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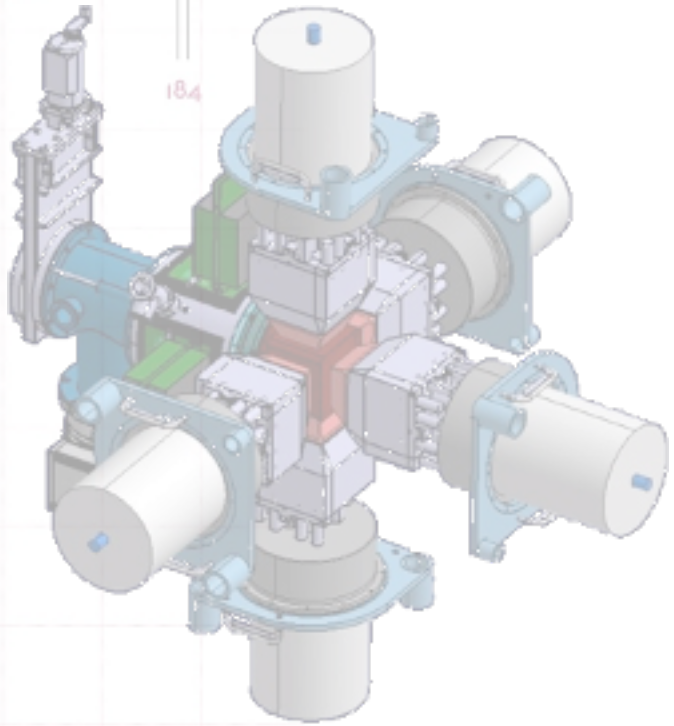
On behalf of the SIRIUS Collaboration

ISOL–France meeting
Online, 19th 2021

Towards the superheavy elements at S³
Status of SIRIUS

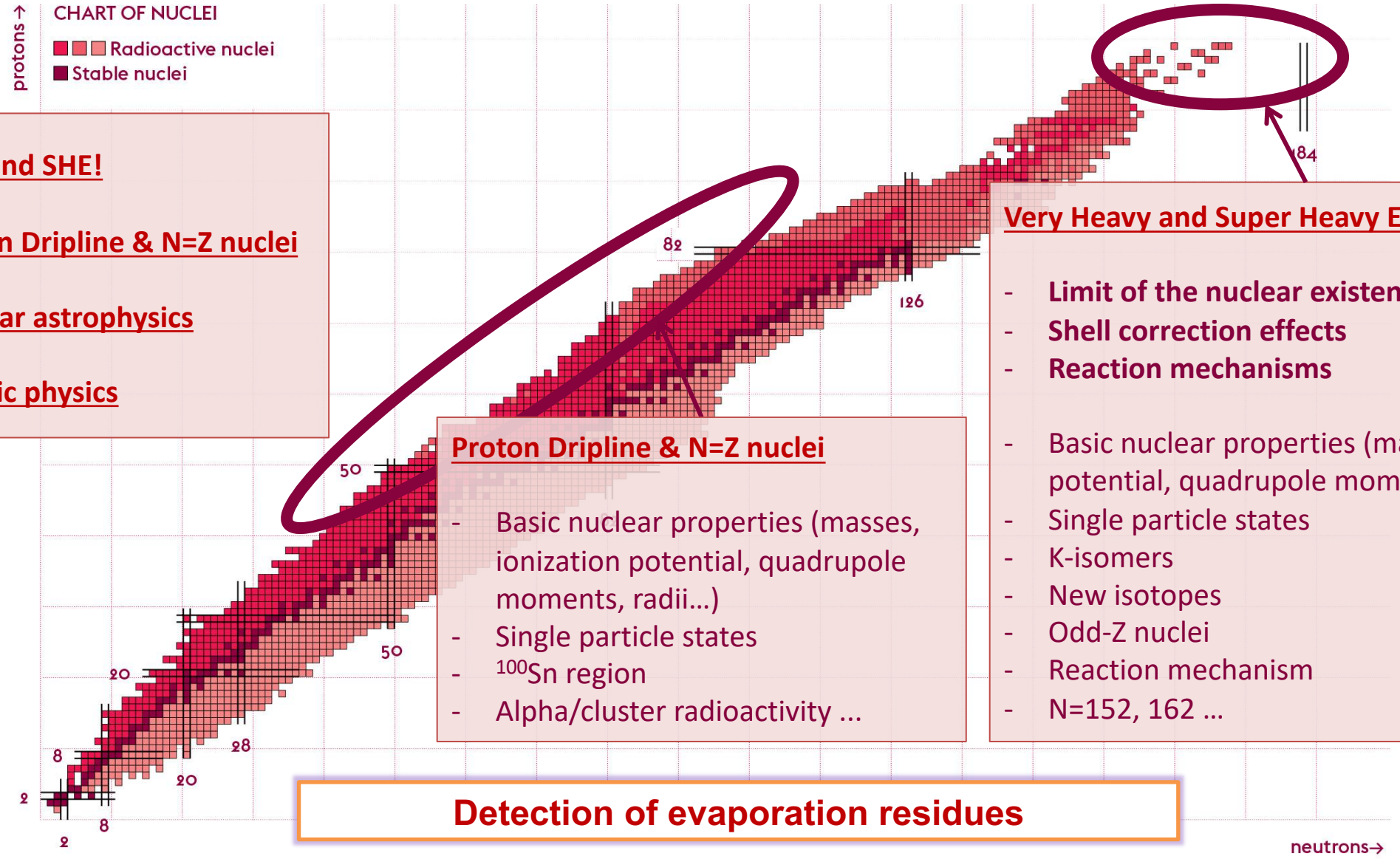
Status of SIRIUS

- Physics motivations
- S^3 in the SPIRAL2 project
- SIRIUS at the focal plane of S^3
- SIRIUS from CEA/Irfu to GANIL
- Perspectives and outlooks



Physics objectives of S^3

Spherical superheavy nuclei?
Island of stability?
Limits of existence of the matter



- **VHE and SHE!**
- **Proton Dripline & N=Z nuclei**
- **Nuclear astrophysics**
- **Atomic physics**

Proton Dripline & N=Z nuclei

- Basic nuclear properties (masses, ionization potential, quadrupole moments, radii…)
- Single particle states
- ^{100}Sn region
- Alpha/cluster radioactivity …

Very Heavy and Super Heavy Elements

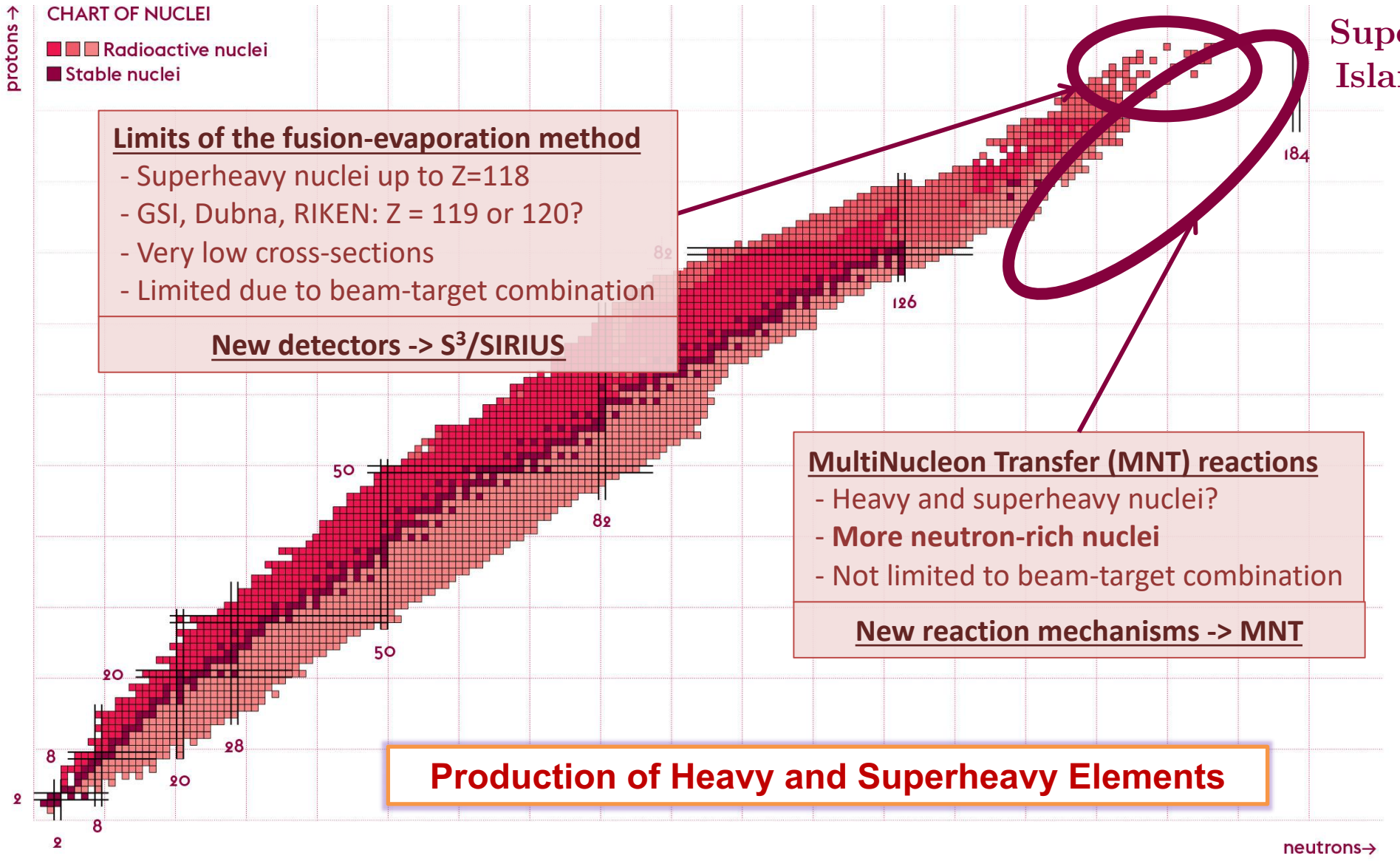
- **Limit of the nuclear existence**
- **Shell correction effects**
- **Reaction mechanisms**

