FAIRNESS

28 May - 3 June 2017

Excitation of baryon resonances in isobaric charge-exchange reactions of heavy-exotic nuclei

JOSÉ LUIS RODRÍGUEZ SÁNCHEZ

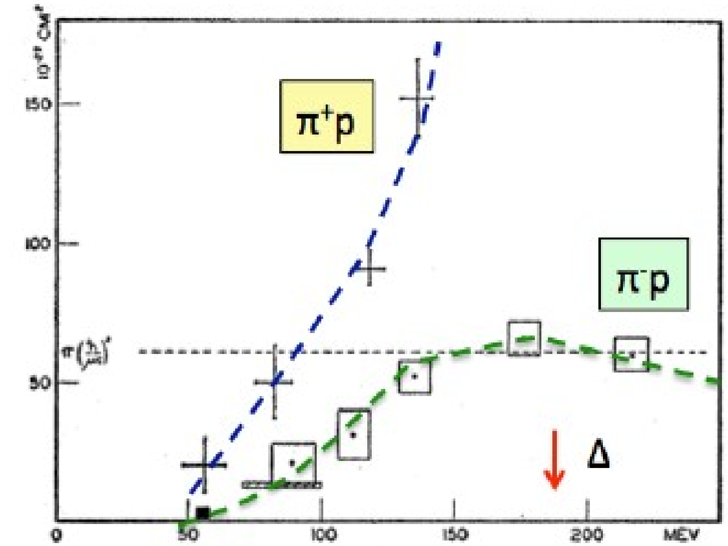
IRFU, CEA, Université Paris-Saclay, France

Layout

- ✗ Production of baryonic resonances
- ✗ Isobar charge-exchange reactions: a tool to investigate the excitation of baryon resonances
- ✗ Measurements carried out at the fragment separator FRS @ GSI
- ✗ Results and comparison with model calculations
- ✗ Future perspectives at FAIR

In 1952 Fermi et al. observed the Δ (1232) for first time in πp scattering

Phys. Rev. 85, 932 (1952)



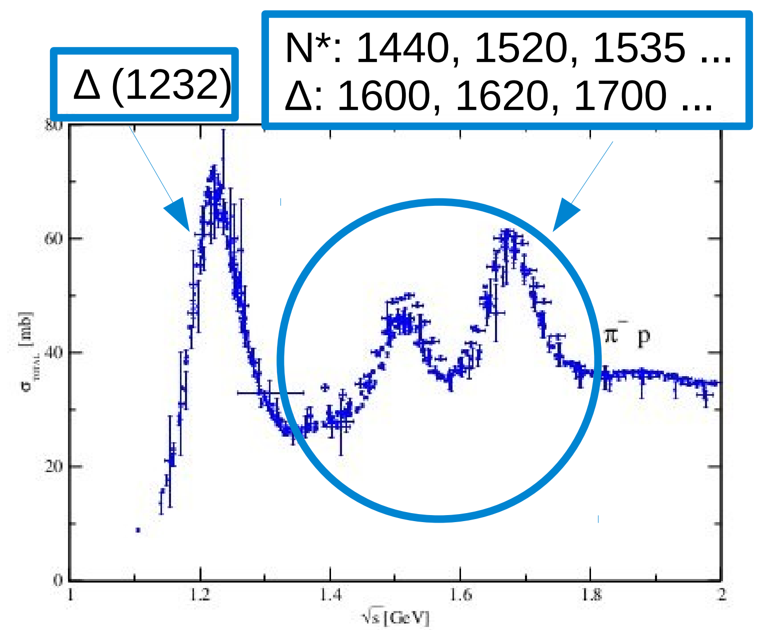
Since them many nucleon resonances have been discovered in

> πN elastic scattering

> πN --> ηN, σN, ωN, ΛK, ΣK, πΔ ... reactions

> Electroproduction γN

> Complex processes like πN --> ππN, πρN



Is the study of baryonic resonances still interesting ?

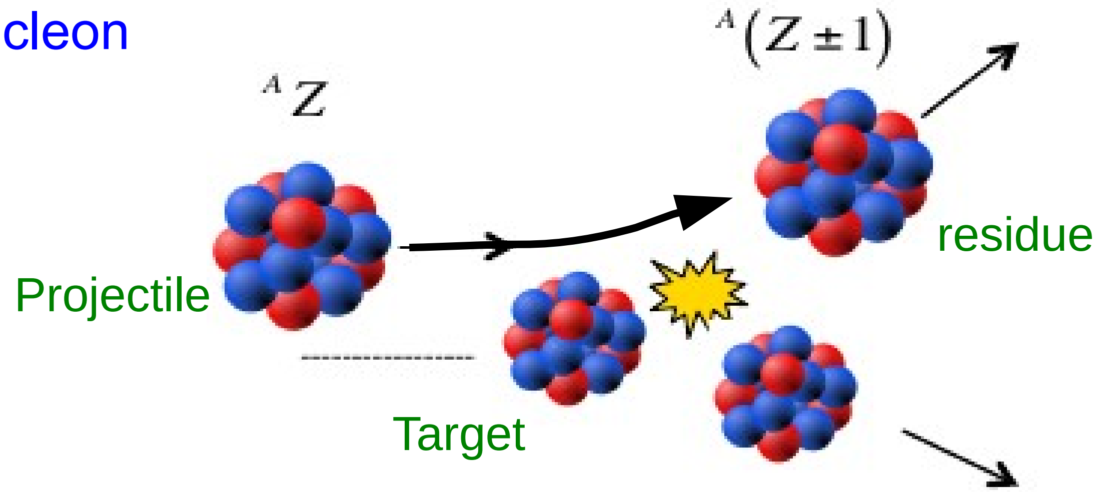
After more than 60 years studying baryon resonances one could think that not, but the constraint of in-medium (density & isospin dependence) properties of baryon resonances is essential for a better understanding of:

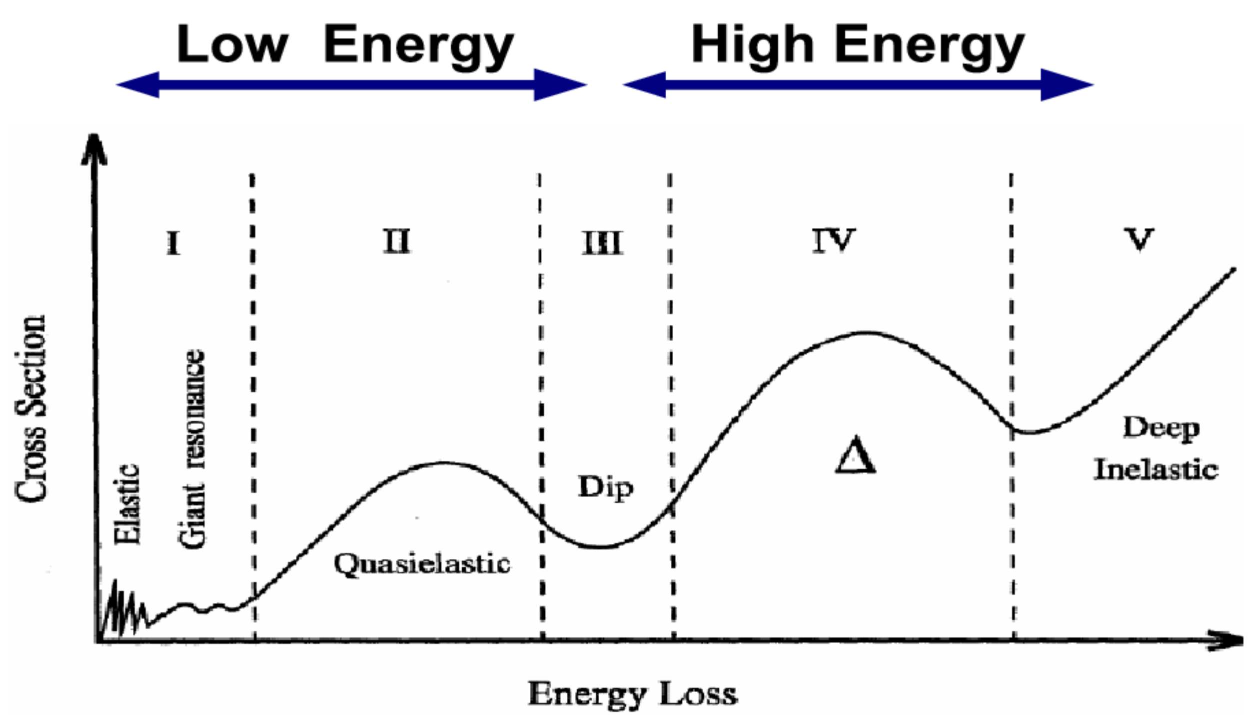
- not yet solved quenching problem of the GT strength
- three-nucleon force mechanisms
- EoS of asymmetric nuclear matter (neutron stars)
- their effects on relativistic heavy ion collisions (fragmentation and spallation reactions)
- ....

What we can investigate with isobar charge-exchange reactions

Allow the investigation of nuclear & nucleon (spin-isospin) excitations in nuclei

- Low energies: Gamow-Teller, spin-dipole, spin-quadrupole, quasi-elastic
- High energies: excitation of baryon resonances such as Δ, N*, …

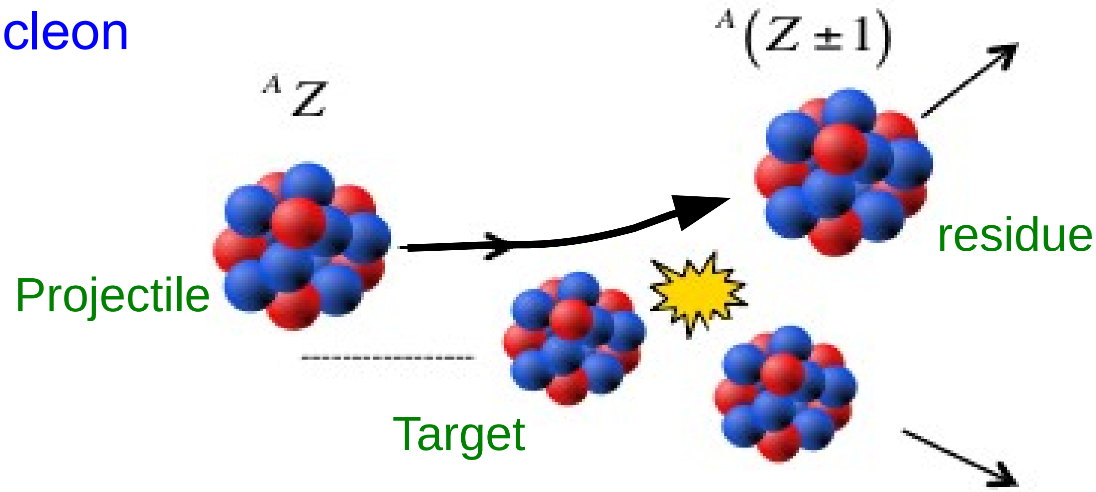




What we can investigate with isobar charge-exchange reactions

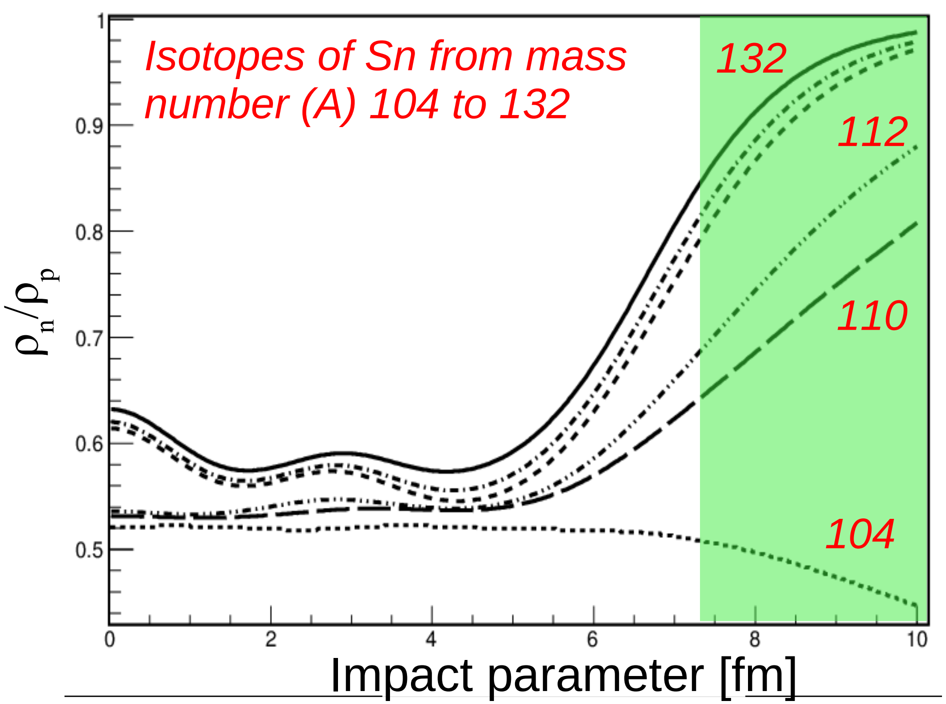
Allow the investigation of nuclear & nucleon (spin-isospin) excitations in nuclei

- Low energies: Gamow-Teller, spin-dipole, spin-quadrupole, quasi-elastic
- High energies: excitation of baryon resonances such as Δ, N*, …



They are peripheral reactions providing information on radial distributions (surface & tail) of protons & neutrons in nuclei (neutron skin thickness)

- Information on (low density) asymmetric nuclear matter that is important to understand the spin-isospin dependence of the nuclear force

