Mirror Symmetry in Medium-Light Nuclei

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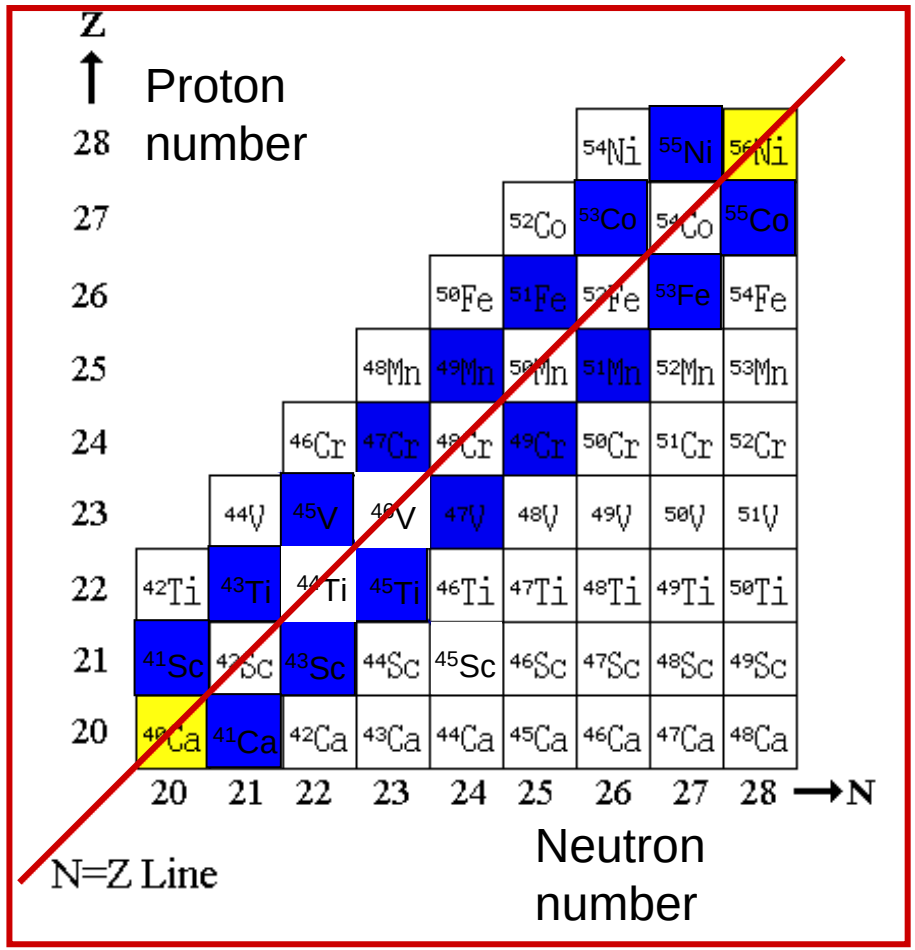
- ***T_z = ±1/2 and T=1* Mirror Nuclei**
  - **Mirror Energy Differences, MED**
  - **Electromagnetic Properties**
    - **Isospin breaking by the Coulomb force**
    - **Isoscalar and isovector effective charges**
    - **Isospin mixing**
    - **Isospin breaking by the nuclear force**
    - **Unexpected phenomena in mirror nuclei**
- **Conclusions**

$T_z = \pm 1/2$ Mirror Nuclei in the $1f_{7/2}$ Shell

$1f_{7/2}$ shell - isolated in energy from other major orbits

Wave functions dominated by $(1f_{7/2})^n$ configurations



= $T_z = \pm 1/2$ pairs studied to high E_x and high J - *Gamma-ray spectroscopy*

Experimental issue: proton-rich $T_z = -1/2$ isobars weakly populated:

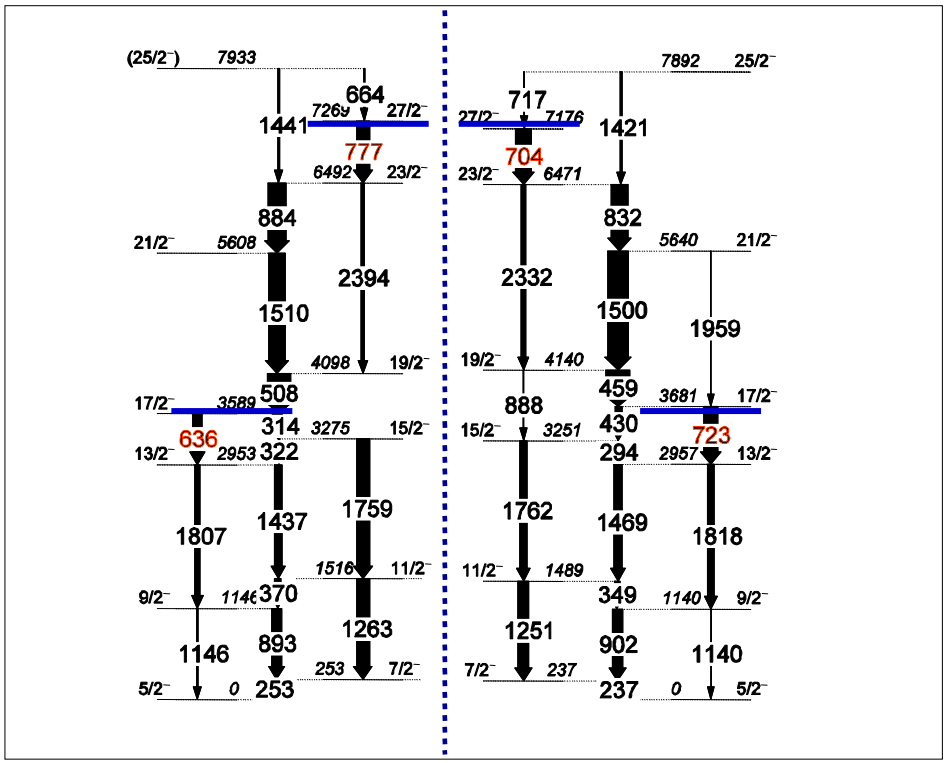
$$\sigma_{T_z=-1/2} / \sigma_{T_z=+1/2} \sim 10^{-2} - 10^{-3}$$

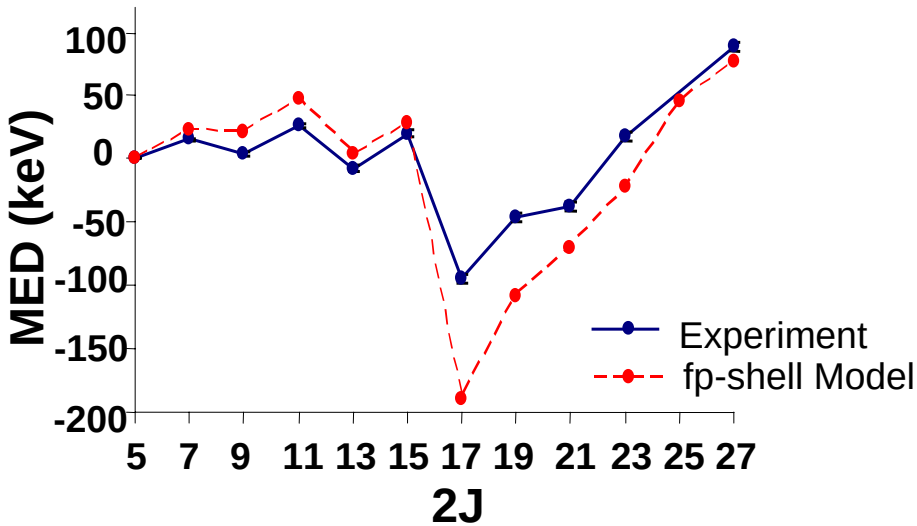
"Mirrored" gamma ray energies almost identical - need very clean reaction channel selection…

Courtesy: Mike Bentley

The A=51 Mirror Nuclei

^{51}Fe **^{51}Mn**





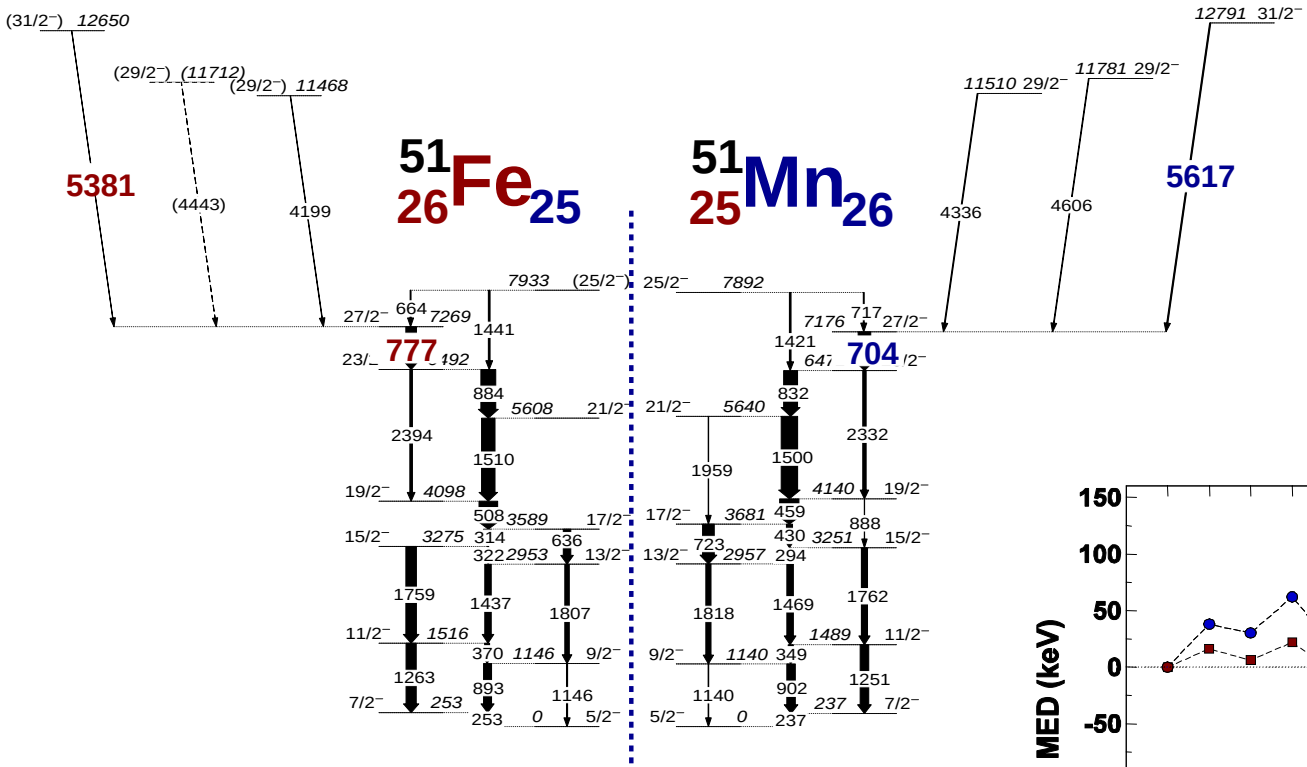
^{51}Fe: $\pi(1f_{7/2})^{-2} \otimes \nu(1f_{7/2})^{-3}$

