Pion Production in Antiproton-Nucleus Interactions

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Antiproton-**I**on-**C**ollider

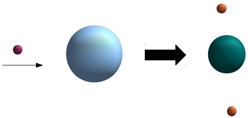
- colliding beam experiment $\longrightarrow \overline{p}$ as probes
- analyse neutron/proton properties in the same experiment
- investigate $\overline{p}$-neutron interactions
- nuclear structure studies

$\overline{N} + A \rightarrow \pi_1 + \pi_2 + B$

$$d^9\sigma_{\alpha\beta} = N_{\alpha\beta}\left(\frac{\hbar c}{2\pi}\right)^9 \frac{d^3k_1}{E_1}\frac{d^3k_2}{E_2}\frac{d^3k_B}{E_B}\left|M_{\alpha\beta}\left(\vec{k_1},\vec{k_2},\vec{k_B};\vec{k_\alpha}\right)\right|^2$$
$$\delta\left(\vec{k_1}+\vec{k_2}+\vec{k_B}\right)\delta\left(E_1+E_2+E_B-\sqrt{s}\right)$$

$$\boxed{M_{\beta\alpha} \approx g^*_{\overline{N}N\rightarrow 2\pi}(s)\langle\chi^{(-)}_{1\beta}\chi^{(-)}_{2\beta}\left|\varphi_B\right|\chi^{(+)}_{\overline{N}A}\rangle} \quad (1)$$

$$\varphi_B = \langle B\left|\psi_N\right|A\rangle = \sum_i \varphi_i\langle B\left|a_i\right|A\rangle \quad (2)$$



Initial State Interaction

Microscopical optical potential in $t\rho$ Approximation:

$$U_{opt}(\mathbf{r}) = \sum_{N=p,n} \int \frac{d^3q}{(2\pi)^3} \rho_N(q) t_{\bar{p}N}(T_{Lab}, q^2) e^{i\mathbf{q}\cdot\mathbf{r}} \qquad (3)$$

Information about the nucleus comes into play via *HFB* density distribution.

Paris
Phys. Rev C 79 (2009) 054001

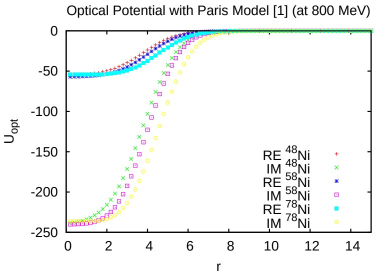
- extracting $\bar{p}N$ from NN
- global optical Potential with linear energy dependence
- fit to scattering data

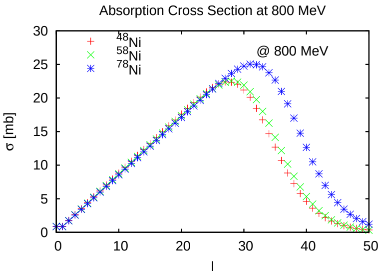
Bonn
Phys. Rev. C 51 (1995) 2360

- extracting $\bar{p}N$ from NN
- pure imaginary Potential with no energy dependence
- no fit to scattering data
- various 2-Meson annihilation channels

Solving Schrödinger equation with partial wave analysis

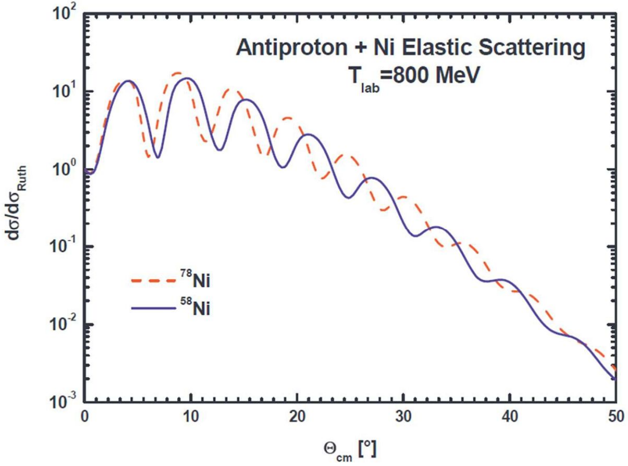
$$-\frac{\hbar^2}{2m}(\vec{\nabla}^2 + V(r))\Psi(r) = E\Psi(r) \quad (4)$$





