Multi-nucleon transfer and their effect on the mechanism of near barrier fusion reaction

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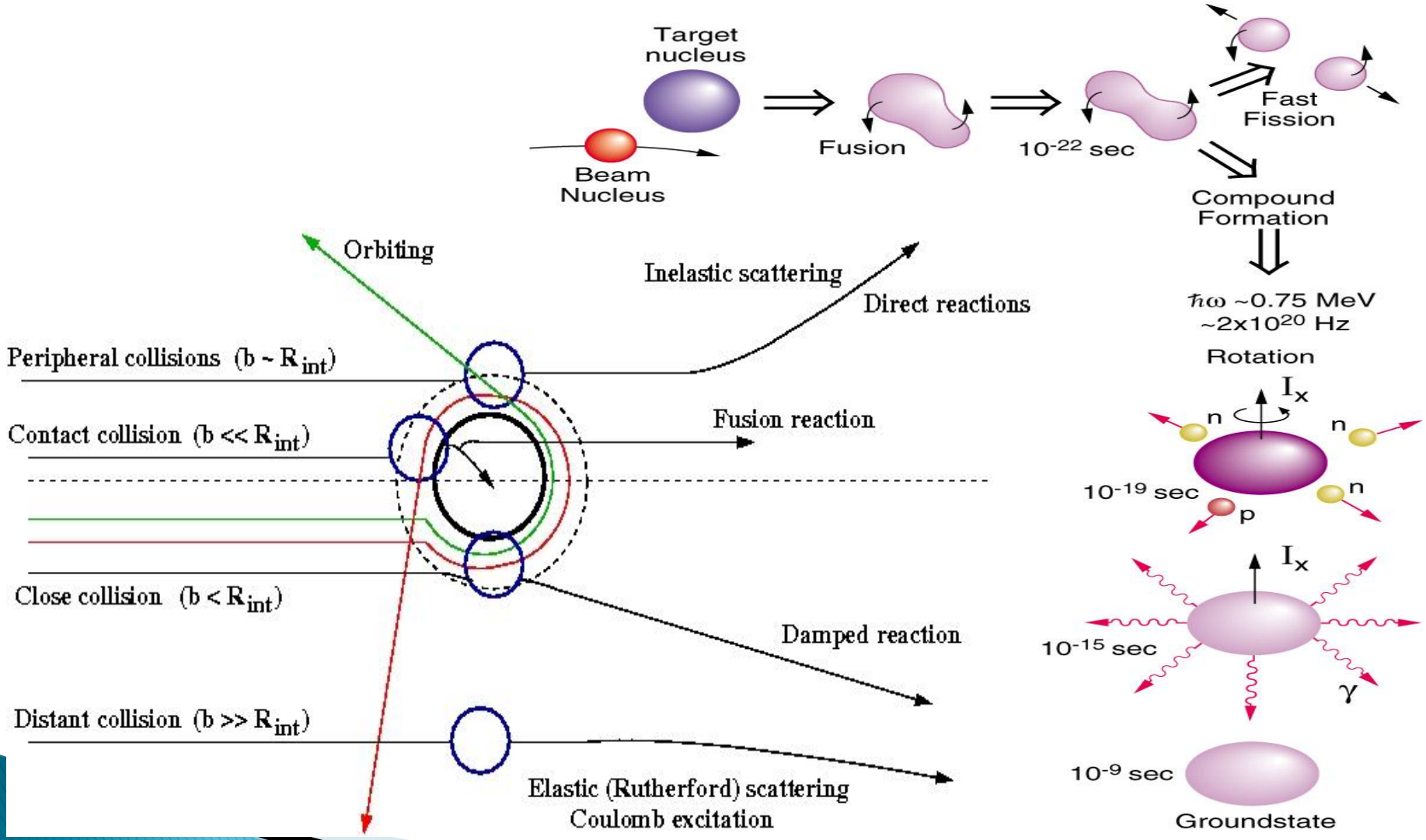
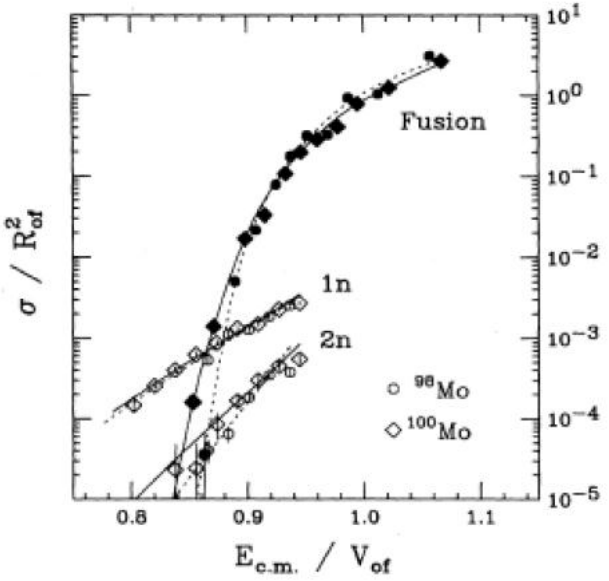
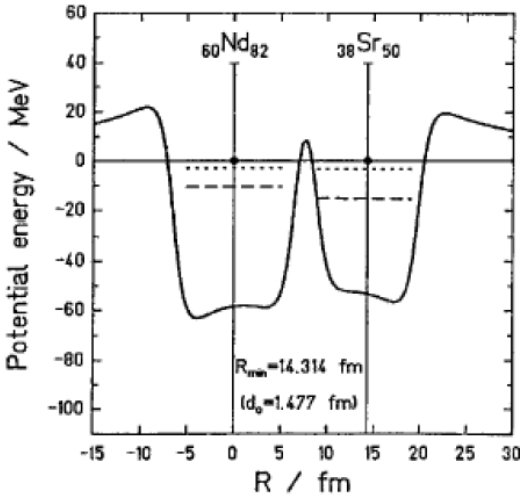
Nuclear Reaction



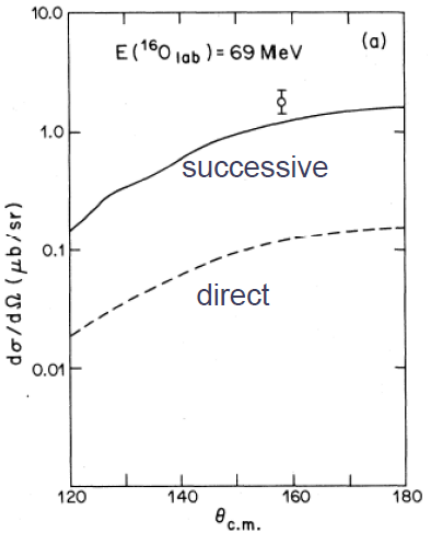
Why multinucleon transfer reaction at and near barrier energies ?

Transfer & Fusion in an and over lapping zone

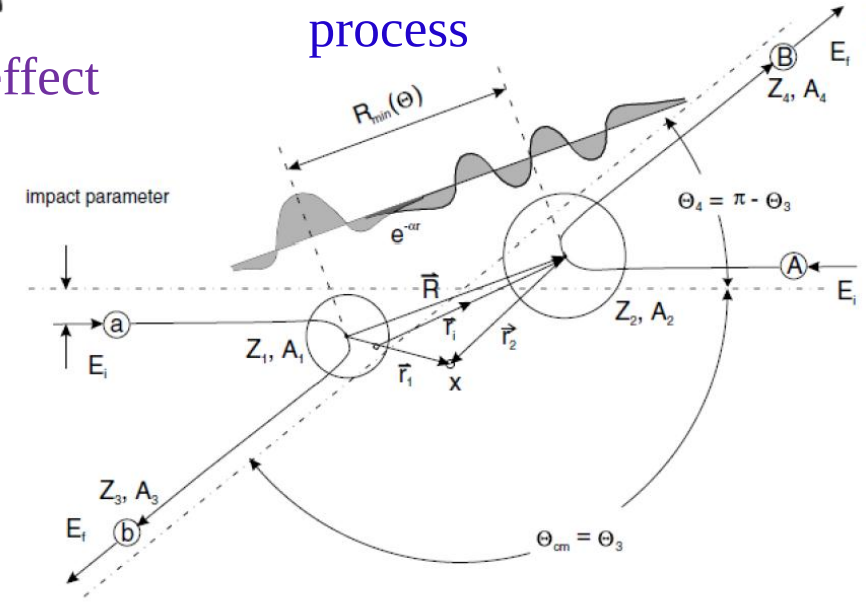




Tunneling effect



Single & multi step process



Near Barrier Transfer → Less no. of open channels

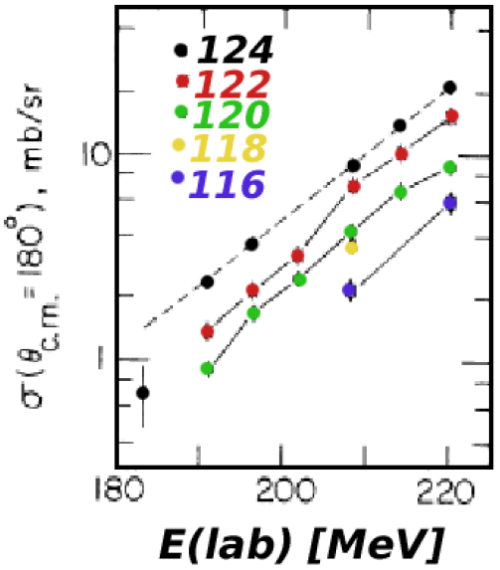
→ Narrow Q-value distribution

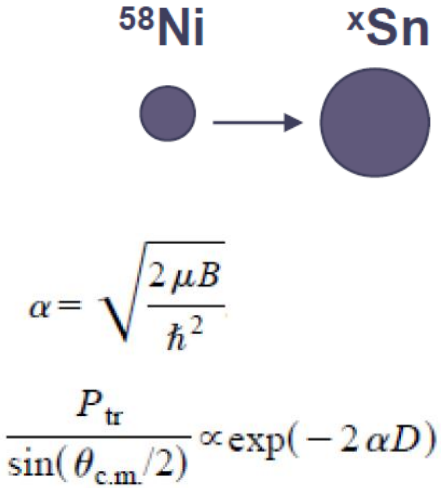
↓

Theoretical Advantage

- → Low kinetic energy
- → Angular Distribution are backward peak
- → Small cross section
- → Difficulty in identification of final reaction products

