Study of very Heavy Nuclei at GANIL-SPIRAL2 facilities

Super Heavy Nuclei International Symposium
Texas A & M University, College Station TX, USA
March 31 - April 02, 2015

Christelle Stodel (GANIL)

Study of very Heavy Nuclei at GANIL-SPIRAL2 facilities

- **SPIRAL 2 Facility**
  - ✓ LINAG
  - ✓ NFS
  - ✓ 
    - ❖ Physics cases
    - ❖ Technical description
    - ❖ Targets issues
- **GANIL**
  - ✓ decay spectroscopy of ^{257}Db
  - ✓ AGATA campaign
- **Conclusions and Perspectives**

Study of very Heavy Nuclei at GANIL-SPIRAL2 facilities

- **SPIRAL 2 Facility**
  - ✓ LINAG
  - ✓ NFS
  - ✓ 
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    - ❖ Technical description
    - ❖ Targets issues
- GANIL
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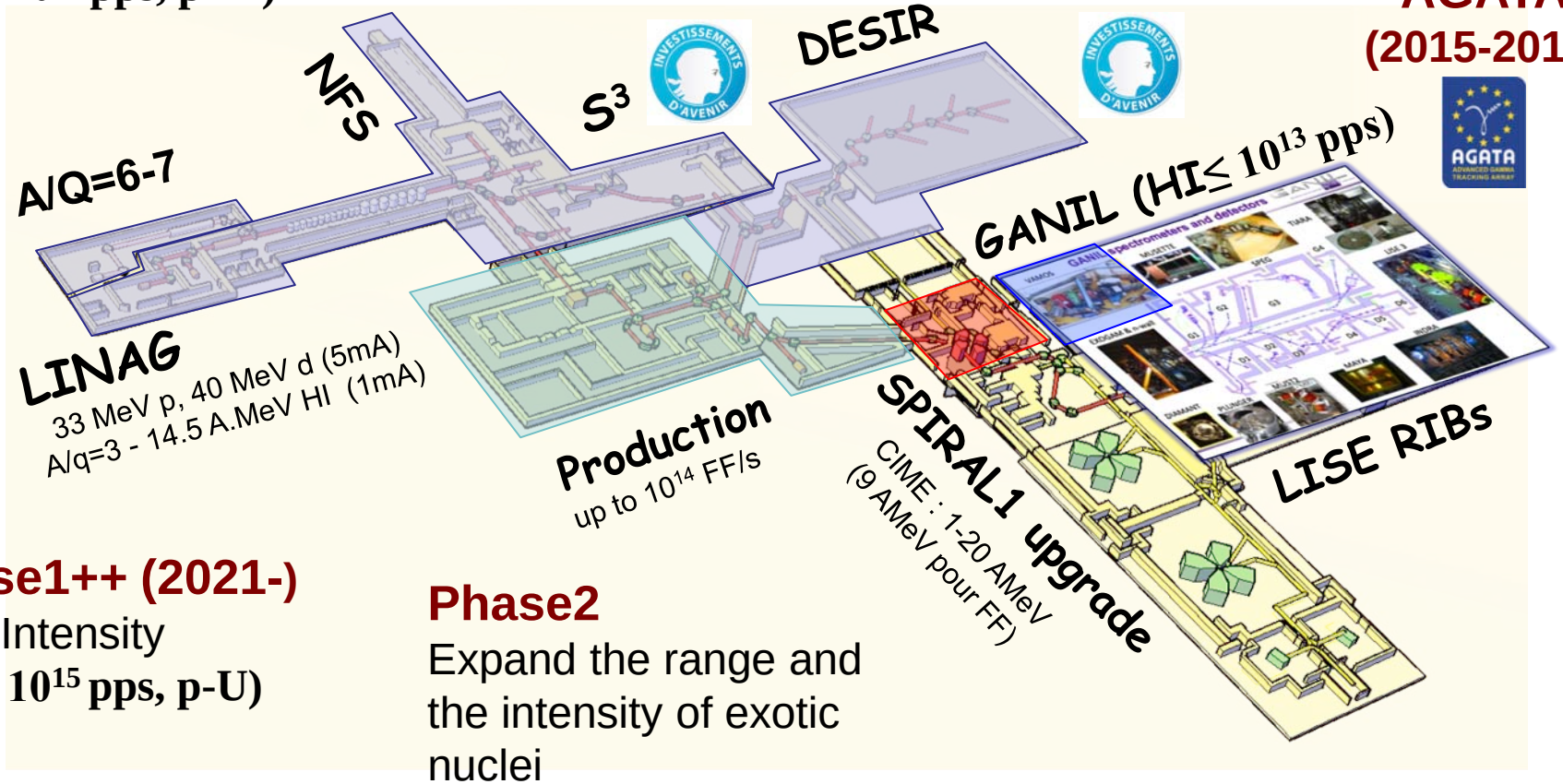
  - ✓ AGATA campaign
- Conclusions and Perspectives

mid term roadmap

Phase1 (2015-)
Increase the intensity of stable beams
High intense neutron source
(HI≤ 10^{15} pps, p-Ni)

DESIR Phase1+ (2019-)
Low energy facility

AGATA (2015-2018)



Phase1++ (2021-)
High Intensity
(HI≤ 10^{15} pps, p-U)

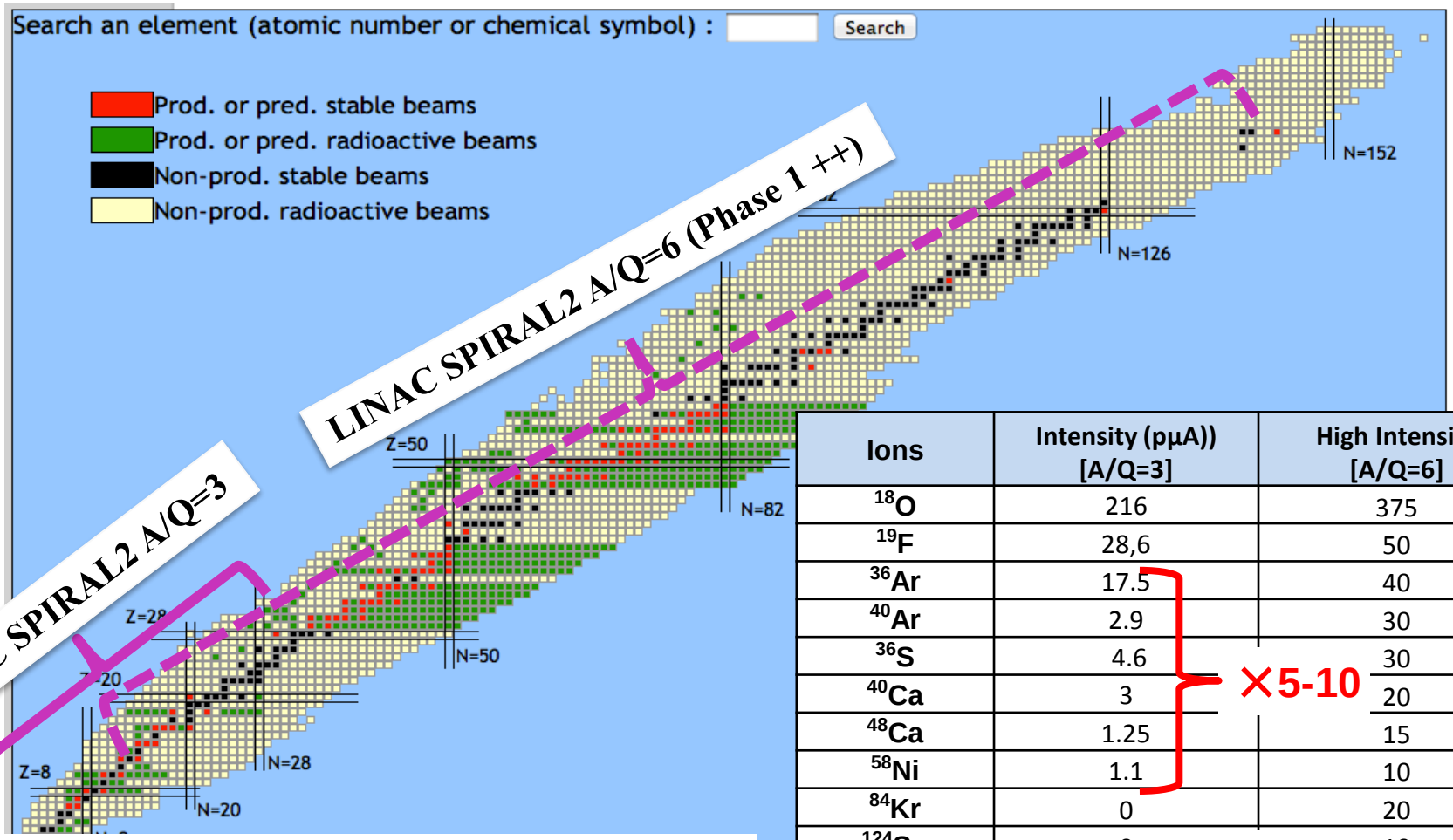
Phase2
Expand the range and the intensity of exotic nuclei

A National & EU priority

SPIRAL1 Upgrade (2016-)
New light RIBs from beam/target fragmentation

High Intensity Project (SPIRAL2 Phase 1++)

- ◎ **Reference project ≤ 10^{15} pps, p-Ni, 0.75 MeV/n – 14.5 MeV/n**
- ◎ **Phase 1++ ≤ 10^{15} pps, p-U, 0.75 MeV/n – 10 MeV/n**



Ions	Intensity (pμA)) [A/Q=3]	High Intensity [A/Q=6]
^{18}O	216	375
^{19}F	28,6	50
^{36}Ar	17.5	40
^{40}Ar	2.9	30
^{36}S	4.6	30
^{40}Ca	3	20
^{48}Ca	1.25	15
^{58}Ni	1.1	10
^{84}Kr	0	20
^{124}Sn	0	10
^{139}Xe	0	10
^{238}U	0	2.5

×5-10

×10^{x}

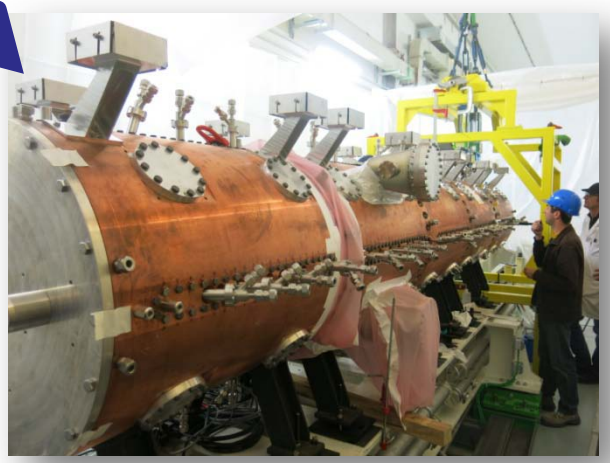
- ➢ Strenghten the phase 1+ scientific program
- ➢ Open new perspectives (Pb,U heavy beams)

