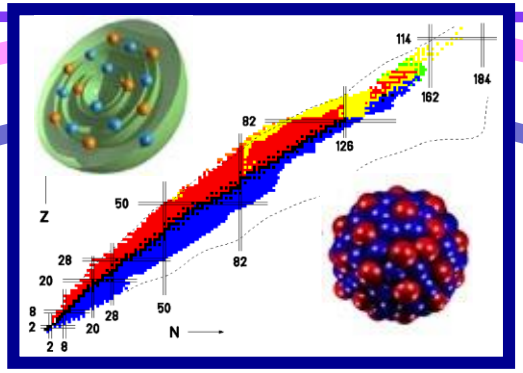
# Nuclear Physics at GANIL-SPIRAL2

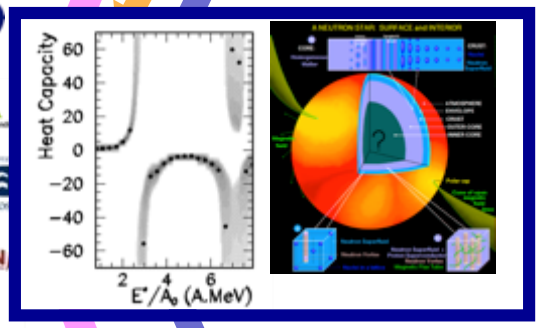
- Scientific program (AGATA)
- Evolution of GANIL-SPIRAL2

# GANIL/SPIRAL2 Science

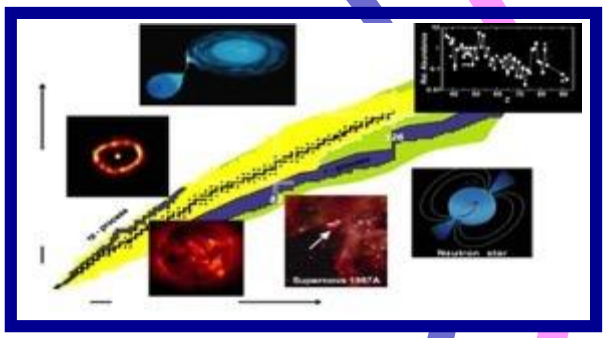
## Nuclear structure



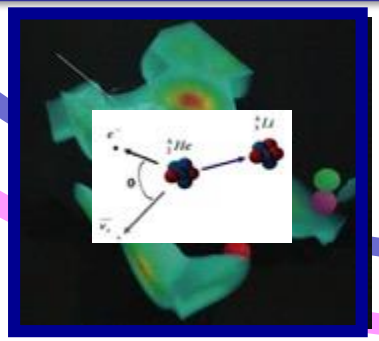

## EOS
Liquid-gas phase
Isospin dependence




## Nuclear Astrophysics



## Fundamental Interactions

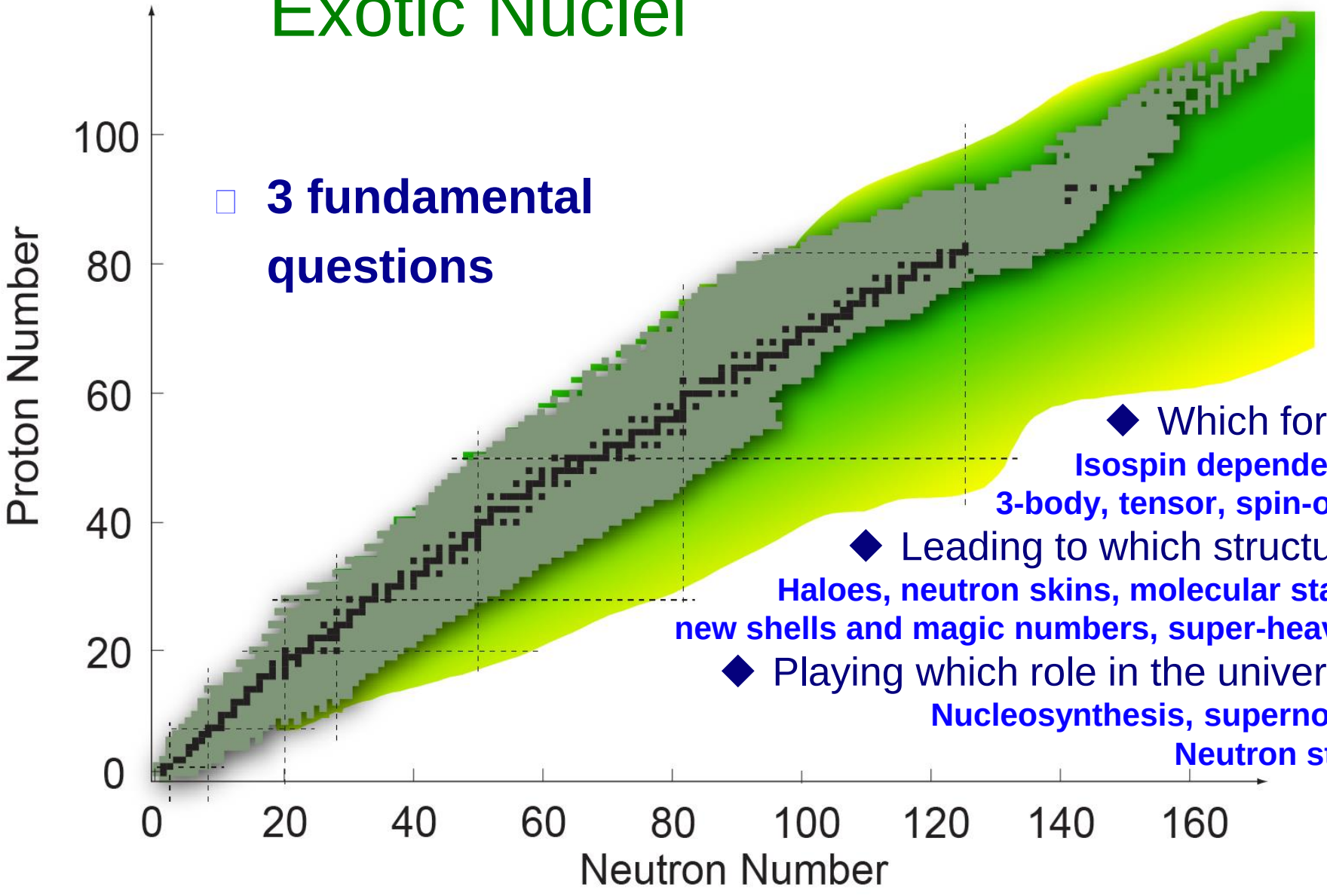


## Multi-disciplinary research & Applications

# A huge discovery potential

## Exotic Nuclei

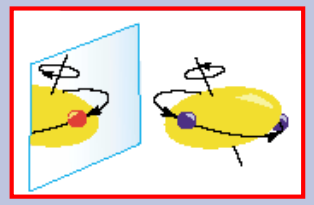
- **3 fundamental questions**

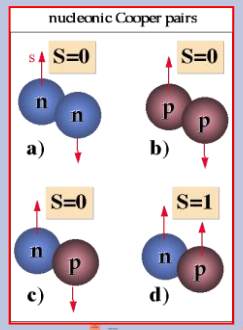



- Which force?
  **Isospin dependence, 3-body, tensor, spin-orbit.**
- Leading to which structure?
  **Haloes, neutron skins, molecular states, new shells and magic numbers, super-heavies.**
- Playing which role in the universe?
  **Nucleosynthesis, supernovae, Neutron stars.**

# The physics of AGATA@GANIL is the in-beam high resolution γ-ray spectroscopy of exotic nuclei populated by heavy-ions collisions

- ***Nucleon-nucleon(-nucleon) interaction close to magic nuclei***
- ***Astrophysical measurements***
- ***Collective mode in nuclear matter***
- ***Clusters in nuclear matter***






$^{208}$Pb

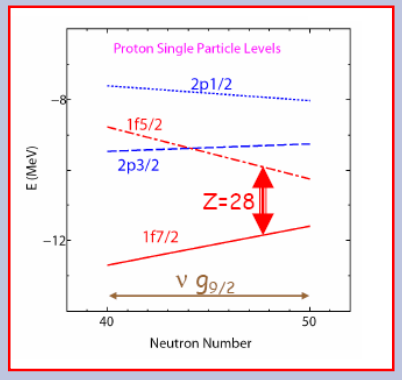
$^{100}$Sn

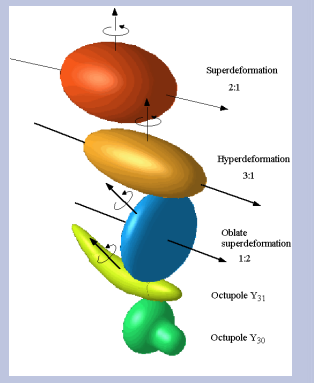
$^{132}$Sn

$^{68}$Ni

$^{78}$Ni

$^{48}$Ca




- *High resolution γ-ray spectroscopy of very exotic nuclei*
- *Lifetime measurement of excited states in the range of fs to μs*

# Physics cases of the 1st run AGATA at GANIL : Nuclear structure in the vicinity of doubly magic nuclei

## 2015 Run

- *p-n , n-n correlations in the vicinity $^{132}$Sn;$^{100}$Sn, $^{68}$Ni, $^{48}$Ca*
- *Terra-incognita $^{208}$Pb*
- *Tensor force and monopole migration around $^{78}$Ni*
- *3 body forces*

G. Georgiev et al; $2^+$ lifetimes and g factor $^{204,206,208}$Hg : 17th -29th July

C. Domingo-Pardo et al ; $4^+$, $2^+$ lifetime in $^{94}$Ru and $^{96}$Pd

$^{208}$Pb

J. J. Valiente Dobon et al $4^+$, $2^+$ lifetime in $^{106,108}$Sn

P. R. John et al ; Shape transition in W isotopes: $^{190}$W and $^{192}$W spectroscopy and fast timing

$^{100}$Sn

$^{132}$Sn

A. Navin et al ; $i_{13/2}$ single particle state in $^{133}$Sn and high spin in $^{108}$Zr

$^{68}$Ni

$^{78}$Ni

D. Verney et al; lifetime measurement in $^{83}$Ge.

G. Duchêne et al; $^{80}$Zn and $^{82}$Ge highest spin structures

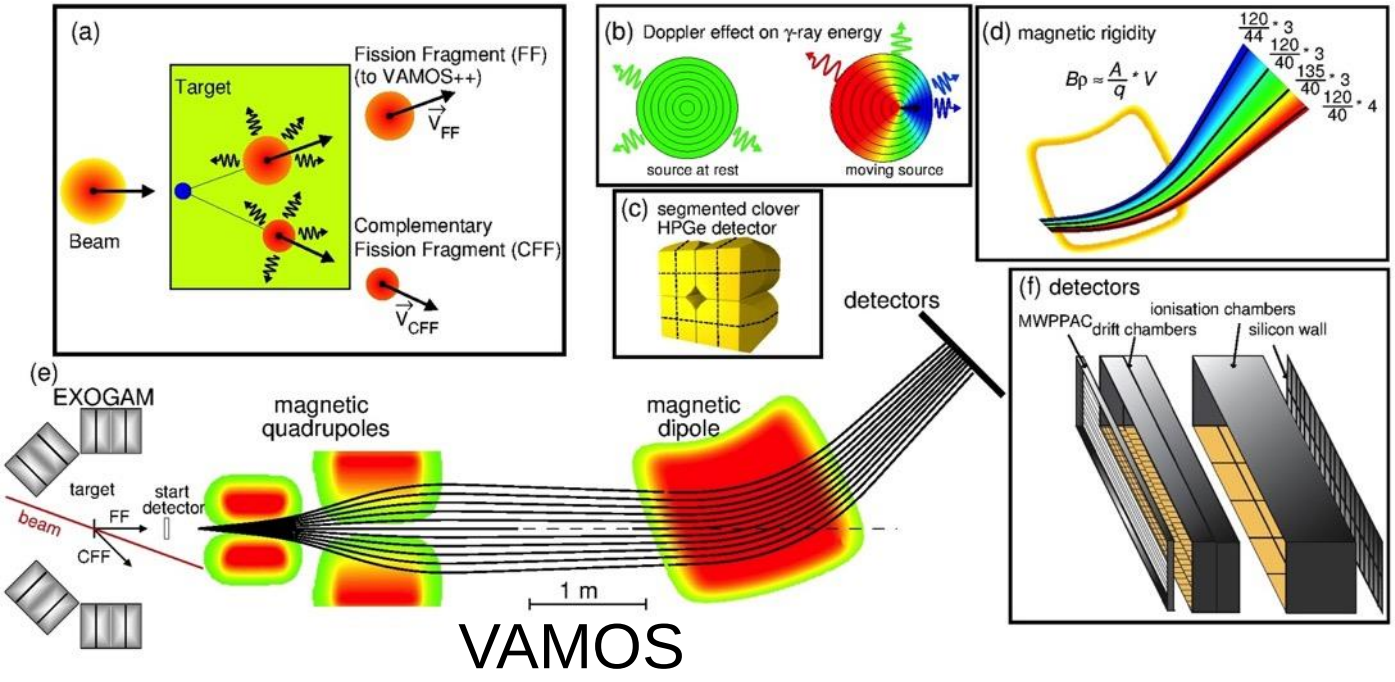
J. Ljungvall et al ; $2^+$, $4^+$ $6^+$ lifetime and g-factor in $^{62,64,66}$Fe

