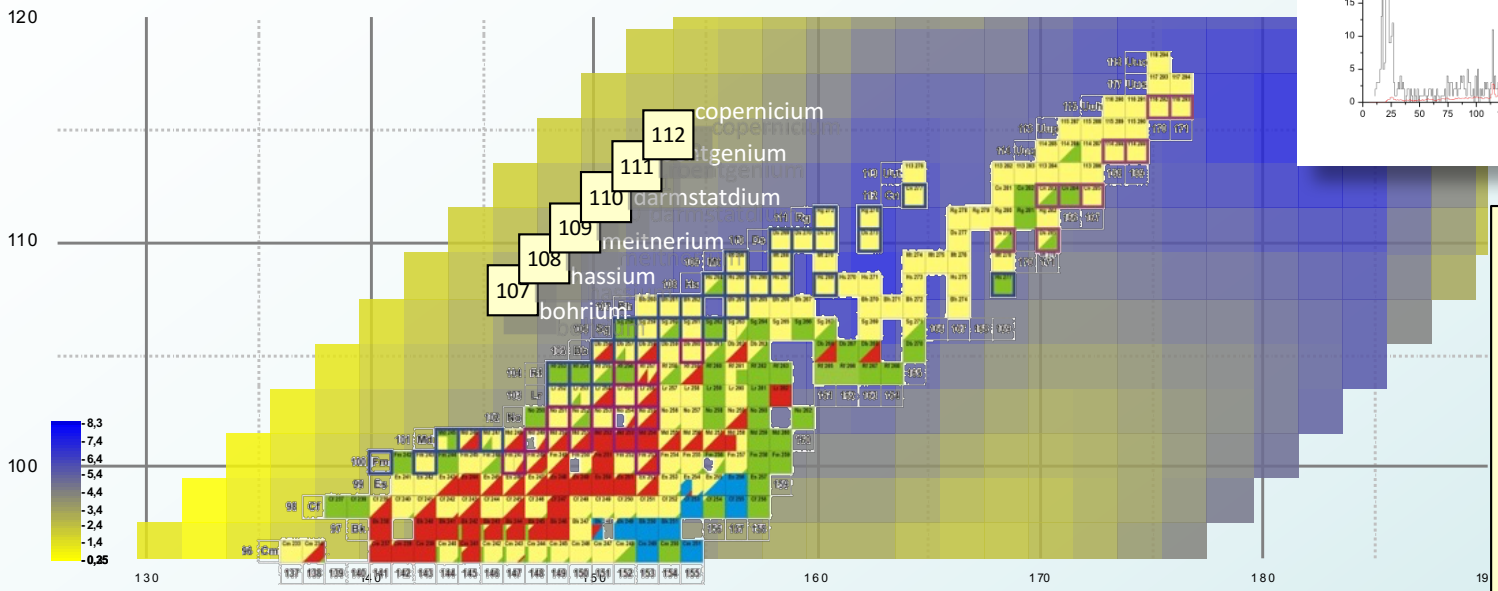
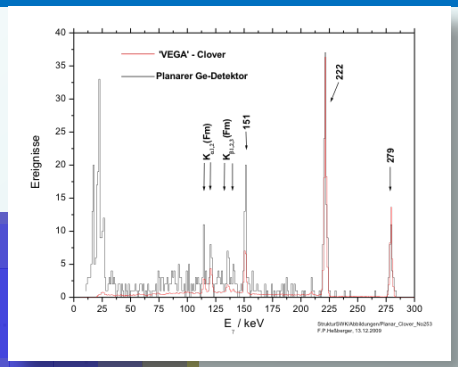
First Physics with the Super Separator Spectrometer S3

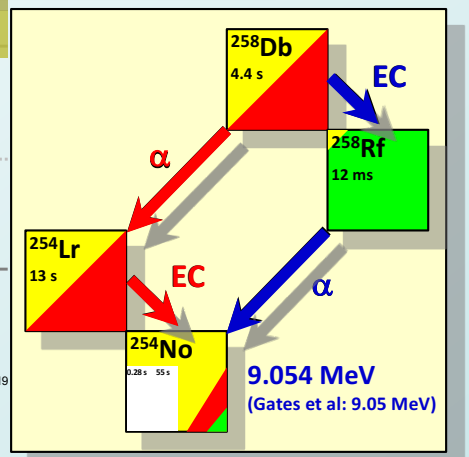
March 27-30 2017
CEA Saclay, Orme des Merisiers

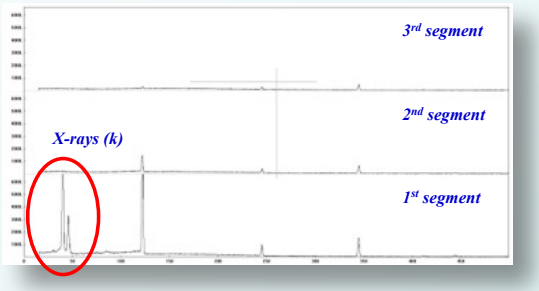
X-ray tagging

– for heavy and superheavy nuclei









Dieter Ackermann

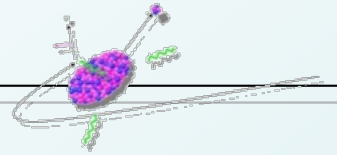
GANIL spiral2

Caen, France

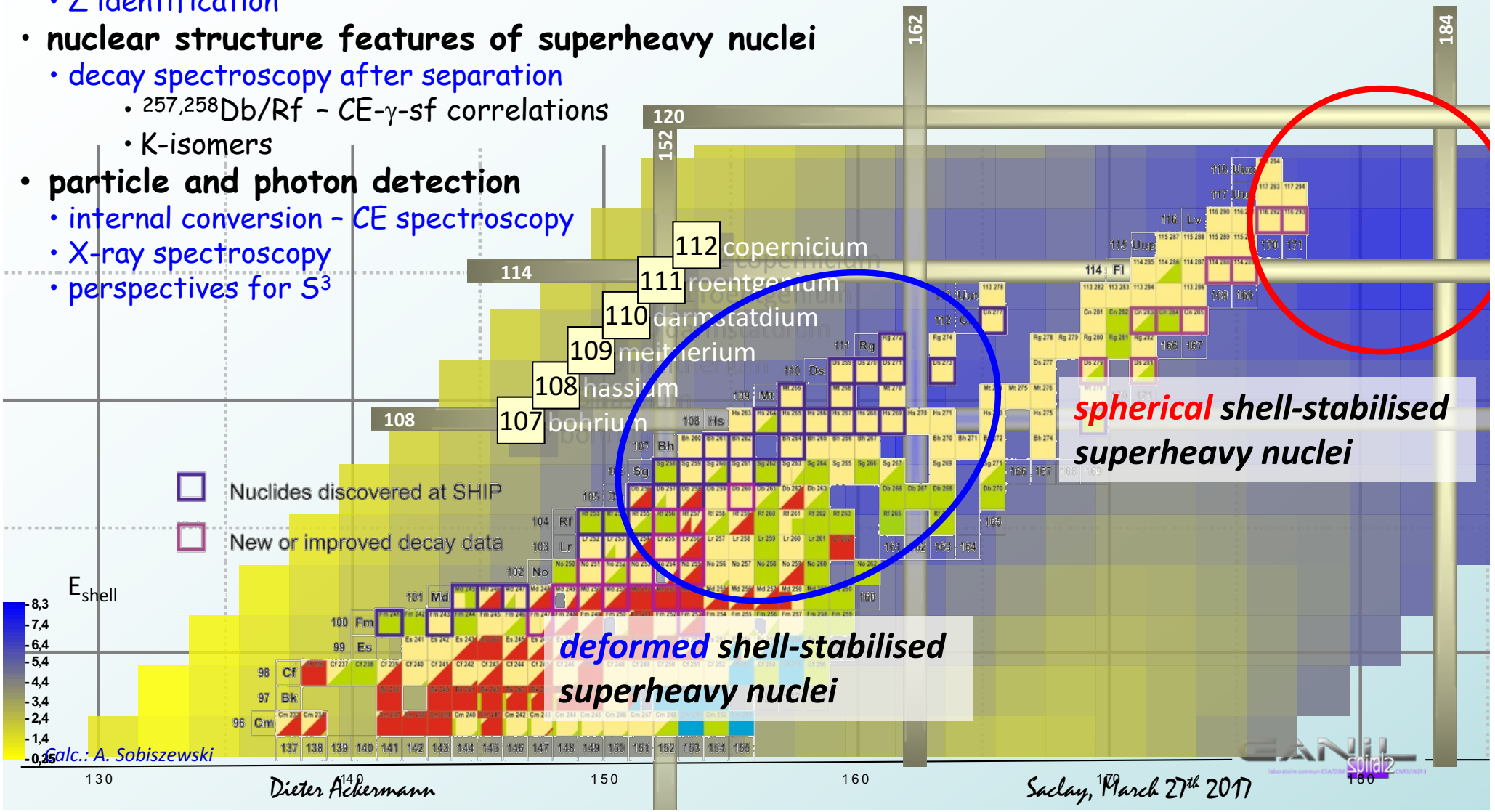
Saclay, March 287th 20167

SHN – decay spectroscopy at GSI and GANIL

- outline



- **challenges of SHE research**
  - extremely low x-sections
  - unconnected chains for hot fusion (Z=114 to118)
  - Z identification
- **nuclear structure features of superheavy nuclei**
  - decay spectroscopy after separation
    - ^{257,258}Db/Rf – CE-γ-sf correlations
    - K-isomers
- **particle and photon detection**
  - internal conversion – CE spectroscopy
  - X-ray spectroscopy
  - perspectives for S^3