SPIRAL2 Phase 1++ civil construction is finished

September 2014

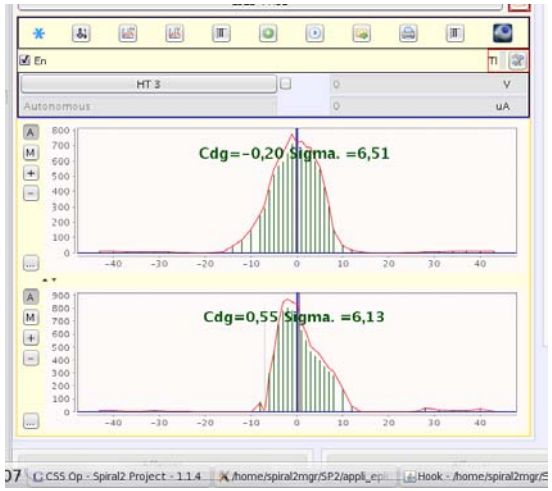
Installation

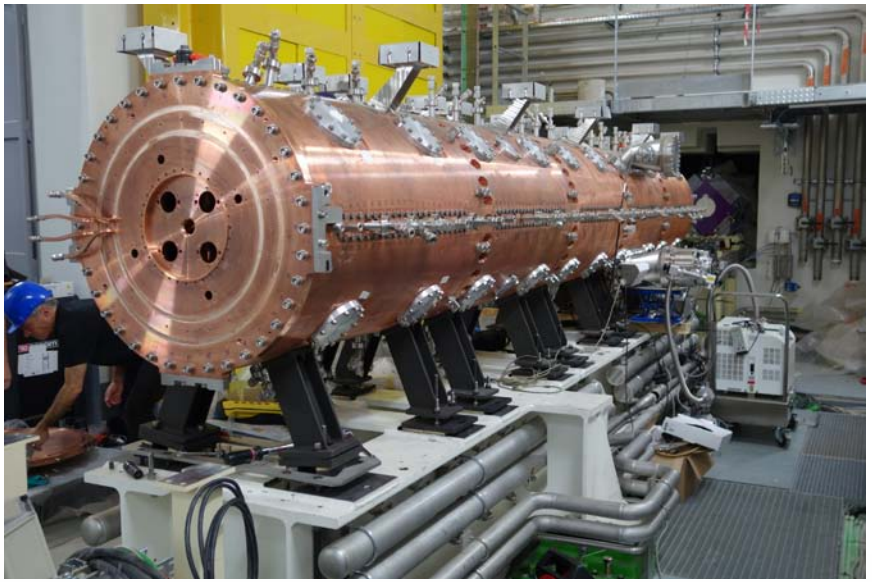
LINAC beams in 2015

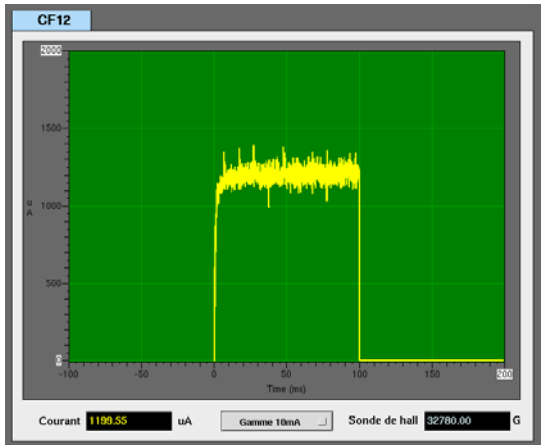


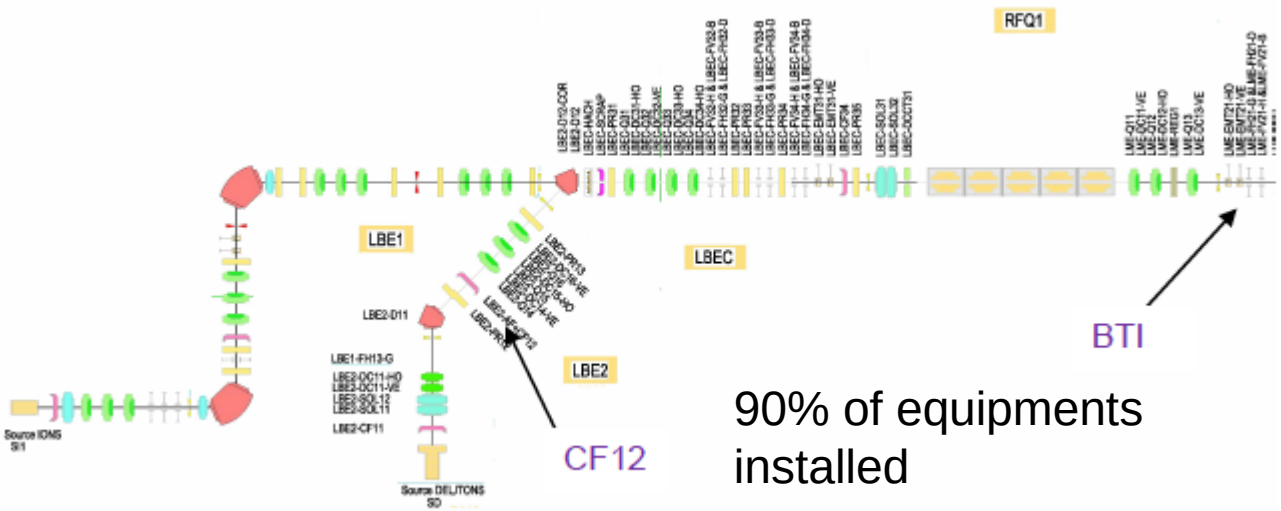
SPIRAL2 - LINAG

December 19th-22nd 2015: 7,7mA H^+ on CF11





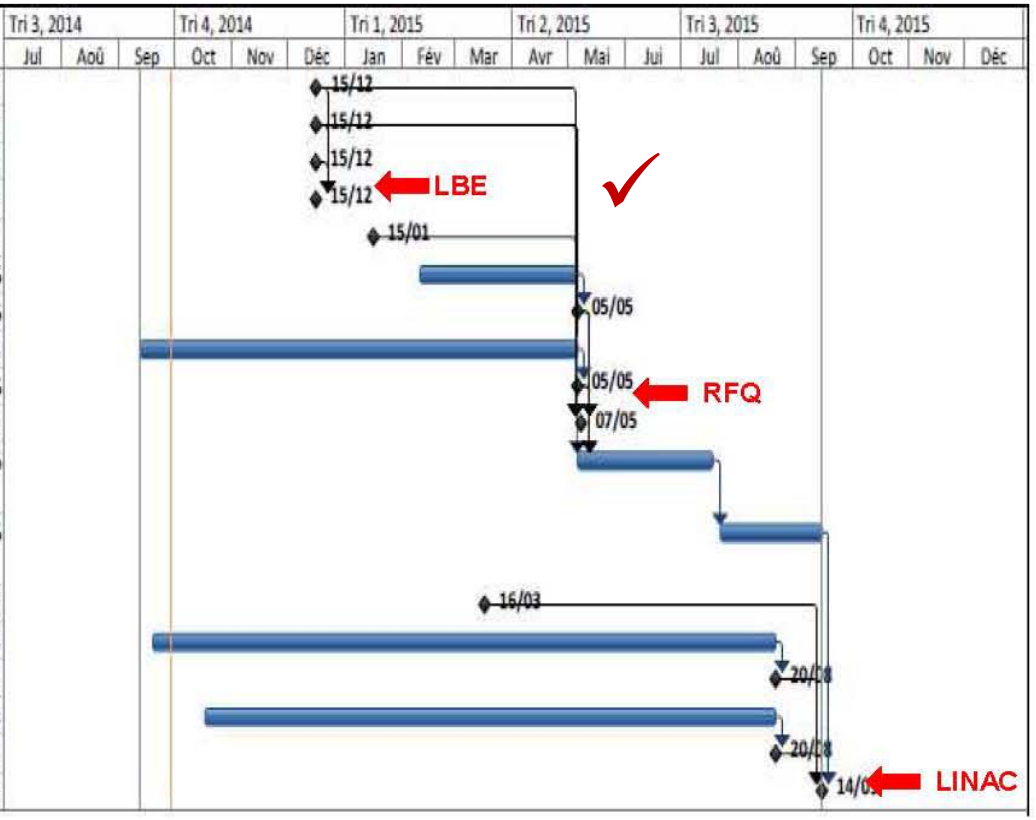




SPIRAL2 - LINAG

Planning de démarrage

N°	Nom de la tâche	Durée	Début
1	Source 1/2 et LBE2 prêts	0 jour	Lun 15/12/14
2	Source 1/3 et LBE1 prêts	0 jour	Lun 15/12/14
3	LBEC prête jusqu'à PR35	0 jour	Lun 15/12/14
4	Sources et LBEs opérationnelles	0 jour	Lun 15/12/14
5	LBEC prête pour tests RFQ-BTI	0 jour	Jeu 15/01/15
6	Installation LME & BTI et tests	3 mois	Mar 10/02/15
7	LME & BTI prêts	0 jour	Mar 05/05/15
8	Installation du RFQ et formation cavité	8 mois	Ven 12/09/14
9	RFQ prêt	0 jour	Mar 05/05/15
10	RFQ et LME-BTI opérationnels	0 jour	Jeu 07/05/15
11	Tests avec faisceau des sources, des LBE, du RFQ et du BTI	2,5 mois	Mer 06/05/15
12	Démontage BTI, montage LME 1ère et 2ème section et tests	1,5 mois	Mer 22/07/15
13	LBEC prête	0 jour	Lun 16/03/15
14	Installation LINAC et tests	11 mois	Ven 19/09/14
15	LINAC prêt	0 jour	Jeu 20/08/15
16	Installation équipements LHE et tests	10 mois	Ven 17/10/14
17	LHE prête	0 jour	Jeu 20/08/15
18	LME, LINAC et LHE opérationnels	0 jour	Lun 14/09/15



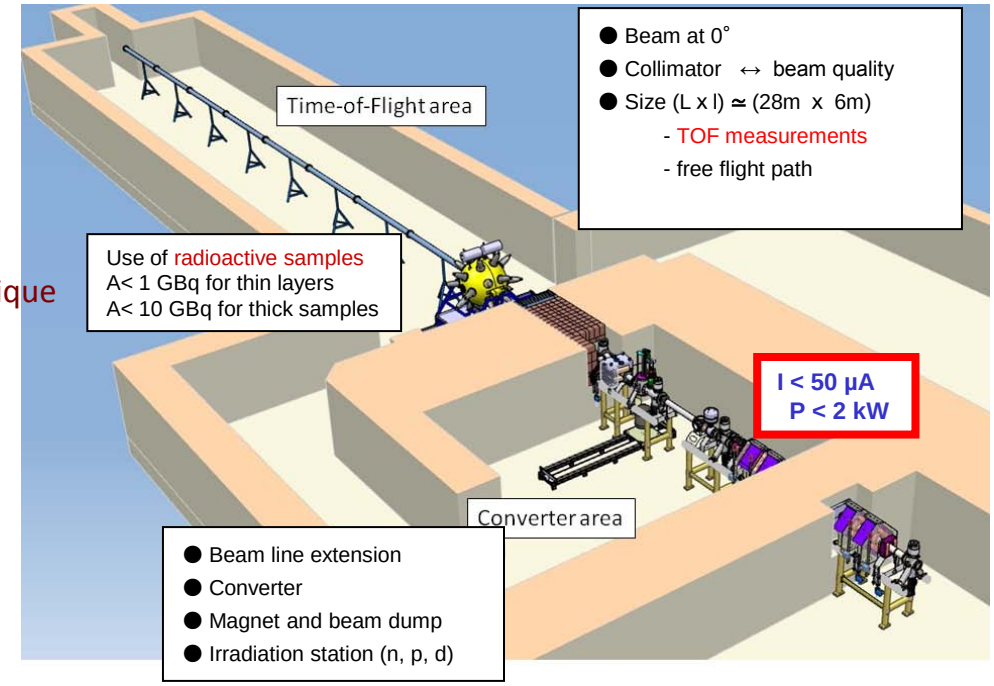
Objectif ambitieux de démarrer la source protons et LBE2 avant Noël 2014

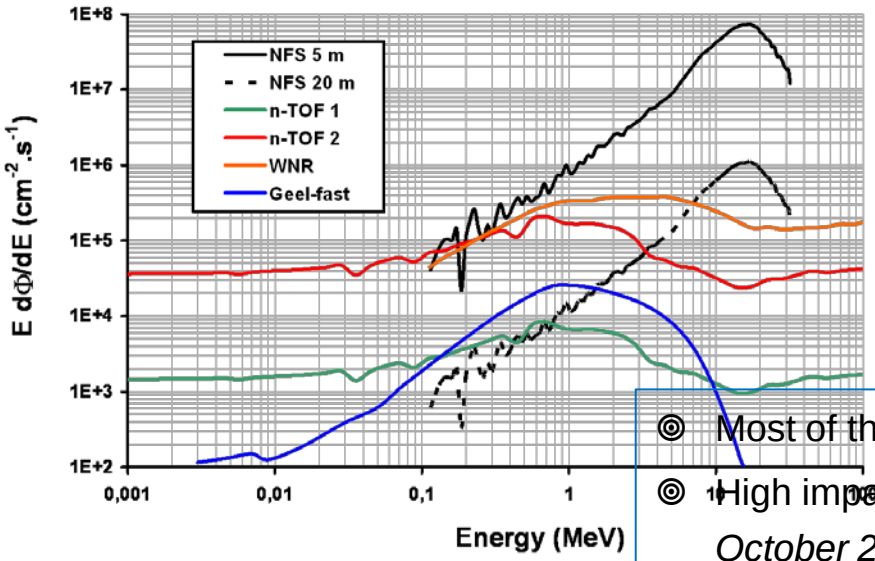
http://pro.ganil-spiral2.eu/events/weeks/ganil-spiral2-week-2014

Neutrons For Science

Physics cases (19 LOIs):

- ✓ Neutron induced reactions studies (n, xlcp) (n,xn)
- ✓ Fission studies
- ✓ Cross-section reaction measurements by activation technique
- ✓ Biology
- ✓ Detector development





- ◎ Most of the detection systems setups already exist
- ◎ High impact day 1 experiments for first SPIRAL2 beams (***PAC** October 2015)*
- ◎ R&D for the production of radioisotopes (^{211}At & ^{64}Cu)

By courtesy of X. Ledoux

Super Separator Spectrometer

The project & the physics opportunities

S³ Collaboration (LoI signed by 28 laboratoires)

ANL (US), CENBG, CSNSM, JINR-FLNR, (Russia), GANIL, France, GSI (Germany), INFN Legnaro, (Italy), IPHC, France, IPNL, , Irfu CEA Saclay, IPNO, France, JYFL (Finland), K.U. Leuven (Belgium), Liverpool-U, (UK), LNS (Italy), LPSC, MSU (US), LMU, (Germany), Nanjing-U (China), Northern Illinois University (US), SAS Bratislava, (Slovaquia), IFJ PAN Cracow (Poland), Smoluchowski Institute (Poland), CEA-DAM; SUBATECH, TAMU (US), U. Mainz (Germany), York-U (UK), Vinca Institute (Serbia)

Physics goals

Study of rare events in nuclear and atomic physics

$^{58}Ni+^{46}Ti \rightarrow ^{100}Sn + 4n$
(I=10pμA) ➔ 3evt/s @ σ_{th}=5nb

Nuclei produced by Fusion-Evaporation

Proton Dripline & N=Z nuclei
- Tests of Shell Model
- Shapes of nuclei
- Exotic decay
- Ground-State Properties

