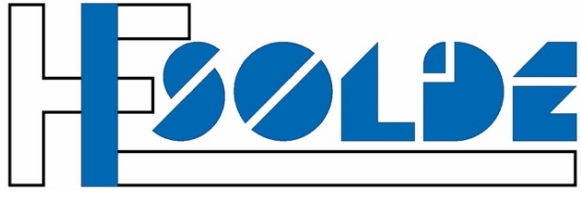
Recent results from the Miniball spectrometer

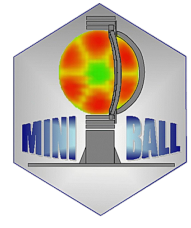
ISOLDE Workshop and Users meeting 2023

Frank Browne

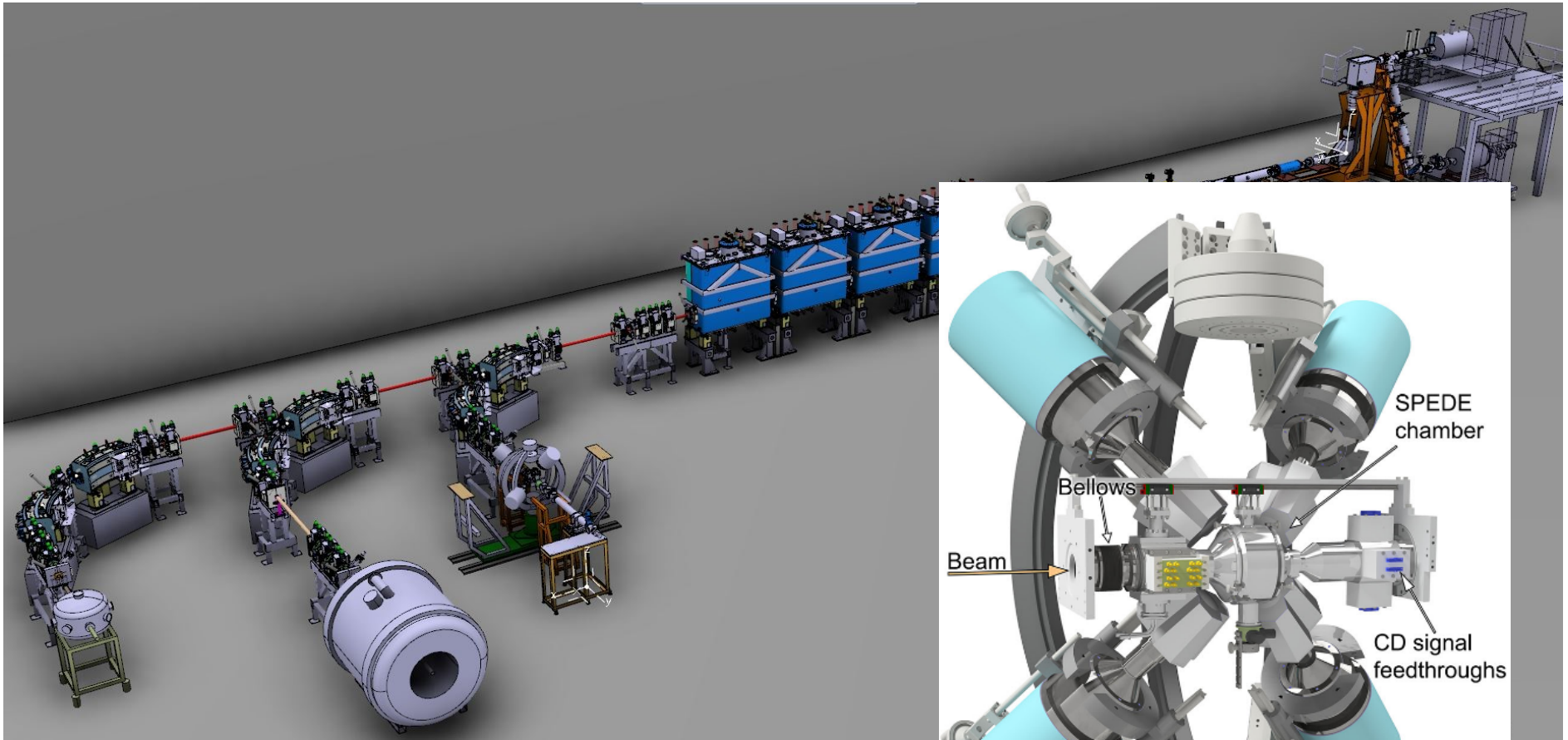
CERN, CH-1211 Geneva 23, Switzerland

Thursday 30th November, 2023





Miniball's place in ISOLDE

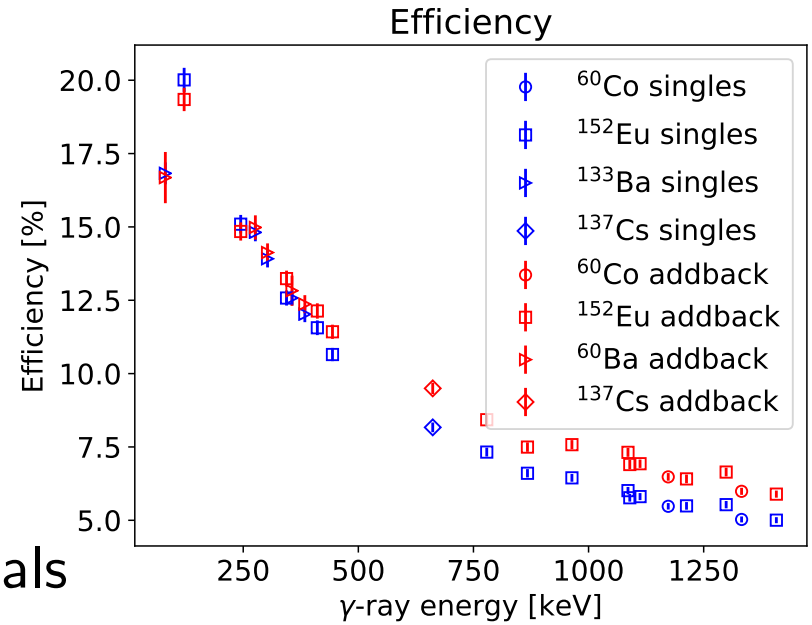


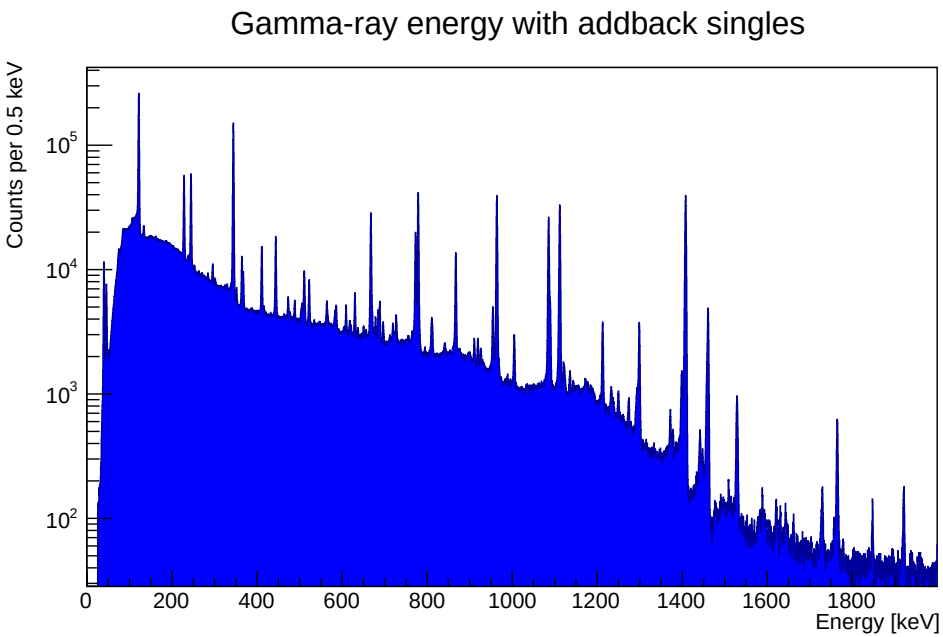
- First dipole after HIE-ISOLDE
  - $\rightarrow E_{\text{beam}} \leq 10$ MeV$/u$
    - Nuclear reactions!
    - Doppler effects significant

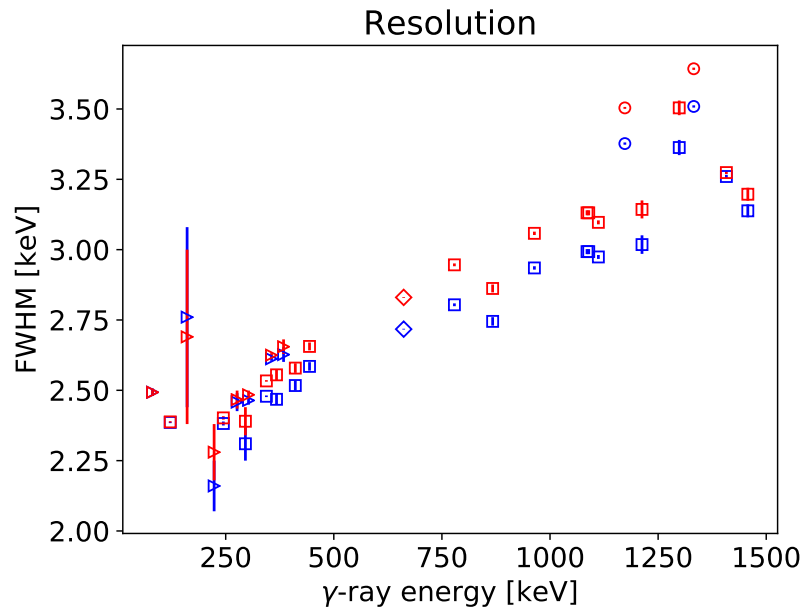
P. Papadakis *et al*, Eur. Phys. J. A **54** 42 (2018).

