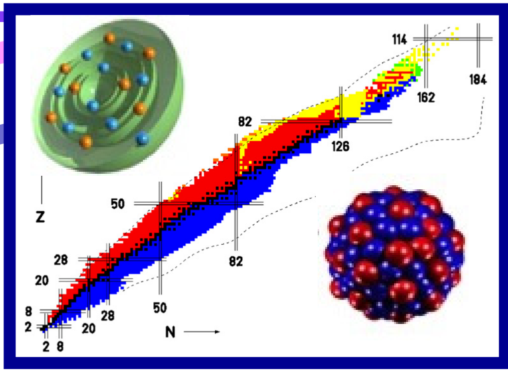
Nuclear Physics at GANIL-SPIRAL2

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

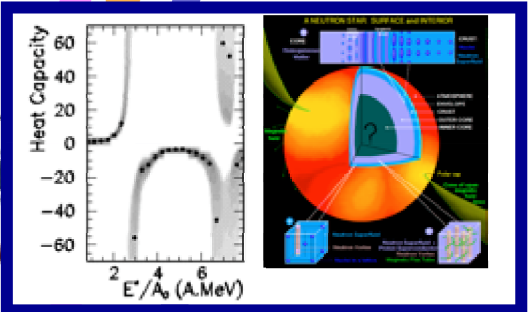
M. Lewitowicz

GANIL/SPIRAL2 Science

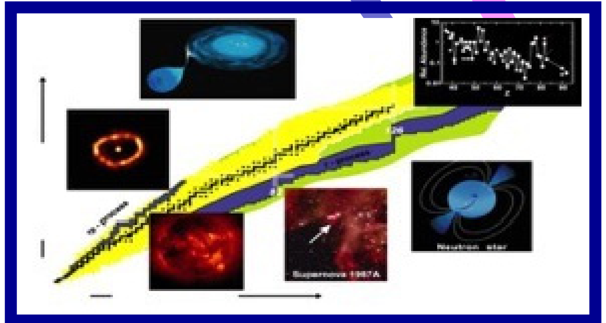
Nuclear structure



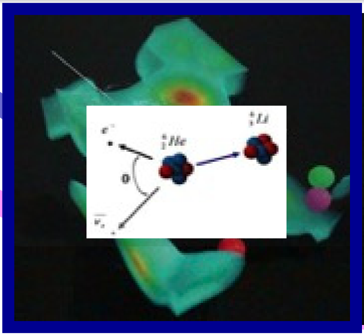
EOS
Liquid-gas phase
Isospin dependence



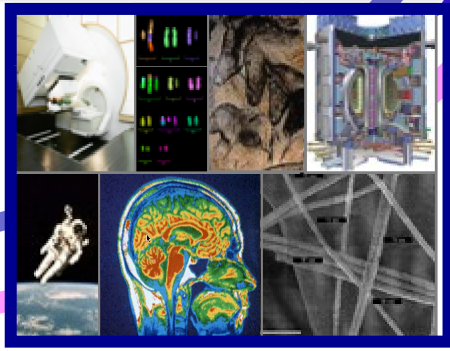
Nuclear Astrophysics



Fundamental Interactions

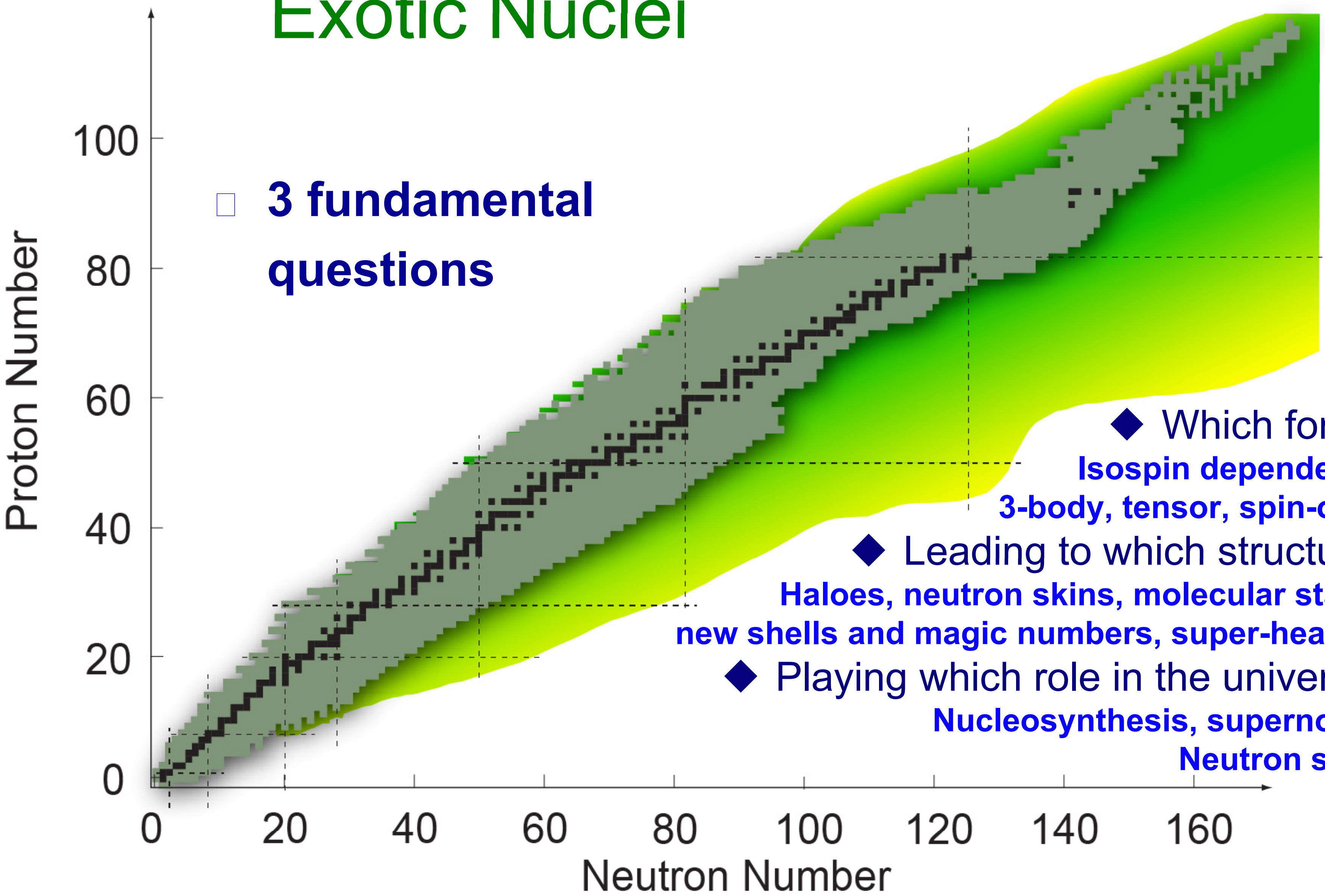


Multi-disciplinary research & Applications



A huge discovery potential

Exotic Nuclei



- **3 fundamental questions**

◆ Which force?

Isospin dependence, 3-body, tensor, spin-orbit.

◆ Leading to which structure?

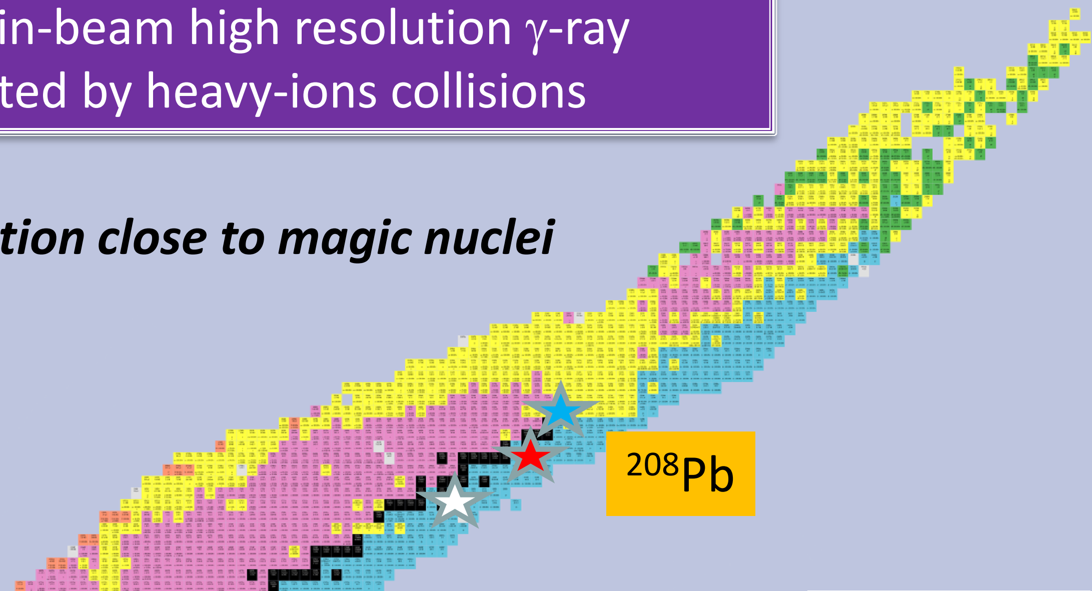
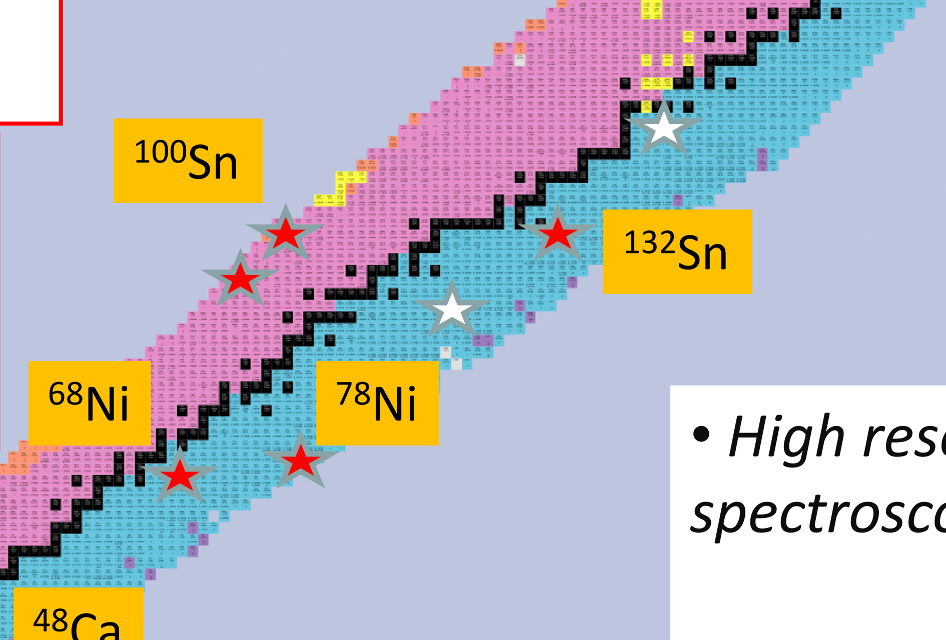
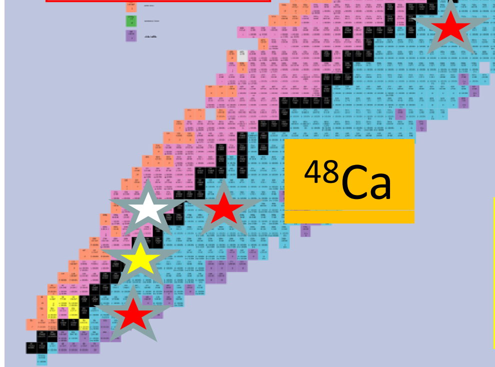
Haloes, neutron skins, molecular states, new shells and magic numbers, super-heavies.

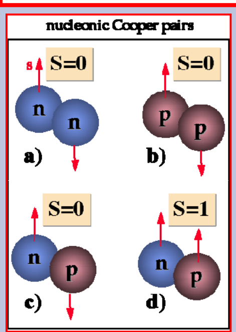
◆ Playing which role in the universe?

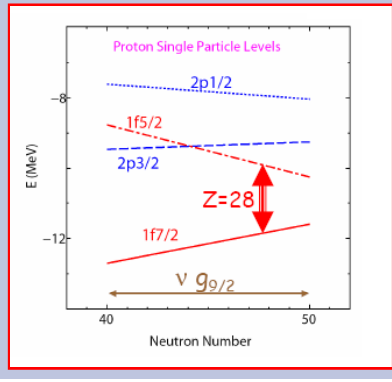
Nucleosynthesis, supernovae, Neutron stars.

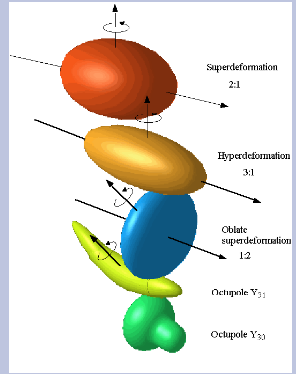
The physics of AGATA@GANIL is the in-beam high resolution γ-ray spectroscopy of exotic nuclei populated by heavy-ions collisions

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







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

AGATA at GANIL

• AGATA at GANIL: 2015-2019
• sub campaigns co-organized: ACC, GANIL management, campaign manager (S. Lenzi from the University of Padova)

Each GANIL PAC has a “PrePac” workshop

- 1st PAC in 2014 : VAMOS (10 experiments approved)
- 2nd PAC in 2015 : VAMOS or NEDA (10 experiments approved)
- 3rd PAC in 2016 : NEDA (6 experiments approved)

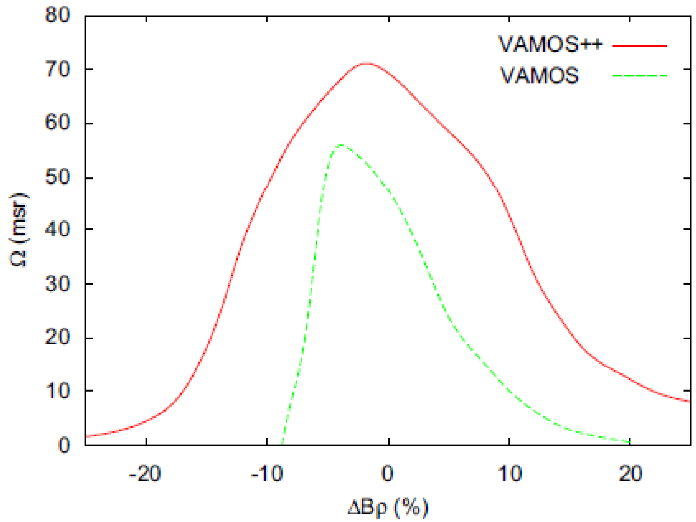
10th-12th February 2016 – AGATA /NEDA
8th-10th February 2016 : SPIRAL1 Workshop

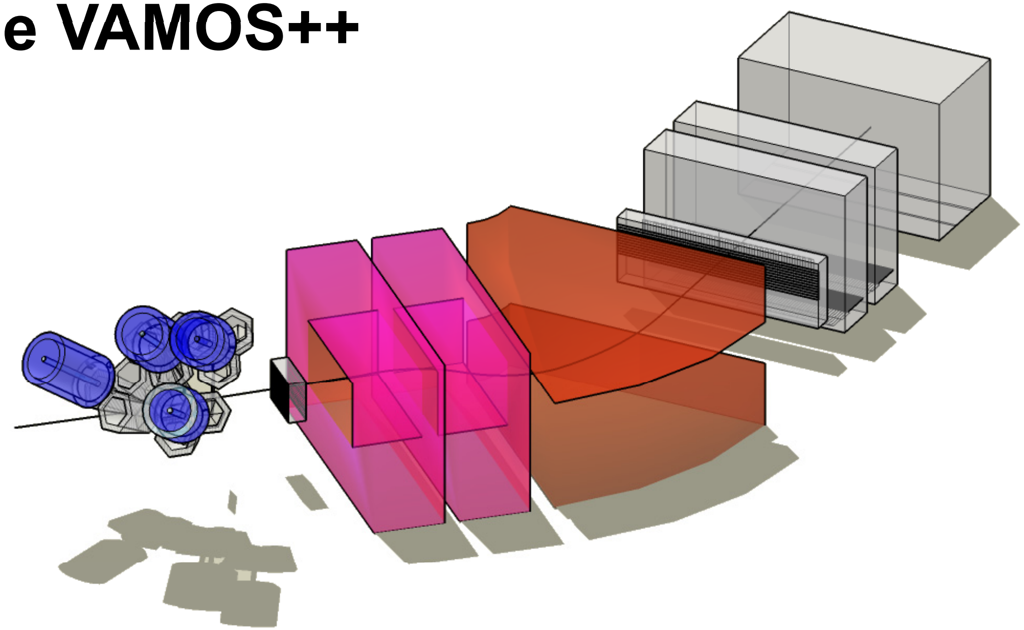
*Proposal for the AGATA-NEDA
*Updated LoI for SPIRAL1 and GFM

