M. A. Famiano

NuSYM Meeting

July 26, 2010

Experimental Investigations of the Symmetry Energy Using Neutron-Proton Ratios

Supported by NSF Grants #PHY-0757257, #PHY-0923087

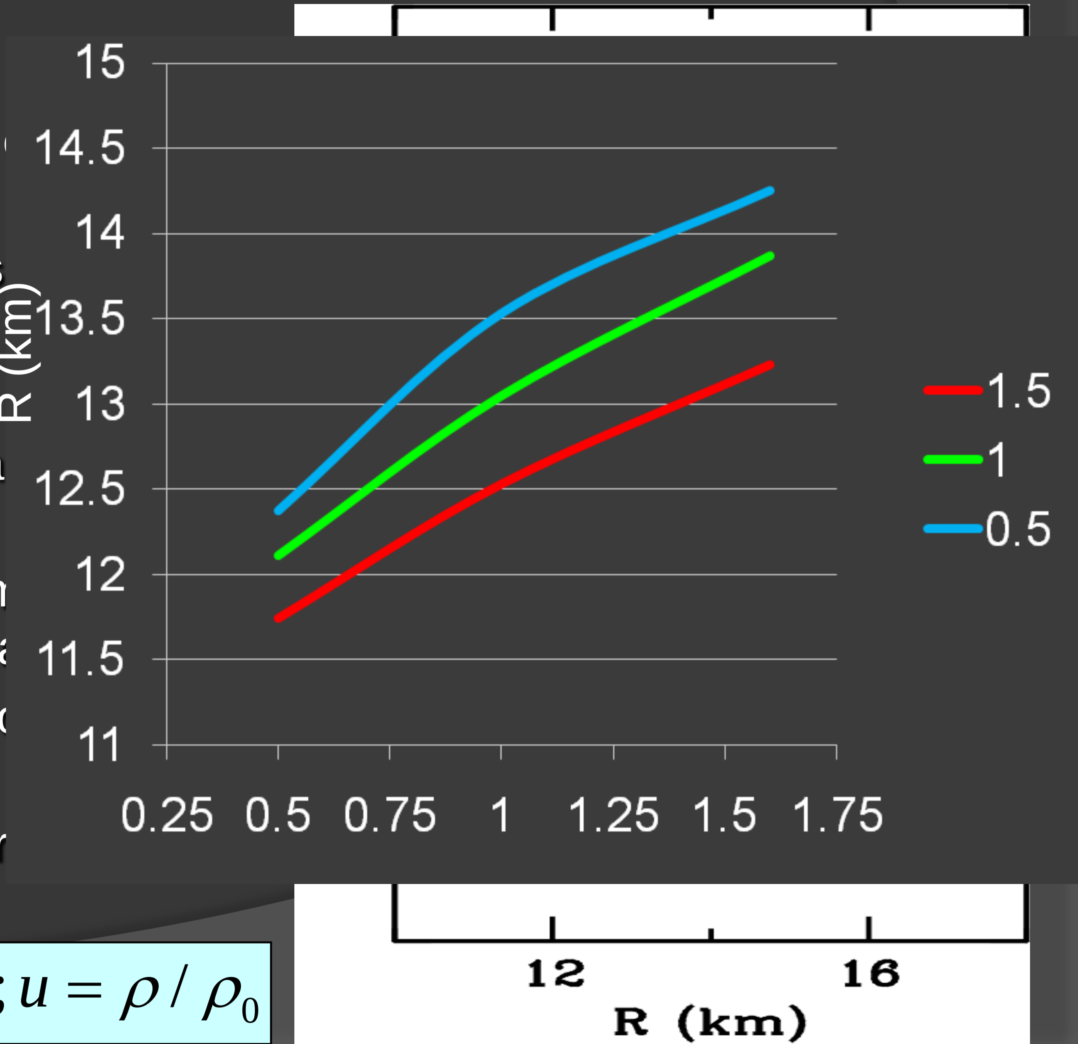
Introduction

- Significance of the symmetry energy at low and high density
- Neutron-proton emission observables
  - Stiffness of the asymmetry energy
  - In-medium cross-sections
  - Correlations
- Experimental plans
  - Exceeding nuclear saturation density

Astrophysical Importance of the Nuclear Asymmetry Term

J. Lattimer et al.

- Macroscopic properties:
  - Neutron star radii, moments
    and central densities.
  - Maximum neutron star mass
    rotation frequencies.
- Thickness of the inner crust.
  - Frequency change accompa
    quakes.
- Role of Kaon condensates and m
  quark-hadron phases in the stella
- Proton and electron fractions thro
  the star.
  - Cooling of proto-neutron star

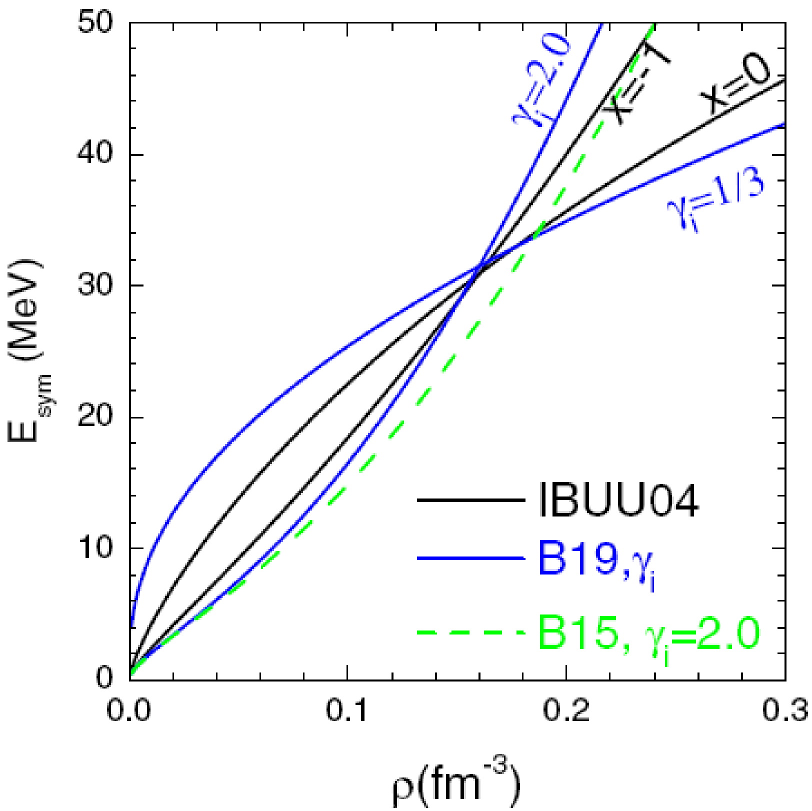


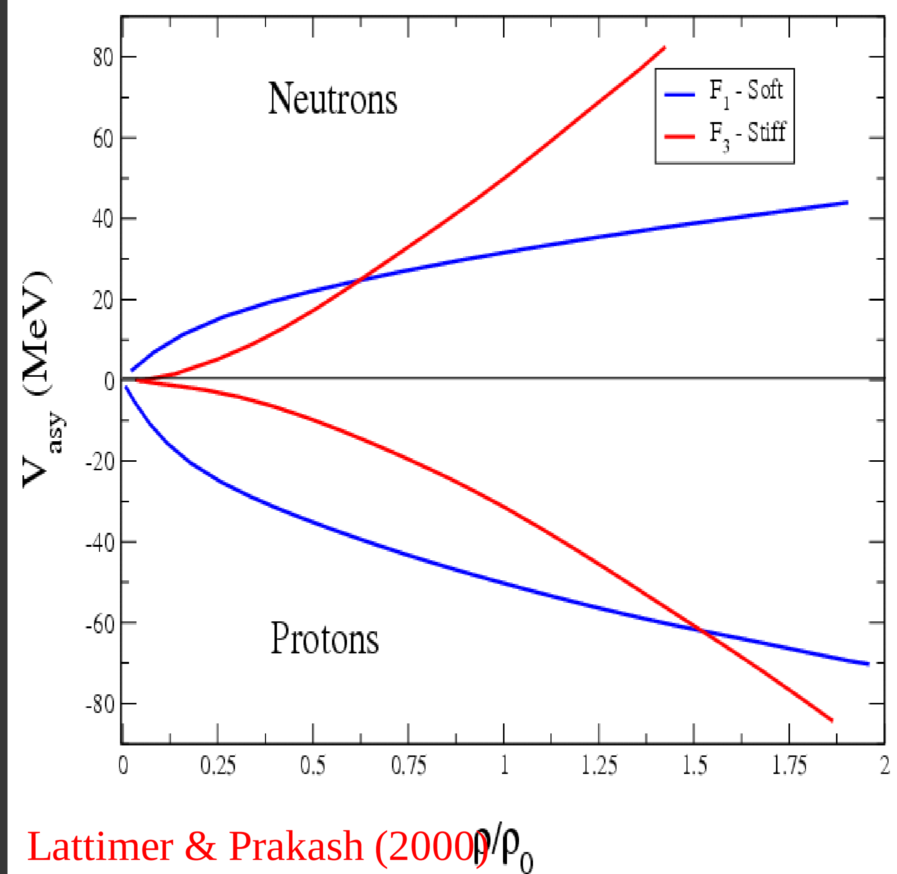
$$S_{pot}(\rho) = const.\cdot F(u); u = \rho / \rho_0$$

