2^+ Anomaly and Configurational Isospin Polarization of ^{136}Te

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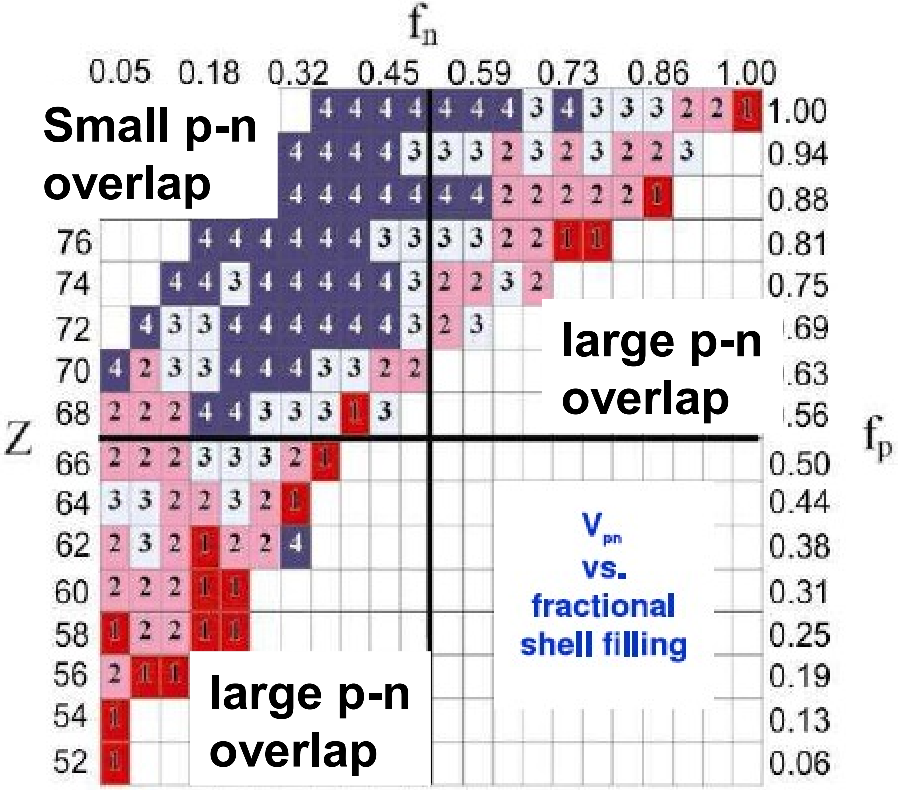
Contact: E. Rapisarda

Observables sensitive to V_{pn}

R.B. Cakirli and R.F. Casten, PRL 96, 132501 (2006)



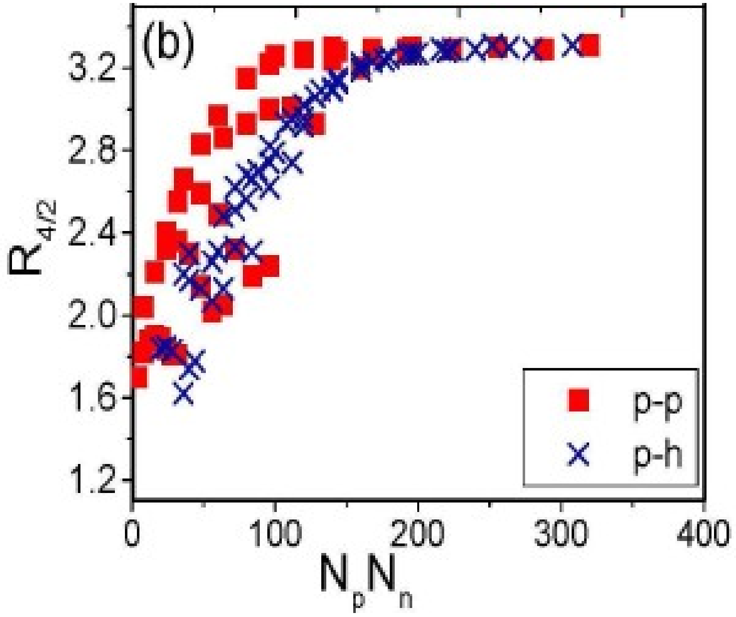
Small p-n overlap

large p-n overlap

large p-n overlap

V_{pn} vs. fractional shell filling

1	> 350 keV	3	300 - 250 keV
2	350 - 300 keV	4	250 - 200 keV



$$\delta V_{pn}(Z,N) = -\tfrac{1}{4}(\{ME(Z,N) - ME(Z,N-2)\} - \{ME(Z-2,N) - ME(Z-2,N-2)\})$$

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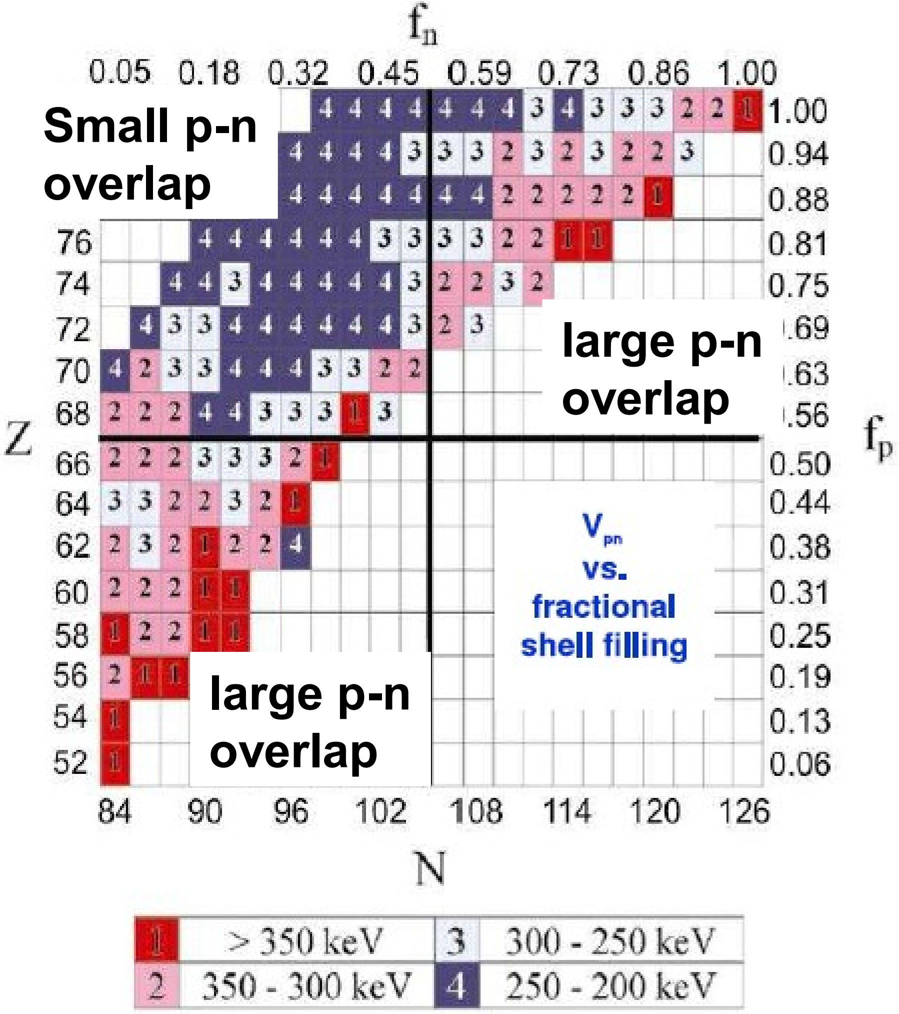


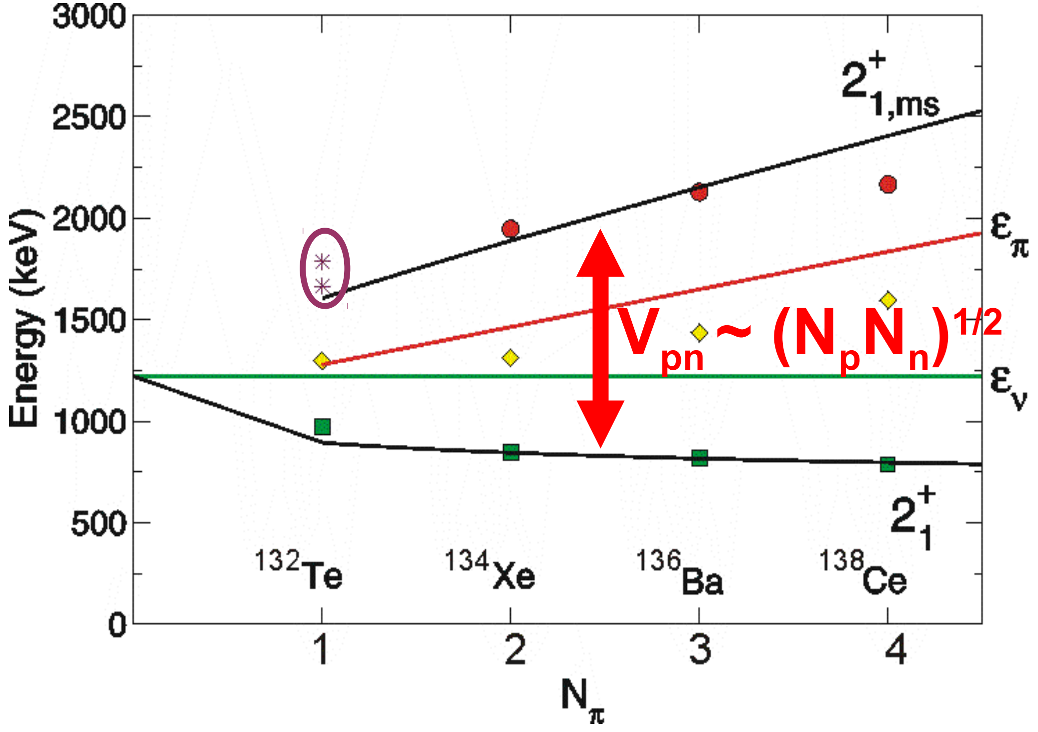
Small p-n overlap

large p-n overlap

large p-n overlap

V_{pn} vs. fractional shell filling

Proton-Neutron degree of freedom in excited-state wave functions



$V_{pn} \sim (N_p N_n)^{1/2}$

$$\delta V_{pn}(Z,N) = -\tfrac{1}{4}(\{ME(Z,N) - ME(Z,N-2)\} - \{ME(Z-2,N) - ME(Z-2,N-2)\})$$

T. Ahn, L. Coquard, N. Pietralla *et al.*, Phys. Lett. B 679, 19 (2010)

What are Mixed-Symmetry States

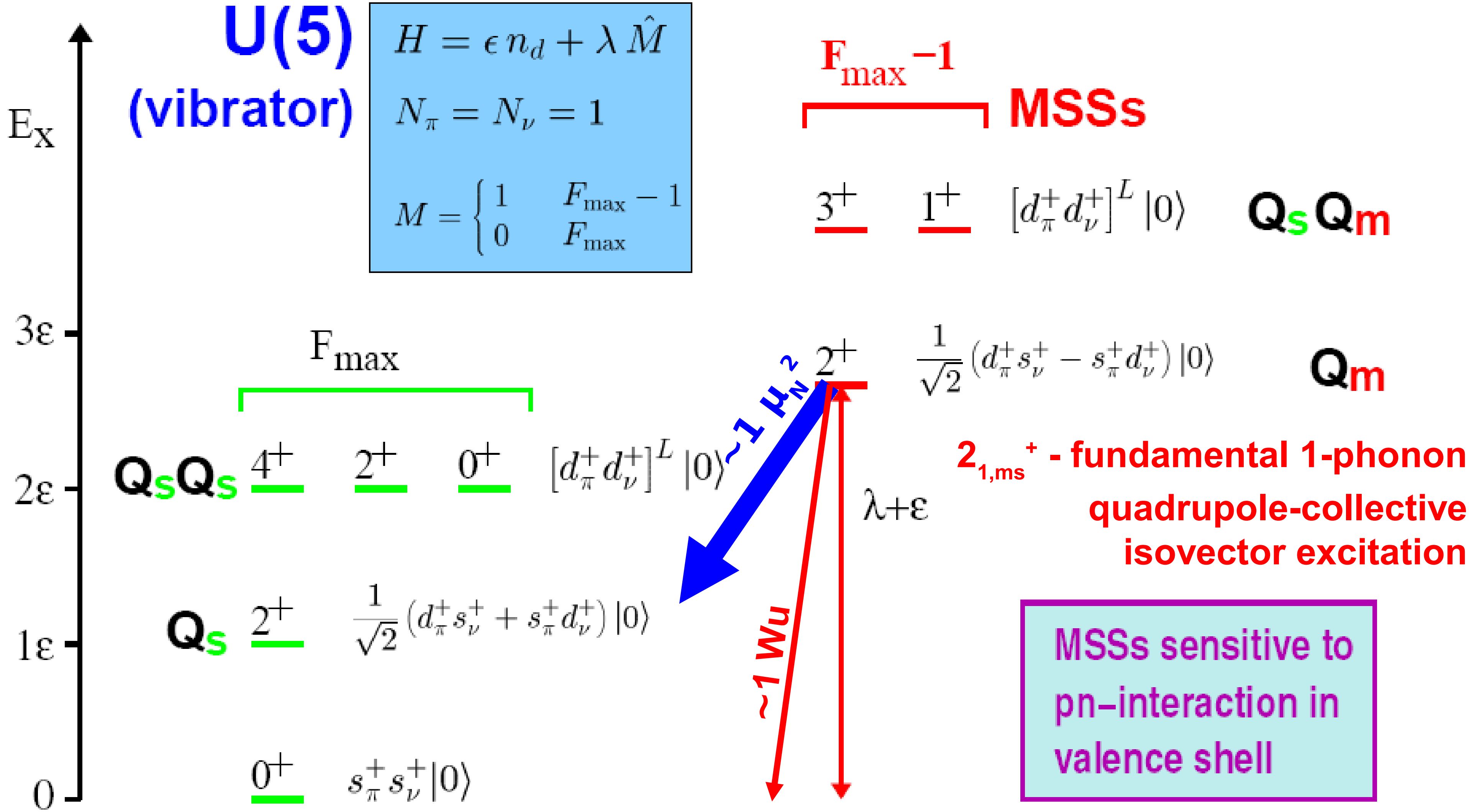
Simple Example: Harmonic Oscillator, N=2

