

Probing the doubly magic shell closure at ^{132}Sn by Coulomb excitation of neutron-rich $^{130,134}\text{Sn}$ isotopes Addendum to IS702

- Status IS702
- Shell model results around ^{132}Sn
- ^{134}Sn experiment at HIE-ISOLDE
- rate estimates, beam time request

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Collaboration

Addendum to the ISOLDE and Neutron Time-of-Flight Committee

IS702: Probing the doubly magic shell closure at ^{132}Sn by Coulomb excitation of neutron-rich $^{130,134}\text{Sn}$ isotopes

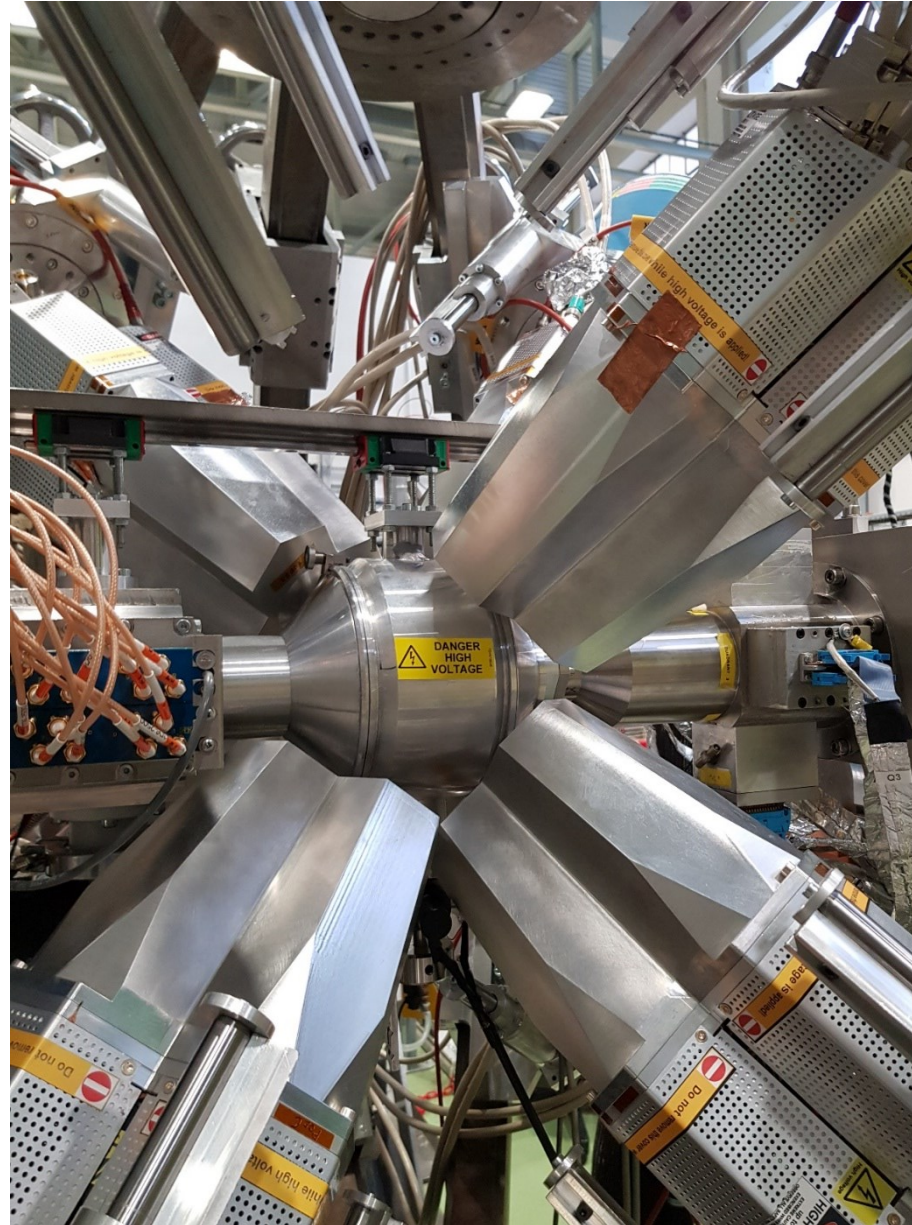
P. Reiter, Th. Kröll, **M. Droste***, K. Arnsward, A. Blazhev, H. Hess, H. Kleis, N. Warr, C. Henrich, A.-L.Hartig, H.-B. Rhee, M. Rudigier, C. Sürder, I. Homm, N. Pietralla, M. Scheck, R. Gernhäuser, H. De Witte, M. Huyse, P. Van Duppen, P. Thioolf, L. P. Gaffney, A. Jungclaus, K. Wimmer, G. Georgiev, J. Cederkäll, G. Rainovski, D. Kocheva, K. Gladnishki, D. Bucurescu, N. Marginean, R. Marginean, D. Deleanu, A. Negret, D. Balabanski, K. Hadynska-Klek, K. Wrzosek-Lipska, P. J. Napiorkowski, M. Komorowska, D. Mücher, V. Bildstein, R. Chapman, T. Grahn, P. T. Greenlees, A. Illana, J. Pakarinen, P. Rahkila, R. Lozeva, A. Andreyev, L. M. Fraile, J. M. Allmond, A. Stuchbery and the MINIBALL and HIEISOLDE collaborations

Univ. of Cologne, Germany; TU Darmstadt, Germany; Univ. West of Scotland, Paisley, UK; TU München, Germany; KU Leuven, Belgium; LMU München, Germany; Univ. of Liverpool, UK; IEM CSIC, Madrid, Spain; Univ. of Tokyo, Japan; IJCLab, Orsay, France; Univ. of Lund, Sweden; Univ. of Sofia, Bulgaria; IFIN-HH, Bucharest, Romania; ELI-NP, Magurele, Romania; Heavy Ion Laboratory, Univ. of Warsaw, Poland; Univ. of Guelph, Canada; Univ. of Jyväskylä, Finland; Helsinki Institute of Physics, Finland; Univ. of York, UK; UC Madrid, Spain; Oak Ridge National Laboratory, USA; Australian National University, Canberra, Australia;

Spokespersons: P. Reiter [preiter@ikp.uni-koeln.de], Th. Kröll [tkroell@ikp.tu-darmstadt.de]
Contact person: F. Browne [frank.browne@cern.ch]

