm

Micha Kilburn, REU 2003

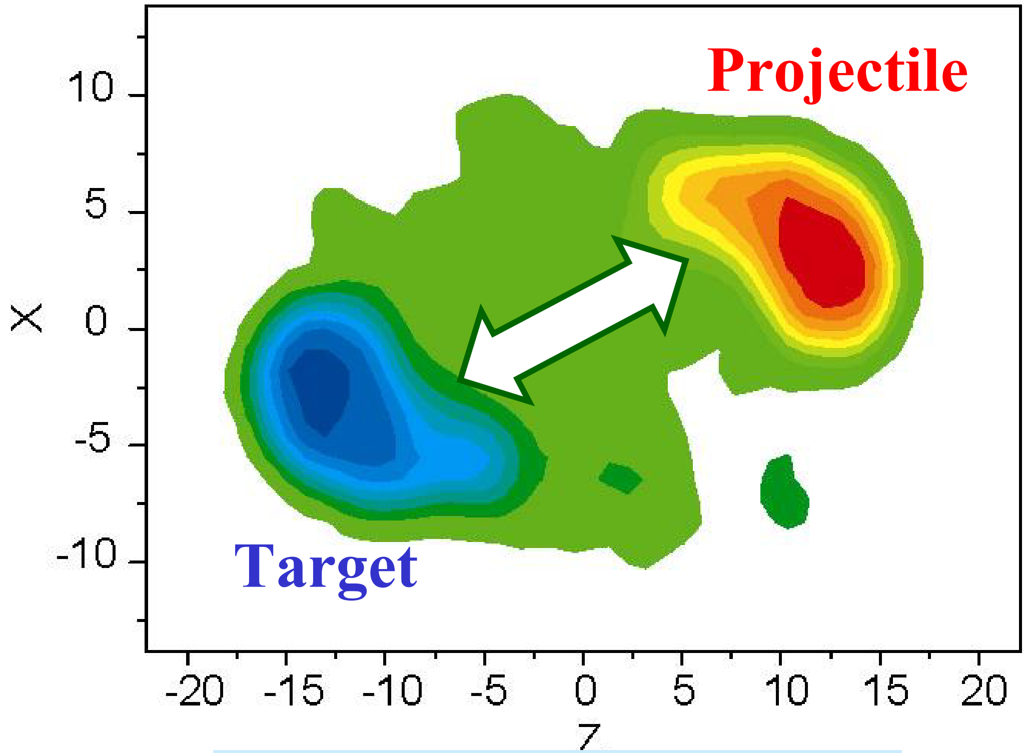


Isospin diffusion in the projectile-like region

Basic ideas:

- *Peripheral reactions*
- **Asymmetric collisions**
  $^{124}Sn+^{112}Sn$, $^{112}Sn+^{124}Sn$
  -- diffusion