$^{48}$Ca

A. Lemasson et al : spectroscopy of $^{39,41,43}$S

S. Leoni et al ; Lifetime in n-rich C and O isotopes: test of the three body forces

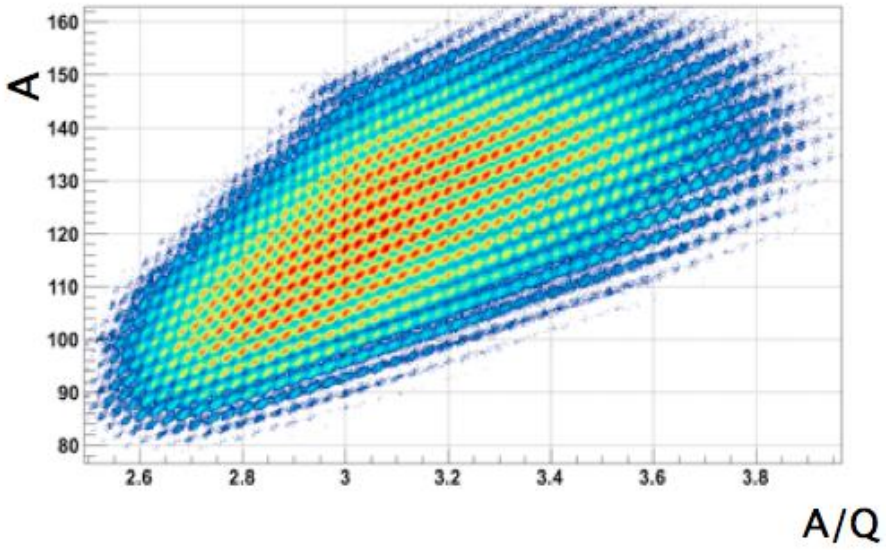
# Z, A & q identification at few MeV/nucleon

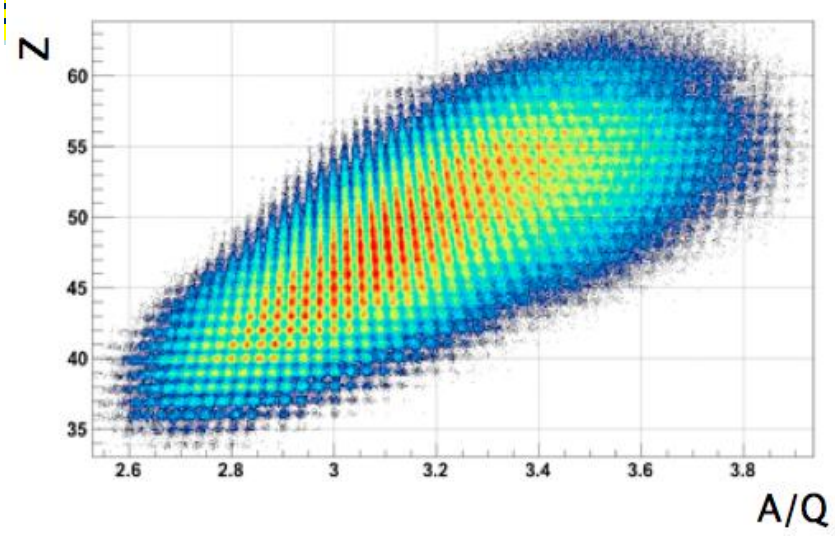


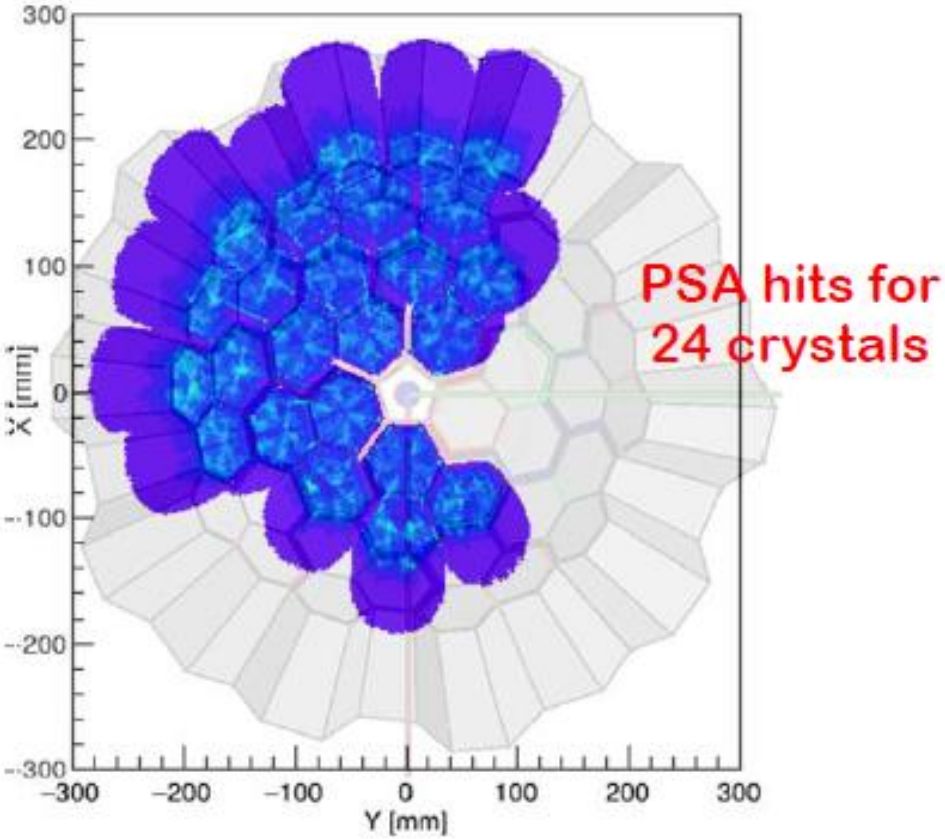

VAMOS

A. Navin and M. Rejmund
McGraw-Hill Yearbook of
Science & Technology (2014)

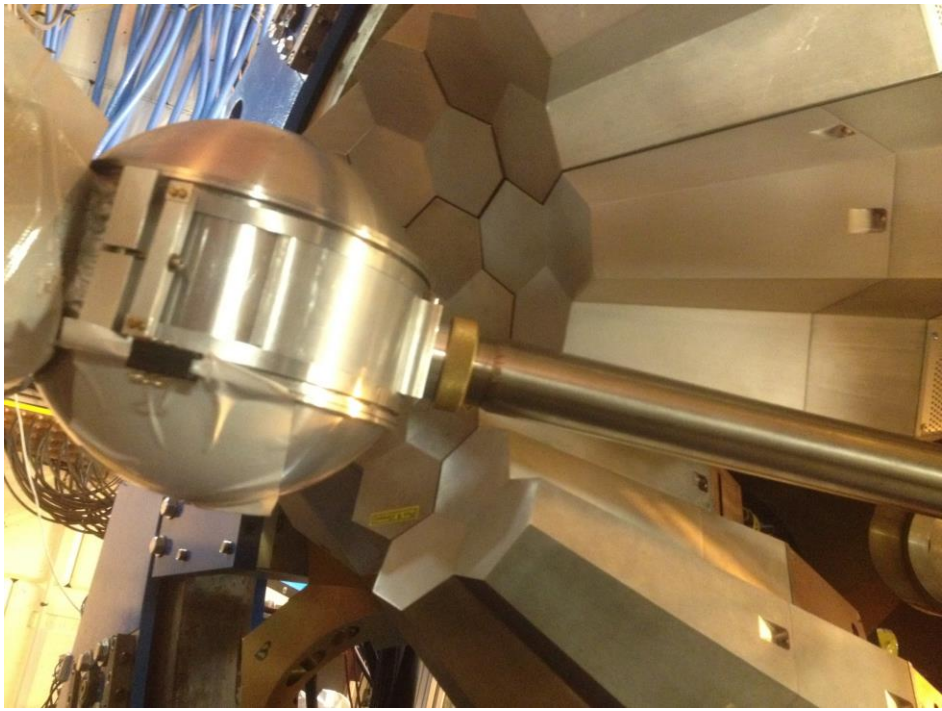
ΔA /A~ 0.4%
Z resolved up to 63
Identified 450 nuclei
and their excited states