M. Droste* thesis project, beam time preparation, data analysis results IS702

Status IS702



First Miniball experiment
3.-7. November 2022

DSSSD + SPEDE + Miniball

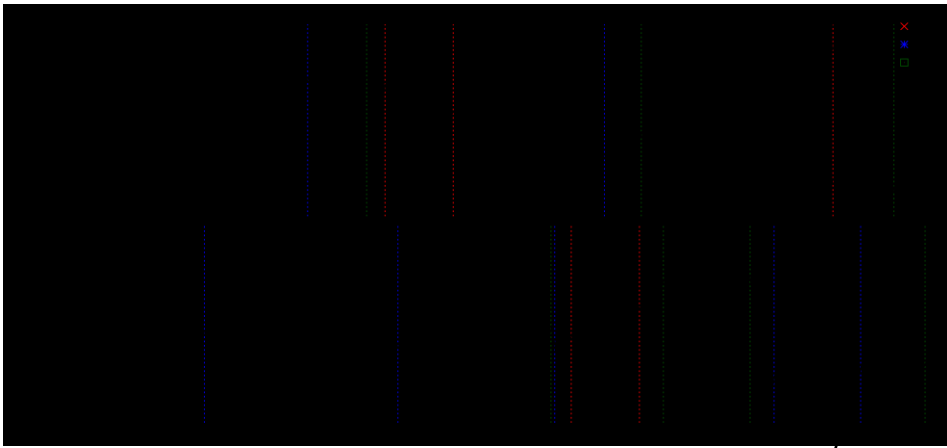
New triple HPGe cluster
detectors

New FEBEX based DAQ

Preliminary version of
FPGA FEBEX readout

Status IS702

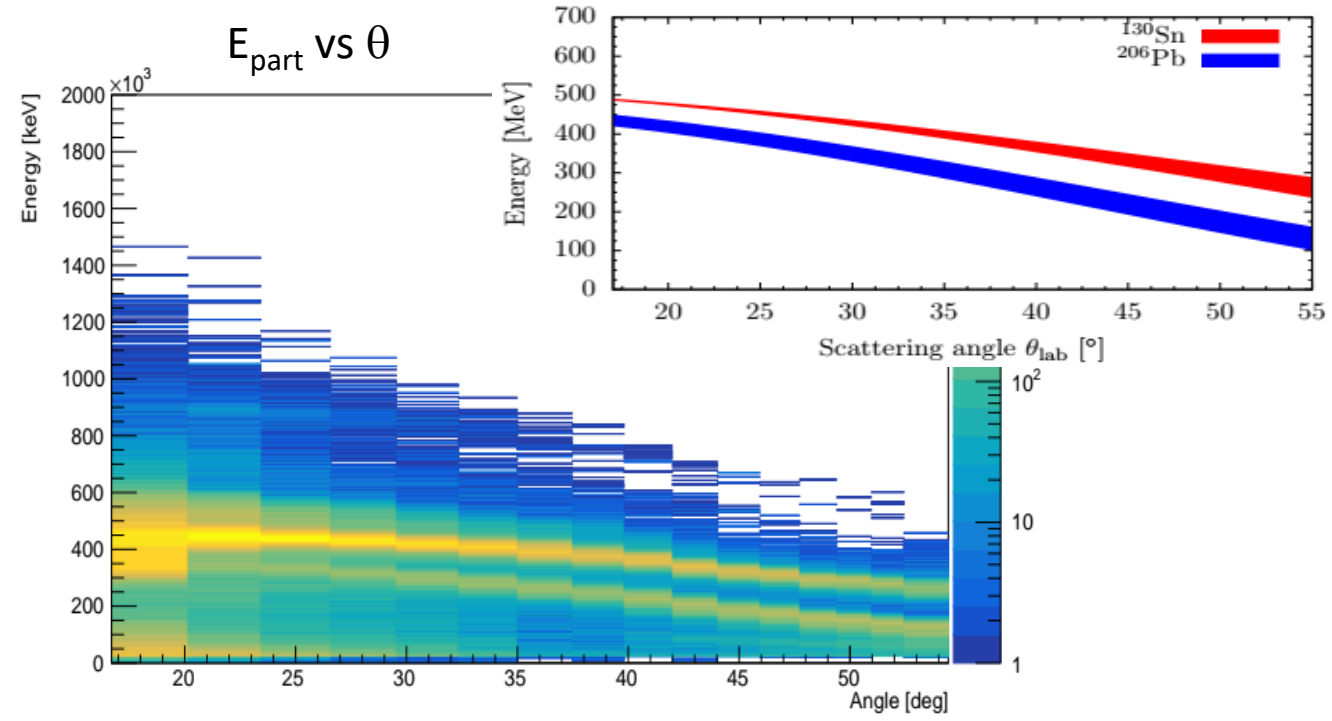
γ -rays after HRS, courtesy U. Köster



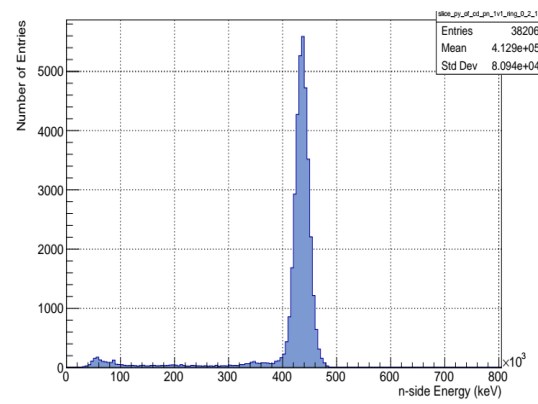
γ -ray transition from decay of $^{130(m)}\text{Sn}$



Line shape due to very high HPGe count rate



Inner ring: beam like nuclei



^{130}Sn beam, 4,4 MeV/u
($^{130}\text{Sn}^{34}\text{S}^{+1}$ molecular ion)

^{206}Pb target, 2 mg/cm²

DSSSD clear separation of beam and target like nuclei

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Beam current: ^{130}Sn beam current $\sim 5 \cdot 10^5$ ions/second
(reduced proton current)

Beam purity: dominating ^{130}Sn (^{130}Sb ?)

- Doppler correction: no γ 's from stable or instable $A=130$, 164 isobars
- No γ 's from $A=164$ isobars in spectra
- ^{130}Sn and ^{130}Sb separation hampered by line shape

Isomeric to ground state ratio: <25% isomeric component

Statistics with uncertainties due to random background:

^{130}Sn ($2^+ \rightarrow 0^+$) ~ 900 (150) + 780 (100) counts

^{206}Pb ($2^+ \rightarrow 0^+$) ~ 1930 (240) + 1970 (220) counts

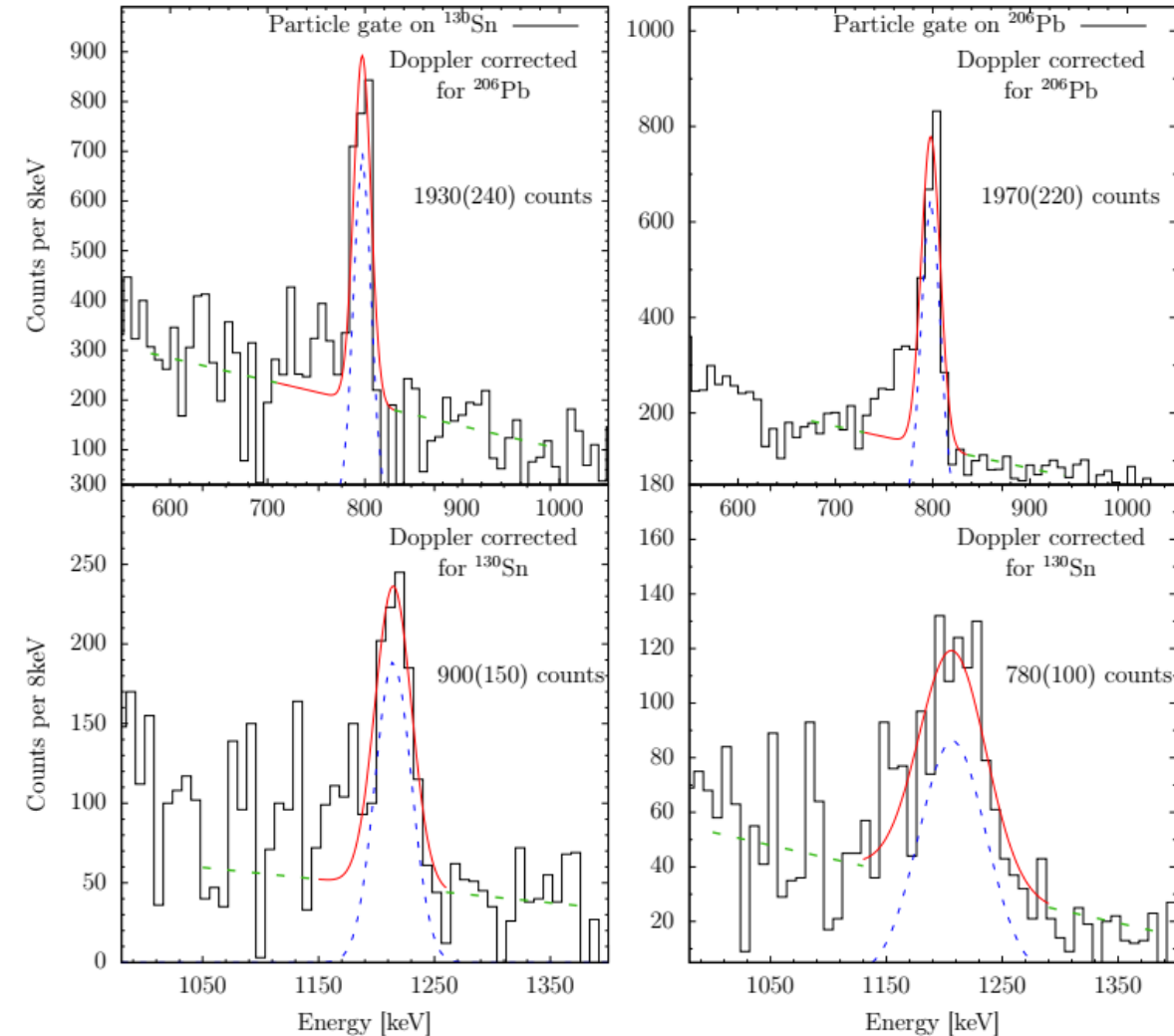
Total beam time: 75 hours vs. 120 hours requested

