Coulomb excitation of neutron-rich Sn, Te and Xe isotopes beyond N=82

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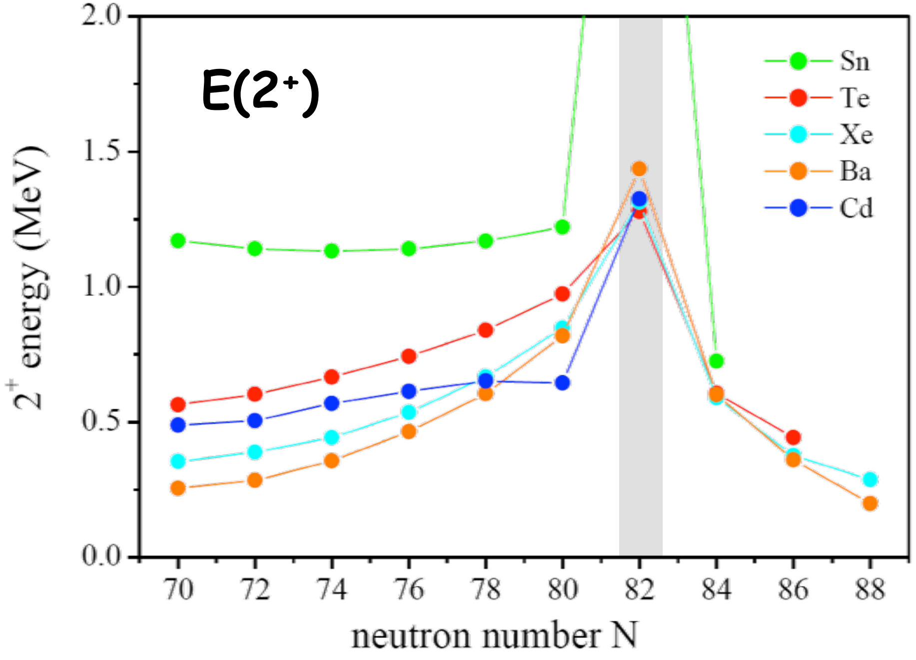
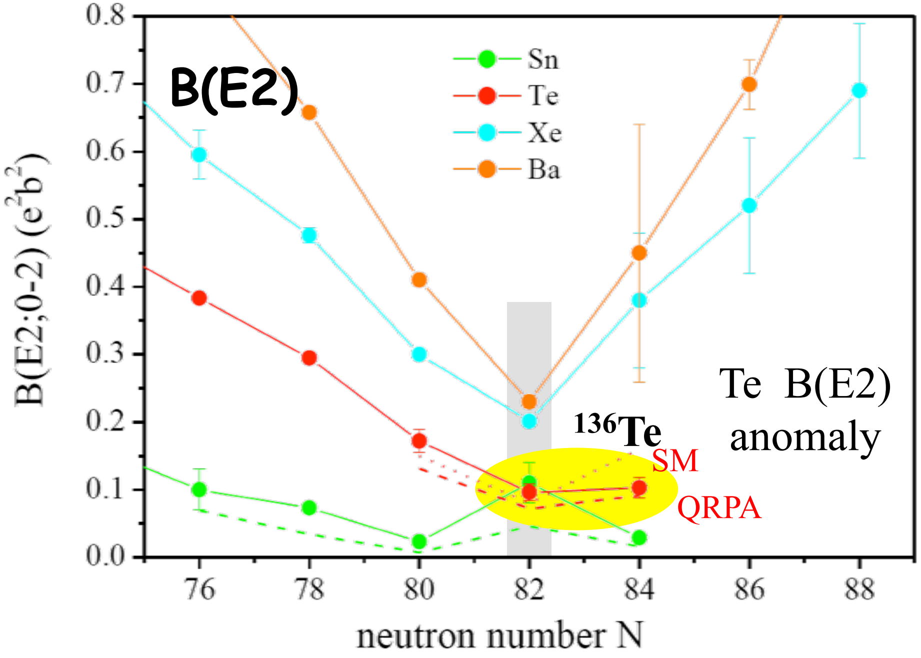
In concertation with the Miniball and PreSpec-AGATA collaboration

