Nucleon Resonances in Isobaric Charge Exchange Reactions

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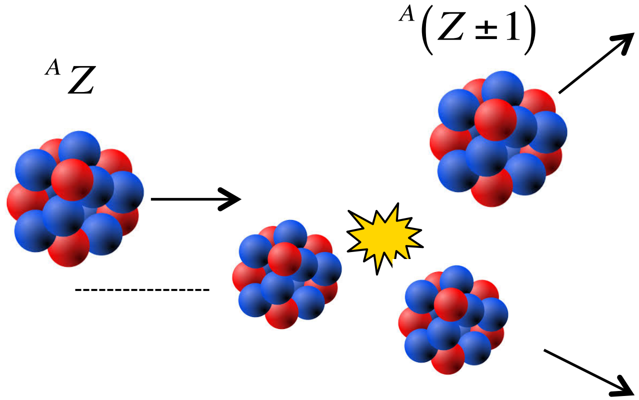
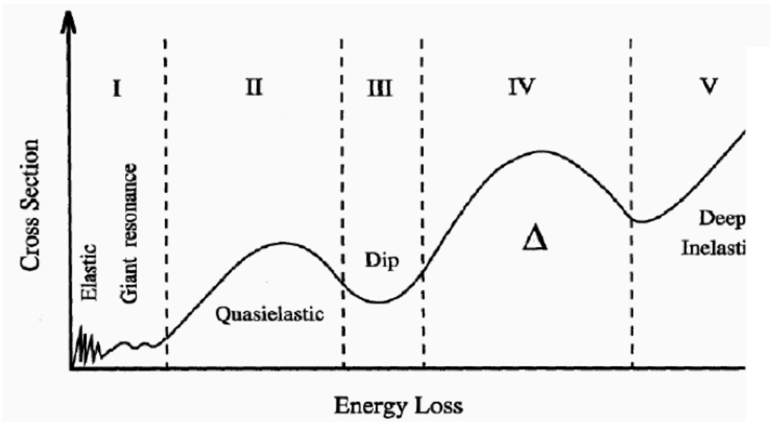
Motivation

✧ Charge exchange reactions:

- Are important tools to study the spin-isospin dependence of the nuclear force
- Allow the investigation of nucleon (spin-isospin) excitations in nuclei
- Being peripheral they can provide information on radial distributions (tail) of protons and neutrons





Ericson & Weise (1988)

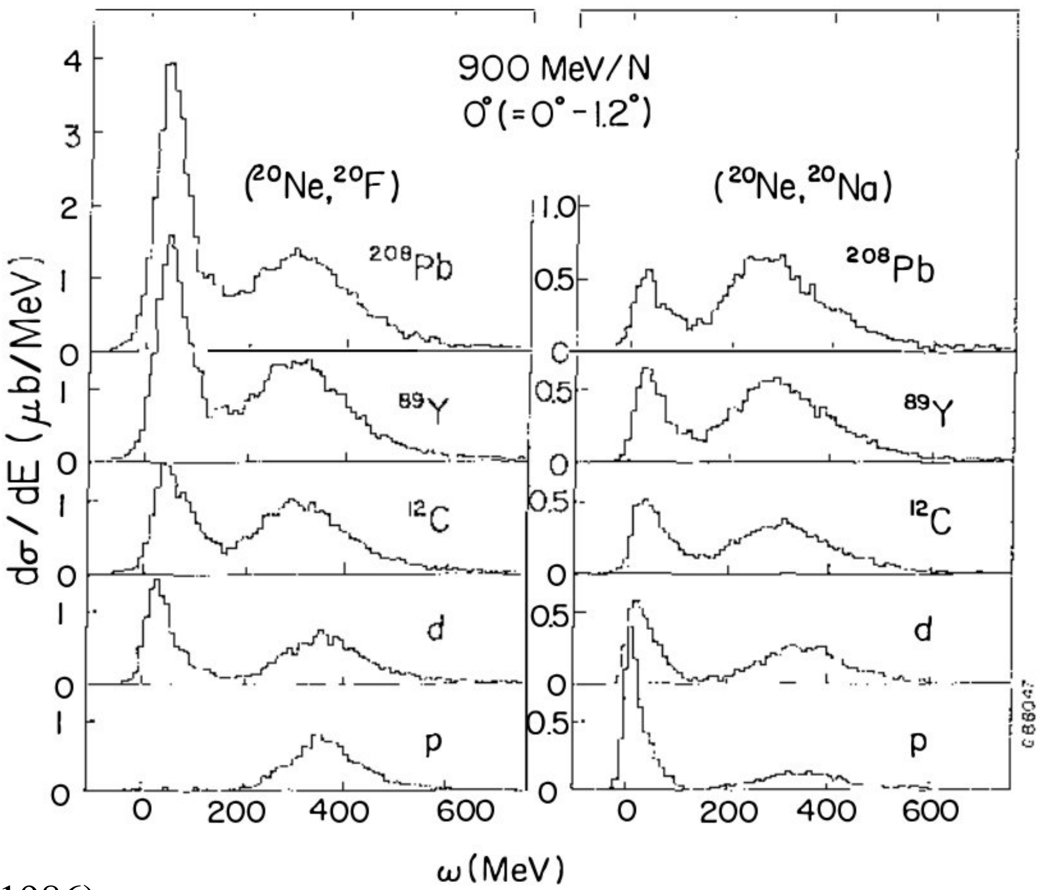
✓ Low energies: GT, spin-dipole, spin-quadrupole, quasi-elastic

✓ High energies: excitation of a nucleon into Δ, N^*, …

Past measurements of Charge Exchange Reactions

1980's complete experimental program to measure Δ excitation in nucleus-nucleus collisions with light & medium mass projectiles at SATURNE accelerator in Saclay

(p,n) reactions (n,p) reactions



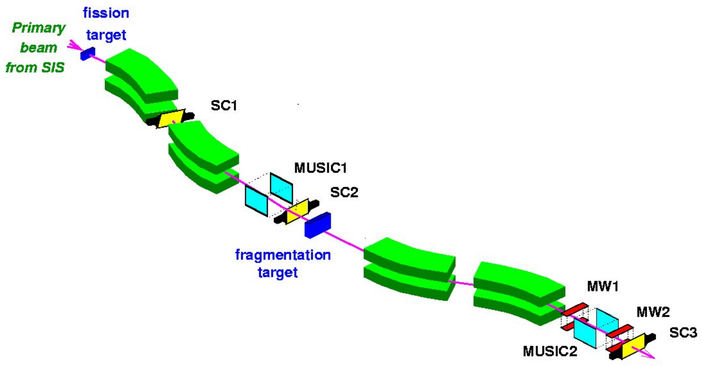
Shift of the Δ peak to lower energies for medium & heavy targets

What's its origin ?

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

Recent measurements

Recent measurements have been performed with the FRS at GSI using stable (^{112}Sn, ^{124}Sn) & unstable (^{110}Sn, ^{120}Sn, ^{122}Sn) tin projectiles



Isotopic identification of Ejectile

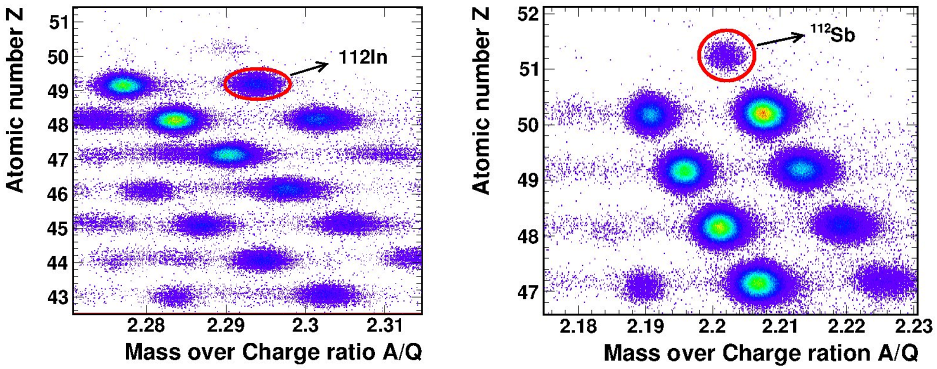
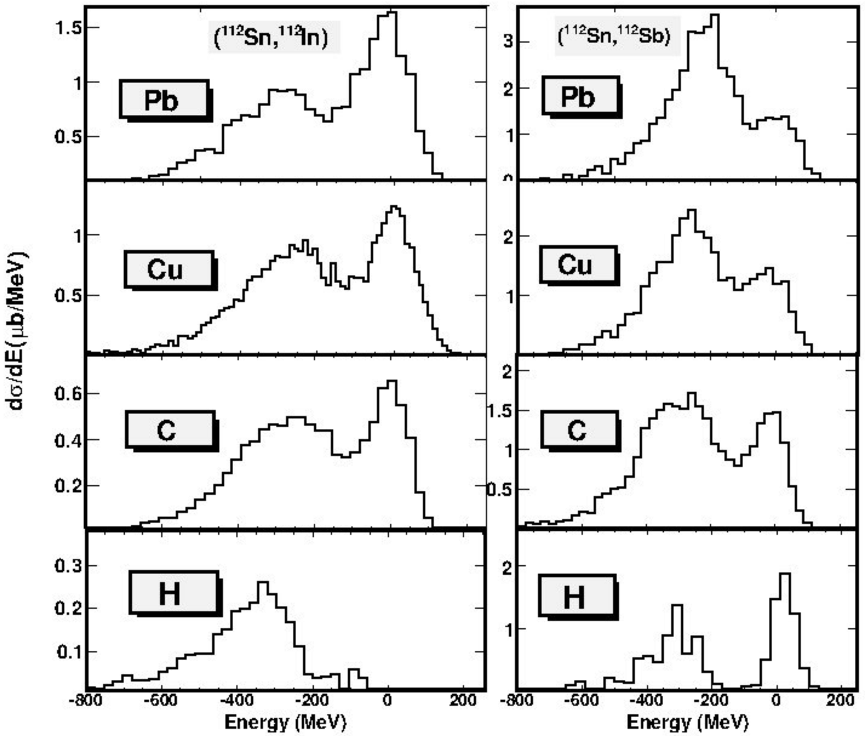


