

Concluding remarks



XXIst Colloque GANIL
September 9th - 13th
Strasbourg

TOPICS
Nuclear structure
Nuclear dynamics
Nuclear astrophysics
Fundamental interactions
Interdisciplinary research
Related theoretical developments
Applications
Instrumentation and technical developments

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« Morceaux choisis » from the presentations

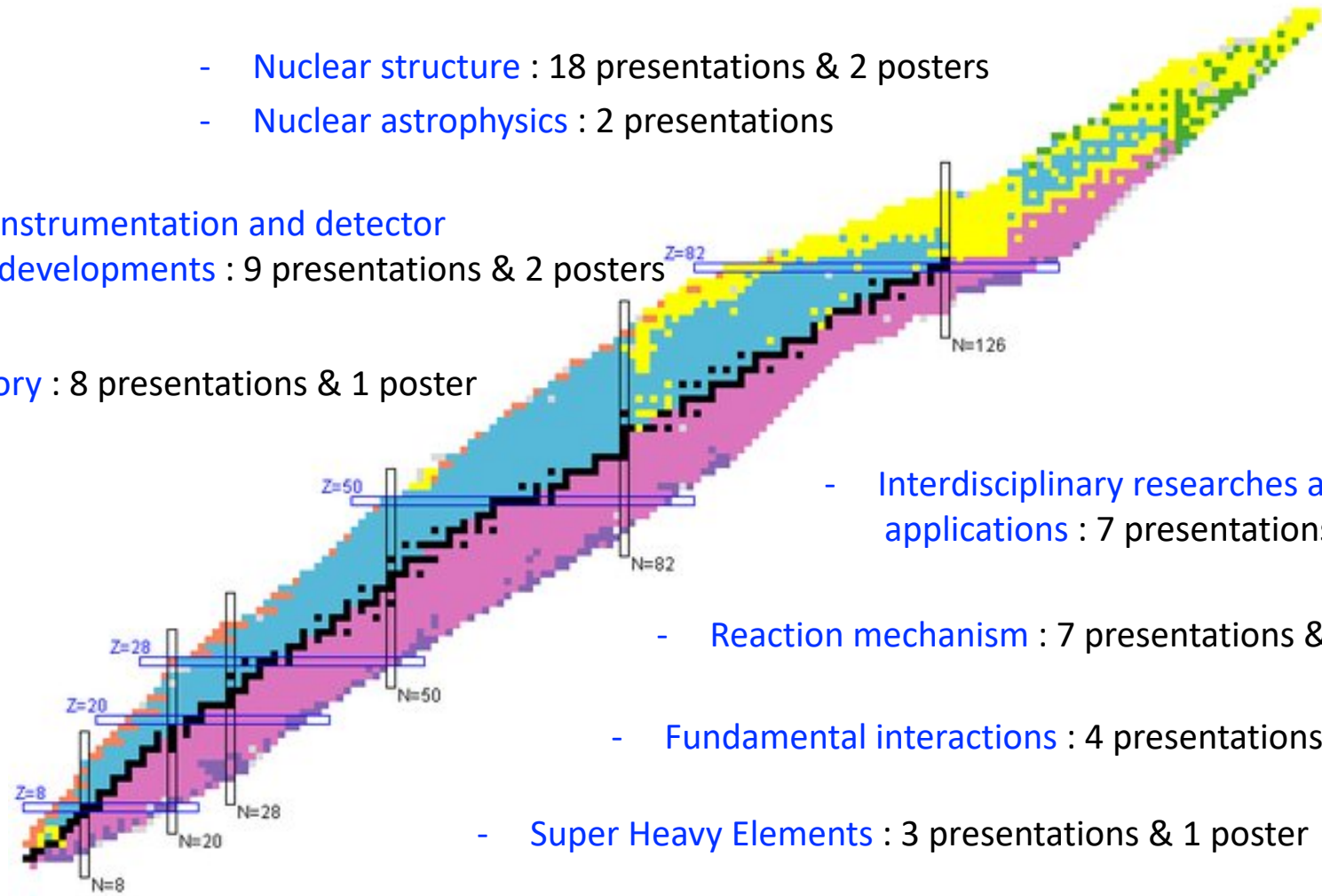
Some words about GANIL

Perspectives 2020-2030

- Nuclear structure : 18 presentations & 2 posters
- Nuclear astrophysics : 2 presentations

- Instrumentation and detector developments : 9 presentations & 2 posters

- Theory : 8 presentations & 1 poster



- Interdisciplinary researches and applications : 7 presentations & 2 poster

- Reaction mechanism : 7 presentations & 2 posters

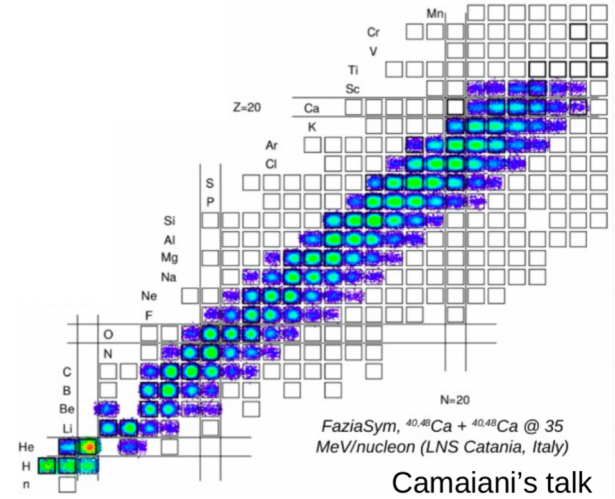
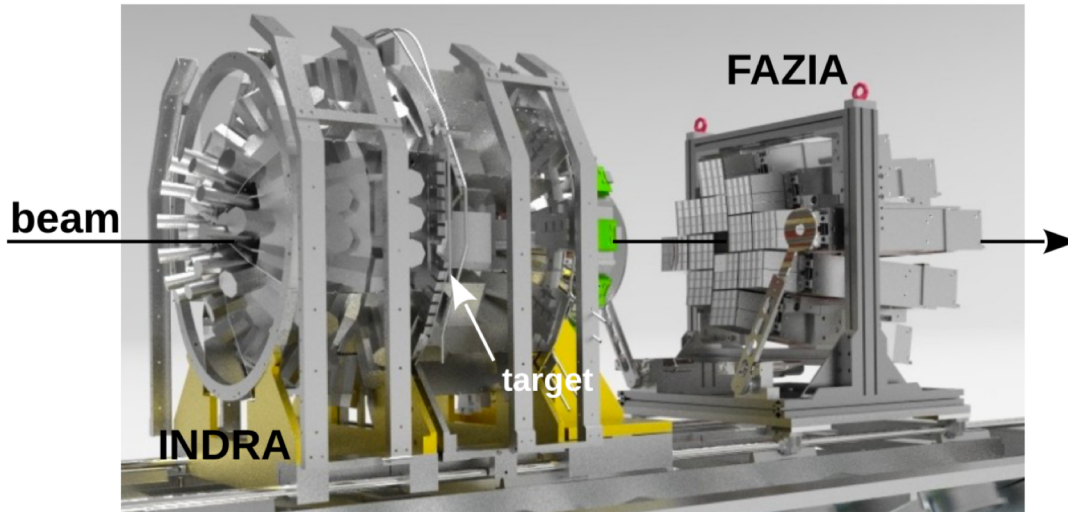
- Fundamental interactions : 4 presentations

- Super Heavy Elements : 3 presentations & 1 poster

65 presentations → 15" per presentation

« Morceaux choisis » : Reaction mechanism

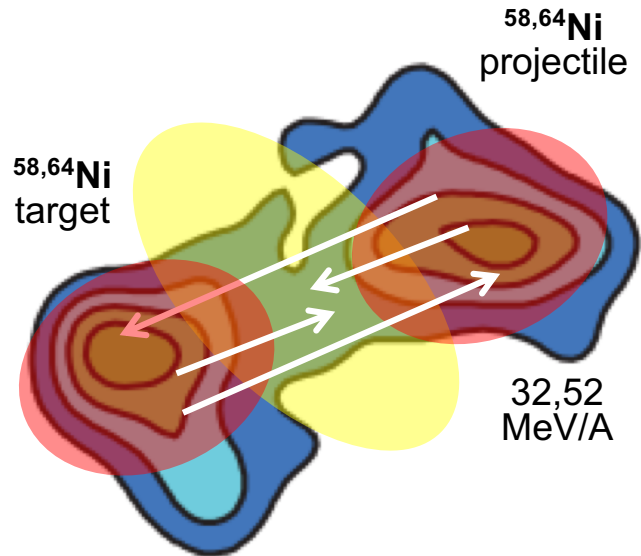
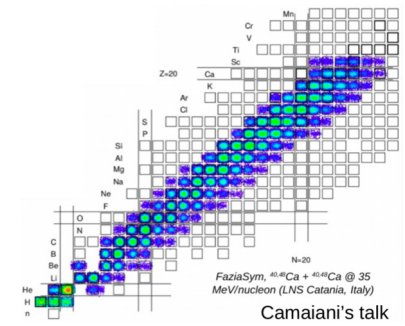
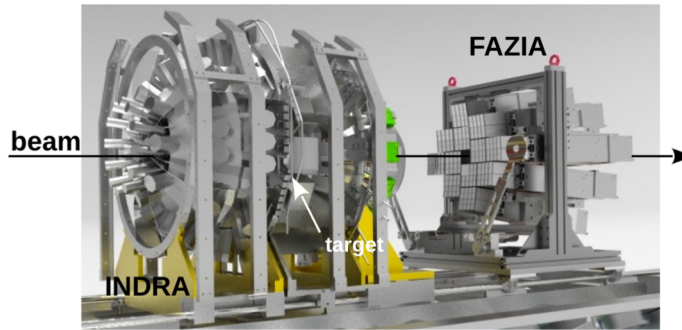
- 2019 : First experiment at GANIL with FAZIA coupled to INDRA
 D. Gruyer



« Morceaux choisis » : Reaction mechanism

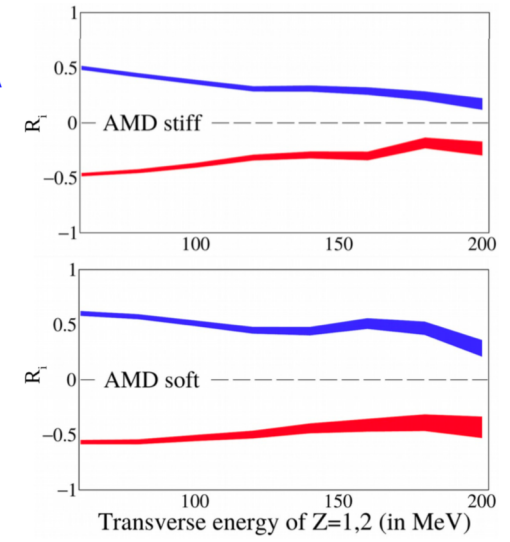
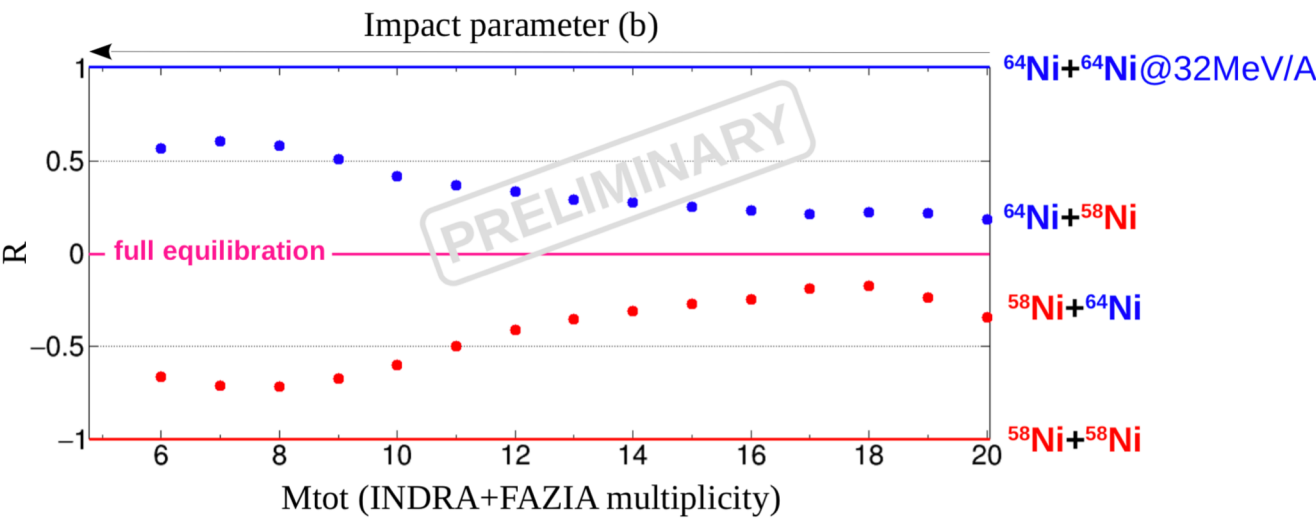
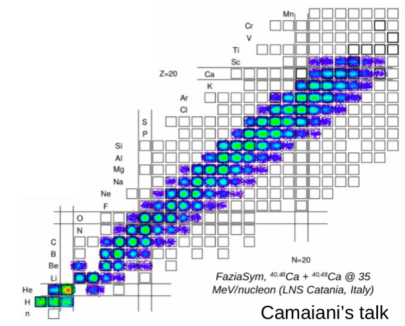
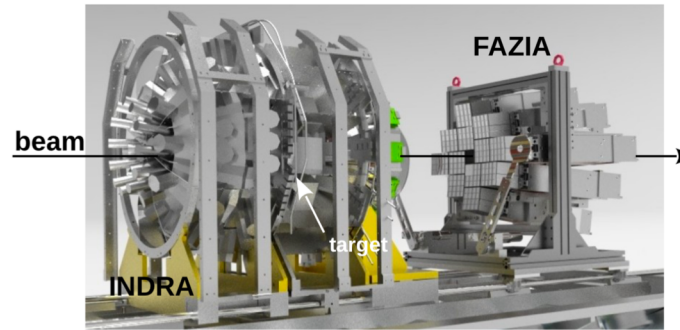
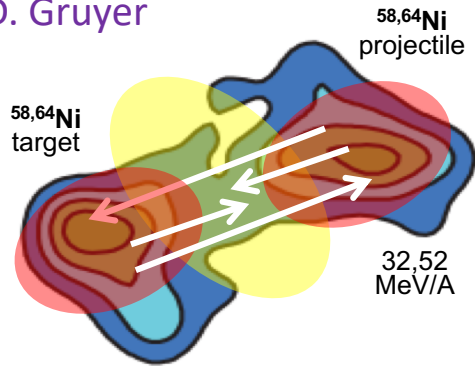
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Isospin transport :
 Redistribution of protons & neutrons
 between projectile, target & neck
 during the reaction (10^{-22} - 10^{-20} sec.)



« Morceaux choisis » : Reaction mechanism

- 2019 : First experiment at GANIL with FAZIA coupled to INDRA
- D. Gruyer



A clear scientific program for the next years to exploit the INDRA+FAZIA setup

« Morceaux choisis » : Reaction mechanism

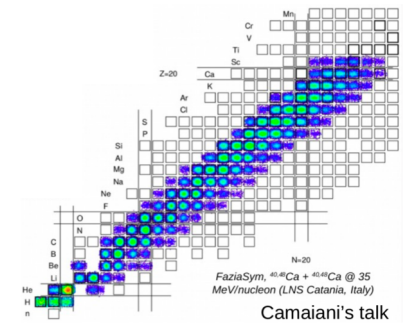
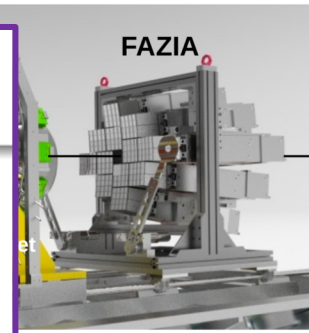
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^{58,64}Ni

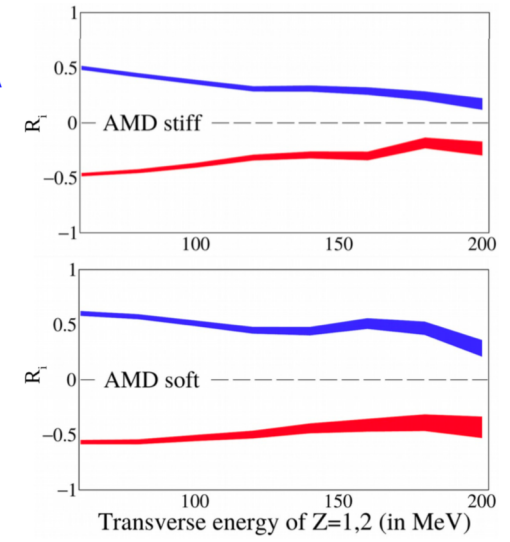
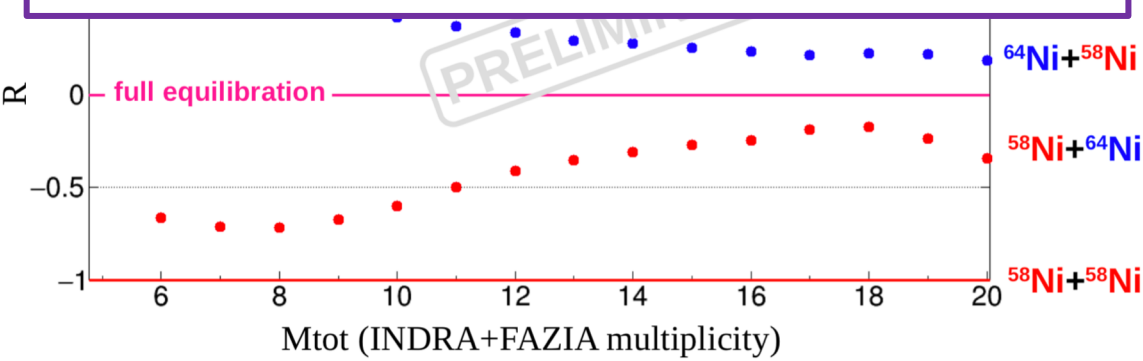
Isospin equilibration in theoretical calculations

K. Mazurek, S. Piantelli, G. Casini, D. Gruyer, J. Frankland, A. Kelic-Heil, D. Lacroix

September 9, 2019



@32MeV/A



A clear scientific program for the next years to exploit the INDRA+FAZIA setup

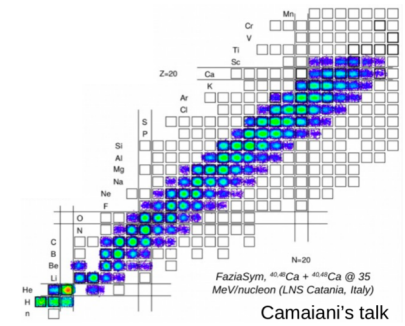
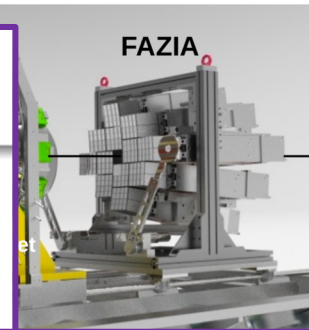
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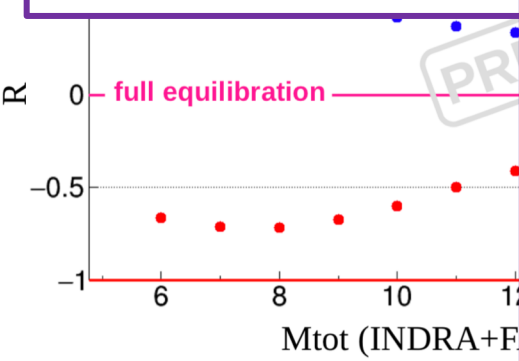
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Summary

- The isotopic equilibration process gives the knowledge about quasiprojectile fission time and contact time between QT i QP.
- The ABRABLA and HIPSE models gives many information about time-space evolution participants of the moderate energy reaction.
- The preliminary estimations of the mass/charge distributions of the asymmetric fragments coming from QP fission don't show any equilibration with increasing alignment angle.
- The imbalance ratio of $\langle N/Z \rangle$ obtained from ABRABLA and HIPSE shows similar behavior with centrality for the reactions: more central - higher imbalance ratio.
- Plans: applying the experimental filters and compare with the data.

Septem



A clear scientific program for the next years to exploit the INDRA+FAZIA setup

« Morceaux choisis » : Reaction mechanism

➤ Structure of nuclei produced by fragmentation with FAZIA J. Quicray



the best poster



STRUCTURE OF NUCLEI PRODUCED BY FRAGMENTATION WITH FAZIA MULTIDETECTOR
J. Quicray, D. Gruber, LPC Caen, quicray@lpc.cnrs.fr

INTRODUCTION : EXPERIMENTAL SETUP AND AIM OF THE STUDY

Significant transfer of energy between the projectile and the target part of this initial kinetic energy is transformed into thermal energy.

