Super Separator Spectrometer

The project & the physics opportunities

Hervé Savajols

on behalf of the S^3 collaboration

S^3 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)

http://pro.ganil-spiral2.eu/spiral2/instrumentation/s3

Overview

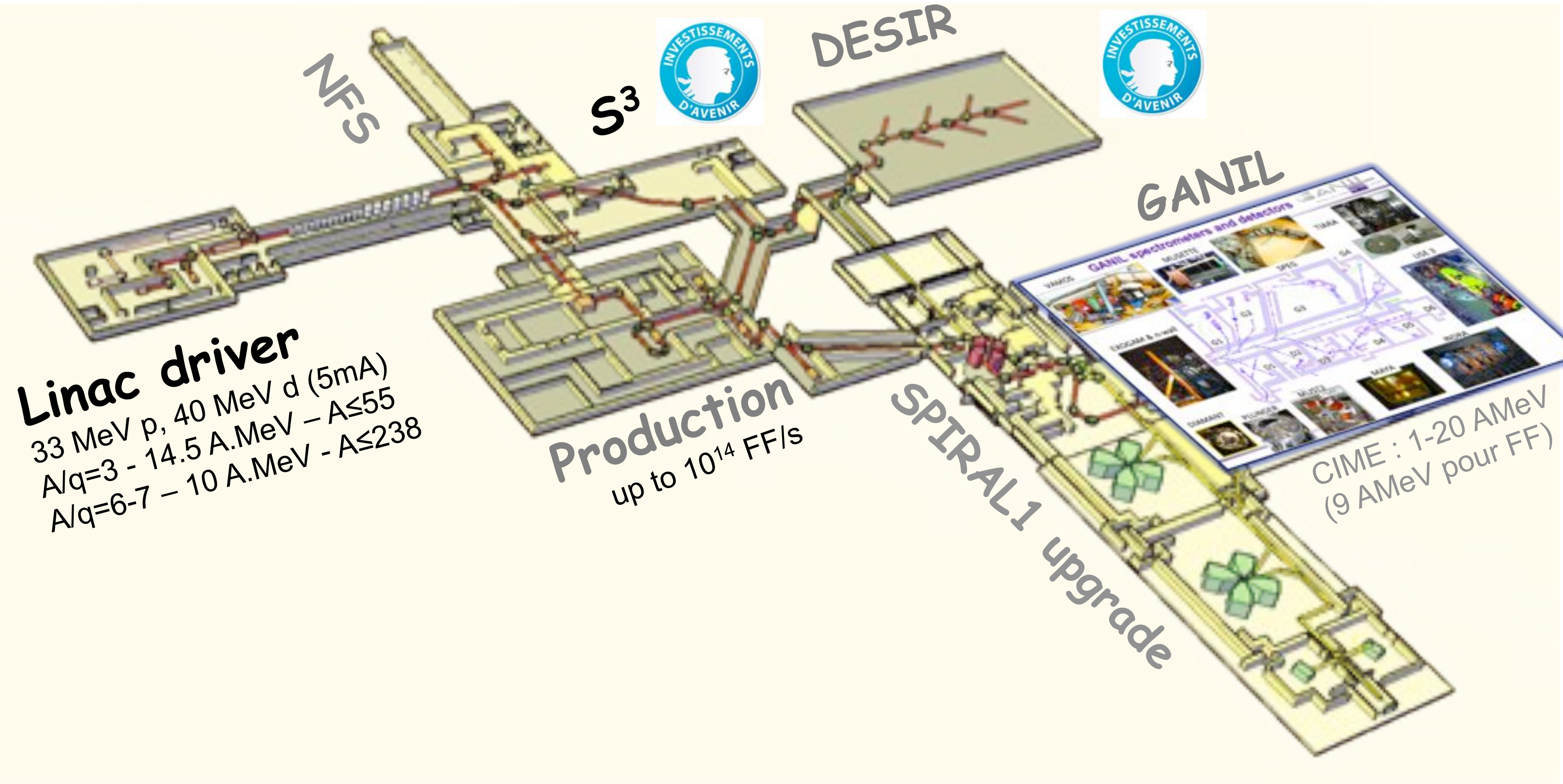
- ✓ **Status of SPIRAL2 phase 1**
- ✓ **Separator Spectrometer**
- ✓ **Experimental techniques**
- ✓ **Physics opportunities**

  Spiral2 Ph1 physics WS – March 2014 – 165 participants
- ✓ **Outlook and conclusions**

SPIRAL2 under construction

Phase 1: High intensity stable beams + Experimental rooms (NFS + S^3 + DESIR) (2015)

Phase 2: High-intensity low-energy & post-accelerated Radioactive Ion Beam facility



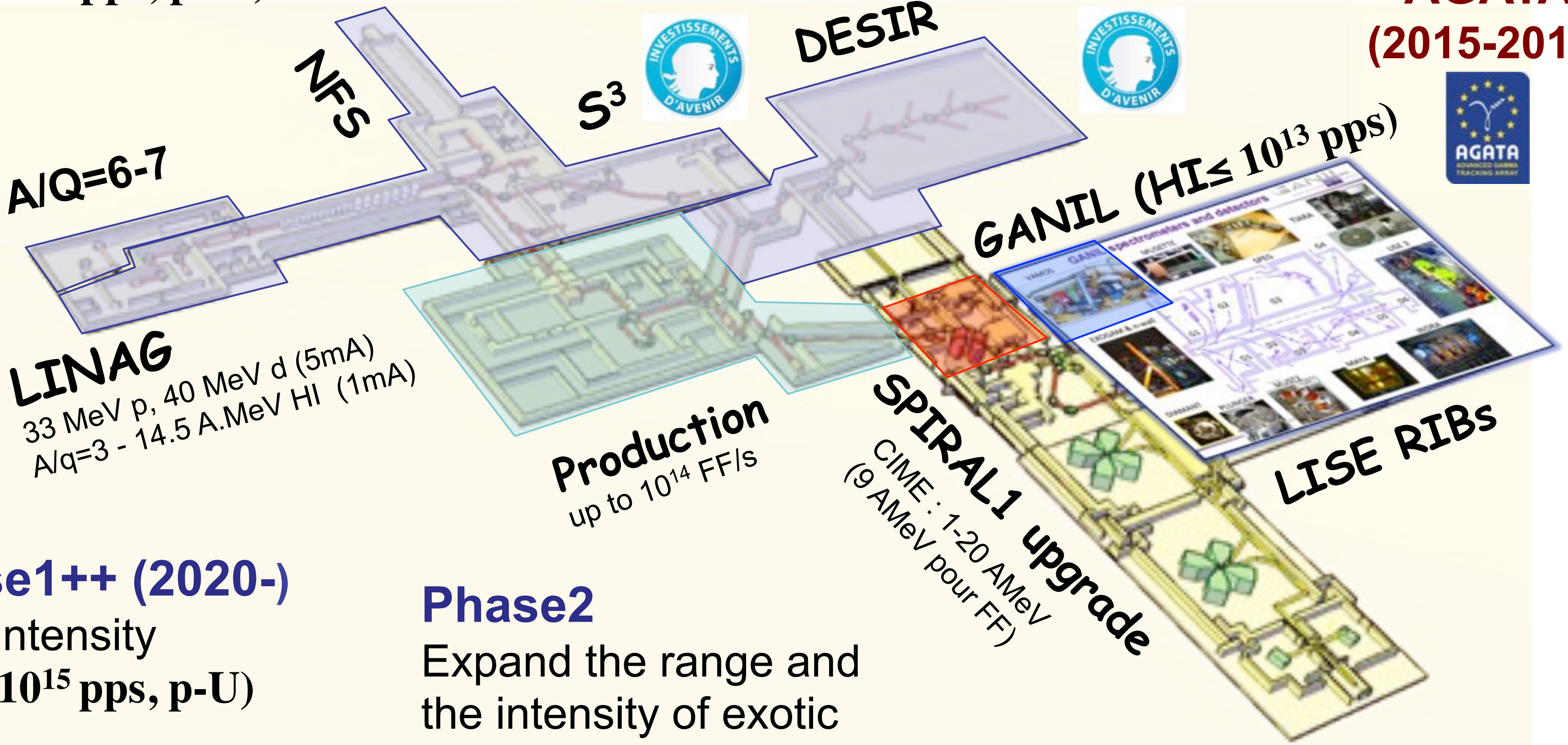
- *SPIRAL2 is on the list of the European Strategy Forum on Research Infrastructures (ESFRI)*

Is under construction

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++ (2020-)
High Intensity
(HI≤ 10^{15} pps, p-U)

