Isomers and Isospin Symmetry Aspects in the $1f_{7/2}$ Shell

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for the RISING Stopped Beam Collaboration

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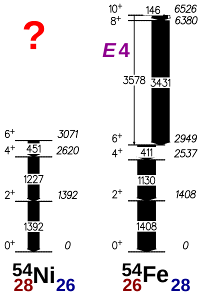
Contents

Why ^{54}Ni?

- Close to a (soft) doubly-magic nucleus, namely $N = Z = 28$ ^{56}Ni.
- Efficiently probes isospin symmetry breaking effects if the *fp* shell.
- The *fp* shell is a well confined, well established shell-model configuration space.
- Spherical shell-model calculations usually provide excellent spectroscopic information, including well-deformed structures and transition rates.



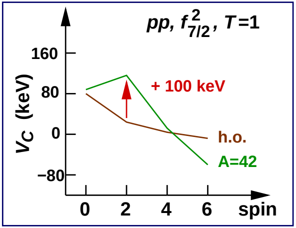
10^{+} isomer:

364(7) ns halflife
el. quad. moment
magnetic moment

A. Gadea *et al.*,
PRL 97, 152501 (2006)

Isospin Symmetry Breaking

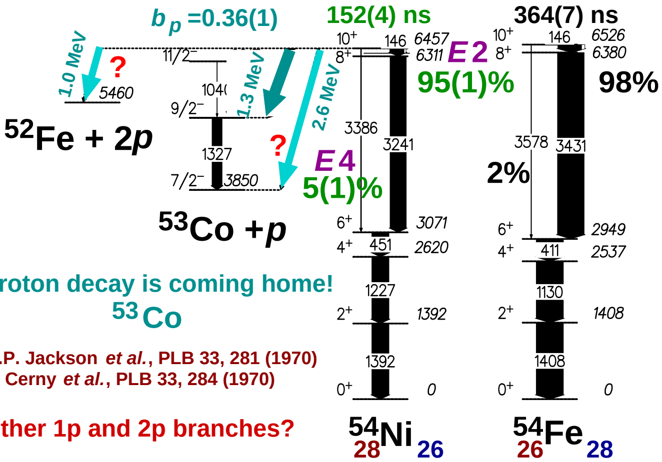
- Coulomb multipole contributions.
- Coulomb monopole contributions (radii, deformation).
- Electromagnetic spin-orbit interaction.
- Nuclear isospin breaking components, V_{BM}.



A.P. Zuker et al., PRL 89, 142502 (2002)

J. Duflo & A.P. Zuker,
PRC66, 051304(R) (2002)

Recent Review:
M.A. Bentley and S.M. Lenzi,
Prog. Part. Nucl. Phys. 59, 497 (2007)



Proton decay is coming home!
^{53}Co

K.P. Jackson *et al.*, PLB 33, 281 (1970)
J. Cerny *et al.*, PLB 33, 284 (1970)

Other 1p and 2p branches?

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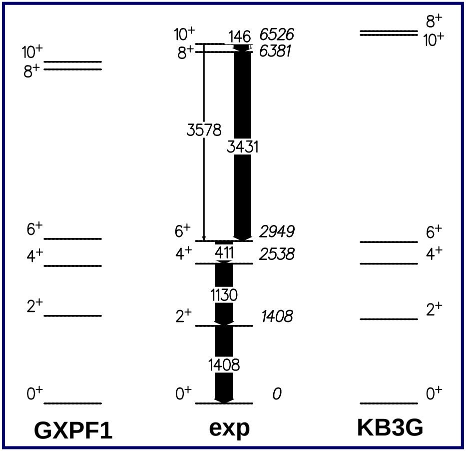
Shell-Model Calculations ^{54}Fe