1st campaign (2015-2017) : AGATA+VAMOS coupling

Multinucleon Transfer
fusion-fission

Recoils identification by the VAMOS++ magnetic spectrometer

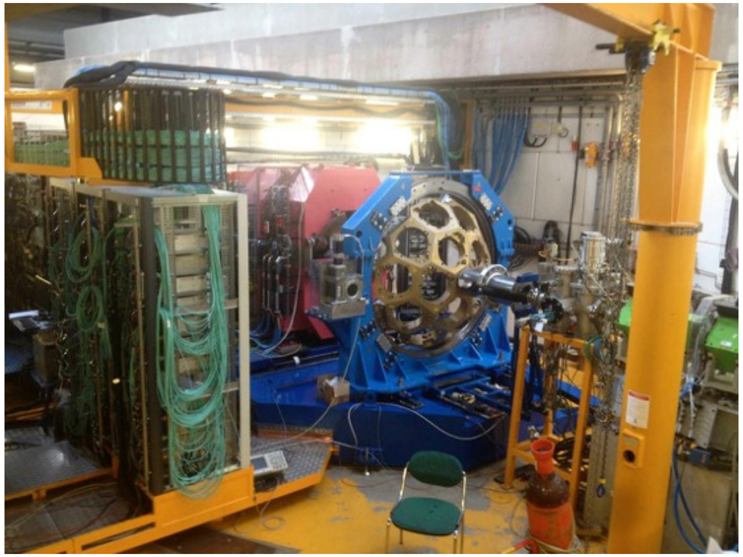




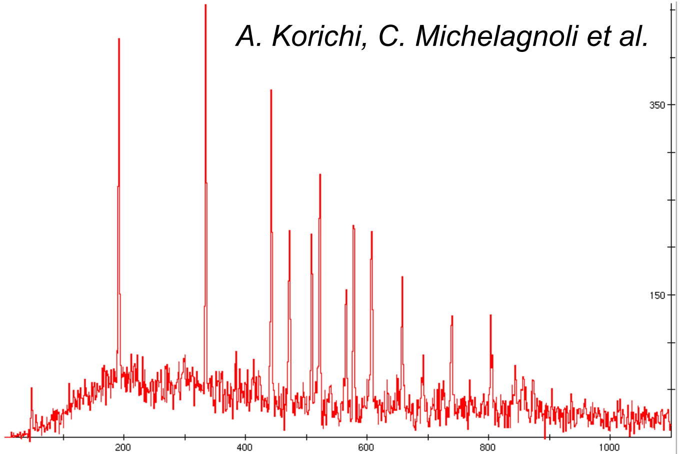
Full reconstruction over the whole acceptance
Mass resolution ~ 1/220
Z identification up to Z= 62

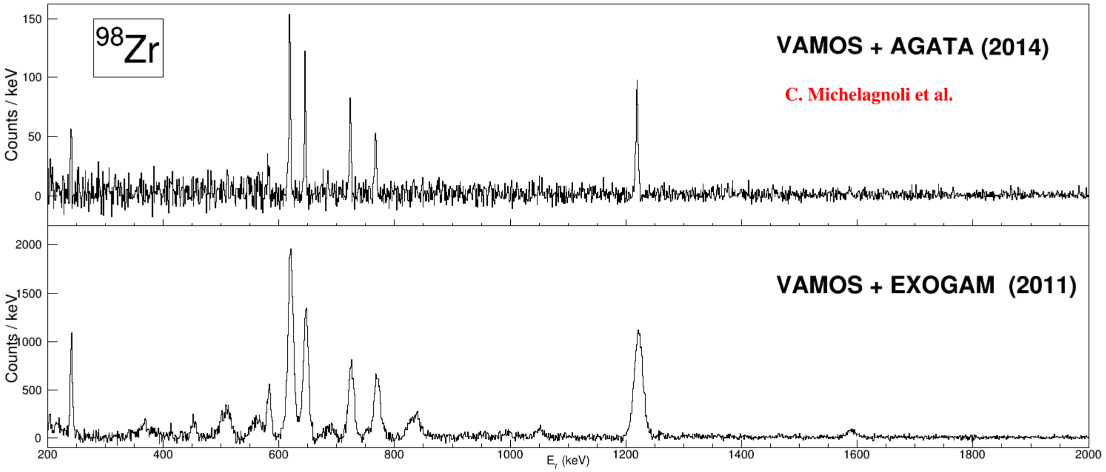
H. Savajols et al, NIM B 204 (2003) 146-153
S. Pullanhiotan, et al NIM A, 593(2008)
M. Rejmund et al, NIM A 646 (2011) 184–191
M. Vandebrouck et al, NIM A 812 (2016) 112–117

Installation & Commissioning & First exp.



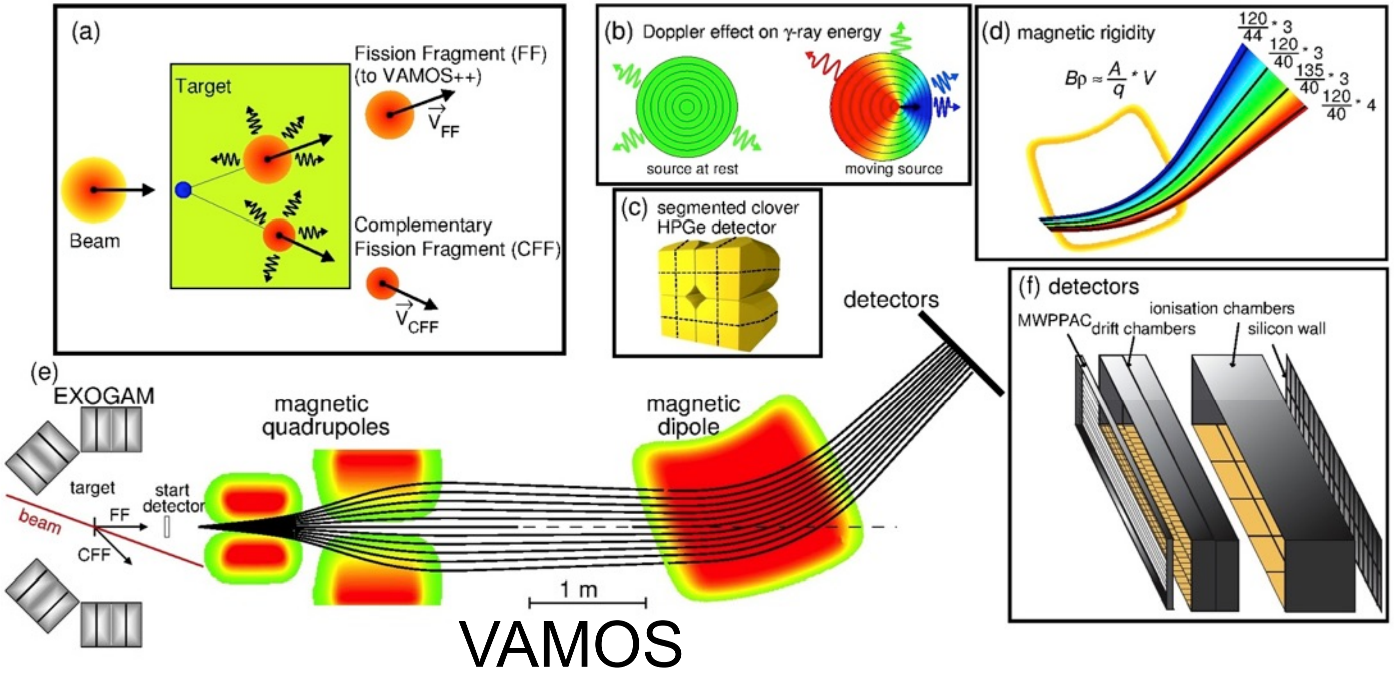
^{40}Ar@4.25 MeV/A 2.8 pnA on ^{122}Sn





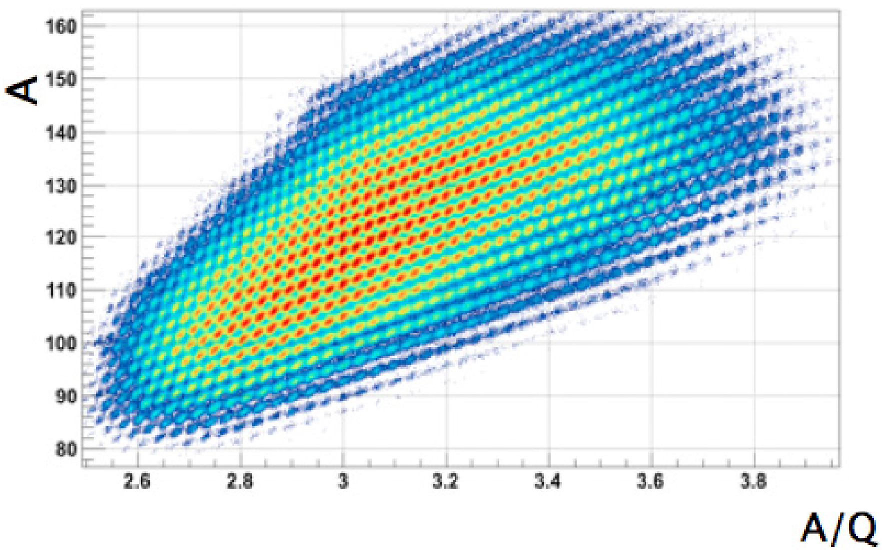
10 triple clusters in the experiments from March 2016 (first 7 exp. accomplished)

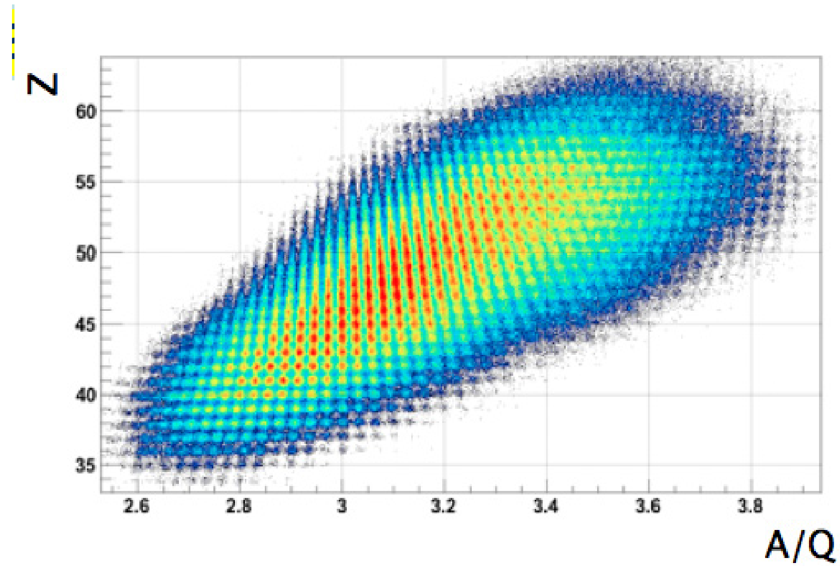
Z, A & q identification at few MeV/nucleon



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





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

- *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*

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

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

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

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

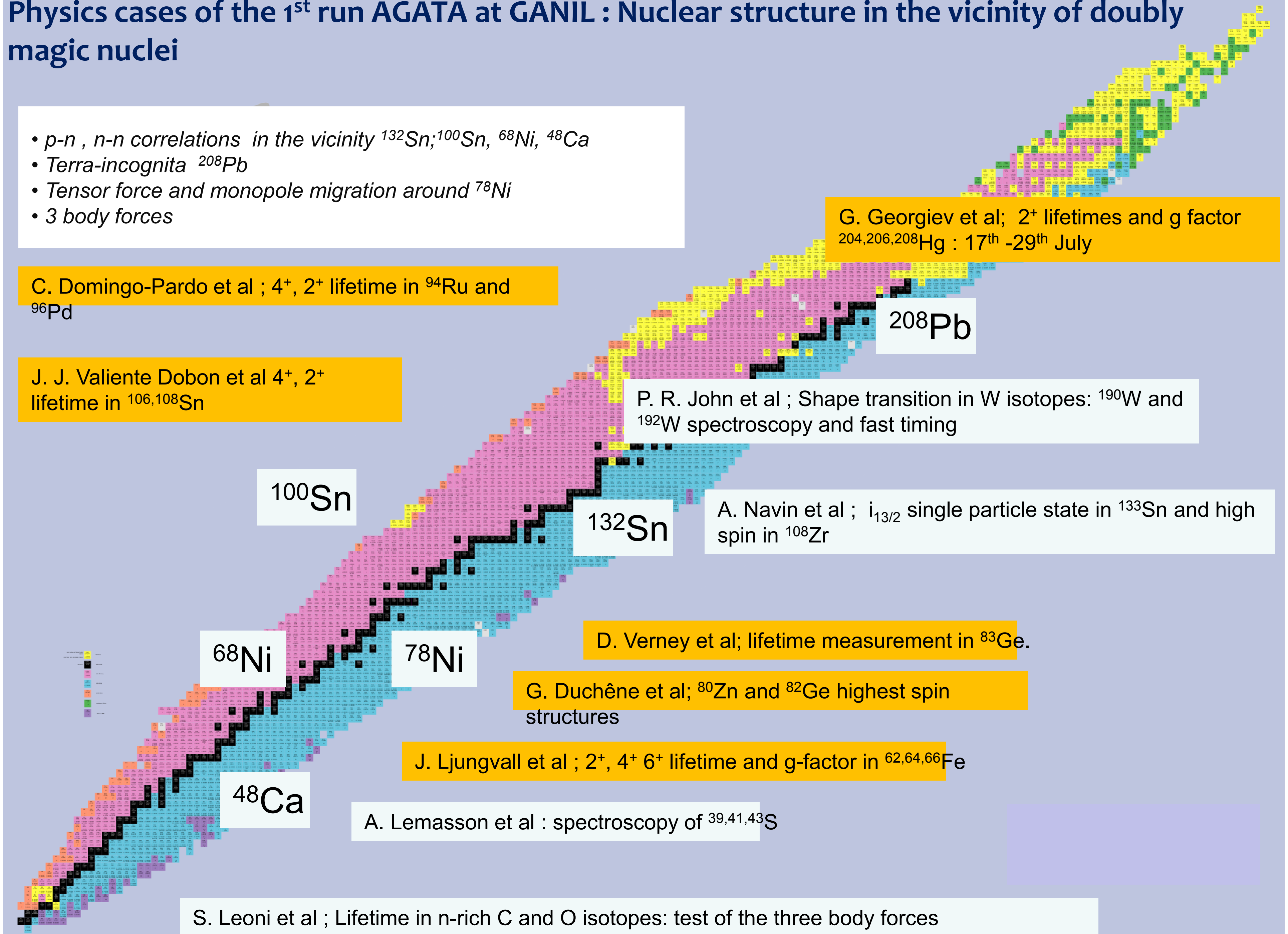
D. Verney et al; lifetime measurement in ^{83}Ge.

