Constraining Symmetry Energy with nuclei far from the stability

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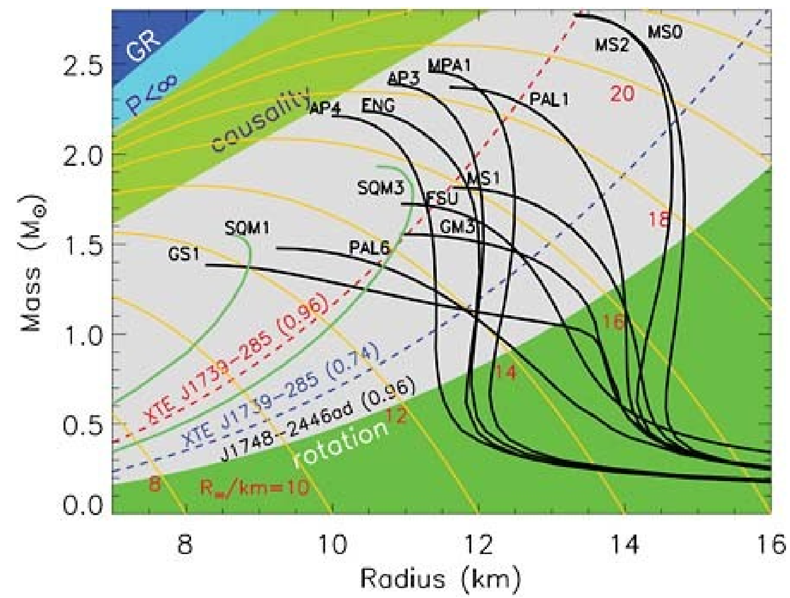
Equation of State

Equation of state for asymmetric nuclear matter:

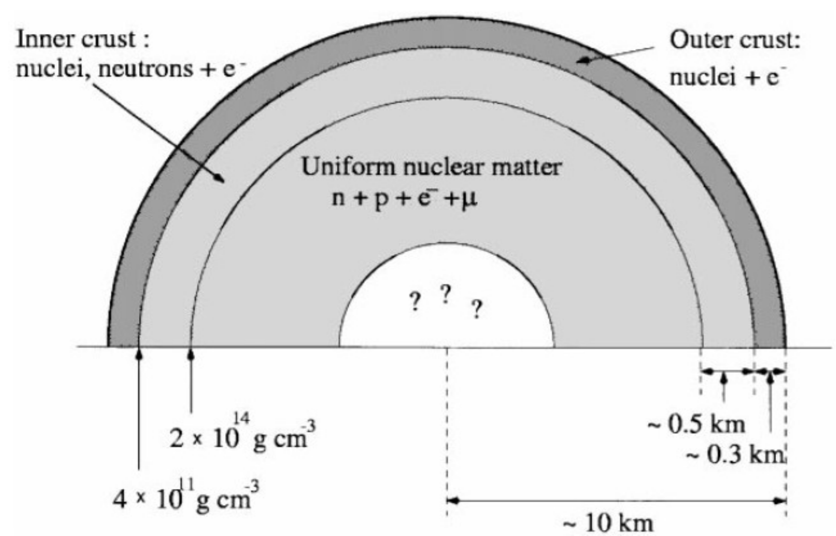
$$E(\rho,\delta)\approx E(\rho,0)+E_{sym}(\rho)\delta^2 \quad \text{with} \quad \delta=\frac{\rho_n-\rho_p}{\rho_n+\rho_p}$$



Determination of an equation of state (EoS) is essential for calculations of neutron star properties:

- Mass-radius relationship
- Crust thickness

Same EoS is required in calculating the energy released in supernova explosions.



Equation of State

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$$E(\rho,\delta) \approx E(\rho,0) + E_{sym}(\rho)\,\delta^2 \quad \text{with} \quad \delta = \frac{\rho_n - \rho_p}{\rho_n + \rho_p}$$

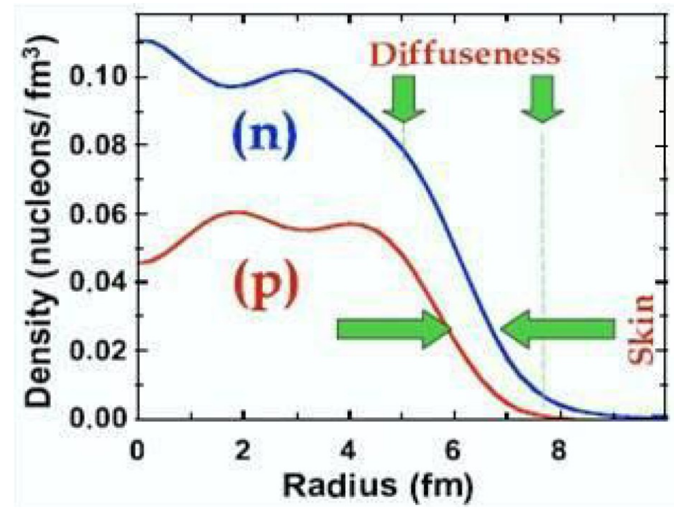
Where the symmetry energy is:

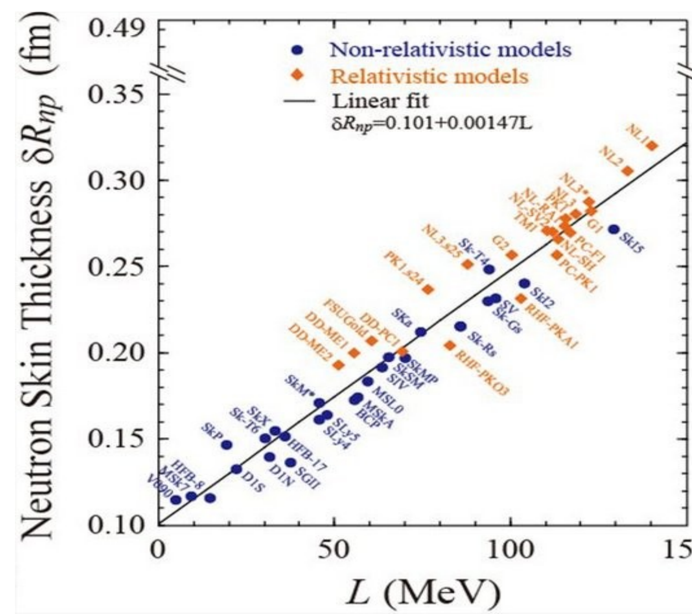
$$E_{sym}(\rho) = E_{sym}(\rho_{sat}) + \frac{L}{3}\left(\frac{\rho-\rho_{sat}}{\rho_{sat}}\right) + \frac{K_{sym}}{18}\left(\frac{\rho-\rho_{sat}}{\rho_{sat}}\right)^2$$

$$E_{sym}(\rho_{sat}) \approx 30\ A\,MeV$$

The first derivative of the EoS:

$$L = 3\,\rho_{sat}\left(\frac{\partial E_{sym}(\rho)}{\partial \rho}\right)_{\rho=\rho_{sat}}$$

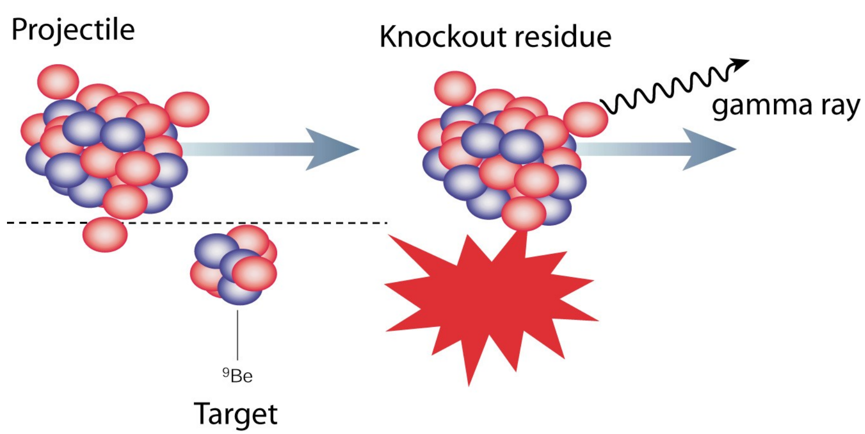


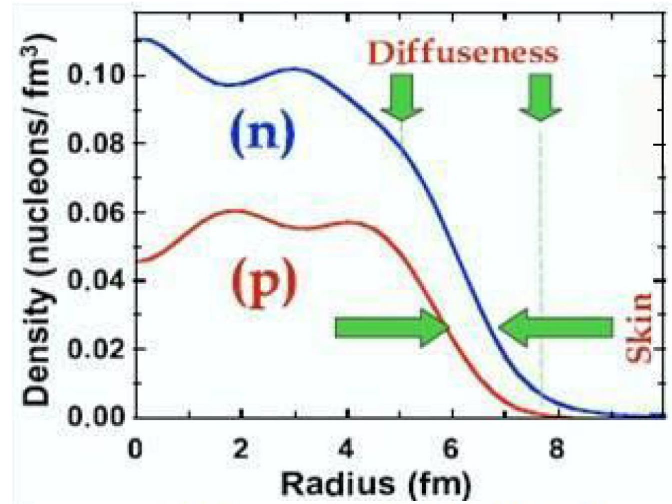


X. Roca-Maza. Phys. Rev. Lett 106 (2011)

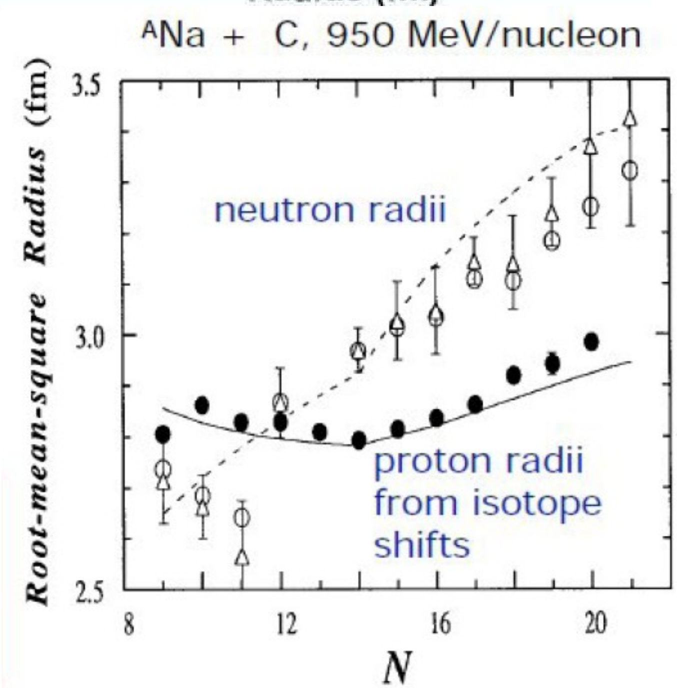
Experimental Procedure

Measuring single-nucleon knockout cross sections, calculations on density distributions:





And interaction cross sections to determine r.m.s matter radius:



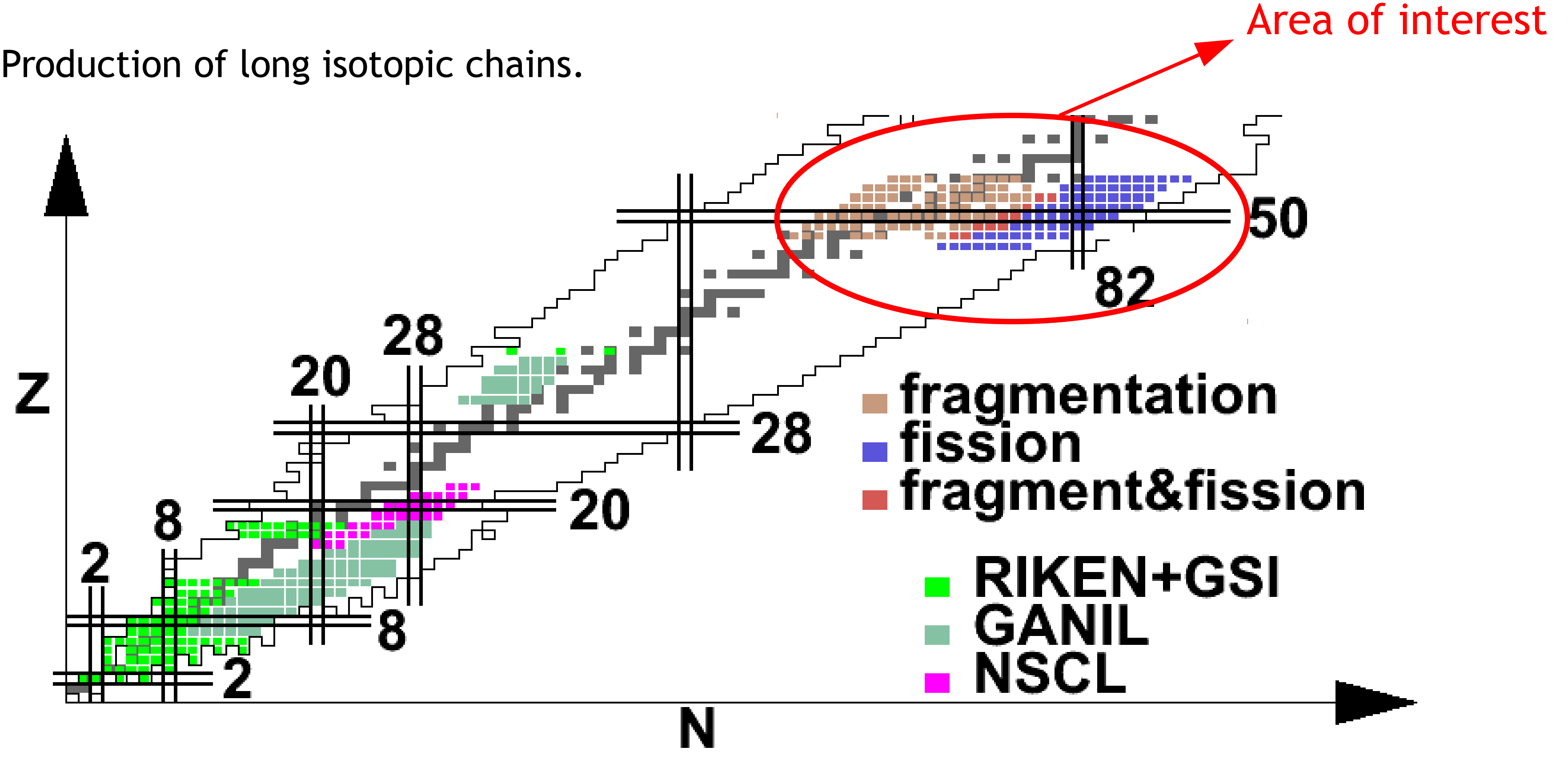
T. Suzuki et al. Phys. Rev. Lett 75 (1995)

Experimental Procedure

Measured with inverse kinematics at relativistic energies.
Two different reaction mechanisms:

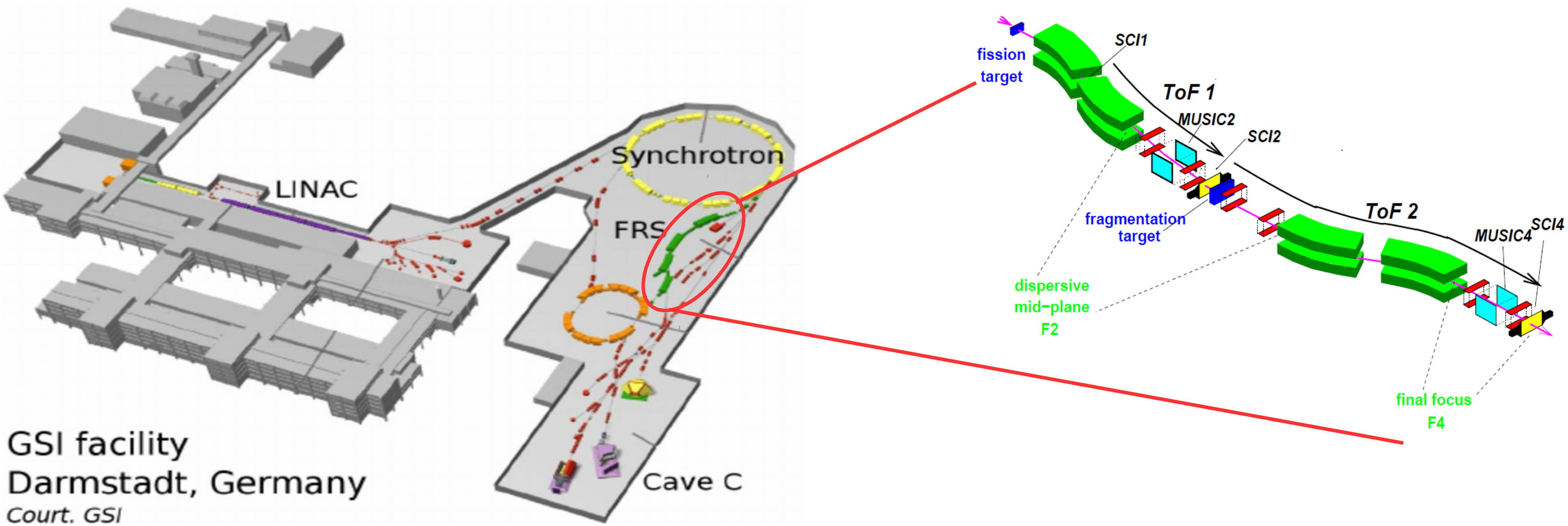
- Fission of ^{238}U
- Fragmentation of ^{132}Xe

Production of long isotopic chains.



Experimental Procedure

- Experiment performed at GSI facility (Germany)



