Perspektiven mit ISOLDE

Status und langfristige Vision

Thorsten Kröll

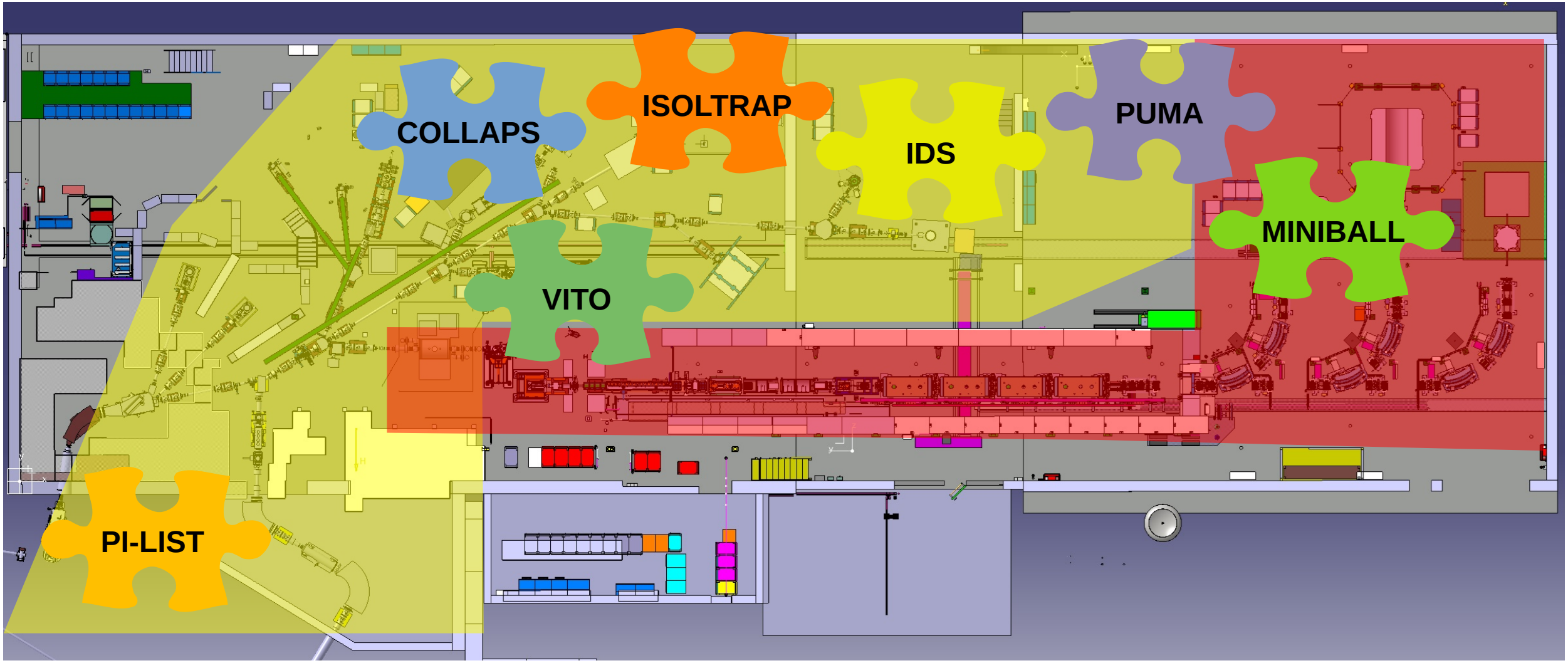
TECHNISCHE UNIVERSITÄT DARMSTADT

KHuK-Jahrestreffen 08.-10.12.2022

Shades of ISOLDE

„Low-energy ISOLDE“

„High-energy ISOLDE“



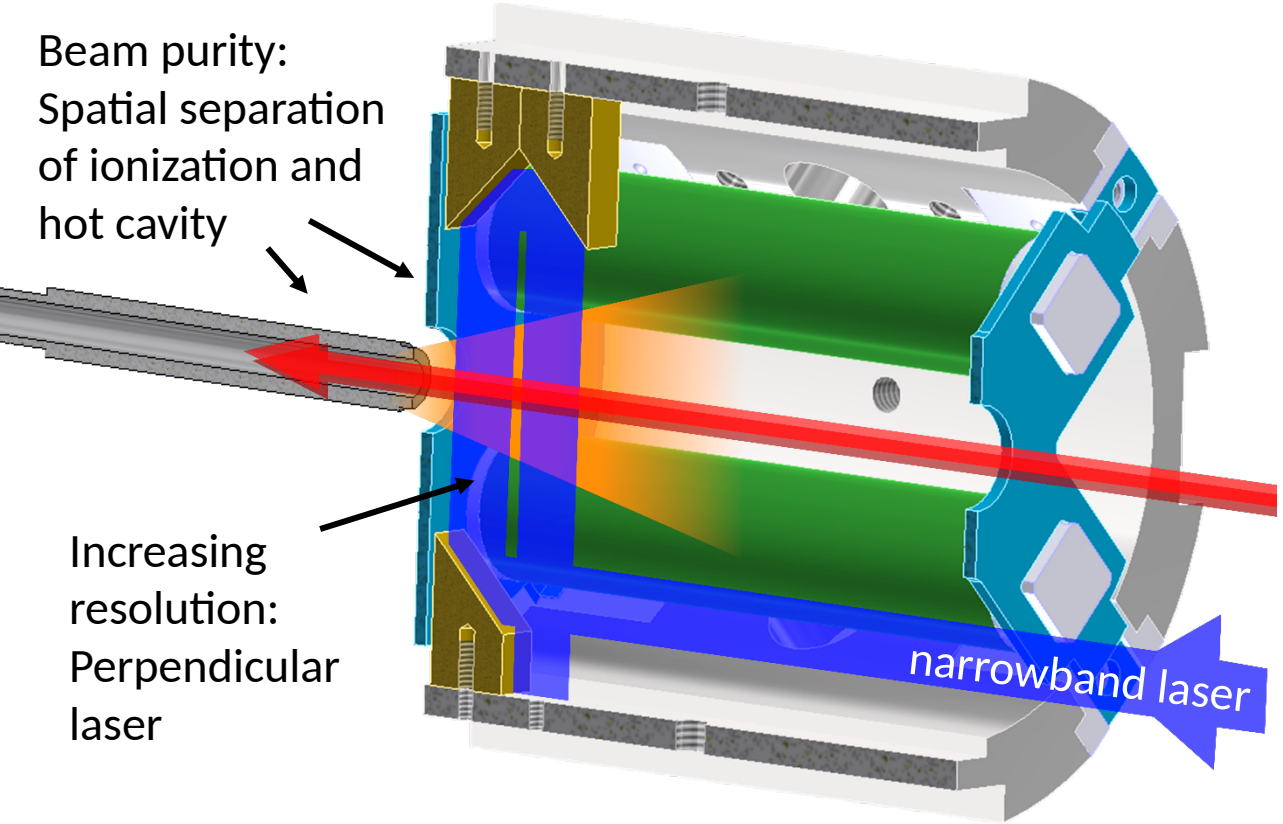
The PI-LIST @ ISOLDE: Pure RIB's and high-resolution spectroscopy

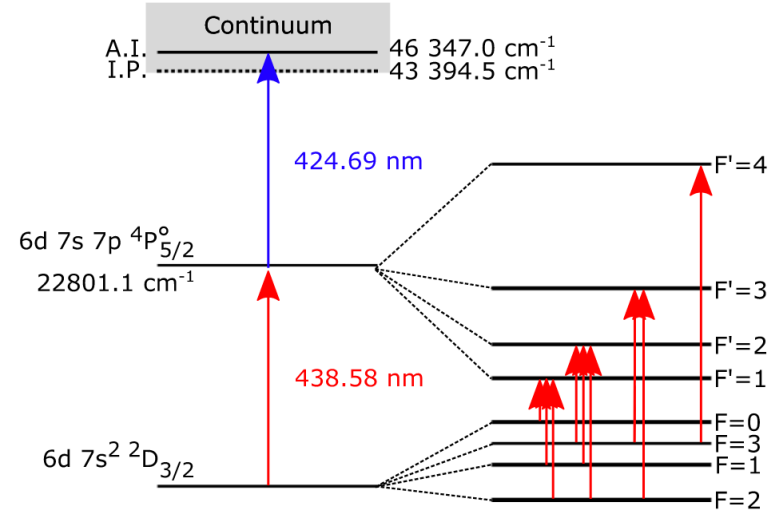
K. Wendt et al.

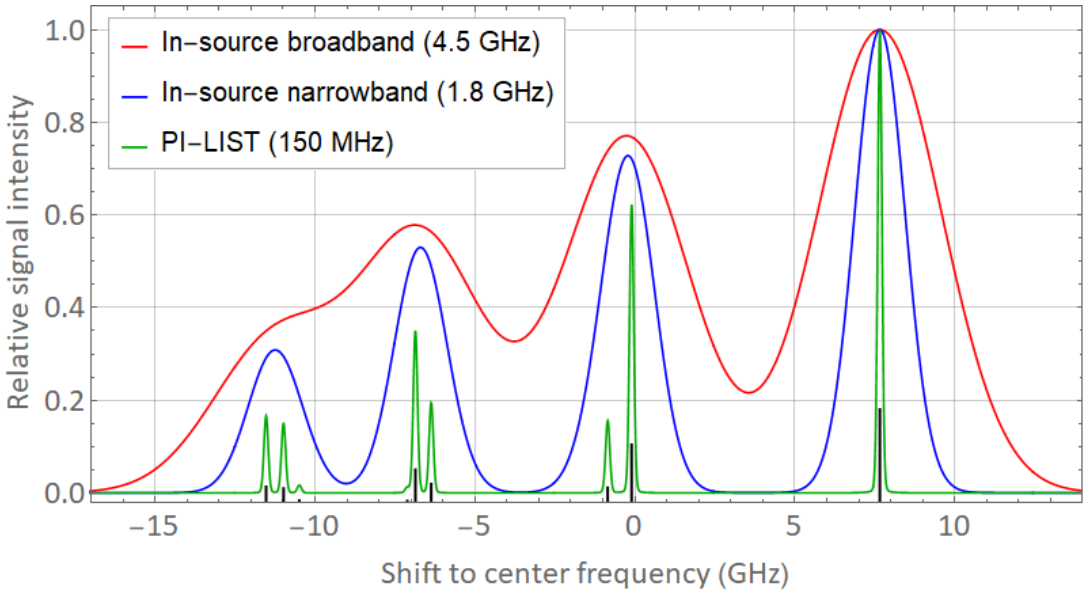
JOHANNES GUTENBERG UNIVERSITÄT MAINZ

Beam purity:
Spatial separation of ionization and hot cavity

Increasing resolution:
Perpendicular laser







- **Standard RILIS:** Doppler broadening as ultimate limit for atomic vapor in-source spectroscopy (some GHz)
- **PI-LIST**: Selection of **reduced Doppler ensemble**

  in **crossed laser intersection** volume in the LIST structure
  - ➢ Improvement by >1 order of magnitude (~100 MHz)
- Adapted for ISOLDE after becoming standard tool at JGU Mainz

