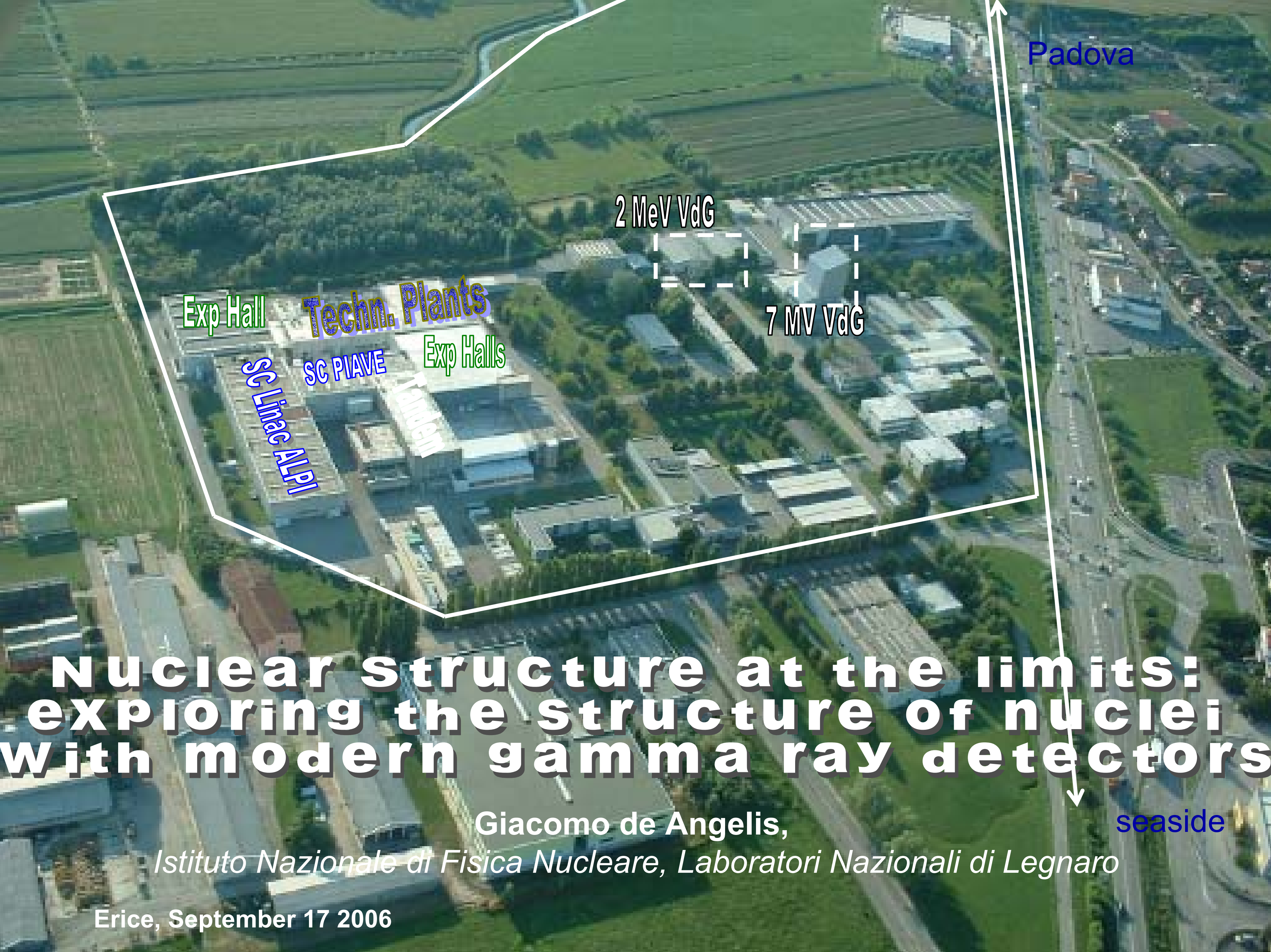


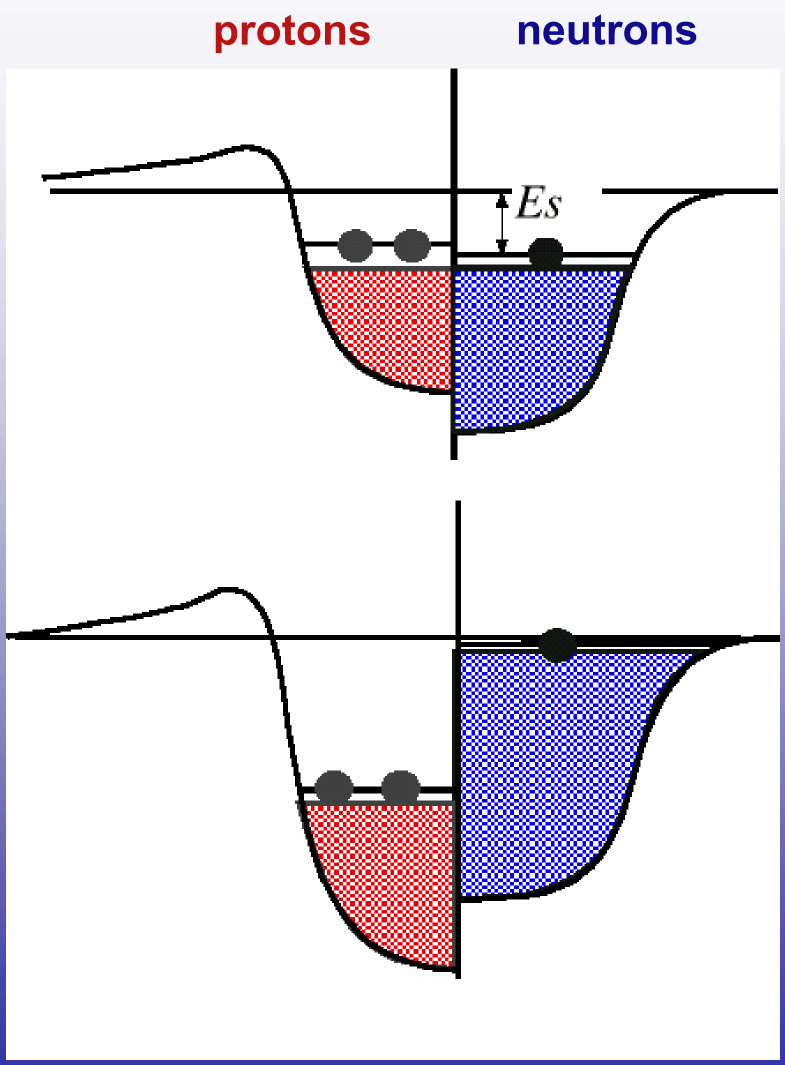
Nuclear structure at the limits: exploring the structure of nuclei with modern gamma ray detectors

Giacomo de Angelis,
Istituto Nazionale di Fisica Nucleare, Laboratori Nazionali di Legnaro

Erice, September 17 2006

Studies of exotic nuclei

- **All the aspects of nuclear interactions in the nuclear structure are** amplified at the driplines. A. Bonaccorso
- **New structure and new phenomena**
  - Neutron halos,
  - Neutron skins
  - Covalent bond molecular states
  - Soft mode of collective motion
  - Change of magic numbers
- **New development of nuclear models**
  - Green function montecarlo
  - Anti-symmetrised molecular dynamics
  - No-core shell model
  - Cluster montecarlo
  - Relativistic mean field



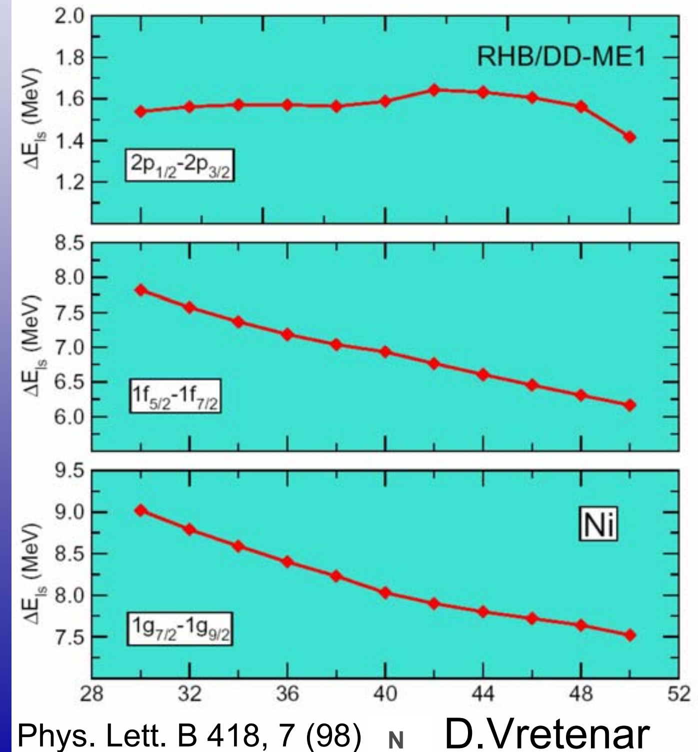
Reduction of spin-orbit potential

$$V_{s.o.} \approx \frac{1}{r}\frac{\partial}{\partial r}V_{ls}(r)$$

$$V_{ls} = \frac{m}{m_{eff}}(V - S)$$

→ reduced energy spacings between spin-orbit partners

$$\Delta E_{ls} = E_{n,l,j=l-1/2} - E_{n,l,j=l+1/2}$$



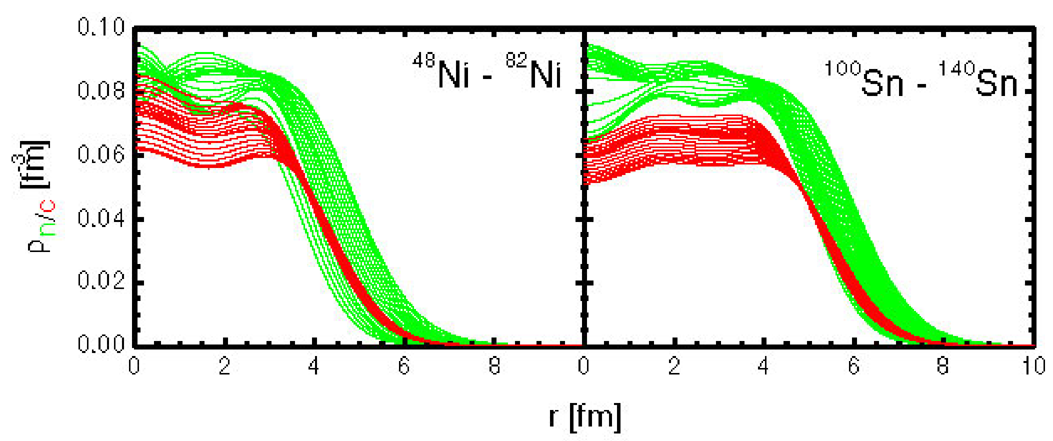
Phys. Lett. B 418, 7 (98)

D.Vretenar

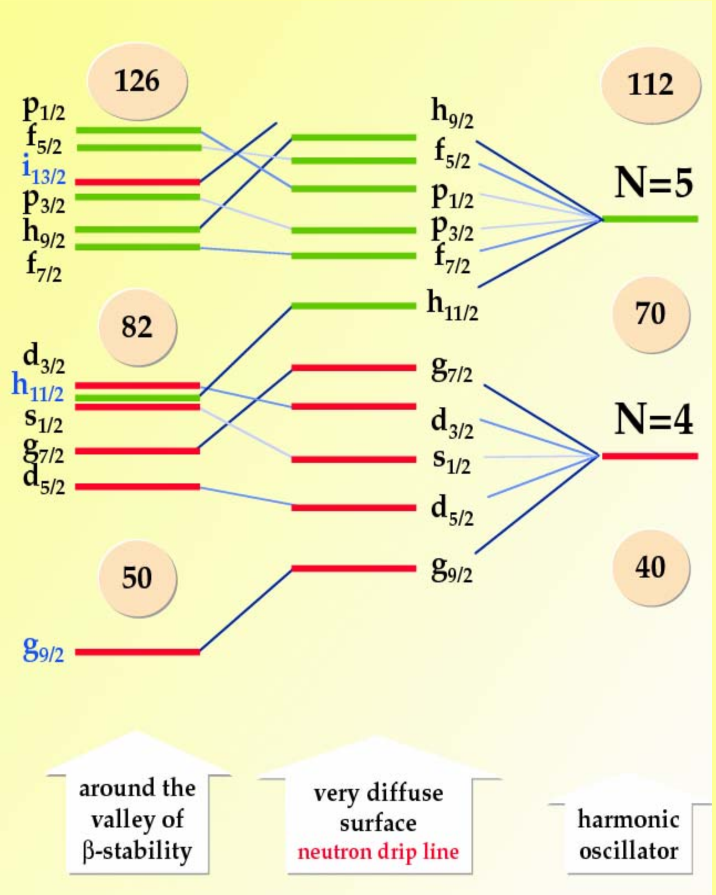
The Properties of Nuclei with Extreme N/Z-Ratios

Single-particle (or shell) structure is the basis of many nuclear properties such as (sub)magic number, deformation, and even the existence of the nucleus.

Weakening of the spin-orbit force due to the diffuse nuclear surface?



DDRH Field Calculations by F.Hofmann, C.M.Keil, H.Lenske, Phys.Rev.C64(01)034314.



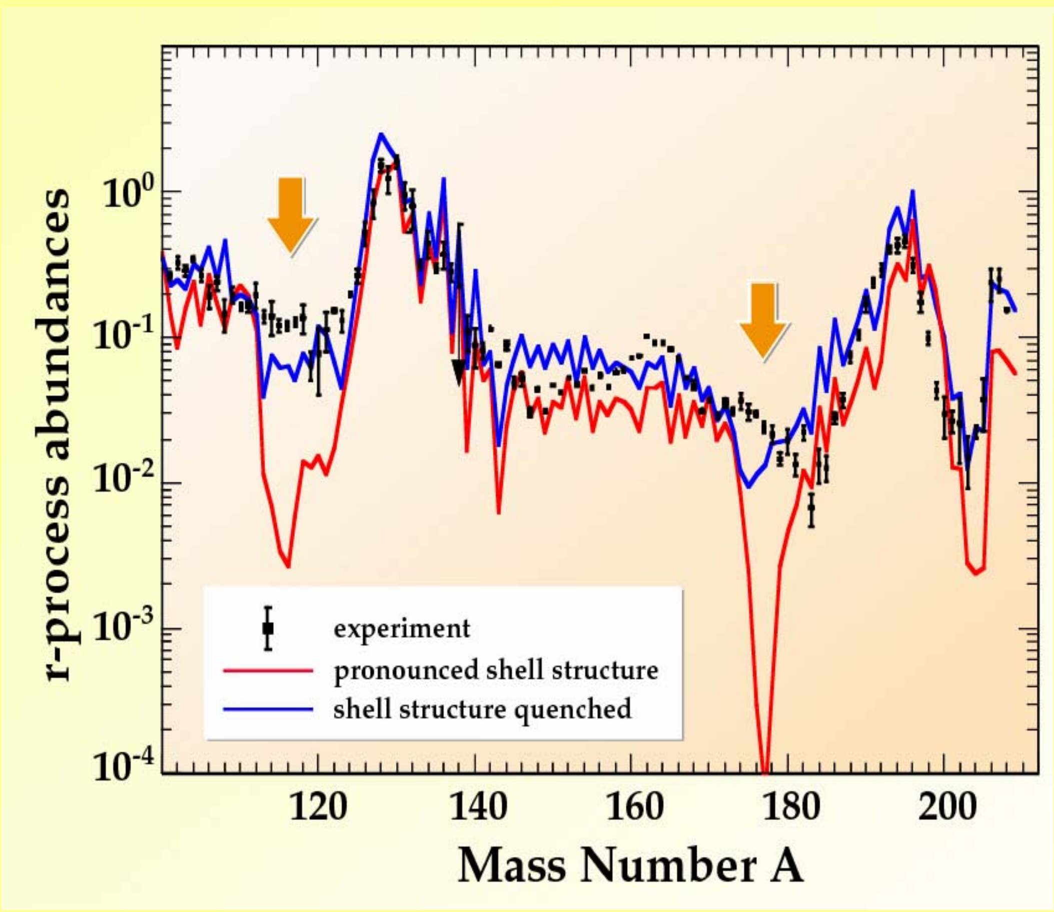
It affects the element formation in r-process: Quenching of shell-structure?

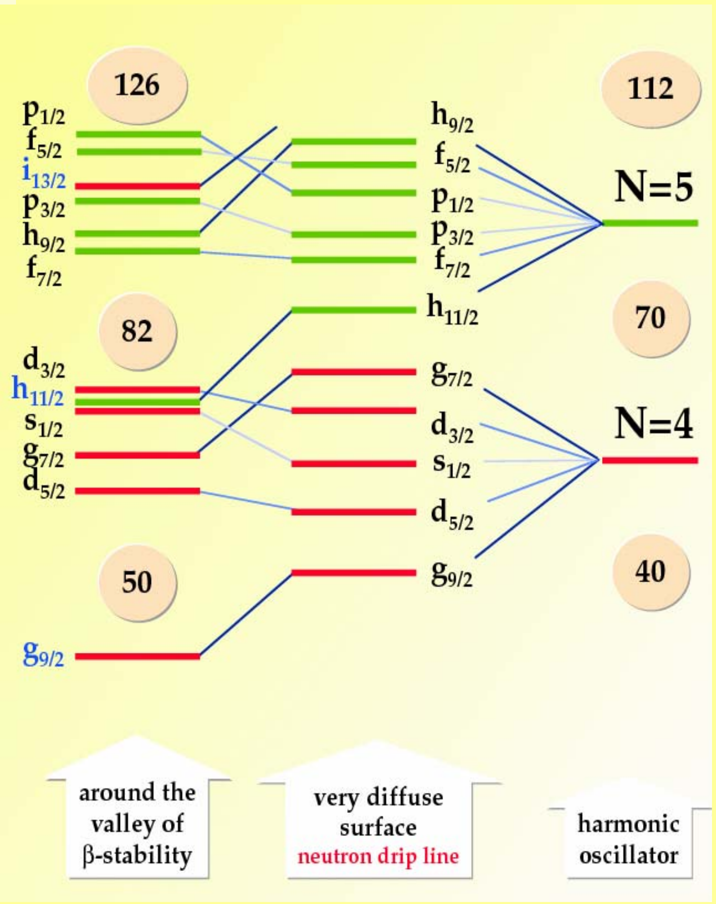
Pfeiffer et al., Z. Phys. A357 (1997) 235

Disappearance of Shell Structure?

The Properties of Nuclei with Extreme N/Z-Ratios

- **Basic nuclear properties of rare isotopes (e.g., masses, half-lives, …) determine element formation in the cosmos**



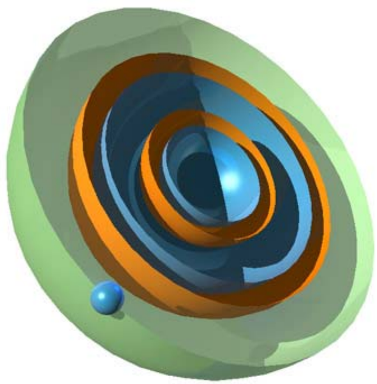


Element formation in r-process: quenching of shell-structure?

Pfeiffer et al., Z. Phys. A357 (1997) 235

Disappearance of Shell Structure?

"Single particle" orbitals are dressed even in semi-magic nuclei

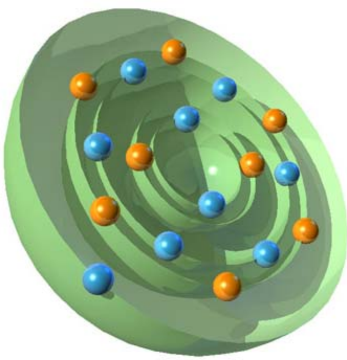


The single-particle levels in exotic nuclei can be affected by

- Loose binding ***Woods-Saxon potential***
- Neutron skin ***Mean-Field models***

Nucleon-Nucleon interaction, particularly, spin-isospin interactions such as **tensor** and 2-body *LS* interactions

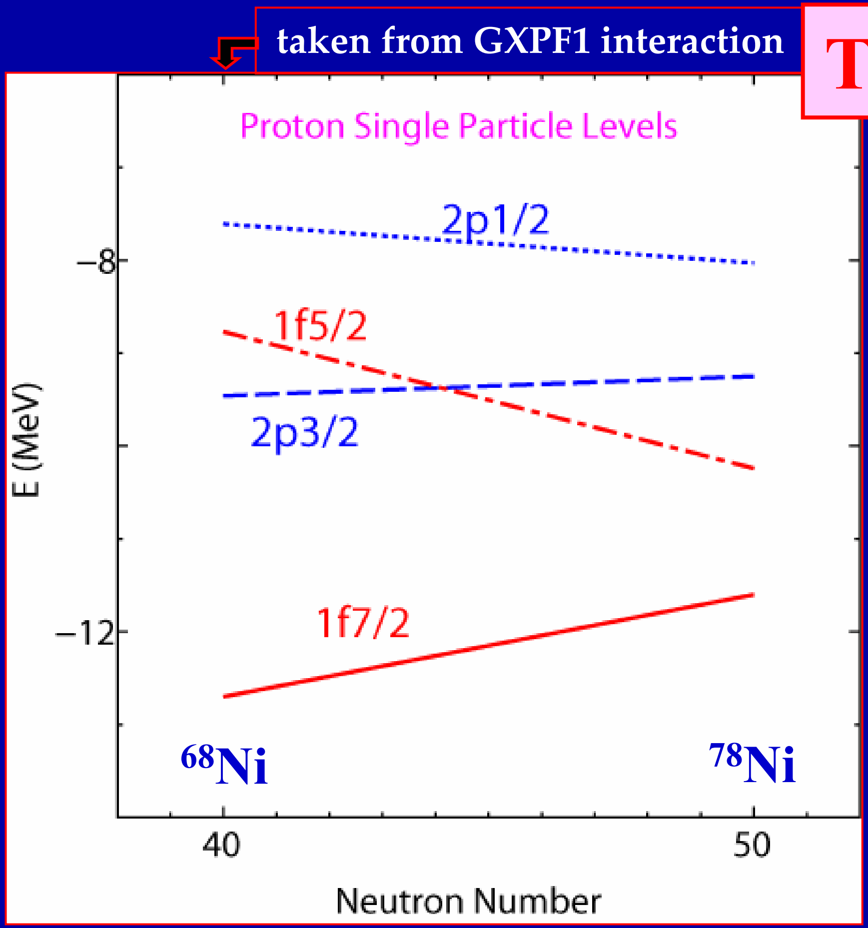
(also in nuclei not very close to drip lines)

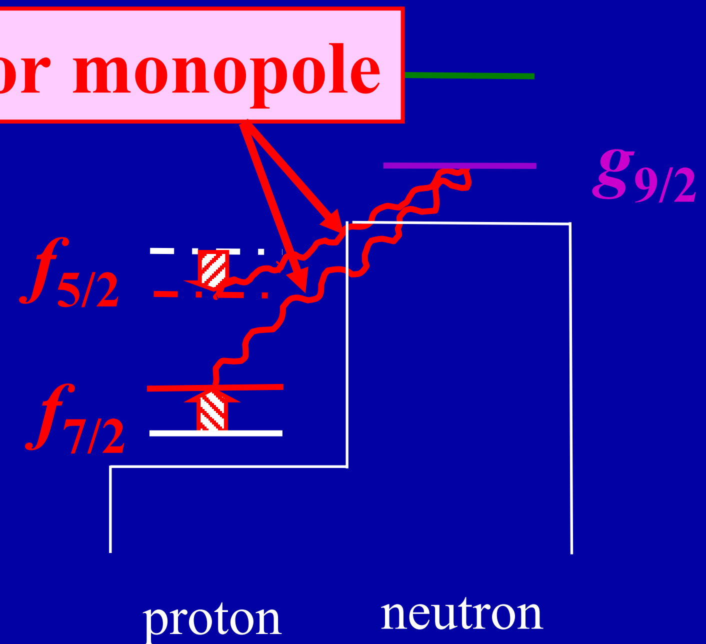


Shell Evolution
(change of single-particle levels)

T. Otsuka et al. Phys. Rev. Lett. 87, 082502 (2001)

Systematic variation of proton effective single-particle energies due to the tensor interaction ($\pi + \rho$ meson)