High continuous Miniball count rate

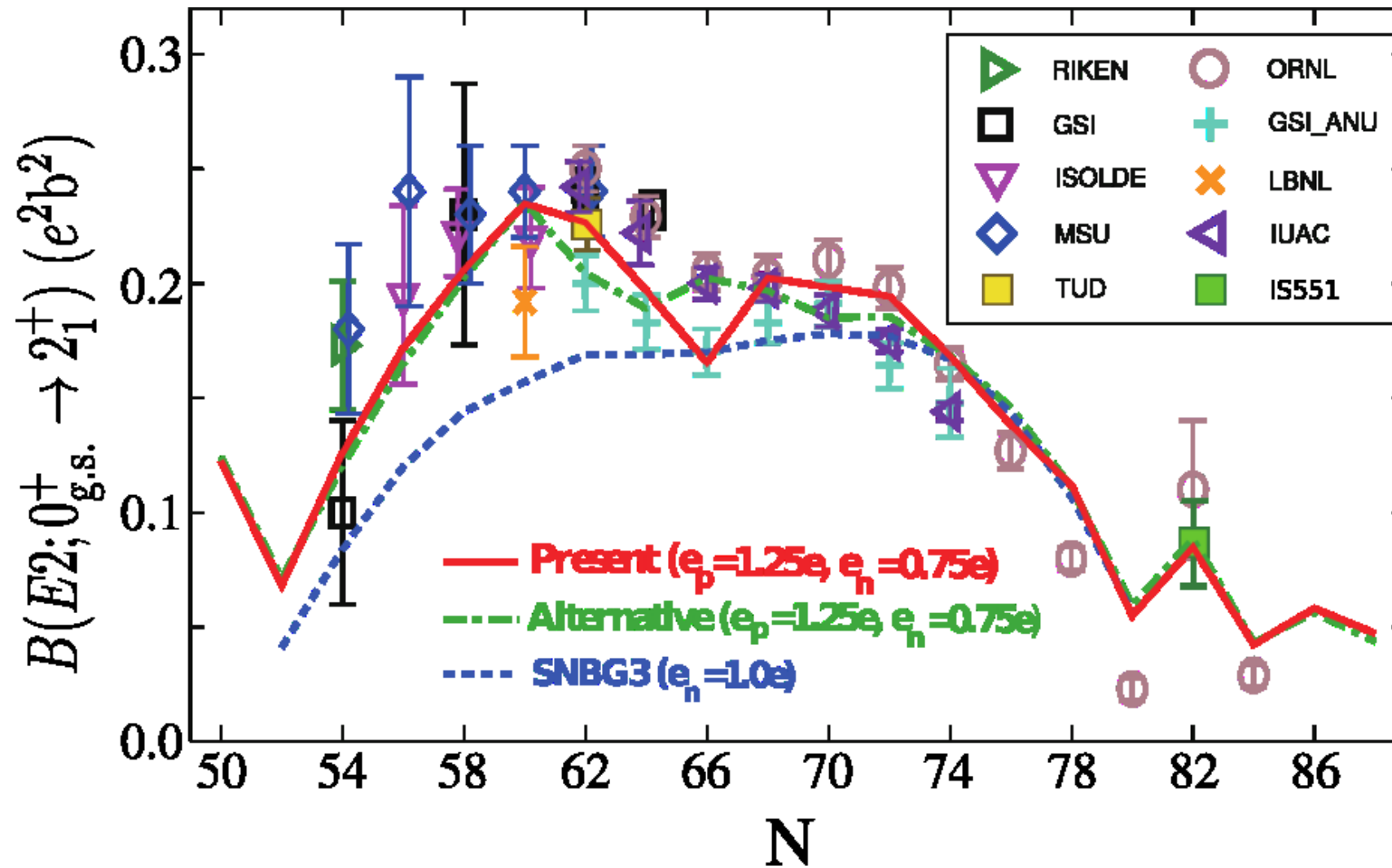
- reduced proton current, replace collimator by 5mm aperture

Preliminary FEBEX DAQ

- No particle gamma trigger, single event read-out, no dedicated FPGA software, high 39% dead time,...



Calculated and measured B(E2) values along Sn isotopic chain



Theorie: T. Togashi; Y. Tsunoda; T. Otsuka; N. Shimizu; M. Honma; Phys. Rev. Lett. 121, 062501 (2018)
 HIE-ISOLDE Miniball experiment IS551 ^{132}Sn value, D. Rosiak et. al.; Phys. Rev. Lett. 121, 252501 (2018)

MCSM: T-plots – $^{130,132,134}\text{Sn}$

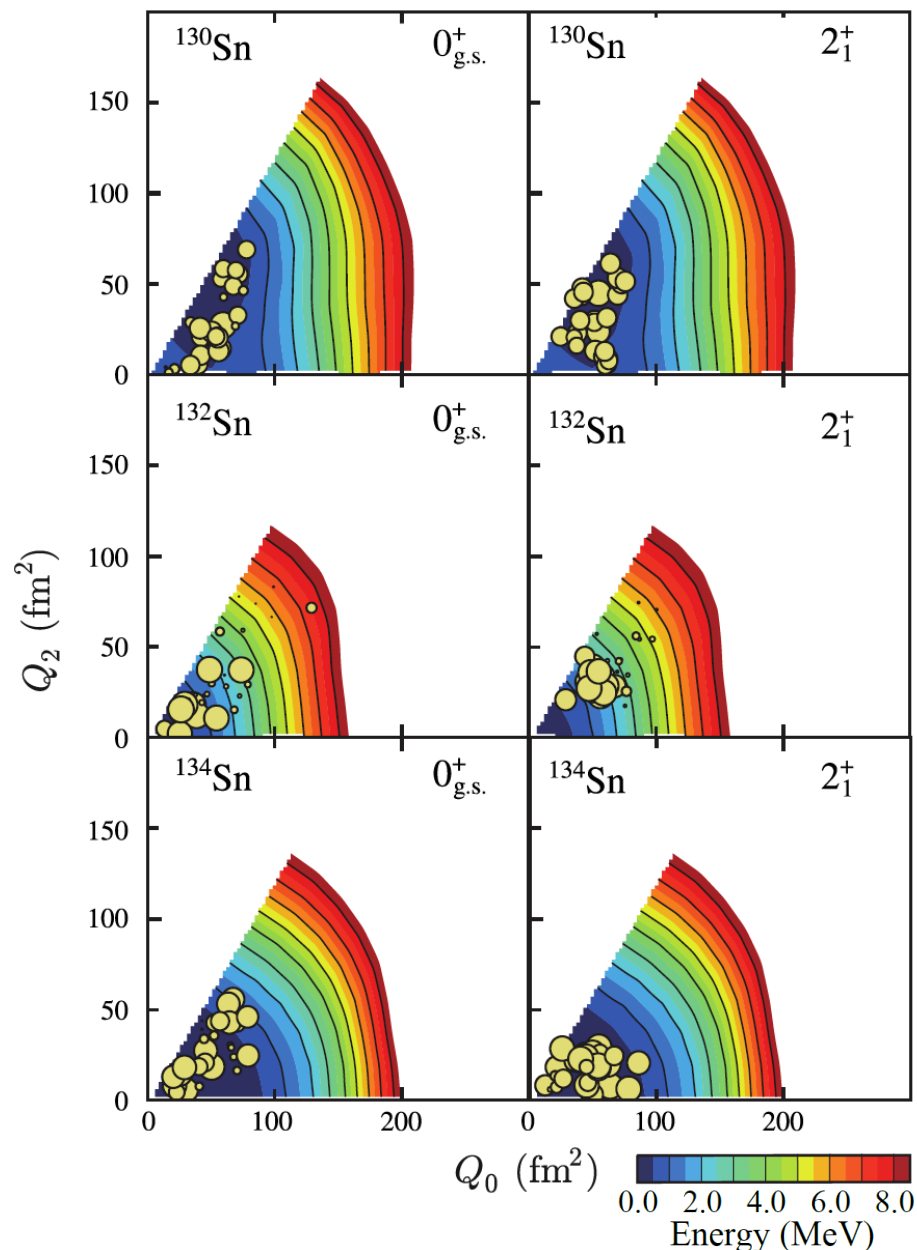
MCSM basis vectors and PES

0^+ ground state:

- spherical minimum for $^{130,132,134}\text{Sn}$
- Probability for spherical, doubly magic configuration of ^{132}Sn : 90% (cf. $^{56,68,78}\text{Ni}$: 60%, 53%, 75%)

2^+ state:

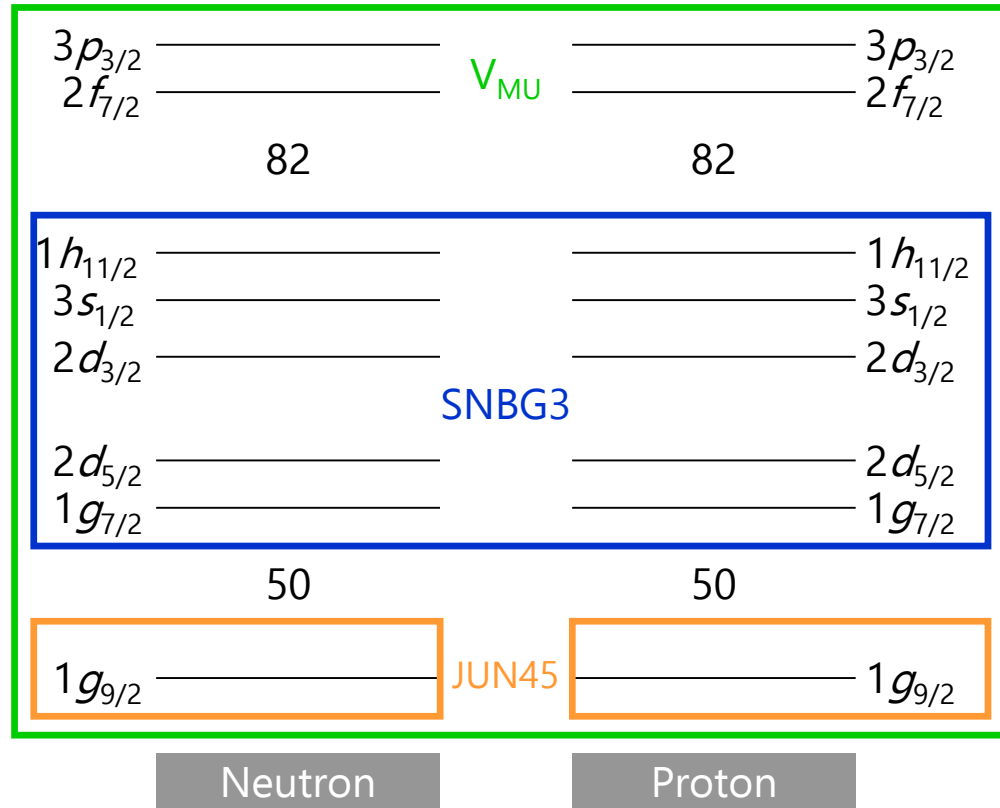
- Notable shift towards oblate for ^{130}Sn and towards prolate for ^{134}Sn



New shell-model calculations

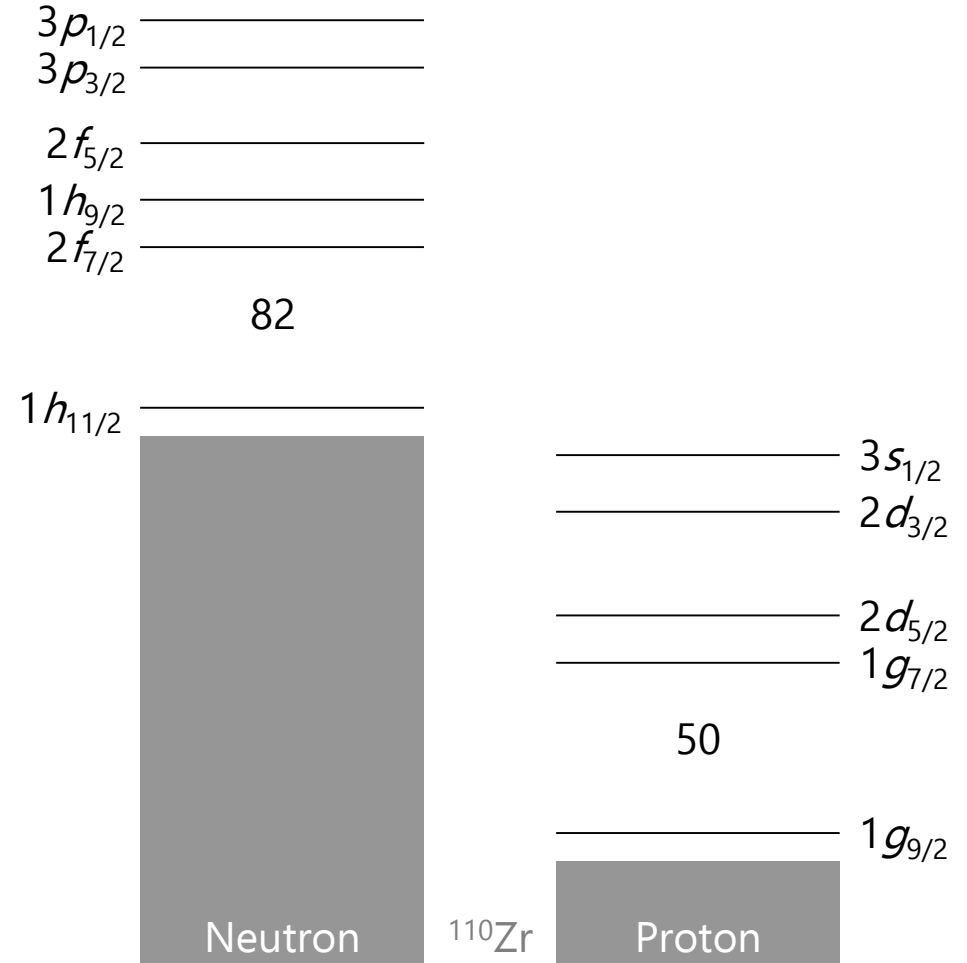
Closed proton/neutron shells
 ⇒ huge model space needed

Monte-Carlo shell model (MCSM)