Miniball characteristics

- The HPGe array
  - → Triplet crystal arrangement
  - → 8× in the array
  - → Good energy resolution
  - → Eff.(1 MeV)≈9%
    - – Measurements with 7 triples
- Add-back:
  - → sum energy of neighbouring crystals



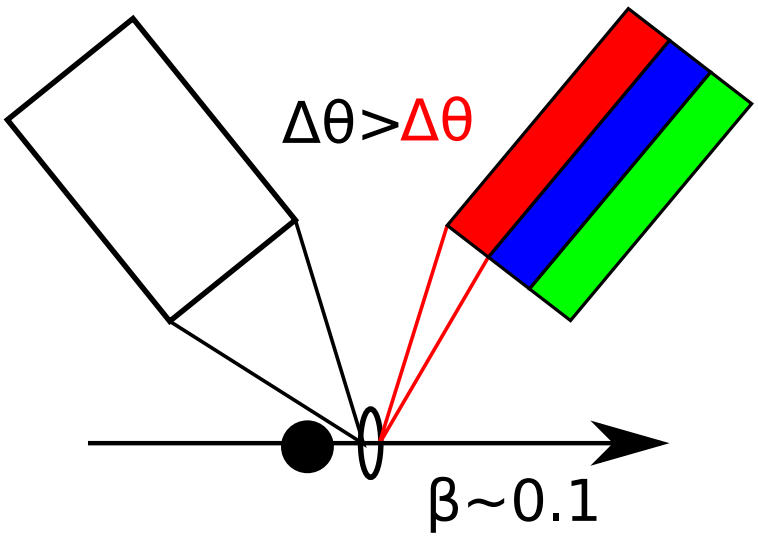


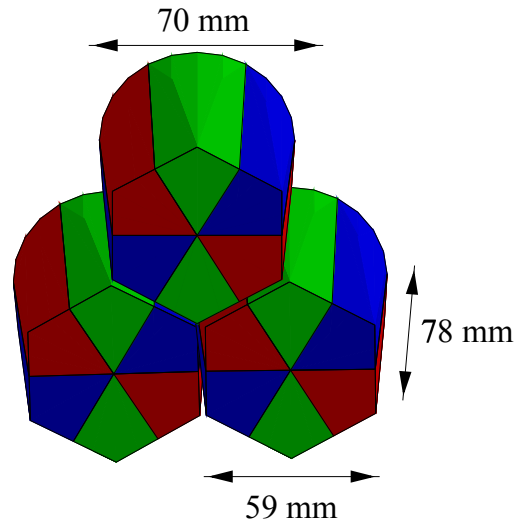


Electrode segmentation

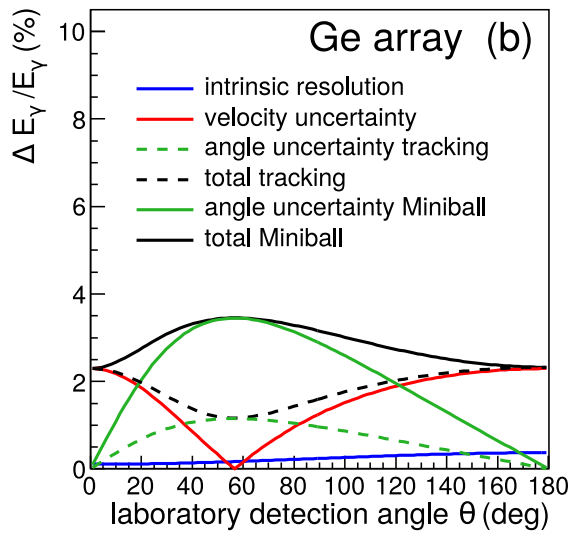
Doppler correction: $E_{\mathrm{CoM}} = \gamma(1 - \beta\cos\theta_{\mathrm{lab}})E_{\mathrm{lab}}$

$$\left(\frac{\Delta E_{\mathrm{CoM}}}{E_{\mathrm{CoM}}}\right)^2 = \left(\frac{\beta\sin\theta_{\mathrm{lab}}}{1-\beta\cos\theta_{\mathrm{lab}}}\right)^2 (\Delta\theta_{\mathrm{lab}})^2 + \left(\frac{\beta\gamma^2(\beta-\cos\theta_{\mathrm{lab}})}{1-\beta\cos\theta_{\mathrm{lab}}}\right)^2 \left(\frac{\Delta\beta}{\beta}\right)^2 + \left(\frac{\Delta E_{\mathrm{lab}}}{E_{\mathrm{lab}}}\right)^2$$



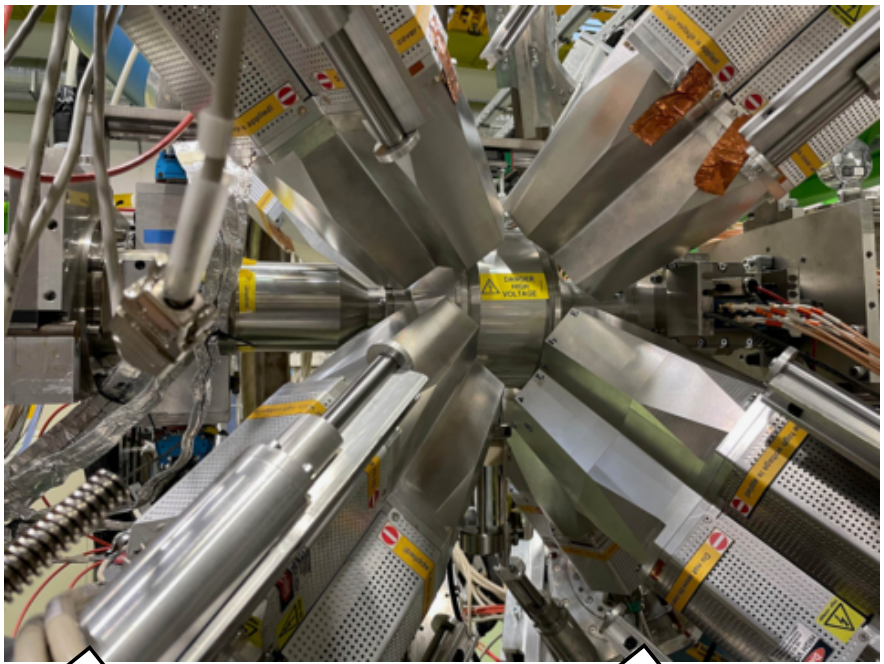


- β from beam measurements
- Sensitive to 1st interaction pos.
- 7 channels/crystal
  $\rightarrow\Rightarrow$ **168 channels**
- Also need ion direction

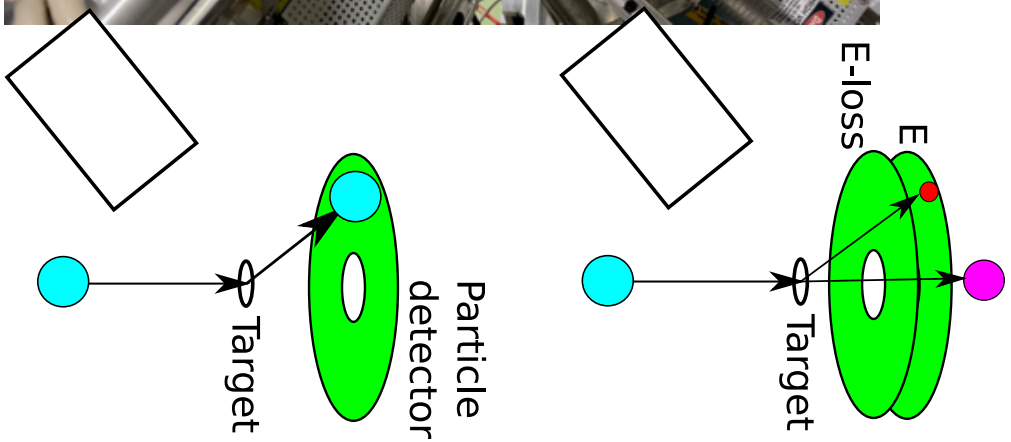


P. Doornenbal, PhD Thesis (2007).

Detecting reaction residues

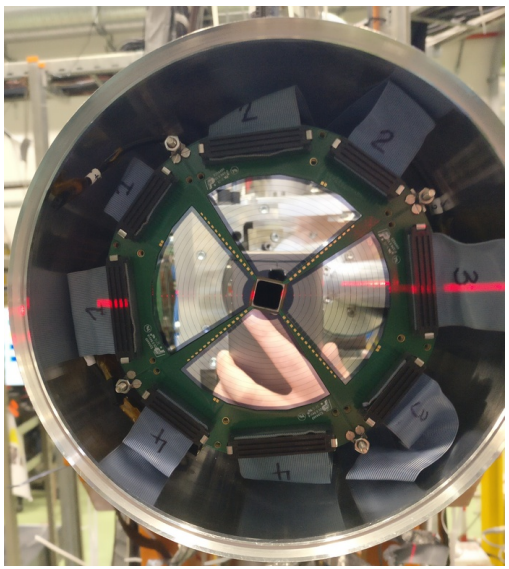


- 4-sector CD detector
  - →Strips: 16 radial, 12 sector
    - –**112 channels**
  - →Position information→Doppler correction
- PAD detector
  - →4 sectors of Si plates
  - →ΔE-E PID



