M. A. Famiano

NIC XI Meeting

July 20, 2010

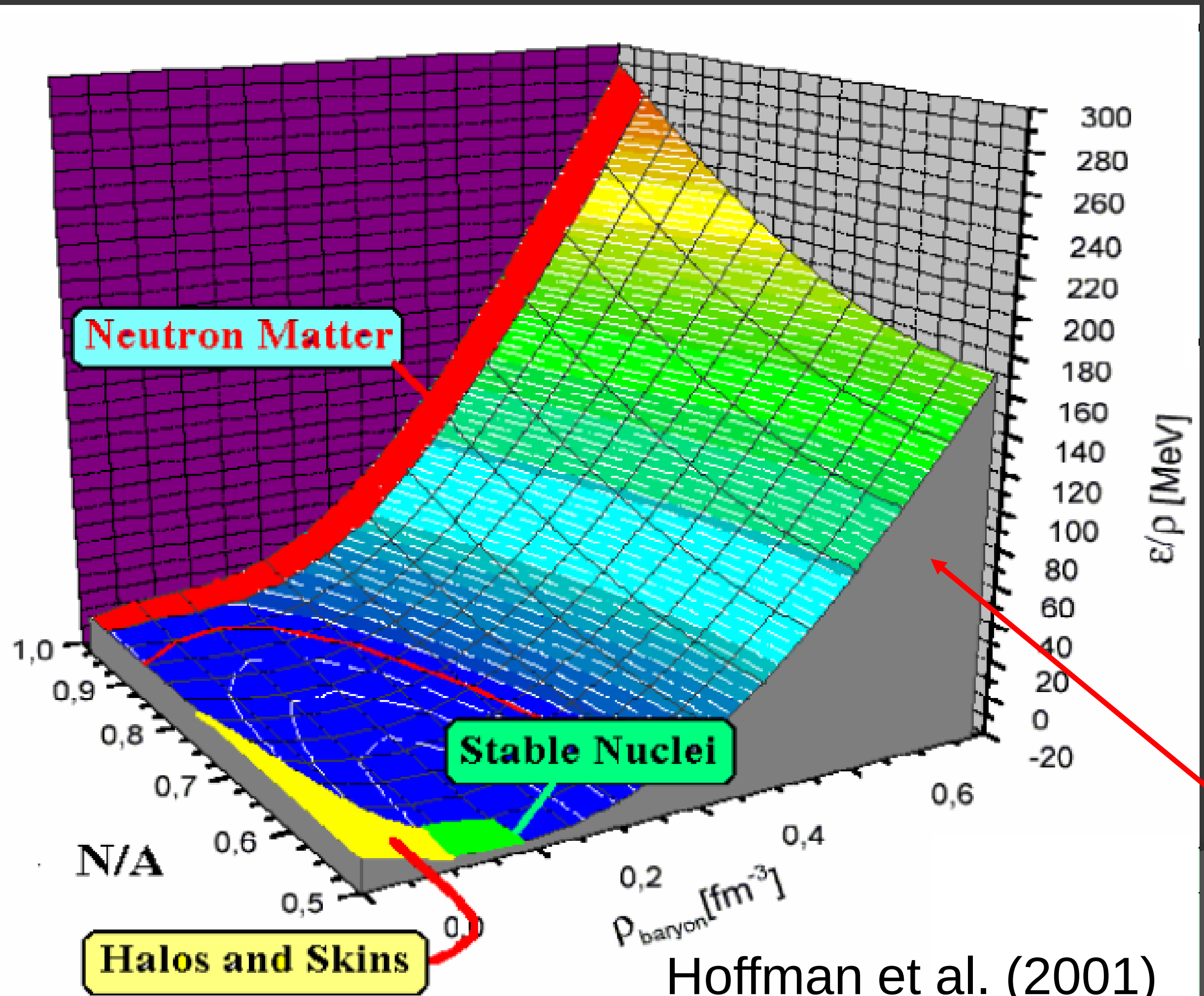
Experimental Applications of the Nuclear Equation-of-State

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

Introduction

- Significance of the symmetry energy at low and high density
- Isotopic observables near saturation density
  - Neutron-proton ratios
  - Constraining parameters
  - Extrapolations: supra-saturation density
- Experimental plans
  - Exceeding nuclear saturation density

Symmetry Energy in Nature



Hoffman et al. (2001)

Equation of state of asymmetric nuclear matter.

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

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

Symmetry energy $S(\rho)$

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

$+ S_{int} \cdot (\rho/\rho_0)^{\gamma_i}$

$$P_{sym} = \rho^2 \frac{dE_{sym}(\rho)}{d\rho} \delta^2$$

Steeper slope means higher pressure.

Neutron Star Radius Depends on Stiffness

- Macroscopic properties:
  – Neutron star radii, moments of inertia and central densities.
  – Maximum neutron star masses and rotation frequencies.
- Thickness of the inner crust.
  – Frequency change accompanying star quakes.
- Role of Kaon condensates and mixed quark-hadron phases in the stellar interior.
- Proton and electron fractions throughout the star.
  – Cooling of proto-neutron star.

