Nuclear Structure and Reaction Mechanism Studies with Radioactive Ion Beams Produced in Batch-Mode

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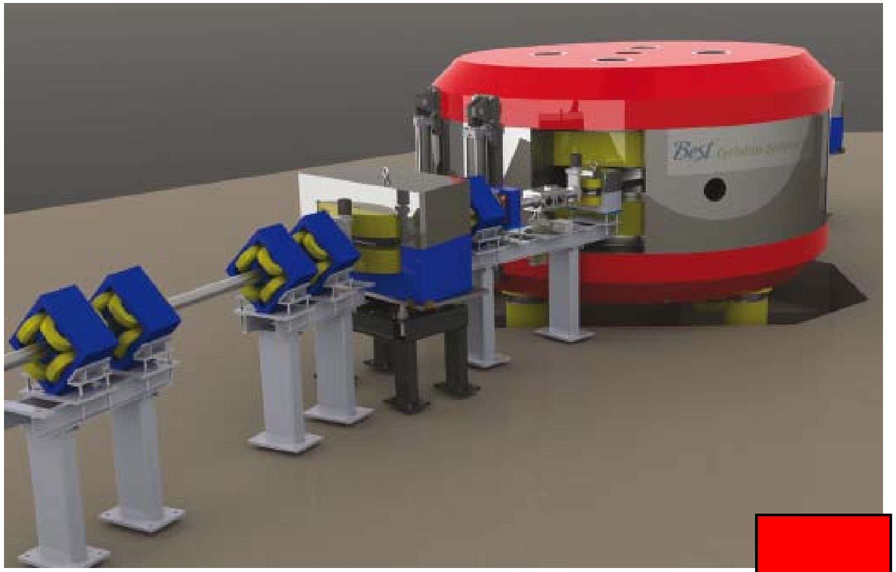
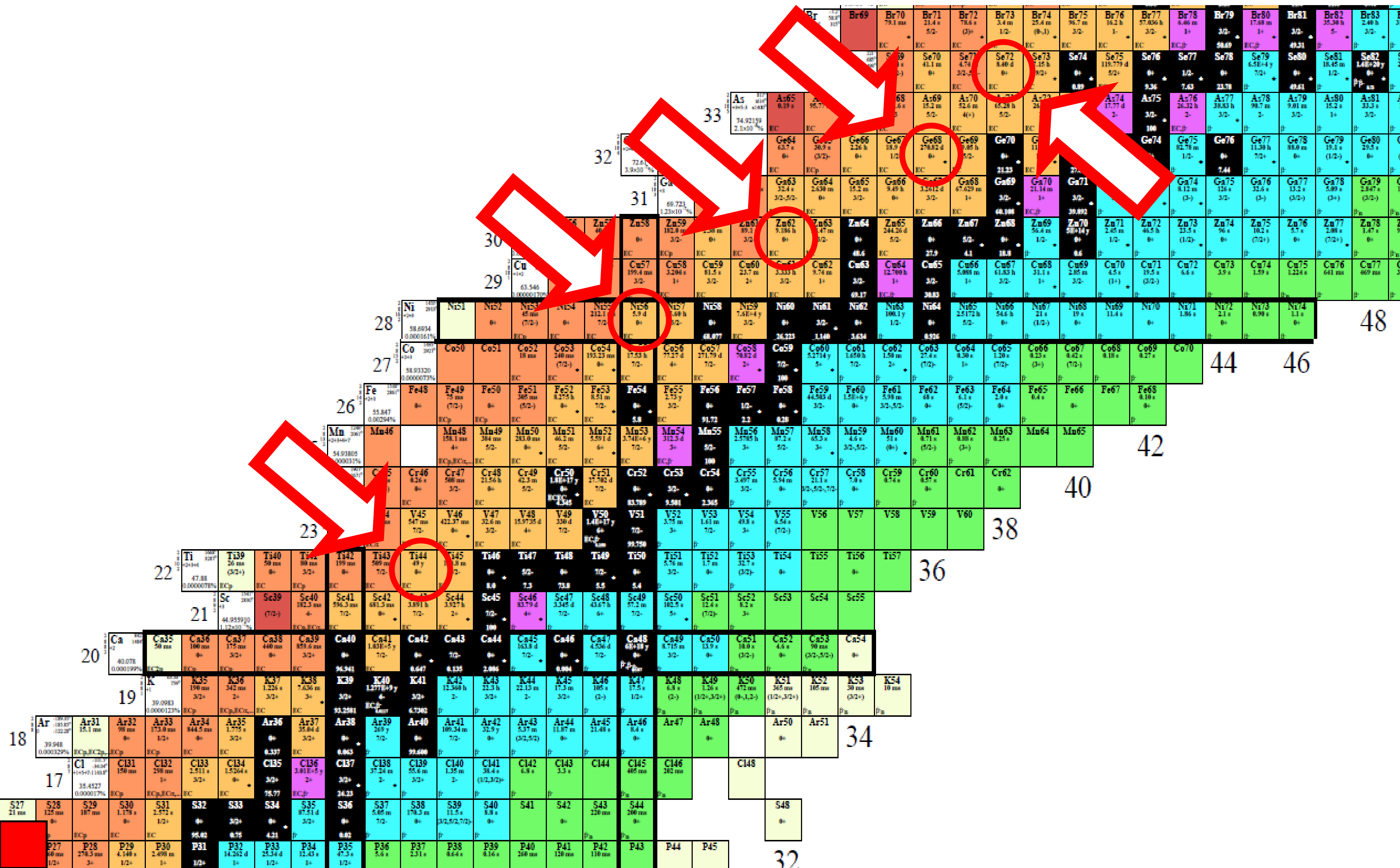
Batch-mode produced ribs



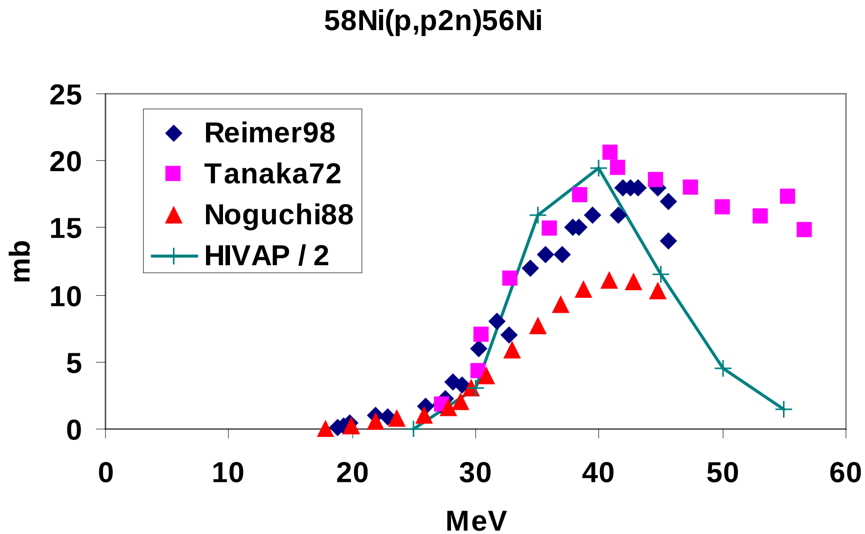
- Irradiation
- Transport
- Re-acceleration

Possible isotopes

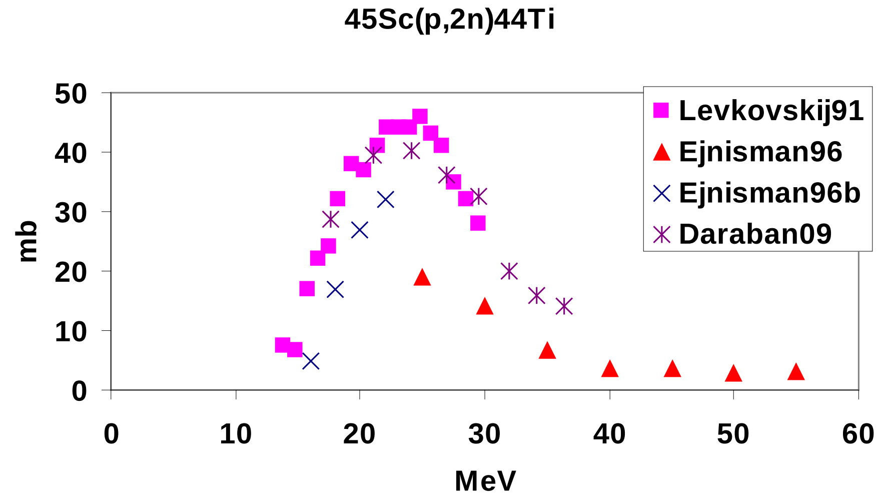


Possible isotopes

- ^{46}Ti (p,p2n) ^{44}Ti T ½ = 60.0y
- ^{58}Ni (p,p2n) ^{56}Ni T ½ = 6.1d
- ^{70}Ge(p,p2n) ^{68}Ge T ½ = 288d
- ^{74}Se (p,p2n) ^{72}Se T ½ = 8.5d
- ^{84}Sr (p,p2n) ^{82}Sr T ½ = 25.5d
- ^{88}Zr (p,p2n) ^{88}Zr T ½ = 83.4d



