HIE-ISOLDE physics campaign 2018

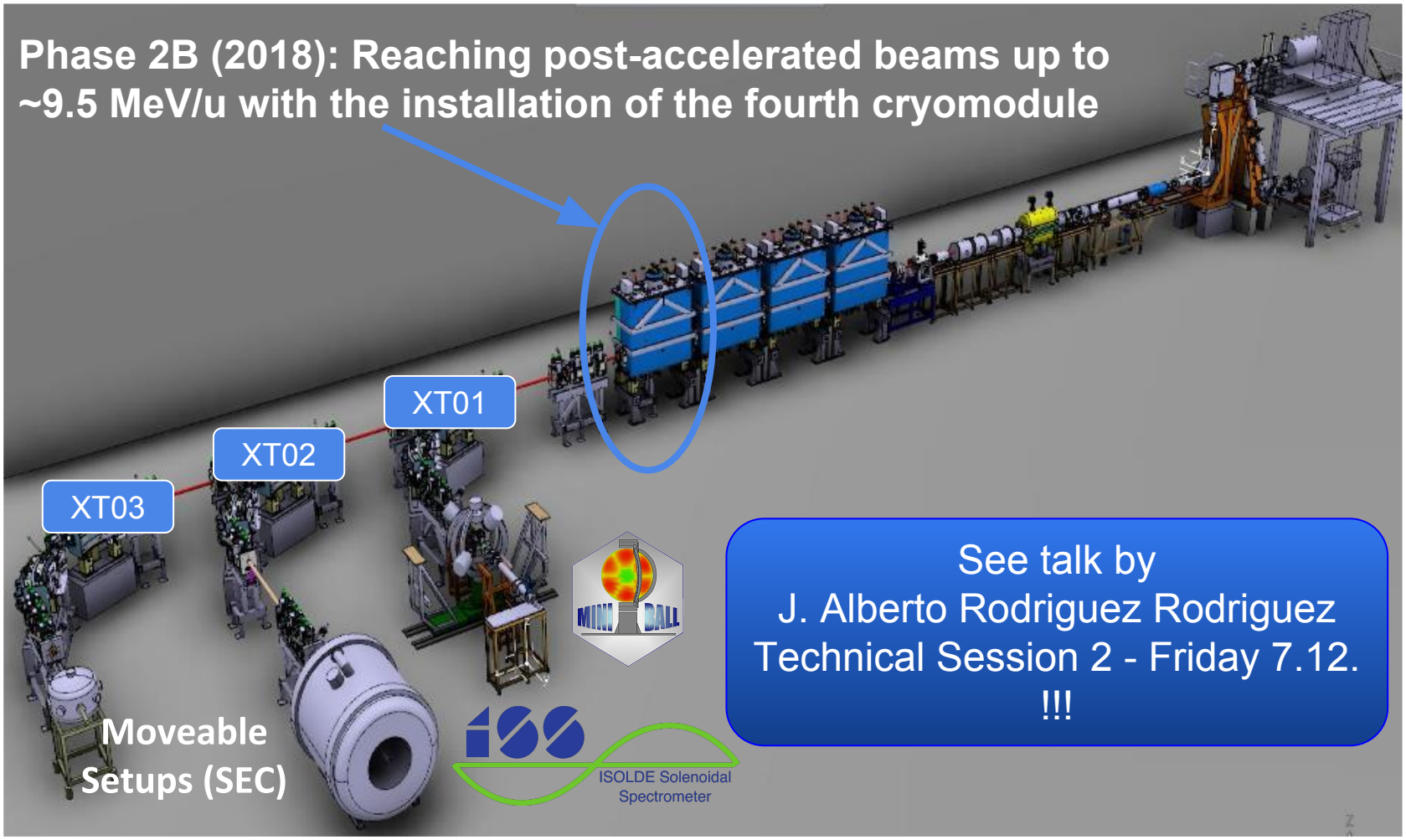
Joonas Konki (CERN)

ISOLDE Solenoidal Spectrometer

Overview

- **HIE-ISOLDE introduction**
- **HIE-ISOLDE physics campaign 2018**
  - ➢ MINIBALL experiments
  - ➢ ISOLDE Solenoidal Spectrometer (ISS) experiments
- **Hot off the press:** 1st HIE-ISOLDE publication (^{132}Sn CoulEx @ MINIBALL)
- **Summary**

HIE-ISOLDE

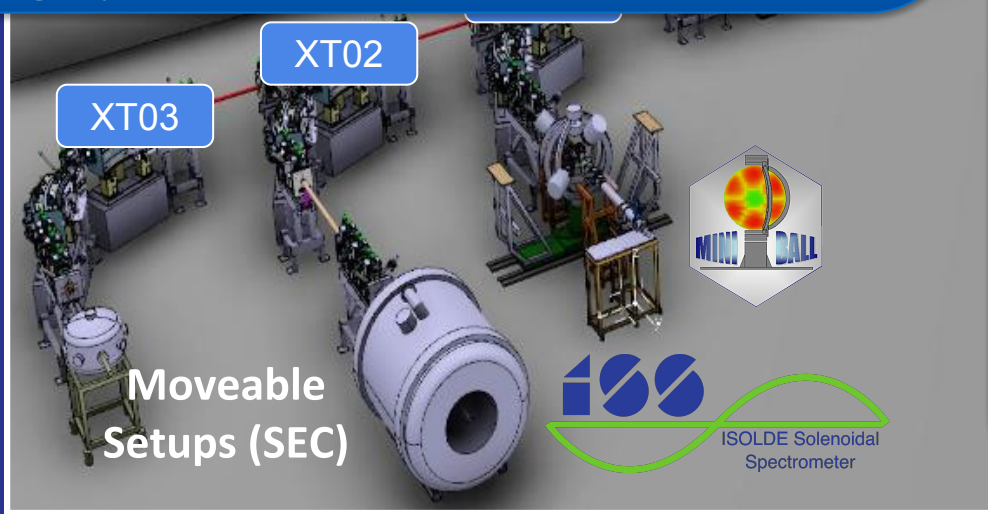


See talk by
J. Alberto Rodriguez Rodriguez
Technical Session 2 - Friday 7.12.
!!!

HIE-ISOLDE

Reactions:

- ^{8}**B**(^{64}Zn) @ 4.900 MeV/*u* *(SEC)*
- ^{7}**Be**(*d*,*p*) @ 5.000 MeV/*u* *(SEC)*
- ^{9}**Li**(*t*,*p*) @ 8.000 MeV/*u* *(SEC)*
- ^{11}**Be**(decay) @ 7.498 MeV/*u* *(SEC-TPC)*
- ^{132,134}**Sn**(*d*,*p*) @ 7.200 MeV/*u* *(Miniball+T-REX)*
- ^{28}**Mg**(*t*,*p*) @ 9.473 MeV/*u* *(Miniball+T-REX)*
- ^{28}**Mg**(*d*,*p*) @ 9.473 MeV/*u* *(ISS)*
- ^{206}**Hg**(*d*,*p*) @ 7.380 MeV/*u* *(ISS)*

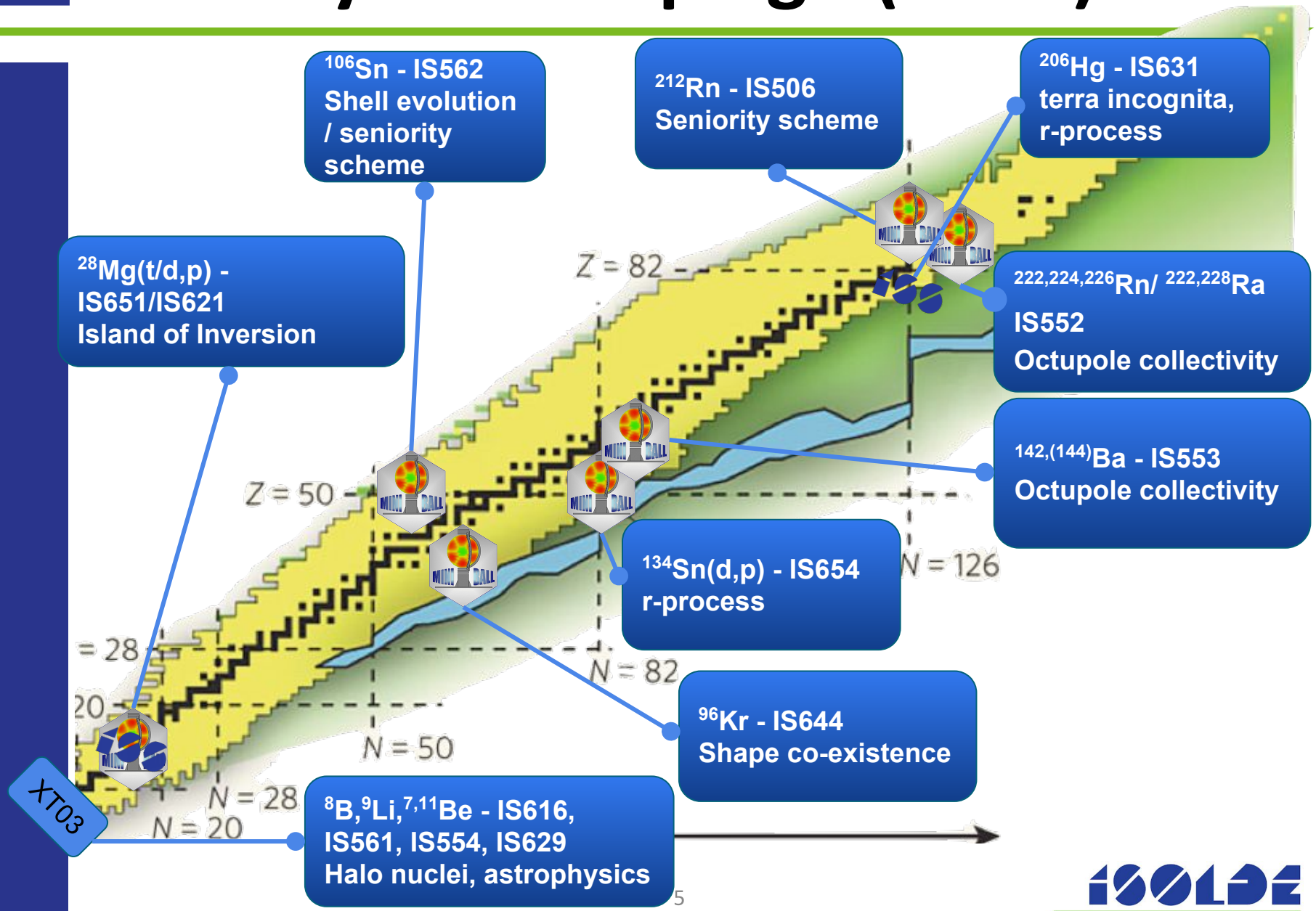


Moveable Setups (SEC)

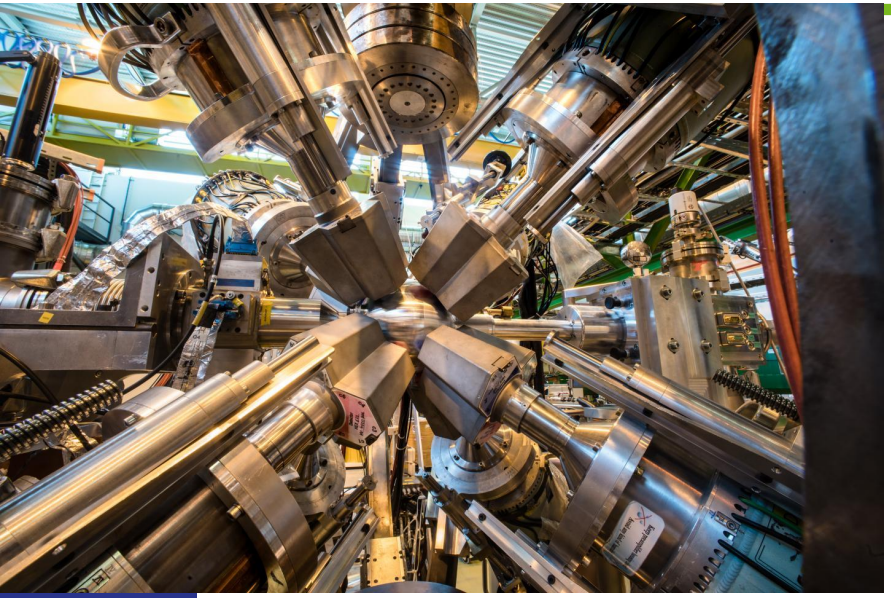
Coulomb excitation (Miniball):

