Charge and matter distributions from isobar charge-exchange reactions

proposal s364
FRS run in June 2011

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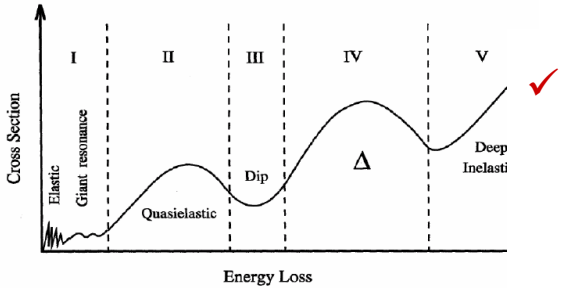
Univ. Santiago de Compostela, GSI, Univ. Giessen

FRS user's meeting, November 2011

Motivation

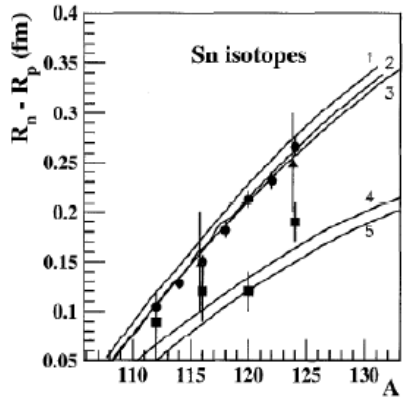
Charge-exchange reactions are governed by the $V_{\sigma\tau}$ term in the nucleon-nucleon interaction so they are particularly interesting for investigating the spin-isopin dependence of the nuclear force. Moreover, some of these excitations have been proven to be sensitive to the radial distributions of protons and neutrons in the nucleus.

Charge-exchange reactions led to spin-isospin excitations in two different energy domains:



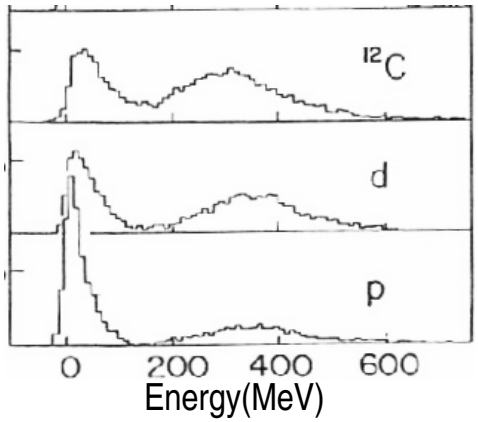
✓ at low energies: particle-hole excitations (Gamow-Teller, spin-dipole, spin- quadrupole or quasi-elastic).

- Gamow-Teller: B_{GT} transition strengths
- spin-dipole: radial distributions of protons and neutrons