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

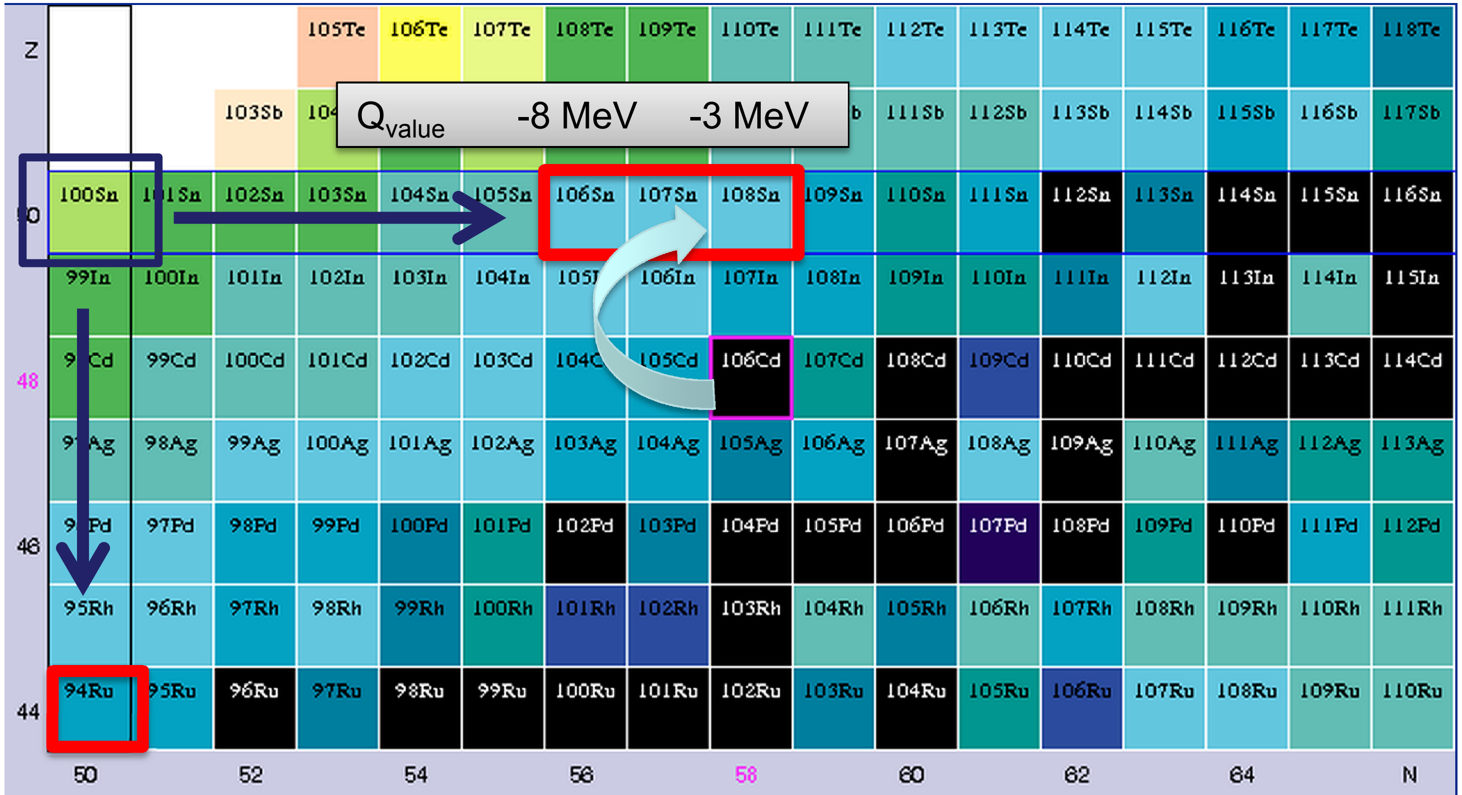
J. Ljungvall et al ; 2$^+$, 4$^+$ 6$^+$ lifetime and g-factor in ^{62,64,66}Fe

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



Liftetime measurement in the ^{100}Sn region



Multinucleon-transfer reactions in the neutron-deficient side to populate the Sn/Ru isotopes and measure the lifetimes of the 2^+ and 4^+ states

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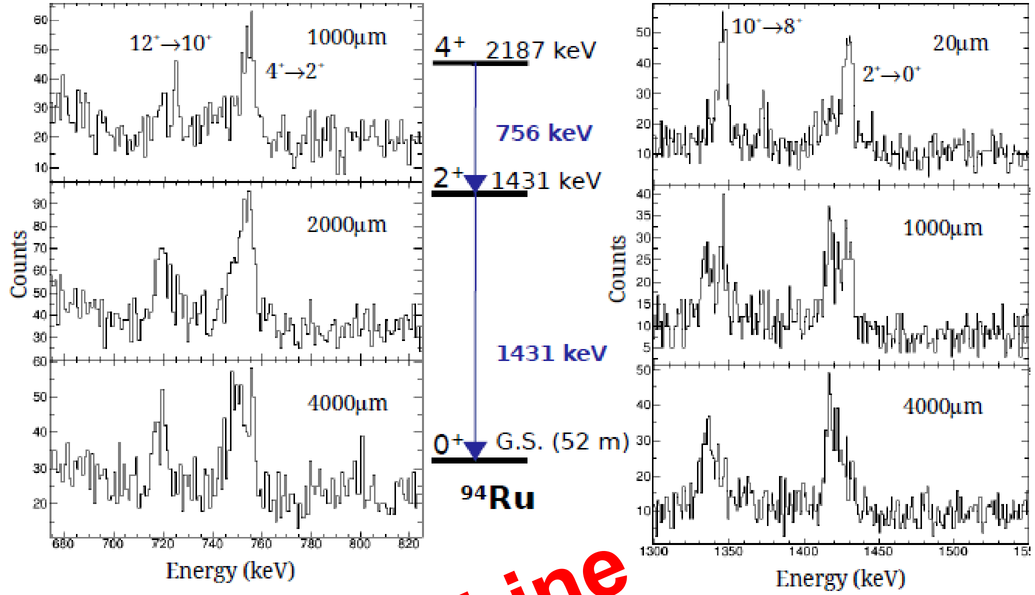
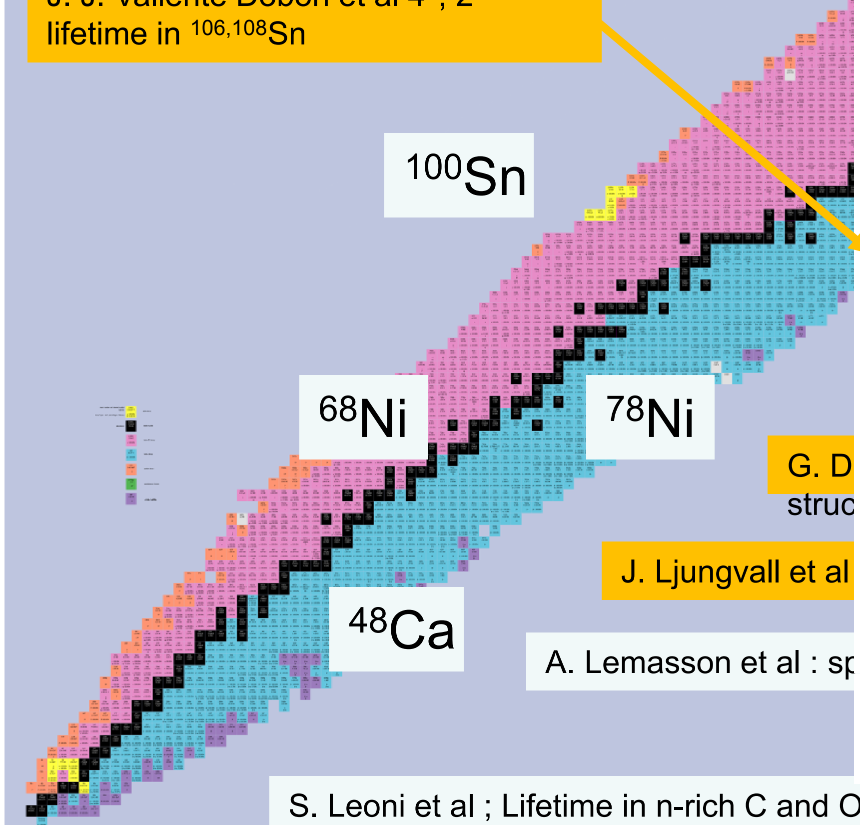
R. Perez, et al. (IFIC)



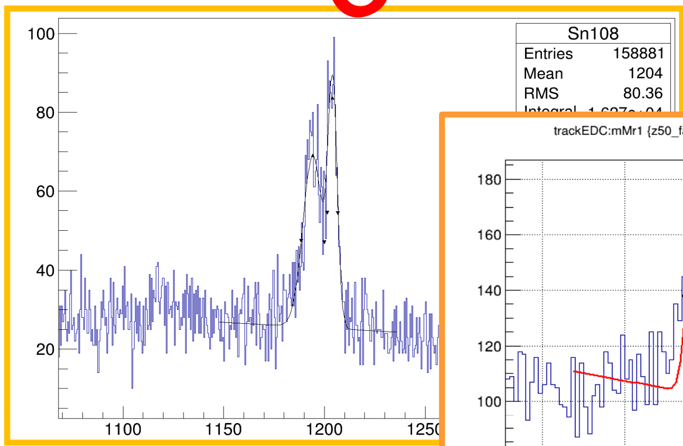
J. J. Valiente Dobon et al 4^+, 2^+ lifetime in $^{106,108}Sn$

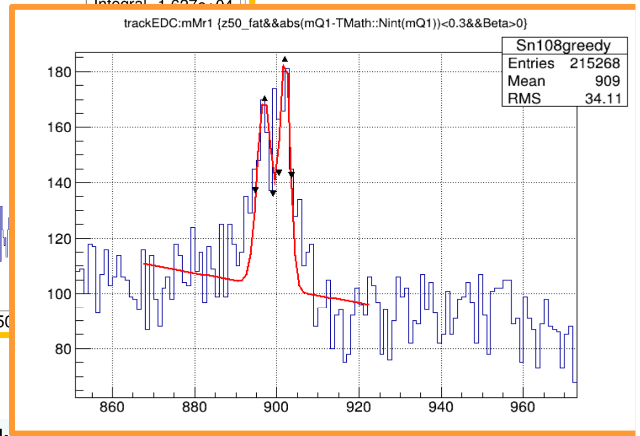


On-Line

$^{106-108}Sn$ 2^+,4^+

M. Siciliano, et al. (LNL)





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J. Ljungvall et al

A. Lemasson et al : sp

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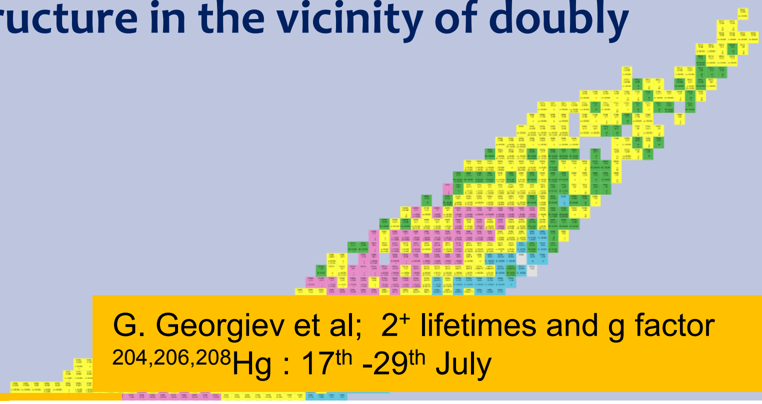

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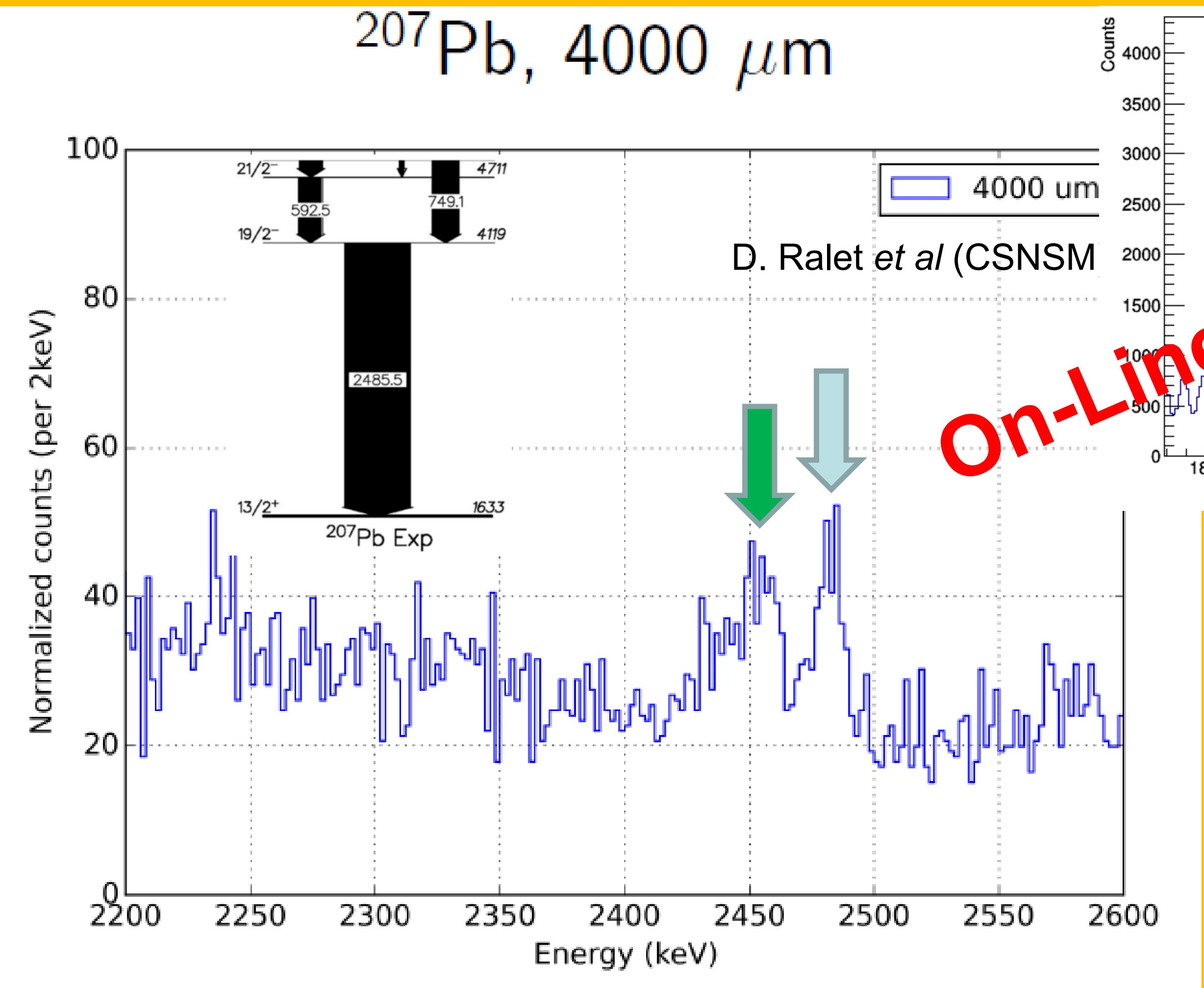
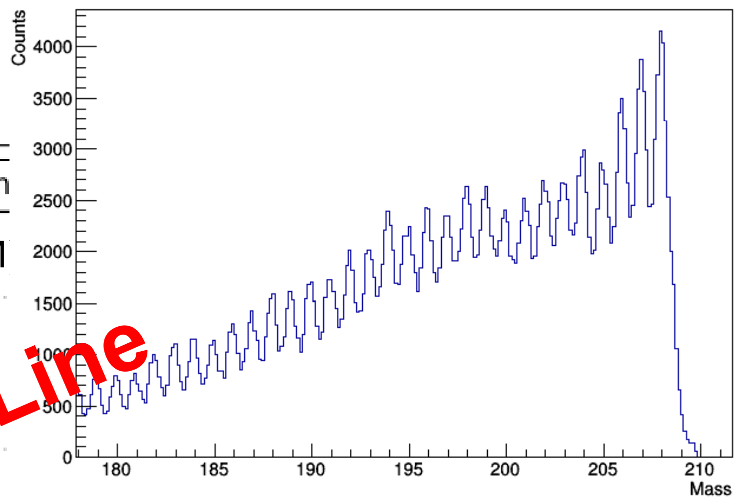




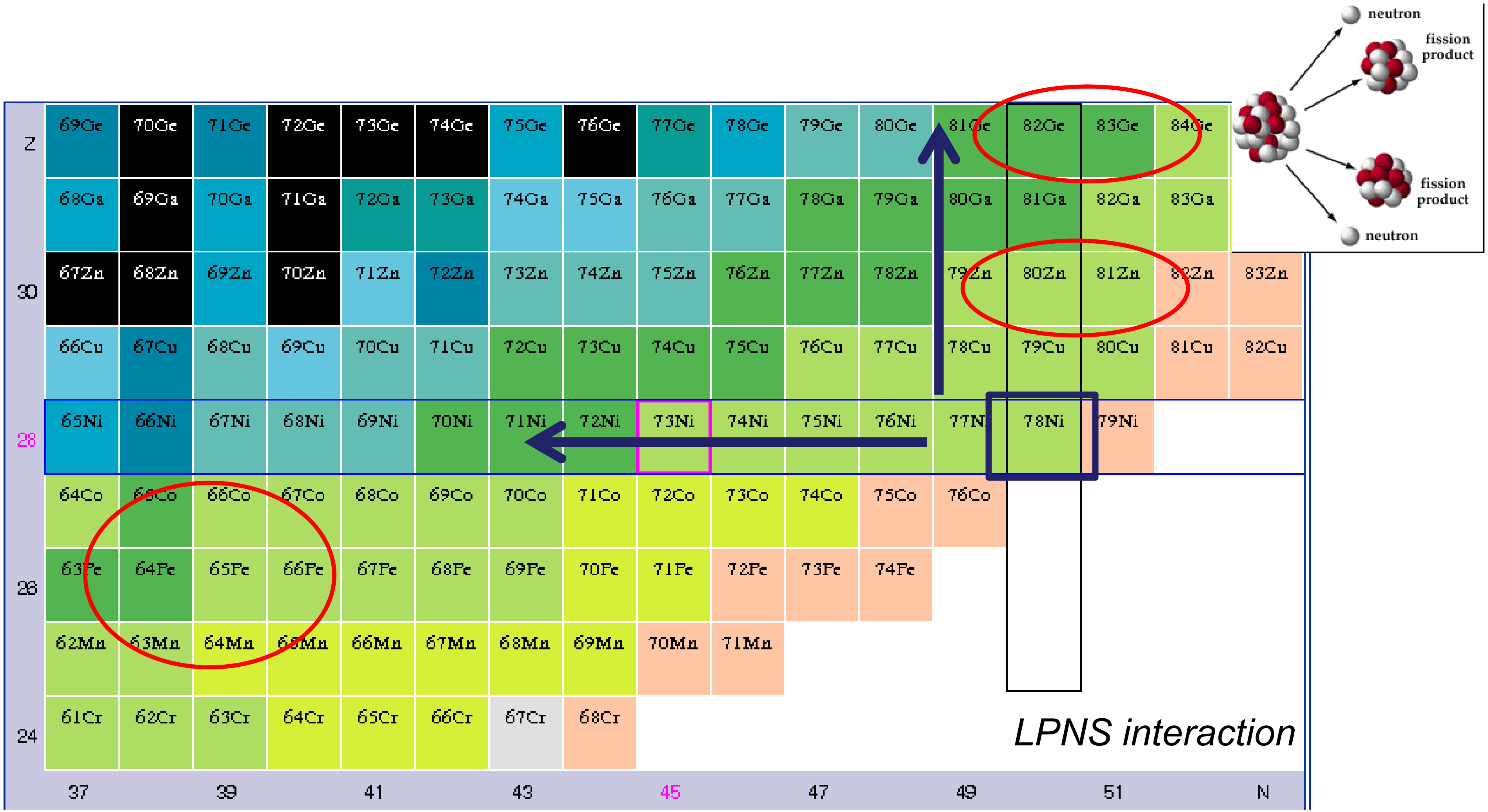
easurement in ^{83}Ge.