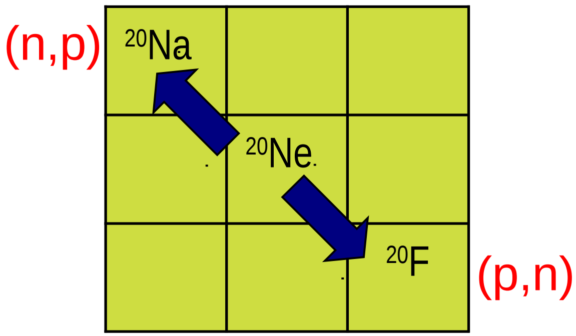


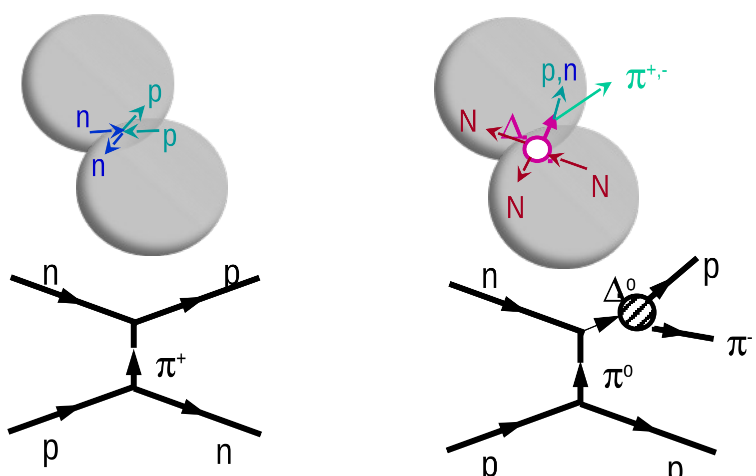
Bao-An Li et al. NPA 533, 749 (1991)

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

Missing-energy spectrum of isobar charge-exchange reactions

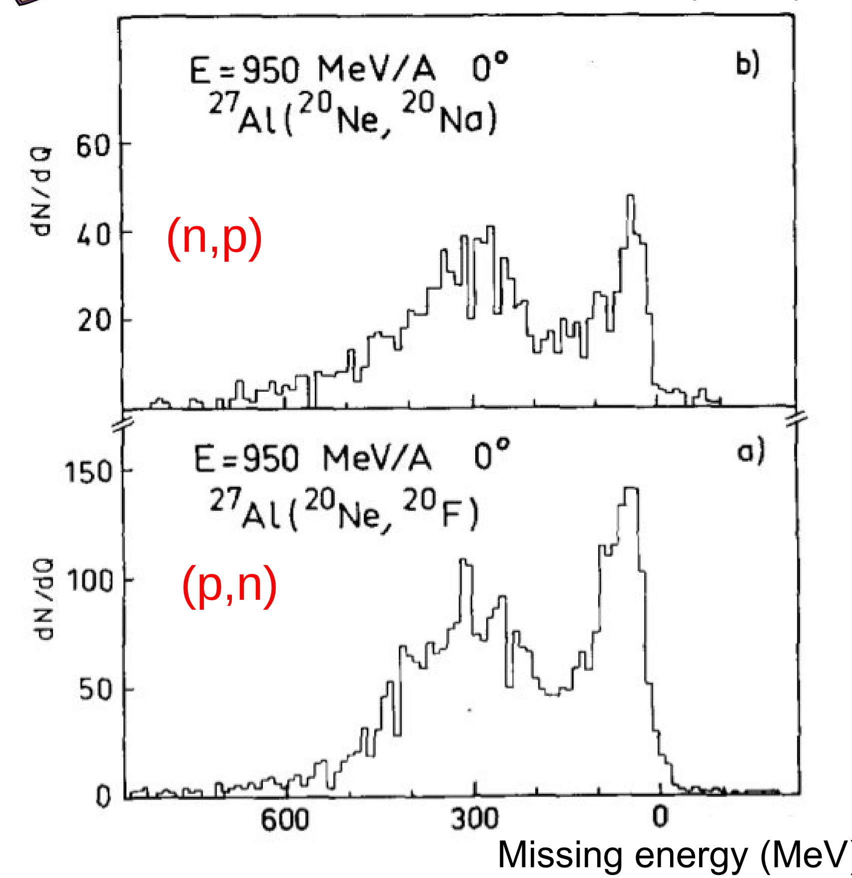
Isobar charge-exchange reactions investigated in inverse kinematics allow for the direct observation of in-medium excitation of the Δ resonance for both (p,n) and (n,p) channels





In the inelastic charge-exchange process the pion must scape in order to preserve the isobar character of the reaction

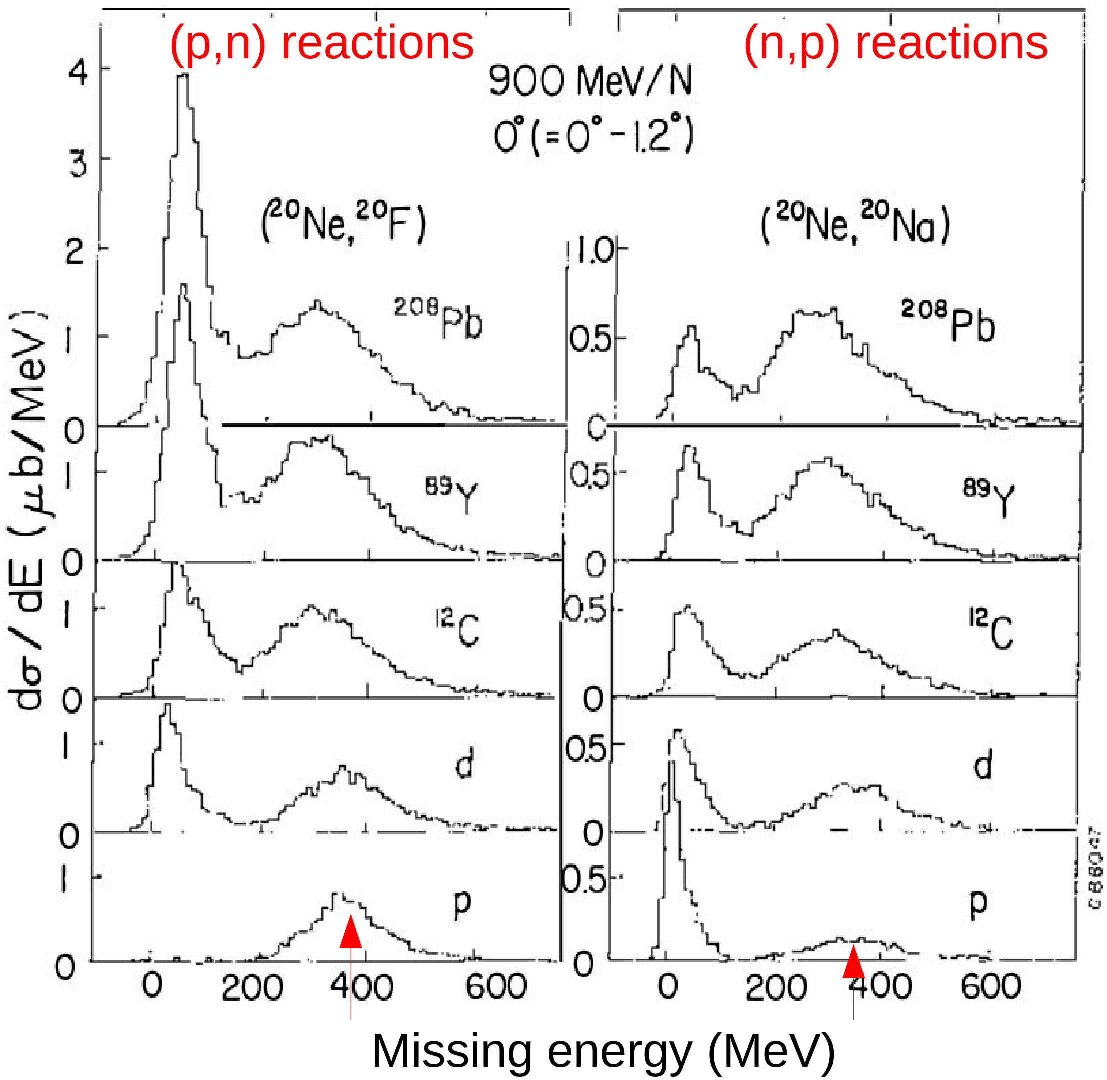
D.Bachelier et al. PLB 172, 23 (1986)



The momentum recoil induced by the pion emission proves the excitation of the resonance

Past observations of the Δ(1232) in isobar charge exchange reactions

1980's complete experimental program to measure Δ(1232) excitation in isobar charge-exchange reactions with light and medium mass projectiles at SATURNE accelerator in Saclay



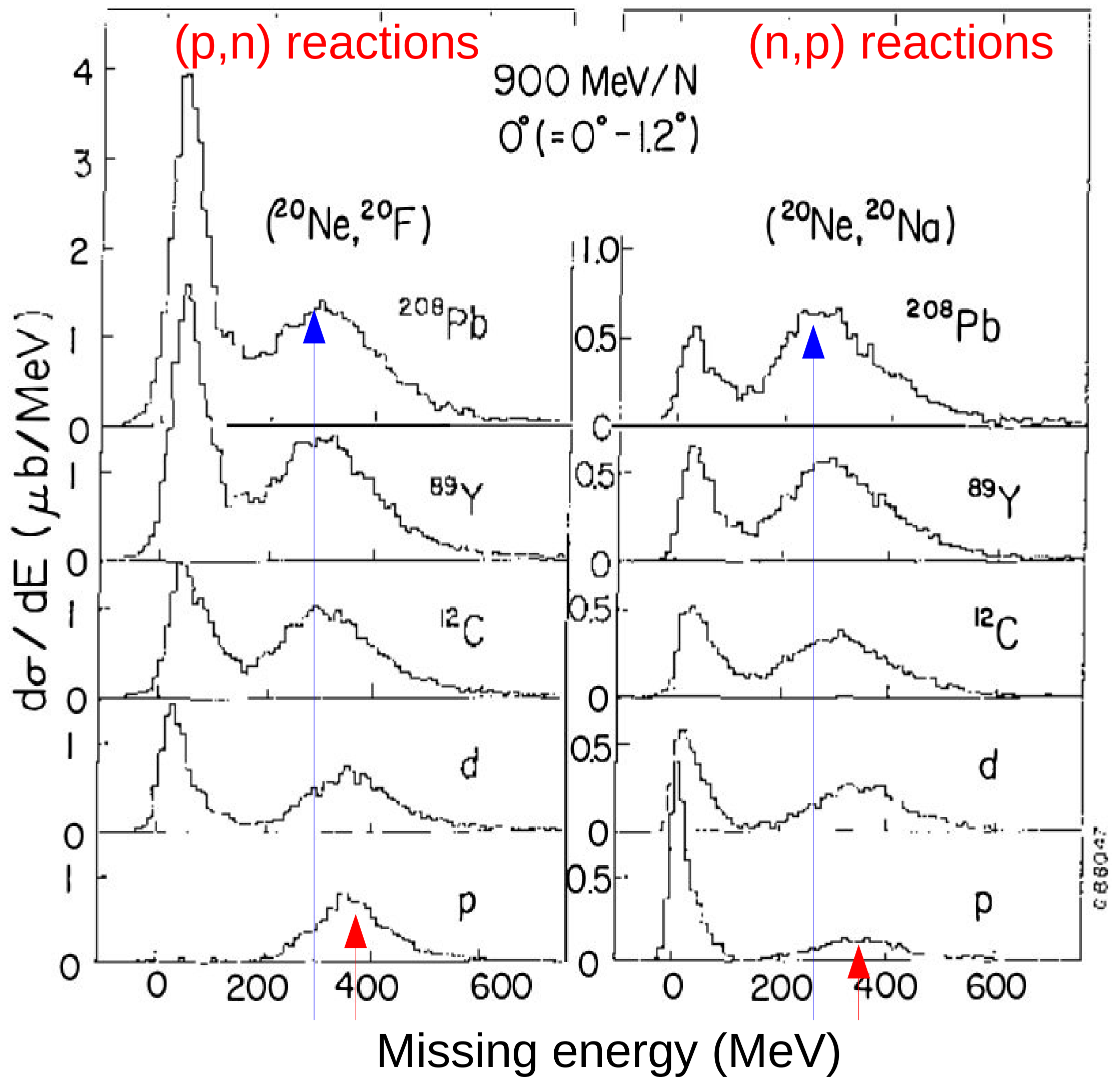
D. Bachelier et al., PLB 172, 23 (1986)

Past observations of the Δ(1232) in isobar charge exchange reactions

1980's complete experimental program to measure Δ(1232) excitation in isobar charge-exchange reactions with light and medium mass projectiles at SATURNE accelerator in Saclay

Shift around 70 MeV of the Δ peak to lower energies for medium and heavy targets

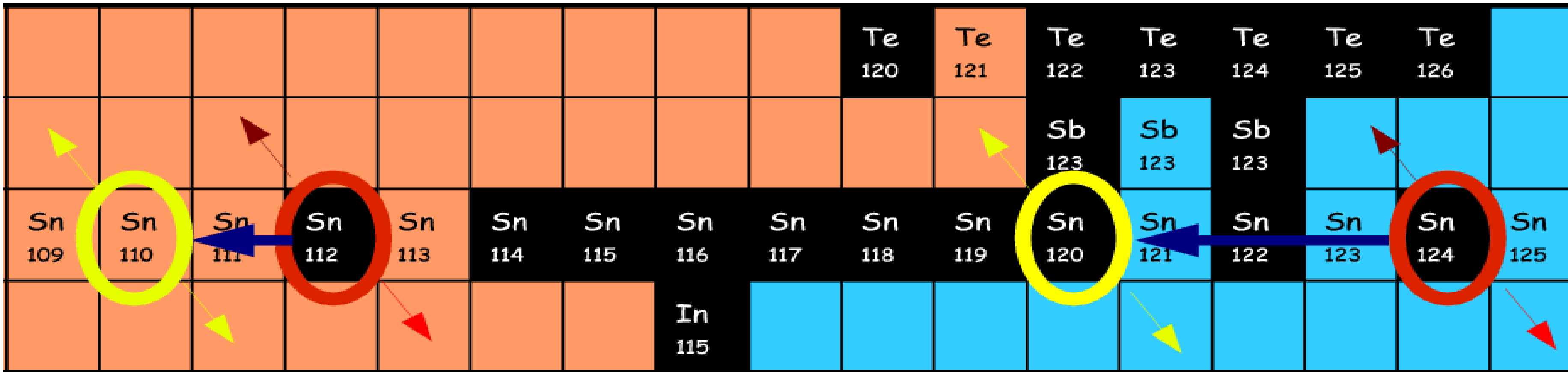
What's its origin ?



