7th High Power Targetry Workshop

Targets for S^3: design, fabrication and control under irradiation

Ch. Stodel, CNRS/IN2P3 –CEA/DSM, GANIL, Caen, France

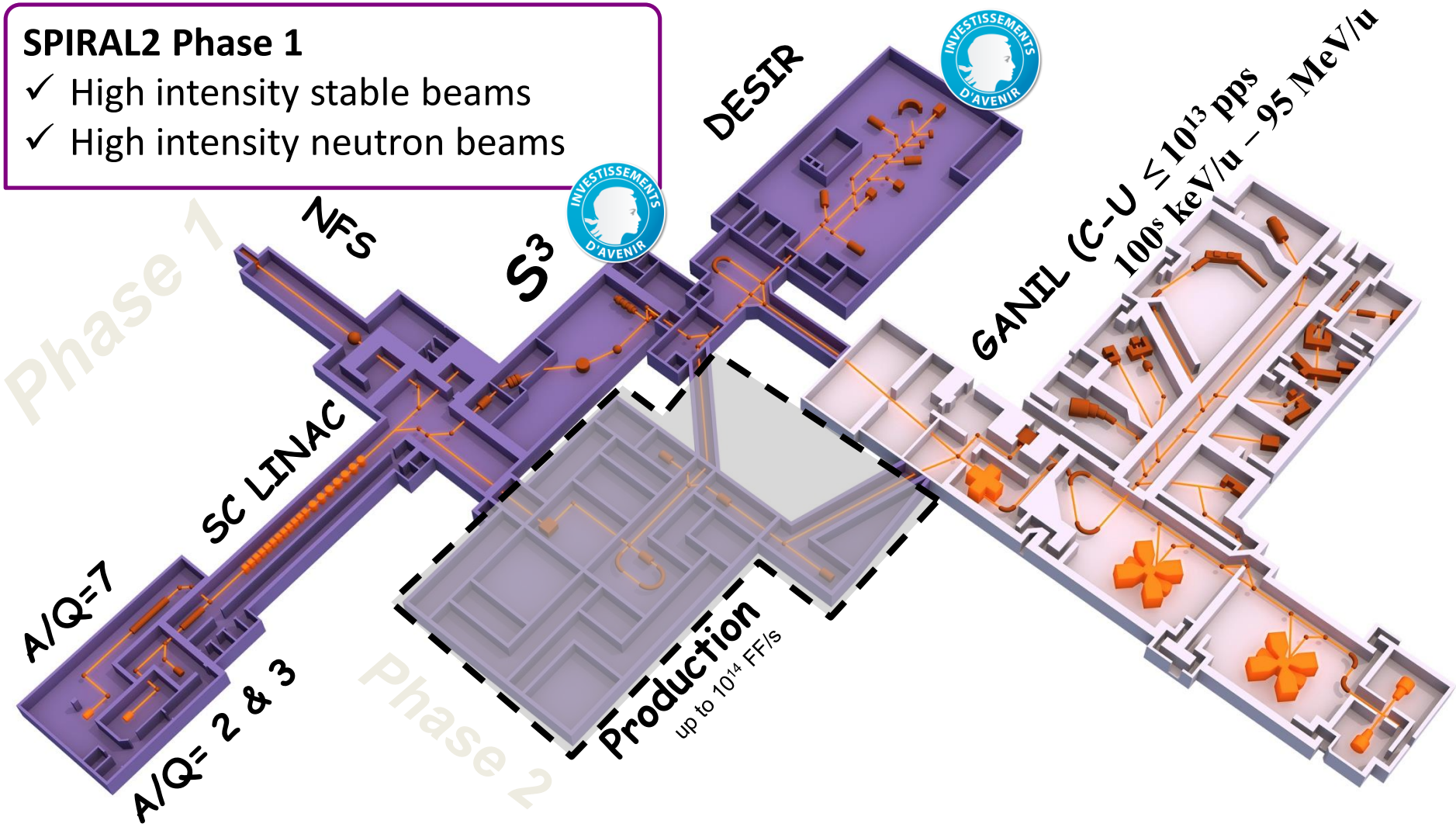
- GANIL & SPIRAL2
- S3
- Targets @S3
  - ✓ Stations
  - ✓ Monitoring (e-gun, IR camera)

Grand Accélérateur National d'Ions Lourds (GANIL)

Système de Production d'Ions Radioactifs Accélérés en Ligne 2eme génération (SPIRAL2)

SPIRAL2 layout

SPIRAL2 Phase 1
- ✓ High intensity stable beams
- ✓ High intensity neutron beams

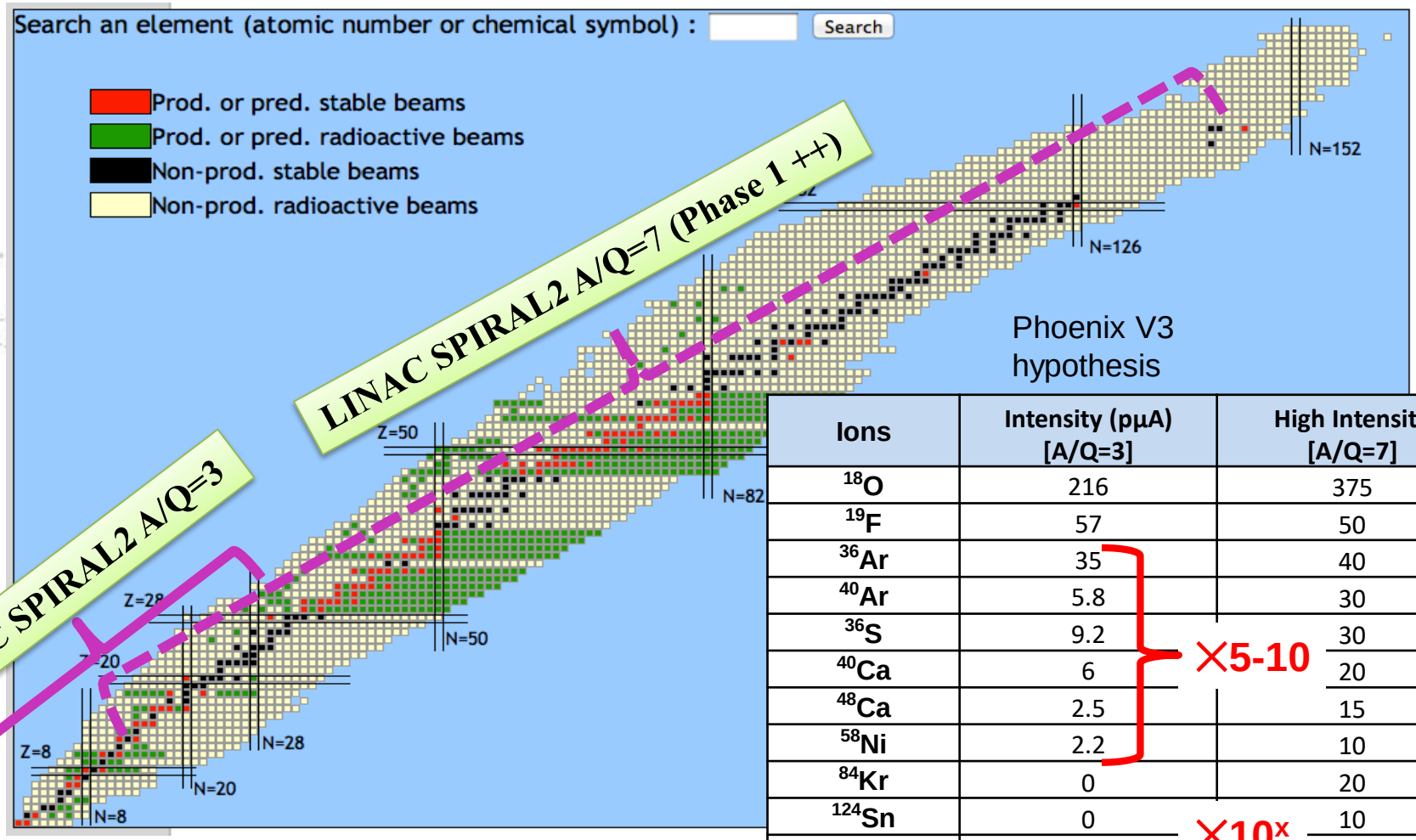


◎ A/Q = 3 : I ≤ 10^{15} pps, p-Ni, 0.75 MeV/n – 14.5 MeV/n

◎ A/Q = 7 : I ≤ 10^{15} pps, p-U, 0.75 MeV/n – 8.5 MeV/n

Stable beams @ SPIRAL2

- 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 – 8.5 MeV/n



Phoenix V3 hypothesis

Ions	Intensity (pμA) [A/Q=3]	High Intensity [A/Q=7]
^{18}O	216	375
^{19}F	57	50
^{36}Ar	35	40
^{40}Ar	5.8	30
^{36}S	9.2	30
^{40}Ca	6	20
^{48}Ca	2.5	15
^{58}Ni	2.2	10
^{84}Kr	0	20
^{124}Sn	0	10
^{139}Xe	0	10
^{238}U	0	2.5

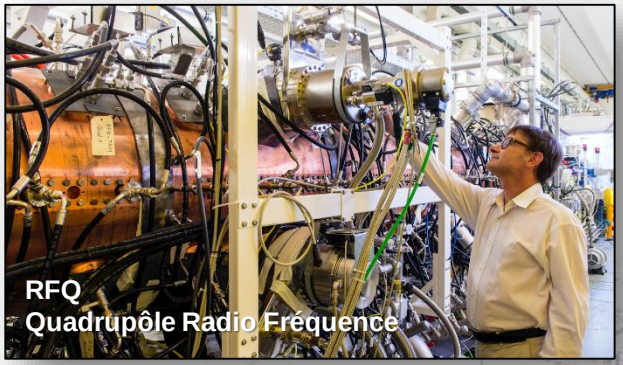
×5-10

×10^x

- 33 MeV p, 40 MeV d – 5mA
- Open new perspectives (Pb,U heavy beams)