ighest spin

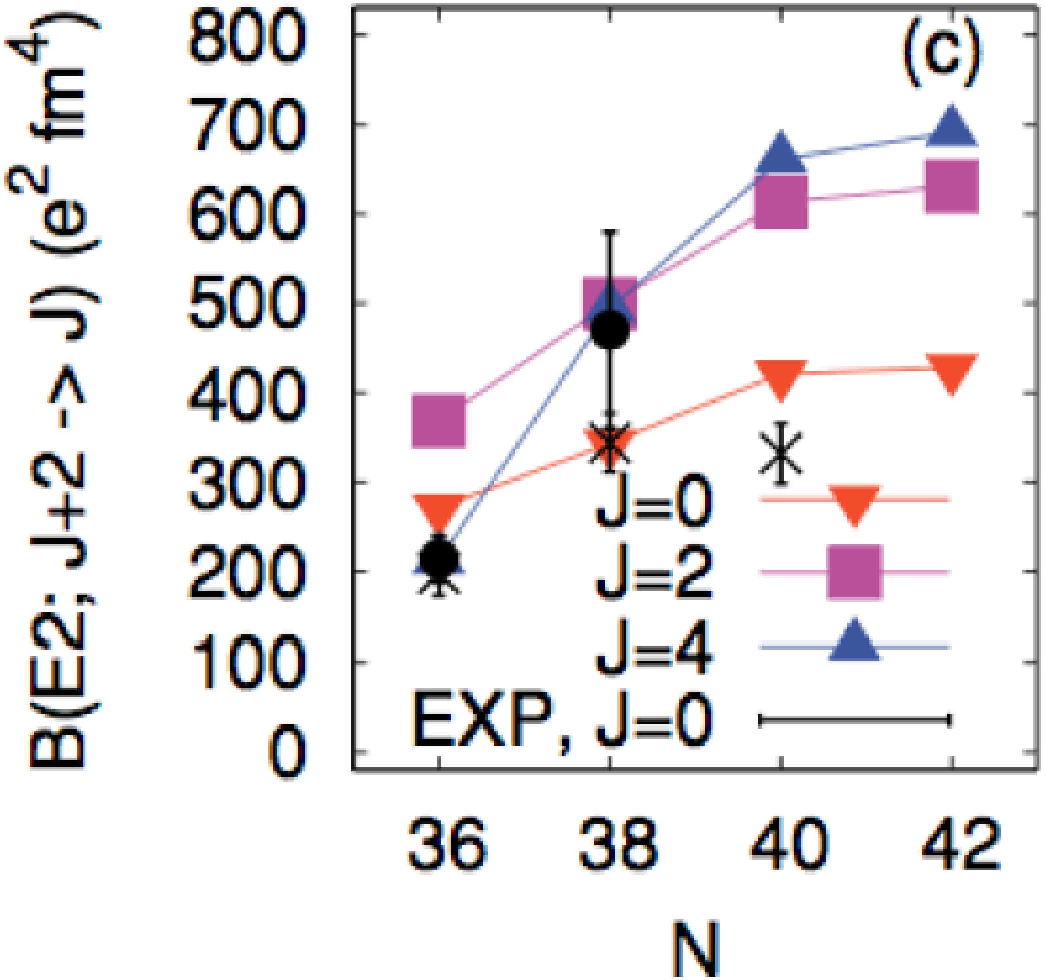
r in $^{62,64,66}Fe$

dy forces

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



Lifetime in the 4^+ states in $^{62,64}Fe$

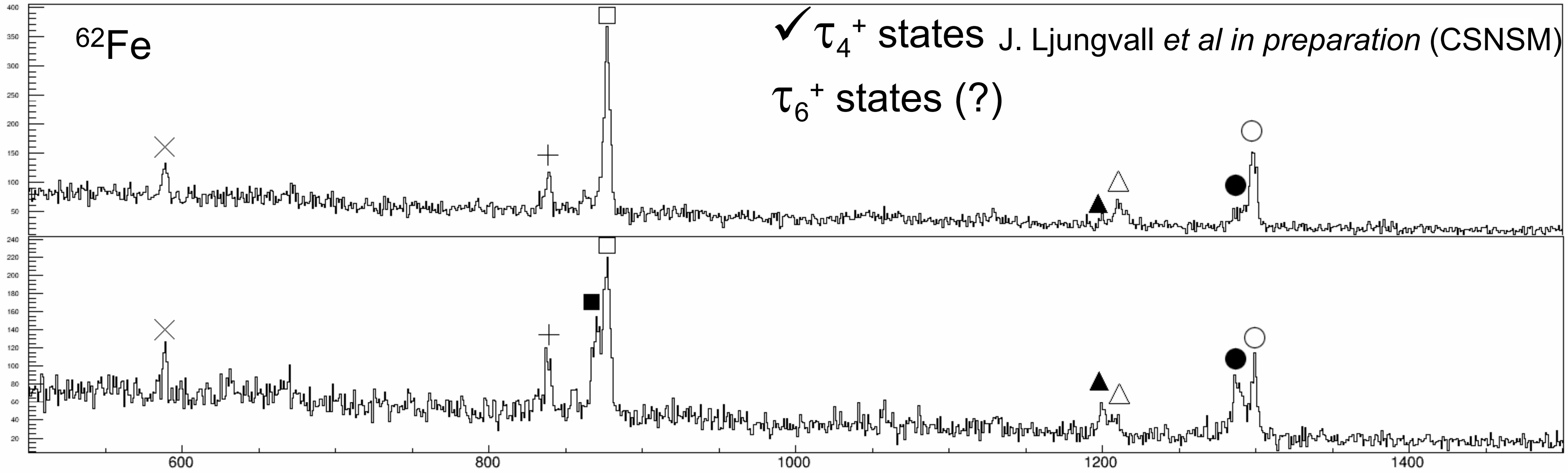


J.Ljungvall et al, Phys.Rev. C 81, 061301 (2010

W.Rother et al, Phys.Rev.Lett. 106, 022502 (20

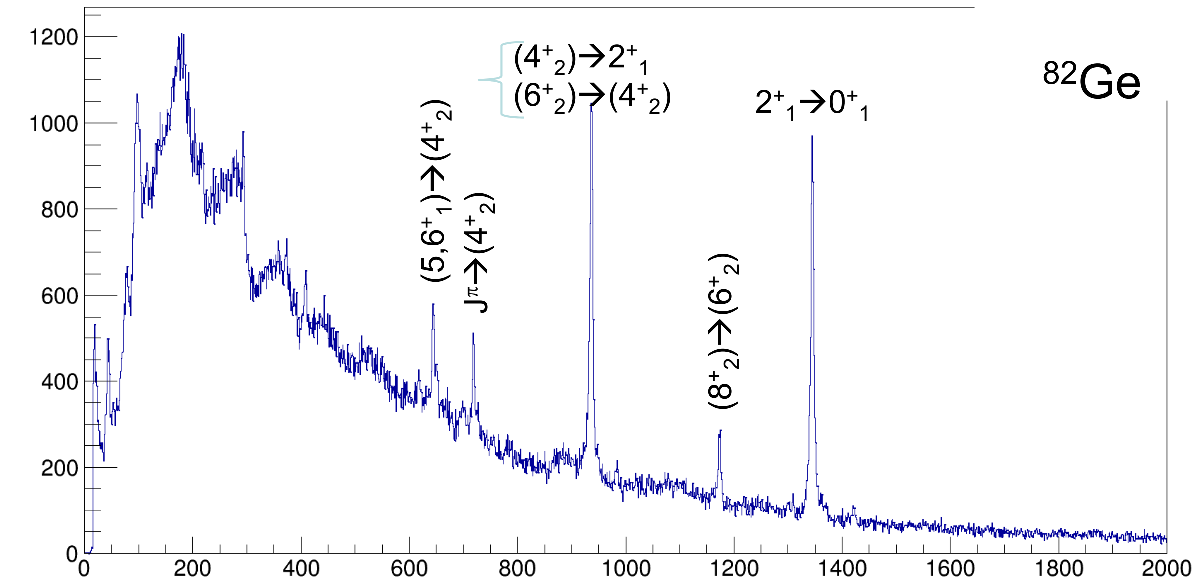
S. M. Lenzi, F. Nowacki, A. Poves, and K. Sieja, Phys. Rev. C 82, 054301 (2010)

Lifetime in the 4^+ states in $^{62,64}Fe$



+ Lifetime in Co and Mn

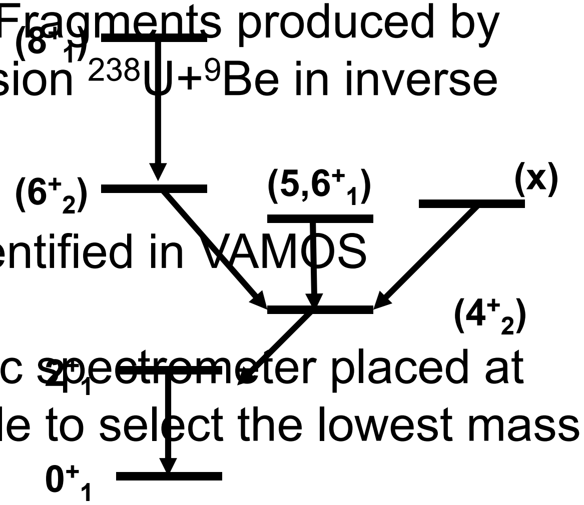
Lifetime and spectroscopy in the ^{78}Ni vicinity

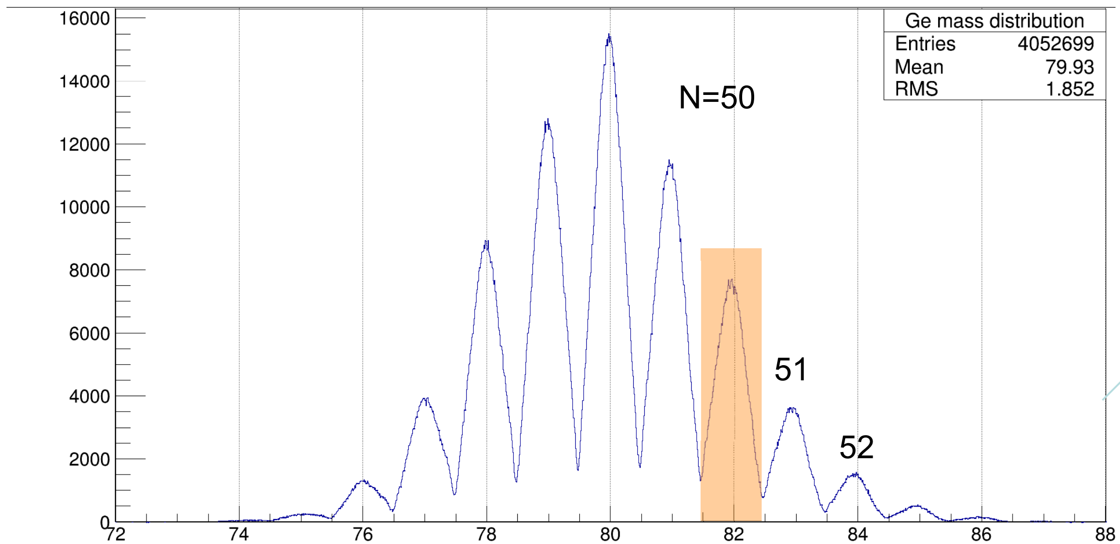


on Fragments produced by
-fission ^{238}U+^{9}Be in inverse
atic

identified in VAMOS

netic spectrometer placed at
angle to select the lowest mass





Unique opportunity for γ-ray spectroscopy of light FF

J. Dudouet et al (IPNL) Preliminary

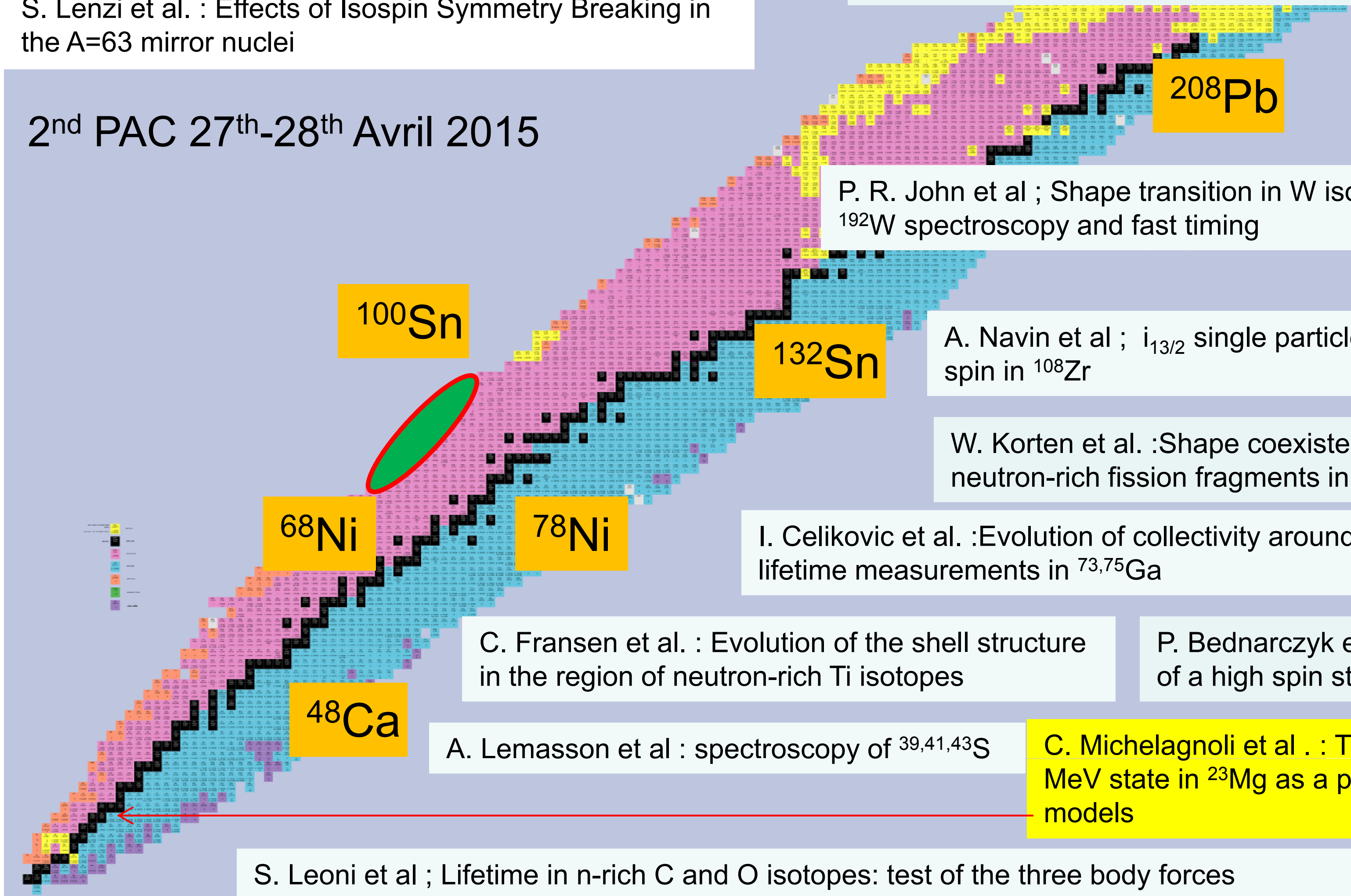
Physics cases for the 2nd run (2016-2017) : nuclear structure in the vicinity of doubly magic nuclei, N=Z nuclei, astrophysic and deformation