$^{48}Ca+^{238}U \rightarrow ^{-283}112+3,4n$
(I=10pμA) ➔20evt/week/pb

erheavy

and Structure
- Reaction mechanism
- Ground-State Properties
- Synthesis

High Resolution and High Transmission versatile separator-spectrometer

Nuclei produced by nucleon transfer reaction

Neutron-Rich Nuclei
- Single-Particle structure
- Quenching of Shell Gaps

Ion-Ion interactions

Atomic physics
FISIC project

➔ test nuclear and atomic models and guide new theoretical development

Day1 experiments: VHE - SHE

◎ SHE Synthesis

I=10pμA

➔ 1evt/month@σ~10fb

◎ Reaction studies

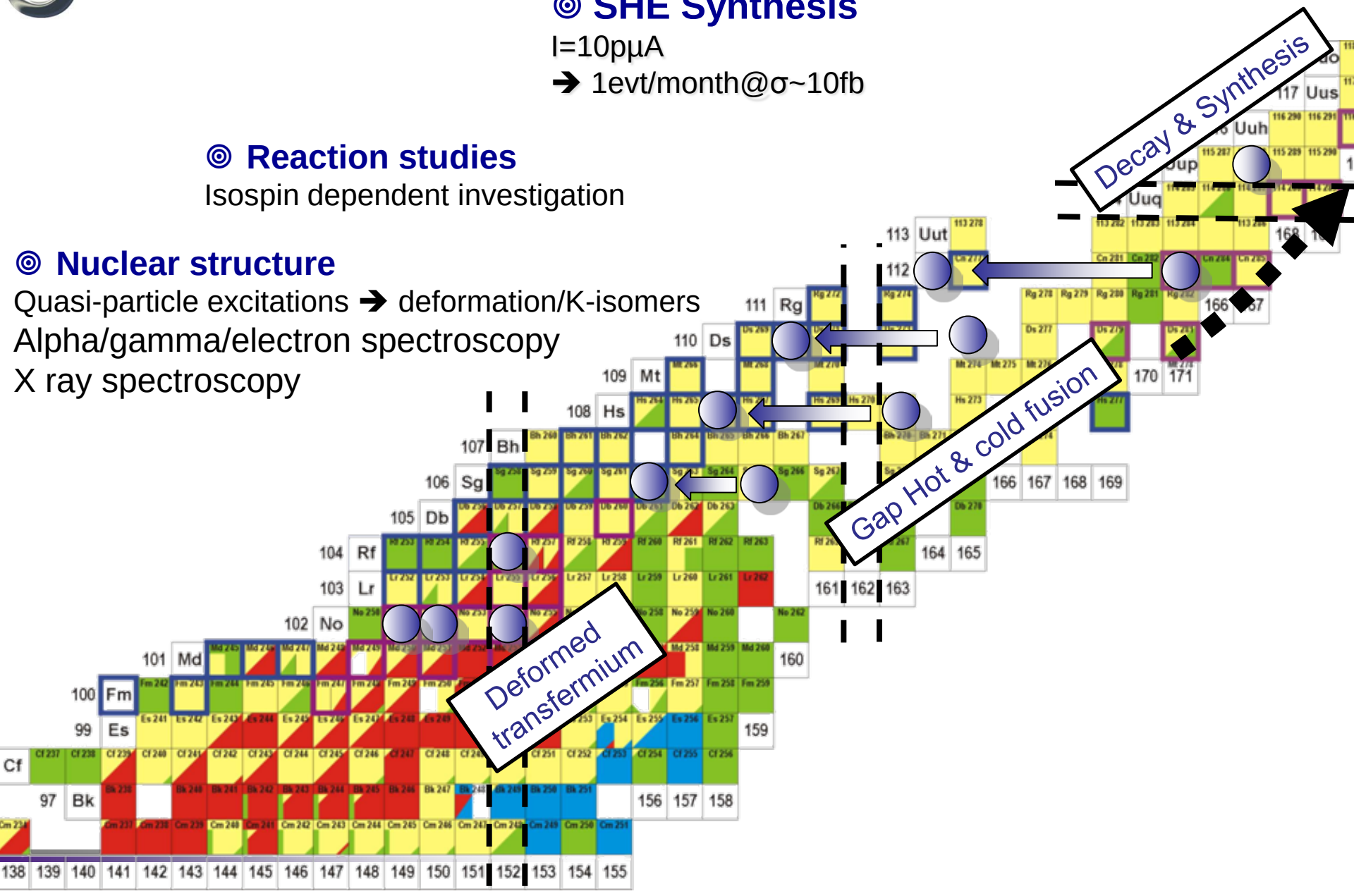
Isospin dependent investigation

◎ Nuclear structure

Quasi-particle excitations ➔ deformation/K-isomers

Alpha/gamma/electron spectroscopy

X ray spectroscopy



Day1 experiments: VHE - SHE

nuclide	feature	X-section [nb]	rate [h^{-1}]	21UT integral	
				day 1	phase 1++
^{254}No	**ER**	2000	60.000	**1×10^{7}**	6×10^{7}
^{256}Rf	**ER**	17	550	**90.000**	5.4×10^{5}
^{266}Hs	**ER**	15 (^{270}Ds)	0.34	**57**	285
^{266m}Hs	**K-isomer**	15 (^{270}Ds)	0.01	**2.5**	12.5
^{270}Ds	**ER**	15	0.45	**76**	380
^{270m}Ds	**K-isomer**	15 (^{270}Ds)	0.22	**38**	190
^{262}Sg	**α-decay**	15 (^{270}Ds)	0.02	**5**	25
^{276}Cn	**ER**	0.5 (^{277}Cn)	0.01	*2.5*	*12.5*
^{288}115	**ER**	10	0.3	*50*	*300*
^{288}115	**L X-rays**	10	1,8	*300*	*1800*

LoI 2009:

"Production and spectroscopy of heavy and superheavy elements using S^3 and LINAG"

- *Neutron deficient nuclei around Z=92 N=126*
- *K-isomerism studies in the Z=100-110 region*
- *study of neutron rich isotopes produced by asymmetric reactions*
- *Production of SHE with Z=106-108-112 with Uranium target*

Addendum 2012:

"Detailed spectroscopy of high-K states in ^{254}No and ^{256}Rf: location of single---particle states close to the Z=100 and N=152 deformed shell gaps"

(Univ Jyvaskyla, CSNSM, GANIL, IRFU and S3 coll)

"Towards the study of Z=115 via the reaction ^{48}Ca + ^{243}Am"

(JINR, GANIL and S3 coll)

Talk of J. Gates on Tuesday

SIRIUS needed

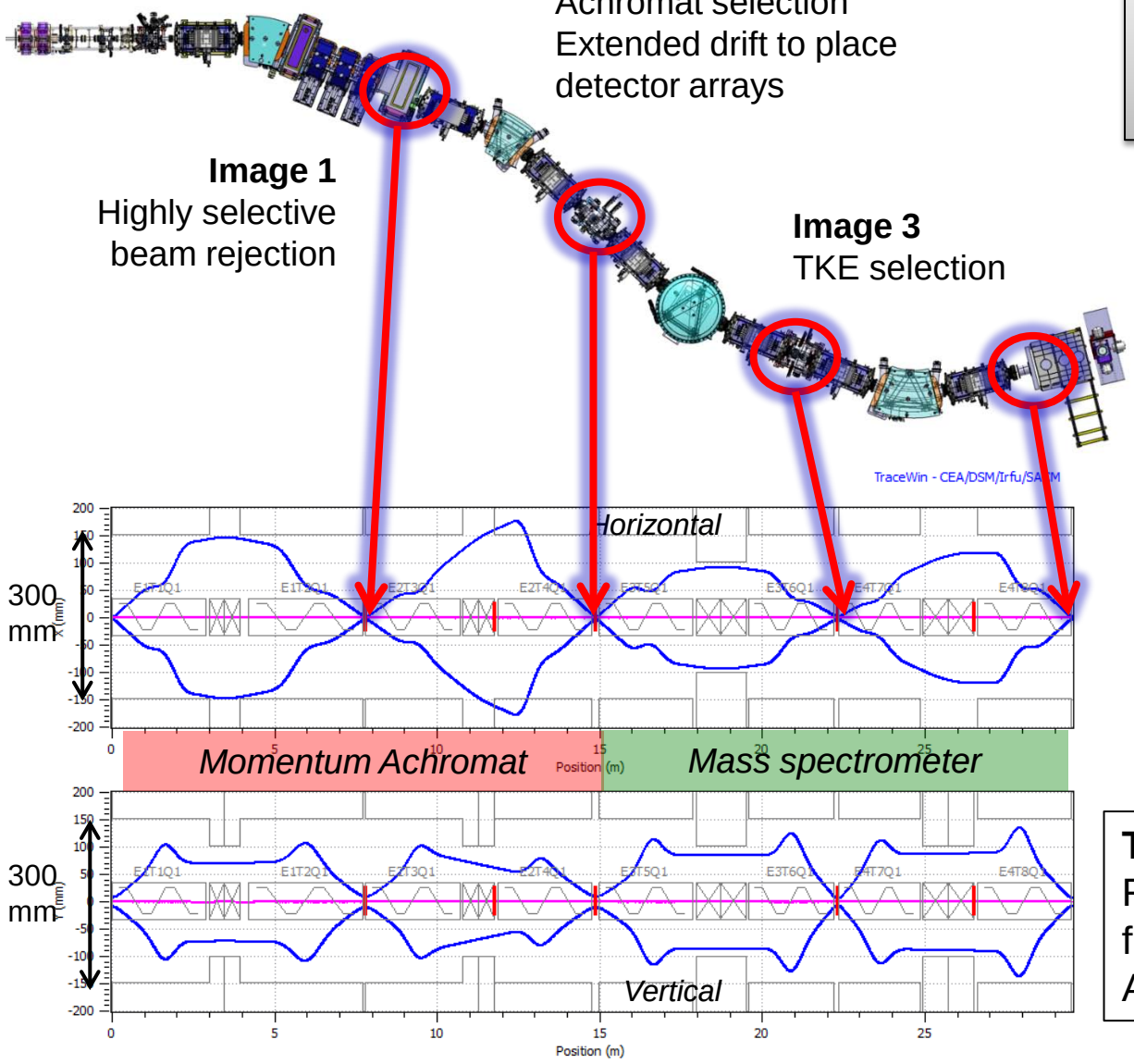
Z > 112 ➔ Actinide targets

Optics

Image 2
Achromat selection
Extended drift to place detector arrays

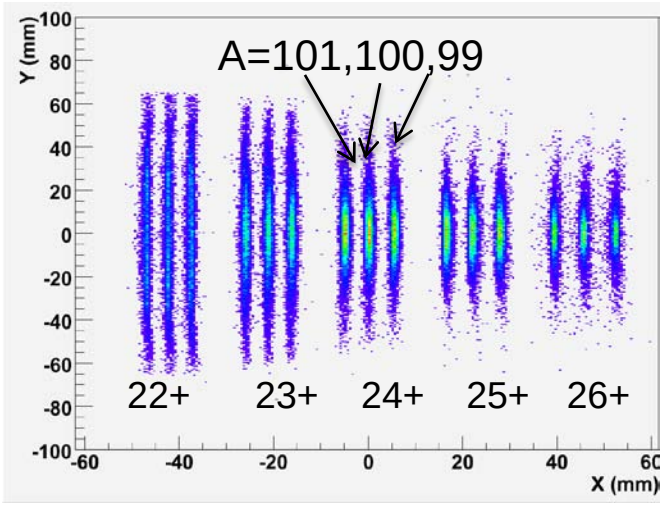
Image 1
Highly selective beam rejection

Image 3
TKE selection



- Multistep separation
- Large acceptance
- Mass resolution (ΔM/M=460)

Image 4 : Mass selection



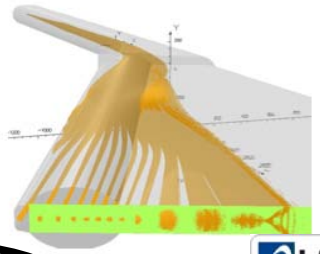
Tracewin simulation code (Irfu):
Full raytracing in the multipole 3D field maps
Automatic optimisation of **80 fields**

Technical highlight

Beam spot :
σ_X=0.5mm, σ_Y[0.5-2.5mm]
Energy precision ≈5.10^{-3}

Dispersive zone

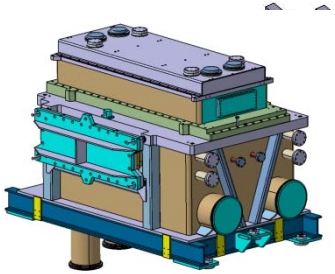
(beam dump & Movable fingers)

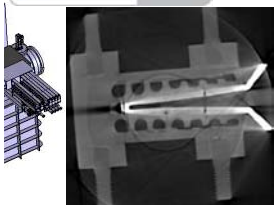


Open triplet

SIGMAPHI
T2 2015

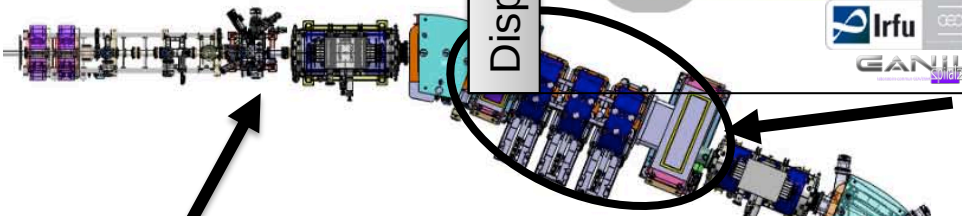
PLUG Beam dump



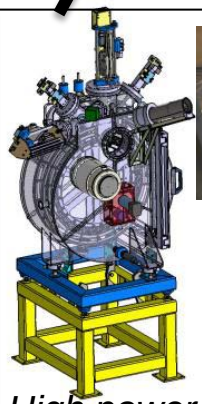


SOMINEX – T4 2015

tested for 5kW/cm²



Target stations



High power rotating targets
(3000-5000 rpm)
Stable & Actinide systems
Integration T2 2015
SOMINEX