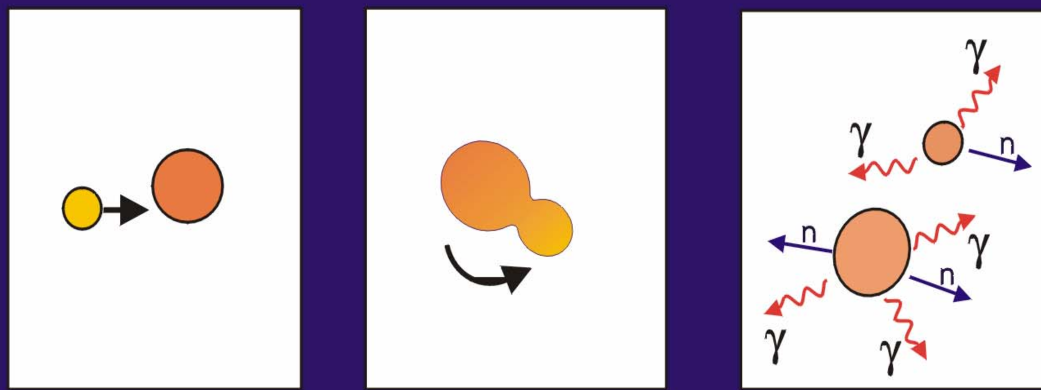


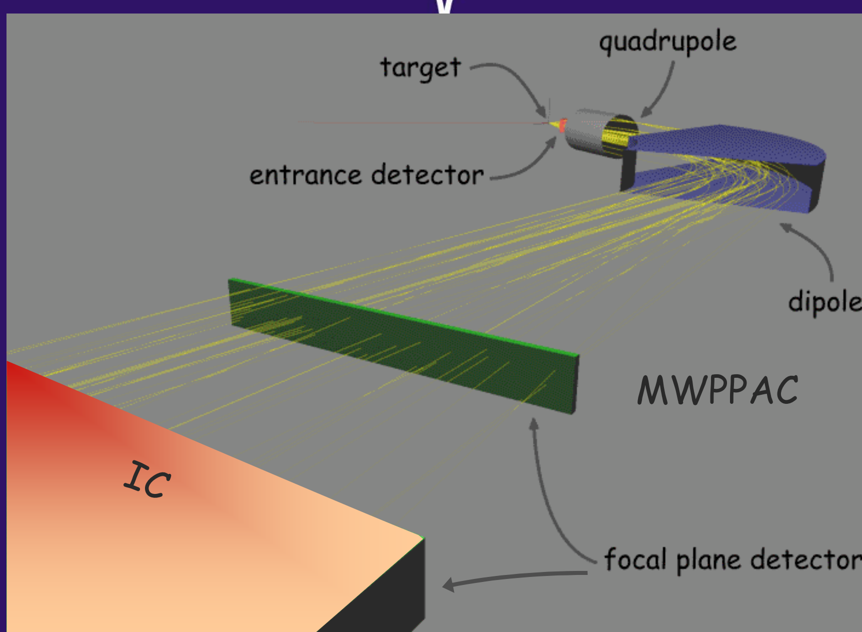
Low-lying 2^+ levels in Ni, M. Sawicka et al., Phys. Rev. C68, 044304 (03)

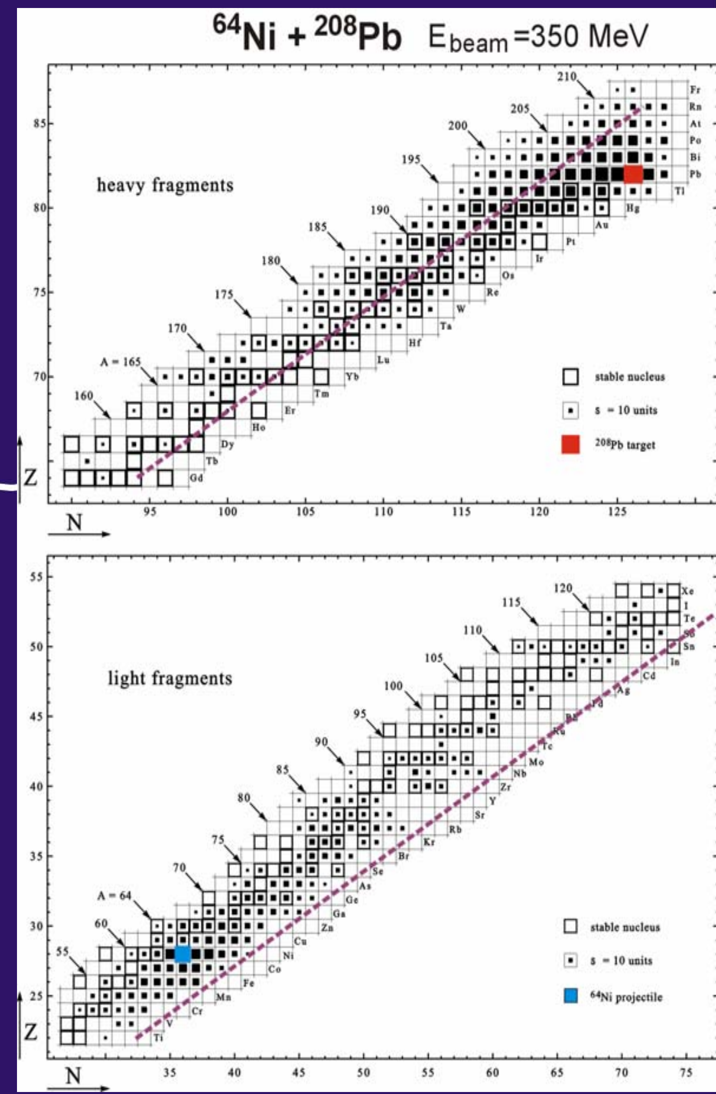
neutrons in $g_{9/2}$

<u>**T. Otsuka et al. PRL 95, 232502 (2005)**</u>

Deep inelastic reactions - a tool for nuclear spectroscopy



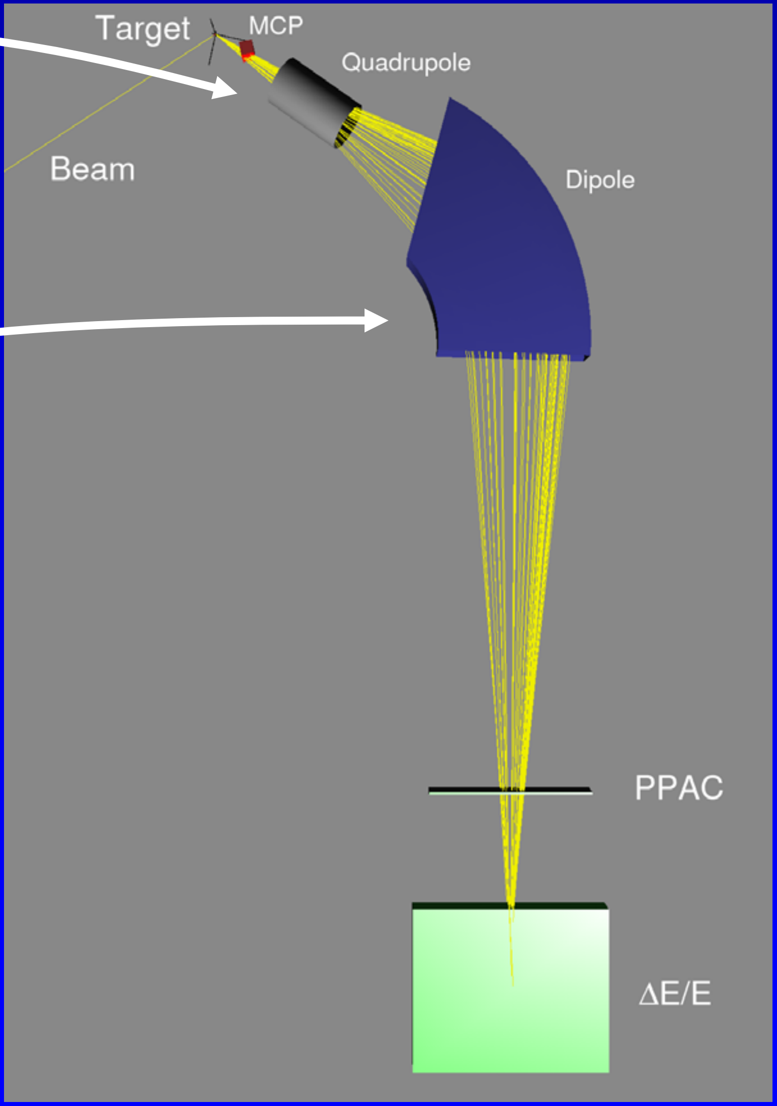




Optical elements

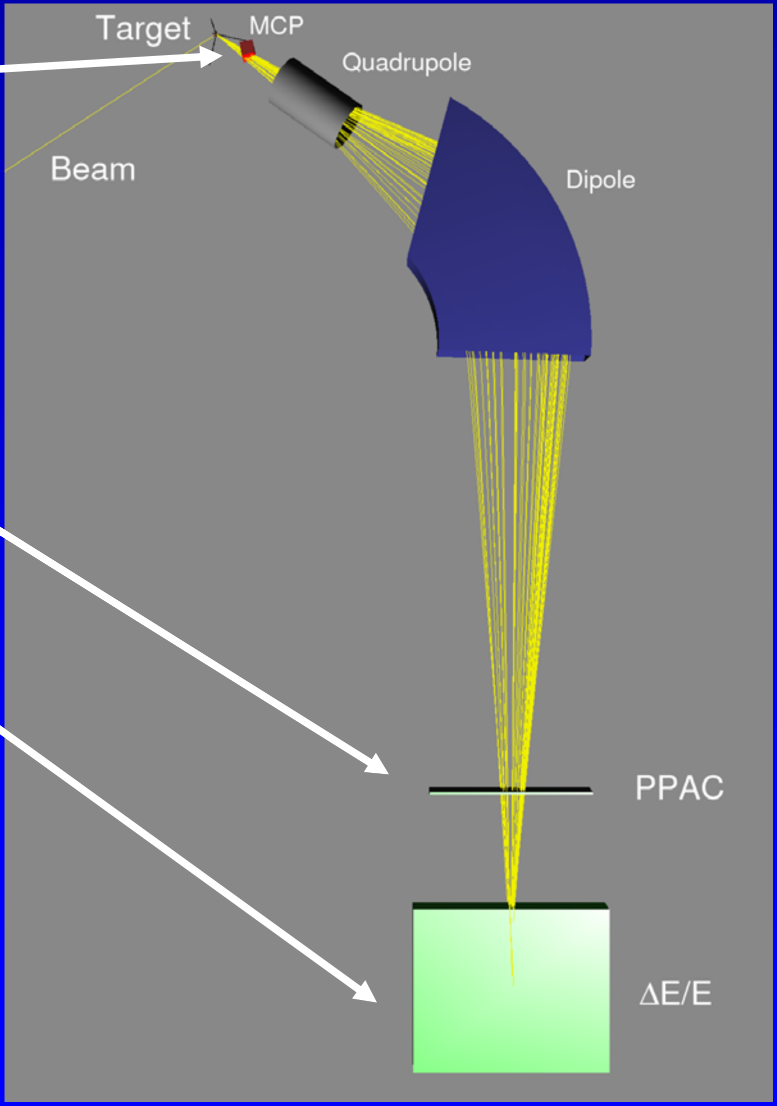
- **Quadrupole:** a singlet, focuses vertically the ions towards the dispersion plane

- **Dipole:** bends horizontally the ions with respect to their magnetic rigidity (Br)



PRISMA detectors

- **Entrance Position**
  position x_s - y_s, time
- **Focal Plane Position**
  position x_f - y_f, time
- **Ionization Chambers**
  energy loss, total energy



Physical Event:

(x_s, y_s, x_f, y_f, TOF, ΔE, E)

PRISMA: Large acceptance tracking Magnetic Spectrometer Q-D

$\Omega = 80$ msr

$\Delta Z/Z \approx 1/60$ (Measured)

$\Delta A/A \approx 1/190$ (Measured) TOF

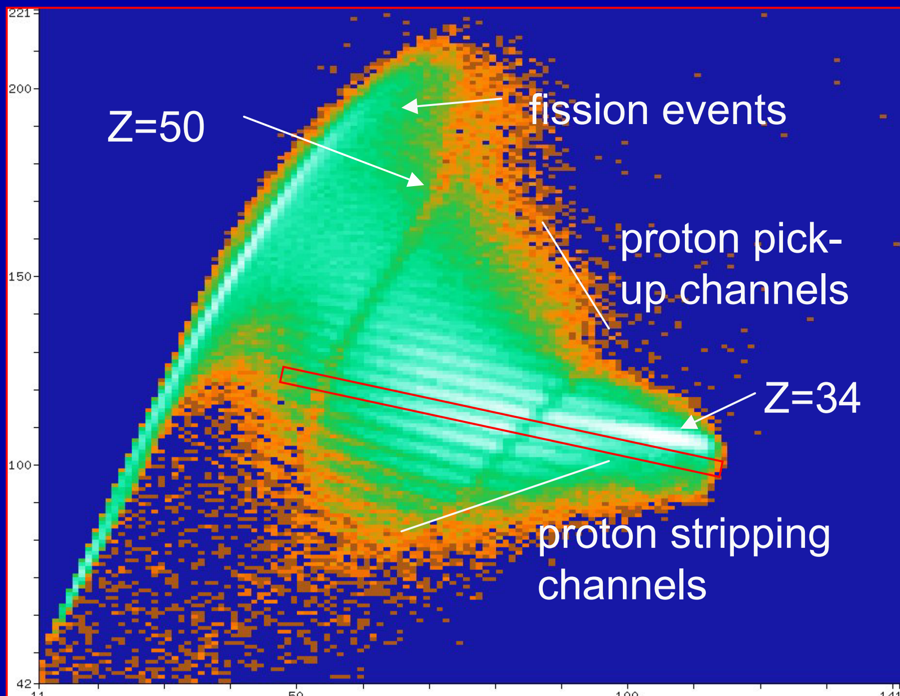
Energy acceptance ±20%

$B\rho = 1.2$ T.m

γ-spectroscopy of neutron rich nuclei
Mass distribution of 505 MeV ^{82}Se + ^{238}U

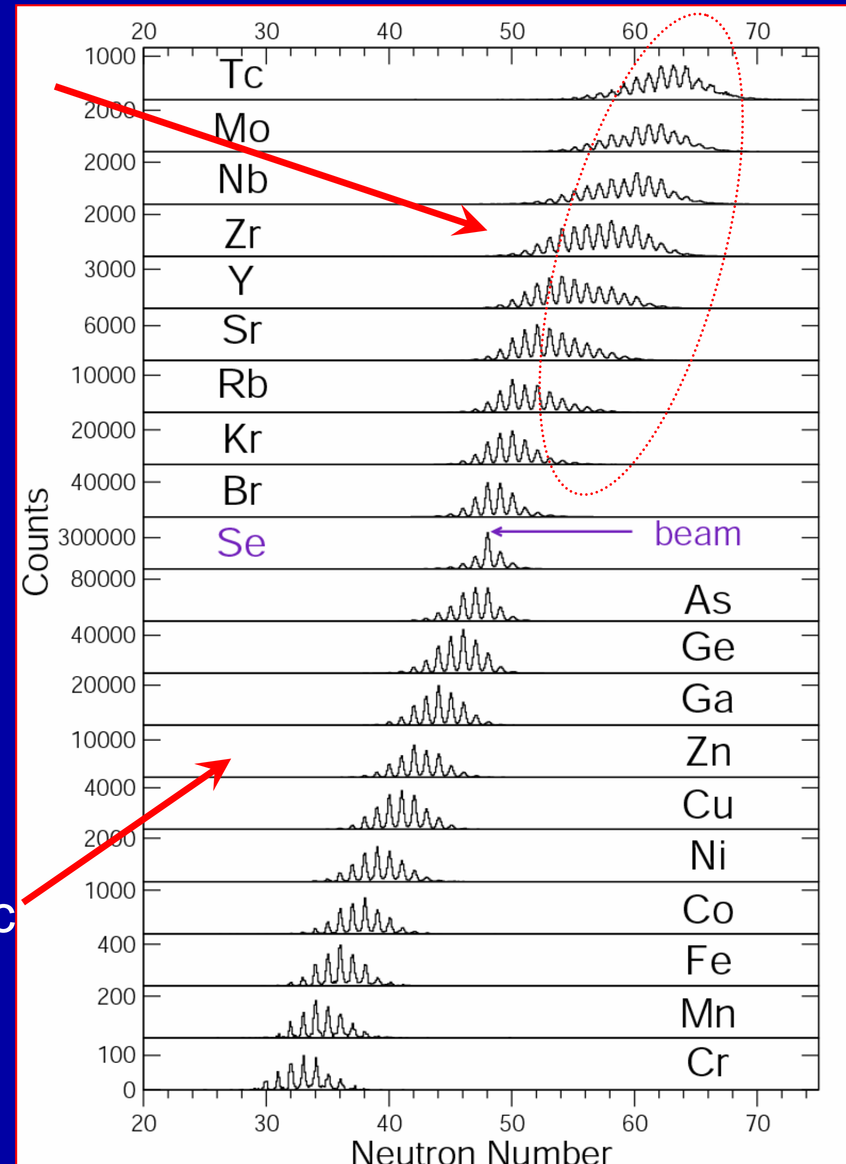
Fission of ^{238}U

ΔE



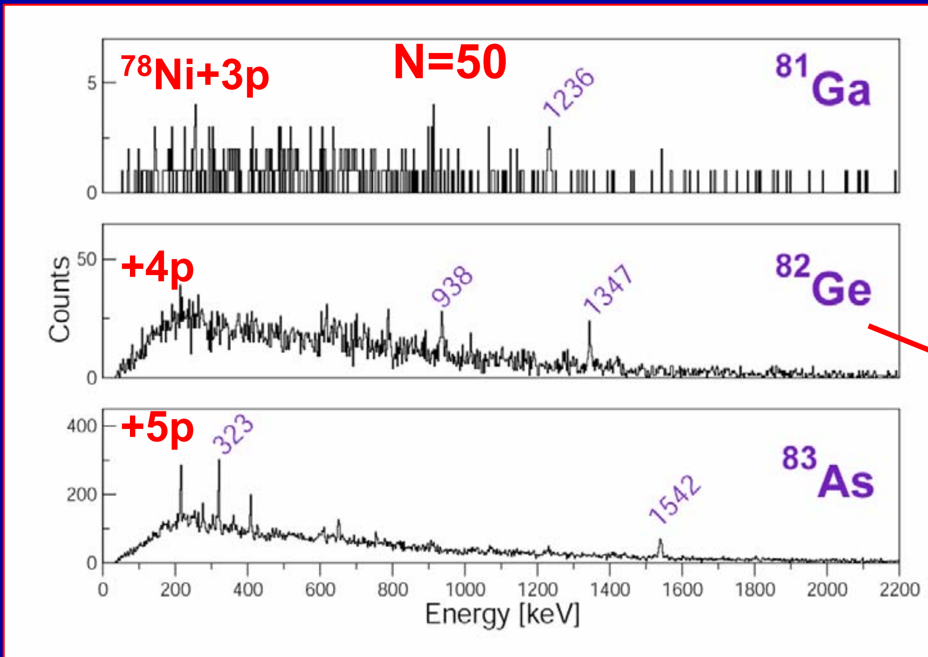
E

Deep-Inelastic

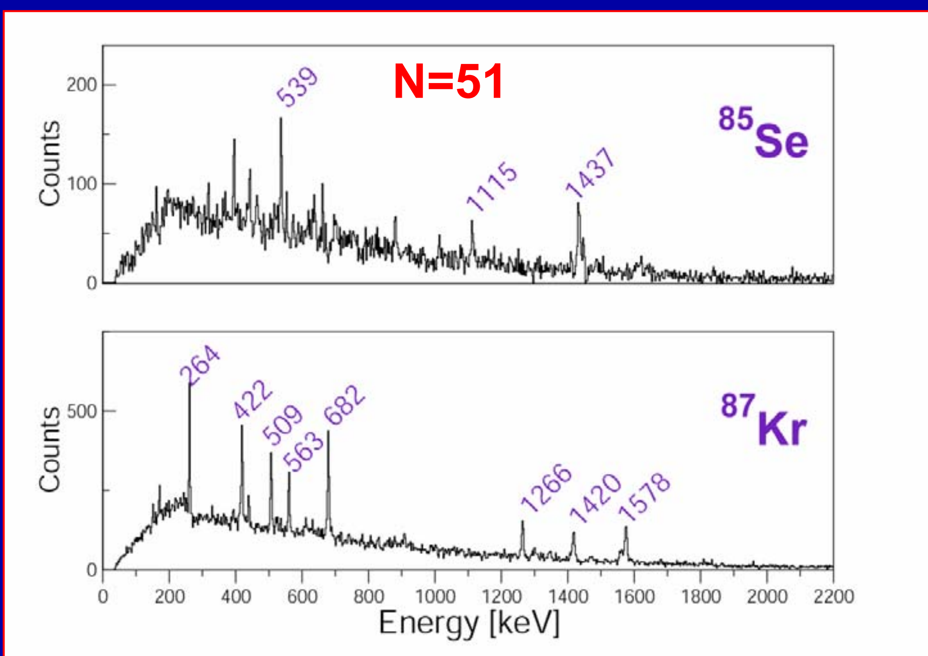


v/c range : 4-10%

Mass range : 50-110



^{78}Ni+3p
N=50
^{81}Ga
1236
+4p
^{82}Ge
938
1347
+5p
^{83}As
323
1542
Counts
Energy [keV]
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200



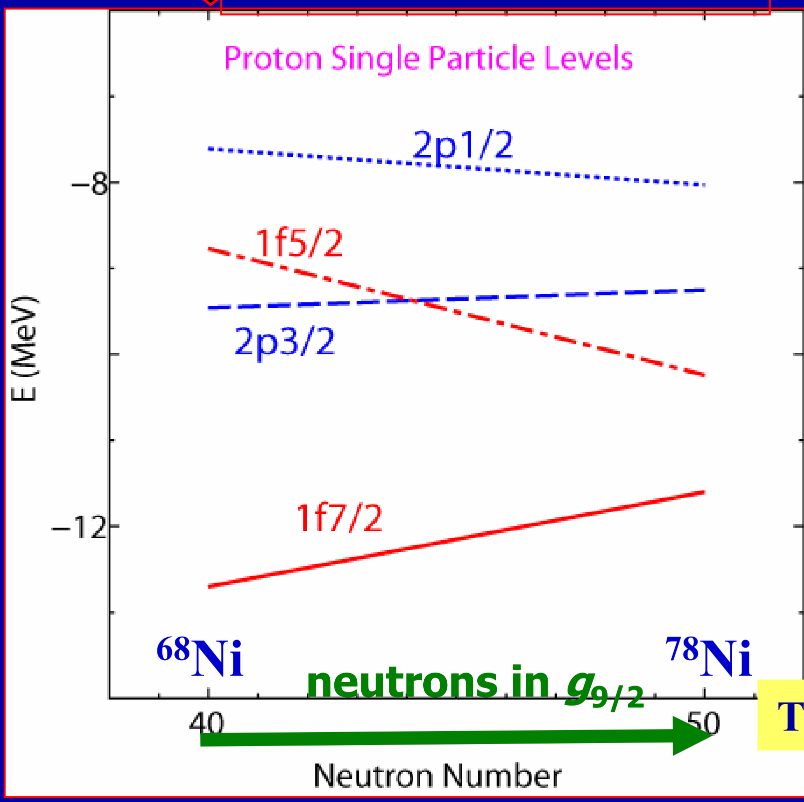
N=51
^{85}Se
539
1115
1437
^{87}Kr
264
422
509
563
682
1266
1420
1578
Counts
Energy [keV]

52
44
46
48
50

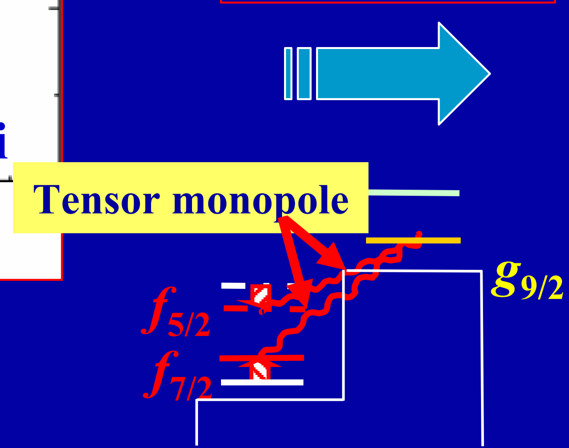
Systematic variation of proton effective single-particle energies due to the tensor interaction

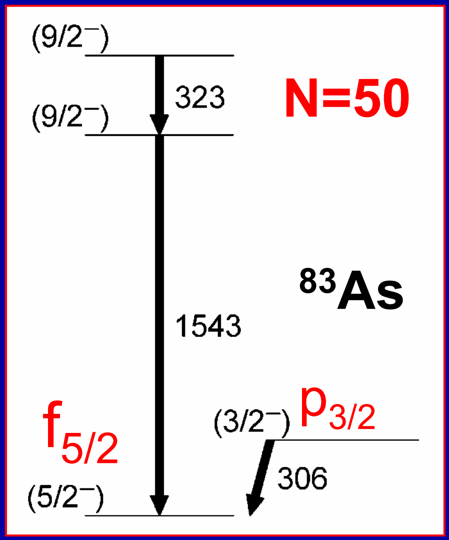
T. Otsuka et al. PRL95, 232502 (2005)