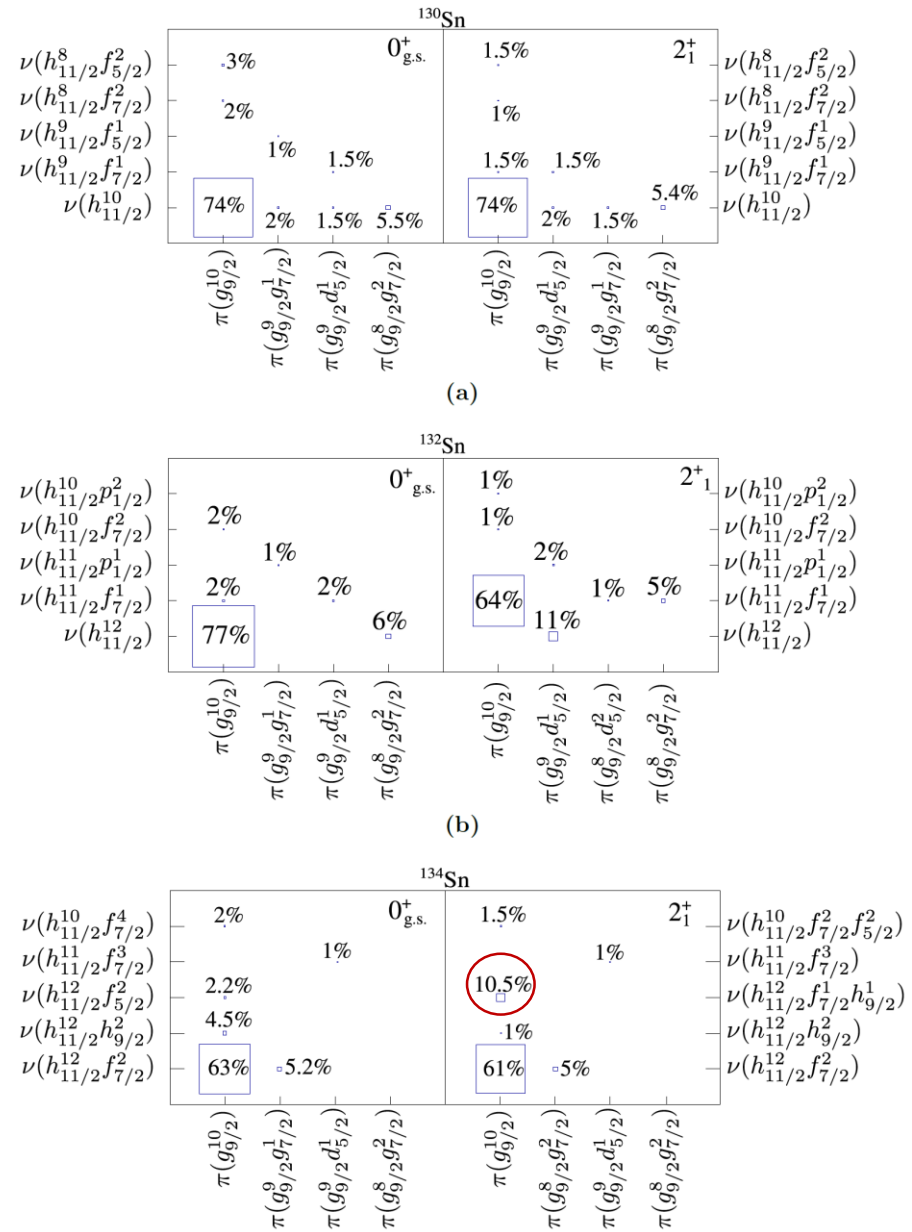
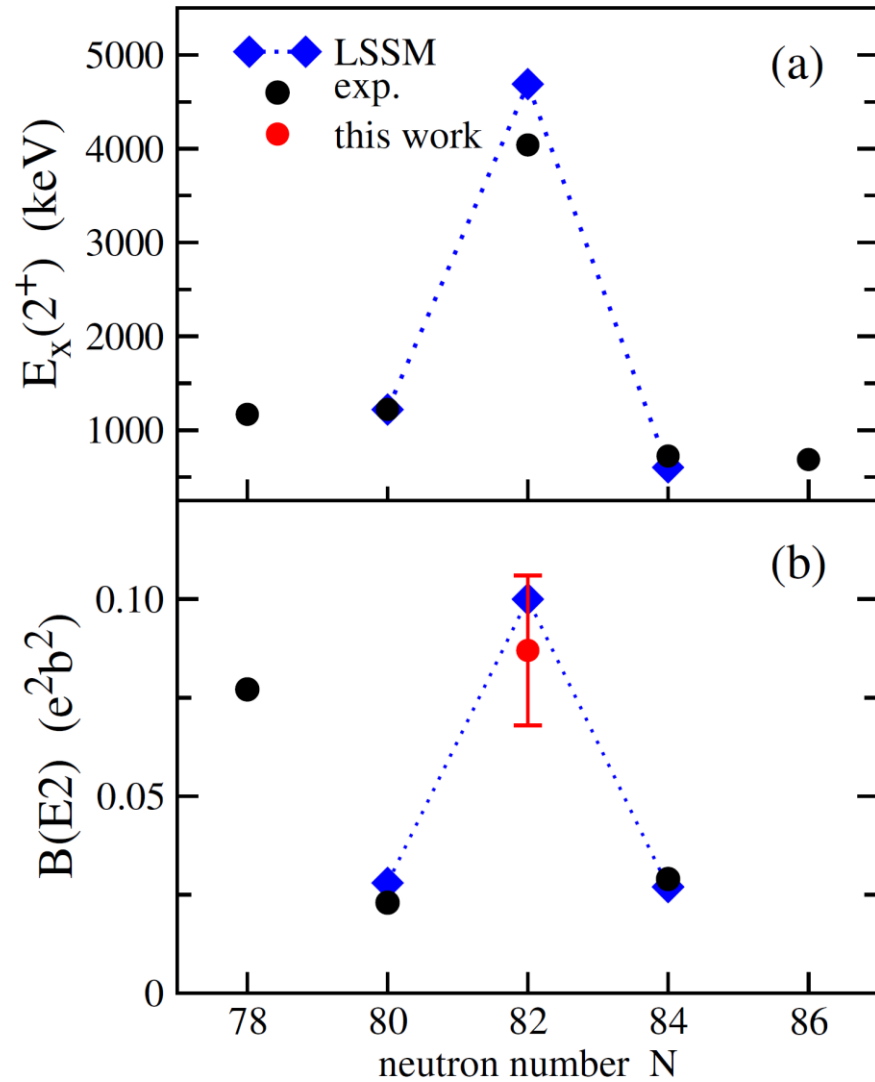
T. Togashi, Y. Tsunoda, and T. Otsuka

Large-scale shell model (LSSM)