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



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2016's run : 4 experiments

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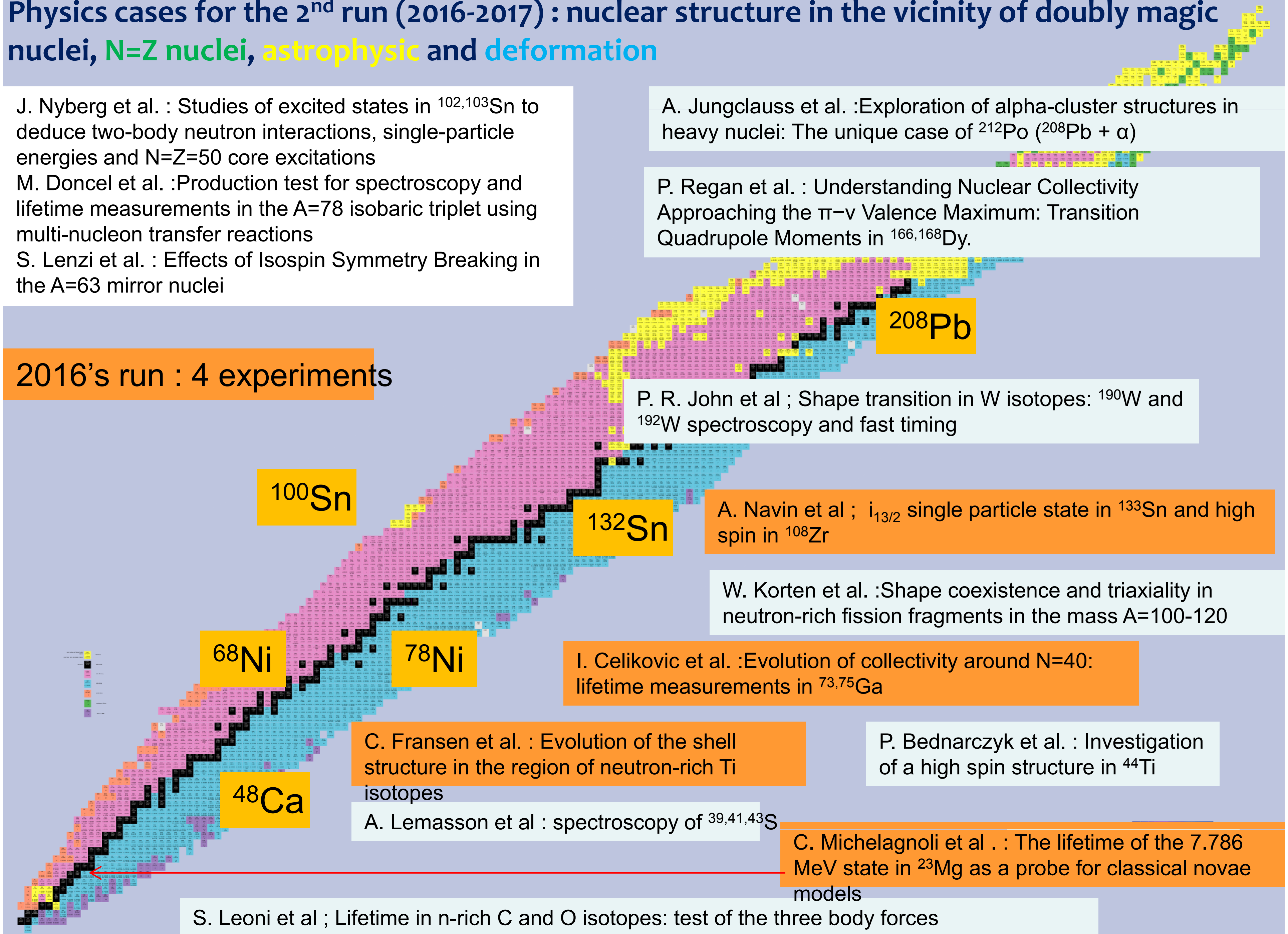
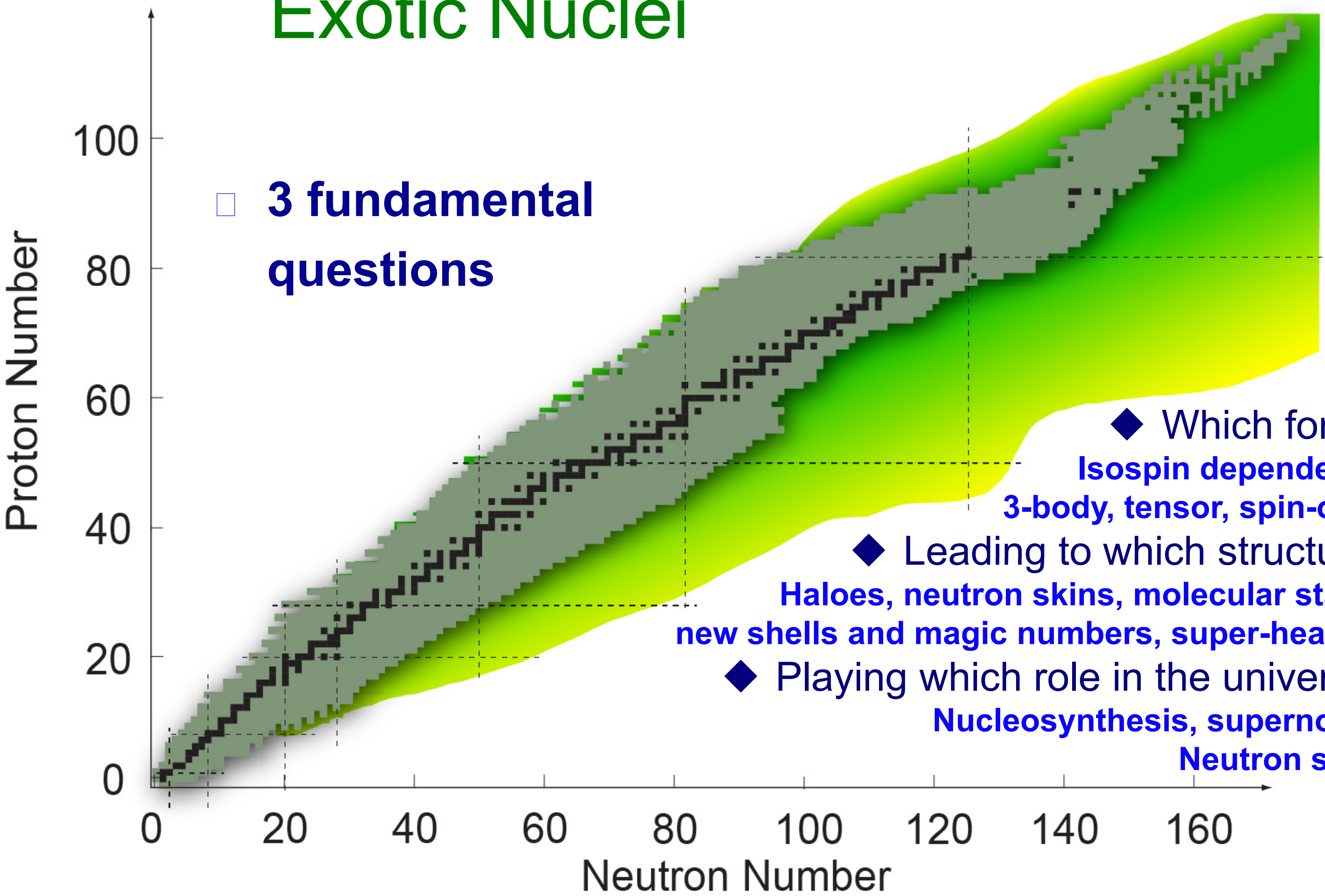


A huge discovery potential

Exotic Nuclei



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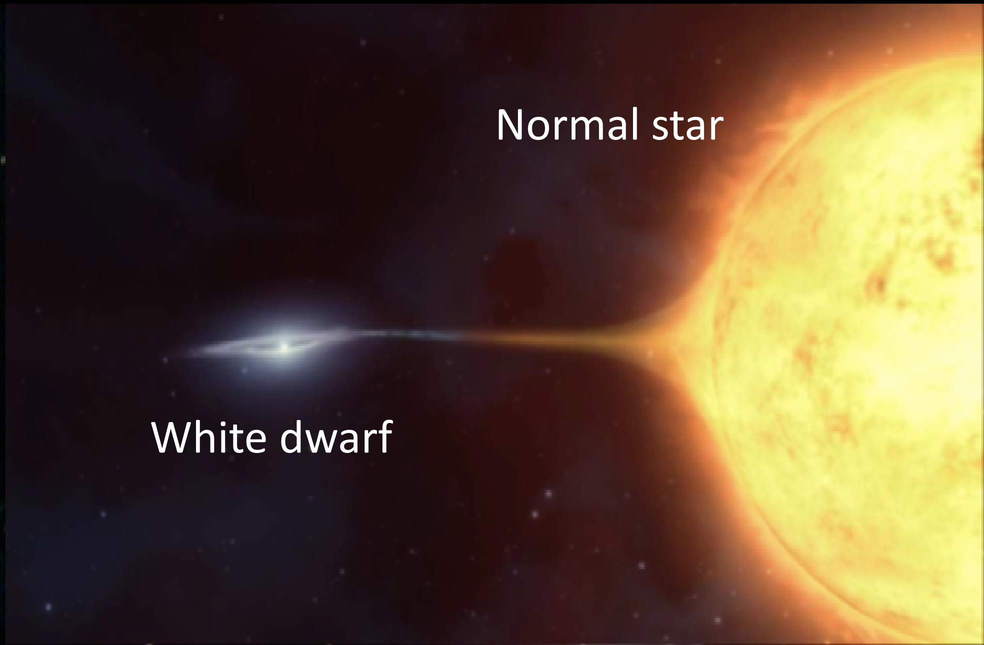
◆ Leading to which structure?

Haloes, neutron skins, molecular states, new shells and magic numbers, super-heavies.

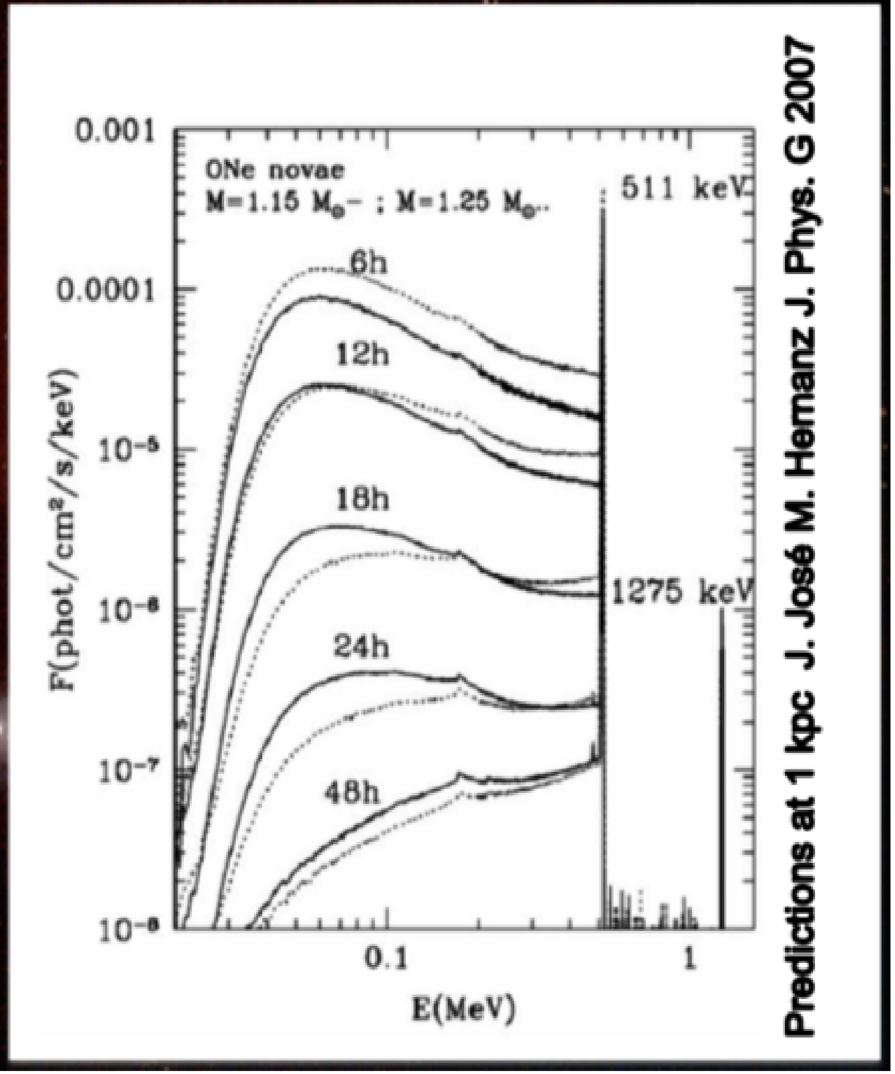
◆ Playing which role in the universe?

Nucleosynthesis, supernovae, Neutron stars.

Spectroscopy of ^{19}Ne via a new method of inelastic scattering
Application to the $^{18}F(p,\alpha)^{15}O$ reaction rate calculation of astrophysical interest.



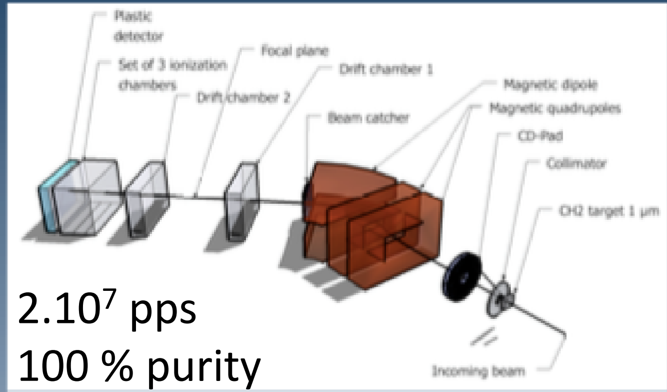
Nova



- A key observable: Gamma rays at 511 keV
- One of the main β+ emitters: ^{18}F
- 2 main reactions constrain the abundance of ^{18}F
- $^{18}F(p,\alpha)^{15}O$ & $^{18}F(p,\gamma)^{19}Ne$.

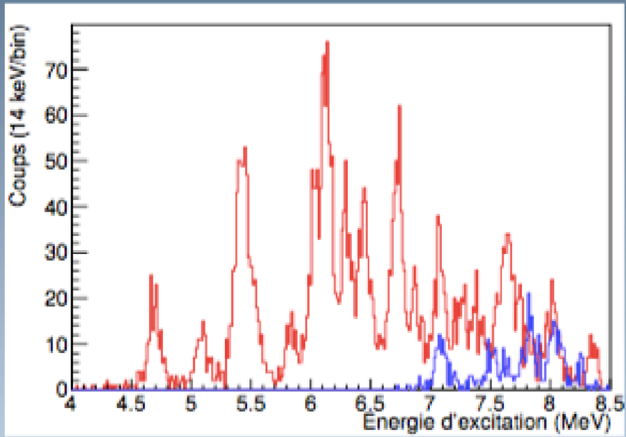
$^{19}Ne + p \rightarrow {}^{20}Na^* \rightarrow {}^{19}Ne^* + p'$ | ^{19}Ne SPIRAL 1 RIB 10 MeV/n

**New experimental setup.
VAMOS used for the first time
to detect protons**



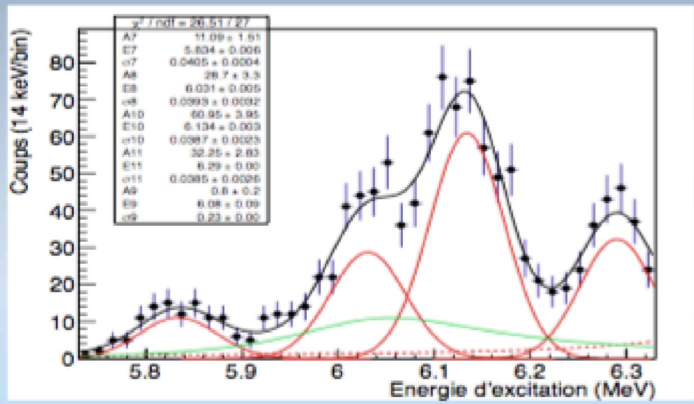
2.10^7 pps
100 % purity

Counts



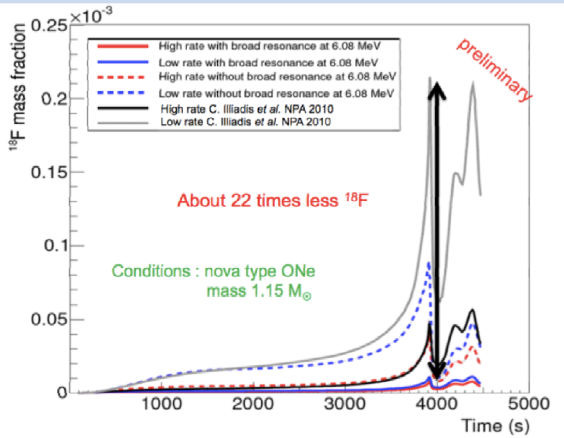
Excitation energy (from proton energy)

Best energy resolution reach for this type of experiment. σ = 33-44 keV

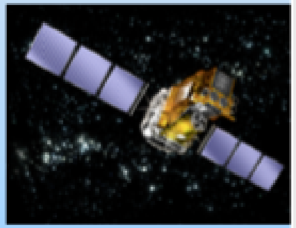


Clues for new a resonance of astrophysical interest

E_r = 6.08(9) MeV
Γ_{tot} = 230(5) keV



New reaction rate $^{18}F(p,\alpha)^{15}O$ is much higher



INTEGRAL has less chance to detect gamma rays from the beginning of the explosion

