Superheavy Elements at SPIRAL2/GANIL

J. Piot for the

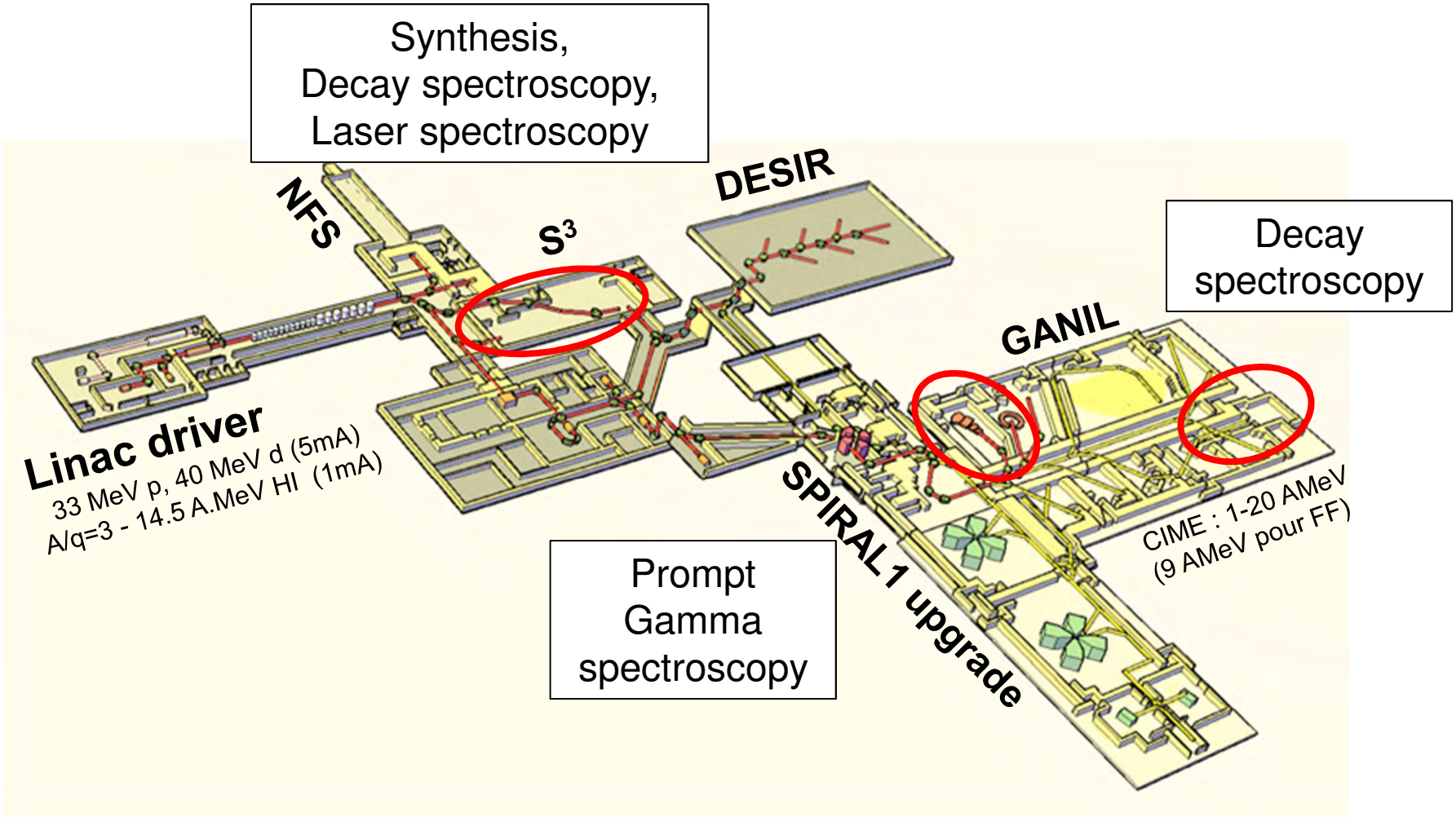
E656-686 Collaboration

VAMOS-GFS Collaboration
And S3 Collaboration

TASCA 14 – Oct 21, 2014 - GSI, Darmstadt

GANIL / SPIRAL 2

Various locations available depending on the Physics Case



Decay Spectroscopy at LISE

Restarting the old toys

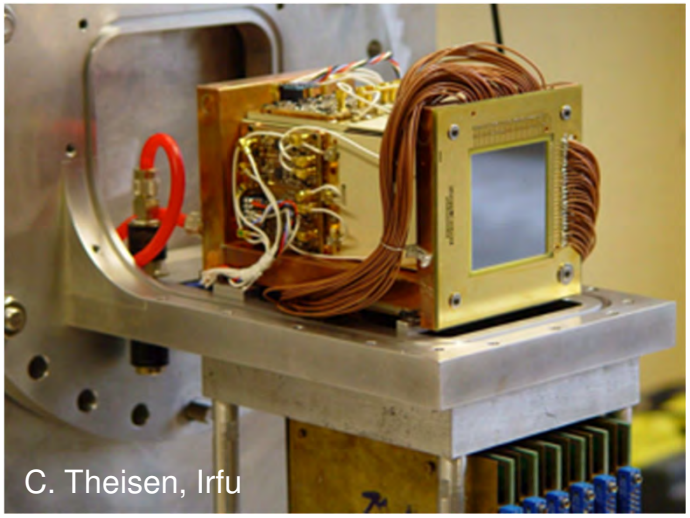
Decay spectroscopy at LISE

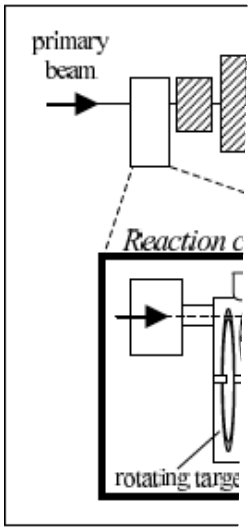
FULIS Mode

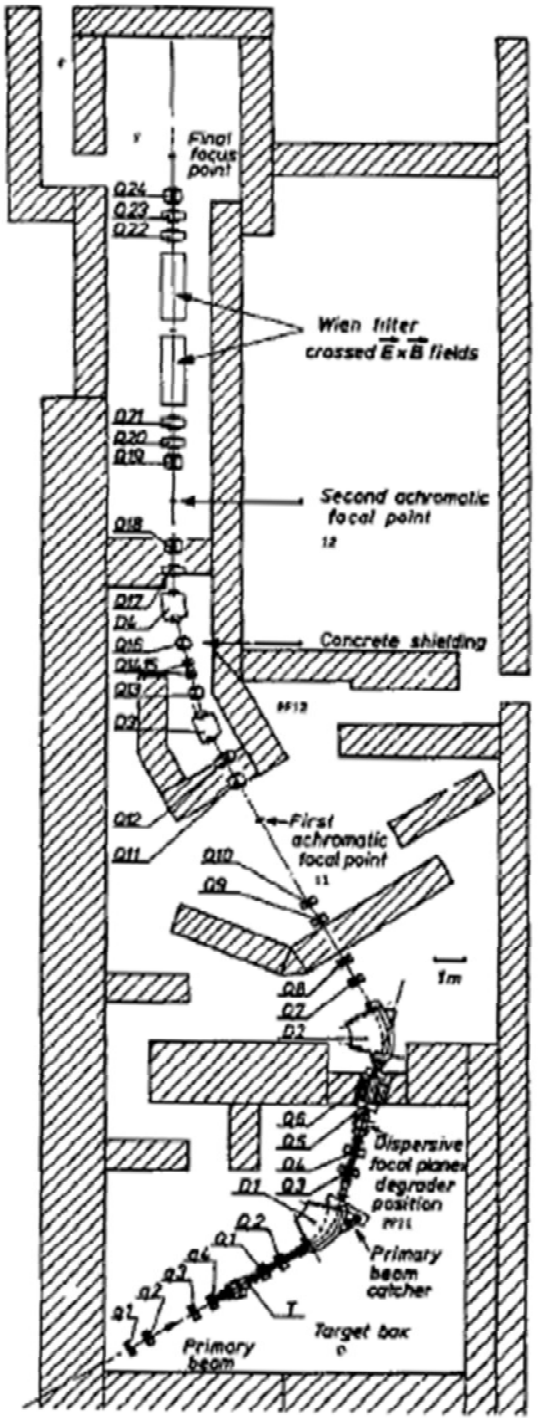
Use the Wien Filter of LISE as a recoil separator