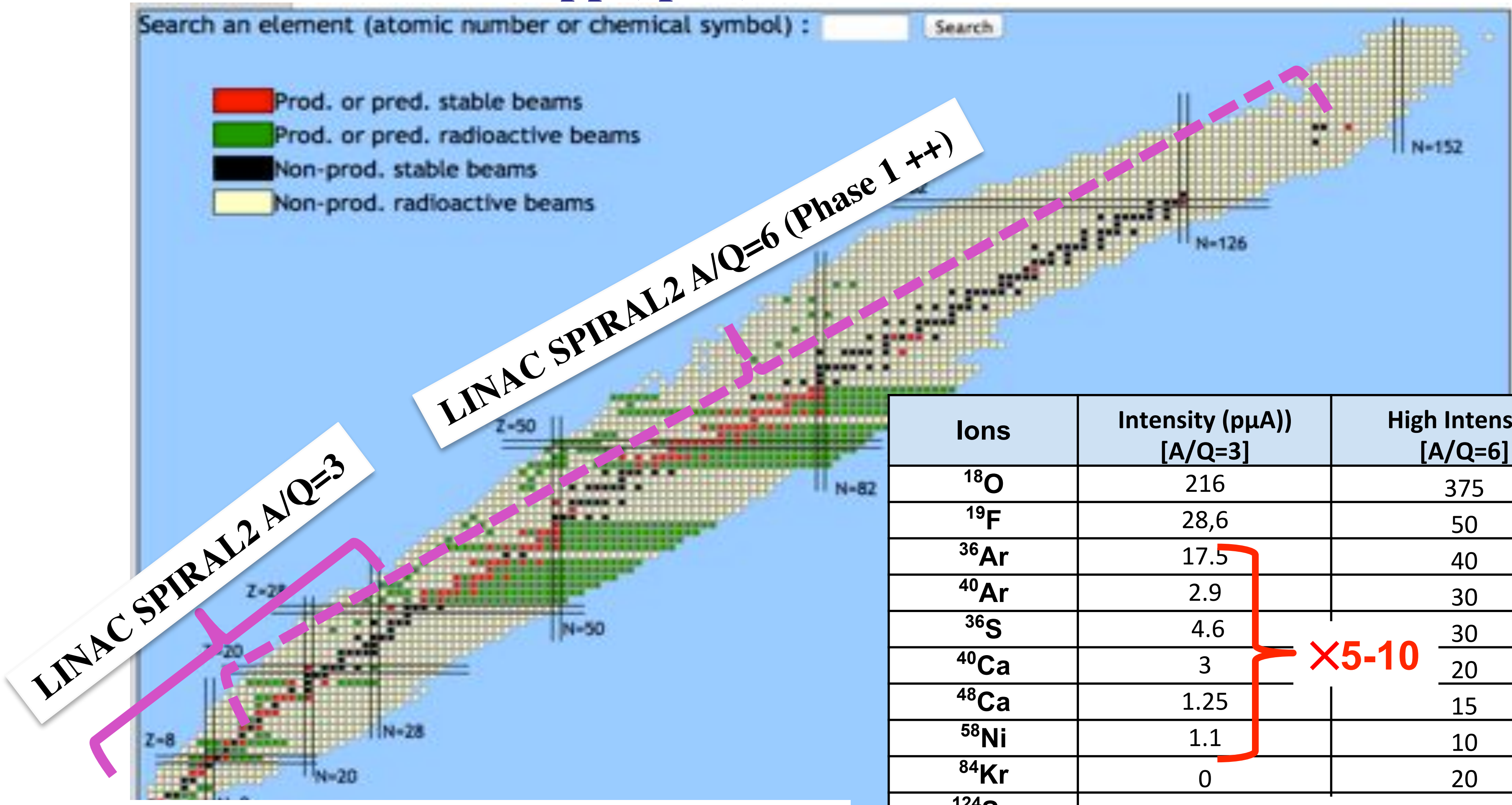
Phase2
Expand the range and the intensity of exotic nuclei

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

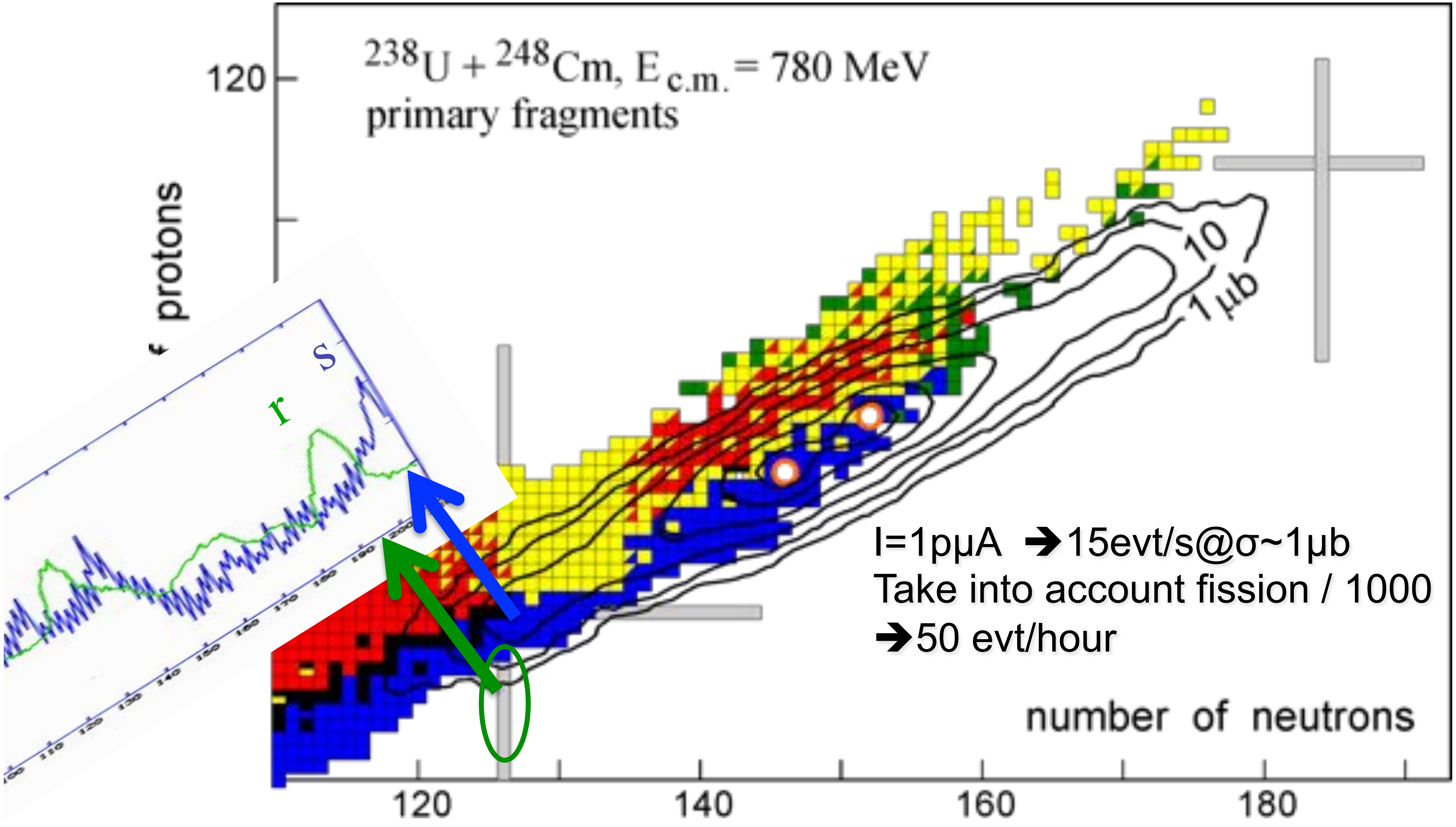
×5-10 (^{36}Ar – ^{58}Ni)

×10^x (^{84}Kr – ^{238}U)

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

Neutron-rich VHE-SHE

New perspectives with the phase1++ high intensity heavy beams (Xe, Pb, U)



V. *Zagrebaev* and W. *Greiner*, Phy. Rev. C 83, 044618 (2011)

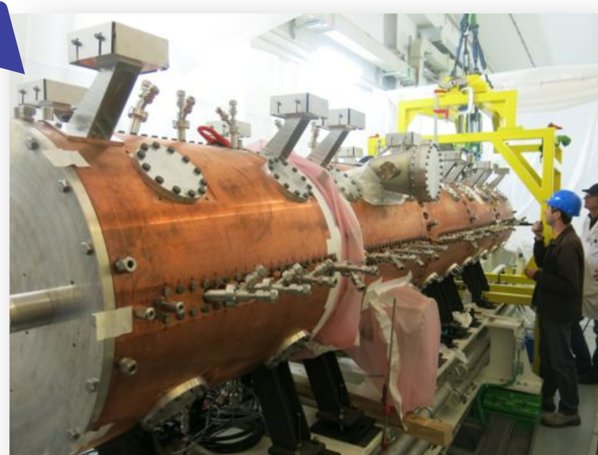
SPIRAL2 Phase 1++ civil construction is finished

September 2014

Installation

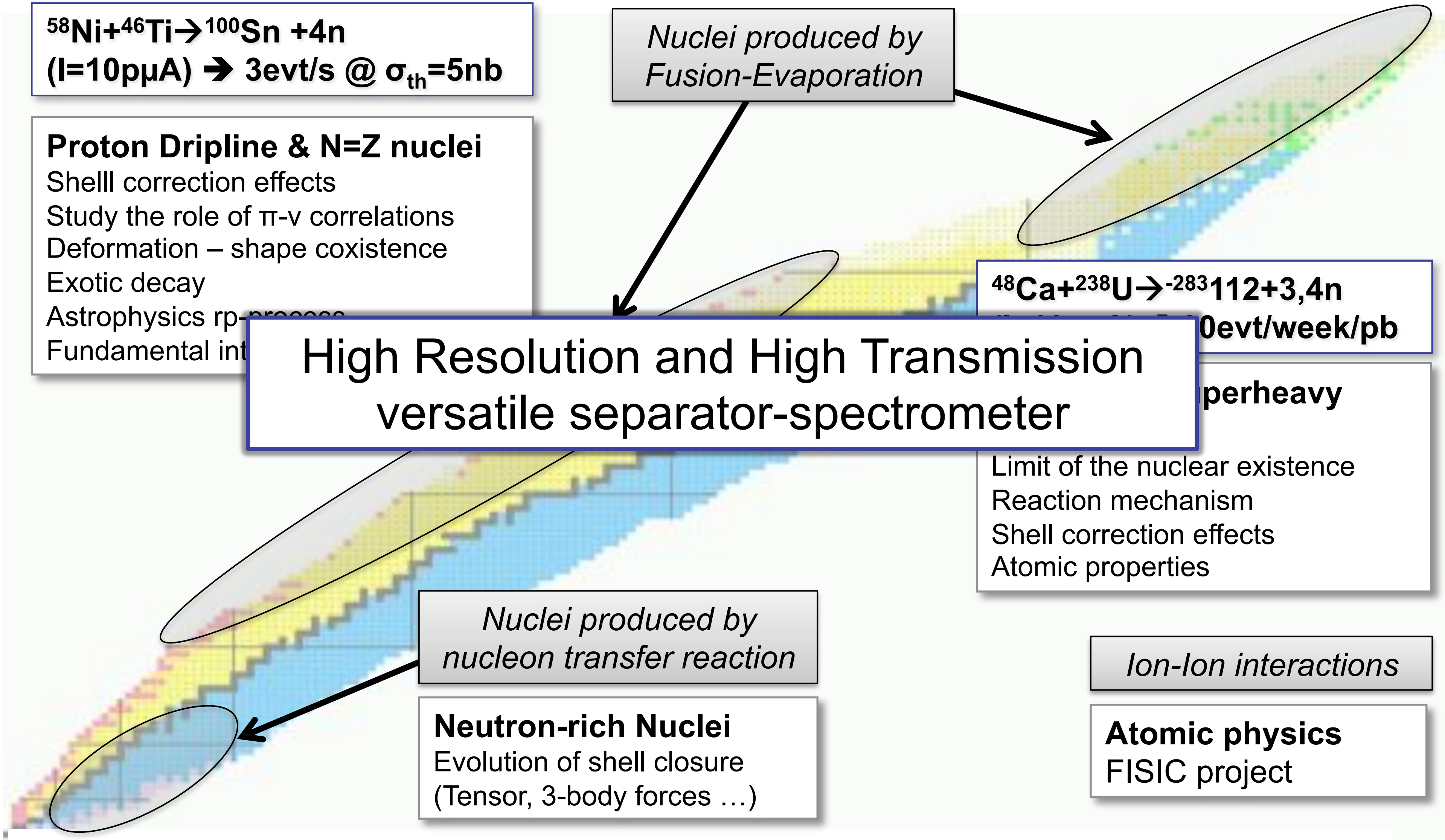
LINAC beams in 2015

"First generation of ECOS facility"