Lijun Shi

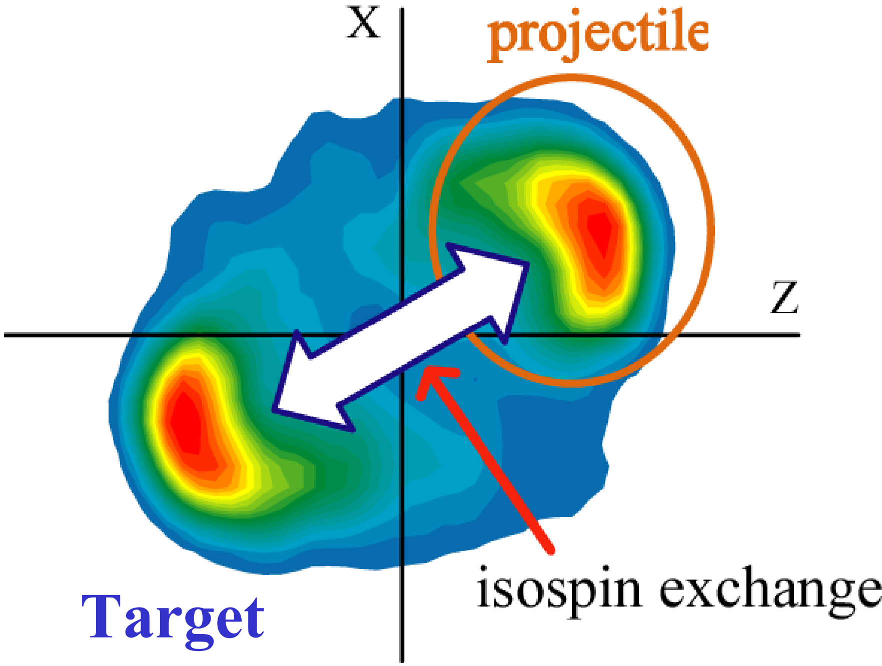


$$\delta = (N - Z)/(N + Z)$$

Isospin diffusion in the projectile-like region

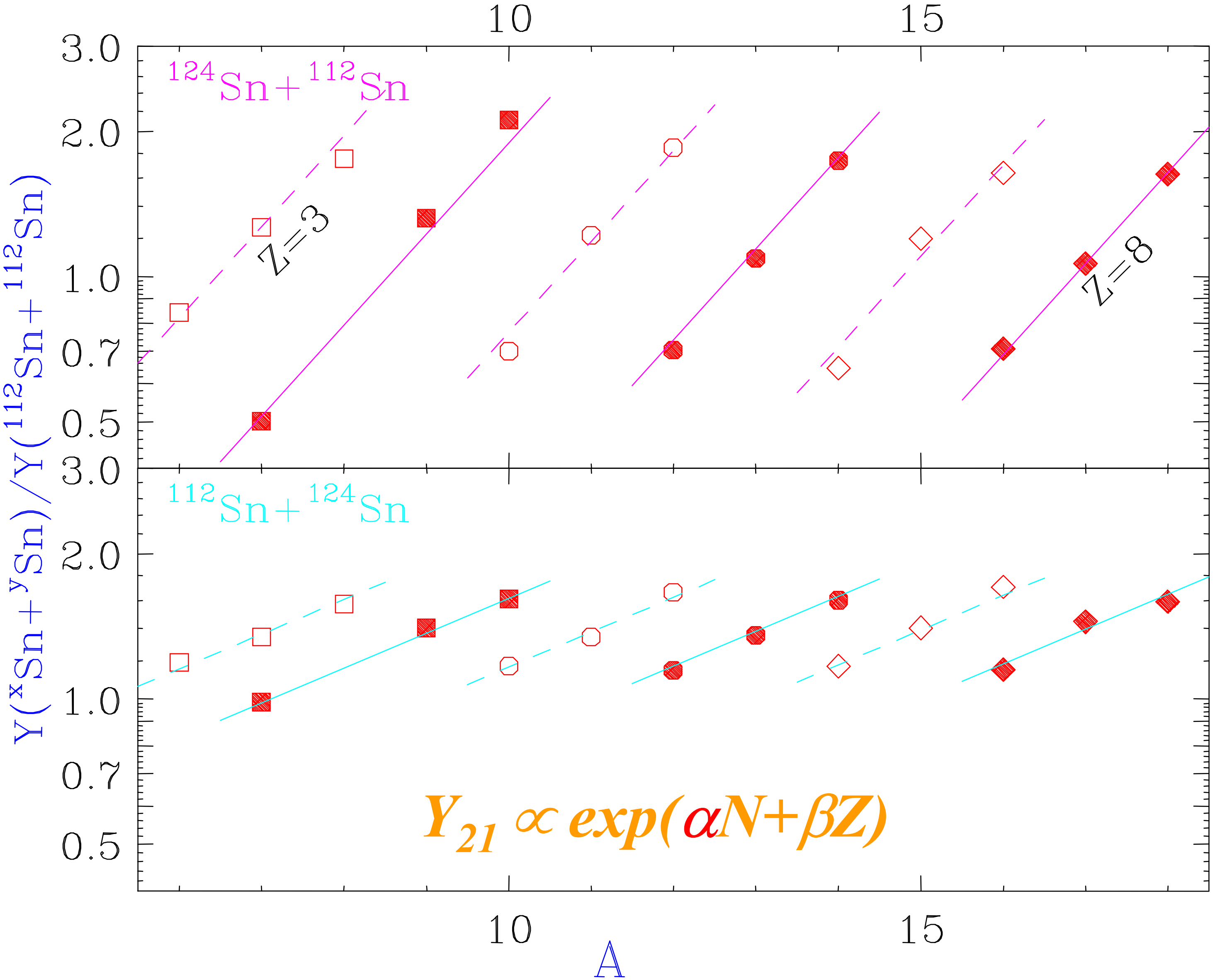
Basic ideas:

- *Peripheral reactions*
- **Asymmetric collisions**
  $^{124}Sn+^{112}Sn$, $^{112}Sn+^{124}Sn$
  -- diffusion
- **Symmetric Collisions**
  $^{124}Sn+^{124}Sn$, $^{112}Sn+^{112}Sn$
  -- no diffusion
- *Relative change between target and projectile is the diffusion effect*



$$\delta = (N - Z)/(N + Z)$$

Isoscaling of mixed systems



Experimental: ***isoscaling;*** $Y_{21} \propto \exp(\alpha N+\beta Z)$

Theoretical : $\delta = (N-Z)/(N+Z)$

$\alpha \propto \delta_1 - \delta_2$ ***(Subal's SMM)***

Isospin Transport Ratio

$$R_i = \frac{2x - x_{124+124} - x_{112+112}}{x_{124+124} - x_{112+112}}$$

Rami et al., PRL, 84, 1120 (2000)

x=experimental or theoretical isospin observable

$x = x_{124+124} \rightarrow R_i = 1.$

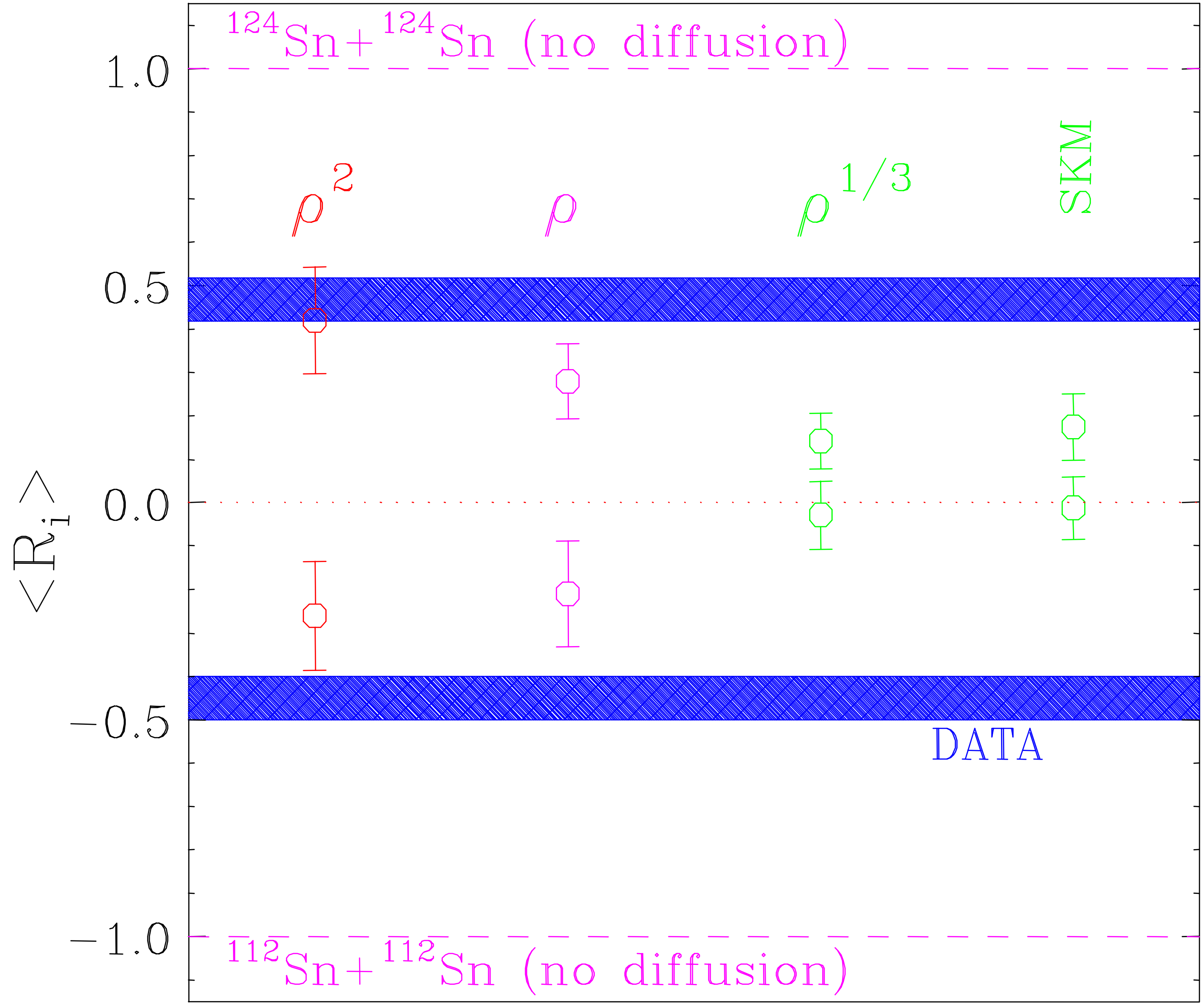
$x = x_{112+112} \rightarrow R_i = -1.$