- Basic nuclear properties (masses, ionization potential, quadrupole moments, radii…)
- Single particle states
- K-isomers
- New isotopes
- Odd-Z nuclei
- Reaction mechanism
- N=152, 162 …

Detection of evaporation residues

(Carte issue de l'Edition n°13 - juin 2020)

Physics objectives of SIRIUS: VHE and SHE!



Limits of the fusion-evaporation method
- Superheavy nuclei up to Z=118
- GSI, Dubna, RIKEN: Z = 119 or 120?
- Very low cross-sections
- Limited due to beam-target combination

New detectors -> S³/SIRIUS

Superheavy nuclei?
Island of stability?

MultiNucleon Transfer (MNT) reactions
- Heavy and superheavy nuclei?
- **More neutron-rich nuclei**
- Not limited to beam-target combination

New reaction mechanisms -> MNT

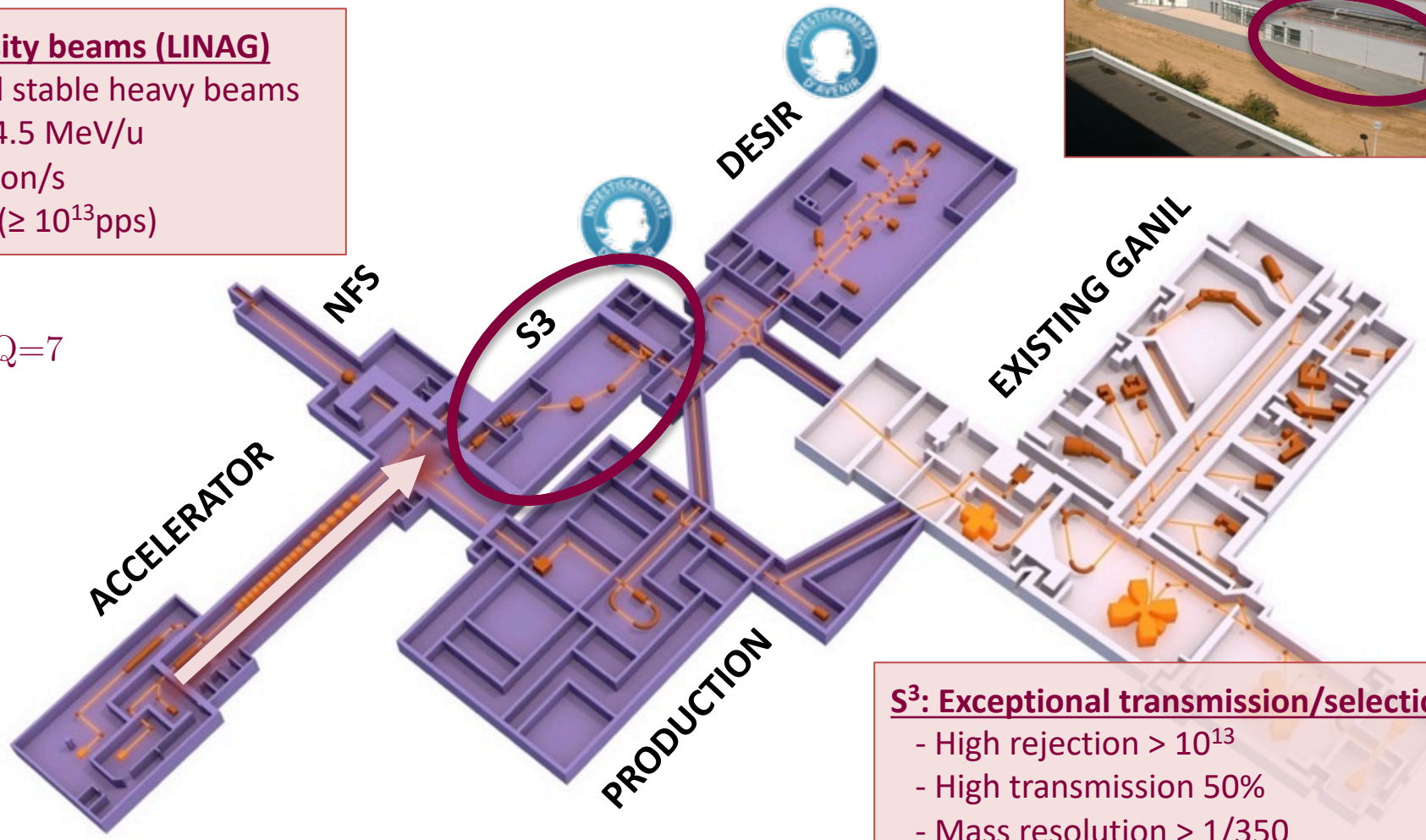
Production of Heavy and Superheavy Elements

(Carte issue de l'Edition n°13 - juin 2020)

S^3 in the SPIRAL2 project

Very high intensity beams (LINAG)
- Deuterons and stable heavy beams
- E_{beam}= up to 14.5 MeV/u
- Intensity 10^{14} ion/s
  beyond 1pμA (≥ 10^{13}pps)

