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

- shell model results vs experiment
- experiment at HIE-ISOLDE
- beam time, rate estimates

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INTC meeting, 23rd – 24th June 2021

Collaboration

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

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

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and the MINIBALL and HIEISOLDE collaborations

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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;

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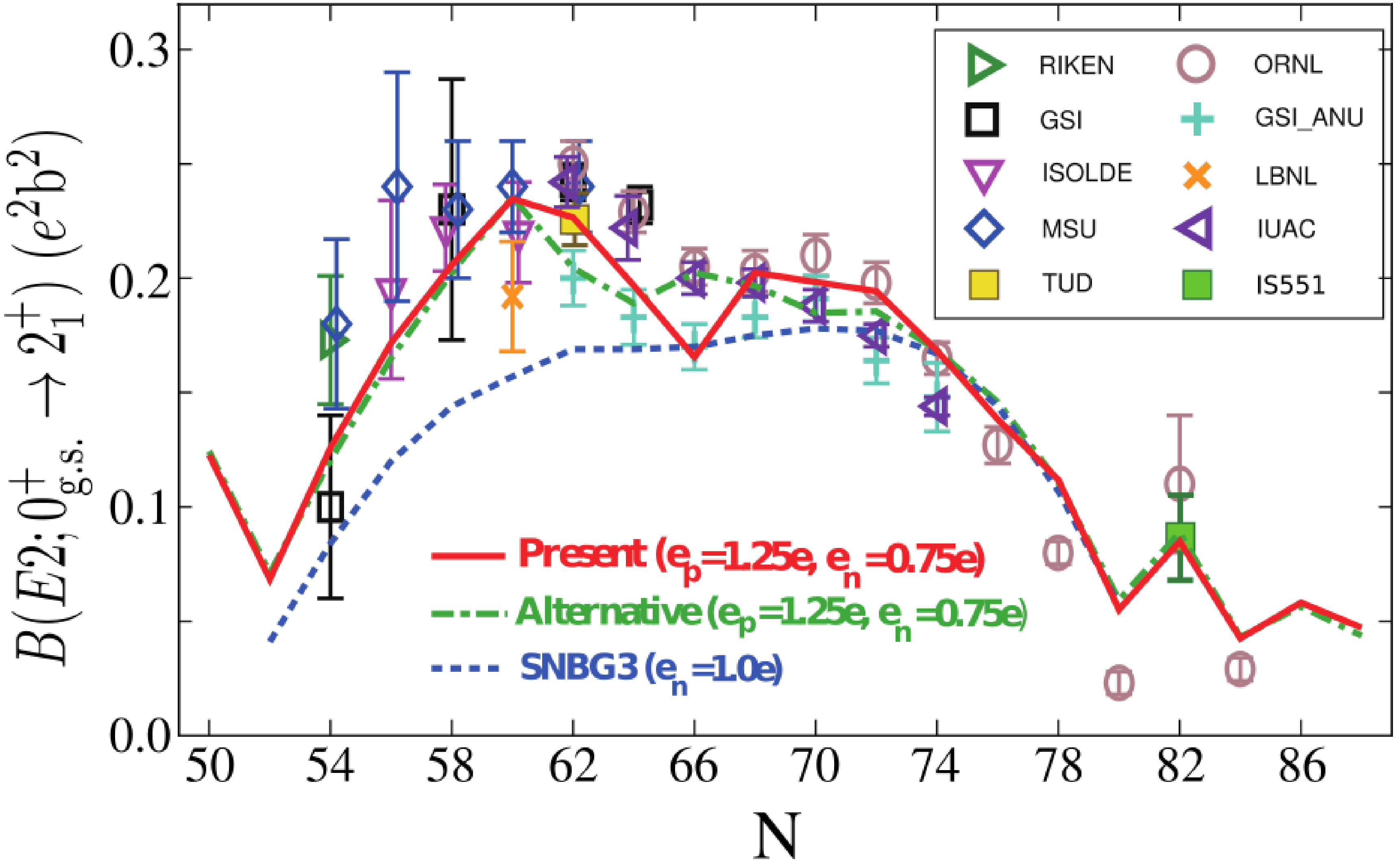
Calculated and measured B(E2) values along Sn isotopic chain



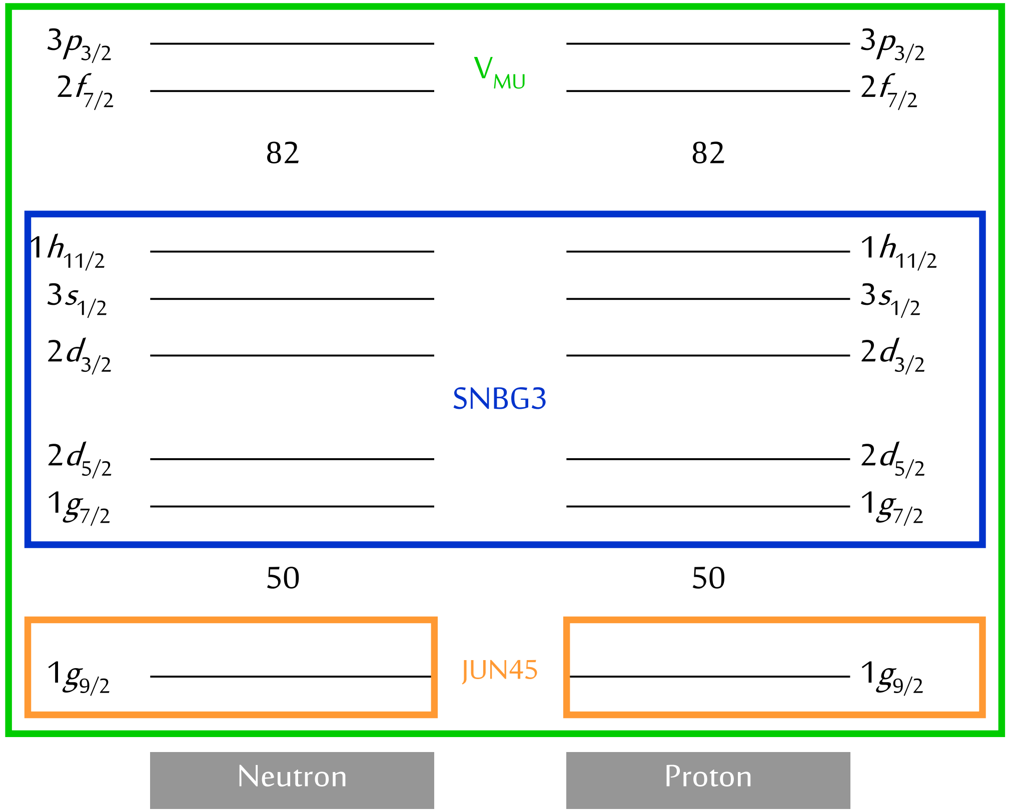
T. Togashi; Y. Tsunoda; T. Otsuka; N. Shimizu; M. Honma; Phys. Rev. Lett. 121, 062501 (2018)
^{132}Sn value by D. Rosiak et. al.; Phys. Rev. Lett. 121, 252501 (2018)

New shell-model calculations

Closed proton/neutron shells

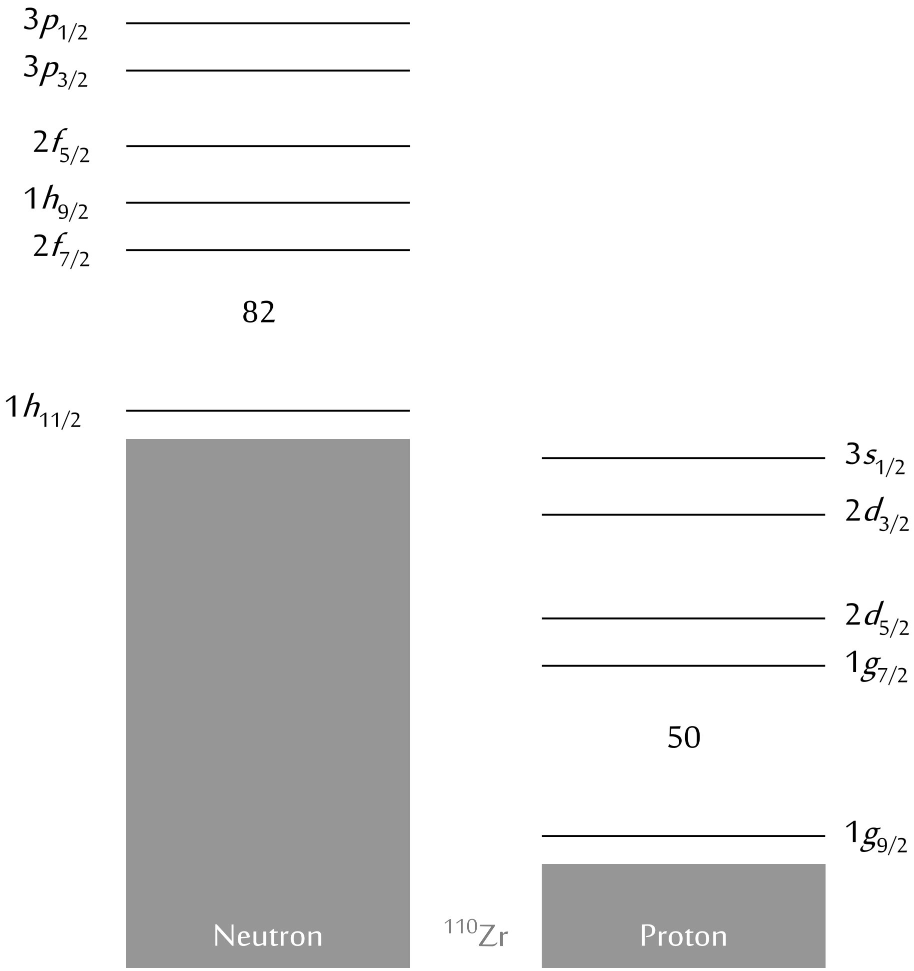
⇒ huge model space needed

Monte-Carlo shell model (MCSM)