Development of collectivity around ^{132}Sn





slight E(2^+) and B(E2) asymmetries with respect to N=82

E(2^+) for N=82+x < E(2^+) for N=82-x

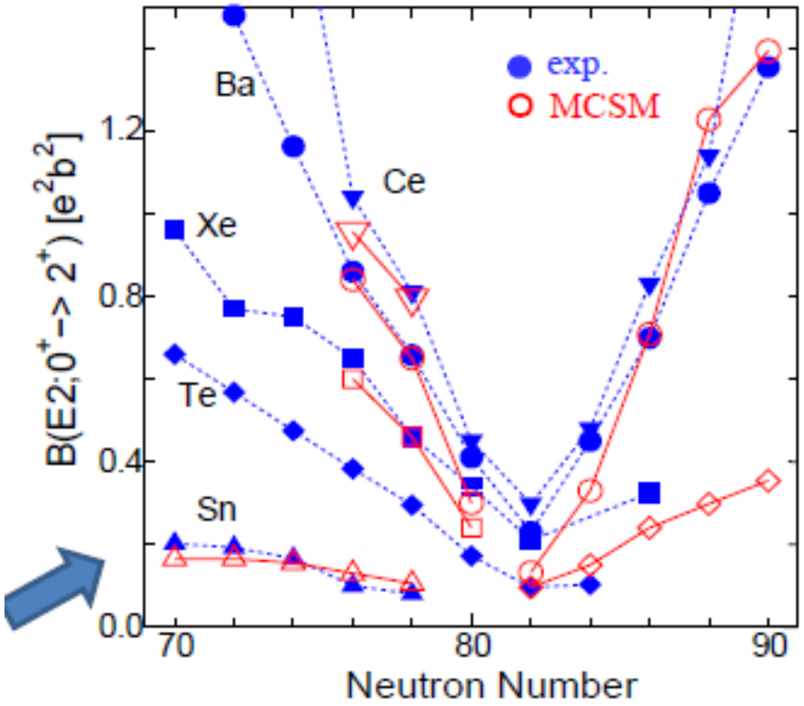
B(E2) for N=82+x > B(E2) for N=82-x

except for the Te isotopes !

$$E(2_1^+)B(E2\uparrow) = \frac{2.57Z^2}{A^{2/3}}\left(1.288 - 0.088(N-\bar{N})\right) \quad \text{with} \quad \bar{N} = \frac{A}{2}\,\frac{1.0070+0.0128A^{2/3}}{1+0.0064A^{2/3}}$$

Raman’s version of Grodzins’ formula

Anomalous behaviour of B(E2) values in ^{136}Te



B(E2) = 0.103(15) e^2b^2
from low-energy Coulex

D. Radford et al., Phys. Rev. Lett. 88 (2002) 222501
D. Radford et al., Nucl. Phys. A752 (2005) 264c

reanalysing the data yielded slightly larger value

D. Radford, private communication

B(E2) = 0.122(24) e^2b^2
from lifetime measurement (fast timing)

L.M. Fraile, H. Mach et al., Nucl. Phys. A805 (2008) 218

shell model B(E2) = 0.25 e^2b^2

D. Radford, A. Covello et al., Phys. Rev. Lett. 88 (2002) 222501

QRPA B(E2) = 0.09 e^2b^2

J. Terasaki et al., Phys. Rev. C66 (2002) 054313

shell model B(E2) = 0.15 e^2b^2

N. Shimizu, T. Otsuka et al., Phys. Rev. C 70 (2004) 054313

Measure B(E2) of higher lying states in ^{136}Te and extend 2^+ systematic to ^{138}Te & ^{140}Te

Structure of excited states in ^{136}Te

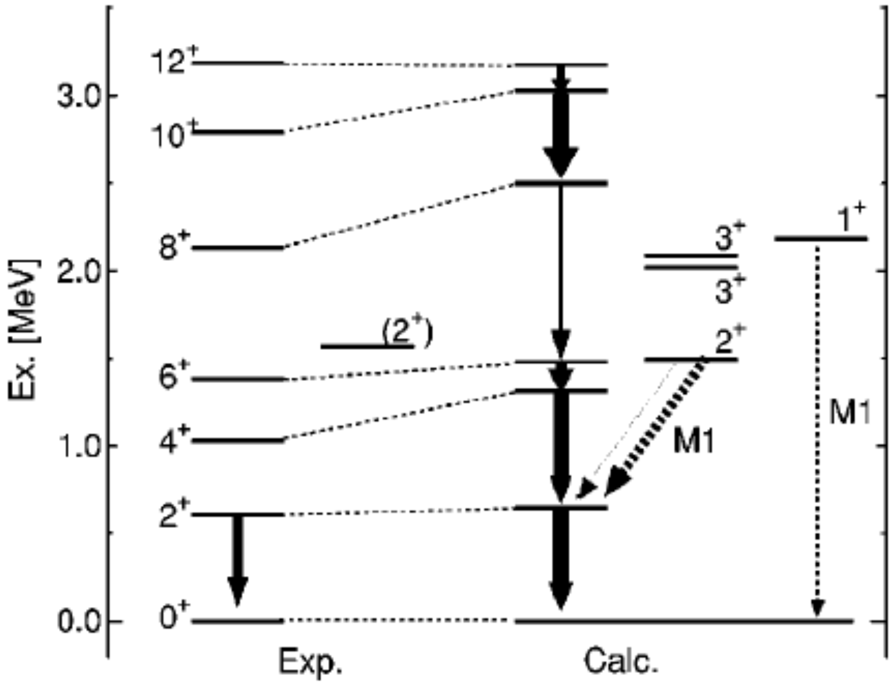
^{136}Te (Z=52, N=84) as ^{132}Sn core
+ 2qp **proton** excitation **D_π**
+ 2qp **neutron** excitation **D_ν**

$$|0_1^+\rangle = 0.91 \times |S_\nu \times S_\pi\rangle + \cdots ,$$

$$|2_1^+\rangle = 0.82 \times |D_\nu \times S_\pi\rangle + 0.45 \times |S_\nu \times D_\pi\rangle + \cdots ,$$

$$|2_2^+\rangle = 0.38 \times |D_\nu \times S_\pi\rangle - 0.76 \times |S_\nu \times D_\pi\rangle + \cdots ,$$