3 × M-dipoles

Large H & V gaps
SIGMAPHI + HAZMEYER
2014

E-Dipole

20 cm gap & +/- 350 kV
Epmax : 12-14 MeV
Open slit in the anode
T4 2015

SC Multipoles

Q+S+O fields

Cryomagnetics
2015-2016

All hardware components are under final construction
Installation completed by september 2016

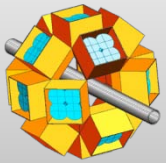
Experimental Techniques

GANIL,IPHC, CSNSM, CEA/Irfu/SPhN

Phase 3

In-beam spectroscopy

Two step reactions
EXOGAM2
PARIS- AGATA
MUST2/GASPARD

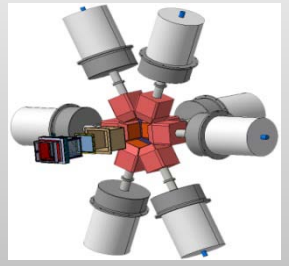


Not in the scope of the project

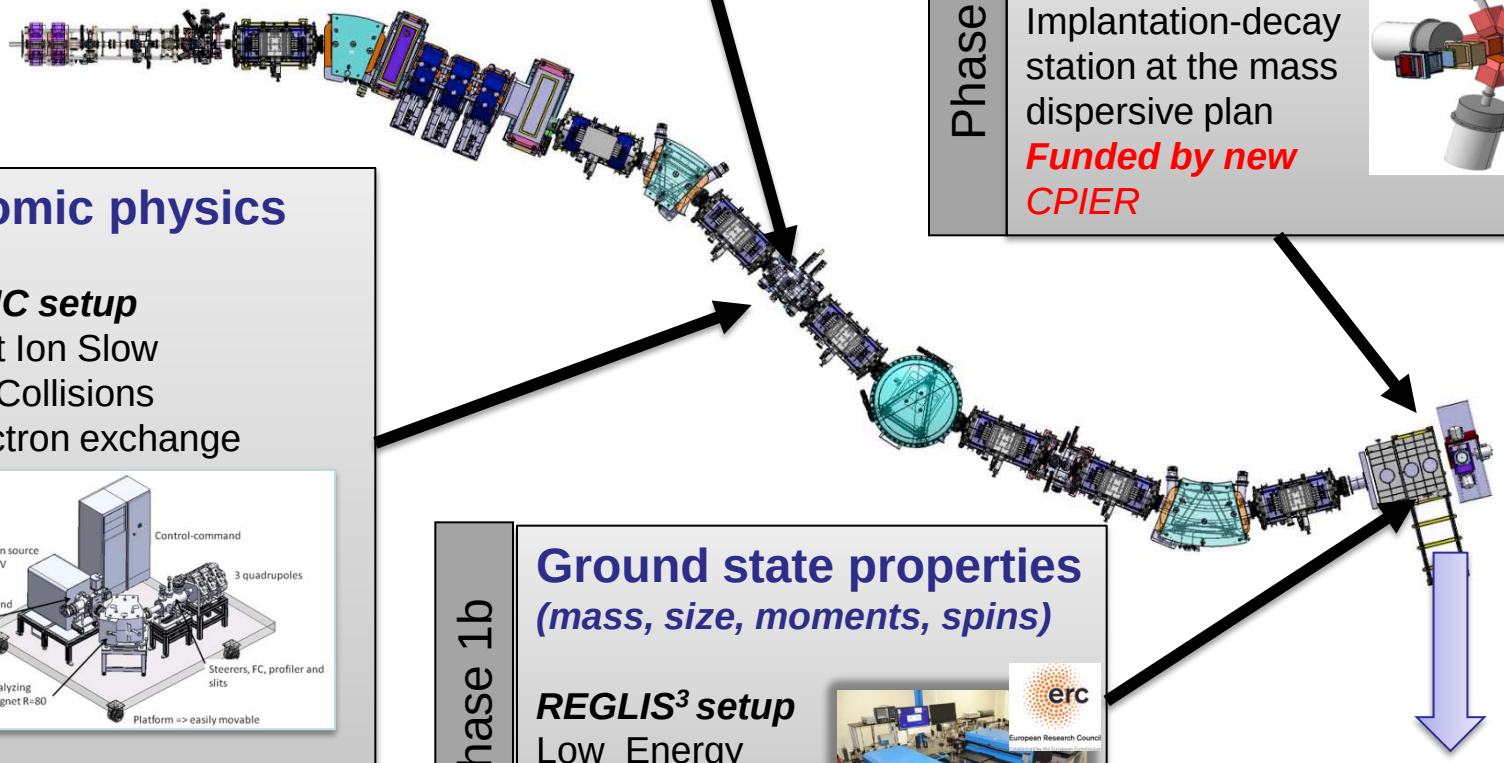
Phase 1a

Delayed spectroscopy

SIRIUS setup
Implantation-decay station at the mass dispersive plan



Funded by new
CPIER



Phase 2

Atomic physics

FISIC setup
Fast Ion Slow
Ion Collisions
Electron exchange

Partially Funded
INSP-CIMAP-JENA/GSI
+ new CPIER

Phase 1b

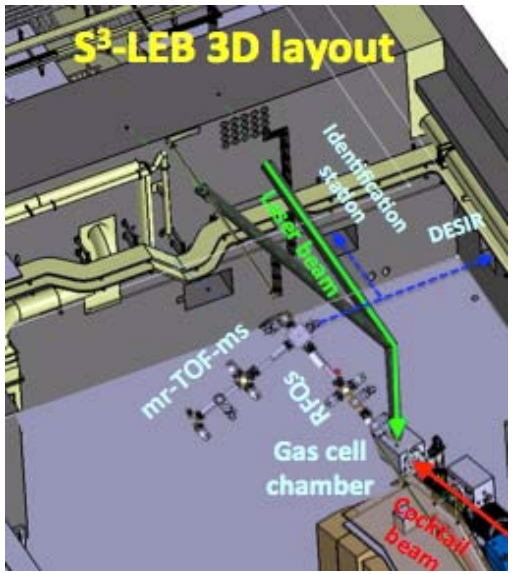
Ground state properties
(mass, size, moments, spins)

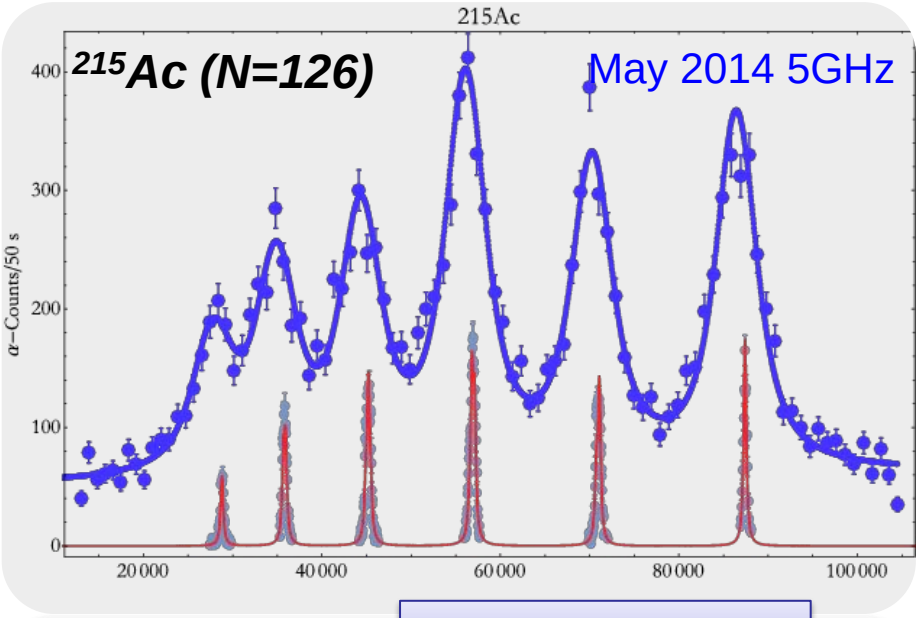
REGLIS³ setup
Low Energy
Branch

Funded

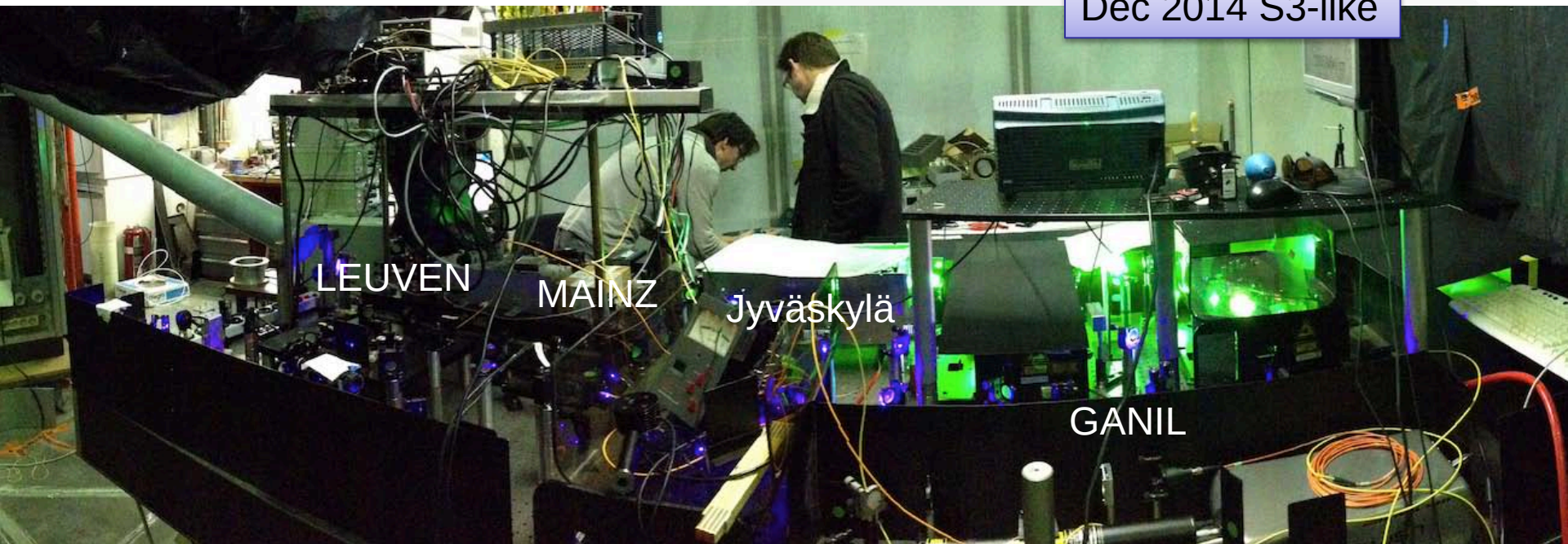
DESIR

REGLIS³ day 1 experiments





Dec 2014 S3-like



Target stations for S3 SUPER SEPARATOR SPECTROMETER

- Prototype Actinide target station
  - ✓ Design & Conception
  - ✓ Target irradiations
- First stable target station

Requirements

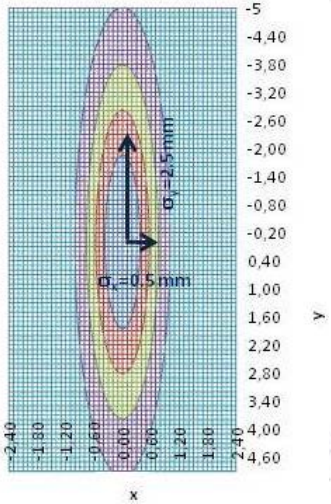
^{70}Zn (10pμA) + ^{208}Pb → $^{278}112$*

Stable

^{208}Pb, ^{209}Bi, Ni, Ca, C....