Rotating target for low fusion point targets

Recoil Decay Tagging Measurements







R. Anne, NIMB 70 (1992) 276

S. Grévy, JNRS 3 (2002) 9

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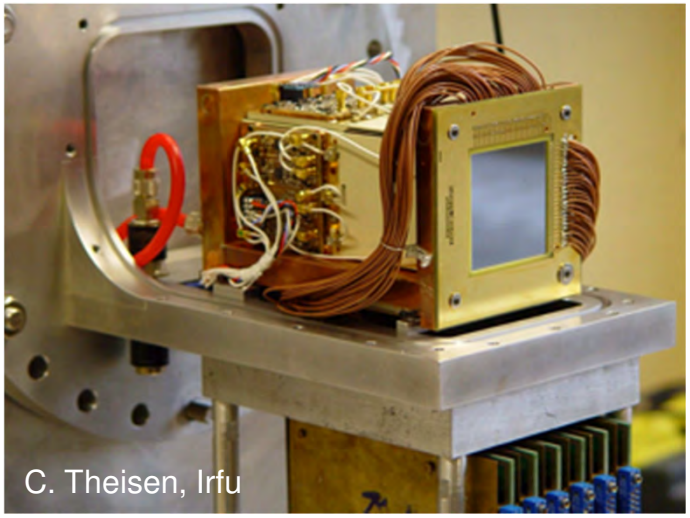
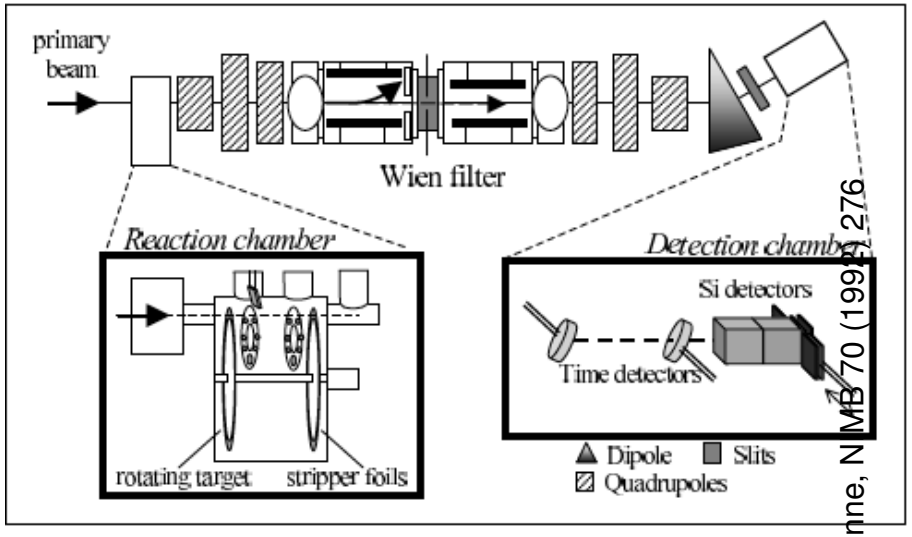




R. Anne, NIMB 70 (1992) 276

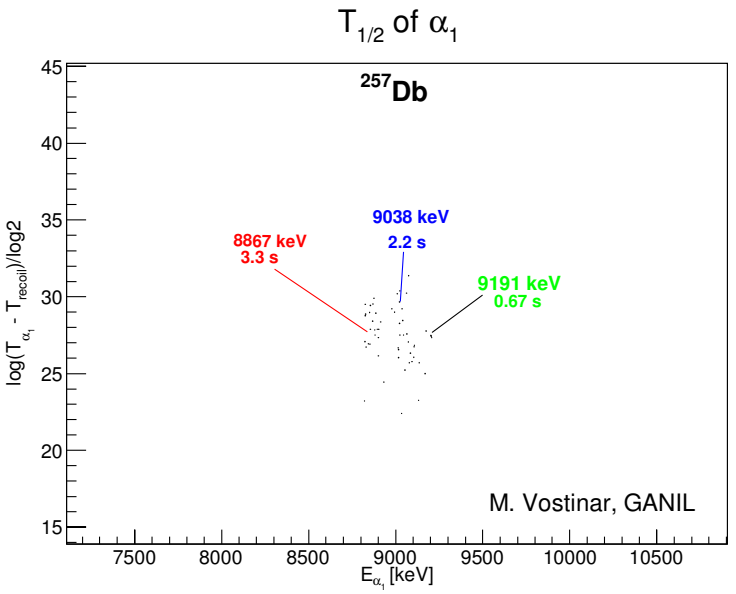
S. Grévy, JNRS 3 (2002) 9

Decay spectroscopy of ^{257}Db

First attempt in 2013 :

450 pnA of ^{50}Ti on target
Incomplete due to leaks in the cooling system

58 Re-α-α events observed



Second attempt scheduled for 2015 :

New detector MoDSS
Thinner ToF foils

Electronics & detectors currently in test

Prompt γ spectroscopy at VAMOS

Pressing on the gas

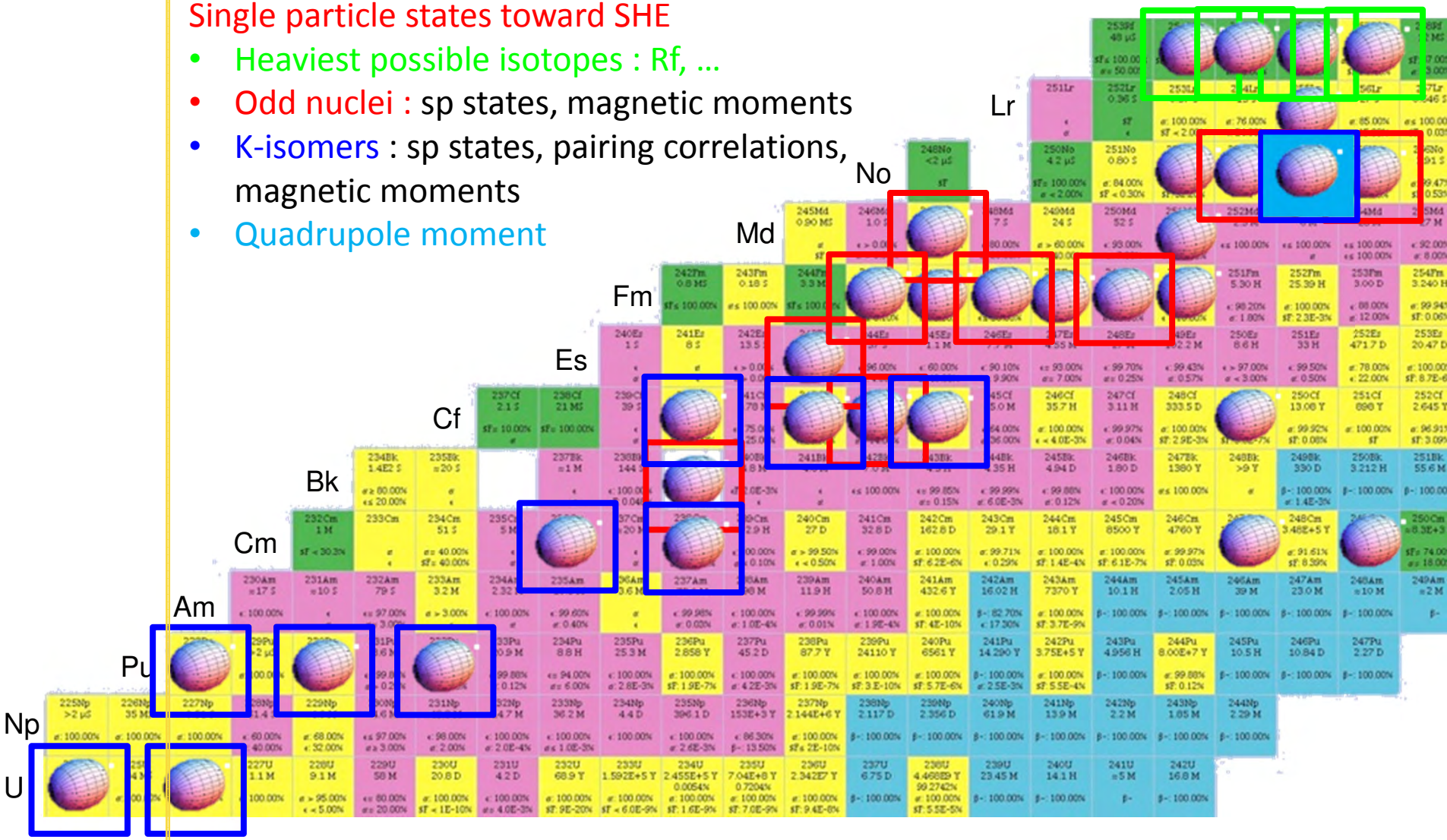
Prompt γ spectroscopy with VAMOS Gas-filled

- Goal : provide a device for prompt spectroscopy of heavy/exotic/rare nuclei using fusion-evaporation reactions
  - Large Physics case
  - AGATA / EXOGAM2 : state of the art spectrometer
  - AGATA@GANIL : a fantastic opportunity
  - Zero degree separator/spectrometer needed, but none available at GANIL
    - S3 not compatible with prompt spectroscopy
    - LISE (FULIS) not compatible with prompt spectroscopy
    - VAMOS Wien Filter mode has poor performances
  - Coupling of AGATA with a zero degree separator
    - Not at Legnaro
    - Not at GSI
    - Not at ISOLDE
    - JYFL campaign is not foreseen
  - Our proposal : VAMOS → VAMOS-GFS