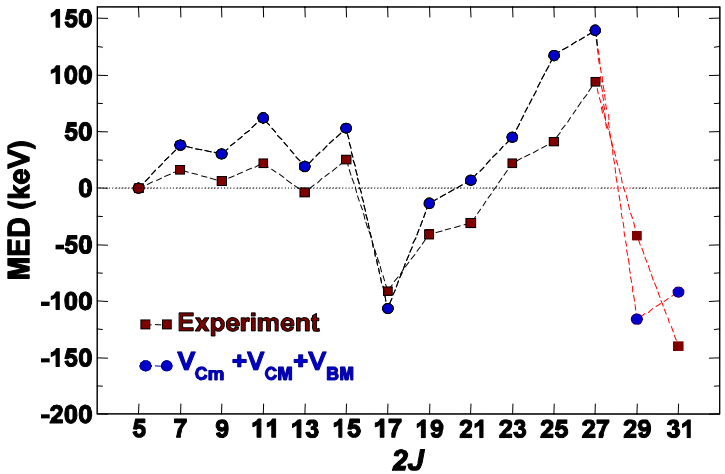
^{51}Mn: $\pi(1f_{7/2})^{-3} \otimes \nu(1f_{7/2})^{-2}$

J.Ekman et al, E. J. P. A9 (00) 13; M.A.Bentley et al, PRC 62 (00) 051303

A. Poves et al., Nucl. Phys. A694, 157 (2001) (Shell Model and KB3G Interaction)

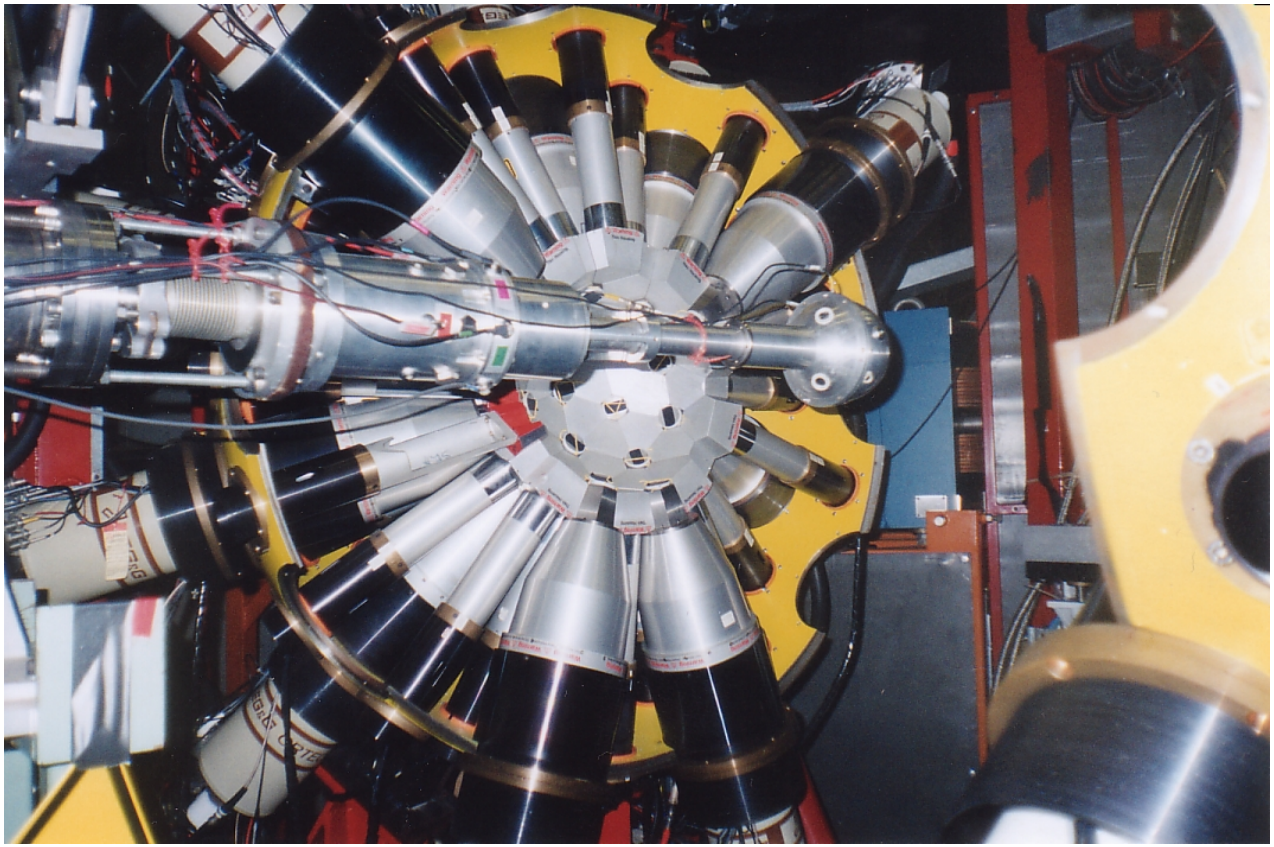
The A=51 Mirror Nuclei; Core excitation





J. Ekman et al., Phys. Rev. C 70, 057305 (2004)

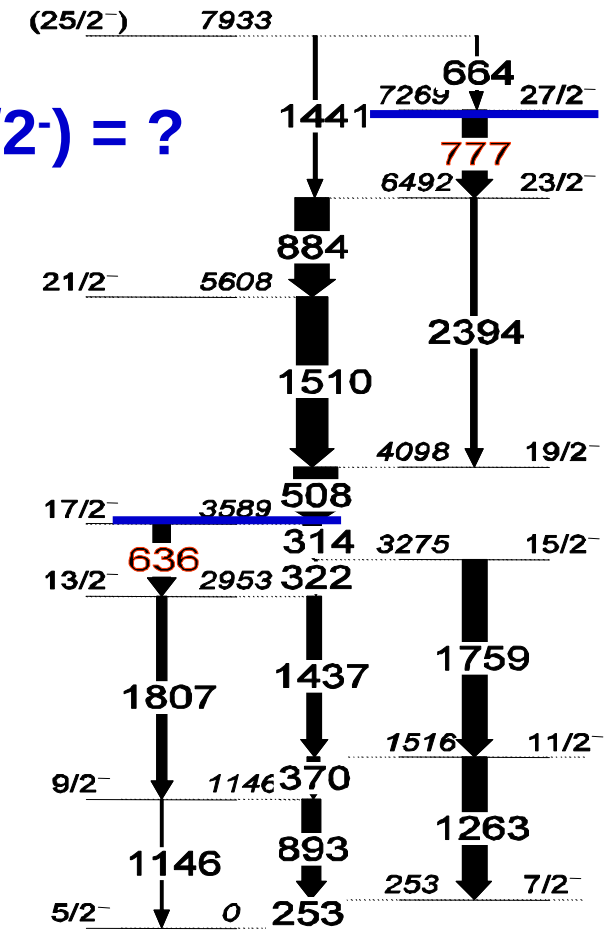
Electromagnetic properties of $T_z = \pm 1/2$ Mirror nuclei