D. Bachelier et al., PLB 172, 23 (1986)

Isobar charge-exchange reactions investigated at GSI

To investigate the baryon resonances excited in isobar charge-exchange reactions we use stable and unstable tin projectiles covering a large range in mass number



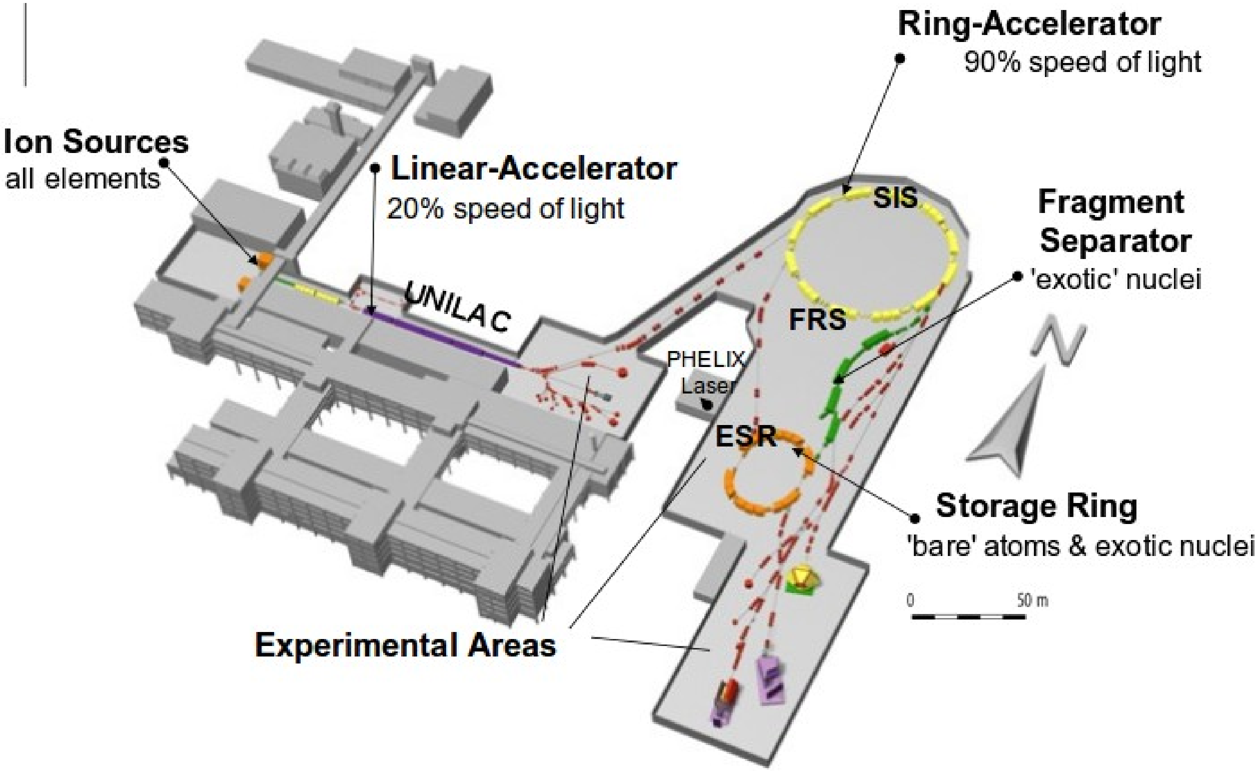
Observables

- ✓ Charge exchange cross sections
- ✓ Missing-energy spectrum

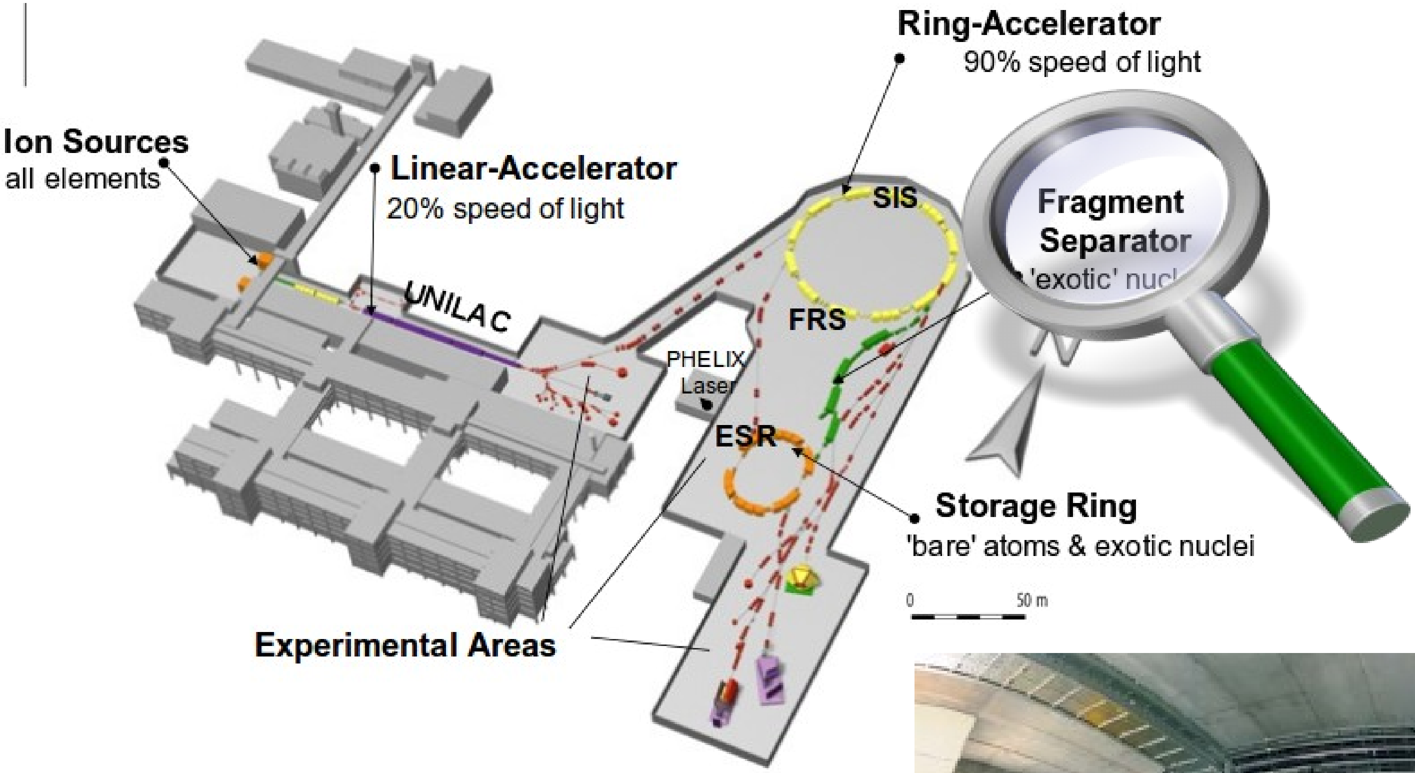
Reactions investigated in this work

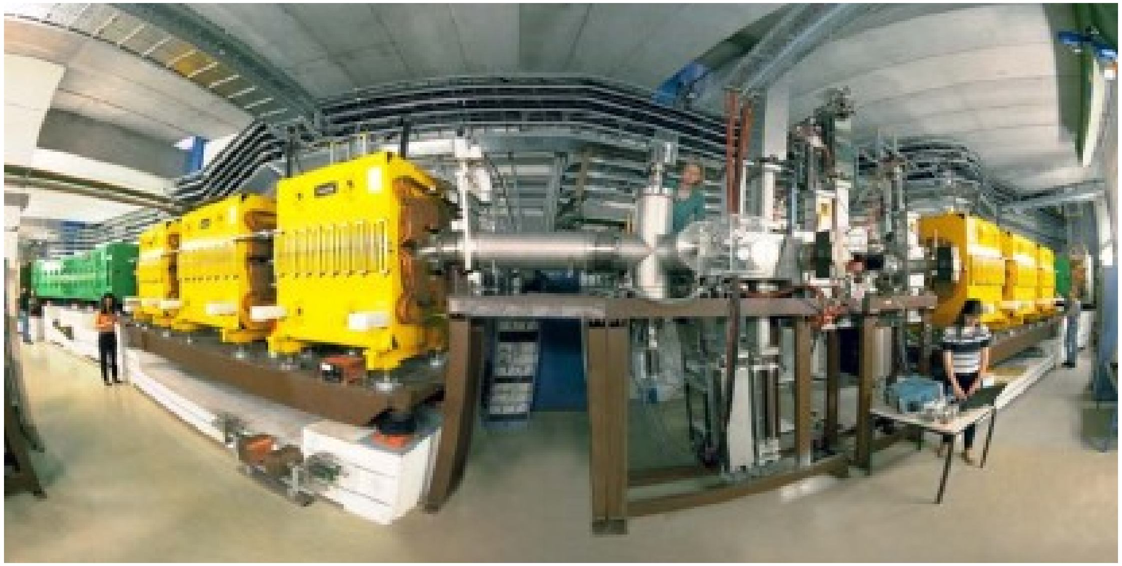
- ✓ ^{124}Sn+CH$_2$,C → ^{124}Sb,^{124}In @ 1000 A MeV
- ✓ ^{124}Sn+Be → ^{120}Sn+CH$_2$,C → ^{120}Sb,^{120}In @ 1000 A MeV
- ✓ ^{112}Sn+CH$_2$, C, Cu, Pb → ^{112}Sb,^{112}In @ 400, 700, 1000 A MeV
- ✓ ^{112}Sn+Be → ^{110}Sn+CH$_2$,C → ^{110}Sb,^{110}In @ 1000 A MeV

