

SPES Project: a Neutron Rich ISOL Facility for re-accelerated RIBs



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INFN Legnaro National Laboratories

ECPM, May 10th 2012

SPES - SPecial Beams for Science

10/05/12 – ECPM XXXVIII

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1

30 slides – 20min



SPES facility goals @ LNL



**A second generation ISOL facility for neutron-rich ion beams
and an interdisciplinary multi-user research center**

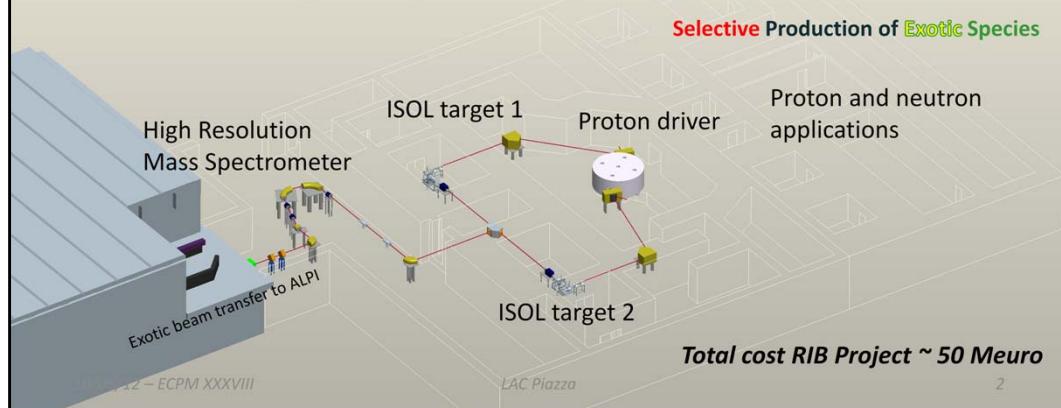
ISOL BEAM FACILITY

Primary Beam: 750 μ A, 70 MeV protons from a 2 exit ports New Cyclotron

8kW Direct Target: UCx 10^{13} fission s^{-1}

Re-accelerator: Existing ALPI Superconductive Linac E>10 AMeV for A=130

Selective Production of Exotic Species



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2

SPES strategy

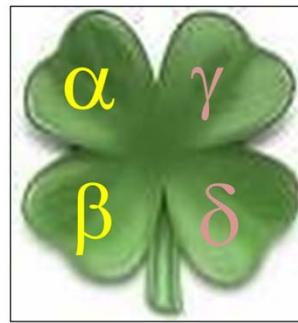
1. Develop a Neutron Rich ISOL facility delivering Radioactive Ion Beams at **10AMeV** using the LNL linear accelerator ALPI as re-accelerator . Make use of a Direct ISOL Target based on UCx and able to reach **10^{13} Fission/s** to produce neutron rich exotic beams.
2. Apply the technology and the components of the ISOL facility to develop **applications** in neutron production and medicine.

Exotic nuclei

ISOL facility for
Neutron rich nuclei by
U fission 10^{13} f/s

high purity beam
selection and
Reacceleration up to
 ≥ 10 MeV/u

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Current Status

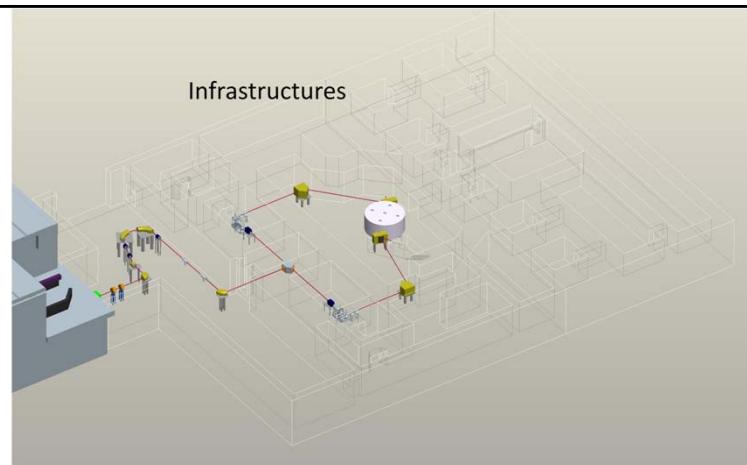
Phase Alfa

| | |
|-----------------|-------------------|
| Cyclotron | construction |
| ISOL Target | construction |
| Infrastructures | construction soon |

Phases Beta, Gamma, Delta

R&D
Feasibility studies

3



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SPES FACILITY INFRASTRUCTURES

Bid for construction and ground breaking expected in 2012.

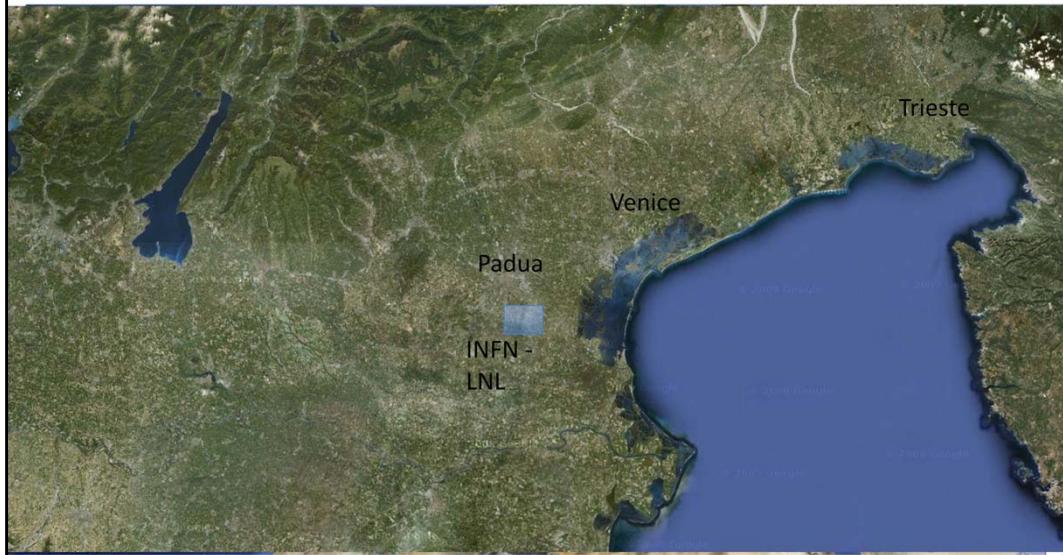
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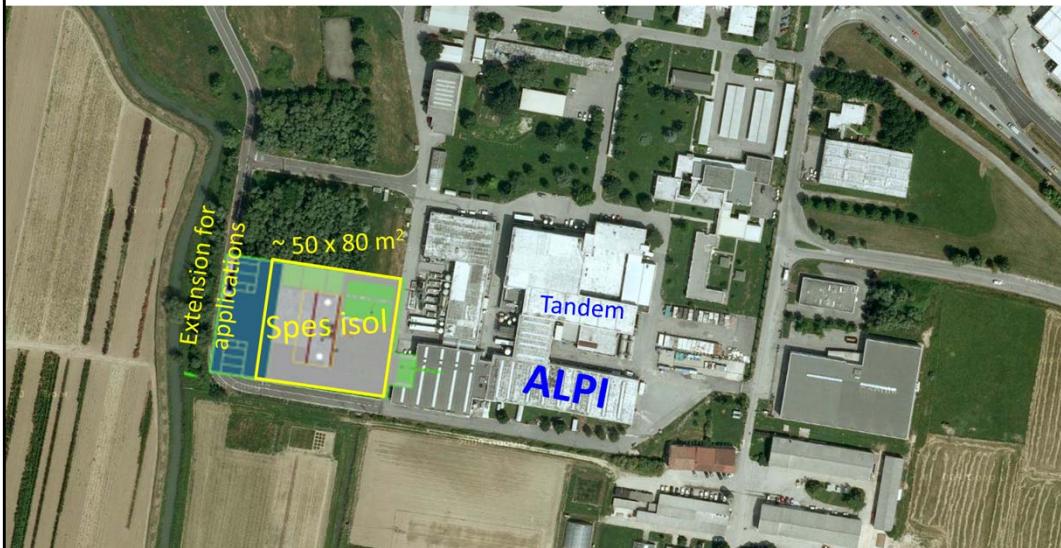
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5