Lifetimes of the fully aligned 27/2- states

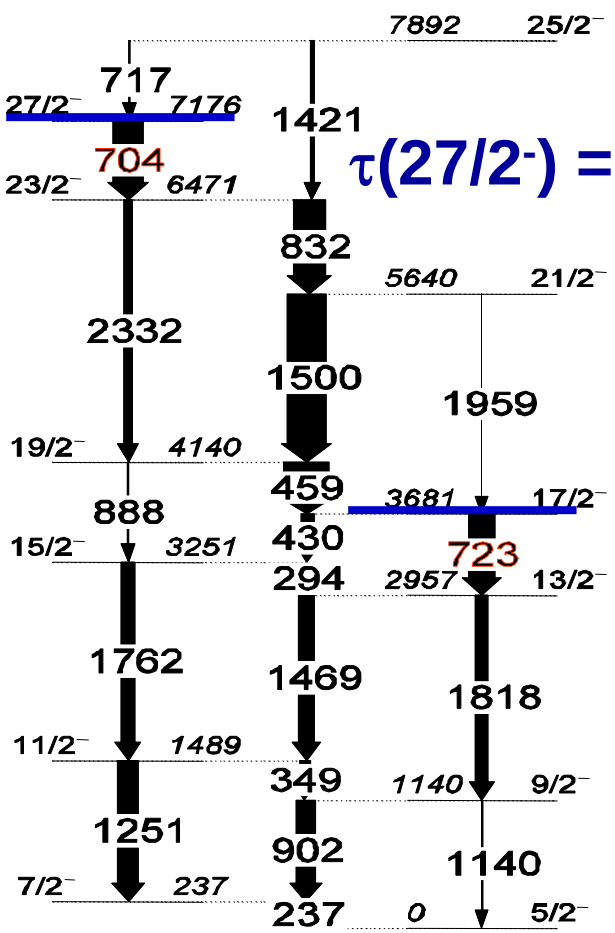
^{51}Fe

$\tau(27/2^-) = ?$

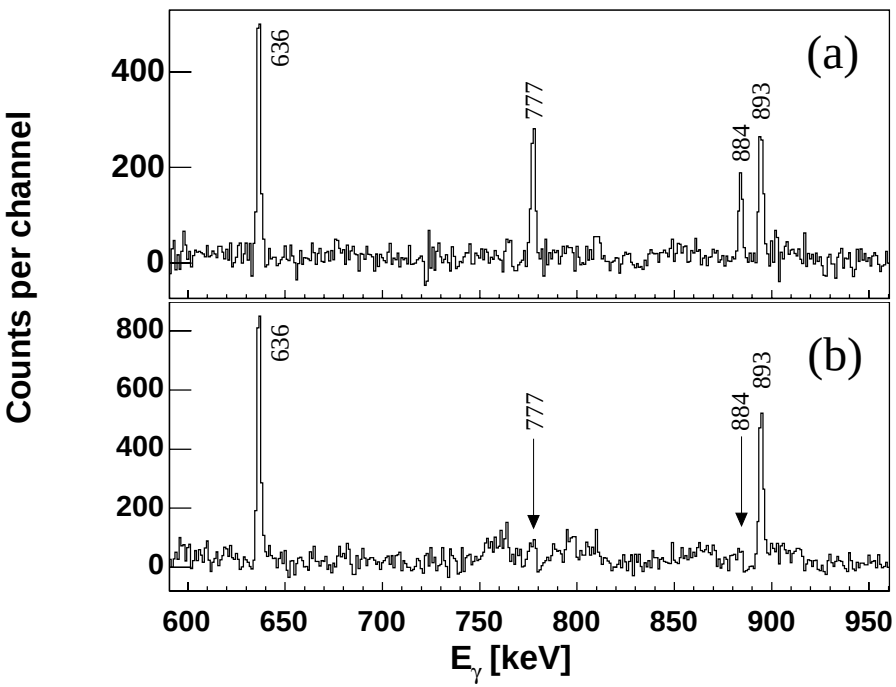


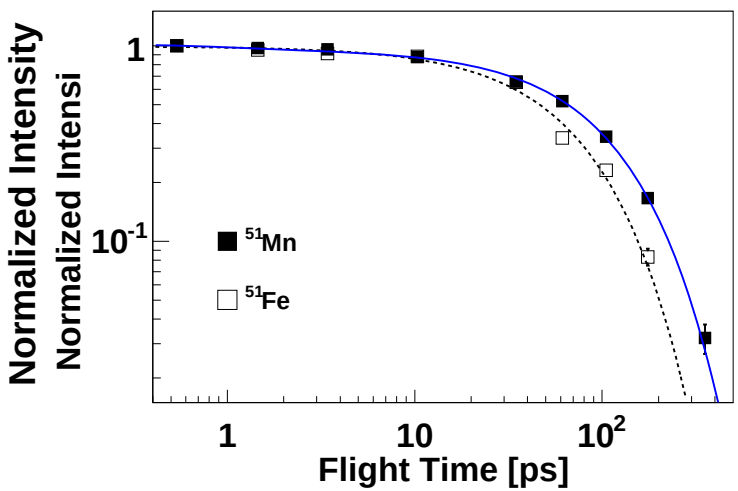
^{51}Mn

$\tau(27/2^-) = 101(3)$ ps



Lifetimes of the fully aligned 27/2- states



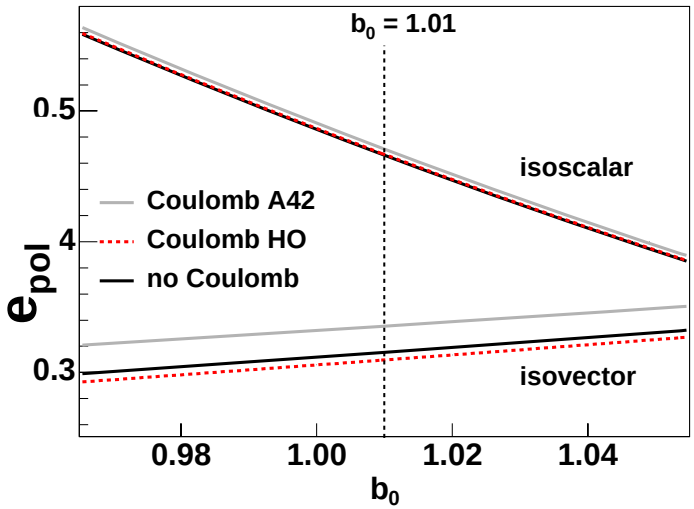


^{51}Mn: $\tau(27/2^-)$ = 101(3) ps

^{51}Fe: $\tau(27/2^-)$ = 70(4) ps

R. du Rietz et al., Phys. Rev. Lett. 93, 222501 (2004)

Effective charges in the fp shell



$$< r^2 >= b_0^2 A^{1/3}(N + 3/2)$$

^{51}Mn: $\tau(27/2^-)$ = 101(3) ps
^{51}Fe: $\tau(27/2^-)$ = 70(4) ps

→

B(E2; $27/2^- \rightarrow 23/2^-$) = 46.7 (14) e^2fm^4
B(E2; $27/2^- \rightarrow 23/2^-$) = 41.3 (24) e^2fm^4

Large scale shell model calculations:
ANTOINE Code, KB3G interaction in fp space

$$\varepsilon_p = 1 + e_{pol}^p = 1 + e_{pol}^{(0)} - e_{pol}^{(1)}$$

$$\varepsilon_n = e_{pol}^n = e_{pol}^{(0)} + e_{pol}^{(1)}$$

R. du Rietz et al., Phys. Rev. Lett. 93, 222501 (2004)

Effective charges in the fp shell

Experiment:

$$e_{pol}^{(0)} = 0.47 \pm 0.01$$

$$e_{pol}^{(1)} = 0.32 \pm 0.04$$

Theory:

$$e_{pol} = e_{pol}^{(0)} + e_{pol}^{(1)} \tau_z$$

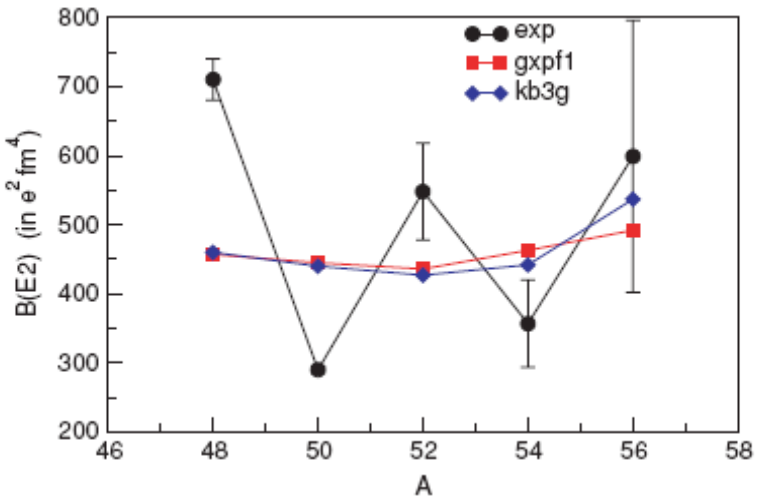
$$e_{pol} = e\left(\frac{Z}{A} - 0.32\frac{N-Z}{A} + \left(0.32 - 0.3\frac{N-Z}{A}\right)\tau_z\right)$$

