Атомните ядра:
основни градивни клетки на материята и гориво на звездите

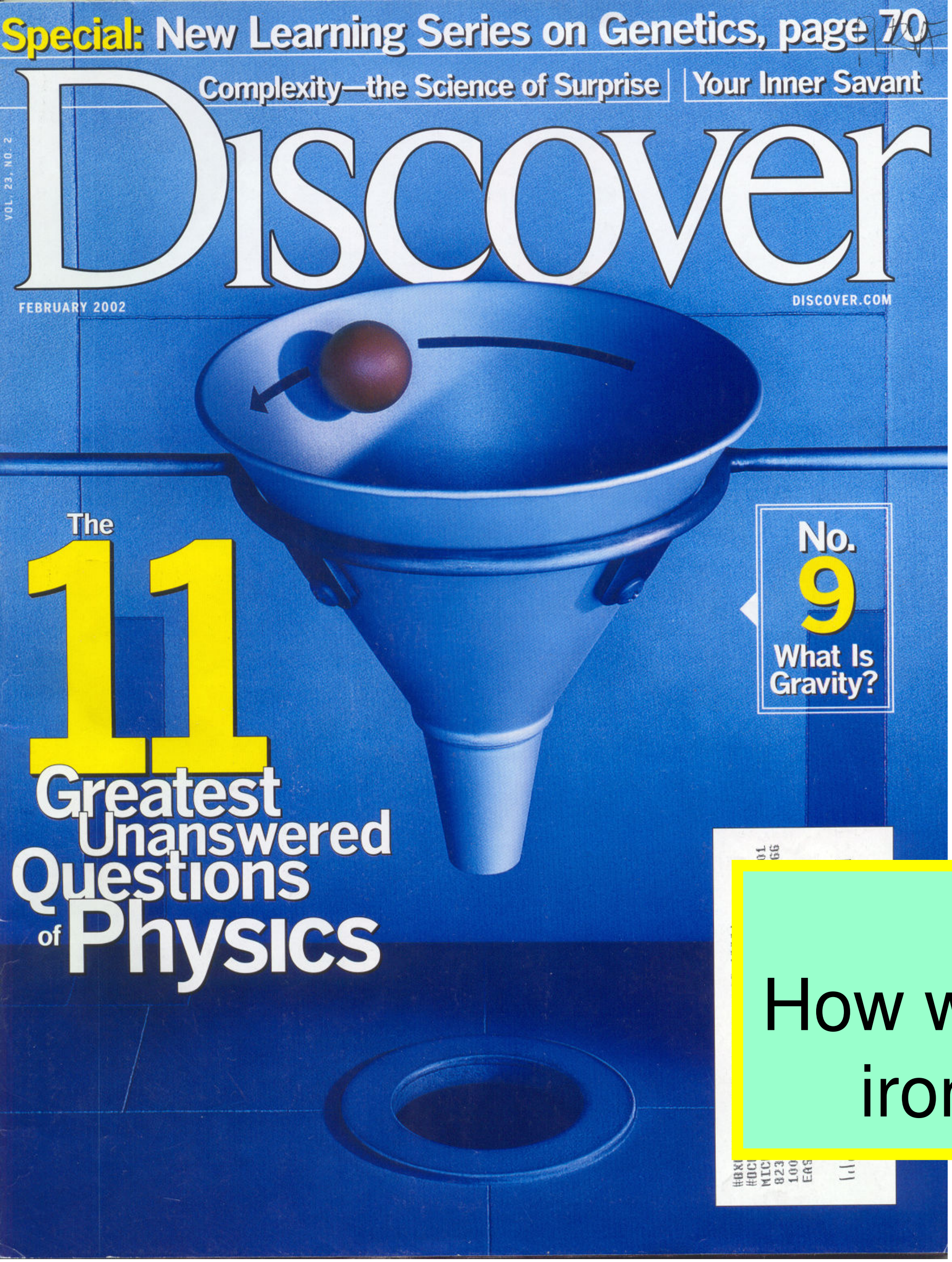
• **Основни задачи пред съвременната ядрената физика**

• **Експериментът ИЗОЛДЕ в ЦЕРН: история, резултати, бъдеще**

• **Българско участие на ИЗОЛДЕ: постижения и перспективи**

Основни задачи на съвременната ядрена физика

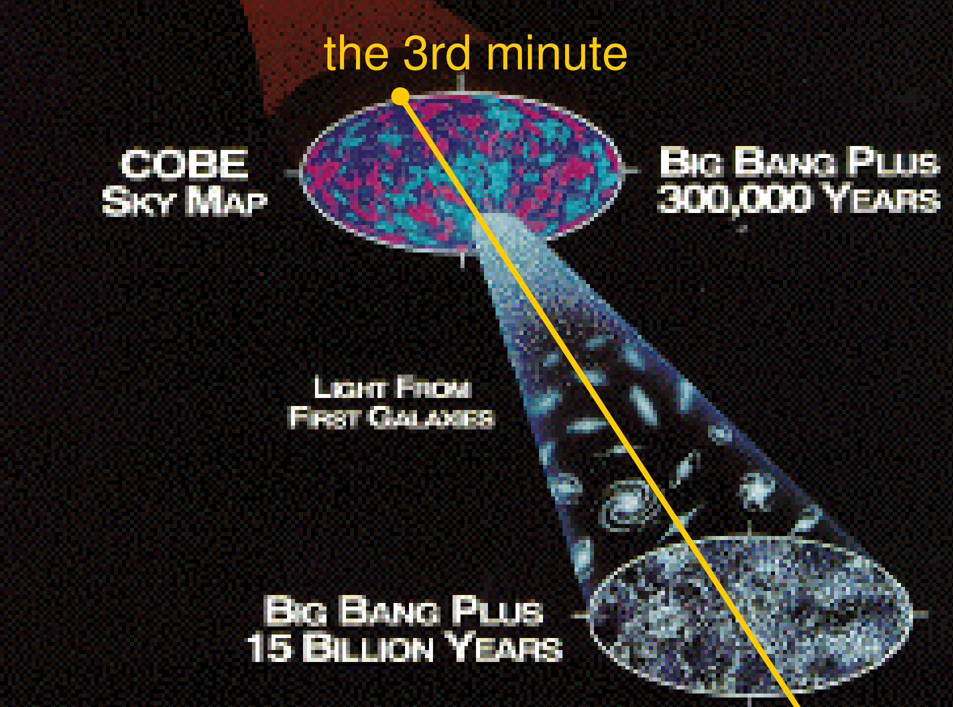
- What are the limits for existence of nuclei? Where are the proton and neutron drip lines situated? Where does Mendeleyev's table end?
- How does the nuclear force depend on varying proton-to-neutron ratios?
- How to explain collective phenomena from individual motion?
- How are complex nuclei built from their basic constituents?

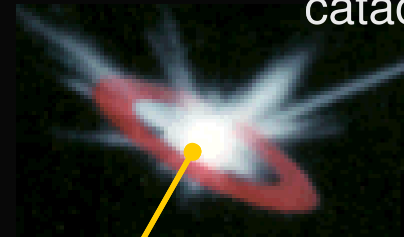


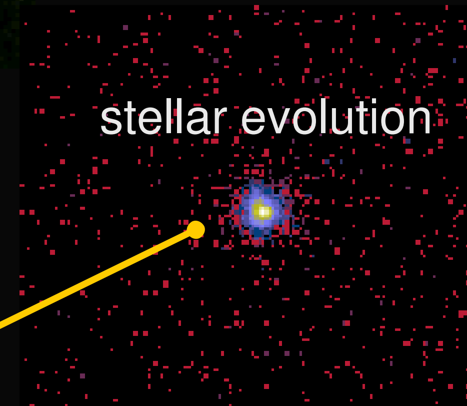
Доклад на Националната академия на науките на САЩ

Комисия по физика на Вселената (CPU)

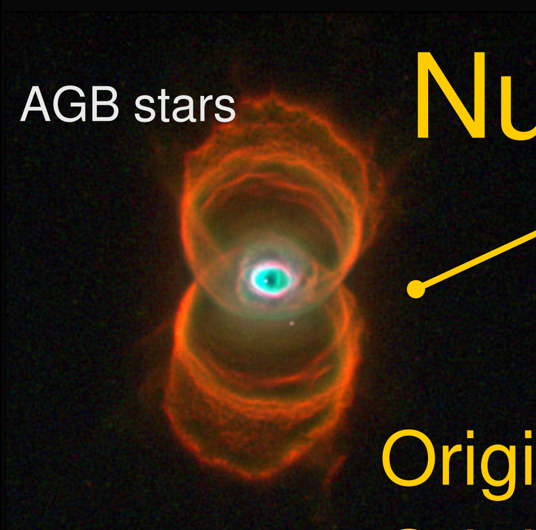
Question 3
How were the elements from iron to uranium made ?

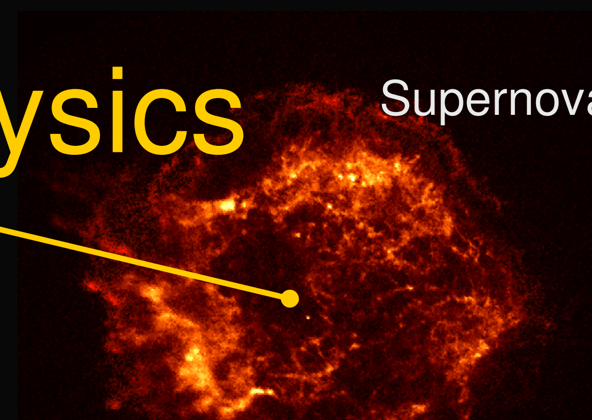






Nuclear Astrophysics





Origin and fate of the elements in our universe

Origin of radiation and energy in our universe

Physics under extreme conditions

Разпространение на елементите – Химичен състав на Вселената

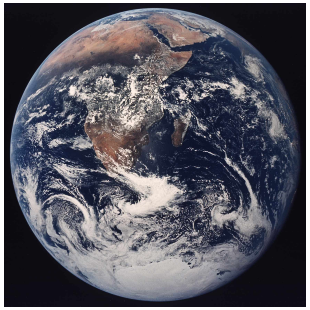
Преди да зададем въпроса за произхода на елементите е добре да знаем кои от тях и доколко са разпространени във Вселената…

От какво се състои Вселената? -Отговор: Не знам….

60% Тъмна енергия (Аз не знам какво е това!)
35% Студена тъмна материя (Аз не знам какво е това!)
5%   Ядра и електрони (видими като звезди ~0.5%)

Какво ни е грижа за 5% ???

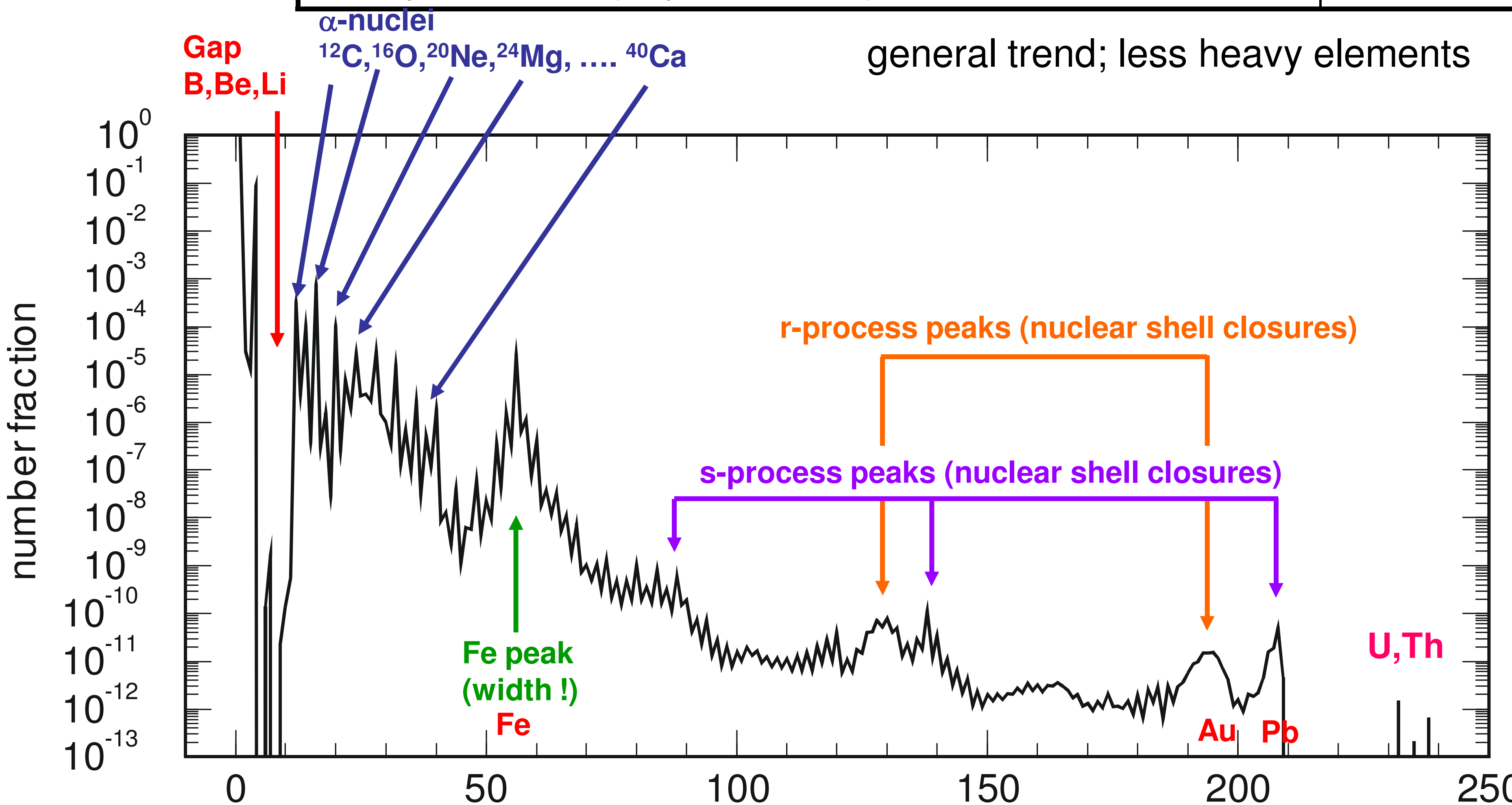
Някои важни обекти са свързани с тях !



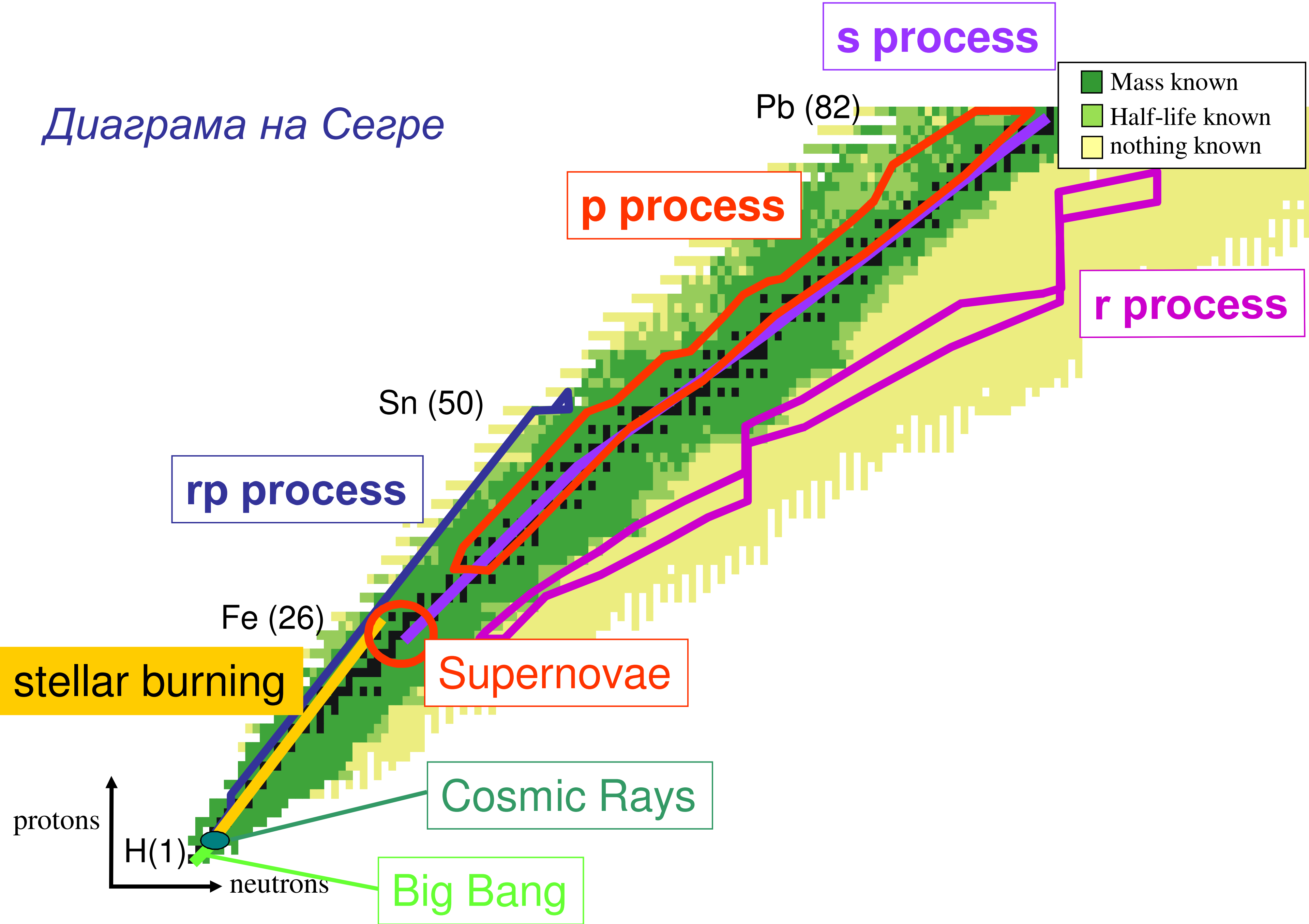
Въпроси, които очакват отговор:

- От кои елементи (изотопи) се състои Вселената ?
- Какво е разпространението на всеки елемент? На всеки изотоп?
- Как е синтезиран всеки елемент ? Всеки изотоп ?

Hydrogen mass fraction	X = 0.71
Helium mass fraction	Y = 0.28
Metallicity (mass fraction of everything else)	Z = 0.019
Heavy Elements (beyond Nickel) mass fraction	4E-6



Диаграма на Сегре



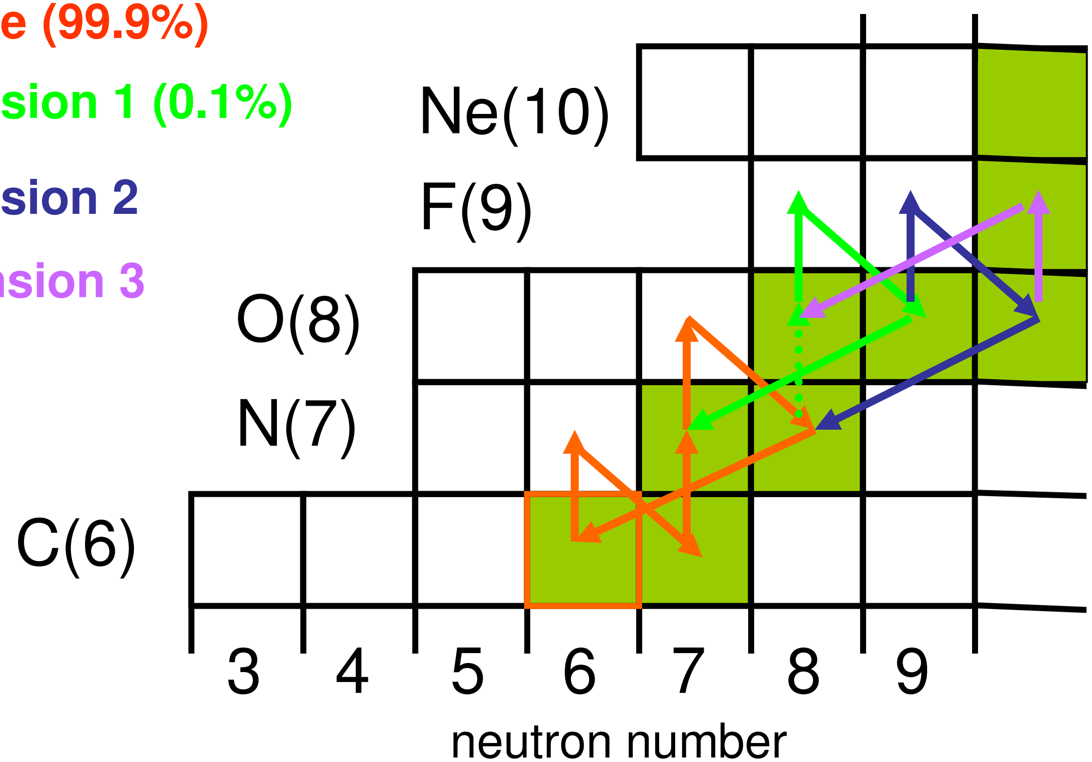
CNO cycle

CN cycle (99.9%)

O Extension 1 (0.1%)