Experiments at the FRS

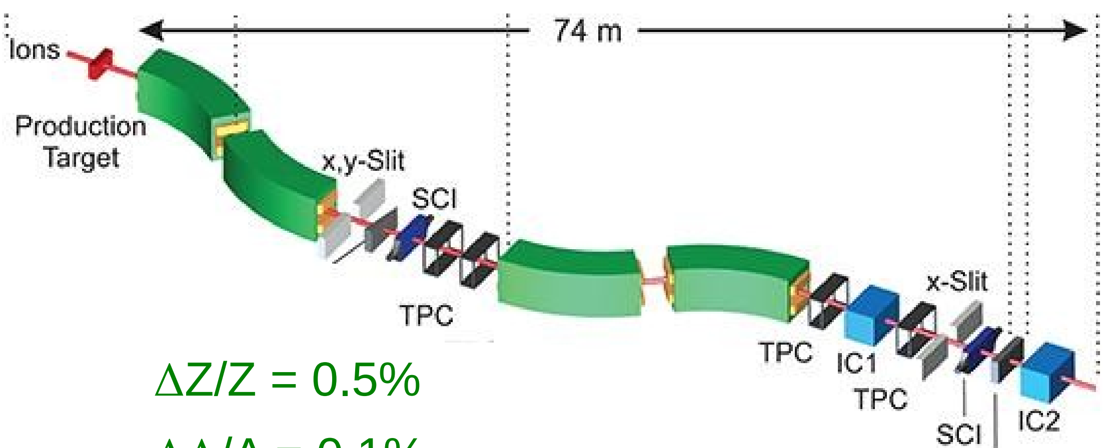


Experiments at the FRS





Fragment separator FRS



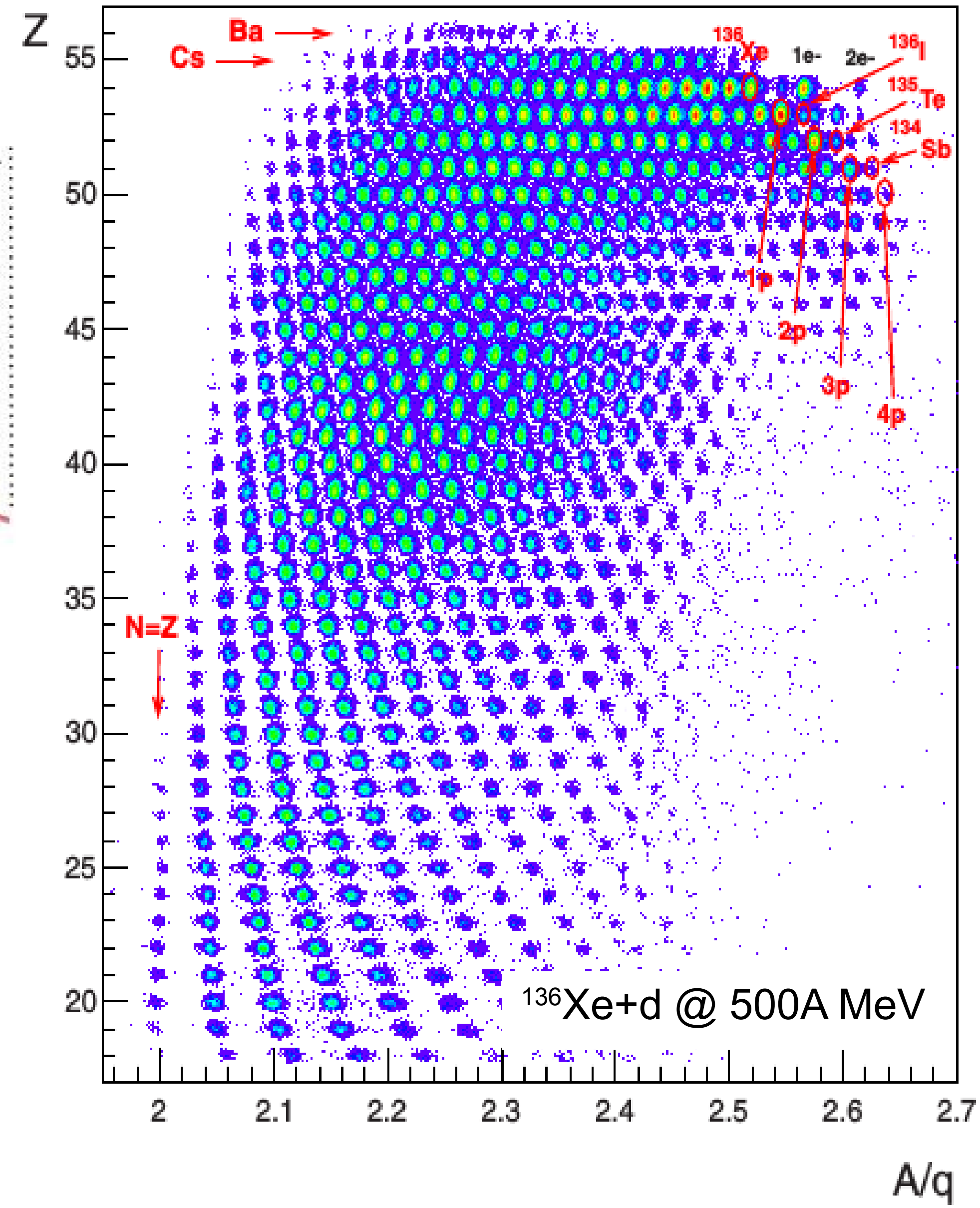
$\Delta Z/Z = 0.5\%$

$\Delta A/A = 0.1\%$

$\Delta B\rho/B\rho = 0.02\%$

Full identification in atomic (Z) and mass number (A) of the nuclear residues

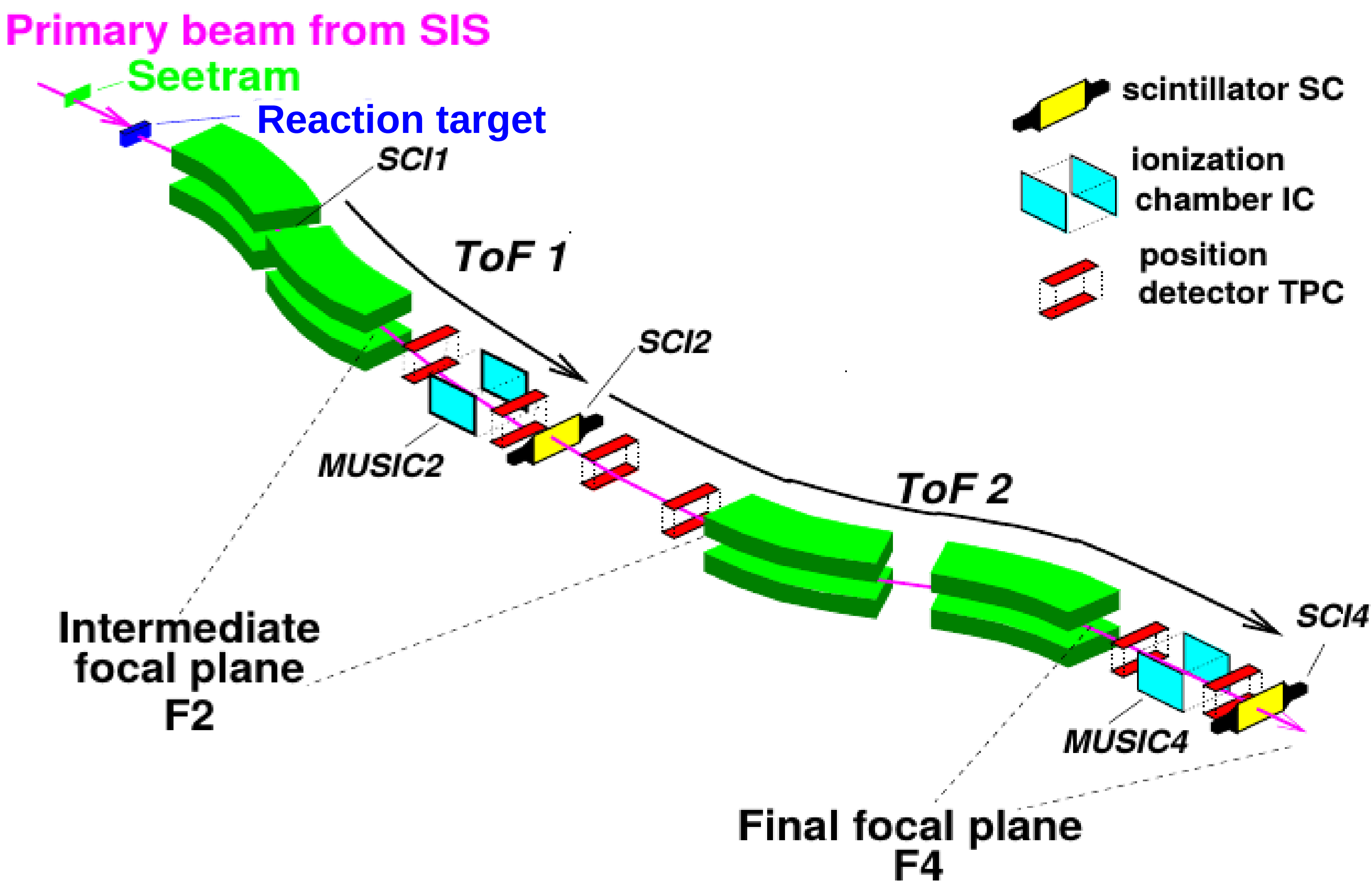
J. Alcantara et al., PRC 92, 024607 (2015)



H. Geissel et al., NIMB 70, 286 (1992)

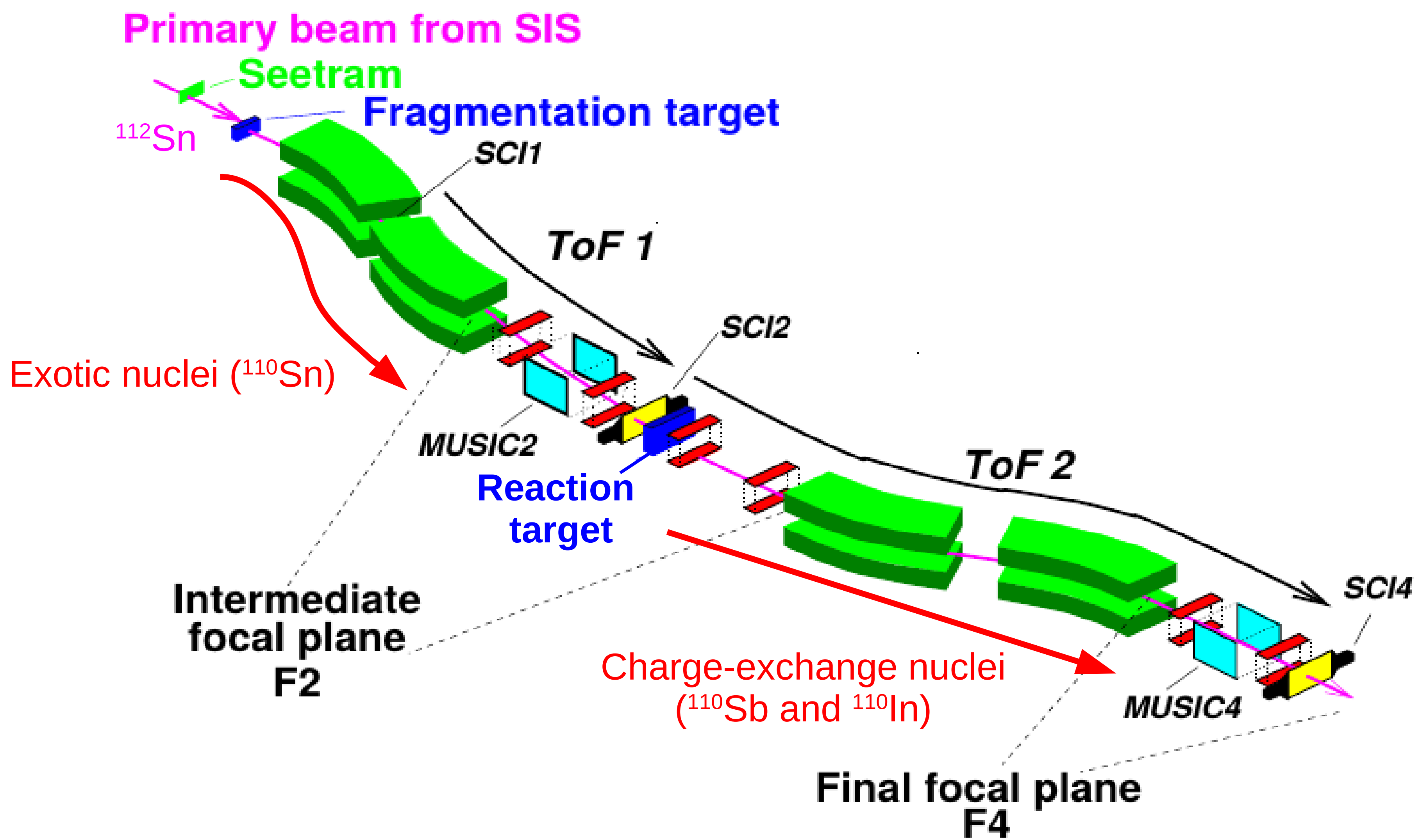
FRS setup for stable nuclei

Reactions with stable beams induced at the primary target



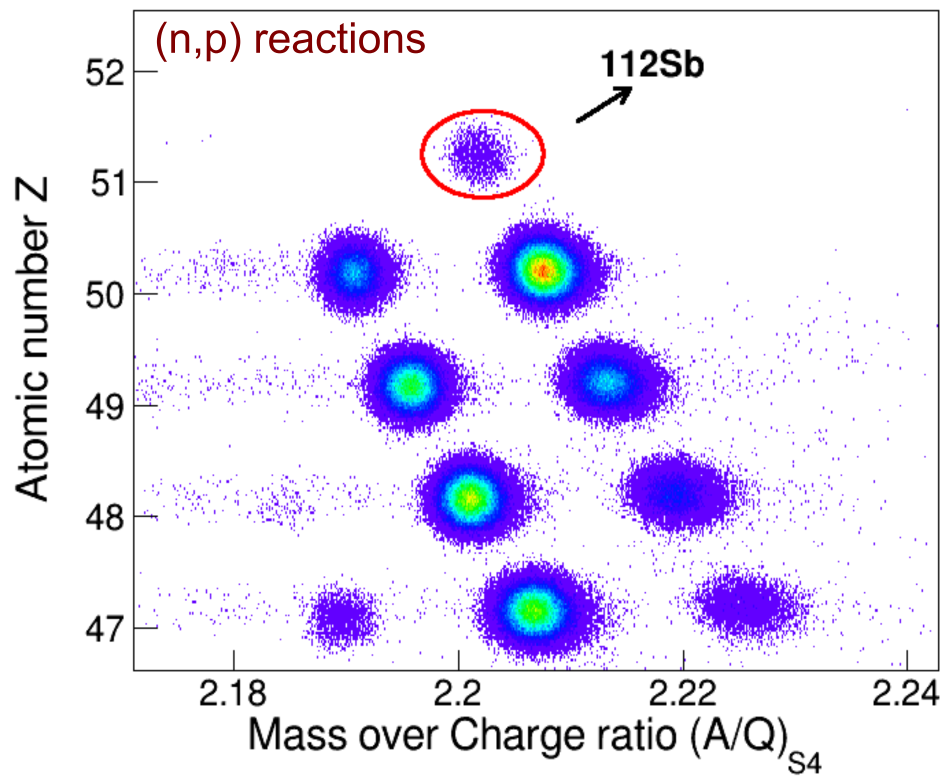
FRS setup for unstable nuclei

Unstable beams produced at the primary target and charge-exchange reactions induced in a second target located at the intermediate focal plane

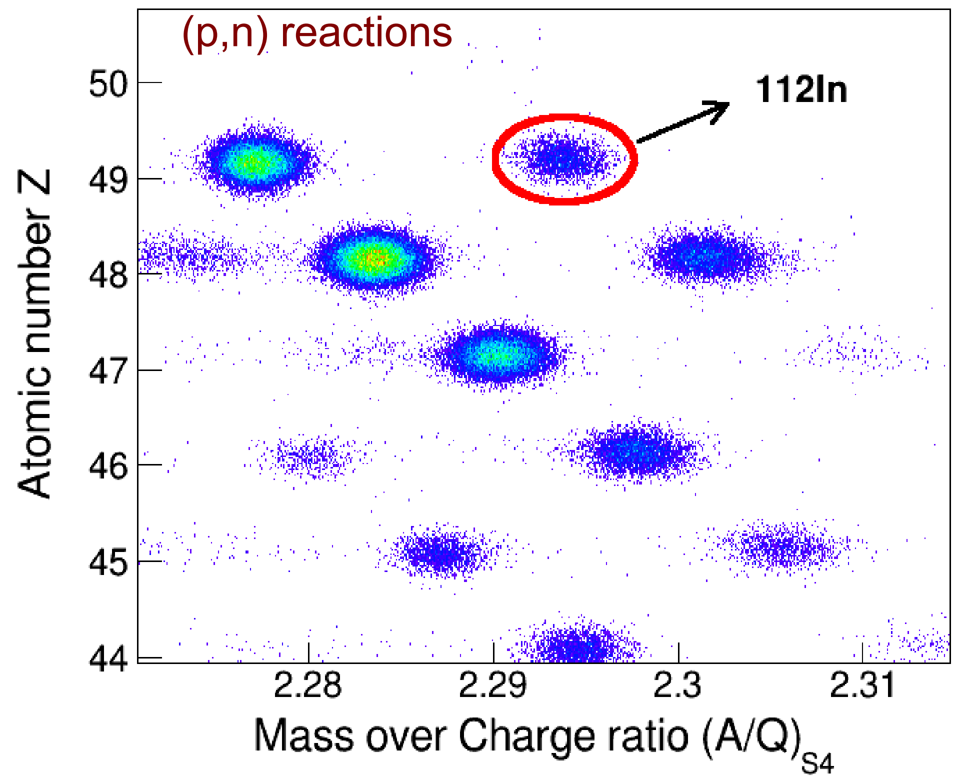


Isotopic identification of nuclear residues produced in isobaric charge-exchange reactions