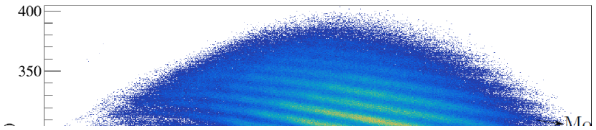



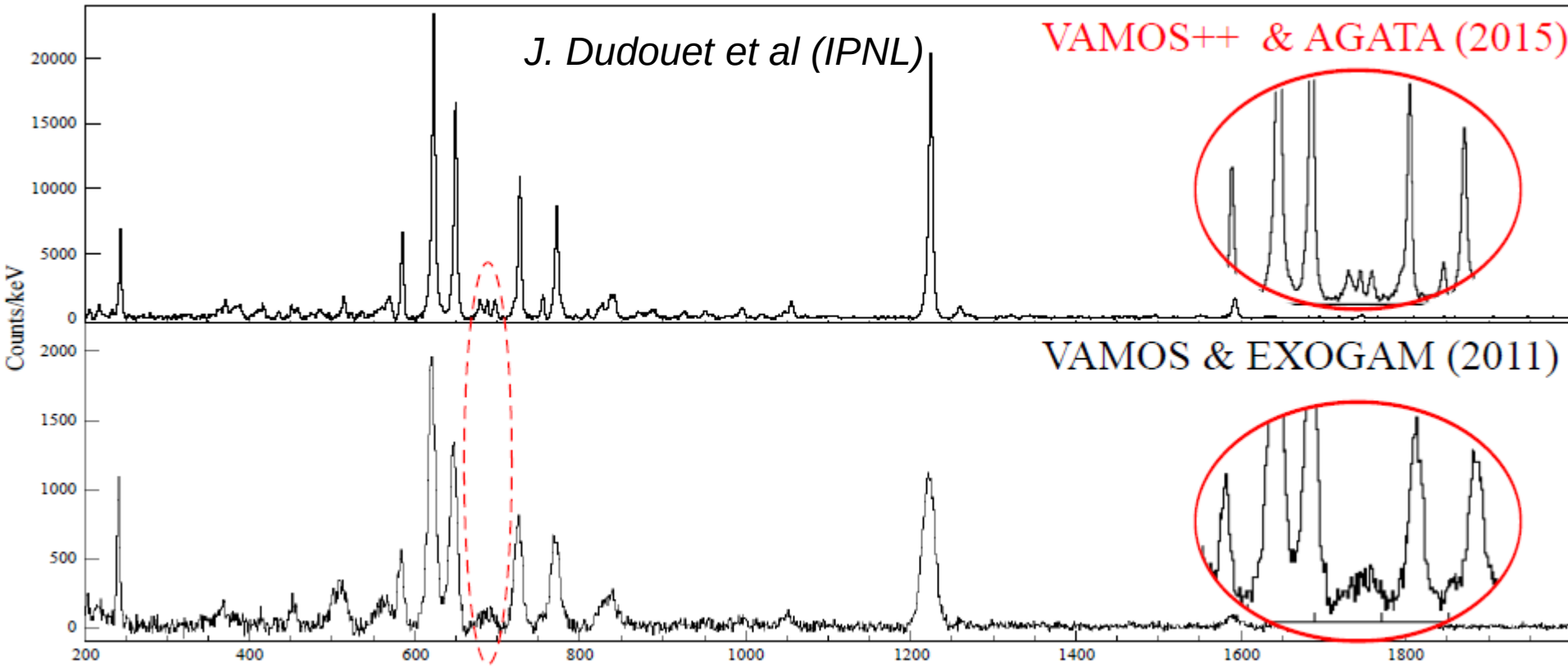


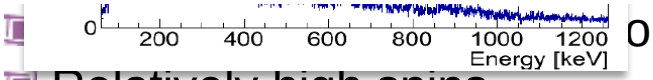

PSA hits for
24 crystals



AGATA@GANIL – April 2015




- on / MNT)
- Relatively high spins
- High Resolution
- Lifetimes measurements [fs to μs]

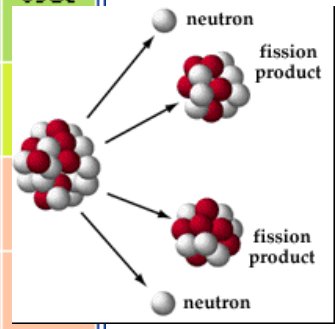
# Spectroscopy in the $^{68-78}$Ni region

Presented at INPC2016 by J. Dudouet (IPNL) & paper under Prep.

$^{96}$Kr

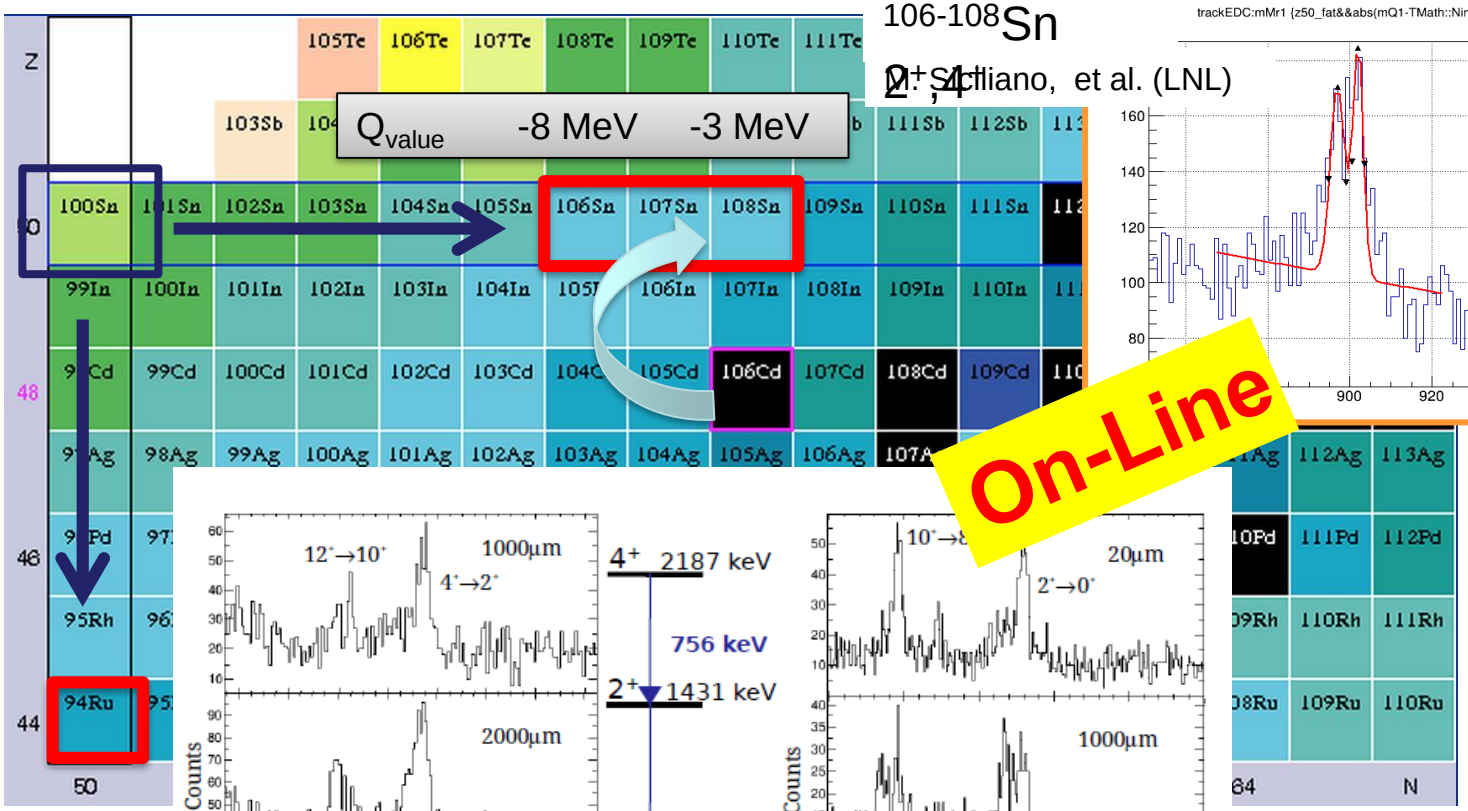
Under Analysis (IPNO & IPHC)

Lifetimes RRDS. Evolution of collectivity arount N=40




*LPNS interaction*

# Liftetime measurement in the $^{100}$Sn region




$^{106\text{-}108}$Sn

$2^+$, $4^+$ Siciliano, et al. (LNL)

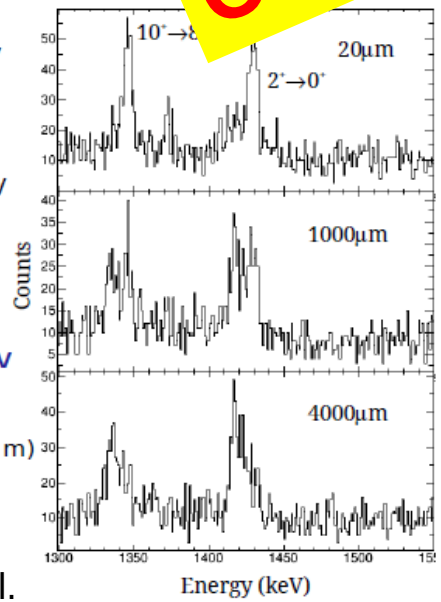



On-Line










Multinu … de to popula … f the $2^+$ and $4^+$ stat …

R. Perez, et al. (IFIC)

$^{208}$Pb region : → D. Ralet (CSNSM)

# Physics cases for the 2nd run (2016-2017) : nuclear structure in the vicinity of doubly magic nuclei, N=Z nuclei, astrophysic and deformation

J. Nyberg et al. : Studies of excited states in $^{102,103}$Sn to deduce two-body neutron interactions, single-particle energies and N=Z=50 core excitations

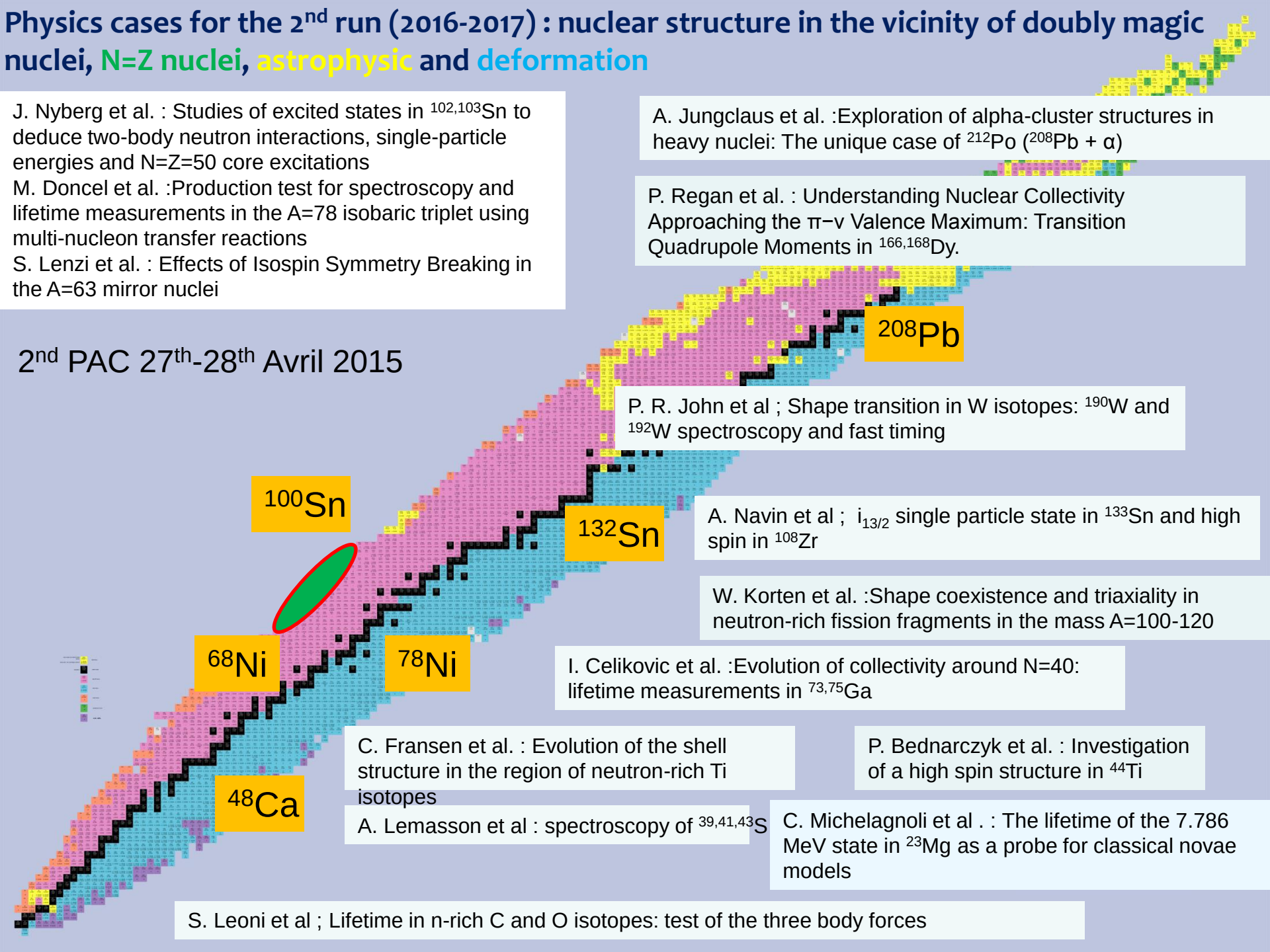
M. Doncel et al. :Production test for spectroscopy and lifetime measurements in the A=78 isobaric triplet using multi-nucleon transfer reactions

S. Lenzi et al. : Effects of Isospin Symmetry Breaking in the A=63 mirror nuclei

A. Jungclaus et al. :Exploration of alpha-cluster structures in heavy nuclei: The unique case of $^{212}$Po ($^{208}$Pb + α)

P. Regan et al. : Understanding Nuclear Collectivity Approaching the π−ν Valence Maximum: Transition Quadrupole Moments in $^{166,168}$Dy.

