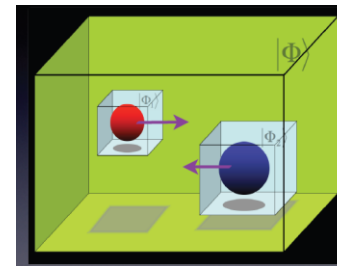
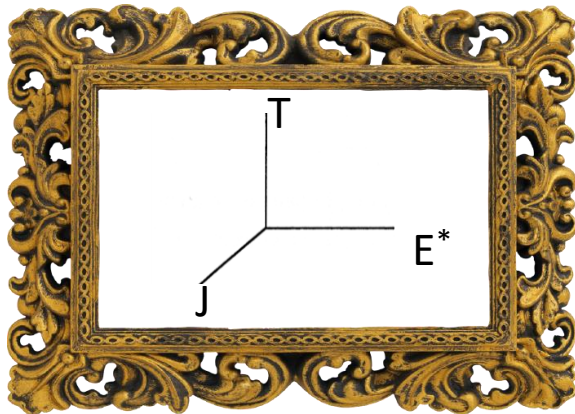
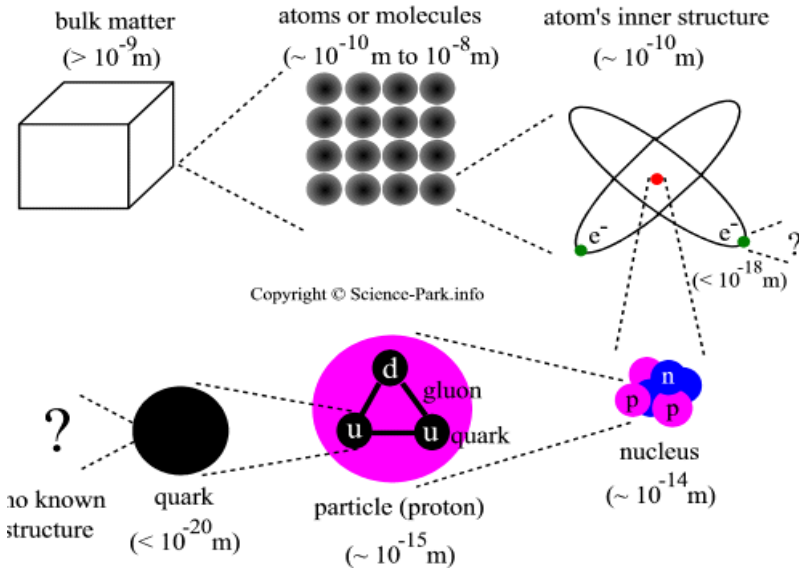


Experimenting Exploring Experiencing Femtoscience at GANIL

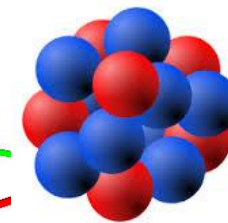
A. NAVIN



ISOL
Radioactive beams

**Fragmentation
beams**

**Intense Stable
beams**

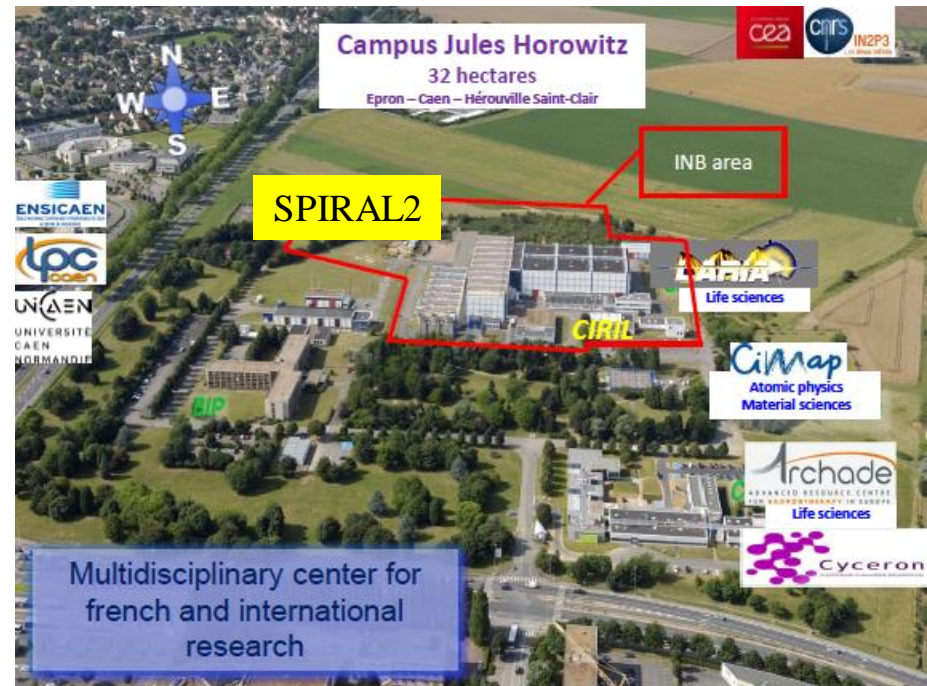


How do regular and simple patterns emerge in the structure of complex nuclei?

What are the key variables governing the dynamics between colliding composite systems of nucleons?

Grand Accélérateur *National* d'Ions Lourds

1978, GANIL in the middle of fields



Bringing science to life and life to science!

POA

Short Overview of GANIL

Status

A flavour of Nuclear Structure

Tomorrow and the day after

The GANIL facility

C01/2+CSS1/CSS2 : High Energy Beams GANIL

[24- 95] MeV/u

Stable +Short lived beams (Fragmentation > 10 μ s)

Status of a nuclear reactor
As far as safety regulations

CYCLOTRONS

C to U

Material science / Atomic physics

C01/2 IRRSUD : [0.3,-1.0] MeV/u

CSS1 SME : Medium energy

[3.7, 13.7] MeV/u

SPIRAL1 (Cyclotrons + CIME) : High Energy
Exotic Beams [1.2,-25] MeV/u

Short lived beams (ISOL) T ~ > 10 ms

Système de Production d'Ions Radioactifs Accélérés en Ligne

Désintégration,
Excitation et Stockage
d'Ions Radioactifs

DESIR

SPIRAL1

SPIRAL2
Phase 2

High intensity re-accelerated fission fragment beams
(ISOL)

Super Séparateur Spectromètre

S3

SPIRAL2
LINAC

33 MeV p, 40 MeV d (5mA)

14.5 A.MeV HI (1mA)

*Plus a wide range of detectors
European collabⁿ
Conceptualized for SP2*

SPIRAL2 is a major
upgrade of GANIL

NFS

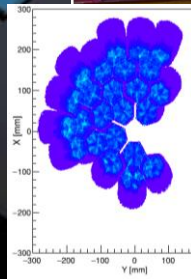
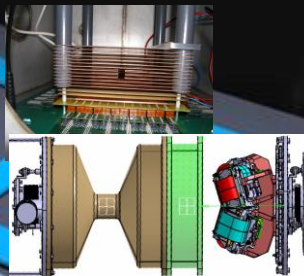
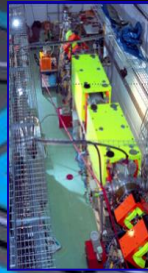
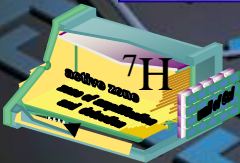
Neutrons For Science

GANIL TODAY

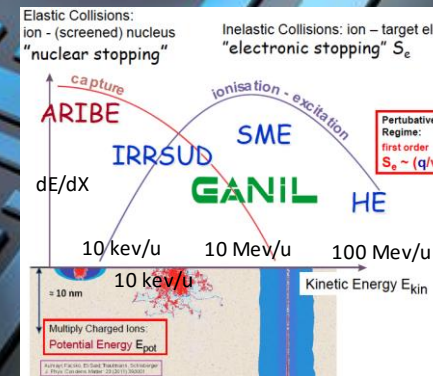
Applications



^{42}Si



ECS



To probe E^*, J, T

Fragmentation primary beams $^{48}\text{Ca}, ^{58}\text{Ni}$ $4\mu\text{A}$ **AXIS-1**