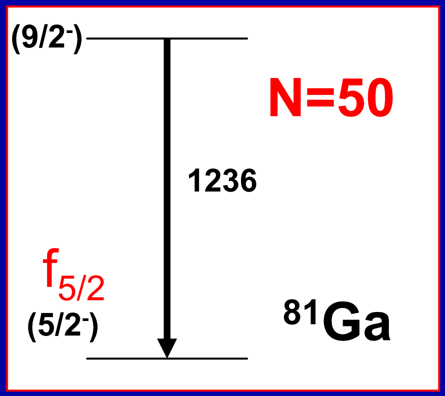
taken from GXPF1 interaction



Inversion of the effective single particle orbitals



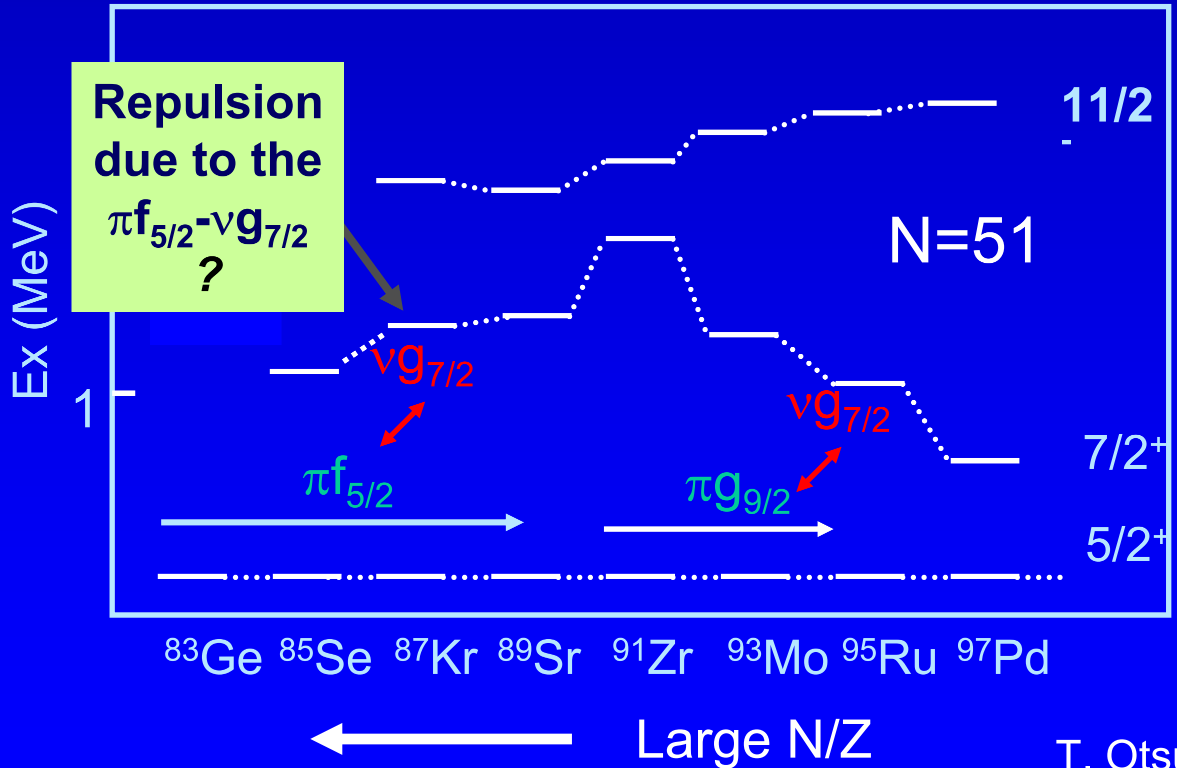


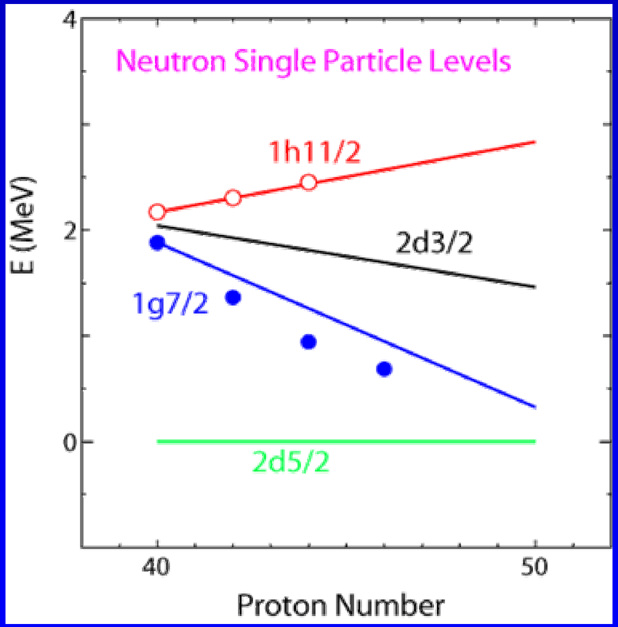


The N=51 isotones

Monopole shift of the single particle levels

Downward shift of the $\upsilon g_{7/2}$ in proton rich N=51 isotones as $\pi g_{9/2}$ is filled





T. Otsuka et al. PRL 95, 232502 (2005)

The N=51 isotones

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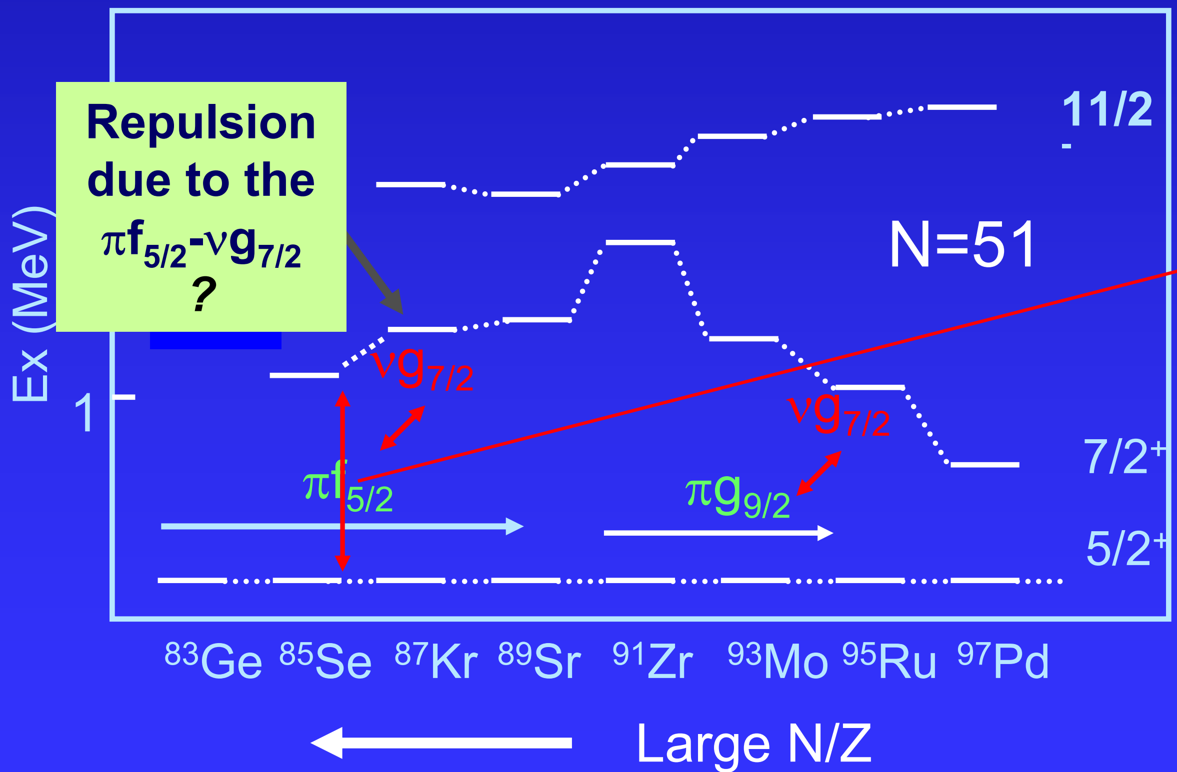
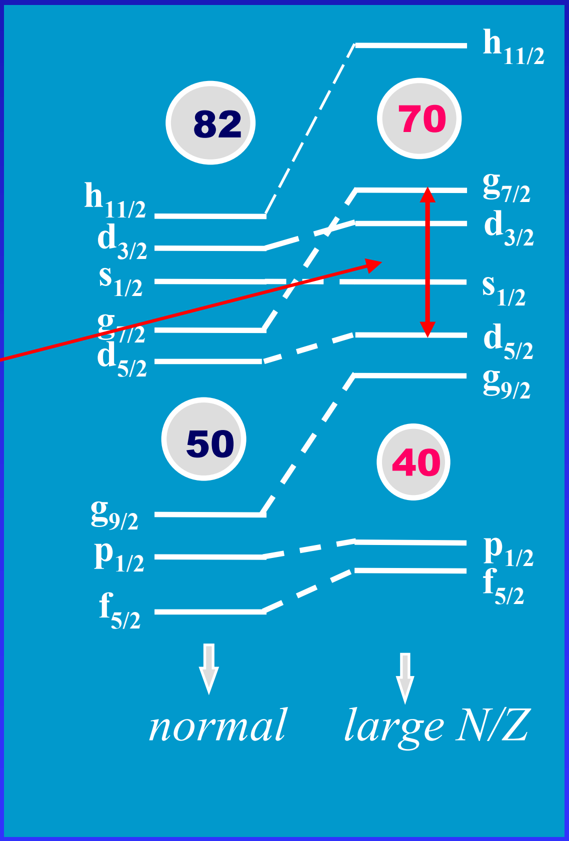
Downward shift of the $\upsilon g_{7/2}$ in proton rich N=51 isotones as $\pi g_{9/2}$ is filled

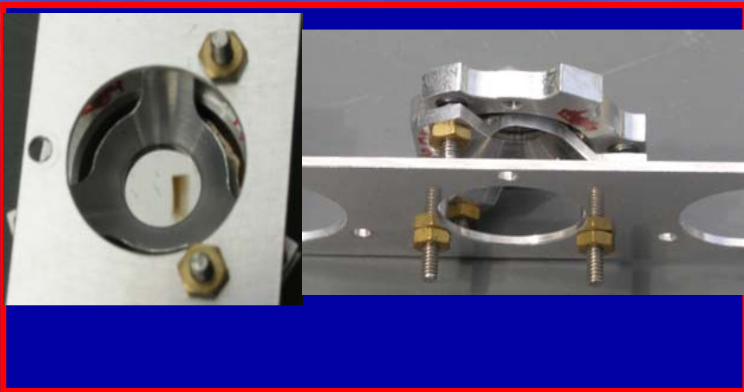


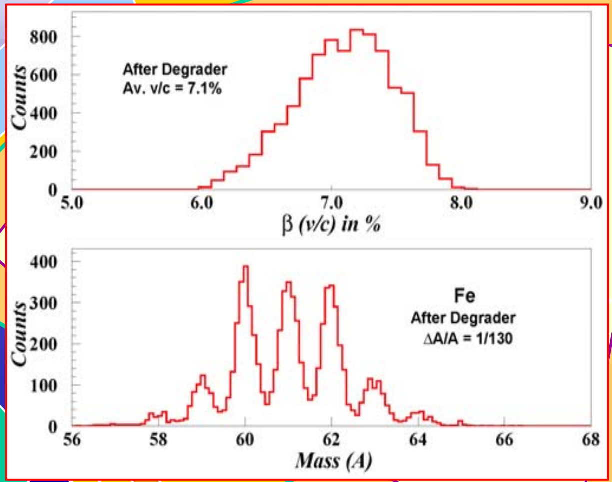


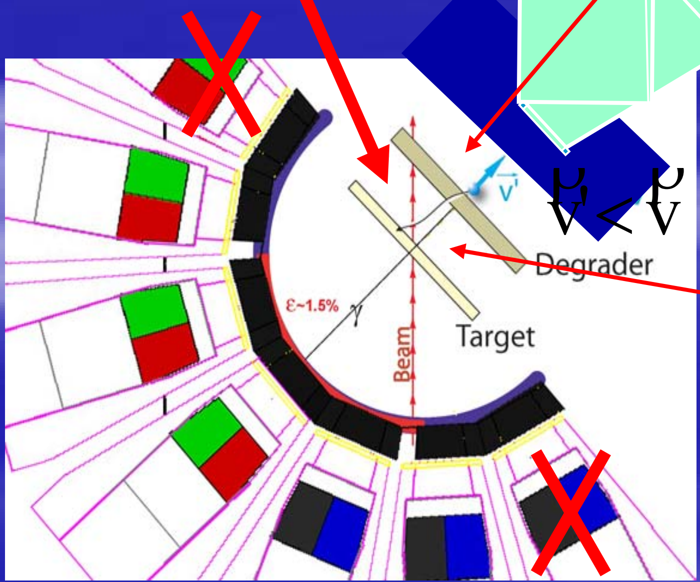
Differential RDDS with CLARA-PRISMA

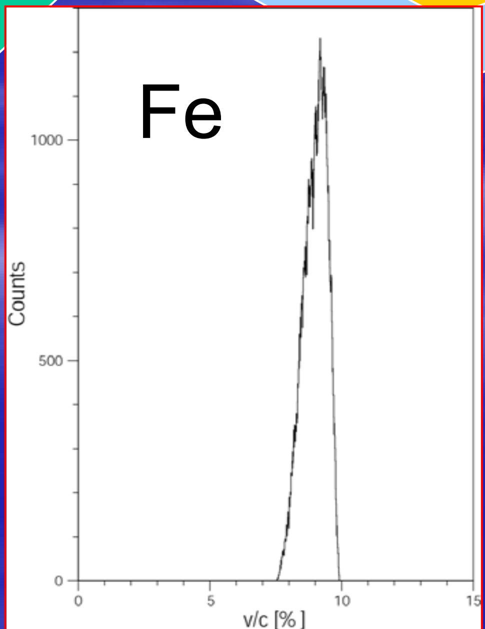
^{64}Ni at 400MeV on ^{208}Pb 1mg/cm^2
Degrader: ^{24}Mg 2mg/cm^2 150,50μm

A,Dewald, N.Marginean, A.Gadea







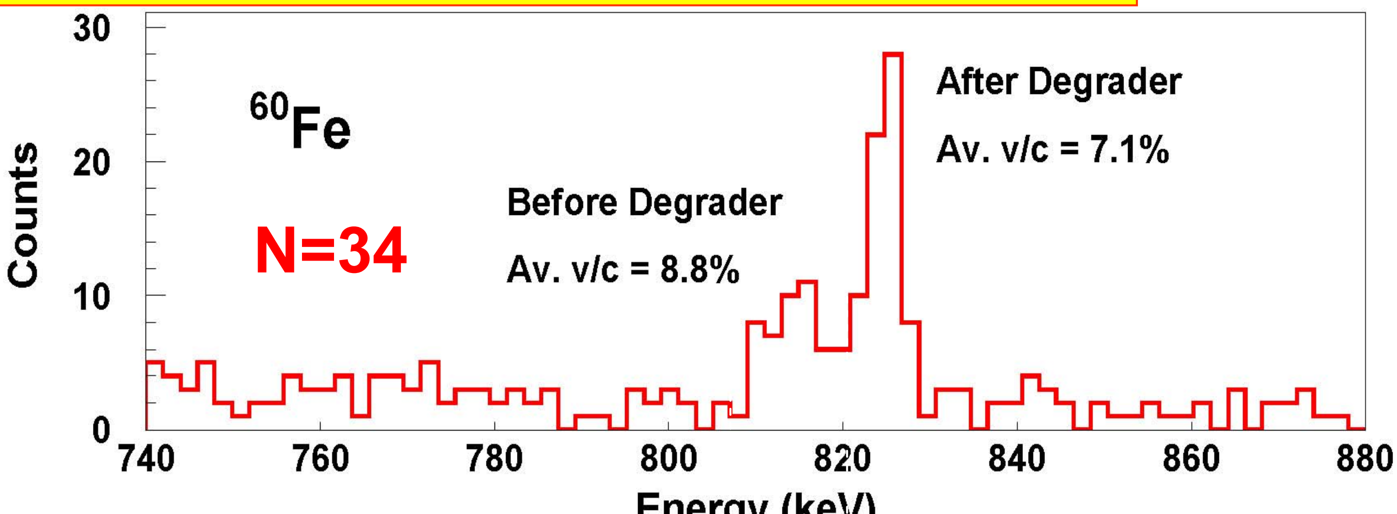


Average v/c after reaction 8.8% and after degrader 7.1%

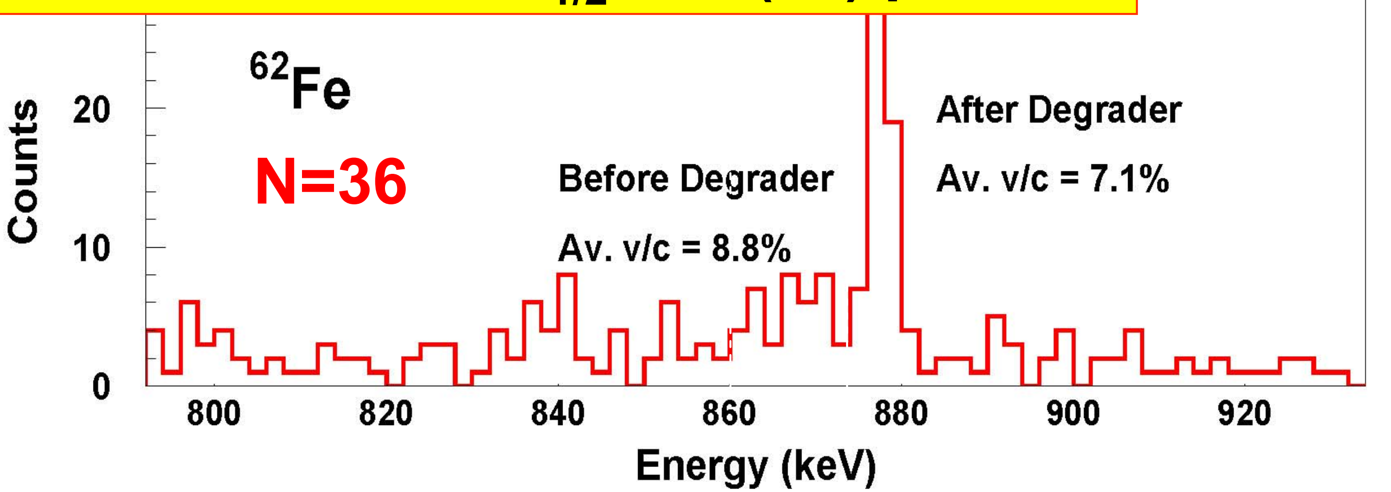
Product Energies ~4MeV.A

Results for 150μm Target-Degrader Distance

2^+ at 824 keV $T_{1/2}$= 8.2(15) ps



2^+ at 877 keV $T_{1/2}$= 9.5(20) ps



known value
8.0(15) ps

B(E2)=0.018 e^2b^2 (13 W.u.)

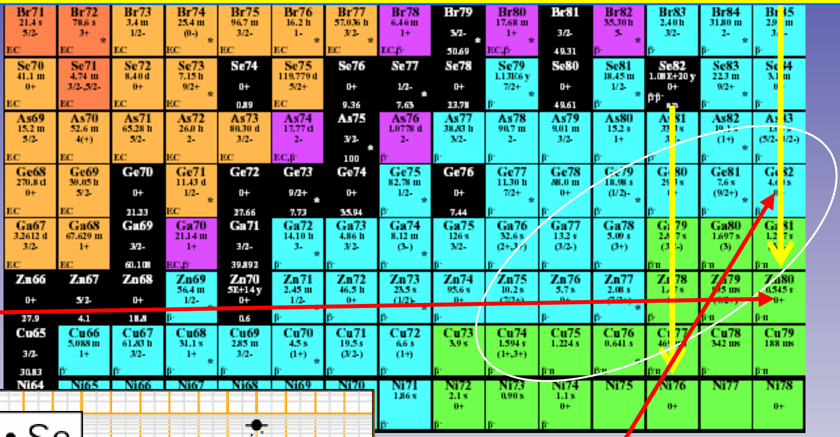
sign of "longer" lifetime in ^{62}Fe

B(E2)~0.012 e^2b^2 (8 W.u.)

Grazing reactions

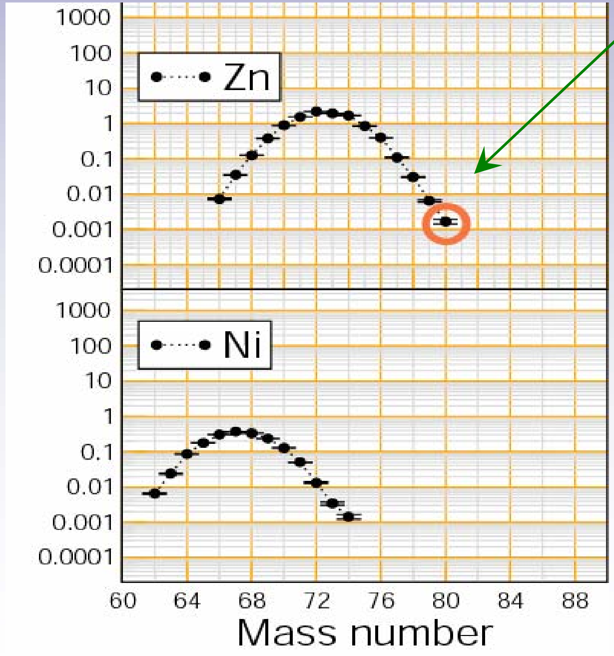
N-rich heavy projectiles allow to use transfer reactions as a *ΔN-ΔZ* filter for driving the multi-nucleon transfer flux to exotic regions