Confirmation of FLNR Results

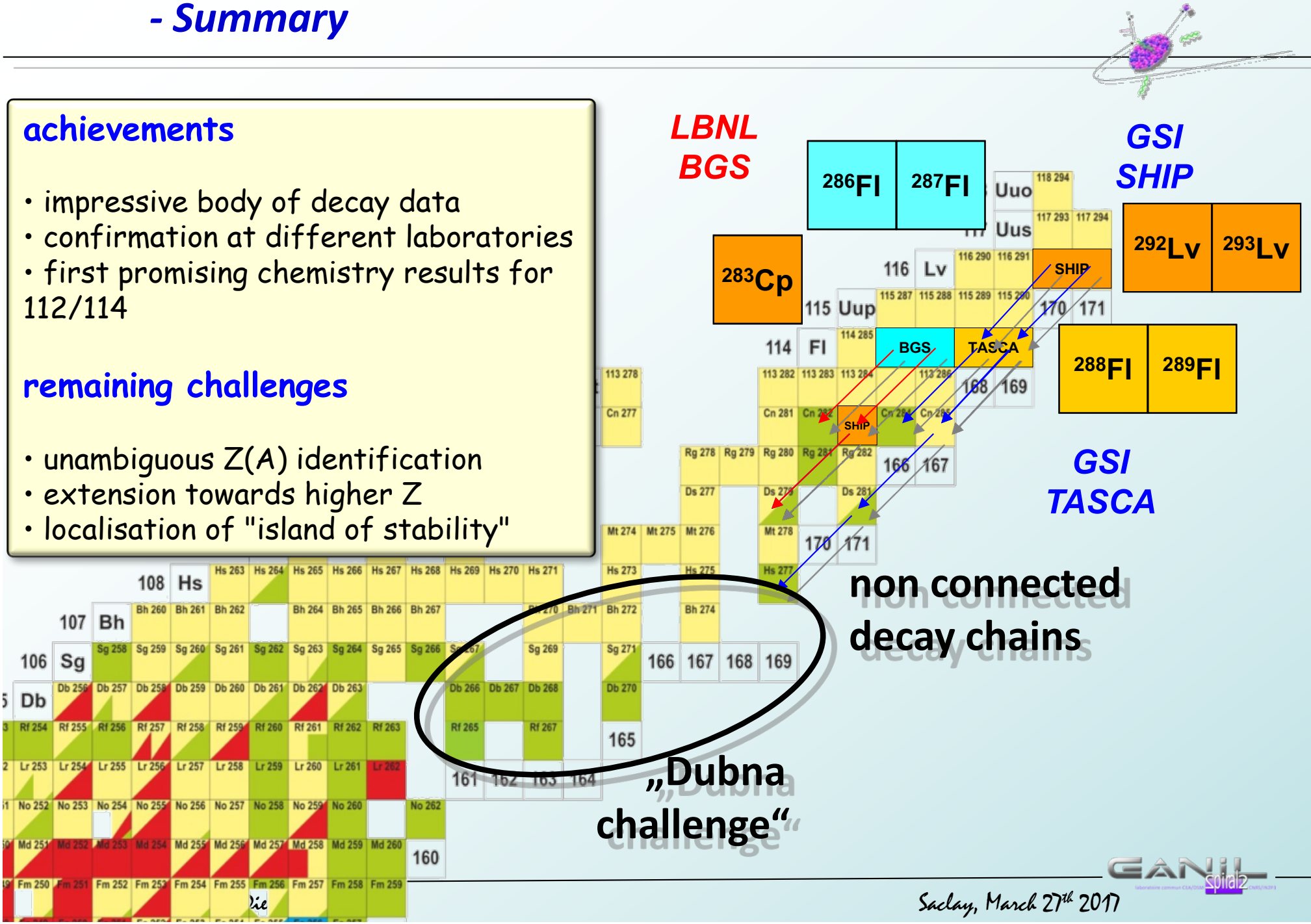
- Summary

achievements

- impressive body of decay data
- confirmation at different laboratories
- first promising chemistry results for 112/114

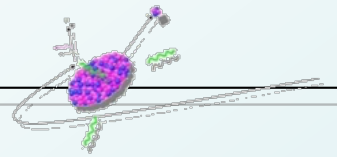
remaining challenges

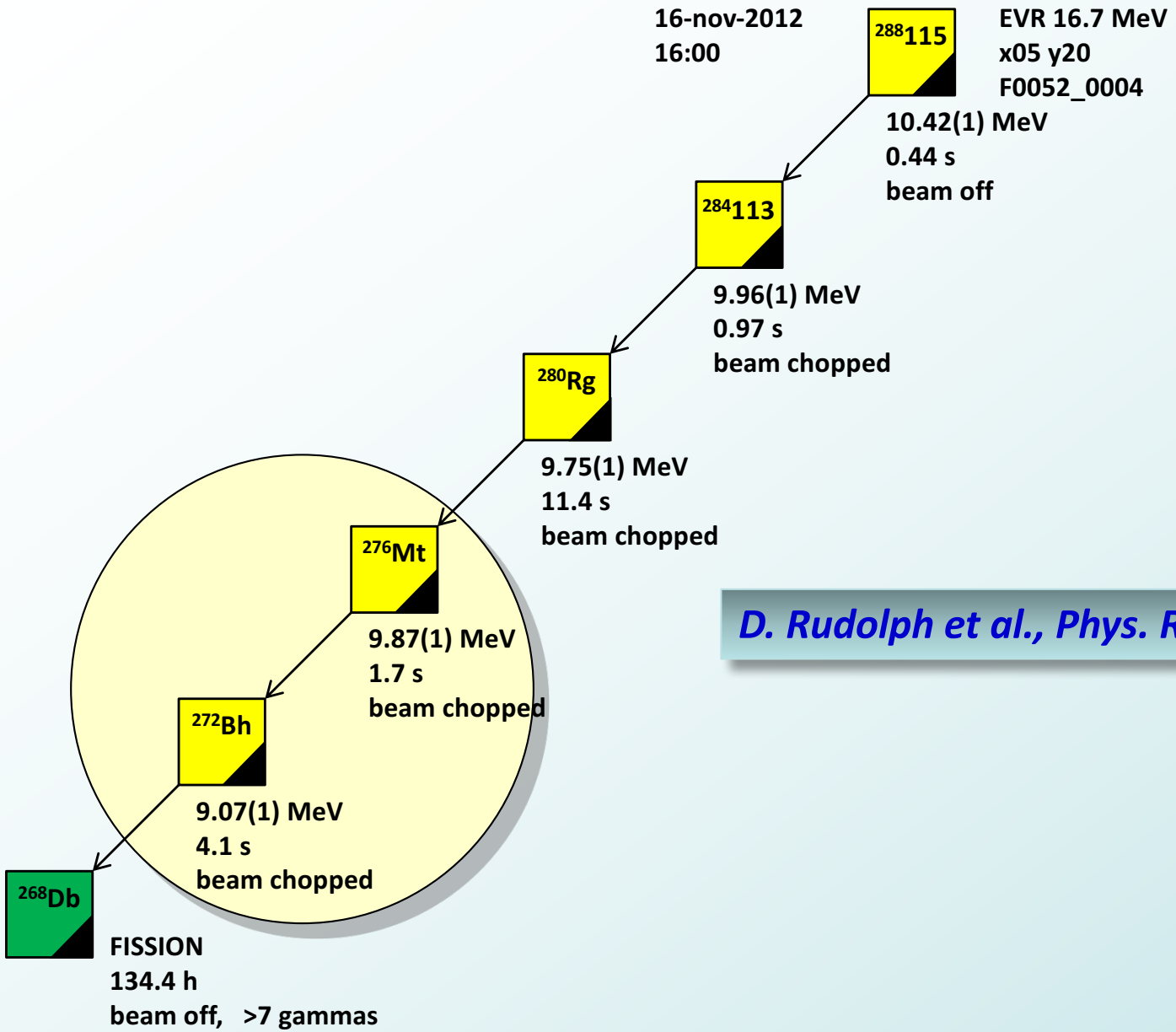
- unambiguous Z(A) identification
- extension towards higher Z
- localisation of "island of stability"



Z=115 X-ray measurement with TASiSpec

- E115 Chain

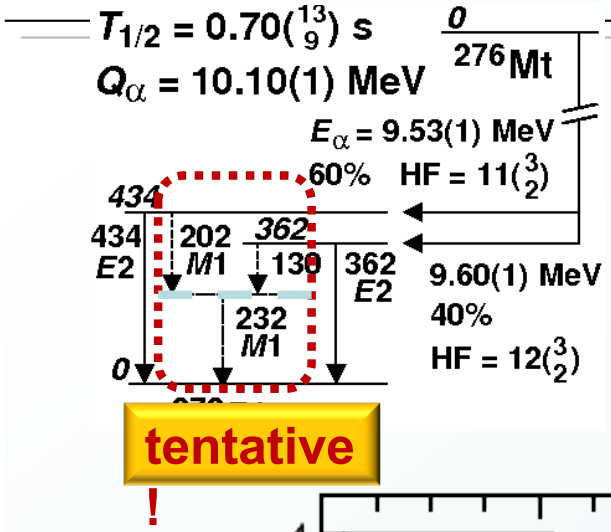




D. Rudolph et al., Phys. Rev. Lett. 111, 112502

courtesy of Dirk Rudolph

Results – $^{288}115$ (3n-chain)



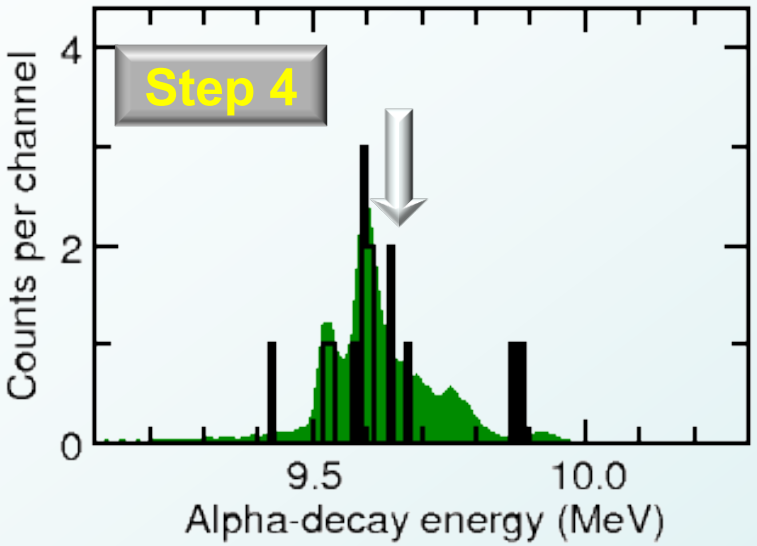
X-ray Case?

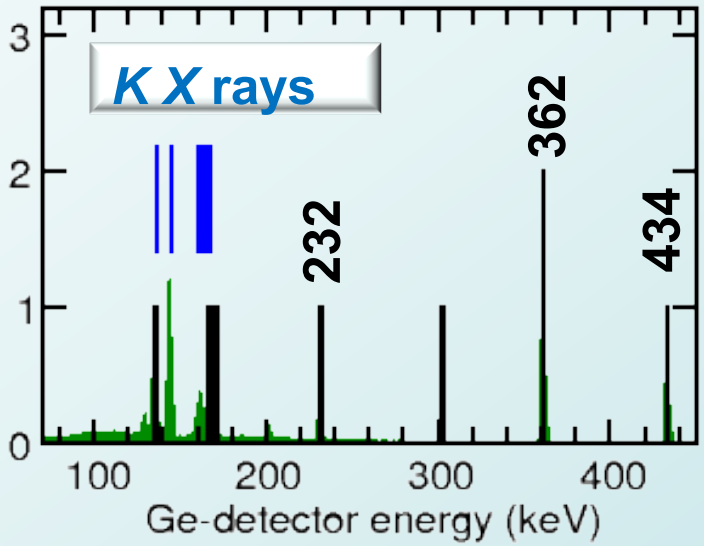
$^{276}Mt \rightarrow {}^{272}Bh$

Chain 1: E_α = 0.825(3) MeV
E_{ph} = 136(1) keV
E_{ph} = 167(1) keV

cascade (of 2 *K X* rays?)