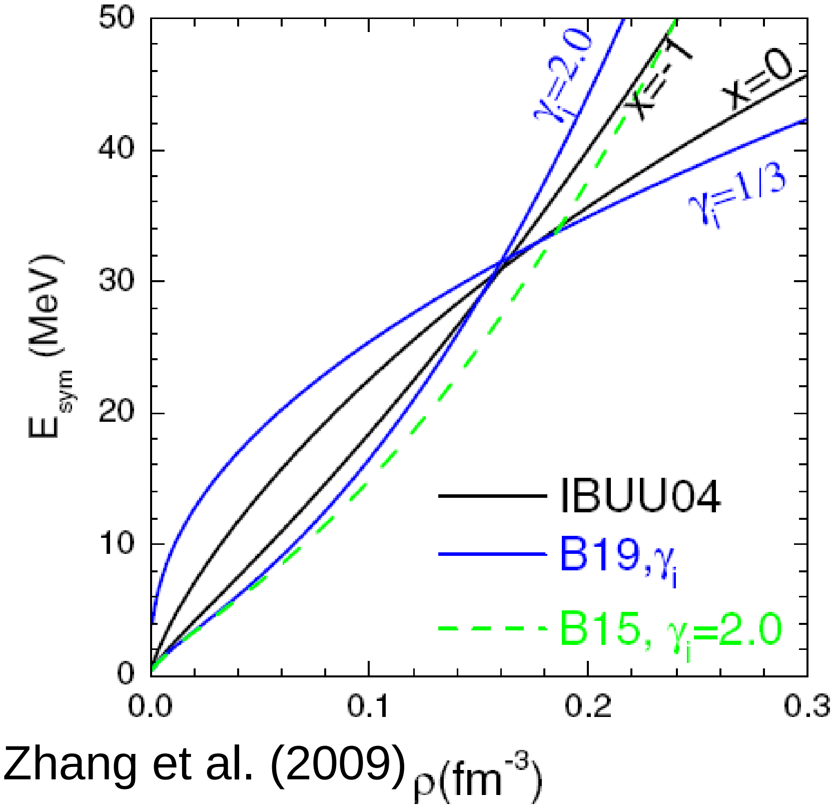
PAL EOS, Lattimer et al. (2001)

Symmetry energy S(ρ)

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

Asymmetric Nuclear Matter

	Stiff	Soft
$\rho<\rho_o$	Less sensitivity to observables	More sensitivity to observables
$\rho>\rho_o$	More sensitivity to observables	Less sensitivity to observables



Zhang et al. (2009)

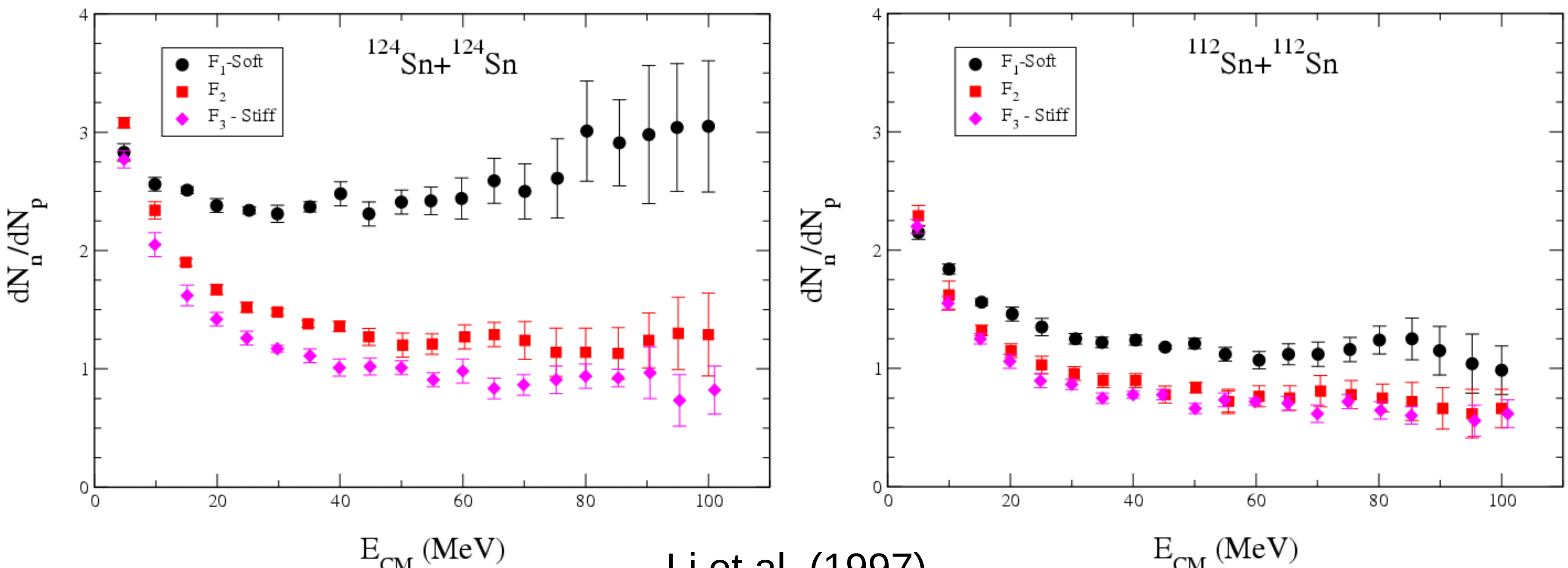
Stiffness of symmetry energy
Contained in parameter γ