Monte-Carlo Shell Model (MCSM)
with quasi-particle basis
Shimizu et al., PRC70, 054313 (2004)



First 2^+ state: **$+D_\nu$ > $+D_\pi$** → **smaller B(E2)** **than in ^{132}Te**
Second 2^+ state: **$+D_\nu$ $-D_\pi$** → **mixed-symmetry state** **(M1 decay dominant)**

Coulomb excitation of ^{136}Te at SPIRAL2 Day-1

Example: ^{136}Te + ^{208}Pb @ 540 MeV (safe energy)
Beam : 10^7 pps → 1600 Hz (elastic rate for $15° < \theta_{Lab} < 50°$)

State	energy	cross section	Rate	γ yield	γ branch
I^p	[keV]	s[b]	[Hz]	[cts/UT]	$I_i^p \rightarrow I_f^p$
0^+	0	55	1600^a	-	-
2_1^+	606.6	2	6	170,000	$2^+ \rightarrow 0^+$
4^+	1030.0	0.04	0.1	3000	$4^+ \rightarrow 2^+$
6^+	1382.6	3.10^{-4}	0.001	30	$6^+ \rightarrow 4^+$
2_2^+	1568.4	0.06^b	0.2	5000 200	$2_2^+ \rightarrow 2_1^+$ $2_2^+ \rightarrow 0^+$
2_3^+	2060.9	0.016^b	0.05	1400 50	$2_3^+ \rightarrow 2_1^+$ $2_2^+ \rightarrow 0^+$

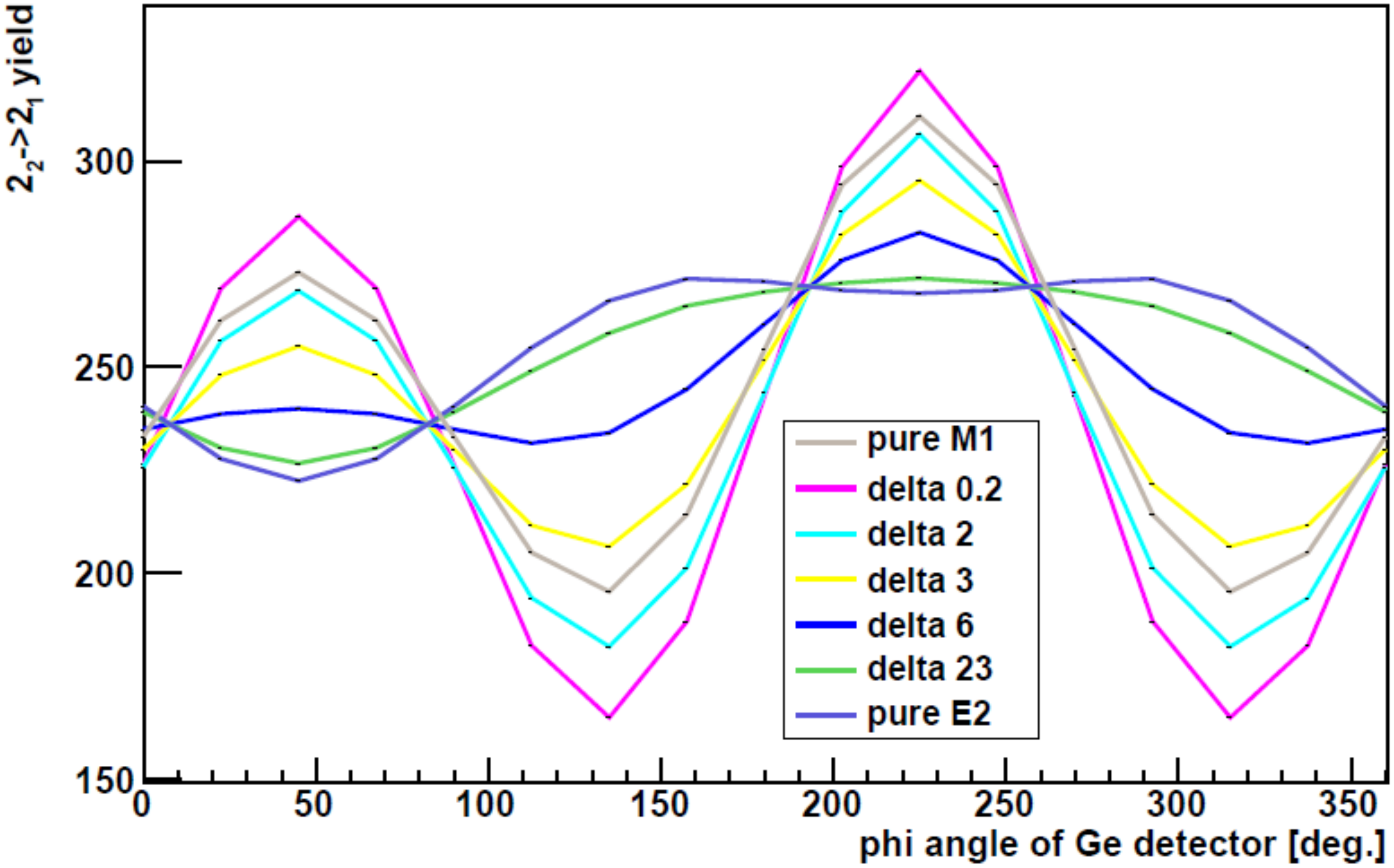
Precision measurement of first 2^+ state : B(E2) and **Q(2^+)**
Evolution of collectivity with spin **up to 6^+ state**
Characterisation of all (collective) **2^+ states up to ~ 2 MeV**