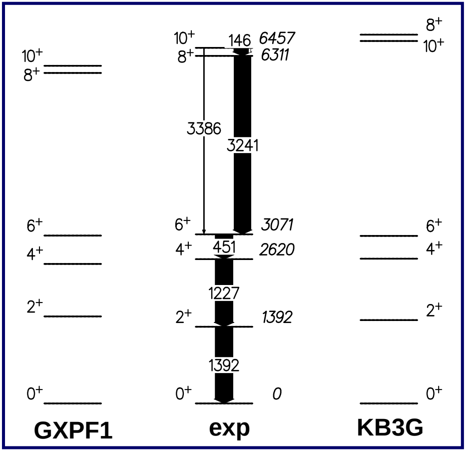


ANTOINE shell−model code
Full *fp* space, *t* =6
Including Coulomb effects and V_{BM}
E2 eff. charges: ε_p =1.15 and ε_n =0.80
(R. du Rietz *et al*.,PRL93, 222501 (2004))
E4 eff. charges: ε_p =1.50 and ε_n =0.50

	exp	GXPF1	KB3G
B(E2) (W.u.)	1.69(4)	1.95	2.03
B(E4) (W.u.)	0.79(8)	1.55	1.30
$\tau_{(\gamma + CE)}$ (ns)*	525(10)	453	437
b (*E*4) (%)*	1.8(2)	3.0	2.4
$\mu(10^+)$ (μ_N^2)	7.281(10)	7.23	6.82
Q (10^+)(efm^2)	52(8)	60.7	55.6

* using the experimental level scheme

Shell-Model Calculations ^{54}Ni



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E4 eff. charges: ε_p =1.50 and ε_n =0.50

	exp	GXPF1	KB3G
B(E2) (W.u.)	2.48(7)	1.86	2.06
B(E4) (W.u.)	5.7(13)	5.28	4.66
$\tau_{(\gamma + CE)}$ (ns)*	342(9)	452	413
b (*E*4) (%)*	5.1(11)	6.2	5.0
$\mu(10^+)$ (μ_N^2)		3.93	4.24
Q (10^+)(efm^2)		63.7	58.5

* using the experimental level scheme

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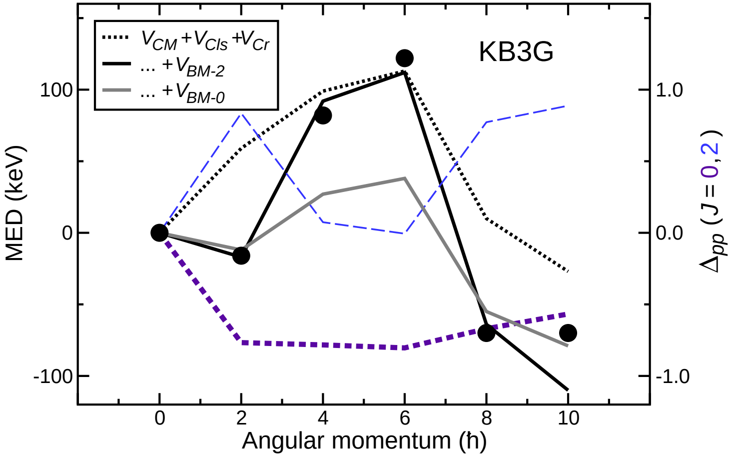
Mirror Energy Differences – KB3G



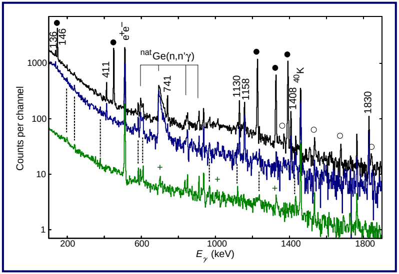
D. Rudolph *et al.*, Phys. Rev. C 78, 021301(R) (2008)

'In-Situ' Production of Isomers

136, 1158, 1830 keV: 19/2$^-$ isomer in ^{43}Sc (470 ns)

411, 1130, 1408 keV: 10$^+$ isomer in ^{54}Fe (365 ns)

Secondary reactions in the passive stopper!



