Nuclear Symmetry Energy in Ca+Ca Collisions

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for the INDRA-VAMOS collaboration

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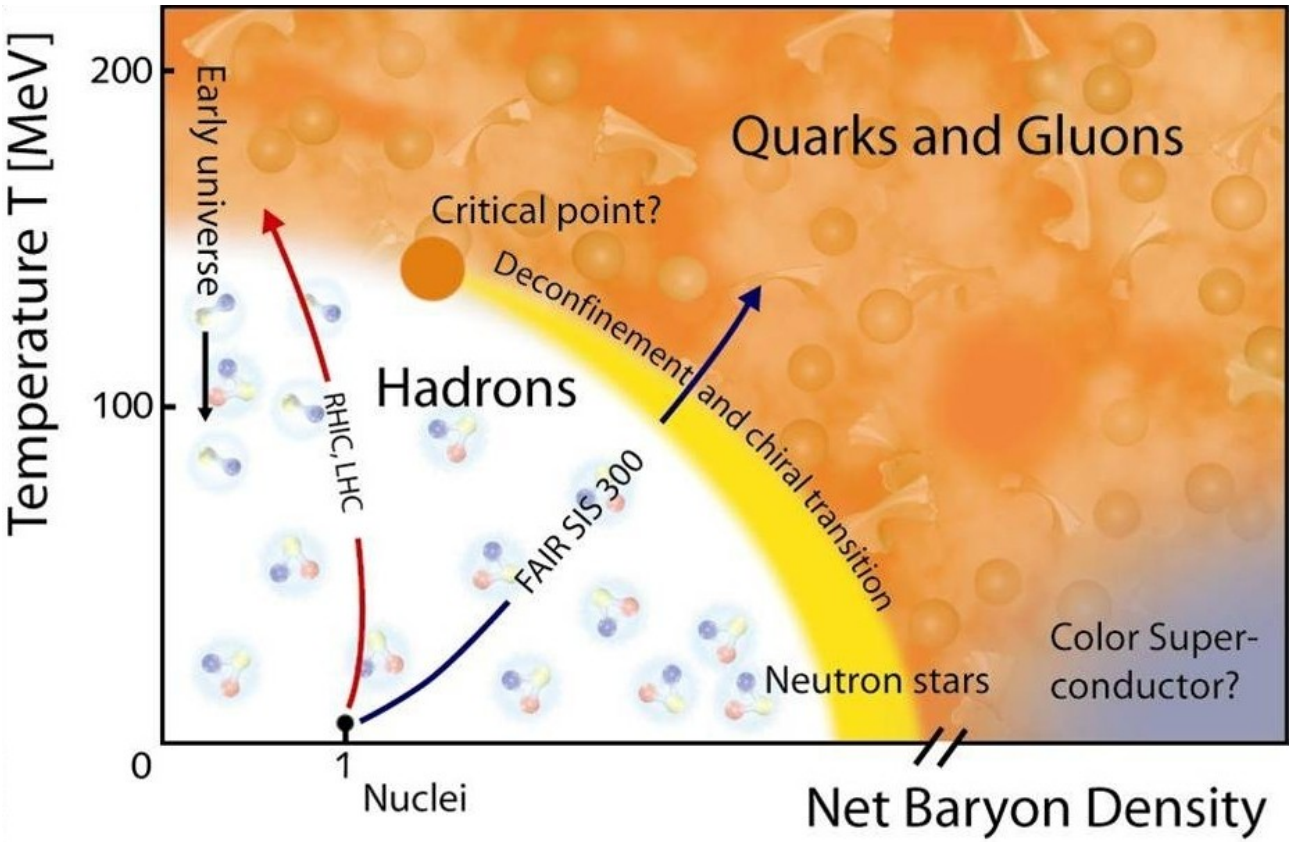
Introduction & Motivation

Nuclear Equation of State (EOS) relates the energy of a nuclear system to its density, pressure, temperature and iso-spin.



$$E(\rho,\delta)=E(\rho,\delta=0)+E_{sym}(\rho)\cdot\delta^2+\ldots \qquad \delta=\frac{\rho_n-\rho_p}{\rho}$$

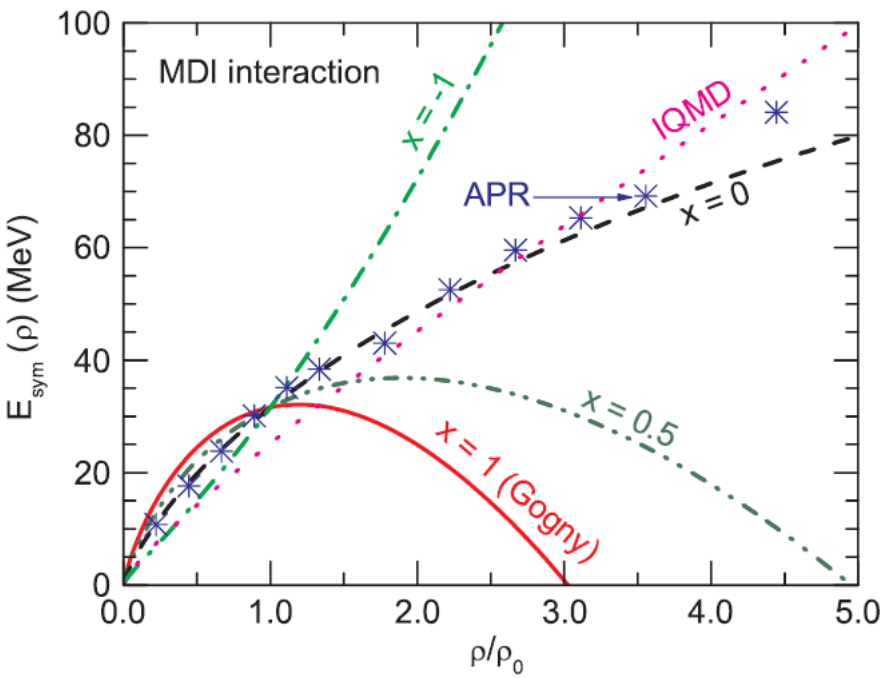
Symmetric Asymmetric

Introduction & Motivation

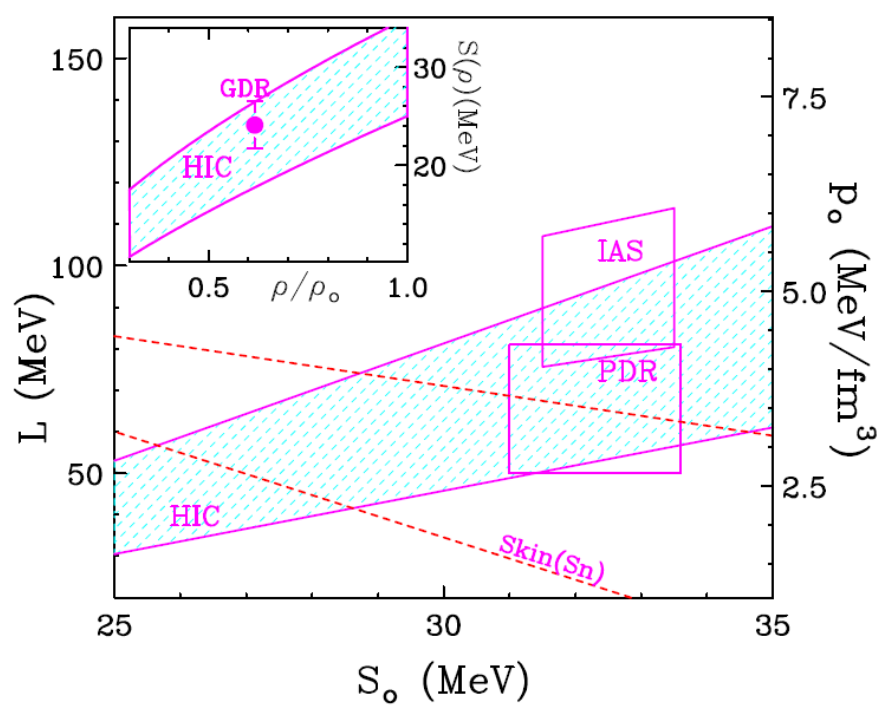
Density dependence of $E_{sym}(\rho)$ is crucial for understanding many phenomena:

- Evolution of matter in Heavy Ion Collisions
- Iso-vector collective vibrations: Pygmy Dipole Resonances, Giant Dipole Resonances
- Neutron star physics: Mass-Radius relation, crustal physics, cooling rates,...
- Neutron skin thickness
- Isobaric Analogue States
- Structure of the drip line

Common parametrisations



Current constraints: sub-saturation

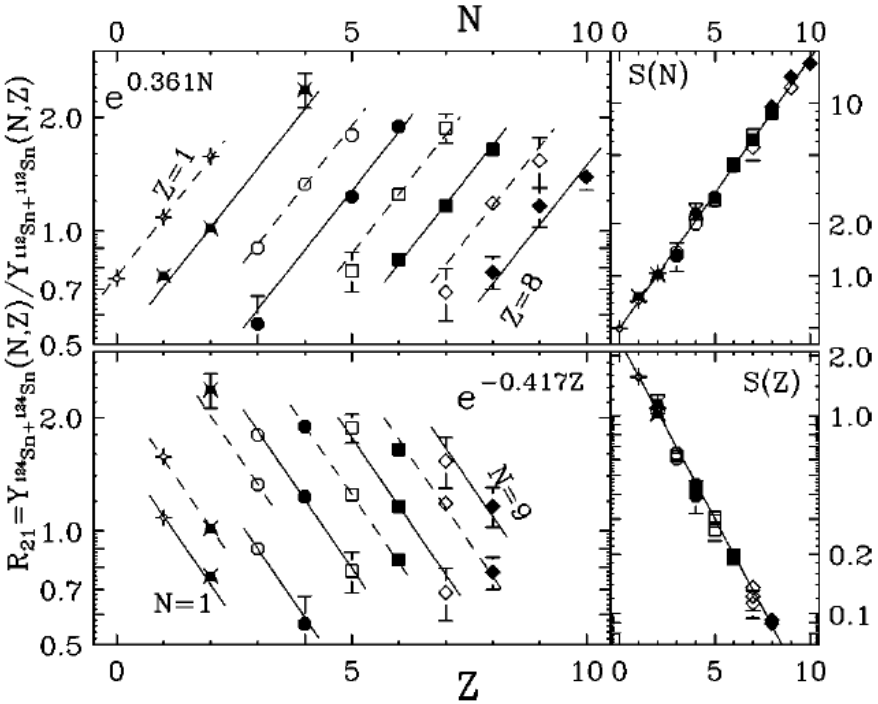


CONSTRAINING THE DENSITY DEPENDENCE OF THE SYMMETRY ENERGY WITH EXPERIMENTAL RESULTS FROM HEAVY-ION COLLISIONS – EJC 2009
MARIE-FRANCE RIVET 27 Jan 2010

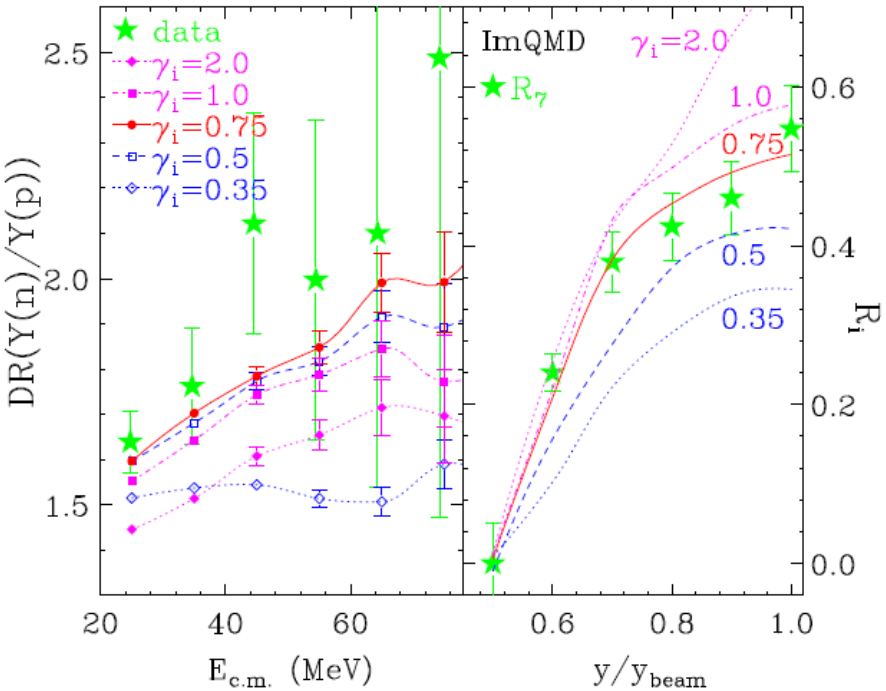
M.B. TSANG et al. arXiv:1101.3648v1 [nucl-ex] 19 Jan 2011

Experimental Observables

Iso-scaling Parameters



Neutron-Proton Double Ratio &
R7 Yield Ratio (right)



$$R_{21}(N,Z)=C\cdot\exp(\alpha N+\beta Z)$$

$$DR(n/p)=\frac{dM_n(A)/dE_{CM}}{dM_p(A)/dE_{CM}}\cdot\frac{dM_n(B)/dE_{CM}}{dM_p(B)/dE_{CM}}$$

Mirror Yield Ratio: $R_7=\ln(Y(^7Li)/Y(^7Be))$

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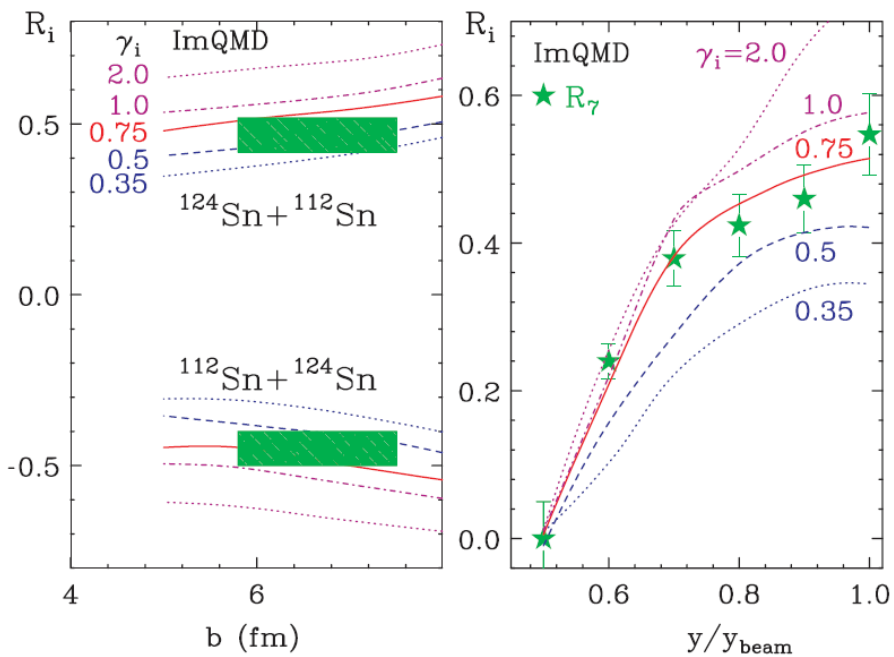
Experimental Observables