Figure courtesy of J. Benlliure & J. W. Vargas



Qualitative agreement with the results of SATURNE

J. W. Vargas, Ph.D. (Univ. Santiago de Compostela 2014)

In this talk …

I will present a theoretical study of nucleon (Δ, N^*) resonances in isobaric charge exchange reactions

- **Nucleon resonances in nucleon-nucleon reactions:**
  - Model based on OPE+short range correlations (Landau-Migdal parameter)
  - Δ & N* excitation in Target & Projectile
- **From nucleon-nucleon to nucleus-nucleus:**
  - (^{112}Sn,^{112}In) & (^{112}Sn, ^{112}Sb) reactions
  - (^{124}Sn,^{124}In) & (^{124}Sn, ^{124}Sb) reactions

Nucleon resonances in nucleon-nucleon reactions

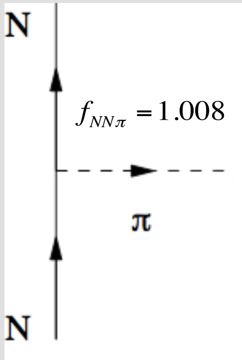
Effective NNπ, NΔπ & NN*π couplings

✧ NNπ vertex

$$L_{NN\pi} = -\frac{f_{NN\pi}}{m_\pi}\bar{\psi}_N \gamma^\mu \gamma_5 \partial_\mu \vec{\phi}\cdot\vec{\tau}\psi_N$$

NR approx. ⟶

$$L^{NR}_{NN\pi} = \frac{f_{NN\pi}}{m_\pi}\varphi^+_N \sigma_i \partial_i \vec{\phi}\cdot\vec{\tau}\varphi_N$$

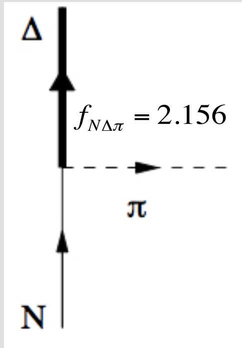


✧ NΔπ vertex

$$L_{N\Delta\pi} = \frac{f_{N\Delta\pi}}{m_\pi}\bar{\psi}^\mu_\Delta \vec{T}^+ \left[g_{\mu\nu} - z\gamma_\mu\gamma_\nu\right]\partial_\nu \vec{\phi}\psi_N + h.c.$$

NR approx. ⟶

$$L^{NR}_{N\Delta\pi} = \frac{f_{N\Delta\pi}}{m_\pi}\varphi^+_\Delta S^+_i \partial_i \vec{\phi}\cdot\vec{T}^+\varphi_N + h.c.$$

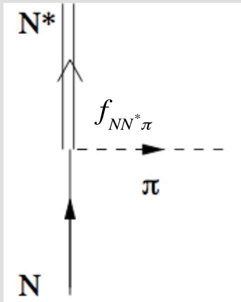


✧ NN*π vertex

$$L_{NN^*\pi} = -\frac{f_{NN^*\pi}}{m_\pi}\bar{\psi}_{N^*} \gamma^\mu \gamma_5 \partial_\mu \vec{\phi}\cdot\vec{\tau}\psi_N + h.c.$$

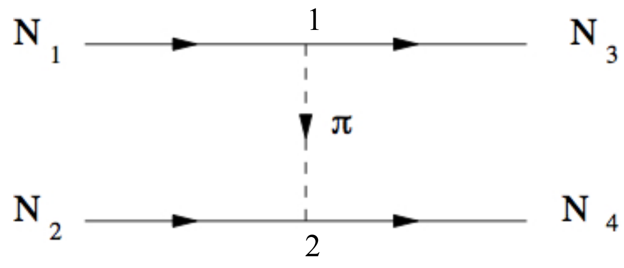
NR approx. ⟶

$$L^{NR}_{NN^*\pi} = \frac{f_{NN^*\pi}}{m_\pi}\varphi^+_{N^*} \sigma_i \partial_i \vec{\phi}\cdot\vec{\tau}\varphi_N + h.c.$$



Elementary Processes

✧ Quasi-elastic channel



- Cross section

$$\frac{d^2\sigma}{dE_3 d\Omega_3} = \frac{2|\vec{p}_3|}{(2\pi)^2} \frac{m_1 m_2 m_3 m_4}{\lambda^{1/2}\left(s, m_1^2, m_2^2\right)} \frac{1}{E_4} \bar{\sum}\sum |M|^2 \delta\left(E_1 + E_2 - \sum_f E_f\right)$$

- Scattering amplitude

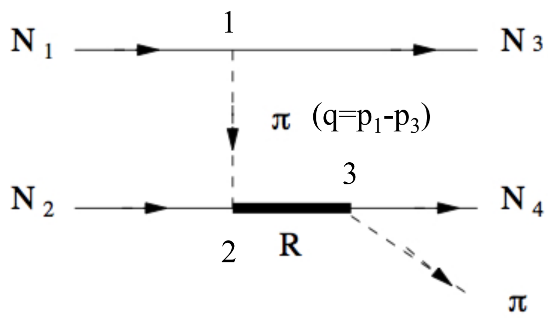
$$M = \left(\frac{f_{NN\pi}}{m_\pi}\right)^2 F_{NN\pi}\left(|\vec{q}|\right)^2 \left[\langle s_3 s_4 | \vec{\sigma}_1 \cdot \vec{q} \vec{\sigma}_2 \cdot \vec{q} | s_1 s_2 \rangle D_\pi\left(|\vec{q}|\right) + g' \langle s_3 s_4 | \vec{\sigma}_1 \cdot \vec{\sigma}_2 | s_1 s_2 \rangle\right] \langle t_3 t_4 | \vec{\tau}_1 \cdot \vec{\tau}_2 | t_1 t_2 \rangle$$

where: $F_{NN\pi}\left(|\vec{q}|\right) = \frac{\Lambda_{NN\pi}^2 - m_\pi^2}{\Lambda_{NN\pi}^2 + |\vec{q}|^2}$ NNπ vertex form factor ($\Lambda_{NN\pi}$=1.3 GeV)

$D_\pi\left(|\vec{q}|\right) = -\frac{1}{|\vec{q}|^2 + m_\pi^2}$ π propagator

$g' = 0.7 - 0.8$ Landau-Migdal parameter (short range correlations)

✧ Inelastic channel: (Excitation in Target)



- Cross section

$$\frac{d^2\sigma}{dE_3 d\Omega_3} = \frac{1}{S}\frac{|\vec{p}_3|}{(2\pi)^5}\frac{m_1 m_2 m_3 m_4}{\lambda^{1/2}\left(s, m_1^2, m_2^2\right)}\int \frac{d^3\vec{p}_\pi}{E_4 E_\pi}\overline{\sum}\sum |M|^2 \delta\left(E_1 + E_2 - \sum_f E_f\right)$$

- Scattering amplitude

Δ:

$$M = \frac{f_{NN\pi} f_{N\Delta\pi}^2}{m_\pi^3} F_{NN\pi}\left(|\vec{q}|\right) F_{N\Delta\pi}\left(|\vec{q}|\right) F_{N\Delta\pi}\left(|\vec{p}_\pi|\right) D_\pi\left(|\vec{q}|\right) D_\Delta(\sqrt{s_T}) \times SIF$$

$$SIF = \langle s_3 s_\Delta | \vec{\sigma}_1 \cdot \vec{q}\vec{S}_2^+ \cdot \vec{q} | s_1 s_2 \rangle \langle s_4 | \vec{S}_3 \cdot \vec{p}_\pi | s_\Delta \rangle \langle t_3 t_\Delta | \vec{\tau}_1 \cdot \vec{T}_2^+ | t_1 t_2 \rangle \langle t_4 | \vec{T}_3 \cdot \vec{\phi} | t_\Delta \rangle$$

N*:

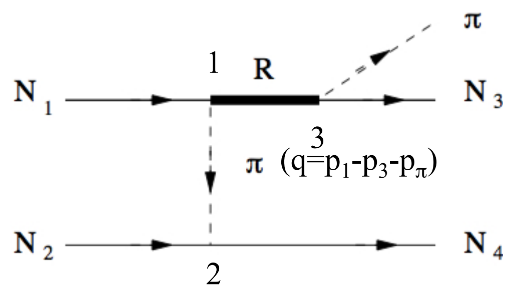
$$M = \frac{f_{NN\pi} f_{NN^*\pi}^2}{m_\pi^3} F_{NN\pi}\left(|\vec{q}|\right) F_{NN^*\pi}\left(|\vec{q}|\right) F_{NN^*\pi}\left(|\vec{p}_\pi|\right) D_\pi\left(|\vec{q}|\right) D_{N^*}(\sqrt{s_T}) \times SIF$$

$$SIF = \langle s_3 s_{N^*} | \vec{\sigma}_1 \cdot \vec{q}\vec{\sigma}_2 \cdot \vec{q} | s_1 s_2 \rangle \langle s_4 | \vec{\sigma}_3 \cdot \vec{p}_\pi | s_{N^*} \rangle \langle t_3 t_{N^*} | \vec{\tau}_1 \cdot \vec{\tau}_2 | t_1 t_2 \rangle \langle t_4 | \vec{\tau}_3 \cdot \vec{\phi} | t_\Delta \rangle$$

where: $s_T = (p_2 + p_1 - p_3)^2$ Δ/N* invariant mass

$$D_R(\sqrt{s_T}) = \frac{1}{\sqrt{s_T} - m_R + i\Gamma(\sqrt{s_T})/2}$$ Δ/N* propagator $$\Gamma(\sqrt{s_T}) = \Gamma(m_R)\frac{p_{\pi,cm}^3(\sqrt{s_T})}{p_{\pi,cm}^3(m_R)}$$

✧ Inelastic channel: (Excitation in Projectile)



- Cross section

$$\frac{d^2\sigma}{dE_3 d\Omega_3} = \frac{1}{S}\frac{|\vec{p}_3|}{(2\pi)^5}\frac{m_1 m_2 m_3 m_4}{\lambda^{1/2}(s, m_1^2, m_2^2)}\int \frac{d^3\vec{p}_\pi}{E_4 E_\pi}\bar{\Sigma}\Sigma|M|^2\delta\left(E_1 + E_2 - \sum_f E_f\right)$$

- Scattering amplitude

Δ:

$$M = \frac{f_{NN\pi} f_{N\Delta\pi}^2}{m_\pi^3} F_{NN\pi}(|\vec{q}|) F_{N\Delta\pi}(|\vec{q}|) F_{N\Delta\pi}(|\vec{p}_\pi|) D_\pi(|\vec{q}|) D_\Delta(\sqrt{s_P}) \times SIF$$

$$SIF = \langle s_\Delta s_4 | \vec{S}_1^+ \cdot \vec{q}\vec{\sigma}_2 \cdot \vec{q} | s_1 s_2 \rangle \langle s_3 | \vec{S}_3 \cdot \vec{p}_\pi | s_\Delta \rangle \langle t_\Delta t_4 | \vec{T}_1^+ \cdot \vec{\tau}_2 | t_1 t_2 \rangle \langle t_3 | \vec{T}_3 \cdot \vec{\phi} | t_\Delta \rangle$$

N*:

$$M = \frac{f_{NN\pi} f_{NN^*\pi}^2}{m_\pi^3} F_{NN\pi}(|\vec{q}|) F_{NN^*\pi}(|\vec{q}|) F_{NN^*\pi}(|\vec{p}_\pi|) D_\pi(|\vec{q}|) D_{N^*}(\sqrt{s_P}) \times SIF$$

$$SIF = \langle s_{N^*} s_4 | \vec{\sigma}_1 \cdot \vec{q}\vec{\sigma}_2 \cdot \vec{q} | s_1 s_2 \rangle \langle s_3 | \vec{\sigma}_3 \cdot \vec{p}_\pi | s_{N^*} \rangle \langle t_{N^*} t_4 | \vec{\tau}_1 \cdot \vec{\tau}_2 | t_1 t_2 \rangle \langle t_3 | \vec{\tau}_3 \cdot \vec{\phi} | t_\Delta \rangle$$

where: $s_P = (p_3 + p_\pi)^2$ Δ(N*) invariant mass

$$F_{NR\pi}(|\vec{q}|) = \frac{\Lambda_{NR\pi}^2 - m_\pi^2}{\Lambda_{NR\pi}^2 + |\vec{q}|^2}$$

NRπ vertex form factor ($\Lambda_{N\Delta\pi}$=0.65 GeV, $\Lambda_{NN^*\pi}$=1.3 GeV)

(p,n) reactions

$\Delta(1232)$ excitation

Excitation in the Target

$$p(p,n)\Delta^{++} = p(p,n)p\pi^{+} \quad (\sqrt{2})$$

$$n(p,n)\Delta^{+} = n(p,n)n\pi^{+} \quad (\sqrt{2}/3)$$

$$n(p,n)\Delta^{+} = n(p,n)p\pi^{0} \quad (-2/3)$$

Excitation in the Projectile

$$p(p,\Delta^{+})p = p(p,n\pi^{+})p \quad (-\sqrt{2}/3)$$

$$n(p,\Delta^{+})n = n(p,n\pi^{+})n \quad (\sqrt{2}/3)$$

$$n(p,\Delta^{0})p = n(p,n\pi^{0})p \quad (2/3)$$

$N^{*}(1440)$ excitation

Excitation in the Target

$$n(p,n)P_{11}^{+} = n(p,n)n\pi^{+} \quad (2\sqrt{2})$$

$$n(p,n)P_{11}^{+} = n(p,n)p\pi^{0} \quad (-2)$$

Excitation in the Projectile

$$p(p,P_{11}^{+})p = p(p,n\pi^{+})p \quad (-\sqrt{2})$$

$$n(p,P_{11}^{+})n = n(p,n\pi^{+})n \quad (\sqrt{2})$$

$$n(p,P_{11}^{0})p = n(p,n\pi^{0})p \quad (-2)$$

(n,p) reactions

Δ(1232) excitation

Excitation in the Target

$p(n,p)\Delta^0 = p(n,p)n\pi^0 \quad (2/3)$

$p(n,p)\Delta^0 = p(n,p)p\pi^- \quad (\sqrt{2}/3)$

$n(n,p)\Delta^- = n(n,p)n\pi^- \quad (\sqrt{2})$

Excitation in the Projectile

$p(n,\Delta^0)p = p(n,p\pi^-)p \quad (\sqrt{2}/3)$

$p(n,\Delta^+)n = p(n,p\pi^0)n \quad (-2/3)$

$n(n,\Delta^0)n = n(n,p\pi^-)n \quad (-\sqrt{2}/3)$

N*(1440) excitation

Excitation in the Target

$p(n,p)P_{11}^0 = p(n,p)n\pi^0 \quad (-2)$

$p(n,p)P_{11}^0 = p(n,p)p\pi^- \quad (2\sqrt{2})$

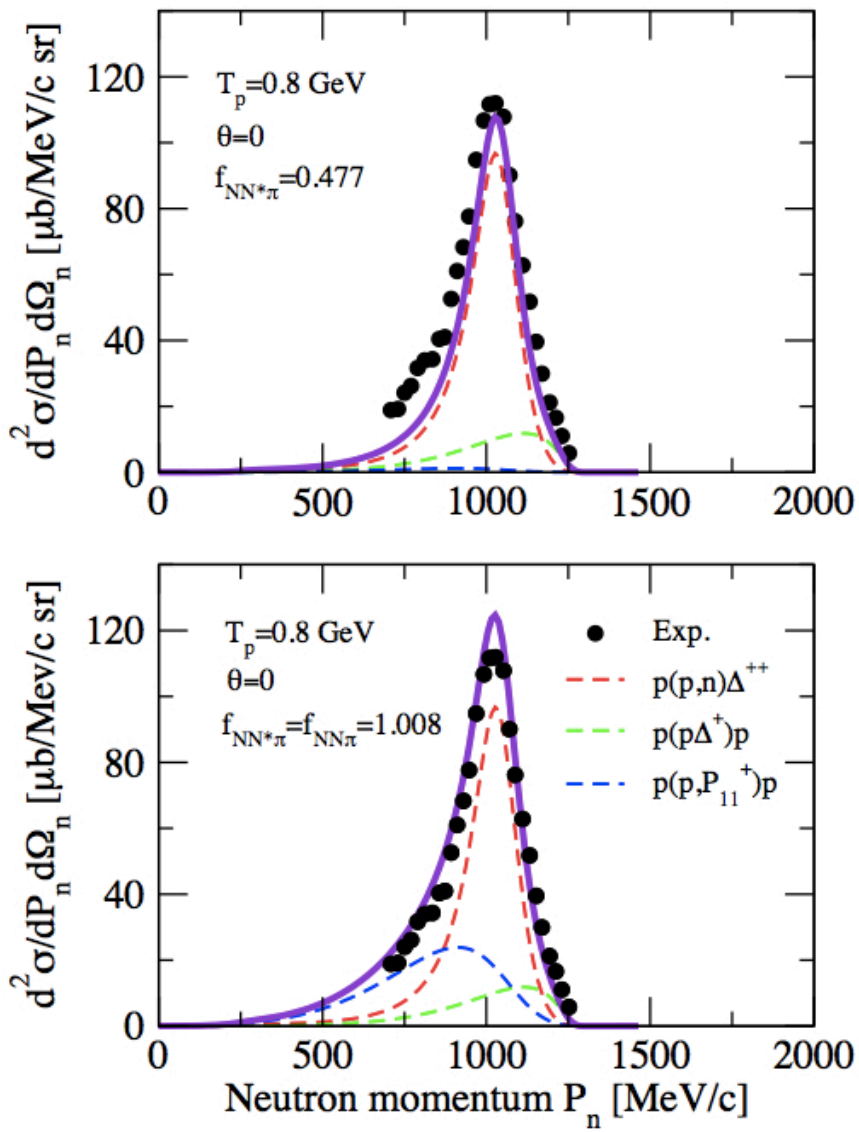
Excitation in the Projectile

$p(n,P_{11}^0)p = p(n,p\pi^-)p \quad (-\sqrt{2})$

$p(n,P_{11}^+)n = p(n,p\pi^0)n \quad (-2)$

$n(n,P_{11}^0)n = n(n,p\pi^-)n \quad (\sqrt{2})$

Example: (p,n) reaction on a proton target



Contribution from 3 processes

✧ Δ^{++} excitation in Target

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

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

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

- Dominance of Δ^{++} excitation in the target
- Better agreement with data if $f_{NN^*\pi}=f_{NN\pi}=1.008$