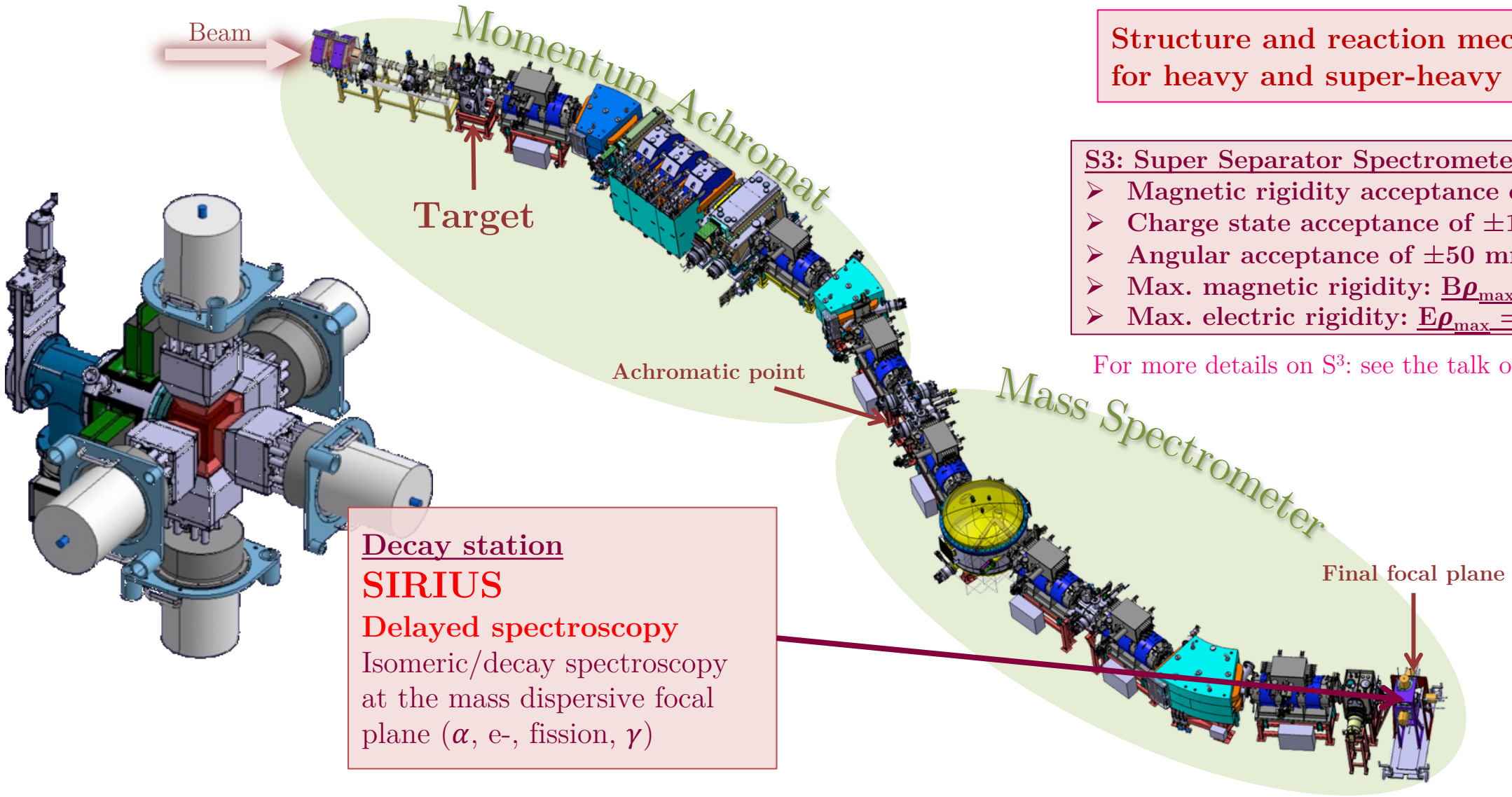
A/Q=3
NEWGAIN A/Q=7



S^3: Exceptional transmission/selection combination
- High rejection > 10^{13}
- High transmission 50%
- Mass resolution > 1/350

A cutting-edge instrumentation for S^3 (SIRIUS, LEB, FISIC…)

S^3: Super Separator Spectrometer



Structure and reaction mechanism for heavy and super-heavy nuclei

S3: Super Separator Spectrometer

- Magnetic rigidity acceptance of ±7%
- Charge state acceptance of ±10%
- Angular acceptance of ±50 mrad
- Max. magnetic rigidity: $B\rho_{max} = 1.8$Tm
- Max. electric rigidity: $E\rho_{max} = 12$MV

For more details on S^3: see the talk of H. Savajols

Decay station

SIRIUS

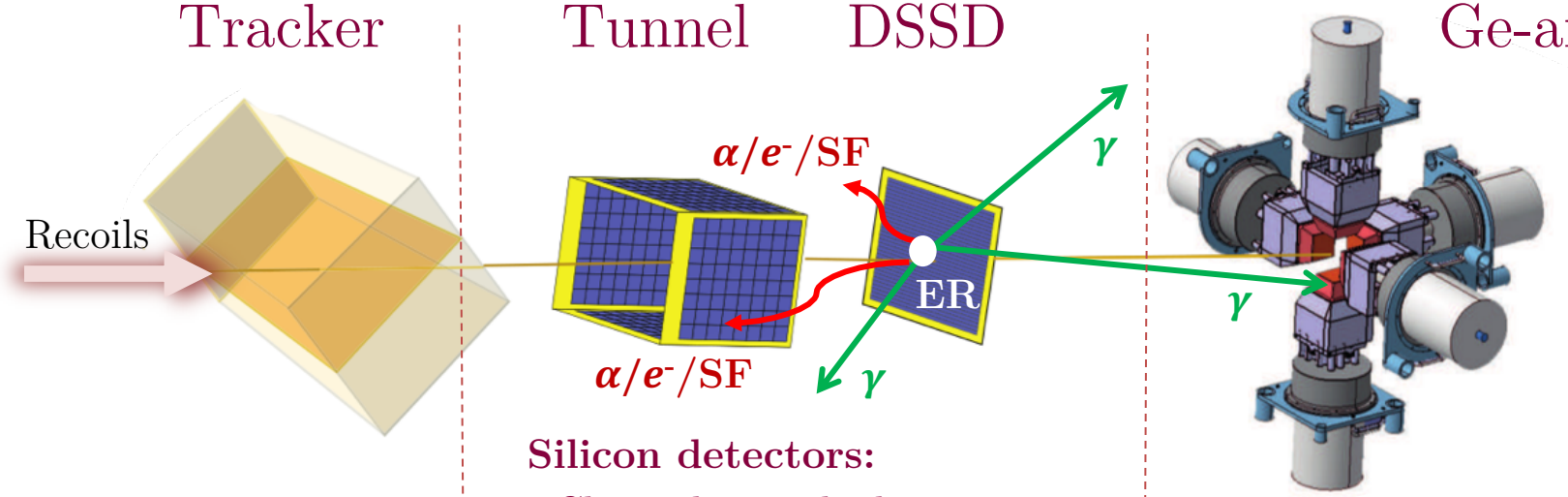
Delayed spectroscopy

Isomeric/decay spectroscopy at the mass dispersive focal plane (α, e-, fission, γ)

SIRIUS decay station

SIRIUS: System for the Investigation of Recoiling Ions Using S3

Tracker | Tunnel | DSSD | Ge-array



Time of Flight:

- Emissive foil
- Thin windows
- High Time resolution
- Mass Identification A/ΔA ~300

Silicon detectors:

- Charged particle discrimination for recoil, beta and decay alpha
- High resolution alpha and conversion electron spectroscopy
- Measurement of TKE for spontaneous fission
- Access to short decay times

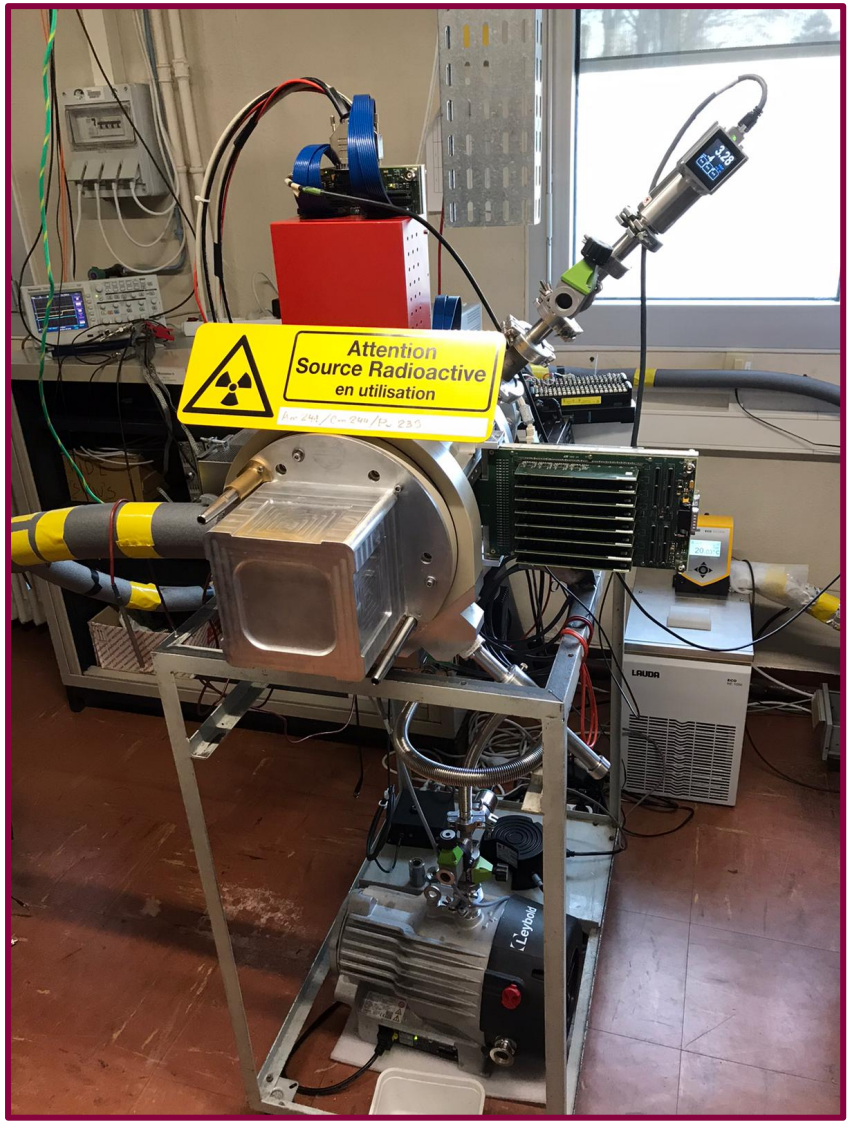
Digital electronics:

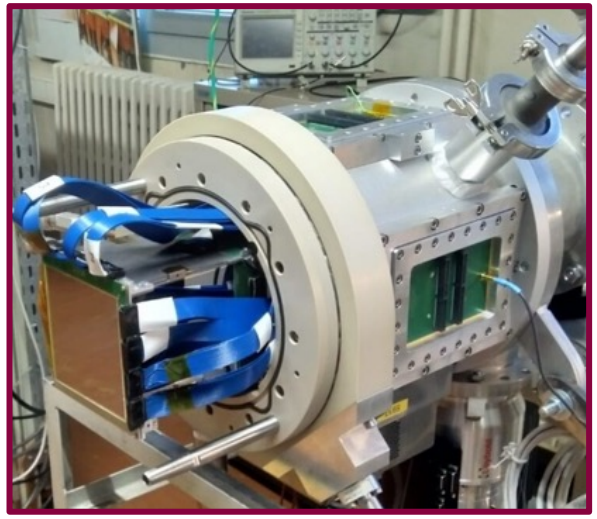
Digital signal processing

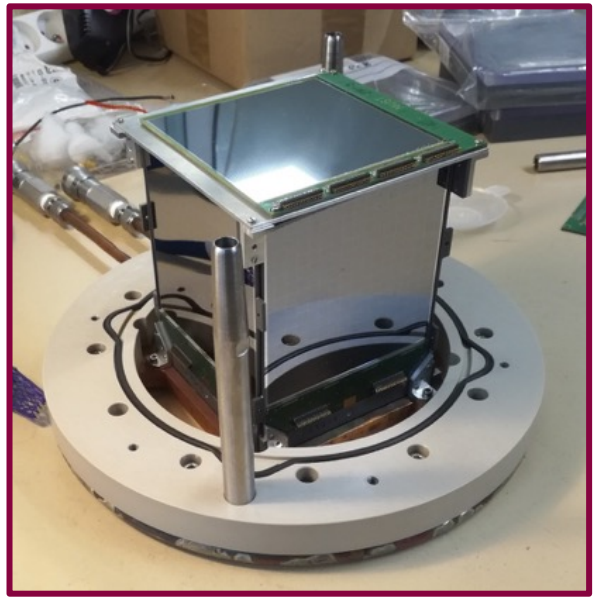
γ-ray detection :

- 5 EXOGAM clover detectors
- Efficiency of 40% at 121 keV

SIRIUS detectors







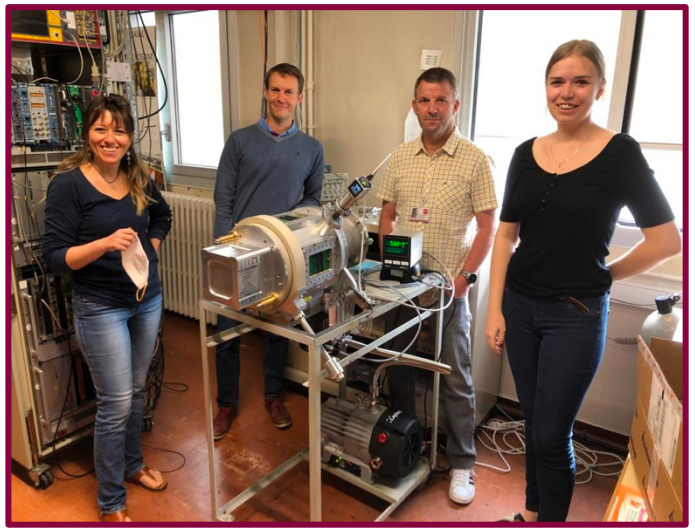
Decay station

SIRIUS

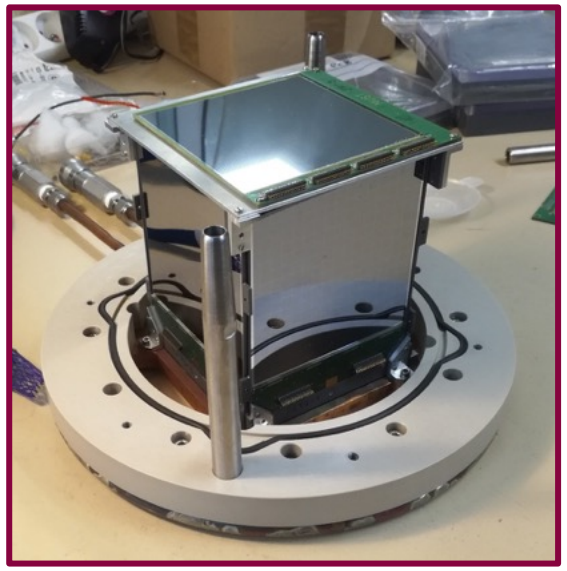
Delayed spectroscopy

Since July 2020 at CEA/Irfu

Complete chamber from Strasbourg.
Tunnels from IJClab.
DSSD and electroncs from CEA/Irfu.
Offline commissioning (sources α, β^-)



DSSD test bench @CEA/Irfu

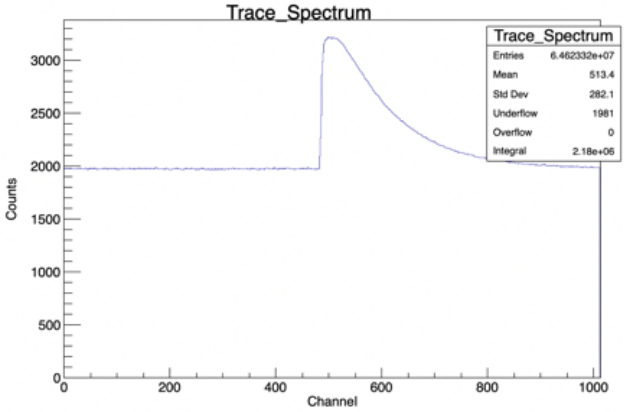


- Testing of DSSD, full electronics chain, with tri-alpha and electron sources
- Digital Signal Processing with Jordanov Filters (optimization of m and k)
- Characterization of the DSSD front-end electronics
- Write online and offline codes for data acquisition (NUMEXO2 cards)
- Different temperatures (-20, 0, +20°C)
- Test of low gain and high gain (0.5pF/1pF and 9pF)