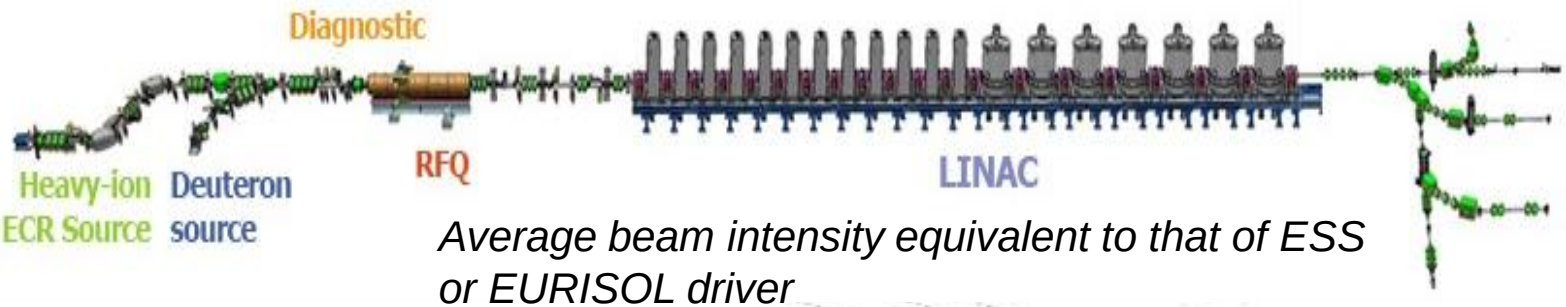
10- 20 kW

SPIRAL2 accelerator


RFQ
Quadrupôle Radio Fréquence

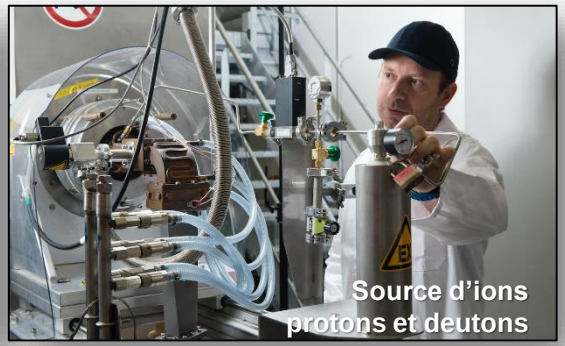

Cryomodules accélérateurs supraconducteurs A


Cryomodules accélérateurs supraconducteurs B



Average beam intensity equivalent to that of ESS or EURISOL driver

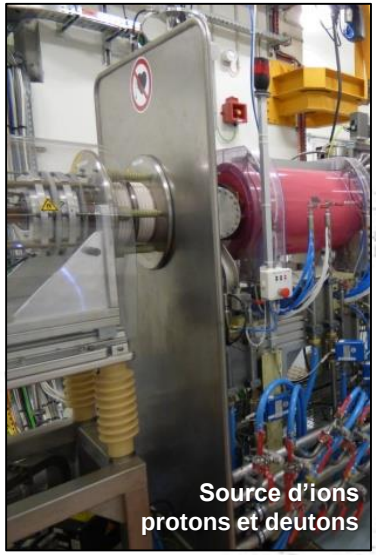

Source d'ions
ions lourds

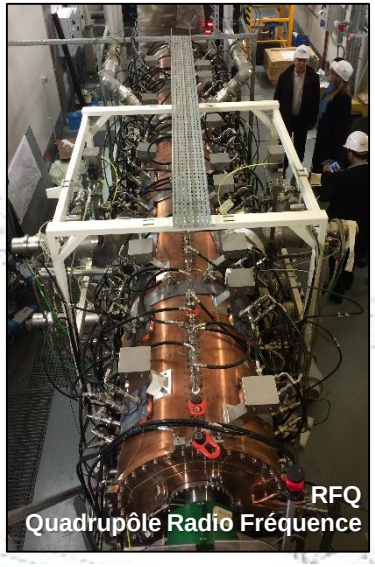

Source d'ions
protons et deutons

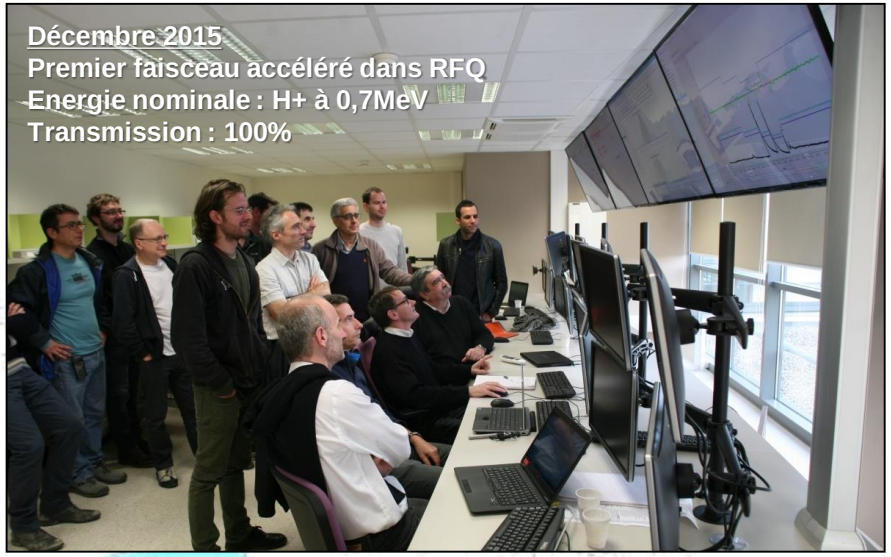

Lignes de faisceaux
LHE

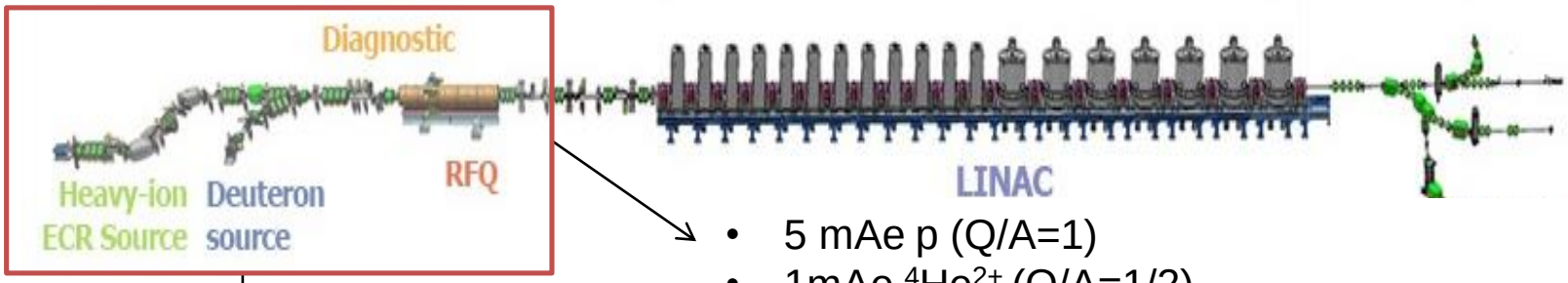
Installation is almost complete

First beams (Ions Sources & RFQ)







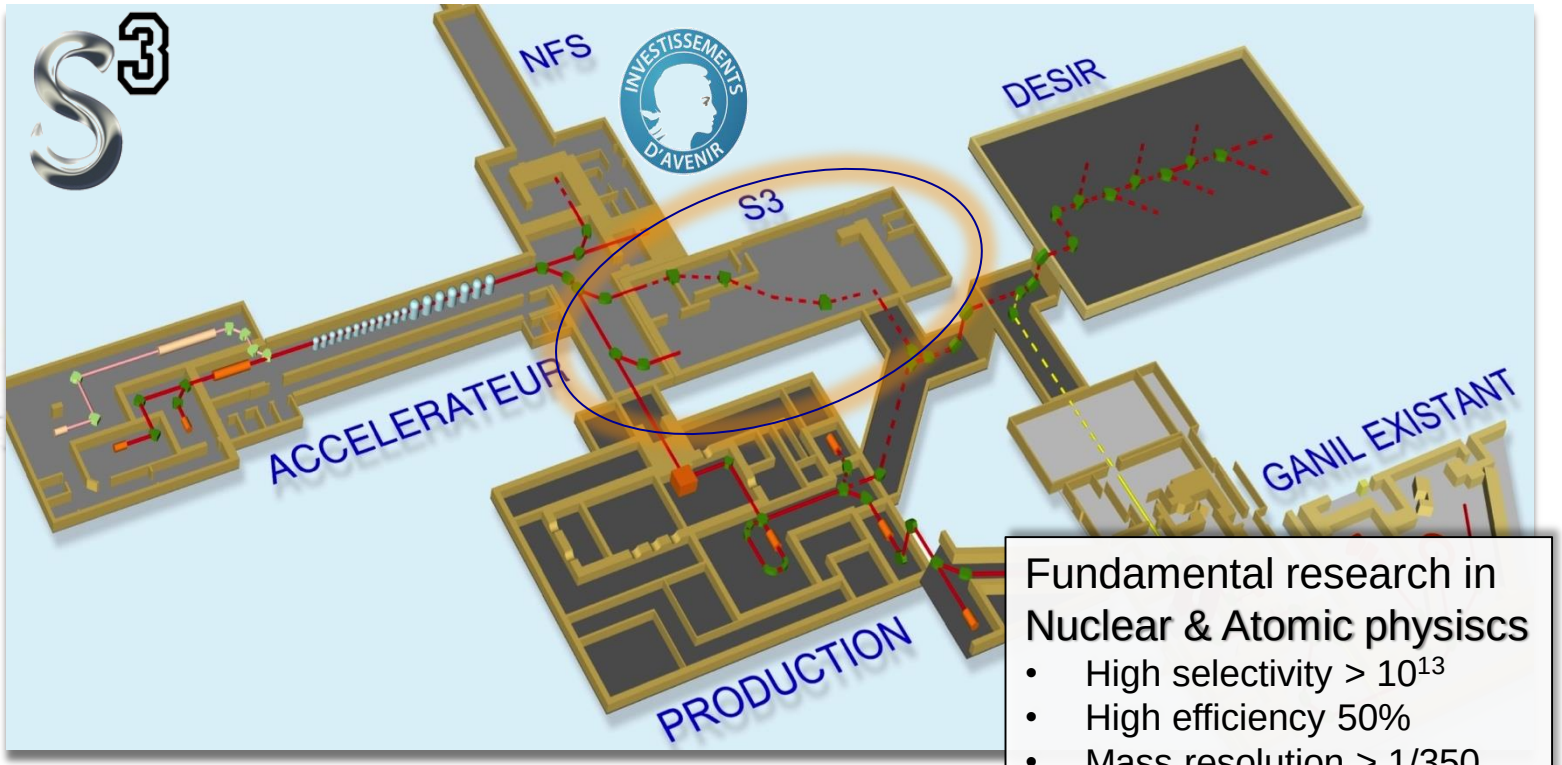


- 45 µAe $^{40}Ar^{14+}$ (60 kV)
- 2 mAe $^{4}He^{2+}$
- 1 mAe $^{18}O^{6+}$

- 5 mAe p (Q/A=1)
- 1mAe $^{4}He^{2+}$ (Q/A=1/2)
- $^{18}O^{6+}$ (Q/A=1/3)

- ➢ Partial commissioning ongoing
- ➢ Cooled down of the LINAC done (Nov 2017)
- ➢ Waiting for the safety authority clearance

Super Separator Spectrometer



Fundamental research in Nuclear & Atomic physiscs

- High selectivity > 10^{13}
- High efficiency 50%
- Mass resolution > 1/350
- Versatility

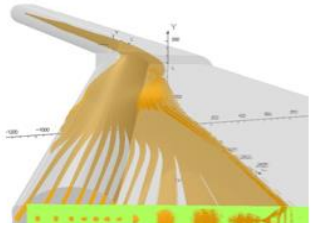
F. Dechery et al., Eur. Phys. J. A (2015) 51: 66
F. Dechery et al., in press NIMB