Example of resolution improvement for Ac

K. Wendt et al.

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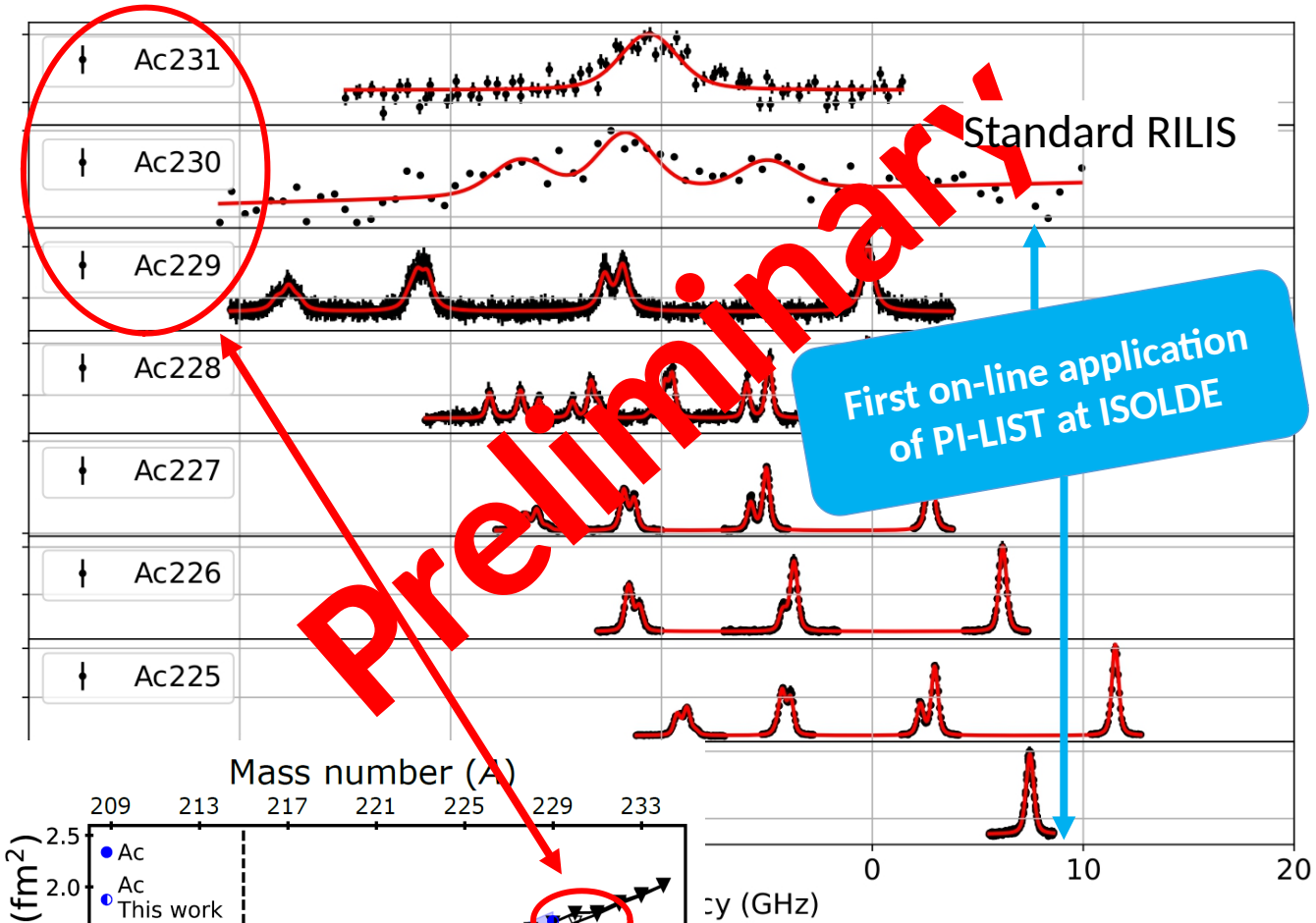
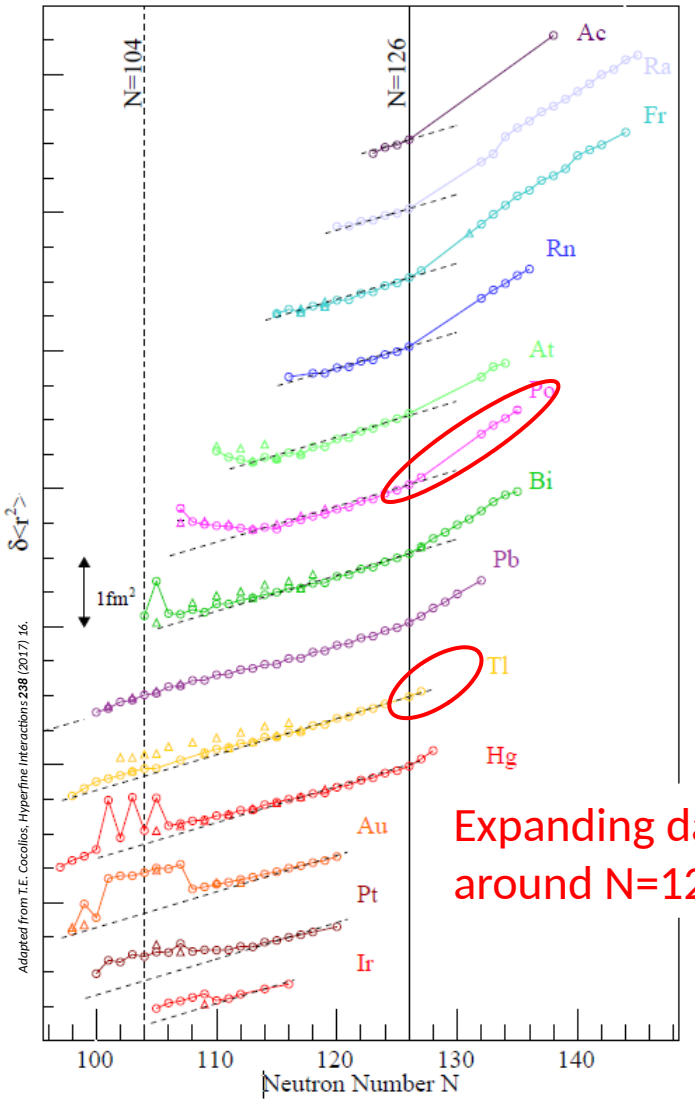
IS664: Octupole deformation in n-rich Ac



Change in trend of isotope shifts/charge radii as signature of octupole deformation (preliminarily) confirmed

IS456 and LoI219: Utilizing Fr suppression of LIST for nuclear structure investigations in Po and Tl



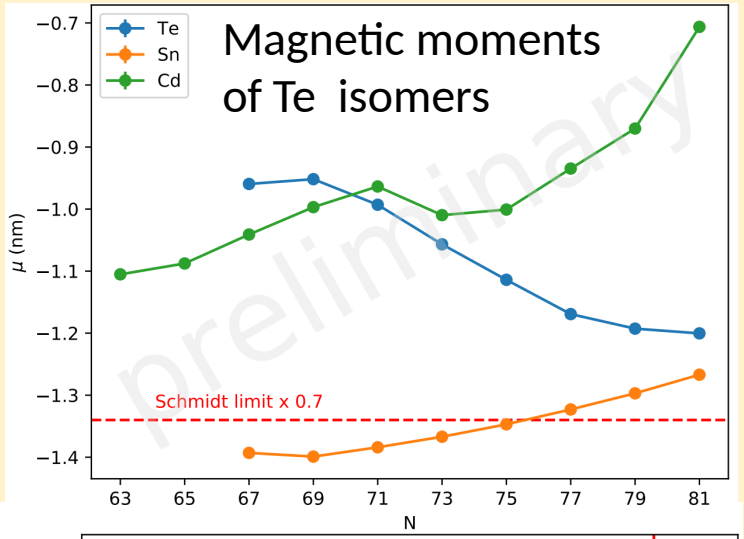
Expanding data around N=126

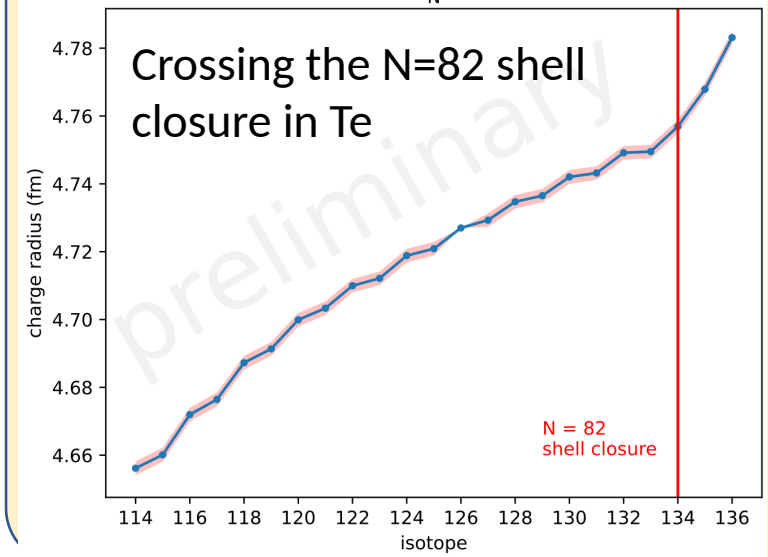
Future plans:
Extensive nuclear physics programme with PI-LIST in the lanthanides around N=82

- **LoI246**

High-Precision Radii and Moments around *N*=82 and beyond *N*=28

New Data / Developments

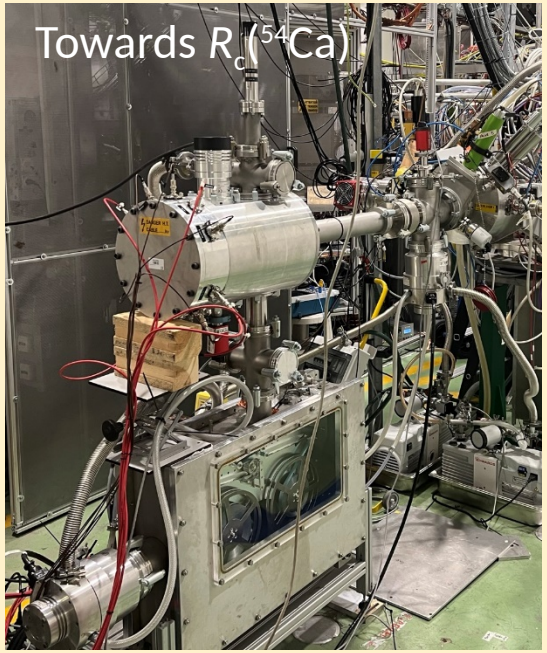


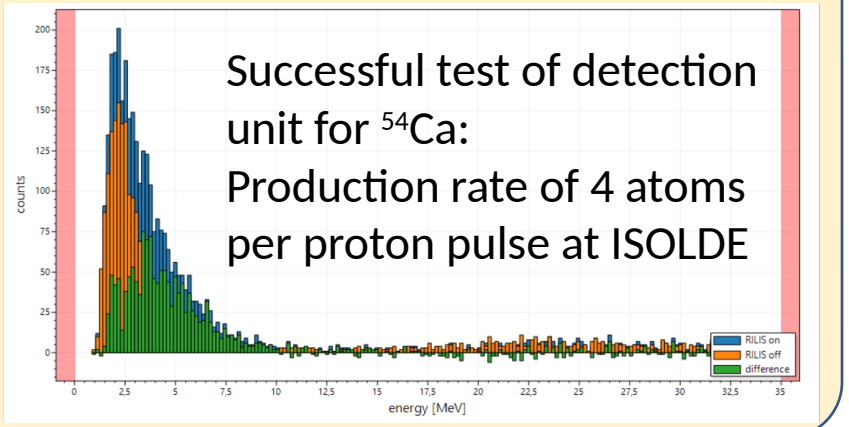


Physics Case:
Moments and Radii in the Tin Region

Continuation of Cd/Sn:
PRL **110**, 192501 (2013)
PRL **116**, 032501 (2016)
PRL **121**, 102501 (2018)
PRL **122**, 192502 (2019)
Comm. Phys. **3**, 107 (2020)

