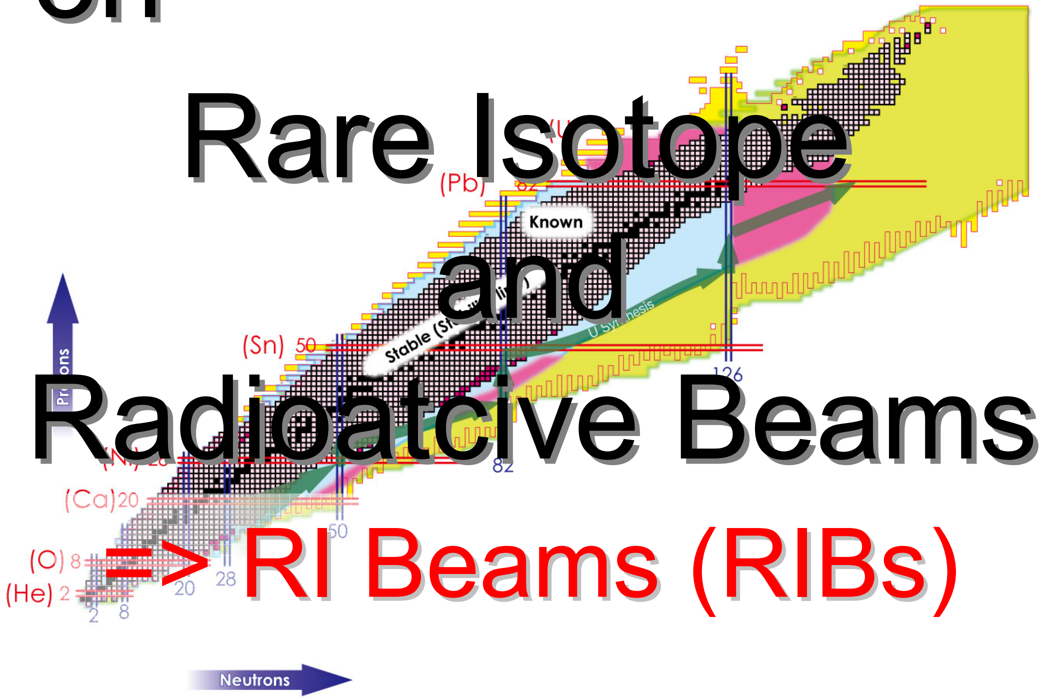
IPAC'10
The 1st International Particle Accelerator Conference

World-Wide Efforts on Rare Isotope and Radioatcive Beams

=> RI Beams (RIBs)