^{12}C (^{112}Sn, ^{112}Sb) X

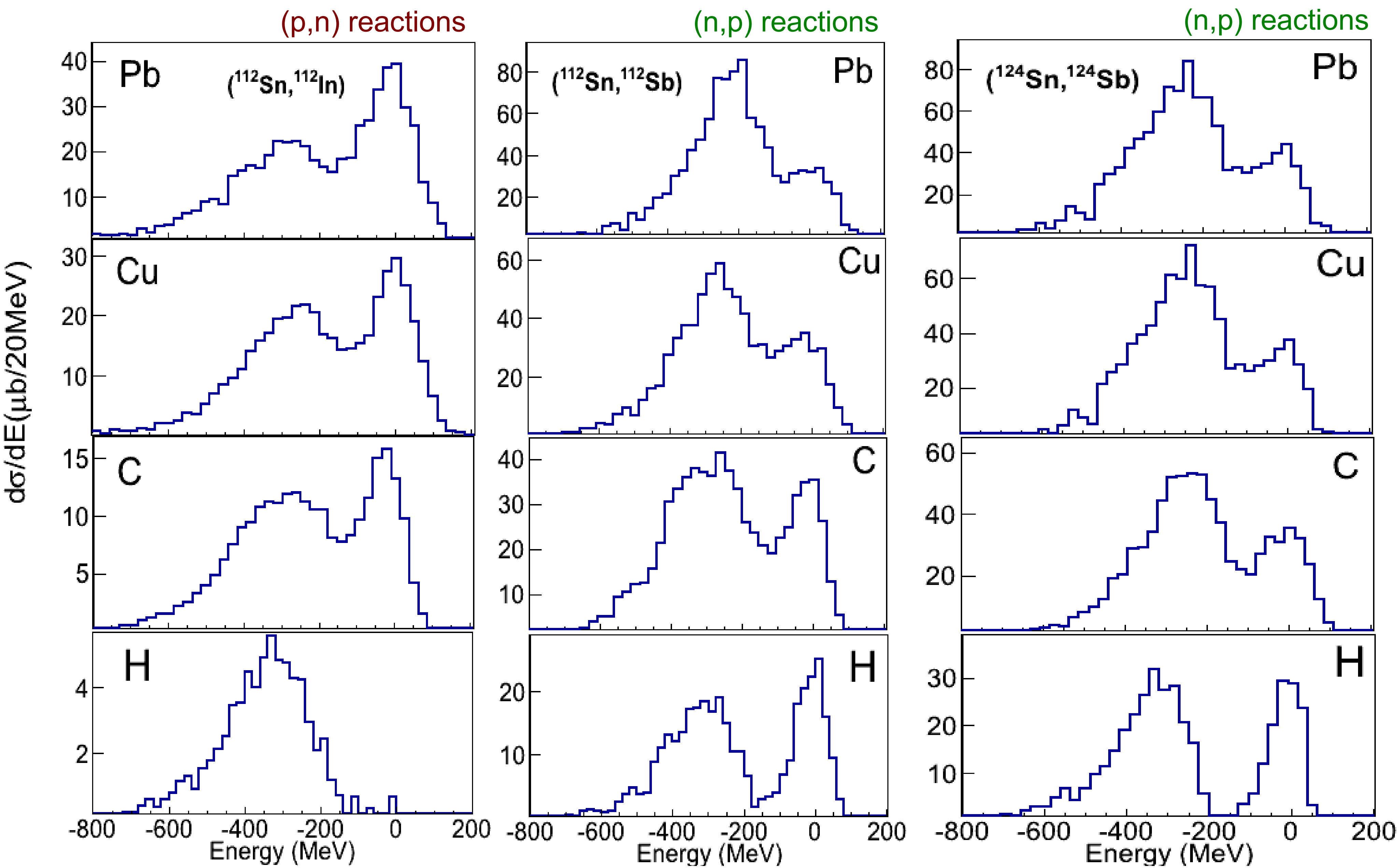


^{12}C (^{112}Sn, ^{112}In) X



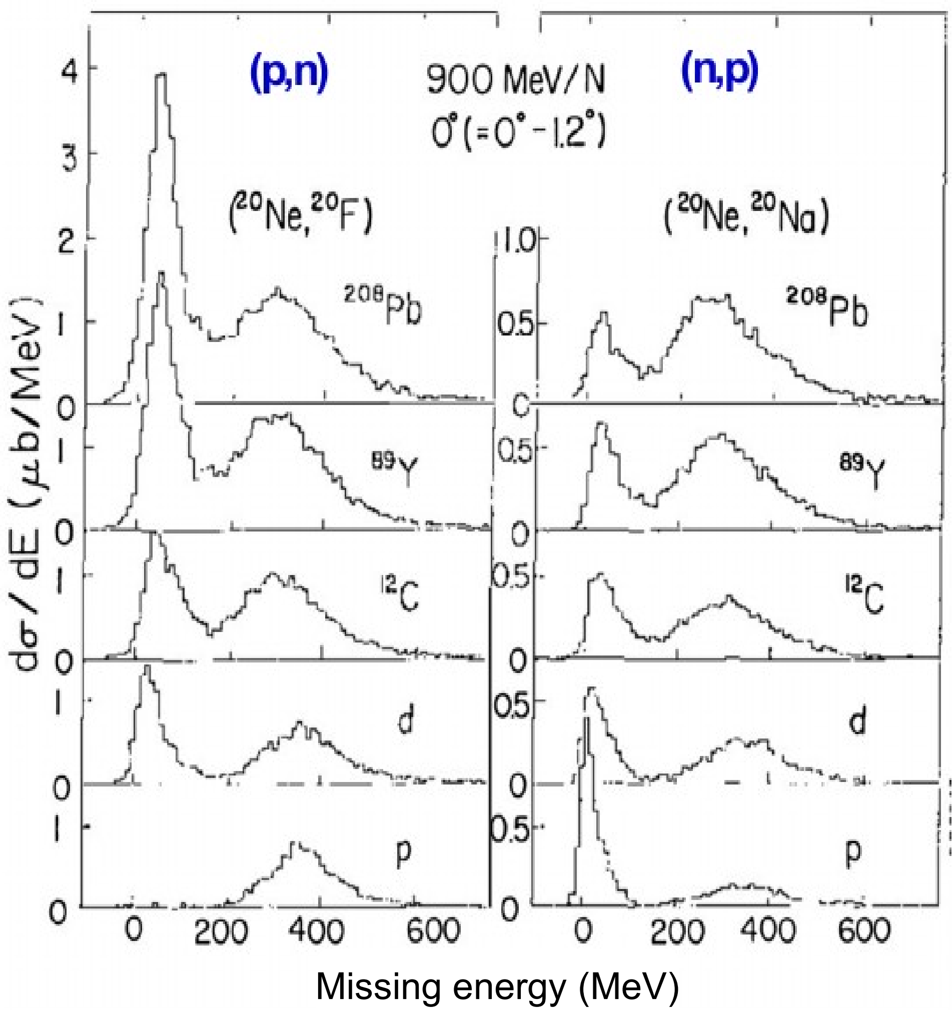
Full identification in atomic and mass number for both channels (n,p) and (p.n)

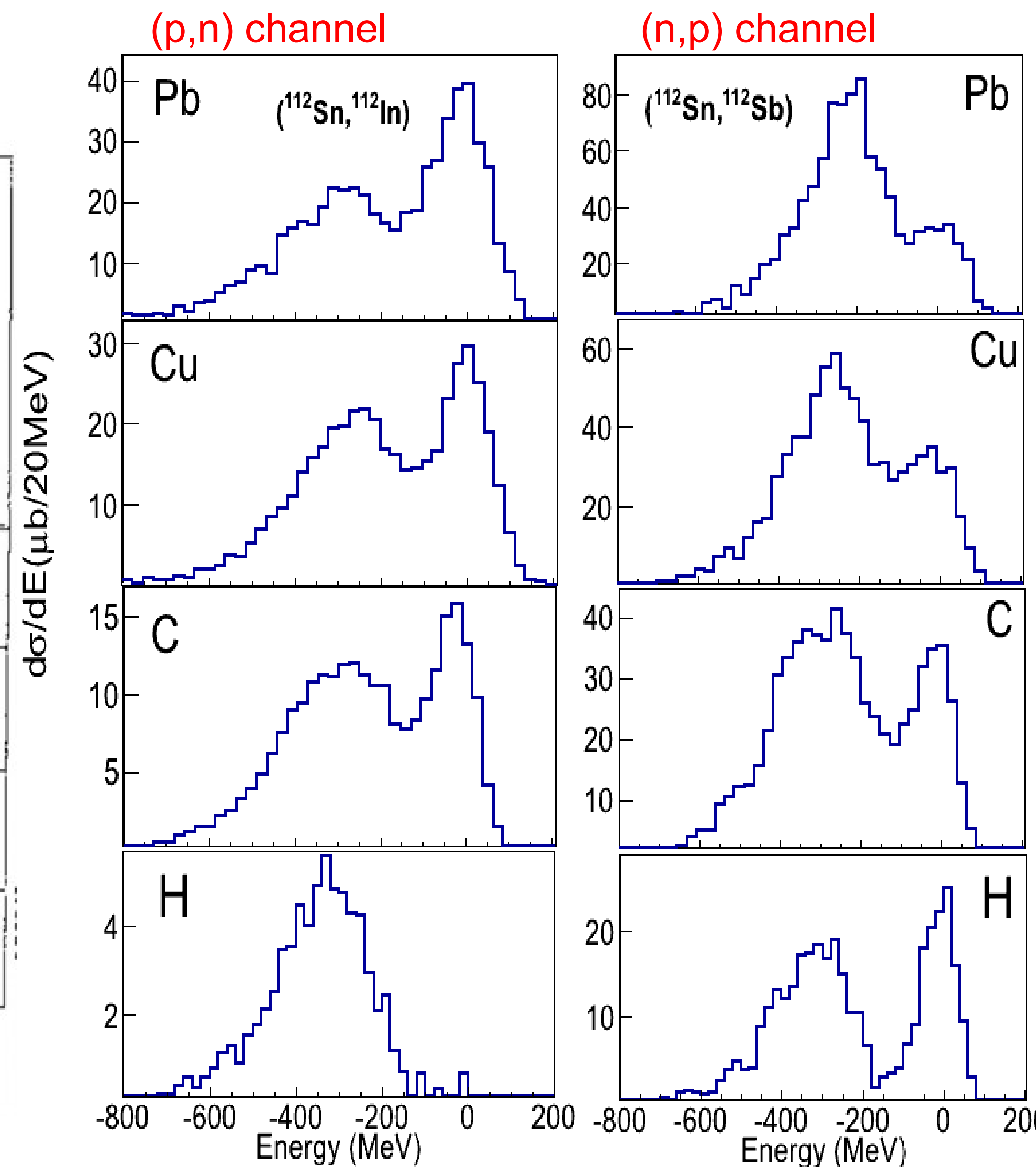
Missing-energy spectrum in different targets