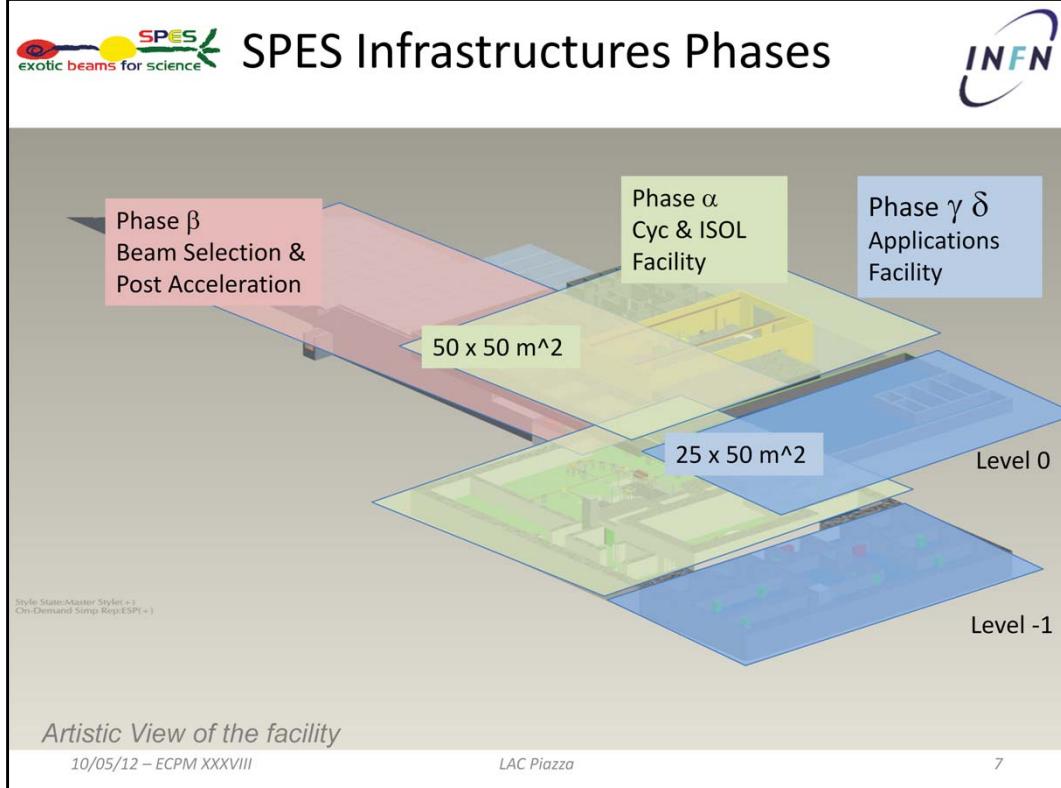
SPES Facility @ LNL



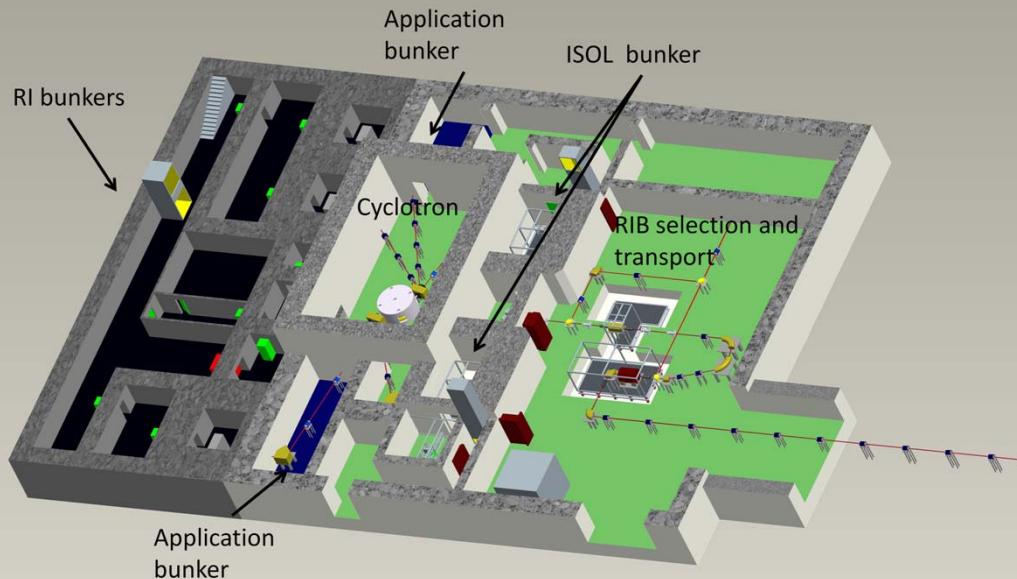
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SPES Layout, Level -1



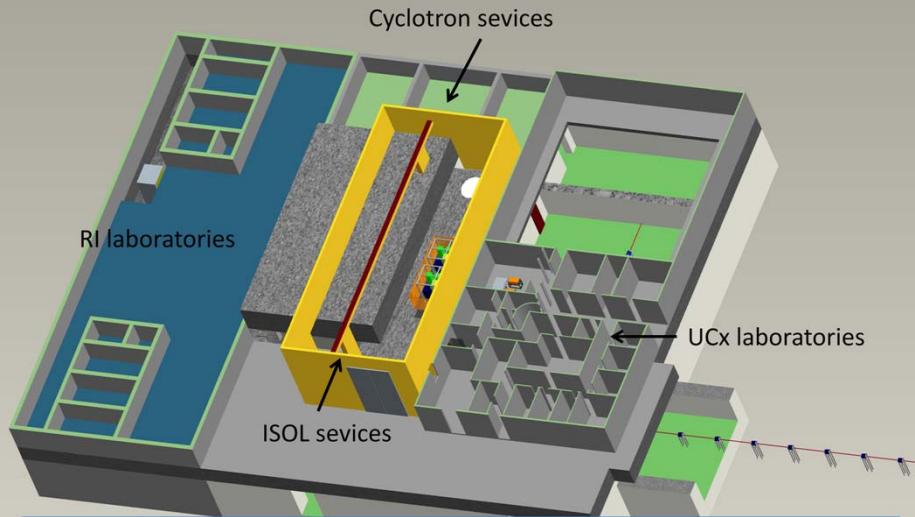
Artistic View of the facility

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SPES Layout, Level 0

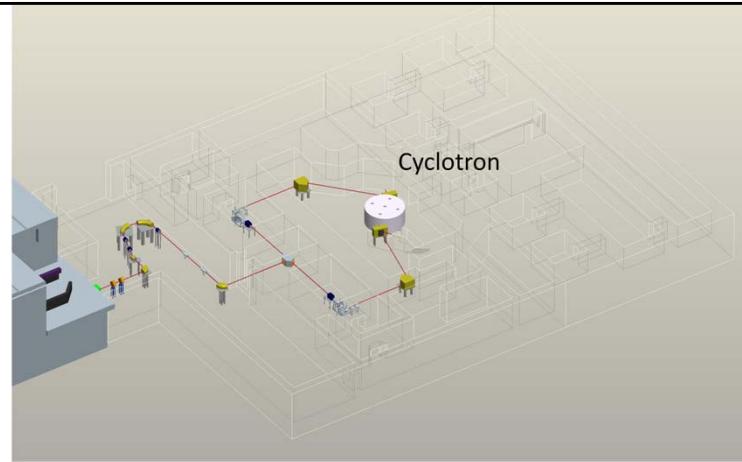


*Recently INFN assigned budget for phase α Infrastructures;
Executive design ready;
Bid for construction and ground breaking will follow.*

Art

10/0

9



SPES Project

SPES CYCLOTRON

Cyclotron realization in progress

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outsourcing

LNS 30yrs experience



BEST CYCLOTRON SYSTEMS



Great News!



www.Thertronics.ca

www.BestCyclotron.com www.TeamBest.com



Best® Cyclotron Systems, Inc.

VANCOUVER
(Design Team)
OTTAWA
(Machining, Assembling and Tests)

Management & Project Leaders
from TRIUMF (more than 15 years
of experience in high intensity
proton cyclotron design, realization
& commissioning TR18-TR30)

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TeamBest™ Companies

BEST MEDICAL INTERNATIONAL, INC.

BEST VASCULAR, INC. / NOVOSTE

BEST MEDICAL CANADA, LTD.

BEST THERATRONICS LTD.

BEST CYCLOTRON SYSTEMS, INC.

BEST PARTICLE THERAPY, INC.

BRACHYTHERAPY SERVICES INC.