Asymmetric Nuclear Matter

$E/A(\rho, \delta) = E/A(\rho, 0) + \delta^2 \cdot S(\rho)$

$\delta = (\rho_n - \rho_p)/(\rho_n + \rho_p) = (N-Z)/A$





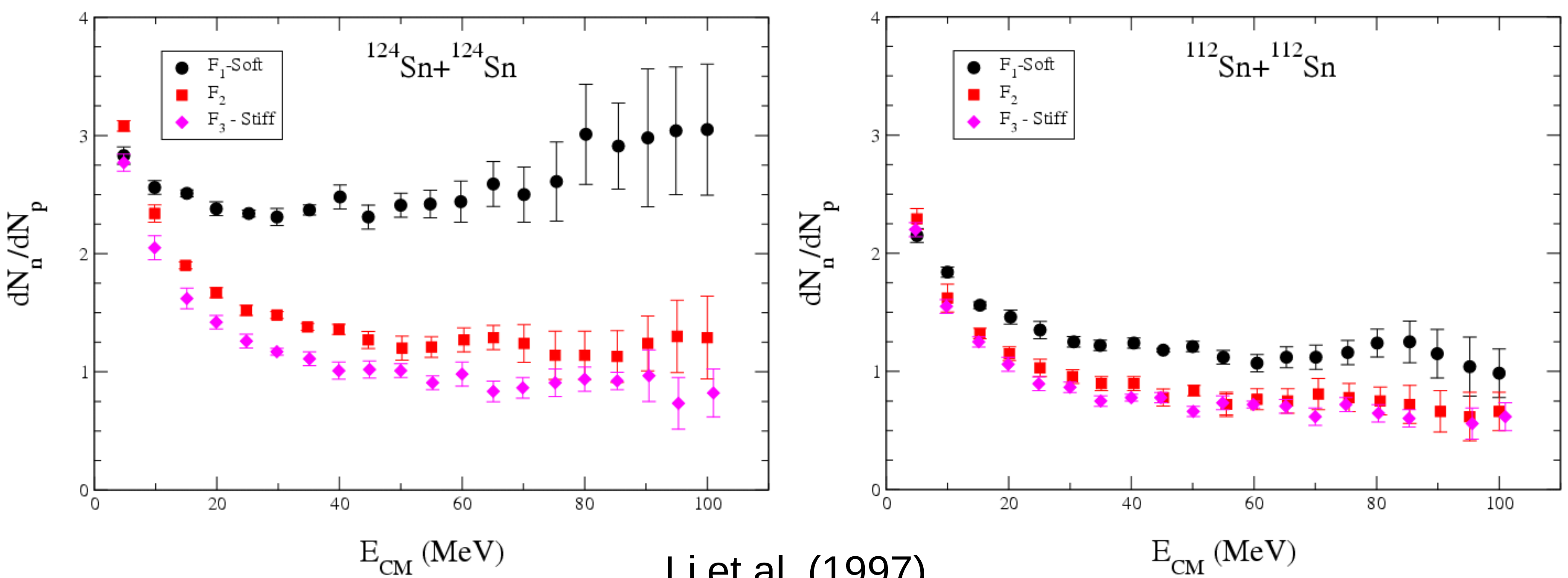
Lattimer & Prakash (2000)

Symmetry energy $S(\rho)$

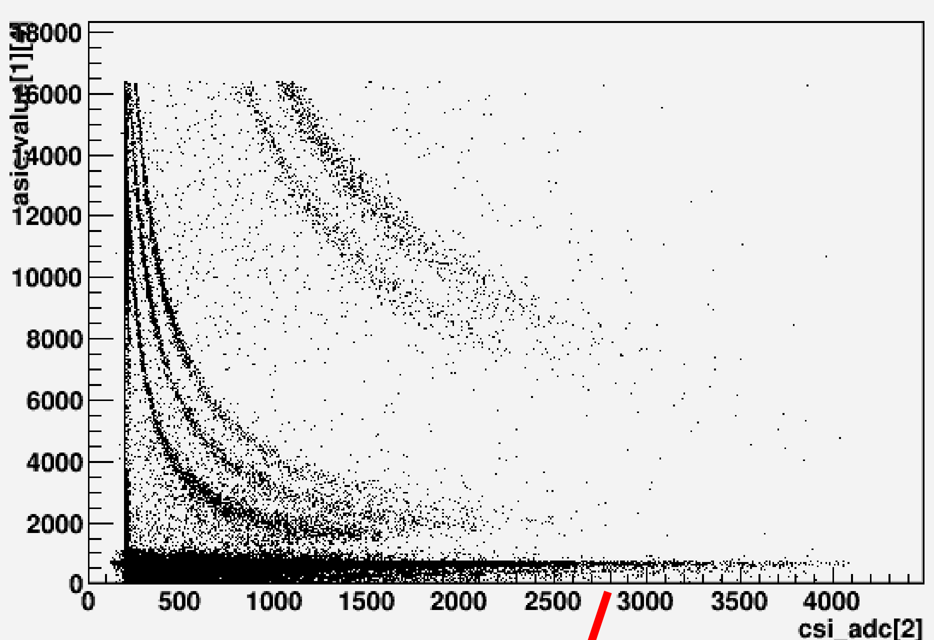
$S(\rho) = S_{kin} \cdot (\rho/\rho_0)^{2/3} + S_{int} \cdot (\rho/\rho_0)^{\gamma_i}$

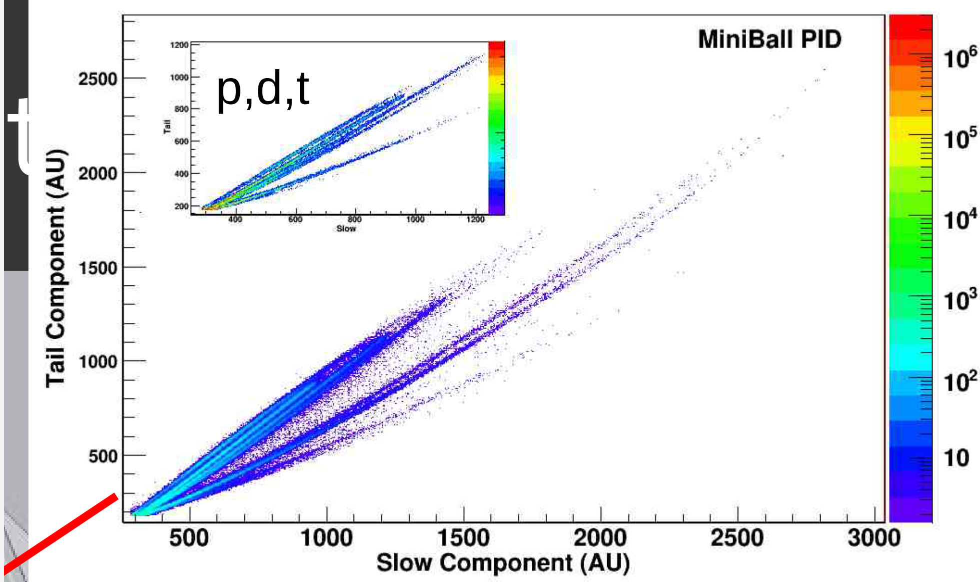
Spectral Ratios

- Neutron-Proton emission ratios at subsaturation densities
  - Pre-equilibrium emission in heavy-ion fragmentations
  - Less variation with δ in asy-stiff EOS than asy-soft EOS: **Larger change = softer asymmetry**
- Double ratios ${}_1R_{124}/{}_1R_{112}=(dn_n/dn_p)_{124}/(dn_n/dn_p)_{112}$
  - Independent of Coulomb and efficiency effects
  - More sensitive to “asy-soft” EOS at **subsaturation density**

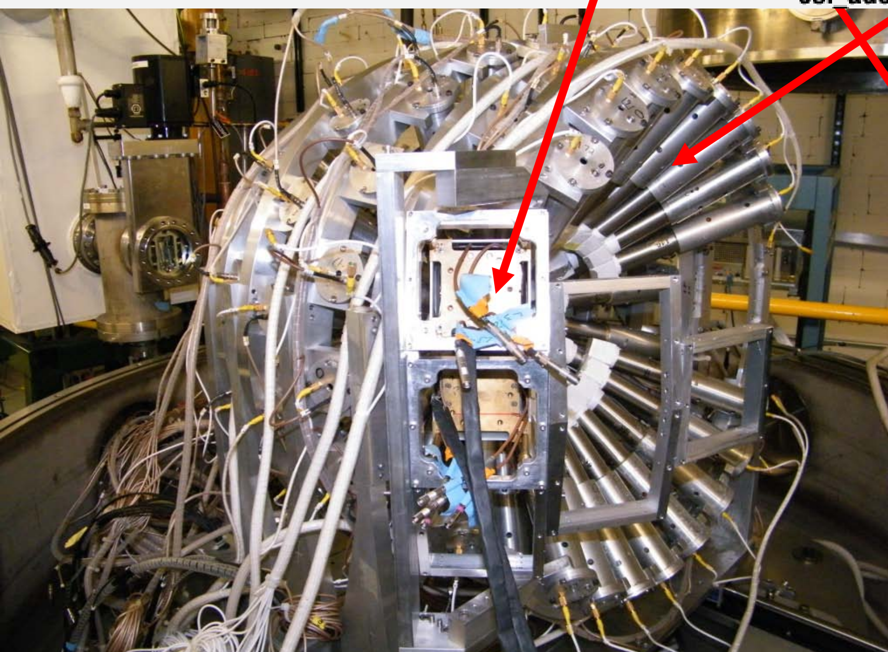


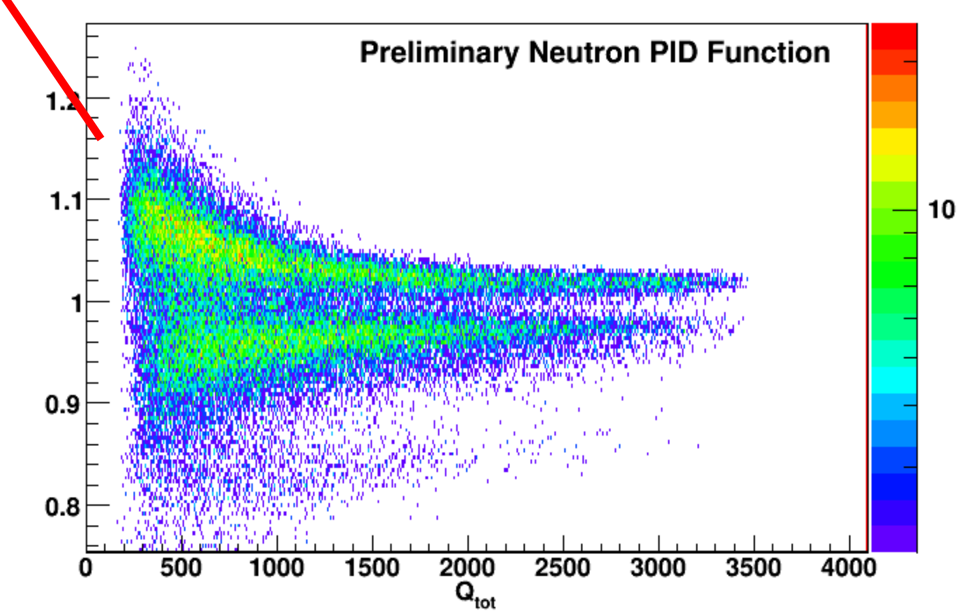
Li et al. (1997)