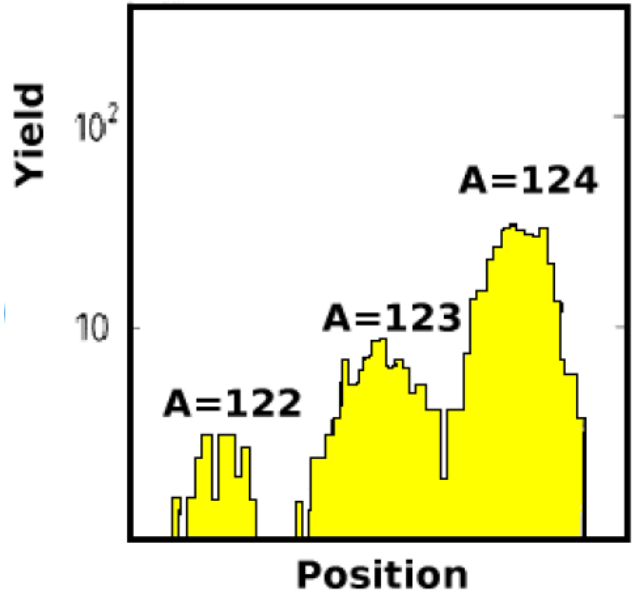
Experimental Challenge





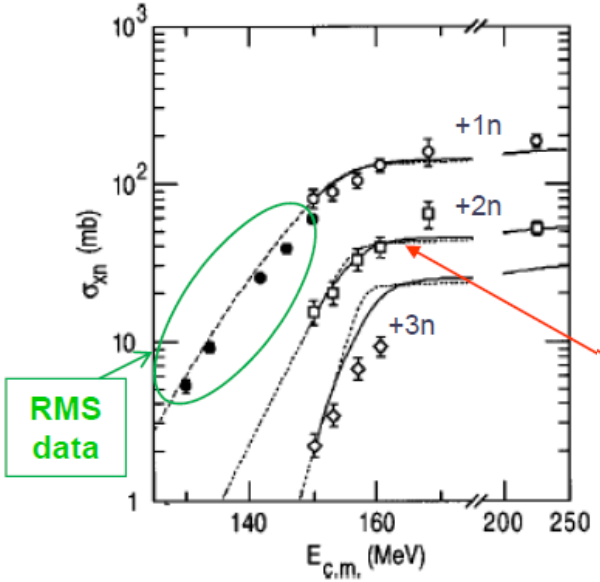
$$\alpha = \sqrt{\frac{2\mu B}{\hbar^2}}$$

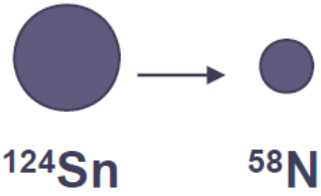
$$\frac{P_{tr}}{\sin(\theta_{c.m.}/2)} \propto \exp(-2\alpha D)$$



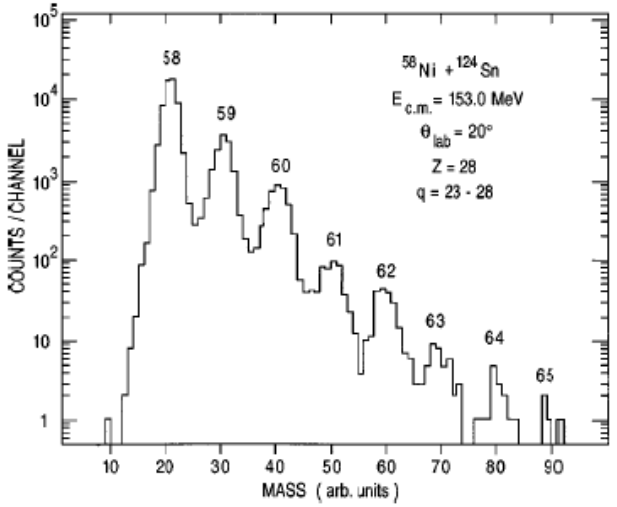
R.Betts et al., PRL59(1987)978

Successive & Pair transfer





$$F_{2n}(r) = \alpha_{2n} V_0 \frac{d}{dr}\left[1 + \exp\left(\frac{r - R_0}{a_{2n}}\right)\right]^{-1}$$



C.L.Jiang et al., PRC57(1998)2393

H.Esbensen et al., PRC57(1998)2401

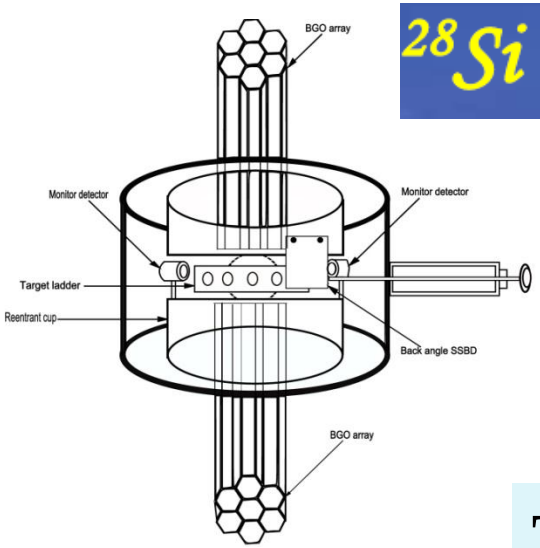
- Multinucleon transfer reaction around Coulomb barrier
- Effect of multinucleon transfer channel on fusion cross section
- Effect of pairing correlation on multinucleon transfer reaction mechanism
- Relative importance of ground state and excited state transfer strength

$^{28}Si + ^{90,94}Zr$

Isotope	$E_x(2^+)$ (KeV)	B(E2) (e^2b^2)	$E_x(3^-)$ (KeV)	B(E3) (e^2b^3)
^{90}Zr	2186.274	**0.0610**	2748	**0.098**
^{94}Zr	918.75	**0.066**	2058	**0.09**
^{96}Zr	1750.498	0.055	1897	0.202

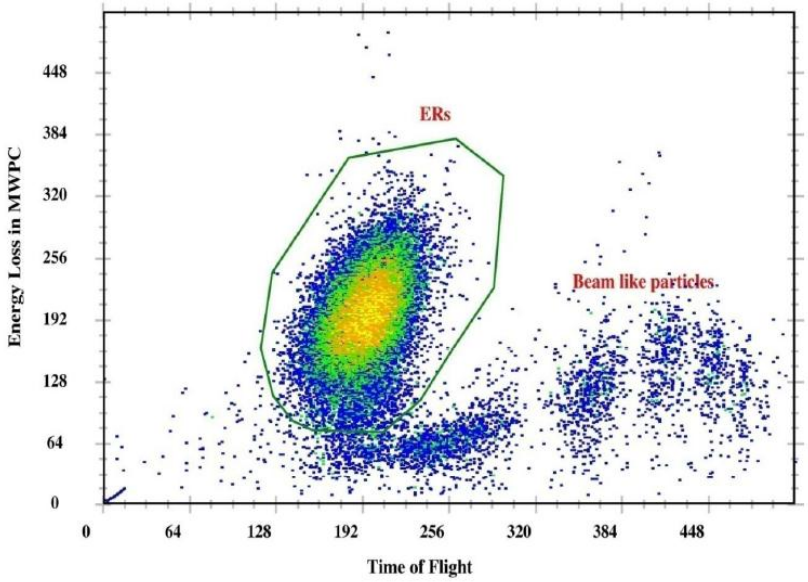
System	+1n	+2n	+3n	+4n	-1p	-2p
^{28}Si + ^{90}Zr	-3.50	-2.20	-7.96	-8.37	-6.43	-7.24
^{28}Si + ^{94}Zr	0.25	4.13	2.08	4.09	-4.78	-3.75

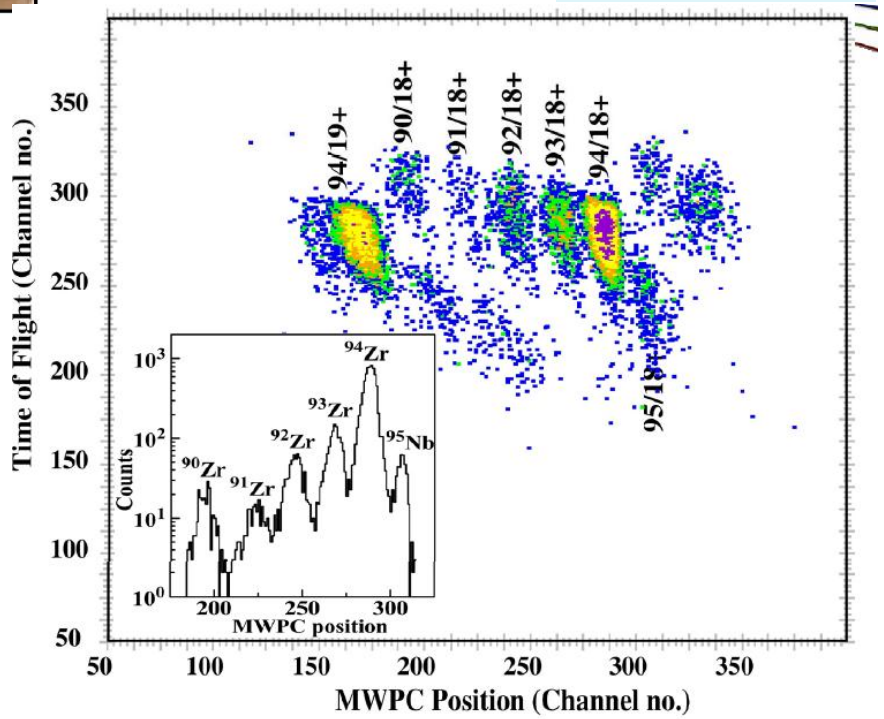
$^{28}Si + ^{90,94}Zr$



Transfer

Fusion

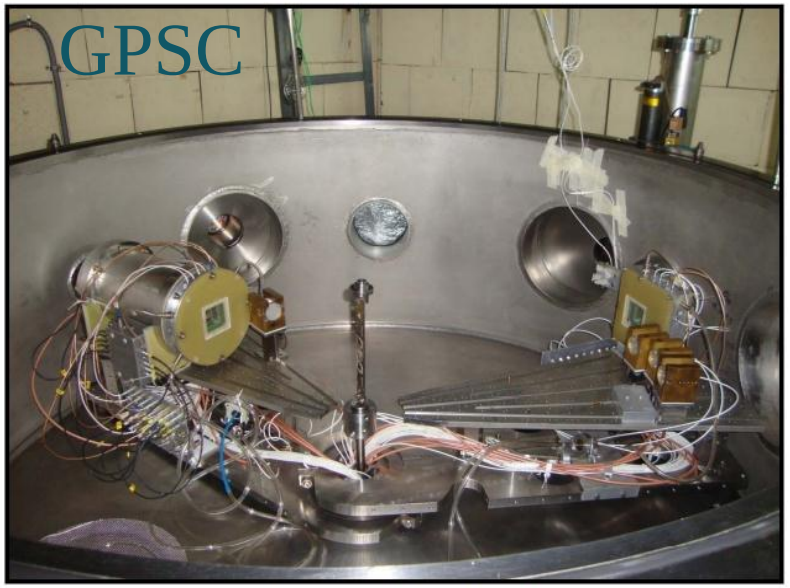




Sunil Kalkal et al. Phys. Rev. C81 (2010)044610

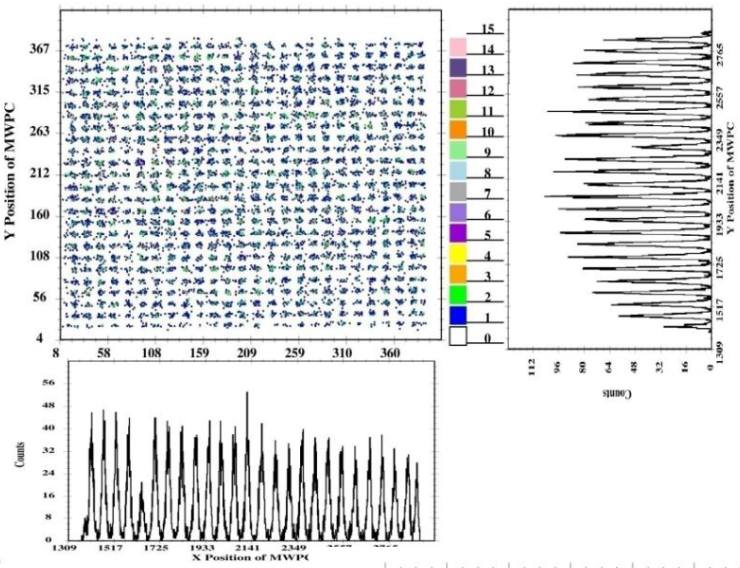
Sunil Kalkal et al. Phys. Rev. C83 (2011)054607