O Extension 2

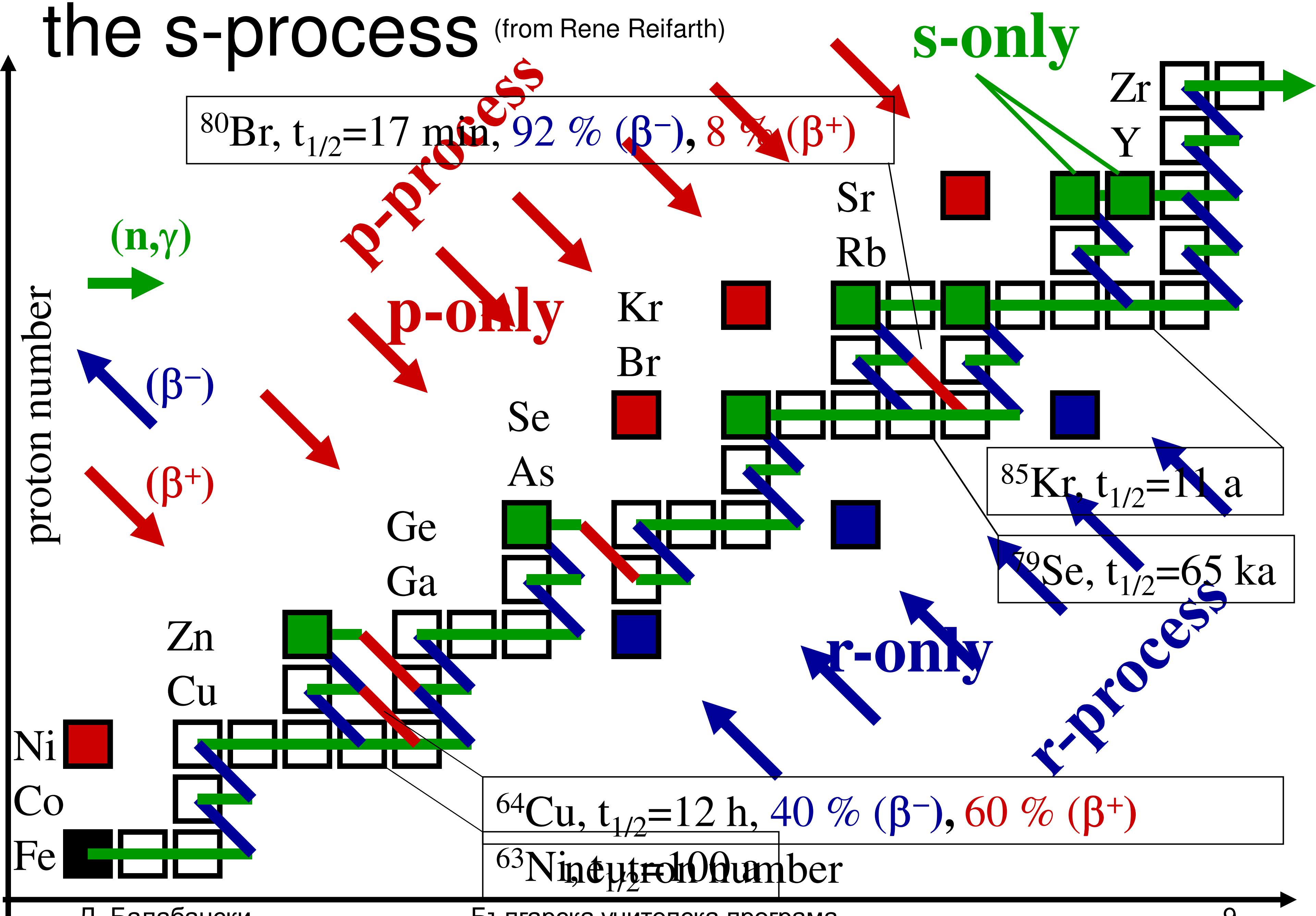
O Extension 3



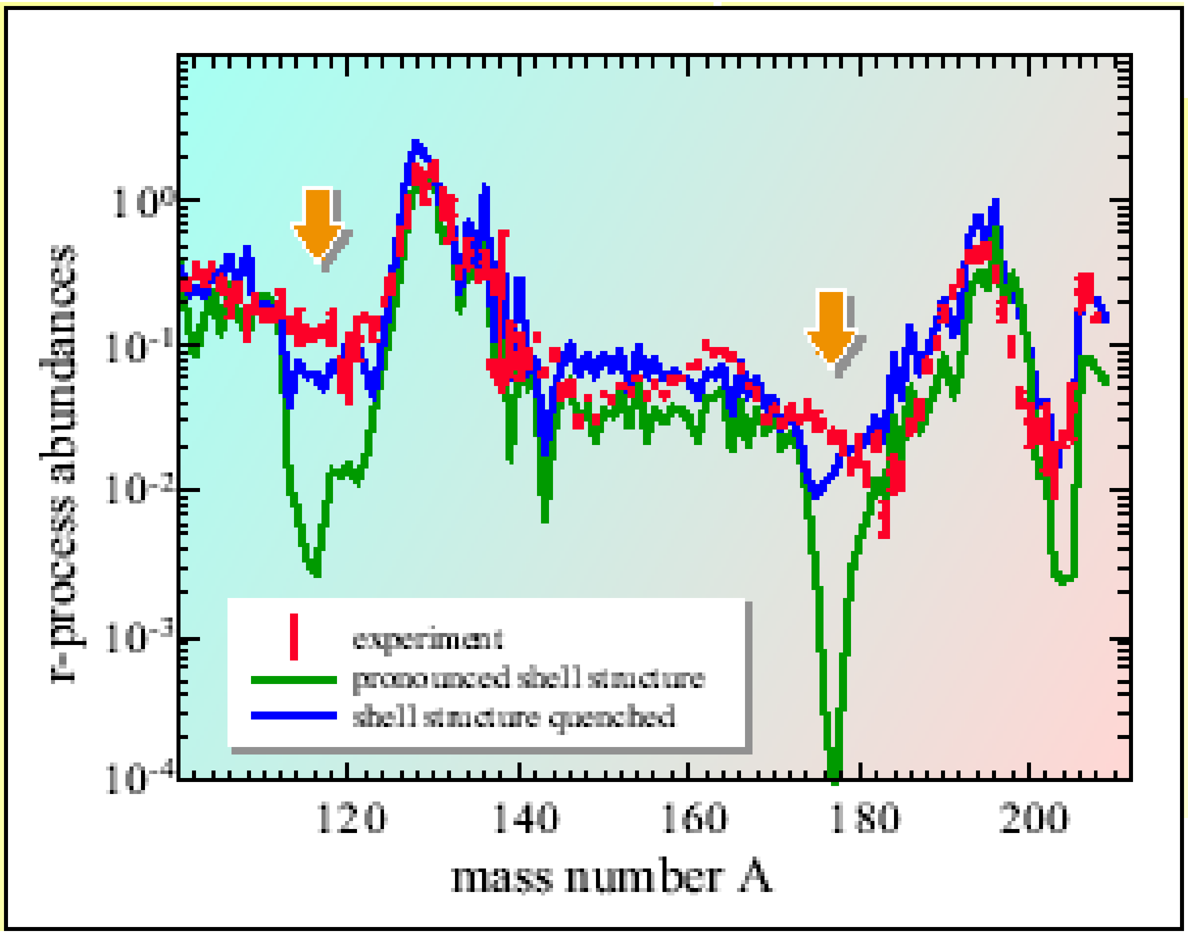
All initial abundances within a cycle serve as catalysts and accumulate at largest τ

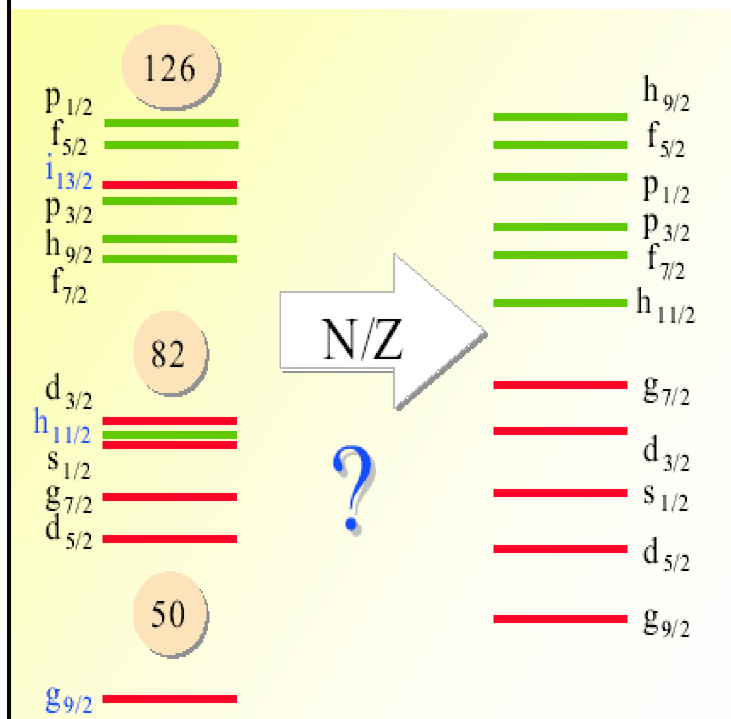
Extended cycles introduce outside material into CN cycle (Oxygen, …)

the s-process (from Rene Reifarth)



Ядрена астрофизика:
Дали наистина сме наясно с процеса на синтез на елементите ?





Кой са магическите числа далеч от стабилност ?

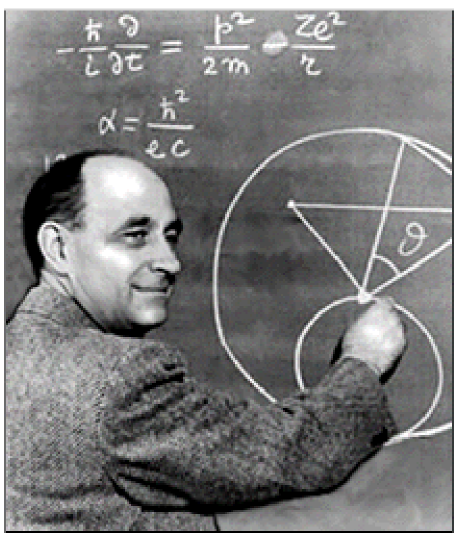
или

- Променя ли се спин-орбиталното взаимодействие?
- Оказват ли влияние и други членове от нуклон-нуклонния потенциал ?

Запълнени слоеве в ядрата

Maria Goeppert Mayer's 1948 theory explained why some nuclei were more stable than others and why some elements were rich in isotopes.

"On closed shells in nuclei" *Phys. Rev.* 74: 235 (1948).
"On closed shells in nuclei II" *Phys. Rev.* 75: 1969 (1949).
"Nuclear configurations in the spin-orbit coupling model.
I. Empirical evidence," *Phys. Rev.* 78: 16 (1950).
II. Theoretical considerations" *Phys. Rev.* 78: 22 (1950).



« Incidentally, is there any evidence of spin-orbit coupling in nuclei ? »

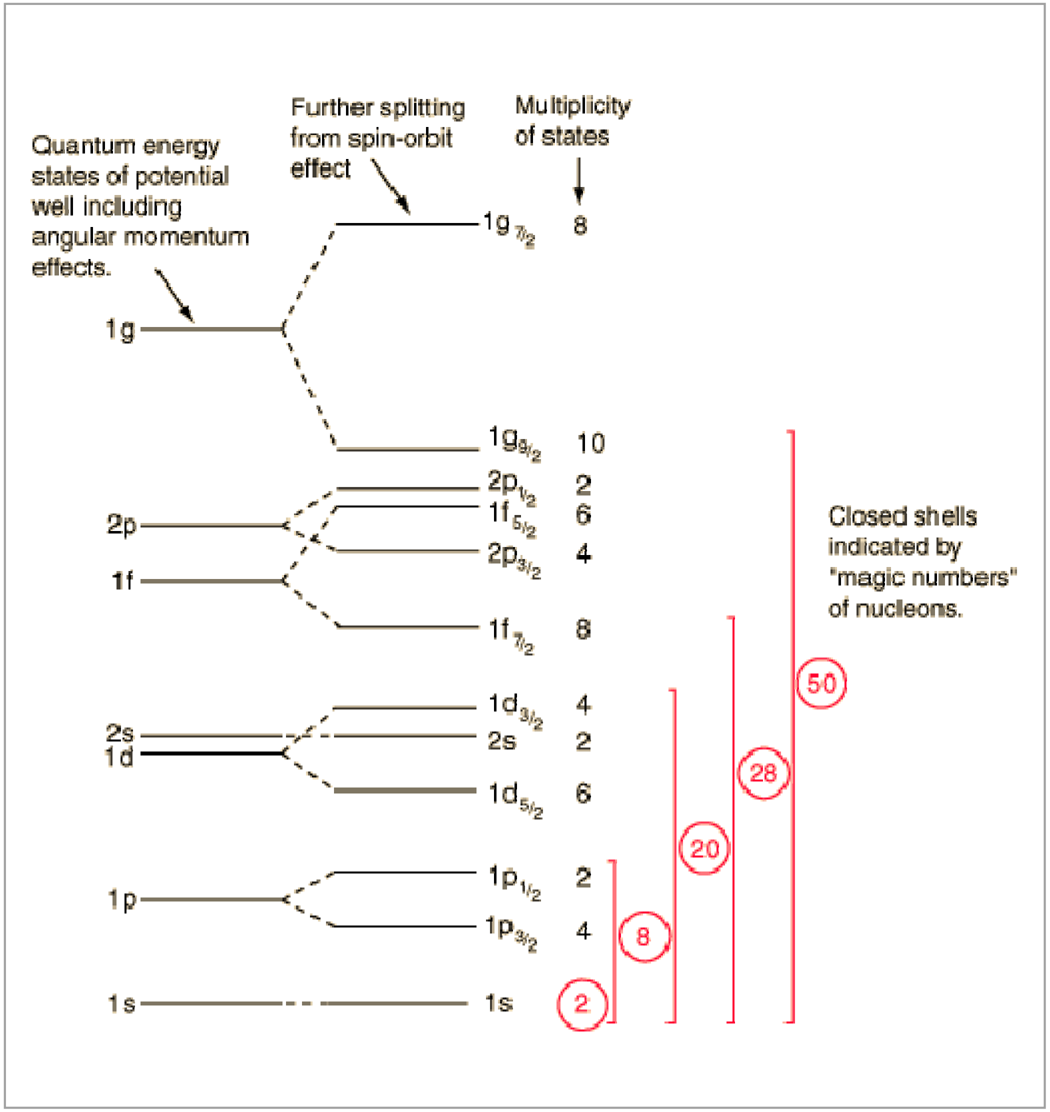
Enrico Fermi

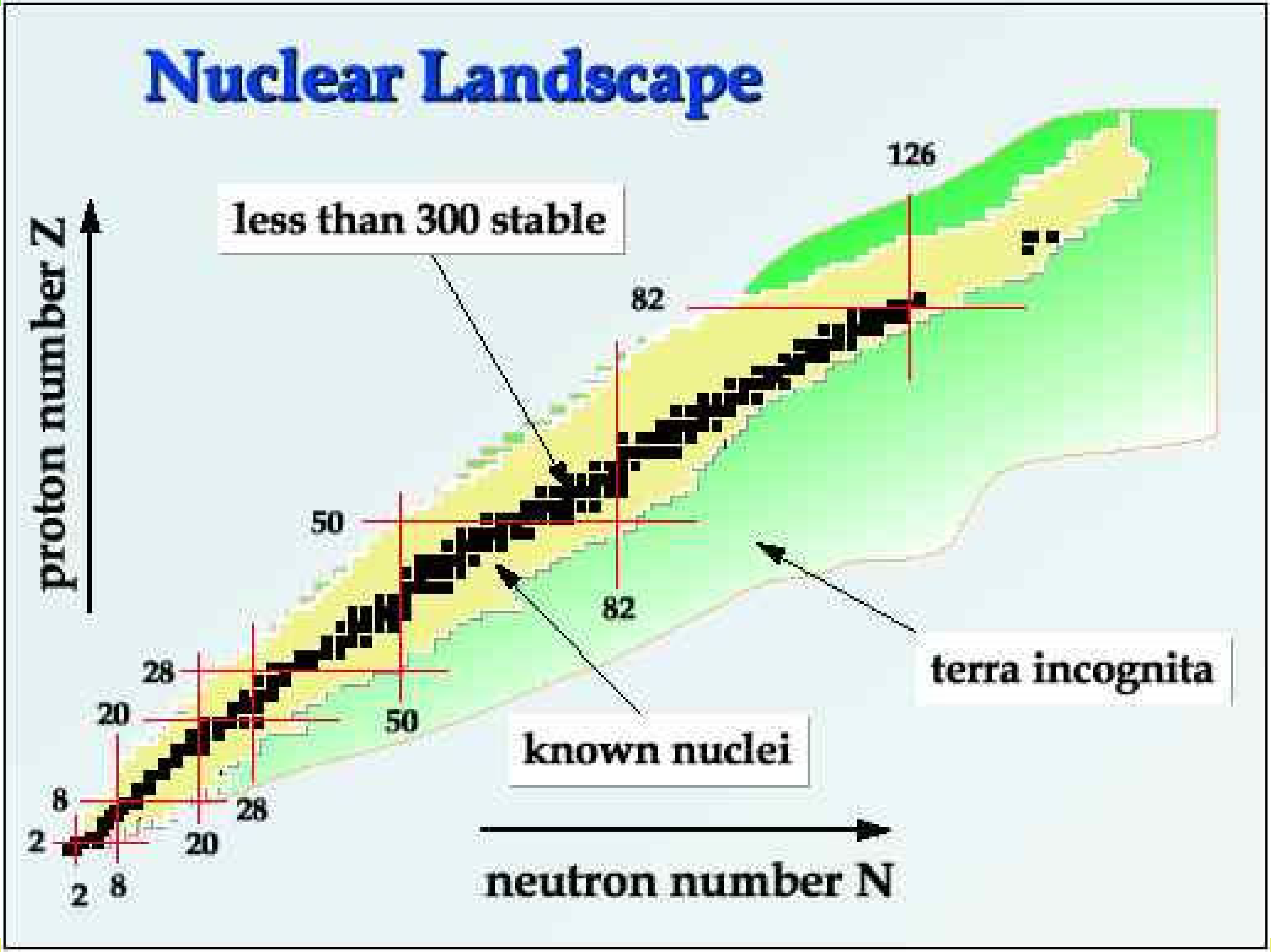
remark on Maria Gepert-Mayer's talk on isotope aboundances, Chicago, 1948

Intruder orbitals

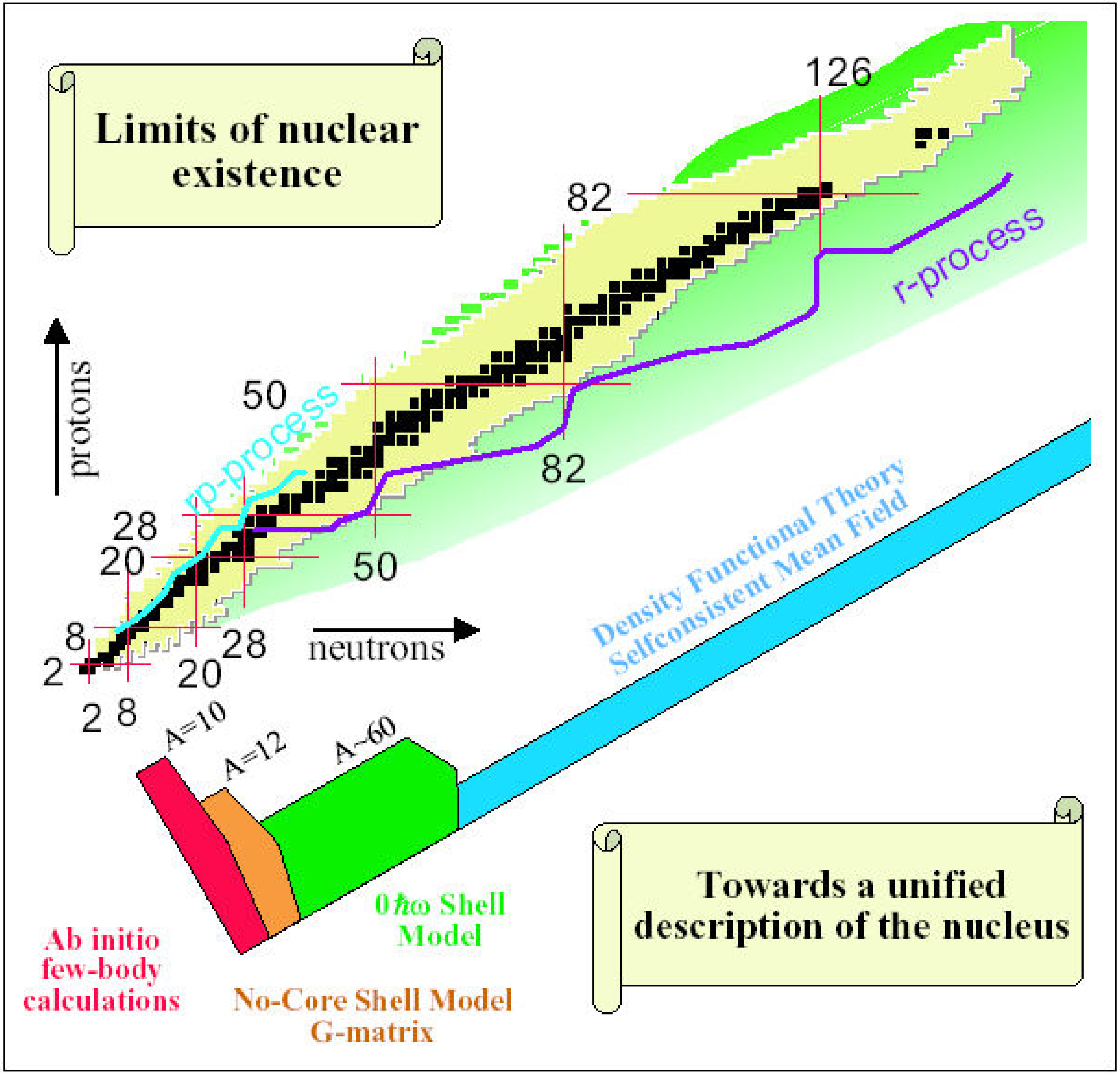
$$V(r) \rightarrow V(r) + V_{so}$$

$$V_{so} = -f(r)\, \underline{l}.\underline{s}$$





Различни експериментални подходи са необходими за изследване на ядра с различни N и Z. За целта са необходими ускорители работещи в различен режим.