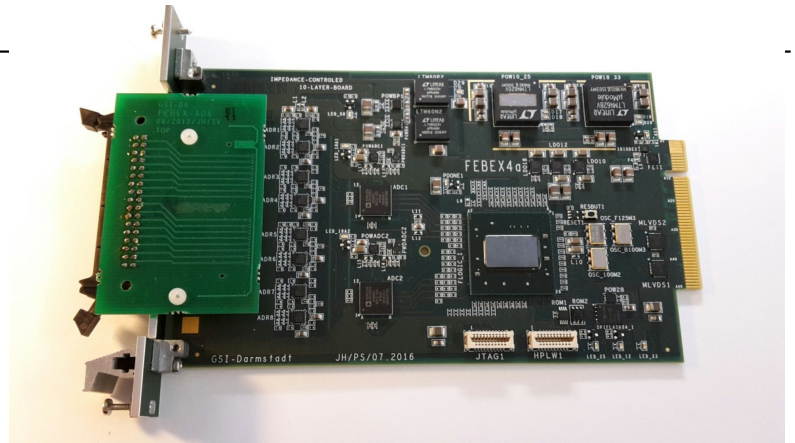
Coulex
→Heavy ion

Transfer
→Light ion

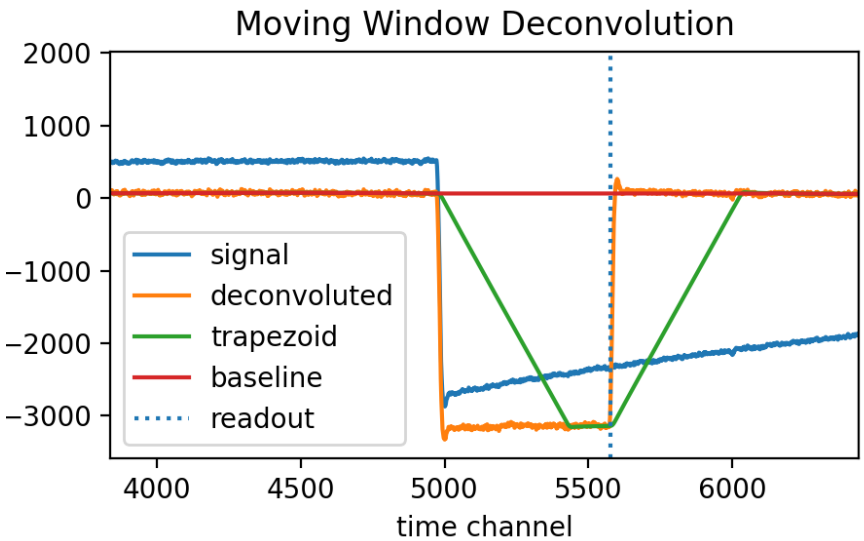


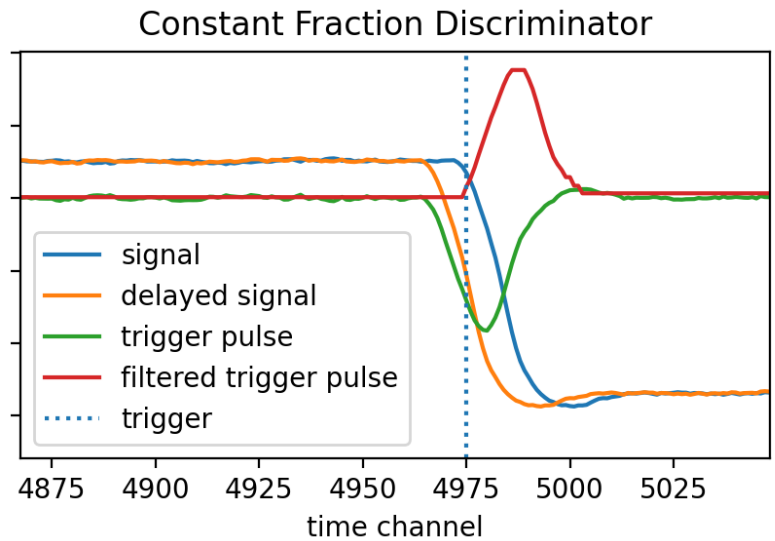
FEBEX data acquisition

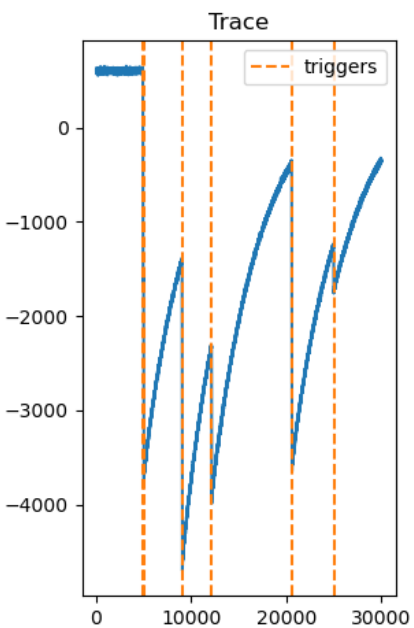
- FEBEX (GSI)
  - → 16-channel ADCs
  - → Differential input
    - – 100 MHz (10 ns) sampling
  - → Highly compact design
  - → $\sim$ 310 channels in $<$ 2 racks
  - → Customisable firmware
  - → Adaptable breakout boards
    - – Ribbon cable, LEMO, single-to-diff. converter
- Channels trigger independently
  - → Continuous readout
    - – Offline event reconstruction
  - → Real-time control of digital filter parameters

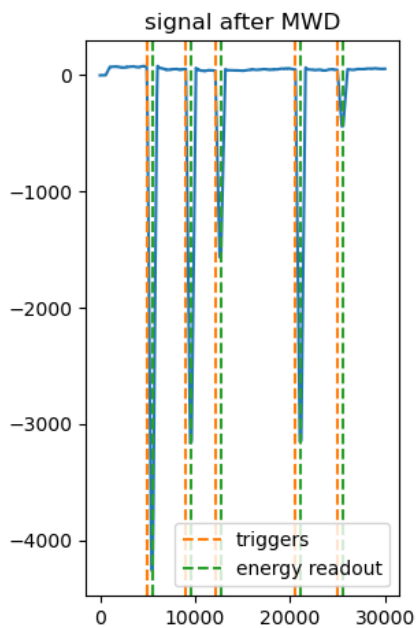


Moving Window Deconvolution







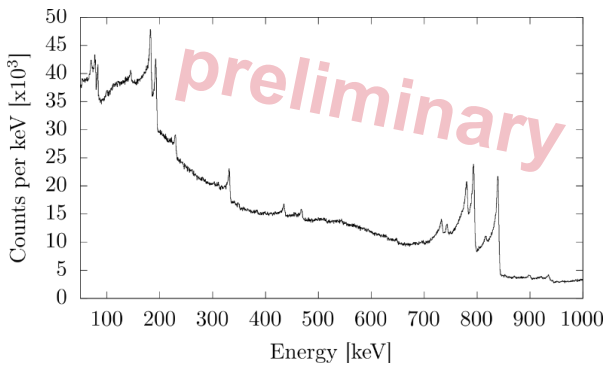


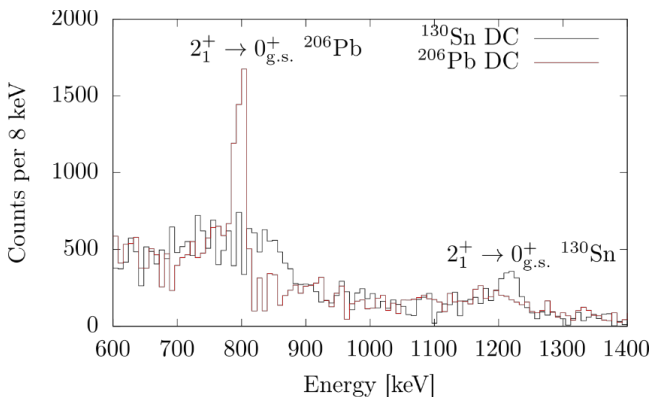
$$A_i = P_i - P_{i-M} + \frac{1}{\tau} \sum_{k=i-M}^{i-1} P_k$$

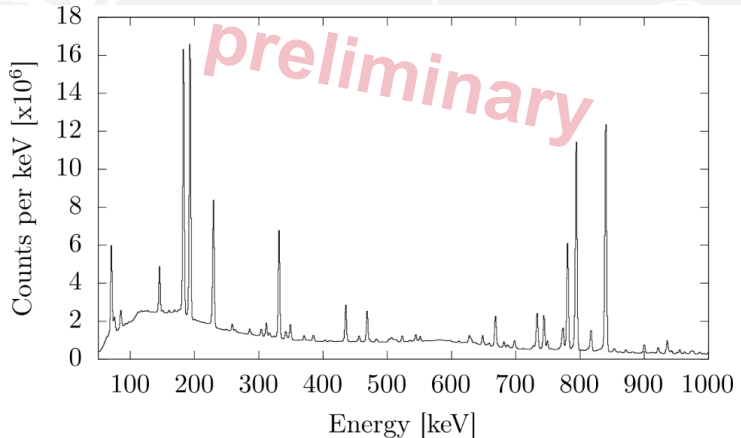
- Energy = Flat top minus baseline
- τ - decay const.
  - $\rightarrow$important at high rates
- M gap from rising edge to baseline
- L length of moving average