Symmetry energy $S(\rho)$

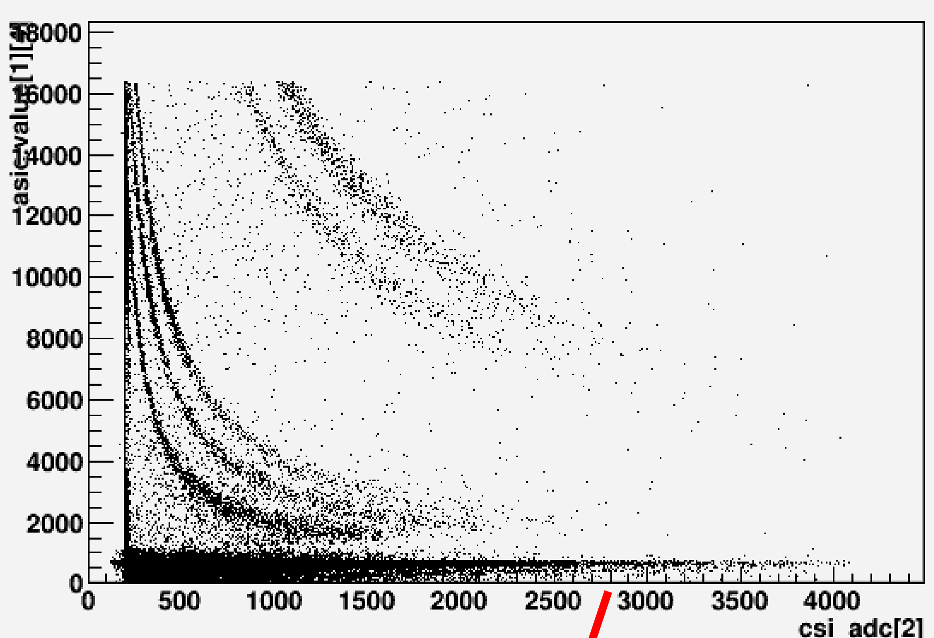
$$S(\rho) = S_{kin} \cdot(\rho/\rho_0)^{2/3} + S_{int}\cdot (\rho/\rho_0)^{\gamma i}$$