U(5)
(vibrator)

$$H = \epsilon n_d + \lambda \hat{M}$$

$$N_\pi = N_\nu = 1$$

$$M = \begin{cases} 1 & F_{\max} - 1 \\ 0 & F_{\max} \end{cases}$$

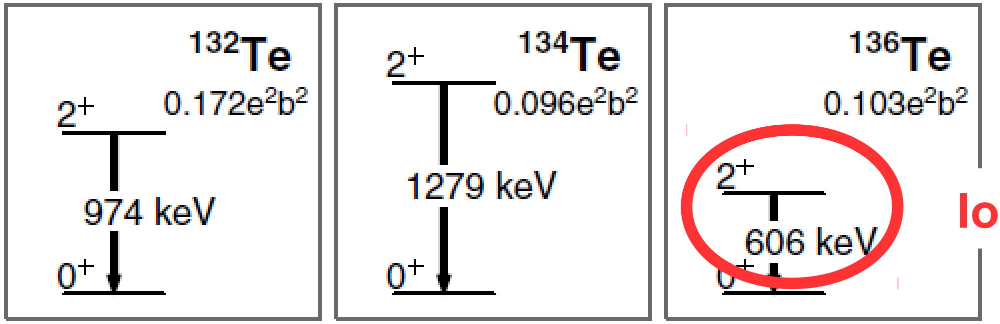


$2^+_{1,ms}$ - fundamental 1-phonon quadrupole-collective isovector excitation

MSSs sensitive to pn–interaction in valence shell

IBM-2 A. Arima, F. Iachello

B(E2) “anomaly” in ^{136}Te

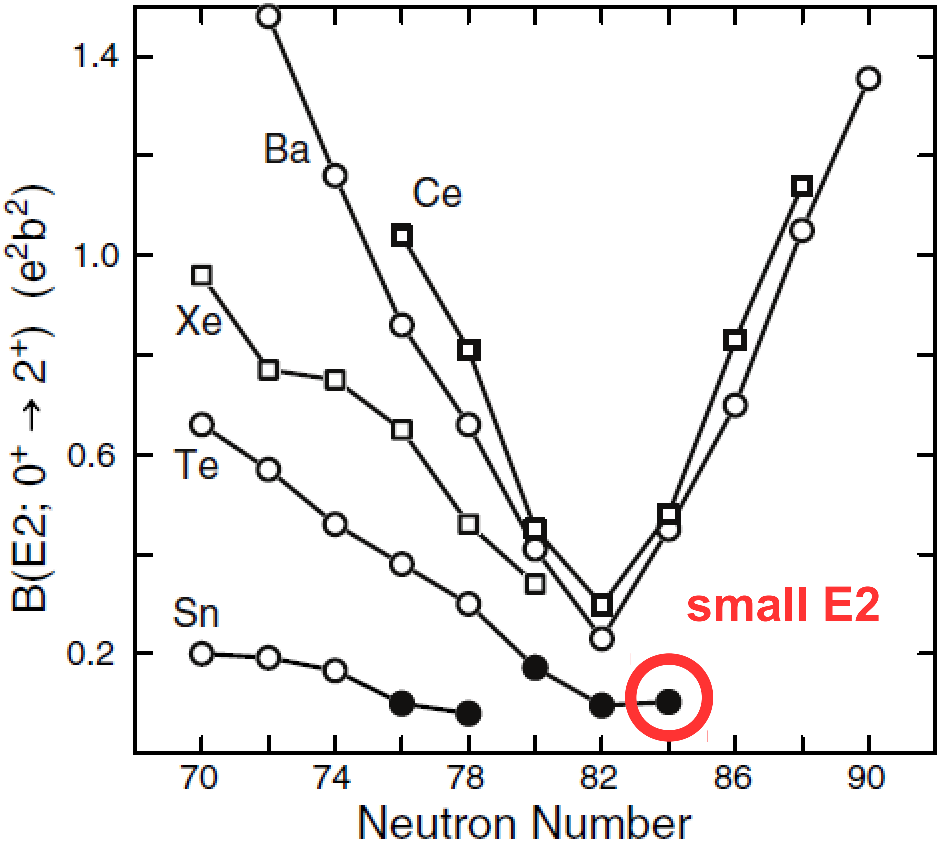


low energy

N = 80

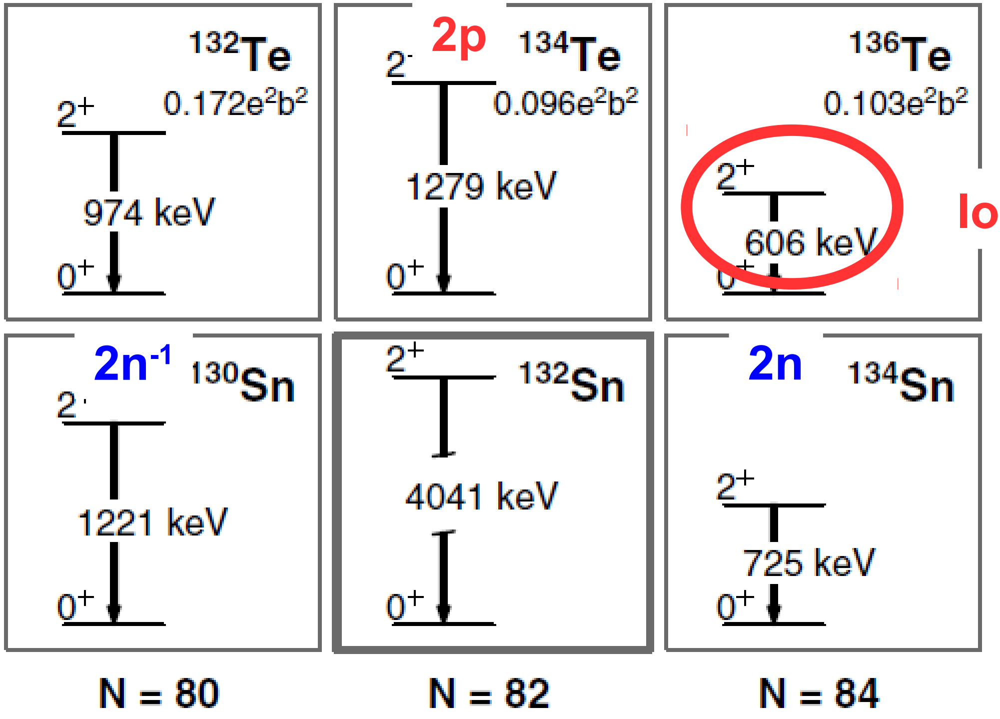
N = 82

N = 84



small E2

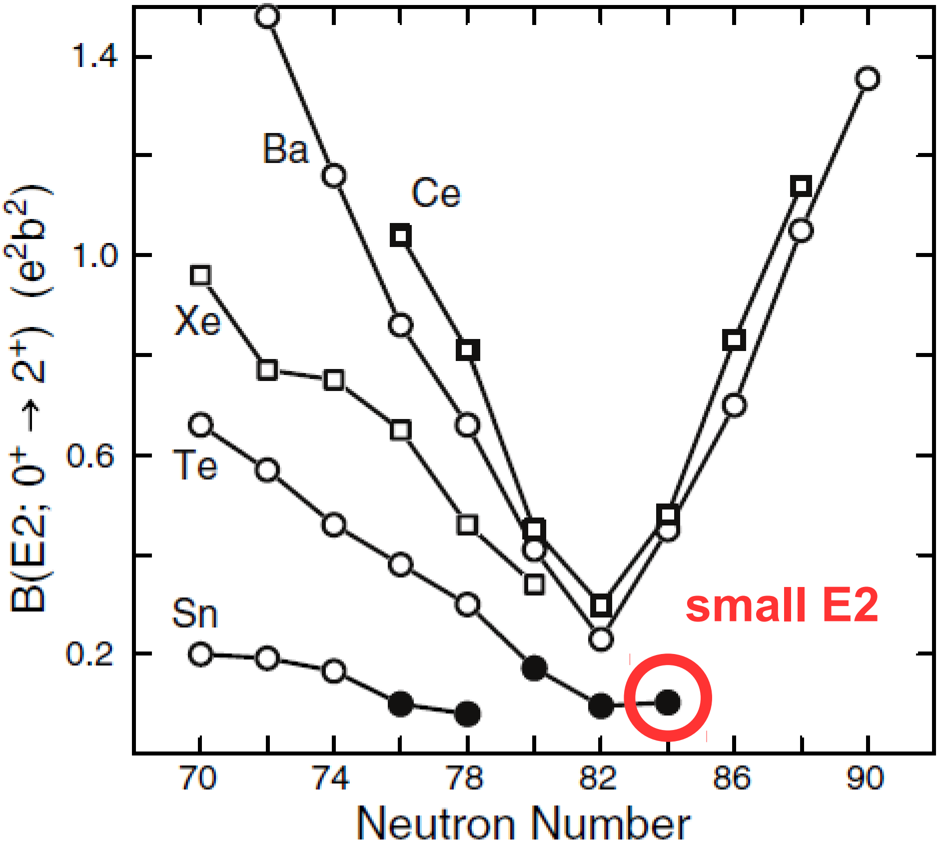
B(E2) “anomaly” in ^{136}Te



low energy

Origin of the anomaly:

Neutron dominance in the 2_1^+ wave function



small E2

Shell Model:
N. Shimizu, T. Otsuka, T. Mizusaki, M. Honma, PRC 70, 054313 (2004)

QRPA:
J. Terasaki et al., PRC 66, 054313 (2002)

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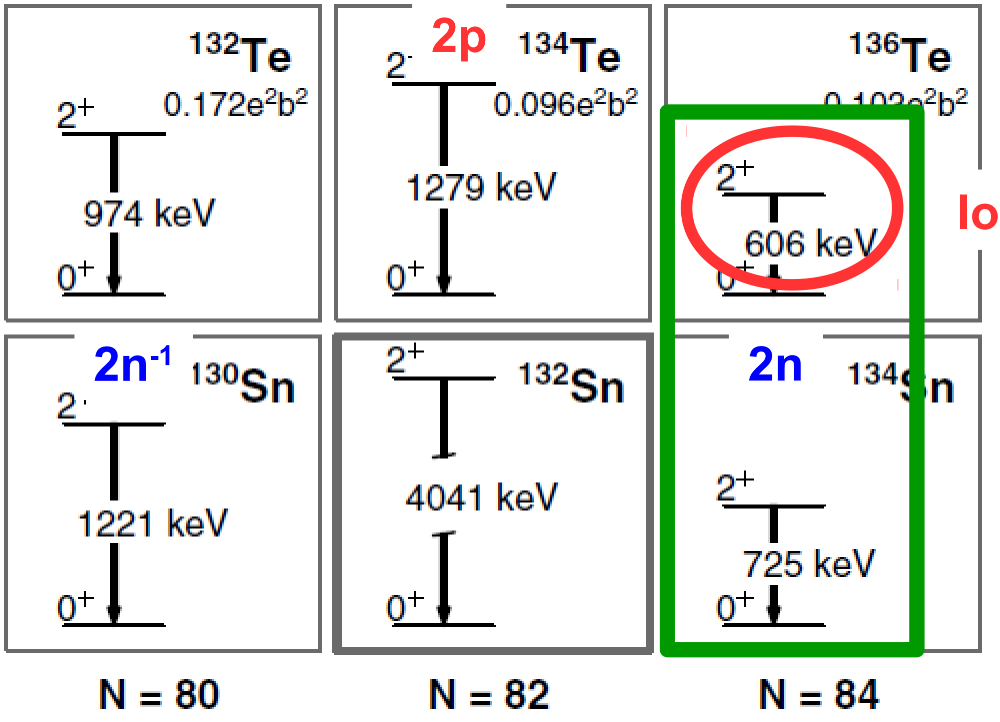

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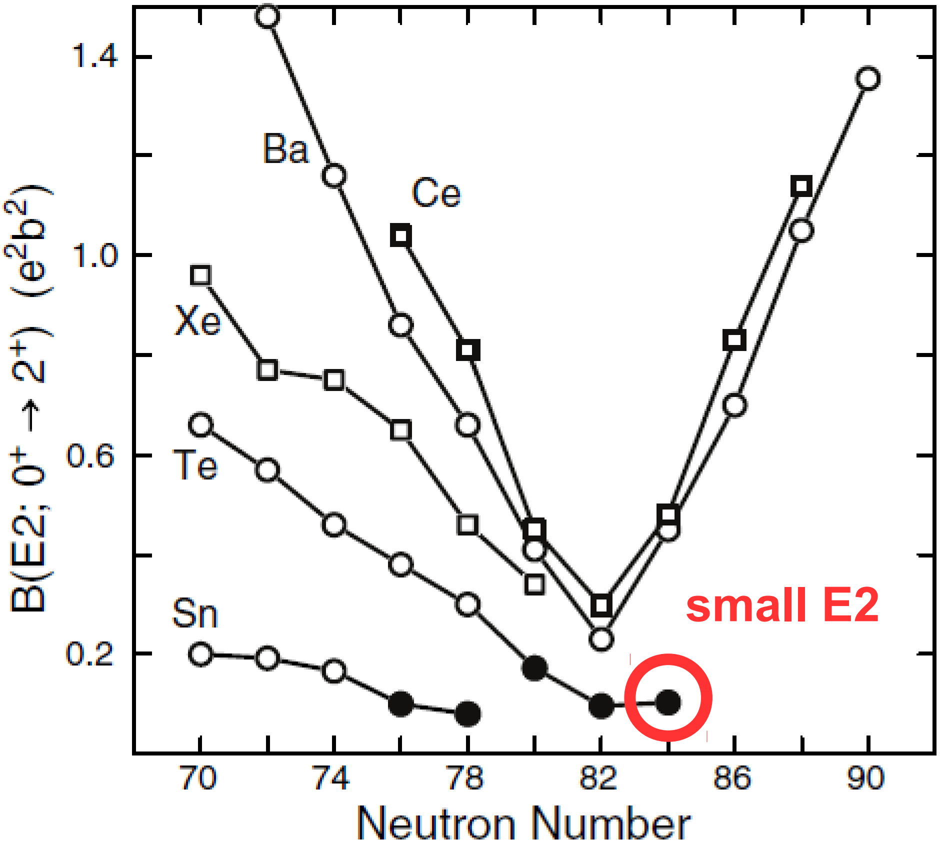