Light RIB ^6He $4 \cdot 10^7$ $5 \cdot 10^5$ pps **AXIS-2**

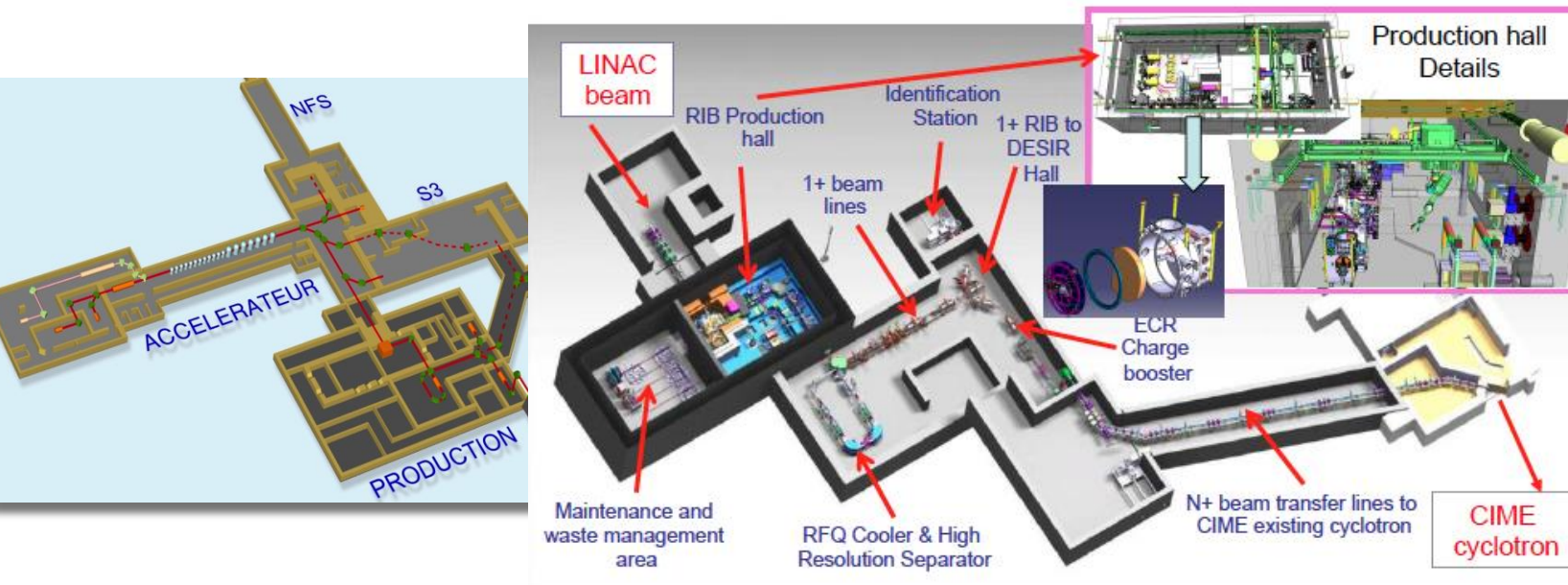
Heavy stable ^{238}U **2-3 pna** 1-95 MeV/u **AXIS-3**

+ Detectors

*Relook at the Spin orbit interaction
Clustering at the @proton drip line : ^{15}F
Quest for New isotopes: $N=126$ and beyond*

>90% uptime in the last 16 Y

The high intensity frontier: Reaccelerated Fission Fragments Phase 2



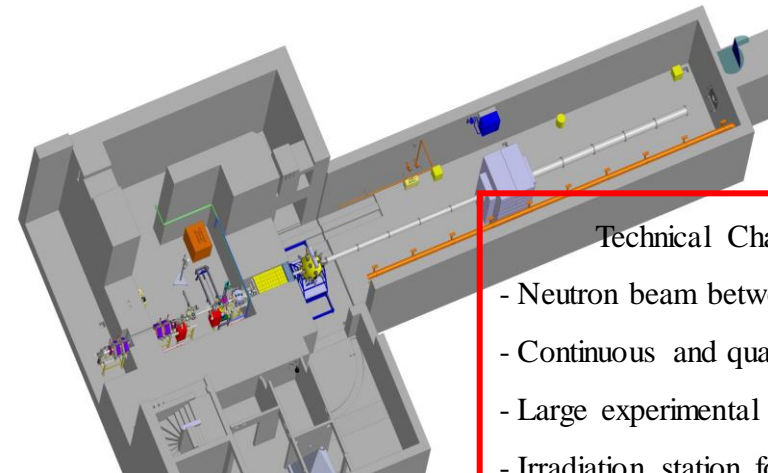
➤ Also a part of the strategy of going to the next generation ISOL facility *EURISOL SPIRAL2 phase 2*

The first step towards high intensity frontier for reaccelerated beams around the Coulomb barrier (10^9 p/s)

➤ 200kW - A crucial step for the next generation.

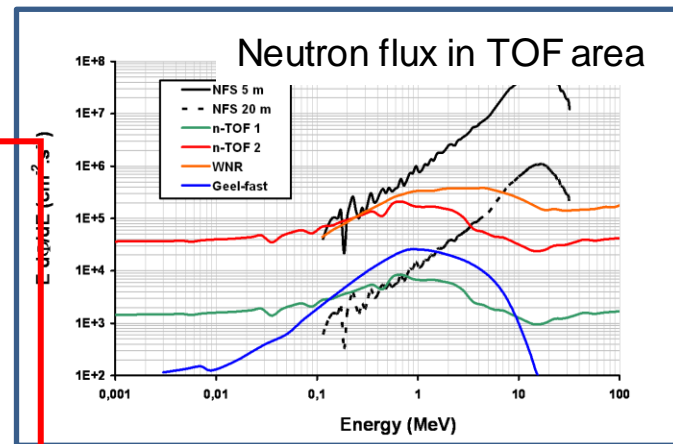
➤ (*EURISOL-DF*) with all ISOL facilities to mutually benefit and put *EUROPE* ahead

Neutrons For Science



Technical Characteristics

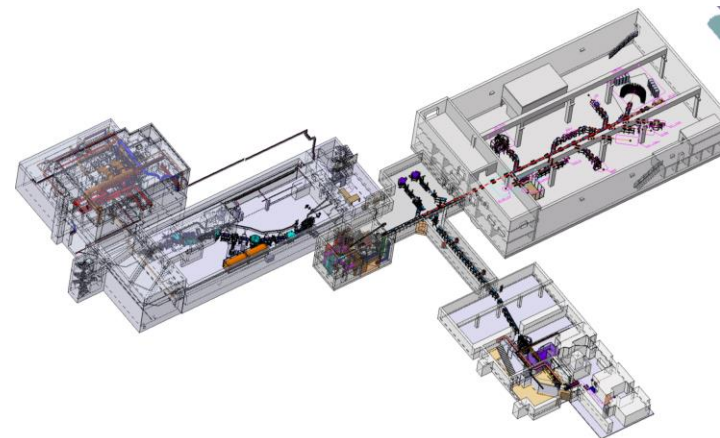
- Neutron beam between 100 keV and 40 MeV
- Continuous and quasi-mono energetic spectra
- Large experimental area for TOF measurement
- Irradiation station for n, p, d and ions induced reactions