Limits of nuclear existence
protons
neutrons
126
82
50
28
20
8
2
2 8
20
28
50
82
rp-process
r-process
Density Functional Theory
Selfconsistent Mean Field
A=10
A=12
A~60
Ab initio
few-body
calculations
No-Core Shell Model
G-matrix
0ħω Shell
Model
Towards a unified
description of the nucleus

status quo

THE BERKELEY DAILY PLANET
THE EAST BAY'S INDEPENDENT NEWSPAPER

Tuesday July 23, 2002

Japanese supercomputer beats top U.S. machine

Scalable from 32 GFLOPS to 7.3 TFLOPS

Hitachi SR8000

U.S. DEPARTMENT OF ENERGY

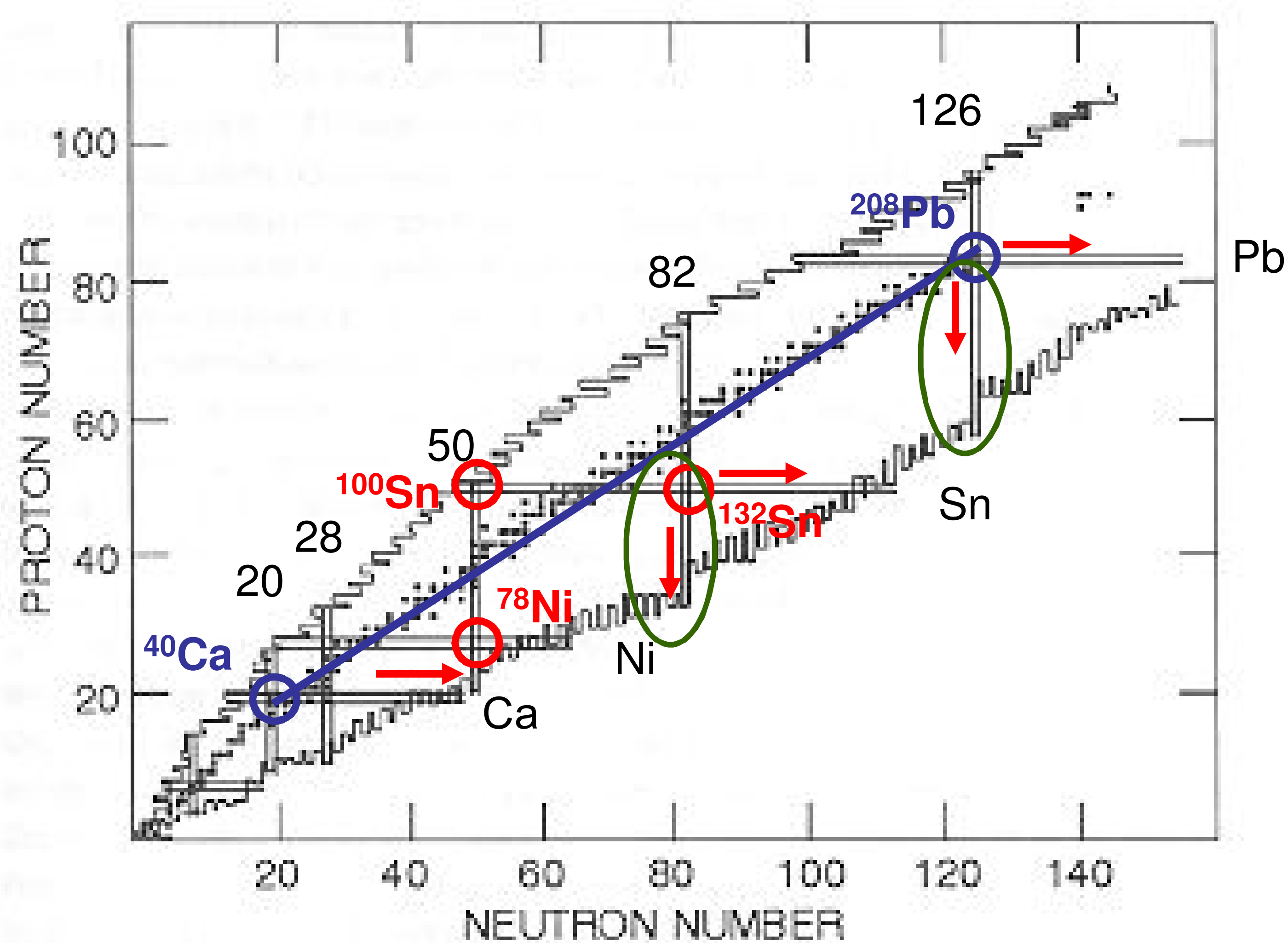
Aug. 25, 2006

ORNL Jaguar supercomputer surpasses 50 teraflops

В Оук Ридж Марио Стоицов е сред основните клиенти на Ягуара…

Apropo, подобна машина работи в Университета в Берген (там Мортен Хьорт-Йенсен разработва своите модели)

DOE’s Oak Ridge Supercomputer Now World’s Fastest for Open Science



- **каква е слоестата структура далеч от стабилност**
- **как се променя формата на “екзотични” ядра**

Сриване на ядрената парадигма

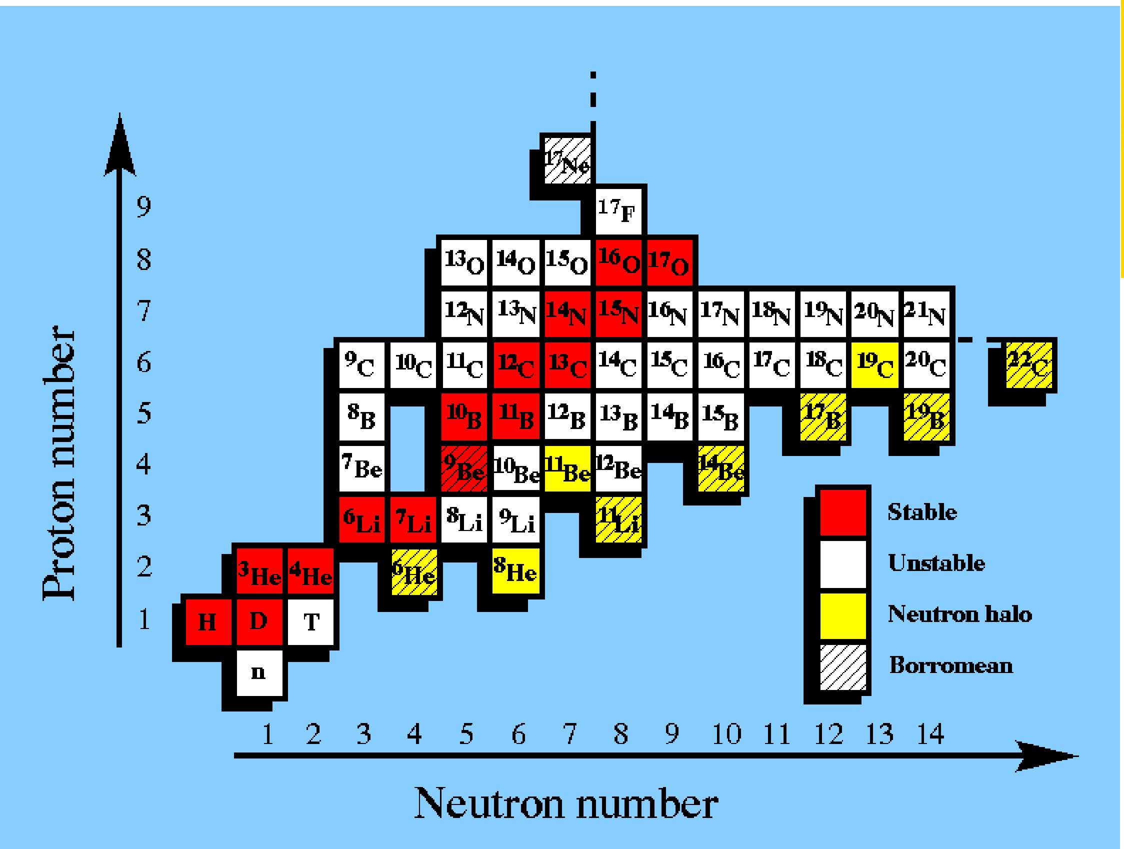
from: NuPECC 2004 Long Range Plan

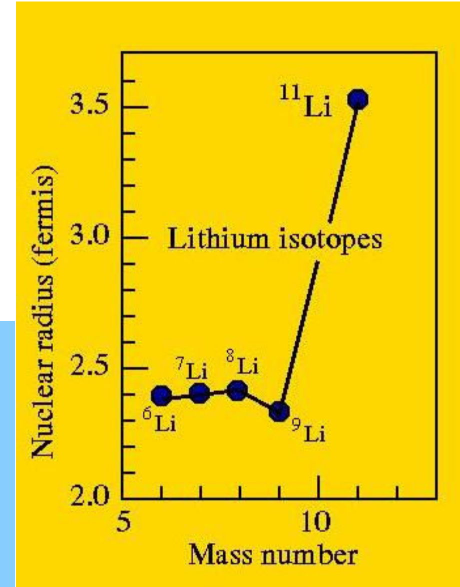
- *Nuclear radii don't go as $A^{1/3}$.* For all stable isotopes the density in the atomic nucleus as well as the diffuseness of the surface are nearly constant. Explorations into the far-unstable regions of the nuclear chart have convincingly shown that the diffuseness, and thus the radii of the atomic nuclei, vary strongly.

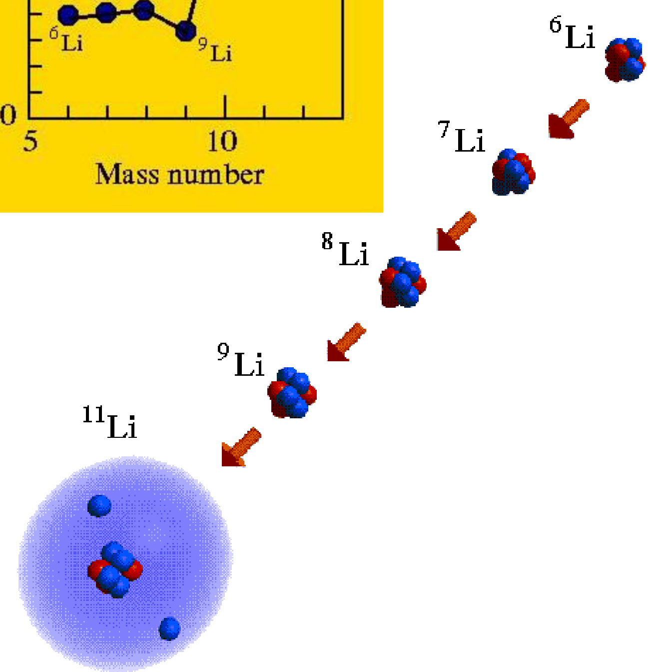
- *Magic Z and N numbers depend on N and Z, respectively.* Shell gaps seem to shrink or disappear, and new ones appear when leaving the valley of stability. Also, experimental evidence for new deformed magic numbers is now available.

- *Many more bound nuclei exist than anticipated.* The neutron drip line is much further out than anticipated twenty years ago. The importance of nucleon correlations and clustering that create more binding for the nuclear system has been underestimated.

The Li chain

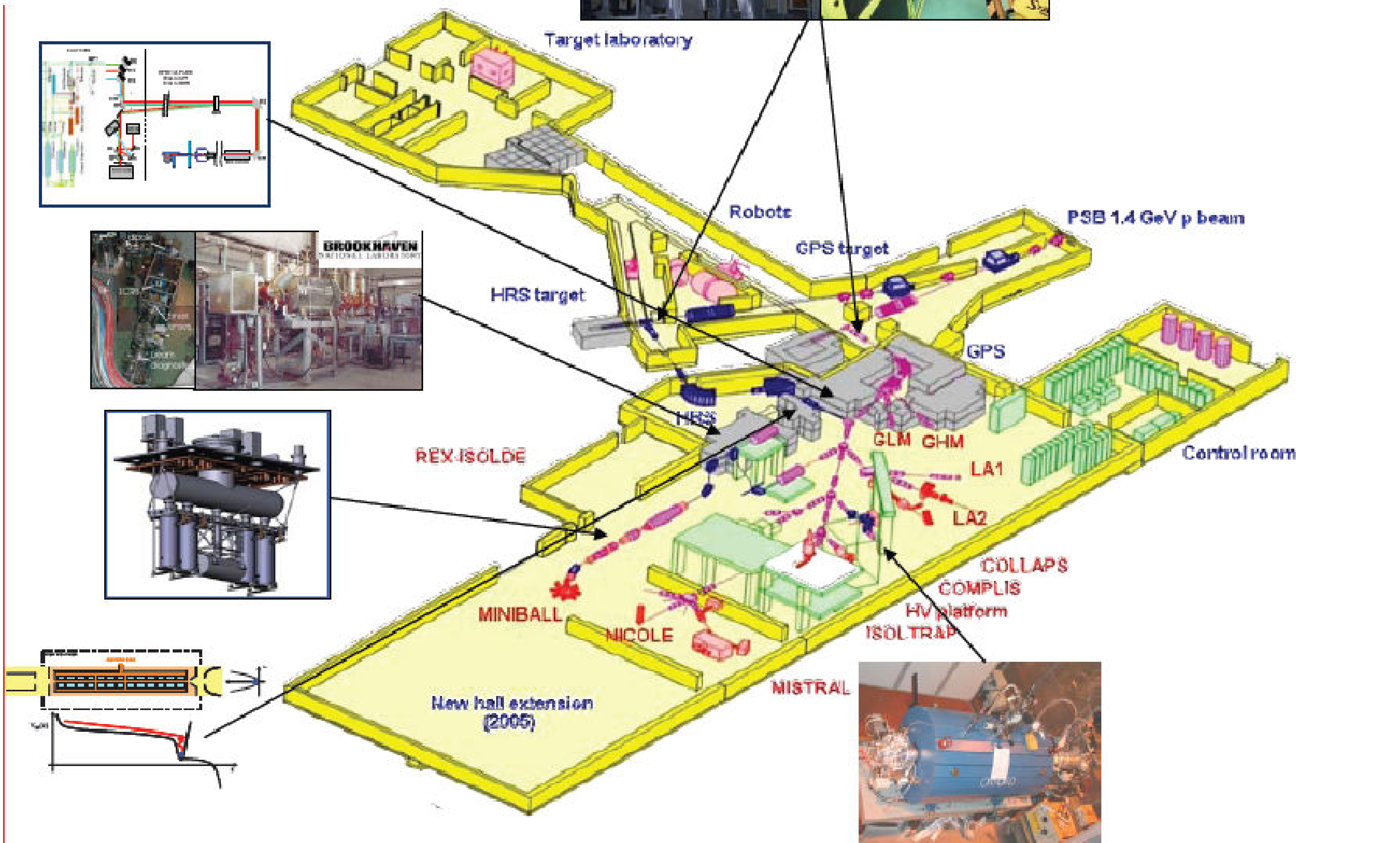






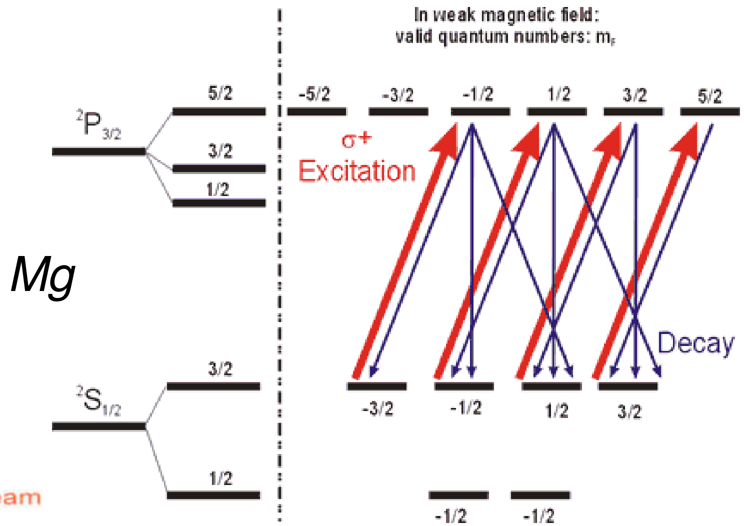
Why is ^{11}Li so big?

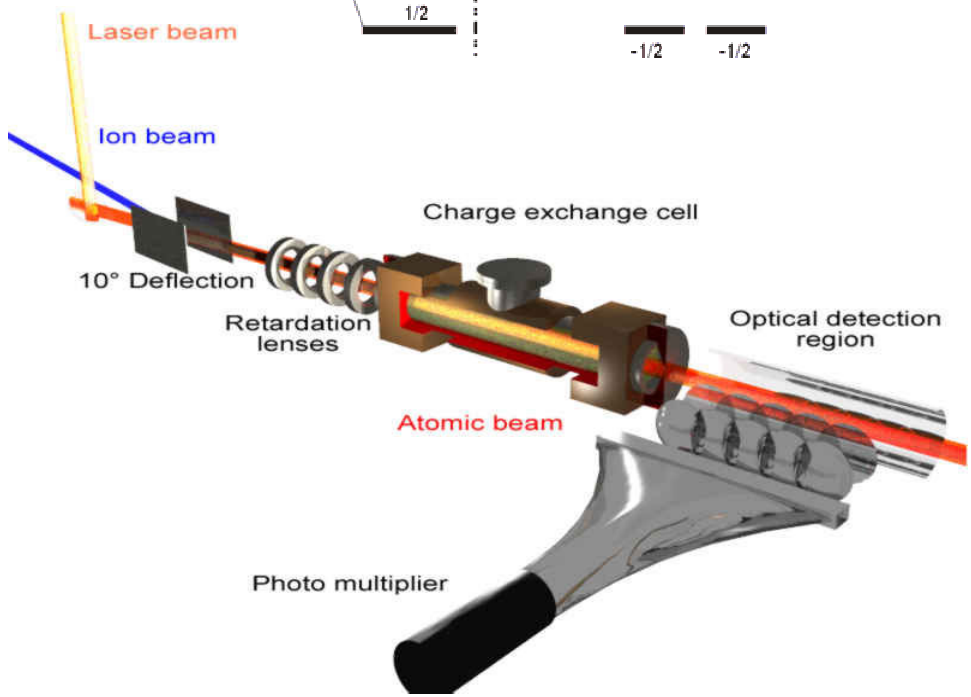
HIE-ISOLDE

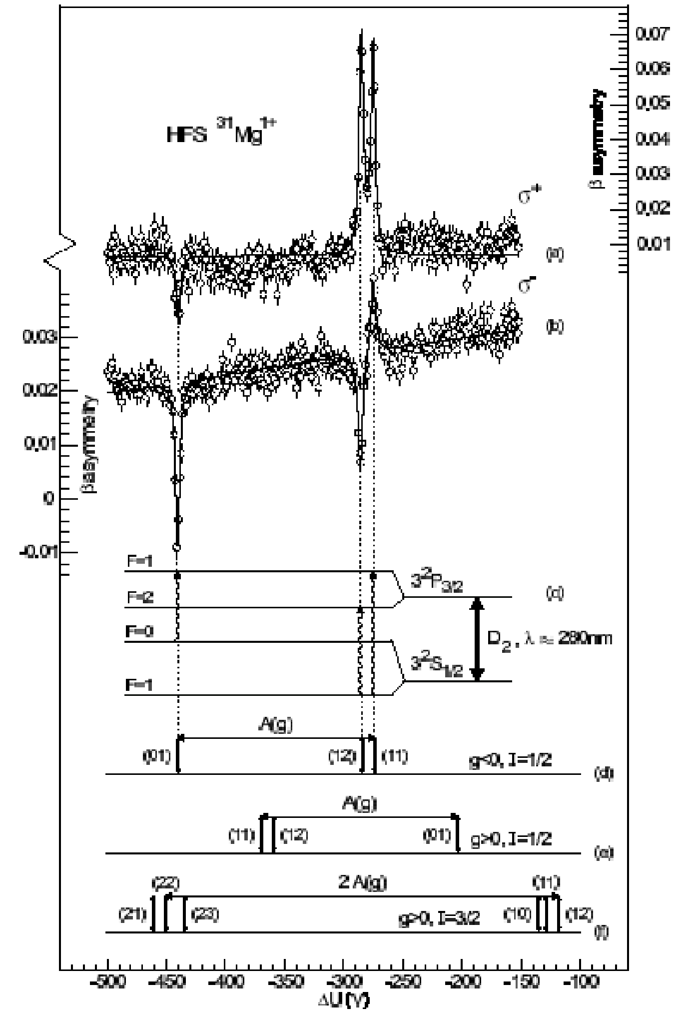


Target laboratory
Robots
PSB 1.4 GeV p beam
GPS target
HRS target
GPS
HRS
GLM
GHM
LA1
LA2
REX-ISOLDE
Control room
COLLAPS
COMPLIS
HV platform
ISOLTRAP
MINIBALL
NICOLE
MISTRAL
New hall extension
(2005)
BROOKHAVEN
ISOLDE

COLLAPS: Collinear laser spectroscopy @ CERN

Optical pumping

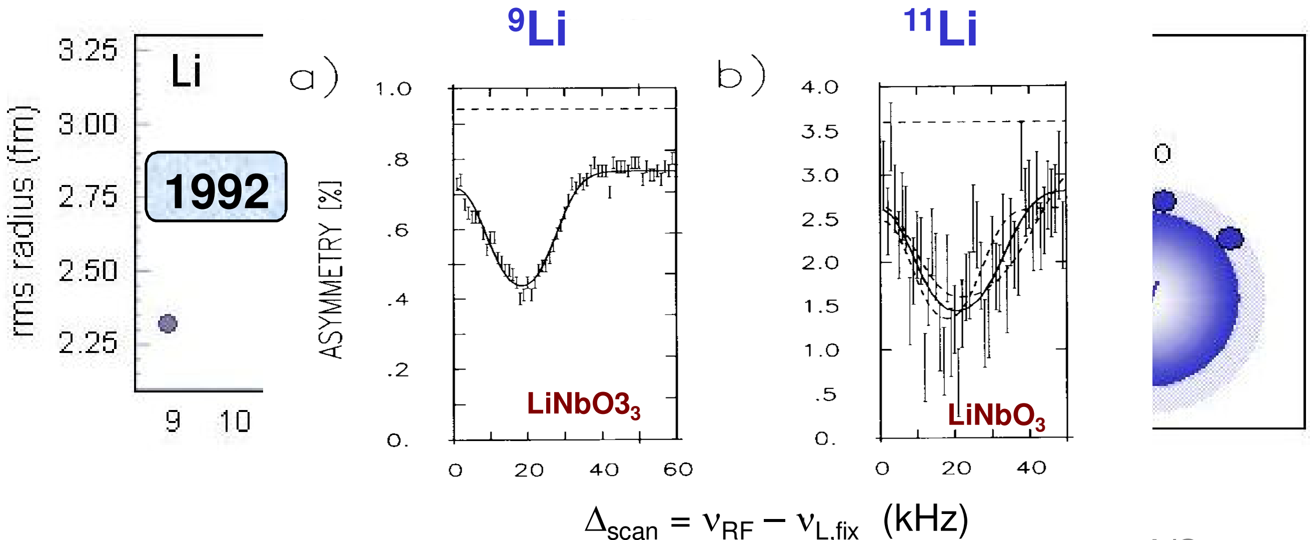




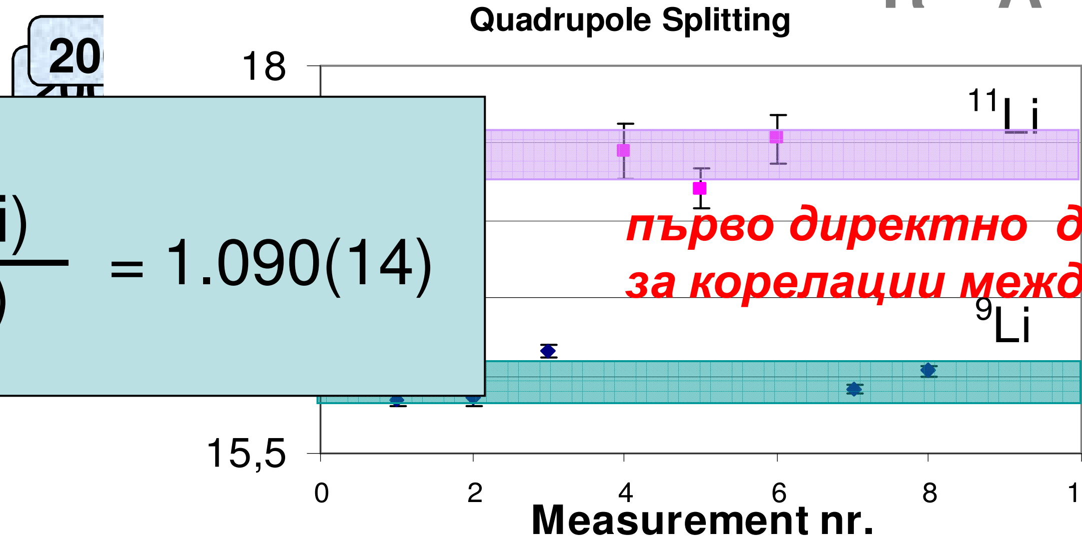


G. Neyens et al, PRL (2005)

The case of ^{11}Li



R ~ $A^{1/3}$????