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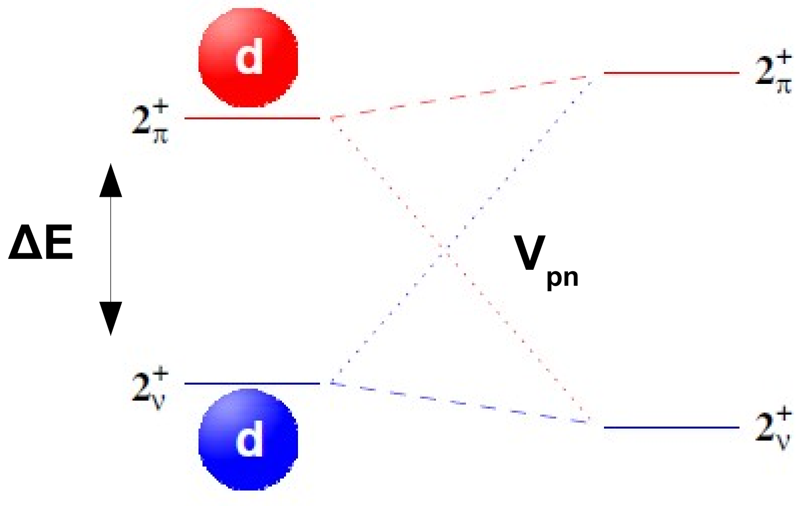
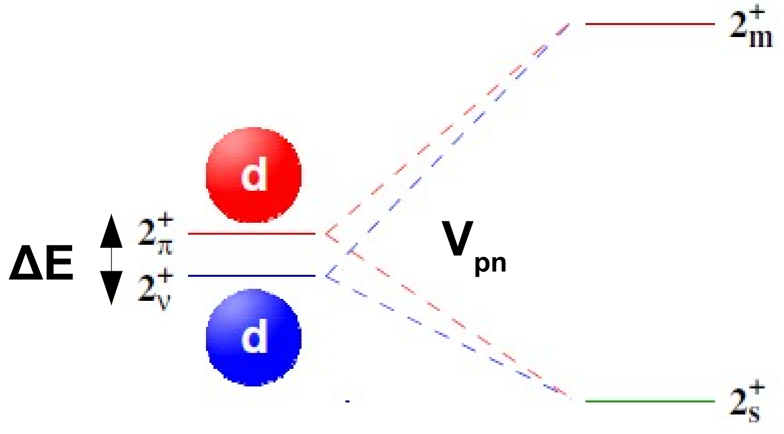
Configurational Isospin Polarization

- **Structure of FS / MS States sensitive to the interplay of ΔE and V_{pn}**





Configurational Isospin Polarization

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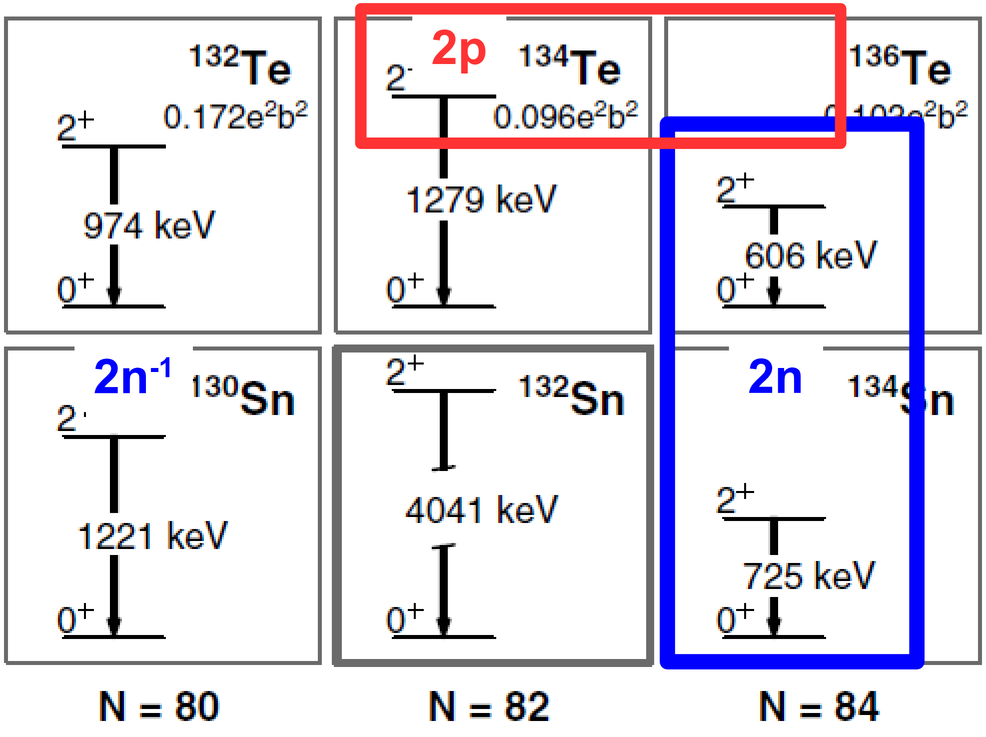
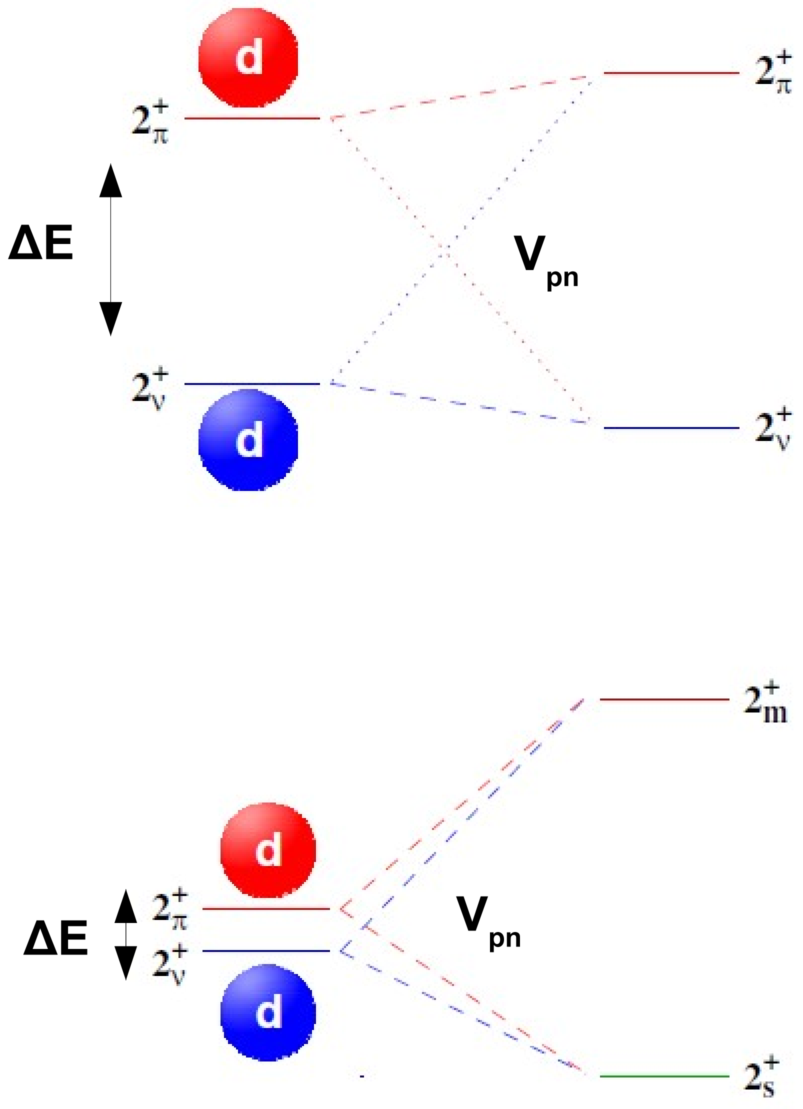
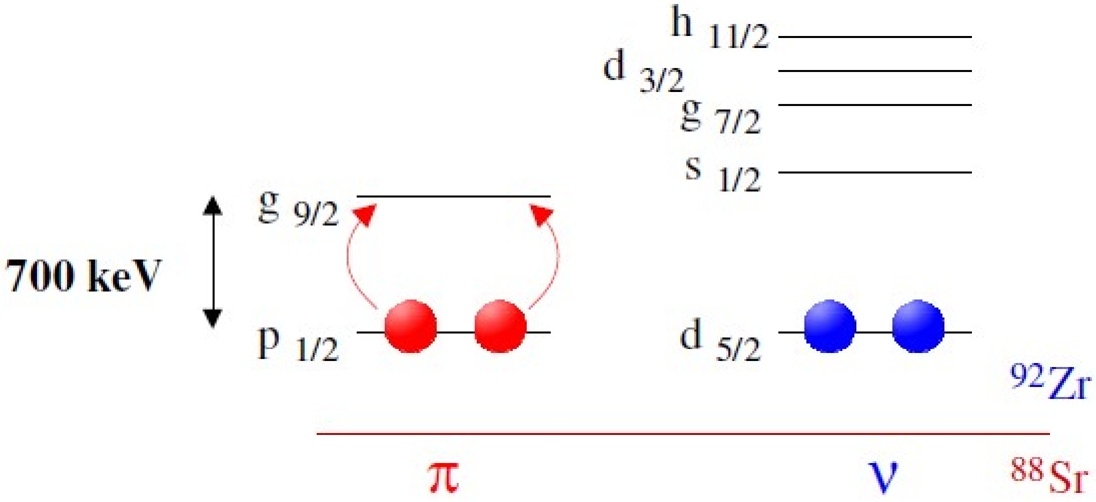
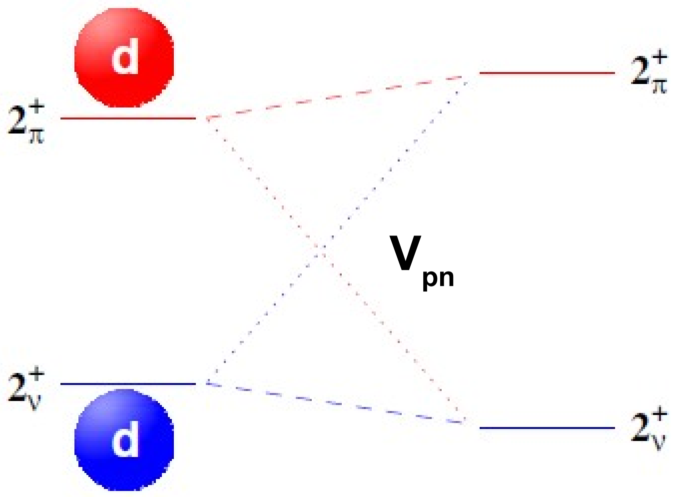


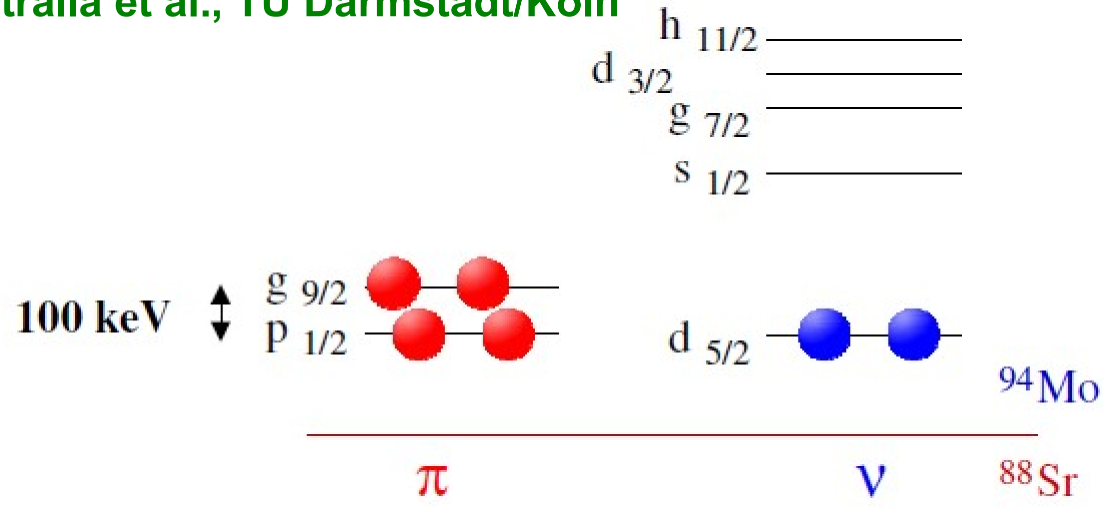


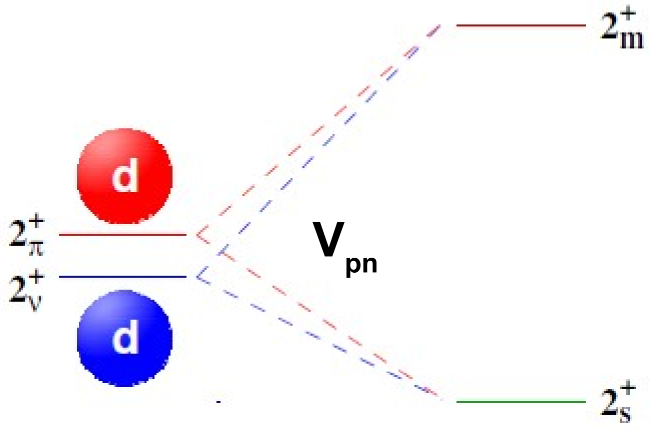
First CIP found at N=52 Zr





VW et al., Yale/Stuttgart
Yates et al., Lexington
Pietralla et al., TU Darmstadt/Köln





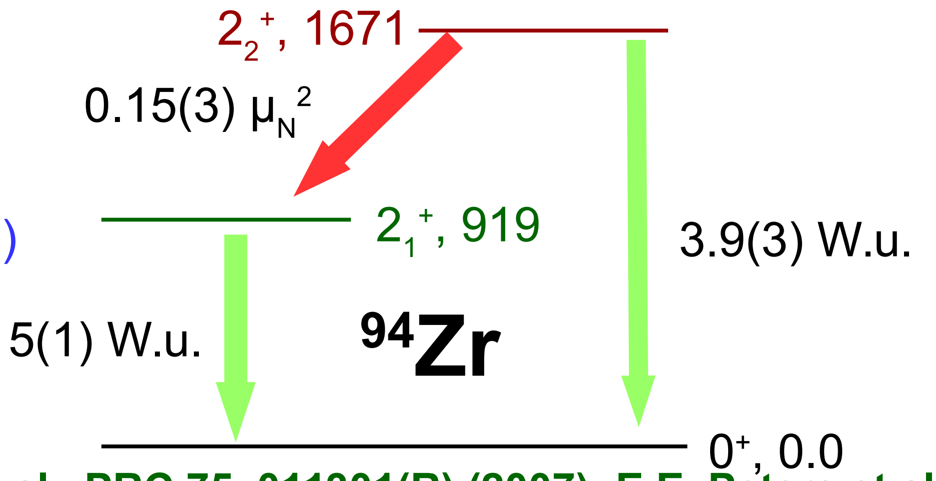
CIP in ^{94}Zr vs. ^{132,136}Te

g_{exp}

+0.9(3)

**V.W. et al.,
PRC 78, 031301(R) (2008)**

-0.31(2)



2_2^+, 1671

0.15(3) μ_N^2

2_1^+, 919

5(1) W.u.