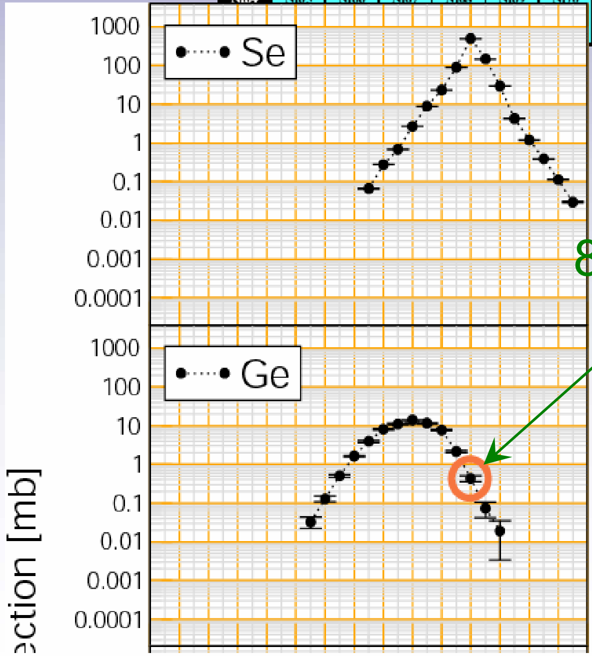
^{82}Se(500 MeV) + ^{238}U



^{80}Zn σ=2μb

-4p, +2n

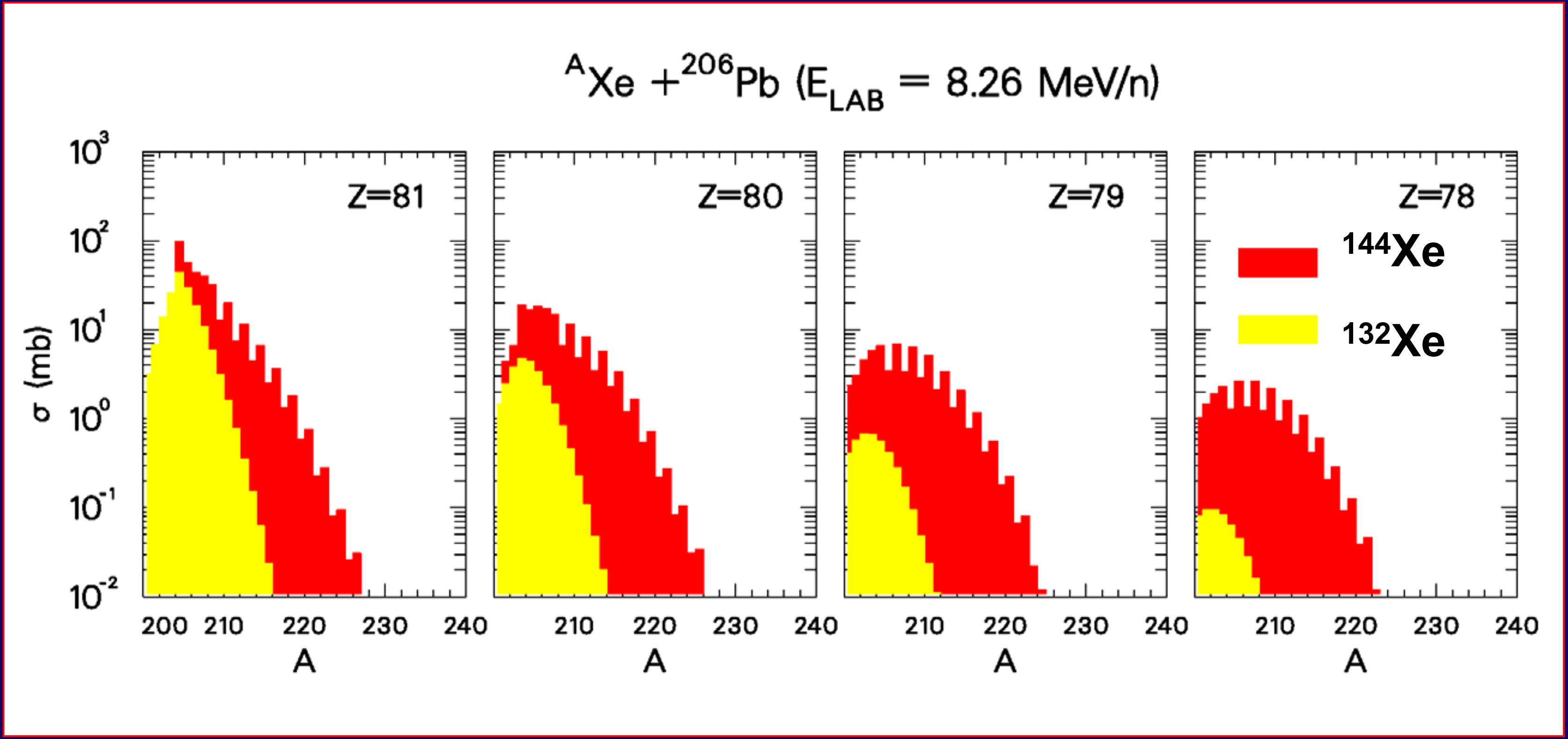




^{82}Ge σ=0.6mb

- 2p, +2n

Neutron rich RIBs: a tool for very neutron rich nuclei

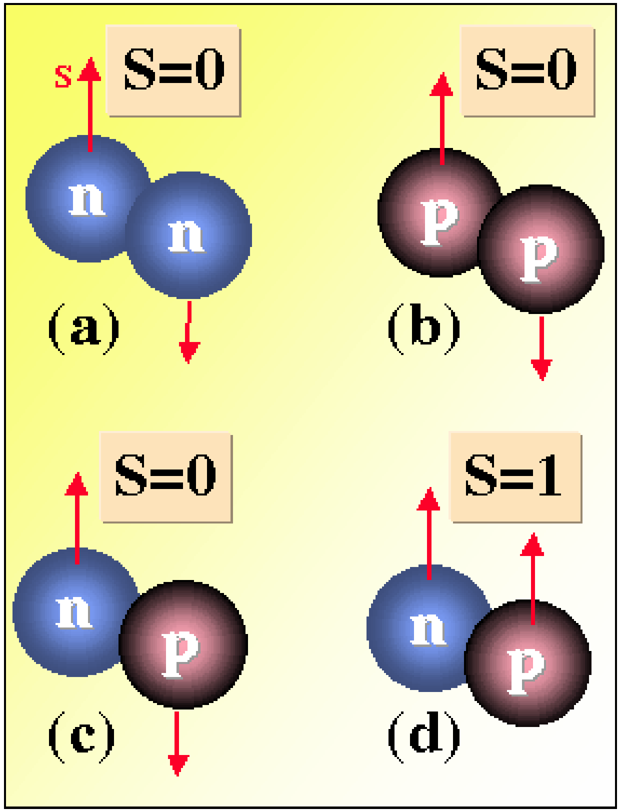


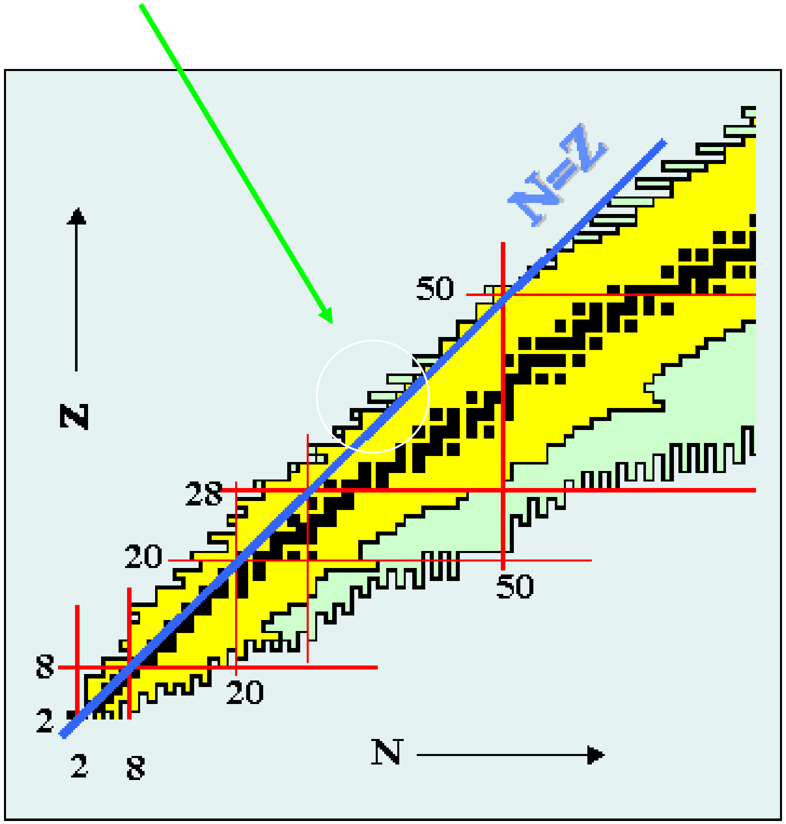
Coupled channel calculations
(Grazing). G. Pollarolo

Future perspective: beams of heavy ions or neutron-rich radioactive beams

Very neutron deficient nuclei: proton-neutron Superfluidity in N=Z Nuclei

A new superfluid phase of nuclear matter based on p-n pairing is expected at N=Z





Energy Differences in Isobaric Multiplets

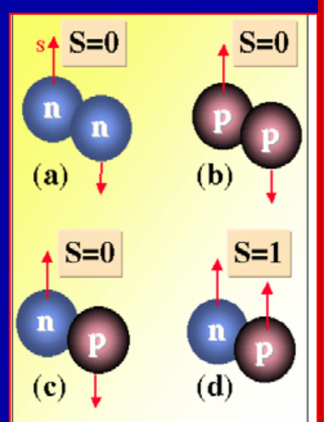
$T_z = \pm 1/2$ Mirror Nuclei

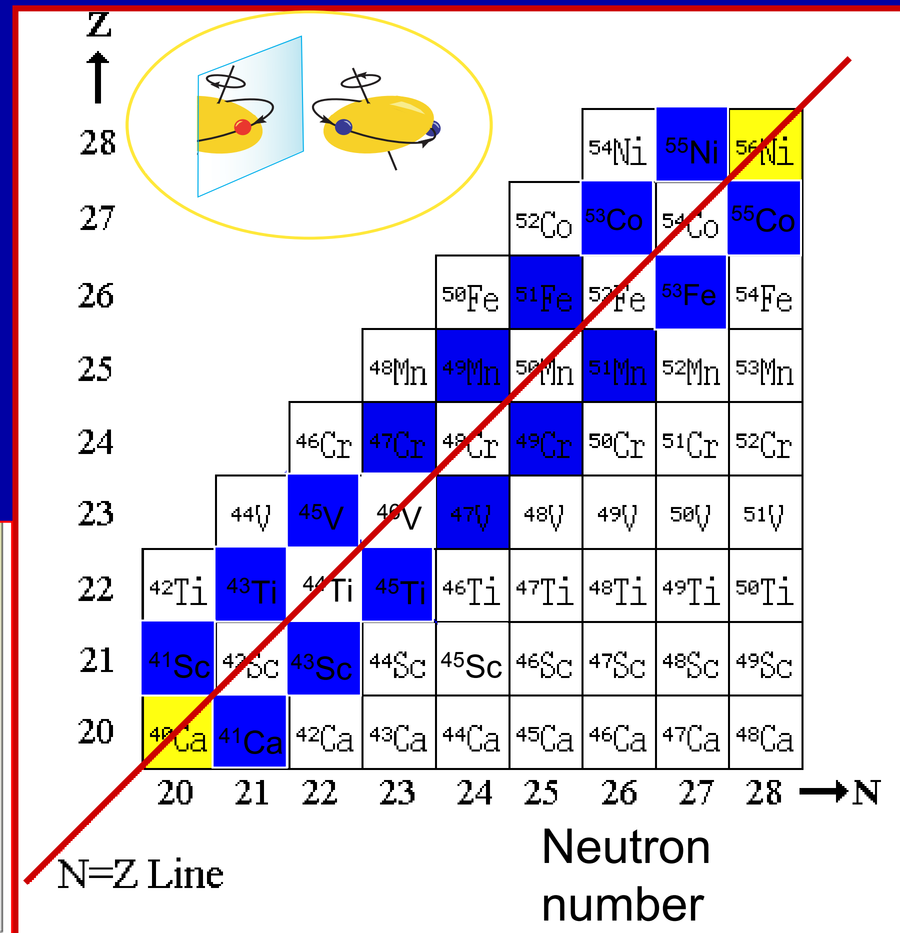
^{67}Se (Z=34, N=33)  ^{67}As (Z=33, N=34)

Study the energy displacement of excited states (*MED*)

$$MED = \left(E_x^J\right)_{T_z=-1/2} - \left(E_x^J\right)_{T_z=1/2}$$

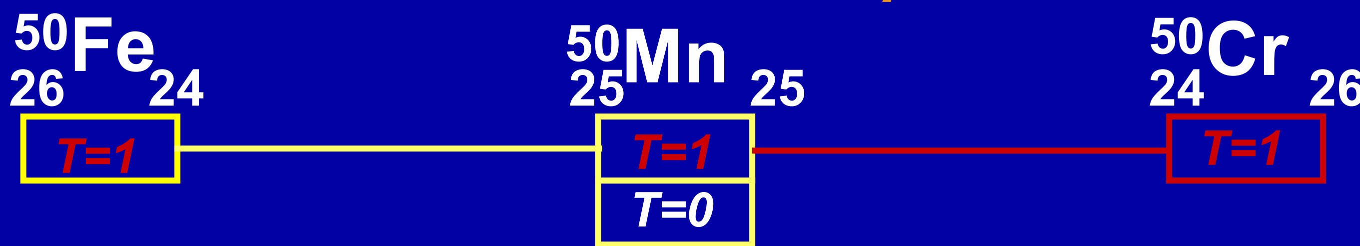
- Nucleon alignment at the backbending
- Evolution of the radii along a rot. band
- Isospin non-conserving terms
- Further Coulomb effects
- Configuration of states
- Isospin mixing
- Coupling to GR
- Induced IS terms
- Coupling to the continuum





Energy Differences in Isobaric Multiplets

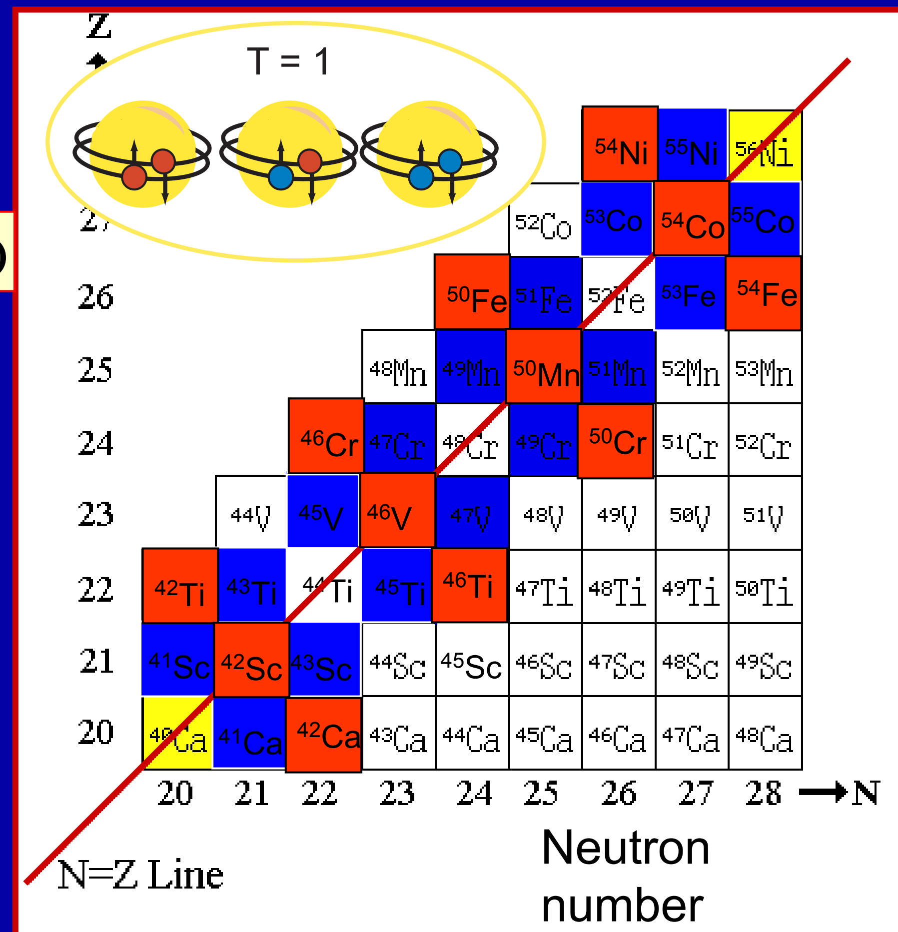
T=1 Isobaric Triplets



Study the energy displacement of excited states (*TED*)

$$\mathrm{TED}_J^{(exp)} = E_J(T_z=1) + E_J(T_z=-1) - 2E_J(T_z=0)$$

- Nucleon alignment at the backbending
- Evolution of the radii along a rot. band
- Isospin non-conserving terms
- Further Coulomb effects
- Configuration of states
- Isospin mixing
- Coupling to GR
- Induced IS terms
- Coupling to the continuum

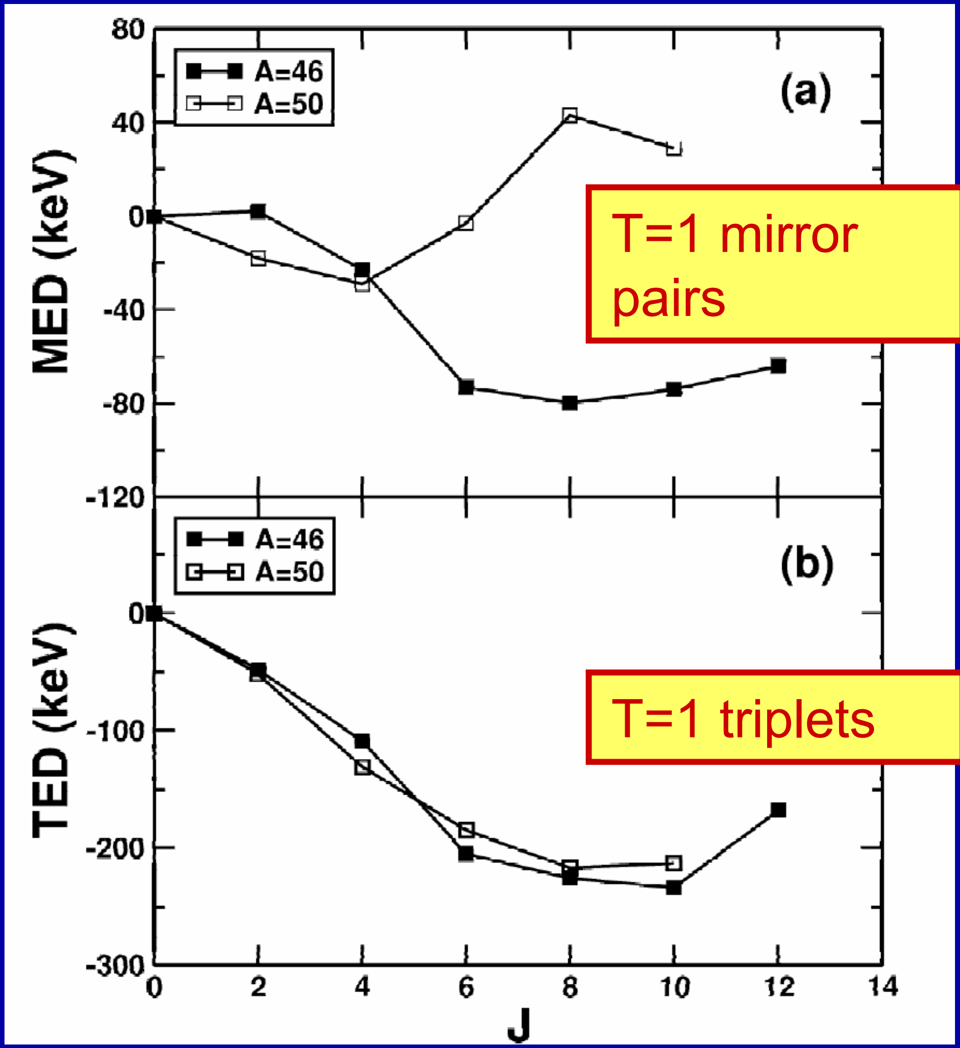


Energy Differences in Isobaric Multiplets

Differences → Coulomb effects

Multipole effects dominate:

- Angular-momentum coupling of pairs of protons
- Changes in alignment → changes in spatial correlation
- 100 keV “alignment” effect typical

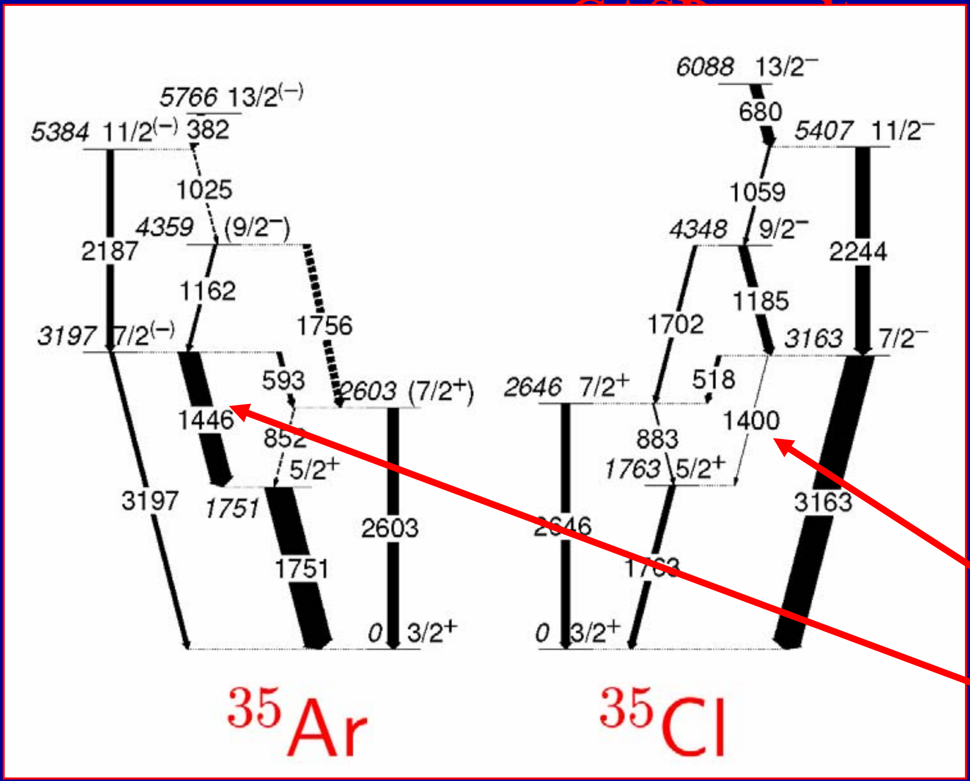


P.E.Garrett et al. *Phys Rev Lett* ***87****(2001)132502*
S.M.Lenzi et al. *Phys. Rev. Lett.* ***87****(2001)122501*
C.D.O’Leary et al. *Phys. Lett. B 525(2002)49*

Isospin Mixing in Mirror Pairs

In the validity of isospin symmetry
1) *Charge invariance* of the *nuclear interaction*
2) *Long-wavelength approximation*

B(E1) strengths are identical in T=1/2 mirror pairs



Isospin mixing via the IVGMR provides an induced isoscalar component

In mirror ΔT=0 transitions

- Isovector terms have opposite sign
- Isoscalar terms have equal sign

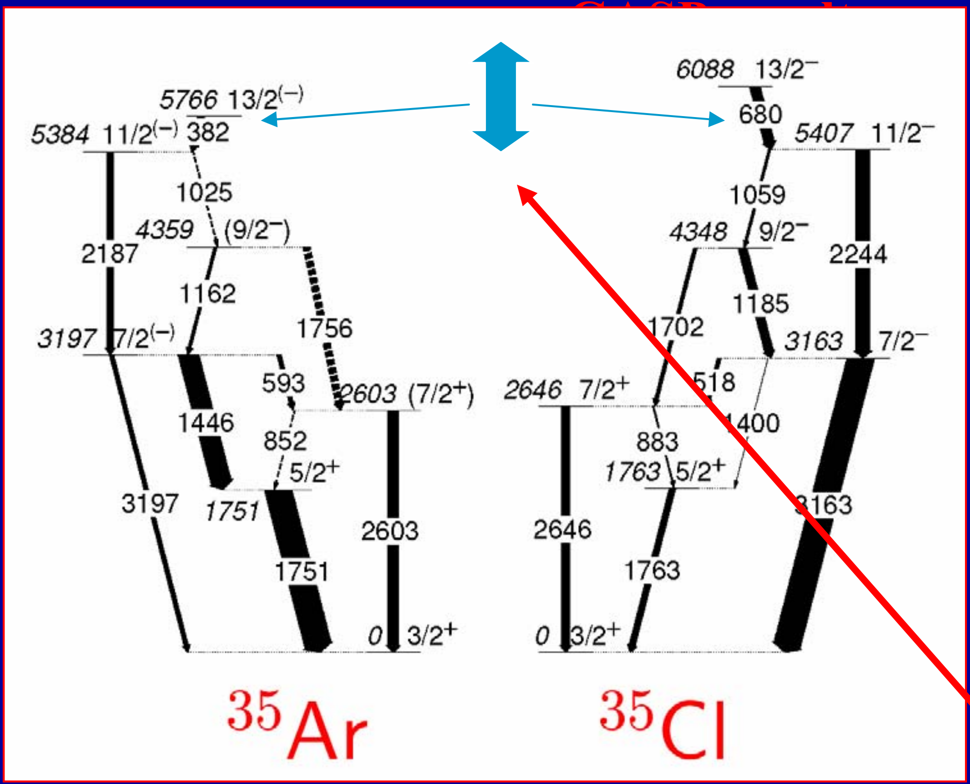
$B(E1) = B^{IS}(E1) - B^{IV}(E1)$

$B(E1) = B^{IS}(E1) + B^{IV}(E1)$

J. Ekman et al. PRL 92, 132502 (2004)

Further Coulomb effects: the e.m. spin-orbit

The electromagnetic spin-orbit coupling results from the Larmor precession of the nucleons in the nuclear electric field due to their intrinsic magnetic moments and to the Thomas precession experienced by a proton because of its charge.



It is important when a nucleon is promoted from a j=l-s level to a j=l+s level. The effect on a proton is opposite to the effect on a neutron orbit

It is proportional to the difference of proton and neutron occupation numbers.

