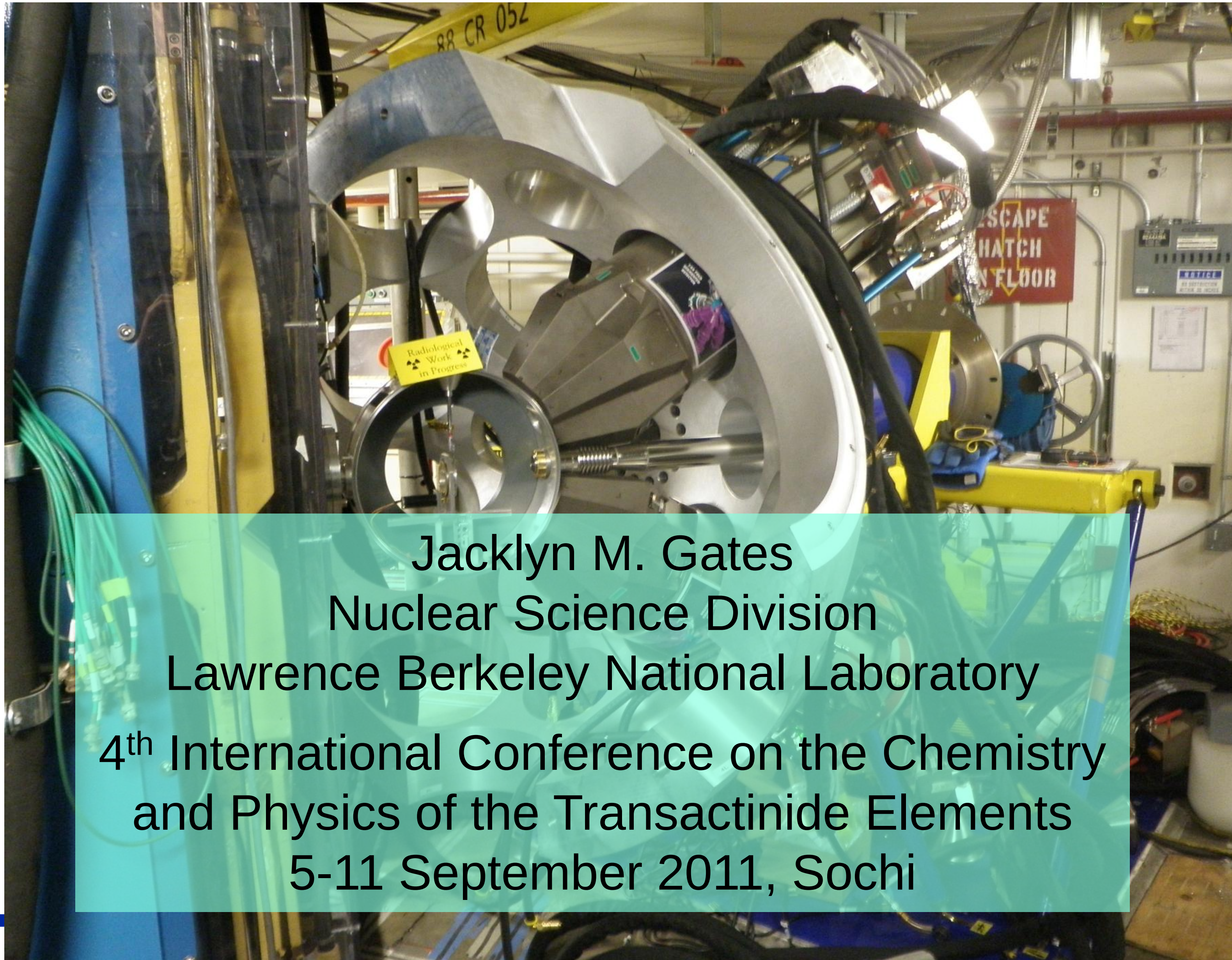
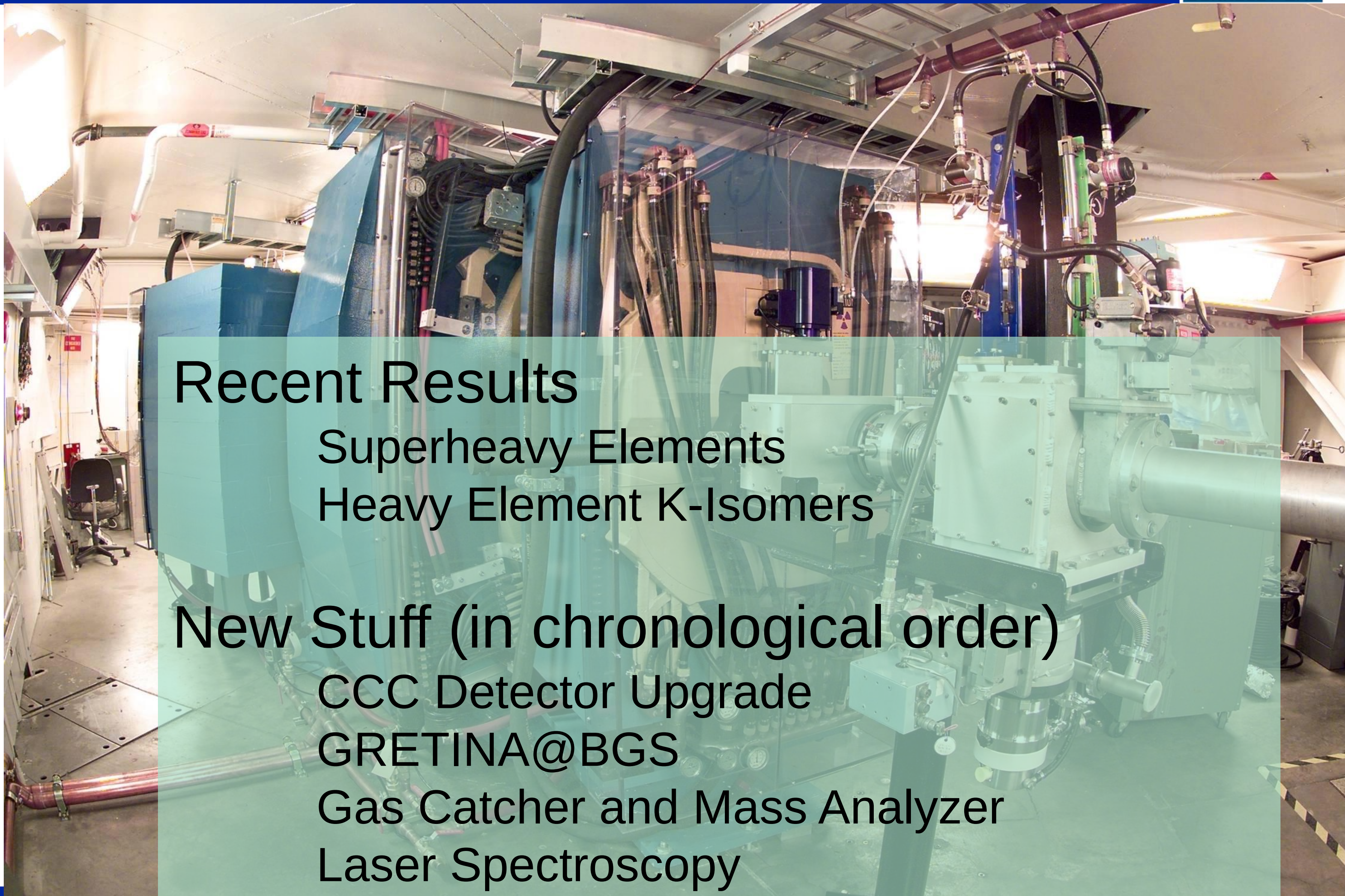
Heavy Elements at LBNL



Jacklyn M. Gates
Nuclear Science Division
Lawrence Berkeley National Laboratory

4th International Conference on the Chemistry and Physics of the Transactinide Elements
5-11 September 2011, Sochi

Outline



Recent Results

- Superheavy Elements
- Heavy Element K-Isomers

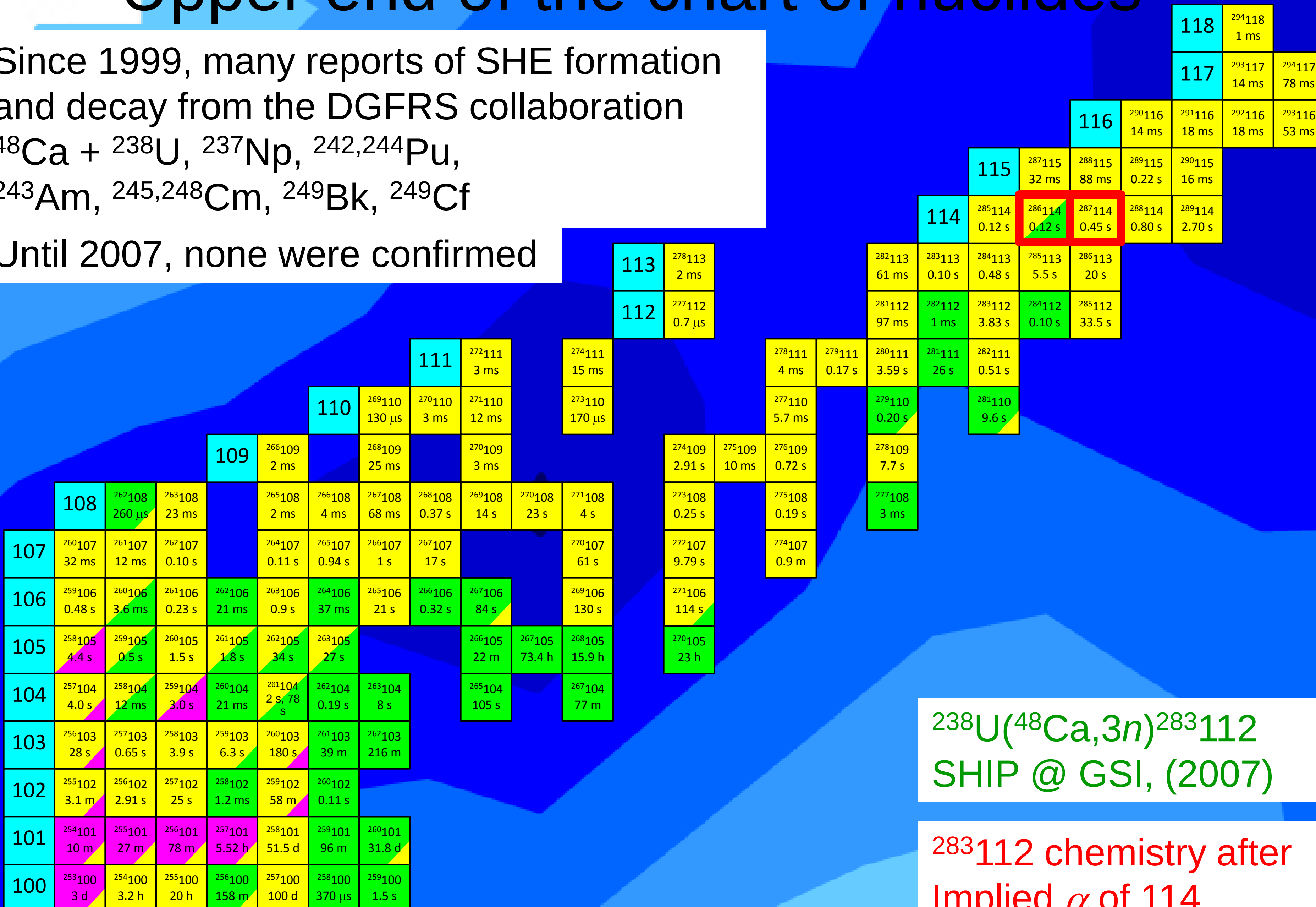
New Stuff (in chronological order)

- CCC Detector Upgrade
- GRETINA@BGS
- Gas Catcher and Mass Analyzer
- Laser Spectroscopy

Upper end of the chart of nuclides

Since 1999, many reports of SHE formation and decay from the DGFRS collaboration ^{48}Ca + ^{238}U, ^{237}Np, ^{242,244}Pu, ^{243}Am, ^{245,248}Cm, ^{249}Bk, ^{249}Cf