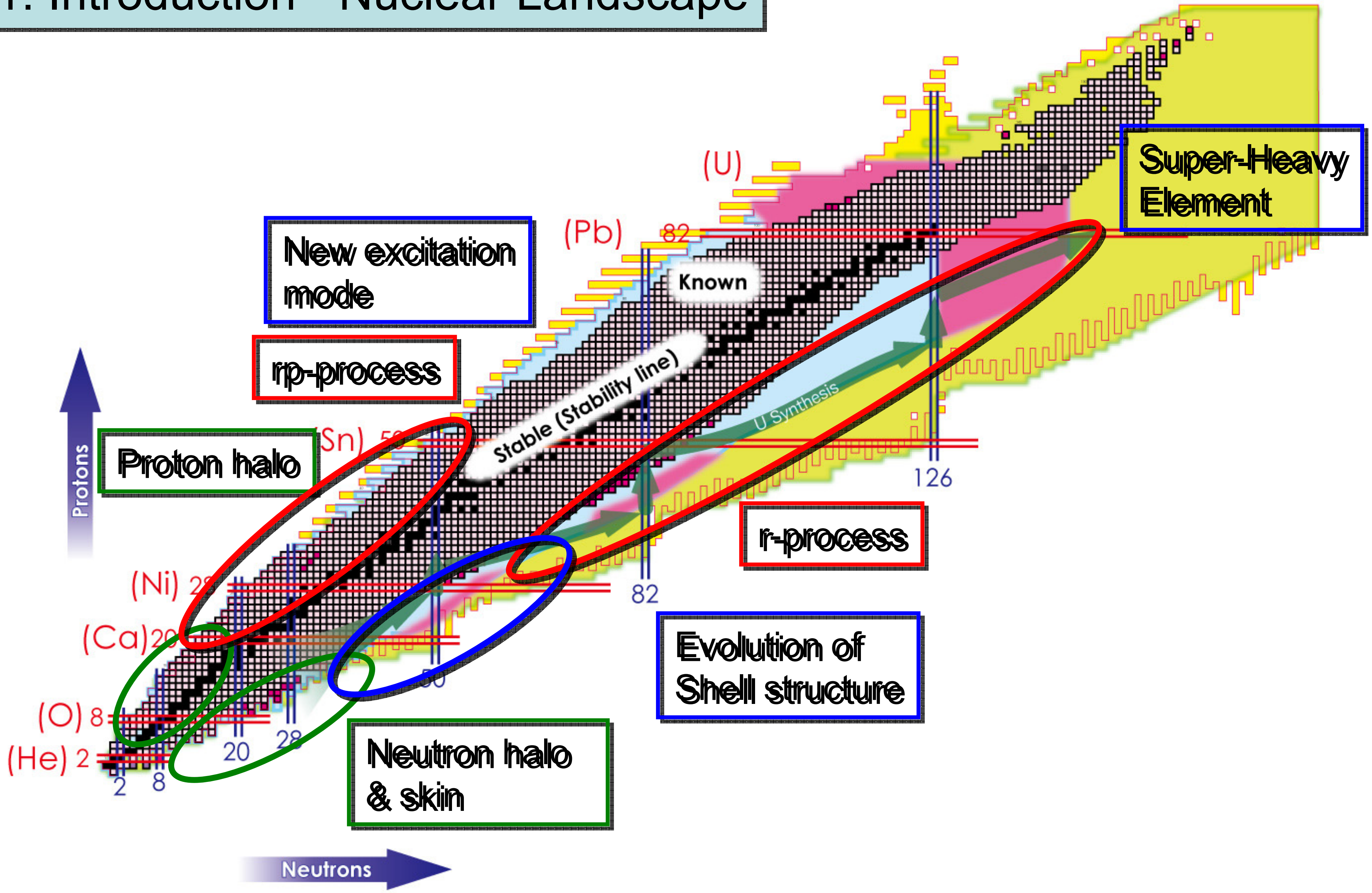
Contents



Osamu Kamigaito
RIKEN Nishina Center

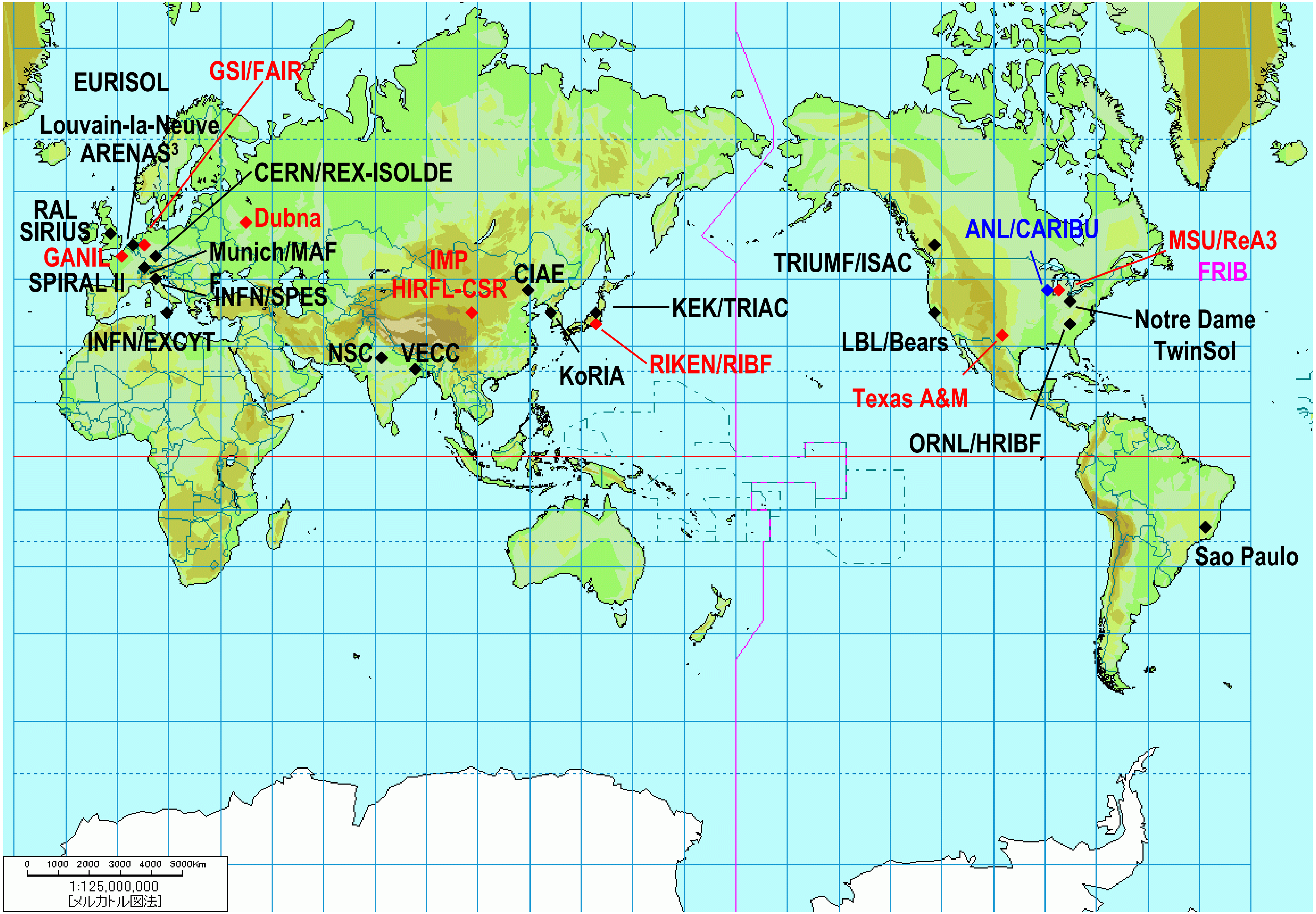