- ^{96}**Kr** @ 5.325 MeV/*u*
- ^{212}**Rn** @ 4.355 MeV/*u*
  @ 3.824 MeV/*u*
- ^{222}**Ra** @ 4.305 MeV/*u*
- ^{228}**Ra** @ 4.310 MeV/*u*
- ^{142}**Ba** @ 4.190 MeV/*u*
- ^{222}**Rn** @ 4.230 MeV/*u*
- ^{224,226}**Rn** @ 5.080 MeV/*u*
- ^{106}**Sn** @ 4.404 MeV/*u*

Physics campaign (2018)



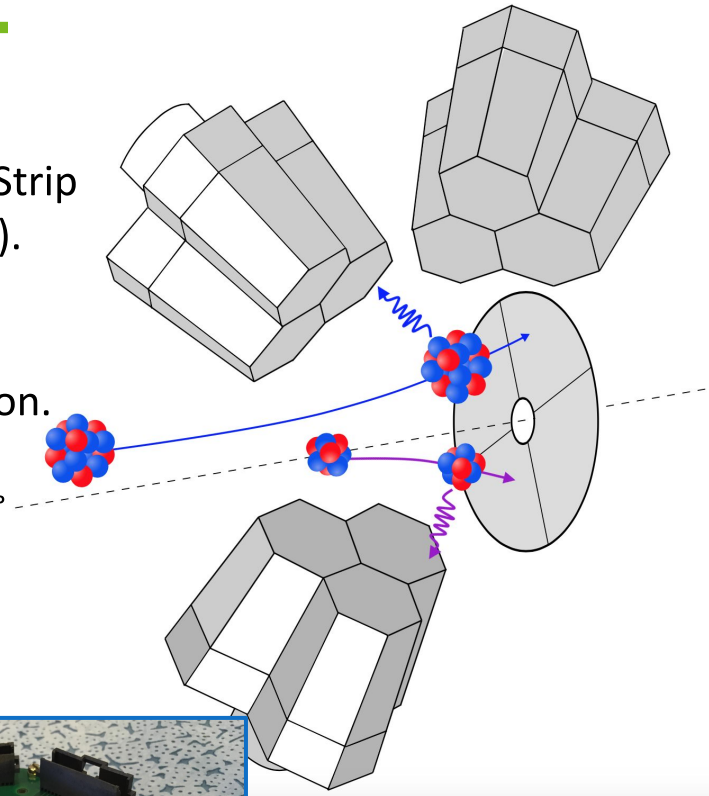
MINIBALL @ HIE-ISOLDE



Particle ID in a Double-Sided Si Strip Detector (DSSSD).

Event-by-event Doppler correction.

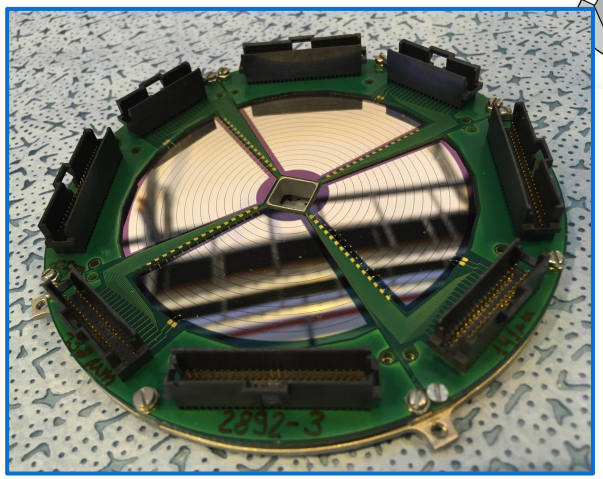
~20˚ < θ_{lab} < ~60˚



Array of 8 HPGe triple clusters

6-fold electronic segmentation

ε > 7% for 1.3MeV γ-rays



N. Warr *et al.*, EPJ A **49**, 40 (2013)

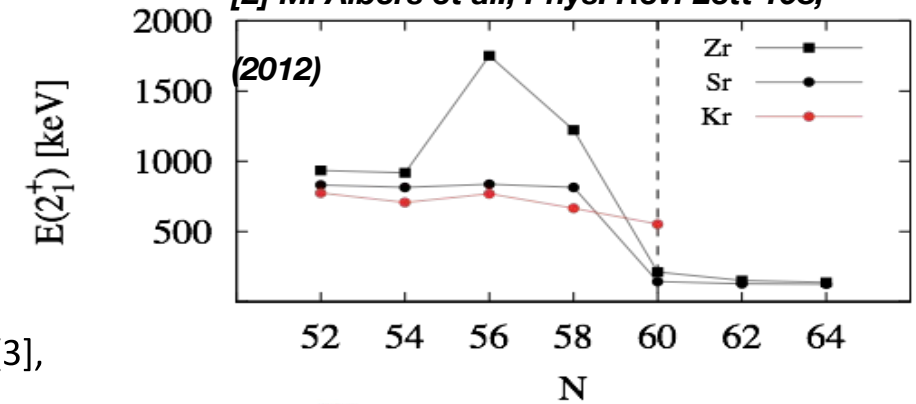
MB: IS644 - ^{96}Kr

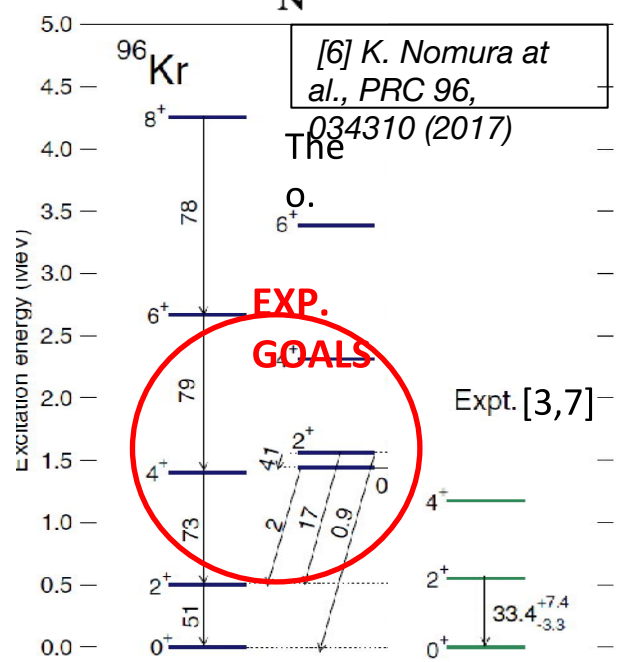
A Coulomb-nuclear excitation study of shape co-existence in ^{96}Kr

K. Moschner (replaced by A. Blazhev), B.S. Nara Singh

- Sudden shape change in Zr+Sr+Rb manifested in rapid drop of $E(2_1^+)$ and sudden increase of 2n separation energies, but not in Kr isotopes [1]
  [1] S. Naimi et al., PRL 105, 032502 (2010)
- 2^+ energy from Coulex at REX-ISOLDE data supported smooth onset of collectivity [2]
  [2] M. Albers et al., Phys. Rev. Lett 108, (2012)
- Various theoretical calculations predict lower lying shape-coexisting yrare states: IBM2 with conf. mixing [3], SCCM [4], 5DCH [5], new IBM-CF [6]
  [3] M. Albers et al., Nucl. Phys. A 899, (2013)
  [4] T. R. Rodríguez, PRC 90, 034306 (2014)
  [5] J.-P. Delaroche et al., PRC 81, 014303 (2010)
  [6] K. Nomura at al., PRC 96, 034310 (2017)
- Further new results, on (4^+) in ^{96}Kr from AGATA at GANIL [7], together with published results on ^{98,100}Kr [8] and preliminary results on ^{96}Kr from RIKEN [9] motivate the high-resolution study of the shape co-existing states in ^{96}Kr at HIE-ISOLDE populated via CNE reaction.
  [7] Dudouet et. al PRL 118, 162501 (2017)
  [8] Flavigny et. al PRL 118, 242501 (2017)
  [9] K. Moschner et al., in preparation.

[2] M. Albers et al., Phys. Rev. Lett 108, (2012)





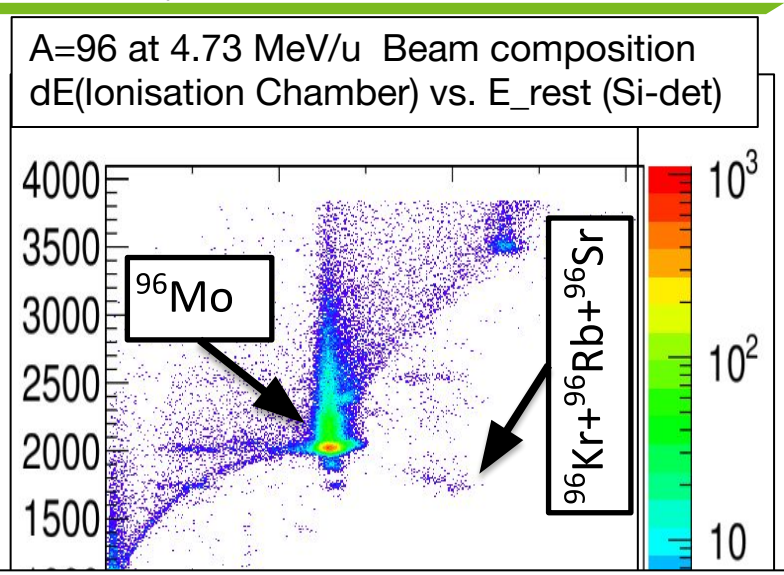
Courtesy of A. Blazhev

MB: IS644 - ^{96}Kr

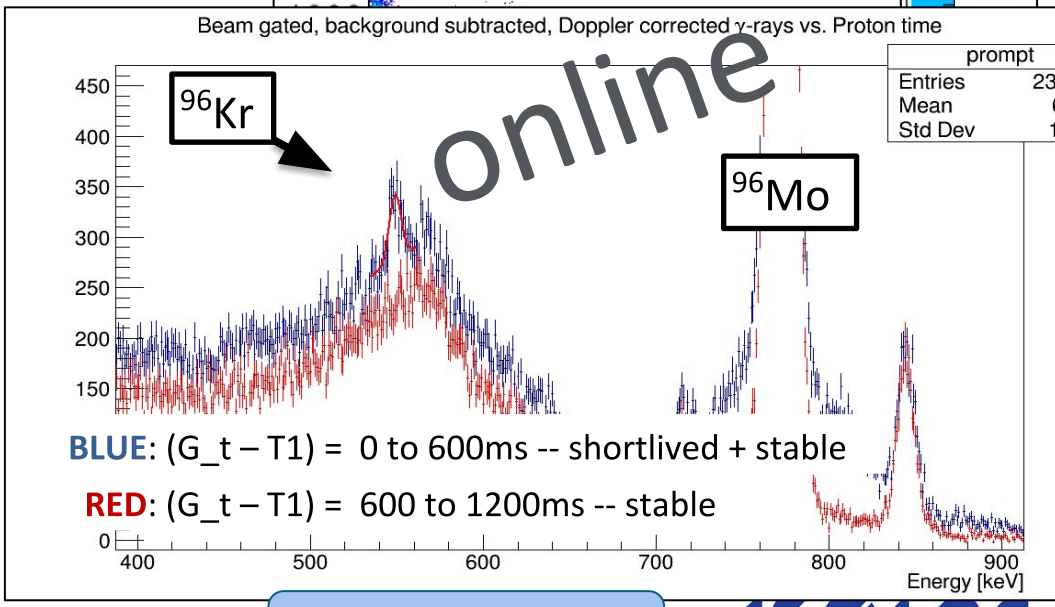
Experiment 12-19.07.2018 @ HIE-ISOLDE / MINIBALL

Current status

- Beam and Detectors Setup and calibrations done by the CERN local group and international MINIBALL experts in June, July 2018 (big thanks to all of them!)
- High amount of contamination of the secondary beam by ^{96}Mo, which is coming from the VADIS Mo cathode. The shortlived ^{96}Kr ($T_{1/2}$ = 80 ms) are decaying already on the way to the MINIBALL target, leading to ^{96}Rb and ^{96}Sr in the beam composition.



- Time gates of g-ray time(G_t) relative to the Proton Pulse (T1) are needed.
  One can see the ^{96}Kr $2^+ \rightarrow 0^+$ g.s. 554 keV transition on top of the ^{96}Mo Coulex Compton edge.
- Second beam energy (5.32 MeV/u) to increase population of higher states



Offline analysis

- From October 2018 till now, extremely careful gain matching and calibration of all detectors and angles have been performed.
  (J. Litzinger and N. Warr)

Courtesy of A. Blazhev

MB: IS506 - ^{212}Rn

Mapping the boundaries of the seniority regime and collective motion:
Coulomb excitation studies of ^{208}Po and ^{210,212}Rn, T. Grahn *et al.*

Seniority scheme:
The $2^+ \longrightarrow 0^+$ transition is a seniority changing transition (Δv != 0). Higher transitions conserve it.