Many fragments produced with different masses (A) and charges (Z): multi-fragmentation.

Primary fragments are excited and then can decay by γ radiations and by emitting charged particles which are detected by the FAZIA multidetector.

FAZIA telescope, side view
Silicon - Silicon - Cesium Iodide

FAZACOR equipment
4 blocks of FAZIA
18 telescopes

Purpose: to explore the possibility of using correlation techniques on fragmentation data obtained by the FAZIA detector.

FAZIA abilities:

- Measure the charge and the mass of fragments up to Z=25 unlike other generation detectors. Pulse Shape Analysis method and AE - E method are to identify particles.
- Good angular coverage and granularity and a mass resolution similar to a spectrometer.

Reconstruction of the decay precise enough = possibility to determine:

- excited states,
- measure their width,
- the branching ratio of different decay channels
- the total angular momentum (L).

Data of $^{16}\text{O} + ^{12}\text{C}$ at 20 MeV/A from the FAZACOR experiment performed at Caen, in July in March 2013, with two FAZIA blocks. Study of the ^{10}B structure using the (α , ^4Li) decay channel.

Collission
Fragmentation
Deexcitation

Nuclei detected by FAZIA when α & ^4Li are detected in coincidence

CONSTRUCTION OF ^{10}B EXCITATION ENERGY SPECTRUM

We build the exc. spectrum of ^{10}B from kinematic properties of α and ^4Li :

$$M^2(\alpha) = E^2(\alpha) - M^2(\alpha) = M^2(^4\text{Li}) + E^2(^4\text{Li}) - 2E(\alpha)E(^4\text{Li})\cos\theta$$

$$E(^4\text{Li}) = A_1 \sqrt{A_2} \sqrt{A_3} \sqrt{A_4} \sqrt{A_5} \sqrt{A_6} \sqrt{A_7} \sqrt{A_8} \sqrt{A_9} \sqrt{A_{10}} \sqrt{A_{11}} \sqrt{A_{12}} \sqrt{A_{13}} \sqrt{A_{14}} \sqrt{A_{15}} \sqrt{A_{16}} \sqrt{A_{17}} \sqrt{A_{18}} \sqrt{A_{19}} \sqrt{A_{20}}$$

In lab velocity in the frame of the laboratory, to rest velocity in the frame of the center of mass.

The excitation energy of the ^{10}B which decays into $\alpha + ^4\text{Li}$ corresponds to the kinetic energy of its fragments in the frame of the center of mass.

We have obtained several known levels.

We compare this spectrum using a home made simulation filtered by a software simulating the detector taking into account different reactions of angular and energy resolution distribution.

From the simulation we build a non-analytic function in order to extract populations from each observed state.

When the decay probability is too low the statistic is negligible. When the width of a level is to high, the statistic is lost in the background.

That's why the third peak is the only one needing a deconvolution of its 3 levels in order to extract states' populations.

INTERPRETATION OF THE RESULTS REGARDING THE THERMAL MODEL

Assuming that the ^{10}B are produced by a thermodynamically balanced source of temperature T, the thermal model tells us that the excitation energy spectrum reconstructed from the (α , ^4Li) channel must have the following form:

Excitation energy

Normalization factor

$$\frac{dN}{dE} = A \exp\left(-\frac{E}{T}\right) \sum_{i=1}^n \frac{\Gamma_i}{\Gamma_i + 1} \times \frac{\Gamma_i}{(E - E_i)^2 + \Gamma_i^2/4}$$

Number of α emission

Average temperature of the system

Resource term

Relative population of the observed states

Treatment: Populations corrected of the detector efficiency. Populations normalized by (2.14) for each level involved.

Expectation: The population should decrease in an exponential way with the energy according to the thermal model.

Observation: No exponential decrease as expected regarding the thermal model. For example the relative population of the 5.972 MeV state is much higher than expected.

Interpretation: Nuclei are produced in different temperature conditions since we could not apply a single temperature on impact parameter.

FUTURE STUDIES: THE INDRRA-FAZIA EXPERIMENT | BRANCHING RATIO

By coupling the multidetector FAZIA with the multidetector INDRRA we can cover almost a 4π of solid angle. 10° is left for FAZIA, 140° is left for INDRRA.

This allows us to make a selection in multiplicity and in impact parameter/temperature.

An experiment has been performed successfully at GANIL, Caen three months ago. Data will be available soon.

INDRRA is a multidetector with 12 telescopes with a maximum charge up to Z = 25, 240 telescopes.

FAZIA side to measure mass and charge up to Z = 25, 192 telescopes.

By making the same study with other decay channels, we could obtain the branching ratio.

21th Colloque GANIL, 9-13 septembre 2019

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In lab velocity in the frame of the laboratory, in rest velocity in the frame of the center of mass apparatus.

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$$\frac{dN}{dE} = A \cdot \exp\left(-\frac{E}{T}\right) \cdot \sum_{L=0}^{\infty} (2L+1) \cdot \frac{\Gamma_L}{(E - E_L)^2 + \Gamma_L^2} \cdot \frac{\Gamma_{\alpha}}{\Gamma_{\alpha} + \Gamma_{^4\text{He}}}$$

Number of α emission

Average temperature of the system

Resource term

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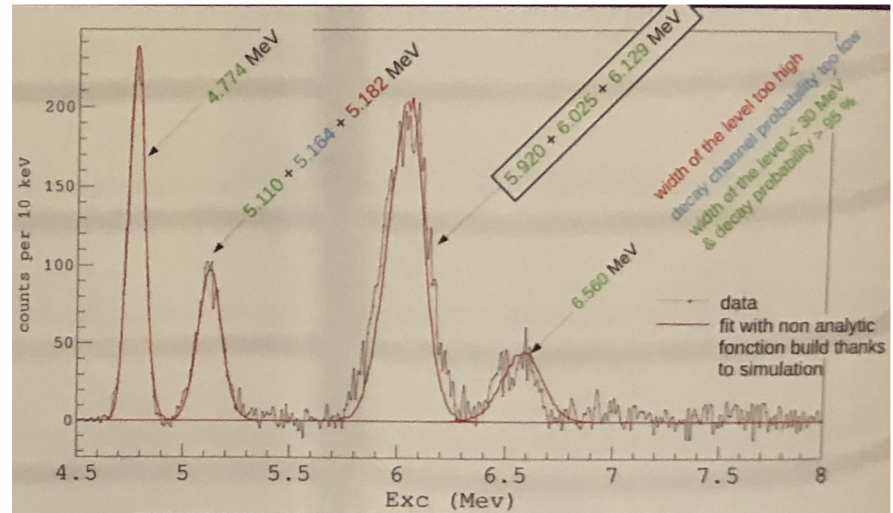


« Morceaux choisis » : Reaction mechanism

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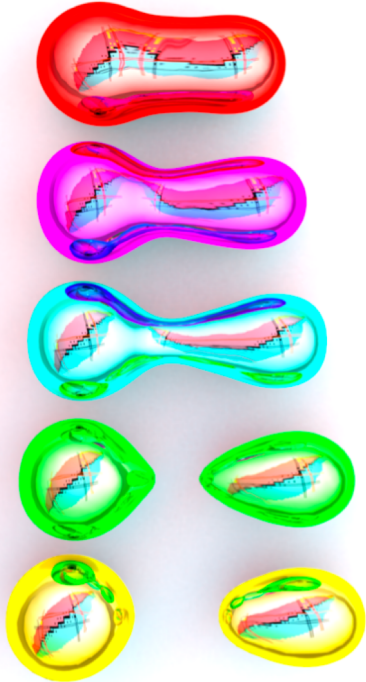
the best poster

Need to understand the relative populations...

« Morceaux choisis » : Reaction mechanism

➤ Study of fission



C. Schmidt → Fission is a very complicated process
 → progress in the understanding from "exclusive measurements"

Most recent measurements in actinides (1)

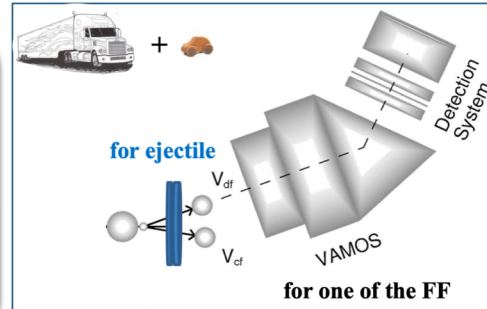
VAMOS@GANIL
 (Farget, Camaano, Ramos, et al.)

SOFIA/ALADIN@GSI
 (Taieb, Chatillon, et al.)

inverse kinematics + advanced heavy-ion spectrometer

complete and fully resolved A, Z, E_{kin} distributions for various (A_{CN}, Z_{CN}, E^*)

- Induce fission in multi-nucleon transfer
- Identify the transfer channel by detecting the light ejectile (i.e. the fissioning nucleus)
- Study fission by detecting in coinc. one of the FF in VAMOS



Fission properties for
 $^{238-239}\text{U}, ^{239}\text{Np}, ^{240}\text{Pu}, ^{244}\text{Cm}, ^{250}\text{Cf}$,
 with $E^* \sim 6$ to 46 MeV

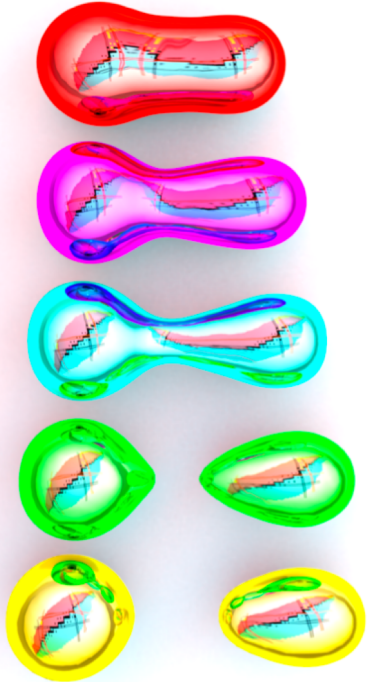


Need A and Z



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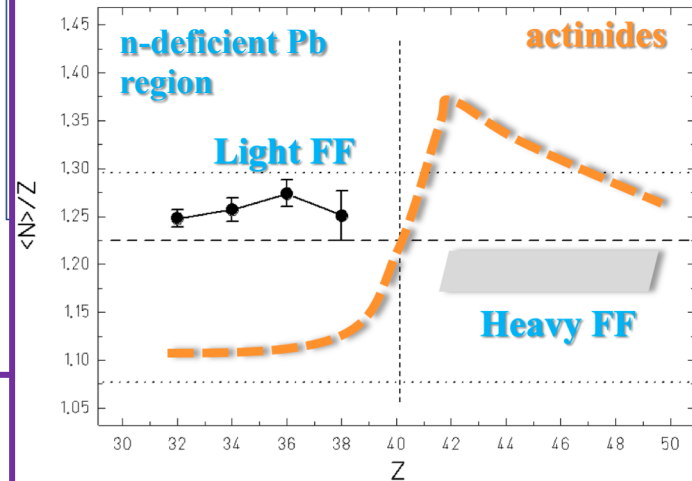
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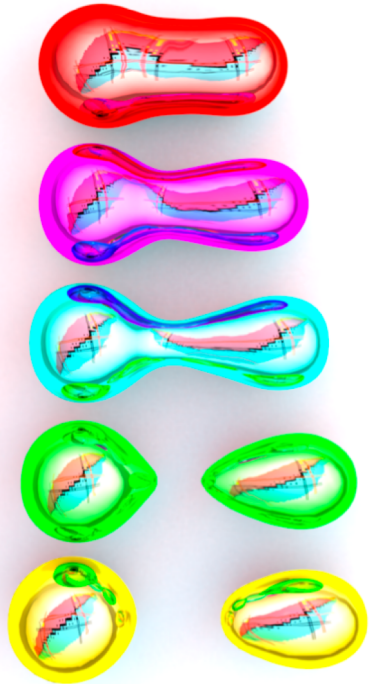


✓ $\langle N \rangle / Z$ new observable

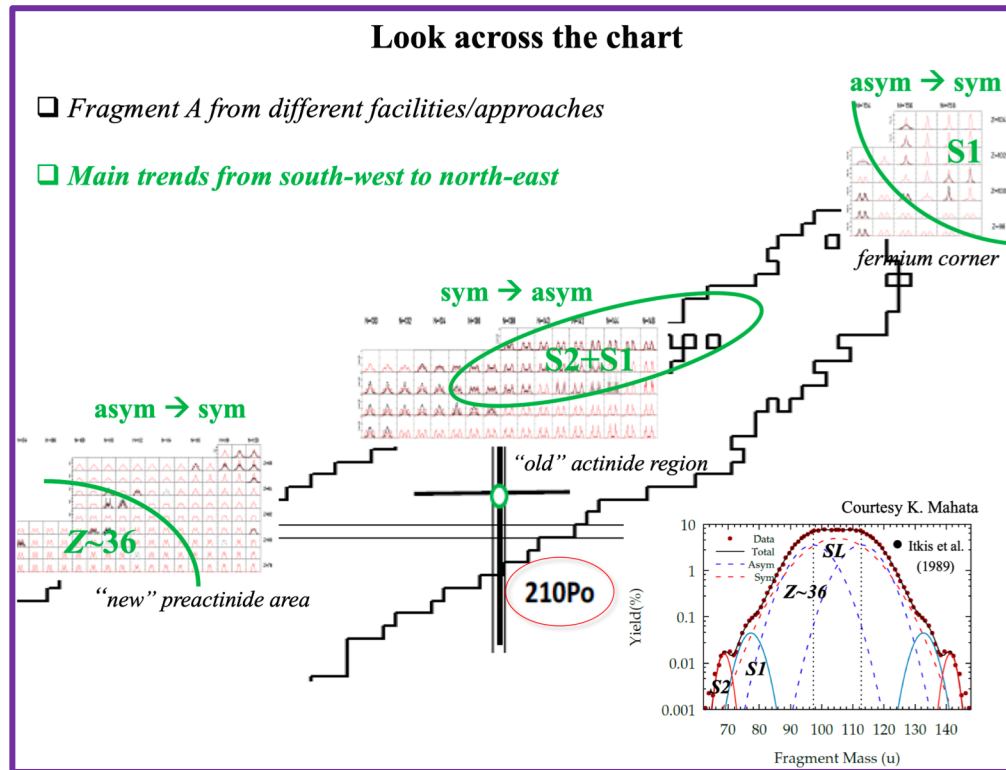


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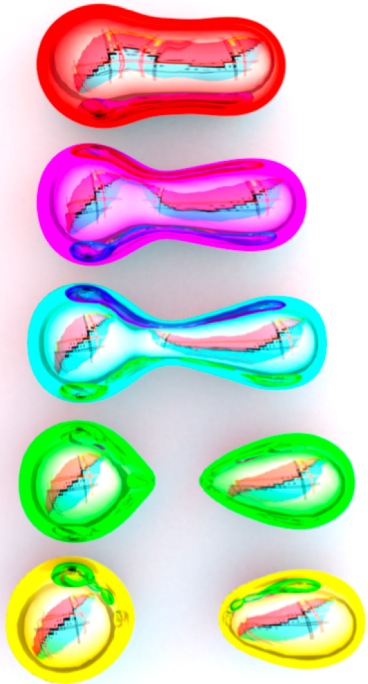


A possible exciting scientific program for the next years with VAMOS

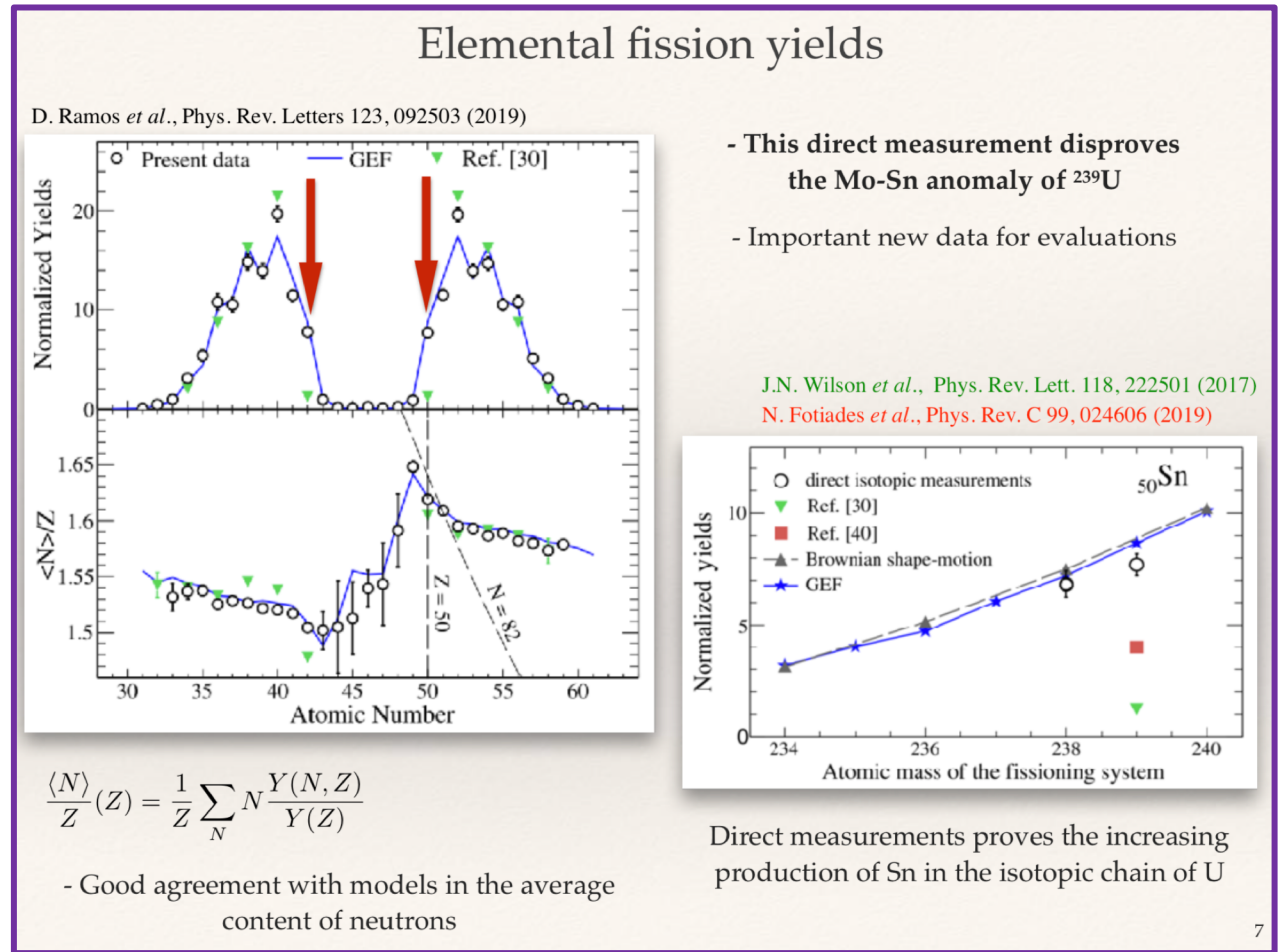
- second arm → detection of both fragments
- transfer induced fission → new regions and control the E^*

« Morceaux choisis » : Reaction mechanism

➤ Study of fission



D. Ramos → First direct measurement of isotopic fission yields of ²³⁹U

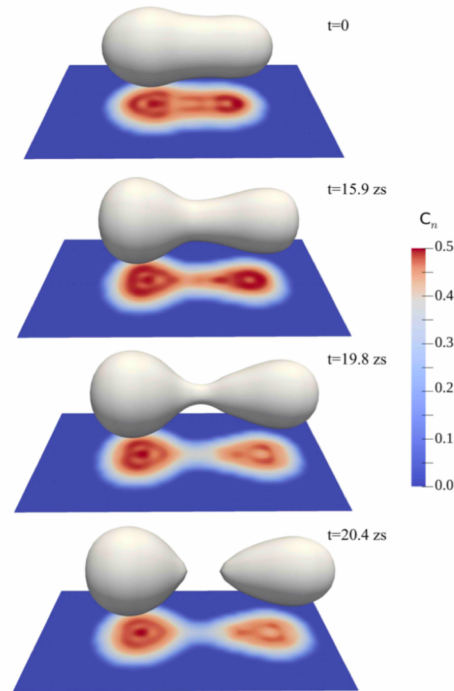
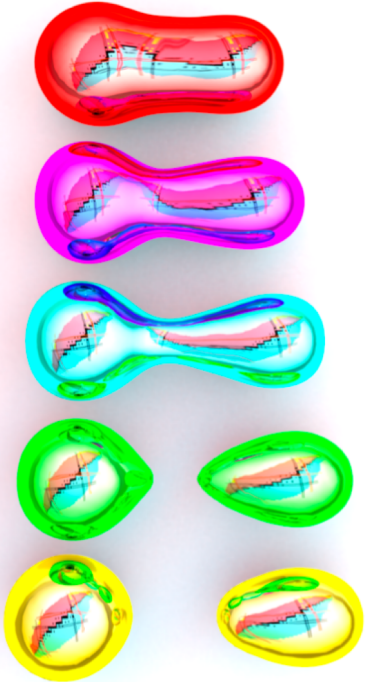