8x α-photon coincidences



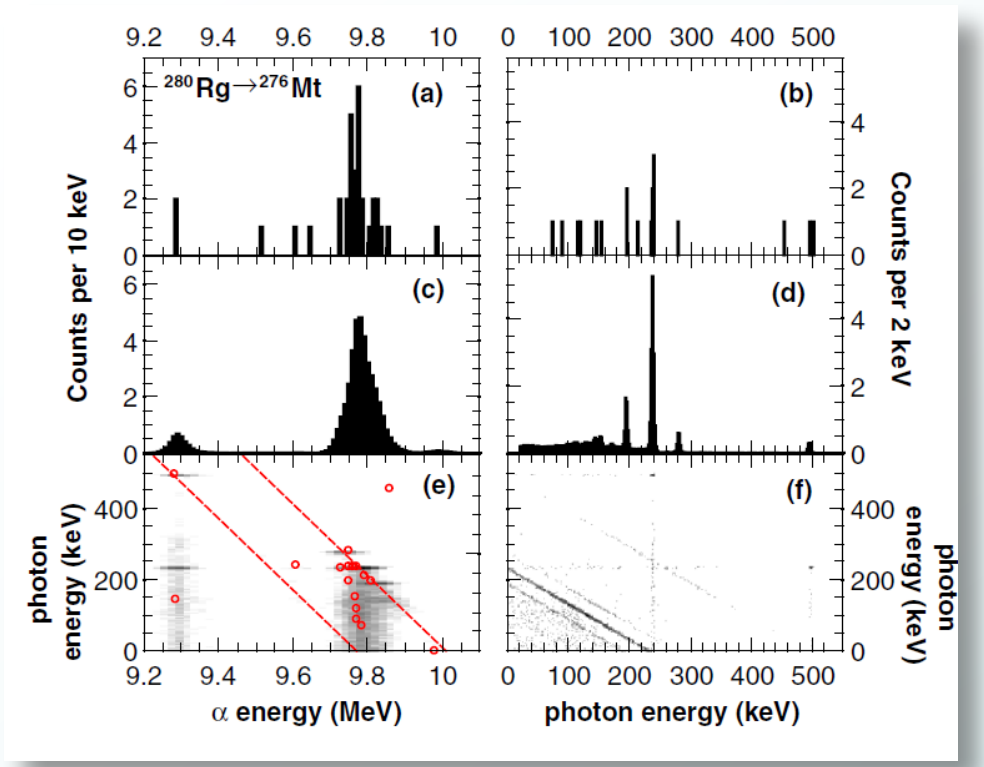


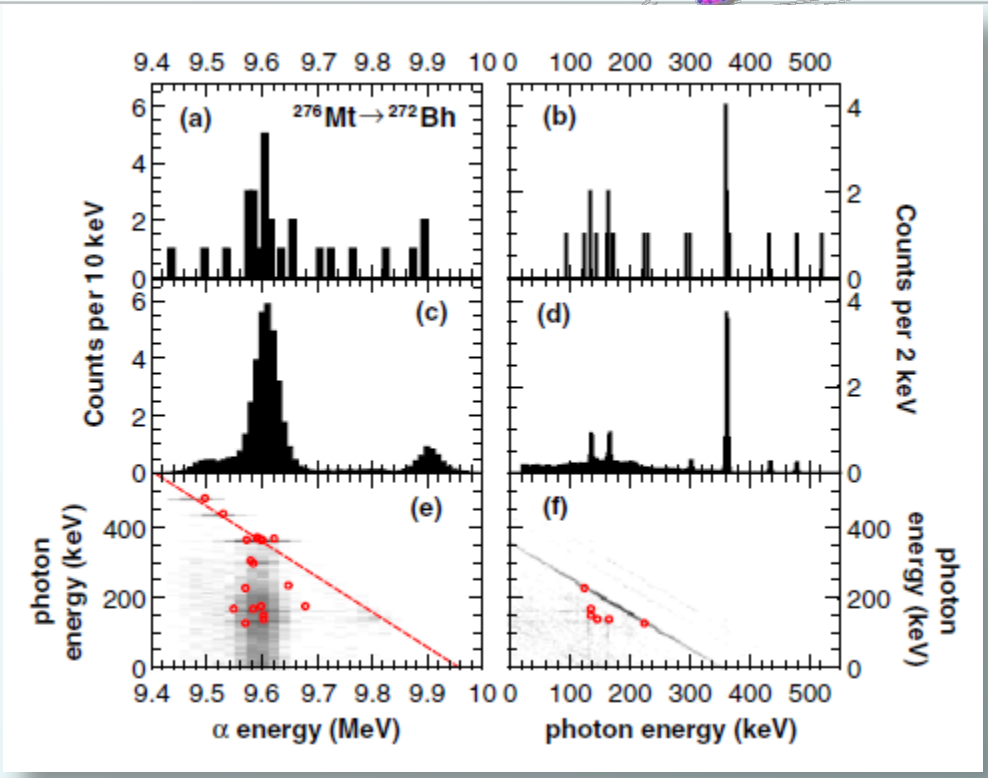
GEANT4 simulations: 100000 decays, normalized to number of α's

courtesy of Dirk Rudolph

X-ray spectroscopy, Z=115

- analysis by simulation - J. Gates et al., PRC 92, 021301 (R) 2015





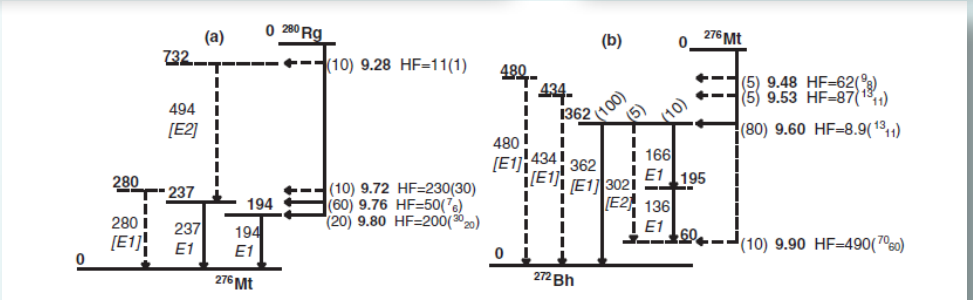
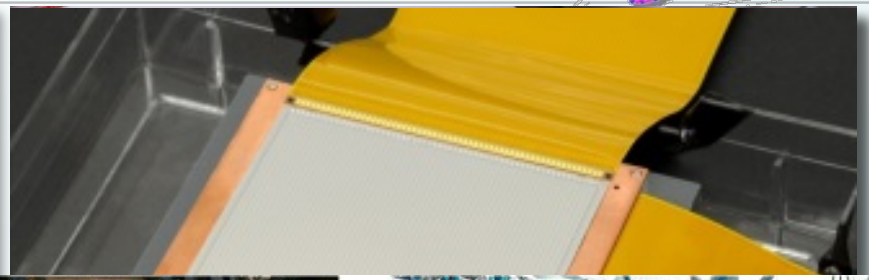
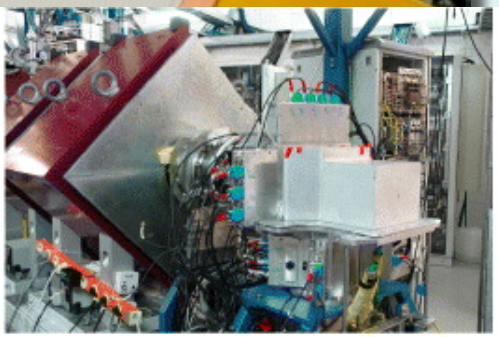


FIG. 2. Proposed level schemes for the decay of (a) ^{280}Rg → ^{276}Mt and (b) ^{276}Mt → ^{272}Bh. Firmly established levels and transition energies are solid lines, and tentative levels and transition energies are dashed lines. Bold numbers represent energy of a given level, numbers in parentheses are relative α-decay populations of a given level or photon intensity from that level. Labels to the left of the vertical arrows indicate the energy and multipolarity of a given transition. Multipolarities that were not experimentally determined and, therefore, assumed for purposes of generating the simulated spectra, are in square brackets. Derived hindrance factors $HF = T^{exp}_{1/2}/T^{sys}_{1/2}$, where experimental half-lives of ^{280}Rg and ^{276}Mt were calculated to be $4.1(^{5}_{4})s$ and $0.63(^{9}_{7})s$, respectively, using data from the LBNL experiment and Refs. [9,22] and $T^{sys}_{1/2}$ was calculated according to Ref. [28].

Mobile Decay Spectroscopy Set-up – MoDSS for SHE research

- Si stop+box (DSSD+SSSD) combined with large volume Ge-detectors





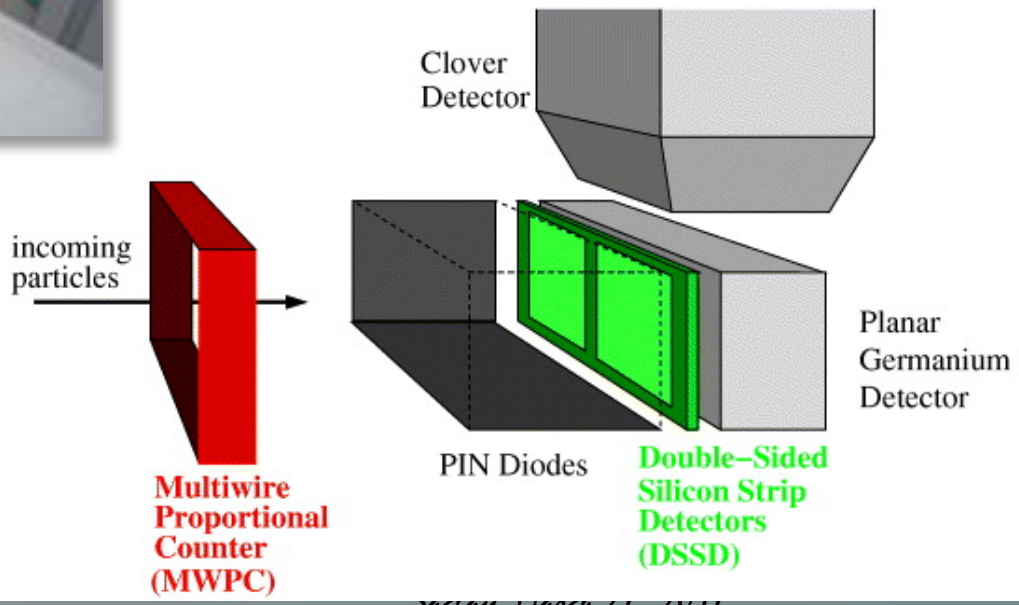
- *Al-cap with thin γ window (1,5 mm)*
- *compatible due to 150 mm standard flange*

DSSD

- *integrated cooling (Cu-frame) and connection (flex-PCB)*
- *60×60 strips/mm (pitch 1 mm)*
- *300 µm*