S³

Looking for Rare phenomena

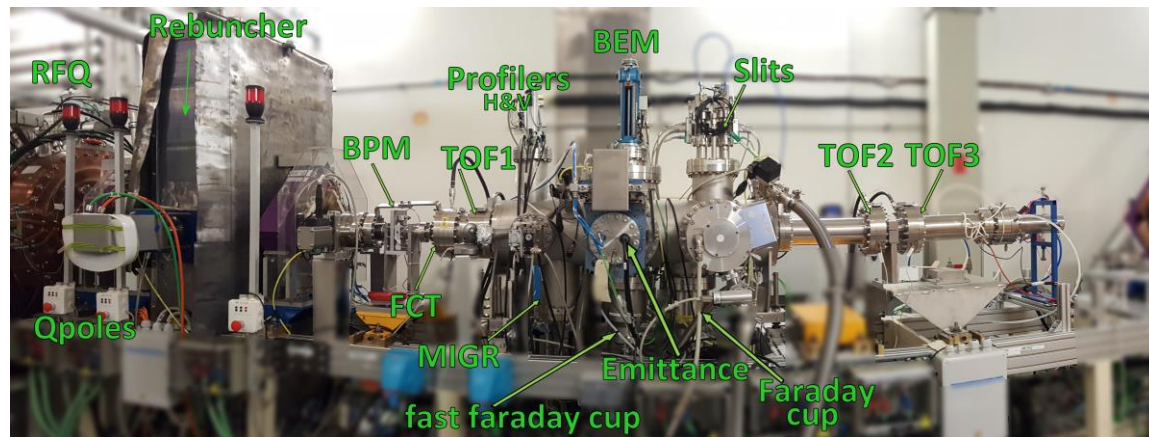
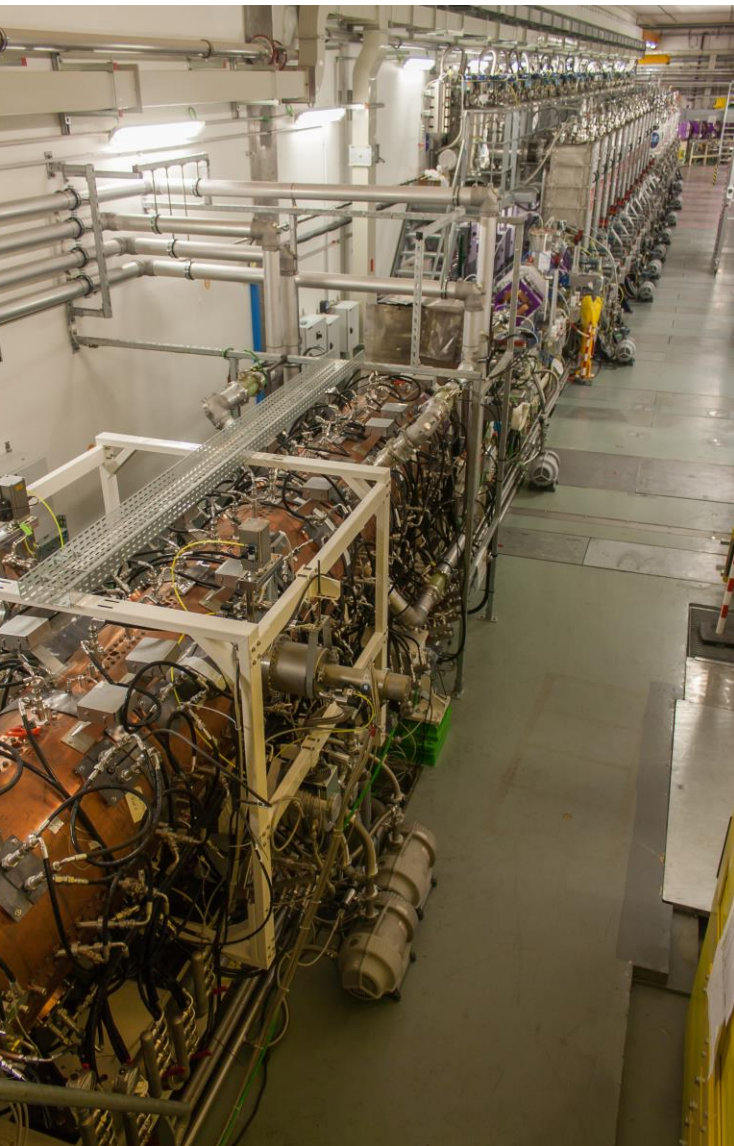
- VHE-SHE nuclei
- Proton drip-line & N=Z
- Nuclear Astrophysics
- Atomic physics



Spiral2 **DESIR**

- collinear laser spectroscopy
- β -delayed p, n and γ spectroscopy
- β -v angular correlation
- mass measurements
- (trap-assisted) β -decay, total absorption spectroscopy (TAS)

SPIRAL2 Where are we today

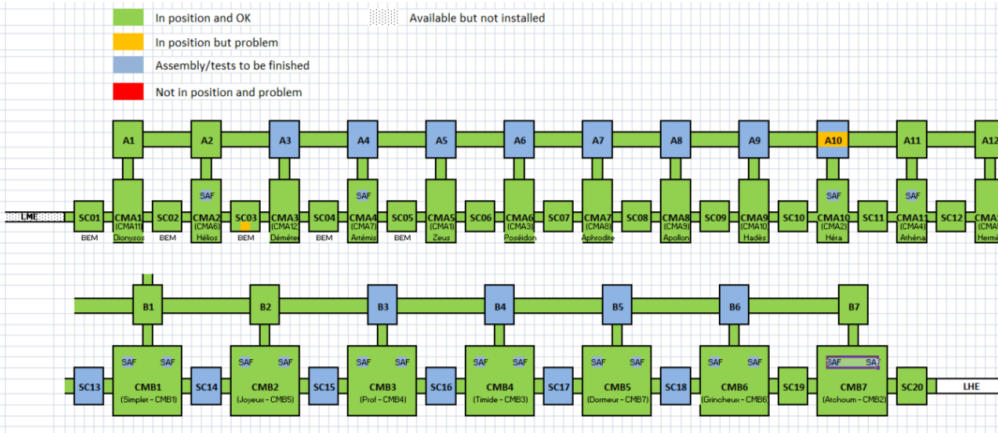


RFQ performances :

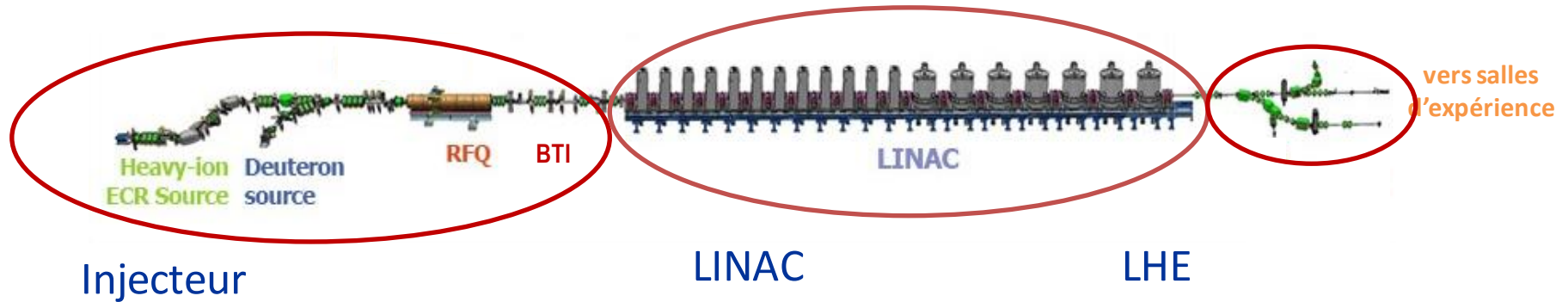
- H^+ beam ($A/Q=1$) : Nominal, 5mA CW
- $^4He^{2+}$ beam ($A/Q = 2$) : Nominal, 1.35 mAe CW
- $^{18}O^{6+}$ ($A/Q=3$): preliminary results, 600 μ Ae ($\approx 100\%$ transmission but beam characteristics to be measured : energy, emittance,...)
- RFQ transmission : $\sim 100\%$:
- RFQ Energy : 730 keV/nucleus : nominal

SPIRAL2 Where are we today

88 MHz QWR 12 x 1 = 12 $\beta = 0.07$ cavities 7 x 2 = 14 $\beta = 0.12$ cavities

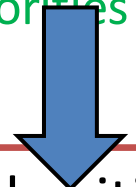


SPIRAL2 Where are we today



- J1: qualification with RFQ beam on BTI (excluding deuterons)
- J2a: Deuteron beam extracted from the source (Commissioning)
- J2b: Deuterons accelerated by the RFQ on the BT
- I J3a: RF qualification of two CMA and one CMB modules
- J3b: LINAC modules cooled
- J3c: all cavities qualified with RF
- J4: first beam accelerated to the Beam Dump LINAC
- J5 Physics

Need
Autorisation
from Nuclear
Security
Authorities



Assumptions for the authorization from the Nuclear safety authorities

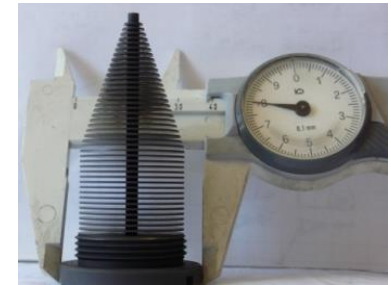
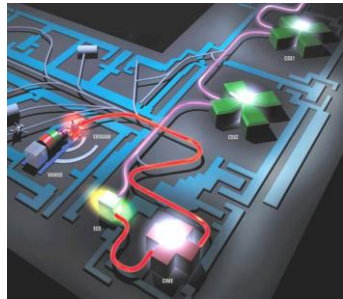
Before 8th of May => 1^{er} october => 1^{er} décembre => Next year

Towards Pulsed deuteron beams for NFS

Reaccelerated beams from SPIRAL 1

J. Phys. G: Nucl. Part. Phys. 38 024004 (2011)

New beams with new sources and new targets



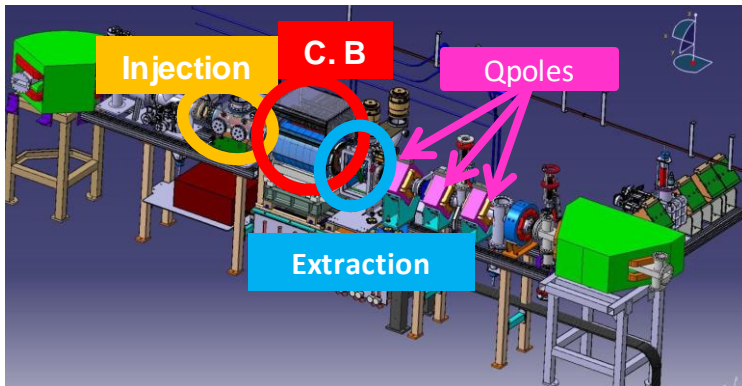
ISOLDE VADIS (FEBIAD source)