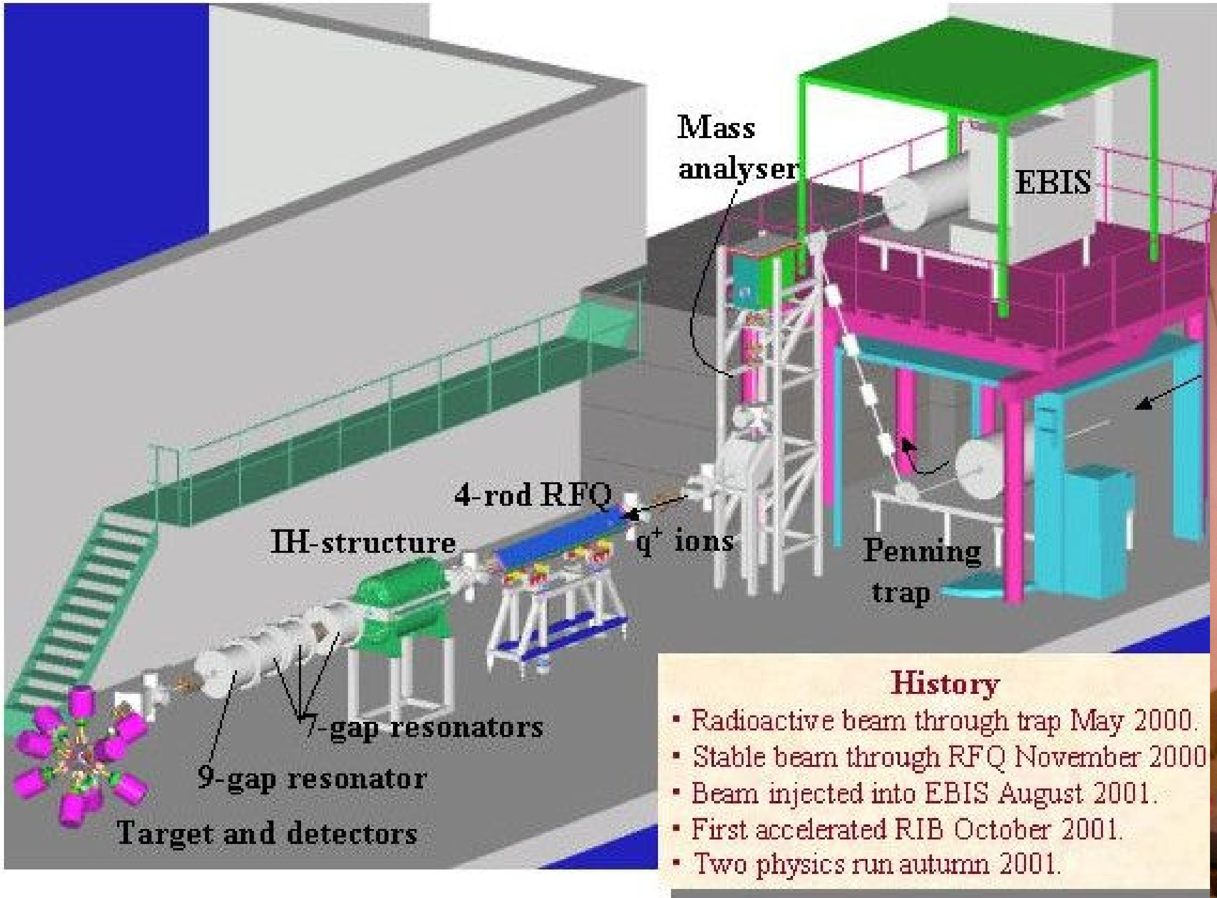
$$\frac{Q(^{11}Li)}{Q(^{9}Li)} = 1.090(14)$$

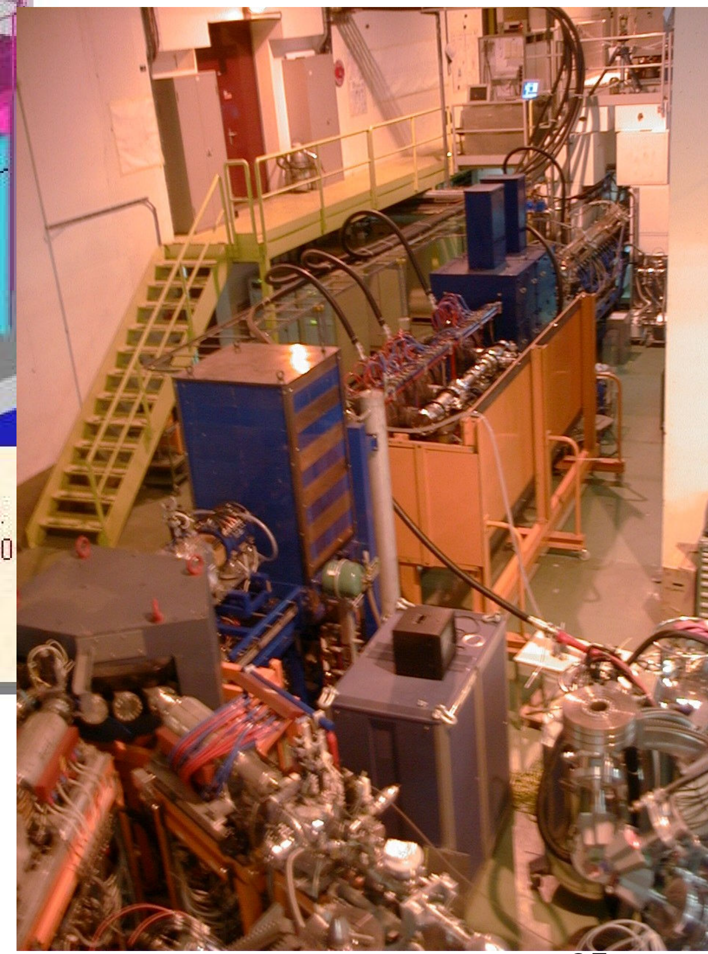
първо директно доказателство за корелации между ядка и хало

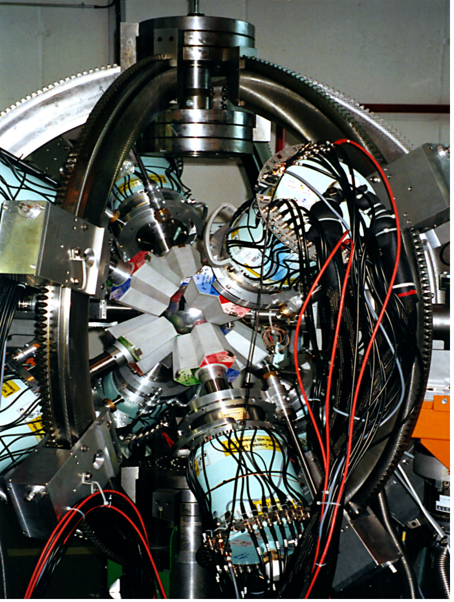
The HIE-ISOLDE linear accelerator

The HIE (High Intensity and Energy)-ISOLDE project embraces new developments in radioisotopes selections, improvements in charge breeding and target-ion source development, as well as construction of the new injector for the PS Booster, LINAC4. For extending the physical reach of the facility, the most significant component is the SC linear accelerator with a minimum energy of 10 MeV/u (HIE-LINAC) which will replace most of the existing REX structure. It will be based on independently phased Quarter Wave Resonators (QWRs).

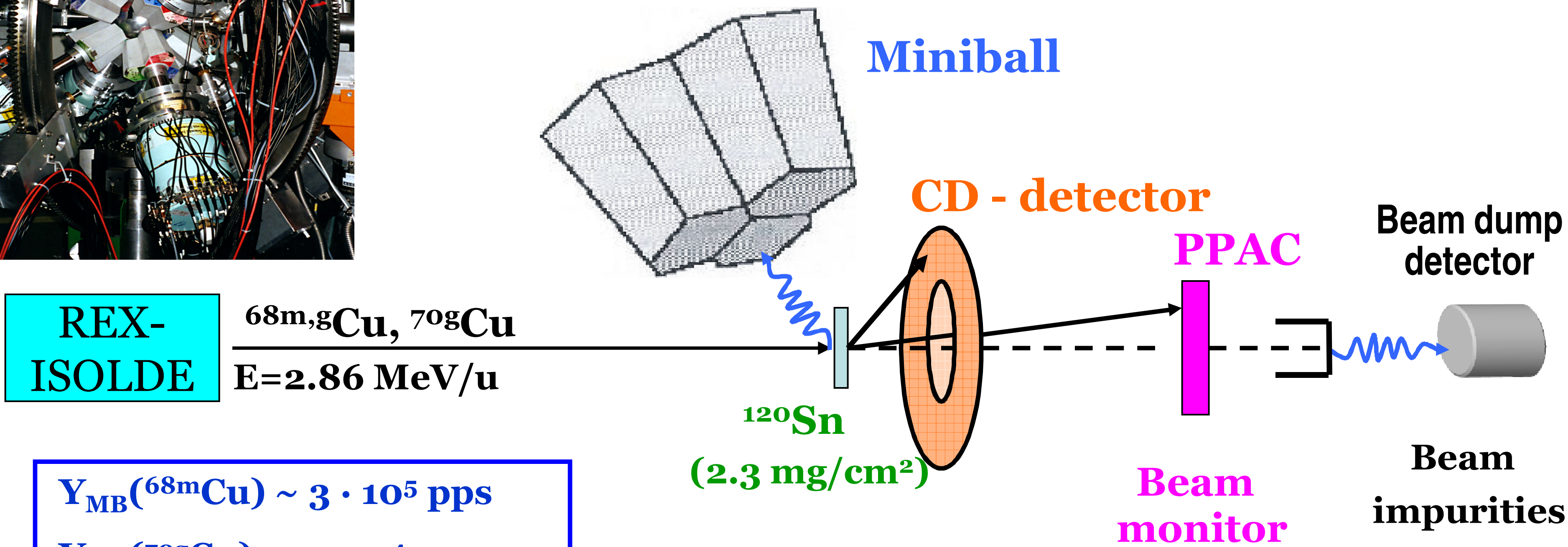
The state-of-the-art instrument







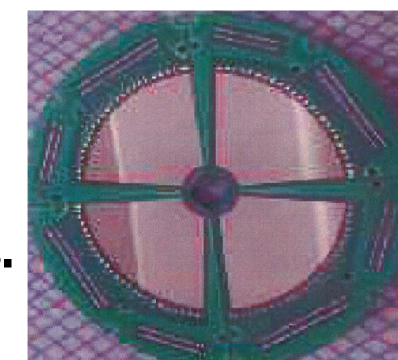
Experimental setup for Coulex @ Isolde



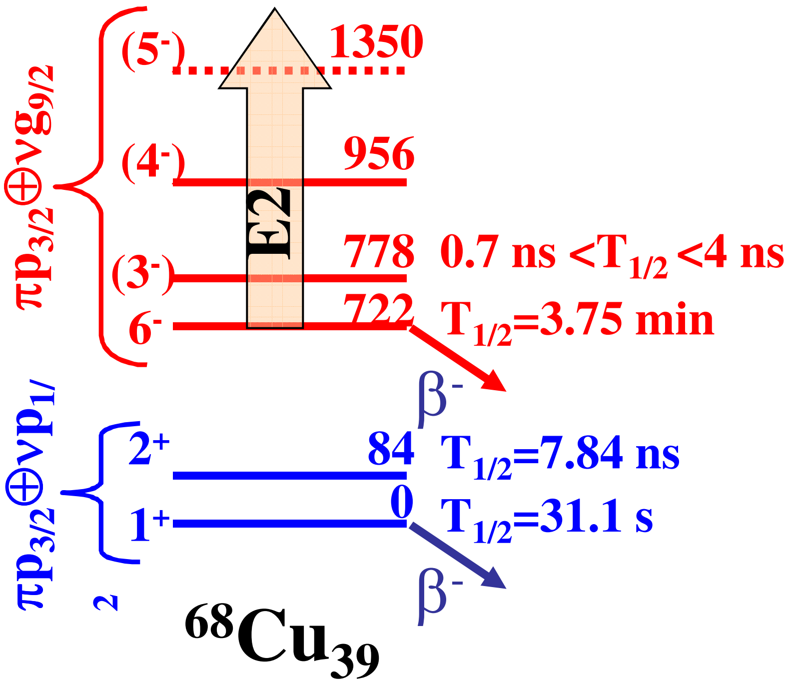
$Y_{MB}(^{68m}Cu) \sim 3 \cdot 10^5$ pps

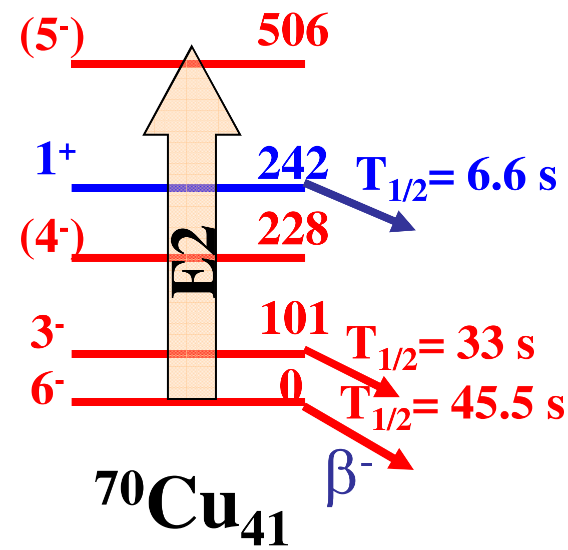
$Y_{MB}(^{70g}Cu) \sim 5 \cdot 10^4$ pps

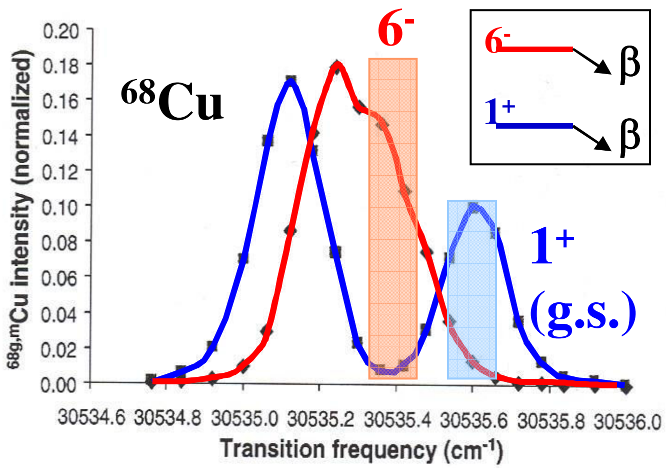
- **particle identification: Double Sided Segmented Silicon Detector;**
- **detection range: 16º-53º in the laboratory system;**
- **4 quadrants, each divided in 16 annular (θ) and 24 sector (φ) strips.**

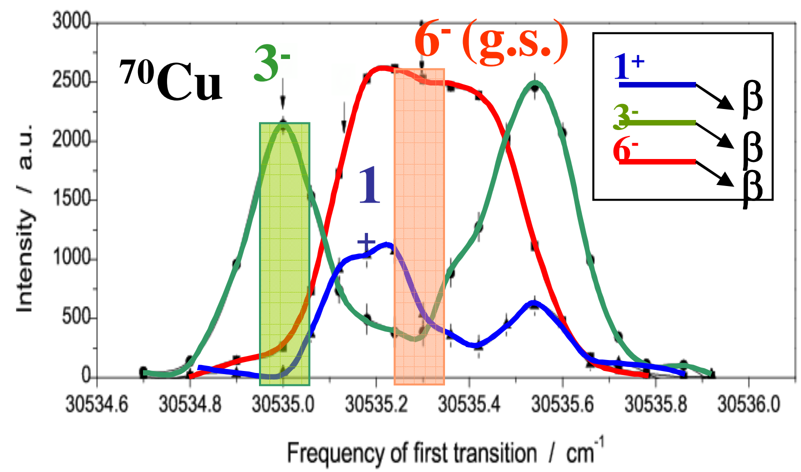


“Non-standard” Coulomb excitation

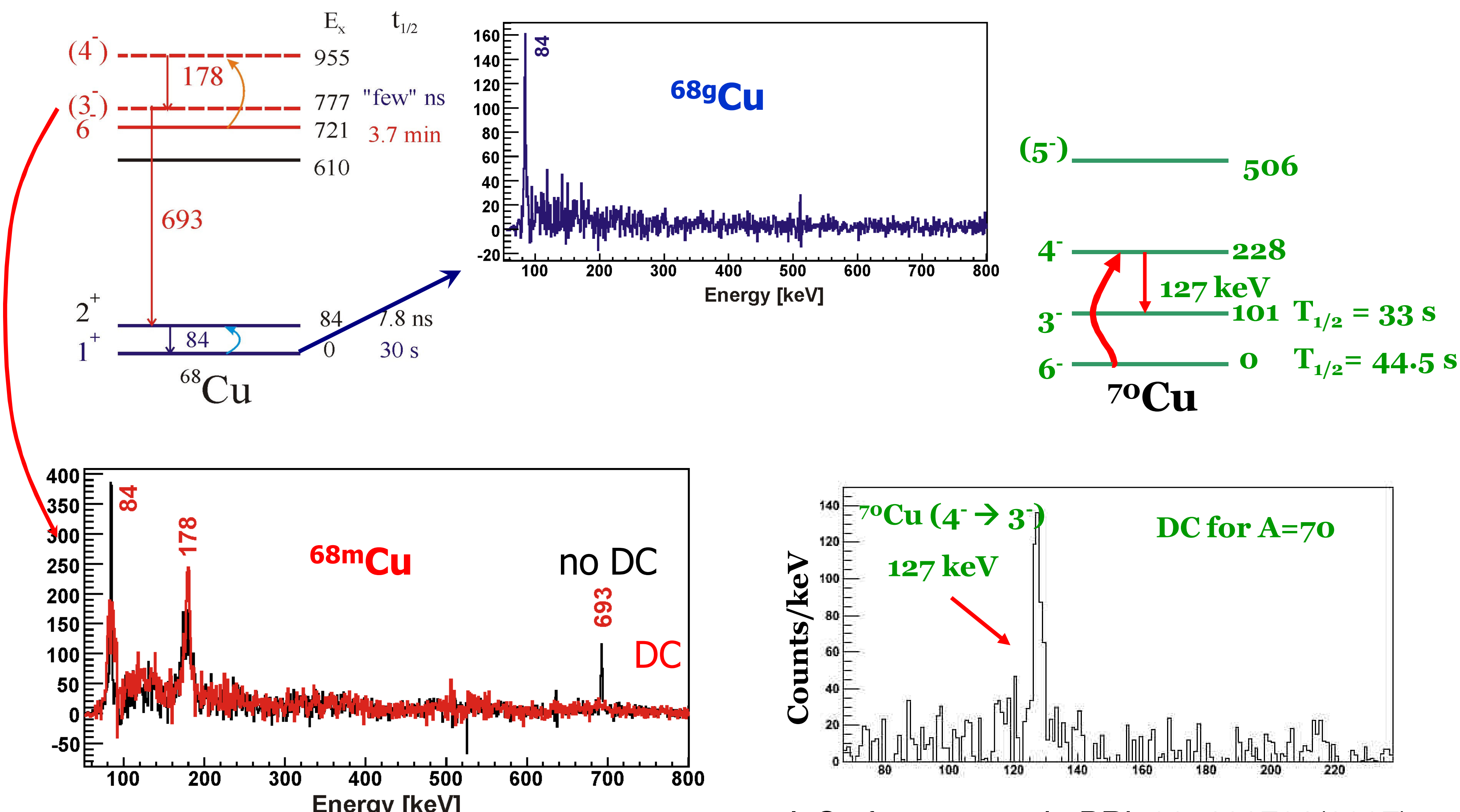








Study of selected structures in the same nucleus



I. Stefanescu et al., PRL 98, 122701(2007).

Polarized beams at HIE-ISOLDE – from dreams to reality.

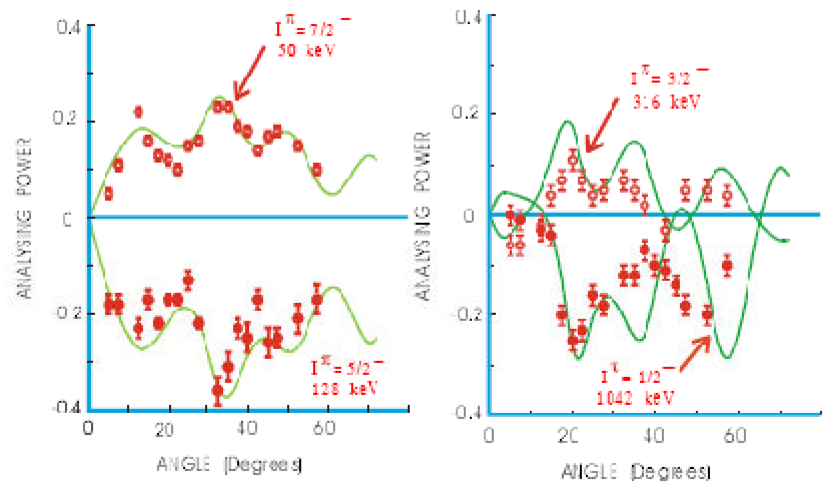
G. Georgiev[1], M. Hass[2], A. Herlert[3], D.L. Balabanski[4], L. Hemmingsen[5], K. Johnston[3], M. Lindroos[3], K. Riisager[6], J. Van de Walle[3], D. Voulot[3], F. Wenander[3], W.-D. Zeitz[7]

*1. CSNSM, Orsay, **France**; 2. The Weizmann Institute, Rehovot, **Israel**; 3. ISOLDE, CERN, Geneva, **Switzerland**; 4. INRNE, BAS, Sofia, **Bulgaria**; 5. IGM, LIFE, University of Copenhagen, **Denmark**; 6. Department of Physics and Astronomy, University of Aarhus, **Denmark**; 7. Helmholtz-Zentrum Berlin für Materialien und Energie GmbH, **Germany***

Polarized beams – WHY?

Precise test of the nuclear models for exotic nuclei:

- transfer reactions (analyzing power) $\rightarrow j = \ell \pm ½$
- Coulomb excitation – spin/parity; multiplicity assignments etc.
- nuclear moments – proton/neutron character, angular momentum *j*



$$A_y = \frac{\left(\frac{d\sigma}{d\Omega}\right)\uparrow - \left(\frac{d\sigma}{d\Omega}\right)\downarrow}{\left(\frac{d\sigma}{d\Omega}\right)\uparrow p\downarrow + \left(\frac{d\sigma}{d\Omega}\right)\downarrow p\uparrow}$$

Can one do it and how?