New Infrastructure:
Collinear beamline for off-line experiments.
Gentner Program:
Tim Lellinger





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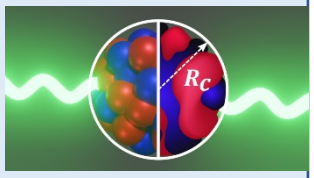
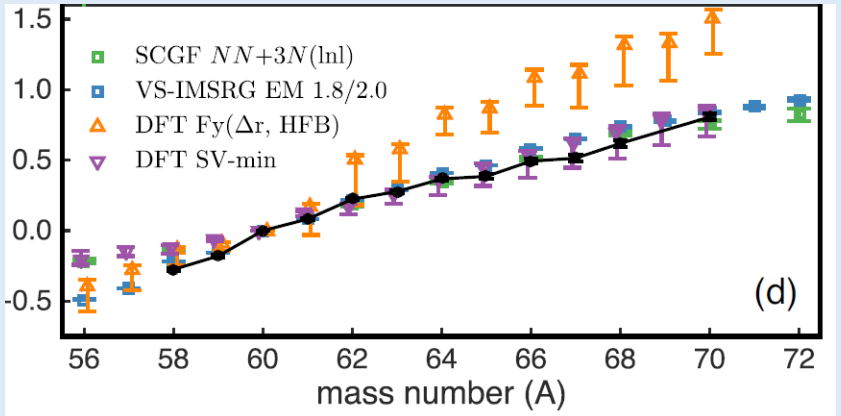
LASER SpHERe
MAX-PLANCK-INSTITUT FÜR KERNPHYSIK HEIDELBERG

W. Nörtershäuser et al.

Publications



S. Malbrunot-Ettenauer et al.
Phys. Rev. Lett. 128, 022502 (2022)



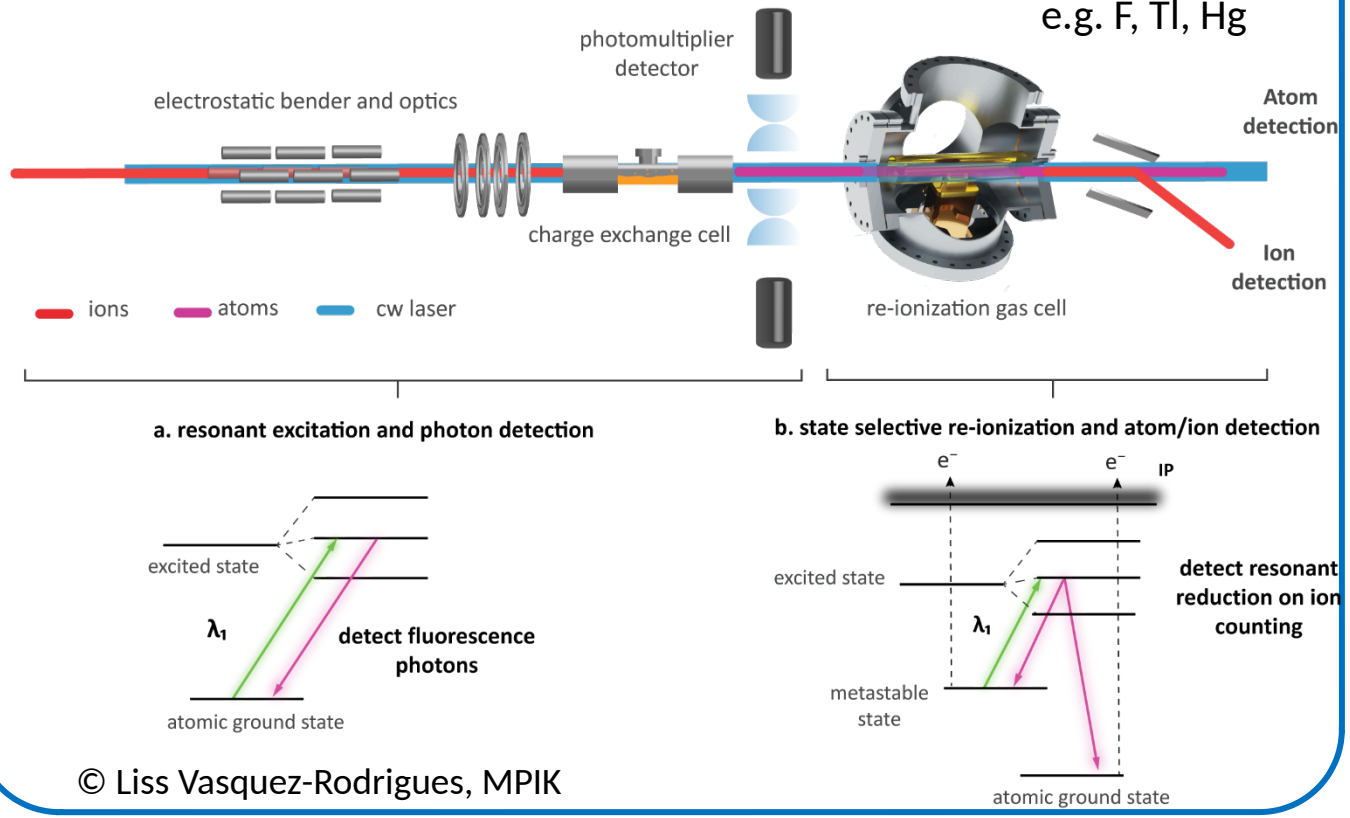
S.W. Bai et al., „Electromagnetic moments of scandium isotopes and *N*=28 isotones in the distinctive 0$f_{7/2}$ orbit",
Phys. Lett. B 829, 137064 (2022)

Future Developments and Applications

(i) Conventional Technique: Radii and moments (esp. isomers) in the Pb region: Beamtime on Tl postponed to spring,
further candidates: Hg, Po,
LoI for thulium measurements (proton emitter ^{147}Tm) accepted by INTC,
Tm test beamtime in 2023

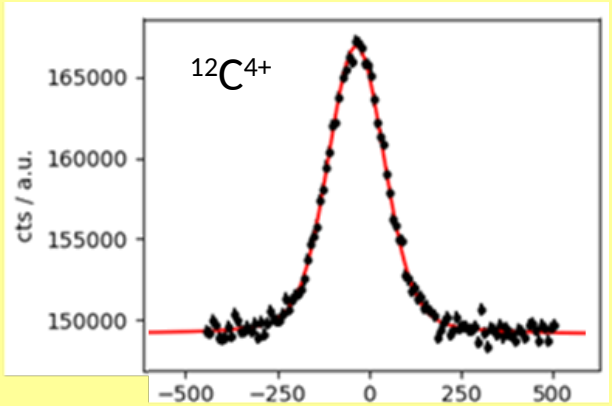
(ii) Sensitivity increase by post-ionization

Applications,
e.g. F, Tl, Hg



© Liss Vasquez-Rodrigues, MPIK

(iii) Feasibility study: Laser spectroscopy of short-lived light highly charged ions



Resonance of $^{12}C^{4+}$ $1s2s\ ^3S_1$ – $1s2p\ ^3P_2$ at KOALA (TU Darmstadt)

Applications: Be^{2+}, $B^{2+,3+}$, C^{4+}, N^{5+}
Radii and moments of, e.g., ^{7}Be, ^{11,15}C

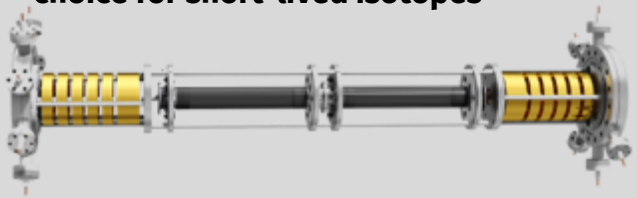
To be studied:
- injection/ejection into EBIS,
- breeding efficiency into the charge (and atomic) state of choice

W. Nörtershäuser et al.

Nuclear Physics Studies through Mass Spectrometry

Excerpt of measurements 2020 - 2022

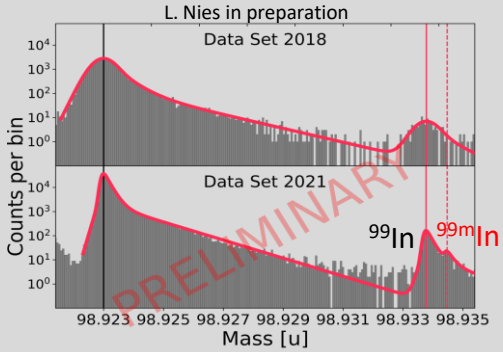
(i) Multi-Reflection Time-of-Flight Spectrometry: The new tool of choice for short-lived isotopes



Versatile and fast ToF mass measurements of short-lived nuclei first demonstrated in Nature **498**, p.346–349 (2013)

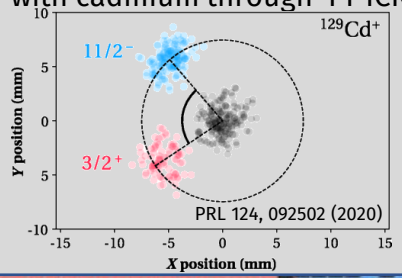
(ii) Latest MR-ToF MS developments:

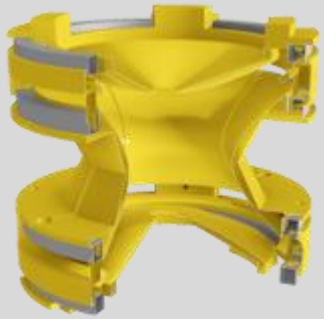
enhanced stabilization leads to increased performance and first-ever measurement of ^{99m}In at N=50, Z=49



(iii) Penning-Trap Mass Spectrometry: at the frontier of high-precision mass measurements for more than 30 years