Isospin Transport Ratios R(X=α) (Left)
& R7 Yield Ratios (Right)

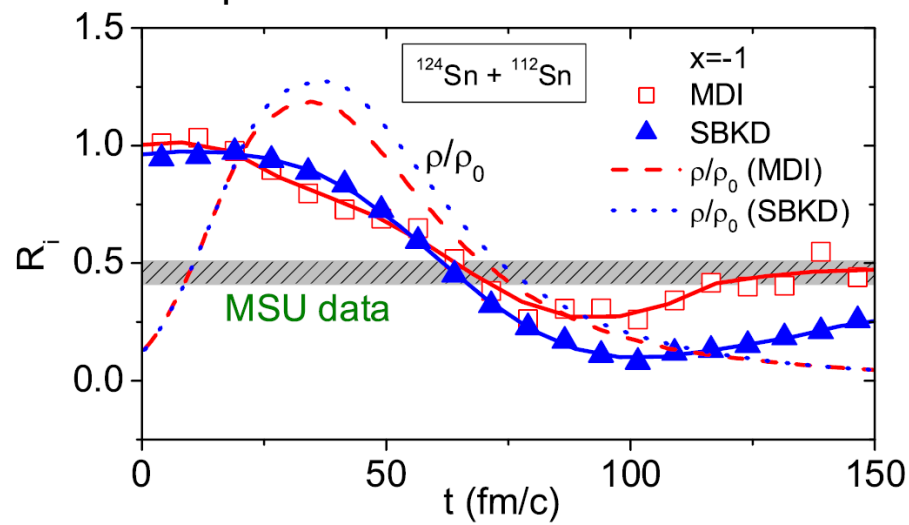


M.B. TSANG et al. PRL 102, 122701 (2009)

$$R=\frac{2X^{A+B}-X^{A+A}-X^{B+B}}{X^{A+A}+X^{B+B}}$$

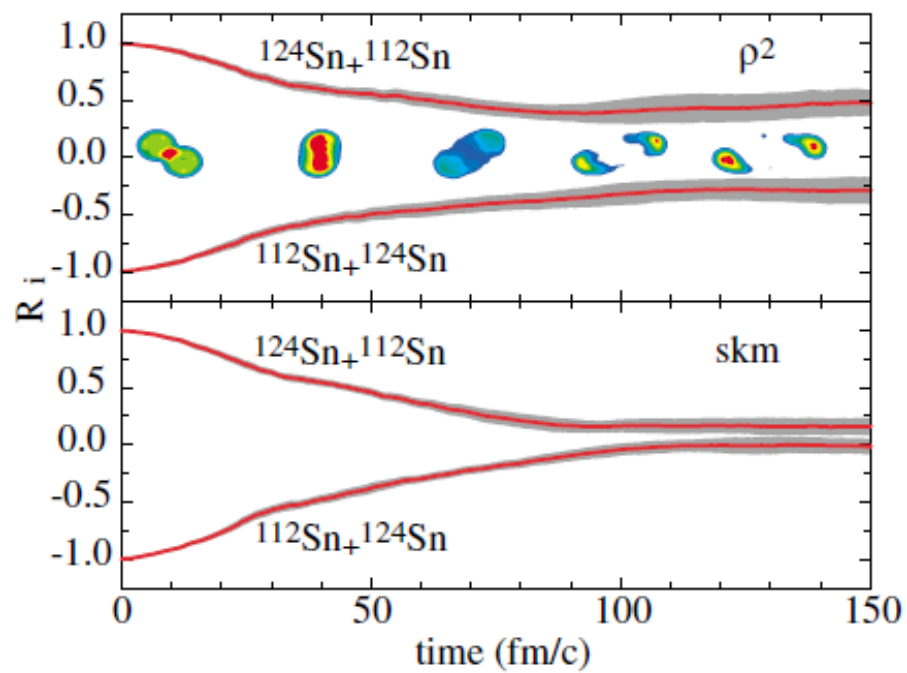
$$R(\alpha)=\frac{2\alpha^{124+112}-\alpha^{124+124}-\alpha^{112+112}}{\alpha^{124+124}+\alpha^{112+112}}$$

Isospin diffusion with time



LIE-WEN CHE et al. PRL 94, 032701 (2005)

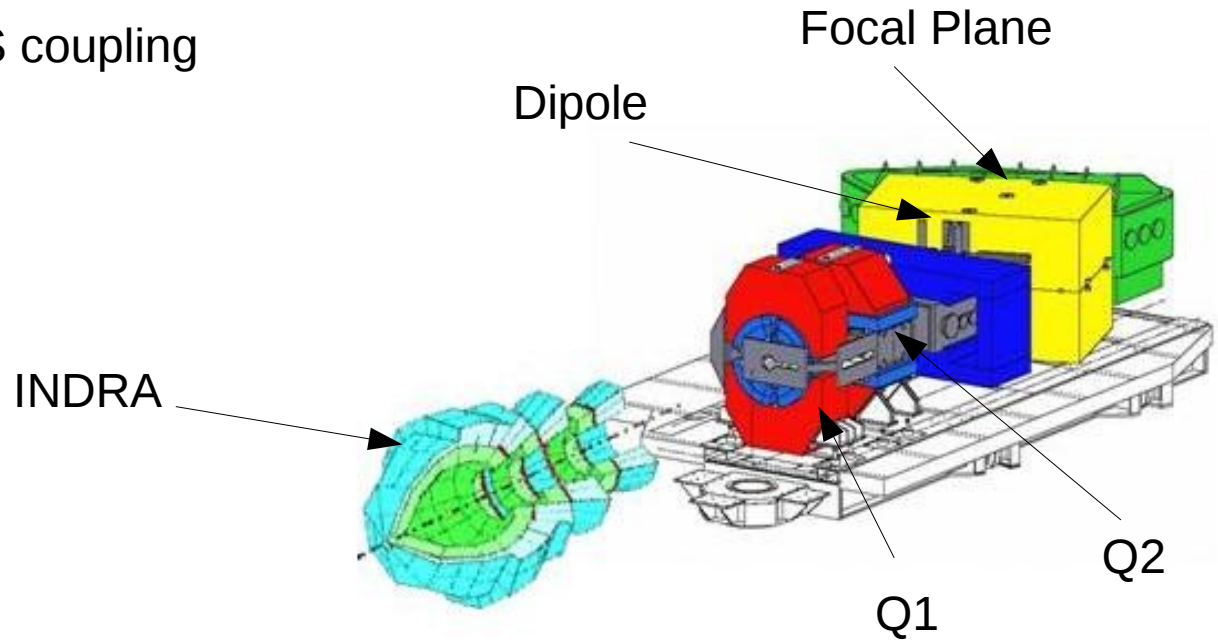
Isospin diffusion – different density dependence