« Morceaux choisis » : Reaction mechanism

➤ Study of fission

G. Scamps → Possible role of the octupole deformation in the asymmetric fission

Example of ^{240}Pu



Hypothesis

The octupole shell effects are important in the fission fragment

« Morceaux choisis » : Nuclear Structure

➤ Light and weakly bound systems

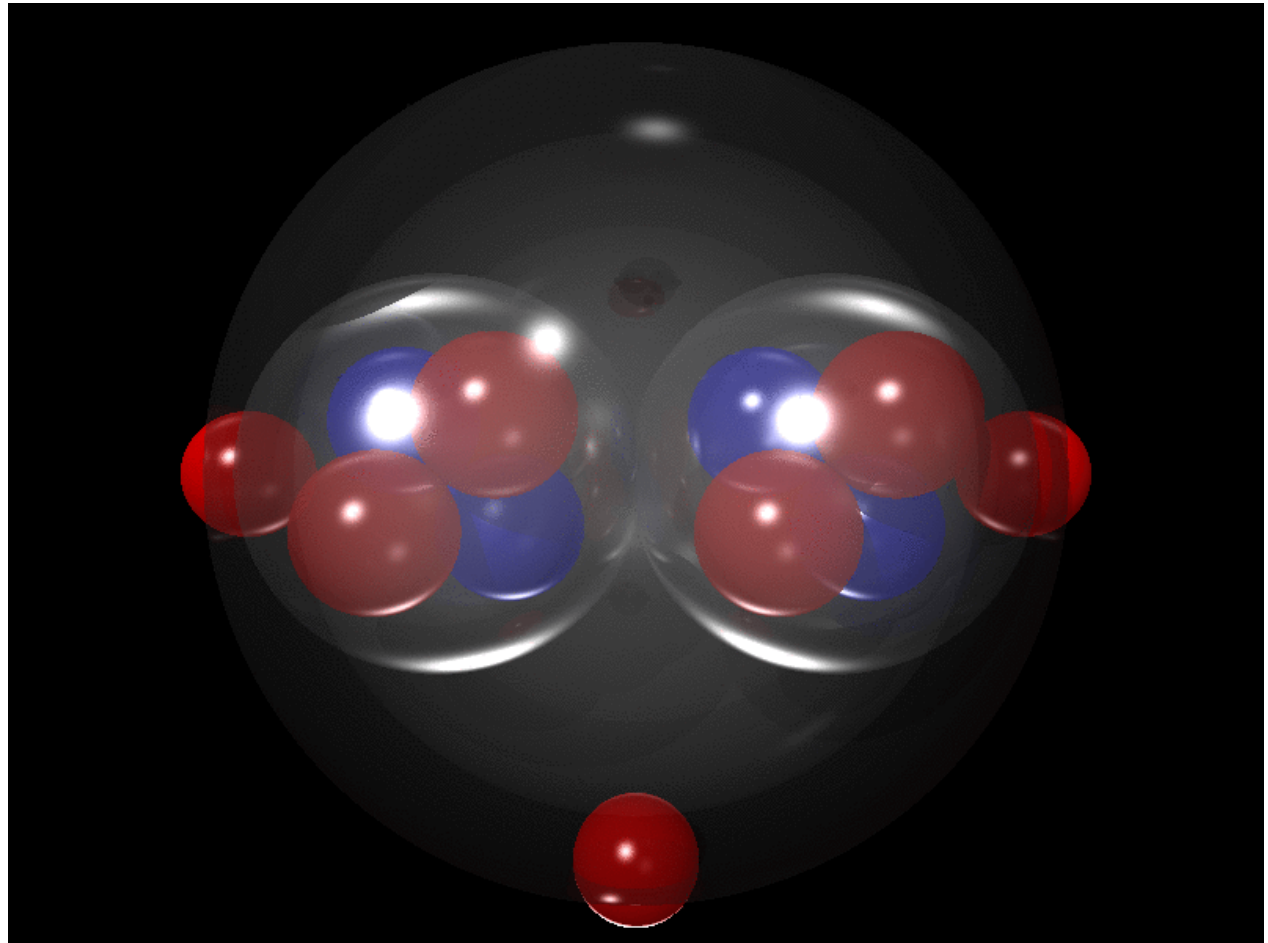
M. Freer → Importance of the clustering in the understanding of the structure of (light) nuclei

« Morceaux choisis » : Nuclear Structure

➤ Light and weakly bound systems

M. Freer → Importance of the clustering in the understanding of the structure of (light) nuclei

Example of
 $^{11}\text{Be} = \alpha\text{-}\alpha\text{-}3\text{n}$

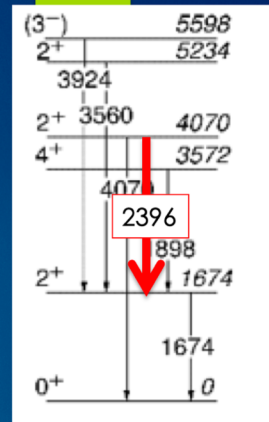
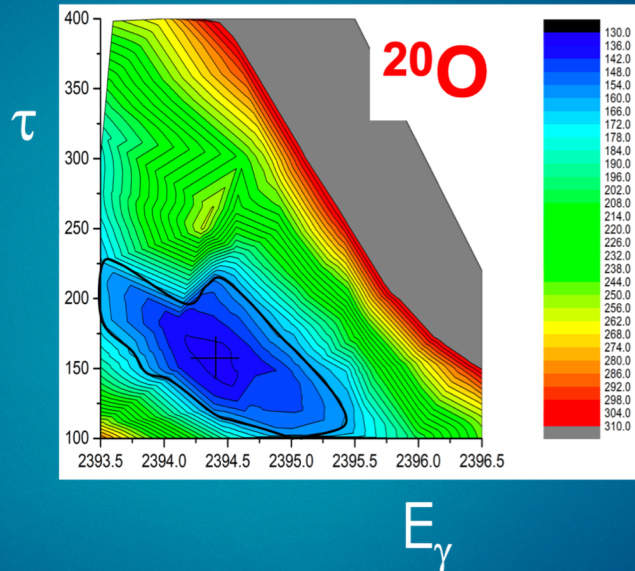
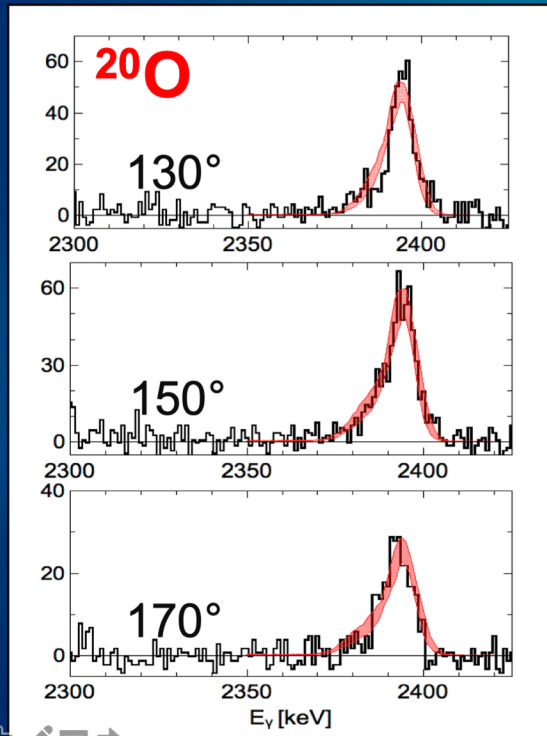


« Morceaux choisis » : Nuclear Structure

➤ Light and weakly bound systems

M. Ciemala → Lifetime measurements of excited states in neutron-rich C and O isotopes as a test of the three-body forces

^{18}O (7 MeV/A) + ^{181}Ta target (6 mg/cm²)



$$\tau = 150^{+80}_{-30} \text{ fs}$$

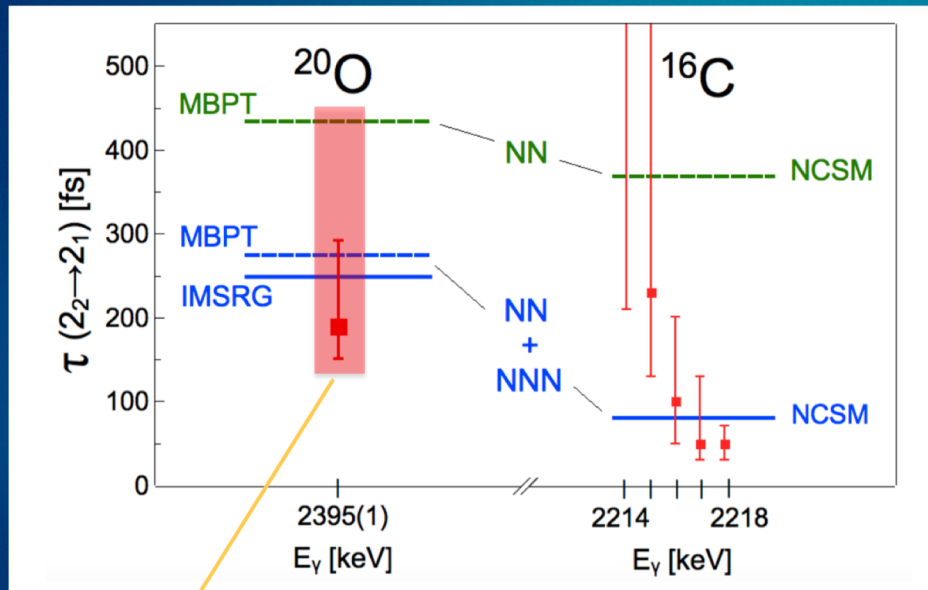
For $2_2 \rightarrow 2_1$ decay (79(5)% branching ratio),
partial $\tau = 190^{+102}_{-39} \text{ fs}$

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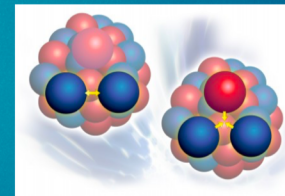
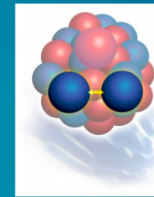
➤ Light and weakly bound systems

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Theory vs. exp. results comparison



NO sensitivity would be obtained with conventional HPGe detectors



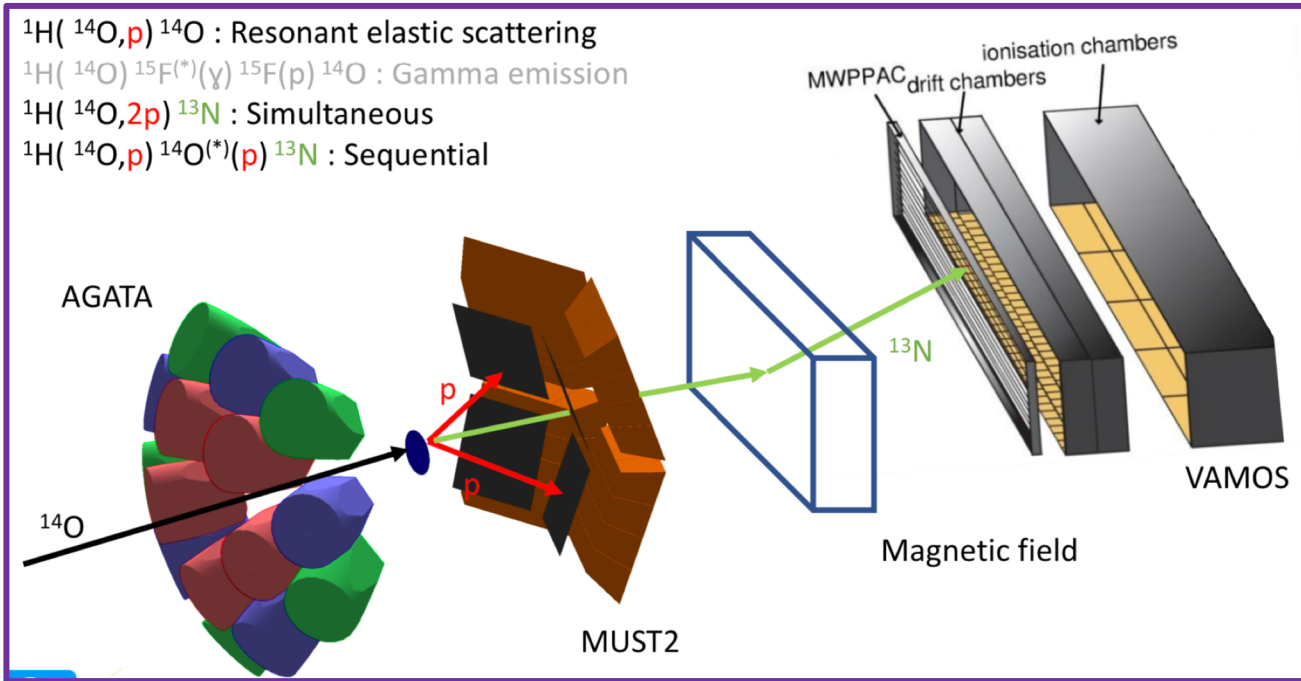
For ¹⁶C most precise measurement gives $E = 2217(2)$ keV, which do not allow to determine exact lifetime value (for now).

« Morceaux choisis » : Nuclear Structure

➤ Light and weakly bound systems

V. Alcindor → Above barrier narrow resonances in the unbound nucleus of ^{15}F

First experiment to combining a RIB (from S1) to AGATA-MUGAST/MUST2-VAMOS



« Morceaux choisis » : Nuclear Structure

➤ Light and weakly bound systems

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First experiment to combining a RIB (from S1) to AGATA-MUGAST/MUST2-VAMOS

1H(¹⁴O, p) ¹⁴O : Resonance
 1H(¹⁴O) ¹⁵F^(*)(γ) ¹⁵F(p)
 1H(¹⁴O, 2p) ¹³N : Simulation
 1H(¹⁴O, p) ¹⁴O^(*)(p) ¹³N

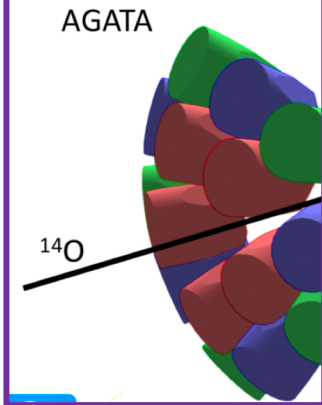
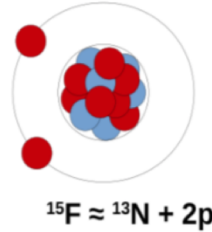
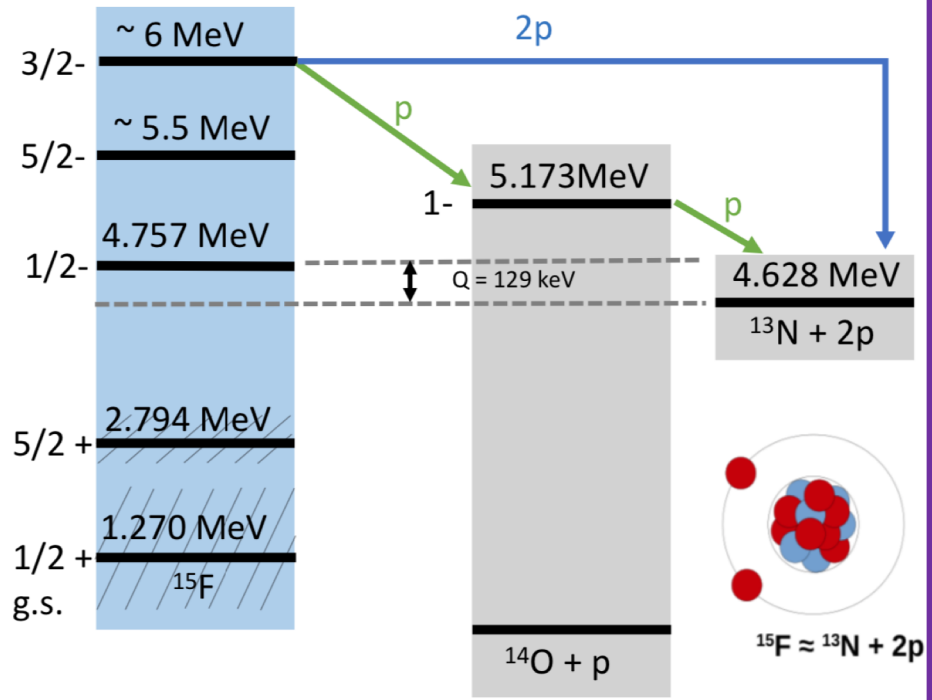
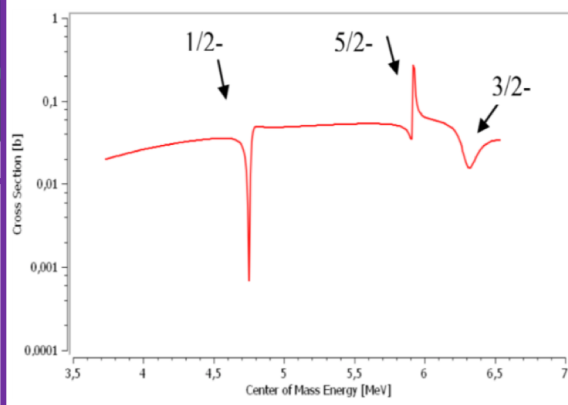


TABLE II. Energies (MeV) and widths (keV) in ¹⁵C and ¹⁵F.

J^π	¹⁵ C			¹⁵ F		
	E_x	Source	Γ	Source	E_p	Γ
1/2 ⁻	3.10	Ref. [1]	2	Ref. [1]	5.49	5
		Present	29(3)	Present	4.63	38
5/2 ⁻	4.22	Ref. [1]	2	Expt (Refs. [4,5])	4.9(2)	200(200)
		Present	Narrow	Present	6.88	10
				Expt (Refs. [4,5])	5.92	6
3/2 ⁻	4.66	Ref. [1]	90	Ref. [1]	7.25	40
		Present	176(15)	Present	6.30	350
				Expt (Refs. [4,5])	6.4(2)	200(200)

H. T. Fortune : Phys. Rev. C 83, 024311 (2011)



« Morceaux choisis » : Nuclear Structure

➤ Light and weakly bound systems

L. Lalanne → Study of ^{36}Ca : broken mirror and two proton decay



**the best presentation
from a PhD student**



« Morceaux choisis » : Nuclear Structure

➤ Light and weakly bound systems

L. Lalanne → Study of ^{36}Ca : broken mirror and two proton decay

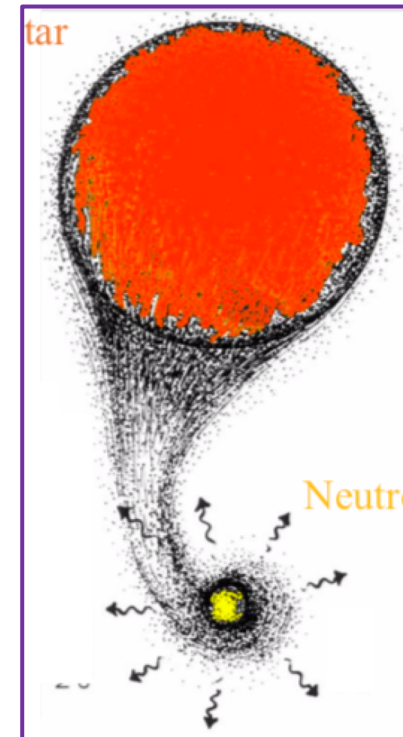
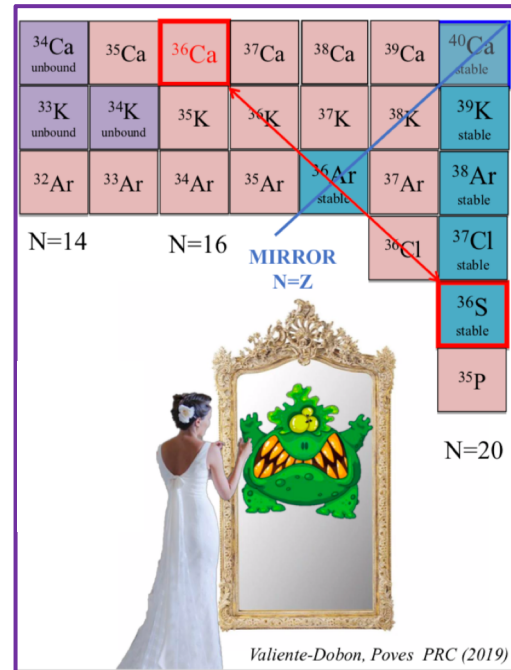
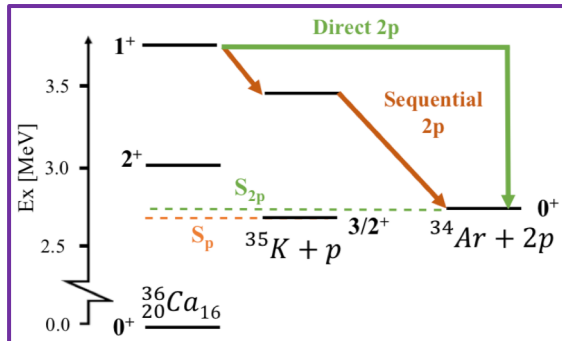


the best presentation
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several motivations