3.9(3) W.u.

^{94}Zr

0^+, 0.0

g_{th}

+0.98

**J.D. Holt et al.
PRC 76, 034325 (2007)**

-0.25

Lifetimes: E. Elhami et al., PRC 75, 011301(R) (2007); E.E. Peters et al., PRC 88, 024317 (2013)

CIP in ^{94}Zr vs. ^{132,136}Te

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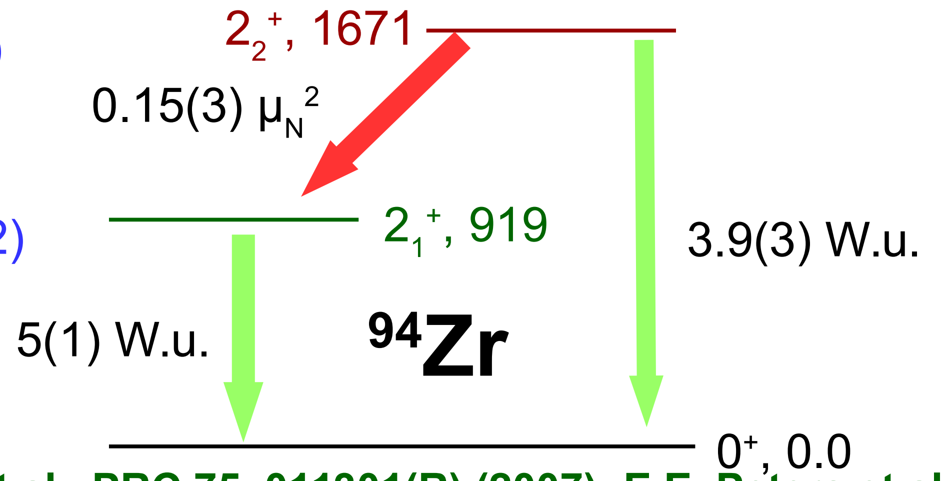

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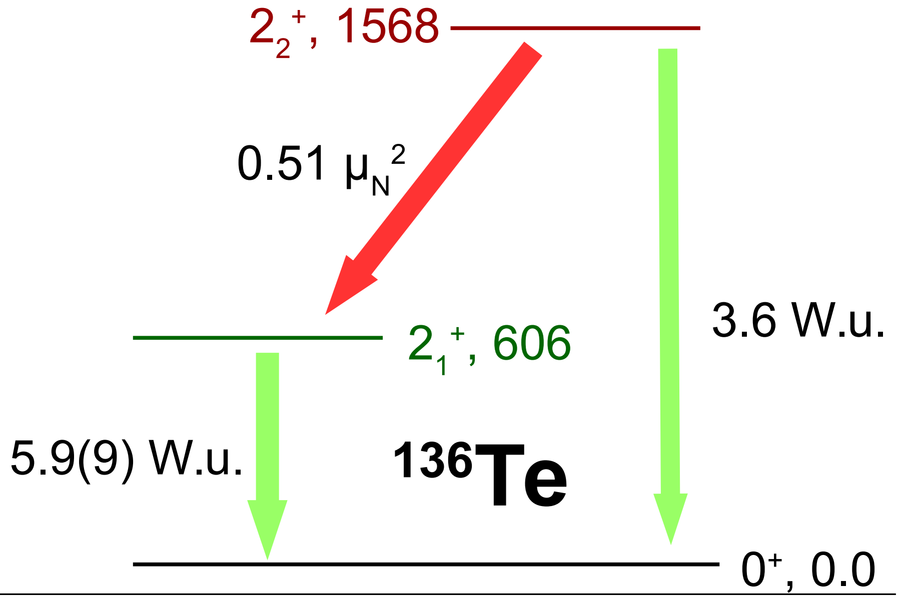


2_2^+, 1568

0.51 μ_N^2

2_1^+, 606

3.6 W.u.

5.9(9) W.u.

^{136}Te

0^+, 0.0

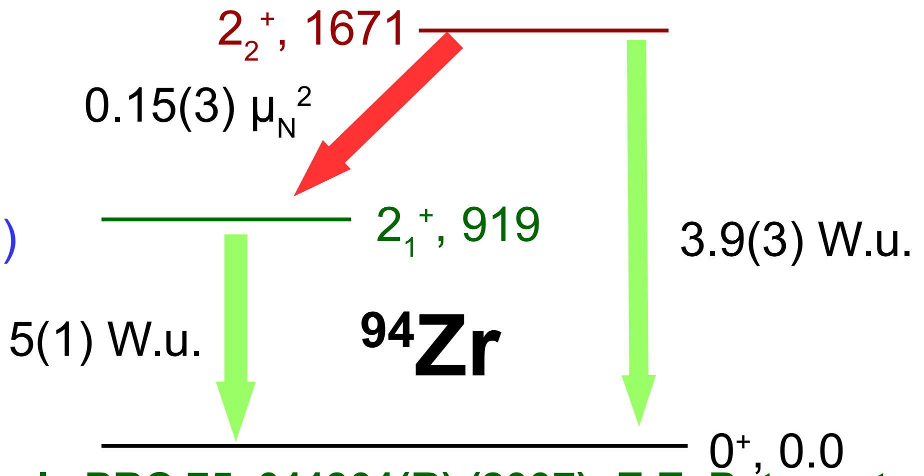
CIP in ^{94}Zr vs. ^{132,136}Te

g_{exp}

+0.9(3)

V.W. et al.,
PRC 78, 031301(R) (2008)

-0.31(2)



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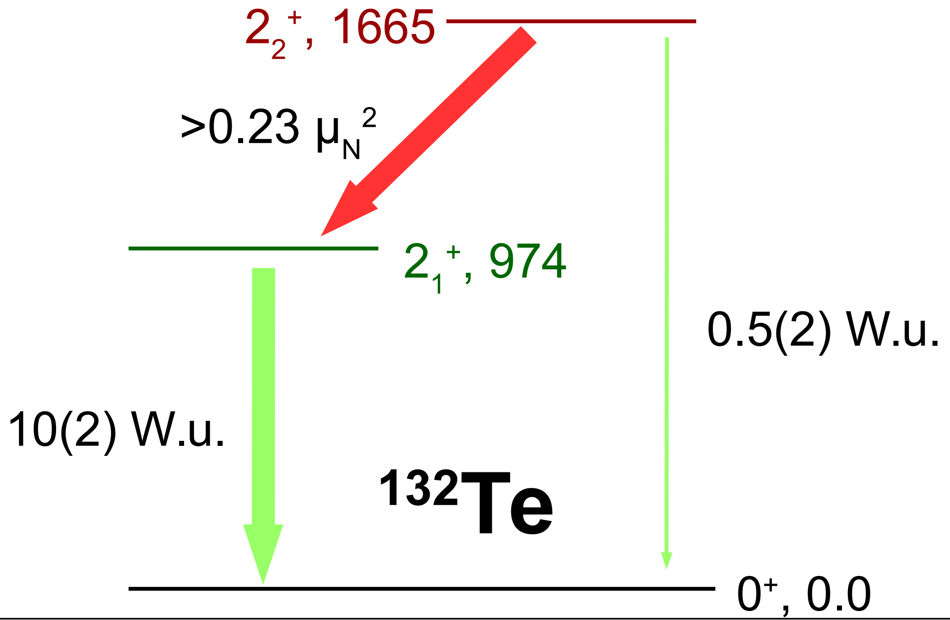
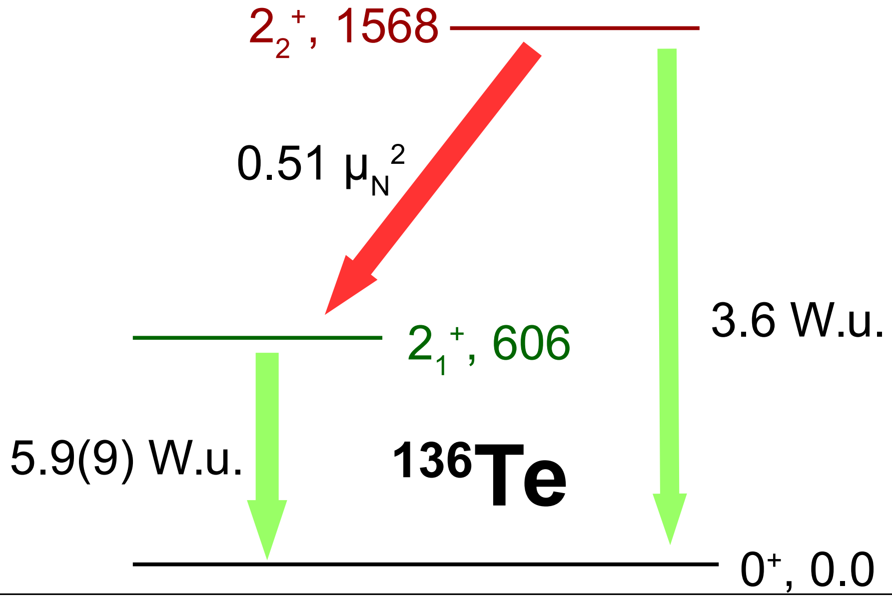
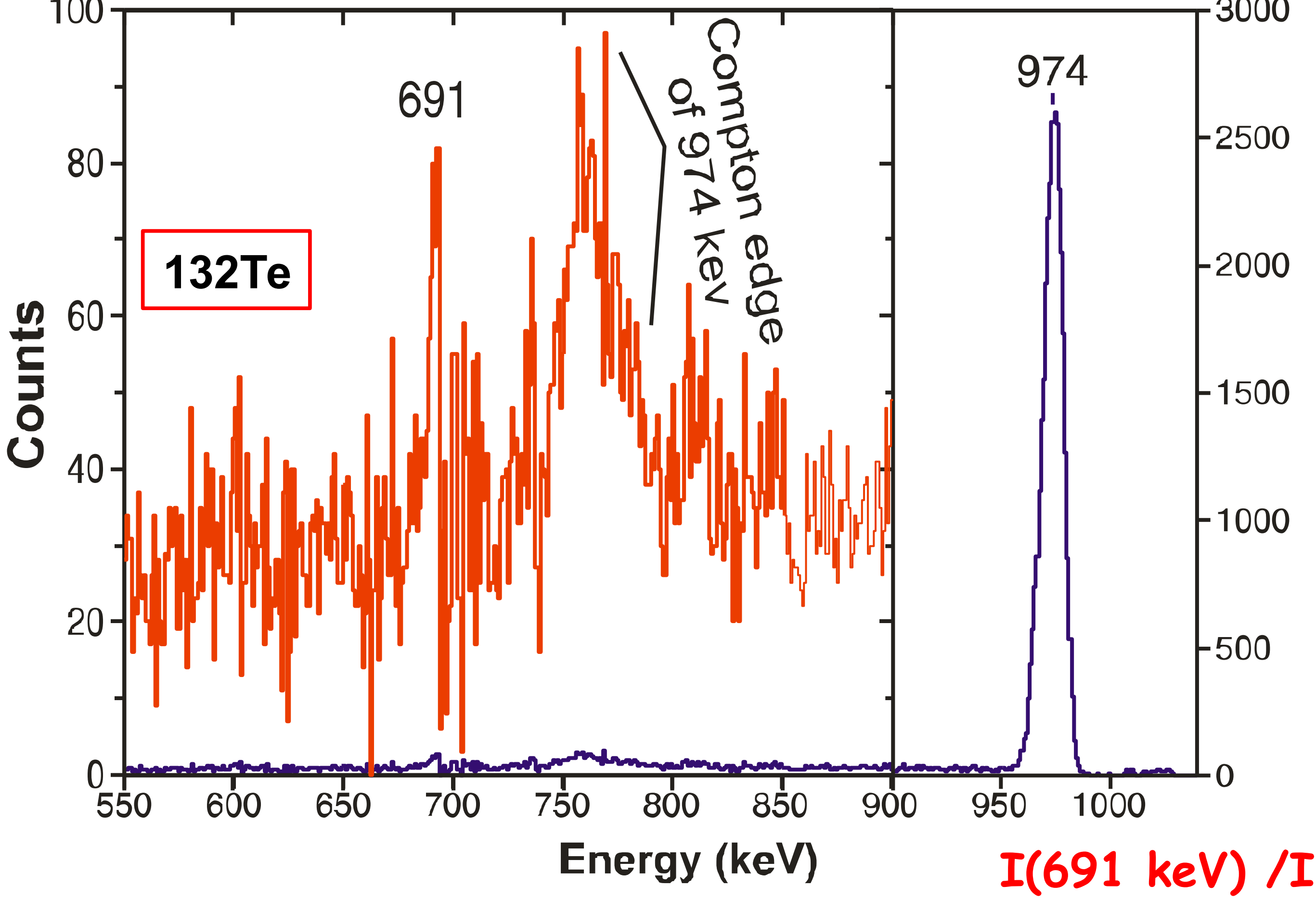
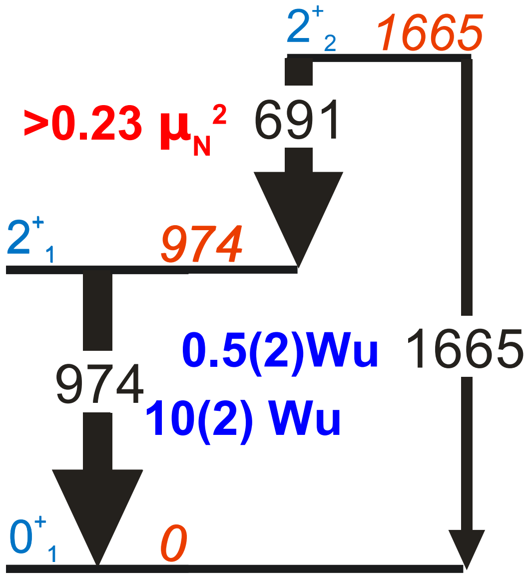




First MS observation with RIB

$2^+_{1,MS}$ observed in coincidence with 12C recoils detected in HyBall.