BEST NOMOS

ARPLAY MEDICAL

CNMC COMPANY

HUESTIS MEDICAL

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11

2010 bid
great event

Total Costs of cyclotron and 1 beam line: 10.5 M€



Best Thertronics

Main Dimensions

Diameter = 4.5 m

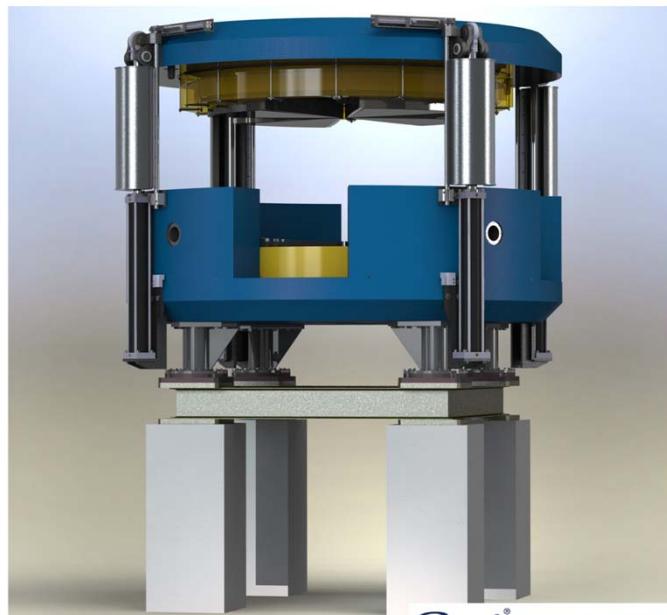
Height= 1.7 m

Weight = 150 tons

| BEST 70 MeV Cyclotron | |
|-----------------------|---|
| Accelerated Particle | H- |
| Extracted Particle | Protons |
| Energy | 35-70 MeV (variable) |
| Current | > 700 uA (variable) |
| Extraction System | By stripping → simultaneous dual beam extraction |
| Injection System | Axial Injection → External Multicusp Ion Source 15-20mA DC |
| Main Magnet | B _{max} = 1,6 T Coil current = 127 kAt Power supply = 30 kW 4 sectors, deep valley |
| RF System | 2 resonators Frequency= 58 MHz Harmonic mode=4 Dissipated Power=15 kW per cavity DEE voltage=60-80 kV |
| Operational Vacuum | 2 e ⁻⁷ mbar |



BEST 70p Model



Best® Theratronics

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13



BEST 70p Magnet



Best Theratronics

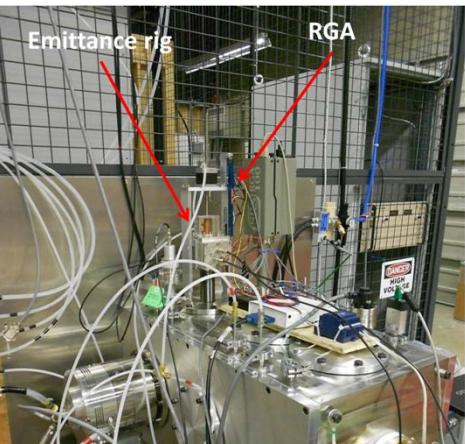


Best Theratronics

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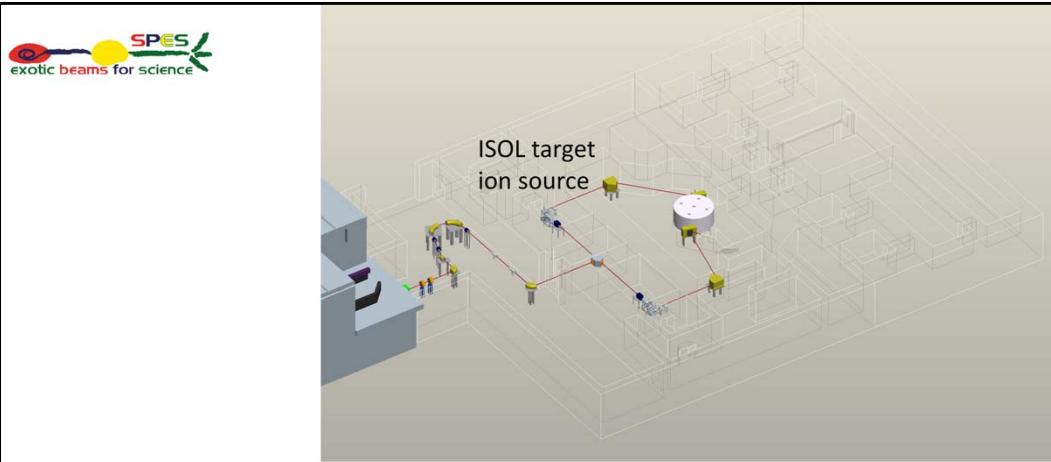
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14

Mapper**ISIS Test Stand**

*70p Cyclotron realization in time.
INFN is satisfied of the relationship with BEST and of the quality of
the Cyclotron project.*

2 months meeting



SPES Project

SPES ISOL TARGET-ION-SOURCE

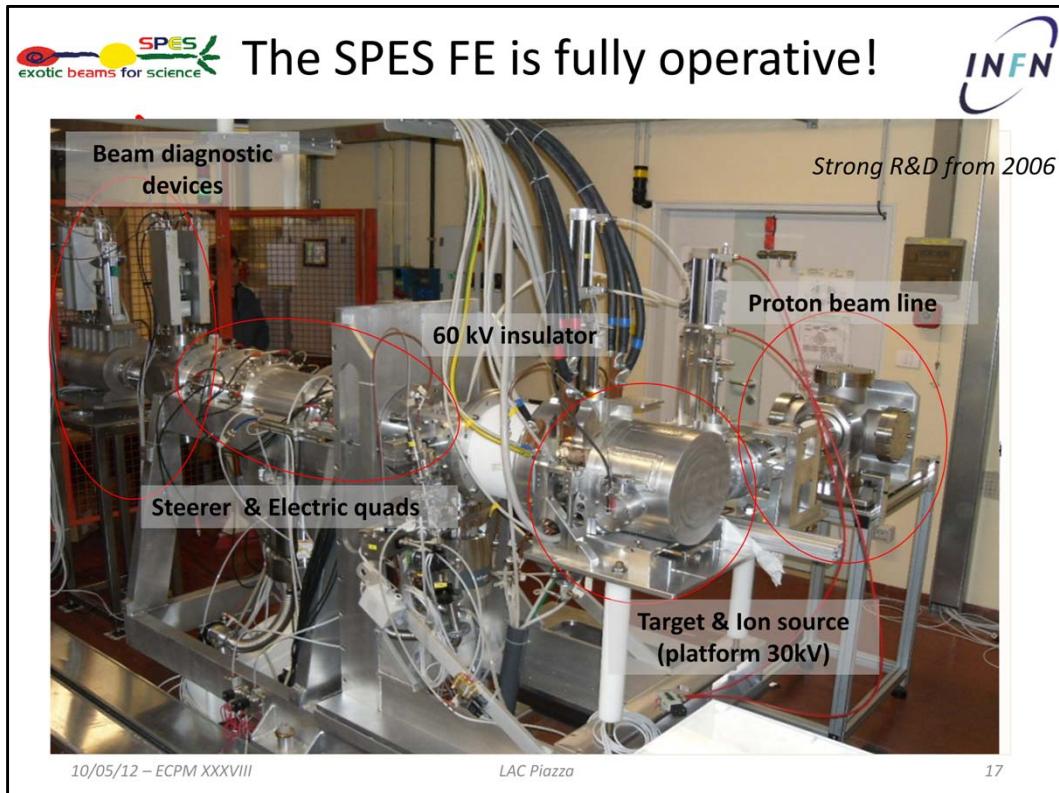
Target Ion Source Complex under characterization

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developed at INFN



OK

The SPES (Selective Production of Exotic Species) offline Front End is an apparatus for the acceleration of stable $Q=+1$ ion up to 30 keV

SAFETY CONTROL SYSTEM: based on Schneider Preventa safety devices

Three critical systems have been selected to be controlled by the safety controls:

- 1) the high voltage power supply,
- 2) the high current power supplies (part of the ion source heating system)
- 3) the pneumatic controlled target chamber movement systems.
- 4) The laser is an excimer XeCl LPX200 by Lambda Phisyk capable of 200 pulses of 100 mJ of energy per second emitted at 308 nm



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SPES target: operation principle

$\sim 200 \mu\text{A} \rightarrow 10^{13} \text{ fissions/sec}$

40 MeV
200 μA
Protons

units

© 7 UCx SLICES ($\rho=3 \text{ g/cm}^3$)

diameter 4cm

1.3 mm thick each (30gr of U)

Power density in UCx = 140W/g

© 3 graphite DUMP

(slowing down protons with low fission cross section and high power density)

Three parameters to

1) a high number of

2) a low power depo

3) a fast isotope rel



mm

Fig. 5.22: The 40 mm UCx pellet (1 mm thick) after thermal treatment (the average bulk density is about 3 g/cm^3).

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Principio di funzionamento: si e' scelta una configurazione basata su un fascio di PROTONI che ottimizzasse la perdita di energia nel bersaglio in relazione alla sezione d'urto di fissione e alla potenza rilasciata nel bersaglio.

Il bersaglio e' costituito da una doppia finestra in grafite, una serie di lamelle in UCx e un beam dump in lamelle di grafite.

Il bersaglio lavora a 2000deg per permettere la diffusione e l'estrazione dei prodotti di reazione e a queste temperature il processo di scambio di temperatura e' governato dall'emissione per irraggiamento che va come la T alla quarta. At 2000deg the radiation phenomena is the responsible for the cooling of the system.

