

The SPIRAL2 Project: Physics and Challenges

Marek Lewitowicz

GANIL, France

on behalf of the SPIRAL 2 Project Group

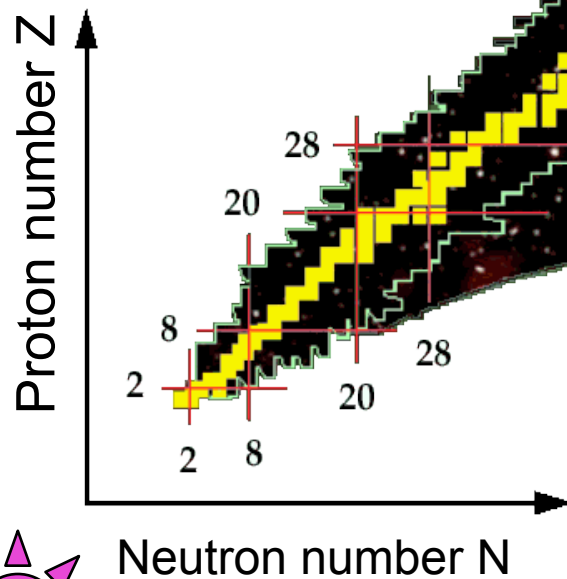
and

Physics Collaborations

A huge discovery potential

Exotic Nuclei

■ 3 fundamental questions



■ Which force?

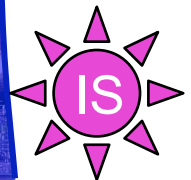
Isospin dependence,
3-body, tensor, spin-orbit.

■ Leading to which structure?

Haloes, neutron skins, molecular states,
new shells and magic numbers, super-heavies.

■ Playing which role in the univers?

Nucleosynthesis, supernovae,
Neutron stars.



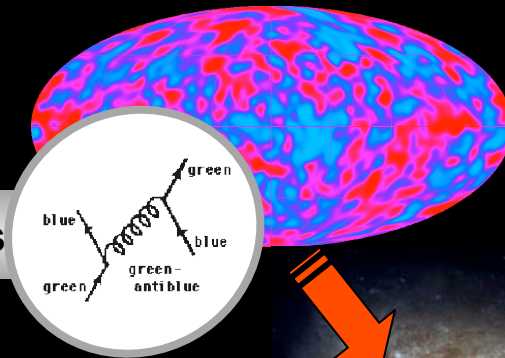
The origin of life

Fête de la science

16 - 22 novembre 2009

Aux origines de la vie et de l'univers :
quelles évolutions, quelles révolutions ?

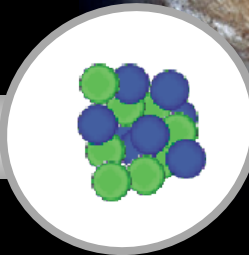
High Energy Physics



Creation
of Matter

Elements

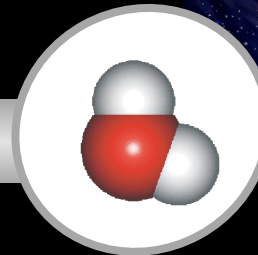
Nuclear Physics



Rare Isotope Beam Facilities

Planets

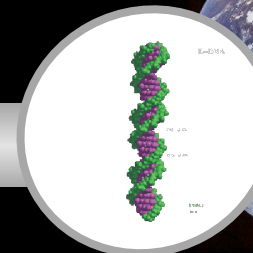
Chemistry

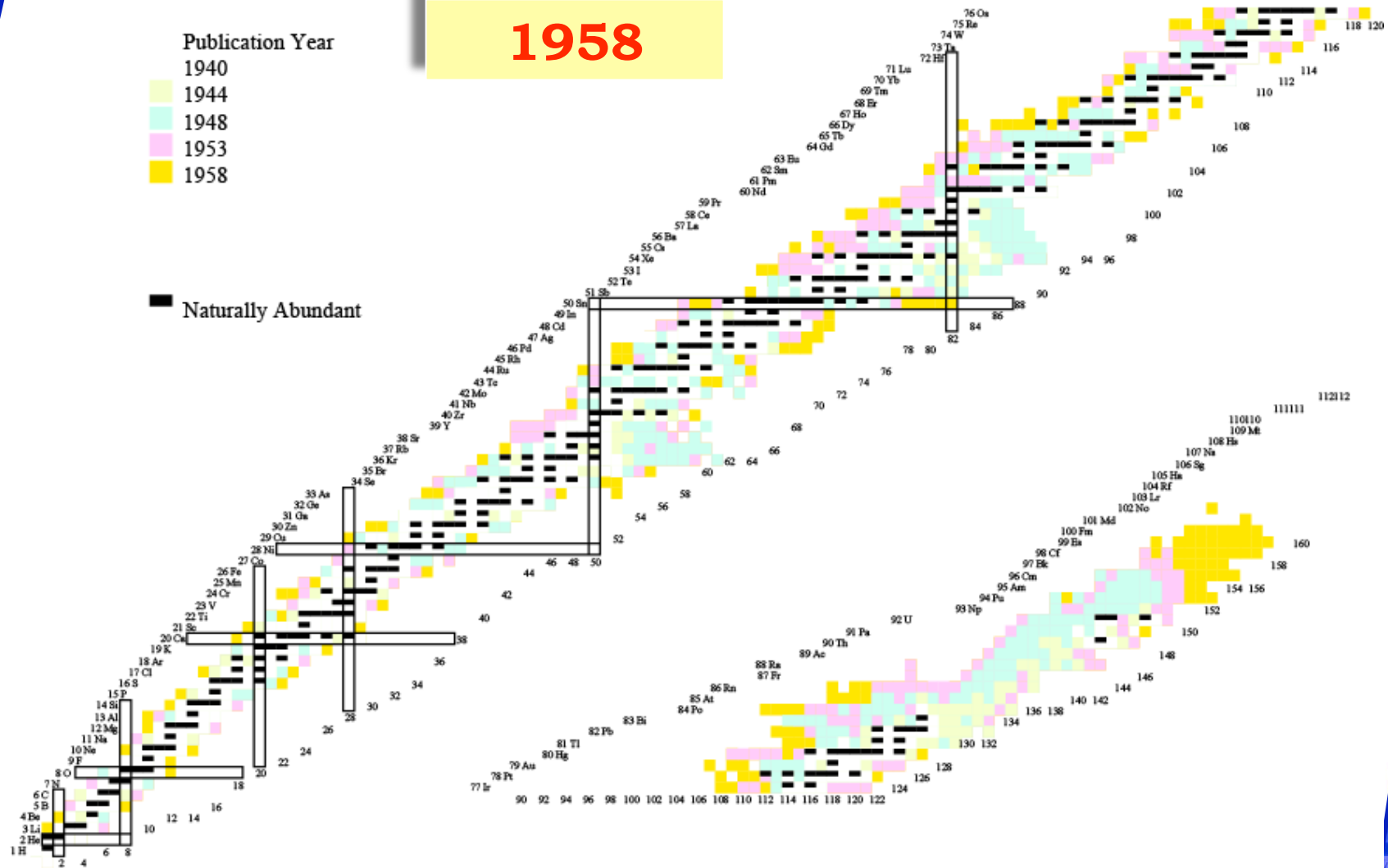


Life

Laboratory Experiments:
Understanding underlying physics

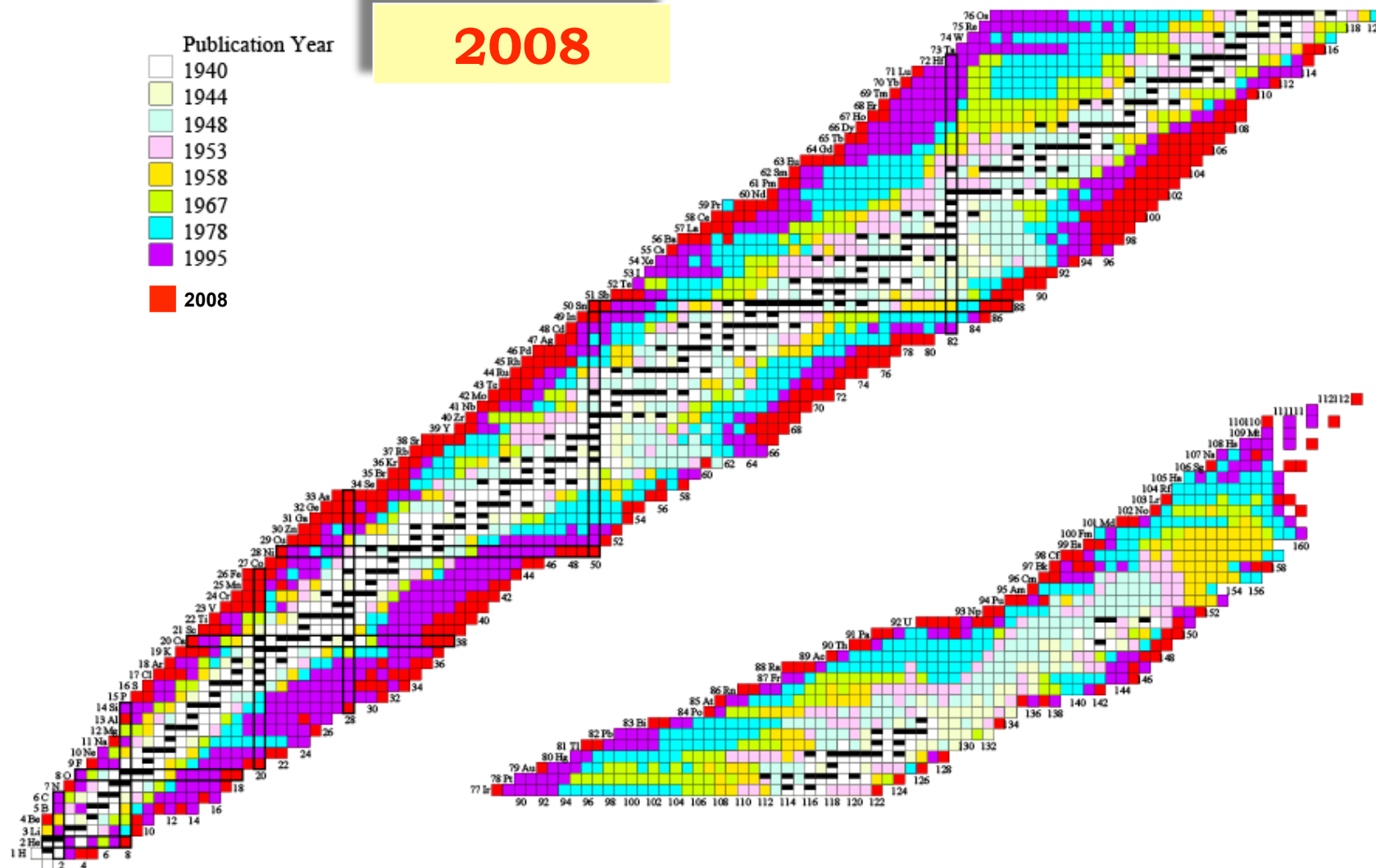
Biochemistry



Evolution of the *Table of Isotopes*

Evolution of the *Table of Isotopes*

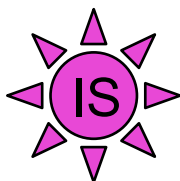
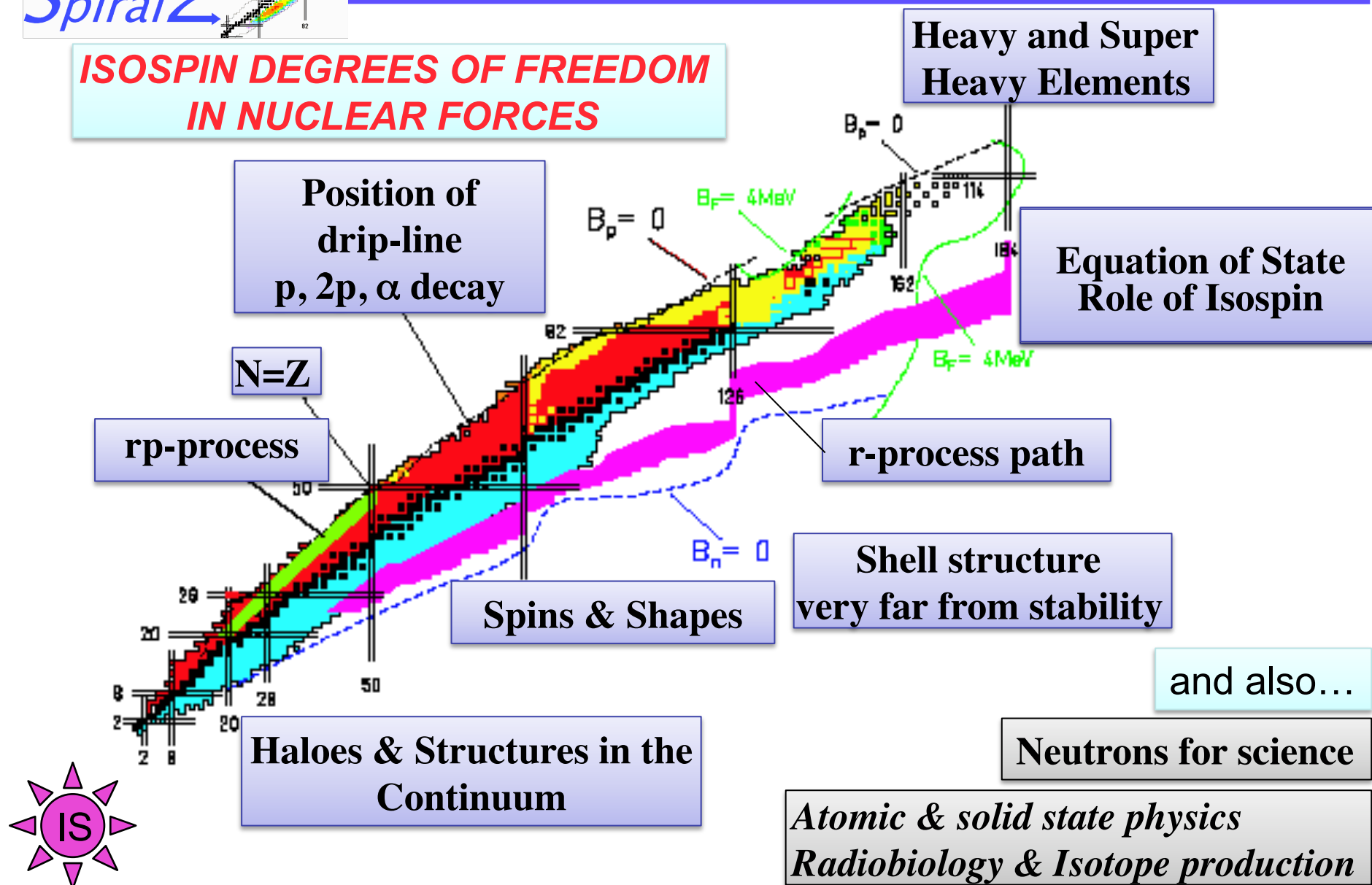
2008

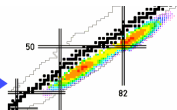




Scientific case of GANIL/SPIRAL 2

ISOSPIN DEGREES OF FREEDOM IN NUCLEAR FORCES





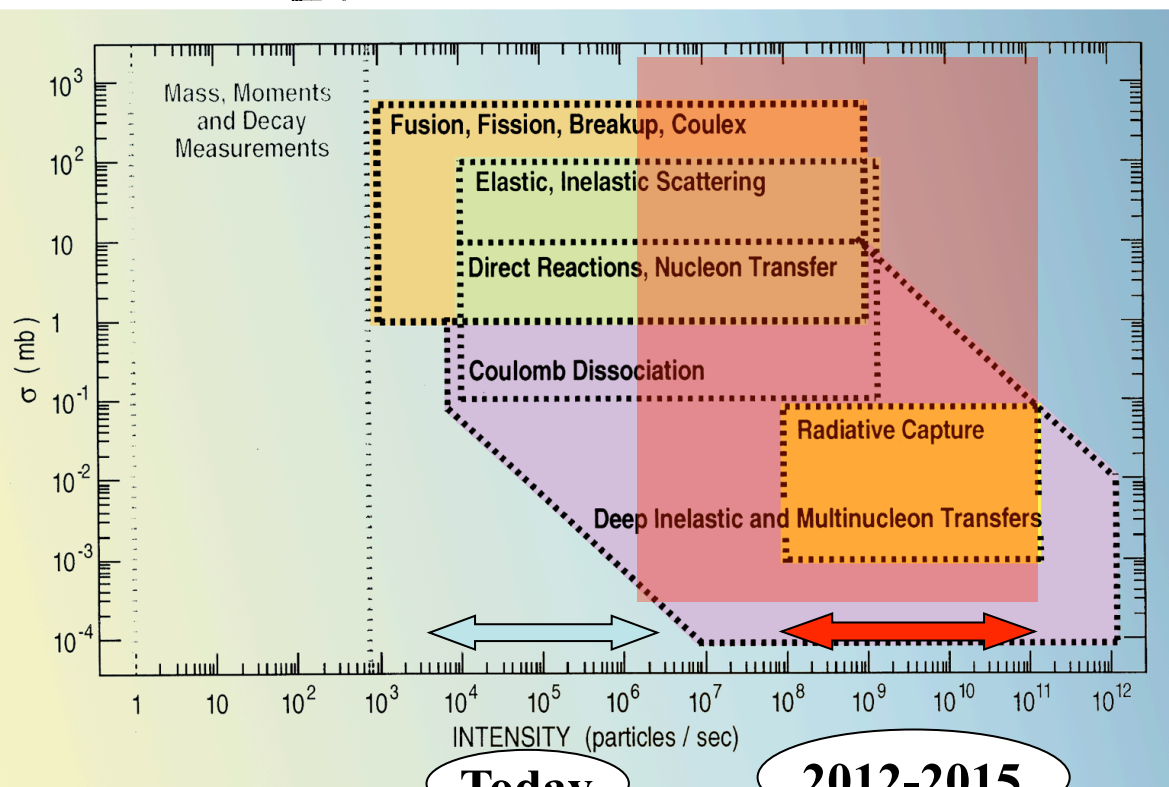
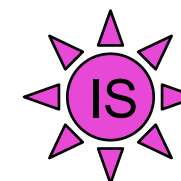
Physics with Radioactive & Stable-ion High-intensity Beams at 1-20 MeV/nucl.