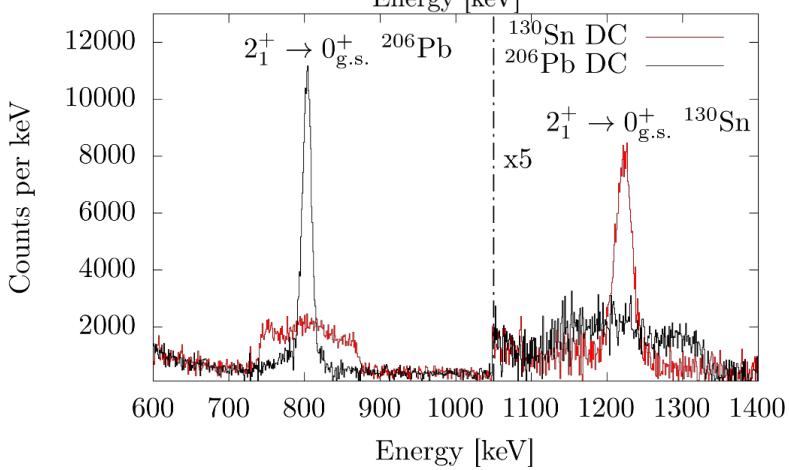
High γ rates vs. MWD

2022 data vs. 2023 data









I(206Pb; 2+->0+)=3.900 (400) FWHM (803keV) = 35 keV

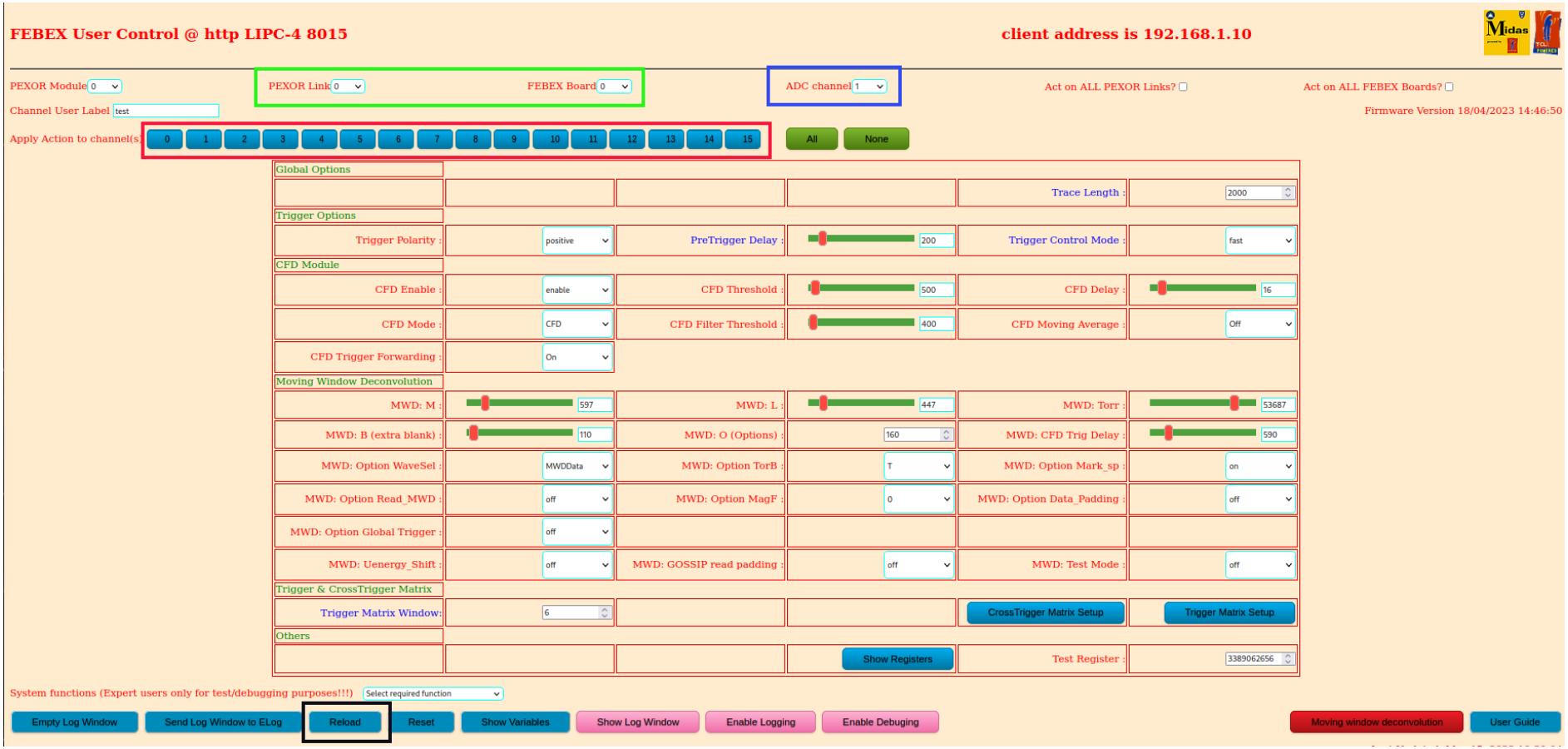
I(206Pb; 2+->0+) =1.500 (300)

I(206Pb; 2+->0+) =162.100 (2.000) FWHM (803keV) = 14.4 keV

I(206Pb; 2+->0+) =40.000 (1.000)

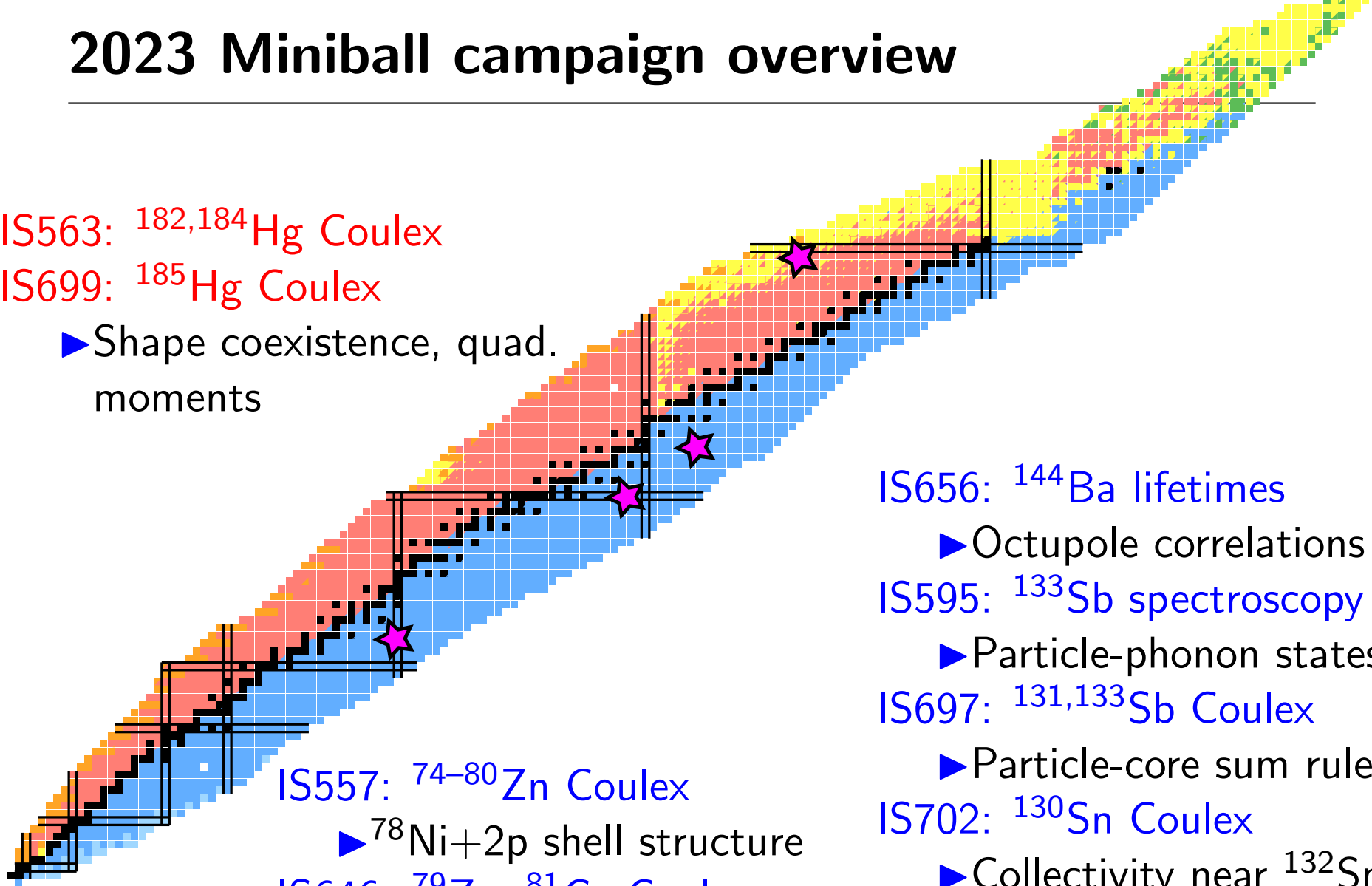
Courtesy of M. Droste

Data acquisition control & performance



- MIDAS web interface
  - → Real time control of MWD
  - → Individual channels
  - → Logic signals OK
- Extremely stable once running
  - → Tested at very high event rate
- New data format being worked on
  - → Useful metadata

2023 Miniball campaign overview



IS563: ^{182,184}Hg Coulex

IS699: ^{185}Hg Coulex

- Shape coexistence, quad. moments

IS656: ^{144}Ba lifetimes

- Octupole correlations

IS595: ^{133}Sb spectroscopy

- Particle-phonon states

IS697: ^{131,133}Sb Coulex

- Particle-core sum rules

IS702: ^{130}Sn Coulex

- Collectivity near ^{132}Sn

IS557: $^{74-80}$Zn Coulex

- ^{78}Ni+2p shell structure

IS646: ^{79}Zn, ^{81}Ge Coulex

- $N = 50$ shape coexistence

IS563&IS699: ^{182,184,185}Hg shape coexistence

Recent results from the Miniball spectrometer — *Frank Browne*
503/1-001 - Council Chamber, CERN — 16:15 - 16:40

Gamma-ray spectroscopy of neutron-rich Sb isotopes by cluster transfer reactions — *Simone Bottoni*
503/1-001 - Council Chamber, CERN — 16:45 - 16:57

The first TDRIV g-factor measurement on a radioactive ion beam: ^{28}Mg — *Konstantin Stoychev*
503/1-001 - Council Chamber, CERN — 17:00 - 17:12

Combined conversion electron and gamma-ray spectroscopy of neutron-deficient Hg isotopes utilising the SPEDE spec...
Joonas Kalervo Ojala

Scattering Studies at the SEC (XT03) beamline at HIE-ISOLDE — *Maria Jose Garcia Borge*
503/1-001 - Council Chamber, CERN — 17:30 - 17:55