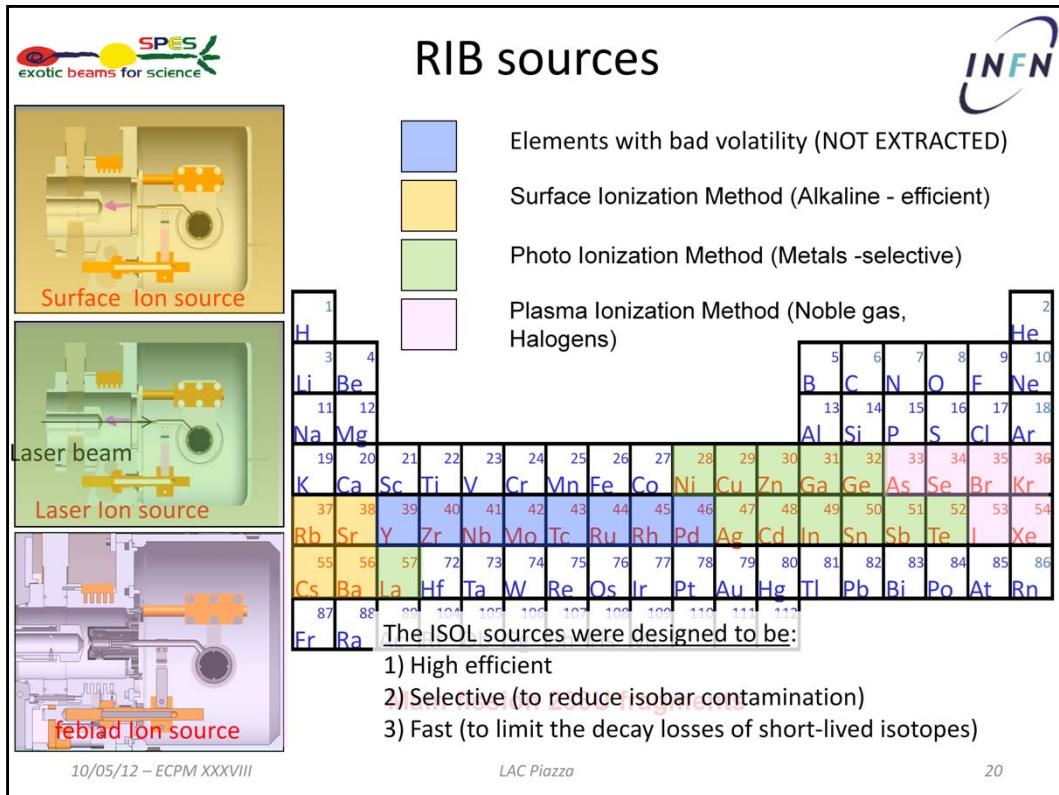
Il fascio di protoni si ferma nel dump di grafite in cui deposita una grossa parte di energia di ionizzazione ma ad una energia cinetica troppo bassa per indurre la fissione.

I prodotti di reazione (fissione) vengono estratti per agitazione termica e ionizzati con carica 1+

In order to optimize the heat dissipation and the release time of the fission products [5], a multiple disks target was proposed [6]: the target is split into

several thin disks opportunely spaced in the axial direction in order to improve the cooling of the UC_x target by thermal radiation and to avoid big temperature differences respect to the graphite box containing it. The advantage of this configuration is the simplicity of the cooling system and the consequent relatively low cost (see figure 5.2). The main characteristics of the SPES target are listed in the following [7]:

to guarantee an efficient RIB production rate the SPES target has to work at very high temperature levels, close to 2000°C ; an additional and independent “target heating and screening system”, that consists of a thin tantalum (Ta) tube. The high temperature target system (composed of disks, box and heating system) is located under vacuum inside a water-cooled chamber (see figure 5.9 at paragraph 5.3): vacuum and high temperature are essential to enhance the radioactive isotopes extraction.



The ISOL source is the element that allows the ionization and the first selection of exotics.

And determines:

- 1) Intensity
- 2) Beam quality
- 3) Number of RIB for experiments.

All ions produced are accelerated towards the ion extraction electrode by a potential up to 60 kV.

To cover the largest production of beams three sources are under design:

- 1) surface ionization, selective for alkalines (+1 ionization potential <6eV), up to 60% of efficiency;
- 2) Laser ionization, for selective photoionization of elements like Ni, Ga, Cd, Sn, Te (6eV < ionization potential <10eV), using up to 3 lasers; most selective method;
- 3) Plasma source, it is not selective but allows to ionize noble gases (10eV < ionization potential), up to 40% of efficiency but not selective.

Surface ionization and laser will operate in the same structure.

The Surface ionization source is developed and in use

The plasma source has been constructed and is under characterization

Laser is under study at Pavia laboratory

On line UCx test at HRIBF

N-Rich Isotopes yields

Experiment March 2010 UCx target

Proton Energy = 40MeV

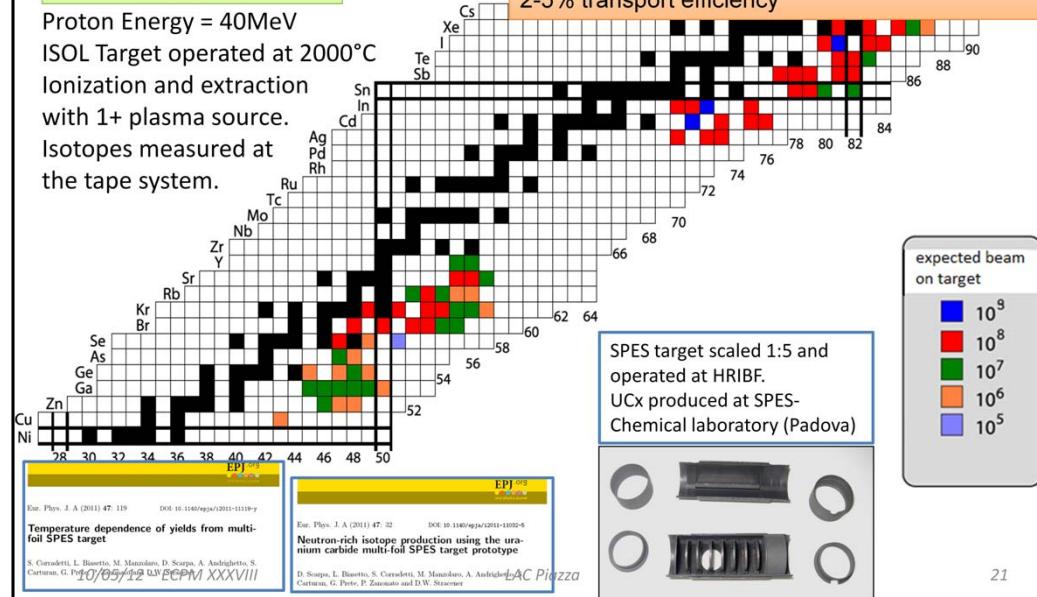
ISOL Target operated at 2000°C

Ionization and extraction

with 1+ plasma source.

Isotopes measured at
the tape system.

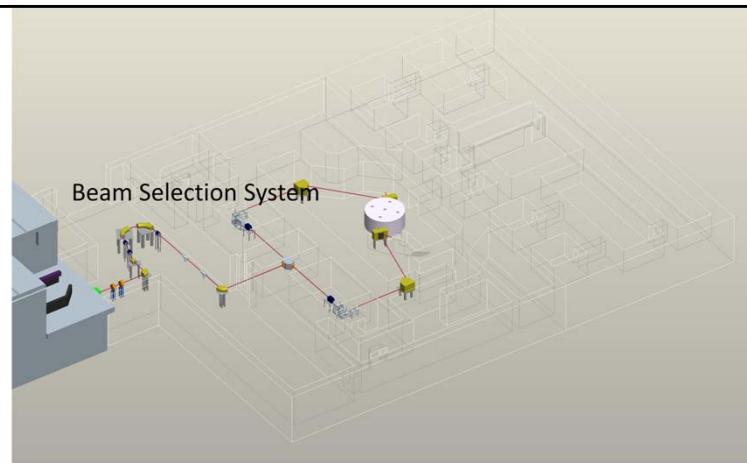
For expected beam on target, data are scaled to:
200 microA proton current
2-5% transport efficiency



Expected beam on target can be roughly evaluated considering a scaling factor for the current to 200 microA and a total trasport efficiency of 2% (5% charge breeder,50% linac transport).