M. B. TSANG et al. DOI:10.1103/PhysRevLett.92.062701

INDRA-VAMOS Experiment

Diagram of the INDRA-VAMOS coupling

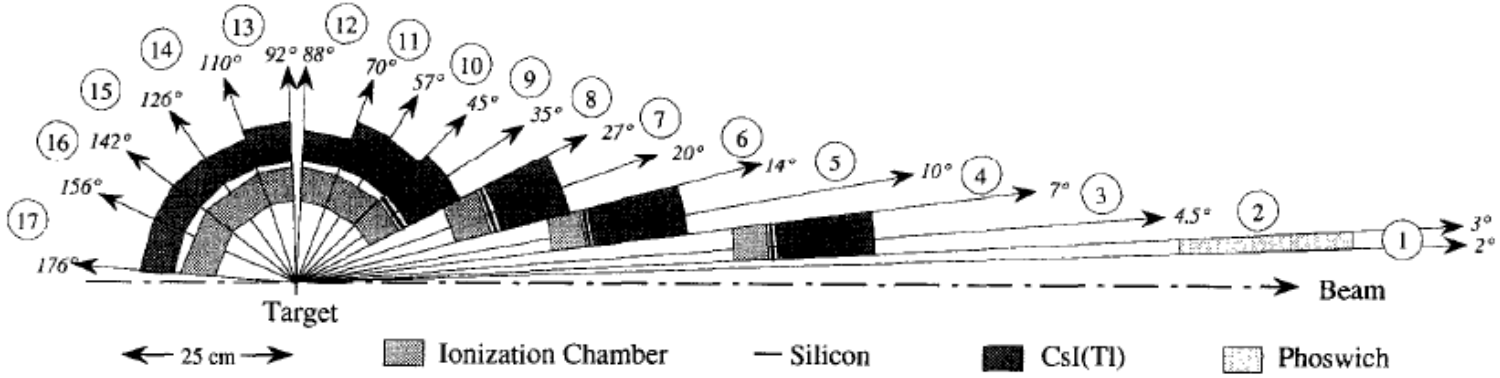


Reaction Systems (35AMeV)

$^{40}Ca + ^{40}Ca$	Symmetric
$^{40}Ca + ^{48}Ca$	Asymmetric
$^{48}Ca + ^{40}Ca$	Asymmetric
$^{48}Ca + ^{48}Ca$	Symmetric

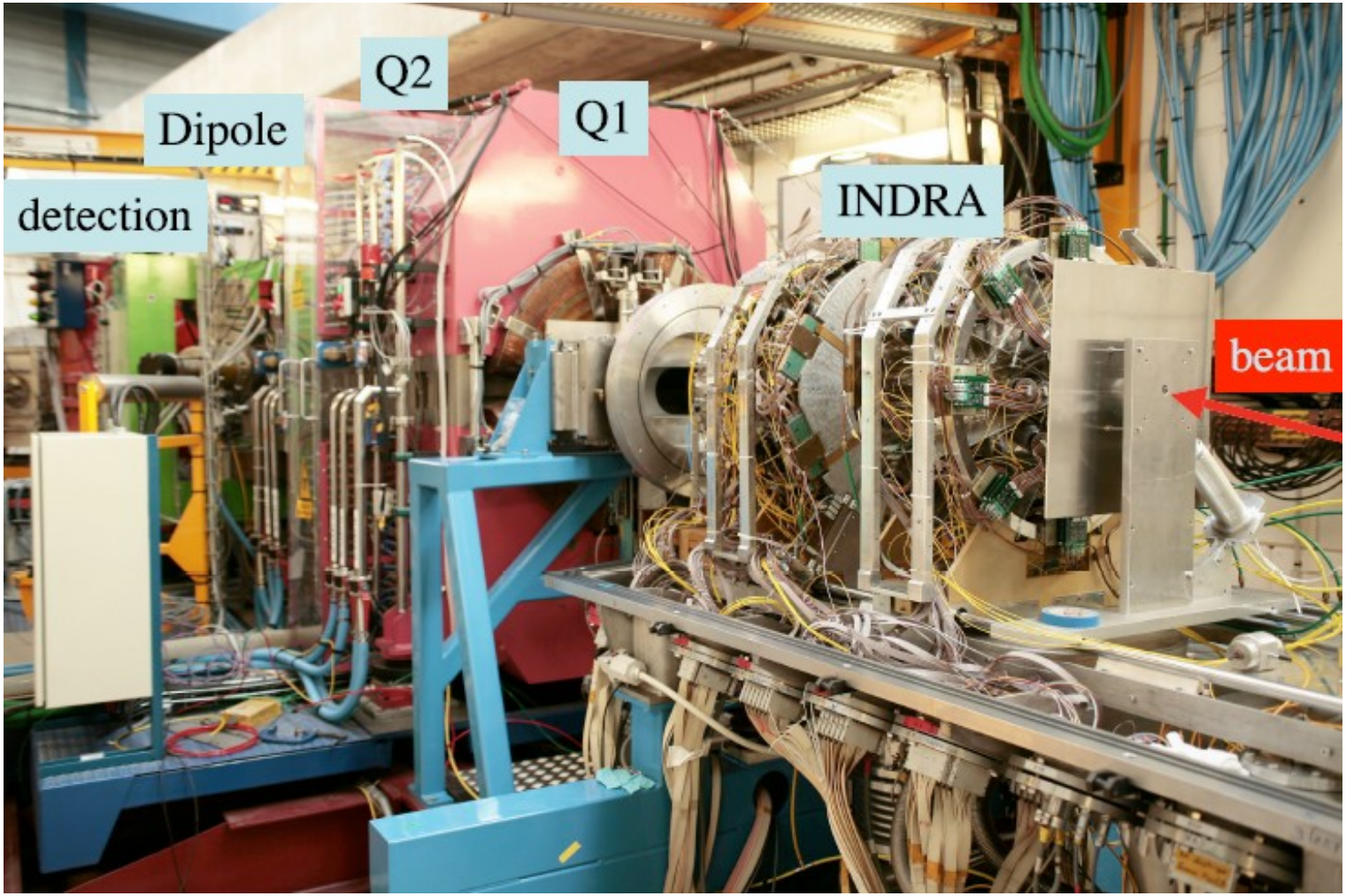
EXPLORING THE SYMMETRY ENERGY WITH ISOSPIN EFFECTS IN HEAVY-ION COLLISIONS
A. CHBIHI et al. (Experiment proposal)