DSSD
128 strips x
128 strips y

Conditions:
U=55V
I=1.4µA
Temp. 20°C

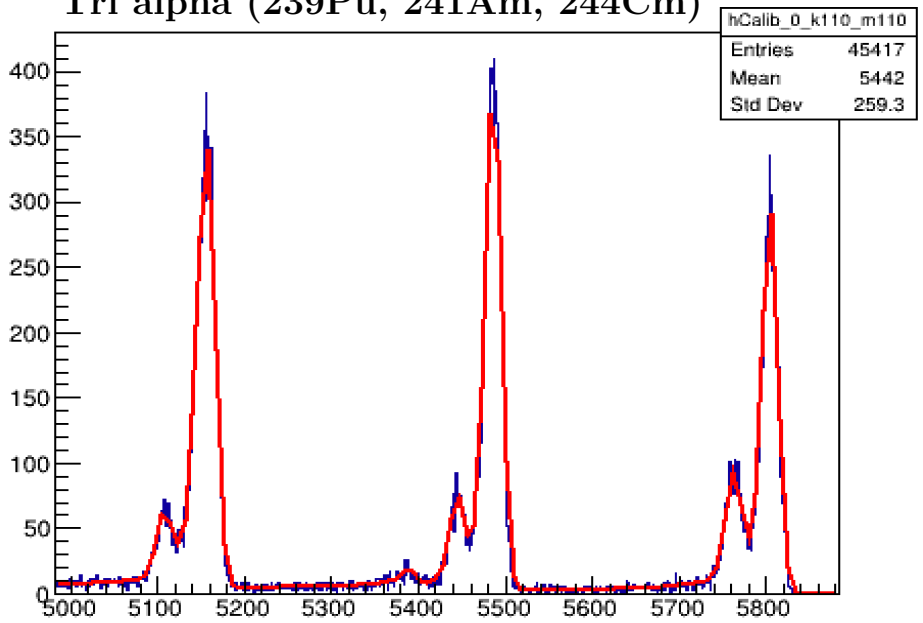
992 samples
Sampling period 5ns



Trace

Jordanov Filter

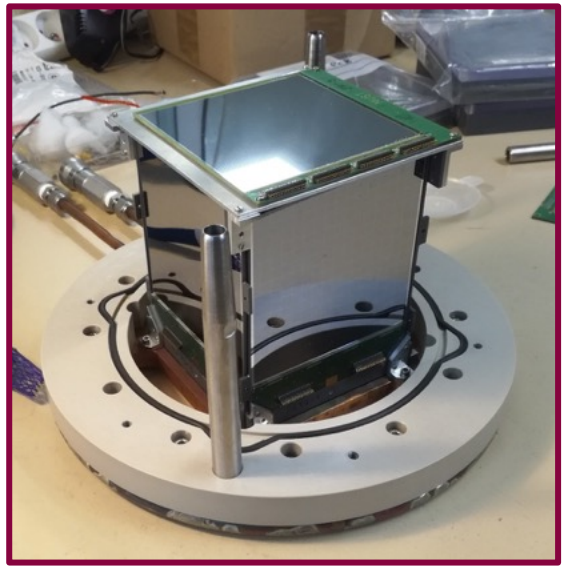
Tri alpha (239Pu, 241Am, 244Cm)

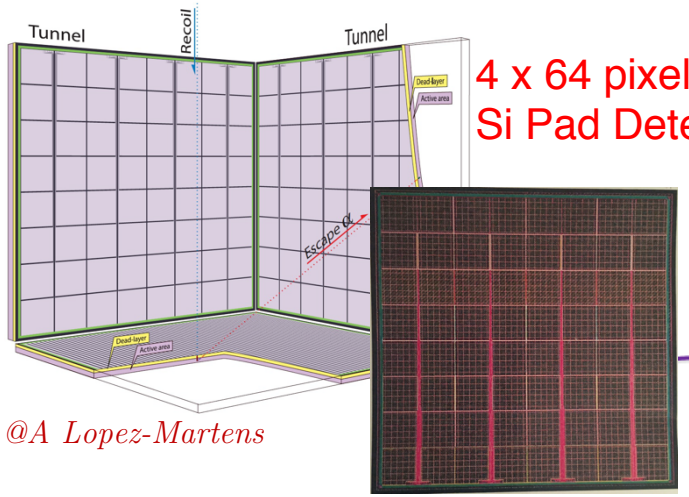


18 keV resolution

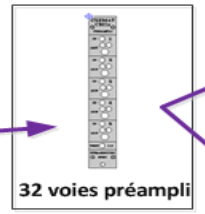
Tunnels test bench @IPHC/IJClab

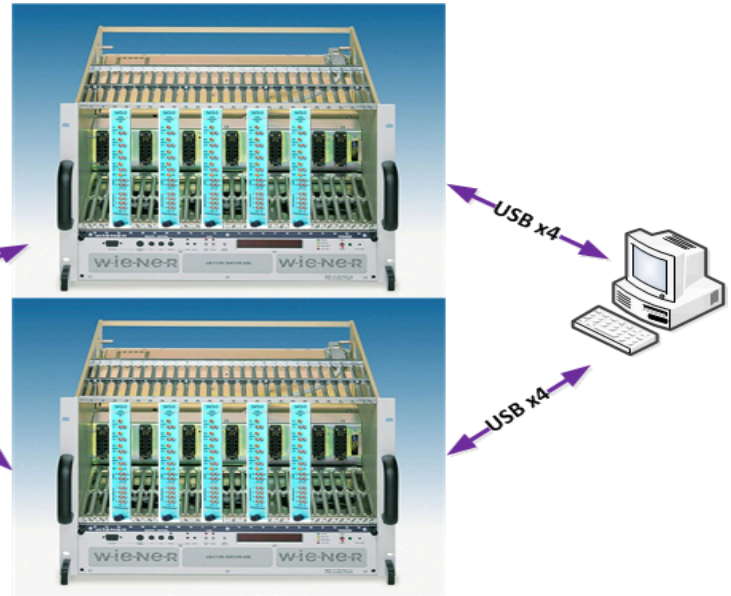
Courtesy of O. Dorvaux



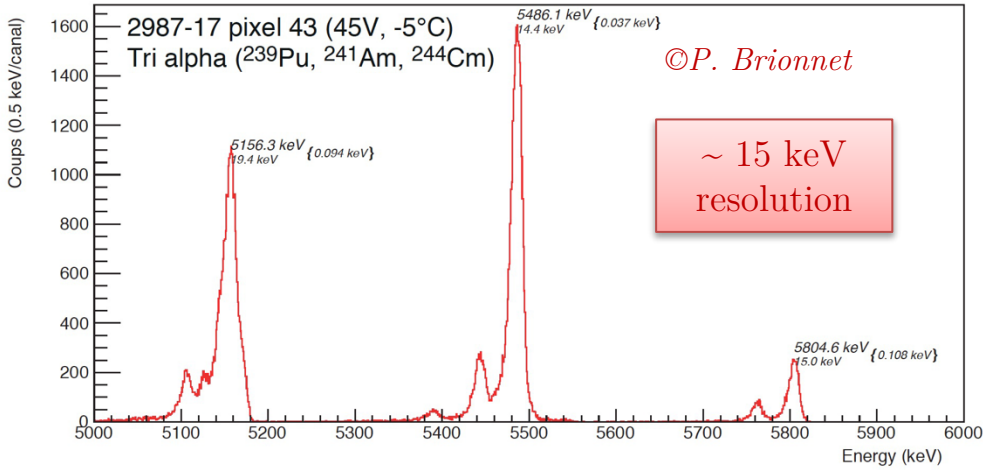


@A Lopez-Martens





Still waiting for tests
with the Numexo2 electronics,
it will be finished at IJClab/GANIL



With CREMAT electronics

SIRIUS online commissioning @LISE2000?

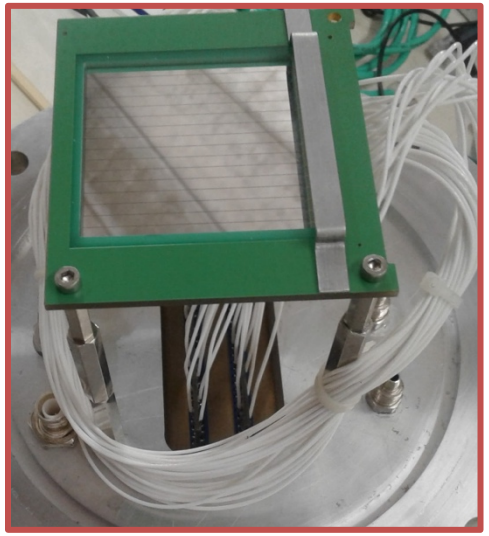
First test in June 2019
→ New test in April 2021

Objectives:
Testing the rejection of the line LISE2000 @GANIL with a small DSSD to study the feasibility of the SIRIUS commissioning at LISE2000.