Eq. 6-386 in B-M II

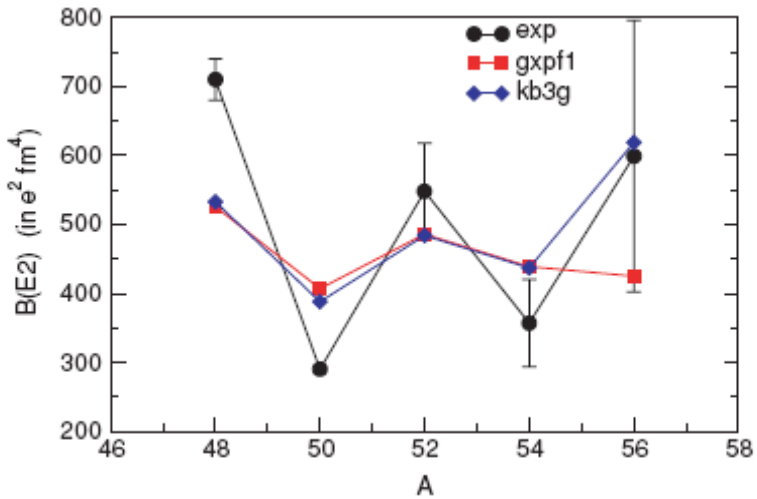
$$e_{pol} = e(0.5 + 0.32\tau_z)$$

Eq. 6-386 in B-M II, N=Z

The strange behaviour of the B(E2)'s in the Ti isotopes



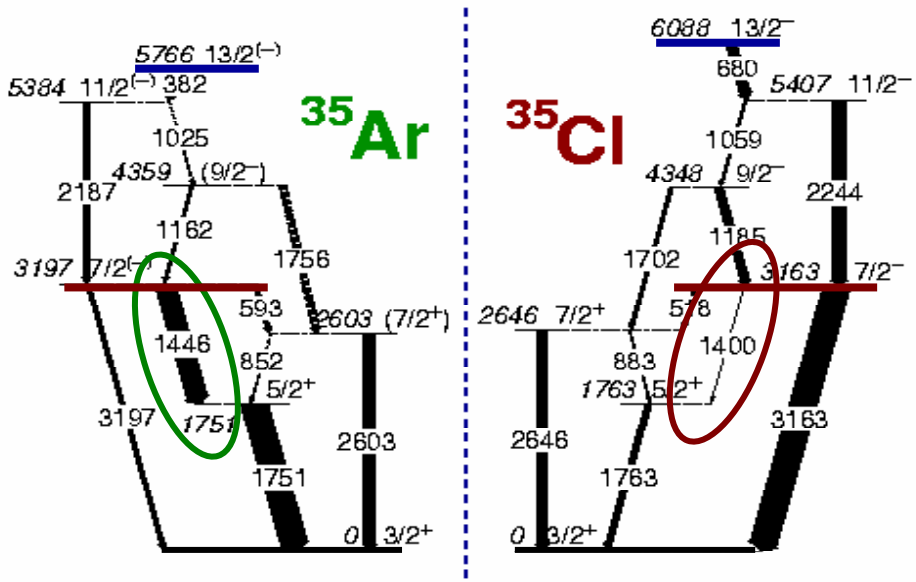
Isovector polarization charge equal to zero



Isovector polarization charge non-zero

A. Poves et al., Phys. Rev. C 72, 047302 (2005)

The A=35 Mirror Nuclei



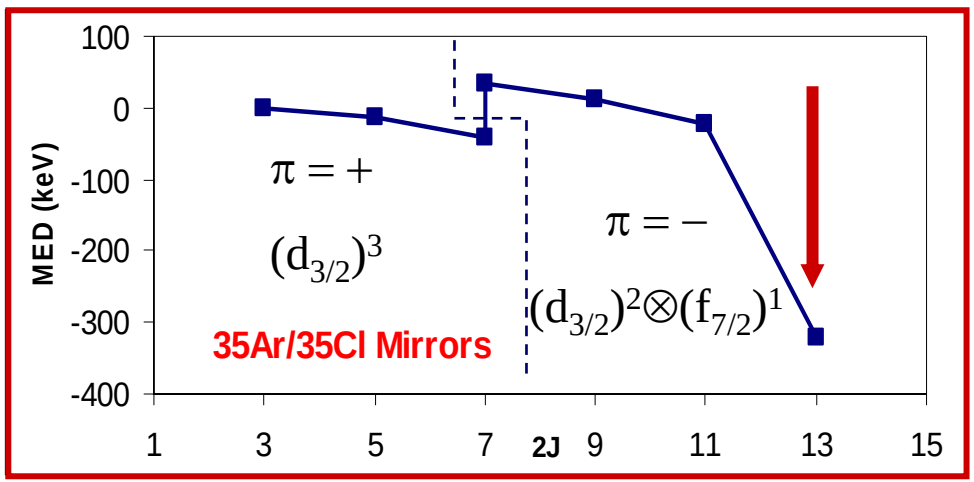
Positive parity:

^{35}Ar: $\pi(1d_{3/2})^{-2} \otimes \nu(1d_{3/2})^{-3}$

^{35}Cl: $\pi(1d_{3/2})^{-3} \otimes \nu(1d_{3/2})^{-2}$

Negative parity:

Promote one particle to $1f_{7/2}$



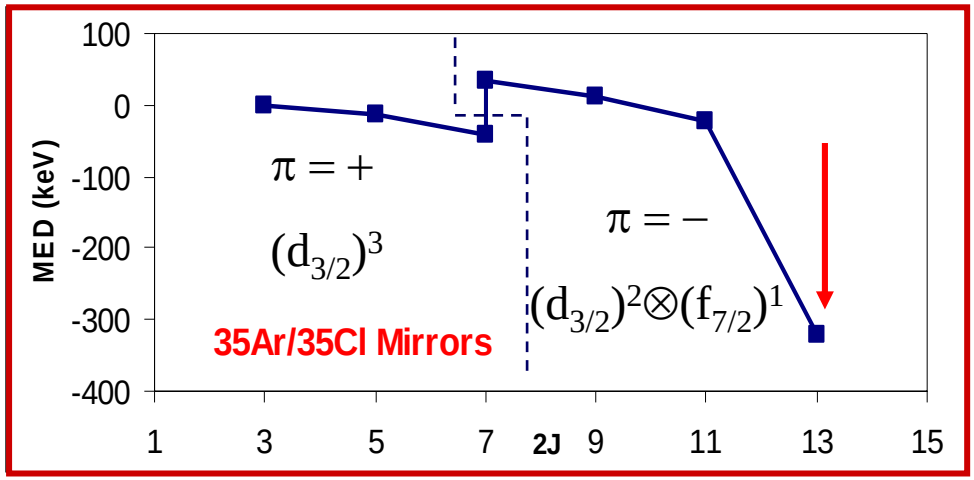
Two very distinct features observed:

The 7/2$^-$ state! Strange decay pattern!

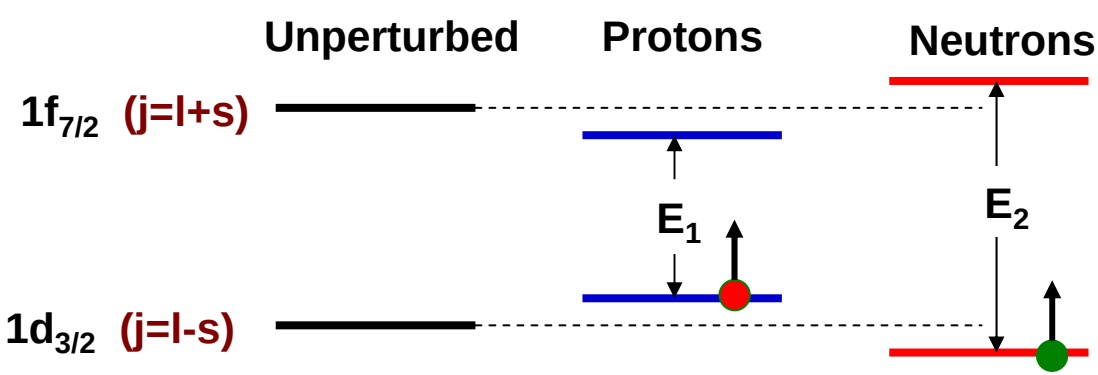
The 13/2$^-$ state! Large MED, -322 keV!

J. Ekman et al., Phys. Rev. Lett. 92, 132502 (2004)

Electromagnetic Spin-Orbit Coupling



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

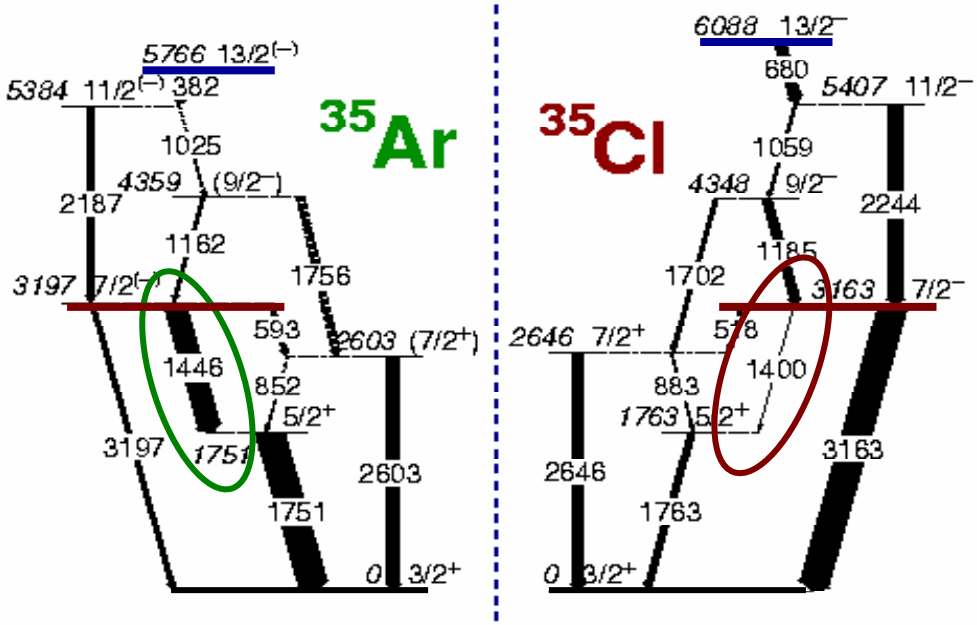


J. Ekman et al., Phys. Rev. Lett. 92, 132502 (2004)

Missing/weak E1 transition

τ = 4(1) ps

Preliminary!!!



τ = 45.3(6) ps

B(M2; $7/2^- \rightarrow 3/2^+$) = 0.43(17) W.u.

B(E1; $7/2^- \rightarrow 5/2^+$) = 5.6×10^{-5} W.u.

B(E1; $7/2^- \rightarrow 7/2^+$) = 1.3×10^{-4} W.u.

B(M2; $7/2^- \rightarrow 3/2^+$) = 0.25(1) W.u.

B(E1; $7/2^- \rightarrow 5/2^+$) = 1.6×10^{-8} W.u.!!!

B(E1; $7/2^- \rightarrow 7/2^+$) = 1.8×10^{-5} W.u.

J. Ekman et al., Phys. Rev. Lett. 92, 132502 (2004)

J. Ekman et al., to be published

Missing/weak E1 transitions: Isospin mixing?