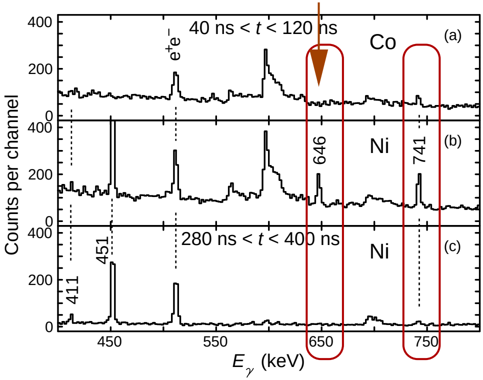
● ○ ^{54}Ni 10$^+$ isomer related

+ specific long−lived background

	time:
^{54}Ni gated, ^{52,53}Co gated	0.1 − 1.0 μs
^{54}Ni gated	15 − 16 μs

'In-Situ' Production of Isomers

741 keV: known 3/2− isomer in ^{53}Fe (63.5 ns)
646 keV: mirror isomer in ^{53}Co!?



Co−gated

Ni−gated

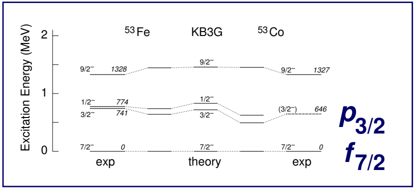
Ni−gated

Comparison with Shell Model – Conclusion

t =7 isospin dependent shell–model calculations

ANTOINE code, KB3G and GXPF1A interactions

Excitation energies



MED values (keV)

	3/2–	9/2–
exp	–95	–1
KB3G	–147	8
GXPF1A	–130	1

everything's fine ...

BUT: transition rates?

Predictions are "too fast"!

D. Rudolph *et al.*, EPJA 36, 131 (2008)

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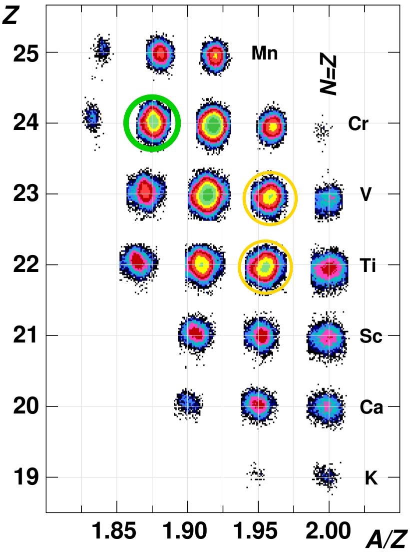
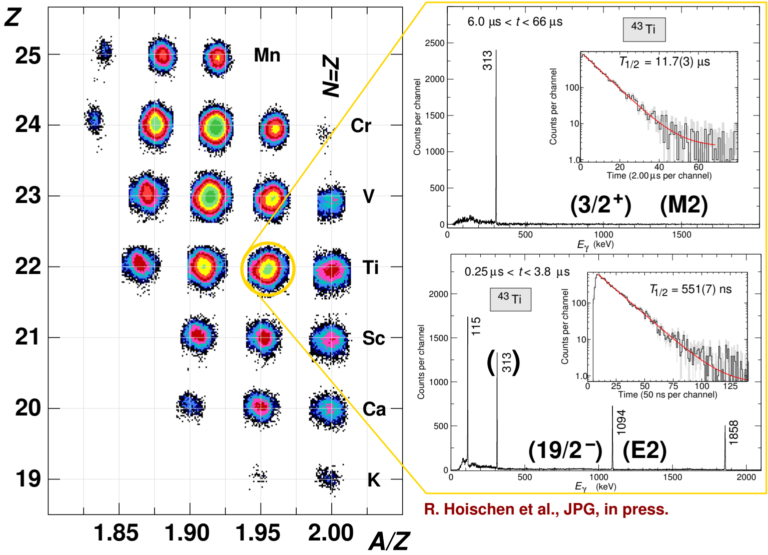
Scan of $1f_{7/2}$, $N \le Z$ Isotopes



$^{45}_{24}Cr_{21}$	$(3/2^+)$	(M2)
$^{45}_{23}V_{22}$	$(3/2^-)$	(E2)
$^{43}_{22}Ti_{21}$	$(3/2^+)$	(M2)
	$(19/2^-)$	(E2)

R. Hoischen et al., JPG, in press.

Clean Spectra & Good Statistics



R. Hoischen et al., JPG, in press.

Orbital-dependent Effective Charges?