A. Krasznahorkay et al. NPA 731 (2004) 224

$^{27}A(^{20}Ne,^{20}Na)$ @ 900 MeV/u



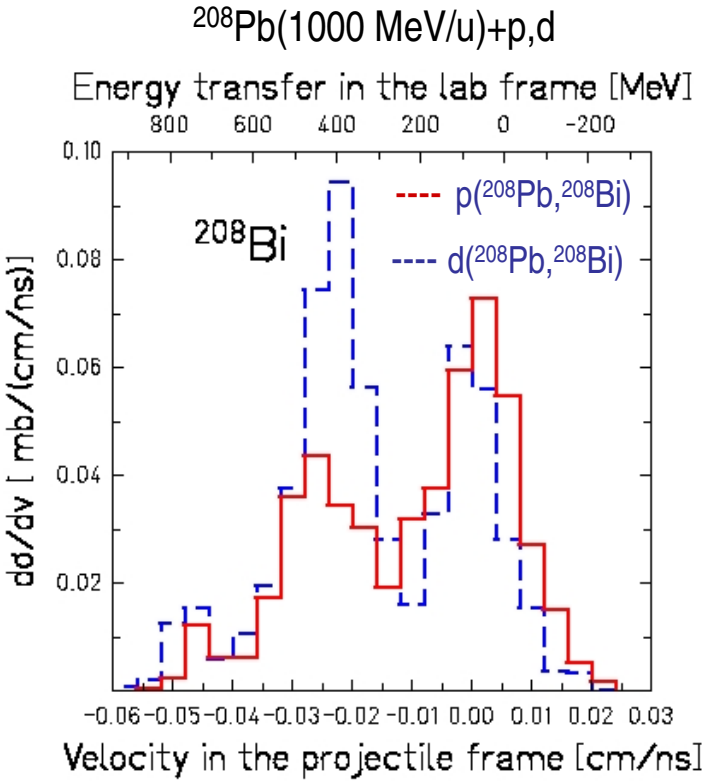
C. Bachelier et al. PLB 172 (1986) 23

✓ at high energies: excitation of a nucleon into a Δ resonance

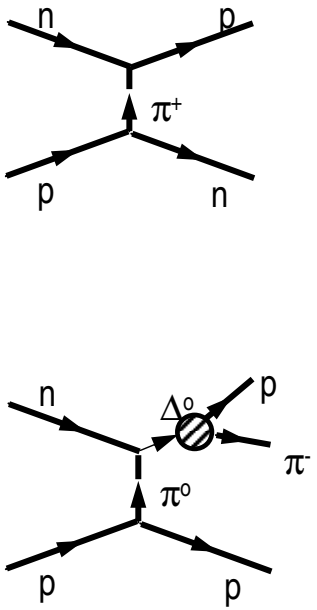
- In-medium effects manifest as a downward shift of the Δ-peak position when excited in nuclei .

Motivation

The FRS has proven to have the sufficient resolving power to disentangle quasi-elastic and Δ-resonant charge exchange reactions in peripheral heavy ion collisions at relativistic energies.