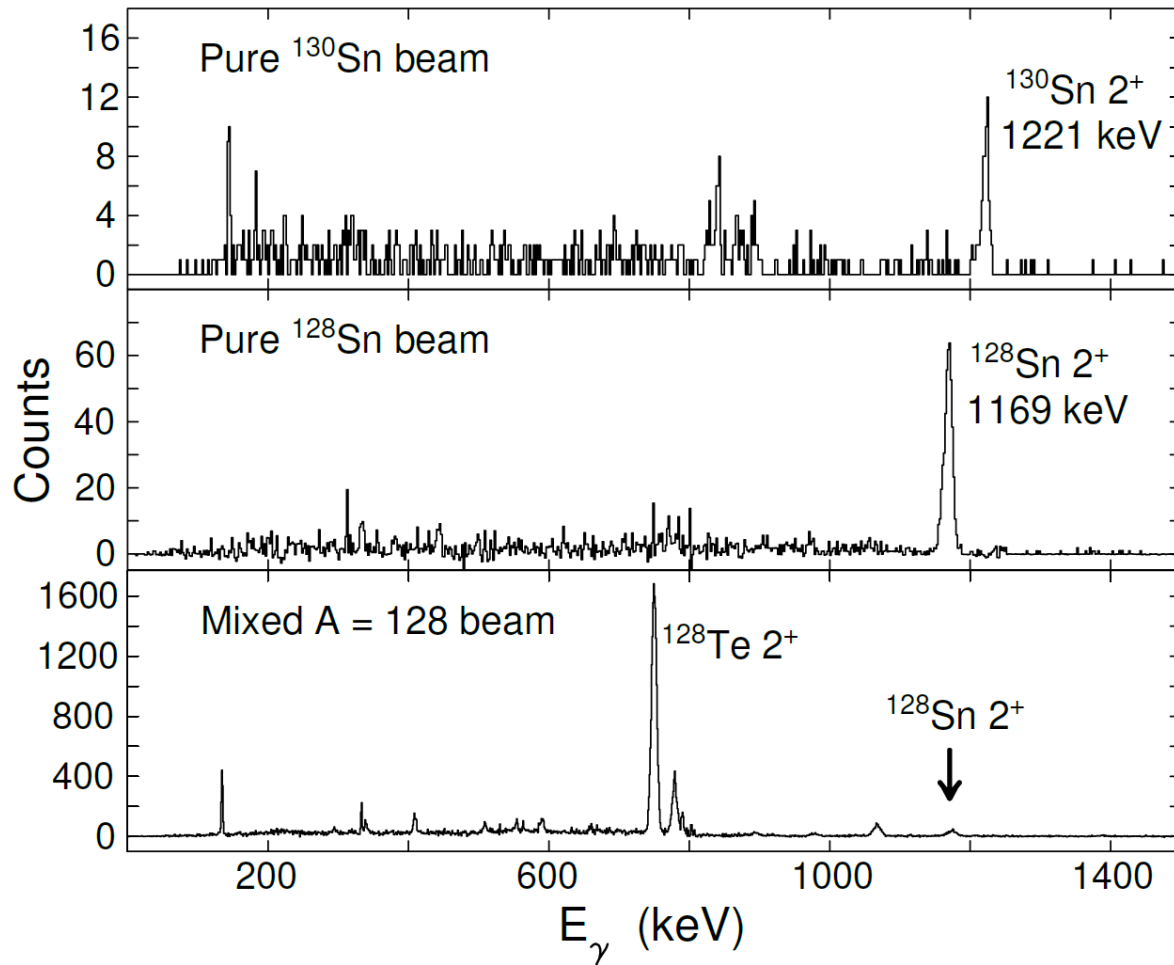
H. Naïdja and F. Nowacki

Large-scale shell-model calculations



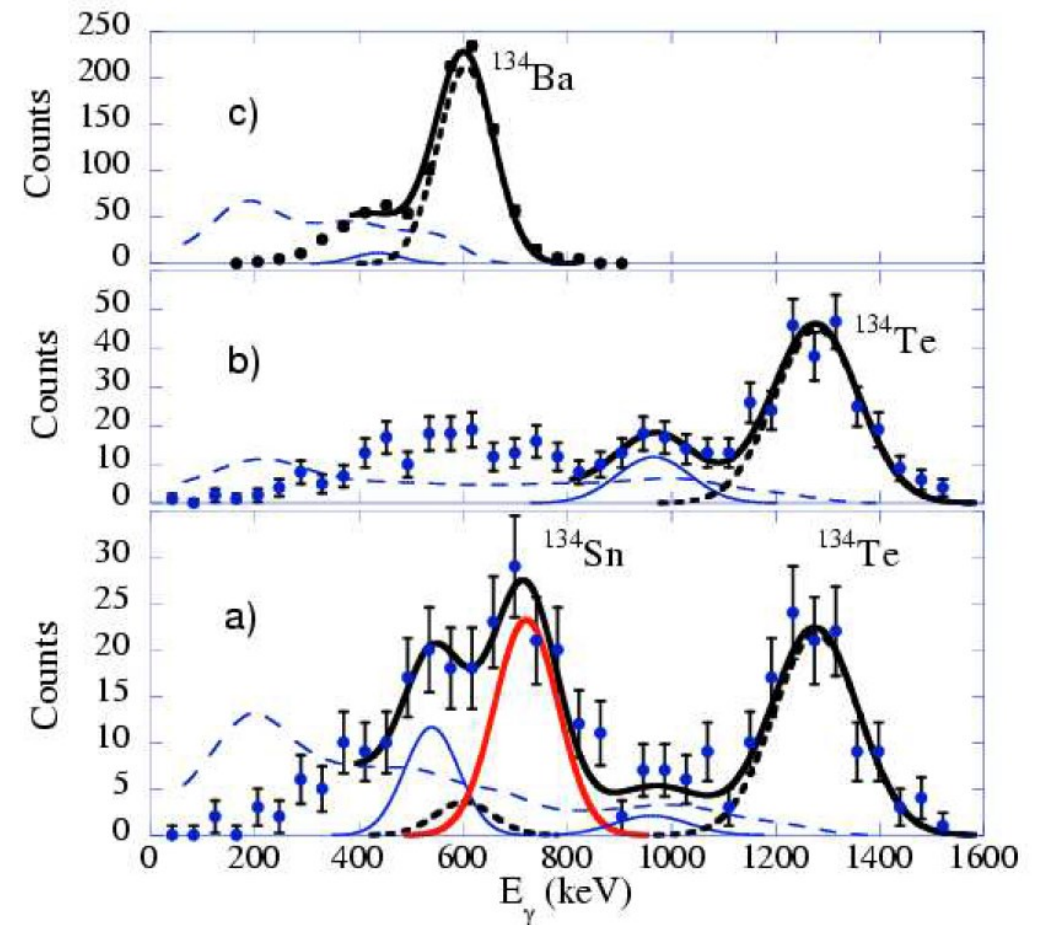
Proton excitation $g_{9/2}^{-1} d_{5/2}$ across shell gap crucial for $E2$ strength in ^{132}Sn

Coulomb excitation of $^{130,134}\text{Sn}$ at ORNL



Coulomb excitation of $^{128,130}\text{Sn}$
 CLARION HPGe array
 ~ 50 counts in $2^+ \rightarrow 0^+$ transitions

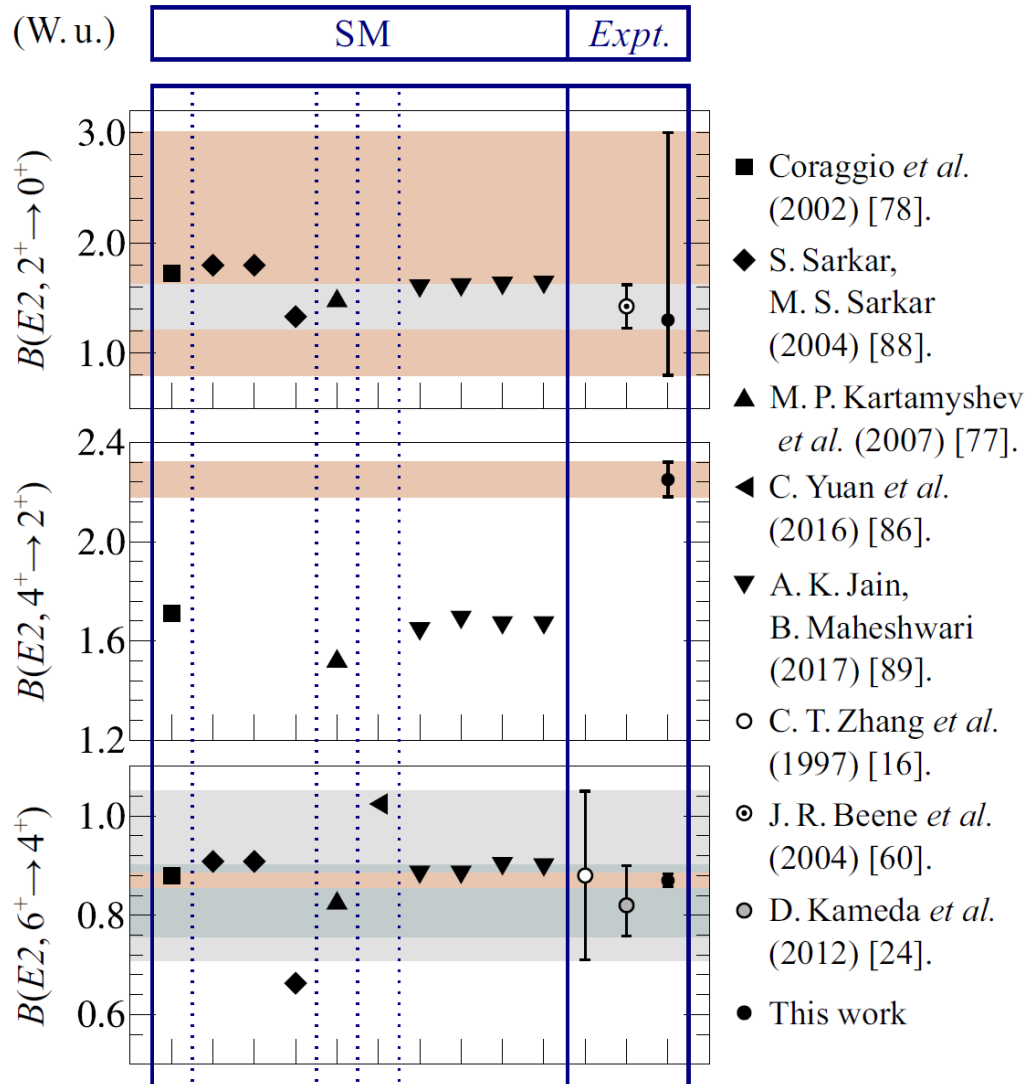
Figure from Nuclear Physics A 752 (2005) 264c–272c



Coulomb excitation of ^{134}Sn .
 γ -ray spectrum from BaF_2 array TAMU
 Beam composition: ^{134}Sn , ^{134}Ba , ^{134}Te
 ~ 60 counts in $2^+ \rightarrow 0^+$ transitions

Figure from Eur. Phys. J. A25, s01,391-394 (2005)