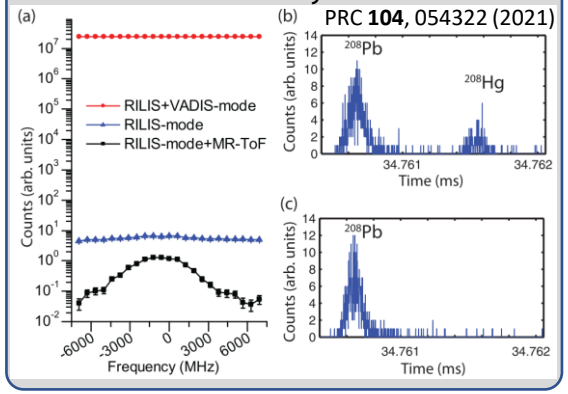
Studying the N=82 shell closure with cadmium through PI-ICR





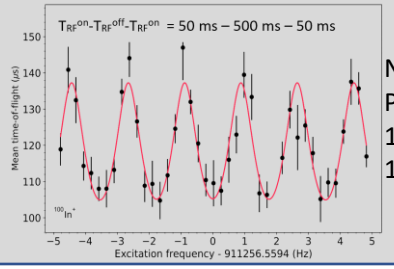
(iv) Capable Combination: Trap-assisted Laser-Spectroscopy

Mass-resolved counting of in-source resonance-ionized elements of mercury and bismuth



(v) Grabbing magic tin by the tail

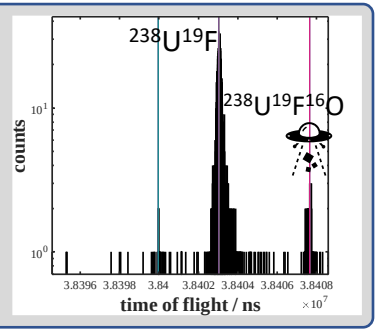
Mass-measurement of neutron-deficient indium isotopes and their isomers reveal constant excitation energy trends and reduce ^{100}Sn mass uncertainty



Nature Physics 17, 1099-1103(2021)

(vi) Actinide Studies with LISA

Supporting target and ion source development through particle identification measurements with the „Laser Ionization and Spectroscopy of Actinides“ ITN consortium



In, Sn
Nature Physics **17**, 1099-1103(2021)
Nies et al, in preparation

Cd
PRL **124**, 092502 (2020)

Zn
Nies et al, in preparation

Ar
PRC **102**, 14301 (2020)

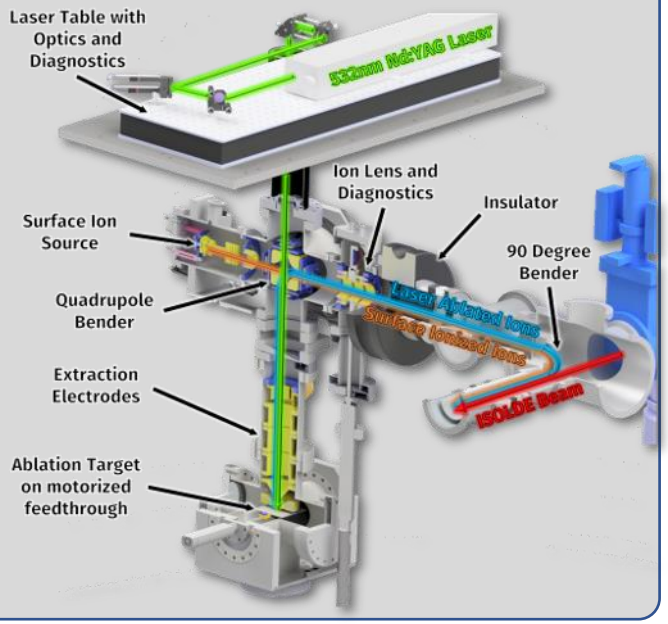
Hg
PRC **104**, 054322 (2021)

L. Schweikhard, L. Nies et al. (U Greifswald)

ISOLTRAP in the Near Future

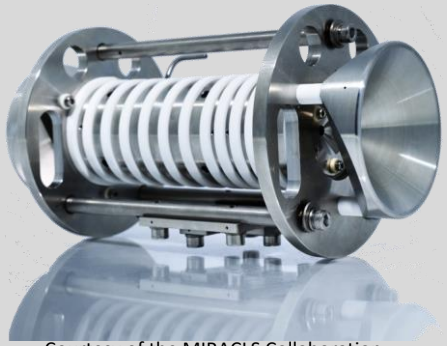
(i) The Newly Commissioned Laser-Ablation Ion Source

- Systematic studies of the MR-ToF MS, ToF-ICR, and PI-ICR techniques planned
- Source for long-lived radioactive ions for the search of suitable EC-transitions to study the electron-neutrino mass
- Source of various mass references for calibration across whole nuclear chart



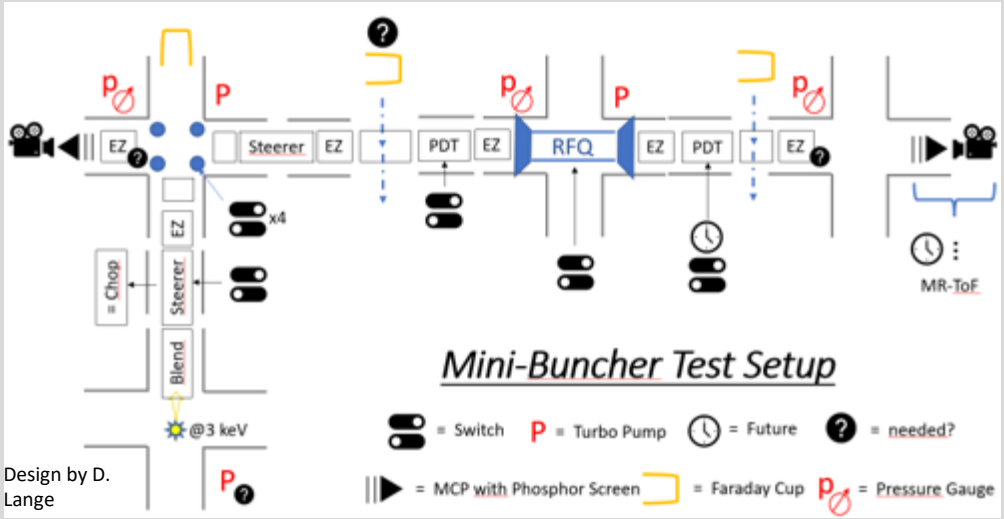
(ii) A new Cooler-Buncher / MR-ToF MS setup

- Upgrading MR-ToF MS to new-generation design: in-trap cleaning of contamination, higher mass-resolving power, less rest-gas pressure
- New RFQ cooler-buncher for higher ion bunching efficiency and retrapping capabilities



Courtesy of the MIRACLS Collaboration

Courtesy of the PUMA / MR-ToF MS Collaboration



Design by D. Lange

(iii) Experimental Program / Accepted Proposals

Nuclear Structure

- Mass spectrometry of ^{98}In (**IS661**) and ^{101}Sn-^{103}Sn (**IS719**) for nuclear shell structure studies close to N=Z=50 and rp-process studies for nuclear astrophysics
- Testing accuracy of Isomeric Multiplet Mass Equation at A=32, T=2 (**IS542**)
- Planned: neutron-rich silver and gold

Nuclear Astrophysics

- *rp*-process beyond ^{56}Ni: mass measurement of ^{58}Zn (**IS625**)
- Astromers: excitation energy of low-lying ^{128m}Sb (**IS704**)

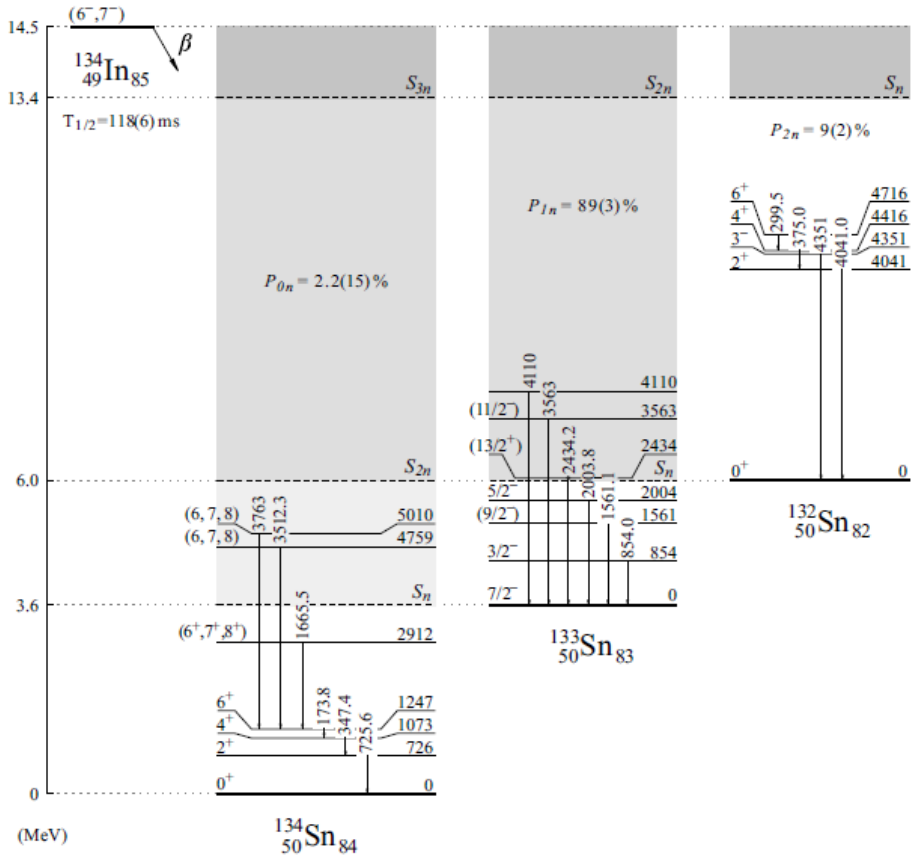
Weak Interaction Studies

- Precision Q_{ec}-value measurement of ^{70}Br > ^{70}Se for global Ft-value determination (**IS642**)

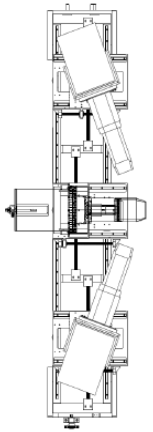
L. Schweikhard, L. Nies et al. (U Greifswald)

Isolde Decay Station (IDS)

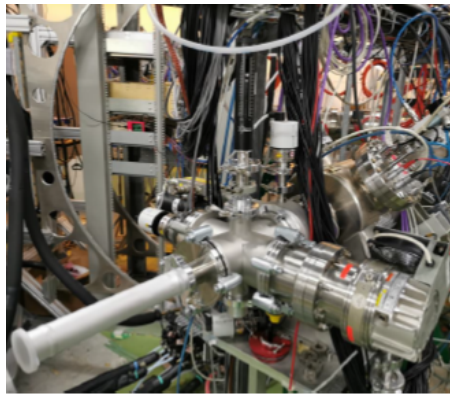
Scientific highlight: beta decay of ^{134}In
Important to describe freeze out of r process.