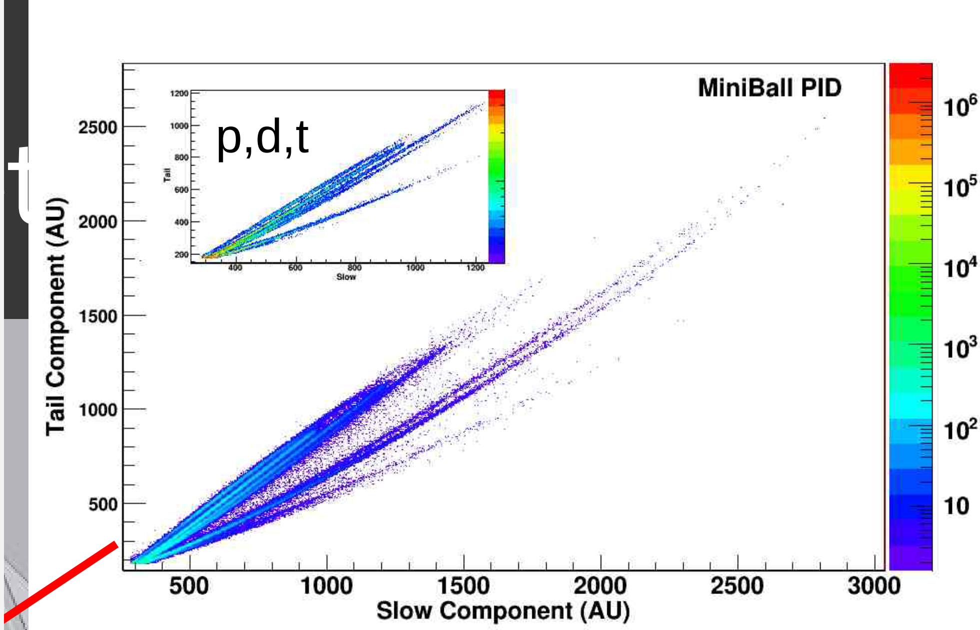
Spectral Ratios

- 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**

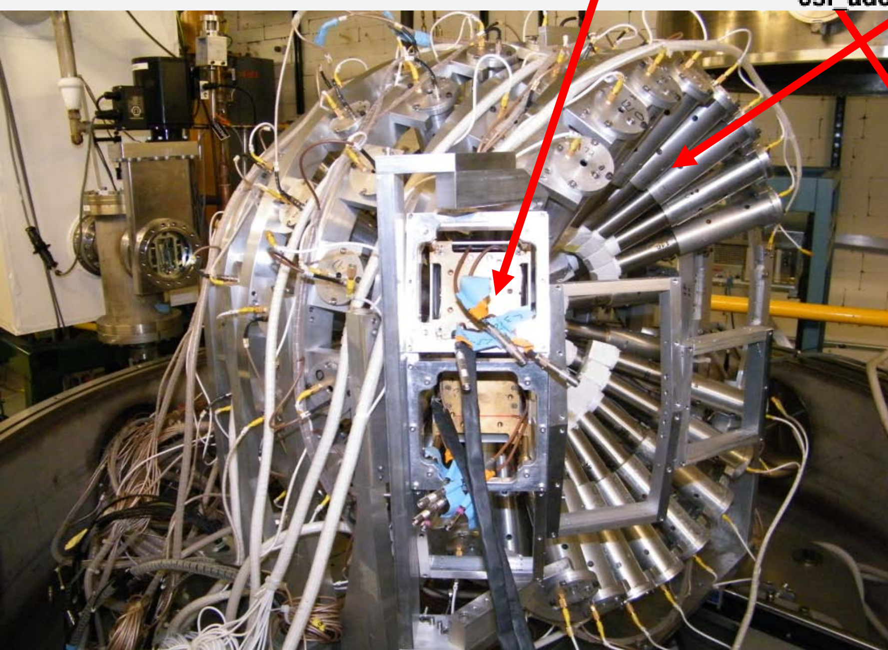


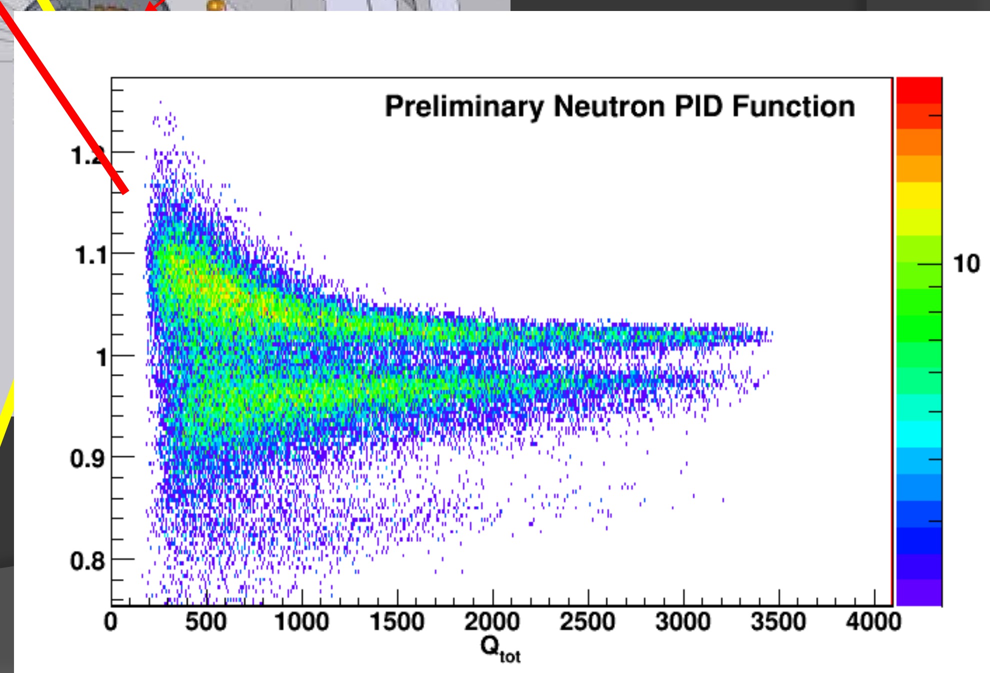
Li et al. (1997)