Wave functions:

$$|7/2^- >= \alpha |7/2^-, \boldsymbol{T} = 1/2 > + \beta |7/2^-, \boldsymbol{T} = 3/2 >$$

$$|5/2^+ >= \gamma |5/2^+, \boldsymbol{T} = 1/2 > + \delta |5/2^+, \boldsymbol{T} = 3/2 >$$

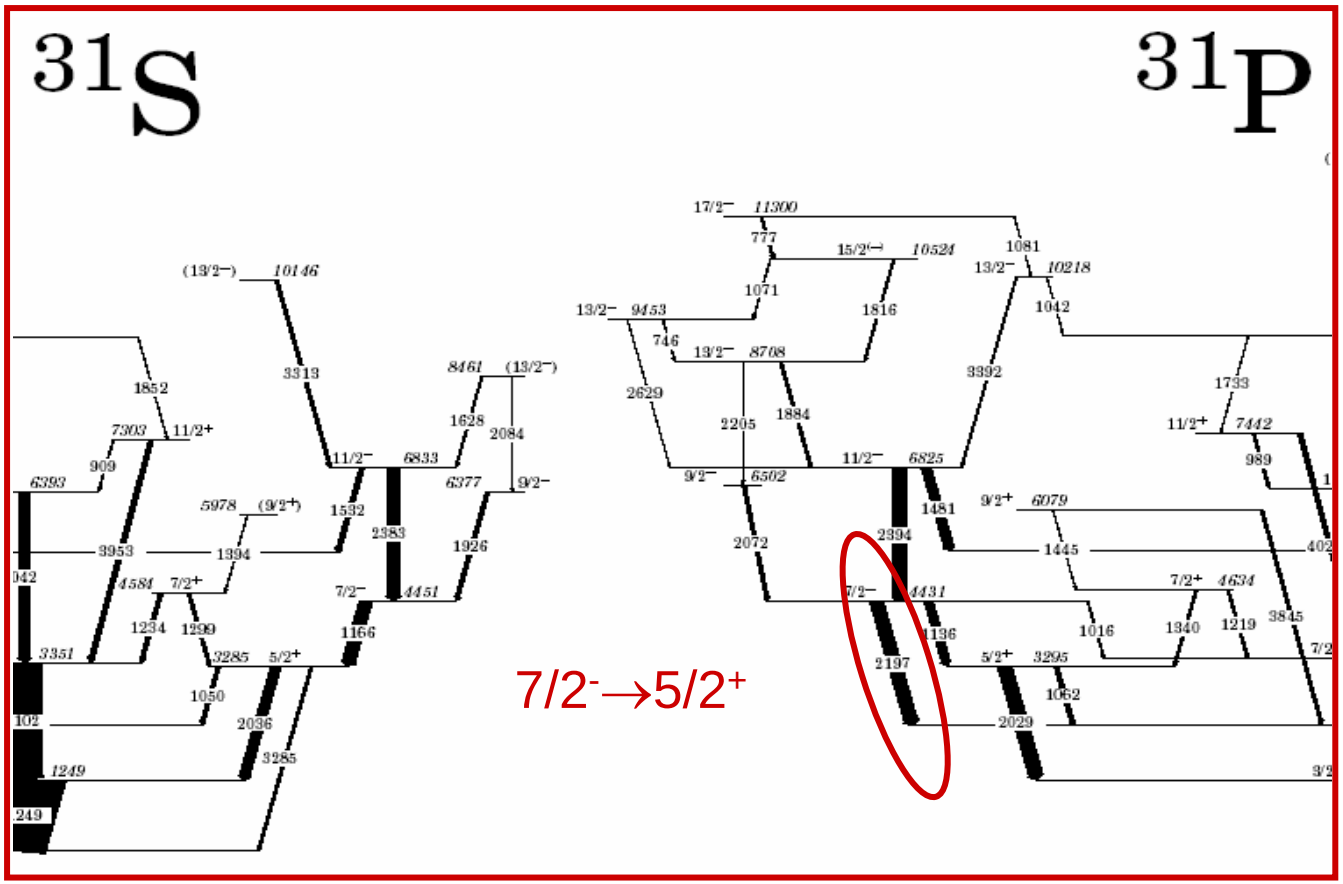
E1 transitional matrix elements:

$$< 7/2^- | \hat{E}_{1\mu} | 5/2^+ >= \alpha\gamma < 7/2^-;1/2 | \hat{E}_{1\mu} | 5/2^+;1/2 > +$$

$$\alpha\delta < 7/2^-;1/2 | \hat{E}_{1\mu} | 5/2^+;3/2 > + \beta\gamma < 7/2^-;3/2 | \hat{E}_{1\mu} | 5/2^+;1/2 >$$

$$+ \beta\delta < 7/2^-;3/2 | \hat{E}_{1\mu} | 5/2^+;3/2 >$$

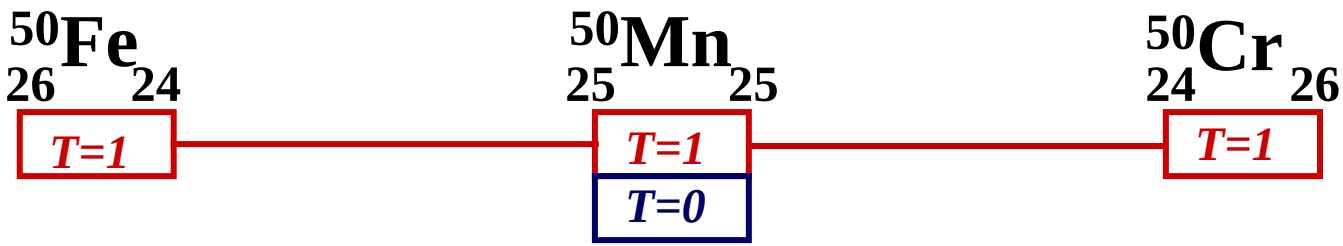
Missing/weak E1 transitions



F. Della Vedova et al., INFN LNL Annual Report 2003
D. G. Jenkins et al., Phys. Rev. C 72, 031303 (2005)

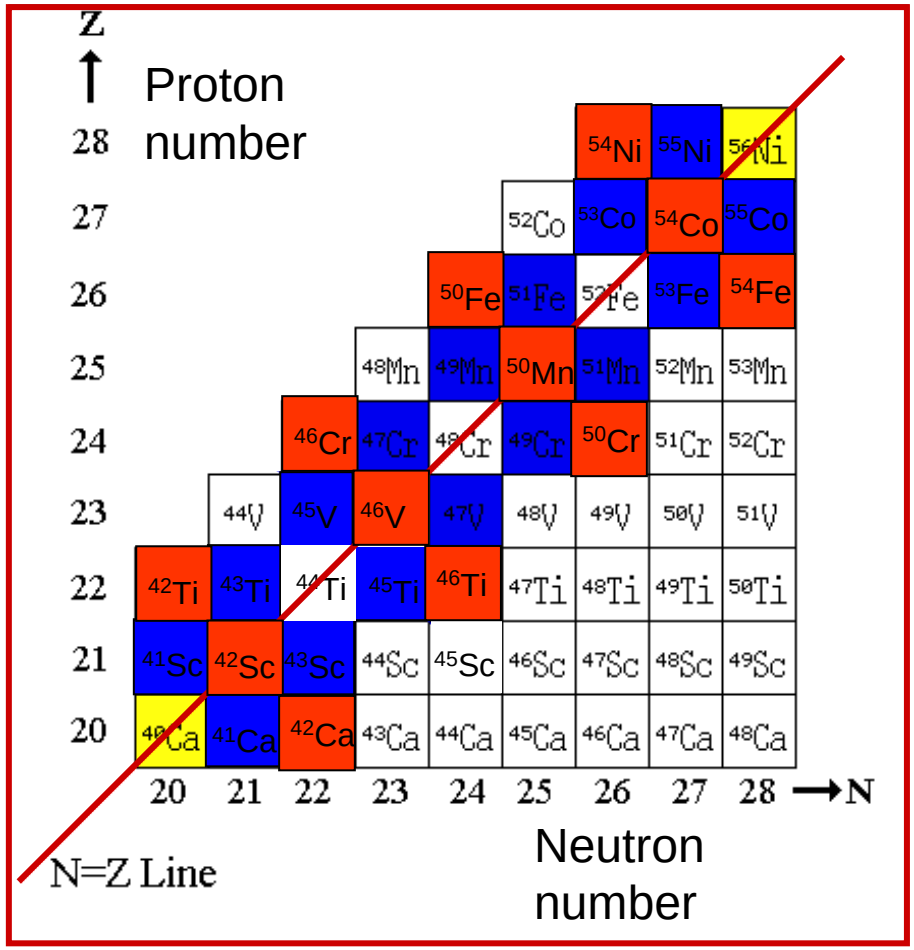
Courtesy: Mike Bentley

T= 1 Isobaric Triplet States



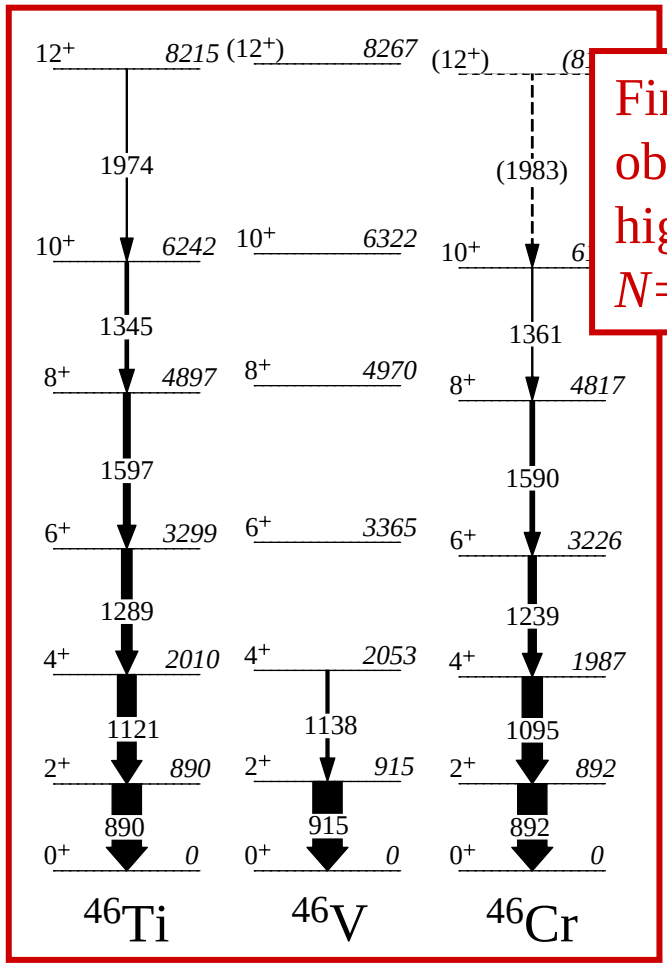
- States of the same (α,J,T) are isobaric analogue states (α=state 'label')
- *MED* from $T_z = \pm 1$ mirrors
- Triplet energy differences…

$$TED = \left(E_x^J\right)_{T_z=-1} + \left(E_x^J\right)_{T_z=+1} - 2\left(E_x^J\right)_{T_z=0}$$