Schematic of INDRA 4π detector



J. POUTHAS et al. NIM A 357 (1995) 418-442

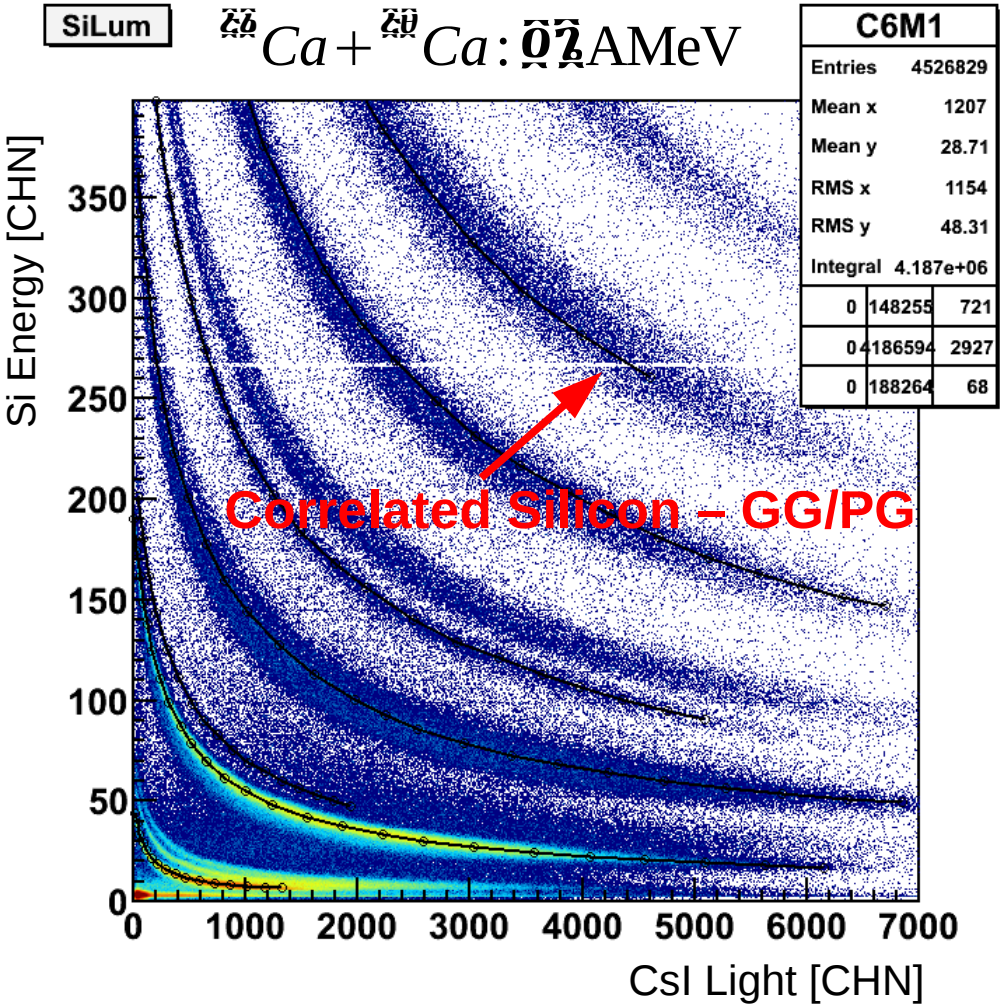
INDRA-VAMOS Experiment

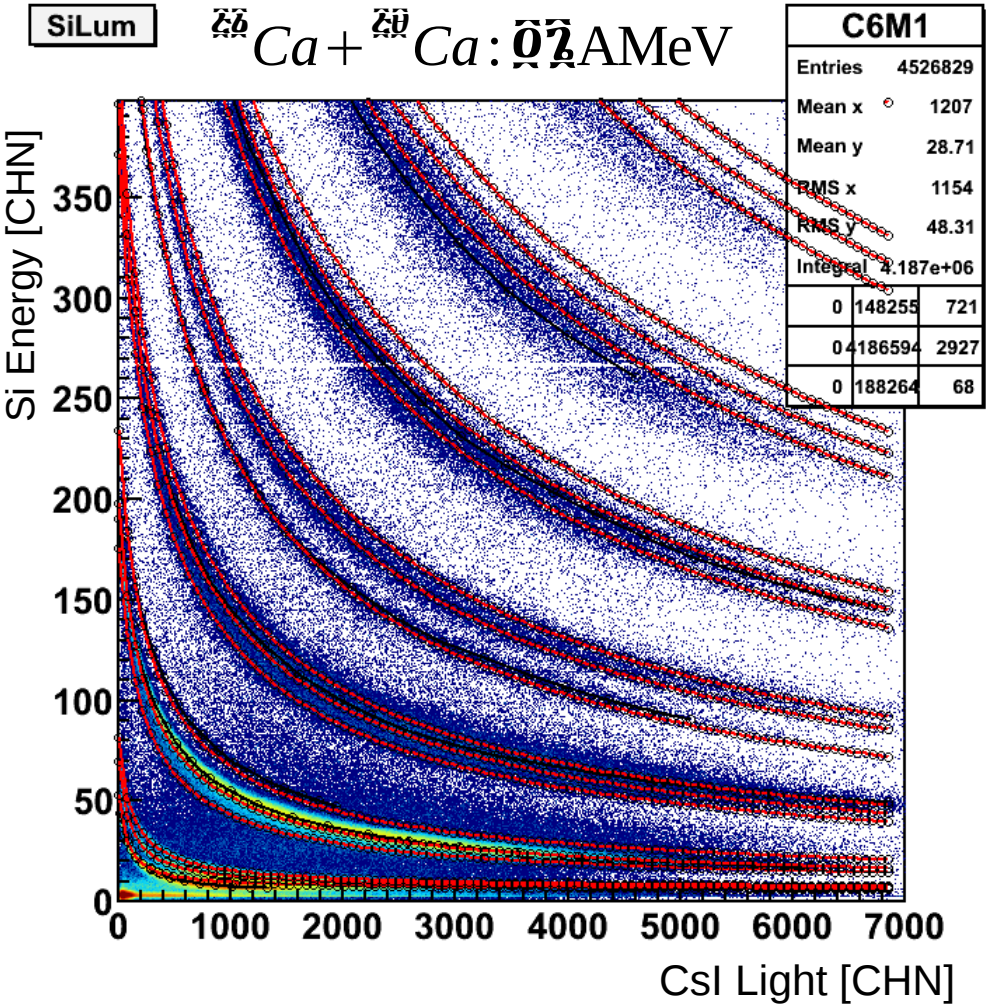


Unique experiment – direct measurement of the Projectile-Like Residue and Light Charged Particles/Intermediate Mass Fragments

Experimental constraints extracted without any assumption on N/Z of the primary fragment or the origin of the detected fragments