- 1+ beams from metallic elements with $T_{\text{fusion}} < 2000^\circ \text{C}$

Already 7 new elements

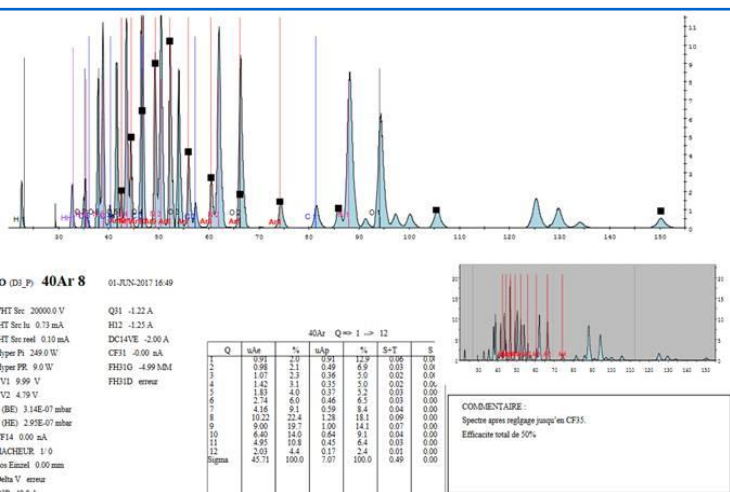
Na, Mg, Al, P, Cl, Cu, Fe + many more to come

Insertion of an **ECR charge breeder**: highly charged ions for CIME cyclotron

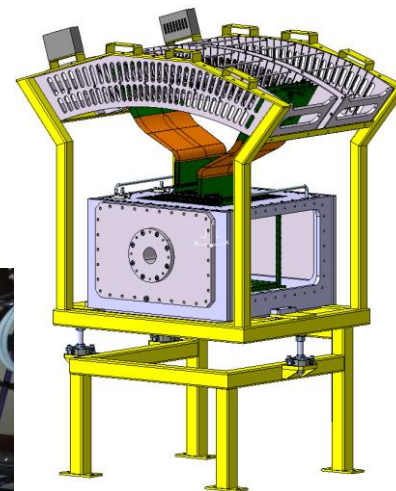


ISOL facility running since 2001

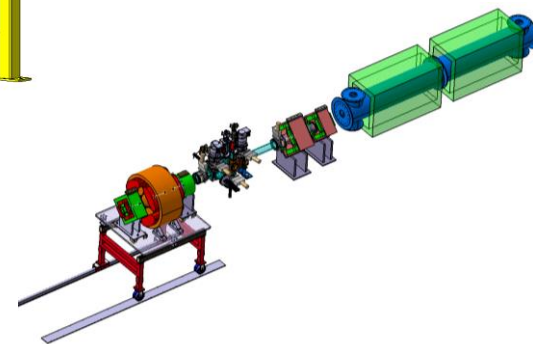
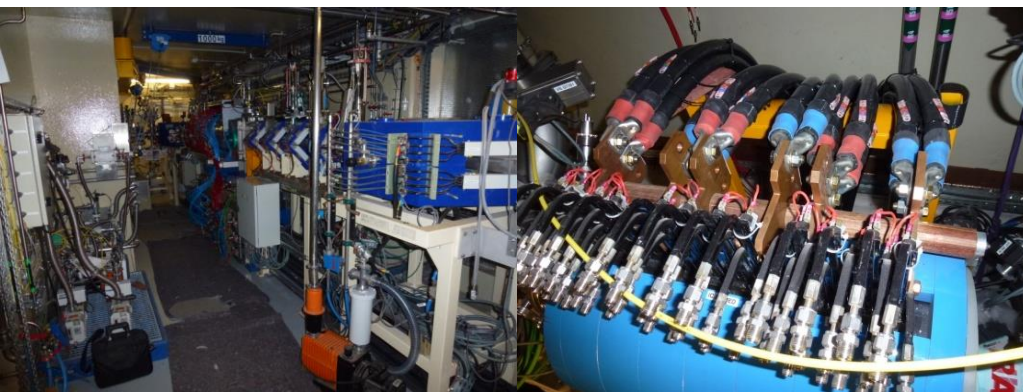
Collaborations within EURISOL/Beamlab within ENSAR2



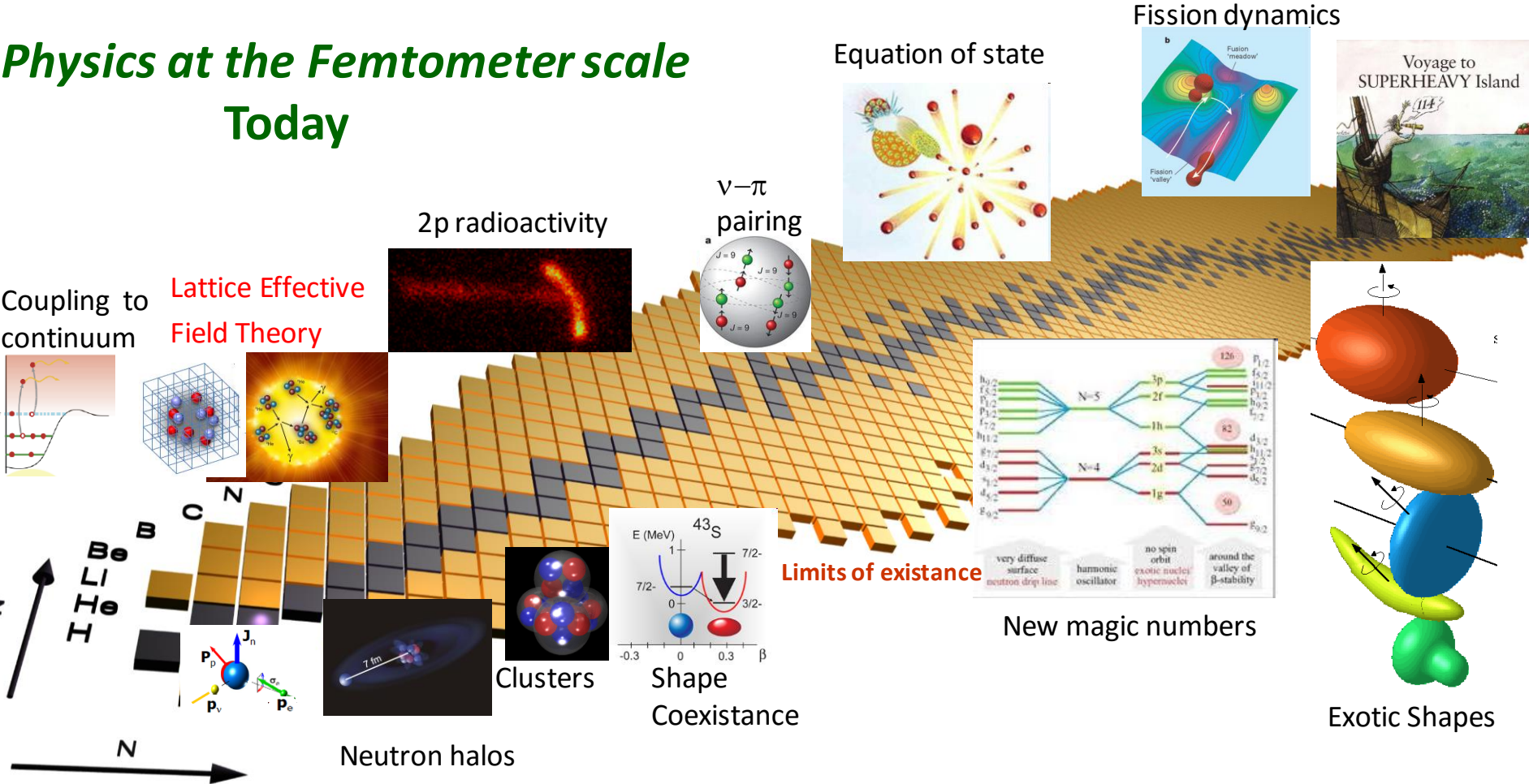
Successful test with stable beams
Continuing tests in Nov
RIB test Run 1 next year April 2017 ^{17}F , ^{38}mK
Experiments subsequently and more beams



charge booster started on 18 may 2017



Physics at the Femtometer scale Today

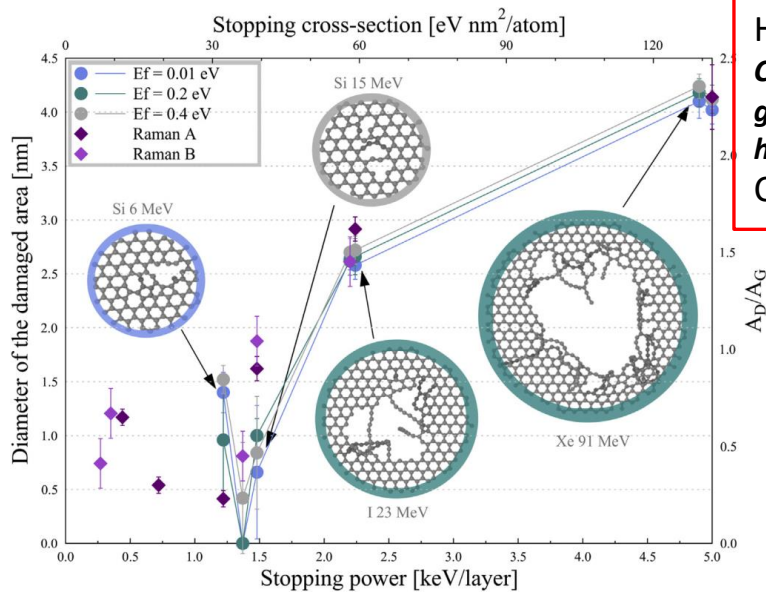


Search and UNDERSTAND regular and simple patterns that emerge in the structure of complex nuclei
By characterizing nuclei under EXTREME conditions (E^*, J, T):
amplify different aspects of the interaction