Technical highlight

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

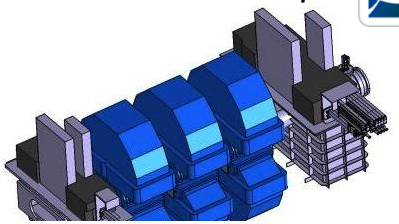
ersive zone

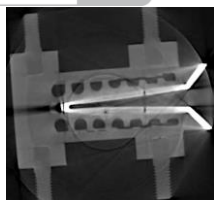
(beam dump & Movable fingers)

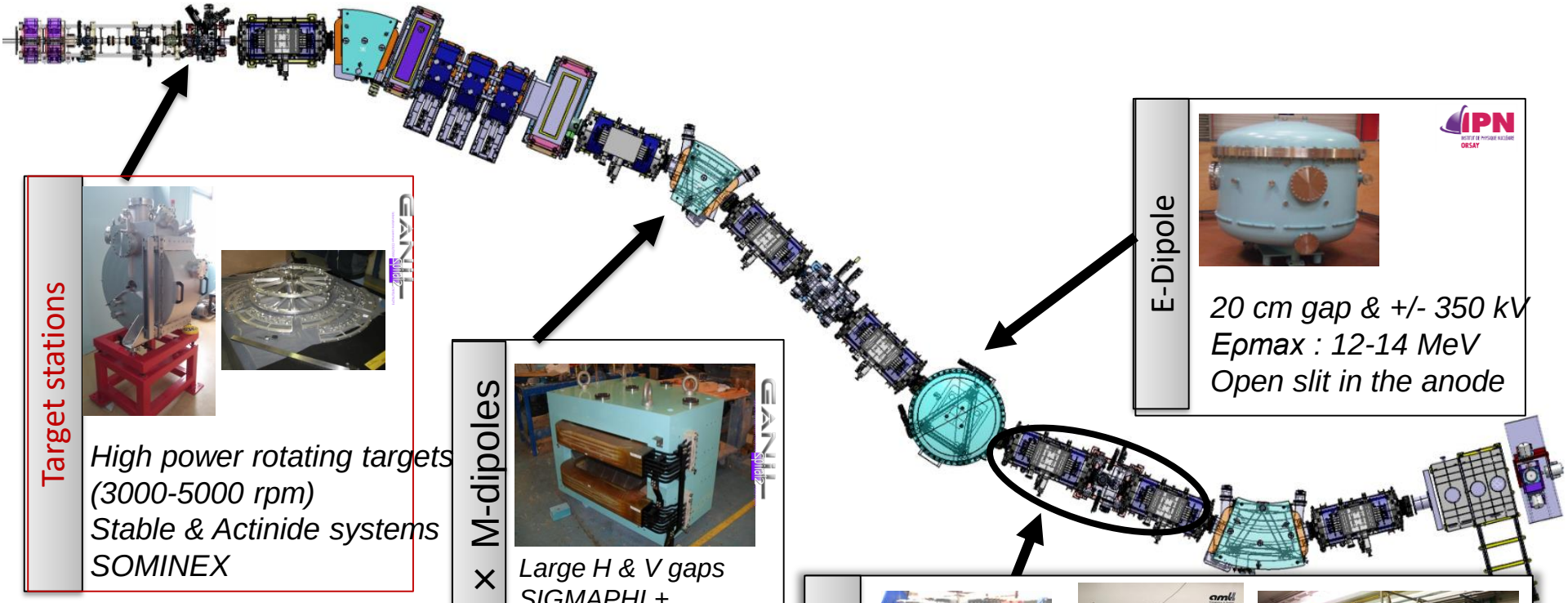


Open triplet

PLUG Beam dump







Target stations

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

3 x M-dipoles

Large H & V gaps
SIGMAPHI +
HAZMEYER

E-Dipole

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

SC Multipoles

Q+S+O fields

PSS

Cold Box

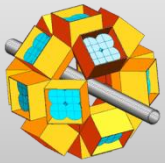
All hardware components are under final construction (L=26m)

Experimental Techniques

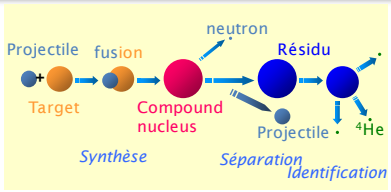
Phase 3

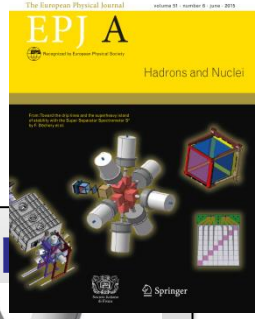
In-beam spectroscopy

Two step reactions
EXOGAM2
PARIS- AGATA
MUST2/GASPARD



Not in the scope of the project

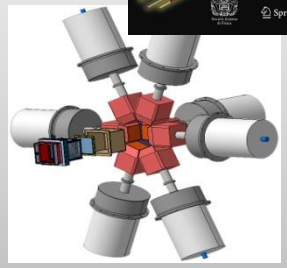




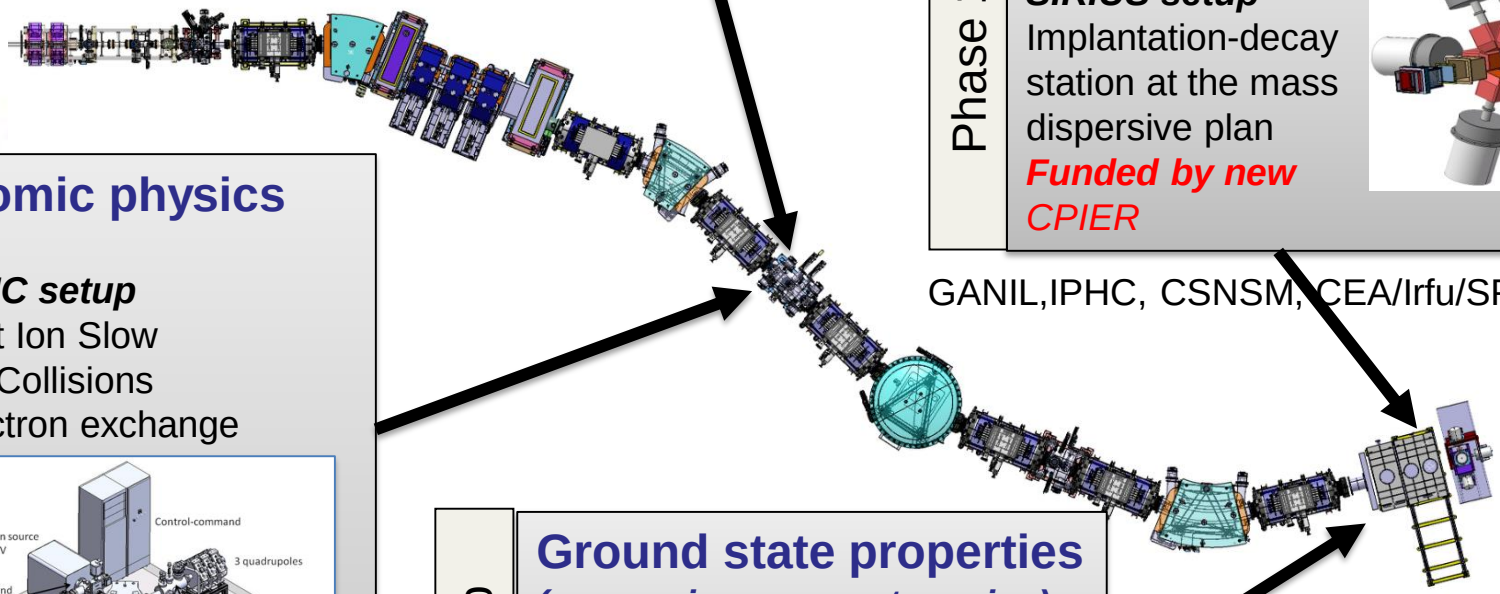
Phase 1a

Delayed spectroscop

SIRIUS setup
Implantation-decay station at the mass dispersive plan
Funded by new
CPIER



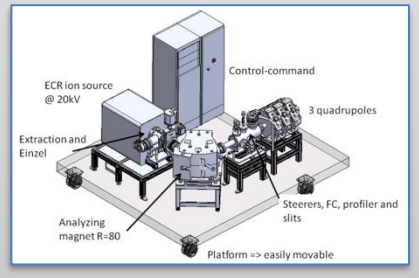
GANIL,IPHC, CSNSM, CEA/Irfu/SPhN



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)

