Pair transfer processes in n-rich nuclei

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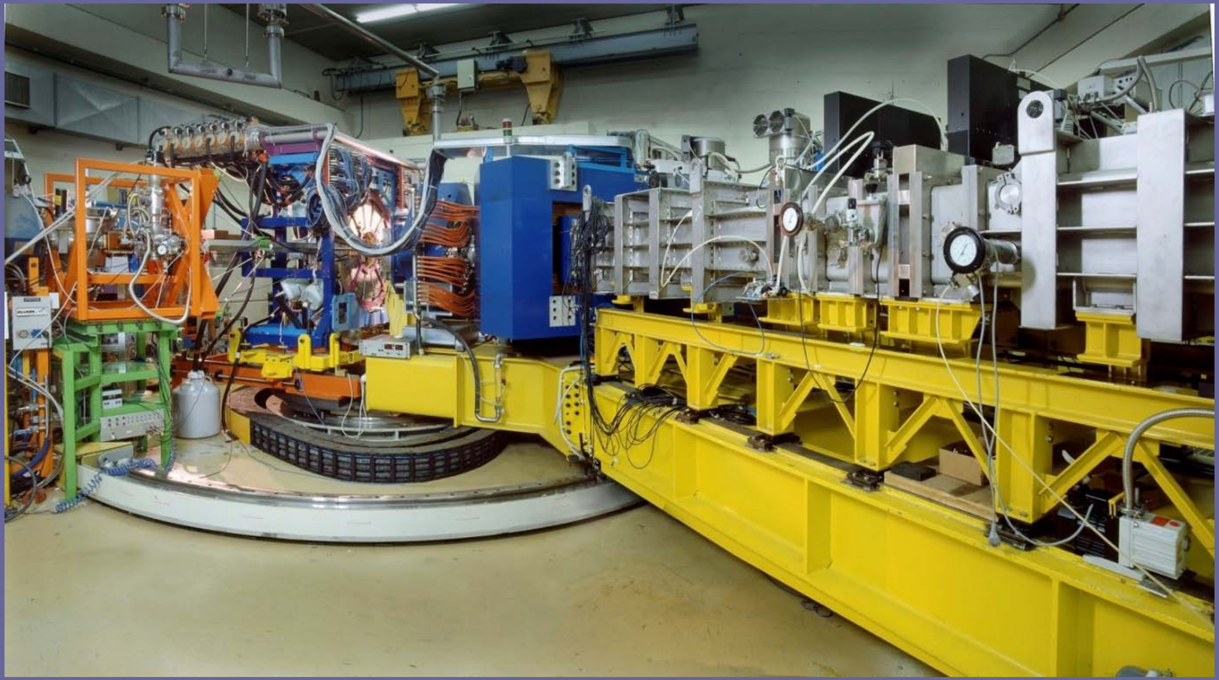
for the PRISMA collaboration



SPES2010 Int. Workshop, LNL,
November 15-17, 2010

Letter of Intent for Spes

Pair transfer processes in n-rich nuclei

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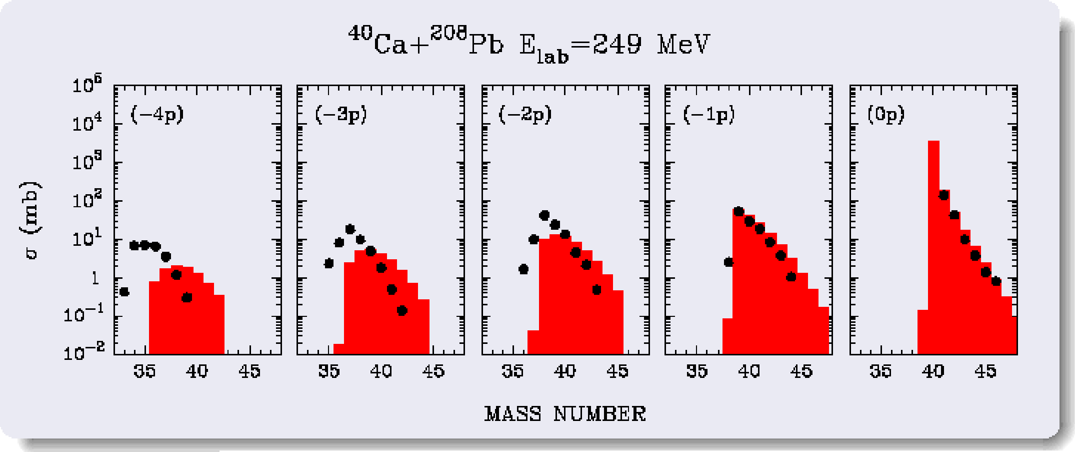
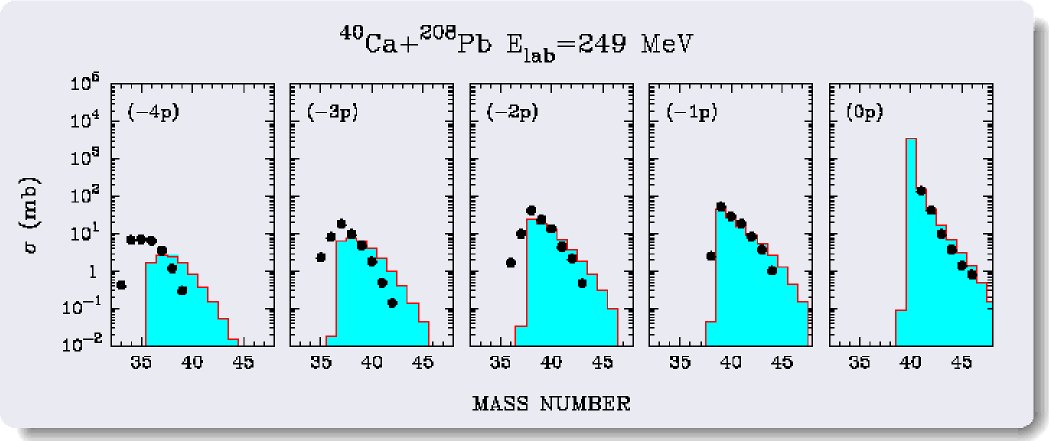
multinucleon transfer : experiment vs. theory



1pt

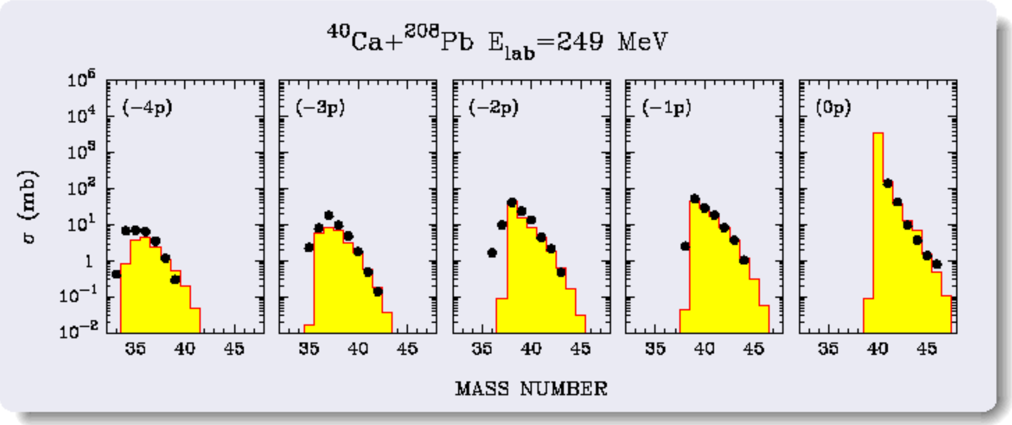
data : LNL

theory :
GRAZING code
and CWKB



1pt+2pt

$$F_{fi}^{pair}(r) = \beta_p \frac{\partial V^{opt}(r)}{\partial A}$$



+Evap.

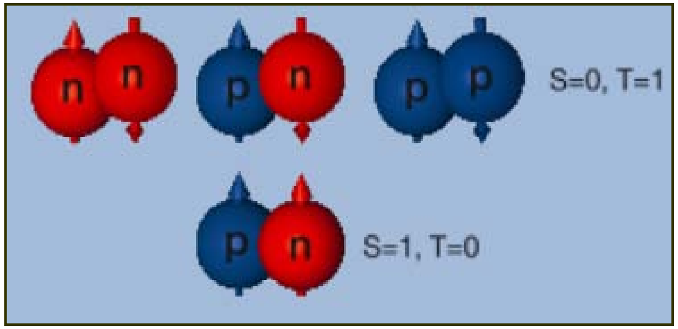
L.Corradi, G.Pollarolo, S.Szilner

J.Phys. G36(2009)113101 (Topical Review)

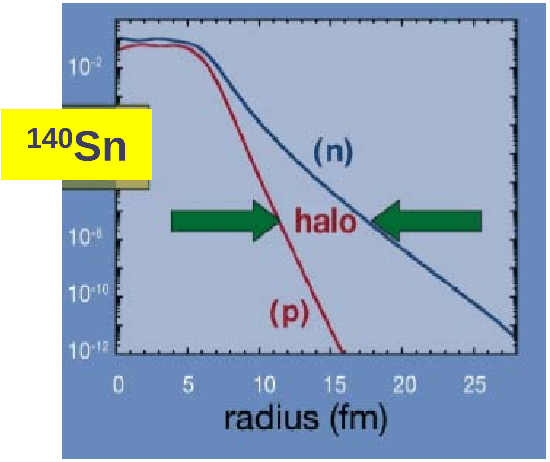
Multinucleon transfer reactions with radioactive beams