IS563&IS699: ^{182,184,185}Hg shape coexistence

Shape coexistence around N = 104 mid-shell

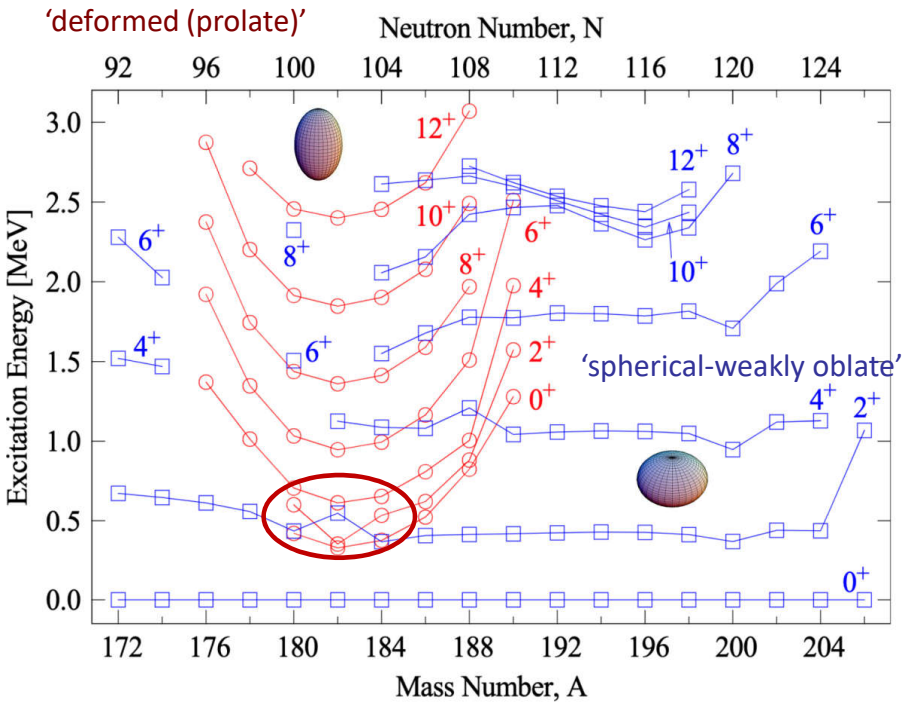
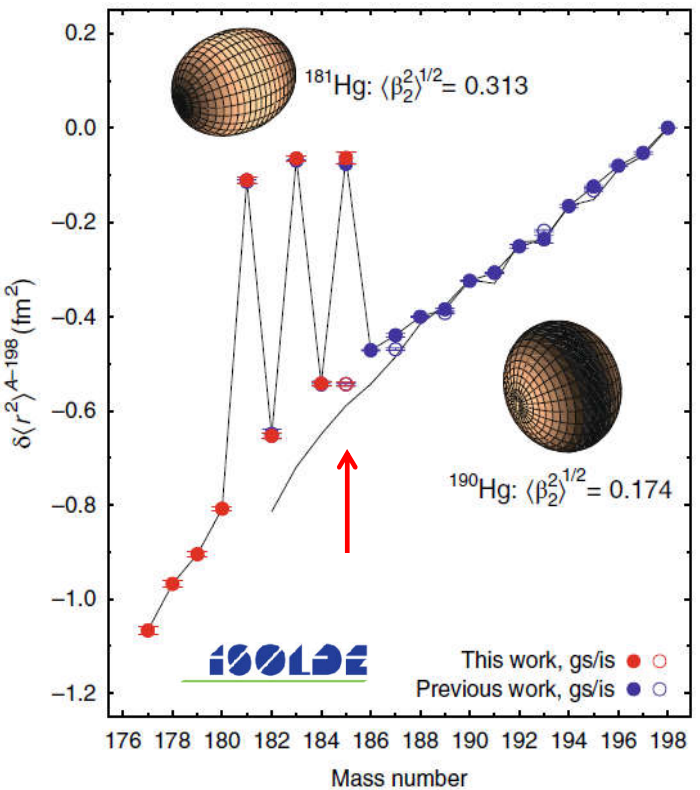


Fig.: L. P. Gaffney, et al., PRC **89** 024307 (2014)

- Parabolic evolution of intruder states.
- Large odd-even mass staggering in $\delta\langle r^2\rangle_{gs}$ around $^{181\text{-}185}$Hg.
- Shape coexistence in ^{185}Hg.



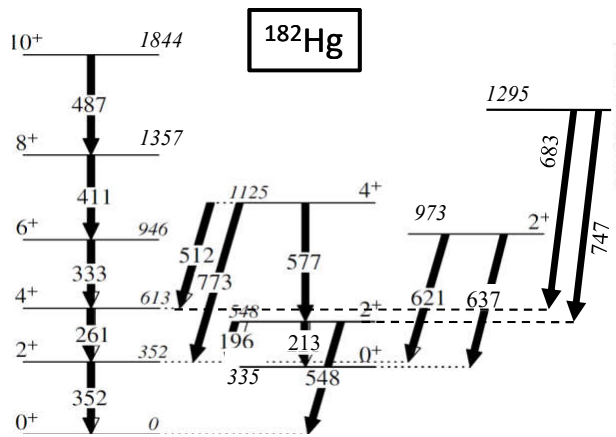
- Large *E*0 transitions → configuration mixing
- nature of underlying deformation ?
- *oblate – prolate:* still model dependent interpretation

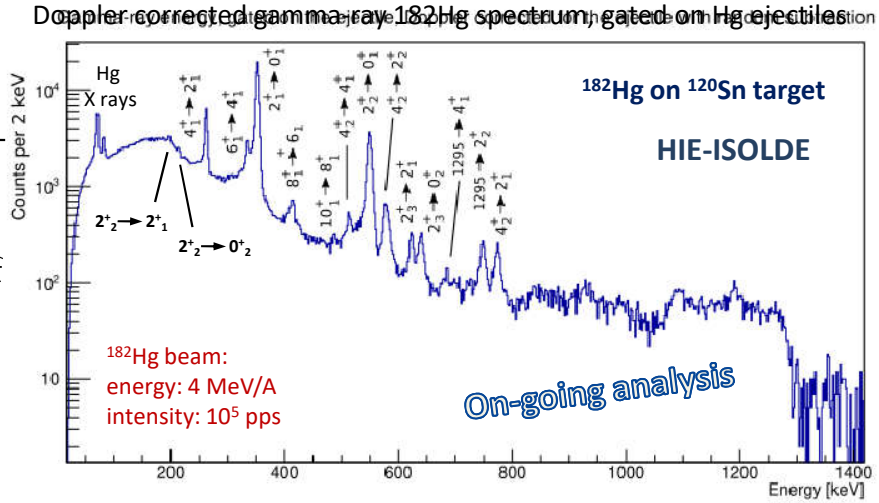
B. A. Marsh et al., Nat. Phys. 14 (2018), S. Sels et al., PRC 99, 044306 (2019)
S. Sels PhD thesis KULeuven 2018, J. Bonn et al., PLB 38, 308 (1972)

Courtesy of K. Wrzsosek-Lipska

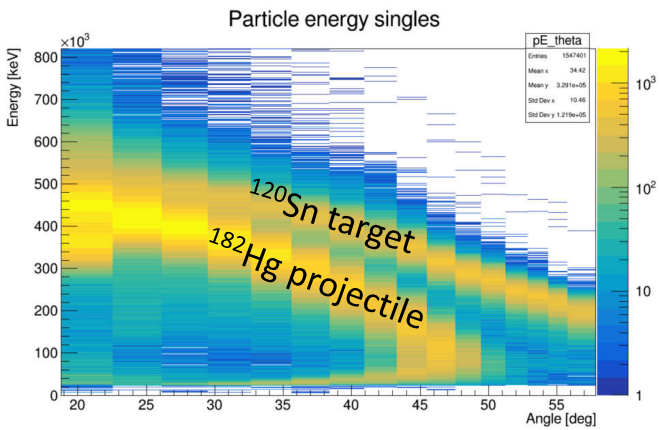
IS563&IS699: ^{182,184,185}Hg shape coexistence

November 2022: Coulomb excitation of ^{182}Hg (IS563) @ HIE-ISOLDE

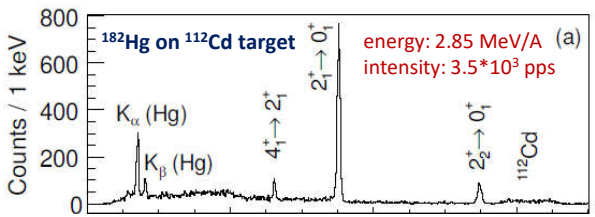




Kinematics from DSSSD: clear recoils and projectiles separation:



182Hg @ 2.85 MeV at REX-ISOLDE

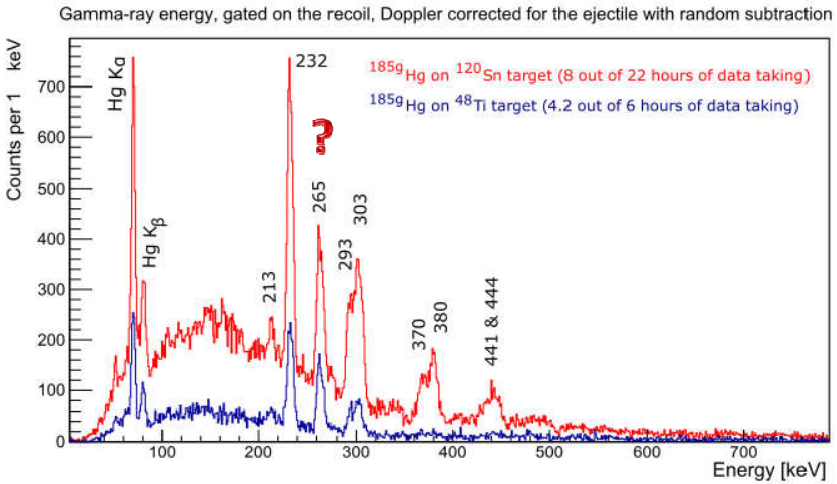


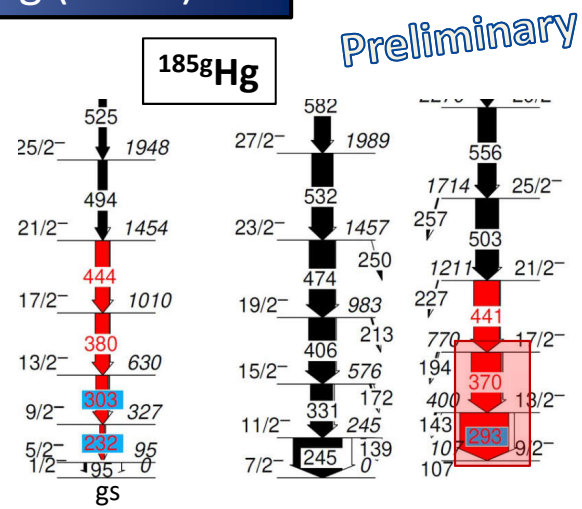
K. Wrzosek-Lipska et al., Eur. Phys. J. A (2019) 55: 130
N. Bree, PhD Thesis KU Leuven 2014