***fp*-shell:**
KB3G, GXPF1A,…

***N~Z*:** **Absolute values and ratio of mirror *B*(*E*2)**

^{56}Ni

***A*=51,54**
$f_{7/2}^{-n}$

$e_{eff,\pi}$=1.15
$e_{eff,\nu}$=0.80

***A*=43**
$f_{7/2}^{n}$

$e_{eff,\pi}$=1.20
$e_{eff,\nu}$=0.55

^{40}Ca

***A*=50,51**
$p_{3/2}^{n}$

^{48}Ca

$e_{eff,\pi}$=1.50
$e_{eff,\nu}$=0.50

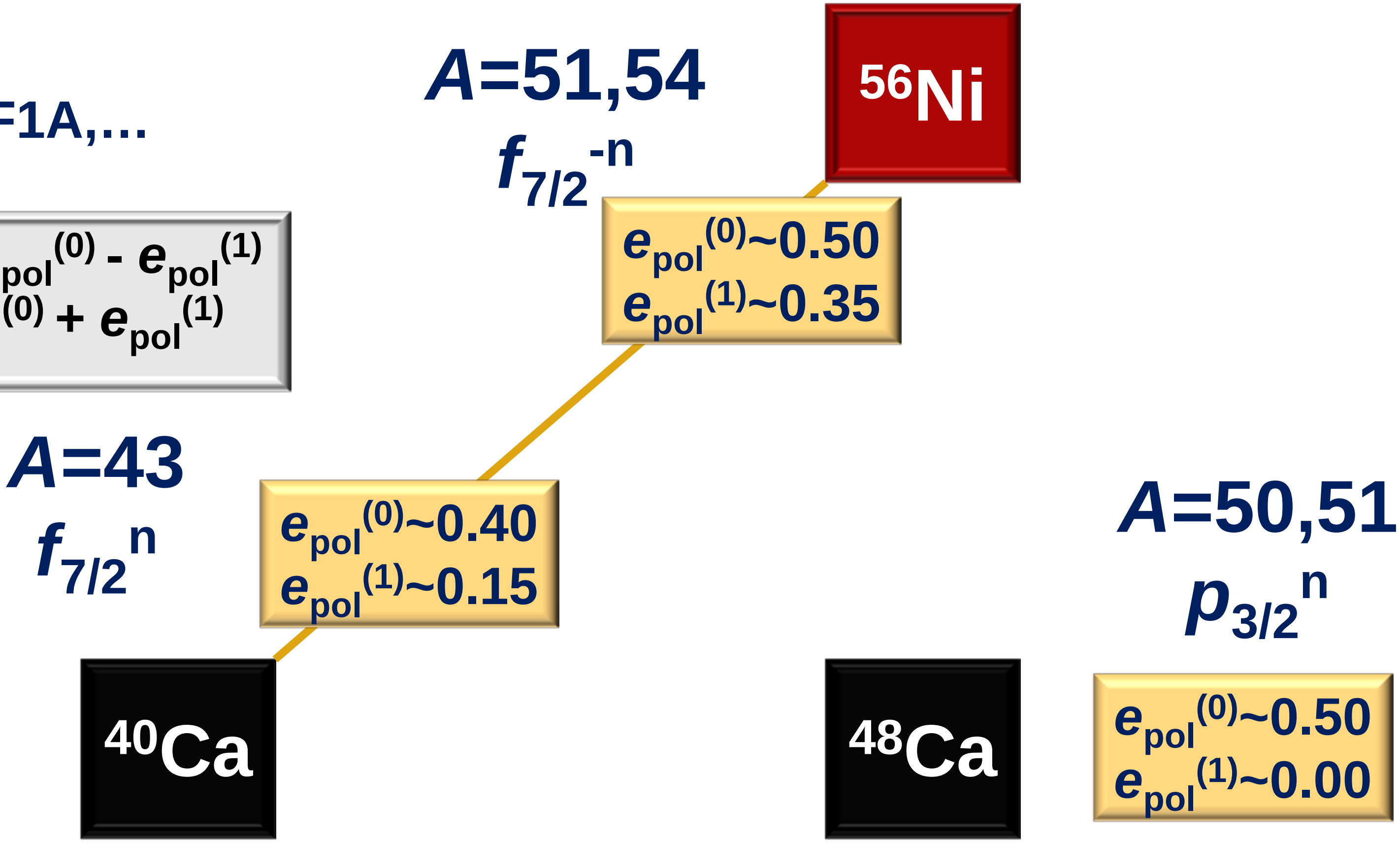
R. du Rietz *et al.*, PRL93, 222501 (2004) — Fusion-evap, plunger
D. Rudolph *et al.*, PRC78, 021301(R) (2008) — RISING
J.J. Valiente-Dobón *et al.*, PRL102, 242502 (2009) — Transfer, PRISMA-CLARA
R. Hoischen *et al.*, JPG, in press (2011) — RISING (also old fusion-evap)
H.L. Ma *et al.*, PRC80, 014316 (2009) — Theory

