Florida State University

Kirby W. Kemper

Current and new facilities for radioactive beam physics

Map of Florida

Florida State University in 1851-First as a seminary for men then in 1904 as a women’s college and then in 1947 became a co-ed university.

Today has 39,000 students.

Westcott Building, Florida State University, Tallahassee.

How do we know we have seen new physics with radioactive beams?

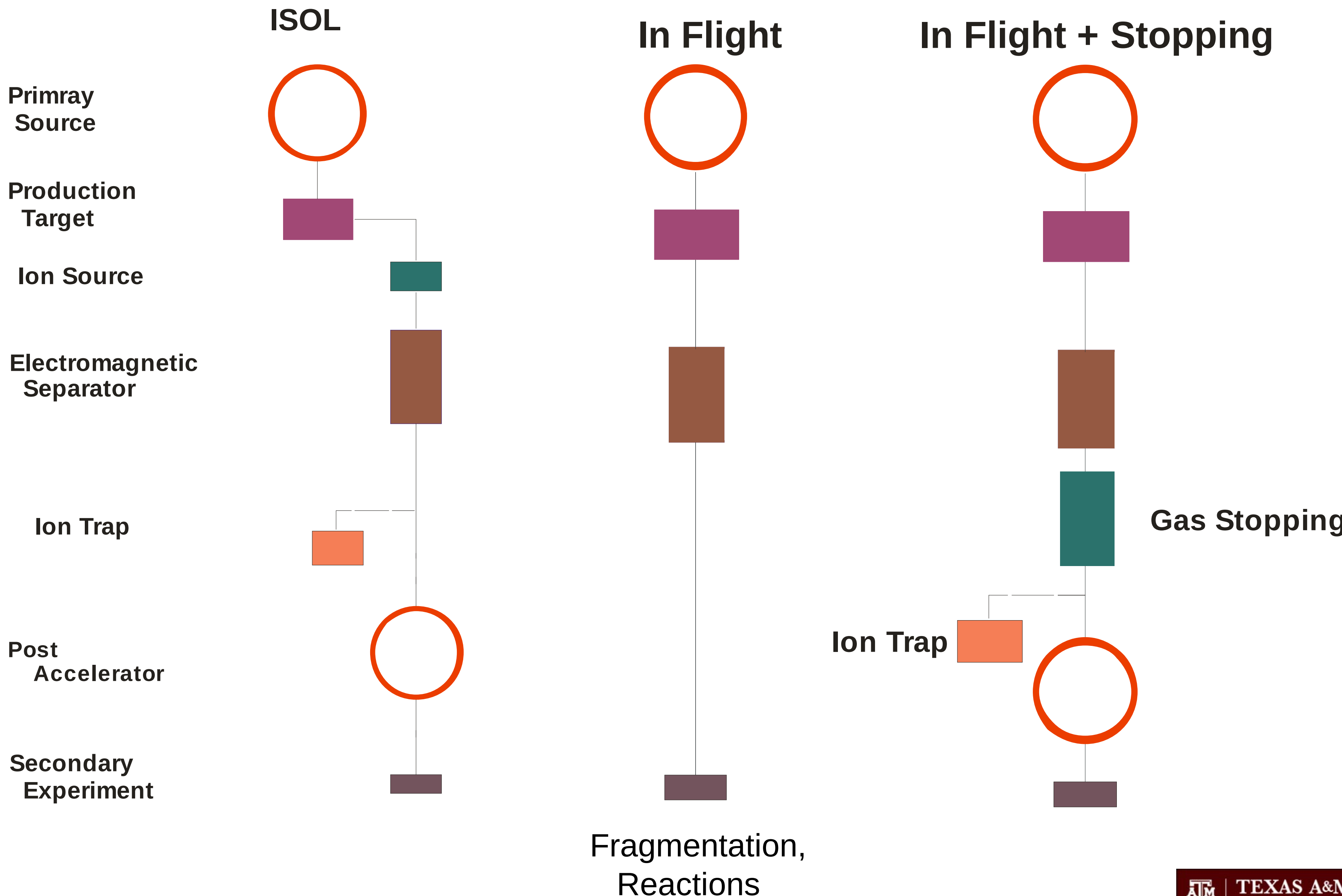
While I will discuss proposed new facilities here please keep in mind that we must have high quality stable beam data for comparison.

RIB* Facilities
Present and Future

Robert Tribble
Texas A&M University
Texas, USA

*Rare Isotope Beam; Radioactive Ion Beam

Basic Techniques for Producing RIBs



ISOL Properties

In ISOL you have a driver beam, often protons that strikes a target say of uranium carbide heated to very high temperatures and then the radio active product is released and accelerated to energy of experiment.

Advantage- can get beams of low energy that are intense.
Disadvantages- target chemistry and beam production very difficult
each beam must be separately developed
not possible to study short lived isotopes
sources are very radioactive so really need several
source boxes (typical cost $1.5M)

In flight beam production

Fragment incoming beam on a Be target to produce product of interest for example use a ^{48}Ca primary beam to produce ^{44}S

Advantages- Study very short lived nuclei, can use very thick targets
Disadvantages-beams are moving at 0.5c so gamma rays have huge Doppler corrections, and theory of transfer reactions not well developed

At present the fragmentation technique is the only one that allows studies close to the neutron dripline for above mass 10

Inflight + Stopping

Use fragmentation to produce beam, stop beam in gas, extract products of interest, reacclerate and then use at energy you want

For example, with fast beams only Coulomb excite first 2+ but with low energy beams could observe first 3- etc

Theory of transfer reactions for low energies(~10 MeV/amu) is well developed so can extract information on location of single particle levels to search for predicted decrease of spin-orbit strength at neutron dripline

You can trap very exotic nuclei and search for exotic effects like anapole moments

Present Facilities*
and
the Science of RIBs

Science topics:

- masses, structure, reactions, astrophysics, . . .
- Enormous growth over past decade!
- See talks at **ENAM08**!!

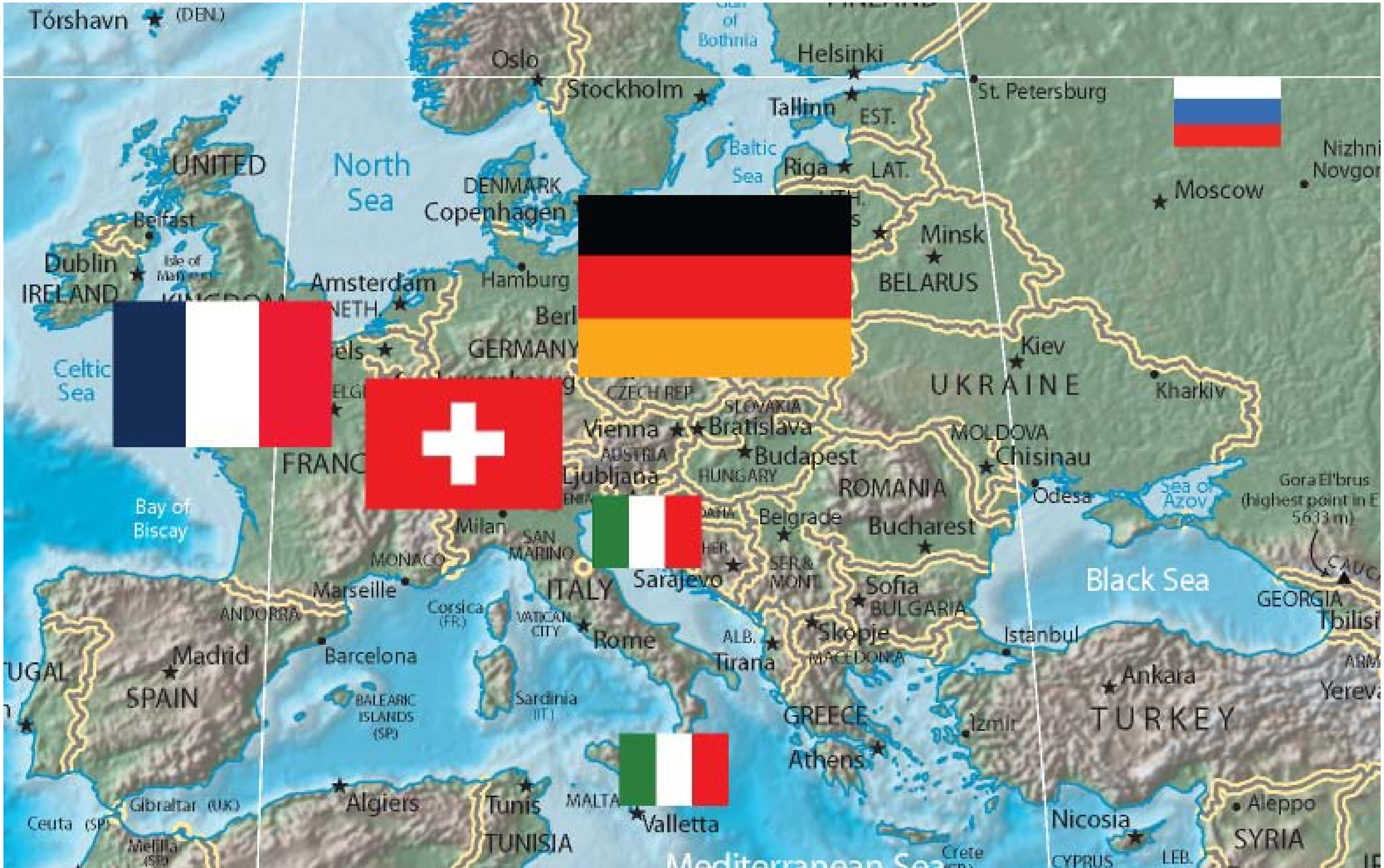
Buckle up for a whirlwind tour!!

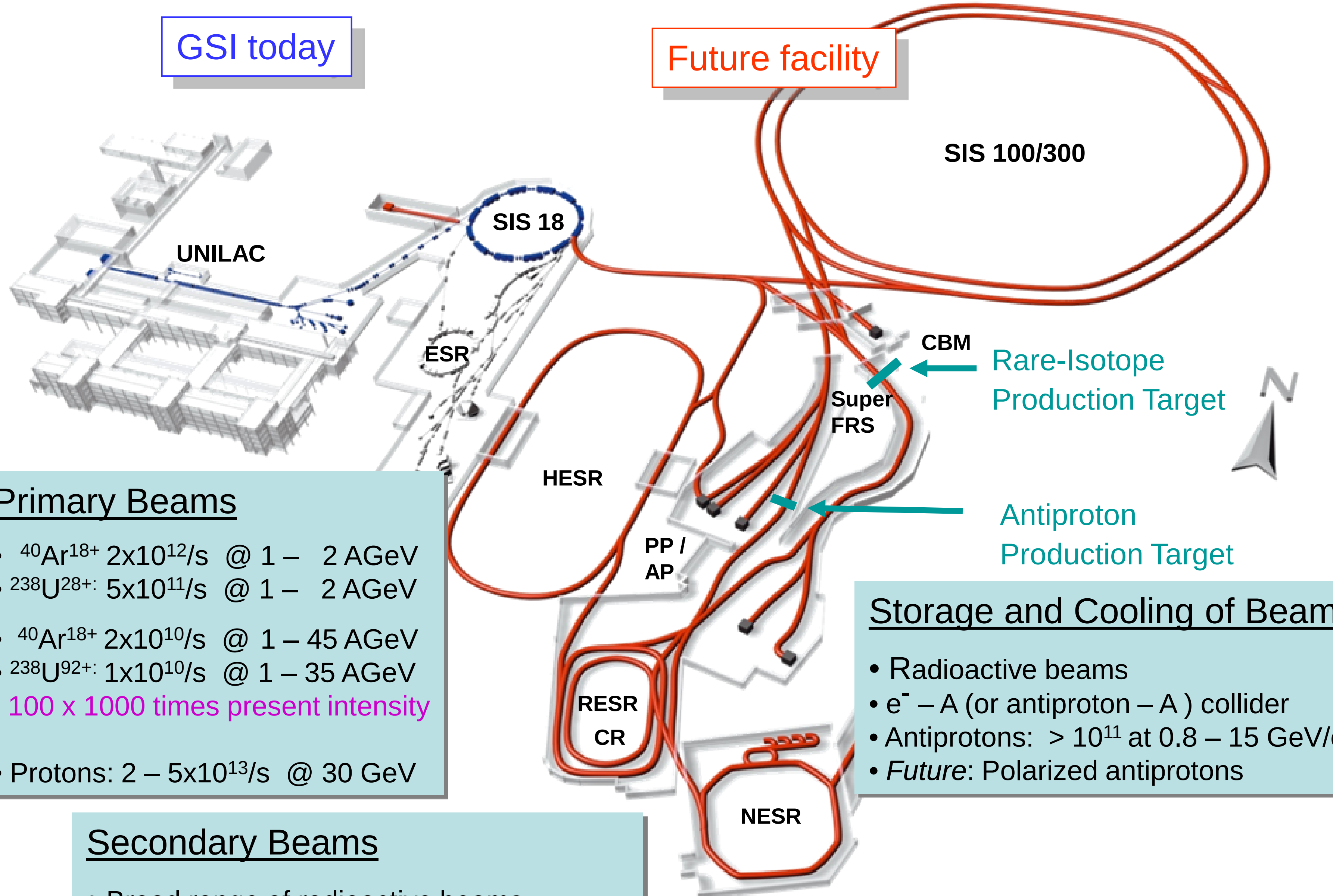
*Limited to facilities with multi-MeV beams

RIB Facilities

(Operating or Under Construction)

European Facilities





Primary Beams

- $^{40}Ar^{18+}$ $2x10^{12}$/s @ 1 – 2 AGeV
- $^{238}U^{28+}$: $5x10^{11}$/s @ 1 – 2 AGeV
- $^{40}Ar^{18+}$ $2x10^{10}$/s @ 1 – 45 AGeV
- $^{238}U^{92+}$: $1x10^{10}$/s @ 1 – 35 AGeV