M. Danchev, G. Rainovski, N. Pietralla *et al.*, PRC84 ('11) 061306(R)

I(691 keV) /I(1665 keV) = 100 (52)

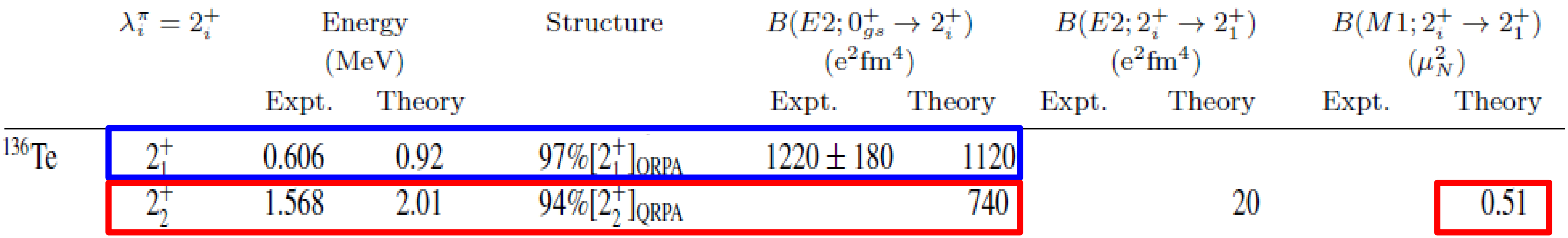
$$^{132}\mathrm{Te}: \frac{I_\gamma(691\mathrm{keV})}{I_\gamma(974\mathrm{keV})} = 1.01(28)\%$$

$$\frac{Y(2^+_2)}{Y(2^+_1)} = \frac{\sigma(0^+_1 \to 2^+_2)}{\sigma(0^+_1 \to 2^+_1)} \mu \frac{B(E2;0^+_1 \to 2^+_2)}{B(E2;0^+_1 \to 2^+_2)}$$

New CIP case predicted: 136Te

2+1 and 2+2 have significant E2 -> 1-phonon states

Strong M1 between them -> 2+2 = 2+1,MS



	$\lambda_i^\pi = 2_i^+$	Energy (MeV) Expt.	Energy (MeV) Theory	Structure	$B(E2;0_{gs}^+ \to 2_i^+)$ (e^2fm^4) Expt.	$B(E2;0_{gs}^+ \to 2_i^+)$ (e^2fm^4) Theory	$B(E2;2_i^+ \to 2_1^+)$ (e^2fm^4) Expt.	$B(E2;2_i^+ \to 2_1^+)$ (e^2fm^4) Theory	$B(M1;2_i^+ \to 2_1^+)$ (μ_N^2) Expt.	$B(M1;2_i^+ \to 2_1^+)$ (μ_N^2) Theory
^{136}Te	2_1^+	0.606	0.92	97%$[2_1^+]_{QRPA}$	1220 ± 180	1120				
	2_2^+	1.568	2.01	94%$[2_2^+]_{QRPA}$		740		20		0.51

$[2_1^+]_{QRPA}$ = ~86% Neutron, $[2_2^+]_{QRPA}$ ~68% Proton (opposite phase)

QPM: A.P. Severyukhin, N.N. Arsenyev, N. Pietralla, and V.W., PRC 90, 011306(R) (2014)

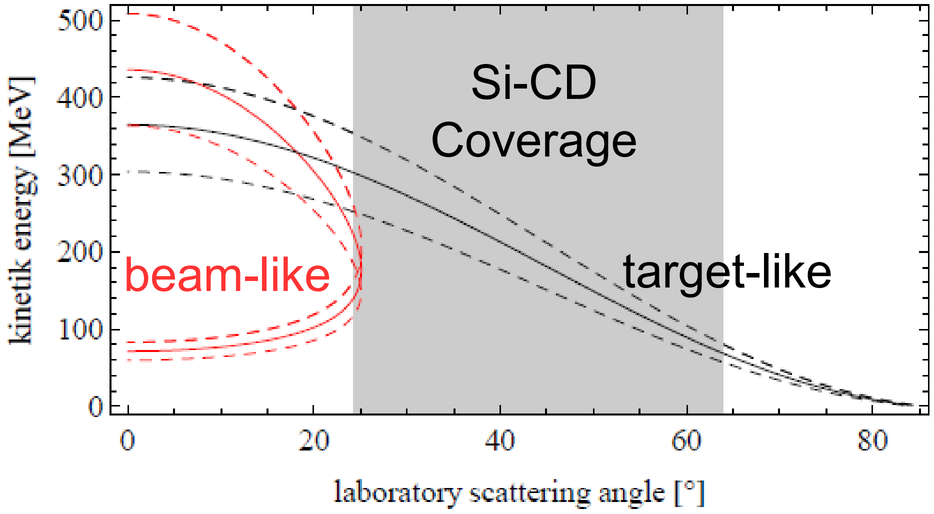
Other theory:

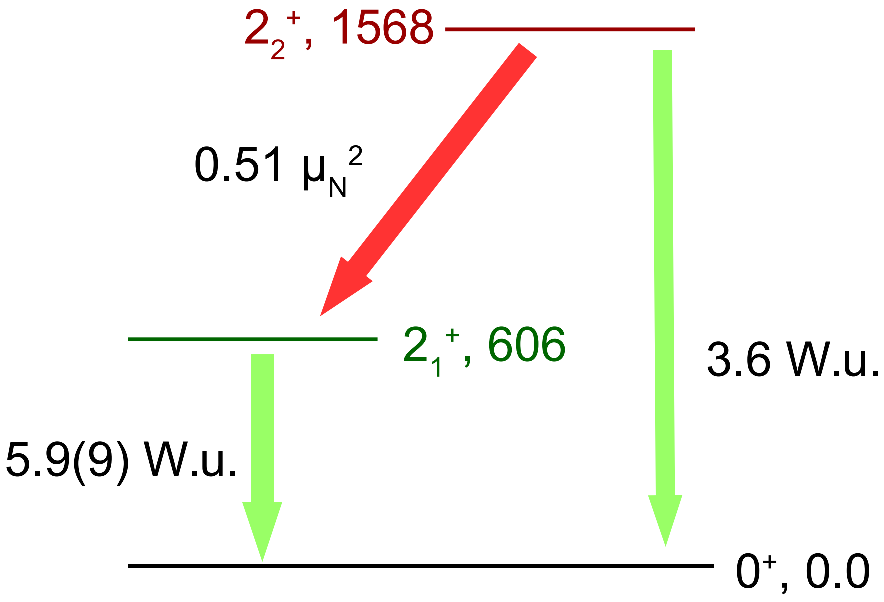
Shell Model: N. Shimizu, T. Otsuka, T. Mizusaki, M. Honma, PRC 70, 054313 (2004)

2_1^+ neutron dominated; 2_2^+ is MS state

CIP in ^{136}Te: Proposed Experiment

Measure E/M matrix elements from Coulex yields using MINIBALL + Si-CD





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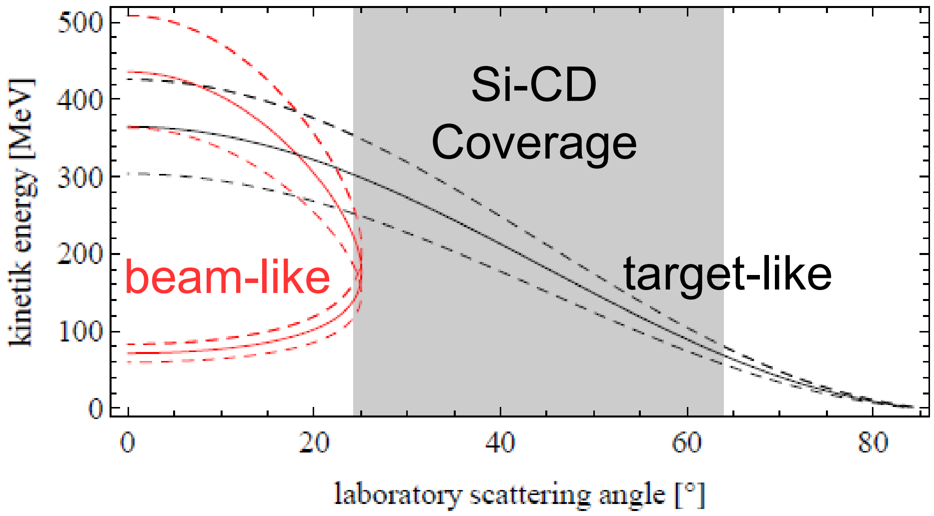
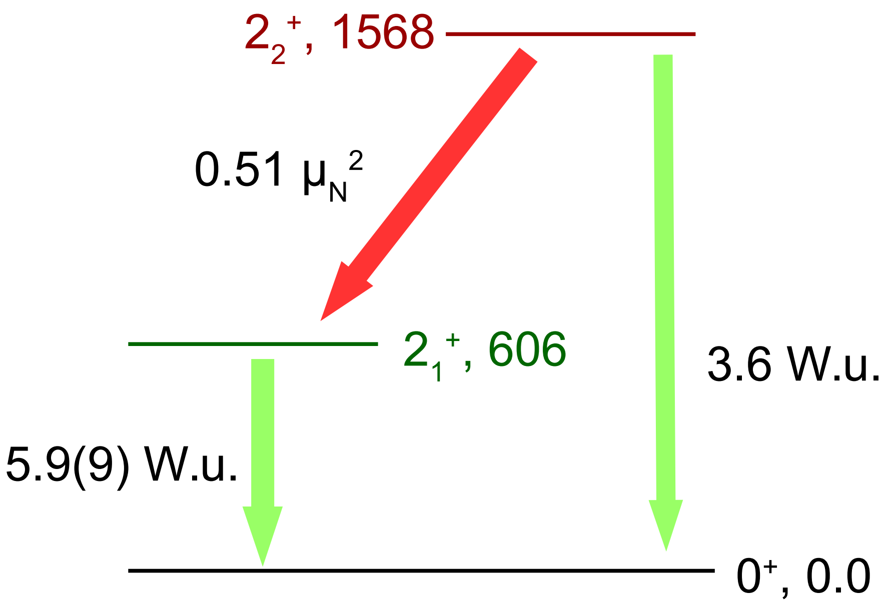
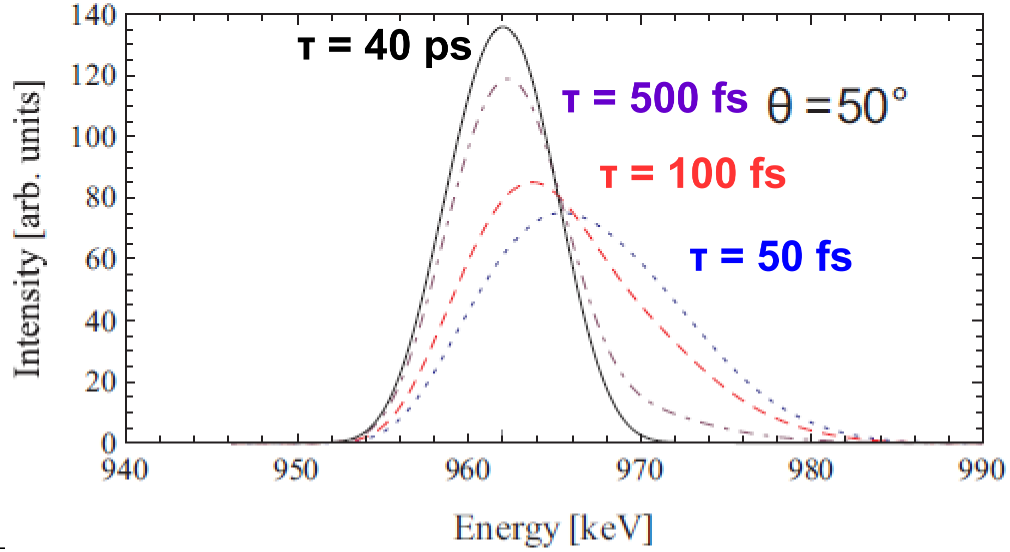
CIP in ^{136}Te: Proposed Experiment

Measure E/M matrix elements from Coulex yields using MINIBALL + DSSD





In addition, measure ~100 fs 2_2^+ lifetime through differential DSAM



Request

^{136}Te beam:

- Contaminants (TAC mentions ^{136}Cs, maybe ^{136}Xe) to be reduced to ~50% of total rate, in order to reduce target excitation from contaminants (->laser ionization would be desirable, needs to be quantified at ISOLDE)

- Te beam needs development / knowledge on contaminants

- INTC already recommended development of beam (P-342, Kröll) (^{136}Te focus 2_1^+ B(E2))

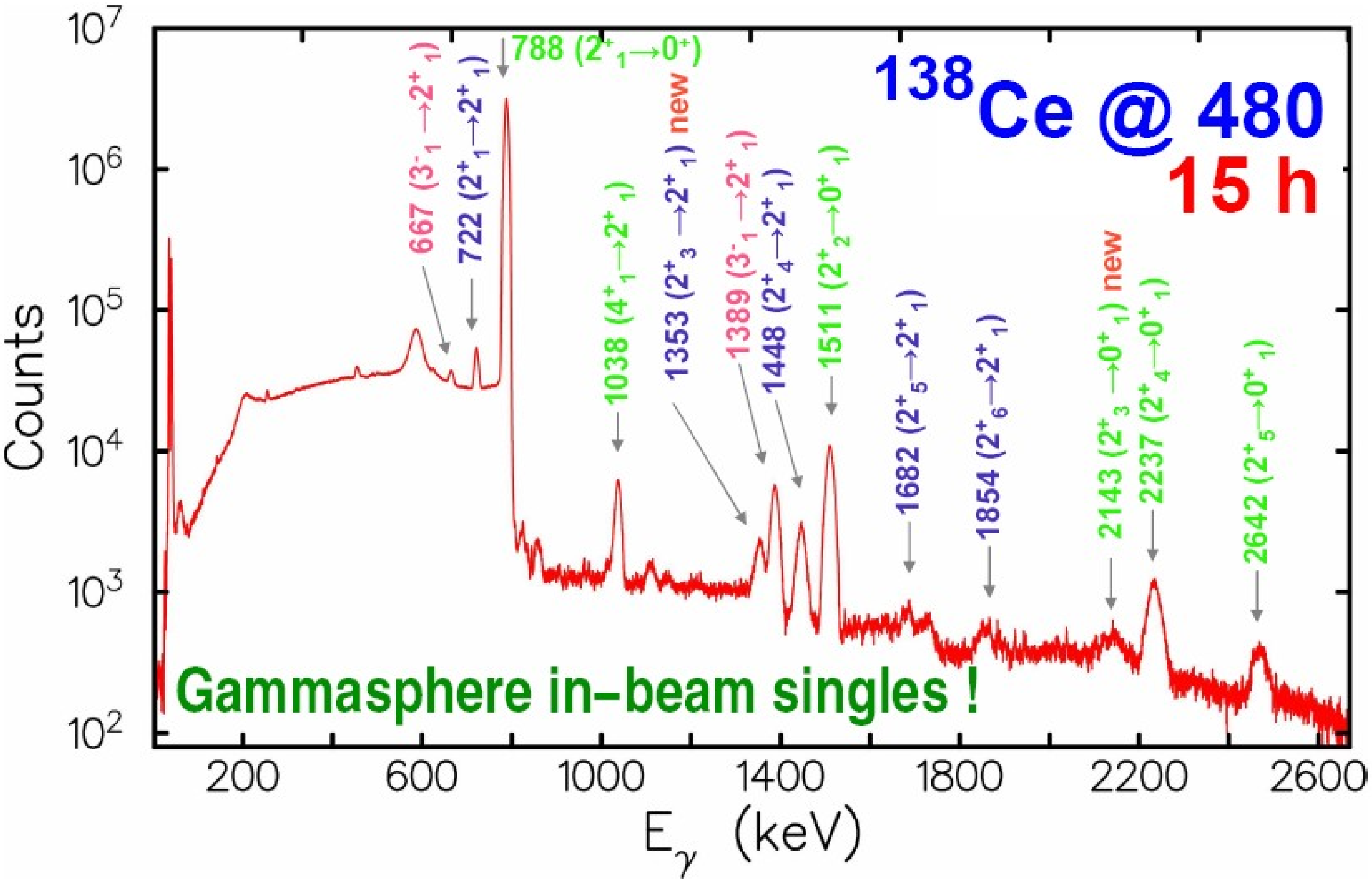
- Synergy with proposal INTC-P-296 (Grahn) (^{116,118}Te)