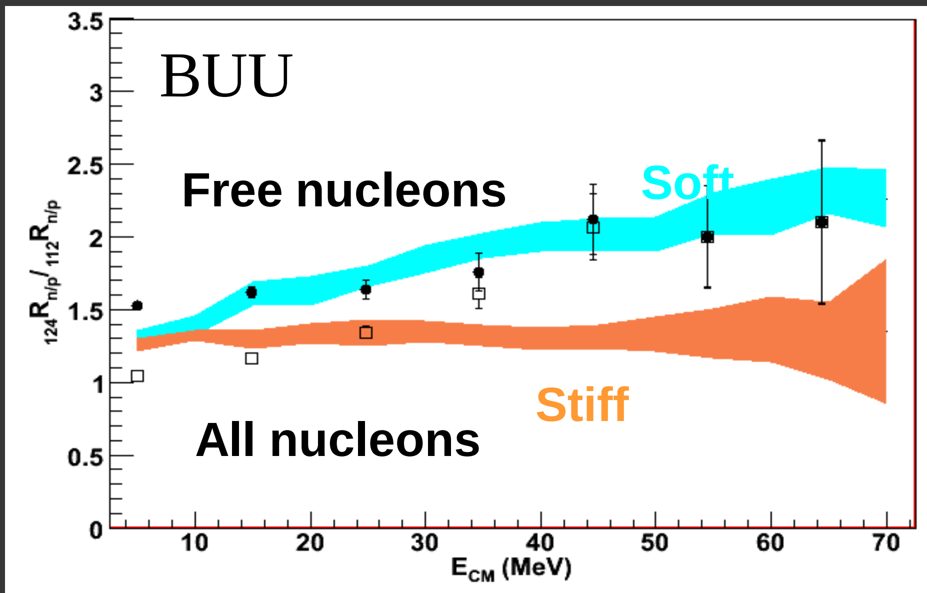
m*, AND get
Increased statistics

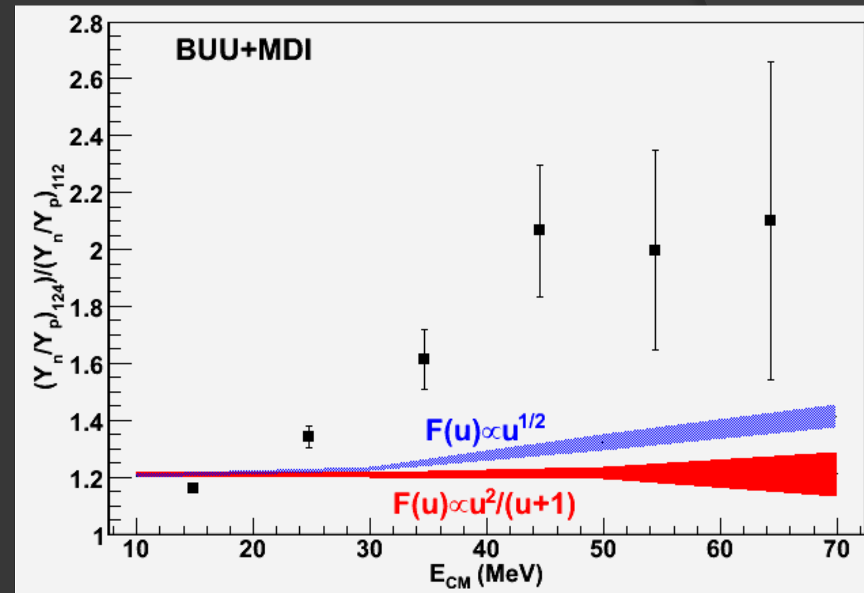


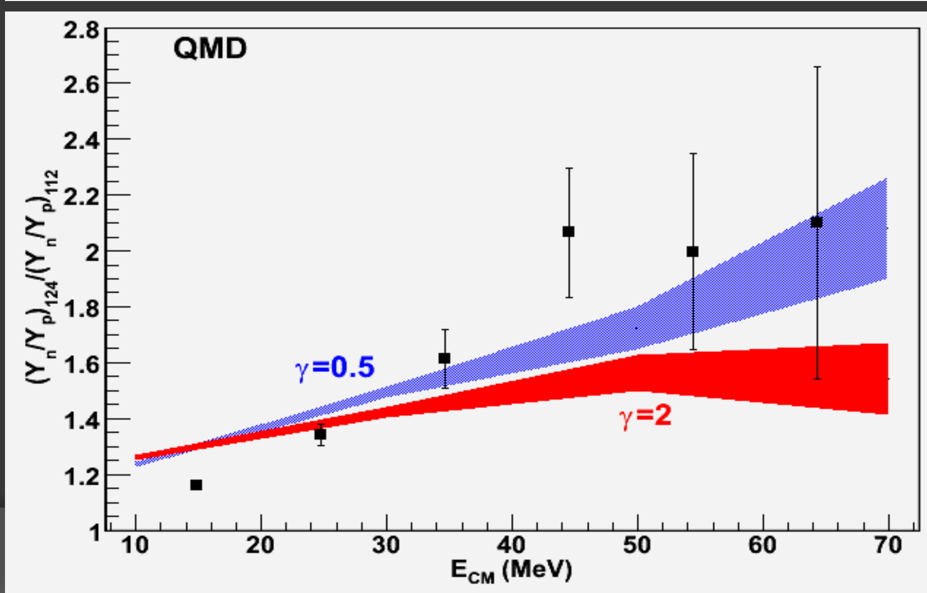


Experimentation complete May 29, 2009

Past Results: N/P Ratios







Double ratio reduces experimental uncertainty.

System asymmetry is our "magnifying glass."

Emission dominated by nucleons at higher C.M. energies.

Central collisions

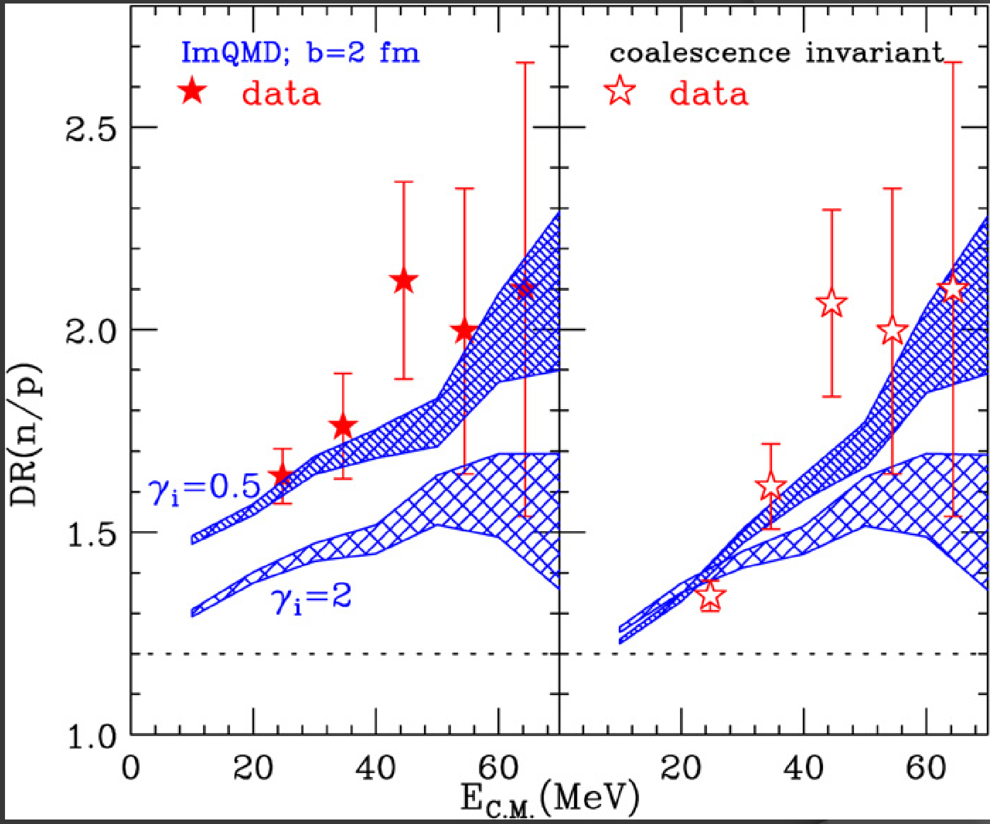
Neutron-Proton Emission ratios.