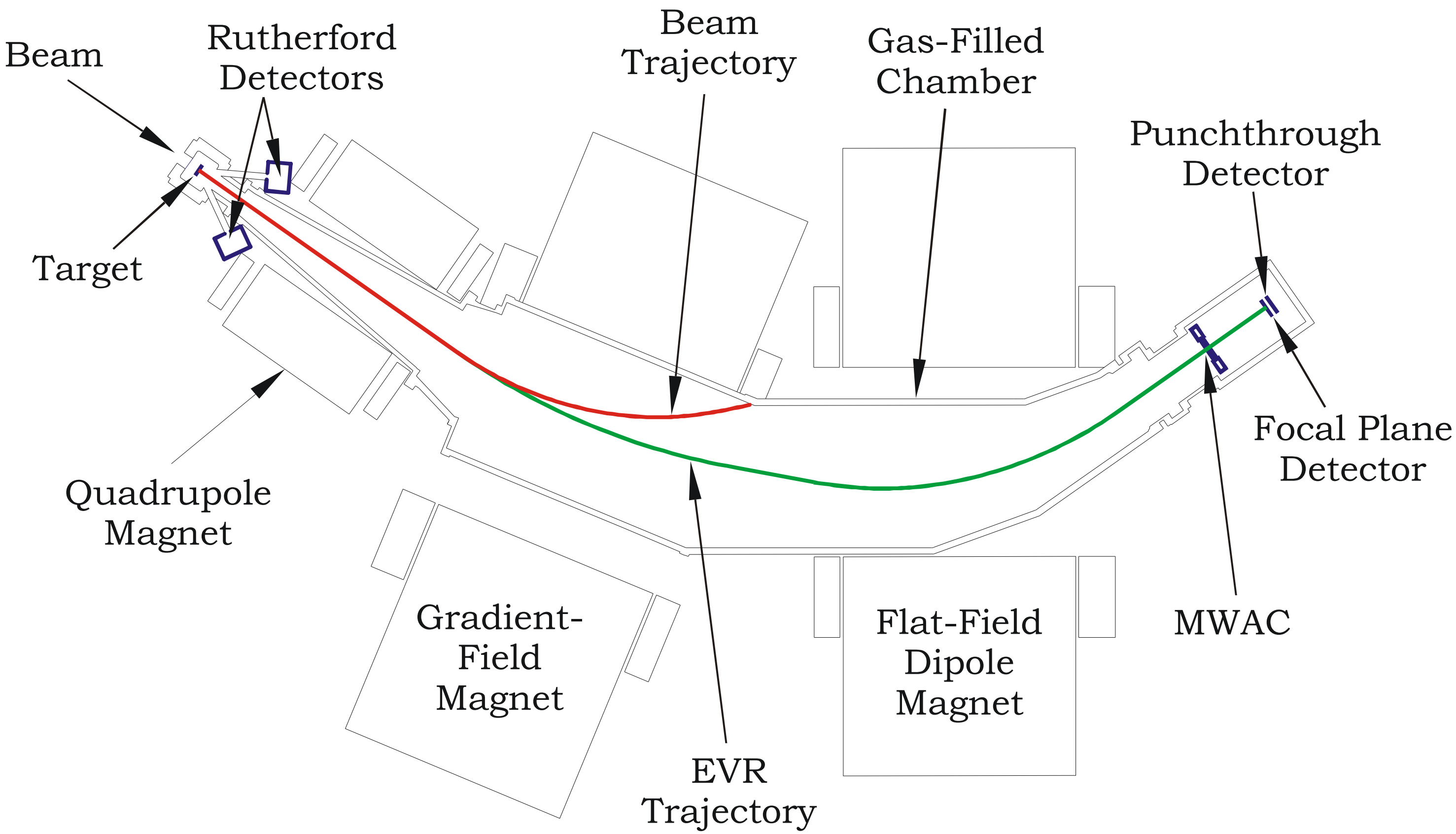
Until 2007, none were confirmed



^{238}U(^{48}Ca,3n)^{283}112
SHIP @ GSI, (2007)

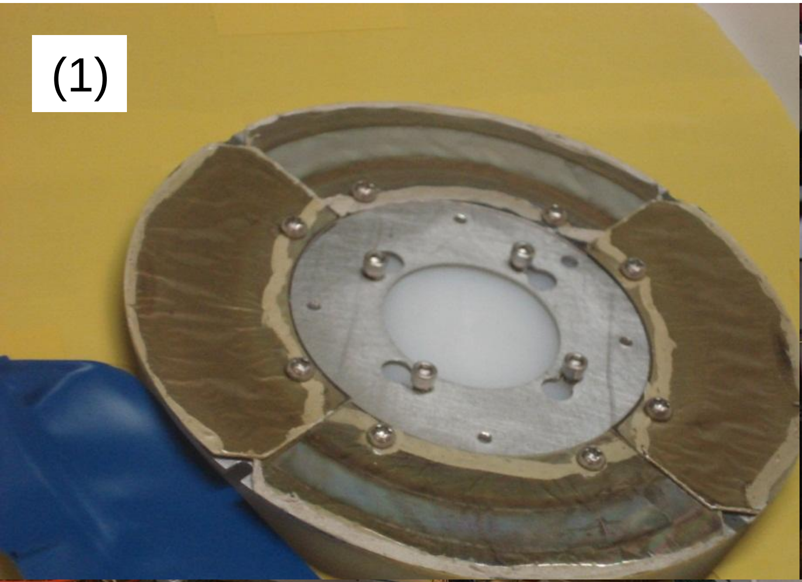
^{283}112 chemistry after
Implied α of 114
PSI @ Dubna, (2007)

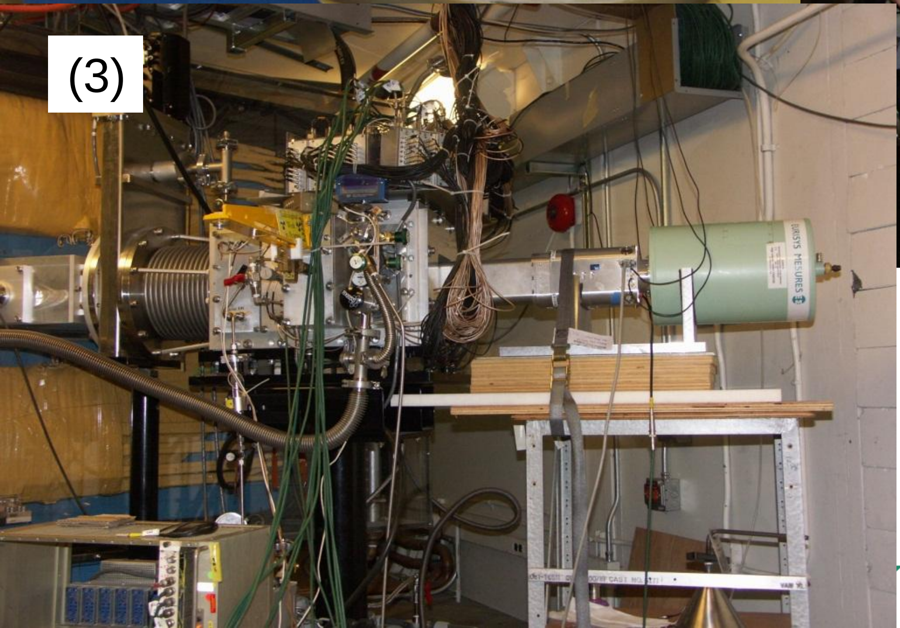
Berkeley Gas-filled Separator



- Compound nucleus recoils are ejected from the target with the momentum of the beam
- In 0.5-Torr He, they experience many charge-changing collisions, giving 100% charge acceptance
- Average charge is (nearly) proportional to velocity, giving *LARGE* velocity acceptance
- Compound nucleus evaporation residues (EVRs) are focused on the detector array everything else has a smaller magnetic rigidity, and takes a left turn

BGS upgrades for ^{242}Pu(^{48}Ca, 3-4n)$^{287-286}$114



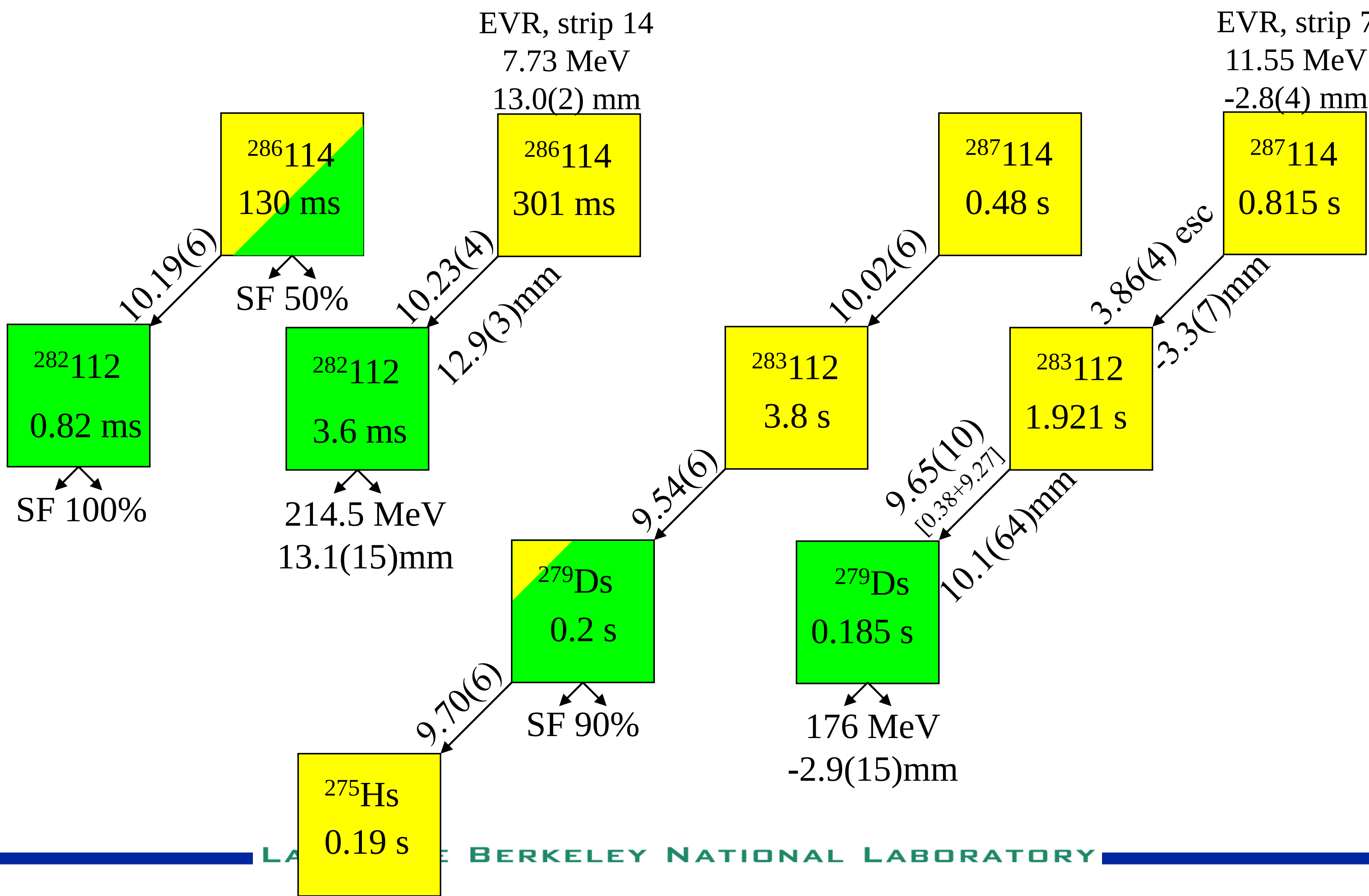


(1) $^{242}PuO_2$ targets on 2.44-µm Ti, 3.75” dia. wheel

(2) Radioactivity containment facility at BGS target

(3) Ge clover γ-ray detector behind BGS detectors

Reported and observed decay properties for $^{286}114$ and $^{287}114$



First independent verification of element 114 production

Decay modes, α-energies, and lifetimes agree with published values.

Cross sections reported in 2009 were 1.4 pb each.

Smaller than the 4.5 pb and 3.6 pb reported by the DGFRS group

Small cross sections might be explained if $B\rho$ in He is > 2.3 *Tm*

$B\rho$ now known to be 2.29 *Tm*, *B*-field saturation in M2 . . . Our cross section is ~ 3.1 pb

Random rate analysis indicates fewer than 5×10^{-7}

EVR-α-*SF* and *EVR*-α-α-*SF* correlations should result from random correlation of unrelated background events.

SHE are real and accessible at production rates of events/week.

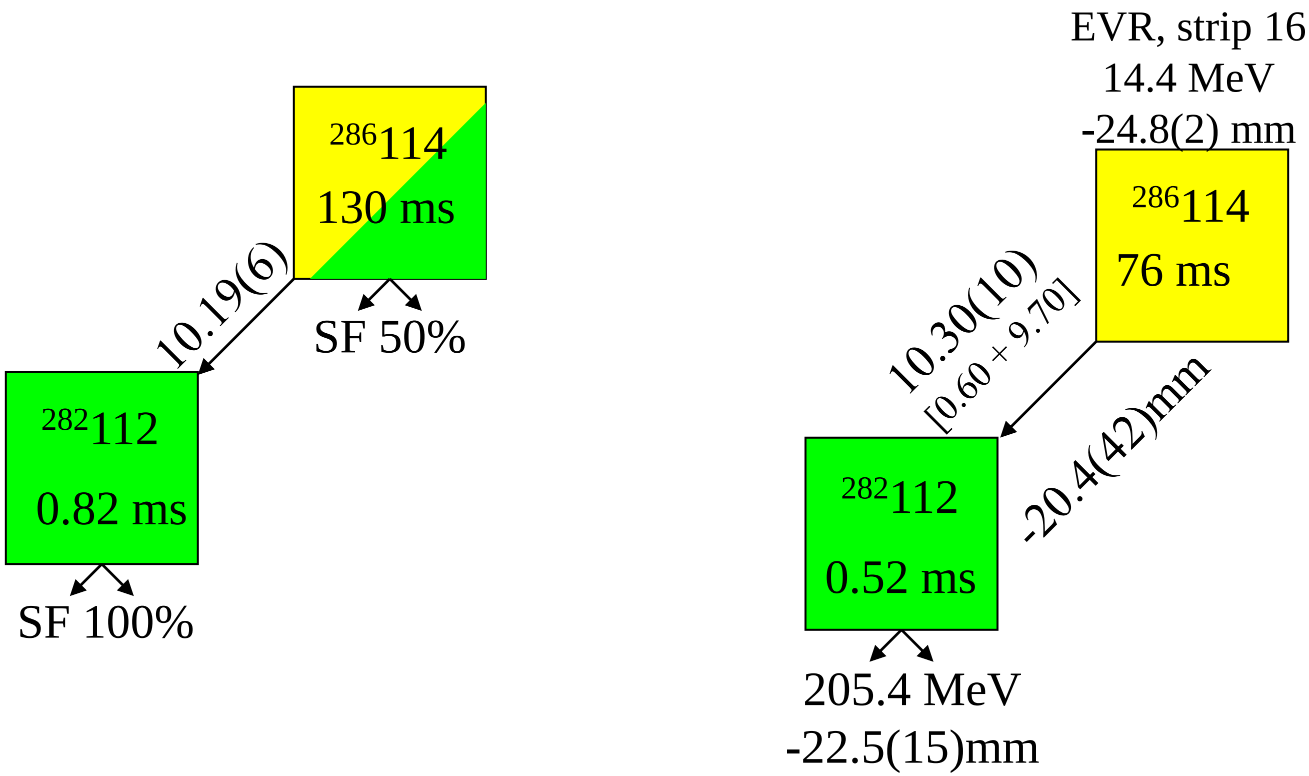
With planned beam intensity upgrades at several accelerators: events/day!