One needs to learn whether and to what extent the degrees of freedom and the corresponding matrix elements tested with stable beams can hold with radioactive beams. In particular whether the form factors for one and two particle transfer and their strength need to be modified

neutron-proton correlations
(np channel)



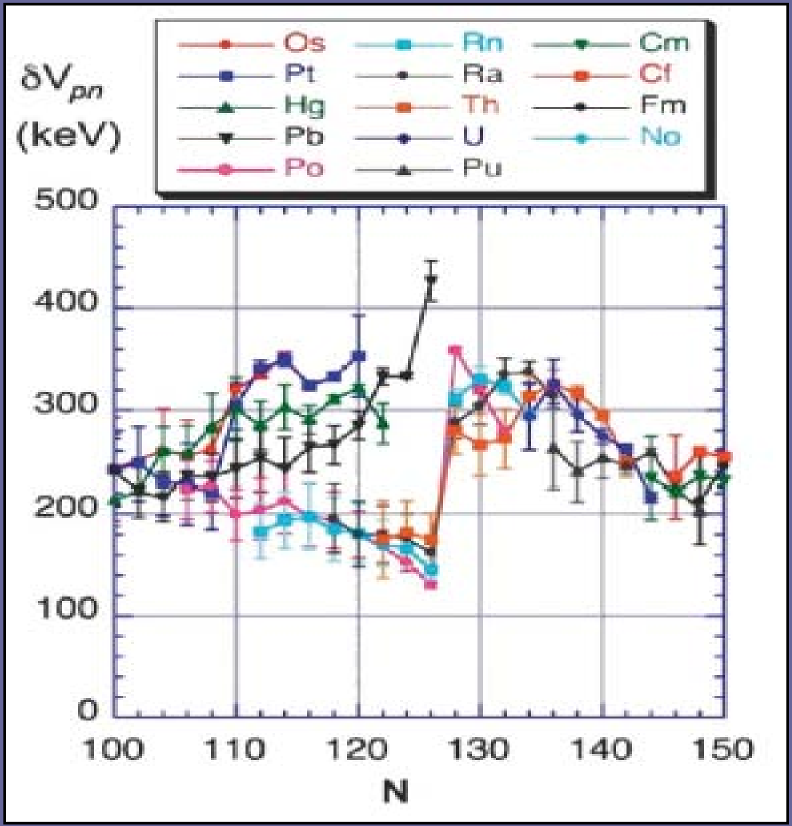
onset of supercurrents
(neutron rich nuclei)



np correlations

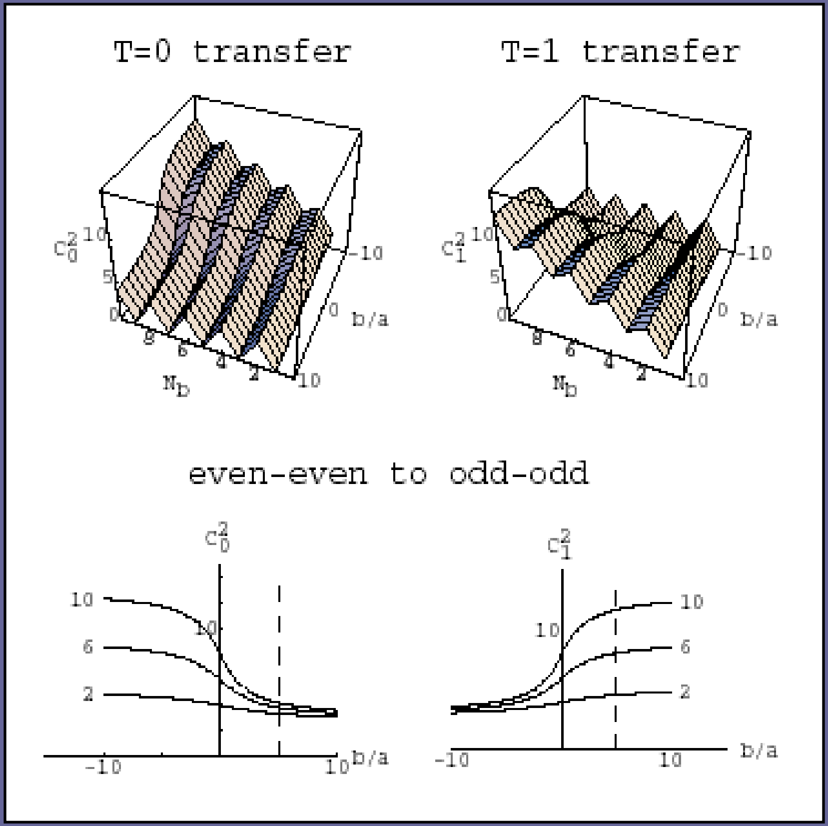
np correlations

nuclear binding energies



R.B.Cakirli et al, PRL94,092501(2005)

deuteron transfer (light ions)



P.Van Isacker et al, PRL94,162502(2005)

about T=0 and T=1 transfer : not really much has been learned so far

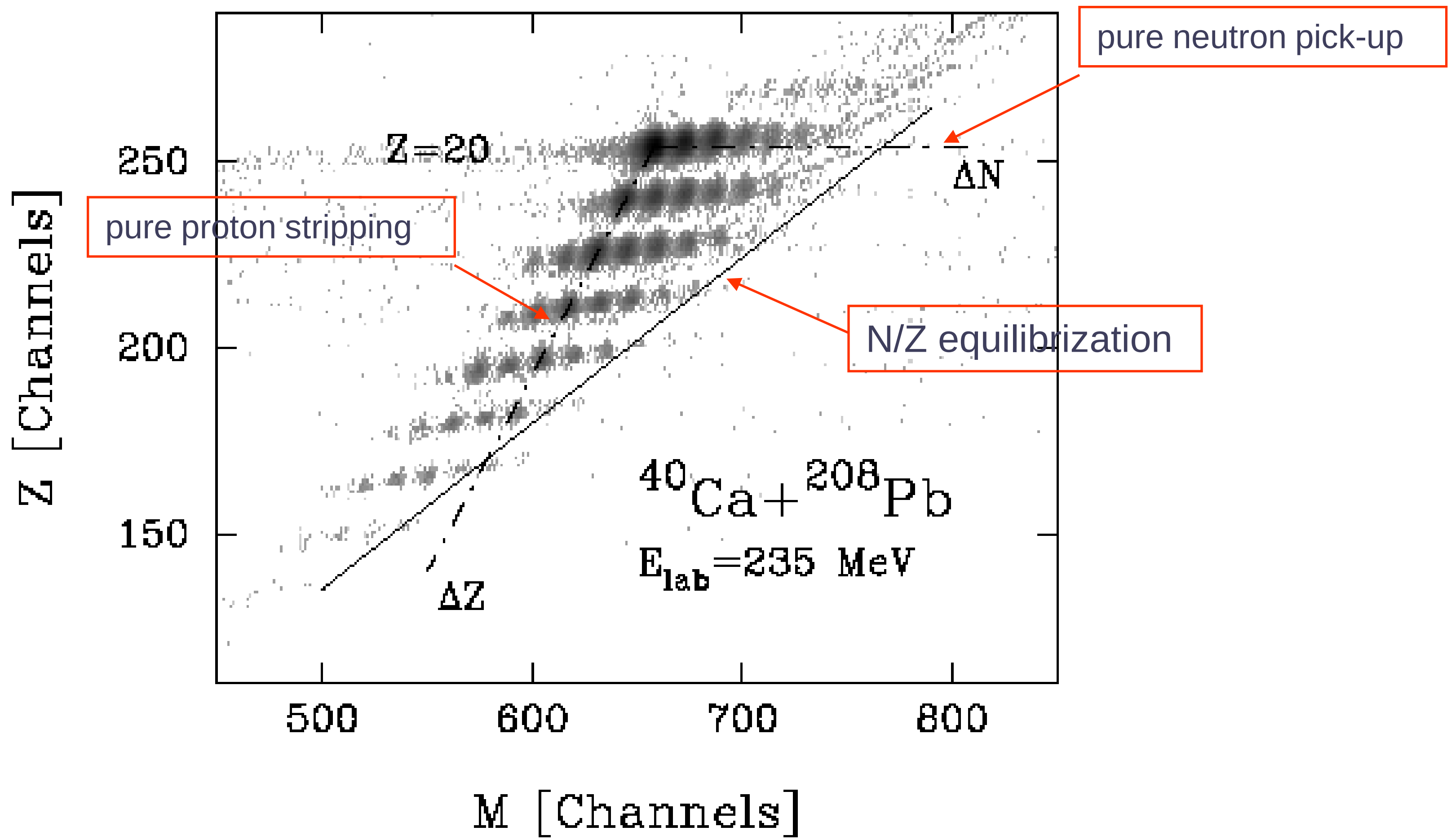
T=1 transfer has been interpreted within pair models, but T=0 (np) transfer has not been clearly identified yet from light ion reactions

[Bes et al., Phys.Rep. 34(1977)1]

calculations show an "enhancement" of 2.44 for deuteron transfer which involves both T=0 and T=1 channels

[P.Frobrich,Phys.Lett. B37(1971)4]