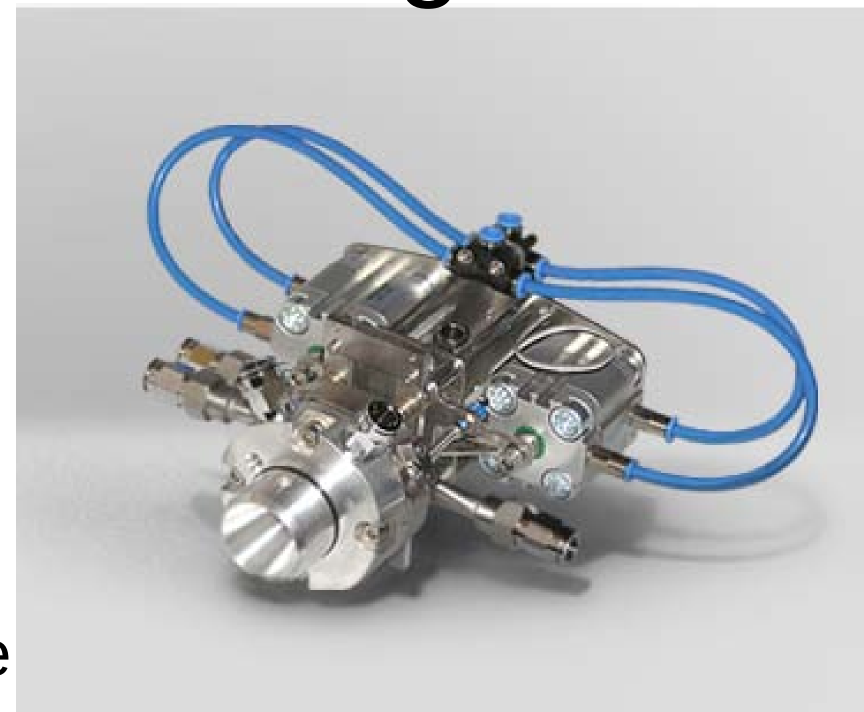
- ^{45}Sc (p,2n) ^{44}Ti T ½ = 47.3y
- ^{63}Cu (p,2n) ^{62}Zn T ½ = 9.13h
- ^{69}Ga(p,2n) ^{68}Ge T ½ = 288d

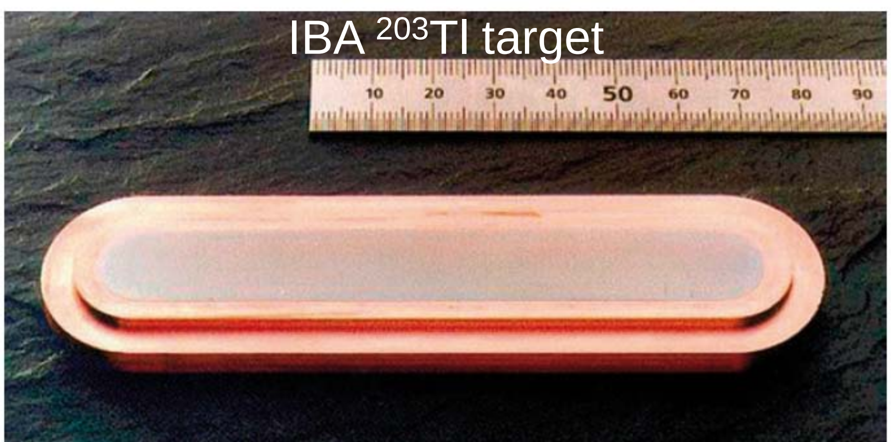


Target manufacturing

- Commercially available
- Production of ^{124}I, ^{76}Br, ^{60}Cu, ^{110}In, etc.
- Modification to the target part
- Simpler process
- Minimum exposure