100 x 1000 times present intensity

- Protons: 2 – $5x10^{13}$/s @ 30 GeV

Storage and Cooling of Beams

- Radioactive beams
- e^- – A (or antiproton – A) collider
- Antiprotons: > 10^{11} at 0.8 – 15 GeV/c
- *Future*: Polarized antiprotons

Secondary Beams

- Broad range of radioactive beams up to 1 – 2 AGeV
- RI- Intensities up to 10 000 over present
- Antiprotons

Comparison of FRS with Super-FRS

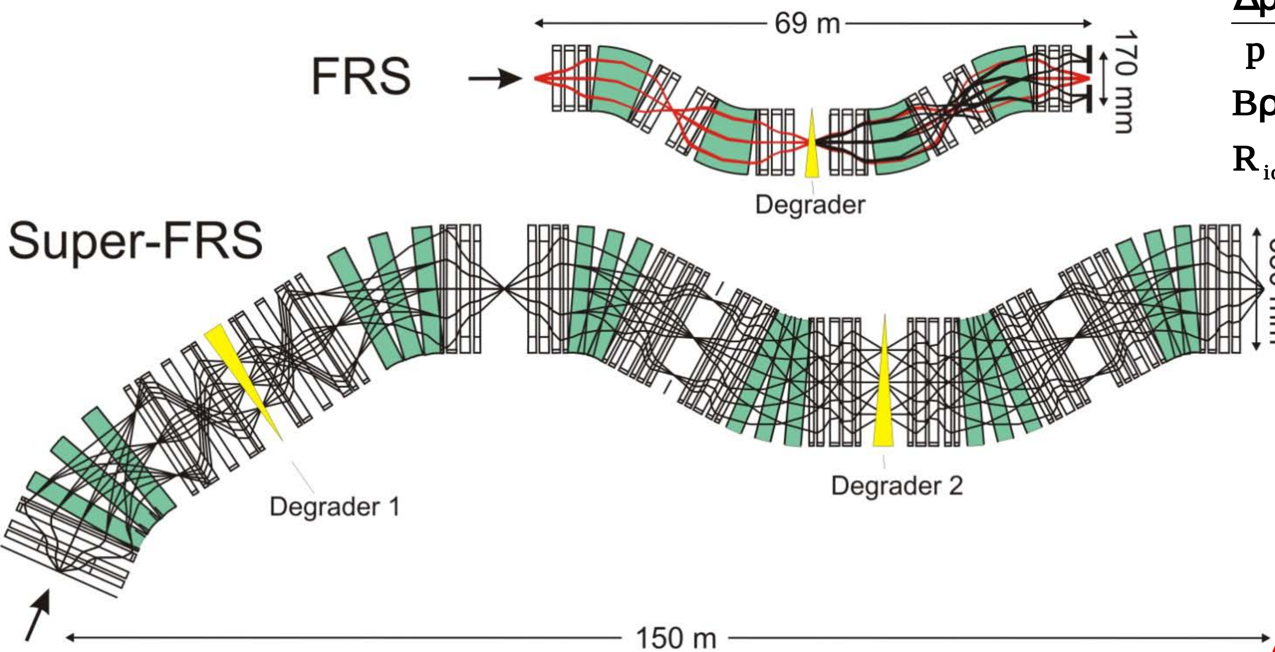
Apertures(Super-FRS) ≈ 2 X Apertures(FRS)