Identification of the 2^+ mixed-symmetry state

Example: ^{136}Te + ^{208}Pb @ 540 MeV

Need **~10^4 counts** in $2_2 \rightarrow 2_1$ to disentangle **M1/E2 decay** (2-10 UT)

Ex.: angular distribution from 90° EXOGAM detectors



Collectivity in doubly-magic ^{132}Sn

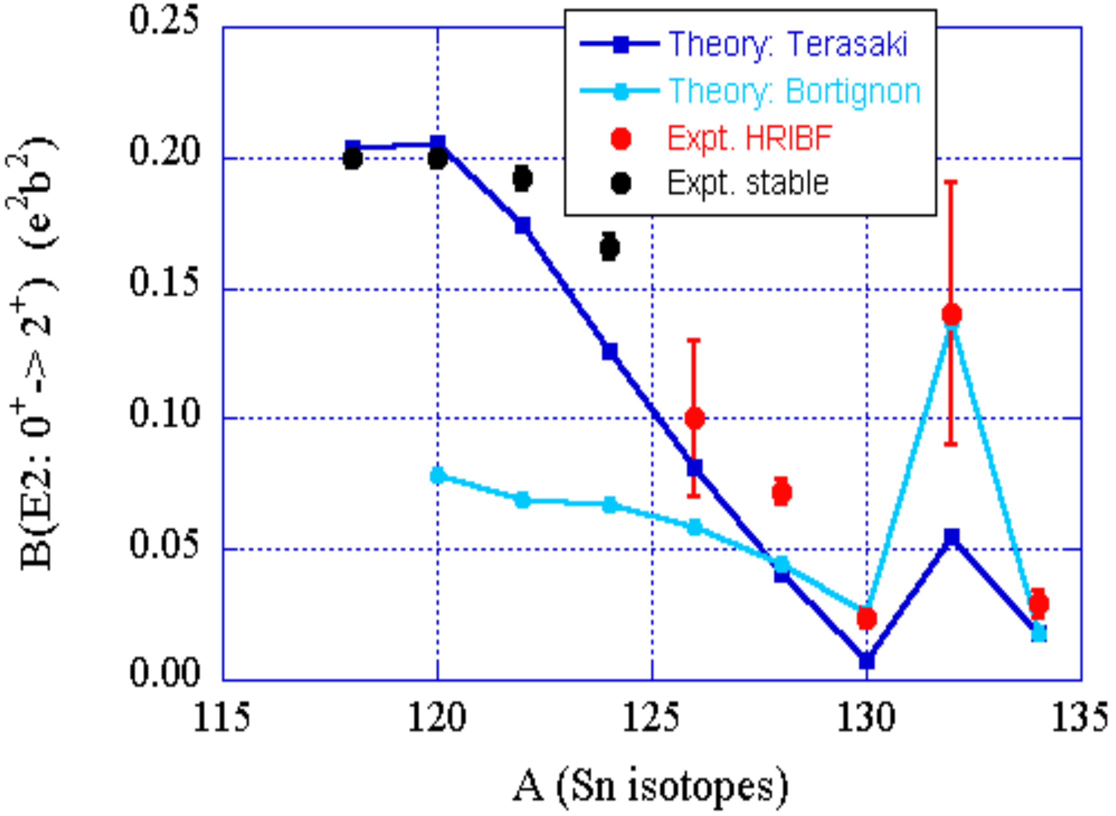
Doubly magic nucleus ^{132}Sn is **key for shell model calculations**

- High lying 2^+ state : **$E(2^+) = 4041$ keV**

➔ Very difficult experiment in low-energy Coulomb excitation

2^+ state is **superposition of 2p-2h proton and neutron excitations**

- **Enhanced B(E2)** value (as compared to neighbouring Sn isotopes)