Physics Areas Considered:

- single-particle structure
- nuclear pairing
- Structure of very-heavy nuclei
- nuclear clustering and nuclear molecules
- Isospin in reaction mechanisms
- applications to astrophysics

Reaction Types

- elastic & resonant el. (p,p) ...
- inelastic (p,p'), (d,d')...
- transfer (d,p), (p,d), (p,t)...
- breakup
- fusion-evaporation
- deep-inelastic
- fission



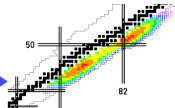
Key words:

ISOL RIB beams:

- high intensity, optical quality & purity

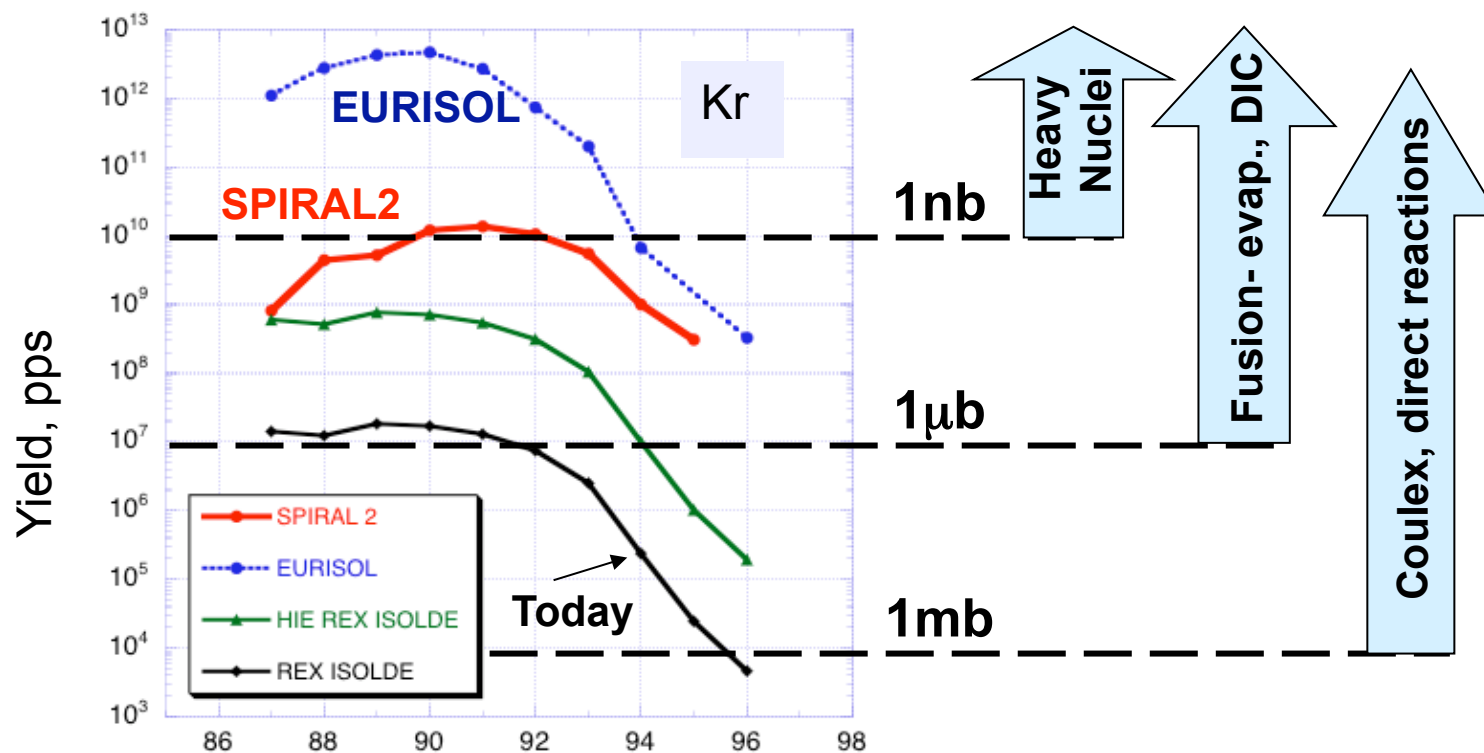
Versatility:

- light & HI, high intensity stable & RI Beams



SPIRAL 2: Advanced ISOL RIB facility

SPIRAL 2: Experiments with RIB at low cross sections and very exotic nuclei at few MeV/nucleon

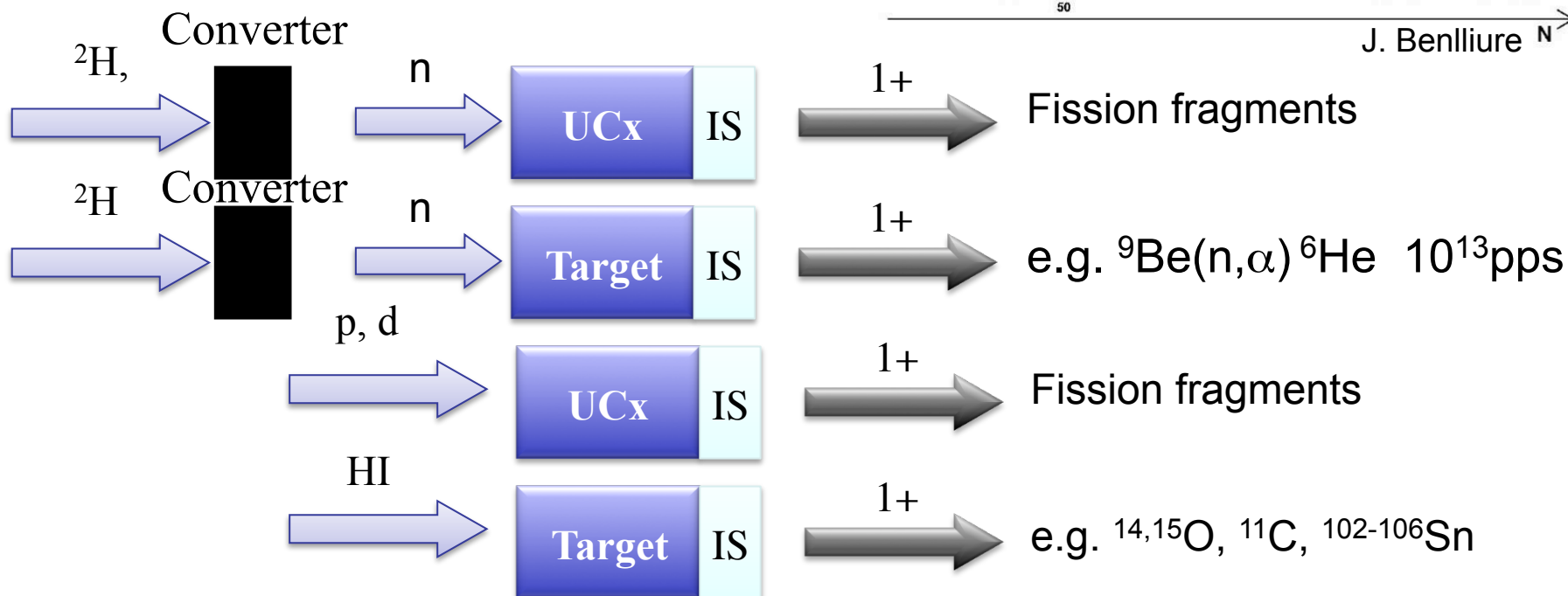
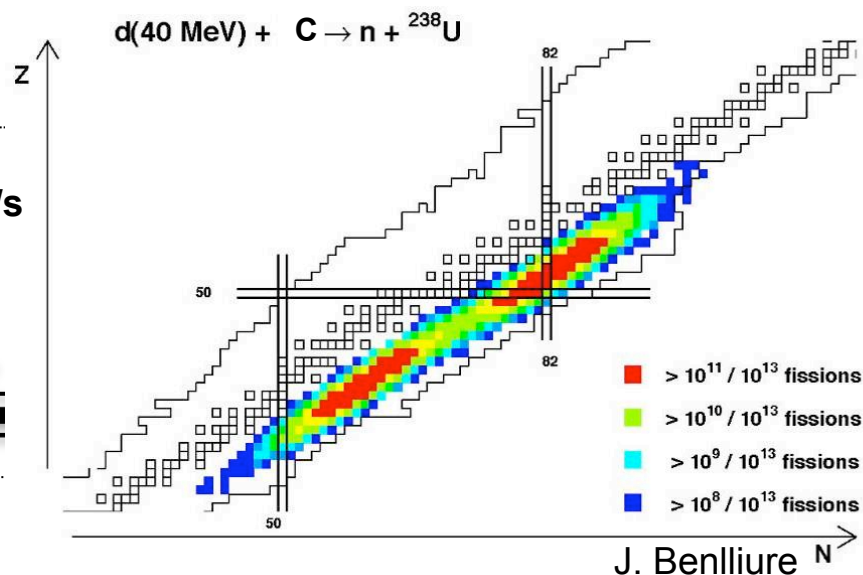
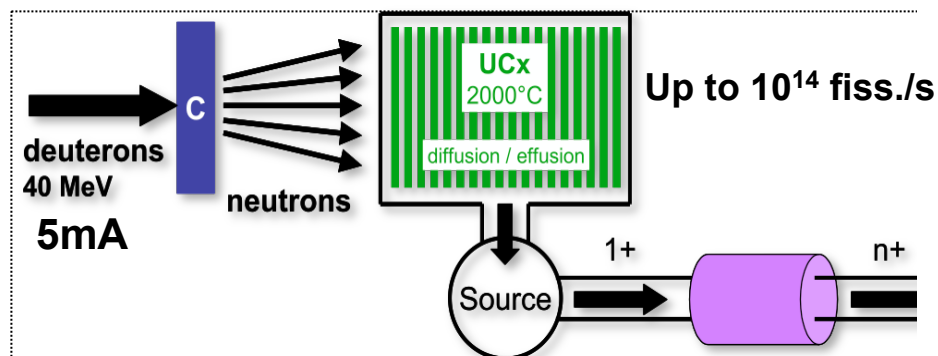


A

Ex.: At 1nb 1 nucl./day via fusion-evaporation

ISOL Rare Isotope Beams at SPIRAL 2

Up to 2.3 kg HD UC₂



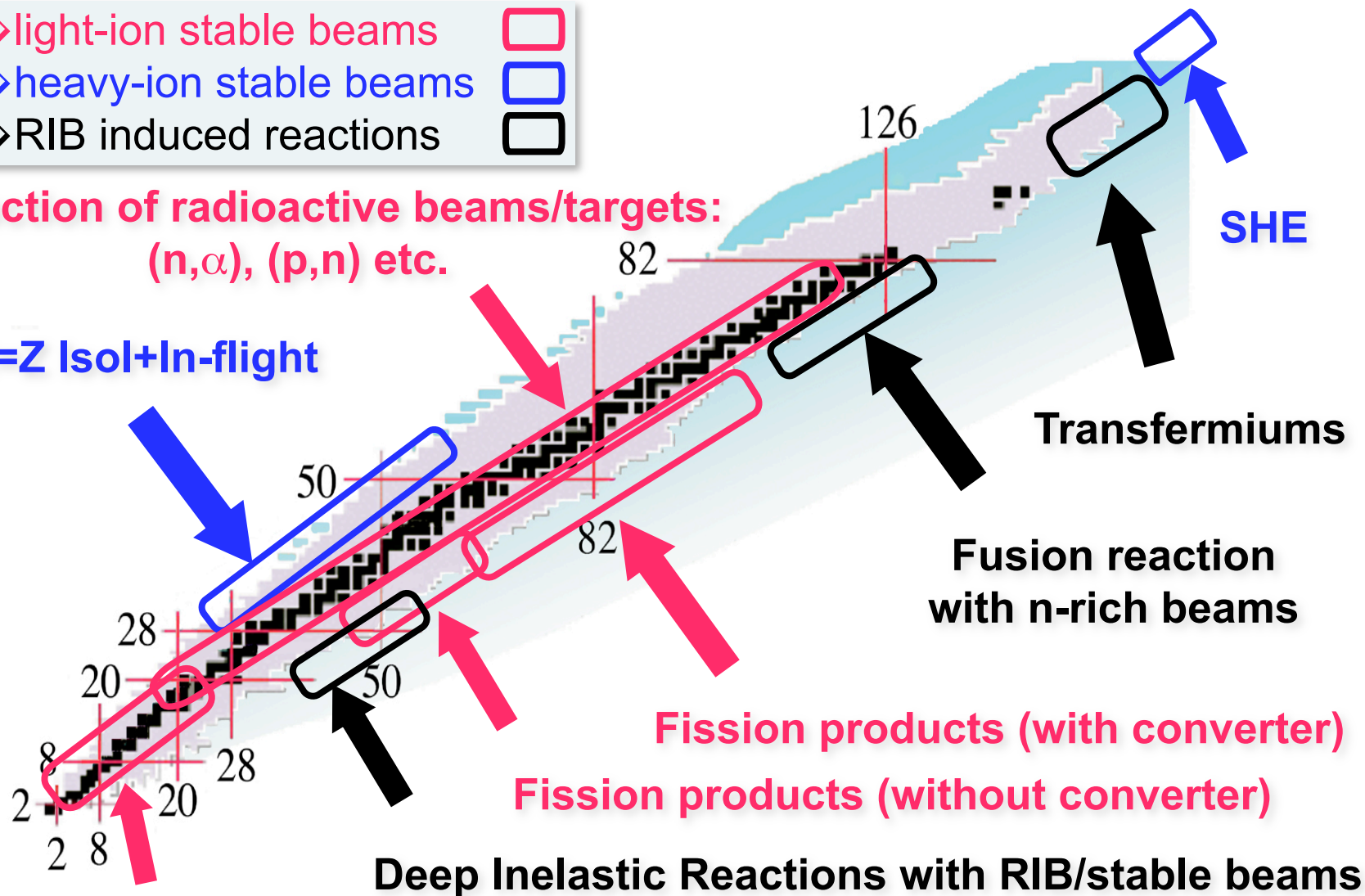


Regions of the Chart of Nuclei Accessible with SPIRAL 2 Beams : LINAC & RIB

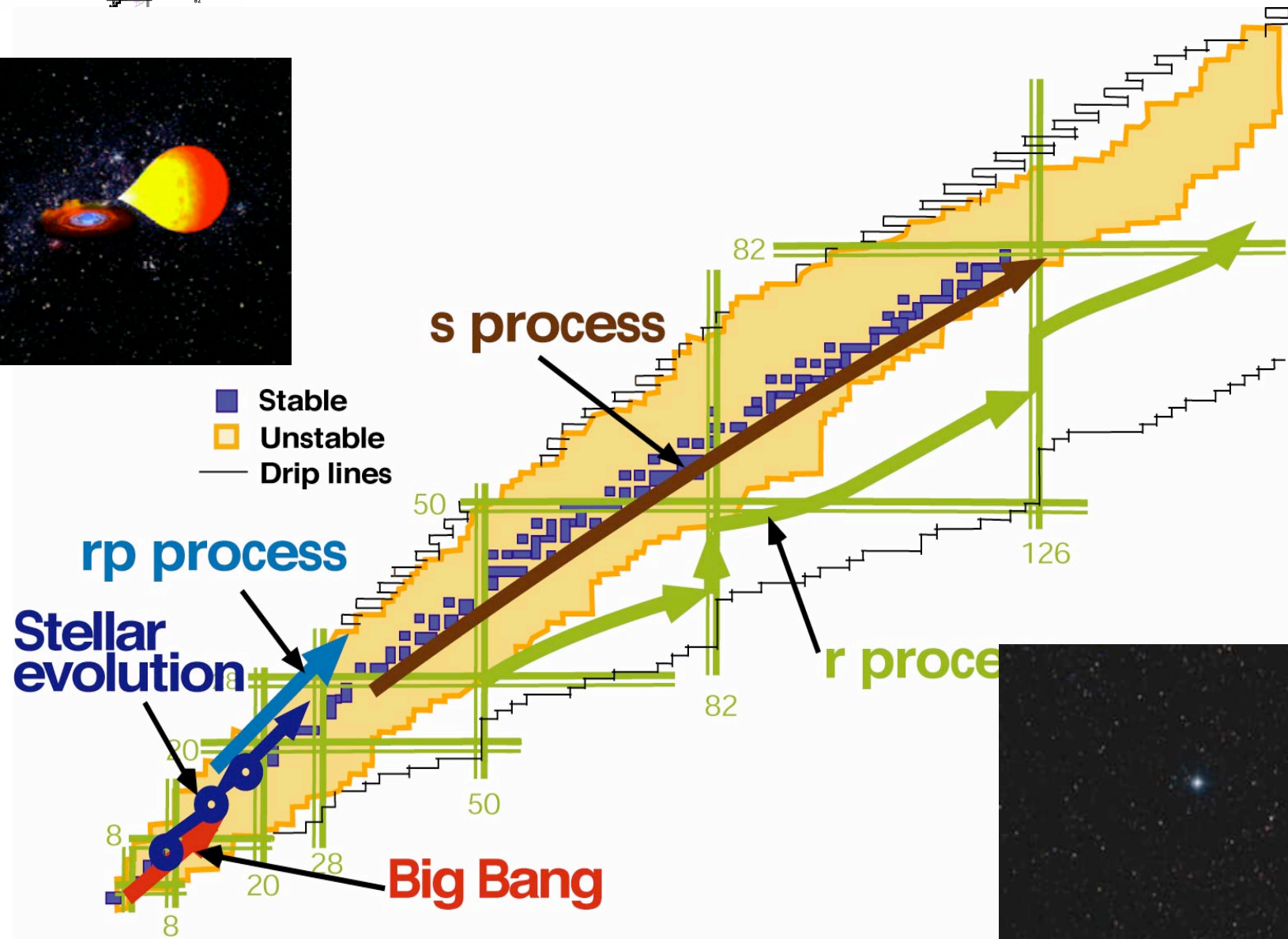
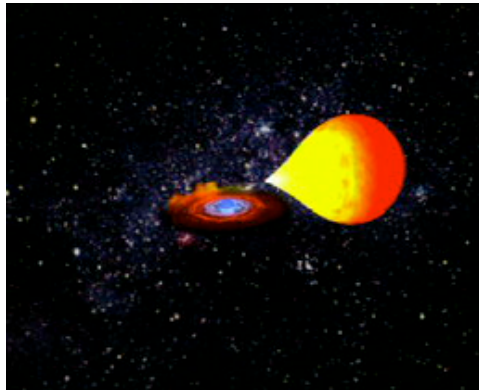
- ⇒ light-ion stable beams
- ⇒ heavy-ion stable beams
- ⇒ RIB induced reactions

Production of radioactive beams/targets:
(n,α), (p,n) etc.

