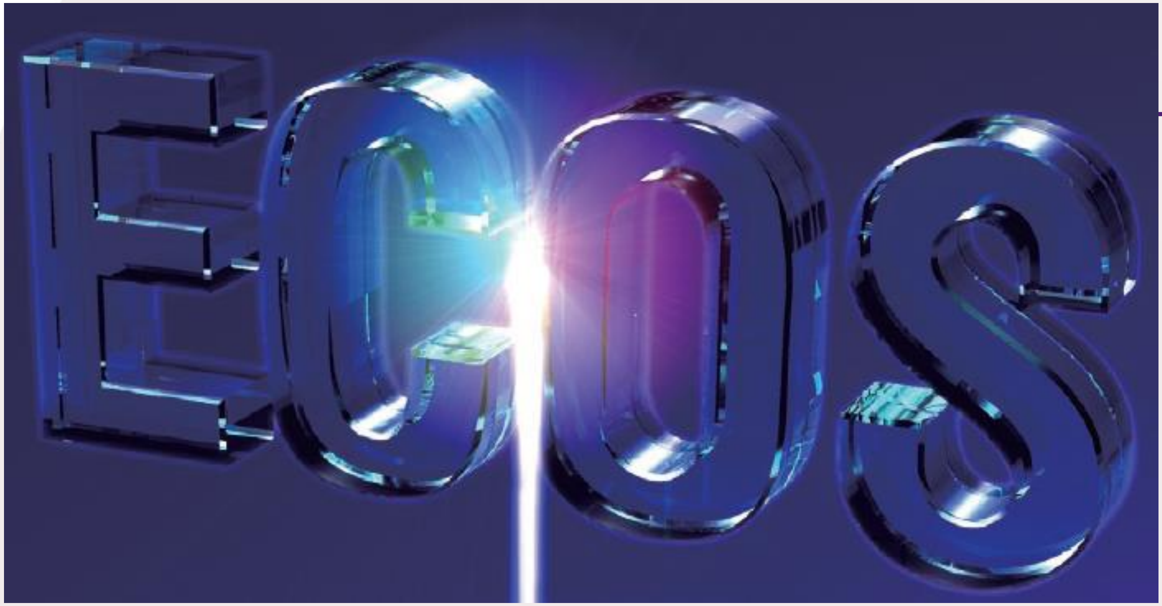
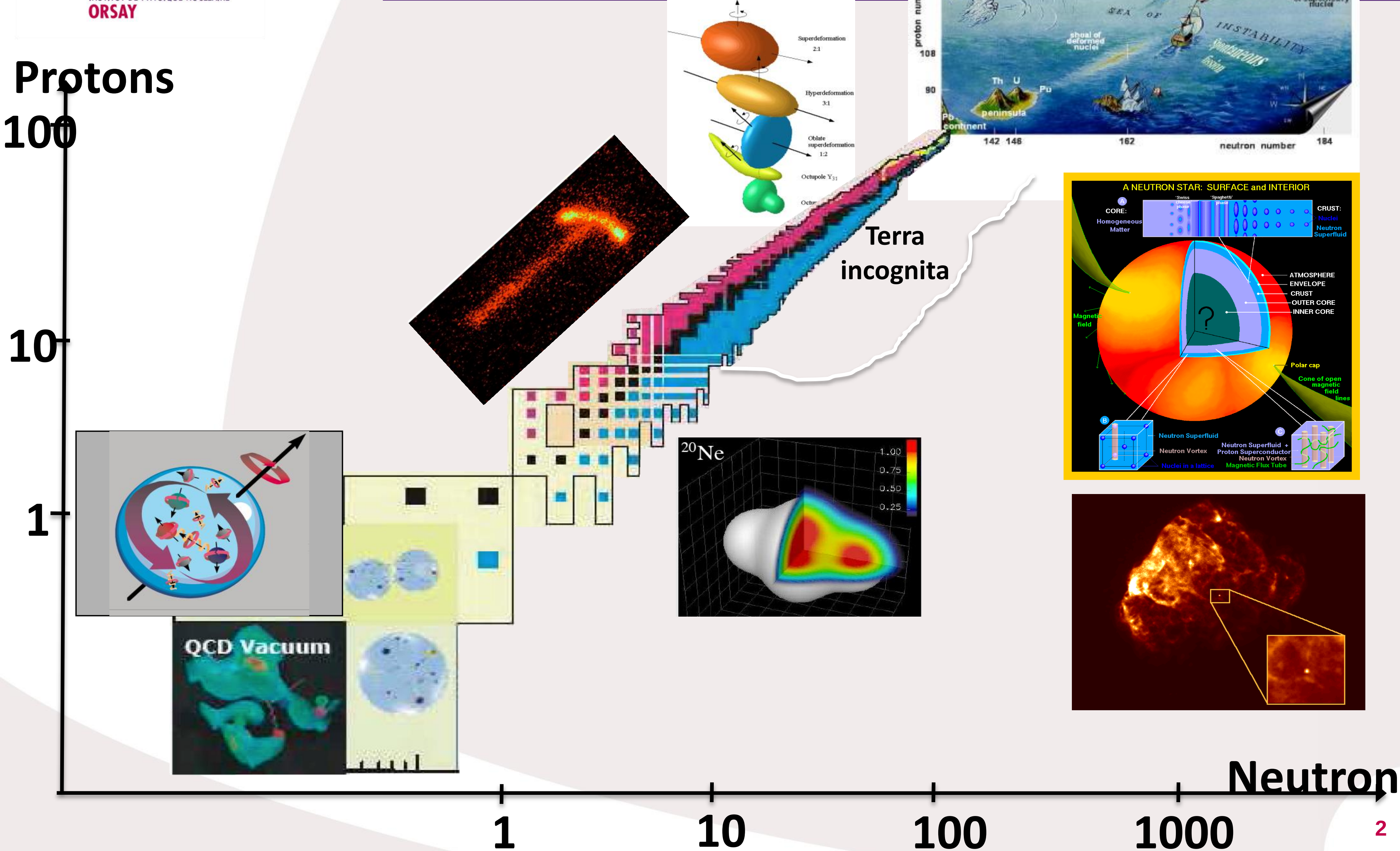
F. Azaiez
IPN
INSTITUT DE PHYSIQUE NUCLÉAIRE
ORSAY



The European Collaboration for Stable Ion Beams – ECOS

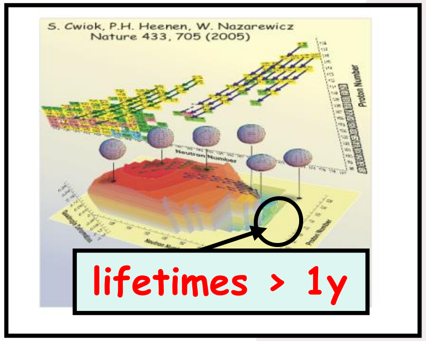
Pushing the limits with high intensity stable beams