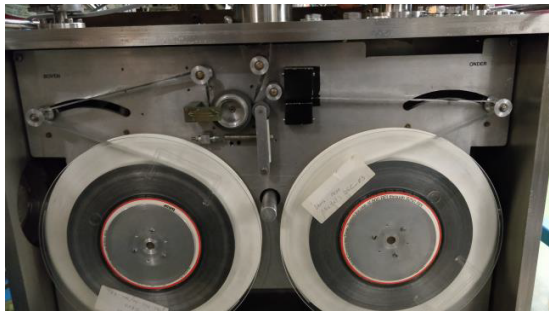
M. Piersa-Silkowska et al. PhysRevC.104.044328



New holding structure
was finished on 4.11
in York



New beamline is in
construction



New tapetransport
system was installed
in January

In 2022 six IDS experiments were performed using different auxiliary detectors (La Br3(Ce), neutron, electron, particle detectors).
For 2023 100 shifts from pending accepted proposals.

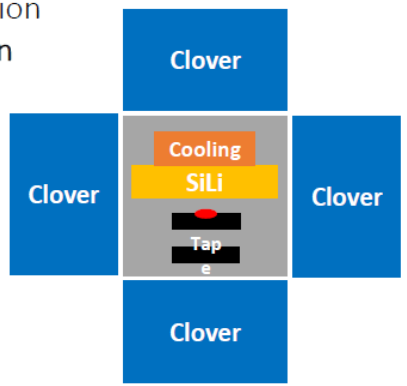
J. Jolie, N. Warr et al. (Universität zu Köln)

Future developments under discussion in the IDS collaboration:

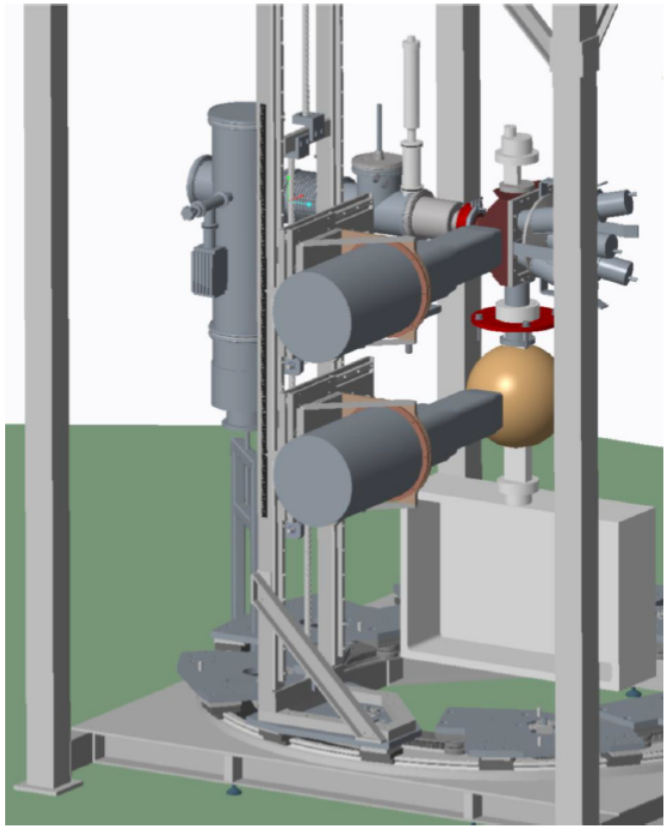
Decay Station 2 @ IDS

Secondary detection setup away from implantation point to:

1. Measure decays of long-lived nuclei/decay products
2. Provide
   (a) High-resolution CE detectors ≈3 keV resolution
   (b) High-efficiency low-energy gamma detection
   (c) High-efficiency silicon setup (close geom)



2 chambers: implantation and decay



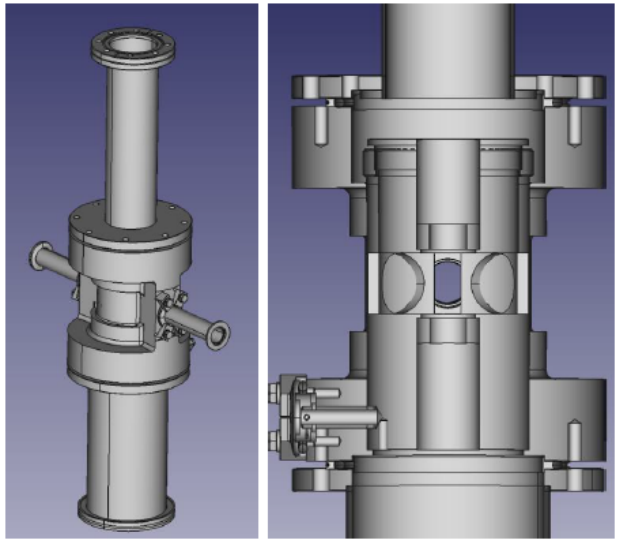
Physics cases:

- **Limits of n-rich nuclei @ ISOLDE**
  long-lived enough $T_{1/2}(^{232}Fr)$≈5 s, $T_{1/2}(^{232}Ra)$≈30 s

- **β-delayed fission in neutron rich Fr and Ac,**
  $T_{1/2}$ of minutes. DS2 large-area Si placed in close geometry would give factor of ≈3 in solid angle compared to WM, beta-fission coincidences.

- **β-decay study of n-rich isotopes in N>126, Z<82**, investigate single-particle states in $^{210\text{-}215}$Tl,Pb, which have $T_{1/2}$>30 s

Design and manufacturing currently on-going for the IDS TDPAC chamber (IFIN-HH, IJCLAB)
-> to be completed mid 2023



On-line TDPAC @ IDS

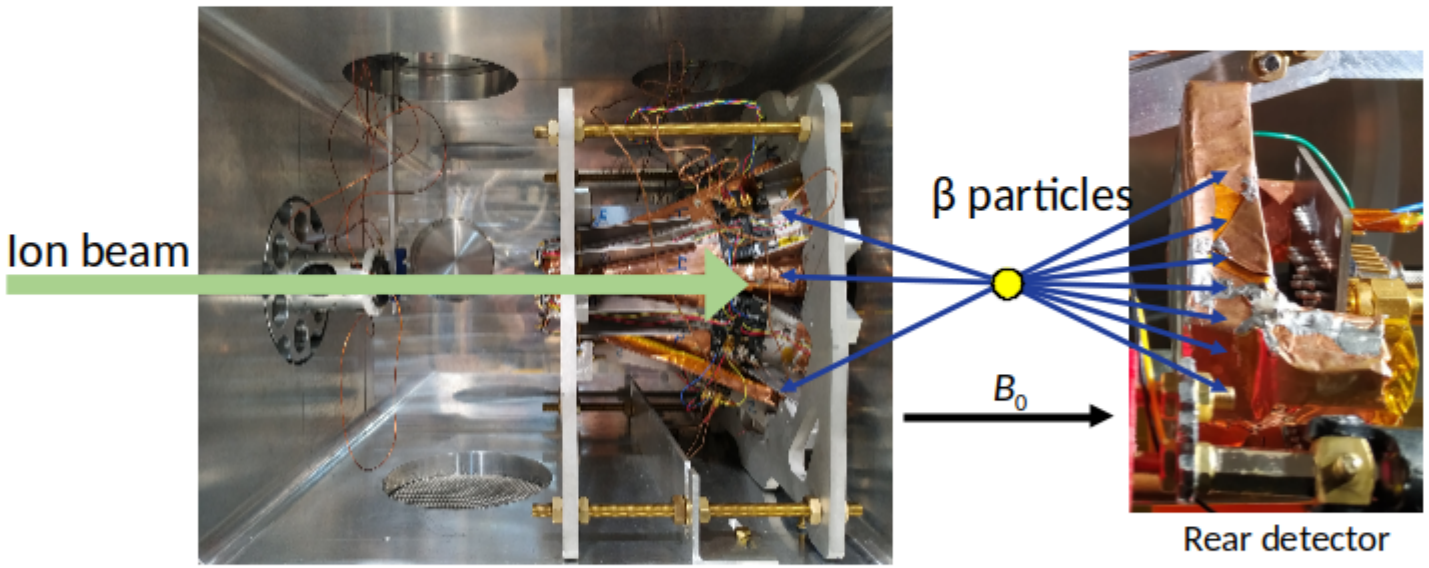
Nuclear moment studies of short-lived isomers (~ 1 ns – 1 µs) using
Time Dependent Perturbed Angular Correlations
- moment studies on neutron-rich isomeric states non accessible by any other means;
- population after β-decay (β – γ – γ), the spin orientation provided through the angular correlations
- TDPAC – standardly used in solid-state physics (long-lived isotopes). ***With IDS one can go on-line.***

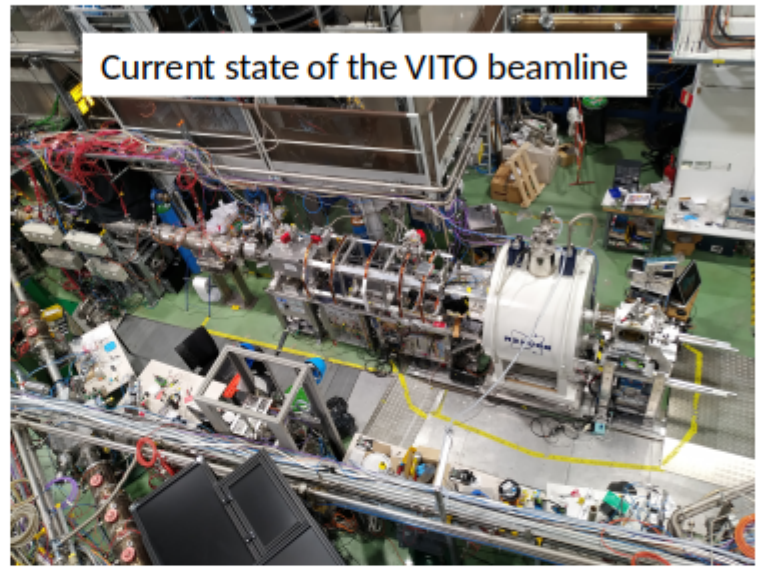
J. Jolie, N. Warr et al.
(Universität zu Köln)

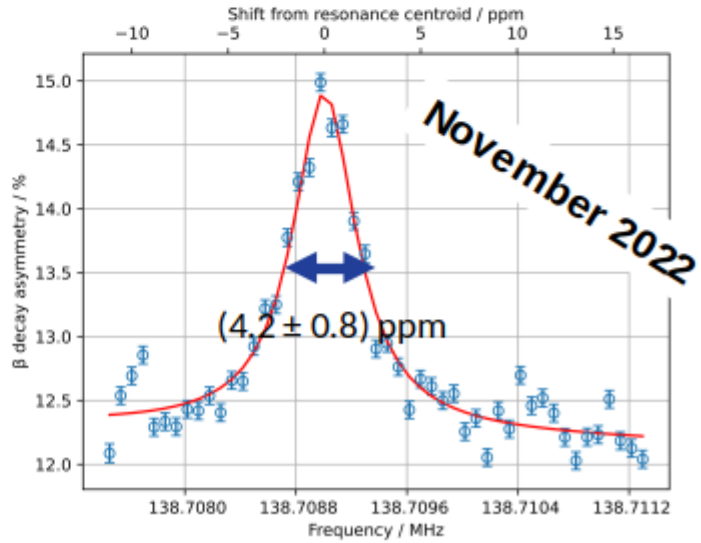
From magnetic moments and biochemistry to future β-NMR studies at VITO