N=Z Isol+In-flight



High Intensity Light RIB



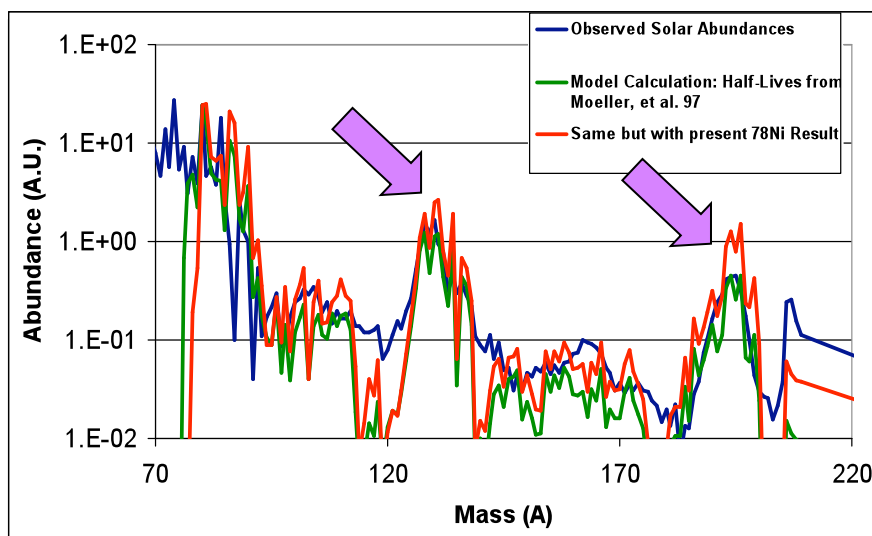


r-process and exotic nuclei

Half-Life of the Doubly Magic
r-Process Nucleus ^{78}Ni

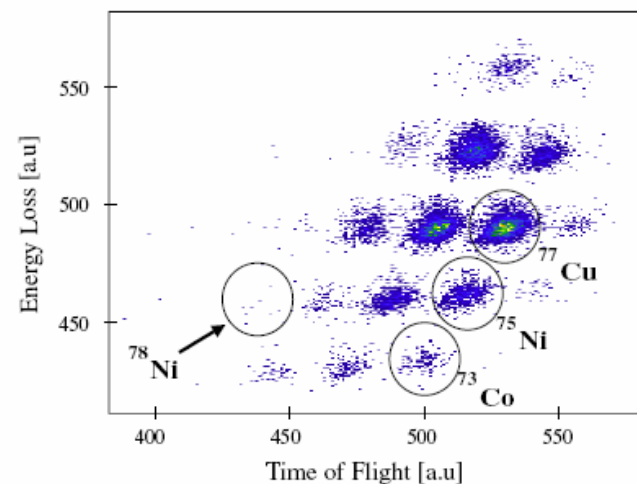


$$T_{1/2} = 100^{+100}_{-60} \text{ ms}$$



Courtesy of H. Schatz

			50
			^{80}Zr 537 ms
			^{79}Cu 146 ms
28	^{76}Ni 288 ms	^{77}Ni 128 ms	^{78}Ni 110 ms

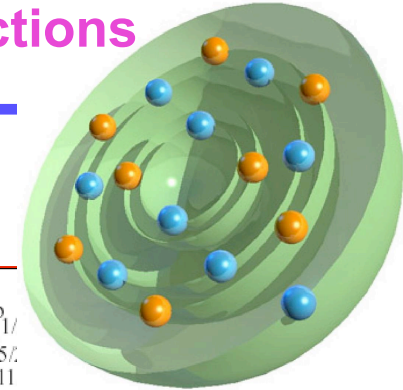
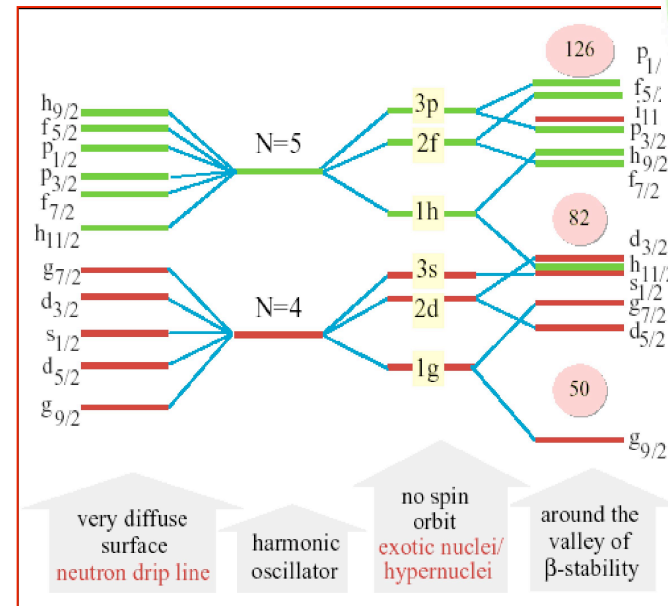
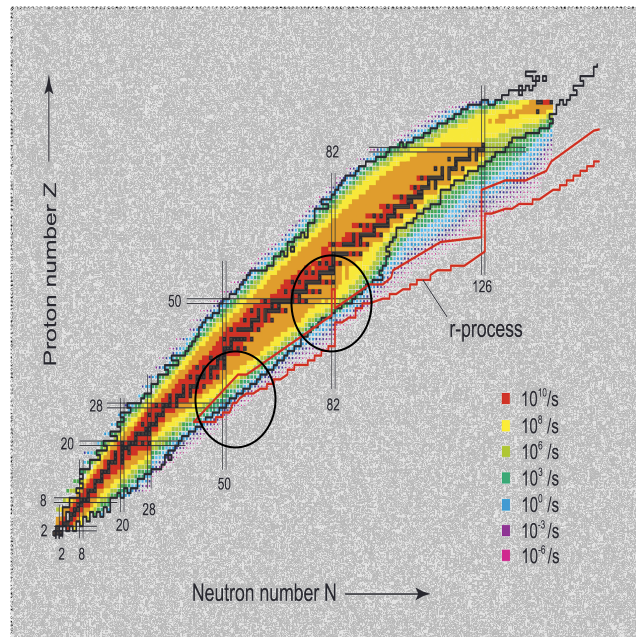


NSCL/MSU (USA)

P.T. Hosmer et al., PRL 94 (2005) 112501

Isospin Dependence of Mean Field and Residual Interactions

Spiral2



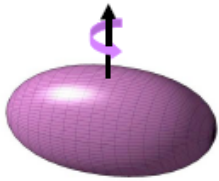
Modifications of mean field and residual interactions by e.g. diffuse surface

Evolution of shell structure towards ^{78}Ni and ^{132}Sn

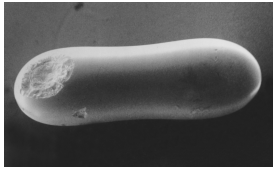
Study using light-ion transfer reactions – (p,d), (d, ^3He)

- measure properties of bound and unbound states
- E^x , L^π , SF

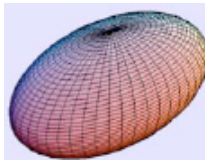
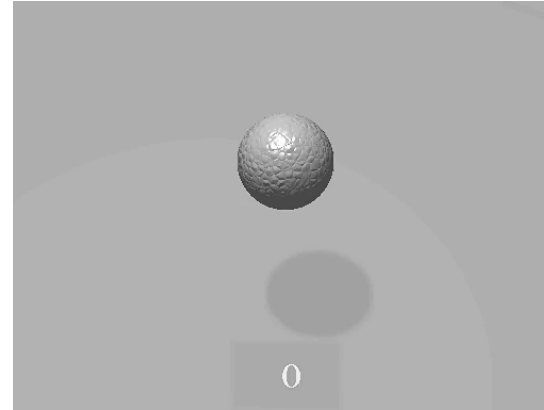
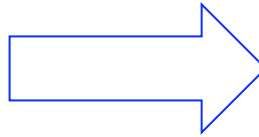
Exotic nuclear shapes



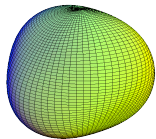
Superdeformation
Hyperdeformation



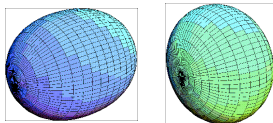
Jacobi
shapes



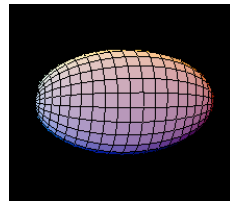
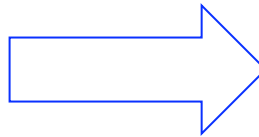
Triaxial shapes
3-dimensional
rotation



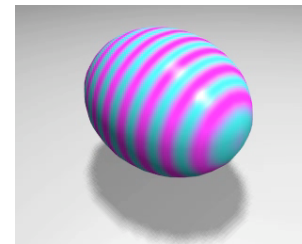
Higher-order shapes
(with high-rank
symmetry) :
tetrahedral, octahedral



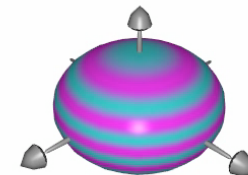
Shape
coexistence



dynamic
deformation
vibrations etc.



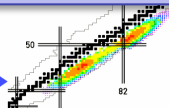
Prolate



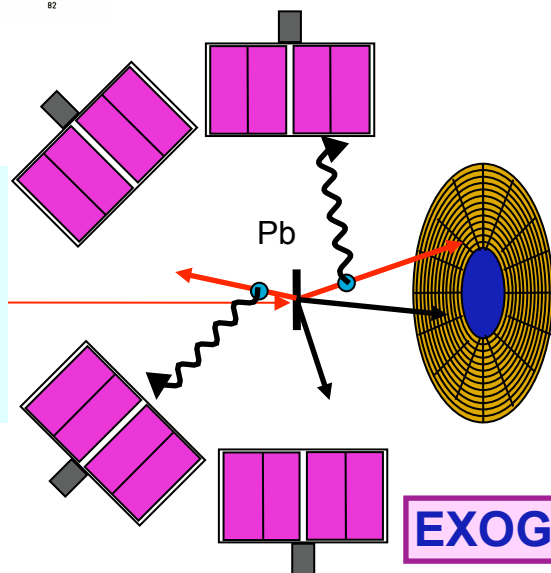
Oblate

Coulomb Excitation of $^{74,76}\text{Kr}$: Evidence for Shape Coexistence

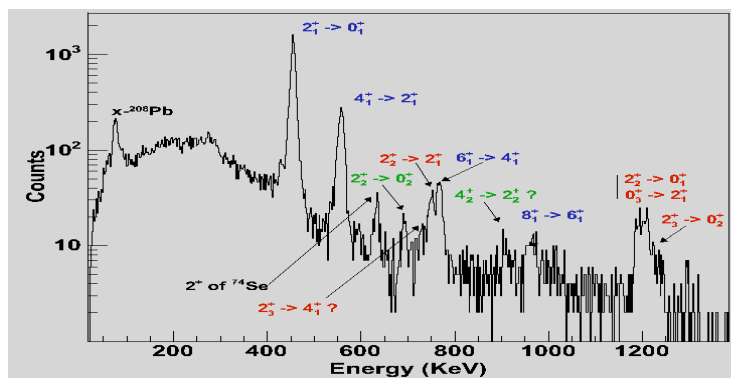
Spiral2



SPIRAL beams
 ^{76}Kr $5 \cdot 10^5$ pps
 ^{74}Kr 10^4 pps
 4.5 MeV/u

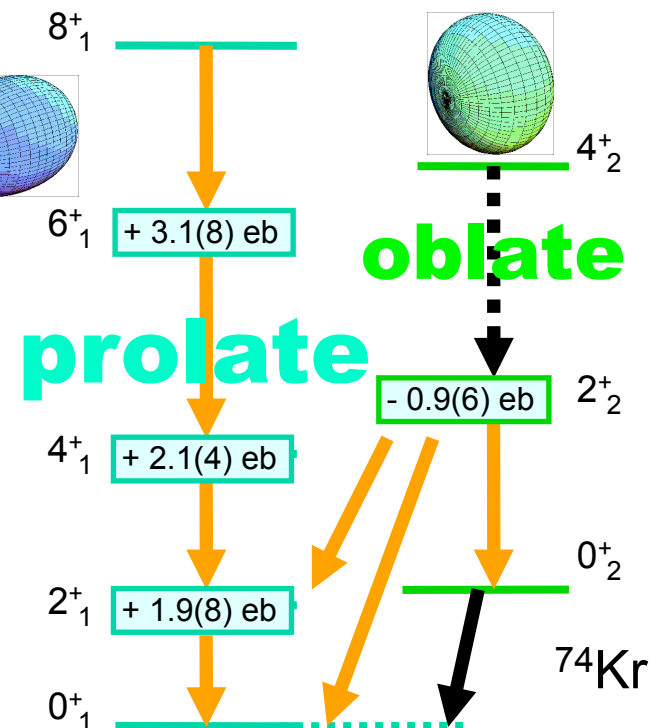
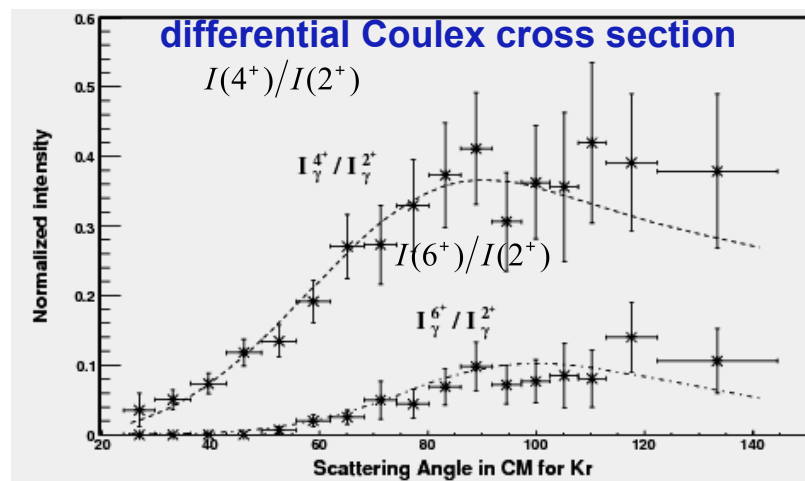