Status of Present Analysis – INDRA LCP/IMF Identification



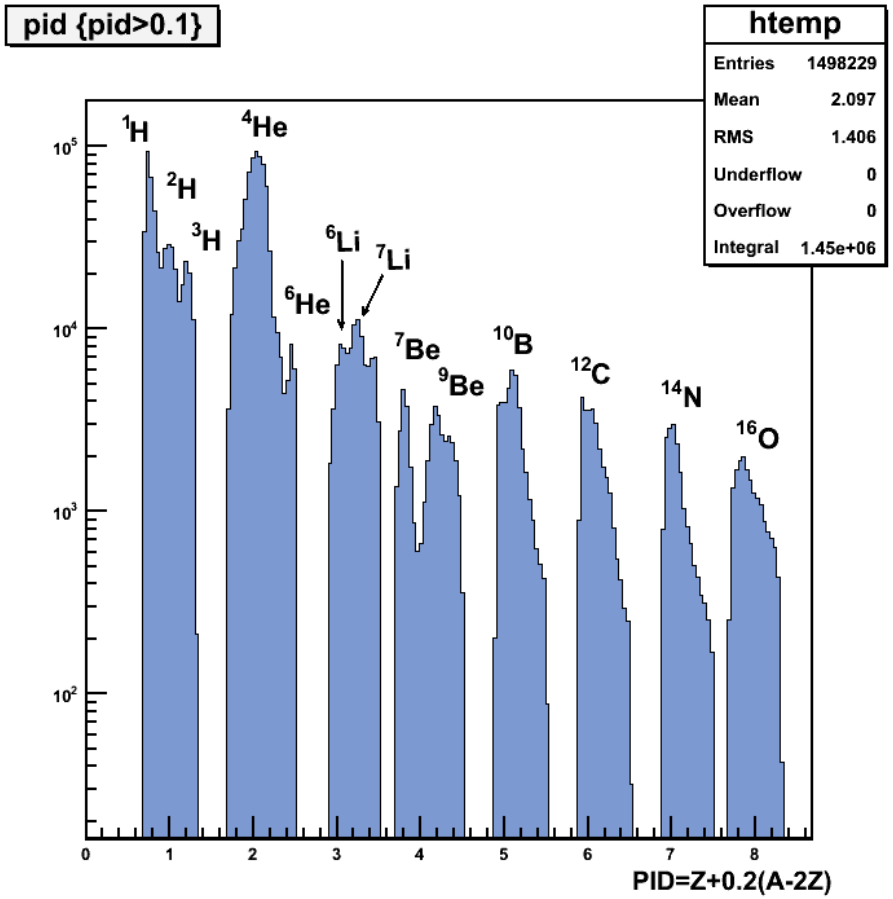


$$\Delta E = \left[(gE)^{\mu+\nu+1} + (\lambda Z^{\alpha} A^{\beta})^{\mu+\nu+1} + \xi Z^2 A^{\mu} (gE)^{\nu}\right]^{\frac{1}{\mu+\nu+1}} - gE$$

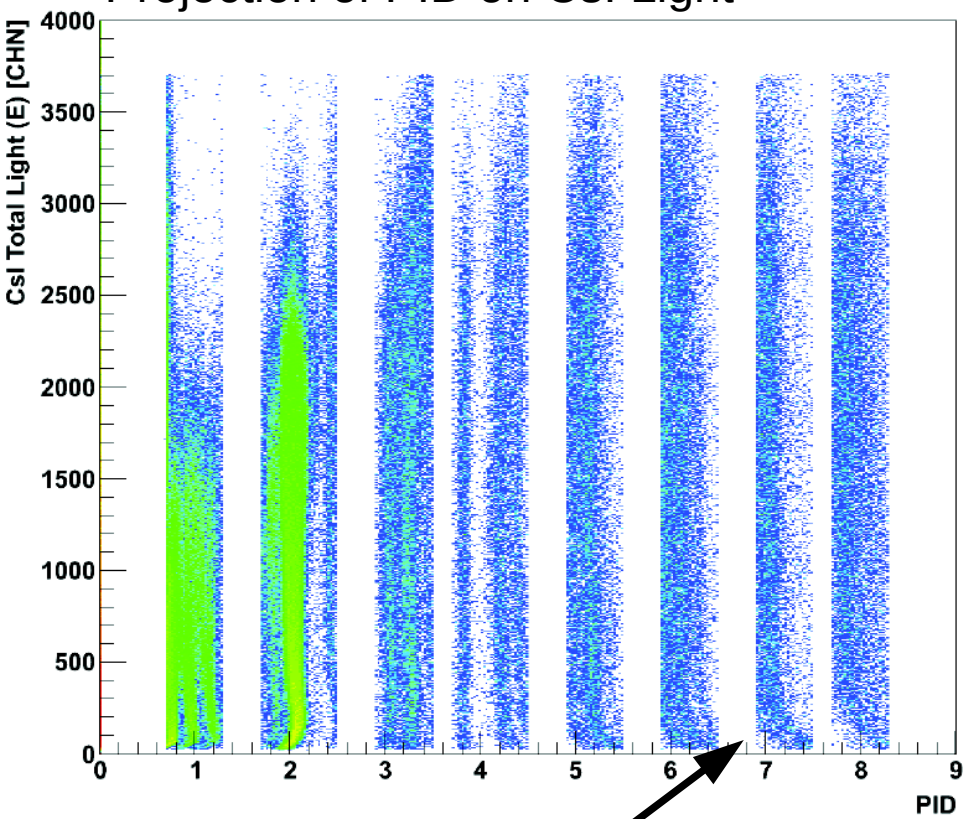
10-Parameter Tassan-Got Fit Functional

Status of Present Analysis – INDRA LCP/IMF Identification

- Isotopic identification up to Be using present T-G fit functional
- Resolution can be improved in the future with modified T-G functional – Proper treatment of CsI light
- Adequate for the present analysis



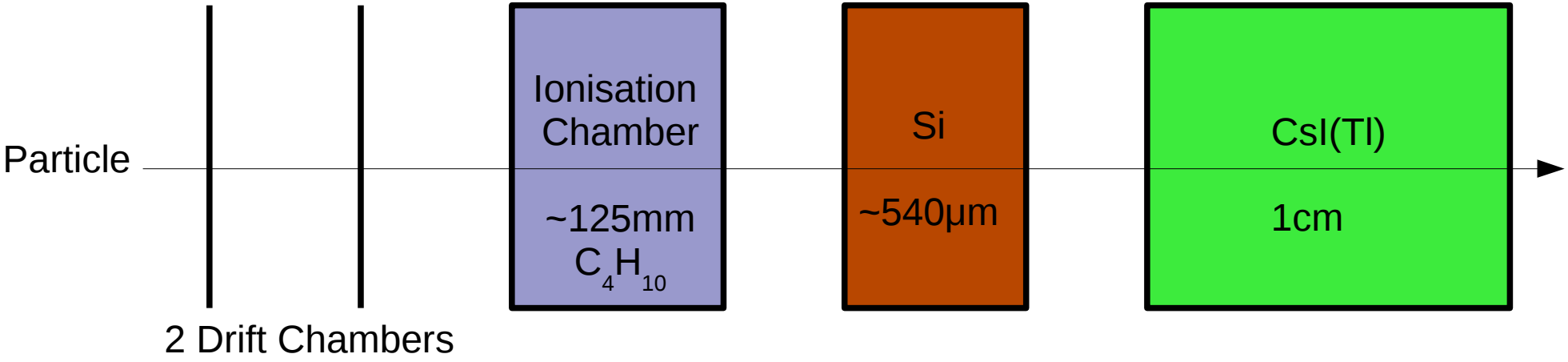
Projection of PID on CsI Light



Curvature at low CsI Light

Status of Present Analysis – VAMOS

Focal Plane Detection System of VAMOS



Simulation written to understand and check the calibration of VAMOS focal plane detectors and allows calibration of the Ionisation Chamber from the Si