m*, AND get
Increased statistics



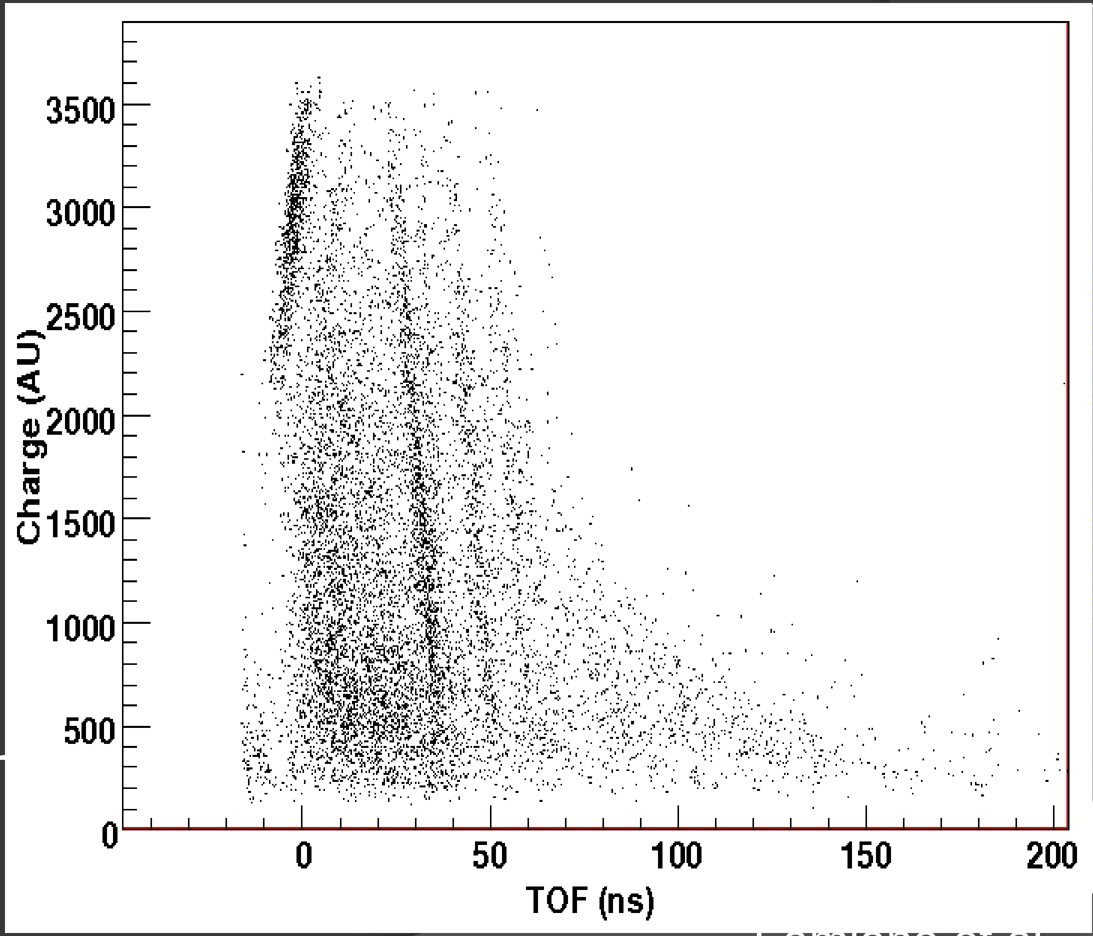


Most Recent Experiment: May 29, 2009

Experimental Configuration

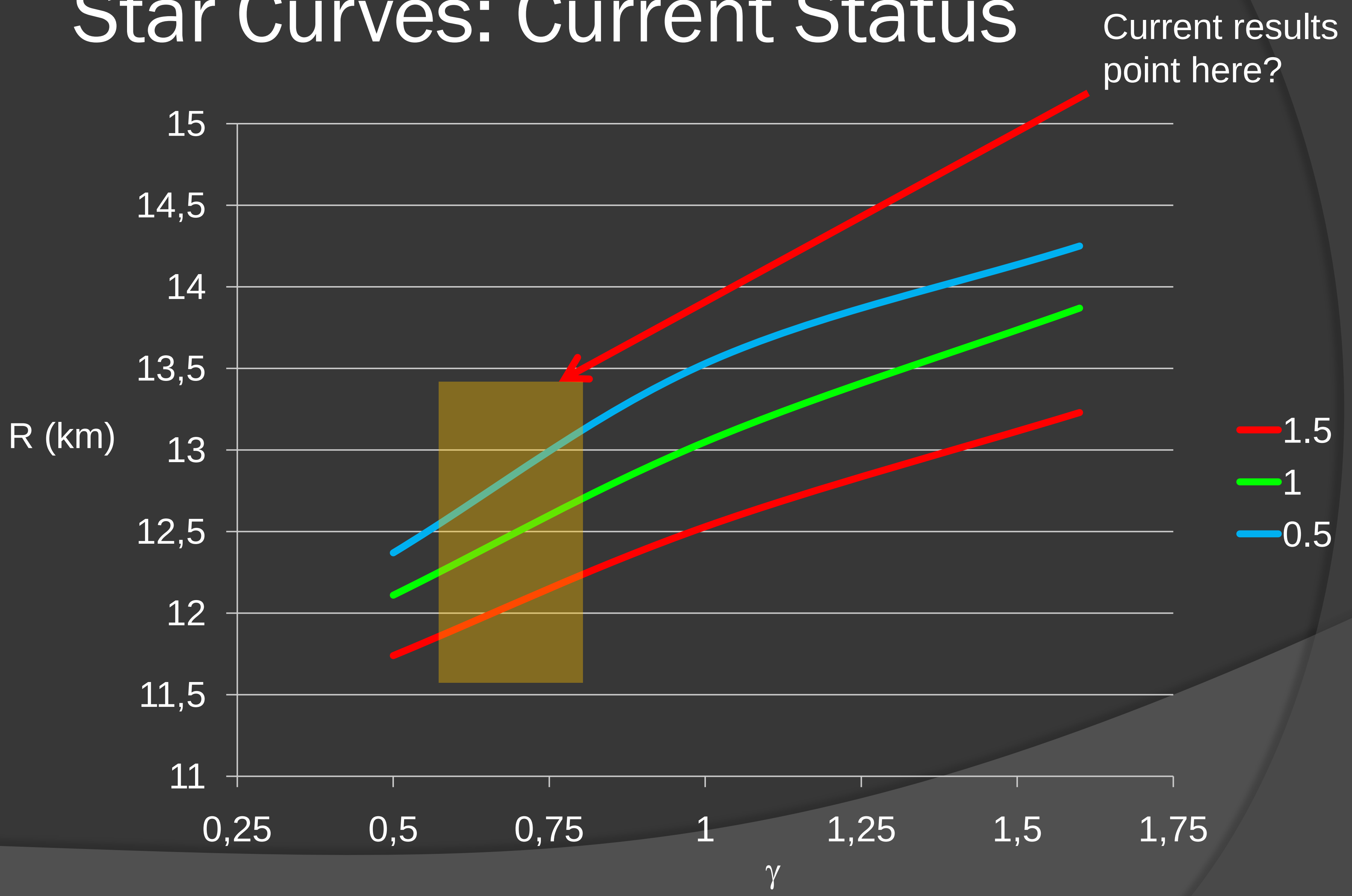
Experimental Results

- Beam: $^{112,124}Sn + ^{112,124}Sn$ 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

