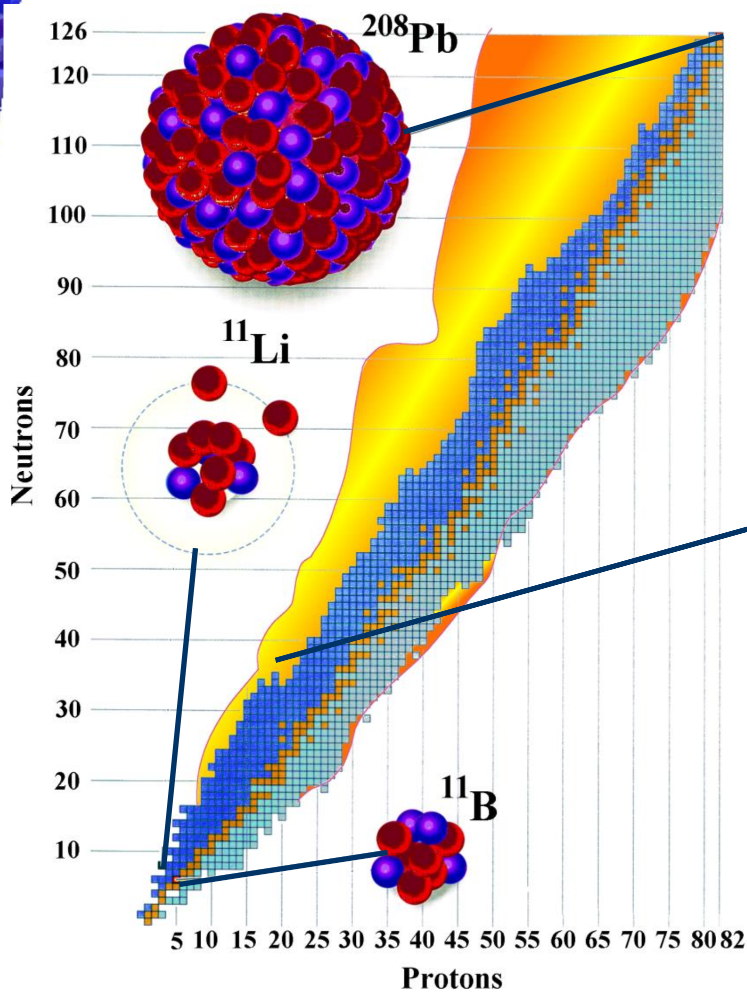
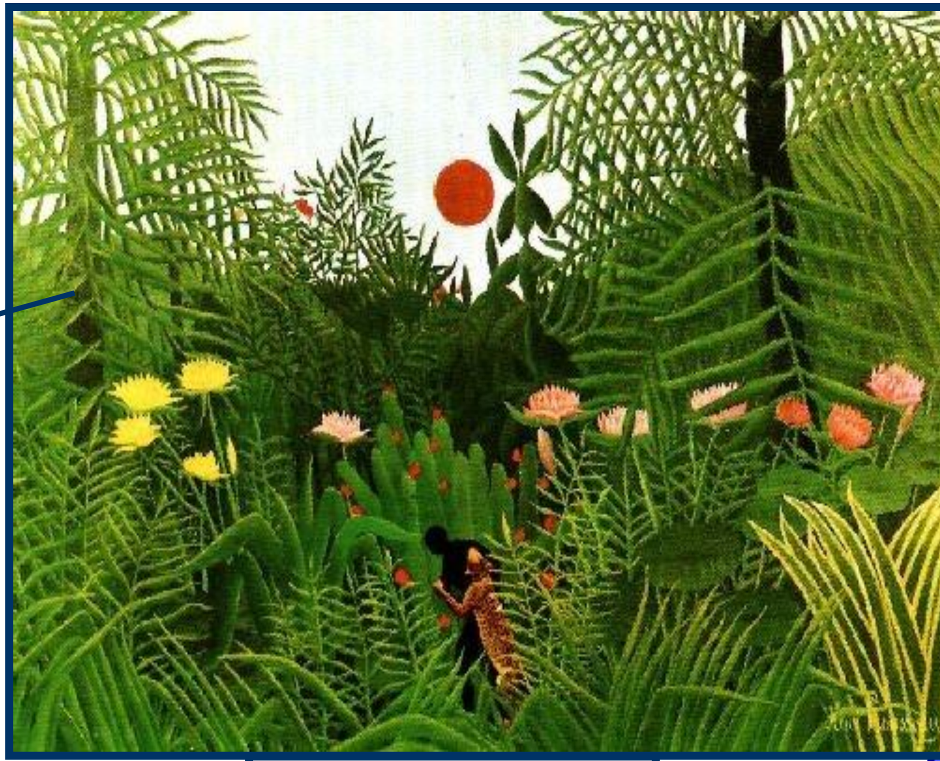
A journey in the world of « exotic nuclei »

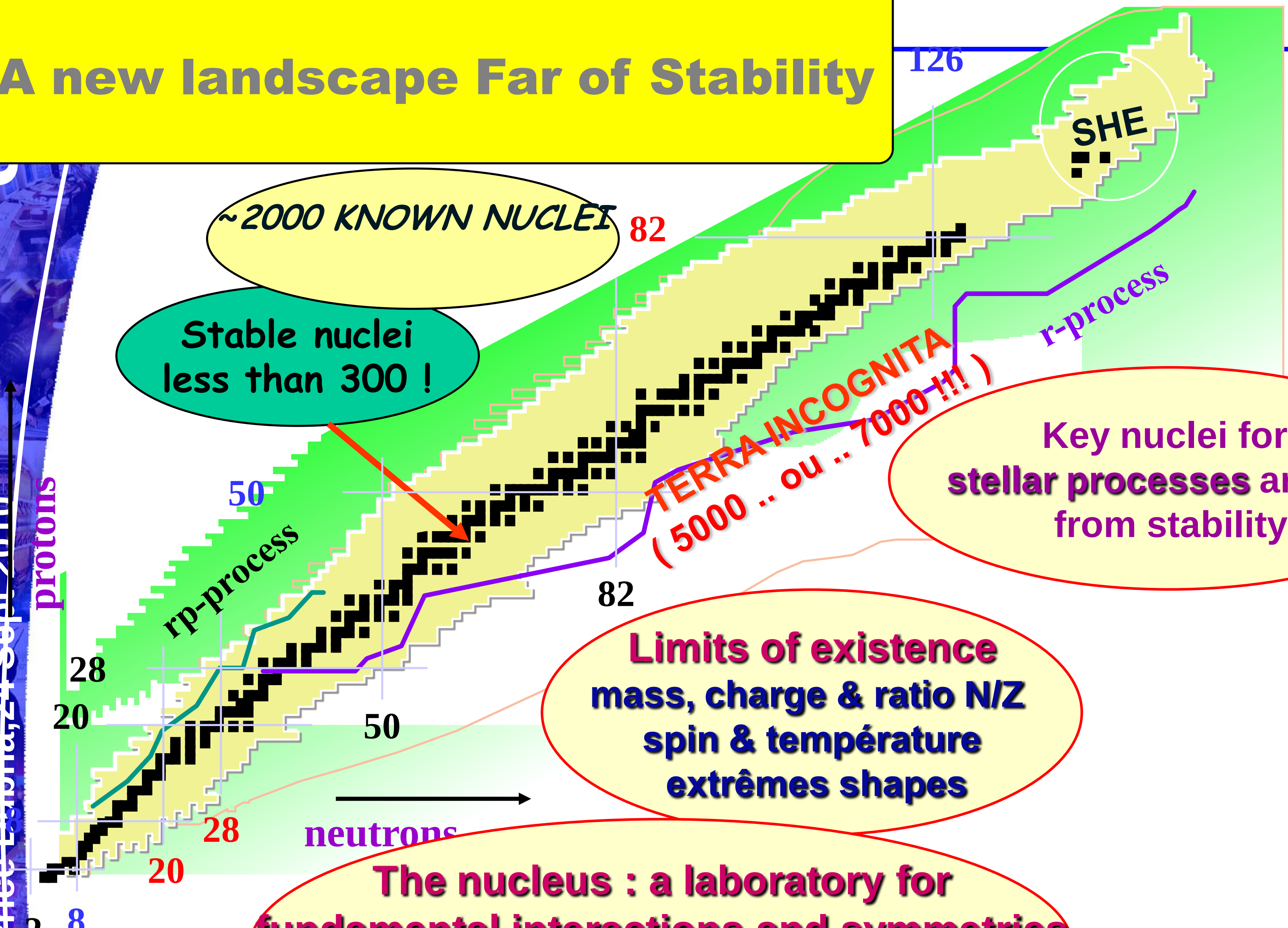


◆**Explore the limits of existence and study new phenomena**



H. Rousseau, *Forêt Vierge ...*

A new landscape Far of Stability



Key nuclei for **stellar processes** are far from stability

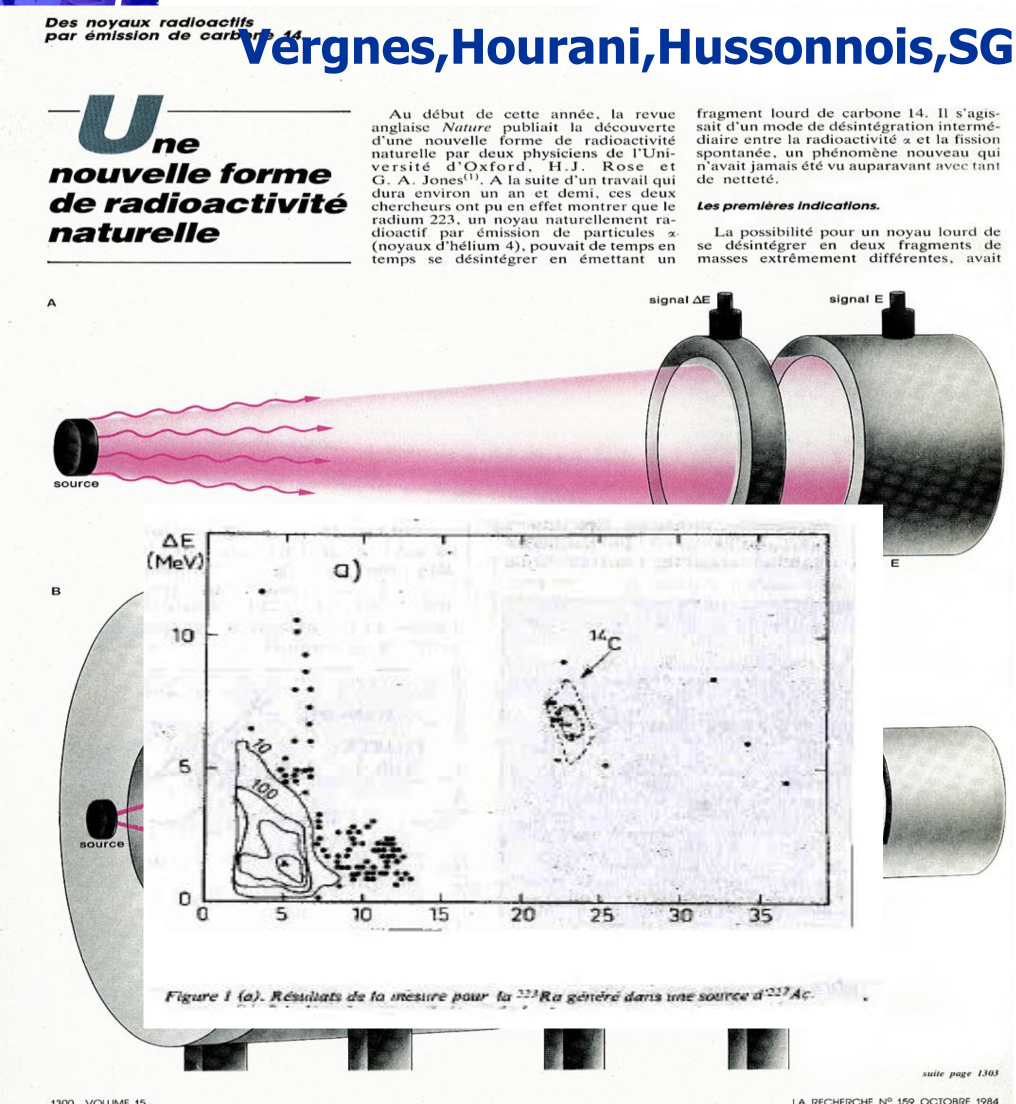
Limits of existence
mass, charge & ratio N/Z
spin & température
extrêmes shapes

The nucleus : a laboratory for fundamental interactions and symmetries
Shell structure and Isospin
Spin and shapes

Sydney Gales

Roses and Jones after 500d of data taking with a Si Telescope discover 14C radioactivity of 227Ra
Thanks to M.Hussonois and SOLENO ,Orsay team confirm it in 5 days at the Orsay MP

Vergnes,Hourani,Hussonnois,SG….



Une nouvelle forme de radioactivité naturelle

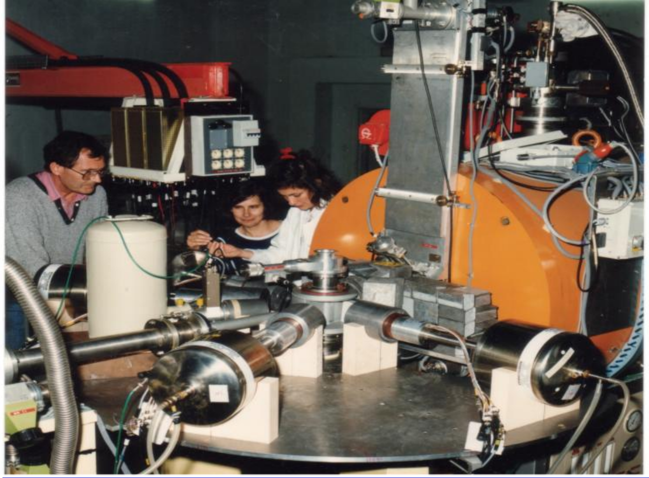
Au début de cette année, la revue anglaise *Nature* publiait la découverte d'une nouvelle forme de radioactivité naturelle par deux physiciens de l'Université d'Oxford, H.J. Rose et G. A. Jones[1]. A la suite d'un travail qui dura environ un an et demi, ces deux chercheurs ont pu en effet montrer que le radium 223, un noyau naturellement radioactif par émission de particules α (noyaux d'hélium 4), pouvait de temps en temps se désintégrer en émettant un fragment lourd de carbone 14. Il s'agissait d'un mode de désintégration intermédiaire entre la radioactivité α et la fission spontanée, un phénomène nouveau qui n'avait jamais été vu auparavant avec tant de netteté.

Les premières indications.

La possibilité pour un noyau lourd de se désintégrer en deux fragments de masses extrêmement différentes, avait

Figure 1 (a). Résultats de la mesure pour la ^{223}Ra généré dans une source d'^{227}Ac.

suite page 1303



Search for proton radioactivity in 65As, 69Br and 77Y.
E. HOURANI, F. AZAIEZ, PH. DESSAGNE, A. ELAYI, S. FORTIER, S. GALES, J.M. MAISON, P. MASSOLO, CH. MIEKE and A. RICHARD.
Zeit., Phys. A334 (1989) 277

Sydney Gales

Dominique!!!

Preparing the « exotic » program with the Orsay MP Tandem

^{18}C

A new physicist At orsay

^{68}Ni, 0^+_2

Mass of ^{18}C from the double-charge-exchange reaction $^{48}Ca(^{18}O, ^{18}C)^{48}Ti$

F. Naulin, C. Détraz, M. Roy-Stéphan, M. Bernas, J. de Boer,* D. Guillemaud, M. Langevin, F. Pougheon, and P. Roussel
Institut de Physique Nucléaire, B.P. No. 1, F-91406 Orsay, France
(Received 13 October 1981)

The ground-state transition is observed in the double-charge-exchange reaction $^{48}Ca(^{18}O, ^{18}C)^{48}Ti$ at 100 MeV. A mass excess of 24.82 ± 0.30 MeV is measured for ^{18}C.

[NUCLEAR REACTIONS $^{48}Ca(^{18}O, ^{18}C)$, $E = 100$ MeV; measured ^{18}C mass; enriched target.]

The observation of the $^{48}Ca(^{18}O, ^{18}C)^{48}Ti$ double-charge-exchange reaction reported in this article bears on two subjects of interest. First, it provides a remeasurement of the mass of the very neutron-rich ^{18}C isotope, only measured once so far, by a (π^-, π^+) experiment[1] at 164 MeV with 150-keV precision. Second, it sheds some light on the feasibility of reactions on this type[2,3] to observe other exotic nuclei.

The reaction was induced by a 100-MeV $^{18}O(7^+)$ beam from the Orsay MP tandem with an intensity of 100 electric nA. The thickness of the self-supporting ^{48}Ca target was deliberately chosen as high as 1.3 mg/cm^2 because of the very low cross section anticipated for the reaction.

A 180° magnetic spectrometer analyzed the emitted nuclei within a 4.8-msr solid angle extending from 4° to 8° in the reaction plane. The nuclei were detected by a system consisting of two resistive-wire proportional counters and one ionization chamber with a split anode providing two energy-loss and one residual-energy measurements. This system[4,5] allows kinematical correction through ray tracing and provides redundant identification of the nuclei detected.

The energy spectrum of the nuclei identified as ^{18}C is presented in Fig. 1. The Q-value calibration is provided by known transitions of ^{16}C and ^{17}C nuclei, but the poor energy resolution due to the unusual target thickness severely limits its accuracy. For ^{18}C, the energy resolution is 1.1 MeV full width at half maximum (FWHM). The two single counts on the left side of the spectrum (Fig. 1) correspond to much lower ^{18}C mass values than predicted and measured.[1] They are assigned to background. Two groups of events appear in the spectrum. They are interpreted as corresponding to transitions to the ground and first excited states of ^{48}Ti, which is consistent with their energy separation. The centroid of the measured Q values of the 14 ground-state events, which correspond to a 40-nb sr^{-1} cross section in the laboratory system, is -21.33 ± 0.30 MeV. It corresponds to a

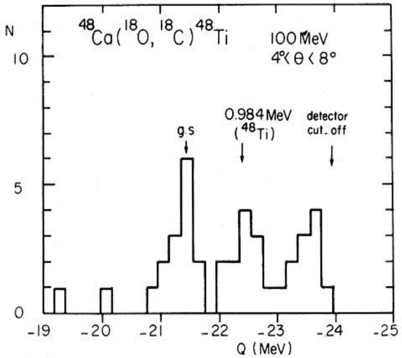


FIG. 1. Energy spectrum of the ^{18}C nuclei emitted from the $^{18}O(100$ MeV$) + {}^{48}Ca$ reaction. The calibration of Q values is obtained from known transitions yielding ^{16}C and ^{17}C nuclei. One count corresponds to a cross section of 3 nb sr^{-1}. Because of the large target thickness necessary to observe the transition, the energy resolution is 1.1 MeV FWHM.