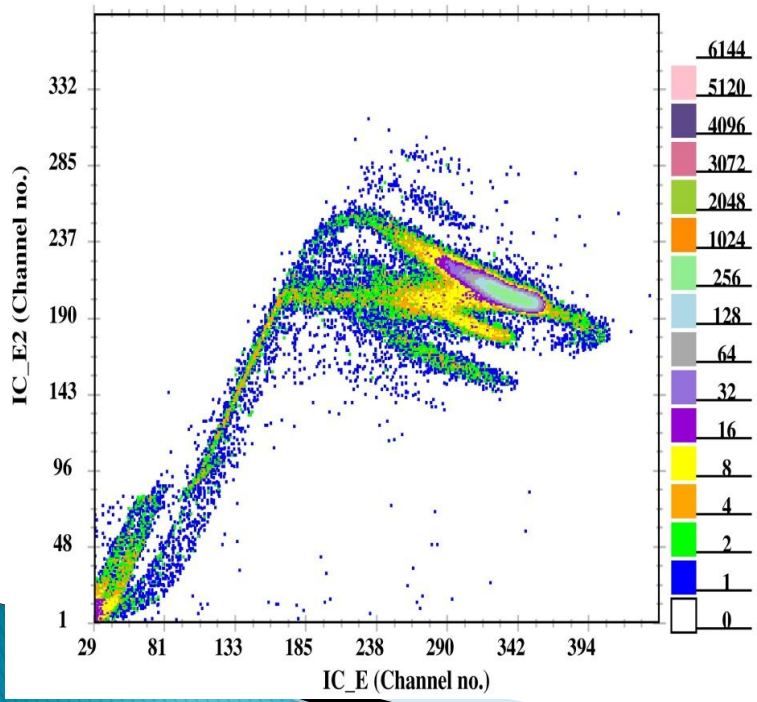
GPSC

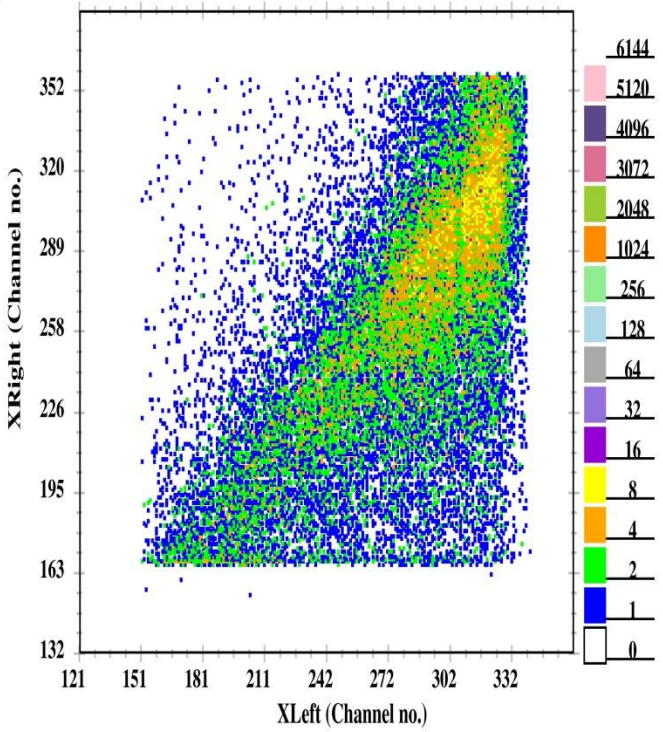


An inside view of the chamber.

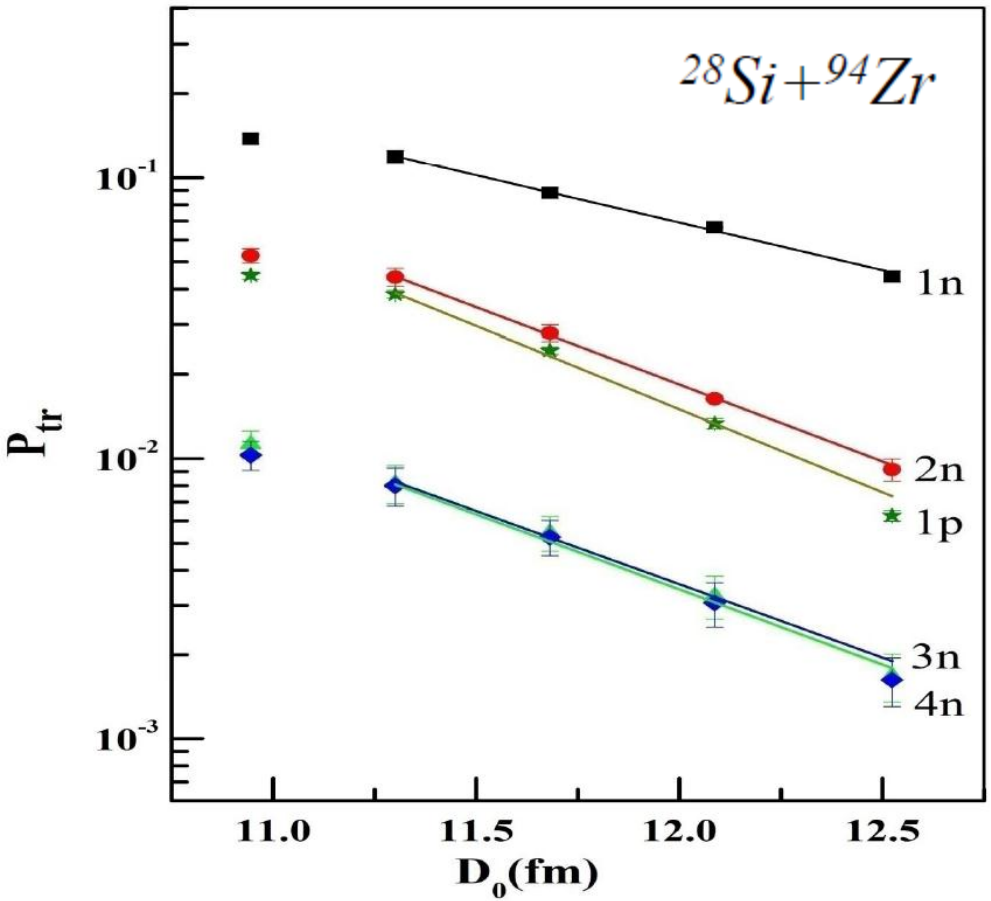
$^{28}Si + ^{90,94}Zr$





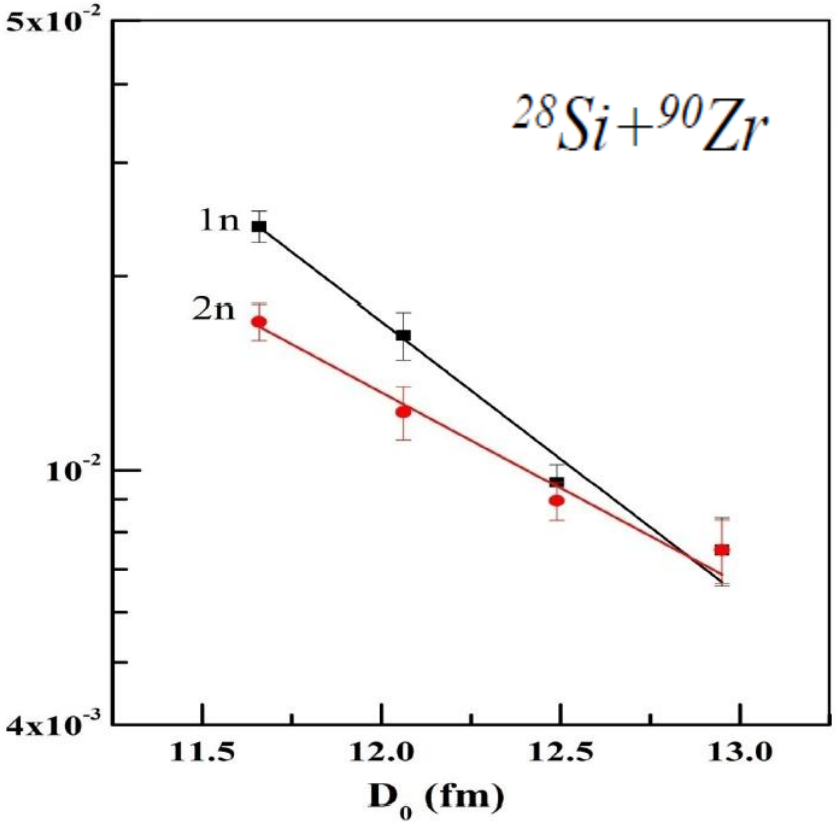


Transfer Probability



$$P_{tr} = \frac{Y_{tr}}{Y_{qe}} \times \eta_m$$

$$D_0 = \frac{Z_P Z_T e^2}{2E_{c.m.}}\left(1 + \cos ec\frac{\theta_{c.m.}}{2}\right)$$



$$P_{tr}(D_0) = \frac{\pi}{\sigma^2}\frac{d\left|F_\beta(D_0)\right|^2}{dQ}\int_{-\infty}^{Q_{gs}} \exp\left[\frac{-(Q_\beta - Q_{opt})^2}{2\sigma^2}\right] dQ.$$

$$\sigma = \sqrt{\frac{\alpha\hbar^2 i}{2}} \qquad Q_{opt} = \left(\frac{Z_P^f Z_T^f}{Z_P^i Z_T^i} - 1\right) E_{c.m.}$$