50nA tandem protons

Calculation of the yield of different isotopes was carried out by analyzing the gamma-ray spectra obtained from the Ge detector coupled to a multi-channel analyzer (MCA)



SPES Project

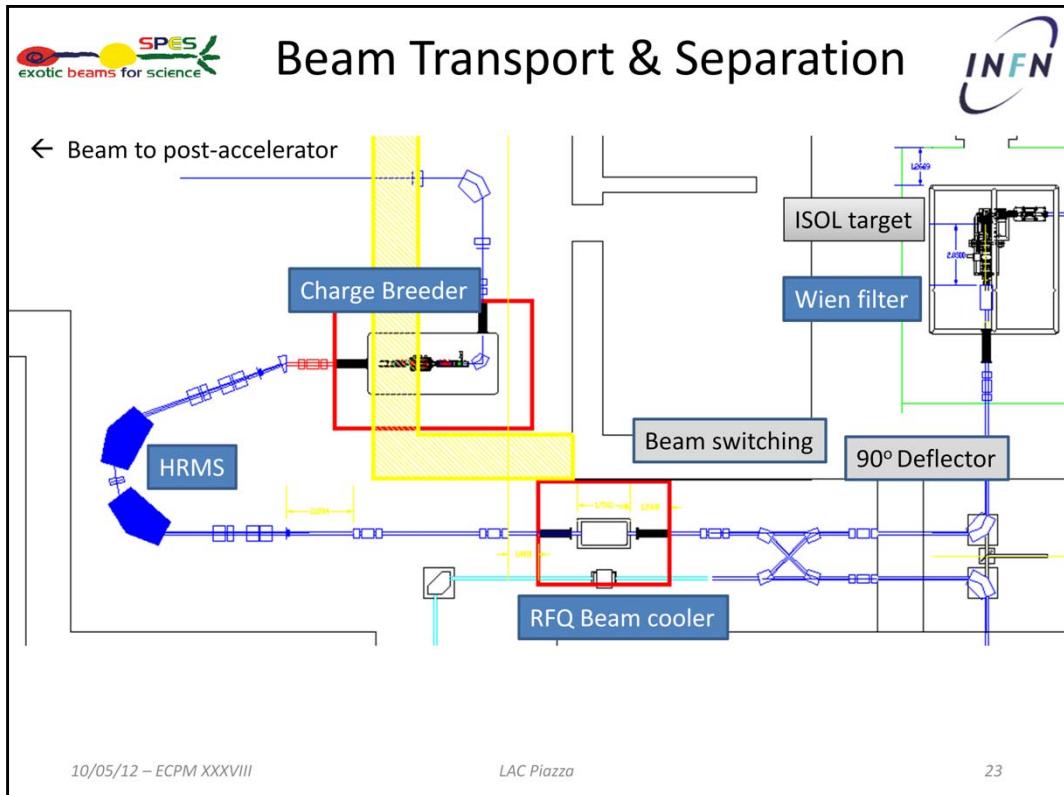
SPES BEAM SELECTION SYSTEM

R&D Design studies in progress

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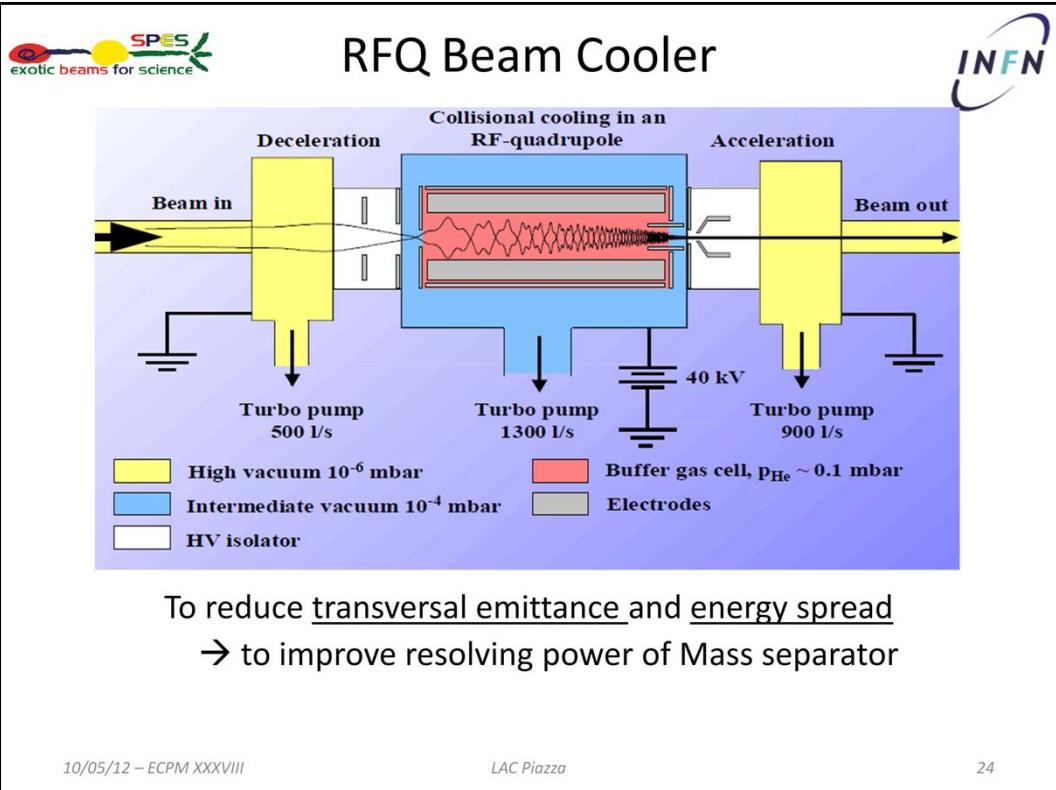
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22



OK

The beam transport line has been designed from the physical point of view. A high resolution mass spectrometer with a mass resolving power of 1/40000 is proposed. This performance take advantage of a beam emittance of less than 10 $\mu\text{m mrad}$. A beam cooler is planned if the 1+source do not meet this performance. **Anche se avremo questa buona emittanza, in ogni caso il beam cooler serve per ridurre lo spread energetico che altrimenti deteriora le prestazioni del HRSM.**



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24

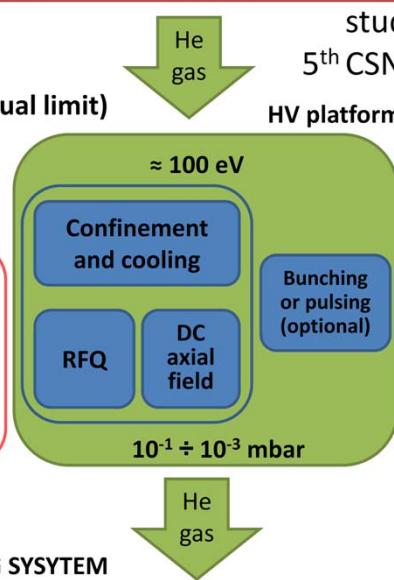
The performance of a high resolution mass separator (HRMS) depends greatly by the beam emittance **and by the energy spread**. Indeed the final beam size depend both on the initial beam size but also and mainly by the higher order aberrations and by the acceptance angle of the spectrometer. So to achieve an high resolving power often it is necessary to cut the beam emittance to reduce the broadening of the beam size at the analyzing slit due to the higher order aberrations. This emittance cut reduce of course the beam transmission and produce a terrible reduction of beam intensity which is not acceptable for the radioactive beam which have a low intensity. A device, generally called beam cooler, have been recently developed to solve this problem

REGATA, feasibility study

REGATA, feasibility
study founded by
5th CSN with test @ LNS

Ion Mass = $9 < A < 170$
Current = up to 100 nA (actual limit)
 $\approx 1 \mu\text{A}$ (challenging)