- …but limited in the radioisotope concentration

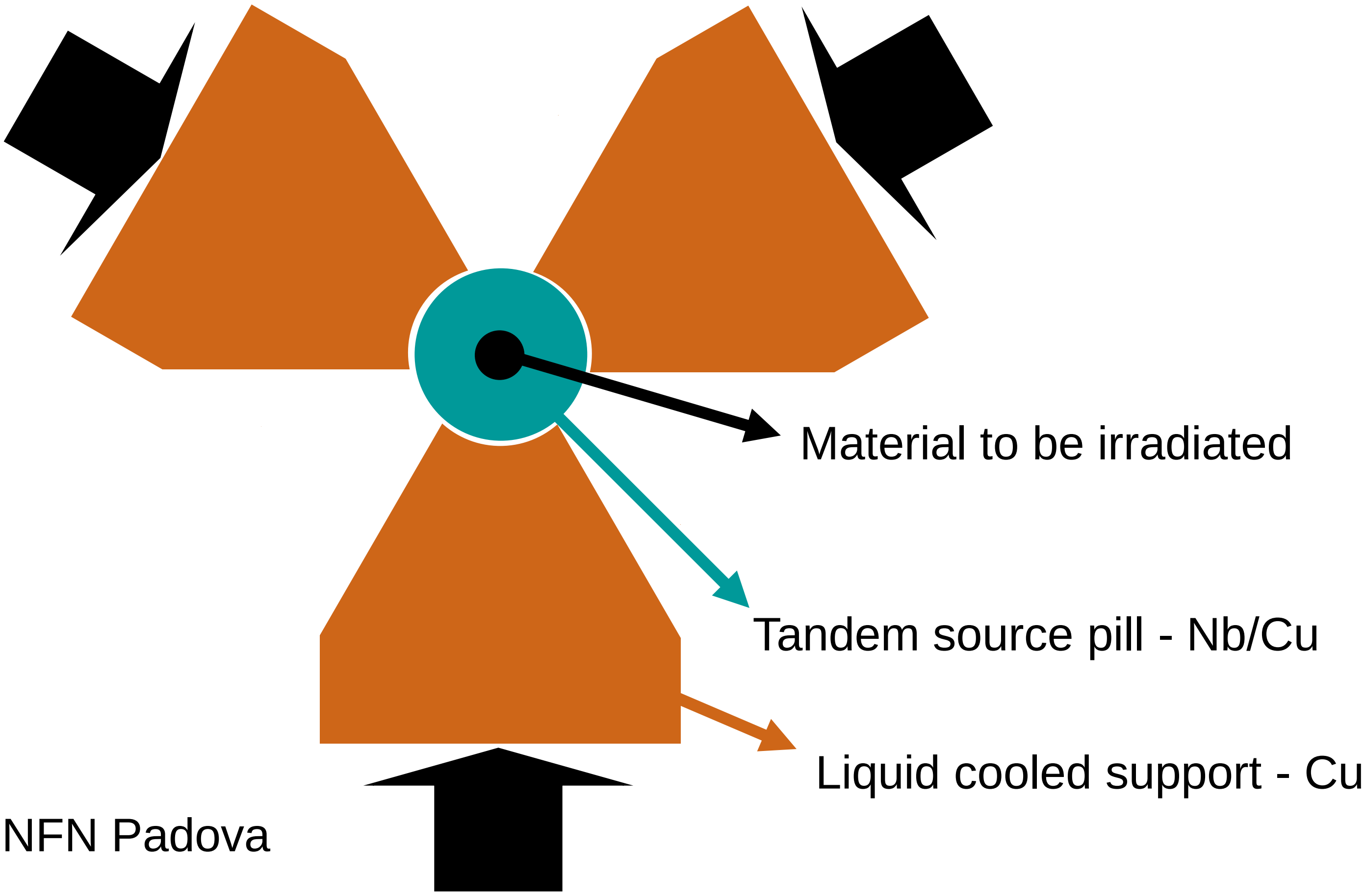




IBA ^{203}Tl target


TANDEM pill

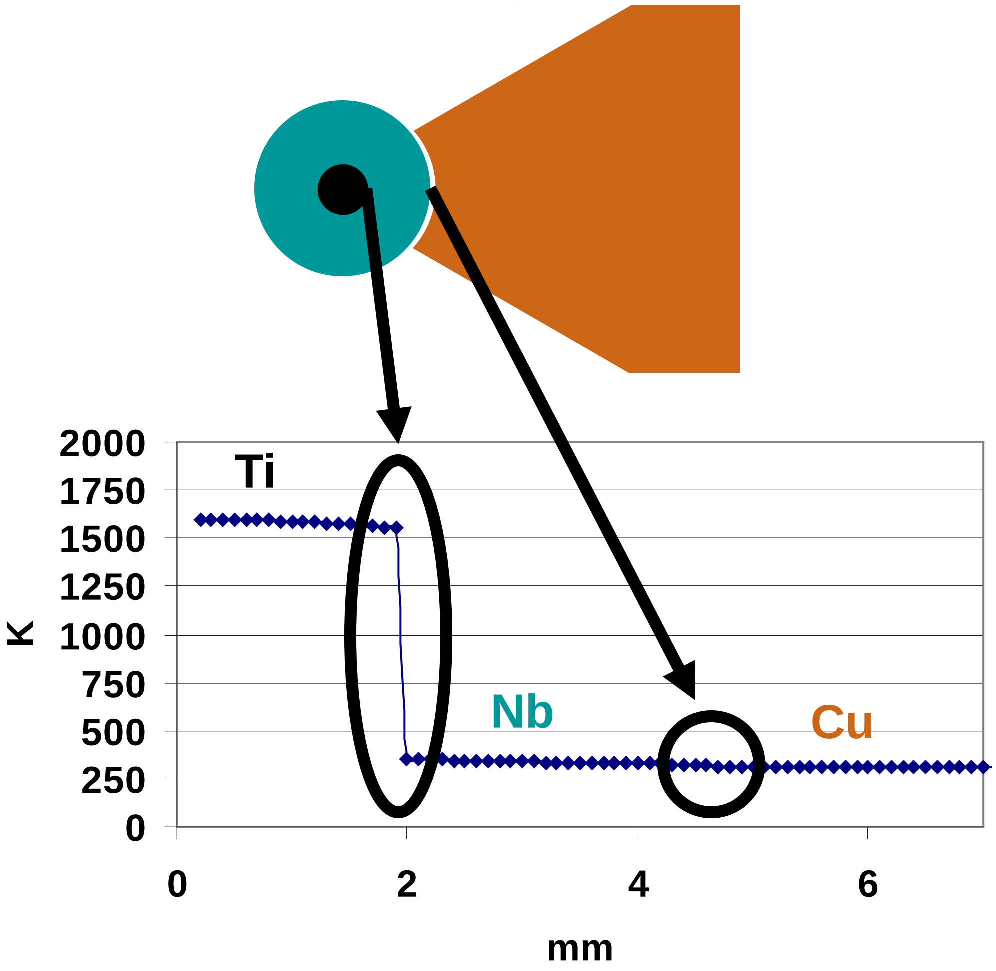
A possible target geometry



C.Fanin INFN Padova

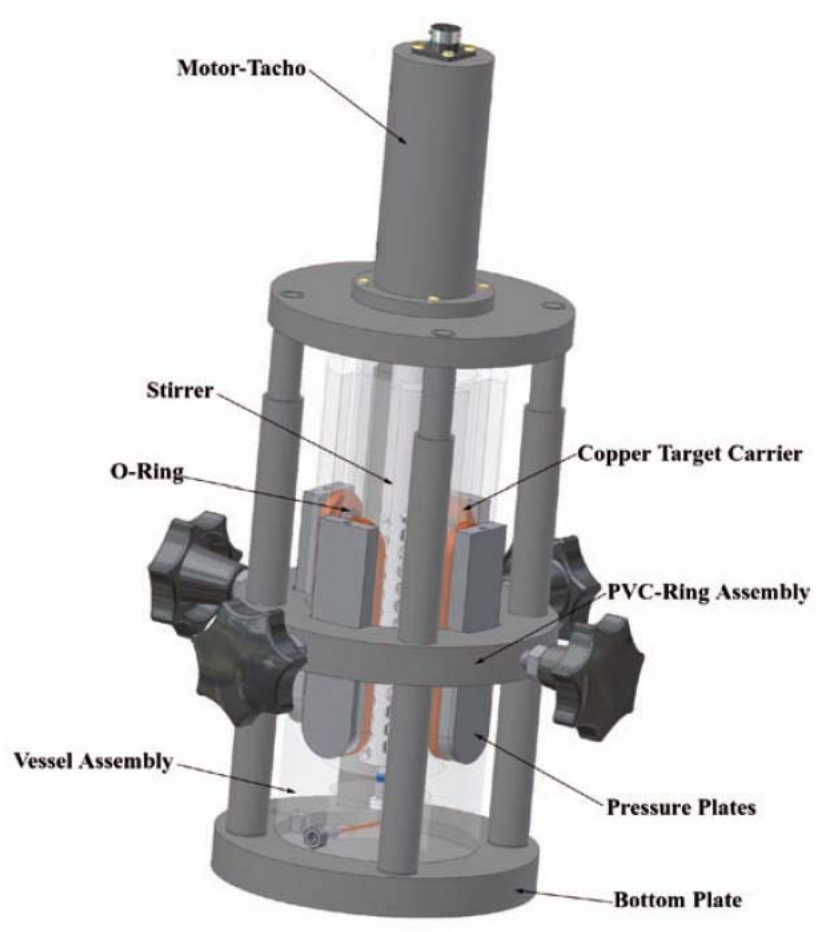
Power dissipation - preliminary calculations

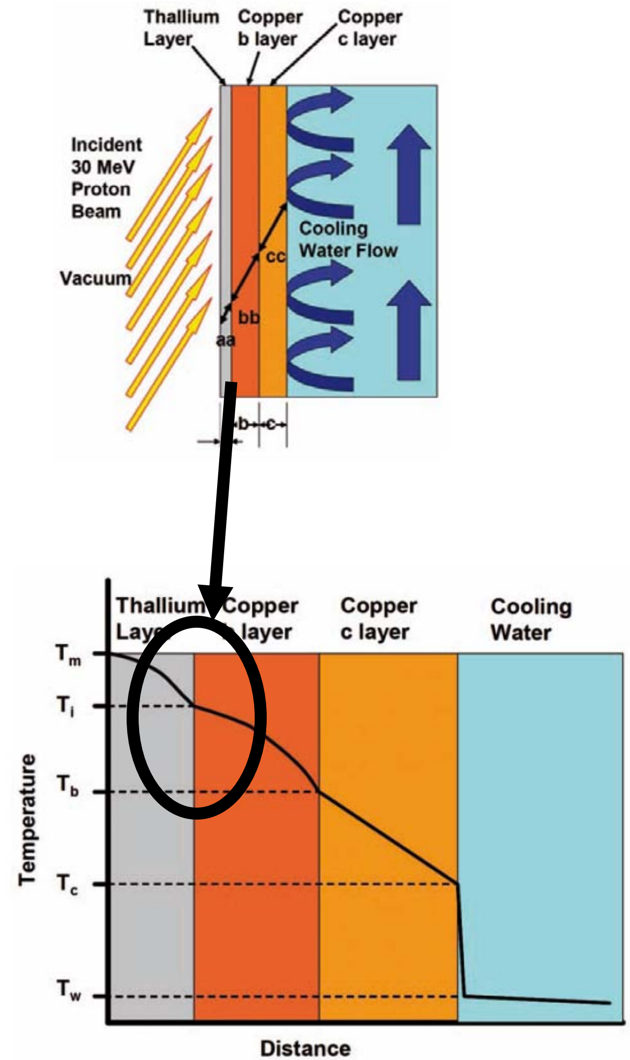
Power: 60 W
Contact resistance: 2000 W/(K*m2)