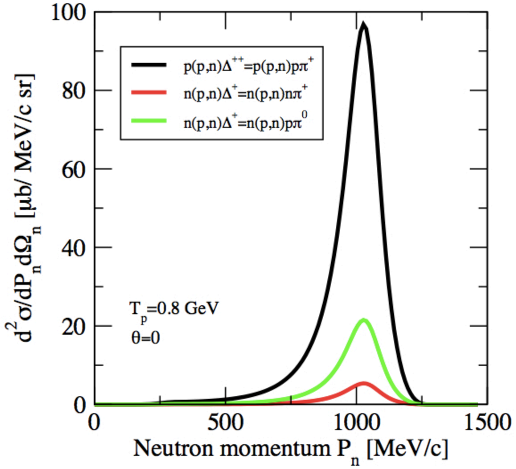
($f_{NN^*\pi}$=0.477 from Gómez-Tejedor & Oset, NPA 571, 667 (1994))

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

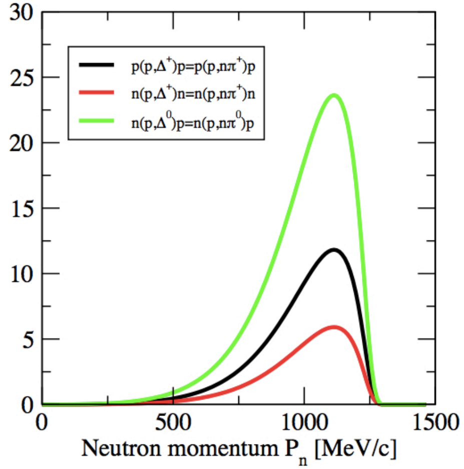
Elementary (p,n) cross sections

✧ Δ(1232) excitation

Excitation in Target

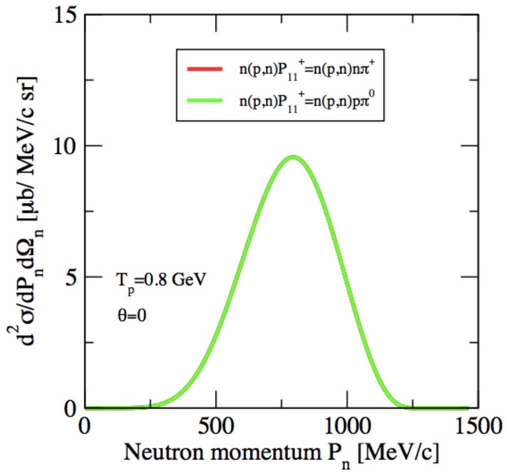


Excitation in Projectile

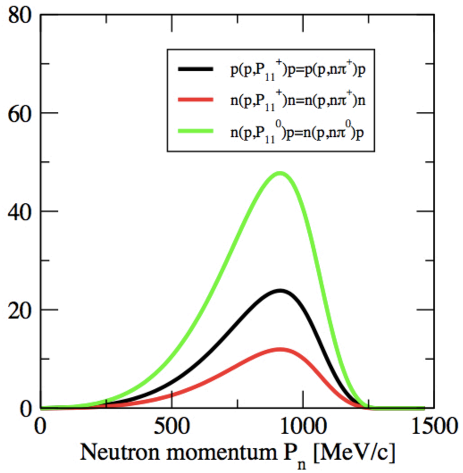


✧ N*(1440) excitation

Excitation in Target



Excitation in Projectile



Different shape & strength of c.s.
→ shift reson. pos. in nuclei ?

✓ Reaction with a proton Target

- c.s. of Δ excitation in target ~ 9 times larger than c.s. of Δ excitation in projectile

✓ Reaction with a neutron Target

- similar strength of the c.s.

✓ Reaction with a proton Target

- P_{11}^{+} excited only in Projectile

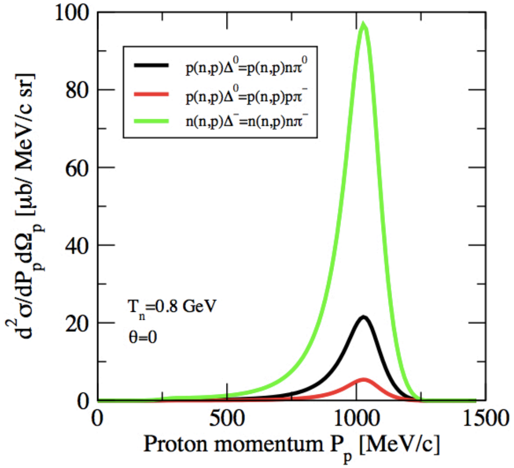
✓ Reaction with a neutron Target

- strength of c.s. for N* excitation in projectile ~ 1 - 5 than of N* in target

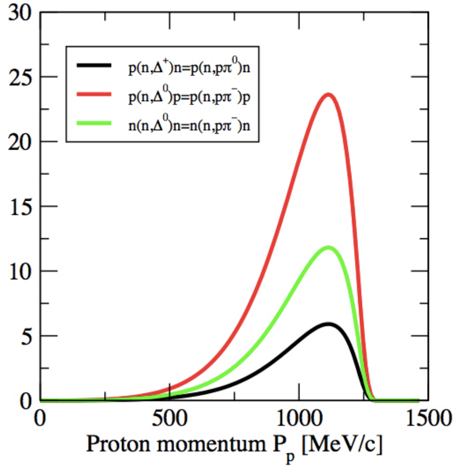
Elementary (n,p) cross sections

✧ Δ(1232) excitation

Excitation in Target



Excitation in Projectile



✓ Reaction with a proton Target

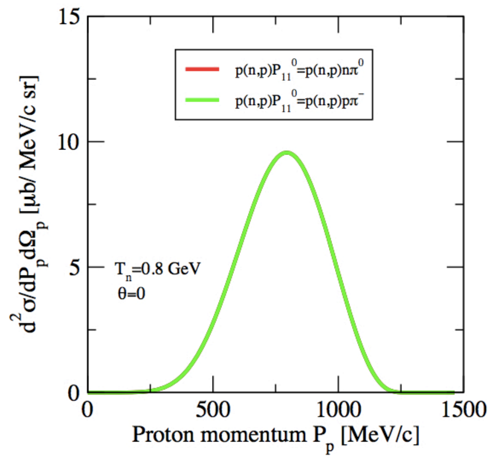
- similar strength of the c.s.

✓ Reaction with a neutron Target

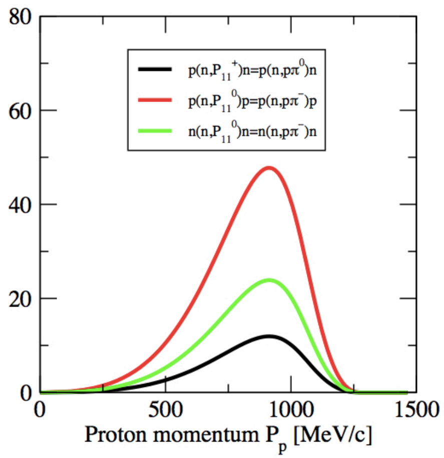
- c.s. of Δ excitation in target ~ 9 times larger than c.s. of Δ excitation in projectile