Tilted Foils - the principles:

- atomic polarization → nuclear polarization
- higher nuclear spins → higher polarization

(>10% achieved so far)

- strong velocity dependence

(poorly studied up to now)

345

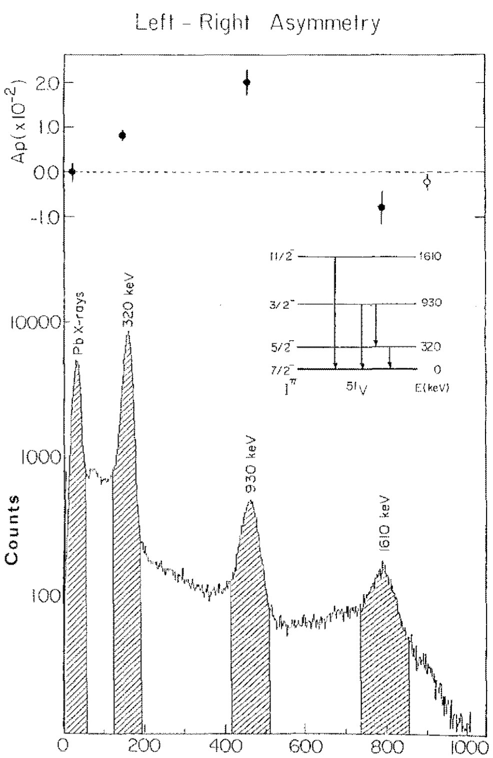
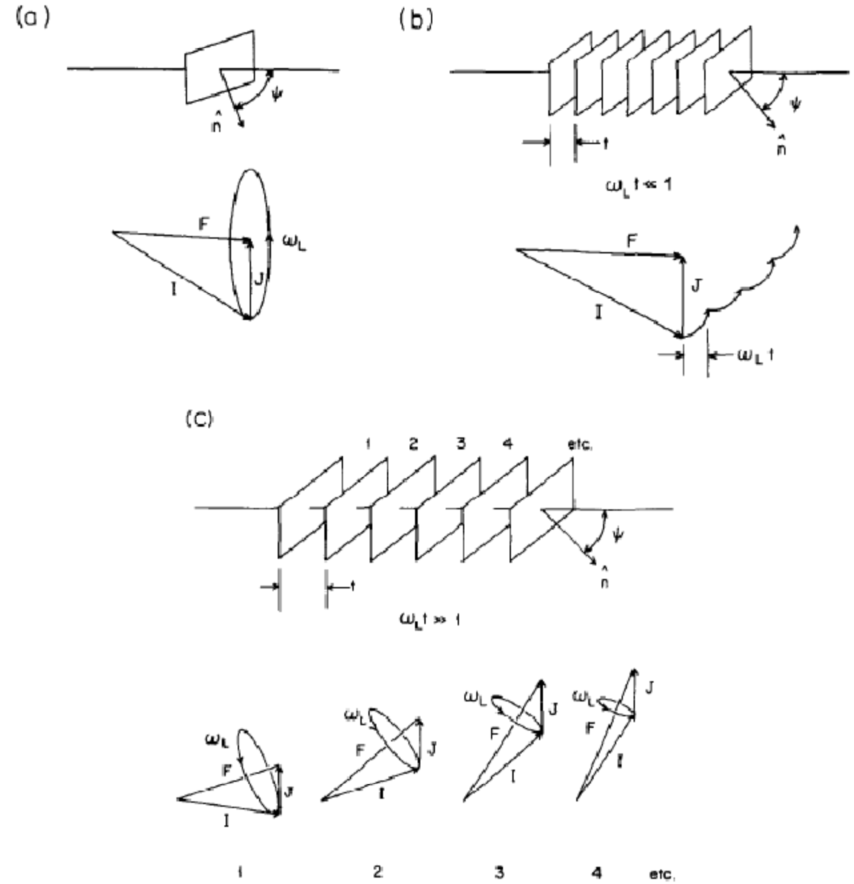


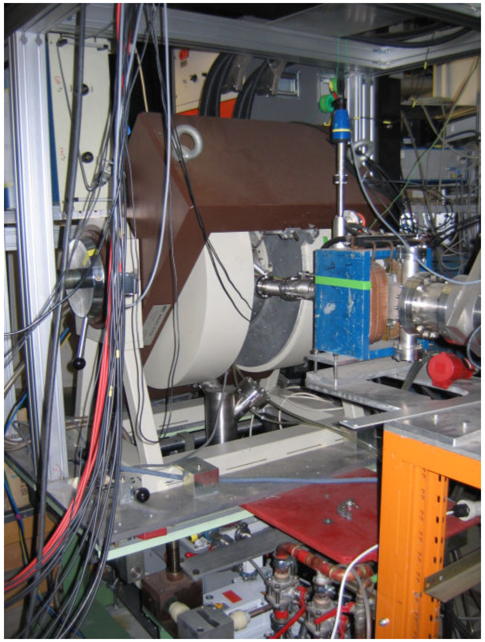
Fig. 3. Left-right asymmetry of the Coulomb excited ^{51}V on ^{208}Pb at 195 MeV for the three main decay γ-rays, Pb x-rays and γ-particle random coincidences (open circle)



M. Hass et al., NPA 414, 316 (84)

•Can one post-accelerate the ions after polarizing them?
done for stable beams - noble-gas like charge states + LINAC
← J. Bendahan *et al.*, ZPA 331, 343 (88)

What do we need to achieve it?



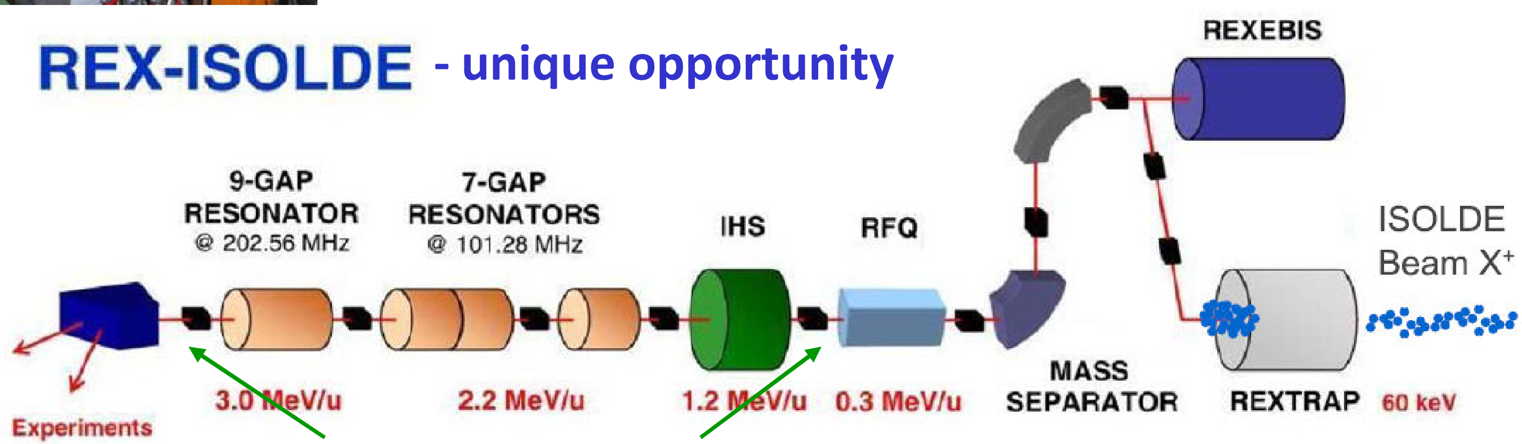
β-NMR setup from HMI Berlin transferred to ISOLDE

- gain of complete control on the TF polarization
- nuclear structure (moments, reactions …),

nuclear methods in the solid-state physics,

biophysics etc. …

REX-ISOLDE - unique opportunity



3 MeV/u and 0.3 MeV/u

The present generation of laboratories and instruments allows to keep the European lead in nuclear structure physics on the international arena

NuPECC Roadmap for Nuclear Science in Europe

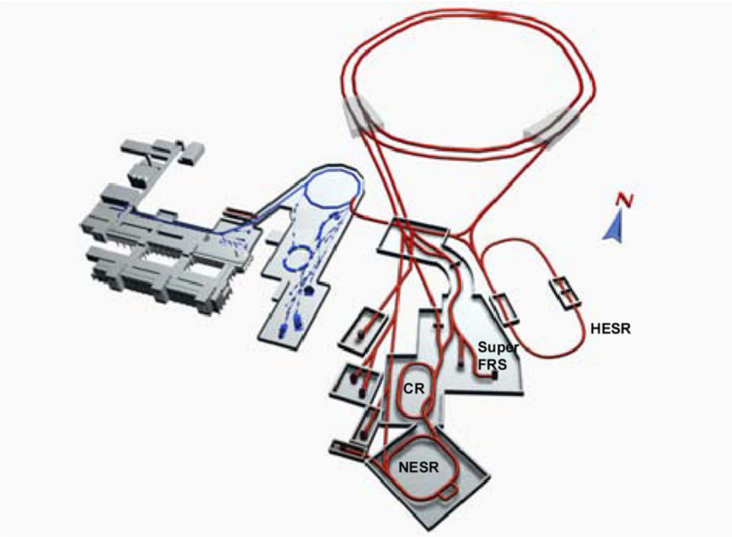
NuPECC recommends as the highest priority for a new construction project the building of the international "Facility for Antiproton and Ion Research (FAIR)" at the GSI, Darmstadt.

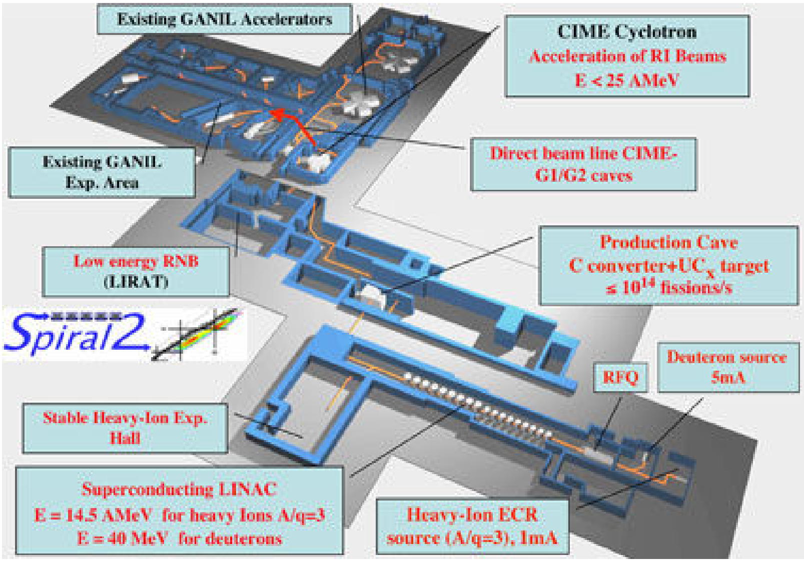
After FAIR, NuPECC recommends the highest priority for the construction of EURISOL.

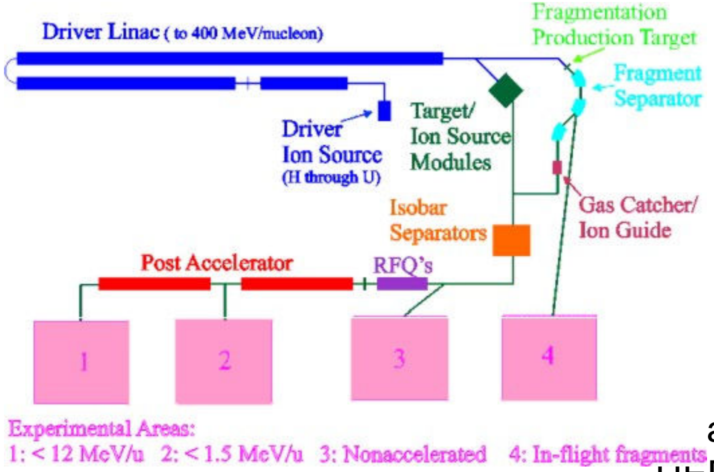
NuPECC gives full support for the construction of AGATA and recommends that the R&D phase be pursued with vigour.

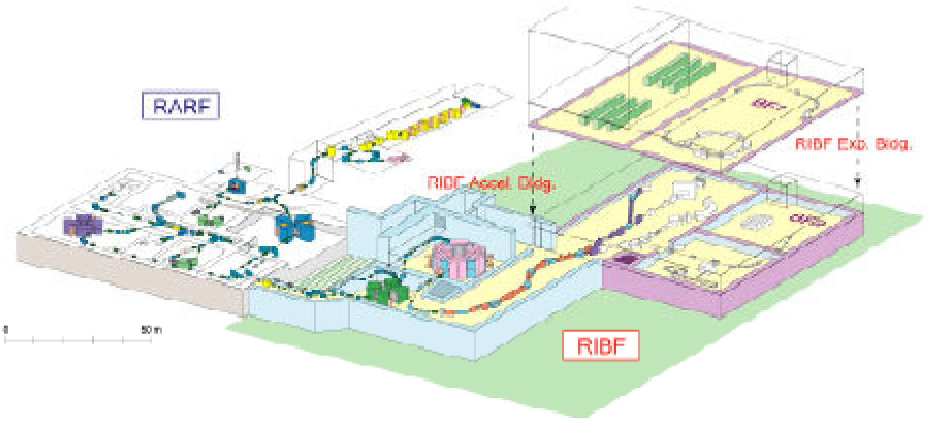
Because of the time-line of EURISOL NuPECC strongly recommends the building of intermediate-generation RIB facilities of the ISOL type. Of these SPIRAL2 meets the criteria of a European large research infrastructure in terms of scientific potential and size of investment and will deliver RIBs in 2009.

RIB Facilities : A Worldwide Effort







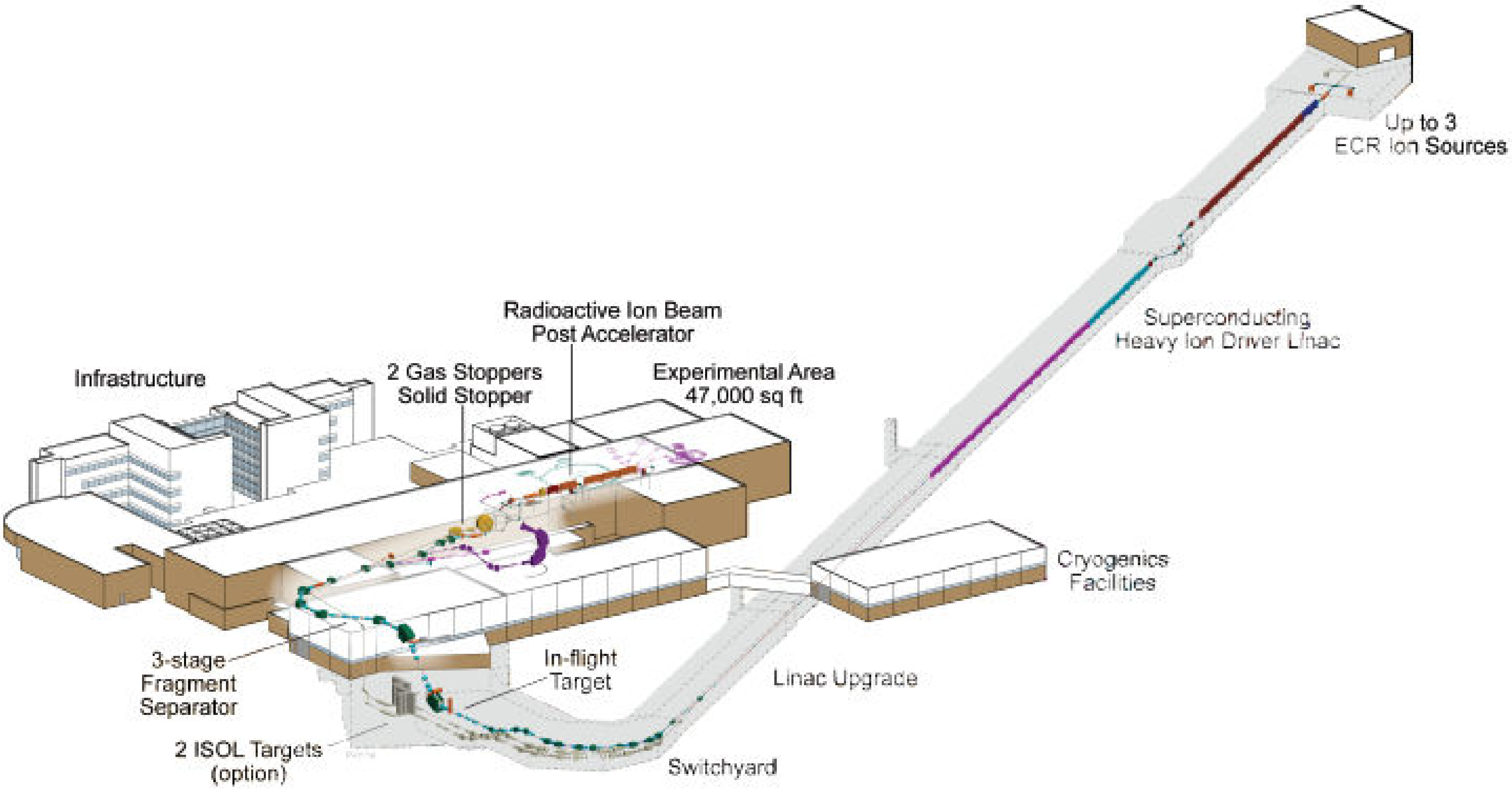


U.S. DEPARTMENT OF ENERGY

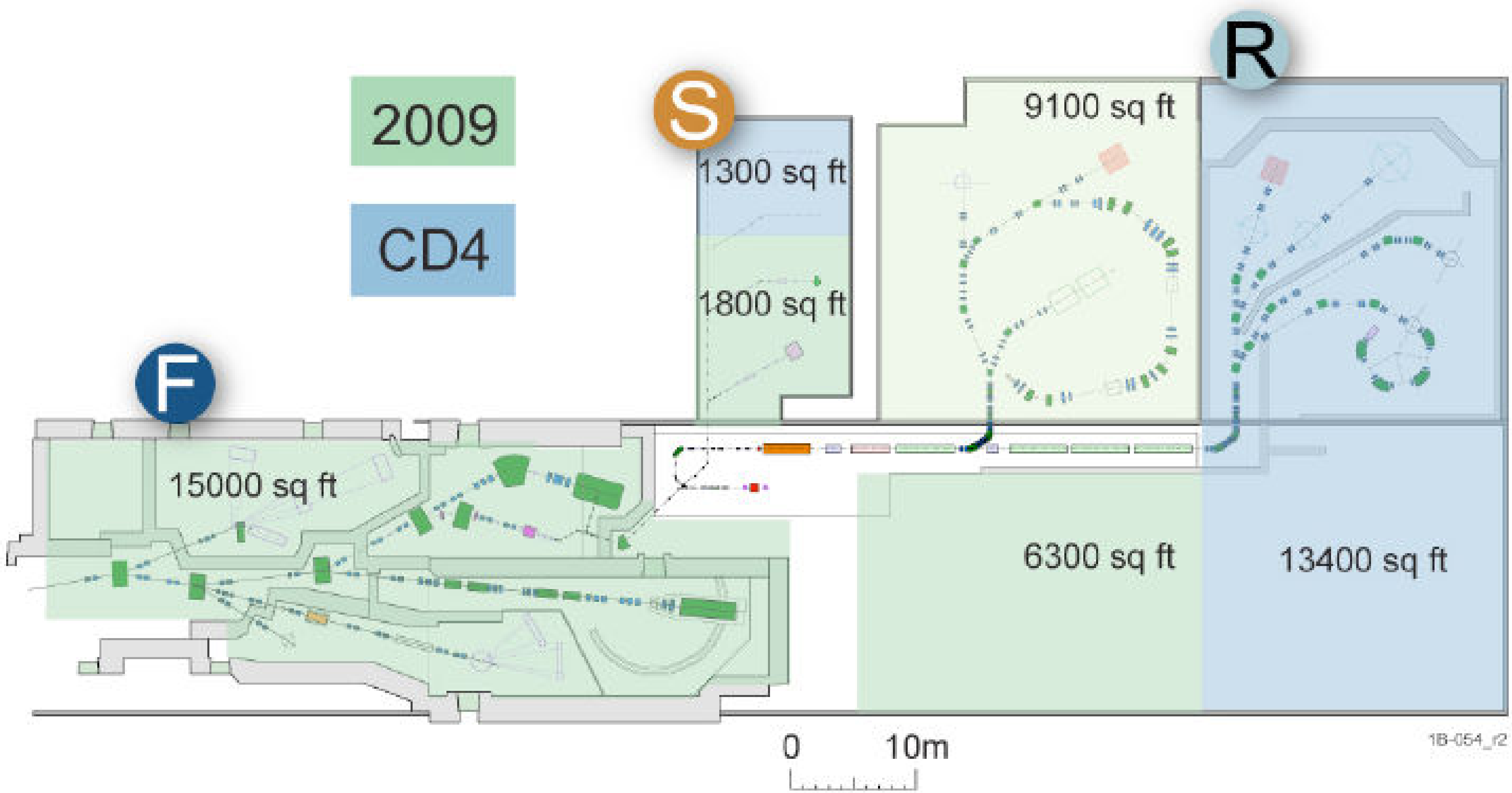
Michigan State University (MSU) was selected to design and establish FRIB based on the evaluation against the Merit Review criteria of the application submitted and information obtained from the applicant’s response to questions of the Merit Review Panel, oral presentations and site visits. Both applicants fully addressed all aspects of the rated criteria, and demonstrated a very good understanding of the major issues. However, MSU’s application provided the strongest proposed budget that was reasonable and realistic.