98% of the visible mass is due to the Stong interaction



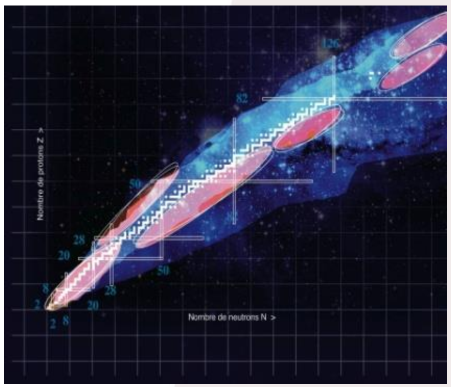
IPN INSTITUT DE PHYSIQUE NUCLÉAIRE ORSAY

Science Key Questions

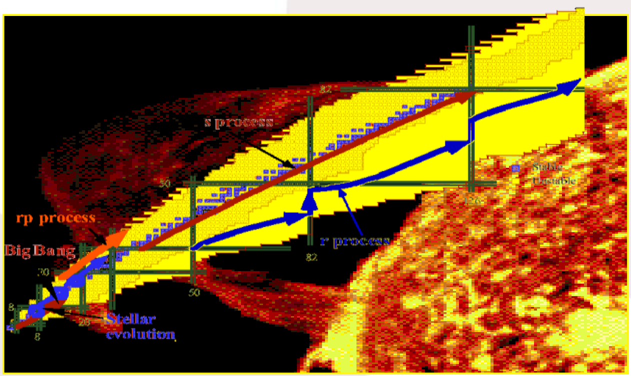


What are the limits of the heaviest elements?

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



What are the limits of stability?



How the elements are made in the Universe?

After the NuPECC town-meeting (GSI-2004)

Letter to NuPECC:

…..We have been discussing such a project in many of the European countries and we are now in the process of forming a working group at the European level for finalizing the physics case and launching the design study related to this project. We believe that NUPECC should play an important role by endorsing the promotion and coordination of the project. While the European Long Range Plan document related to nuclear structure includes in some of its sections the need for a high intensity stable beam facility for the nuclear structure study, the recommendations elaborated during the last town-meeting did not mention this need at all. In order to preserve the vitality of the nuclear structure field and the nuclear physics community, we suggest the recommendations to be completed by including "direct support for new actions towards a European high-intensity stable beam facility", besides the presently expressed "strong support to maintain and develop the current stable beam facilities in Europe"…..

Two important arguments ….

i) Using stable beams facilities and new generation of detection techniques, the low energy nuclear physics community has proven to be impressively productive with new results and future perspectives!

ii) Some of the key questions in the nuclear structure field are and will remain for the coming 10 years well addressed using the state of the art detection systems and <u>higher</u> intensity stable beams!

the ECOS 'Working Group'

2005-2010

INSTITUT DE PHYSIQUE NUCLÉAIRE
ORSAY

ECOS: European COnsortium for Stable (ion beams)

Marie-Helene Moscatello / M. Levitowicz (GANIL)
Annamaria Porcellato (Legnaro)
Uli Ratzinger (GSI)

Sigurd Hofmann (GSI)
Rauno Julin (JYFL)
Faisal Azaiez (IPN-Orsay)
Jacomo Deangelis (Legnaro)
Rolf-Dietmar Herzberg (Liverpool)

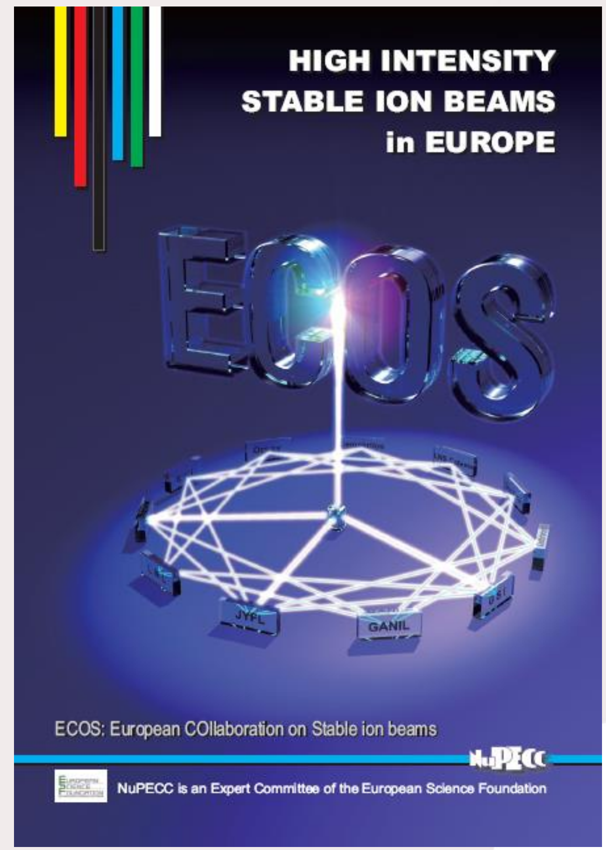
Task: Produce a document to NUPECC with:

--The Science with high intensity stable ion beams, Beam intensity limitations and technical developments for various types of research lines!
--Status and future developments of existing facilities
--Recommendations

INSTITUT DE PHYSIQUE NUCLÉAIRE ORSAY

--The Science with high intensity stable ion beams, Beam intensity limitations and technical developments for various types of research lines!

N=Z nuclei (in–beam spectroscopy and decay studies) : *G. DeAngelis*
SHE search : *S. Hofmann*
Super heavy nuclei (in-beam spectroscopy and decay studies) : *R. D. Herzberg*
Neutron-deficient nuclei (in-beam spectroscopy and decay studies) : *R. Julin*
Exotic shapes and decay modes in nuclei : *F. Azaiez*
Neutron rich nuclei using DIC reactions : *F. Azaiez & G. DeAngelis*
Nuclear astrophysics*: S.V. Harissopulos*



--Status and future developments of existing facilities

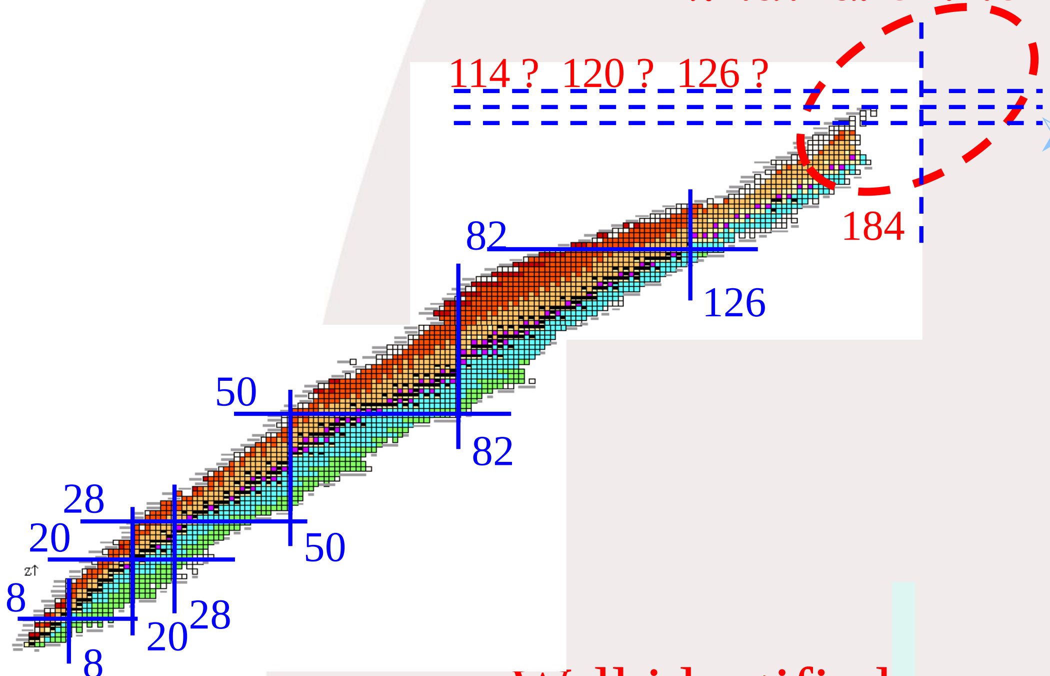
LEGNARO : *A. Porcellato*
GANIL : *M. H. Moscatello/M. Lewitovicz*
GSI : *S. Hofmann&U. Ratzinger*
JYVASKYLA : *R. Julin*
KVI *: S. Brandenburg*
CATANIA: *S. Gammino*