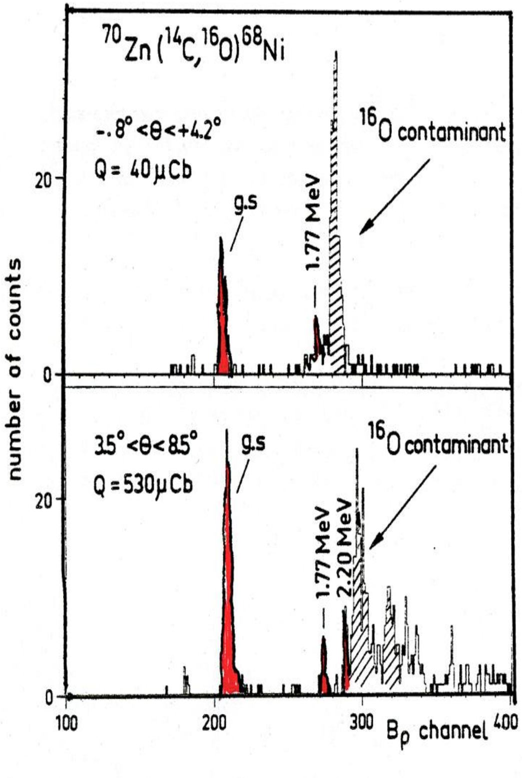


Figure 2

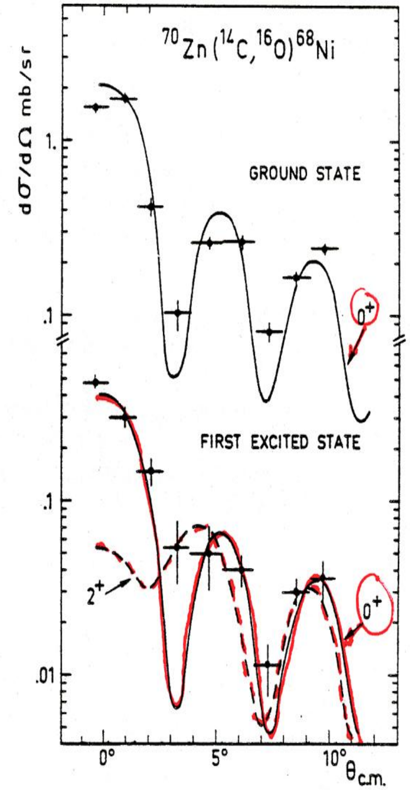
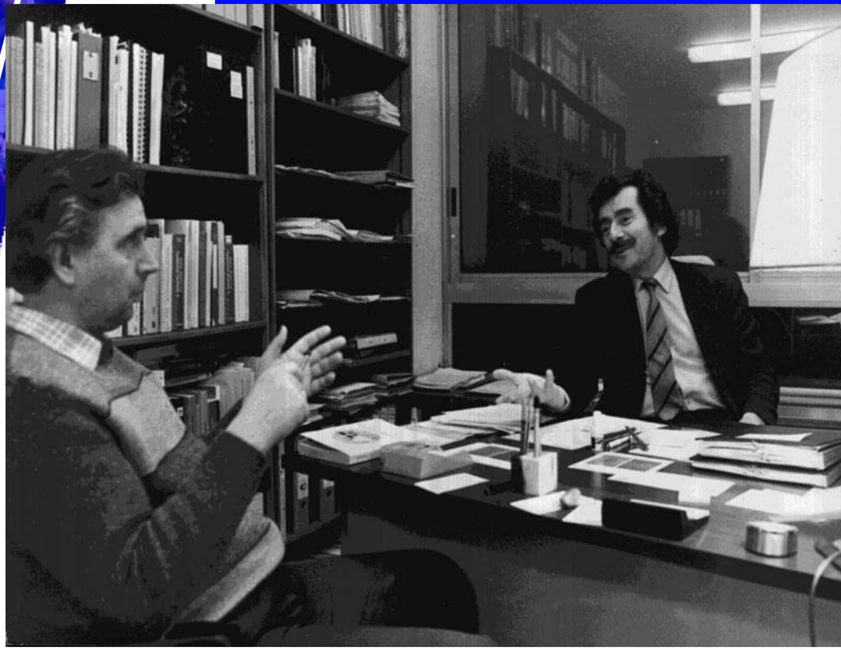


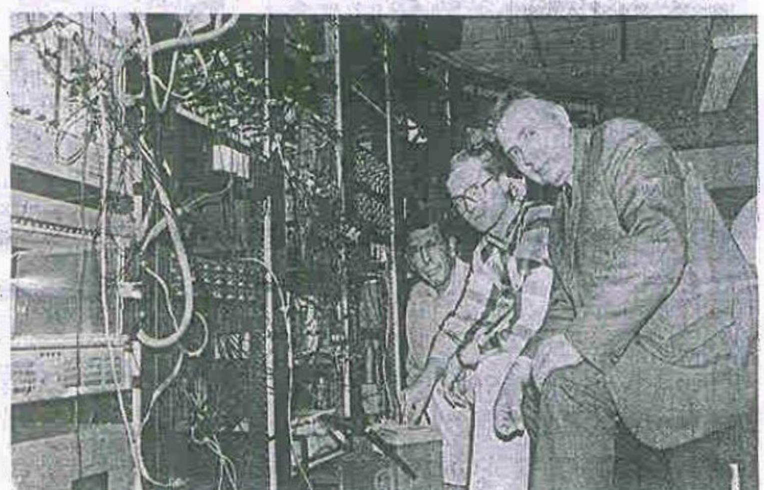
Figure 3

The start of FLEROV-GANIL Collaboration on « exotic nuclei



Au Ganil

Les expériences des physiciens russes



De gauche à droite, Samuel Harrar, directeur du Ganil, Ivan Pecina, chercheur tchécoslovaque, et le professeur Yuri Penionzhkevich, de Dubna : « Nous mettons ensemble notre savoir ».

Кан, Франция. В новом микрорайоне, рядом с ускорительным центром ГАНИЛ, одна из самых больших и красивых улиц именуется «авеню де Дубна»

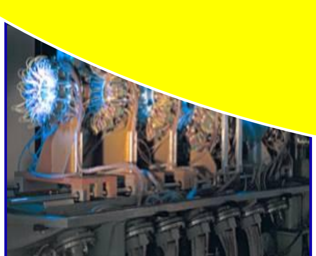
Caen, France. In a new residential area, situated near the accelerator centre GANIL, one of the biggest and beautiful streets is called «Avenue de Dubna»

GANIL SPIRAL

ISOL

Heavy ion beams ,among the most intense in the world
From Carbone to Uranium
0 to 95 MeV/n
“Exotic” Beams In Flight or SPIRAL 0-25 MeV/n
An ensemble of detectors and spectrometers rather unique
In the world !!