Previous estimate: 2 novae /y

New estimate (this work) = 0.1 novae /y

GANIL-SPIRAL2

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

M. Lewitowicz

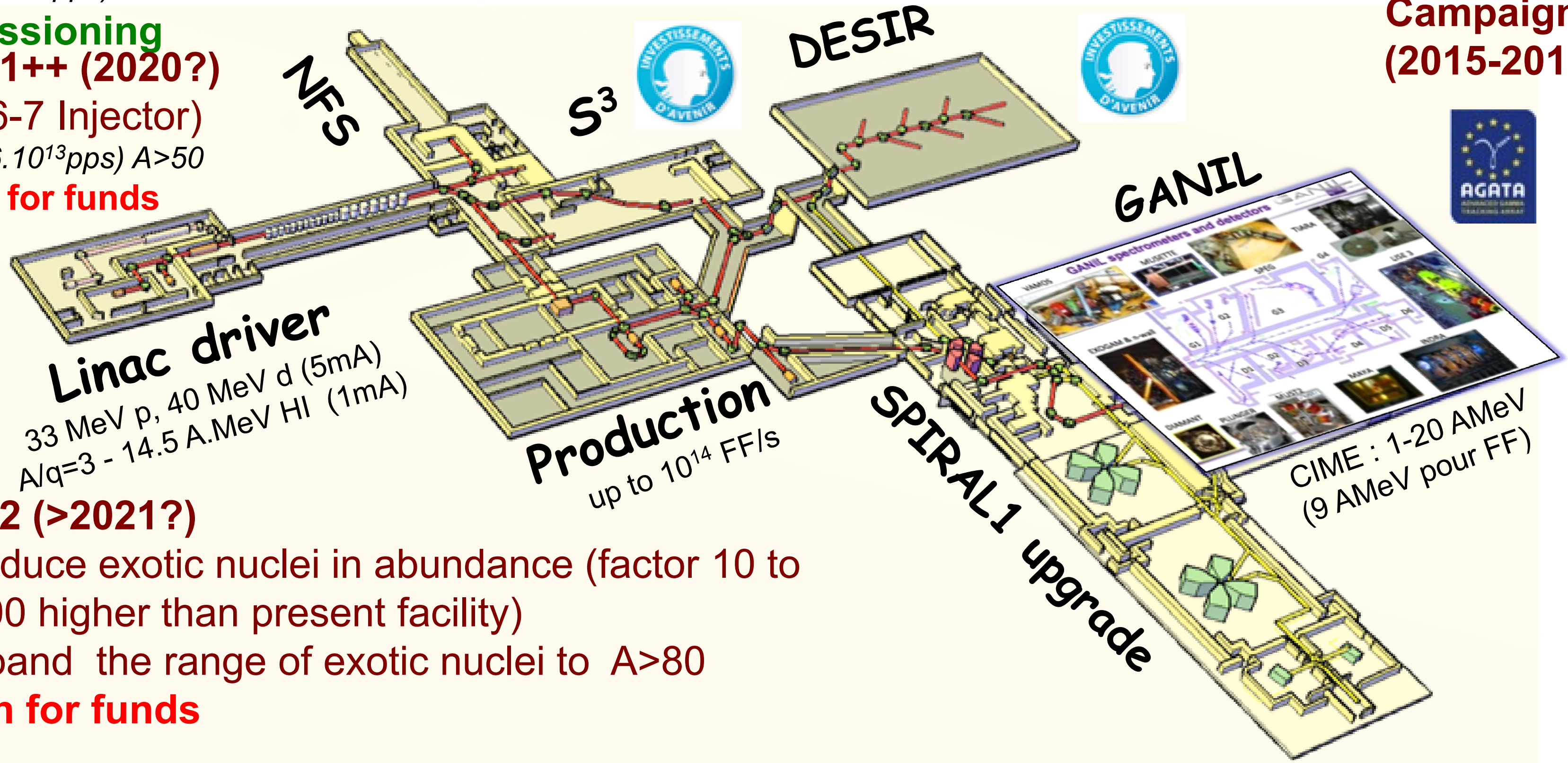
GANIL-SPIRAL2 facility

Phase1 (2015)
Increase the intensity of stable beams by a factor 10 to 100 –
High intense neutron source
10pμA (6.10[13]pps) A<50 **End of construction & commissioning**

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

AGATA Campaigns (2015-2019)

Phase1++ (2020?)
(A/Q=6-7 Injector)
10pμA (6.10[13]pps) 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

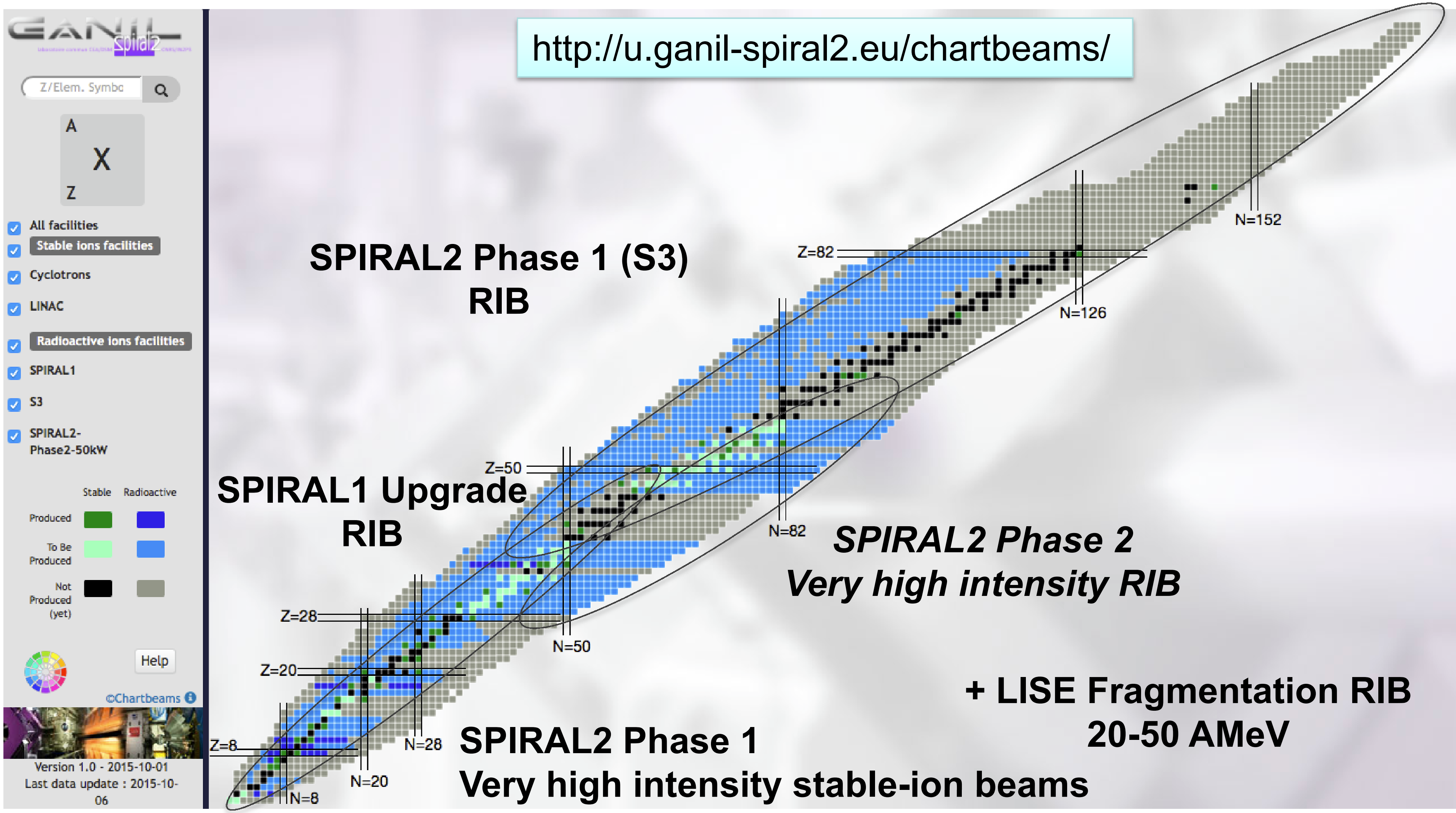
SPIRAL1 Upgrade (2016)
New light RIBs
Fully funded

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)

GANIL-SPIRAL1-SPIRAL2 Phase 1 Stable & RIB



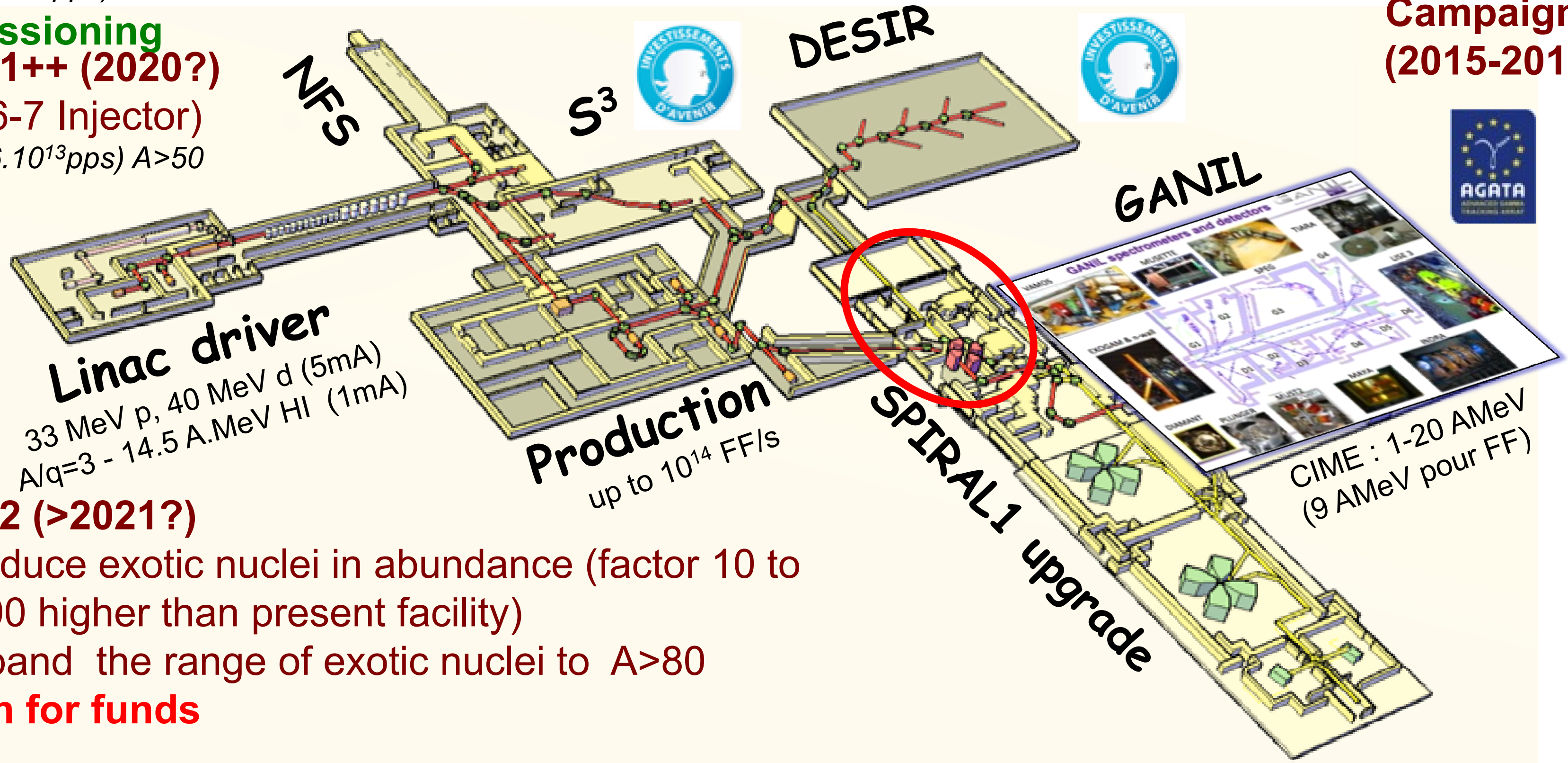
GANIL-SPIRAL2 facility

Phase1 (2015)
Increase the intensity of stable beams by a factor 10 to 100 –
High intense neutron source
10pμA (6.10[13]pps) A<50 **End of construction & commissioning**

Phase1++ (2020?)
(A/Q=6-7 Injector)
10pμA (6.10[13]pps) A>50

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

AGATA Campaigns (2015-2019)



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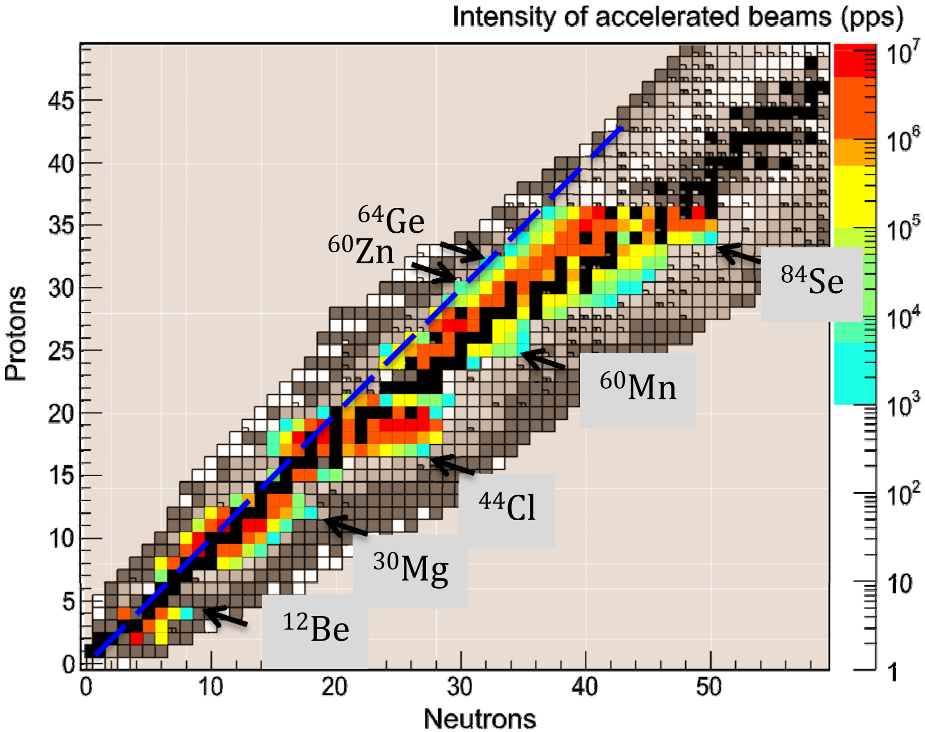
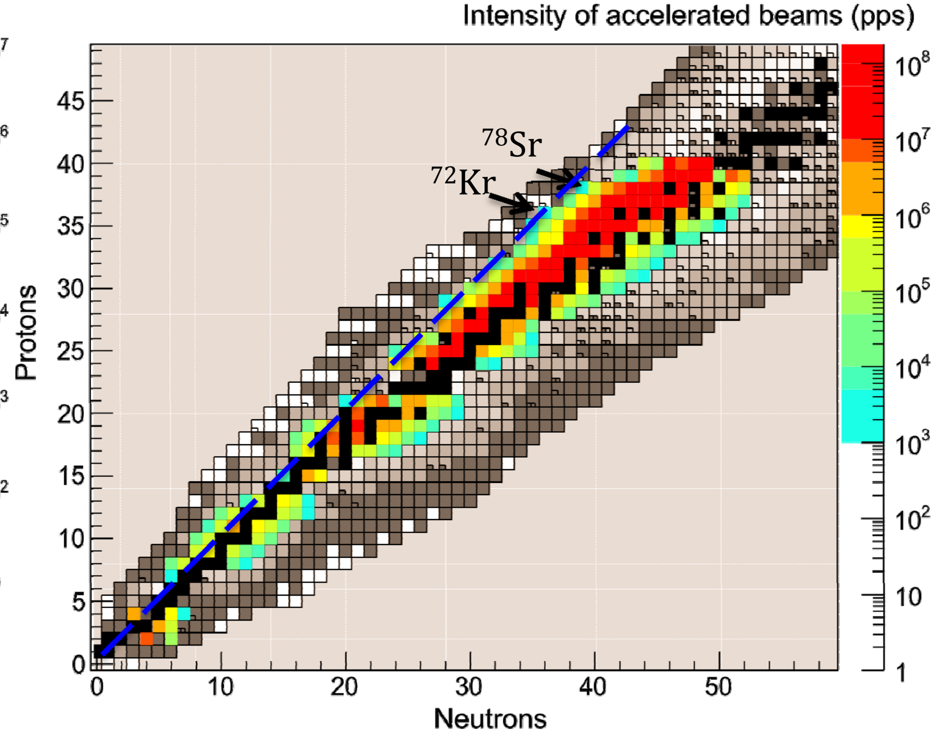
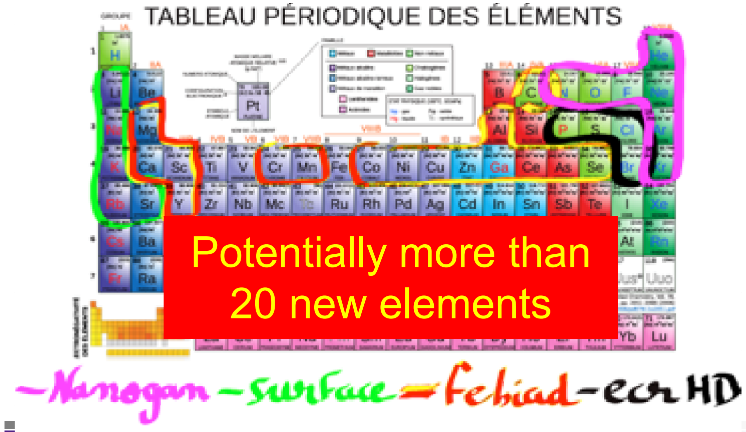
SPIRAL 1 upgrade