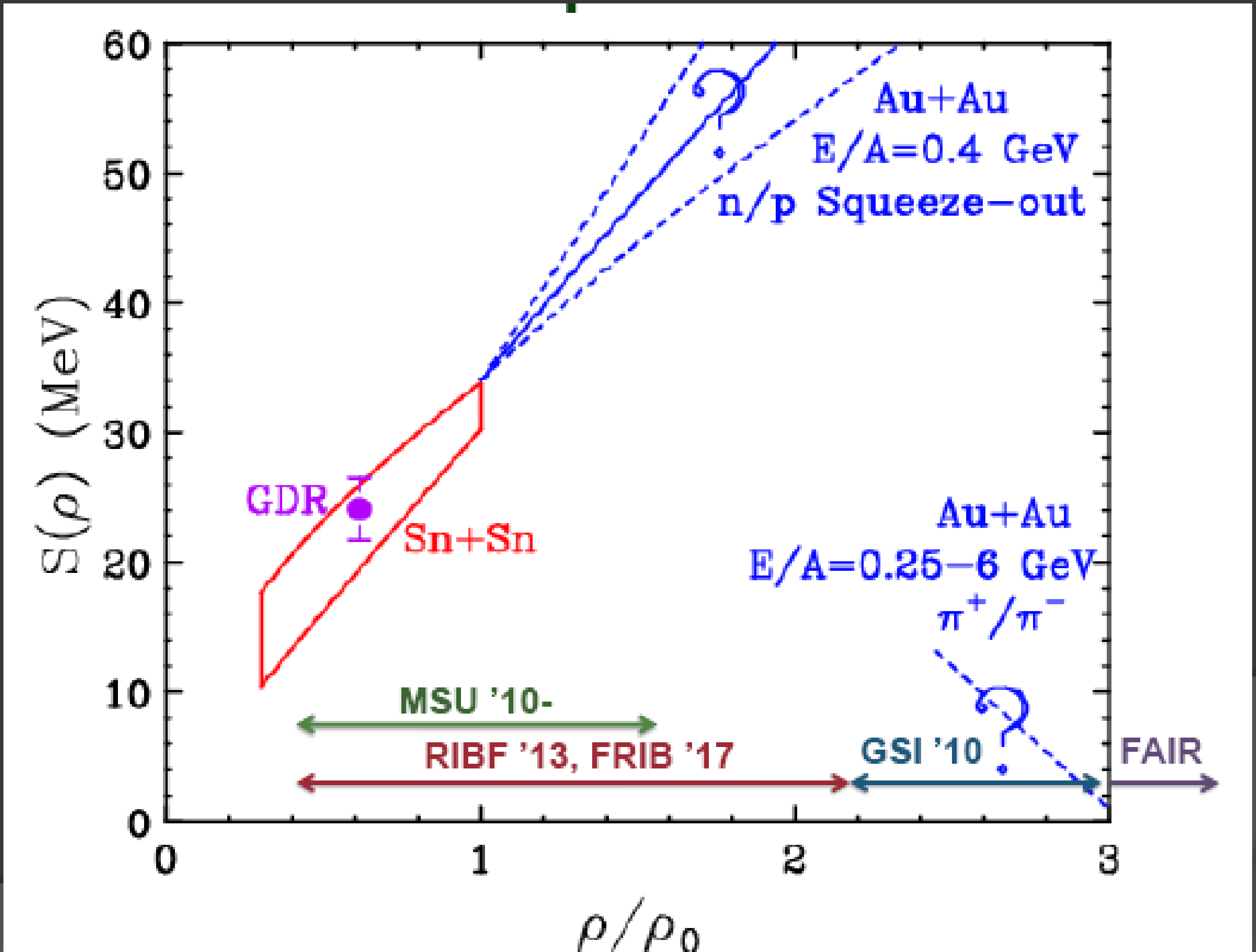


Famiano et al.

Results Compared to Neutron Star Curves: Current Status



Current Landscape



Summary

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

Astrophysical Importance of the Nuclear Asymmetry Term

$E/A(\rho, \delta) = E/A(\rho,0) + \delta^2 \cdot S(\rho)$ $\delta = (\rho_n - \rho_p)/(\rho_n + \rho_p) = (N-Z)/A$