$\varepsilon_x = 20\ \pi\text{mm mr}$

$\frac{\Delta p}{p} = \pm 1\,\%$

$B\rho_{max} = 18\ \text{Tm}$

$R_{ion} = 1500$



$\varepsilon_x = \varepsilon_y = 40\ \pi\text{mm mr}$

$\varphi_x = \pm 40\ \text{mr},$

$\varphi_y = \pm 20\ \text{mr}$

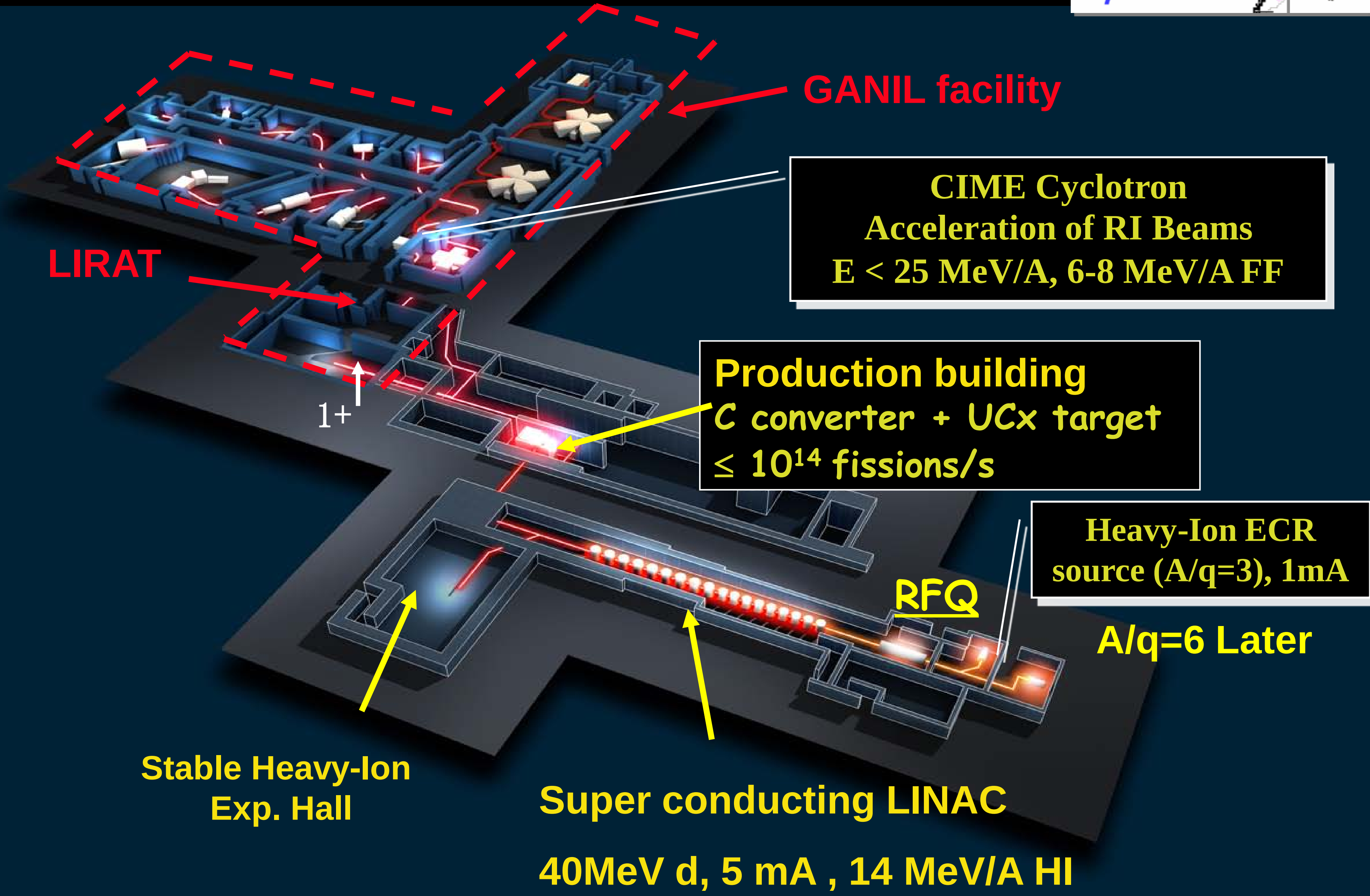
$\frac{\Delta p}{p} = \pm 2.5\,\%$

$B\rho_{max} = 20\ \text{Tm}$

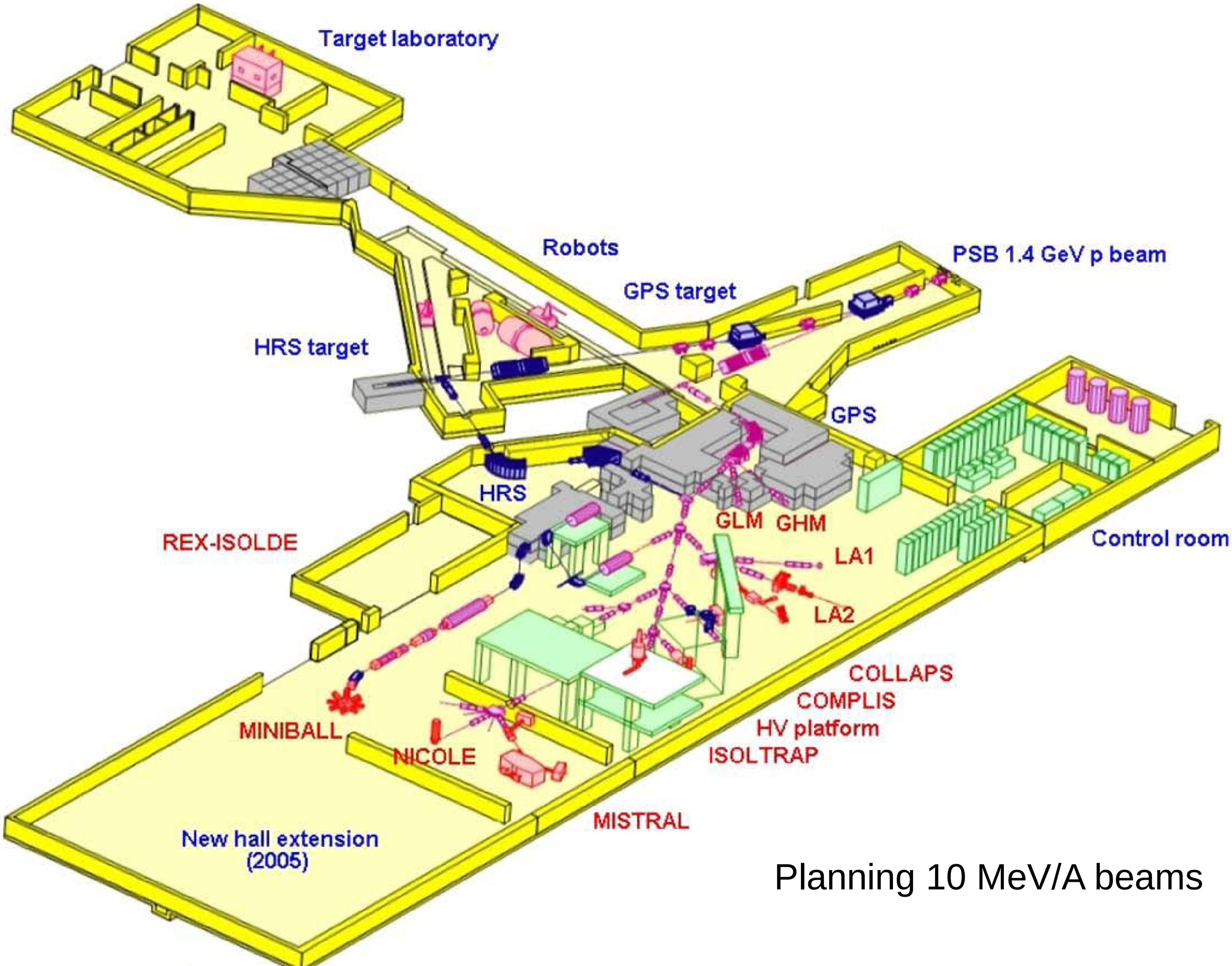
$R_{ion} = 1500$

Separation with two degrader stages

SPIRAL 2@GANIL - A world leading ISOL Facility

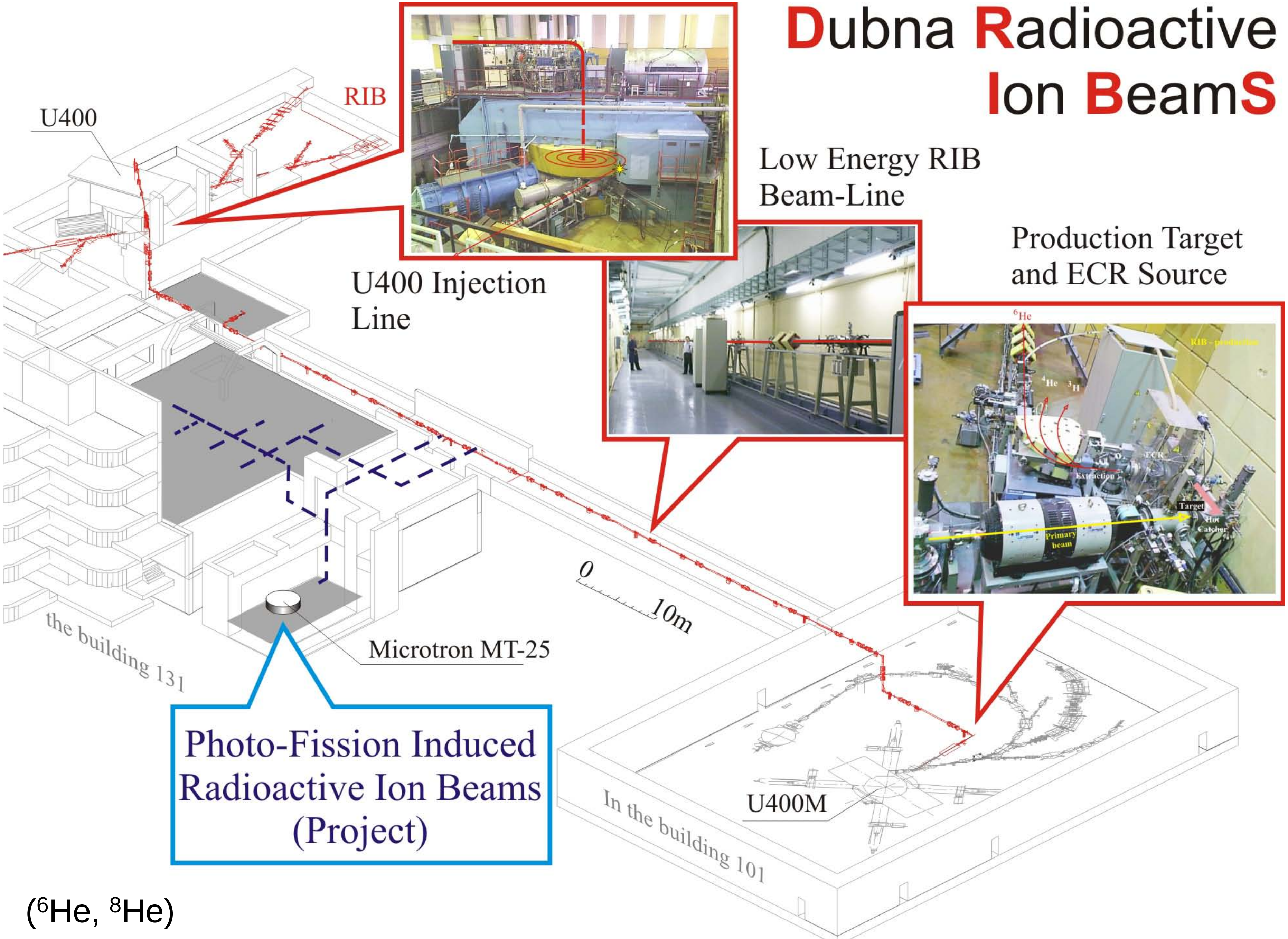


ISOLDE Hall

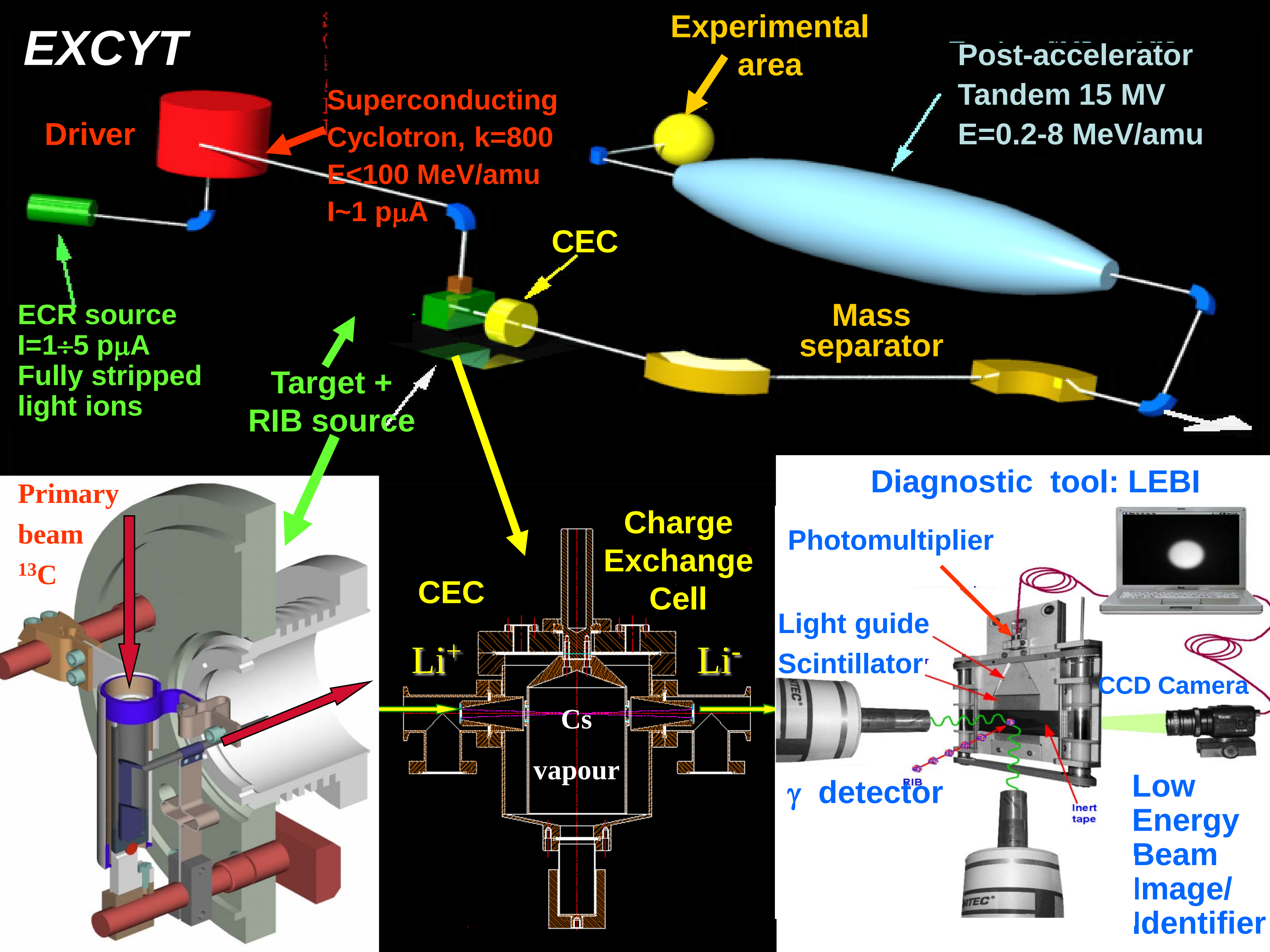


Planning 10 MeV/A beams

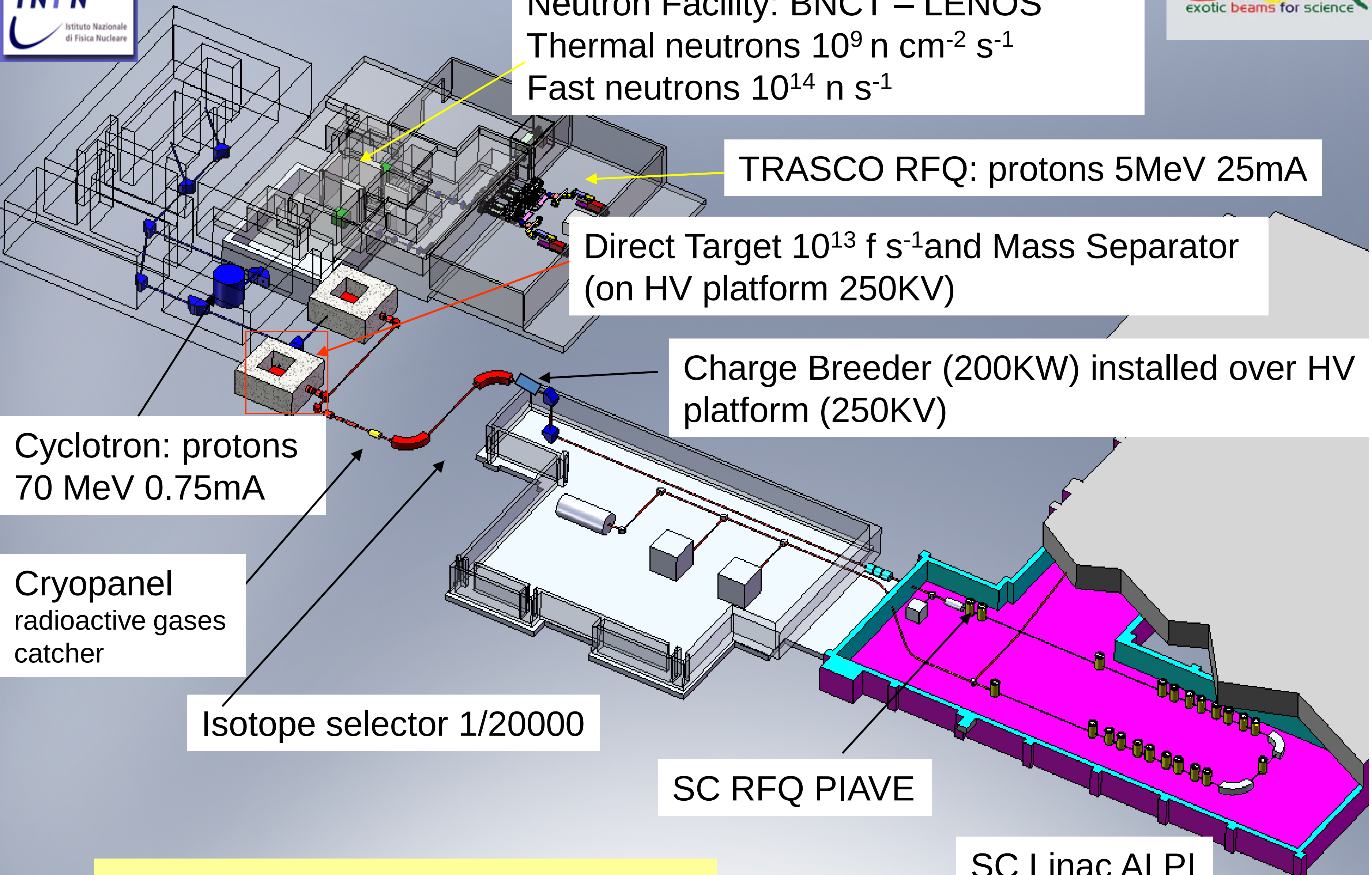
Dubna Radioactive Ion BeamS



(^{6}He, ^{8}He)



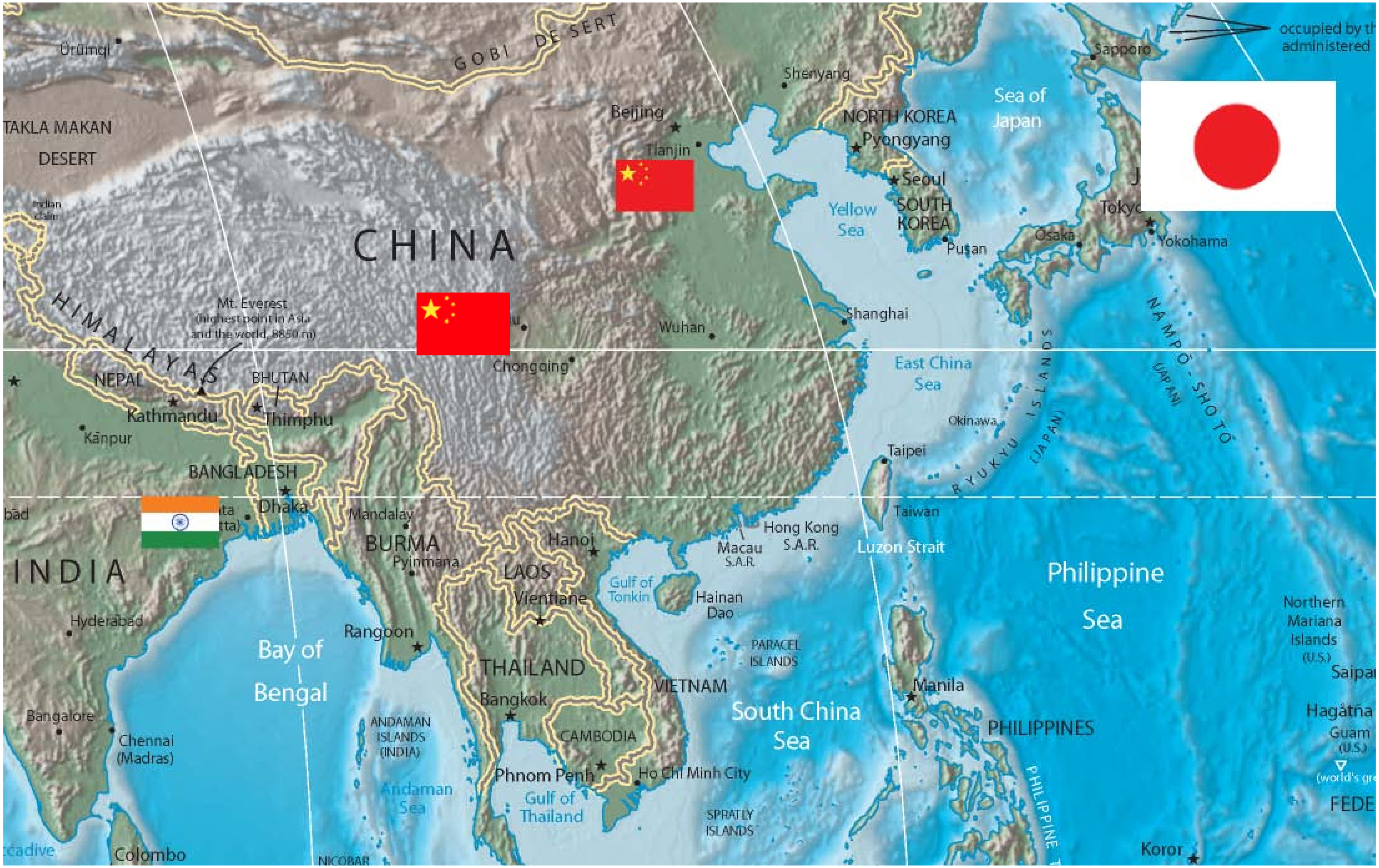
EXCYT
Driver
Superconducting
Cyclotron, k=800
E<100 MeV/amu
I~1 pμA
Experimental
area
Post-accelerator
Tandem 15 MV
E=0.2-8 MeV/amu
CEC
ECR source
I=1÷5 pμA
Fully stripped
light ions
Target +
RIB source
Mass
separator
Primary
beam
13C
CEC
Charge
Exchange
Cell
Li+
Li-
Cs
vapour
Diagnostic tool: LEBI
Photomultiplier
Light guide
Scintillator
CCD Camera
γ detector
RIB
Inert
tape
Low
Energy
Beam
Image/
Identifier