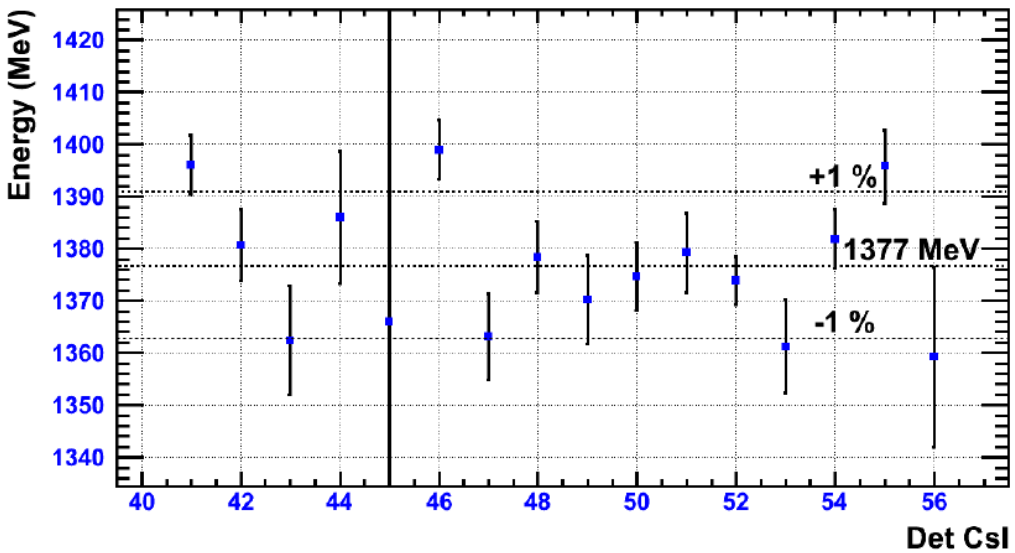
Simulation written using energy loss tables and linking with KaliVeda libraries (J.D. Frankland)

Gives access to simulated information:

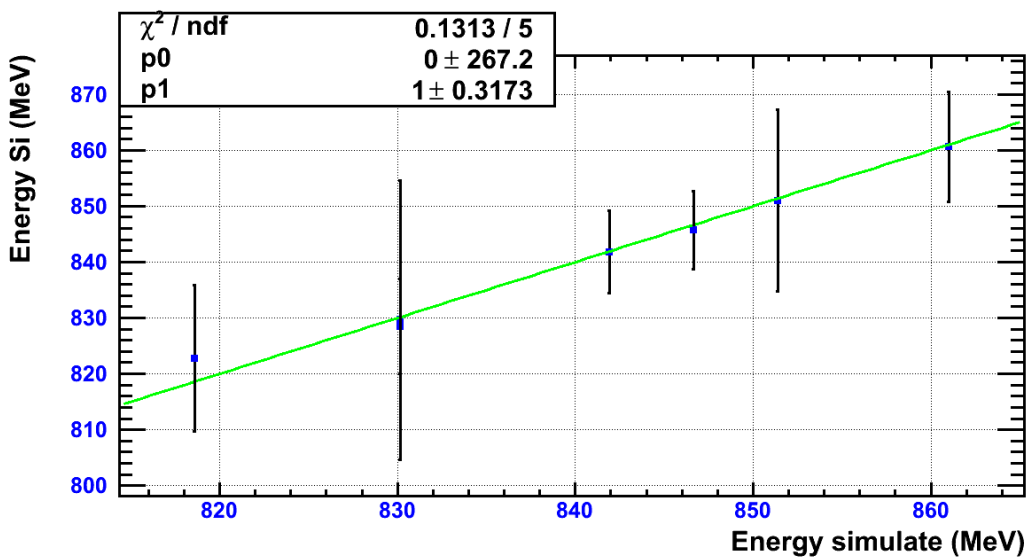
- Energy Loss
- Energy Detected
- TOF
- Velocity

Status of Present Analysis – VAMOS

Total Energy (including dead layers)



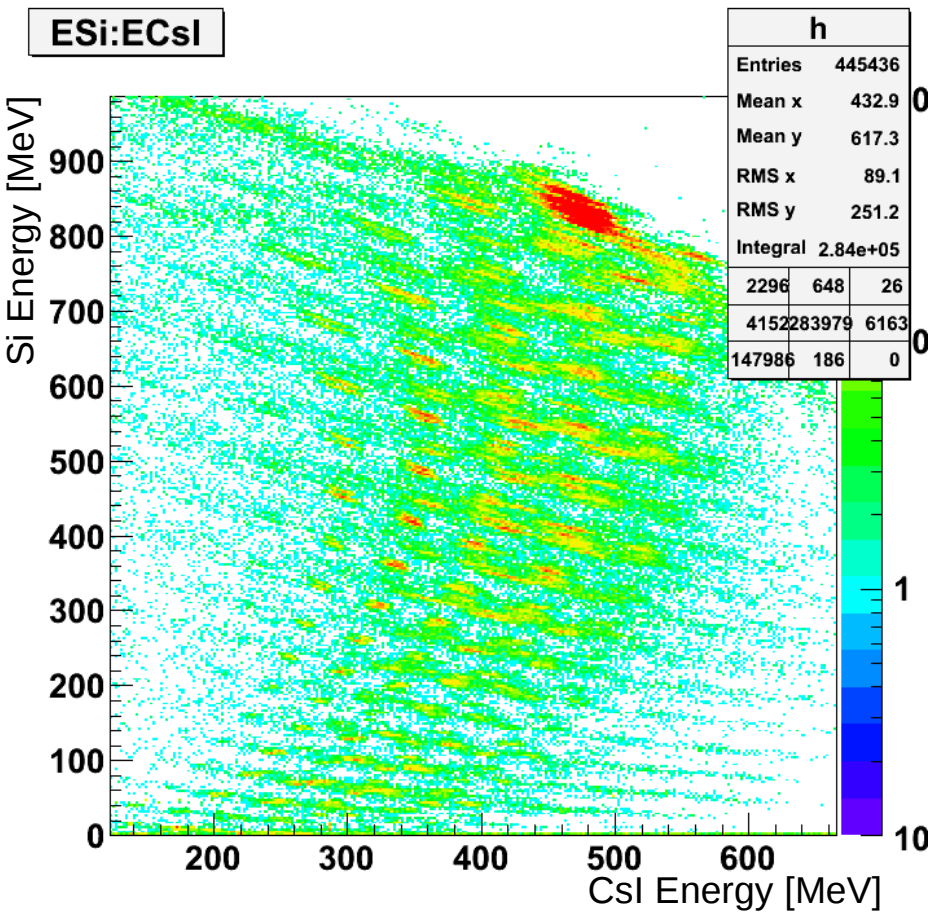
Direct simulation/calibration comparison



Almost complete

Still a few minor problems with the reconstruction in VAMOS

2 possible sets for distances from the target to focal plane elements



Summary

- Previous studies of isospin diffusion have all made assumptions concerning the behaviour of the primary fragments or the origins of the detected particles.

- E503 INDRA-VAMOS experiment is unique in detecting the PLR + LCP/IMF fragments – no assumptions necessary.

- Comparison of isospin transport with the transport codes BUU and QMD will yield further constraints on the symmetry energy at sub-saturation density.

- Will also provide quantitative evidence whether previous assumptions made about the primary fragments are applicable.

- It remains now to merge the INDRA and VAMOS data sets – correlating the events in time – to achieve full phase space coverage.

