The 5th international conference on
"COLLECTIVE MOTION IN NUCLEI UNDER EXTREME CONDITIONS"

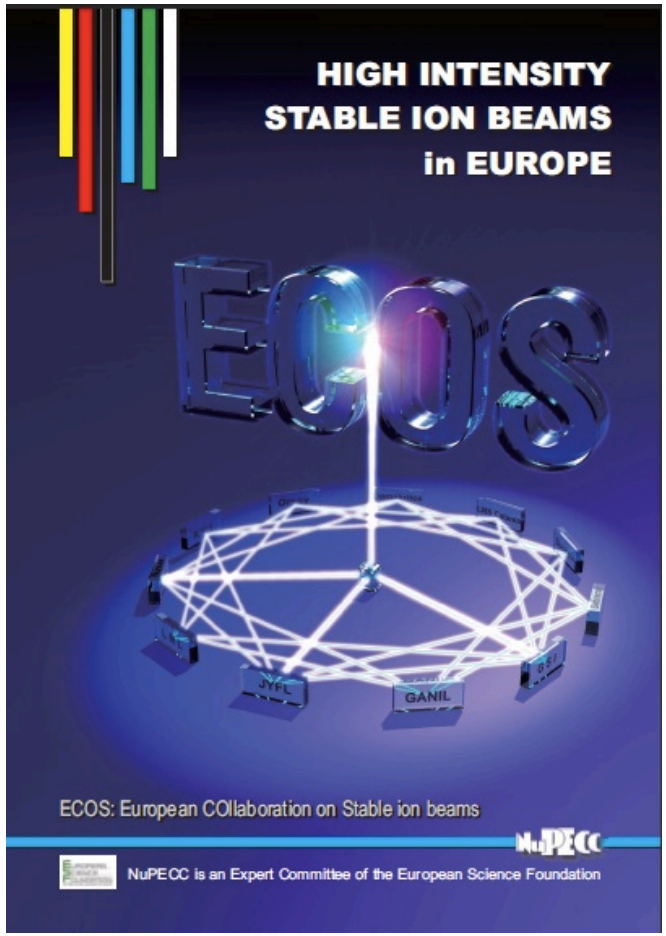
September 14-18, 2015 Kraków, Poland

THE ECOS-LINCE PROJECT

Ismael Martel,
for the ECOS collaboration

Department of Applied Physics, University of Huelva (Spain)
&
PH-ISOLDE, CERN (Geneve, Switzerland)

ECOS: HIGH INTENSITY STABLE ION BEAMS IN EUROPE



ECOS: **E**uropean **Co**llaboration on **S**table ion Beams. (http://www.ensarfp7.eu/project/ecos)

Expert working group of the Nuclear Physics European Collaboration Committee (NuPECC)

ECOS REPORT (2007): Describe the research perspectives at EU with high intensity stable ion beams, categorize existing facilities and identify the opportunities for a dedicated new facility in EUROPE

IV: Concluding remarks and recommendations

…"The long-term goal for a new dedicated high intensity stable ion beam facility in Europe, with energies at and above the Coulomb barrier, is considered to be one of the important issues to be discussed in the next Long Range Plan of the nuclear physics community."…

ECOS-LINCE: a proposal for building a new EUROPEAN FIRST CLASS High intensity heavy-ion accelerator for stable ions, with energies at and above the Coulomb barrier.

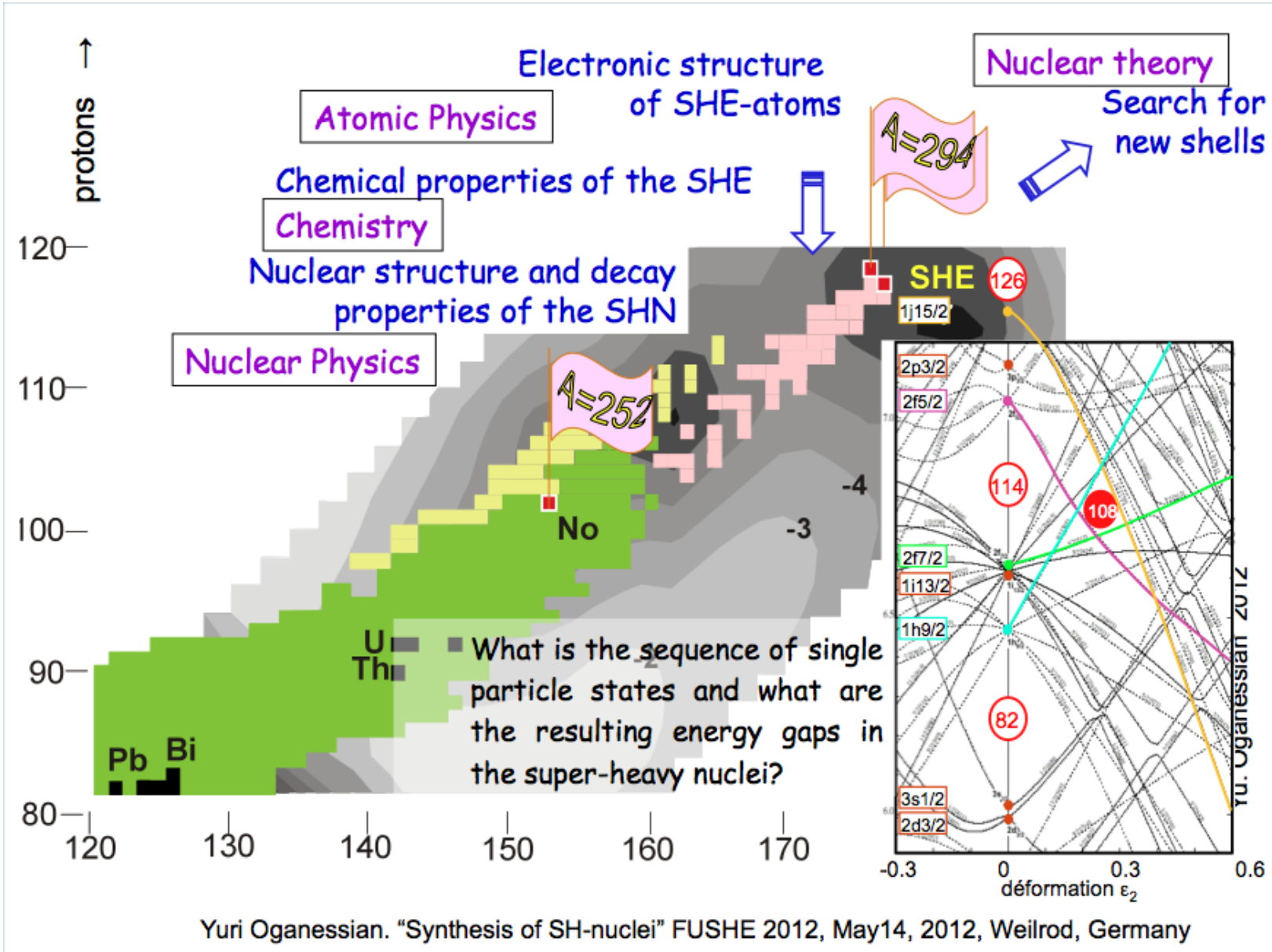
→ Carry out studies demanding high intensity stable beams and/or long beam time experiments (months of continuous beam time!)