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

Large-scale shell model (LSSM)



H. Naïdja and F. Nowacki

MCSM: T-plots – ^{130,132,134}Sn

MCSM basis vectors and PES

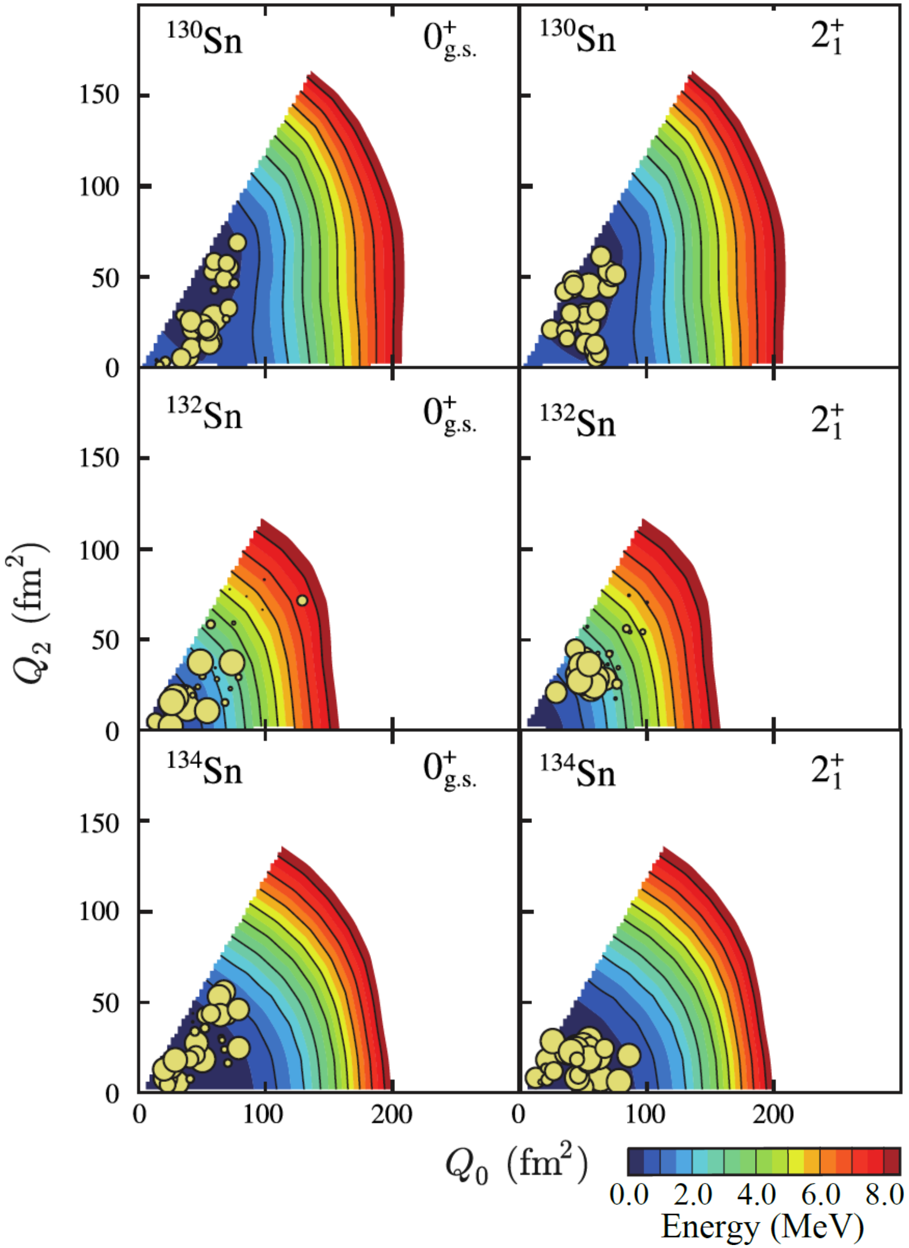
0^+ ground state:

- spherical minimum for ^{130,132,134}Sn

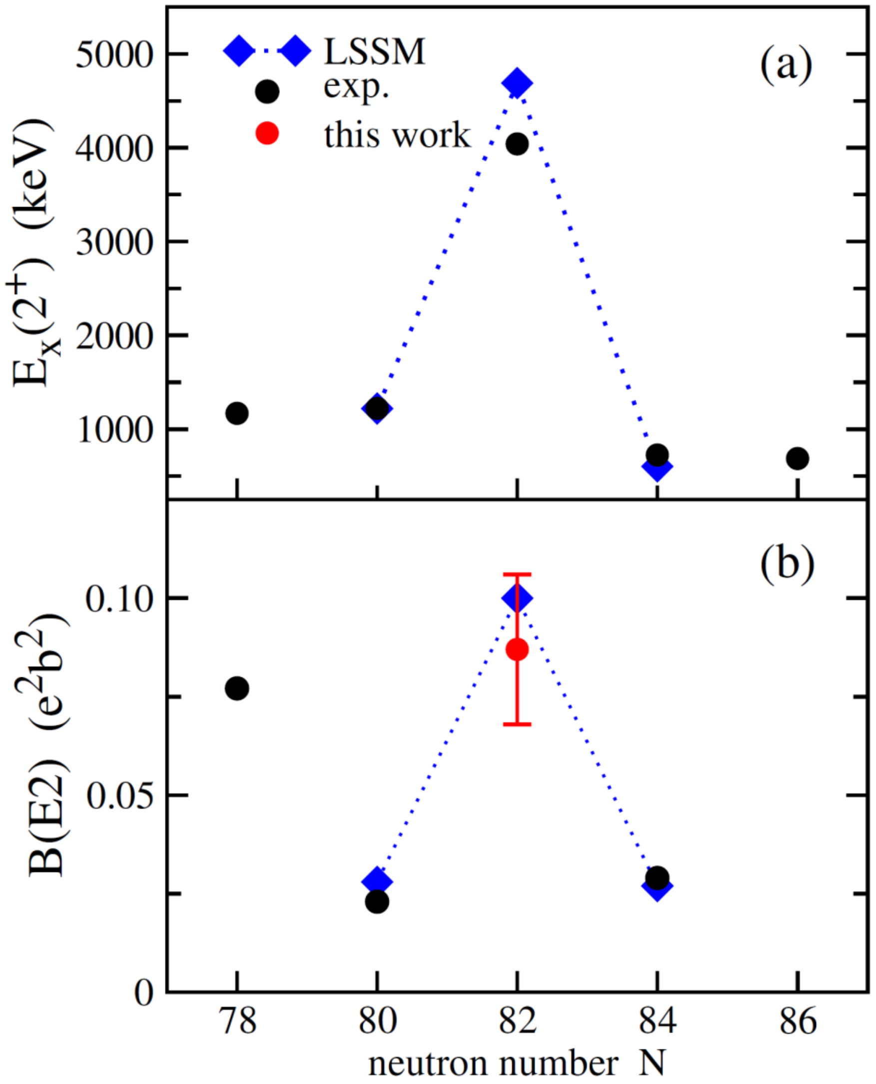
- Probability for spherical, doubly magic configuration of ^{132}Sn: 90% (cf. ^{56,68,78}Ni: 60%, 53%, 75%)