Double Ratios for Y(124Sn+124Sn)/ Y(112Sn+112Sn)

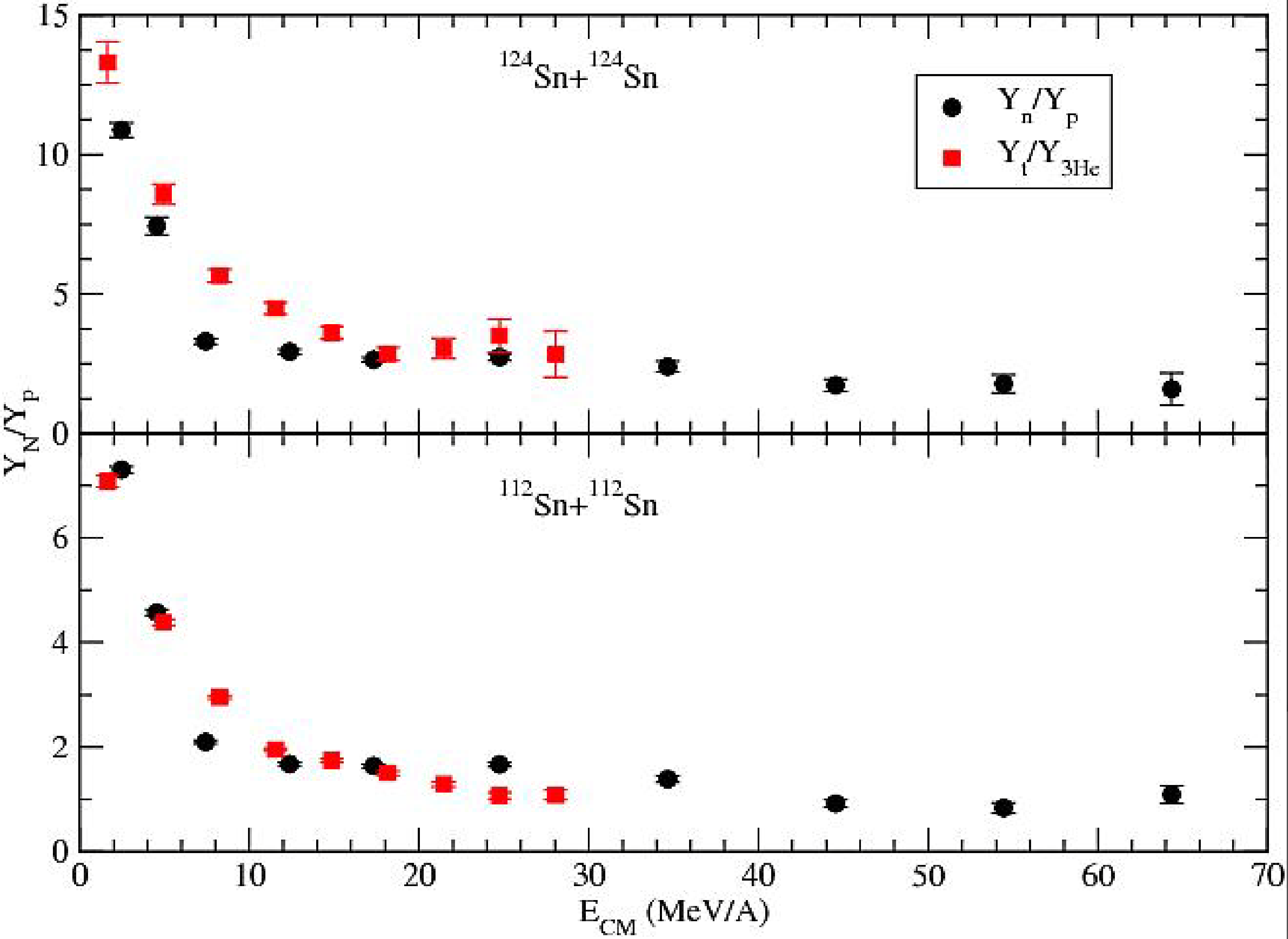
Li et al. (1997), Famiano et al. (2006), Zhang et al

Experimental Details

- Beam: $^{40,48}Ca$ + $^{112,124}Sn$ 140MeV/A
- Also $^{112,124}Sn$ + $^{112,124}Sn$ 50 MeV/A
- Neutron-proton observables
  - N/P ratios
  - Average rapidity dist.
  - N-P correlations?
- Sensitivity near saturation
- Data necessarily includes clustering in exactly the right amounts

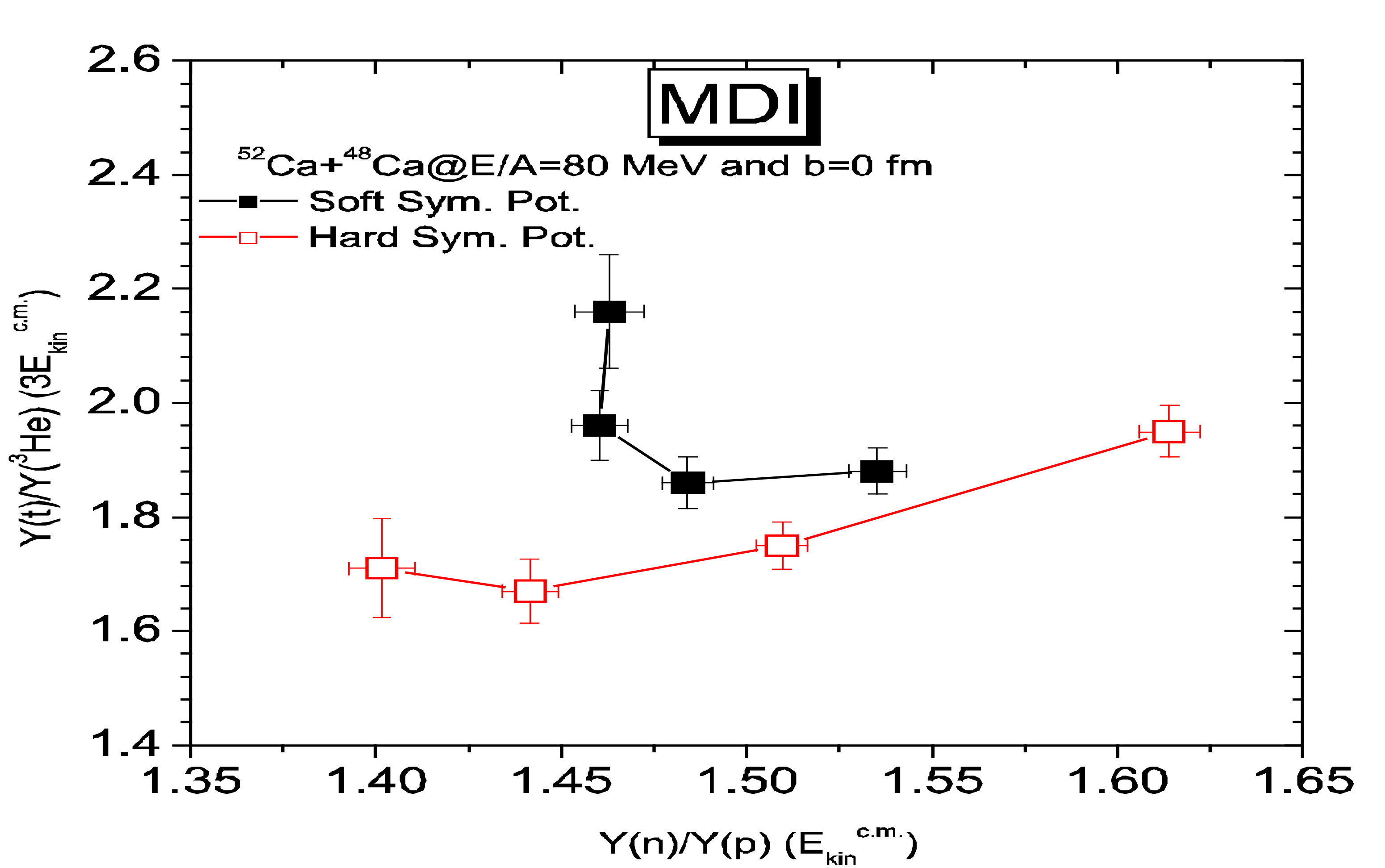


Experimental Results Comparison



Binding energy neglected in coalescence.