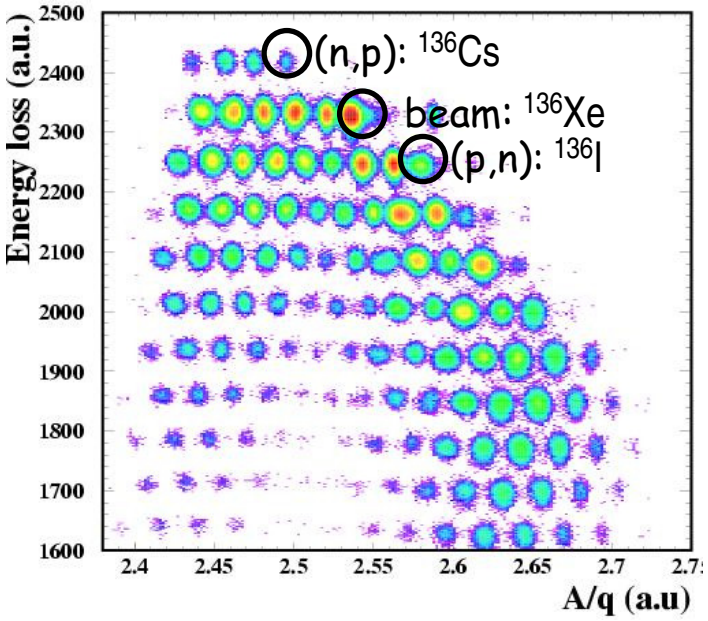


A. Kelic et al., Phys. Rev. C 70 (2004) 64608

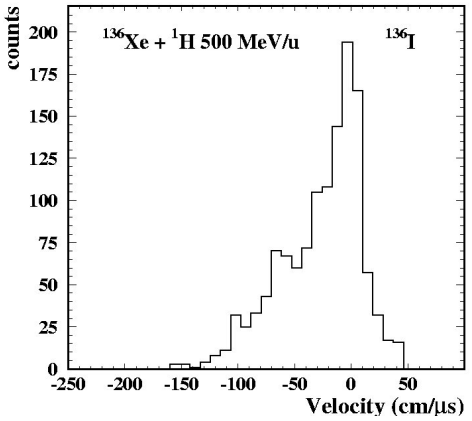


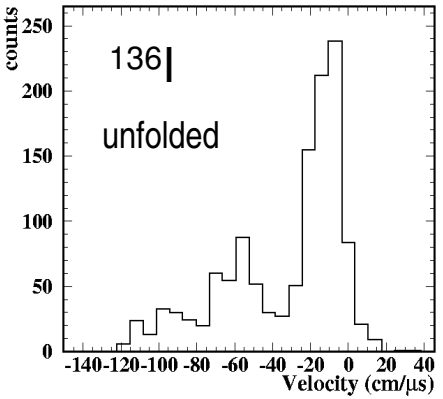
Motivation

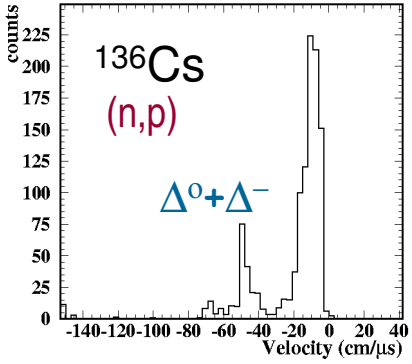
Isotopic identification: ^{136}Xe+Be

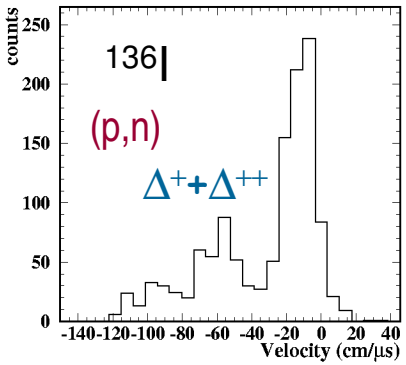


Momentum distributions of projectile residues



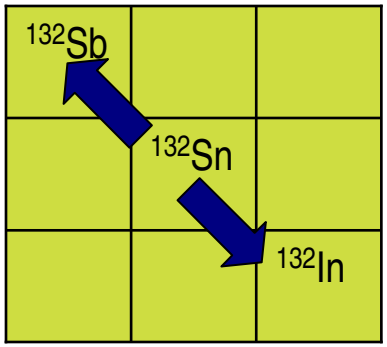






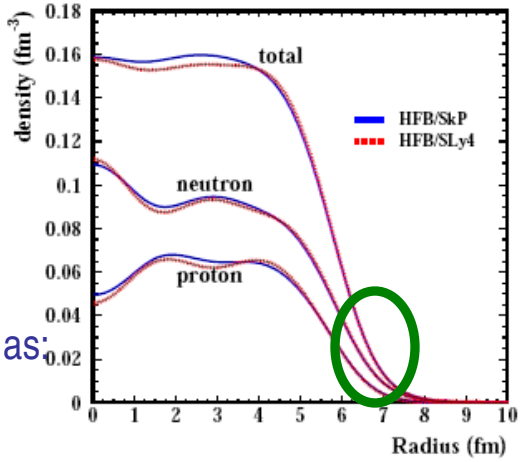
Proposal

To investigate the isospin dependence of spin-isospin excitations at low and high momentum transfer for both isobar charge-exchange channels (p,n) and (n,p) using relativistic exotic projectiles.



✓ Radial distributions of neutron and protons. (Δ-resonant channel)

- isobar charge-exchange: peripheral collisions
- isobar (n,p) reactions: only projectile neutrons involved n-n or n-p
  → proving projectil ρ_n
- isobar (p,n) reactions: only projectile protons involved p-n or p-p
  → proving projectile ρ_p
- Δ-resonance as a pion source: scattered pions as a probe



The charge-exchange cross sections can be obtained in the eikonal approximation as:

$$\sigma = 2\pi \int_0^\infty bP(b)db \qquad P(b) \propto \frac{1}{v_a^2} T(b) \sum_{m_a,m_b} \left| \langle \Psi_a | V_{\sigma\tau} | \Psi_b \rangle \right|^2$$

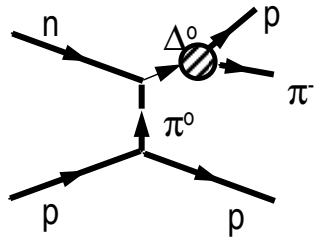
S. Das et al. PRC 66 (2002) 014604

Matrix elements from real pion-nucleon scattering

$$\sum_{m_a,m_b} \left| \langle \Psi_a | V_{\sigma\tau} | \Psi_b \rangle \right|^2 \propto \left\langle \left| \Gamma_{\pi ab}(q^2) \right|^2 \right\rangle \left| G_\pi(q^2) \right|^2 \frac{|q|}{\pi} \sigma_\pi(q)$$

and the transparency

$$T(b) = \exp\left\{ -\sigma_{NN} \int_{-\infty}^{\infty} dz \int \rho_P(r) \rho_T(R+r) d^3r \right\} \quad R = (b,z)$$