To be proposed as ESFRI facility: European Strategy Forum on Research Infrastructures

Preliminary physics program based on the original ECOS report:

- Nuclear structure at low, medium and high spin
- Reaction mechanisms
- Charge exchange reactions
- Isomers
- Ground state properties
- Nuclear astrophysics
- Superheavies
- Nuclear equation of state (EOS) and symmetry energy
- Fundamental physics (e.g: neutrinoless double-beta decay)

Superheavies



Yuri Oganessian. "Synthesis of SH-nuclei" FUSHE 2012, May14, 2012, Weilrod, Germany

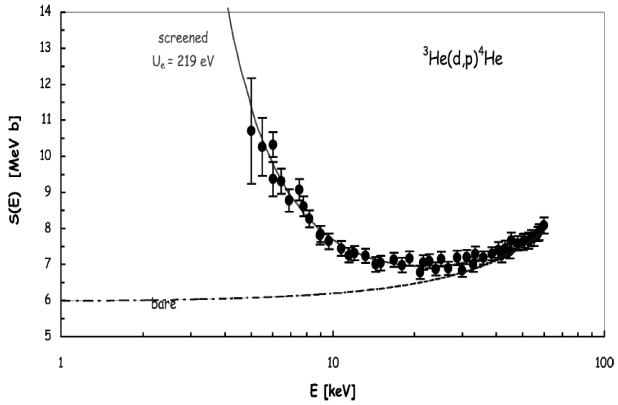
Astropysics

σ ~picobarn!! at relevant energies < 1 MeV, few GK

Extrapolation from higher energies by using the astrophysical S(E) factor:

$S(E) = \sigma(E)\, E \exp(2\pi\eta)$

→ **DIRECT & INDIRECT METHODS**



DIRECT METHODS

-Increase number of detected particles ("brute force": → intensity, → detector eff.)

- Reduce the background

- Fight with electron screening: theory does not work!!

INDIRECT METHODS

Coulomb dissociation: Determine the absolute S(E) factor of a radiative capture reaction **A+x → B+γ** studying the reversing photodisintegration process **B+γ → A+x ~100 MeV/A**

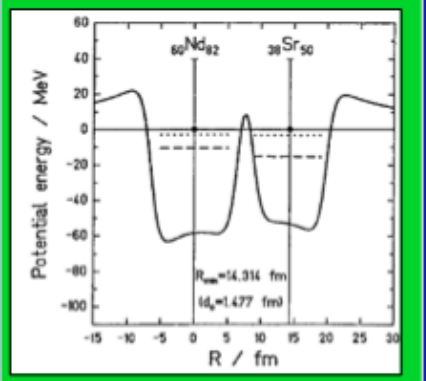
Asymptotic Normalization Coefficients (ANC): Determine the S(0) factor of the radiative capture reaction, **A+x → B+γ** studying a peripheral transfer reaction into a bound state of the B nucleus.

Trojan Horse Method (THM): Determine the S(E) factor of a charged particle reaction **A+x→c+C** selecting the Quasi Free contribution of an appropriate **A+a(x+s)→ c+C+s** reaction.

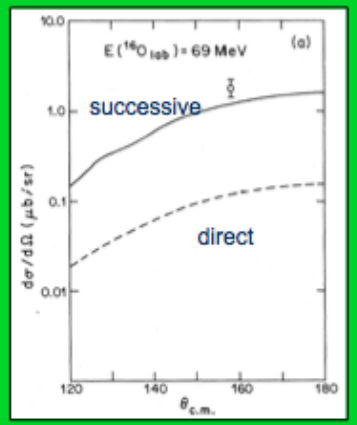
Transfer and fusion reaction studies

- Pair correlations (nn,pp,np channels) in transfer reactions at sub-barrier energies
- Charge exchange reactions
- Multinucleon transfer reactions (neutron rich nuclei) and effects on induced fission and quasi fission processes
- Hindrance phenomenon in sub-barrier fusion reactions…

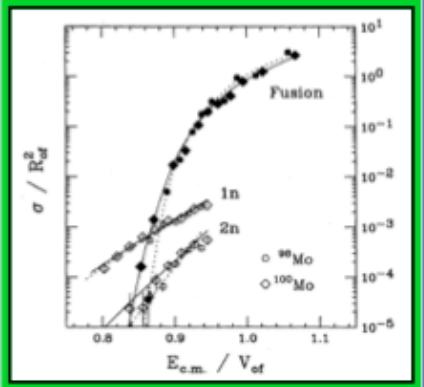
one probes tunnelling effects between interacting nuclei , which enter into contact through the tail of their density distributions



one can better study the interplay between single and multiple particle transfers



one probes transfer and fusion in an overlapping range of energies and angular momenta