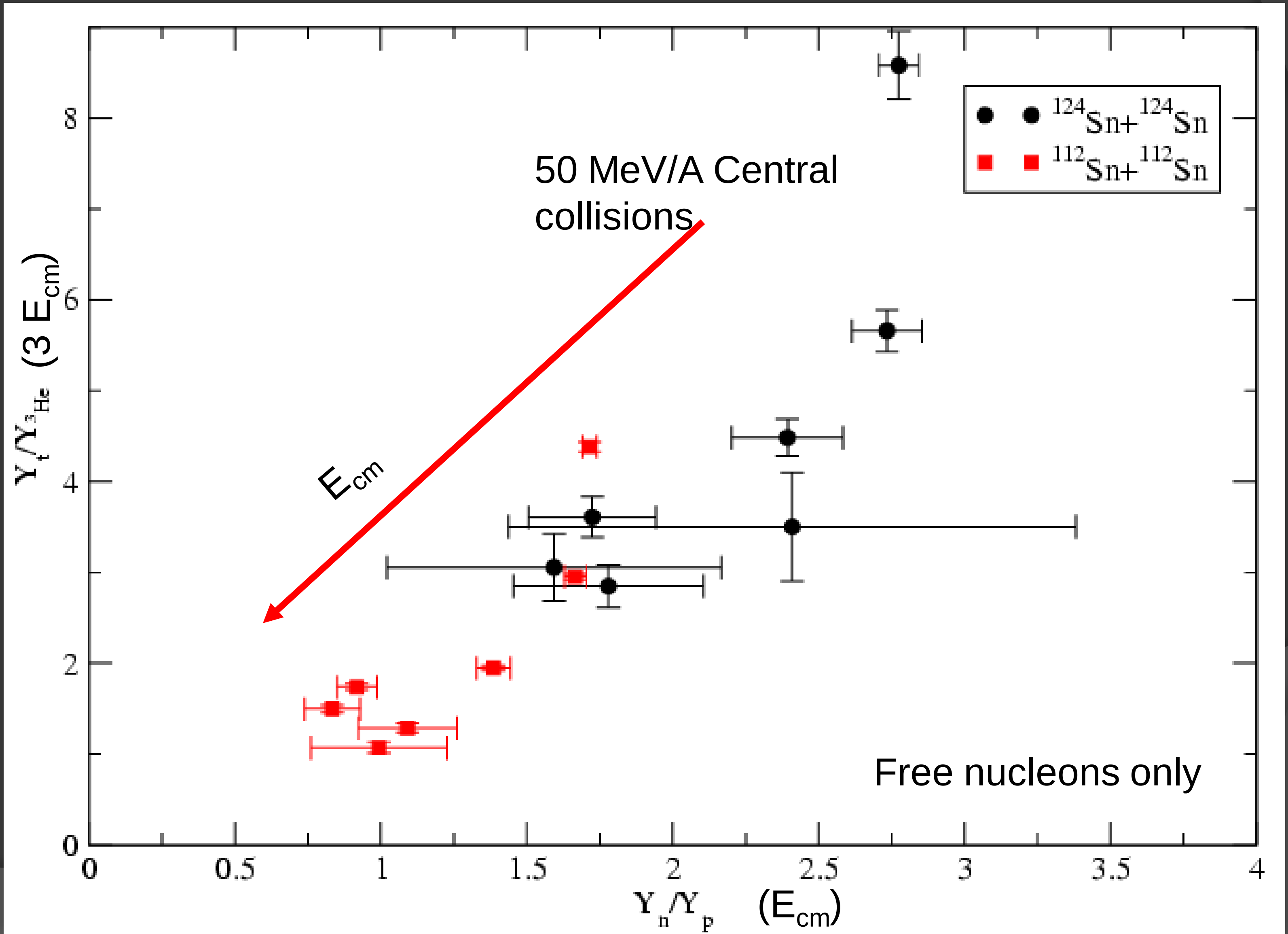
Mirror Nuclei Ratios



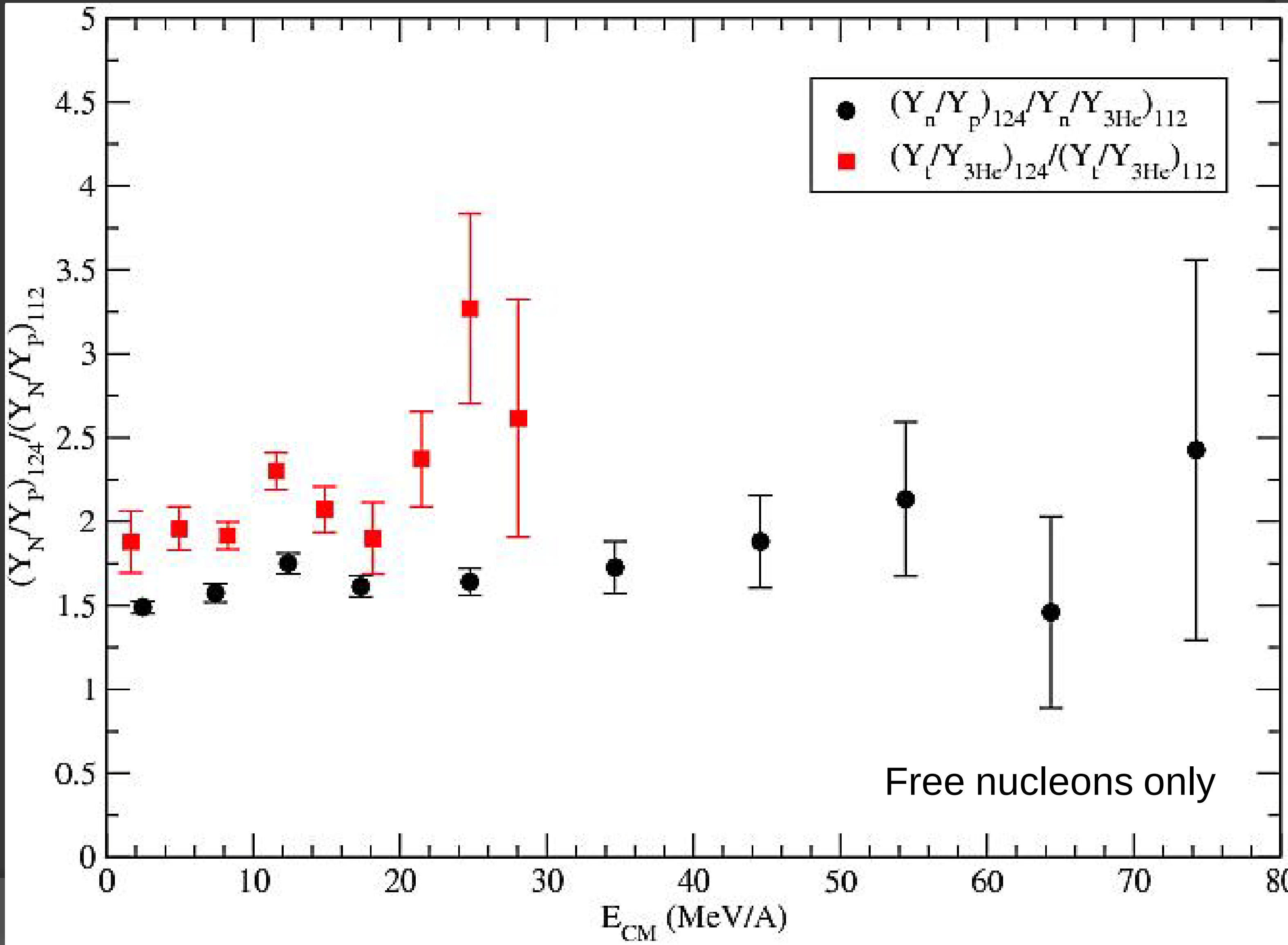
$$\frac{dN_t}{dN_{^3He}} = \frac{d^3N_t}{dK^3} \Bigg/ \frac{d^3N_{^3He}}{dK^3} = \frac{dN_n}{dN_p}$$

Calculations courtesy of B.-A. Li, Calculations relevant to ^{112,124}Sn+^{112,124}Sn underway.

