DE LA RECHERCHE À L'INDUSTRIE

Towards spectroscopy of very heavy elements at S^3

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NUSTAR ANNUAL MEETING 2019
GSI DARMSTADT, 25.02 – 1.03.2019

Where is located the island of stability?

Ground state properties @LEB S3

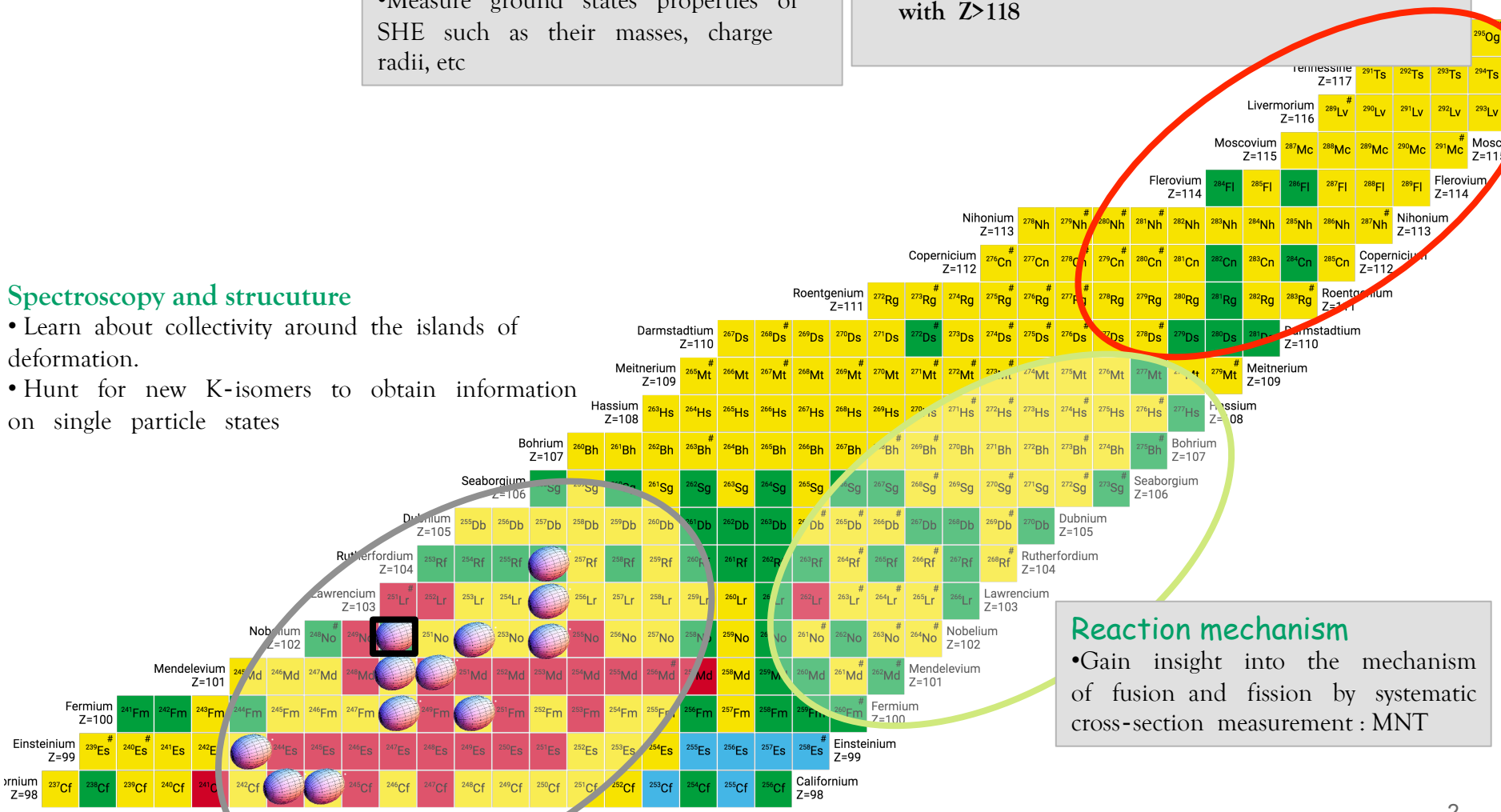
•Measure ground states properties of SHE such as their masses, charge radii, etc

Superheavy nuclei @ Super Separator Spectrometer

- Synthesize new elements, with Z>118

Spectroscopy and strucuture

- Learn about collectivity around the islands of deformation.
- Hunt for new K-isomers to obtain information on single particle states



Reaction mechanism

•Gain insight into the mechanism of fusion and fission by systematic cross-section measurement : MNT

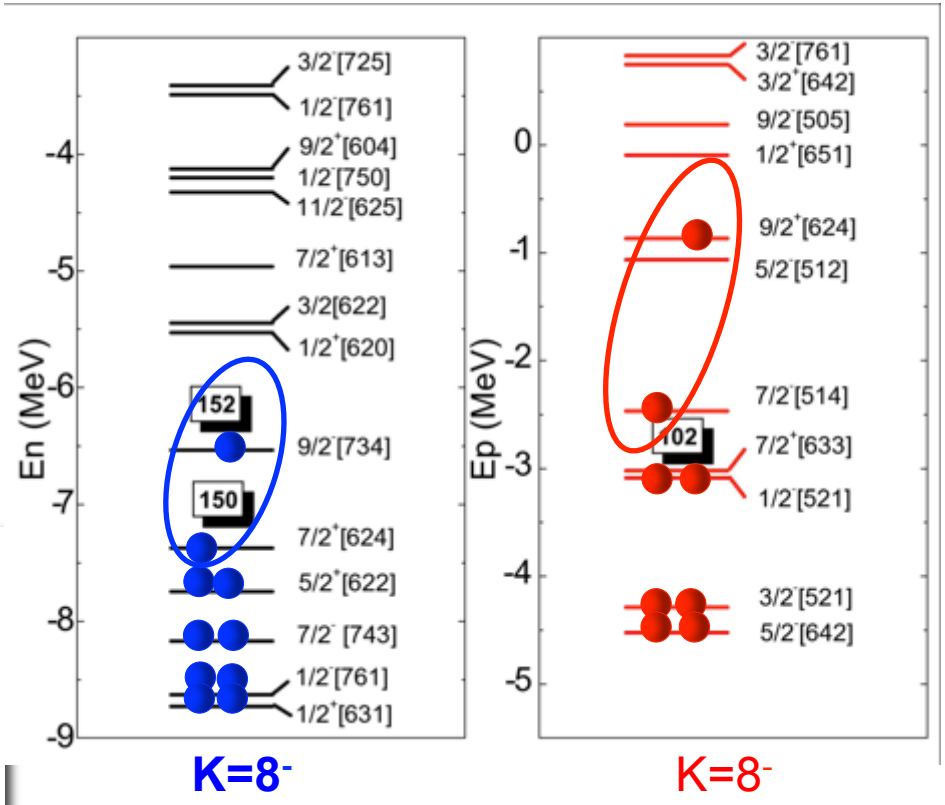
ISOMERIC STATES IN EVEN EVEN NUCELI

Why K isomers occur?

- Deformed nucleus
- Selection rule for electromagnetic transition λ ≥ ΔK is not fulfilled
- Breaking of particle pairs at Fermi Surface

What we can learn?

- Information about Nilsson level energy gaps
- Influence on stability of super heavy elements
- Constrains parameters that define nuclear mean filed → Benchmark nuclear theory :pairing interaction



B. Sulignano, et al. PHYSICAL REVIEW C **86**, 044318 (2012)

$^{48}Ca+^{204}Pb \rightarrow ^{250}No$ Previous studies

Oganessian experiment 2001:

- σ= 9.5 (-4.9+7.6) nb @ E=216.7 MeV
- $t_{1/2}$=46 (-11+6) μs
- 5 × 10^8 times smaller than the half-life of ^{254}No

Blezorv 2003:

42 events $t_{1/2}$=5,9 μs

22 events $t_{1/2}$=54,2 μs

→ is this ^{249}No decay or isomeric decay of ^{250}No?