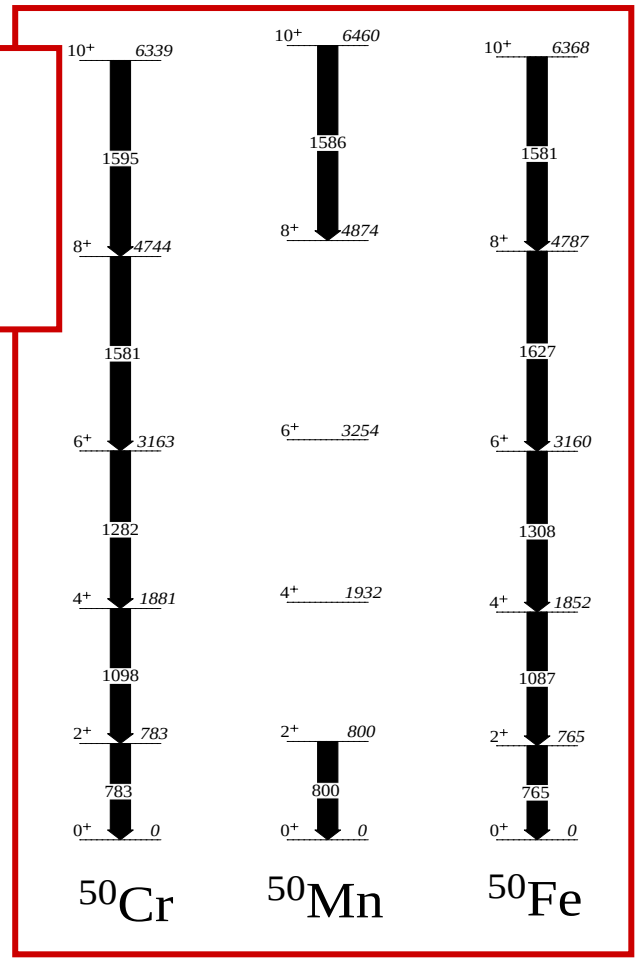


Courtesy: Mike Bentley

The A=46 and A=50 *T*= 1 Mirror Nuclei



First observation at high spin of *N*=*Z*-*2* nuclei.

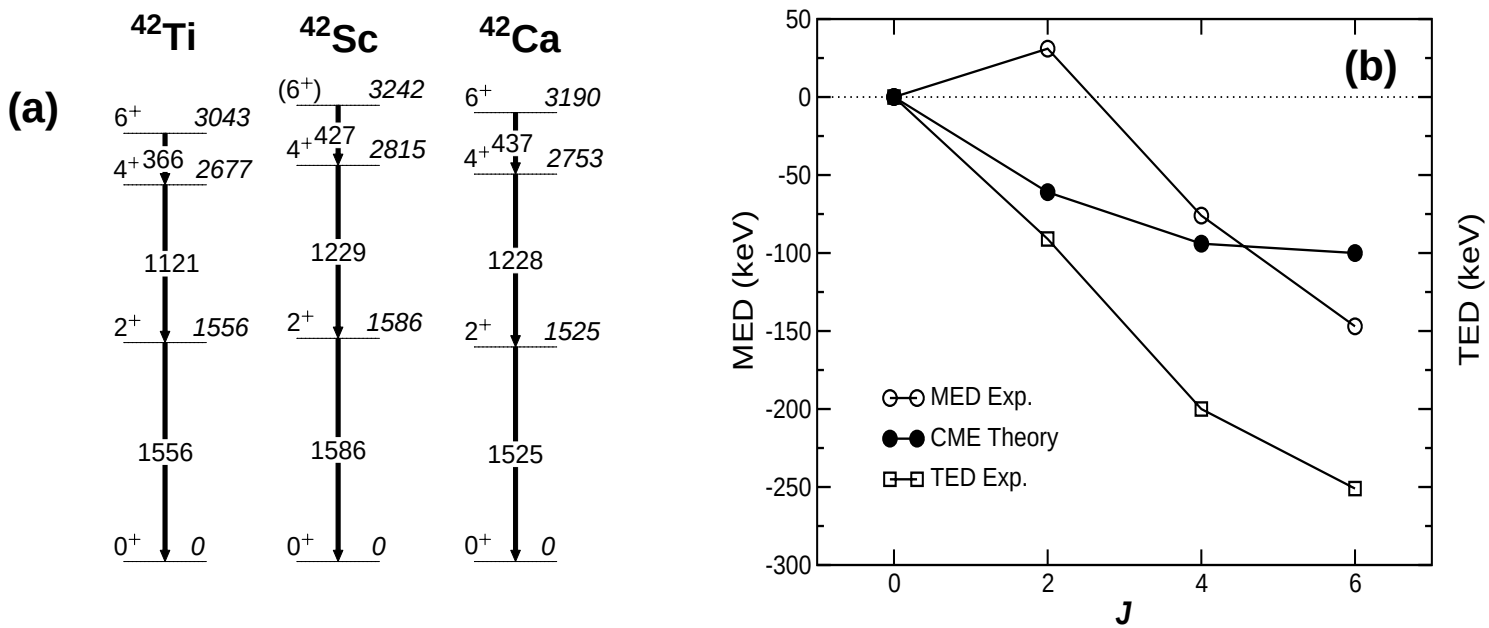


^{46}Cr - P. J. Garrett et al
Phys. Rev. Lett. ***87****(2001)132502*

^{50}Fe - S. M. Lenzi et al.
Phys. Rev. Lett. ***87****(2001)122501*

Courtesy: Mike Bentley

The A=42 T=1 Mirror Nuclei

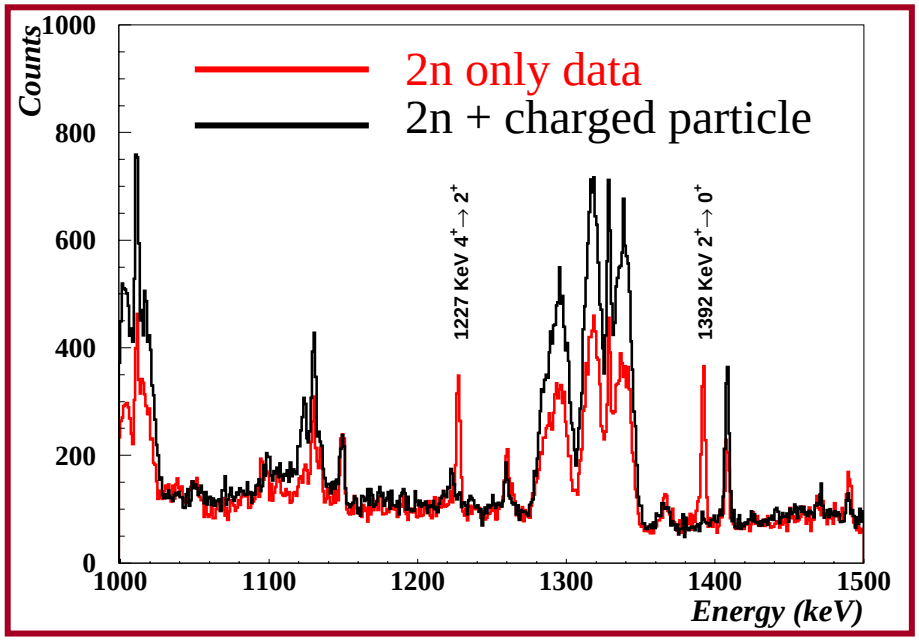


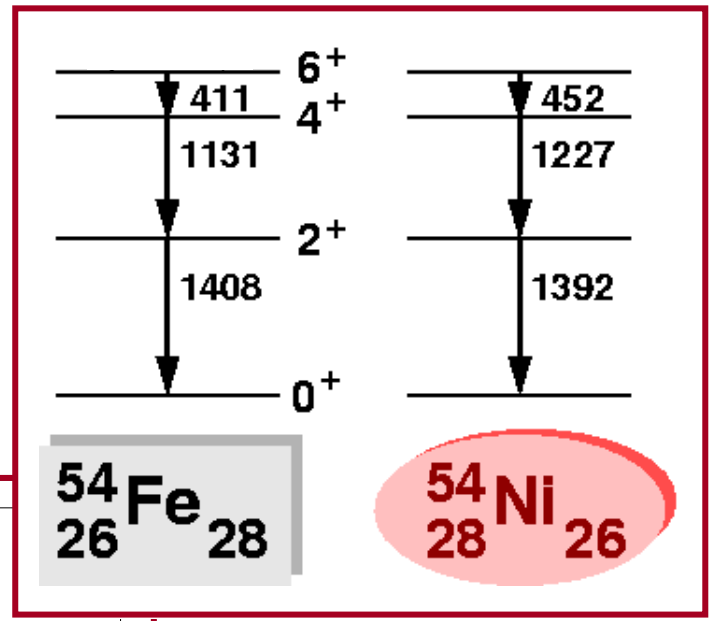
A. P. Zuker et al., Phys. Rev. Lett. 89, 14502 (2002)