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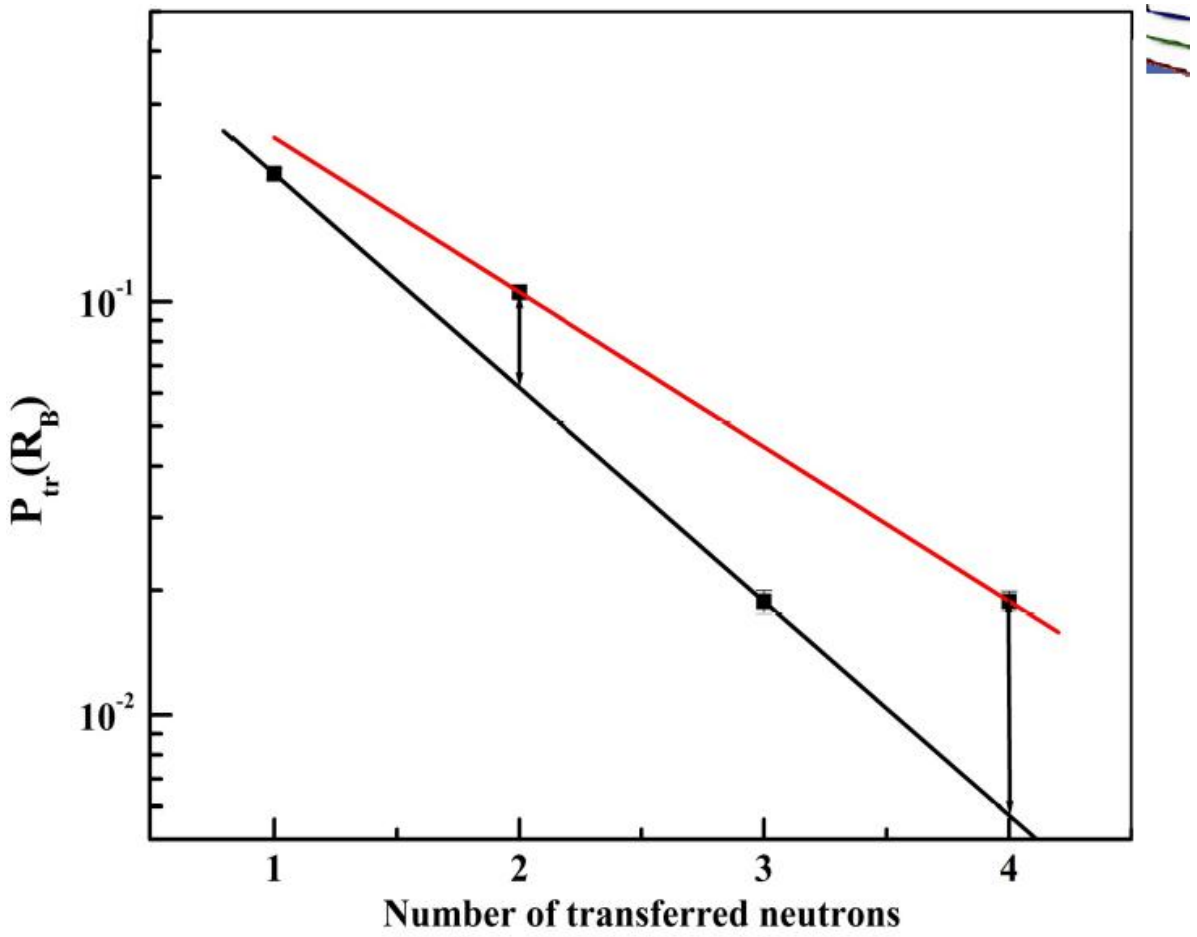
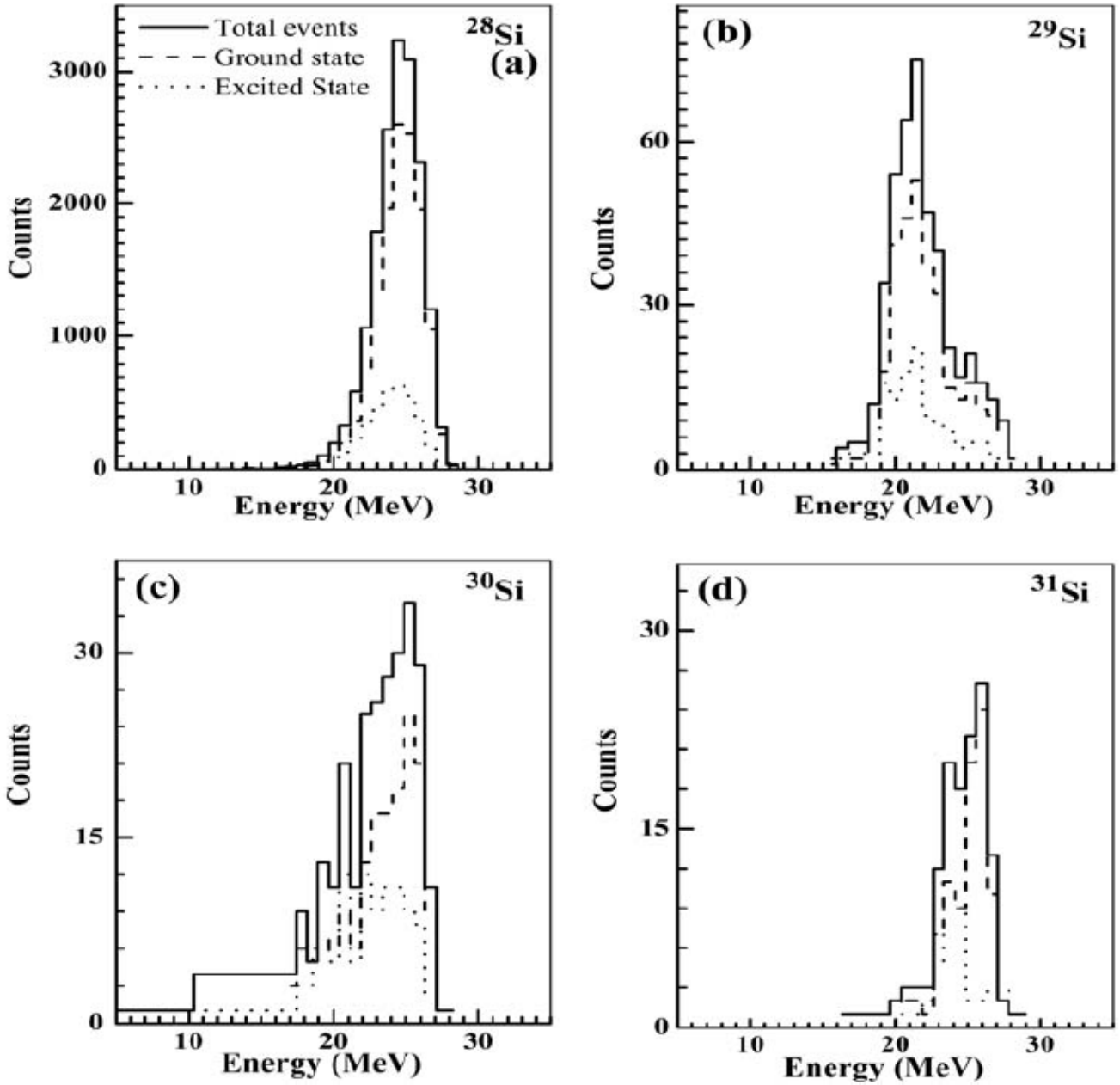
Odd - Even Effect !!



$^{28}Si+^{90}Zr$



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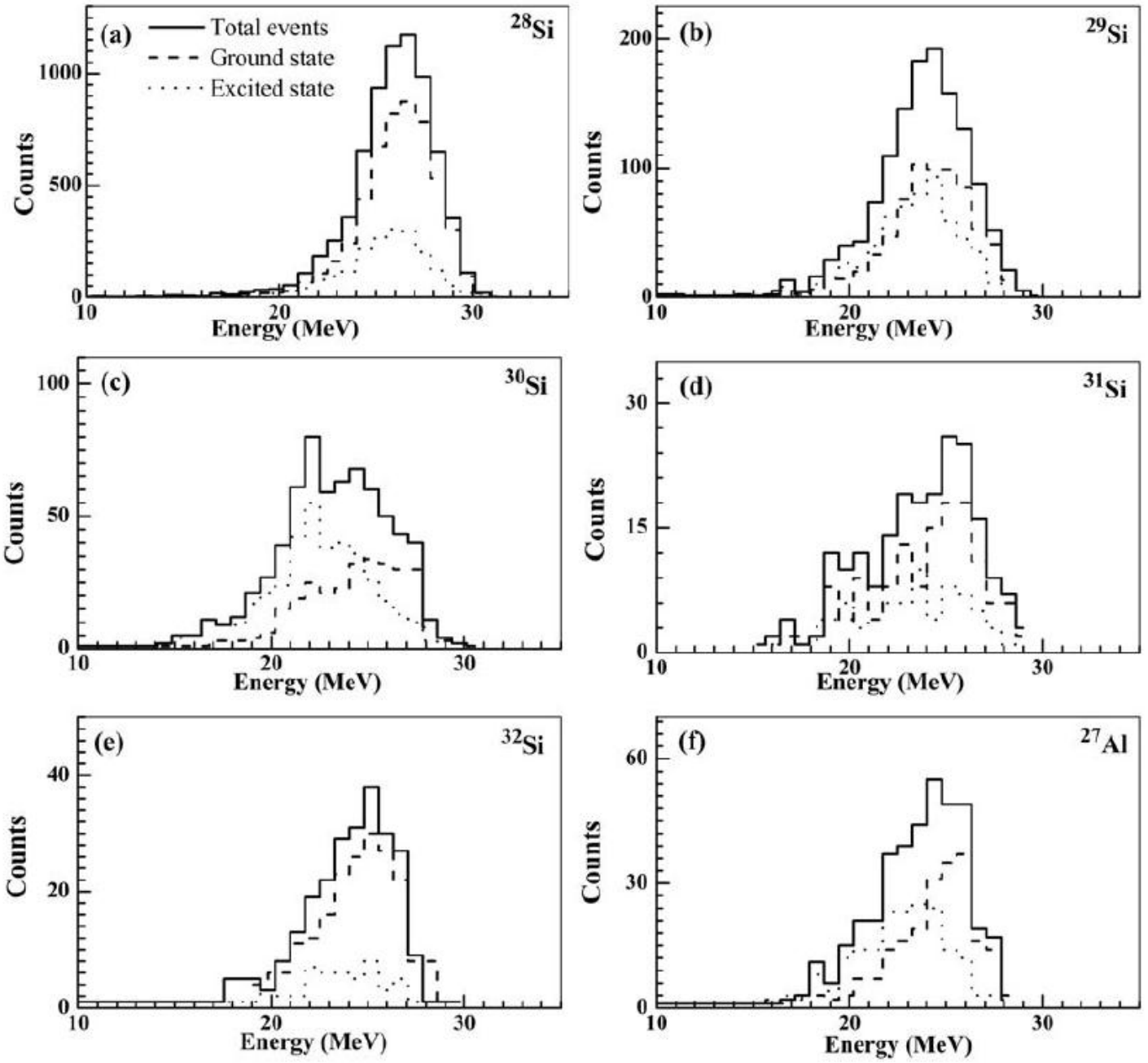