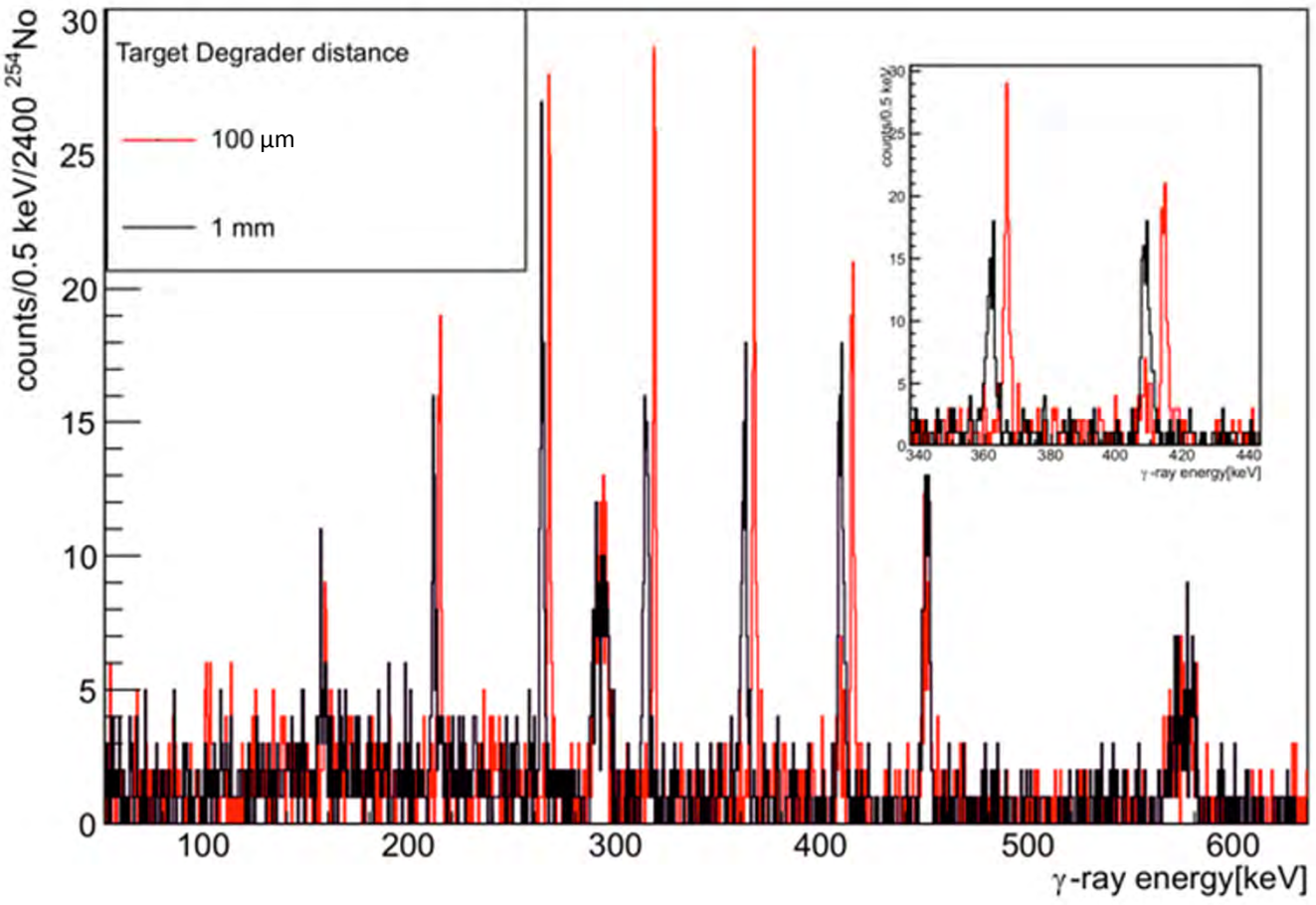
Heavy nuclei : the dream list

Single particle states toward SHE

- Heaviest possible isotopes : Rf, …
- Odd nuclei : sp states, magnetic moments
- K-isomers : sp states, pairing correlations, magnetic moments
- Quadrupole moment



Simulation lifetime measurement ^{254}No



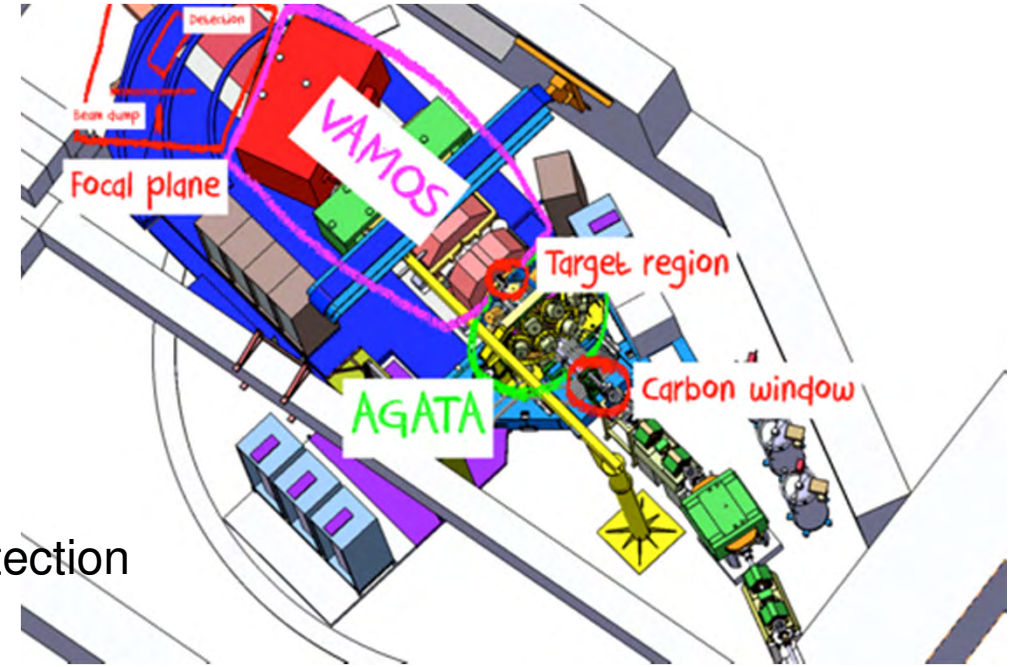
J. Ljungvall, CSNSM

^{48}Ca(^{208}Pb,2n)^{254}No

Simulations made of g.s.b populated at 18+, 2400 detected ^{254}No ions, 10 random rays/ion and Au Coulex. 48 hours of beam time.

The VAMOS-GFS upgrade

Improvements needed to run routinely and achieve best performance compared to 2009 test



1. Focal plane
   - Beam dump
   - MUSETT & ToF detection
   - Detection shielding

   → New focal plane chamber
2. Low pressure regulation
3. Transition He - vacuum
   - C Window
4. Adaptation of AGATA target chamber

S^3

Beam me up Scotty !

SPIRAL 2

Phase1

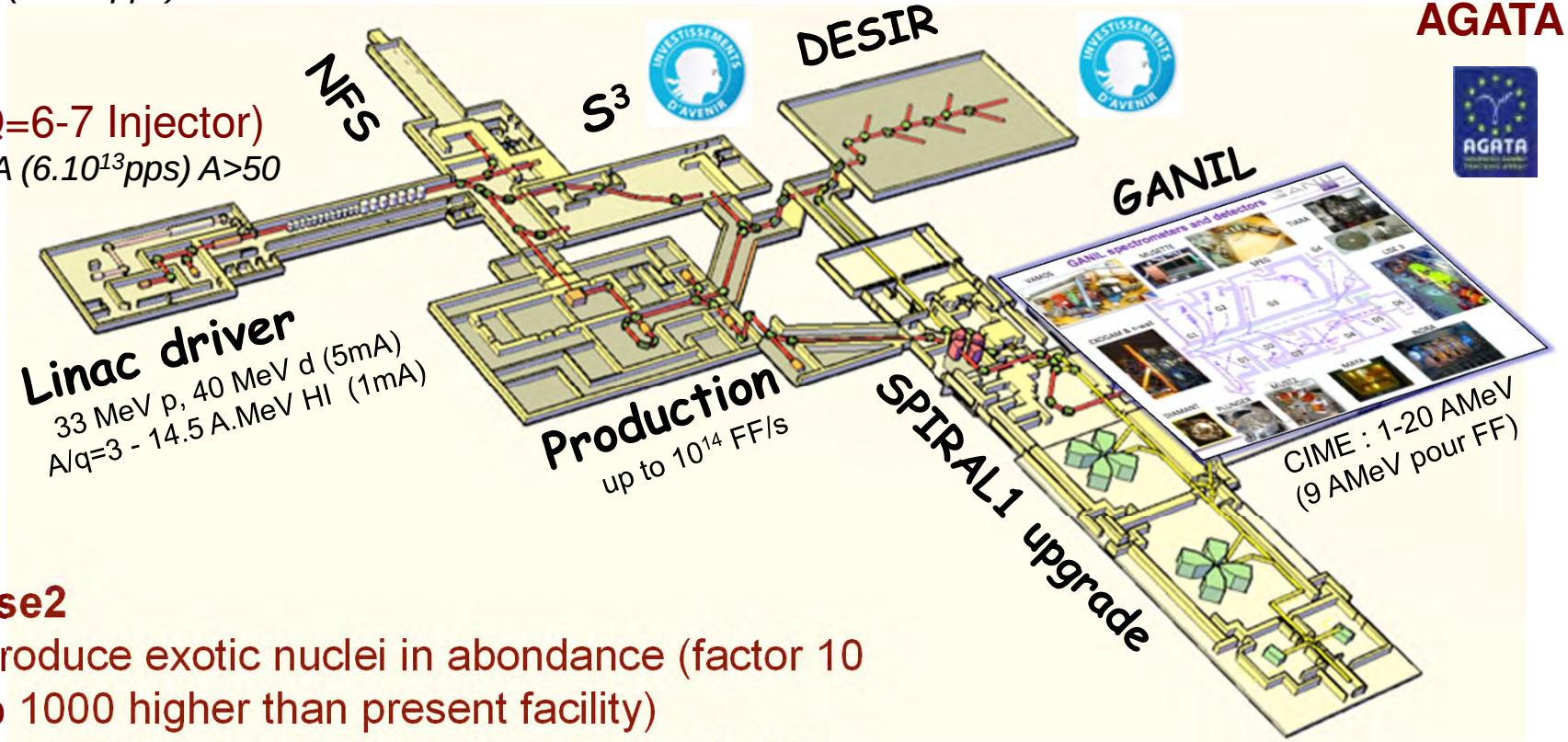
Increase the intensity of stable beams by a factor 10 to 100 – High intense neutron source