D.Peterson 2006 @atlas using ^{204}Pb target:

158 recoil fission correlation

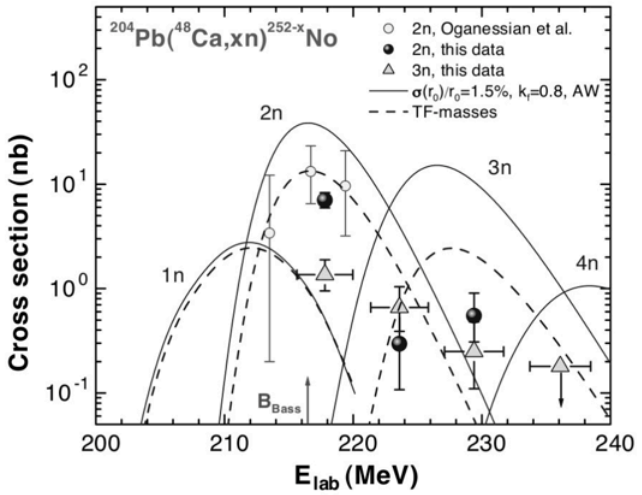
$t_{1/2}$= 3,7 μs σ = 12 nb short component σ = 12^{+18}_{-4} nb

$t_{1/2}$= 43μs σ= 5 nb long compononet σ = 5^{+3}_{-2} nb

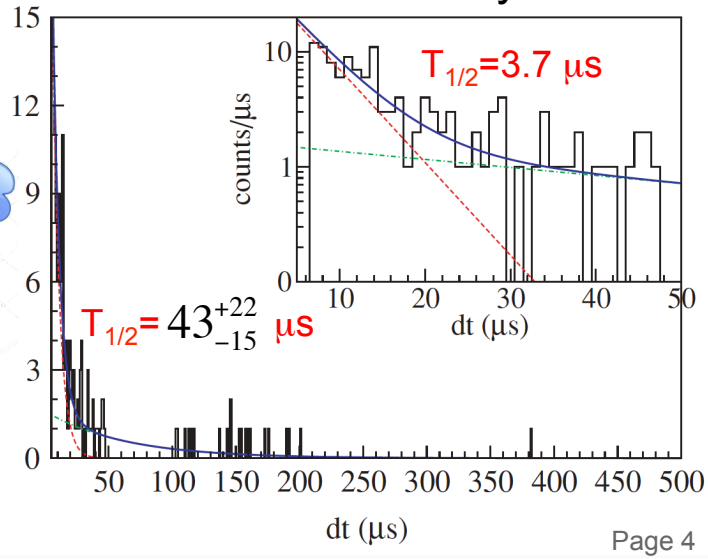
From $\sigma_{long}/\sigma_{short}$ → they deduced the ground state and isomeric state

Did the ground state is the short or long activity?

Cross section



Recoil-fission decay time



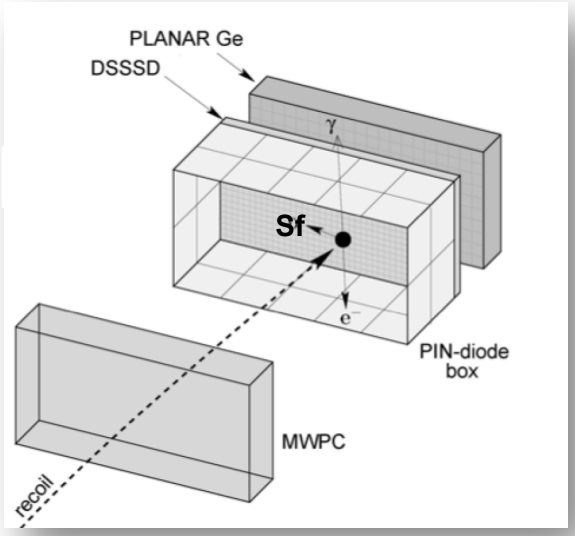
$^{48}Ca+^{204}Pb \rightarrow ^{250}No$ @ JYVÄSKYLÄ

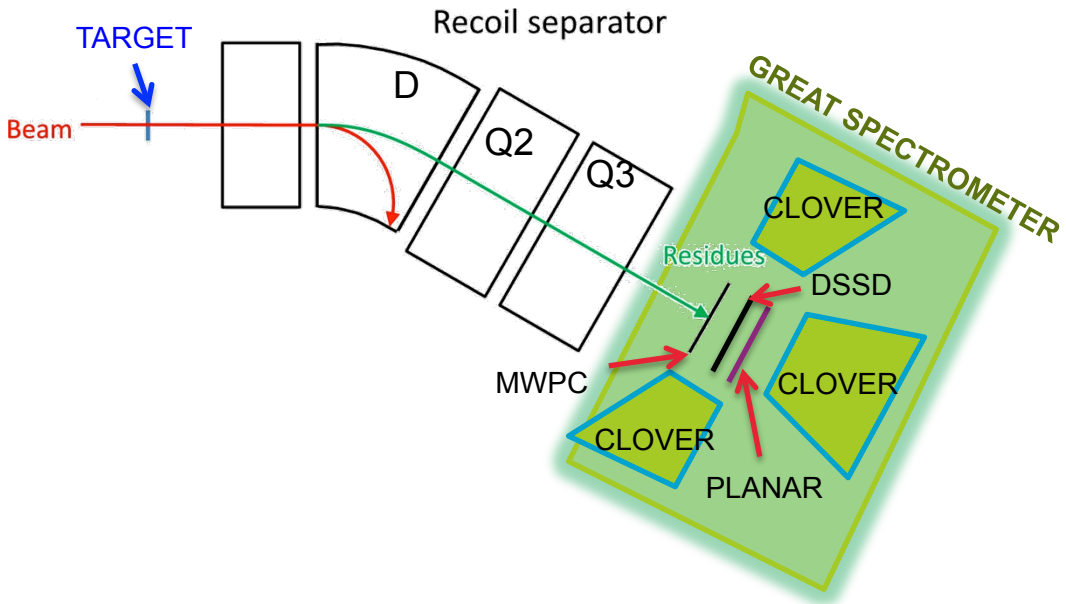
$^{204}Pb(^{48}Ca,2n)$ 6 days :

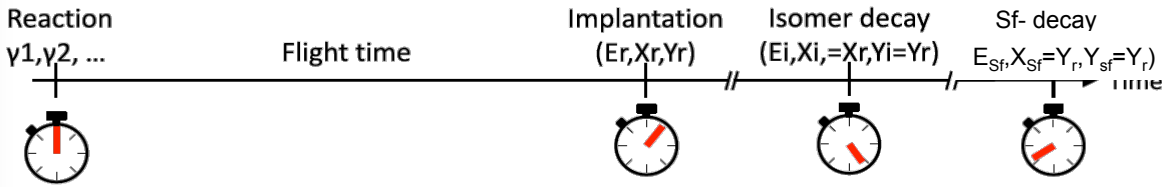
> DSSD-Y (80 strips) "digital" electronics

➢ 1040 recoil-fission correlation

➢ $\sigma \approx$ 15.54(4.2) nb I_{beam}=100 pnA



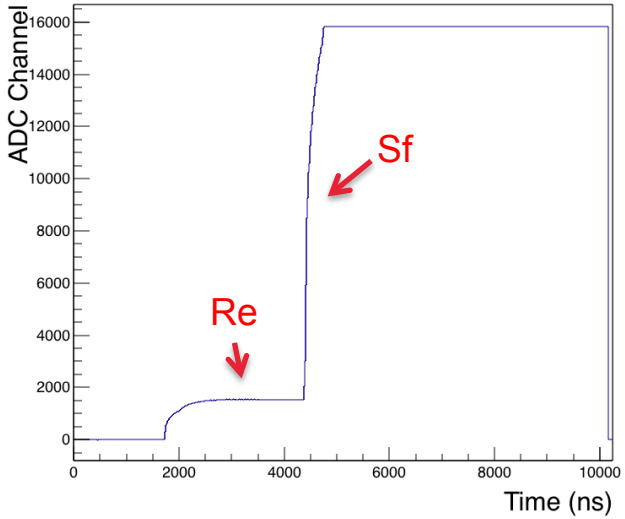




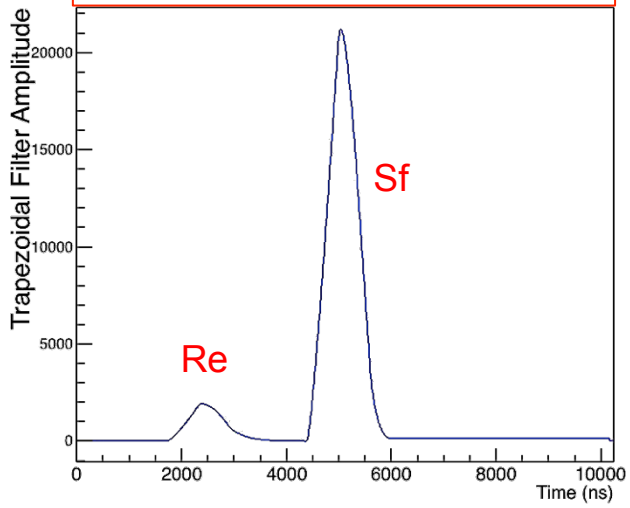
J. Kallunkatharyil, B.Sulignano, P.T. Greenlees et al. in preparation

^{250}No @ JYVÄSKYLÄ USING DIGITAL ELECTRONICS

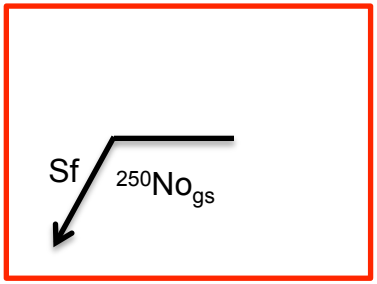
Example of digitized trace of recoil followed by an Sf event.