Request

- ^{136}Te beam ~10^5 pps on target, 510 MeV = 3.75 A MeV
- ^{58}Ni target, 3 mg/cm^2 for relative Coulex yields and diff. DSAM
- MINIBALL + Si-CD detector
- 3 shifts (one day): test beam production / impurity analysis
- 6 shifts (two days): data run
- -> est. Yield 2^+_{ms}: ~1000 counts

Example of Data (e.g. ^{138}Ce @ 480 MeV [1])

- Background subtraction
- Doppler shift corrections
- Lorentz boost corrections (v~6% c)
- Angular distributions (Gammasphere=17 rings, 17 θ)
- Coulex analysis: Coulex codes (CLX, Gosia)



[1] G.Rainovski, N. Pietralla et al., Phys. Rev. Lett. ***96*** *122501 (2006).*

Multipolarities from angular distribution (^{138}Ce)

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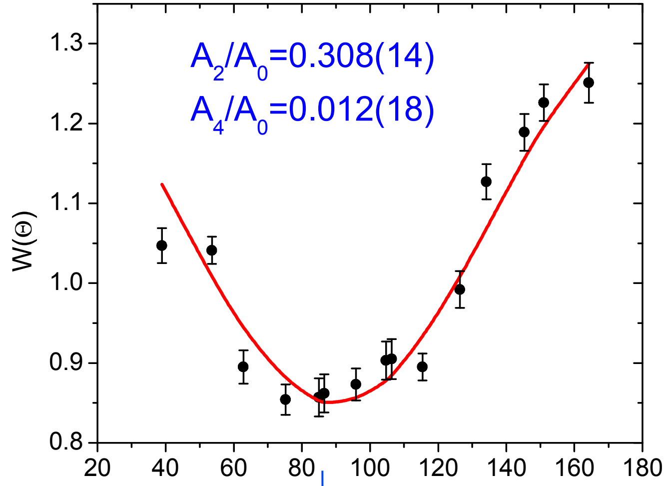
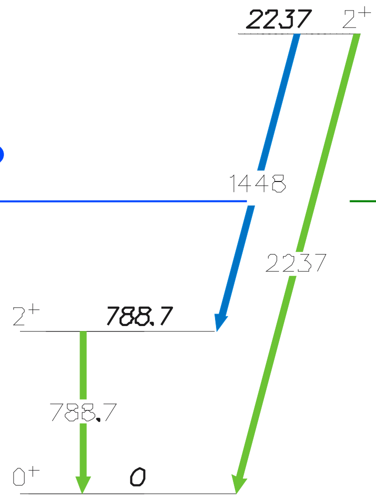
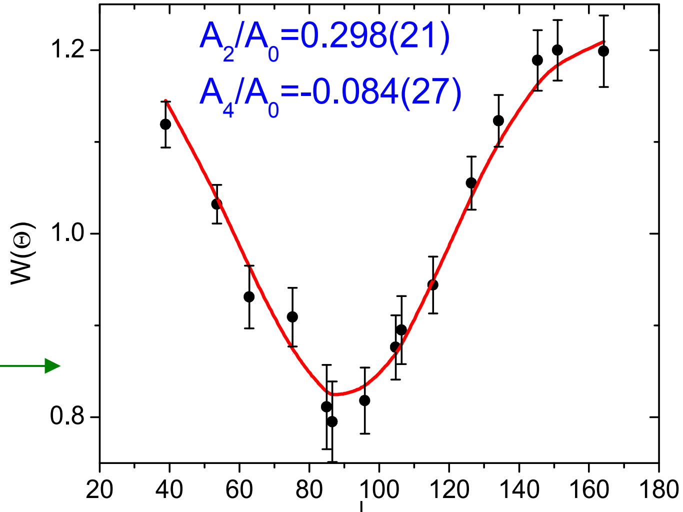
$$W(\theta,J_i,J_f,\delta) = \sum_{\kappa(even)=0}^{2} \rho_k(J_i)A_k(J_i,J_f,\delta)P_k(\cos\theta)$$



δ ?

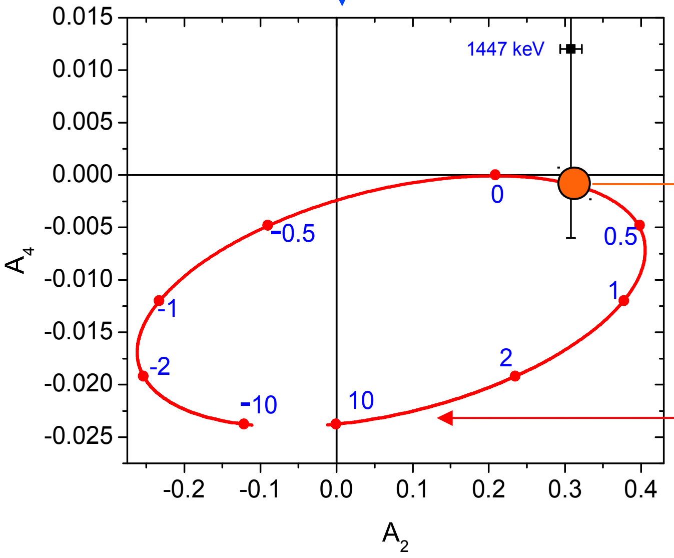


δ=0



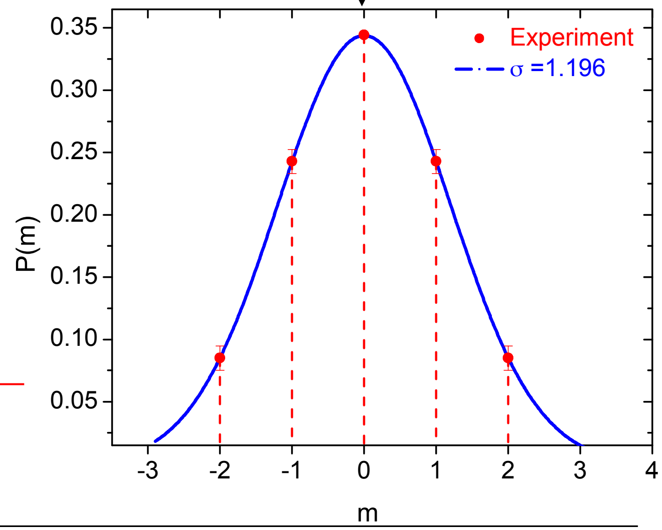
Θ

$^{\Theta}A_2/A_0$, A_4/A_0



$$\delta = 0.184^{+52}_{-42}$$

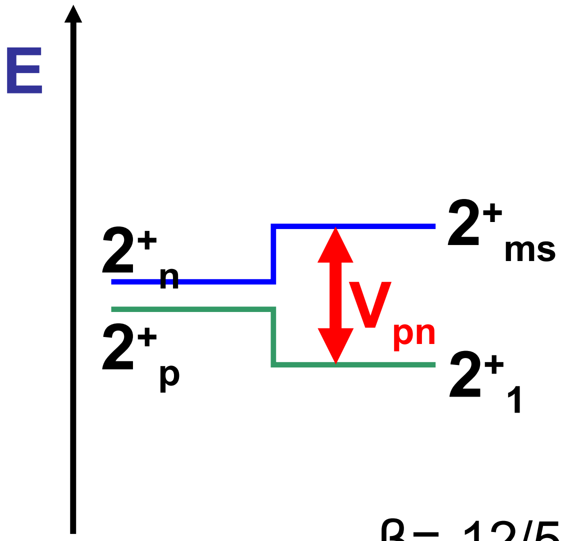
ρ_k

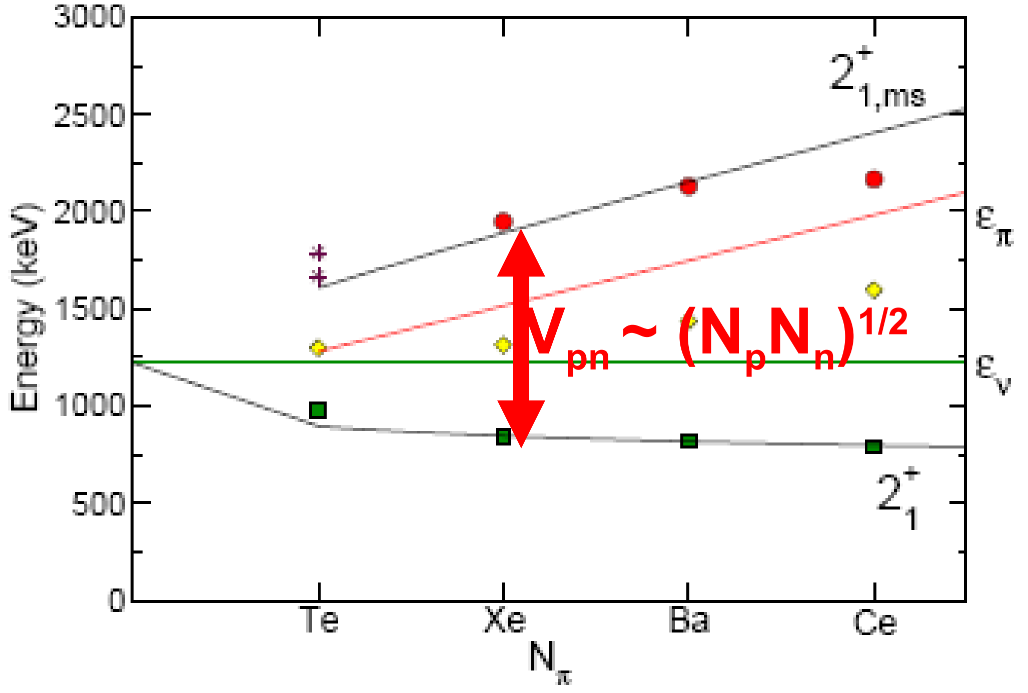


Evolution of the $2^+_{1,ms}$ in N=80

$$H=\begin{pmatrix} \varepsilon_\pi & V_{\pi\nu} \\ V_{\pi\nu} & \varepsilon_\nu \end{pmatrix}$$

with $V_{\pi\nu}=\beta\,(N_\pi N_\nu)^{1/2}$





Fit

↓

β=-0.35(1) MeV

β=-12/5 κ for j→∞

↓

κ=-0.15(1) MeV

agrees with Sau & Heyde 1981

$\epsilon_\pi = a + b*(N_\pi - 1)$ with a=E(2^+_1) of ^{134}Te

$\epsilon_\nu = cst$=E(2^+_1) of ^{130}Sn

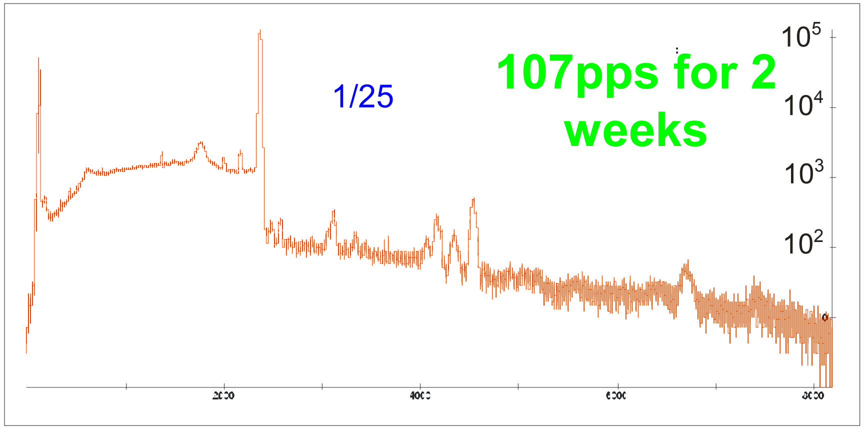
$\epsilon_{AV} = \frac{\epsilon_\pi+\epsilon_\nu}{2}$

$$E(2^+_{1,ms}) = E_{AV} + \sqrt{\tfrac{1}{4}*(\epsilon_\pi-\epsilon_\nu)^2+\beta^2*N_\pi}$$
$$E(2^+_1) = E_{AV} - \sqrt{\tfrac{1}{4}*(\epsilon_\pi-\epsilon_\nu)^2+\beta^2*N_\pi}$$