✧ N^*(1440) excitation

Excitation in Target



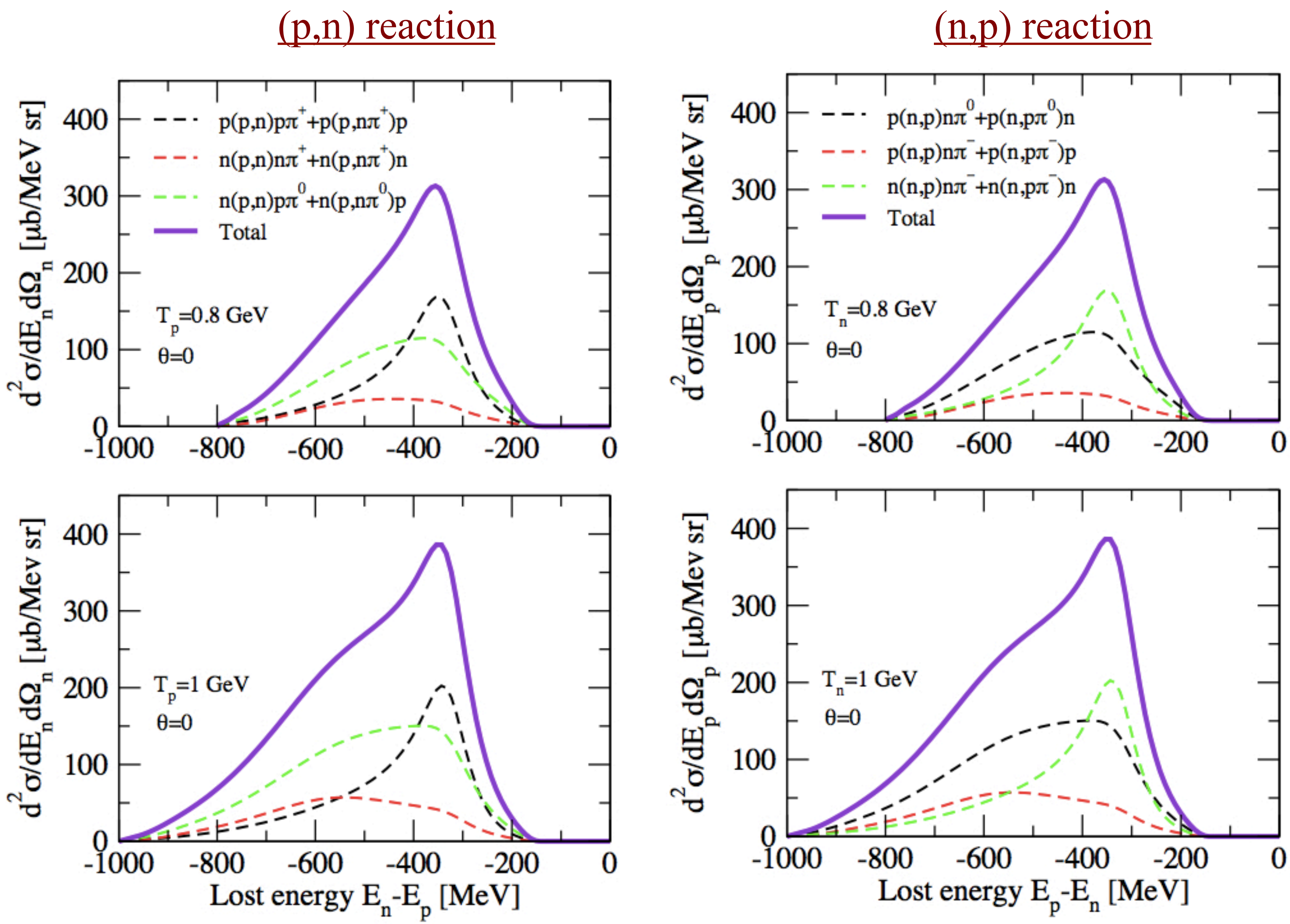
Excitation in Projectile



✓ N^* excited in reaction with both proton & neutron targets

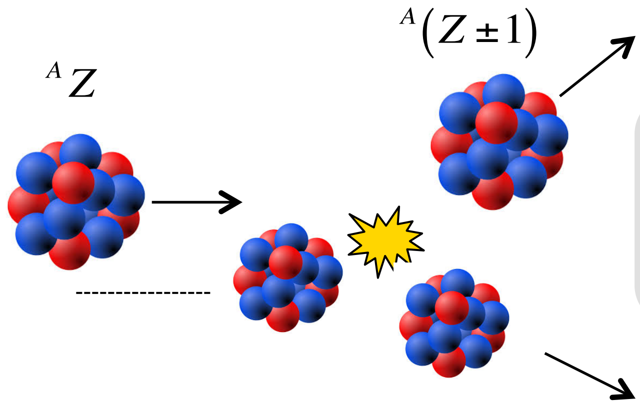
- P_{11}^{+} state excited only in projectile
- P_{11}^{0} state excited both in projectile & target.
- strength of c.s. for N^* excitation in projectile ~ 1 - 5 than of N^* in target

Total elementary cross sections



From nucleon-nucleon to nucleus-nucleus collisions

Eikonal Description



$$d\sigma = \frac{8M_P M_T M_E M_R}{\lambda^{1/2}\left(s, M_P^2, M_T^2\right)} \prod_f \frac{d^3\vec{p}_f}{(2\pi)^3 2E_f} \bar{\Sigma}\Sigma \left|M\right|^2 (2\pi)^4 \delta^4\left(P_P + P_T - \sum_f P_f\right)$$

- Matrix element (DWBA)

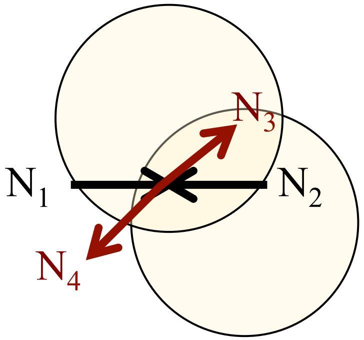
✧ Quasi-elastic channel $\quad M \propto \int \exp\left[i\chi(b)\right] \sum \left\langle \phi_N^E \phi_N^R \middle| V \middle| \phi_N^P \phi_N^T \right\rangle$

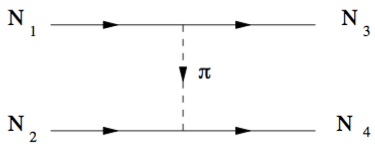
✧ Inelastic channel $\quad M \propto \int \exp\left[i\chi(b)\right] \times \left(T_1 + T_2\right)$

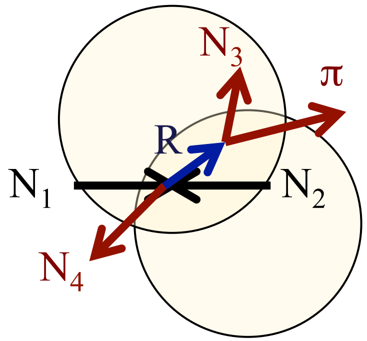
where: $T_1 = \sum \left\langle \phi_N^R \pi \middle| \hat{O} \middle| \phi_{\Delta/N^*}^R \right\rangle D_{\Delta/N^*} \left\langle \phi_N^E \phi_{\Delta/N^*}^R \middle| \tilde{V} \middle| \phi_N^P \phi_N^T \right\rangle$ Excitation in Target

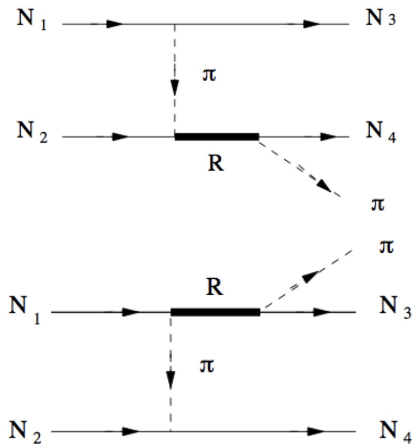
$T_2 = \sum \left\langle \phi_N^E \pi \middle| \hat{O} \middle| \phi_{\Delta/N^*}^E \right\rangle D_{\Delta/N^*} \left\langle \phi_{\Delta/N^*}^E \phi_N^R \middle| \tilde{V} \middle| \phi_N^P \phi_N^T \right\rangle$ Excitation in Projectile

$\hat{O}$ spin-isospin transition operator $\qquad \chi(b)$ eikonal phase









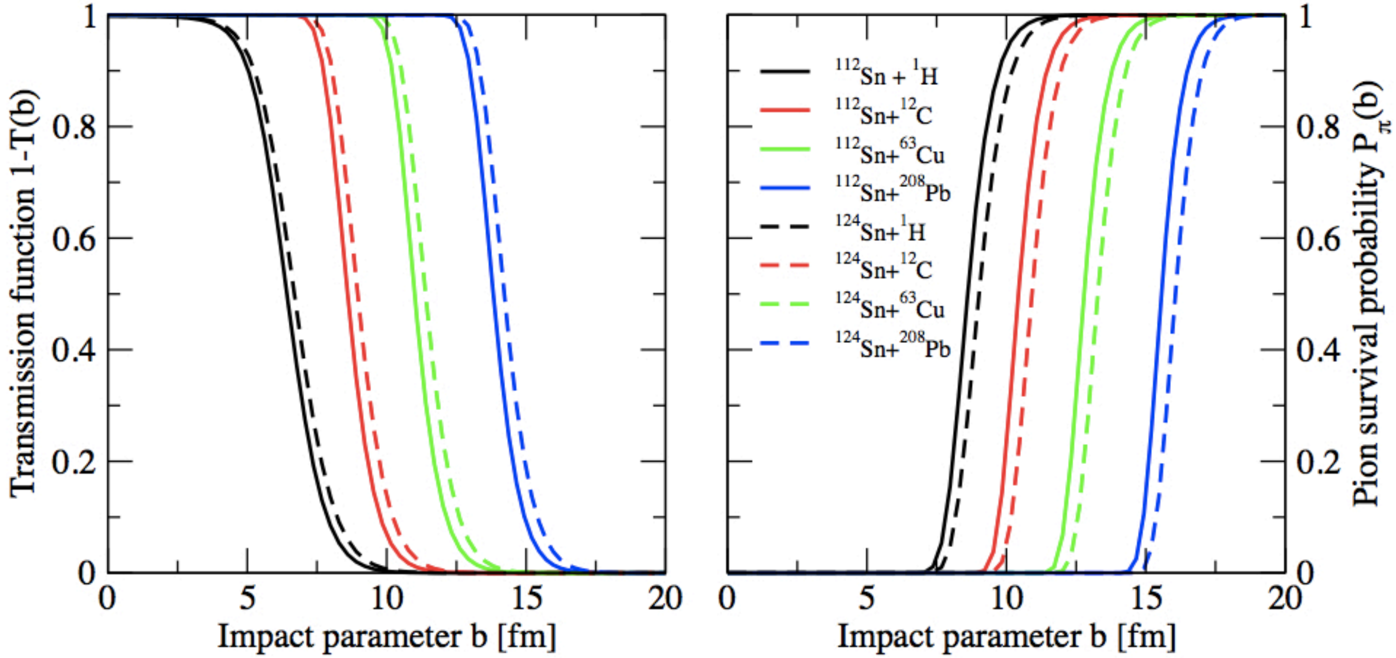
$$\left.\frac{d^2\sigma}{dEd\Omega}\right|_{({}^{A}Z,{}^{A}(Z\pm 1))} = \sum_{N_2=n,p} \frac{d^2\sigma}{dE_3 d\Omega_3} \times N_{N_1N_2}, \quad N_1 = n, p$$