Power dissipation bottle-neck: small surface between material and cone

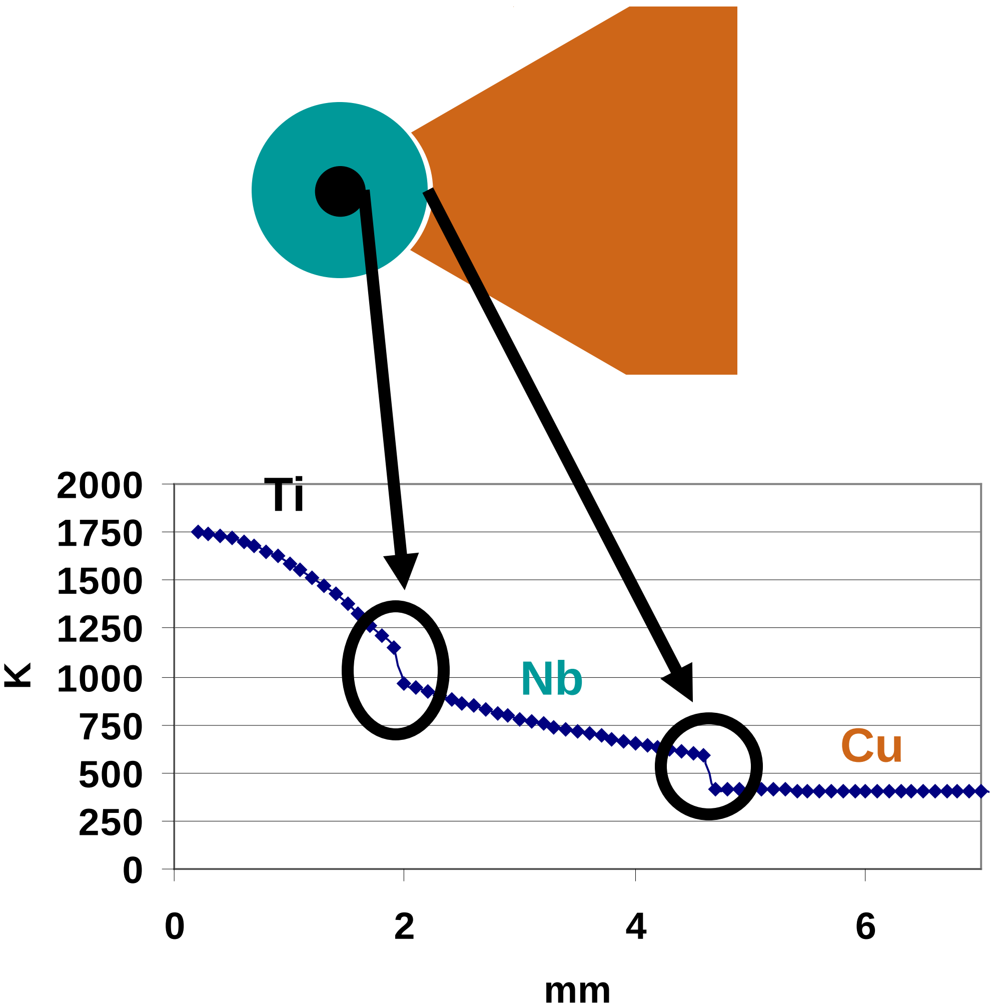
Electroplated targets for radiopharmaceuticals





Power dissipation - preliminary calculations

- Various options considered:
  - Electroplating
  - Welding
  - Only one piece



Power: 750 W (upper limit)
Low contact resistance

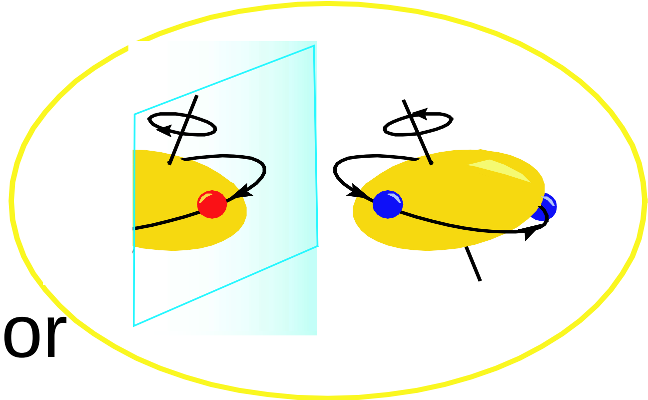
Our goal, the best case

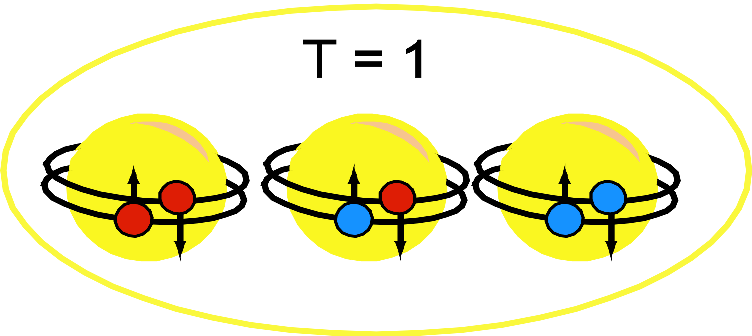
- Irradiation:
  - $T_{irr}=T_{fus}-100K$
  - For 10 days

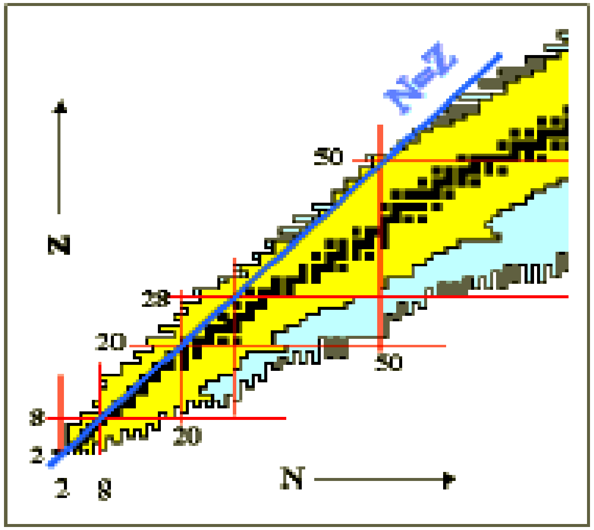
	Primary current	Nuclei produced	Secondary beam
^{44}Ti	15 µA	$6\ 10^{16}$	**$2.5\ 10^{7}$ pps**
^{56}Ni	35 µA	$3.5\ 10^{16}$	**$2\ 10^{7}$ pps**
^{68}Ge	12 µA	$1.5\ 10^{17}$	**$1.5\ 10^{8}$ pps**

Some topics

- Near-barrier fusion
- Isospin symmetry (T_z= 1/2)
- Isospin mixing isospin-forbidden or mirror E1 decays
- p-n pairing (N=Z, A>80)
- single-particle character in ^{56}Ni region
- (d,p) (p,d) (d,^{3}He) … reactions for astrophysics





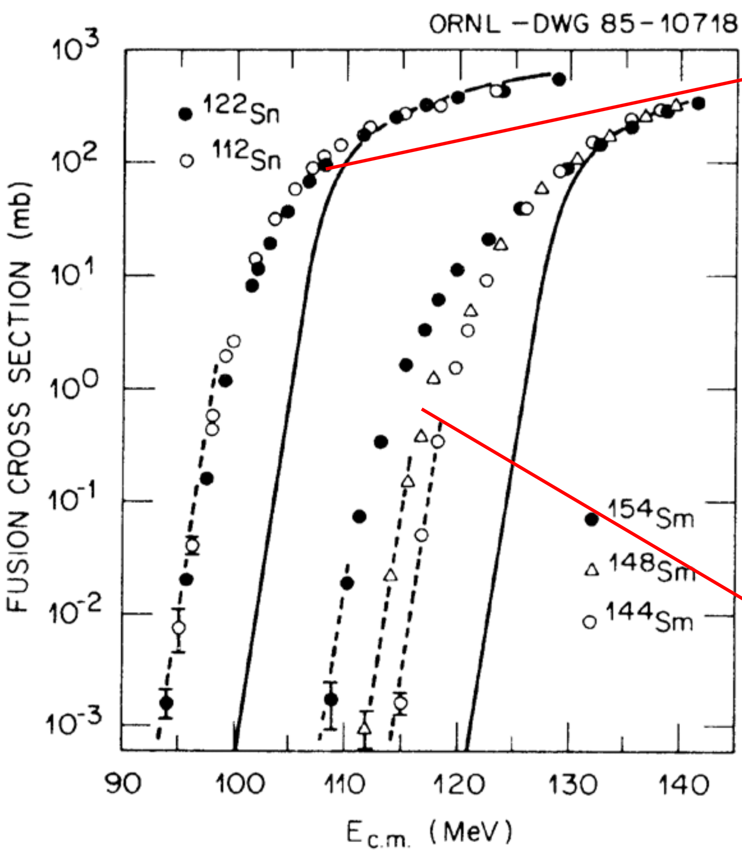


Near barrier fusion

- Generally speaking, heavy-ion fusion near the Coulomb barrier is governed by channel coupling effects
- Medium-mass systems are best suited to studying such effects, since, on one side, the couplings are strong enough and, on the other side, fusion-evaporation is the only significant reaction channel following capture inside the Coulomb barrier
- However, from the experimental point of view, measurements at 0^0 and near-by angles may not be simple

Early studies of sub-barrier fusion in medium-mass systems taught us that cross sections strongly depend on the structure of colliding nuclei …

M. Beckerman, Subbarrier fusion of atomic nuclei



^{40}Ar + ^{112,122}Sn

→ very similar x-sections

^{40}Ar + ^{144,148,154}Sm

→ very different x-sections

W.Reisdorf et al.,NPA 438 (1985) 212

… and that sub-barrier fusion cross sections may also depend on couplings to transfer channels (?)