10pμA (6.10^{13}pps) A<50

DESIR
(low energy facility)

AGATA

(A/Q=6-7 Injector)
10pμA (6.10^{13}pps) A>50



Phase2

- Produce exotic nuclei in abondance (factor 10 to 1000 higher than present facility)
- Expand the range of exotic nuclei to A≥80
- Post-acceleration of high intensity RIB

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

SPIRAL 2

Phase1

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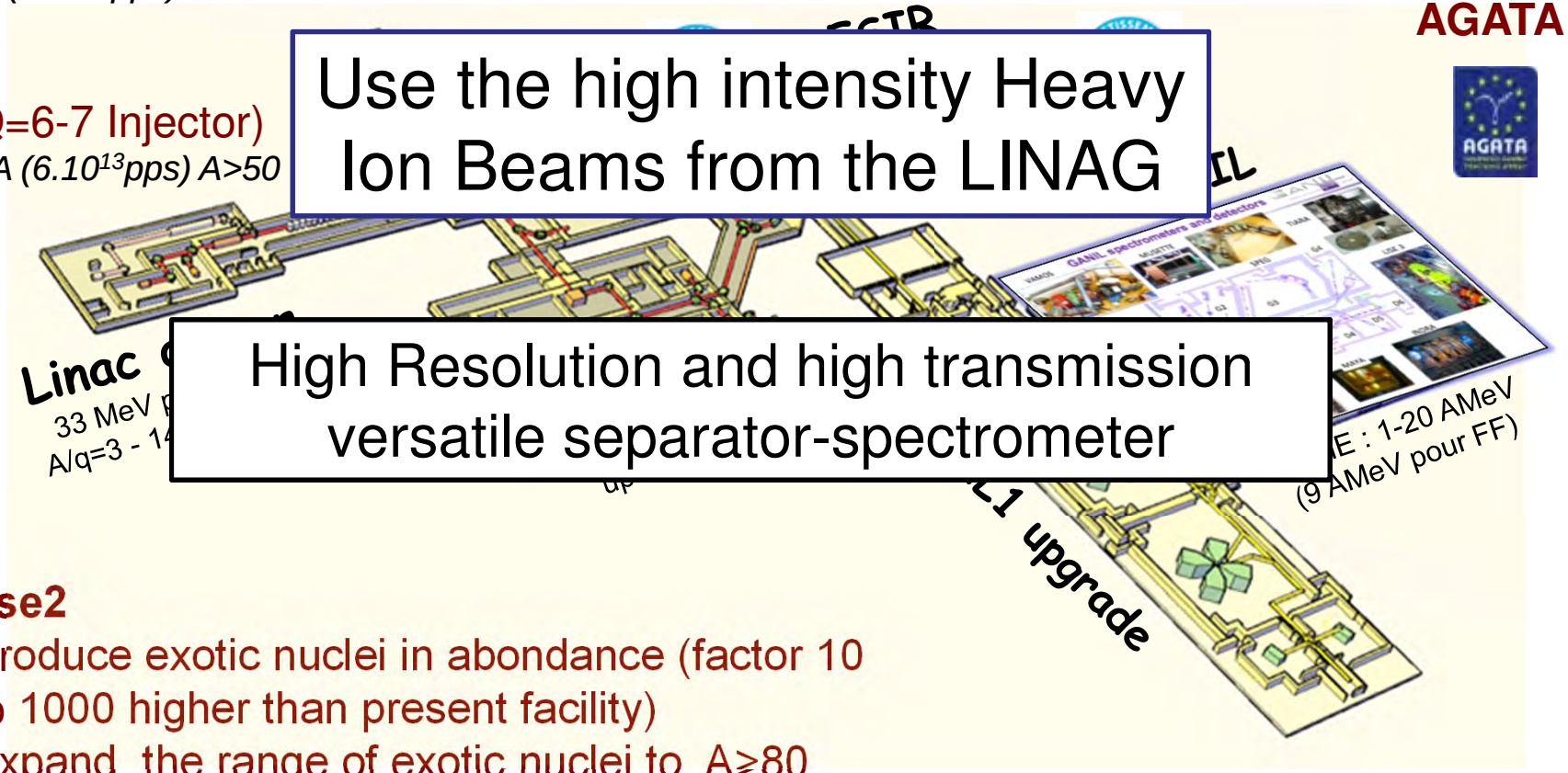
AGATA

(A/Q=6-7 Injector)

10pμA (6.10^{13}pps) A>50

Use the high intensity Heavy Ion Beams from the LINAG



High Resolution and high transmission versatile separator-spectrometer

Phase2

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S3

Beam dump & Movable fingers

Momentum Achromat

Rejection : 10^{13} at 0°
Acceptance:
➔ ± 60 mrad in X and ± 80 mrad Y
➔ Bρ acceptance +/- 10%
➔ 5 charge states transmitted
^{58}Ni+^{46}Ti ⊗ ^{100}Sn + 4n :
➔⊗M/M ~ 300 & 55% transmission

High power Rotating targets including actinides

Mass Separator

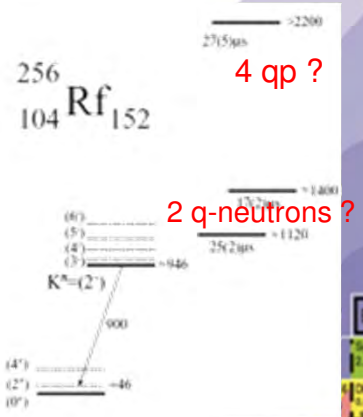
Brushing slits

Large acceptance SC Multipoles

SHE Studies *Extracted from the S³ day1 Letters of Intent*

PRODUCTION AND SPECTROSCOPY OF HEAVY AND SUPERHEAVY ELEMENTS USING S³ AND LINAG (P. GREENLEES, JYVÄSKYLÄ)

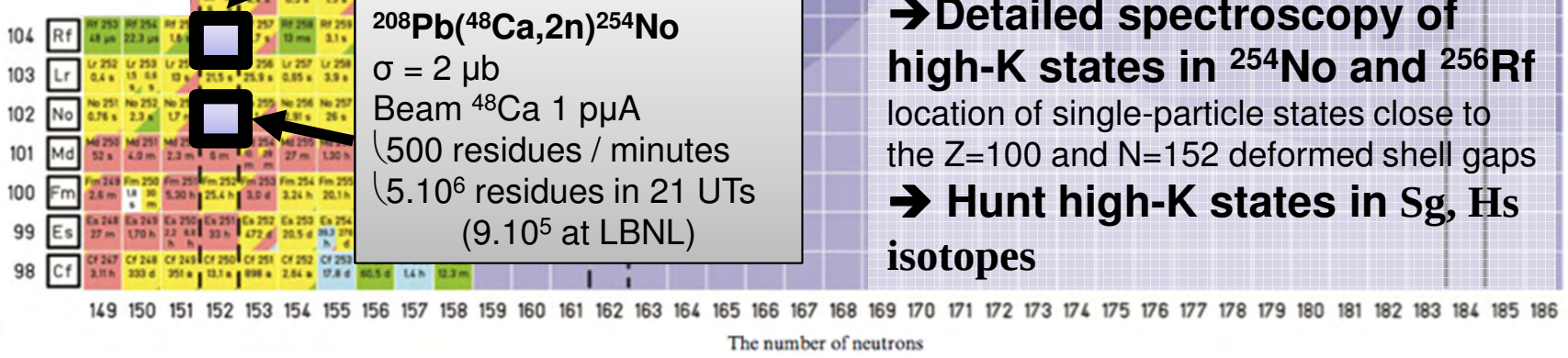
- Isomerism studies in the Z=100-110 region (^{254}No,^{256}Rf,…)
- Production of SHE from Z=104 to 112 with U target
- Study of Z=115 via de reaction ^{48}Ca + ^{243}Am