- study of the Isospin Symmetry Breaking
- X-ray burst / proton capture rate ^{35}K
- study of the 2p decay from the 1+ state



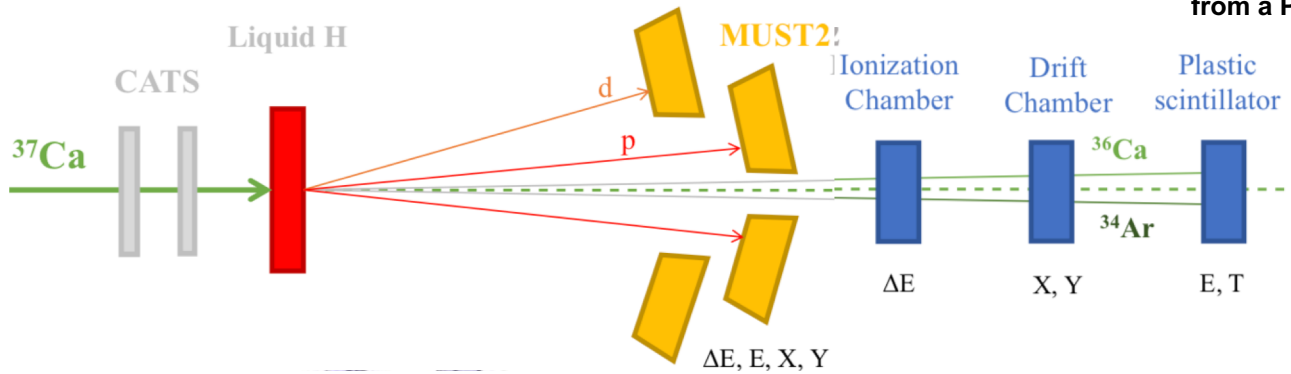
« Morceaux choisis » : Nuclear Structure

➤ Light and weakly bound systems

L. Lalanne → Study of ^{36}Ca : broken mirror and two proton



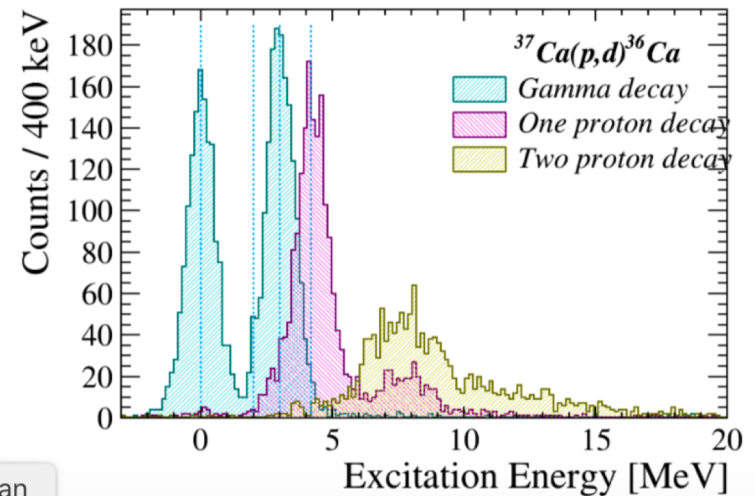
the best presentation
from a PhD student



Combining the fragmented beams of LISE produced at Fermi energies with powerful devices like :

- tracking detectors
- innovative targets
- charged particle arrays
- (gamma array)
- Zero Degree Detection (to be developed)

→ exciting perspectives for the next years



an

« Morceaux choisis » : Nuclear Structure

➤ Shell evolutions

A. Gade → Recent experimental studies of shell evolution in exotic nuclei

- Overview of recent highlights in Ca, Ni and Sn isotopes

→ need to combine the observables to really understand the evolution along isotopic/isotonic chains : example of Ca isotopes : charge radii, masses, gamma spectroscopy

- More detailed discussion on ^{42}Si , ^{70}Fe and ^{56}Ni

« Morceaux choisis » : Nuclear Structure

➤ Shell evolutions

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- More detailed discussion on ⁴²Si, ⁷⁰Fe and ⁵⁶Ni

Structure of ⁴²Si: A brief history experiment

■ Present-generation RIB facilities

• Beta-decay half-life of ⁴²Si and particle stability of ⁴³Si → *N*=28 broken down

S. Grevy *et al.*, PLB 594, 252 (2004)

M. Notani *et al.*, PLB 542, 49 (2002)

• Pronounced *Z*=14 sub-shell gap may prevent ⁴²Si from being deformed

J. Fridmann *et al.*, Nature 435, 922 (2005)

J. Fridmann *et al.*, PRC 74, 034313 (2006)

• Finally: 2⁺ at 770(19) keV demonstrates collectivity and breakdown of *N*=28

B. Bastin *et al.*, PRL 99, 022503 (2007)

■ New generation facility

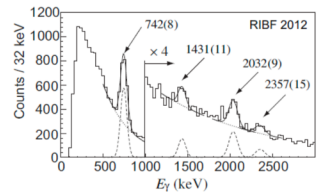
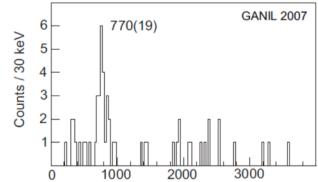
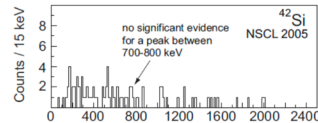
• First spectroscopy beyond the first 2⁺ state *R*_{4/2} ratio claimed to prove deformation

S. Takeuchi *et al.*, PRL 109, 182501 (2012)

■ At the frontier of experimentation

• Heaviest Si isotope known: ⁴⁴Si

• Lightest *N*=28 isotone: ⁴⁰Mg



A. Gade, Eur. Phys. J. A 51, 118 (2015)

Is the structure of ⁴²Si understood?

A. Gade,^{1,2} B. A. Brown,^{1,2} J. A. Tostevin,³ D. Bazin,^{1,2} P. C. Bender,^{1,*} C. M. Campbell,⁴ H. L. Crawford,⁴ B. Elman,^{1,2} K. W. Kemper,⁵ B. Longfellow,^{1,2} E. Lunderberg,^{1,2} D. Rhodes,^{1,2} and D. Weisshaar¹

¹National Superconducting Cyclotron Laboratory, Michigan State University, East Lansing, Michigan 48824, USA

²Department of Physics and Astronomy, Michigan State University, East Lansing, Michigan 48824, USA

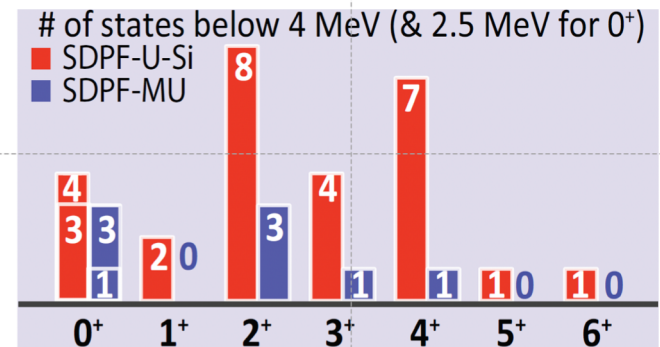
³Department of Physics, University of Surrey, Guildford, Surrey GU2 7XH, United Kingdom

⁴Nuclear Science Division, Lawrence Berkeley National Laboratory, California 94720, USA

⁵Department of Physics, Florida State University, Tallahassee, Florida 32306, USA

(Dated: April 23, 2019)

SDPF-U and SDPF-MU could not be more different!



« Morceaux choisis » : Nuclear Structure

- Shell evolutions : many results from lifetime measurements

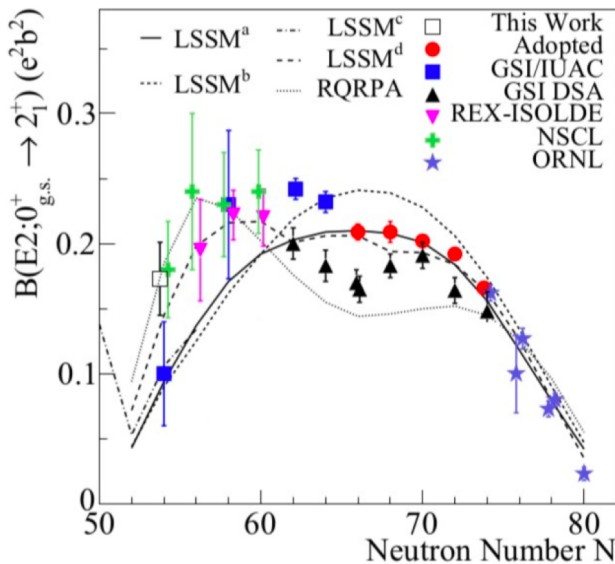
« Morceaux choisis » : Nuclear Structure

➤ Shell evolutions : many results from lifetime measurements

M. Siciliano → Nuclear structure of the semi-magic tin isotopes close to ¹⁰⁰Sn: Lifetime measurements of low-lying states in ¹⁰⁶Sn and ¹⁰⁸Sn decay



the best "GANIL" PhD work



P. Doornenbal et al., *Phys. Rev. C* 90 (2014) 061302R

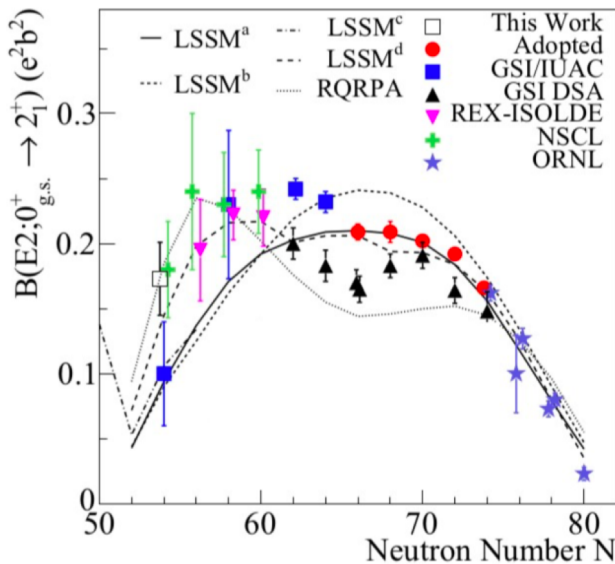
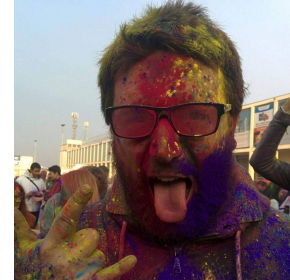
« Morceaux choisis » : Nuclear Structure

➤ Shell evolutions : many results from lifetime measurements

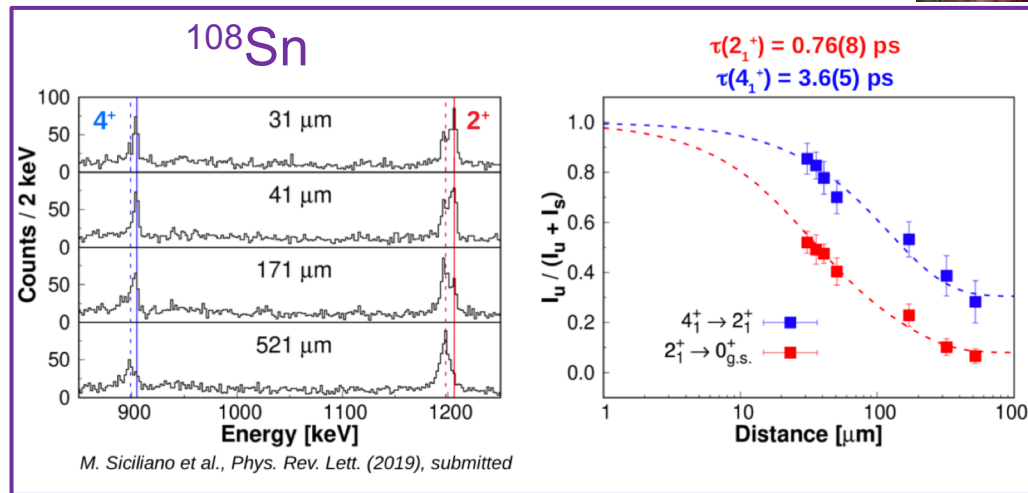
M. Siciliano → Nuclear structure of the semi-magic tin isotopes close to ¹⁰⁰Sn: Lifetime measurements of low-lying states in ¹⁰⁶Sn and ¹⁰⁸Sn decay



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PhD work

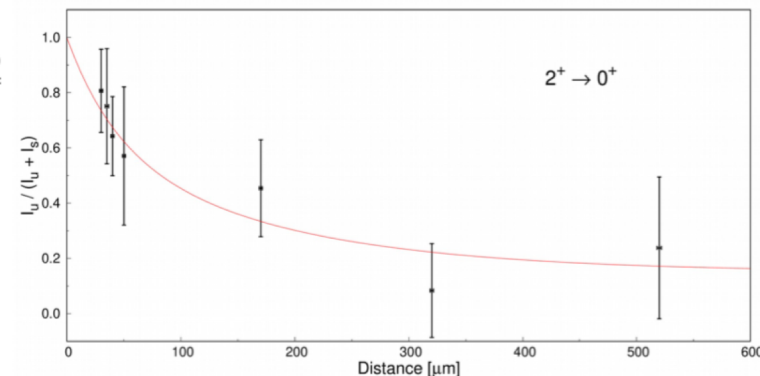


P. Doornenbal et al., *Phys. Rev. C* 90 (2014) 061302R



The statistics of ¹⁰⁶Sn allow to extract only the decay curve of 2⁺₁ → 0⁺_{g.s.} transition.

$\tau(2_1^+) = 1.2(7)$ ps
 $\tau(4_1^+) = 5.2(39)$ ps
¹⁰⁶Sn



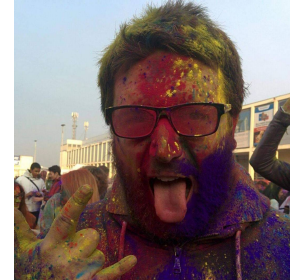
« Morceaux choisis » : Nuclear Structure

➤ Shell evolutions : many results from lifetime measurements

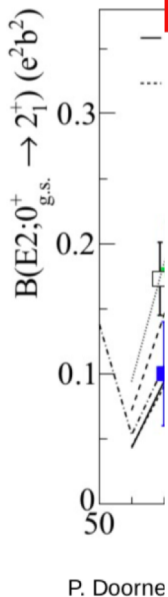
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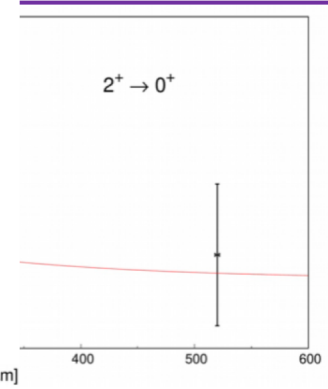
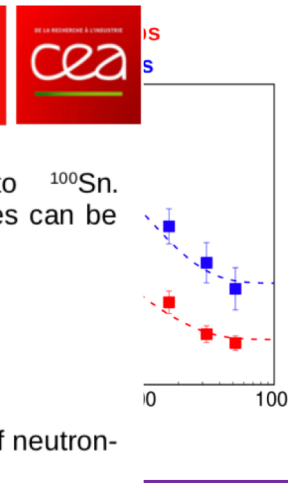


CONCLUSIONS



- Deep-inelastic collisions are a powerful tool for populating the region close to ¹⁰⁰Sn. Thanks to the direct population of the states, electromagnetic properties of the low-lying states can be investigated.
- For the very first time **the lifetime of the 2₁⁺ and 4₁⁺ states has been measured for ¹⁰⁶⁻¹⁰⁸Sn.**
- The extracted B(E2) values have been compared with LSSM calculations to explain the trend of neutron-deficient Sn isotopes.
 - Despite quadrupole force is reduced to its realistic value, the **B(E2; 2₁⁺ → 0_{g.s.}⁺) values are not affected by pairing** renormalization. Quadrupole correlations dominate.
 - The **B(E2; 4₁⁺ → 2₁⁺) values are sensitive** to the form of the nuclear interaction. The precise results in ¹⁰⁸Sn allow to firmly define the amount of pairing renormalization

The very precise measurements in ¹⁰⁸Sn have shown to open new perspectives in the understanding of the quadrupole-pairing interplay.

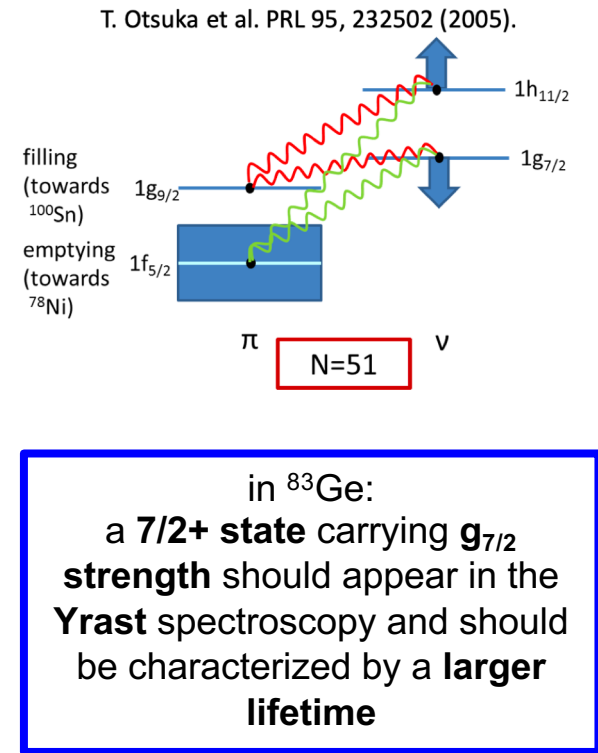
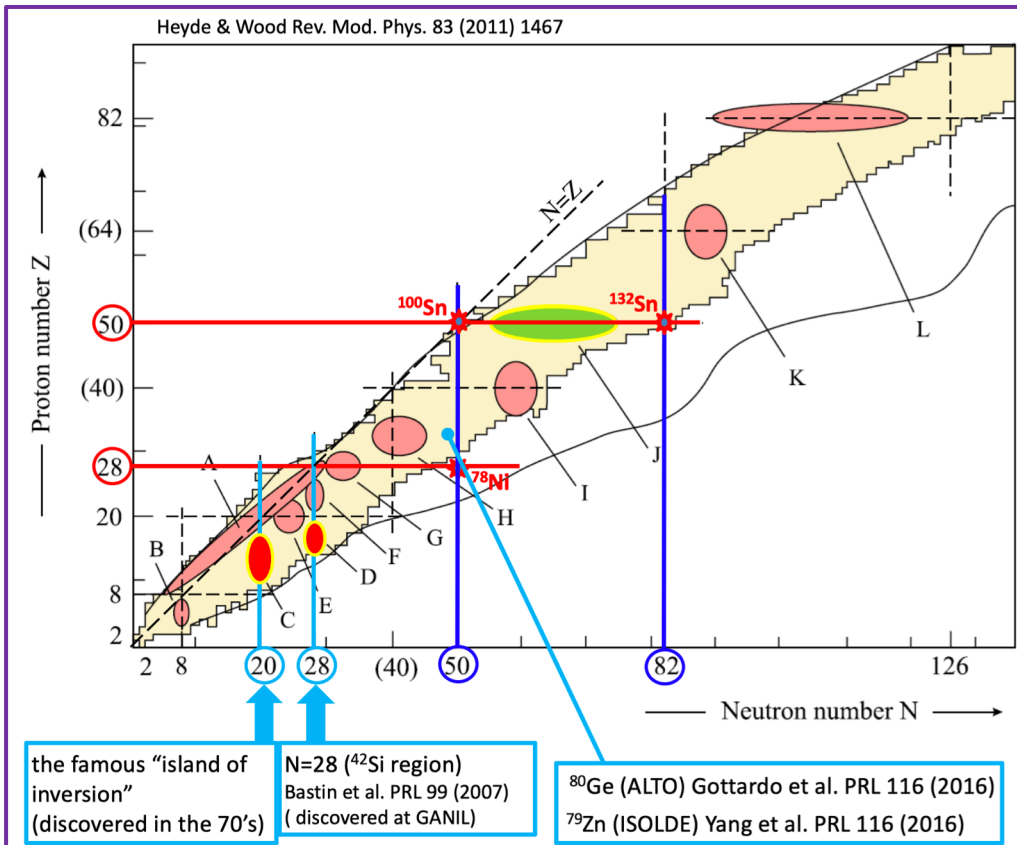


