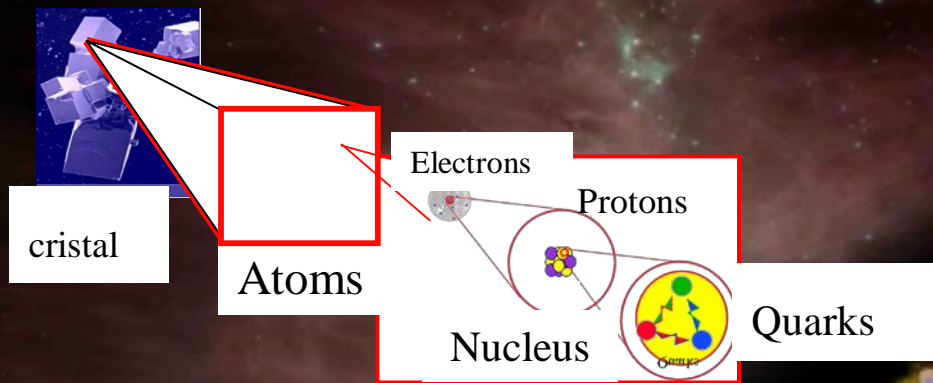
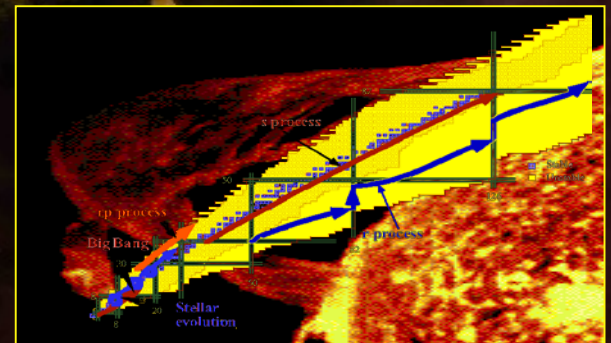


# Large Scale Facilities in Nuclear Physics Science and Society Impact



*Nuclear Physics :  
The heart of matter, the fuel of stars*



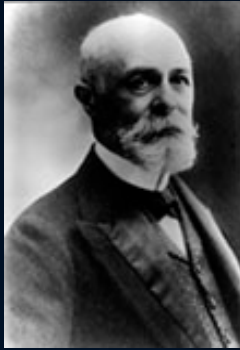
# On the shoulders of Giants

$\beta^-$

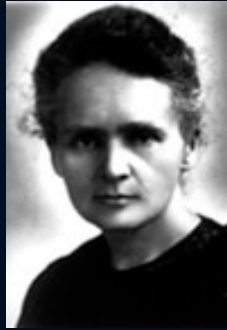
$\alpha$

Nucleus

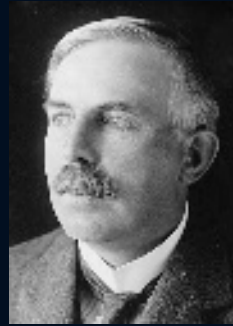
$\beta^+$



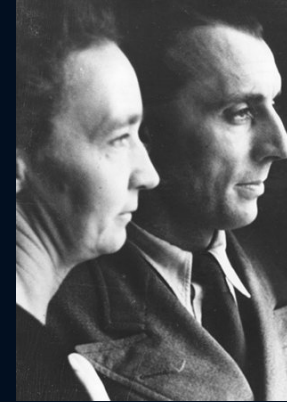
Henri Becquerel  
1896



Marie Curie  
1903



E. Rutherford  
1911

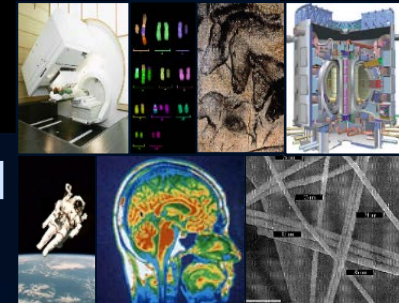


Irène et Frédéric  
Joliot-Curie 1932

100 years after Becquerel , Marie Curie, Rutherford, Irene and Joliot Curie  
*The frontiers of nuclear science today require new tools, technologies, and accelerators. The quest is to answer the open questions of the emergence of the complexity, the nature of the nuclear force and the origin, evolution, and structure of the visible matter in the universe. Intense Stable beams and Secondary Radioactive Ion Beams are central to this quest worldwide.*

***A science with major societal applications.***

The concepts and techniques of nuclear physics have had exceptional impact in this regard

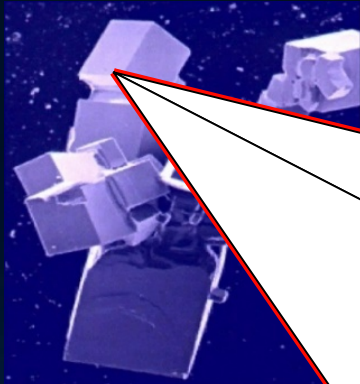


# Probing the structure of matter, its constituents and their interactions

How to see and study the invisible?

**Accelerators are Giant microscopes**  
**The eyes are our detectors**

$10^{-6}m$



crystal

$10^{-10}m$

Atoms

Electrons

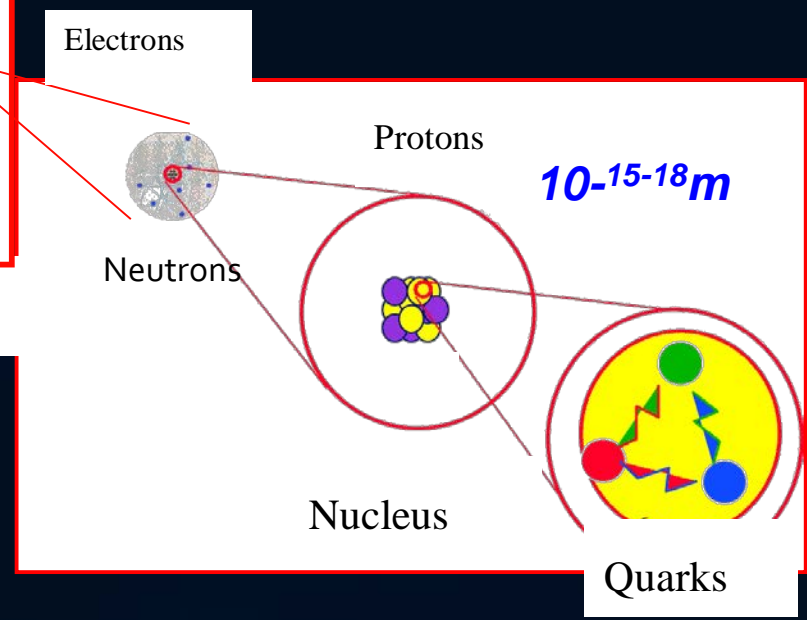
Neutrons

Protons

Nucleus

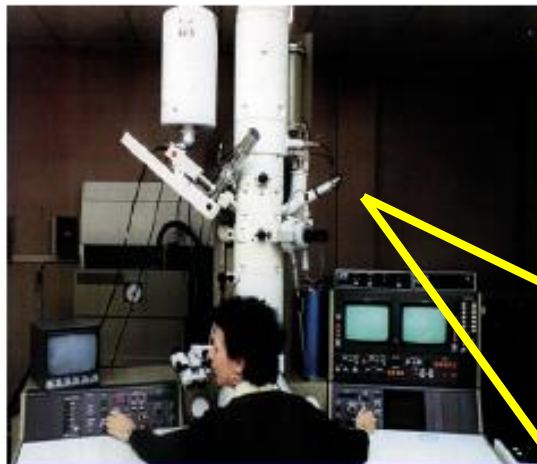
$10^{-15-18}m$

Quarks



# Particle accelerators : larger and larger microscopes

Scales ( $\mu\text{m}$  to  $10^{-18}\text{m}$ ) are correlated with Energy ( $\text{eV}$  to  $\text{TeV}$ )



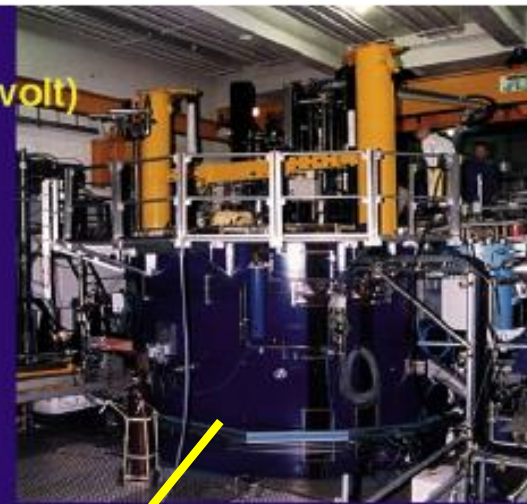
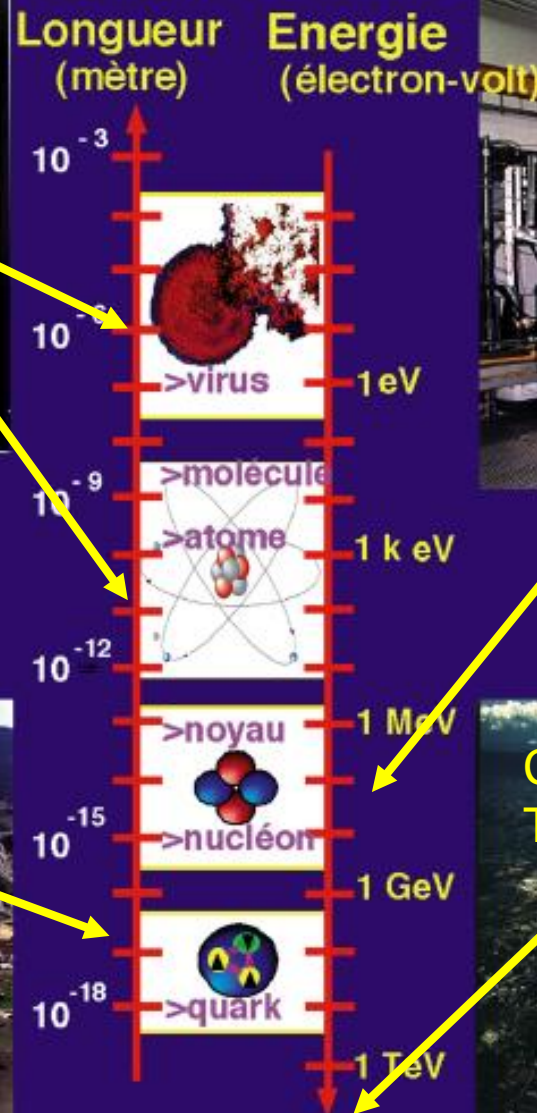
Microscope électronique  
<1m