Upgrades during LS2 and after

- New detectors with SiPM
- 4.7 T superconducting magnet with sub-ppm homogeneity
- new FPGA-based DAQ characterising each single β event





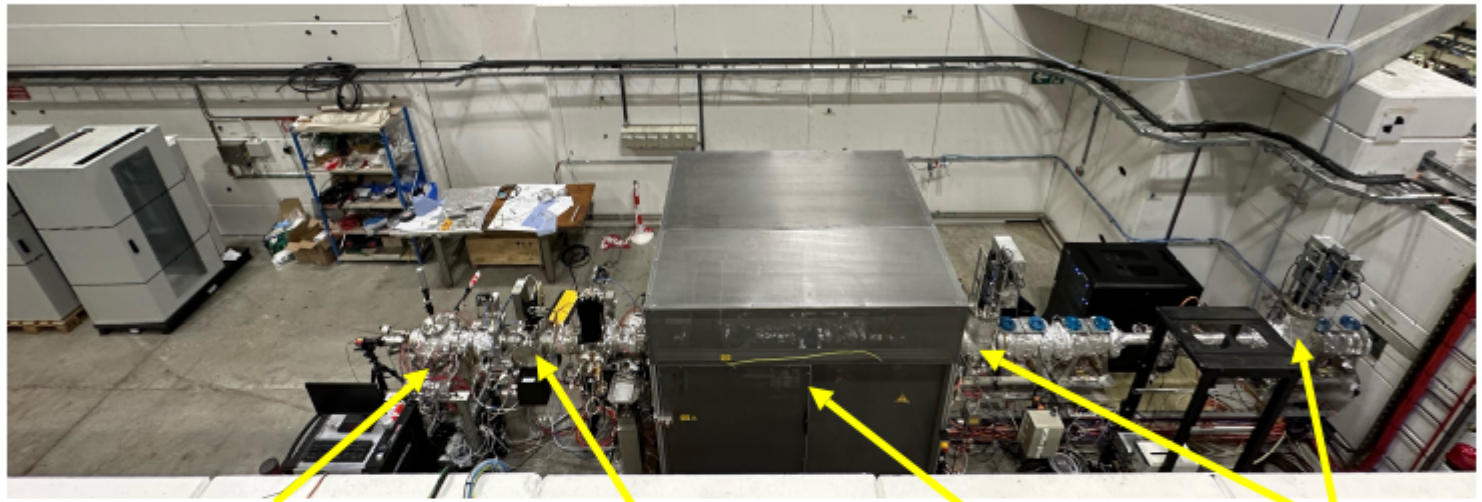


M. Jankowski (CERN/TU Darmstadt),
M. Kowalska (CERN), Th. Kröll (TU Darmstadt)...

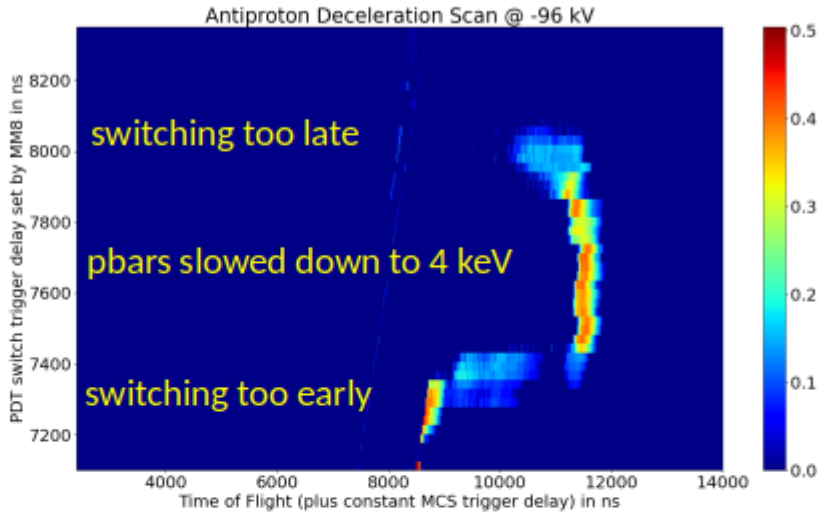
Towards DNA ... DNA and alkali cations of different concentrations in ionic liquid (glycholine) with liquid dispenser system: β-NMR scan on glycholine after several hours in vacuum. FWHM: (4.2 ± 0.8) ppm

Status of PUMA@CERN

Current PUMA installation at AD (ELENA):



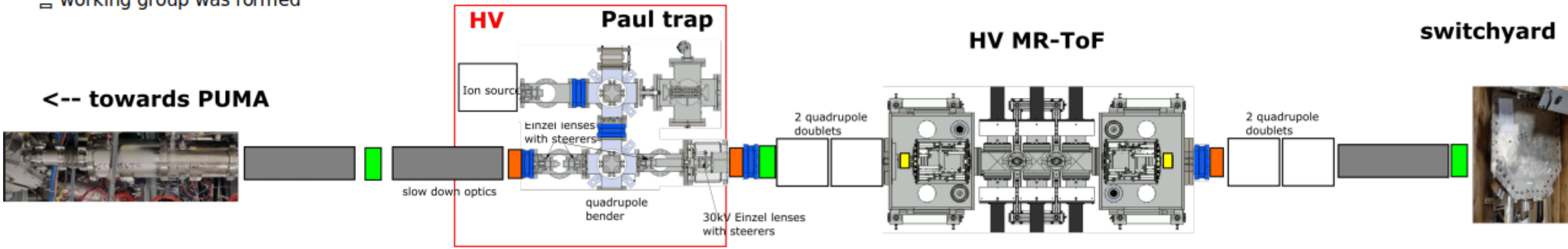
Successful deceleration of 100keV pbars to 4keV:



Detailed planning of the HV-MR-ToF XHV beamline at RC6 for PUMA and other traveling experiments at ISOLDE started:

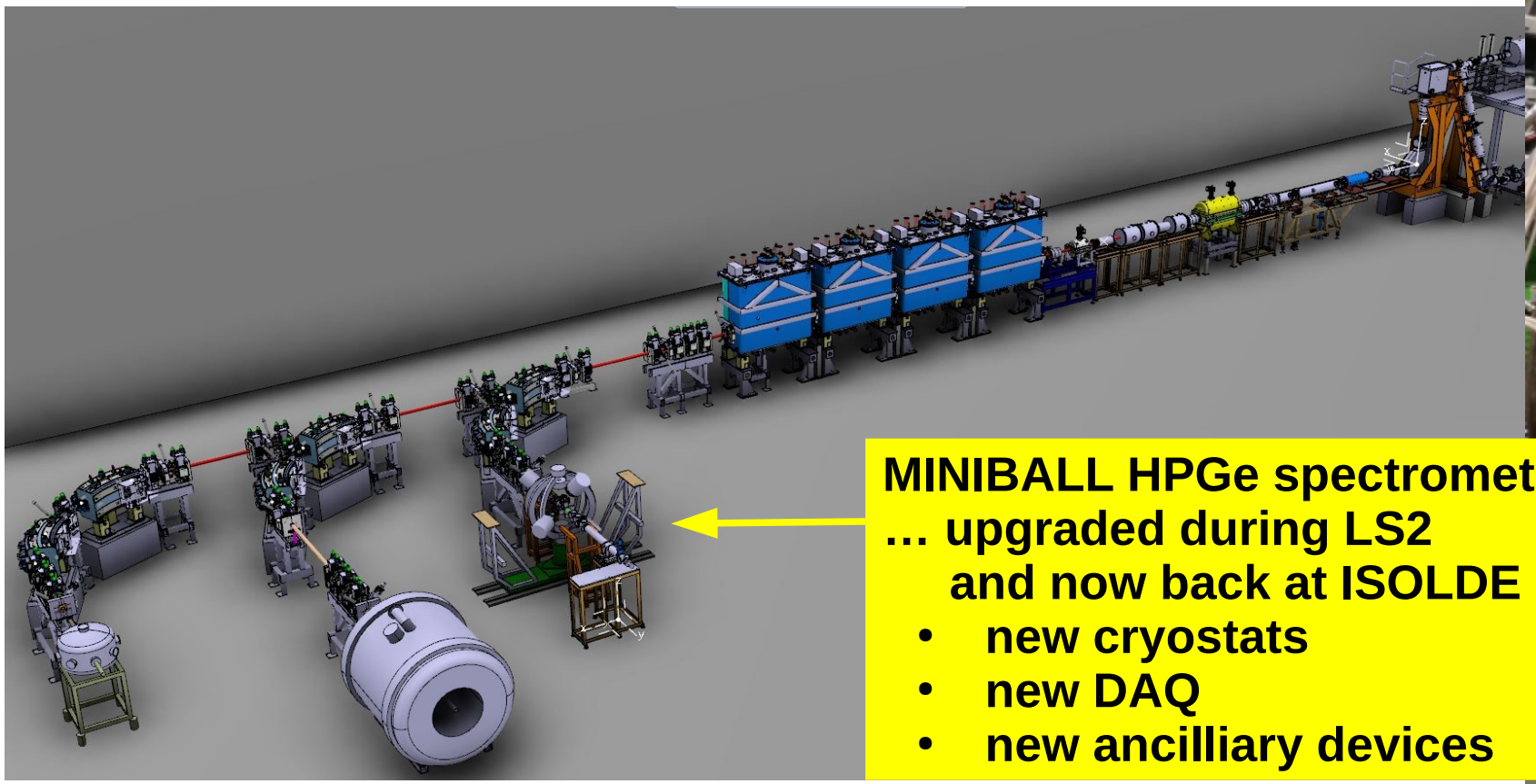
Oliver Aberle assigned Technical Coordinator for PUMA@ISOLDE