Nuclear structure at low, medium and high spin

In-flight production of exotic nuclei at reaction targets

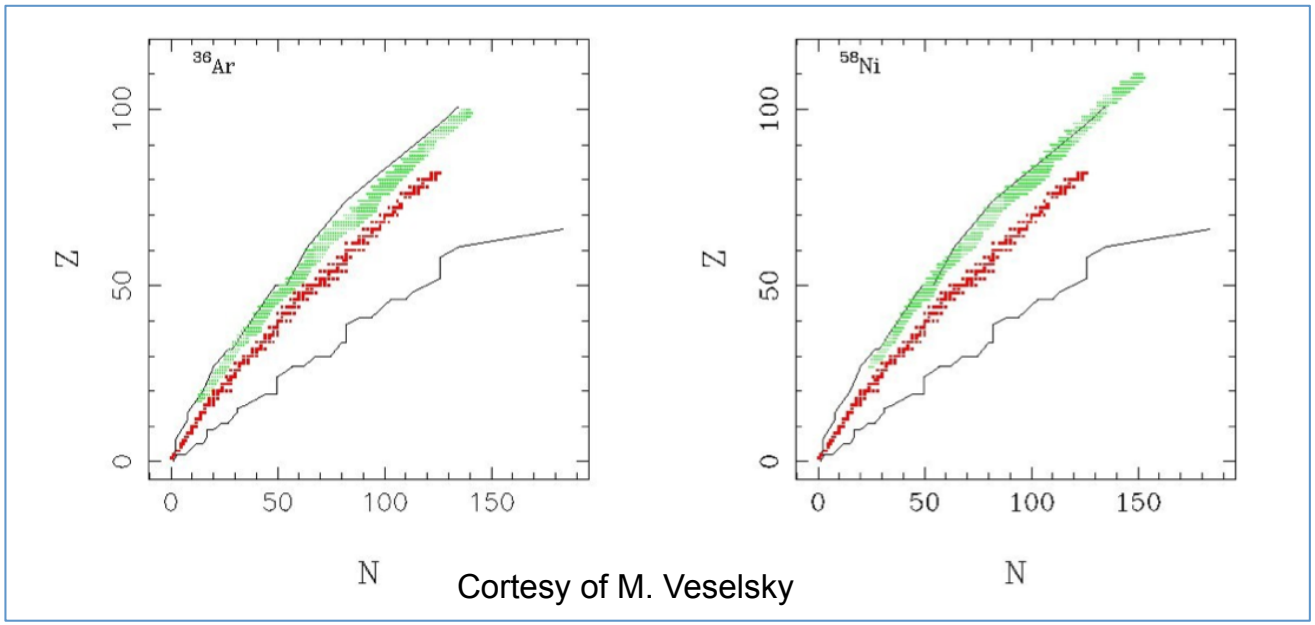
Typical beams

^{40}Ar ~ 14 MeV/u
^{86}Kr ~ 8.5 MeV/u
^{84}Kr ~ 10 MeV/u
^{136}Xe ~ 7 MeV/u

Exotic isotope production:

Height of the Coulomb barrier ~ 4 to 5 MeV/nucleon:
→ compound nucleus/fus.evap reactions, E ~ Eb → proton rich
→ reactions of nucleon exchange, E>> Eb → neutron rich

Compound nucleus/fus. evap reactions → Basic mechanism for production of proton rich nuclei de- excitation channels: 3-6n, p2-5n, a2-5n



Cortesy of M. Veselsky

M. Veselsky, G.A. Souliotis, Nuclear Physics A 765 (2006) 252; A 781 (2007) 521.
G.A.Souliotis et al., PRC 84, 064607 (2011); M. Veselsky,et al., Nucl. Phys. A 872 (2011) 1.

Physics beyond the Standar Model

Search for 0νββ decay. A worldwide race

Completed experiments:
- Gotthard TPC
- Heidelberg-Moscow
- IGEX
- NEMO1, 2 and 3

Experiments currently taking data:
- COBRA
- CUORICINO and CUORE
- DCBA
- EXO
- GERDA
- MOON
- KamLAND-Zen

Proposed/future experiments:
- CANDLES and XMASS at Kamioka Observatory
- MAJORANA
- NEXT
- SNO+
- SuperNEMO

$$T^{0\nu}_{1/2}(0^+ \to 0^+) = G_{01}\left|M^{\beta\beta 0\nu}\right|^2\left|\frac{\langle m_\nu \rangle}{m_e}\right|^{-2}$$

Double charge-exchange reactions:
Xsections: ~nanobarn

Courtesy of F. Cappuzzello, INFN-Catania

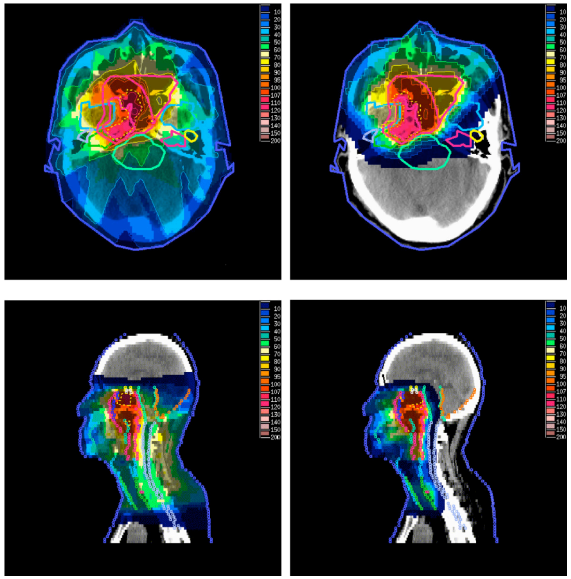
Radioisotope production

Modern radioisotopes are currently investigated/used to treat in a more efficient way the different tumours and cancer disease of our society.

Radio-nuclide	Target	Reaction	Projectile	Energy (MeV)
F-18	O-16	(α,pn)&(α,2n)	^{4}He	40
F-18	Ne-20	(d,α)	d	15
Sc-43	Ca-40	(α,n)&(α,p)	^{4}He	24
Cu-61	Co-59	(α,2n)	^{4}He	40
Cu-64	Ni-64	(d,2n)	d	30
Cu-67	Ni-64	(α,p)	^{4}He	40
In-111	Ag-109	(α,2n)	^{4}He	40
Sn-117m	Cd-116	(α,3n)	^{4}He	42
I-124	Sb	(α,xn)	^{4}He	42
At-211	Bi-209	(α,2n)	^{4}He	29
Rn-211	Bi-209	(^{7}Li,5n)	^{7}Li	≈60