30 π mm mrad @ 60keV
Focusing elements **Injection Deceleration**
 10^{-7} mbar

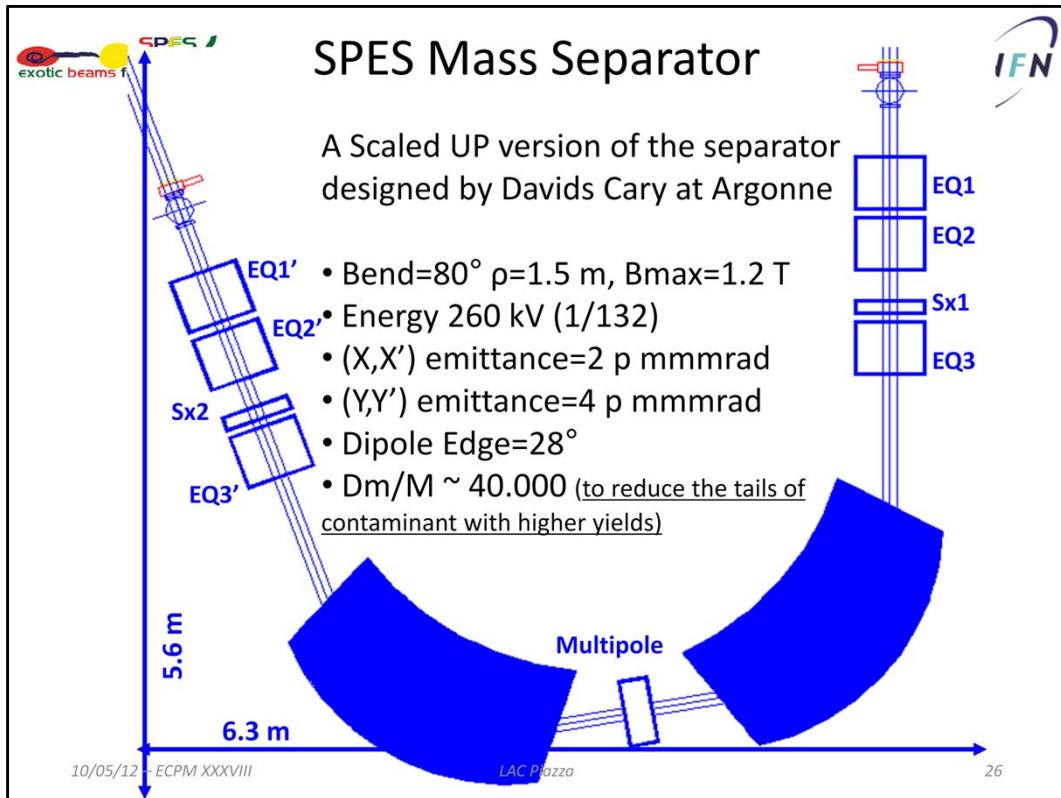


(1 ÷ 5) π mm mrad @ 60keV
Extraction Acceleration
 10^{-7} mbar

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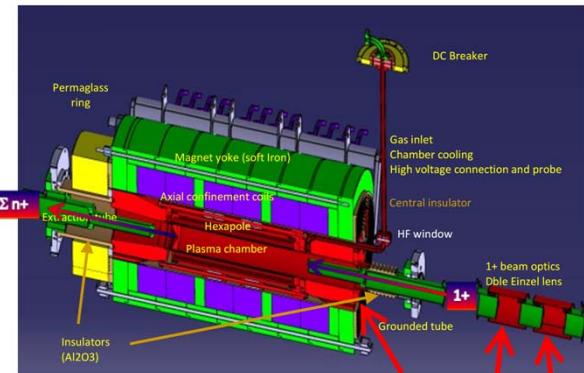
25



OK

This separator is an essential device for the production of Radioactive Ion beams since it allows to select a specific isotopic specie, with high resolution, for further acceleration into the ALPI complex.

It is located before the charge breeder, which will be fed by (nearly) only one isotopic specie. This mass (**no** spectrometer **ma**) **separator** consists of two anti symmetric bending dipoles



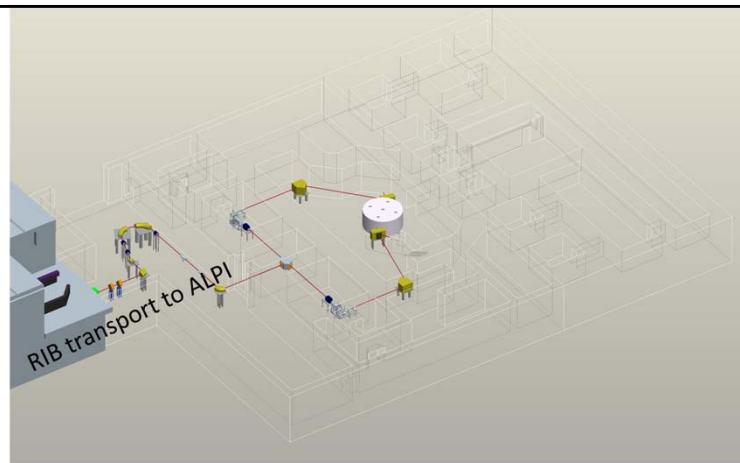
Schematic drawing of the PHOENIX Charge Breeder R&D on:

- New exapole -> higher charge states
- Trap process understanding -> improve efficiency
- Removal of grounded tube -> higher efficiency

Phoenix Charge Breeder Parameters

| | |
|------------------------|-------------------|
| f[GHZ] | 14.5 |
| P_max[W] | 1000 |
| B_inj [T] | 1.5 |
| B_ext[T] | 1 |
| B_rad[T] | 1.35 |
| eff_max for gas [%] | 8-10 |
| eff_max for metals [%] | 3-5 |
| Charge breeding time | 3-4 to 10-15 ms/q |

SIMION 3D Calculations



SPES Project

SPES POST ACCELERATION SYSTEM

LINAC Upgrade in progress

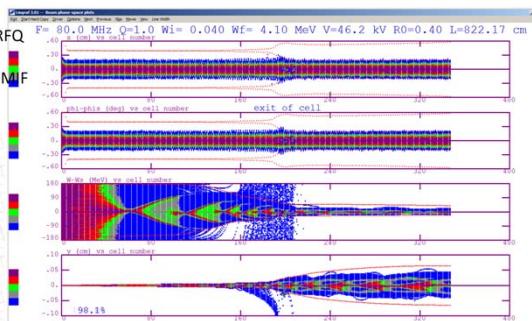
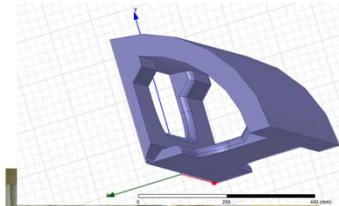
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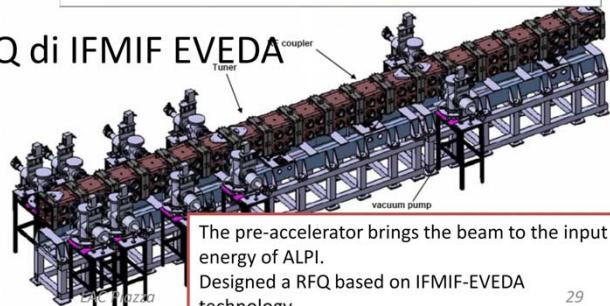
28

new RFQ acceleration

- Energy $5.7 \rightarrow 585.7 \text{ KeV/A}$ ($A/q=7$)
- Beam transmission >95%
- Length 822 cm intervane voltage=46kV
- RF power Ladder 89 kW Q=9000
- DB Electronics amplifier 100kW CW 80 Mhz as SPIRAL2 RFQ can be used
- Mechanical design and realization, taking advantage of IFMIF experience, possible collaboration with INFN Padova

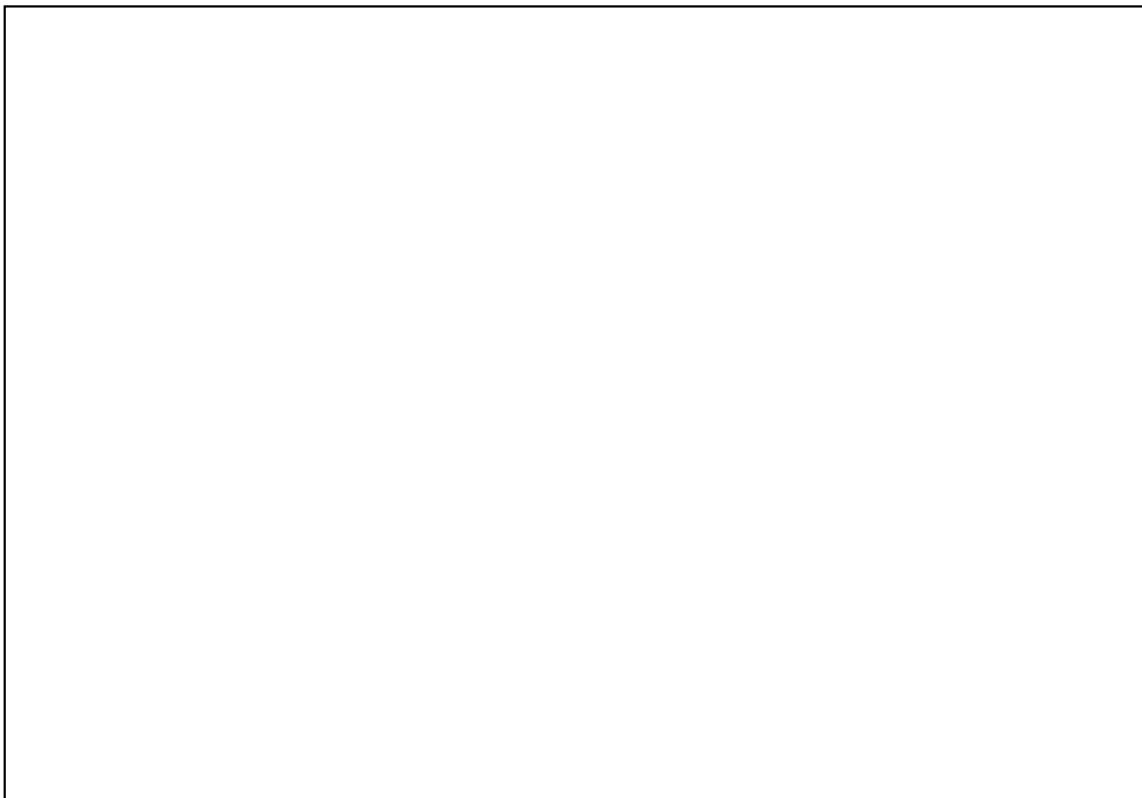


RFQ di IFMIF EVEDA



The pre-accelerator brings the beam to the input energy of ALPI.
Designed a RFQ based on IFMIF-EVEDA technology.