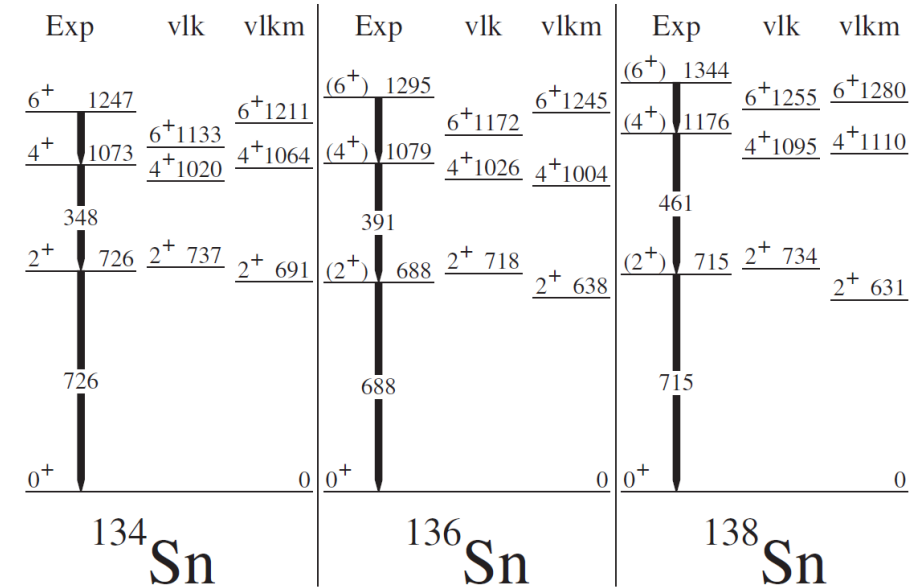
^{134}Sn results



G.S. Simpson, et al,

PRL **113**, 132502 (2014)

PHYSICAL REV



Only short lived isomers in ^{134}Sn
 6^+ isomer ($E=1247.4$ keV, $T_{1/2} = 80$ ns)

HIE-ISOLDE beam intensities

Element	A number	Half life	SC or PSB*	Yield at ISOLDE (ions/ μC)	Target material
Sn	123 - g	129.2 d	SC	5.0E+08	UC _x
Sn	125 - g	9.64 d	SC	1.3E+08	UC _x
Sn	127 - g	2.10 h	SC	6.0E+07	UC _x
Sn	129 - g	2.23 m	SC	5.0E+07	UC _x
Sn	131 - m	58.4 s	SC	1.5E+07	UC _x
Sn	132 - g	39.7 s	SC	3.0E+07	UC _x

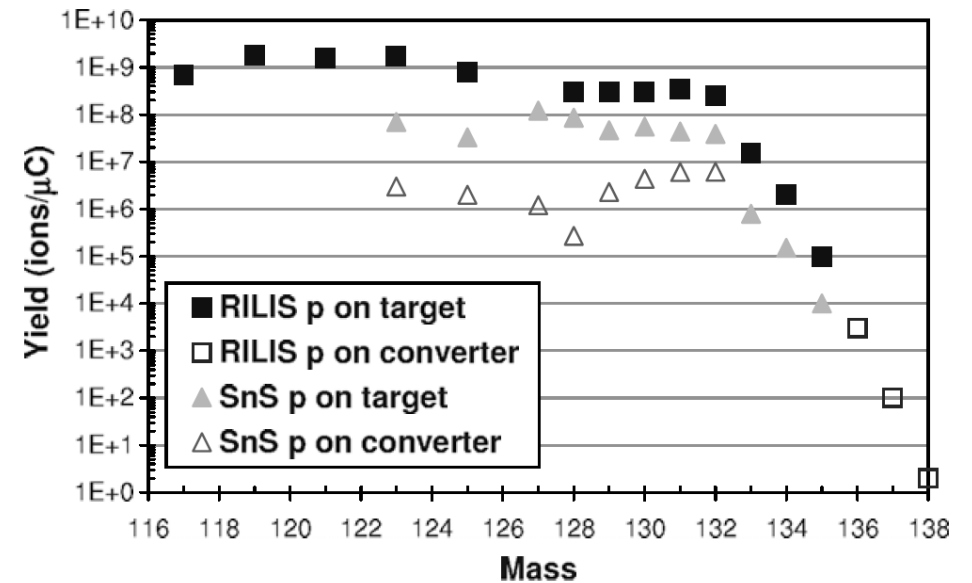
accelerator efficiency of HIE-ISOLDE for ^{134}Sn beams: 5%

Expected beam intensities at MINIBALL:

- $I(^{130}\text{Sn}) = 1 \times 10^6$ ions/s
- $I(^{134}\text{Sn}) = 1 \times 10^4$ ions/s

Previous experiments (2016, 2022):

- beam intensity at MINIBALL $I(^{132}\text{Sn}) = 3 \times 10^5$ ions/s
- PSB proton beam current 1.4 μA
- $I(^{130}\text{Sn}) \sim 5 \times 10^5$ ions/s (proton current < 0.5 μA)



U. Köster et al. Nucl. Instr. and Meth. B 266 (2008) 4229

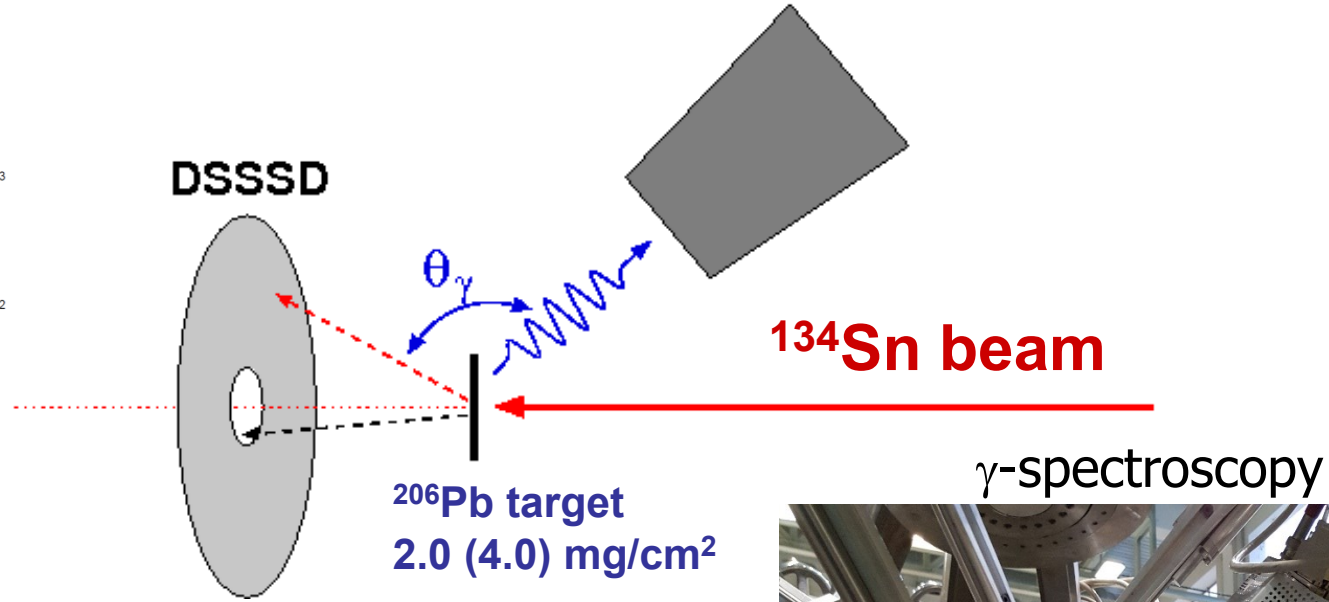
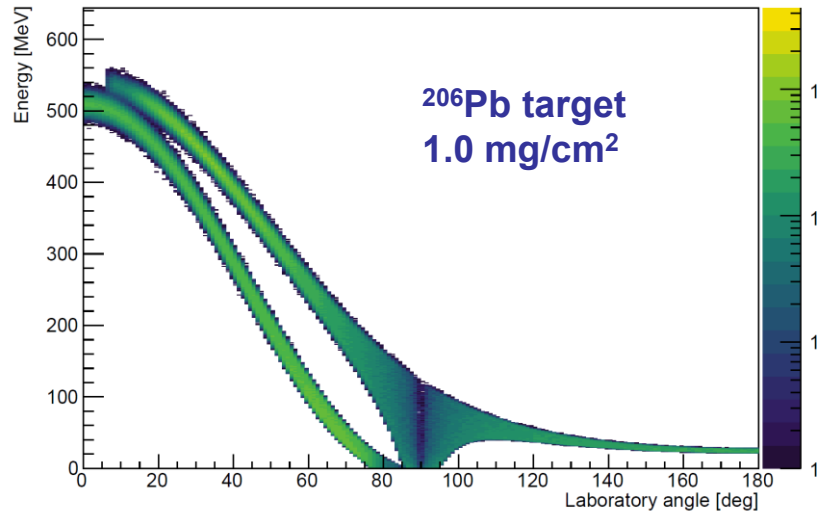
HIE-ISOLDE beam energy: 4.4 MeV/u