MICHIGAN STATE UNIVERSITY

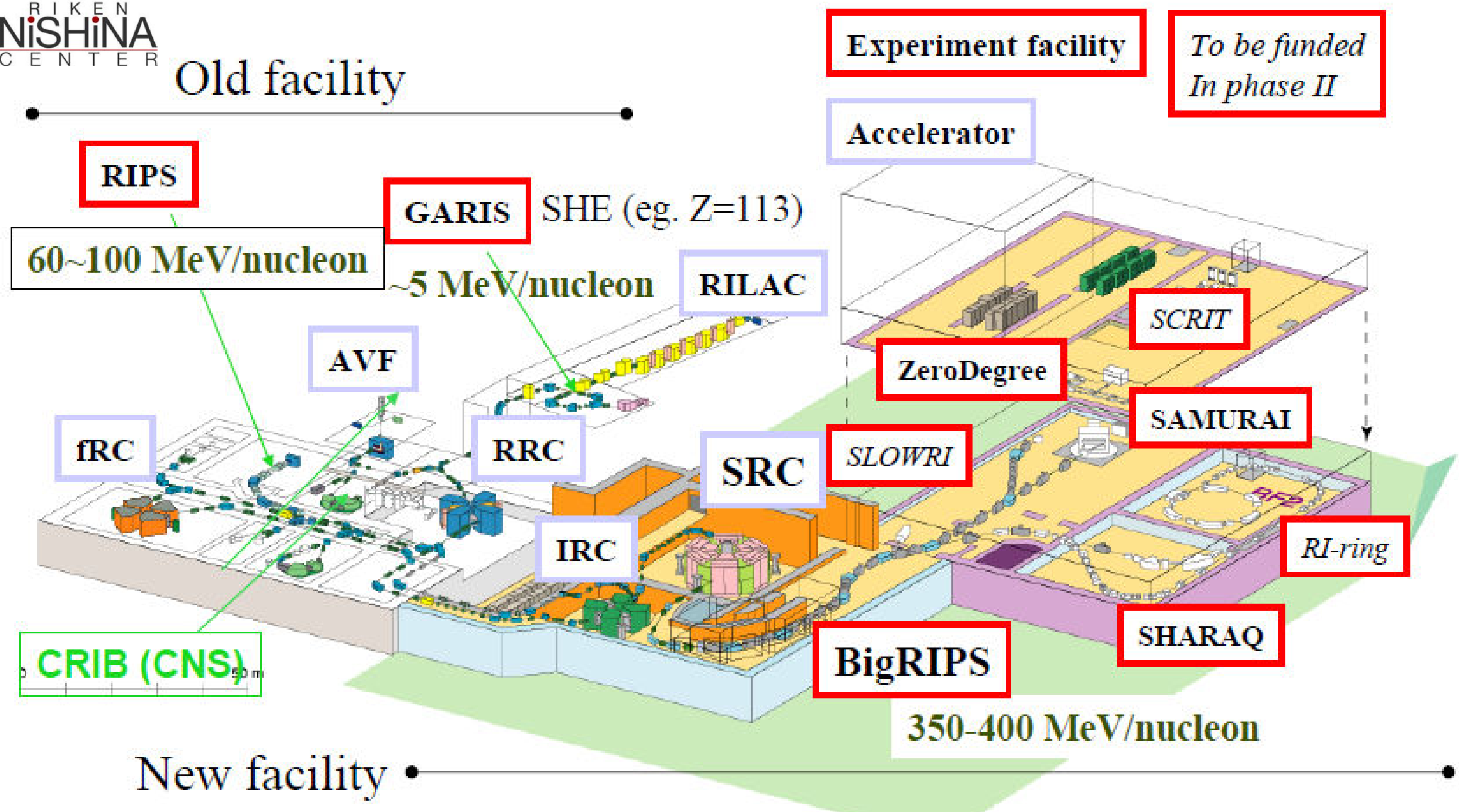
Proposed configuration of FRIB at MSU



FRIB experimental areas



RIKEN RI Beam Factory (RIBF)

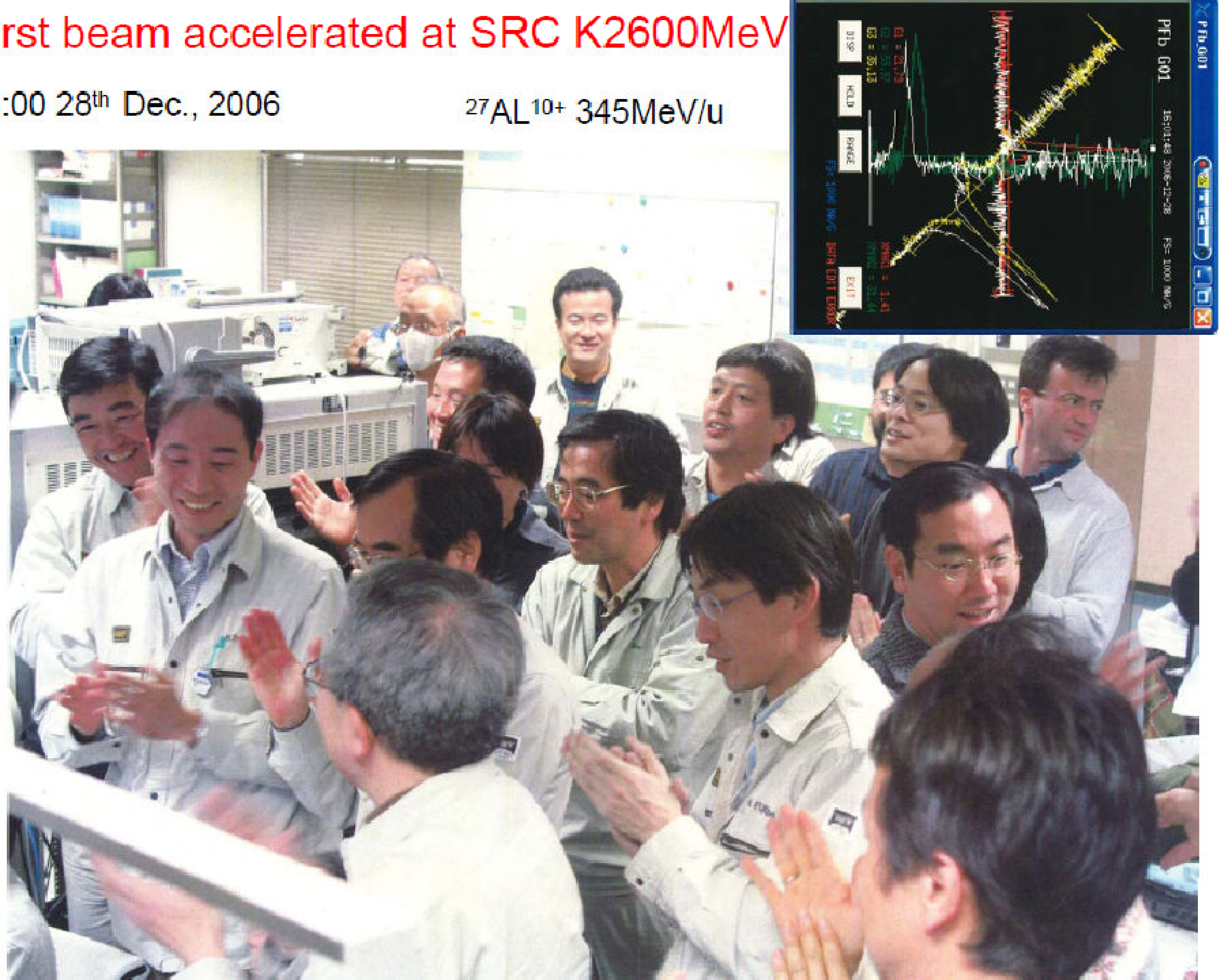


Intense (80 kW max.) H.I. beams (up to U) of 345AMeV at SRC
Fast RI beams by projectile fragmentation and U-fission at BigRIPS
Operation since 2007

First beam accelerated at SRC K2600MeV

16:00 28th Dec., 2006

$^{27}AL^{10+}$ 345MeV/u




EVROPA
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ASIÆ
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BARBARIA
MARE MEDITERRANEVM
MARMARICA

European Strategy Forum on Research Infrastructures

About ESFRI

The European Strategy Forum on Research Infrastructures - ESFRI - was launched in April 2002 to support a coherent approach to policy-making on Research Infrastructures in Europe. The Forum brings together representatives, nominated by Research Ministers, of the 25 EU Member States and of 7 European countries associated with the Framework Programme, and a representative of the European Commission. ESFRI has set up various thematic working groups, has acted as an incubator for some Research Infrastructure projects and has started to prepare a Roadmap for Research Infrastructures of pan-European interest in the next 10-20 years.

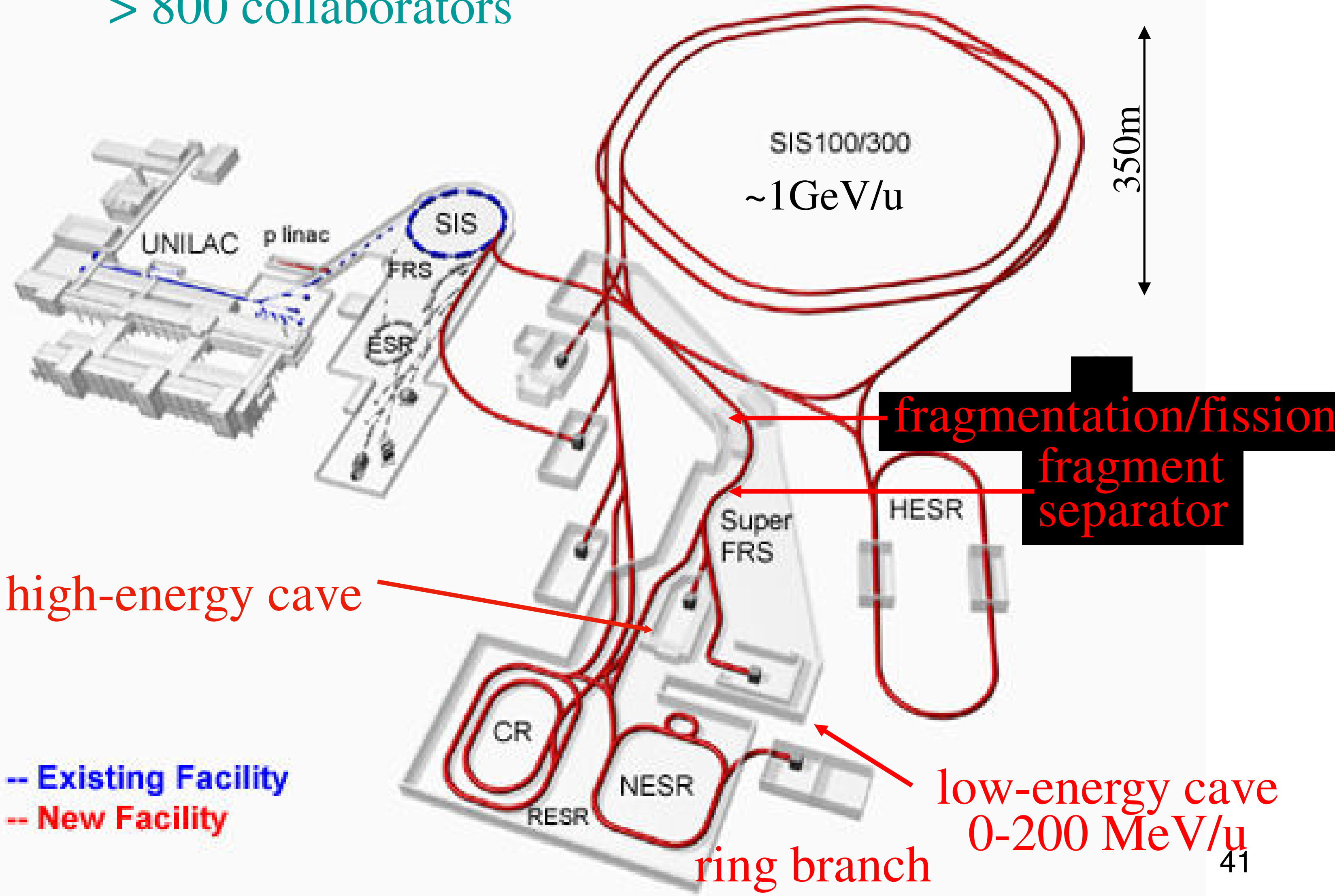
For more information on the Forum: http://www.cordis.lu/esfri/

Facility for Antiproton and Ion Research (FAIR)
Facility for intense secondary beams of unstable isotopes (SPIRAL II)

HISPEC/DESPEC

NUSTAR: SuperFRS and experiments on three branches

> 800 collaborators



NUSTAR - The Project

DESPEC	γ-, β-, α-, p-, n-decay spectroscopy
ELISE	elastic, inelastic, and quasi-free e^--A scattering
EXL	light-ion scattering reactions in invere kinematics
HISPEC	in-beam γ spectroscopy at low and intermediate energy
ILIMA	masses and lifetimes of nuclei in ground and isomeric states
LASPEC	Laser spectroscopy
MATS	in-trap mass measurements and decay studies
R3B	kinematically complete reactions at high beam energy
Super FRS	RIB production, identification and spectroscopy

The Collaboration

> 800 scientists

146 institutes

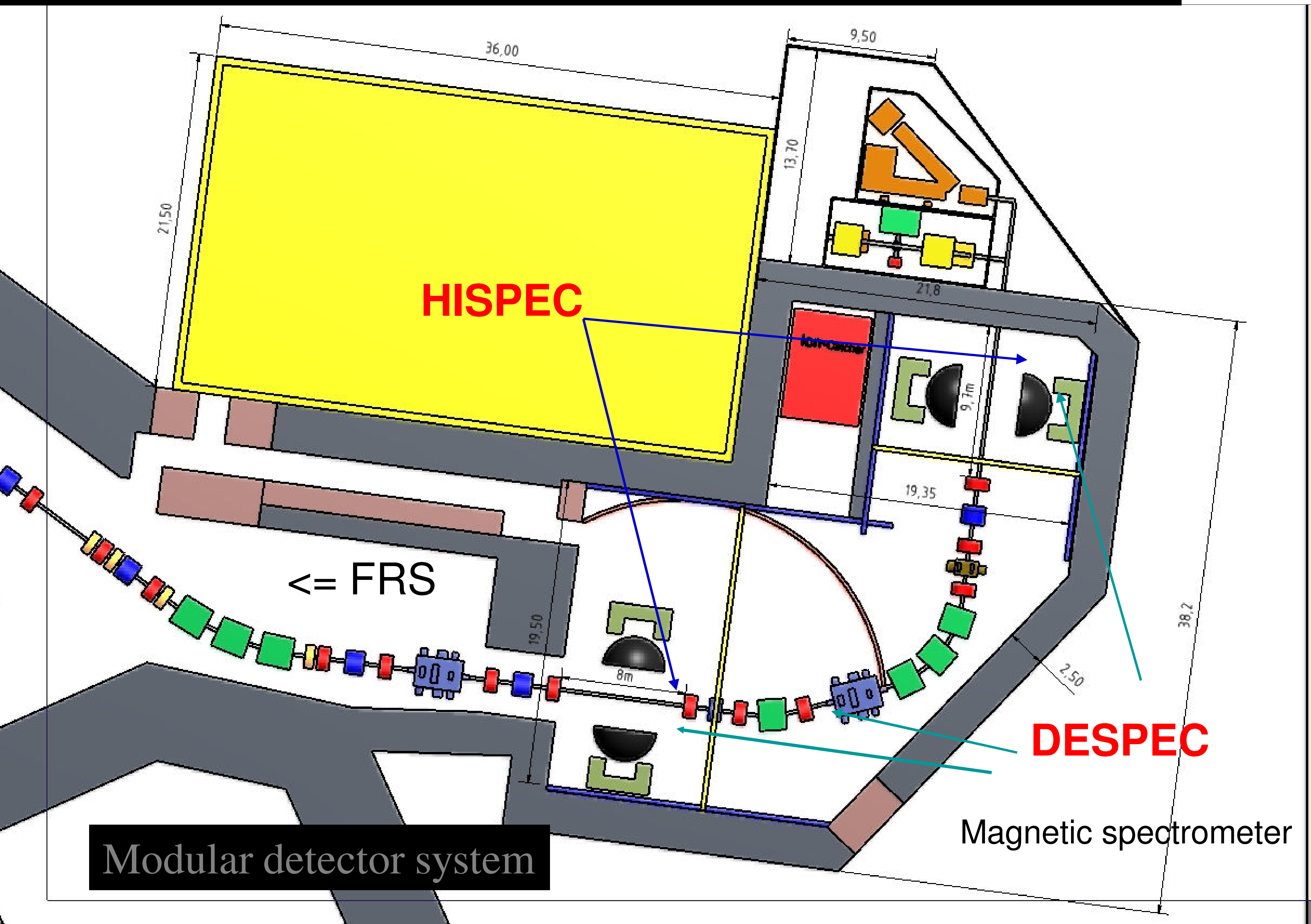
38 countries

The Investment

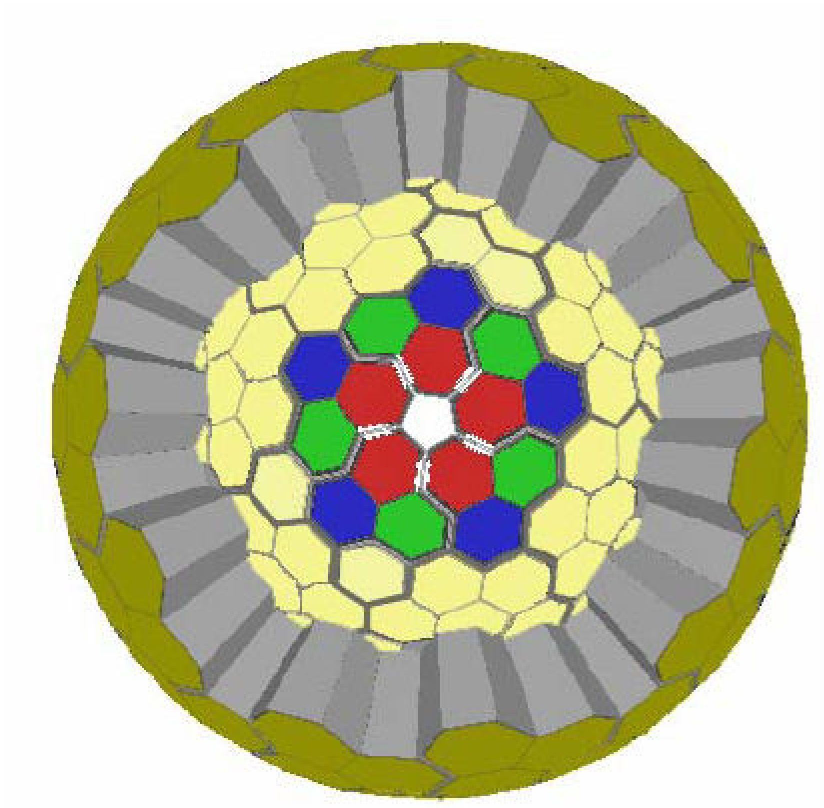
82 M€ Super FRS

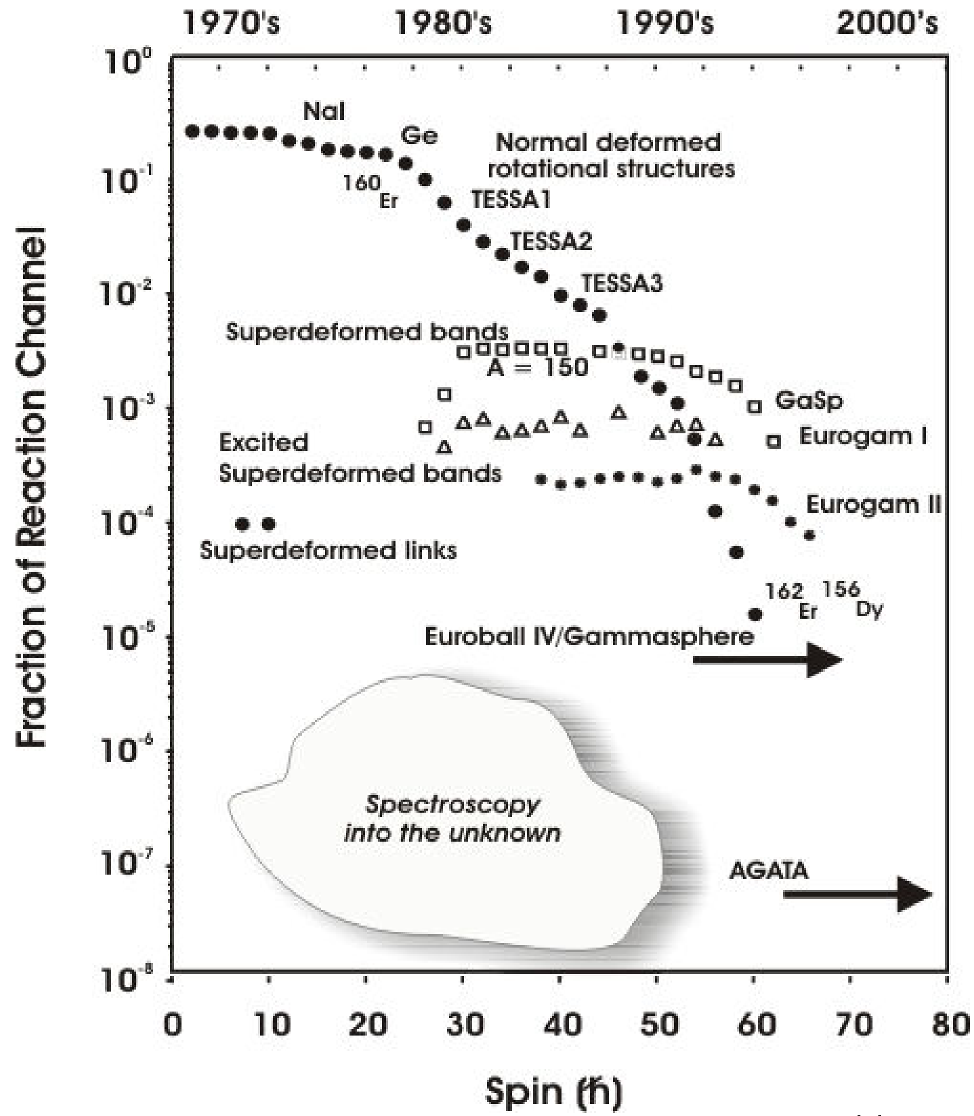
73 M€ Experiments

HISPEC/DESPEC at the low energy branch of the Super FRS



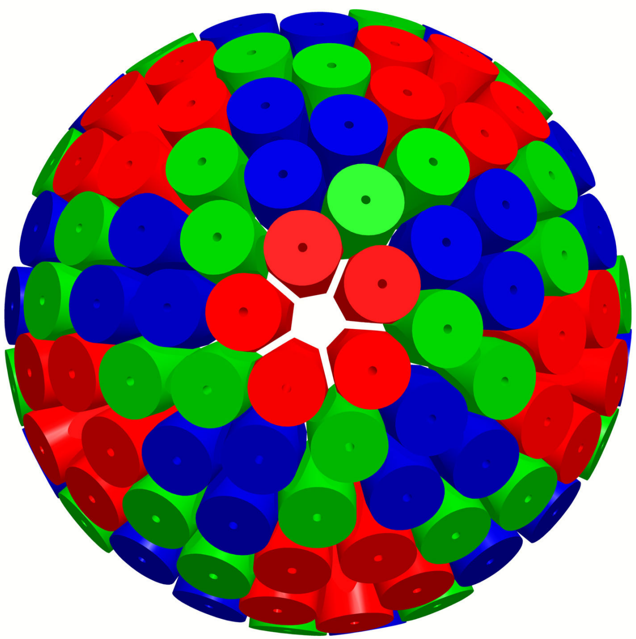
The AGATA spectrometer





AGATA
(Design and characteristics)

4π γ-array for Nuclear Physics Experiments at European accelerators providing radioactive and stable beams



Main features of AGATA

Efficiency: 43% (M_γ=1) 28% (M_γ=30)
today's arrays ~10% (gain ~4) 5% (gain ~1000)

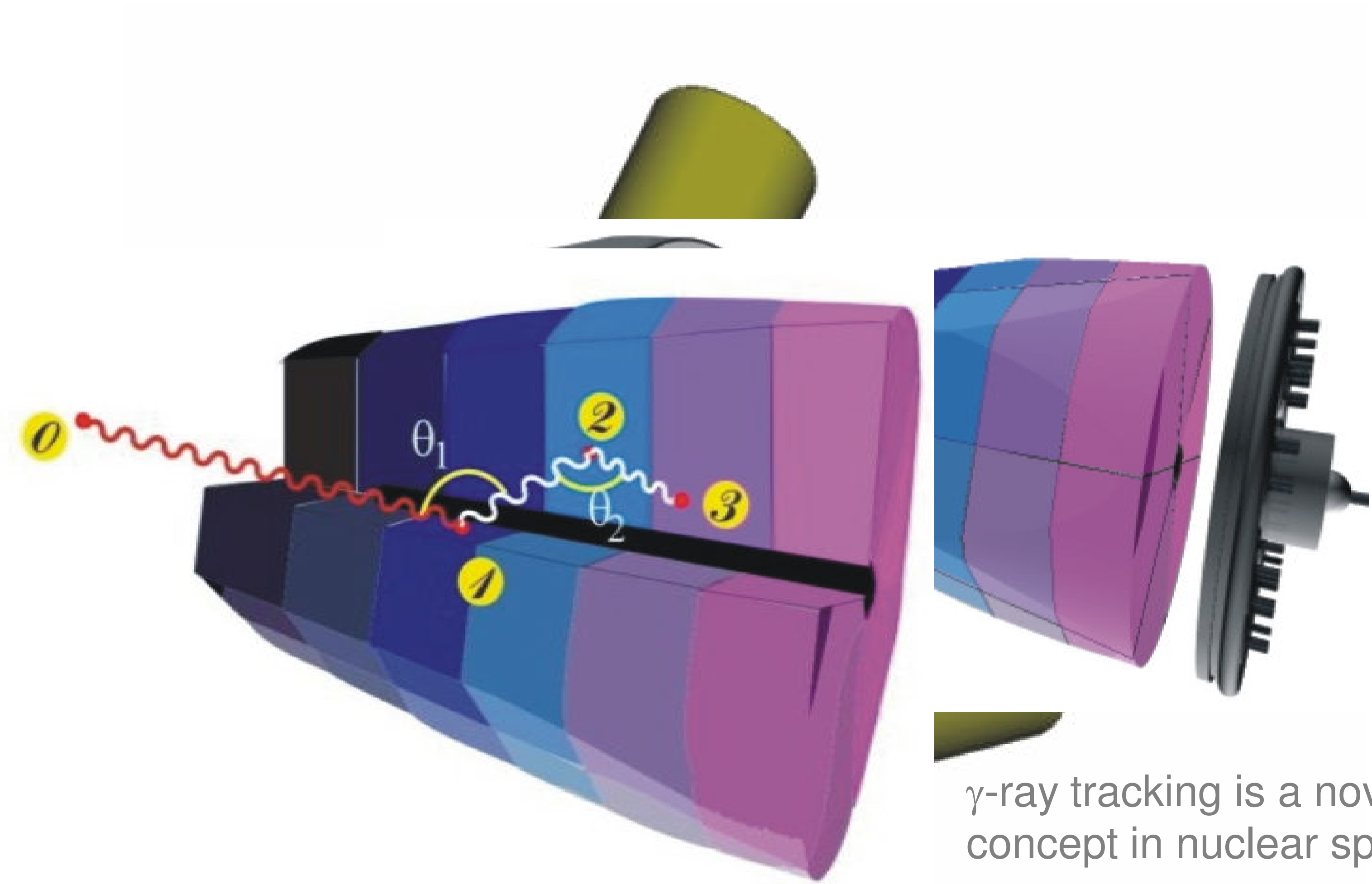
Peak/Total: 58% (M_γ=1) 49% (M_γ=30)
today ~55% 40%