2nd PAC 27th-28th Avril 2015




P. R. John et al ; Shape transition in W isotopes: $^{190}$W and $^{192}$W spectroscopy and fast timing

A. Navin et al ; $i_{13/2}$ single particle state in $^{133}$Sn and high spin in $^{108}$Zr

W. Korten et al. :Shape coexistence and triaxiality in neutron-rich fission fragments in the mass A=100-120

I. Celikovic et al. :Evolution of collectivity around N=40: lifetime measurements in $^{73,75}$Ga

C. Fransen et al. : Evolution of the shell structure in the region of neutron-rich Ti isotopes

P. Bednarczyk et al. : Investigation of a high spin structure in $^{44}$Ti

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S. Leoni et al ; Lifetime in n-rich C and O isotopes: test of the three body forces

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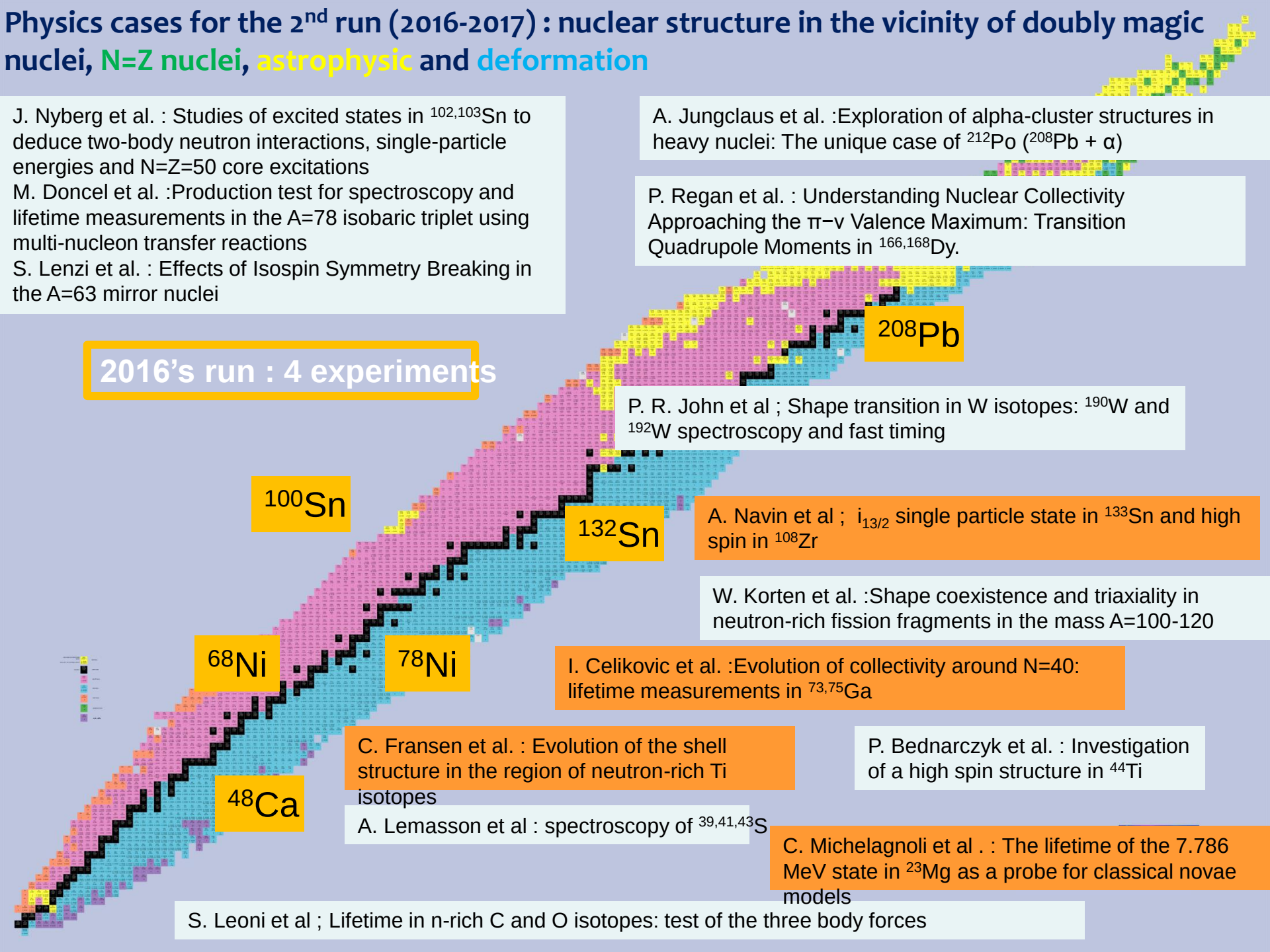


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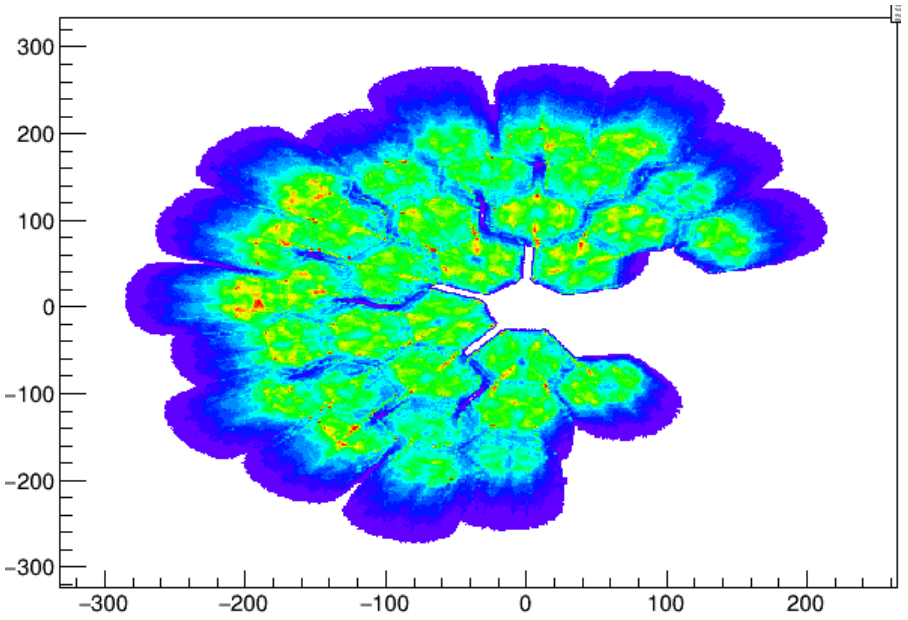
# AGATA 2016

- ❑ 10 Triple Clusters and 1 Double Cluster
- ❑ 32 channels (1184 HPGe Channels)

**→ This is a great success of the AGATA collaboration**



# GANIL-SPIRAL2

- Scientific program
- **Evolution of GANIL-SPIRAL2**

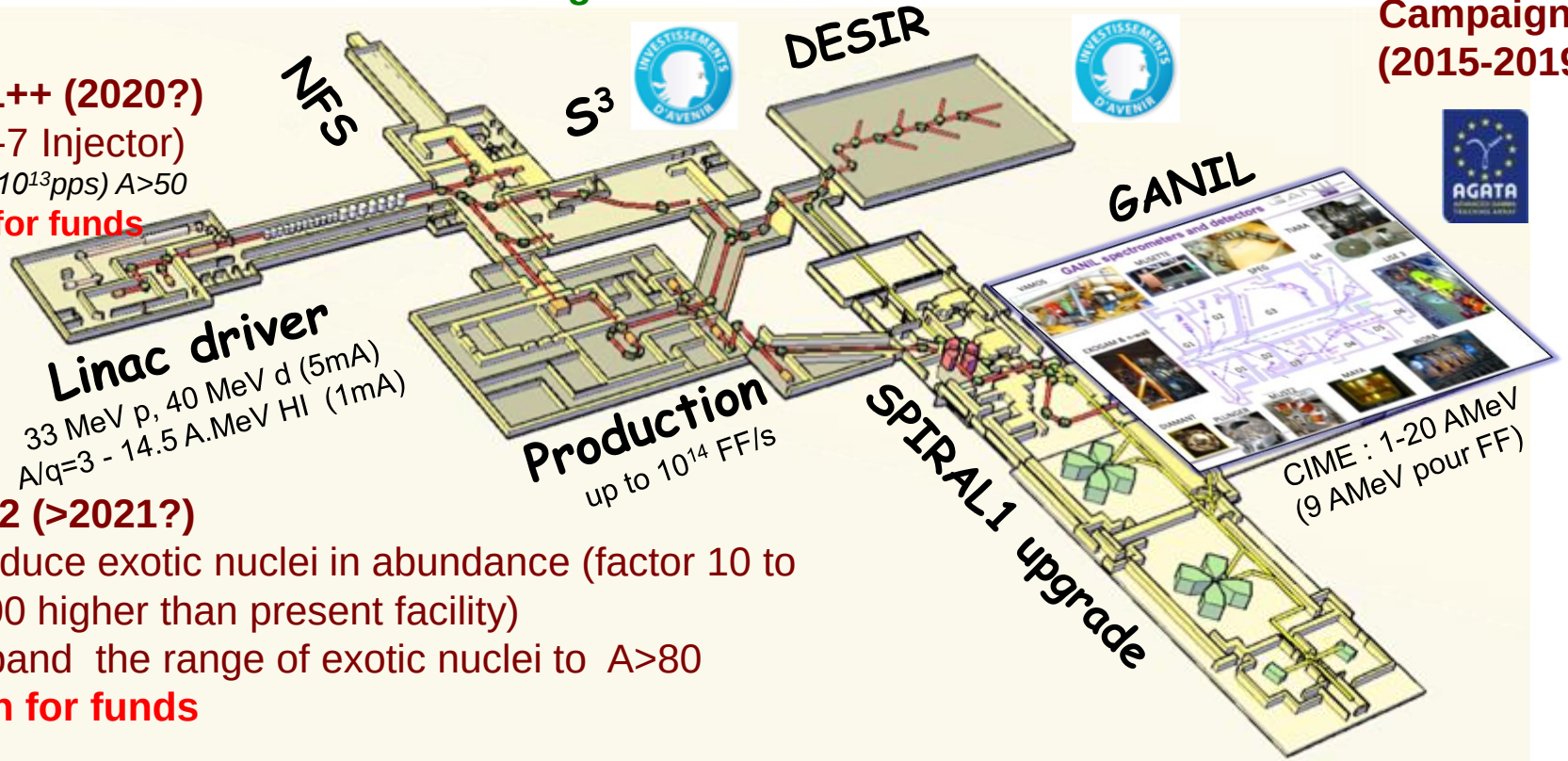
# GANIL-SPIRAL2 facility

**Phase1 (2015)**
Increase the intensity of stable beams by a factor 10 to 100
High intense neutron source
**End of construction & commissioning**