Quasi-elastic regime in multinucleon transfer reactions : A,Z yields



S.Szilner et al, Phys.Rev.C71(2005)044610

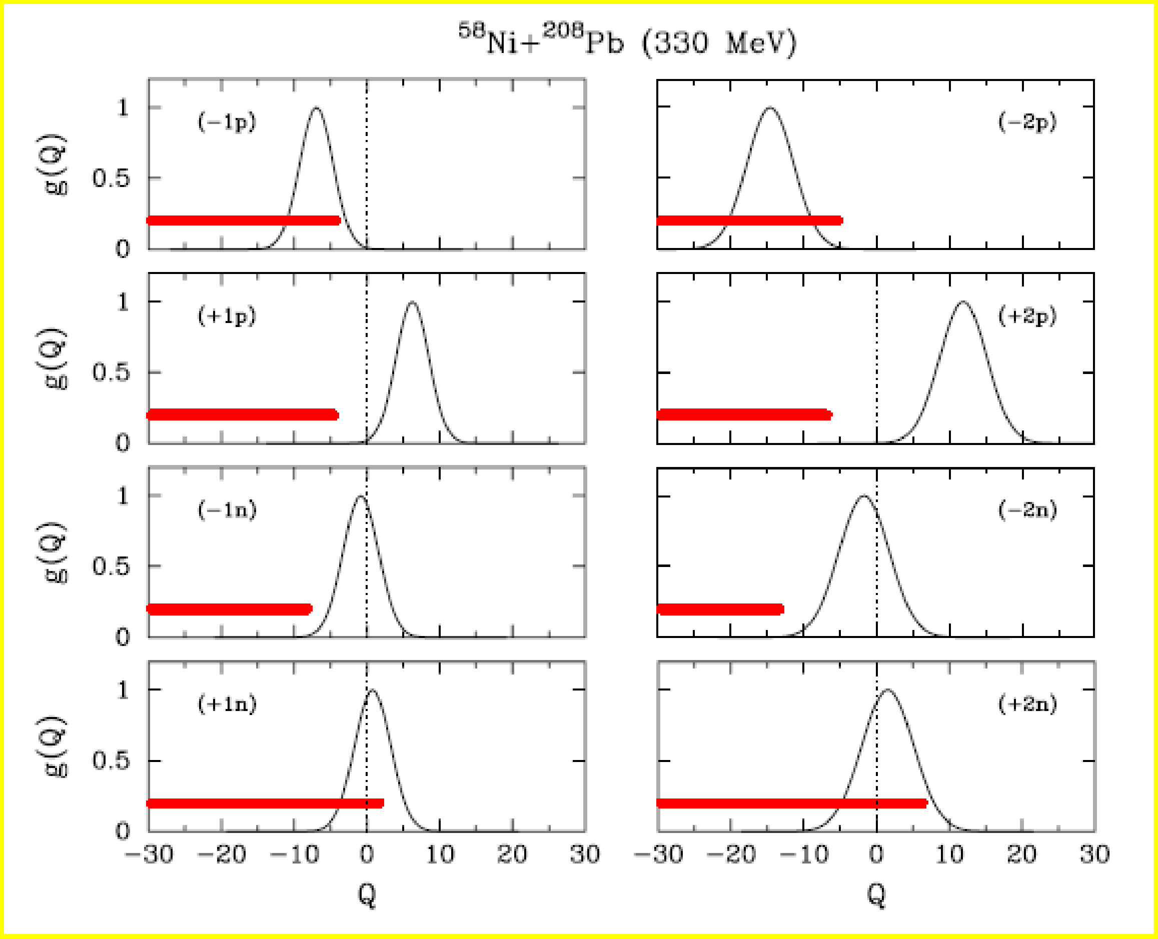
Quasi elastic processes : optimum Q-value

cut-off function

$$g(Q) = \exp\left(-\frac{(Q-Q_{\text{opt}})^2}{\hbar^2 \ddot{r}_0 \kappa_{a_1'}}\right)$$

transfer probability

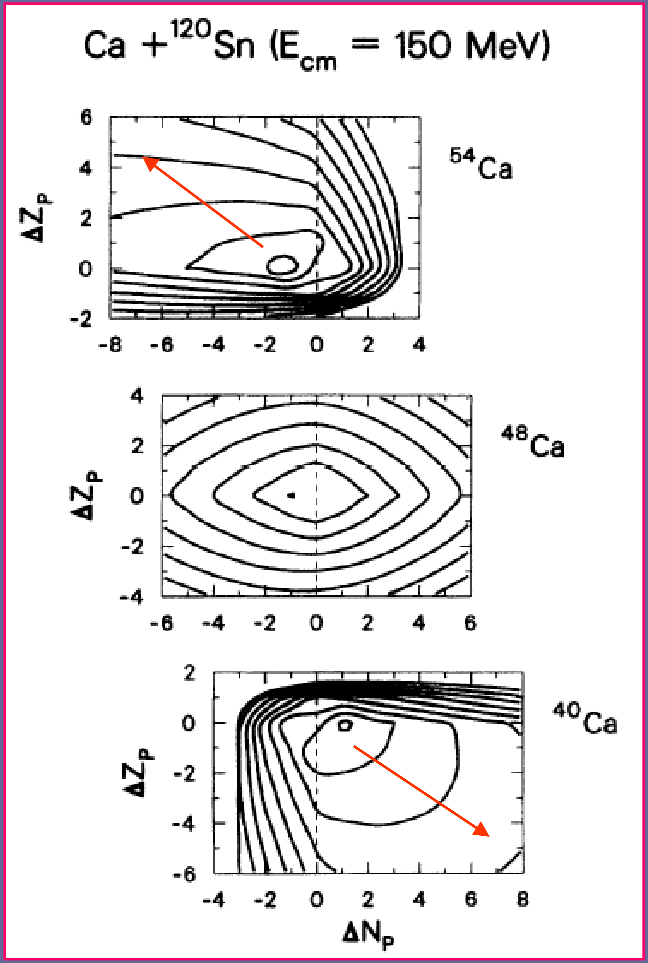
$$P_{\beta\alpha} = \sqrt{\frac{1}{16\pi\hbar^2|\ddot{r}_0|\kappa_{a_1'}}}\,|f_{\beta\alpha}(0,r_0)|^2 g(Q_{\beta\alpha})$$



open reaction channels are those compatible with the optimum Q-value window (kinematical condition). This window has its origin in the matching of the orbits before and after the transfer process

G.Pollarolo et al, NPA406 (1983)369

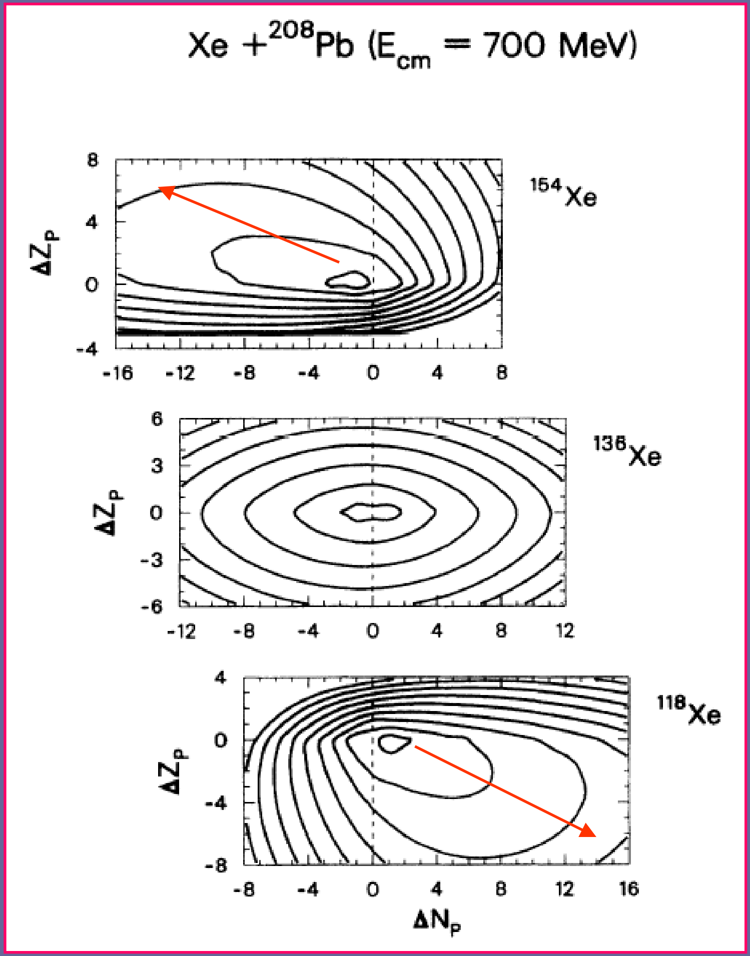
Change of population pattern in going from neutron poor to neutron rich nuclei (theoretical)