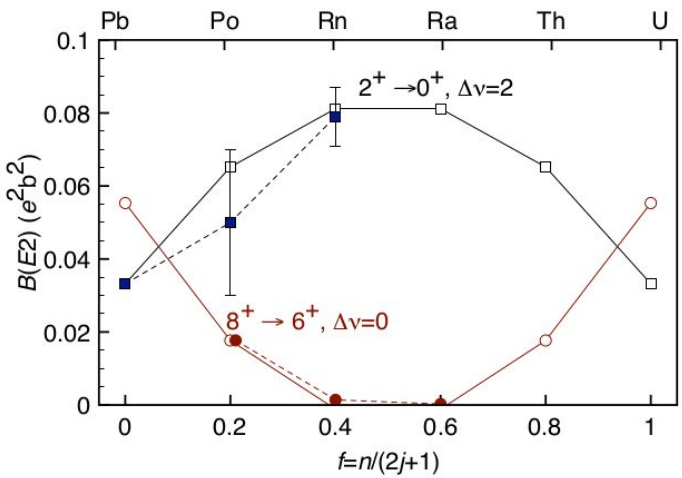


Figure 6. Calculated (open symbols) and experimental (filled symbols) $B(E2)$ values as a function of fractional filling f of the $\pi h_{9/2}$ orbital for the $\Delta v = 2$ $2^+ \rightarrow 0^+$ (black squares) and $\Delta v = 0$ $8^+ \rightarrow 6^+$ (red circles) transitions in the $N = 122$ isotones. The calculated values are obtained within the seniority scheme (for equations, see e.g. Ref. [1]) and have been normalised to the experimental values of ^{204}Pb ($\Delta v = 2$ transitions) and ^{206}Po ($\Delta v = 0$ transitions). The experimental $B(E2)$ values have been extracted from the present work and from Refs. [2, 3].

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THE EUROPEAN PHYSICAL JOURNAL A

Regular Article – Experimental Physics

Collective 2_1^+ excitations in ^{206}Po and ^{208,210}Rn

T. Grahn[1,2,a], J. Pakarinen[1,2,10], L. Jokiniemi[1], M. Albers[3], K. Auranen[1,2,b], C. Bauer[4], C. Bernards[5], A. Blazhev[3], P.A. Butler[6], S. Bönig[4], A. Damyanova[7], T. De Coster[8], H. De Witte[8], J. Elseviers[8], L.P. Gaffney[6,8,9], M. Huyse[8], A. Herzáň[1,2], U. Jakobsson[1,2], R. Julin[1,2], N. Kesteloot[8], J. Konki[1,2], Th. Kröll[4], J. Lewandowski[3], K. Moschner[3], P. Peura[1,2], M. diger[3], M.-D. Salsac[11], P. Thoele[3], M. Thürauf[4], N. [2], A. Vogt[3], K. Wrzosek-Li

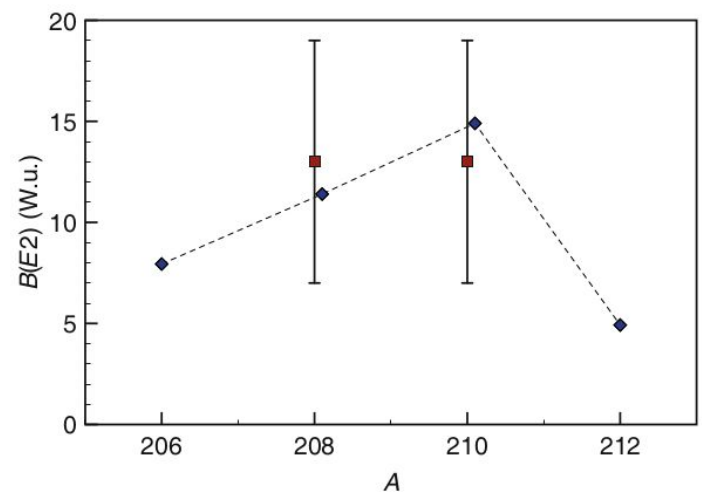


Fig. 13. The experimental (filled squares) and theoretica (filled diamonds) $B(E2; 2_1^+ \rightarrow 0_1^+)$ values obtained in th present work for the radon isotopes. Some of the values ar offset of their actual A location for the clarity of the presenta tion

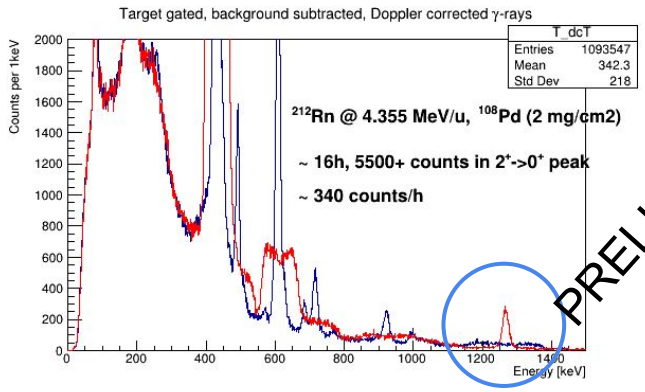
MB: IS506 - ^{212}Rn

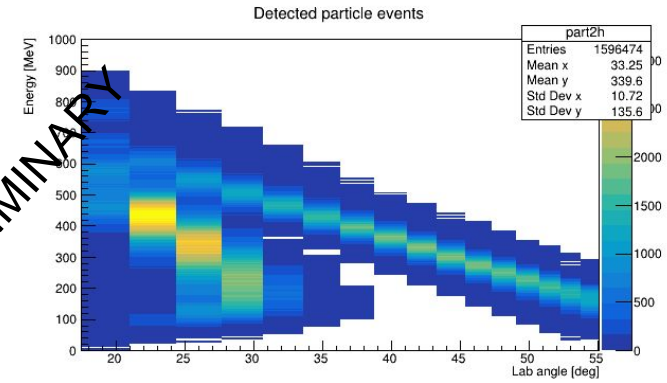
Experiment 20-22.07.2018 @ HIE-ISOLDE / MINIBALL

- ^{212}Rn at two beam energies:
  4.355 MeV/u
  3.824 MeV/u
- Targets: ^{108}Pd, ^{94}Mo

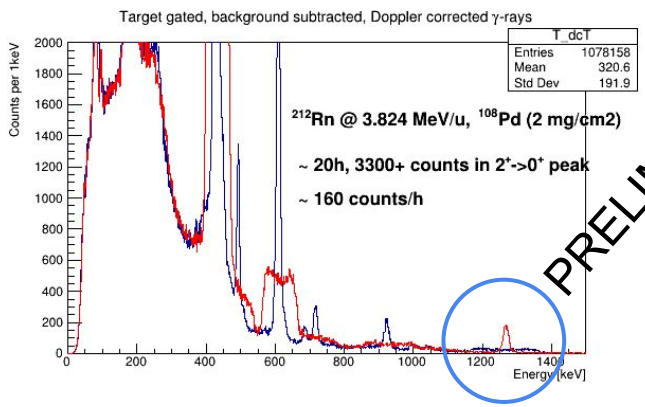
Going from 3.824 MeV/u to 4.355 MeV/u there is a gain of 2x in yield !

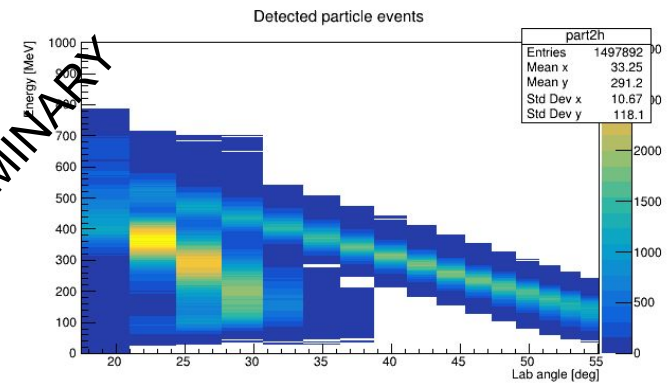
Very good statistics obtained for the $2^+ \rightarrow 0^+$ transition (order of magnitude more than in the proposal)



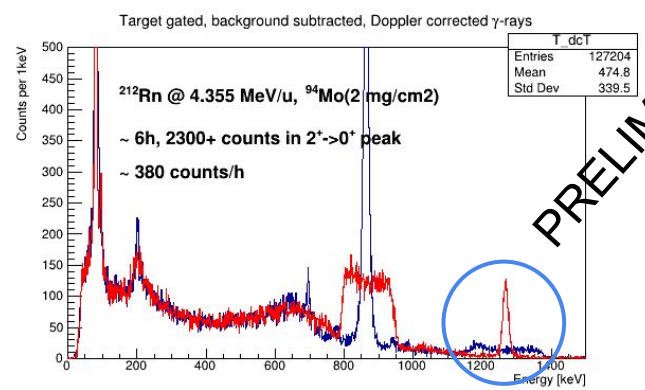


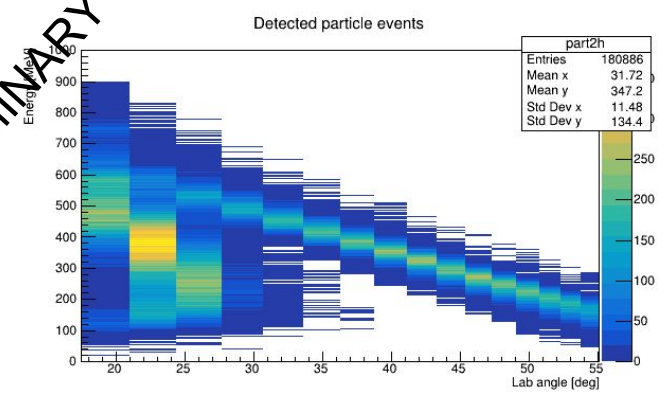
PRELIMINARY





PRELIMINARY





PRELIMINARY

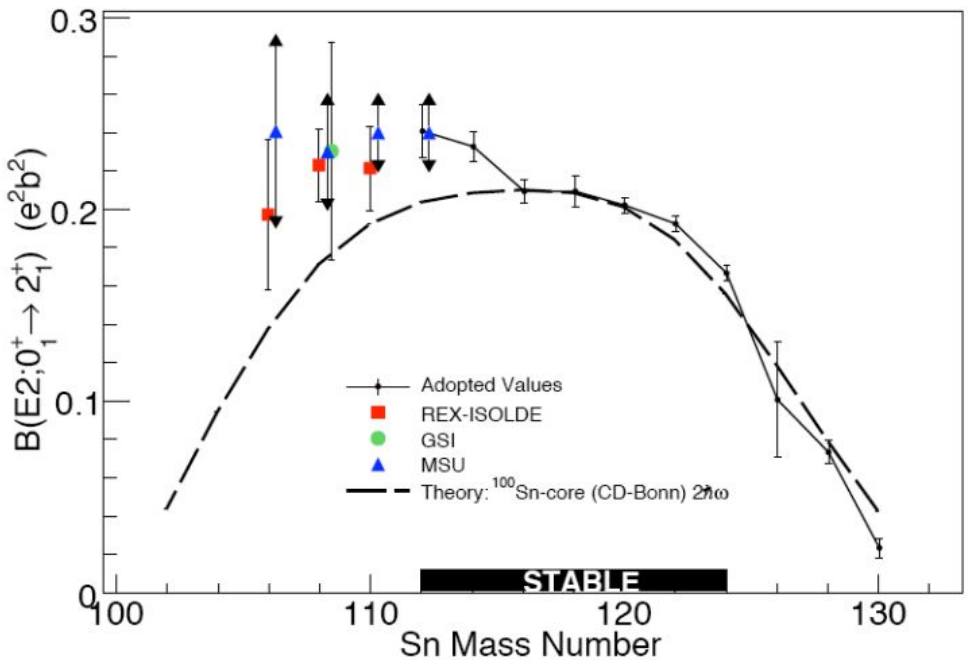
MB: IS562 - ^{106}Sn

Transfer Reactions and Multiple Coulomb Excitation in the ^{100}Sn Region,
J. Cederkäll *et al.*

- Study discrepancies of B(E2)s in light Sn isotopes (textbook seniority scheme example!)