Coulomb excitation of ^{132}Sn at HRIBF

- ^{132}Sn beam, doubly stripped
    - 96% pure
    - 1.3 x 10^5 ions/s
    - 3.75 & 3.56 MeV/nucleon
- ^{48}Ti target
- High γ efficiency BaF_2 array (~40%)
- Two-week experiment
- Fast γ–ion coincidences to suppress background

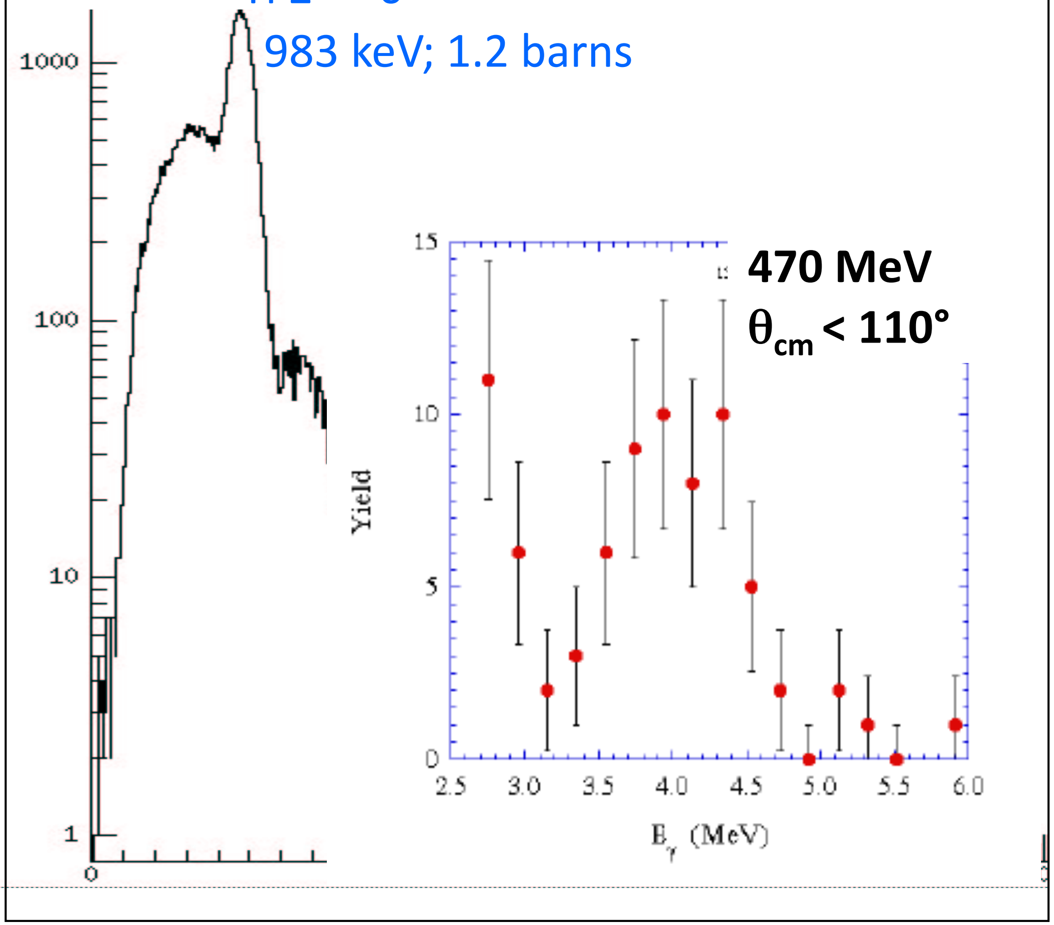
B(E2; $0^+ \rightarrow 2^+$) ~ 0.11(3) e^2b^2

R.L. Varner et al., Eur. Phys. J. A25, 391 published in ENAM 2005 proceedings

Sample gamma-ray spectrum:

- *~30% of data*
- *Crystal gain matching & background suppression not yet optimum*