EXOGAM

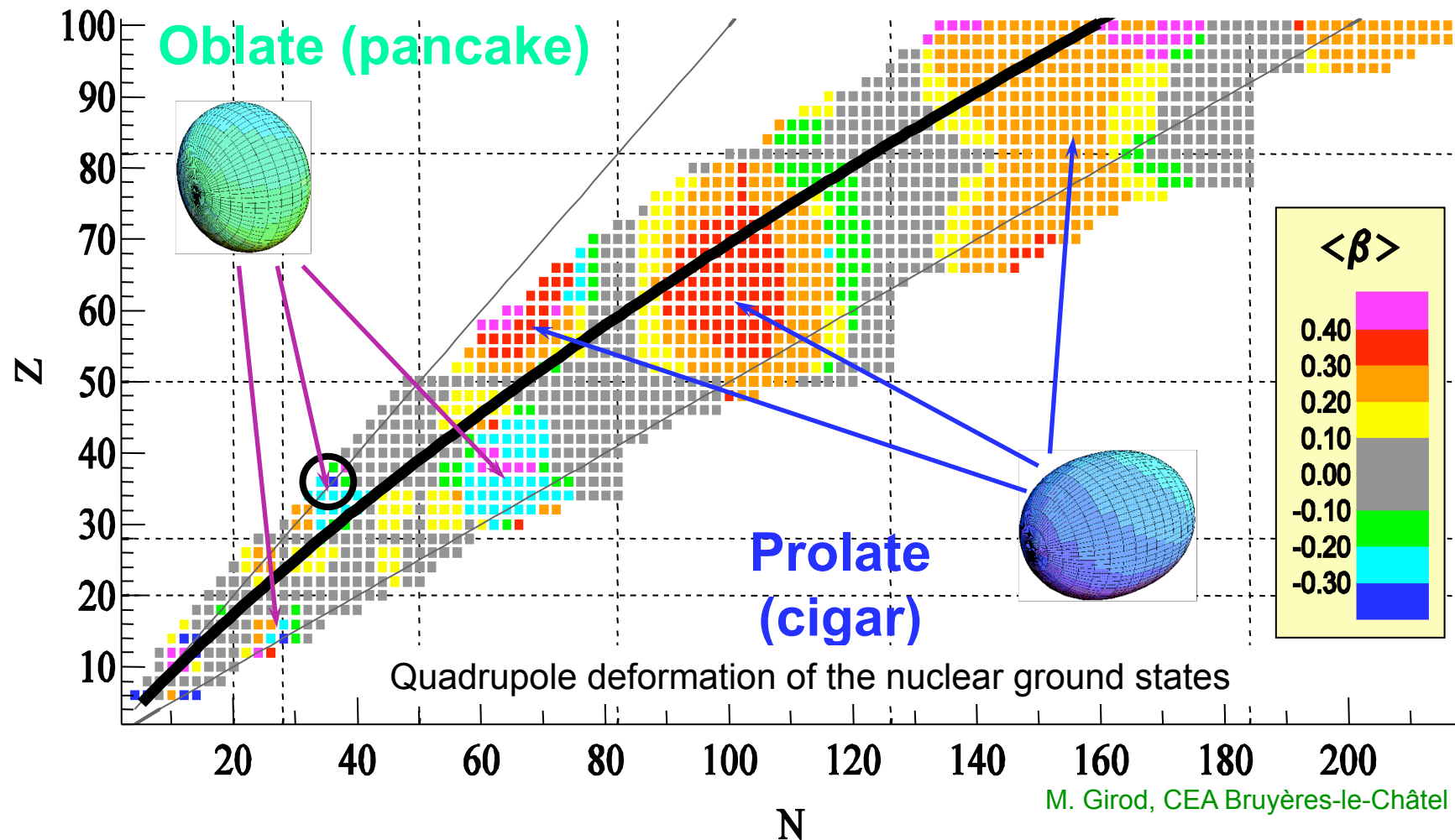


E. Clément et al.

- complete set of transitional and diagonal matrix elements (including sign)
- first reorientation measurement with RIB
- direct confirmation of shape coexistence



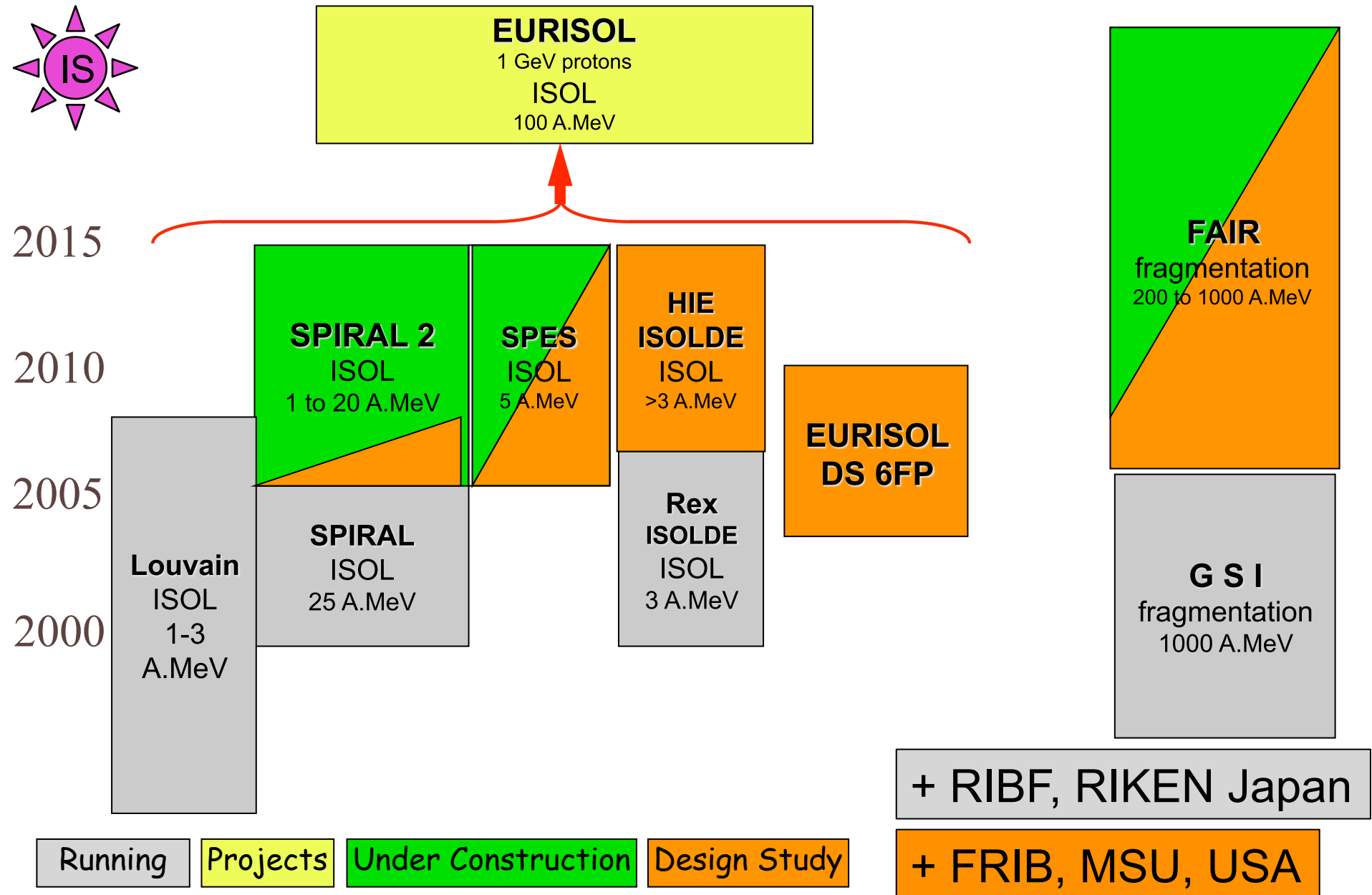
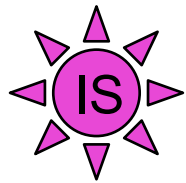
Shapes of atomic nuclei



M. Girod, CEA Bruyères-le-Châtel

- oblate ground states predicted for $A \sim 70$ near $N=Z$
- prolate and oblate states within small energy range
⇒ shape coexistence

European RNB Facilities - NuPECC Road Map



GANIL

CNRS/IN2P3-CEA/DSM
Caen, France

An Interdisciplinary Large Scale Facility for the French, European and International Communities

Nuclear Physics :

Nuclear structure far from stability
Nuclear dynamics
Nuclear Astrophysics

Applied Physics :

Irradiation of material (electronics, nuclear power plans, ...)
Technological transfer (electronics, Ion sources, ...)

Interdisciplinary Researches :

Atomic and Molecular Physics
Surface - Ions Interaction
Material (polymers, organic molecules) - Ions Interaction
Radiobiology (Chromosomic instabilities)

CSS1

CSS2

EXOGAM

VAMOS

ECS

CIME







Courseulles-sur-Mer

Luc-sur-Mer

GANIL, Caen, France

Caen



Image © 2006 TerraMetrics
© 2006 Europa Technologies
Image © 2006 DigitalGlobe

© 2006 Google™

Pointer 49° 12'49.96"N 0° 21'37.35" W

Streaming 100%

Eye alt 15.96 km

GANIL at Jules Horowitz Campus

Accelerators

Experimental Area

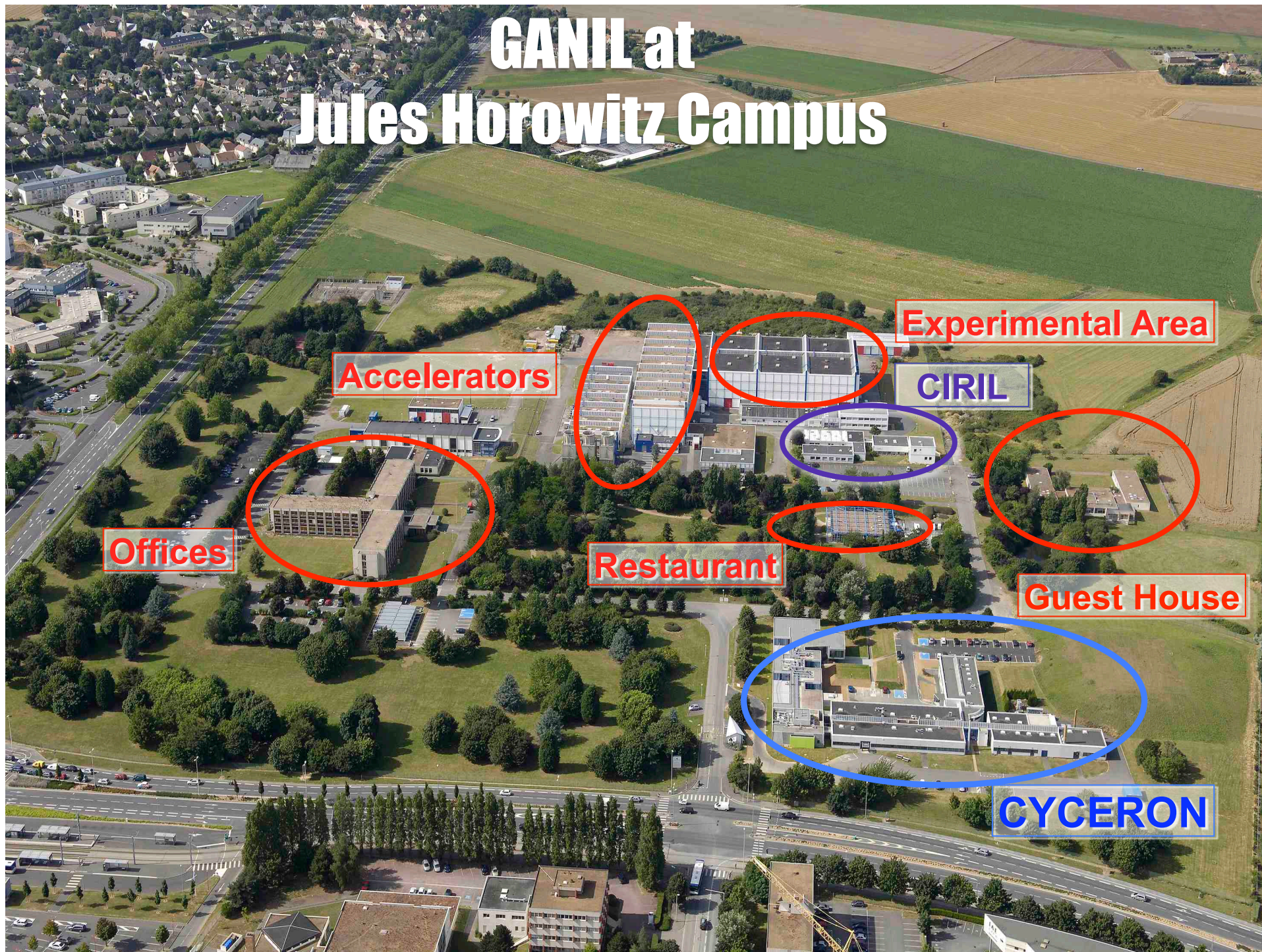
CIRIL

Offices

Restaurant

Guest House

CYCERON



First beam in 1983

STABLE BEAMS

- from C to U
- energies up to 95 A.MeV
- intensities up to $2 \cdot 10^{13}$ pps (6 kW)

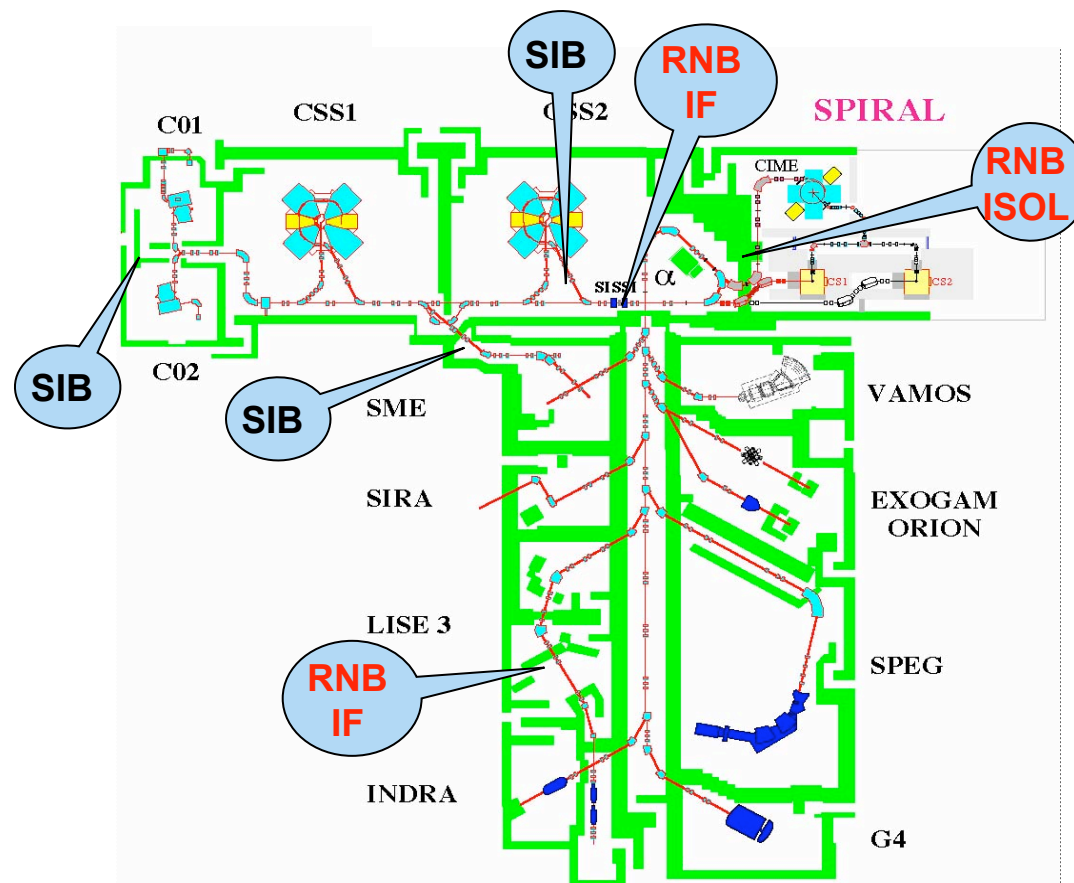
RIB production schemes

- in-flight method : SISSI, LISE
- ISOL method : SPIRAL (SIRA)
- Inverse kinematics: HI+C target

Up to 10000 hours of stable and radioactive beams per year
600 users/year (40% outside of France)

Operation budget
(without salaries): 9M€/year

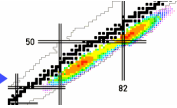
Staff 250 (10% physicists)



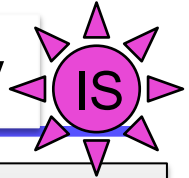
Primary Beams:

Ion:	^{12}C	^{36}Ar	^{86}Kr	^{238}U
Energy (A.MeV):	95	95	60	24
Int. (pps)	10^{13}	3×10^{12}	5×10^{11}	10^{10}

Spiral2



GANIL/SPIRAL1/SPIRAL2 facility



GANIL/SPIRAL 1 today

DESIR Facility
low energy RIB

S3 separator-
spectrometer

Neutrons For
Science

Cost: 200M€

SP2 Beam time: 44 weeks/y
GANIL Beam time: 35 weeks/y
ISOL RIB Beams: 28-33 weeks/y
GANIL+SP 2 Users: 700-800/y

CIME cyclotron RIB at 1-20 AMeV
(up to 9 AMeV for fiss. fragments)

HRS+RFQ Cooler

RIB Production Cave
Up to 10^{14} fiss./sec.