--Conclusions and Recommendations

Some of the key questions in the Nuclear structure field are and will remain for the coming 10 years well addressed using the state of the art detection systems and higher intensity stable beams!

SHE: Where the isle of stability is located?

what are the corresponding shell effects ?



➤ testing spin-orbit and more generally effective interactions at the extreme!

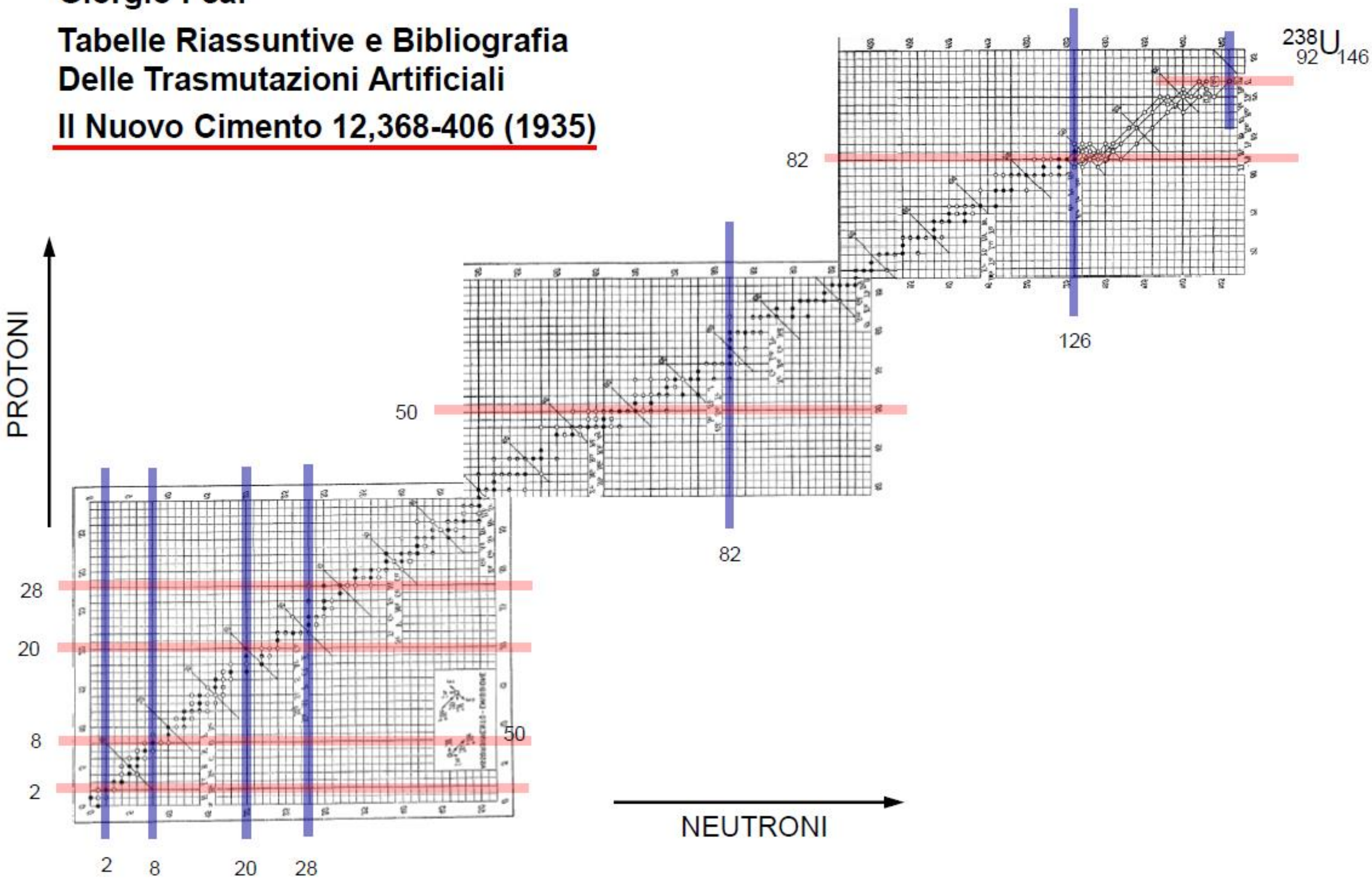
Well identified research program:

-Systematic search of SHE
-Study of the 'stabilizing' shell structure
-Study of complete fusion - fission processes