Experiment 8.-13.8.2018:

- ^{106}Sn @ 4.404 MeV/u on ^{206}Pb target
- Contamination from ^{106}In
- Obtained very good statistics on 2^+->0^+
- 4^+->2^+ overlaps with ^{206}Pb transition but may be recovered using more careful particle selection by reaction kinematics



MB: IS552 - ^{222,224,226}Rn, ^{222,228}Ra

Measurements of octupole collectivity in Rn and Ra nuclei using Coulomb excitation, P. Butler *et al.*

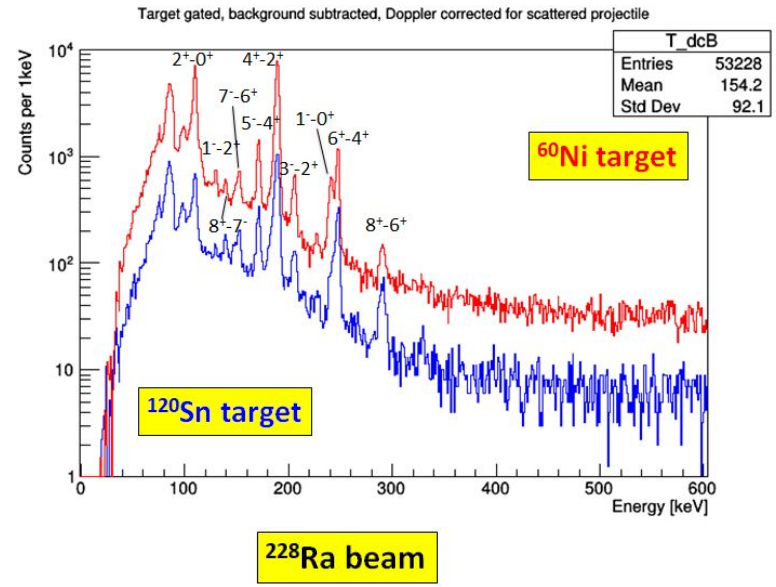
- Determine B(E3)s in Rn, Ra to investigate static and vibrational cases of octupole deformation
- Level schemes of ^{224,226}Rn unknown
  - ➢ Relevance to EDM searches

Was able to measure:

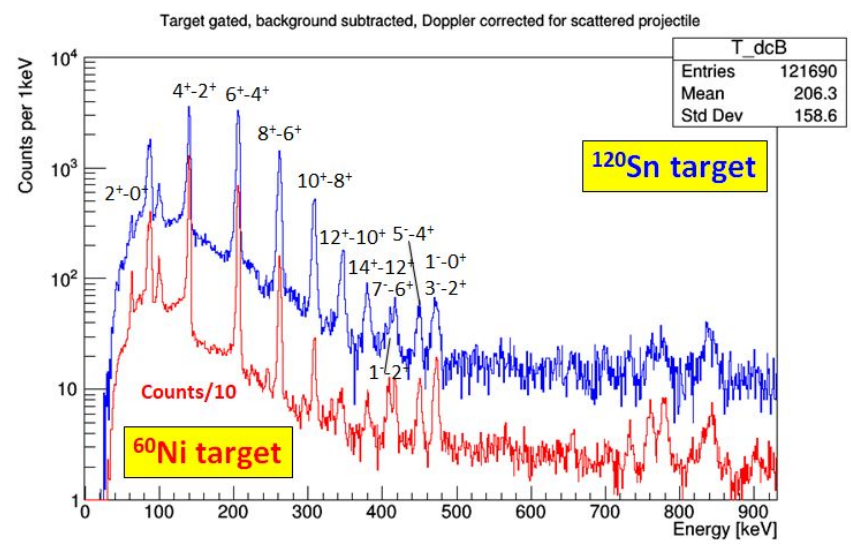
- ^{222,228}Ra, ^{222}Rn on ^{120}Sn, ^{60}Ni
- ^{224,226}Rn on ^{120}Sn

Unfortunately, ThC target failed before safe-CoulEx measurement of ^{224}Rn

Courtesy of P. Butler, **see talk later in this session!**



228Ra beam



MB: IS553 - $^{142,(144)}$Ba

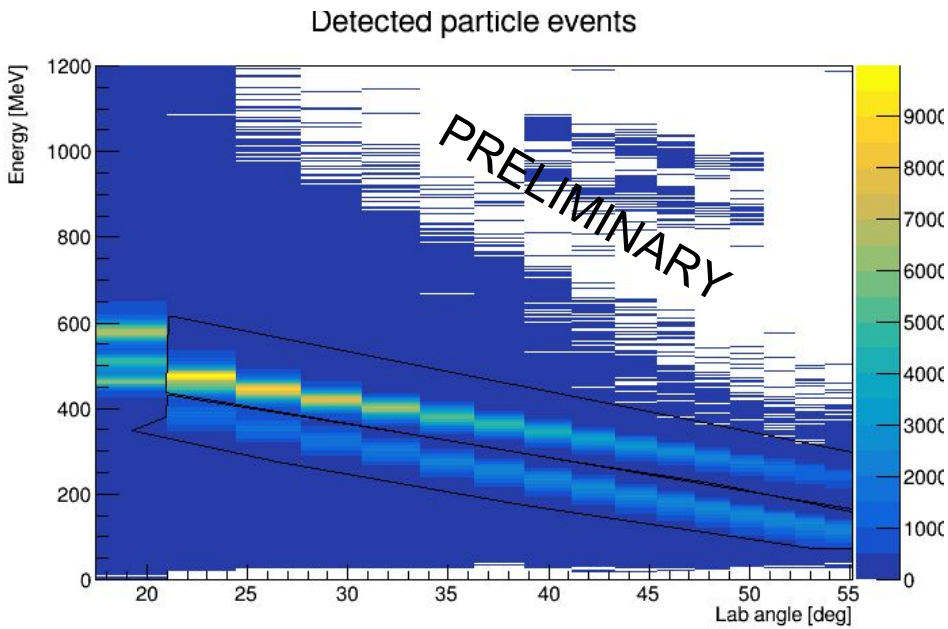
Determination of the B(E3,$0^+ \rightarrow 3^-$) strength in the octupole correlated nuclei ^{142,144}Ba using Coulomb excitation, M. Scheck, D.T. Joss *et al.*

- Determine B(E3)s in ^{142,144}Ba to investigate octupole collectivity
- ^{144}Ba experiment done in 2017

2018:

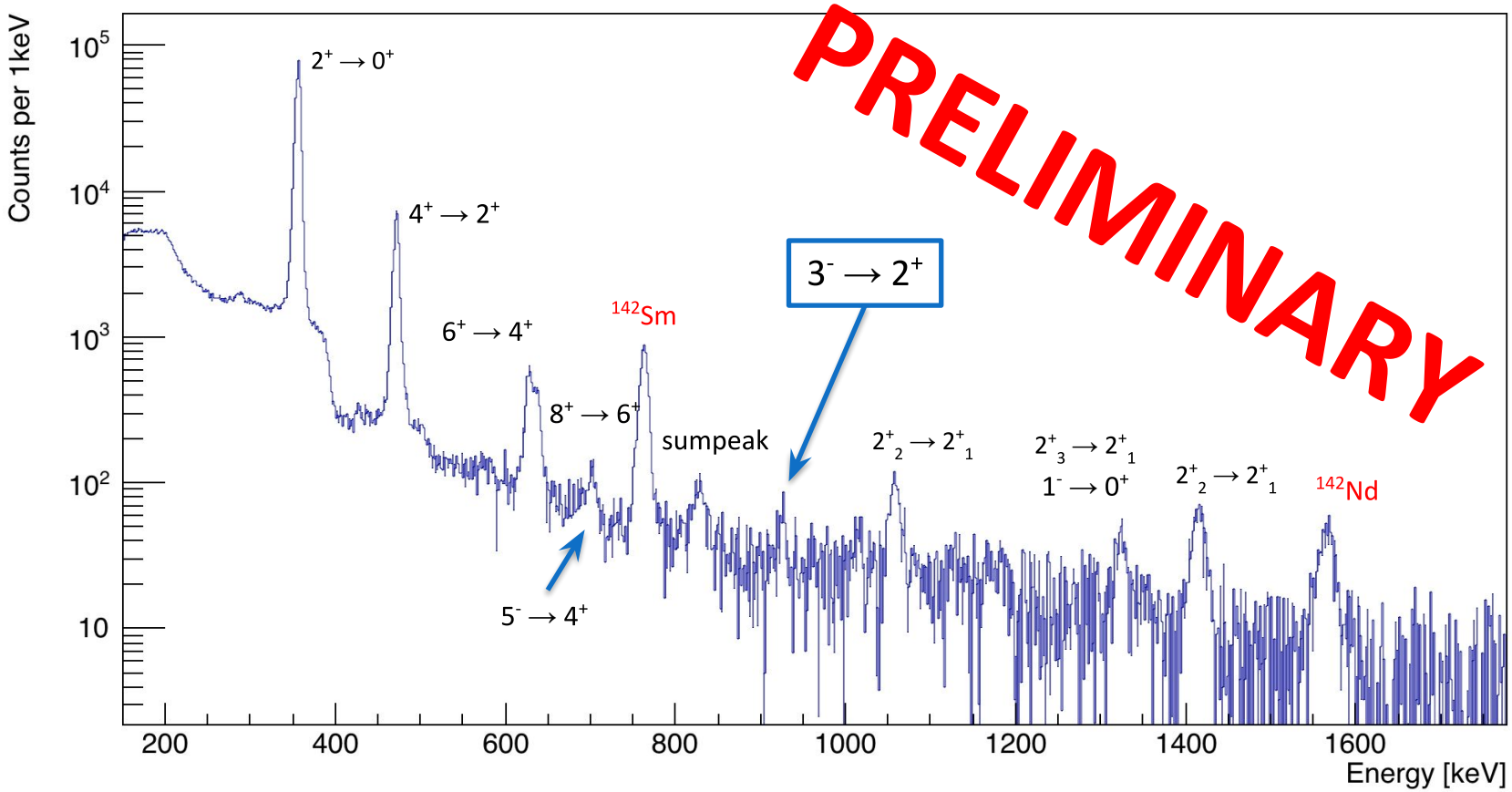
- ^{142}Ba @ 4.19 MeV/u on ^{208}Pb
- Contaminant ^{142}Cs <~ 2% with beam-gate implemented

Unfortunately, a CERN wide power cut caused issues at PSBooster & ISOLDE during experiment



MB: IS553 - $^{142,(144)}$Ba

Determination of the B(E3,$0^+ \rightarrow 3^-$) strength in the octupole correlated nuclei ^{142,144}Ba using Coulomb excitation, M. Scheck, D.T. Joss *et al.*



- Laser ionised (RILIS) with Cs suppressed using beam gate.
- Small contamination from isobars, but 50% duty cycle from beam gate.

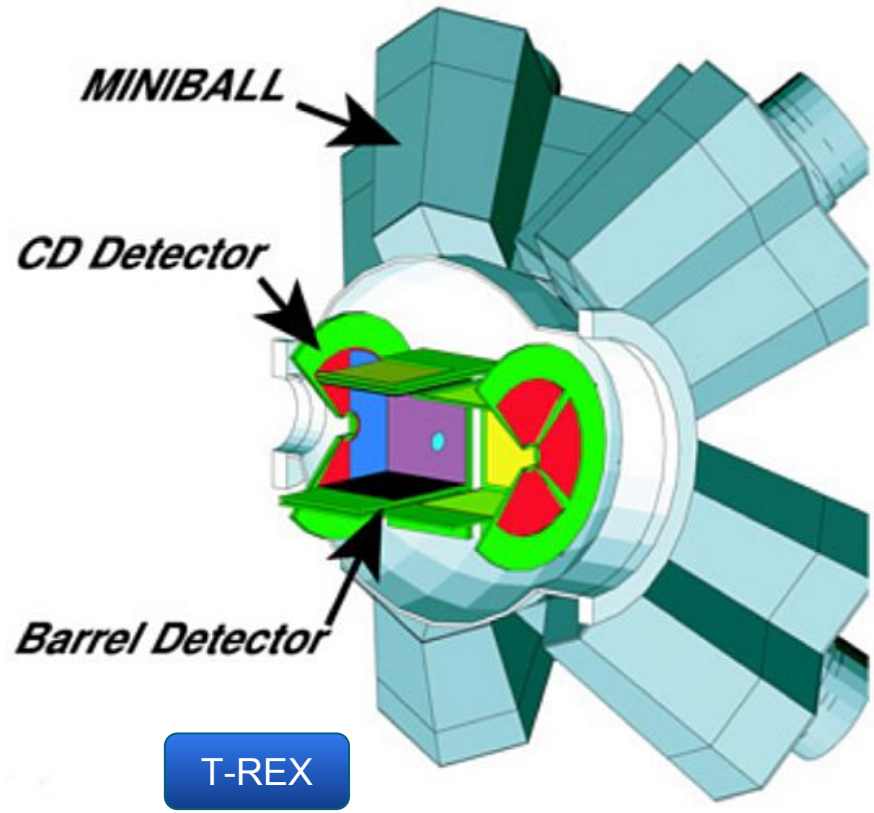
MB+T-REX: IS654 - ^{134}Sn(d,p)

First spectroscopy of the the r-process nucleus ^{135}Sn,

Th. Kröll, K. Wimmer *et al.*

Experiment 5.-9.9.2018:

- ^{134}Sn @ 7.3 MeV/u on CD_2 target
- Molecular $^{134}Sn^{34}S$ beam from primary HRS target
- Very low intensity observed at MB (~$3x10^3$ pps at best) despite a lot of effort + many contaminants
- Switched to ^{132}Sn beam (8.9.)
- But the HRS target failed… (9.9.)