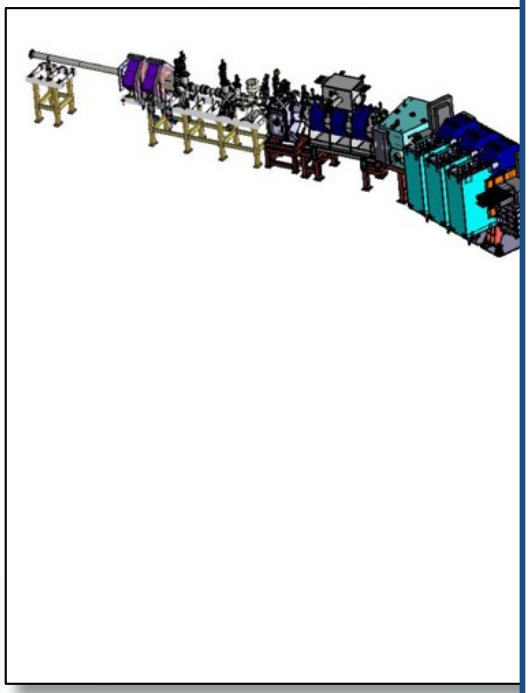
electronics (partly integrated in the vacuum)

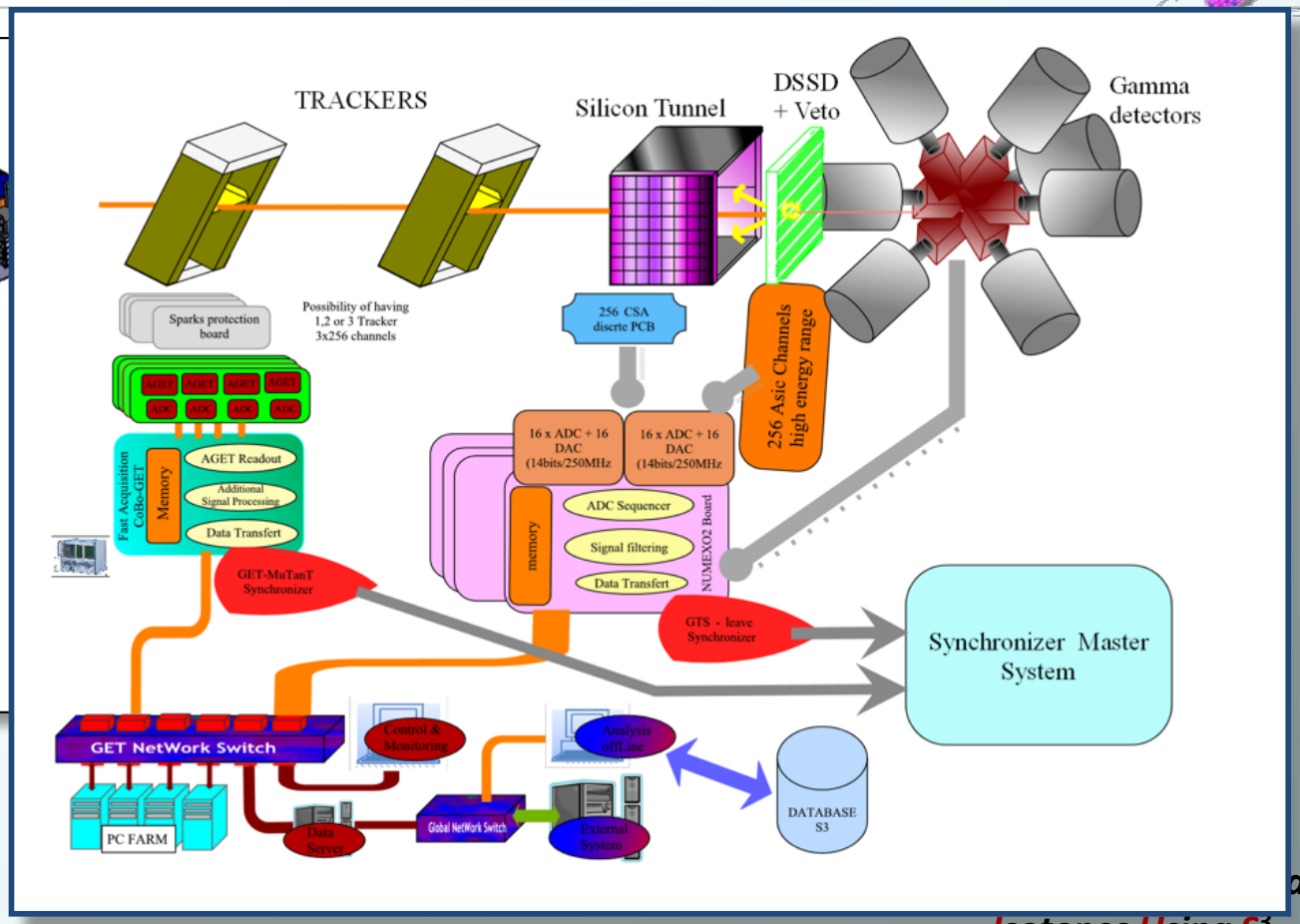
- *analog and digital (FEBEX) options*



SHN research at SPIRAL2/GANIL

- decay spectroscopy at S³





...are

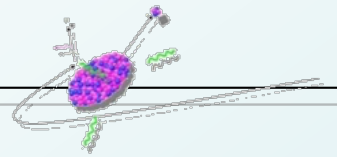
Isotopes Using S³

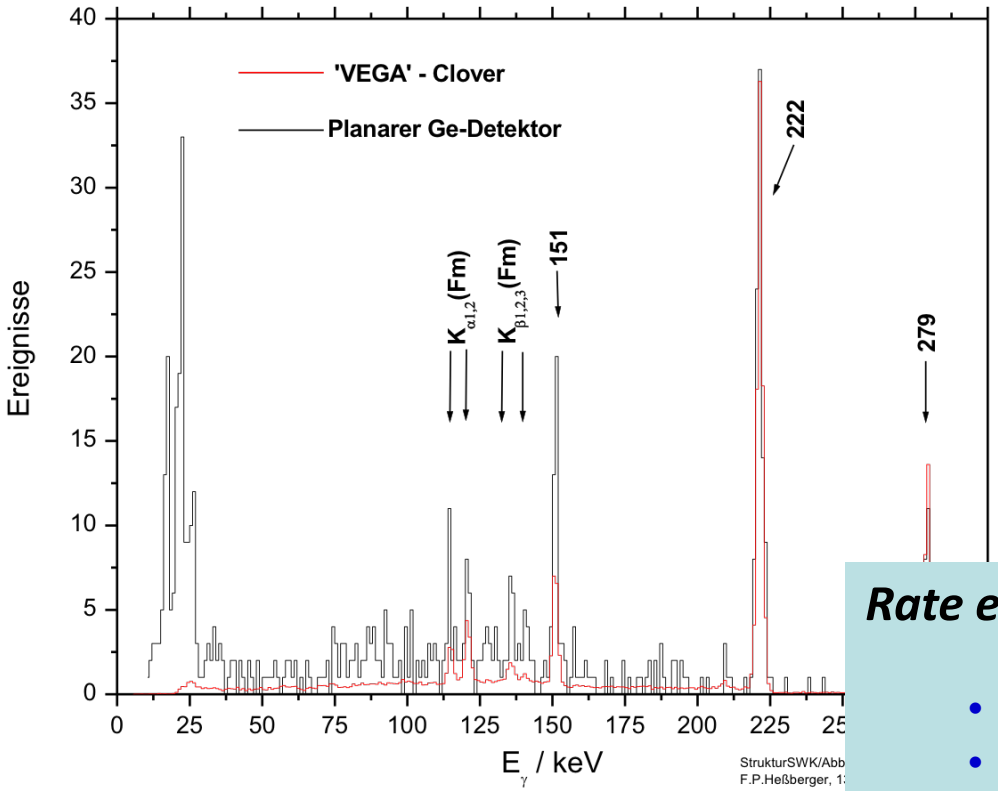
comprehensive focal plane detector setup SIRIUS

- *trackers for ToF and veto*
- *Si detector array for charged particle detection*
  - *ER, α's, e⁻*
- *photon detector array*
  - *γ's, X-rays*

X-Ray spectroscopy

- comparison clover outside/planar inside vacuum





α-γ coincidence spectra for ^{253}No (^{48}Ca + ^{207}Pb → ^{255}No*)

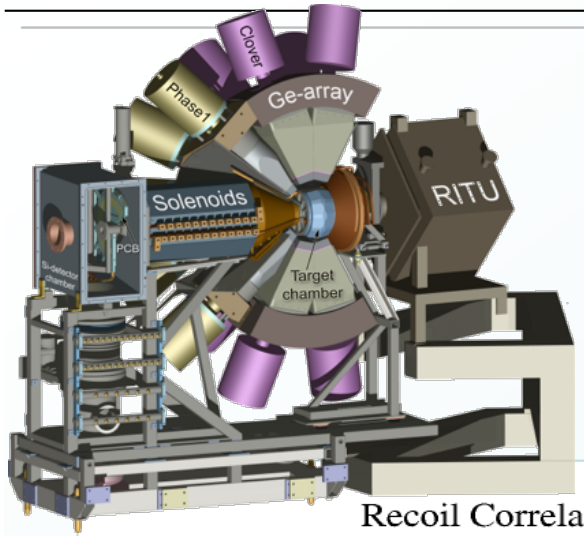
- normalized on 222 keV transition
- ratio L/K X-rays: ≈ 100

Rate estimate for ^{288}115

• I_{beam}	2 pμA
• S3 transmission	50%
• production cross section	≈10 pb
• expected rate:	≈0.005 ER/min
	≈0.3 ER/h
• integral for 21 UT	≈50 ER
• integral for 21 UT	≈300 L X-rays

X-ray spectroscopy

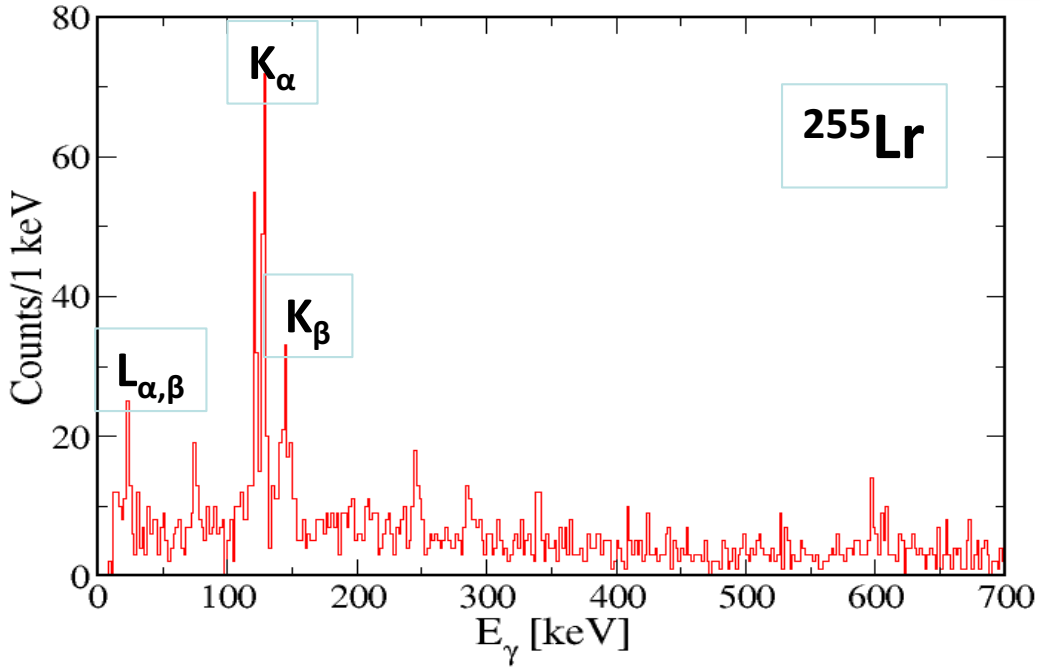
- further perspectives: detection at the target position?