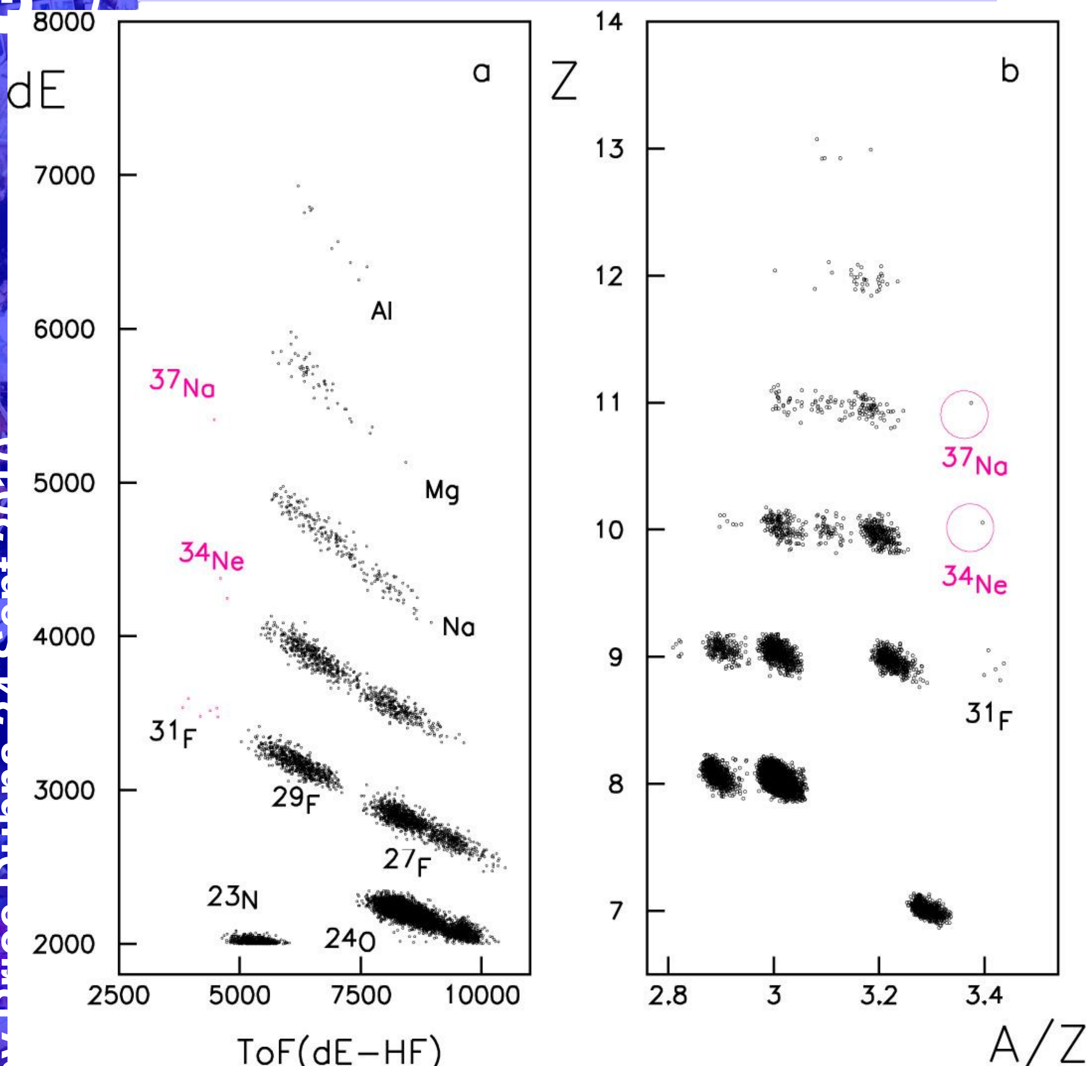
MUST MU

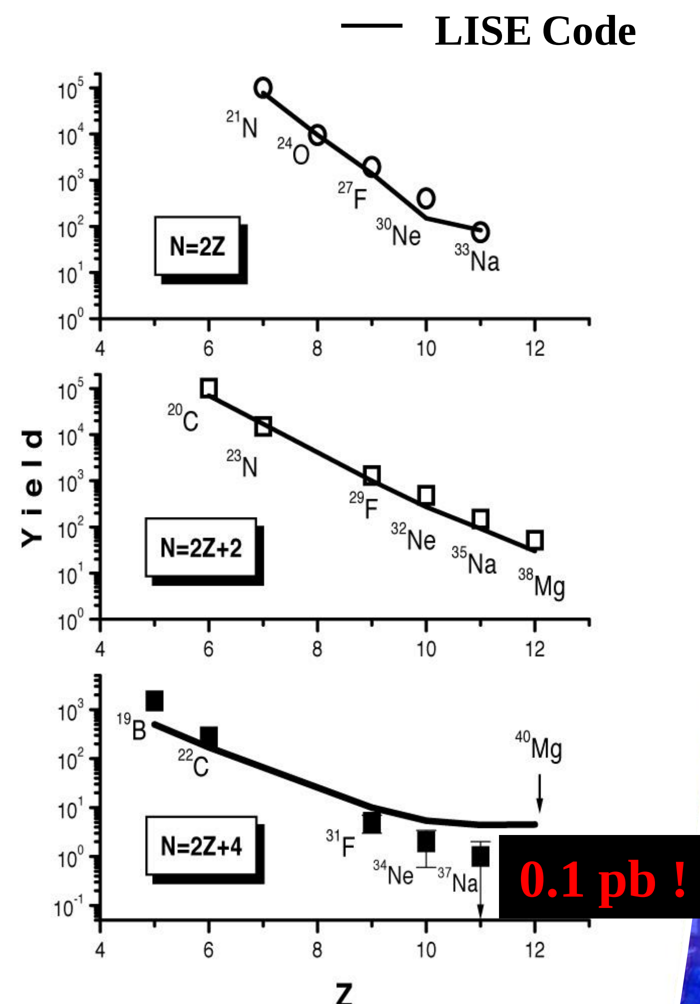


TIARA

Mapping neutron drip-line

^{48}Ca(58 AMeV,150pnA)+^{181}Ta





S. Lukyanov et al. J. Phys. G. 28 (2002) L41

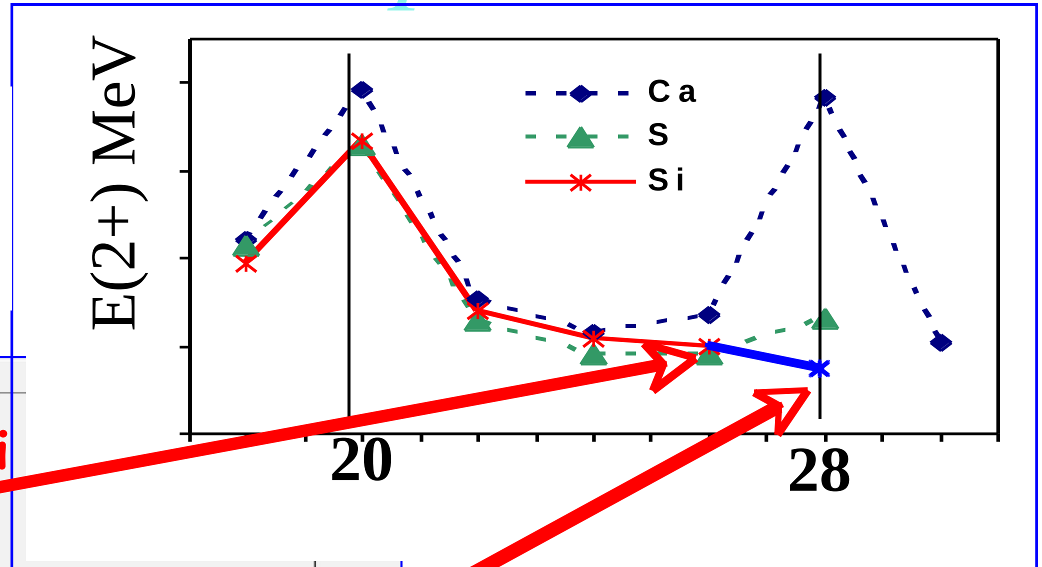
France-FLNR Collaboration

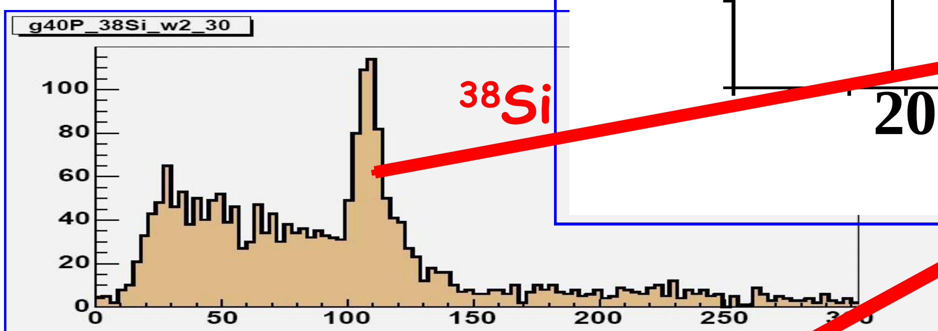
Shell Structure N=28

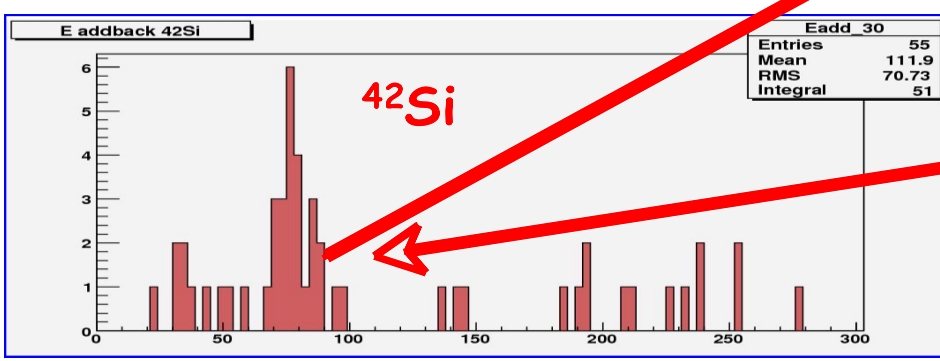
One example

S. Grevy et al.

^{42}Si Results



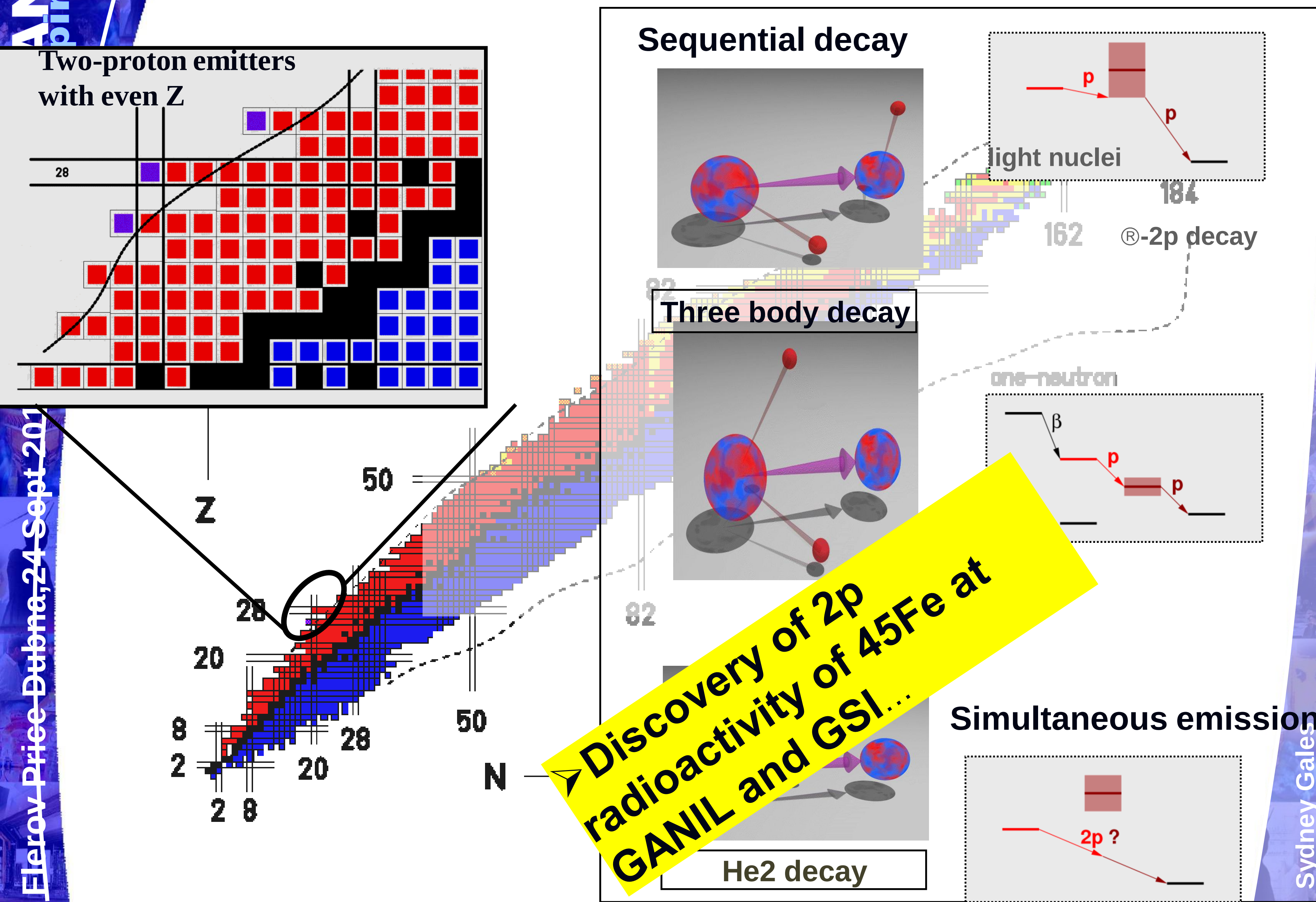




$E(2^{+}) = 765 \pm 25$ keV

France-FLNR Collaboration

1960 – Goldansky predicts *1-proton* and *2-proton* radioactivity



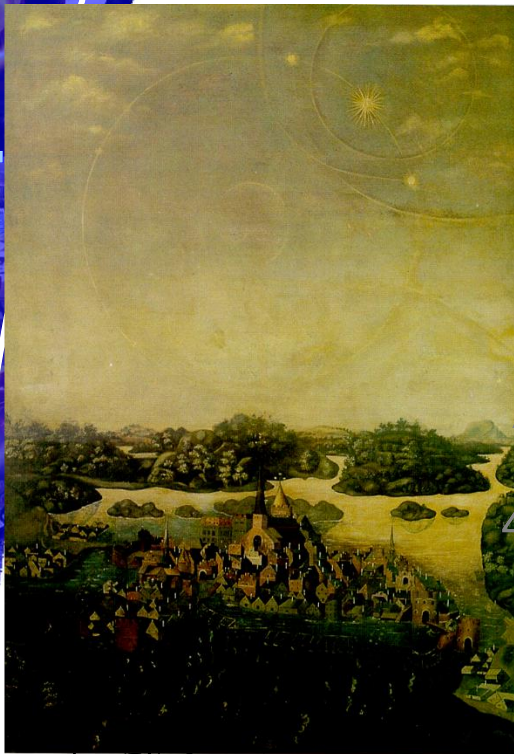
➢Discovery of 2p radioactivity of 45Fe at GANIL and GSI…

GANIL Spiral 2

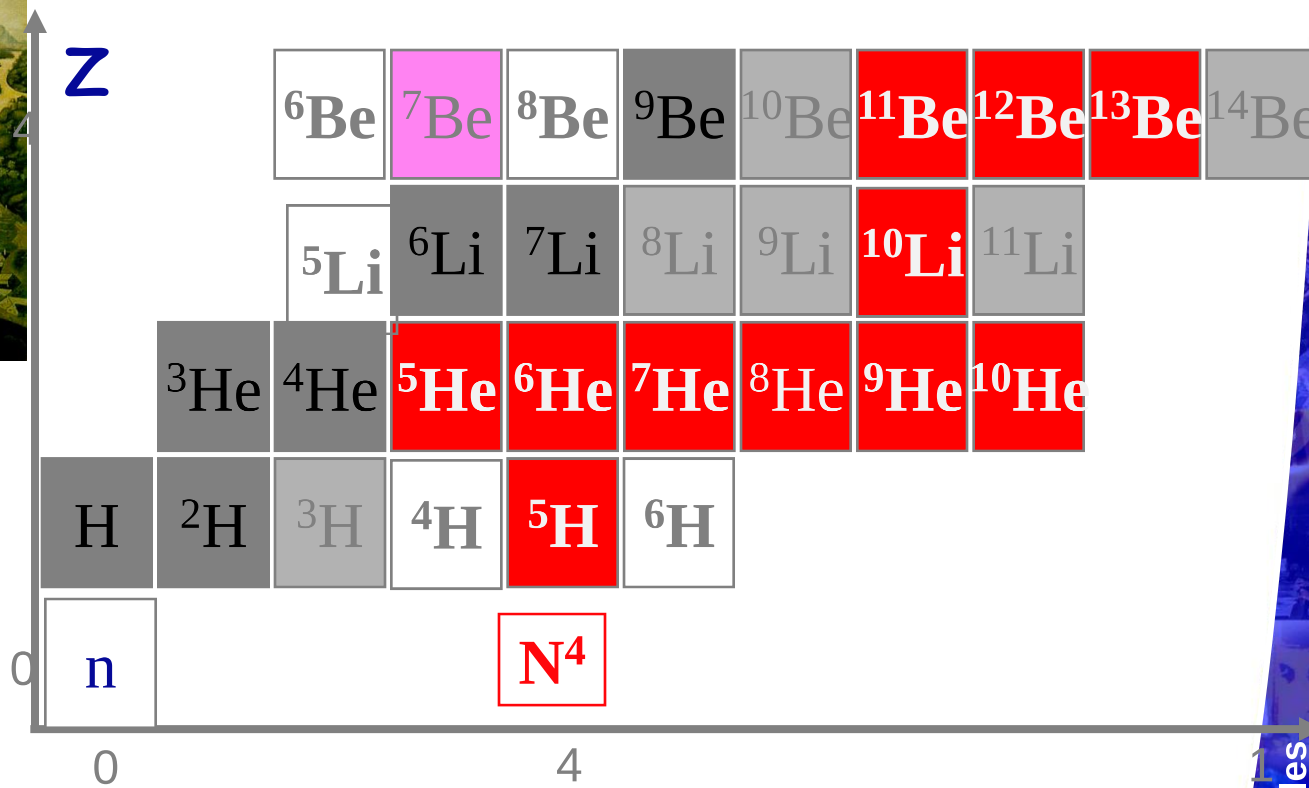
« Halo » Nuclei @GANIL-SPIRAL

1p splitting , ^{8}He,$^{12\text{-}14}$Be,^{20}C,^{22}O

Mainly (p,d) and (d,p)



John Elbfas, 1535,
Storkyrkan, Stockholm



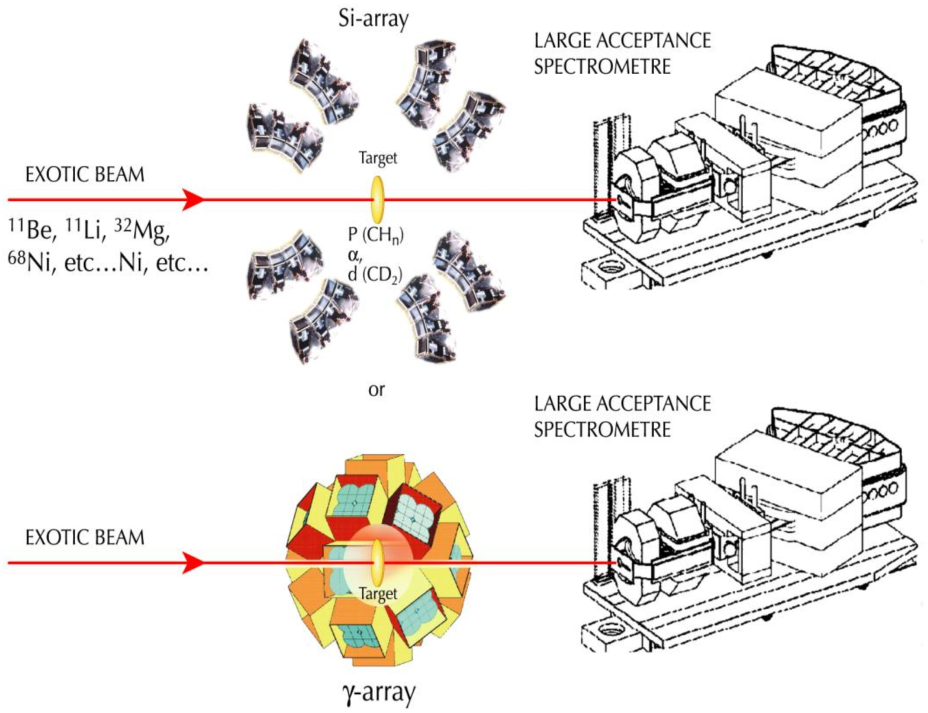
Search for 4 "n" system via D(8He,6Li)4N

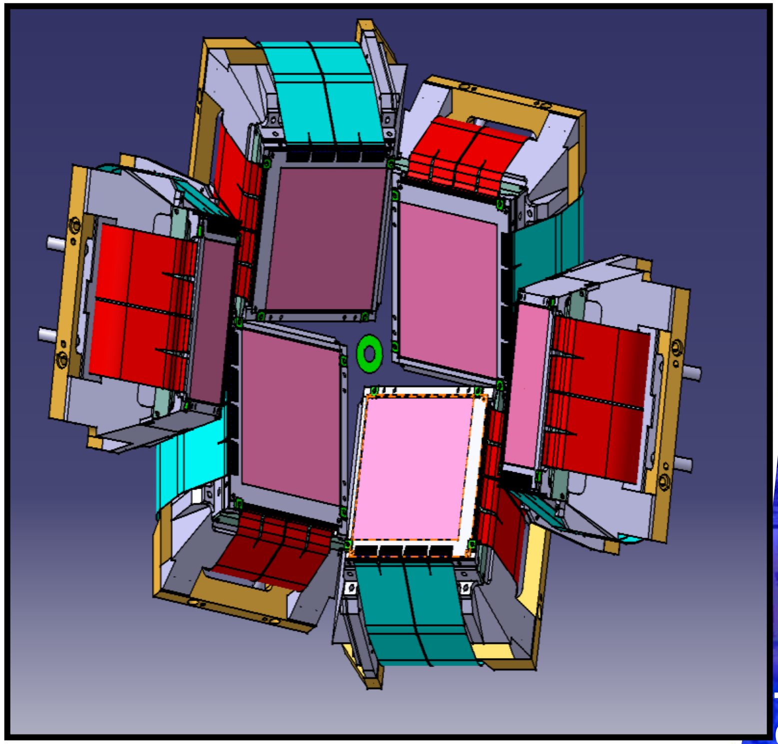
Inverse kinematics:

Reactions with secondary beams

Lecture at Joliot-Curie School 1990

From MUST to MUST2
IPNO-GANIL-SPhN-DAPNIA





Structure of ^{11}Be g.s. through (p,d) reaction

$H(^{11}Be,^{10}Be)^{2}H$

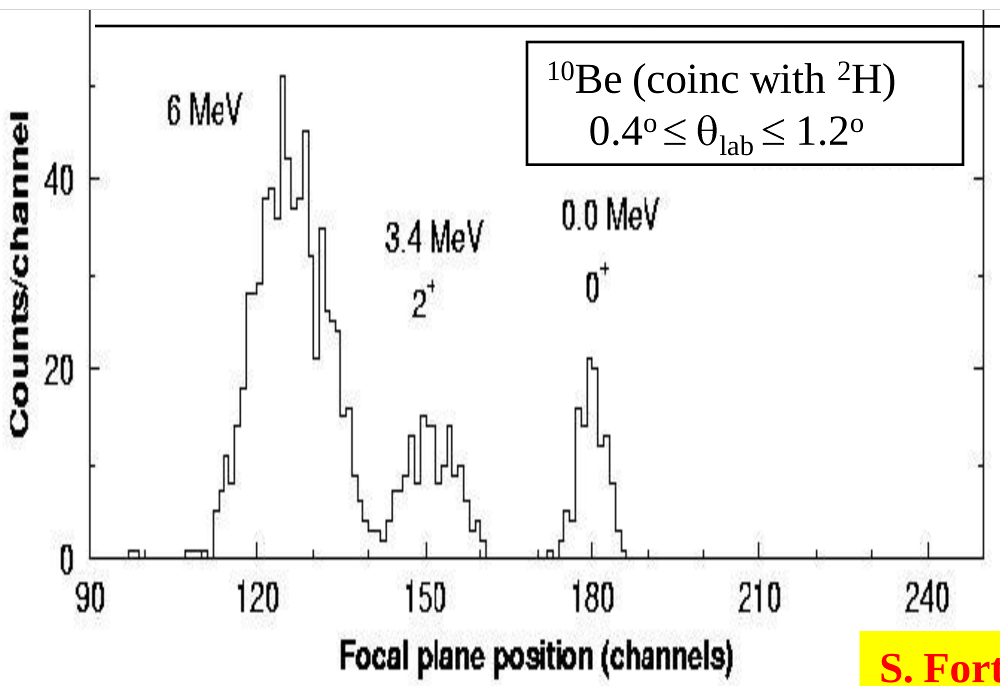
E = 35 A.MeV

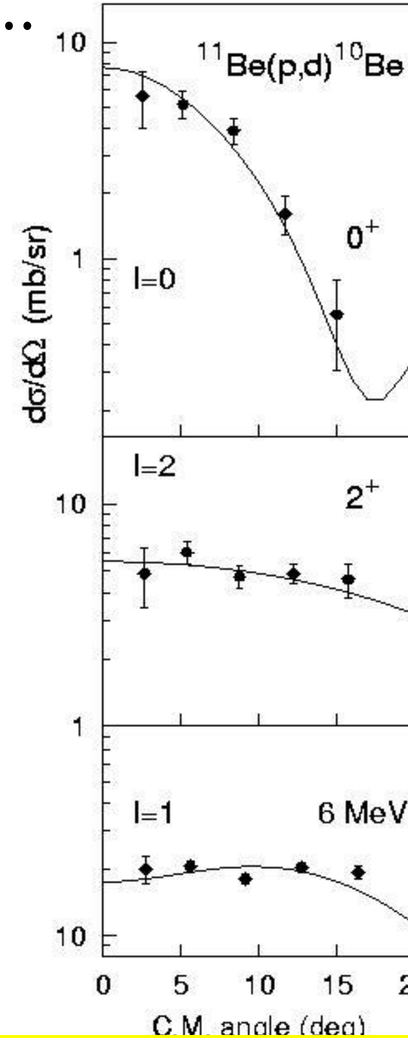
$$|^{11}_{4}Be_{g.s.}\rangle = S^{1/2}(0^{+})\,|^{10}Be_{0+}\otimes 2s\rangle + S^{1/2}(2^{+})\,|^{10}Be_{2+}\otimes 1d\rangle + \ldots..$$

$$(d\sigma/d\Omega)_{exp} = S(d\sigma/d\Omega)_{calc}$$

10^{5} ^{11}Be /s

$$\frac{S(2+)}{S(2+) + S(0+)} = 0.2$$





S. Fortier et al. PLB 461 (1999) 22
J.S. Winfield et al. NPA 683 (2001) 48

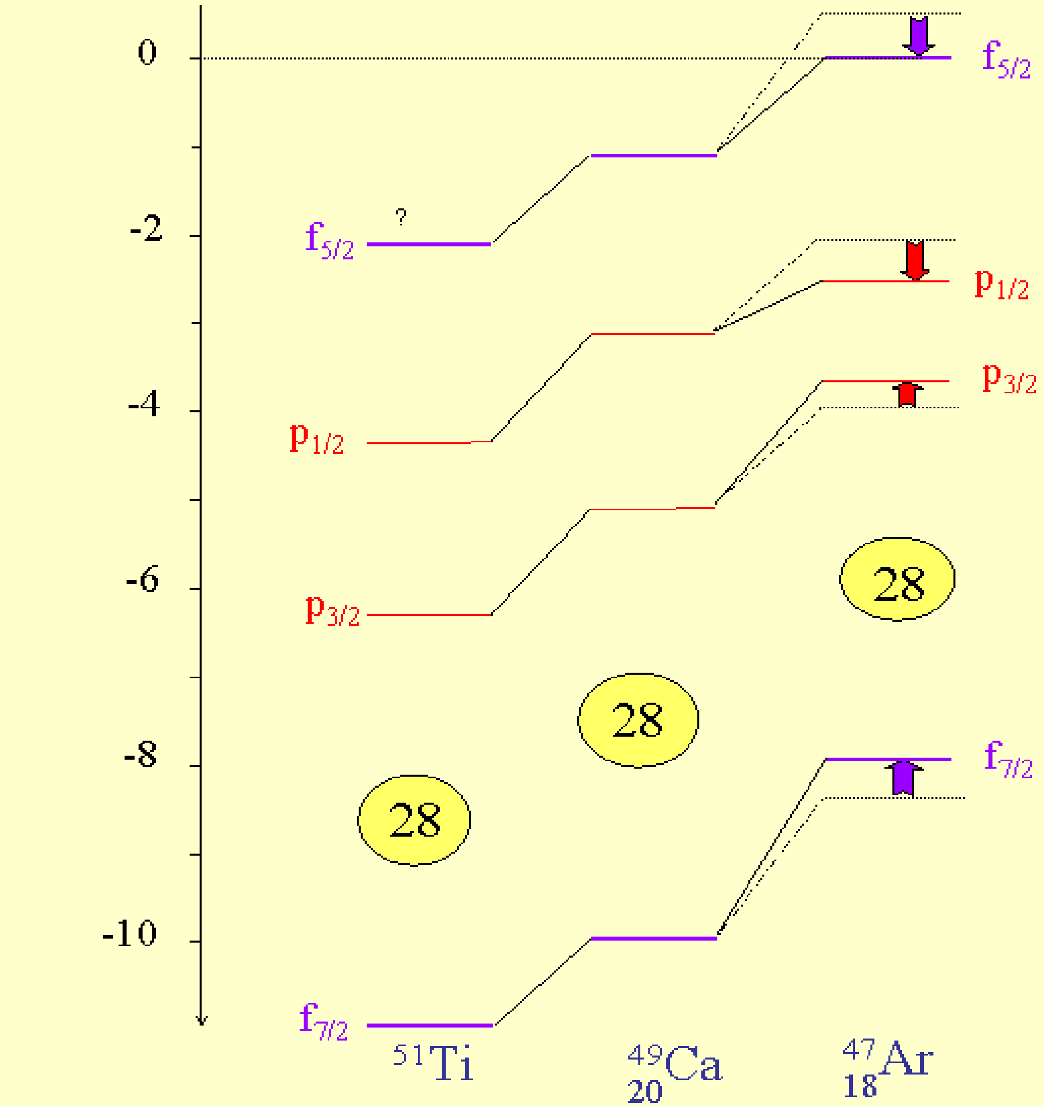
GANIL Spiral 2

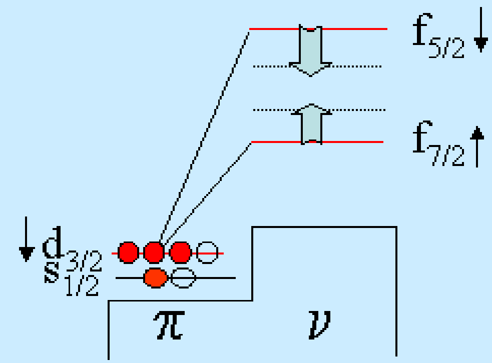
Flerov Price Dubna, 24 Sept 2010

$^{46}Ar(d,p)^{47}Ar$ N=28+1

Gaudefrois et al PRL97(2006)

Evolution of single particle energies at N=29





Tensor monopole interaction (*T. Otsuka*)

$\pi d_{3/2} - \nu(f_{7/2}-f_{5/2})$

or/and

Density dependence effect (*J. Piekarewicz*)

$\pi s_{1/2} - \nu(p_{1/2}-p_{3/2})$

First evidence of the tensor force in nuclei !