S3 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

Proton Dripline & N=Z nuclei
Shelll correction effects
Study the role of π-v correlations
Deformation – shape coxistence
Exotic decay
Astrophysics rp-
Fundamental int

Nuclei produced by Fusion-Evaporation

High Resolution and High Transmission versatile separator-spectrometer

$^{48}Ca+^{238}U \rightarrow ^{283}112$+3,4n
0evt/week/pb

perheavy
Limit of the nuclear existence
Reaction mechanism
Shell correction effects
Atomic properties

Nuclei produced by nucleon transfer reaction

Neutron-rich Nuclei
Evolution of shell closure
(Tensor, 3-body forces …)

Ion-Ion interactions

Atomic physics
FISIC project

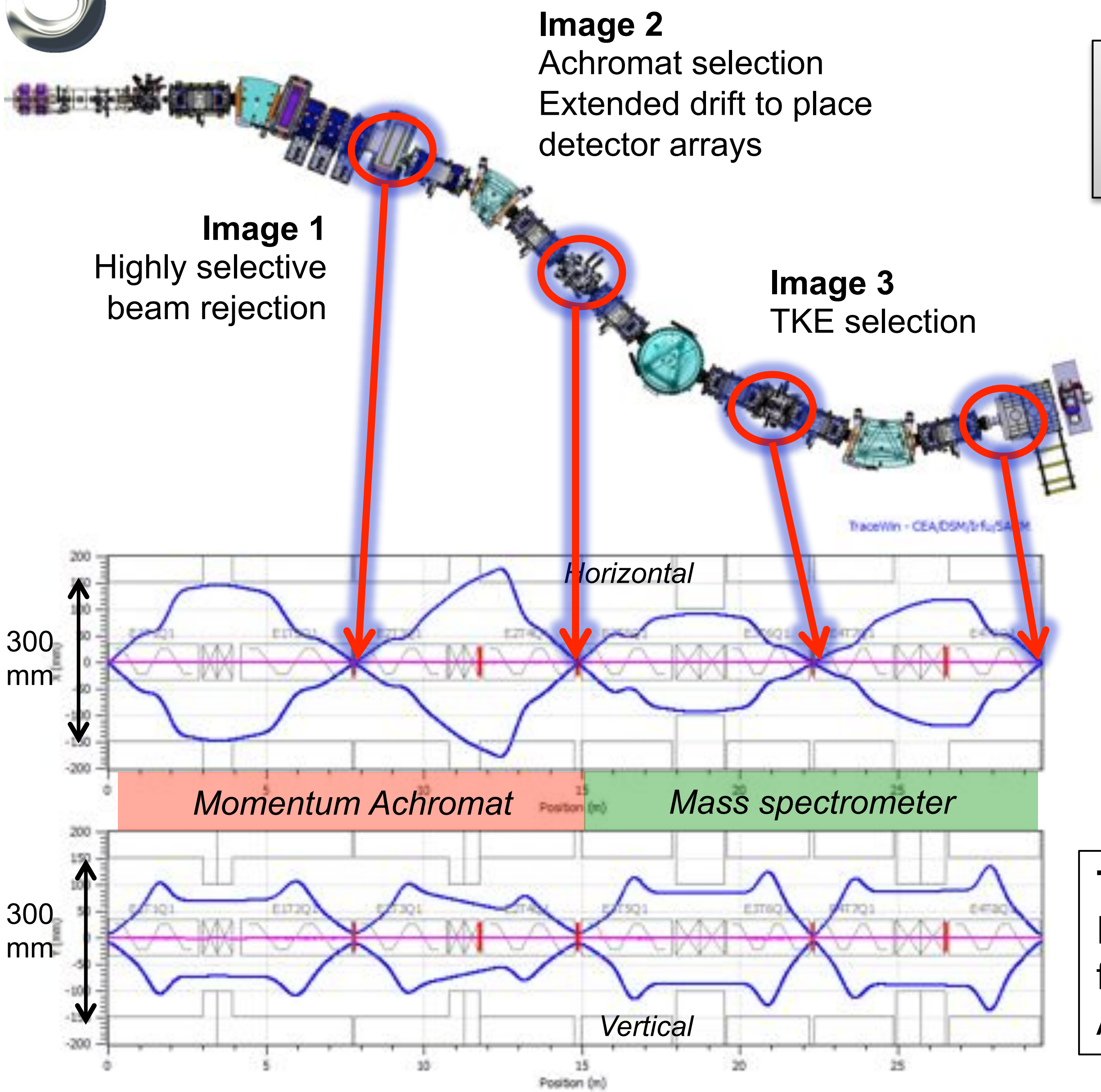
➔ **test nuclear and atomic models and guide new theoretical development**

S3 Technical challenges

laboratoire commun CEA/DSM CNRS/IN2P3

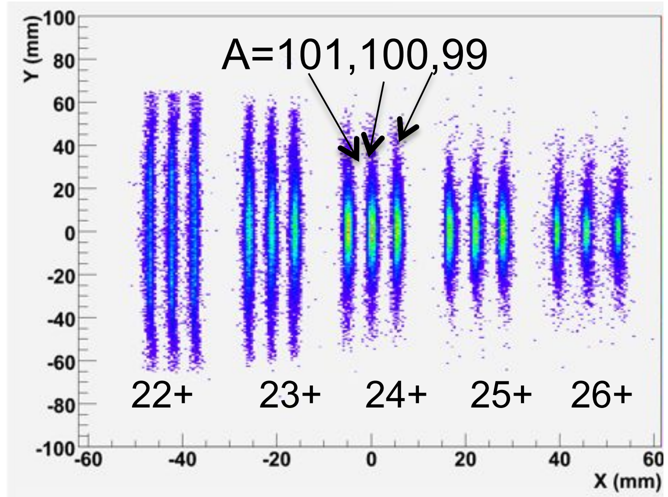
- **High Beam intensity** (10pμA = 6.10^{13}p/s or more)
  - ➔High power loss density in target and beam dump
  - ➔Rejection of the beam : >10^{13}
- **Reactions at Low Energy** (fusion-evaporation residues)
  - ➔Large solid angle : +/- 80 mrad X and +/- 80 mrad Y
  - ➔Charge state acceptance of +/- 10% ($q=20^+$)
  - ➔Momentum acceptance for each charge state Bρ: +/- 10%
- **Many reaction channels** (evaporation channels)
  - ➔M/q selection : 1/350 (FWHM) resolution
  - ➔Identification in Z when possible
- **Versatility** (transfer reactions & ion-ion collisions)
  - ➔ High range in energy [$B\rho_{max}$ = 1.8Tm]
  - ➔ Secondary reactions

S3 Optics



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

Image 4 : Mass selection



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

Operational modes & performances

◎ High Resolution mode

- Designed for maximum selection
- Weighted mass resolution: ΔM/M **= 460**
- Folded transmission: 50% for $^{58}Ni + ^{46}Ti \rightarrow ^{100}Sn^{24+} + 4n$

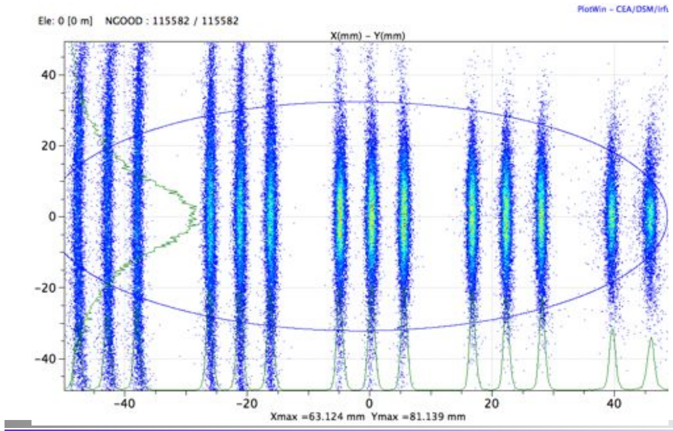
◎ High Transmission mode

- Designed for very asymmetric reactions
- Weighted mass resolution: ΔM/M **= 260**
- Folded transmission: 15-20% for $^{22}Ne + ^{238}U \rightarrow ^{255}No + 5n$

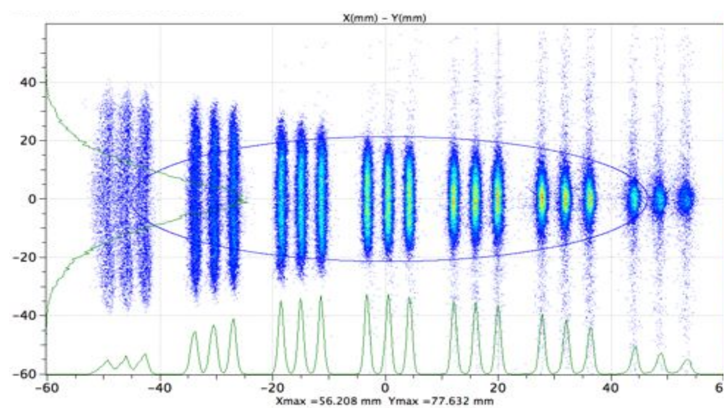
◎ Converging mode

- Designed for gas cell – Laser spectroscopy
- Folded transmission: 68% for $^{58}Ni + ^{40}Ca \rightarrow ^{94}Ag + p3n$