$$\sigma_l^{abs} = \frac{\pi}{k^2}(2l+1)(1-\eta_l^2) \quad (5)$$

[1] J. Phys. G: Nucl. Part Phys 15 (1989) 1699


Antiproton + Ni Elastic Scattering
T$_{lab}$=800 MeV
^{78}Ni
^{58}Ni
dσ/dσ$_{Ruth}$
10^{2}
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
0
10
20
30
40
50
Θ$_{cm}$ [°]

final state

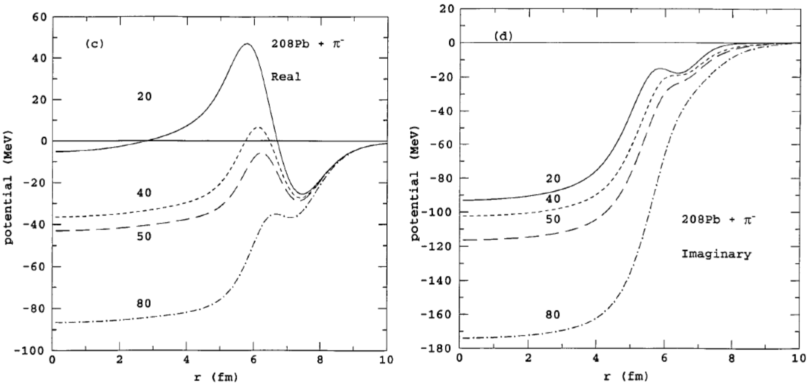
Pion-nucleus potential of Kisslinger type:

$$U = \frac{(\hbar c)^2}{2\omega}\left(U_s + \vec{\nabla}\cdot U_p\vec{\nabla}\right) \tag{6}$$

After Krell-Ericson transformation $\Phi = (1 - U_p)^{-1/2}\psi$ the local potential looks like this (Johnson and Satchler):

$$U_N(r) = \frac{(\hbar c)^2}{2\omega}\left\{\frac{U_s}{1-U_p} - \frac{k^2 U_p}{1-U_p} - \left[\frac{\frac{1}{2}\vec{\nabla}^2 U_p}{1-U_p} + \left(\frac{\frac{1}{2}\vec{\nabla} U_p}{1-U_p}\right)^2\right]\right\} \tag{7}$$

Pion Local Potential



Name (E_r)	Γ [MeV]	R	I J^P	rank
$N(1535)$	150	0.35	$1/2$ $1/2^-$	
$N(1650)$	165	0.60	$1/2$ $1/2^-$	
$\Delta(1600)$	350	$0.10 - 0.25$	$3/2$ $3/2^+$	$***$
$\Delta(1620)$	145	$0.20 - 0.30$	$3/2$ $1/2^-$	$****$
$\Delta(1700)$	300	$0.10 - 0.20$	$3/2$ $3/2^-$	$****$
$\Delta(1750)$	300	$0.10 - 0.20$	$3/2$ $1/2^+$	$*$
$\Delta(1900)$	200	$0.10 - 0.30$	$3/2$ $1/2^-$	$**$
$\Delta(1905)$	330	$0.09 - 0.15$	$3/2$ $5/2^+$	$****$
$\Delta(1910)$	250	$0.15 - 0.30$	$3/2$ $1/2^+$	$****$
$\Delta(1920)$	200	$0.05 - 0.20$	$3/2$ $3/2^+$	$***$
$\Delta(1930)$	270	$0.05 - 0.15$	$3/2$ $5/2^-$	$***$
$\Delta(1940)$	~ 200	$0.05 - 0.15$	$3/2$ $3/2^-$	$*$
$\Delta(1950)$	285	$0.35 - 0.45$	$3/2$ $7/2^+$	$****$
$\Delta(2000)$	~ 200	$0.00 - 0.07$	$3/2$ $5/2^+$	$**$