LINAC: 33MeV p, 40 MeV d, 14.5 A MeV HI

A/q=3 HI source
Up to 1mA

A/q=2 source
p, d, ^3He , ^4He 5mA

A/q=6 Injector option



Construction in 2 Phases

**Phase 1
Accelerator & S3, NFS**

**Phase 2
RIB production Building
& DESIR**



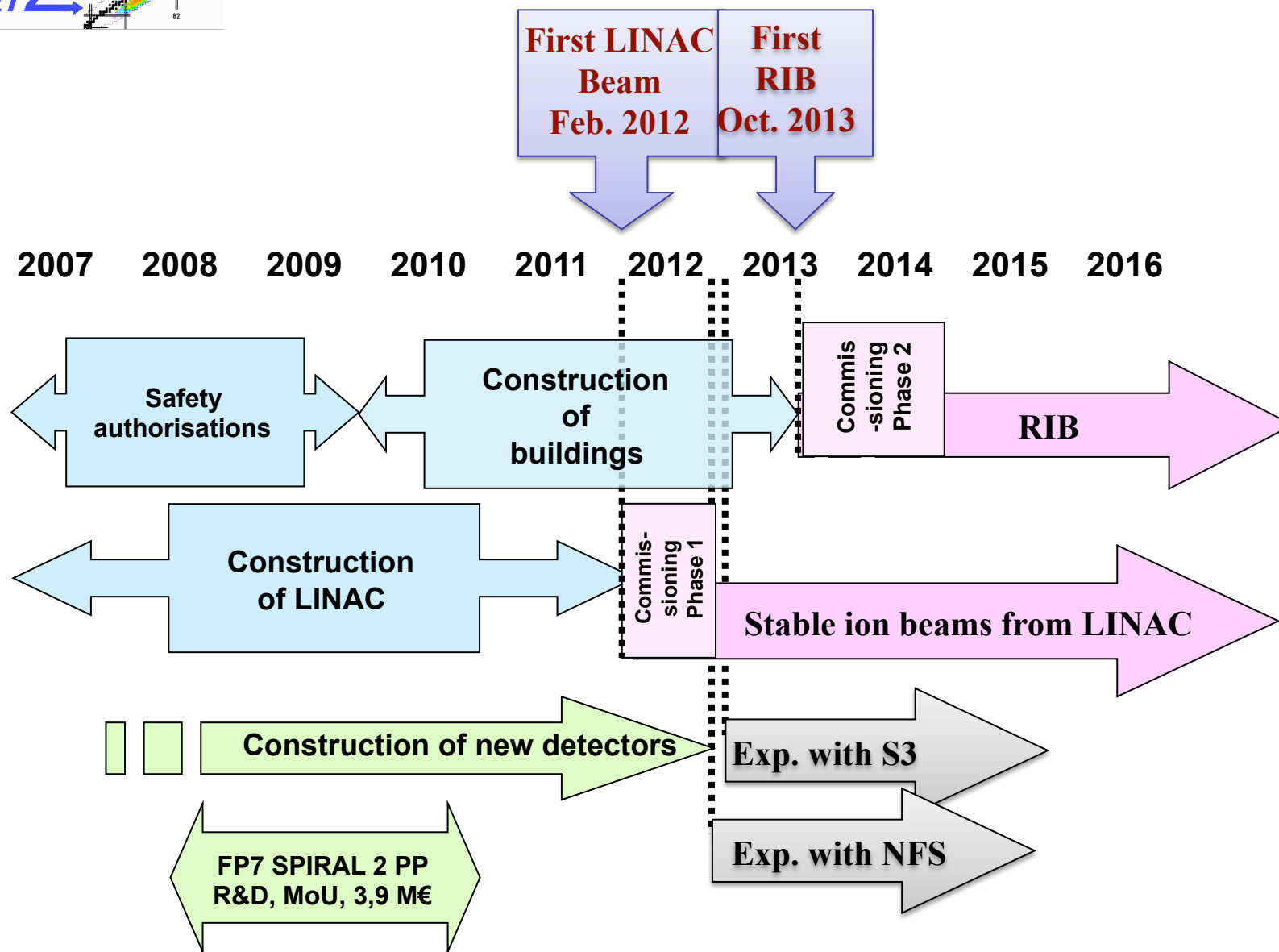
Civil construction: 2010 - 2012



26

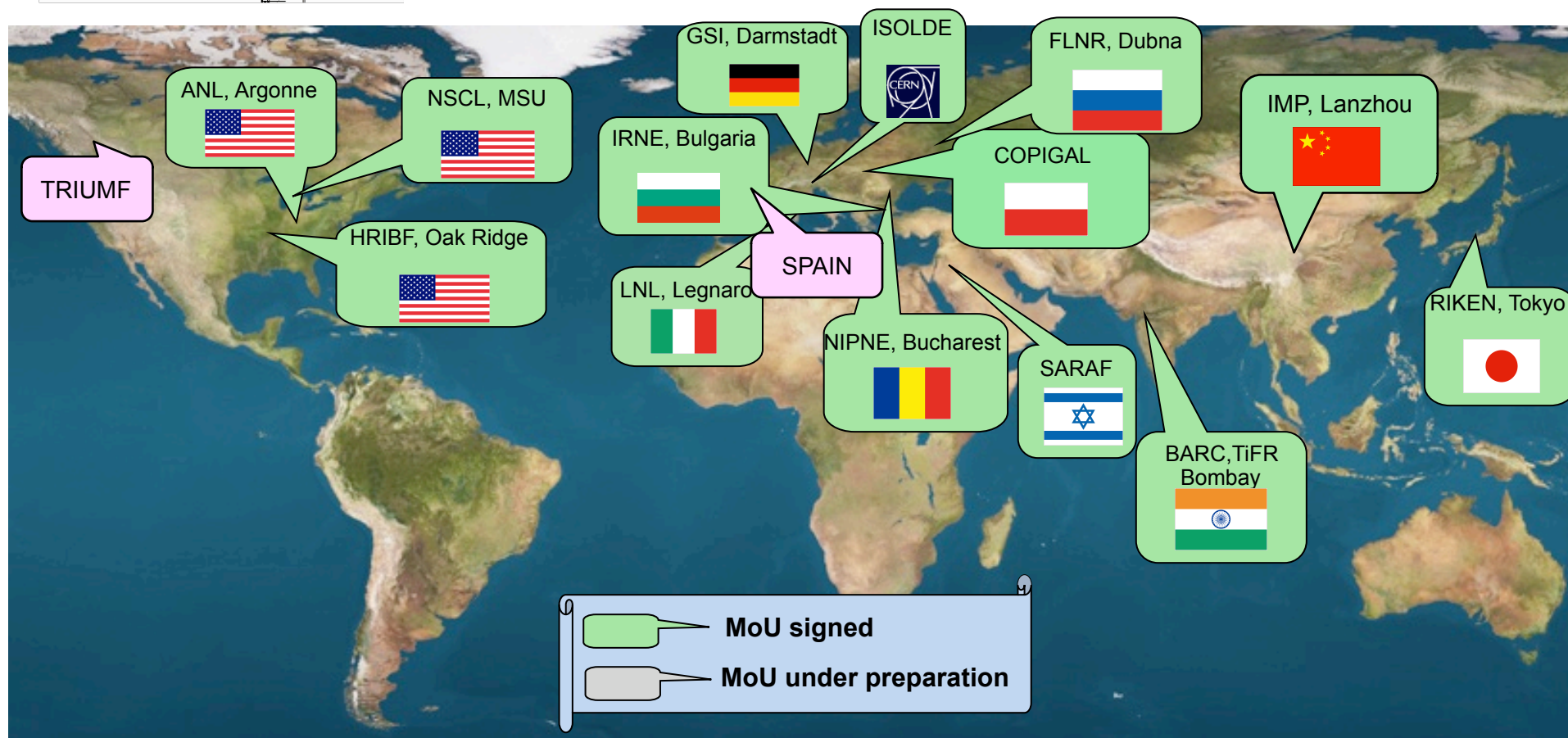


Planning SPIRAL 2





International Collaborations



EU FP7 3,9 M€ Preparatory Phase Contract

14 signed (LEA*, LIA**, MoU***) agreements
2 agreements under preparation

**LEA = Laboratoire Européen Associé*
 ***LIA = Laboratoire International Associé*
 ****MoU = Memorandum of Understanding*

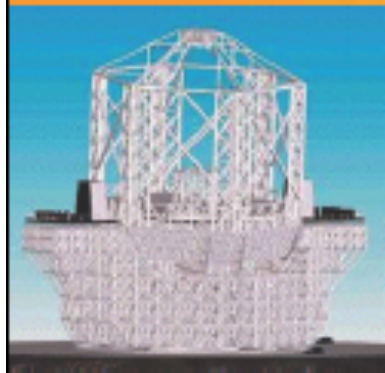
SPIRAL 2 on the ESFRI list -> FP7 Preparatory Phase



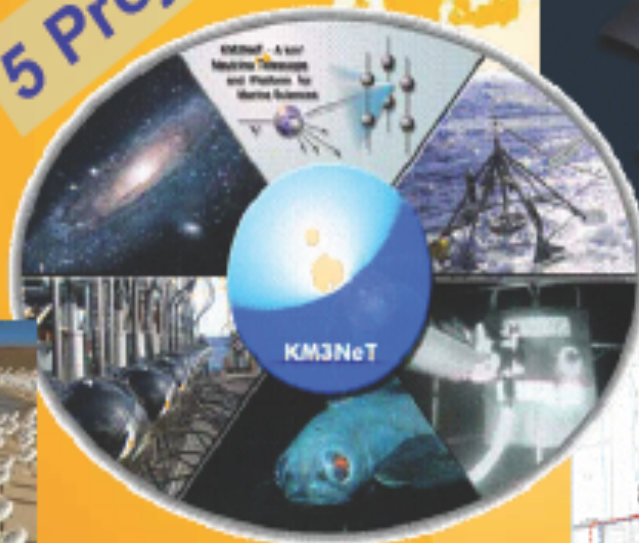
Report 2006

Astronomy, Astrophysics and Nuclear Physics

5 Projects



European ELT



KM3NeT



SPIRAL2



SKA



FAIR

Brussels, 19
October 2006
European
Research
Infrastructures
–
*The ESFRI
roadmap
identifies 35
large-scale
infrastructure
projects*



FP7 SPIRAL2 Preparatory Phase



25 Partners - 13 Countries - 1 Coordinator =

GANIL
GRAND ACCELERATEUR NATIONAL D'IONS LOURDS
LABORATOIRE COMMUN DSM/CEA - IN2P3/CNRS



ESFRI process and EU FP7 SPIRAL 2 Preparatory Phase contract (EC grant: 3,9 M€, 2008-2010, 25 partners) aims in the organisation and signature of the International Consortium for the construction of SPIRAL2 and the associated detectors -> **future intern. status of GANIL**

<http://www.spiral2pp.eu>



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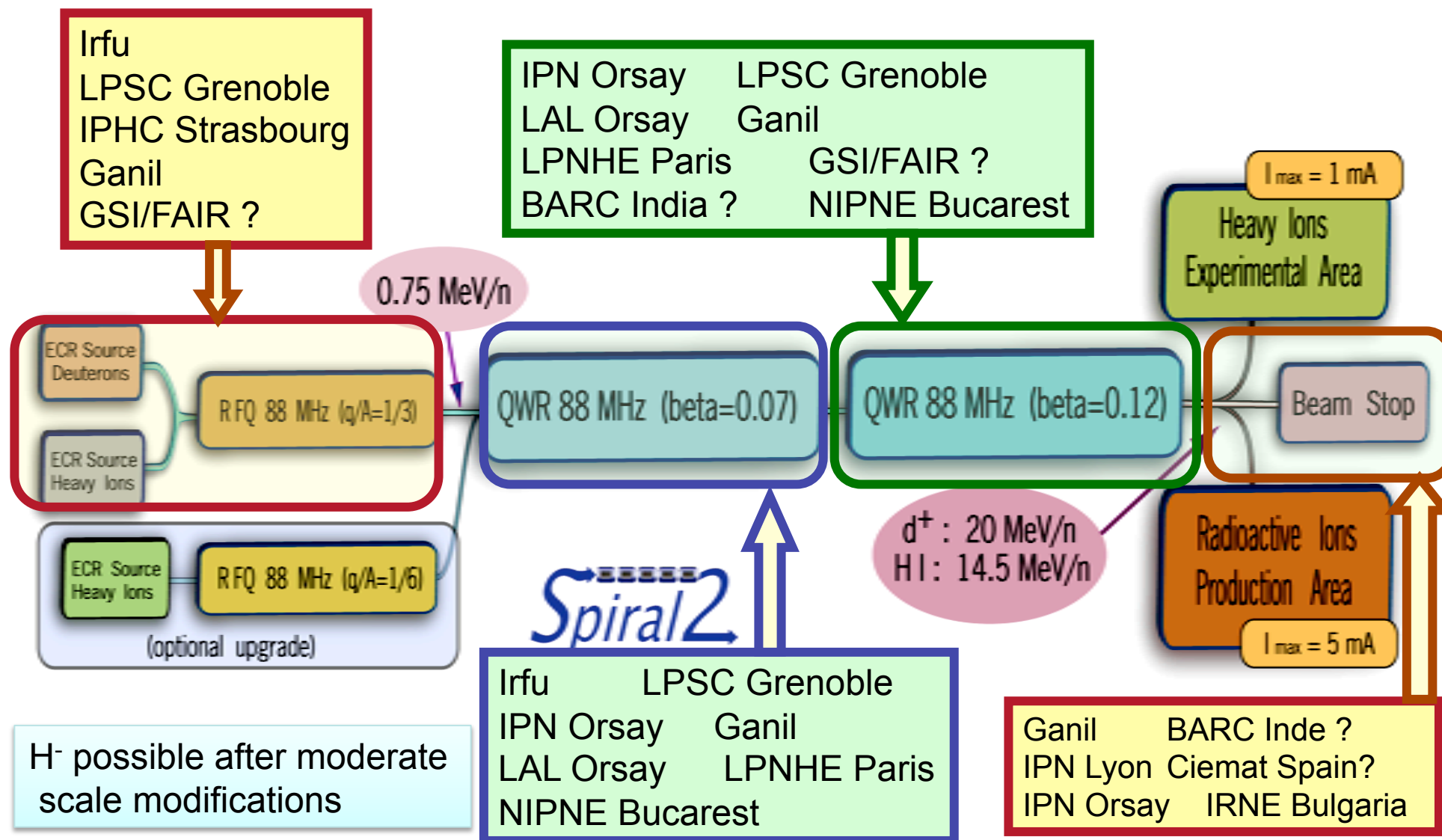
A/q=3 HI source
Up to 1mA

A/q=2 source
p, d, ^3He , ^4He 5mA

A/q=6 Injector option



SPIRAL2 Superconducting Linac



Construction of SPIRAL 2



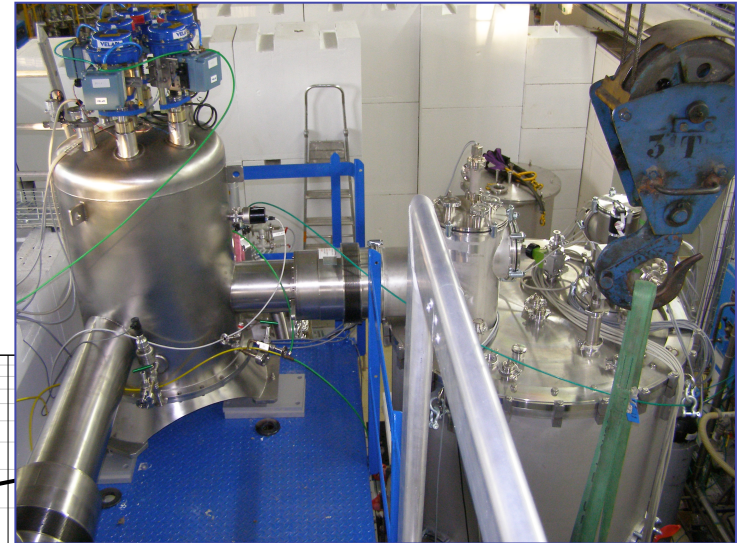
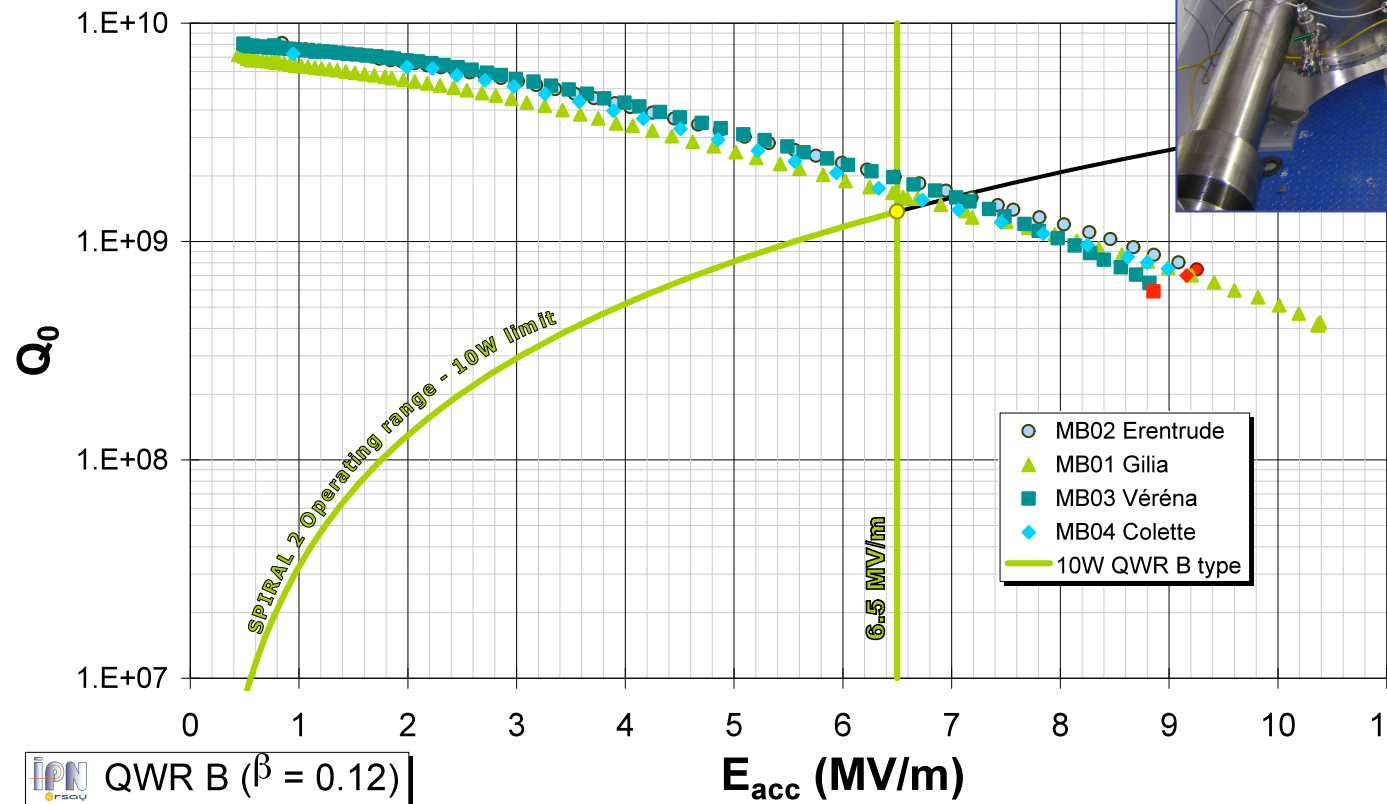
Heavy-Ion injector constructed at Grenoble, first mass separated beam two weeks ago