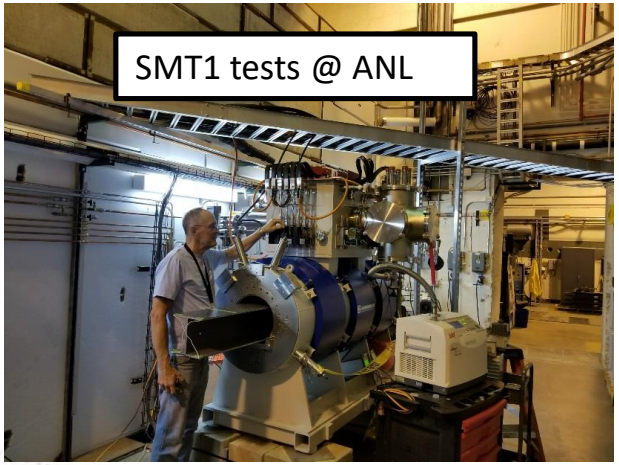
REGLIS³ setup
Low Energy Branch
Funded

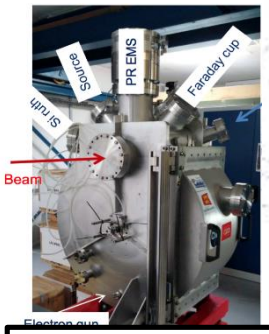
DESIR

Full assembly & tests planned in 2020


S3-LEB @ LPC


Mdipole @ S3

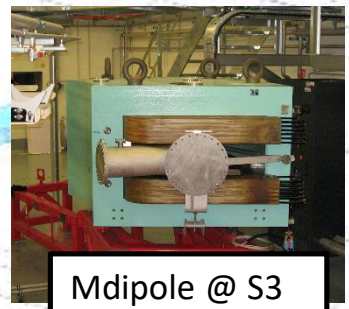

SMT1 tests @ ANL



Target System @ GANIL

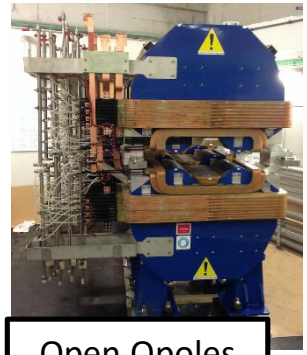

Beam dump @ Irfu


PSS @ AML

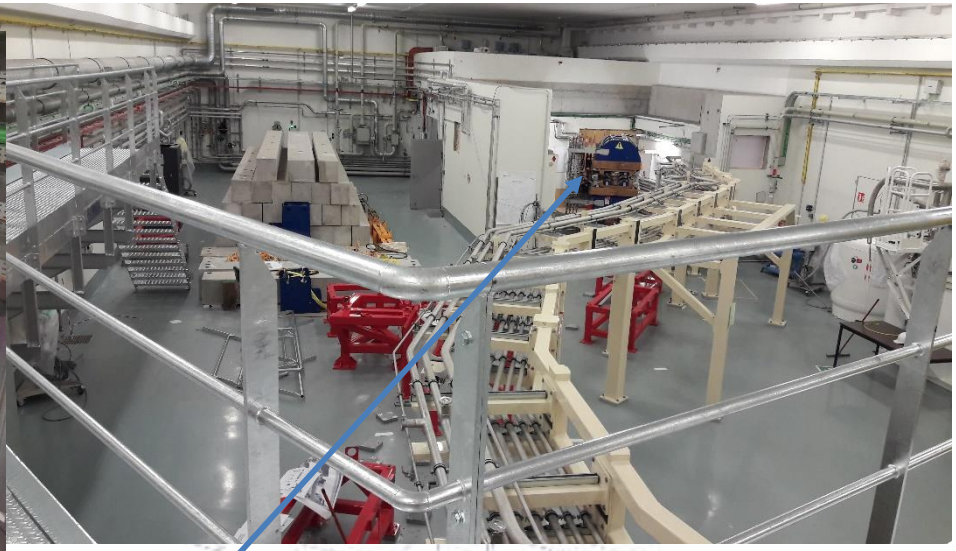

Mdipole @ S3

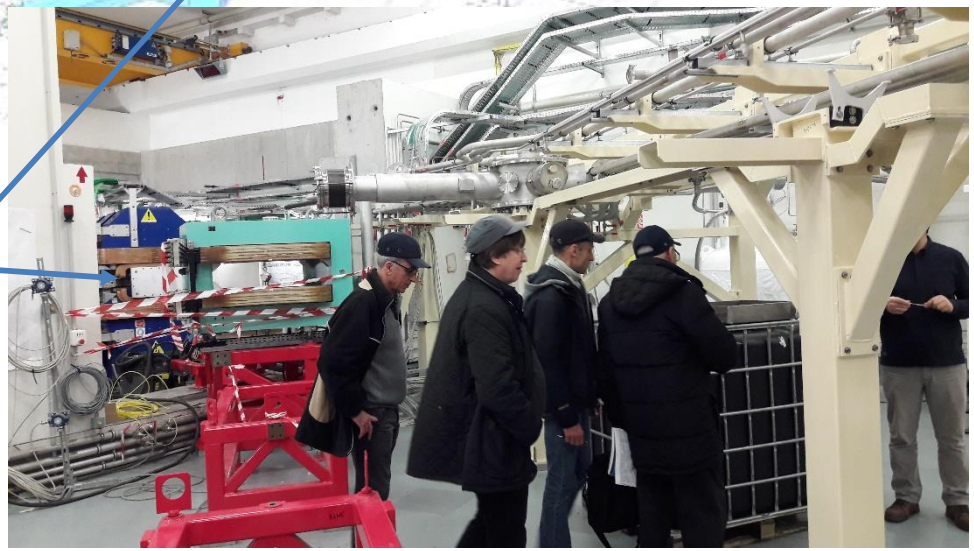

Installation @ S3


Cold Box @ S3


Open Qpoles @ S3

Edipole @ IPNO





Physics goals

Study of rare events in nuclear and atomic physics

$^{58}Ni+^{46}Ti \rightarrow ^{100}Sn + 4n$
(I=10pμA) ➔ 1-2 evt/s

Nuclei produced by Fusion-Evaporation (with refractory elements)

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

VHE/SHE Science opportunities

nuclide	feature	X-section [nb]	rate [h^{-1}]	21UT integral	
				day 1	phase 1++
^{254}No	ER	2000	60.000	**6×10^{7}**	1×10^{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*

D. Ackermann et al

Rate summary vs GSI UNILAC

- ✕ 2-4 [A/Q=3]
- ✕ **15-20 [A/Q=7]**

◎ Nuclear structure

Quasi-particle excitations ➔ deformation/K-isomers

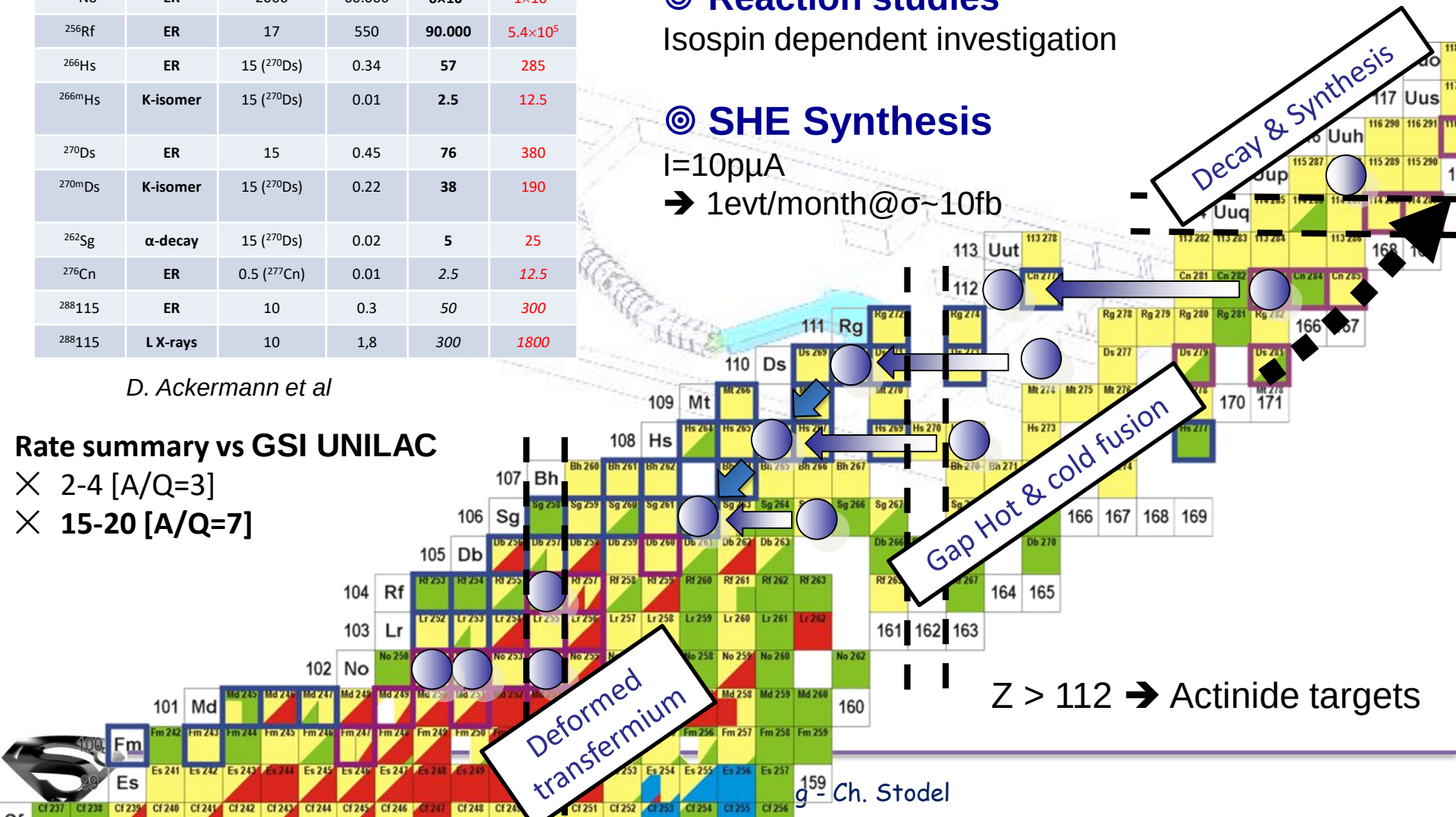
◎ Reaction studies

Isospin dependent investigation

◎ SHE Synthesis

I=10pμA

➔ 1evt/month@σ~10fb



Z > 112 ➔ Actinide targets

« Targets for S³» : requirements & Challenges

Stable
^{208}Pb, ^{209}Bi, Ni, Ca, C....
0,3 -2 mg/cm²

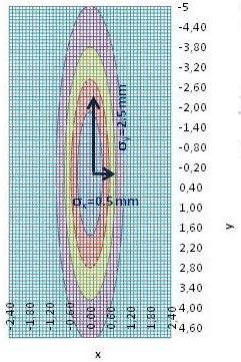
Actinides
^{232}Th, ^{238}U, ^{239}Pu, ^{242}Pu, ^{244}Pu, ^{243}Am, ^{248}Cm
0,3 - 0,5 mg/cm² ≈ 25 mg ≈ 10^2 -10^8 Bq

Stripper
C, Al
30-100 µg/cm²

Fabrication

Thickness ±5%

dP/dV = 10^s kW /mm³



σ_t = 0.5 mm
σ_r = 2.5 mm
I=10 pµA

Tmax < Tfus
ΔT = +-50° C (arbitrary)

R (cm)	35	7
ω (rpm)	3000	5000

See M. Michel poster [5]
F. Pellemoine…NIM A613(2010)480

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

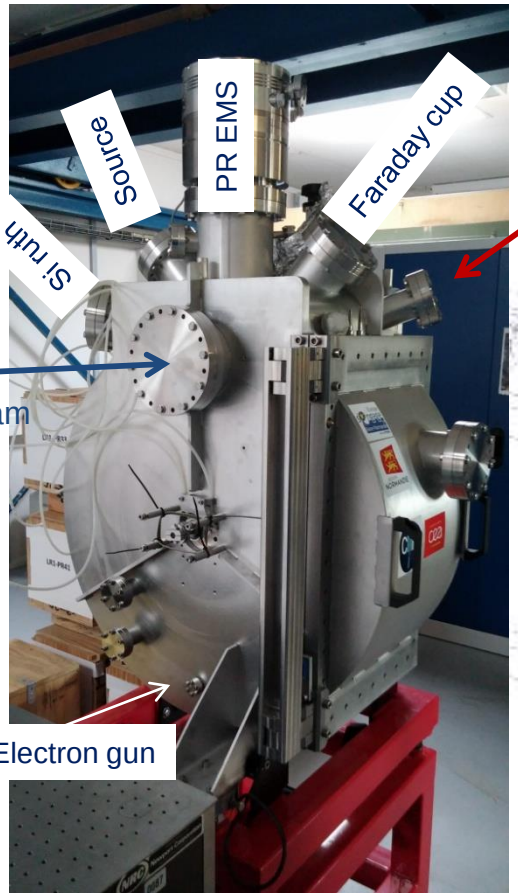
Fragility & failures of targets to be controlled

Lifetime of a target ???

I_{max} ?