Distance [μm]

« Morceaux choisis » : Nuclear Structure

➤ Shell evolutions : many results from lifetime measurements

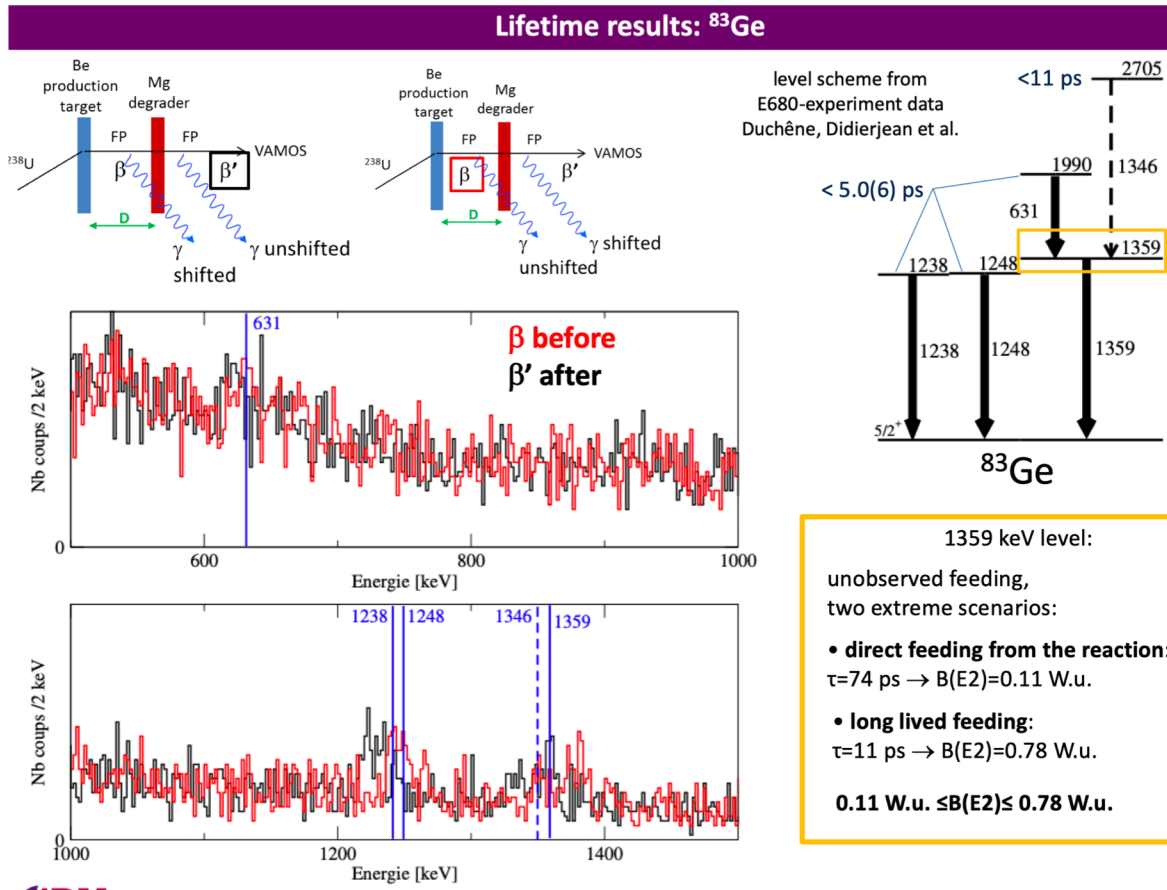
D. Verney → Shape coexistence in the ^{78}Ni region: additional evidence from lifetime measurements in light N=51 isotones with AGATA@VAMOS



« Morceaux choisis » : Nuclear Structure

➤ Shell evolutions : many results from lifetime measurements

D. Verney → Shape coexistence in the ⁷⁸Ni region: additional evidence from lifetime measurements in light N=51 isotones with AGATA@VAMOS



- No evidence for $7/2+$ of $g_{7/2}$ nature at low energy : tensor mechanism seems inactive

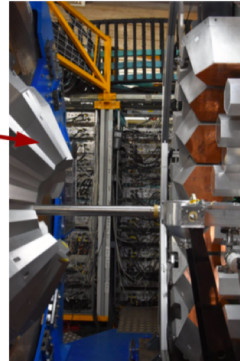
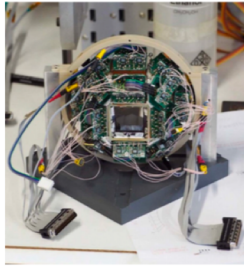
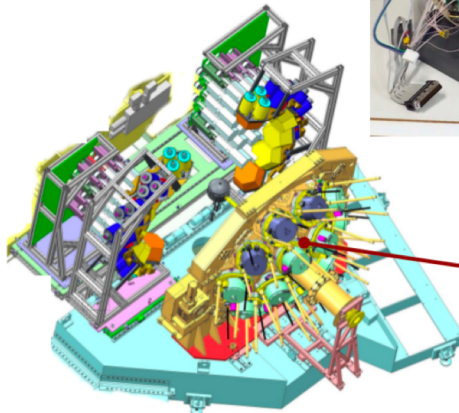
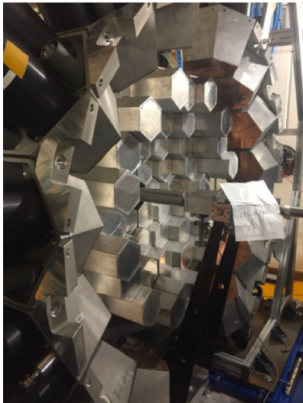
« Morceaux choisis » : Nuclear Structure

➤ Shell evolutions : many results from lifetime measurements

M. Jurado → Shell evolution of neutron-deficient Xe isotopes: Octupole and Quadrupole Correlations above ^{100}Sn

3.1. Experimental Setup: Detectors

- GANIL



CAD drawing of the experimental set-up. From the left to right, the different detectors are drawn: NEDA+NEUTRON WALL, DIAMANT (placed in the target chamber) and AGATA.

« Morceaux choisis » : Nuclear Structure

➤ Shell evolutions : many results from lifetime measurements

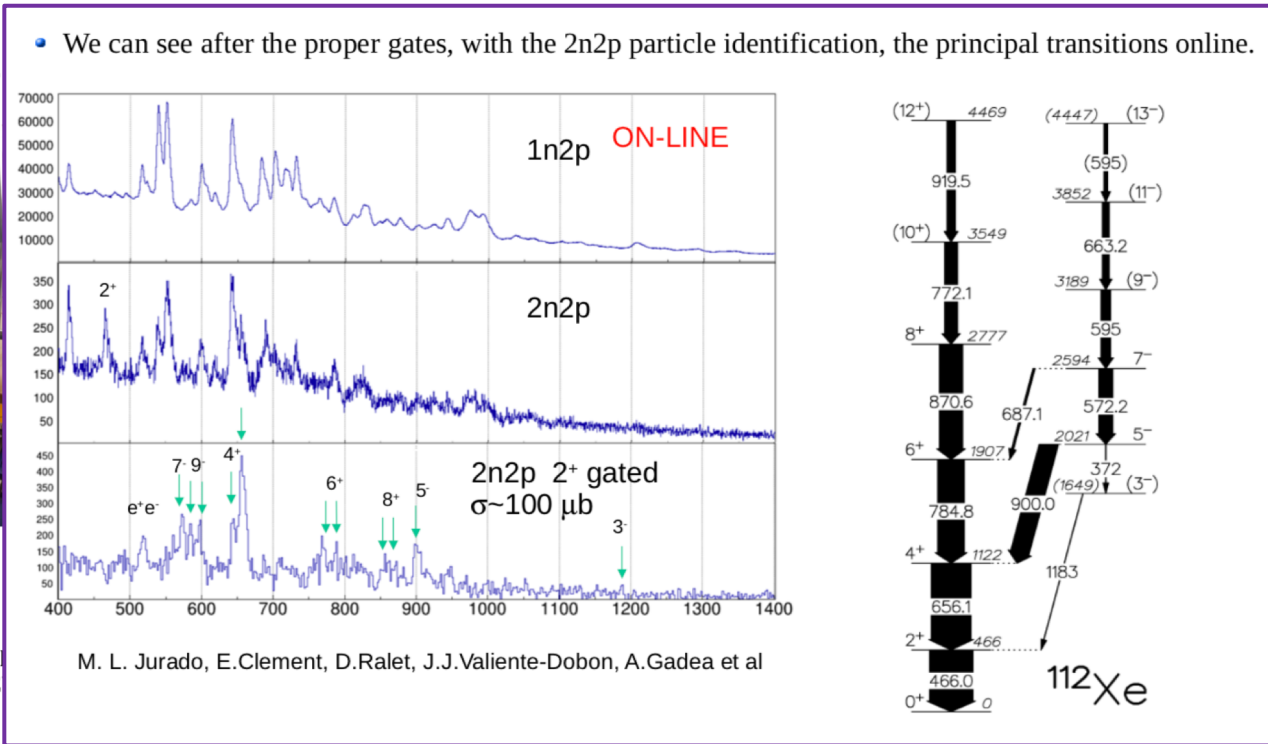
M. Jurado → Shell evolution of neutron-deficient Xe isotopes: Octupole and Quadrupole Correlations above ¹⁰⁰Sn

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CAD drawing of the NEDA+NE



« Morceaux choisis » : Nuclear Structure

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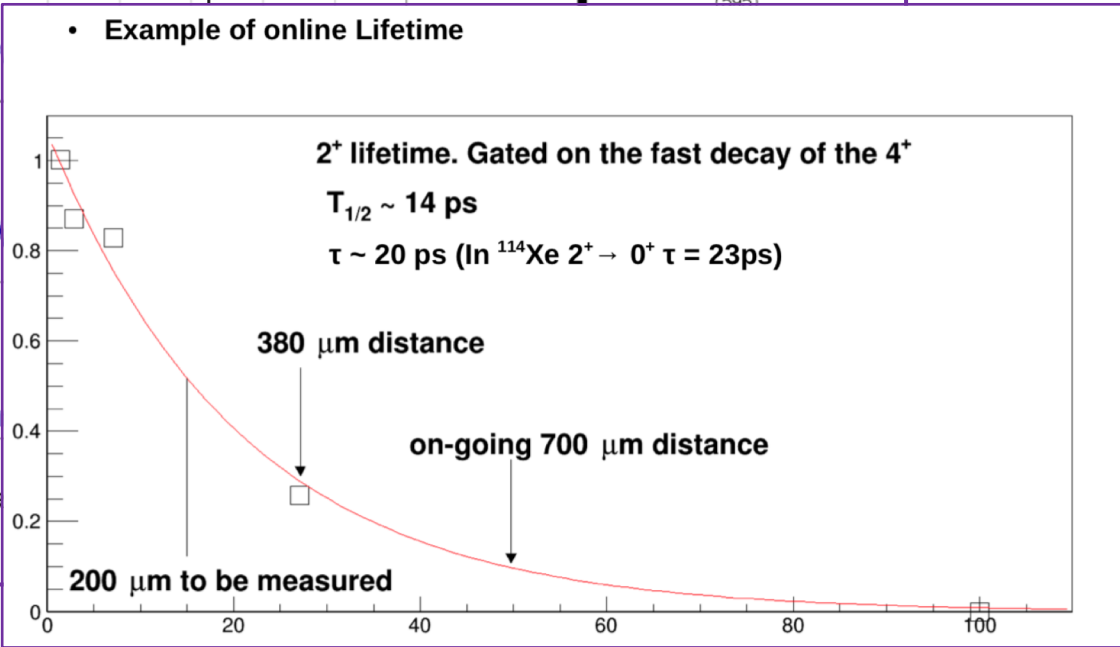
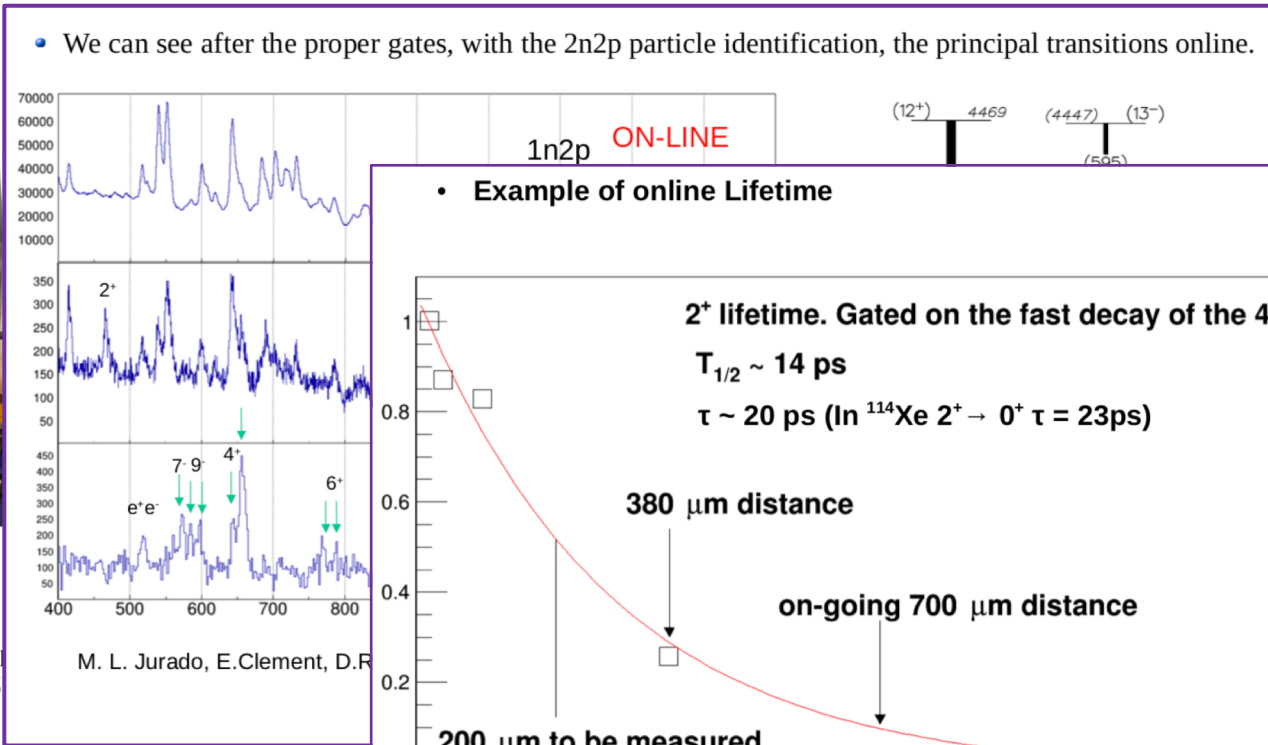
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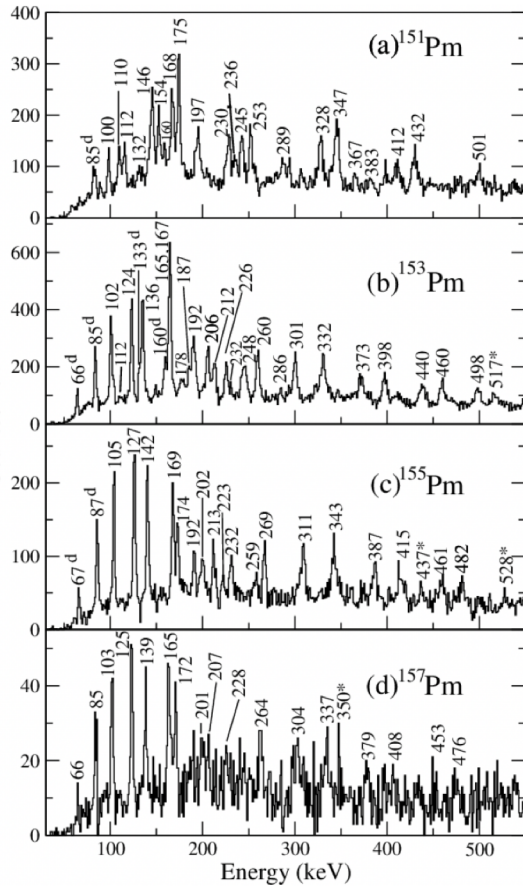


M. L. Jurado, E.Clement, D.R

« Morceaux choisis » : Nuclear Structure

➤ Shell evolutions : gamma spectroscopy

S. Bhattacharaya → Spectroscopy of isotopically identified neutron-rich Pm isotopes



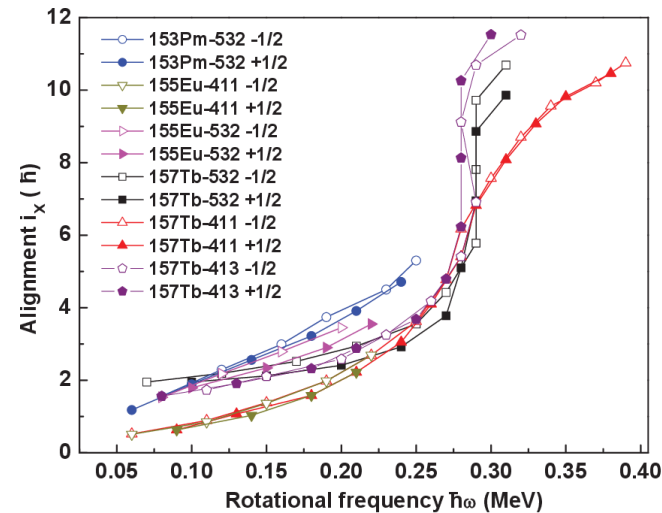
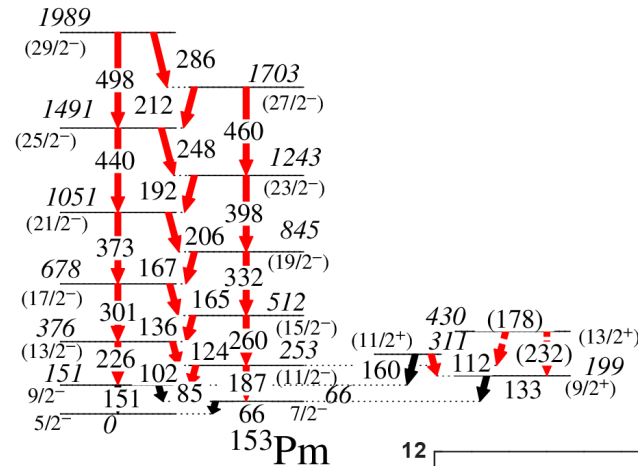
N/Z=1.47
N=90

N/Z=1.51
N=92

N/Z=1.54
N=94

N/Z=1.57
N=96

Fragment - γ coincidences
 obtained from
 VAMOS++ & EXOGAM from
²³⁸U + ⁹Be-induced fission



« Morceaux choisis » : Interdisciplinary researches and applications

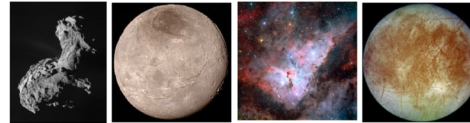
- Overview and prospects of interdisciplinary researches with GANIL ion beams
- I. Monnet

Interdisciplinary research

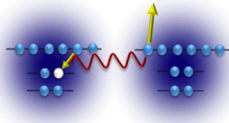
Dilute matter, molecules, clusters



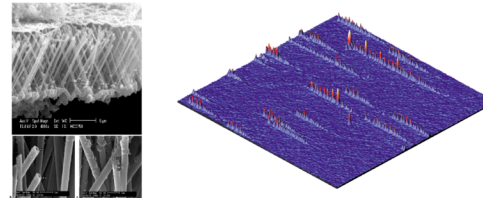
Radiochemistry, Astrophysics/chemistry



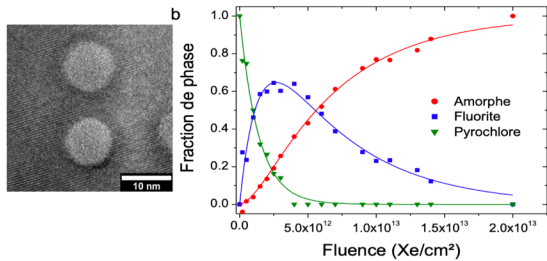
Atomic and plasma physics



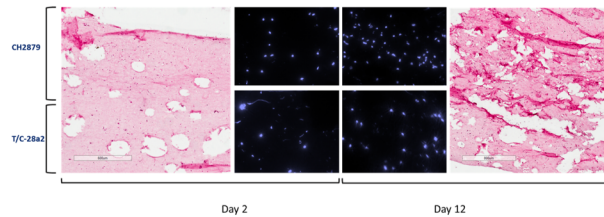
Nano structuration



Materials science



Radiobiology



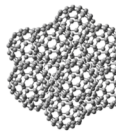
« Morceaux choisis » : Interdisciplinary researches and applications