^{208}Pb(^{50}Ti,2n)^{256}Rf
σ = 17 nb
Beam ^{50}Ti 1 pμA
\4,6 residues / minutes
\45000 residues in 21 UTs
(5400 at LBNL)

^{208}Pb(^{48}Ca,2n)^{254}No
σ = 2 μb
Beam ^{48}Ca 1 pμA
\500 residues / minutes
\5.10^{6} residues in 21 UTs
(9.10^{5} at LBNL)

➔Detailed spectroscopy of high-K states in ^{254}No and ^{256}Rf
location of single-particle states close to the Z=100 and N=152 deformed shell gaps
➔ Hunt high-K states in Sg, Hs isotopes



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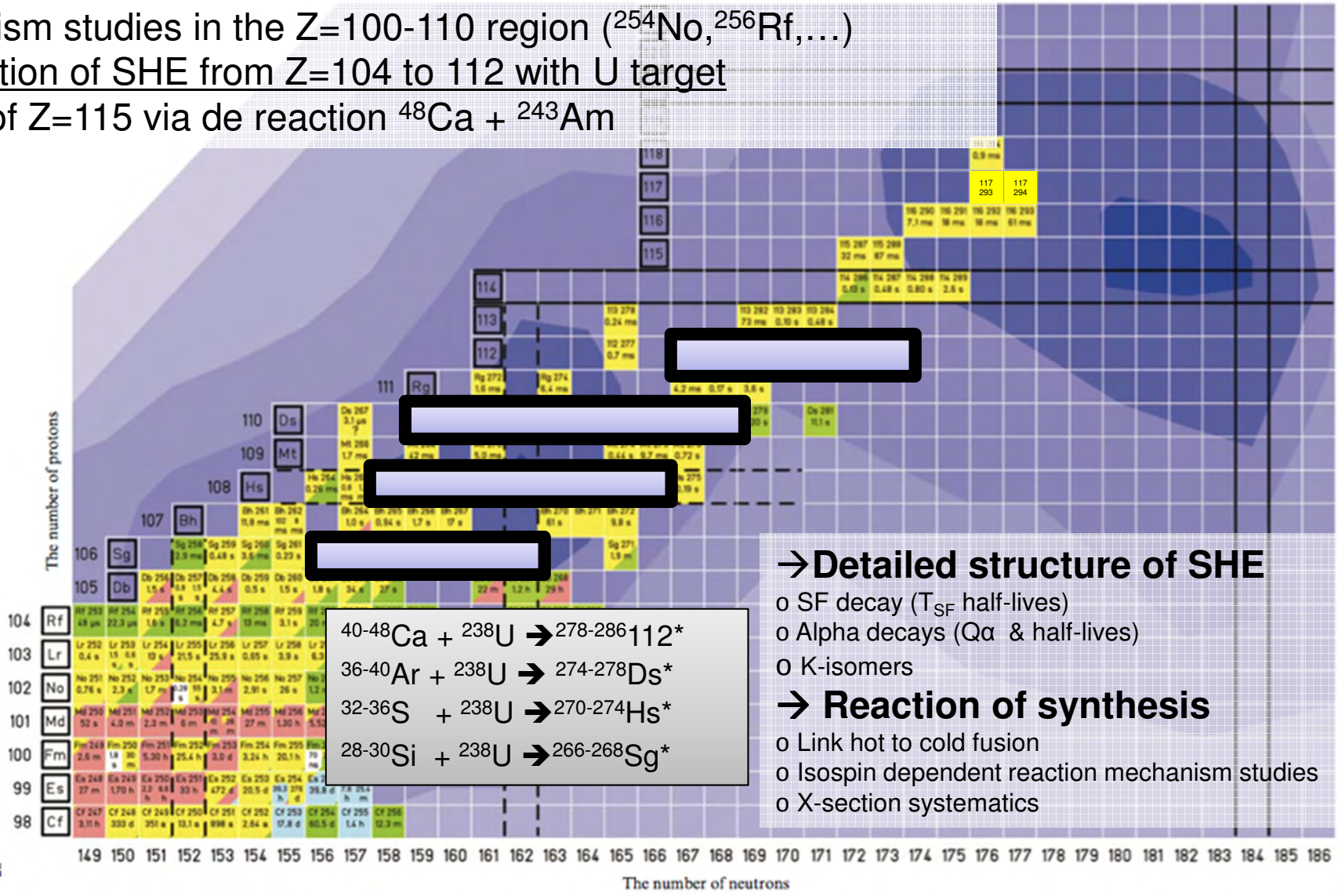

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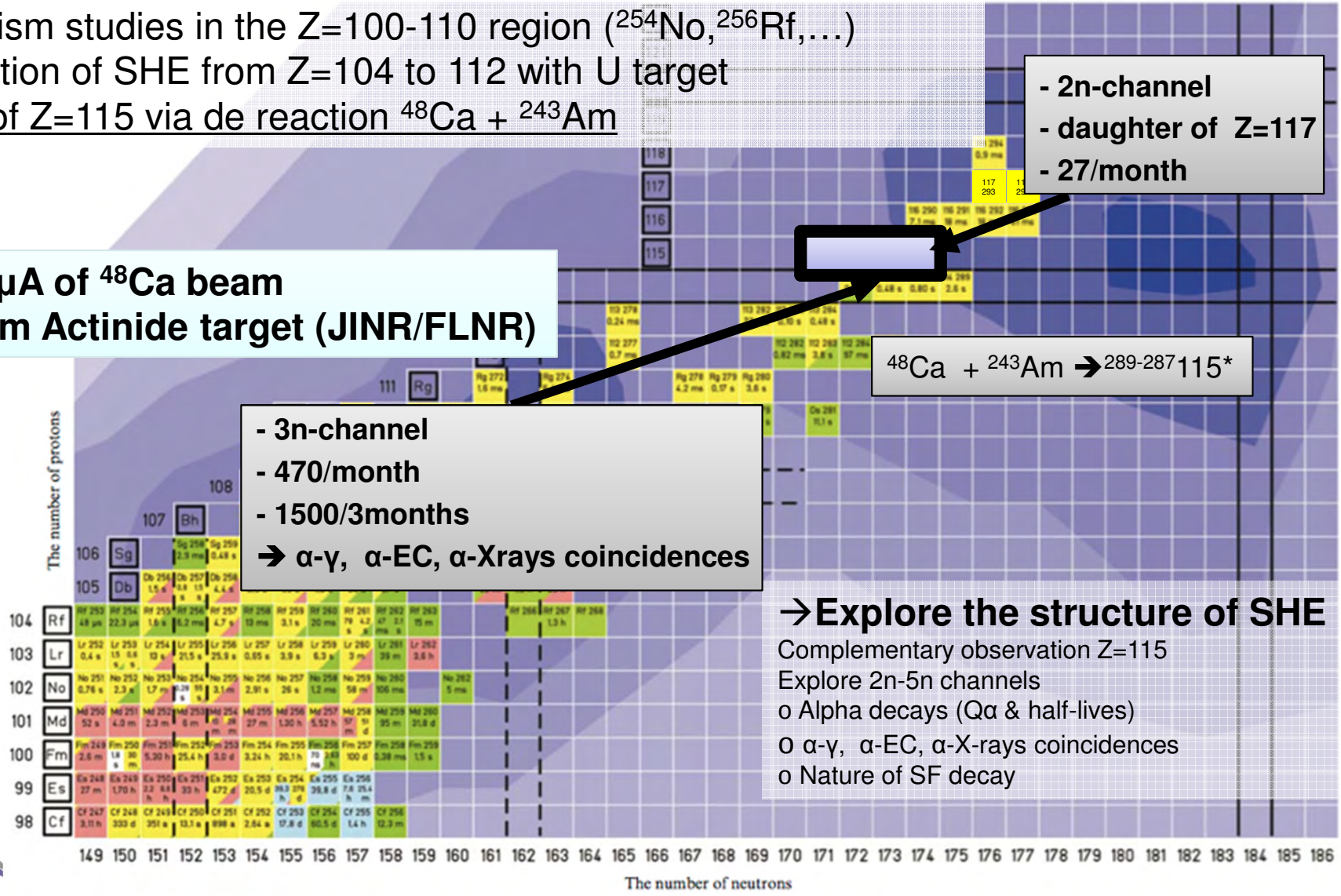
➔ 10pμA of ^{48}Ca beam
➔ ^{243}Am Actinide target (JINR/FLNR)