BUU predictions

Lijun Shi

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

$S_{sym}(\rho) \propto \rho^{\gamma}$

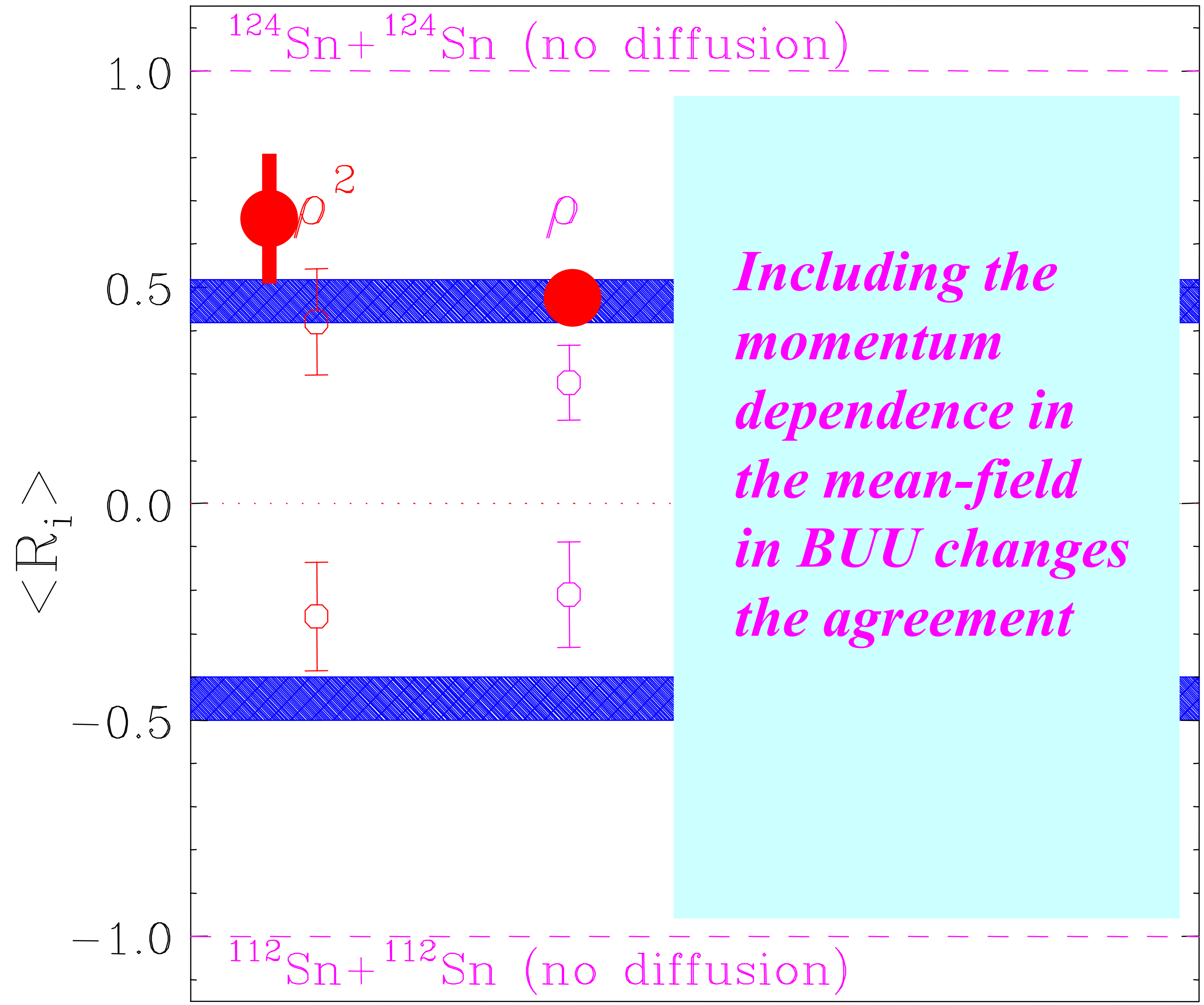


Experimental results are in better agreement with predictions using hard symmetry terms

BUU predictions

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

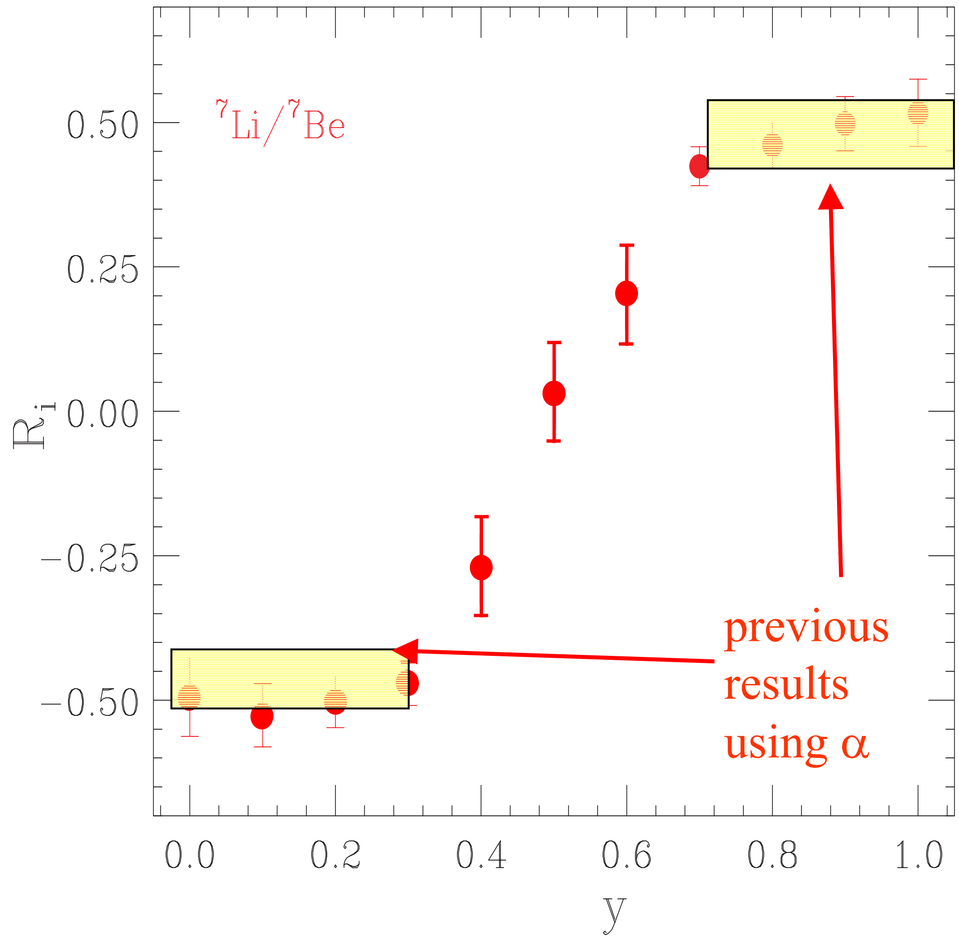
$$S_{sym}(\rho) \propto (\rho)^{\gamma}$$