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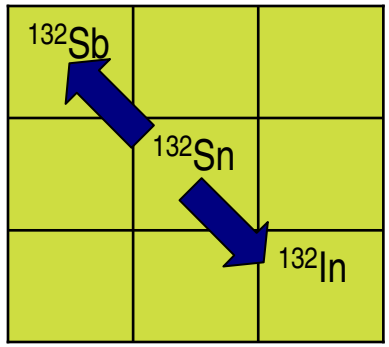
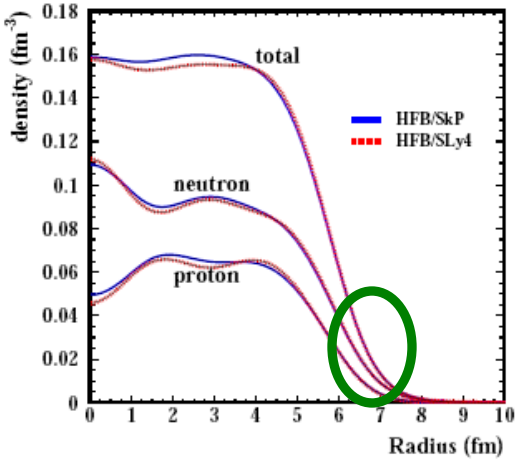


✓ Radial distributions of neutron and protons. (Δ-resonant channel)



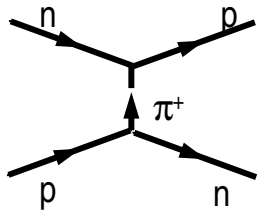
✓ Gamow-Teller transition strengths (quasi-elastic channel)

- the proportionality between the charge exchange cross section at 0 degrees and the GT strength is stablished

$$P_{\pi,\rho}(b) \propto \frac{1}{v_a^2} T(b) \sum_{m_a,m_b} \left| \langle \Psi_a | V_{\sigma\tau} | \Psi_b \rangle \right|^2$$

C.A. Bertulani et al. NPA 674 (2000) 527

$$\sum_{m_a,m_b} \left| \langle \Psi_a | V_{\sigma\tau} | \Psi_b \rangle \right|^2 \propto B_{GT}(P \to P') B_{GT}(T \to T') \sum_{\nu} |H(\nu, b)|^2$$



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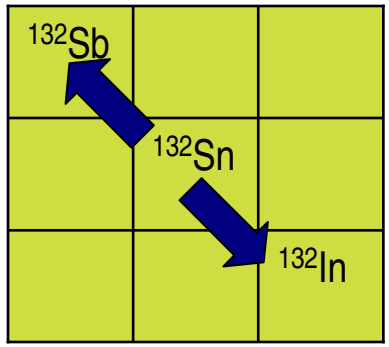
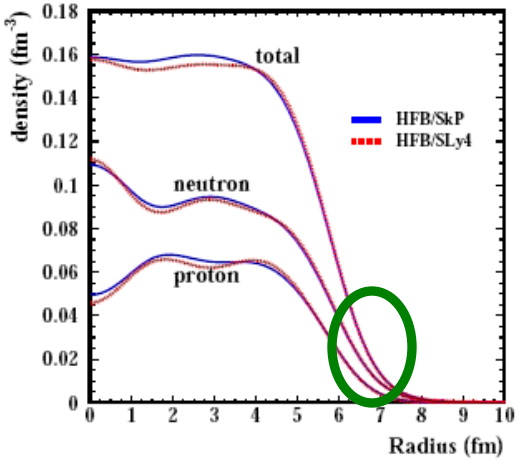


✓ Radial distributions of neutron and protons. (Δ-resonant channel)

✓ Gamow-Teller transition strengths (quasi-elastic channel)

✓ In-medium properties of the Δ-resonance in isospin asymmetric nuclear matter. (mean energy and width of the Δ-resonance)

- Δ-resonance excitation in nuclei far from stability
- isovector component in the self-energy