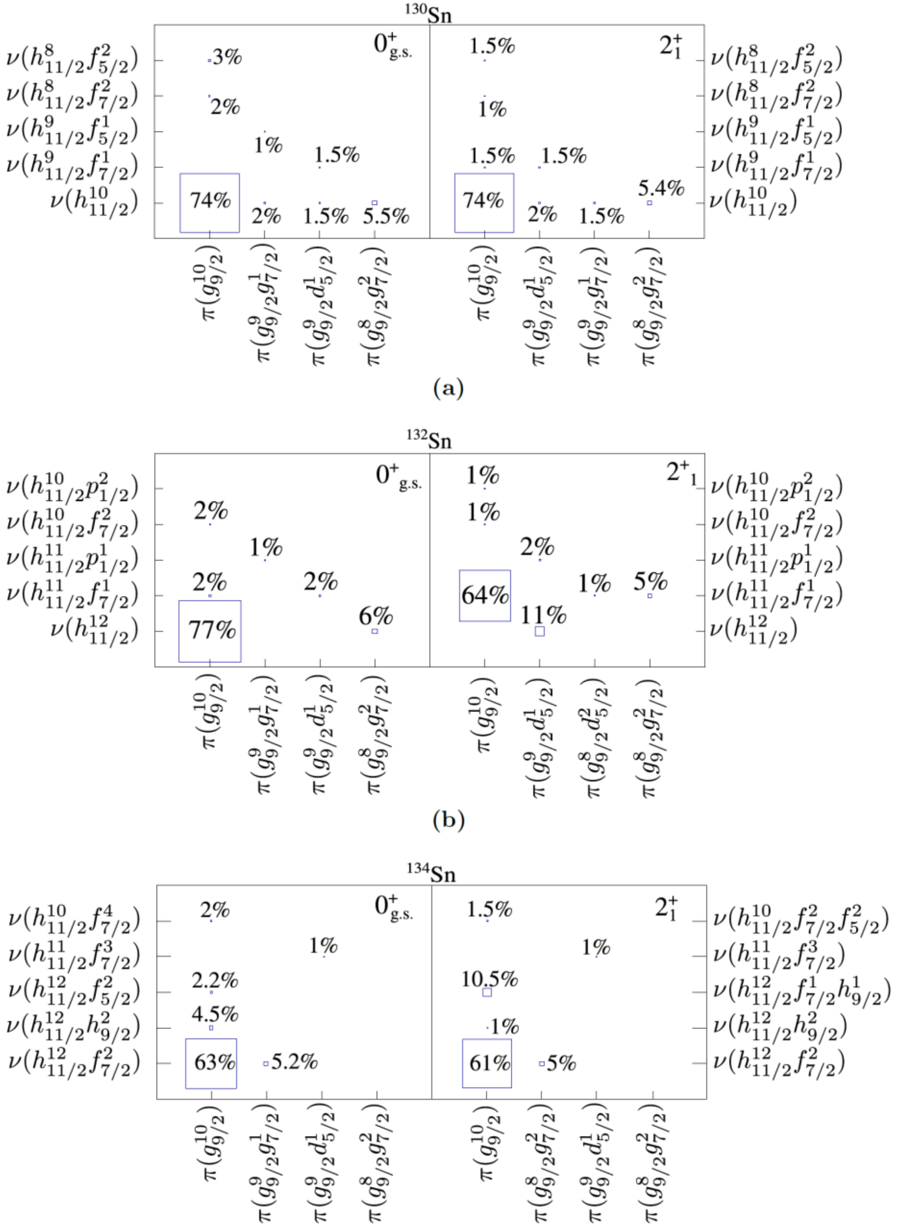
2^+ state:

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



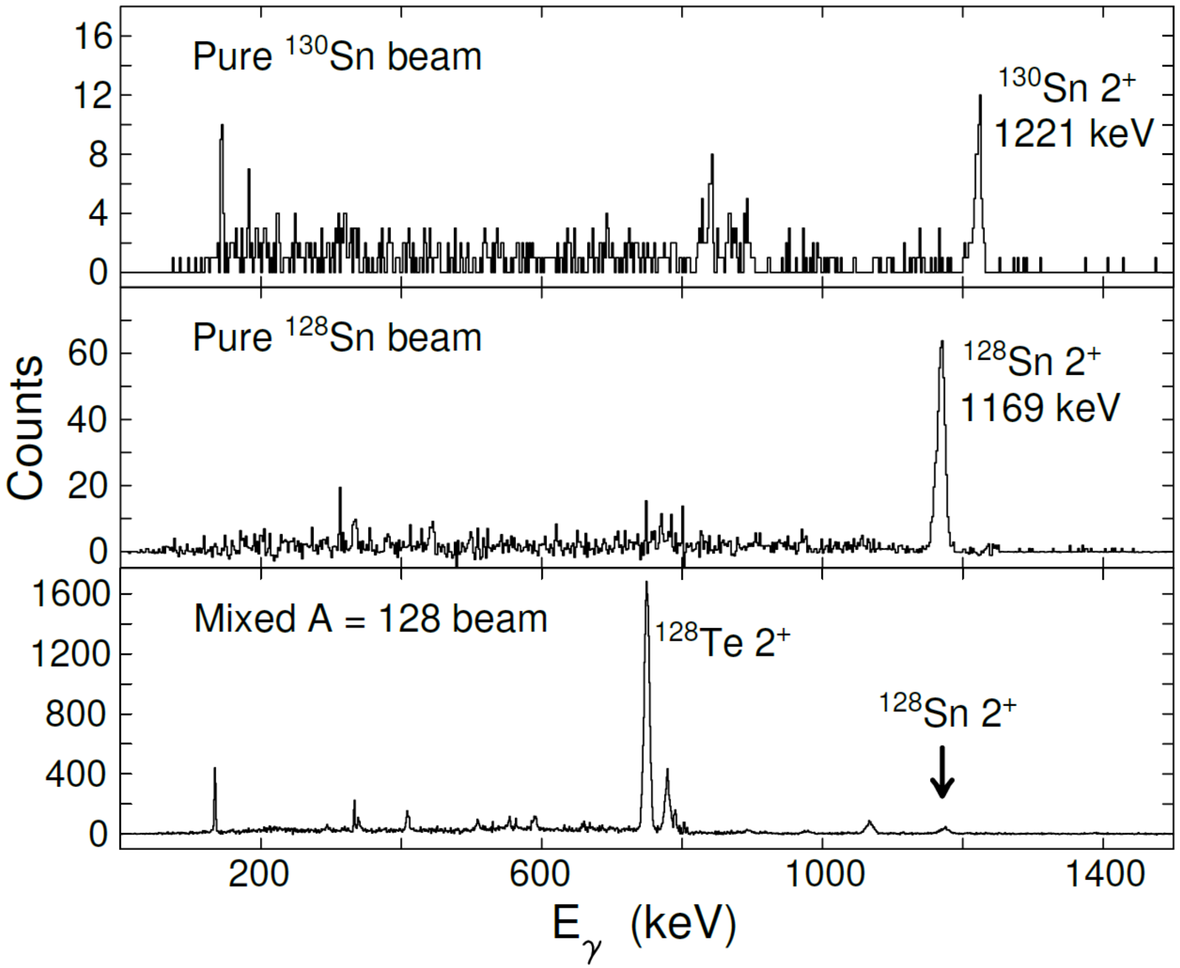
Large-scale shell-model calculations



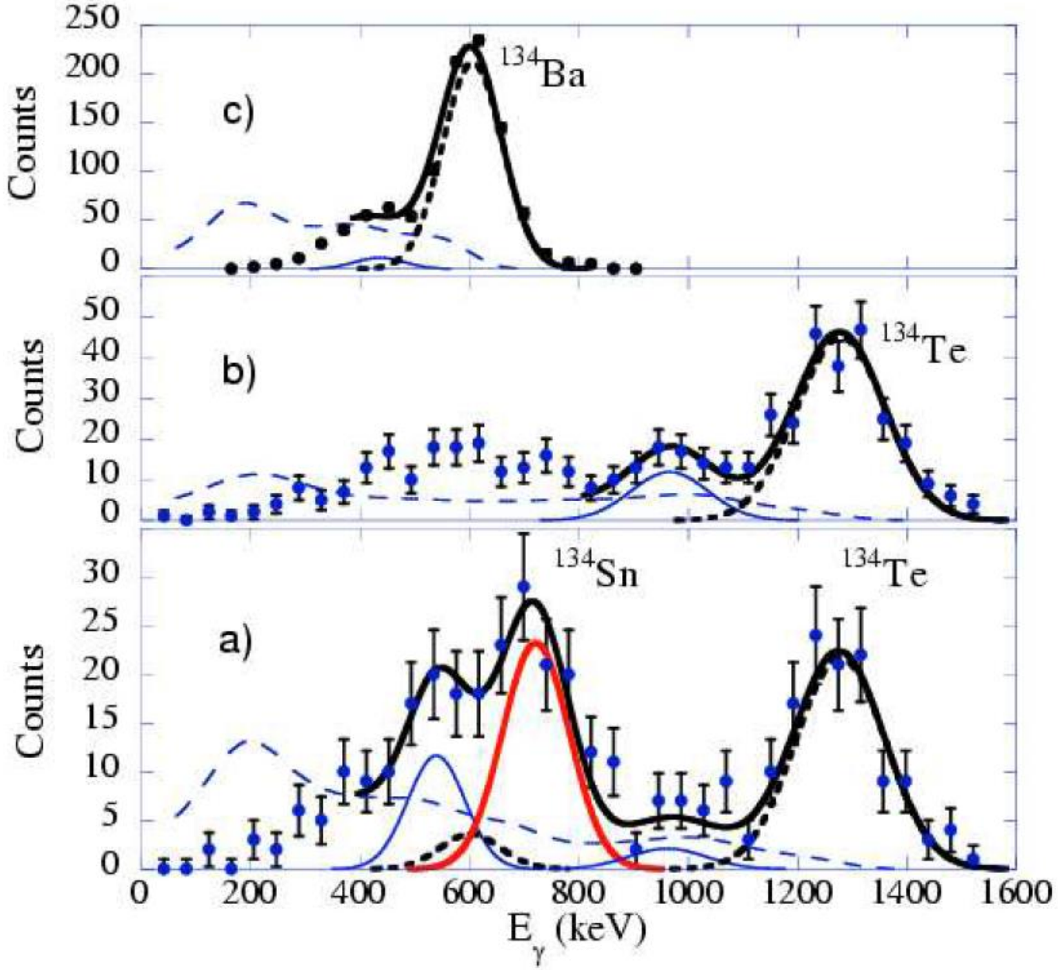


Proton excitation $g_{9/2}^{-1}d_{5/2}$ across shell gap crucial for *E*2 strength in ^{132}Sn