- 2n-channel
- daughter of Z=117
- 27/month

^{48}Ca + ^{243}Am ➔ $^{289\text{-}287}$115*

- 3n-channel
- 470/month
- 1500/3months
➔ α-γ, α-EC, α-Xrays coincidences

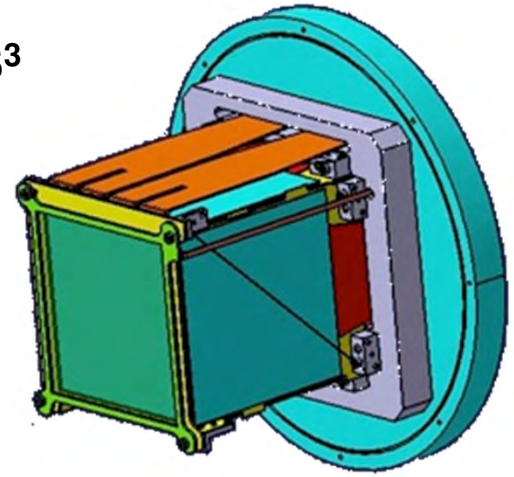


➔Explore the structure of SHE

Complementary observation Z=115
Explore 2n-5n channels
o Alpha decays (Qα & half-lives)
o α-γ, α-EC, α-X-rays coincidences
o Nature of SF decay

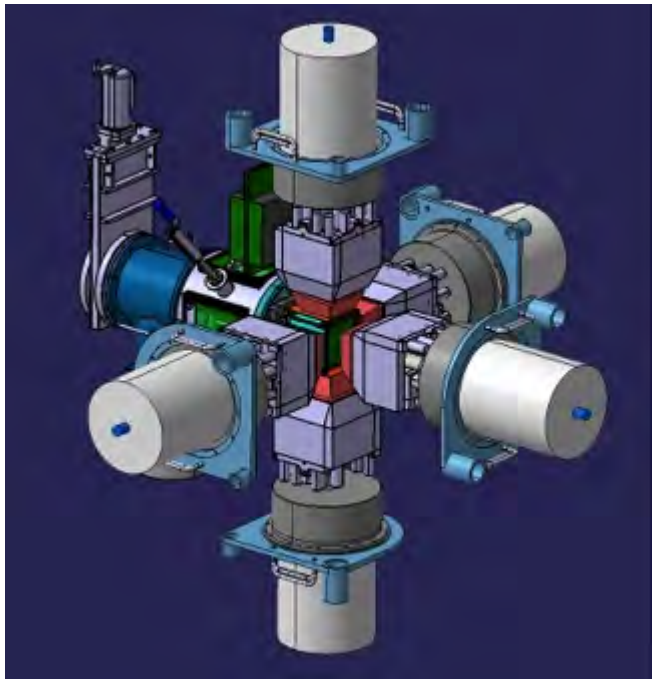
Decay Spectroscopy : SIRIUS

System for the Investigation of Recoiling Ions Using S^3



Decay spectroscopy for rare events

- Recoil-decay tagging
- Escape particles reconstruction
- Short decay times
- High gamma efficiency



- **Bi-gain** front-end electronics for short decay times
- **<50 nm** window Si detectors
- **e-** / **Alpha discrimination** through PSA
- Close Ge array
- **Ions tracking** for mass separation

Implantation-decay station

Tracker detectors

Test with MWPC and Secondary Electron detectors

- Position resolution : 0.7mm FWHM
- Time resolution : 250ps FWHM

Very thin emissive foils built : 0.15µ

High-dynamics Front-End electronics

- Floating point CSA Asic
- Digital Feedback CSA

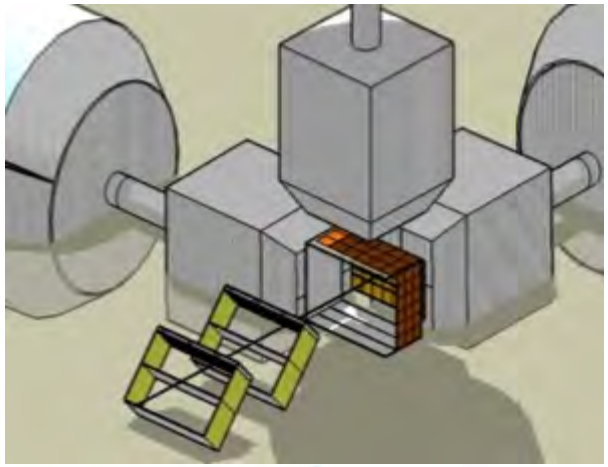
→ test with a detector in progress

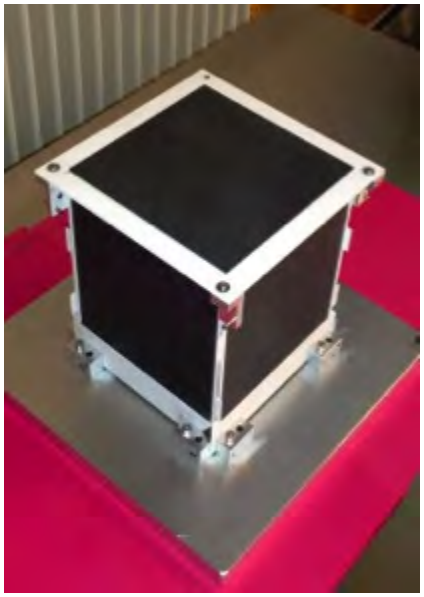
Back-end electronics

- NUMEXO2

Gamma-array

- 4 EXOGAM clovers
- CLODETTE Clover at back
- E ~ 38% @ 100 keV





Silicon Detectors

- Aluminum frame for the Si box
- Detector produced
- Resolution with Jordanov 16keV (FWHM)

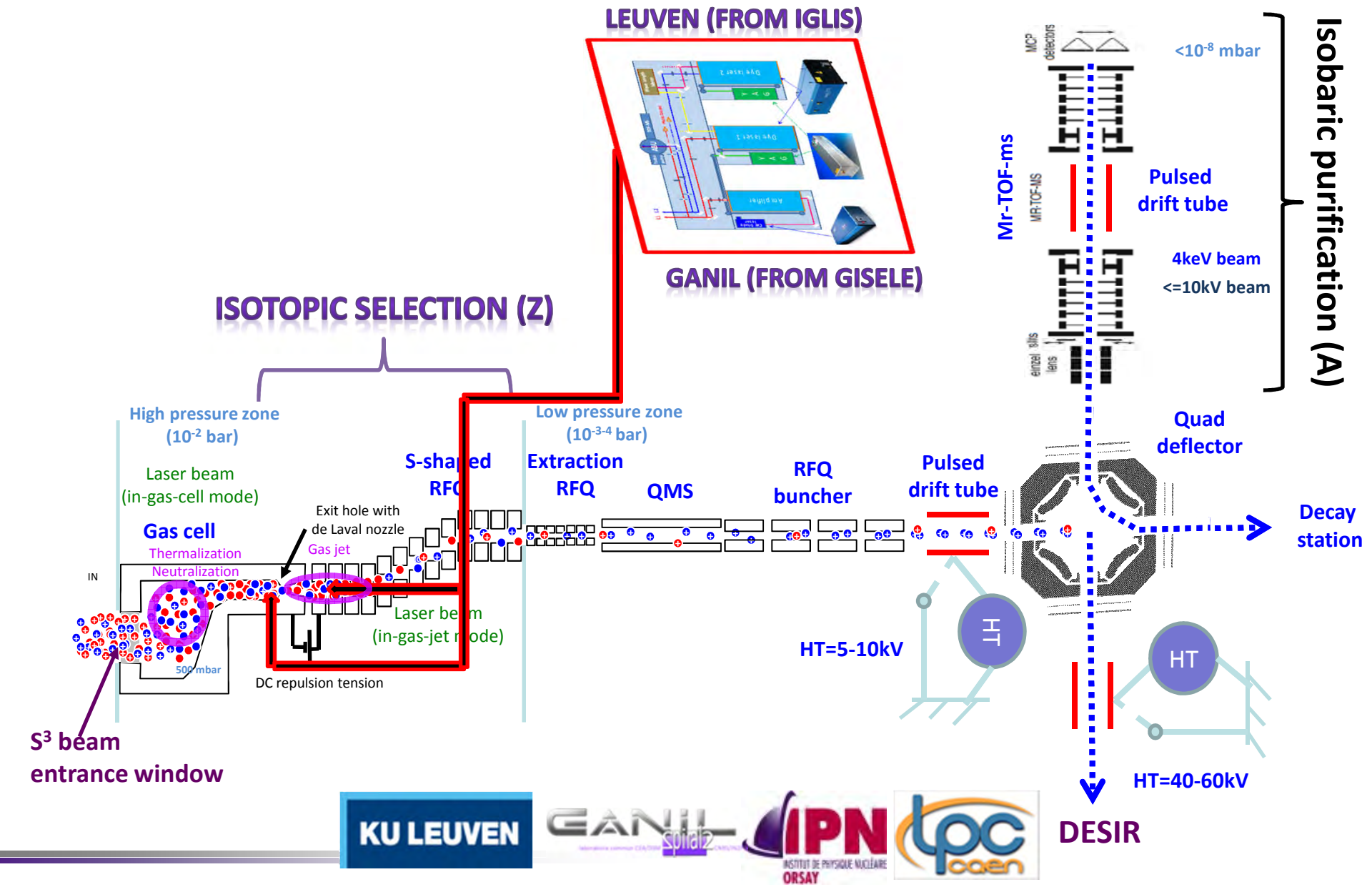
Low Energy Branch – REGLIS^3

- Use S^3 as first selection stage
- Access to fusion-evaporation residues
- In gas-jet or in gas-cell ionisation
- Custom designed gas-cell
- High repetition rate lasers