General SPES layout

LEGNARO

China, India and Japan



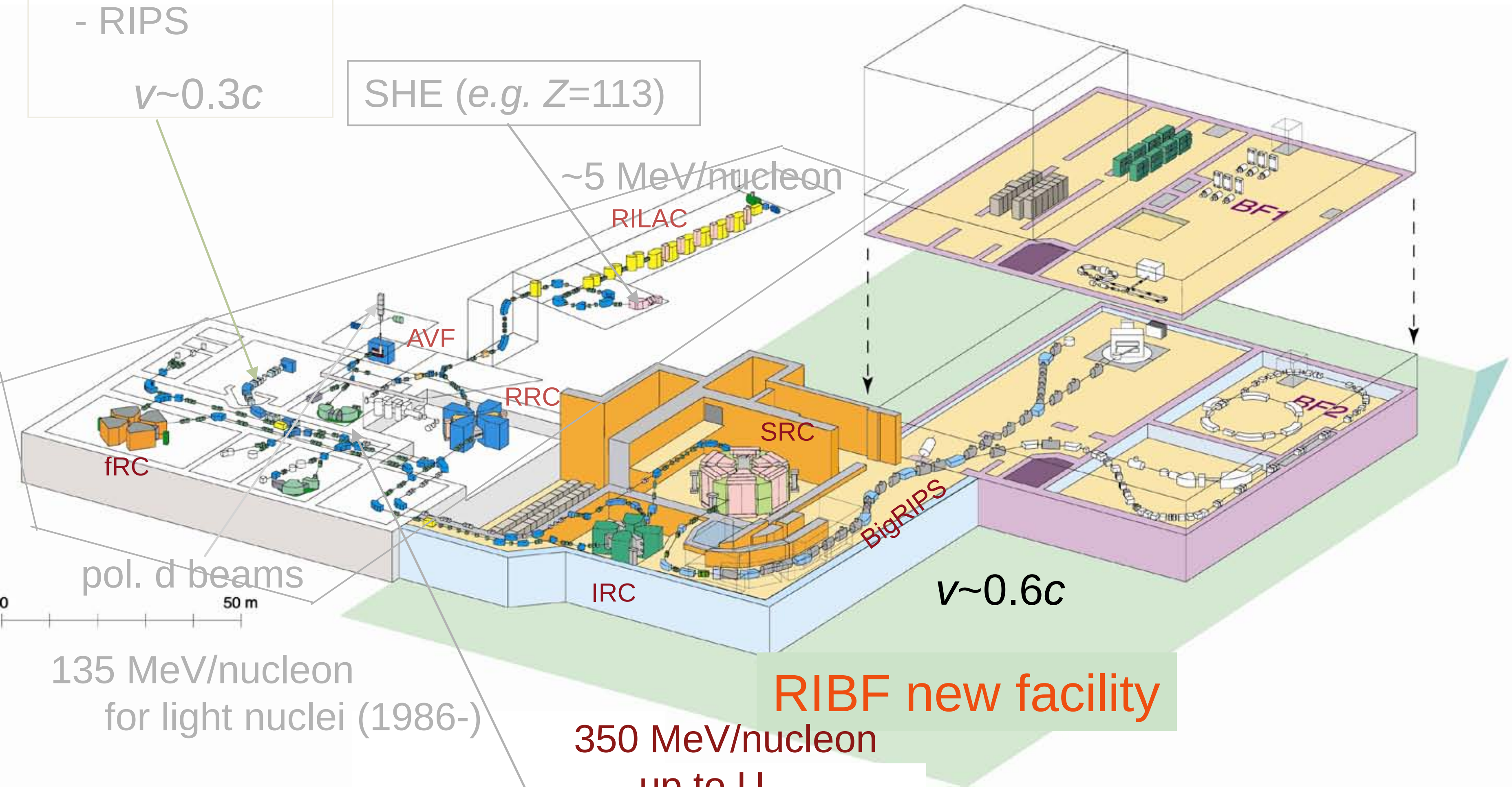
RIKEN RI-Beam Factory (RIBF)

Fast RI beams
- RIPS

v~0.3c

SHE (*e.g.* Z=113)

~5 MeV/nucleon



pol. d beams

v~0.6c

135 MeV/nucleon
for light nuclei (1986-)

RIBF new facility

350 MeV/nucleon
up to U

RI beams (<5 AMeV) - CRIB
CNS v~0.1c

1st beam in Dec. 2006
U beam in Mar. 2007
1st new isotope (^{125}Pd): May 2007

June 2008

RIKEN NISHINA CENTER

RIB Facilities at IMP - Lanzhou (China)

- **RIBLL 1**

  RIBs produced via PF & transfer with primary beams up to Kr

- **RIBLL 2**

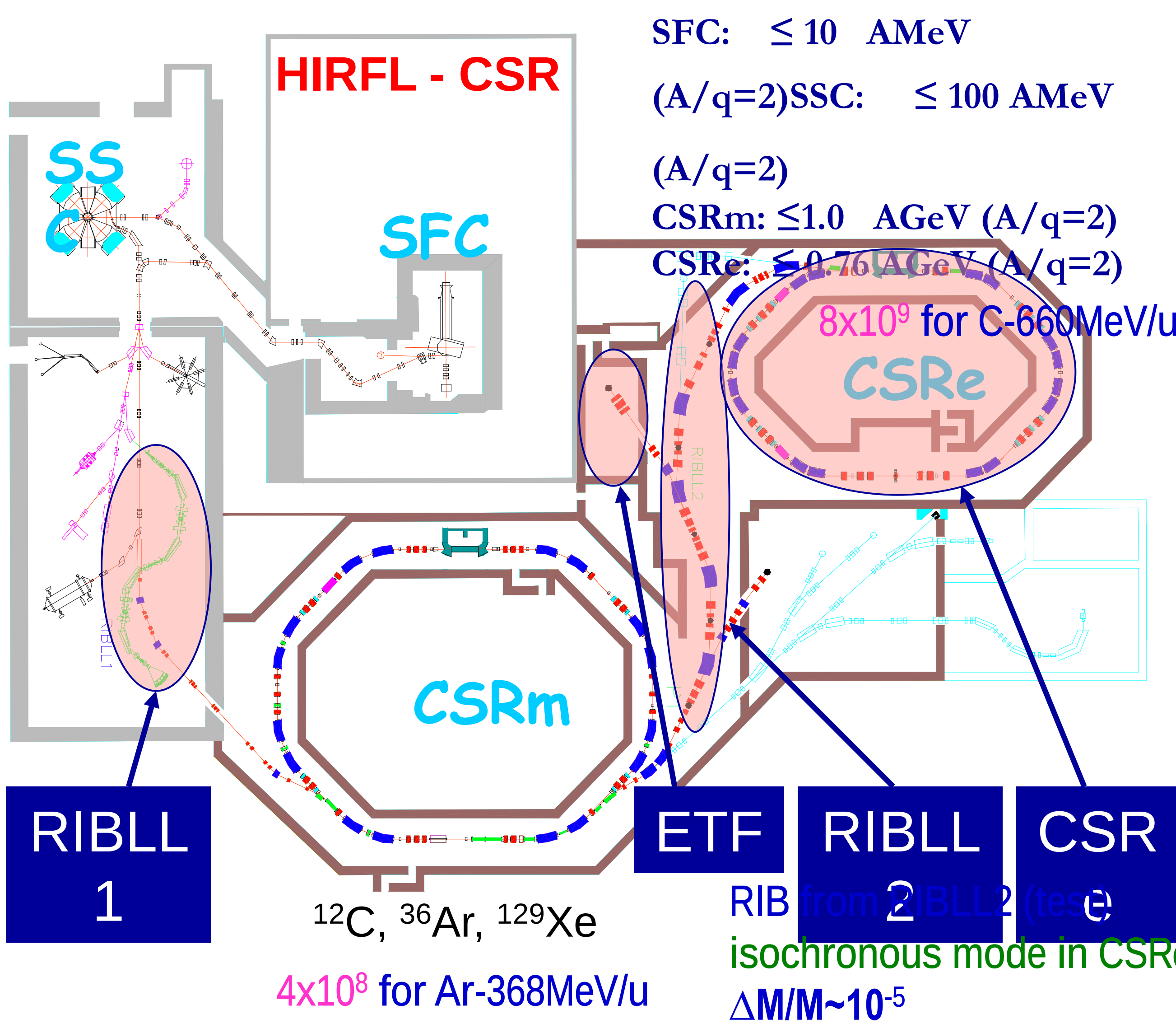
  RIBs produced via PF & TF with primary beams up to U (Xe up to now)

- **ETF**

  External **T**arget **F**acility for RIB experiment & asymmetry nuclear matter research

- **CSRe**

  Mass measurement with cooling storage ring

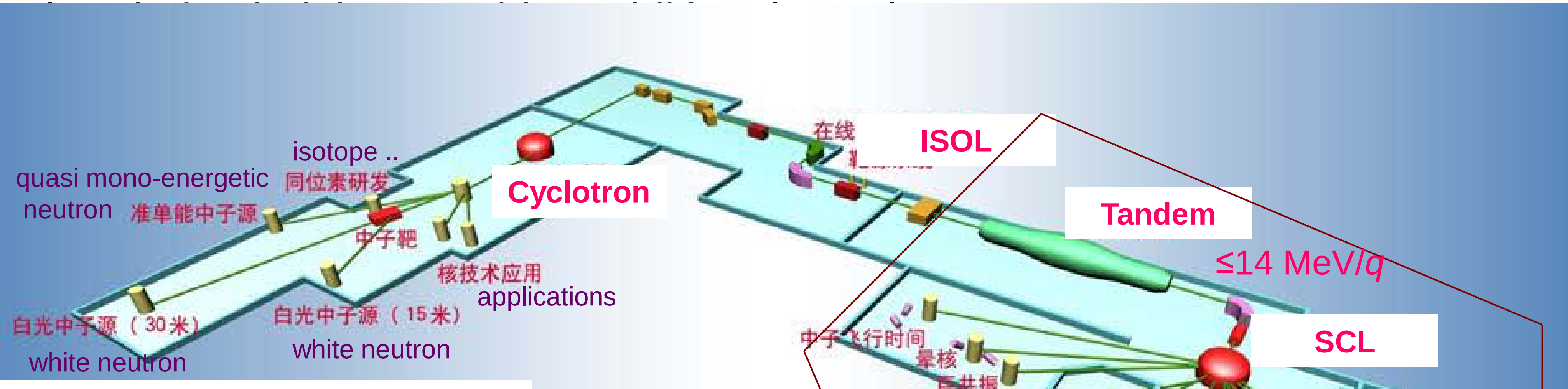


Hushan Xu

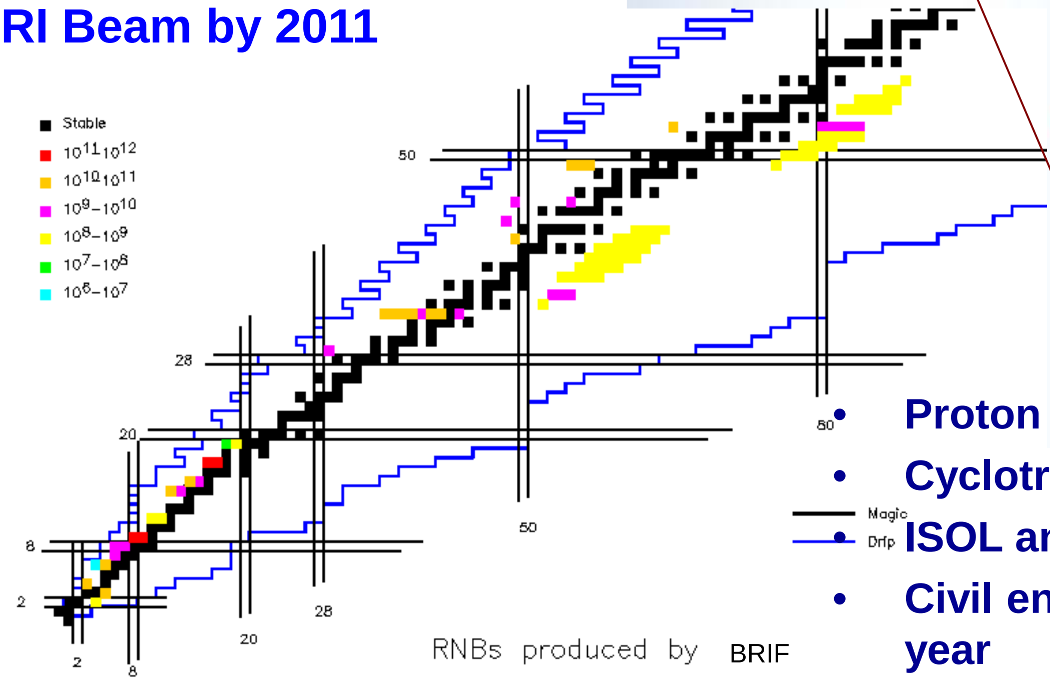
BRIF - CIAE Beijing (China)