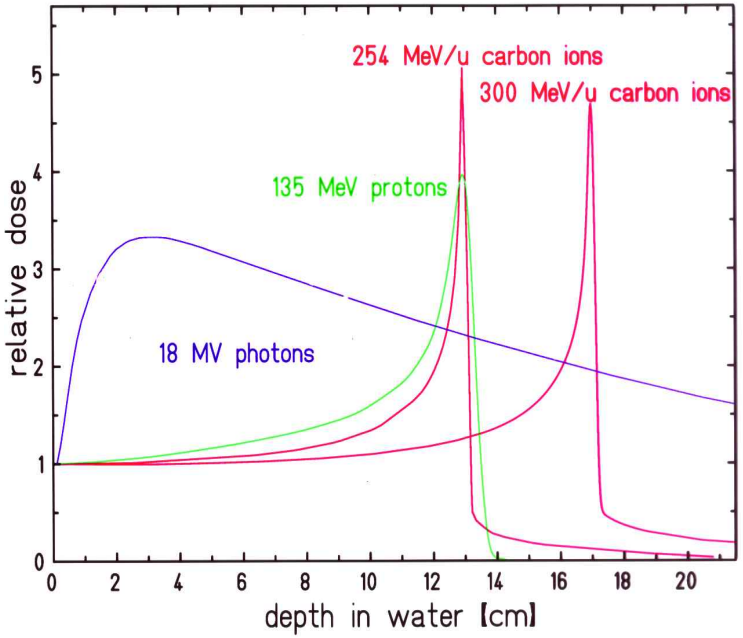
Ecos-Lince 2013, Ulli Coester, Grenoble

Hadron (proton) therapy



Cancer research using light-heavy ions

Protons:
Adapted from Pawel Olko, IEEE meeting, 30.06.2008



E (MeV)	Depth (mm)
10	1
20	4
50	22
100	76
120	105
150	155
200	256

Uveal melanoma

Intracraneal

All

Aerospace

High energy ion beams are used in **aerospace programs** for radiation resistant electronics and in nuclear energy applications. Quality tests are required in order to accomplish with UE safety regulations for energy control and aerospace on-board electronics. Research can be centred on the impact of radiation on the response of new device technologies and single-event effects in new technologies and ultra-small devices.

Highly demanded ions & energies ~10 MeV/u

Ion	Energía [MeV/u]	LET^{MEAS} @superficie [MeV/mg/cm^2]	LET^{MEAS} @Pico de Bragg [MeV/mg/cm^2]
$^{15}N^{+4}$	139	1.87	5.92 (@191 um)
$^{20}Ne^{+6‡}$	186	3.68	9.41 (@138 um)
$^{30}Si^{+8}$	278	6.74	13.7 (@114 um)
$^{40}Ar^{+12‡}$	372	10.08	18.9 (@100 um)
$^{56}Fe^{+15}$	523	18.84	29.7 (@75 um)
$^{82}Kr^{+22}$	768	30.44	41.7 (@68 um)
$^{131}Xe^{+35}$	1217	54.95	67.9 (@57 um)

Typical figures from RADEF, Finland

ECOS-LINCE: Main characteristics (as proposed today):

- Light and heavy ion accelerator, from protons to Uranium

- High Intensity: ~ mA's of beam intensity at target → eg., ^{48}Ca (8+) ~ 10 pμA

-Energies up to ~ 10 MeV/u – 50 MeV/u to 200 MeV for light ions.

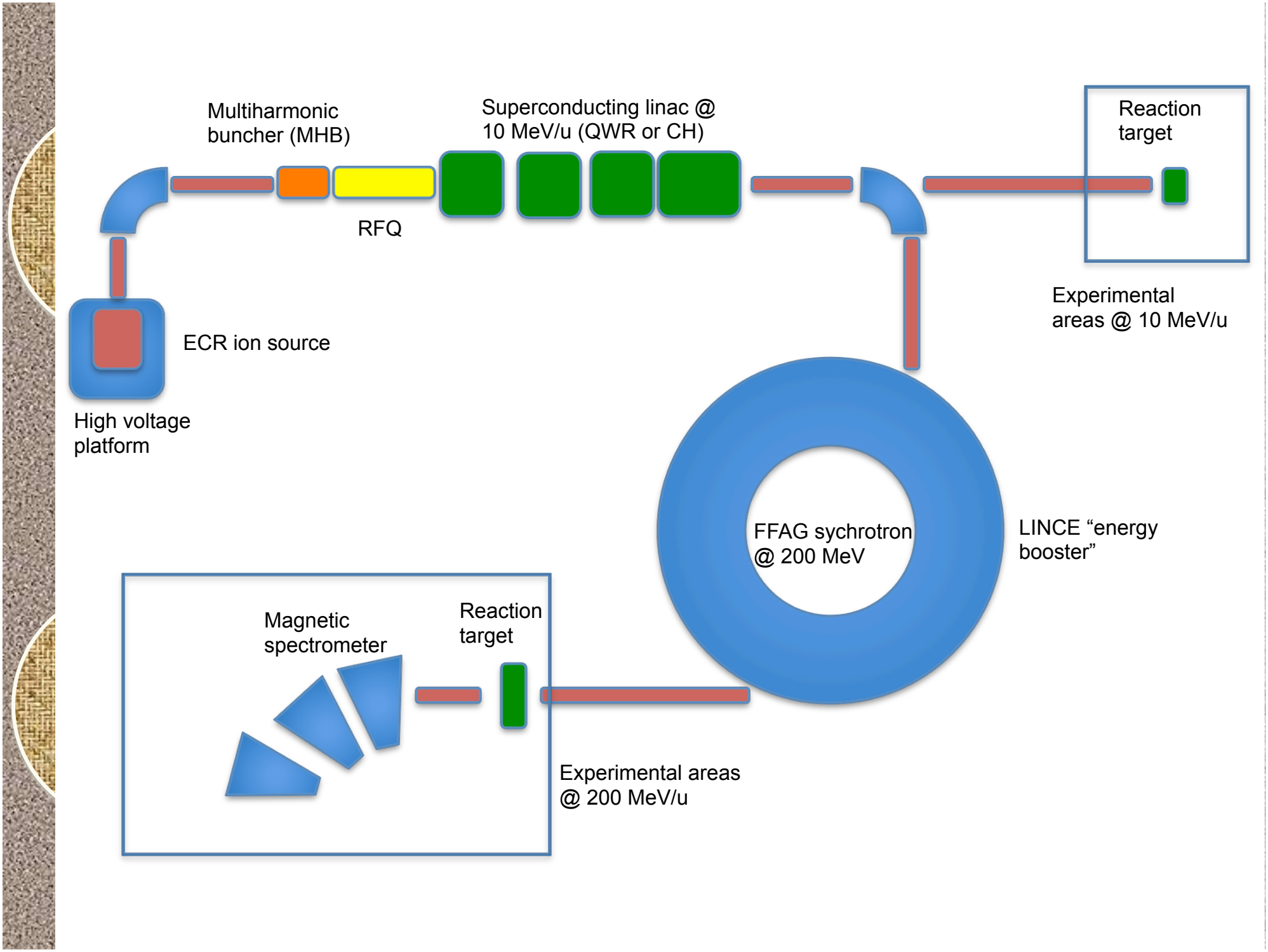
Multiuser facility: LINCE must provide 7000 hours of availability/year, with high stability and reliability for long run experiments:

~ 5000 hours for ECOS science and 2000 hours for Applications.