Dynamic Influence of Valence Neutrons upon the Complete Fusion of Massive Nuclei

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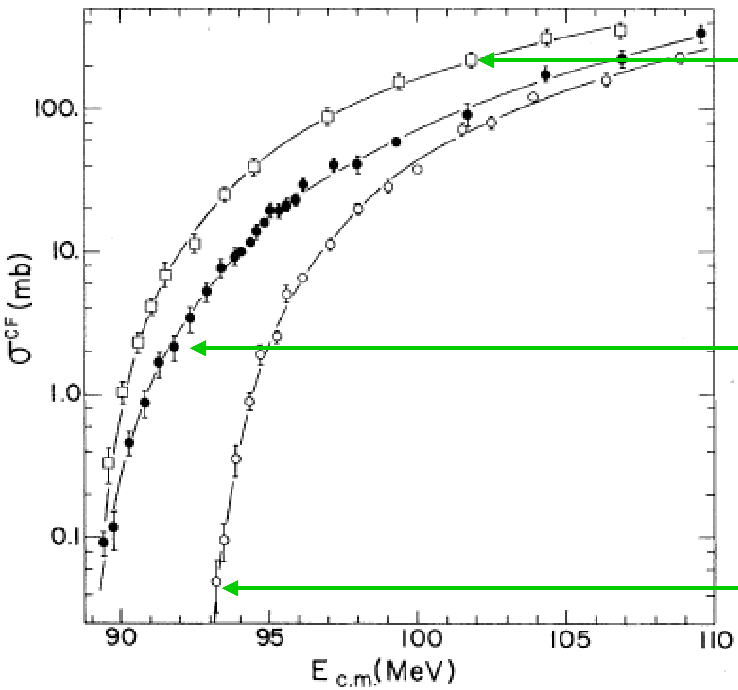
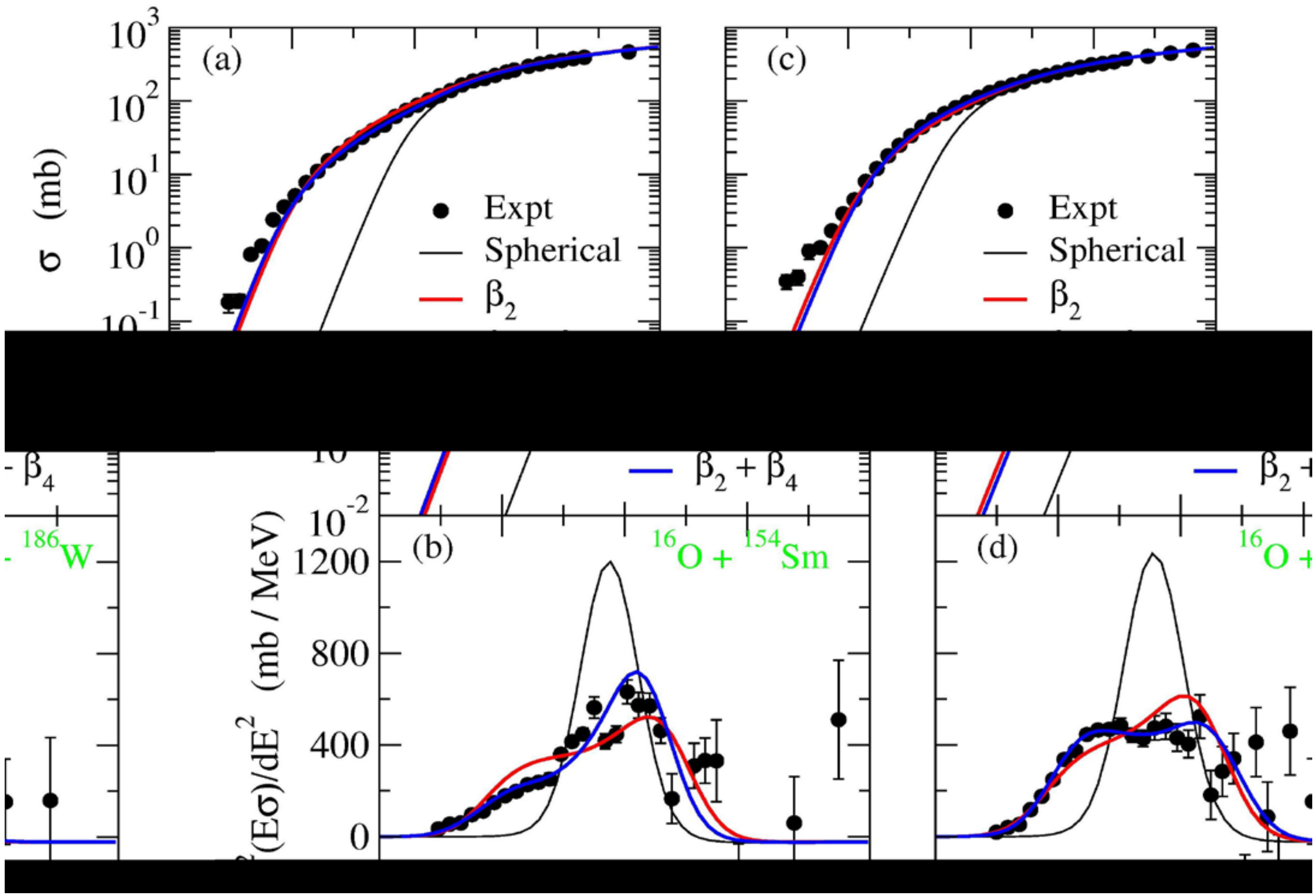


M. Beckerman Phys. Rev. Lett. 45, 1472 (1980)

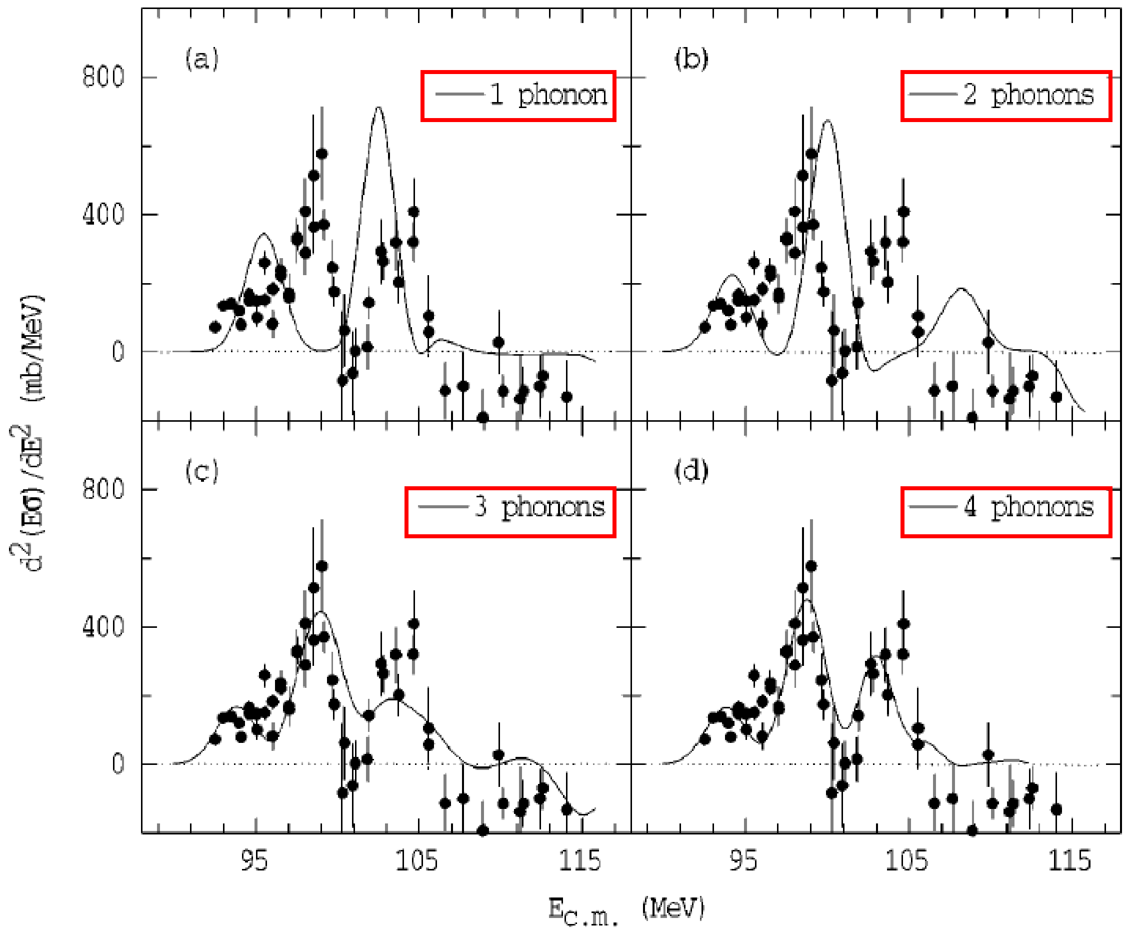
System	+1n	+2n	+3n	+4n	+5n	+6n
^{58}Ni + ^{64}Ni	−0.65	3.89	1.11	3.89	−0.65	0