- working group was formed



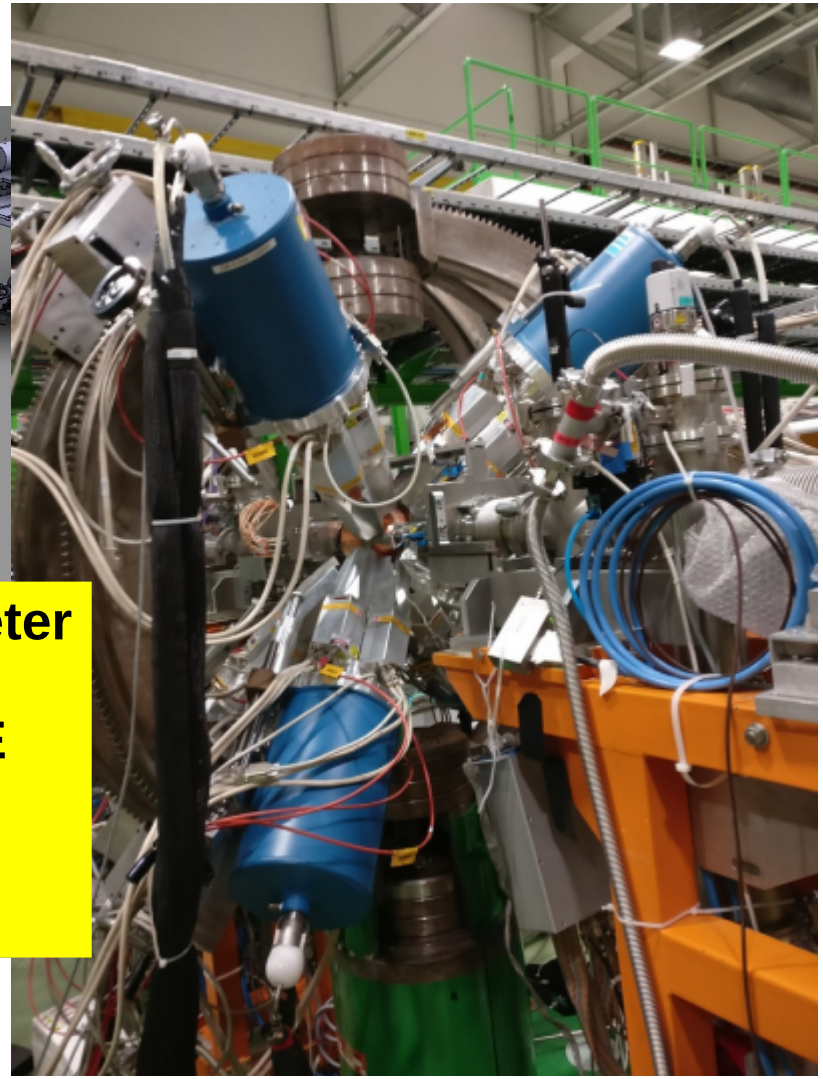
F. Wienholtz, A. Obertelli (TUDa), PUMA collaboration

Beam energy: 30-60 keV → post-accelerated up to 10 MeV/A

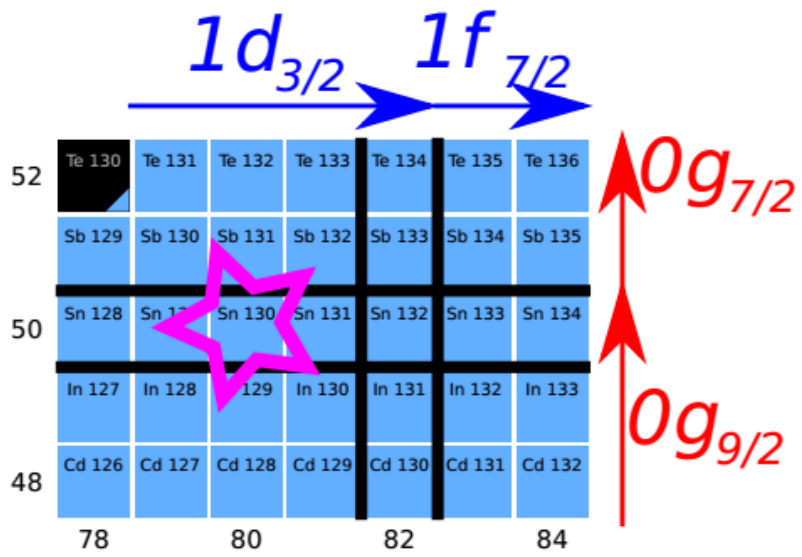


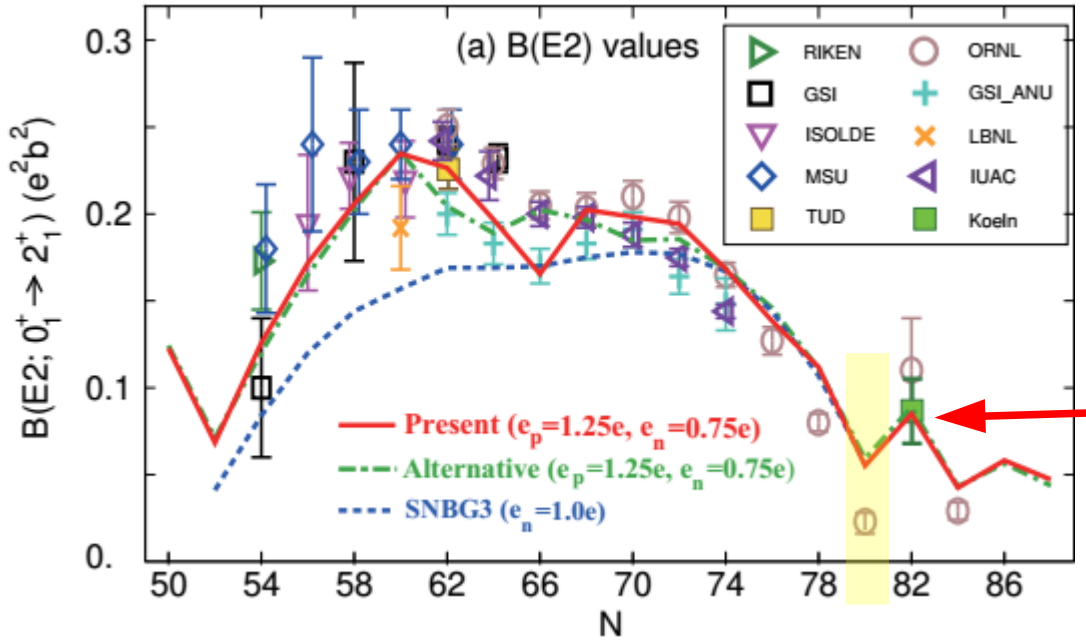
MINIBALL HPGe spectrometer
… upgraded during LS2
and now back at ISOLDE

- **new cryostats**
- **new DAQ**
- **new ancilliary devices**



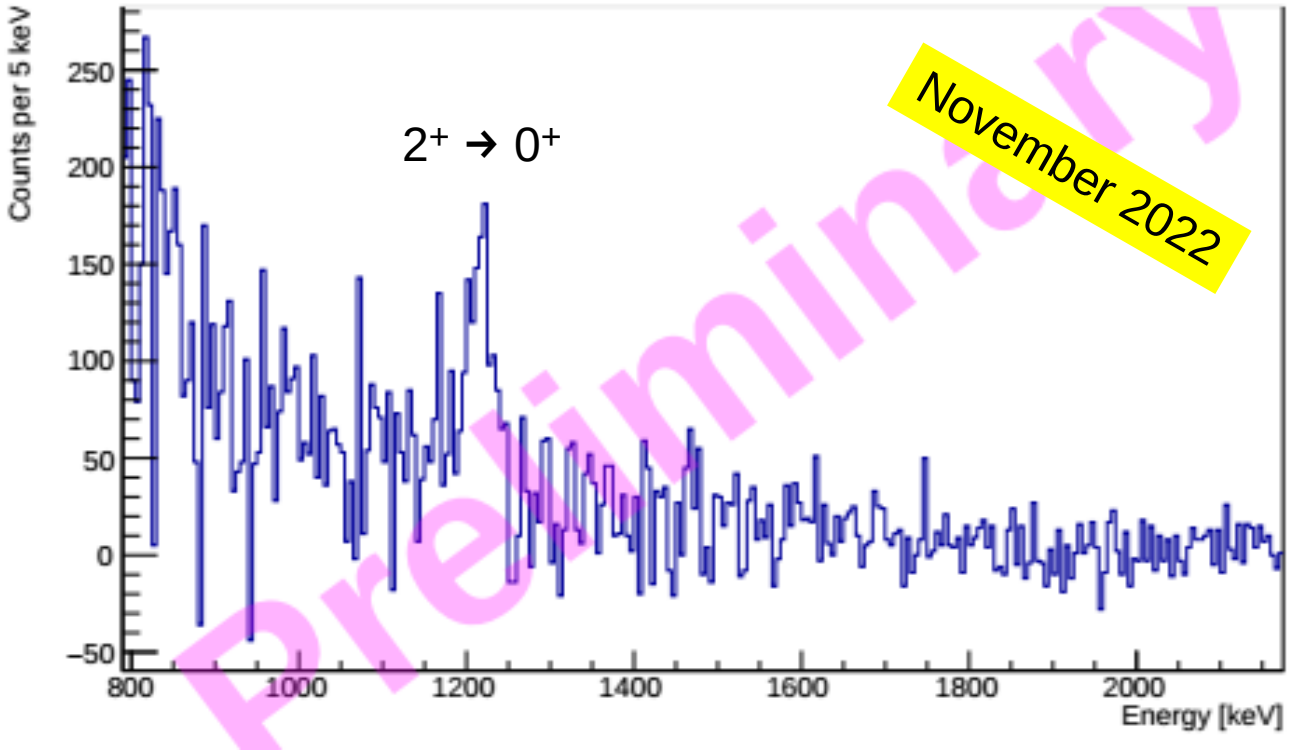
Coulomb excitation of ^{130}Sn





T. Togashi *et al*, Phys. Rev. Lett. **121**, 062501 (2018).

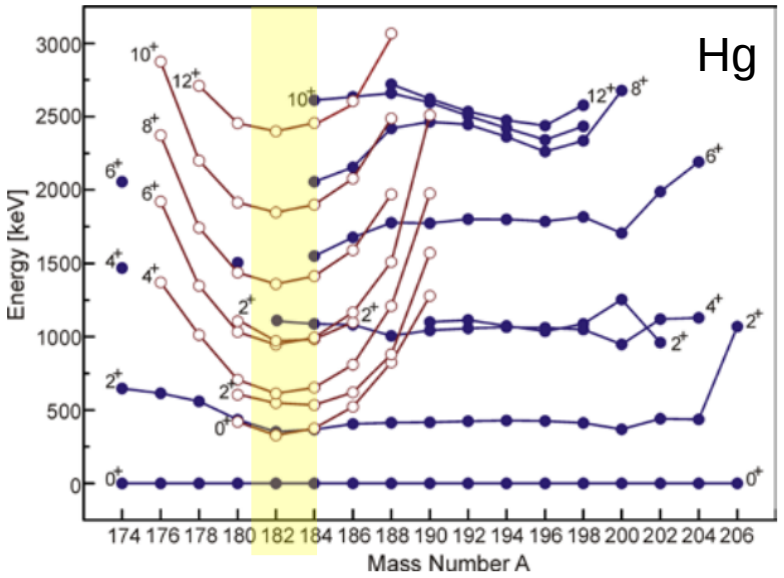
First experiment with MINIBALL after LS2