GSI

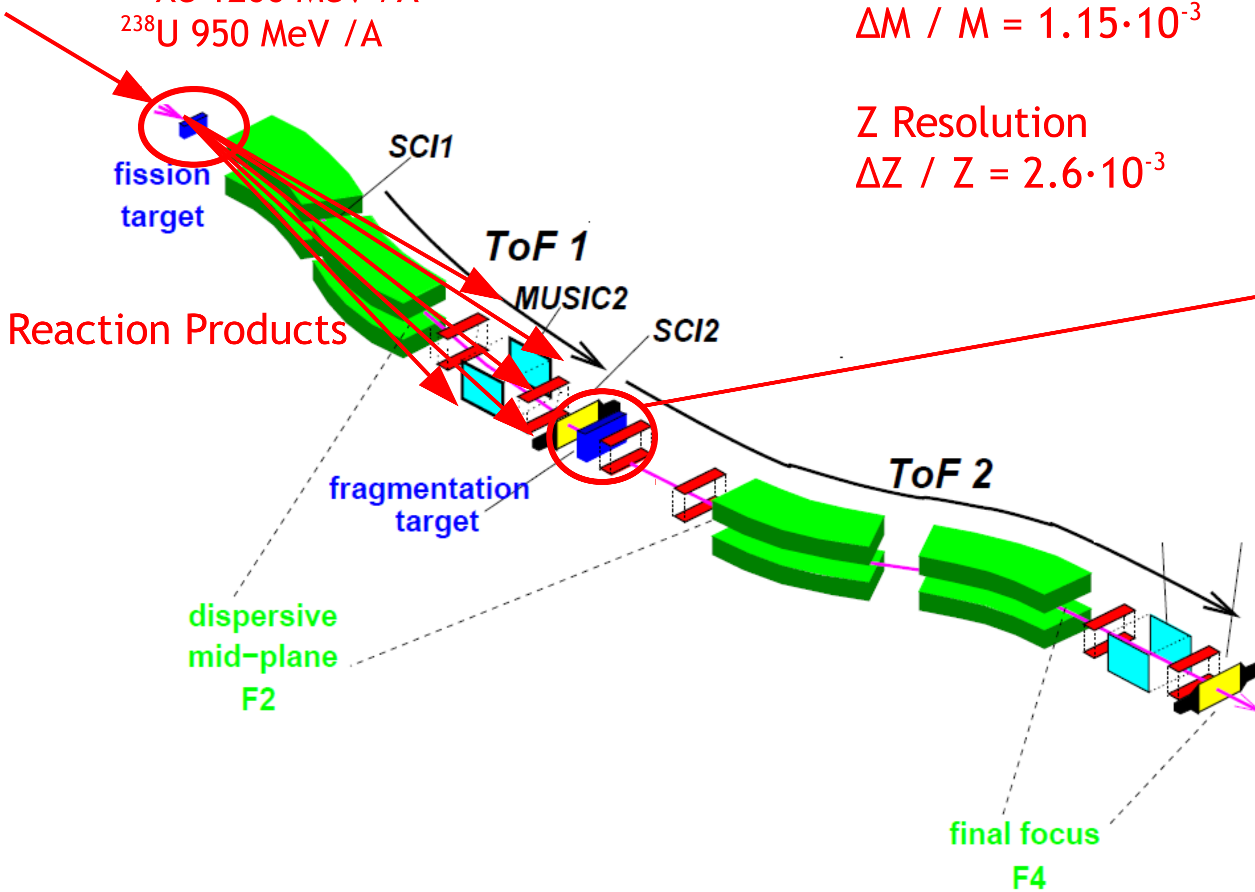
Experimental Procedure

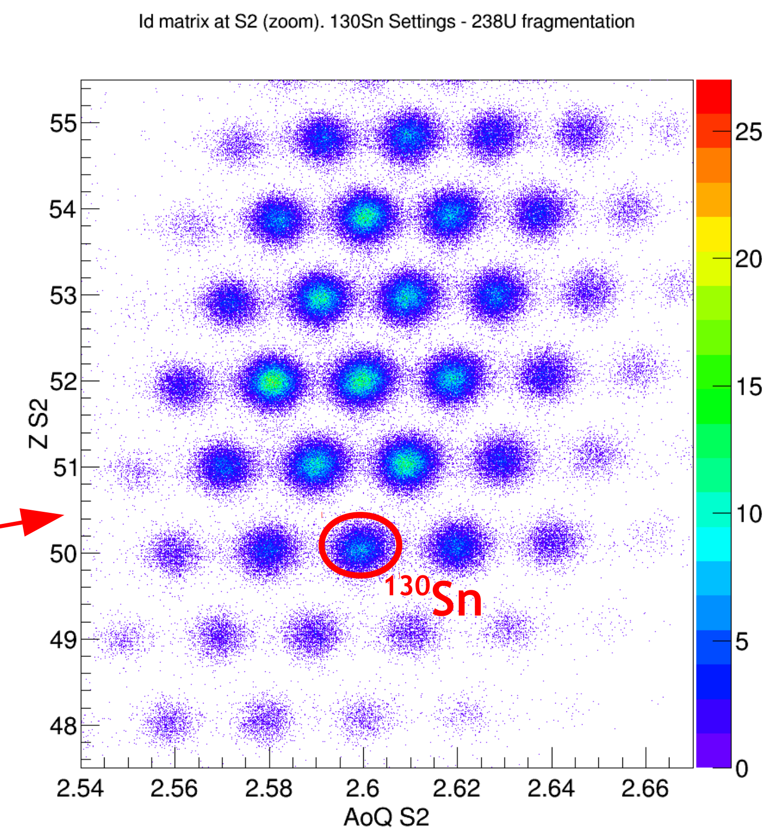
- Experiment performed at GSI facility (Germany)
  - FRS magnetic spectrometer