neutron stripping and proton pick-up

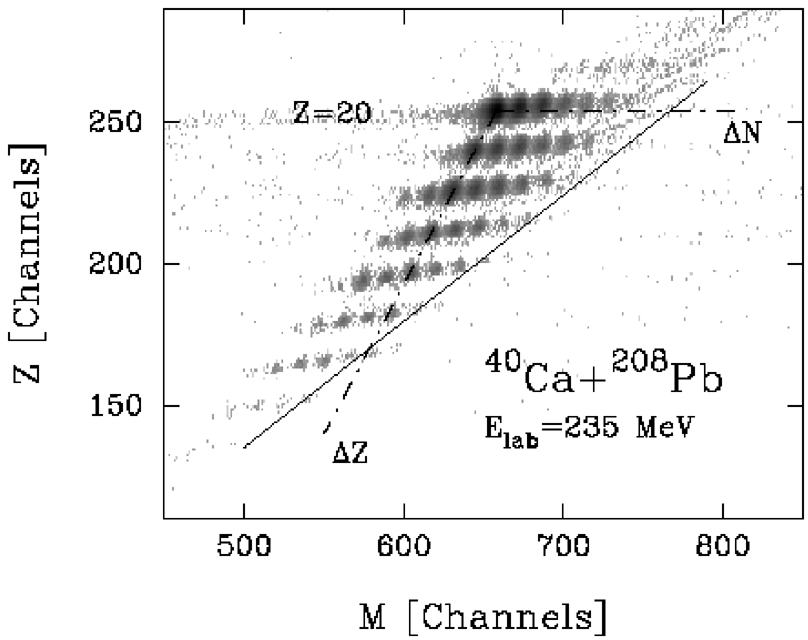
equal directions

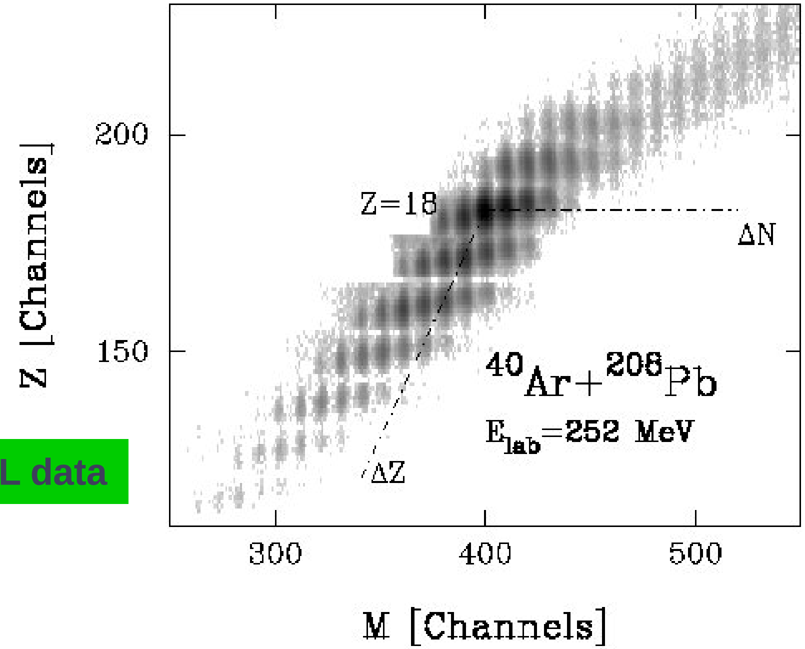
neutron pick-up and proton stripping



C.H.Dasso, G.Pollarolo and A.Winther, Phys.Rev.Lett.73, 1907 (1994)

Multinucleon transfer reactions : from neutron poor to neutron rich nuclei

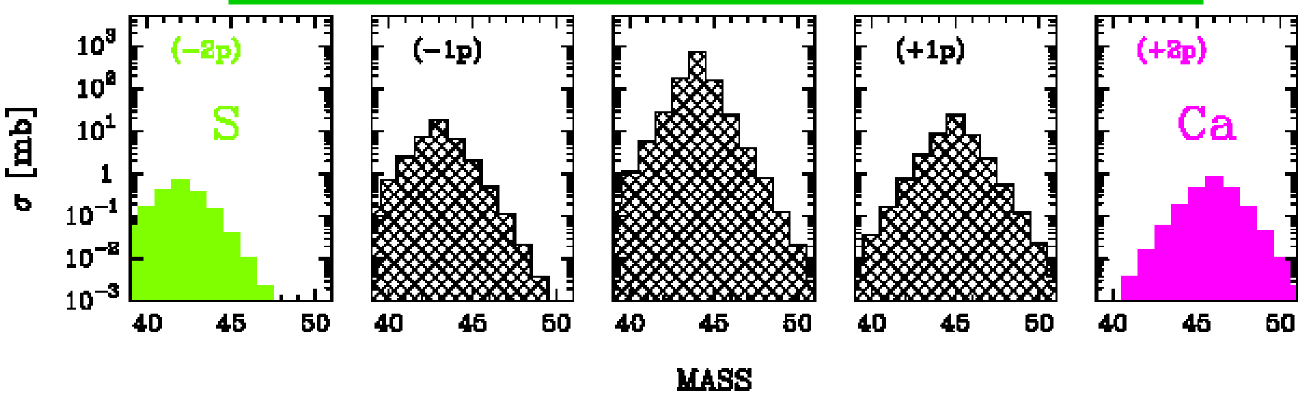




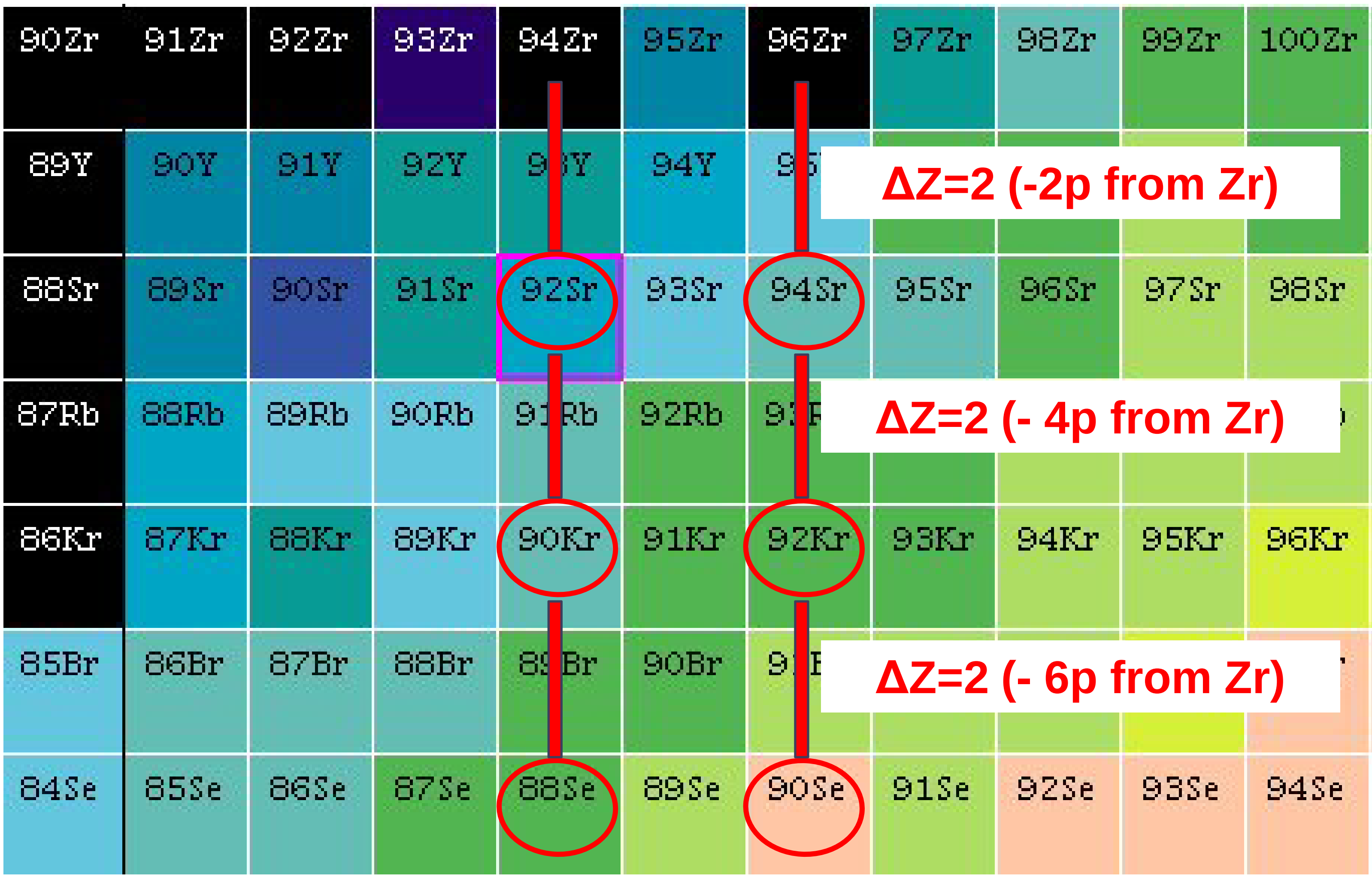
LNL data

with (moderately n-rich) heavy ions one can populate (nn), (pp) and (np) channels with comparable strength