Angular Resolution: ~1° →
FWHM (1 MeV, v/c=50%) ~ 6 keV !!!
today ~40 keV

Rates: 3 MHz (M_γ=1) 300 kHz (M_γ=30)
today 1 MHz 20 kHz

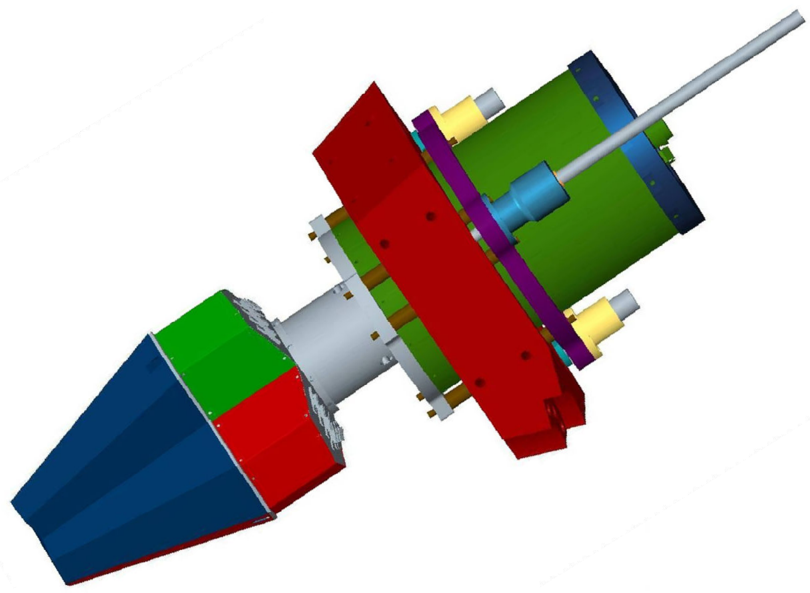
- 180 large volume 36-fold segmented Ge crystals in 60 triple-clusters
- Digital electronics and sophisticated Pulse Shape Analysis algorithms allow
- Operation of Ge detectors in position sensitive mode → γ-ray tracking

What is AGATA



γ-ray tracking is a novel concept in nuclear spectroscopy

AGATA triple-detector module



First prototype summer 2005

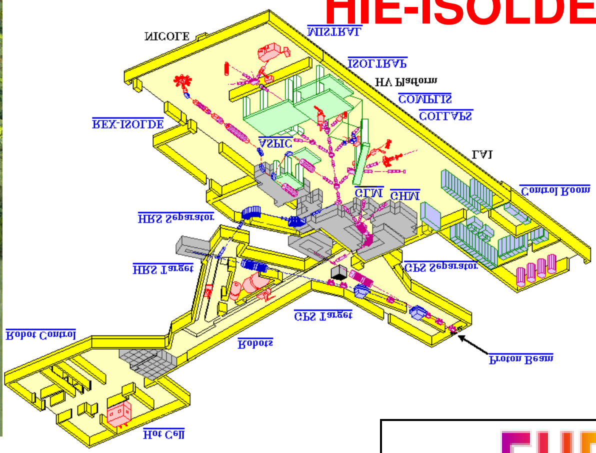
3 encapsulated Ge crystals in one cryostat

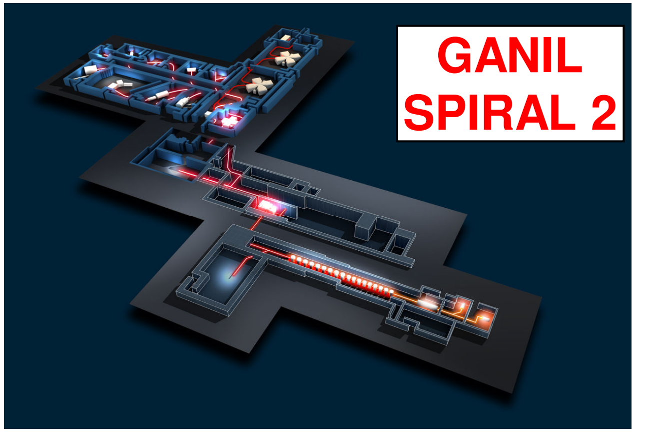
111 preamplifiers with cold FET

~230 vacuum feedthroughs

LN_2 dewar, 3 litre, cooling power ~8 watts

HIE-ISOLDE

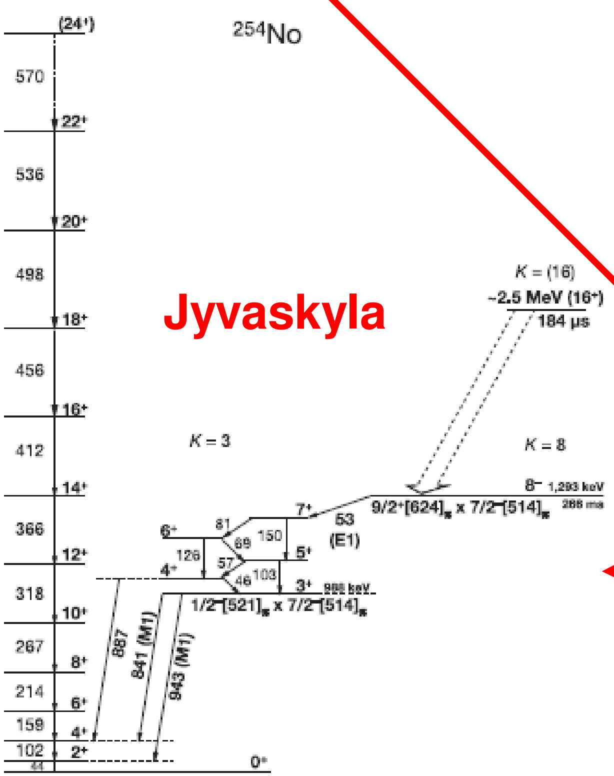




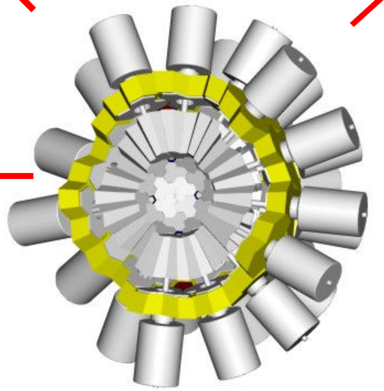
EURISOL
European Separator On-Line
Radioactive Nuclear Beam Facility

INSTRUMENTATION

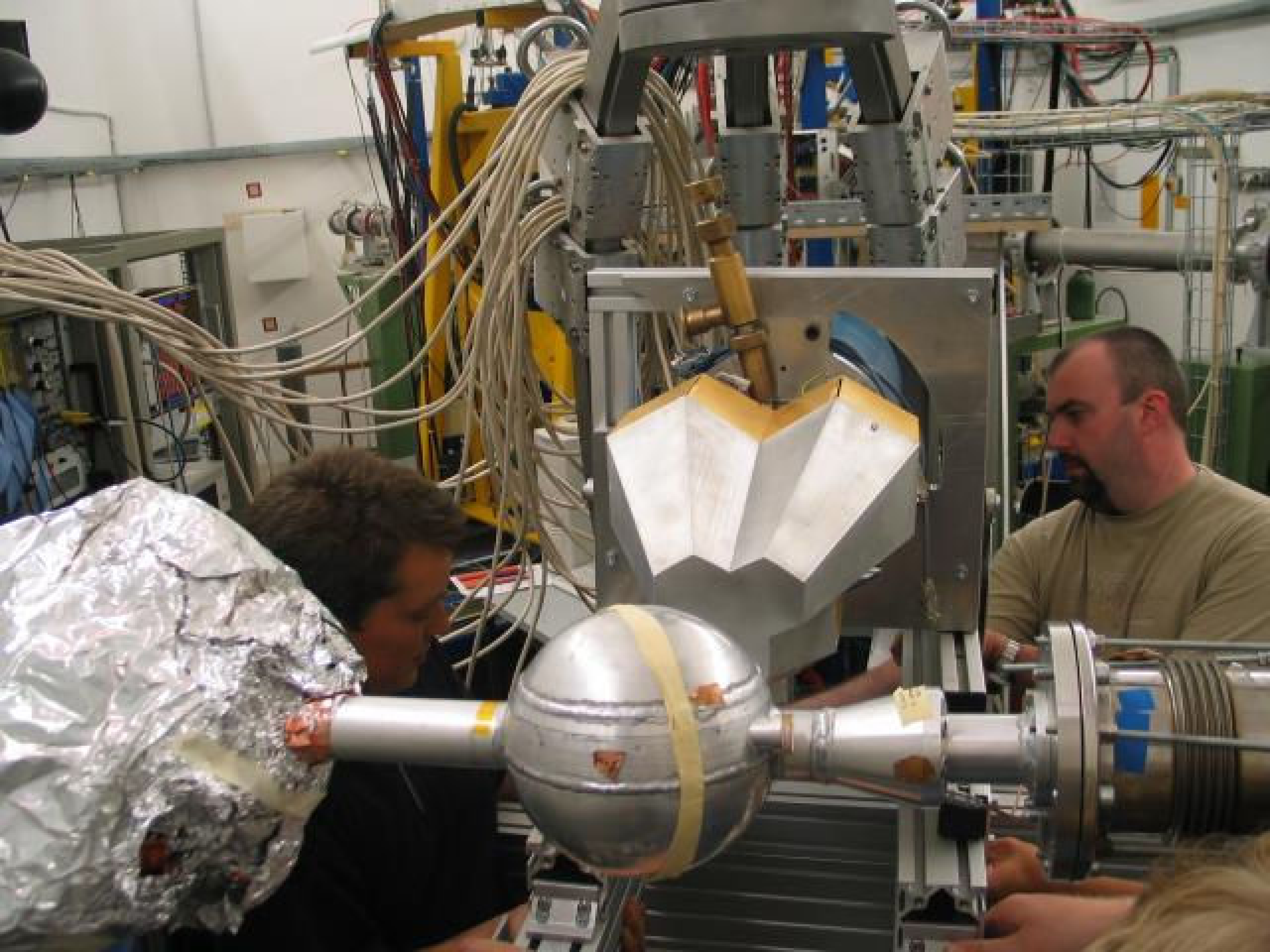
Jyvaskyla



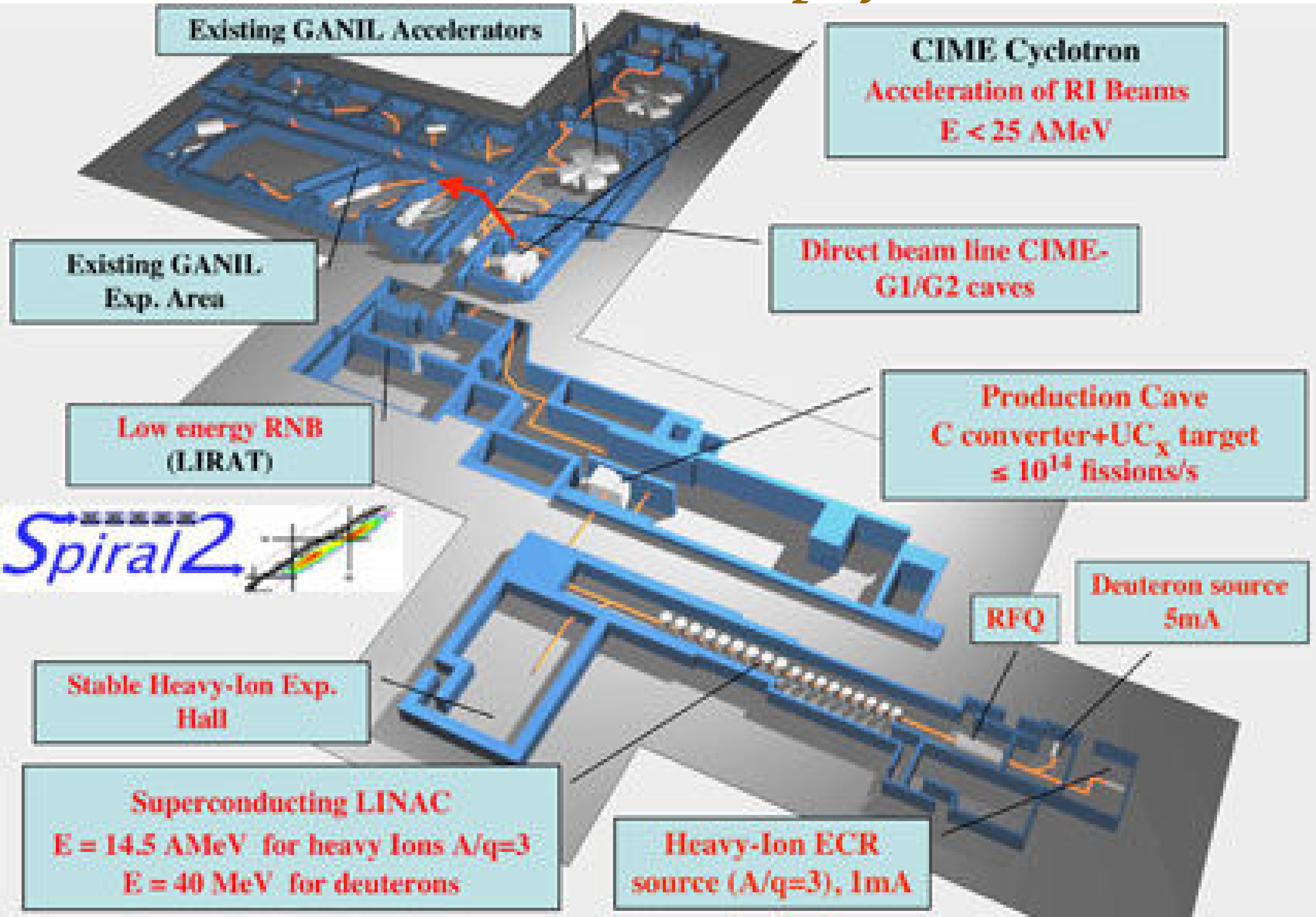
AGATA



LEGNARO



The SPIRAL 2 project



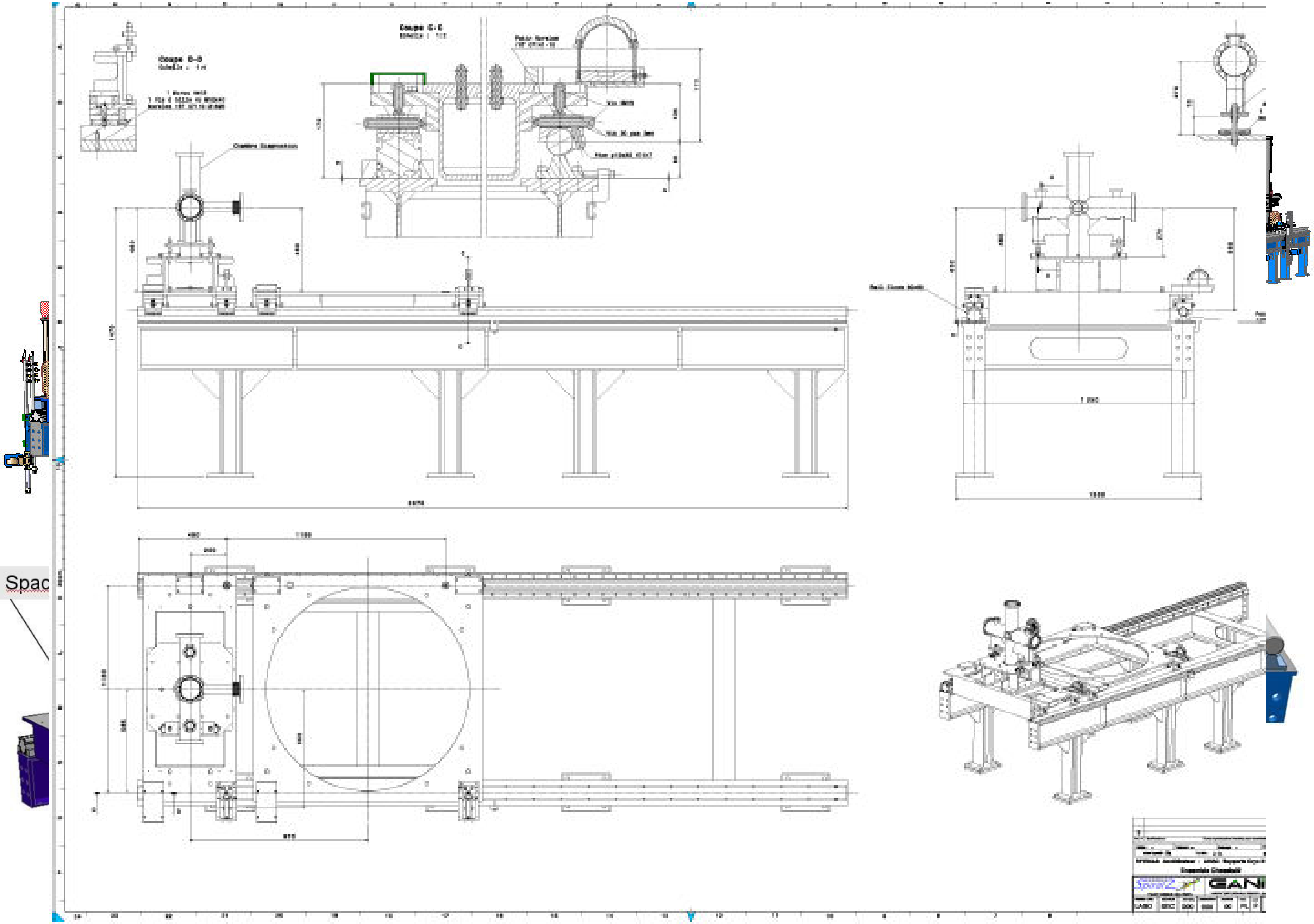
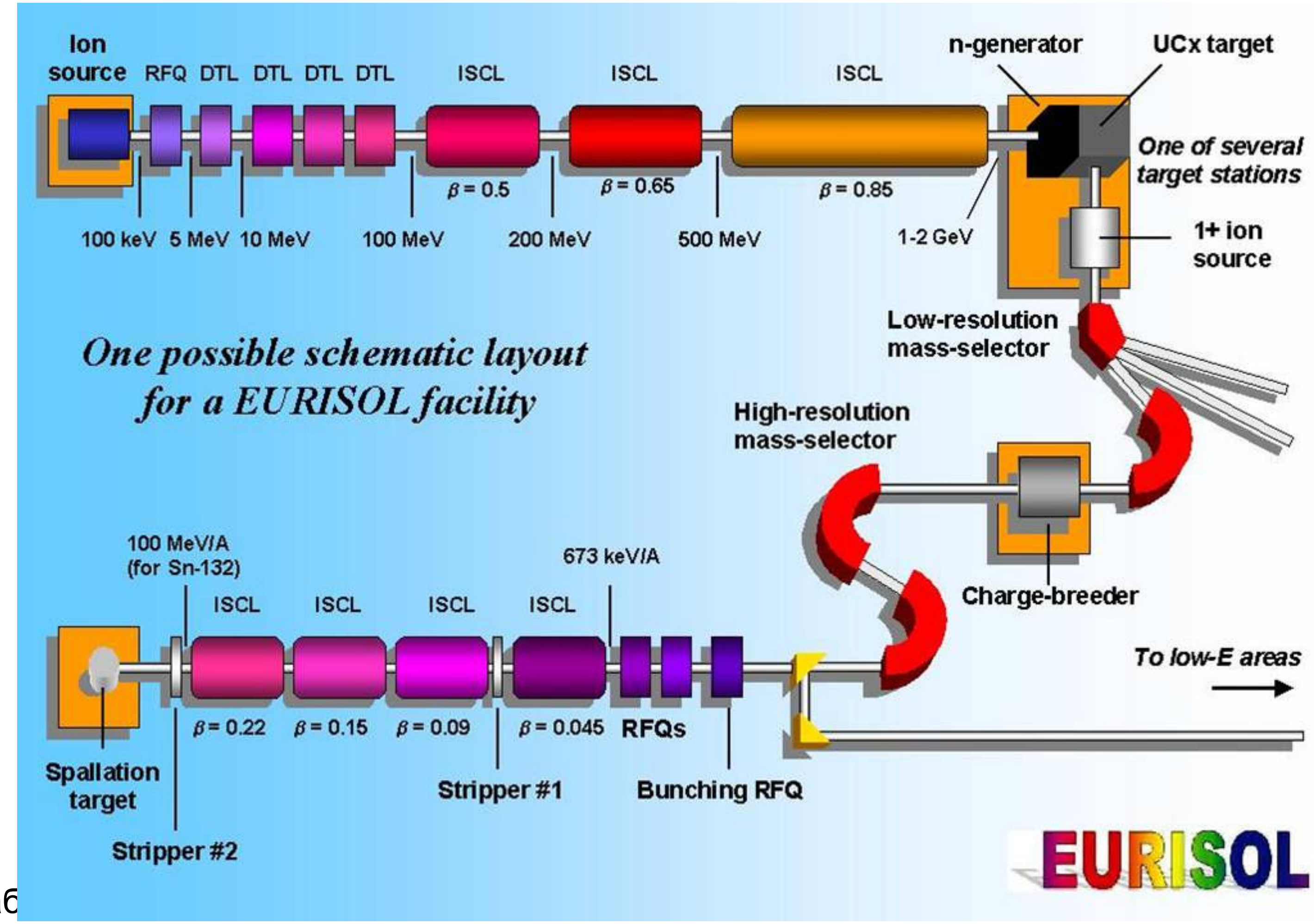