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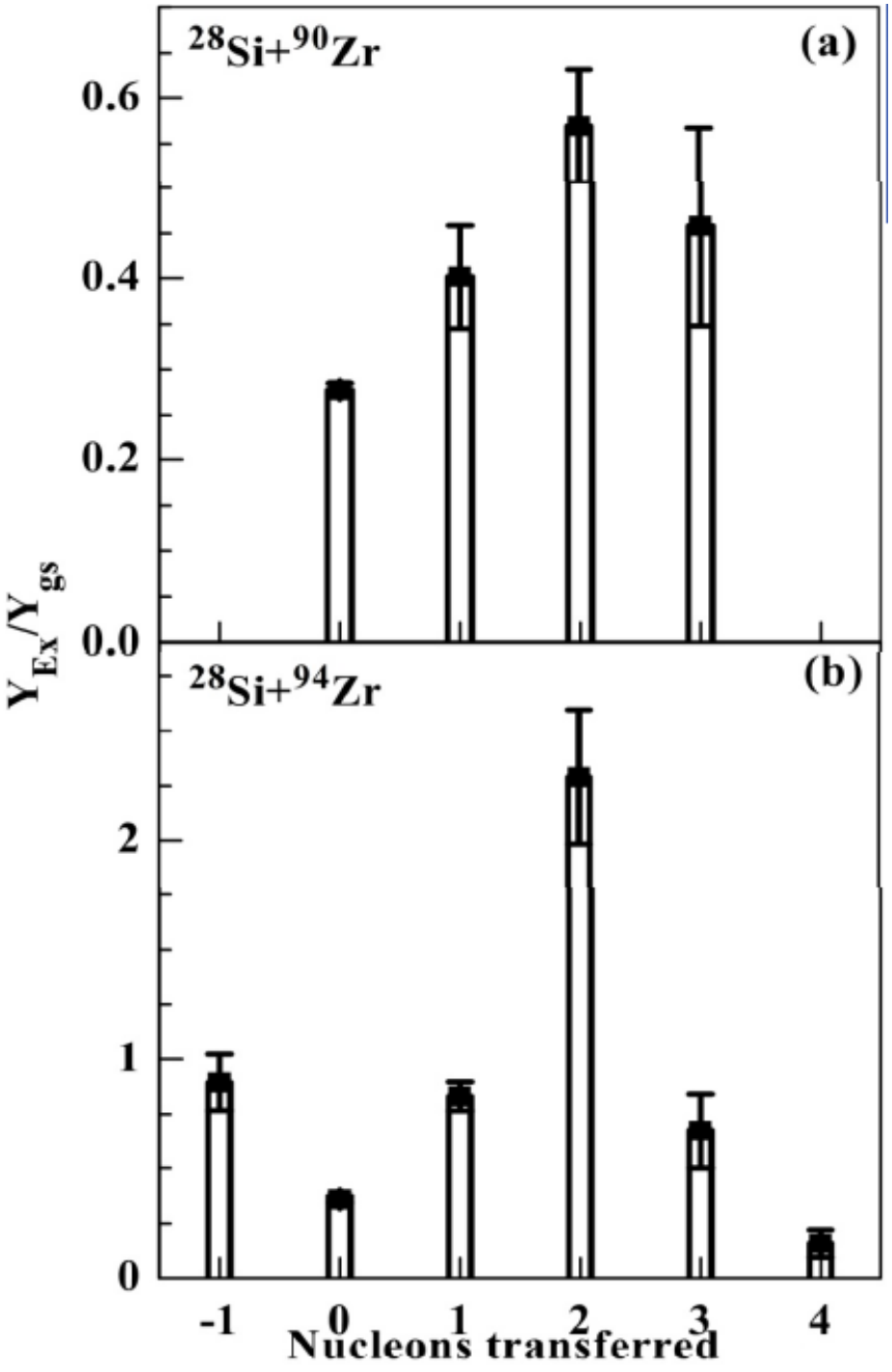
Ratio of Excited state to the Ground State Transfer evens



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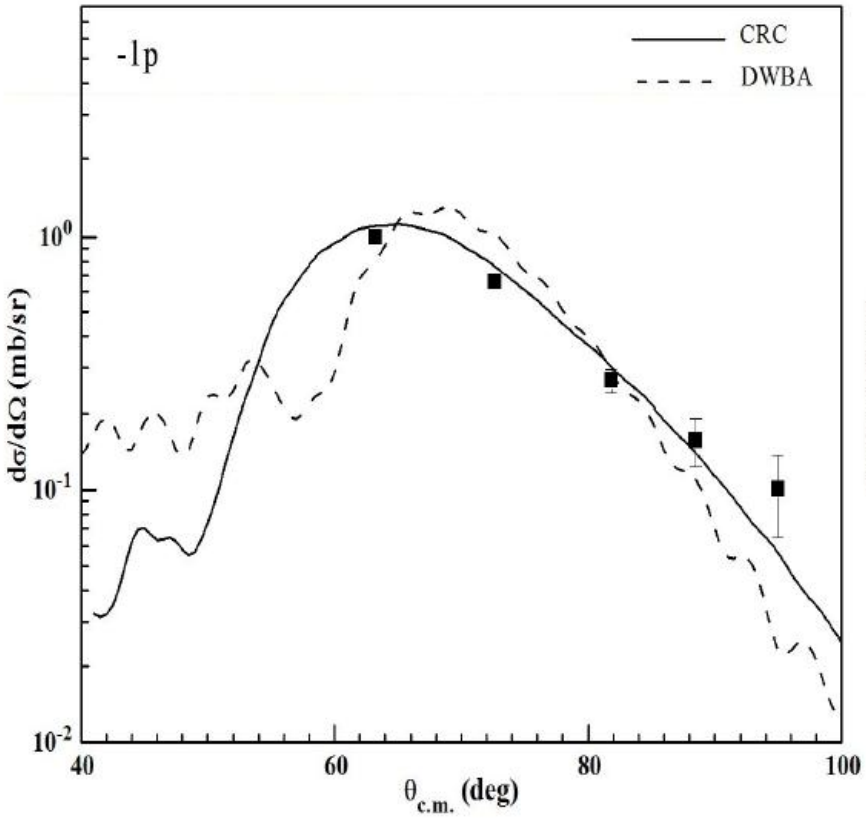
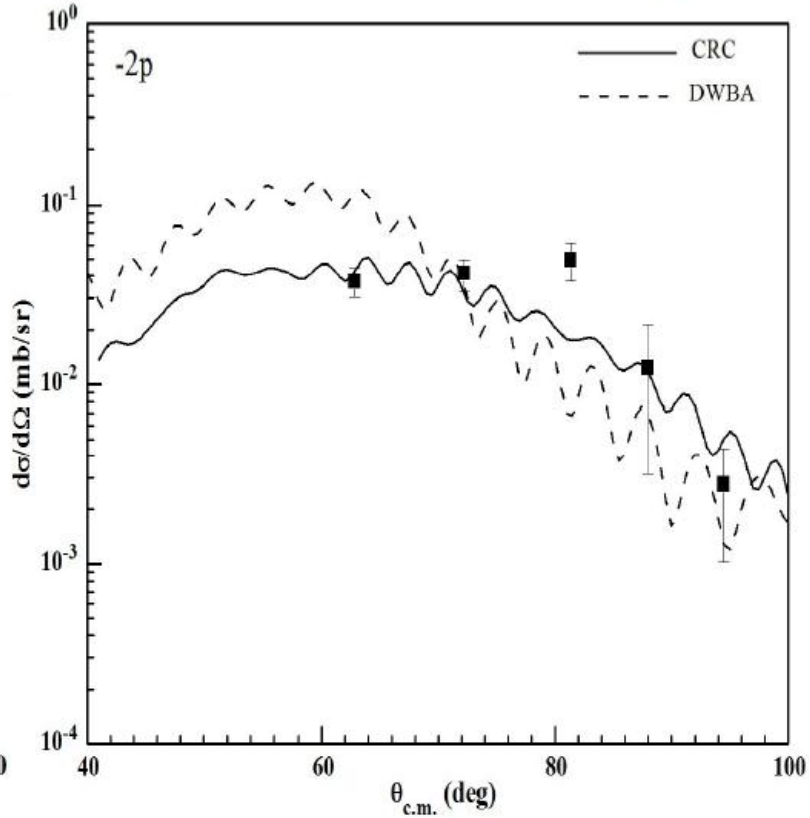
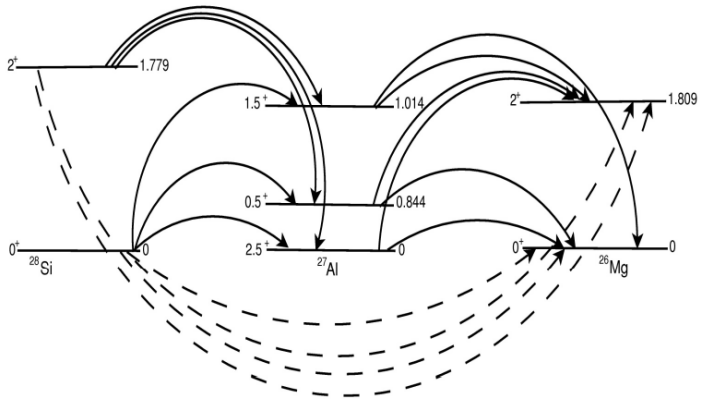