More recent measurements exploited the concept of a “fusion barrier distribution”: its sensitivity to the static nuclear deformation was evidenced …



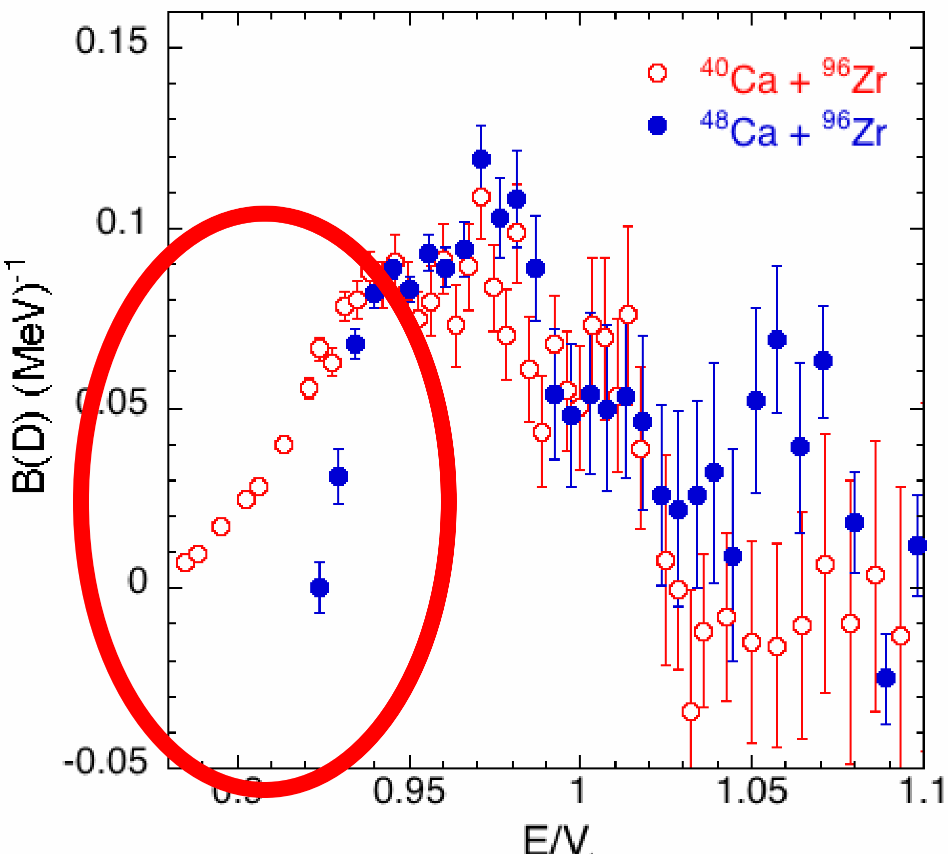
J.Leigh et al., Phys. Rev. C 52, 3151 (1995)

… and the experimental study of $^{58}Ni+^{60}Ni$ revealed for the first time the existence of a barrier distribution with several well-defined peaks that could only be explained by multiphonon couplings.



A.M.Stefanini et al., PRL 74, 864 (1995)

The fusion barrier distributions of $^{40,48}Ca + ^{96}Zr$



- Phonons
- Doubly magic $^{40,48}Ca$

- Open transfer channels in ^{40}Ca
- Different barriers for $E < 0.95V_b$

Transfer with positive Q-value

Ground state Q-values for neutron pick-up channels in ^{40,48}Ca + ^{90,96}Zr and **^{56}Ni**+ ^{90,96}Zr

System	+1n	+2n	+3n	+4n	+5n	+6n
^{40}Ca + ^{90}Zr	−3.61	−1.44	−5.86	−4.17	−9.65	−9.05
^{40}Ca + ^{94}Zr	0.14	4.89	4.19	8.12	3.57	4.65
^{40}Ca + ^{96}Zr	0.51	5.53	5.24	9.64	8.42	11.62
^{48}Ca + ^{90}Zr	−6.82	−9.79	−17.73	−22.67	−31.93	−37.60
^{48}Ca + ^{96}Zr	−2.71	−2.82	−6.63	−8.69	−13.87	−17.00
^{56}Ni + ^{96}Zr	2.39	8.15	8.93	13.58	12.76	16.17
^{56}Ni + ^{90}Zr	−1.72	1.18	−2.17	−0.39	−5.30	−4.43

PET-isotope production at the IBA 30 MeV cyclotron:

Chemical separation provided by the production of radioisotopes

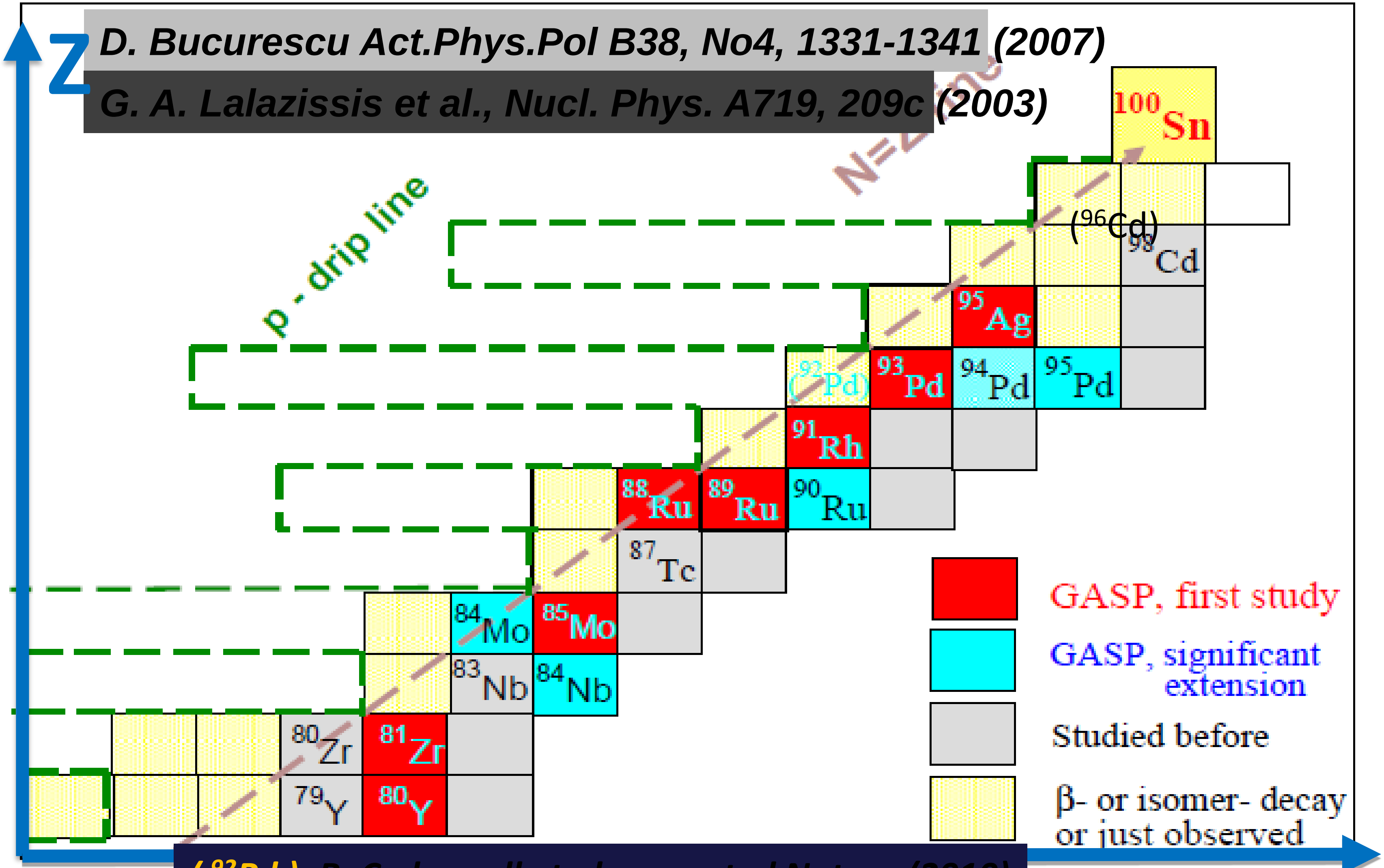
Target station at the end of one beam line equipped with 5 target ports

^{18}F: $H_2{}^{18}O$ target
^{11}C: N_2-target
^{15}O: N_2-target
2 positions free