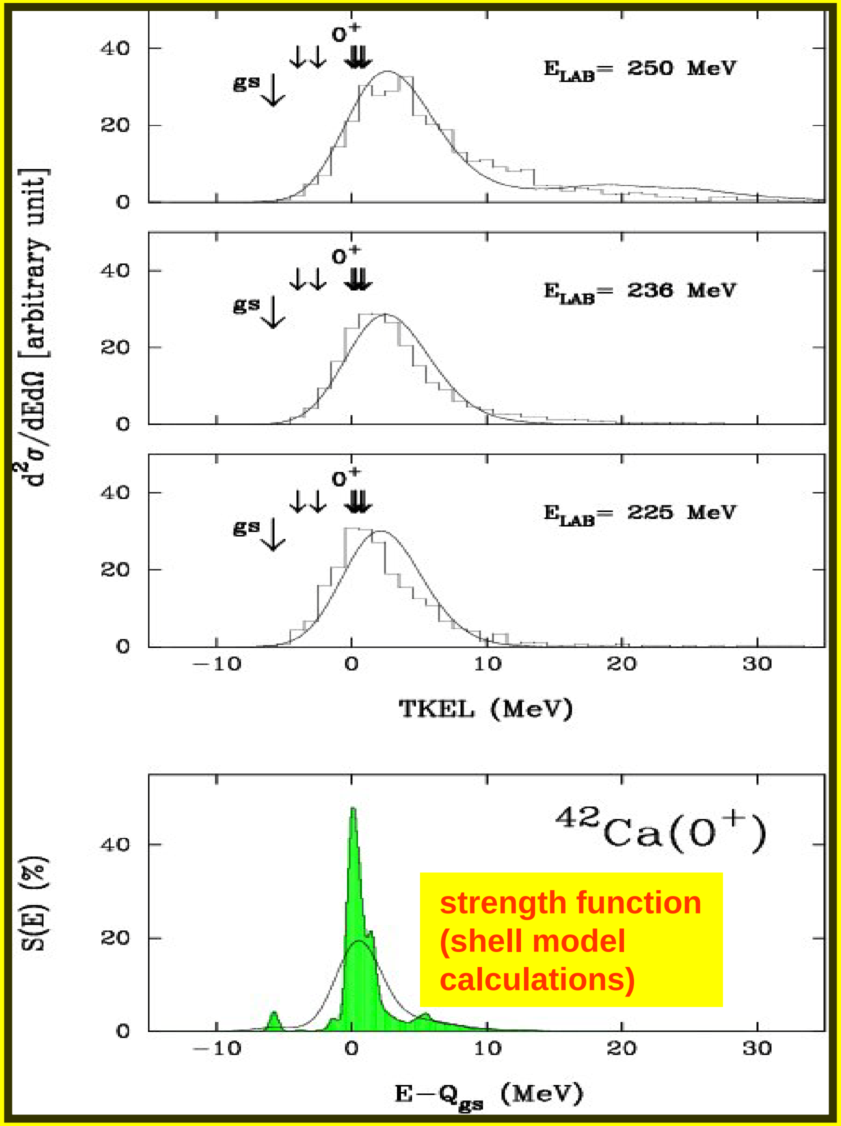
GRAZING code calculations ^{44}Ar + ^{208}Pb E=320 MeV

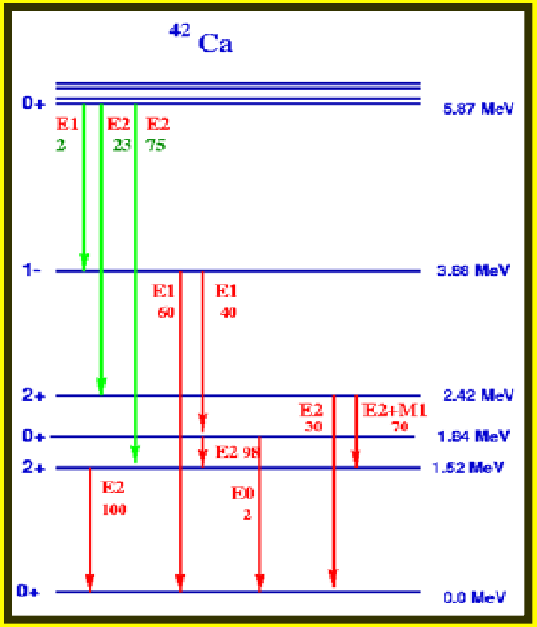


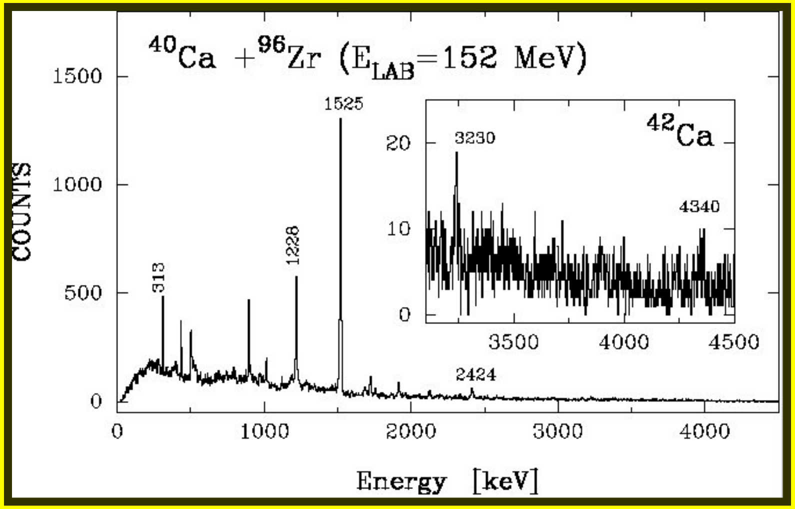
Some proposed beams for SPES : $^{92,94}Sr$, $^{90,92}Kr$, $^{88,90}Se$



Strong population close to the pairing vibrational region in $^{40}Ca+^{208}Pb$







S.Szilner et al, Eur.Phys.J. A21, 87(2004)

S.Szilner et al, Phys.Rev.C76(2007)024604

Sub-Coulomb transfer

Transfer studies at energies below the Coulomb barrier

$$\sigma_{tr} \sim e^{-\frac{2}{\hbar}\int W(r(t))dt} \sum \left| \int F_{if}(r(t)) e^{i\omega_{if}} dt \right|^2$$

few reaction channels are opened → W(r) is small

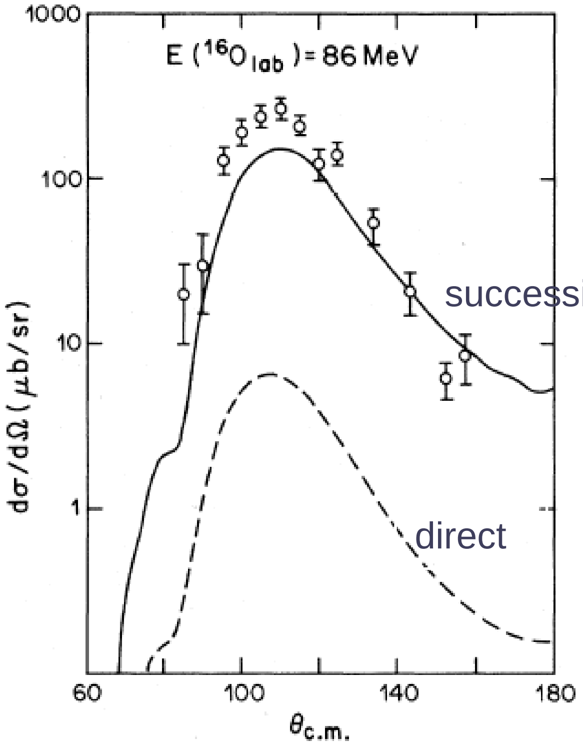
$F(r)_{inel}$ has a decay length ~ 0.65 fm
$F(r)_{tr}$ has a decay length ~ 1.3 fm
→ nuclear couplings are dominated by transfer processes

Q-value distributions get much narrower → one can probe nucleon correlation close to the ground states

Absolute cross sections for one and two-nucleon transfer reactions

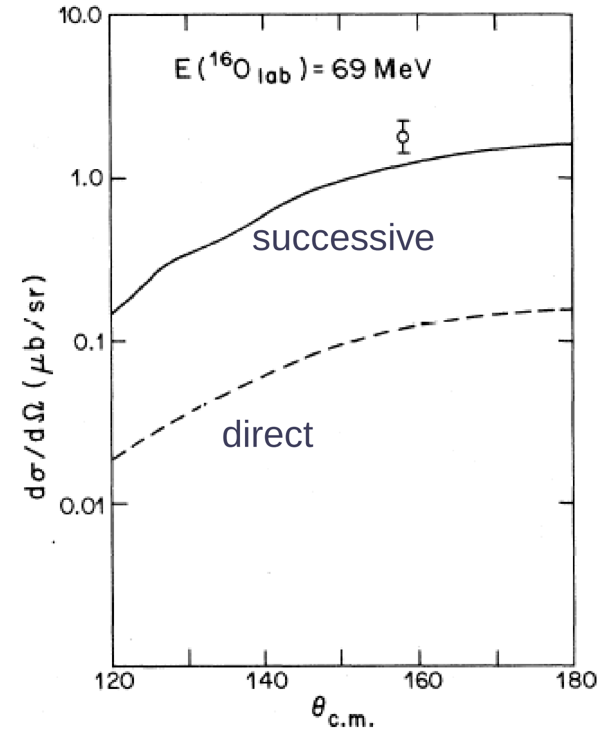
$^{208}Pb(^{16}O,^{18}O_{g.s.})^{206}Pb$