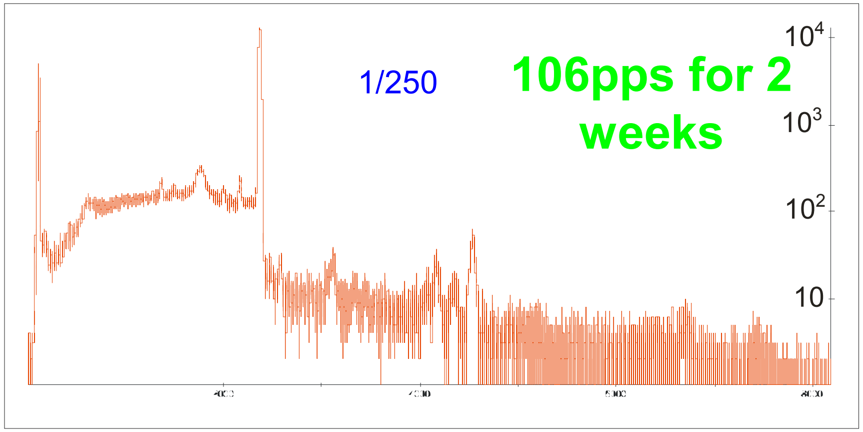
Experimental approach

Coulomb excitations in inverse kinematics on C target

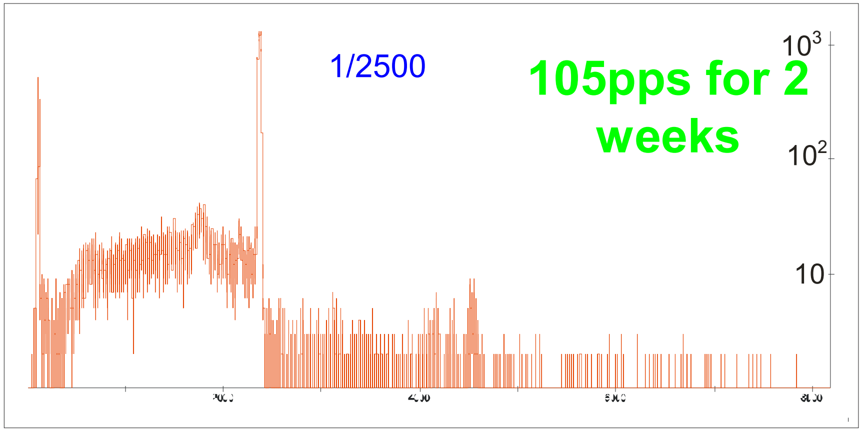
predominantly one-step processes and clean γ-spectrum (no target excitations)


1/25

107pps for 2 weeks

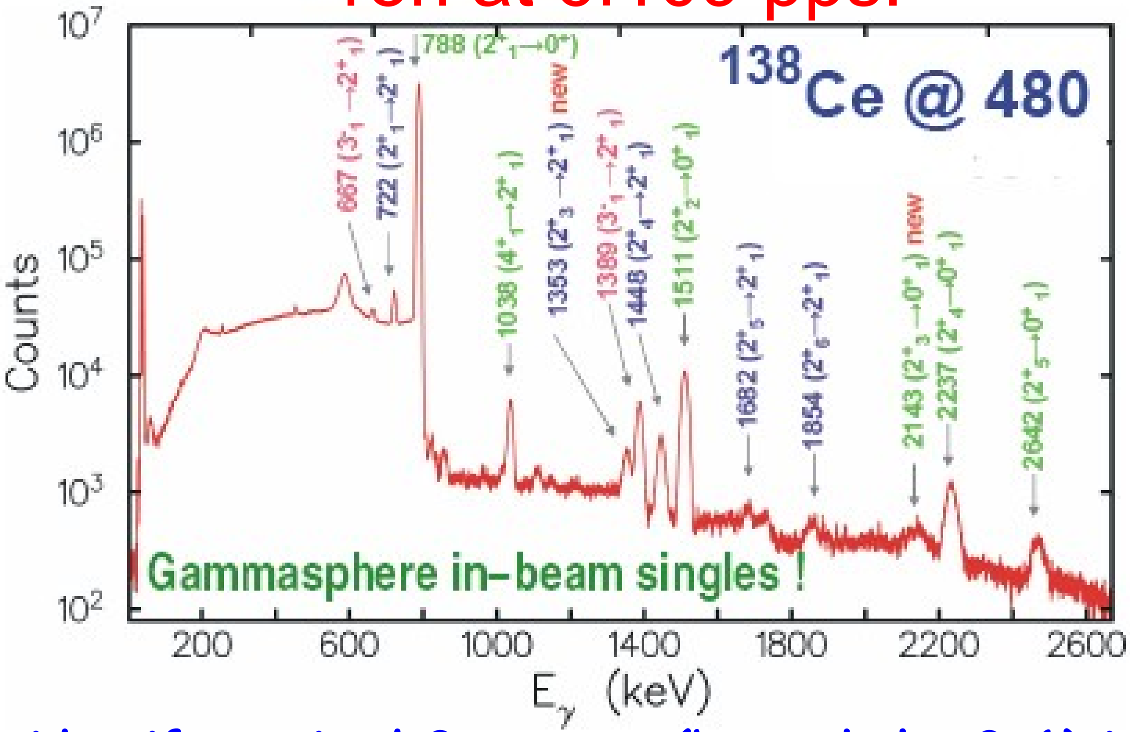

1/250

106pps for 2 weeks


1/2500

105pps for 2 weeks

15h at 6.109 pps!



To identify excited 2+ states (beyond the 2+1) in vibrational nucleus (B(E2)~1Wu) with a 10% array for 2 weeks beam time we need 105pps. For complete spectroscopy 106-107 pps will be needed!

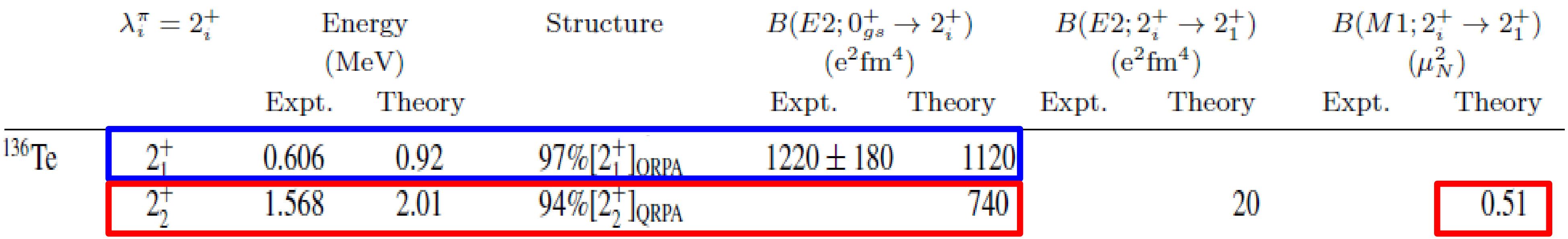
Feasible, but requires beam energy ~85% CB (3.5-4 MeV/n)

well within the capability of H-I

New CIP case predicted: 136Te

2+1 and 2+2 have significant E2 -> 1-phonon states

Strong M1 between them -> 2+2 = 2+1,MS



	$\lambda_i^\pi = 2_i^+$	Energy (MeV)		Structure	$B(E2; 0_{gs}^+ \rightarrow 2_i^+)$ (e^2fm^4)		$B(E2; 2_i^+ \rightarrow 2_1^+)$ (e^2fm^4)		$B(M1; 2_i^+ \rightarrow 2_1^+)$ (μ_N^2)	
		Expt.	Theory		Expt.	Theory	Expt.	Theory	Expt.	Theory
^{136}Te	2_1^+	0.606	0.92	$97\%[2_1^+]_{QRPA}$	1220 ± 180	1120				
	2_2^+	1.568	2.01	$94\%[2_2^+]_{QRPA}$		740		20		0.51

QPM: A.P. Severyukhin, N.N. Arsenyev, N. Pietralla, and V.W., PRC 90, 011306(R) (2014)

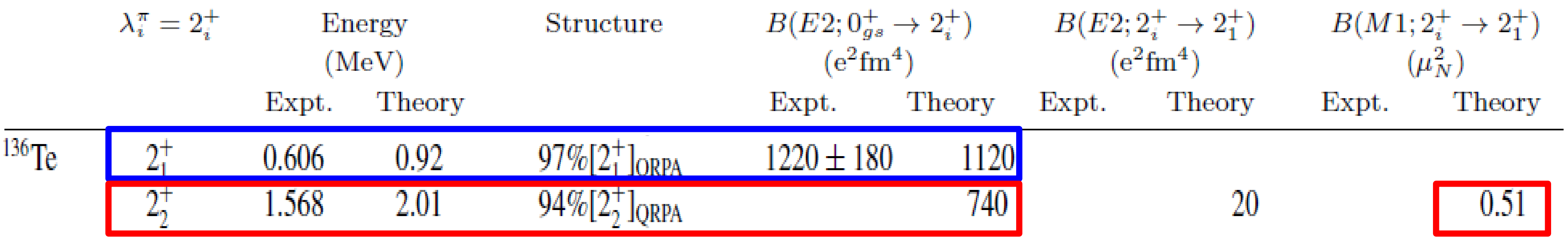
New CIP case predicted: 136Te

2+1 and 2+2 have significant E2 -> 1-phonon states

Strong M1 between them -> 2+2 = 2+1,MS

2+1 neutron dominated, 2+2 large proton amplitudes

-> CoulEx



	$\lambda_i^\pi = 2_i^+$	Energy (MeV) Expt.	Energy (MeV) Theory	Structure	$B(E2; 0_{gs}^+ \to 2_i^+)$ (e^2fm^4) Expt.	$B(E2; 0_{gs}^+ \to 2_i^+)$ (e^2fm^4) Theory	$B(E2; 2_i^+ \to 2_1^+)$ (e^2fm^4) Expt.	$B(E2; 2_i^+ \to 2_1^+)$ (e^2fm^4) Theory	$B(M1; 2_i^+ \to 2_1^+)$ (μ_N^2) Expt.	$B(M1; 2_i^+ \to 2_1^+)$ (μ_N^2) Theory
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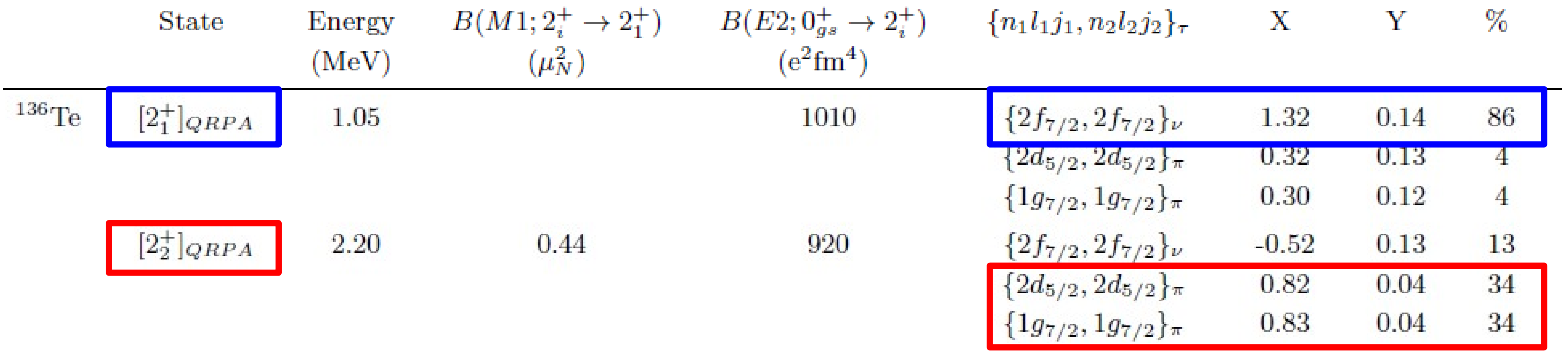
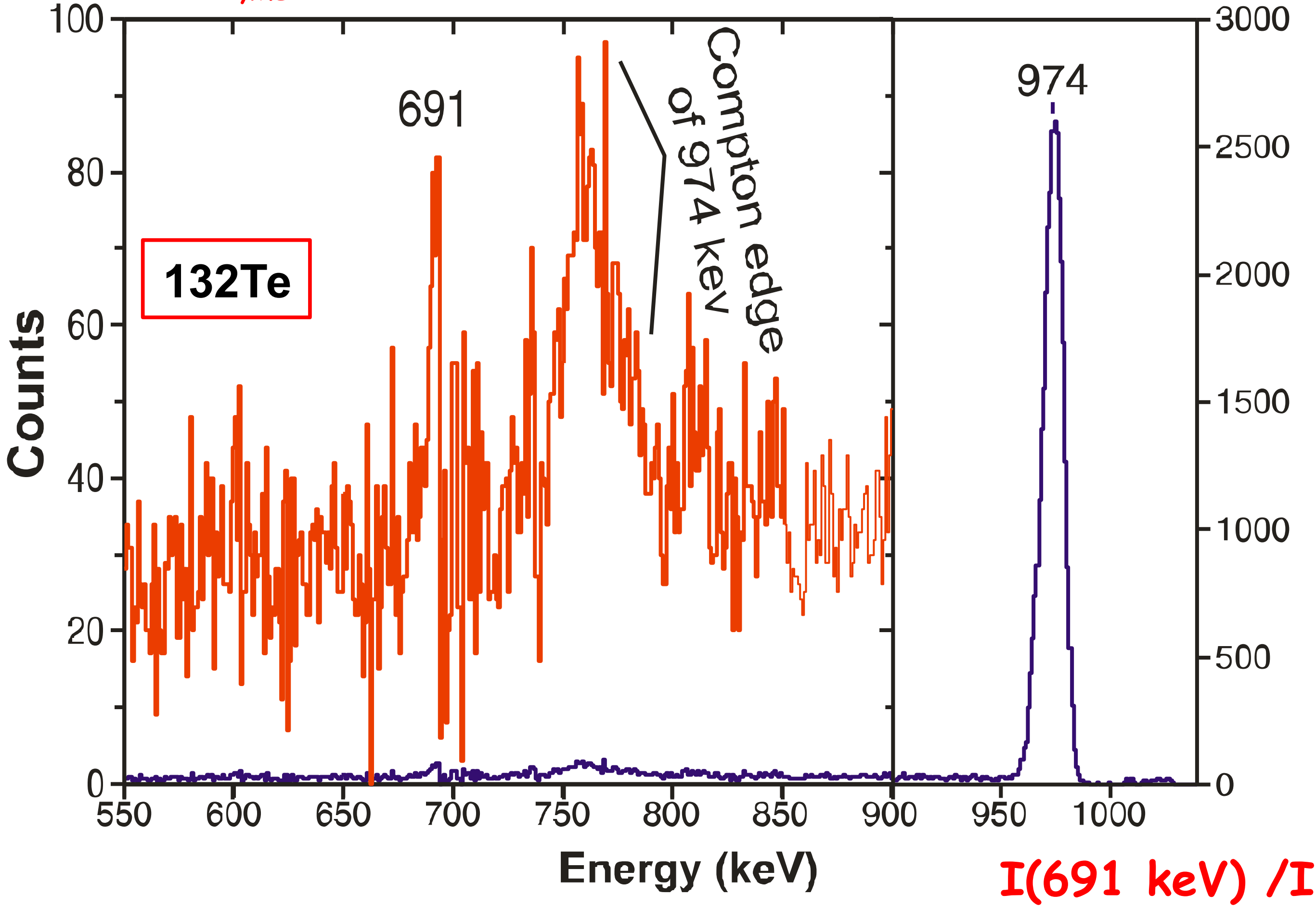