➤ Overview and prospects of interdisciplinary researches with GANIL ion beams

I. Monnet

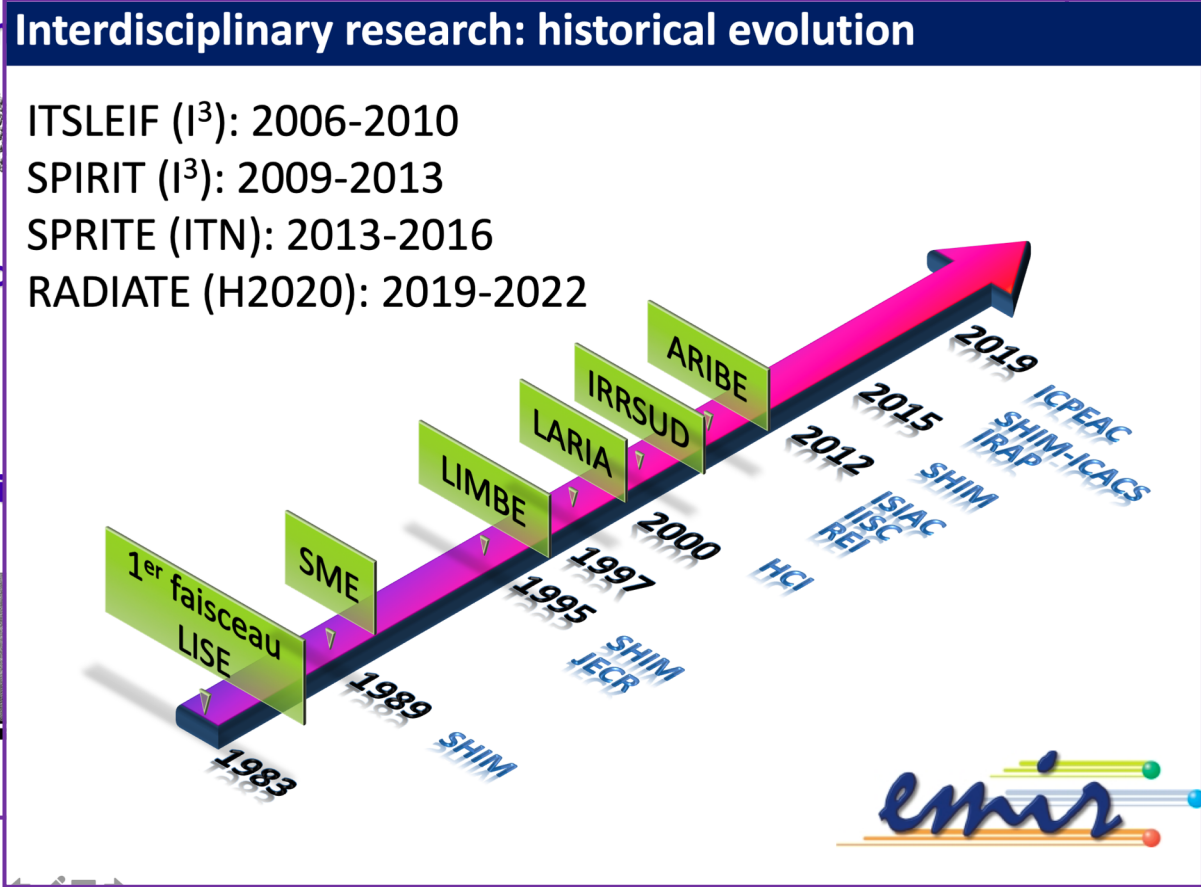
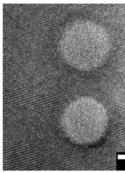
Interdisciplinary research

Dilute r



Atomic

Materi



« Morceaux choisis » : Interdisciplinary researches and applications

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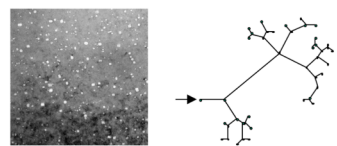
Interdisciplinary research

Dilute Interdisciplinary research: historical evolution

- ITSLEIF (I³): 2
 - SPIRIT (I³): 2
 - SPRITE (ITN)
 - RADIATE (H₂)
- Atomic
- Material

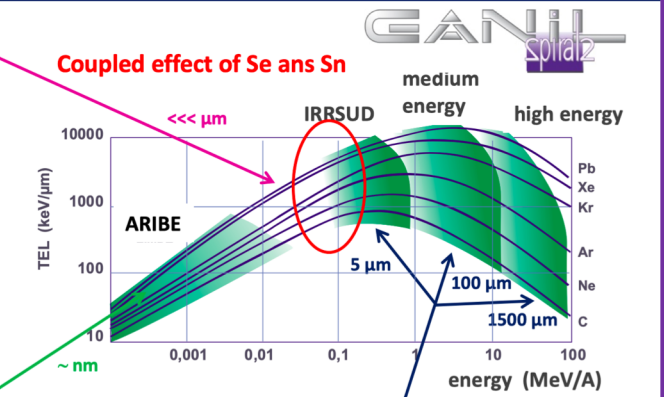
GANIL facility beamlines vs energy deposition regime

Nuclear energy loss



Frenkel pairs, Displacement cascades

>> Cavities, bubbles, dislocation loops, segregation, precipitation, amorphization, phase transitions

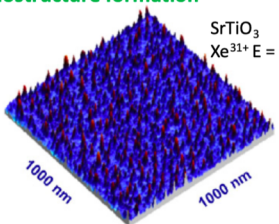


Potential energy deposition

Capture, decay, emission, sputtering

>> Nanostructure formation

SrTiO₃
Xe³¹⁺ E = 110 keV



7.6 nm
0.0 nm

1000 nm 1000 nm

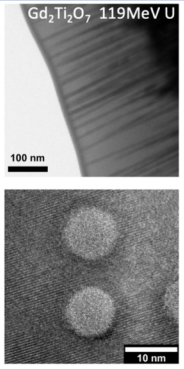
El Said et al, NIMB 269-1234(2011)
Aumayr et al, JPCPM 23-393001(2011)

Electronic energy loss

Defect formation by radiolysis

Collective effect: atomic motions by intense electronic excitations -> extended defects

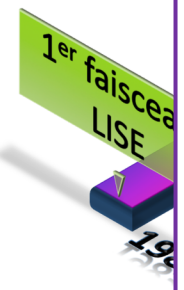
>> Track formation, disorder, phase transitions, surface nanostructures



Gd₂Ti₂O₇, 119MeV U

100 nm 10 nm

Sattonnay et al, Acta Mat 60-22 (2012)



« Morceaux choisis » : Interdisciplinary researches and applications

➤ Isotope production for medical applications : what can be done F. Haddad

Nuclear medicine needs radionuclides

- with different **decay radiations**:
 - imaging / therapy
 - short range High LET vs long range Low LET
- with different **Chemical properties**
- with different **Half-lives**: to match with vector distribution time in targeted therapy
- To be used for the Theranostics approach
 - pair of isotopes
- With an appropriate purity

Nuclear Physics can help by developing **efficient large scale** production of **high purity** radionuclides (innovative or not)

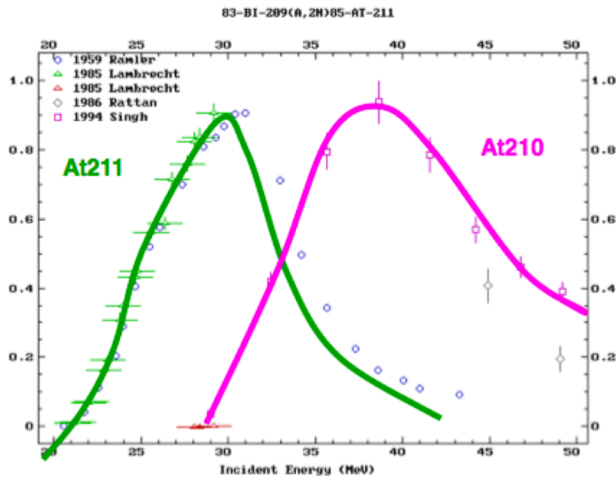
« Morceaux choisis » : Interdisciplinary researches and applications

➤ Isotope production for medical applications : what can be done F. Haddad

What can we do ?

High purity:

- ☐ Nuclear data
 - Allow to estimate production yield
 - Allow to define level of contaminants
 - Allow to adjust energy range of interest



Production route:



Energy range of interest:

[20 MeV - 28,3 MeV]

« Morceaux choisis » : Interdisciplinary researches and applications

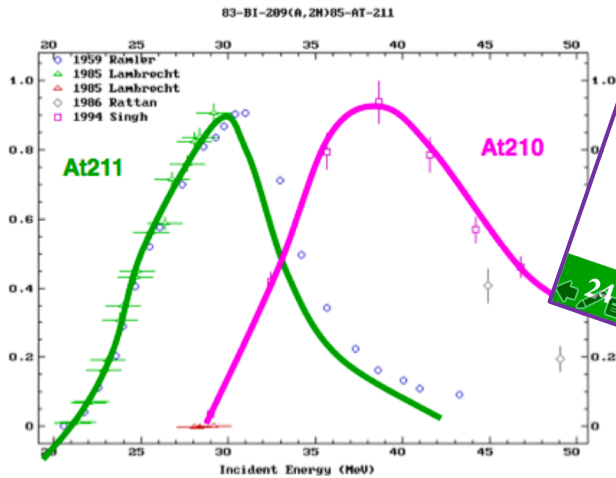
➤ Isotope production for medical applications : what can be done F. Haddad

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- Allow to adjust energy range of



ANR Repare (granted July 2019)

REPARE: research and developments for the Production of innovative radioelements

Partners: GANIL(Leader), Subatech, GIP Arronax, LDM-TEP, CERN

Duration : 4 years

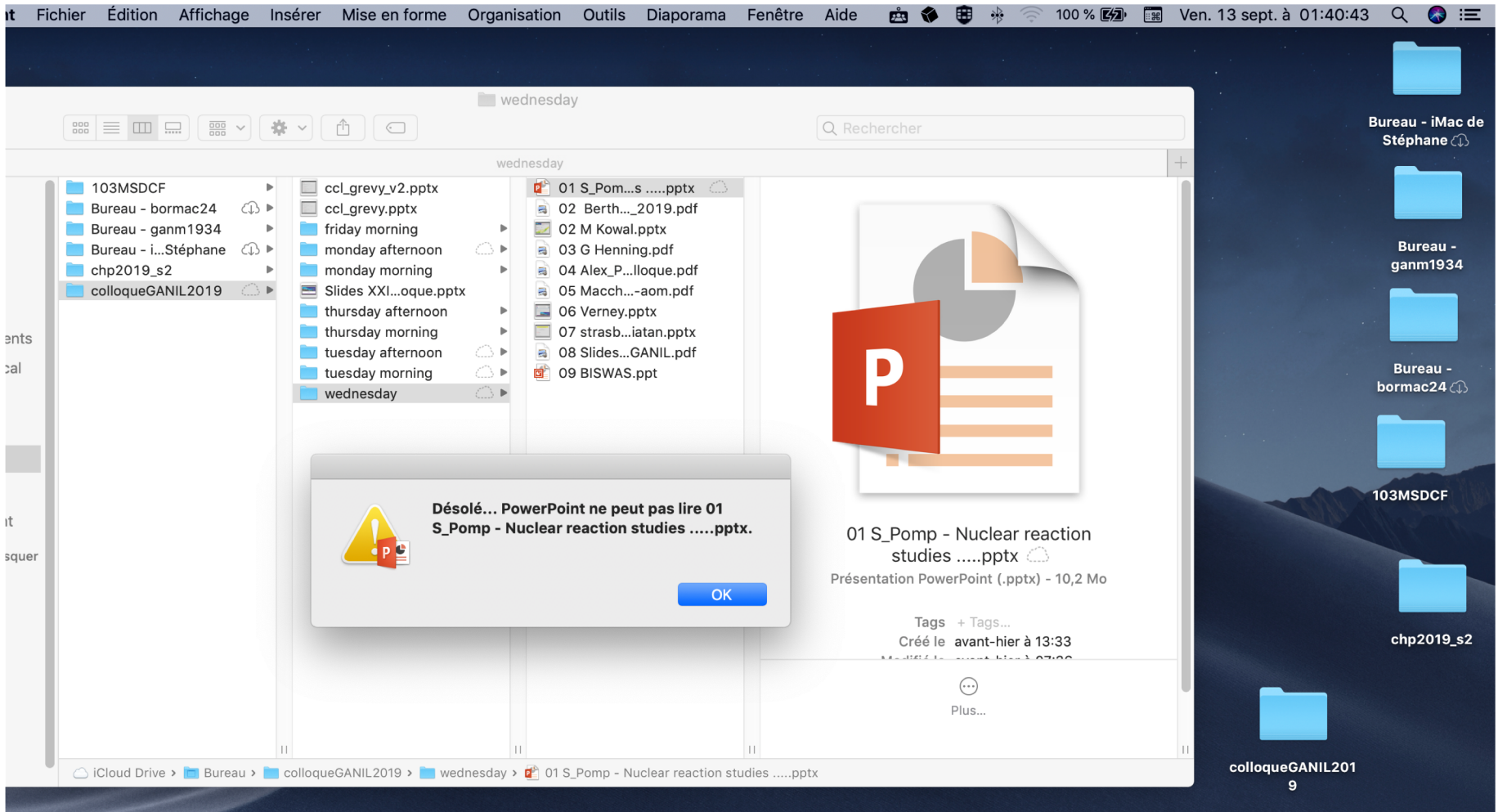
Production of Astatine-211

- Cross section measurements of alpha and lithium induced reaction on Bi and Pb
- Solid target technology
- Liquid target with on line extraction
- Indirect production $^{211}\text{Rn} \rightarrow ^{211}\text{At}$ using Li beam

[20 MeV

« Morceaux choisis » : Interdisciplinary researches and applications

➤ Nuclear reaction studies for improved nuclear data for science and technology S. Pomp



« Morceaux choisis » : Fundamental interactions

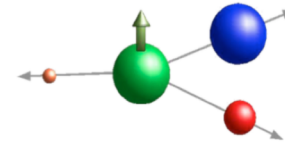
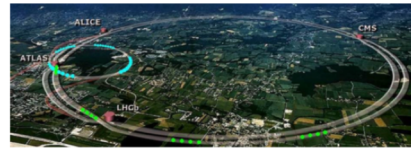
➤ How can nuclear physics put constraints on the standard model ?

The search for ‘New Physics’

Standard Model

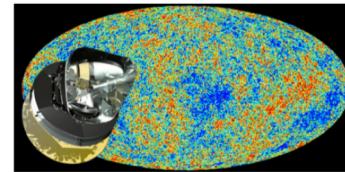
	I	II	III	
mass	2.4 MeV	1.27 GeV	171.2 GeV	0
charge	$\frac{2}{3}$	$\frac{2}{3}$	$\frac{2}{3}$	0
spin	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1
name	u up	c charm	t top	γ photon
				Higgs!
Quarks				
	4.8 MeV	104 MeV	42 GeV	0
	$-\frac{1}{3}$	$-\frac{1}{3}$	$-\frac{1}{3}$	0
	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1
	d down	s strange	b bottom	g gluon
	<2.2 eV	<0.17 MeV	<15.5 MeV	0
	0	0	0	0
	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1
	ν_e electron neutrino	ν_μ muon neutrino	ν_τ tau neutrino	Z weak force
Leptons				
	0.511 MeV	105.7 MeV	1.777 GeV	80.4 GeV
	-1	-1	-1	±1
	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1
	e electron	μ muon	τ tau	W weak force

NEW PHYSICS : a new theory that completes the SM and solves (at least some of) the current puzzles.



New Physics experimental searches...

- Energy frontier → LHC, ...
- Intensity frontier → Nuclear physics, muon, ...
- Cosmic frontier → Planck, ...



« Morceaux choisis » : Fundamental interactions

➤ How can nuclear physics put constraints on the standard model ?

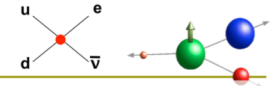
The search for ‘New Physics’

Standard Model

	I	II	III	
mass	2.4 MeV	1.27 GeV	171.2 GeV	0
charge	$\frac{2}{3}$	$\frac{2}{3}$	$\frac{2}{3}$	0
spin	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1
name	u up	c charm	t top	γ photon
				Higgs!
Quarks				
	4.8 MeV	104 MeV	42 GeV	0
	$-\frac{1}{3}$	$-\frac{1}{3}$	$-\frac{1}{3}$	0
	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1
	d down	s strange	b bottom	g gluon
	<2.2 eV	<0.17 MeV	<15.5 MeV	0
	0	0	0	1
	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	0
	ν_e electron neutrino	ν_μ muon neutrino	ν_τ tau neutrino	Z weak force
Leptons				
	0.511 MeV	105.7 MeV	1.777 GeV	80.4 GeV
	-1	-1	-1	±1
	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1
	e electron	μ muon	τ tau	W weak force
				Bosons (Forces)

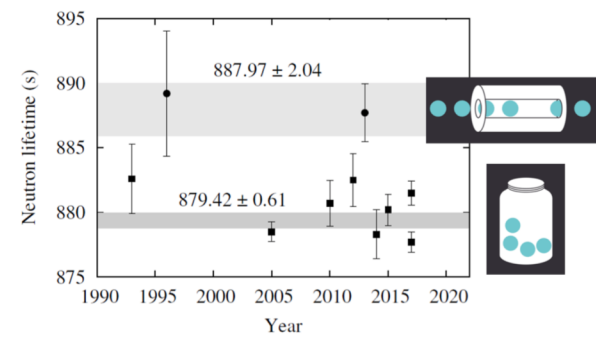
NEW PHYSICS : a new theory that completes the SM and solves (at least some of) the current puzzles.

Probing the Fierz term



Heavy NP cannot explain the beam vs. bottle tension

... Light NP?
[Fornal & Grinstein PRL (120 (2018))]



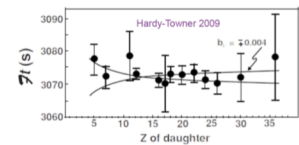
New Physics experimental searches

- Energy frontier → LHC
- Intensity frontier → Nucl
- Cosmic frontier → Planck

✓ Indirect effect in the Ft-values & neutron lifetime:



$$\delta\tau_n, \delta Ft \sim -b \left\langle \frac{m_e}{E_e} \right\rangle$$



« Morceaux choisis » : Fundamental interactions

➤ How can nuclear physics put constraints on the standard model ?

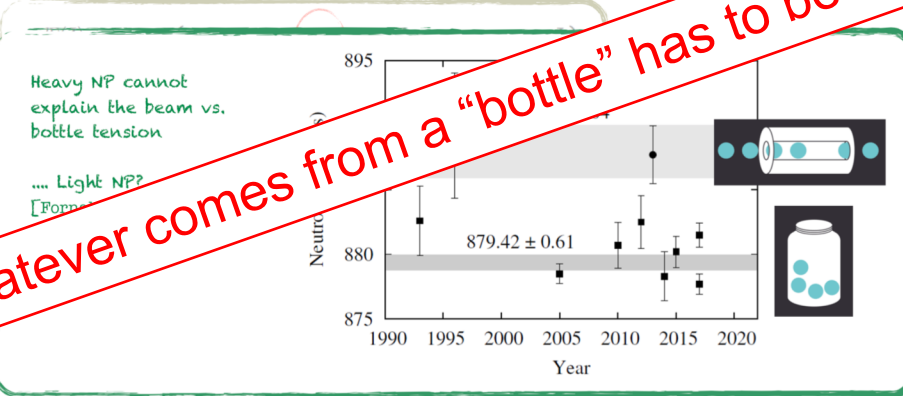
The search for ‘New Physics’

Standard Model

	I	II	III	
mass	2.4 MeV	1.27 GeV	171.2 GeV	0
charge	2/3	2/3	2/3	0
spin	1/2	1/2	1/2	1
name	u up	c charm	t top	γ photon
				g gluon
Quarks				
	4.8 MeV	104 MeV	42 GeV	0
	-1/3	-1/3	-1/3	0
	1/2	1/2	1/2	1
	d down	s strange	b bottom	Z weak force
				W weak force
				Higgs!
	<2.2 eV	<0.17 MeV	<15.5 MeV	0
	0	0	0	1
	1/2	1/2	1/2	1
	ν_e electron neutrino	ν_μ muon neutrino	ν_τ tau neutrino	Z weak force
				W weak force
Leptons				
	0.511 MeV	105.7 MeV	1.777 GeV	80.4 GeV
	-1	-1	-1	1
	1/2	1/2	1/2	2
	e electron	μ muon	τ tau	W weak force
				W weak force

NEW PHYSICS : a new theory that completes the SM and solves (at least some of) the current puzzles.