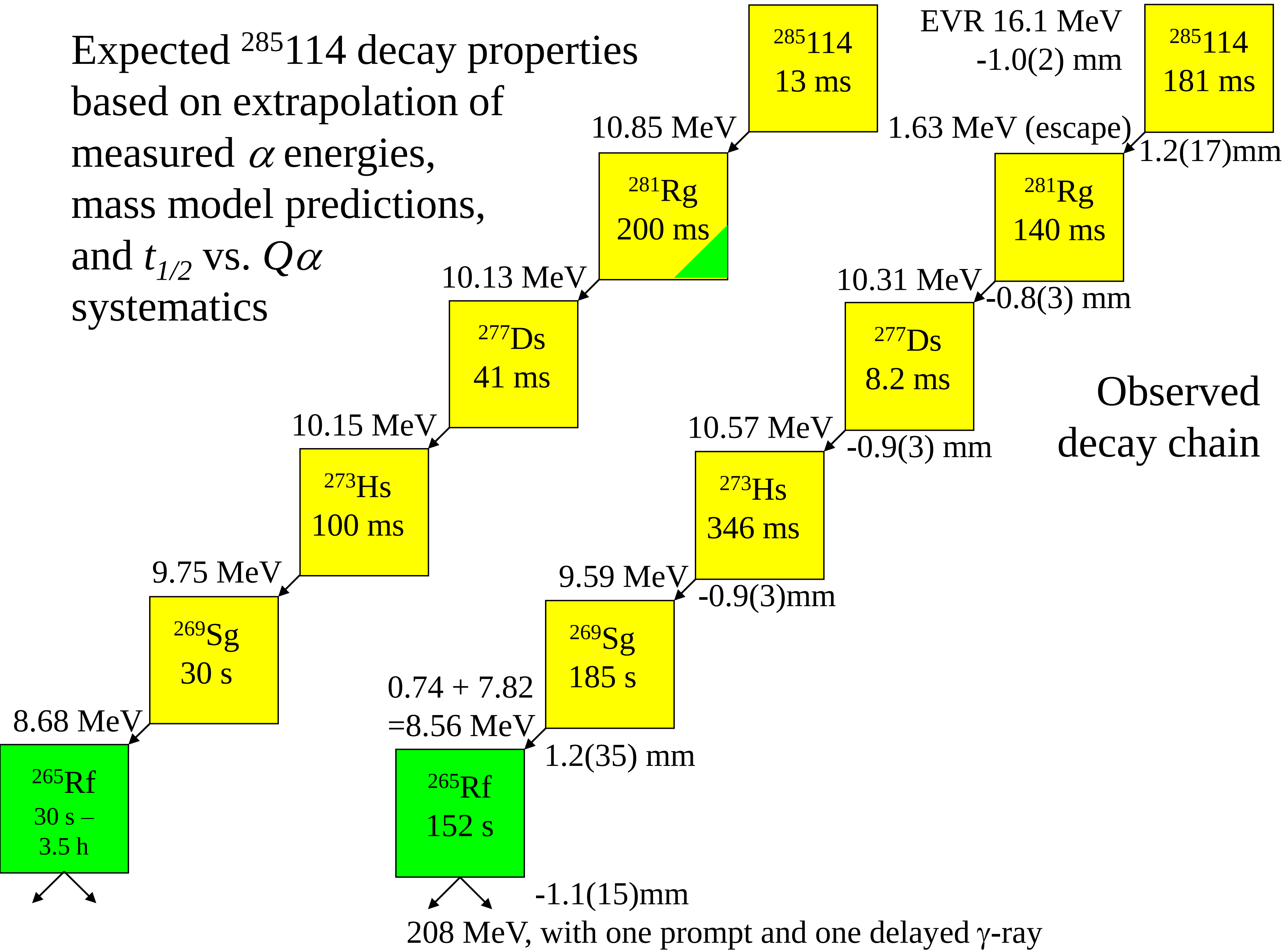
^{242}Pu(^{48}Ca,4-5*n*)$^{286\text{-}285}$114 experiment (2010)

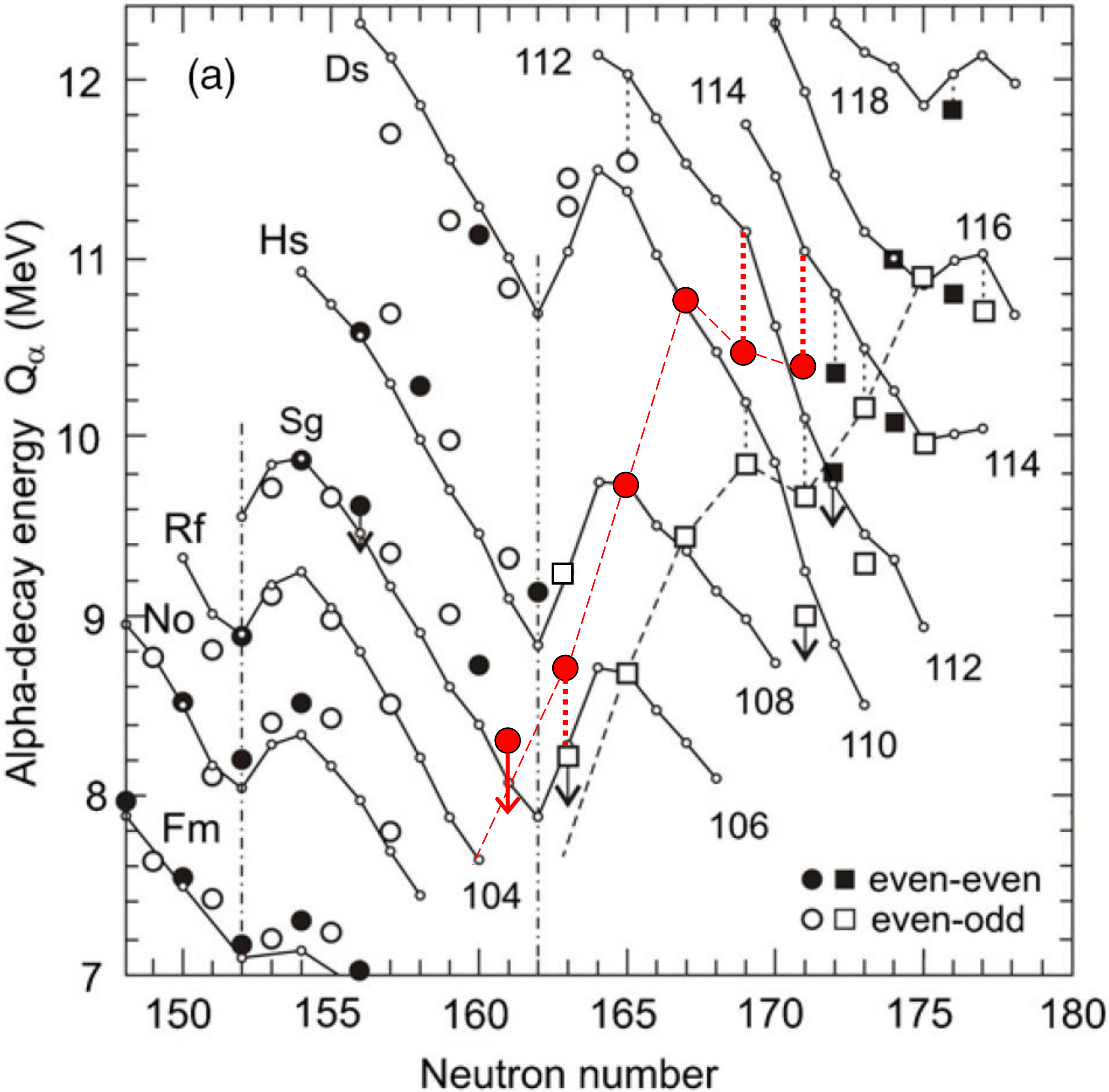
One event seen from ^{242}Pu(^{48}Ca, 4*n*)^{286}114

Reported decay properties for ^{286}114

Observed




Expected 285114 decay properties based on extrapolation of measured α energies, mass model predictions, and $t_{1/2}$ vs. $Q\alpha$ systematics
285114
13 ms
10.85 MeV
281Rg
200 ms
10.13 MeV
277Ds
41 ms
10.15 MeV
273Hs
100 ms
9.75 MeV
269Sg
30 s
8.68 MeV
265Rf
30 s –
3.5 h
EVR 16.1 MeV
-1.0(2) mm
285114
181 ms
1.63 MeV (escape)
1.2(17)mm
281Rg
140 ms
10.31 MeV
-0.8(3) mm
277Ds
8.2 ms
10.57 MeV
-0.9(3) mm
273Hs
346 ms
9.59 MeV
-0.9(3)mm
269Sg
185 s
0.74 + 7.82
=8.56 MeV
1.2(35) mm
265Rf
152 s
-1.1(15)mm
208 MeV, with one prompt and one delayed γ-ray
Observed decay chain



Comparison with Q_α predictions of Muntian, Patyk, and Sobiczewski

Differences (dotted lines) show that a revision of calculated shell effects may be needed.

Positive *Z* and *A* Identification for SHE

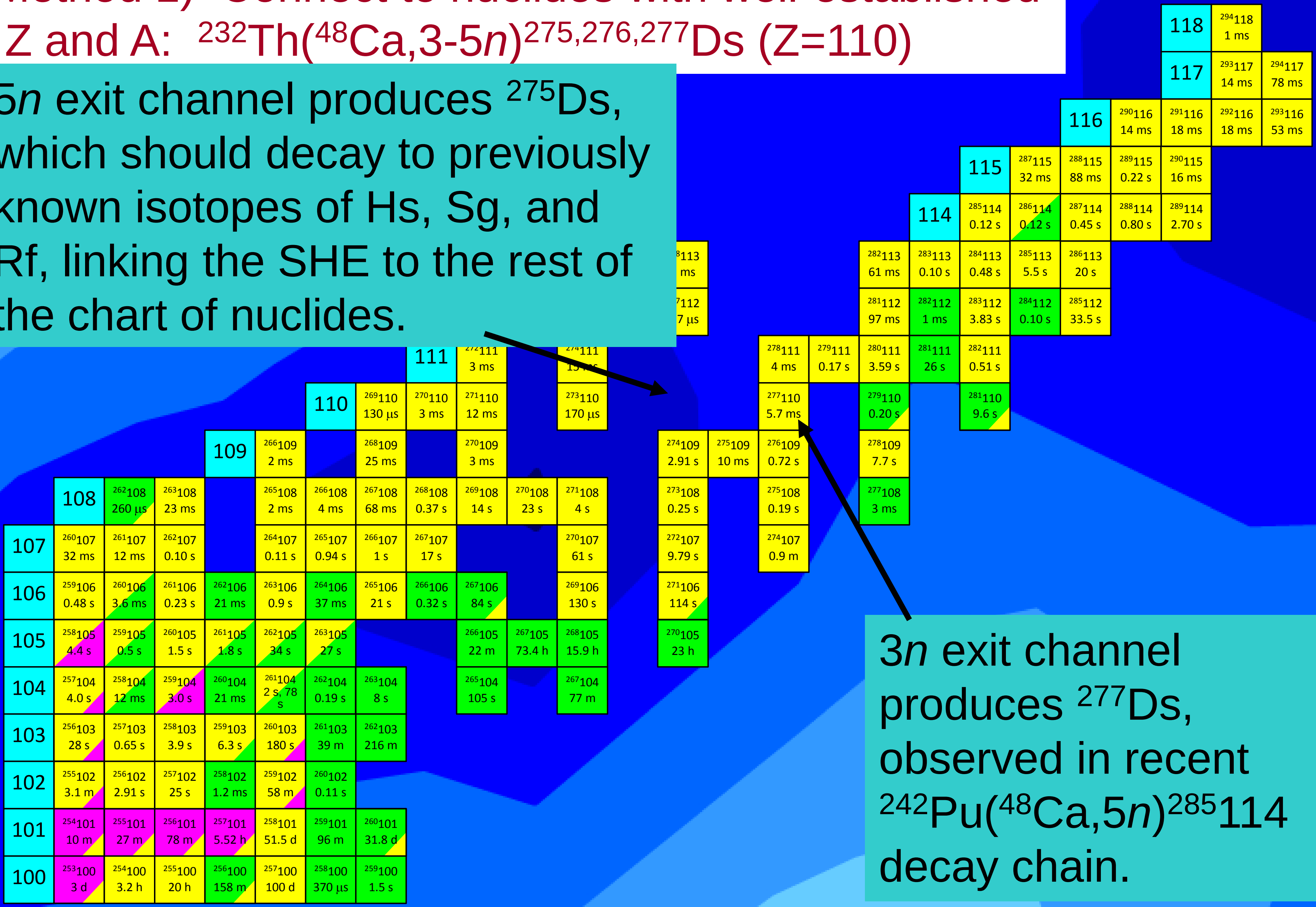
- SHE *Z* and *A* assignments are probably correct, but not proven.
- SHE *Z* and *A* assignments are based largely on mass models.
  - Before using SHE $Q\alpha$ to refine mass models,
  - we better be ***sure*** the assignments are correct.