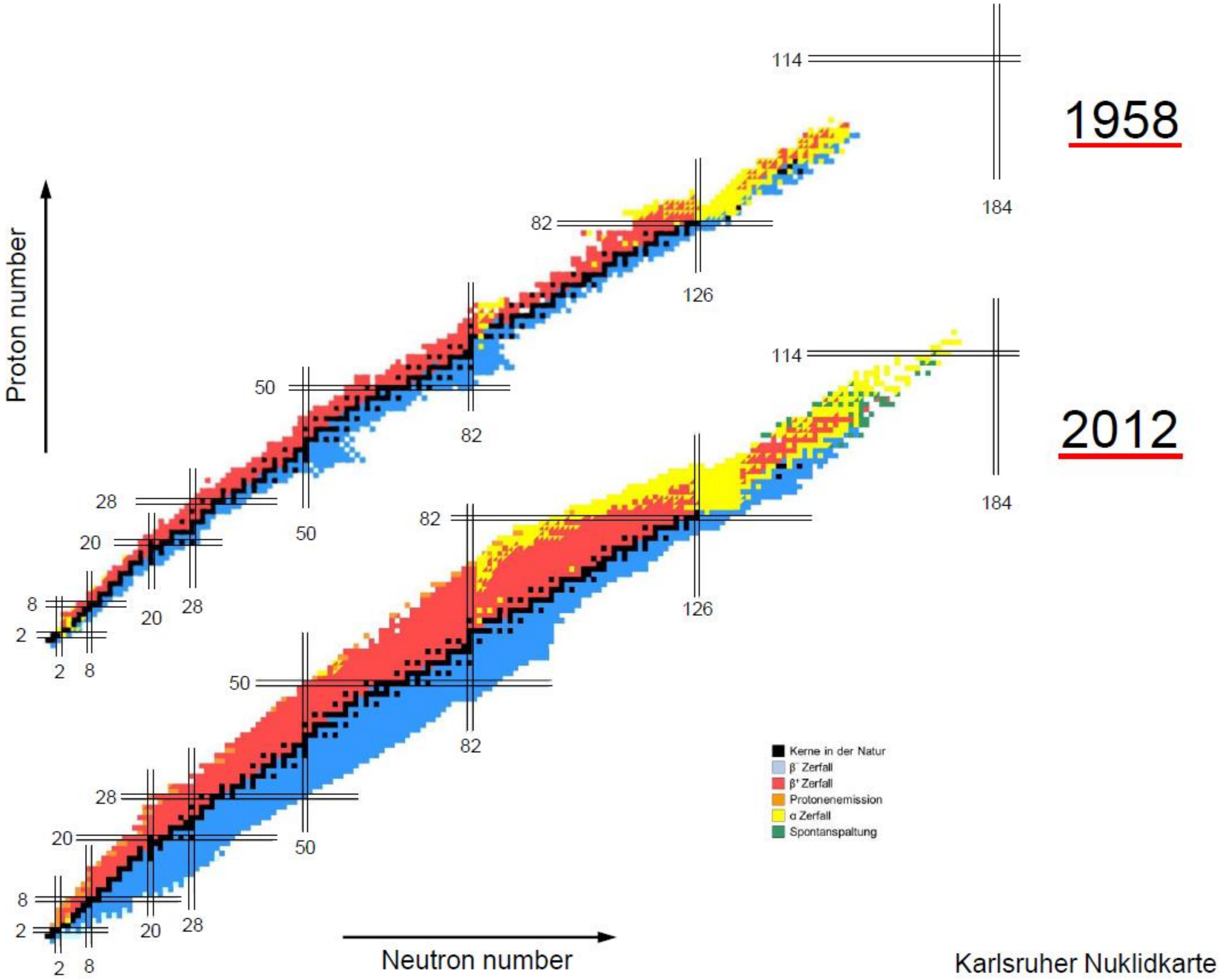
Giorgio Fea:

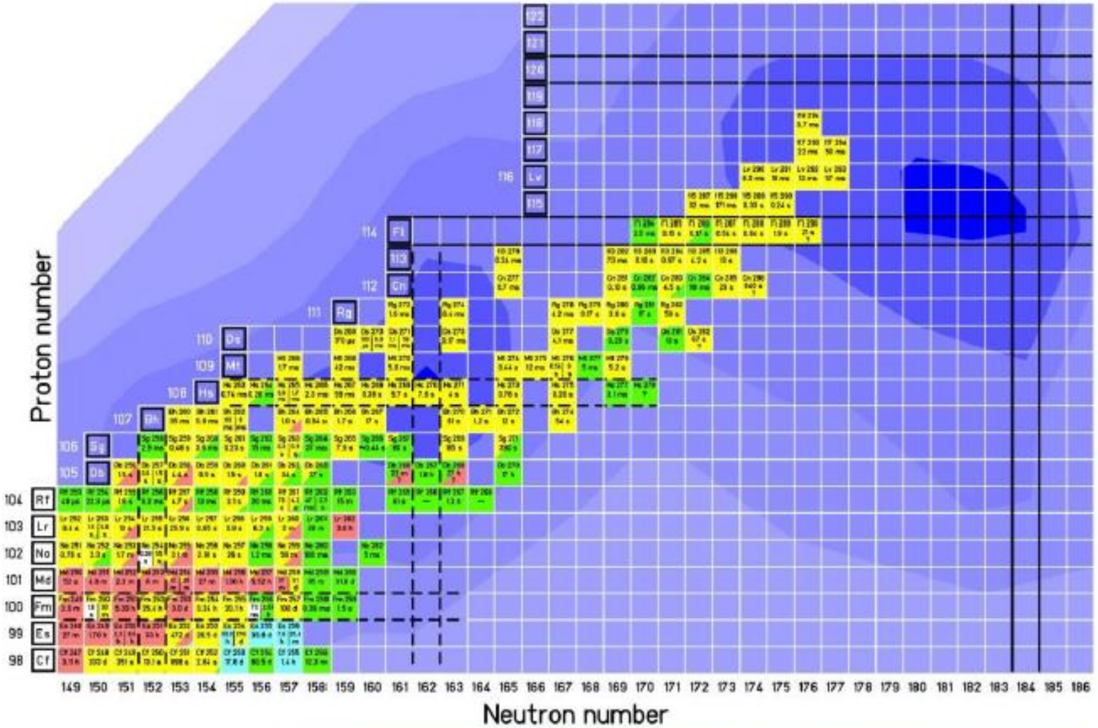
Tabelle Riassuntive e Bibliografia Delle Trasmutazioni Artificiali

Il Nuovo Cimento 12,368-406 (1935)

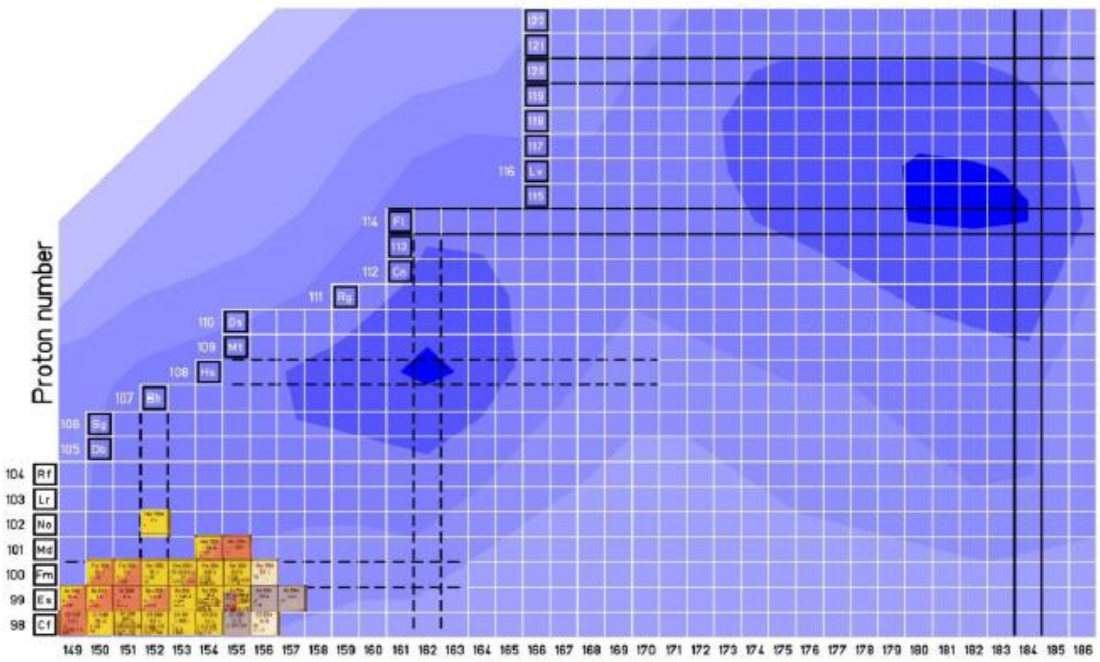


Ringrazio vivamente il Prof. F. RASETTI e il Prof. E. SEGRÈ, che mi sono stati di prezioso consiglio e aiuto in questo lavoro.