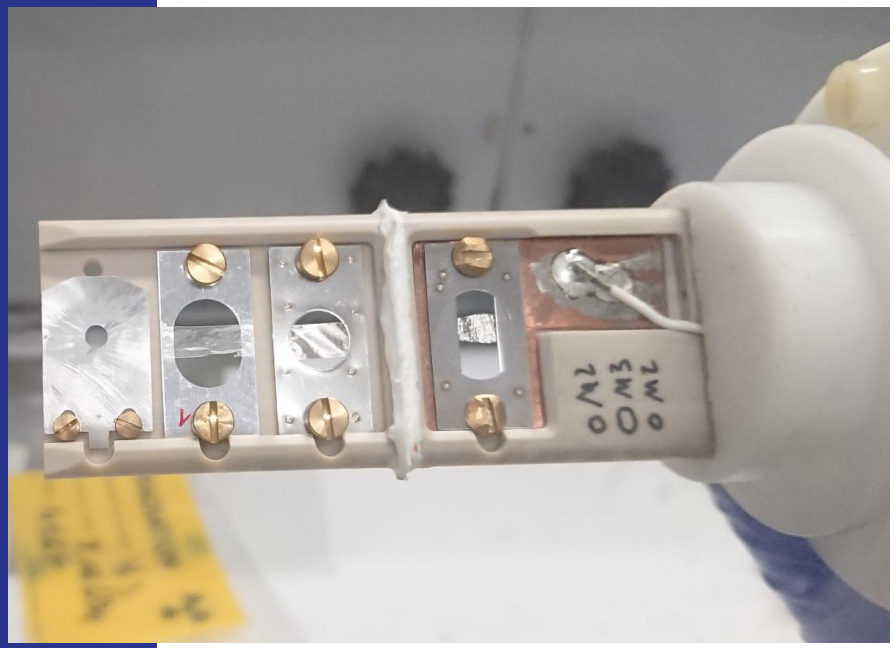
MB+T-REX: IS651 - ^{28}Mg(t,p)

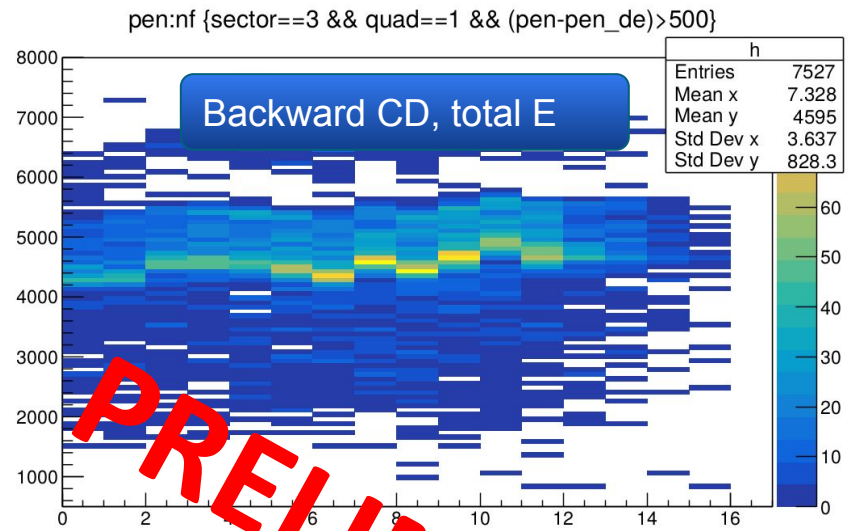
Nuclear Shell Evolution in the Island of Inversion Studied via the ^{28}Mg(t, ^{30} Mg)p reaction, D. Muecher *et al.*

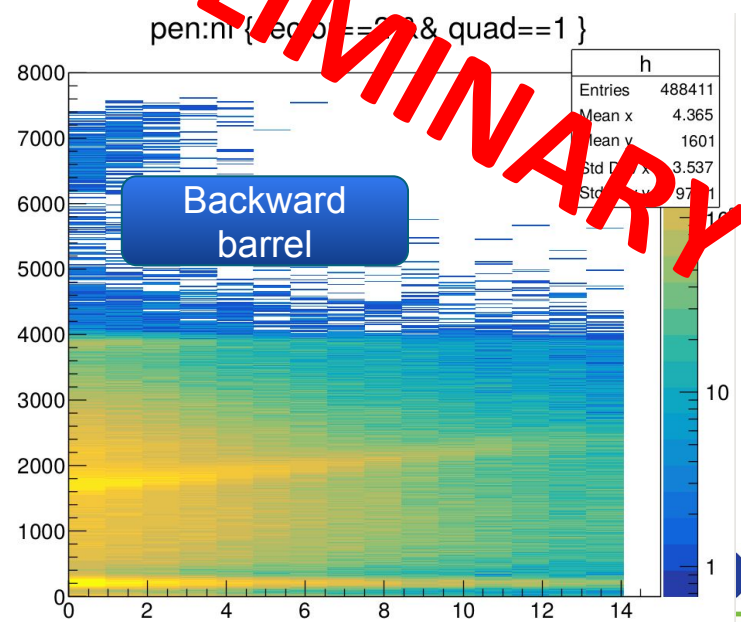
Experiment 20.-26.9.2018:

- ^{28}Mg @ 9.473 MeV/u, ~ 2x10^{6} pps
- Used a ~10 GBq tritium target foil
- Obtained data show evidence of transfer lines --- need to use gating with coincident gamma rays to clean spectra

  Analysis on-going!





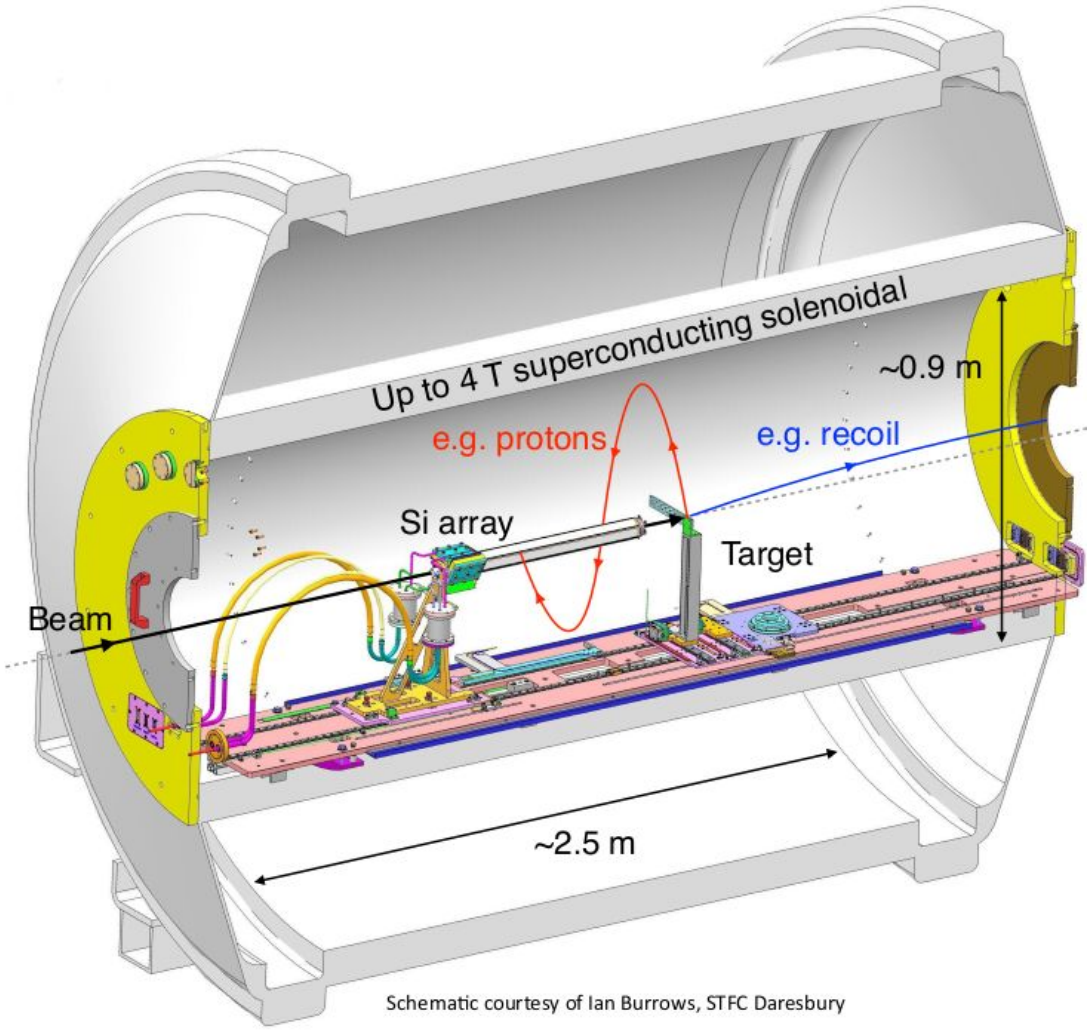


ISOLDE Solenoidal Spectrometer (ISS)

- Based on the HELIOS concept at Argonne National Lab (ANL)
- Utilised Si array and DAQ from ANL
- Performed first two successful experiments in 2018 !

  IS621 - ^{28}Mg(d,p)^{29}Mg

  IS631 - ^{206}Hg(d,p)^{207}Hg



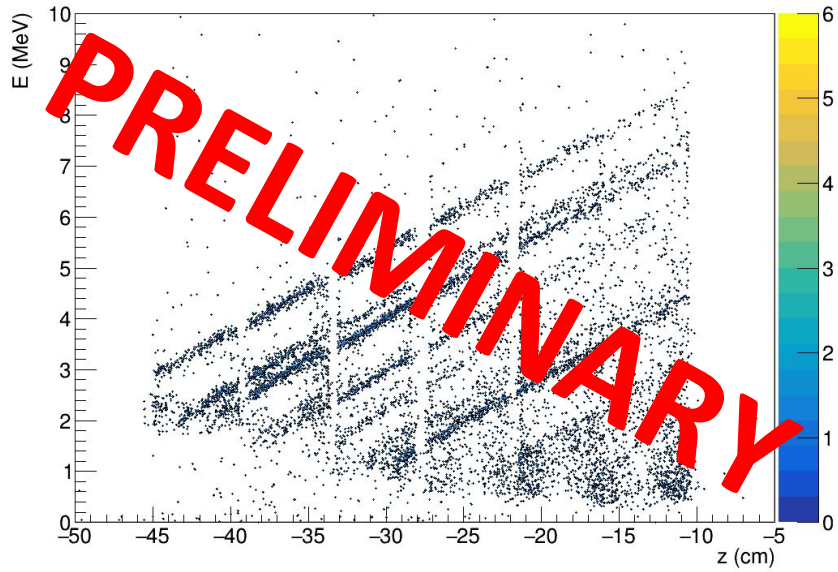
Schematic courtesy of Ian Burrows, STFC Daresbury

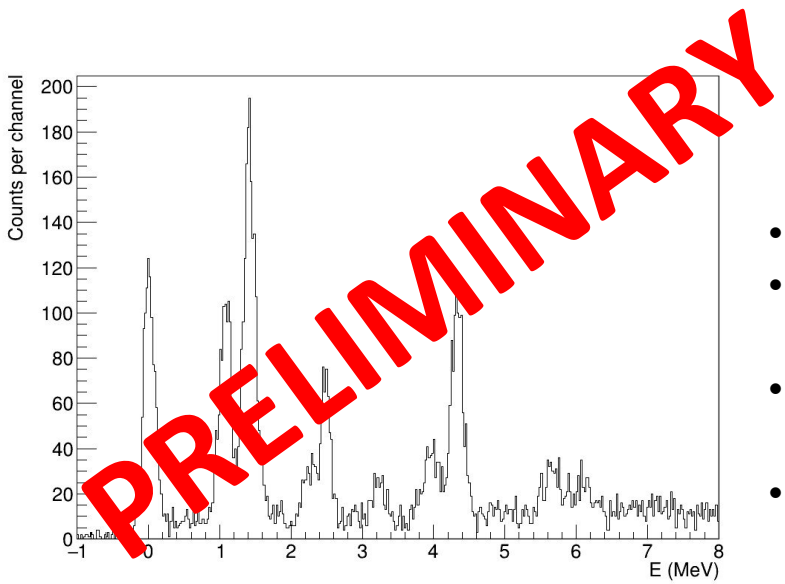
ISS : IS621 - ^{28}Mg(d,*p*)^{29}Mg

Probing single-particle properties near Island of Inversion.