Z and A assignments techniques:

1) Decay to isotopes with well-established *Z* and *A*
2) *Z*-assignment by observation of characteristic *x*-rays
3) Direct measurement of mass

Method 1) Connect to nuclides with well-established Z and A: $^{232}Th(^{48}Ca,3\text{-}5n)^{275,276,277}Ds$ (Z=110)

5*n* exit channel produces ^{275}Ds, which should decay to previously known isotopes of Hs, Sg, and Rf, linking the SHE to the rest of the chart of nuclides.



3*n* exit channel produces ^{277}Ds, observed in recent $^{242}Pu(^{48}Ca,5n)^{285}114$ decay chain.

Method 2) *Z*-assignment by observation of characteristic *x*-rays

- α-decay of odd or odd-odd nuclides could lead to α K *x*-ray coincidences
- Simulations show that only 3 α – K *x*-ray coincidences are needed for *Z* identification at 95% confidence level

GSI-Lund: ^{243}Am(^{48}Ca,3n)^{288}115

- Recent results from Dubna-LLNL-ORNL suggest that K *x*-rays may be produced in decay to Mt

LBNL: ^{237}Np(^{48}Ca,3n)^{282}113

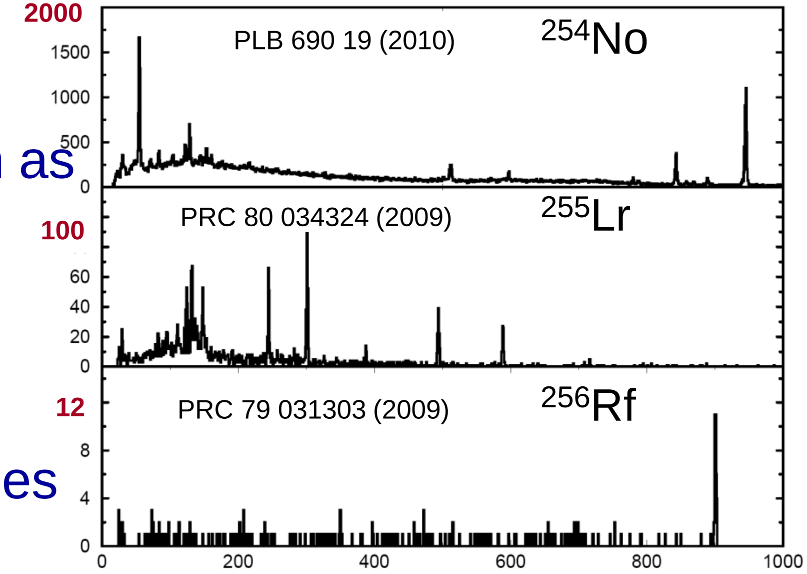
- We prefer this reaction because it should result in positive assignments by
  - method 1) - decay through well-established isotopes ^{262}Lr and ^{262}No
  - method 2) - α k *x*-ray coincidences in ^{282}113, ^{278}Rg, ^{274}Mt, ^{270}Bh, ^{266}Db
  - method 2) – EC decay of ^{262}Lr followed by SF of 5-ms ^{262}No

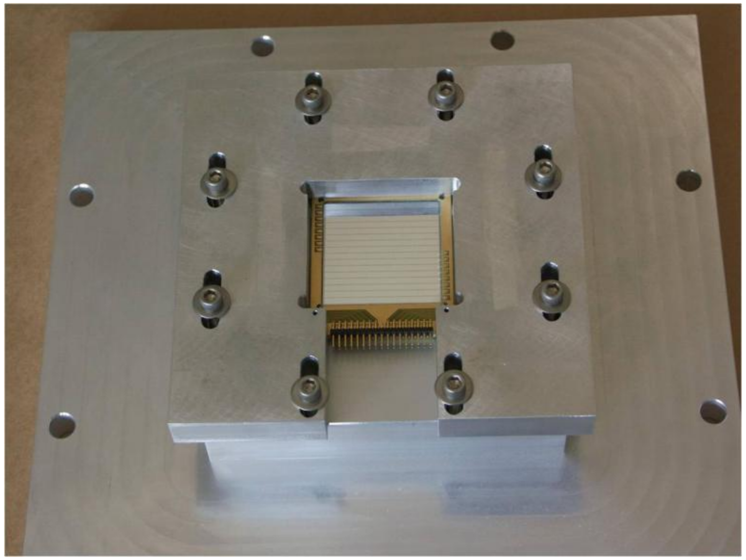
Method 3) Direct measurement of mass

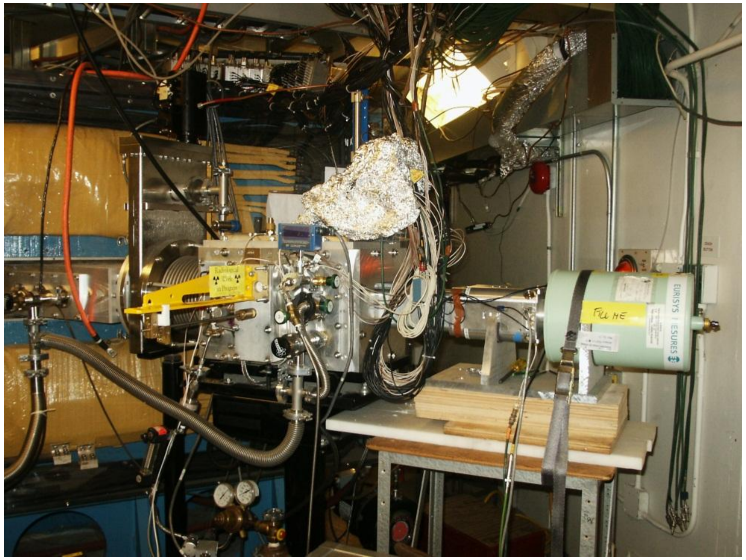
Coming up in a few minutes

Isomer spectroscopy Z>100

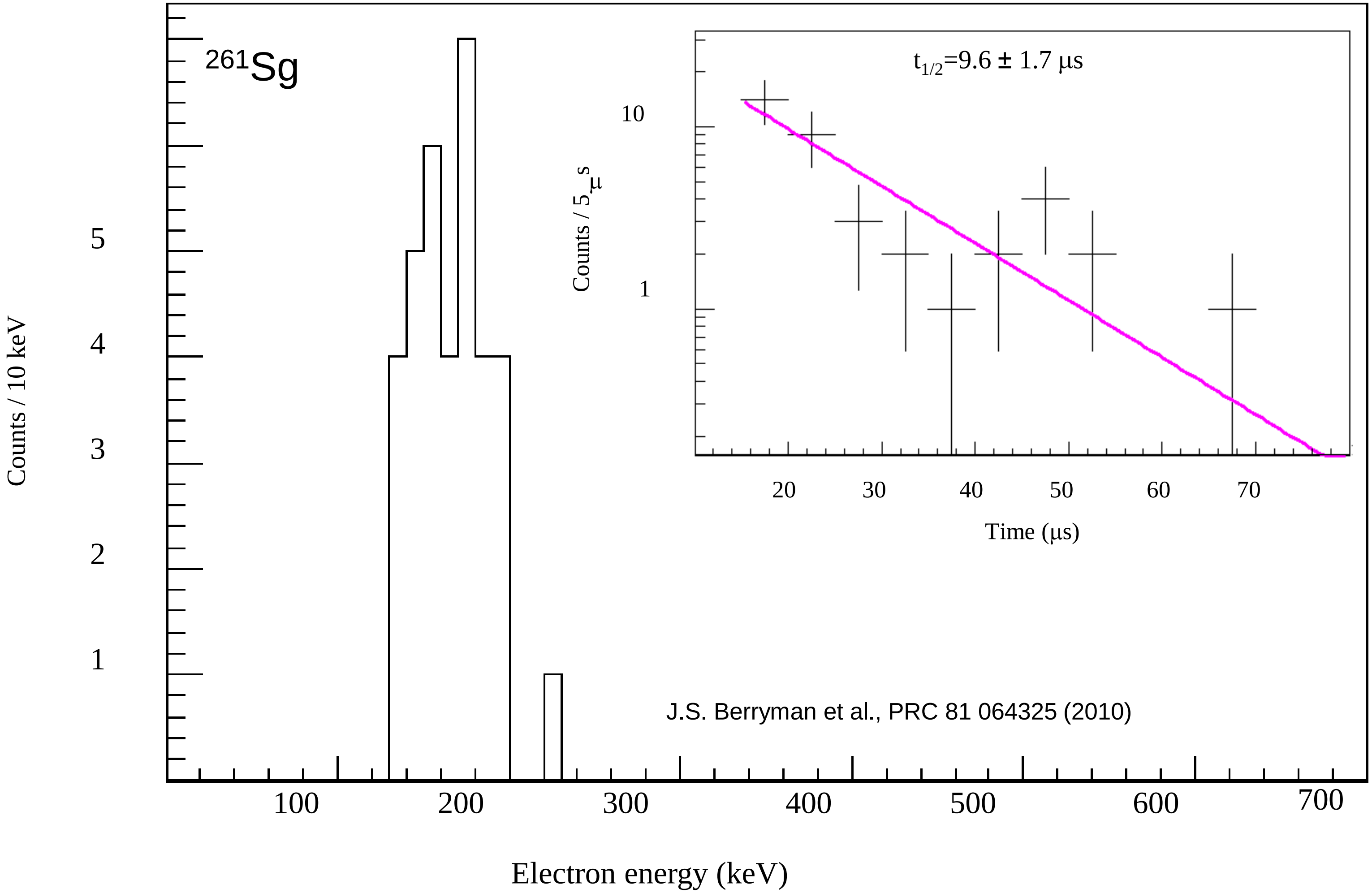
- Studying the decay of isomers at BGS focal plane
- Determining properties for Z>100 nuclei such as
  - single quasi-particle structure
  - pairing strength
  - deformation
  - excitation modes
- Testing the same models that predict properties of super-heavy nuclei near Z=114, N=184.