Electromagnetic spin orbit term

J. Ekman et al. PRL 92, 132502 (2004)

Single-particle shifts: Electromagnetic S-O effect

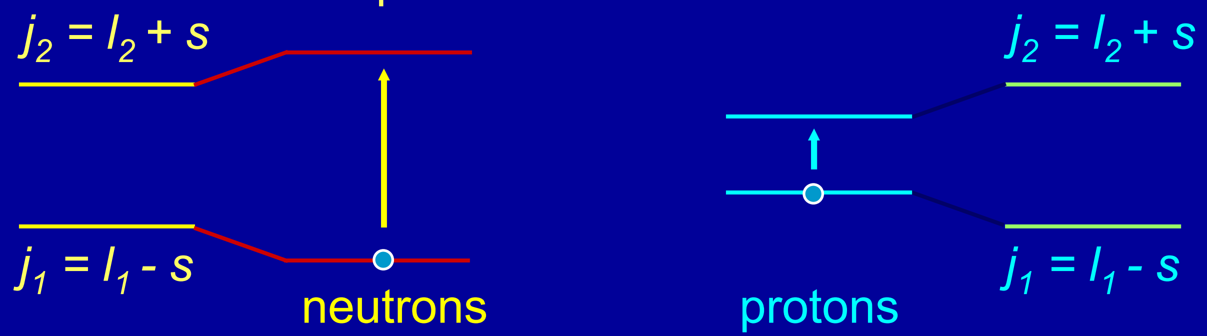
- **Electromagnetic spin-orbit effect is configuration dependent.**
- given by…

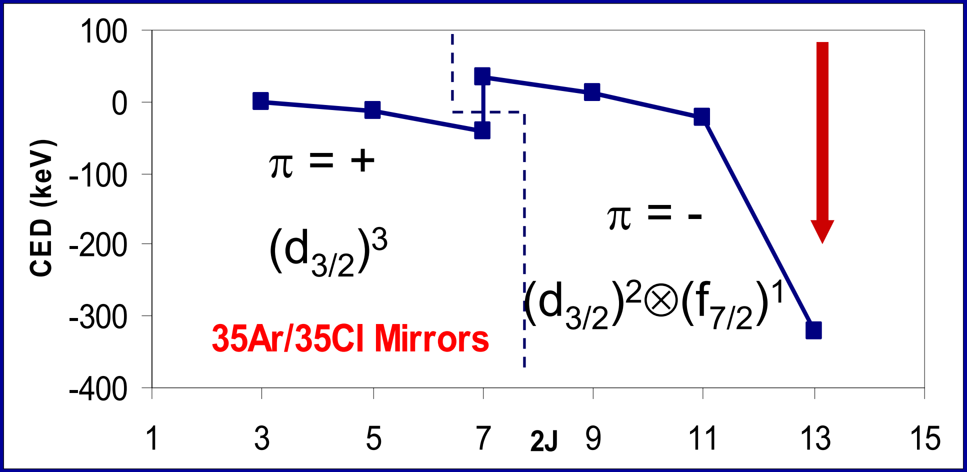
$$W_{so}^{N} = (g_s - g_l)\frac{e}{2m_N^{2}c^{2}}\left\langle \frac{1}{r}\frac{dV_c(r)}{dr}\right\rangle \langle \vec{l}.\vec{s}\rangle$$

Nolen & Schiffer, Ann. Rev. Nuc. Sci, 1969

- Acts in opposite directions for protons and neutrons

It is sensitive to the proton and neutron content of the wave-function



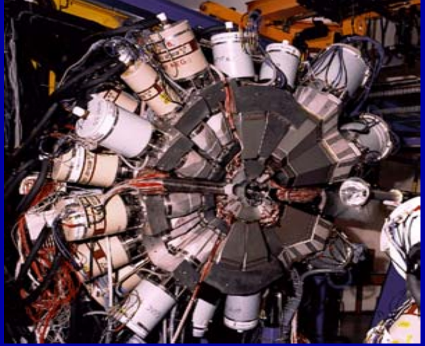


$J^{\pi}=13/2^-$ requires "pure" sp excitation from $d_{3/2}$ to $f_{7/2}$ (proton in Ar, neutron in Cl)

CED~300 keV

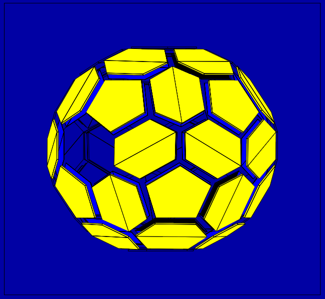
***J.Ekman et al PRL** 92(2004)132502*

The heaviest T=1/2 mirror pair: A=67



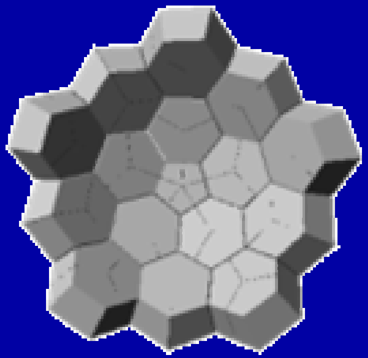
Gamma rays

+



Charged particles

+

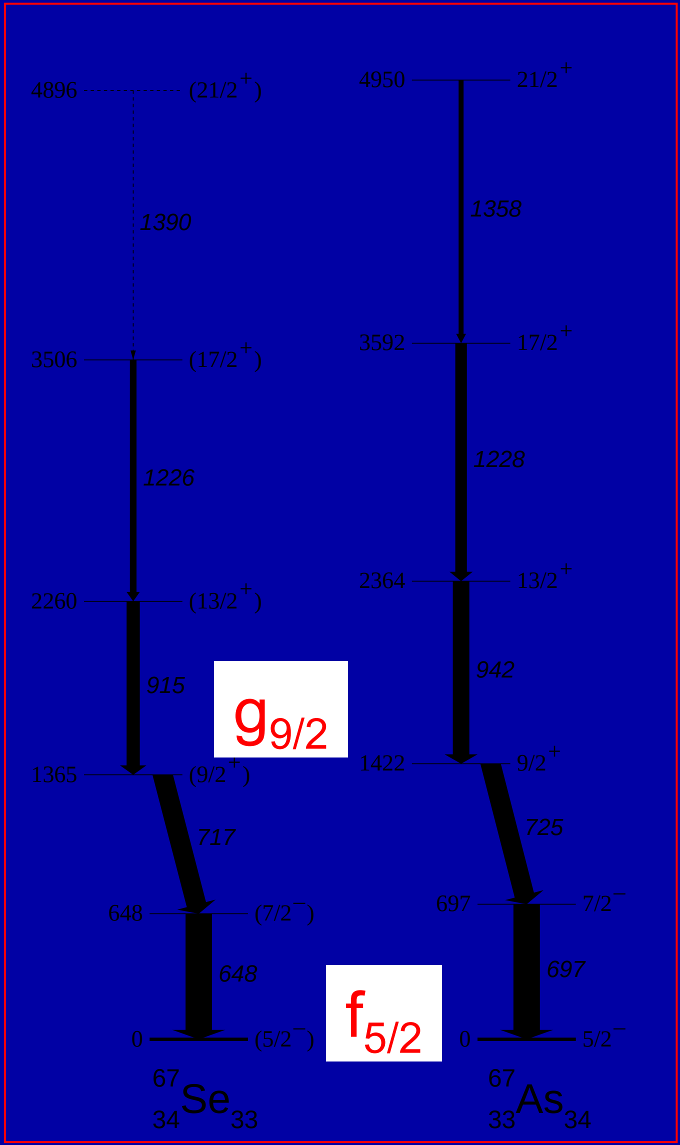


neutrons

Large L value

$j_2 = l_2 + s$

$j_1 = l_1 - s$



MED ($9/2^+$) = - 57 keV
from the $g_{9/2}$ to the $f_{5/2}$

G. de Angelis et al., Proceedings of ENAM 2001

Single-particle shifts: Electromagnetic S-O effect

Assuming: Uniformly charged sphere, non-diffuse surface….

$$W_{so}^{N} = (g_s - g_l)\frac{e}{2m_N{}^2c^2}\underbrace{\left\langle \frac{1}{r}\frac{dV_c(r)}{dr}\right\rangle}_{\alpha\ Z/A}\langle \boldsymbol{l}.\boldsymbol{s}\rangle$$

M. Bemtley, FINUSTAR 05

A	*J,T*	*lower*	*higher*	*“theo”(keV)*	*exp(keV)*
31	9/2,1/2	$s_{1/2}$	$f_{7/2}$	-117	-125
31	13/2,1/2	$s_{1/2}$	$f_{7/2}$	-117	-247
35	13/2,1/2	$d_{3/2}$	$f_{7/2}$	-233	-320
39	13/2,1/2	$d_{3/2}$	$f_{7/2}$	-233	-314
47	3/2,1/2	$d_{3/2}$	$f_{7/2}$	232	212
48	***1,1***	$\boldsymbol{d_{3/2}}$	$\boldsymbol{f_{7/2}}$	***232***	***174***
48	***4,1***	$\boldsymbol{d_{3/2}}$	$\boldsymbol{f_{7/2}}$	***232***	***170***
61	5/2,1/2	$p_{3/2}$	$f_{5/2}$	194	147

Single-particle shifts: Electromagnetic S-O effect

Assuming: Uniformly charged sphere, non-diffuse surface….

$$W_{so}^{N} = (g_s - g_l)\frac{e}{2m_N^2 c^2}\left\langle \frac{1}{r}\frac{dV_c(r)}{dr}\right\rangle \langle \mathbf{l}.\mathbf{s}\rangle$$

$\alpha\ Z/A$

M. Bemtley, FINUSTAR 05

A	*J,T*	*lower*	*higher*	*"theo"(keV)*	*exp(keV)*
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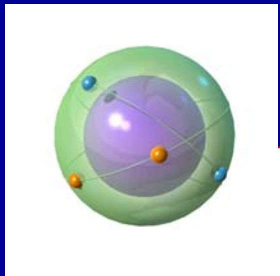
47	3/2,1/2	$d_{3/2}$	$f_{7/2}$	232	212
48	***1,1***	$\boldsymbol{d_{3/2}}$	$\boldsymbol{f_{7/2}}$	***232***	***174***
48	***4,1***	$\boldsymbol{d_{3/2}}$	$\boldsymbol{f_{7/2}}$	***232***	***170***
61	5/2,1/2	$p_{3/2}$	$f_{5/2}$	194	147
67	**9/2,1/2**	**f5/2**	**g9/2**	**300**	**- 57**

Simultaneous occupation of the same orbital by protons and neutrons



P+QQ Hamiltonian + T=0 monopole field

odd nucleus

M. Hasegawa et al. / Physics Letters B 617 (2005) 150–156 155

Expectation values of proton and neutron numbers in the four orbitals, calculated for those low-lying states in ^{67}As. Calculated spectroscopic Q-moments (in e fm^2) are also tabulated

^{67}As	$\langle n_a^\pi \rangle$				$\langle n_a^\nu \rangle$				Q
	$p_{3/2}$	$f_{5/2}$	$p_{1/2}$	$g_{9/2}$	$p_{3/2}$	$f_{5/2}$	$p_{1/2}$	$g_{9/2}$	
$1/2_1^-$	1.99	2.15	0.72	0.15	2.33	2.30	1.19	0.17	1.1
$3/2_1^-$	2.17	2.12	0.54	0.17	2.48	2.60	0.73	0.19	23.9
$5/2_1^-$	2.06	2.13	0.68	0.13	2.36	2.74	0.74	0.17	−13.8
$7/2_1^-$	2.04	2.19	0.62	0.15	2.36	2.78	0.68	0.18	−24.2
$7/2_2^-$	2.16	1.66	1.00	0.18	2.33	2.35	1.12	0.20	−1.5
$9/2_1^+$	1.69	1.93	0.65	0.73	2.26	2.43	0.81	0.51	−57.9
$13/2_1^+$	1.78	1.88	0.62	0.72	2.22	2.62	0.63	0.53	−57.8
$11/2_1^+$	1.75	1.77	0.75	0.73	2.19	2.34	0.88	0.59	−51.6
$15/2_1^+$	1.85	1.90	0.61	0.64	2.14	2.52	0.66	0.69	−56.4

$n^\nu = 0.51$

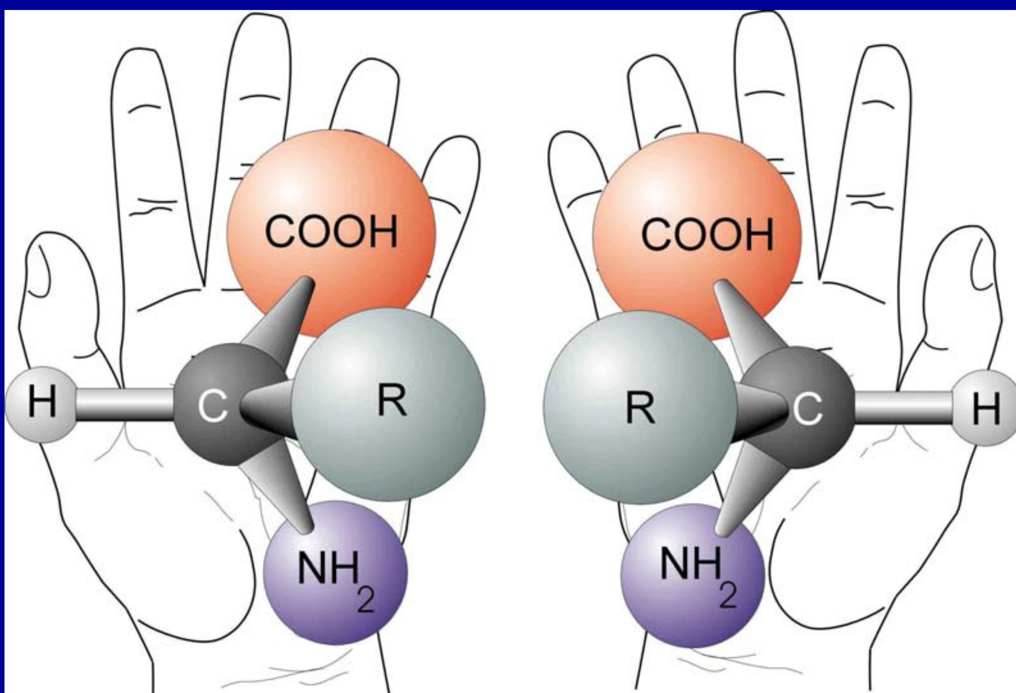
$n^\pi = 0.73$

M. Hasegawa et al., PLB 617 150 (2005)

Admixture of ^{66}Ge * $\pi g_{9/2}$ and ^{66}As * $\nu g_{9/2}$ Unique property of N=Z

Using the calculated wave function Wso(^{67}Se-^{67}As) = 20 keV

Spontaneous formation of chirality in rotating nuclei ?

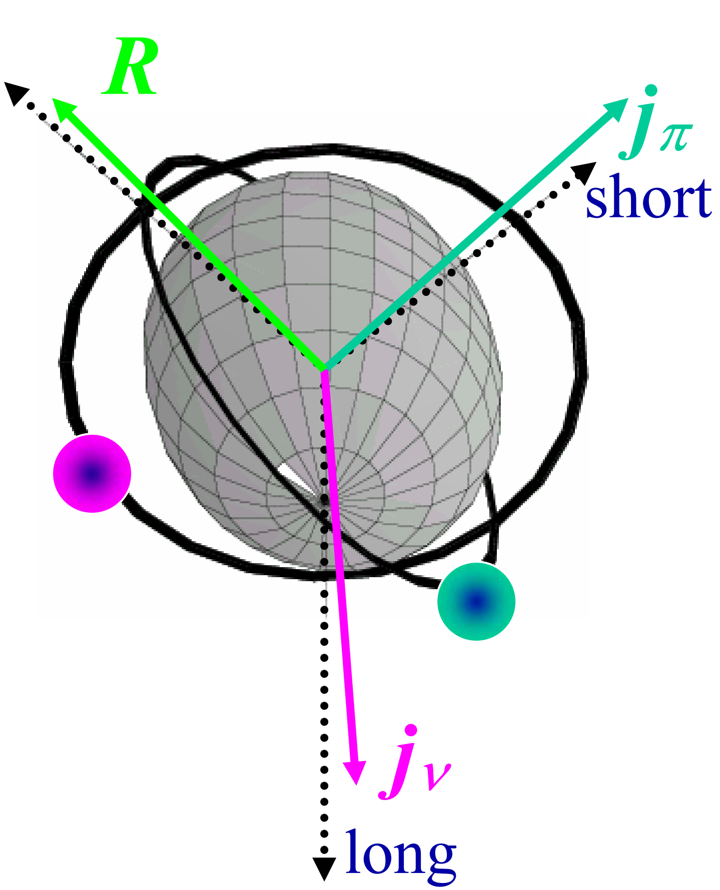


What is Chirality?

"I call any geometrical figure, or group of points, chiral, and say it has chirality, if its image in a plane mirror, ideally realized, cannot be brought to coincide with itself." - Lord Kelvin 1904

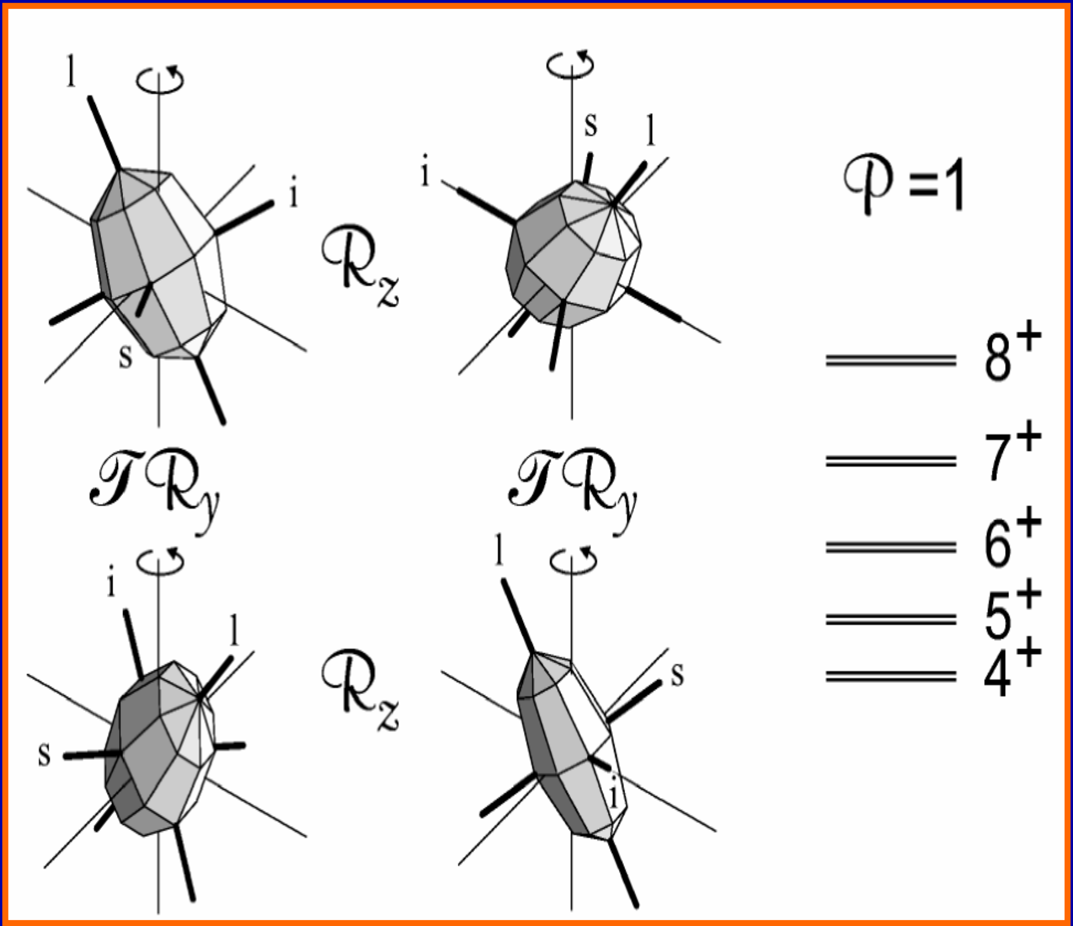
Chirality via coupling of three angular momenta: odd-odd nuclei in the A~130 region

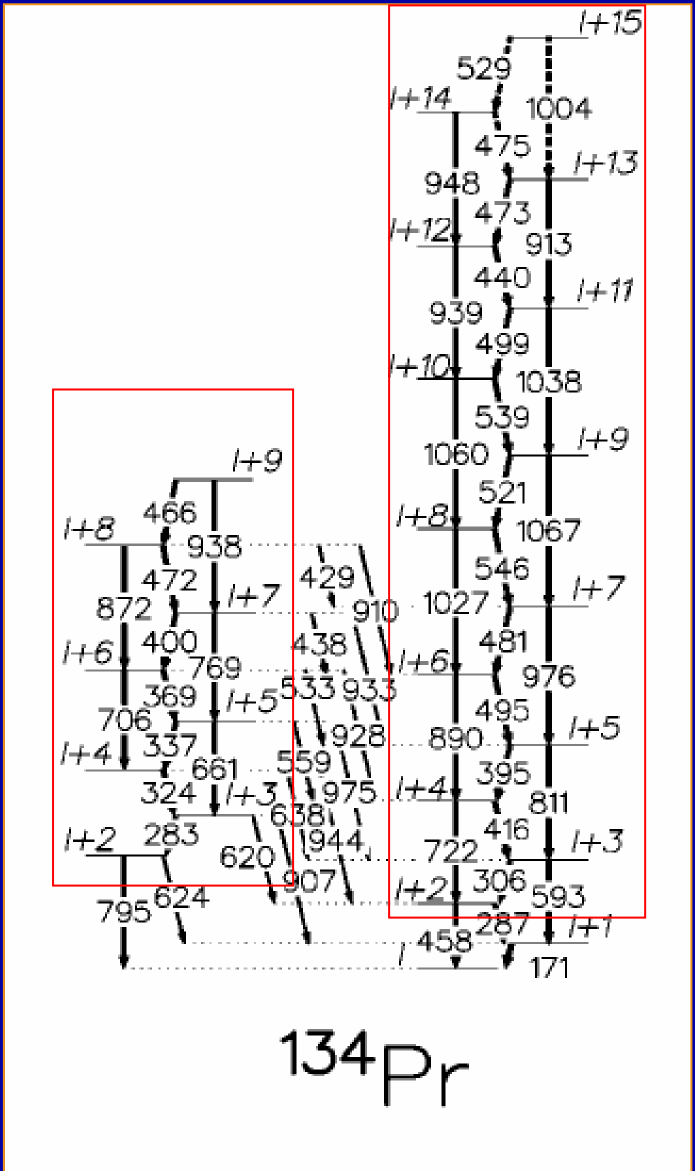
- Z=~55 N=~75
- Triaxial mass distribution (shape).
- Fermi level lies
  - *low* in proton $h_{11/2}$ subshell,
  - *high* in neutron $h_{11/2}$ subshell
- Collective rotation of triaxial rotor with ***irrotational*** *flow* moment of inertia.



S. Frauendorf and J. Meng, Nucl. Phys. A 617 131 (1997);
V. Dimitrov et. al., Phys. Rev. Lett. 84 5732 (2000).

The energies of the excited states for the left-handed and right-handed systems should be identical

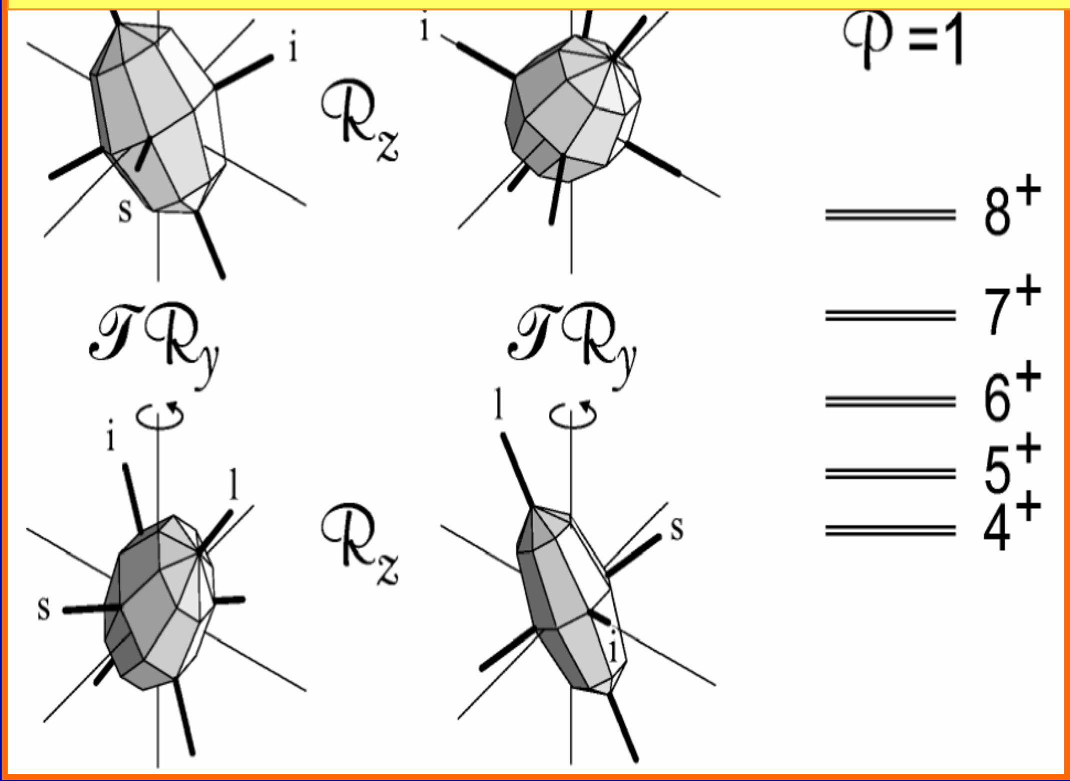


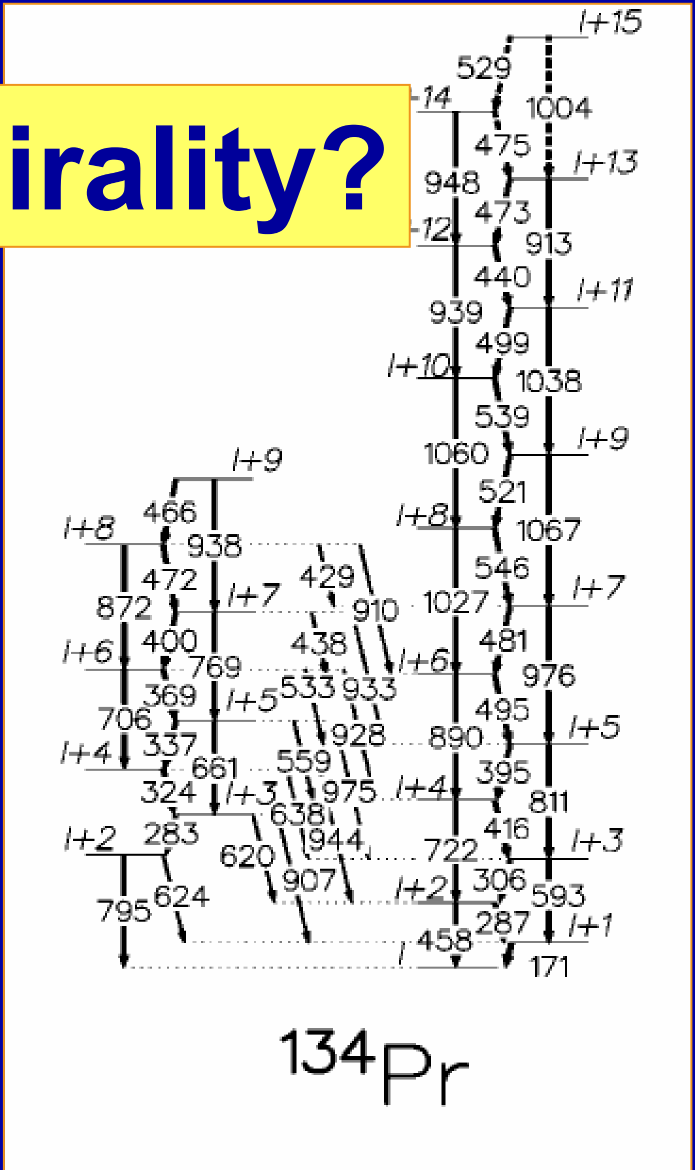


V. I. Dimitrov et al, PRL 84 (2000) 5732

The energies of the excited states for the left-handed and right-handed systems should be identical

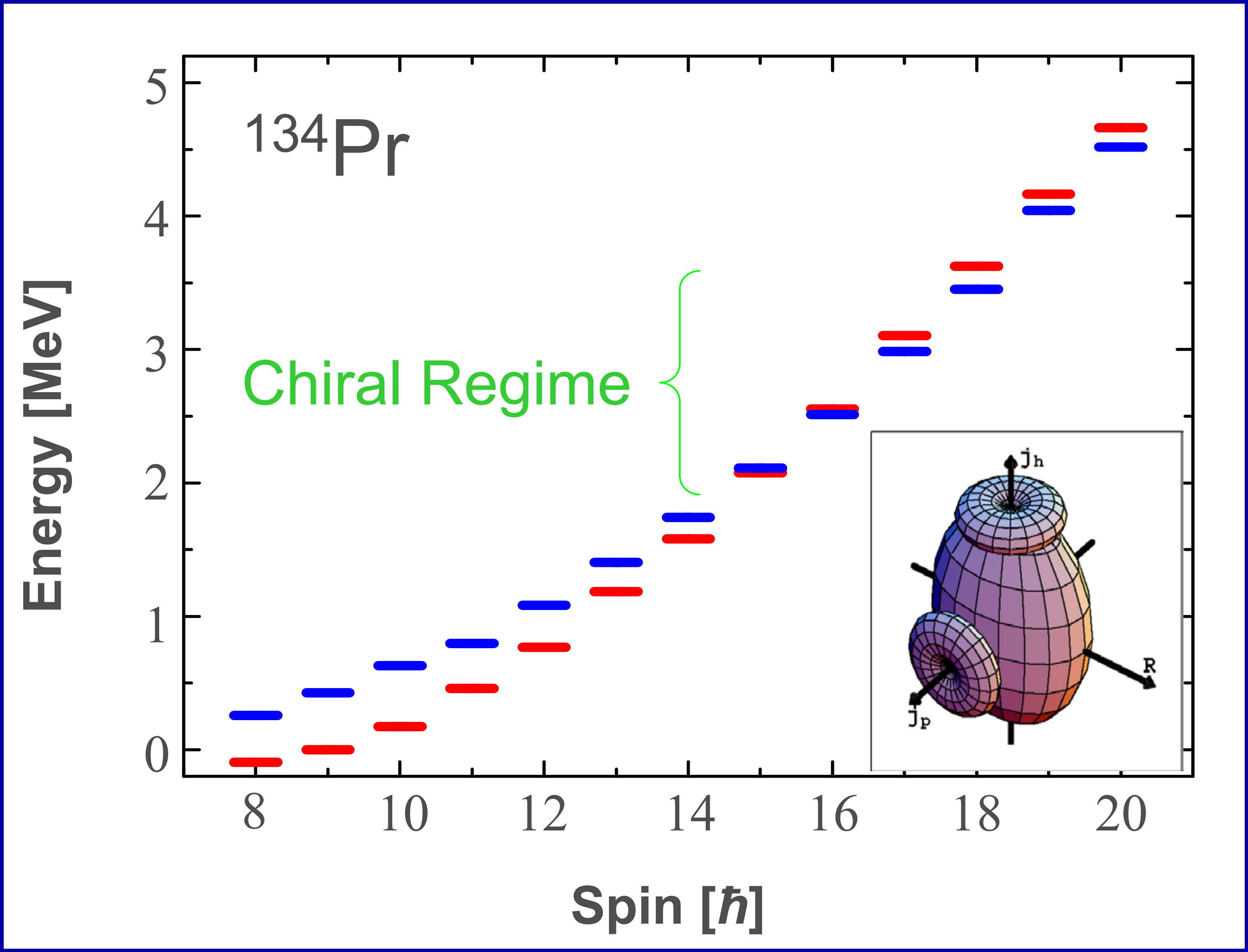
How can we test chirality?