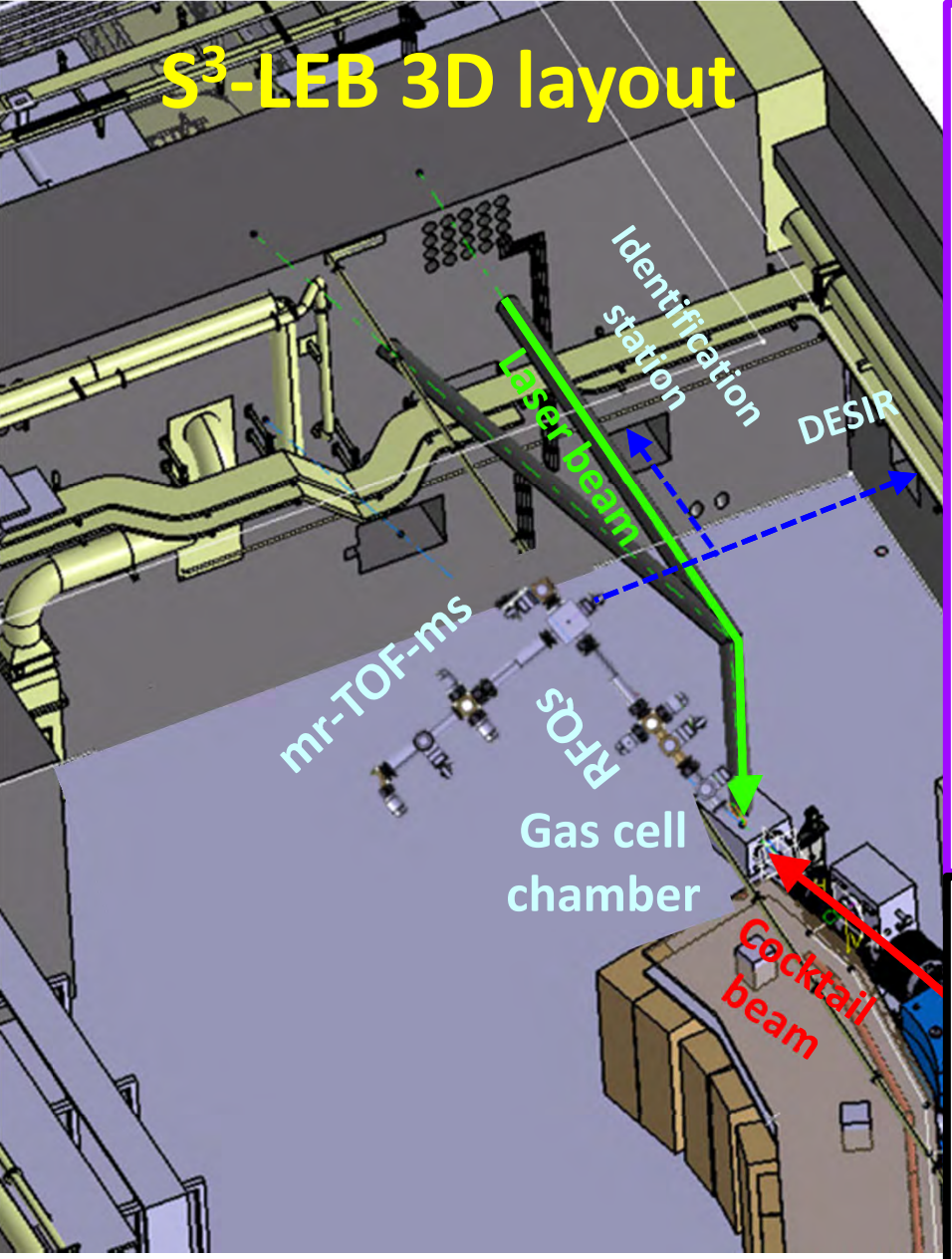
Measure the spins, mean charge radius, quadrupole moment and magnetic moment of rare nuclei

Letters of intent for Day 1: ^{94}Ag, ^{215}Ac, ^{80}Zr, ^{100}Sn

Low Energy Branch



S^3-LEB 3D layout



MAJOR ATTRIBUTS OF THE DEVICE

✓**Efficient :**
produced in very small quantities (-> ~ 1 pps)*

✓**Selective :**
suppression of unwanted isotopes
(1/10 000 lower limit demonstrated)

✓**Relatively fast :**
short life time (up to ~ 250 ms)

✓**Sufficient spectral resolution**
(-> few hundred MHz):
determine the isotope/isomer shift and hyperfine structure, spin, moments…

=> 2 in 1 : Laser spectroscopy + Laser Ion Source (pure (isomeric) beams)

Expected performances

Transmission through S^3	40-50 %
Thermalization, diffusion and transport through the exit hole	50-90 %
Neutralization	50-100 %
Laser ionization	50-60 %
Transport efficiency	80-90 %
Total efficiency	**4-24 %**

R. Ferrer *et al.*, NIMB 317 (2013) 578

* Collinear laser spectroscopy studies require ~ 10^3 pps (better resolution (few MHz) -> better suited to extract moments)

Experimental Techniques

High Resolution mode

- Designed for maximum selection
- Weighted mass resolution: **ΔM/M ~ 300**
- Folded transmission: 55%
  (for $^{48}Ca+^{248}Cm$ ➔ $^{292}116+4n$, *transmission ≈ 40%)*

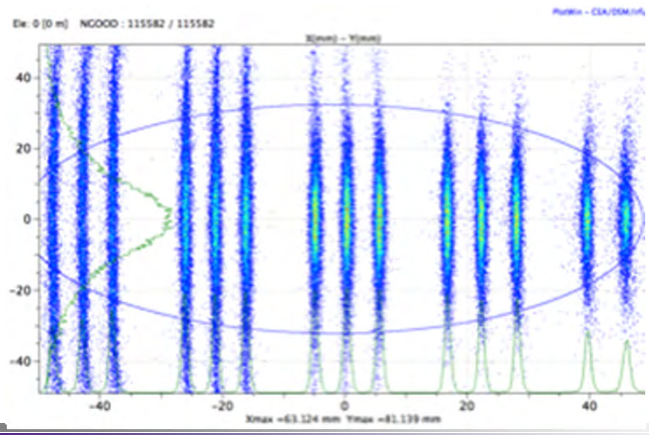
High Transmission mode

- Designed for very asymmetric reactions
- Folded transmission: 15-20% for $^{22}Ne + ^{238}U$ ➔ $^{255}No + 5n$

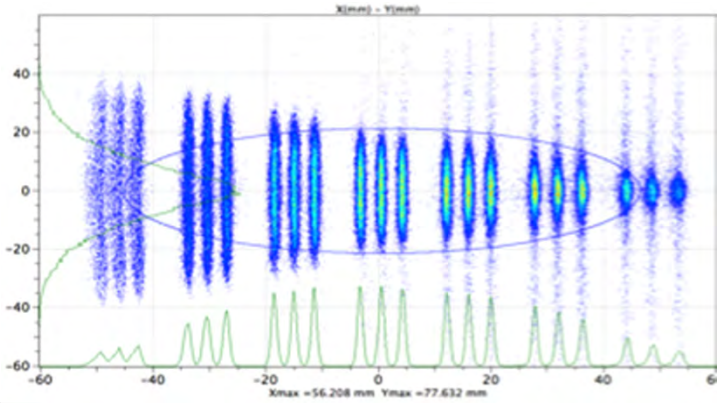
Converging mode

- Designed for Laser spectroscopy
- Folded transmission: 68% for $^{58}Ni + ^{40}Ca$ ➔ $^{94}Ag + p3n$