1958
2012
Proton number
Neutron number
114
184
82
126
50
28
20
8
2
Kerne in der Natur
β⁻ Zerfall
β⁺ Zerfall
Protonenemission
α Zerfall
Spontanspaltung
Karlsruher Nuklidkarte

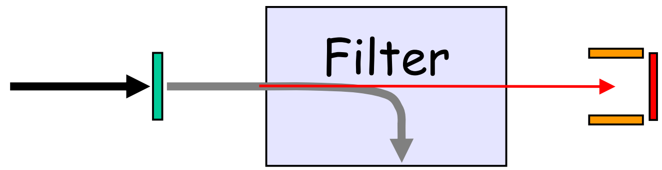

Proton number
Neutron number
98 Cf
99 Es
100 Fm
101 Md
102 No
103 Lr
104 Rf
105 Db
106 Sg
107 Bh
108 Hs
109 Mt
110 Ds
111 Rg
112 Cn
113
114 Fl
115
116 Lv
117
118
119
120
121
122
149 150 151 152 153 154 155 156 157 158 159 160 161 162 163 164 165 166 167 168 169 170 171 172 173 174 175 176 177 178 179 180 181 182 183 184 185 186

2015


Proton number
98 Cf
99 Es
100 Fm
101 Md
102 No
103 Lr
104 Rf
105 Db
106 Sg
107 Bh
108 Hs
109 Mt
110 Ds
111 Rg
112 Cn
113
114 Fl
115
116 Lv
117
118
119
120
121
122
149 150 151 152 153 154 155 156 157 158 159 160 161 162 163 164 165 166 167 168 169 170 171 172 173 174 175 176 177 178 179 180 181 182 183 184 185 186

1958

• Experimental Thechniques



$$N_{SHE} \propto \sigma \,.\, N_i \,.\, N_t \,.\, \varepsilon_f \,.\, \varepsilon_d$$

N_i : number of incident ions

➢ beam intensity

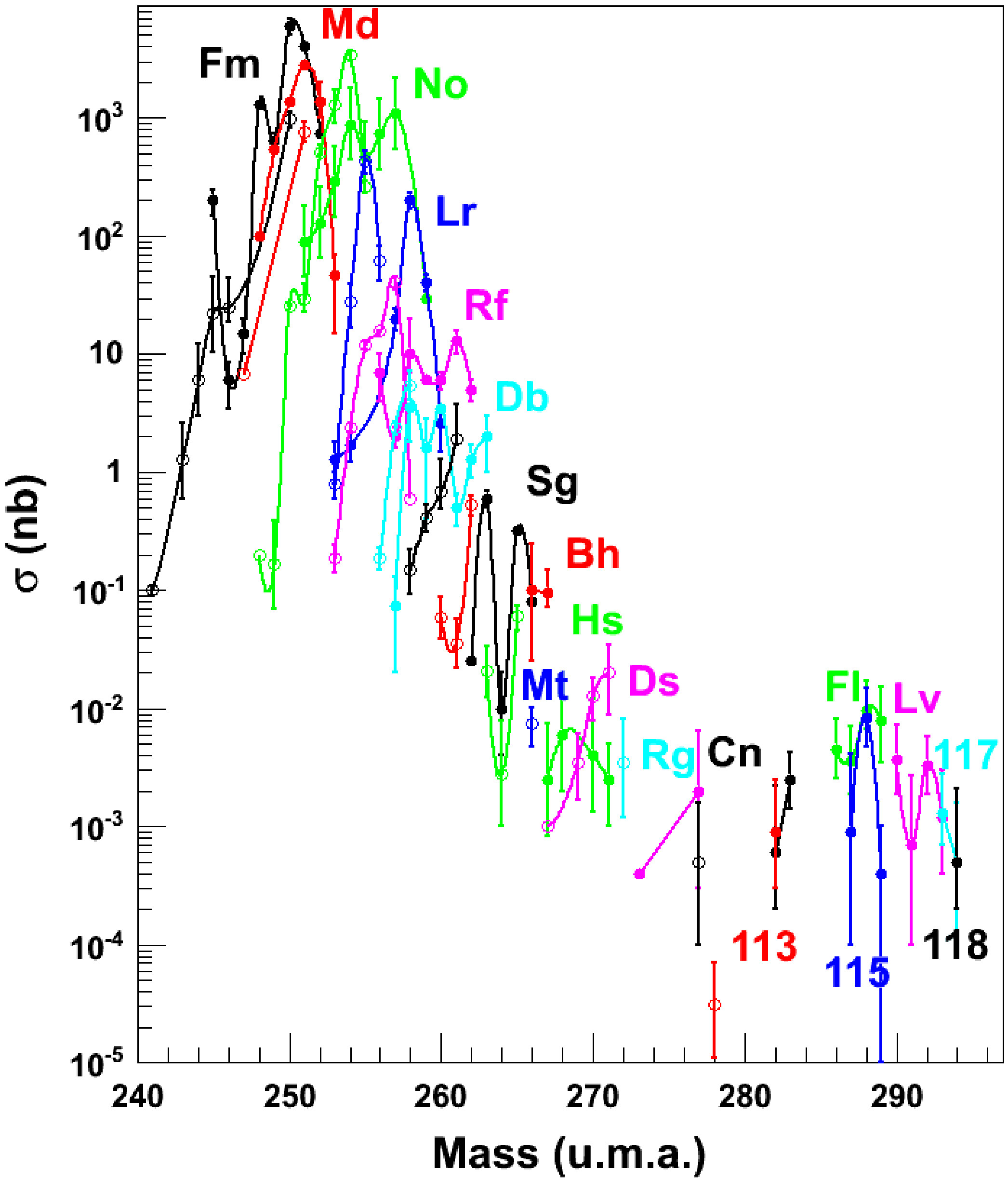
N_t: number of target ions

ε_f : selection efficiency → ~ 65%

ε_d : detection efficiency → ~ 85%

→ High Intensity beams are essential!

The highest possible intensity (few 100pμA) will be necessary up to *A* = 200 and for energies around the Coulomb barrier.