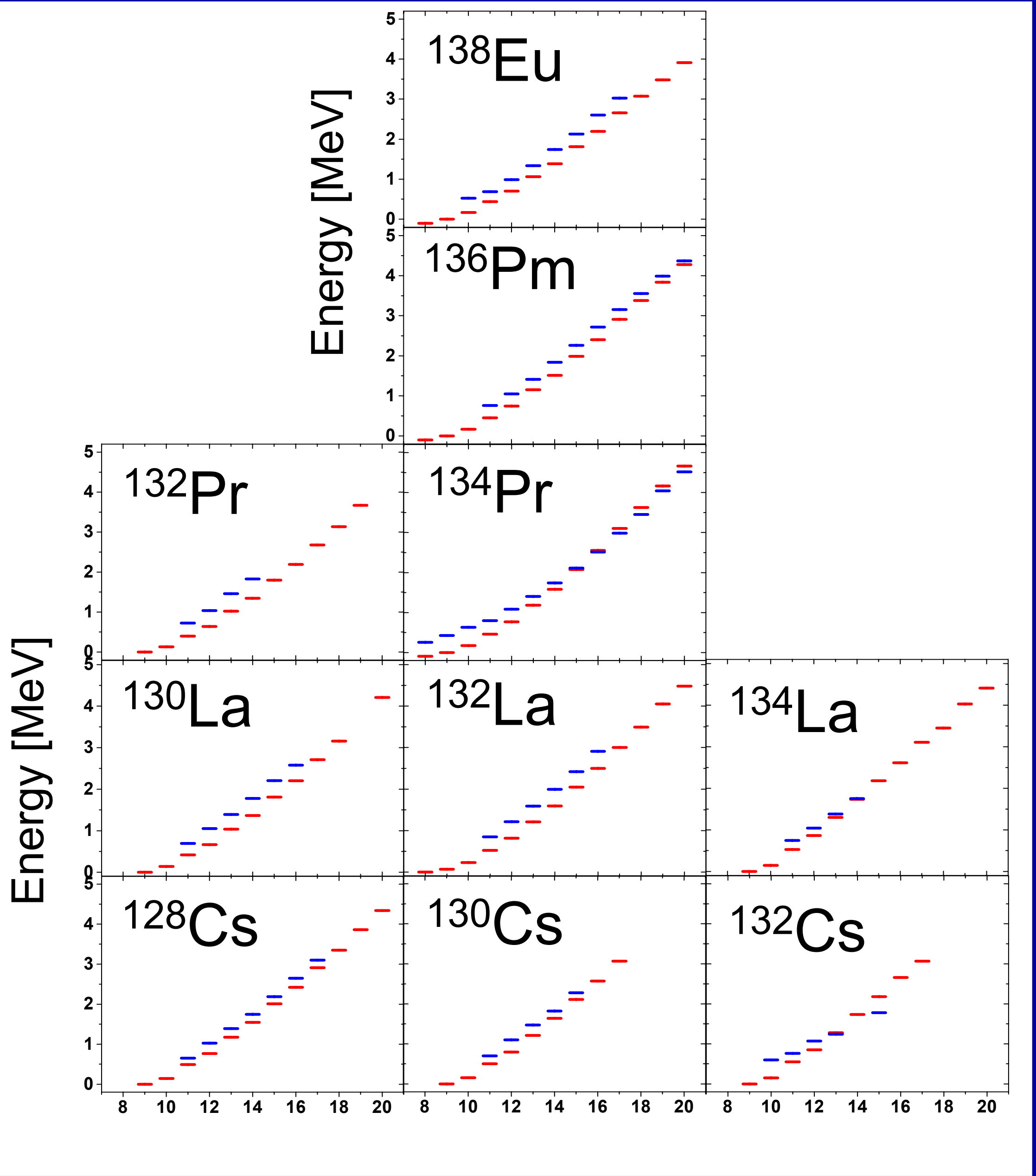


V. I. Dimitrov et al, PRL 84 (2000) 5732

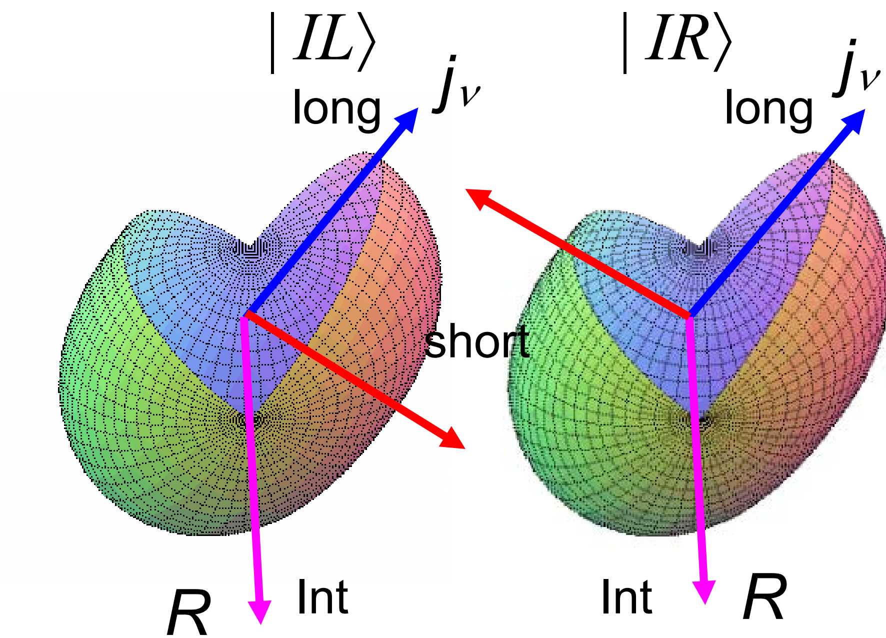
^{134}Pr : a case of chiral rotator ?



Systematics of partner bands in odd-odd A~130 nuclei



EM properties of chiral geometry



TME identical for the two bands

$$\langle IL \,|\, E2 \,|\, IR\rangle \approx 0$$

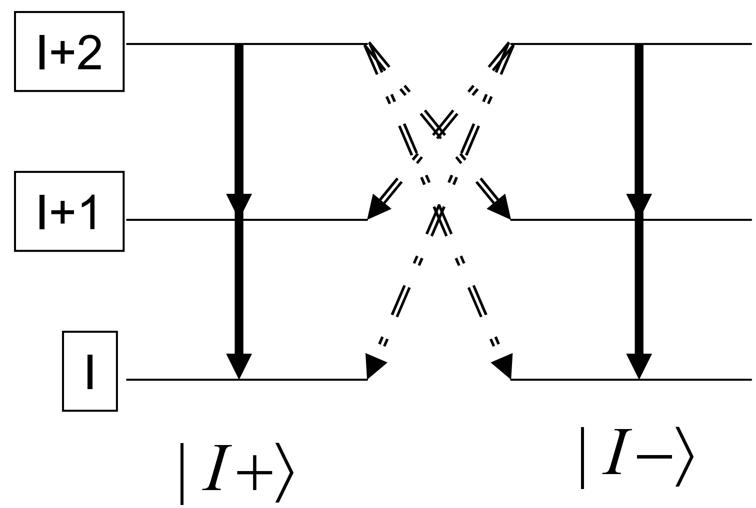
$$\langle IL \,|\, M1 \,|\, IR\rangle \approx 0$$

$$B(EM; I_i+ \rightarrow I_f+) \approx B(EM; I_i- \rightarrow I_f-)$$

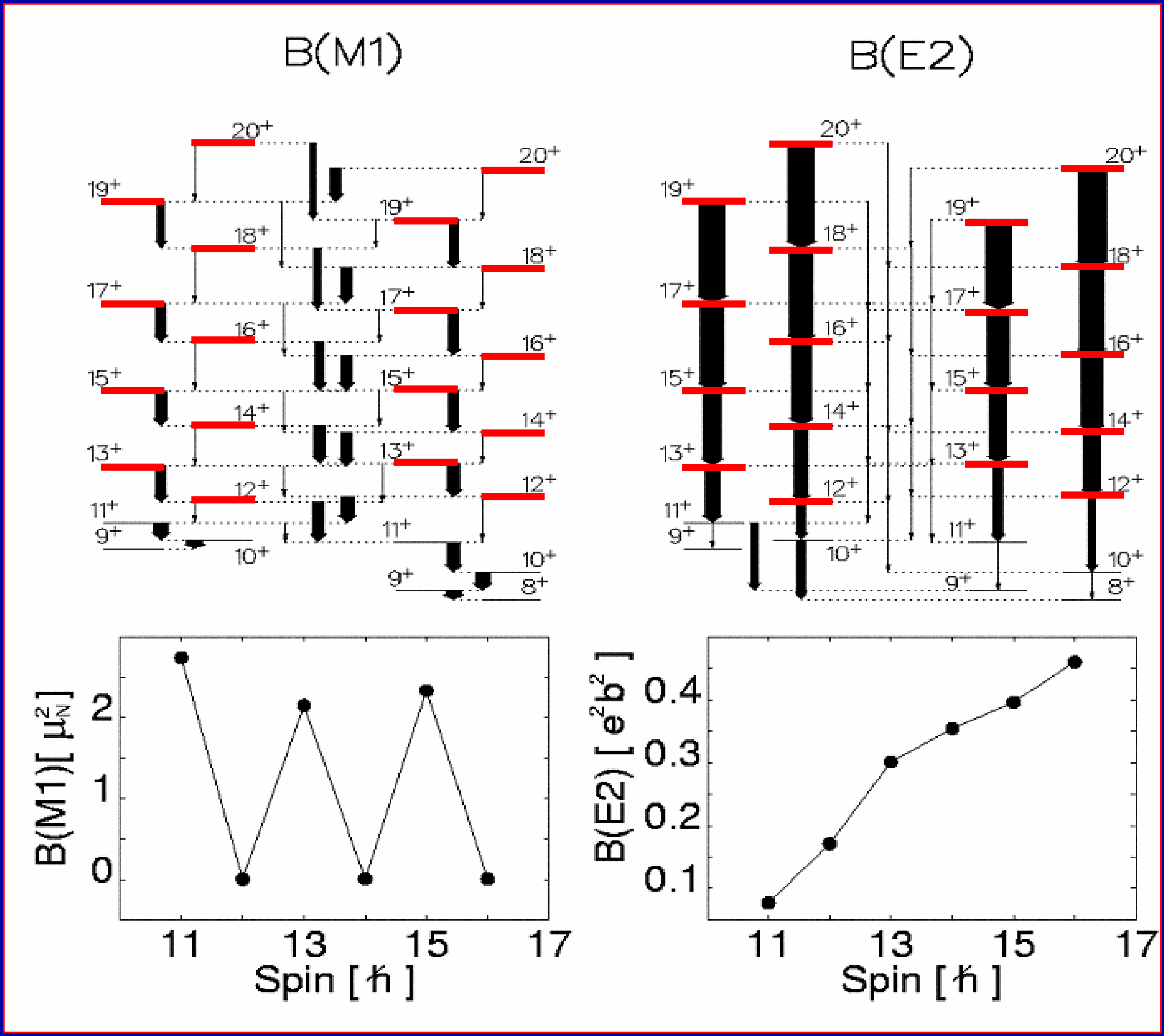
$$B(EM; I_i+ \rightarrow I_f-) \approx B(EM; I_i- \rightarrow I_f+)$$

$$|I+\rangle = \frac{1}{\sqrt{2}}(|IL\rangle + |IR\rangle)$$

$$|I-\rangle = \frac{i}{\sqrt{2}}(|IL\rangle - |IR\rangle)$$

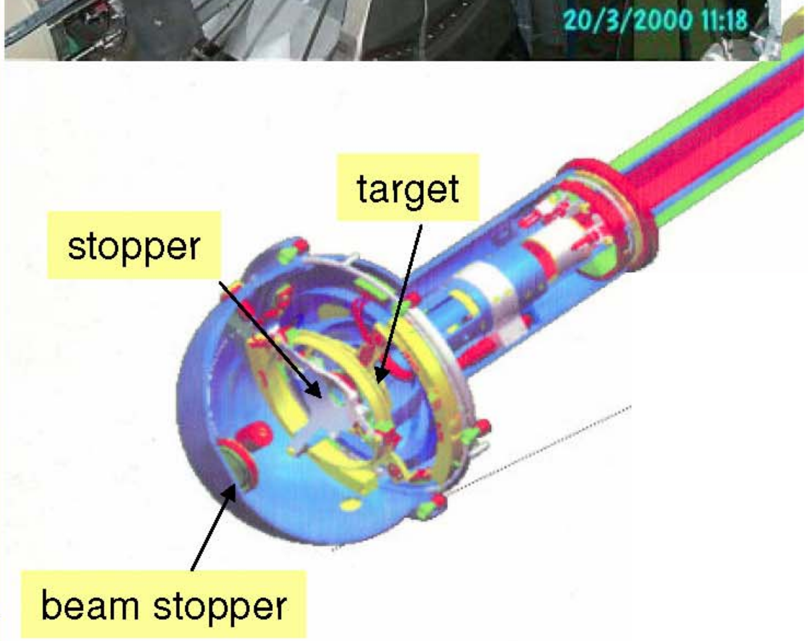


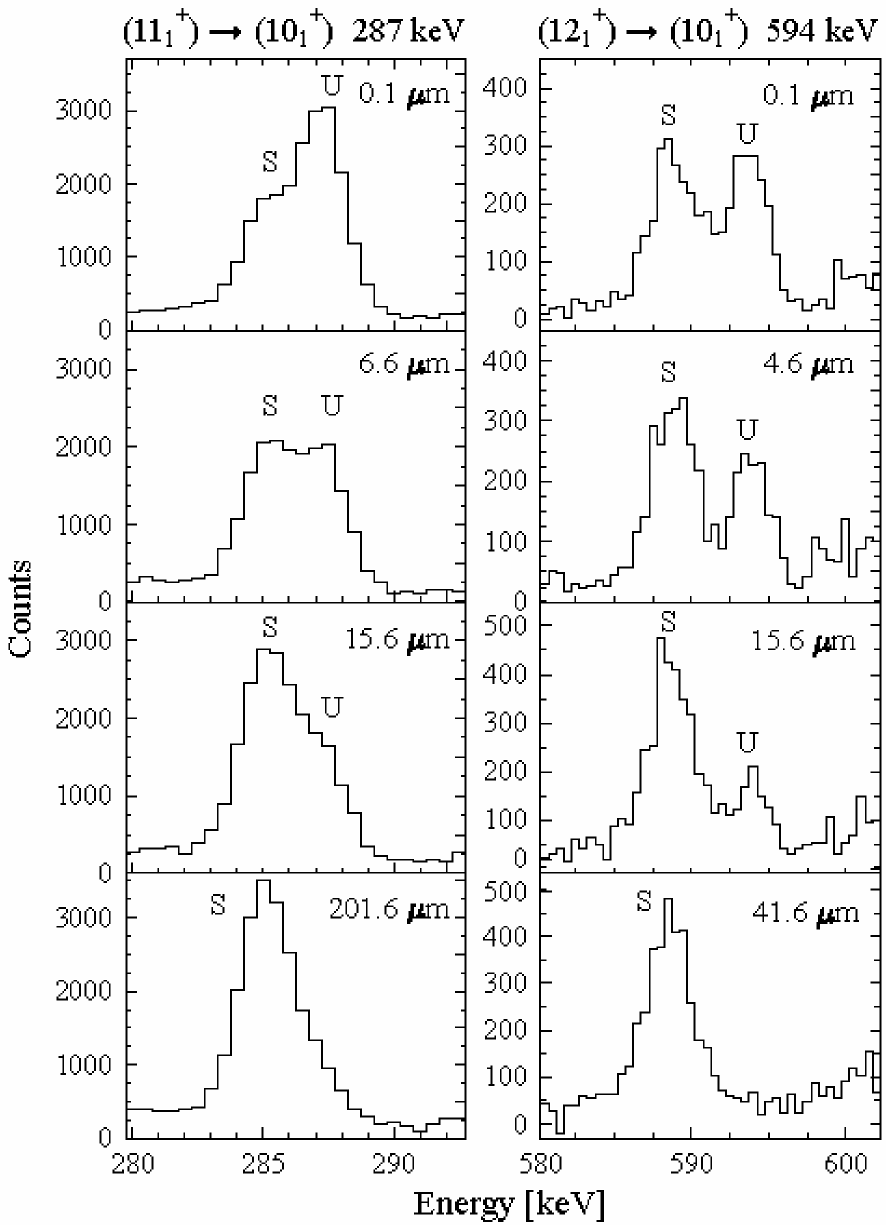
❖Calculated transition rates for $\pi h_{11/2}\nu h_{11/2}$ p-h configuration in triaxial odd-odd nuclei



❖Lifetime measurements by RDDS in ^{134}Pr

The Köln Plunger



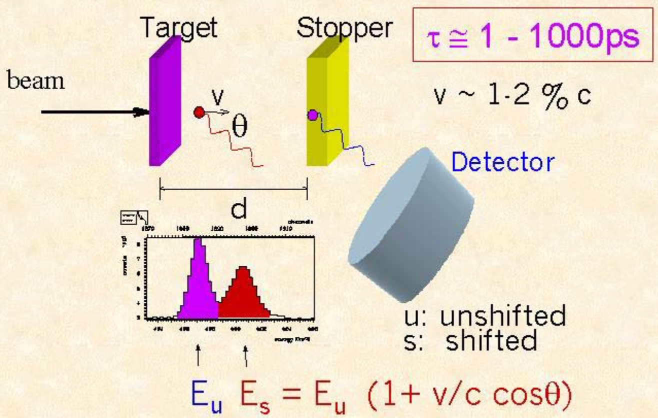


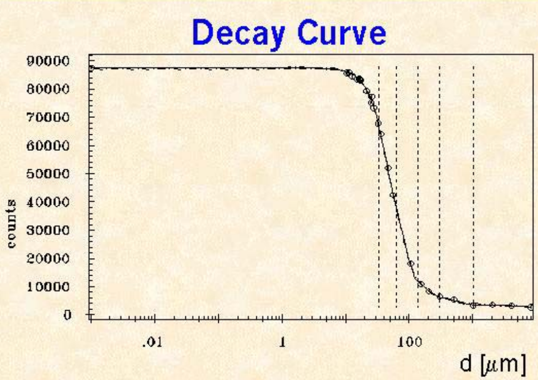
❖Lifetime measurements by RDDS and DSAM in 134

Measurement of level lifetimes in the picosecond range

- measure matrix elements between nuclear wave functions
- direct measure of quadrupole moments (deformation)
- very important observable in nuclear structure

The Recoil Distance Doppler-Shift Method





in fusion reactions

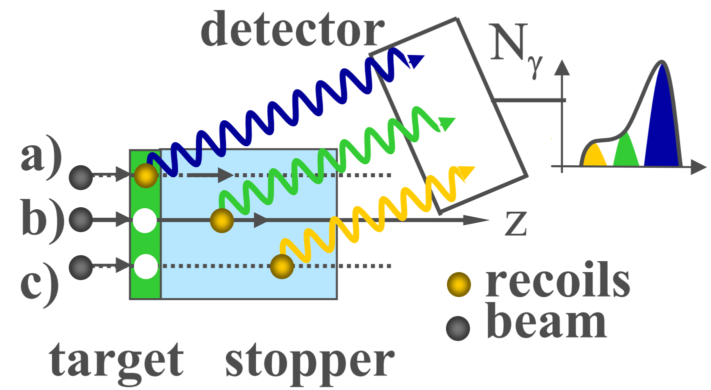
v ~ 1-2 % c

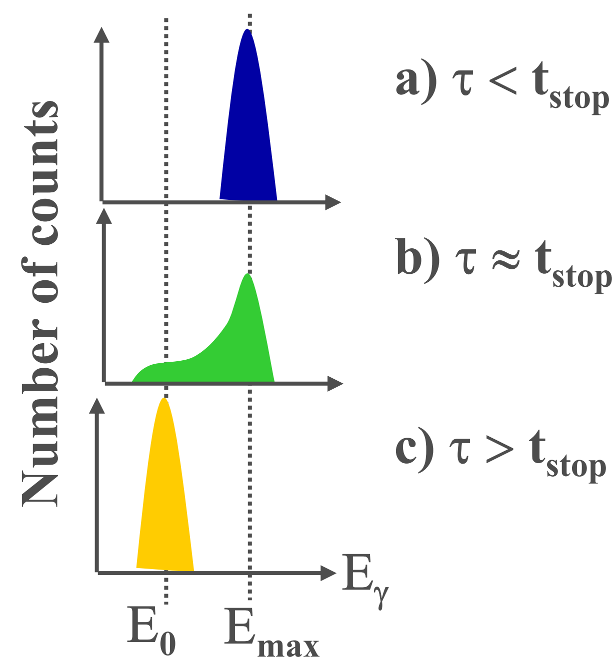
flight time:

$t_f = d / v$

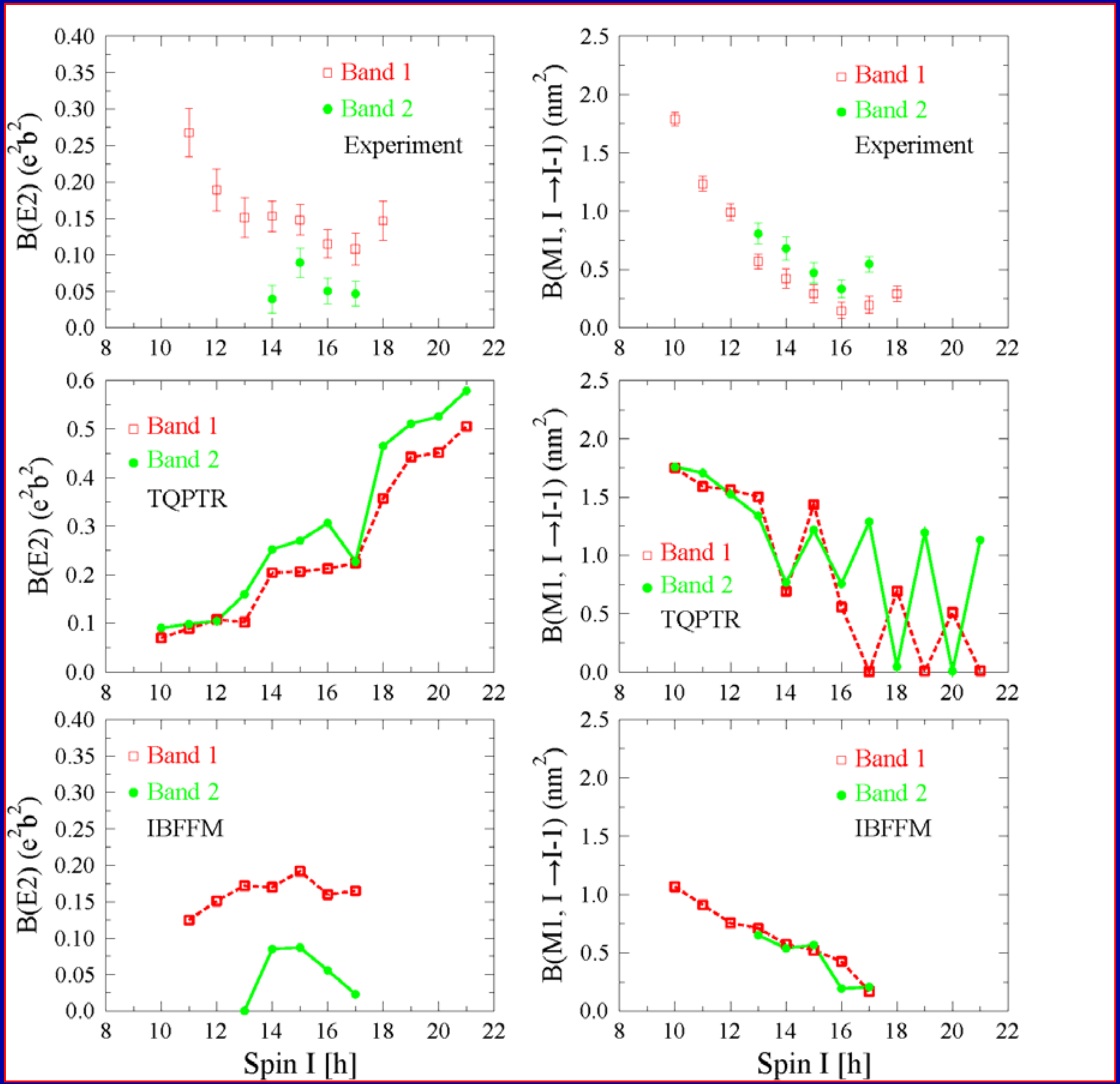
v= 0.01c, t_f = 5 ps

⇒ **d = 15 μm**





B(E2) B(M1)



Experiment

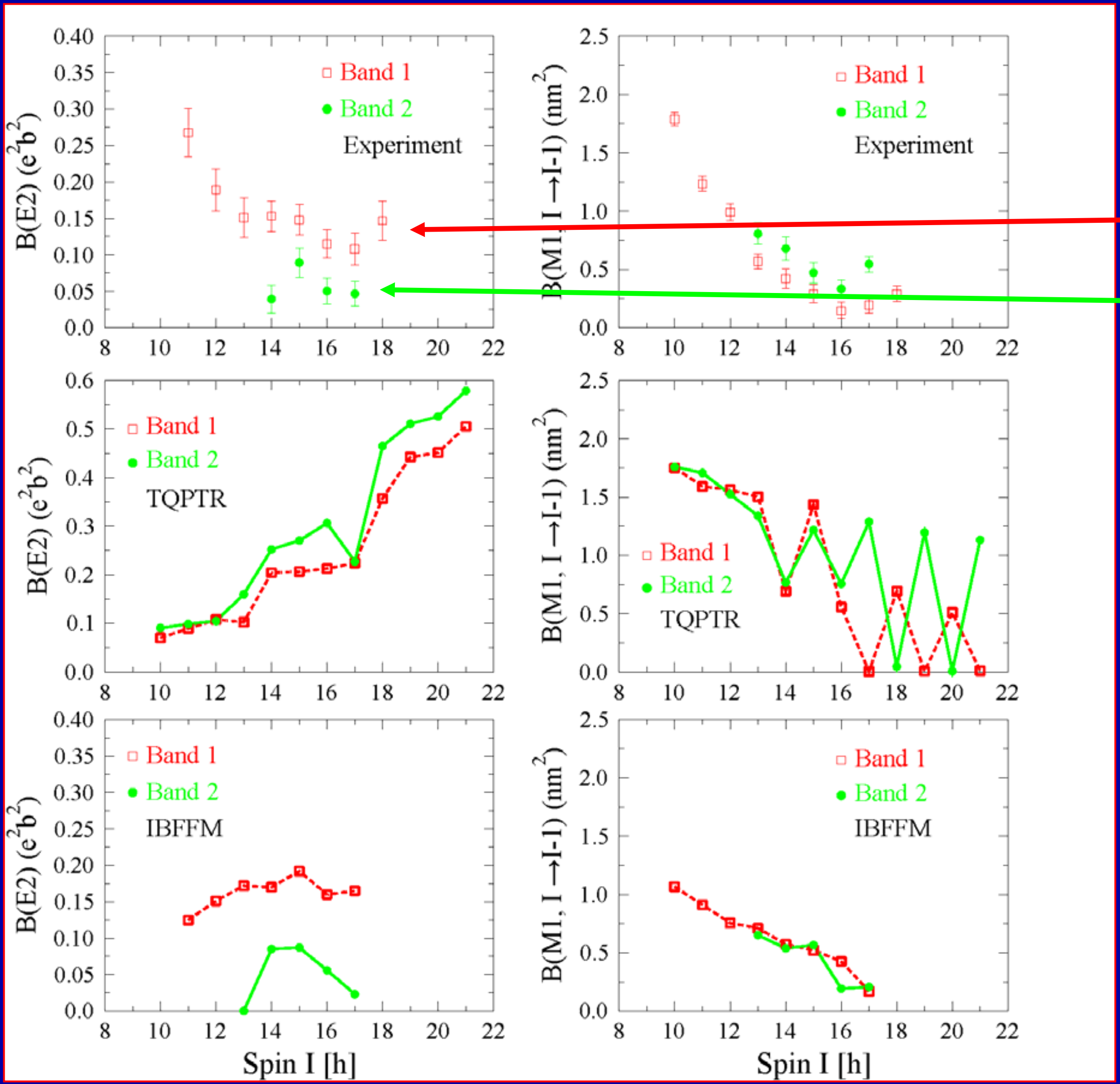
Chirality

Triaxial Vibrator

D. Tonev et al., PRL 96, 052501 (2006)

B(E2)

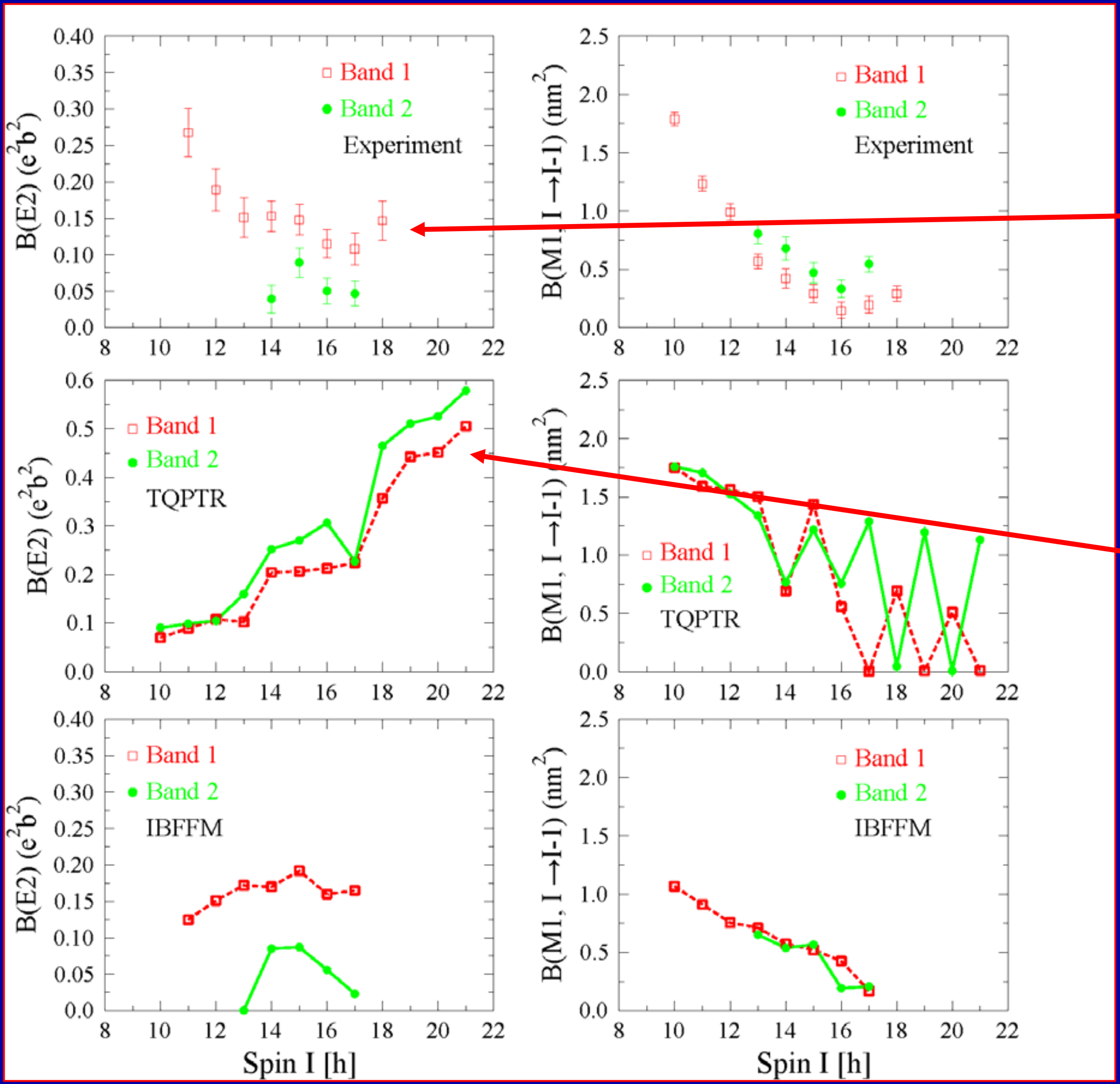
B(M1)



B(E2) band1 and 2 differ

D. Tonev et al., PRL 96, 052501 (2006)

B(E2) B(M1)



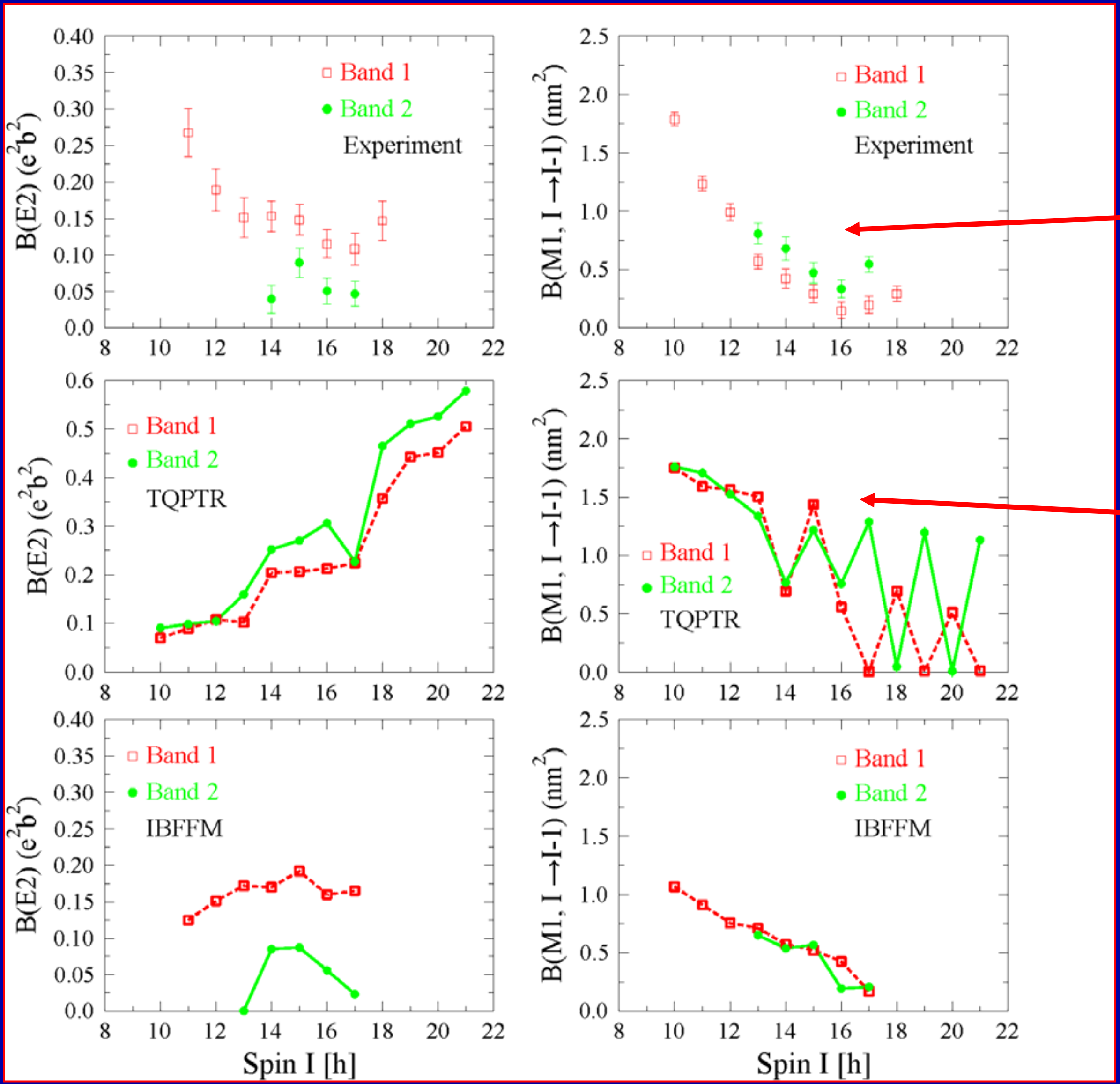
Exp. B(E2) down-sloping

Chirality predicts: B(E2) up-slope

Good agreement with IBFFM

D. Tonev et al., PRL 96, 052501 (2006)

B(E2) | B(M1)



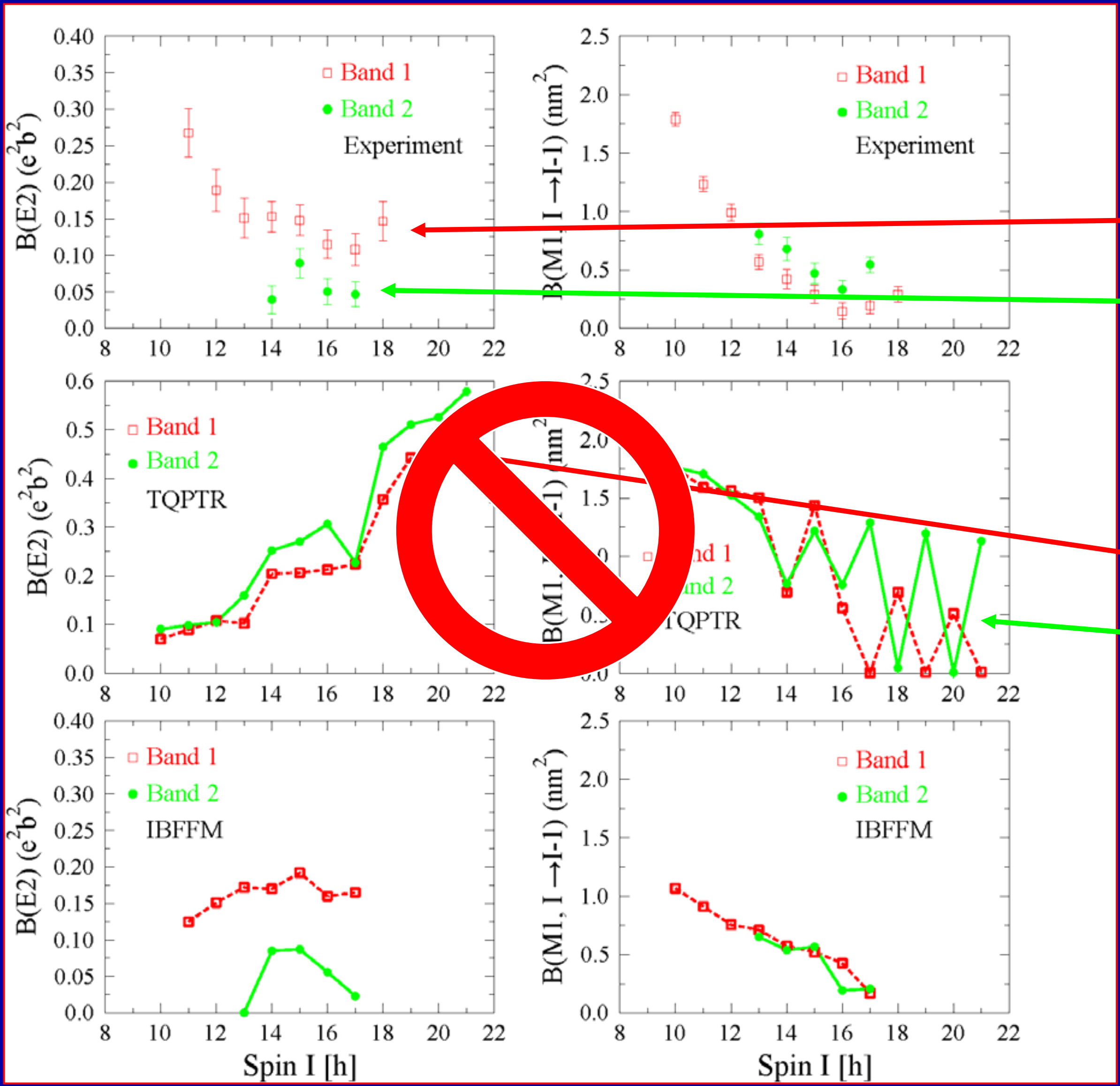
Exp. B(M1) NO staggering

Chirality predicts: B(M1) staggering

Good agreement with IBFFM

D. Tonev et al., PRL 96, 052501 (2006)

Incompatible with the predictions of static chirality!



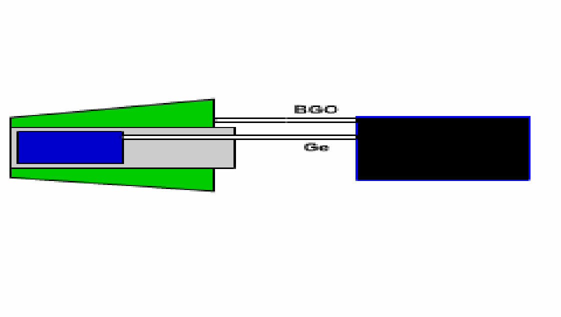
B(E2) band1 and 2 differ

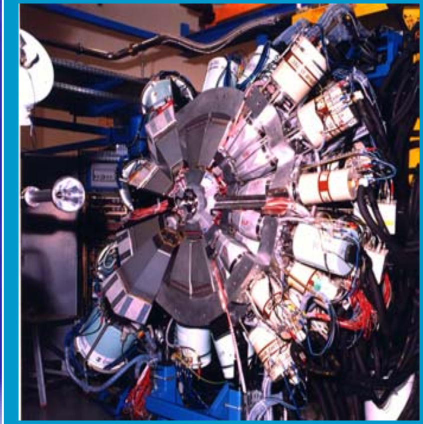
Chirality predicts: B(E2) up-slope B(M1) staggering

Good agreement with IBFFM

D. Tonev et al., PRL 96, 052501 (2006)

Gamma Arrays based on Compton Suppressed Spectrometers





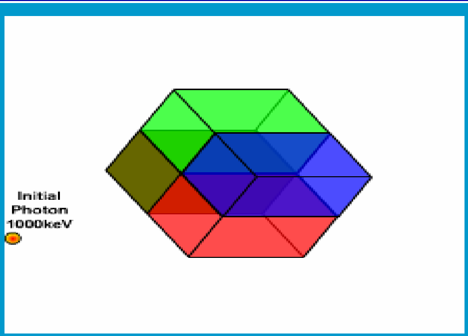
EUROBALL

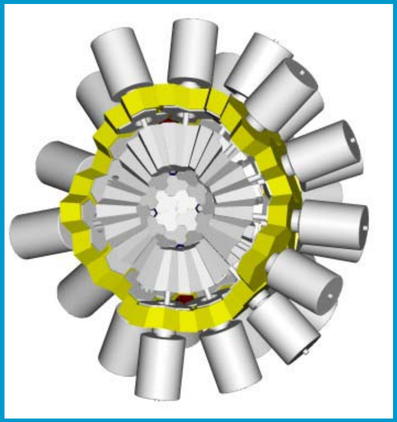
GAMMASPHERE

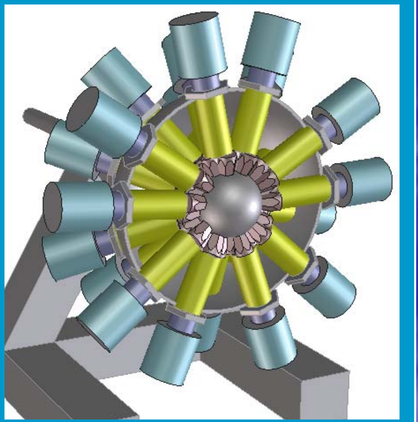
$\varepsilon \sim$ **10 — 5 %**

(M_γ=1 — M_γ=30)

Tracking Arrays based on Position Sensitive Ge Detectors







AGATA

GRETA

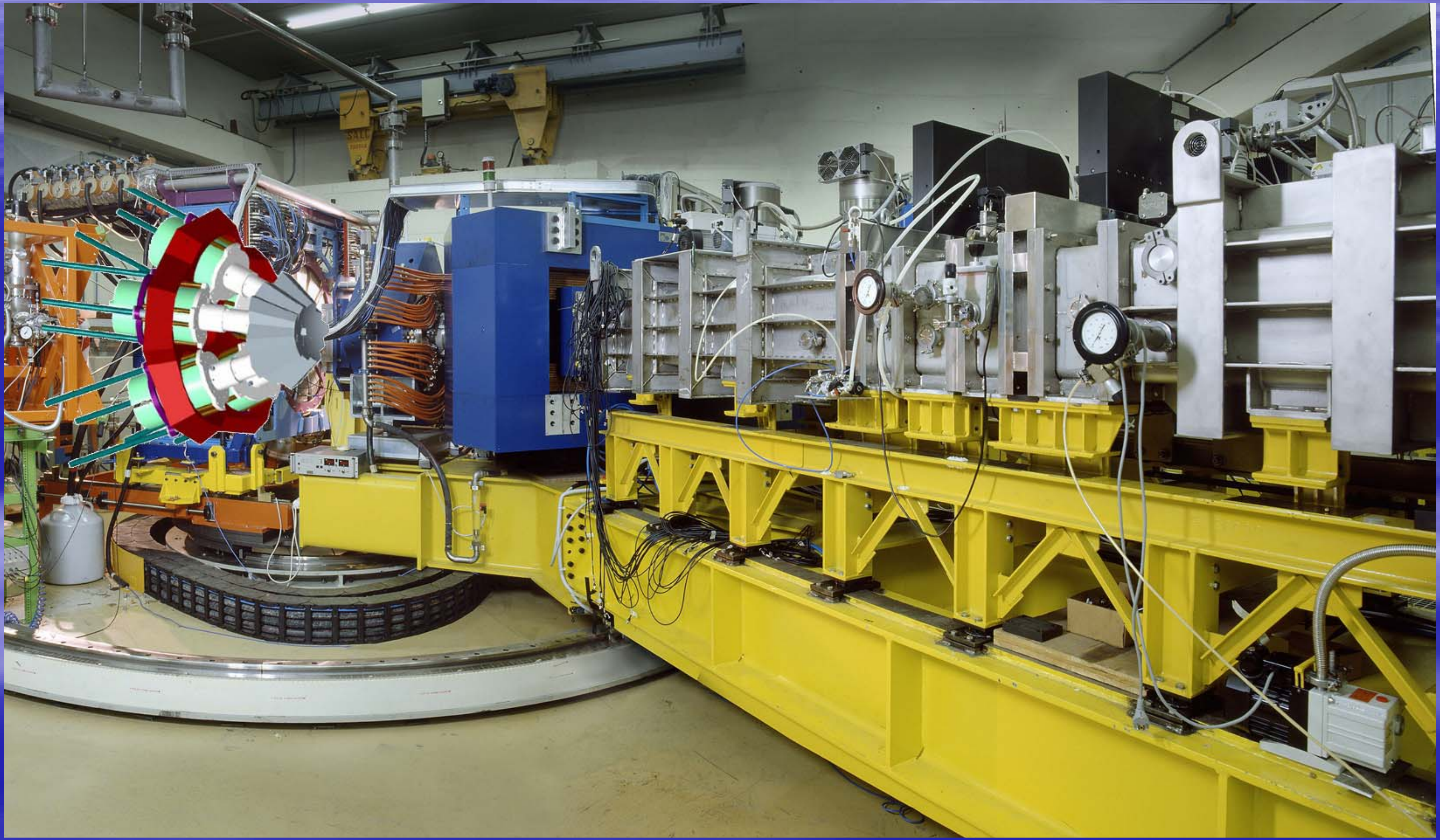
$\varepsilon \sim$ **40 — 20 %**

(M_γ=1 — M_γ=30)