0,3 -2 mg/cm²

(R ≈ 35 cm)



Stripper

C, Al

30-100 µg/cm²

^{48}Ca (10pμA) + ^{248}Cm → $^{296}116$*

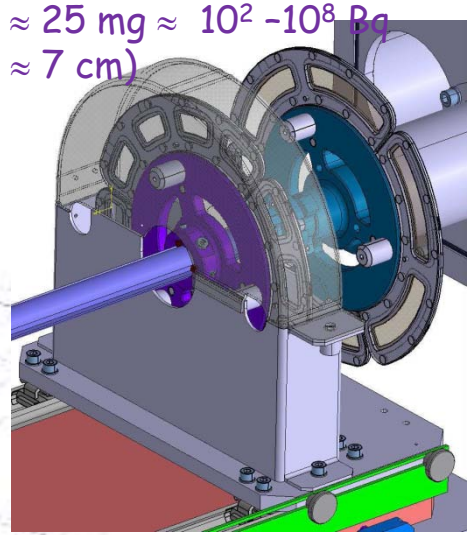
$^{48}Ca^{16+}$ 10pµA == 160µAe (phase 1)

Actinides

^{232}Th, ^{238}U, ^{239}Pu, ^{242}Pu, ^{244}Pu, ^{243}Am, ^{248}Cm

0,3 - 0,5 mg/cm² ≈ 25 mg ≈ 10^2 -10^8 Bq

(R ≈ 7 cm)



beam	^{70}Zn	^{48}Ca
E(MeV/u)	5	5
target	C/Pb/C	Ti/Cm/C
thickness (µg/cm²)	10/450/10	2µm/450/10
w (rpm)	**3000**	**5000**
R(cm)	**33,5**	**7**
Tmax < Tfus	Pb ou PbS	U ou $Cm(_2O_3)$
Imax (µAe)	90-800	100-400
DT +- 50°C		(Ti)
Imax (µAe)	60-80	30-70
dP (w)	35-50	15-35 (*3 Ti)

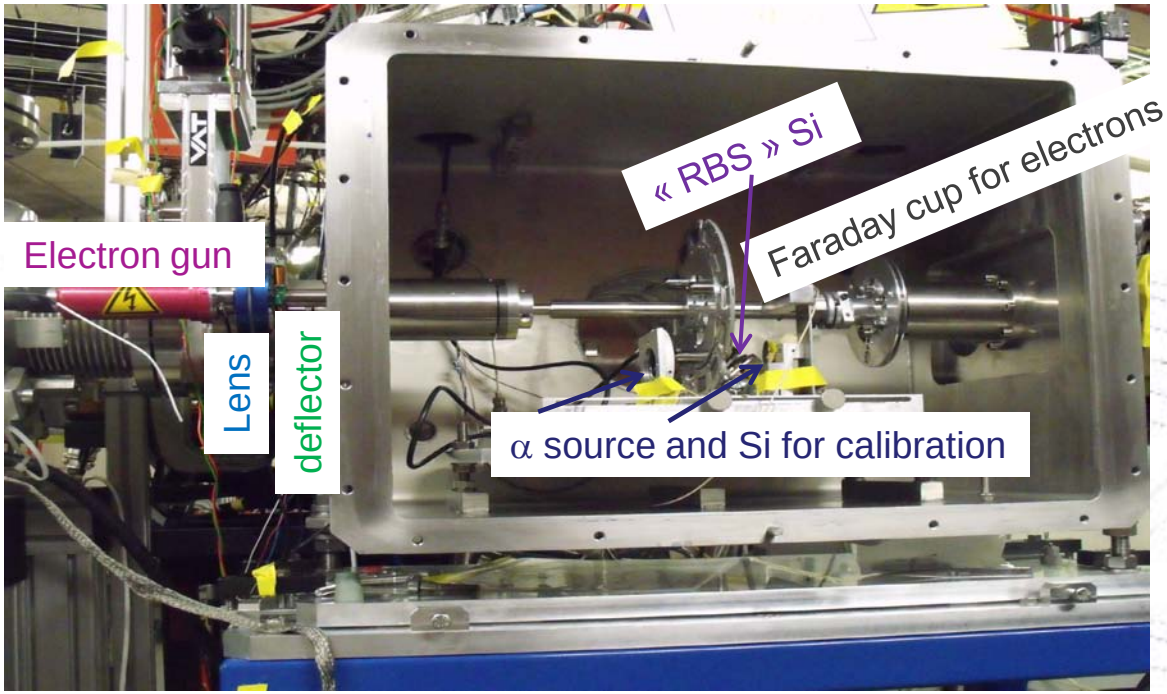
oxidation of backings, irradiation modification, sputtering….???

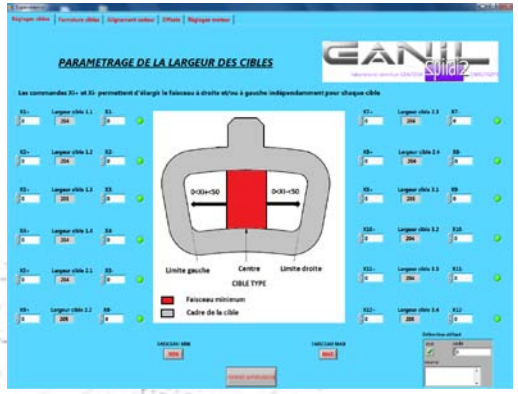
F. Pellemoine, SP2-NT-8514-I02018V0.0

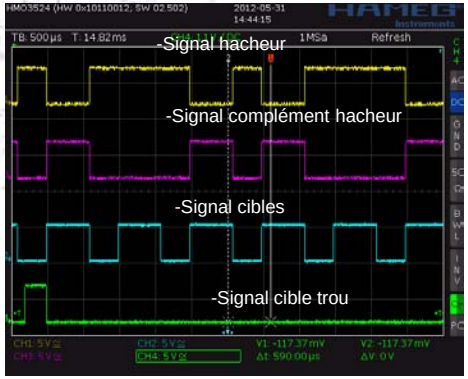
Prototype ActinideTarget Station

2009

- Reliability tests
- Instrumentation of the dedicated electronics for target control (e- beam, silicons…)







2011 - 2012

- command/control of target wheel
- GANIL beam tests (^{129}Xe @8 MeV/A, 250pnA)

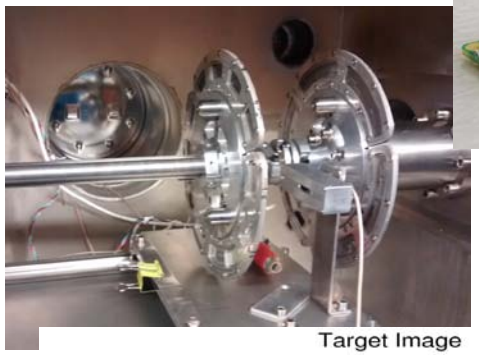
Ch. Stodel et al, JRNC 2015 (DOI) 10.1007/s10967-015-3936-5

S^3 target monitoring with an electron gun

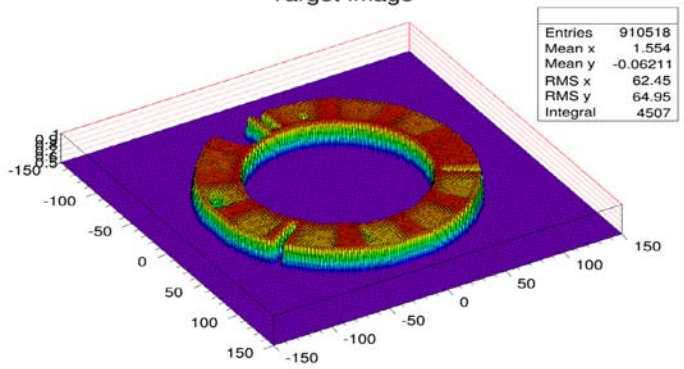
Test at LISE 2000 in 2014

Automated Scanning of the e-Gun using

Raspberry Pi and digital Potentiometer

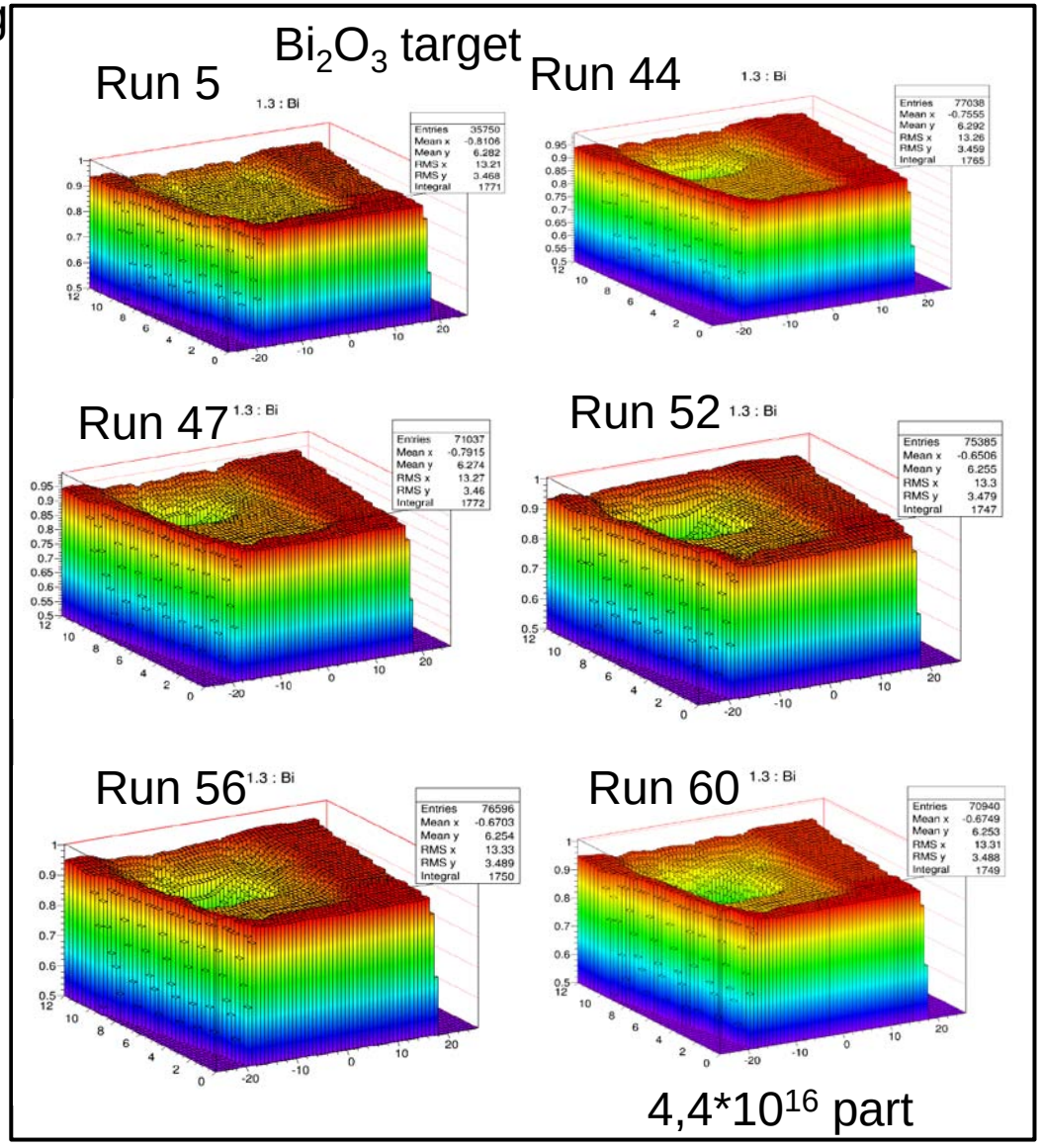


Target Image



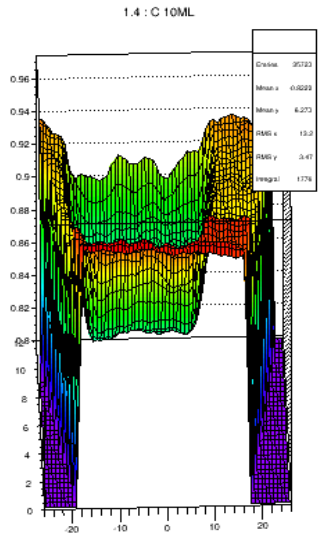
-Online 3D imaging of each target is possible

- We observed some degradation according to the material and the dose

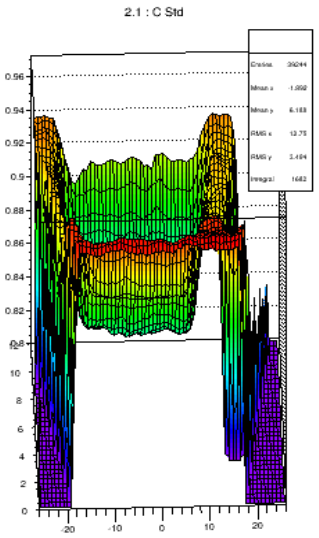


Carbon – 500 µg/cm²

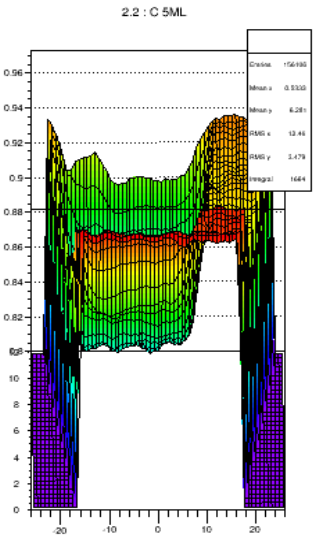
Before irradiation (R5)