Courtesy of K. Wrzsosek-Lipska

IS563&IS699: ^{182,184,185}Hg shape coexistence

First multistep Coulomb excitation of ^{185g}Hg (IS699) :



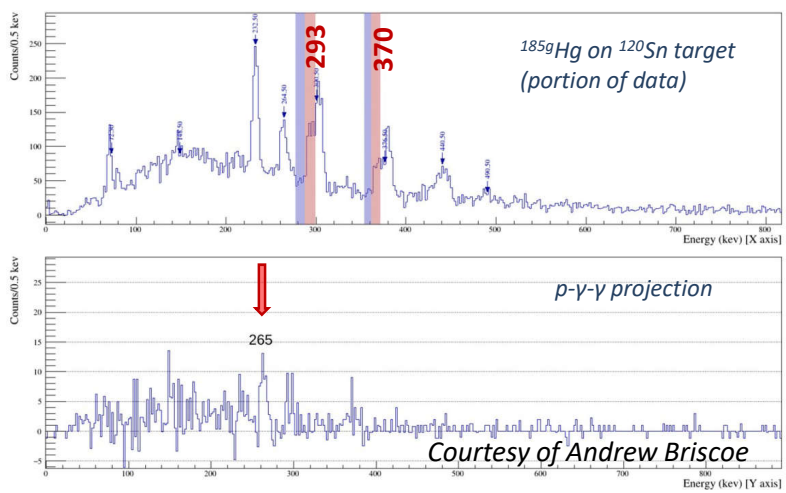


Level scheme: courtesy of J. Pakarinnen

- 9 states populated above the ground 1/2$^-$ state,
- 9 γ-ray transitions observed.

- Unknown 265-keV γ-ray transition clearly visible in the p-γ spectra collected with the use of both ^{48}Ti and ^{120}Sn targets.

- 265-kev line in coincidence with 293 keV and 370 keV lines → may be the interband γ-ray transition between the 1/2- gs and side band (requires further analysis)



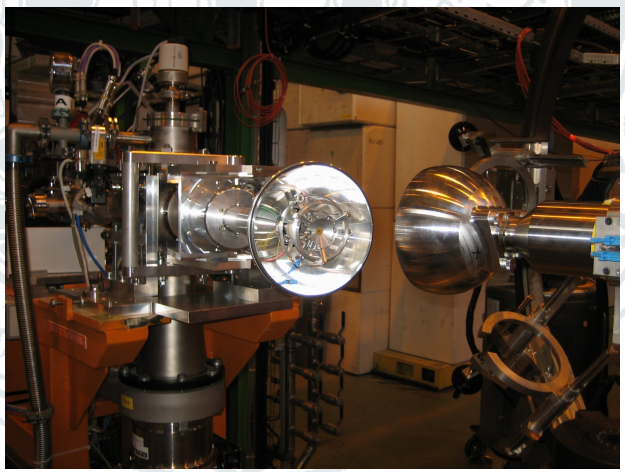
Courtesy of K. Wrzsosek-Lipska

IS656: Octupole correlations in ^{144}Ba

IS 656: Investigation of Octupole Correlations in ^{144,145}Ba using the Recoil Distance Doppler-shift Technique

C. Fransen, F. Dunkel, A. Blazhev, I. Anastasov, F. Browne, L. Gaffney, K. Gladnishki, H. Hess, J. Jolie, B. Jones, D. Kocheva, T. Kröll, C.D. Lakenbrink, R. Novak, J. Ojala, G. Rainovski, P. Reiter, M. Satrazani, F. von Spee, N. Warr

University of Cologne, Germany
University of Liverpool, UK
Technical University of Darmstadt, Germany
ISOLDE, CERN
University of Sofia, Bulgaria



→ First plunger experiment at ISOLDE
→ Incomplete fusion ^{144}Cs with ^{3}H after ^{7}Li breakup: 2n/3n channels to ^{144,145}Ba
Beam: ^{144}Cs @ 4.7 MeV/u
Target: ^{7}Li, 1.8 mg/cm^2 on ^{51}V fronting
Degrader: ^{197}Au, 10 mg/cm^2

Supported by the German BMBF, Grant 05P18PKCI1 and by EURO-LABS, Grant No. 101057511

Bundesministerium für Bildung und Forschung

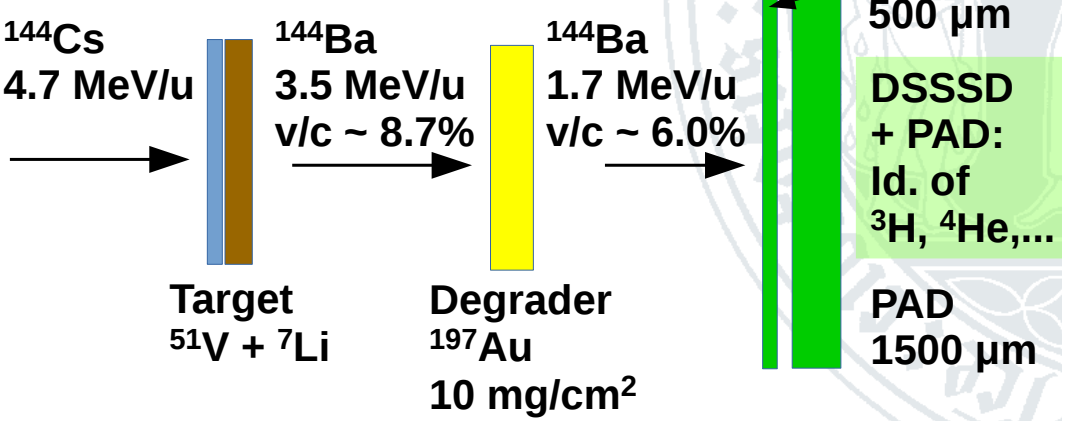
EURO-LABS EUROPEAN LABORATORIES FOR ACCELERATOR BASED SCIENCES

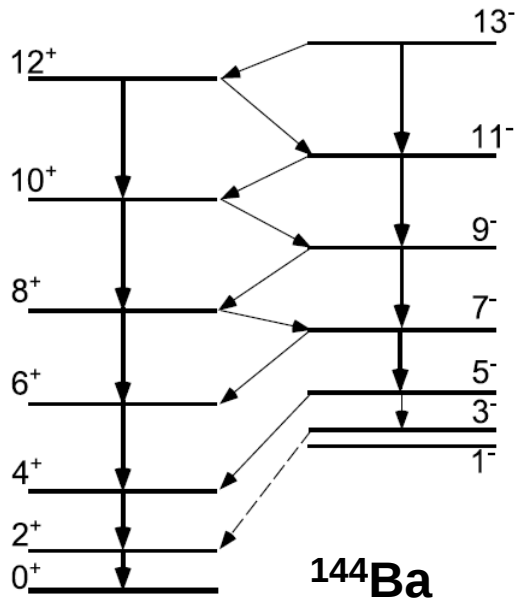
Courtesy of C. Fransen

IS656: Octupole correlations in ^{144}Ba

IS 656: Investigation of Octupole Correlations in ^{144,145}Ba using the Recoil Distance Doppler-shift Technique

→ **Experiment performed at ISOLDE, Sep 2023**





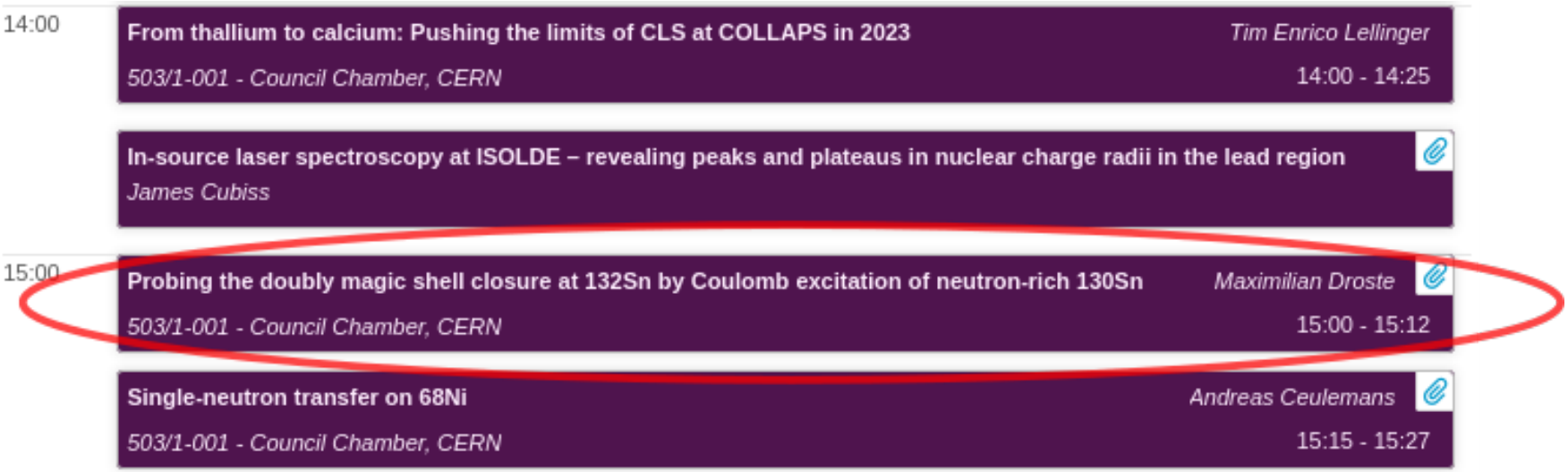
Status:
→ **analysis started**
(PhD thesis F. Dunkel, Cologne)

RDDS:
τ(2⁺, 4⁺, 6⁺, 1⁻, 3⁻, 5⁻,...)
→ B(E2), B(E1)

Supported by the German BMBF, Grant No. XXX
and by the European Commission, Grant EURO-LABS