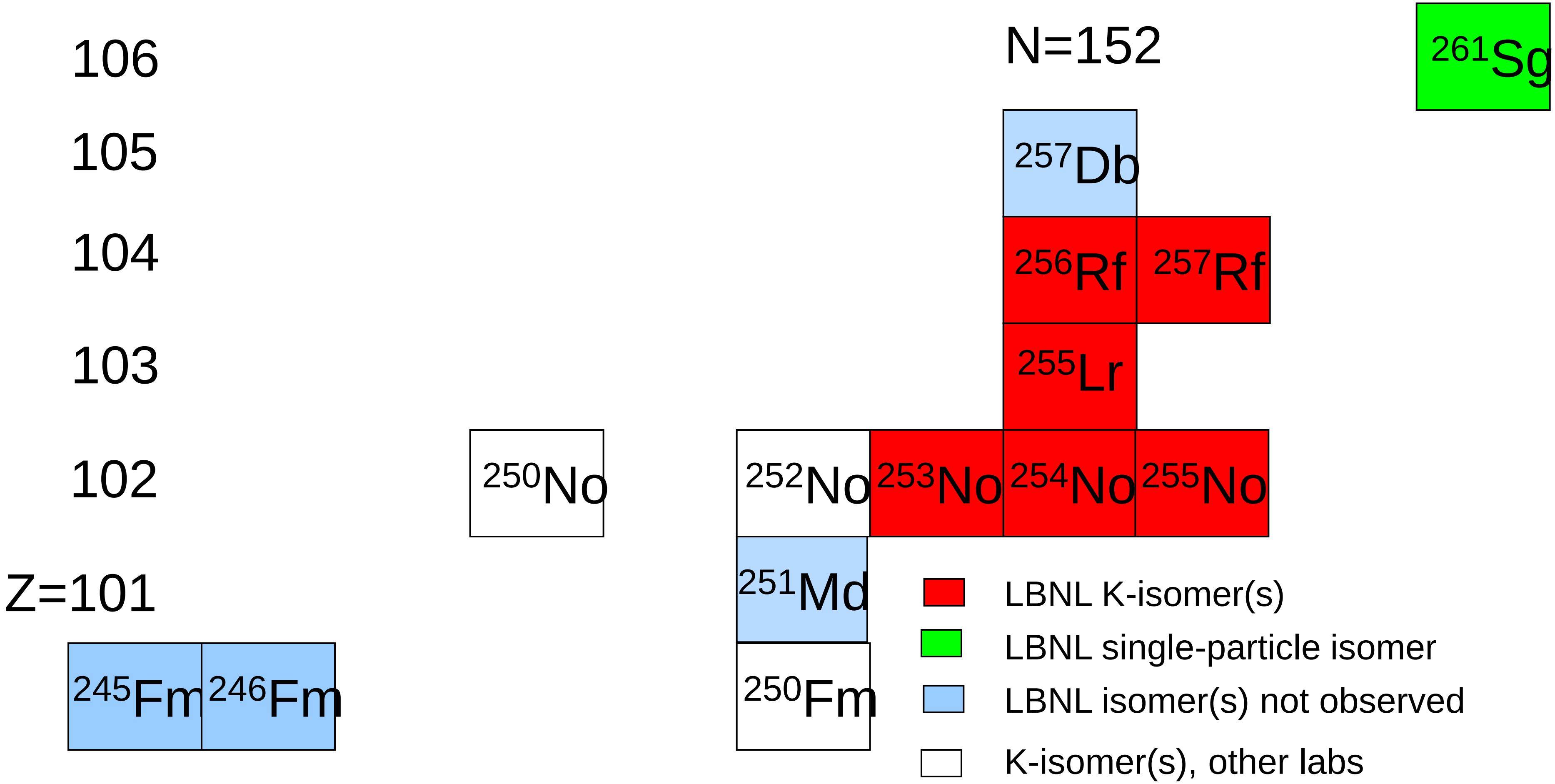
^{261}Sg Single Particle Isomer



Seaborgium is at the current limit for spectroscopy measurements

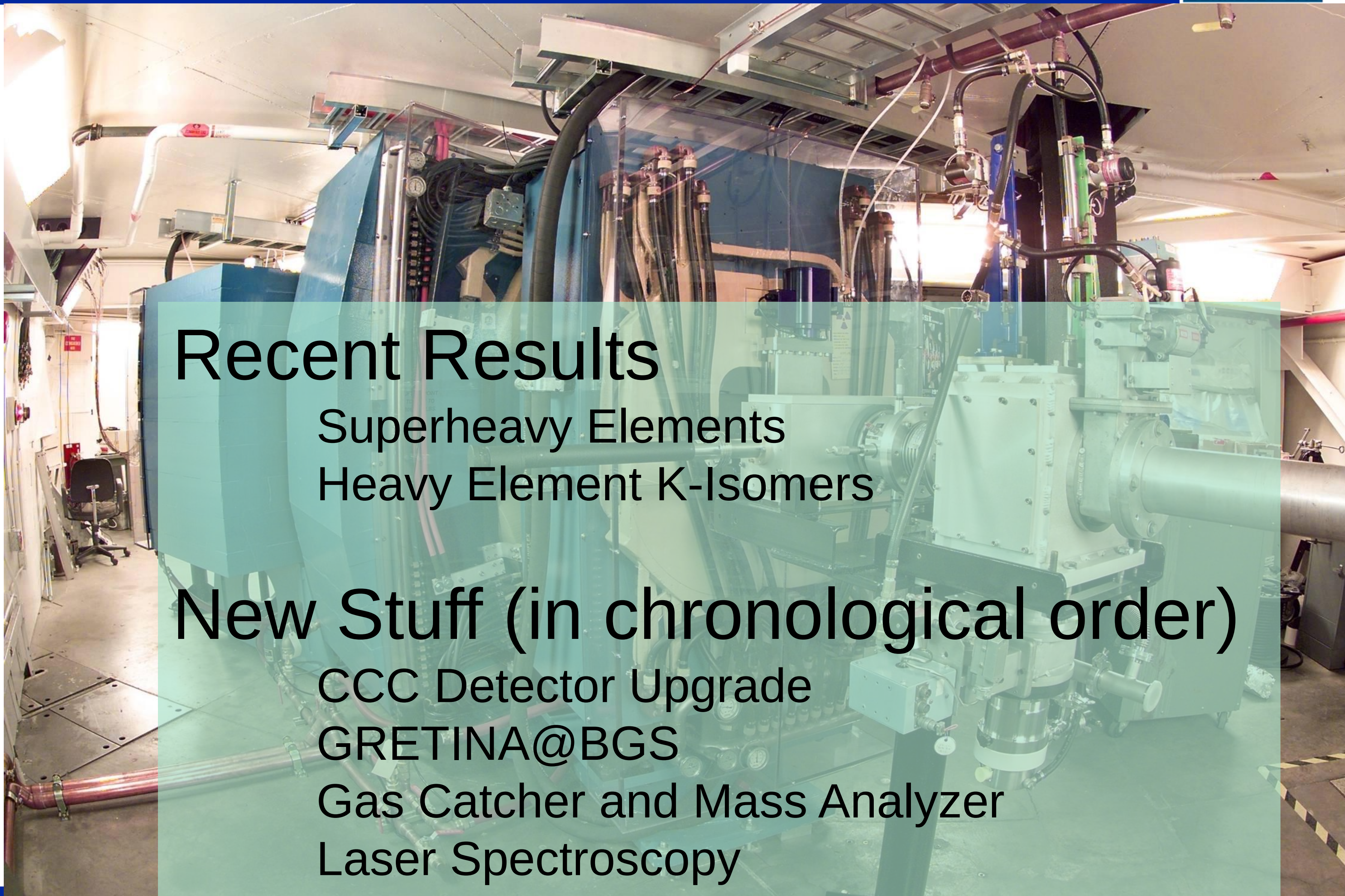
Summary

Known excited isomeric states in elements with Z>100



- A new generation of experiments is underway addressing the fundamental issue of the maximum limit of nuclear mass and charge.

Outline



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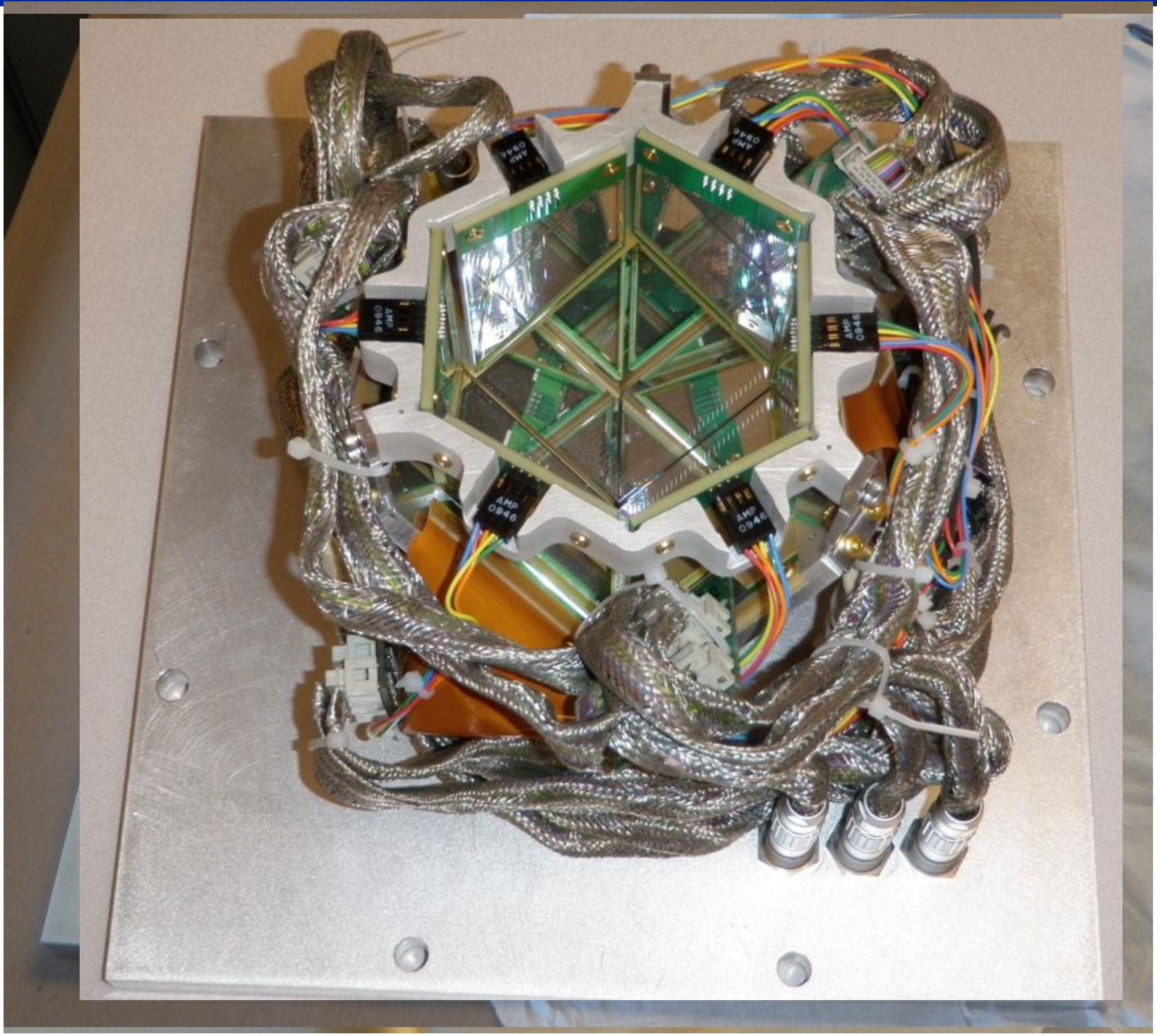
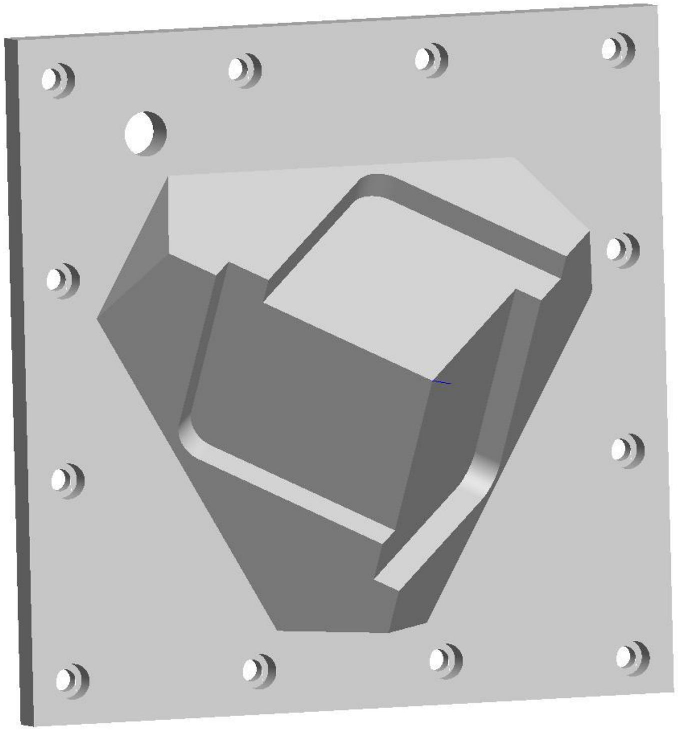
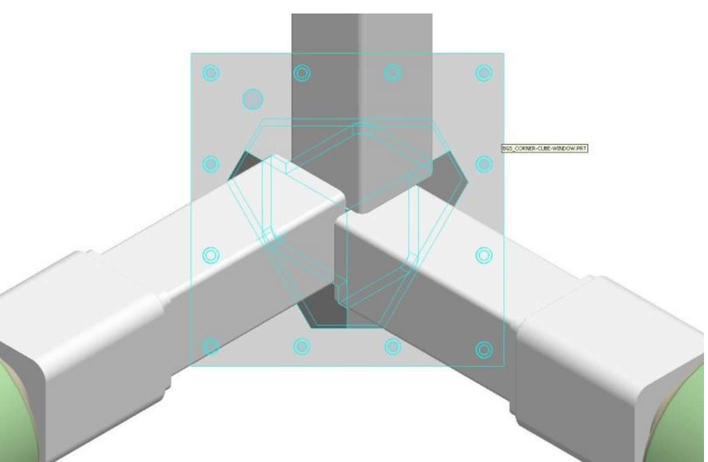
New detector for increased sensitivity in K-isomer and SHE experiments