→ VERY STABLE AND RELIABLE FACILITY

CONCEPTUAL LAYOUT

- CW LINAC, energy up to 10 MeV/u (Range: protons 45 MeV, ^{238}U @ 8.5 MeV/u). Based on superconducting QWR cavities and/or CH structures.
- SYNCHROTON, energy booster up to 50 MeV/u and 200 MeV (light ions). Based on FFAG (superconducting cavities & magnets).
- Full-SC ECR ion source for high-charged & high-intensity ion beams (eg, ^{238}U @ 34+). High stability and reliability.
- CW RFQ for $1 \leq A/q \leq 7$ (room temperature).
- Instruments: High resolution magnetic spectrometer.


Multiharmonic buncher (MHB)
Superconducting linac @ 10 MeV/u (QWR or CH)
Reaction target
RFQ
ECR ion source
Experimental areas @ 10 MeV/u
High voltage platform
FFAG sychrotron @ 200 MeV
LINCE “energy booster”
Magnetic spectrometer
Reaction target
Experimental areas @ 200 MeV/u

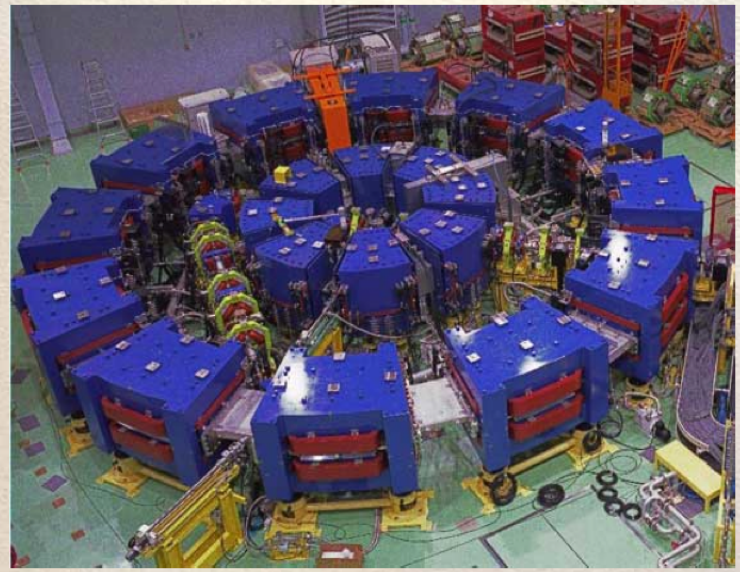
LINCE "energy booster"

HEAVY-ION SYNCHROTON (FFAG ¿?):

- LINAC injection at 10 MeV/u
- OUTPUT: 50 MeV/u for light ion species & ~200 MeV for p, d, t, 3He

FFAG KURRI Complex

Kyoto University Research Reactor Institute (Japan)



2.5 MeV

25 MeV

150 MeV

…

	Injector (Ion-beta)	Booster	Main ring
Lattice	spiral (8 cell)	DFD radial (8 cell)	DFD radial (12 cell)
Acceleration	Induction	RF	RF
k-value	2.5 (variable)	2.5	7.5
Energy	1.5 MeV (2.5 MeV)	11 MeV (20 MeV)	100 MeV (150 MeV)
average radius	0.60 - 0.99 m	1.42 - 1.71 m	4.54 - 5.12 m

Giardinii di Naxos -- October 3, 2007 A.G. Ruggiero, BNL Cyclotrons 2007 -- 5/17

ECOS-LINCE:
Possible European Sites

…ANY REGION AT THE UNION!!

Possibilities of "LINCE" in Spain

- Spain has no dedicated nuclear physics facility: boost visibility and impact of Nuclear, Particle, Astroparticle physics communities.

- ECOS-LINCE is an opportunity to build in Spain an European facility with the support of NuPECC and European Labs, taking advantage of structural EU funding. (Example: ELI-NP at Romania).

- A young and dynamic group in accelerators/instruments is being formed in Spain (CONECTA: CIEMAT (Madrid) -ALBA/CELLS (Barcelona)-UPC (Barcelona)-IFIC (Valencia)- UHU (Huelva)-CNA (Sevilla))

- Strong support from Spanish High-Tech. Companies and Industrial associations (INEUSTAR, FOE, AIQBE, etc):
  - Technology transfer & technological return
  - Improve competiveness in the international markets, and in particular nuclear and particle physics projects for international collaborations (CERN, FAIR, ILC, ESS, etc).
  - National needs of industry (Aerospace, Medicine, Materials,…)
- Why not Andalusia/Huelva? → "Convergence European region"

- HUELVA, A POSSIBLE SITE FOR LINCE

PARQUE CIENTÍFICO TECNOLÓGICO DE HUELVA (PCTH, Aljaraque)

Spanish National Grant for R&D on accelerator technology with industry (2012-2014)

→ preliminary study of ECOS-LINCE faicility (LINAC)

LINAC design team:

Univ. Huelva –Spain (Coord.)
Univ. Sevilla -Spain
Univ. Granada -Spain
Univ. Bilbao -Spain
IPNO –France
ANL –USA
LNL –Italy