Courtesy of C. Fransen

IS702: Collectivity close to ^{132}Sn

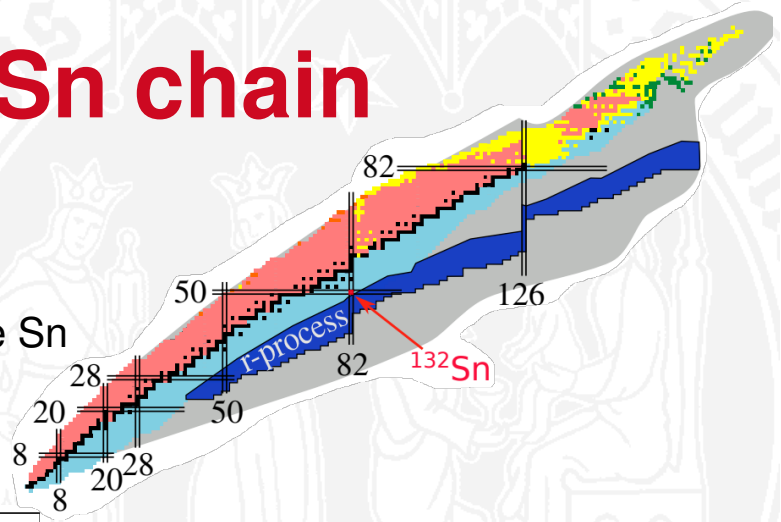


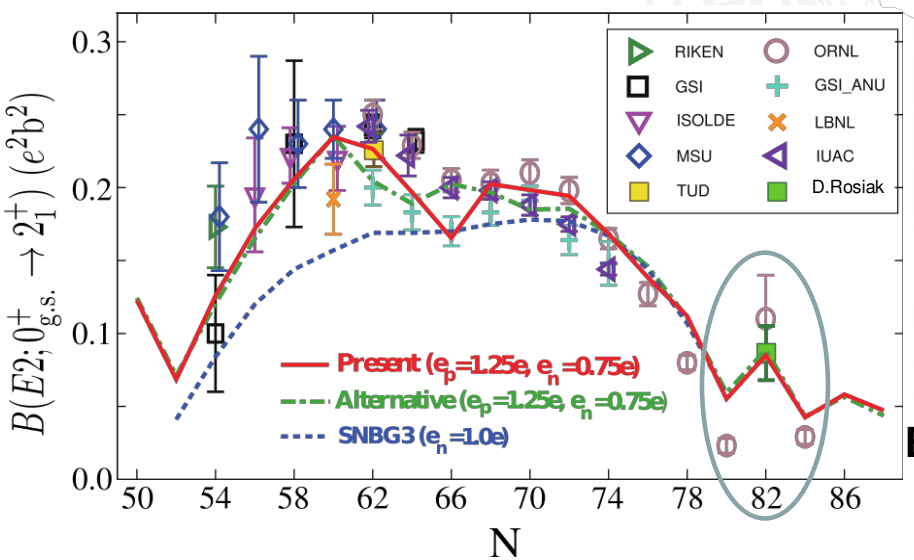
IS702: Collectivity close to ^{132}Sn

B(E2) values along Sn chain

^{132}Sn region of interest for r-process

MCSM calculations [1] able to describe whole Sn isotope chain using one Hamiltonian?





$B(E2; 0^+ \rightarrow 2^+)_{ORNL} = 0.023(5)\ e^2b^2$ [2]

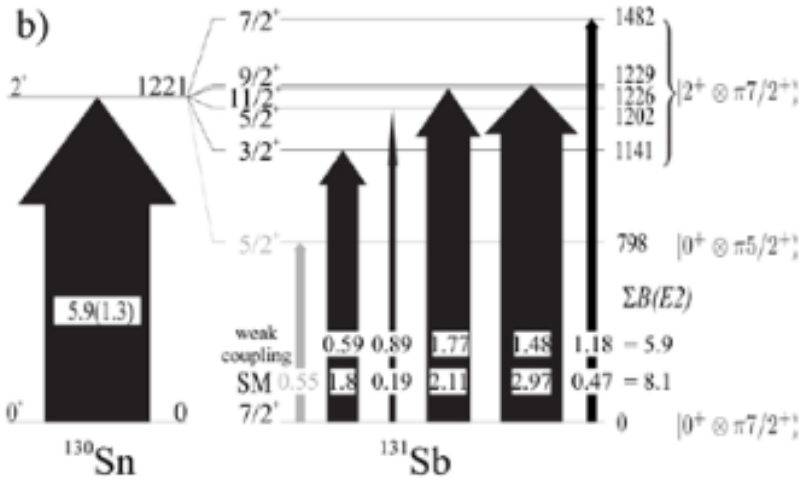
$B(E2; 0^+ \rightarrow 2^+)_* = 0.054(10)_{stat.}\ e^2b^2$

*Miniball @ ISOLDE 2022

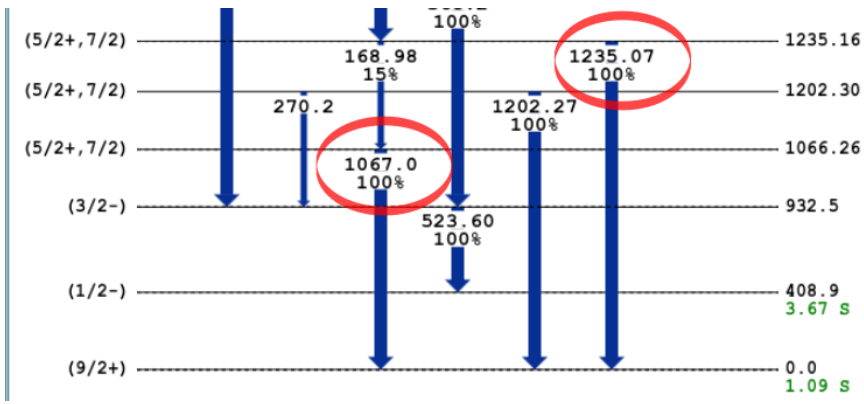
[1] T. Togashi; Y. Tsunoda; T. Otsuka; N. Shimizu; M. Honma; Phys. Rev. Lett. 121, 062501 (2018)
^{132}Sn value by D. Rosiak, *et. al.*; Phys. Rev. Lett. 121, 252501 (2018)
[2] D.C. Radford, *et al.* Nucl. Phys. A 752 (2005) 264c272c

Courtesy of M. Droste

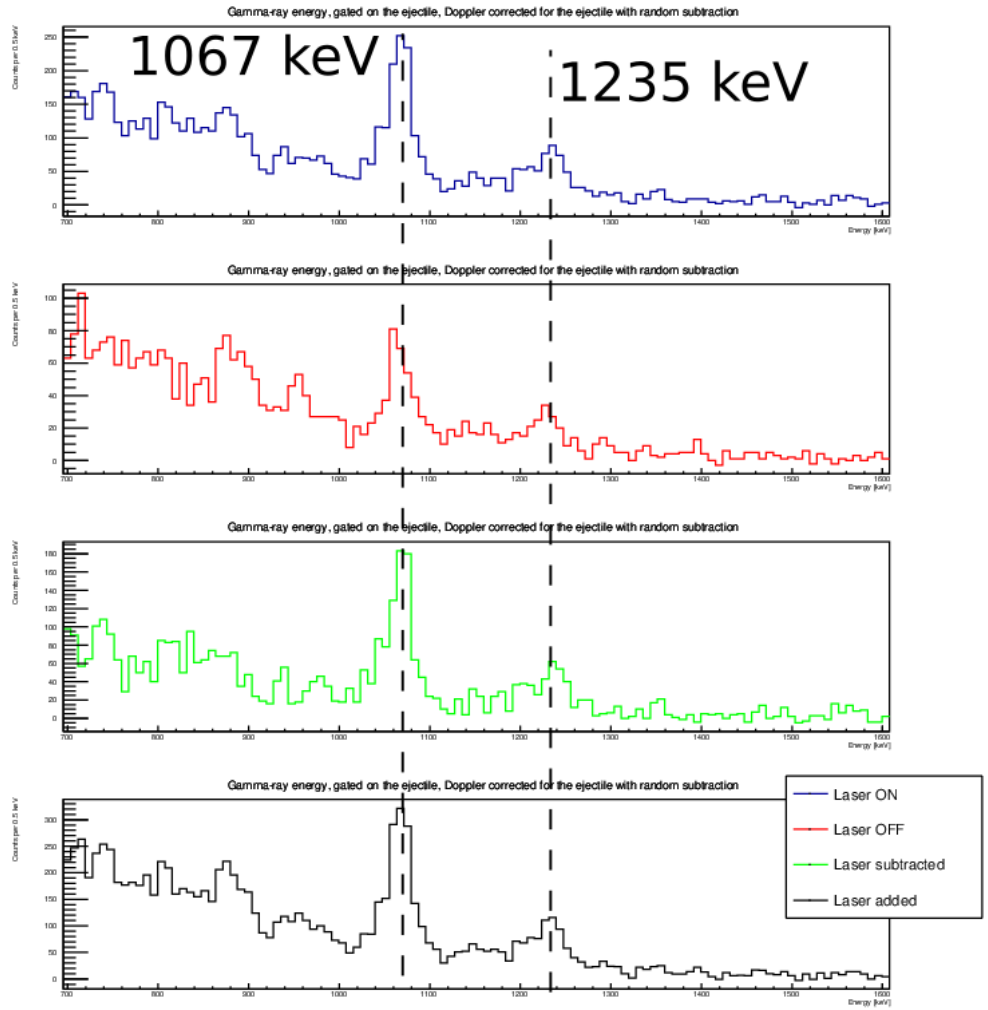
IS697: Coulex sum rules close to ^{132}Sn



Coulex to core-coupled multiplet *should* be the same



^{127}In level scheme



^{127}In Coulex spectrum

IS595: Spectroscopy of ^{133}Sb

Recent results from the Miniball spectrometer — *Frank Browne*
503/1-001 - Council Chamber, CERN — 16:15 - 16:40