Orbital-dependent Effective Charges?

***fp*-shell:**

KB3G, GXPF1A,…

$$e_{eff,\pi} = 1 + e_{pol}^{(0)} - e_{pol}^{(1)}$$
$$e_{eff,\nu} = e_{pol}^{(0)} + e_{pol}^{(1)}$$



R. du Rietz *et al.*, PRL93, 222501 (2004) — Fusion-evap, plunger

D. Rudolph *et al.*, PRC78, 021301(R) (2008) — RISING

J.J. Valiente-Dobón *et al.*, PRL102, 242502 (2009) — Transfer, PRISMA-CLARA

R. Hoischen *et al.*, JPG, in press (2011) — RISING (also old fusion-evap)

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Fast-Timing: $T_{1/2}$(ps) for A=42,43,54?

A=43

Nucleus		$15/2^-$
^{43}Sc	th1	4.95
	th2	5.25
	exp	5.6(7)?
^{43}Ti	th1	5.26
	th2	7.96
	exp	??

A=54

Nucleus		2^+	4^+	6^+	8^+
^{54}Fe	th1	1.08	4.40	1400	0.056
	th2	0.81	3.29	1080	0.065
	exp	0.80(3)	4.0(8)	1215(15)	0.11(3)
^{54}Ni	th1	1.47	3.80	1100	0.052
	th2	1.87	4.89	1340	0.040
	exp	0.85(23) ?	??	????	

Easy population of ^{43}Ti and ^{54}Ni via $19/2^-$ and 10^+ isomer decay sequence

A=42

Nucleus		2^+	4^+	6^+
^{42}Ca	exp	0.82(2)	3.0(4)	5360(80)
^{42}Ti	exp	0.44(11)	>1.4	3120(21)

Difficult population of ^{42}Ti:
- **no isomer**
- **^{42}V unbound (< 55 ns)**
- **^{43}Cr β^+p populates 2^+_2**

C. Dossat *et al.*, NPA792, 18 (2007)

Collaboration ^{54}Ni Experiment

R. Hoischen[1], D. Rudolph[1], M. Hellström[1], E.K. Johansson[1], S. Pietri[2], Zs. Podolyák[2], P.H. Regan[2]
F. Becker[3], P. Bednarczyk[3,4], L. Caceres[3,5], P. Doornenbal[3], J. Gerl[3], M. Górska[3] J. Grębosz[4,3],
I. Kojouharov[3], N. Kurz[3], W. Prokopowicz[3,4], H. Schaffner[3], H.J. Wollersheim[3] L.-L. Andersson[1],
L. Atanasova[6], D.L. Balabanski[7,8], M.A. Bentley[9], A. Blazhev[10] C. Brandau[2,3], J. Brown[8], C. Fahlander[1],
A.B. Garnsworthy[2,11], A. Jungclaus[5] S.J. Steer[2] S.M. Lenzi