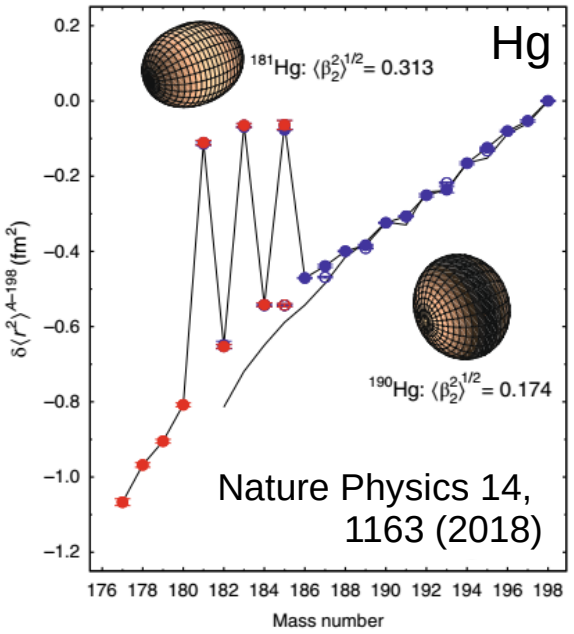


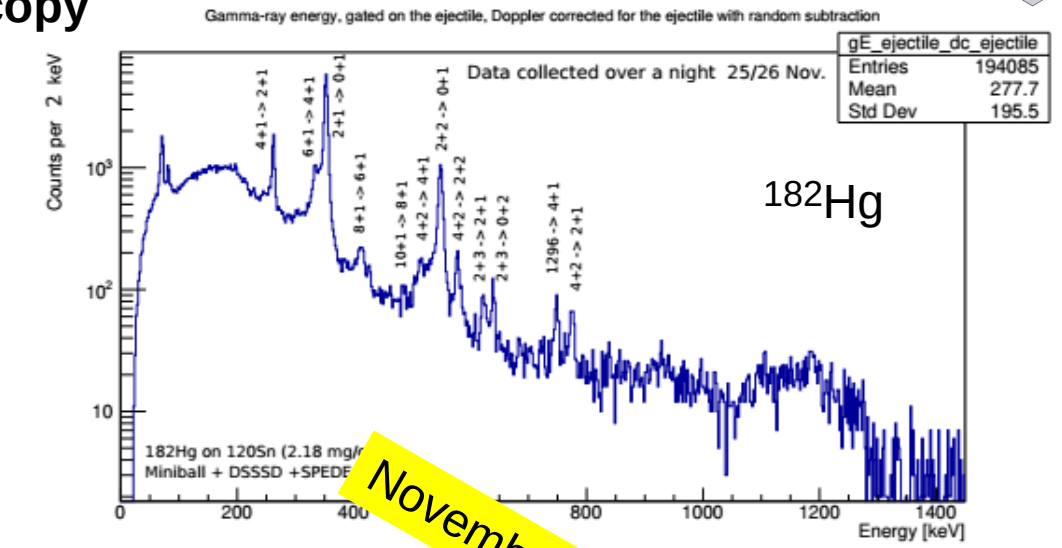
Value for ^{132}Sn from MINIBALL
PRL 121, 252501 (2018)

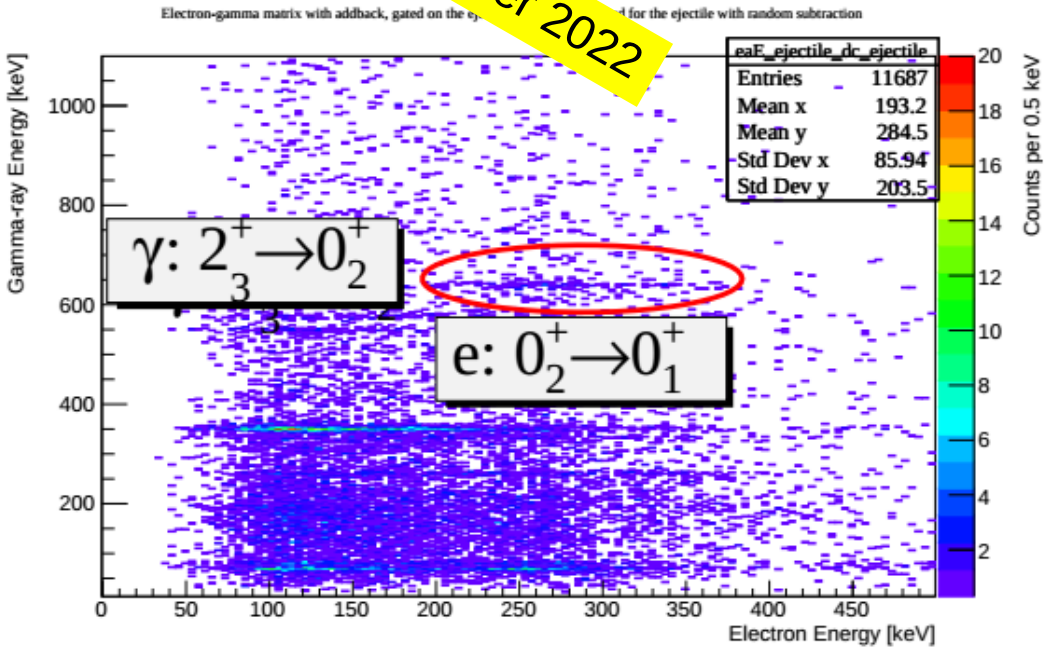
Shape coexistence in ^{182}Hg - Coulomb excitation @ HIE-ISOLDE

Investigated at ISOLDE in laser spectroscopy, decay spectroscopy (IDS) and in Coulomb excitation with MINIBALL at REX









Complementary information from „safe“ Coulomb excitation combining MINIBALL with conversion electron spectrometer

- **B(E2) values**
- **Q_2 values for short-lived states**

New in 2022 …
… in-beam conversion electron spectroscopy with SPEDE

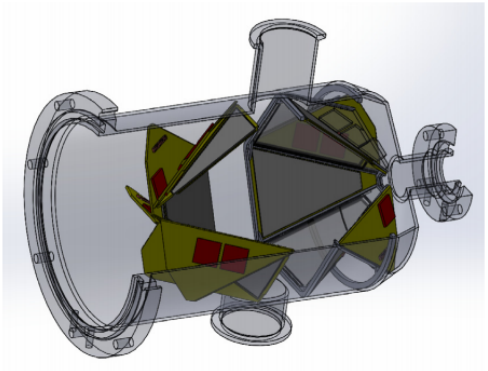
Nucleon-transfer reactions with MINIBALL+HI-TREX

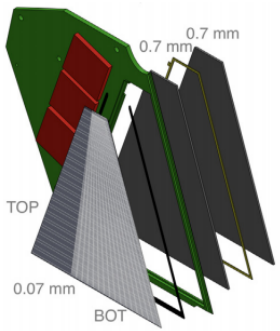
HI-TREX—A highly integrated transfer setup at REX-(HIE)ISOLDE

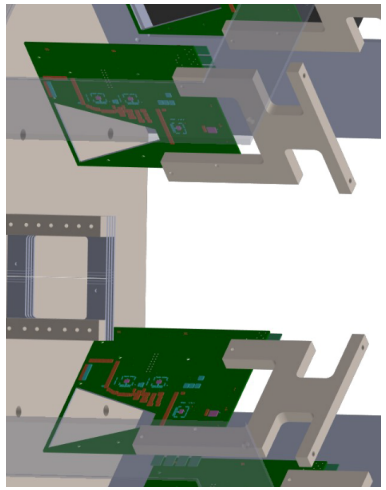
C. Berner [a,*], L. Werner [a], R. Gernhäuser [a], Th. Kröll [b]

Nuclear Inst. and Methods in Physics Research, A 987 (2021) 164827

… to meet conditions at HIE-ISOLDE with 10 MeV/u beam energy and heavy ions for (d,p), (t,p) etc. reactions

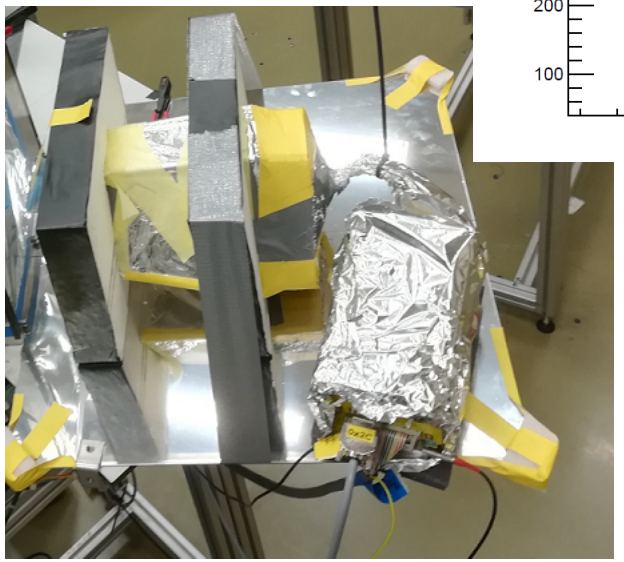


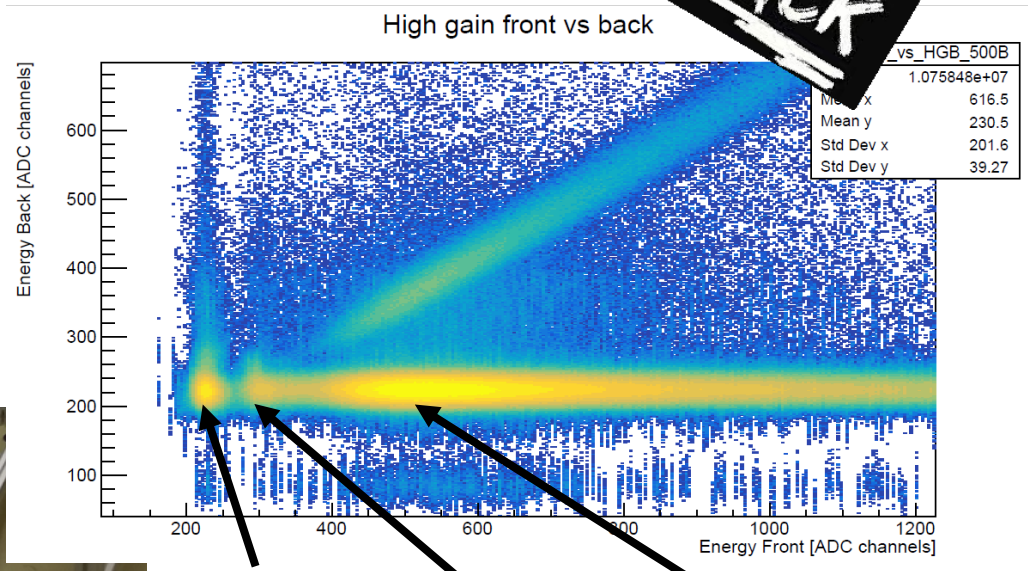




2 x 2 DSSDs
128 x 32 strips
TRB + Skiroc readout

Test with proton beam
@ CCB, Kraków





Baseline

Trigger Threshold
around 80 keV

400 keV

Ready for experiments
at HIE-ISOLDE in 2024

Perspektiven mit ISOLDE: Status und langfristige Vision

- **breites und vielfältiges Forschungsprogramm**
- **nutzt die weltweit einzigartige Vielfalt radioaktiver Isotope als**
  - Niederenergiestrahlen
  - nachbeschleunigte Strahlen bei HIE-ISOLDE
  … viele Synergien und Komplementaritäten beider „Welten“
- **ständige Verbesserung von Methodik, Instrumentierung und Analysetechniken**
- **hohe Sichtbarkeit der deutschen Forschergruppen bei ISOLDE**
- **starke Einbindung von Nachwuchswissenschaftler*innen**
- **Aufbau und Erhalt von experimenteller Expertise**
- **Synergien und Komplementaritäten mit FAIR**