- Macroscopic properties:
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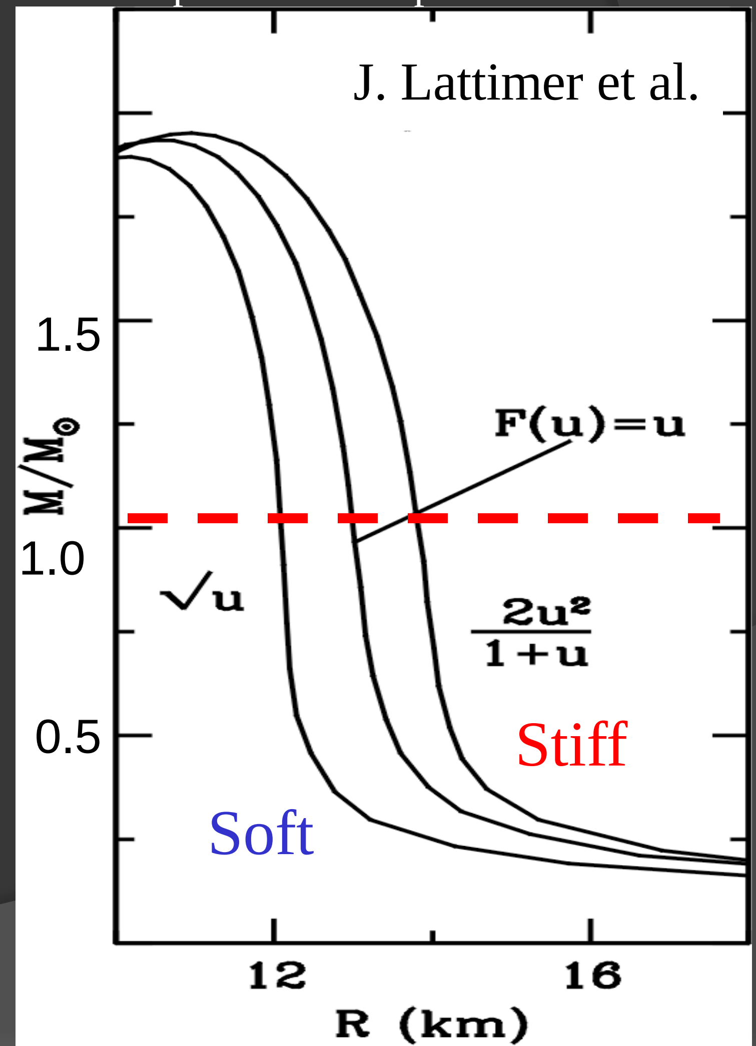
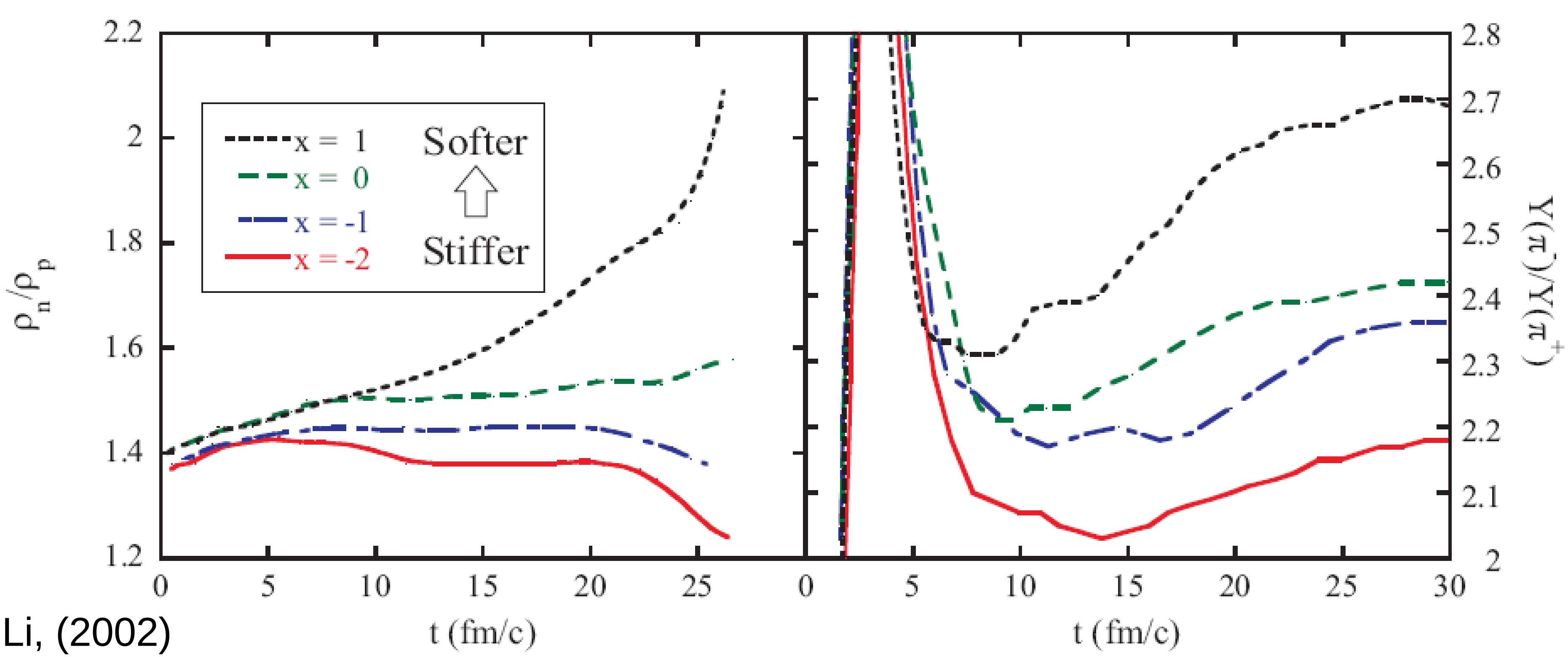


$$S_{pot}(\rho) = const. \cdot F(u); u = \rho / \rho_0$$

Towards Higher Density

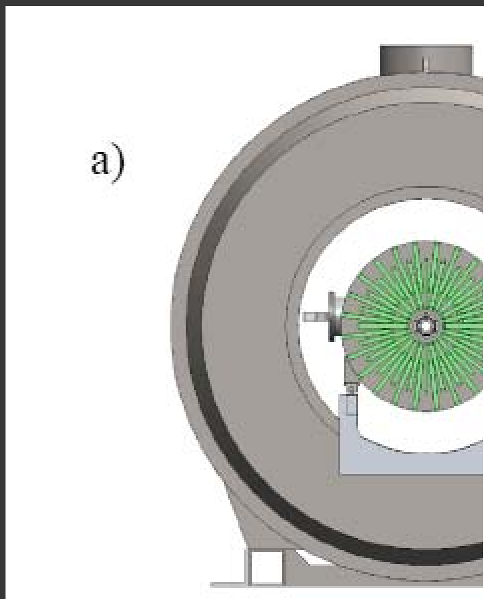
- Isotopic observables
  - Possible difficulties in “freeze out” conditions?