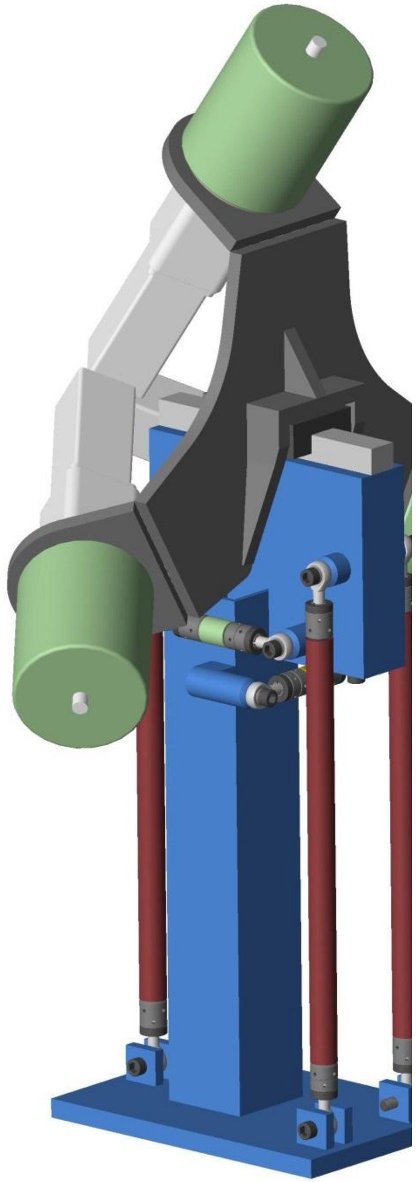


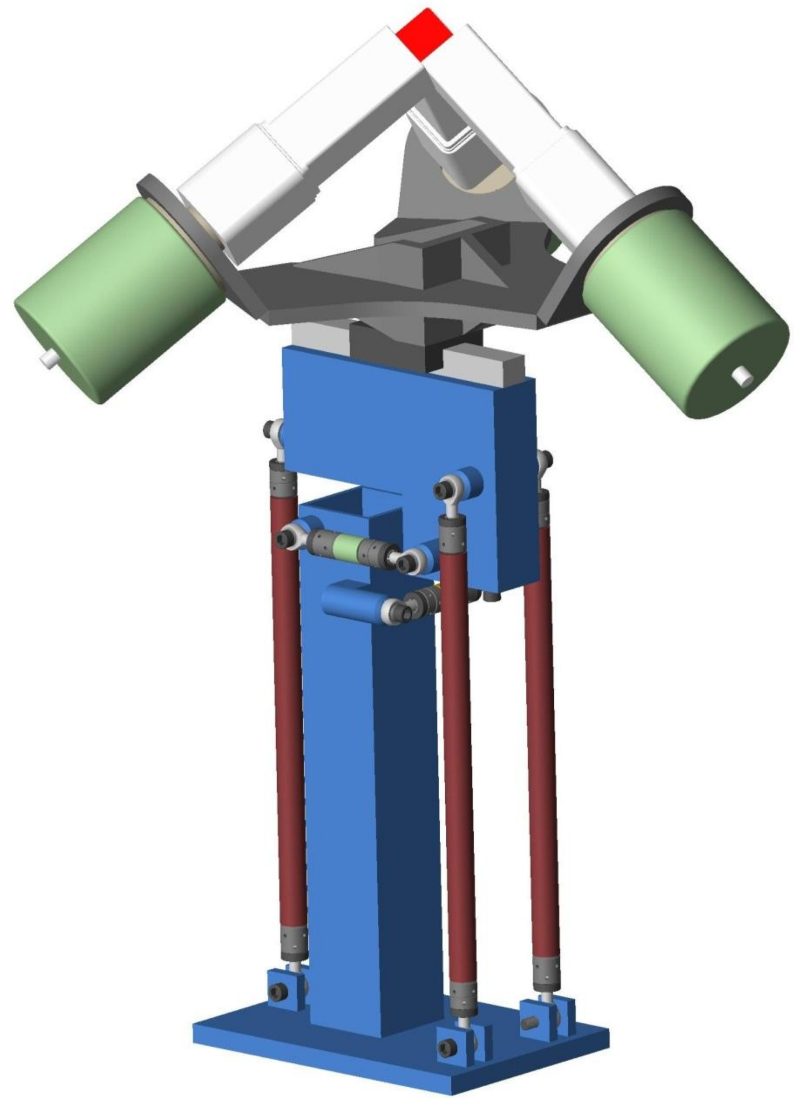
CCC Clover Detector Positioning

Berkeley Lab

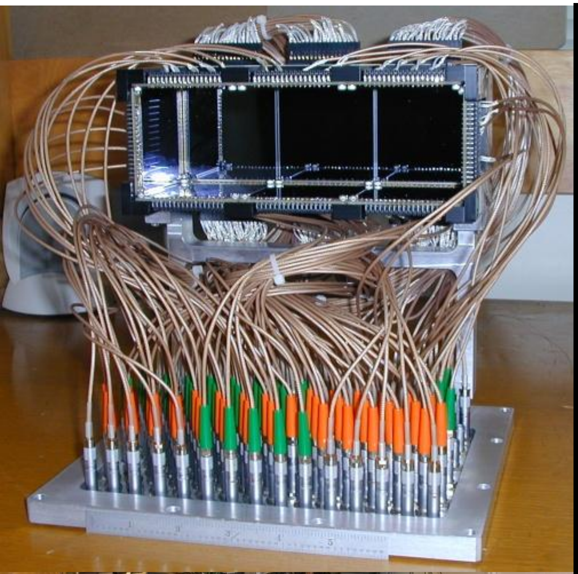


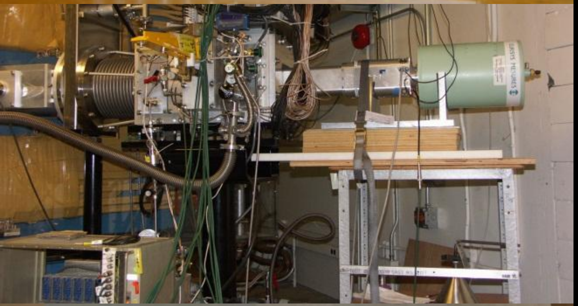


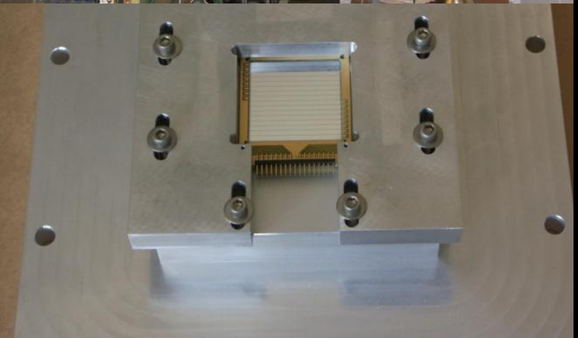




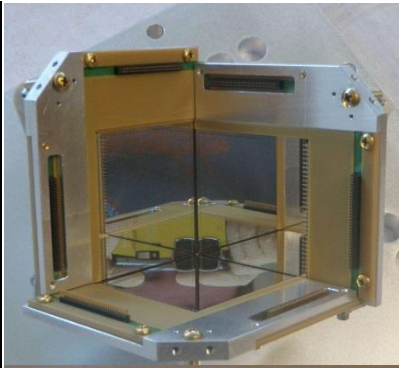
Efficiency gains with new DSSD configuration

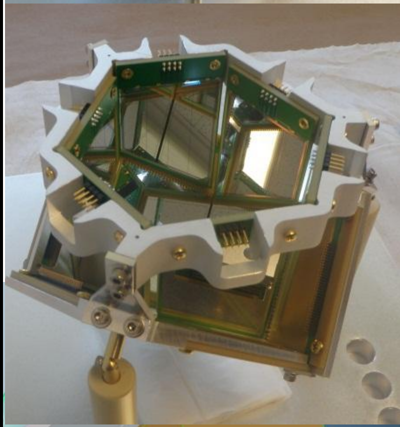


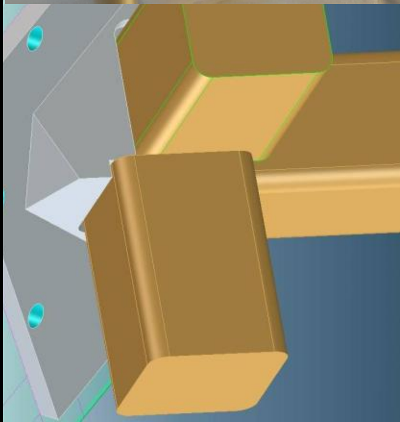




event type	eff. 1 DSSD 1 clover	C^3 eff. 3 DSSDs 3 clovers	eff. gain
recoil	50%	87%	1.74
α	50%	92%	1.84
122 keV Kx 900 keV γ	16% 4.0%	30% 7.5%	1.88
recoil-γ_{900}-α (K-isomer)	1.0%	6.0%	**6.0**
Recoil-α-Kx (SHE Z id.)	4.0%	24.%	**6.0**