RIKEN NISHINA CENTER

1. Introduction - Nuclear Landscape



2. How to produce RI beams

1) In-flight fragmentation method



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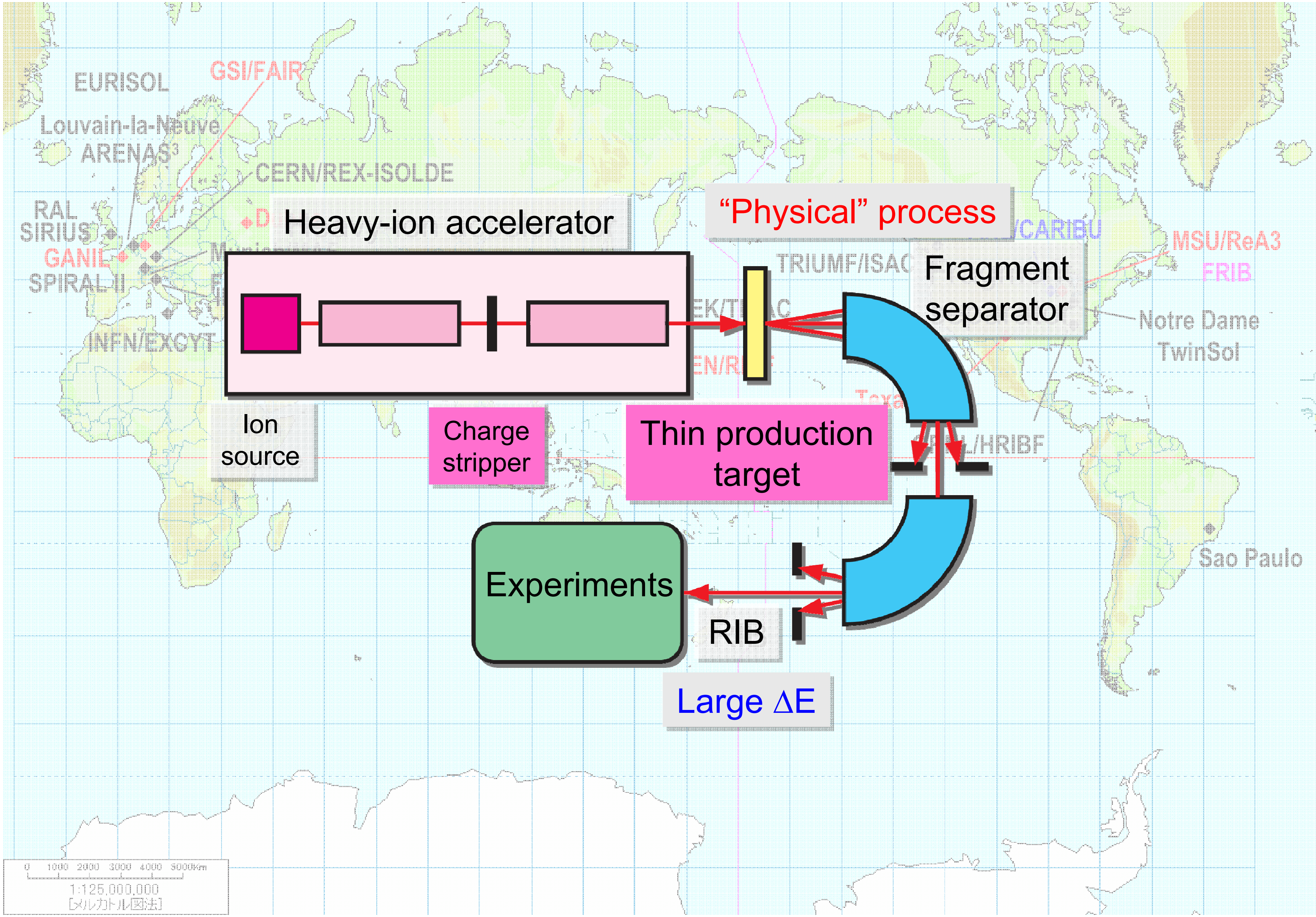
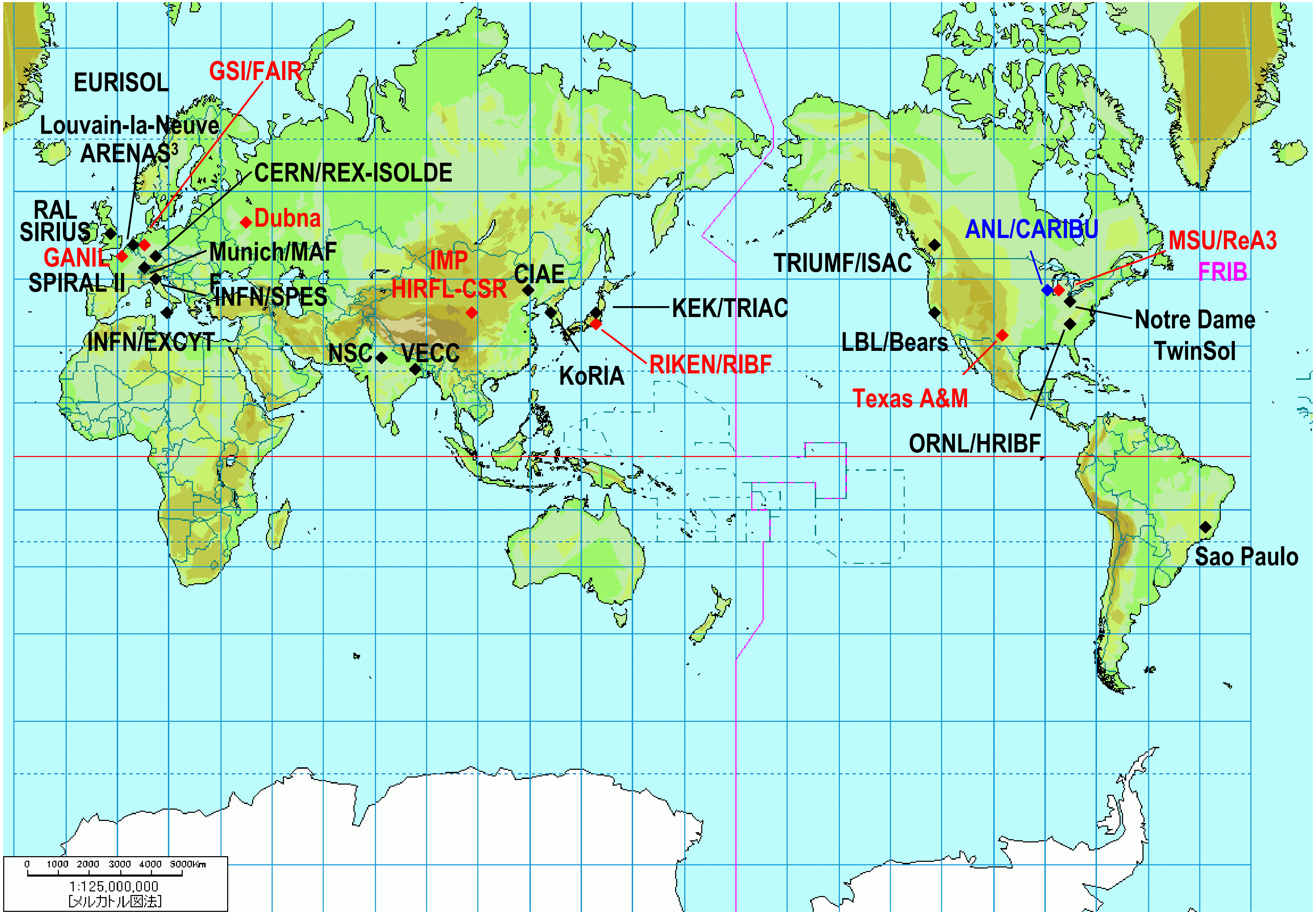