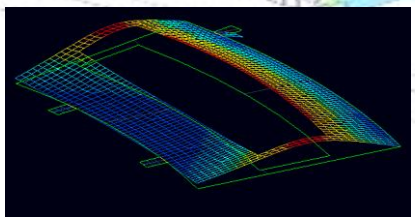
Station

Stable Station

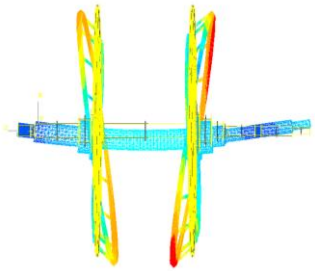


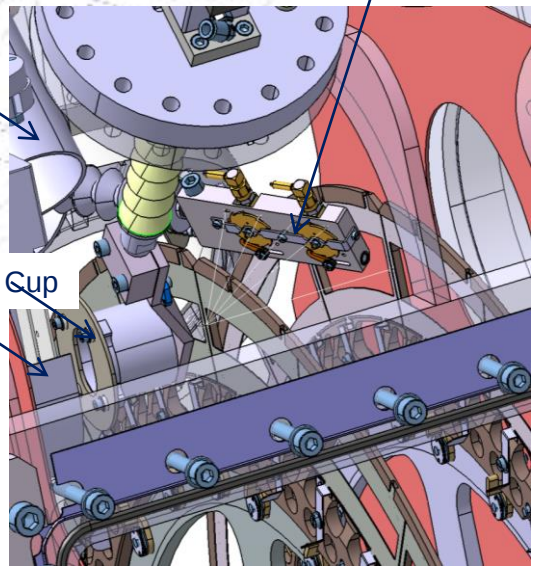
IR caméra

- ✓ Wheels balancing : class G2.5 == 0,06 mm/s vibration velocity @ 0-2200 rpm
- ✓Proto developments transferred to S^3 stable station
  - Motors and coding
  - Command & Control and supervision
  - Beam synchronization
- ✓Integration of detectors

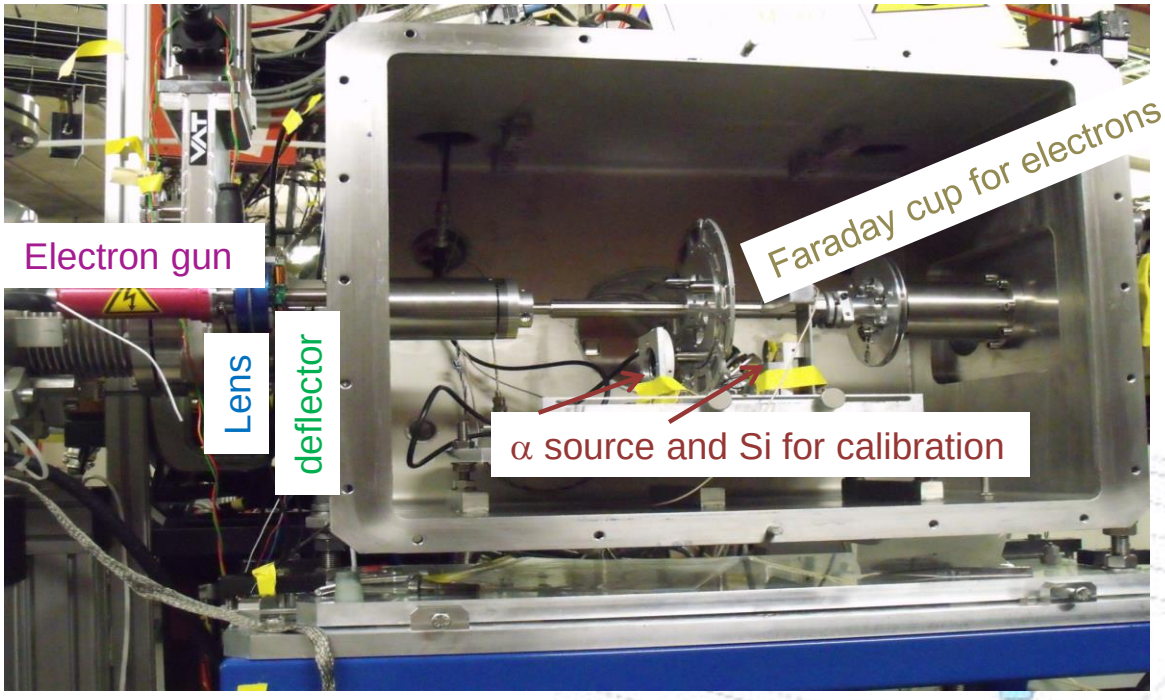


ω =0-3000 rpm
R=335mm





Prototype ActinideTarget Station



High Intensity Targets Stations for S3

27th International Conference of the International Nuclear Target Development Society, Tokyo, Japon, September 2014

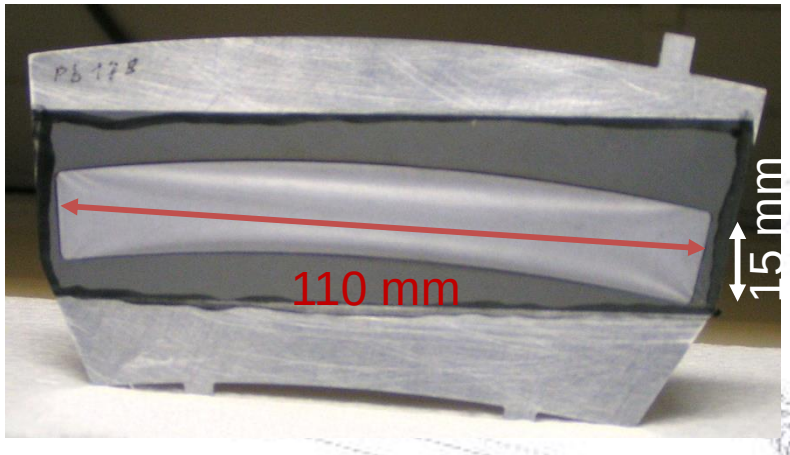
Journal of Radioanalytical and Nuclear Chemistry, (DOI) 10.1007/s10967-015-3936-5 September 2015, Volume 305, Issue 3, pp 761-767

Oct / Nov 2014 :

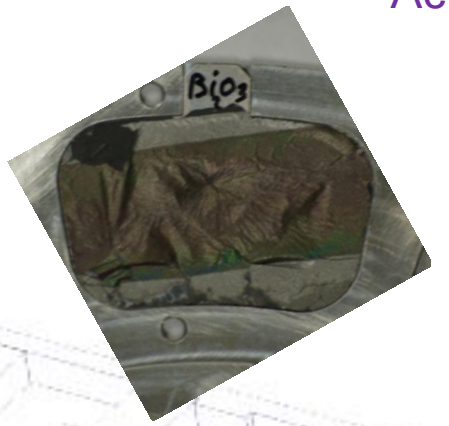
Electron gun improved with automatic scan of the deflector

I_{max} ? S^3 and GANIL conditions?

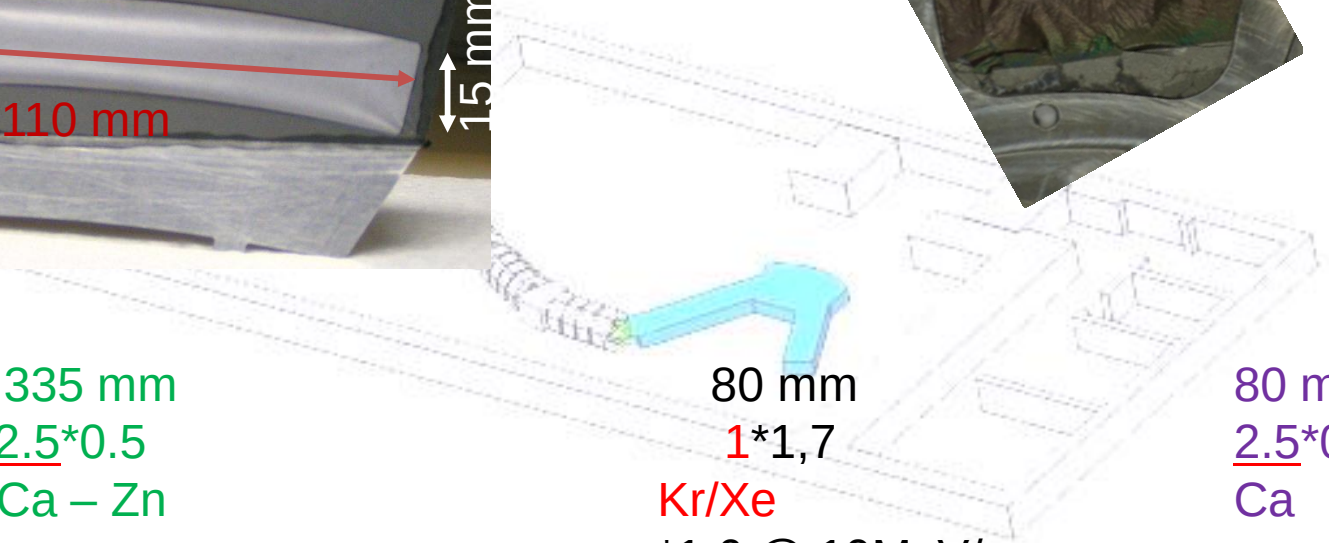
Stable S3



Proto S3 @ GANIL



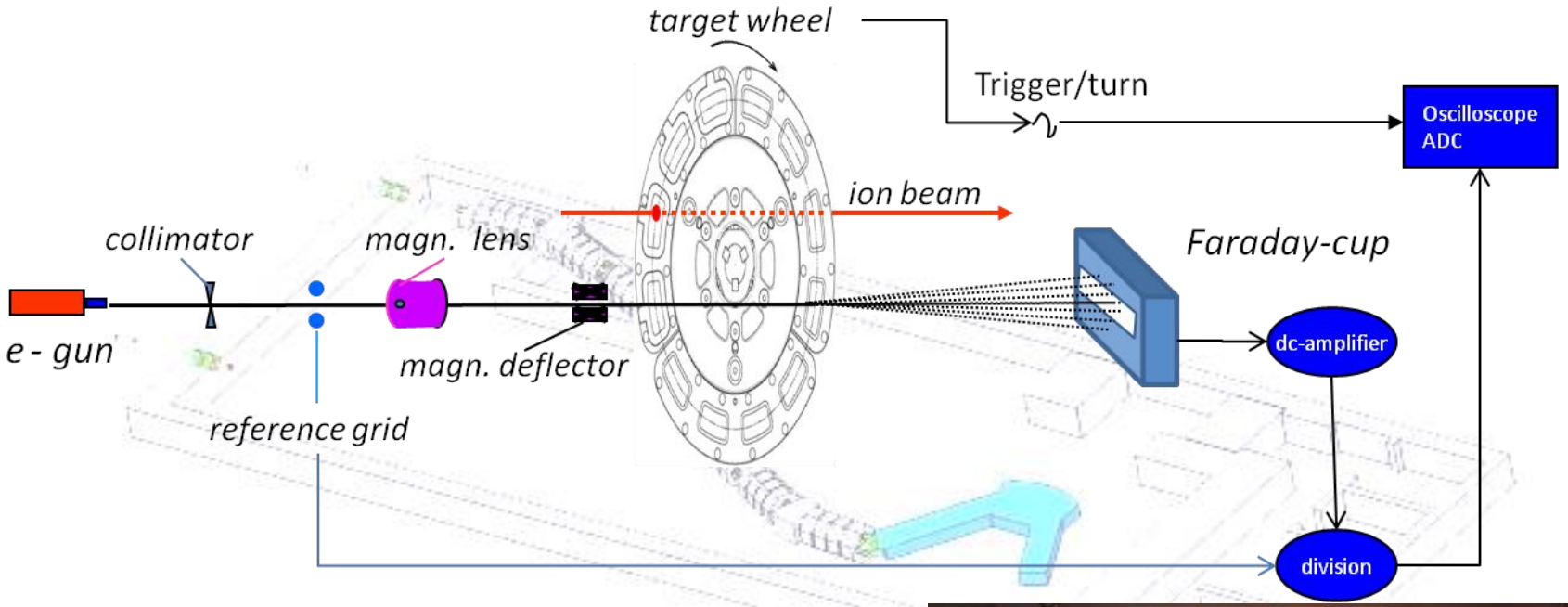
Actinide S3



Wheel radius:	335 mm	80 mm	80 mm
Beam profile:	2.5*0.5	1*1,7	2.5*0.5
Beams:	Ca – Zn	Kr/Xe	Ca
DE		*1,6 @ 10MeV/u *2 /3,5@5MeV/u	
W(rpm)	<3000	<5000	<5000