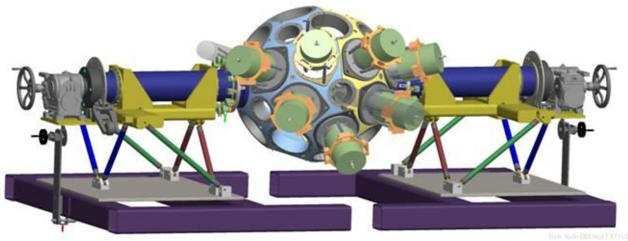


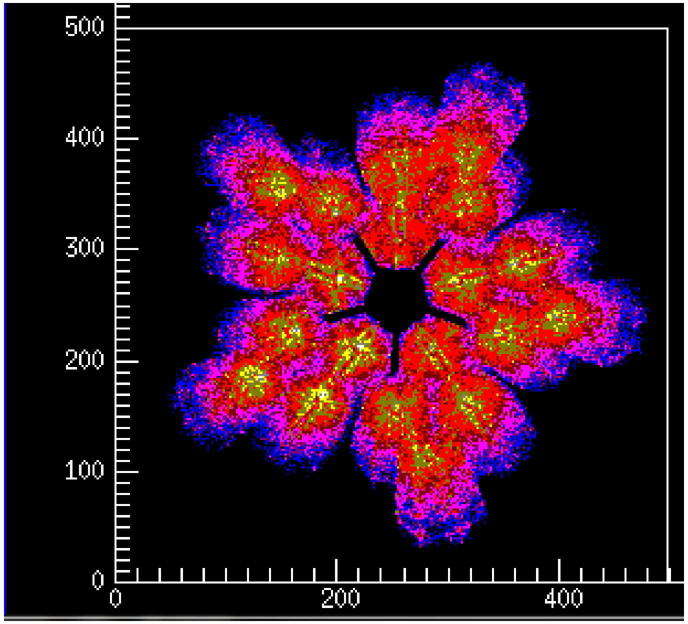


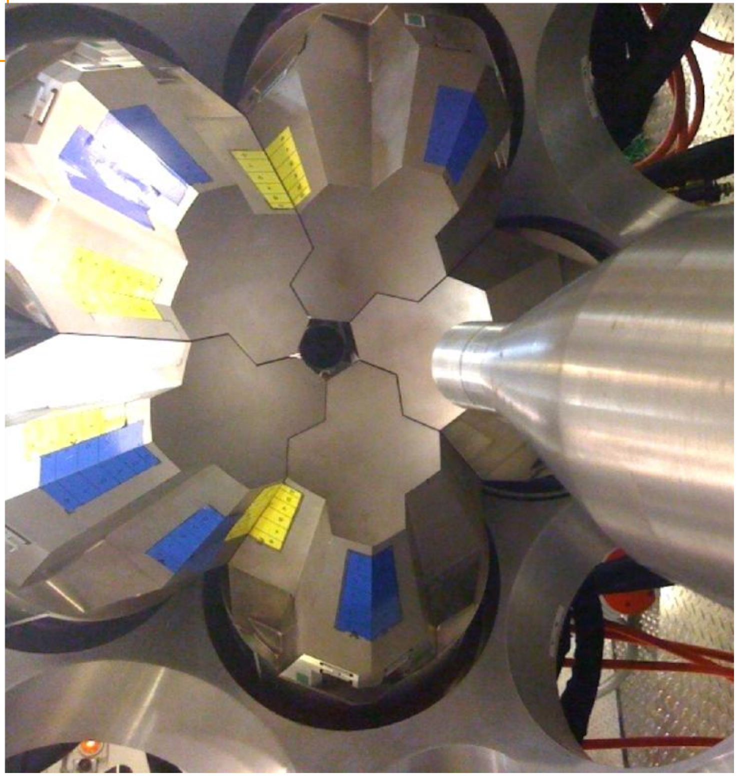


GRETINA@BGS Project

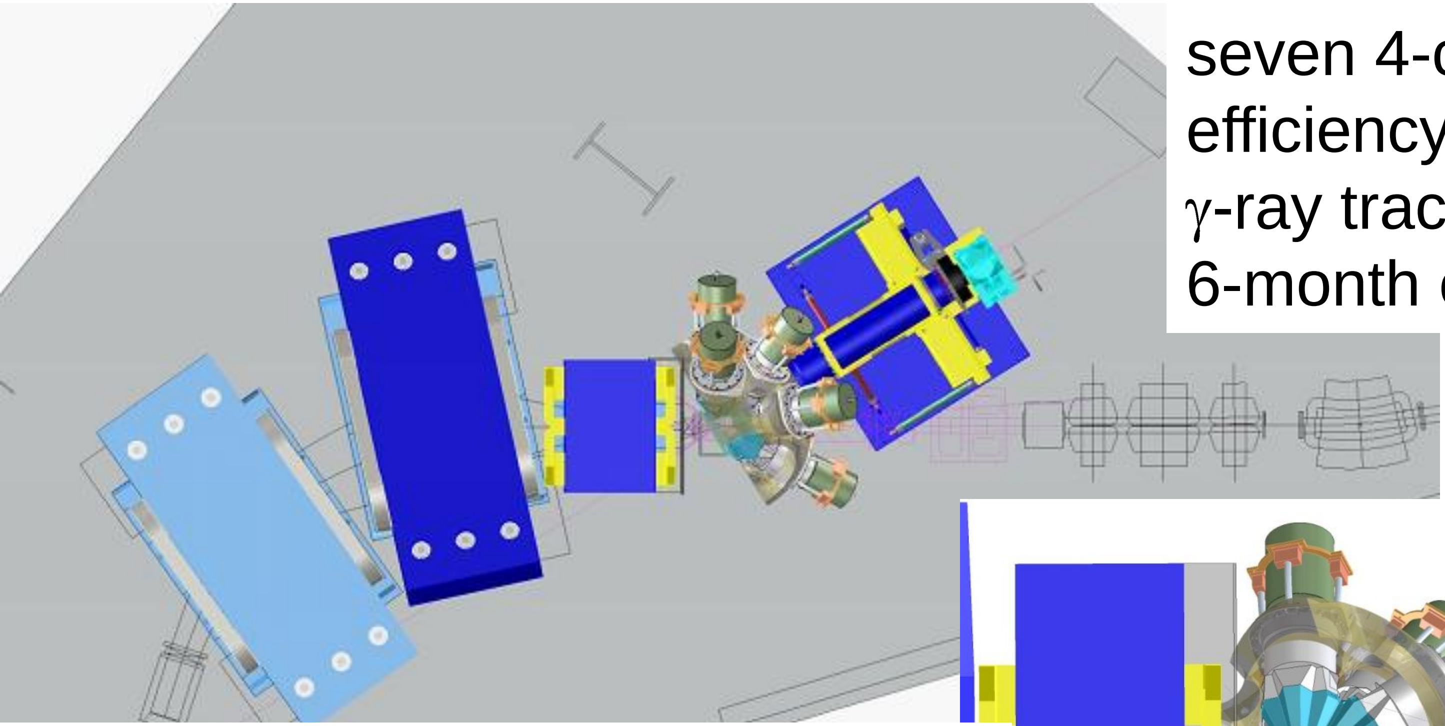
- Gamma-ray energy tracking array
- Covering ¼ of 4π solid angle with 28 segmented Ge crystals
- Mechanical support structure
- Acquisition system



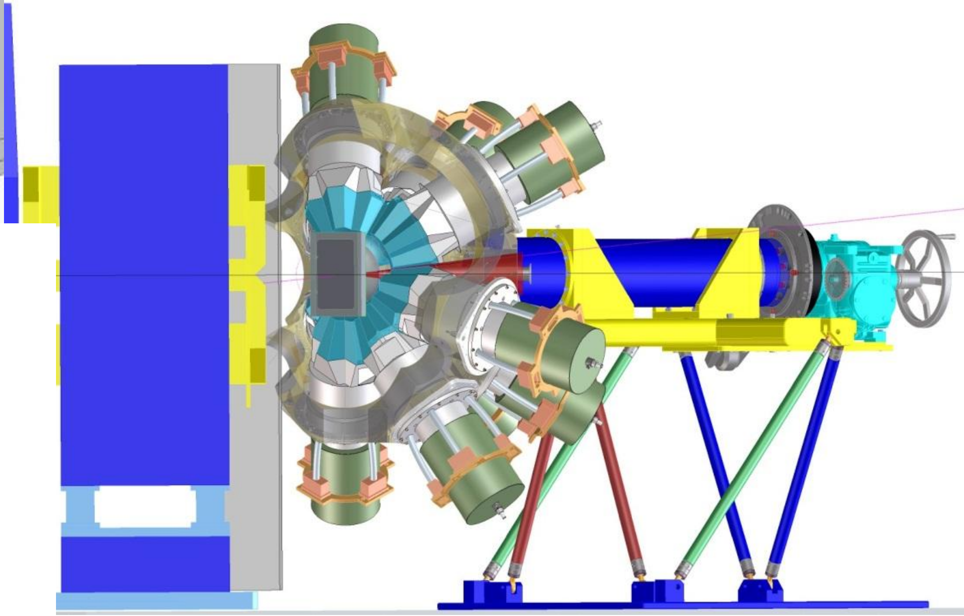




GRETINA@BGS Expeiments, Fall 2011

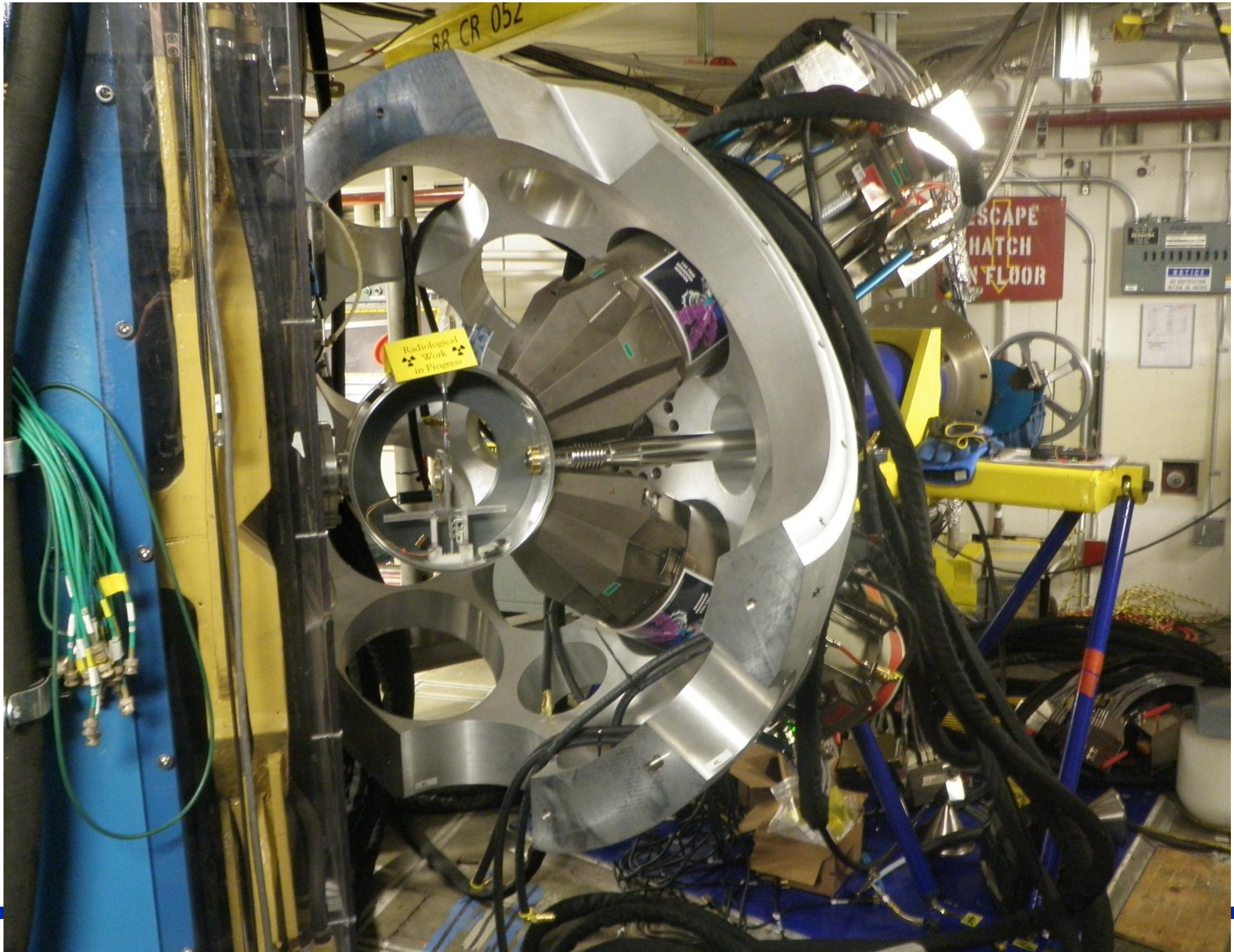


seven 4-crystal modules
efficiency similar to GS
γ-ray track reconstruction
6-month campaign



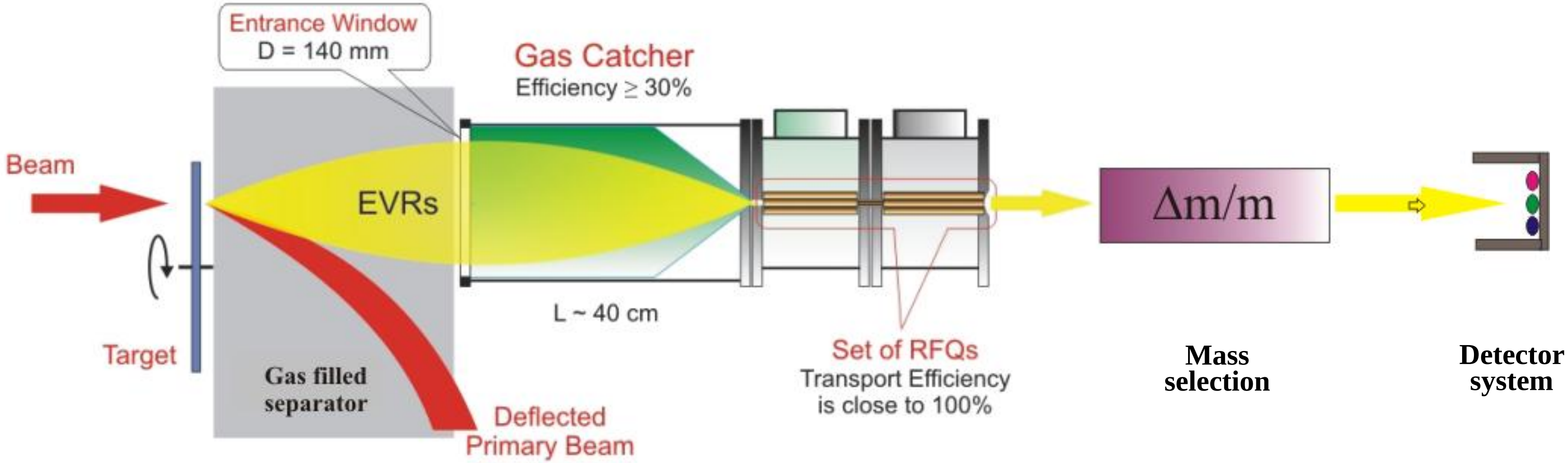
In-beam spectroscopy exp:
^{208}Pb(^{48}Ca,2n)^{254}No,
•10x statistics improvement
^{208}Pb(^{50}Ti,1-2n)^{257,256}Rf,
•highest-Z for in beam spect.