Accélérateur linéaire

SLAC, Cal, USA- Km



IN2P3  
INSTITUT NATIONAL DE PHYSIQUE NUCLEAIRE  
25 25 F 91890 CEDEX 2



Cyclotron- 4meters

Synchrotron

CERN, Genève, EU  
Tens of Km



# Types of Acceleration

Churro-like



Pancake-like



Doughnut-like

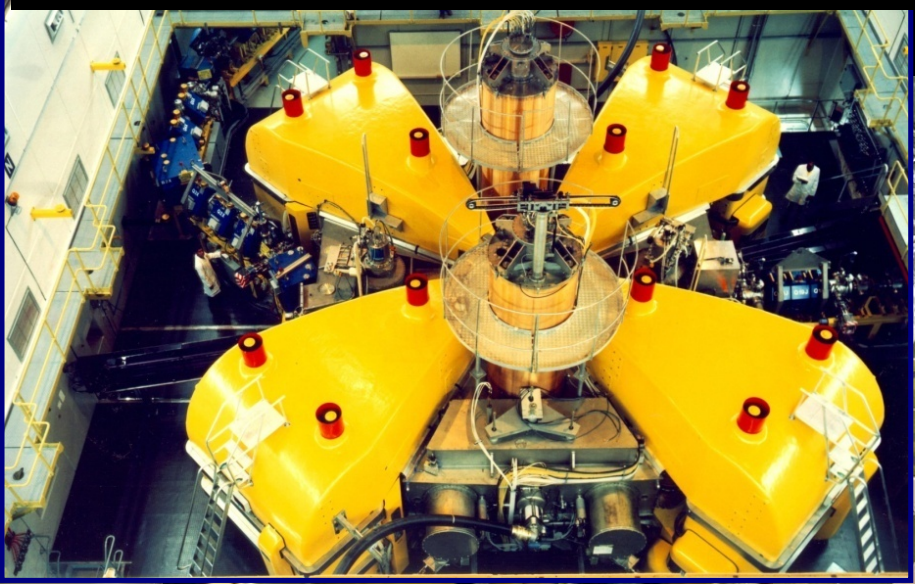


SPIRAL2 SC-LINAC

2019



iThemba Labs version of Pancake



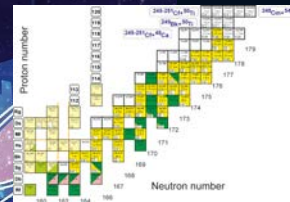
Proton Fair - Germany

2025





*Exotic Limit of stability  
Limit in Mass, Shells and Magicity*



# *Extreme of Nuclear Physics Landscape*

Nombre de protons Z



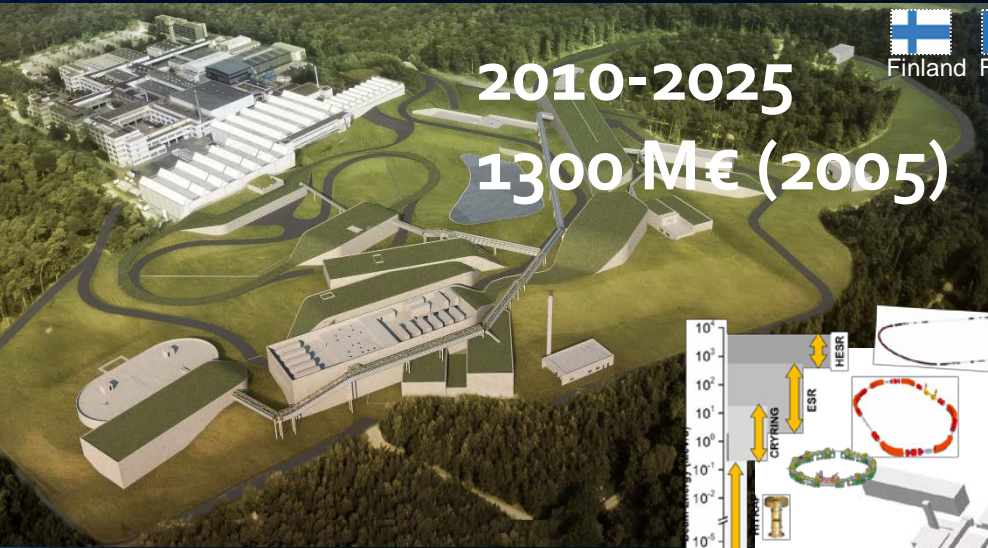
Nombre de neutrons N >



*Heavy elements  
in the Universe*

**Next Generation of Intense Stable Beams and RIB Facilities  
International Gold Rush**

# FAIR: Facility for Antiproton and Ion Research – A World-Wide Unique Accelerator Facility

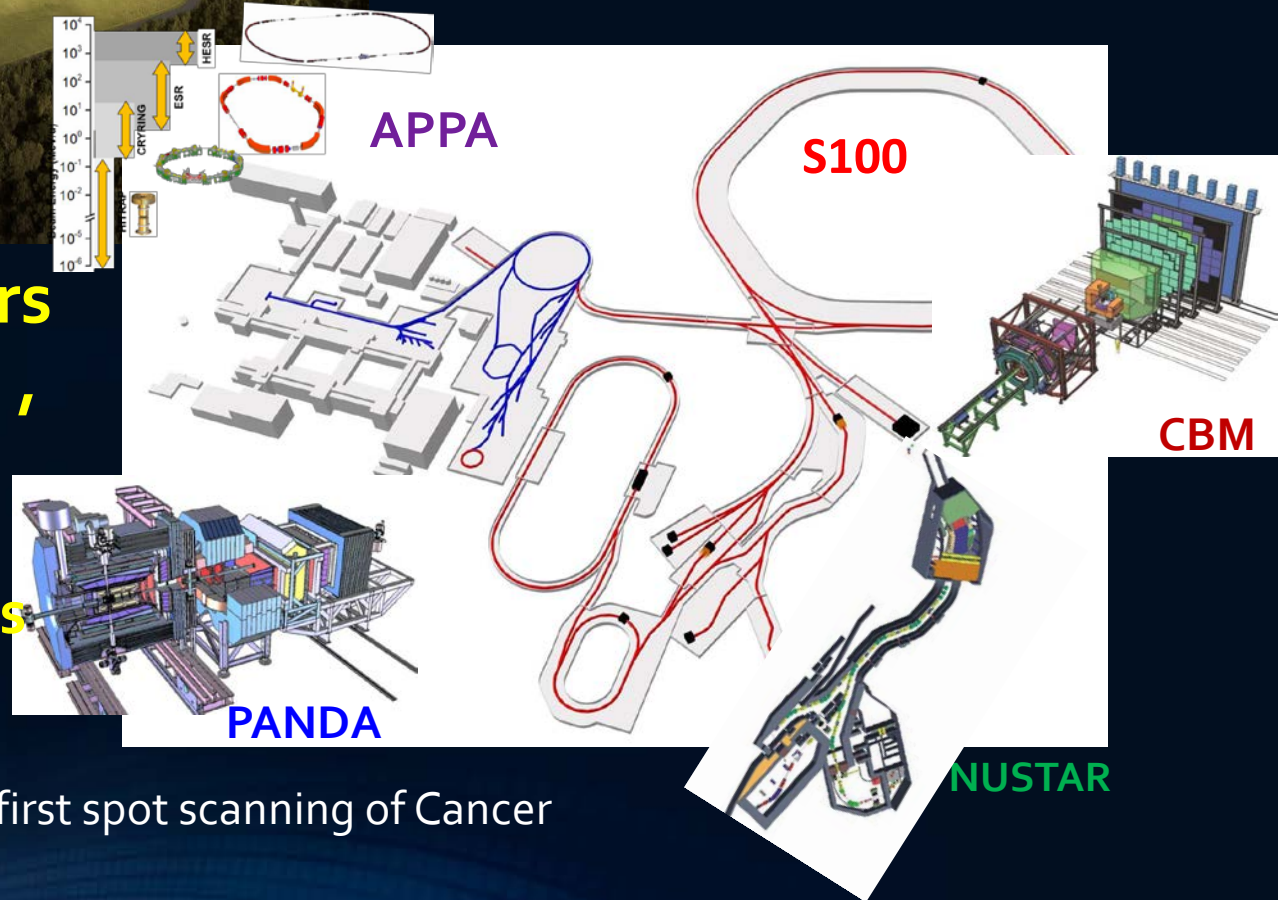


2010-2025  
1300 M€ (2005)



- ESFRI Landmark
- Driver for Innovation in Science and Technology

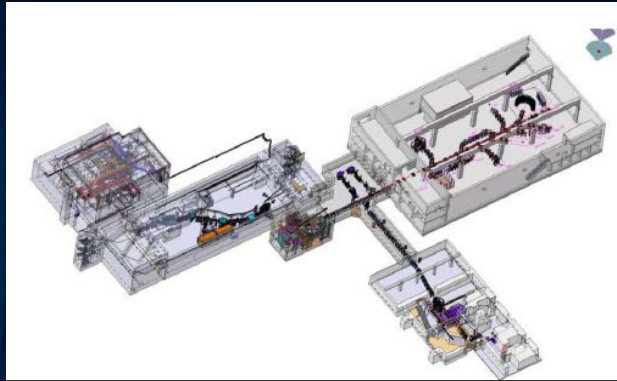
**FAIR Science 4 Pillars**  
Broad science program ,  
multi disciplinary , //  
beams  
Large Int collaborations  
About 3000 users.