$E \sim E_b$



one+two step calculations undepredict the data by a factor ~ 2

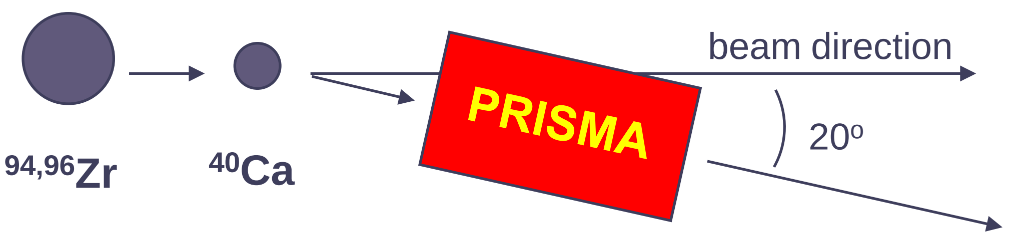
$E \ll E_b$

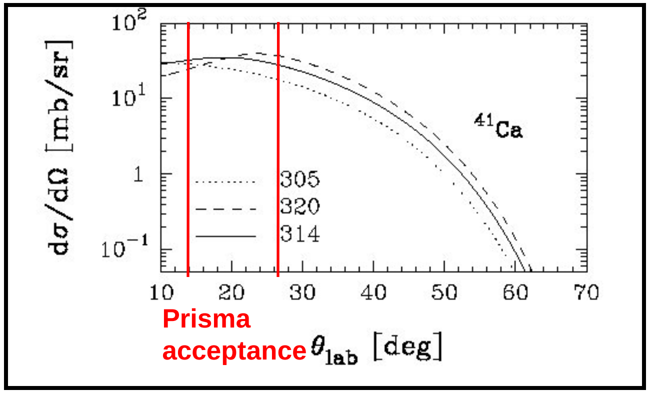


one+two step calculations undepredict the data by 25-30%

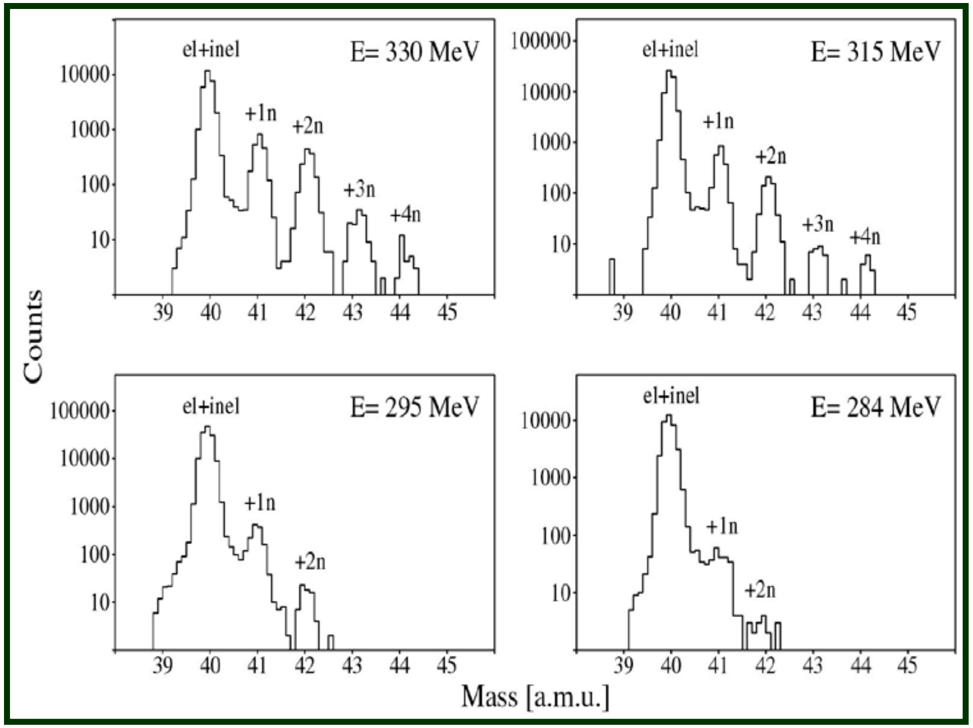
B.F.Bayman and J.Chen, PRC26(1982)1509

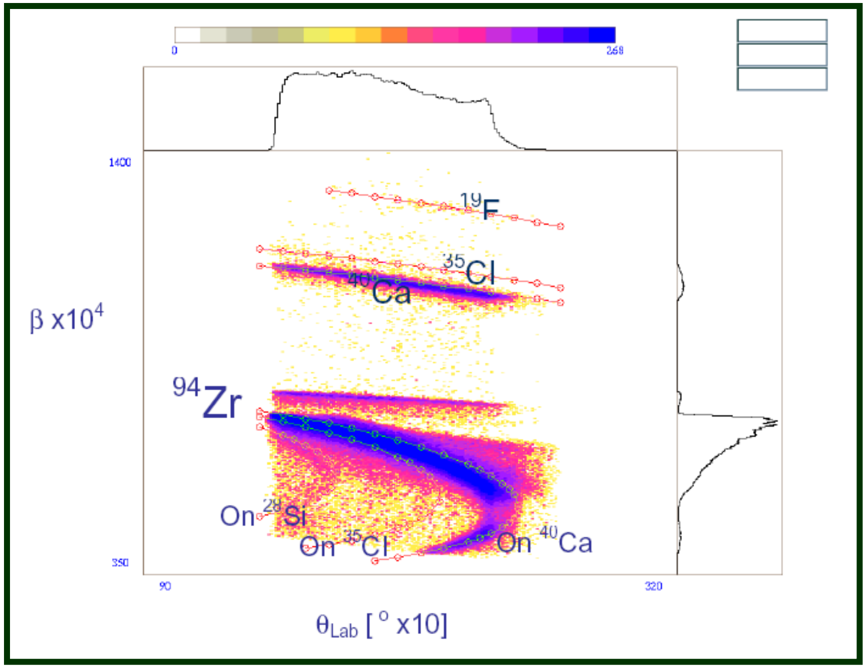
Detection of (light) target like ions in inverse kinematics with PRISMA





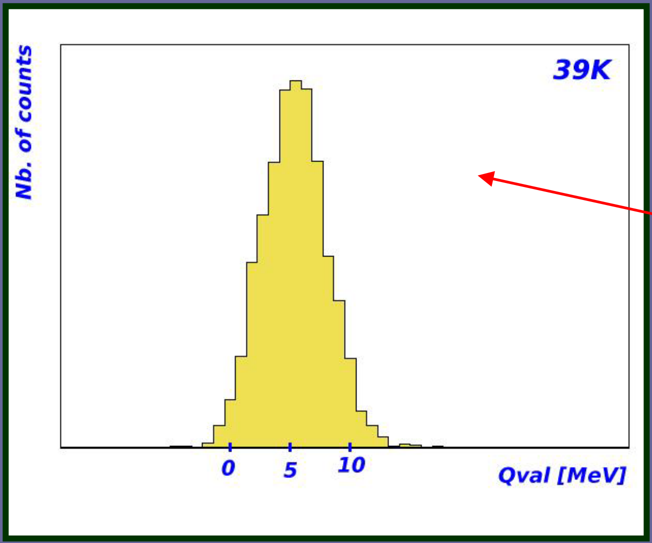
MNT channels have been measured down to 25 % below the Coulomb barrier

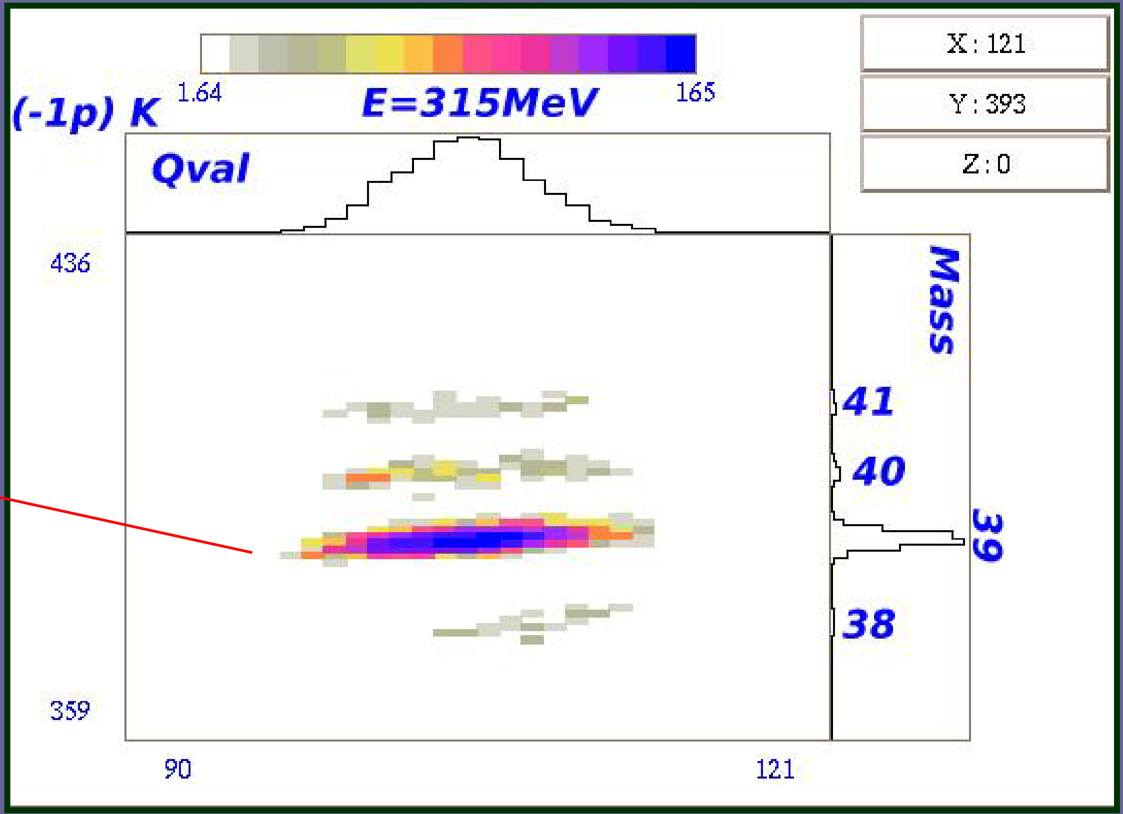




L.Corradi et al, LNL exp. March 2009

Mass vs Q-value matrix for (-1p) channels channels (E_{lab}=315 MeV)