Construction of SPIRAL 2

IPN Orsay

6 serial Cavities type B constructed & tested

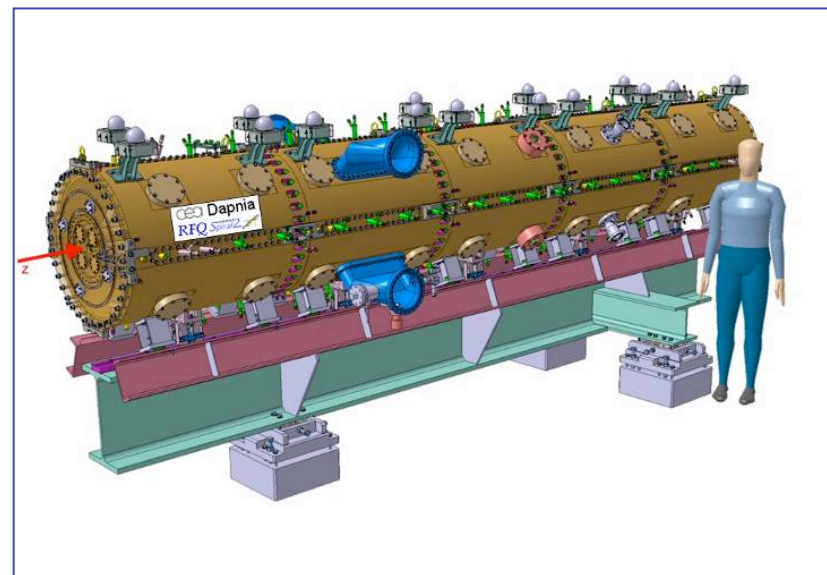
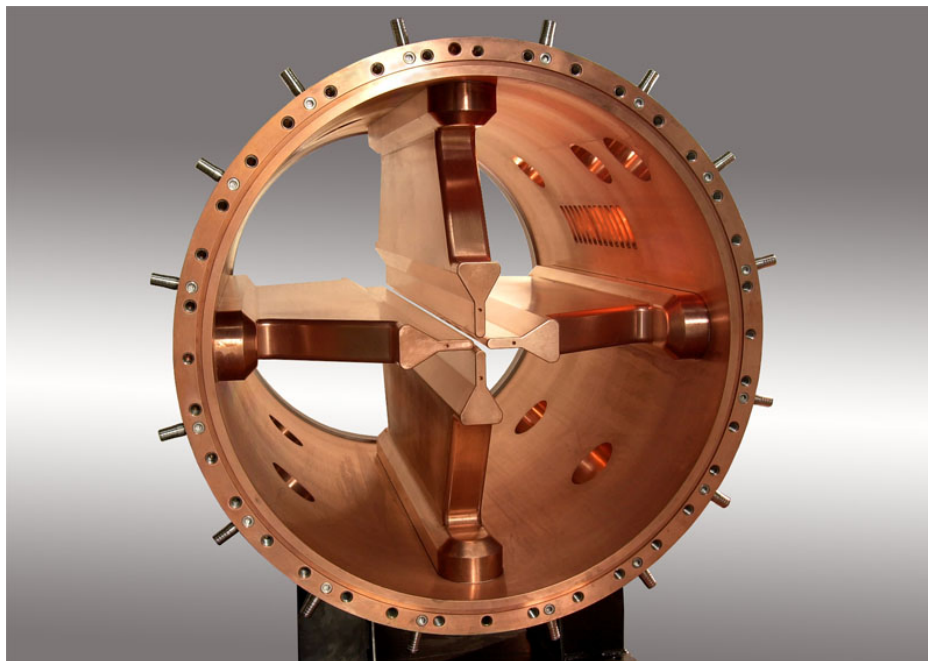




Construction of SPIRAL 2

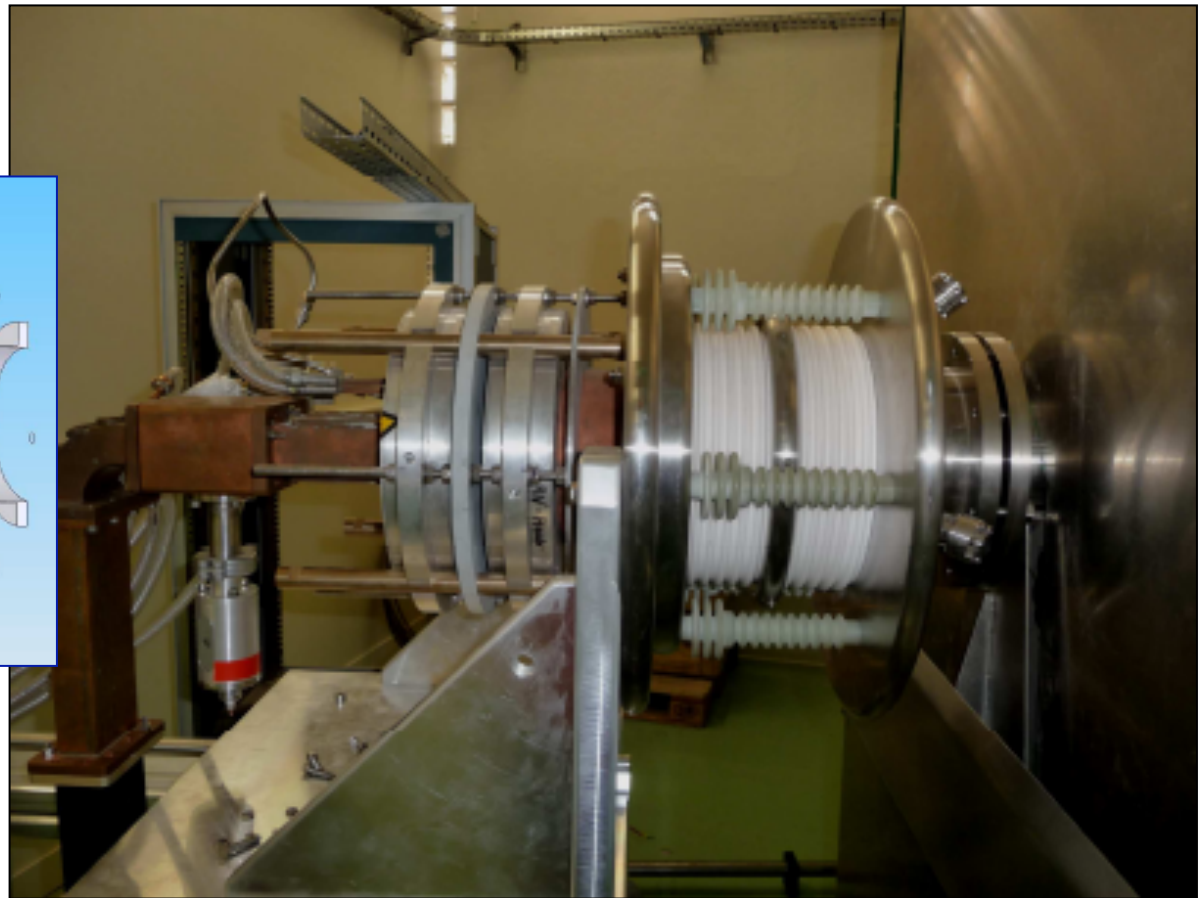
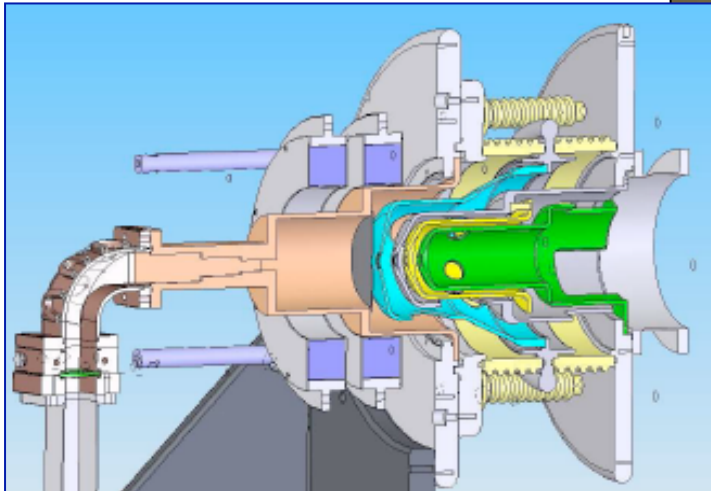
Irfu Saclay

RFQ Contract signed, first part under construction (ACCEL)

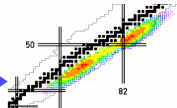


Irfu Saclay

Deutons Source constructed, test by september 2009



Spiral2



GANIL/SPIRAL1/SPIRAL2 facility layout



GANIL/SPIRAL 1 today

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A/q=2 source
p, d, ^3He , ^4He 5mA

A/q=6 Injector option



Collaboration



Super Separator Spectrometer (S3)

104 physicists, 30 institutions, 12 countries

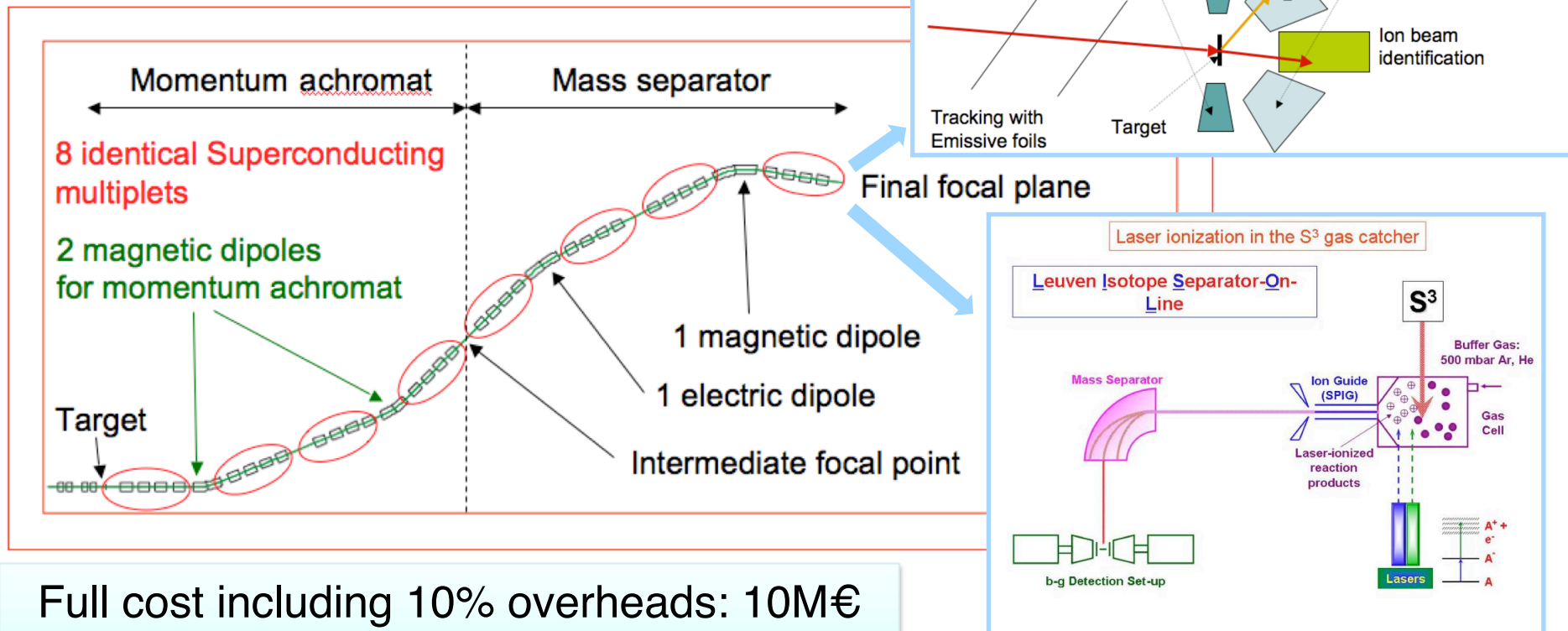
Spokespersons:

Hervé SAVAJOLS – GANIL, France

Antoine DROUART – Irfu/SPhN (CEA), France

Jerry A. NOLEN – Argonne National Laboratory, USA

Schematic layout



Full cost including 10% overheads: 10M€



Super Separator Spectrometer (S3)



- Heavy and Superheavy Elements

- ▶ Synthesis
- ▶ Spectroscopy and Structure
- ▶ Ground-State Properties
- ▶ Chemistry

- Region of ^{100}Sn

- ▶ Tests of Shell Model
- ▶ Single-Particle Structure
- ▶ Development of Collectivity
- ▶ Ground-State Properties

- Proton Dripline

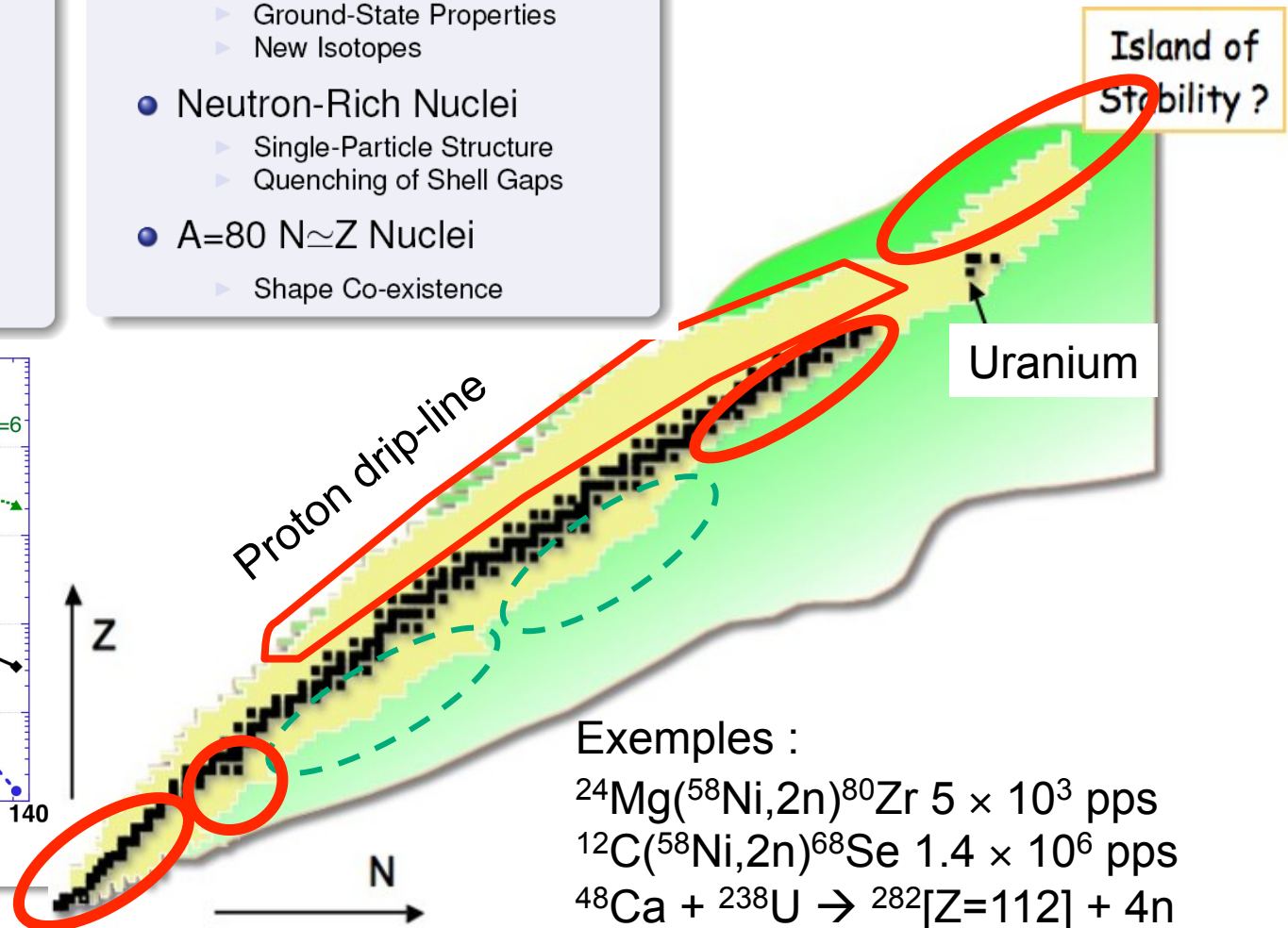
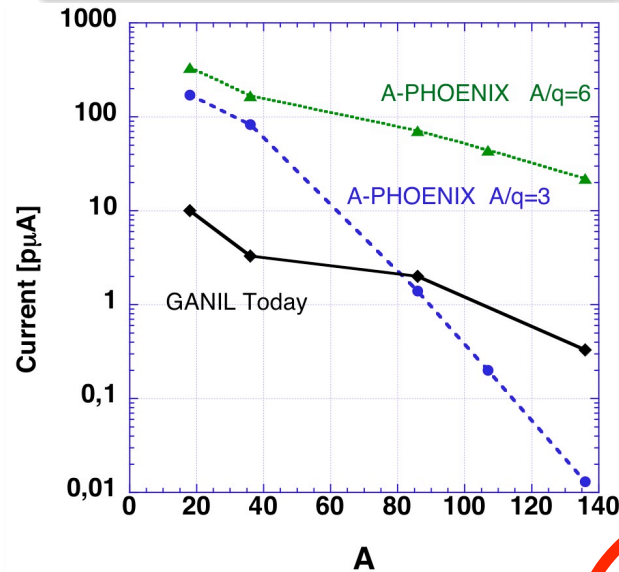
- ▶ Single-Particle Structure
- ▶ Development of Collectivity
- ▶ Ground-State Properties
- ▶ New Isotopes