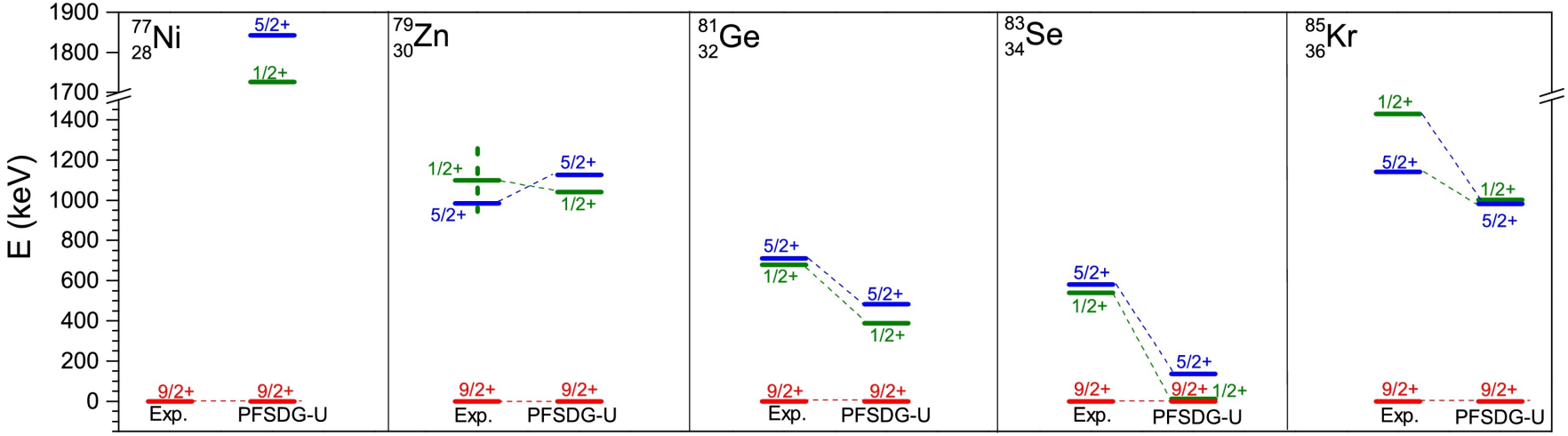
Gamma-ray spectroscopy of neutron-rich Sb isotopes by cluster transfer reactions — *Simone Bottoni*
503/1-001 - Council Chamber, CERN — 16:45 - 16:57

The first TDRIV g-factor measurement on a radioactive ion beam: ^{28}Mg — *Konstantin Stoychev*
503/1-001 - Council Chamber, CERN — 17:00 - 17:12

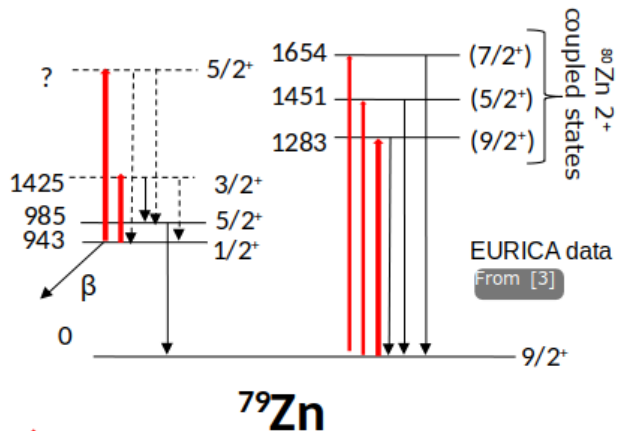
Combined conversion electron and gamma-ray spectroscopy of neutron-deficient Hg isotopes utilising the SPEDE spec...
Joonas Kalervo Ojala

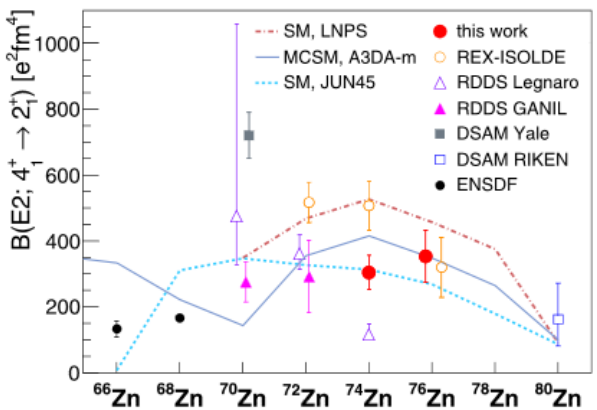
Scattering Studies at the SEC (XT03) beamline at HIE-ISOLDE — *Maria Jose Garcia Borge*
503/1-001 - Council Chamber, CERN — 17:30 - 17:55

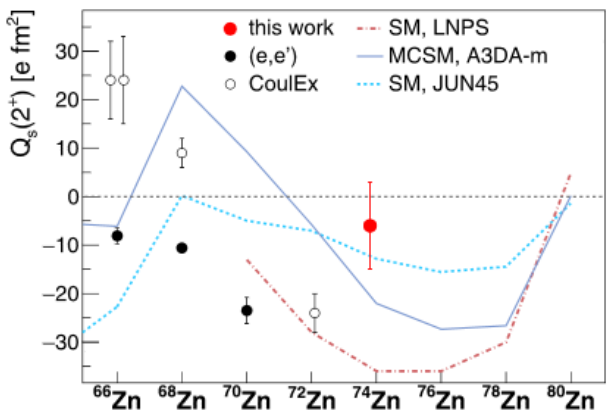
IS557&IS646: Shapes in neutron-rich Zn



$E(1/2^+)$ recently measured in ^{79}Zn by Lukas/ISOLTRAP, synergy!





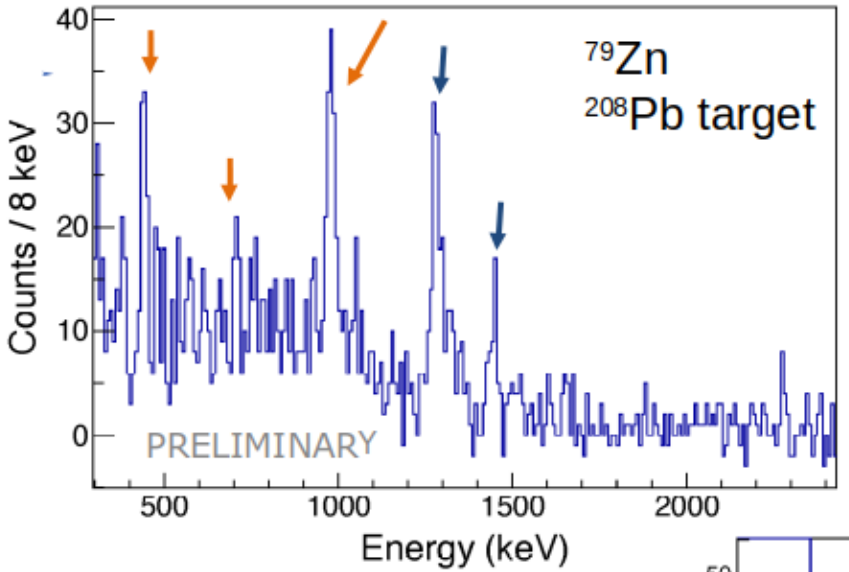


- Build on success of 1st HIE-ISOLDE expt.
- Shape coexistence around ^{78}Ni

A. Illana et al. (ISOLDE Collaboration), Phys. Rev. C **108**, 044305 (2023)

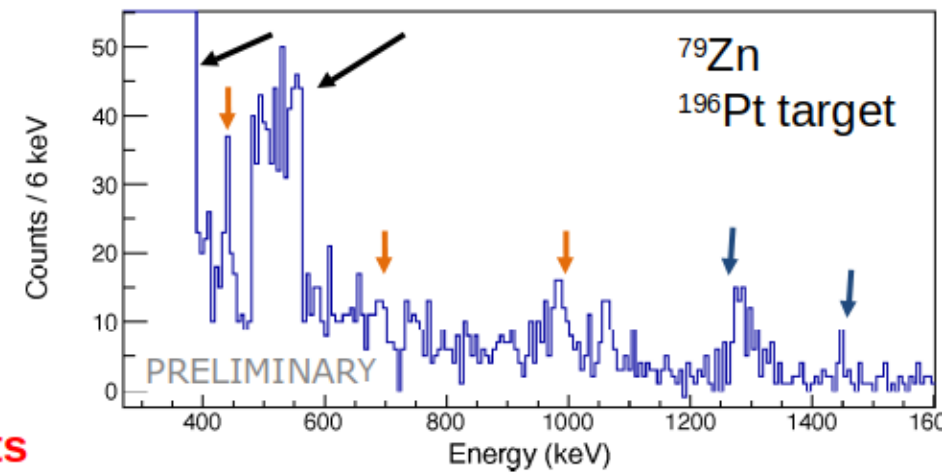
IS557&IS646: Shapes in neutron-rich Zn

cay of
ions



Ongoing analysis

g.s. Coulex
1/2⁺ isomer Coulex
Target Coulex



CONCLUSIONS

- **Pure, intense Zn beams from ISOLDE**
- **Coulex of intruder isomeric state works !**
- **With the remaining assigned shifts we will probe the deformation of intruder states near ^{78}Ni**

Poster of A. Gottardo

Summary

- Where have we been?
  - → Miniball characteristics/performance
  - → Reaction product detection
  - → Data acquisition developments
  - → Successful campaign using Coulex & transfer
- Where are we going?
  - → **MORE PHYSICS!**
  - → New developments of DAQ
  - → Return of T-REX...?

Thank you to

Setting up, etc: L. P. Gaffney, U. Grönroos, H. Hess, H. Kleis, B. Jones, M. Komoroska, J. Lawson, T. Kröll, K. Arnswald, S. Thiel, C. Unsworth, N. Warr, A. Illana, P. Reiter, J. Pakarinen, Z. Podolyák, J. Ojala, N. Kurz, M. Labiche, V. Pucknell, J. Cederkäll, S. Minami, R. Abels, K. Henseler, R. Hirsch, H. De Witte, H.-G. Thomas, P. Papadakis

Machine supervisors: Alberto, Miguel, Simon, Cristiano, Erwin
RILIS: Katti, Cyril, Reinhardt
Targets: Simon, Mia, Sebastian

Collaborations: IS563, IS699, IS557, IS646, IS656, IS595, IS697, IS702

Sorry if I missed anyone!

The research leading to these results has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement no. 101057511.

Merci beaucoup