Chosen reaction:

^{40}Ar+^{174}Yb → ^{209,210}Ra. 4,62MeV/u
Cross section: 1.4 mb

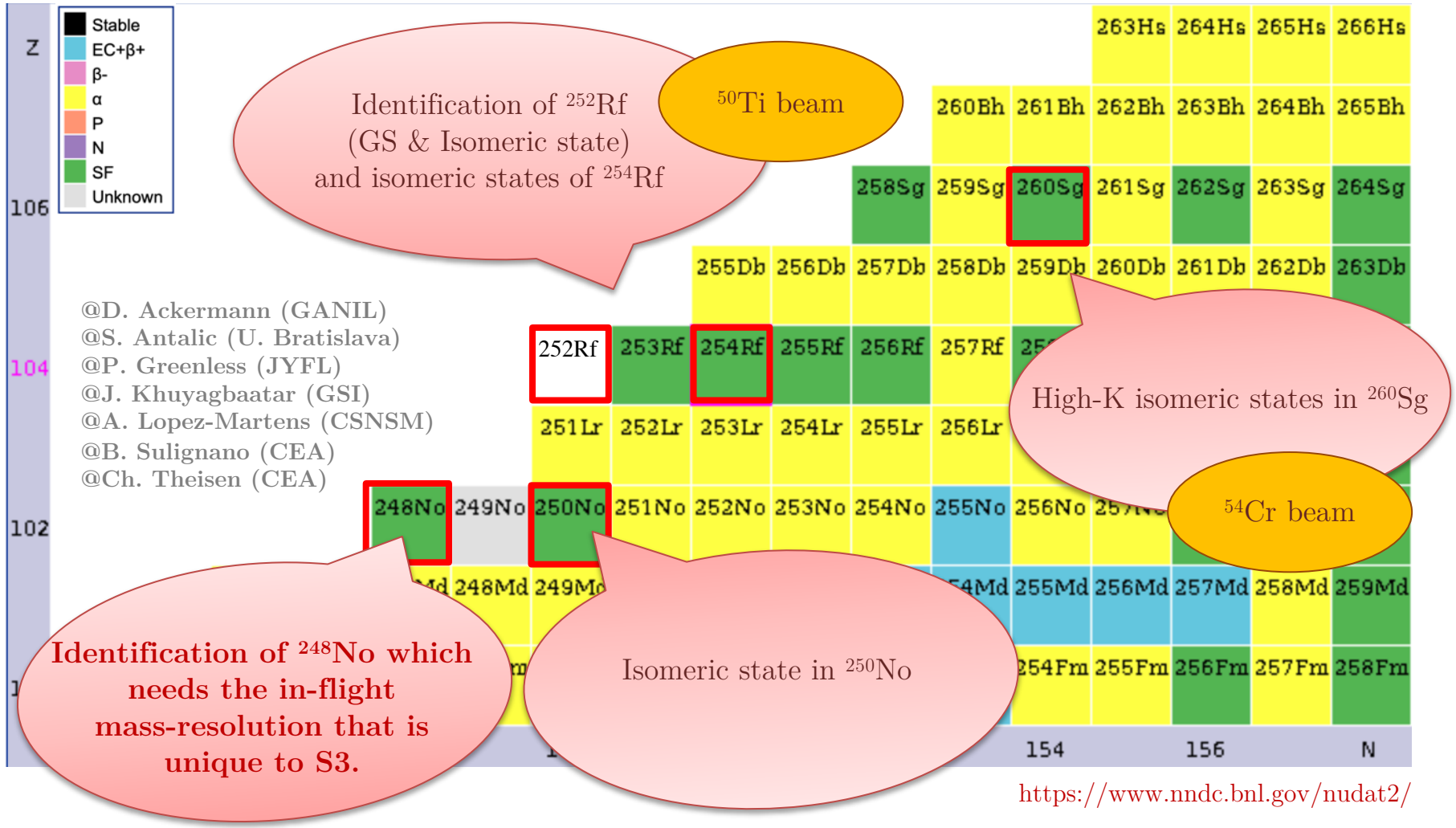
Set-up:
- 1 DSSD 16x16 strips 300 µm
(50x50 mm^2 active area with PAC 15mV/MeV)
- 2 amplifiers CAEN N568B
(OUT1: GANIL ADC,
FOUT1: 16 strips CFD CAEN N843)
- 1 MWPC (50x50 mm^2) for TOF measurements



Work has been done to improve the transmission of LISE2000!

SIRIUS Day1 experimental plan (A/Q=3)

The selection of day one experiments for S³ was made to determine out the list of pre-proposals with "high impact" (discovery & unique proposals for S³) and feasibility.



https://www.nndc.bnl.gov/nudat2/

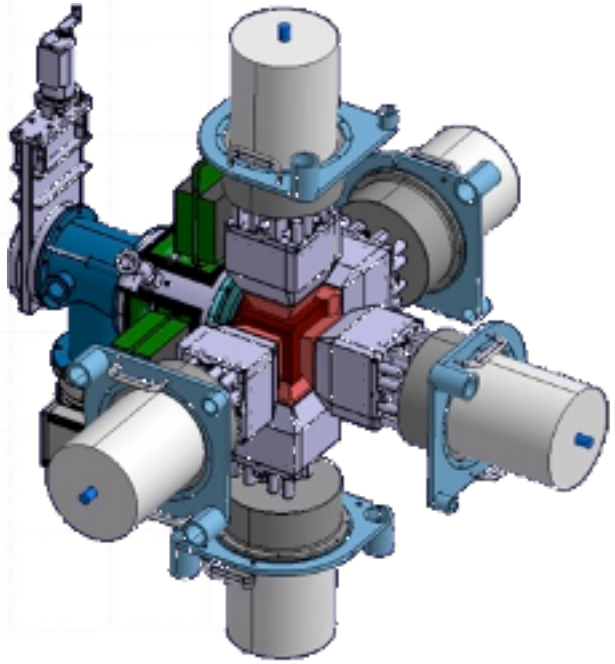
Conclusions and perspectives

- **Developing a cutting-edge technology**
  - **SIRIUS in the SPIRAL2/S³ framework**
  - SIRIUS: **"Spectroscopy and Identification of Rare Isotopes Using S3"**
  - All the different parts of SIRIUS have been tested offline @IPHC, IJClab, GANIL and IRFU test benches
  - Since July 2020, SIRIUS @CEA/Irfu (DSSD+Tunnels)
  - **Offline commissioning and tests of the complete acquisition chain!**

- **March 23-24, 2021:**
  - **Move SIRIUS from CEA-Saclay to GANIL!**

- **March-April 2021:**
  - **Continuation of the tests of SIRIUS @GANIL (Trackers, HPGe, electronics...)**

- **April 23, 2021:**
  - **T21-01 new test with LISE2000**
    $^{40}Ar^{6+}$ 4,6 MeV/u
  - **$^{40}Ar + ^{174}Yb \rightarrow ^{209,210}Ra$**
  - Online commissioning of SIRIUS with LISE2000?



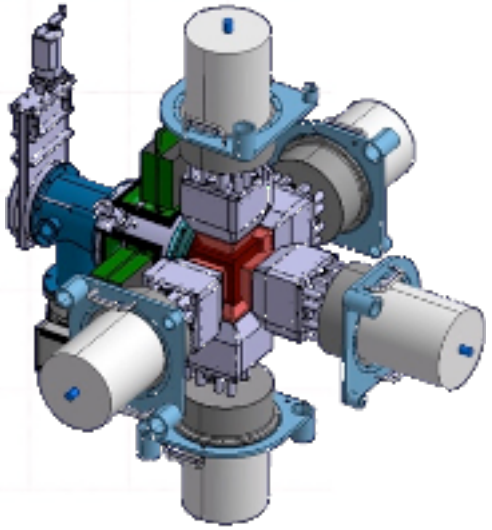
SIRIUS Collaboration

CEA/IRFU : ZF, Th. Chaminade, B. Sulignano, M. Authier,, E. Delagnes, D. Desforge, A. Drouart, A.Grabas, W. Korten, H. Le Provost, Ch. Theisen, M. Vandebrouck, M. Zielinska

GANIL : D. Ackermann, M. Blaizot, A. Boujrad, R. Chakma, E. Clément, S. Coudert, S. Herlant, G. Lebertre, C. Maugeais, J. Piot, F. Saillant, H. Savajols, G. Wittwer