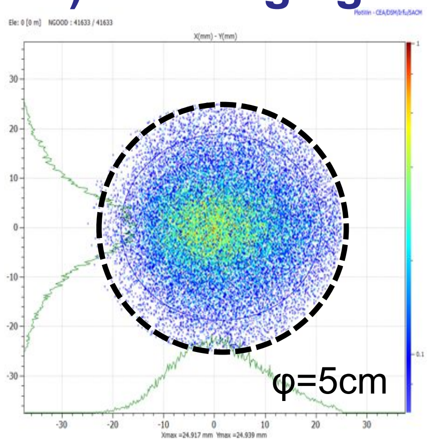
1) High resolution



2) High transmission

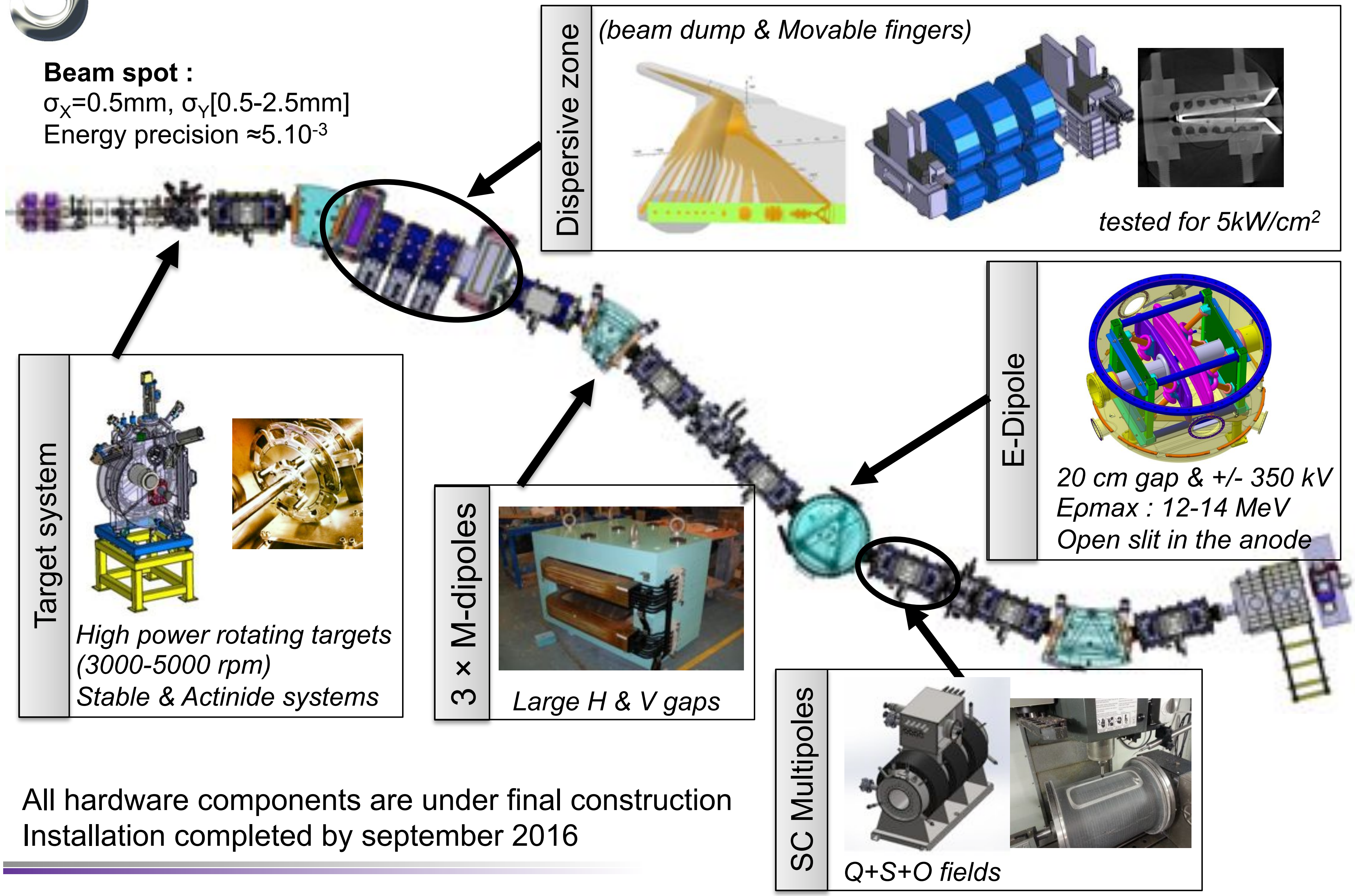


3) Converging



S3 Technical highlight

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



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

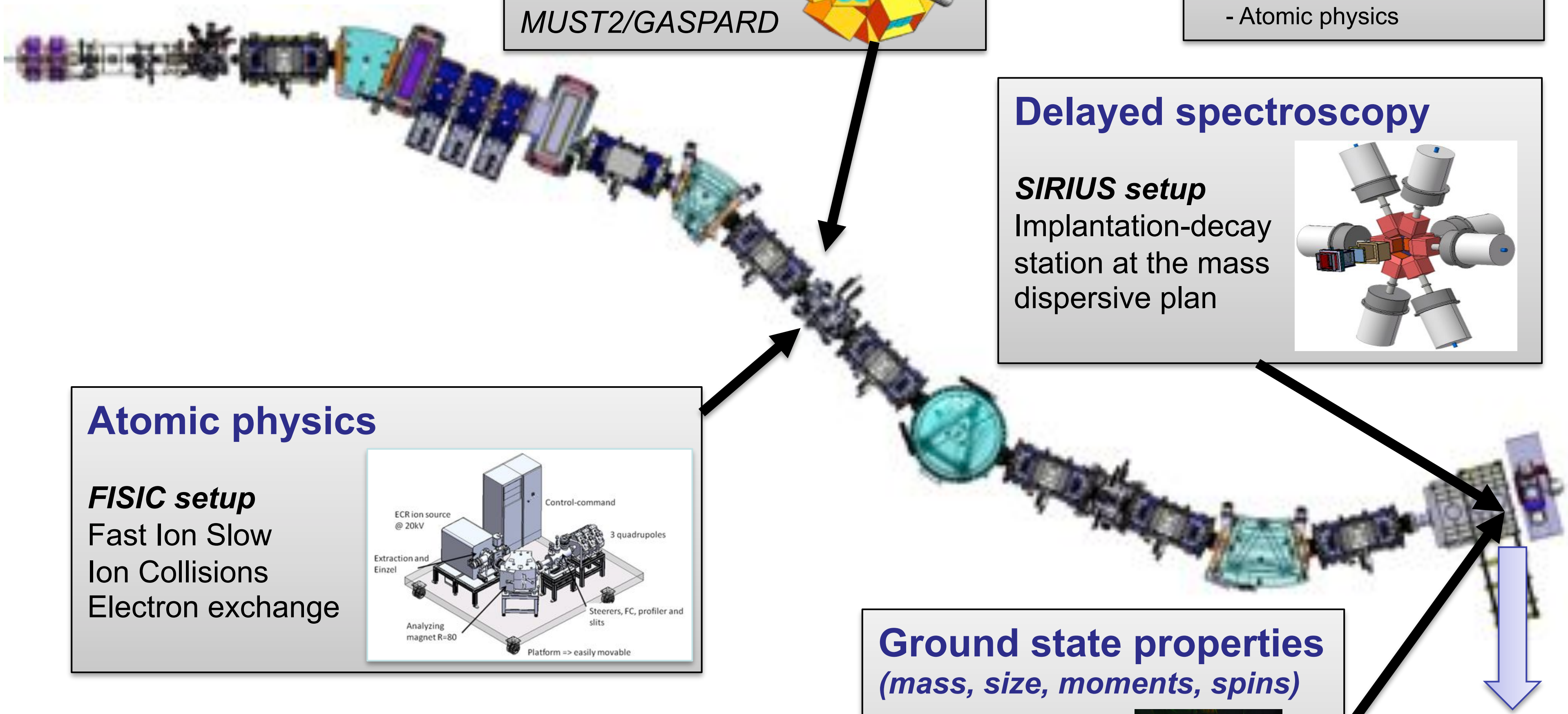
S3 Experimental Techniques

In-beam spectroscopy

Two step reactions
EXOGAM2
PARIS
AGATA
MUST2/GASPARD

S3 Physics case (16 LoIs)

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



Delayed spectroscopy

SIRIUS setup
Implantation-decay station at the mass dispersive plan

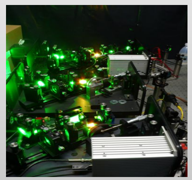
Atomic physics

FISIC setup
Fast Ion Slow Ion Collisions
Electron exchange

Ground state properties

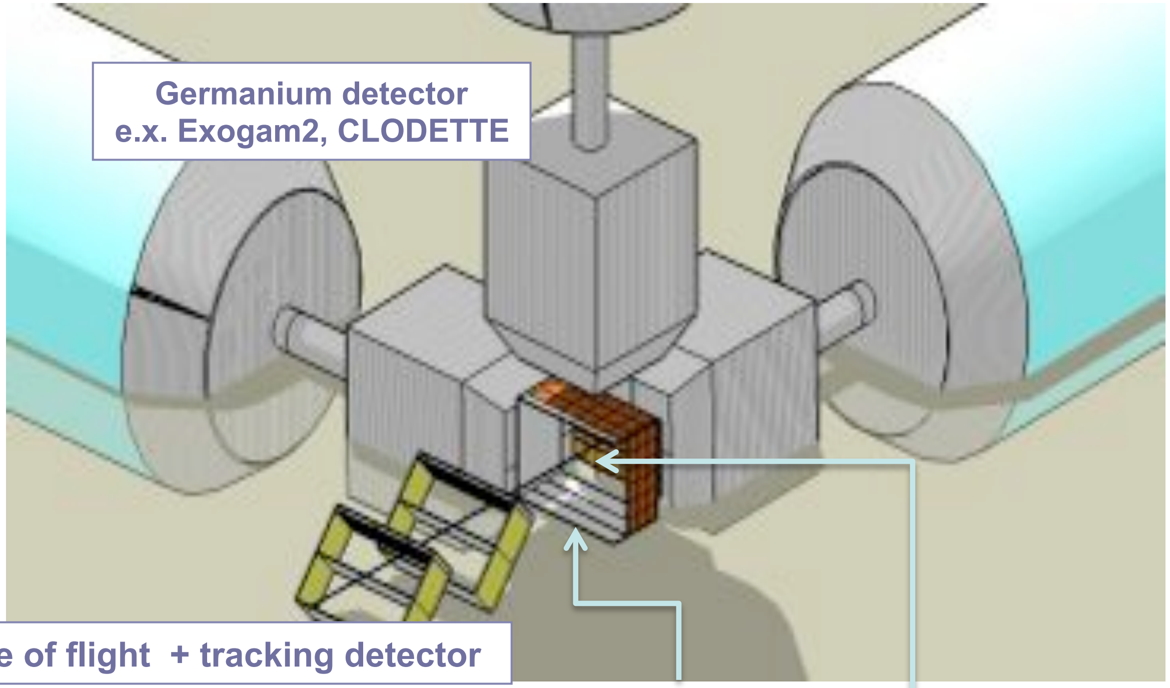
(mass, size, moments, spins)