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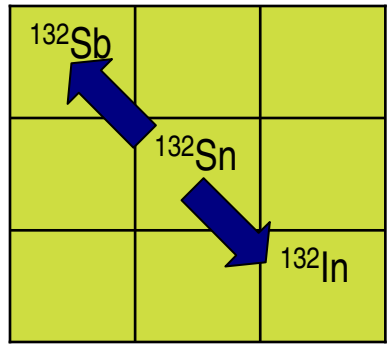
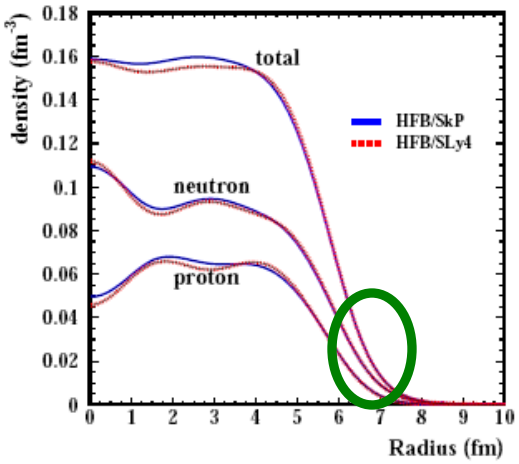




✓ Radial distributions of neutron and protons. (Δ-resonant channel)

✓ Gamow-Teller transition strengths (quasi-elastic channel)

✓ In-medium properties of the Δ-resonance in isospin asymmetric nuclear matter. (mean energy and width of the Δ-resonance)

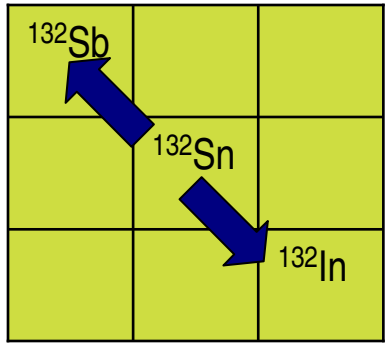
✓ Density dependence of the in-medium nucleon-nucleon cross section.

- for nuclei with known radial distributions
- key parameter in transport calculations used for investigating the symmetry energy using heavy-ion collisions.

Experimental requirements

Quasi-elastic and Δ-resonant isobar charge exchange reactions, (p,n) and (n,p), in isospin asymmetric nuclear matter:

- ✓ relativistic heavy-ion collisions induced by exotic projectiles (isospin asymmetry and radial dependence)
- ✓ isobar charge-exchange (clean reaction channel)



Observables:

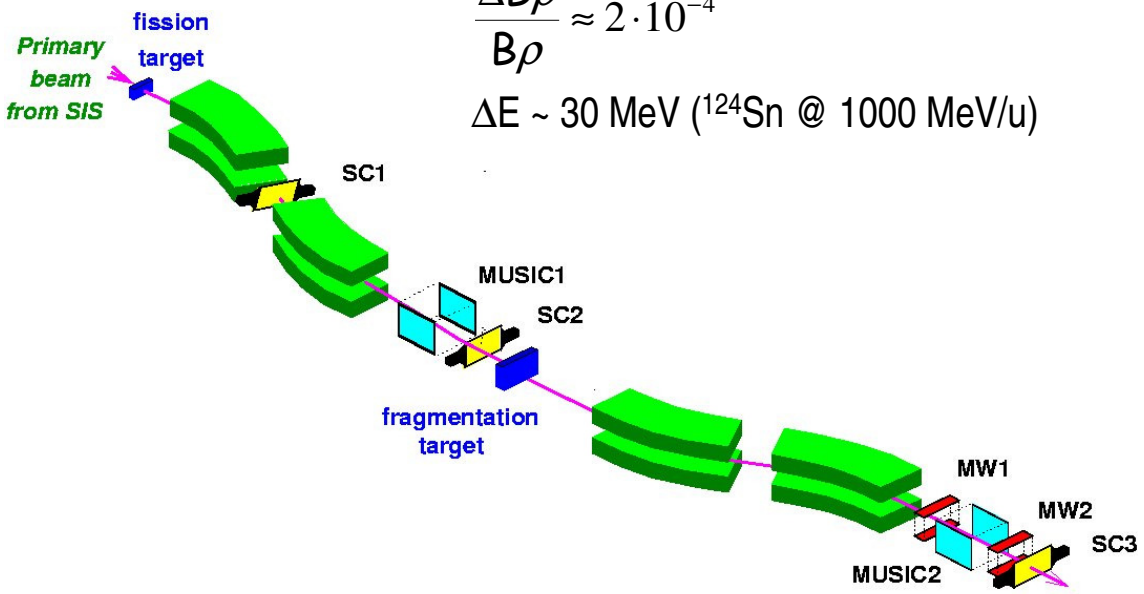
- ✓ cross sections for both charge exchange reactions and channels
- ✓ mean energy and width of the Δ-resonance