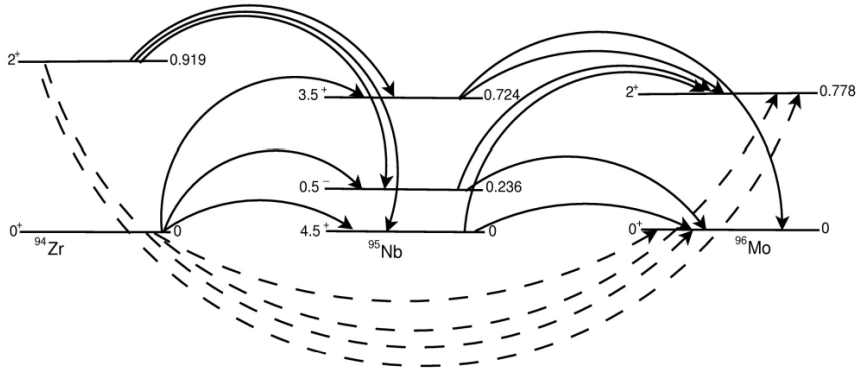


$^{28}Si + ^{94}Zr$

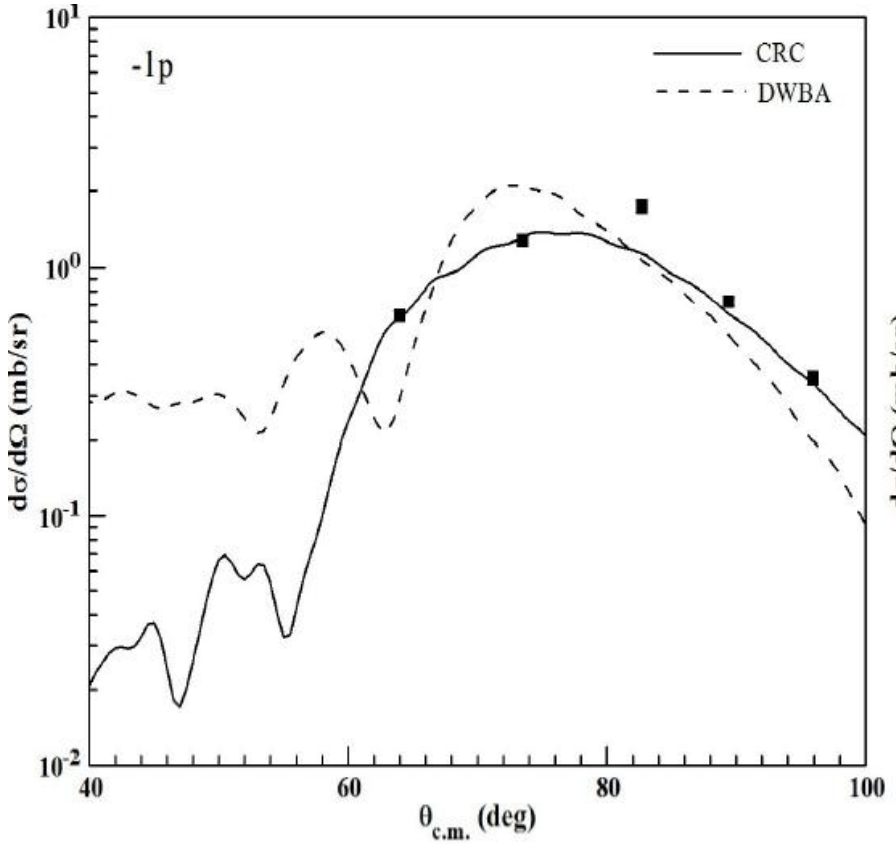
Coupling Scheme for CRC Calculations

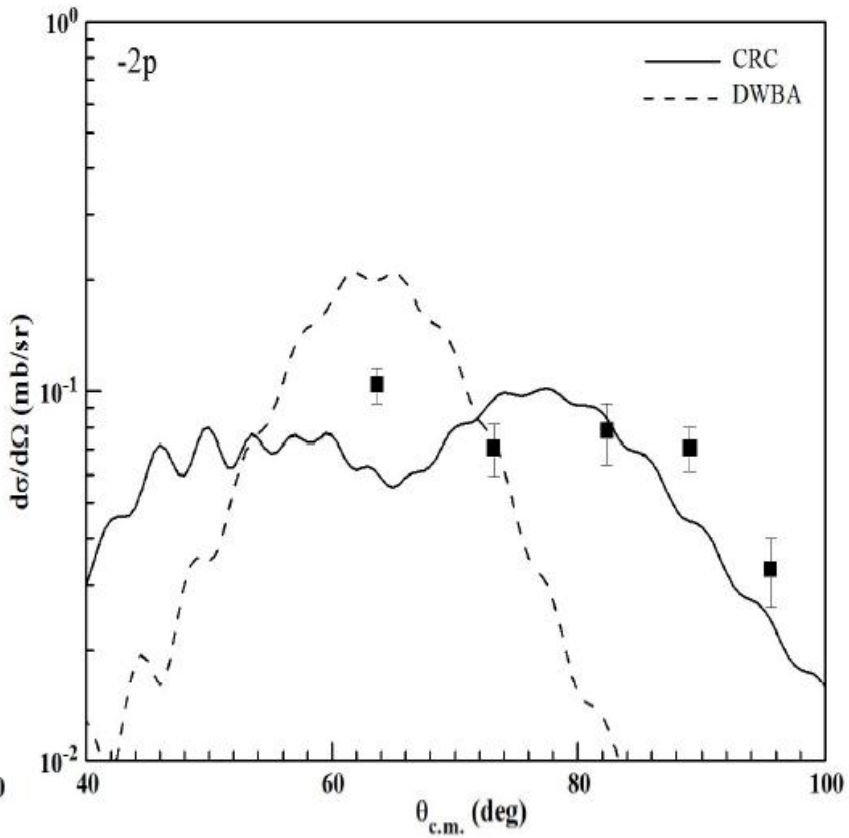


A schematic of the couplings of the projectile-like nuclei.



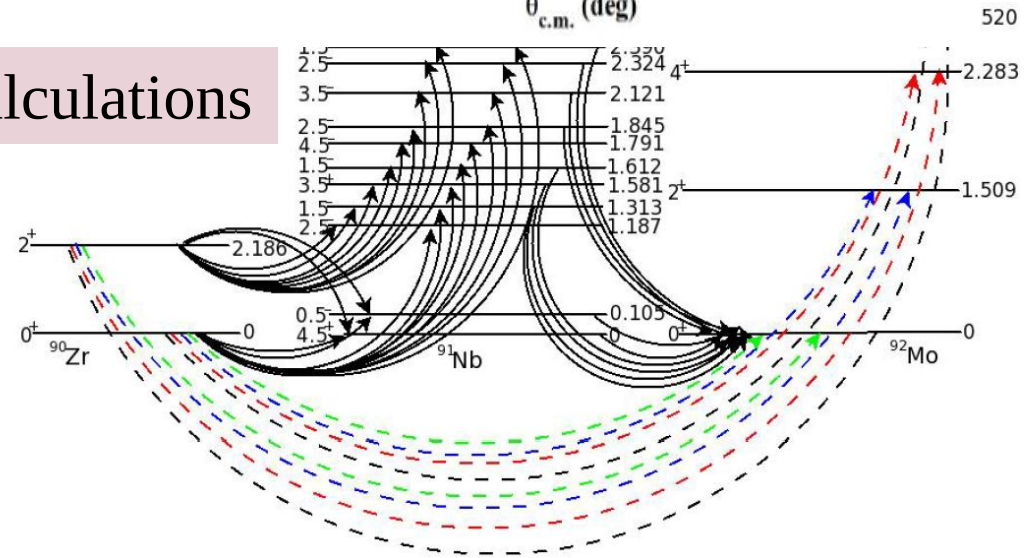
A schematic of the couplings of the target-like nuclei.





Coupling Scheme for CRC Calculations

$^{28}Si + ^{90}Zr$



A schematic of the couplings of the target-like nuclei.

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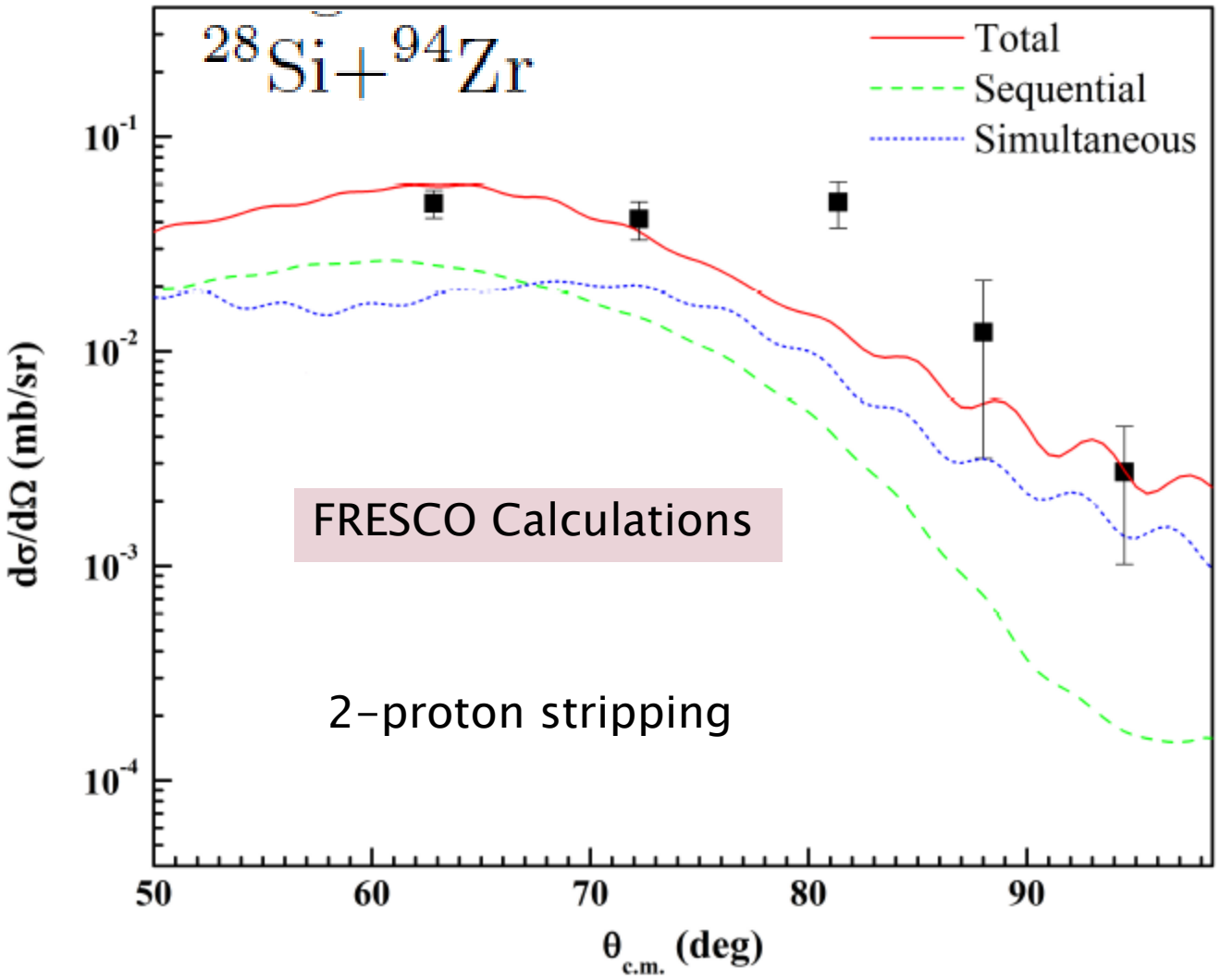