^{132}Xe 1200 MeV /A
^{238}U 950 MeV /A

Mass Resolution
$\Delta M / M = 1.15 \cdot 10^{-3}$

Z Resolution
$\Delta Z / Z = 2.6 \cdot 10^{-3}$





Identification matrix at S2 focal plane
Before the fragmentation Target

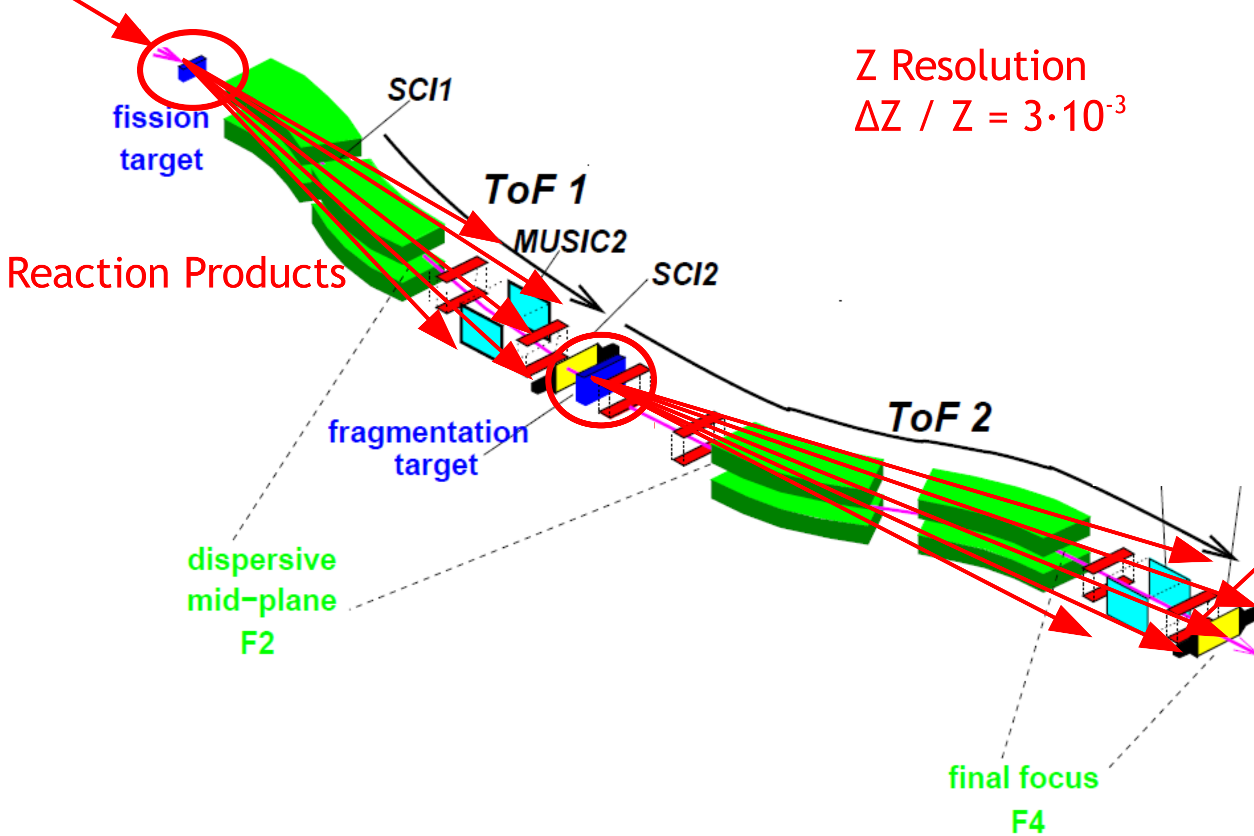
Experimental Procedure

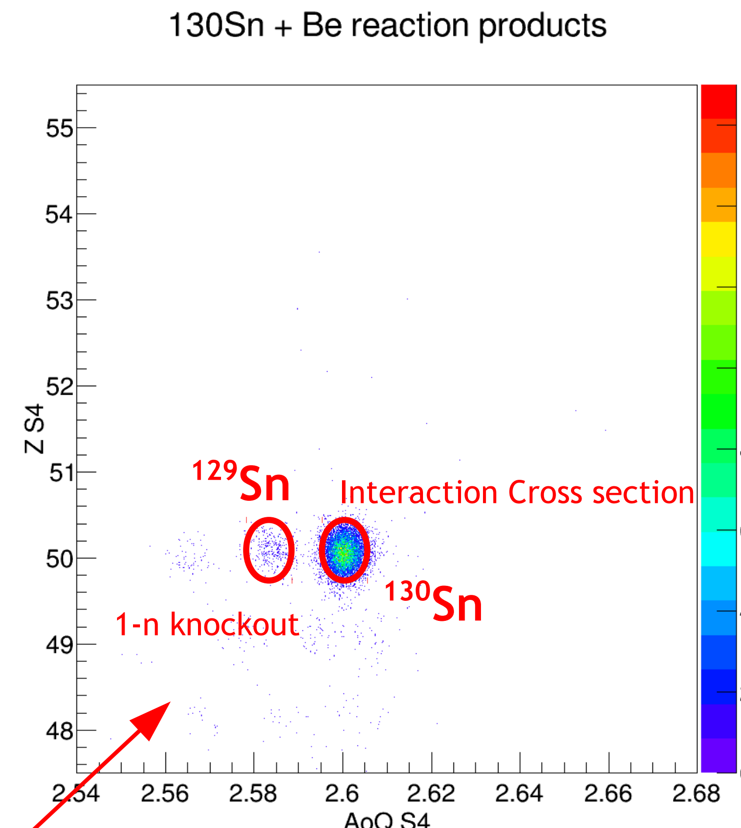
- Experiment performed at GSI facility (Germany)
  - FRS magnetic spectrometer