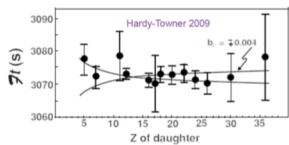
Probing the Fierz term



✓ Indirect effect in the Ft-values & neutron lifetime:



$$\delta\tau_n, \delta Ft \sim -b \left\langle \frac{m_e}{E_e} \right\rangle$$



New Physics experimental searches

- Energy frontier → High Energy
- Intensity frontier → Nuclear
- Cosmic frontier → Planck

« Morceaux choisis » : Fundamental interactions

➤ How can nuclear physics put constraints on the standard model ?

The search for 'New Physics'

Standard Model

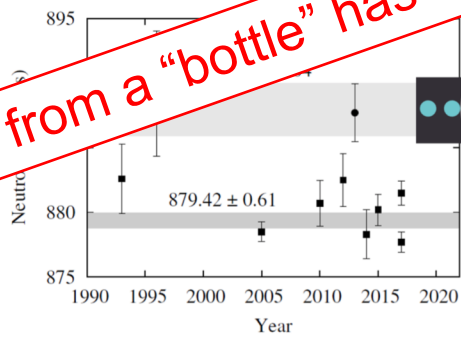
	I	II	III	
mass	2.4 MeV	1.27 GeV	171.2 GeV	0
charge	$\frac{2}{3}$	$\frac{2}{3}$	$\frac{2}{3}$	0
spin	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1
name	u up	c charm	t top	γ photon
				g gluon
Quarks	d down	s strange	b bottom	Z weak force
	ν_e electron neutrino	ν_μ muon neutrino	ν_τ tau neutrino	W weak force
Leptons	e electron	μ muon	τ tau	

+ Higgs!
Bosons (Forces)

NEW PHYSICS : a new theory that completes the SM and solves (at least some of) the current puzzles.

Probing the Fierz term

Heavy NP cannot explain the beam vs. bottle tension
... Light NP? [Fierz]



Whatever comes from a "bottle" has to be correct

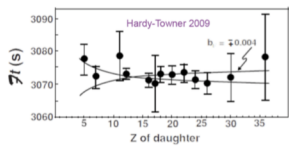
New Physics experimental sectors

- Energy frontier → IHEP
- Intensity frontier → JLab
- Cosmic frontier → Planck

✓ Indirect effect in the Ft-values & neutron lifetime:



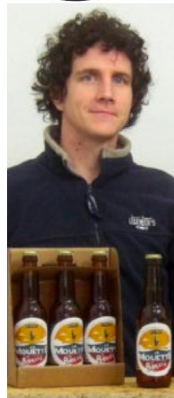
$$\delta\tau_n, \delta Ft \sim -b \left\langle \frac{m_e}{E_e} \right\rangle$$



M. González-Alonso

Cap

Capture d'écran

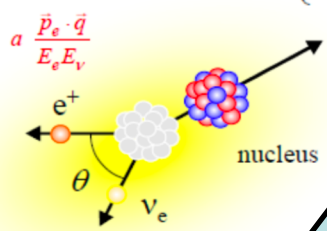


« Morceaux choisis » : Fundamental interactions

- How can nuclear physics put constraints on the standard model ?

$$\omega \langle \langle \bar{J} \rangle \rangle | E_e, \Omega_e, \Omega_\nu \rangle dE_e d\Omega_e d\Omega_\nu \propto \frac{F(\pm Z, E_e)}{\text{Fermi function}} \frac{p_e E_e (E_0 - E_e)^2 dE_e d\Omega_e d\Omega_\nu}{\text{phase space}}$$

x $\xi \left\{ 1 + a \frac{\vec{p}_e \cdot \vec{q}}{E_e E_\nu} + b \frac{\gamma m_e}{E_e} + A \frac{\vec{J} \cdot \vec{p}_e}{J E_e} + D \frac{\vec{J} \cdot (\vec{p}_e \times \vec{q})}{J (E_e E_\nu)} \right\}$



$a \frac{\vec{p}_e \cdot \vec{q}}{E_e E_\nu}$

e^+

ν_e

θ

nucleus

β -v correlation

Fierz interference term
($b = 0$ in standard model)

β -asymmetry

D-correlation

on, S.B. Treiman, H.W. Wyld, Nucl. Phys. 4 (1957) 206

LPCTrap & WISArD

Mora

« Morceaux choisis » : Fundamental interactions

➤ How can nuclear physics put constraints on the standard model ?

$$\omega \langle \langle \bar{J} \rangle \rangle | E_e, \Omega_e, \Omega_\nu \rangle dE_e d\Omega_e d\Omega_\nu \propto \frac{F(\pm Z, E_e)}{\text{Fermi function}} \frac{p_e E_e (E_0 - E_e)^2 dE_e d\Omega_e d\Omega_\nu}{\text{phase space}}$$

x $\xi \left\{ 1 + a \frac{\vec{p}_e \cdot \vec{q}}{E_e E_\nu} + b \frac{\gamma m_e}{E_e} + A \frac{\vec{J} \cdot \vec{p}_e}{J E_e} + D \frac{\vec{J} \cdot (\vec{p}_e \times \vec{q})}{J (E_e E_\nu)} \right\}$

$a \frac{\vec{p}_e \cdot \vec{q}}{E_e E_\nu}$

β - ν correlation

Fierz interference term
($b = 0$ in standard model)

β -asymmetry

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on, S.B. Treiman, H.W. Wyld, Nucl. Phys. 4 (1957) 206

LPCTrap & WISArD

Weak interaction studies in ³²Ar Decay
 X. Flechard

Mora


Search for CP violation in nuclear b-decays
 E. Lienard

« Morceaux choisis » : Fundamental interactions

➤ How can nuclear physics put constraints on the standard model ?

Search for CP violation in nuclear b-decays : MORA E. Liénard

MORA: perspectives



	Trapped ions/cycle	Data taking (days)	Num. of events (<i>P</i>)	σ_P (%)	Num. of coinc. (<i>D</i>)	Sensitivity on <i>D</i>		
from 2021	JYFL: <i>P</i>	2.0×10^4	8	1.7×10^5	1.9	1.5×10^6	1.0×10^{-3}	
	JYFL: <i>D</i>	2.0×10^4	32	6.7×10^5	0.94	6.1×10^6	5.2×10^{-4}	☑
from 2025?	DESIR: <i>D</i>	1.0×10^6	24	2.5×10^7	0.15	2.3×10^8	8.5×10^{-5}	☑
	DESIR: <i>D</i>	5.0×10^6	24	1.3×10^8	0.07	1.2×10^9	3.8×10^{-5}	

with optimal trapping

- ☑ best precision in nuclear beta decay (i.e. compared to ^{19}Ne)
- ☑ best precision (i.e. compared to *n*) – constraint on D_{FSI} ($\sim 1.2 \times 10^{-4}$)? (DESIR/SPIRAL1: $I(^{23}\text{Mg}) > 10^8$ pps)


Next candidate: ^{39}Ca ?

{

→ better sensitivity to NP ($D_{FSI} \sim -3 \times 10^{-5}$)


→ production? *perspectives@S³* ($> 10^6$ pps?) ...

MORA is funded by



RÉGION
NORMANDIE

&

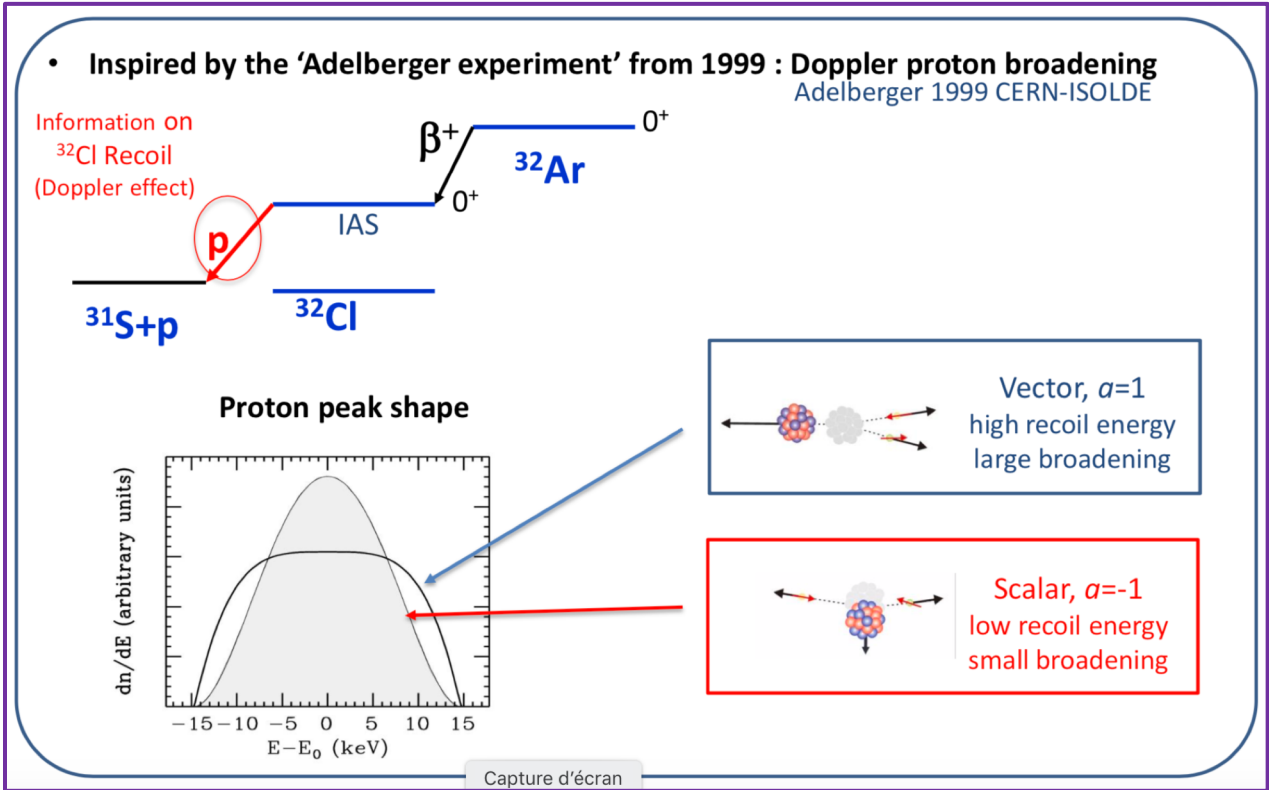


ANR

« Morceaux choisis » : Fundamental interactions

➤ How can nuclear physics put constraints on the standard model ?

WISArD : Weak interaction studies in ^{32}Ar Decay. X. Flechard



Experiment @ ISOLDE

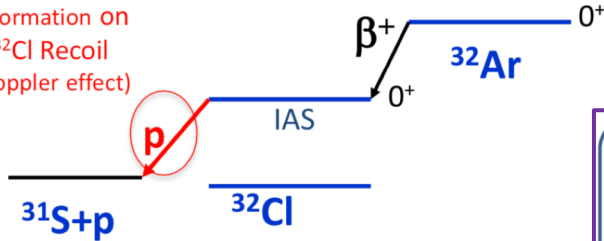
« Morceaux choisis » : Fundamental interactions

➤ How can nuclear physics put constraints on the standard model ?

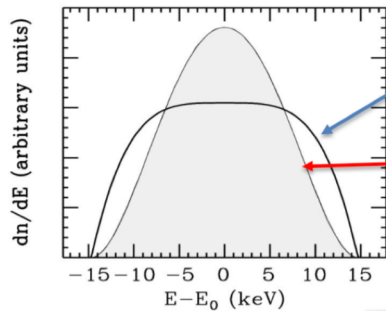
WISArD : Weak interaction studies in ³²Ar Decay. X. Flechard

- Inspired by the 'Adelberger experiment' from 1999 : Doppler proton broadening
 Adelberger 1999 CERN-ISOLDE

Information on
³²Cl Recoil
 (Doppler effect)



Proton peak shape

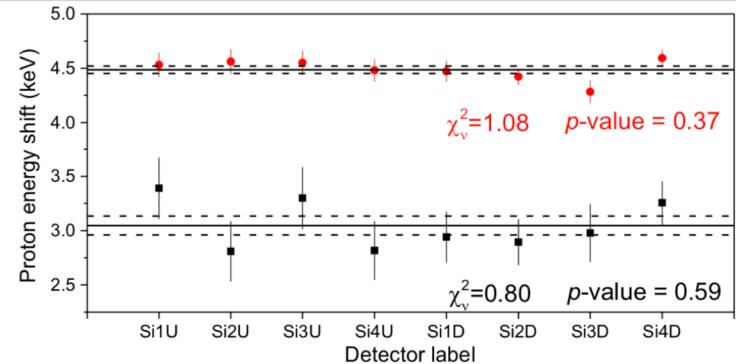


Capture d'écran

$$\Delta E = |\bar{E}_{coinc} - \bar{E}_{single}|$$

Fermi (IAS): 4.49(3) keV

GT: 3.05(9) keV



- Extraction of \tilde{a} : MC simulation (GEANT4 for β^+ & $pstar$ for protons)

- with decay involving different values of a (-1, -1/3, 0, 1/3, 1)

$$\rightarrow \tilde{a} = \alpha \times E_{\text{shift}} + \text{Cst}$$

- varying instrumental parameters in MC \rightarrow Systematic errors estimation

$$\tilde{a}_{\beta\nu}^F = 1.01(3)_{\text{(stat)}}(2)_{\text{(syst)}}$$

$$\tilde{a}_{\beta\nu}^{\text{GT}} = -0.22(9)_{\text{(stat)}}(2)_{\text{(syst)}}$$

V. Araujo-Escalona et al., submitted to PRL, arXiv:1906.05135 [nucl-ex]

Experiment @ ISOLDE

\rightarrow Perspectives @ DESIR

« Morceaux choisis » : Super Heavy Nuclei

➤ Spectroscopy of heavy elements measured with GABRIELA at the FLNR, Dubna

K. Hauschild

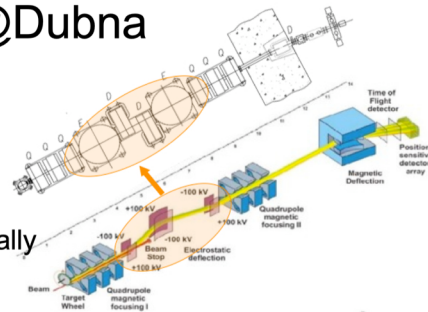


SHELS@Dubna

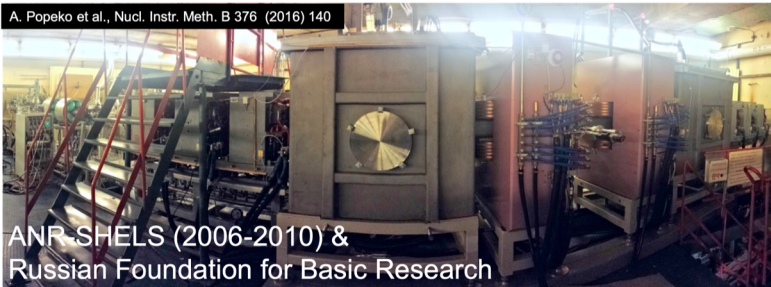
& RFBR

VASSILISSA (Energy filter)
→ SHELS (velocity filter)

Gain in transmission, especially
for asymmetric reactions



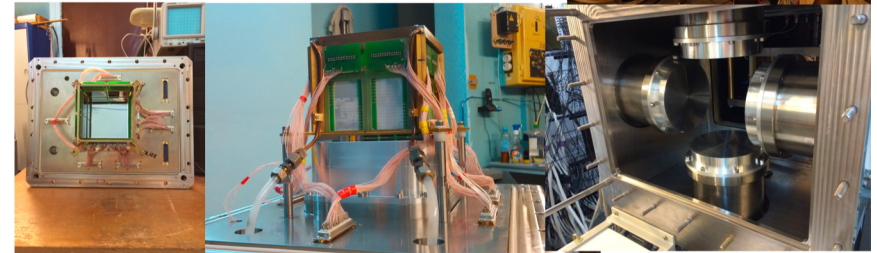
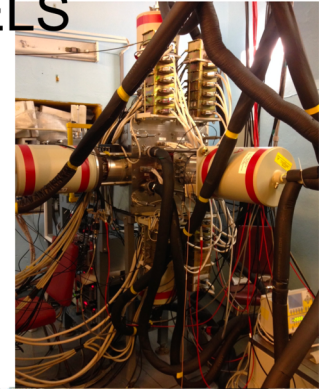
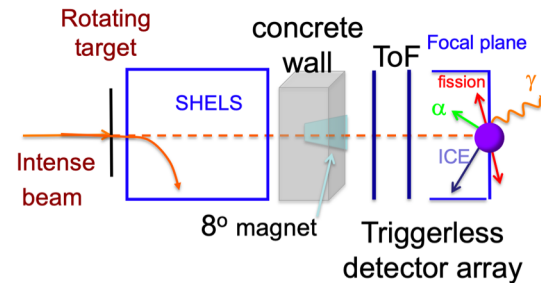
A. Popeko et al., Nucl. Instr. Meth. B 376 (2016) 140



ANR-SHELS (2006-2010) &
Russian Foundation for Basic Research

ANR GABRIELA@SHELS

ANR-CLODETTE (2013-2017) & RFBR



several results presented

- Mapping single particle levels around N=152 gap
- K-isomers : - probing s-p structure
- Enhanced stability wrt fission
- pxn reactions : access to heavier SHE?

« Morceaux choisis » : Super Heavy Nuclei

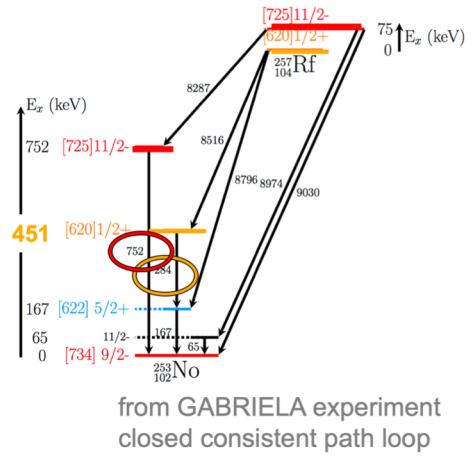
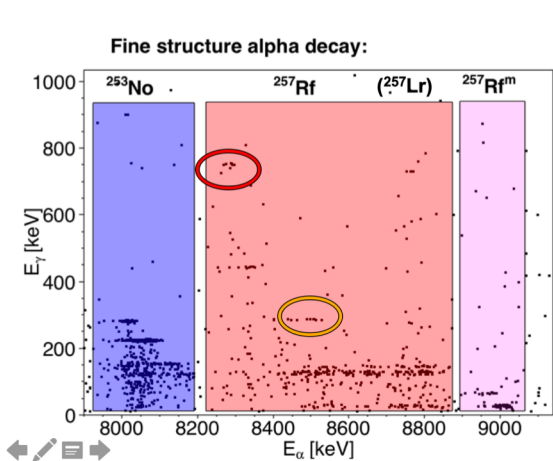
➤ Spectroscopy of heavy elements measured with GABRIELA at the FLNR, Dubna

K. Hauschild

Probing the N=152 at Z=102

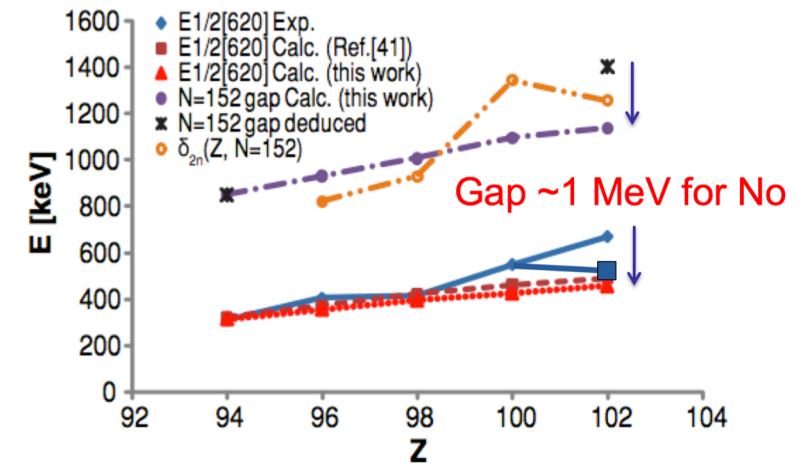
- Excited states in ^{253}No
 - populated via α decay of ^{257}Rf
 - $^{208}\text{Pb}(^{50}\text{Ti}, 1n)^{257}\text{Rf}$: $\sigma \sim 10$ nb

PROTONS		NEUTRONS	
$f_{5/2}$	$1/2^- [521]$	$j_{15/2}$	$11/2^- [725]$
$i_{13/2}$	$7/2^+ [633]$	$d_{5/2}$	$3/2^+ [622]$
$f_{7/2}$	$3/2^- [521]$	$g_{9/2}$	$7/2^+ [613]$
$i_{13/2}$	$5/2^+ [642]$	$d_{5/2}$	$1/2^+ [620]$
		$j_{15/2}$	$9/2^- [734]$
		$i_{11/2}$	$7/2^+ [624]$
		$g_{9/2}$	$5/2^+ [622]$
		$g_{7/2}$	$1/2^+ [631]$



Evolution of N=152 shell gap vZ

“this work” J.Qian et al., Phys. Rev. C79 (2009) 064319
[41] A. Parkhomenko and A. Sobczewski, Acta Phys. Pol. B 36, 3115 (2005).