2) ISOL method

(ISOL = ISotope On-Line)



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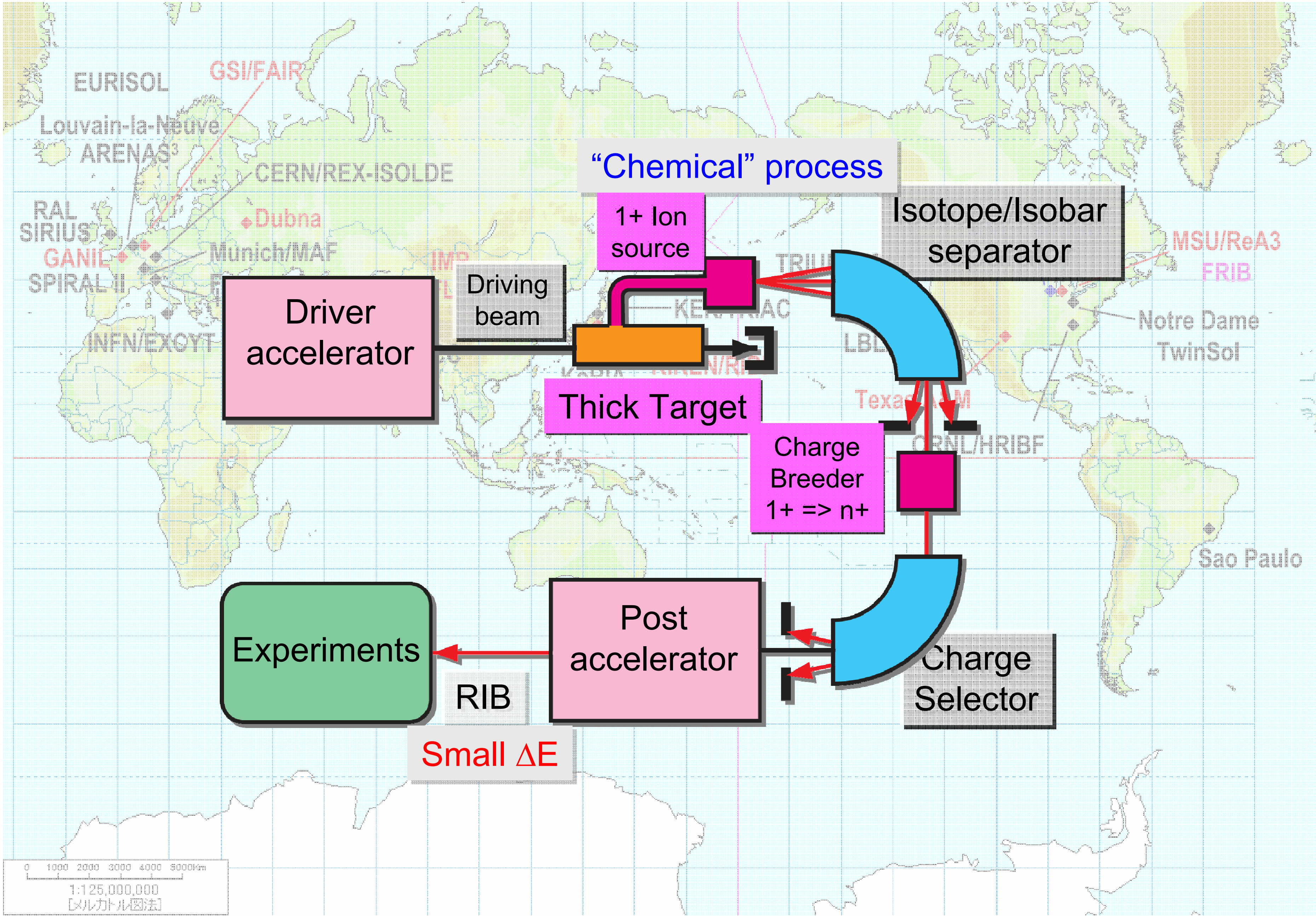
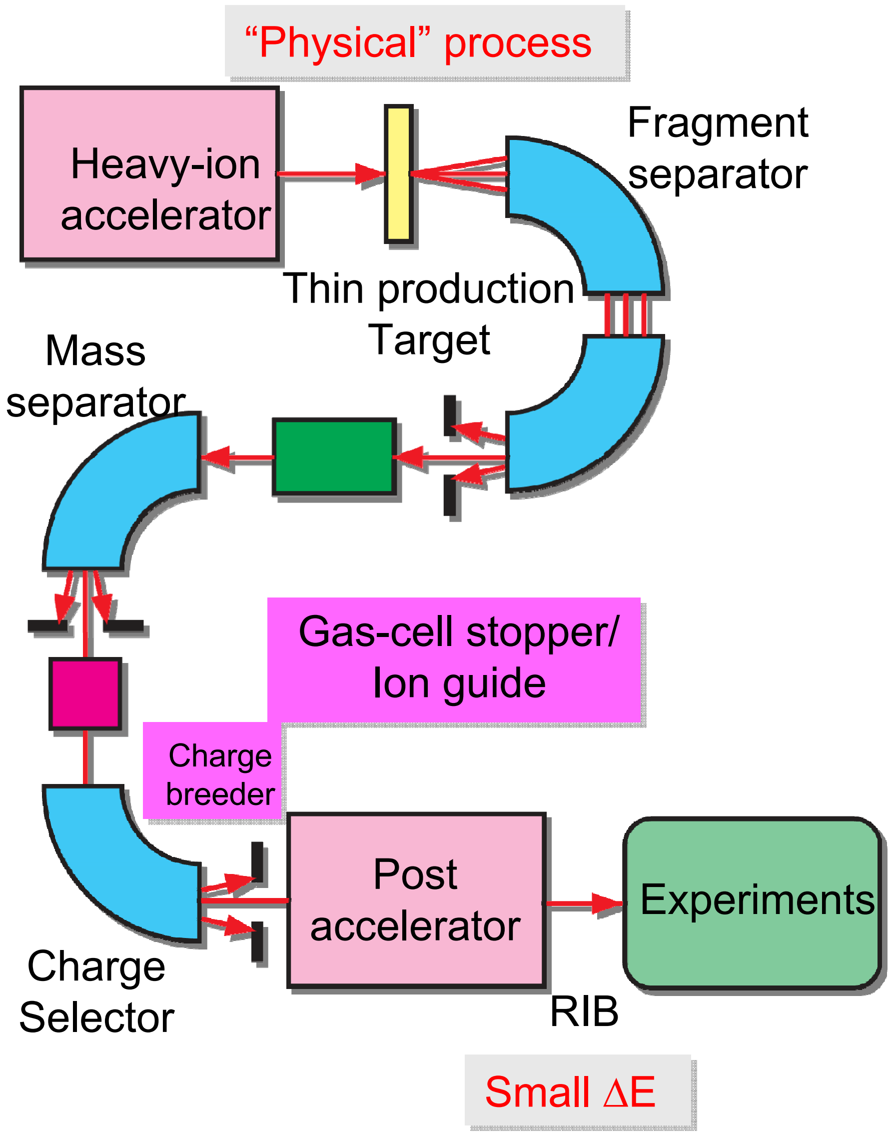