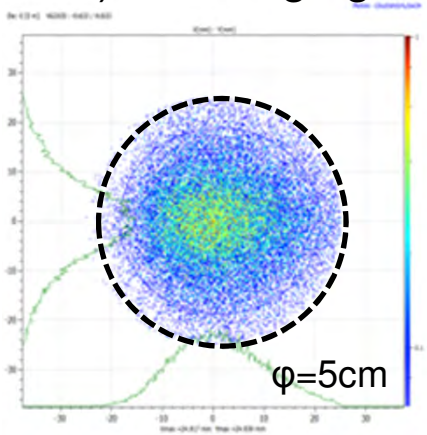
1) High resolution



2) High transmission



3) Converging



Experimental Techniques

Image 1
Highly selective
beam rejection

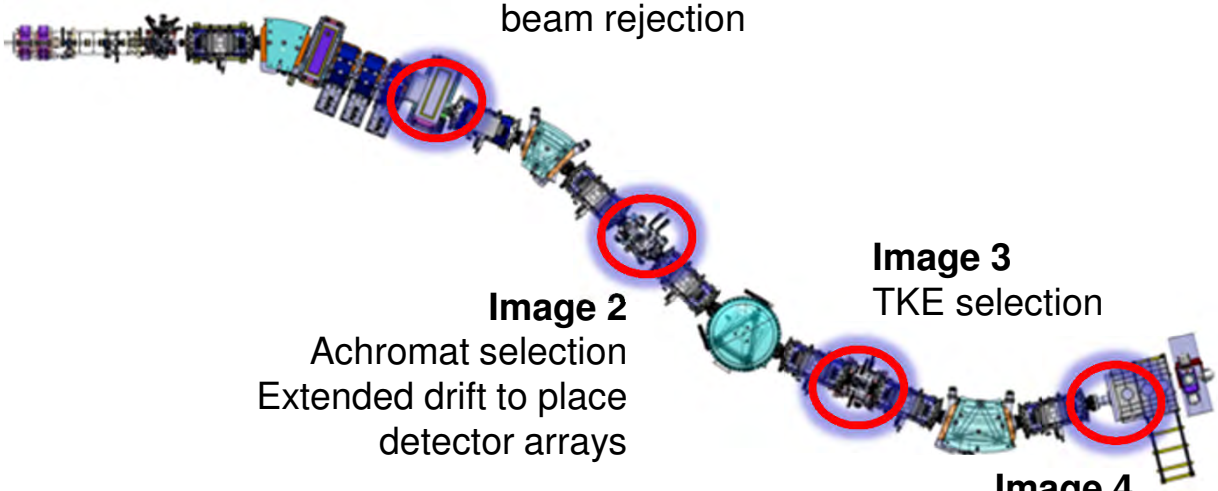
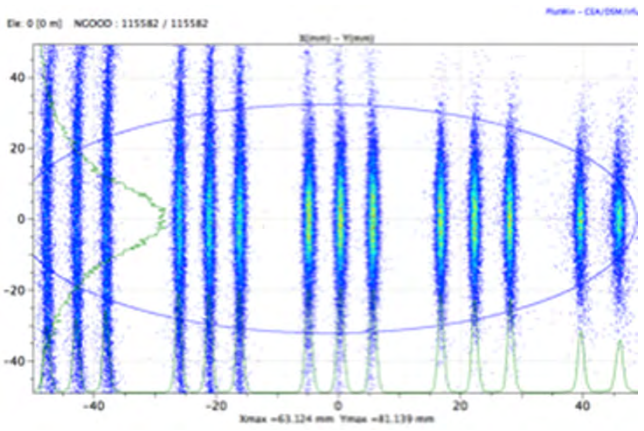


Image 2
Achromat selection
Extended drift to place
detector arrays

Image 3
TKE selection

Image 4
Δ(M/Q) ≈ 300

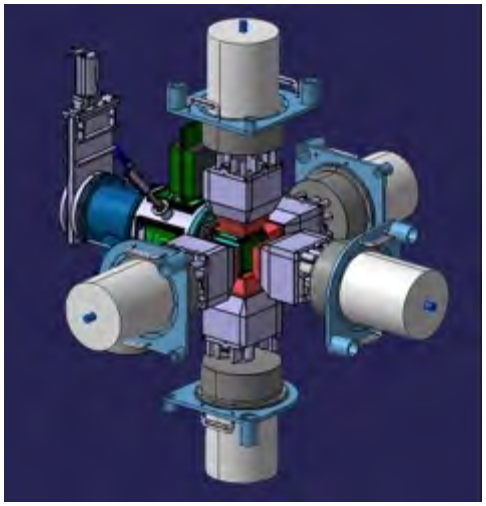


PHASE 0 - Delayed spectroscopy (VHE-SHE,N=Z)
p, α, γ, e- decay
Implantation-decay station at the mass dispersive plan

$^{50}Ti+^{208}Pb->^{256}Rf$ (SHE spectroscopy)
$^{58}Ni+^{54}Fe->^{108}Xe-^{104}Te-^{100}Sn$ (super-allowed α-decay chain)

Commissioning & first experiments
➔*MUSETT*

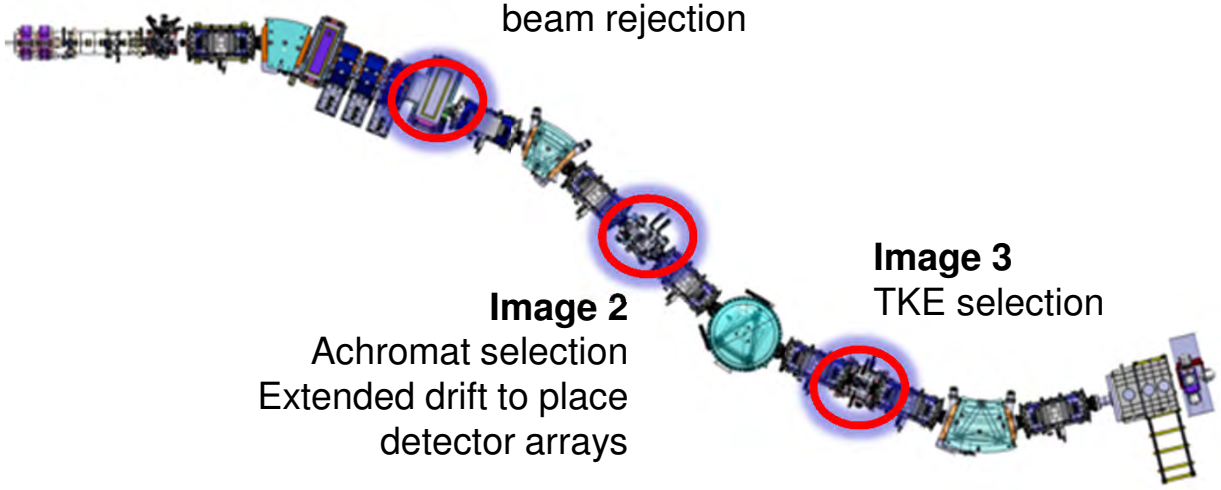
PHASE 1.1 World class experiments
➔*SIRIUS*



SIRIUS
(GANIL,Irfu,CSNSM,IPHC)

Experimental Techniques

(GANIL,LPC,IPNO,K.U.LEUVEN, …)



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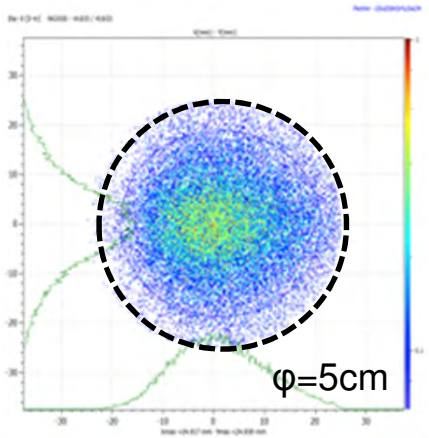

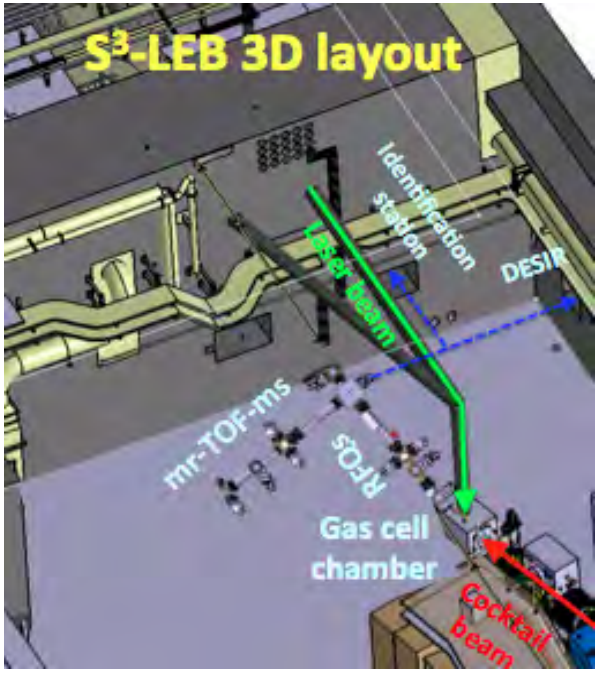

PHASE 1.2 Gas Catcher (S3-LEB)
ANR REGLIS3/ERC HELIOS + mr-TOF-ms +ID station

Ground state property measurements of very rare events
➔Decay spectroscopy (N=Z)
➔Laser spectroscopy (HFS of $^{94-96}$Ag, $^{101-105}$Sn, trans-actinides)
➔Mass measurement (ex: ^{100}Sn)

Laser ion source RIB production
➔DESIR

Thank you For your Attention

ANL (US), CENBG(France), CSNSM (France), JINR-FLNR, (Russia), GANIL (France), GSI (Germany), INFN Legnaro, (Italy), IPHC (France), IPNL (France), Irfu CEA Saclay, IPNO (France), JYFL (Finland), K.U. Leuven (Belgium), Liverpool-U, (UK), LNS (Italy), LPSC (France), MSU (US), LMU, (Germany), Nanjing-U (China), Northern Illinois University (US), SAS Bratislava, (Slovaquia), IFJ PAN Cracow (Poland), Smoluchowski Institute (Poland), CEA-DAM (France), SUBATECH (France), TAMU (US), U.Mainz (Germany), York-U (UK), Vinca Institute (Serbia)