recoil-e^--γ coincidence spectra for ^{255}Lr

- clean X-ray detection of the ER
- problem: rate limitation presently:
  70 particle nA
- possible rate reduction for thin planar Ge detectors

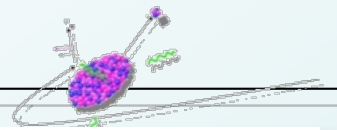
Recoil Correlated Gamma-ray Spectrum



courtesy of Mikael Sandzelius, JYFL

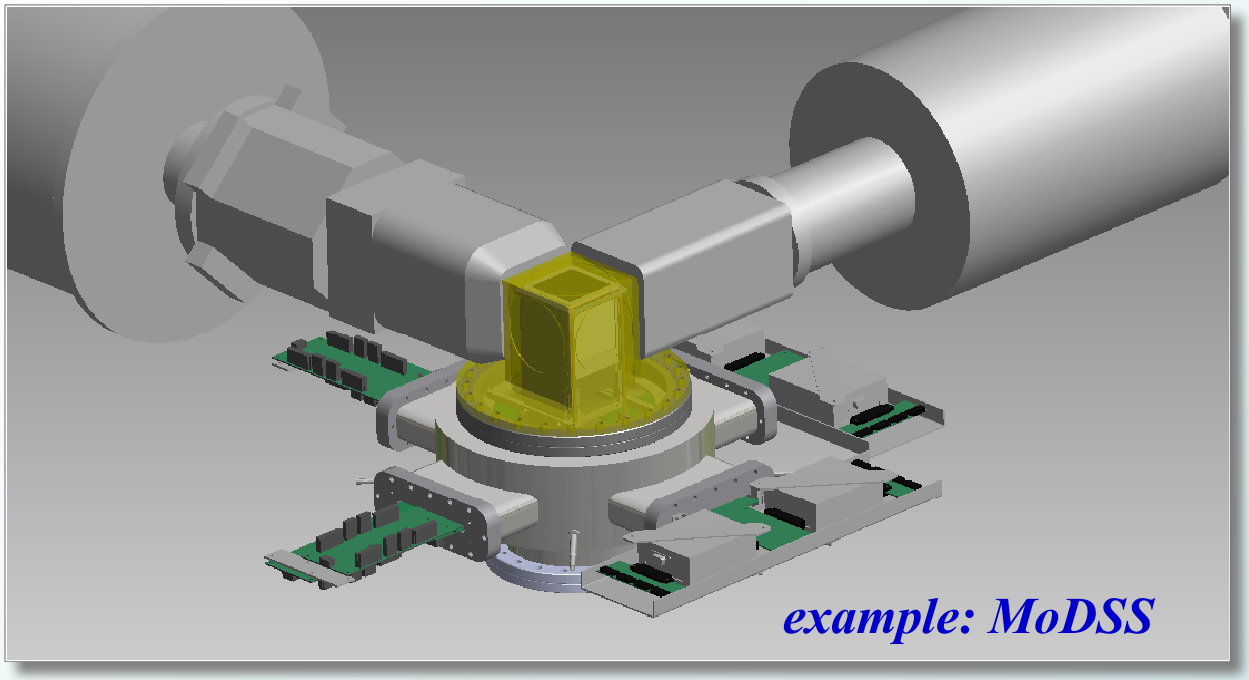
Particle – X-ray - γ telescope

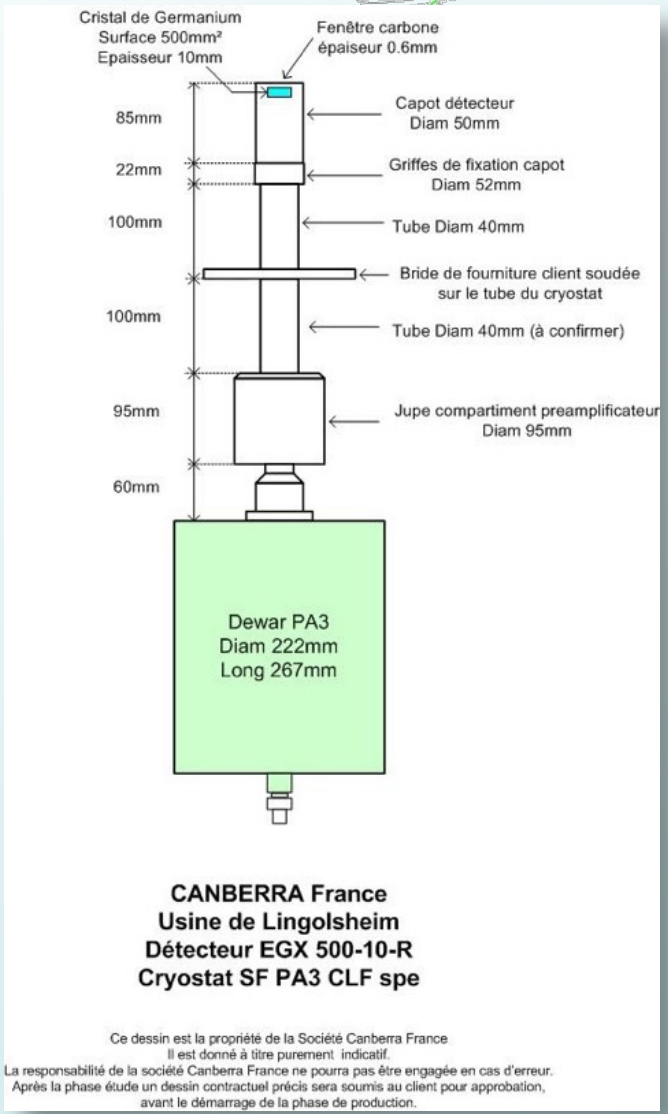
- particle and photon detection at the same time



modification of a compact silicon-germanium array:

- *combined particle and photon detection in vacuum/ separated by a thin window (Be, C?) instead of a few mm of aluminium*

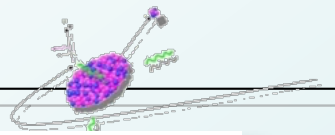




courtesy of Maurice Morjean, GANIL

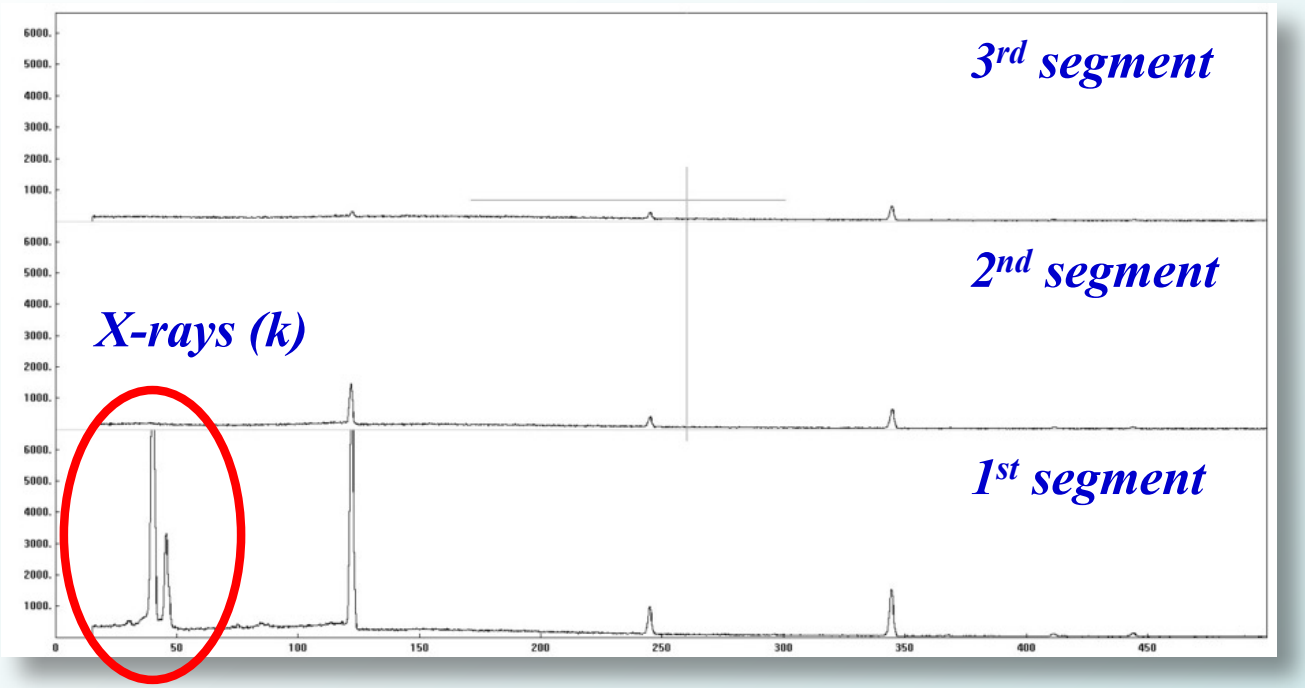
Particle – X-ray - γ telescope

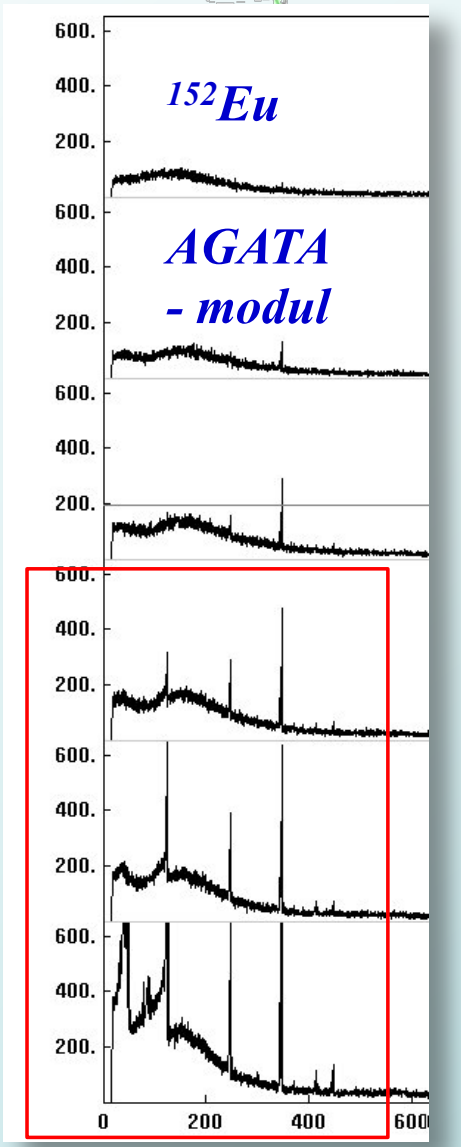
- particle and photon detection at the same time



modification of a compact silicon-germanium array:

- *combined particle an photon detection in vacuum/ separated by a thin window (Be, C?)*
- *possible alternative solution: segmented Ge (e.g. AGATA)*

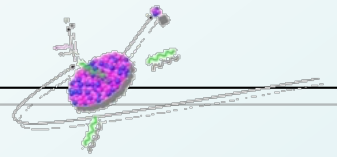




courtesy of Emanuel Clement, GANIL

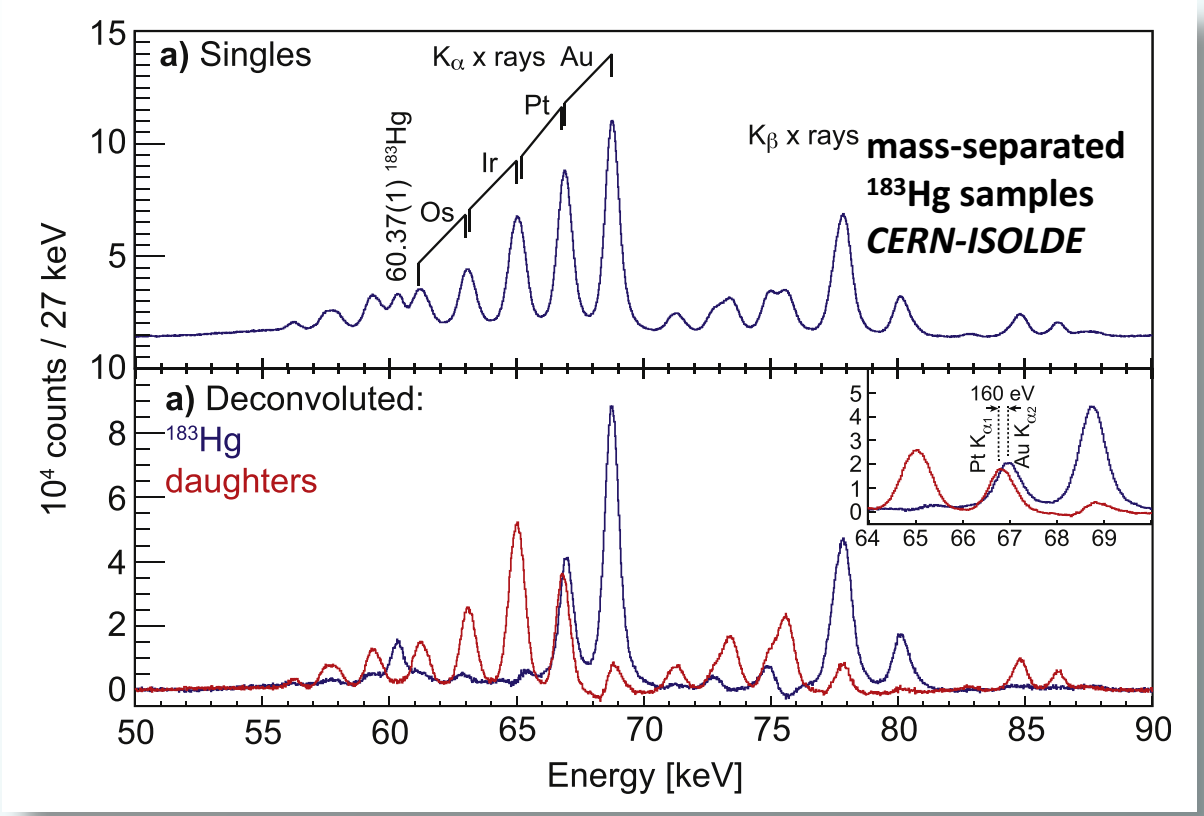
X-ray - detection

- alternative: BEGe detectors



Broad Energy germanium detectors (BEGe):

- *high resolution*
- *low energy threshold*
- *∅ 51 mm/20 mm thickness*



M. Venhart et al.,
NIM A 849 (2017) 112–118

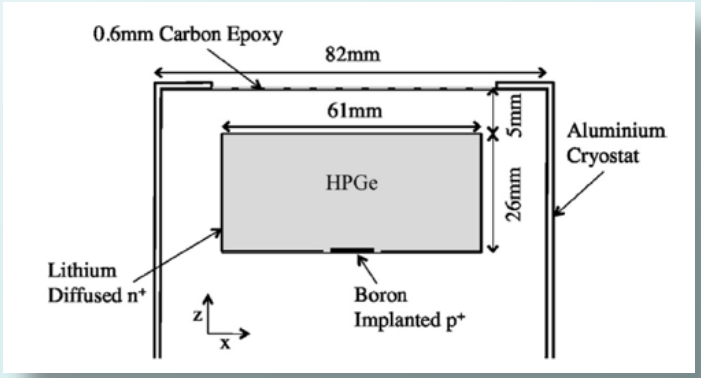
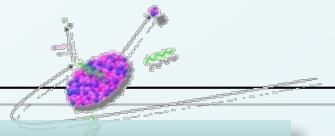


Fig. from:
L.J. Harkness-Brennan, NIM A 760 (2014) 28-39

X-ray - detection

- alternative: Si(Li) detectors



Large-Volume Si(Li) Compton Polarimeter

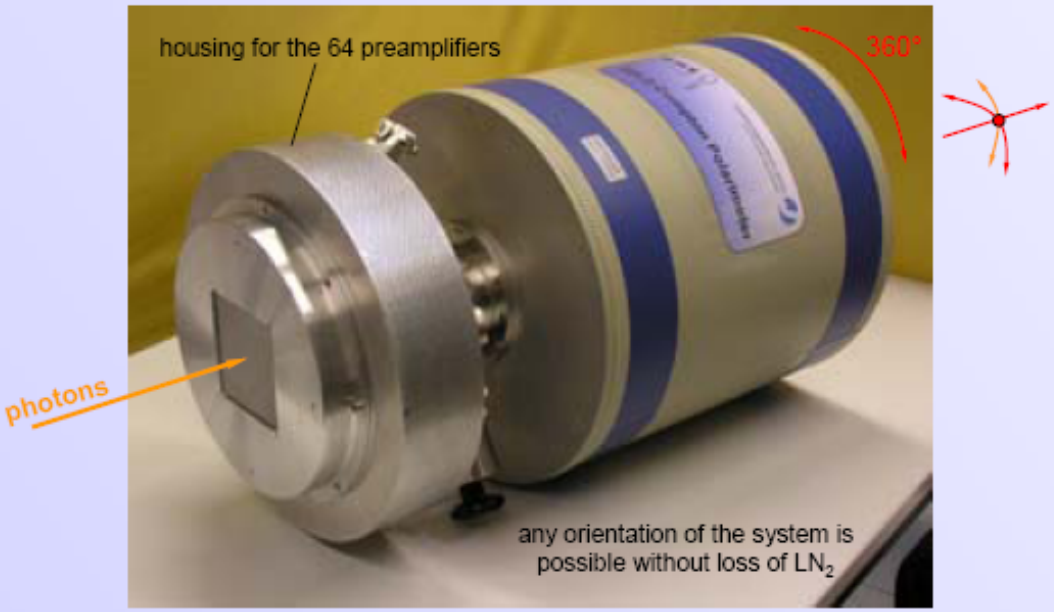
D. Protić, T. Krings, I. Mohos, Forschungszentrum Jülich, Institut für Kernphysik (IKP), Jülich, Germany
Th. Stöhlker, U. Spillmann, Gesellschaft für Schwerionenforschung (GSI), Darmstadt, Germany

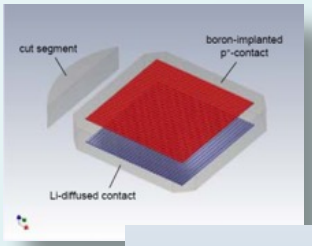
for the SPARC collaboration

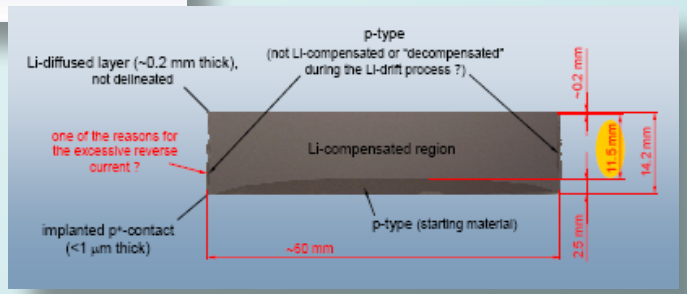
Position sensitive large volume/area Si(Li) detector:

- *double-sided strip configuration*
  - *64×64 mm*
  - *32×32 strips (→ 2mm pitch)*
  - *14 mm thickness*
- *original application: Compton polarimeter for X-ray spectroscopy of highly-charged ions at GSI, Darmstadt*

Cryostat + dewar



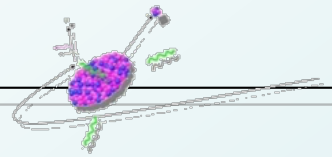




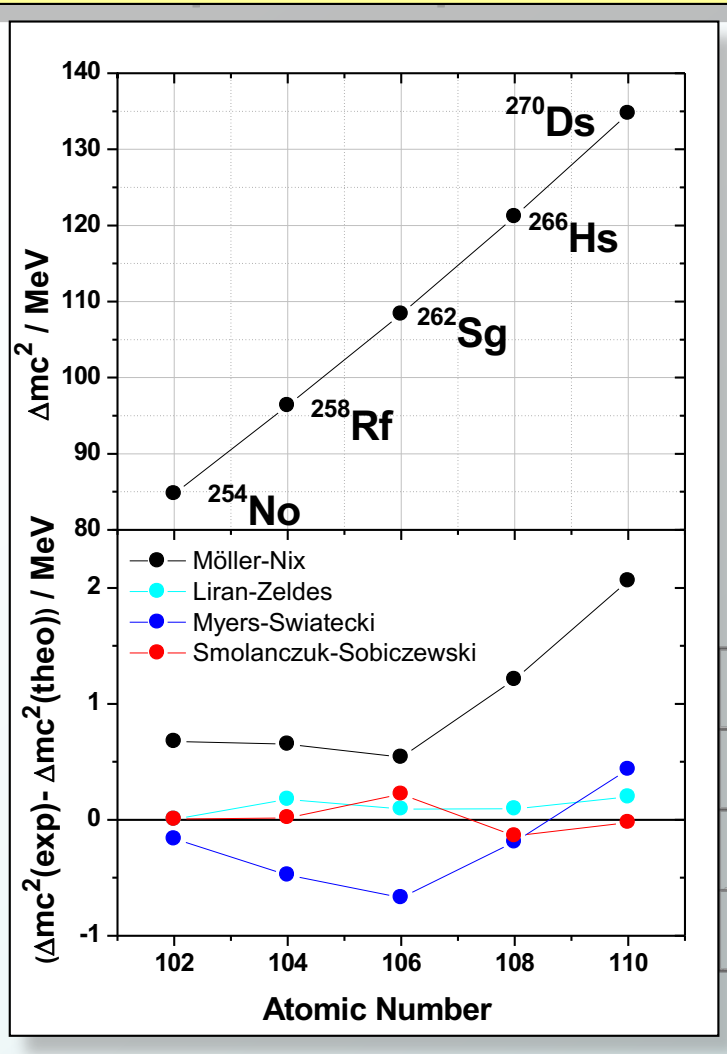
https://www.gsi.de/en/work/research/appamml/atomic_physics/research/ap_und_fair/sparc/working_groups/photon_detector_development.htm