Courtesy of Olivier Sorlin

The N=28 gap has decreased by 330(80) keV between Ca and Ar

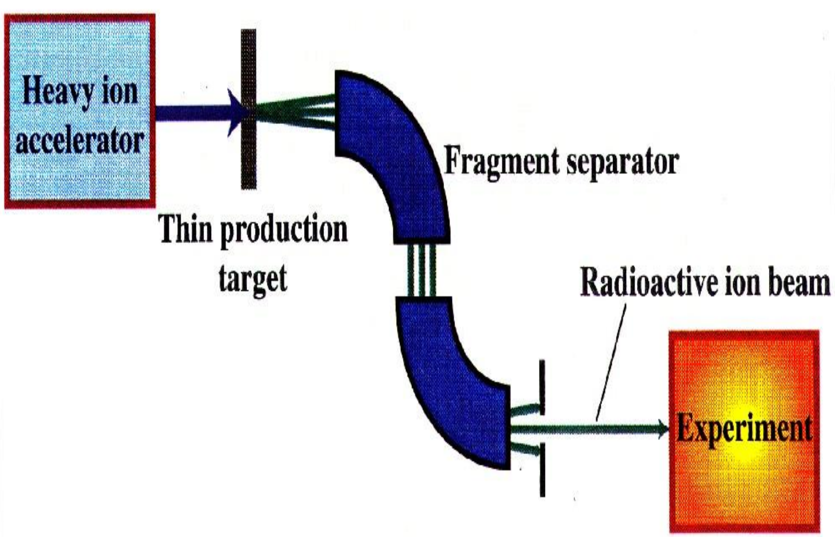
Decrease of the *f* and *p* spin-orbit splittings not predicted by mean field calculations

Conclusions of the NuPECC Working group on the "Next Generation European Radioactive Ion Beam Facilities in Europe" (April 2000)

Next generation of RIB facilities should aim at intensities 1000 times higher than in the facilities presently running or at the commissioning stage. Two truly complementary facilities based respectively on the « In flight and Isol » methods are needed to cover the foreseen physics issues, and they should be second to none world-wide

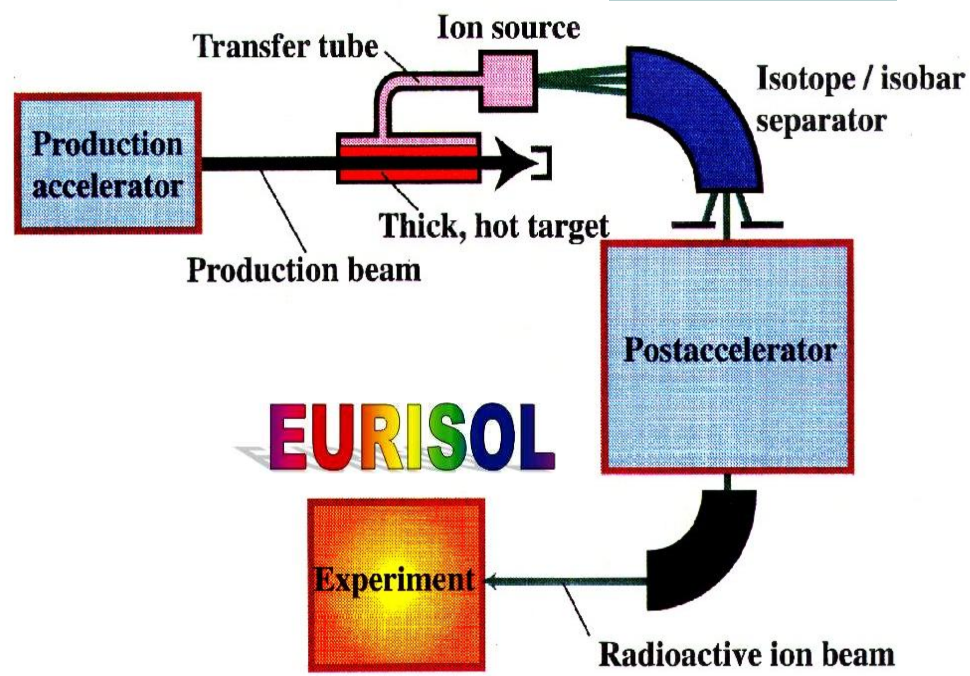
HIC for FAIR
Helmholtz International Center