$\overline{N} + A \rightarrow \pi_1 + \pi_2 + B$

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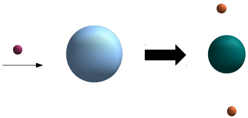
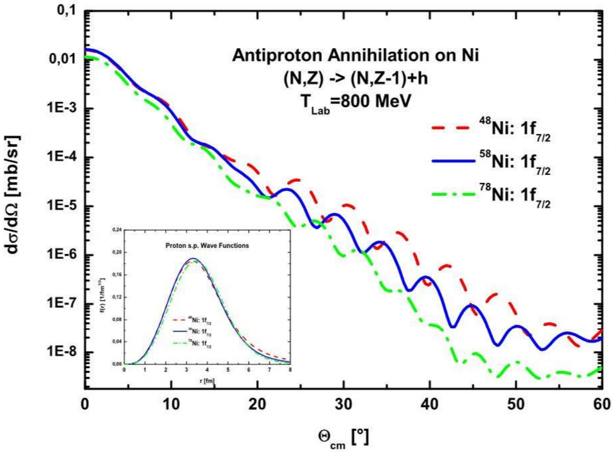
$$\delta\left(\vec{k_1}+\vec{k_2}+\vec{k_B}\right)\delta\left(E_1+E_2+E_B-\sqrt{s}\right)$$

$$\boxed{M_{\beta\alpha} \approx g^*_{\overline{N}N\rightarrow 2\pi}(s)\langle\chi^{(-)}_{1\beta}\chi^{(-)}_{2\beta}\left|\varphi_B\right|\chi^{(+)}_{\overline{N}A}\rangle} \quad (8)$$

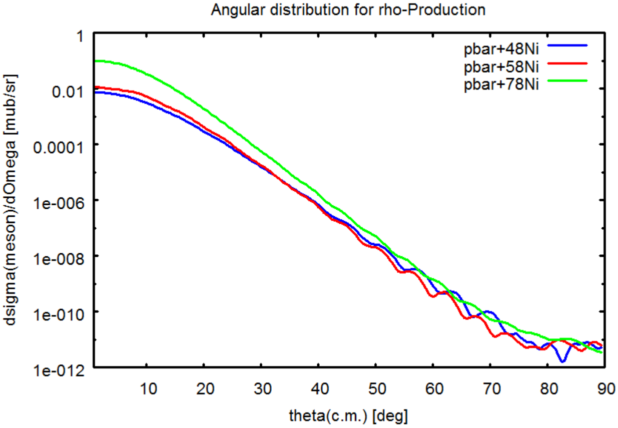
$$\varphi_B = \langle B\left|\psi_N\right|A\rangle = \sum_i \varphi_i \langle B\left|a_i\right|A\rangle \quad (9)$$



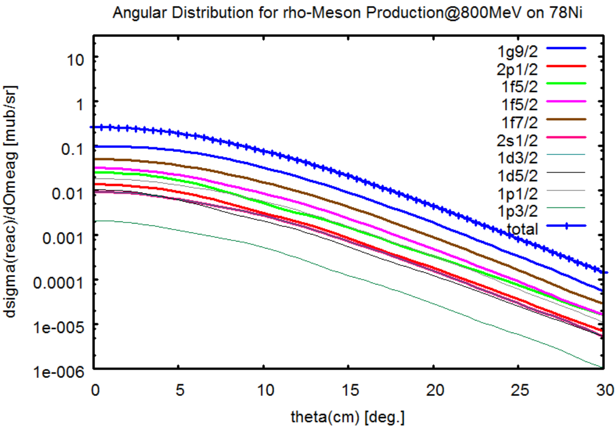
$(N, Z) \rightarrow (N, Z-1) + h$



$\overline{p} + A \rightarrow \rho$



$\overline{p} + A \rightarrow \rho$



Summary

- the $\bar{p}A$ amplitudes are derived in $t\rho$-approximation by folding the $\bar{p}N$ amplitudes with the *HFB*-nucleus densities
- the $\bar{p}N$ amplitudes are calculated from G-parity-transformed *NN* amplitudes within an microscopic optical approach
- pion model is the Krell Ericson transformation of Kisslinger type optical pion-nucleus potential with extension to higher energies.
- elastic scattering of antiprotons is sensitive to nuclear structure properties
- hadron production on complex nuclei
- pion production as probe for nuclear spectroscopy