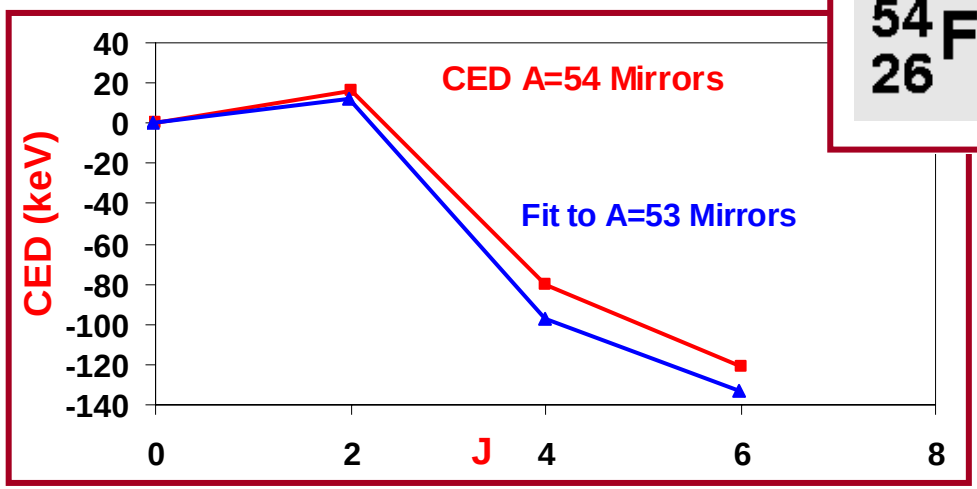
The A=54 T=1 Mirror Nuclei

Euroball + Euclides + n-wall 2003

A.Gadea et al, Priv. Comm.