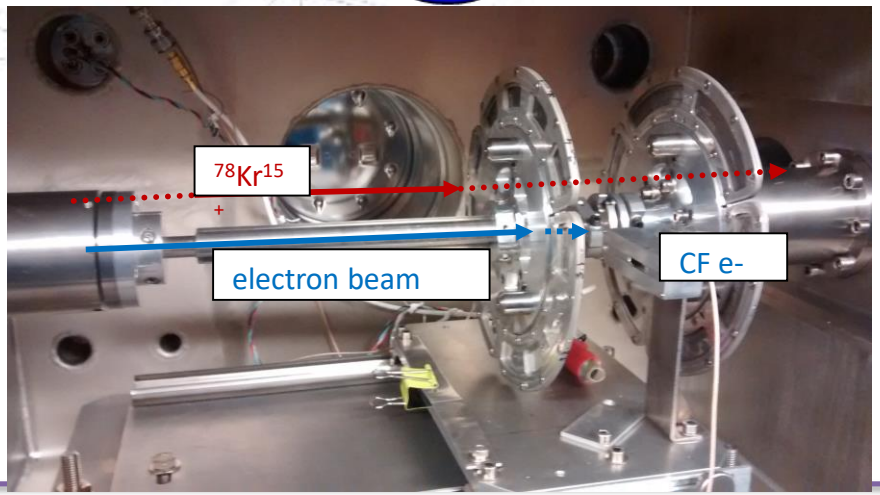
Electron Gun - R. Mann (patent DE 10242962 A1-GSI)

Principle : measuring attenuation of electron current using angular scattering and absorption



Adjustements: sensitivity (E_e),

resolution (≤ 0.4mm , 15µs)

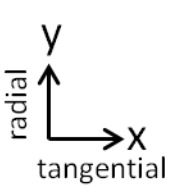


1.1 Hole

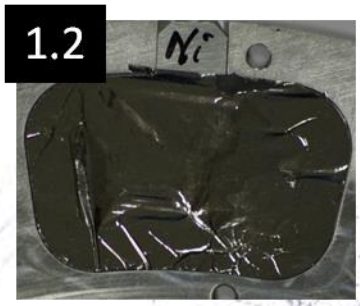
1.2 Ni

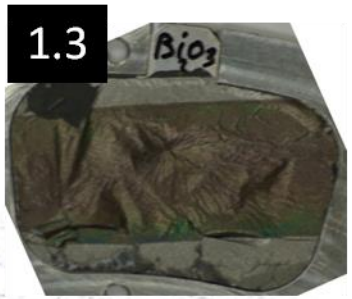
1.3 C+ Bi_2O_3 (+C)