^{270}Ds

– ^{266}Hs sf-branch - ^{262}Sg α-branch → link to ^{254}No



- 26 decay chains (^{270}Ds: 25, ^{271}Ds:1)
- new spectroscopic data



E_α = (10.897–12.116) MeV

$T_{1/2}$ = 100 µs, 6.0 ms *

^{270}Ds ^{271}Ds

^{266}Hs

new fission branch and K-isomer in ^{266}Hs

10.205 MeV
2.3 ms *

^{262}Sg

α-decay link ^{262}Sg → ^{258}Rf

9.453 MeV
6.9 ms

^{258}Rf

^{254}No

→J. M. GATES et al. PRC 77, 034603 (2008)

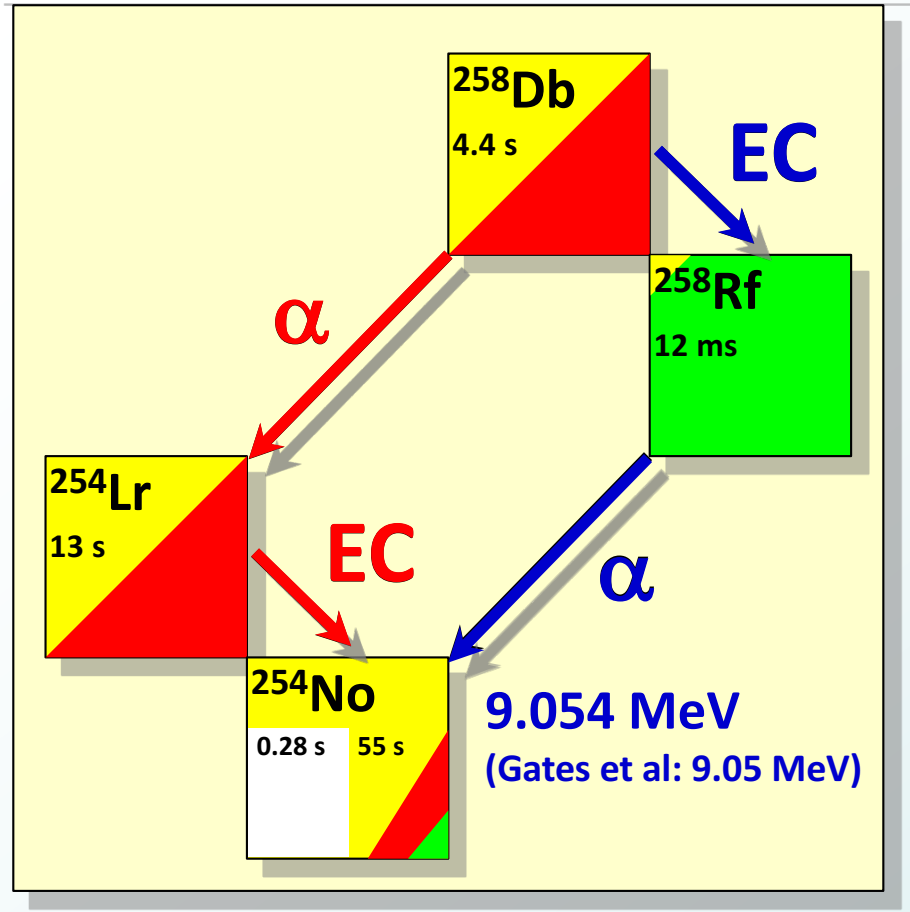
→ new data from ^{258}Db EC dacay (SHIP 2014)

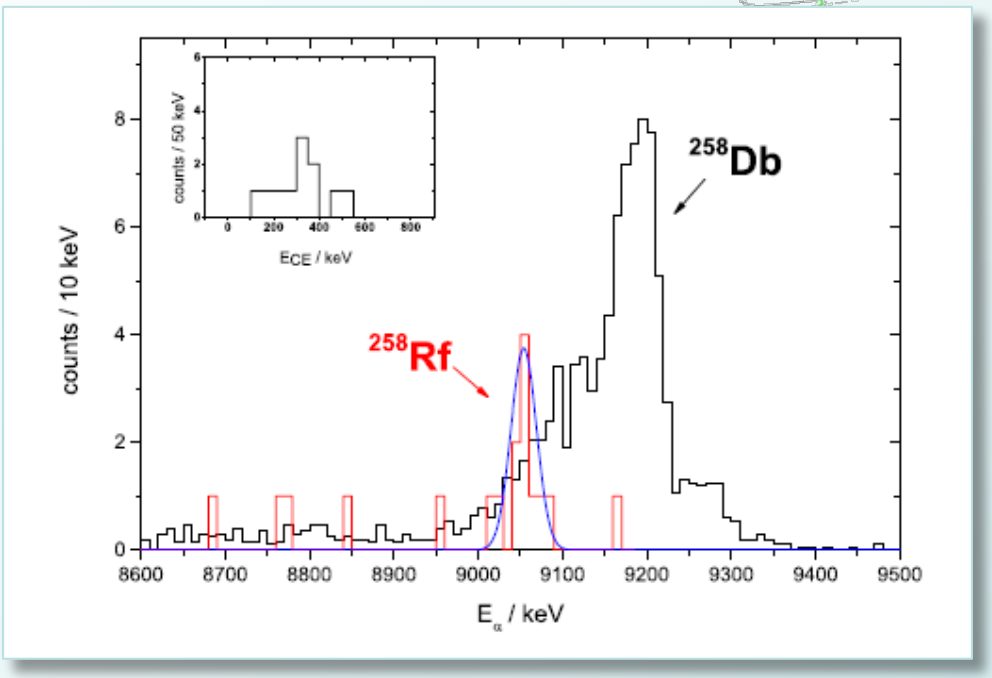
D. Ackermann, Special Issue SHE of Nuclear Physics A 944 (2015) p.376–387

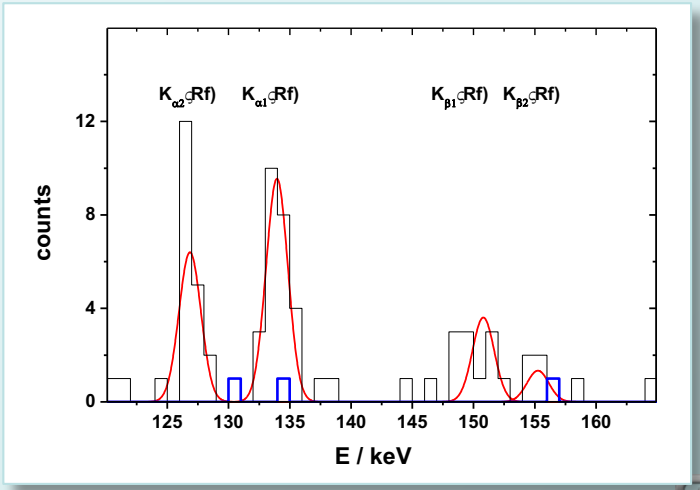
* $T_{1/2}$ from *S. Hofmann et al., Eur. Phys. J. A 10, 5 (2001)*