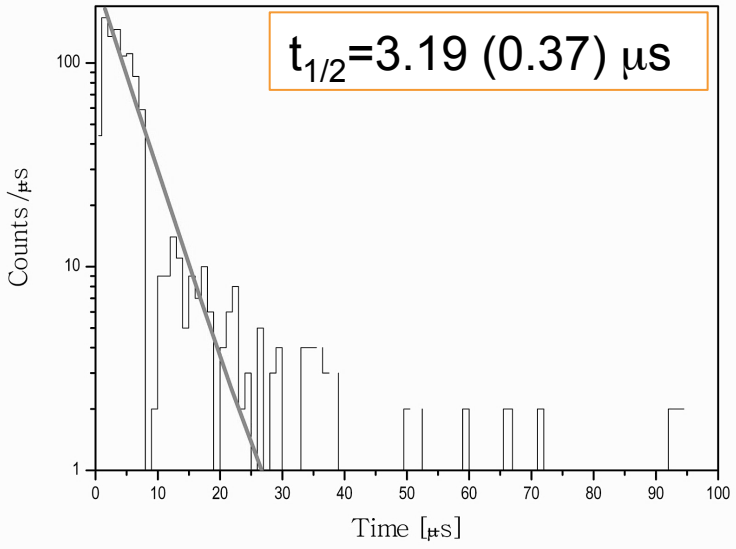
Trapezoidal filtered Recoil-Sf trace.



Ground state decay of ^{250}No



Decay time distribution for the ^{250}No ground state fission events.

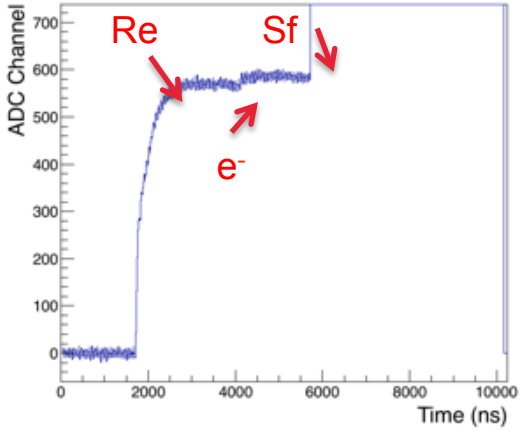


J. Kallunkathariyil, B.Sulignano, P.T. Greenlees et al. in preparation

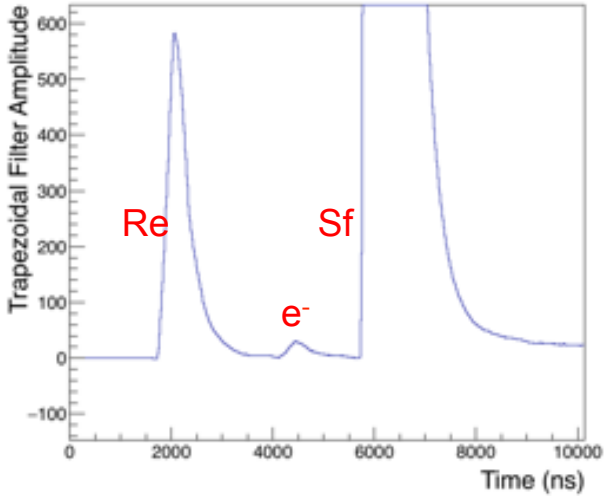
^{250}No @ JYVÄSKYLÄ USING PSA PRELIMINARY RESULTS

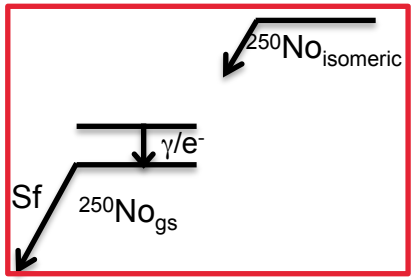
Looking for electromagnetic branch

Example of digitized trace of recoil followed by an electron and Sf event.

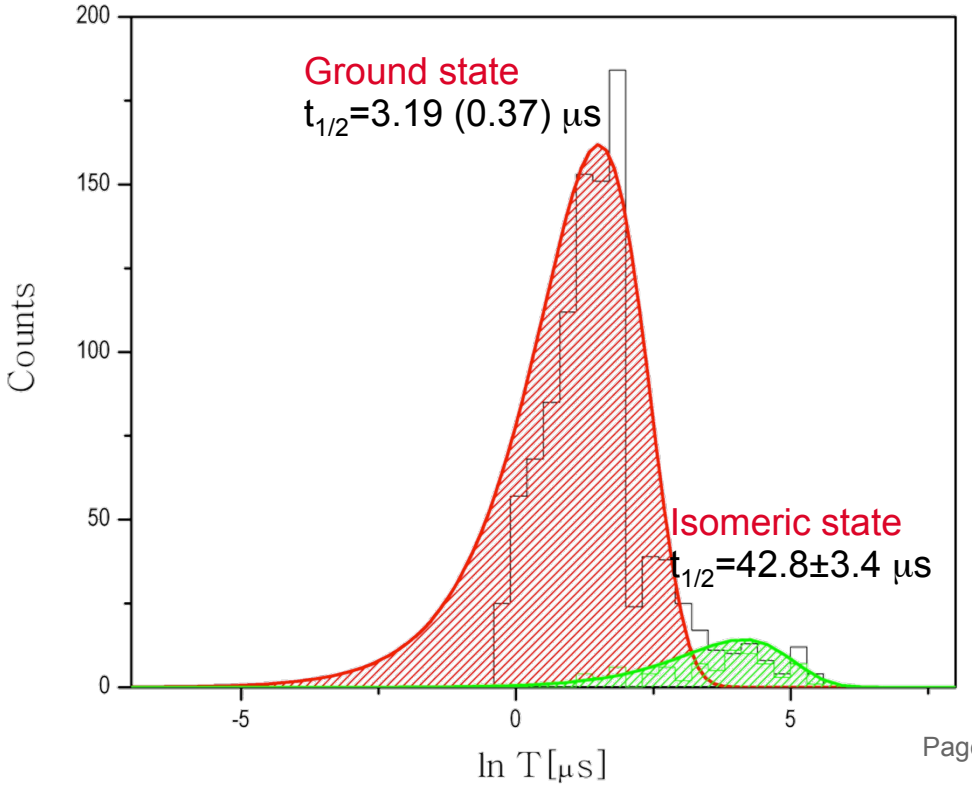


Trapezoidal filtered Recoil-electron-Sf trace.