- Neutron-Rich Nuclei

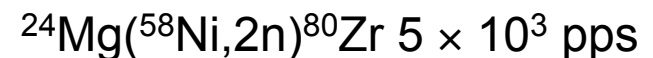
- ▶ Single-Particle Structure
- ▶ Quenching of Shell Gaps

- $A=80$ $N \simeq Z$ Nuclei

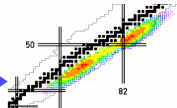
- ▶ Shape Co-existence



Exemples :



Spiral2



GANIL/SPIRAL1/SPIRAL2 facility layout

GANIL/SPIRAL 1 today

SP2 Beam time: 44 weeks/y
GANIL Beam time: 35 weeks/y
ISOL RIB Beams: 28-33 weeks/y
GANIL+SP 2 Users: 700-800/y

DESIR Facility
low energy RIB

CIME cyclotron RIB at 1-20 AMeV
(up to 9 AMeV for fiss. fragments)

HRS+RFQ Cooler

RIB Production Cave
Up to 10^{14} fiss./sec.

S3 separator-
spectrometer

LINAC: 33MeV p, 40 MeV d, 14.5 A MeV HI

Neutrons For
Science

A/q=3 HI source
Up to 1mA

Cost: 200M€

A/q=6 Injector option

A/q=2 source
p, d, ^3He , ^4He 5mA



Neutrons For Science (NFS)

Collaboration

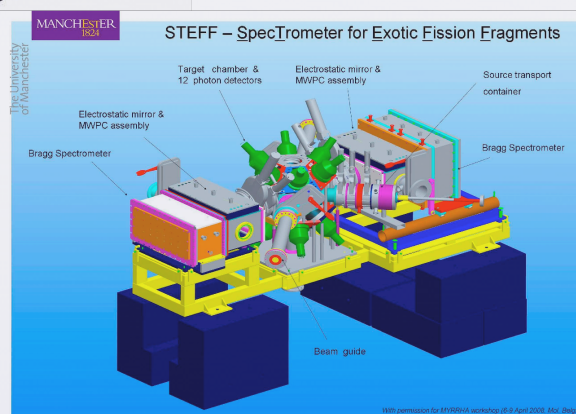
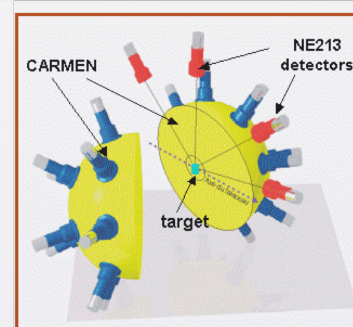
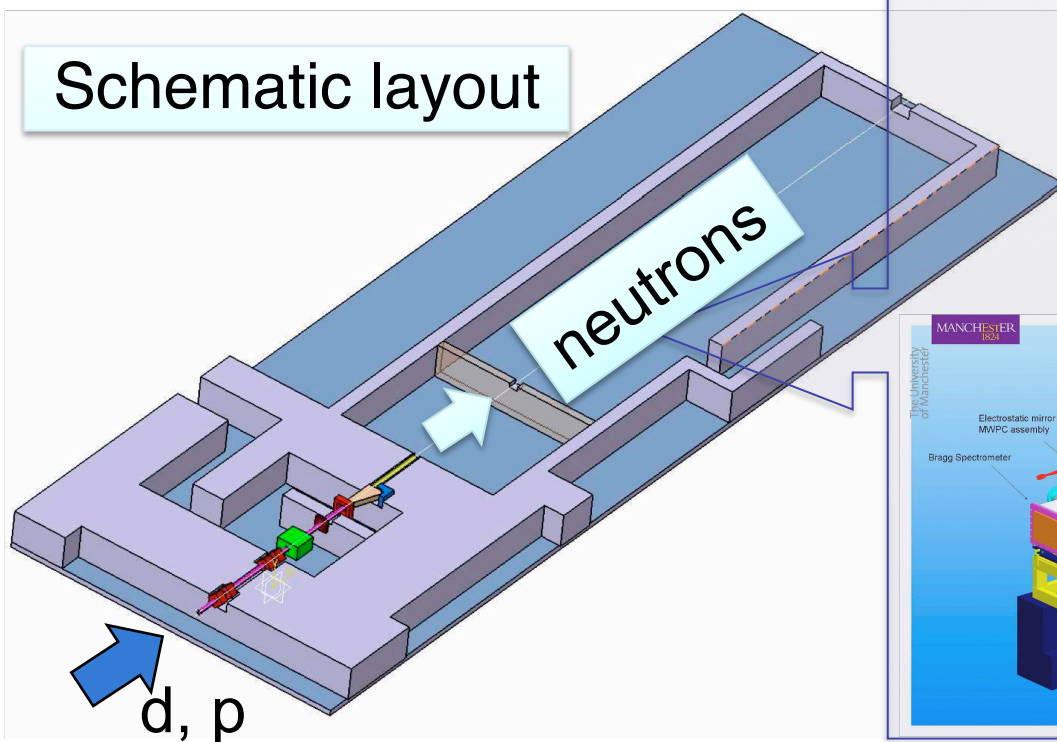
50 physicists, 18 institutions, 8 countries

Spokespersons:

Xavier Ledoux, CEA/DIF/DPTA/SPN, France

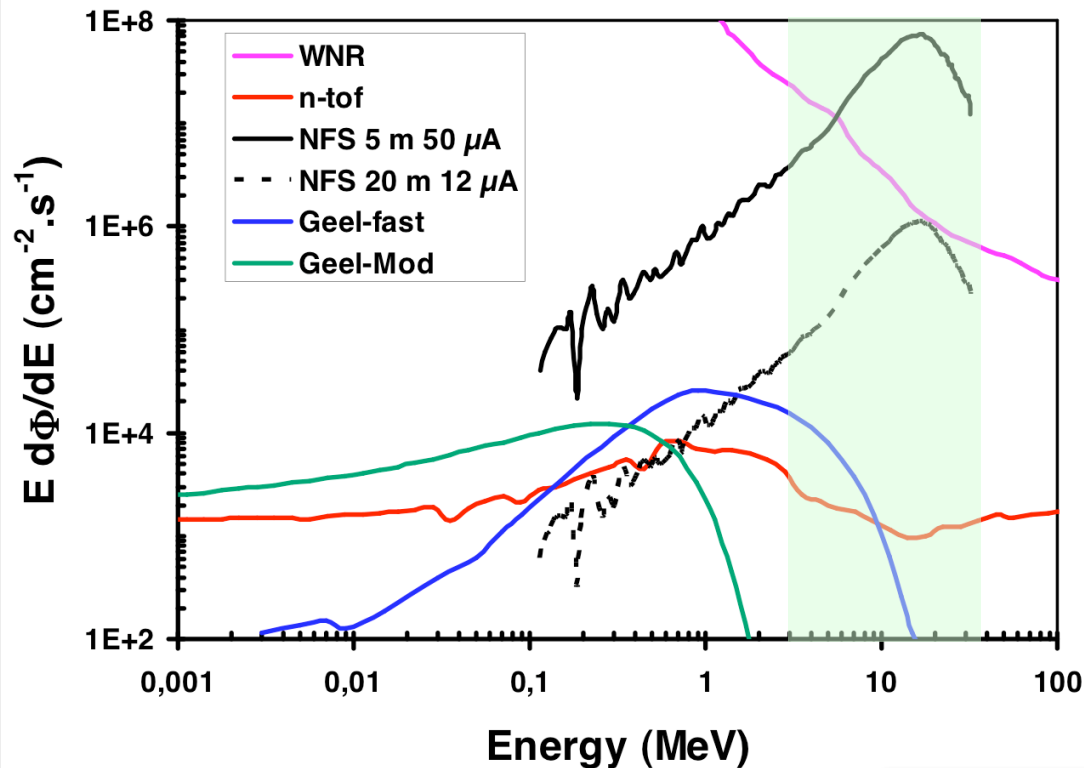
Stanislav Simakov, FZK, Germany

Schematic layout



Full cost including 10% overheads: 0,3 M€

Physics topics



Fission

- Minor actinides, main isotopes
- Cross section
- Neutron spectrum, multiplicity
- Prompt fission gammas
- Detailed A and Z distributions
- Delayed neutron yields and precursor characteristics

Scattering

- Secondary neutron energy and angle differential cross sections
- Inelastic scattering

Fusion reactors

Astrophysics

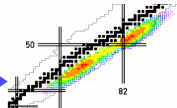
The (n,X) reactions play an important role in :

- Fission reactors of new generation
- Fusion technology (LOI appendix 5)
- Studies related to hybrid reactors (ADS)
- Nuclear medicine
- Reliable nuclear data evaluations

First experiments:

- Measurement of $(n,n'\gamma)$ et $(n,xn\gamma)$ cross-sections
- Study of the pre-equilibrium in the (n,xn) reactions
- Measurement of neutron-induced Minor Actinides fission-fragment yields In the 1-20 MeV range

Spiral2



GANIL/SPIRAL1/SPIRAL2 facility layout



GANIL/SPIRAL 1 today

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Up to 10^{14} fiss./sec.

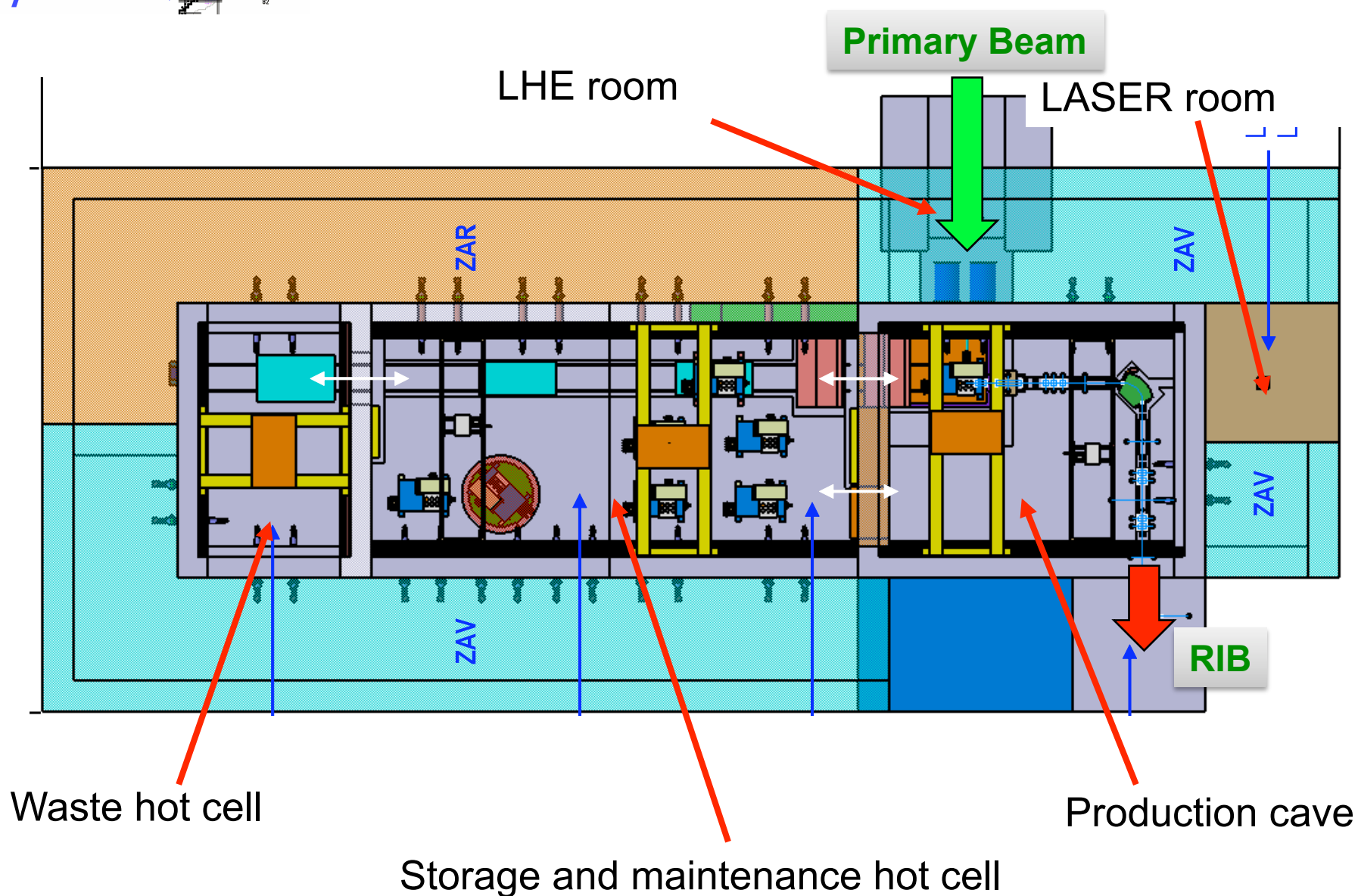
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A/q=3 HI source
Up to 1mA

A/q=2 source
p, d, ^3He , ^4He 5mA

A/q=6 Injector option

Production cave architecture

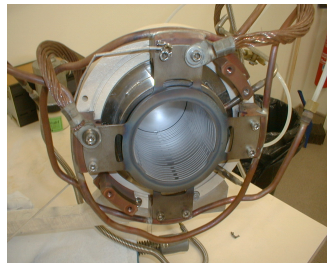


Production of RIB

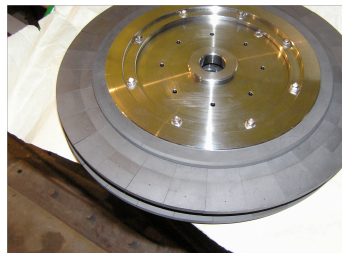
UC_x target (up to 2.3 kg, $\rho=11\text{g/cm}^3$)
 Tests at Gatchina of up to 100g target
 Construction and test of low density UC_x
 target at IPN Orsay/ALTO



Target oven
 tests IPN Orsay



Graphite Converter
 tests LNL Legnaro



p,d,HI beam

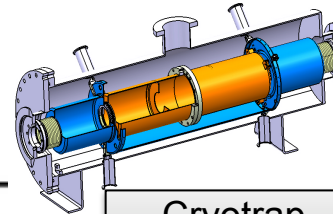
Target Station

1+ ion-sources:
 - Surface ionisation
 - ECR
 - Laser
 - FEBIAD

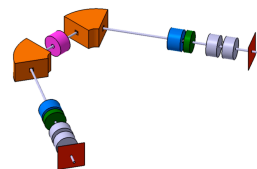
RFQ Cooler+HRS



RFQ Cooler
 LPC Caen



Cryotrap
 GANIL/IPNO

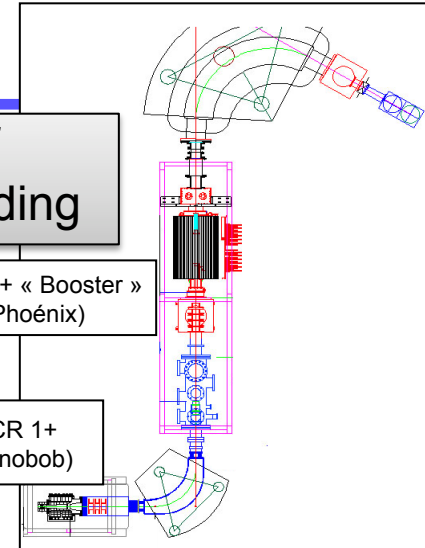


HRS
 CENBG Bordeaux

Tests at Grenoble of
 the 1+ $\rightarrow$ n+ charge breeding

ECR N+ « Booster »
 (Phoénix)

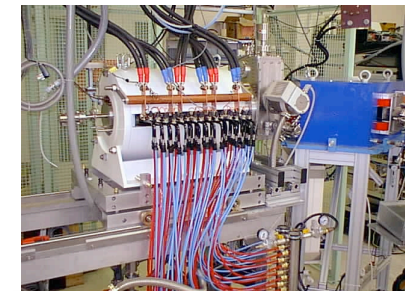
ECR 1+
 (monobob)