Figure 8 : Prototype assembly drawing

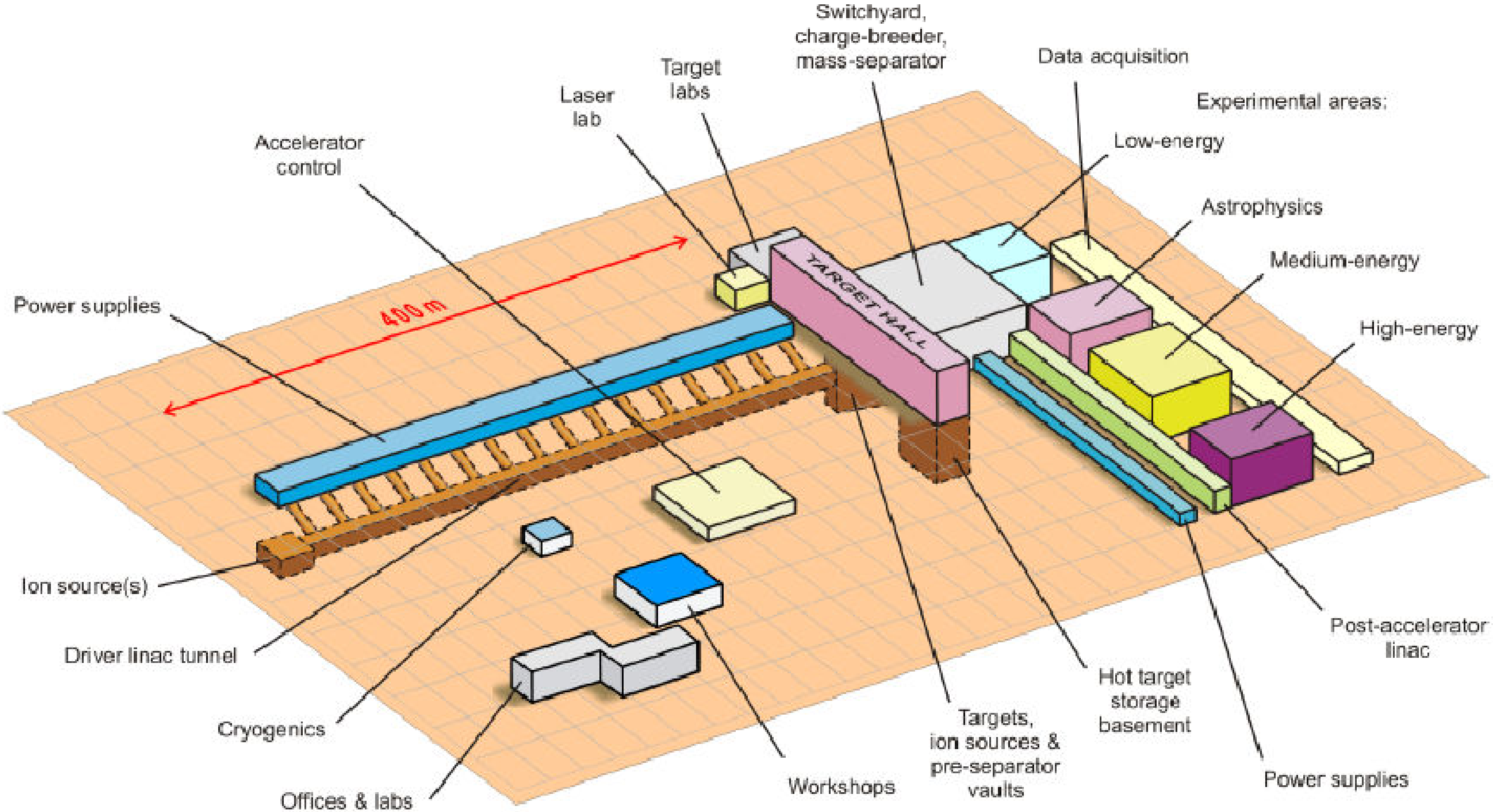
The EURISOL Concept
(based on 5th framework RTD)

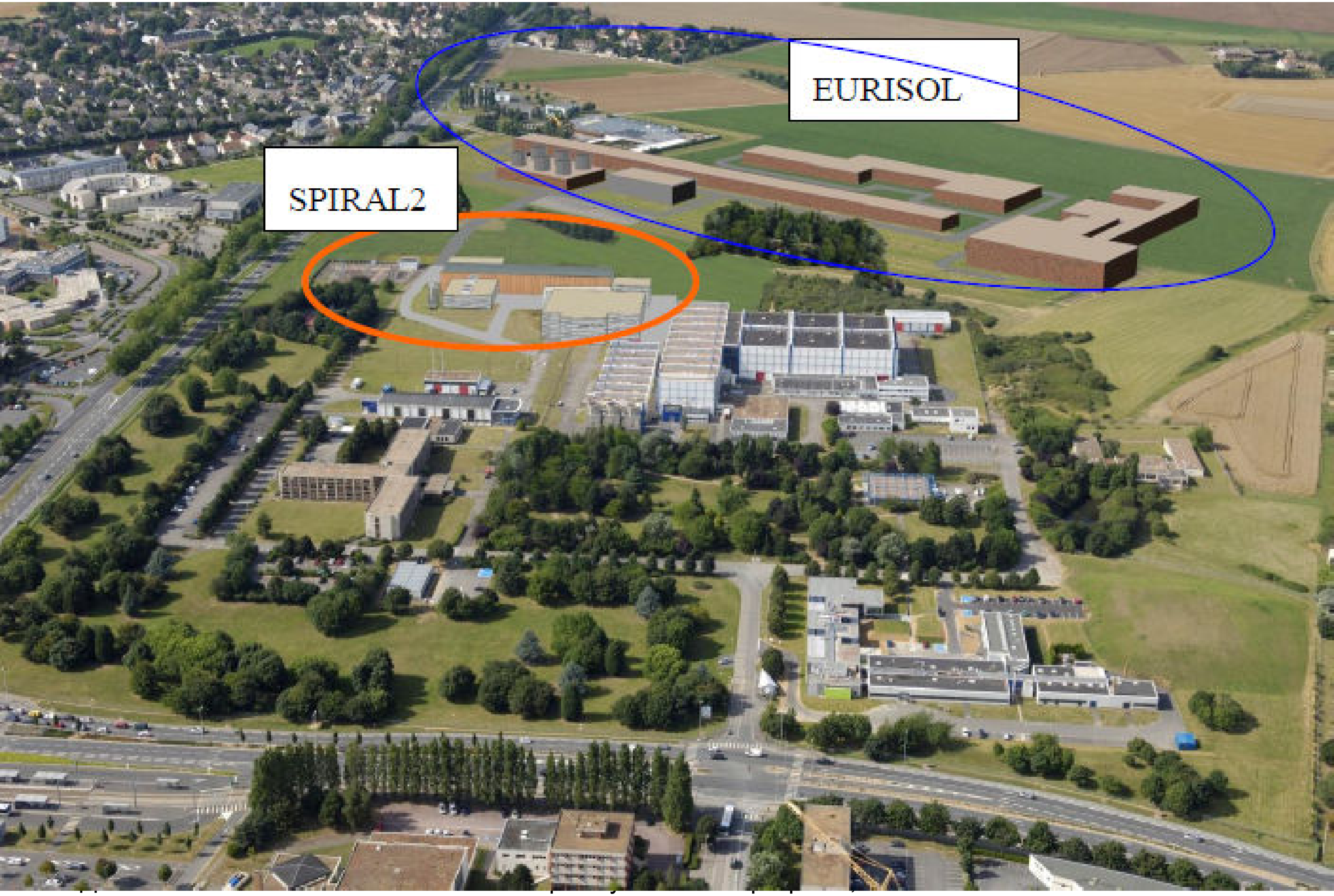


EURISOL: The Main Challenges

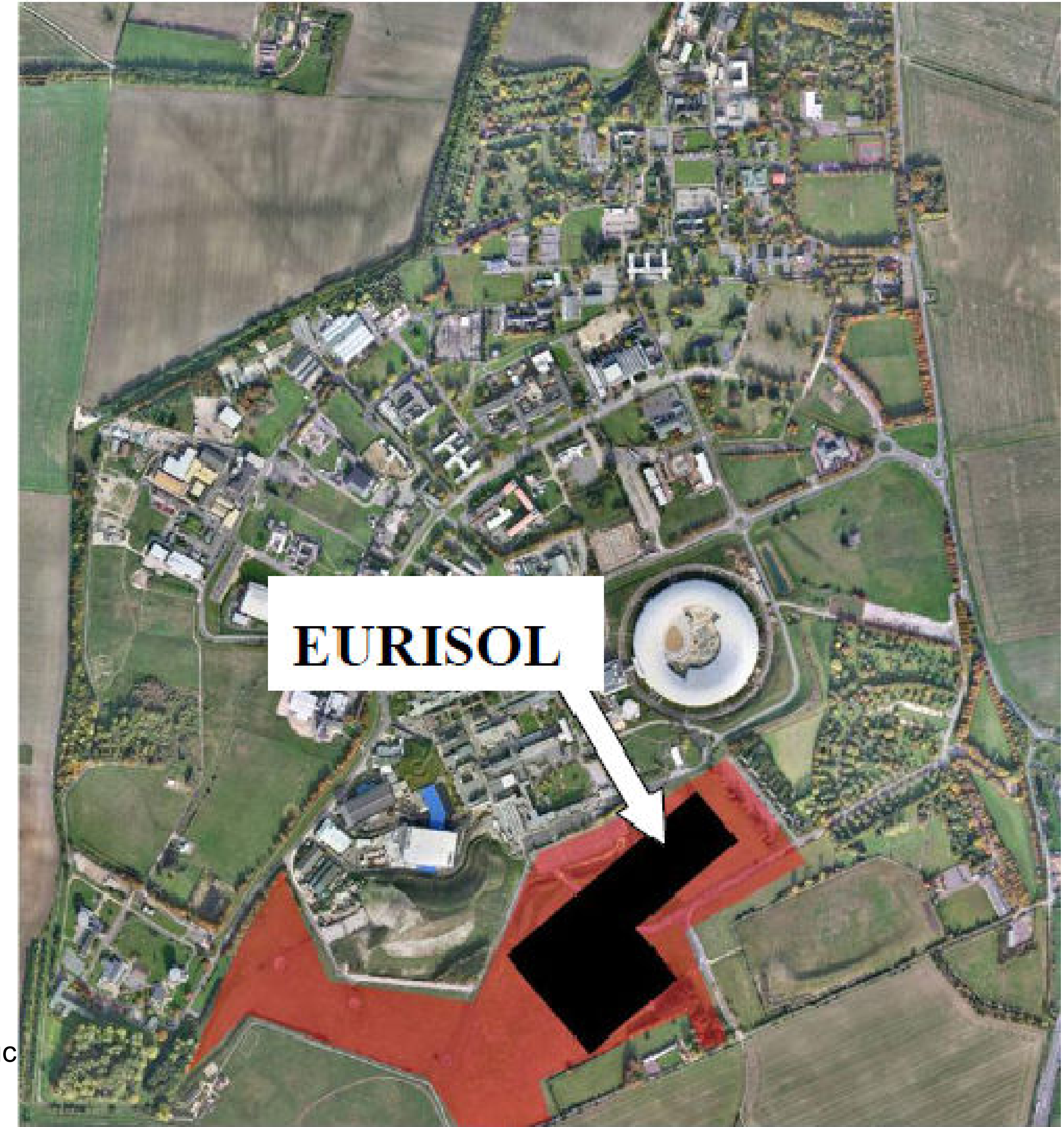
- Design a 5MW; 1GeV proton driver with additional capability of 200 AMeV deuterons and A/Q=2 Heavy Ions; build and test prototypes of the cavities.
- Design a liquid Hg converter which will accept 5 MW of beam power.
- Design a UCx target which will make the most efficient use of the neutrons produced.
- Evaluate the safety constraints of the above set up.
- Design an efficient multi-user beam distribution system.
- Design a superconducting HI LINAC capable of accelerating ^{132}Sn up to 150 AMeV
- Investigate technologies for the instrumentation of the future
- Provide a conceptual study for a beta-beam neutrino facility.

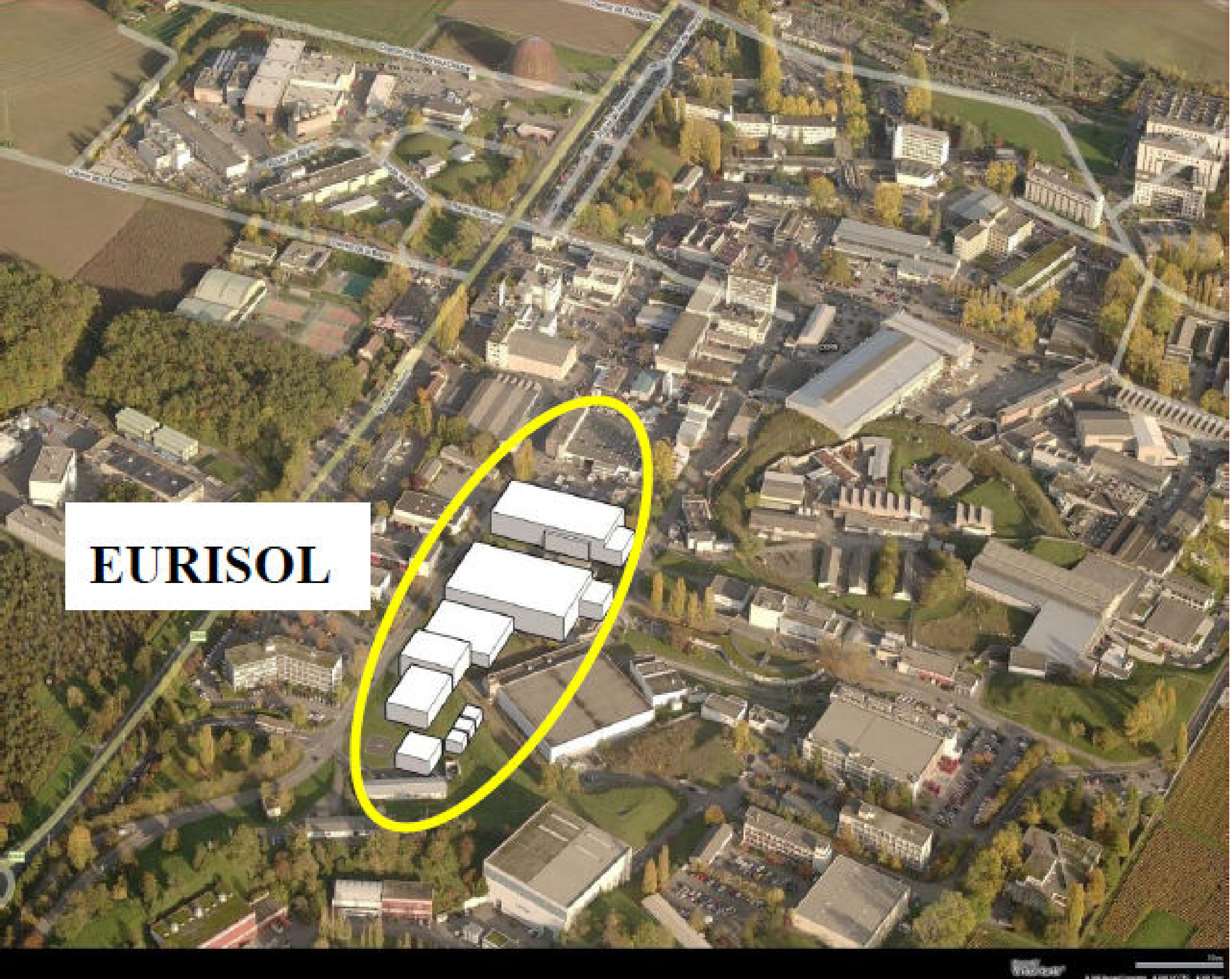
EURISOL layout




EURISOL
SPIRAL2

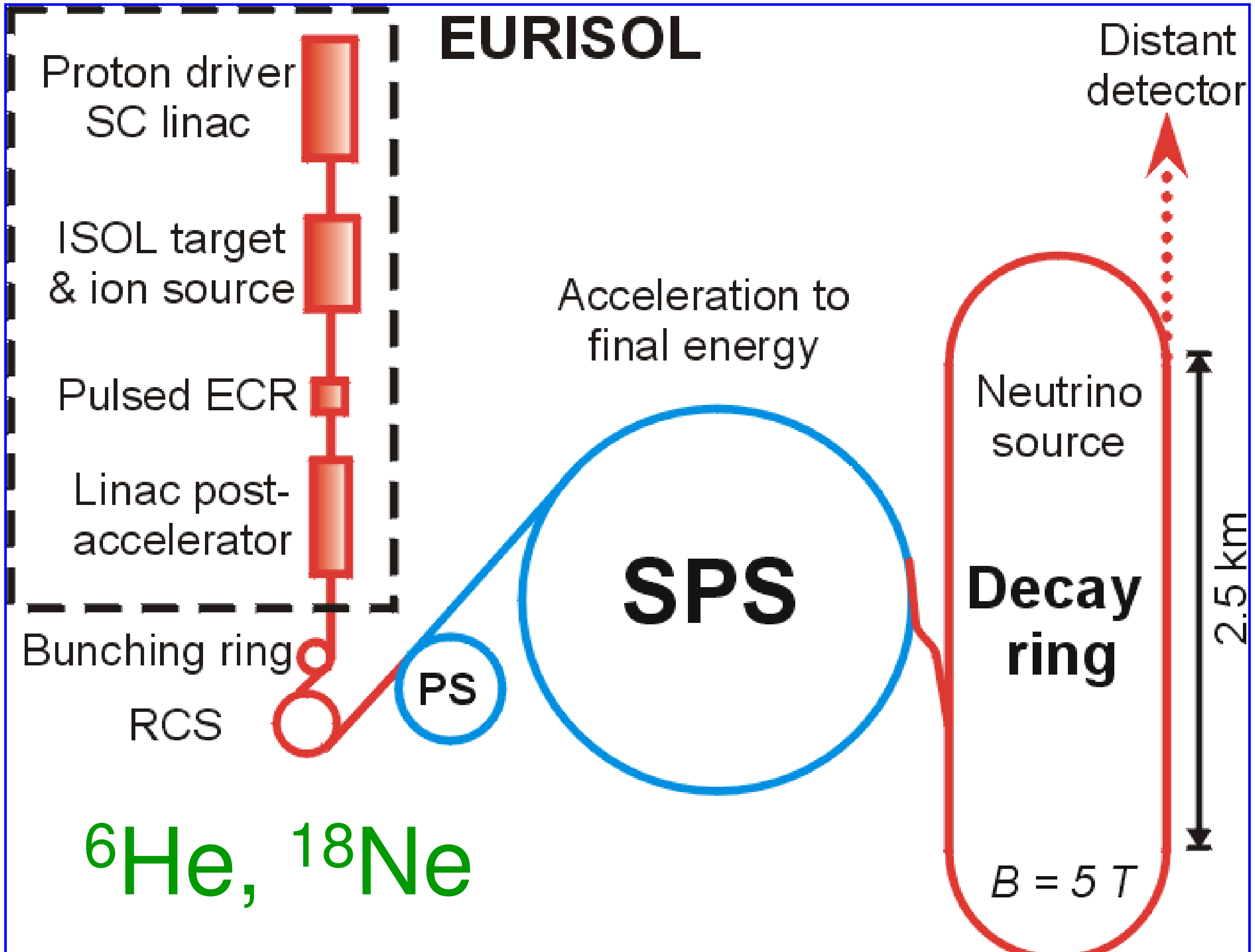

EURISOL


EURISOL


EURISOL

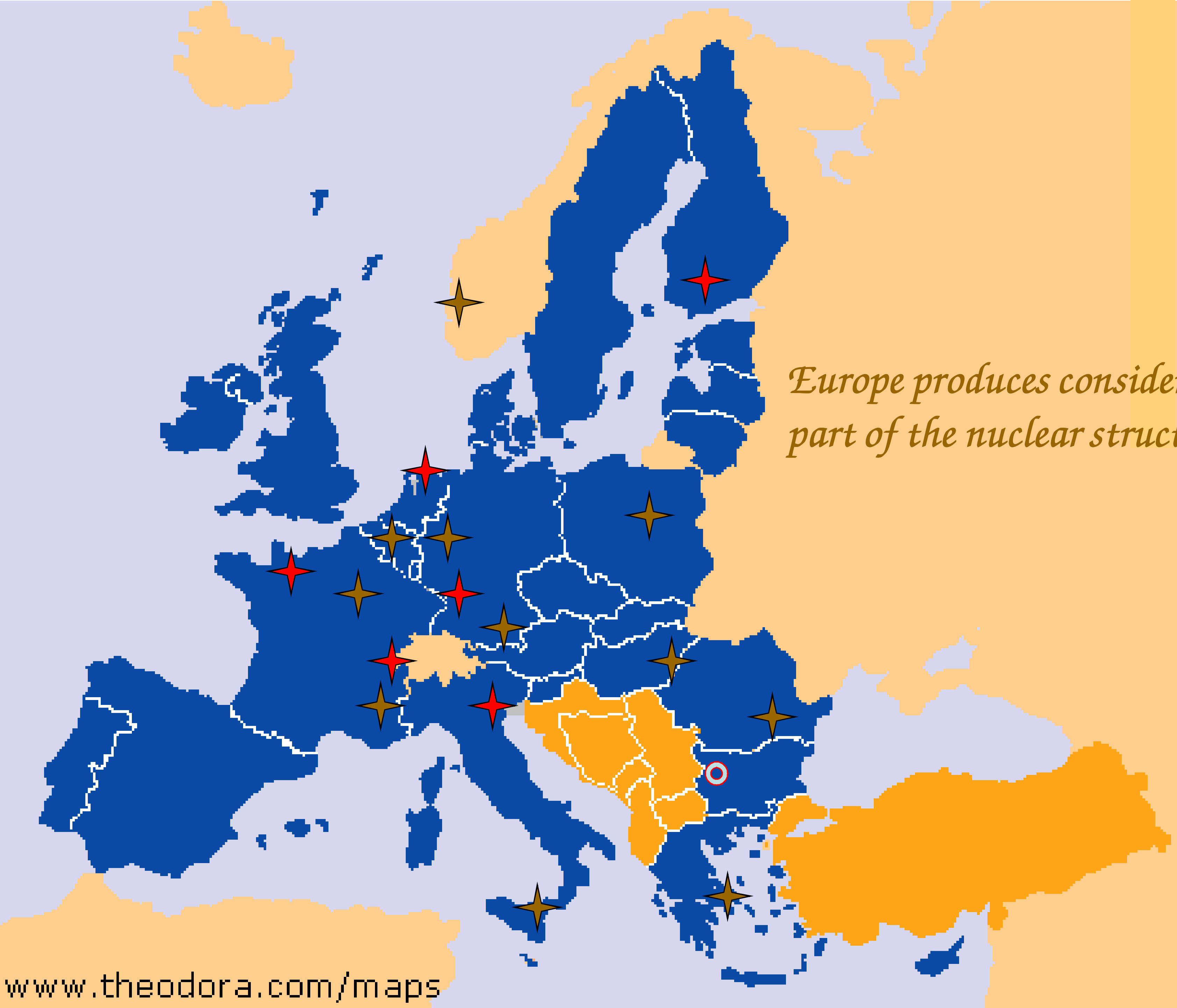
Beta-Beams

a collaboration between Nuclear and Particle communities



^{6}He, ^{18}Ne

From: Mats Lindroos, CERN



Europe produces considerable part of the nuclear structure data