Comparison with results from SATURNE experiment

SATURNE data for different targets

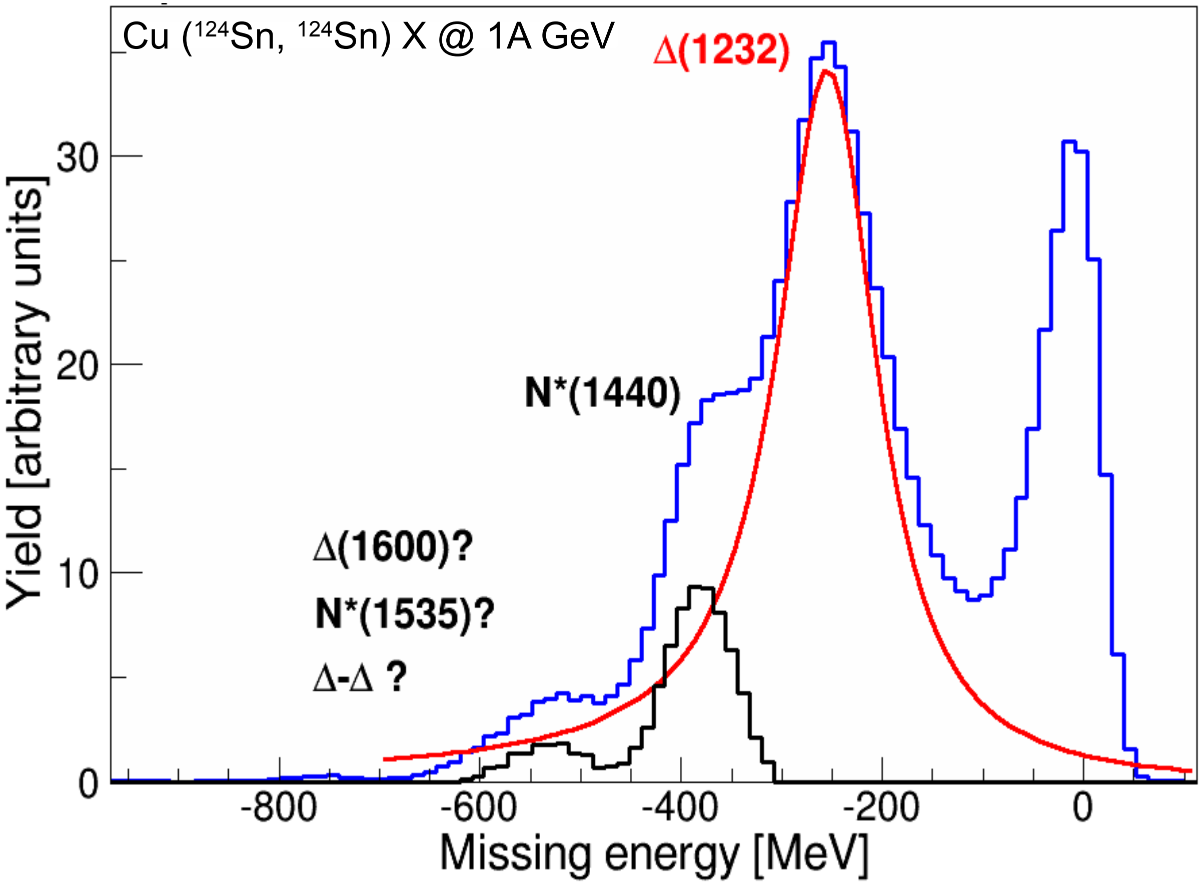


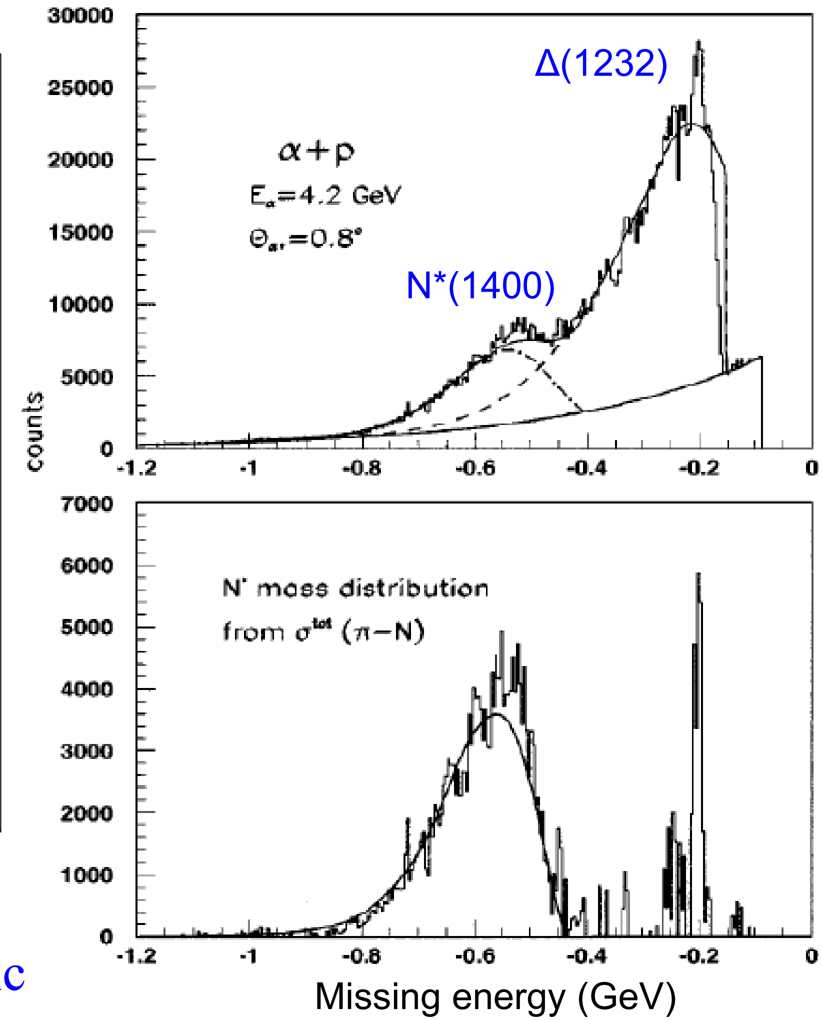


D. Bachelier et al., PLB 172, 23 (1986)

Missing-energy spectrum

Excitation of baryonic resonances

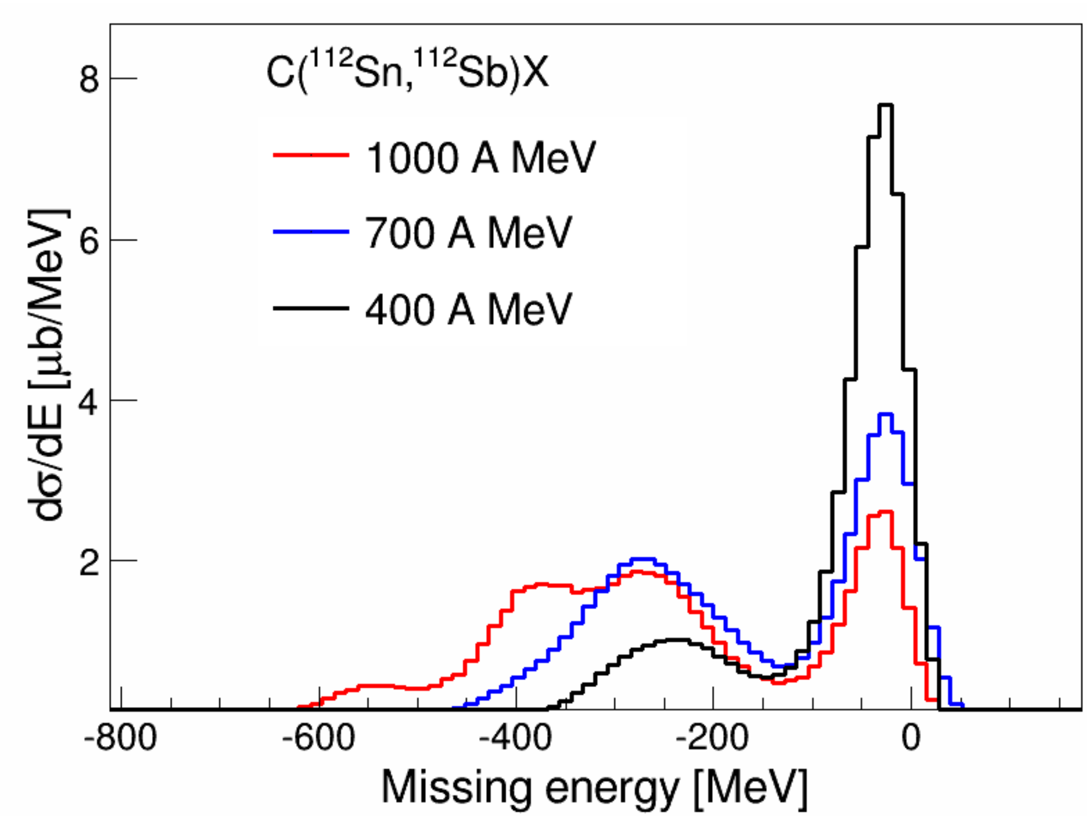


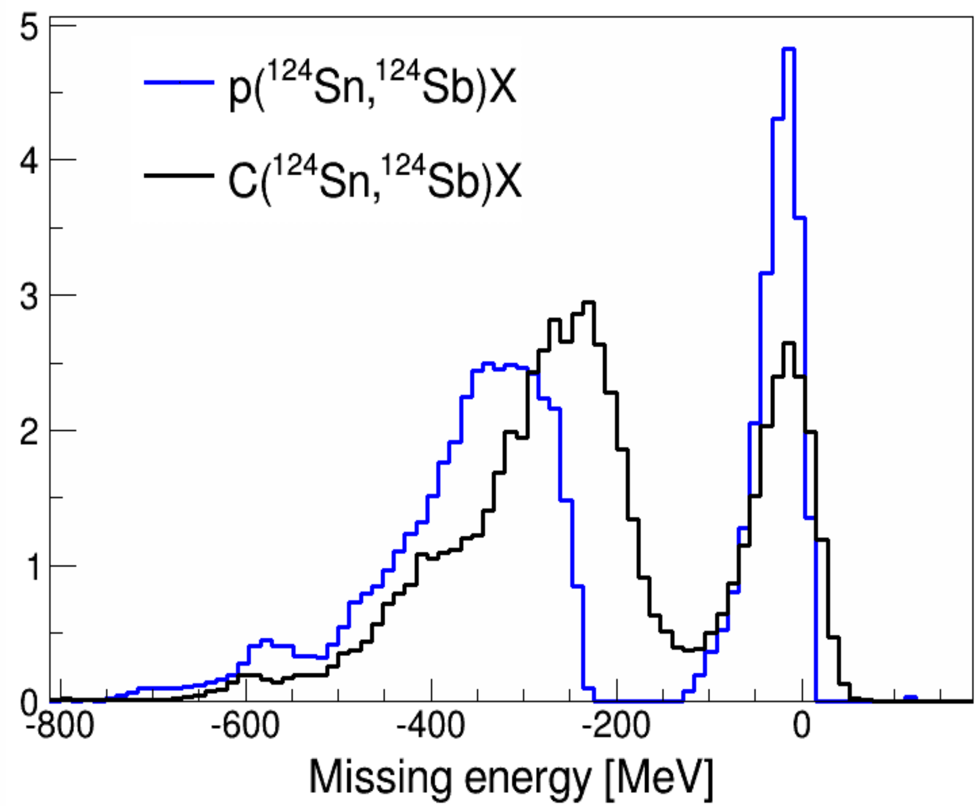


H.P. Monsch et al., PRL 69, 1336 (1992)

- ✗ Identification of different resonances in the inelastic component of the missing-energy spectrum
- ✗ Clear excitation of the Delta and Roper resonances

Dependences on projectile kinetic energy and target





- ✗ The excitation probability of the resonances scales with the projectile energy as expected
- ✗ A shift in the energy of the resonances is also observed between light and medium targets

Comparison with model calculations

Glauber model

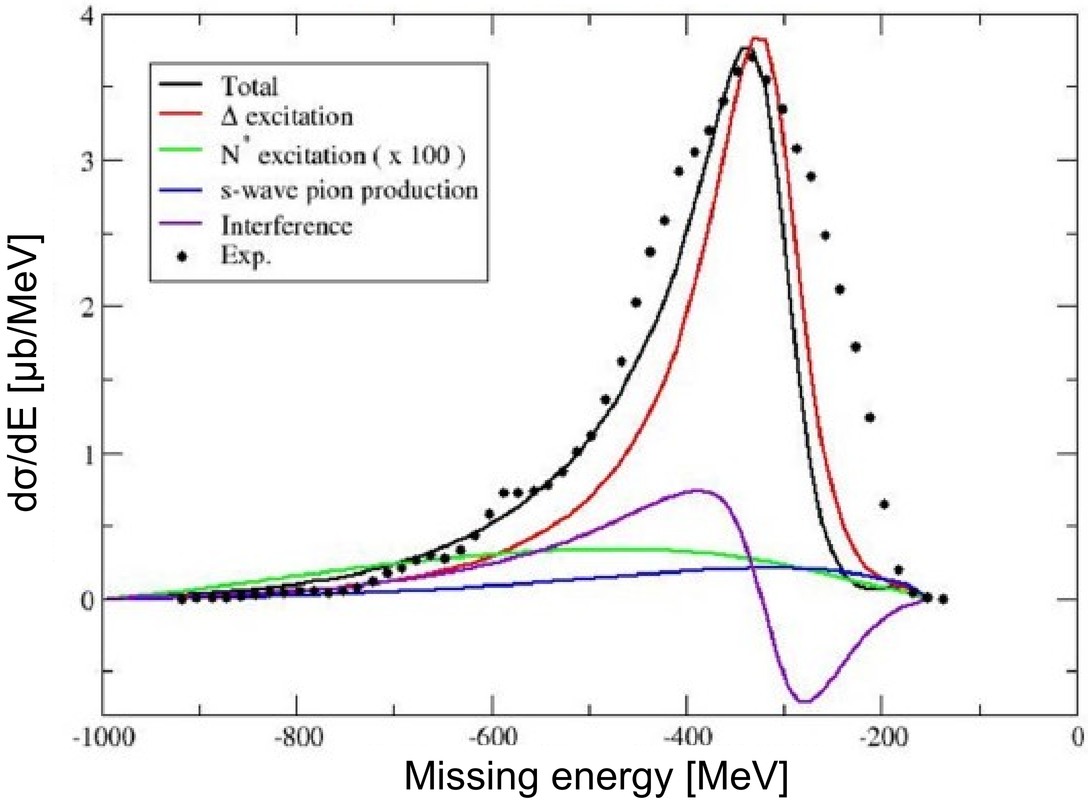
Nuclear density distributions according to Hartree-Fock calculations

Experimental parametrizations of the N-N cross sections

Production of Δ, N* and no resonant channels

Calculations courtesy of Isaac Vidaña
University of Coimbra, Portugal
EPJ web of conferences 107, 10003 (2016)