Fm
Md
No
Lr
Rf
Db
Sg
Bh
Hs
Mt
Ds
Rg
Cn
113
Fl
115
Lv
117
118
σ (nb)
Mass (u.m.a.)
10^3
10^2
10
1
10^-1
10^-2
10^-3
10^-4
10^-5
240
250
260
270
280
290

INSTITUT DE PHYSIQUE NUCLÉAIRE ORSAY

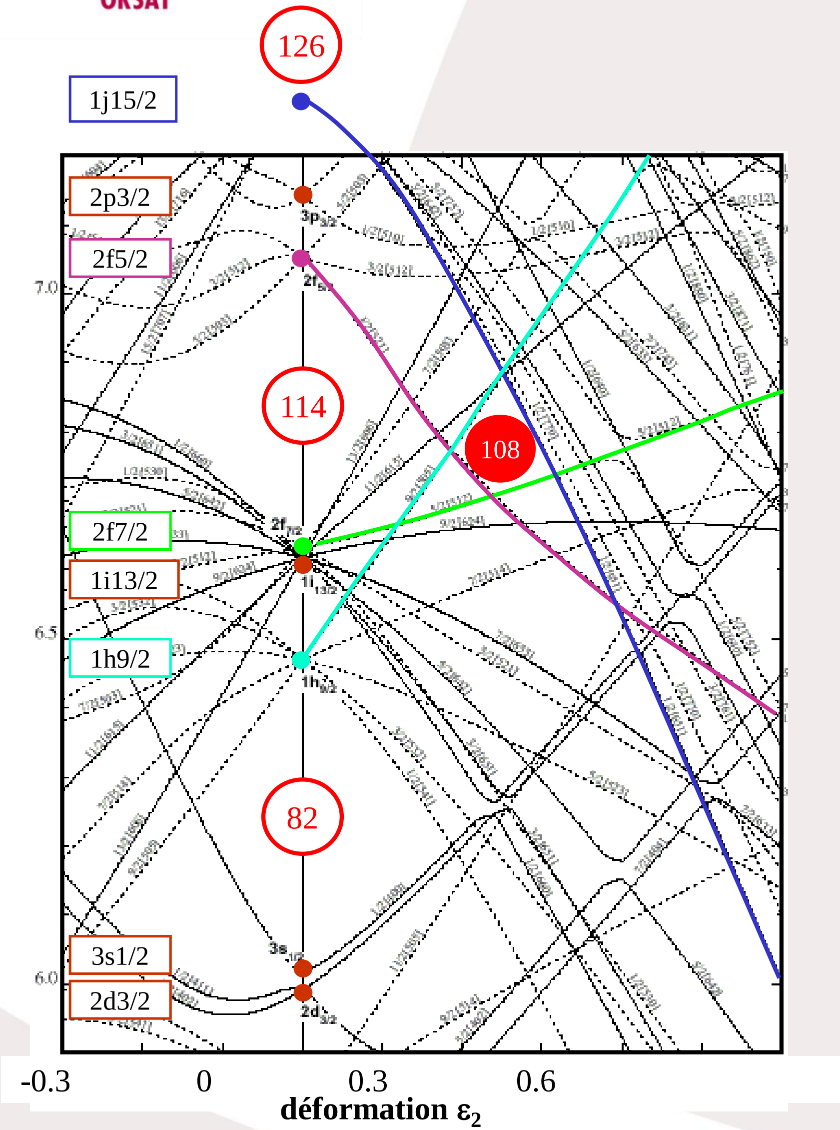
INTENSITIES FOR SHE SYNTHESIS – OVERVIEW: PRESENT AND FUTURE

	FLNR (*)	RIKEN (*)	GSI (*)	GANIL (*)
Beam time (days/ year)	~ 120 (→ 300)	~ 300	~ 100 (→ 300)	~ 15 (→ 200)
Duty factor	100%	100%	25% (→ 100%)	100%
Beam intensity on target (^{48}Ca)	≈ 1,0 pμA (→15)	≈ 0,7 pμA	≈ 1,2 pμA (→20)	≈ 1 pμA (→ 10)
projectiles / year **Luminosity (fb^{-1})**	**≈ $0,6 \times 10^{20}$** **0,1**	**≈ $1,1 \times 10^{20}$** **0,2**	**≈ $0,6 \times 10^{20}$** **0,1**	**≈ $0,08 \times 10^{20}$** **0,01**
Future: **Projectiles / year** **Luminosity (fb^{-1})**	**SHE factory:** **≈ $2,3 \times 10^{21}$** **4**		**sc cw linac:** **≈ $6,2 \times 10^{21}$** **9**	**LINAG:** **≈ $1,0 \times 10^{21}$** **2**

(*) all numbers represent typical average numbers (as of today) and best realistic estimates for the future; beam intensities refer to 48Ca

(**) integrated luminosities: assuming targets with $1,5 \times 10^{18}$ at/cm2 (~600 $\mu g/cm^2$)

Spectroscopy to probe Shell Structure of Super-heavy Nuclei



What is the sequence of single particle states and what are the resulting energy gaps in the super-heavy nuclei?

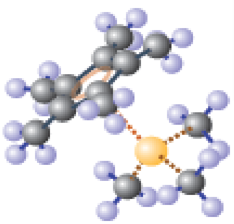
- Prompt γ and e⁻ spectrscopy (in-beam)
- Decay studies (off-beam)

Recent highlights of ion source R&D (2011)

- **Metal ion beam production – first isotopic MIVOC ^{50}Ti beam**

19 μA $^{50}Ti^{11+}$ from 14 GHz ECRIS → 45 pnA on target

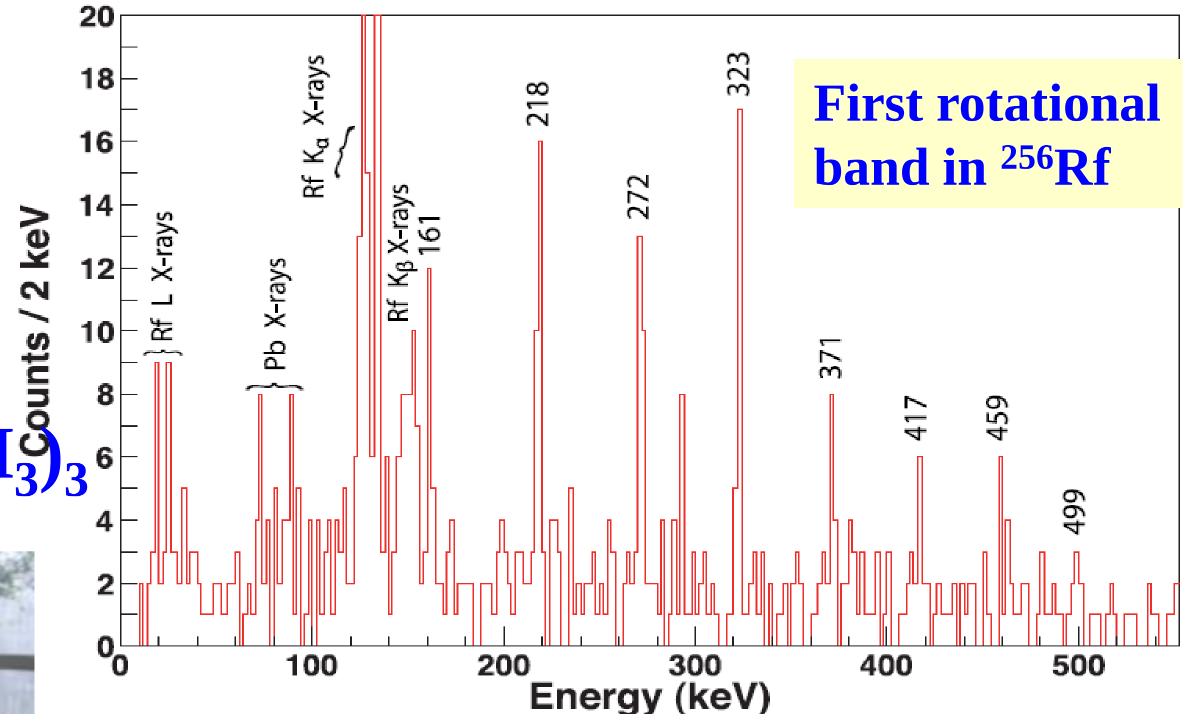
$^{50}Ti + ^{208}Pb \rightarrow ^{256}Rf + 2n$