Impact GSI has developed the first spot scanning of Cancer tumors with C12 beams

# FUTURE of ISOL in EUROPE

GANIL-SPIRAL2, Phase 1  
2005- 2019 136M€



## ESFRI project

High Power Linac (200Kw) SC linac driver for Light & Heavy Ions ,  
Intense neutron source NFS  
N=Z, SHE with S<sub>3</sub>  
Isol physics at rest with SP<sub>1</sub>, SP<sub>2</sub> and DESIR  
More than 400 users  
Large international collaborations  
On Instruments

HIE ISOLDE  
@CERN 2017



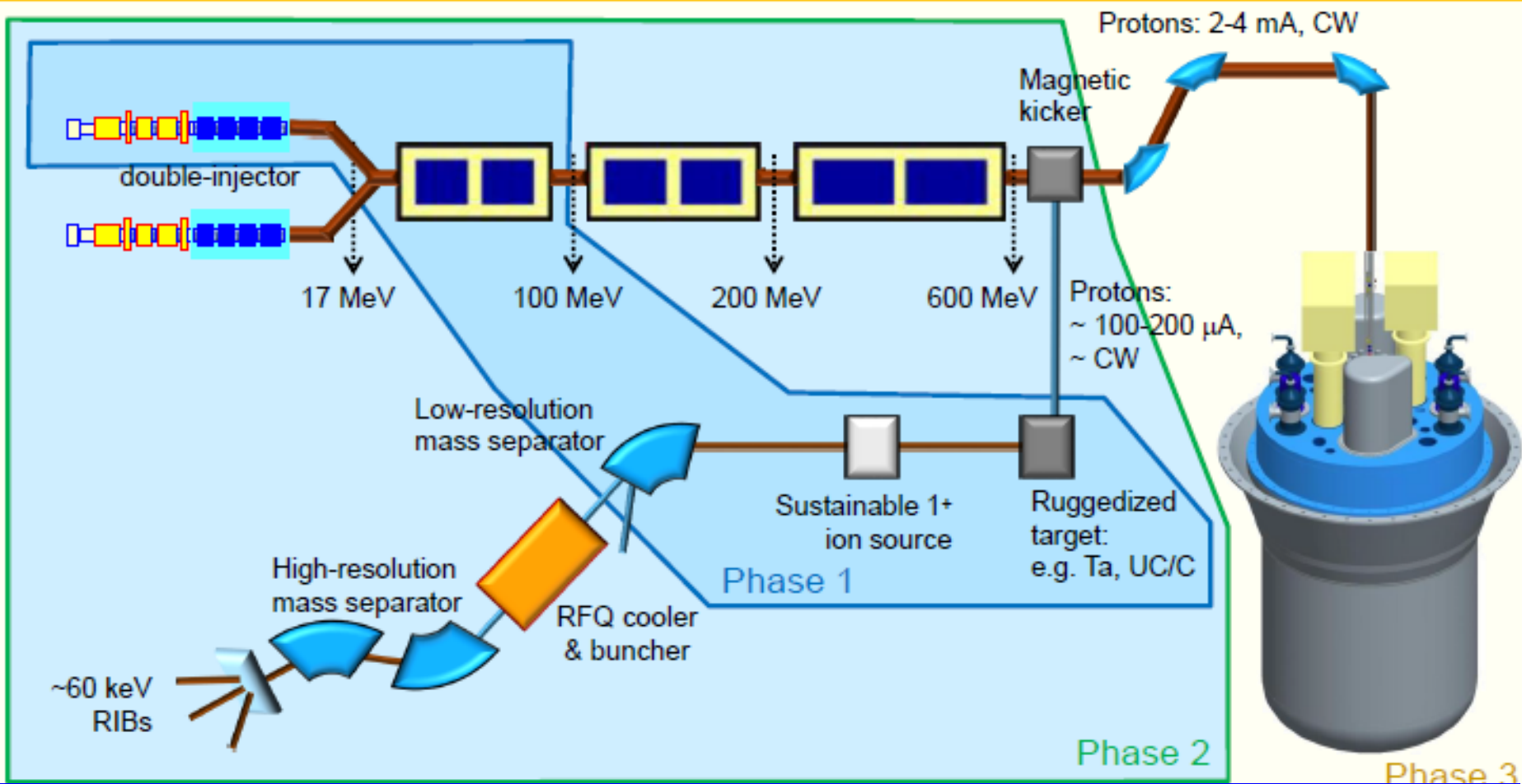
The best ISOL Facility of the world since 1965  
Production of RIB for more than 65 elements  
Among the best expt set up  
HIE post accelerator up to 7 MeV/n for Hg beams

SPES@Legnaro  
2009-2020/2022



H- 70 MeV Cyclotron Driver > 200μA, 8Kw  
ISOL Ucx foils Targets 10\*13 fissions/s  
ALPI SC LINAC Booster up to 15MeV/n  
Neutron beam , Radio Isotopes production  
Start day one expt 2021





And a new Partner ISOL@MYHRRRA Phase 1 of a Multi-Disciplinary project  
 Founded By Belgium up to 2030 to 528 M€ includes ADS Transmutation, ISOL and  
 Radio-Isotopes

**NOW FOUR ISOL RIB facilities in Europe**

**Cooperation and complementarity of Science program are under discussion**

# The first new generation RIB facility :RIBF started 2007



**400 MeV/u Light-ion beam**  
**345 MeV/u Uranium beam**

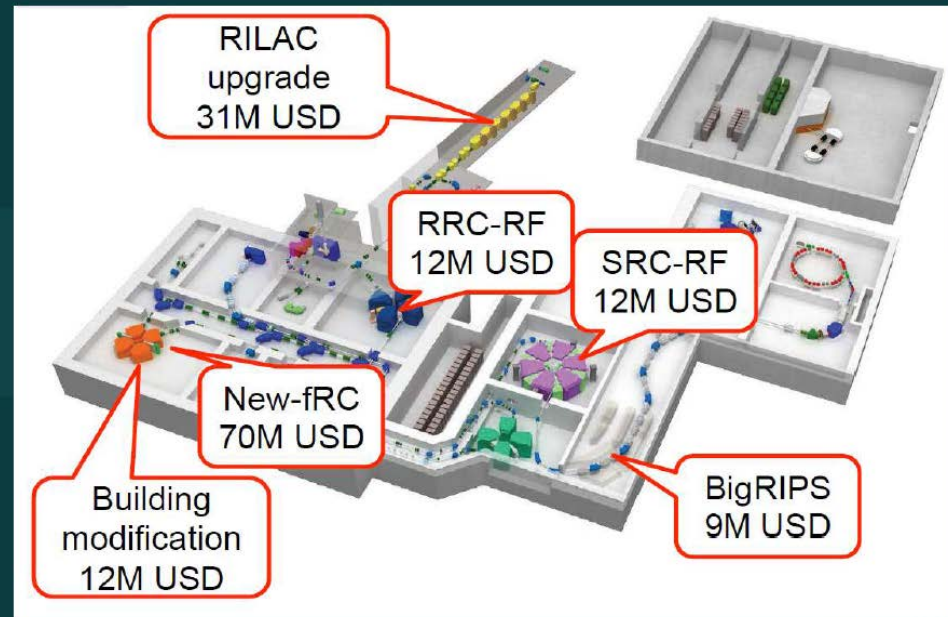
**SRC World's First and Strongest  
K2600MeV RIKEN –Started 2007  
Superconducting Ring Cyclotron  
+ BIGRIPS, 0° Spectr, SHARAQ  
SAMOURAI**



**They build it in Japan !!**

## RIBF Upgrade

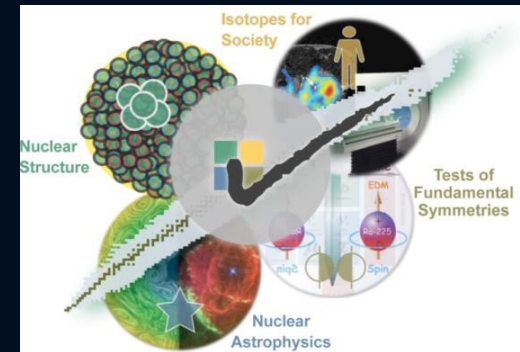
Project at 146M\$ in total  
Intensity will be 5x RILAC, 30x RRC, 30x SRC



# Future Facilities FRIB USA 2009-2021

- SC Linac Primary beam power of 400 kW and beam energies of  $\geq 200$  MeV/u!!!

*The US RIB Flagship Project 2009-2021  
Inv >750M\$ expect more than 1500 users*



- FRIB Fragment Separator
- Three-stage fragment separator for production and delivery to maximize FRIB science reach

## FRIB NSCL-USA 2021



Users are organized as part of  
**Users Organization (FRIBUO)**

- Approximately 1,388 members (>100 U.S. colleges and universities, 12 national laboratories, 52 countries)

# Large Scale Regional Research Infrastructures

## *New frontiers of Nuclear Physics Worldwide*

### JINR Dubna

#### Super-Heavy Elements (SHE) Factory Dubna High HI Intensity



DC-280 cyclotron


Start expts 2019



**NICA (Nuclotron-based Ion Collider fAcility)**

Main targets: <http://nica.jinr.ru/>

- study of hot and dense baryonic matter at the energy range of *max baryonic density*
- investigation of nucleon spin structure, polarization phenomena



Construction of Collider of relativistic ions from p to Au, polarized protons and deuterons

with max energy up to  $\sqrt{s_{NN}} = 11$  GeV (Au<sup>79+</sup>) and =27 GeV (p)  
 $\sqrt{s_{NN}} = 11$  GeV (Au<sup>79+</sup>, L ~ 10<sup>27</sup> cm<sup>-2</sup> c<sup>-1</sup>)  
 $\sqrt{s} = 27$  GeV (p, L ~ 10<sup>32</sup> cm<sup>-2</sup> c<sup>-1</sup>)

*Relativistic HI Colliders N-N  
And p-p spin physics  
Start operation 2021*

# Large Scale Regional Research Infrastructures

## Rare Isotope Science Project (RISP, KoREA)



Goal: To build a heavy ion accelerator complex RAON for rare isotope science research in Korea.