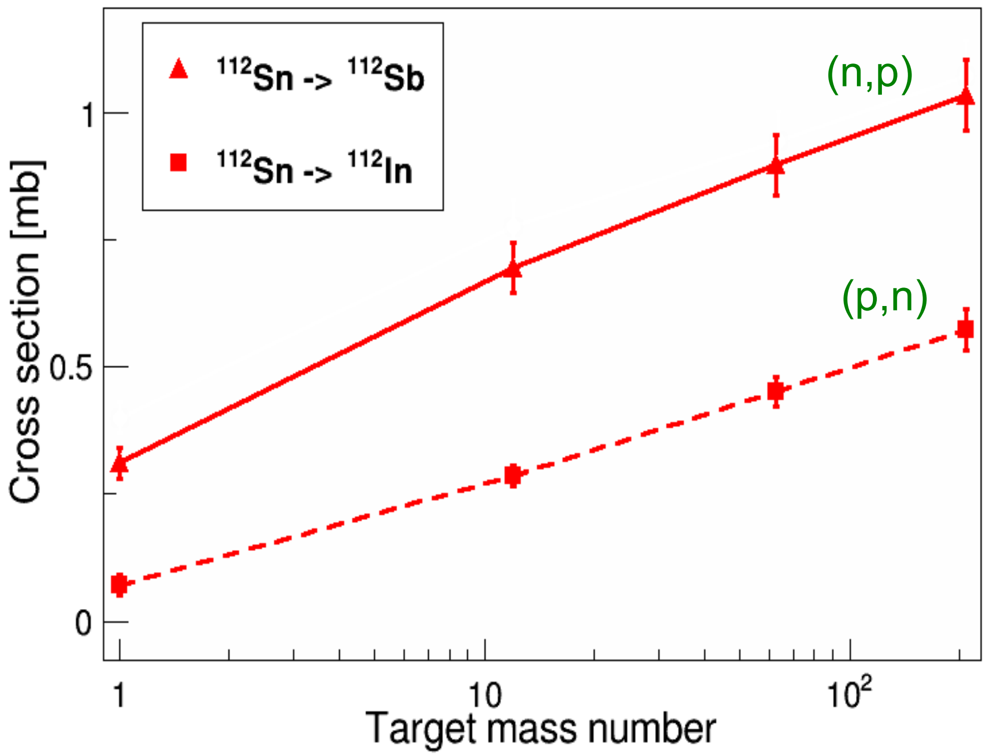
p(^{112}Sn,^{112}In)X @ 1A GeV

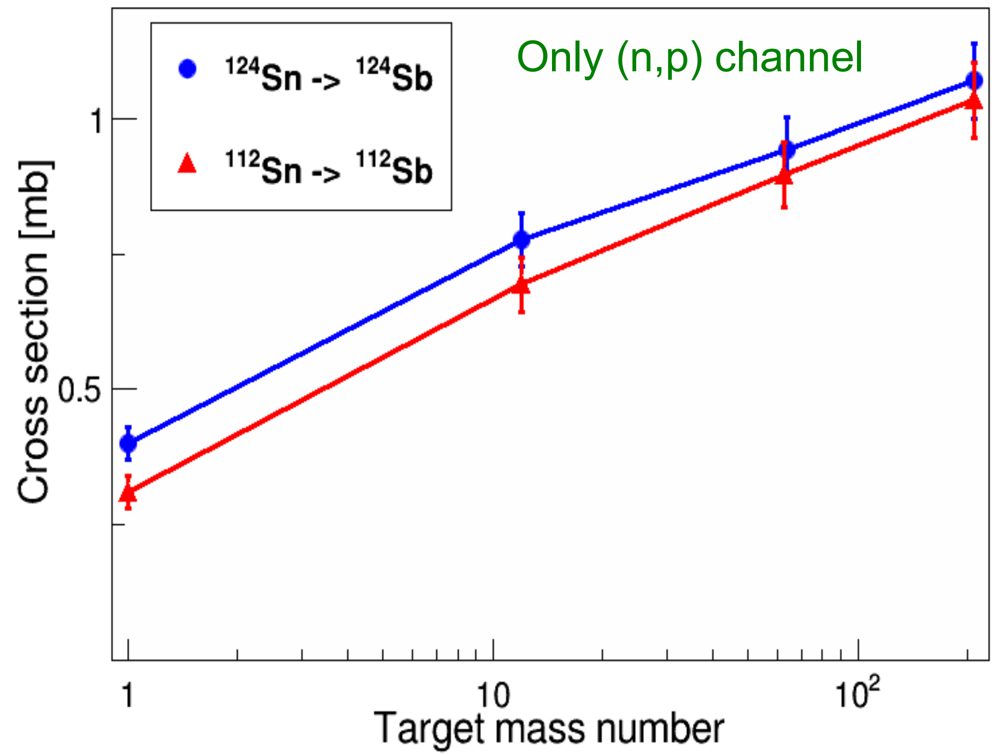


✗ The difference between the experimental data and the calculations could indicate the presence of nuclear medium effects: N-N correlations, Fermi momentum, ...

Abundance of neutrons and protons in the nuclear surface

Charge-exchange cross sections





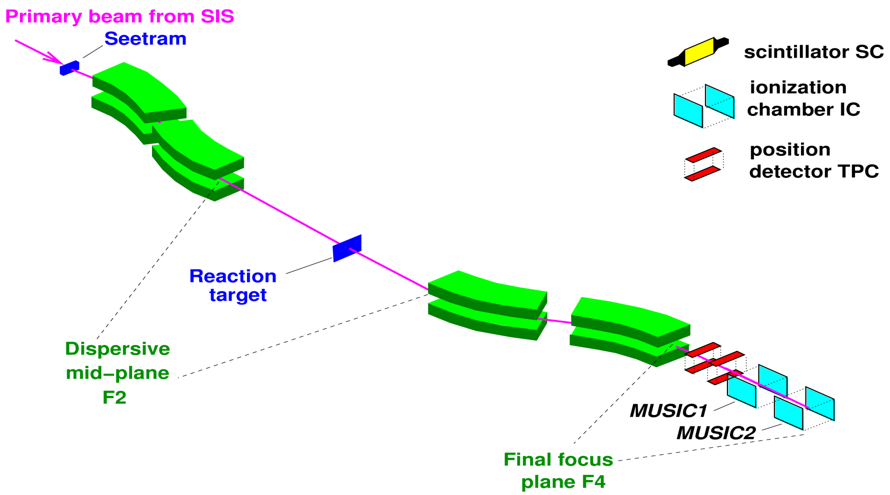
Cross sections are sensitive to the neutron excess at projectile periphery $\sigma(n,p) > \sigma(p,n)$ and to the neutron skin thickness $\sigma(^{124}Sn \rightarrow {}^{124}Sb) > \sigma(^{112}Sn \rightarrow {}^{112}Sb)$

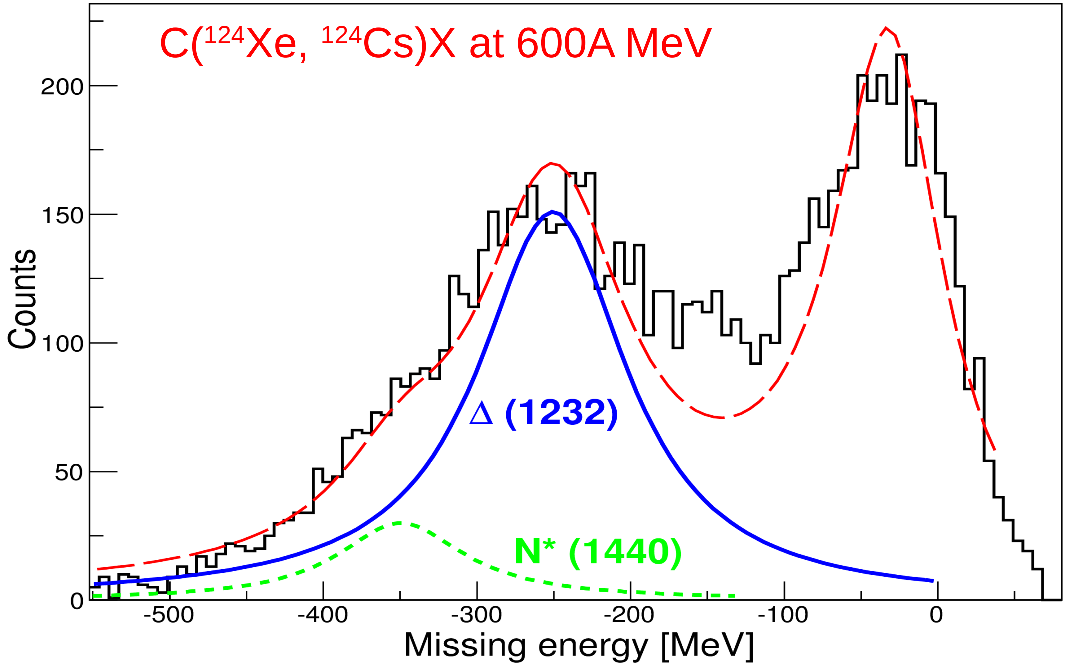
Light targets such as protons or carbons seem better suited to study the relative abundance of protons and neutrons at the projectile periphery

Future perspectives at FAIR

Nuclear residues produced in the isobaric charge-exchange reactions will be identified with the fragment separator FRS

- ✗ Vacuum from SIS synchrotron to the final focal plane of the FRS to reduce the energy and angular matter straggling
- ✗ Thin carbon and liquid-hydrogen targets in the dispersive mid-plane

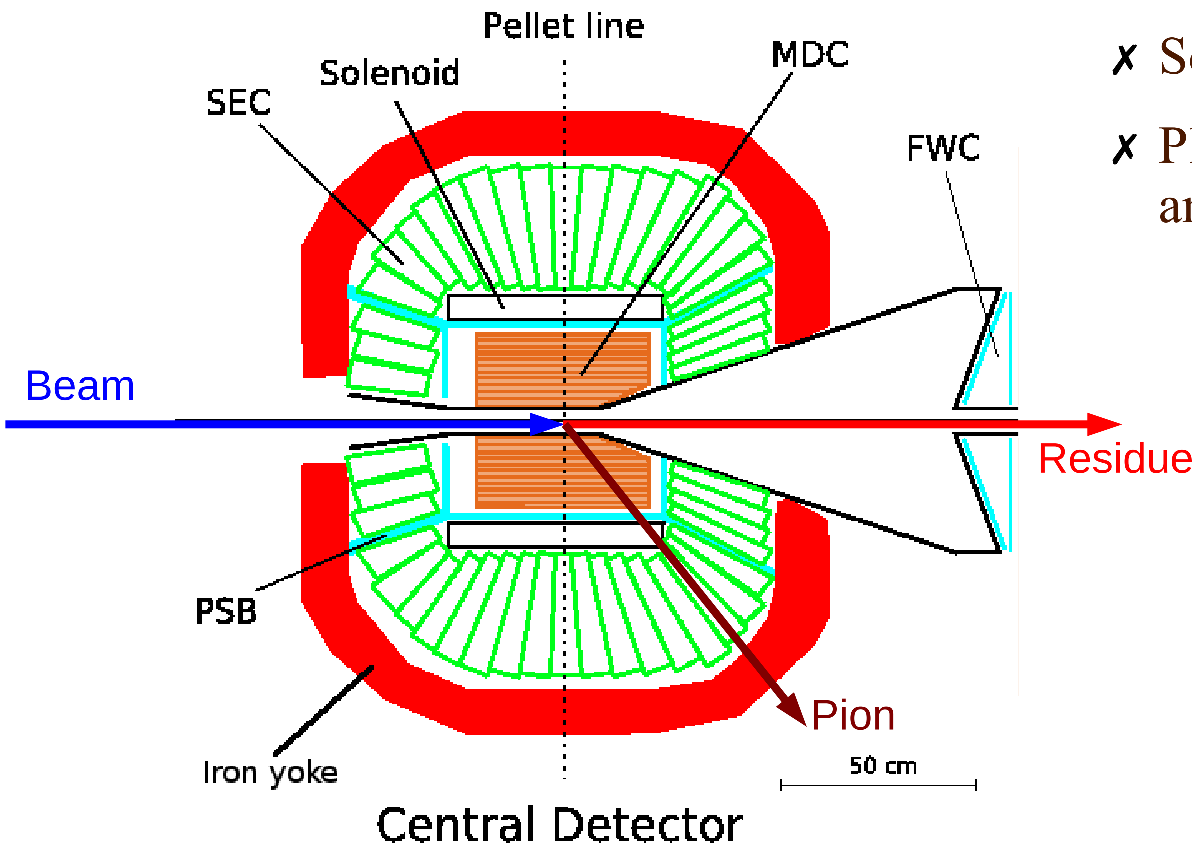




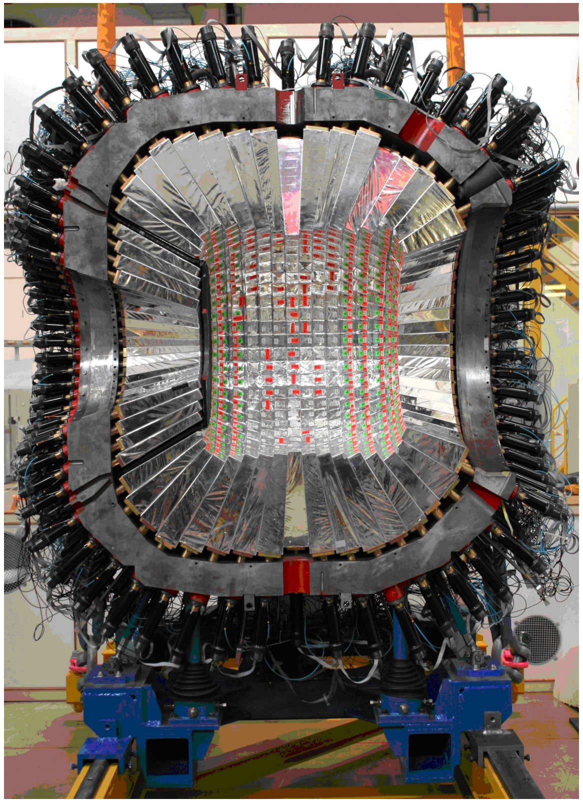
First test at the FRS perfomed in July of 2016 with projectiles of ^{124}Xe at 600A MeV impinging on a thin carbon target of 89 mg/cm²: energy resolution around 7 MeV

Future perspectives at FAIR

WASA (Wide Angle Shower Apparatus) detector will be used to measure the pions in coincidence with the isobaric charge-exchange reactions in 2019



- ✗ Solenoid for pion identification
- ✗ Plastic scintillators covering polar angles from 3º to 170º



- ✗ Expected energy resolution between 3 and 12 %
- ✗ Geometrical efficiency ~ 92%

Summary and conclusions

Delta and roper resonance were investigated with isobar charge-exchange reactions identified with the Fragment Separator FRS at GSI

- Full identification of the isobar charge-exchange nuclei
- Missing-energy spectrum obtained with a resolution around 15 MeV

Missing-energy distributions are in agreement with SATURNE data

- Energy shift in the inelastic peak observed between light and medium target nuclei
- Comparison with model calculations could indicate nuclear medium effects

Isobar charge-exchange cross sections are sensitive to the abundance of neutrons and protons in the nuclear surface, we could extract information about the neutron skin thickness

Exclusive measurements will be performed in 2019 using the Wasa detector

- Full identification of the isobar charge-exchange nuclei using the FRS
- Missing-energy spectrum obtained with a resolution around 7 MeV
- Pion identification with a expected detection efficiency around 90%

Collaborators

University of Santiago de Compostela:

H. Alvarez, Y. Ayyad, S. Beceiro, J. Benlliure, D. Cortina, P. Díaz, M. Mostazo, C. Paradela,D. Perez, J. Vargas

CEA, University Paris-Saclay: J.-C. David, S. Leray

GSI: T. Aumann, J. Atkinson, K. Boretzky, A. Estrade, H. Geissel, A. Kelic, Y. Litvinov, S. Pietri, A. Prochazka, M. Takechi, C. Scheidenberger, H. Weick, J. Winfield