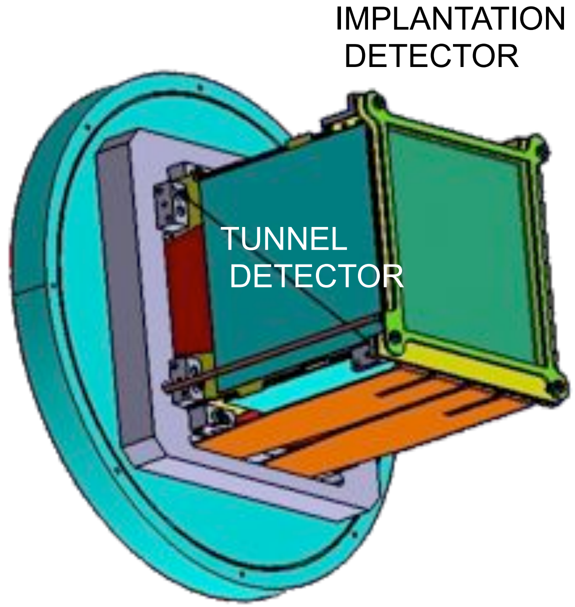
REGLIS^3 setup
Low Energy Branch



Experimental Techniques

SIRIUS (Spectroscopy & Intendification of Rare Ions Using S^3)





Time of flight + tracking detector

- Large size (200x150 mm^2)
- Time Resolution < 1ns
- Position resolution = 1mm
- Very low thickness

Tunnel detector for escaped e^- and α

- Conversion electrons FWHM <5 keV
- Escaped alpha FWHM 15 keV

Implantation detector
(HI, α and e^- decay)

- Large detector size $10x10cm^2$
- High resolution FWHM
- **Ability to detect large> 50MeV pulse Followed (≈ 10μs) by a weak (<15MeV) pulse.**
- No Dead time

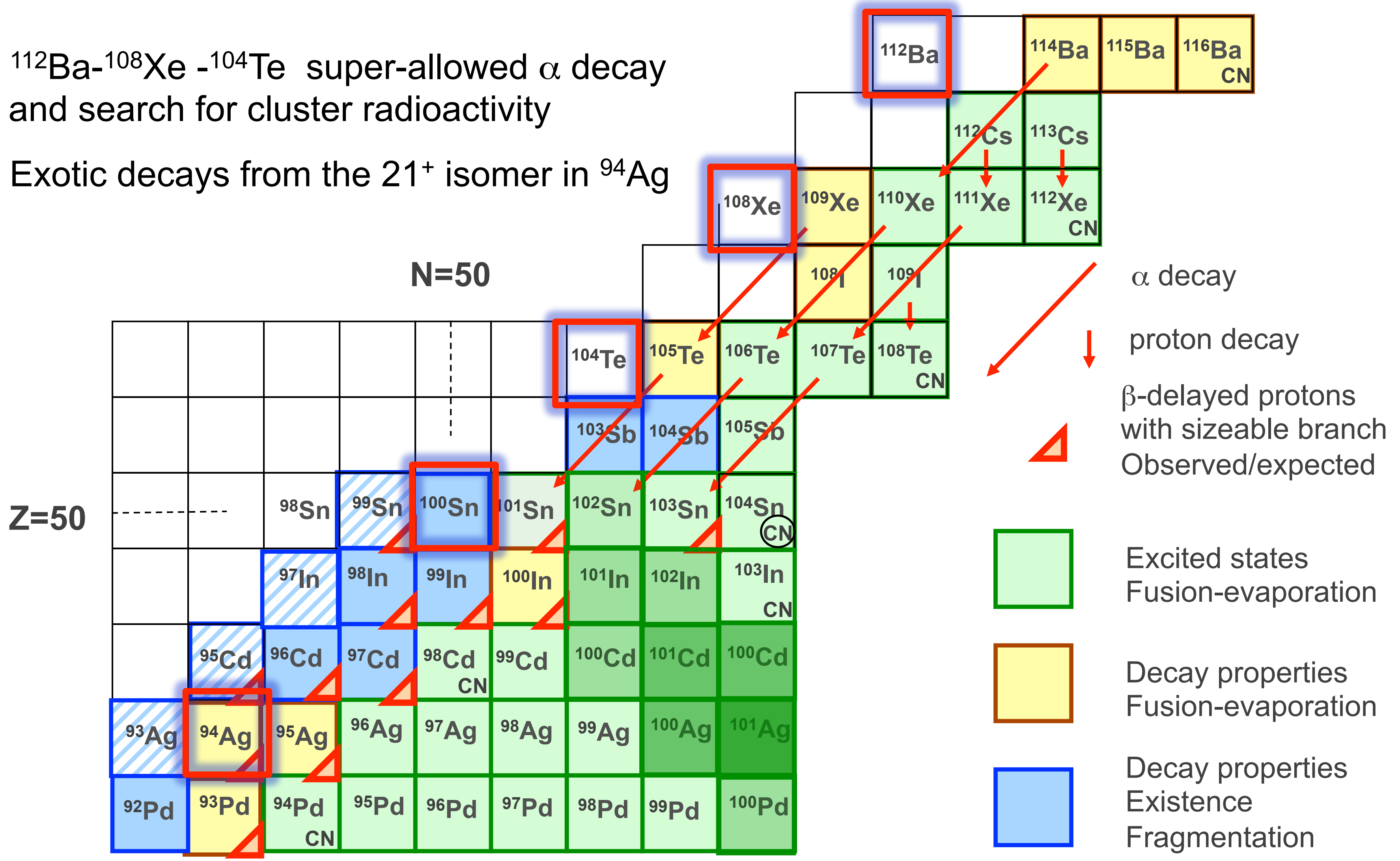
- Recoil-decay tagging
- Short decay times
- High Resolution High efficiency
- Mass separation

(GANIL,IPHC, CSNSM, CEA/Irfu/SPhN)

Day1 experiments: N=Z

^{100}Sn region experimental status

- ^{112}Ba-^{108}Xe -^{104}Te super-allowed α decay and search for cluster radioactivity
- Exotic decays from the 21^{+} isomer in ^{94}Ag



Day1 experiments: VHE - SHE

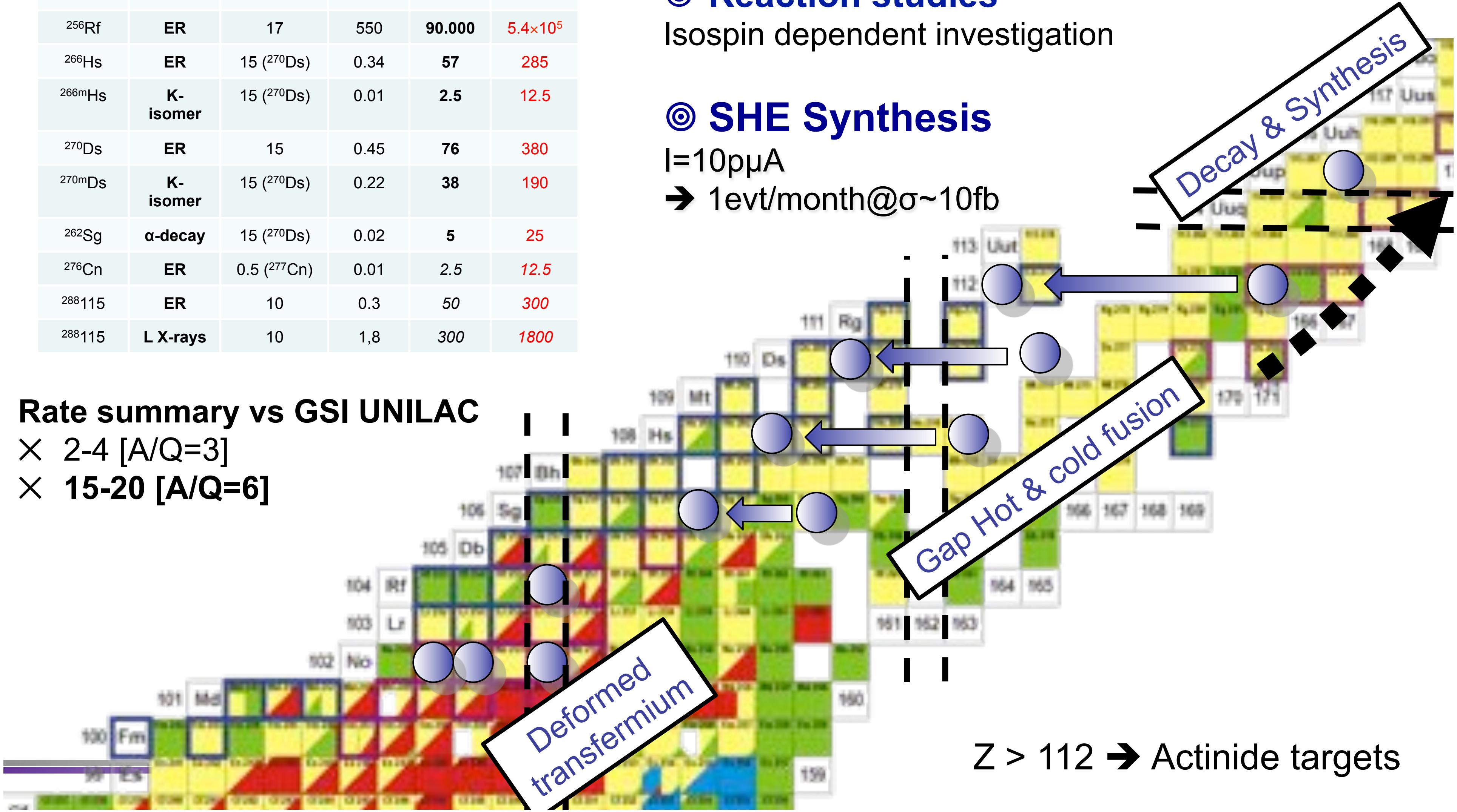
nuclide	feature	X-section [nb]	rate [h^{-1}]	21UT integral	
				day 1	phase 1++
^{254}No	ER	2000	60.000	**6×10^{7}**	1×10^{7}
^{256}Rf	ER	17	550	**90.000**	5.4×10^{5}
^{266}Hs	ER	15 (^{270}Ds)	0.34	**57**	285
^{266m}Hs	K-isomer	15 (^{270}Ds)	0.01	**2.5**	12.5
^{270}Ds	ER	15	0.45	**76**	380
^{270m}Ds	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*