**DESIR Phase1+ (2019?)**
(low energy facility)
**Fully funded**

**AGATA Campaigns (2015-2019)**

**Phase1++ (2020?)**
(A/Q=6-7 Injector)
*10pμA (6.10¹³pps) A>50*
**Search for funds**




**Phase2 (>2021?)**
- Produce exotic nuclei in abundance (factor 10 to 1000 higher than present facility)
- Expand the range of exotic nuclei to A>80

**Search for funds**

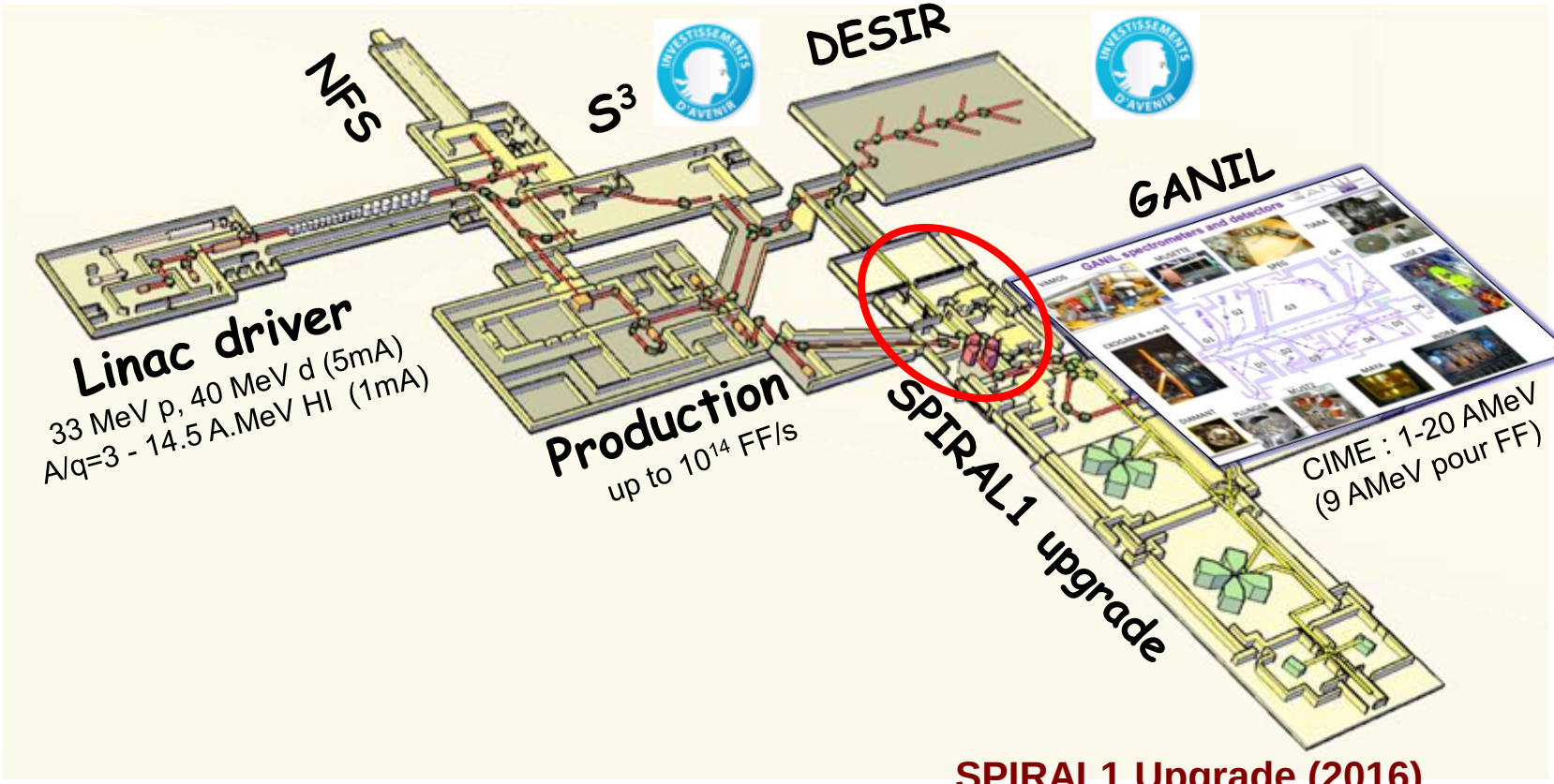
**SPIRAL1 Upgrade (2016)**
New light RIBs
**Fully funded**

## Investment:

- **SPIRAL2 Phase 1 (2015 secured): 100 M€**
- **New exp. halls and detectors (2014 secured) ≥30 M€**