Decay time distribution for total recoil fission correlation



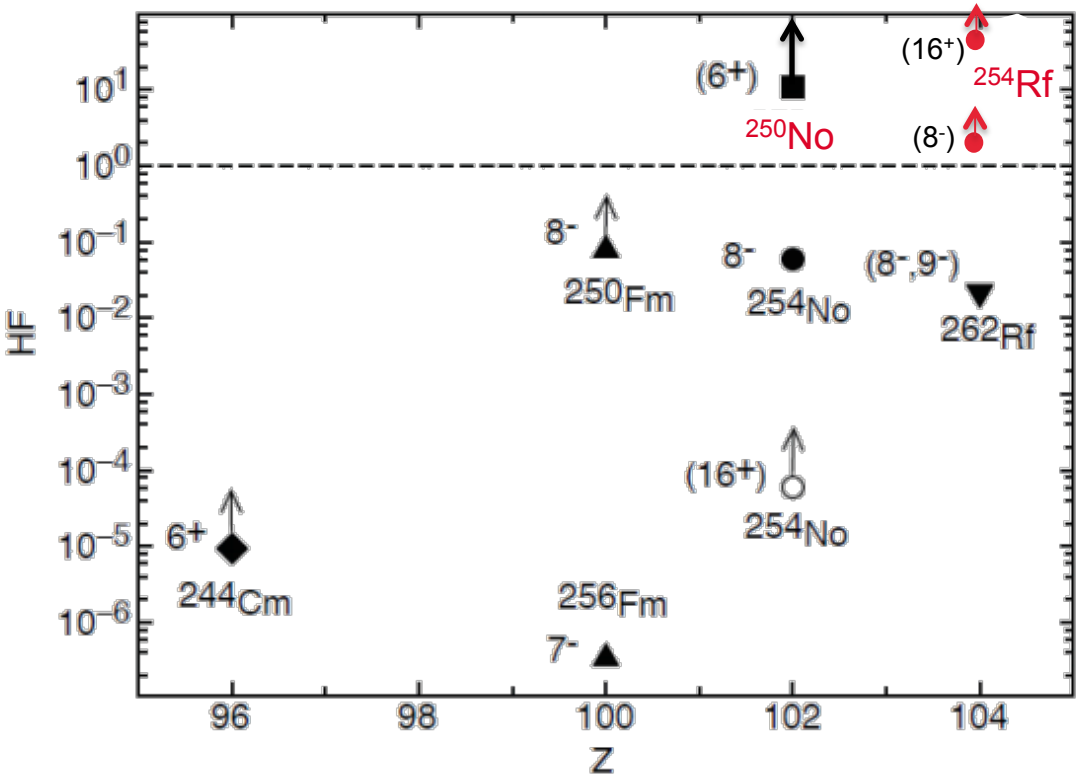
J. Kallunkatharyil, B.Sulignano, et al. in preparation

J. Kallunkatharyil, B.Sulignano, P.T. Greenlees et al. in preparation

HINDRANCE FACTOR

- ^{250}No - ^{254}Rf are the only known case where fission from a k-isomer is hindered respects to ground state

- HF= $t_{1/2}$(Isomer)/$t_{1/2}$(ground state)



A. Belozerov et al., Eur. Phys. J. A 16 (2003) 447

- **Quasi-particle configurations increase the barrier to fission leading to enhanced stability**

  →K isomer in SHN could live significantly longer then g.s.

Open questions

- Which is the spin and parity of the isomeric state?
- Which is the decay path of the isomeric state decay?
- There is more-substantial fission inhibition from the isomer (increasing barrier heights for multi-quasiparticle excitation)?

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- Which is the decay path of the isomeric state decay?
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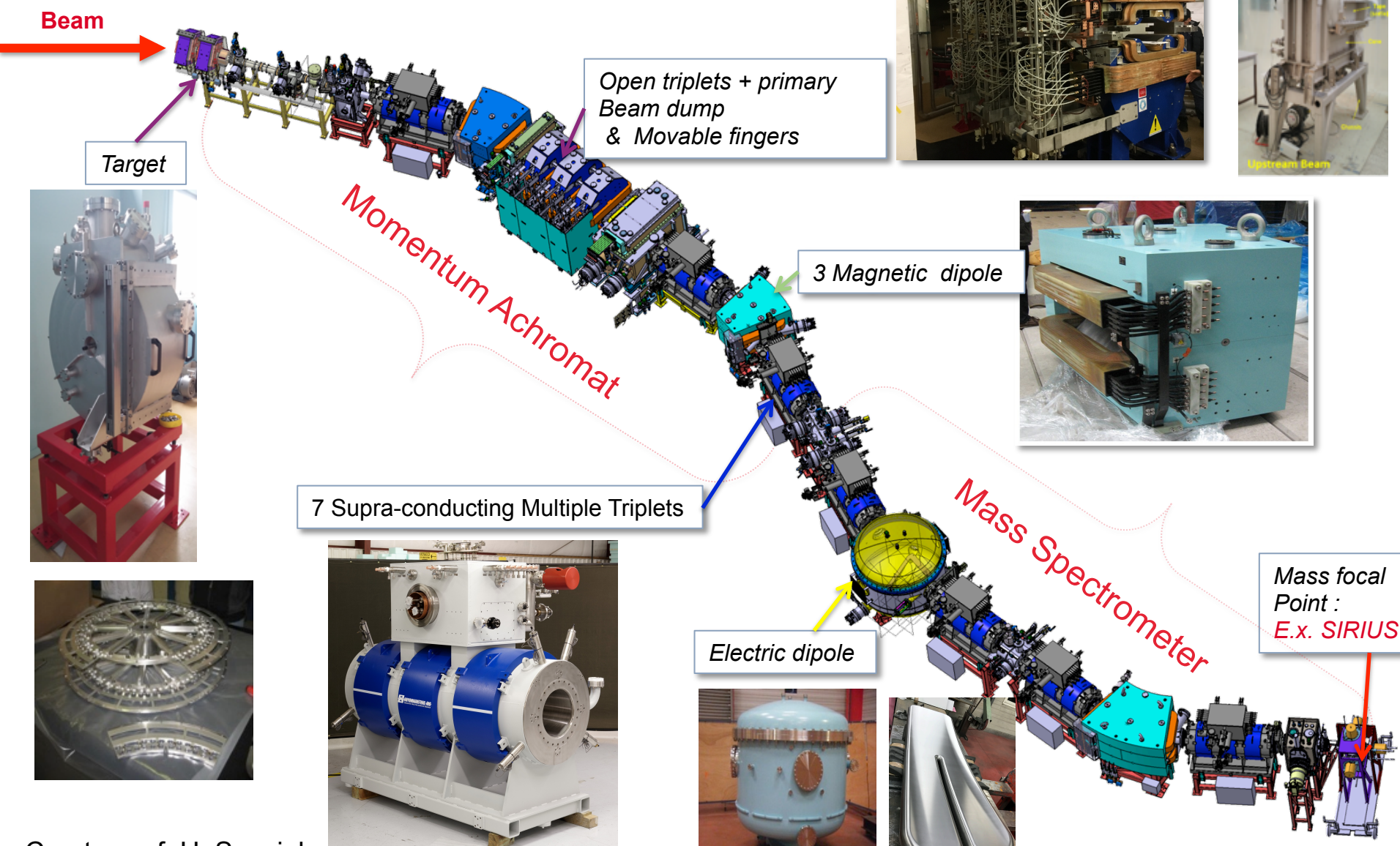
What we need for VHE - SHE studies

- More intense beams, more beam time
- More efficient separator
- More efficient detectors
- Faster electronics

SPIRAL 2 @ GANIL

S³ STATUS



Courtesy of H. Savajols

INSTALLATION IN THE S3 HALL

Optical modes : Ultra High Resolution Mode

Target point
High power rotating target

Image 2
Achromat selection
Extended drift to place detector arrays

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

- Transmission (20%)
- *Acceptance* σ_θ = *34mrad* σ_p = *2.2%*
- Mass resolution ($\Delta M/M \approx 500$)
- Versatility ($B\rho_{max}$=1.6Tm; $E\rho_{max}$ = 12MV)