29



The linear accelerator ALPI, with a b range between about 0.04 and 0.2 and CW operation, represe



Status of the SPES Project



Phase α

- α **Infrastructures** Executive Design done; construction follows;
- α **Safety** report for cyclotron operation approved by Italian safety agencies;
- α **Cyclotron** realization by BEST Theratronics on time;
- α The **ISOL Target and Ion Source** are under characterization;

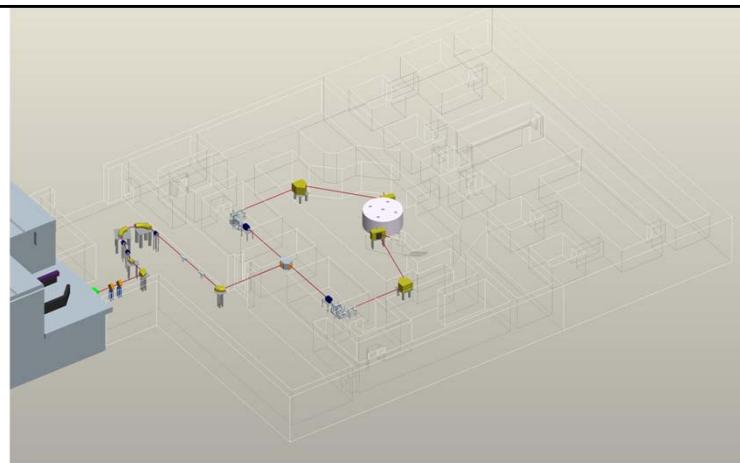
Phases β, γ, δ

- β **Beam Selection** analysis in progress;
- β **ALPI Linac** upgrade in progress;
- γ Letters of Intent was presented for **experiments** with SPES;
- δ **Applications** feasibility studies in progress.

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31



SPES Project

SPES RIB SCIENTIFIC PROGRAM

more details : <http://spes.lnl.infn.it/index.php/what-is-spes/physics-case/50-physics-case>

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32



Call for
Letters of Intent:

24

SPES2010 Workshop
(LNL- November 15th-17th, 2010)



First Day Experiments

15 Nuclear Structure 8(1) Nuclear Reactions

Instrumentation:

International
collaborations:

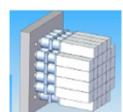
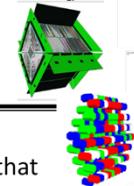
Italy
Bulgaria
Hungary
France
Poland
Spain
Great Britain
Turkey
USA
Slovakia
Romania
Croatia
Russia
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Germany
Canada

- 1 [GARFIELD](#)
- 2 [PRISMA](#)
- 3 [8PLP](#)
- 4 [RIPEN](#)
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- 6 [TRACE](#)
- 7* [AGATA](#)
- 8* [FAZIA](#)
- 9* [NEDA](#)
- 10* [PARIS](#)
- 11 [CHIMERA](#)

- Low threshold 4π LCP-Fragment array - [F. Gramagna](#)
Large acceptance spectrometer - [A.M. Stefanini](#)
4π LCP-Fission Fragment array - [M. Cinausero](#)
Neutron array - [M. Cinausero](#)
γ-array - [C. Ur](#)
Compact LCP array - [D. Mengoni](#)
High performance γ-array - [E. Farnea](#)
High performance LCP-Fragment array - [G. Casini](#)
New generation neutron array - [J.J. Valiente Dobon](#)
New generation high energy γ-ray array - [A. Maj](#)
Low threshold 4π LCP-Fragment array - [S. Pirrone](#)

* detectors developed under UE collaborations

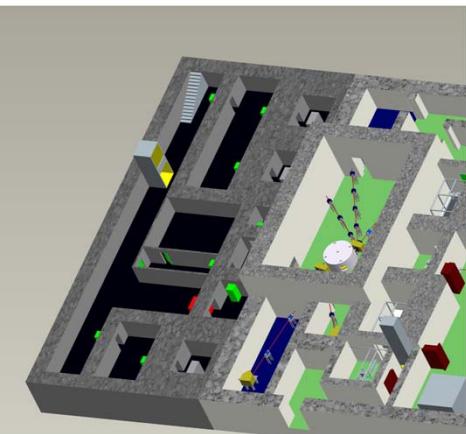
The goal: to build around SPES scientific collaborations that will lead to the definition of priorities in the development of exotic beams and instrumentation.



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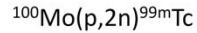


LARAMED Facility:
Production of radionuclides of interest for medicine using the SPES cyclotron

IAEA- Coordinated Research Project (CRP)

Accelerator-based Alternatives to Non-HEU Production of Molybdenum-99/Technetium-99m

IAEA Consultant meeting, July 26-29, 2011
 IAEA Headquarters Vienna, Austria



application forms on <http://www-crp.iaea.org/>

INFN – ARRONAX:

New target technology for the production of radionuclides
 Development of new radiopharmaceuticals of copper-67/64
 Development of new radiopharmaceuticals of rhenium-188
 Investigation of the biological effect of alpha radiation

INFN – BEST Thertronics:

Production of Mo-99/Tc-99m at clinical levels
 Direct Production of p+100Mo
 Production via Ucx Target

Evaluated Total cost: 20Meuro (Lab. Extension)

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34

Purpose of the Consultants' Meeting

The consultants meeting was expected to deliberate on the current status of R&D and prospective on accelerator-based production of Mo-99/Tc-99m with emphasis on:

- development and optimization of production methods of Tc-99m in large quantities via the (p,2n) reaction
- target design and construction
- development of methodologies for recovering and recycling of enriched Mo-100 targets,

LINCE: Legnaro Italian Neutron CEnter

LIFAN

(Legnaro Intense FAst Neutron facility):

- SEE Single Event Effect used for electronics' irradiation
- DIRECT proton irradiation facility

scope:

The facility produces a beam similar to the atmospheric spectrum (limited to 70MeV) and allows to study the behavior of complex systems subjected to neutrondamage.



Union for Compact
Accelerator-based
Neutron Sources

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FARETRA

(FAst REactor simulator for TRAnsmutation studies)

Moderated neutron facility with Neutron spectra similar to Gen IV reactors

scope:

The facility reproduces a spectrum typical of a fast neutron fission reactor to perform measurements of integral cross sections of fission and capture of

- minor actinides (MA),
- short-lived fission fragments (FF)

and activation measures of structural parts and materials for cooling for Generation IV fast reactors.

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35

FARETRA, (FAst REactor simulator for TRAnsmutation studies) è mirato alla realizzazione di un dispositivo in grado di riprodurre uno spettro neutronico tipico di un reattore a fissione veloce (da qualche KeV a qualche MeV). (di un sistema ADS o dei futuri reattori veloci GenIV). Tale sistema permetterebbe di eseguire misure integrali di sezioni d'urto di fissione e di cattura, sia su attinidi minori (MA), sia su frammenti di fissione (FF) a breve vita media, o per misure di attivazione di parti strutturali e materiali per raffreddamento per i reattori veloci di IV Generazione

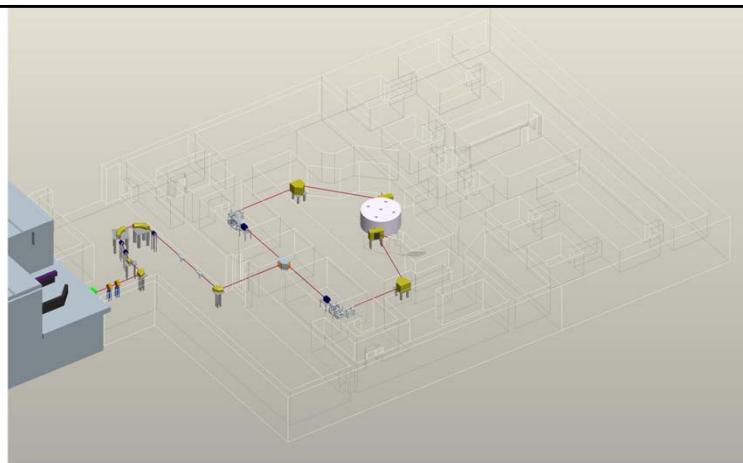
LIFAN (Legnaro Intense FAst Neutron facility) per la produzione di fasci di neutroni per irraggiamento di dispositivi elettronici con la realizzazione di un fascio per SEE (Single Event Effect) e per irraggiamenti diretti con fasci di protoni da 70 MeV. La facility produce un fascio simile allo spettro atmosferico (limitato a 70 MeV) e permette di studiare il comportamento di sistemi complessi sottoposti a danneggiamento neutronico. Queste misure sono di estremo interesse per l'avionica, la strumentazione nucleare e in genereale per la componentistica elettronica.

LINCE: Legnaro Italian Neutron CEnter

Il fascio di protoni del ciclotrone permette di generare neutroni con uno spettro energetico non disponibile ai reattori nucleari e con caratteristiche spettrali che possono essere calibrate con moderatori opportuni o agendo direttamente sul fascio di protoni.