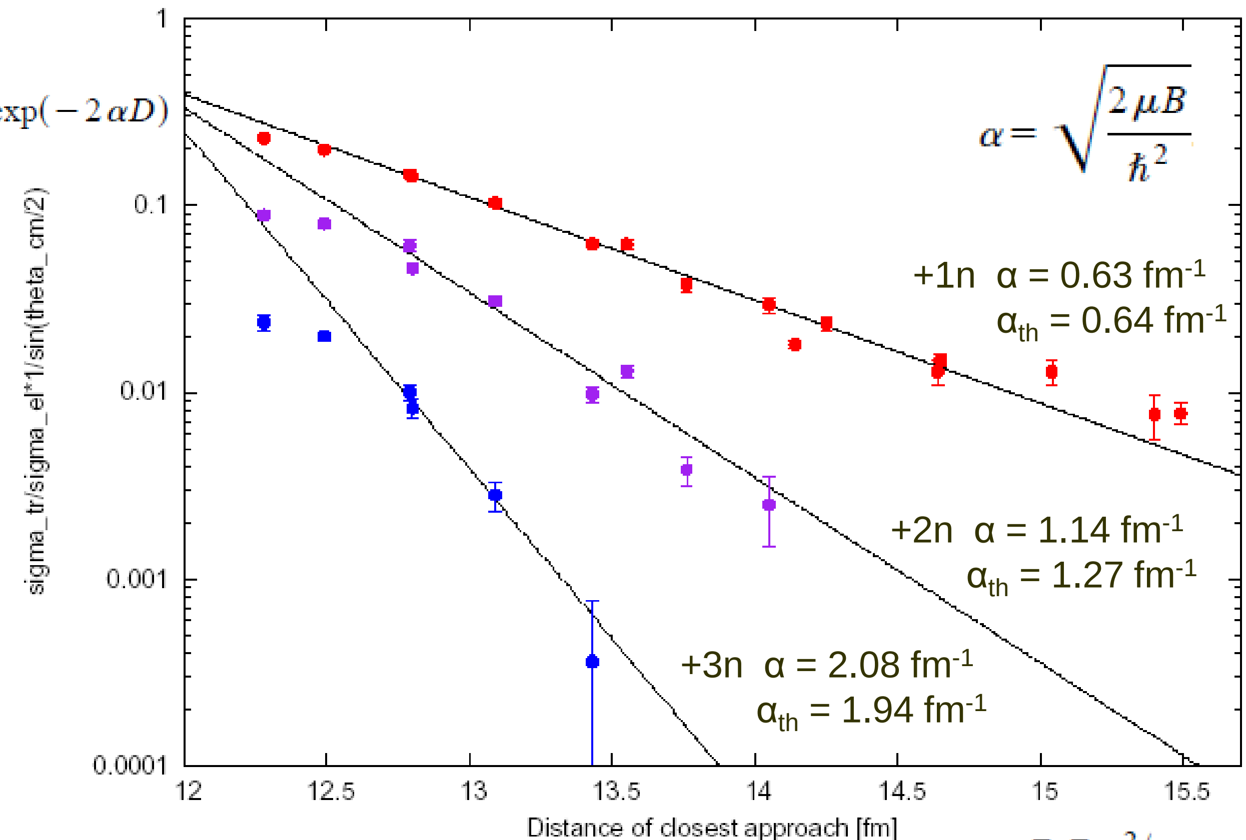




background free spectra with transfer products at very low excitation energy : no evaporation effects and cleanest conditions for comparison with theory

Transfer probabilities for multineutron transfer in $^{96}Zr+^{40}Ca$

$$\frac{P_{tr}}{\sin(\theta_{c.m.}/2)} \propto \exp(-2\alpha D)$$

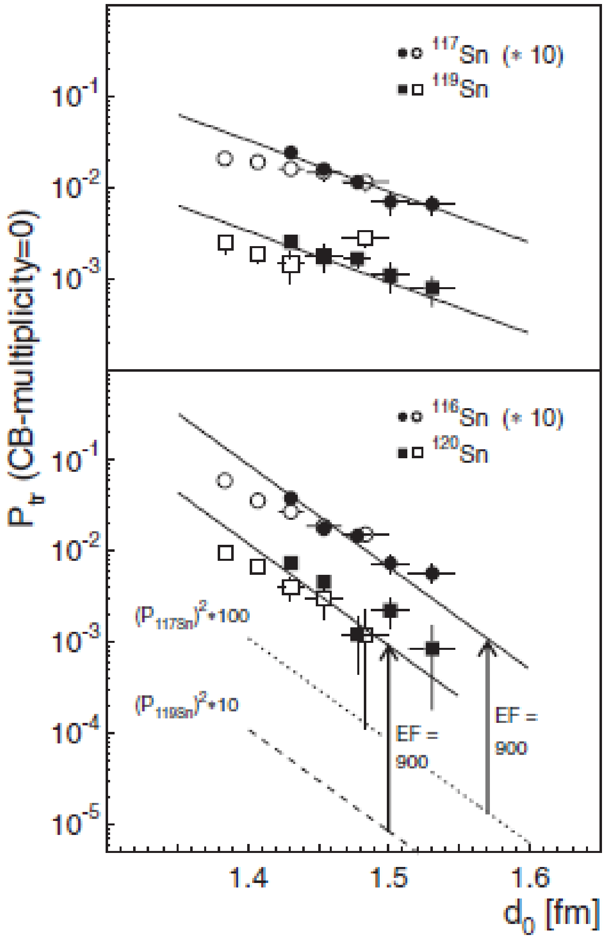


$$\alpha = \sqrt{\frac{2\mu B}{\hbar^2}}$$

$$D = \frac{Z_1 Z_2 e^2}{2E_{c.m.}}\left(1 + \frac{1}{\sin(\theta_{c.m.}/2)}\right)$$

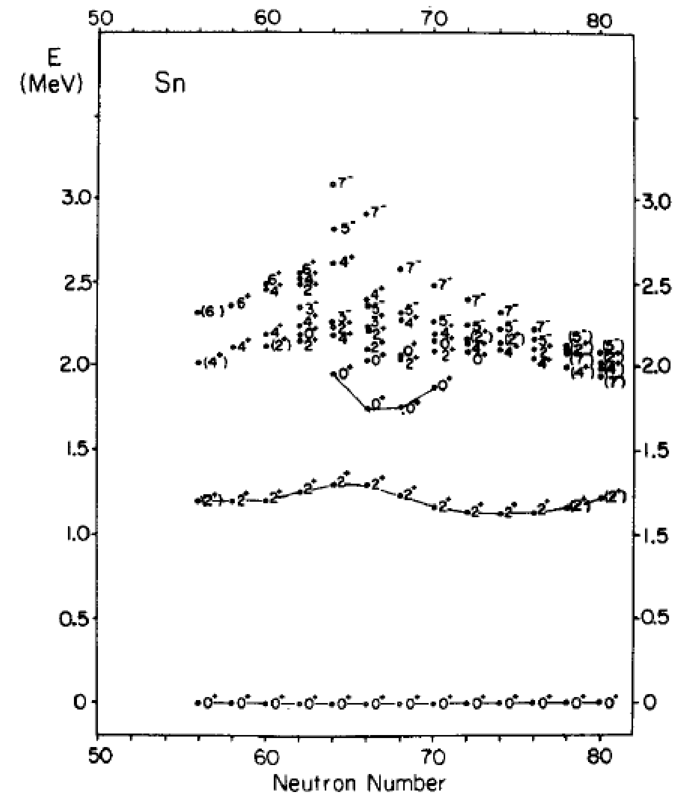
Probing pairing rotational effects in heavy ion transfer reactions

$^{206}Pb+^{116}Sn$ E=5.14,5.32 MeV/A
particle-γ data (crystal ball)



I.Peter et al., EPJ A16(2003)509

Excitation energies of 2^+ states and other excitations in Sn isotopes



F.Iachello, NPA 570(1994)145

Requests

Beams : ^{44}Ar, $^{92,94}Sr$, $^{90,92}Kr$, $^{88,90}Se$, $^{126-132}Sn$, Mo, Pd

Energies close to the Coulomb barrier (well matching ALPI range)

Beam I on target : 10^6 - 10^8 ions/sec

Set-up : PRISMA (100 msr) + Gamma detectors
^{208}Pb, $^{40,48}Ca$, $^{58,64}Ni$ target thickness : 100-300 $\mu g/cm^2$

Goals : measurements of multinucleon transfer channels
(+1n,+2n,-1n,-2n,+1p,+2p,-1p,-2p + mixing of them)