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



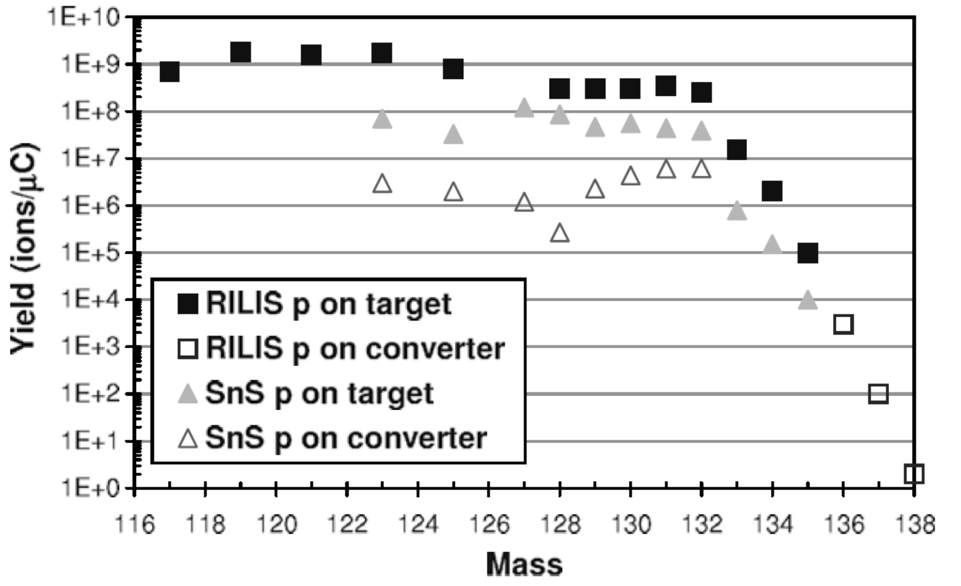
γ-ray after Coulomb excitation of ^{128,130}Sn recorded by CLARION array. $2^+ \rightarrow 0^+$ transitions are labeled. Figure from Nuclear Physics A 752 (2005) 264c–272c



Coulomb excitation of ^{134}Sn.
γ–ray spectrum from BaF_2 array TAMU
Contaminations: ^{134}Ba and ^{134}Te
Figure from Eur. Phys. J. A25, s01,391-394 (2005)

ISOLDE beam intensities

Element	A number	Half life	SC or PSB*	Yield at ISOLDE	Target material
				(ions/μC)	
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



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

accelerator efficiency of HIE-ISOLDE for ^{130,134}Sn beams 5%
PSB proton beam current 2.0 μA

Beam intensities at MINIBALL:

- I(^{130}Sn) = 1 x 10^6 ions/s
- I(^{134}Sn) = 1 x 10^4 ions/s

Previous experiment in 2016:

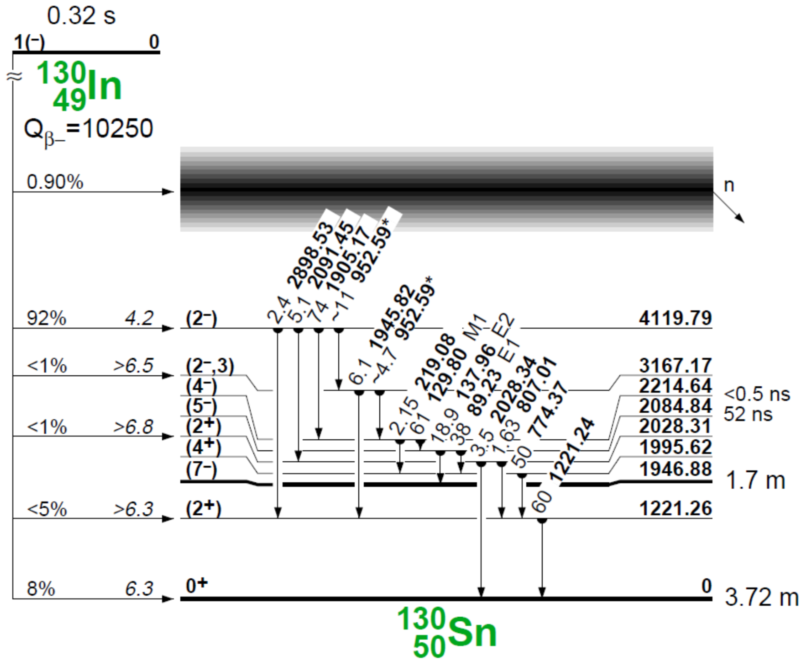
- beam intensity at MINIBALL I(^{132}Sn) = 3 x 10^5 ions/s
- PSB proton beam current 1.4 μA

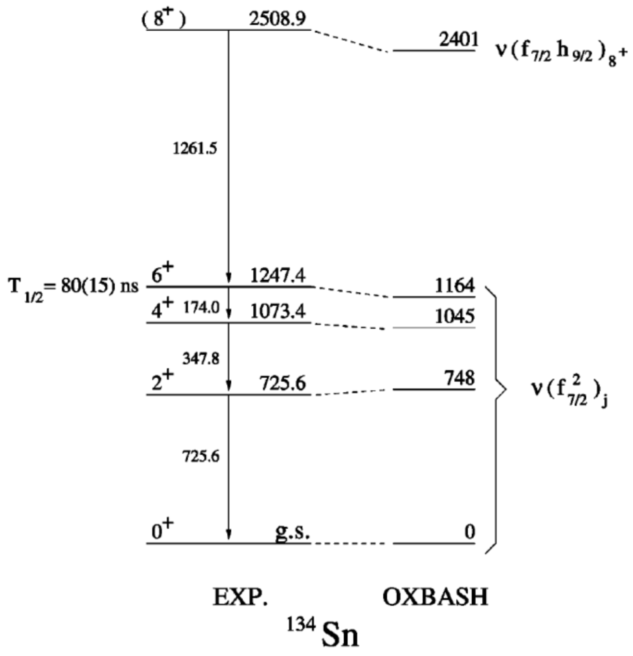
HIE-ISOLDE beam energy: 4.4 MeV/u

‘safe’ Coulex ^{130,134}Sn (@ 4.4 MeV/u) + ^{206}Pb

‘safe’ criterion $d > R_p + R_t + 5$ fm = 18.8 fm
fulfilled for target projectile distance at θ_{Lab}= 180°