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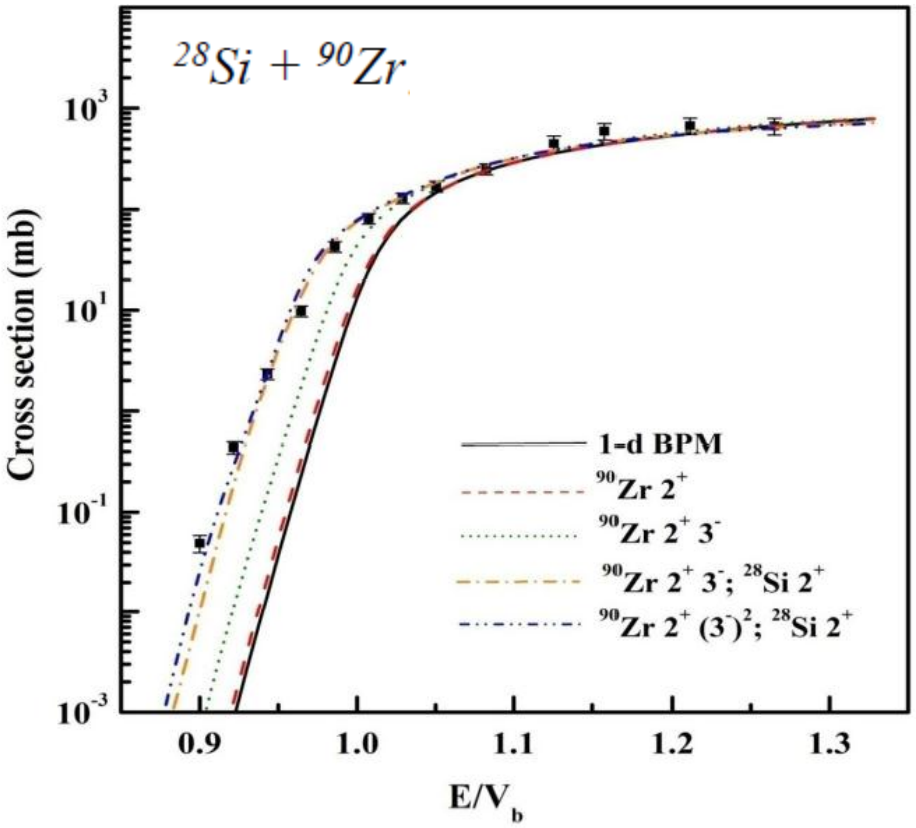
FUSION EXCITATION FUNCTIONS



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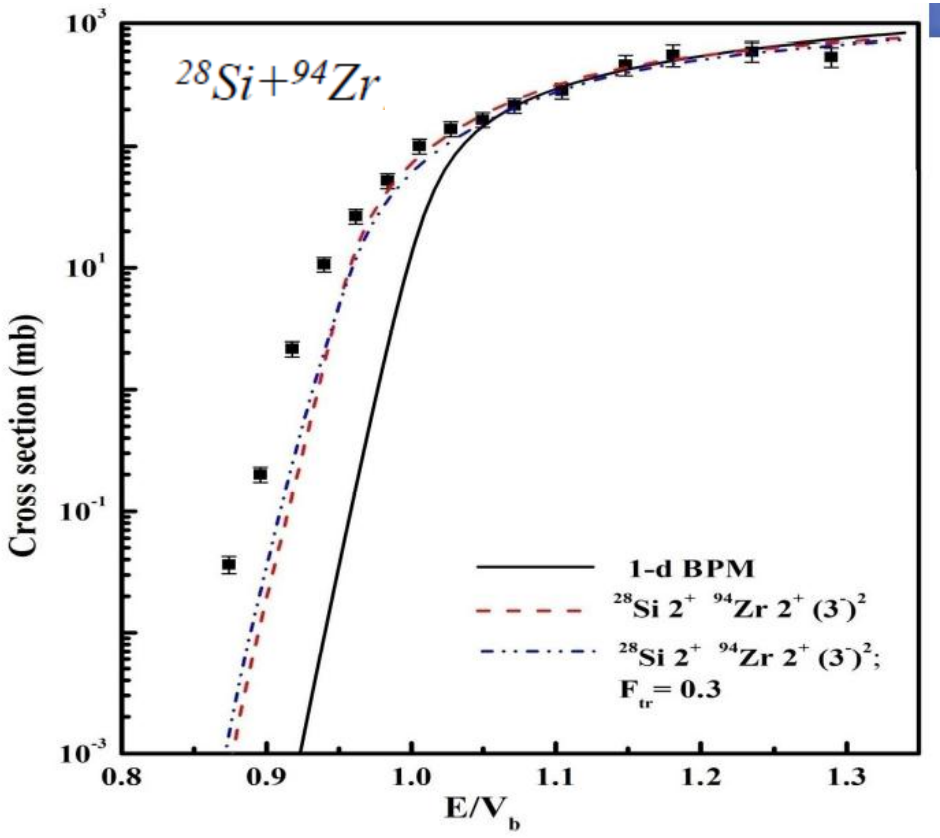


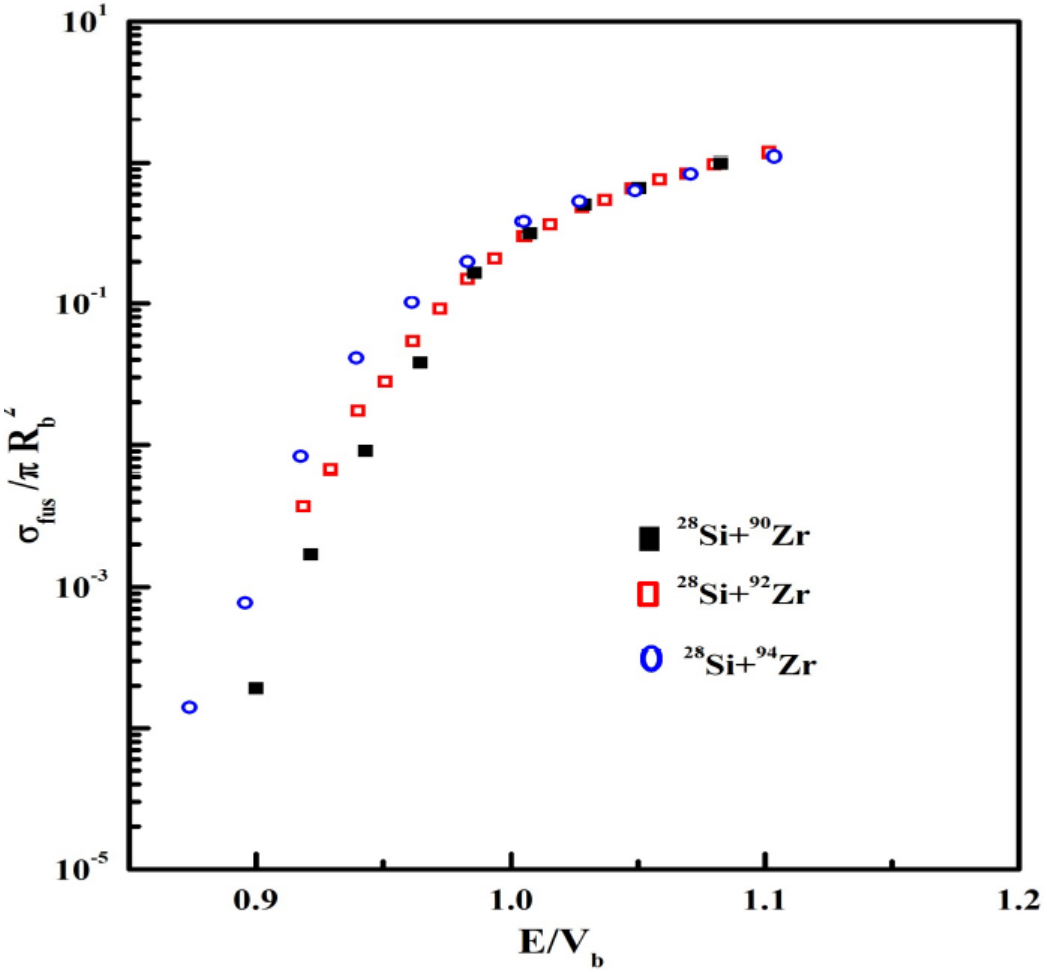
FUSION EXCITATION FUNCTIONS

Wong's formula

$$\sigma_{fus} = \frac{R_b^2 \hbar\omega}{2Ec.m.} \ln[1 + \exp\{\frac{2\pi}{\hbar\omega}(E_{c.m.} - V_b)\}]$$

$$\sigma_{red} = 2\sigma_{fus} E_{c.m.} \Big/ R_b^2 \hbar\omega$$

$$E_{red} = (E_{c.m.} - V_b)/\hbar\omega.$$



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J.O. Newton et al Phys. Rev. C64 (2007) 064608