100 MeV 200 μA compact proton cyclotron

20000 mass resolution ISOL, 2 MeV/q super-conducting LINAC



RI Beam by 2011



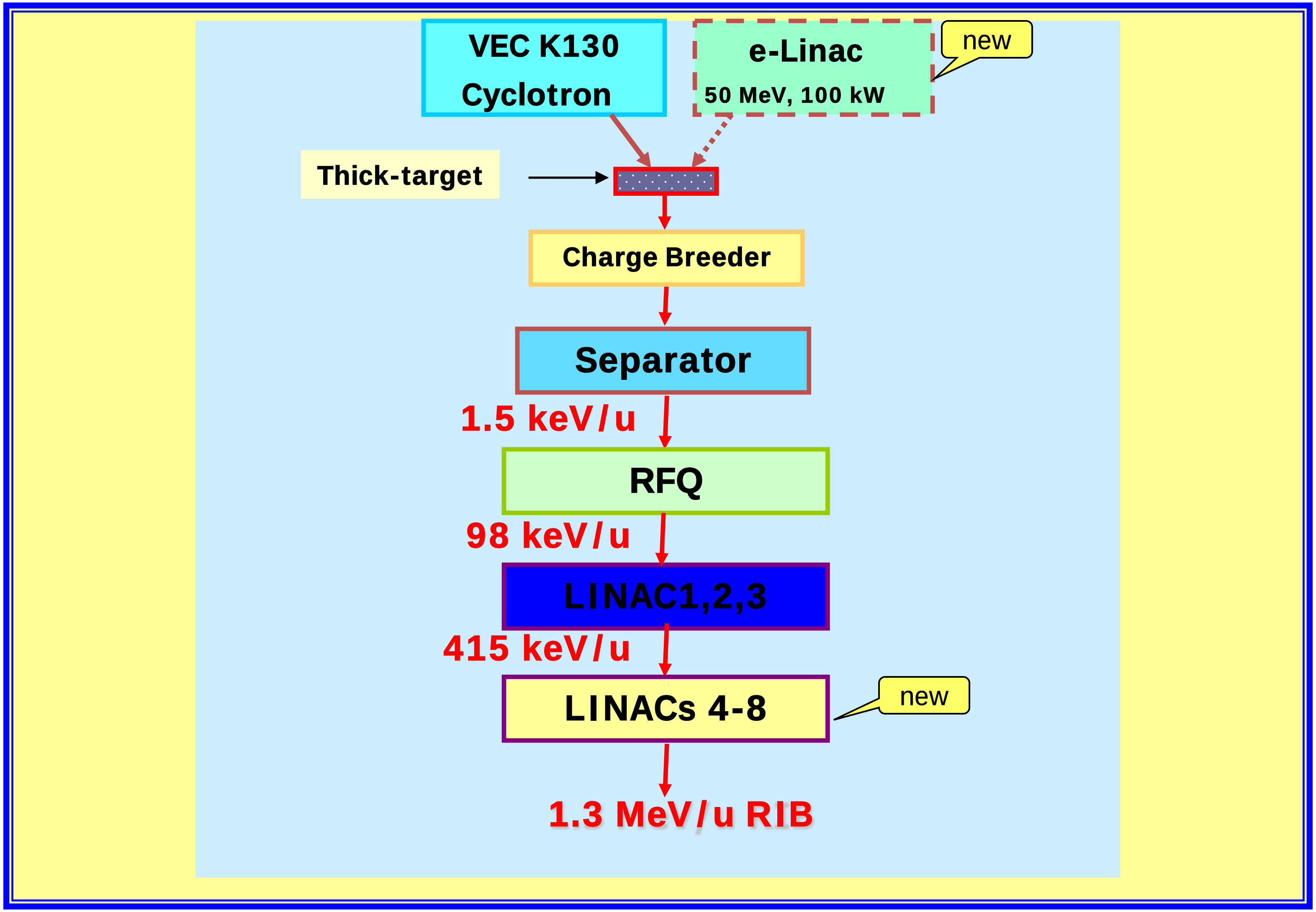
2008

- **Proton cyclotron design finished**
- **Cyclotron magnet rough finish in August**
- **ISOL and SC design finished**
- **Civil engineering will start by the end of year**

Weiping Liu

XIth plan: Acceleration up to 1.3 MeV/u & Electron Linac as new primary accelerator

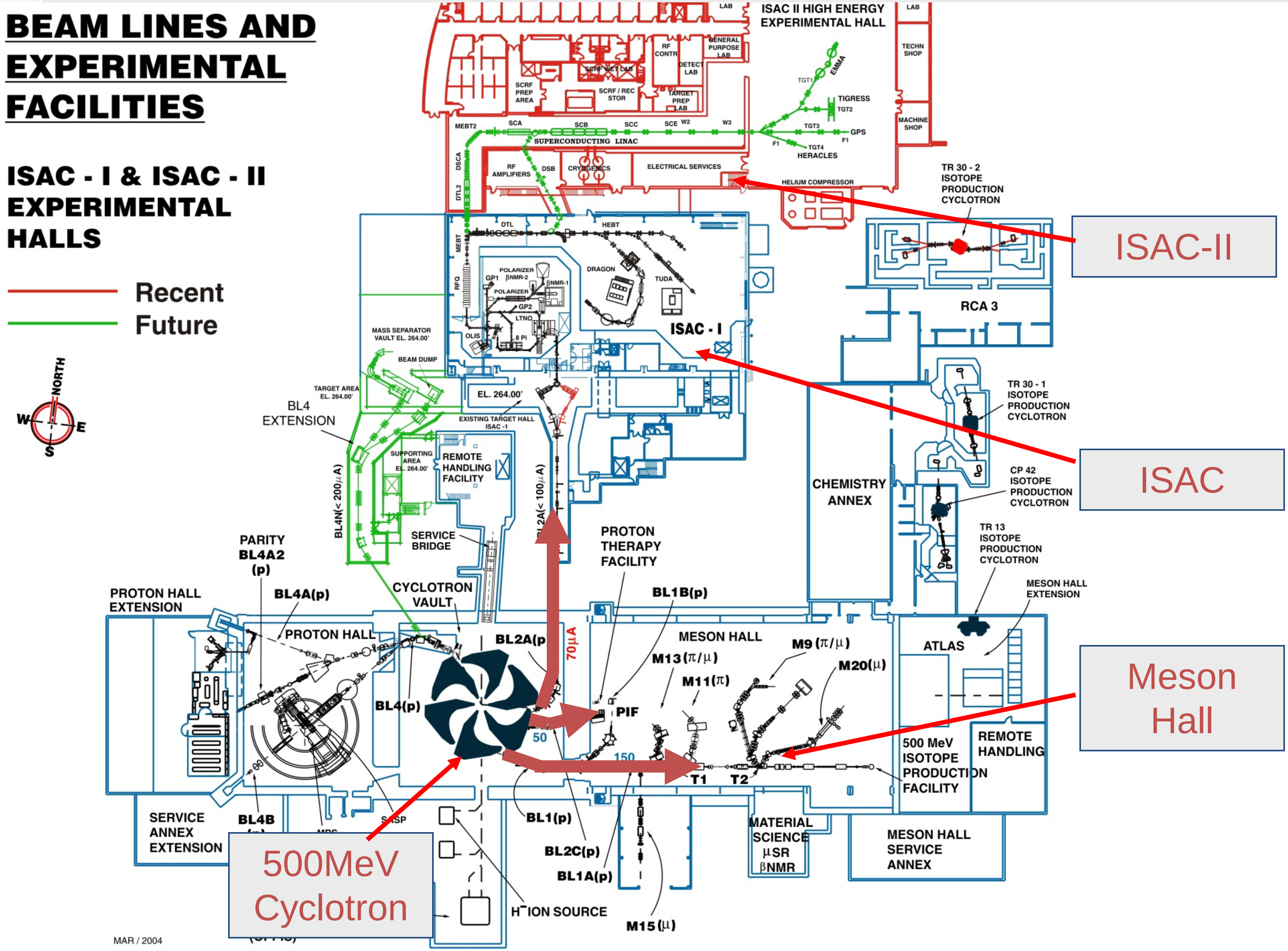
(funding obtained in December 2007)



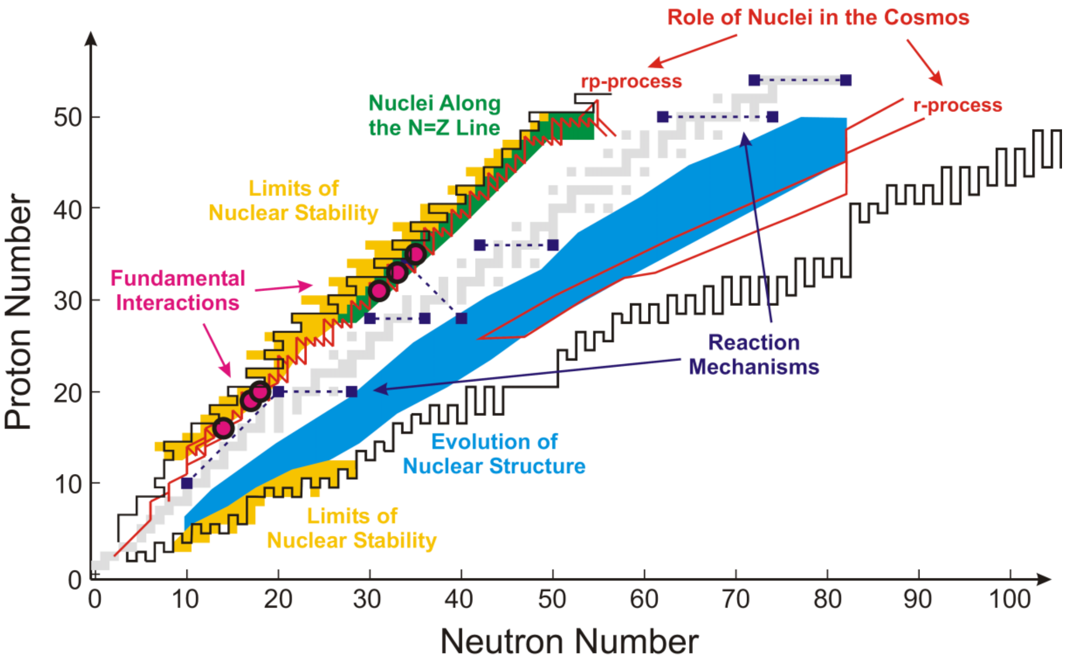
North American Facilities

TRIUMF

Canada's National Laboratory for Particle and Nuclear Physics



National Superconducting Cyclotron Laboratory
Coupled Cyclotron Facility



Primary beams (He–U): E/A ≤ 200 MeV
Fast and stopped rare isotopes beams
Reaccelerated beams in 2010

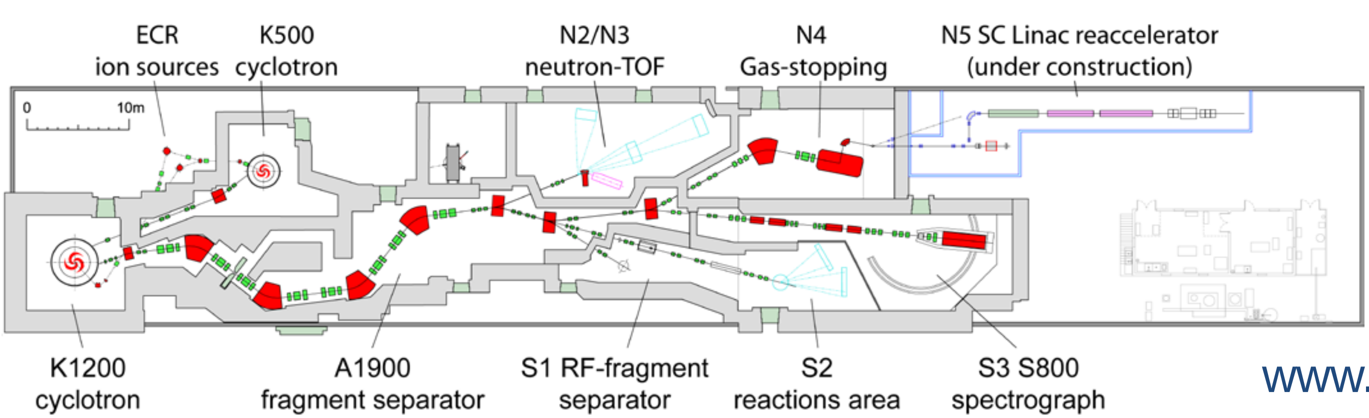
Research themes:

Properties of nuclei very far from stability

Nuclear processes responsible for the chemical evolution of the universe

Equation of state (EOS) of neutron-rich nuclear matter

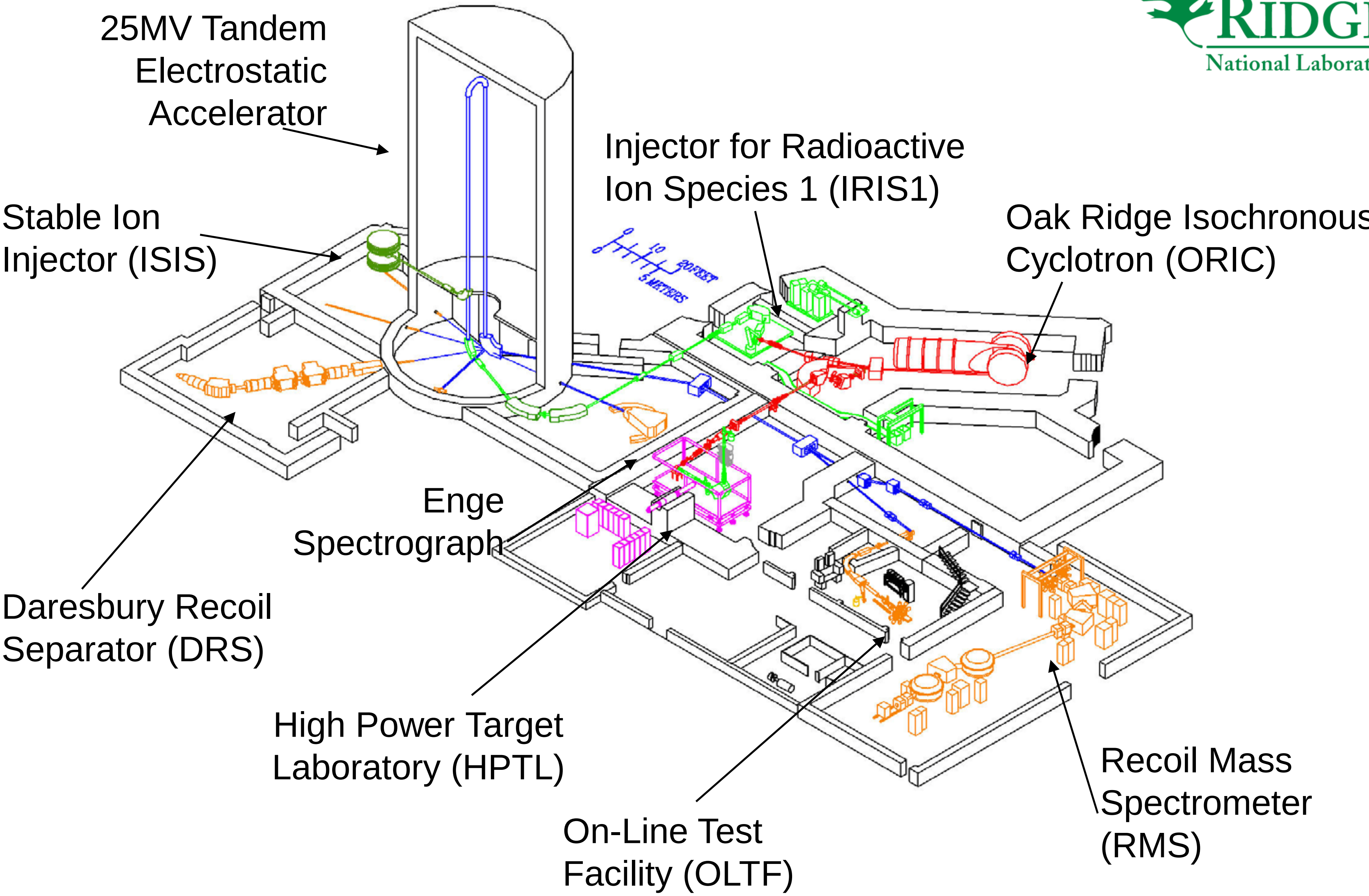
Beam dynamics and accelerator physics: superconducting cyclotrons, linacs, and magnets



Main funding comes from the U.S. National Science Foundation (NSF) and Michigan State University

www.nscl.msu.edu

Holifield Rare Isotope Beam Facility

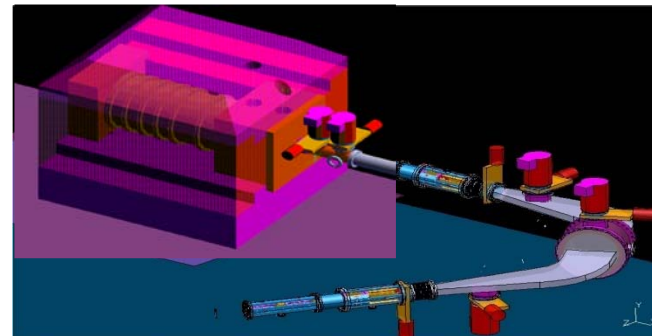


CARIBU & Energy Upgrade

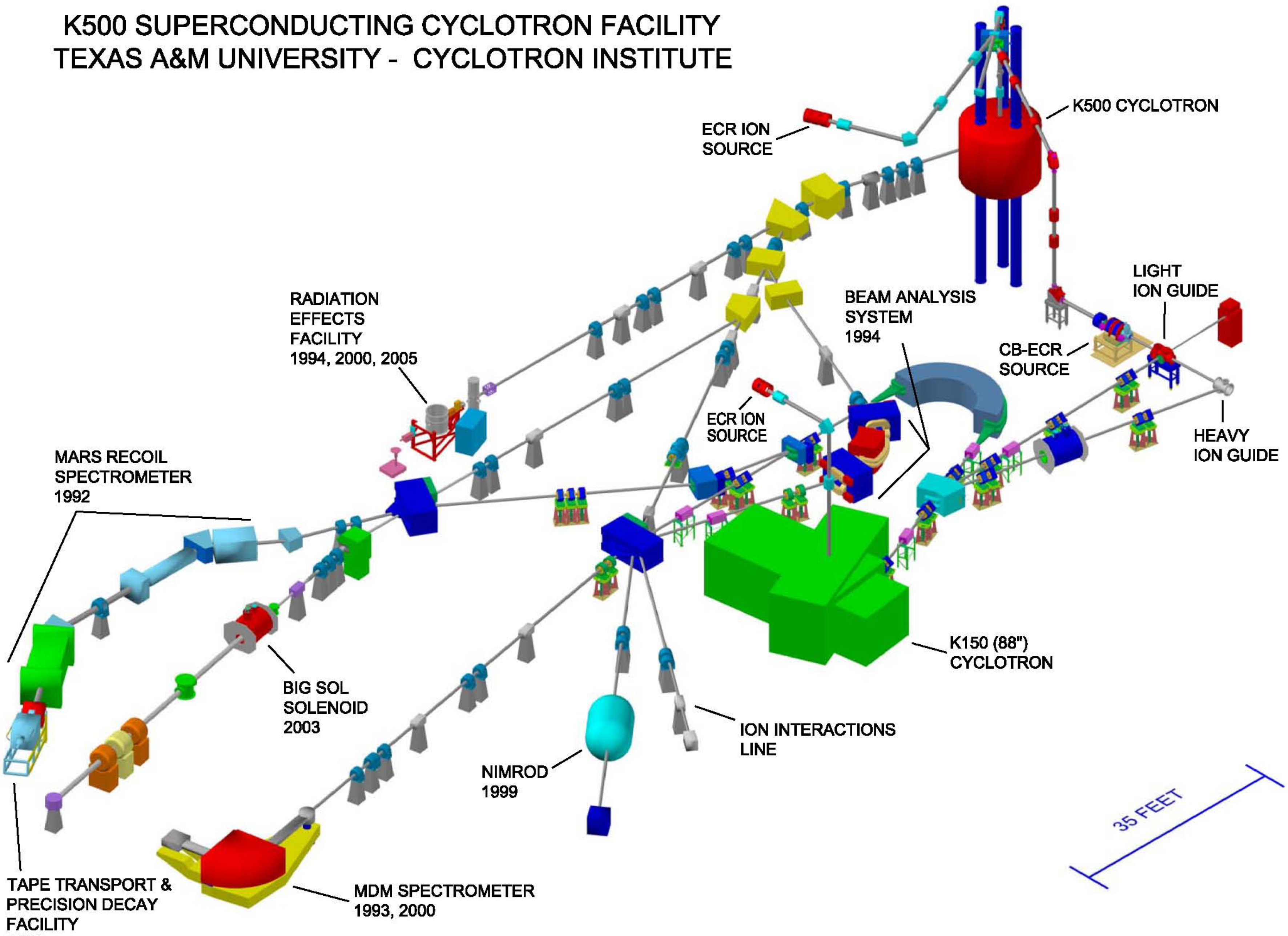
- **CARIBU gives access to exotic beams**
- **Energy Upgrade provides beams from CARIBU in the energy regime of 12 MeV/u**