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

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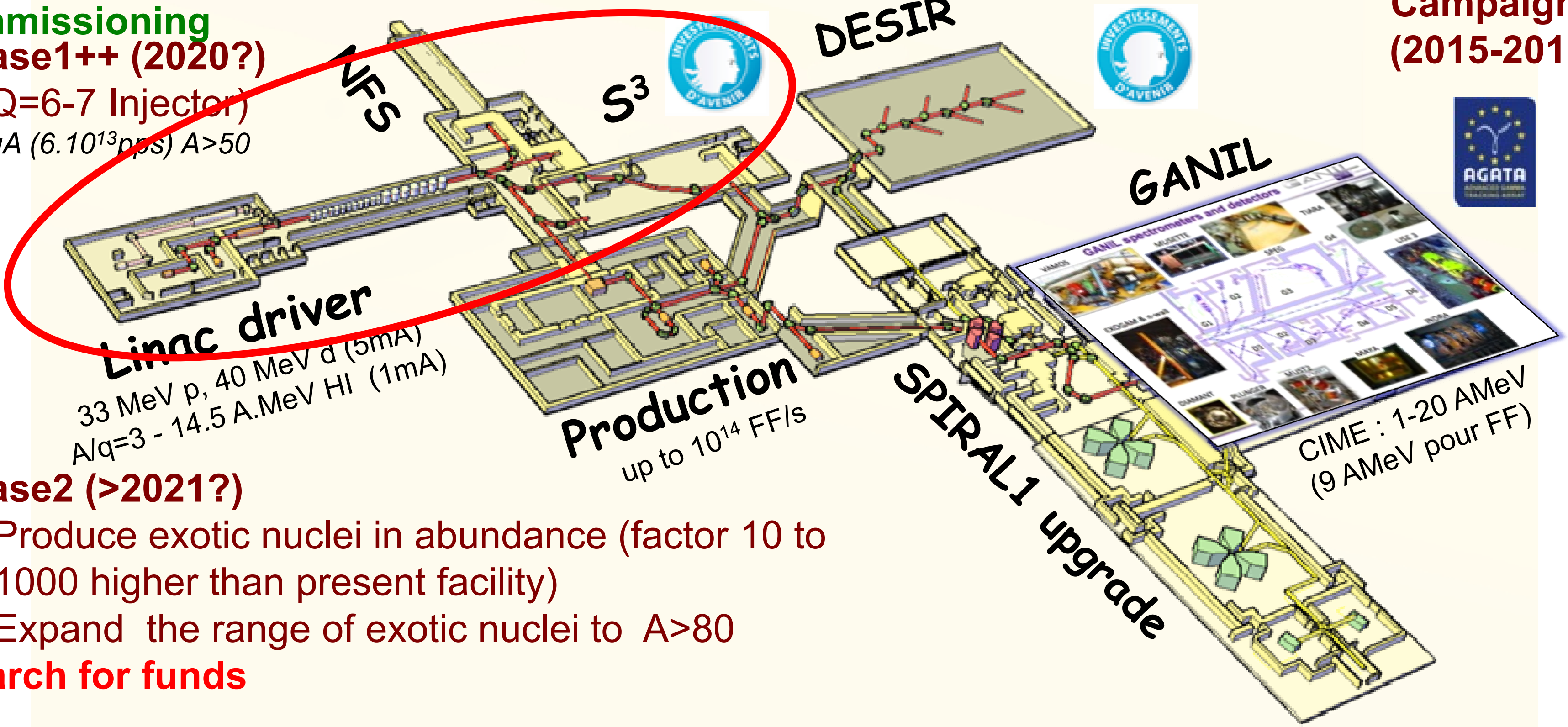

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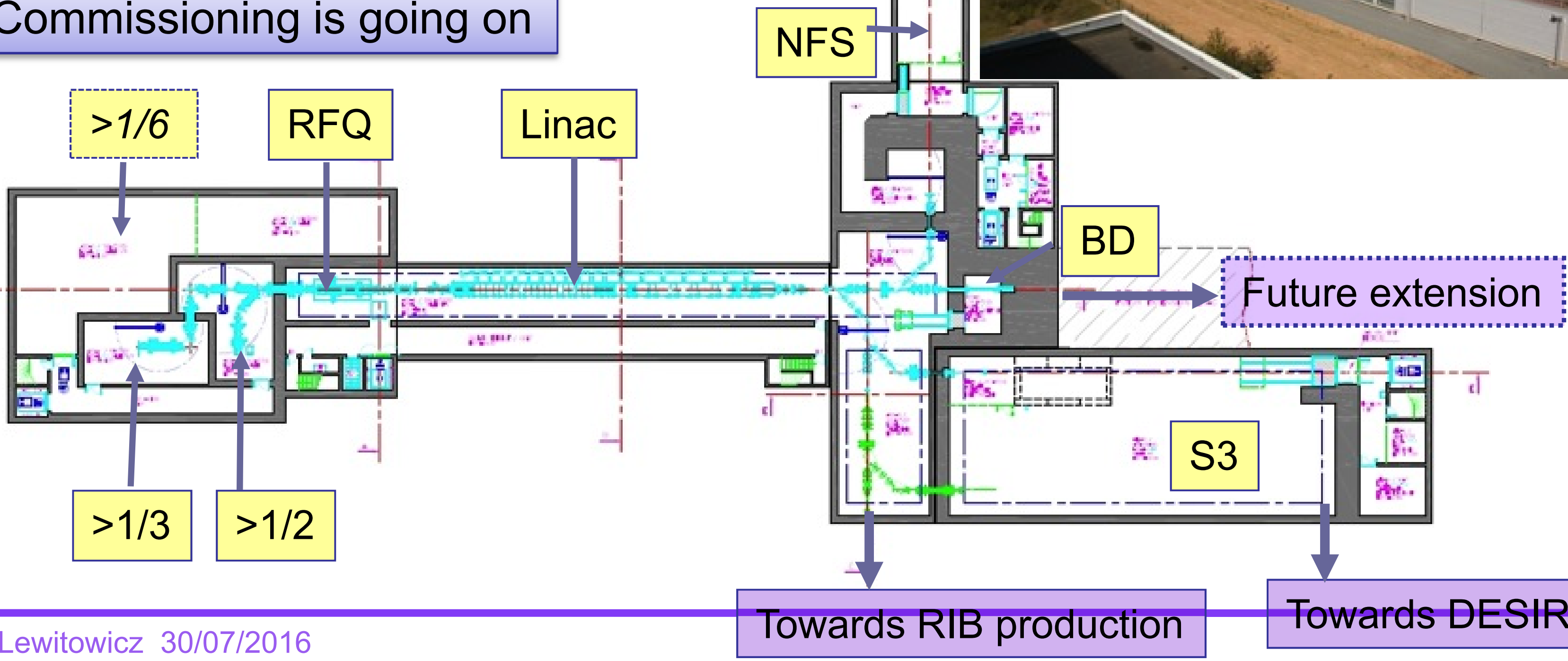
SPIRAL2 Phase 1

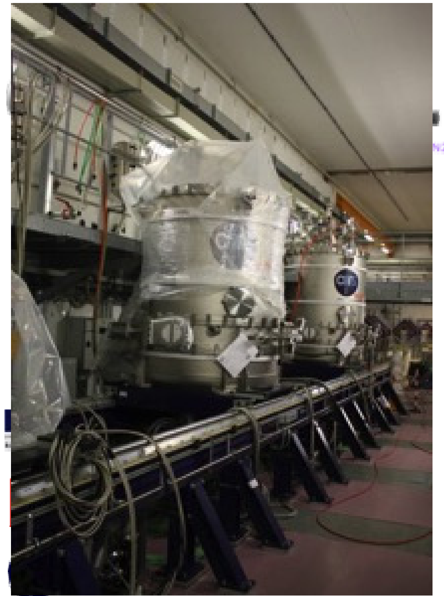
	Q/A	I (mA)	Energy (Mev/u)	Max beam Power (KW)
Protons	**1/1**	**5**	**2 - 33**	**165**
Deuterons	**1/2**	**5**	**2 - 20**	**200**
Ions	**1/3**	**1**	**2 - 14.5**	**45**
Ions (option)	***1/7***	***1***	***2 - 8***	***48***

Average beam intensity equivalent to that of ESS or EURISOL driver

Commissioning is going on

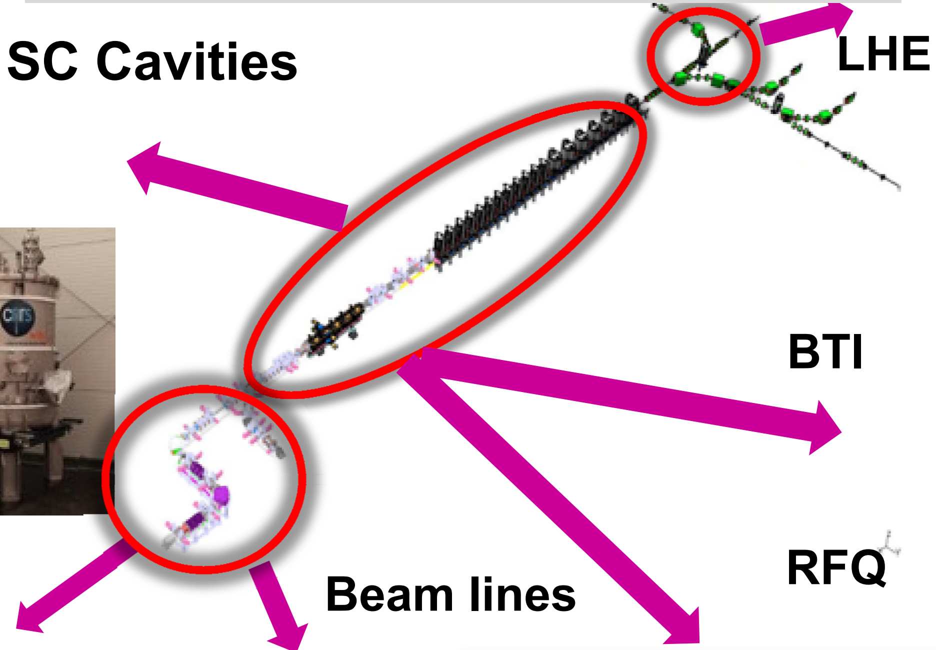


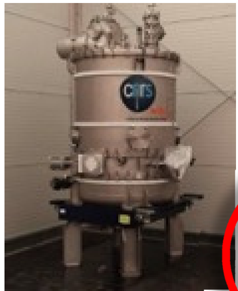
Installation & Commissioning of LINAC



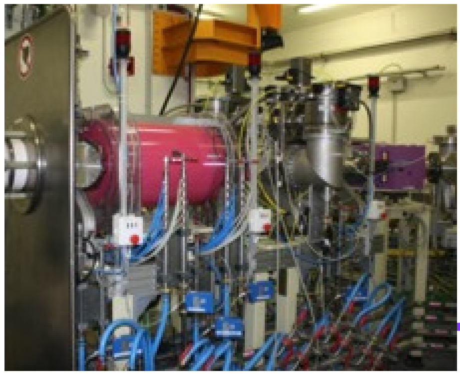
Low energy beam : Dec 2014
RFQ beam : Dec. 2015: protons 5mA
4He beam in March 2016
LINAC beam : End of 2016

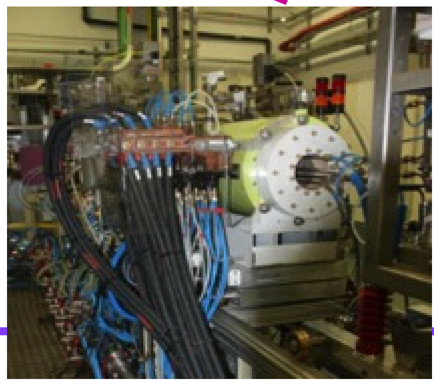
Beam lines & support





Ion Sources





GANIL-SPIRAL2 facility

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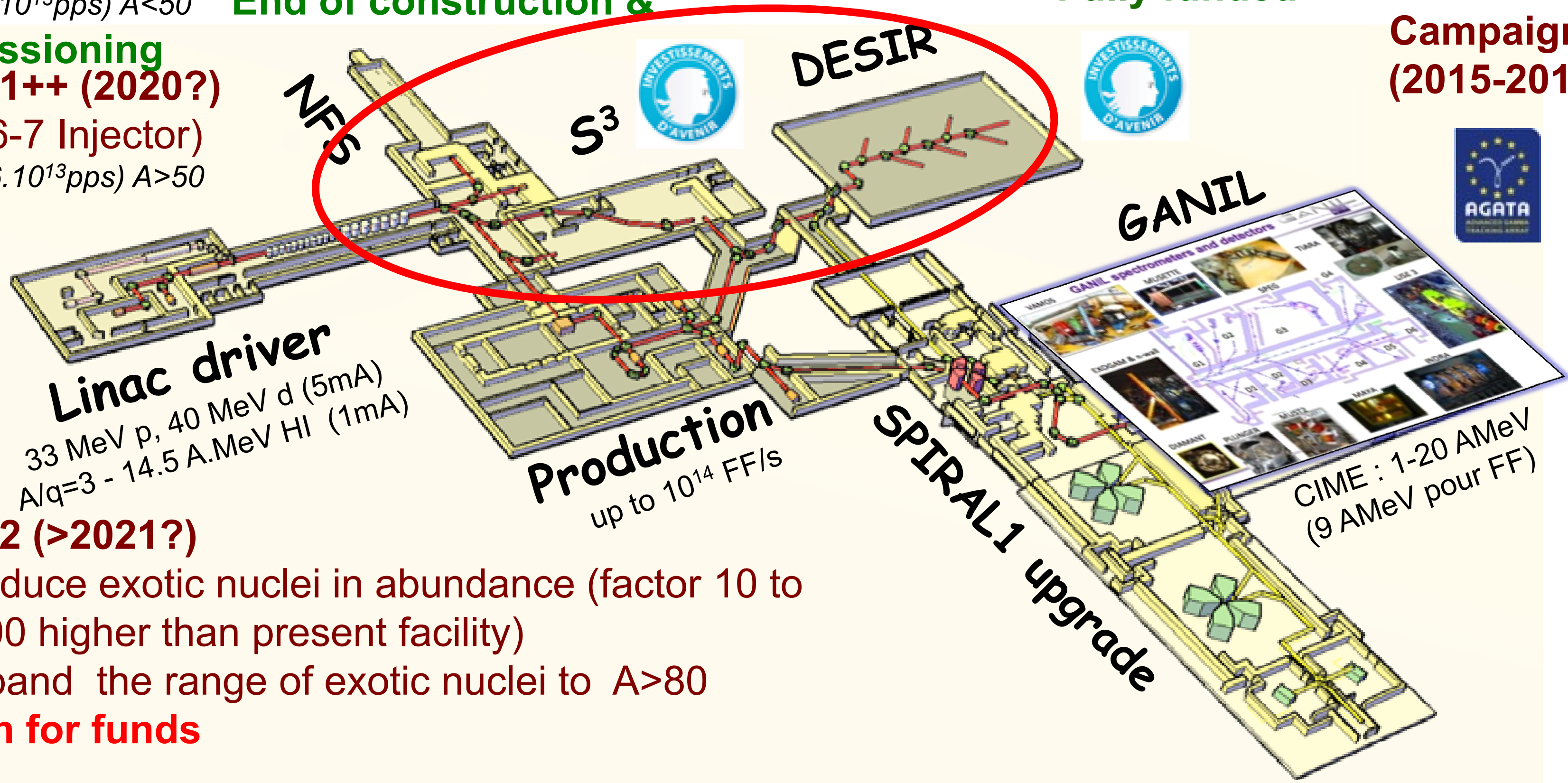