0.2 mg/hr

Cp*$^{50}Ti(CH_3)_3$

J. Rubert, J. Piot *et al*, NIMB 276 (2012) 33



First rotational band in ^{256}Rf

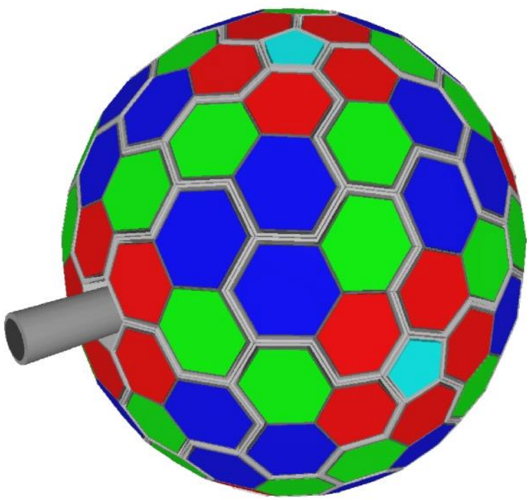
P.T. Greenlees, J. Rubert *et al*, accepted PRL (2012)

In the future

For in-beam γ and e^- spectroscopy

Highly segmented detectors, digital electronics and higher beam intensity (up to few 100pnA)!

Cross section below 100pb will be reachable



high granularity
+
digital electronics, time stamping
Ultra fast processing

AGATA will be able to handle
10 – 100 times more beam

focal plan α, e- and γ-spectroscopy

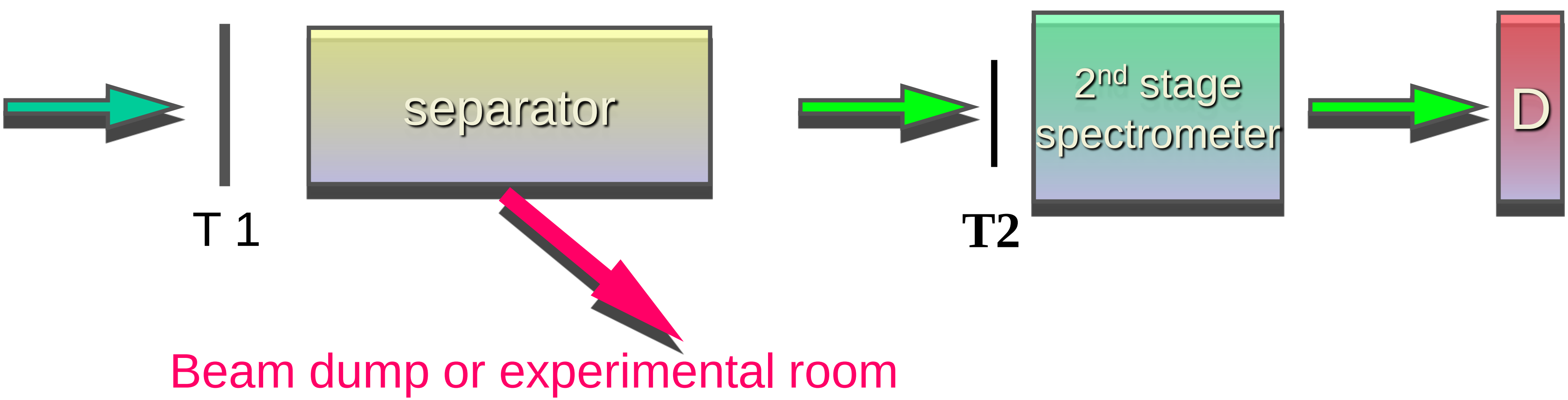
higher beam intensity (up to few tens of pμA)

Cross section down to few pb will be reachable

Secondary reactions at the focal plan (F. Azaiez et al. Spiral2 week 2006):

With very high beam intensity and inverse kinematics,
Coulomb excitation of recoils at the focal plan of the separator will be possible

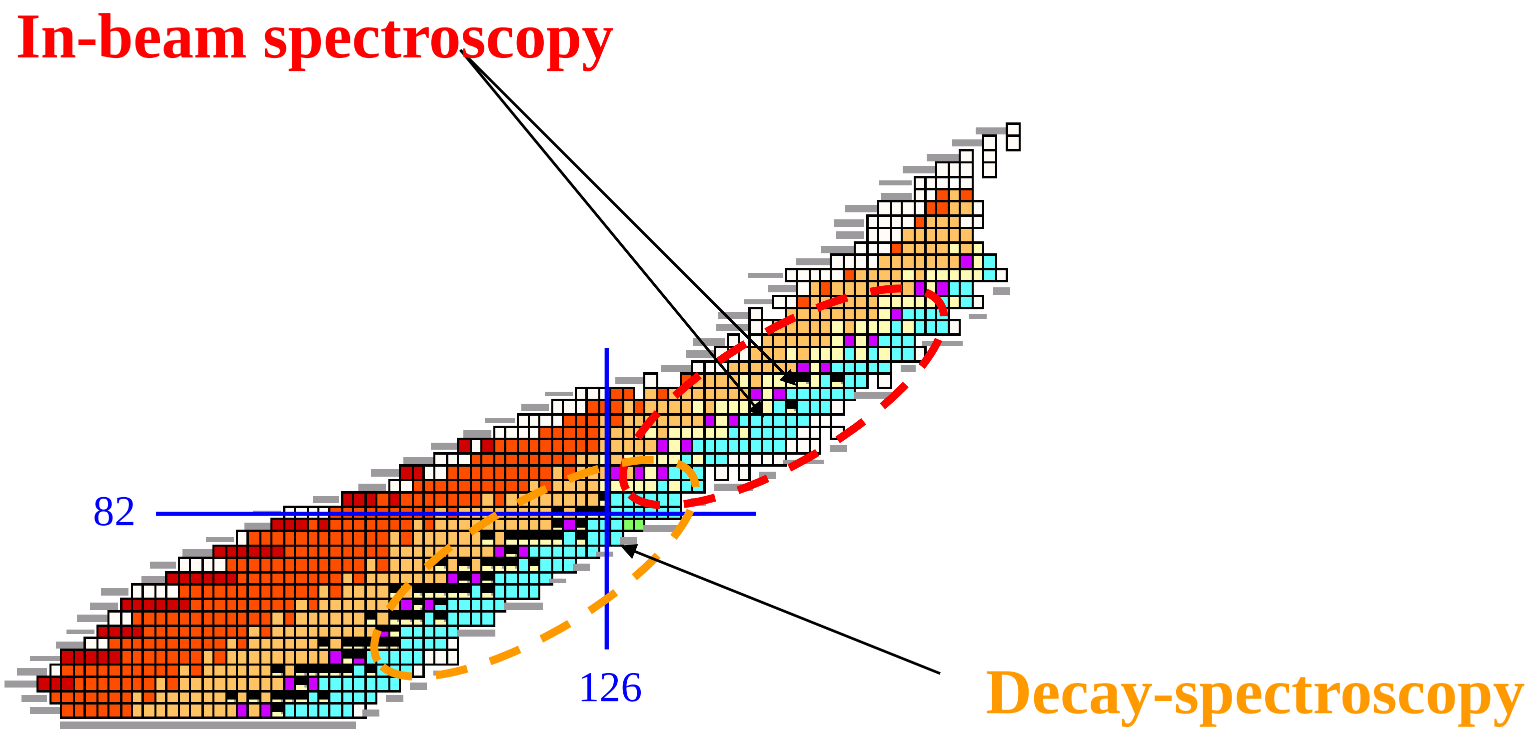
With a pμA primary beam the Coulomb excitation of superheavy nuclei or N=Z nuclei produced with cross section down to the μb becomes feasible