Projectile Fragmentation

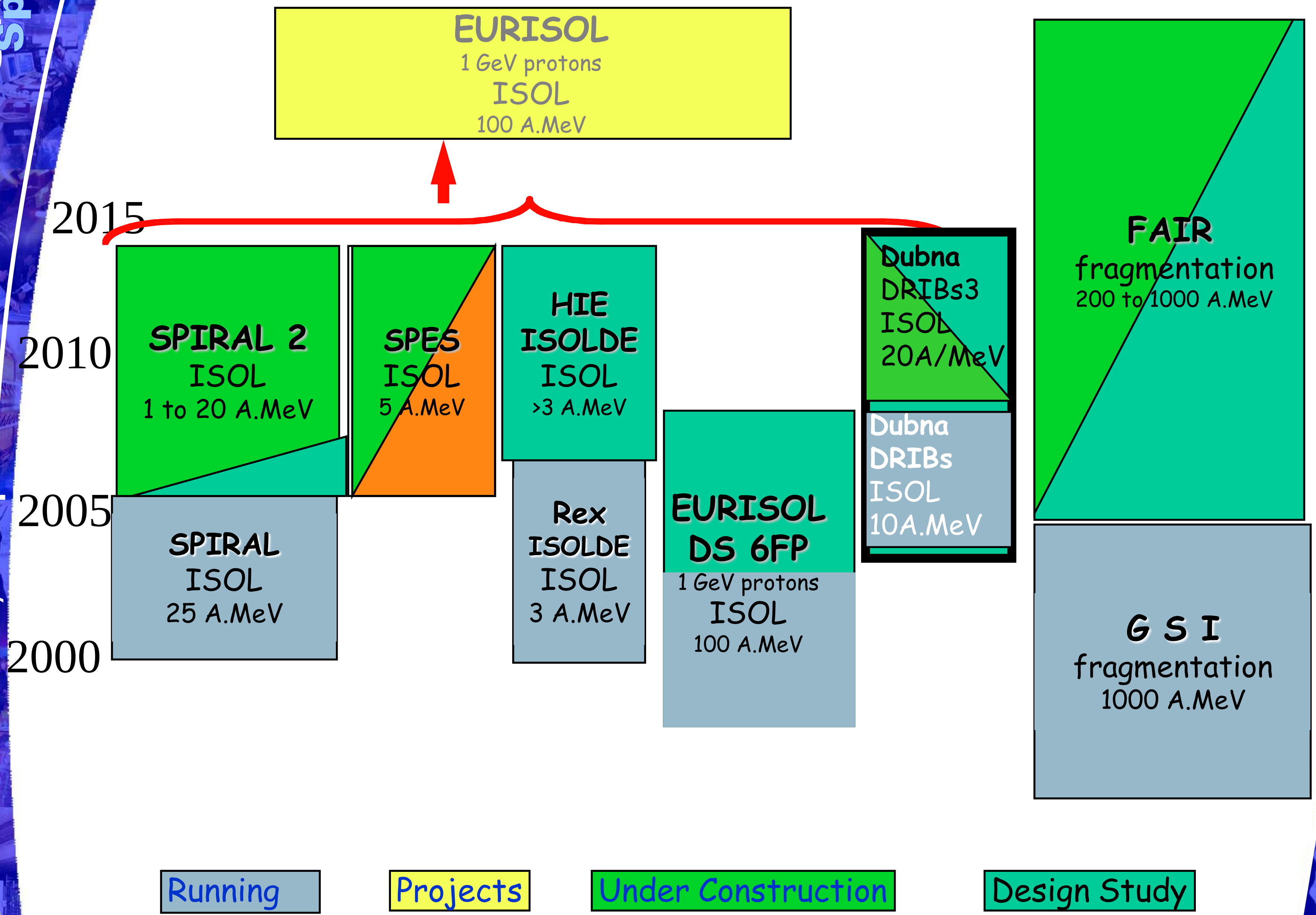


ISOL

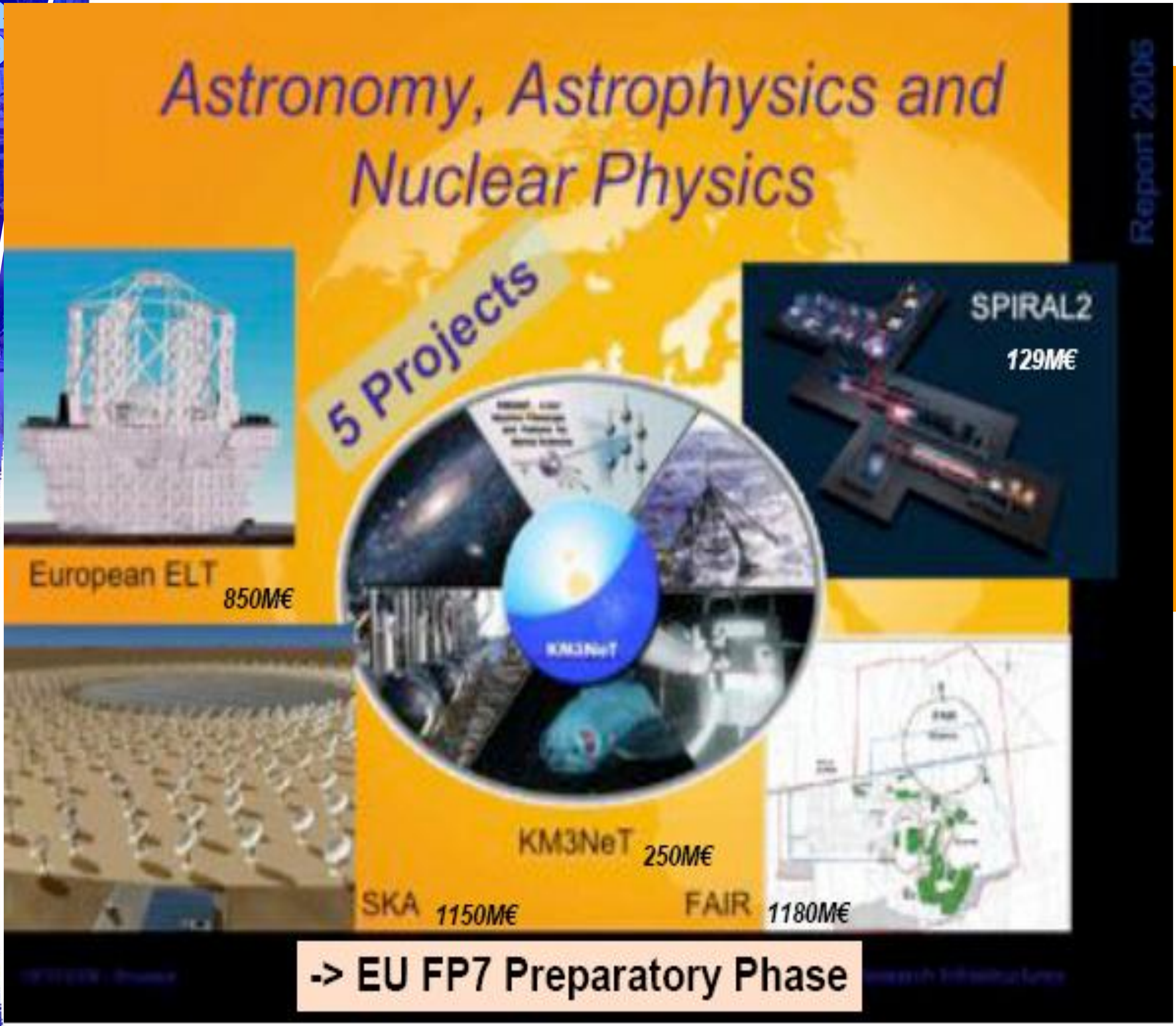
GANIL Spiral2



European RNB Facilities - NuPECC Road Map



FAIR & SPIRAL 2 on the ESFRI list



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

GANIL/SPIRAL1/SPIRAL2 facility

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

Neutrons For Science

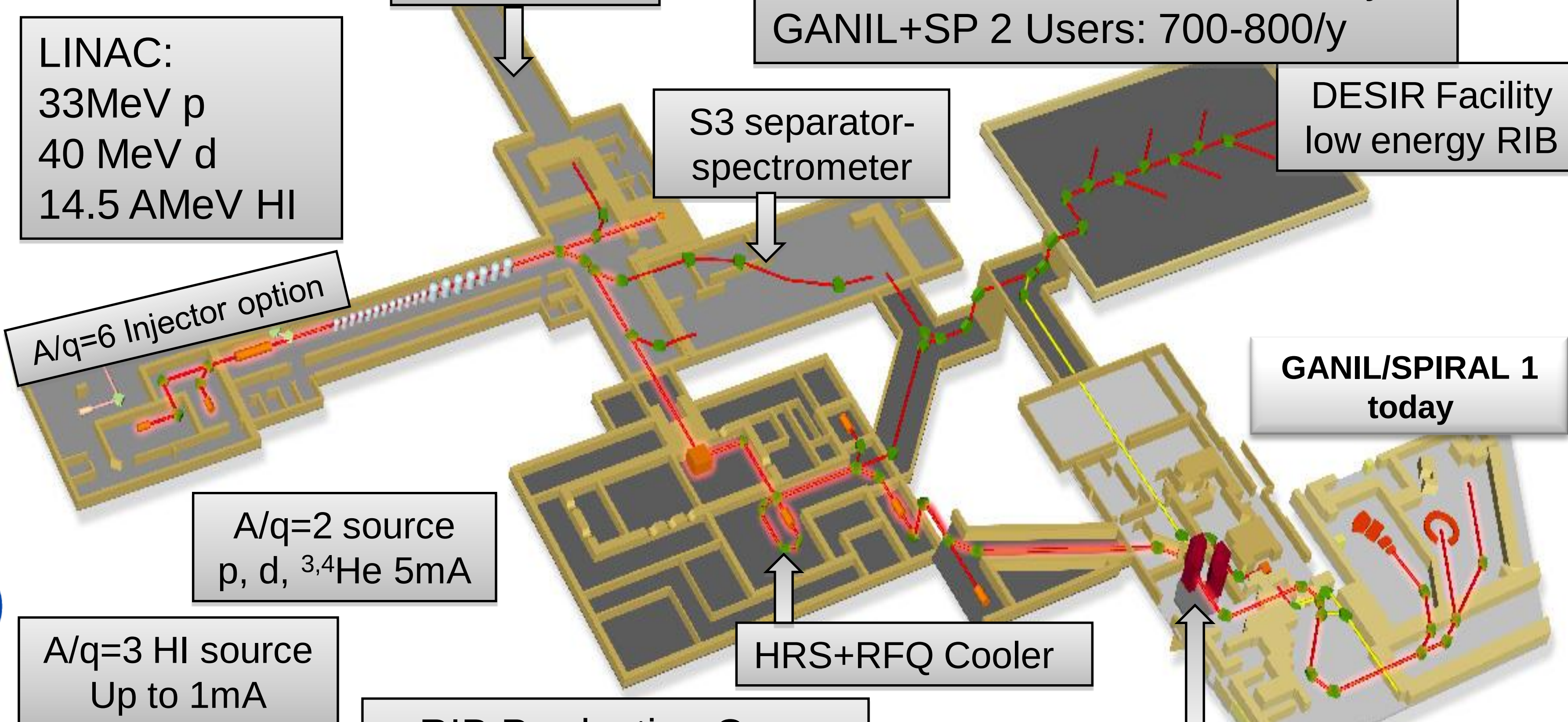
LINAC:
33MeV p
40 MeV d
14.5 AMeV HI

S3 separator-spectrometer

DESIR Facility low energy RIB

A/q=6 Injector option

GANIL/SPIRAL 1 today



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

A/q=3 HI source
Up to 1mA

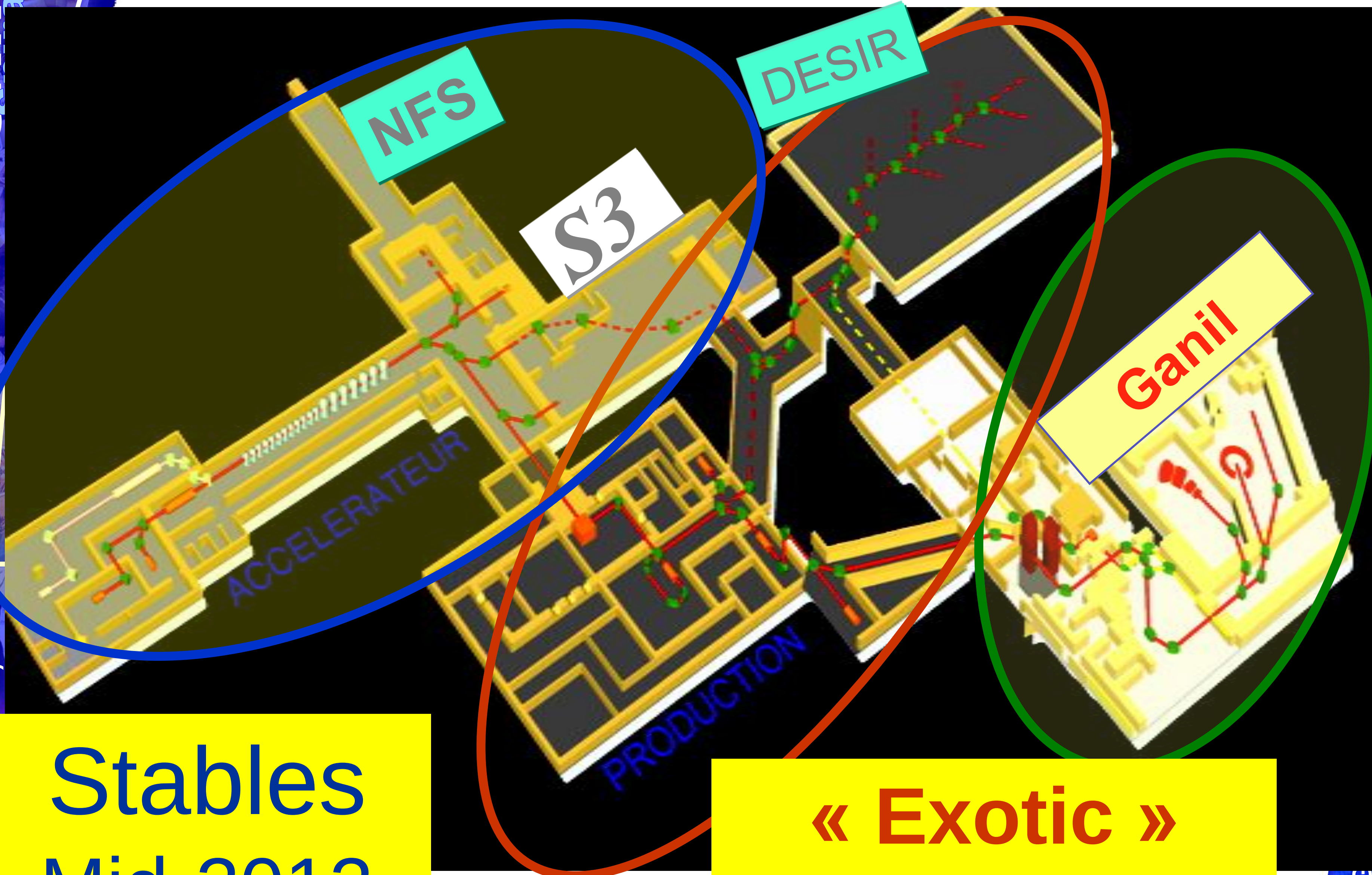
HRS+RFQ Cooler

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

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

Cost: 200M€
Funded

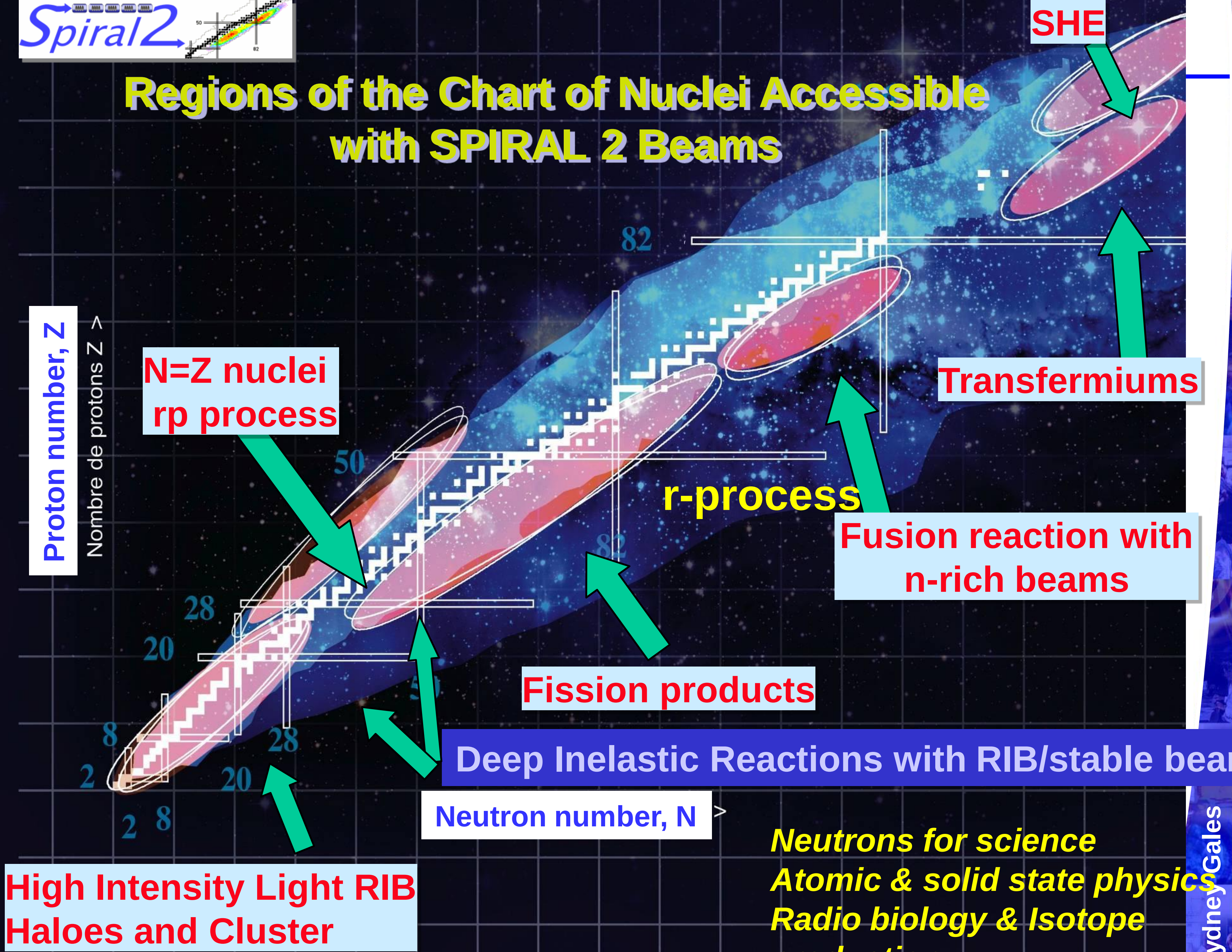
SPIRAL2 is one of the ESFRI list projects (40 most important EU research infrastructure projects)



Stables
Mid-2012

« Exotic »
2014

Regions of the Chart of Nuclei Accessible with SPIRAL 2 Beams



Neutrons for science
Atomic & solid state physics
Radio biology & Isotope production

SPIRAL2 main goal
The high intensity frontier
both for stable heavy ions
and secondary Radioactive Ion Beams

136 M€ 2006-2012

Construction in 2 Phases

Phase 2 2014
RIB production Building & DESIR

Phase 1 mid 2012
Accelerator & S3, NFS

Investment (with 10% contingencies): 136 M€
CNRS, CEA, Local Region
Total cost: 196 M€ (136+60 Manpower)
In the investment budget 26M€ are expected to come from EU and international partners

Civil construction: 2010 - 2012

A large National and International Collaboration

French Partners

CNRS IN2P3 Les deux infinis

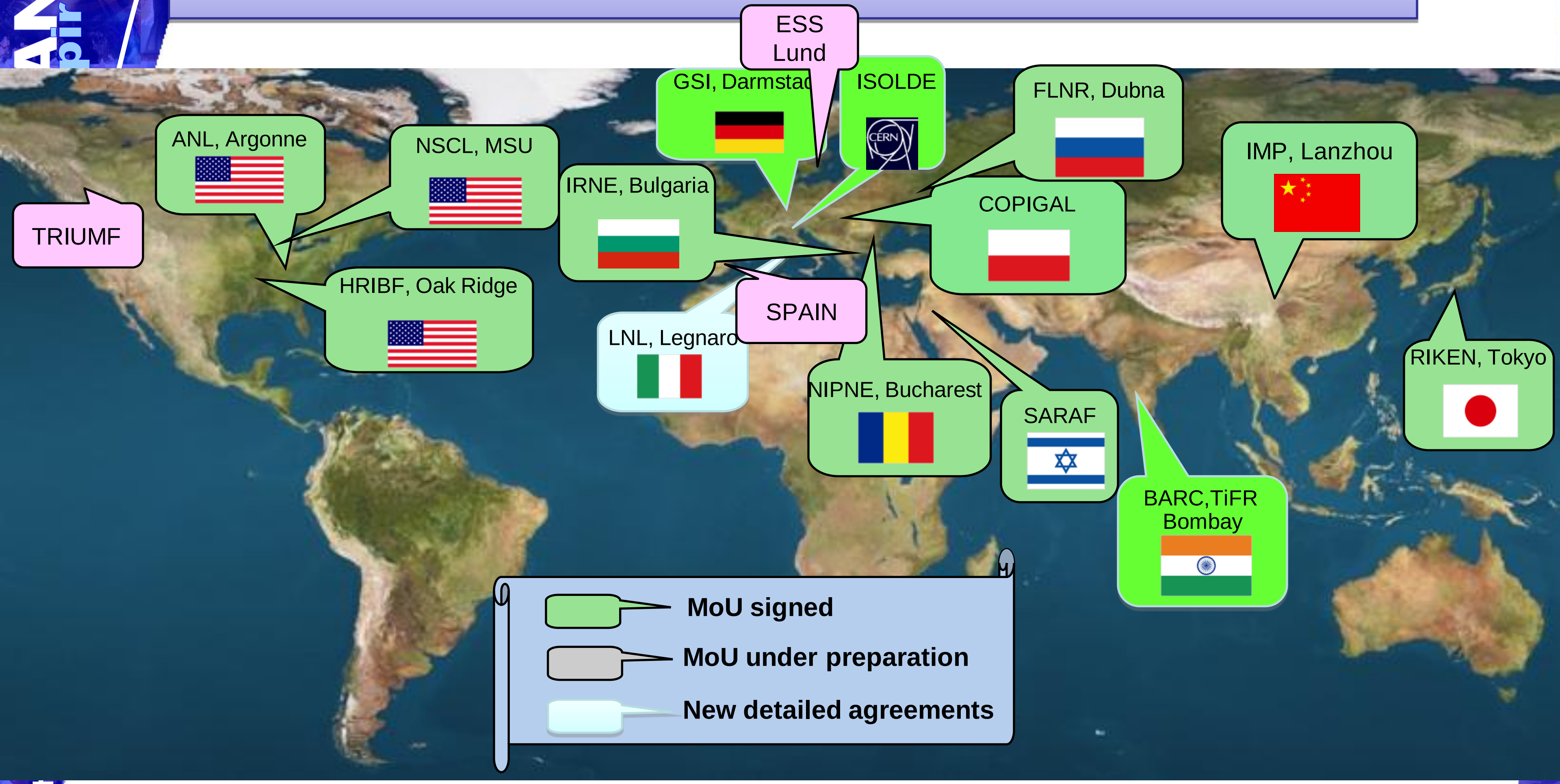
- CEN de Bordeaux-Gradignan
- Centre de Spectro. Nucléaire et Spectro. de Masse Orsay
- **Institut de Physique Nucléaire Orsay**
- Institut de Physique Nucléaire Lyon
- Institut Pluridisciplinaire Hubert Curien Strasbourg
- Laboratoire Accélérateur Linéaire Orsay
- Laboratoire de Physique Corpusculaire de Caen
- Laboratoire de Physique Nucléaire et de Htes Energies Paris
- Laboratoire de Physique Subatomatomique et de Cosmologie Grenoble

CEA

DSM	**Irfu/SPhN**	
		Irfu/SACM
DSM		Irfu/SIS
DSM		Irfu/SENAC
DSM		Irfu/SEDI
DSM – Saclay		Expertise
DAM	DPTA	DASE et DP2I
DEN		Expertise
DPSN		Expertise

GANIL Spiral2 laboratoire commun CEA/DSM CNRS/IN2P3

International Collaborations



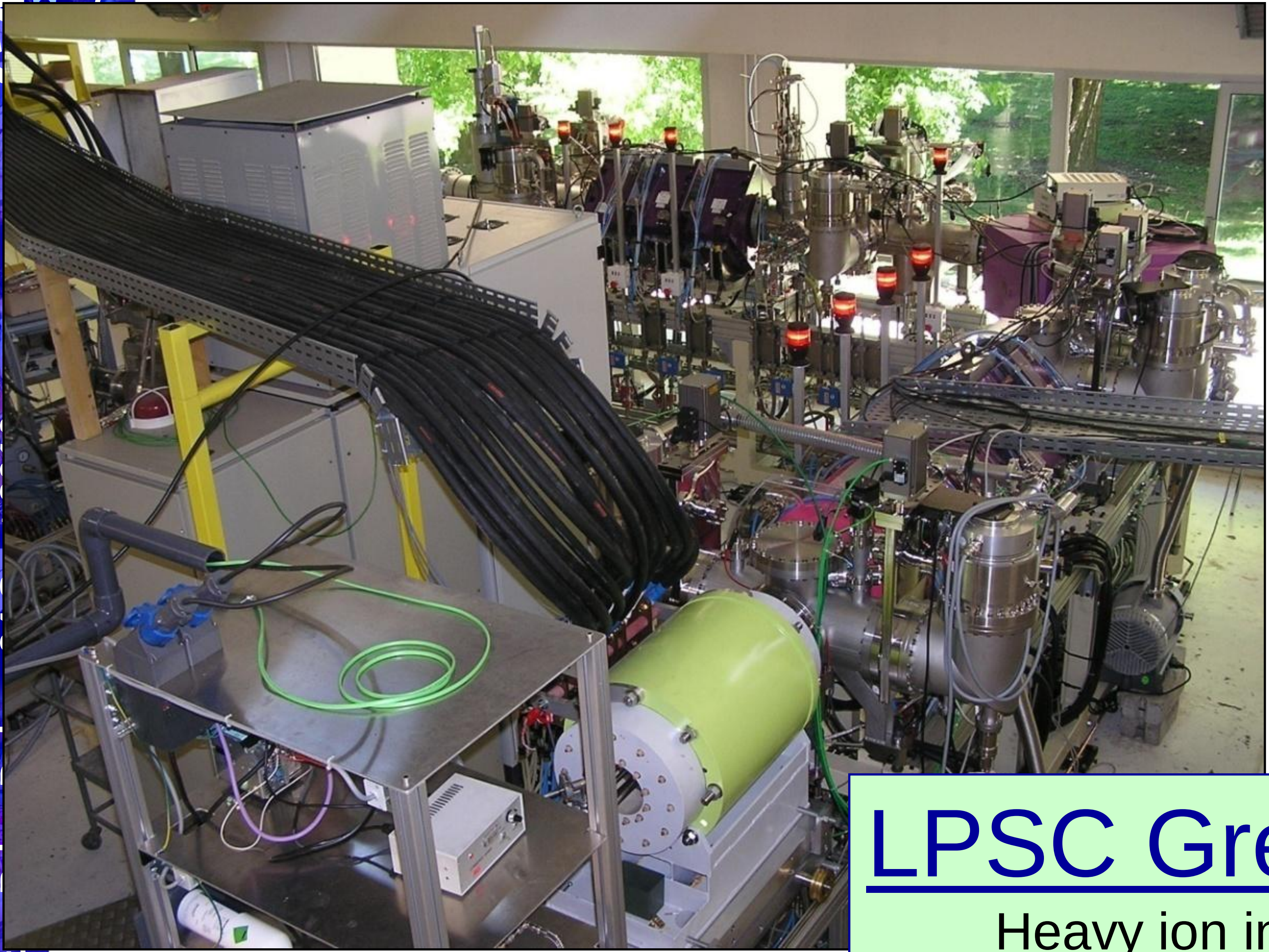
EU FP7 3,9 M€ Preparatory Phase Contract