- Number of elementary processes contributing to the reaction:

$$N_{N_1N_2} = \int d^2\vec{b}\,\rho^{N_1N_2}_{overlap}(b)\left[1 - T(b)\right]P_\pi(b)$$

- ✓ N_1N_2 density of overlap region $\rho^{N_1N_2}_{overlap}(b) = \int dz \int d^3\vec{r}\,\rho^{N_1}_P(\vec{r})\rho^{N_2}_T(\vec{b}+\vec{z}+\vec{r})$
- ✓ Transparency function $T(b) = \exp\left(-\int dz \int d^3\vec{r}\,\sigma_{NN}\rho_P(\vec{r})\rho_T(\vec{b}+\vec{z}+\vec{r})\right)$
- ✓ Pion survival probability $P_\pi(b) = \exp\left(-\int dz \int d^3\vec{r}\,\sigma_{\pi N}\rho_P(\vec{r})\rho_T(\vec{b}+\vec{z}+\vec{r})\right)$

Transmission Function & Pion Survival Probability



$$1 - T(b) = 1 - \exp\left(-\int dz \int \sigma_{NN}(E,\rho,\beta)\,\rho_P(\vec{r})\,\rho_T\left(\vec{b}+\vec{z}+\vec{r}\right)d^3\vec{r}\right)$$

$$P_\pi(b) = \exp\left(-\int dz \int \sigma_{\pi N}(E,\rho,\beta)\,\rho_P(\vec{r})\,\rho_T\left(\vec{b}+\vec{z}+\vec{r}\right)d^3\vec{r}\right)$$

in-medium NN, πN cross sections

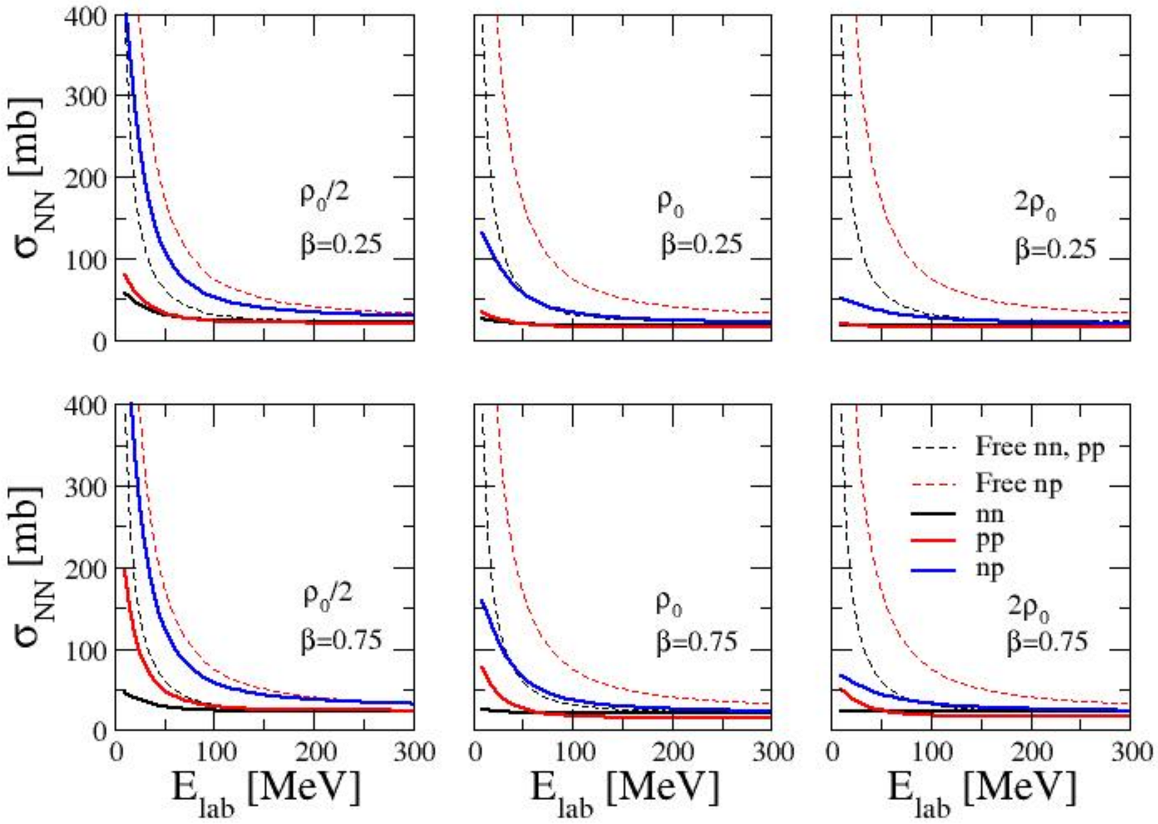
Density distributions from RMF (FSU model)

However, reaction very peripheral
→ small densities

In-medium NN cross sections

G-matrix gives access to in-medium NN cross sections

$$\sigma_{\tau\tau'} = \frac{m^*_\tau m^*_{\tau'}}{16\pi^2\hbar^4} \sum_{LL'SJ} \frac{2J+1}{4\pi} \left| G^{LL'SJ}_{\tau\tau' \to \tau\tau'} \right|^2, \quad \tau\tau' = nn, pp, np$$

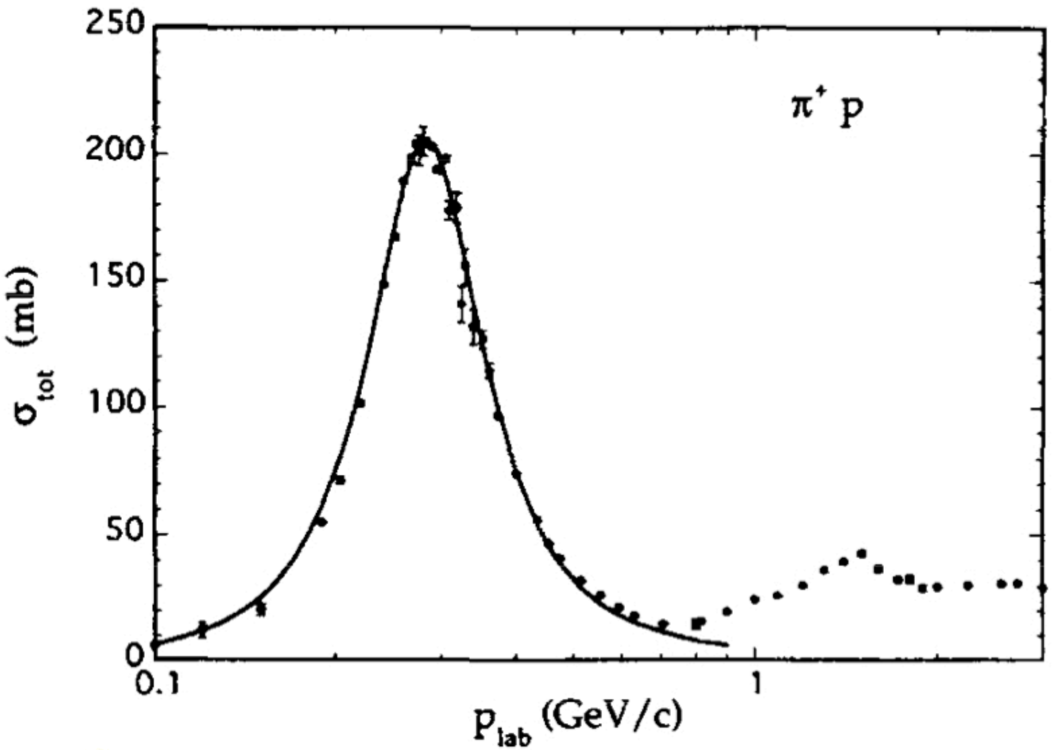


- ✓ microscopically based
- ✓ density dependence (Pauli blocking)
- ✓ isospin dependence (ρ_n different from ρ_p)