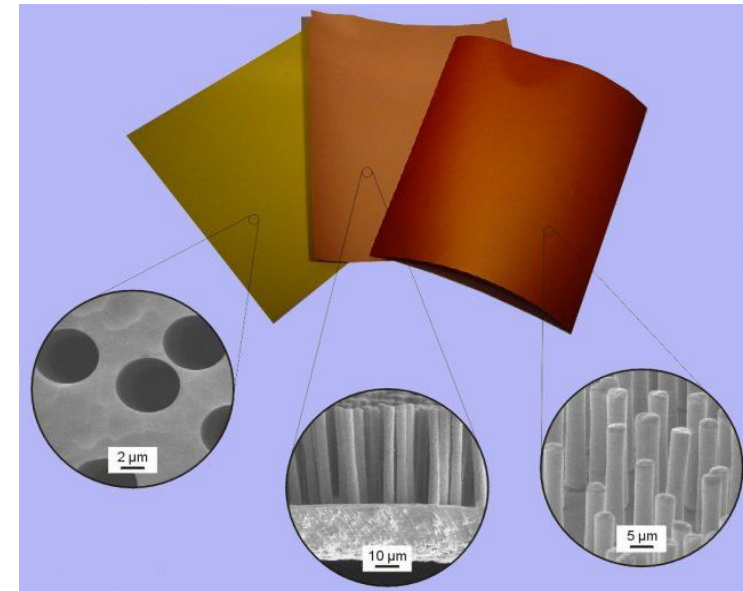
EXPLOIT

- Elemental Abundances in the Universe
- Improved reactors, Burning of nuclear waste ..
- New isotopes for medicine ...

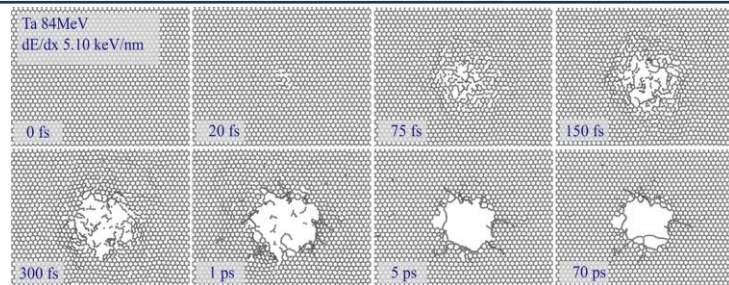
Nanopores in self-supporting Graphene



H. Vázquez *et al.*
Creating nanoporous graphene with swift heavy ions
 Carbon **114** (2017) 511

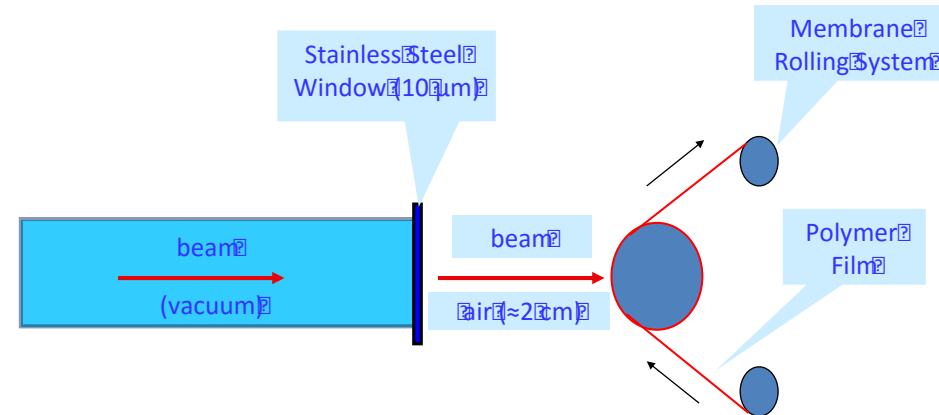


Experiment:
 pore diameter vs. heavy ion stopping power



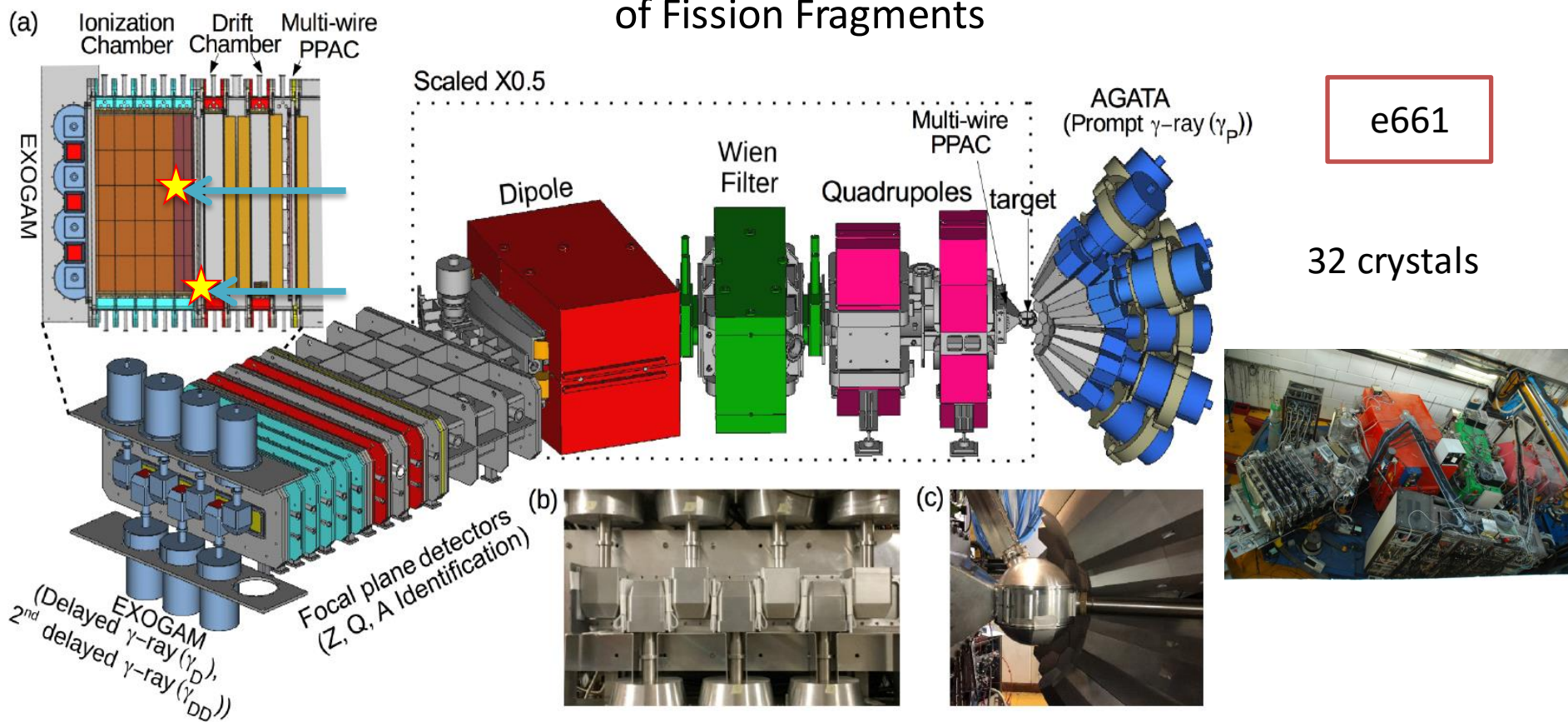
Simulation
 pore diameter vs.
 Time (highest
 stopping power)

Application:
 De-salting of seawater
 affiliated project NU TEGRAM
 flagship Graphene



Companies Germany, Belgium, Sweden, China...
 Applications: agri-food, pharmaceutical, biological, etc...