Budget: US\$ 1.44 B (1 B\$~1T Won)

- accelerators and experimental apparatus : 0.46 B\$
- civil engineering & conventional facilities : 0.98 B\$ ( incl construction site purchase)

Period: 2011.12 ~ 2021.12 (10.1 years)

Phase 1 Inj Cycl p 70 Mev +ISOL+SC LINAC , RIB up to Fermi energy

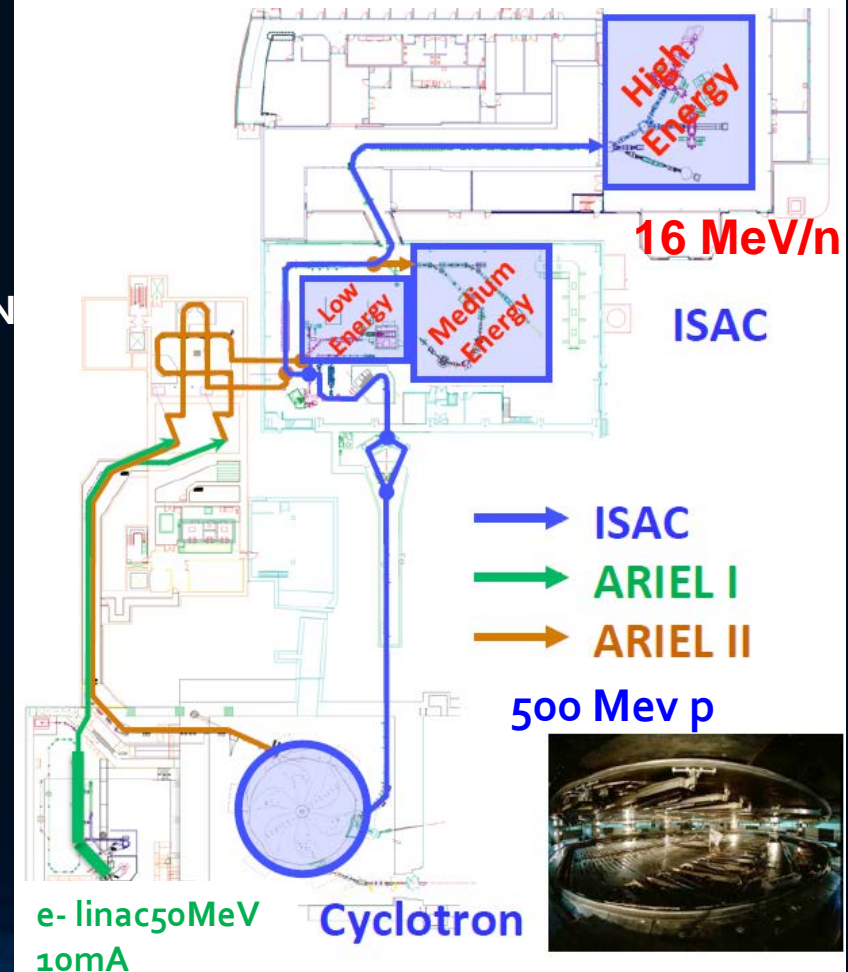
1990-2025 TRIUMF-ARIEL

Advanced Rare-IsotopE Laboratory

1 RIB → 3 simultaneous RIBs

ARIEL Project:

- new electron linac driver for photo-fission
- new target stations and front end
- new proton beamline



# Accelerator Facilities at IMP (LANZHOU, CHINA)

Ions 5kqV to 1GeV/n , protons 10Mev-2,8 GeV ,electron cooler

Two new SC linac injectors project 2014-20---

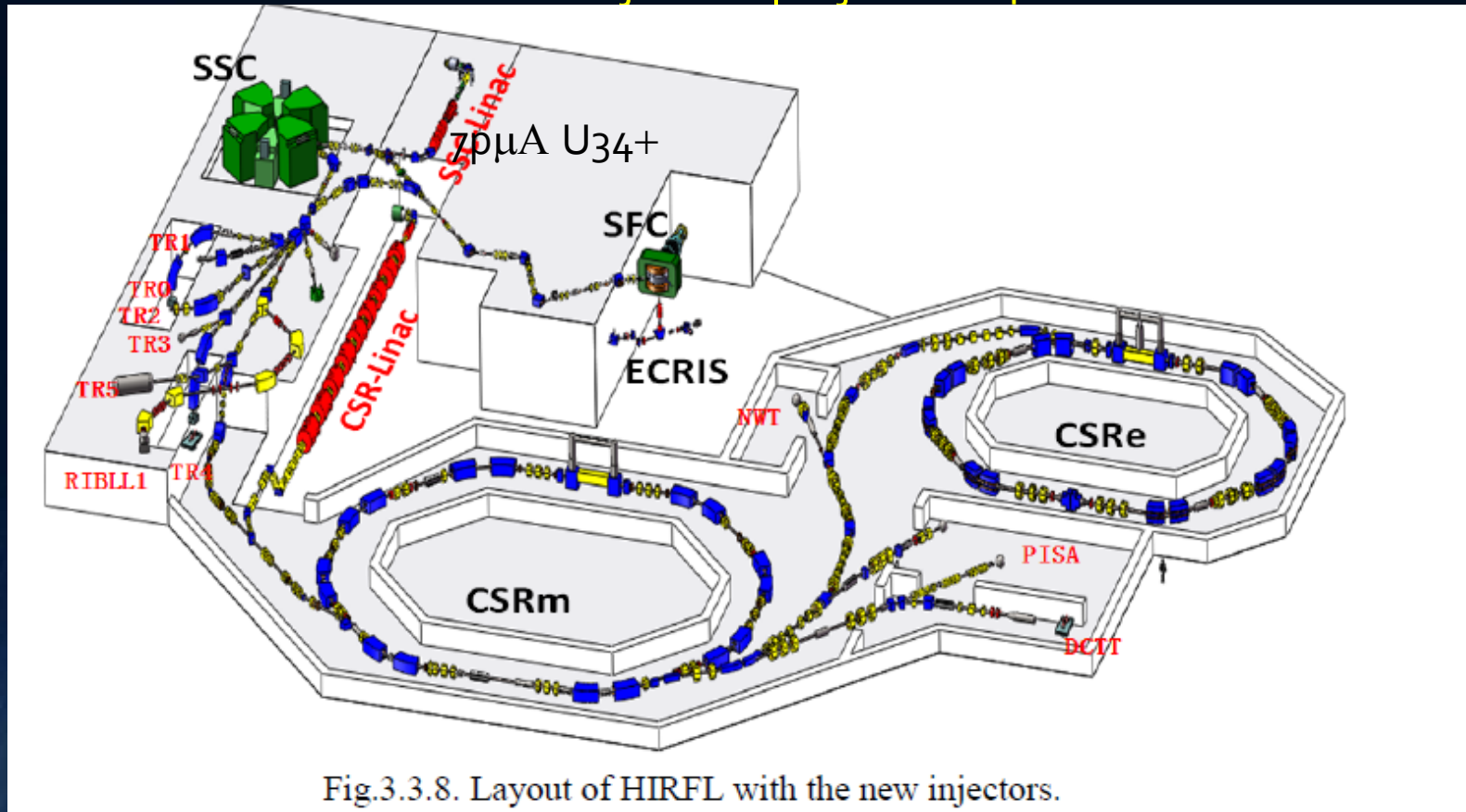


Fig.3.3.8. Layout of HIRFL with the new injectors.

**NEW LONG TERM Project**  
**HIAF (High-Intensity heavy ion Accelerator Facility)**

**2-5 GeV/u ( $^{238}\text{U}^{74+}$ )**  
 **$10^{12}$  pps Stacking**  
**Electron-Ion collisions**

- High intensity ion source
- High intensity pulse SC-Linac
- 2 more Multi-function synchrotron 2

# Up-coming Facilities

- 1) Ultra-short High power laser pulse  
(25fs) 2 X10 PW, 1/mn

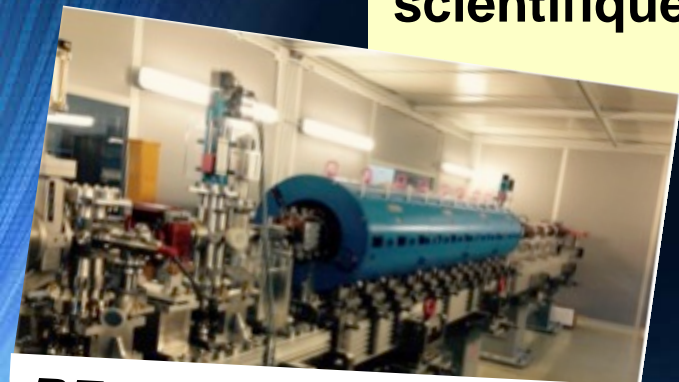
Gerard Mourou  
Founding father of ELI-NP  
Physics Nobel Prize winner 2018

Nuclear Photonics Brasov June 2018

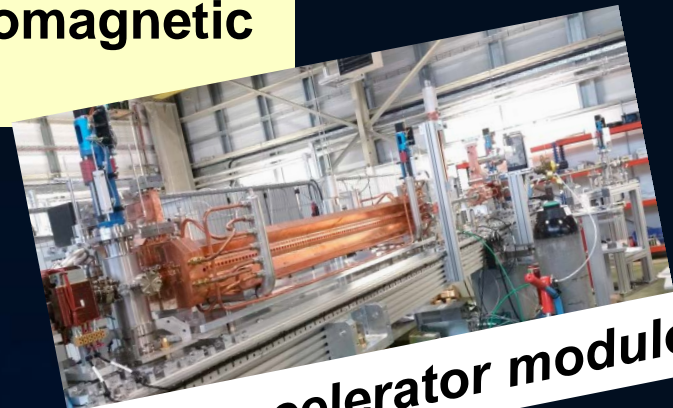
- 2) GAMMA beams high flux , monochromatic,  $\Gamma \sim 10^{-3}$ ,  $E = 0.2-19 \text{ MeV}$