◎ Nuclear structure
Quasi-particle excitations ➔ deformation/K-isomers

◎ Reaction studies
Isospin dependent investigation

◎ SHE Synthesis
I=10pμA
➔ 1evt/month@σ~10fb

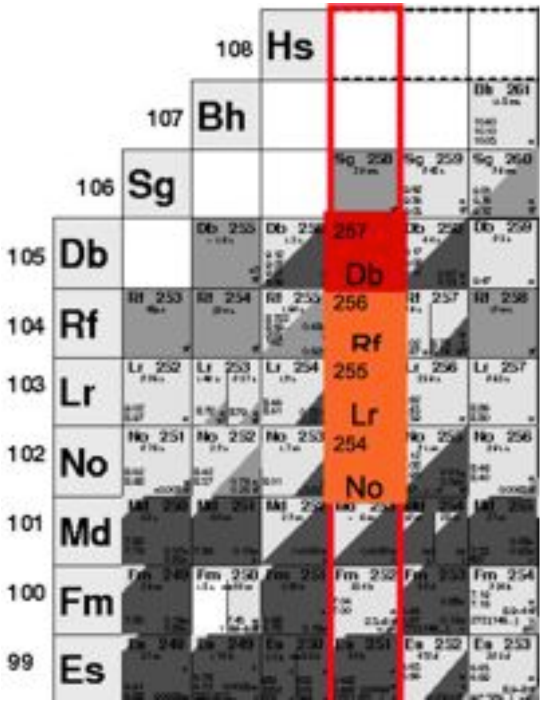
Rate summary vs GSI UNILAC
- × 2-4 [A/Q=3]
- × **15-20 [A/Q=6]**



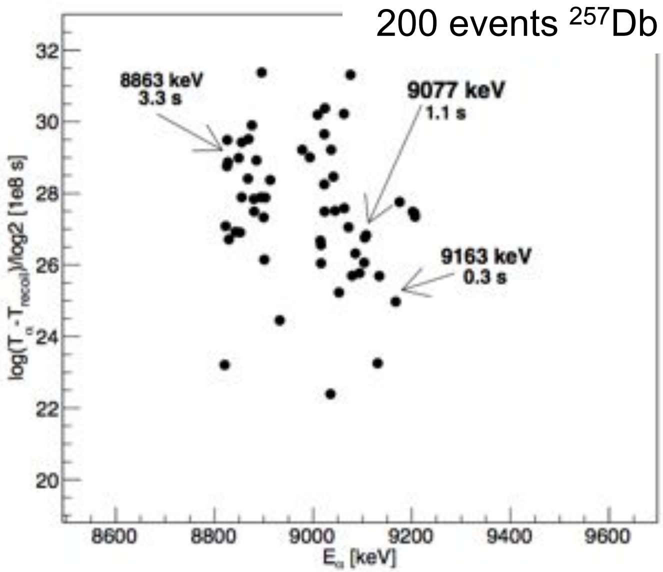
Z > 112 ➔ Actinide targets

Synthesis of ^{257}Db @ GANIL

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

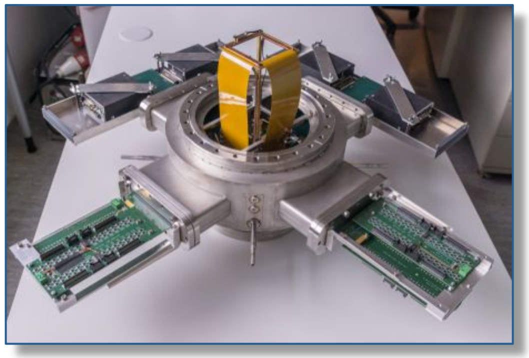


^{209}Bi(^{50}Ti,2n)^{257}Db σ=2.4 nb



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)

Set the course for the S^3 VHE-SHE researches

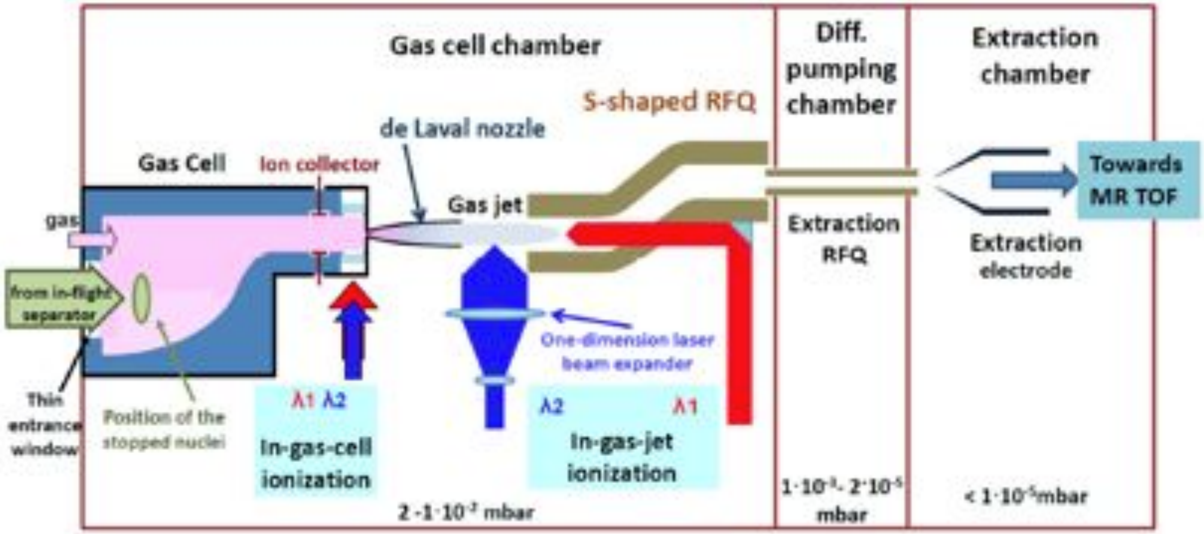


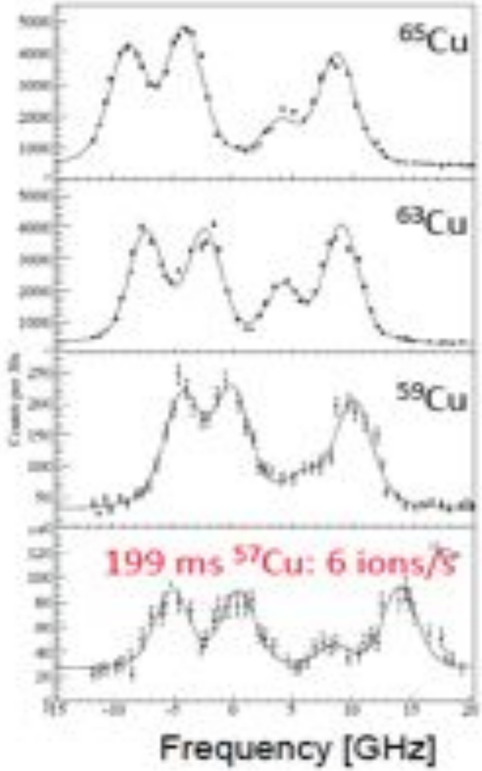
E656 experiment : J. Piot & M. Vostinar (GANIL)

Low energy branch

(Some experiments require higher purity, low energy ions in vacuum,…)

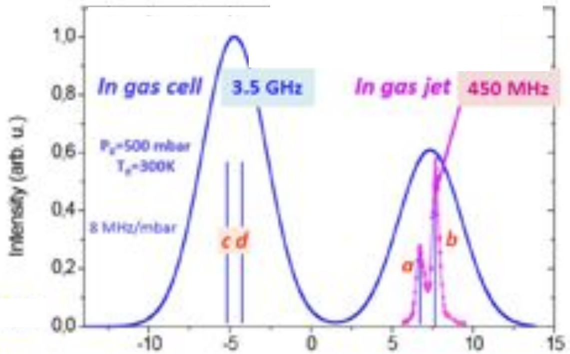
REGLIS³: In-gas cell laser ionization and spectroscopy