D.K. Sharp *et al.*

- First experiment with ISOLDE Solenoidal Spectrometer
- **9.473 MeV/u** beam – **the highest HIE-ISOLDE beam energy**
- **dE/E = 0.3%**
- FWHM at target position **<1.5 mm**
- Maximum beam intensity **10^6 pps**





- Measured properties E_p, z, recoil dE/E.
- Preliminary excitation energy spectrum – states populated **up to ~6 MeV**. $12^o<\theta_{cm}<40^o$.
- Resolution ~**100 keV** – able to resolve majority of states of interest. No need for γ-ray detection.
- Can probe single-particle properties of both **bound** and **unbound** states in ^{29}Mg.

Courtesy of D.K. Sharp, **see talk later in this session!**

ISS : IS631 - ^{206}Hg(d,*p*)^{207}Hg

Exploring terra incognita - A study of the hitherto unknown single-neutron structure of ^{207}Hg, B.P. Kay, C.R. Hoffman *et al.*

- **7.4 MeV/u** beam, purity ~ 98%
- ~ 5×10^5 pps for ~ 82 hours
- >30 deuterated polyethylene targets of thickness around 165 µg/cm2 (to deal with target degradation)
- ISS set to a B-field of 2.5 T

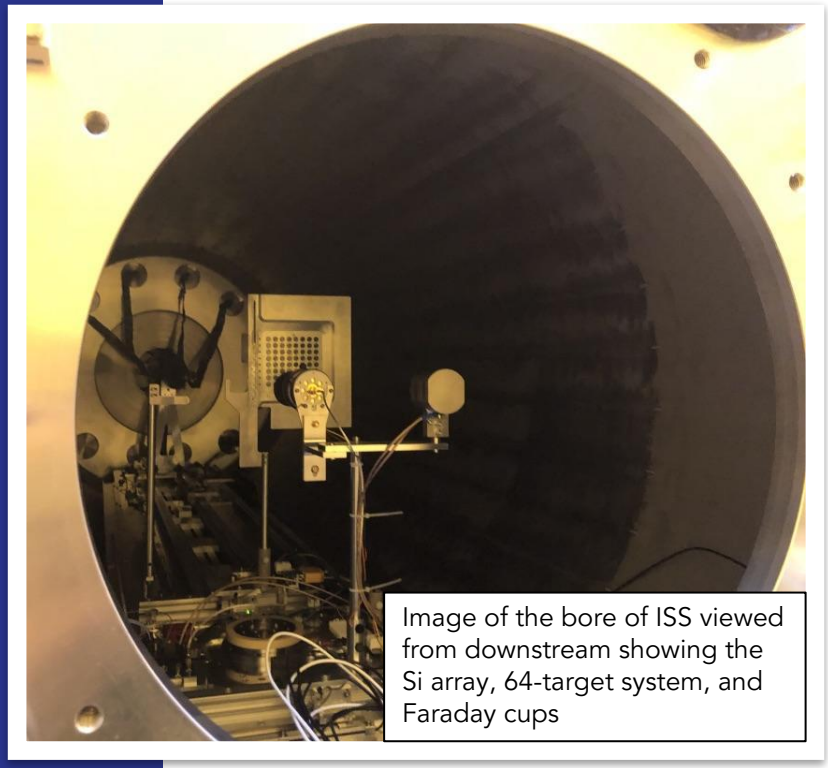
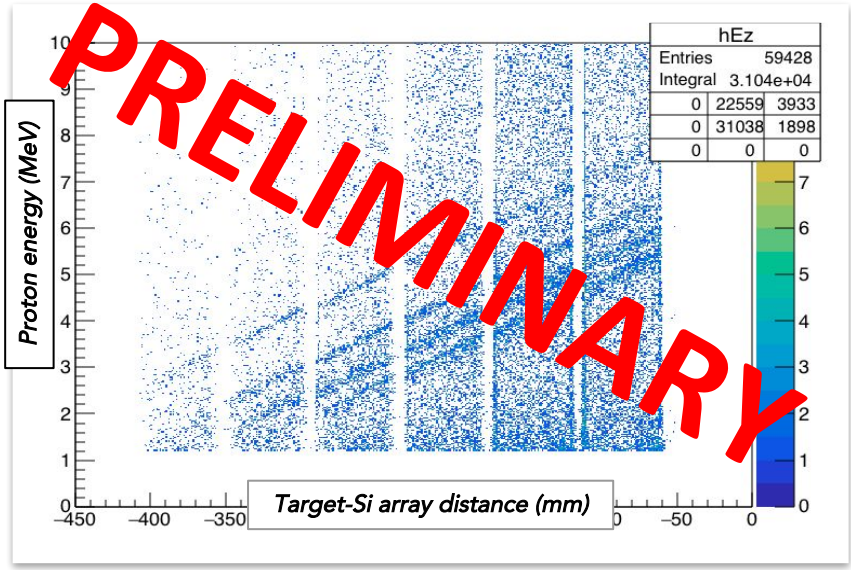


Image of the bore of ISS viewed from downstream showing the Si array, 64-target system, and Faraday cups



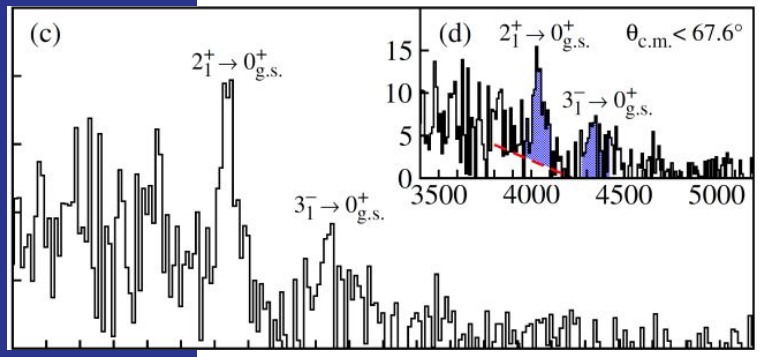
- Measured properties E_p, z (singles meas.)
- First exploration of single-particle states outside N = 126, south of Pb, made possible by ISS.
- Resolution ~**100 keV** – able to resolve majority of states of interest. No need for γ-ray detection.

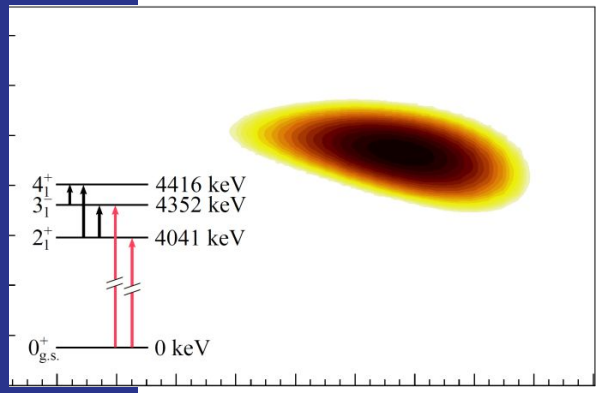
Courtesy of B.P. Kay

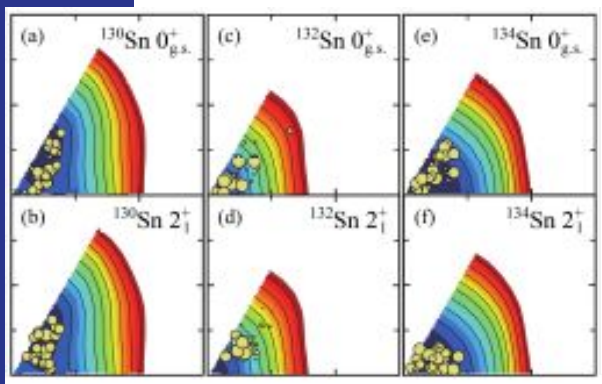
Hot off the press: ^{132}Sn in PRL

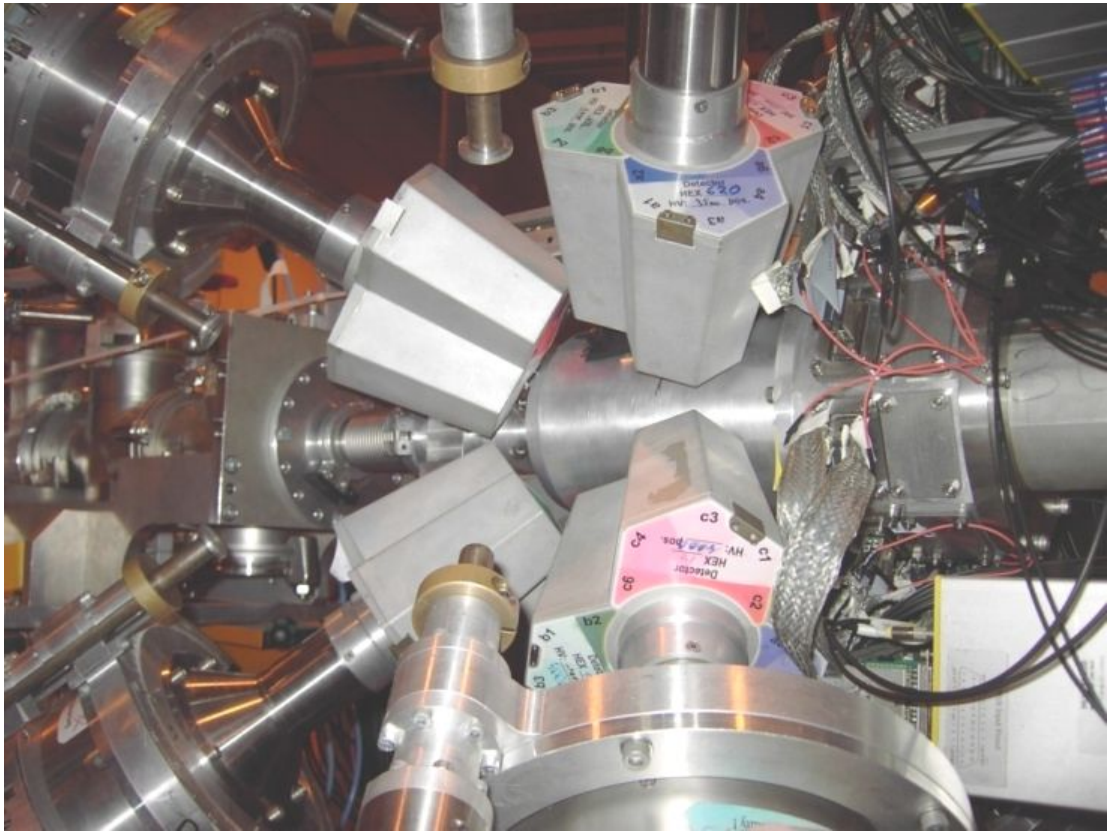
Enhanced quadrupole and octupole strength in doubly-magic ^{132}Sn