Courtesy: Mike Bentley

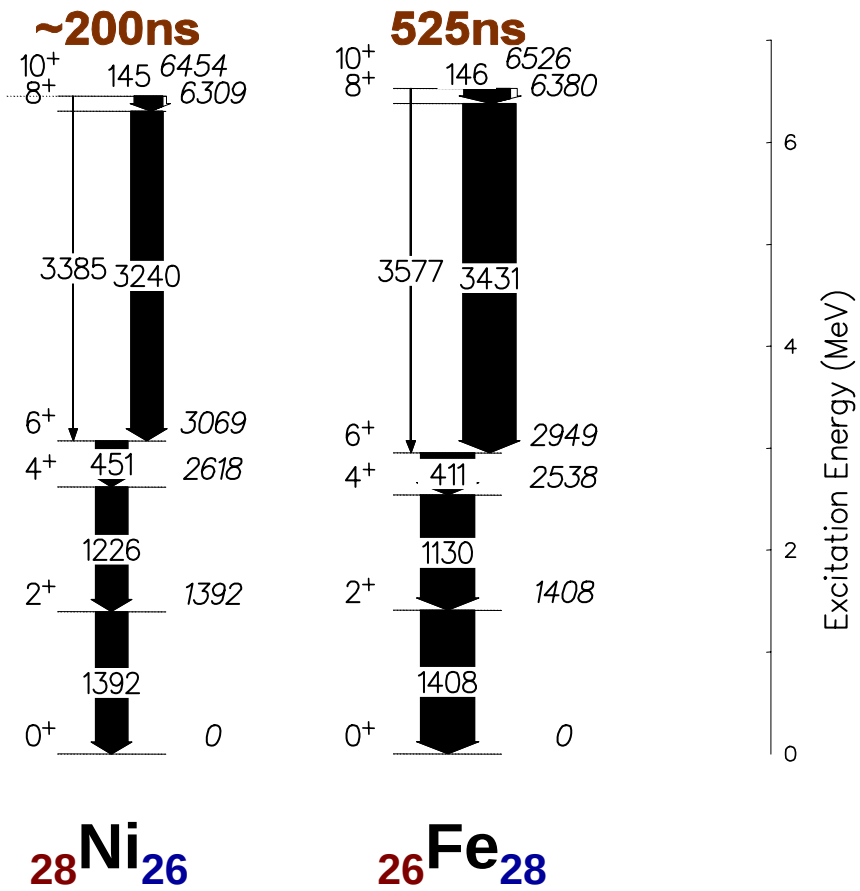
The A=54 T=1 Mirror Nuclei

RISING Stopped Beam Campaign March 2006

Fragmentation

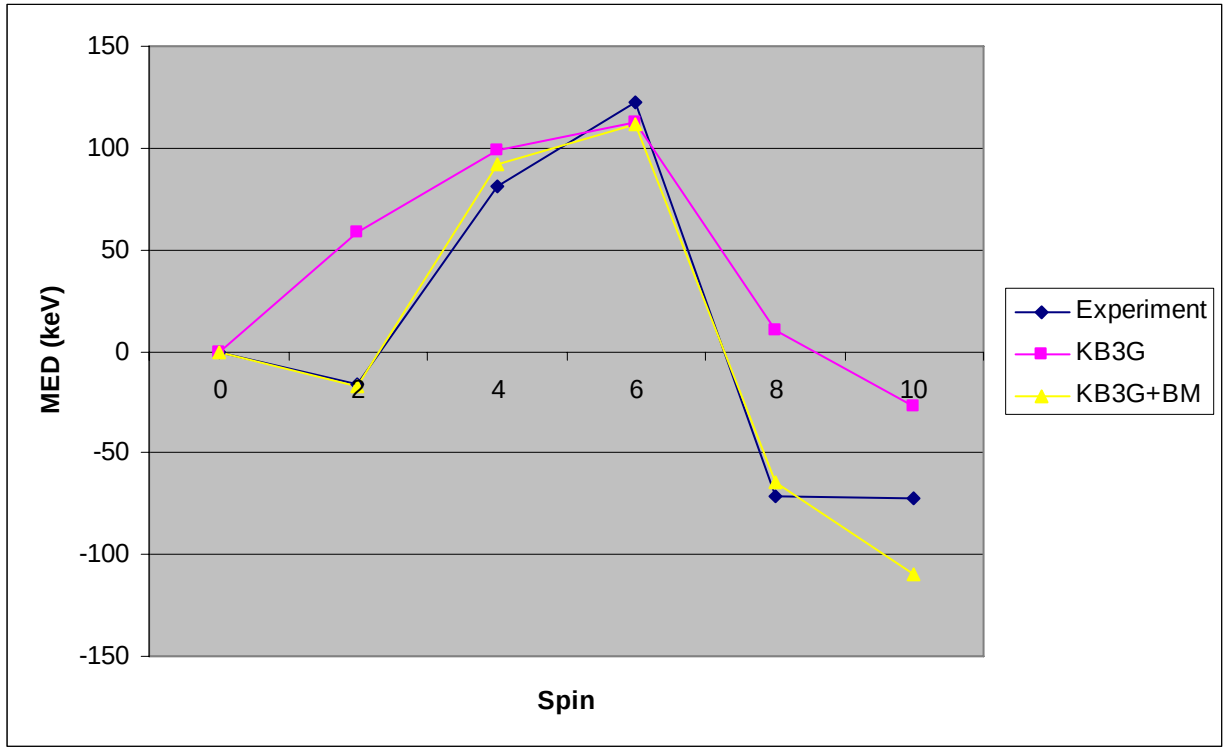
Implantation

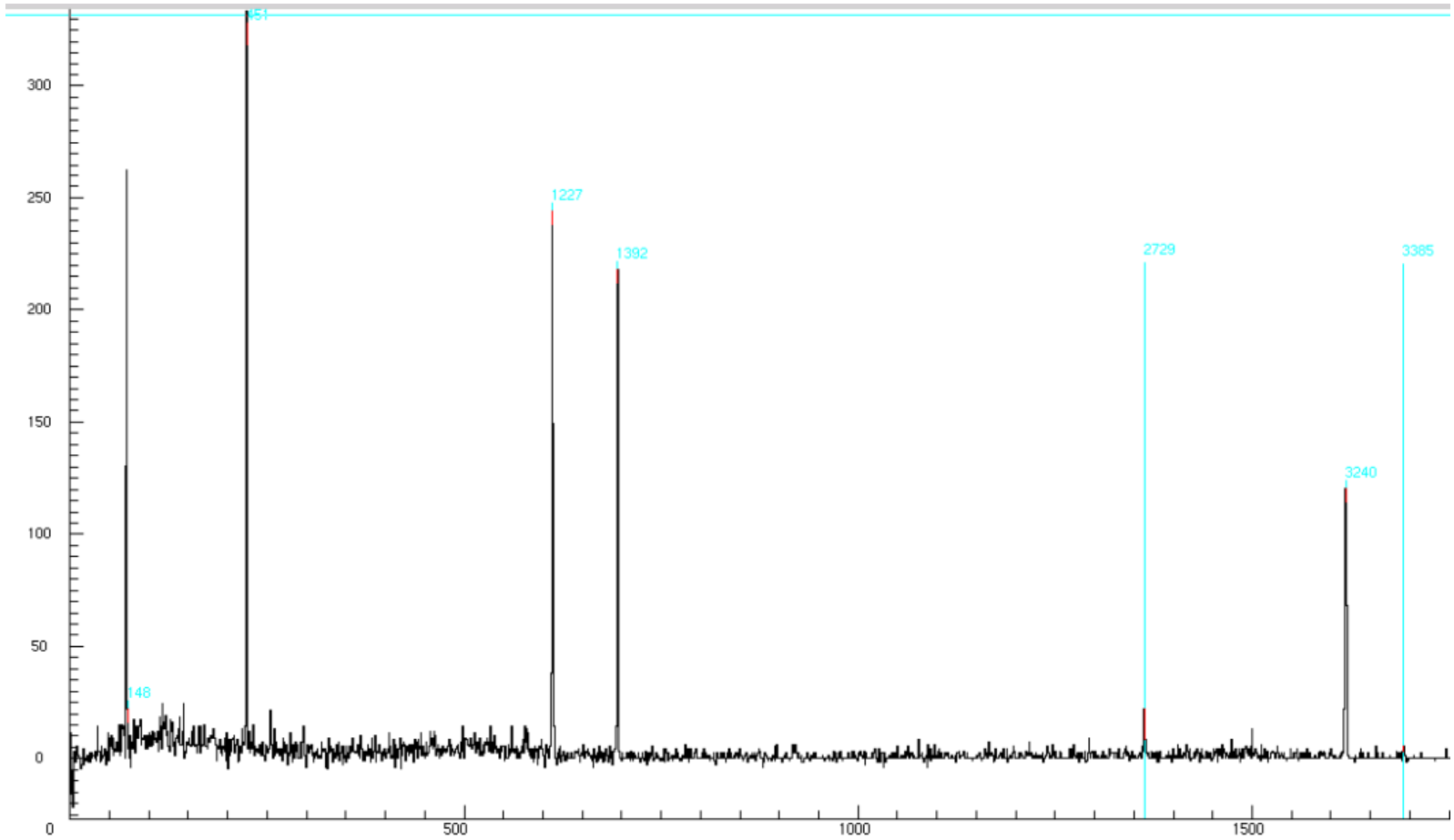
Isomeric decay



D. Rudolph et al., To be published

The A=54 T=1 Mirror Nuclei

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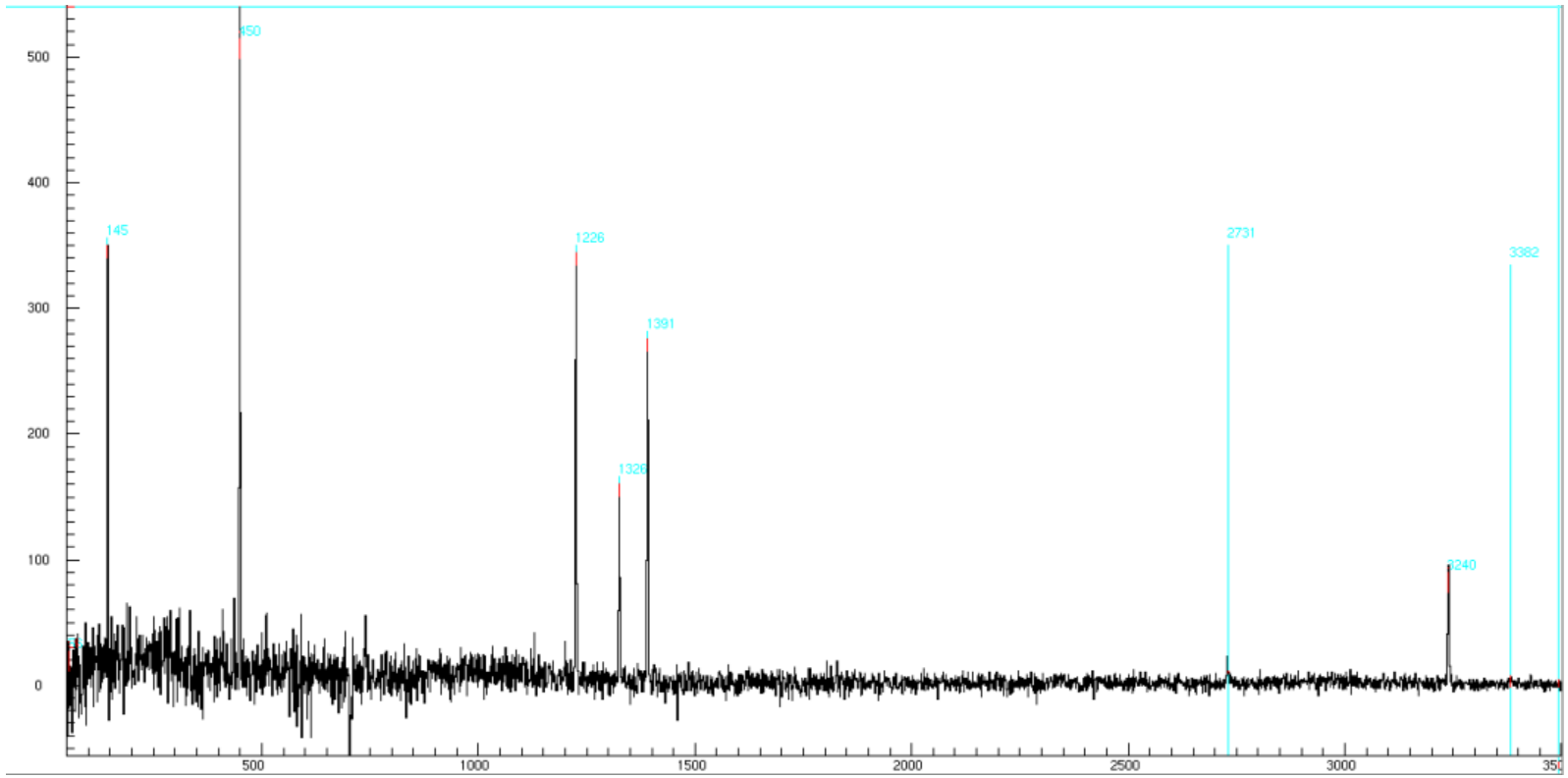
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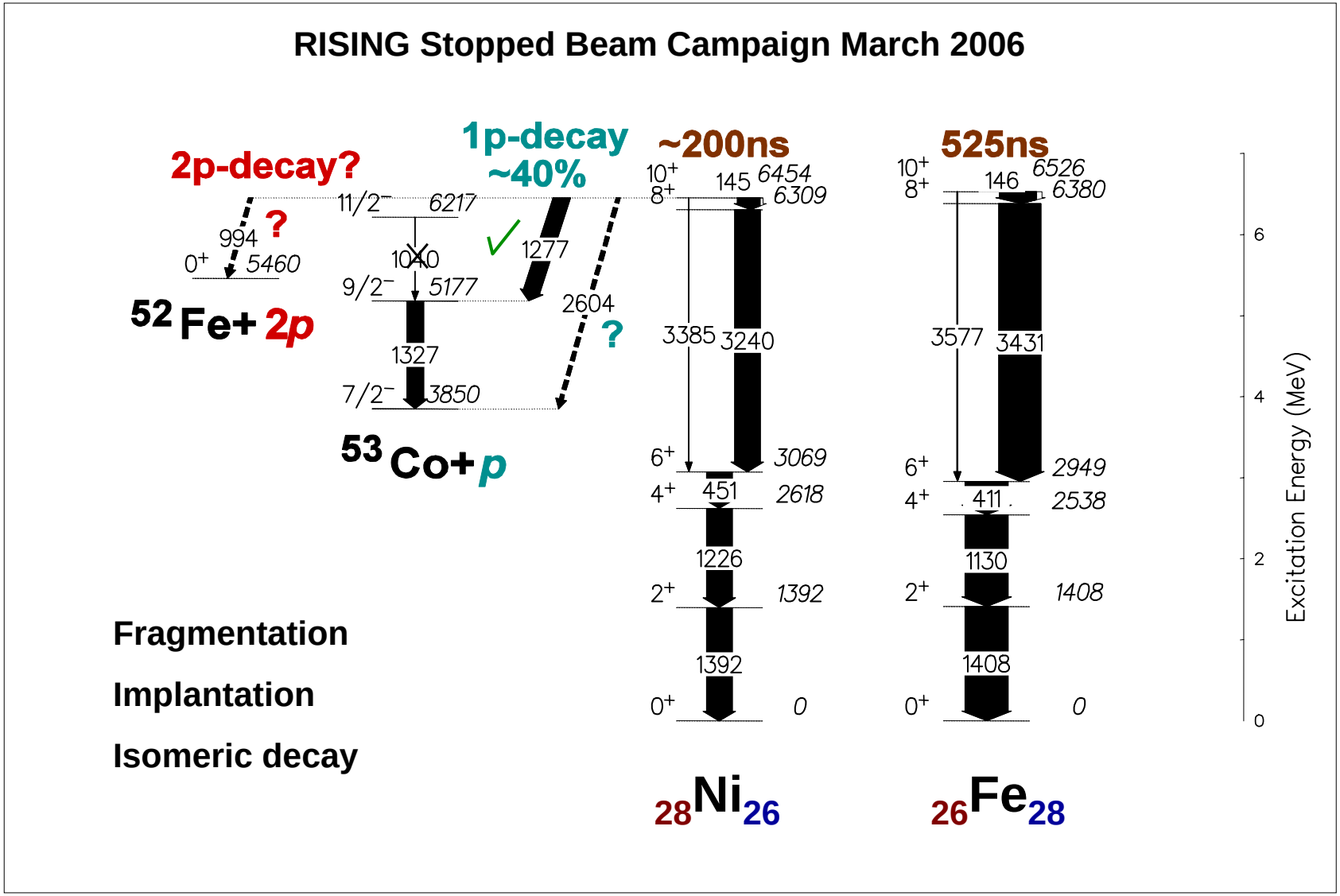
The A=54 T=1 Mirror Nuclei



D. Rudolph et al., To be published