3) Combined method

MSU/ReA3 - FRIB



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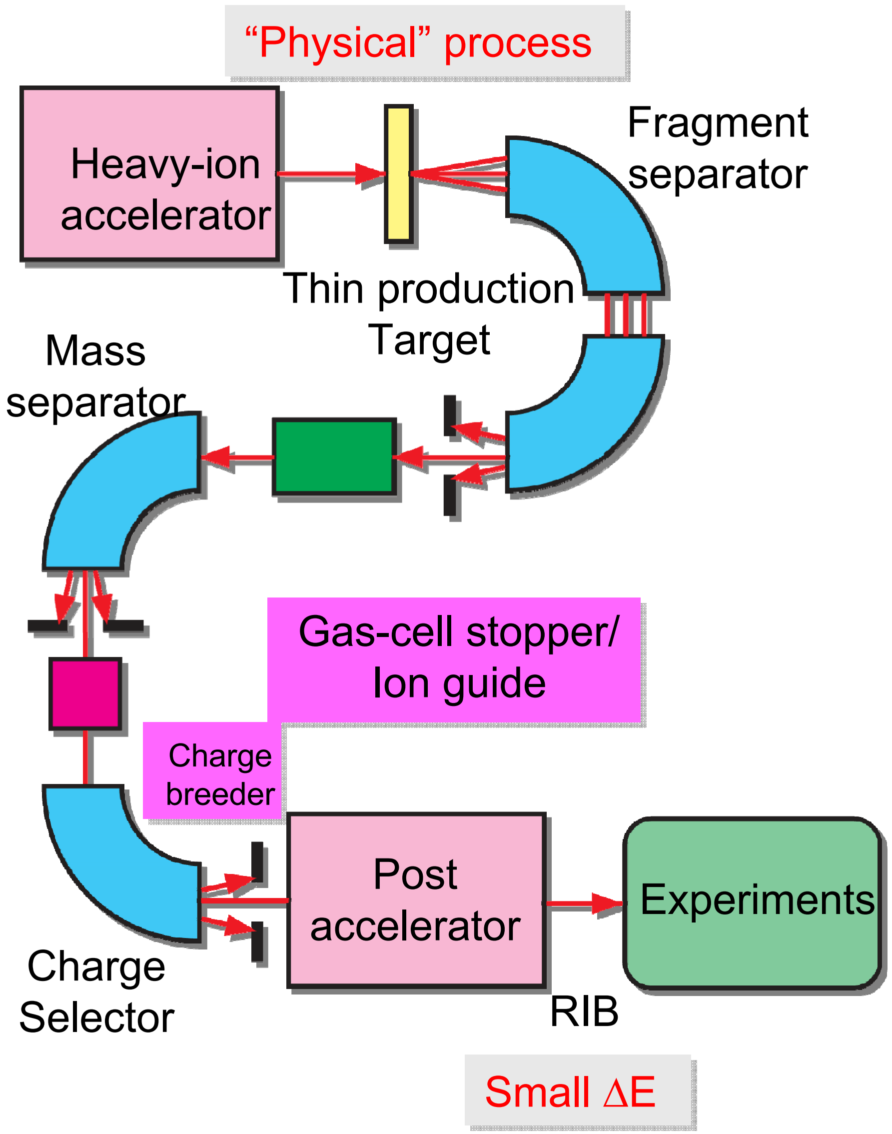
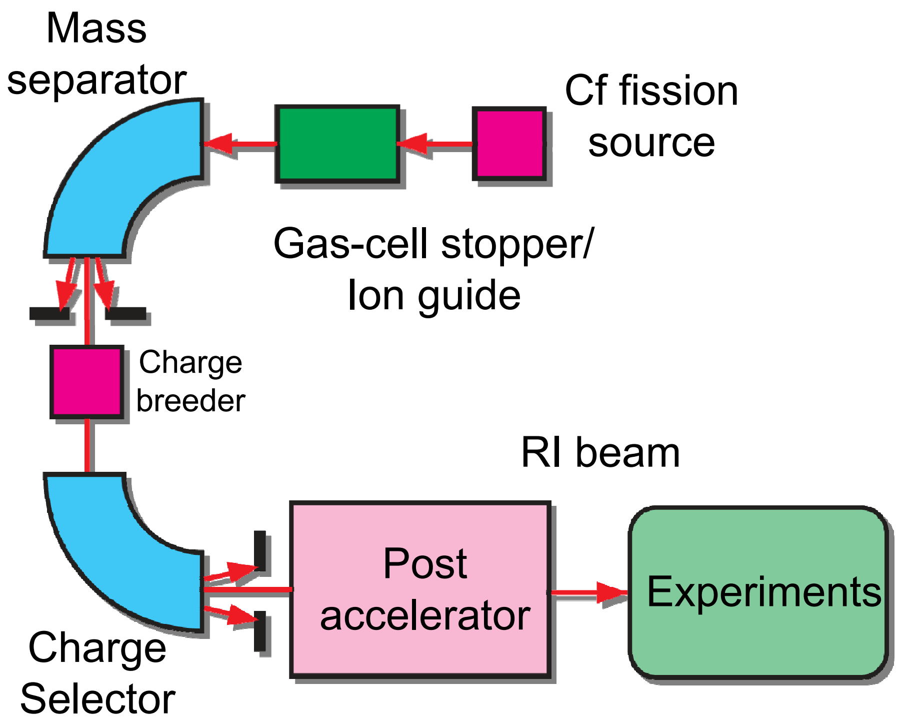
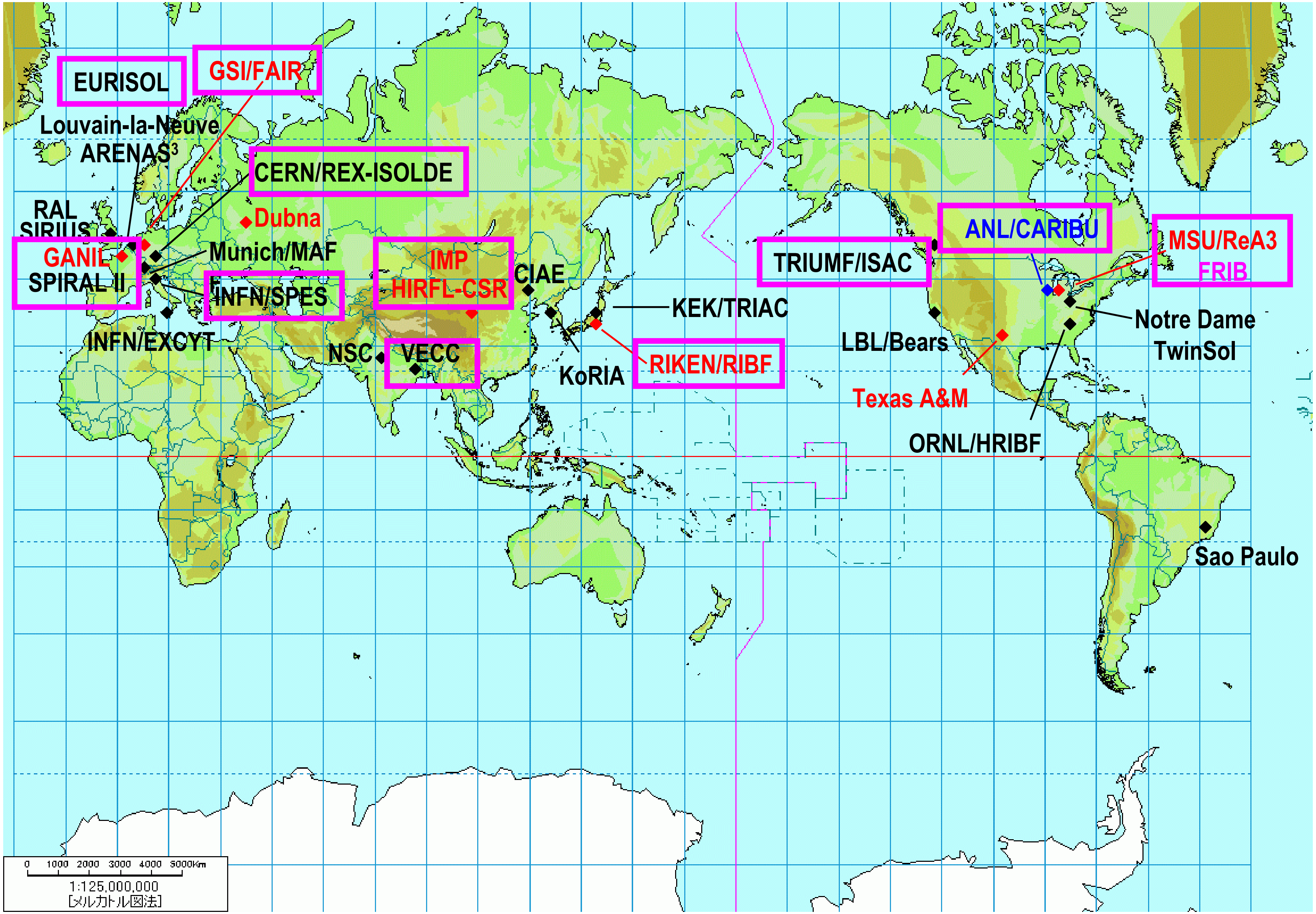