^{252}Cf cask

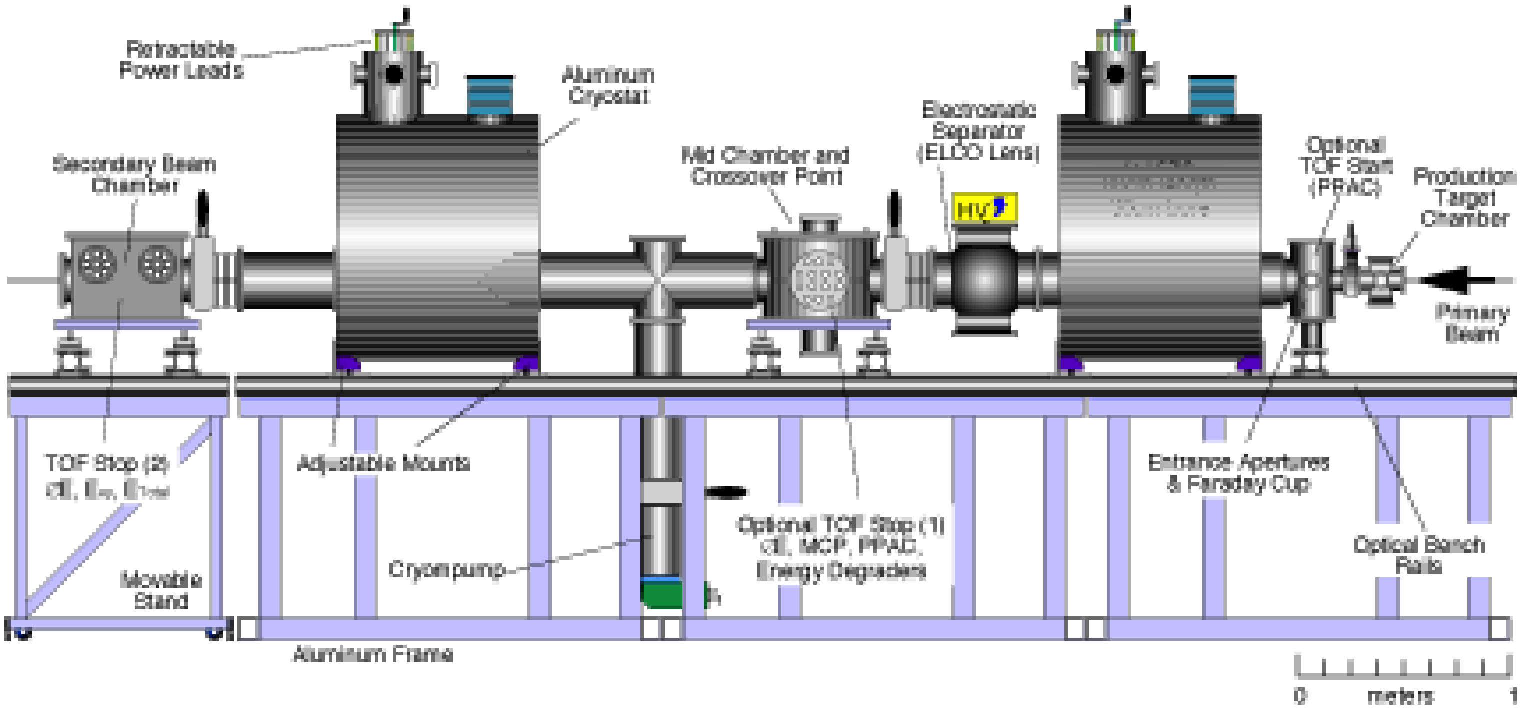
Isobar separator



K500 SUPERCONDUCTING CYCLOTRON FACILITY
TEXAS A&M UNIVERSITY - CYCLOTRON INSTITUTE

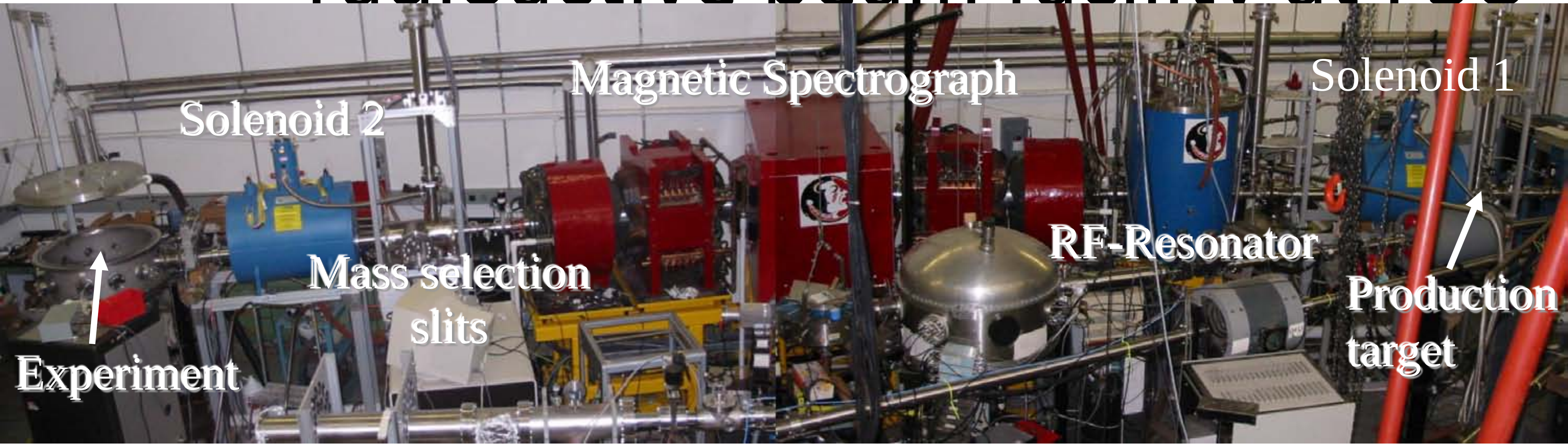


TwinSol at the Univ. of Notre Dame



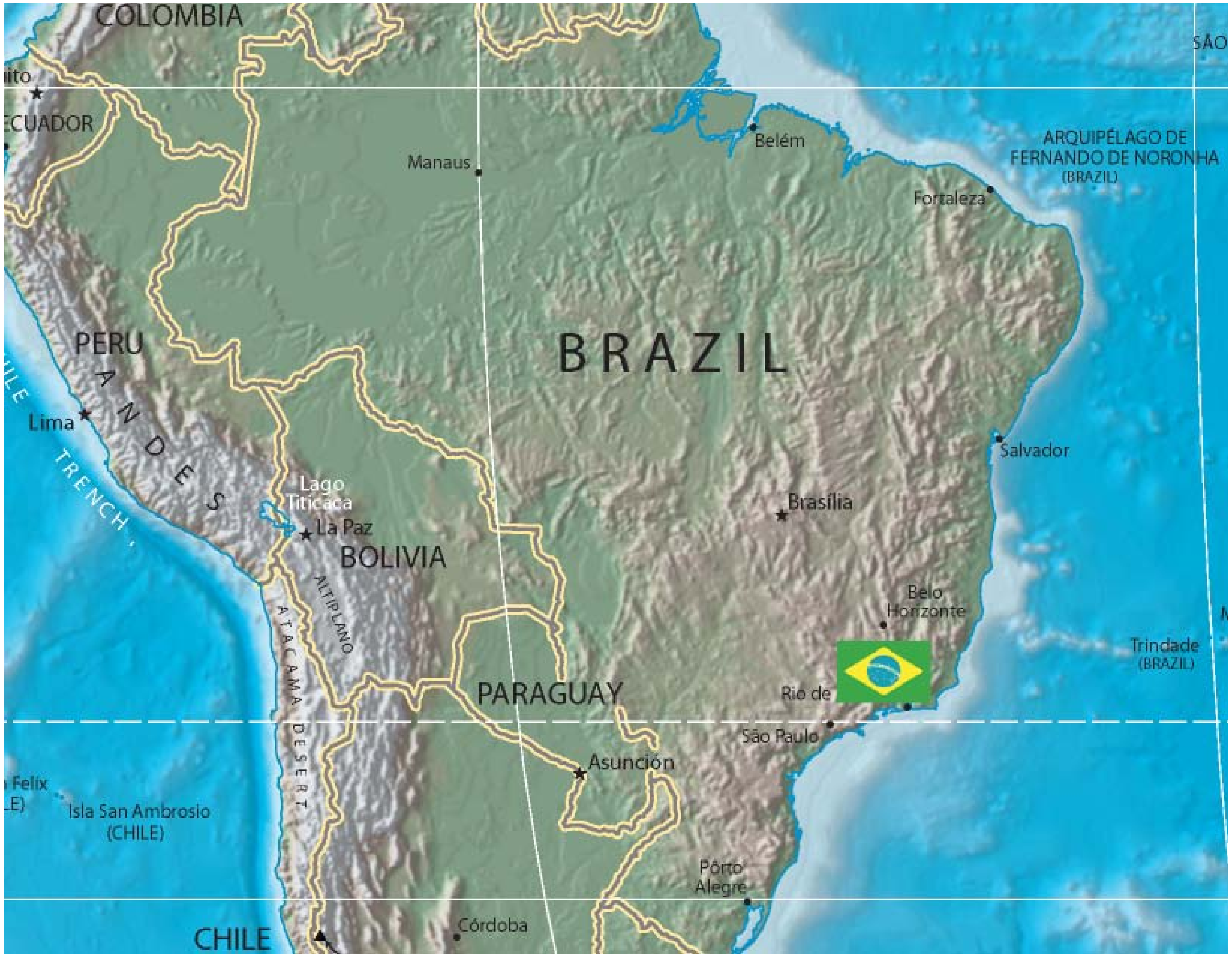
- **Two 6T superconducting solenoids act as thick lenses to focus an intense beam of short-lived radioactive ions onto a secondary target (in-flight production).**
- **Primary beams from a 10.5 MV FN-tandem accelerator.**
- **One of the first instruments to produce beams of radioactive ions at energies near the Coulomb barrier.**

RESOLUT: a new radioactive beam facility at FSU



- In-flight production of radioactive beams in inverse kinematics
- Combination of Superconducting RF-Resonator with high acceptance magnetic Spectrograph to create mass spectrometer for E~5 MeV/u secondary beams

South America

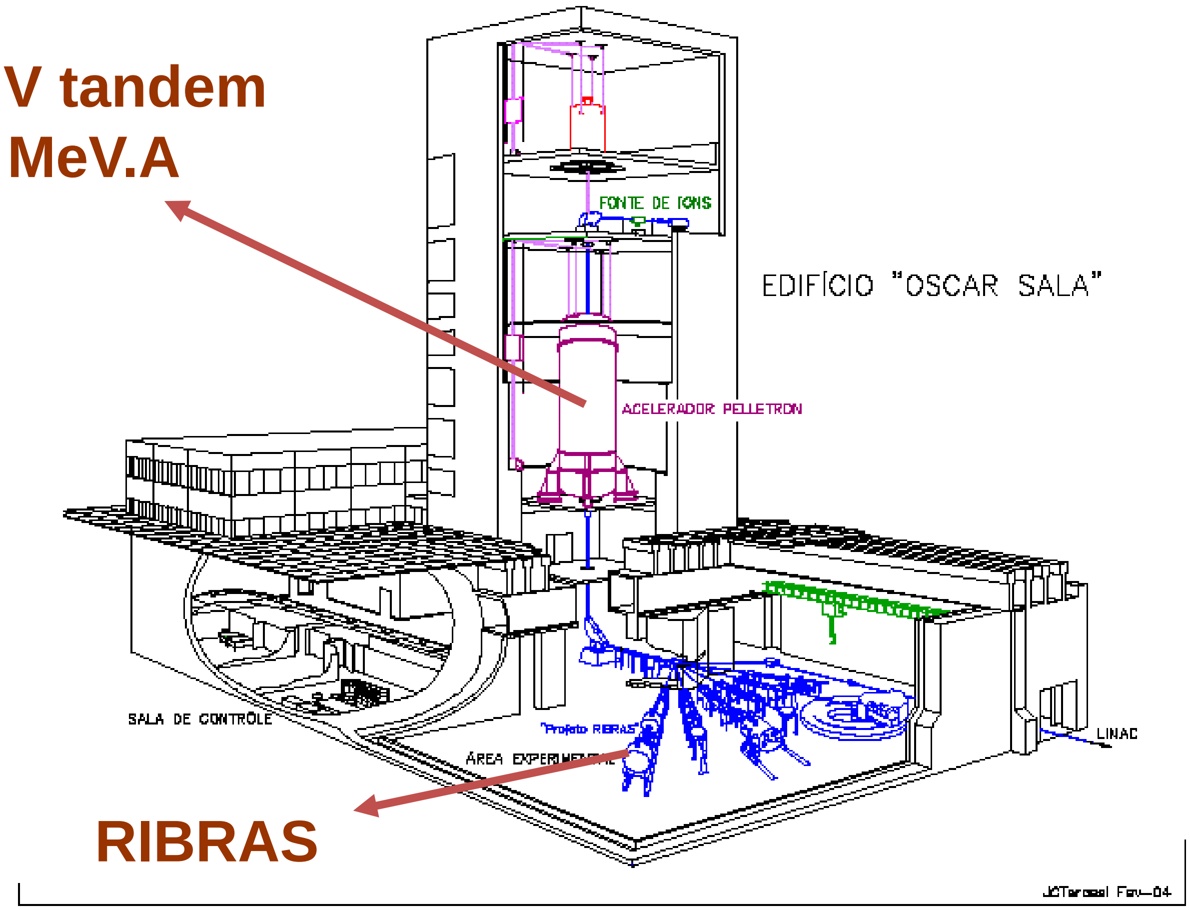


The Fifth International Conference ENAM '08 on Exotic Nuclei and Atomic Masses

TEXAS A&M UNIVERSITY

São Paulo Pelletron Laboratory

8 MV tandem
3-5 MeV.A



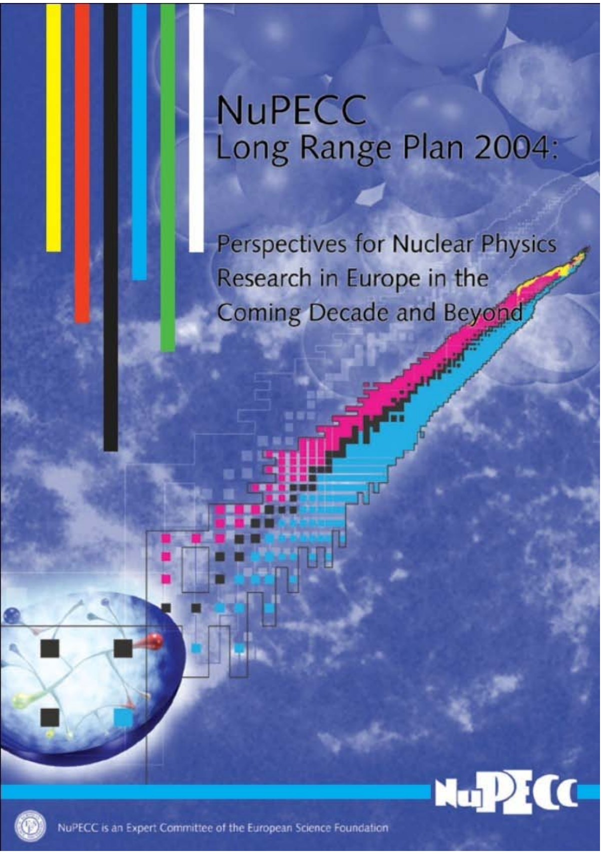
RIBRAS

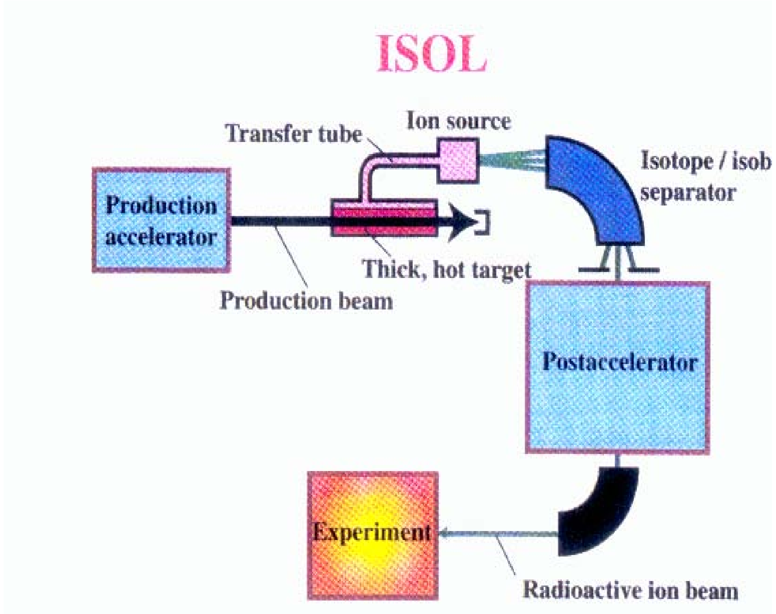
RIBRAS = Radioactive Ion Beams Brasil

The Future

- Continuing upgrades at existing facilities
- Completion of GSI/FAIR
- Development of high power at RIKEN
- **New facilities**