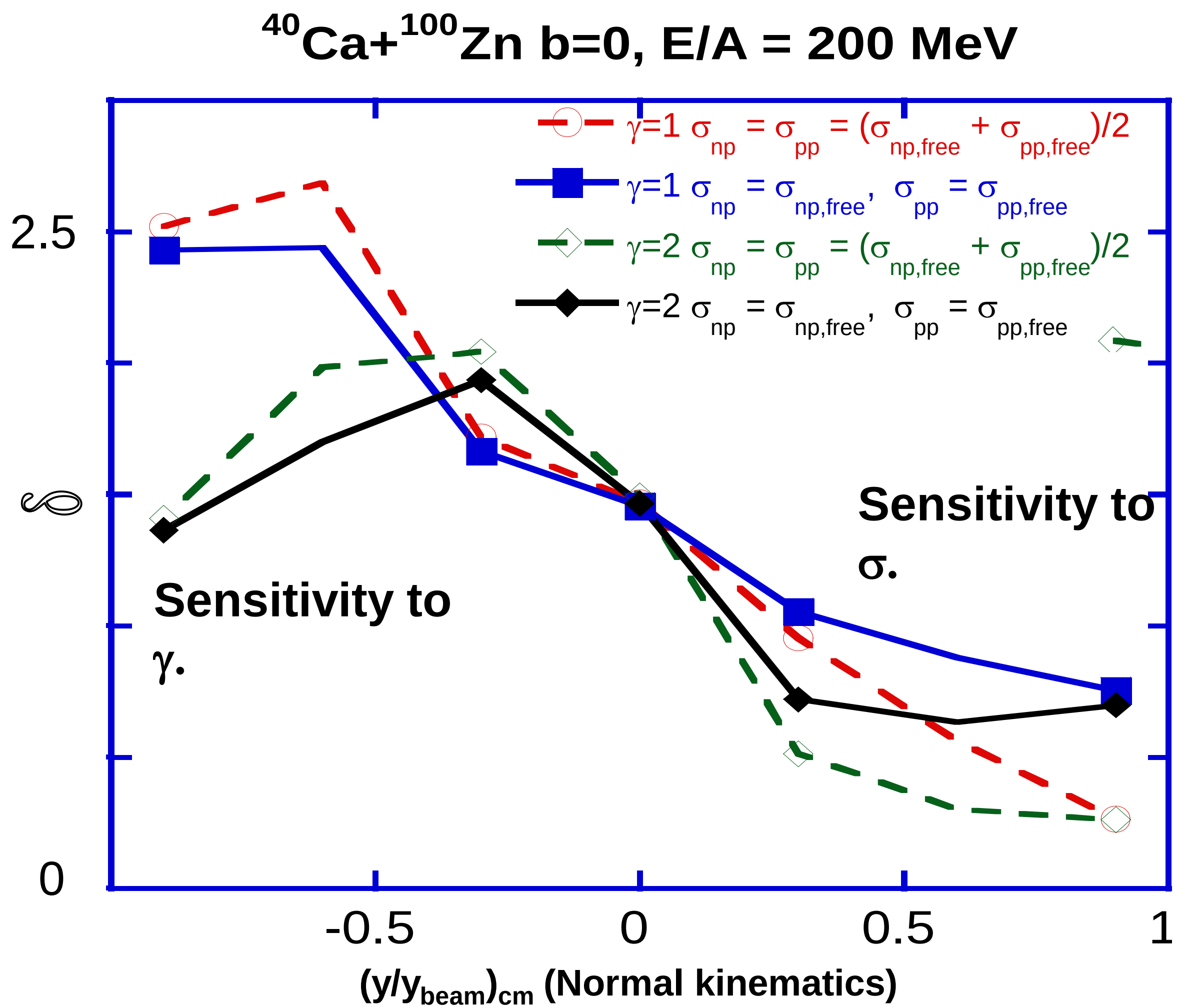
Mirror Nuclei Ratios



Mirror Nuclei Ratios



Effective Masses Alter In-Medium Cross-Sections



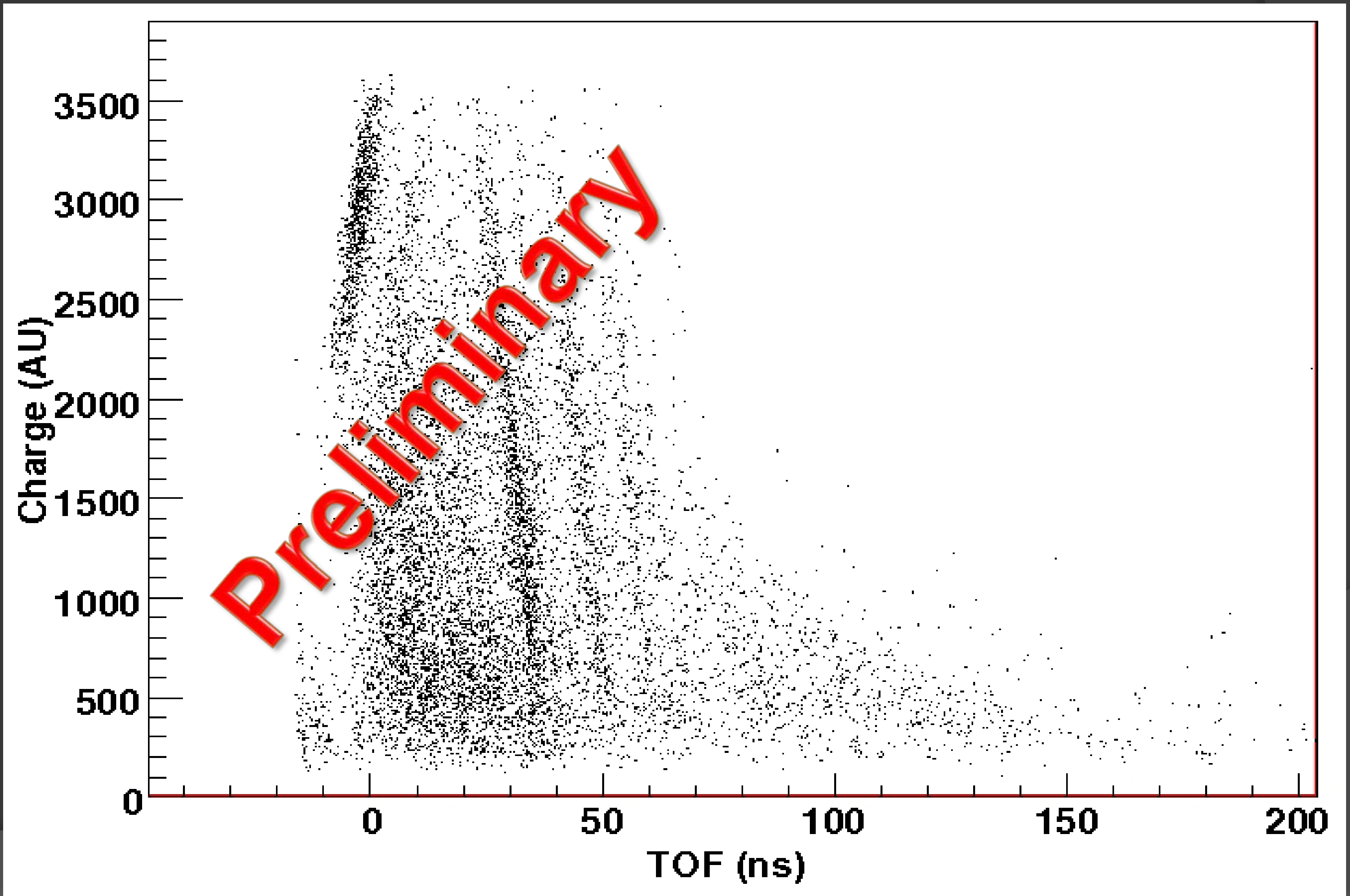
Chen et al. (2004)

Same Line Type:
Different γ but same in-medium σ.

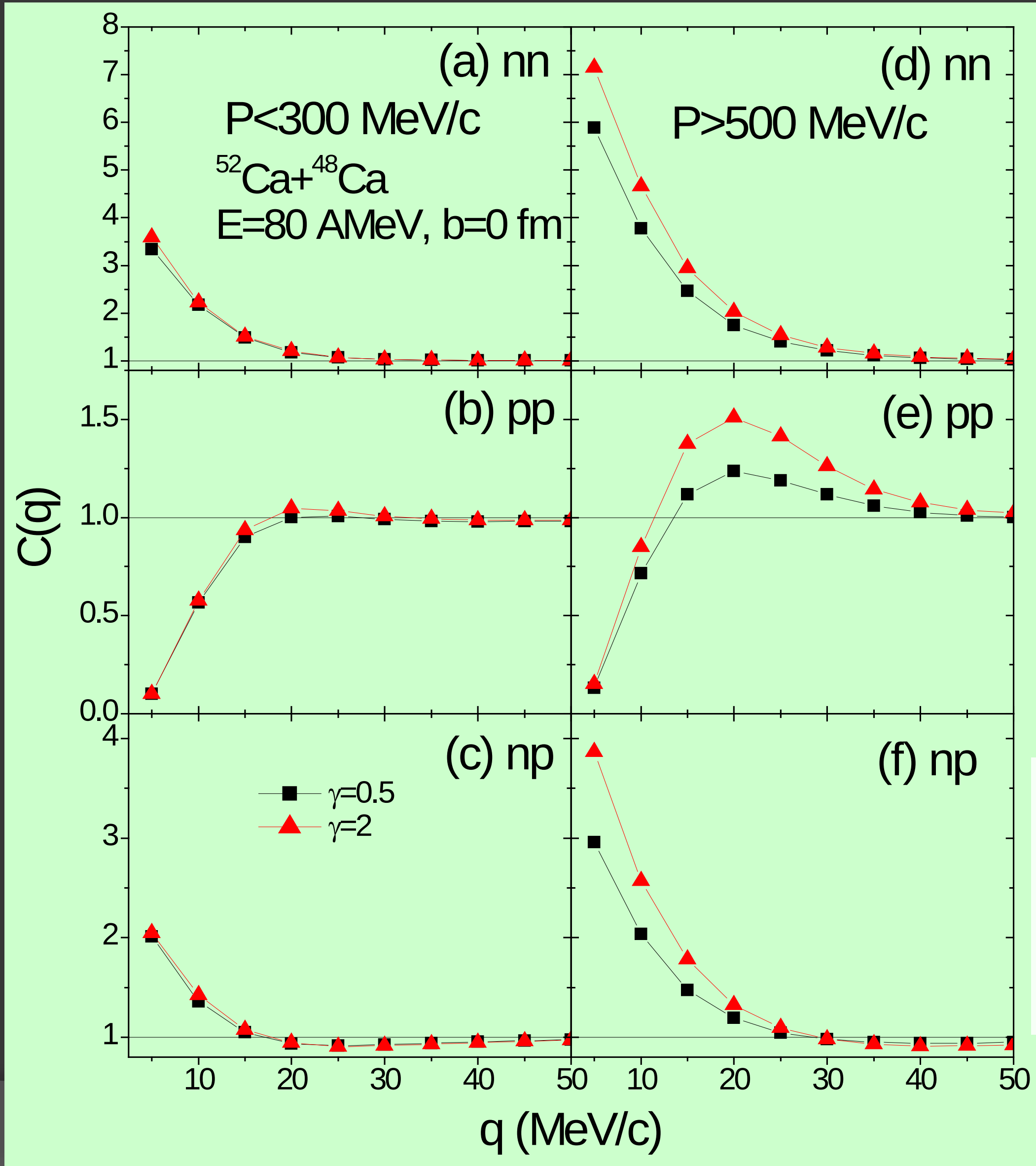
Diamonds:
Same γ and different in-medium σ.

$$\sigma_{medium} / \sigma_{free} \approx \left(\frac{\mu^*_{NN}}{\mu_{NN}} \right)^2$$

Neutron Spectra, Correlations



Predicted Correlation Function



-Sensitivity of correlation function
- -Proton pairs
- -Neutron pairs
- -Neutron-proton pairs

-Dependence on fast particles
- -High momentum
- -Early emission in excitation
- -Compact source: Smaller spatial separation

$$C(\mathbf{P},\mathbf{q}) = \frac{\int d^4x_1 d^4x_2 g(\mathbf{P}/2, x_1) g(\mathbf{P}/2, x_2) \left|\phi(\mathbf{q},\mathbf{r})\right|^2}{\int d^4x_1 g(\mathbf{P}/2, x_1) \int d^4x_2 g(\mathbf{P}/2, x_2)}$$

$\mathbf{P} = \mathbf{p}_1 + \mathbf{p}_2, \quad \mathbf{q} = (\mathbf{p}_1 - \mathbf{p}_2)/2$

$\phi(\mathbf{q},\mathbf{r})$ is the relative two-particle wavefunction

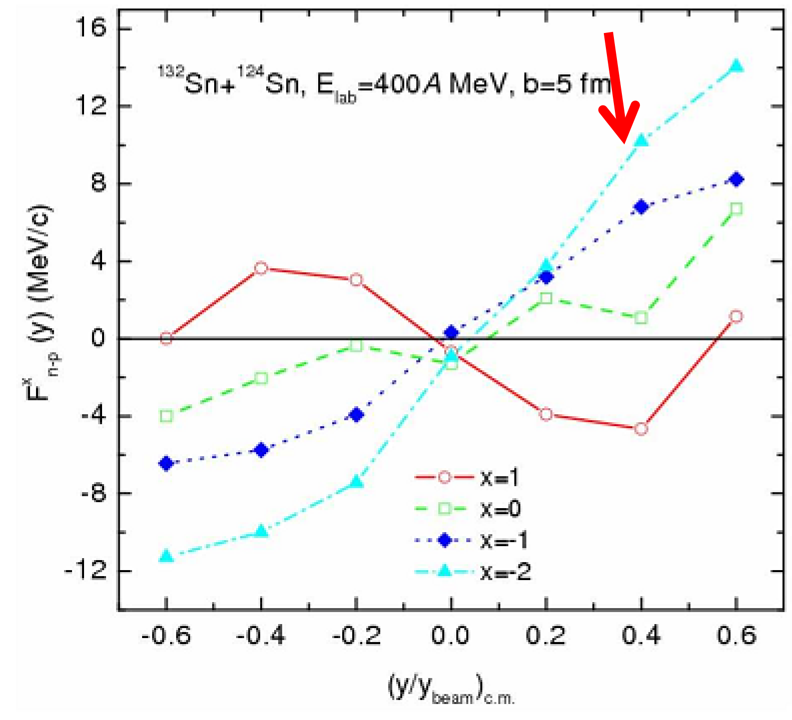
Chen,Greco,Ko,Li, PRL90, PRC68, (2003)