We use, however, free NN cross sections

Total πN scattering cross section

$\sigma_{\pi N}$ is largerly dominated by the Δ resonance



J. Cugnon et al., Nuc. Inst. & Met. Phys. Res. B 111, 215 (1996)

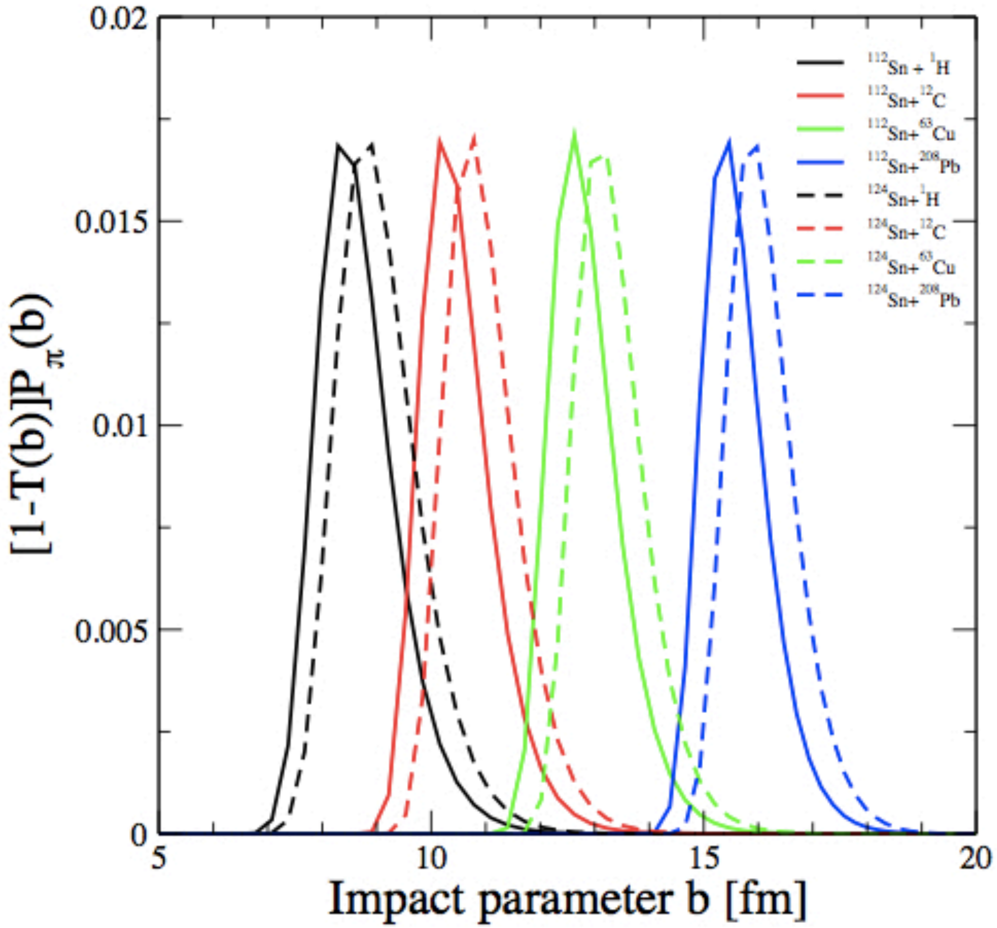
$$\sigma_{\pi^+ p \to \Delta^{++}} = 3\sigma_{\pi^+ n \to \Delta^+} = \frac{3}{2}\sigma_{\pi^0 p \to \Delta^+}$$

$$= \frac{3}{2}\sigma_{\pi^0 n \to \Delta^0} = 3\sigma_{\pi^- p \to \Delta^0}$$

$$= \sigma_{\pi^- n \to \Delta^-}$$

We take the average of all them in the region of the Δ peak

Peripheral character of the reaction



The reaction is peripheral

✓ Low impact parameters

- Strong pion absorption makes $[1\text{-}T(b)]P_\pi(b)$ very small

✓ High impact parameters

- Short-range character of exchange potentials makes $[1\text{-}T(b)]P_\pi(b)$ very small

Number of elementary processes N_R

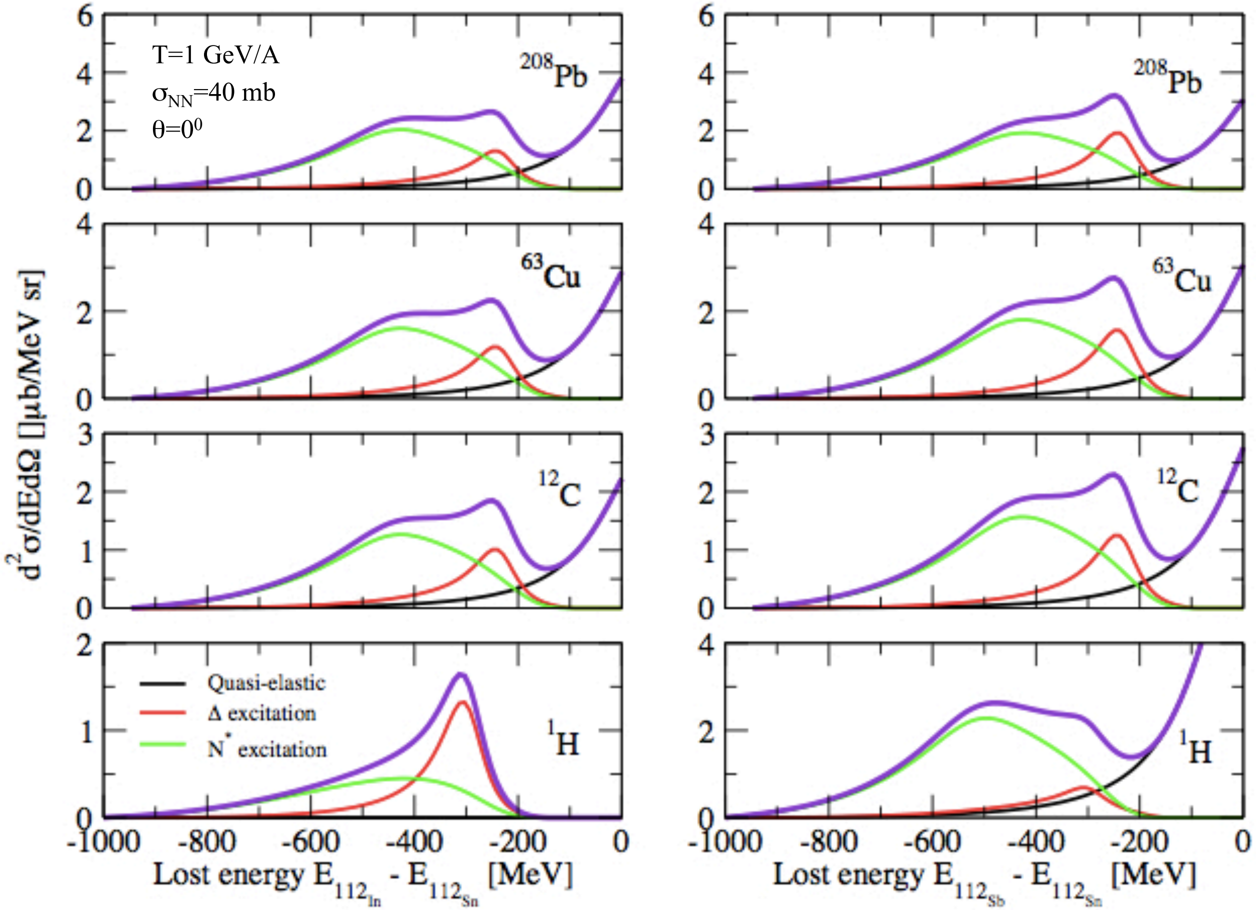
$$N_{N_1N_2} = \int d^2\vec{b}\,\rho^{N_1N_2}_{overlap}(b)\left[1-T(b)\right]P_\pi(b),\quad \rho^{N_1N_2}_{overlap}(b) = \int dz \int d^3\vec{r}\,\rho^{N_1}_P(\vec{r})\rho^{N_2}_T(\vec{b}+\vec{z}+\vec{r})$$

reaction	N_R	N_{pp}	N_{pn}	N_{np}	N_{nn}
$^{112}Sn+^{1}H$	0.018	0.006	0	0.011	0
$^{112}Sn+^{12}C$	0.019	0.003	0.003	0.007	0.006
$^{112}Sn+^{63}Cu$	0.022	0.003	0.004	0.006	0.009
$^{112}Sn+^{208}Pb$	0.027	0.001	0.007	0.004	0.015

reaction	N_R	N_{pp}	N_{pn}	N_{np}	N_{nn}
$^{124}Sn+^{1}H$	0.019	0.004	0	0.015	0
$^{124}Sn+^{12}C$	0.023	0.002	0.002	0.010	0.009
$^{124}Sn+^{63}Cu$	0.024	0.001	0.002	0.009	0.010
$^{124}Sn+^{208}Pb$	0.029	0.0006	0.003	0.005	0.020

(^{112}Sn,^{112}In) & (^{112}Sn,^{112}Sb) reactions

(^{112}Sn,^{112}In) (^{112}Sn,^{112}Sb)