State of the Knowledge of N ≈ Z Nuclei Above Mass 80

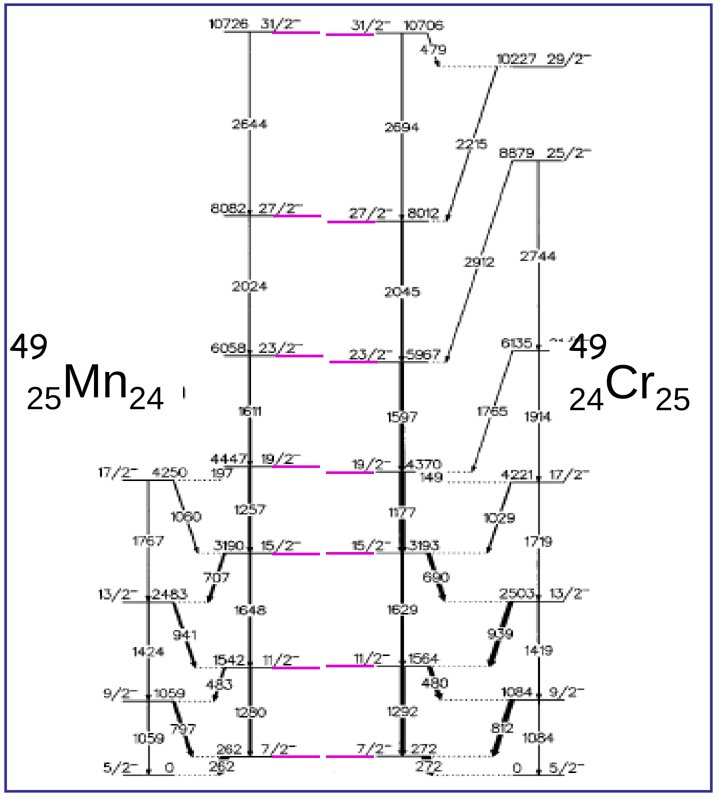
D. Bucurescu Act.Phys.Pol B38, No4, 1331-1341 (2007)

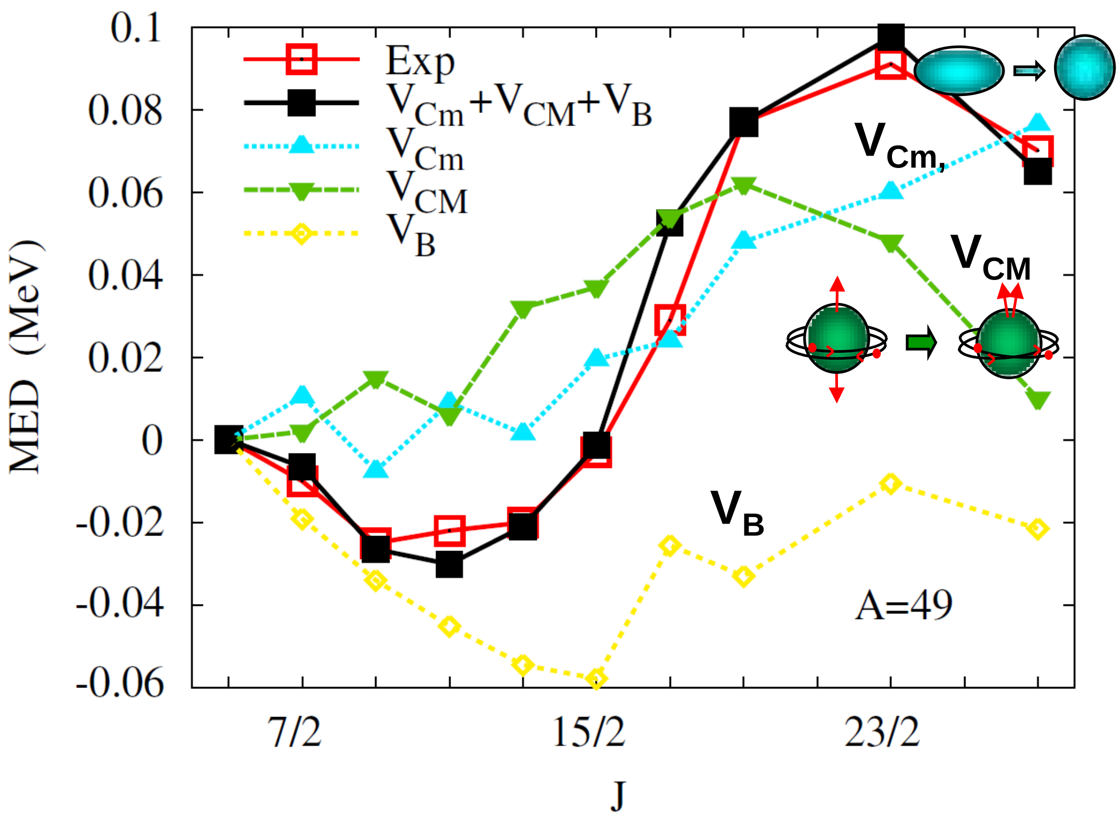
G. A. Lalazissis et al., Nucl. Phys. A719, 209c (2003)



(^{92}Pd): B. Cederwall et al., accepted Nature (2010)

MED and INC nuclear forces





From the MED
we extract information
of nuclear structure
properties

- How the nucleus generates its angular momentum
- Evolution of the deformation along a rotational band
- Isospin non-conserving terms in the nuclear interaction
- Learn about the configuration of the states

Test E1 selection rules

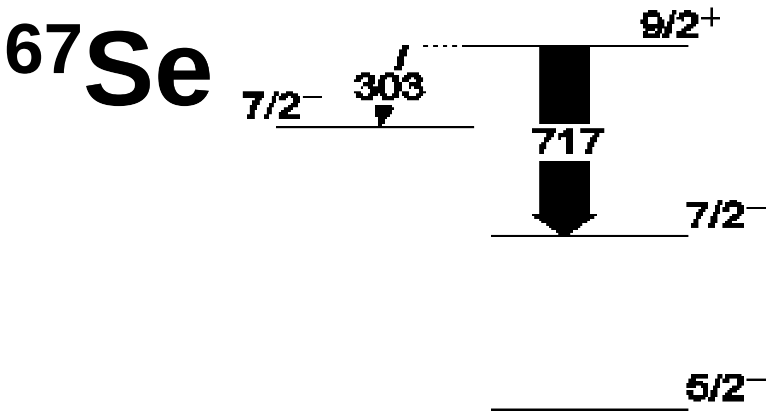
- Consider B(E1) $^{67}As_{34}$ and $^{67}Se_{33}$ mirror nuclei ($T_z = \pm½$)
- Isospin formalism leads to:

$$B(E1)\left(T_z = \pm \tfrac{1}{2}\right) \approx \left\langle J_i; T_i T_z \left\| \cancel{M(E1)_{IS}} \pm M(E1)_{IV} \right\| J_i; T_i T_z \right\rangle^2$$

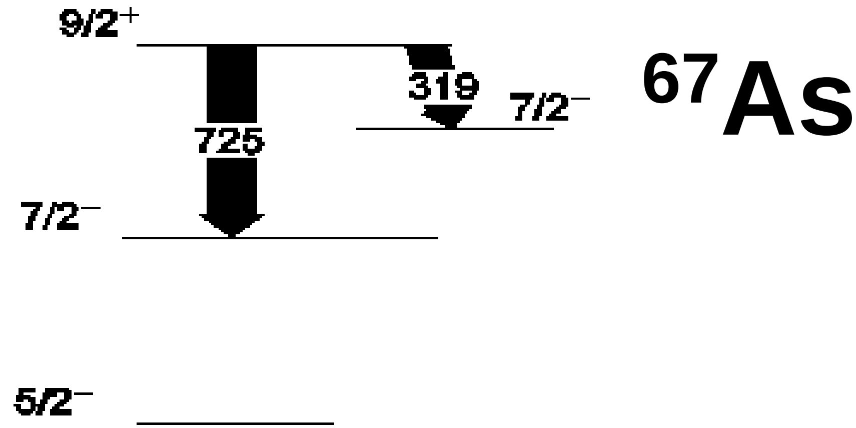
- Selection Rules for charge-symmetric nuclear interaction
  - In T_z = ½ nuclei, IS = 0 in long wavelength approximation (kR << 1)
  - **E1 pure isovector character** (but different sign in mirror nuclei)
  - **E1 transitions** in T_z = ½ nuclei should **exhibit same strength**
- If differences, may arise from interference between IV and non-zero IS term

Measured B(E1)