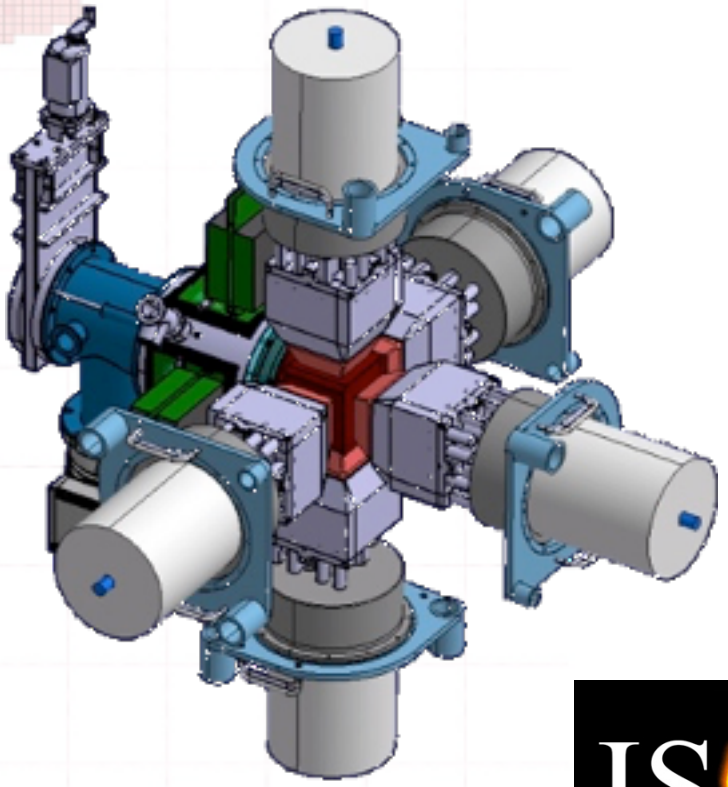
IJClab : V. Alaphilipe, L. Gibelin, K. Hauschild, N. Karkour, X. Lafay, L. LeBlanc, D. Linget, A. Lopez-Martens

IPHC : P. Brionnet, O. Dorvaux, B. Gall, Th. Goeltzenlichter, C. Mathieu



Thank you

for your kind attention

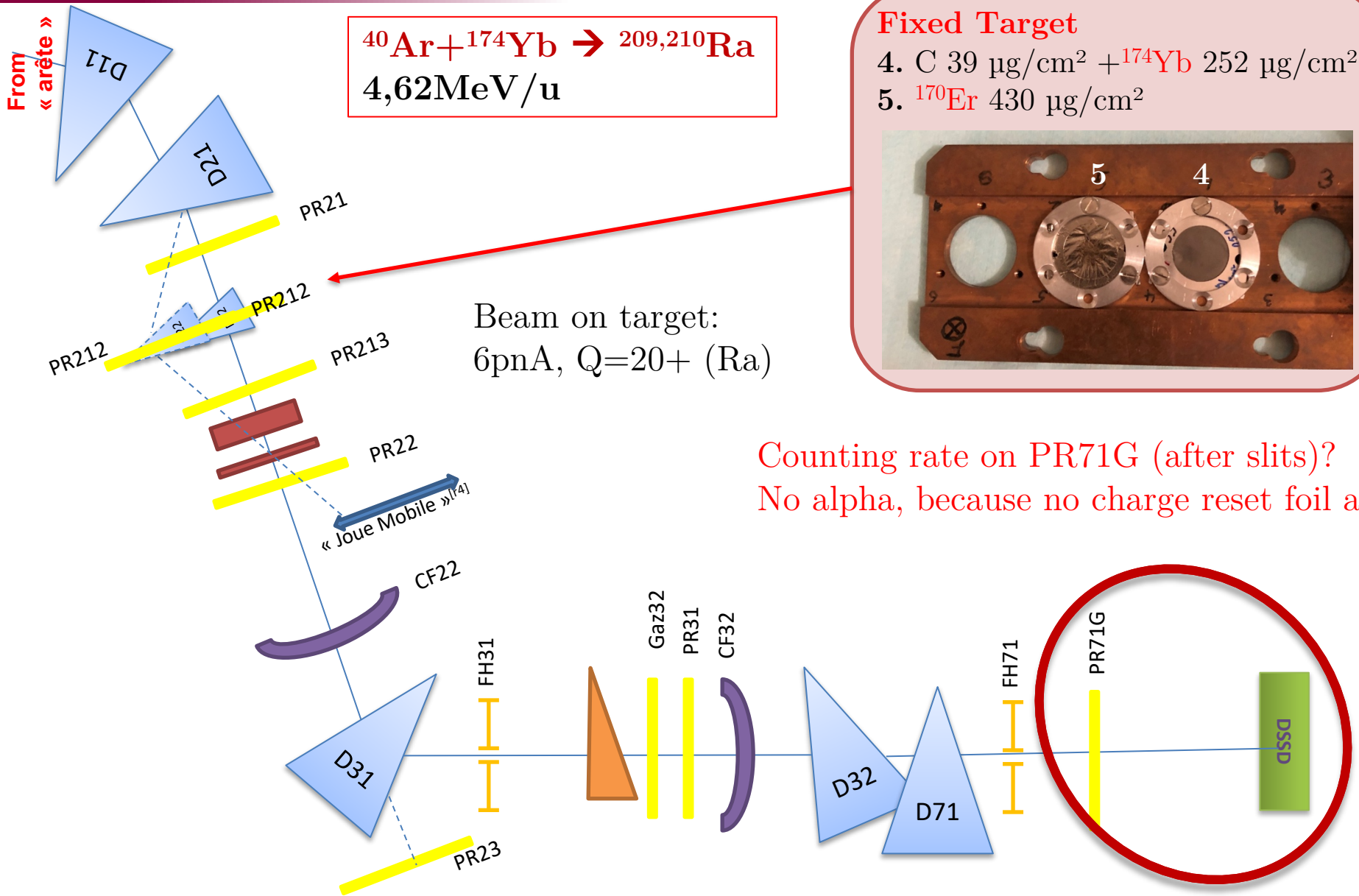


ISOL FRANCE

SIRIUS Commissioning @LISE2000

$^{40}Ar + ^{174}Yb \rightarrow ^{209,210}Ra$
4,62MeV/u

Fixed Target
4. C 39 µg/cm² + ^{174}Yb 252 µg/cm²
5. ^{170}Er 430 µg/cm²



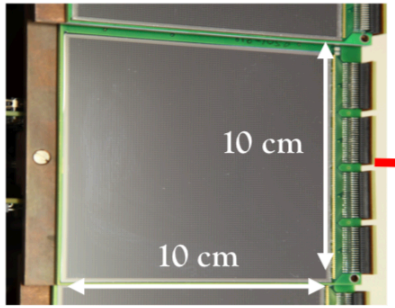
Beam on target:
6pnA, Q=20+ (Ra)

Counting rate on PR71G (after slits)?
No alpha, because no charge reset foil after the target?

DSSD test bench @CEA/Irfu

DSSD

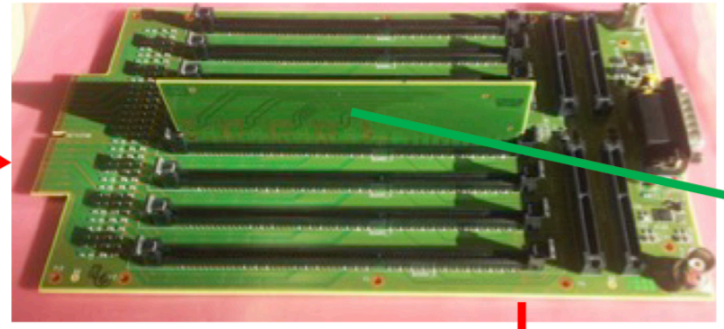
128 strips x
128 strips y



Thickness: 300 µm

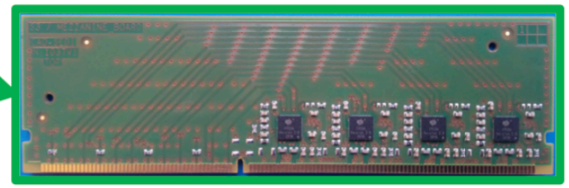
Mother board

- Each motherboard control 32 channels
- 8 mother boards are needed to control DSSD

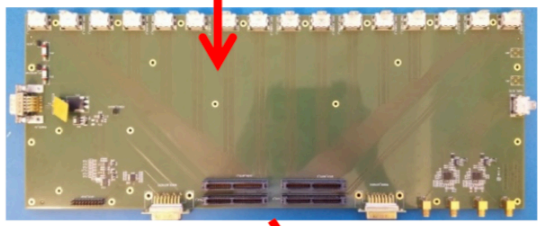


Daughter board

- Each daughter board carry 4 ASICs (2 strips)
- 8x8 cards are needed to control DSSD