D. Radford RNB6 (2003)



^{48}Ti $2^+ \rightarrow 0^+$

983 keV; 1.2 barns

470 MeV

θ_{cm} < 110°

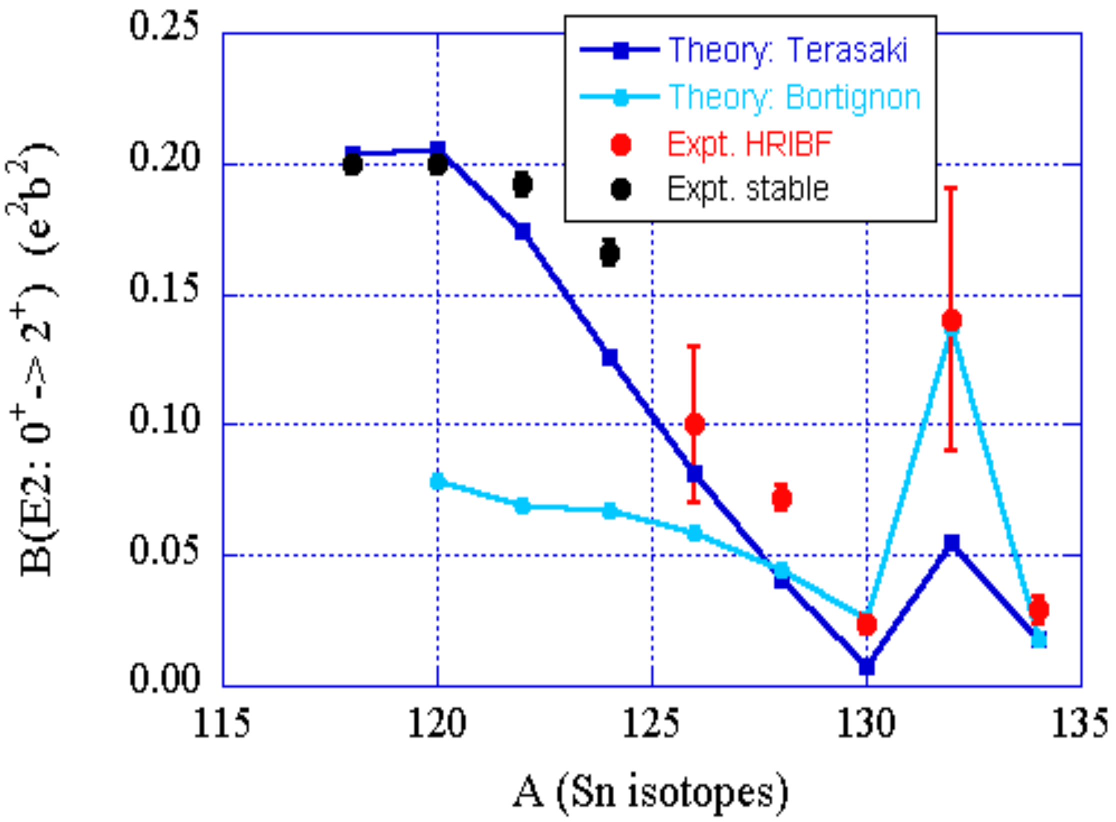
Day 2: Coulomb excitation of ^{132}Sn at SPIRAL2

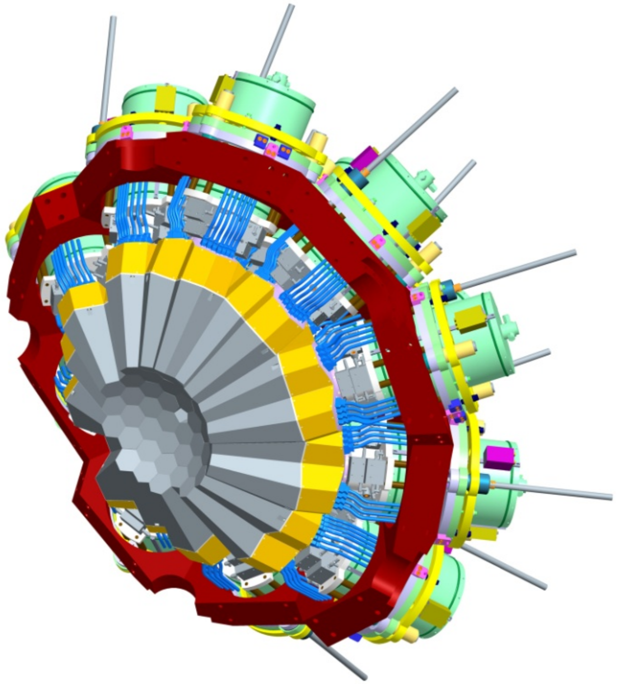
SPIRAL2 "Day-1 intensities" :

1 x 10^7 ions/s @ 4.5 MeV/u; ^{208}Pb target

$\sigma(2^+)$ ~3mb & $\sigma(3^-)$ > 5mb (from τ limit)

→ 1000 cts in ~10UT will allow precise determination of **π vs. ν contribution**





AGATA 1π (ε~5%@4 MeV)
EXOGAM or PARIS 1-2π

Conclusions

Proposed SPIRAL2 Day-1 Coulomb excitation experiments

- Te isotopes
  - ^{136}Te ($10^7 s^{-1}$): full study of collectivity up to ~2 MeV
  - ^{138}Te ($10^5 s^{-1}$): B(E2) and Q of first 2^+ state
  - ^{140}Te ($10^3 s^{-1}$): Energy and B(E2) of first 2^+ state
- Sn isotopes (see also Loi of Lozeva et al.)
  - ^{132}Sn ($10^7 s^{-1}$): B(E2; $0^+ \rightarrow 2^+$) and B(E3; $0^+ \rightarrow 3^-$)
  - ^{133}Sn ($6.10^5 s^{-1}$): search for collective states $2^+ \times nl_j$
- Xe isotopes
  - Study of octupole collectitvity beyond N=82
  - ^{142}Xe/^{144}Xe ($10^{7/5} s^{-1}$)

- **g-factor measurements** after Coulomb excitation also possible through recoil-in-vacuum method (see Loi of Stuchberry et al.)