$^{32}S+^{40}Ca \rightarrow \alpha n$ channel



$^{32}S+^{40}Ca \rightarrow \alpha p$ channel



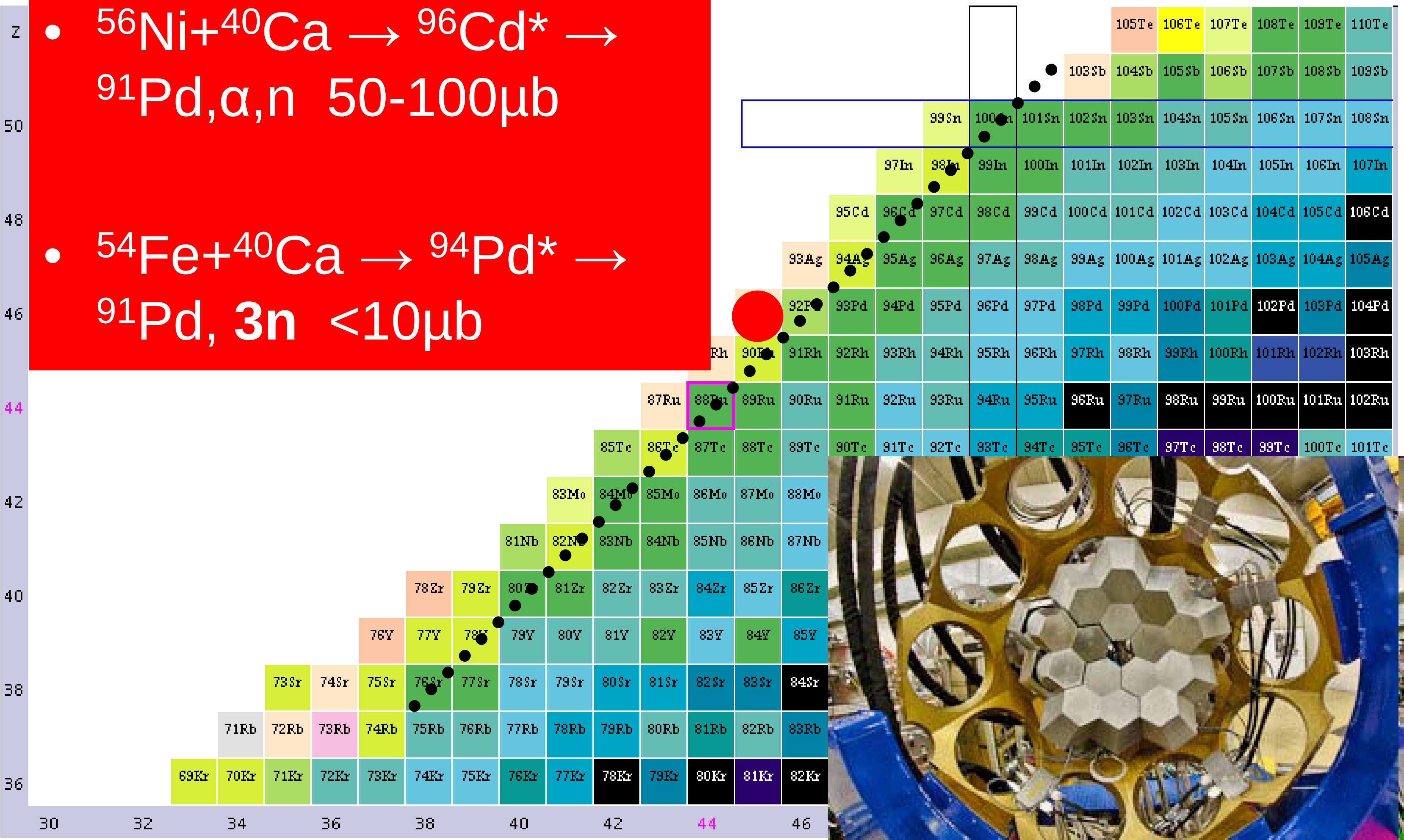
Energy (KeV)	B(E1) (10^{-6} wu)	B(E1) (10^{-6} wu)	Energy (KeV)
717	0.4(4)	1.4(4)	725
303	<1.4(9)	8.3(2.4)	319

Both transitions consistent with large isoscalar/isovector ratio:

IS/IV~ 0.35(20)

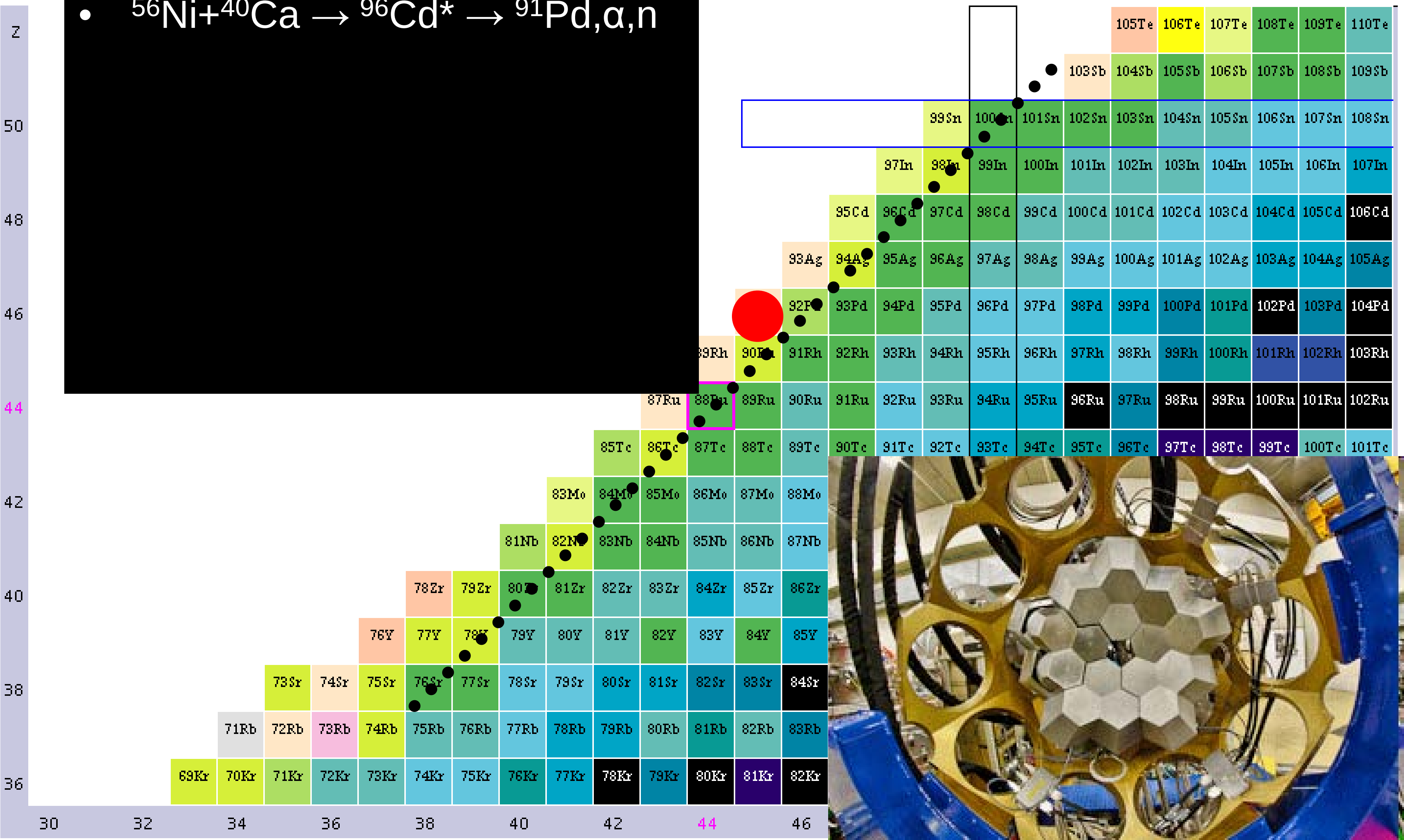
Reactions for Tz=-1/2

- $^{56}Ni + ^{40}Ca \rightarrow ^{96}Cd^* \rightarrow$ $^{91}Pd, \alpha, n$ 50-100μb
- $^{54}Fe + ^{40}Ca \rightarrow ^{94}Pd^* \rightarrow$ ^{91}Pd, **3n** <10μb



Reactions for T_z=-1/2

- $^{56}Ni + ^{40}Ca \rightarrow ^{96}Cd^* \rightarrow ^{91}Pd,\alpha,n$



Reactions for T_z=-1/2 and T_z=0

- $^{56}Ni+^{40}Ca \rightarrow ^{96}Cd^* \rightarrow ^{91}Pd,\alpha,n$
- $^{56}Ni+^{32}S \rightarrow ^{88}Ru^* \rightarrow ^{83}Mo,\alpha,n$

- $^{56}Ni+^{40}Ca \rightarrow ^{96}Cd^* \rightarrow ^{94}Ag,p,n$
- $^{56}Ni+^{39}K \rightarrow ^{83}Nb^* \rightarrow ^{90}Rh,\alpha,n$
- $^{56}Ni+^{32}S \rightarrow ^{88}Ru^* \rightarrow ^{86}Tc,p,n$
- $^{44}Ti+^{40}Ca \rightarrow ^{84}Mo^* \rightarrow ^{82}Nb,p,n$