Nuclear astrophysics-Nuclear structure-applications – start in 2019-20

Experimental set ups under construction-  
scientific program with electromagnetic  
probes unique



RF Photoinjector -S-band



C-band accelerator module



# ***iTHEMBA LABS - The South African Isotope Facility (SAIF)***

***OPENING NEW AFRICAN FRONTIERS IN NUCLEAR SCIENCE & APPLICATIONS***

***National Facility for pure and applied research,  
development and training  
a centre for Accelerator Based Sciences in Africa***



Copyright H

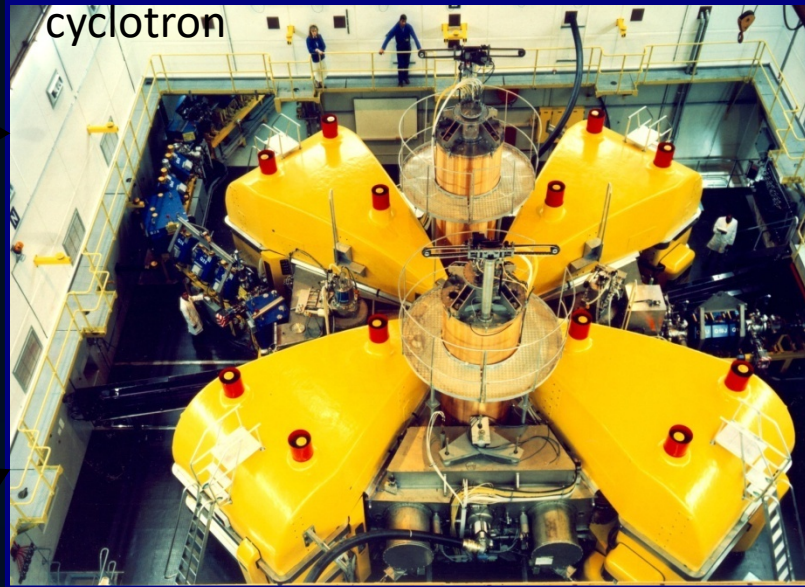


# iThemba: Laboratory Accelerators Based Science

K8 Injector cyclotron 1



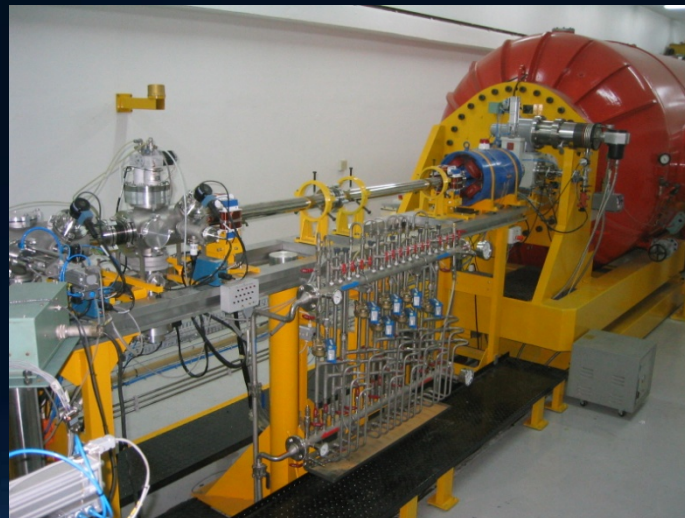
K200 Separated sector cyclotron  
cyclotron



K11 Cyclotron



6MV Tandem



3MV Van de Graaff



K8 Injector cyclotron 2

# A Long Range Plan

## iThemba LABS : 2017-2027

### SHARING THE VISION FOR THE FUTURE



- Phase 1- **Accelerator Centre for Exotic ISOTOPES (ACE-ISOTOPES)**
  - Increased capacity for the R&D as well as production of Isotopes
  - Timeline - 4 years to operations
- Phase 2- **Accelerator Centre for Exotic BEAMS (ACE-BEAMS)**
  - Isotopes for Astrophysics - synthesis of elements in the universe
  - Timeline – 8 Years to operations

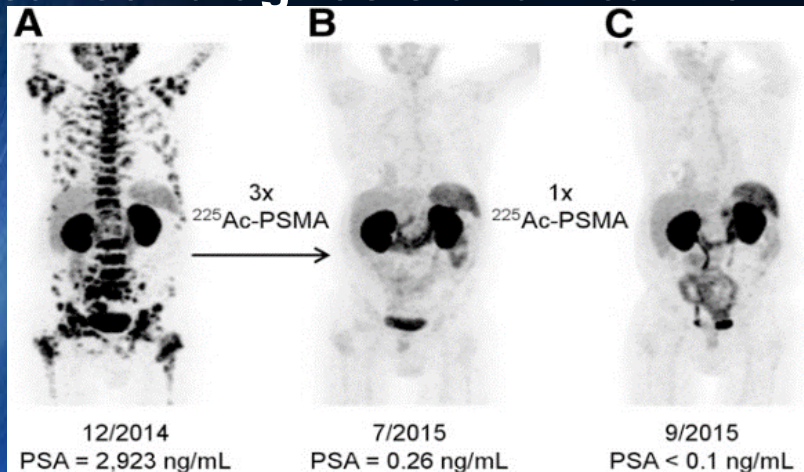
# A Long Range Plan

iThemba LABS : 2017-2027

Establishment of the South African Isotope Facility (SAIF) at iThemba Labs through acquisition of a 70 MeV cyclotron

ACCELERATOR CENTRE FOR EXOTIC ISOTOPES (INNOVATION DRIVER)

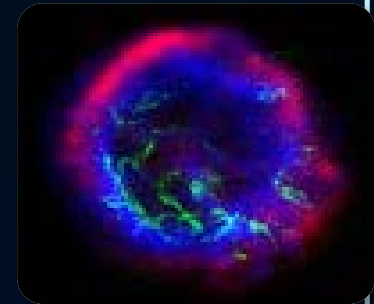
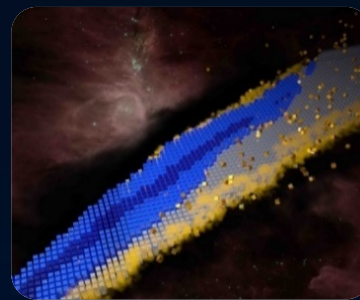
- 5-fold increase in isotope production capacity
- Novel radiopharmaceuticals for cancer diagnosis and treatment



ACCELERATOR CENTRE FOR EXOTIC BEAMS (BASIC SCIENCE DRIVER)

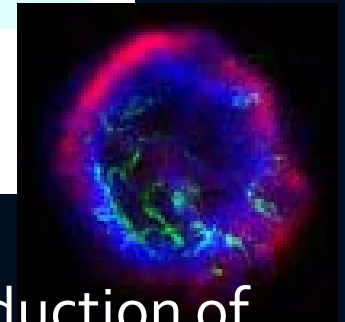
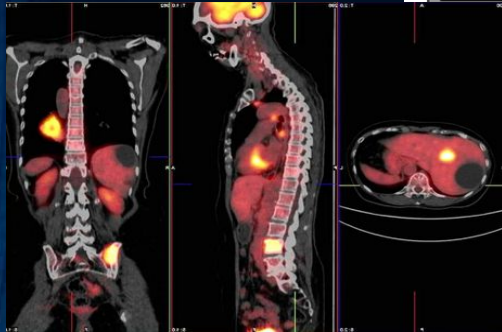
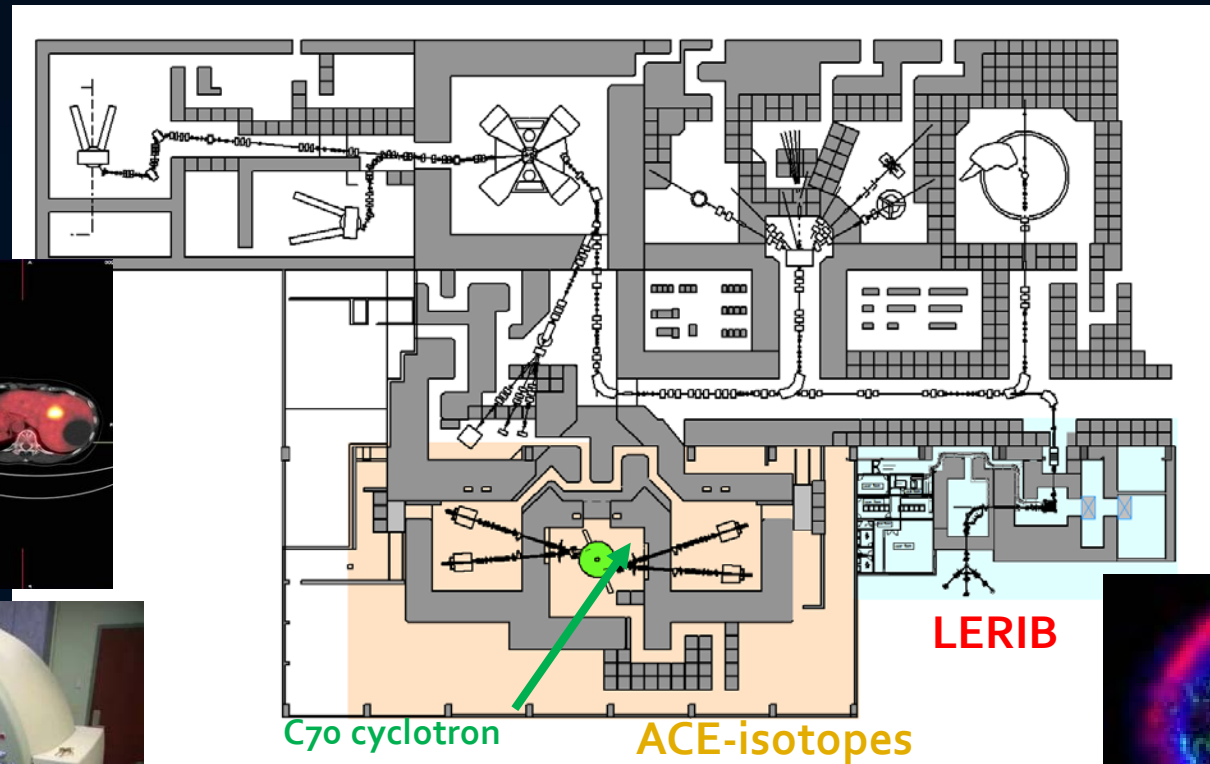
3-fold increase in beam availability for research