Prompt-Delayed Spectroscopy@VAMOS++ of Fission Fragments



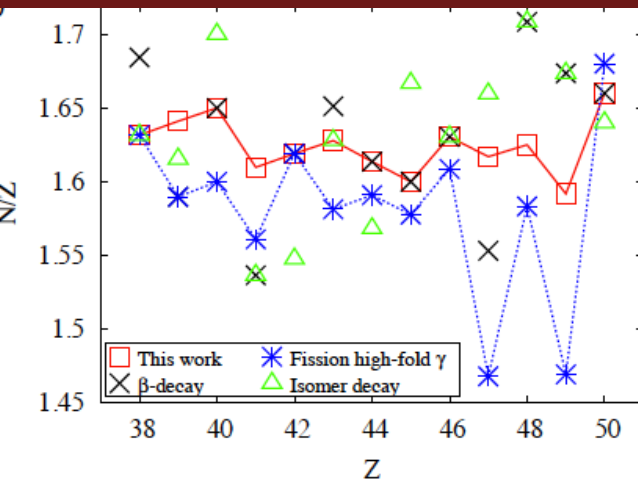
Y-H Kim et al, submitted to EPJA (2017)

Unique Features :

- **Isotopic Identification (A,Z)**
- **Prompt-Delayed correlation**
- Delayed-Delayed coincidence (γ - γ)
- Delayed-Delayed correlations
- Range : **0.1 - 200 μ s**
(focal plane rate \sim 7kHz)

- Wall of 7 EXOGAM clovers at the end of the Focal Plane
- Stopping in IC gas (50-100mb)
- implantation- γ correlation using timestamp

Look for new “effects”
With the next level of sensitivity
EXOGAM



In-Sb

Nature of electromagnetic transitions in spin
orbit partner around a magic gap from the study
of $^{118-128}\text{In}$ and $^{124-128}\text{Sb}$ isotopes,

repetitive regular pattern $\Delta I = 1$ (M1) cascade of transitions
dominating over $\Delta I = 2$ (E2) transitions at relatively high spin (more
general)

Evolution of triaxial shapes far from stability
 $^{114-119}\text{Rh}$

$^{118-121}\text{Ag}$ isotopes Shell model calⁿ triaxiality

The structural evolution of the neutron-rich Zr isotopes
at high angular momentum $^{104-106}\text{Zr}$

a region where tetrahedral deformation

^{96}Zr

Examining the p - n interaction in widely used
shell model interactions through states at high
angular momentum $^{121,123,125}\text{Cd}$

States above isomer ^{132}Te (also n-n)

Impact on prediction around ^{78}Ni

Advances in the spectroscopy of heavy *deformed*
nuclei $Z > 59$. Corrected the misidentification of
certain isotopes in the literature and new $^{143-153}\text{Pr}$

^{141}Pr

Reflection asymmetric deformation in neutron
rich $^{149-}$

68

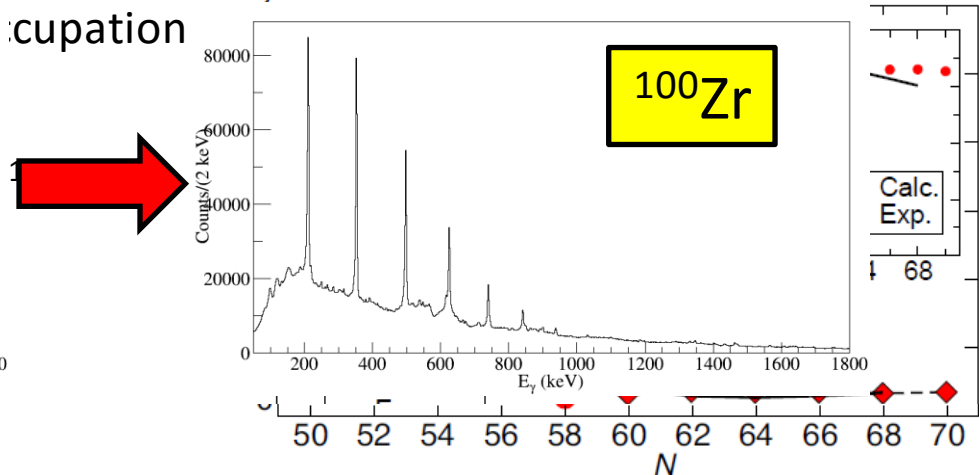
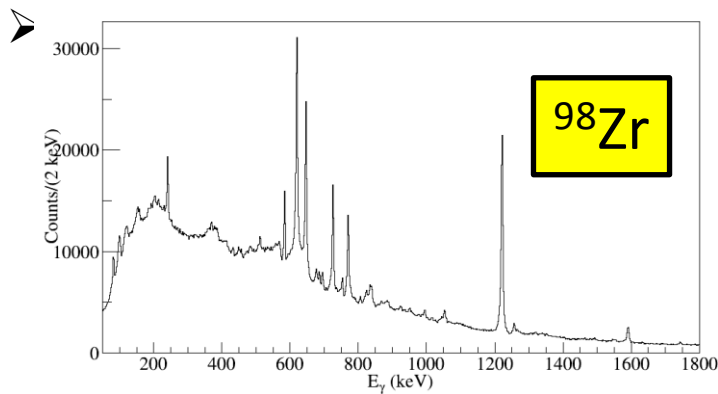
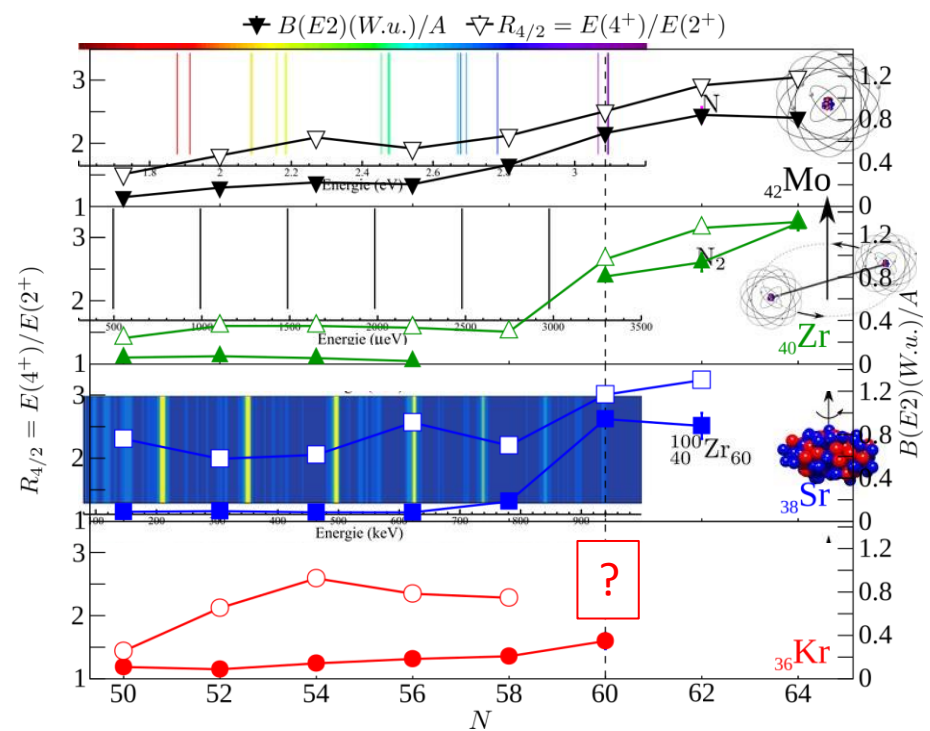
Se - Kr

Scientific output (single experiment E585 - 2011)

1. A. Navin, M. Rejmund, McGraw-Hill Yearbook of Science and Technology, 137 (2014)
2. A. Navin et al., PLB **728**, 136 (2014)
3. E. H. Wang et al., PRC **92**, /034317 (2015)
4. M. Rejmund et al., PLB **753**, 86 (2016)
5. M. Rejmund et al. PRC **93**, 24312 (2016)
6. S. Biswas et al., PRC **93**, 034324 (2016)
7. A. Navin et al., PLB **767**, 480 (2017)
8. Y-H. Kim et al, accepted PLB (2017)
9. E-H Wang, et al, submitted to PRL (2017)
10. S. Bhattacharyya et al., in preparation (2017)

Nuclear shape and deformation at N=60

- Sudden deformation increase at N=60 ($^{104}\text{Mo} \Rightarrow ^{97}\text{Rb}$ (Z=37))
 - Singularity in the nuclear chart
 - Quantum Shape transition
 - Shape coexistence
- What is the low-Z edge of this island of deformation?
- Session 7 10:55 J. Dudouet
- Recently : Monte Carlo Shell Model :