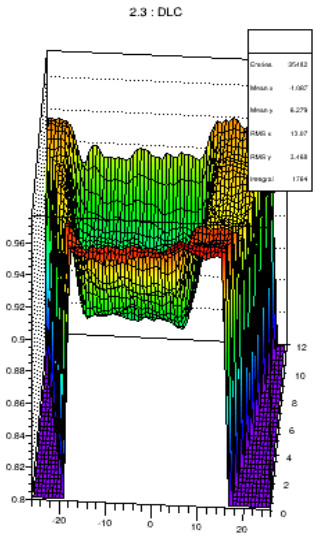
10 Multilayer



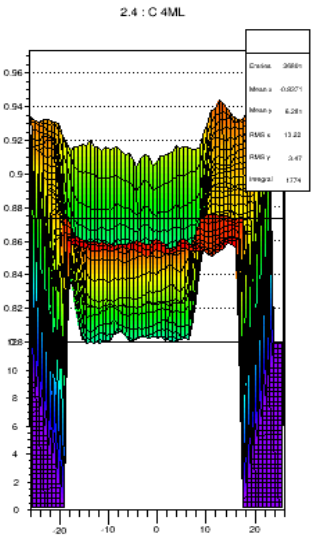
standard



5 Multilayer

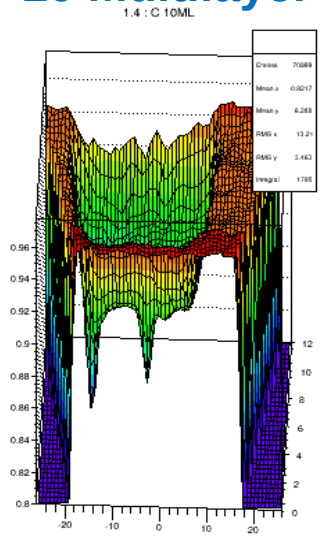


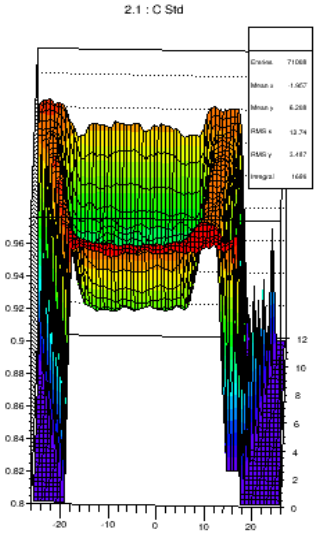
DLC

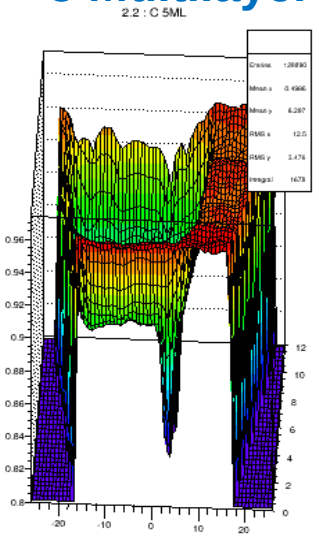


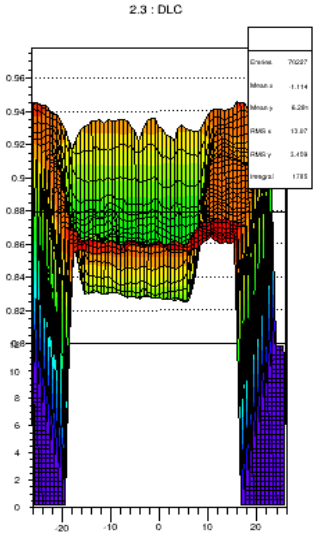
4 Multilayer

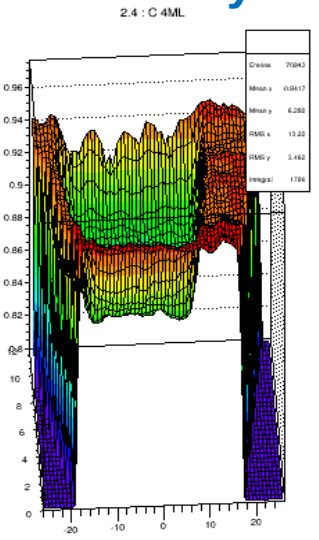
4.4E16 part (R60)





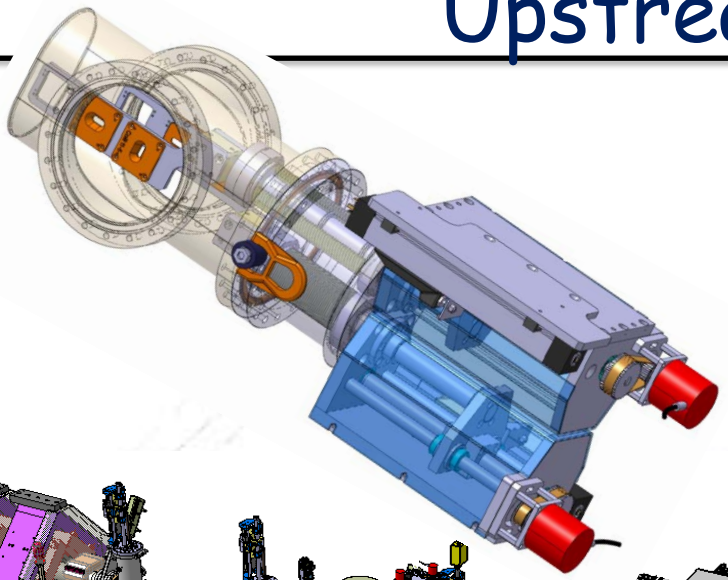




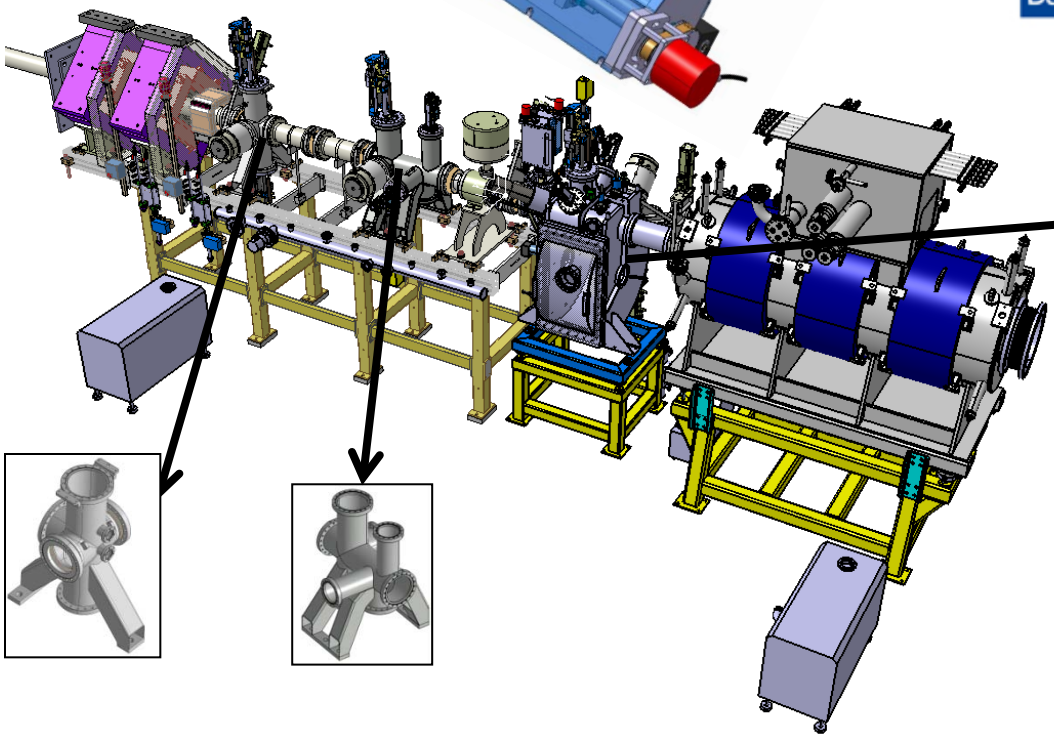


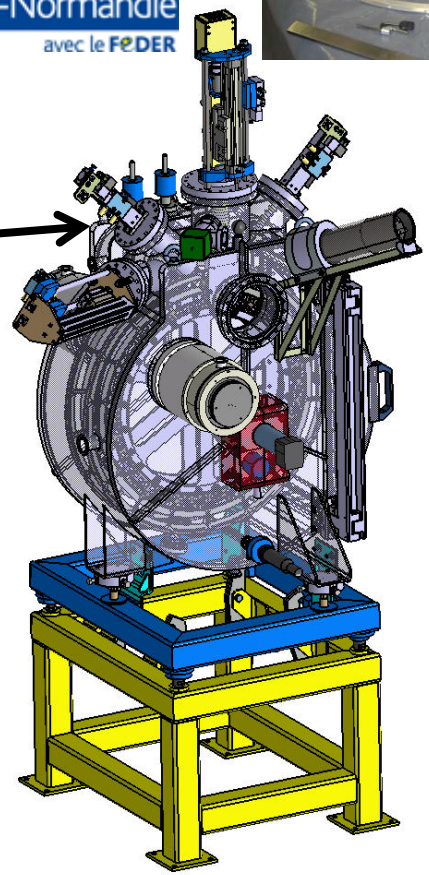
C Targets from W. Mittig, F. Pellemoine, MSU

Upstream beam line



Collimator with beam current measurement





F. Lutton, P.Gangnant, C. Marry, J.F. Libin, P. Lecomte …

Conclusions – Perspectives – SPIRAL2

2015

- LINAC under test
- First LINAC Beams end 2015-2016
- "Actinide test bench" available

- **1st S3 stable target station:**
  - Manufacture et receipt
  - Integration of instrumentation
  - Mechanical tests
  - Development of the Command/control
- Pyrometer / thermal camera

l'Europe s'engage en Basse-Normandie avec le FEDER

2016-2015

- Installation
- Off-beamTests
- commissioning

➢ **R&D target technologies**
- ✓ Cacao/GSI/MAINZ/Dubna …
- ✓ backings
- ✓ fabrication methods
- ✓ FISIC strippers
- ✓ Characterization

2017……

- Design + manufacture of **actinide station** + Glove box
- Tests with actinides targets

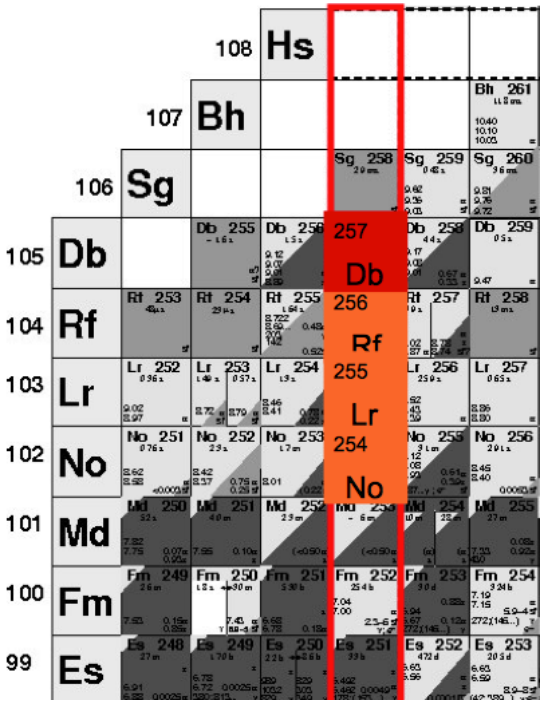
Study of very Heavy Nuclei at GANIL-SPIRAL2 facilities

- SPIRAL 2 Facility
  - ✓ LINAG
  - ✓ NFS
  - ✓ 
    - ❖ Physics cases
    - ❖ Technical description
    - ❖ Targets issues
- **GANIL**
  - ✓ **decay spectroscopy of ^{257}Db**
  - ✓ AGATA campaign
- Conclusions and Perspectives

Spectroscopy of ^{257}Db

J. Piot, M. Vostinar et al, (GANIL, IPHC, Dpt of Physics, Jyväskylä, GSI, DNPB, Bratislava, CEA, IRFU, LPC, CNSNSM, Dpt of Physics, Liverpool, JINR Dubna)

Measure new electromagnetic transitions in ^{257}Db, ^{253}Lr and ^{249}Md



152

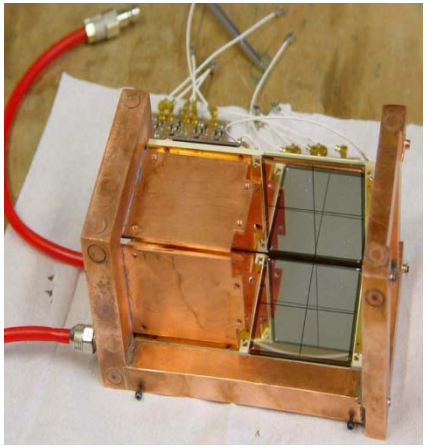
^{209}Bi(^{50}Ti,2n)^{257}Db σ=2.4 nb

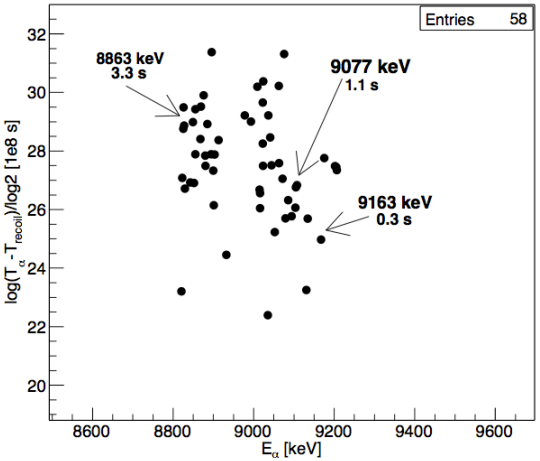
- Isomeric levels in ^{255}Lr [Hauschild *et al*. PRC, 2008.] and ^{256}Rf [Jeppesen *et al*. PRC, 2009.]
- ^{257}Db, ^{258}Sg?