γ and e⁻ spectroscopy using transfer reactions on radioactive targets with high intensity stable beams

few 100pnA

(need radioactive targets and dedicated spectrometer)



Off-beam spectroscopy - Decay studies: up to few 100pμA

(target technology and spectrometer with appropriate rejection power).

Cross section down to 1pb will be reachable!

In-beam γ and e^- spectroscopy :up to few 100pnA

(highly segmented detectors, digital electronics,time stamping)

Cross section below 100pb will be reachable!

The low energy nuclear structure community has well defined and promising research programs for the future. Many of them are based on measurements to be carried out using higher intensity stable beams.

The in-beam studies will benefit from the high segmentation of new detection Systems and from digital electronics, in order to allow the increase of beam intensity by one order to two orders of magnitude (up to few 100pnA).

Other approaches using detection systems after a separator (focal plan) require a stable beam facility with very high intensities (up to 100pμA)

In all the cases a dedicated detection system is needed to run experiments with longer beam time.

Existing European facilities Legnaro, JYFL, GSI (unilac), Ganil (CSS1)

Projects of very high intensity injector for SPIRAL2

the ECOS

‘ Network within ENSAR’

2011~2015

ECOS-NA

6 Beneficiaries

GANIL (France)

IN2P3 **(France)**

GSI-Darmstadt (Germany)

INFN (Italy)

University of Jyvaskyla (Finland)

IFJ PAN Krakow - HIL UW Warsaw(Poland)

30 associate partners

NIPNE-Bucarest (Roumania)

IN2P3 (France)

Department of Physics, University of Liverpool (UK)

KVI –Groningen (Nederlands)

CEA-Saclay (France)

LMU Munich (Germany)

IRMM Geel, (Belgium)

University of Sofia (Bulgaria)

Paul Scherrer Institute (Switzerland)

Royal Institute of Technology - Stockholm (Sweden)

University of Surrey (UK)

University of Paisley (UK)

University of Mainz (Germany)

Comenius University, Bratislava (Slovakia)

Nigde University (Turkey)

NCSR Demokritos (Greece)

Atomki- Bebrecen (Hungary)

HIL UW warsaw (Poland)

SAFE –University of Oslo (Norway)

CEA-Bruyeres-le –Chatel (France)

TU Munich (Germany)

INRNE-BAS, Sofia (Bulgaria)

Lund University (Sweden)

University of Bern (Switzerland)

University of Manchester (UK)

University of York (UK)

STFC Daresbury (UK)

University of Aarhus (Denmark)

Istanbul University (Turkey)

NR-Dubna (Russia)

The objectives of ECOS:

--Bring together and coordinate the expertise that is available in the European countries in order to achieve the research and developments activities needed in all aspects related to the production and use of high intensity heavy ion beams.

--Optimize resources and manpower for the up-grade and development of various stable ions beam facilities in Europe in order to optimize their scientific output. From this point of view, NA02-ECOS has a direct link to the TNA delivering stable ion beams to the users community in Europe.

Synergies between SIB facilities

Dubna
Unilac-GSI
Ganil

LNL
LNS
IPNO
JYFL

Warsaw
Krakow
Bucarest
Democritos

-Interactive map of beams in Europe.
-Technical Forum

ECOS project:

SHE Factory Dubna

cw-LINAC GSI

LINAG- GANIL

LINCE- Huelva

Need for a strategy (future task)!

Proposal for a High-Intensity, light and heavy ion facility in Andalucía: LINCE

I. Martel

DFA-UHU, Spain

INSTITUT DE PHYSIQUE NUCLÉAIRE
ORSAY

2016-2020 :
' ECOS -JRA within ENSAR2: TecHIBA'

- Accelerator R&D: High power accelerator subsystems
-Novel focal plan detection systems for spectrometers
-Radio-isotopes productions techniques

Added value:
(Accommodate a continuation of the ECOS-NA activities and coordination!)

THE TECHIBA JRA

Task 1: ISACA: Improvement of Superconducting Accelerating Cavities

Task 2: RITMI: Radio-Isotopes for Therapy and Medical Imaging

Task 3: NEWDOMS: NEW Detection Opportunities for Magnetic Spectrometers

Task 4: ILERI: Identification of Low-Energy Radioactive Ions

Task 5: GES: Generic Electronics Systems

Task 6 - TecHIBA-COOR : TecHIBA coordination

ECOS FUTURE

- NuPECC will prepare the next LRP:
  - where will ECOS physics be done in the coming 5 years
  - how will ECOS look like in 15 years
- Develop a scheme:
  - identify goals/expected results, physics+applications, facility, instrumentation
  - complementary to facilities existing in 15-year(?) future
  - use synergies in Europe! How?
  - national – European, one site or distributed, connected to RIB facility, new project?
- Practical:
  - beamtime >>300 d/year (multi-user?)
  - running scenarios, costs
  - physics goals, instrumentation
- Opportunities:
  - build on an existing laboratory? Any „offers“?
  - new ideas, new „windows“
  - .... etc. ...

ECOS FUTURE - SOME CONCLUSIONS

- Physics goals need to be identified first
  - SHE: three projects underway, will run in 3+ years
  - Astro, material research, applications (! important !), spectroscopy,.... remain to do
  - Physics and facility/instrumentation need to be discussed with community and laboratories, and need to be iterated with respect to technical opportunities and financing; ideally, new user groups will be involved from neighbouring fields (e.g. double beta decay, high energy community, ...)
  - The physics case must be convincing, the physics opportunities must be appealing and complementary to existing possibilities,
- Facility options
  - Think big! Consider new schemes (e.g. multi-user, multi-beam,...)
  - larger investments (>100M€) need a coherent (European?) effort
  - smaller (few 10M€) investments can be done by existing laboratories