University of Coimbra: I. Vidaña

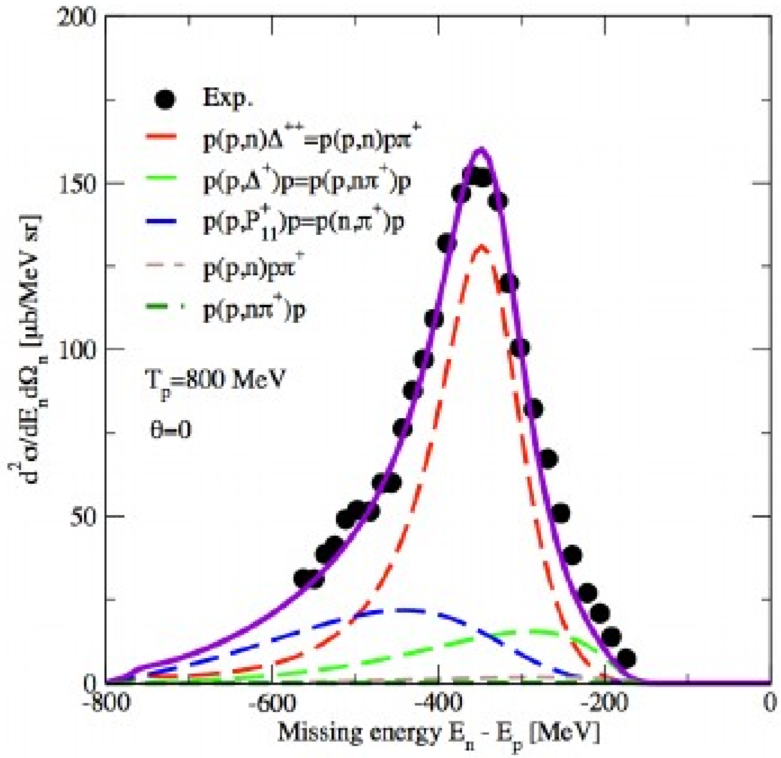
University of Giessen: H. Lenske

University Beihang, RCNP : I. Tanihata

Thank you for your attention!

Calculations for elementary reactions

$$pp \to np\pi^+$$



- Clear dominance of Δ^{++} excitation in the target

Data from G. Glass et al., PRD 15, 36 (1977)

Contribution from 5 processes

✧ s-wave π emission in Target

$$p(p,n)p\pi^+$$

✧ s-wave π emission in Projectile

$$p\left(p,n\pi^+\right)p$$

✧ Δ^{++} excitation in Target

$$p(p,n)\Delta^{++} = p(p,n)p\pi^+$$

✧ Δ^+ & $P_{11}{}^+$ excitation in Projectile

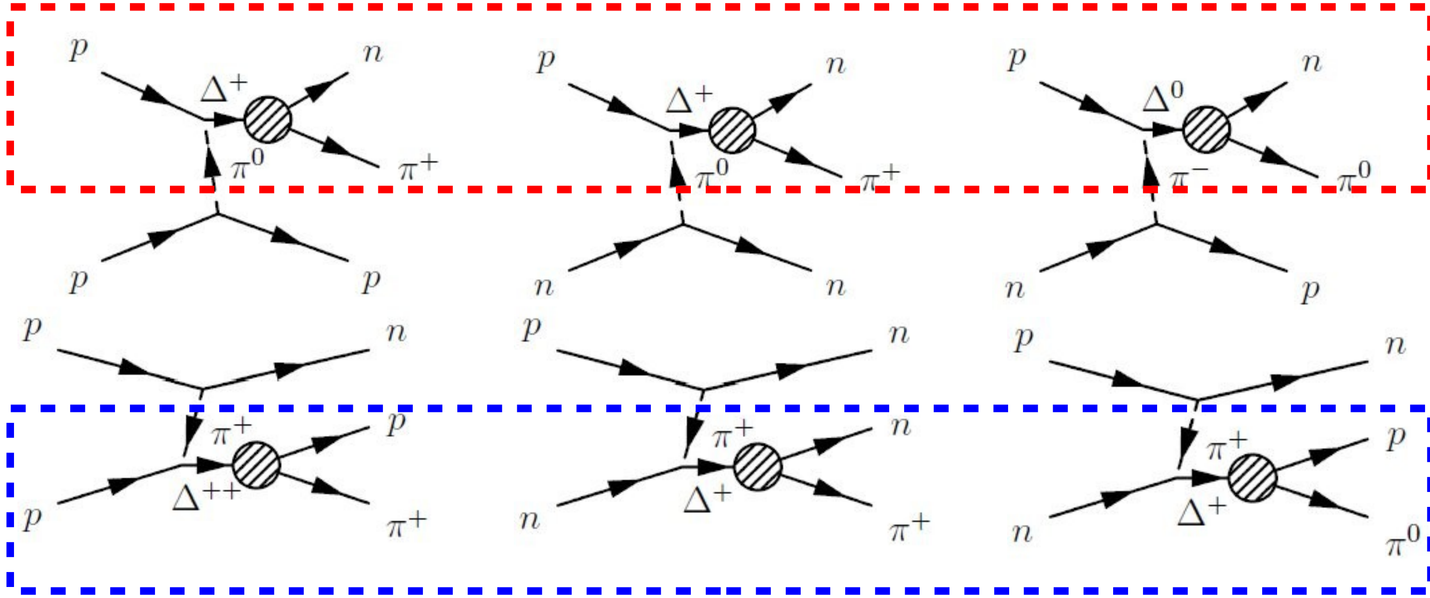
$$p(p,\Delta^+)p = p(p,n\pi^+)p$$
$$p(p,P_{11}^+)p = p(p,n\pi^+)p$$

Calculations courtesy of Isaac Vidaña

Excitation of baryon resonances in projectile and target

Projectile excitations

Target excitations



(p,n) reactions

Δ(1232) excitation

Excitation in the Target		Excitation in the Projectile	
$p(p,n)\Delta^{++} = p(p,n)p\pi^{+}$	$(\sqrt{2})$	$p(p,\Delta^{+})p = p(p,n\pi^{+})p$	$(-\sqrt{2}/3)$
$n(p,n)\Delta^{+} = n(p,n)n\pi^{+}$	$(\sqrt{2}/3)$	$n(p,\Delta^{+})n = n(p,n\pi^{+})n$	$(\sqrt{2}/3)$
$n(p,n)\Delta^{+} = n(p,n)p\pi^{0}$	$(-2/3)$	$n(p,\Delta^{0})p = n(p,n\pi^{0})p$	$(2/3)$

$N^*(1440)$ excitation

Excitation in the Target		Excitation in the Projectile	
$n(p,n)P_{11}^{+} = n(p,n)n\pi^{+}$	$(2\sqrt{2})$	$p(p,P_{11}^{+})p = p(p,n\pi^{+})p$	$(-\sqrt{2})$
$n(p,n)P_{11}^{+} = n(p,n)p\pi^{0}$	(-2)	$n(p,P_{11}^{+})n = n(p,n\pi^{+})n$	$(\sqrt{2})$
		$n(p,P_{11}^{0})p = n(p,n\pi^{0})p$	(-2)

(n,p) reactions

Δ(1232) excitation

Excitation in the Target		Excitation in the Projectile	
$p(n,p)\Delta^{0} = p(n,p)n\pi^{0}$	$(2/3)$	$p(n,\Delta^{0})p = p(n,p\pi^{-})p$	$(\sqrt{2}/3)$
$p(n,p)\Delta^{0} = p(n,p)p\pi^{-}$	$(\sqrt{2}/3)$	$p(n,\Delta^{+})n = p(n,p\pi^{0})n$	$(-2/3)$
$n(n,p)\Delta^{-} = n(n,p)n\pi^{-}$	$(\sqrt{2})$	$n(n,\Delta^{0})n = n(n,p\pi^{-})n$	$(-\sqrt{2}/3)$

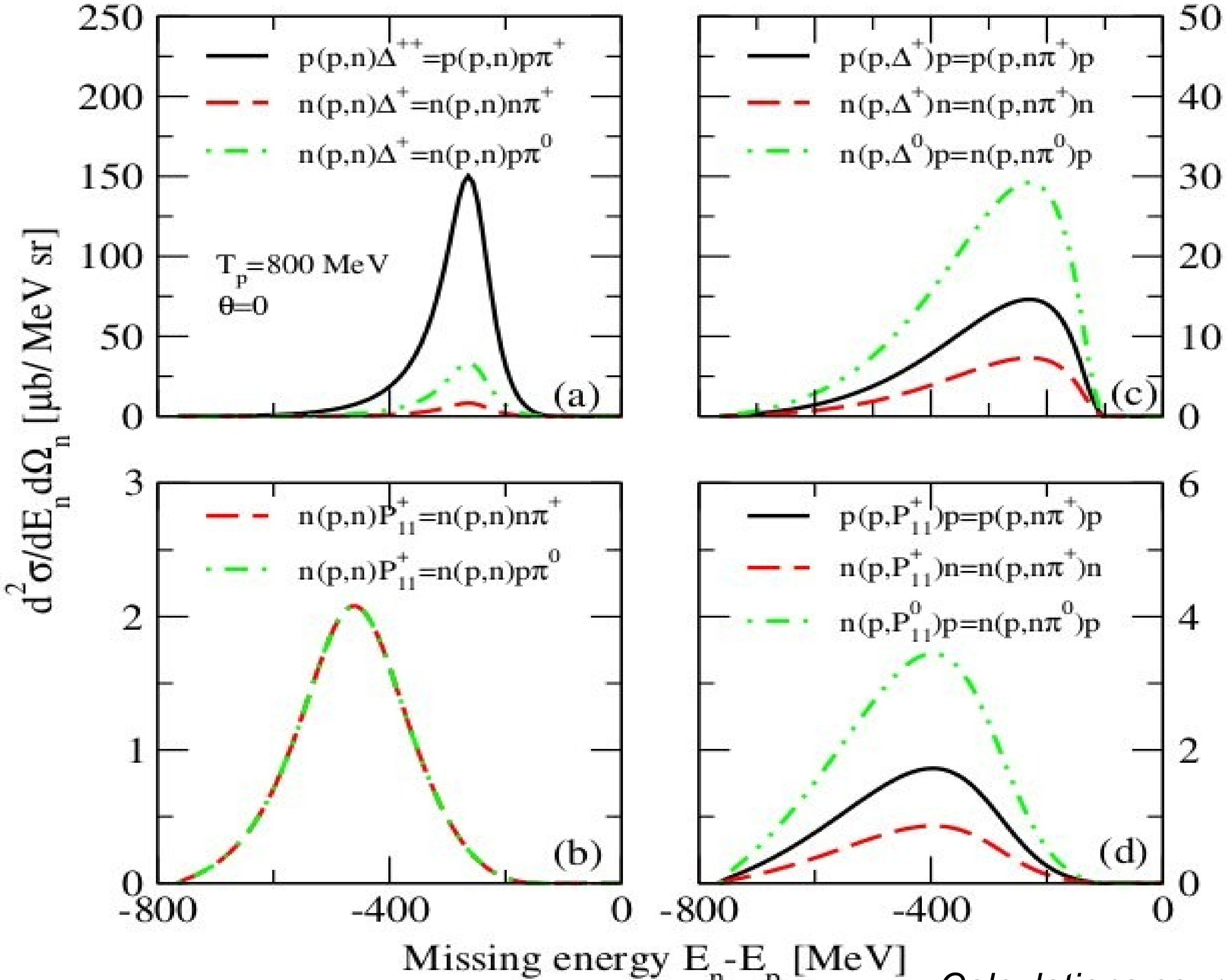
$N^*(1440)$ excitation

Excitation in the Target		Excitation in the Projectile	
$p(n,p)P_{11}^{0} = p(n,p)n\pi^{0}$	(-2)	$p(n,P_{11}^{0})p = p(n,p\pi^{-})p$	$(-\sqrt{2})$
$p(n,p)P_{11}^{0} = p(n,p)p\pi^{-}$	$(2\sqrt{2})$	$p(n,P_{11}^{+})n = p(n,p\pi^{0})n$	(-2)
		$n(n,P_{11}^{0})n = n(n,p\pi^{-})n$	$(\sqrt{2})$

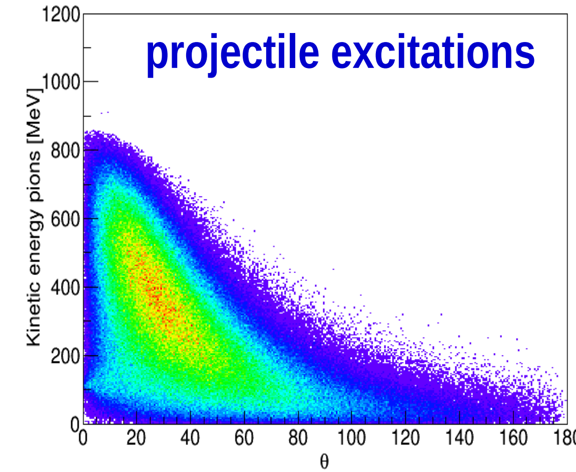
Excitation of baryon resonances in projectile and target

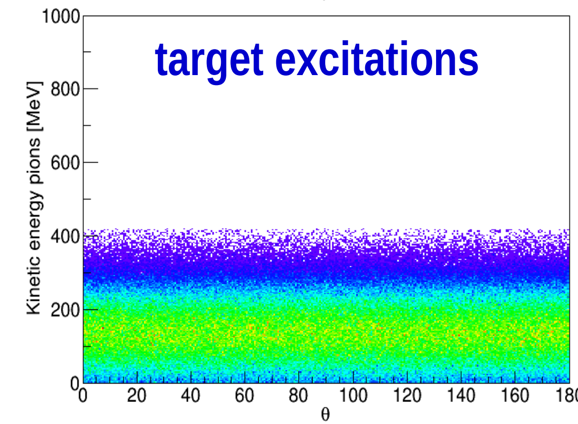
target excitations

projectile excitations



Pion kinematics





Calculations courtesy of Isaac Vidaña