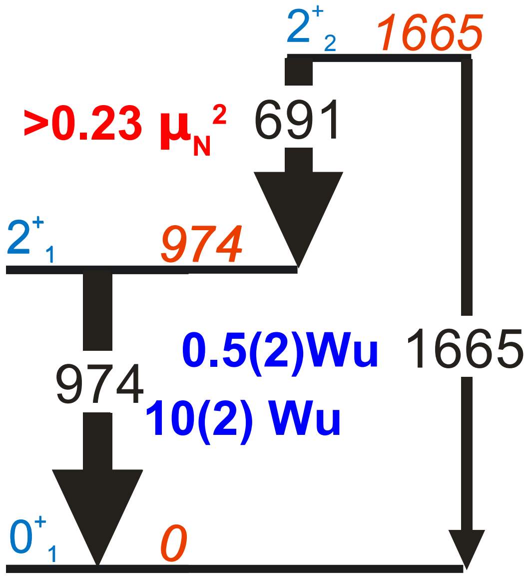
	State	Energy (MeV)	$B(M1; 2_i^+ \to 2_1^+)$ (μ_N^2)	$B(E2; 0_{gs}^+ \to 2_i^+)$ (e^2fm^4)	$\{n_1l_1j_1, n_2l_2j_2\}_\tau$	X	Y	%
^{136}Te	$[2_1^+]_{QRPA}$	1.05		1010	$\{2f_{7/2}, 2f_{7/2}\}_\nu$	1.32	0.14	86
					$\{2d_{5/2}, 2d_{5/2}\}_\pi$	0.32	0.13	4
					$\{1g_{7/2}, 1g_{7/2}\}_\pi$	0.30	0.12	4
	$[2_2^+]_{QRPA}$	2.20	0.44	920	$\{2f_{7/2}, 2f_{7/2}\}_\nu$	-0.52	0.13	13
					$\{2d_{5/2}, 2d_{5/2}\}_\pi$	0.82	0.04	34
					$\{1g_{7/2}, 1g_{7/2}\}_\pi$	0.83	0.04	34

QPM: A.P. Severyukhin, N.N. Arsenyev, N. Pietralla, and V.W., PRC 90, 011306(R) (2014)

First MS observation with RIB

$2_{1,MS}^+$ observed in coincidence with 12C recoils detected in HyBall.





M. Danchev *et al.*, PRC84 ('11) 061306(R)

I(691 keV) /I(1665 keV) = 100 (52)

Note: in ^{136}Te E(2_1^+ -> 0_1^+) = 606 keV ; E(2_2^+ -> 2_1^+) = 962 keV => no Compton, cleaner !!

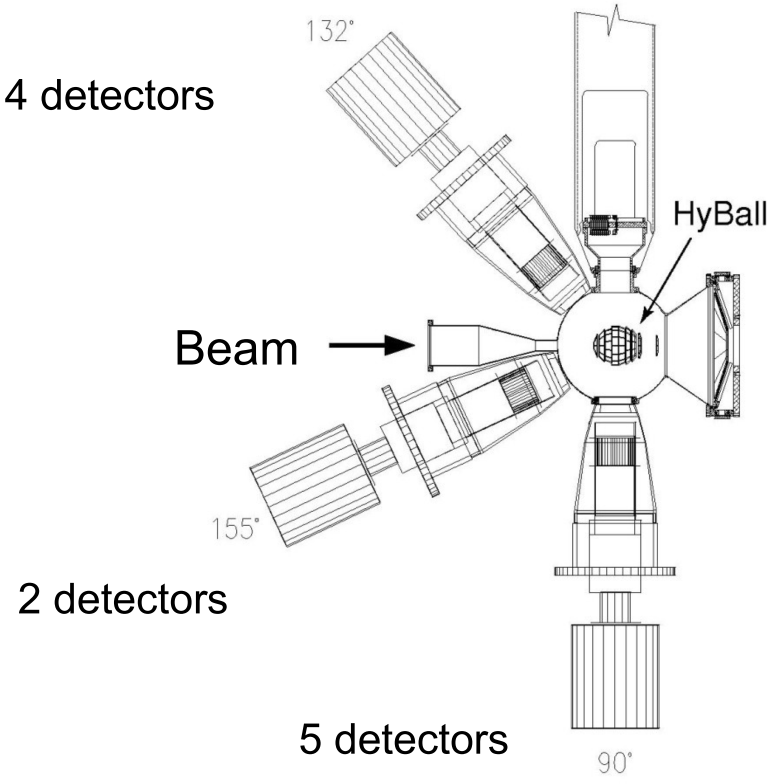
ORNL – 2_1^+ g factor Experiment

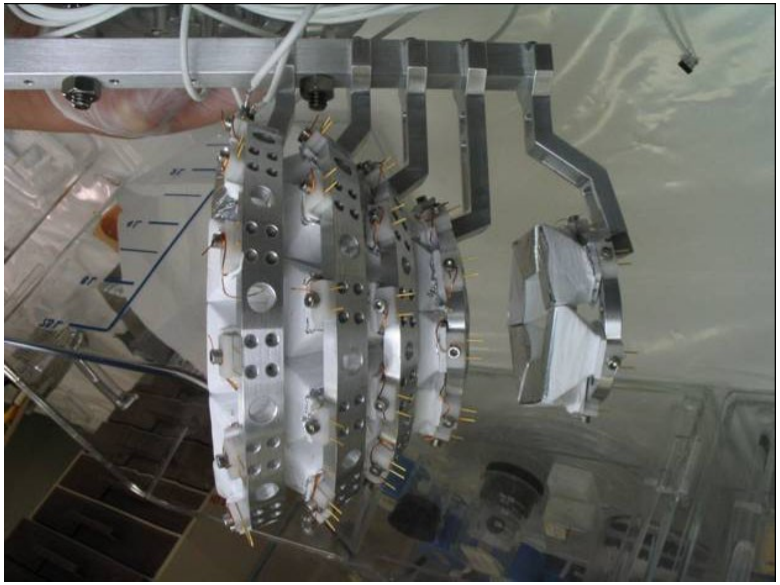
Experimental details:

- inverse kinematic reaction 132Te on a C target (0.83 mg/cm2);
- beam energy 3 MeV/u (80% CB);
- beam intensity 3 x 10^7 pps, run time 64 hours;

Clarion array – 11 clovers

HyBall array



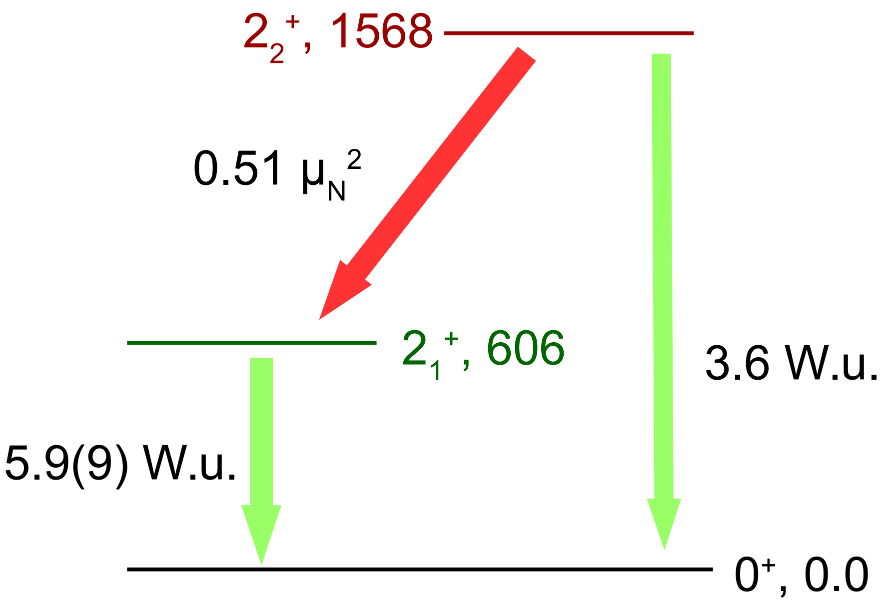


CsI charged particle detectors:

Ring 1 –	6 detectors	7° - 14°
Ring 2 –	10 detectors	14° - 28°
Ring 3 -	12 detectors	28° - 44°

CIP in ^{136}Te

Enhanced Proton Content in second 2^+ yields exceptionally large B(E2)



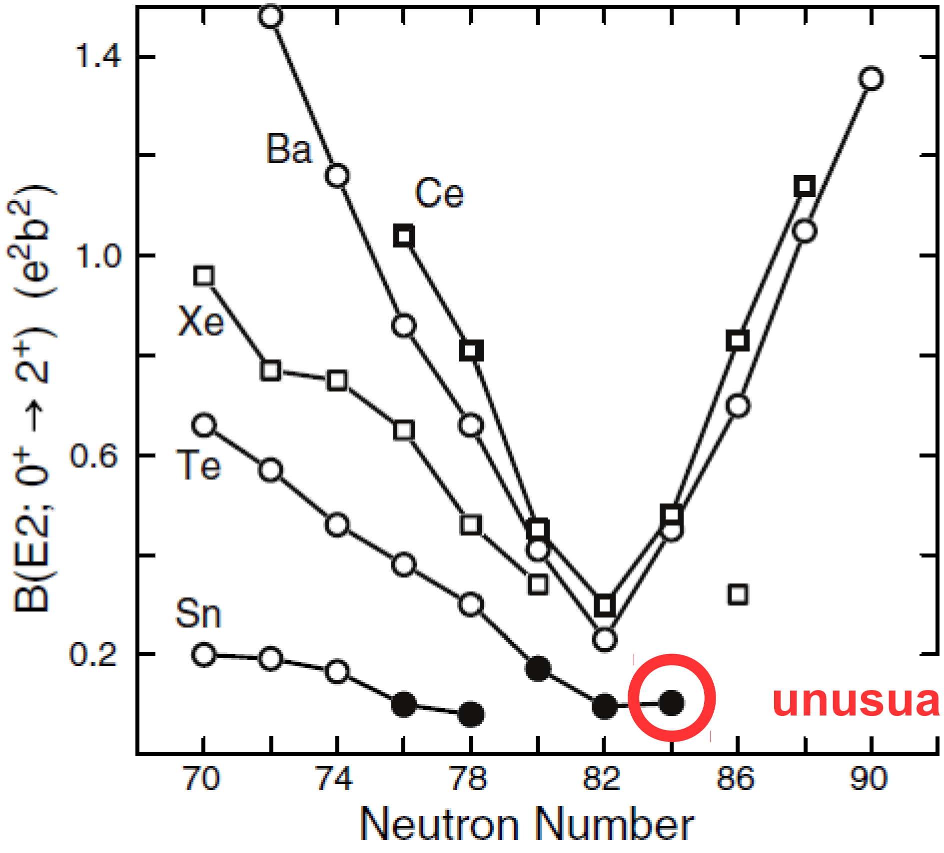
Other theory:

Shell Model:
N. Shimizu, T. Otsuka, T. Mizusaki, M. Honma, PRC 70, 054313 (2004)
2_1^+ neutron dominated;
2_2^+ is MS state, M1: $0.24\ \mu_N^2$, E2 300 e^2fm^4

QRPA:
J. Terasaki et al., PRC 66, 054313 (2002)

M. Danchev, G. Rainovski,
N. Pietralla et al.,
PRC 84, 061306(R) (2011)
B(E2)up = 1220(180) e^2fm^4

B(E2) “anomaly” in ^{136}Te



unusually small

Origin of the anomaly:

Neutron dominance in the 2_1^+ wave function

Shell Model:
N. Shimizu, T. Otsuka, T. Mizusaki, M. Honma, PRC 70, 054313 (2004)
2_1^+ neutron dominated; 2_2^+ is MS state

QRPA:
J. Terasaki et al., PRC 66, 054313 (2002)

D.C. Radford et al., PRL 88, 222501 (2002)

Configurational Isospin Polarization (CIP)

$$2^+_{sym} = a_1 \cdot 2^+_n + b_1 2^+_p$$

$$2^+_{ms} = a_2 \cdot 2^+_n - b_2 2^+_p$$

protons and neutrons contribute about equally: large mixing

$$|a_i| \approx |b_i|$$

imbalance in proton and neutron contributions: small mixing

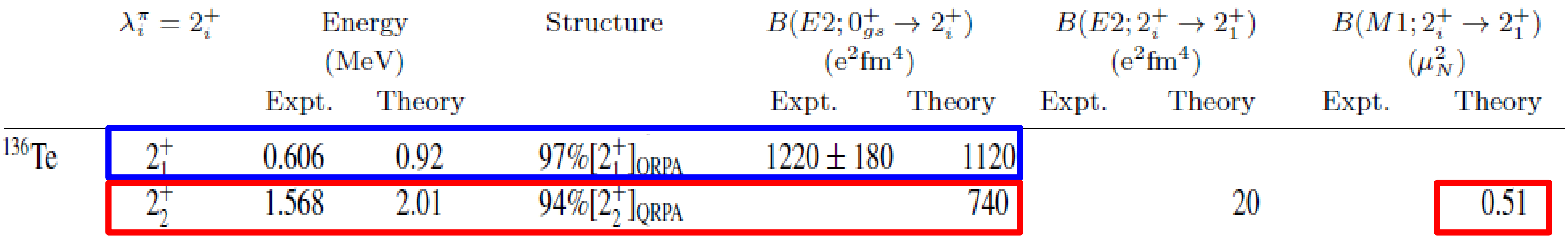
$$|a_i| \neq |b_i|$$

observables which are sensitive to p/n content:
B(E2)'s and M1

New CIP case predicted: 136Te

2+1 and 2+2 have significant E2 -> 1-phonon states

Strong M1 between them -> 2+2 = 2+1,MS



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$[2_1^+]_{QRPA}$ = ~86% Neutron, $[2_2^+]_{QRPA}$ ~68% Proton

QPM: A.P. Severyukhin, N.N. Arsenyev, N. Pietralla, and V.W., PRC 90, 011306(R) (2014)

Other theory:

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