High Intensity Beams

Image 1
Momentum Selection and beam rejection

Image 3
TKE selection

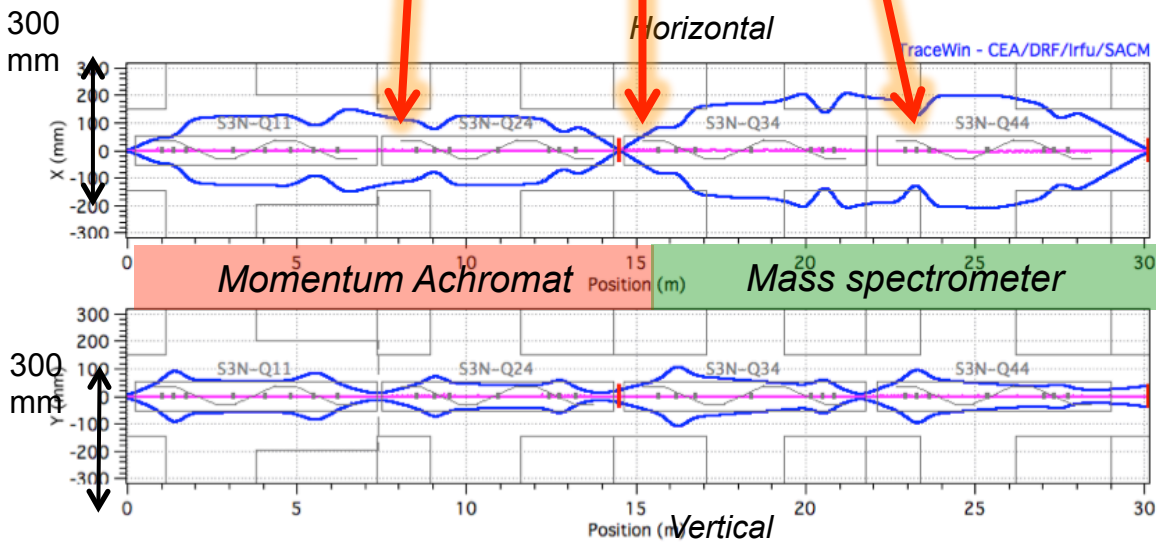
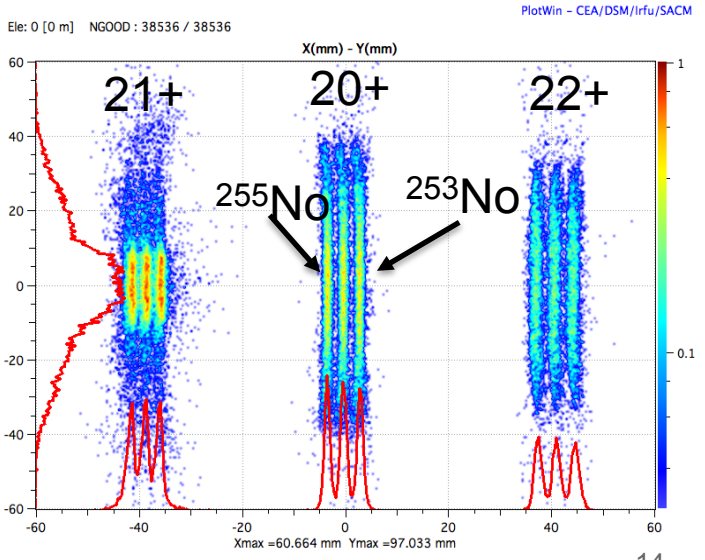


Image 4
Mass selection



Optical modes : Converging Mode

Target point
High power rotating target

Image 2
Achromat selection
Extended drift to place detector arrays

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

- Transmission (40%)
- *Acceptance* σ_θ = *34mrad* σ_p = *2.2%*
- Mass resolution ($\Delta M/M \approx 0$)
- Versatility ($B\rho_{max}$=1.6Tm; $E\rho_{max}$ = 12MV)

High Intensity Beams

Image 1
Momentum Selection and beam rejection

Image 3
TKE selection

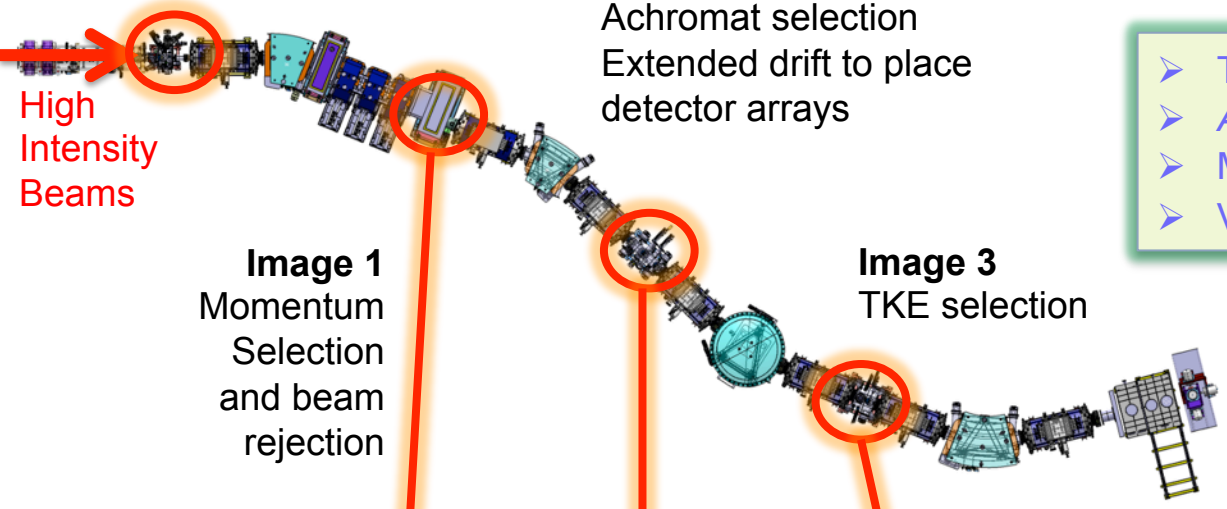
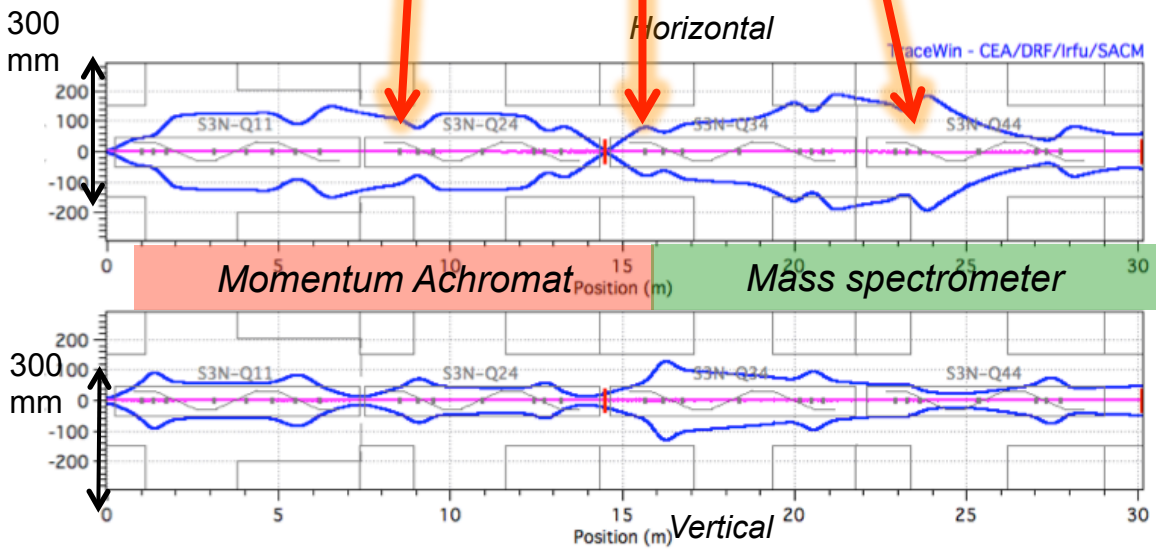
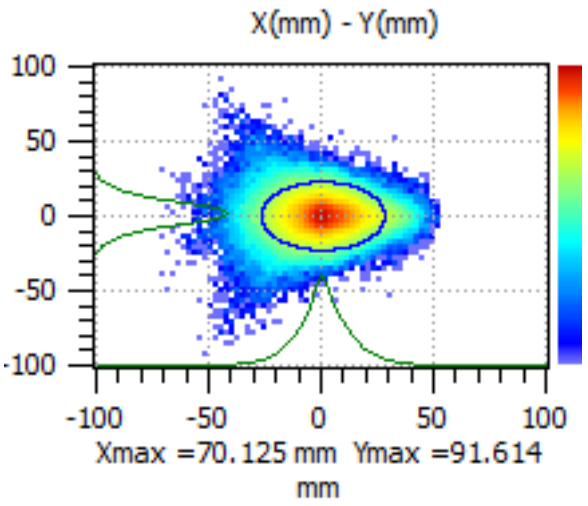