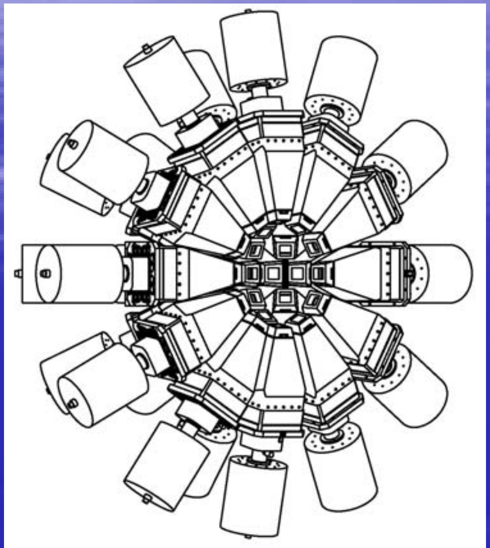
Intermediate step → Exogam, Miniball, SeGa : optimized for Doppler correction at low γ-multiplicitiy

The AGATA-PRISMA setup

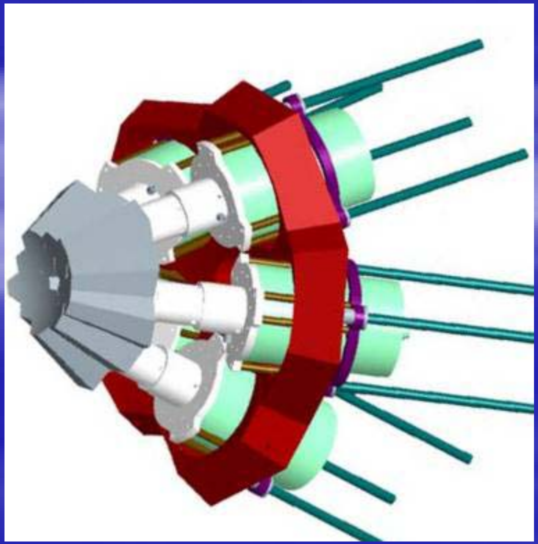
The AGATA demonstrator



CLARA vs. AGATA demonstrator



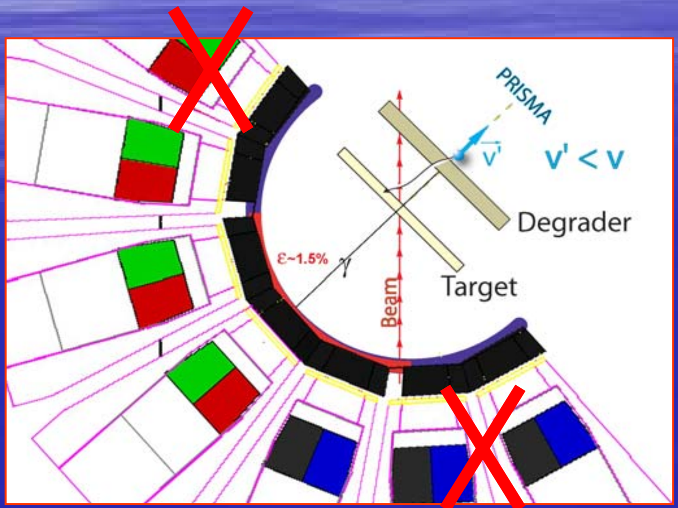
- Efficiency at 1MeV: ~2.6%
- Peak/Total: ~40%
- Angles covered: from 102^o to 180^o
- FWHM, β~10%, 1MeV: 7 to 10 keV



- Efficiency at 1MeV: ~6% at 14cm
- Peak/Total: ~50%
- Angles covered: from ~135^o to 180^o
- FWHM, β~10%, 1MeV: <4 keV

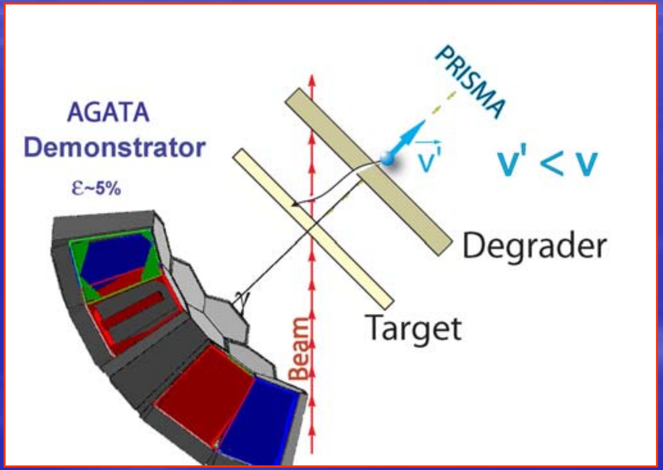
Ex. Lifetime measurements by multinucleon transfer and Differential Plunger method

CLARA

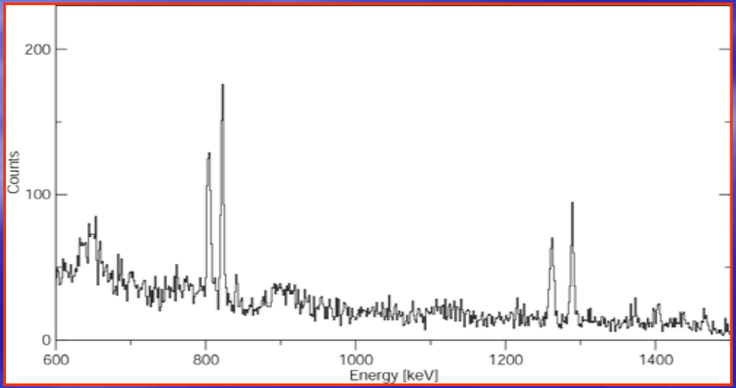


102° ring (1/2 efficiency) not usable

AGATA



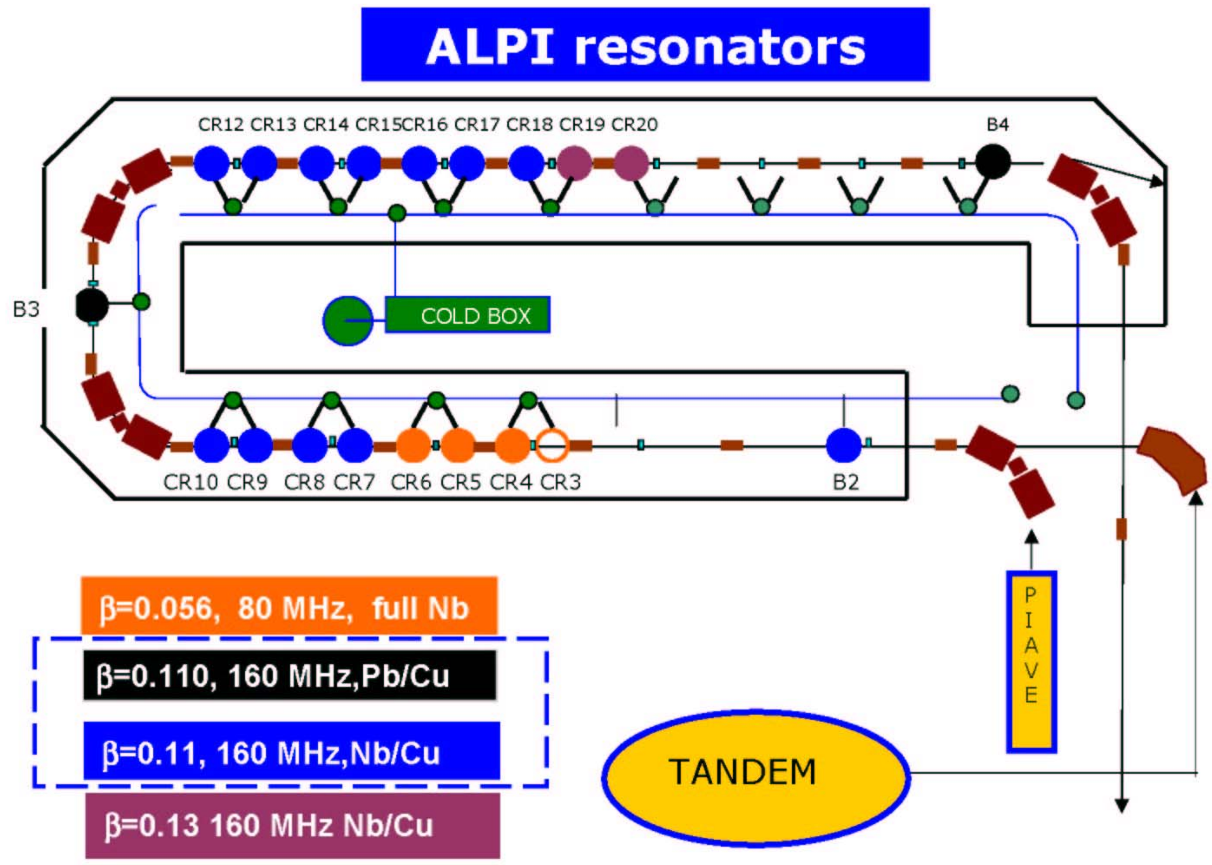
Full demonstrator (6% efficiency)



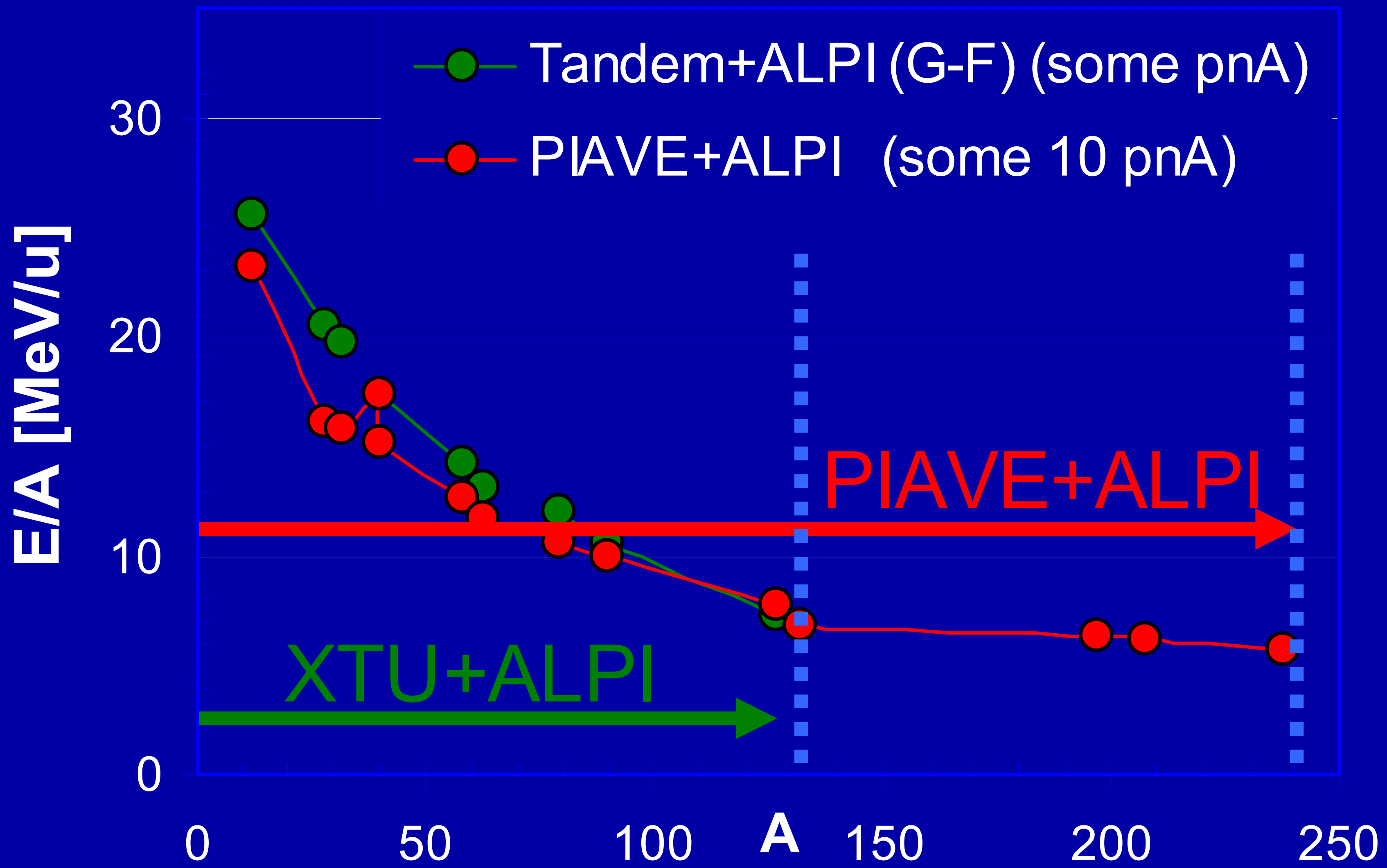
At v/c ~ 10% lifetimes in the range 1 to 10ps can be measured with target-degrader distances ranging from 30 to 400 μm

^{60}Fe – simulation based on existing experimental data

Perspectives:
New ion injector: Beams up to ^{238}U.
Up-grading of the SC cavities: Beam intensities up to 100 pnA



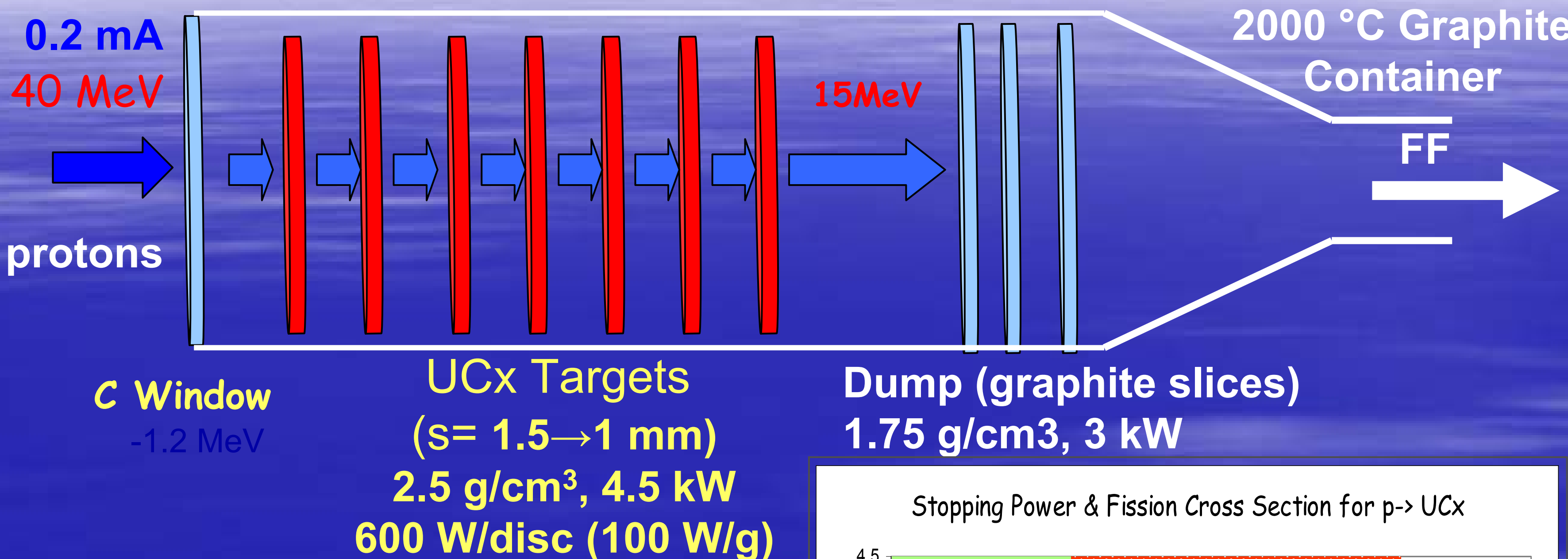
ALPI Output with the two Injectors

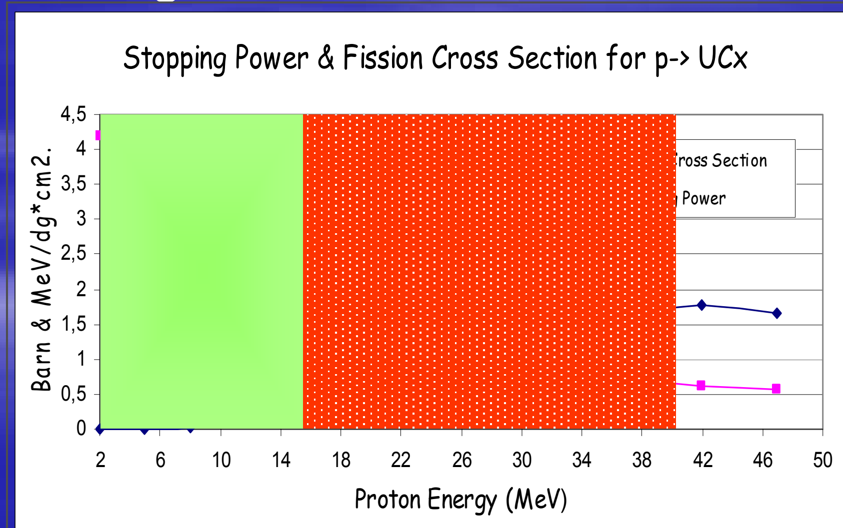


SPES

A Mid-term RNB Facility Based on a 40 MeV Proton Driver and on the Multi-Slice Direct Target Concept

The Multi-Slice Direct Target Concept





Eur. Phys. J. A (2005)
DOI 10.1140/epja/i2005-10064-8

THE EUROPEAN PHYSICAL JOURNAL A

Fission fragment production from uranium carbide disc targets

A. Andrighetto[1,a], S. Cevolani[2], and C. Petrovich[2]

Evolution of the DT Approach

ORNL p, 42 MeV, 10÷12 μA

LNL p, 40 MeV, 200 μA

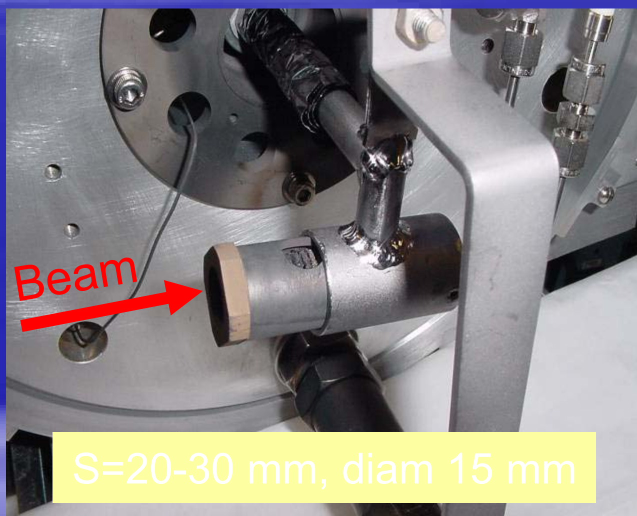
^{238}U (UC_x)

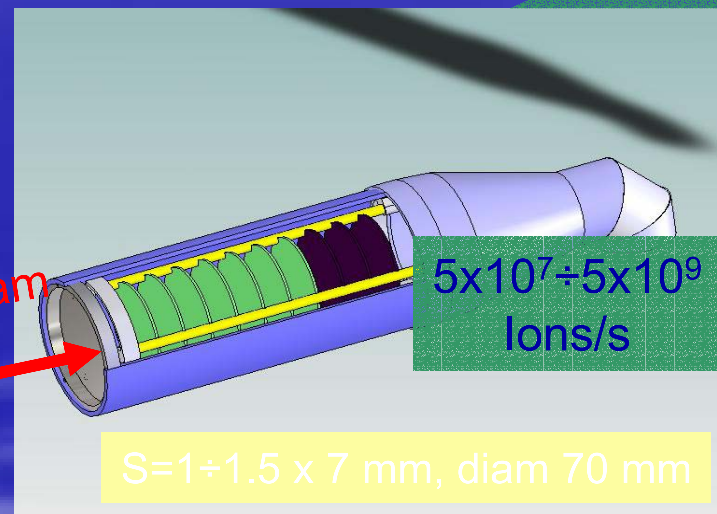
FF

~ $4x10^{11}$

~10^{13}

Ga	67÷84
Ge	75÷85
As	69÷85
Se	81÷88
Br	83÷91
Kr	86÷92
Rb	88÷94
Sr	90÷97
Y	91÷95
Ag	112÷121
Cd	117÷121
In	117÷127
Sn	123÷136
Sb	126÷134
Te	129÷136
I	130÷139
Xe	135÷139
Cs	138÷143
Ba	139÷142
La	142÷144

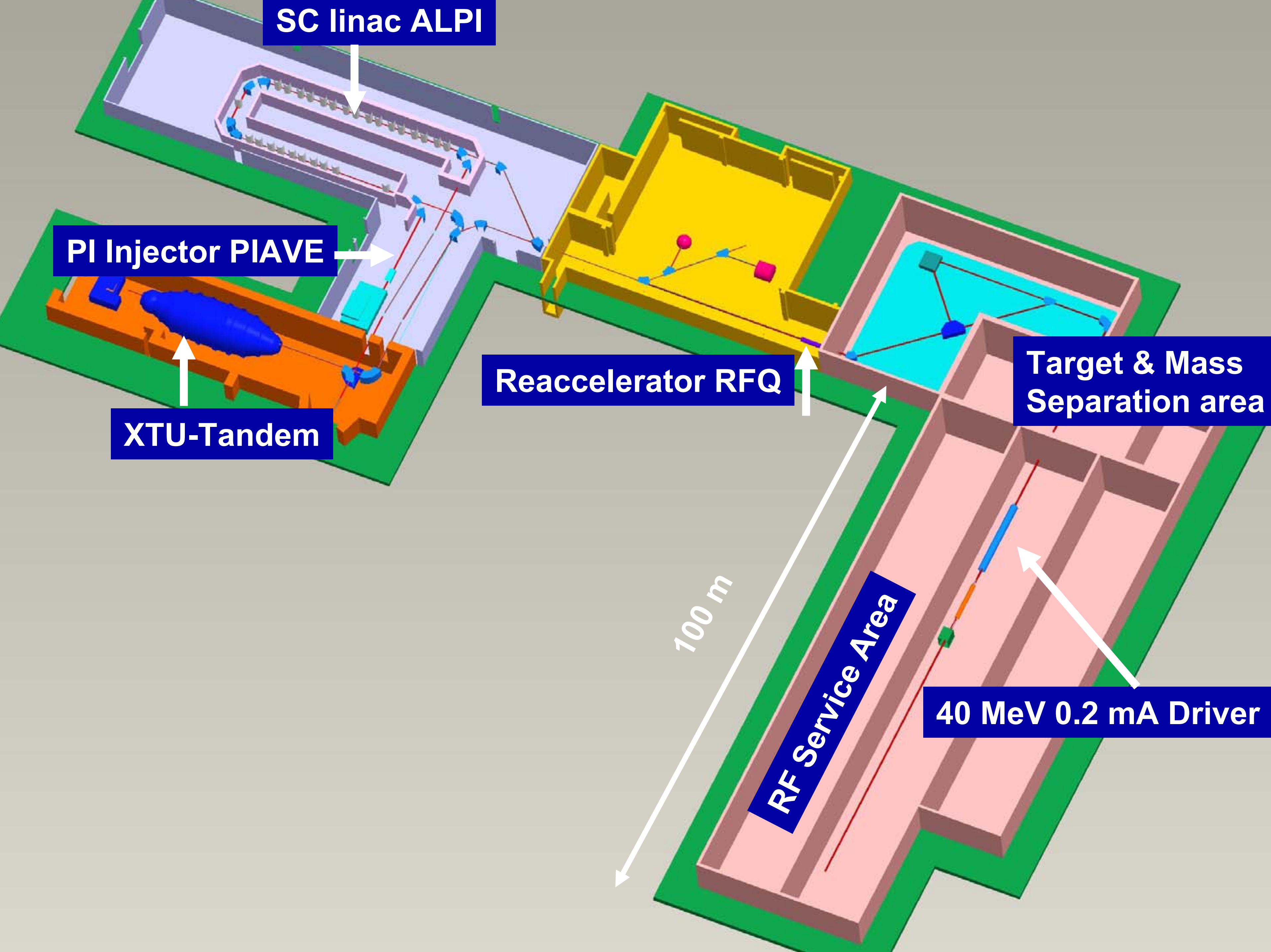




- Total of 1200 hours operation with 10-12 μA of 42 MeV protons
- More than 120 different radioactive beams extracted
- 400 W deposited in target (power density is 97 W/g, as LNL-project)

Some ISOL facilities towards EURISOL

	Primary beam		P on target	Target	Fissions/s
ISOLDE	p	1 GeV 2 μA	0.4 KW	Direct onto U Convert.	~5x10^{12}
HRIBF	p	40 MeV 10 μA	0.4 KW	DT	~5x10^{11}
TRIUMF	p	450 MeV	25 KW	DT (metal)	(Spallation)
EXCYTE	^{12}C	45 AMeV	0.4 KW	DT	1.5x10^{4} ^{8}Li beam
SPIRAL2	d	40 MeV 5 mA	200 KW	Converter	~10^{13}
SPES-DT	p	40 MeV 0.2 mA	8 KW	DT - Multislice	~10^{13}


SC linac ALPI
PI Injector PIAVE
XTU-Tandem
Reaccelerator RFQ
Target & Mass Separation area
100 m
RF Service Area
40 MeV 0.2 mA Driver

Summary

- Multi-nucleon transfer reactions using stable heavy beams are a powerful spectroscopic tool for neutron-rich nuclei. Future perspectives are based on high intensity beams of stable ions or neutron-rich RIBs

- Proton-rich nuclei are an efficient observatory for a direct insight into **nuclear structure properties**

- Electromagnetic properties at high spin are an essential test for new symmetries

- New techniques and powerful Ge detectors based on gamma ray tracking are needed to realize such goal