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

# SPIRAL1 upgrade

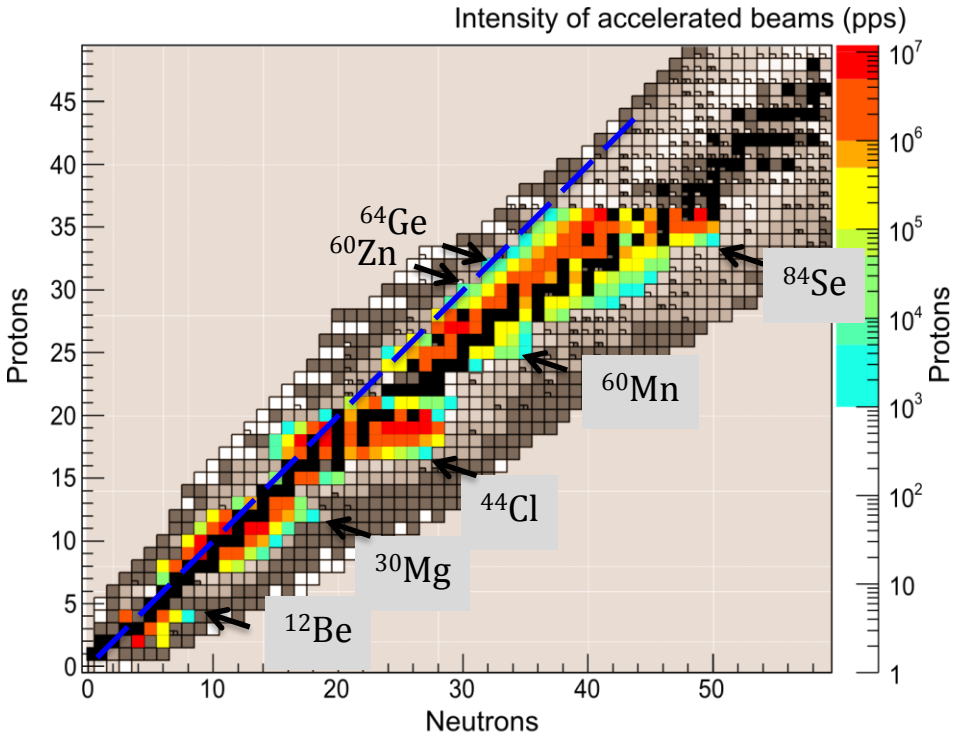



**SPIRAL1 Upgrade (2016)**

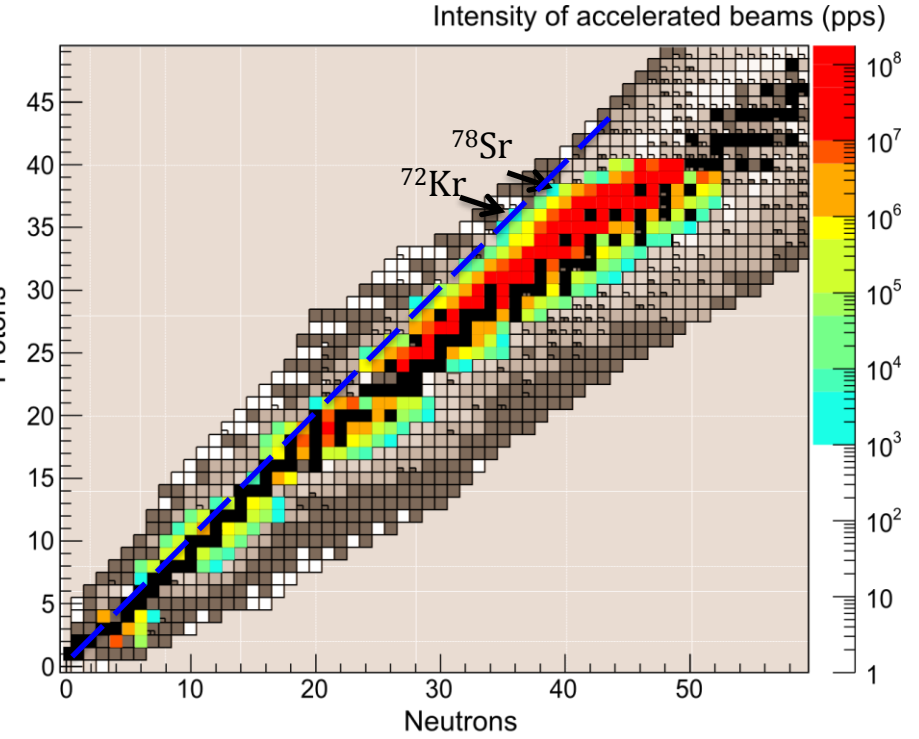
New light RIBs

**Fully funded**

# SPIRAL 1 upgrade




SPIRAL: Expected production from 12C target




SPIRAL: Expected production from Nb target


**New beams begining of 2017 available in particular for AGATA@GANIL and ACTAR-TPC experiments**

*P. Delahaye*

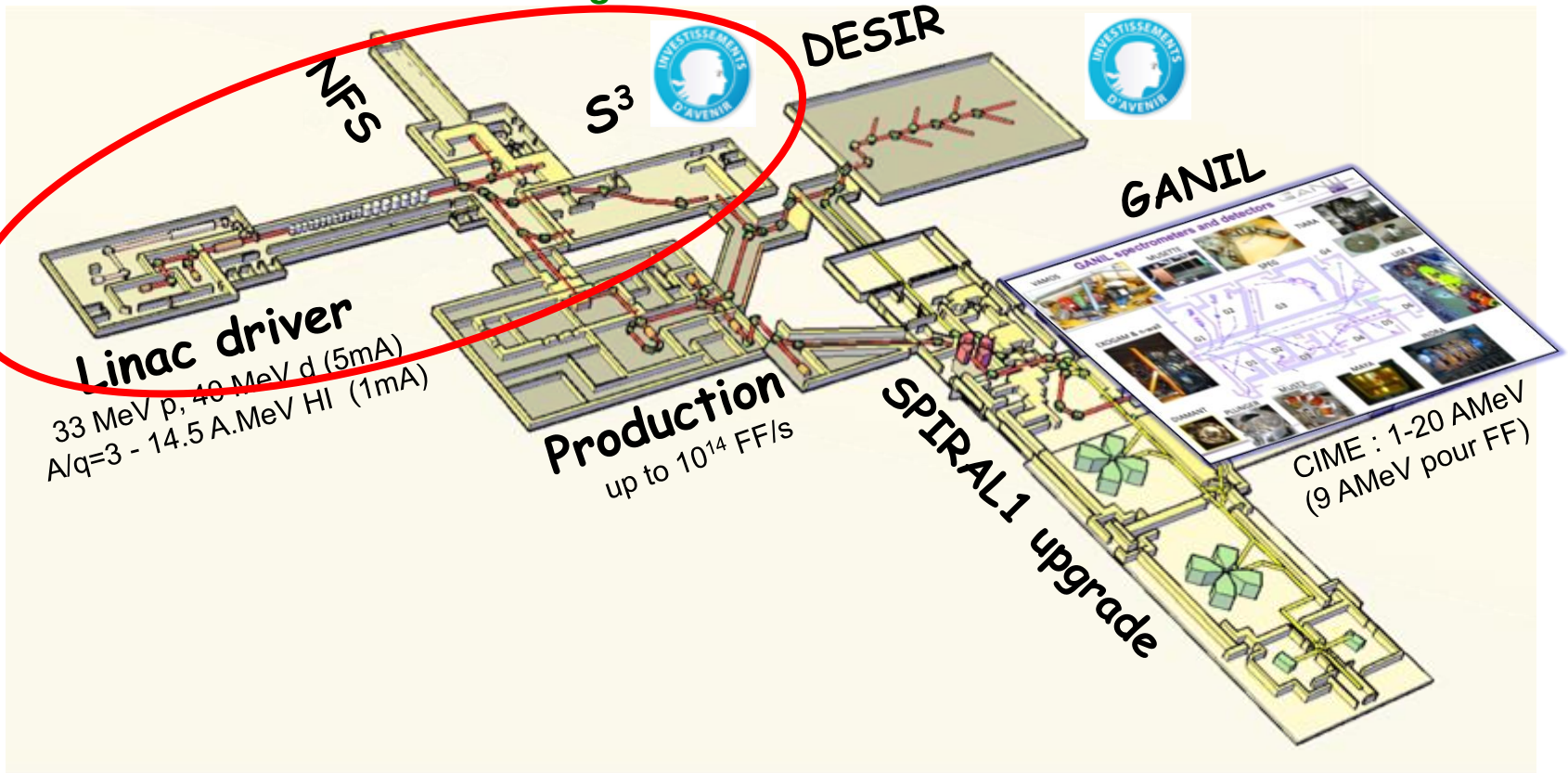
# GANIL-SPIRAL2 facility

**Phase1 (2016-17)**

Increase the intensity of stable beams by a factor 10 to 100

High intense neutron source

**End of construction & commissioning**



# SPIRAL2 Phase 1

| | Q/A | I (mA) | Energy (Mev/u) | Max beam Power (KW) |
|---|---|---|---|---|
| **Protons** | **1/1** | **5** | **2 - 33** | **165** |
| **Deuterons** | **1/2** | **5** | **2 - 20** | **200** |
| **Ions** | **1/3** | **1** | **2 - 14.5** | **45** |
| ***Ions (option)*** | ***1/7*** | ***1*** | ***2 - 8*** | ***48*** |

Average beam intensity equivalent to that of ESS or EURISOL driver

Commissioning is going on

# Installation & Commissioning of LINAC

**Low energy beam : Dec 2014**
**RFQ beam : Dec. 2015: protons 5mA**
**4He beam in March 2016**
**LINAC beam : Spring 2017**

Beam lines & support

**SC Cavities**

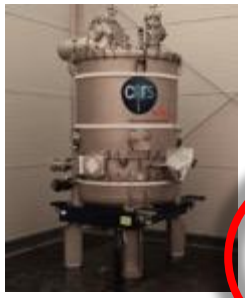
**LHE**

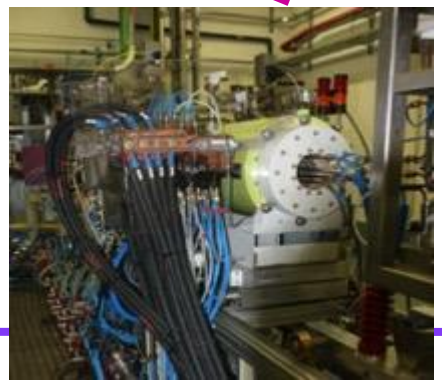
**BTI**

**RFQ**

**Beam lines**

**Ion Sources**

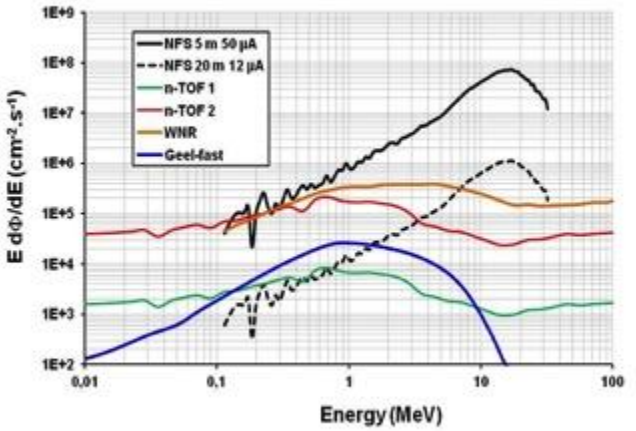




# Neutrons For Science

**NFS Physics case (11 LoIs)**

- Fission reactors of new generation
- Fusion technology
- Studies related to hybrid reactors (ADS)
- Basic data for evaluated data bases
- Nuclear medicine and biology
- Development of new detectors

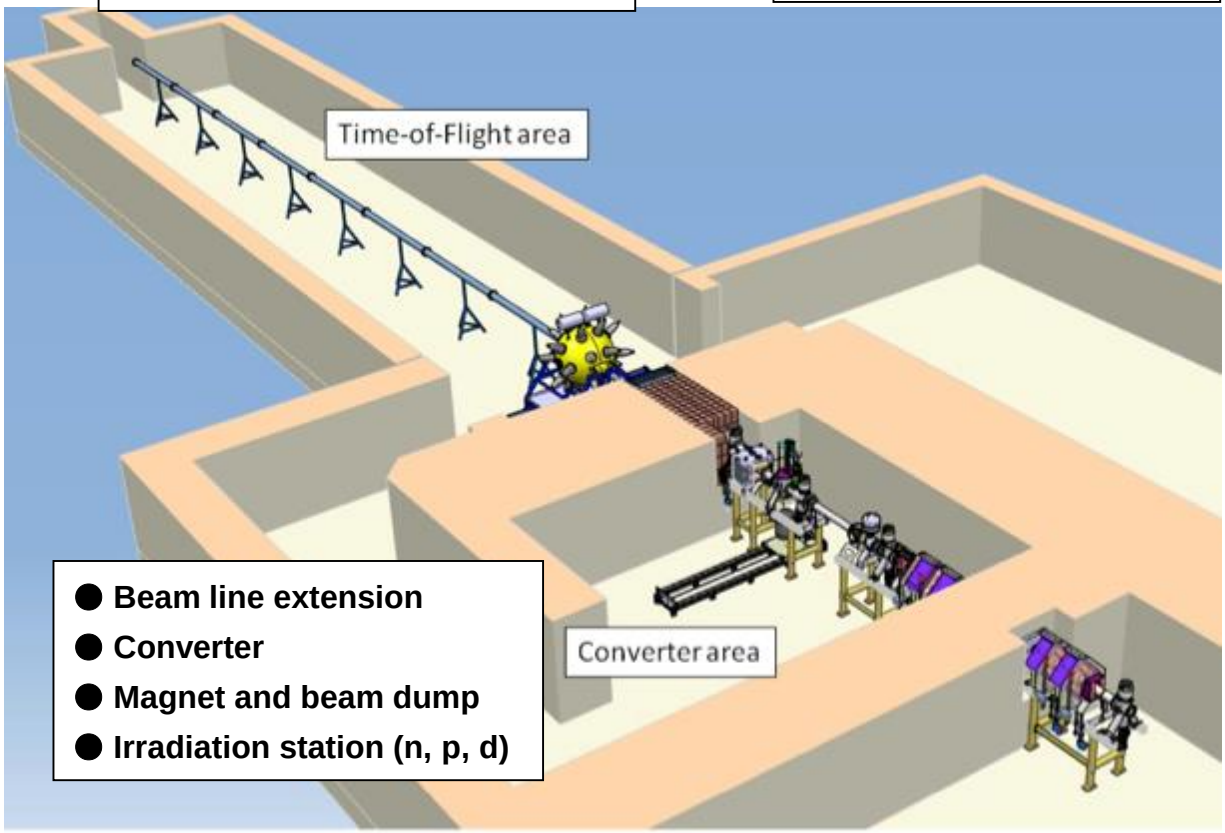



**High intense neutron flux :**
**Φ >1,5.10$^{13}$ n/s in 4π**
**Continuous or mono energetic spectra**
**Well collimated neutron beam**

- **Beam at 0°**
- **Collimator ↔ beam quality**
- **Size (L x l) ≃ (28m x 6m)**
  - **TOF measurements**
  - **free flight path**

**I < 50 µA**
**P < 2 kW**

**Use of radioactive samples**
**A< 1 GBq for thin layers**
**A< 10 GBq for thick samples**



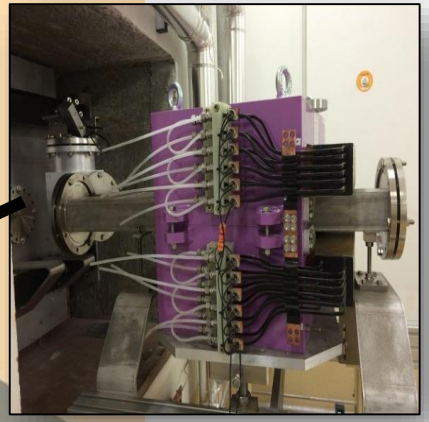

- **Beam line extension**
- **Converter**
- **Magnet and beam dump**
- **Irradiation station (n, p, d)**

**PAC June 2016**

**First experiment in 2017**

Collimateur: Installé

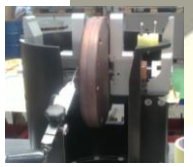
Arrêt faisceau proton installé

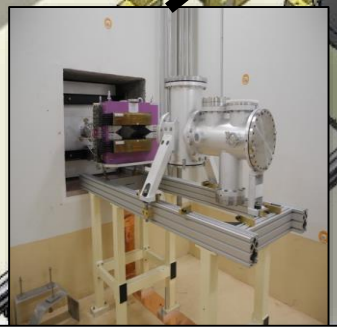


Convertisseur Li : livré

Station d'irradiation : test

Convertisseur Rotatif



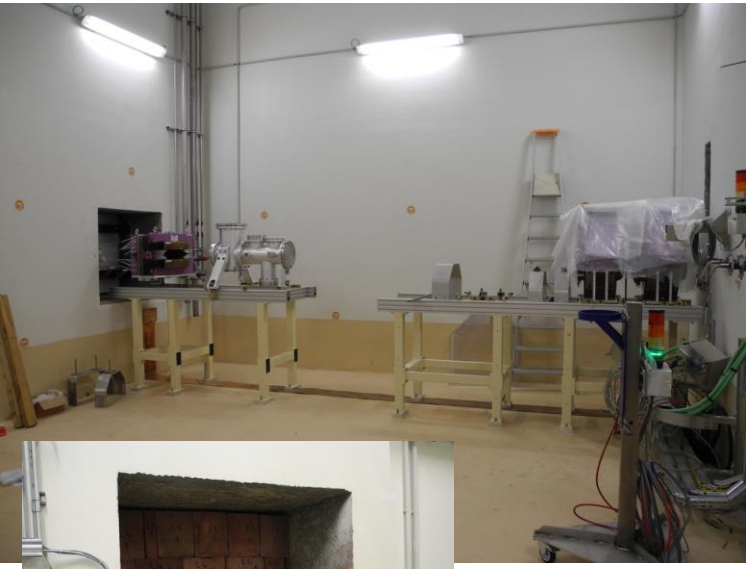


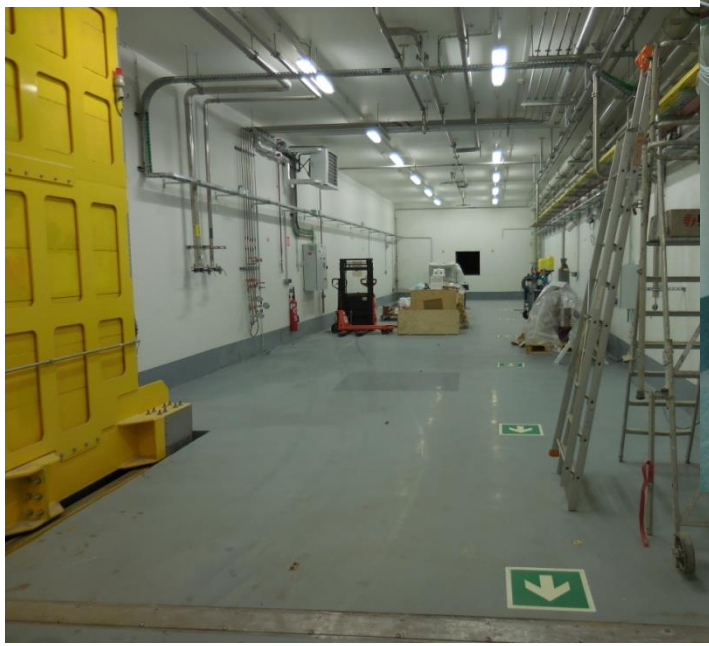
Chambre du convertisseur installée

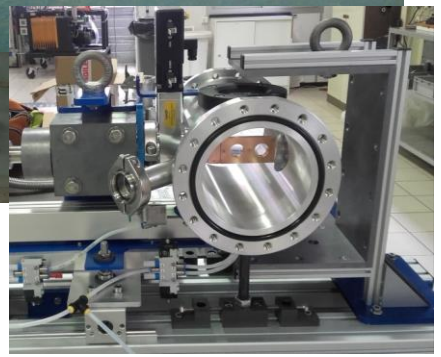
Diagnostiques faisceau, système de vide: livrés