To be measured : $d\sigma/d\Omega$, σ_{tot}, TKEL, gamma decay properties

selection rules for (one step) two nucleon transfer reactions

Reaction	S^{a}	T^{a}	ΔT^{b}	J^{a} j^2	J^{a} $j_1 j_2$
(α,d)	1	0	0	odd	$\cdots$
(t,p) or (He^3,n)	0	1	1 or 0 if $T_1 \neq 0$	even	$J+\Delta\pi$ even
(t,n) or (He^3,p)	1	0	0	odd	$\cdots$
	0	1	1 or 0 if $T_1 \neq 0$	even	$J+\Delta\pi$ even

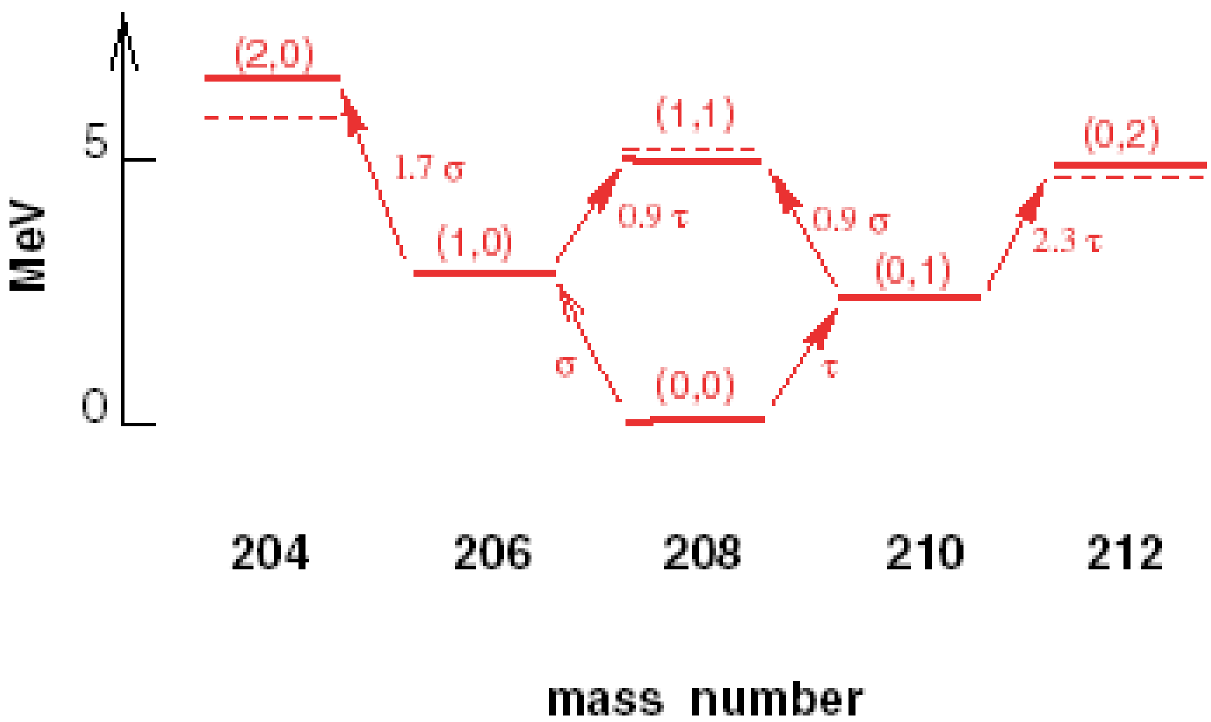
[a] Belongs to transferred pair.
[b] Isospin change of nucleus.

In (^{3}He,p) reactions p-n pairs may be transferred either with S=0,T=1 or with S=1,T=0. In (α,d) reactions only S=1,T=0 is possible.

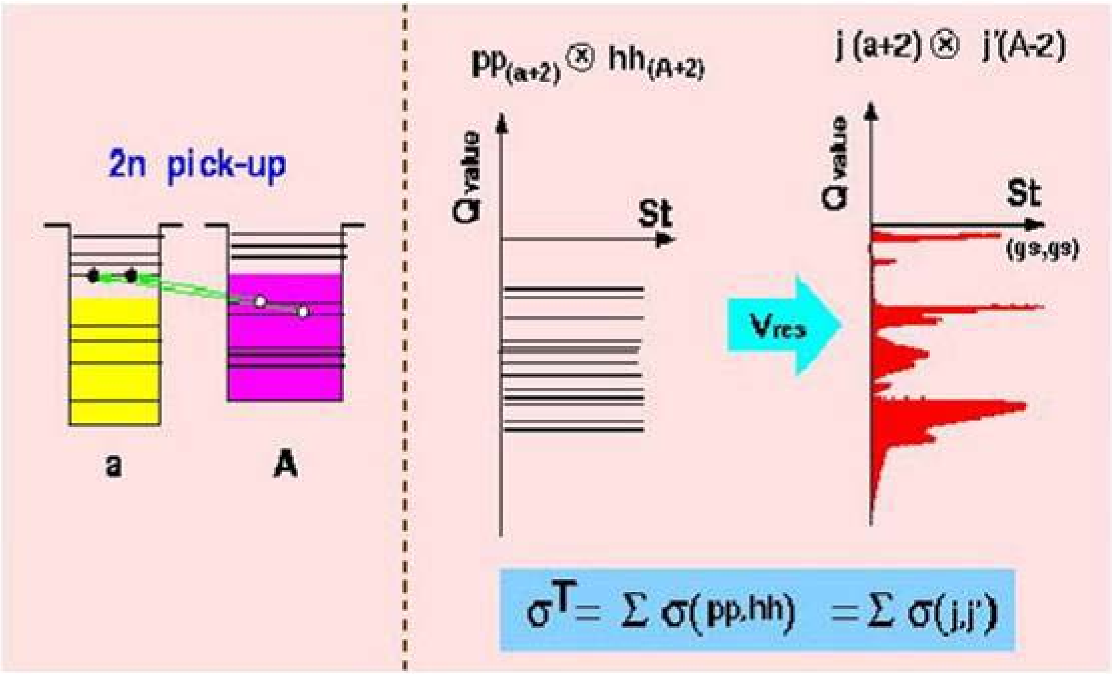
Pairing vibration model

$$H_p = \frac{1}{2} g \, Q^\dagger Q$$

$$Q^\dagger = \frac{1}{\sqrt{2}} \sum_{kk'>0} [q_{kk'} a_k^\dagger a_{\bar{k}'}^\dagger + q_{kk'}^* a_{\bar{k}'} a_k]$$



How the residual interaction acts in transfer processes



Two nucleon transfer : simultaneous vs successive contributions

$$a(l) = [a(l)]_{(1)} + [a(l)]_{\mathrm{succ}} + [a(l)]_{\mathrm{orth}}$$

$$[a(l)]_{(1)} = -\mathrm{i} \sum_{a_1 a_1'} B^{(\mathrm{A})}(a_1 a_1 ; 0)\, B^{(\mathrm{b})}(a_1' a_1' ; 0) \left(\frac{2j_1' + 1}{2j_1 + 1} \right)^{1/2} \sum_{\lambda \mu'} \frac{(-1)^{\lambda + \mu'}}{2\lambda + 1}$$

$$\times\, 2 \int_{-\infty}^{\infty} \frac{\mathrm{d}t}{\hbar}\, \tilde{f}_{\lambda \mu'}^{a_1 a_1'}(k_\parallel k_\perp r)\, \tilde{g}_{\lambda -\mu'}^{a_1 a_1'}(k_\parallel k_\perp r) \exp\{(\mathrm{i}/\hbar)[(E_\beta - E_\alpha)t + \gamma_{\beta\alpha}(t)]\}$$

$$[a(l)]_{\mathrm{succ}} = - \sum_{\substack{a_1 a_1' \\ \gamma I_{\mathrm{f}} I_{\mathrm{F}}}} B^{(\mathrm{A})}(a_1 a_1 ; 0) B^{(\mathrm{b})}(a_1' a_1' ; 0)\, |C^{(\mathrm{A})}(0 a_1 ; I_{\mathrm{F}})|^2\, |C^{(\mathrm{b})}(0 a_1' ; I_{\mathrm{f}})|^2 \left(\frac{2j_1' + 1}{2j_1 + 1} \right)^{1/2}$$

$$\times \sum_{\lambda \mu \mu' \mu''} \frac{(-1)^{\lambda + \mu}}{2\lambda + 1} D^{\lambda}_{\mu \mu'}(0 \tfrac{1}{2}\pi\, 0)\, D^{\lambda}_{-\mu \mu''}(0 \tfrac{1}{2}\pi\, 0)$$

$$\times \int_{-\infty}^{\infty} \frac{\mathrm{d}t}{\hbar}\, \tilde{f}_{\lambda \mu'}^{a_1 a_1'}(k_\parallel k_\perp r) \exp\{(\mathrm{i}/\hbar)[(E_\beta - E_\gamma)t + \gamma_{\beta\gamma}(t) + \mathrm{i}\mu\phi(t)]\}$$

$$\times \int_{-\infty}^{t} \frac{\mathrm{d}t'}{\hbar}\, \tilde{f}_{\lambda \mu''}^{a_1 a_1'}(k_\parallel k_\perp r) \exp\{(\mathrm{i}/\hbar)[(E_\gamma - E_\alpha)t' + \gamma_{\gamma\alpha}(t') - \mathrm{i}\mu\phi(t')]\} .$$