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

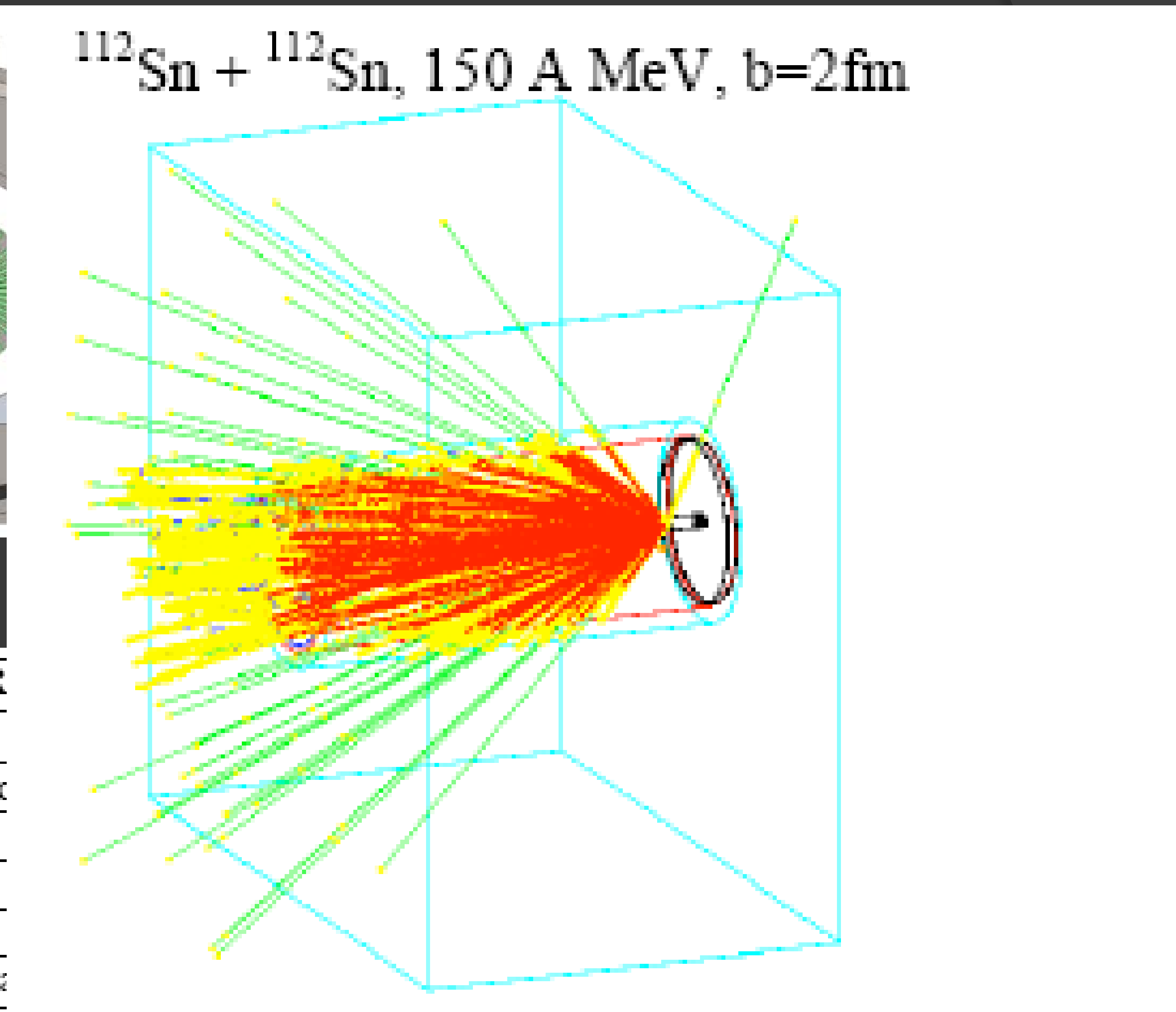


Li, (2002)

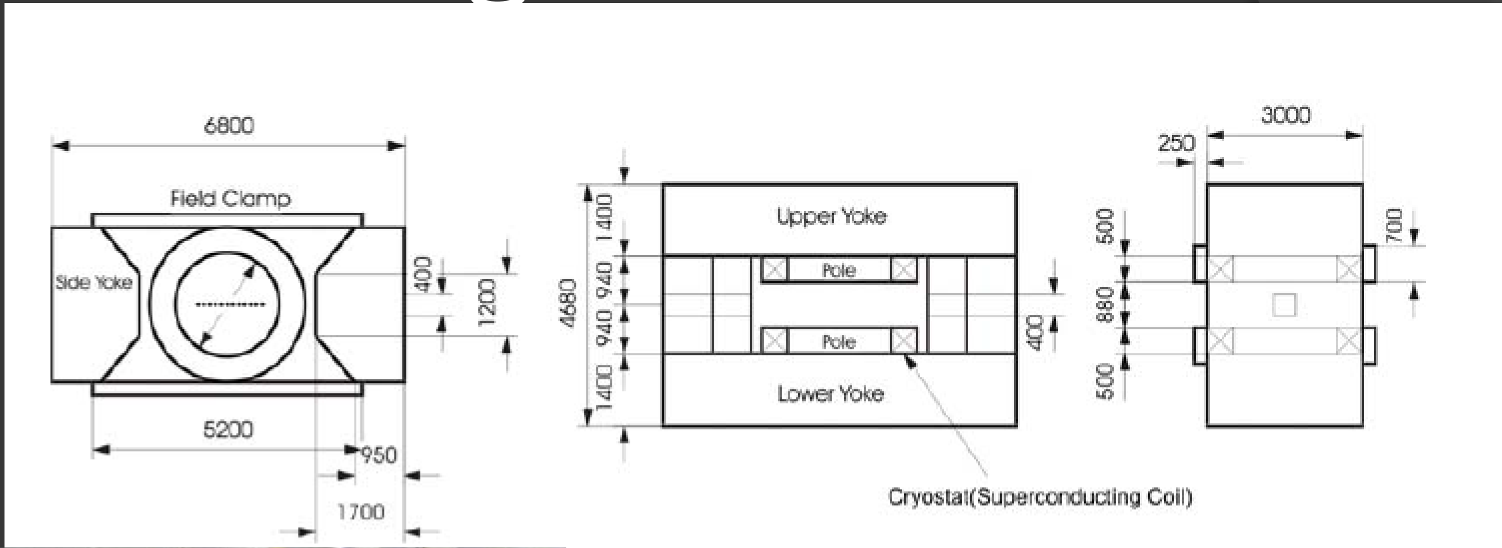
AT-TPC



	Density R
✓	t/^{3}He production
✓	Pre-equilibrium nuclec
✓	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