« Morceaux choisis » : Super Heavy Nuclei

➤ High intensity metallic beams for superheavy elements

B. Gall

IPHC
 Institut Pluridisciplinaire
 Hubert CURIEN
 STRASBOURG

beams
 How to go
 of meta

B. JP. Gall¹, Z. Asfari¹, J. Piot^{1,4}, J. Rubert^{1,†},
 J. Ärje², H. Koivisto², R. Seppälä², P.T. Greife³,
 S. Bogomolov³, V. Loginov³, A. Bondarchenkov³,
 F. Lemagnen⁴, C. Barue⁴, B. Osmond⁴, P. Jarrold⁵,
 M. Kidera⁵, H. Haba⁵, K. Morimoto⁵, K. Morita⁵

¹ Institut Pluridisciplinaire Hubert Curien, F-67037 Strasbourg, France
² Department of Physics, University of Jyväskylä, FIN-40014 Jyväskylä, Finland
³ FLNR / JINR, Joliot-Curie 6, Dubna, Moscow region, 141980, Russia
⁴ GANIL, CEA/DSM / CNRS/IN2P3, Bd Henri Becquerel, 14070 Sarrebourg, France
⁵ Nishina Center, RIKEN, Wako-shi, Saitama 351-0198, Japan

COLLOQUE GANIL Strasbourg Sept 9-13 2019

Summary

- ⁵⁰Ti MIVOC beams coming close to the μA level => 2-8 μA on DC280,
- Almost one year of integrated beam on target (JYFL, FLNR, GANIL, RIKEN)
- Already nice results with ⁵⁰Ti MIVOC (²⁵⁶Rf, ²⁵⁷Db),
- New MIVOC compounds of Vanadium and Chromium,
- R&D for ²³⁸U MIVOC should give results soon.

... Start SHE synthesis with MIVOC ⁵⁰Ti & ⁵⁴Cr @ SHE factory

PROGRAM 2019-2030 ...

- Ti, V, Cr, U Beams @ SHE Factory
- improve MIVOC-plasma coupling
- Inductive oven (in preparation)
- Laser ionisation ?
- 60 GHz ECRIS ?
- + High temperature targets ...

COLLOQUE GANIL - Strasbourg - Sept 9-13 2019

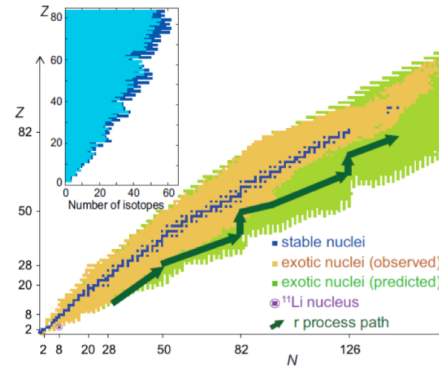
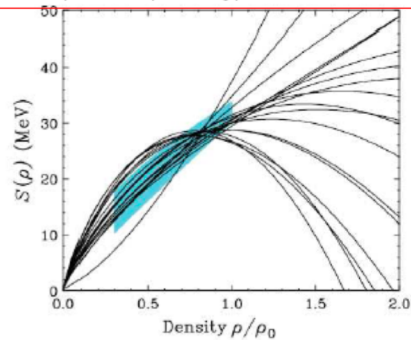
« Morceaux choisis » : Theory

- Challenges in theory in connection to GANIL experiments
 M. Colonna

Physics @ GANIL

- Structure and reaction dynamics of exotic nuclei

The symmetry energy of the nuclear EoS



[Otsuka et al, arXiv:1805.06501v4]

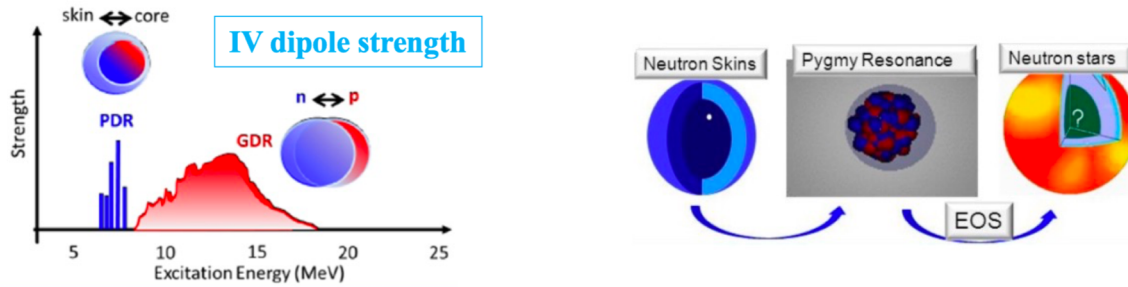
- Nuclear collisions under various conditions.
 Nuclear matter dynamics and thermodynamics
 Equation of State

- Fundamental interactions, atomic, condensed matter physics, radiobiology, medical applications, ...

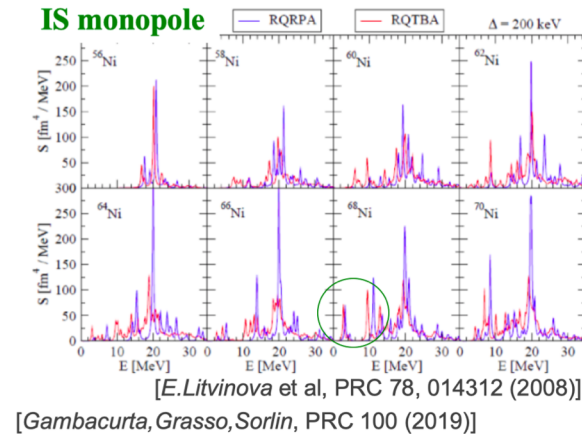
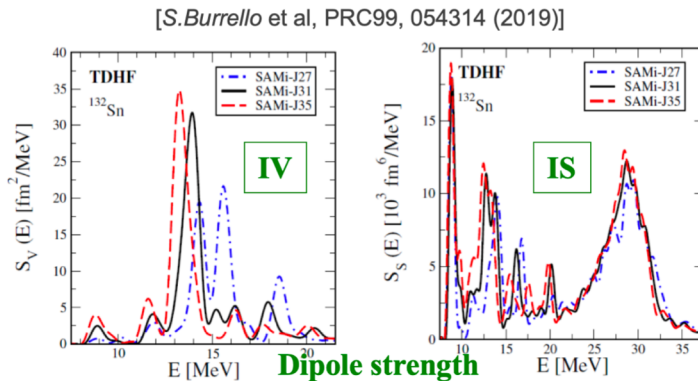
« Morceaux choisis » : Theory

- Challenges in theory in connection to GANIL experiments
 M. Colonna

Collective motion in nuclei



- Collective motion → ‘macroscopic’ features (NM compressibility, symm. energy..) → **EOS**



→ exp. with active targets

- **ISGMR**: Extraction of symm. matter **K** and symmetry energy compressibility **K_s**
- **IS/IV Dipole response**: neutron skin, symmetry energy slope **L**

« Morceaux choisis » : Instrumentation and detector developments



Perspectives with the SPIRAL 1 new beams for upcoming physics campaigns

P. Delahaye, GANIL

And the SPIRAL 1 upgrade team!

Zoé Favier¹
B. Sülignano¹, A. Drouart¹, T. Chaminade², T. Goigoux¹
W. Korten¹, M. Siciliano¹, Ch. Theisen¹, M. Vandebroutck¹, M. Zielinska¹
¹CEA Saclay, IRFU/DPN, France
²CEA Saclay, IRFU/DEDIP, France
On behalf of the SIRIUS Collaboration

Status and perspective of the S³ Low

Branch at SPIRAL2-GANIL

Nathalie Lecesne
GANIL
S³-LEB collaboration

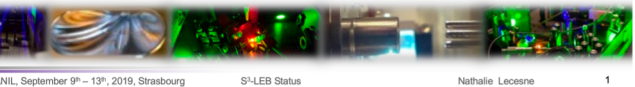
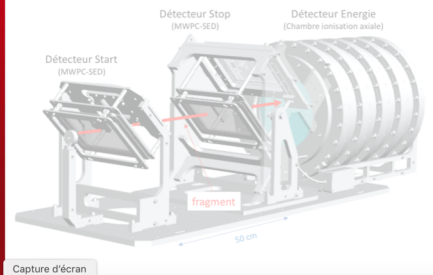
Towards the superheavy elements at S³
Status of SIRIUS

FROM RESEARCH TO INDUSTRY
cea
Ifremer Institut de recherche sur les lois fondamentales de l'Univers
SPIRAL2
P2IO
DS
www.cea.fr

Recent developments of the FALSTAFF spectrometer

E. Berthoumieux¹, Q. Deshayes¹, D. Doré¹, L. Thuilliez¹, S. Herlant², X. Ledoux², J. Pancin², M. Combet¹, M. Kebbiri¹, P. Legou¹, A. Marcel¹, J.P. Mols¹, Y. Piret¹, M. Riallot¹

Ifremer, CEA, Université Paris Saclay, France
GANIL, Caen, France



Colloque GANIL, September 9th - 13th, 2019, Strasbourg S³-LEB Status Nathalie Lecesne 1

Status of the SPIRAL2-DESIR project

J.-C. Thomas, on behalf of the project management and collaboration

XXIst Colloque GANIL
Strasbourg
September 12, 2019

« Morceaux choisis »

I apologize for the presentations of this morning...

Friday, September 13, 2019

Nuclear Astrophysics (Orangerie AB)

09:00 - 10:55

- 09:00 - 09:30 The critical role of nuclear physics in interpreting astrophysical observations
A. LAIRD (University of York)
- 09:30 - 10:00 The r-Process in Neutron Star Mergers and Core-Collapse Supernovae
L. ROBERTS (MSU)
- 10:00 - 10:20 Sensitivity of Giant Resonances Energies of Nuclei to Properties of Nuclear Matter
S. SHLOMO (Texas AM)
- 10:20 - 10:40 Measurement of light charged particle Equilibrium constants using heavy-ion reactions
R. BOUGAULT (LPC Caen)
- 10:40 - 10:55 Determination of Photoneutron Cross Sections for ¹⁶⁵Ho Using Direct Neutron-Multiplicity Sorting
M. KRZYSIEK (IFIN-HH Bucharest)

10:55 - 11:20 Coffee break

N=Z nuclei (Orangerie AB)

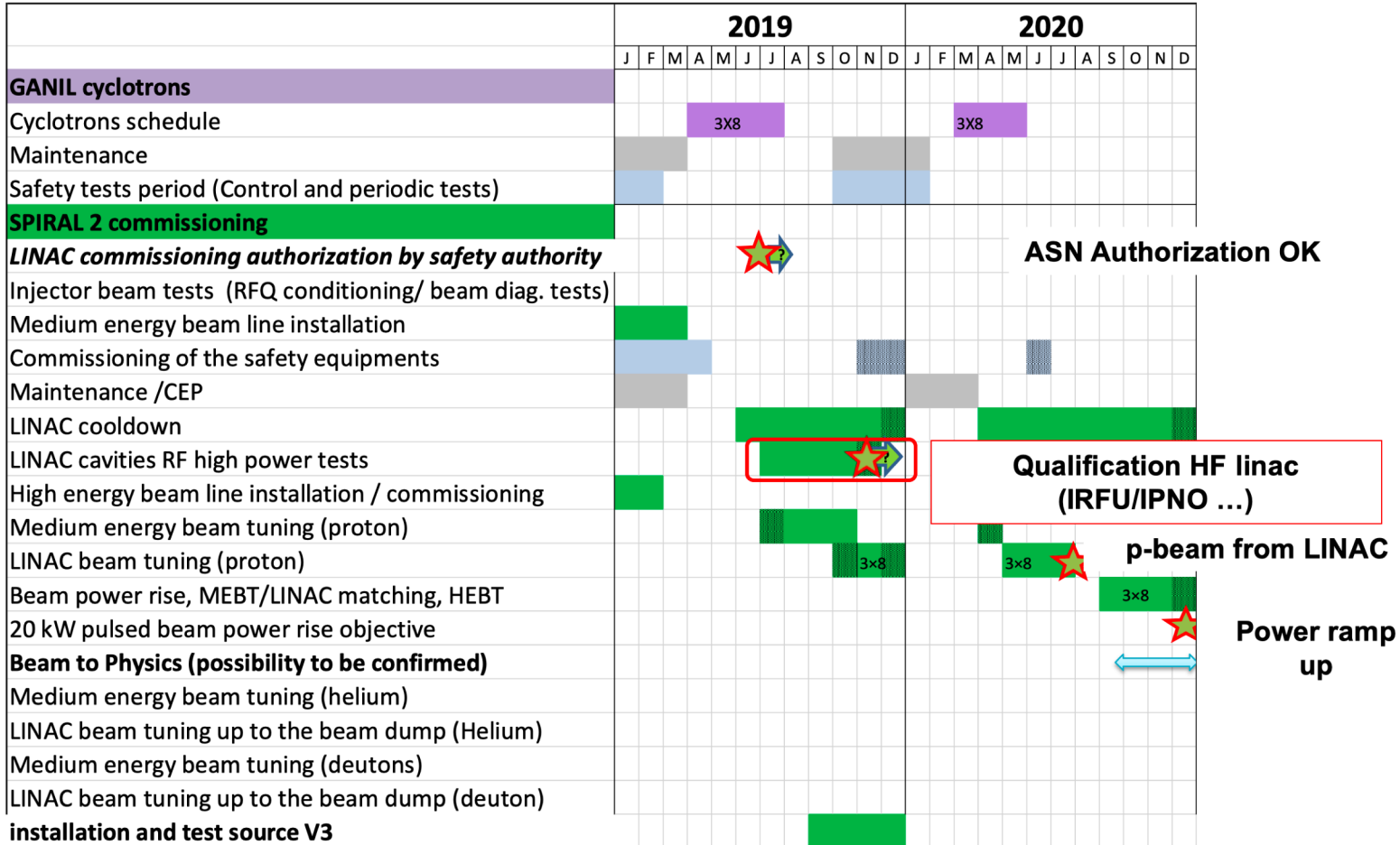
11:20 - 13:00

- 11:20 - 11:50 Nuclear structure along the N~Z line
G. DE FRANCE (GANIL)
- 11:50 - 12:10 The Super Separator Spectrometer (S3) for the very high intensity beams of SPIRAL2
H. SAVAJOLS (GANIL)
- 12:10 - 12:30 Nuclear moment studies of short-lived excited states of radioactive ions. TDRIV on ²⁸Mg from HIE-ISOLDE
G. GEORGIEV (CSNSM Orsay)
- 12:30 - 13:00 Concluding remarks
S. GREVY (CENBG)

13:00 - 14:30 Lunch and departure (Orangerie CDE)

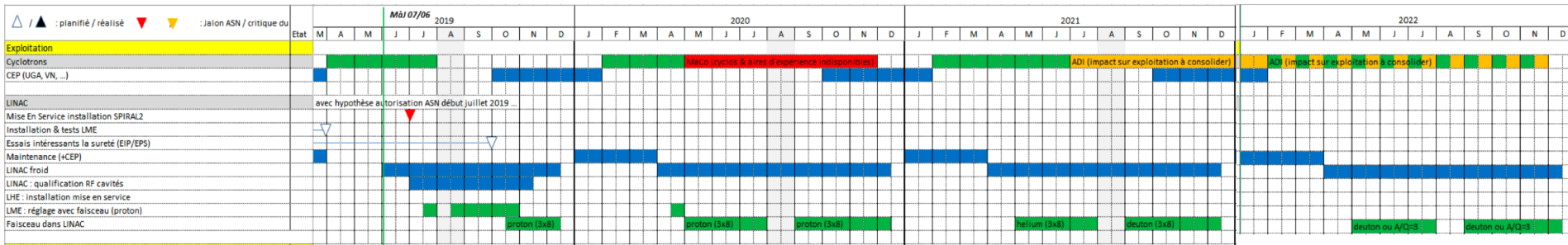
Few words about GANIL

- The commissioning of LINAC started but it takes some time to start an accelerator !



Few words about GANIL

- Beam time in 2020, 2021...
 the aim is to increase



2019

2020

6 months of functioning

- 4 months cyclotrons
- 2 months commissioning Linac protons

9 months of functioning :

- 3 months cyclotrons
- 6 months Linac protons :
 - ✓ 3 months commissioning protons
 - ✓ 3 months commissioning NFS
 - ✓ First simple experiments

2022

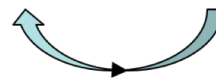
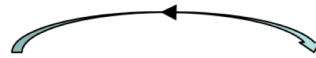
2021

11 months of functioning

- 5 months cyclos with 2 months // Linac
- 6 months Linac

11 months of functioning :

- 5 months cyclos with 2 months // Linac
- 6 months Linac :
 - ✓ 3 months commissioning helium
 - ✓ 3 months experiments deutons NFS



Few words about GANIL

- The commissioning of LINAC started but it takes some time to start an accelerator !

	2019												2020											
	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
GANIL cyclotrons																								
Cyclotrons schedule																								
Maintenance																								
Safety tests period (Control and periodic tests)																								
SPIRAL 2 commissioning																								
LINAC commissioning authorization by safety authority																								
Injector beam tests (RFQ conditioning/ beam diag. tests)																								
Medium energy beam line installation																								
Commissioning of the safety equipments																								
Maintenance /CEP																								
LINAC cooldown																								
LINAC cavities RF high power tests																								
High energy beam line installation / commissioning																								
Medium energy beam tuning (proton)																								
LINAC beam tuning (proton)																								
Beam power rise, MEBT/LINAC matching, HEBT																								
20 kW pulsed beam power rise objective																								
Beam to Physics (possibility to be confirmed)																								
Medium energy beam tuning (helium)																								
LINAC beam tuning up to the beam dump (Helium)																								
Medium energy beam tuning (deutons)																								
LINAC beam tuning up to the beam dump (deuton)																								
installation and test source V3																								

- commissioning of NFS in 2020

- first experiments in NFS in 2021

- start of DESIR construction in 2022

- start of commissioning of S3 in 2022

- commissioning of DESIR in 2024

....

OK

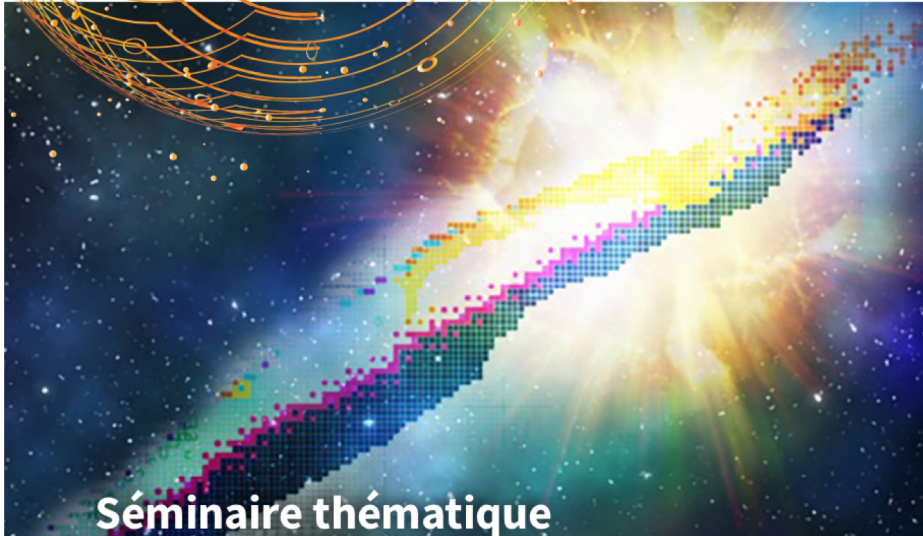
c

n LINAC

ver ramp up

**Exercice de prospective nationale
en physique nucléaire, physique
des particules et astroparticules**

Développements technologiques et applications associés



Séminaire thématique

Physique et astrophysique nucléaire

LPCC, Caen

30-31 Janvier 2020

Pour consulter l'agenda et obtenir plus d'informations
sur l'exercice de prospective nationale :

<https://prospectives2020.in2p3.fr>

- déclarations d'intentions : September 15
- contributions : November 1st
- “séminaire thématique” : January 31-31, 2020
Caen
- production of a “document de synthèse”
- “colloque de restitution” : spring-summer 2020
Giens

Thank you for your attention

and to those who contributed to the entertainment part of this talk
(PA, JD... and others)