Need more experimental constraints

B.-A. Li, C. B. Das, S. Das Gupta, and C. Gale
Phys. Rev. C **69**, 011603 (2004)

Ln(Y(^{7}Li)/Y(^{7}Be)) & R_i(^{7}Li, ^{7}Be)



- Mirror nuclei ratios provide another observable:

$$R_7 = Ln(Y_{7Be} / Y_{7Li}) \propto \mu_p - \mu_n$$

- Rapidity dependence is weak except at mid rapidity

May provide better constraints on the momentum dependence of the mean field

Summary

- ***A lot of work has been done on isoscaling.***
  - ***Robust observable***
  - ***Seen in many different reactions***
  - ***Promising tool to study symmetry energy with heavy ion collisions – Isospin Diffusion***

Acknowledgements

Subal Das Gupta

P. Danielewicz, C.K. Gelbke, T.X. Liu, X.D. Liu, W.G. Lynch, L.J. Shi, R. Shomin, M.B. Tsang, W.P. Tan, M.J. Van Goethem, G. Verde, A. Wagner, H.F. Xi, H.S. Xu, Akira Ono,

Bao-An Li, *B. Davin, Y. Larochelle, R.T. de Souza,* R.J. Charity, L.G. Sobotka, *S.R. Souza, R. Donangelo*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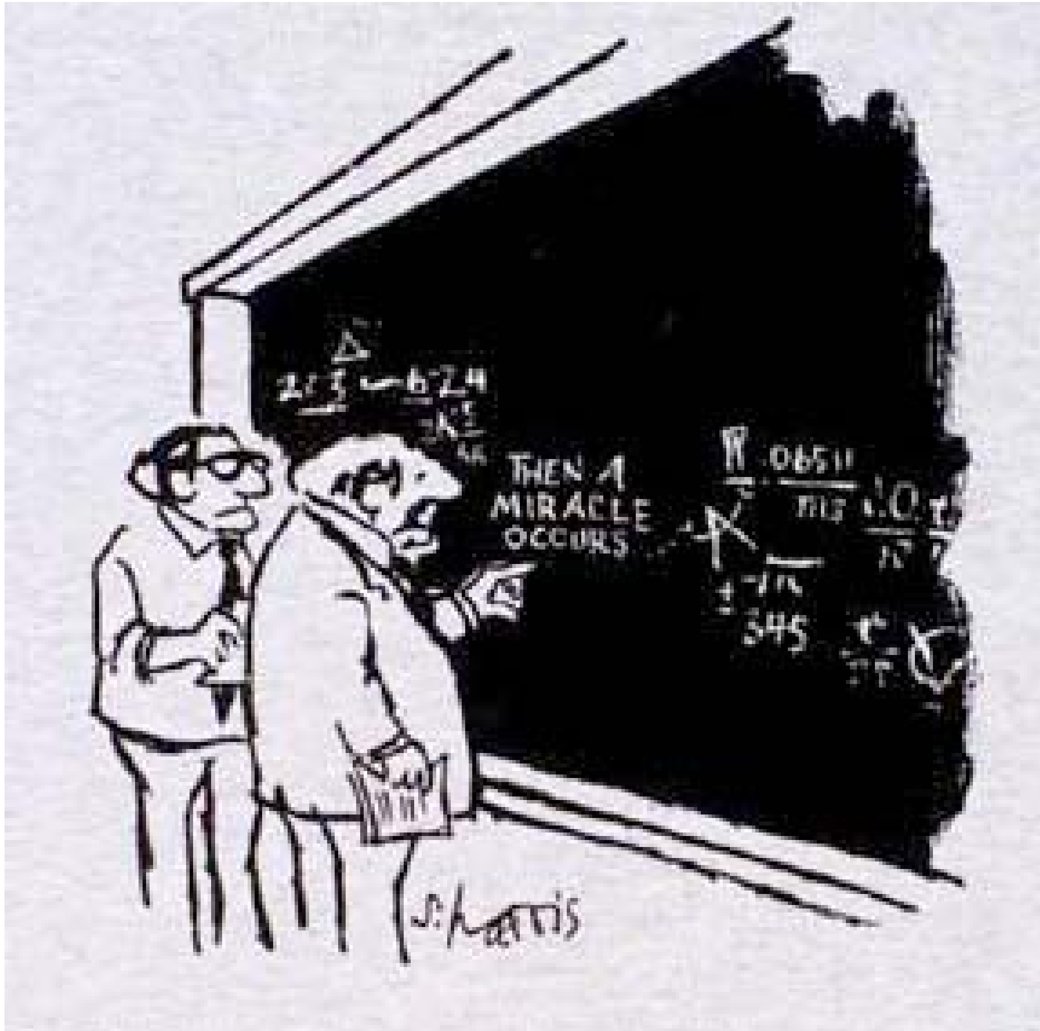