^{132}Xe 1200 MeV /A
^{238}U 950 MeV /A

Mass Resolution
$\Delta M / M = 7.69 \cdot 10^{-4}$

Z Resolution
$\Delta Z / Z = 3 \cdot 10^{-3}$

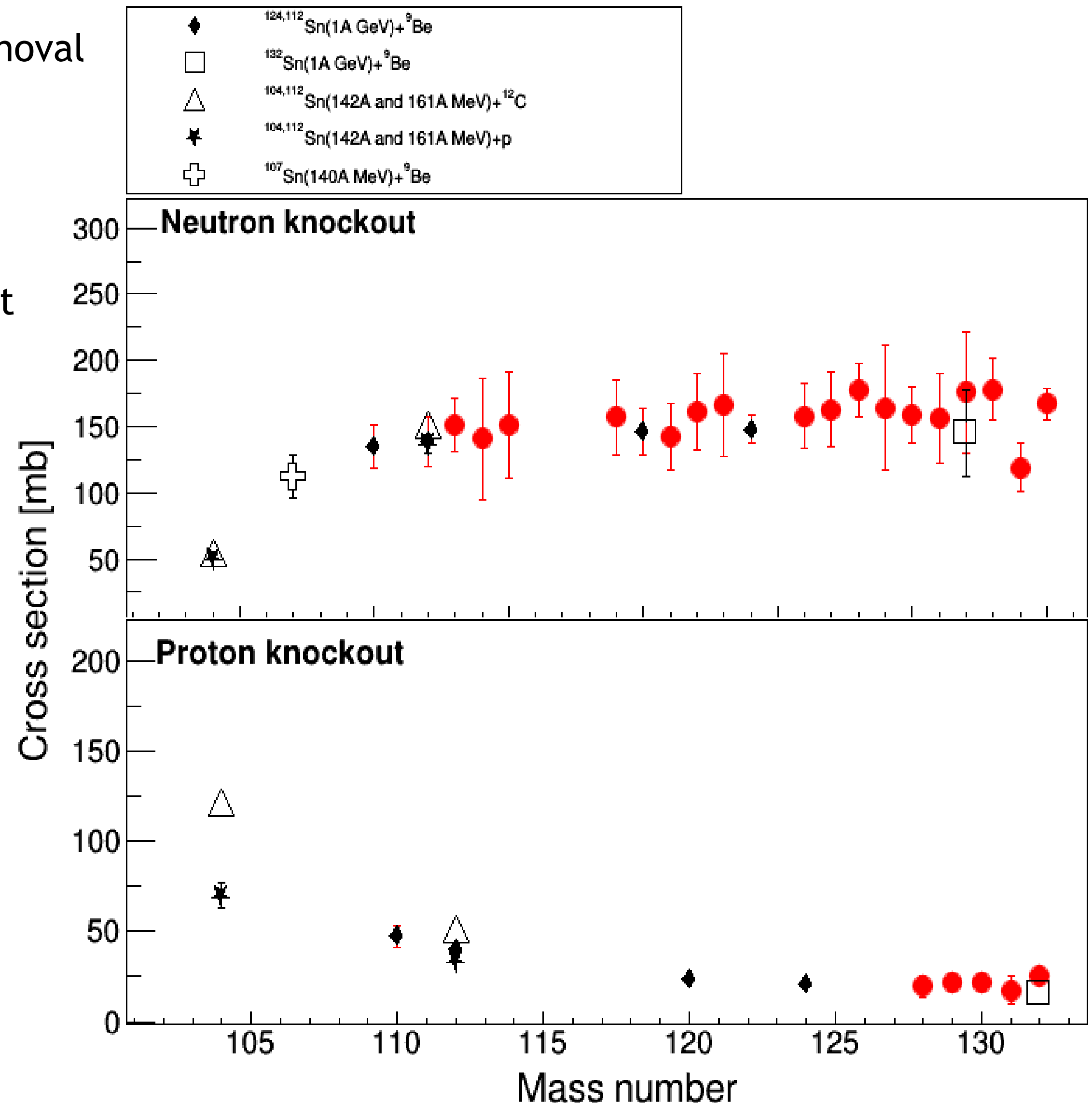




Identification matrix at S4 focal plane

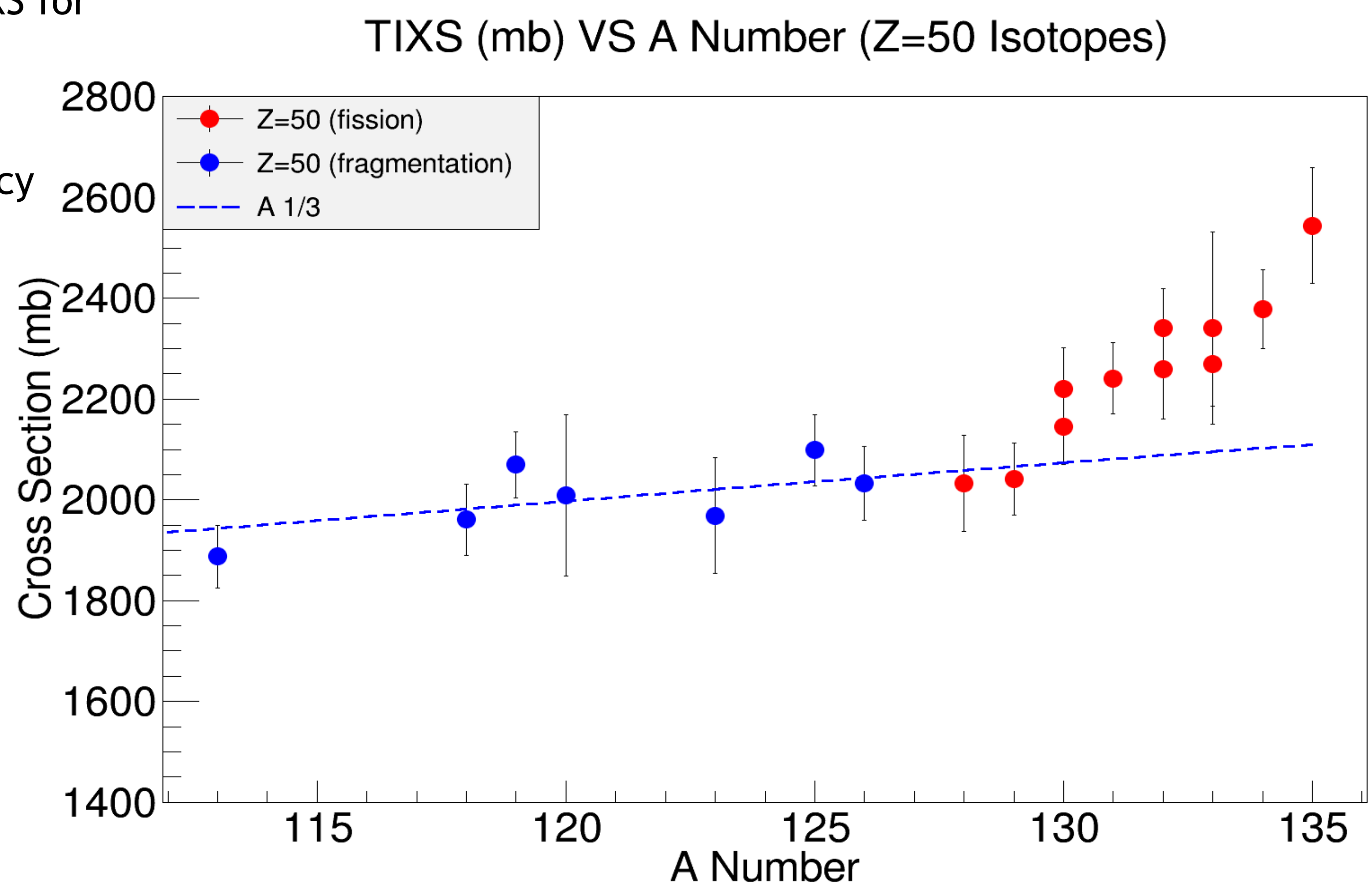
Analysis and results

- First systematic measurement of 1-nucleon removal cross section for Z=50 isotopes
- Two reaction channels measured:
  - 1-neutron removal
  - 1-proton removal
- Neutron knockout channel favored with respect to proton knockout for stable and neutron-rich isotopes.
- Good agreement between our measurements and other experiments.