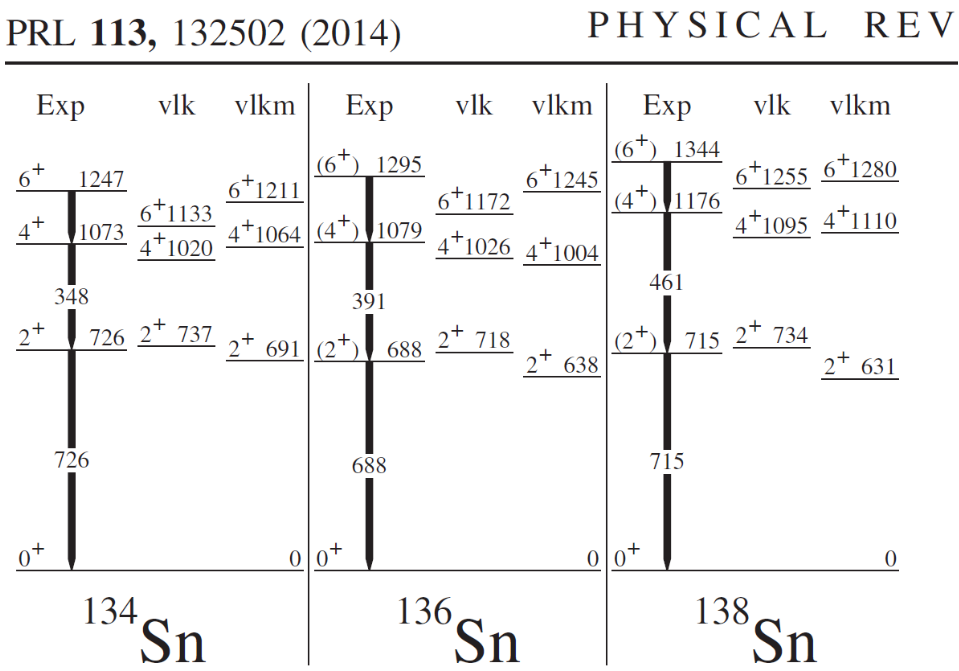
Beam composition and isomers





A. Korgul et al, EPJ A 7, 167 (2000)

G.S. Simpson, et al,



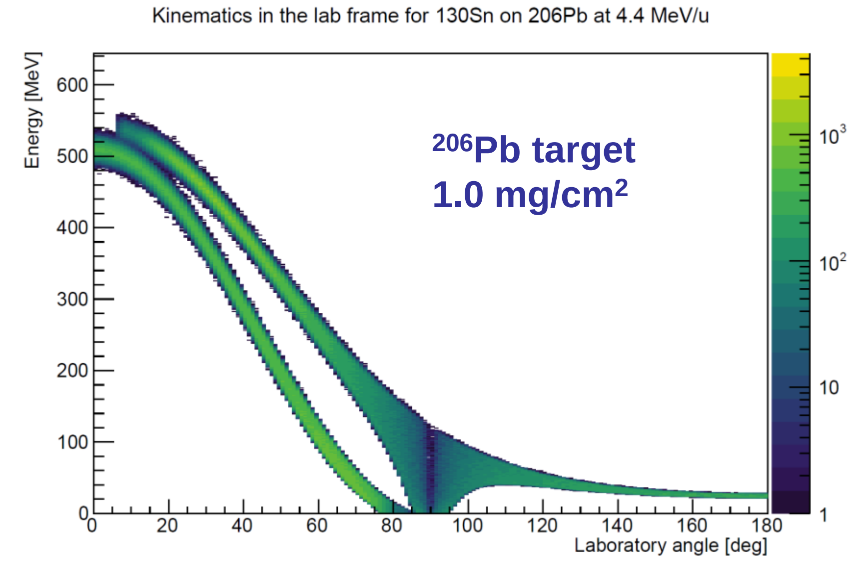
PRL **113,** 132502 (2014) PHYSICAL REV

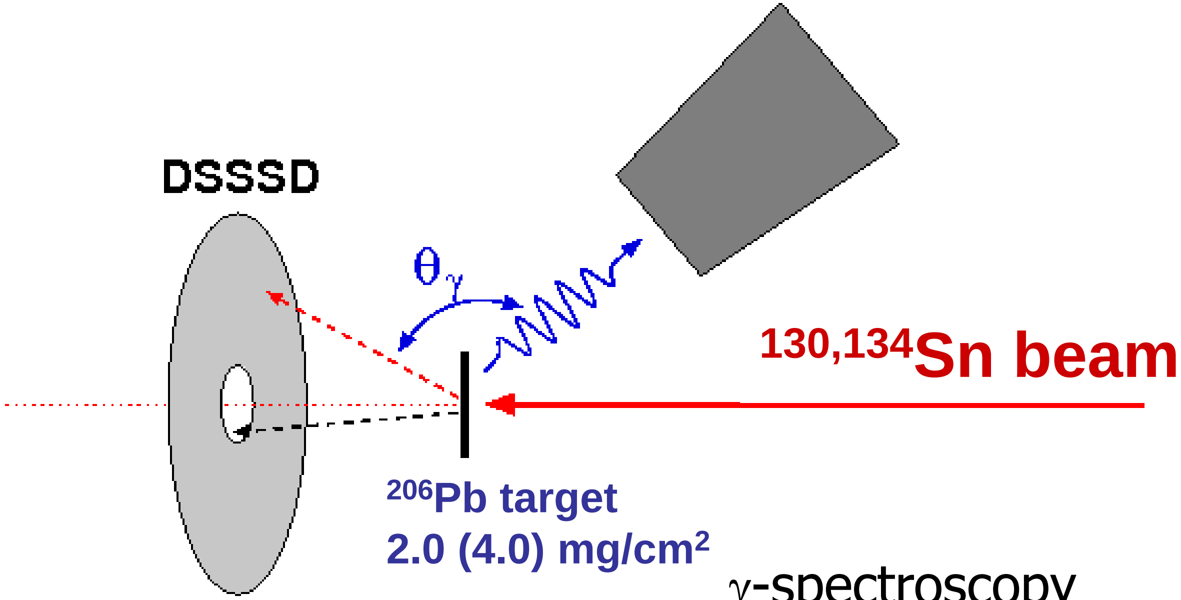
Fraction of ^{130}Sn beam is expected to be produced as 7$^-$ isomer (E=1946.88 keV, $T_{1/2}$ = 1.7 m)

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

Different β decay paths of ^{130}Sn 0^+_{gs} and 7$^-$ isomer
- γ–spectroscopy of β decay products
- request of additional 3 shifts for decay spectroscopy, longest half life is 39.5 m of ^{130}Sb ground state decay