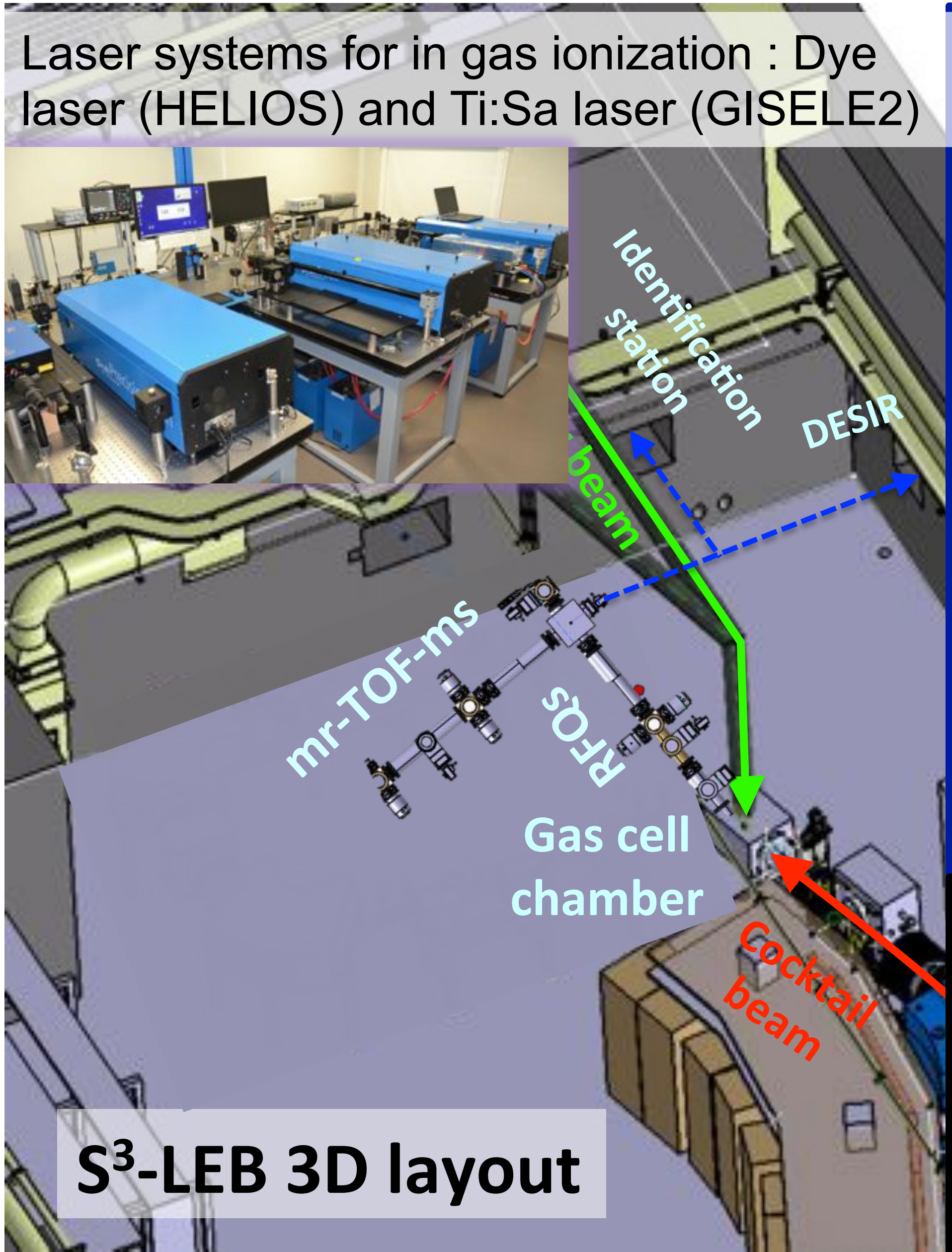




T.E. Cocolios et al., PRL103 (2009) 102501

- ◎ Pre-selection by S³ in-flight separator
- ◎ Products thermalized and neutralized in a buffer gas
- ◎ Re-ionization of stopped reaction products
- ◎ Selective ionization for decay spectroscopy, mass measurements, DESIR
- ◎ High resolution laser spectroscopy in gas jet





(GANIL,LPC,IPNO,KU LEUVEN, …)

MAJOR ATTRIBUTS OF THE DEVICE

✓**Efficient :**
produced in very small quantities (-> ~ 1 pps)

✓**Selective (isotopic & isobaric selections) :**
suppression of unwanted isotopes
(1/10 000 lower limit demonstrated)

✓**Relatively fast :**
short life time (up to ~ 100 ms)

✓**Sufficient spectral resolution**
(-> few hundred MHz):
determine the isotope/isomer shift and hyperfine structure, spin, moments…

=> 2 in 1 : Laser spectroscopy + Laser Ion Source (pure (isomeric) beams)

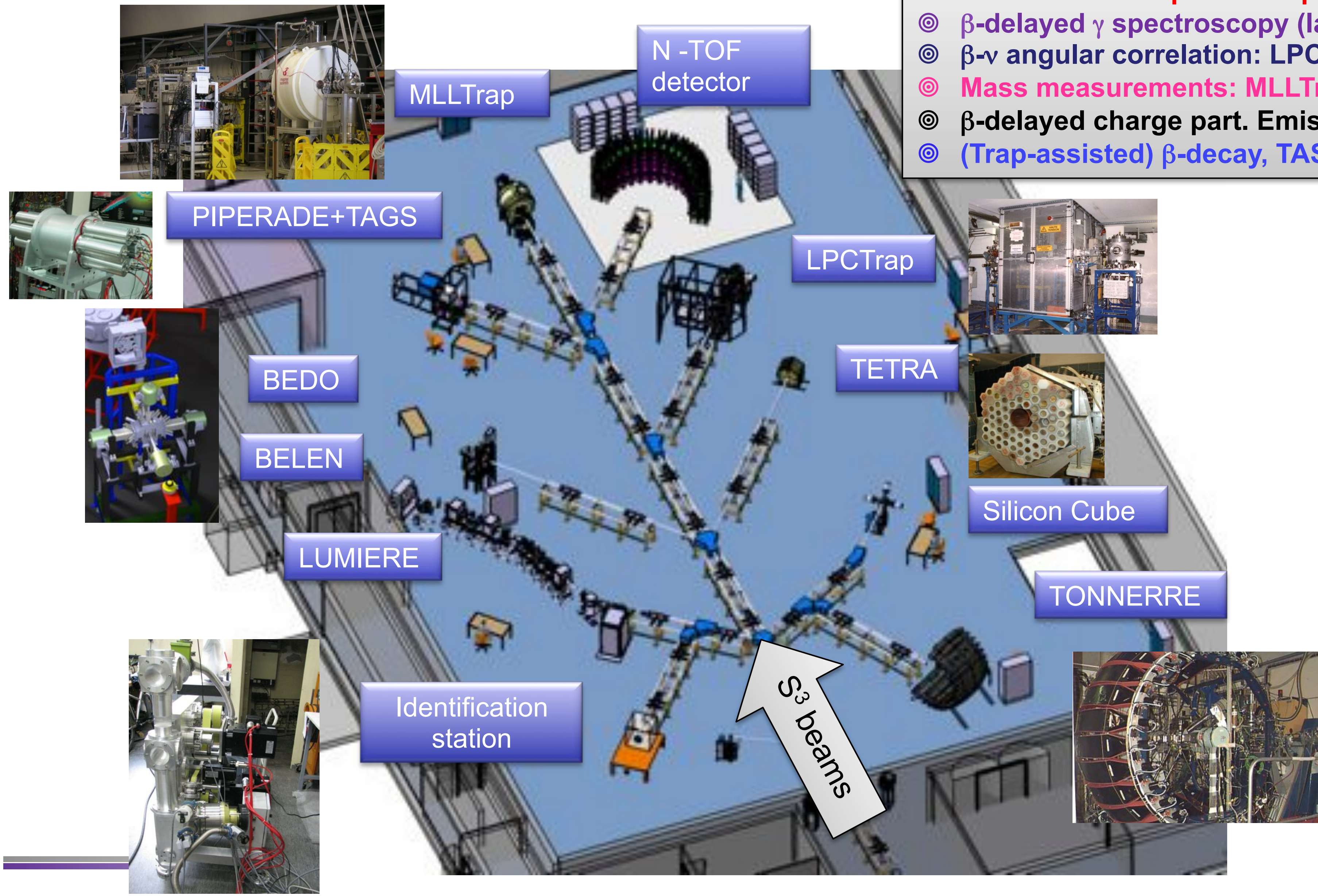
Expected performances

Transmission through S^3	40-50 %
Thermalization, diffusion and transport through the exit hole	50-90 %
Neutralization	50-100 %
Laser ionization	50-60 %
Transport efficiency	80-90 %
Total efficiency	**4-24 %**

R. Ferrer *et al.*, NIMB (2013) in press

Low energy platform

- Collinear laser spectroscopy
- β-delayed γ spectroscopy (laser)
- β-ν angular correlation: LPCtrap
- Mass measurements: MLLTrap
- β-delayed charge part. Emission
- (Trap-assisted) β-decay, TAS