- Radiation hardness testing
- Nanomaterials development
- Astrophysical origin of the elements
- Understanding the fuel of stars



# The South African Isotope Facility (SAIF)

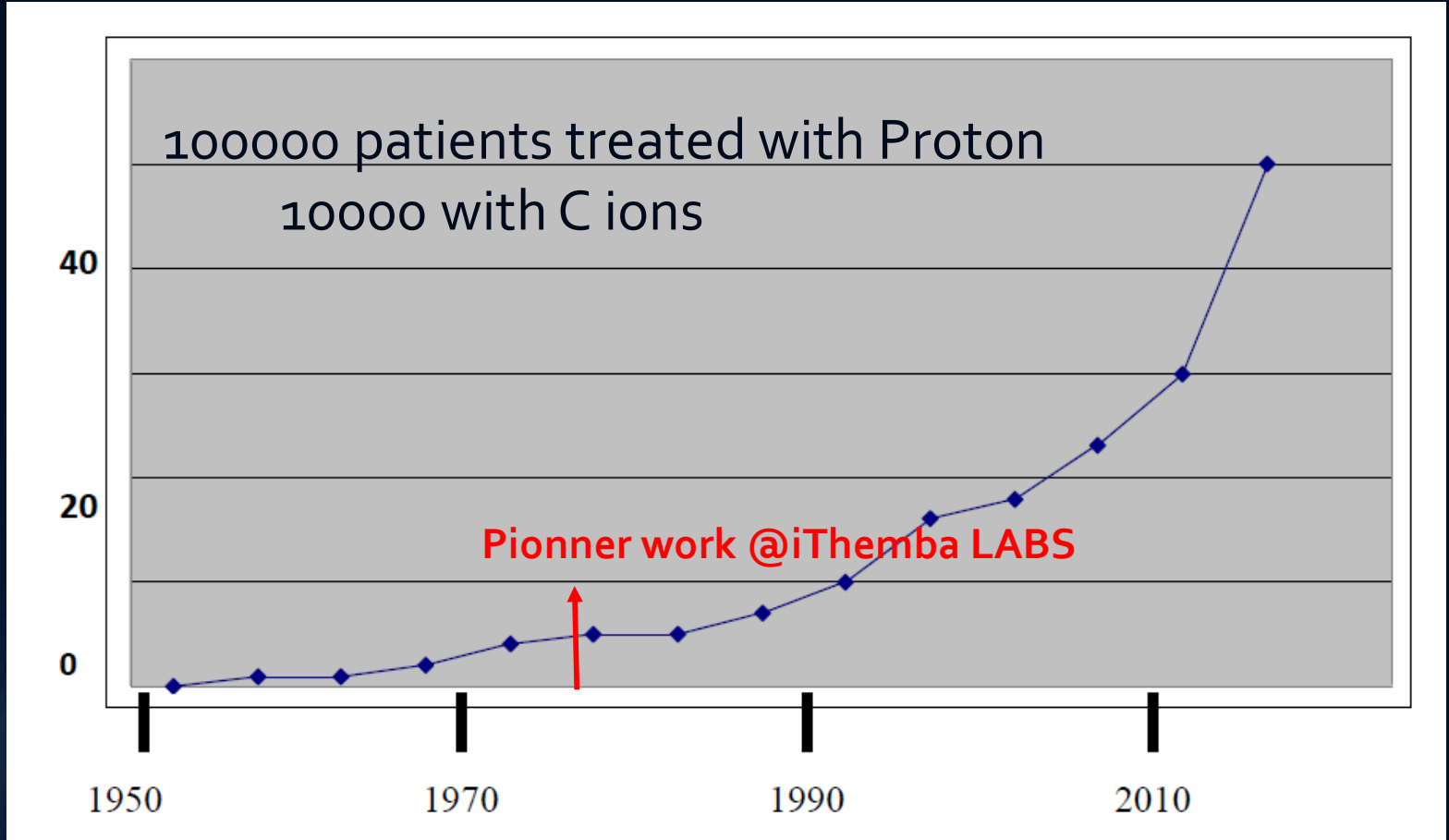
## Phase 1 - ACE Isotopes



- Increased capacity for the production of Isotopes dedicated cyclotron driver
- New low energy "exotic" beam via ISOL
- Timeline - 4 years to operations

In 1946 accelerator physicist R. Wilson laid the foundation for Hadrontherapy

Number of proton therapy centers



*Evolution of the number of proton therapy centers in the world between 1950 and 2015*

**47 New Protons centers in construction**

## From Therapy to research



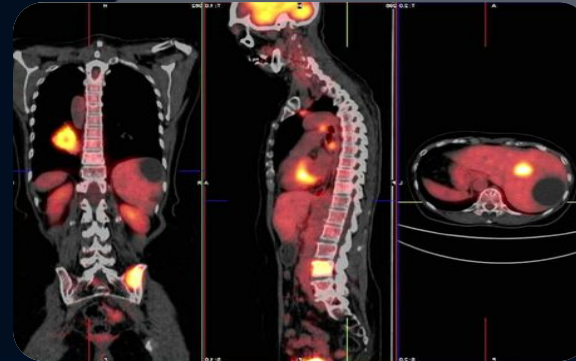
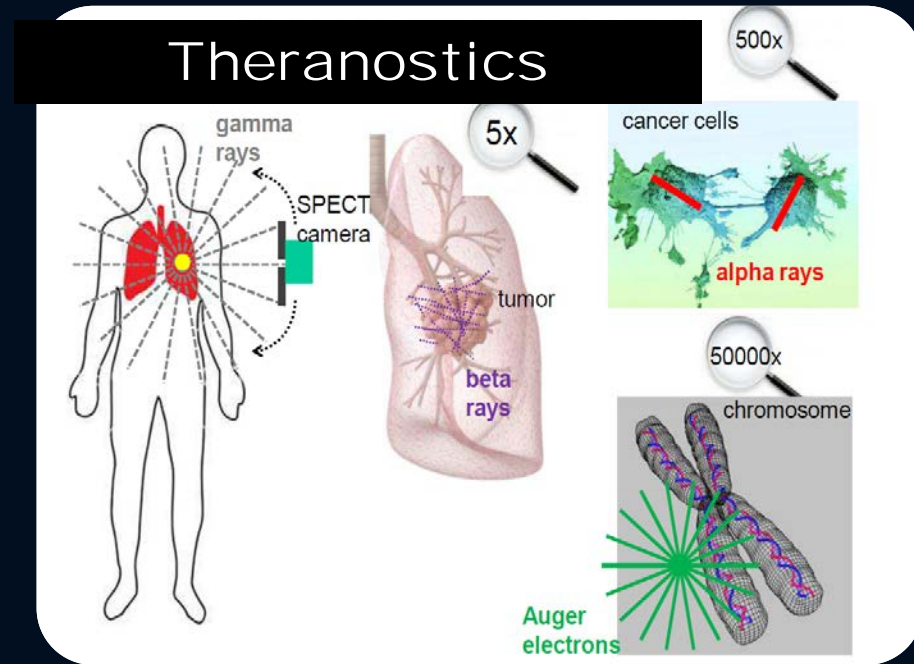
➤ Research in radiobiology and radiation physics related to hadron therapy, with a strong emphasis on radiobiological modelling for treatment planning

# Future opportunities: medical isotopes

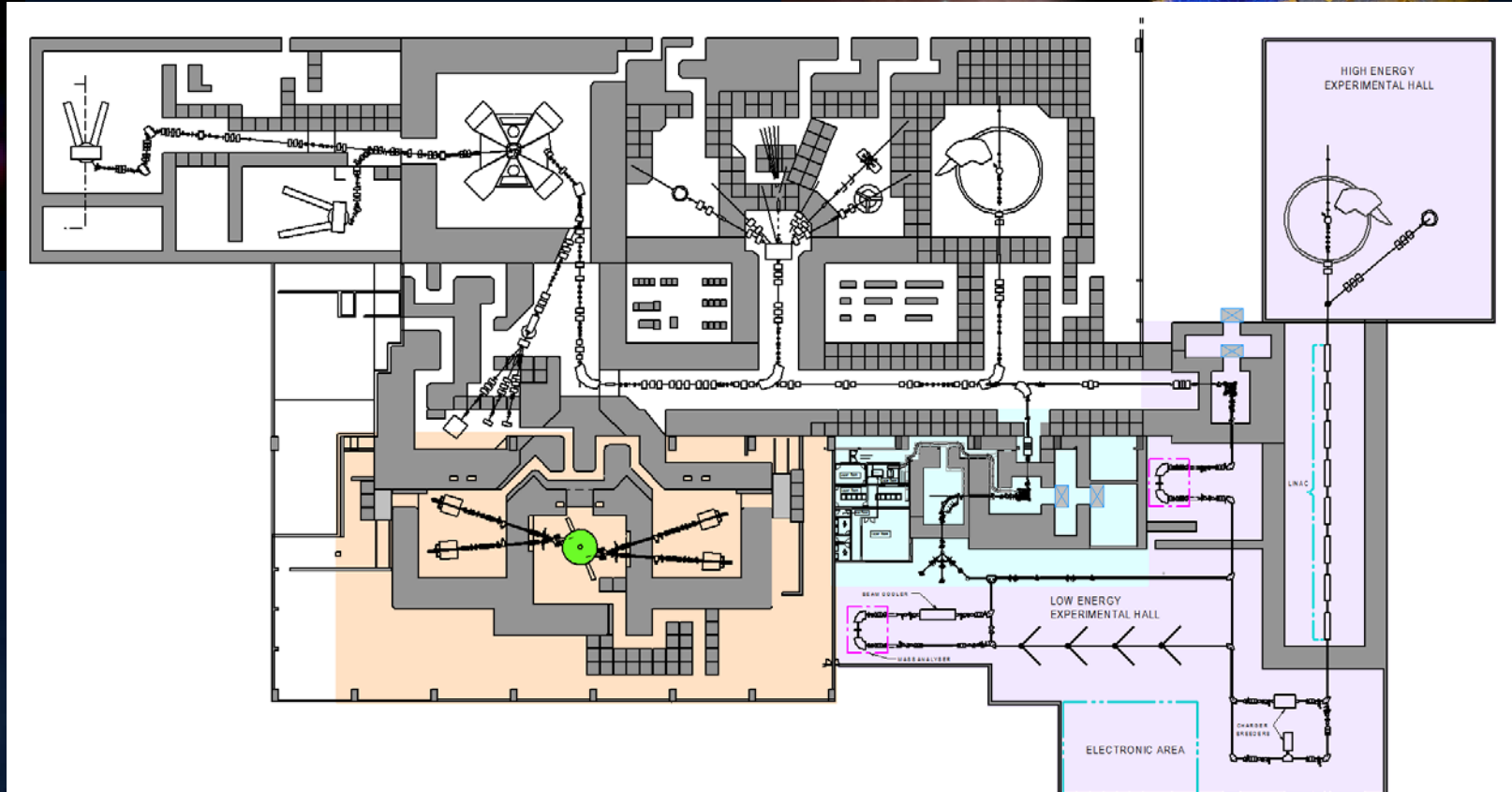
**Research opportunities** exist with respect to **new radioisotopes** used for imaging and targeted therapies:

**Targeted Alpha Therapy** uses the alpha-emitter  $^{225}\text{Ac}$  Actinium

- Targets and destroys cancer cells and also provides early diagnostic imagery of the tumors
- Targeted therapy limits the damage to healthy cells unlike conventional treatments for cancer



# PHASE 2 - ACE-Beams: The Universe in a Laboratory



Isotopes for Astrophysics - synthesis of elements in the universe

Timeline – 8 Years to operations

**Be part of the gold Rush in NP**

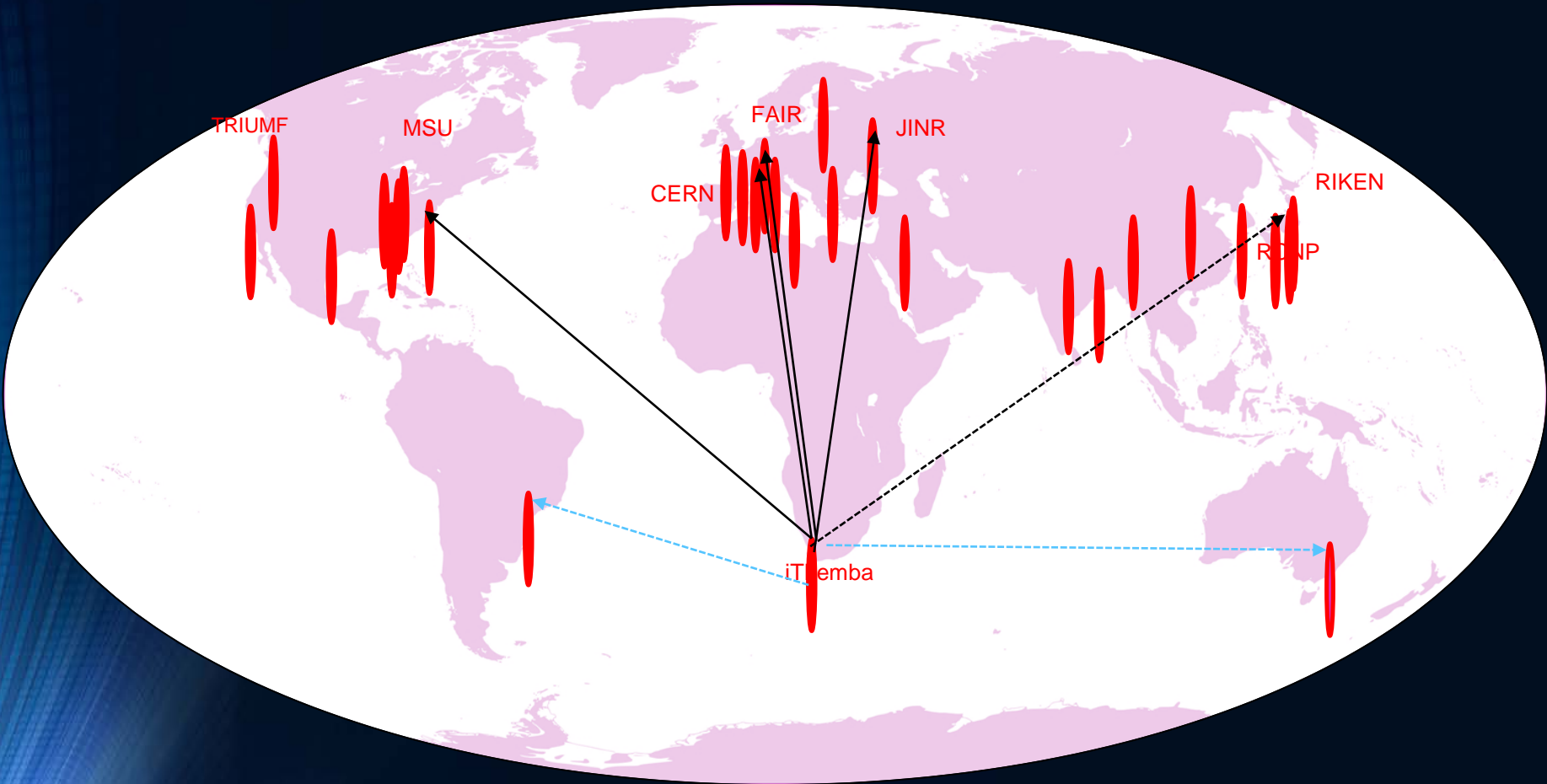
## ACE-Beams

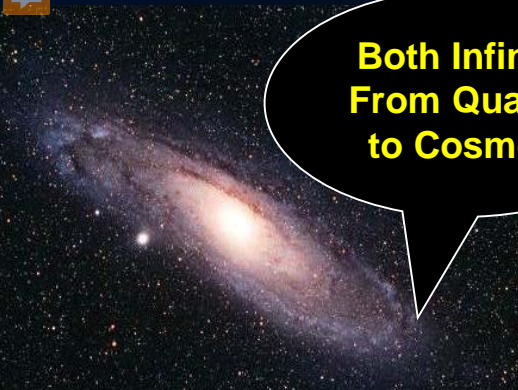
The addition of a post accelerator to LERIB - ACE Beams



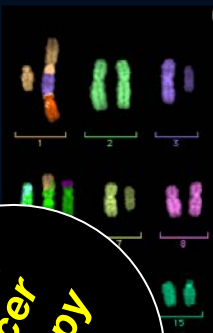
# Internationalisation: iThemba LABS

The African hub to International Large Scale Research Infrastructures



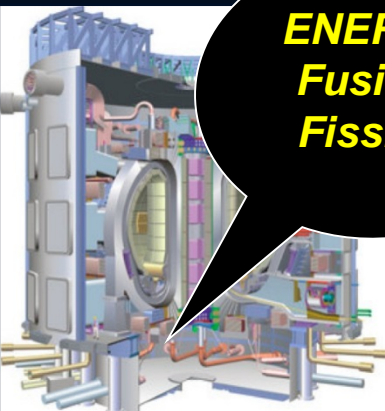


**Both Infinity  
From Quarks  
to Cosmos**



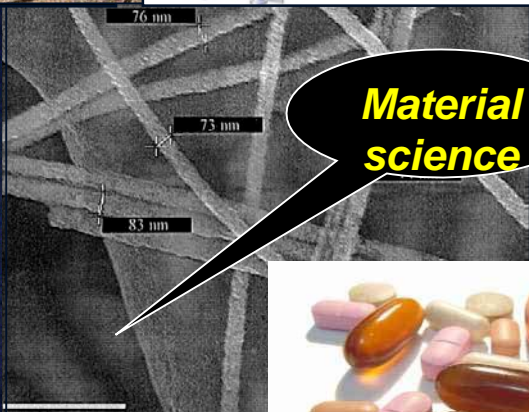
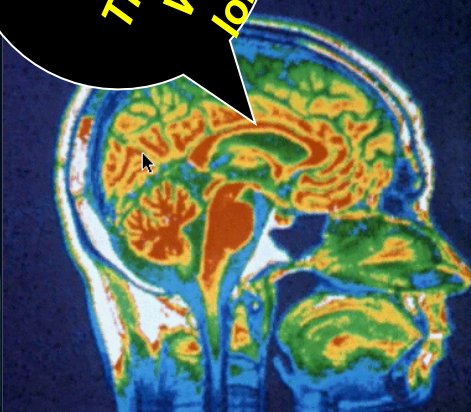
**Imaging  
Cancer  
Therapy  
With  
Ions**

**Art**



**ENERGY  
Fusion,  
Fission**

**SPACE**

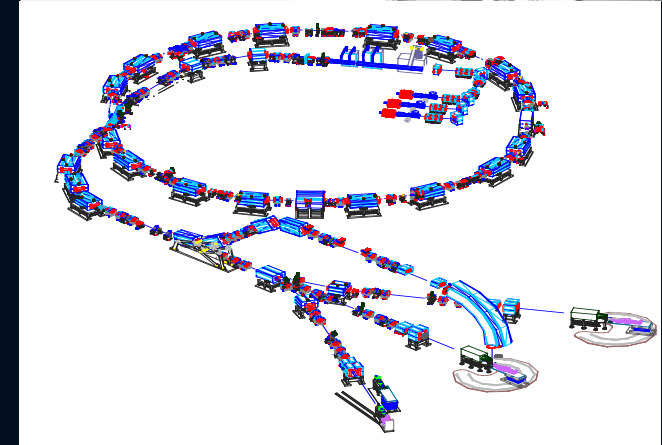
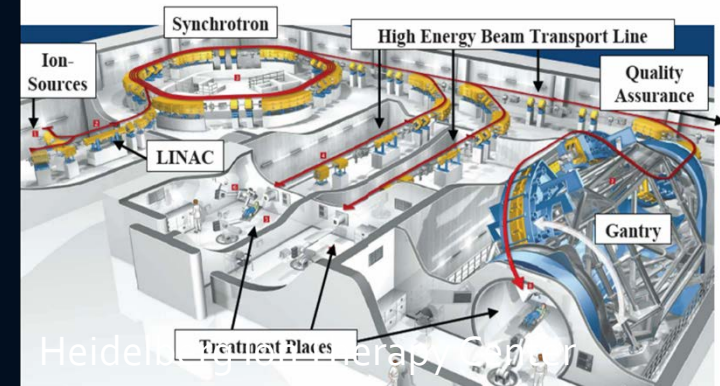