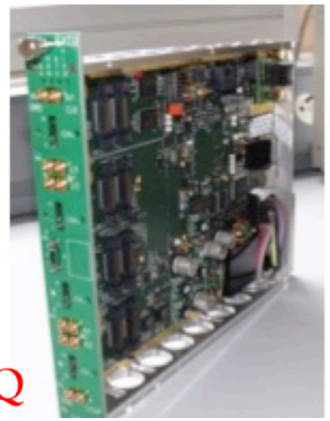


Adaptation board



Software analysis

16 Numexo2
with 4FADC-DAQ



FEE specifications

Low gain resolution	65 keV
High gain resolution	16 keV
Linearity	<1.5%
Dead time	2.5 µs

Optimizations for Digital Signal Processing

Objectives:

- Testing of DSSD, full electronics chain, at CEA/Irfu with tri-alpha sources
- Digital Signal Processing with Pulse Shaping Analysis
- Characterization of the DSSD/ front-end electronics

Digital processing - Trapezoidal Filtering

- Optimum Signal to Noise Ratio
- Reduction of pile up events

V. T. Jordanov et al. NIMA,345(1994),337-345.

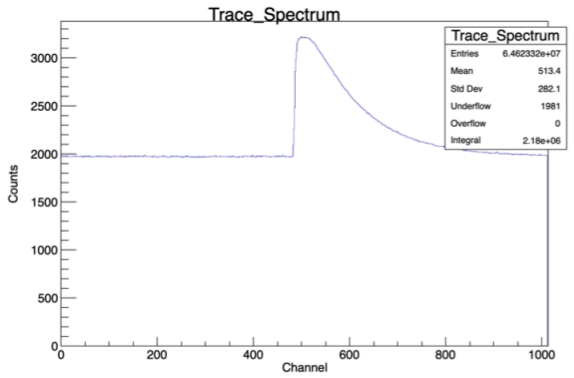
$$d^{k,l}(n) = v(n) - v(n-k) - v(n-l) + v(n-k-l), \quad (1)$$

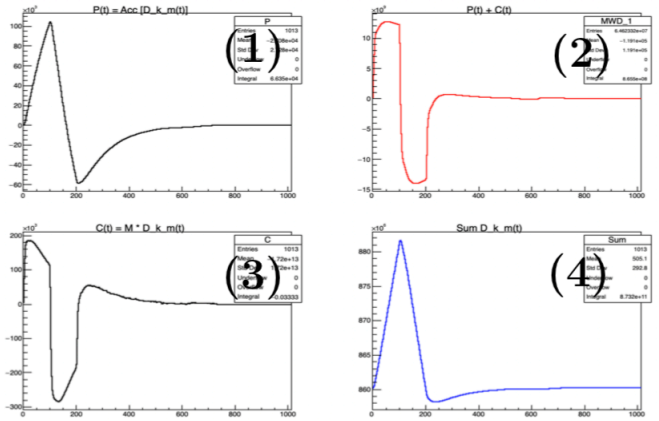
$$p(n) = p(n-1) + d^{k,l}(n), \quad n \geq 0, \quad (2)$$

$$r(n) = p(n) + Md^{k,l}(n), \quad (3)$$

$$s(n) = s(n-1) + r(n), \quad n \geq 0, \quad (4)$$

$$M = \frac{1}{\exp(T_{clk}/\tau) - 1}.$$

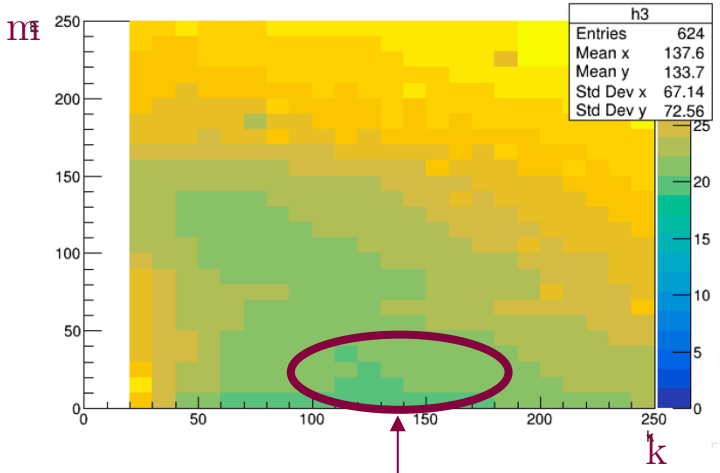




Trace

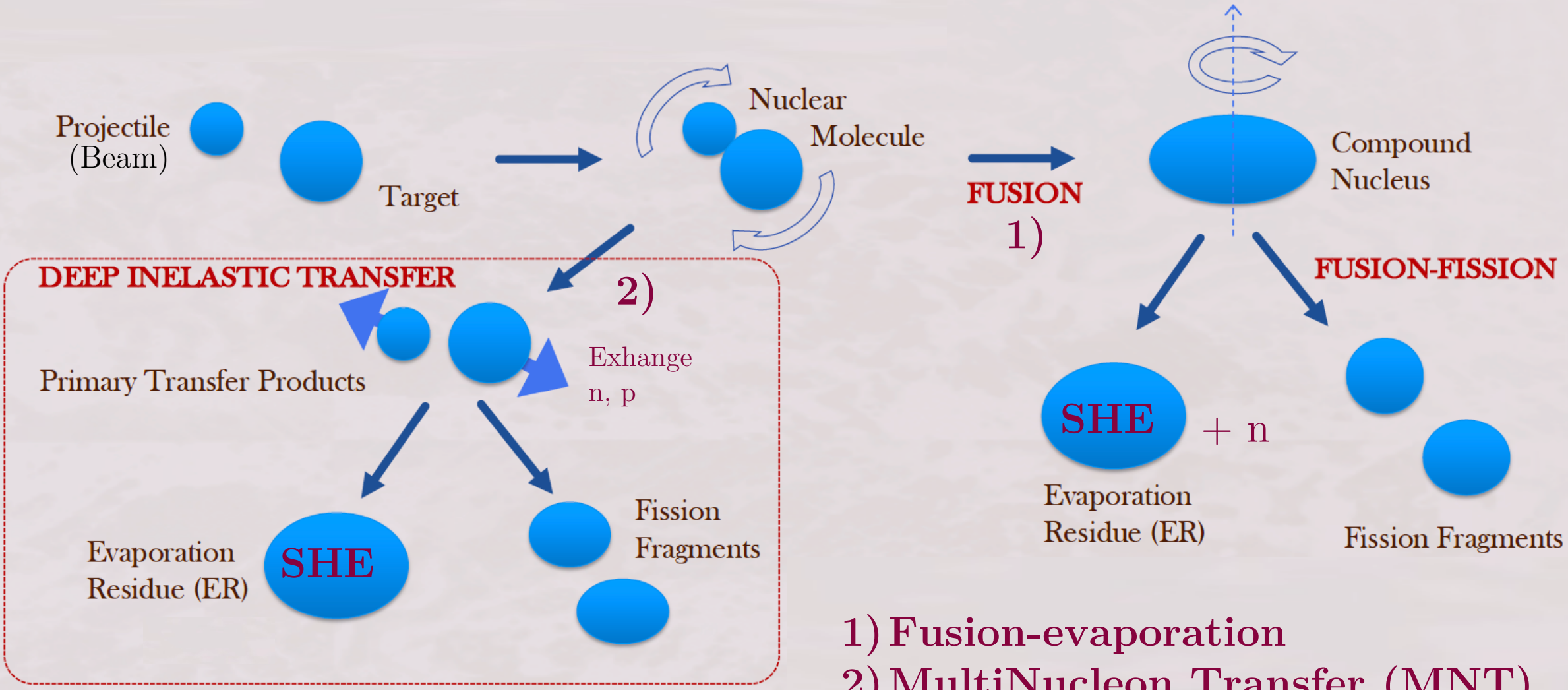
Trapezoidal filter (with PZ correction)

Digital Signal Processing with Jordanov Filters (optimization of the FWHM w.r.t. m and k)



m close to 0
k around 150

Reaction mechanisms to produce SHE



1) Fusion-evaporation
2) MultiNucleon Transfer (MNT)