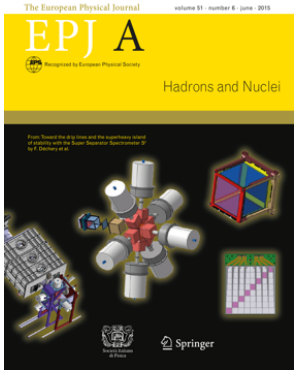
Image 4
No Mass resolution



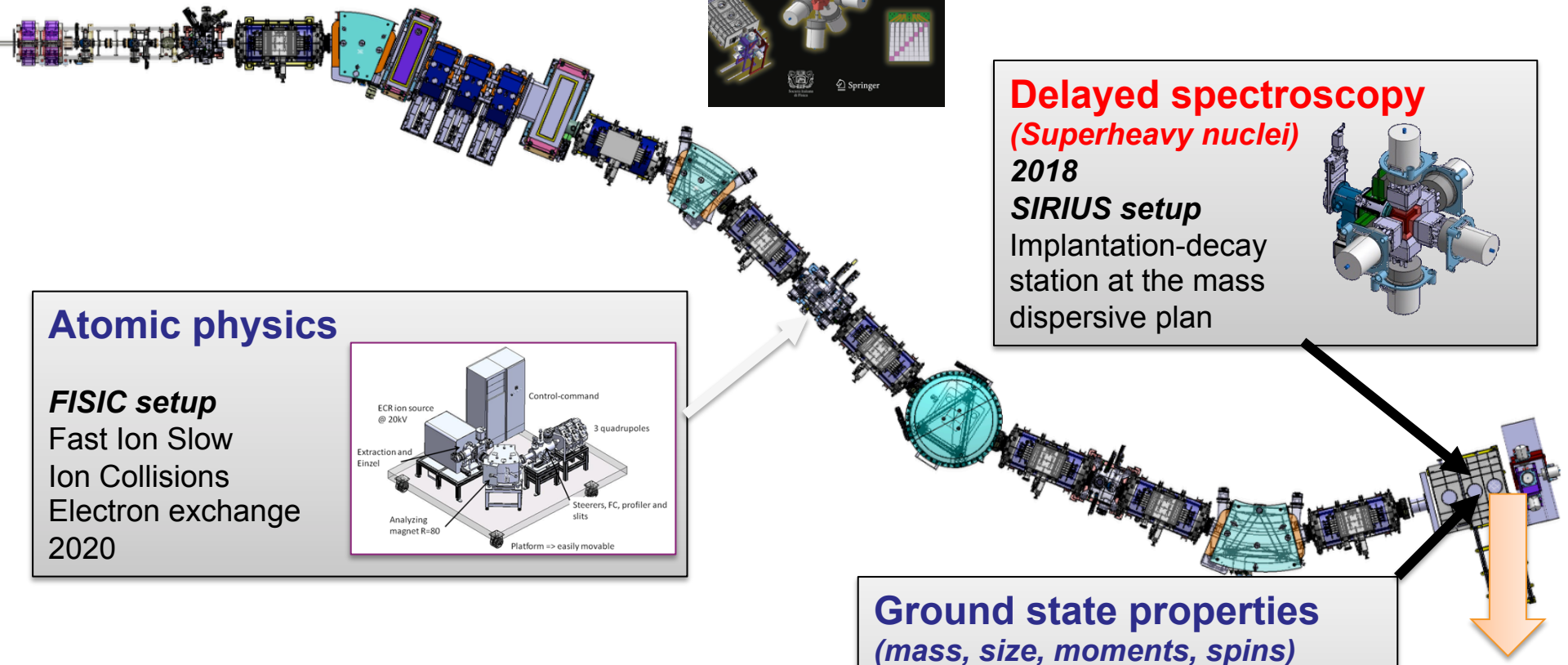


S3 versatile instrumentation

S3 Physics case (26 LoIs)
- VHE-SHE nuclei
- Proton drip-line & N=Z
- Nuclear Astrophysics
- Atomic physics



J. A (2015) 51: 66

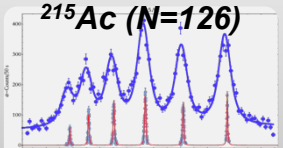


Delayed spectroscopy
(Superheavy nuclei)
2018
SIRIUS setup
Implantation-decay station at the mass dispersive plan

Atomic physics

FISIC setup
Fast Ion Slow Ion Collisions
Electron exchange
2020

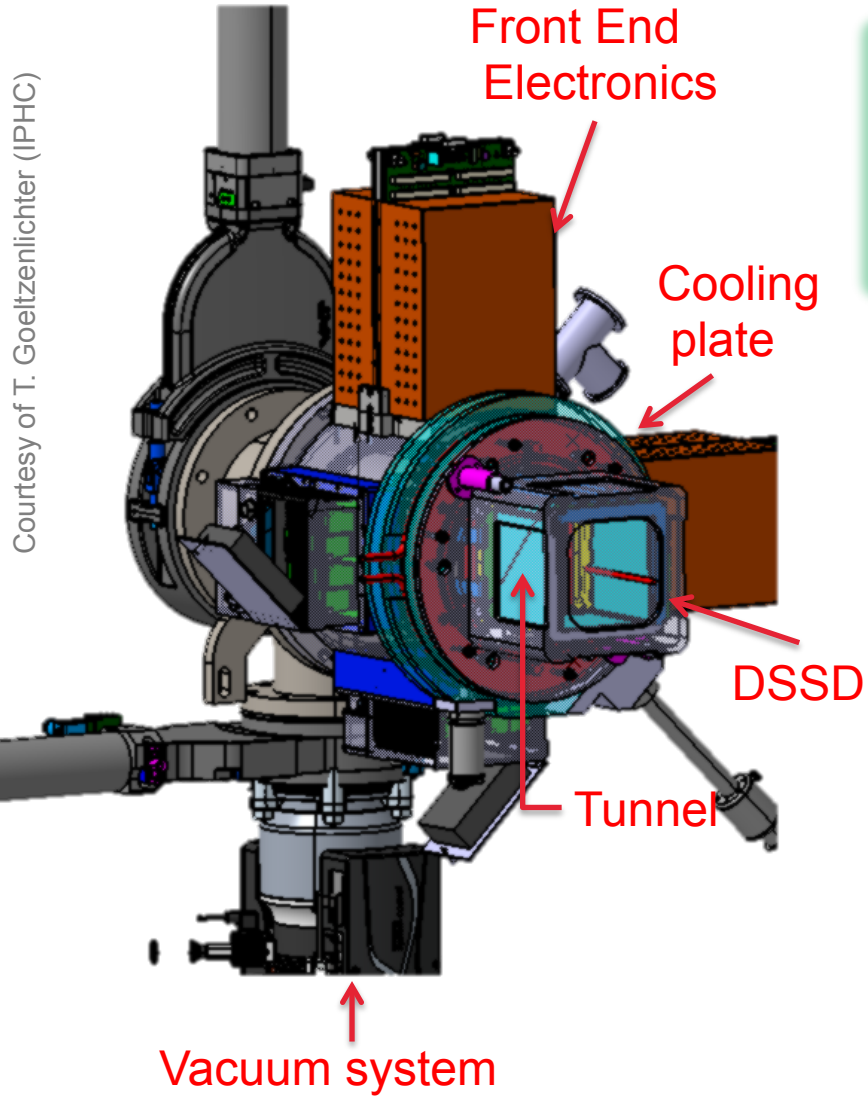
Ground state properties
(mass, size, moments, spins)
2018
S3-LEB setup
IGLIS + Mr-ToF