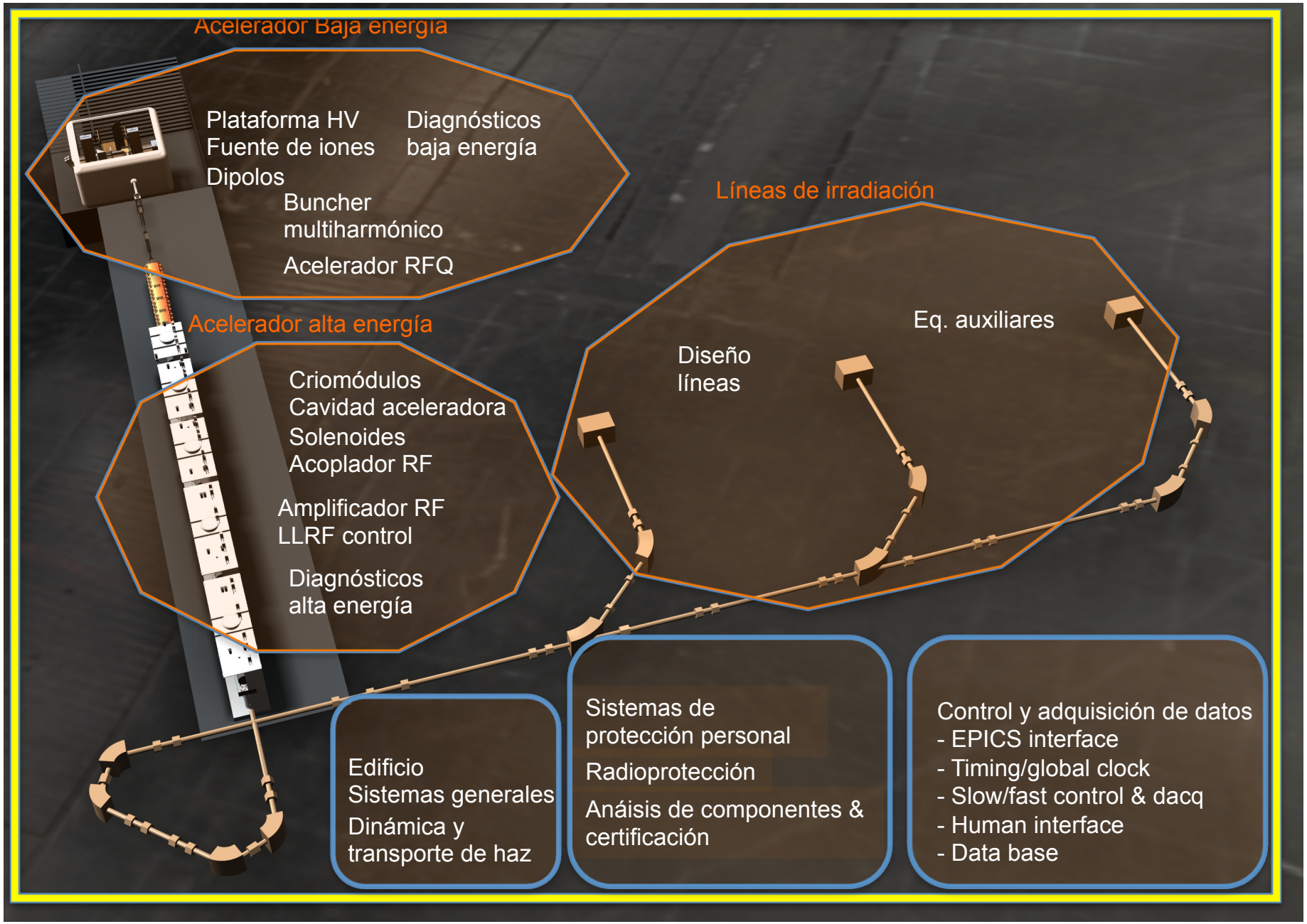
Funding: CDTI-MINECO Spain

IDOM SA
ALTER TECH.-TÜV
ELYTT ENERGY
AVS
TTI Norte
CIBERNOS
FAYSOL

→Collaboration with:

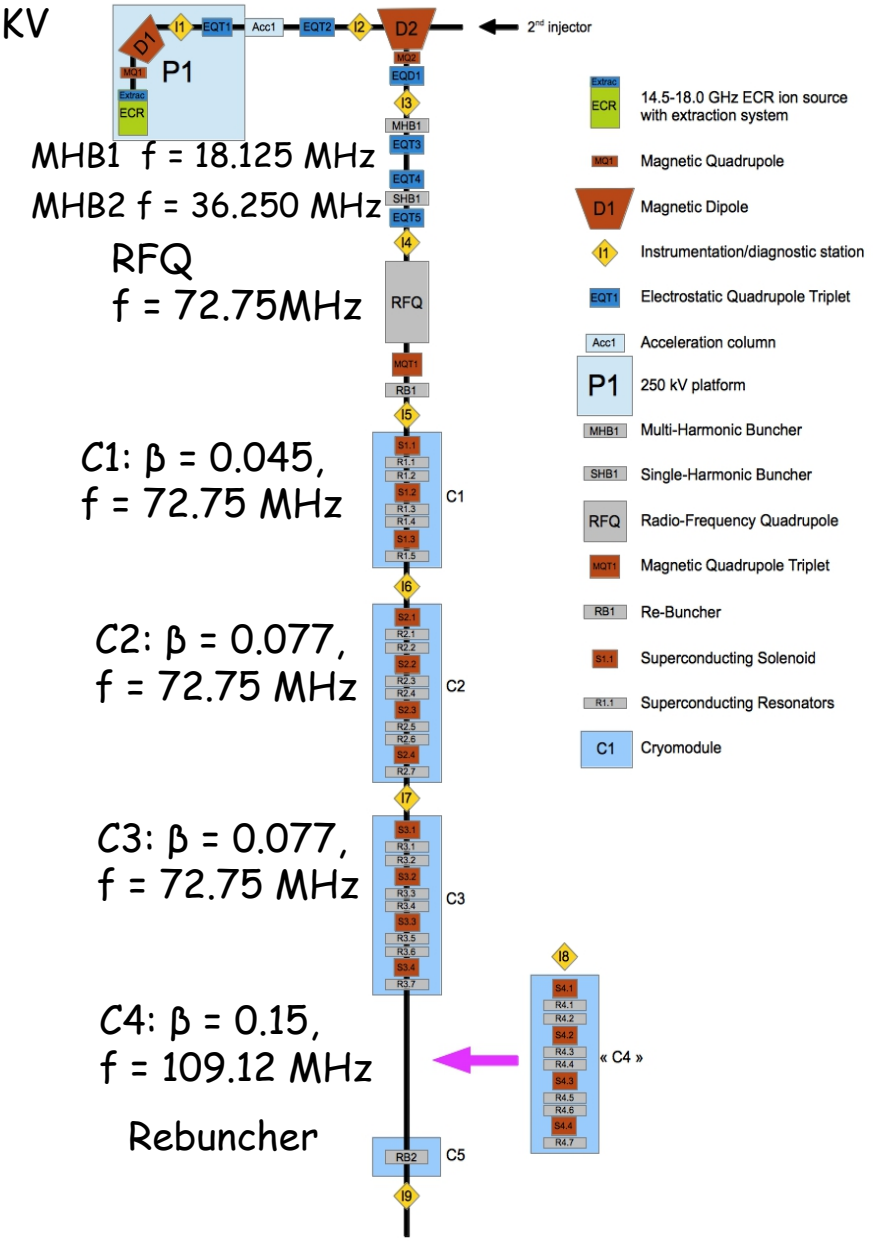
- Argonne National Lab-USA
- Laboratori Nazionali di Legnaro (INFN)-Italy
- Orsay Institute of Nuclear Physics IPNO-France