DESIR

(low energy RIB)

Charge
 Breeder ECR



Charge breeder
 (Phoenix ECR source)
 LPSC Grenoble

CIME

(fast RIB)



GANIL/SPIRAL1/SPIRAL2 facility



GANIL/SPIRAL 1 today

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S3 separator-
spectrometer
by H. Savajols

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DESIR Facility

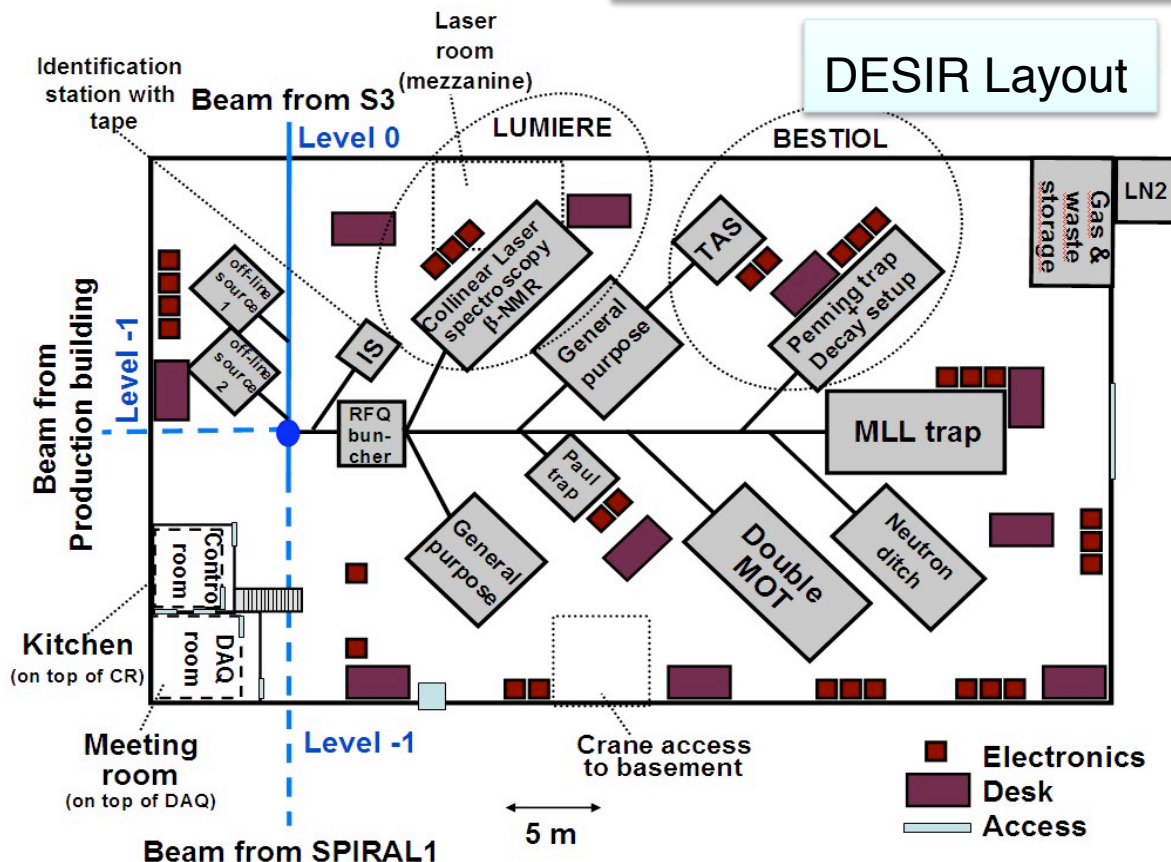
Collaboration

>100 physicists, 34 institutions, 15 countries

Spokesperson:

Bertram Blank, CENBG, France

DESIR Layout



Topics:

- nuclear fine structure
- charge radii & moments
- masses, ion-purification
- weak interaction studies

Tools:

- decay spectroscopy
- laser spectroscopy
- ion / atom trapping



GANIL/SPIRAL1/SPIRAL2 facility



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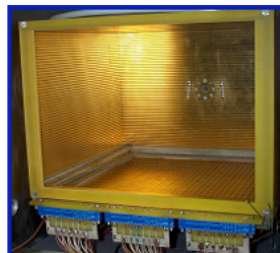
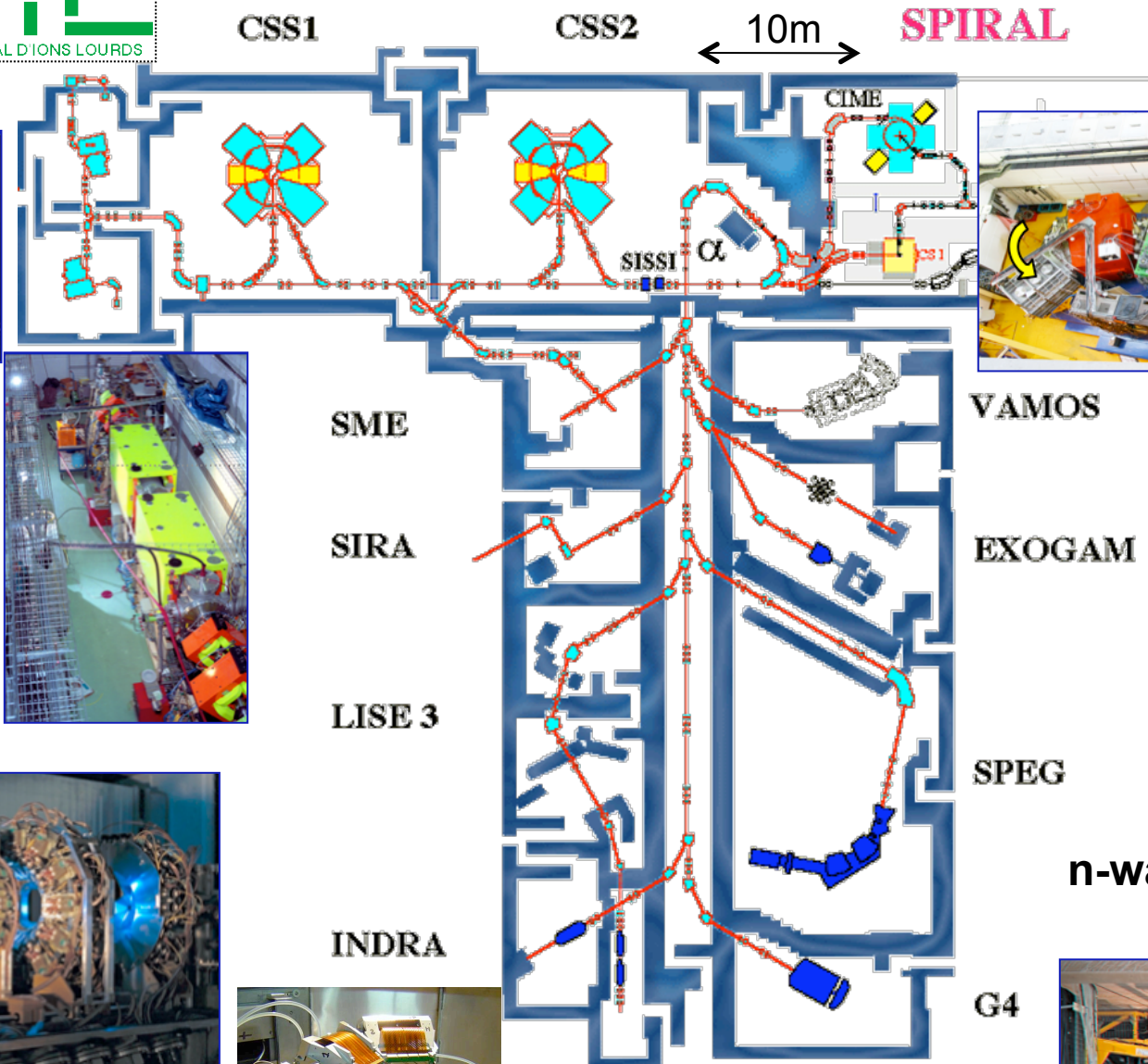
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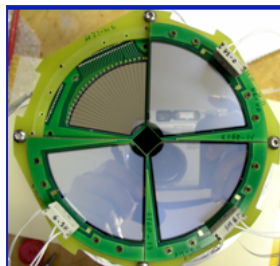
A/q=3 HI source
Up to 1mA

A/q=2 source
p, d, ^3He , ^4He 5mA

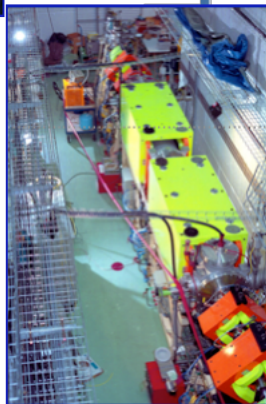
A/q=6 Injector option



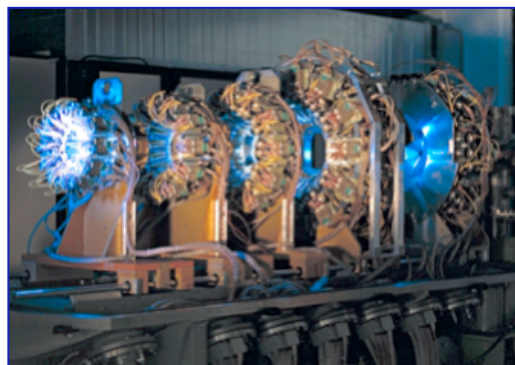
MAYA



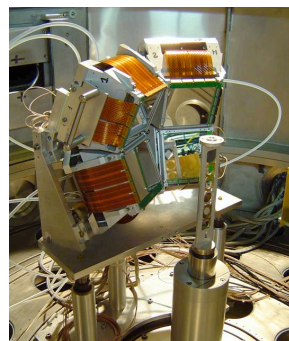
DSSSD



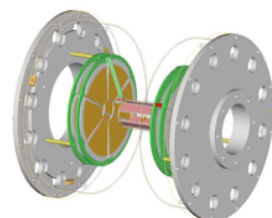
MUST 2



INDRA



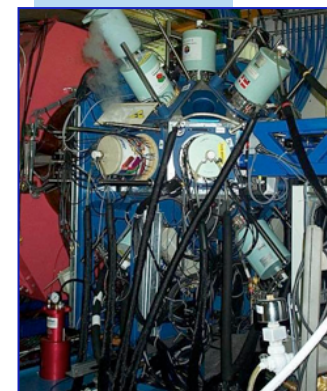
MUST 2



TIARA



VAMOS



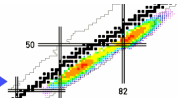
EXOGAM



n-wall



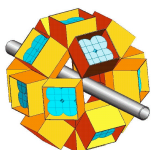
G4



New detectors to be used at SPIRAL 2

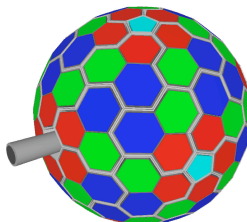
2006-2009: 19 Letters of Intent & TDR, 600 physicists from 34 countries

EXOGRAM 2



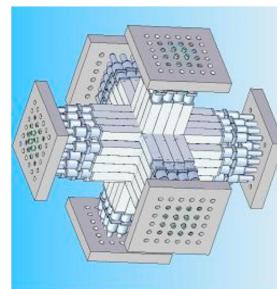
Upgrade of existing
Ge array

AGATA



New advanced
Ge array

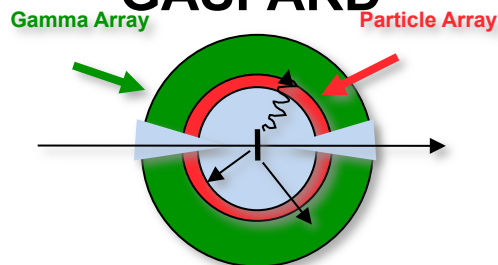
PARIS



LaBr₃/BaF₂
array

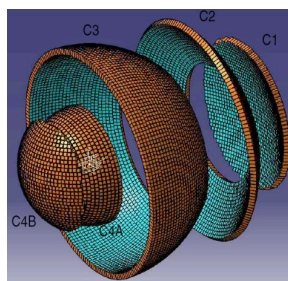
Gamma arrays

GASPARD



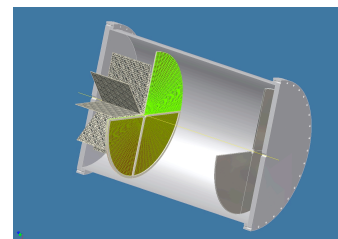
Advanced Charge particle
& gamma array
for direct reactions

FAZIA



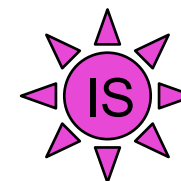
Charge particle
4 π array
for reaction studies

ACTAR



Active target

Charge particle
detectors

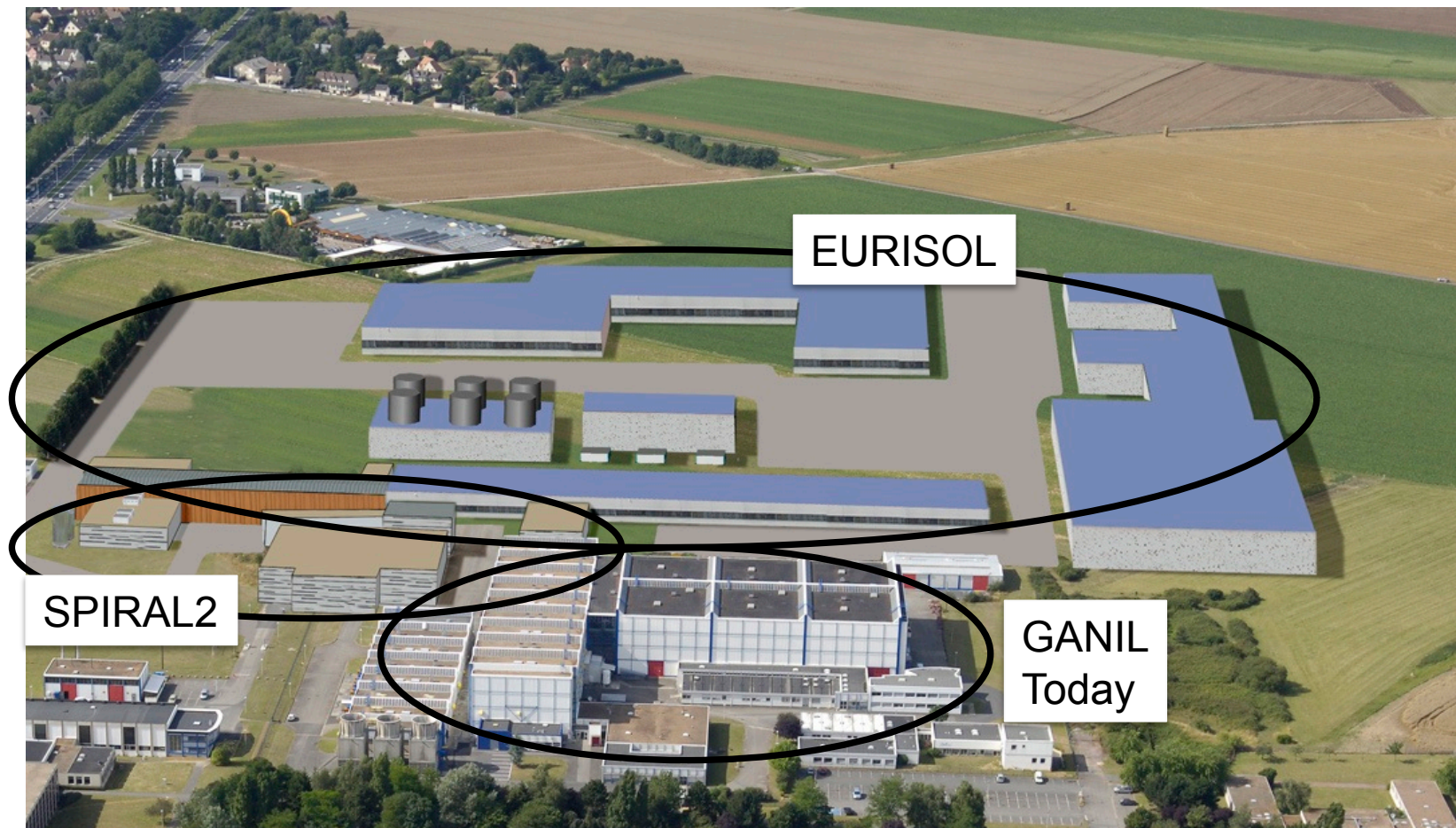




EURISOL at GANIL ?

SPIRAL 2 LINAC as a first part of the EURISOL driver?

- SPIRAL 2 LINAC is high-power machine (5mA)
- Possible and cost effective upgrade to H⁻ beam



Conclusions



- The SPIRAL 2 facility at GANIL entered in the construction phase with first beams expected in the beginning of 2012
 - ✓ High-intensity HI beams + S3 = SHE & N=Z
 - ✓ Low-energy very exotic RIB + DESIR
 - ✓ Intense Rare Isotope ISOL beams $E < 20$ AMeV
- SPIRAL2 as important intermediate step towards EURISOL

-> Huge Discovery Potential for the next decades

Useful links:

- www.ganil.fr
- www.spiral2pp.eu
- ***Any questions on SPIRAL2 -> Lewitowicz@ganil.fr***