MINIBALL setup & particle kinematics




DSSSD

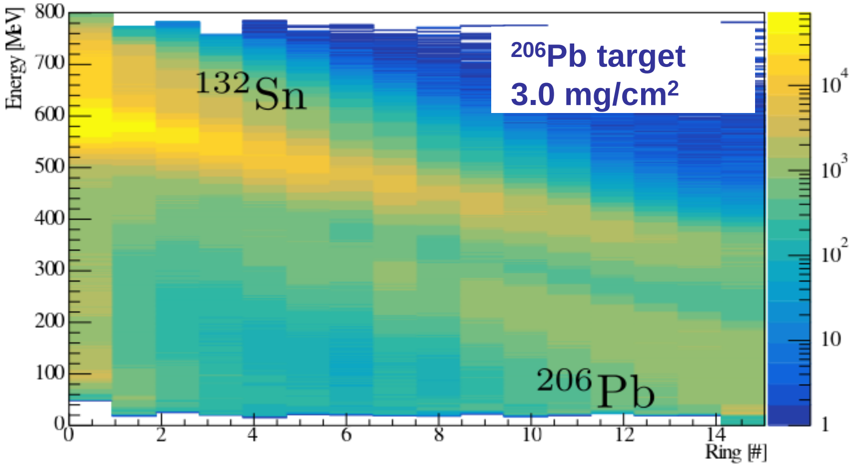
θ_γ

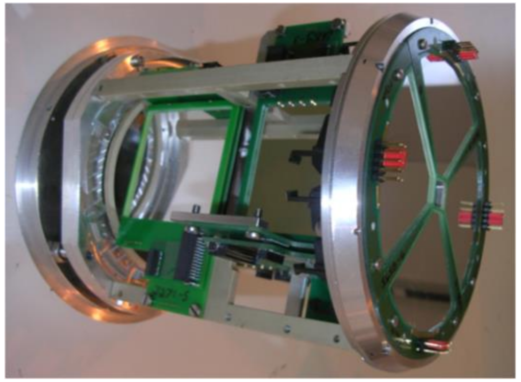
^{130,134}Sn beam

^{206}Pb target
2.0 (4.0) mg/cm^2

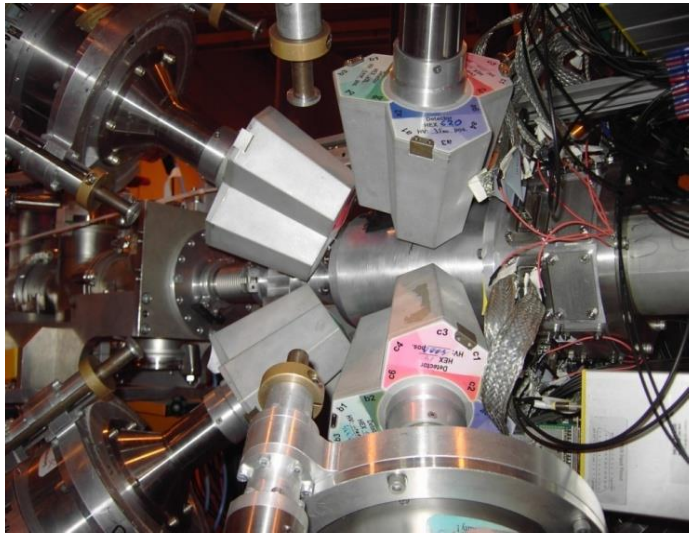
γ-spectroscopy

Particle detection
- scattering angle
- energy





TU München, K.U. Leuven



Uni Köln, K.U. Leuven

Cross sections & count rate estimate

Transition, energy	Transition strength	Integr. CLX cross-section $15^\circ < \theta_{Lab} < 50^\circ$ DSSSD	Integr. CLX cross-section $105^\circ < \theta_{Lab} < 172^\circ$ C-REX	cts/h	cts/ run	statistical error		isotope
$0_1^+ \rightarrow 2_1^+$ 1221.2 keV ^{130}Sn	$B(E2, 0_1^+ \rightarrow 2_1^+)$ 0.023 e^2b^2 *Nucl. Phys. A 752 (2005) 264c*	$\sigma(2_1^+)$ 130 mb	$\sigma(2_1^+)$ 90 mb	370	35000 *12 shifts*	<2%		^{130}Sn
$2_1^+ \rightarrow 4_1^+$ 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 *12 shifts*	~7%		^{130}Sn
$0_1^+ \rightarrow 2_1^+$ 725.6 keV ^{134}Sn	$B(E2, 0_1^+ \rightarrow 2_1^+)$ 0.029 e^2b^2 *Eur. Phys. J. A 25, s01, 391 (2005)*	$\sigma(2_1^+)$ 400 mb	$\sigma(2_1^+)$ 320 mb	15	3530 *15 shifts*	<2%		^{134}Sn
$2_1^+ \rightarrow 4_1^+$ 347.8 keV ^{134}Sn	$B(E2, 2_1^+ \rightarrow 4_1^+)$ 0.031 e^2b^2 *Phys. Rev. C 76, 024313 (2007)*	$\sigma(4_1^+)$ 2.6 mb	$\sigma(4_1^+)$ 10 mb	0.3	73 *15 shifts*	~12%		^{134}Sn

Summary and beam time request

- Measurements of the B(E2,$2_1^+ \rightarrow 0^+$)- and B(E2,$4_1^+ \rightarrow 2_1^+$) values for the neutron-rich isotopes ^{130,134}Sn are proposed.

- B(E2,$2_1^+ \rightarrow 0^+$) values will be improved significantly and will allow for crucial test of MCSM- and large scale SM calculations.

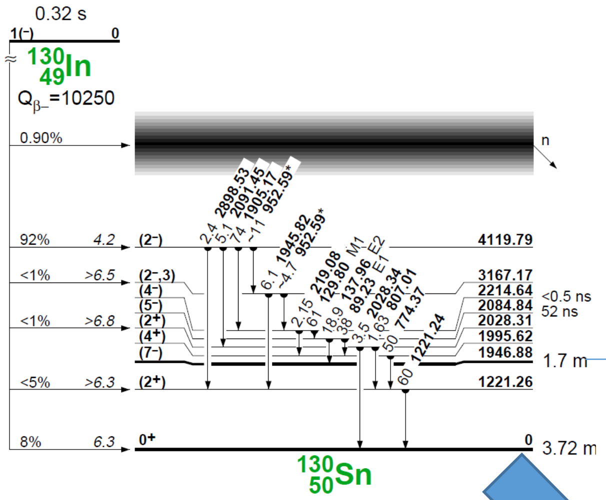
- B(E2,$4_1^+ \rightarrow 2_1^+$) values will be accessible in this region for the first time.

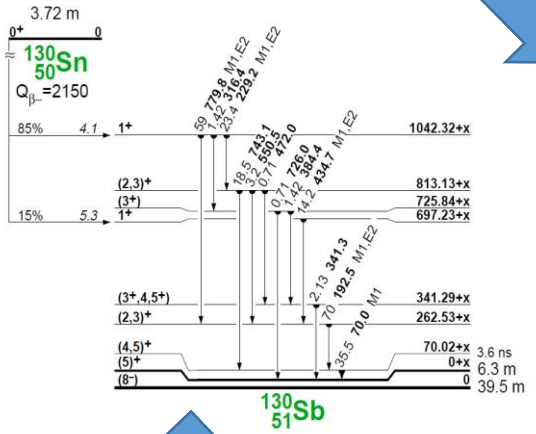
- Electric quadrupole moments Q_2 will be extracted from data. For short-lived states, this quantity is only accessible by safe Coulomb excitation via the reorientation effect.

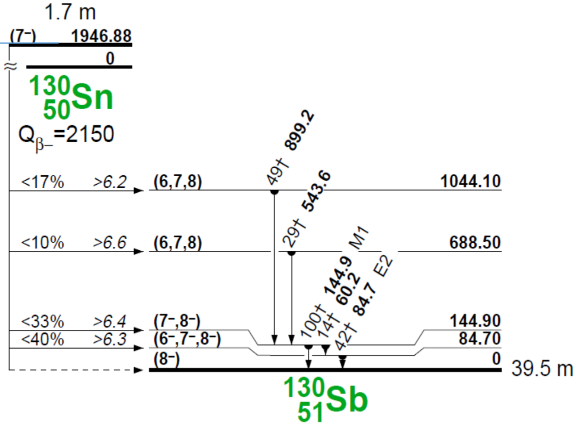
- Beam time request:
  12 shifts in beam spectroscopy + 3 shifts decay spectroscopy for ^{130}Sn
  15 shifts for ^{134}Sn

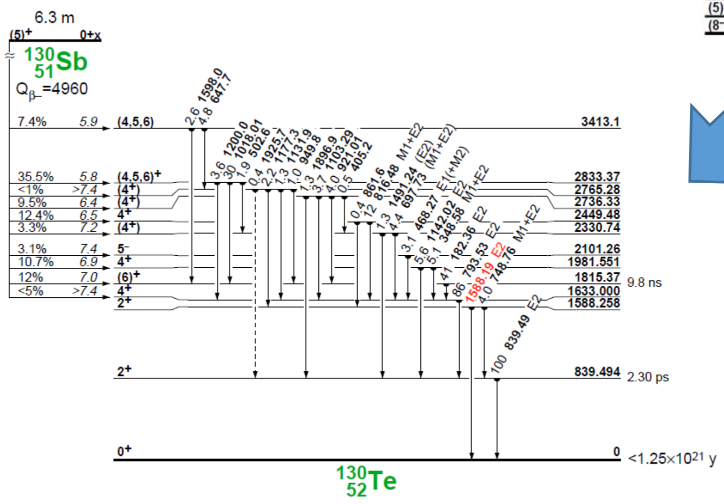
Backup slides

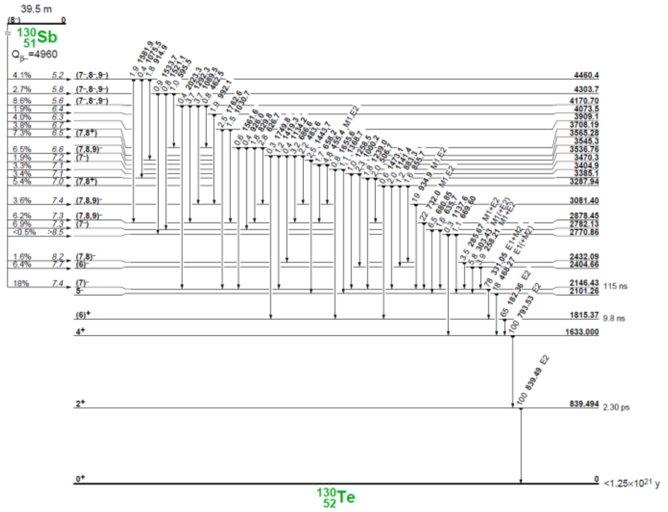
^{130}Sn beam composition



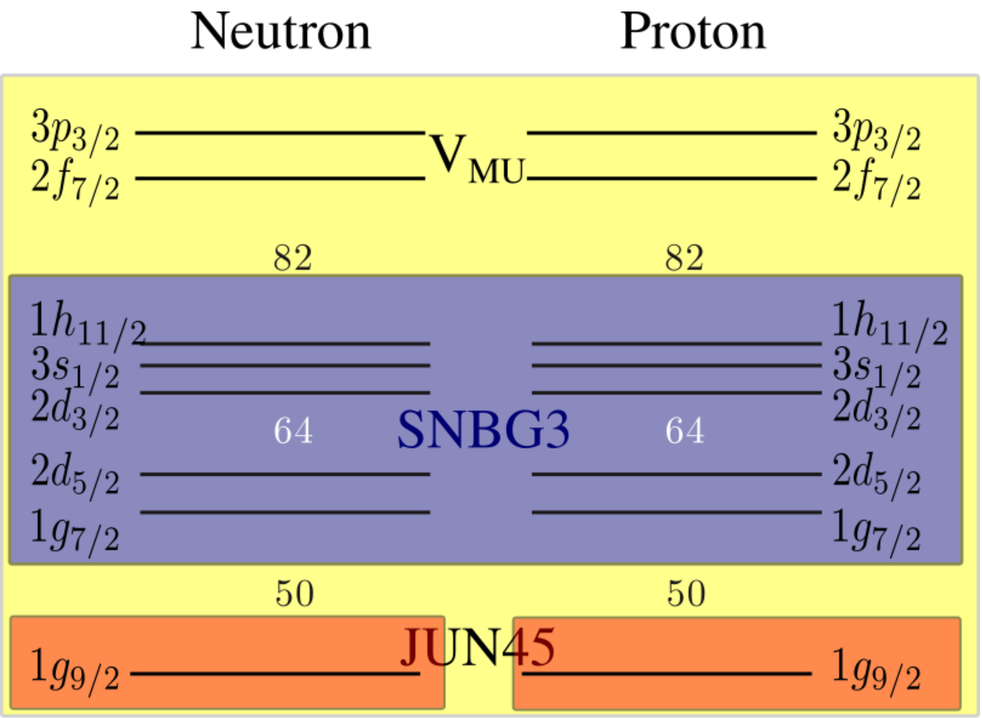








Monte-Carlo Shell Model



→ V_{MU} No T=0 interaction adjustments;
T=1 reduced by a factor of 0.75

Dimension and calculation:

→ realistic interactions JUN45 (CD-Bonn), SNGB3 (N3LO) and V_{MU} (central Gaussian part + meson exchange)

→ Fine tuning to reproduce 2^+_1 and 4^+_1 levels of $^{102-138}$Sn (TBME scaled to $A^{-1/3}$)

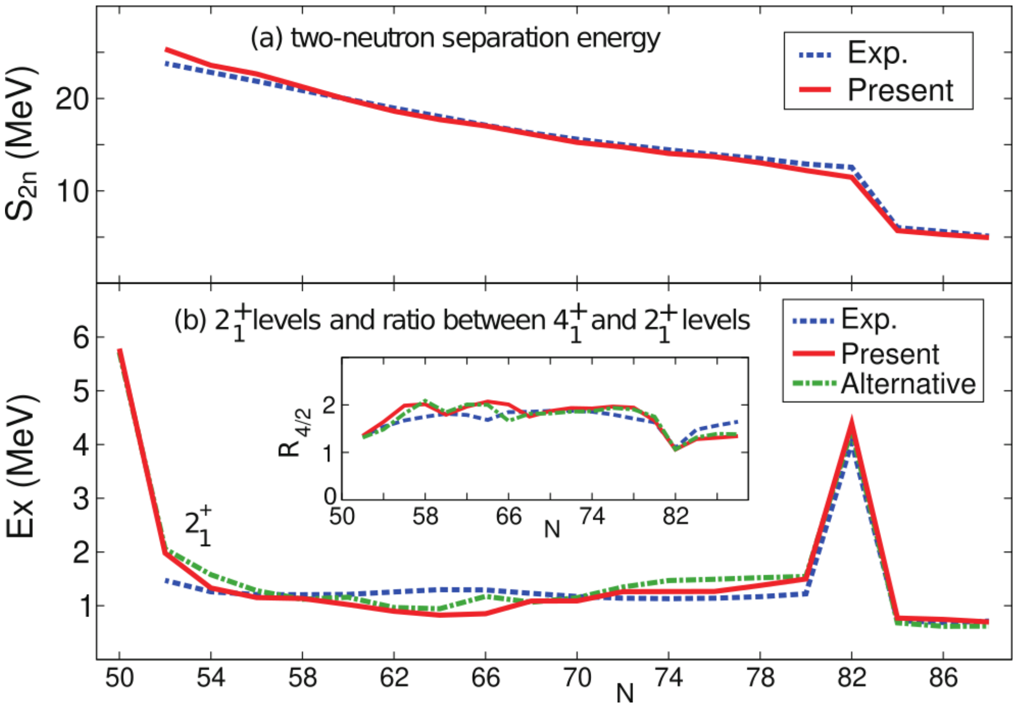
→ Model space dimension 7.5 x 10^{23}
(current calculation limit 10^{12})

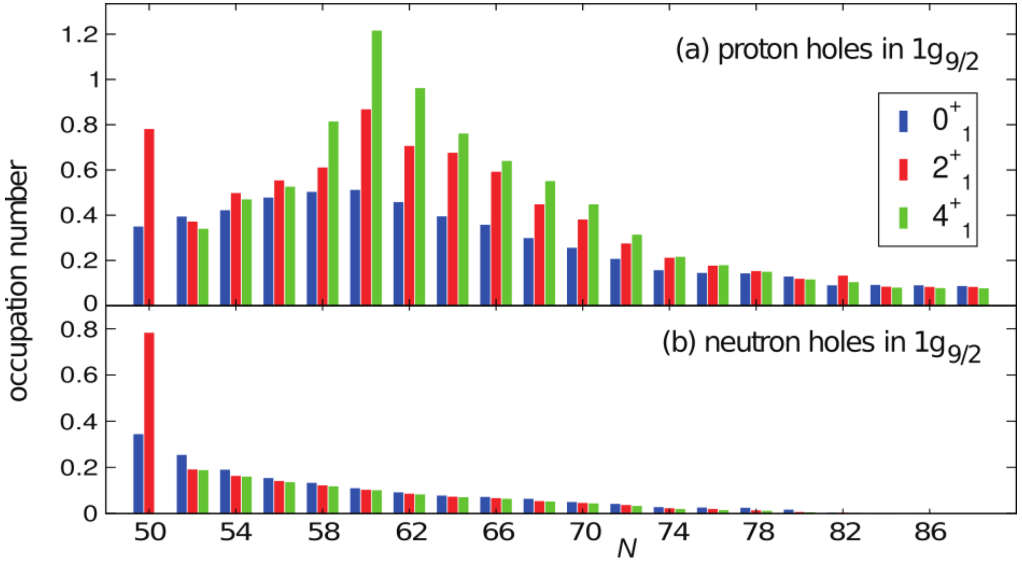
→ MCSM with no truncations

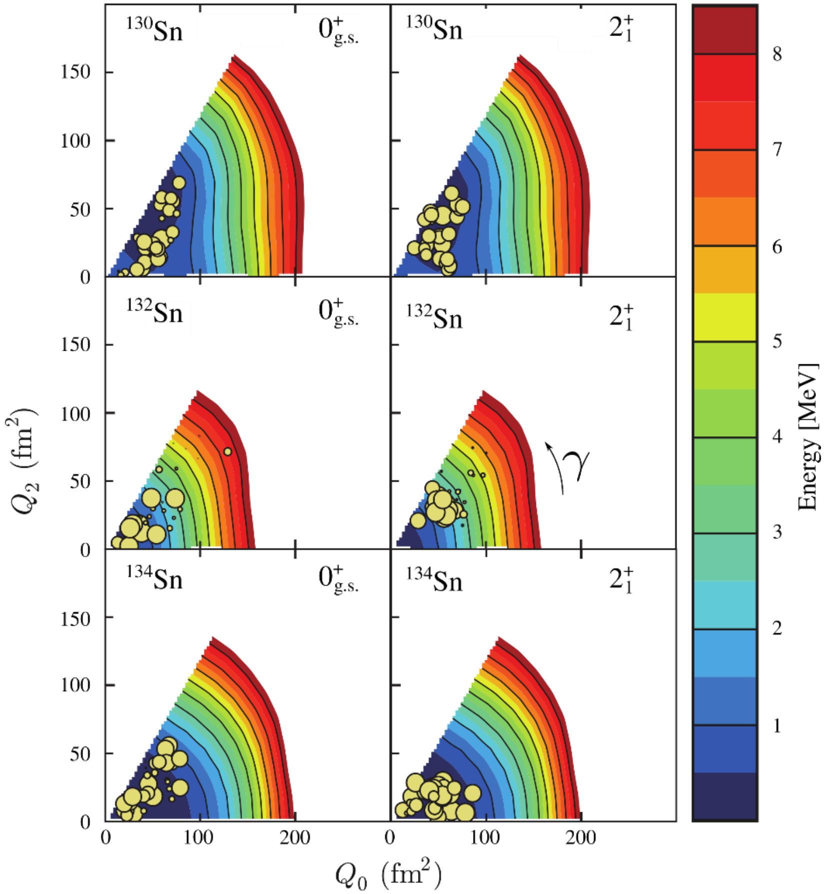
→ single Hamiltonian with active p and n representation by TBME of effective N-N interaction (coupled to J and T)

→ $\pi g_{9/2}$ prolate shape + $\nu h_{11/2}$ oblate shape + enhanced shell gap → magic