INDRA-VAMOS Collaboration

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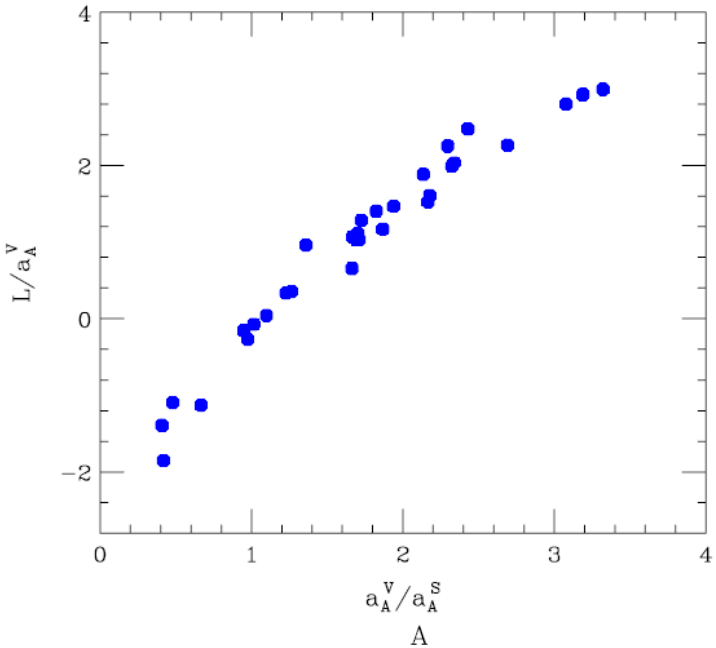
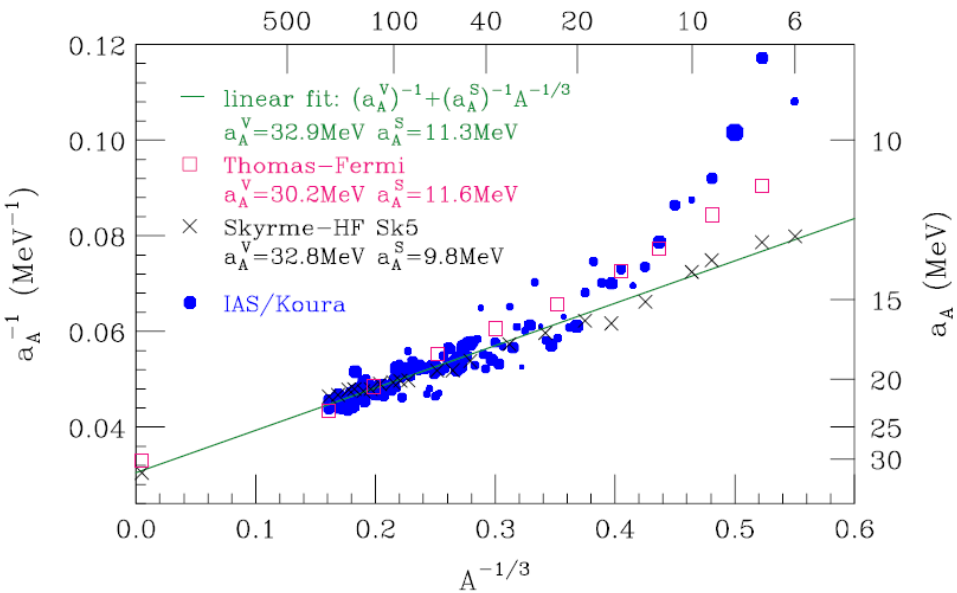
Experimental Observables

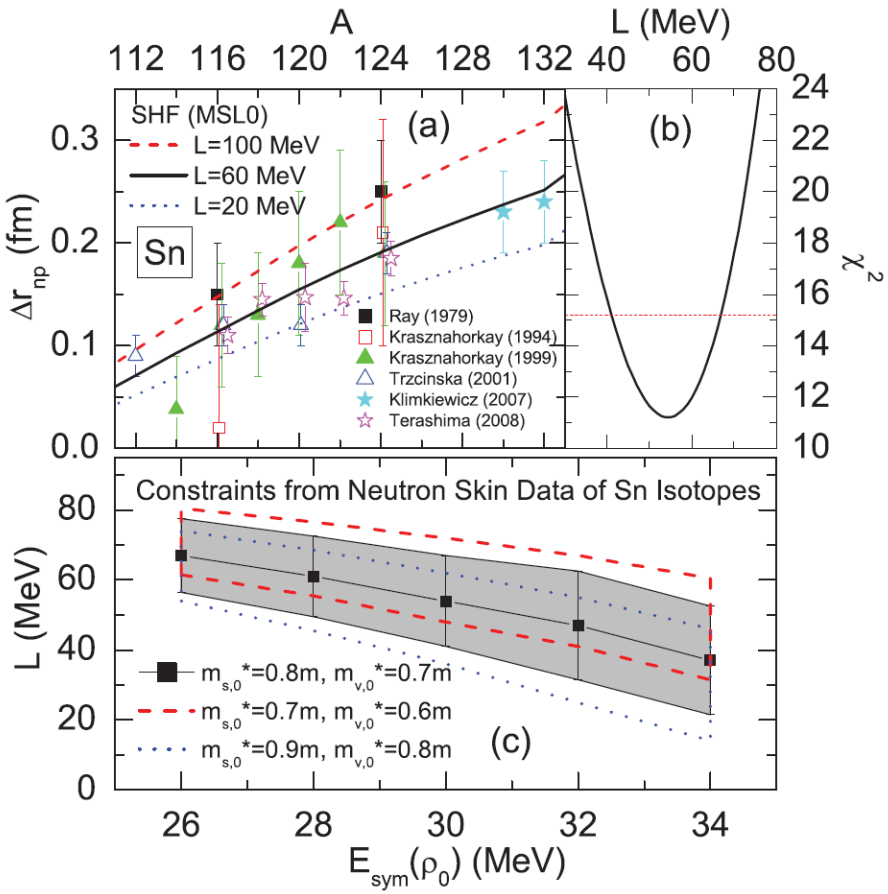
Isobaric Analogue States – L dependence



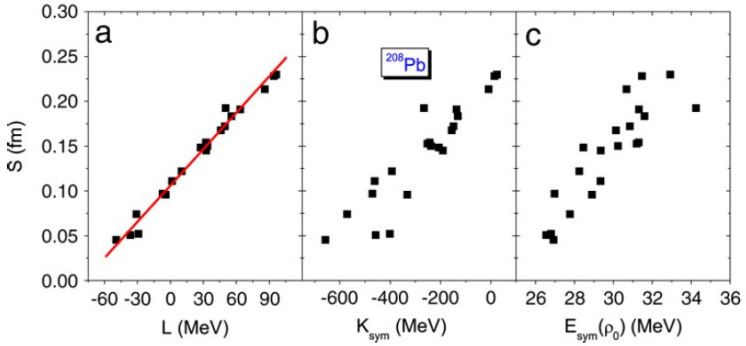


PAWEL DANIELEWICZ AND JENNY LEE
arXiv:0708.2830v1 [nucl-th] 21 Aug 2007

Neutron Skin Thickness



LIE-WEN CHEN et al. PRC 82, 024321 (2010)



L. W. CHEN, C. M. KO AND B. A. Li, PRC 72 (2005) 064309.