Requirements for the setup:

- ✓ isotopic identification of relativistic projectile residues
- ✓ separation of elastic and resonant charge-exchange channels
  - magnetic analysis of projectile residues

Experimental setup

Δ-resonance and quasi-elastic charge exchange reactions identified at the FRS:
(standar detection setup)



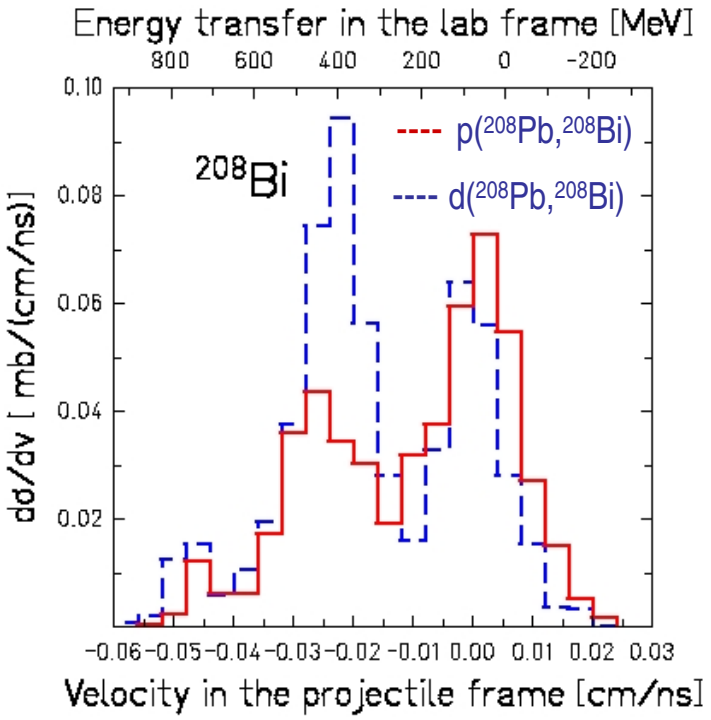
$$\frac{\Delta B\rho}{B\rho} \approx 2 \cdot 10^{-4}$$

ΔE ~ 30 MeV (^{124}Sn @ 1000 MeV/u)