15 signed (LEA*, LIA**, MoU***) agreements
3 agreements under preparation

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

Sydney Gales

Accelerator



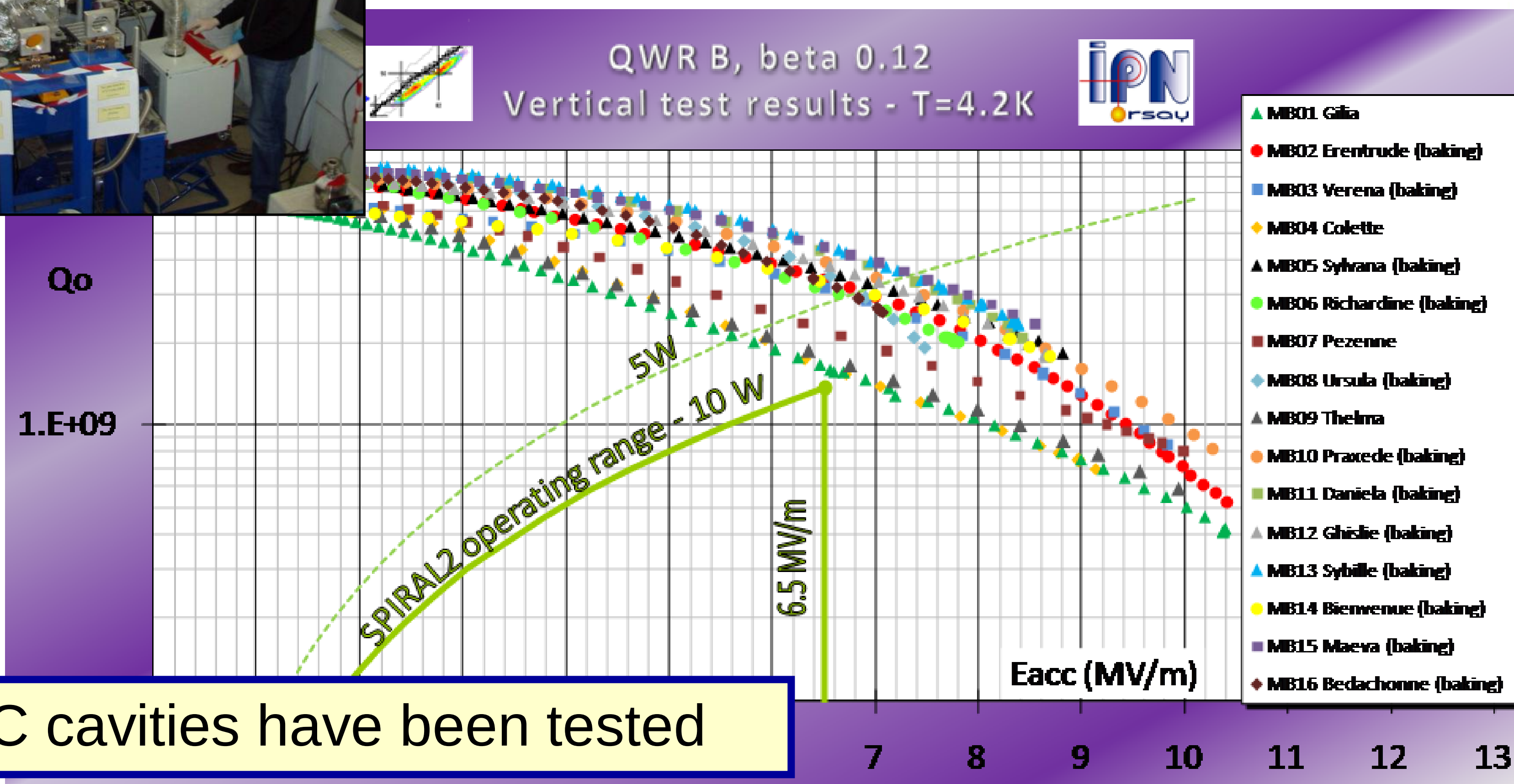
LPSC Grenoble

Heavy ion injector
June 2010

Accelerator

IPN Orsay

SC B



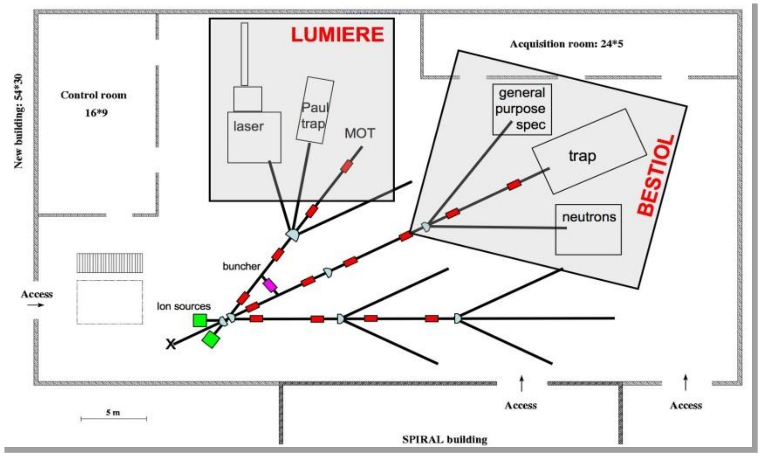
All SC cavities have been tested

GANIL Spiral 2

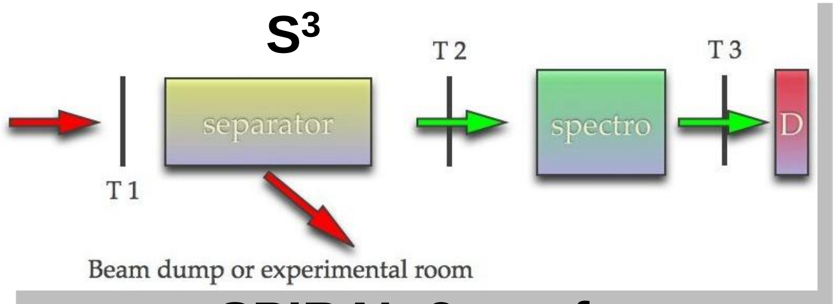
New detectors for SPIRAL 2

Letters of Intent: 600 physicists from 34 countries

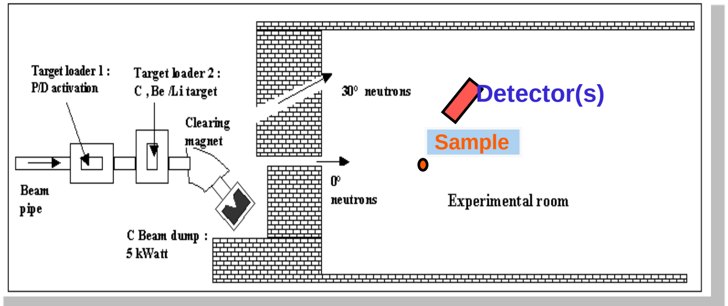
DESIR



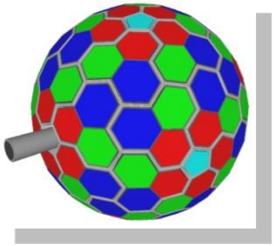
S^3



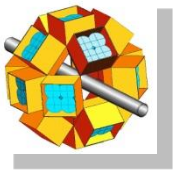
SPIRAL 2 n-tof



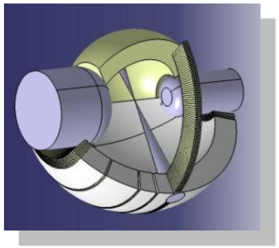
AGATA



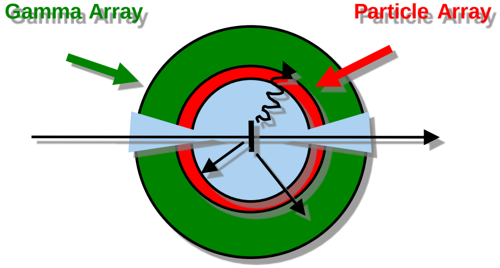
EXOGAM 2



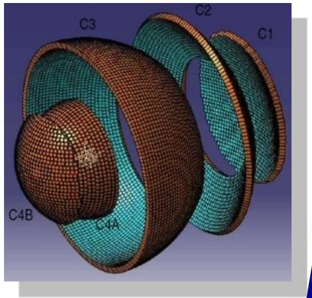
PARIS



GASPARD



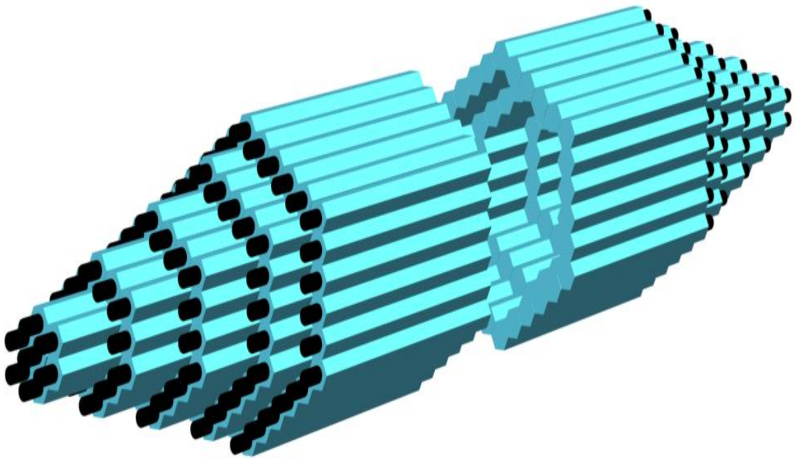
FAZIA



Flerov Price Dubna,24 Sept 2010

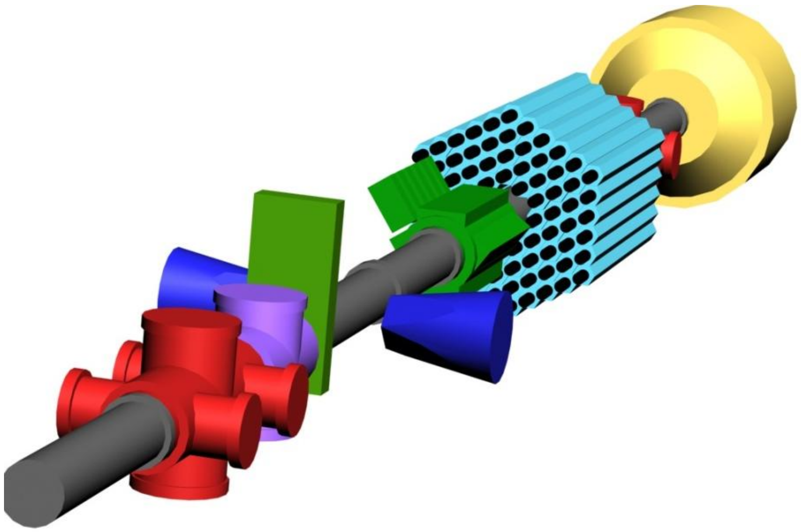
Sydney Gales

3He – neutron counter for DESIR



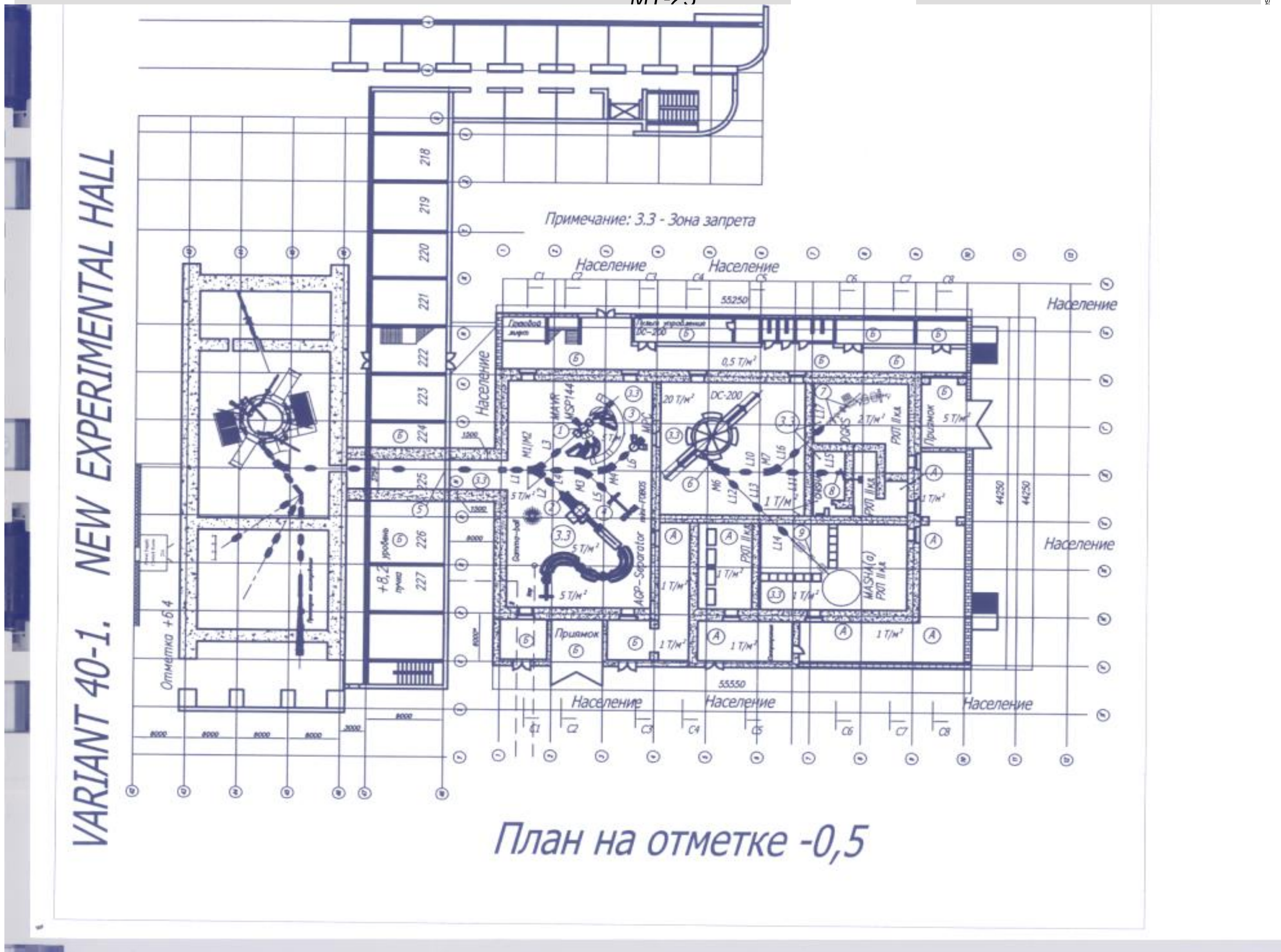
LNR- GANIL -cooperation

Total number of counters – 342
Counters: diameter-3 cm, length- 25 cm, helium pressure- 7 atm.
Moderator – polyethylene, the spacing between parallel planes of moderate module is 5 cm.
Efficiency – 30-60% (for different geometry)
Life time- 15-30 μs (for different geometry)



Concept of the RIB Accelerator Complex of the FLNR (JINR)

MT-25



ssian FLNR (JINR) Aug.199

EXON 2009 SOCHI

International Symposium on Exotic Nuclei

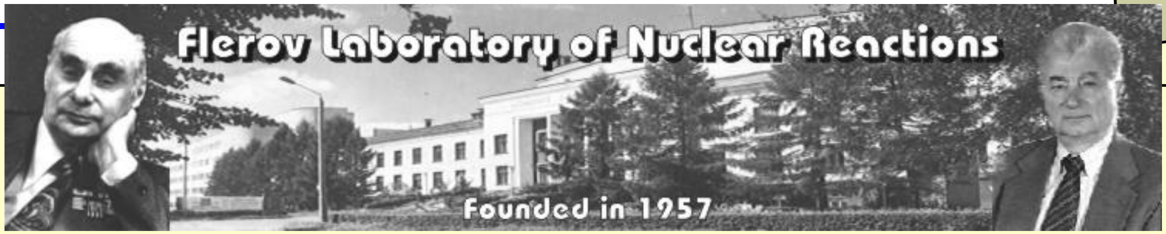
Sochi, Russia

28 September - 2 October 2009

The world leading laboratories meet and discuss the future

EXON 2009 SOCHI — EXON 2006 Khanty-Mansiysk — EXON 2004 PETERHOF — EXON 2001 BAIKAL

HIC for FAIR Helmholtz International Center — GANIL Spiral2 — RIKEN NISHINA CENTER — FLNR DRIBs



Thanks to all colleagues from Dubna and France involved in this great adventure and specially to our friends from the FLNR who supported it and participated in it from the beginning:

Yuri Oganessian

Yuri Penionzhkevich

… next 50 years of the common research have just begun.

- END

High -lying single-particule modes and Quasiparticle-Phonons Nuclear Model

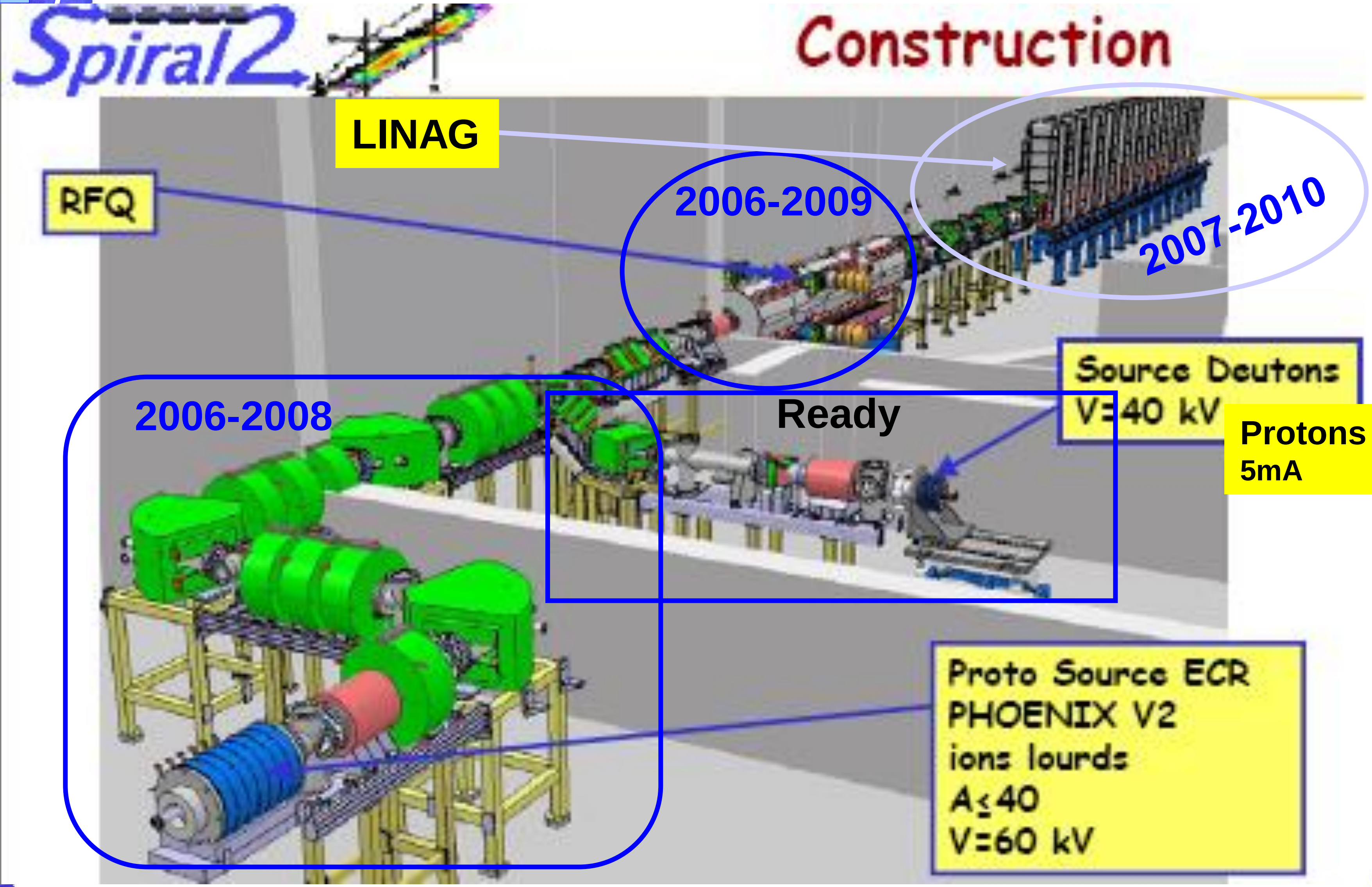
- **Damping mechanisms**
- **Deep-hole and Single-particle excitation in the continuum**

Very sucessfull series of International Nuclear Structure Conferences

- ***VG Soloviev, V.Voronov,Ch Stoyanov, A.I.Vdovin,Ponomarev, N Van Giai***
- ***H.Langevin-Joliot, S.Gales, +.....many others***

1980-2000 Collaborations with the laboratory of Theoretical Physics(Bogolioubov La