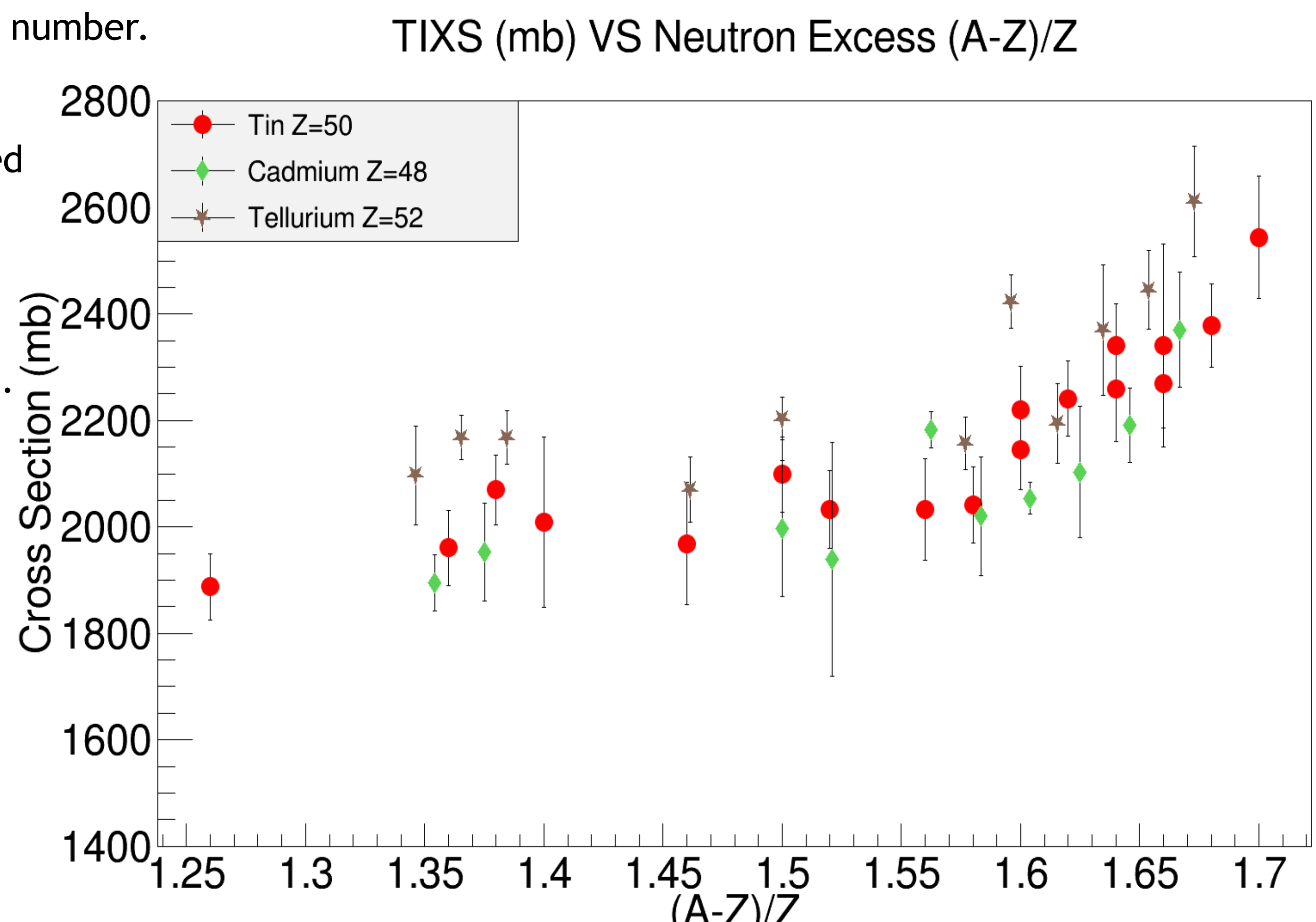
Analysis and results

- Systematic measurement of total interaction cross sections for Z=50 isotopes.
- Ranging from ^{113}Sn to ^{135}Sn.
- Clear enhancement of the XS for most neutron-rich nuclei
- Geometrical expression $A^{1/3}$ fails to describe this tendency
- Possible explanations:
  - Neutron Skin
  - Deformation
  - ...



Analysis and results

- Preliminary measurements for Z =48 and Z=52.
- Same tendency as Sn isotopes.
- Possible dependence with Z number. XS bigger with Z.
- Same enhancement observed when represent TIXS vs neutron excess.
- Calculations being performed at the moment...



Conclusions

- New measurements of knockout and total reaction cross sections of tin isotopes were obtained by using inverse kinematics at relativistic energies.
- Due to the two-reactions mechanism of the experiment, a wide range in isospin is covered. Long isotopic chains are studied ranging from the proton-rich side to the neutron-rich side.
- 1-neutron and 1-proton knockout cross sections were measured and studied.
- Results obtained for the total reaction cross sections show an increase in the value of the experimental results due to the possibility of the existence of a neutron skin.
  More calculations are being performed in order to put some light in this situation.
- Subtracting the thickness of the neutron skin will allow us to constraint the energy symmetry term of the equation of state (EoS).
- Important implications in neutron-stars structure or supernovas explosions.