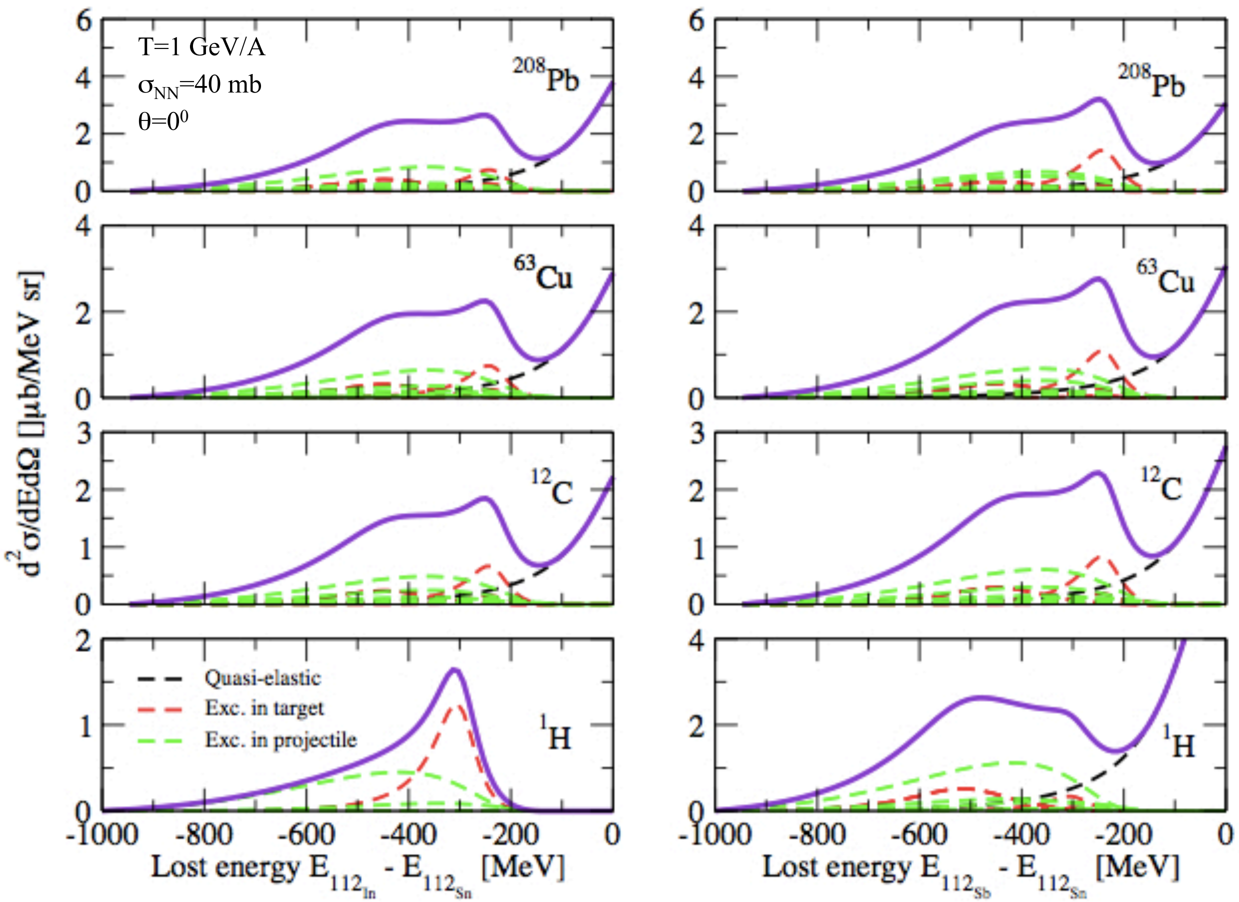


- ✓ Good agreement with experiment
- ✓ Shift of Δ peak to lower energies for medium & heavy targets

Is the shift due to in-medium effects ?. If yes, then why it seems to be almost the same for all targets ?

$(^{112}Sn,^{112}In)$ & $(^{112}Sn,^{112}Sb)$ reactions

$(^{112}Sn,^{112}In)$ $(^{112}Sn,^{112}Sb)$



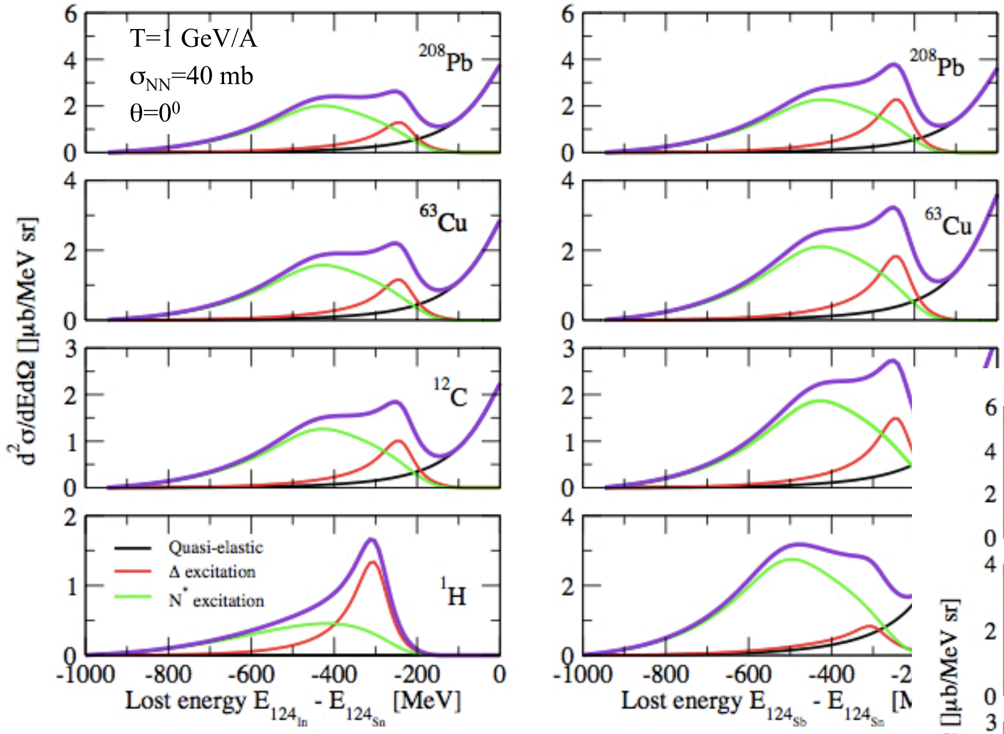
Origin of the Shift

NO: in-medium (density) modification of Δ & N^* properties because the reaction is very peripheral & density is small

YES: excitation mechanisms of Δ (N^*) in both Target & Projectile

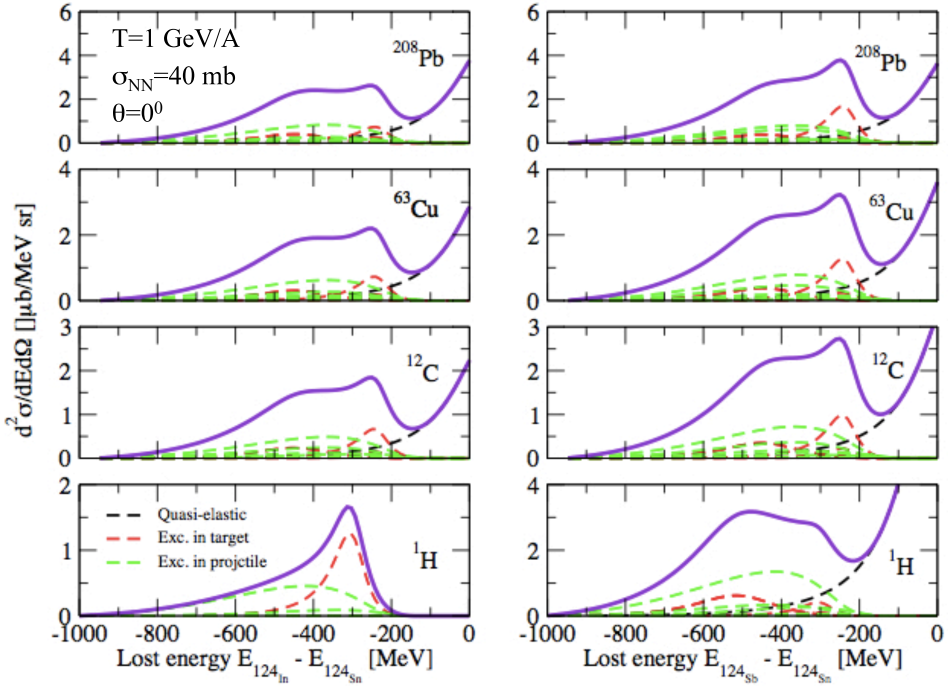
(^{124}Sn,^{124}In) & (^{124}Sn,^{124}Sb) reactions

(^{124}Sn,^{124}In) (^{124}Sn,^{124}Sb)



Similar shift of Δ peak for medium & heavy targets

(^{124}Sn,^{124}In) (^{124}Sn,^{124}Sb)



Excitation mechanisms of Δ (N*) in both Target & Projectile

Summary & Future Perspectives

✧ Summary

Study of nucleon (Δ, N*) resonances in charge exchange nucleon-nucleon & nucleus-nucleus collisions

- Model based on OPE+short range correlations. Δ & N* excitation in Target & Projectile
- Good agreement with recent measurements
- Origin of Δ shift in medium & heavy targets due to different excitation mechanisms in Target & Projectile. Not to in-medium (density) effects

✧ Future Perspectives

<u>Experiment</u>

- Exclusive measurements to identify the different reaction mechanisms

<u>Theory</u>

- Nuclear structure must be included in a better way
- Use of more realistic microscopically based densities

- My collaborators:
  J. Benlliure & J.W. Vargas (USC)

- You for your time & attention

- The organizers for their invitation

- The sponsors for their support