**Material  
science**

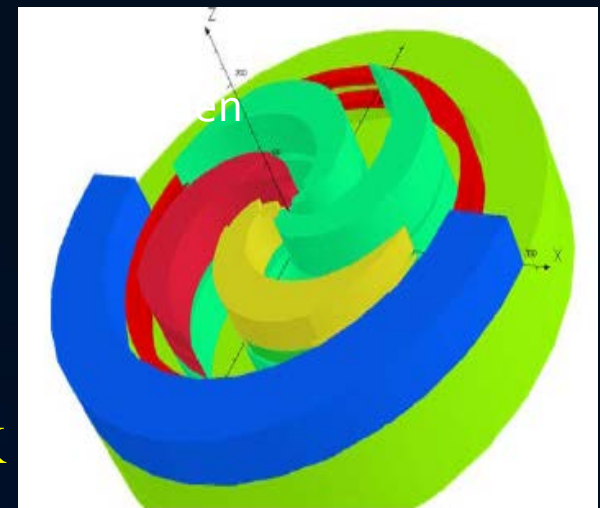


Research Infrastructures are facilities where **basic** research as well as **applied** research are interacting to generate **innovations** for our daily life

# Hadrontherapy European Projects

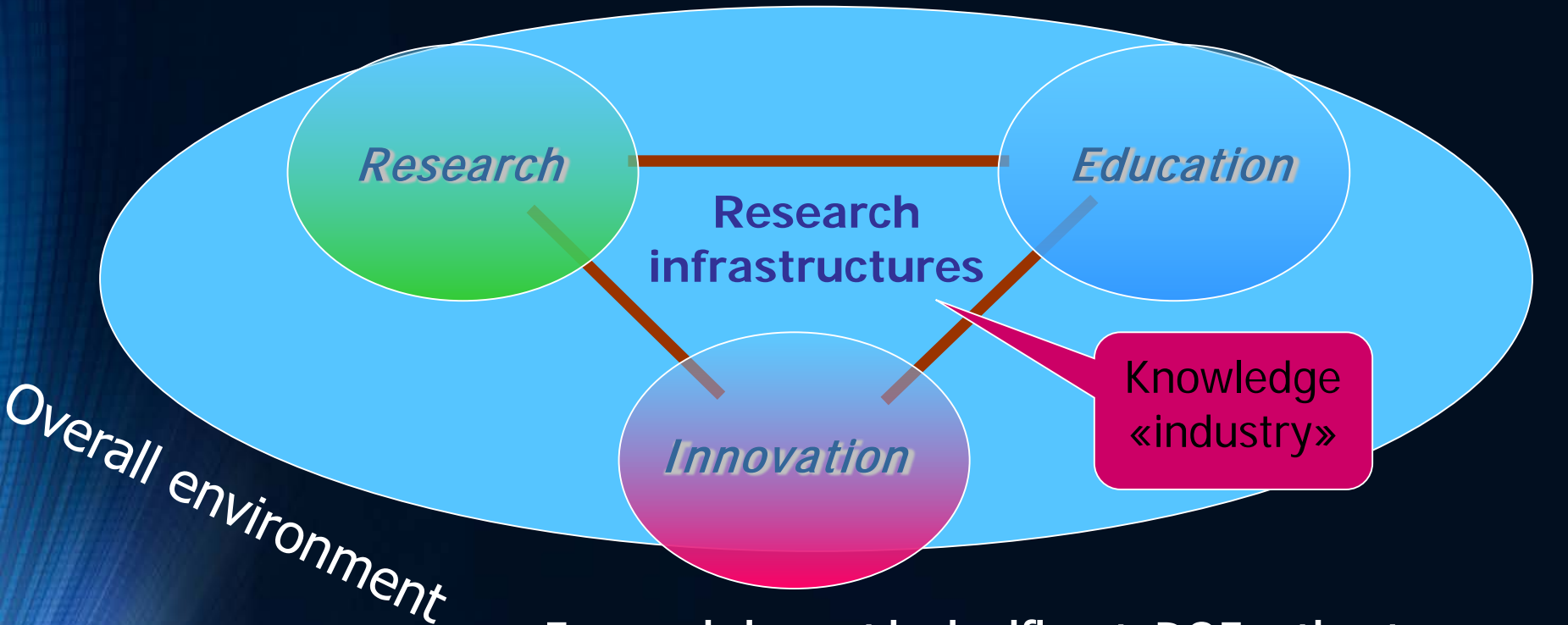


CNAO, Italy



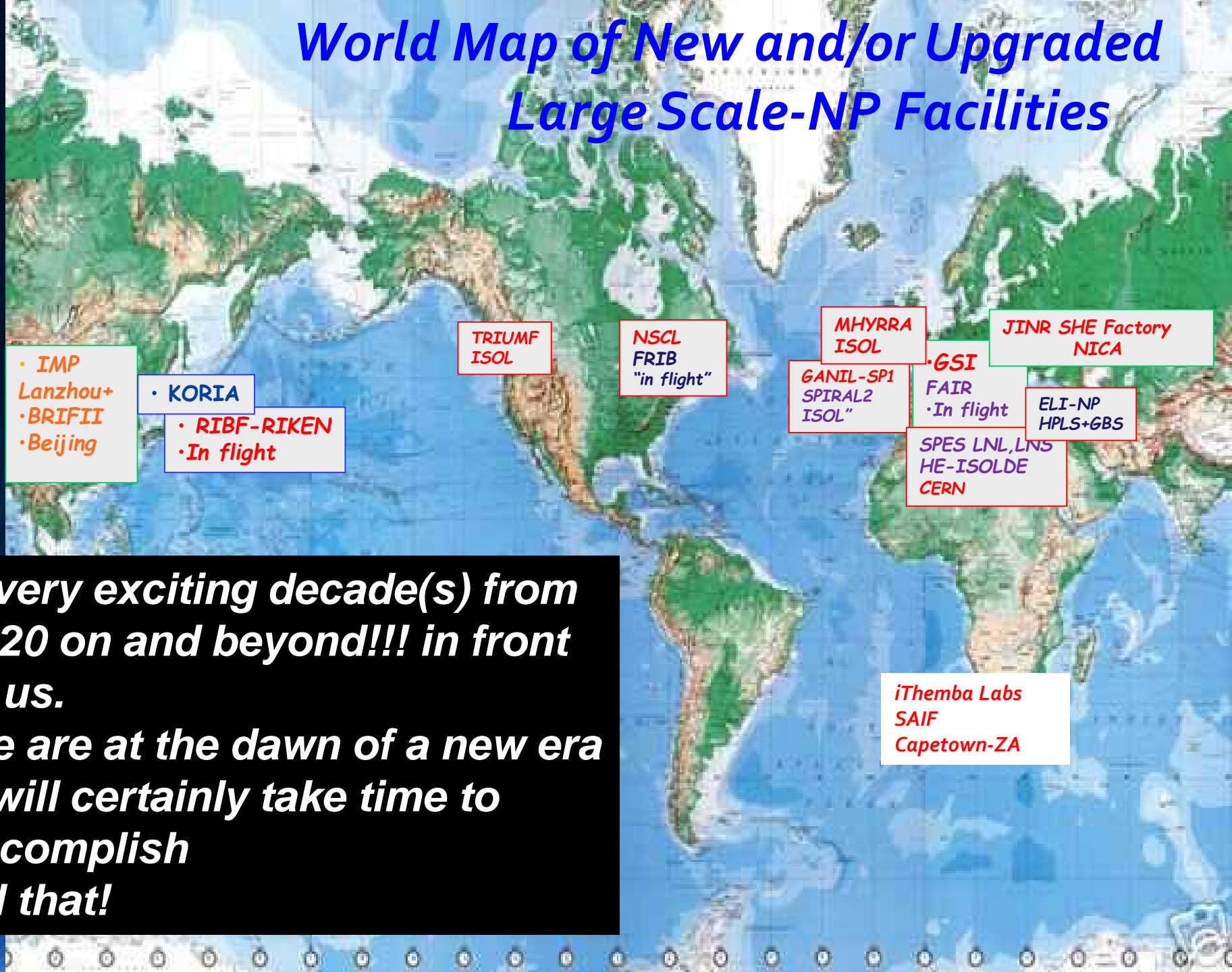
- \*Uppsala: protons, IBA
- \*Prague: protons, IBA
- \*Dresden: protons, IBA, R+D-oriented
- \*Krakow: protons, IBA, fixed-beam, R+D
- \*Essen: protons, IBA
- \*Trento: protons, IBA
- KVI Groningen protons
- Halle, Berlin, ...
- Marburg: carbon/protons, Siemens test facility
- \*CNAO, Pavia, carbon/protons
- \*MedAustron, Wiener Neustadt, carbon/protons
- \*Caen/ARCHADE: carbon (protons), status OK

# Impacts of Research Infrastructures, at centre of the knowledge triangle, relate also to an efficient environment



- Economic impact is significant: DOE estimates \$500 bn from particle beam accelerators; EPS estimated a total turnover from physics activity in Europe of €3760 bn in 2010;

# World Map of New and/or Upgraded Large Scale-NP Facilities



**A very exciting decade(s) from 2020 on and beyond!!! in front of us.**  
**We are at the dawn of a new era**  
**It will certainly take time to accomplish**  
**All that!**

**END**