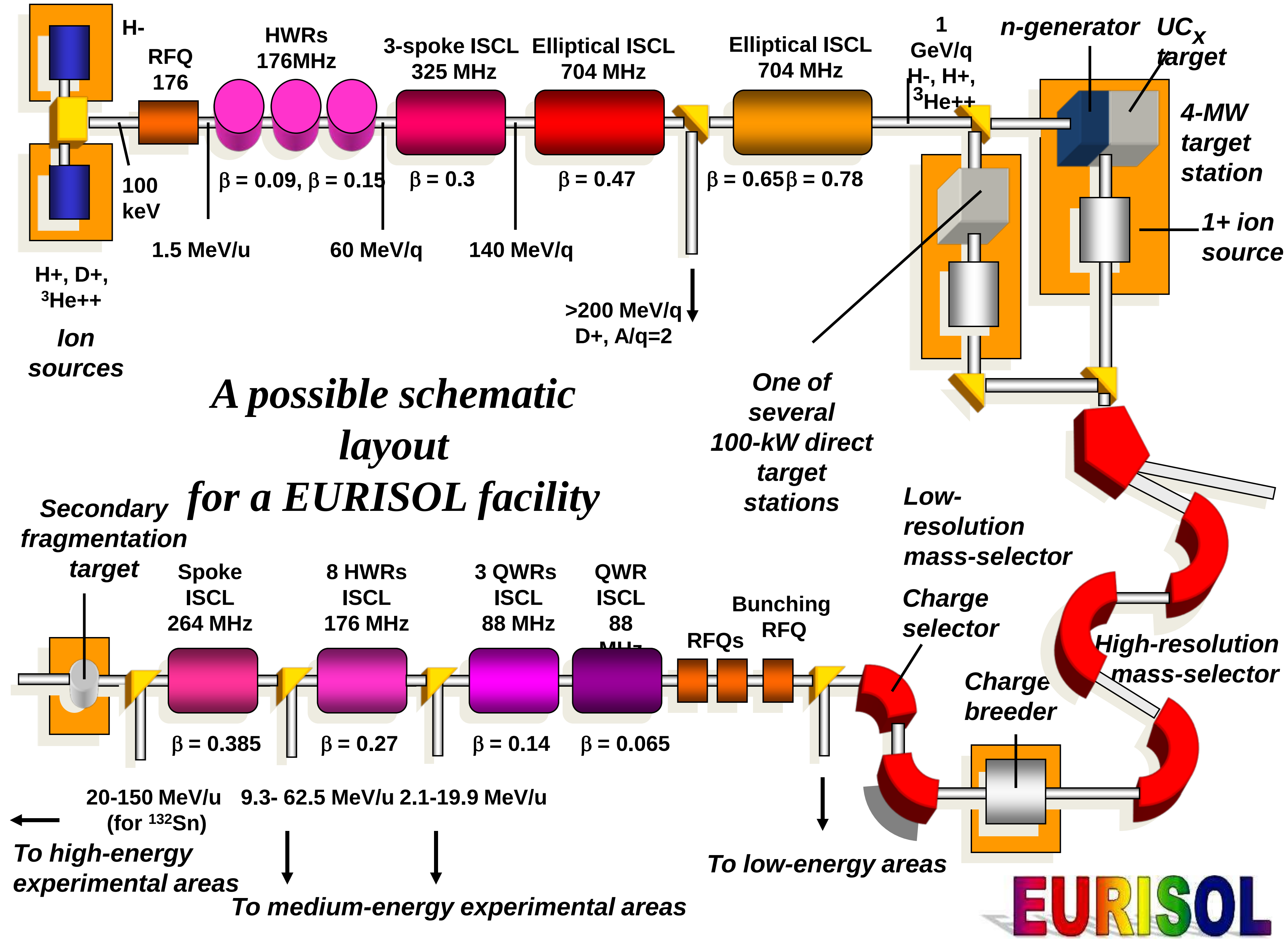
The European ISOL Road Map



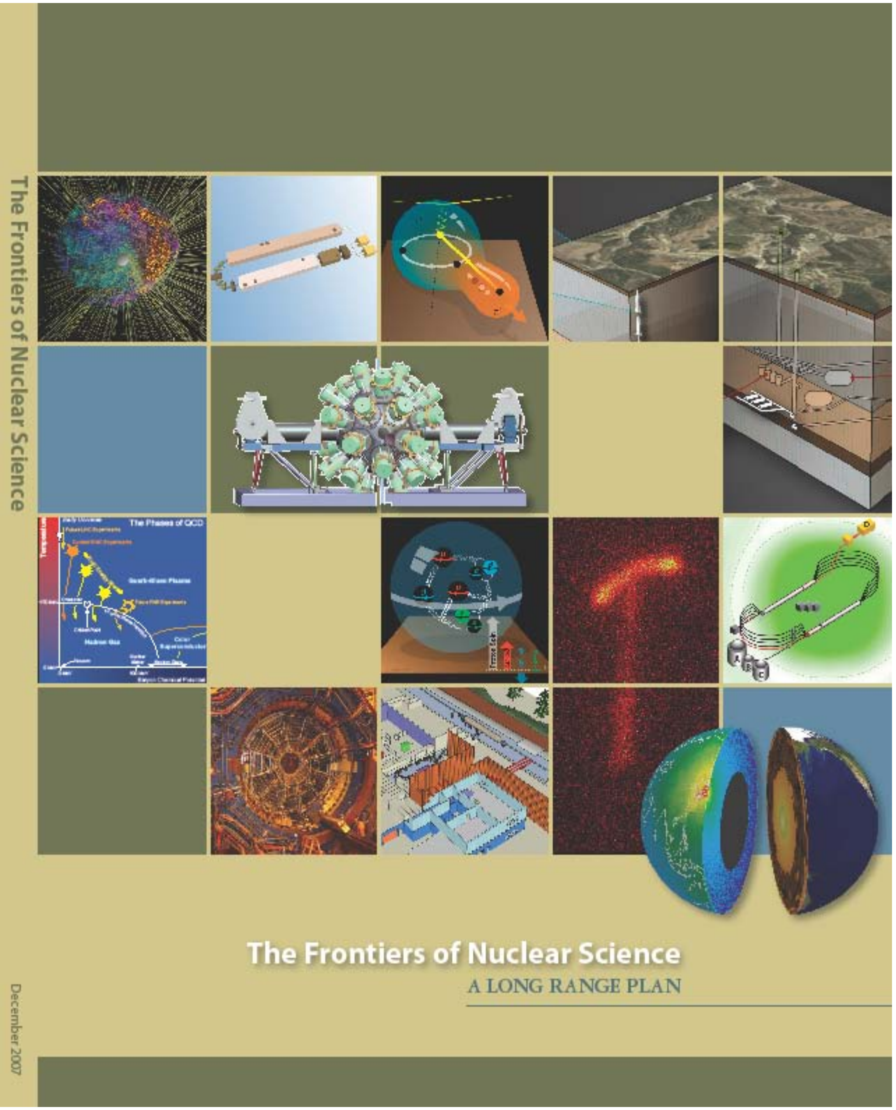


- Vigorous exploitation of current ISOL facilities : EXCYT, REX/ISOLDE, SPIRAL
- Construction of intermediate generation facilities: SPIRAL2, HIE-ISOLDE, SPES
- Design and prototyping in the framework of EURISOL Design-Study (20 Labs, 14 Countries, 30M€)

A possible schematic layout for a EURISOL facility



U.S. – FRIB



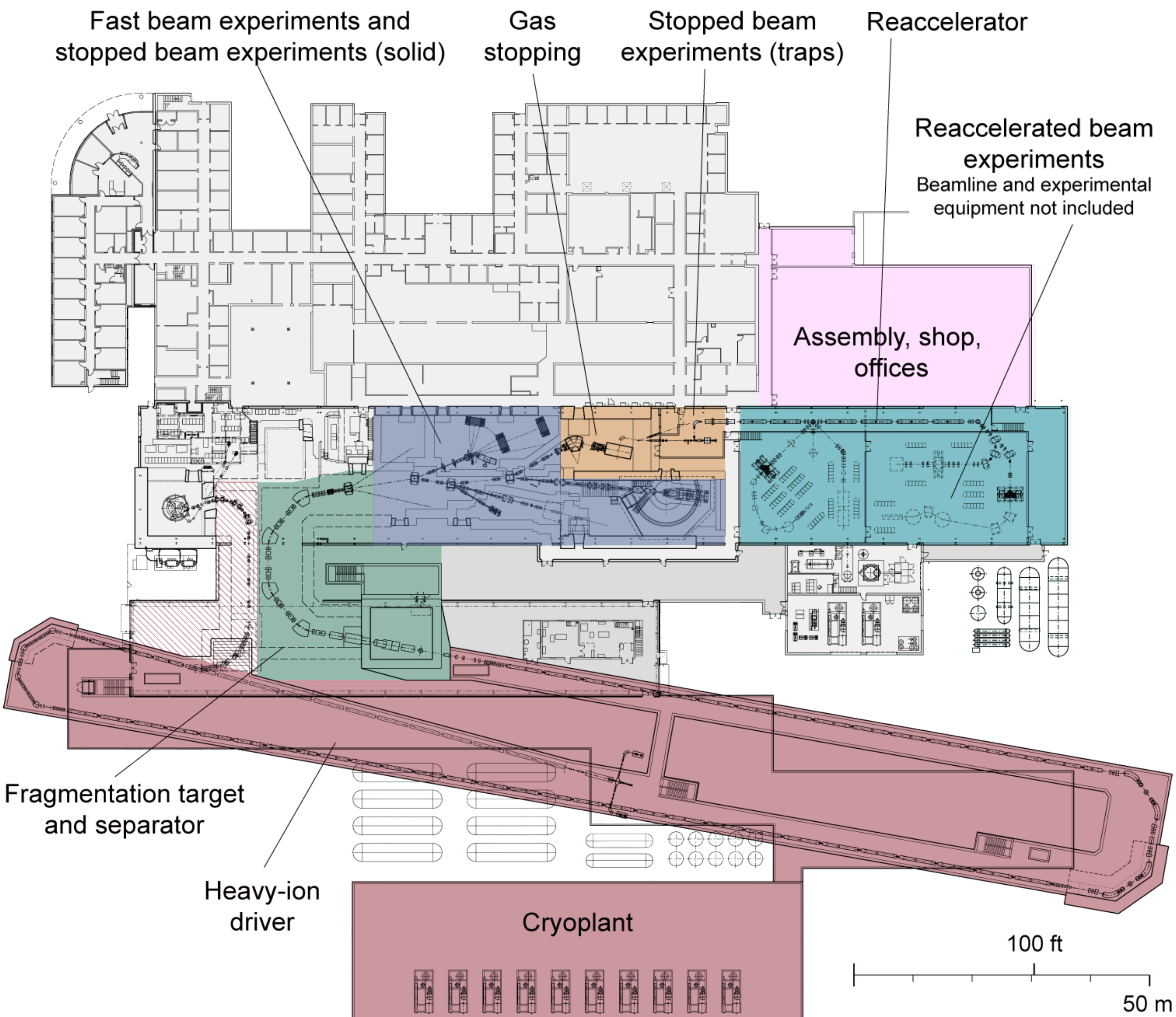
2007 Long Range Plan

Recommendation 2:

We recommend construction of the Facility for Rare Isotope Beams, FRIB, a world-leading facility for the study of nuclear structure, reactions and astro-physics. Experiments with the new isotopes produced at FRIB will lead to a comprehensive description of nuclei, elucidate the origin of the elements in the cosmos, provide an understanding of matter in the crust of neutron stars, and establish the scientific foundation for innovative applications of nuclear science to society.

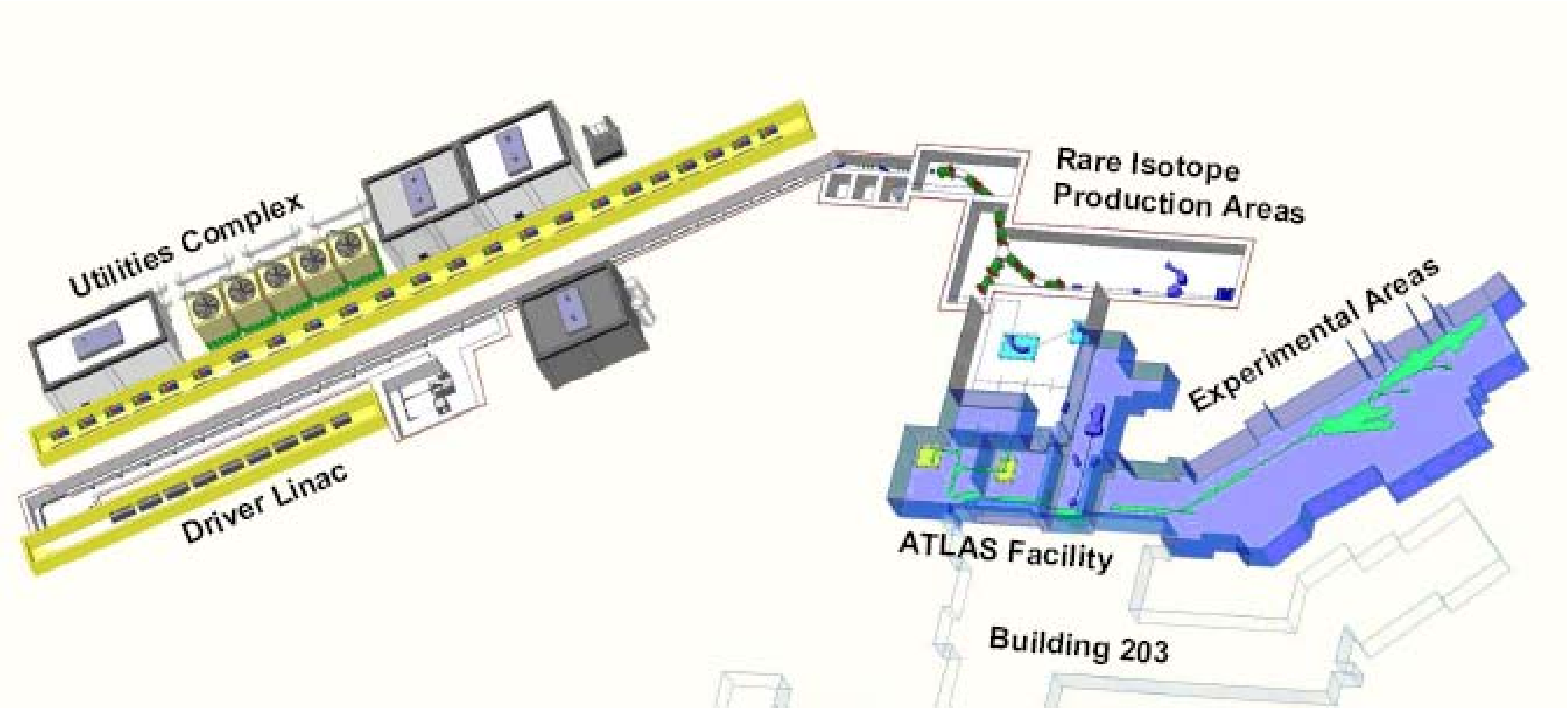
Site selection underway soon!

FRIB at NSCL



Fast beam experiments and stopped beam experiments (solid)
Gas stopping
Stopped beam experiments (traps)
Reaccelerator
Reaccelerated beam experiments
Beamline and experimental equipment not included
Assembly, shop, offices
Fragmentation target and separator
Heavy-ion driver
Cryoplant
100 ft
50 m

FRIB at ANL



•*Driver linac: 200 MeV/u ^{238}U, 400 kW ($5x10^{13}$ uranium ions/s). All required accelerator structures prototyped at ANL;*
•*Rare isotopes for experimental program with stopped, reaccelerated and fast beams;*
•*Rare isotopes for reacceleration from ANL's gas stopping technique;*
•*Reacceleration to ~ 15 MeV/u through ATLAS.*

FROM ENAM'04 to ENAM'08

- **GSI/FAIR** started
- **RIKEN** operating
- **SPIRAL 2** started
- **ISOLDE** upgrade
- **TRIUMF ISACII**
- RIA ® **FRIB**
- **EURISOL** R&D

- New smaller projects
  - **SPES**
  - Beam at **EXCYT**
  - **CARIBU** at ATLAS
  - **TAMU** upgrade
  - High power target at **HRIBF**
  - Low energy beams at **MSU**
  - Solenoids at **Florida State**
  - **VEC** upgrade
  - **Beijing** upgrade
  - **Lanzhou** Facility