ΔZ/Z ~ 7 10^{-3}

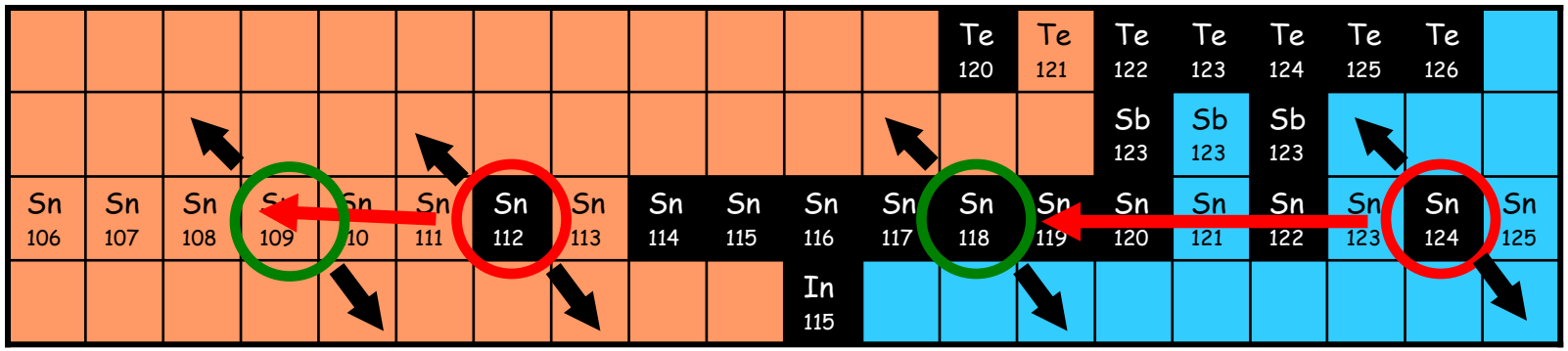
ΔA/A ~ 2.4 10^{-3}

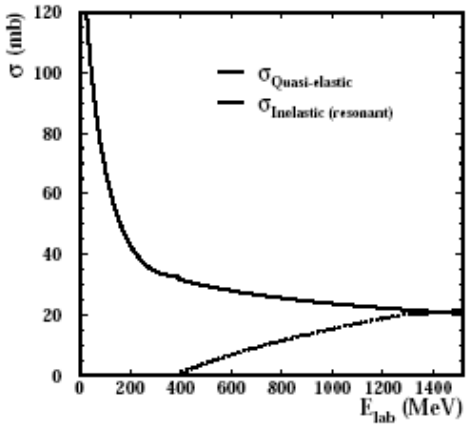
^{208}Pb(1000 MeV/u)+p,d



A. Kelic et al., Phys. Rev. C 70 (2004) 64608

Measurements

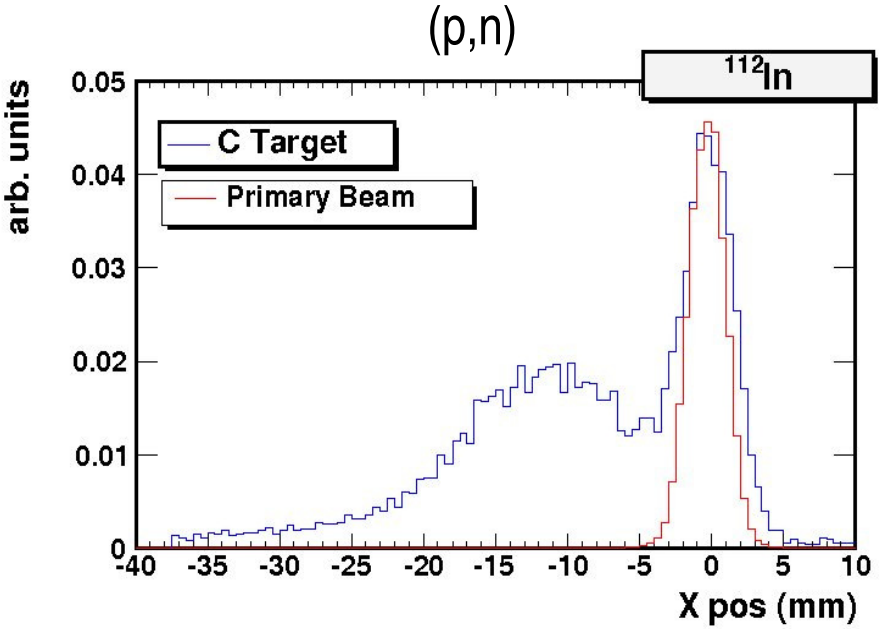


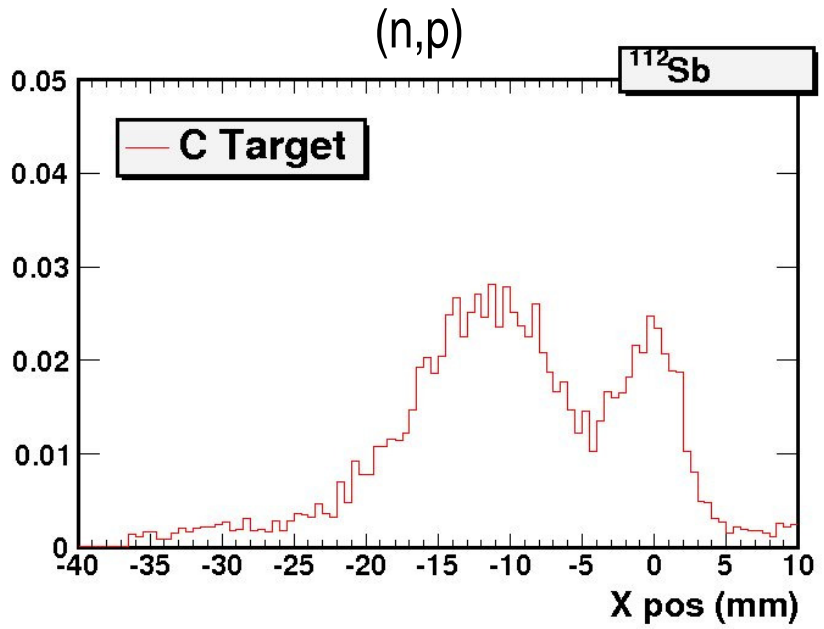


Reactions investigated:

- ✓ $^{124}Sn+CH_2,C \rightarrow {}^{124}Sb,{}^{124}In$ @ 1000 A MeV