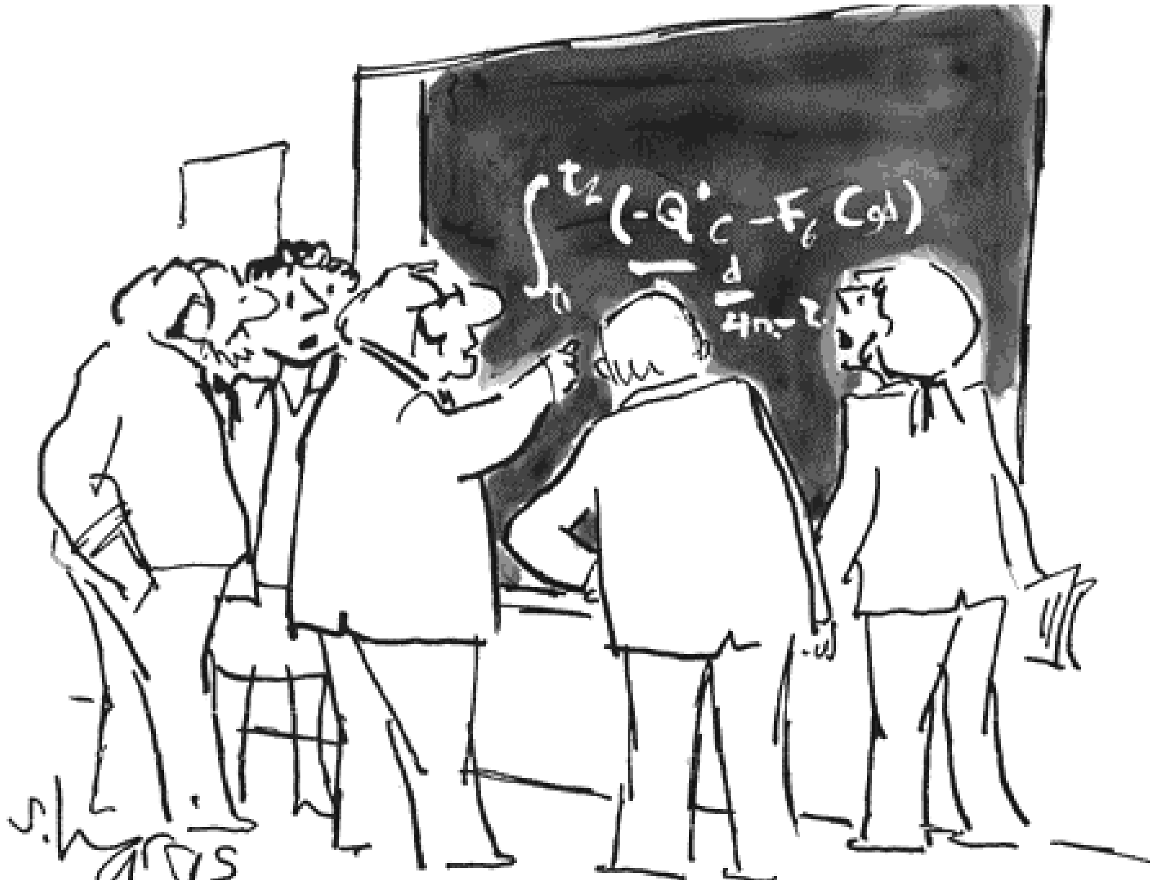
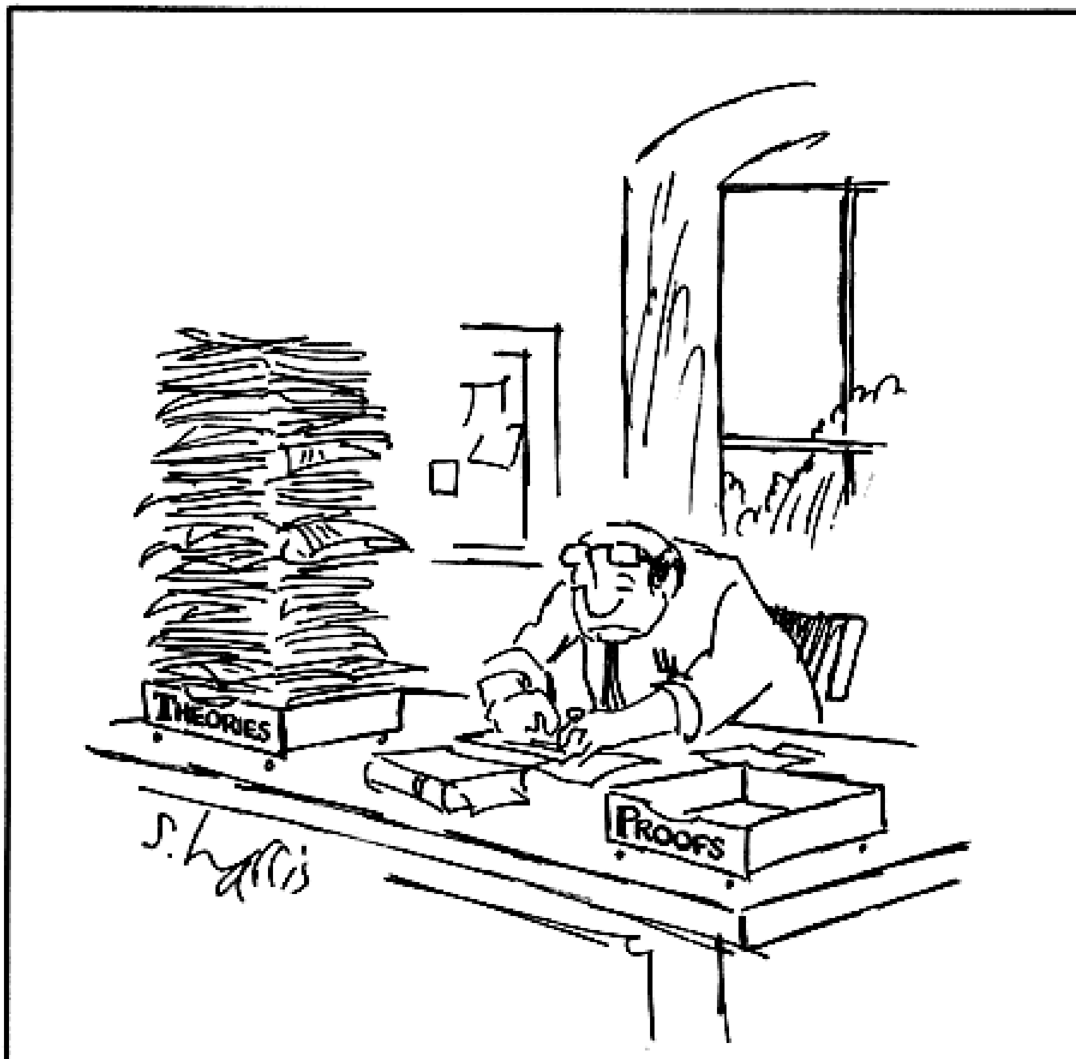
THE END



"I THINK YOU SHOULD BE MORE EXPLICIT HERE IN STEP TWO."



"Let's see now. Wilkes is nine years younger than Gottlieb, and Gottlieb is one-third older than me. Foster's age minus Rivera's age..."


THEORIES
PROOFS
S. Harris

"QUARKS. NEUTRINOS. MESONS. ALL THOSE DAMN PARTICLES YOU CAN'T SEE. THAT'S WHAT DROVE ME TO DRINK. BUT NOW I CAN SEE THEM!"