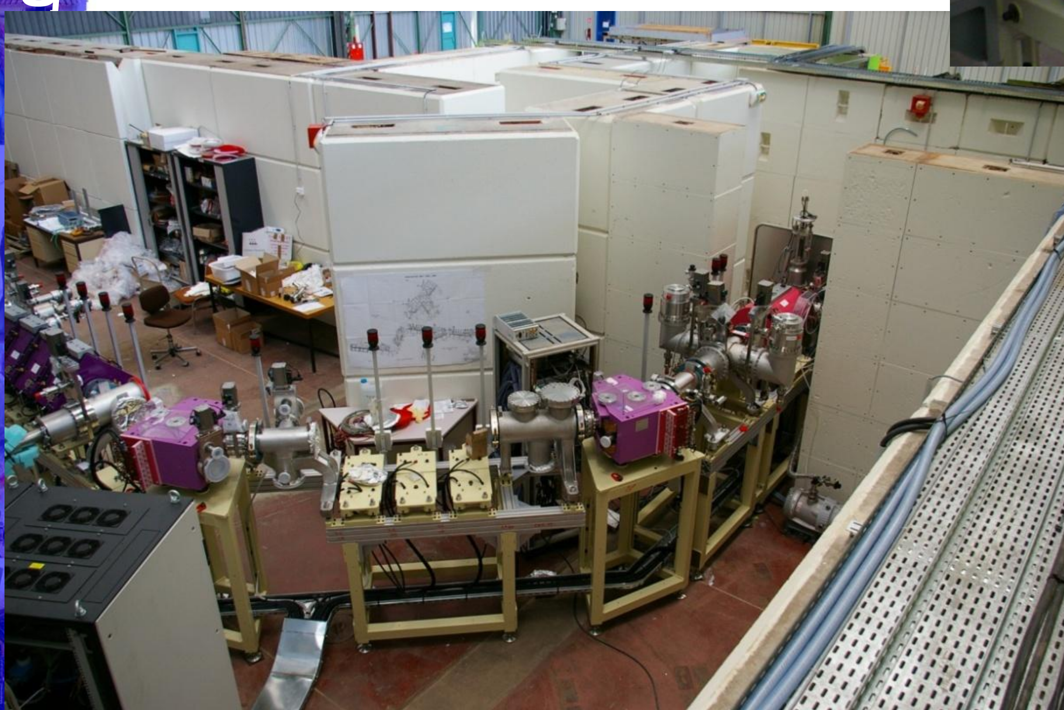
SPIRAL2 :Construction

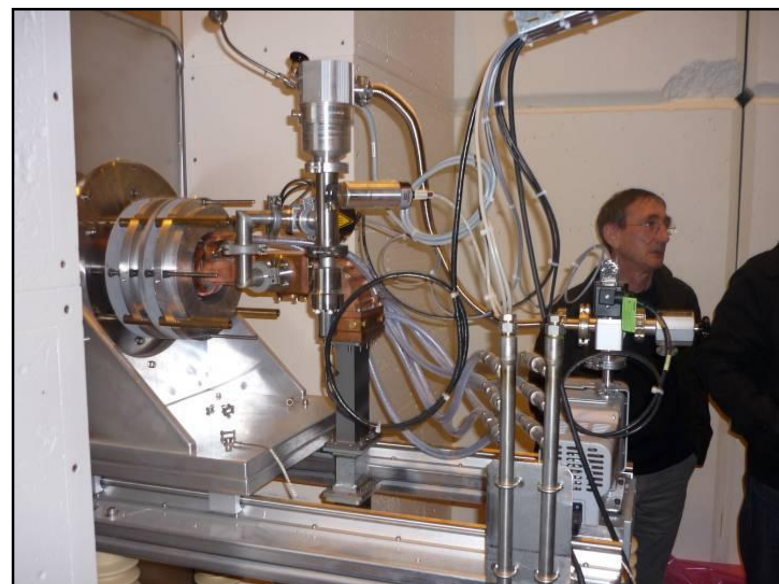


Accélérateur

Irfu Saclay

P,D injector

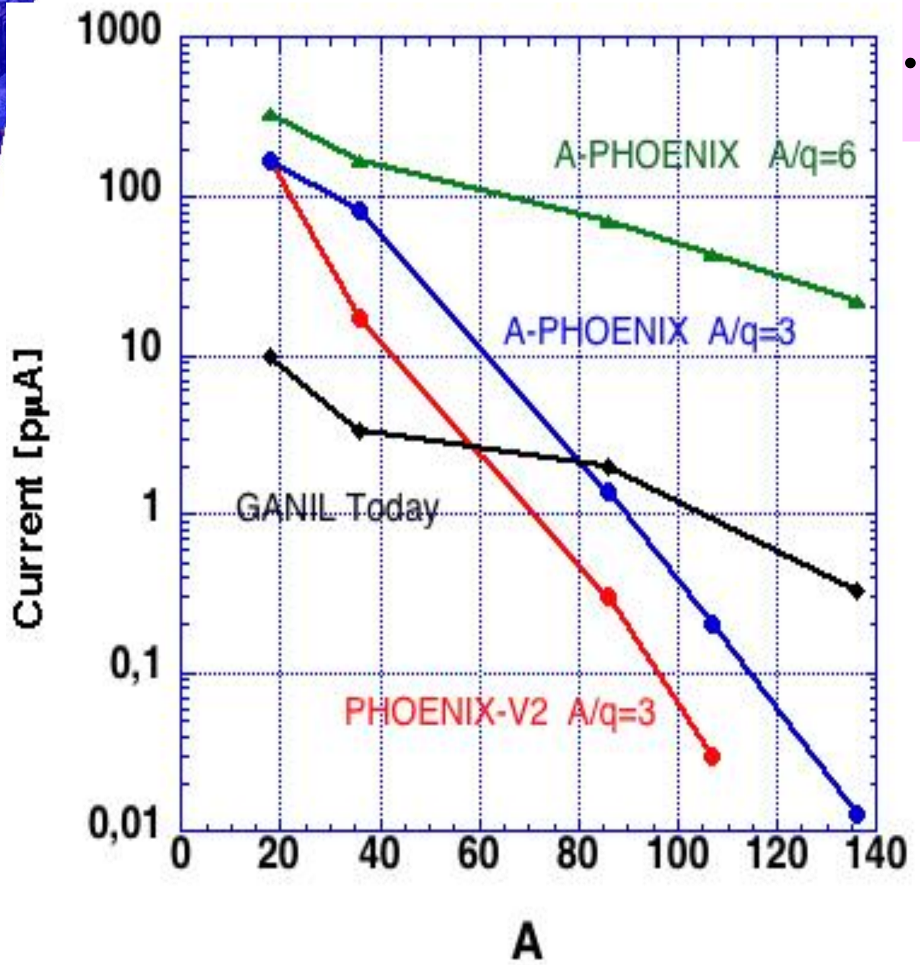




LINAG Heavy-Ion Beam Intensities

- PHOENIX V2 - tested ECR source
- A-PHOENIX - new ECR source (first tests at Grenoble in 2007)
- A/q=6 requires new injector (extension not funded today)- Argonne Coll

Gases



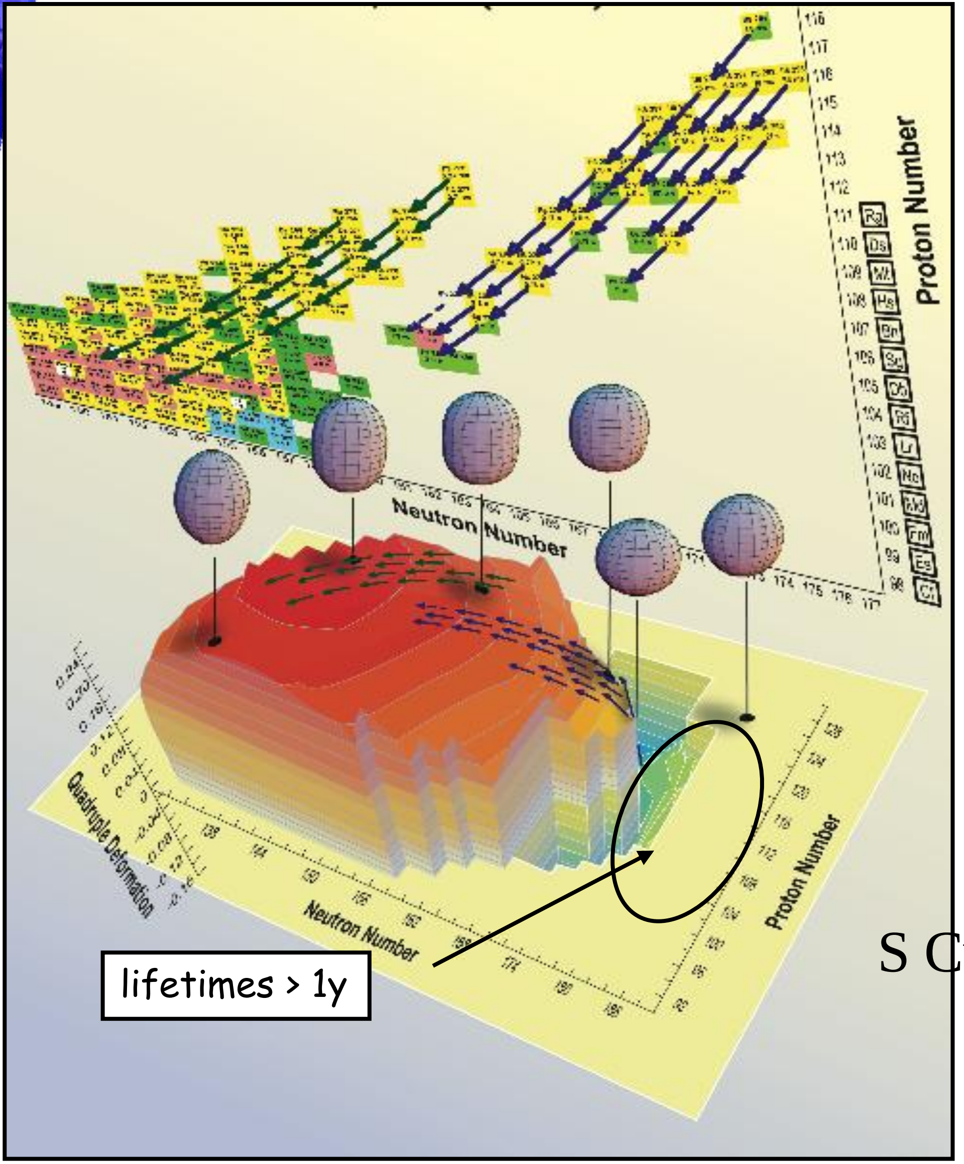
0.75 AMeV < E < 14.5 AMeV

Development of metallic beams

Choice of the best HI source in the coming two years

A-PHOENIX

What are the limits of the heaviest elements?



SCIENCE Magazine- July 2005 Top 125 Questions: Are there stable high-atomic-number elements?

S Cwiok, PH Heenen, W Nazarewicz
Nature, 433, 705 (2005)

Day 1 experiments with S3

Proton Dripline & N=Z nuclei

LoI_Day1_6, LoI_Day1_8, LoI_Day1_9 LoI_Day1_11

- Tests of Shell Model
- Single-Particle structure
- Development of Collectivity
- Shape coexistence

LoI_Day1_3 & LoI_Day1_4

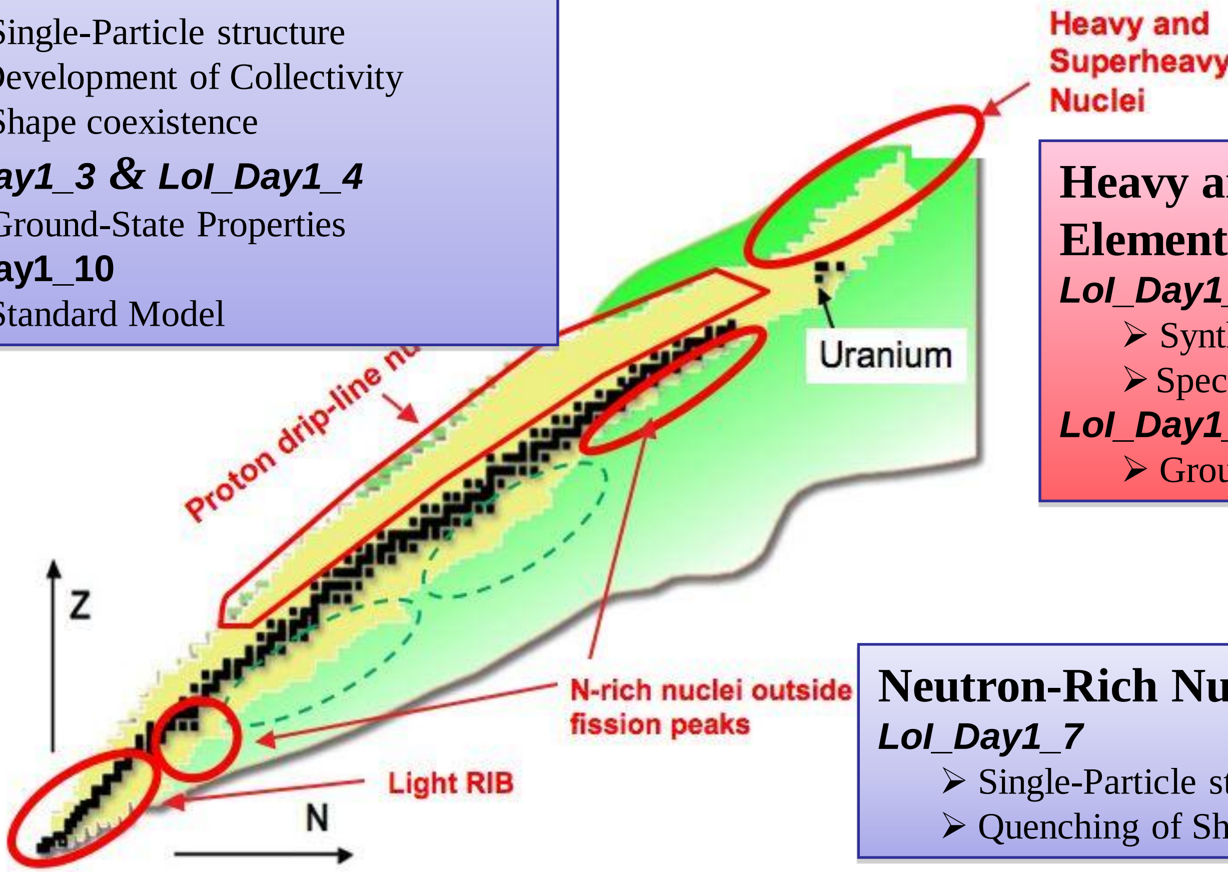
- Ground-State Properties

LoI_Day1_10

- Standard Model

FISIC project

LoI_Day1_1



Heavy and Superheavy Elements

LoI_Day1_2

- Synthesis
- Spectroscopy and Structure

LoI_Day1_5

- Ground-State Properties

Neutron-Rich Nuclei

LoI_Day1_7

- Single-Particle structure
- Quenching of Shell Gaps

Super Separator Spectrometer (S3)

Collaboration

104 physicists, 30 institutions, 12 countries

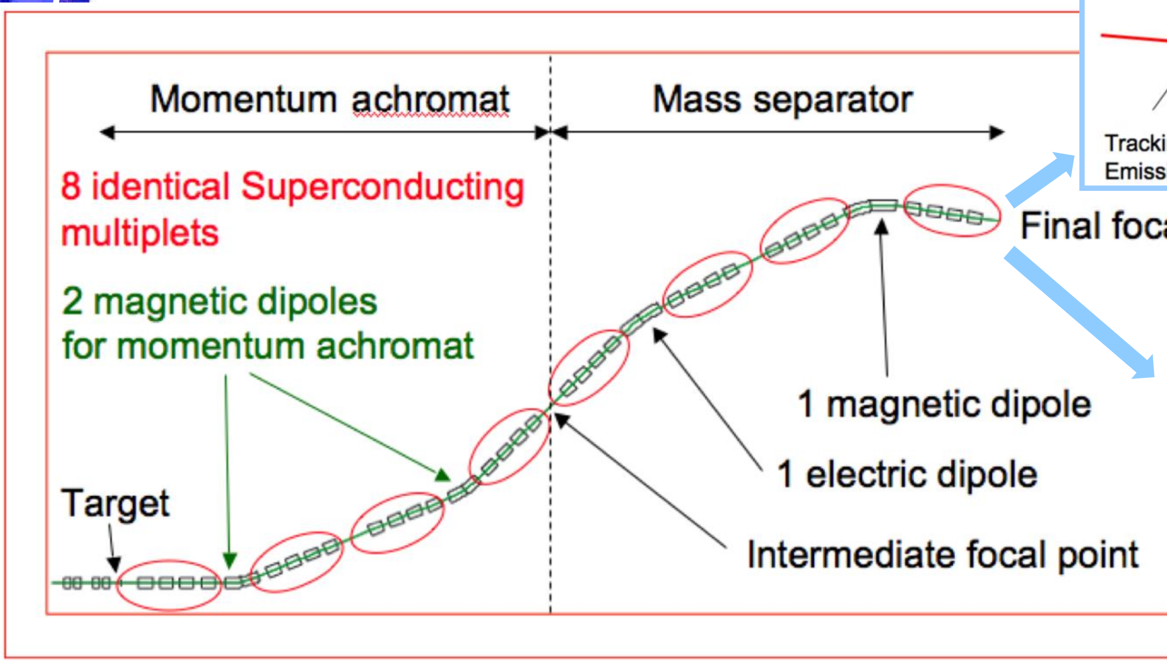
Spokespersons:

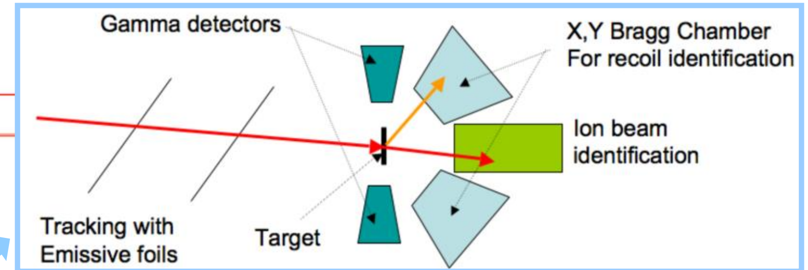
Hervé SAVAJOLS – GANIL, France

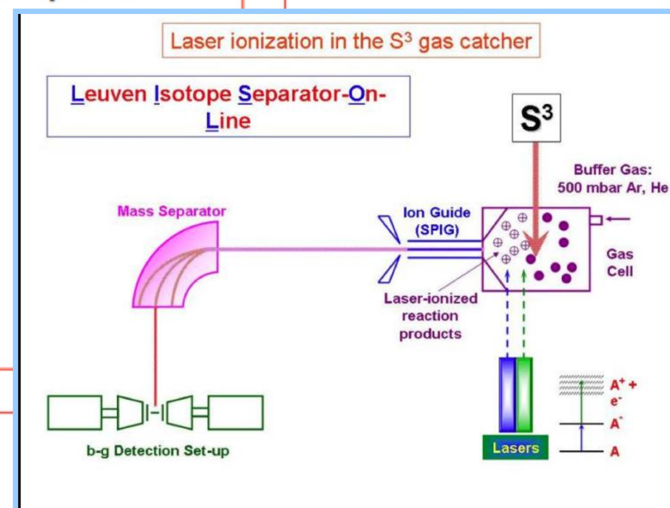
Antoine DROUART – Irfu/SPhN (CEA), France