Synthesis of ^{257}Db @ GANIL, LISE in FULIS MODE

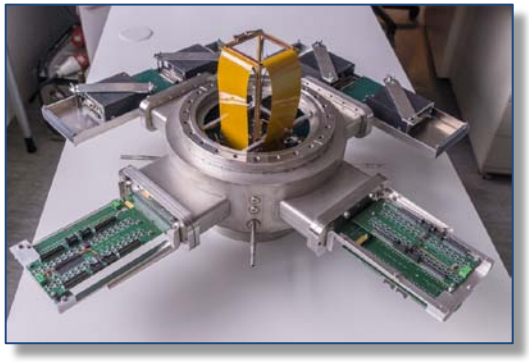
First experiment using ^{50}Ti GANIL - up to **0.5 pμA** on target
Separation by LISE **velocity filter Rejection : 3.10^{10}**
Transmission : 15% (➔ Gain factor 15-20 with S^3)

2013



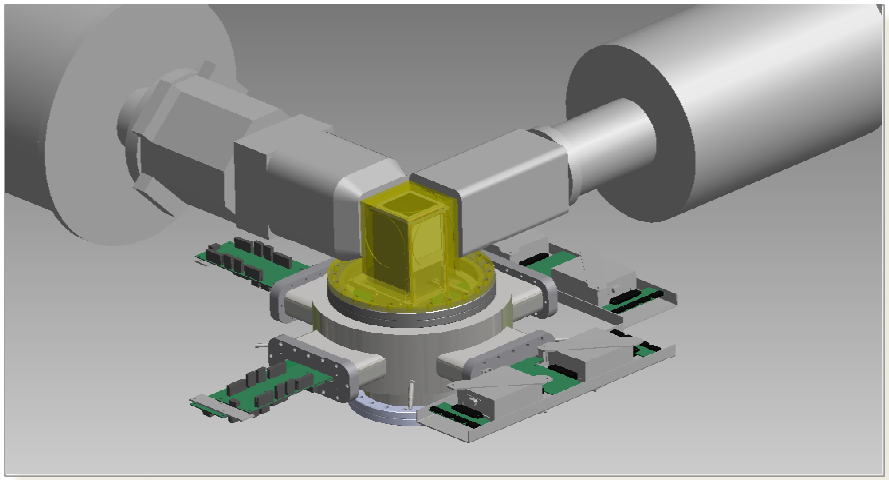


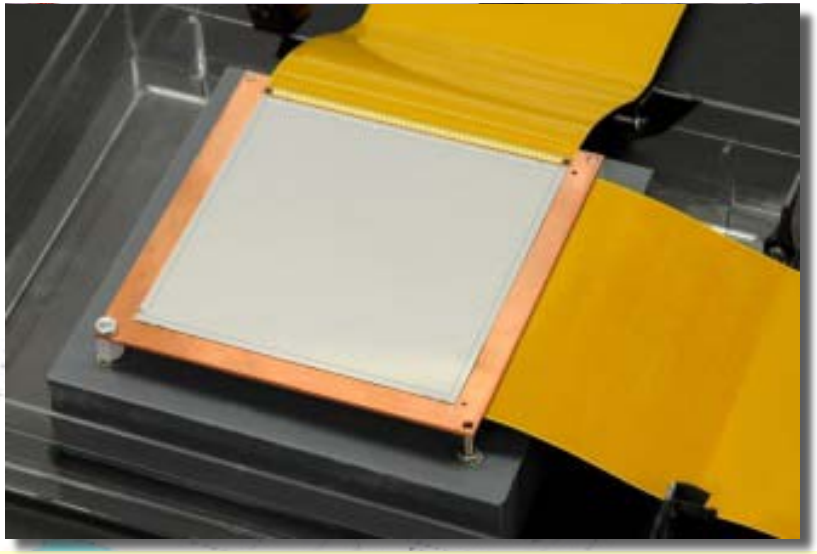
2014-2015



E656, E686 experiments : J. Piot & M. Vostinar (GANIL)

Mobile Decay Spectroscopy Set-up – MoDSS for SHE research
- Si stop+box (DSSD+SSSD) combined with large volume Ge-detectors





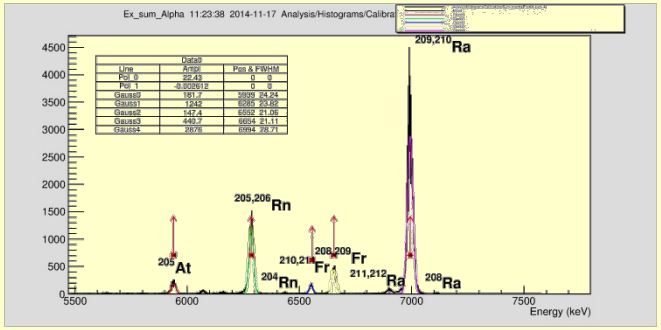
configuration
- *stop detector:* *1 × DSSD (60×60 strips)*
- *box detectors:* *4 × SSSD (32 strips)*
- *γ efficiency ≈ 40%*

chamber
- *compact (overall length 35 cm)*
- *Al-cap with thin γ window (1,5 mm)*
- *compatible due to 150 mm standard flange*

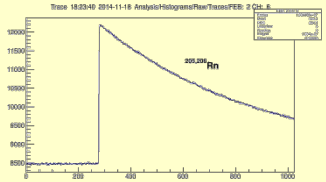
DSSD
- *integrated cooling (Cu-frame) and connection (flex-PCB)*
- *60×60 strips/mm (pitch 1 mm)*
- *300 µm*

electronics (partly integrated in the vacuum)
- *analog and digital (FEBEX) options*

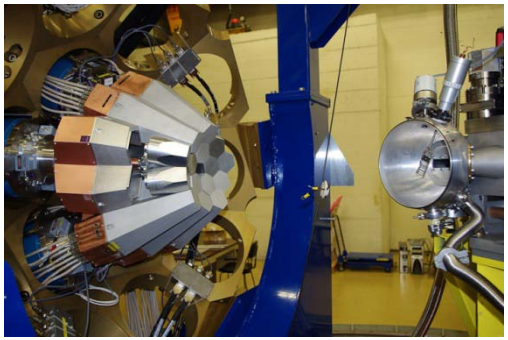
first α spectrum (test run at LISE/GANIL 2014)
(ΔE: 20 keV)



typical α-decay trace (FEBEX)



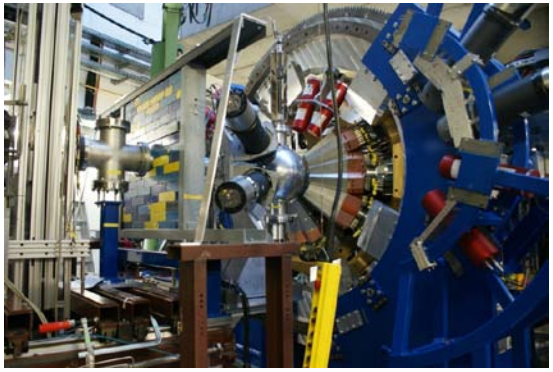
2010 → 2011
LNL : 5TC



AGATA D.+PRISMA

Total Eff $_{Nominal}$. ~2.6%

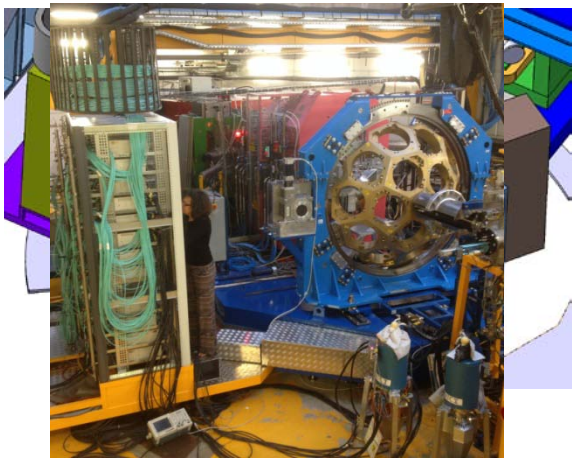
2012 → 2014
GSI/FRS : 6TC+3 DC



AGATA @ FRS

Total Eff. (β=0.5) ~ 10%

2014 → 2018
GANIL/SPIRAL2 : 15TC

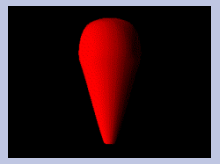


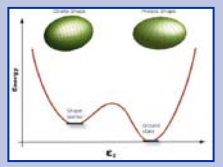
AGATA @G1 (→ π)

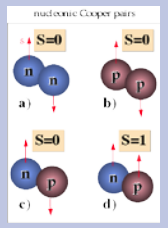
Total Eff ~ 8% to 14%

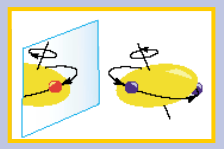
E. Clément, A. Lemasson, et al

Physics cases for the AGATA campaign in GANIL









$^{48}Ca,^{50}Ti \rightarrow$ SHE

^{256}Rf

^{254}No

Cm,Bk

Cf,Es

^{194}Pb

^{176}Hg

Sm,Pm

^{102}Sn

^{100}In

^{206}Hg

Dy,Er,Yb

Ru, Pd

^{80}Zr

$^{58}Ni,^{40}Ca \rightarrow$ N=Z

Xe,Te

Zr, Mo

^{77}Y

^{132}In

^{75}Sr

^{78}Ni ^{80}Zn

^{63}Ge

$^{68}Ni,Fe,Co,Cu$

^{46}Ti

$^{238}U,^{208}Pb \rightarrow$

^{38}K

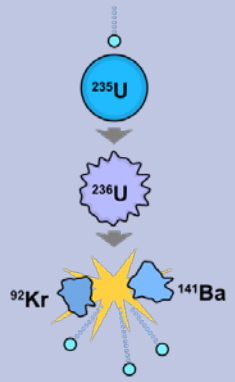
^{34}Ar

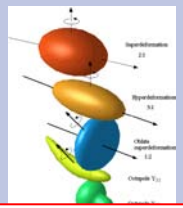
$^{46,48}Ca$

S,Cl,Ar,K

Ne,Na

SPIRAL1





- 47 Letters of Intents
- The equivalent of ~2006 UT are proposed
  → 16048 hours of beam on target (669 days
- 4 main setups
  - Vamos in magnetic spectromet
  - Vamos in gas-filled
  - Nwall + Diamant
  - DSSSD (SPIRAL1)