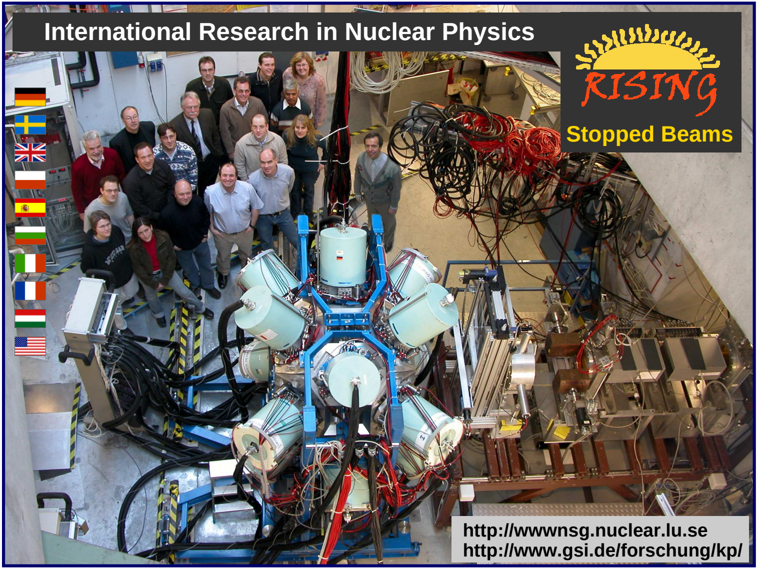
11 institutions

GSI technical & scientific work force

External preparation force (Surrey & Lund)

Theory support

Experimental Principle - Happy Collaboration



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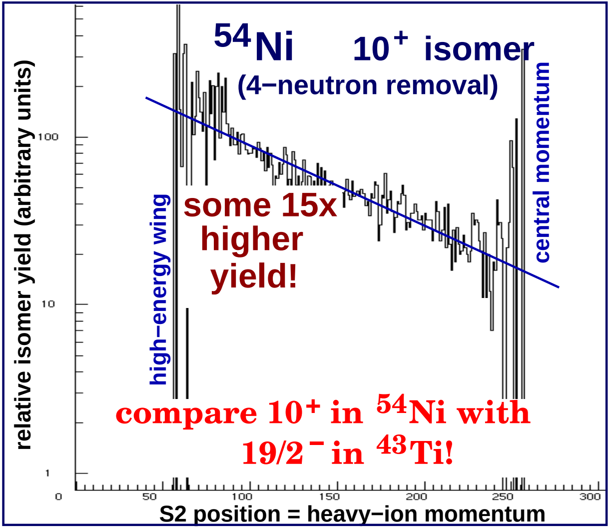

Similar to early case ^{43}Sc

W.D. Schmidt−Ott *et al.*,
Z. Phys. A 350, 215 (1994)

Spectroscopic Factors

	Q_p (MeV)	ℓ_p ($\hbar$)	$T_{1/2}$ (s) WKB[1]	$T_{1/2}$ (s) exp	S_{exp}
^{53}Co [2]	1.59(3)	9	$1.3 \cdot 10^{-6}$	~17	$\sim 8 \cdot 10^{-8}$
^{54}Ni	1.27(5)	5	$7.1 \cdot 10^{-13}$	$4.1 \cdot 10^{-7}$	$1.7 \cdot 10^{-6}$
				$5.1 \cdot 10^{-7}$	$1.4 \cdot 10^{-6}$
	2.65(5)	7	$2.9 \cdot 10^{-13}$		
				$2.8 \cdot 10^{-7}$	$1.0 \cdot 10^{-6}$
^{94}Ag [3]	0.79(3)	4	$2.0 \cdot 10^{-5}$	21(6)	$1 \cdot 10^{-6}$
	1.01(3)	5	$5.5 \cdot 10^{-6}$	18(4)	$3 \cdot 10^{-7}$
^{58}Cu [4]	2.341(5)	4	$2.0 \cdot 10^{-16}$	$\sim 2 \cdot 10^{-13}$	$\sim 1 \cdot 10^{-3}$

[1] S. Hofmann, priv. comm. and in *Nuclear Decay Modes* (IOP Publishing, Bristol, 1996), p. 143