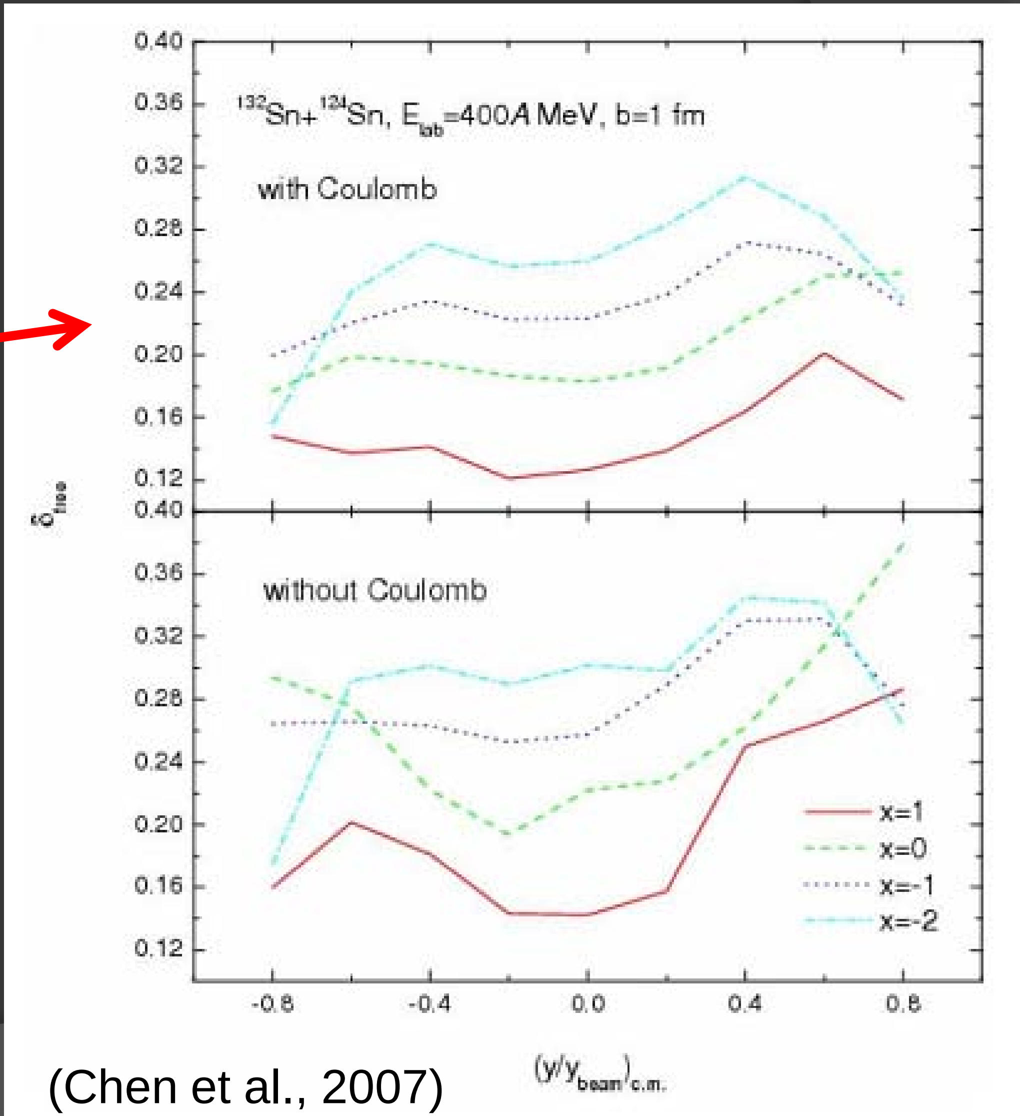
Neutron-Proton Emission Above Saturation Density

Isospin asymmetry and Differential flow:

Possible sensitivity at larger Beam energies.

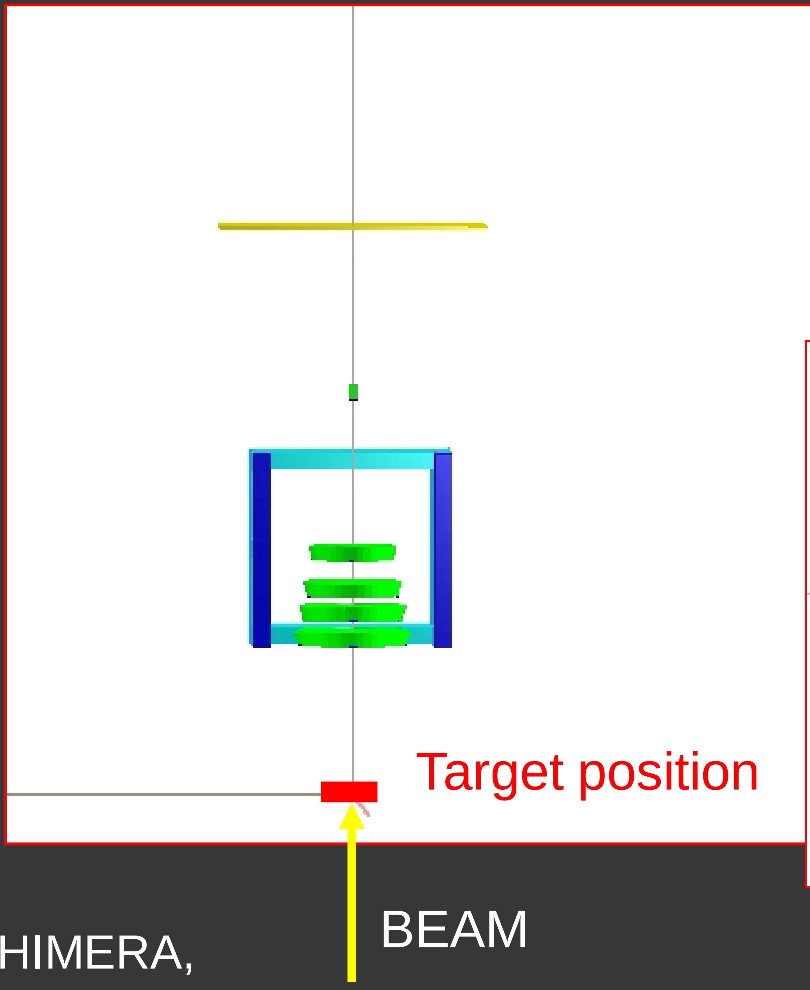
NOTE: Free nucleons only.

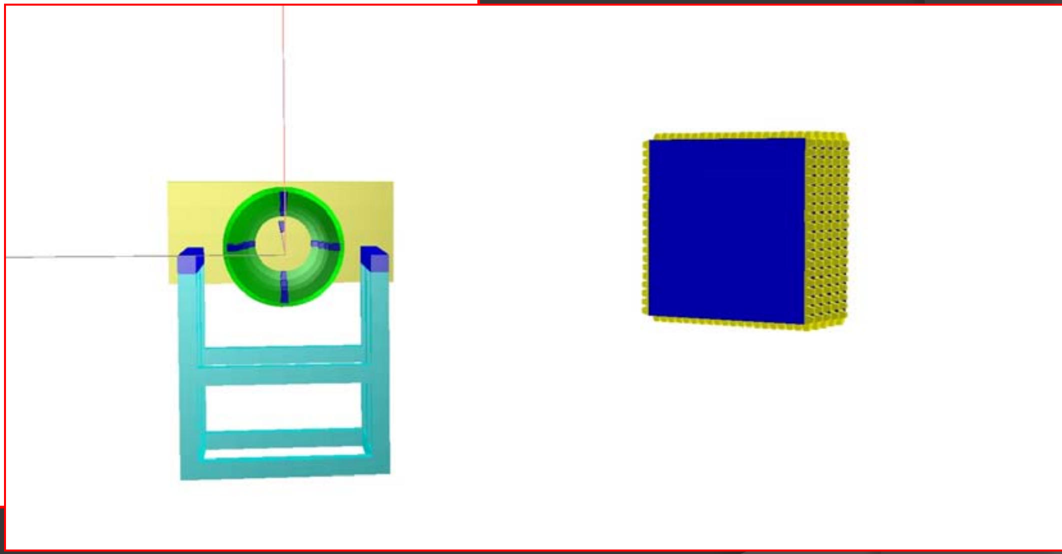




(Chen et al., 2007)

Asymmetry Above Saturation Density: Possibility for n/p Ratios?