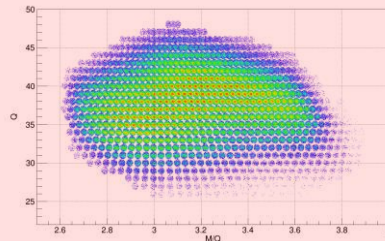


Courtesy A. Lemasson

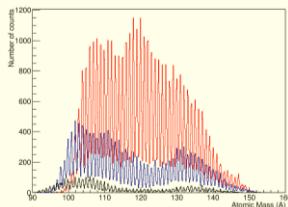
J. Dudouet et al, PRL **118** 162501 (2017)

Unique setup for γ -ray spectroscopic studies

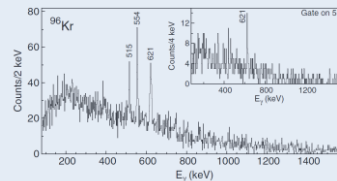
VAMOS :
Unambiguous
isotopic identification



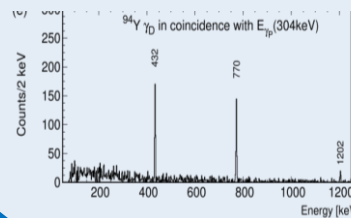
Second Arm :
Fission process



AGATA :
high resolution
prompt γ -rays



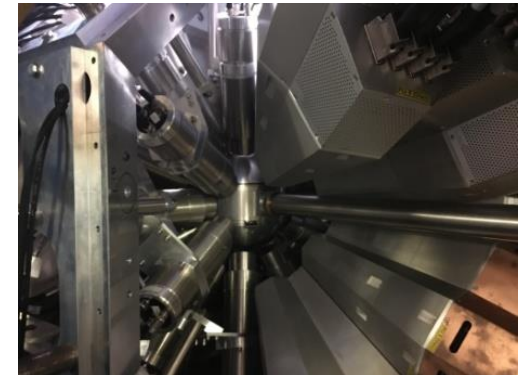
EXOGRAM:
delayed γ -rays



Scientific opportunities

- **Nuclear Structure**
(Prompt, delayed, Isotopic chains)
- Diff reaction processes
- Lifetimes
- **Fission dynamics**
(yields, pre-, post-neutrons, Total Kinetic Energy)

Now in GANIL
VAMOS + AGATA (35 crystals)
+ FATIMA (24 LaBr₃)