- ✓ $^{124}Sn+Be \rightarrow {}^{118}Sn+CH_2,C \rightarrow {}^{118}Sb,{}^{118}In$ @ 1000 A MeV
- ✓ $^{112}Sn+CH_2,C,Cu,Pb \rightarrow {}^{118}Sb,{}^{118}In$ @ 400, 700, 1000 A MeV
- ✓ $^{112}Sn+Be \rightarrow {}^{109}Sn+CH_2,C \rightarrow {}^{109}Sb,{}^{109}In$ @ 1000 A MeV

Preliminary results





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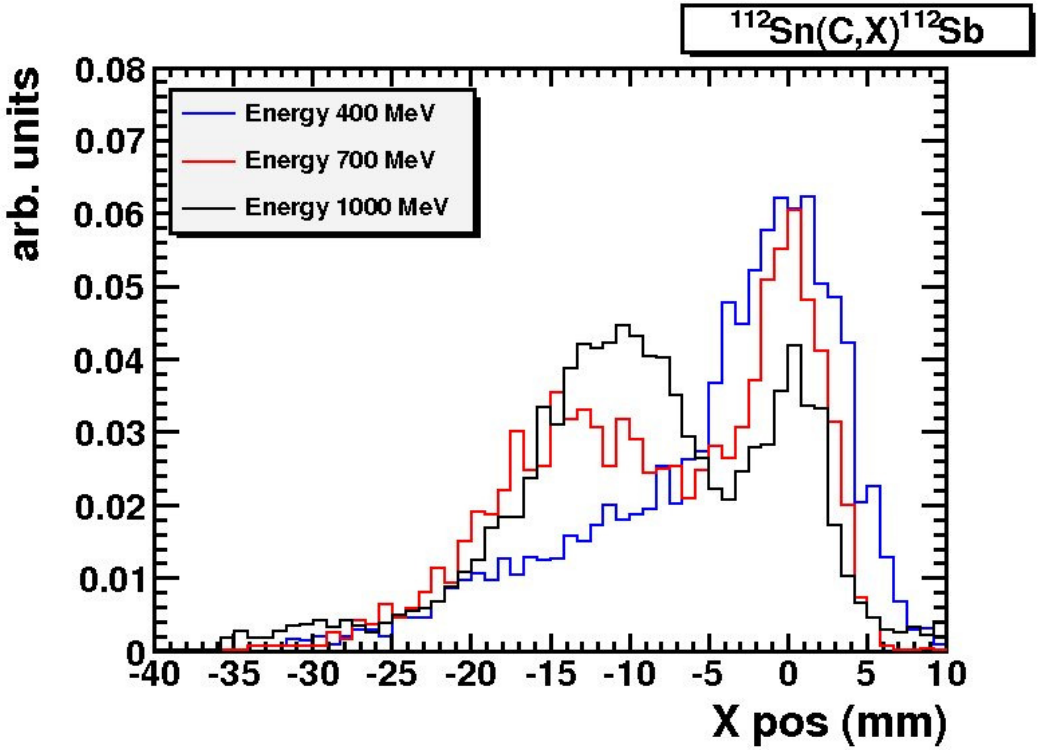

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