DESIR

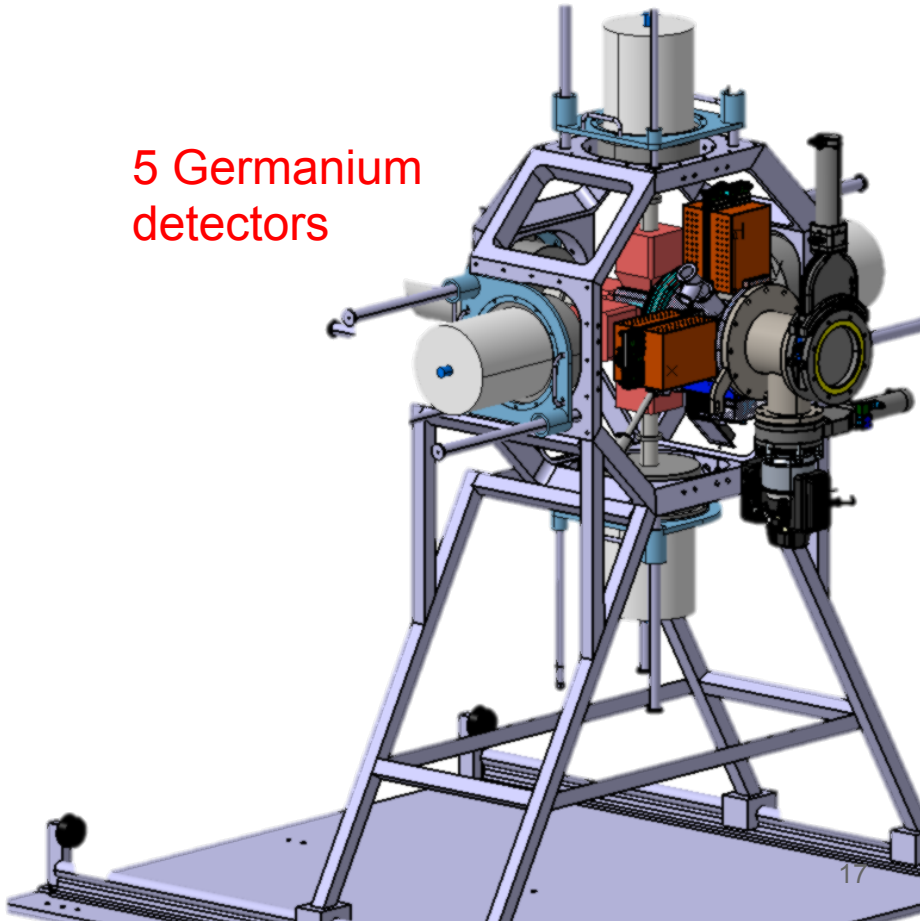
Courtesy of H. Savajols

SPECTROSCOPY AND IDENTIFICATION OF RARE IONS USING S3



Courtesy of T. Goeltzenlichter (IPHC)

- Time of flight (**σ(t) < 1ns**) and tracking (**σ(x) <0.5mm**)
- Large size Implantation detecotor (**10x10cm²**, 128x128ch DSSD)
- Digital electronics : ability to detect large> 50MeV pulse followed (≈ 10µs) by a weak (<15MeV) pulse with good energy resolution.

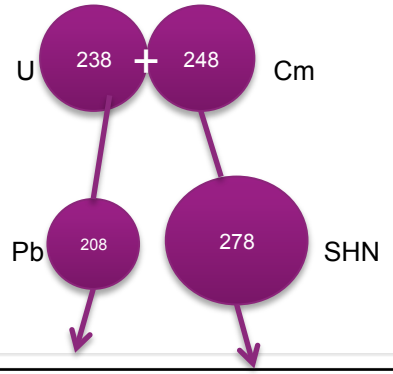


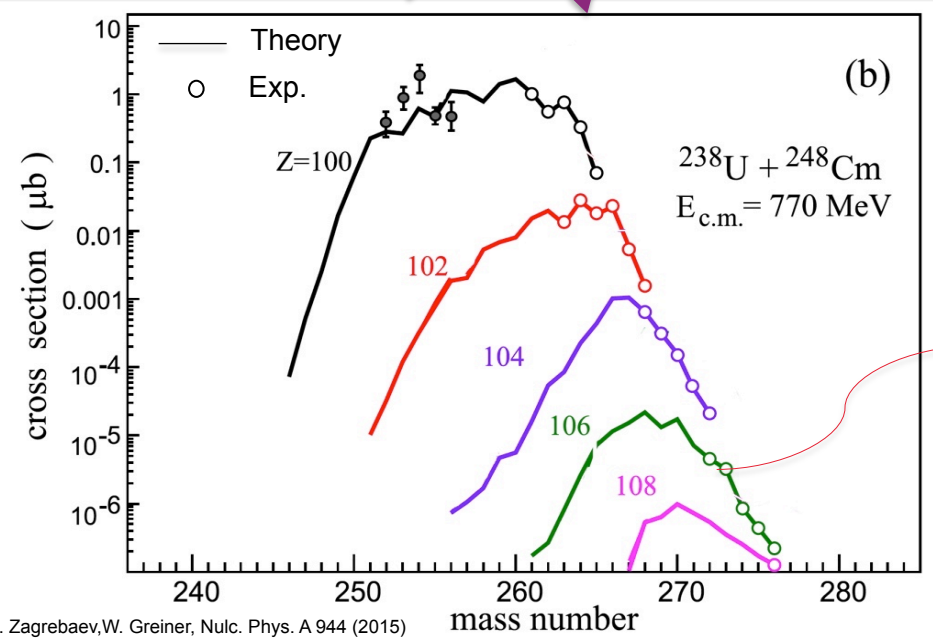
OUTLOOK 1

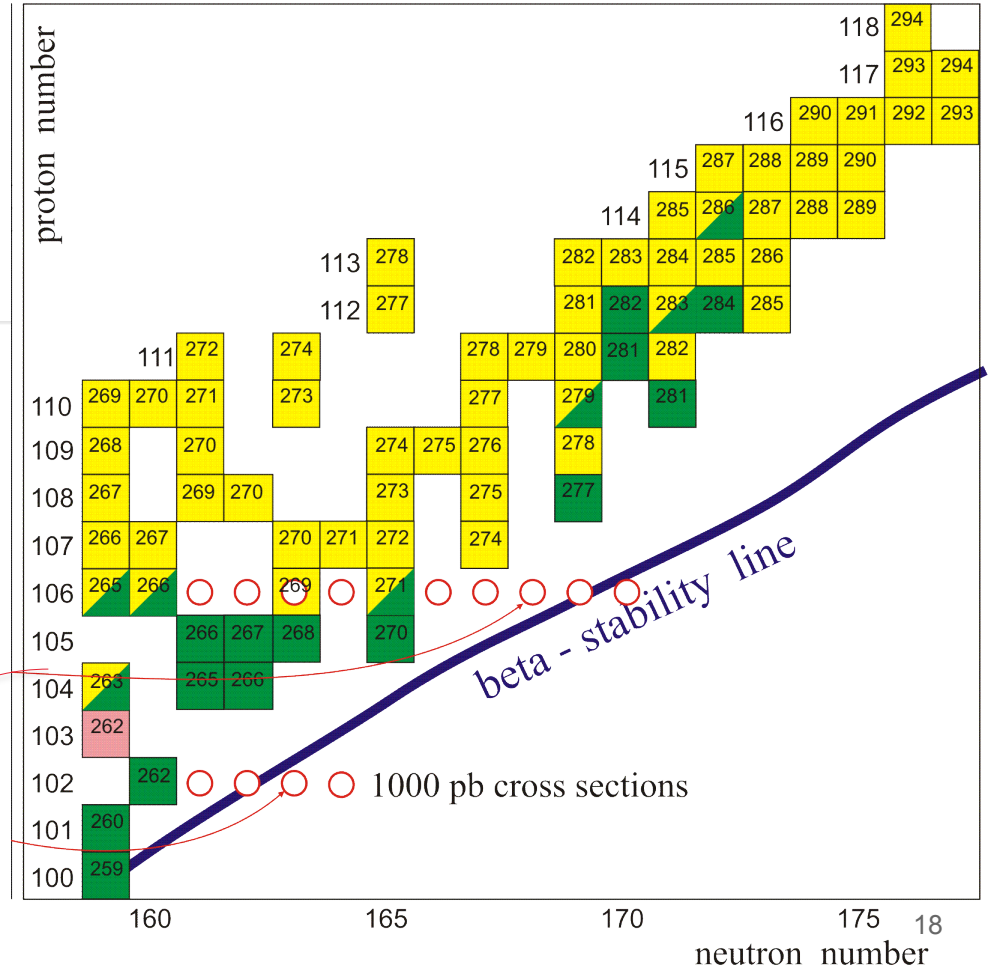
Spectroscopy

Spectroscopy of odd nuclei and hinting for K-isomer

Reaction mechanism studies: Multinucleon transfer reaction ($^{137}Xe+^{238}U$)







. Zagrebaev,W. Greiner, Nulc. Phys. A 944 (2015)

OUTLOOK 2

Commissioning S3

- Commissioning experiments
- Measure and optimize the rejection; Estimate the transmission
- Qualify the detection setup ^{116}Sn(^{40}Ar,4n) ^{152}Er
- ^{64}Ni(^{64}Ni,3-4n) ^{124,125}Ba
- ^{208}Pb(^{48}Ca,2n) ^{254}No ($T_{1/2}$=50 s, alpha-branching = 90 %)

SIRIUS

- SIRIUS will be installed at GANIL in T4 2019.
- Commissioning of SIRIUS planned with alpha/electron sources at GANIL.
- In-beam commissioning of SIRIUS @ LISE 2000 using the reaction ^{40}Ar(^{174}Yb,4-5n)^{209,210}Ra.