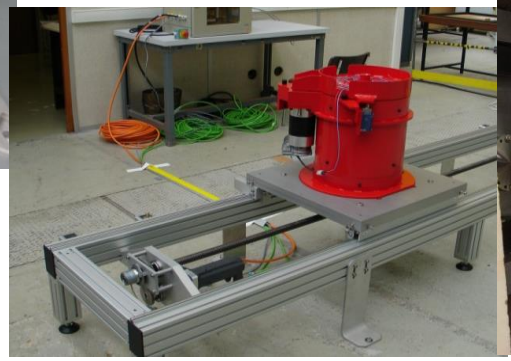
# NFS_1D Avancement installation

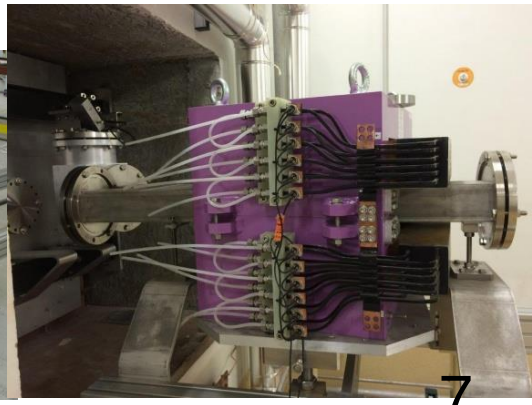
## T1 2017







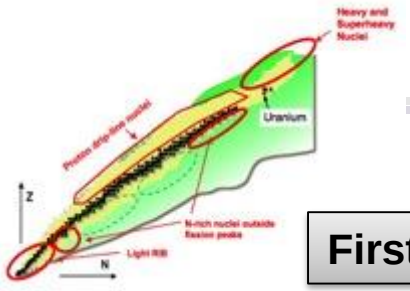




# S3

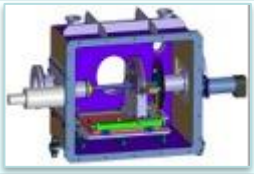
**S3 Physics case (16 LoIs)**

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

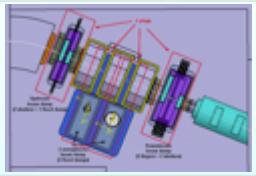



**First experiment in 2018-19?**

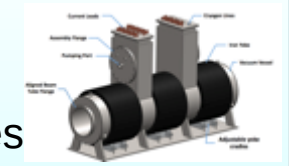
High power Rotating targets including actinides

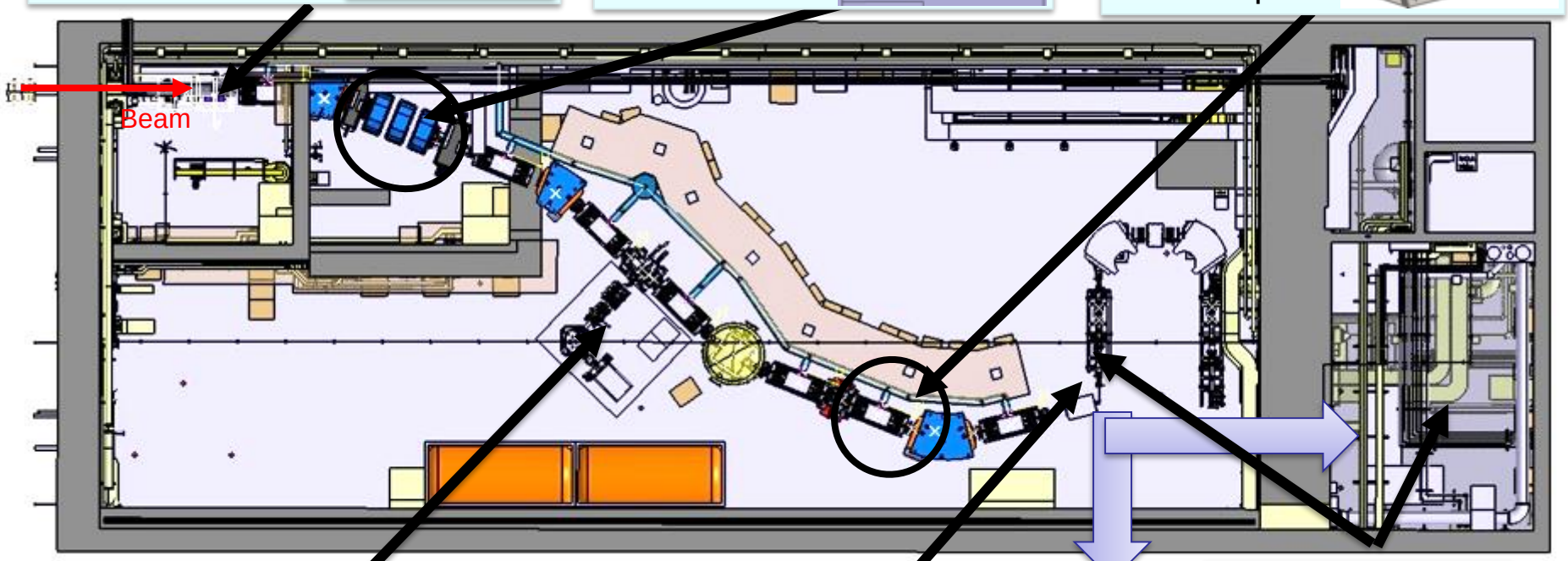


Beam dump & Movable fingers



Large acceptance SC Multipoles






FISIC setup Fast Ion Slow Ion Collisions

Implantation-decay station at the mass dispersive plan

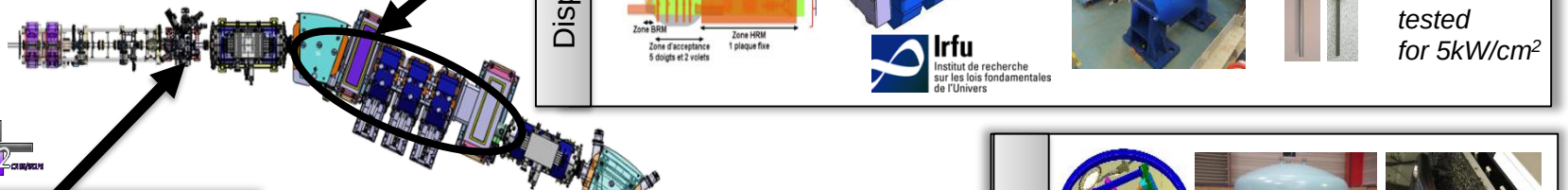
***DESIR***

Low Energy Branch

# S3 main components (Phase 0)

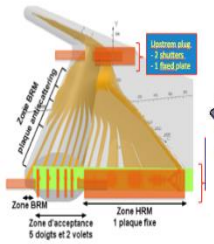
(L=26m)

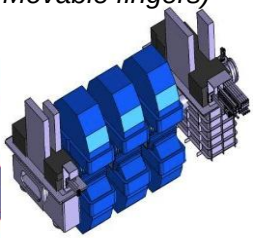
**Beam spot :**
$\sigma_X$=0.5mm, $\sigma_Y$[0.5-2.5mm]
Energy precision ≈$5.10^{-3}$



## Dispersive zone

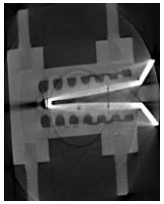
*(beam dump & Movable fingers)*



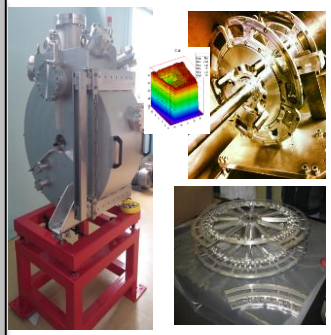
Irfu Institut de recherche sur les lois fondamentales de l'Univers