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

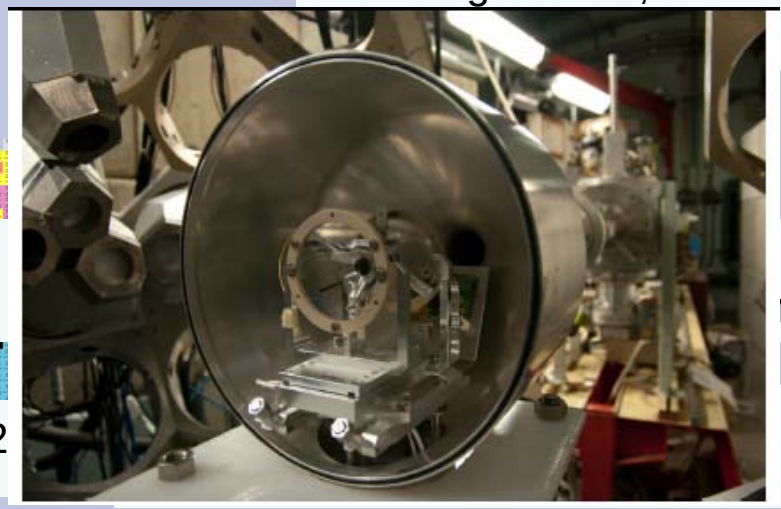
^{238}U,^{208}Pb → n-rich

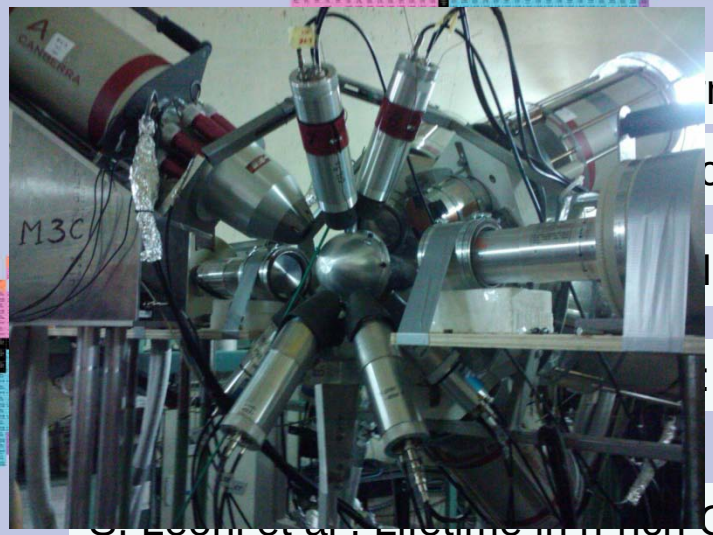
BROOKHAVEN NATIONAL LABORATORY

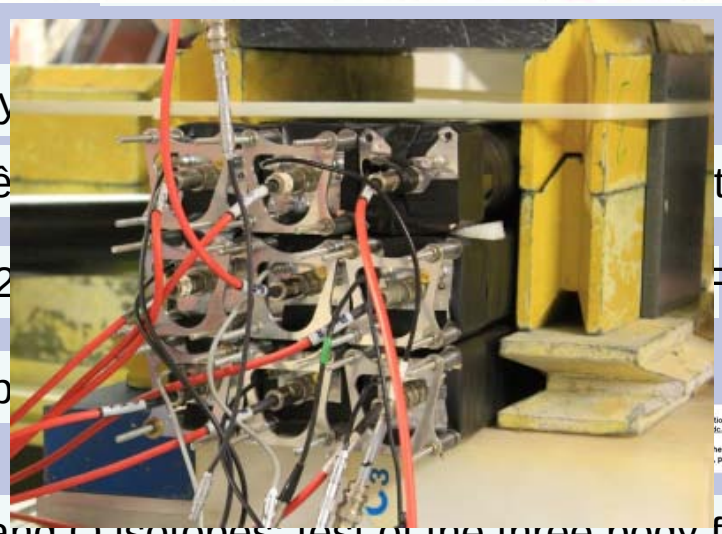
National Nuclear Data Center

G. Georgiev et al; 2^+ lifetimes

J. J. Vali
2^+ lifetim

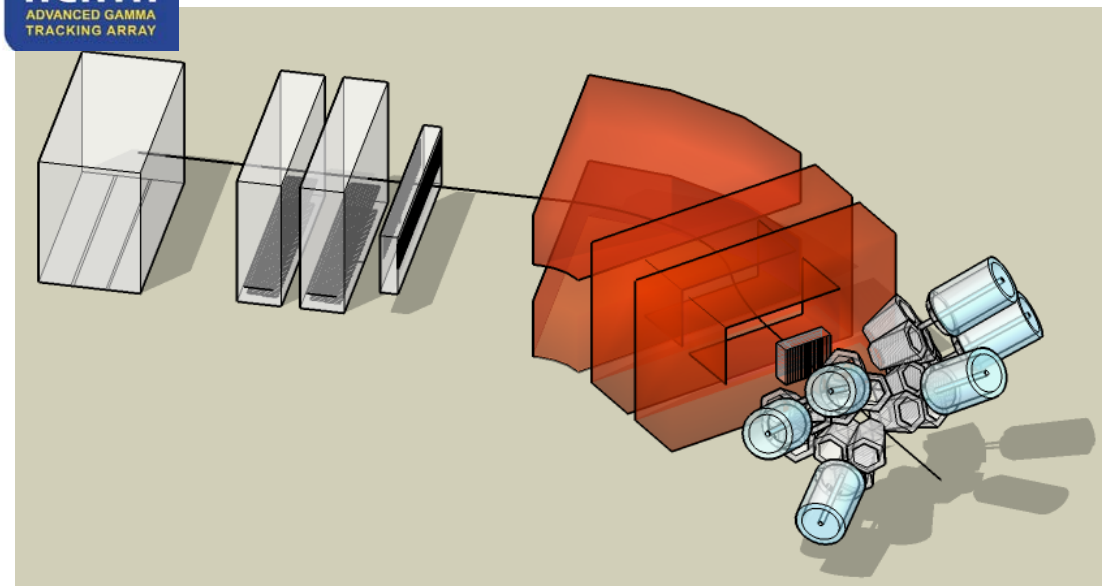


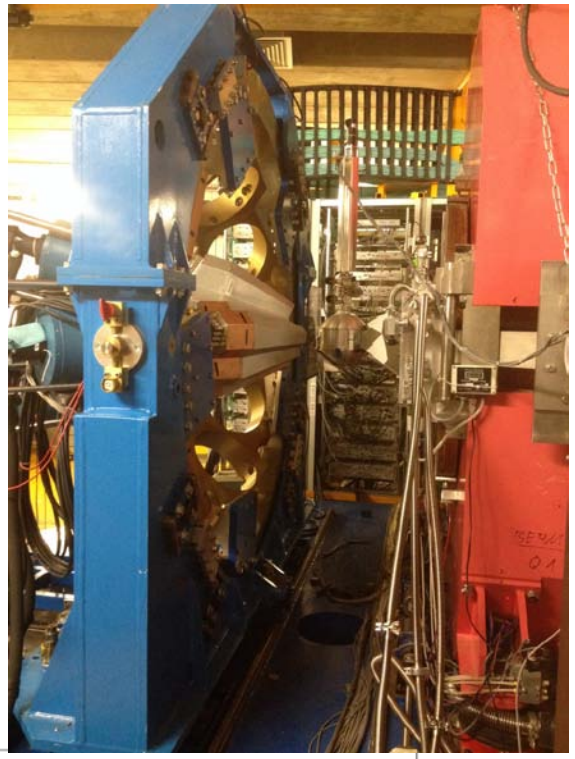




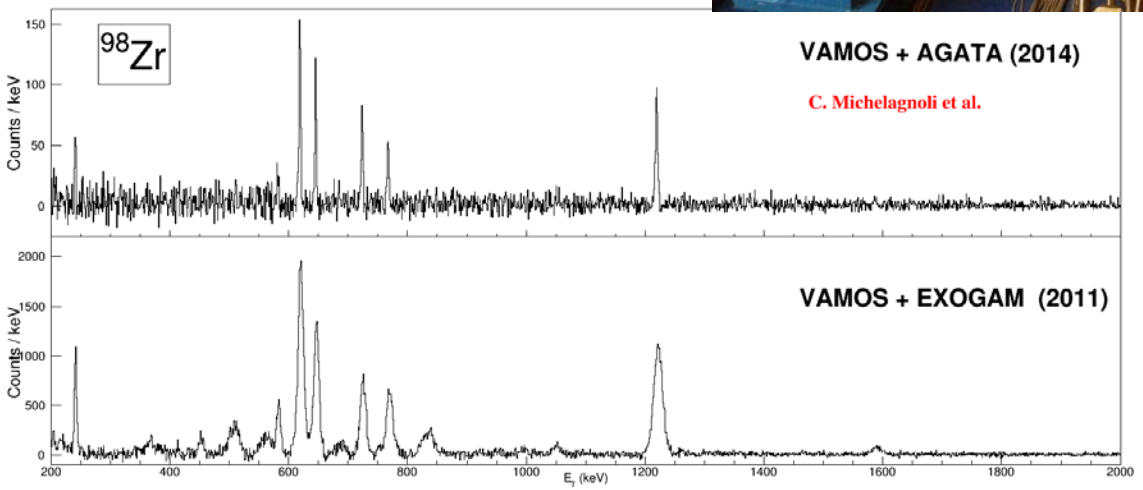
S. Zuchi et al.; Lifetime in N rich C and O isotopes: test of the three body forces

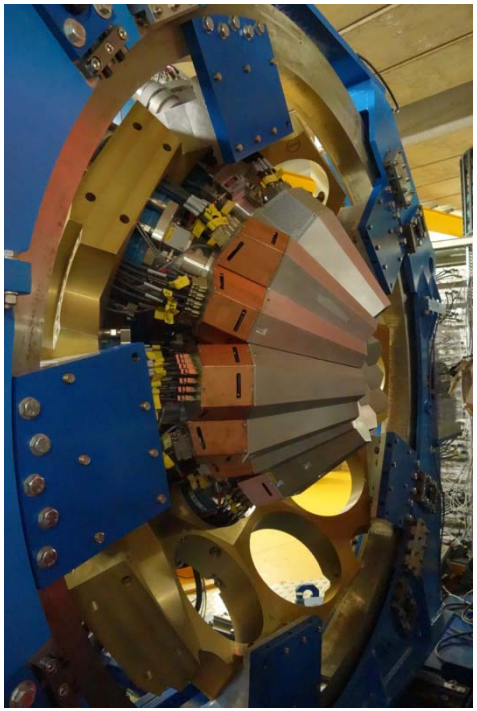
In-beam test VAMOS-AGATA



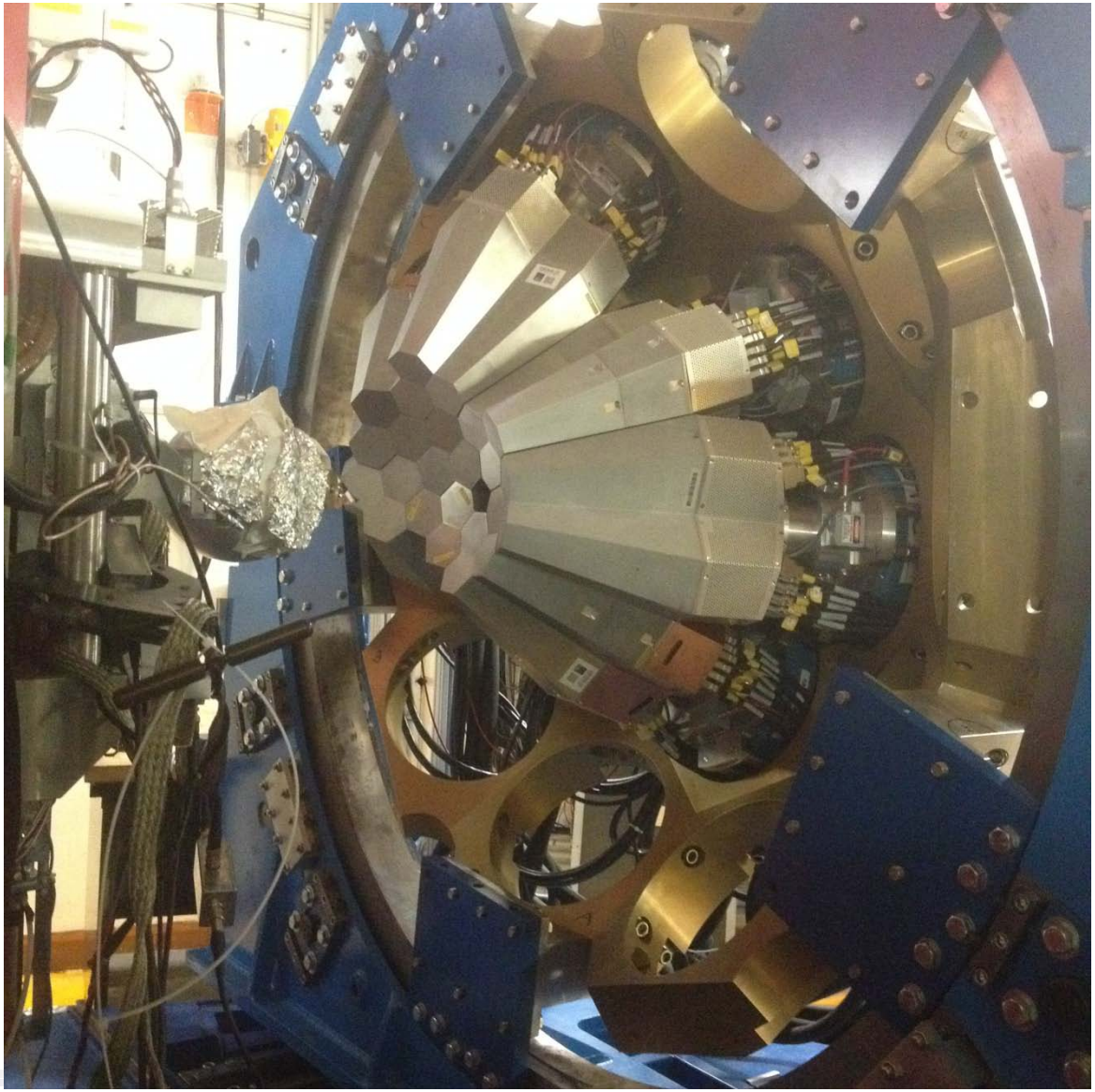


→^{238}U beam for the commissioning of the AGATA-VAMOS coupling.
27 November : 17 UT
8 December : 19 UT





NOW DATA TAKING !



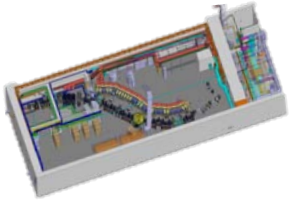
Study of very Heavy Nuclei at GANIL-SPIRAL2 facilities

- SPIRAL 2 Facility
  - ✓ LINAG
  - ✓ NFS
  - ✓ 
    - ❖ Physics cases
    - ❖ Technical description
    - ❖ Targets issues
- GANIL
  - ✓ decay spectroscopy of ^{257}Db
  - ✓ AGATA campaign
- **Conclusions and Perspectives**

SPIRAL2/GANIL *Road map*

2016: Start of the scientific program of SPIRAL2

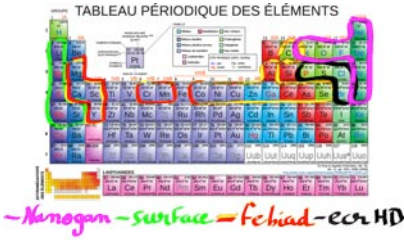
- 2015: Commissioning and exploitation of SPIRAL2-Phase 1
- Beginning of 2016: First NFS beams
- End 2016-2017: First S^3 beams



2015 - …. GANIL Scientific program

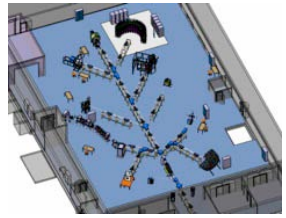
- AGATA Campaigns 2015-2018 - PARIS, NEDA, GASPARD
- LISE & new SPIRAL1 beams (end 2016) – ACTAR-TPC
- FAZIA-INDRA campaigns, …
- France-hadron, industrial applications

2019- … Start of DESIR Scientific program



- Low energy S^3 beams (ANR REGLIS^3)
- SPIRAL1 new beams

2015- … study of the new injector A/Q=1-7



Next steps:

- Long-range strategy for GANIL/SPIRAL2: Working group GANIL/SP2 2025
- Final report on a long-range strategy for GANIL/SPIRAL2, **XIXth COLLOQUE GANIL** (12th-16th October, 2015 Anglet (Aquitaine))