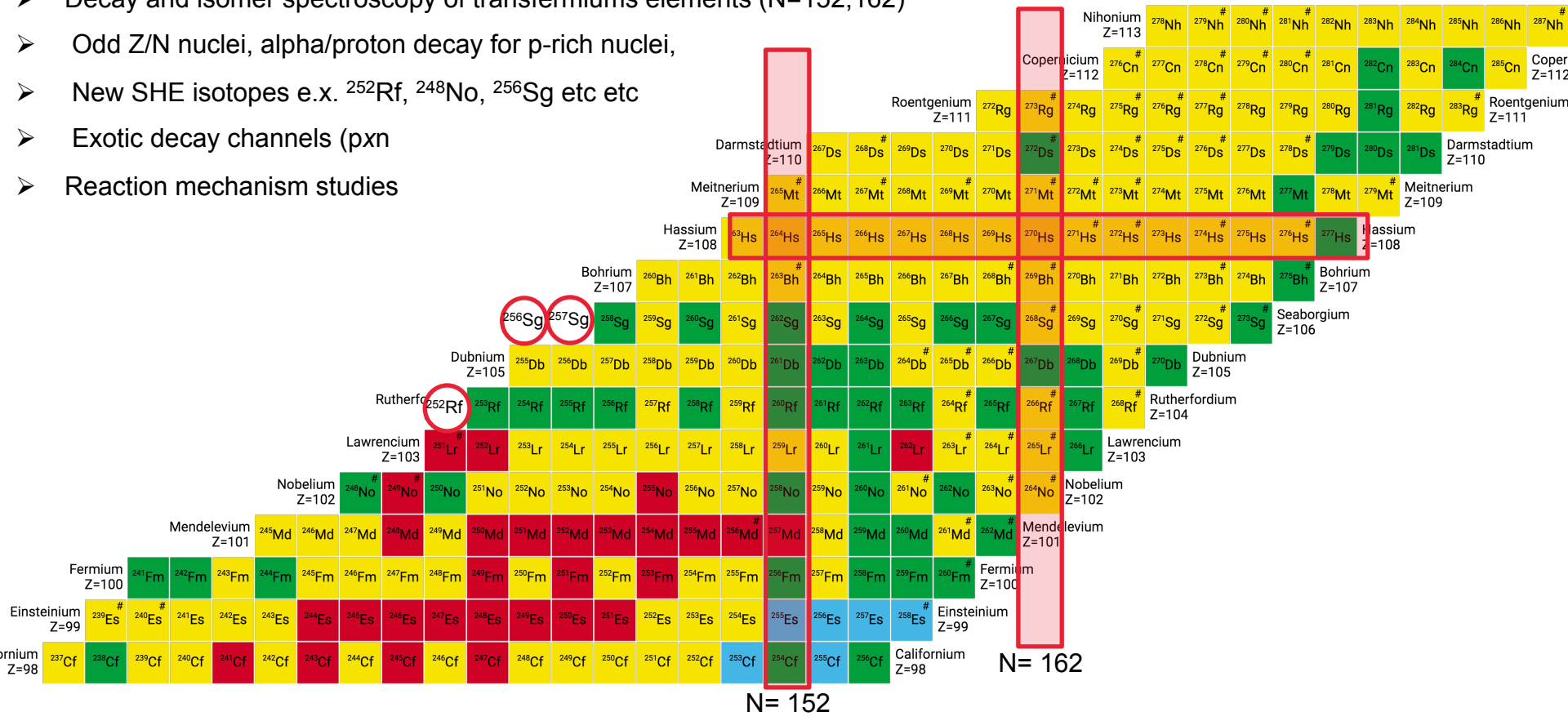
OUTLOOK 3

First experiments @ S3+ SIRIUS

(LOI S3 Collaboration Workshop 18-22 June 2018)

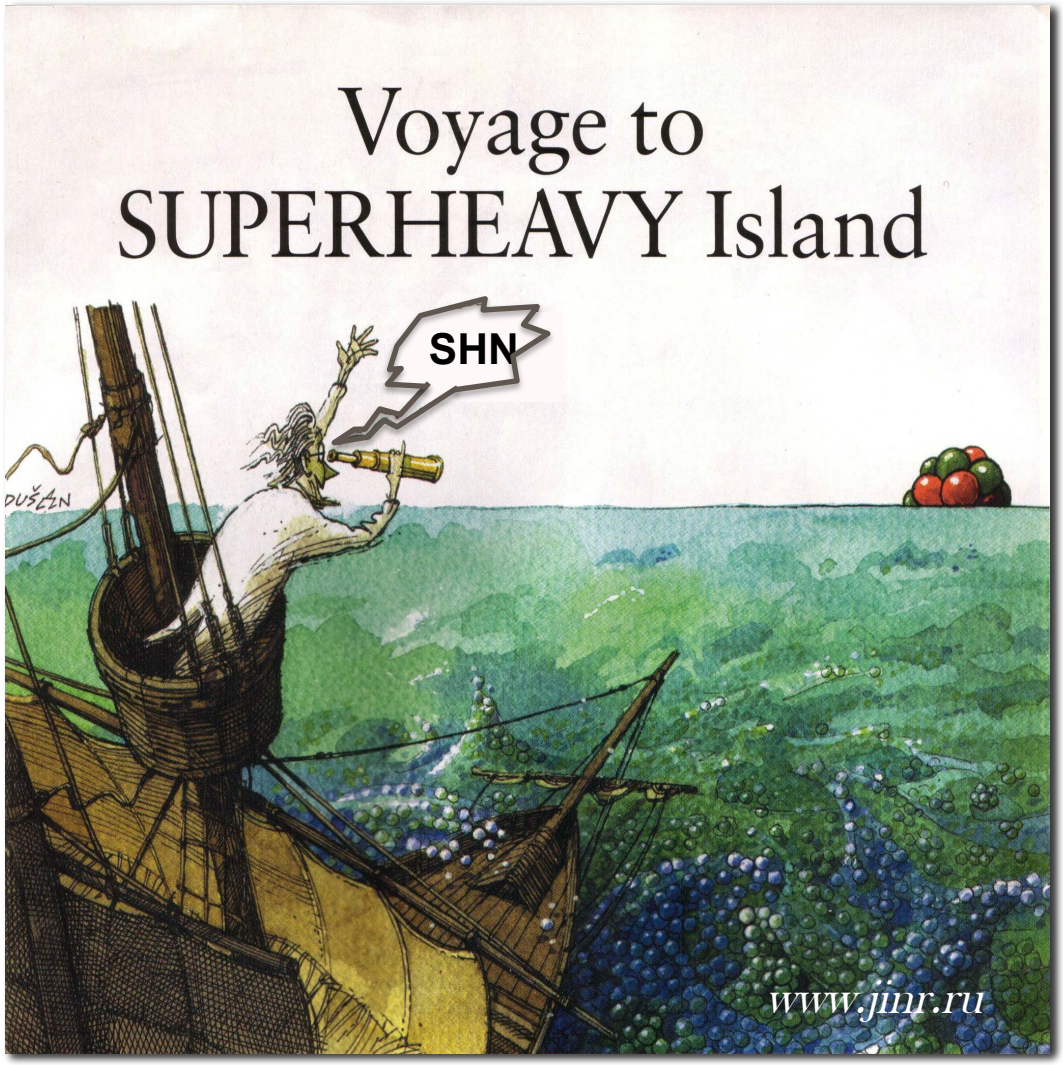
Understanding nuclear structure responsible for shell stabilization in SHE and understand the influence of nuclear structure on fusion-evaporation for SHE.

- Decay and isomer spectroscopy of transfermiums elements (N=152,162)
- Odd Z/N nuclei, alpha/proton decay for p-rich nuclei,
- New SHE isotopes e.x. ^{252}Rf, ^{248}No, ^{256}Sg etc etc
- Exotic decay channels (pxn
- Reaction mechanism studies



5 research groups from France, and from Germany, UK, Finland, Slovakia, Russia

- Challenging field of research
- Many open questions, some of which can be addressed at the SPIRARL2 project



TASK FORCE

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GRAZIE !