[2] K.P. Jackson *et al*., Phys. Lett. 33B, 281 (1970)

[3] I. Mukha *et al*., Phys. Rev. Lett. 95, 022501 (2005)

[4] D. Rudolph *et al*., Phys. Rev. Lett. 80, 3018 (1998); Eur. Phys. J. A14, 137 (2002)

Assuming an additional 25% proton branch into the ground state of ^{53}Co

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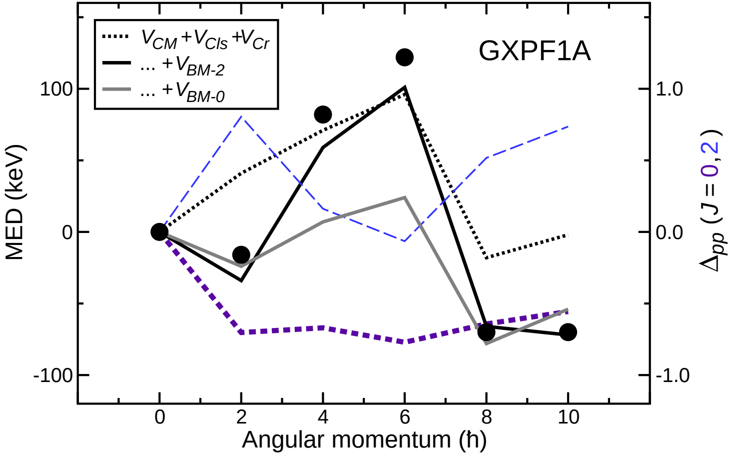
Mirror Energy Differences – GXPF1A



Mirror Configurations

Example: 10^+ states in A=54 mirrors:

Configuration	Partition (%) Fe	Partition (%) Ni	Interaction
$f_{7/2}^{-2} \times f_{7/2}^{-1}\, p_{3/2}$	34.3	38.8	GXPF1A
	38.4	43.1	KB3G
$f_{7/2}^{-2} \times f_{7/2}^{-1}\, f_{5/2}$	14.8	11.0	GXPF1A
	11.9	7.9	KB3G

} + 4%

} – 3%

Δ ~ +/– 4%

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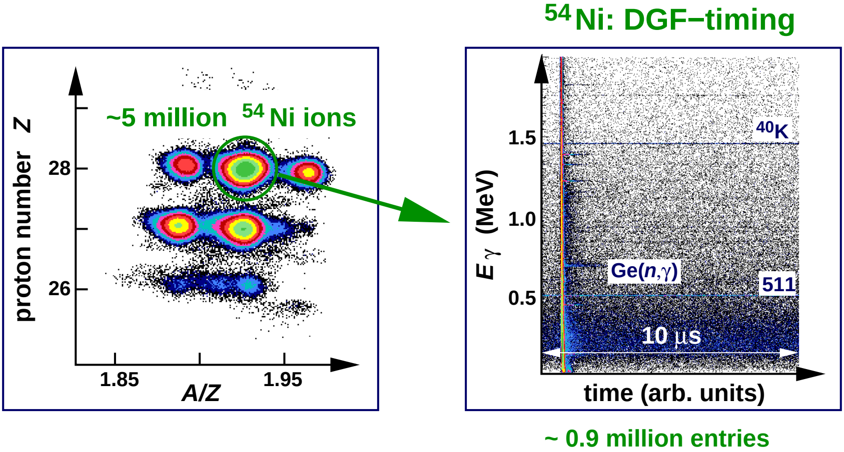
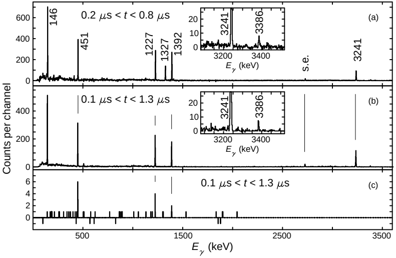
Identification and Energy-Time Correlations





γ −singles

γγ −coincidences:

known ground−state cascade

3386 keV (E4)

Time Spectra of ^{54}Ni