*tested for 5kW/cm²*

## Target system



*High power rotating targets (3000-5000 rpm)*
*Stable & Actinide systems*

## 3 × M-dipoles

*Large H & V gaps*

## E-Dipole

*20 cm gap & +/- 350 kV*
*Epmax : 12-14 MeV*
*Open slit in the anode*

IPN INSTITUT DE PHYSIQUE NUCLÉAIRE ORSAY

## SC Multipoles

*Q+S+O fields*

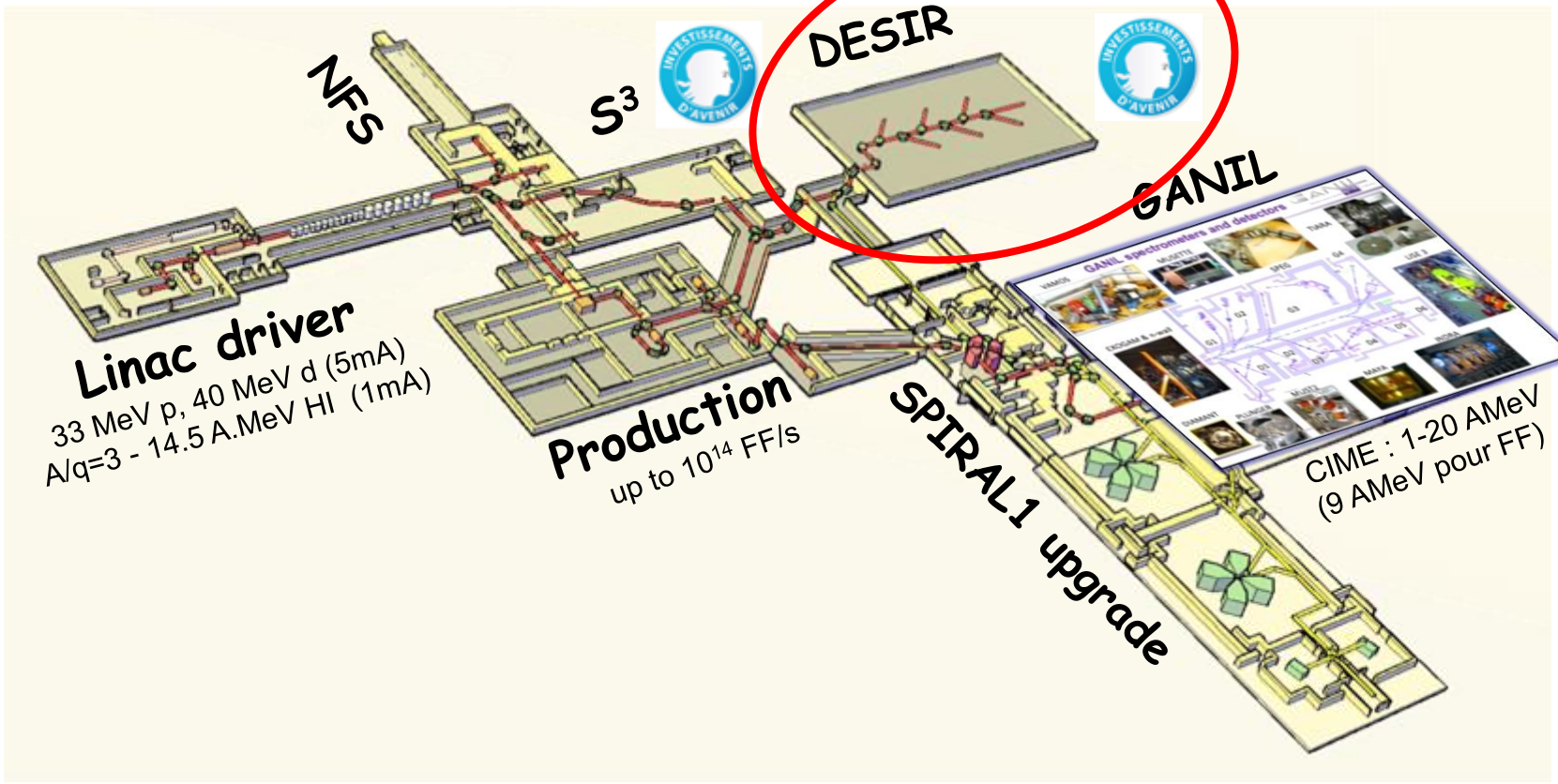
*PSS*

*Cold Box*

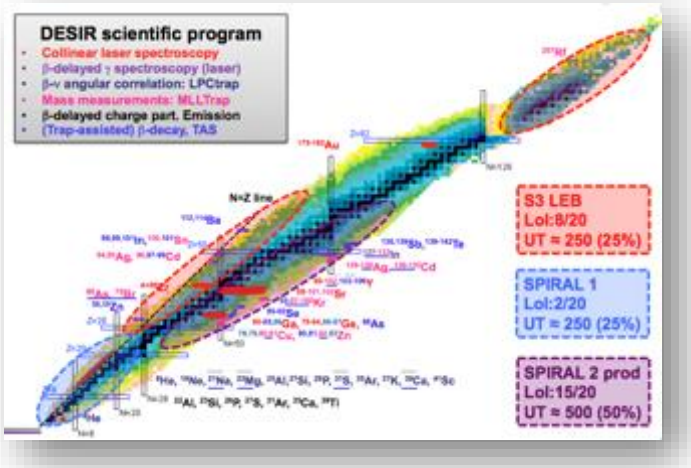

F. Dechery et al., Eur. Phys. J. A (2015) 51: 66
F. Dechery et al., in press NIMB

# GANIL-SPIRAL2 facility

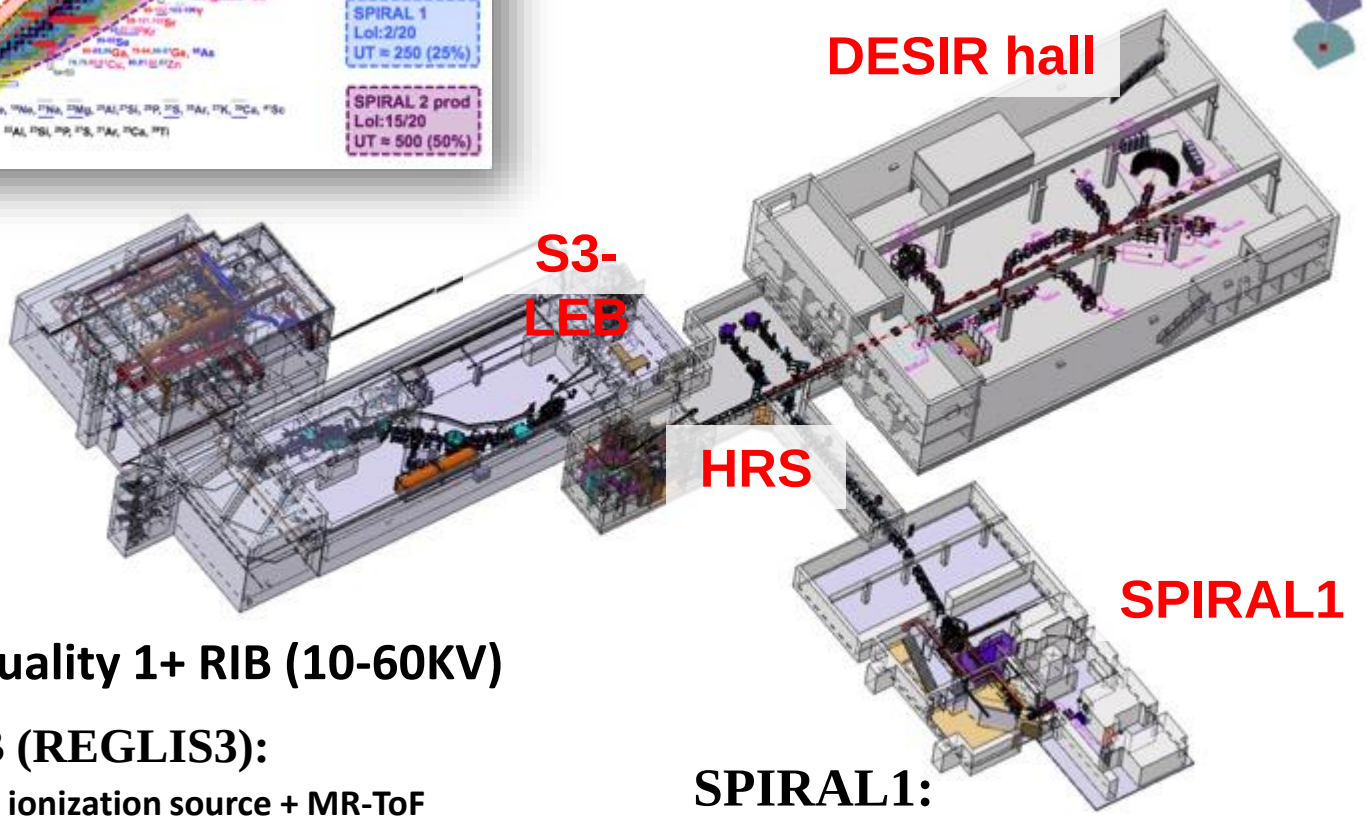
**DESIR Phase1+ (2019?)**
(low energy facility)
**Fully funded**



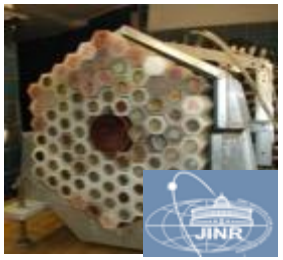
# Facility – SPIRAL2 Phase 1+











**High quality 1+ RIB (10-60KV)**

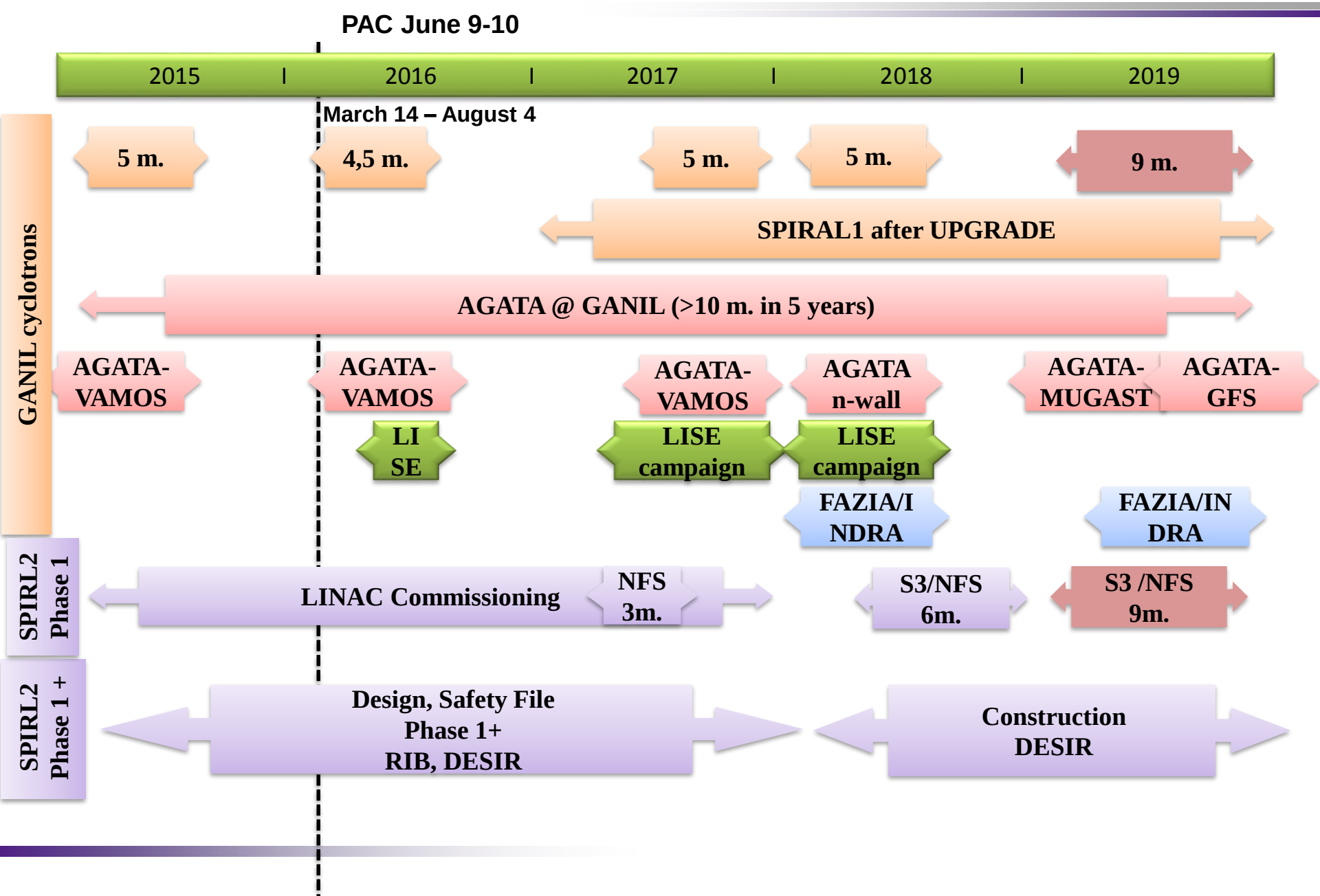
**S³ LEB (REGLIS3):**

- laser ionization source + MR-ToF
- refractory elements
- n-deficient nuclei & very heavy nuclei

**SPIRAL1:**

- beam + target fragmentation
- ECR + FEBIAD + Surface ionization
- light nuclei

# Timeline GANIL & SPIRAL2 (goal)



# Summary

- AGATA at GANIL 2015-2019: a priority for the lab. Several campaigns:
  - AGATA+VAMOS (+LaBr3, PARIS)
  - AGATA+NEDA
  - in the future: +MUGAST, +GFM
- Upgrade SPIRAL1: new beams available in 2017
- SPIRAL2 Phase 1:
  - Green light from ASN for full start: mid january 2017
  - First experiment in NFS: fall 2017
- Phase 1+ (DESIR): funded. Online in ~2021?
- Phase 1++ (A/q~6-7): looking for funds
- Phase 2: looking for funds