'safe' Coulex ^{134}Sn (@ 4.4 MeV/u) + ^{206}Pb

'safe' criterion $d > R_p + R_t + 5 \text{ fm} = 18.8 \text{ fm}$
fulfilled for target projectile distance at $\theta_{\text{Lab}} = 180^\circ$

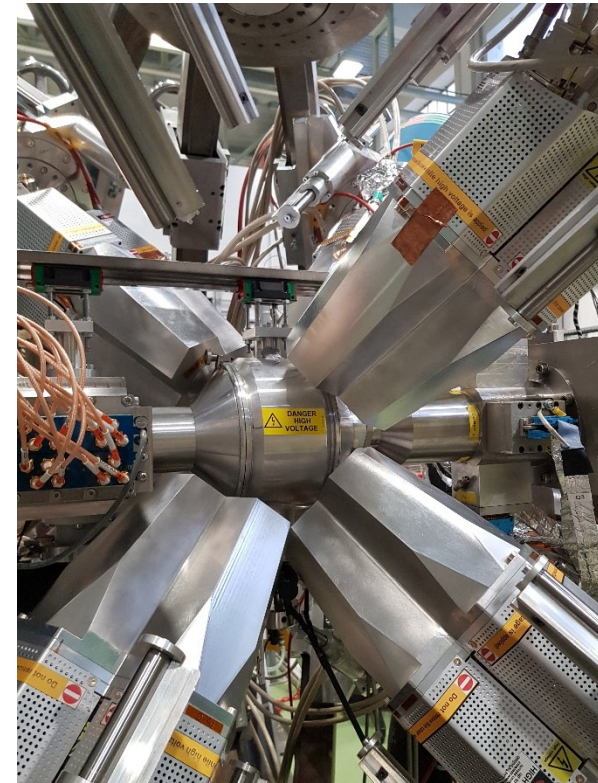
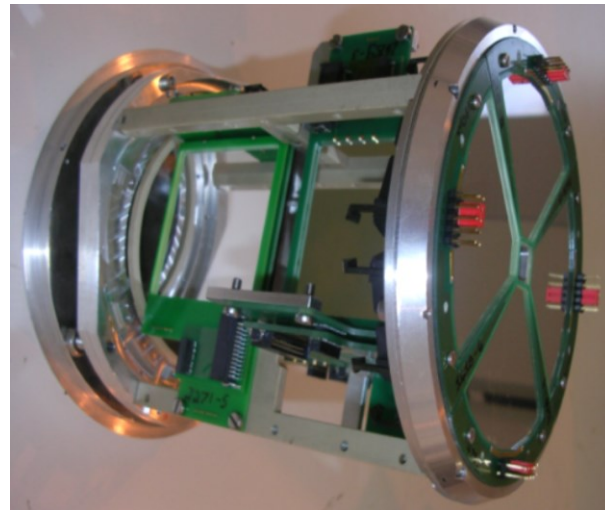
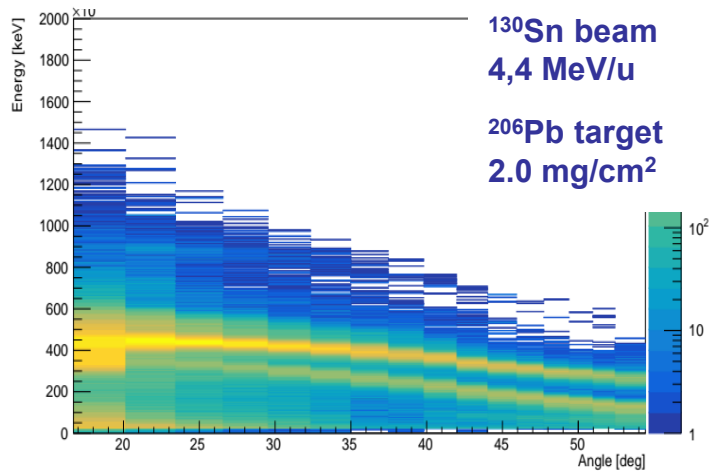
MINIBALL setup & particle kinematics

Kinematics calculation



Particle detection: DSSSD + C-REX
- scattering angle & energy

Kinematics experiment IS702



Cross sections & count rate estimate

Transition, energy	Transition strength	Integr. CLX cross-section $15^\circ < \theta_{\text{Lab}} < 50^\circ$ DSSSD	Integr. CLX cross-section $105^\circ < \theta_{\text{Lab}} < 172^\circ$ C-REX	cts/h	cts/ run	Stat. error	IS702 Result Cts/run
$0_1^+ \rightarrow 2_1^+$ 1221.2 keV ^{130}Sn	$B(E2, 0_1^+ \rightarrow 2_1^+)$ $0.023 e^2b^2$ <i>Nucl. Phys. A</i> <i>752 (2005) 264c</i>	$\sigma(2_1^+)$ 130 mb	$\sigma(2_1^+)$ 90 mb	370	35000 <i>12 shifts</i>	<2%	~1700 <i>9 shifts, 140 mb,</i> <i>dead time 40%,</i> <i>red.proton beam</i>
$2_1^+ \rightarrow 4_1^+$ 774 keV ^{130}Sn	$B(E2, 2_1^+ \rightarrow 4_1^+)$ $0.024 e^2b^2$	$\sigma(4_1^+)$ 0.19 mb	$\sigma(4_1^+)$ 0.46 mb	2	200 <i>12 shifts</i>	~7%	
$0_1^+ \rightarrow 2_1^+$ 725.6 keV ^{134}Sn	$B(E2, 0_1^+ \rightarrow 2_1^+)$ $0.029 e^2b^2$ <i>Eur. Phys. J. A</i> <i>25, s01, 391 (2005)</i>	$\sigma(2_1^+)$ 400 mb	$\sigma(2_1^+)$ 320 mb	15	1800 <i>15 shifts</i>	<2.5%	^{134}Sn
$2_1^+ \rightarrow 4_1^+$ 347.8 keV ^{134}Sn	$B(E2, 2_1^+ \rightarrow 4_1^+)$ $0.031 e^2b^2$ <i>Phys. Rev. C</i> <i>76, 024313 (2007)</i>	$\sigma(4_1^+)$ 2.6 mb	$\sigma(4_1^+)$ 10 mb	0.3	34 <i>15 shifts</i>	~18%	^{134}Sn

Summary and beam time request

- Measurements of the $B(E2, 2_1^+ \rightarrow 0^+)$ value for the neutron-rich isotopes ^{134}Sn is proposed. Due to short lifetime, Coulex is only viable method.
- $B(E2, 2_1^+ \rightarrow 0^+)$ values will be improved significantly and will allow for crucial test of MCSM- and large scale SM calculations.
- Under favourable conditions $B(E2, 4_1^+ \rightarrow 2_1^+)$ value will be accessible in this region from Coulomb excitation.
- Electric quadrupole moments Q_2 will be extracted from data. For short-lived states, this quantity is only accessible by safe Coulomb excitation via the reorientation effect.
- Beam time request of IS702 addendum
 - 15 shifts in beam spectroscopy + 3 shifts decay spectroscopy for ^{134}Sn
 - 18 shifts for ^{134}Sn

Backup slides

INTC 67 minutes Page | 14

The proposed experiment is considered feasible, although it is not certain that the required beam intensities can be maintained over an extended period.

... value in establishing precise and reliable experimental data for ^{130}Sn , where the discrepancy with theory is largest. The committee recommends approving the requested beam time for the ^{130}Sn case. The proponents would have to demonstrate the impact of the ^{130}Sn results on the physics case in a new proposal for ^{134}Sn .