^{258}Db decay at GSI/SHIP in May 2014

– ^{50}Ti + ^{209}Bi → ^{258}Db + 1n



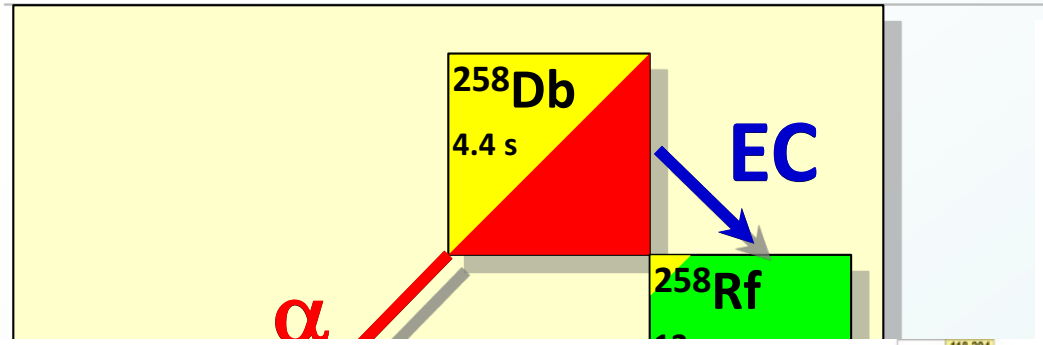


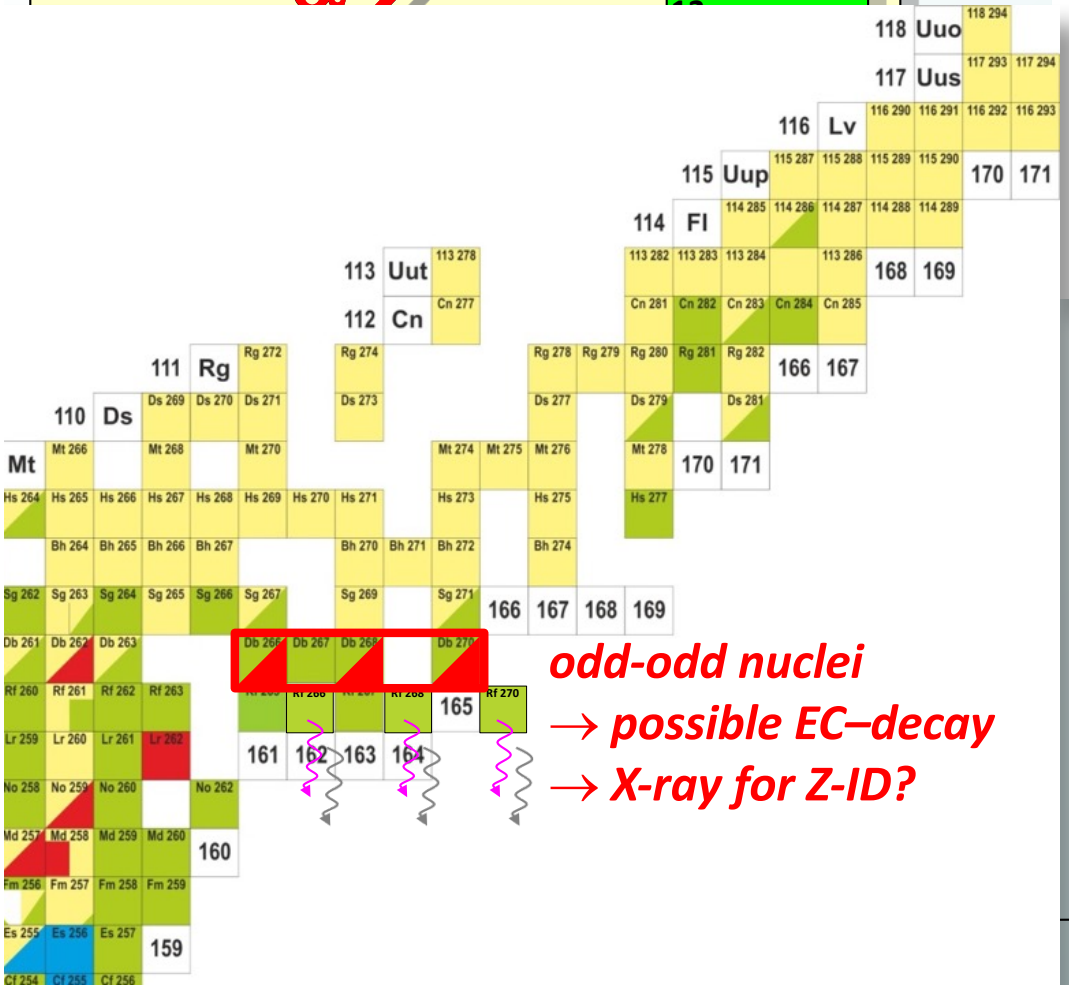


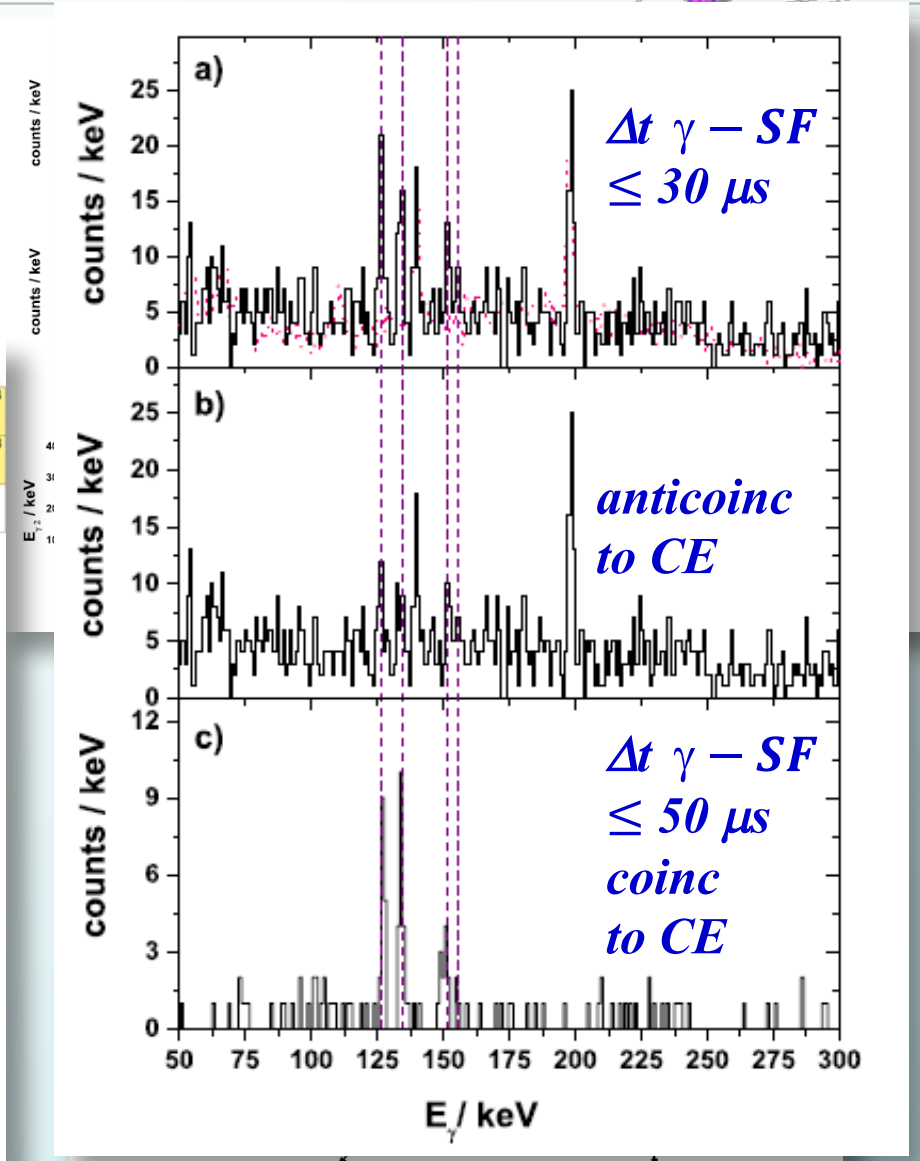
F.P Heßberger et al., Eur. Phys. J. A (2016) 52: 38

^{258}Db decay at GSI/SHIP in May 2014

– ^{258}Rf SF-γ coincidences

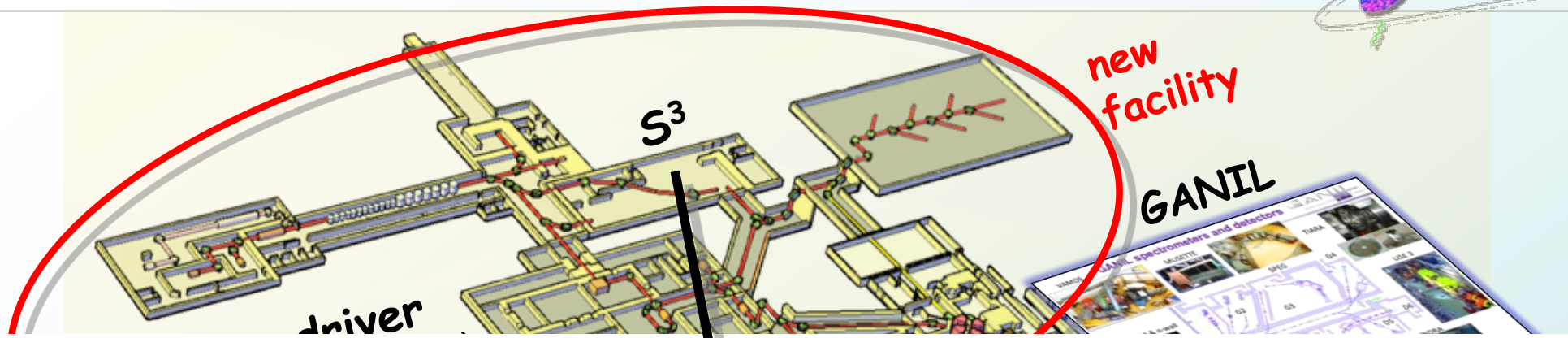


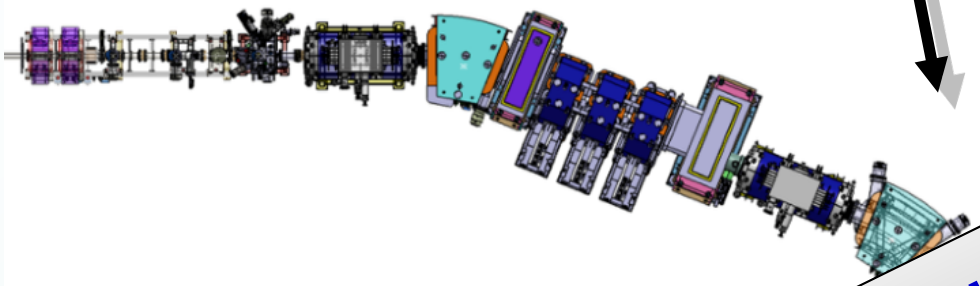




GANIL-SPIRAL2 facility

Caen, Normandy, France





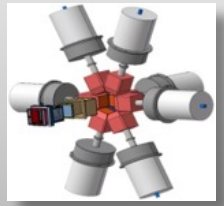
S3 Super Separator Spectrometer - Ph

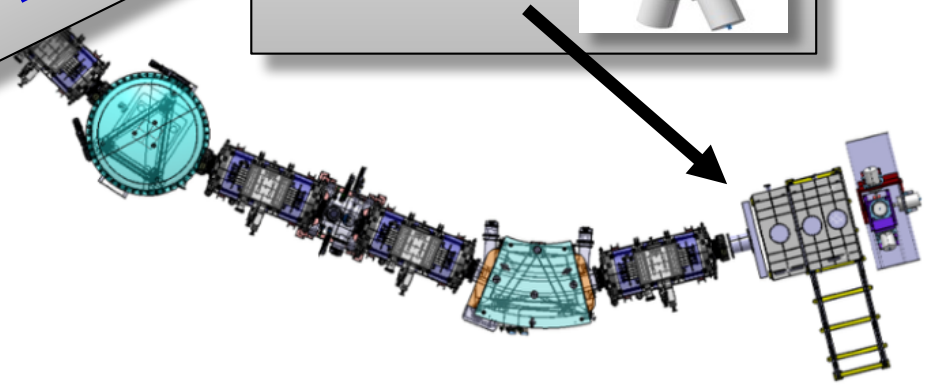
- **VHE – SHE elements**
- **Proton drip-line and N=Z**
- Nuclear astrophysics
- Atomic physics

commissioning 2018

Decay spectroscopy

SIRIUS setup
Implantation-decay station at the mass dispersive plan

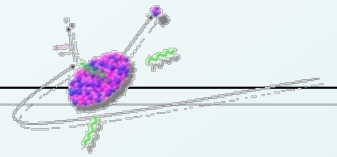




SPIRAL2 is on the list of the European Strategy Forum on Research Infrastructures (ESFRI)

Day 1 experiments at S³ (SPIRAL2/GANIL)

- rate summary



nuclide	reaction	feature	X-section [pbarn]	rate [Hz]	integral counts (21UT/7d)	
					day 1	phase 1++
^{254}No	^{48}Ca+^{208}Pb	K-isomer	2000×10³	60.000	1×10⁷	6×10⁷
^{256}Rf	^{50}Ti+^{208}Pb	K-isomer	17×10³	550	90.000	540.000
^{266}Hs	^{64}Ni+^{207}Pb	ER	15 (^{270}Ds)	0.34	57	285
^{266m}Hs	^{64}Ni+^{207}Pb	K-isomer	15 (^{270}Ds)	0.01	2.5	12.5
^{270}Ds	^{64}Ni+^{207}Pb	ER	15	0.45	76	380
^{270m}Ds	^{64}Ni+^{207}Pb	K-isomer	15 (^{270}Ds)	0.22	38	190
^{262}Sg	^{64}Ni+^{207}Pb	α-decay	15 (^{270}Ds)	0.02	5	25
^{276}Cn	^{70}Zn+^{207}Pb	K-Isomer search	0.5 (^{277}Cn)	0.01	*2.5*	12.5
^{288}115	^{48}Ca+^{243}Am	ER	10	0.3	*50*	300
^{288}115	^{48}Ca+^{243}Am	L X-rays	10	1,8	*300*	1800

D. Ackermann, NPA 2015, doi:10.1016/j.nuclphysa.2015.09.002

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