CHIMERA,
LAND,
MicroBall
Au + Au
400 MeV/A Elliptic Flow

Good PID in
CHIMERA and LAND

Test run Fall 2010
Experiment Summer 2011

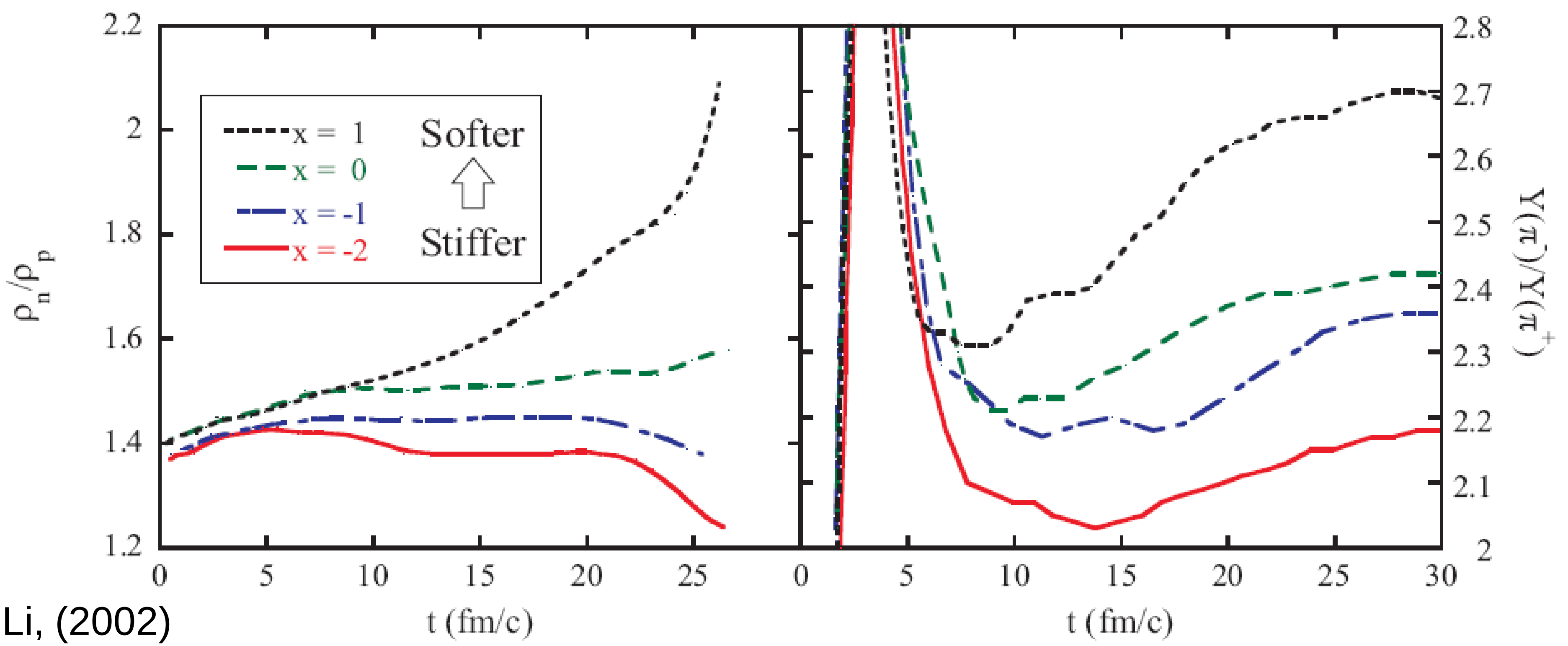
Summary

- Recent progress in isotopic observables of the low-density asy-EOS: Many isotopic observables at low density
- Work towards expansing isotopic observables to the high-density asy-EOS
  - Ratios
  - Correlations
- Constraining theory: effective masses
- Equipment for the high-density asy-EOS

Towards Higher Density

- Isotopic observables
  - Possible difficulties in "freeze out" conditions?

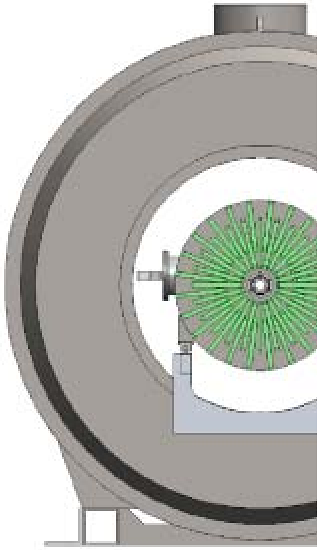
Stiffer EOS favors symmetric Dense regions: More +: Lower π^-/π^+.
Softer EOS is less strongly Symmetric: Suppression of π^+.

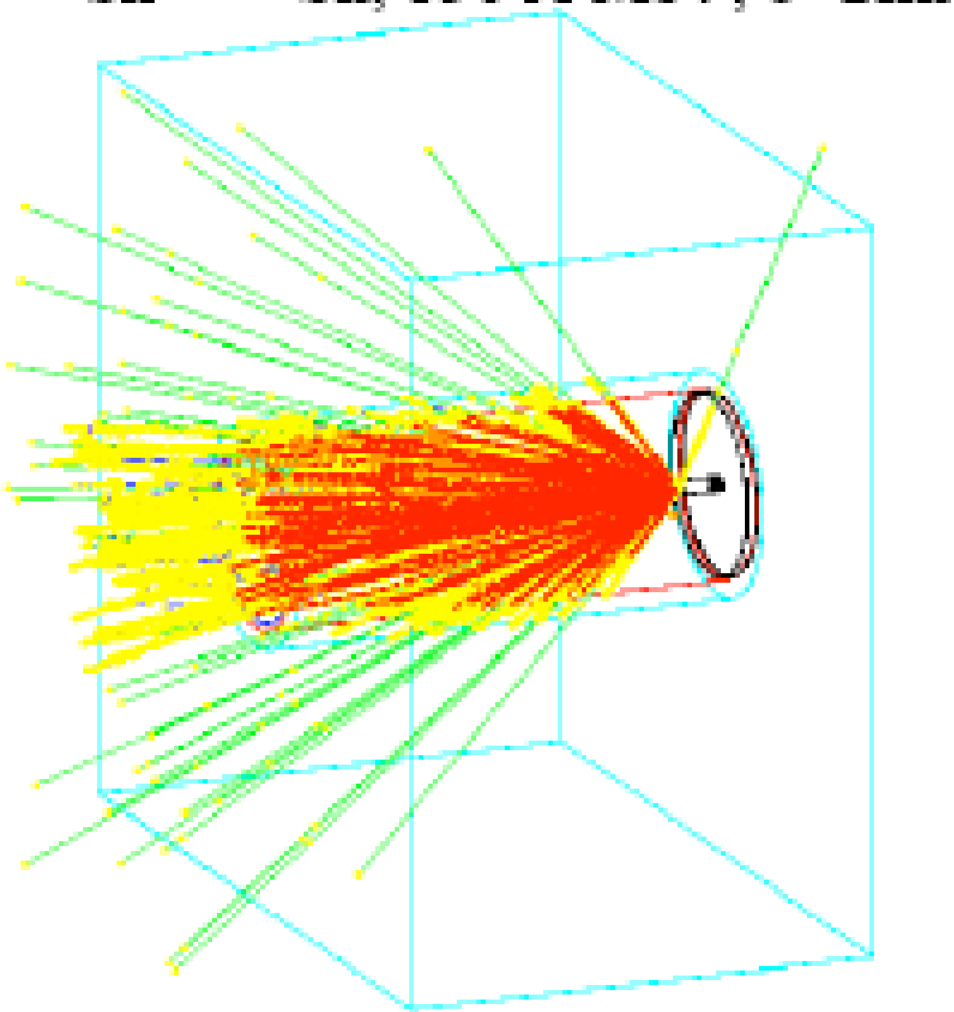


Li, (2002)

AT-TPC

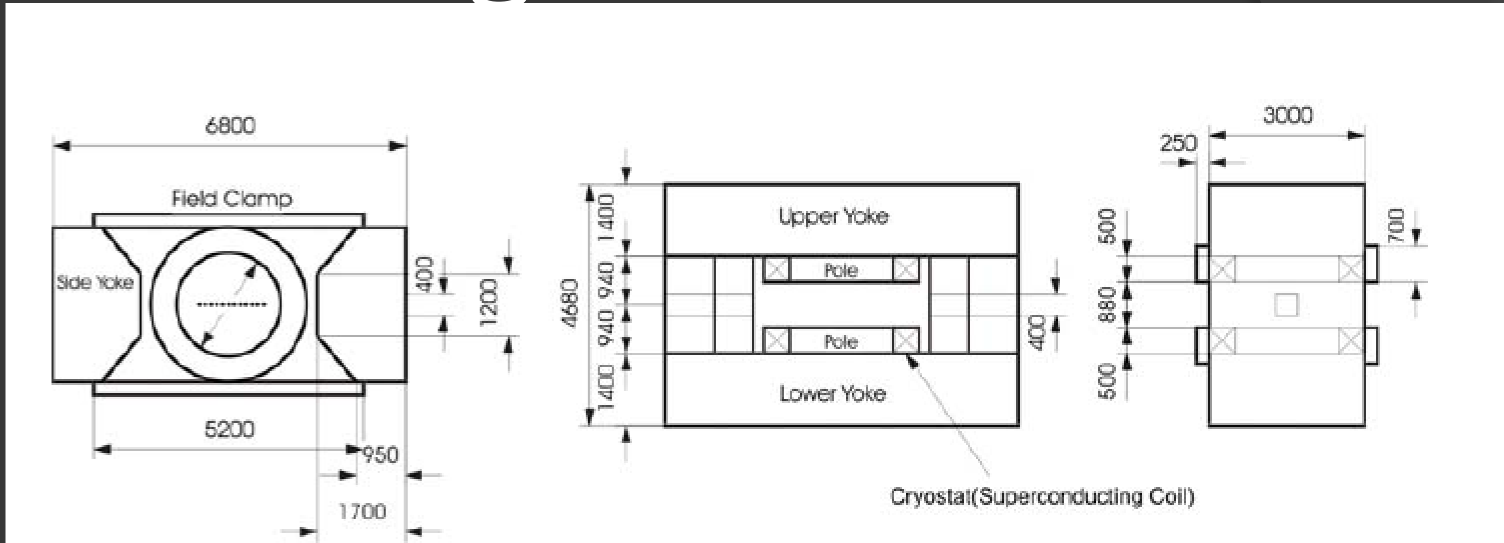
a)





	Density R
✓	t/^{3}He production
✓	Pre-equilibrium nucle
✓	Isospin fractionation
✓	Isoscaling
✓	Isospin diffusion
×	Neutron-proton correl

SAMURAI Configuration



Current Concept: Modification of EOS TPC.

SAMURAI Dipole Specifications	
Magnet Type	H
Maximum Rigidity	7 Tm
Pole Diameter	2m
Return Yoke Dimensions Top and Bottom	6.8m x 3m x 1.4 m
Return Yoke Dimensions Sides	1.7m x 0.7m x 1.88m
Central Field	0.4-3 T (at the center)
Magnet Gap	0.88 m – 0.8 m with vacuum chamber
Mounting	Rotatable Base
Total Weight	630 T

SAMURAI TPC Parameters

Pad Plane Area	**1.3m x 0.9 m**
Number of Pads	11664 (108 x 108)
Pad Size	12 mm x 8 mm
Drift Distance	55 cm
Pressure	1 atm
Gas Composition	90% Ar + 10% CH_4
Gas Gain	3000
E Field	120 V/cm
Drift Velocity	5cm/μs
dE/dx range	Z=1-8, π, p,d,t,He,Li-O
Two Track Resolution	2.5 cm
Multiplicity Limit	200

Current Landscape