Wong's formula

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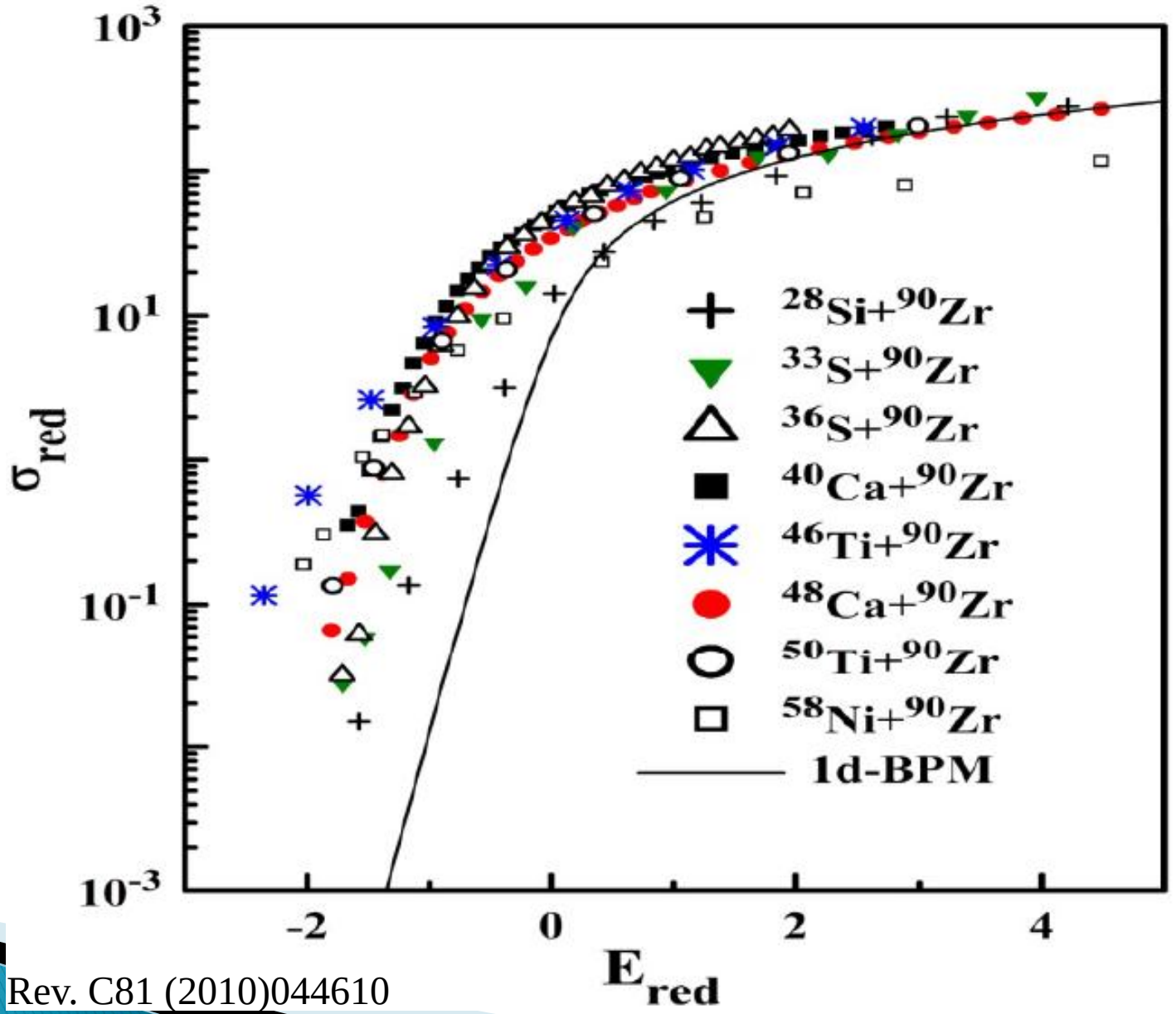

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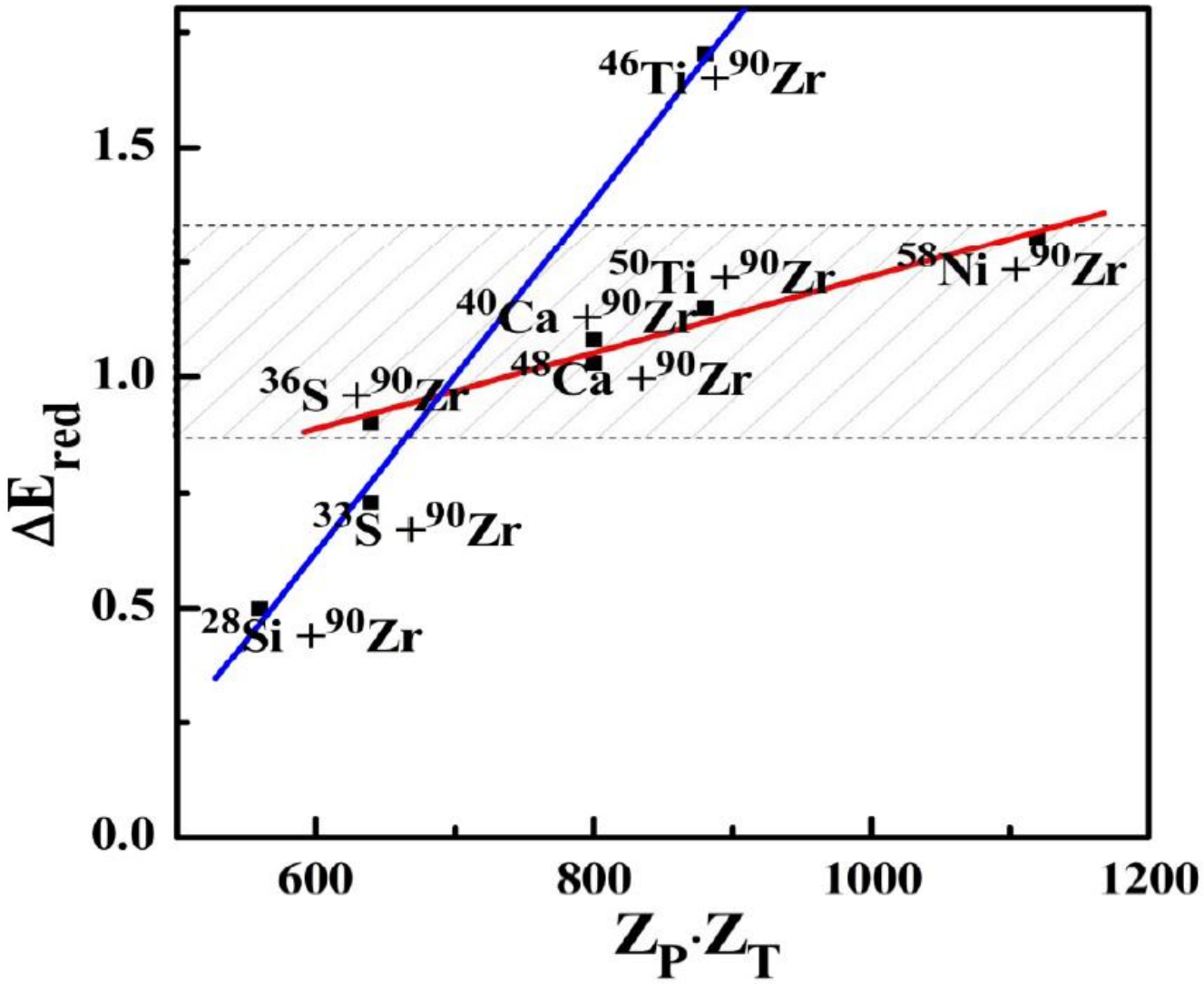

ΔE_{red} : difference in the value of E_{red} correspond to the cross section (~ 0.1mb) for various system

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Summary

- *Strong correlation between the transfer and fusion reactions.*
- *Sequential transfer of nucleons is an important mechanism of transfer in multi nucleon transfer reactions at above barrier energies.*
- *Indication of cold pair transfer at sub-barrier energies.*
- *Odd-even staggering is observed in multi neutron transfer case for $^{28}Si+^{90,94}Zr$ systems.*
- *The ratio of excited to ground state transfer is much more in $^{28}Si+^{94}Zr$ as compared to $^{28}Si+^{90}Zr$.*

Collaboration

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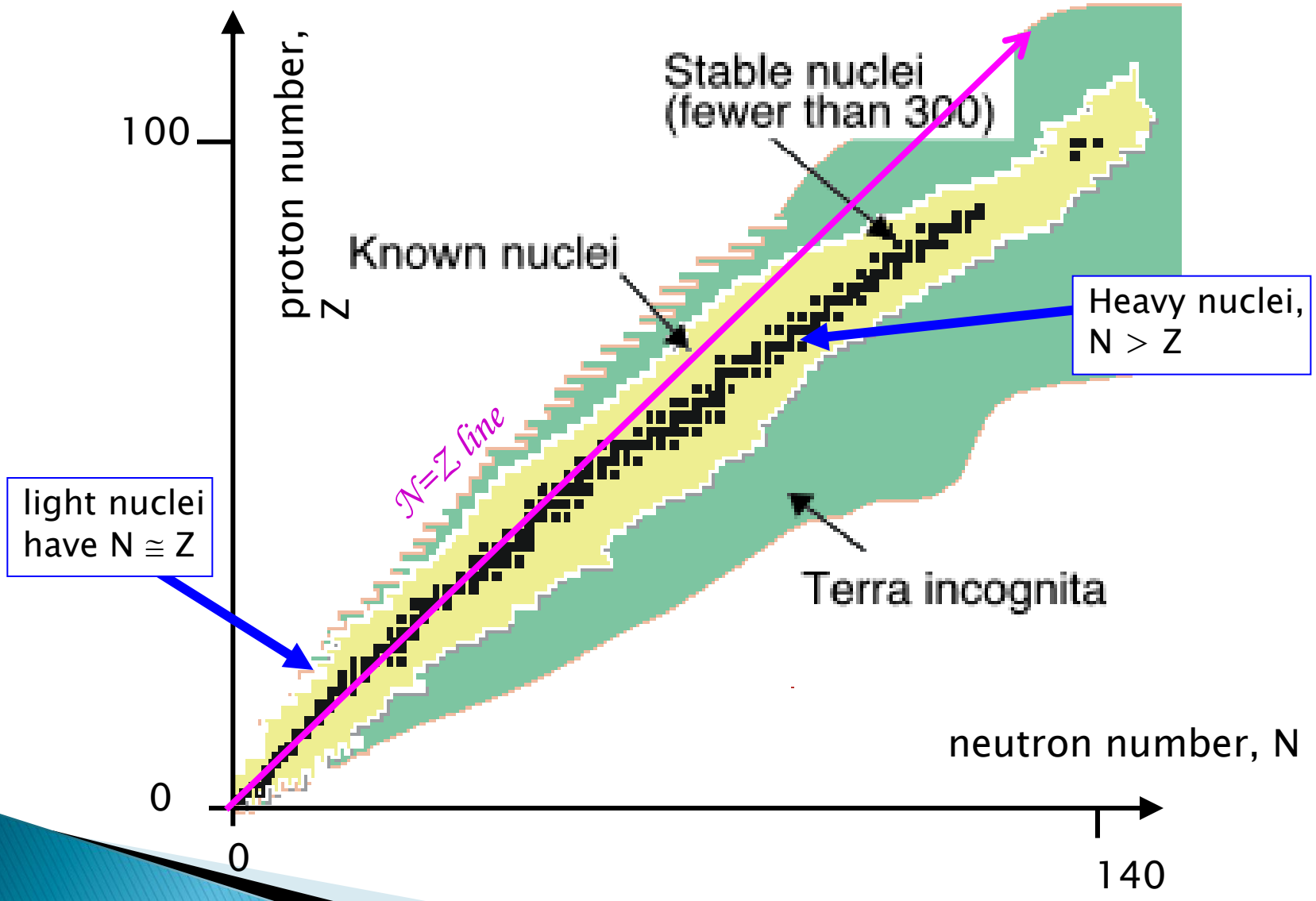
Calicut University, Kerala	*E. Prasad*
Panjab University, Chandigarh	*Rohit Sandal & Bivash Behera*
UGC-DAE Consortium for Scientific Research, Kolkata	*A. K. Sinha*
Saha Institute of Nuclear Physics, Kolkata	*U. D. Pramanik*
GSI, Darmstadt	*G. Eleonora & H. J. Wollersheim*

Landscape of stable and unstable nuclei



http://www.nscl.msu.edu/future/ria/science/toi.php


THANKS