SPES partecipa a UCANS (Union for Compact Accelerator-driven Neutron Sources).

L'Unione per le sorgenti compatte di neutroni basate su acceleratori è nata nel 2010 ed ha lo scopo di dare supporto e coordinamento ad una comunità in via di rapida espansione soprattutto in USA, Cina e Giappone.



SPES Project

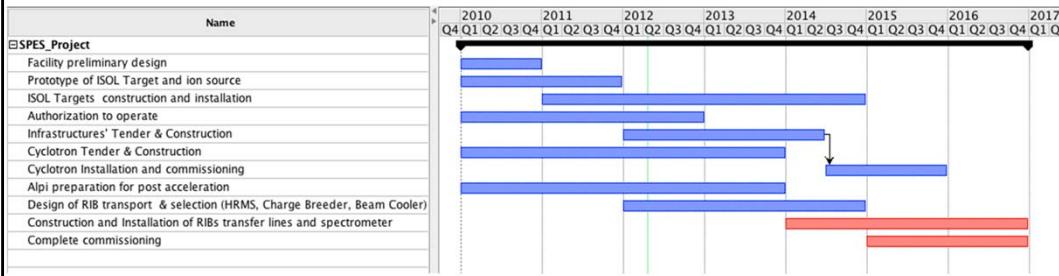
PROJECT ORGANIZATION

10/05/12 – ECPM XXXVIII

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36

SPES Schedule



New Schedule after Infrastructures bid assigned

Project Leader : G.Prete
Project Manager: LAC Piazza

Scientific Coordinator: A.Covello

Radiation Protection Procedures:
D.Zafiropoulos

Management Board:

G.Prete, A.Pisent, A.Covello, D.Zafiropoulos,
F.Gramegna, P.Favaron, A.Andriguetto,
L.Calabretta, A.Bisoffi, A.Lombardi, LAC Piazza

International Referee Committee:
Yorick Blumenfeld, Luigi Celona, Danilo
Rifuggiato

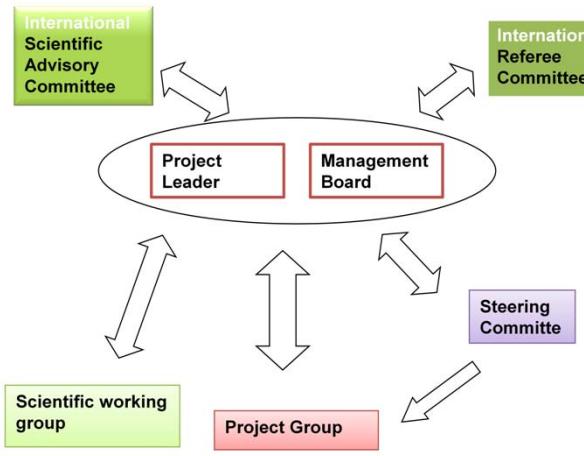
Scientific Committe:

A.Covello (Napoli), G. de Angelis (LNL), G. Casini
(Firenze), G. Colò (Milano), N. Colonna(Bari), A.
Di Pietro (LNS), A. Gargano (Napoli), S. Lenzi
(Padova), S.Pirrone (Catania), G. Pollaro
(Torino).

Steering Committee:

Prof. Giovanni LaRana, (Sez. Di Napoli)
Prof. Mauro Bruno (Sez. di Bologna)
Dott. Sara Pirrone (Sez. di Catania)
Dott. Giovanni Casini (Sez. di Firenze)
Dott. Benedicte Million (Sez. di Milano)
Prof. Santo Lunardi (Sez. di Padova)
Dott. Lorenzo Corradi (LNL)
Dott. Rosa Alba (LNS)
Dott. Paolo Finocchiaro (LNS)

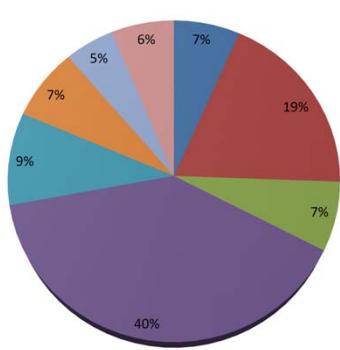
SPES Project Organization



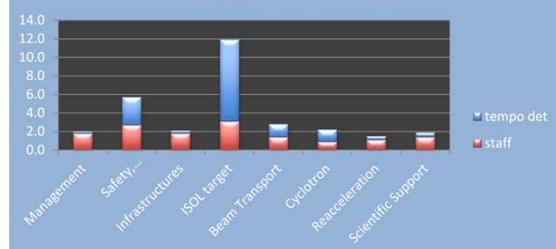
SPES Personnel 2012

FTE per Task

SPES Personnel 2012 – 62 Units, FTE=30



FTE: Staff & Temporary



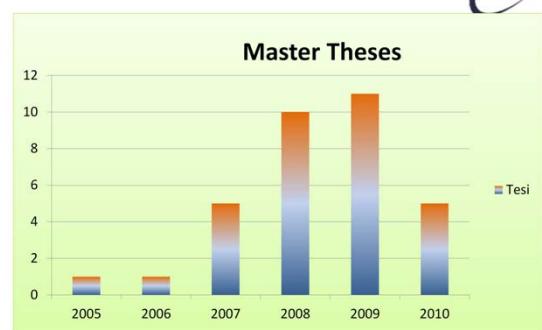
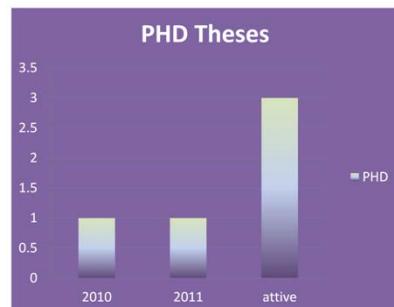
- Management
- Infrastructures
- Beam Transport
- Reacceleration

- Safety, RadioProtection & Control
- ISOL target
- Cyclotron
- Scientific Support

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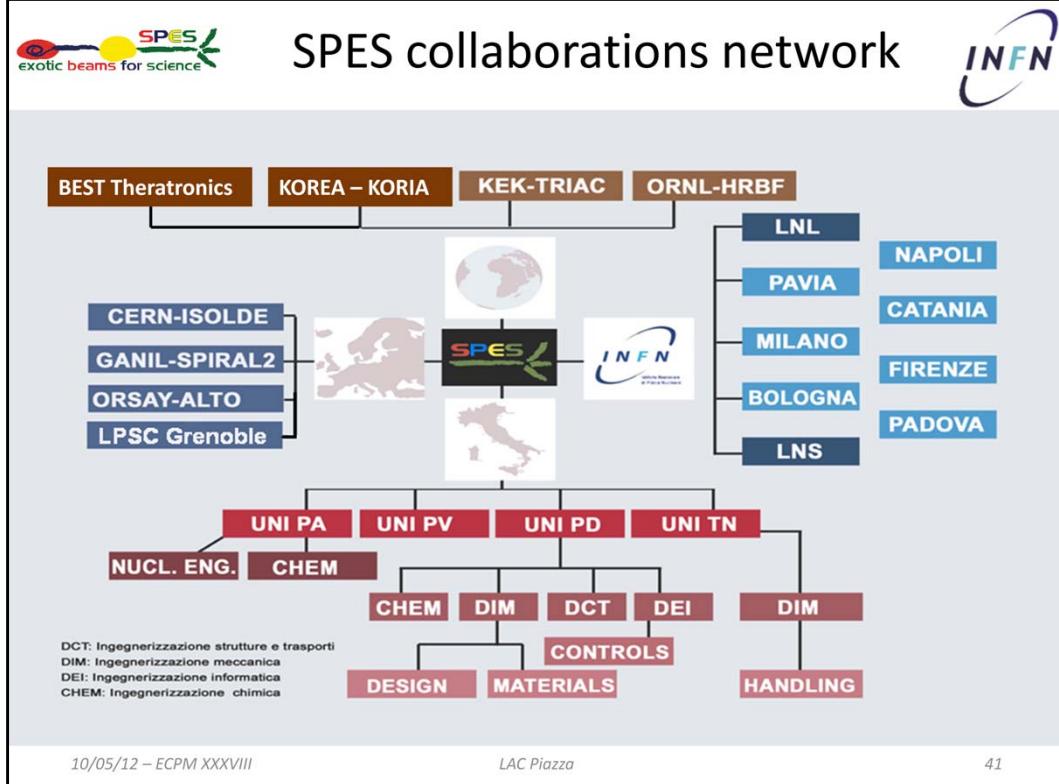
39



10/05/12 – ECPM XXXVIII

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40



Summary

*ISOL Facilities are good for both **users** and **education***

*Today: SPES is a successful project for **education**, due to the past 10 years R&D studies.*

*Tomorrow: SPES project is now mature to be successfully realized: we are&will do our best to give to the **users** community what they deserve.*

SPES Project is now under realization.

For further information, please contact me at

leandro.piazza@lnl.infn.it

10/03/12 – ECPM XXXVIII

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42