GRETINA@BGS installation

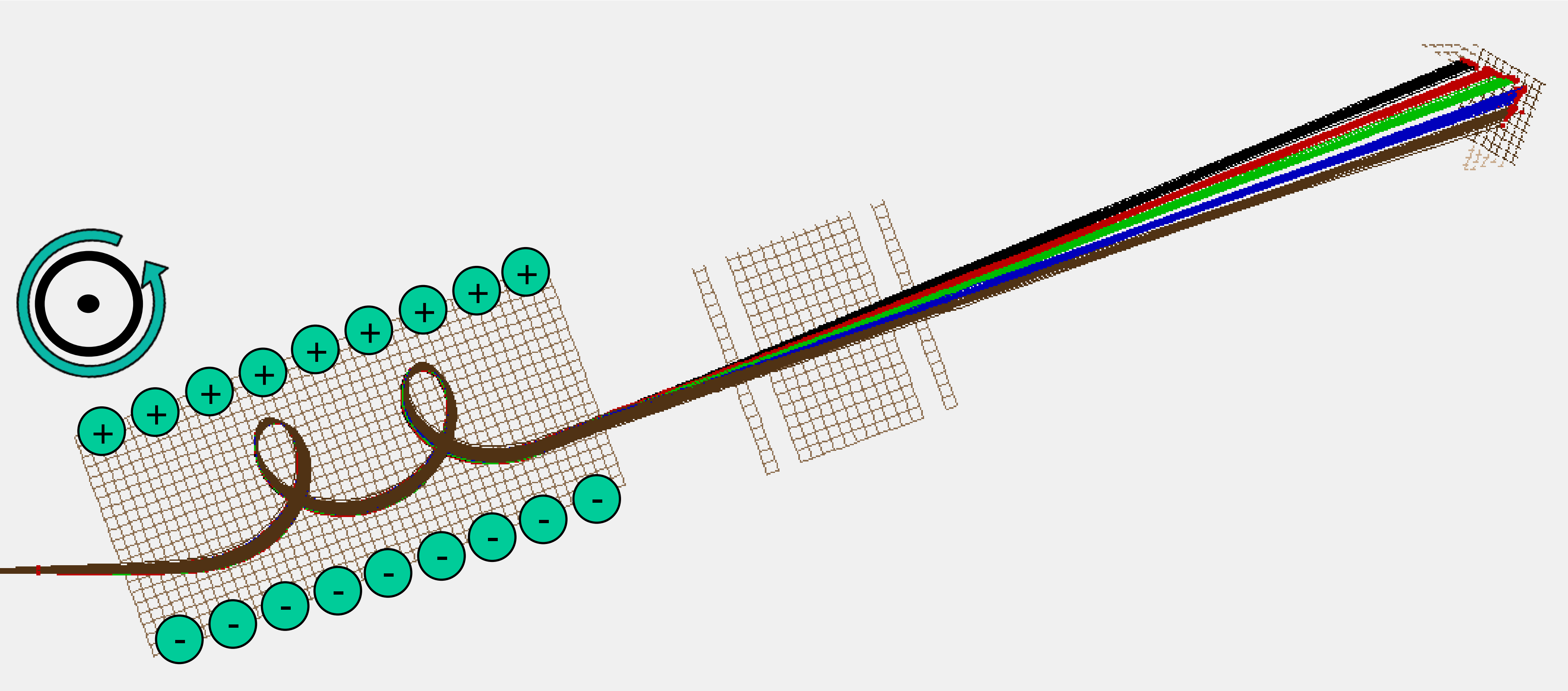


Mass Analysis and Detector Facility

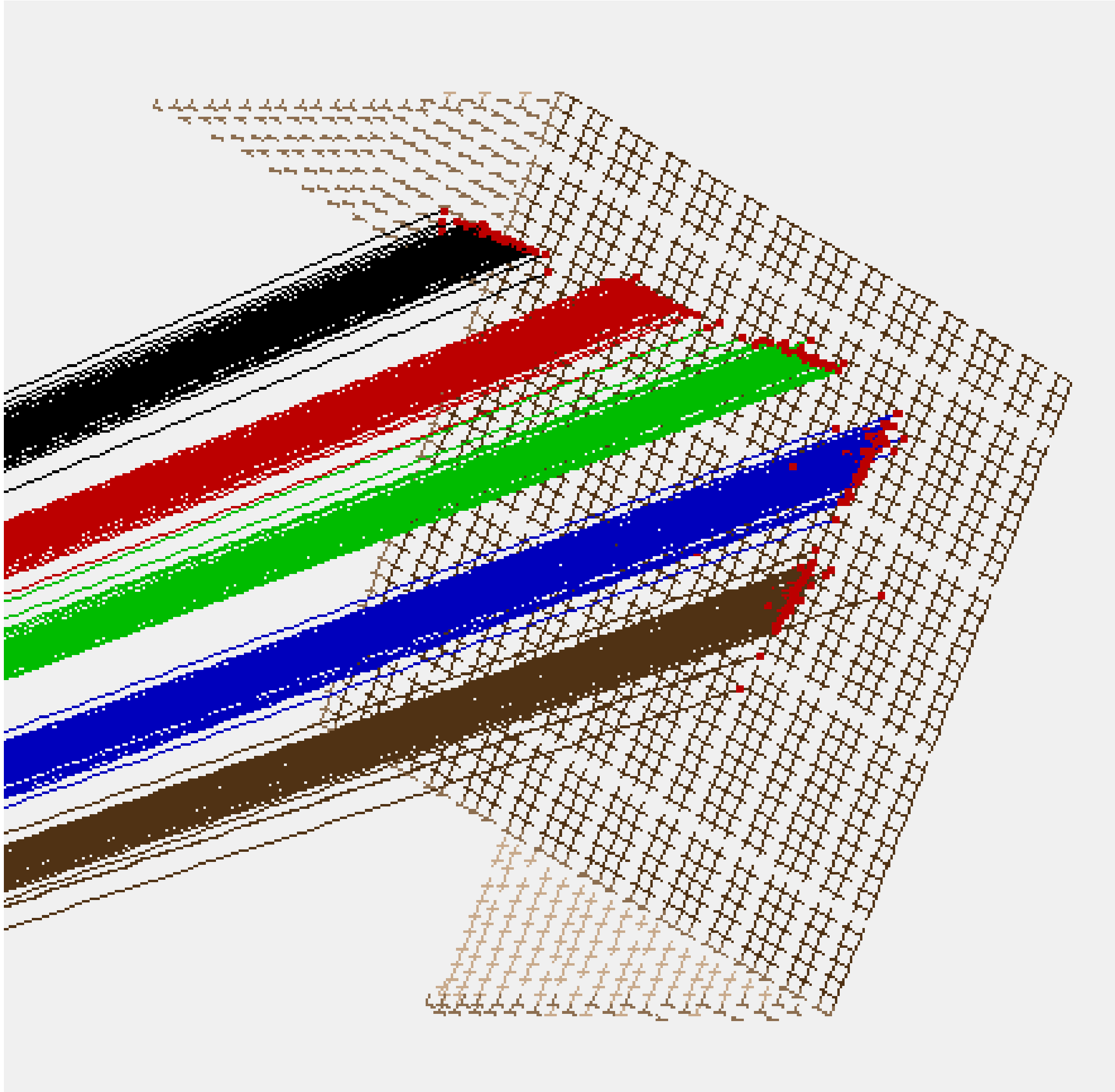
- Provides means of mass identification of superheavy nuclei behind gas-filled spectrometer
- remove recoils from focal plane
- deliver small beam spot to detector
- Contracted with Guy Savard at ANL to provide gas catcher and RFQs
- Currently designing two different mass analyzers



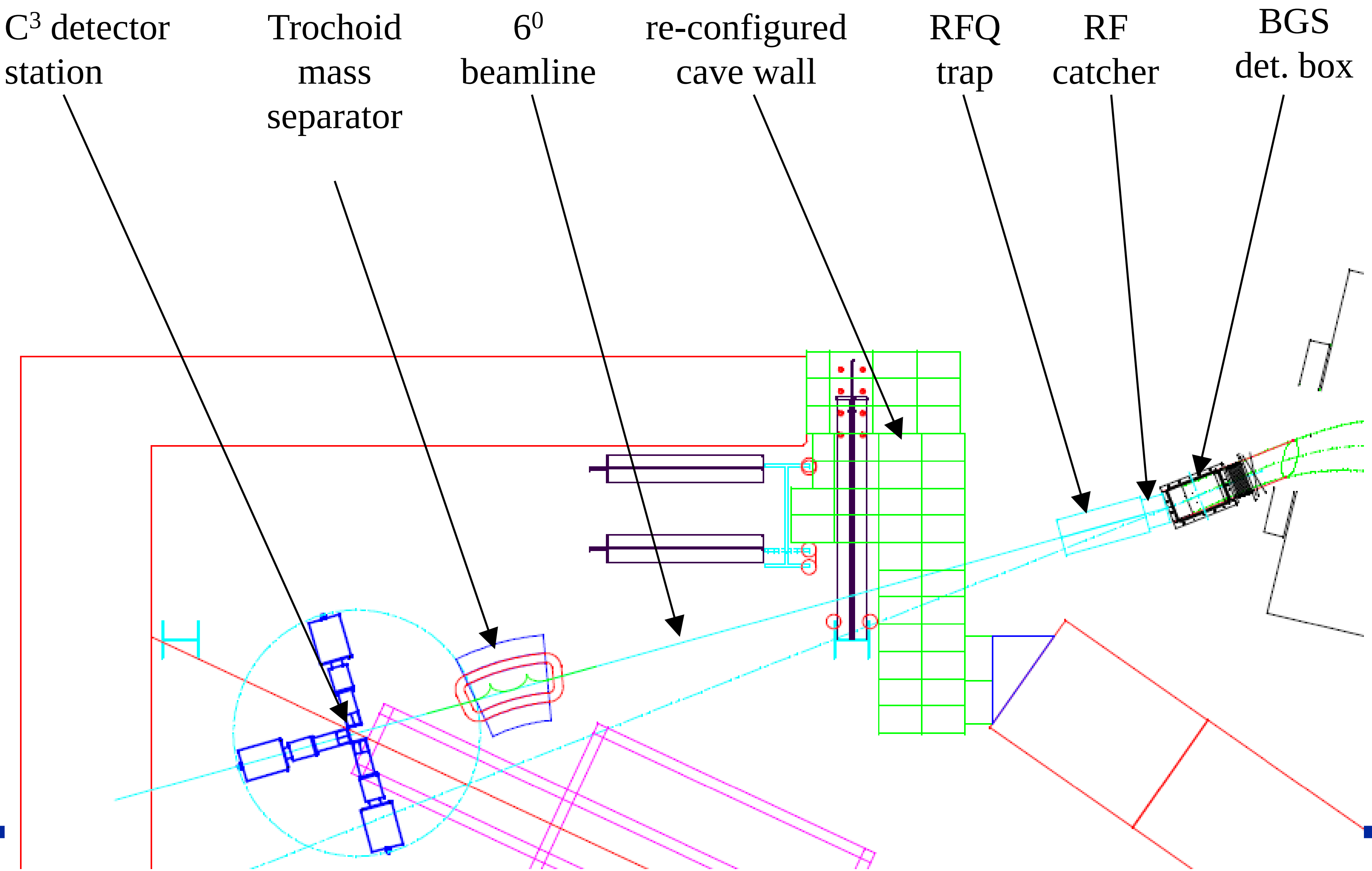
Trochoid Separator



Trochoid Separator



Mass Analysis Detector Facility Layout



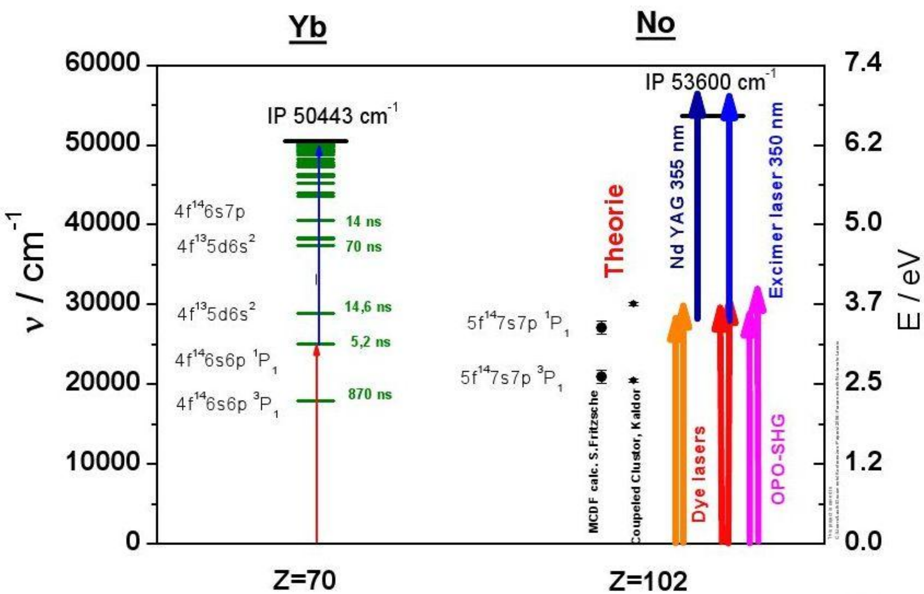
Heavy Element Laser Spectroscopy

Science

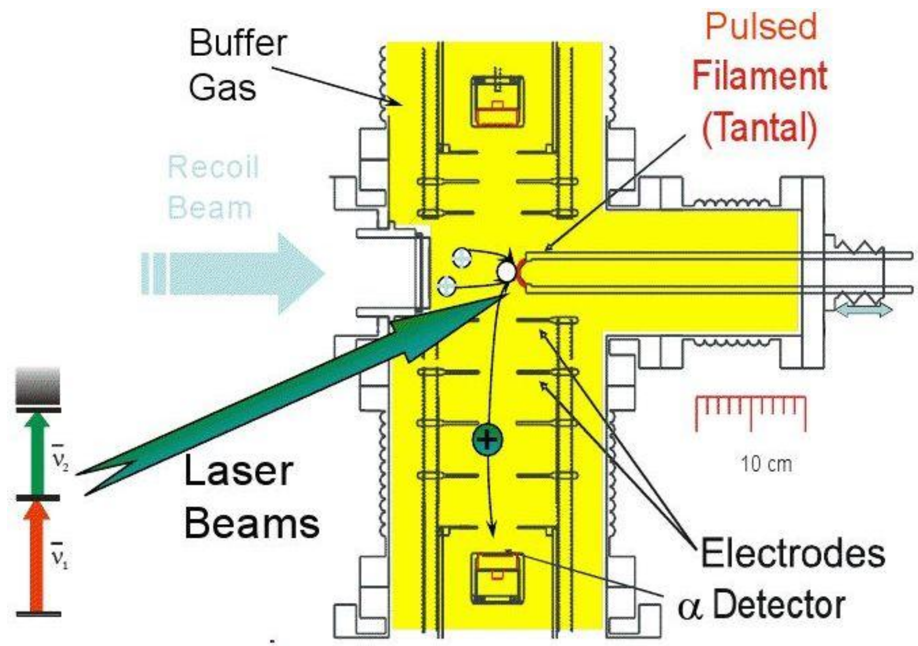
a) Ionization energies
b) Isotope shifts
c) Nuclear magnetic moments
d) Quadrupole moments

No excitation scheme

comparison w/ atomic theory



[Xe]$4f^{14}6s^2\ {}^1S_0$ [Rn]$5f^{14}7s^2\ {}^1S_0$



Technique

1) Stop ions in a buffer gas cell.
2) Collect charged ions on Ta filament.
3) Re-evaporate as neutral atoms.
4) Two- or three-step laser ionization.
5) Collect ions on α-detector & watch decay.

Summary and Conclusions

What we have done:

- Confirmation of element 114
- New isotope of 114 and its daughters
- Isomer studies on 11 nuclides

In the near future:

- New CCC focal plane detector currently being commissioned
- GRETINA@BGS beginning September 2011
- Building and commissioning new mass analysis and detector facility beginning in Summer 2012
- Laser spectroscopy beginning in 2014