LINCE: LINAC DESIGN STUDY AT UNIVERSITY OF HUELVA



LINAC design study

ECR Source 14/18GHz
HV Platform 250 KV



MHB1 f = 18.125 MHz
MHB2 f = 36.250 MHz

RFQ
f = 72.75MHz

C1: β = 0.045,
f = 72.75 MHz

C2: β = 0.077,
f = 72.75 MHz

C3: β = 0.077,
f = 72.75 MHz

C4: β = 0.15,
f = 109.12 MHz

Rebuncher

COMPACT DESIGN:

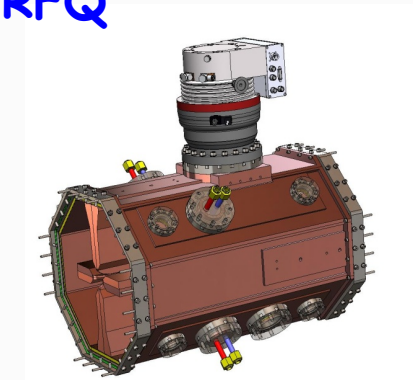
- 26 cavities
- 4 cryomodules

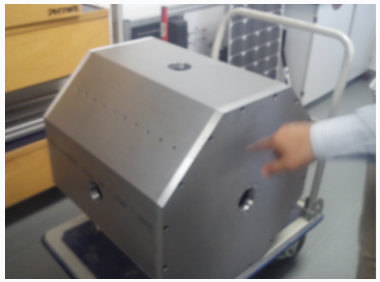
LINCE LINAC:

"60 MV equivalent electrostatic accelerator"

Prototypes designed and produced by local industry

RFQ

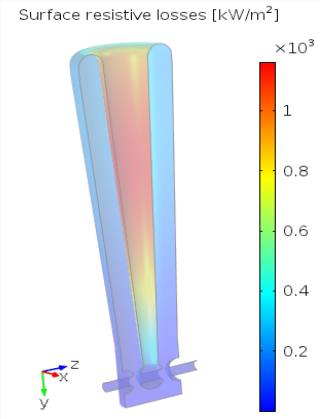




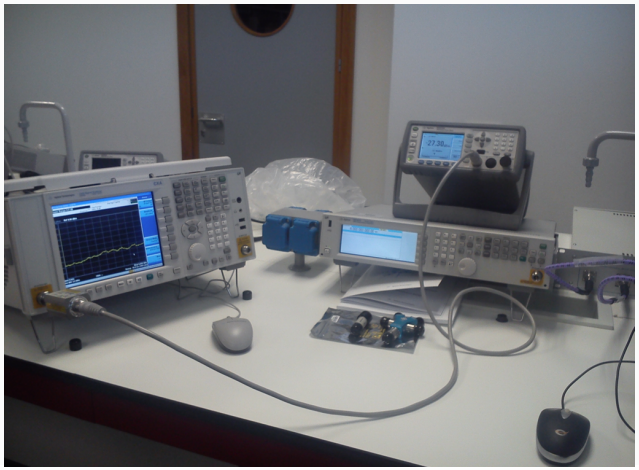
Cold model

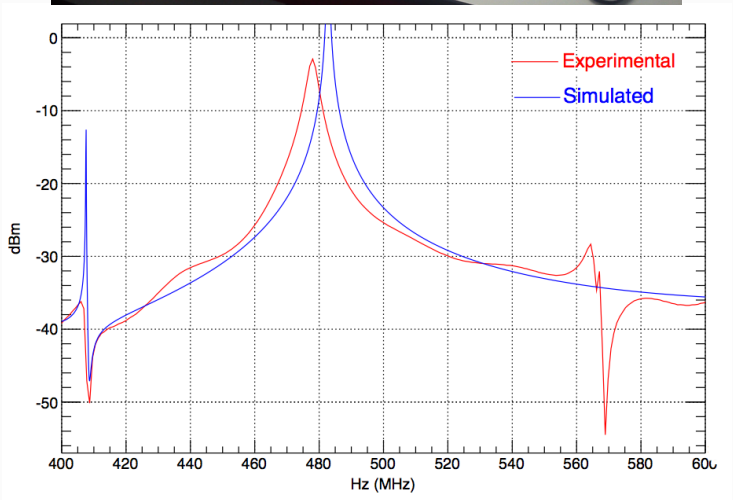
Test model section OFC with LNL (Italy)

QWR beta = 0.045



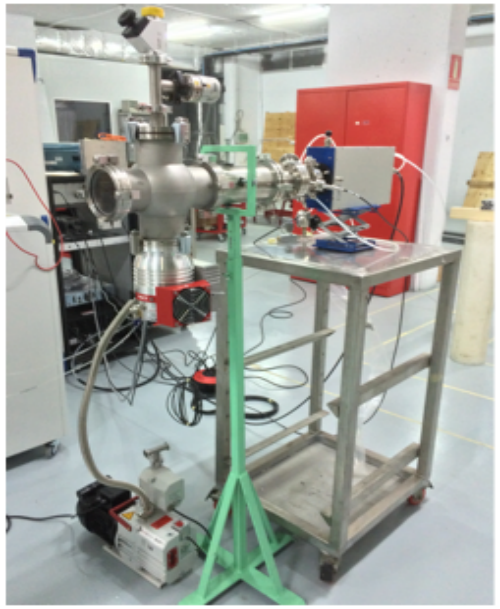
RF LAB AT UNIVERSITY OF HUELVA



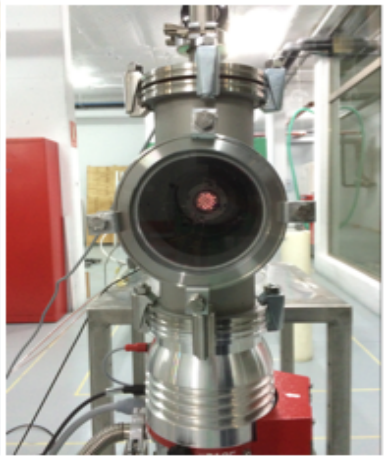


Accelerator Lab & RF, cryogenics (Univ. Huelva)