Jerry A. NOLEN – Argonne National Laboratory, USA

Schematic layout







Full cost including 10% overheads: 10M€

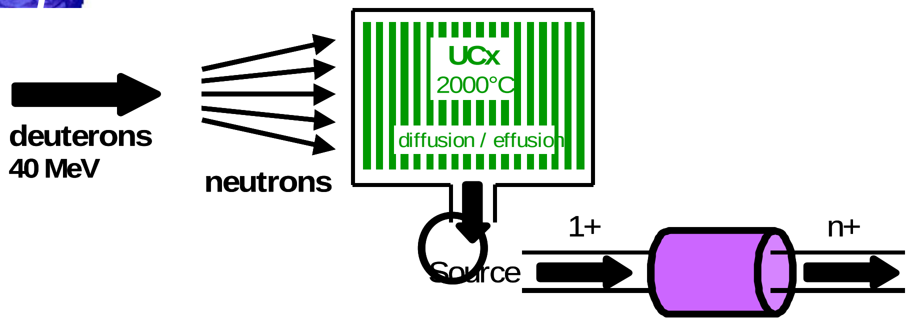
Infrastructures Phase 2

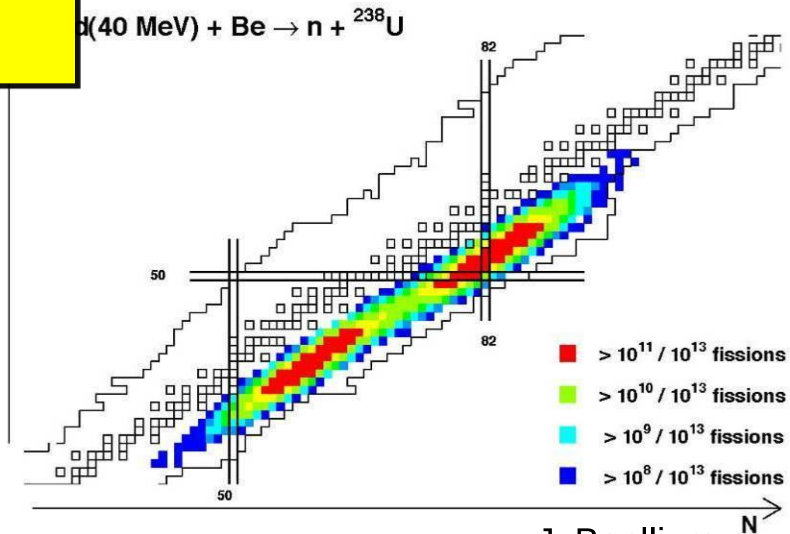
Production Building and Hall DESIR

July 2010 choice of the tender

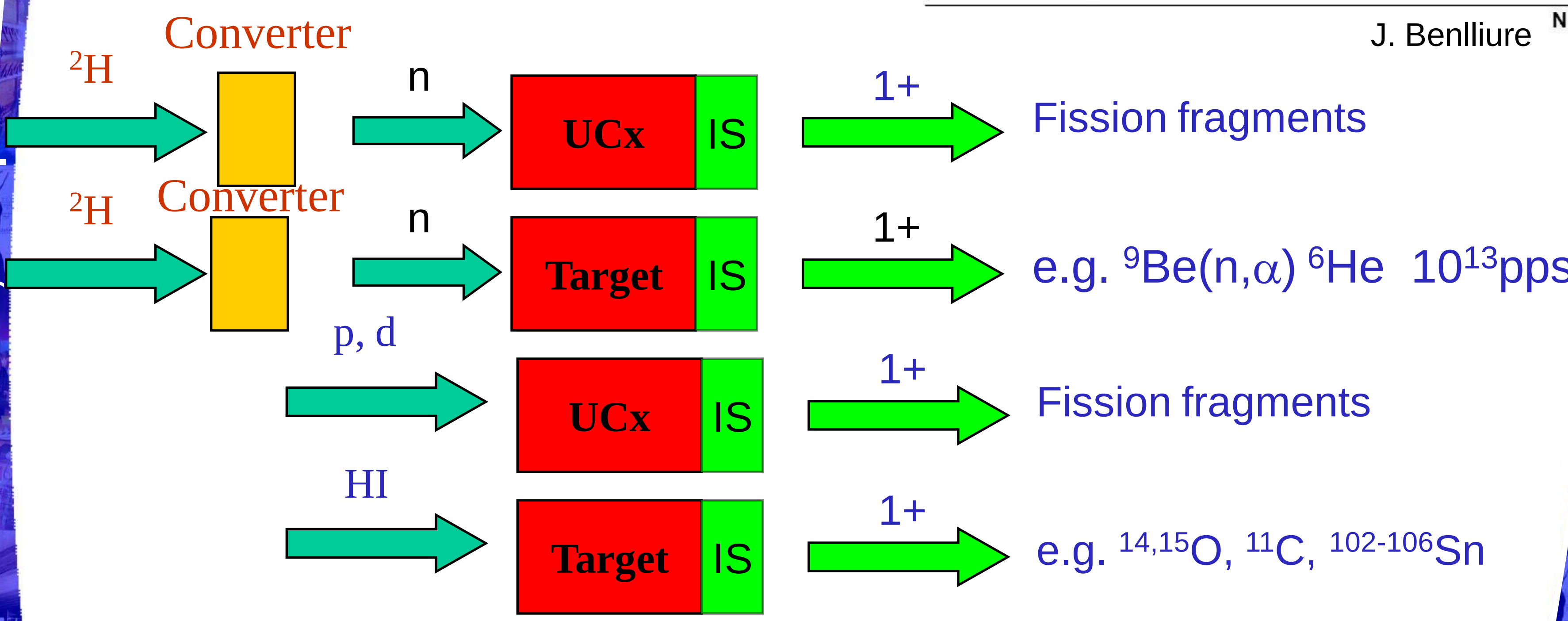
ISOL Rare Isotope Beams at SPIRAL 2

SPIRAL 2 Challenge
Up to 10^{14} fissions/s

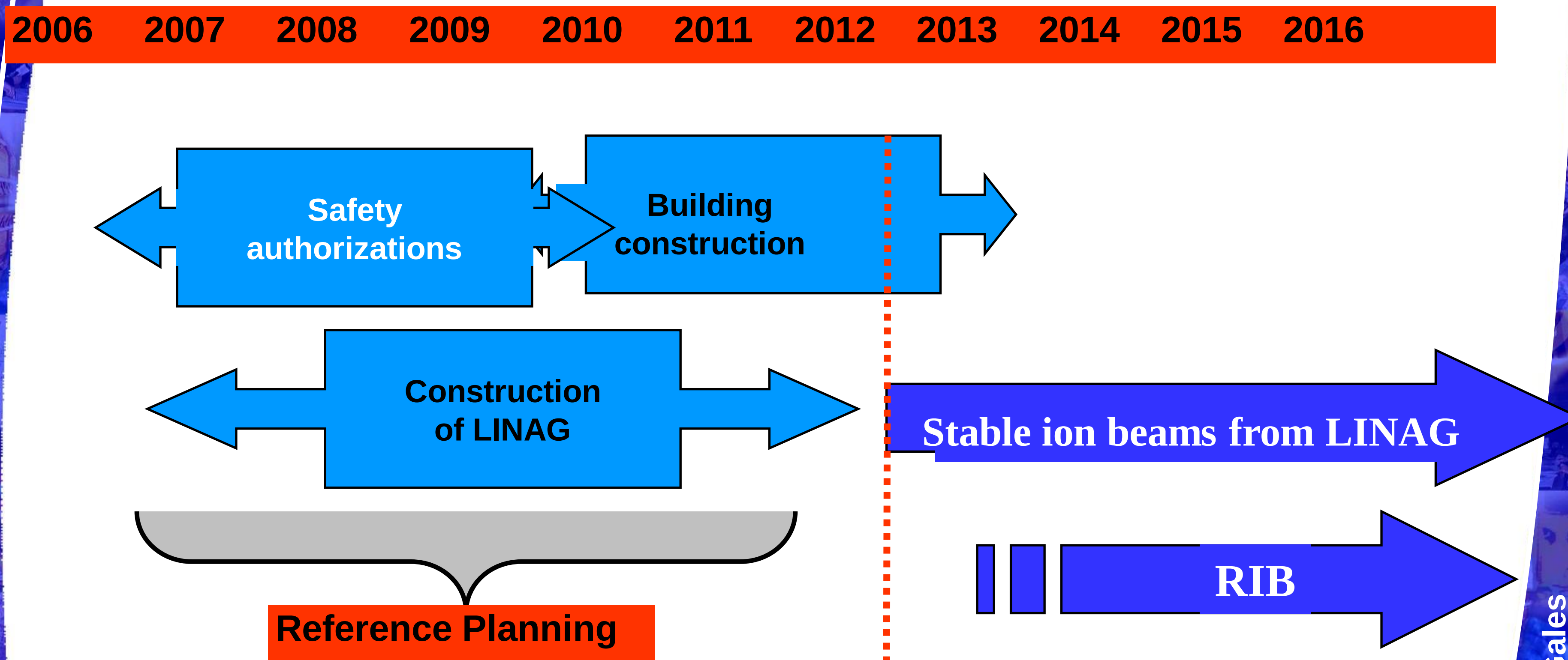




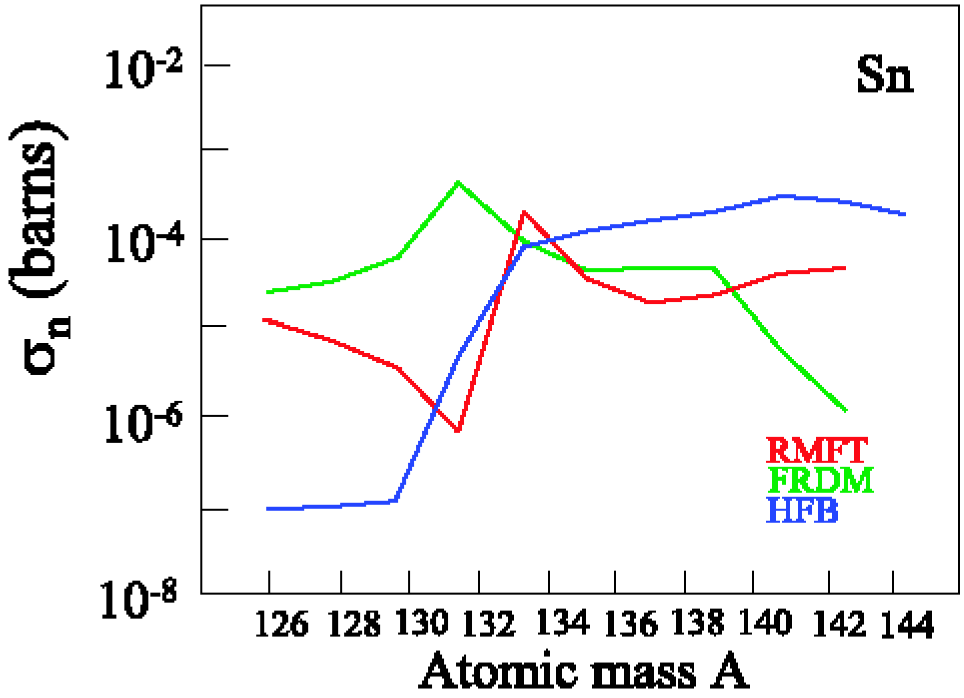
J. Benlliure



SPIRAL 2 Schedule



Neutron Capture for tin isotopes N=82 waiting point in r- process

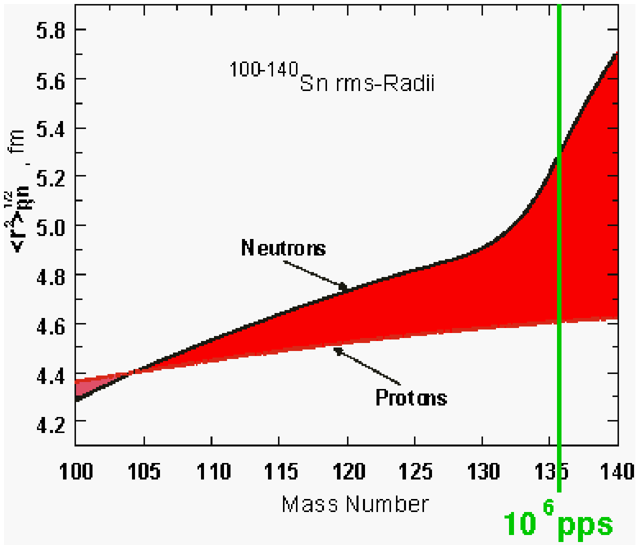


Calculated neutron direct capture cross-sections for the Sn Isotopic chain assuming differents models for masses and level scheme

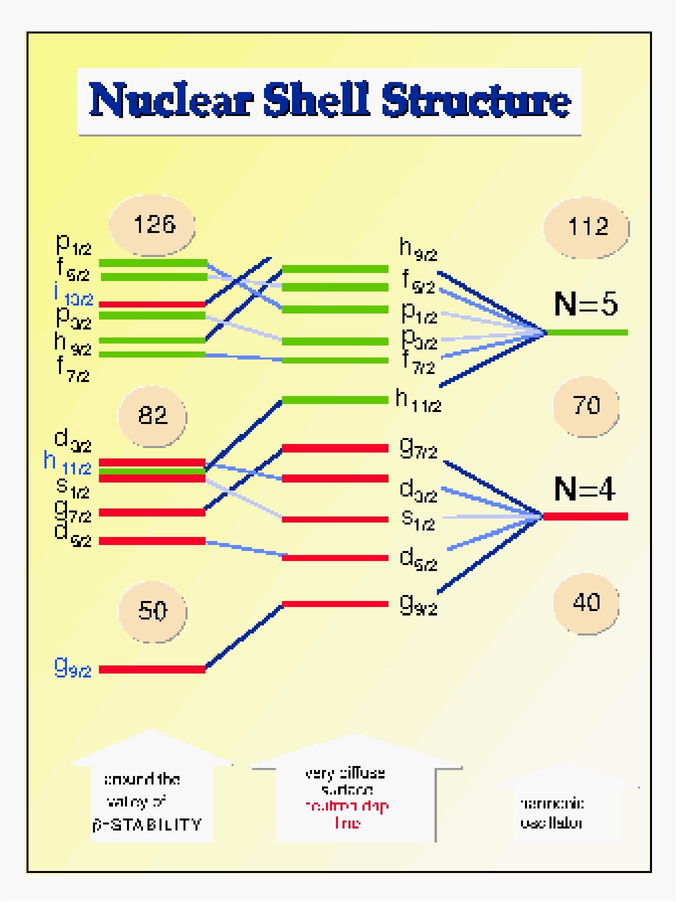
Towards a broadly applicable model of nuclei

Neutron skins (study of neutron matter)

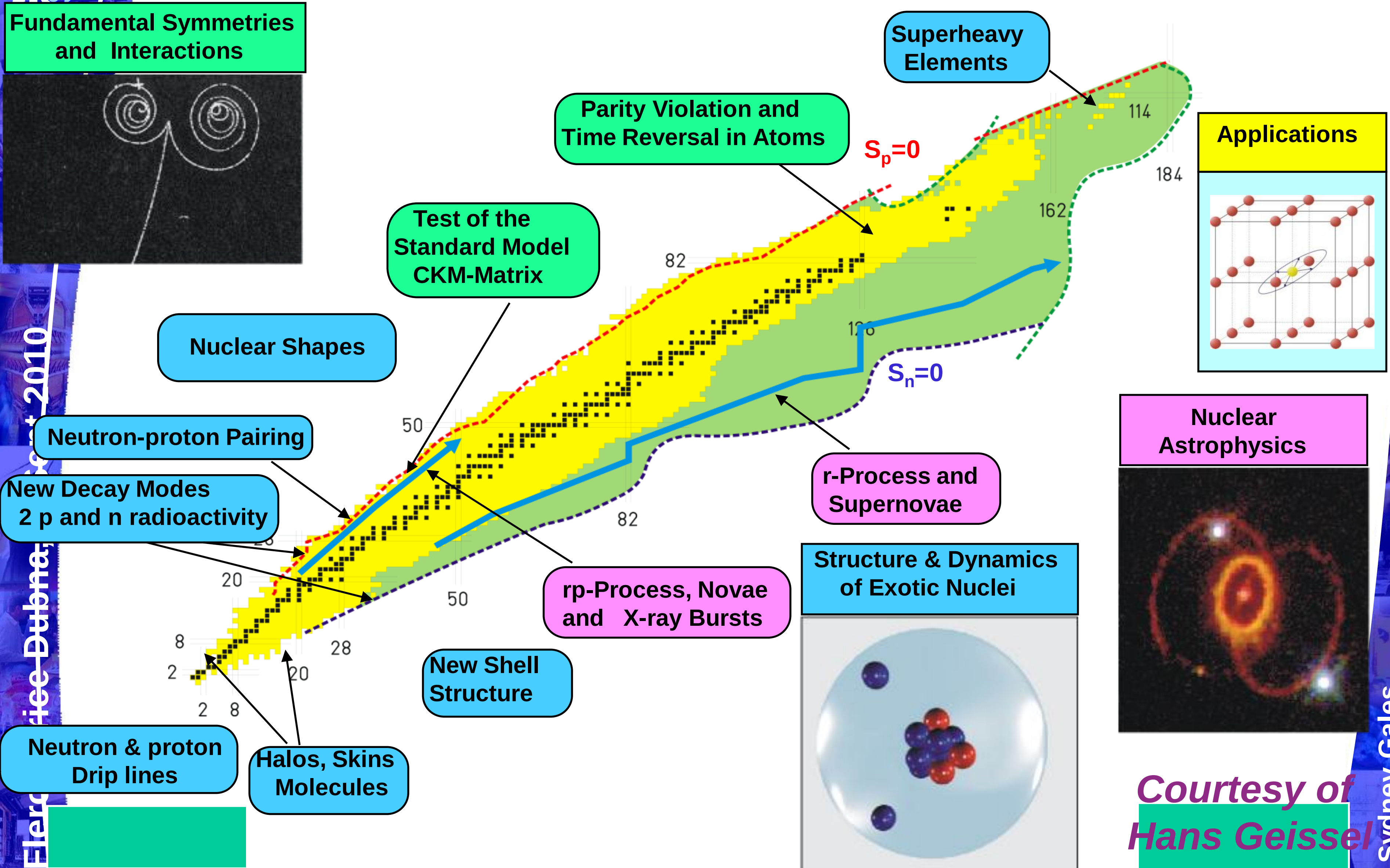
- **Shell Structure change far off stability**



Estimated difference in neutron and proton root-mean-square radii of the Sn isotopes (H.Lenske).



Physics with Exotic Nuclei



Courtesy of Hans Geissel

Sydney Gales