@ HIE-ISOLDE, IS551 MINIBALL + C-REX (2017), P. Reiter *et al.*









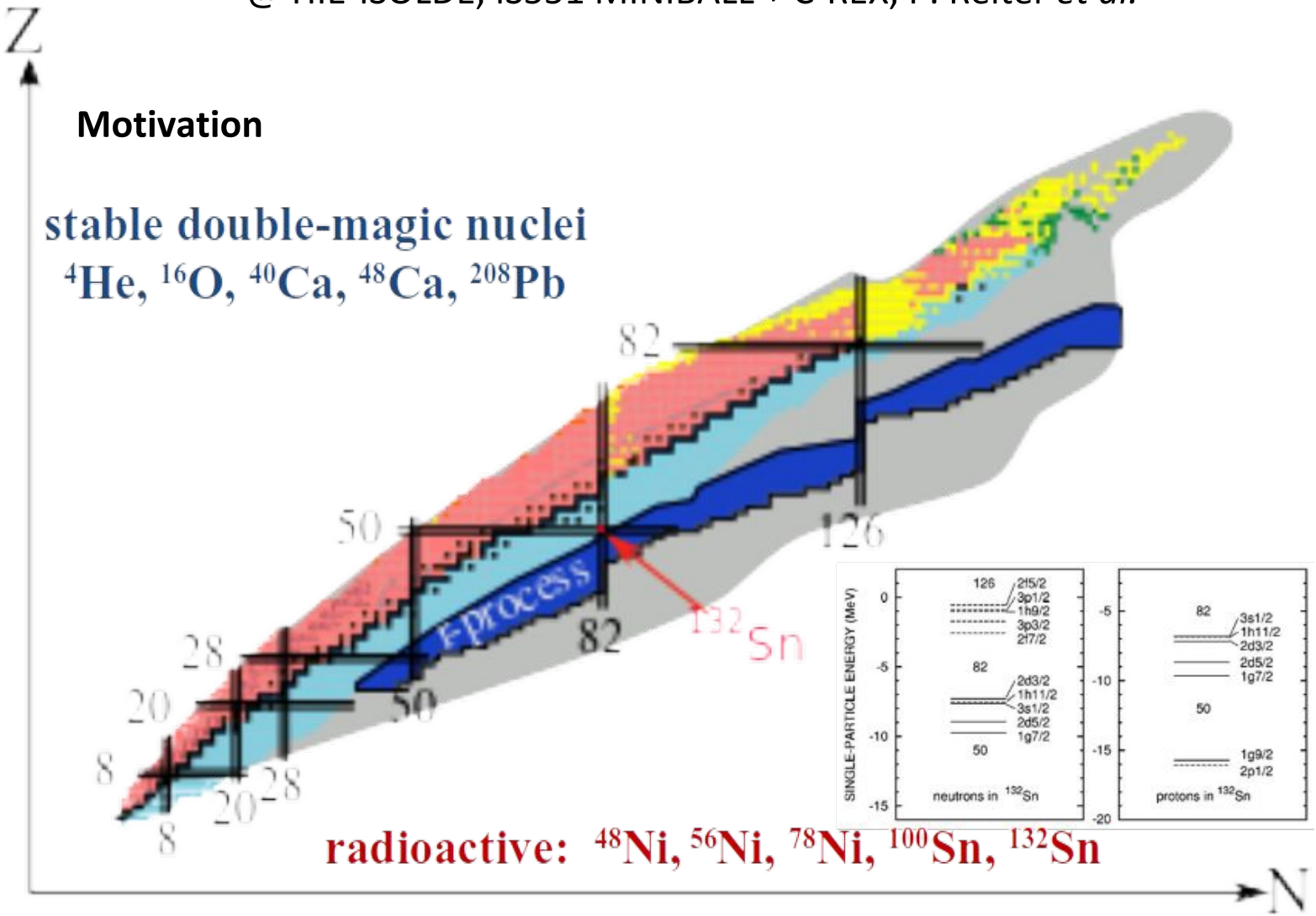
D. Rosiak *et al.*, accepted for publication in Physical Review Letters (PRL)

Hot off the press: ^{132}Sn in PRL

Enhanced quadrupole and octupole strength in doubly-magic ^{132}Sn

@ HIE-ISOLDE, IS551 MINIBALL + C-REX, P. Reiter *et al.*

Motivation



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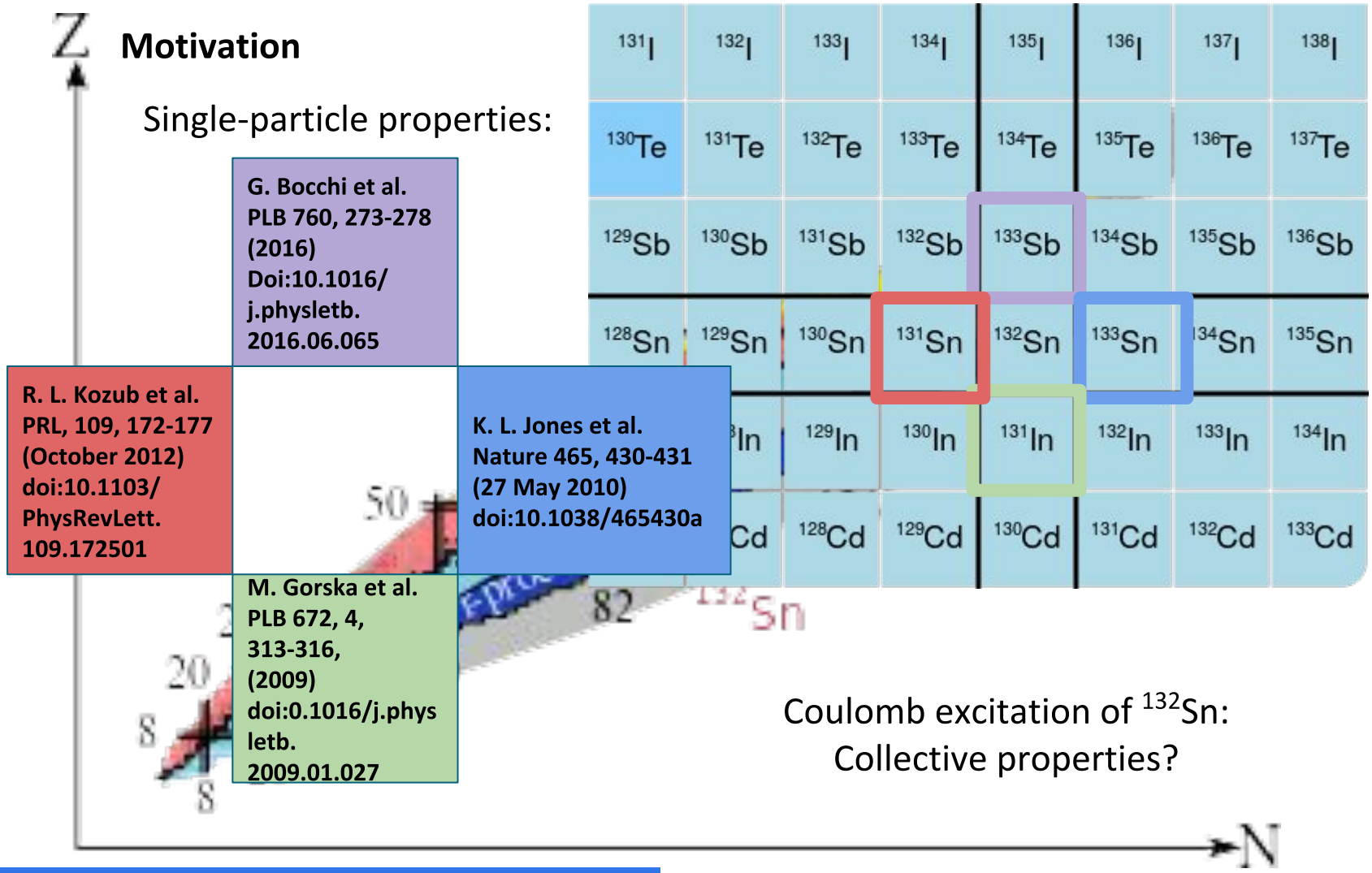
Motivation

Single-particle properties:



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Coulomb excitation of ^{132}Sn: Collective properties?

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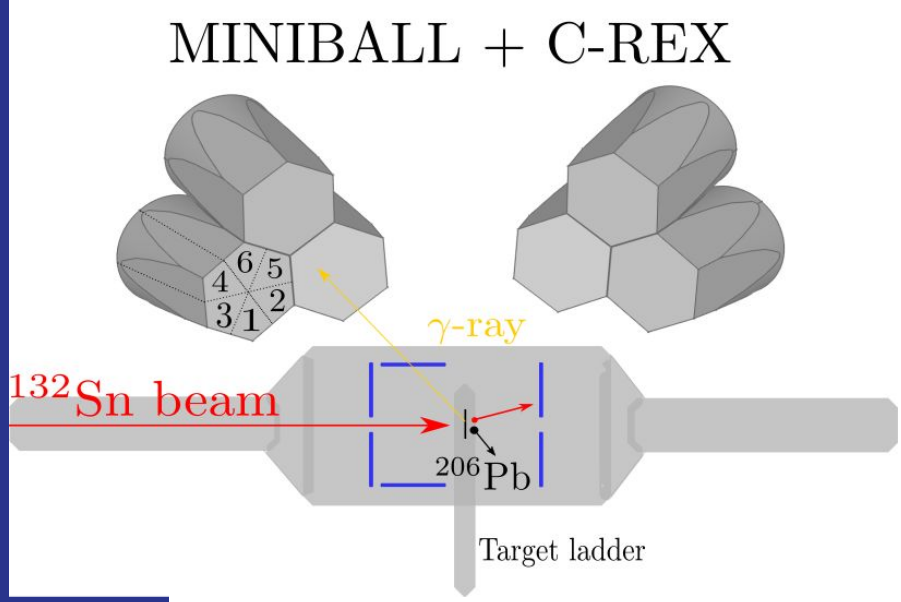
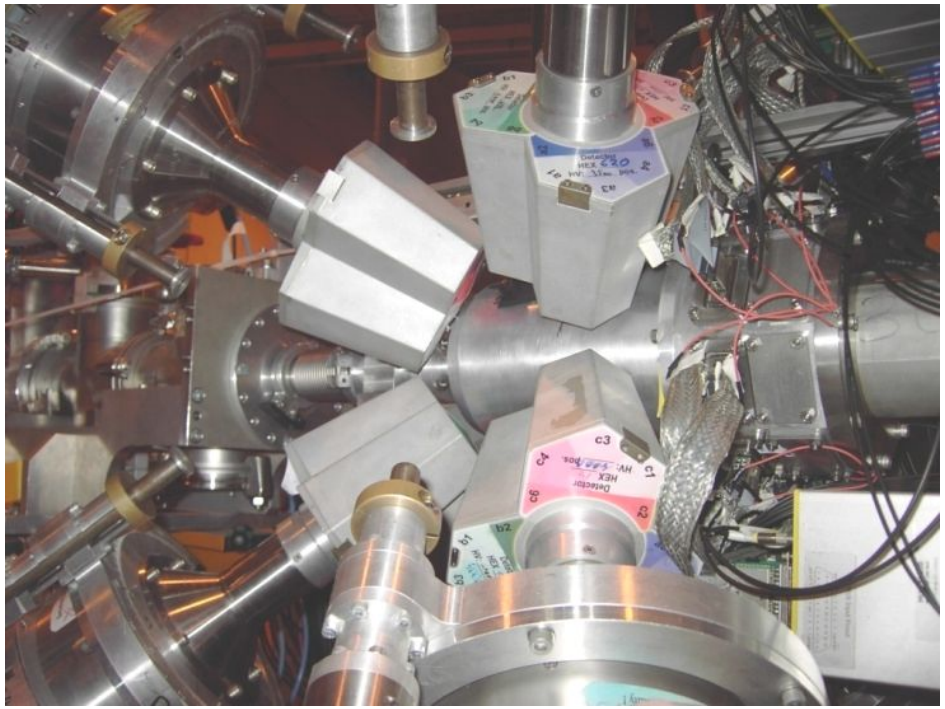
Experimental setup





- Molecular ISOLDE beam: $^{132}Sn^{34}S$
- HIE-ISOLDE beam: $^{132}Sn^{31+}$ @ 5.49 MeV/u
- Total RIB intensity: **~3.0 x 10^5** ions/s
- 'safe' scattering angles: lab = 17.8 - 41.5°
- Beam composition: ^{132}Sn, ^{132}Sb, ^{132}Ba, ^{166}Yb