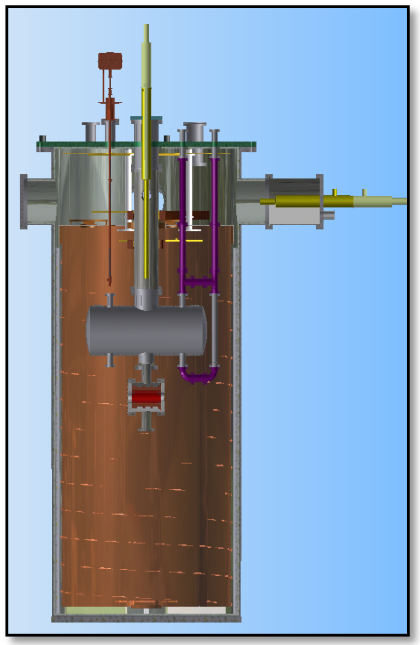
HV platform & ion source



ECR ion source



Cryostat for testing SC cavities

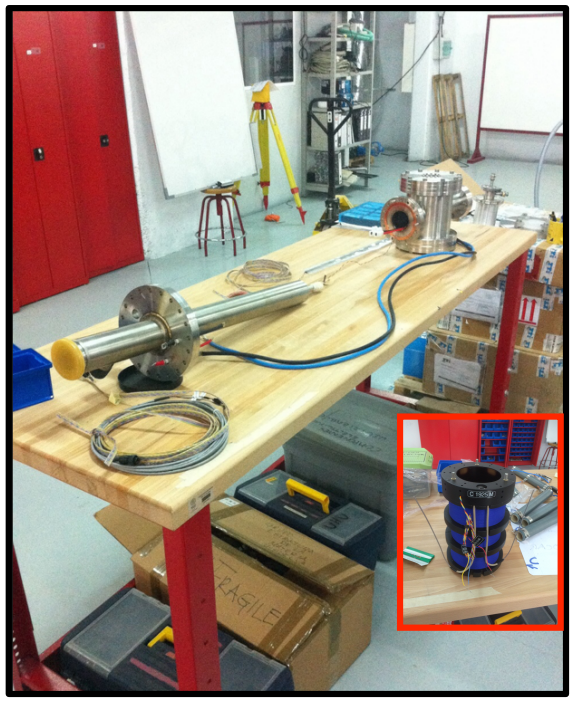


RF test bench facility

RF AMPLIFIERS & MEASUREMNTS

RFQ cold model & bead-pull system

Superconducting solenoids for beam focussing



Clean room 50 m^2

ECOS-LINCE LINAC
Recent Publications

1. I.Martel, et al. ECOS-LINCE: A High Intensity Multi-ion Superconducting Linac for Nuclear Structure and Reactions. Proc. IPAC'14, Dresden (Germany), 2014. Ref. thpme036.

2. C. Bontoiu et al.; Development of a 14.5 – 18 GHz ECR Ion Source at University of Huelva. Proc. IPAC'14, Dresden (Germany), 2014. Ref. mopri013.

3. L. Acosta, et al., Beam Transfer Studies for LINCE Experimental Areas. Proc. IPAC'14, Dresden (Germany), 2014. Ref. thpme032.

4. D. Gordo et al., High-performance Accelerating Cryomodule for the LINCE Project. Proceedings of IPAC'14, Dresden (Germany), 2014. Ref. thpme035.

5. J. Labrador et al. Design of a Multi-harmonic Buncher for LINCE. Proc. IPAC'14, Dresden (Germany), 2014. Ref. mopme059.

6. C. Bontoiu, et al. Particle Tracking Studies for the LINCE SC Linac. Proc. IPAC'14, Dresden (Germany), 2014. Ref. thpme033.

7. A.K. Orduz, et al. Development of a 72.75 MHz RFQ for the LINCE Accelerator Complex. Proc. IPAC'14, Dresden (Germany), 2014. Ref. thpme037.

8. A.K. Orduz, et al. Proposal for a 72.75 MHz RFQ for the LINCE Accelerator Complex. Proc. IPAC'15, Richmond, Virginia, USA.

9. A.K. Orduz, et al. Thermal and structural analysis of the 72.75 MHz LINCE. Proc. IPAC'15, Richmond, Virginia, USA.

Status & planning

WORKSHOPS:

ECOS-LINCE WORKSHOP: Huelva (Spain), 29 Oct – 1 November 2013

ECOS-LINCE WORKSHOP: → Huelva (Spain) 8-10 July 2015.

Pre-design	Detailed design	Construction	Commissioning
2012-15	2017/18	2019/22	2023

Proposal for Ecos-Lince full design study

To be presented at next INFRADEV call at HORIZON2020 program during **2017!!**

INFRADEV CALL 2014	
Participant	Country
ALBA	Spain
CEA/IRFU	France
CNRS-IPNO	France
FABIS	Spain
GANIL	France
GSI	Germany
IFJ-PAN	Poland
INFN-LNS/LNL	Italy
STFC-Oxford	United Kingdom
UHU	Spain
CERN	Switzerland
TOTAL	**3 Meuro**

WORK PACKAGES	
WP1	**Beam dynamics**
WP2	**Technology of accelerators**
Task 1	Ion source
Task 2	Buncher
Task 3	RFQ
Task 4	Cryomodules & cavities
Task 5	Thin Target developments
WP3	**Post acceleration (FFAG)**
WP4	**Spectrometer**
Task1	Superconducting magnet
Task2	Optical design
Task3	GEM detector
WP5	**Hardware/Software for safe operation**
WP6	**Dissemination and outreach**
WP7	**Site location study**
WP8	**Economical and legal issues**

Summary and conclusions

- ECOS: physics cases and applications must be updated and new report should be produced.
- Preliminary design of ECOS-LINCE (LINAC part) has been carried out (~10 MeV/u).
- Full study of the facility layout up to 50 MeV/u ~ 200 MeV (including instrumentation) still to be carried out.
- INFRADEV application for "ECOS-LINCE Design Study" expected **for 2017.**

Special acknowledgements to:

ECOS Group:

D. Ackermann, GSI, Germany
F. Azaiez, IPNO, France
G. de Angelis, LNL, Italy
M. N. Harakeh, KVI, The Netherlands
A. Jokinen, Univ. Jyväskylä, Finland
M. Lewitowicz, GANIL, France
A. Maj, IFJ-H. N. PAN, Krakow, Poland
I. Martel, Univ. Huelva, Spain

LINAC design team:

Univ. Huelva -Spain
Univ. Sevilla -Spain
Univ. Granada -Spain
Univ. Bilbao -Spain
IPNO -France
ANL -USA
LNL -Italy

CDTI-MINECO Spain
IDOM SA
ALTER TECH.-TÜV
ELYTT ENERGY
AVS
TTI Norte
CIBERNOS
FAYSOL

Universidad de Huelva

ISOLDE