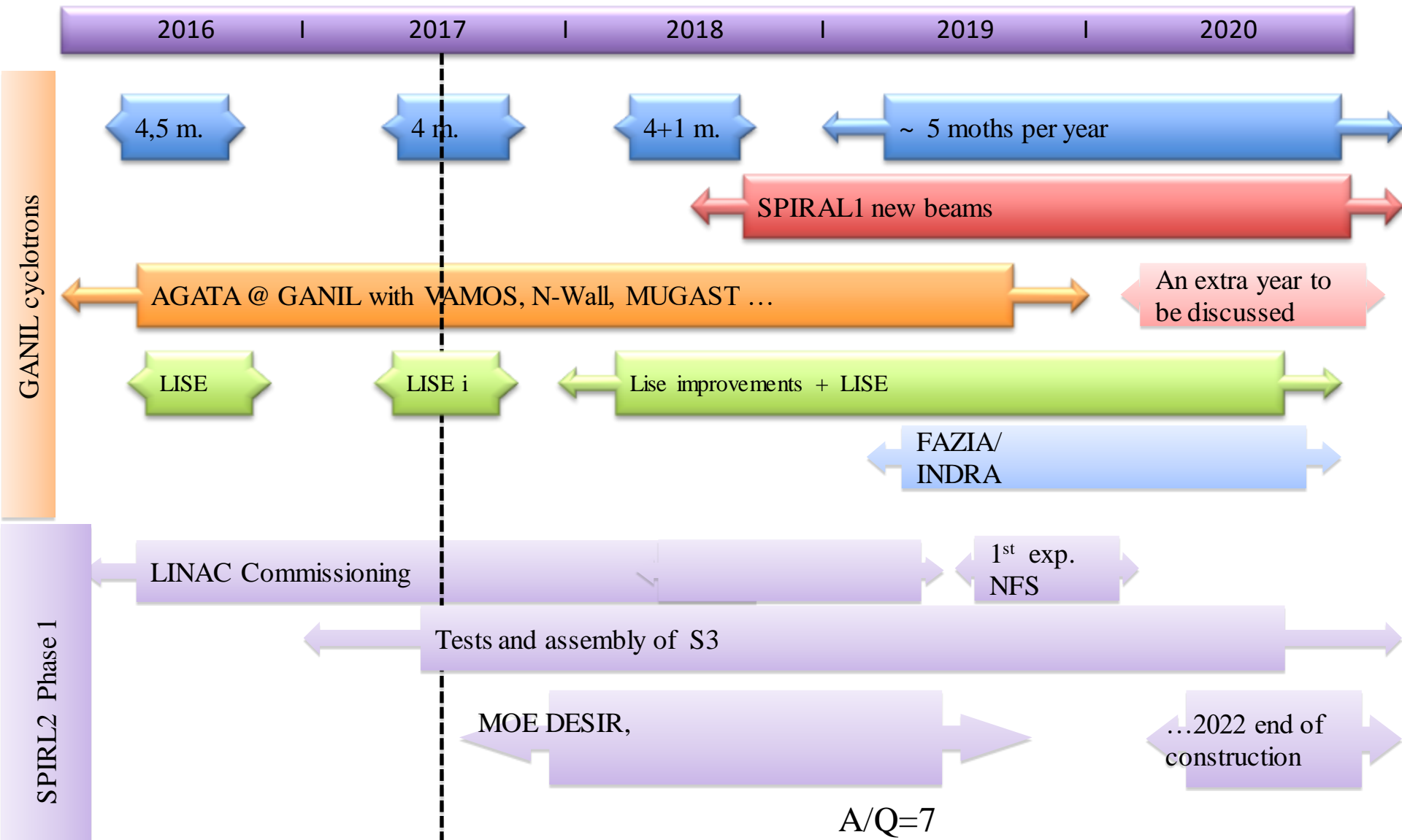


Next month



- Continuous developments of VAMOS
- Coupled to sensitive γ -ray detectors

A Possible Scenario



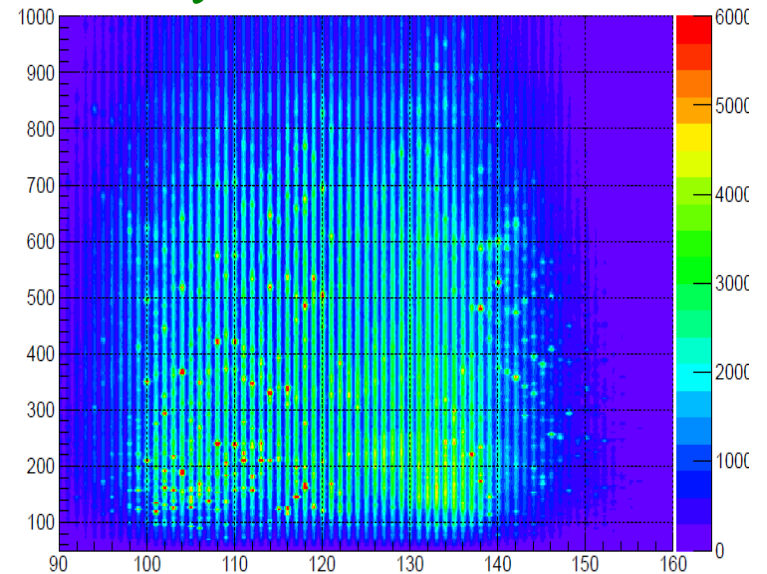
Next GANIL PAC 29 Nov 1st Dec 2017

Reaching for the stars at GANIL

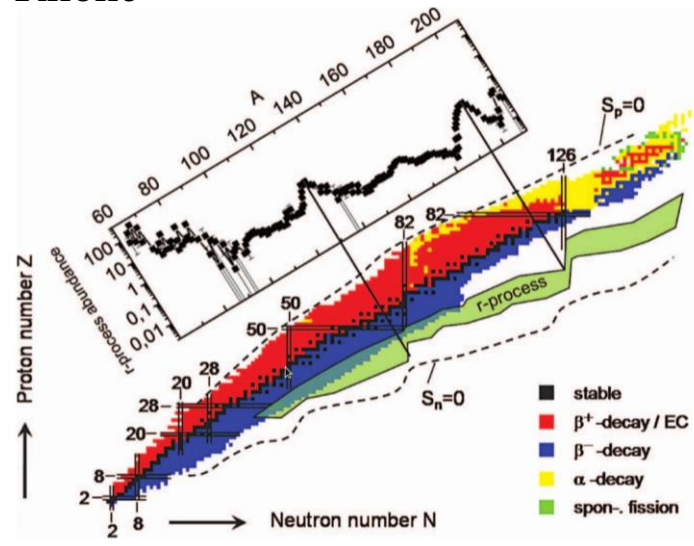
Thanks to the user community

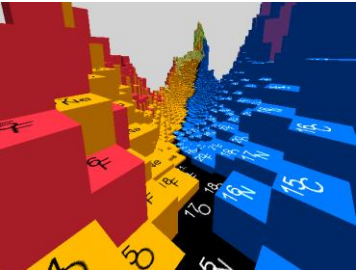


VanGogh-Starry Night Over Rhone



GANIL: Stars in a night shift





Summary

*Transforming our future to the present
and it CONNOT be done without you*

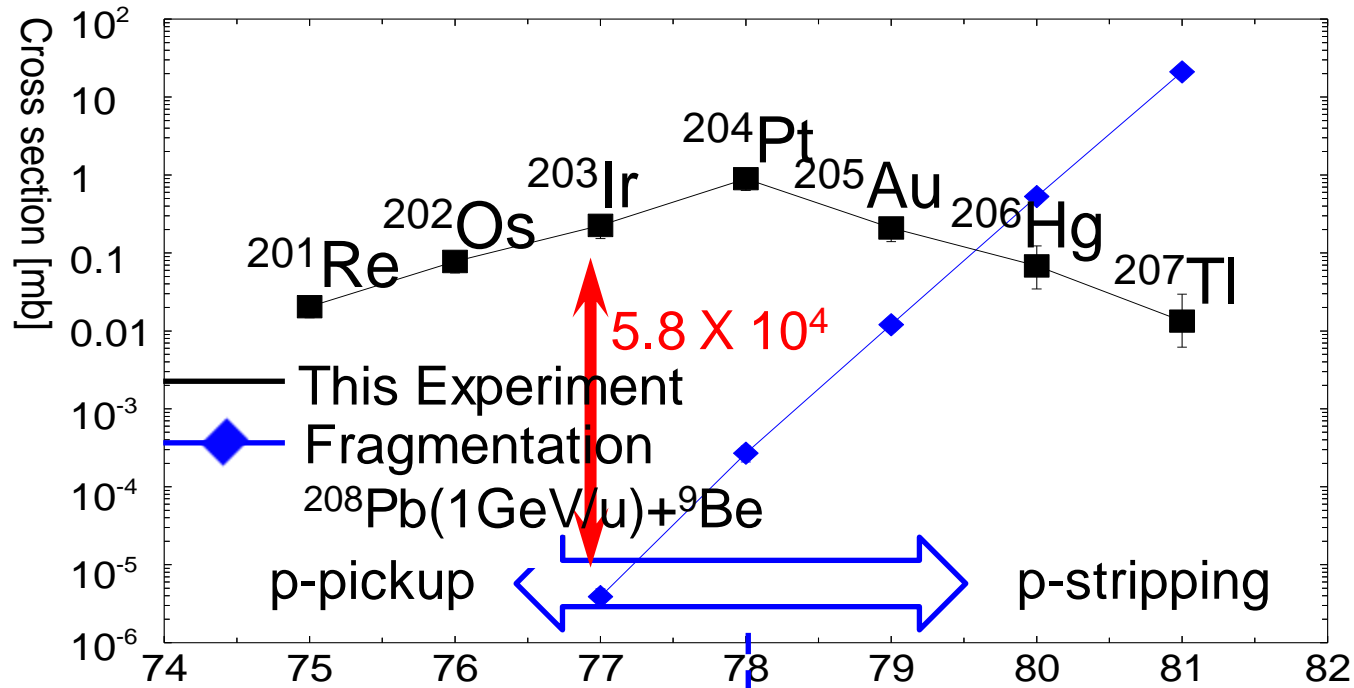
***How can we do better
in Europe***

*The woods are lovely dark and deep,
But **we** have miles to go before we sleep,
Miles to go before **we** sleeps.....*

Robert Frost (with modifications)

Thank you

GOAL : N=126 isotone cross sections



PRL 115, 172503 (2015)

PHYSICAL REVIEW LETTERS

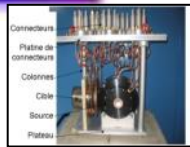
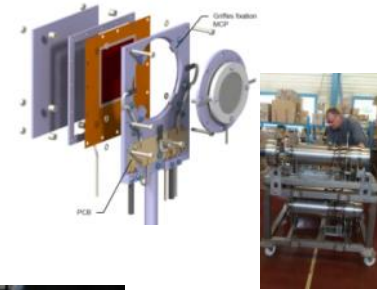
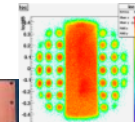
week ending
23 OCTOBER 2015

Pathway for the Production of Neutron-Rich Isotopes around the $N = 126$ Shell Closure

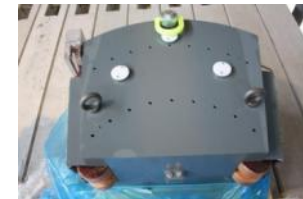
Y. X. Watanabe,^{1,§} **Y. H. Kim,^{2,*,†}** S. C. Jeong,^{1,‡} Y. Hirayama,¹ N. Imai,^{1,§} H. Ishiyama,^{1,‡} H. S. Jung,¹ H. Miyatake,¹ S. Choi,^{2,3} J. S. Song,^{2,3,4} E. Clement,⁵ G. de France,⁵ A. Navin,^{5,||} M. Rejmund,⁵ C. Schmitt,⁵ G. Pollaro,⁶ L. Corradi,⁷ E. Fioretto,⁷ D. Montanari,⁸ M. Niikura,^{9,¶} D. Suzuki,^{9,**} H. Nishibata,¹⁰ and J. Takatsu¹⁰

→ Next step : Nuclear structure in N=126 isotones

LoI submitted in 2016 at GANIL

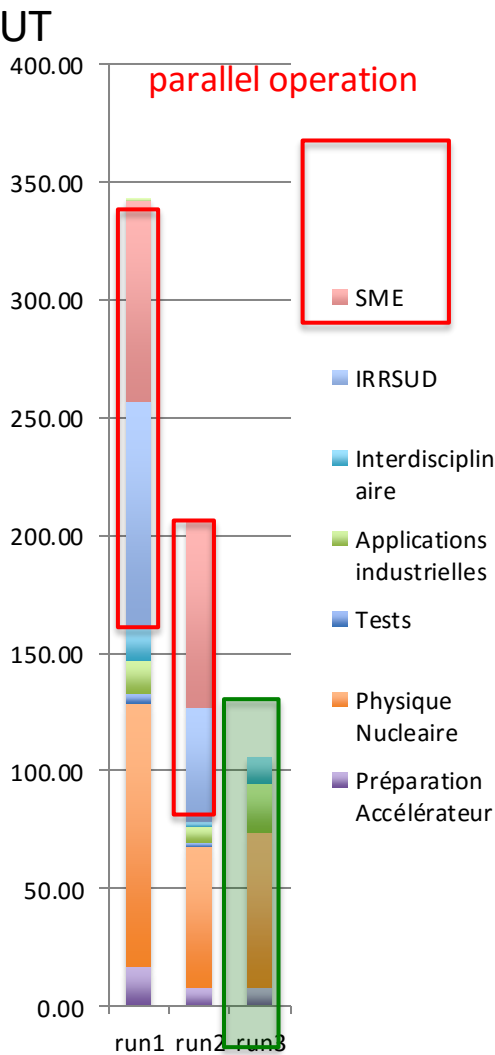


Presently On hold...



Operation

Date	hour	C01	C02	CSS1, CSS2	CIME	SME	Auxiliary beam
Thursday 20-Jul	2h00	P1174					
	6h00						
	11h00	<div>Up to four experiments in parallel</div> <ul style="list-style-type: none">CSS1/2IRRSUDCIMESME					
	11h00						
	11h00						
	22h00						
Friday 21-Jul	2h00						T17-03 (G.F. Grinyer) ACTAR TPC 3,5 UT
	6h00						G3
	11h00						
	11h00						
	11h00						
	22h00						
Saturday 22-Jul	2h00						
	6h00						
	11h00						
	11h00						
	11h00						
	22h00						
Sunday 23-Jul	22h00						
	2h00						
	6h00						
	10h00	P1075 (K. Marquardt E. Gardes)					
	14h00						
	18h00						
Monday 24-Jul	22h00						
	2h00						
	6h00						
	10h00						
	14h00						
	18h00						
Tuesday 25-Jul	22h00						
	2h00						
	6h00						
	10h00						
	14h00						
	18h00						
Wednesday 26-Jul	22h00						
	2h00						
	6h00						
	10h00						
	14h00						
	18h00						



Planning in progress Run3