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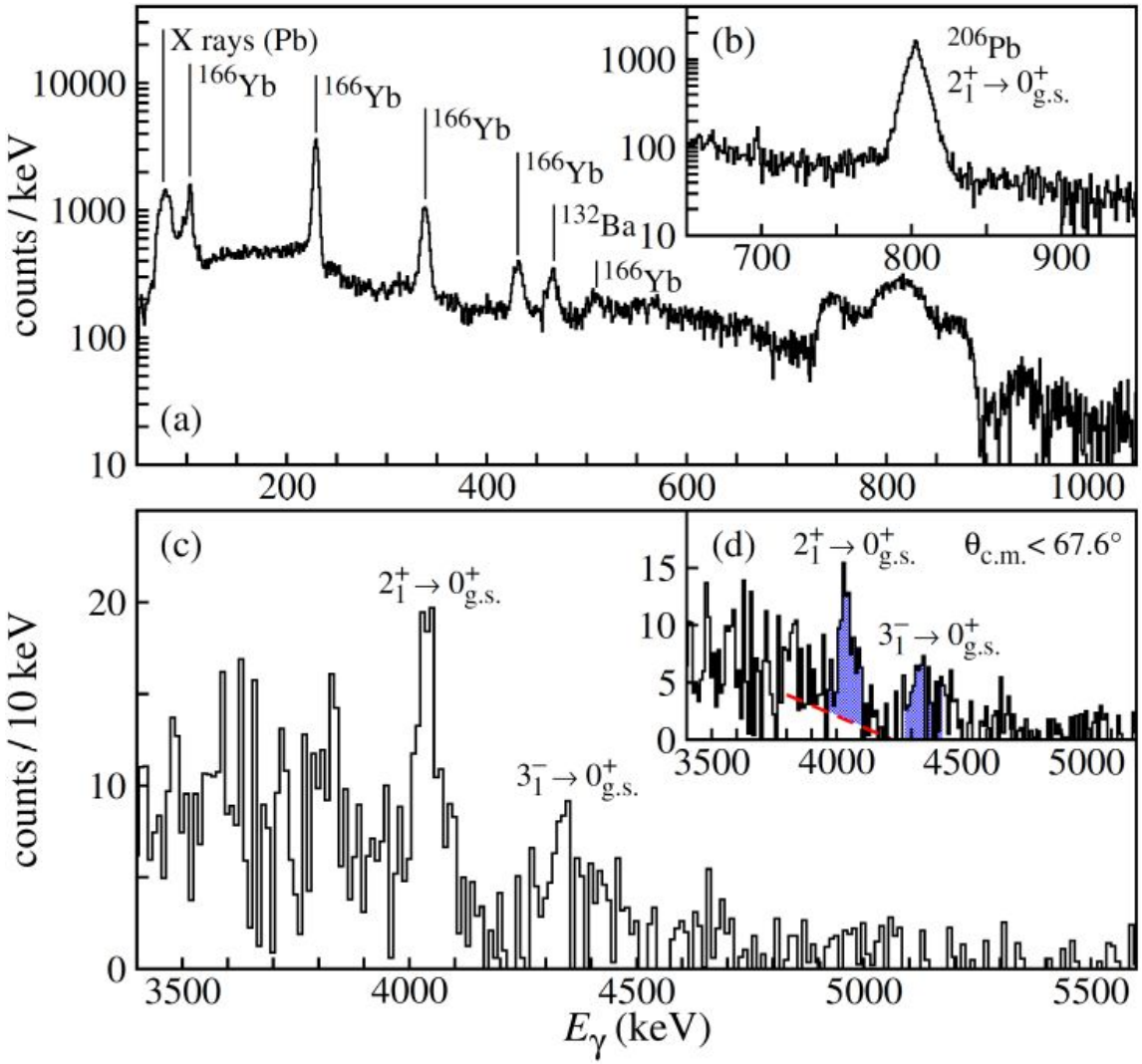

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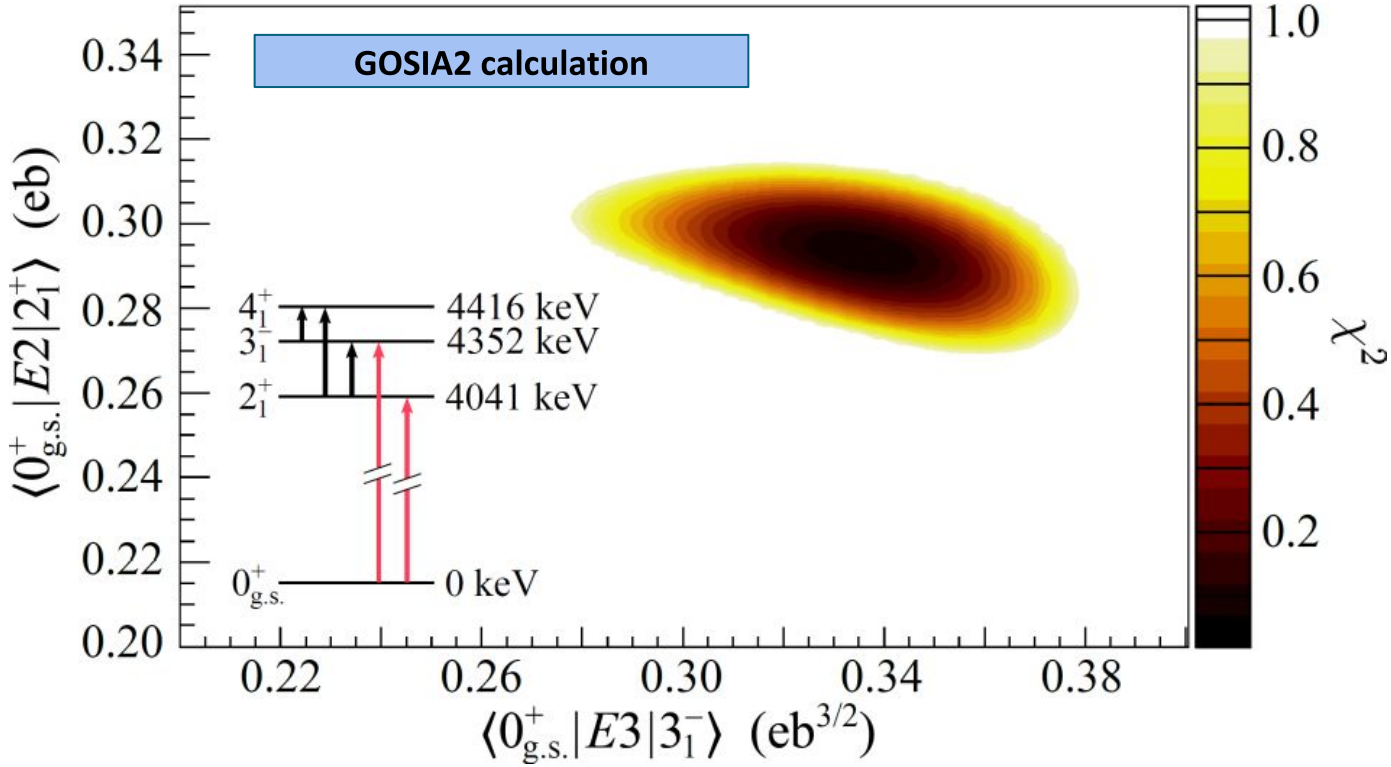

	this work	previous
B(E2; $0^+ \rightarrow 2^+$)	0.087(19) e^{2}b^2	0.14(6) e^{2}b^2 / 0.11(3) e^{2}b^2
B(E3; $0^+ \rightarrow 3^-$)	0.11(4) e^{2}b^3	> 0.0512 e^{2}b^3
B(E1; $2^+ \rightarrow 3^-$)	9.1(31) x 10^{-6} e^{2}b	> 3.97 x 10^{-6} e^{2}b

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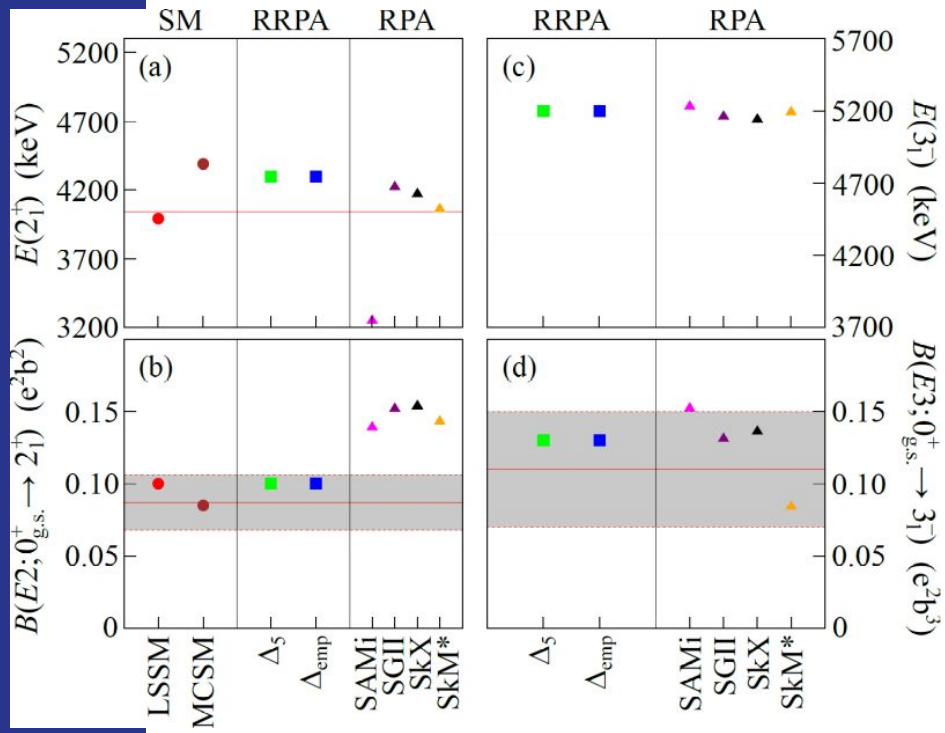
New theoretical results for ^{132}Sn



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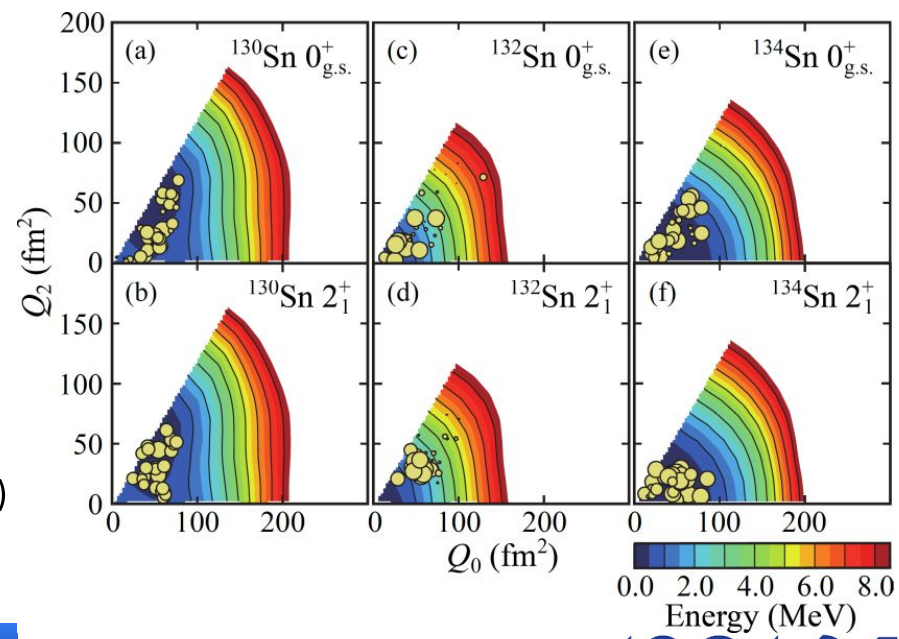

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Enhanced quadrupole and octupole strength in doubly-magic ^{132}Sn

D. Rosiak,[1] M. Seidlitz,[1,*] P. Reiter,[1] H. Naïdja,[2,3,4] Y. Tsunoda,[5] T. Togashi,[5] F. Nowacki,[2,3] T. Otsuka,[6,5,7,8,9] G. Colò,[10,11] K. Arnswald,[1] T. Berry,[12] A. Blazhev,[1] M. J. G. Borge,[13,†] J. Cederkäll,[14] D. M. Cox,[15,16] H. De Witte,[8] L. P. Gaffney,[13] C. Henrich,[17] R. Hirsch,[1] M. Huyse,[8] A. Illana,[8] K. Johnston,[13] L. Kaya,[1] Th. Kröll,[17] M. L. Lozano Benito,[13] J. Ojala,[15,16] J. Pakarinen,[15,16] M. Queiser,[1] G. Rainovski,[18] J. A. Rodriguez,[13] B. Siebeck,[1] E. Siesling,[13] J. Snäll,[14] P. Van Duppen,[8] A. Vogt,[1] M. von Schmid,[17] N. Warr,[1] F. Wenander,[13] and K. O. Zell[1]

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GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung

Summary

- HIE-ISOLDE Phase 2B pushed maximum energy of post-accelerated beams up to ~ **9.5 MeV/u**
- In total 13 experiments performed in 2018 physics campaign:
  - ➢ 7 @ MINIBALL
  - ➢ 4 @ XT03 (various setups)
  - ➢ 2 @ ISS
- First two experiments performed successfully using ISOLDE Solenoidal Spectrometer (ISS)
- First HIE-ISOLDE publication accepted in PRL (^{132}Sn CoulEx)

Thank you for your attention

Acknowledgements

ISOLDE technical staff (operators, RILIS, …) !!

MINIBALL collaboration

ISS collaboration