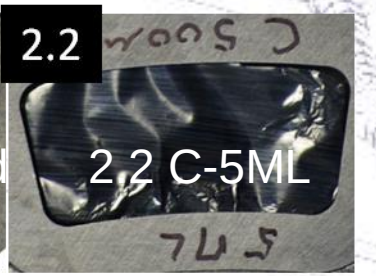
1.4 C-10ML

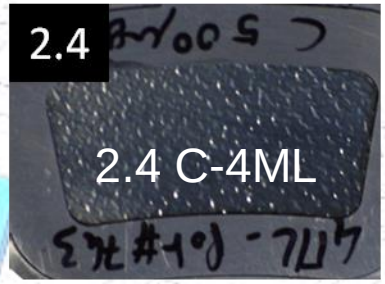


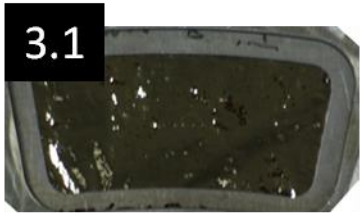
beam ⊗

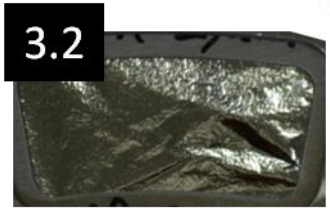


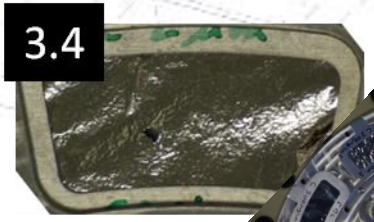










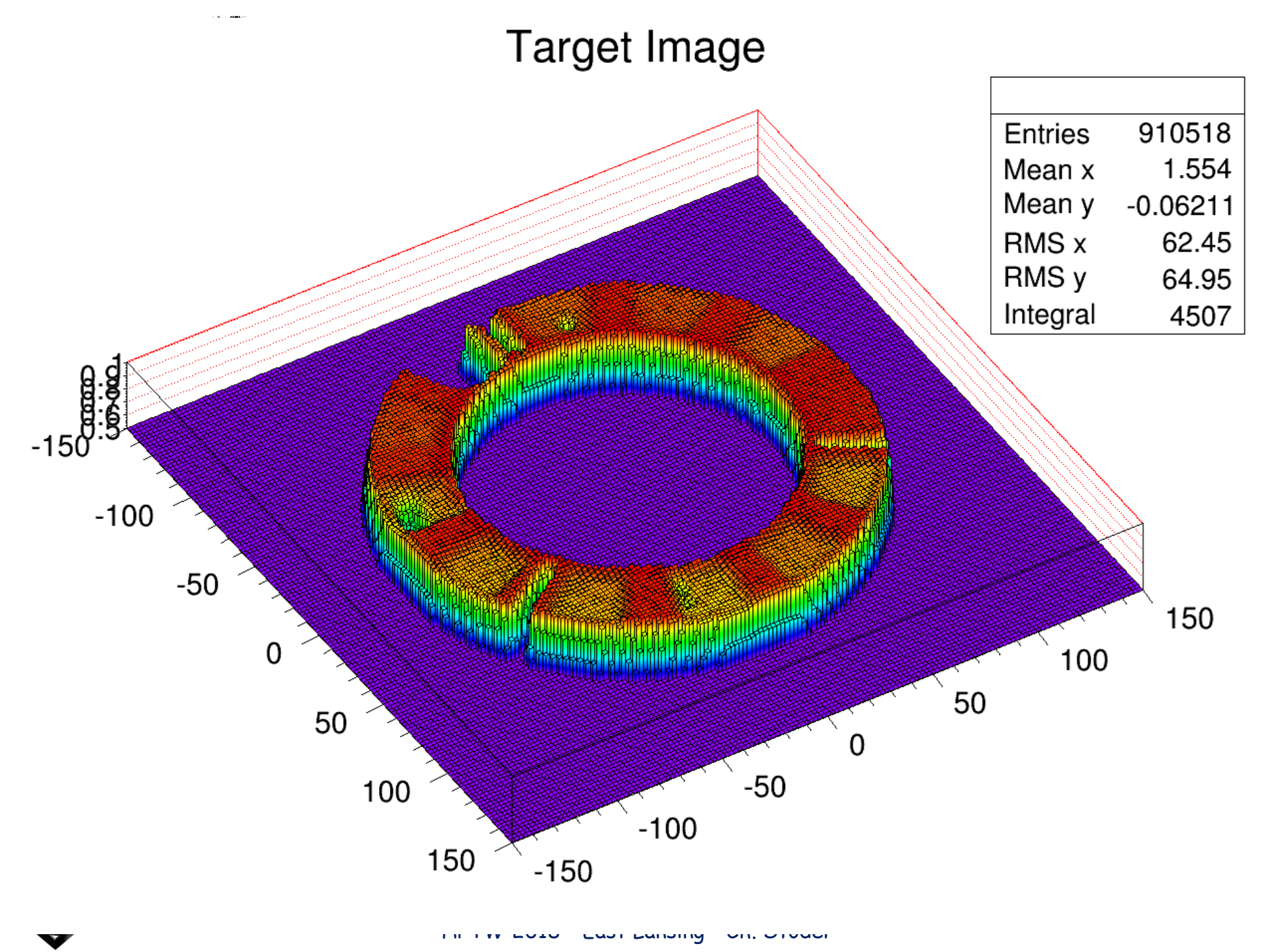


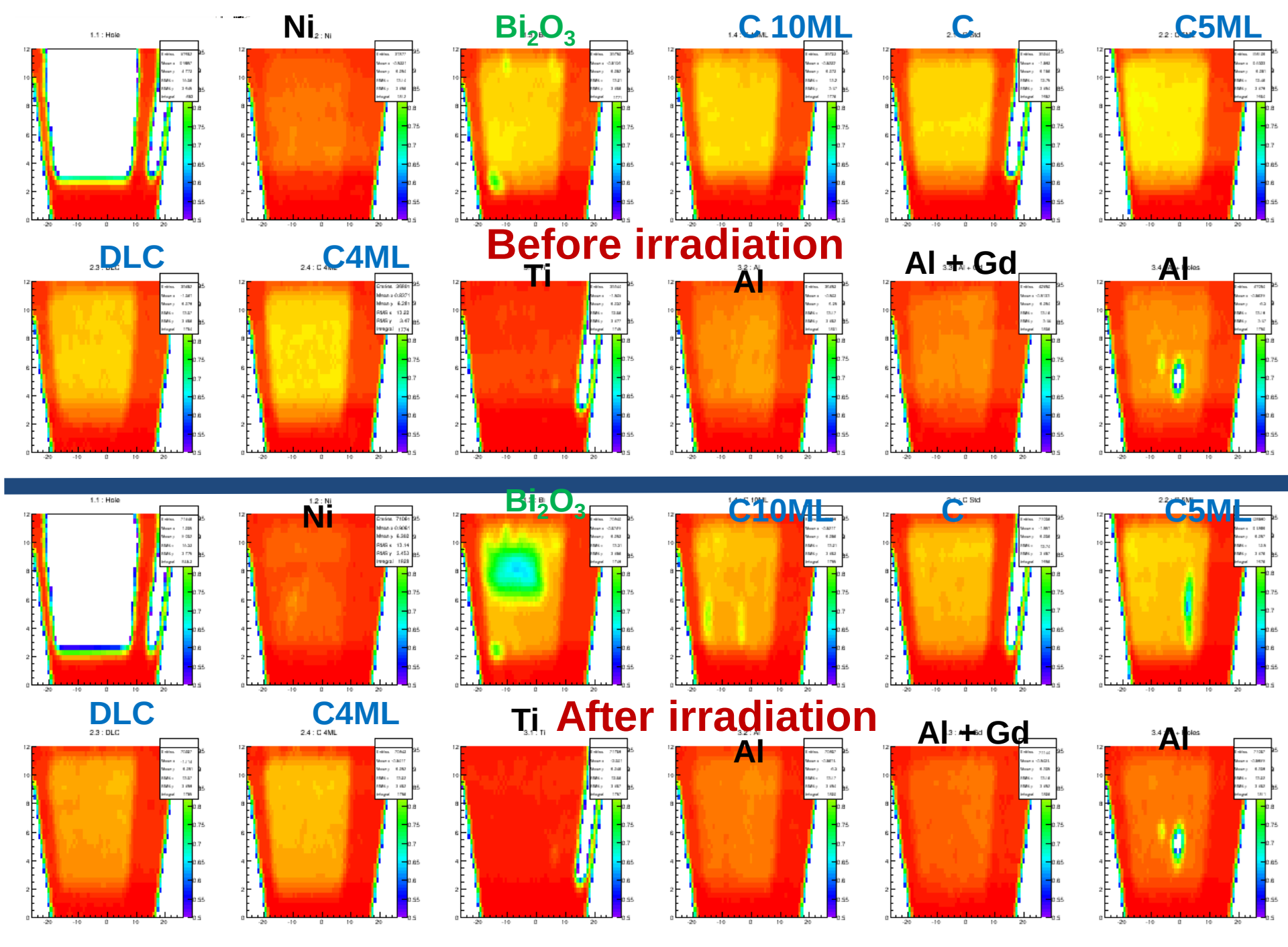
3.1 Ti

3.2 Al

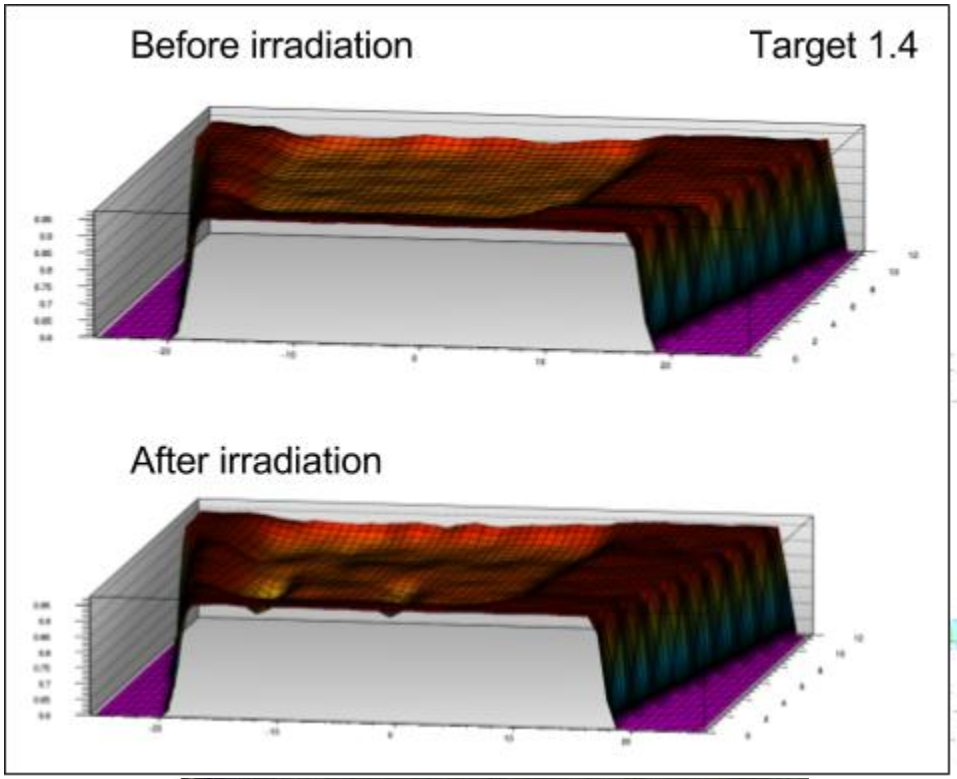
3.3 Al+ Gd_2O_3

3.4 Al
(2 pin holes)

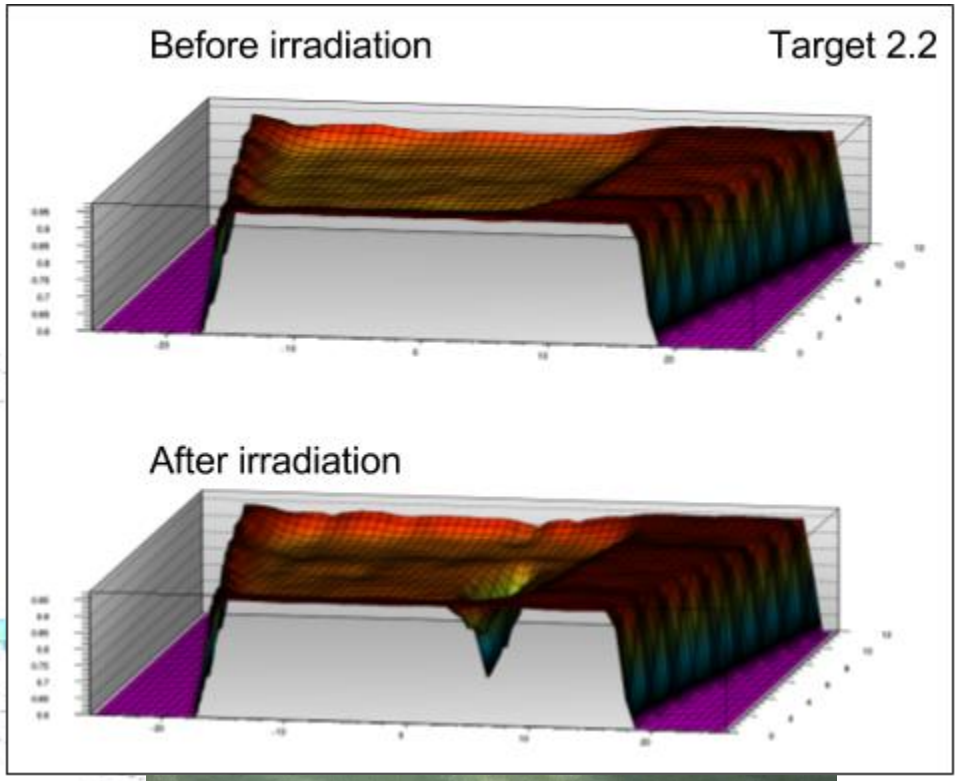

Target Image
Entries 910518
Mean x 1.554
Mean y -0.06211
RMS x 62.45
RMS y 64.95
Integral 4507
-150
-100
-50
0
50
100
150


Ni
Bi_2O_3
C 10ML
C
C5ML
Before irradiation
DLC
C4ML
Ti
Al
Al + Gd
Al
Bi_2O_3
Ni
C10ML
C
C5ML
After irradiation
DLC
C4ML
Ti
Al
Al + Gd
Al