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Neutrons For Science

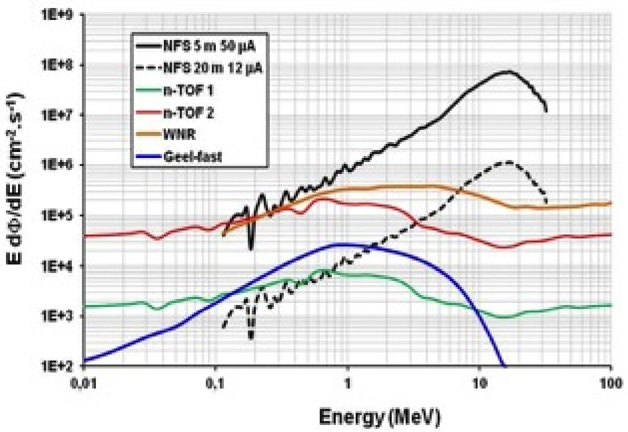
NFS Physics case (11 LoIs)

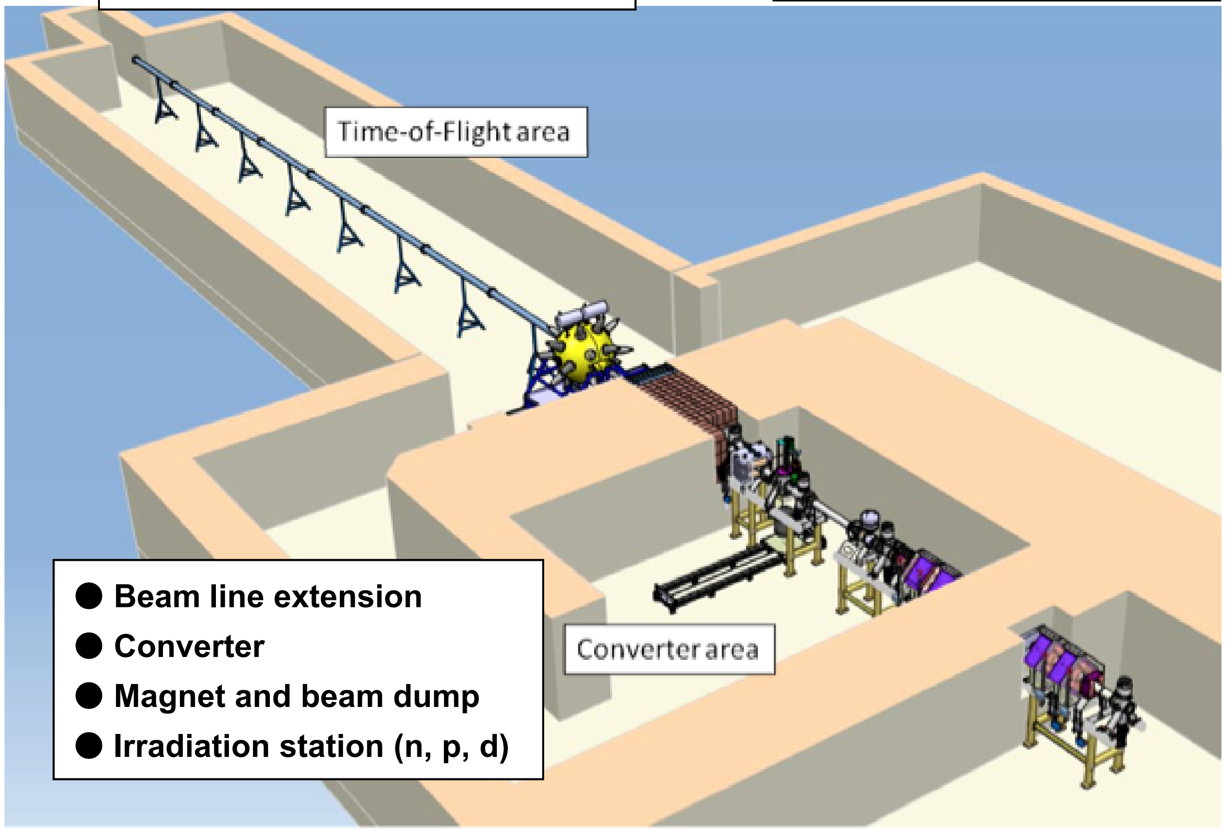
- Fission reactors of new generation
- Fusion technology
- Studies related to hybrid reactors (ADS)
- Basic data for evaluated data bases
- Nuclear medicine and biology
- Development of new detectors

- 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)

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

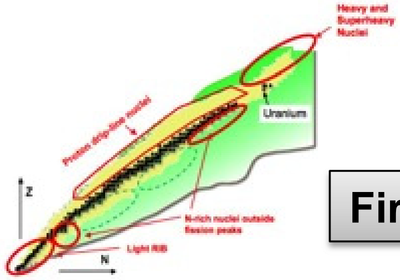
PAC June 2016

First experiment in 2017

S3

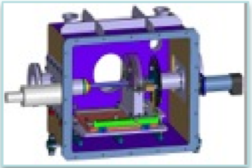
S3 Physics case (16 LoIs)

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

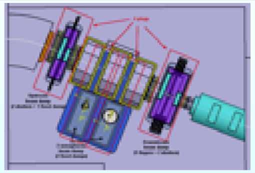


First experiment in 2017-18

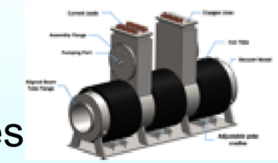
High power Rotating targets including actinides

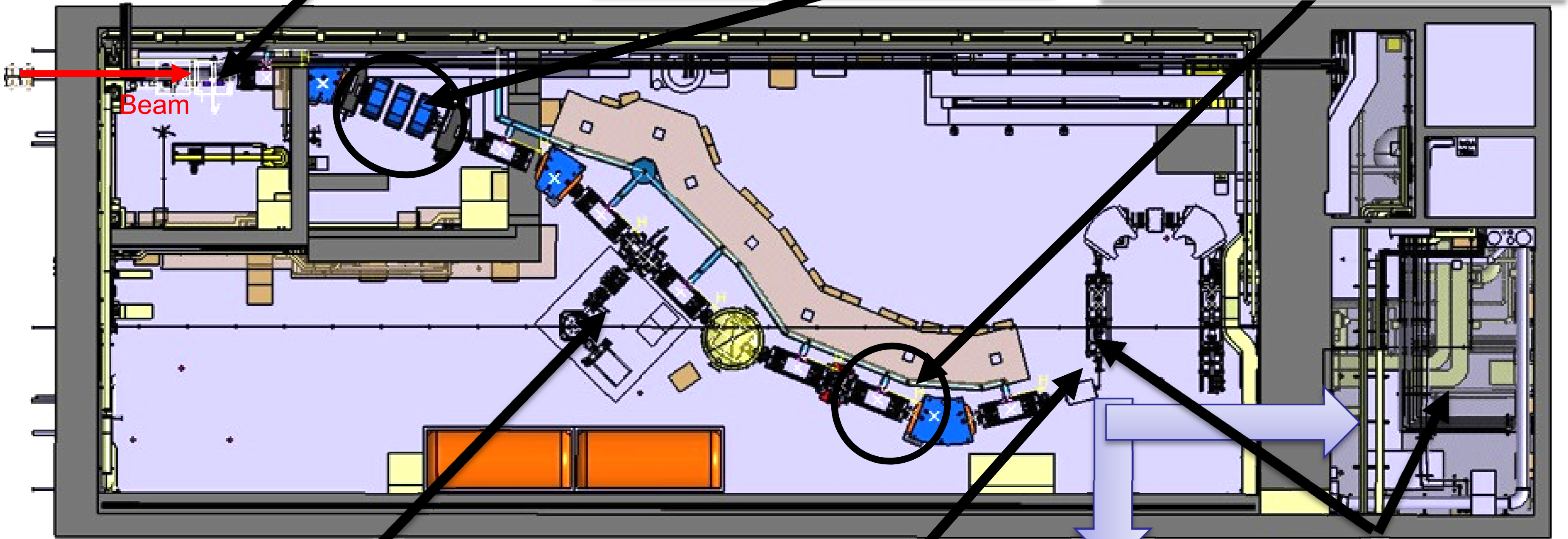


Beam dump & Movable fingers



Large acceptance SC Multipoles



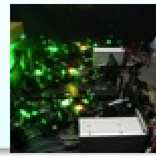


FISIC setup Fast Ion Slow Ion Collisions

Implantation-decay station at the mass dispersive plan

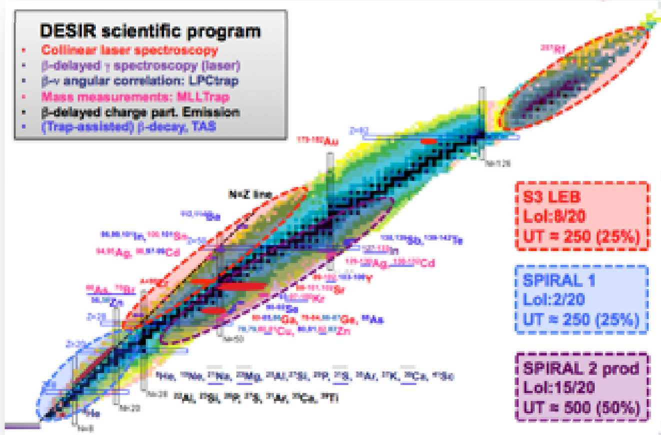
DESIR

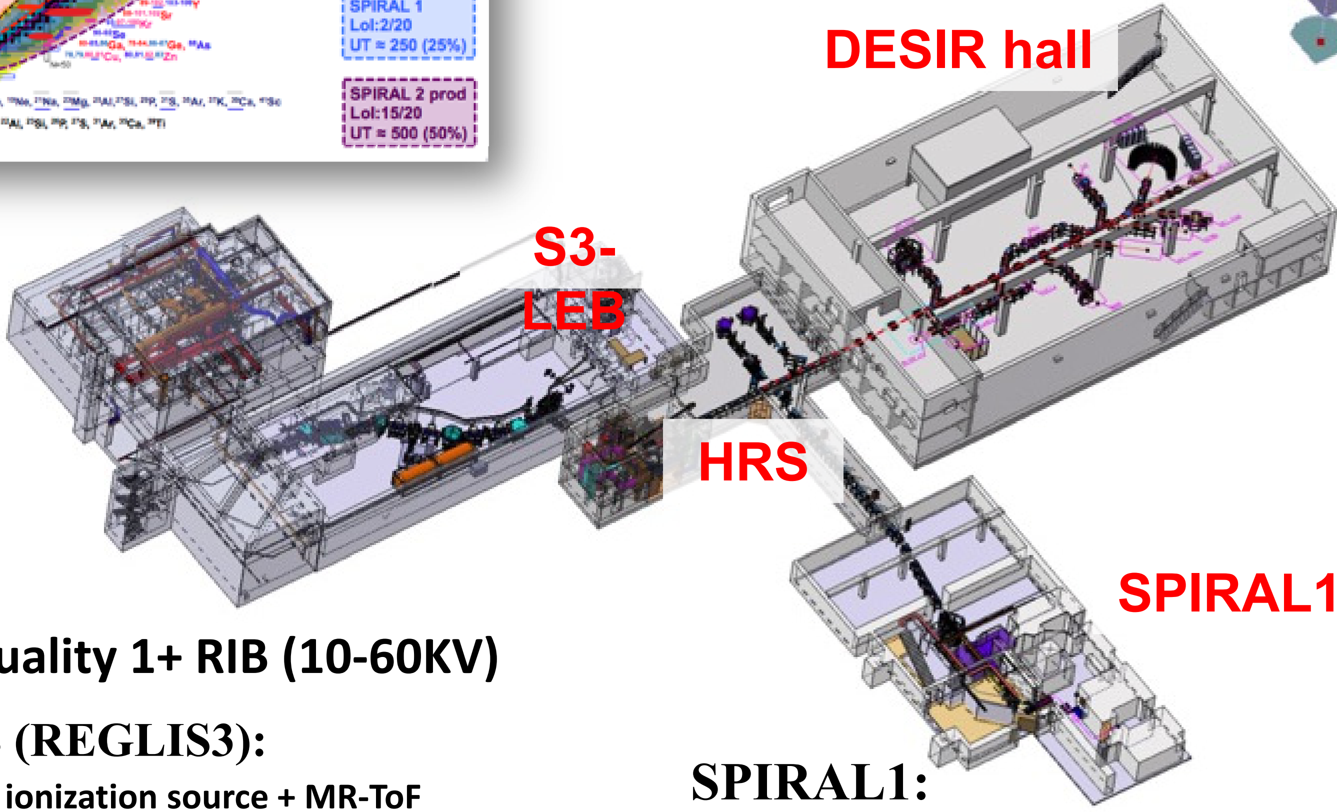
Low Energy Branch

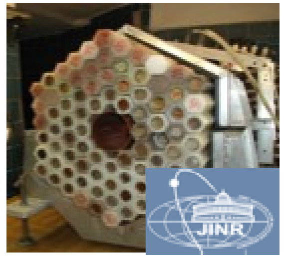


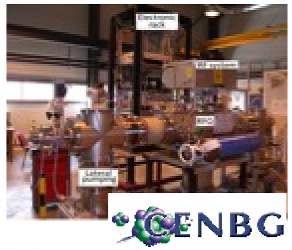
GANIL spiral2 · CNRS IN2P3 · Irfu - CEA Saclay · Argonne · IKS · KU Leuven · Investissements d'Avenir

DESIR Facility – SPIRAL2 Phase 1+









High quality 1+ RIB (10-60KV)

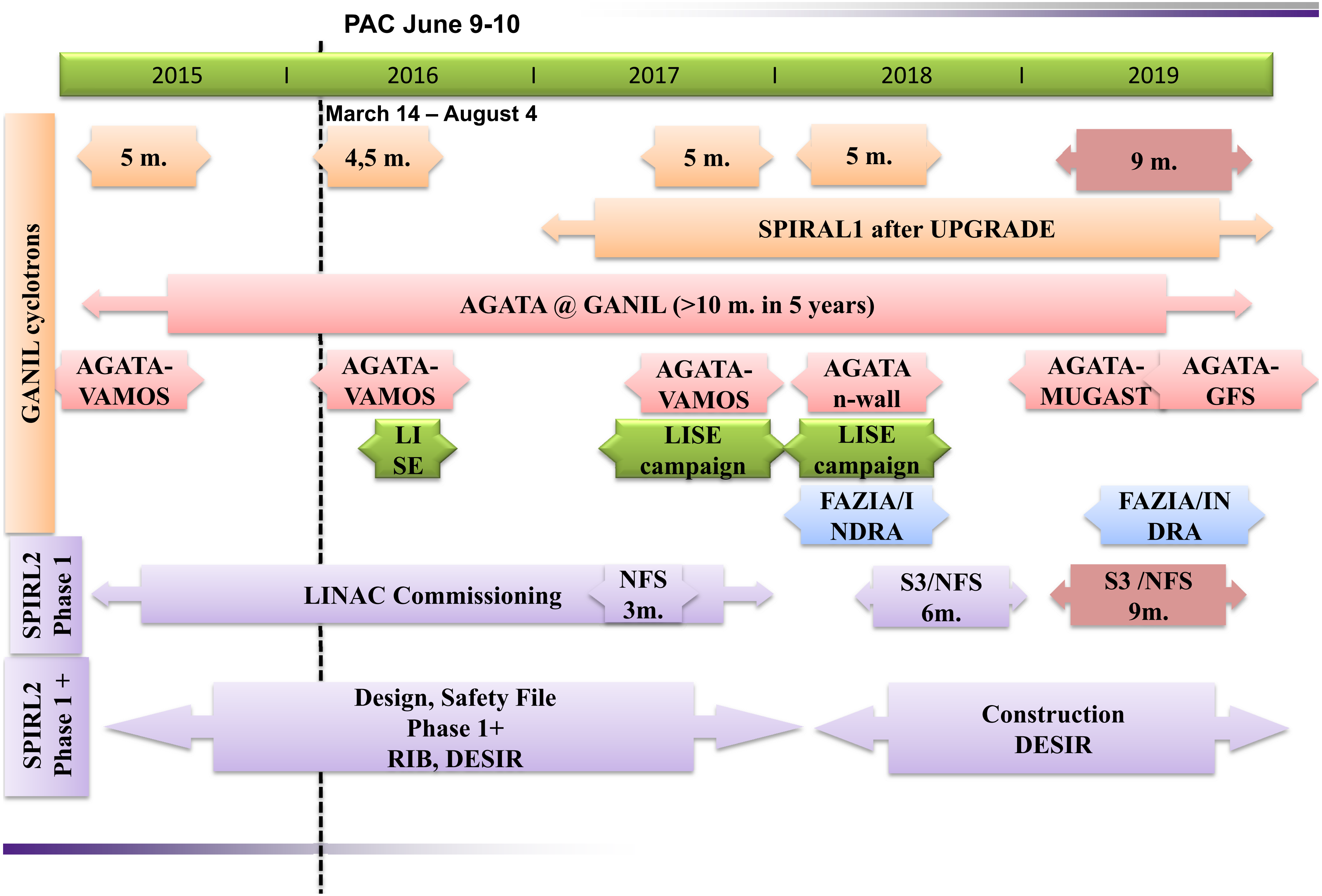
S[3] LEB (REGLIS3):

- 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: first beams early 2017 for experiments
- Phase 1+ (DESIR): online in ~2019-2020
- Phase 1++ (A/q~7): looking for funds
- Phase 2: looking for funds