SPIRAL2 projected Day 1 intensities

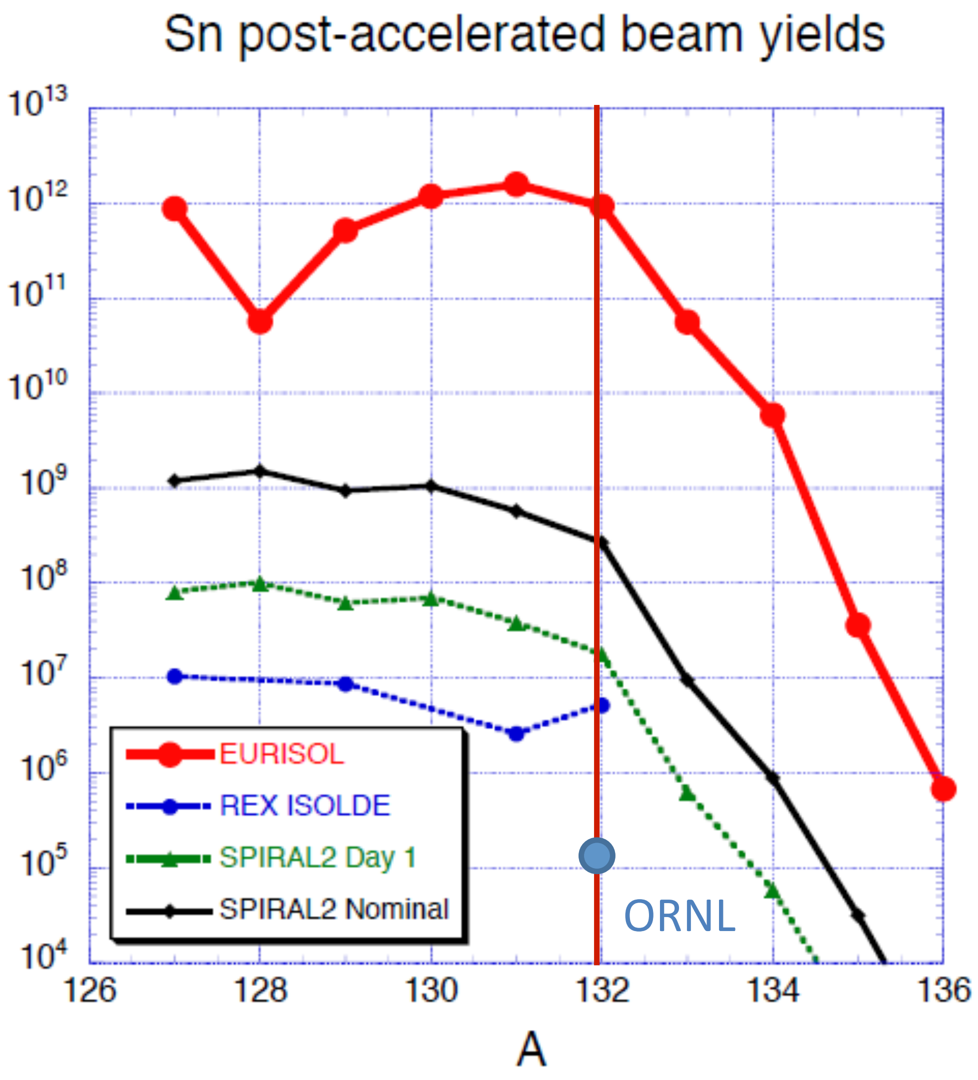
Isotope	Half life	E_{nom} / A·MeV	$I(E_{nom})$ / pps	E_{min} / A·MeV	$I(E_{min})$ / pps	E_{max} / A·MeV	$I(E_{max})$ / pps
79Zn	995 ms	6.2	2.1E+04	1.5	2.1E+04	12.3	2.0E+03
80Zn	545 ms	6.0	6.2E+03	1.5	6.4E+03	12.0	6.1E+02
86Kr	stbl	7.1	5.8E+08	1.8	5.7E+08	14.4	5.8E+07
87Kr	76.3 m	6.9	5.9E+08	1.7	5.9E+08	14.1	5.9E+07
88Kr	2.84 h	6.8	7.0E+08	1.7	7.0E+08	13.8	7.0E+07
89Kr	3.15 m	6.6	7.5E+08	1.6	7.5E+08	13.5	7.5E+07
90Kr	32.32 s	6.5	6.4E+08	1.6	6.4E+08	13.2	6.4E+07
91Kr	8.57 s	6.3	5.2E+08	1.6	5.2E+08	12.9	5.2E+07
92Kr	1.84 s	6.2	2.6E+08	1.5	2.7E+08	12.6	2.6E+07
93Kr	1.286 s	6.1	8.8E+07	1.5	8.9E+07	12.3	8.6E+06
94Kr	210 ms	5.9	1.2E+07	1.5	1.3E+07	12.1	1.1E+06
95Kr	114 ms	5.8	1.1E+06	1.4	1.3E+06	11.8	1.0E+05
96Kr	80 ms	5.7	1.1E+05	1.4	1.2E+05	11.6	9.2E+03
131Sn	56 s	5.1	8.2E+06	1.3	8.2E+06	9.7	8.2E+05
131Sn	58.4 s	5.1	3.0E+07	1.3	3.0E+07	9.7	3.0E+06
132Sn	39.7 s	5.0	1.8E+07	1.2	1.8E+07	9.6	1.8E+06
133Sn	1.45 s	4.9	6.3E+05	1.2	6.4E+05	9.4	6.2E+04
134Sn	1.12 s	4.8	5.9E+04	1.2	6.0E+04	9.3	5.8E+03
136Te	17.63 s	5.2	1.6E+07	1.3	1.6E+07	9.8	1.6E+06
135Xe	9.14 h	5.3	1.6E+09	1.3	1.6E+09	9.9	1.6E+08
135Xe	15.29 m	5.3	2.7E+08	1.3	2.7E+08	9.9	2.7E+07
136Xe	stbl	5.2	1.9E+09	1.3	1.9E+09	9.8	2.0E+08
137Xe	3.818 m	5.1	1.4E+09	1.3	1.4E+09	9.6	1.4E+08
138Xe	14.08 m	5.1	1.2E+09	1.3	1.2E+09	9.5	1.2E+08
139Xe	39.68 s	5.0	8.2E+08	1.2	8.2E+08	9.3	8.2E+07
140Xe	13.6 s	4.9	4.9E+08	1.2	4.9E+08	9.2	4.9E+07
141Xe	1.73 s	4.9	1.0E+08	1.2	1.0E+08	9.1	1.0E+07
142Xe	1.22 s	4.8	2.9E+07	1.2	2.9E+07	9.0	2.8E+06