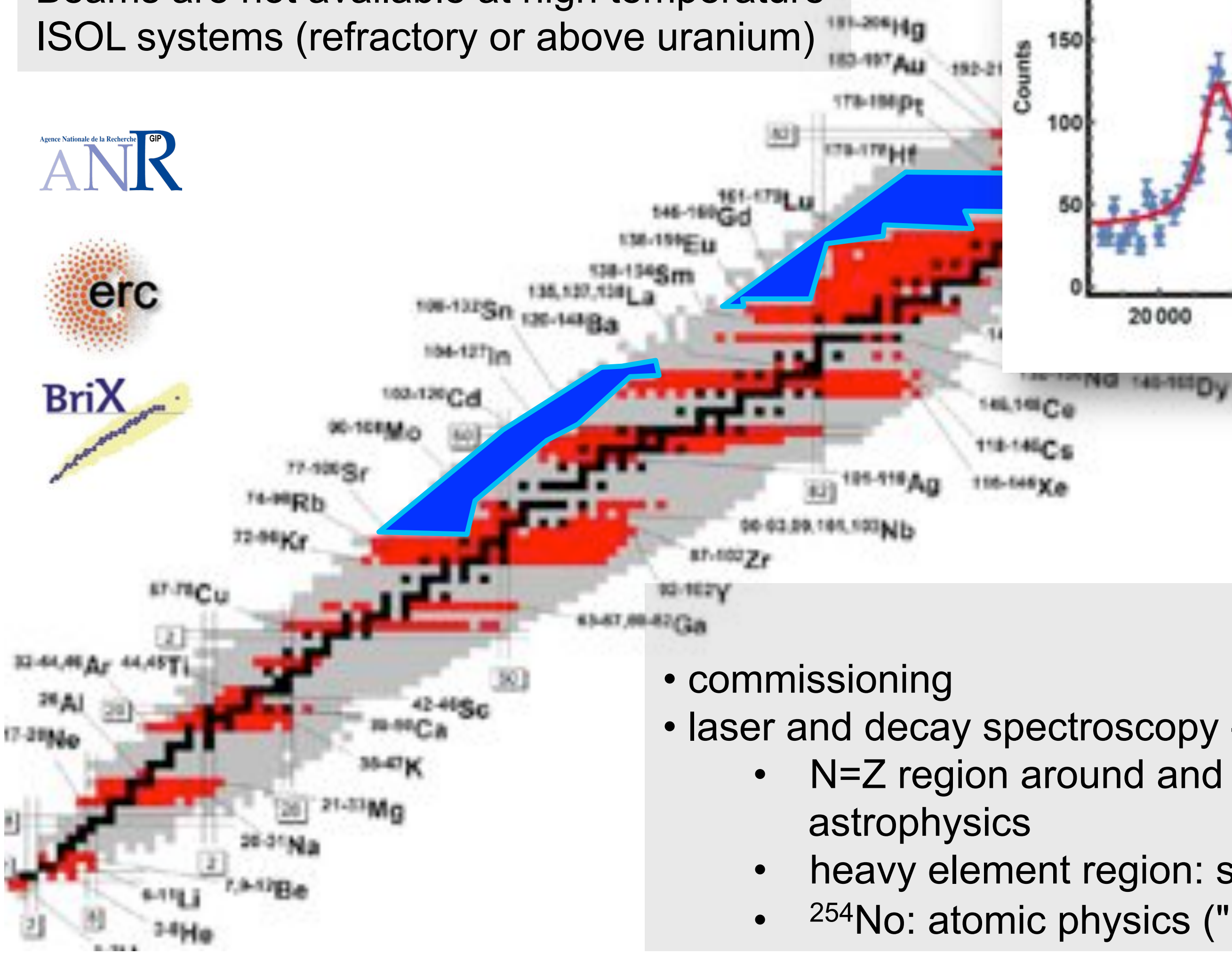
REGLIS³ day 1 experiments

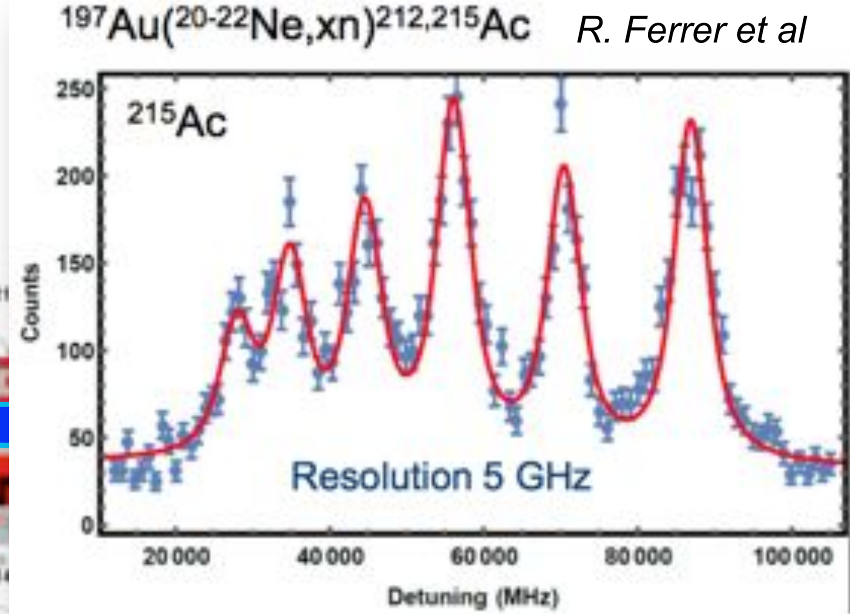
- Red boxes:

Laser (optical) spectroscopy data available

- Empty 'gaps':

Beams are not available at high temperature ISOL systems (refractory or above uranium)



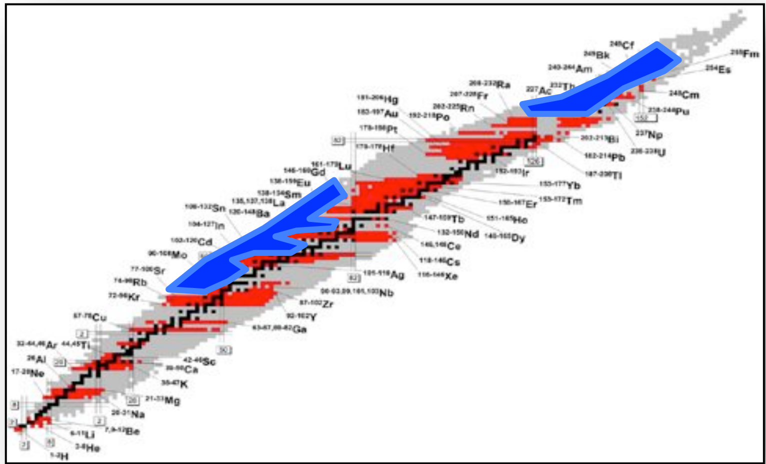


"Day 1" experiments

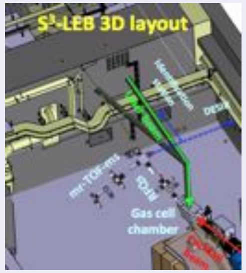
- commissioning
- laser and decay spectroscopy - mass measurements MR-TOF
  - N=Z region around and below 100Sn: shell evolution, astrophysics
  - heavy element region: shapes, stability
  - ^{254}No: atomic physics ("Day 2" experiment)

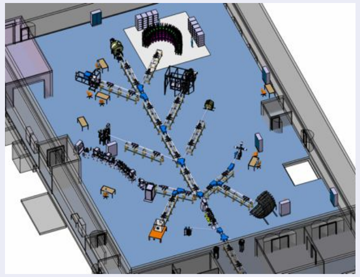
UNIQUE Opportunities :
SPIRAL2 Phase 1 + - GANIL (AGATA, …)

Probing nuclei properties with unique complementarity techniques



REGLIS³ | Spiral2 DESIR

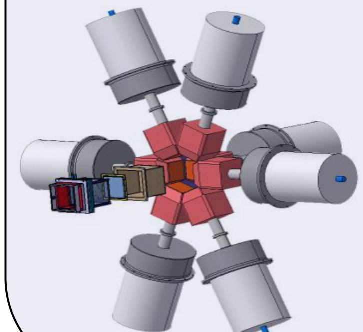


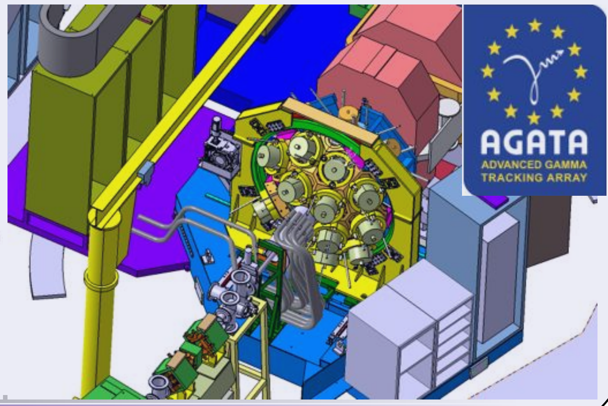


Ground State properties

Excited state properties

SIRIUS



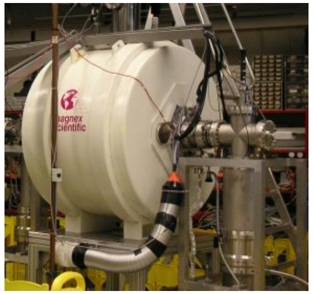


- ◎ Ground state properties
  - ➔ S^3-SIRIUS/DESIR
  - *(Mass – Size – J^π– Moments)*
- ◎ Decay spectroscopy
  - ➔ S^3-SIRIUS/DESIR
- ◎ In-Beam spectroscopy
  - ➔AGATA-VAMOS@GANIL
  - ➔S^3

Détermination de V_{ud} depuis les transitions 0+→0+ et miroirs

➢Détermination de V_{ud} à une précision équivalente des 0+ 0+ depuis les transitions mirroirs

MLLTrap



Q-values

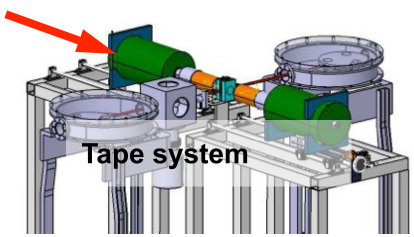
LPCTrap

Corrélations ($a_{\beta\nu}$, A_{β})

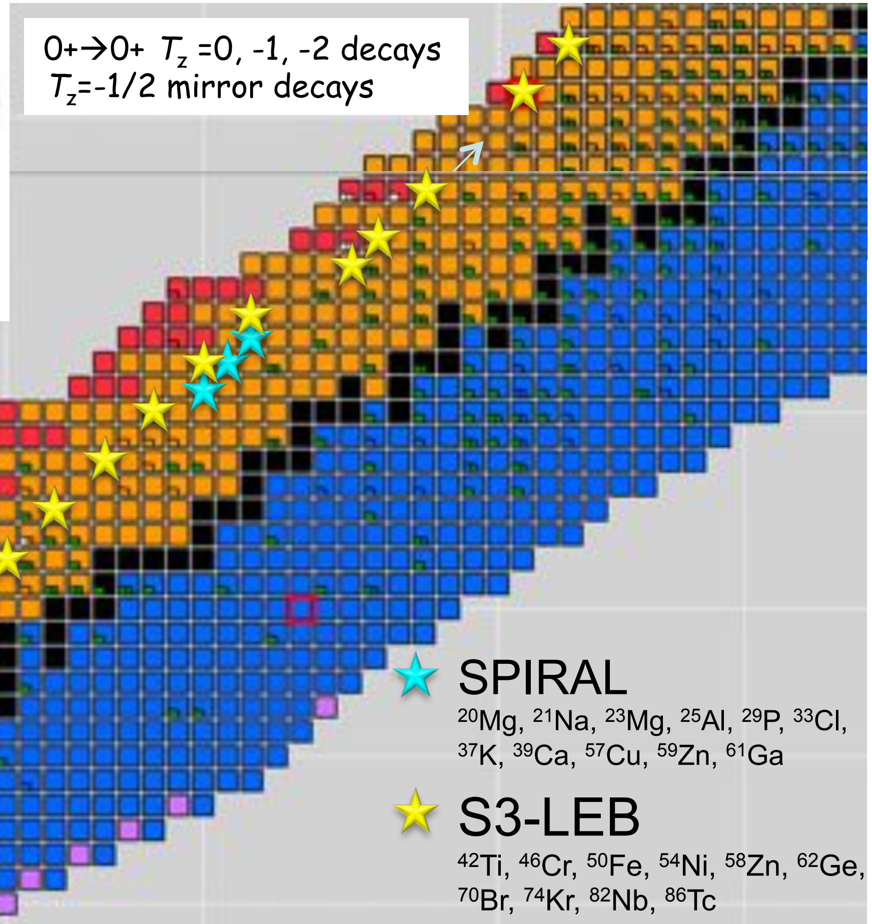
V_{ud} = 0.97425 (22)

*Hardy J C and Towner I S 2009 Nucl. Phys. A **254** 221*

CENBG tape station



$T_{1/2}$, BR



S^3 Conclusions

- **SPIRAL2 phase 1 under final construction: "First generation ECOS accelerator"**
  - Commissioning of the accelerator will start in 2015
- **SPIRAL2 phase 1++ (new injector A/Q=7) design will start 2015**
- **S^3 is a low energy in-flight separator for the Spiral2 stable beams**
  - Fusion-evaporation, two-step reactions, rare channels, electron exchange…
- **Designed for the selection and identification of rare events**
  - 2 steps rejection and >350 Mass resolution
  - High transmission of evaporation residues
  - High versatility
- **Two basic detection set-ups**
  - Implantation-decay spectroscopy station
  - In gas cell laser ionization & spec.

  ➔ **First beam in 2016**

You are welcome to join the collaboration