C-10 ML

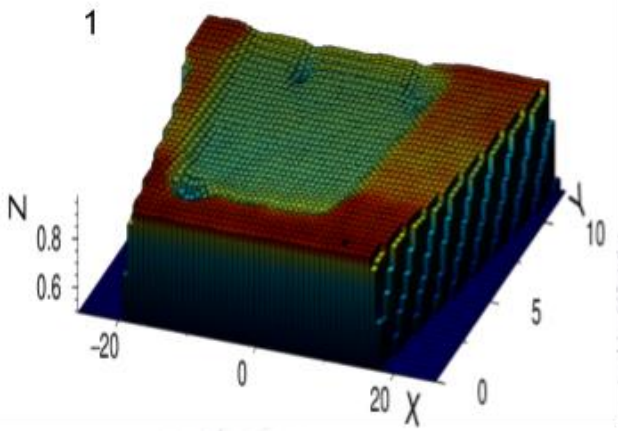

Before irradiation
Target 1.4
After irradiation

C-5 ML

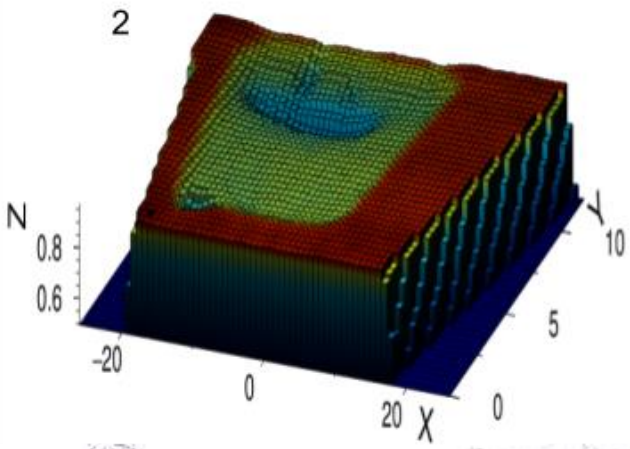

Before irradiation
Target 2.2
After irradiation

Time evolution of Bi target with beam

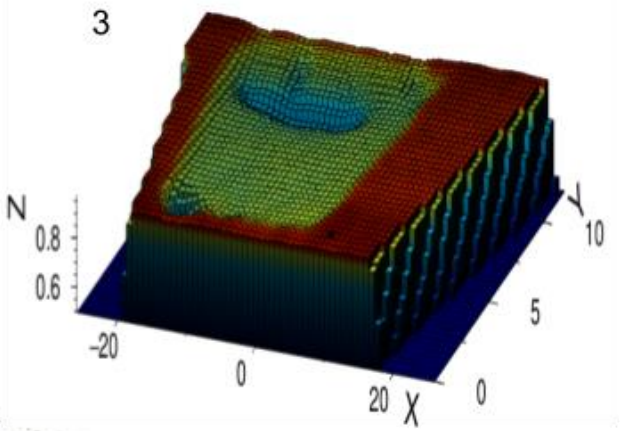
before irradiation



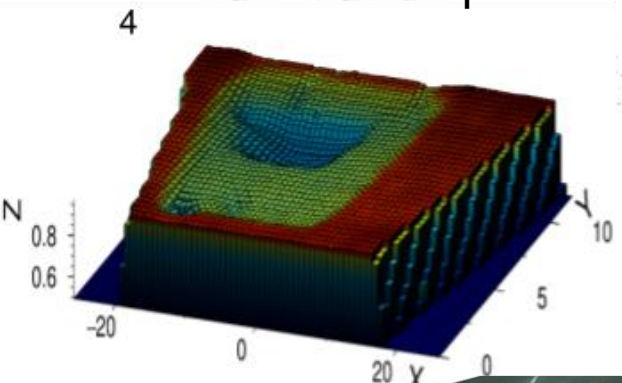
$2.4 \times 10_{16}$ part



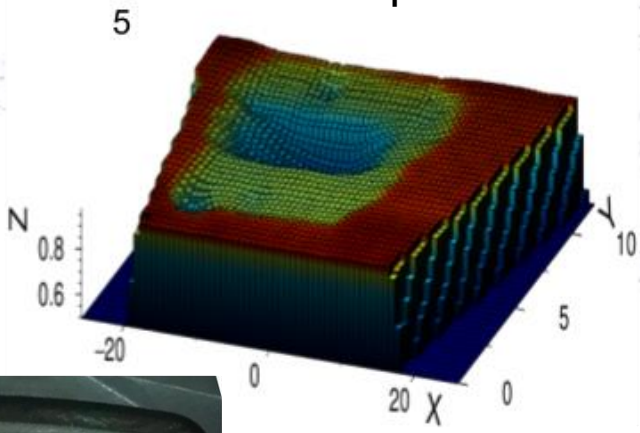
$2.8 \times 10_{16}$ part



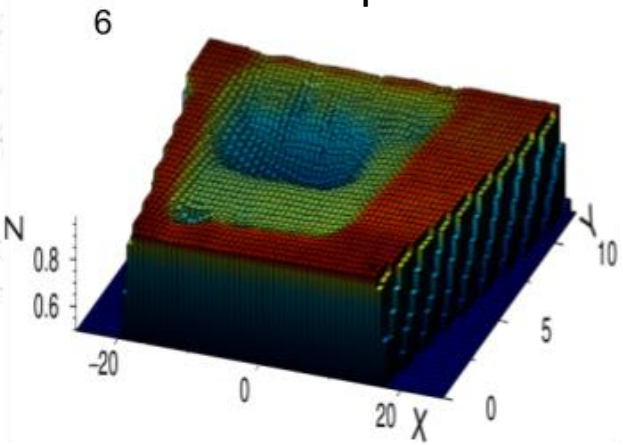
4: $3.7 \times 10_{16}$ part



$4.1 \times 10_{16}$ part

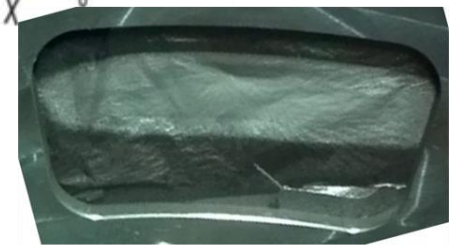


$4.4 \times 10_{16}$ part



Front

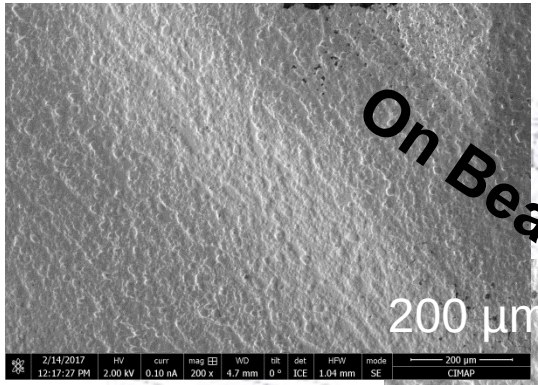
⊗



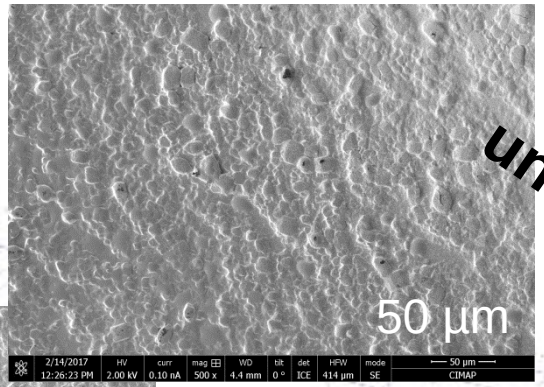
S3 targets monitoring with an electron gun
*J. Kallunkathariyil, et al - AIP Conference Proceedings **1962**, 030019 (2018)*

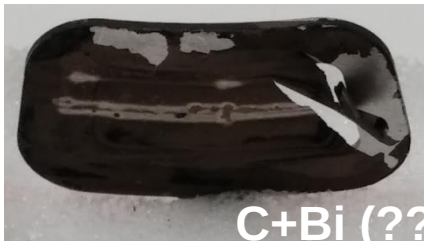
CIMAP Caen, MAtériaux, Défauts, IRradiation

SEM @ 2kV

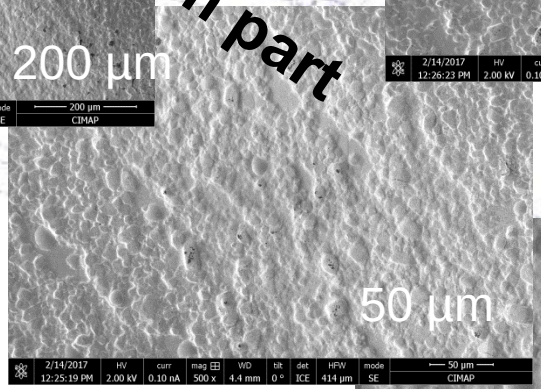


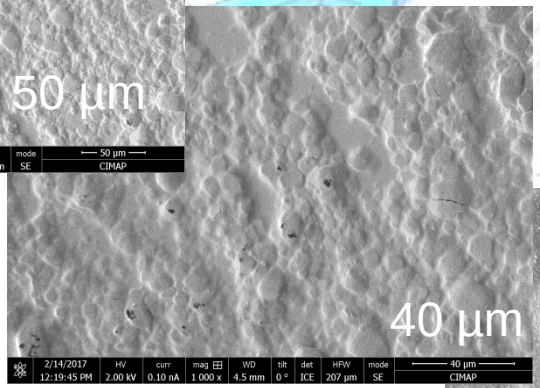
On Beam part

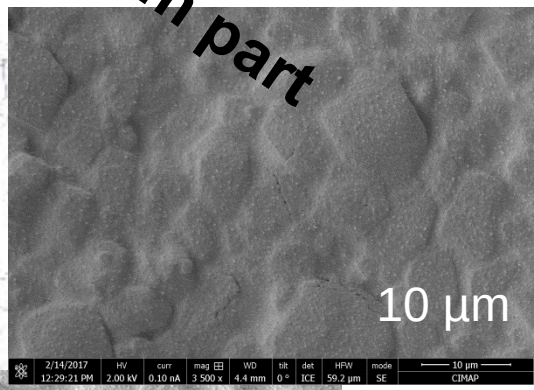


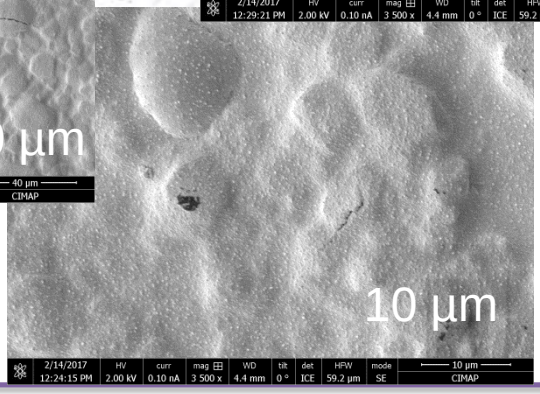


under Beam part







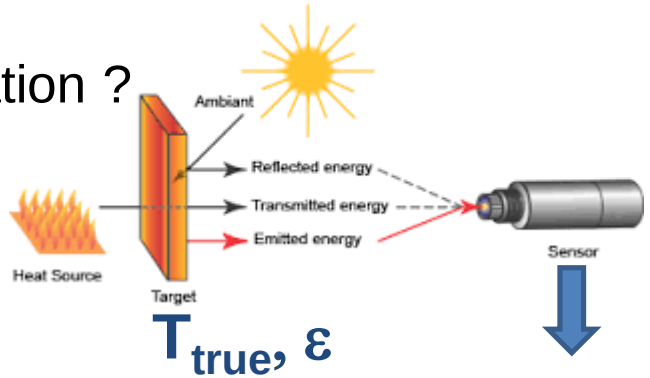


Photos from I. Monnet

AFM, Profilometers @ CIMAP labs

IR imaging ?

- Can we control target temperature under irradiation ?
  - Temperature = fct (emissivity)



- Can we measure beam spot dimensions?
- How to deport it ?

Technical data of FLIR SC7000:

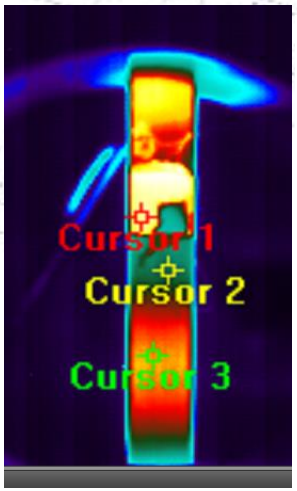
1.5 à 5 µm

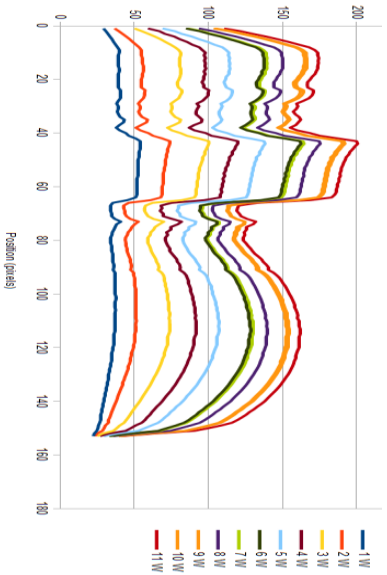
5-1500° C

320*256:380 Hz // 80*64: 3500Hz

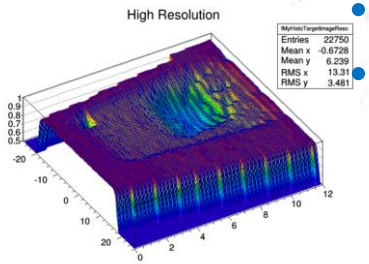
(3000 rpm = 50 Hz; 3500Hz= 70 images)

Resolution of 0.3mm per pixel





Conclusions & Perspectives



- **Control with electron gun = Online Monitoring**
  - Proof of principle successful
  - Qualitative results
  - Interpretation of measurements:
    - Stable target (C+Bi): Kr @ 0,2 pμA === Zn @ 1,7 pμA
    - Actinide (Ti + Act): Kr @ 0,2 pμA === Ca @ 0,6 pμA
    - Alpha comparisons ?
    - Thresholds ?
    - Pre/Post Irradiation Imaging (SEM)
  - Electronics to be upgraded / egun spares
- **IR camera**
  - Methodology for emissivity, reflexion and transmission measurements
  - Deport studies

7th High Power Targetry Workshop

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Thanks for your attention