ORNL:

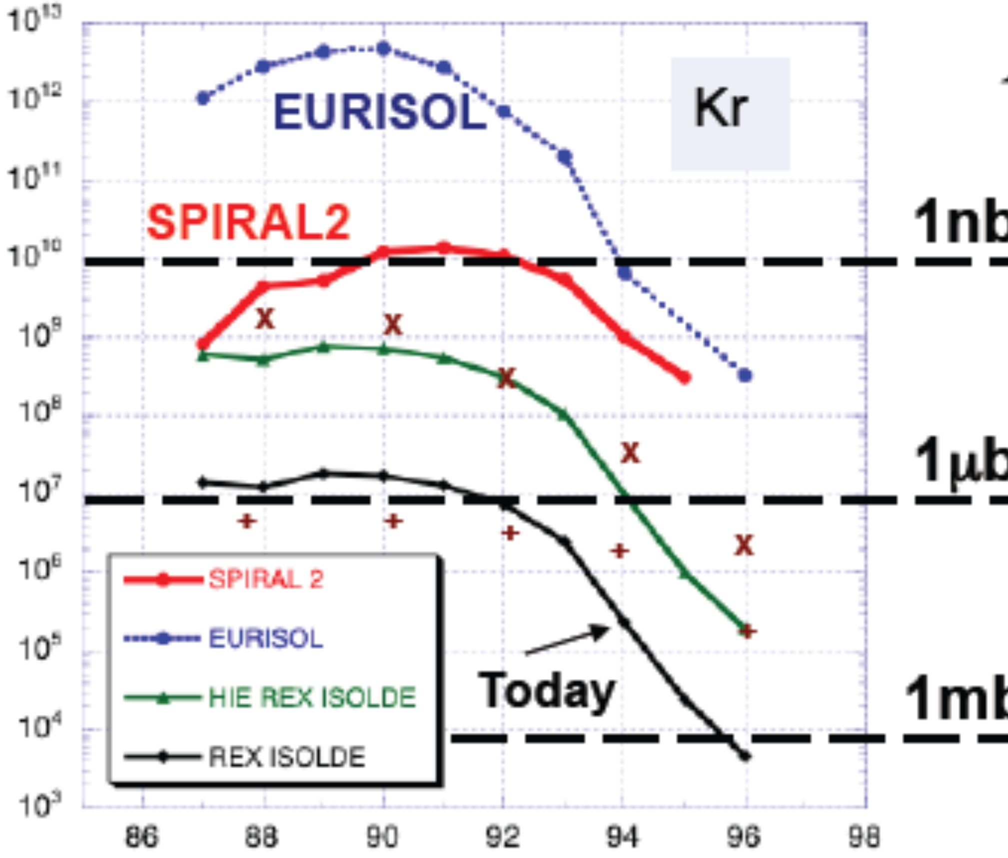
1.3 10^5 pps@3.7 MeV/u (96% pure)

2 10^4 pps

Comparison of SPIRAL2 projected intensities



Sn post-accelerated beam yields



All intensities projected numbers, besides ORNL