T. Togashi; Y. Tsunoda; T. Otsuka; N. Shimizu; M. Honma; Phys. Rev. Lett. 121, 062501 (2018)







→ Occupation numbers ^{132}Sn 2+

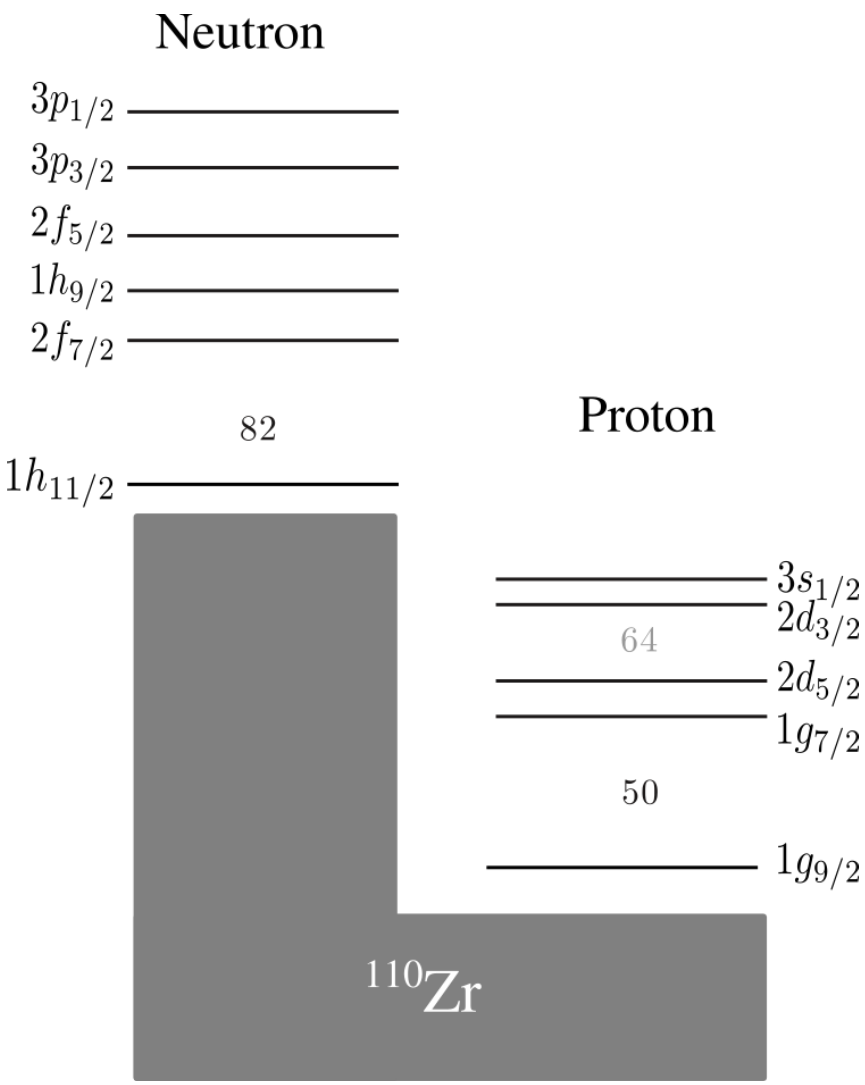
πg 9/2 → 0.09

νh 11/2 → 0.13

→ Proton contributes with ¼ to total E2 strength

→ Protons in g9/2 prolate – Neutrons in h11/2 oblate shape + enhanced shell gap → MAGIC

Large-scale shell-model calculation with ^{110}Zr



Dimension and conditions:

→ realistic interactions NNS100 derived from CD-Bonn

→ renormalized by $V_{\text{low-k}}$ (G-Matrix) to exclude repulsive short range (cutoff = 2.2 fm^{-1})

→ many-body perturbation up to second order

- → monopole adjustments to get SPE of ^{133}Sn + ^{133}Sb
- → p-p and n-p monopole matrix elements to get SPE for N=82 and N=83 isotones

→ fixed neutron gap of ^{132}Sn and proton gap of ^{120}Sn

→ Dimension 2x10^{19}

→ truncation scheme by limiting 7p7h excitation (ANTOINE)

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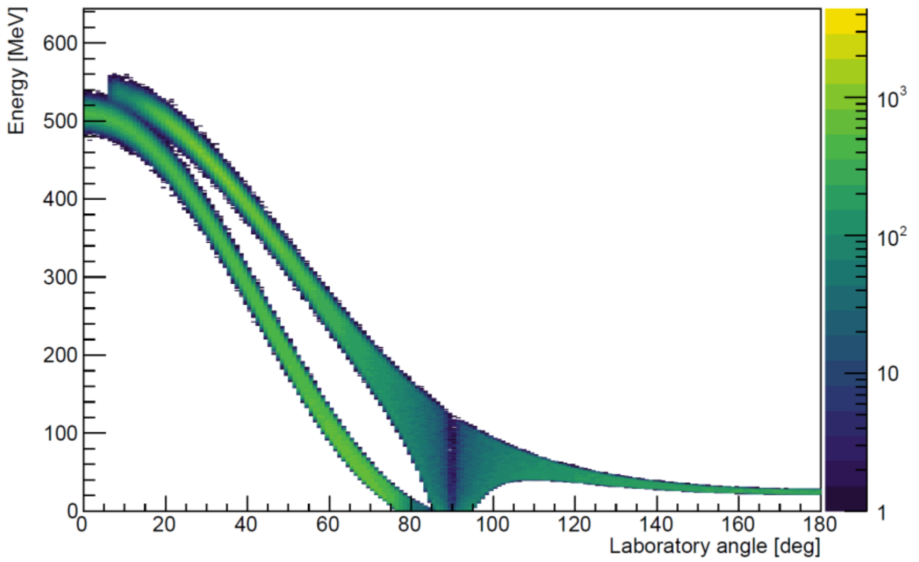
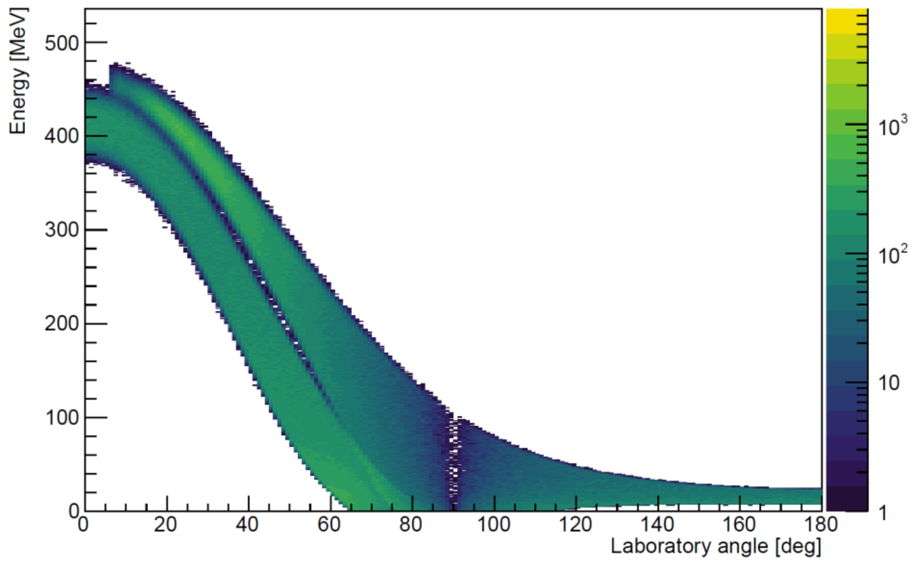
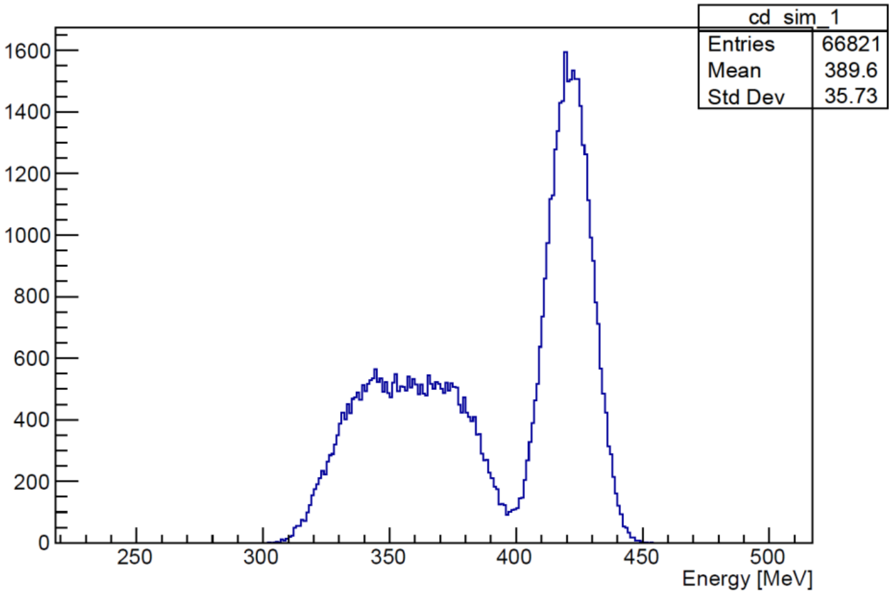
2) LPMS, Université Constantine 1, Algeria.
priv. comm. January 2018

Backup: Experimental considerations


Kinematics in the lab frame for 130Sn on 206Pb at 4.4 MeV/u


Kinematics in the lab frame for 130Sn on 206Pb at 4.4 MeV/u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