4) Direct method

ANL/CARIBU



3. Facilities in the World



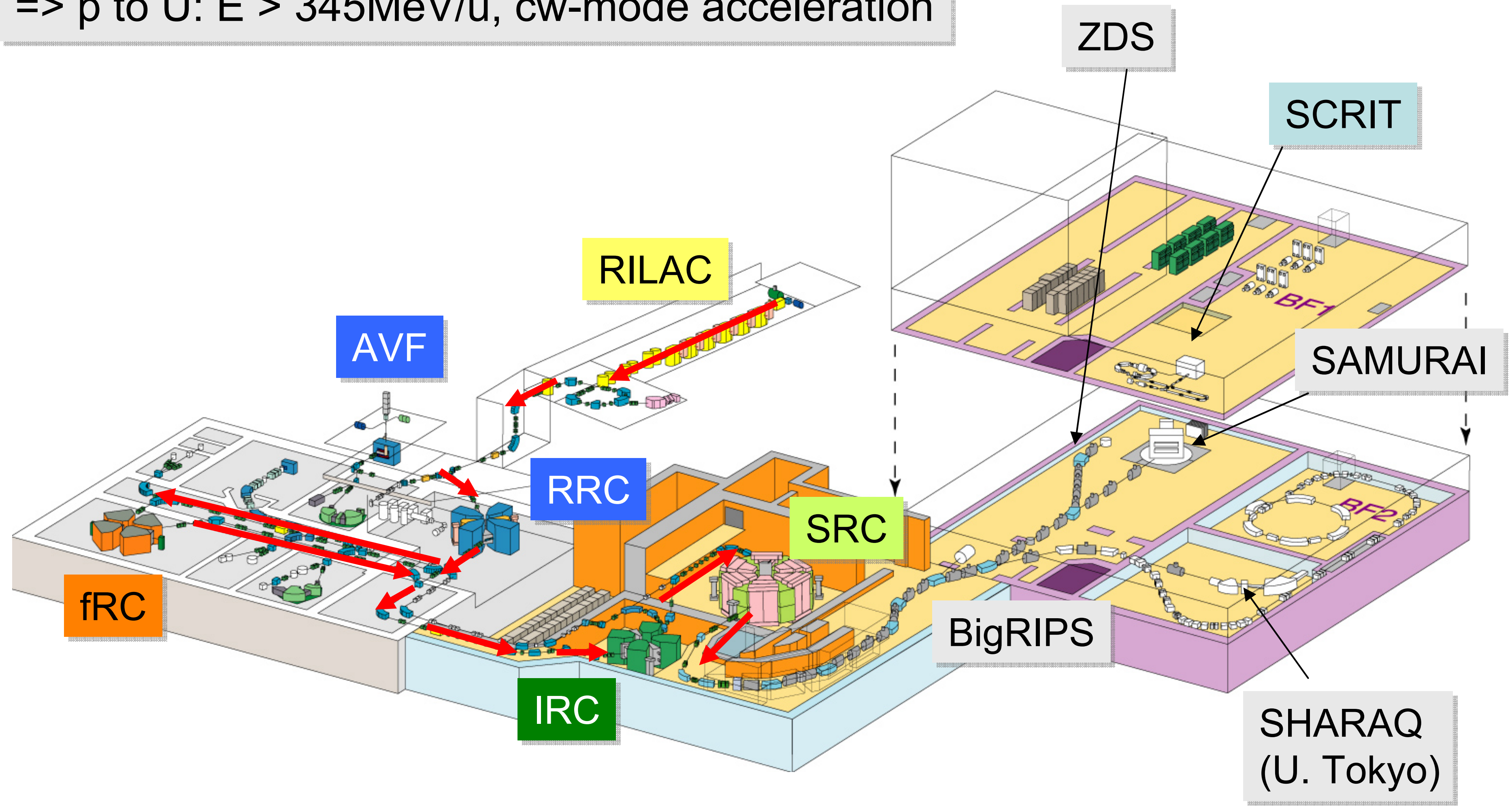
1) RIKEN RIBF

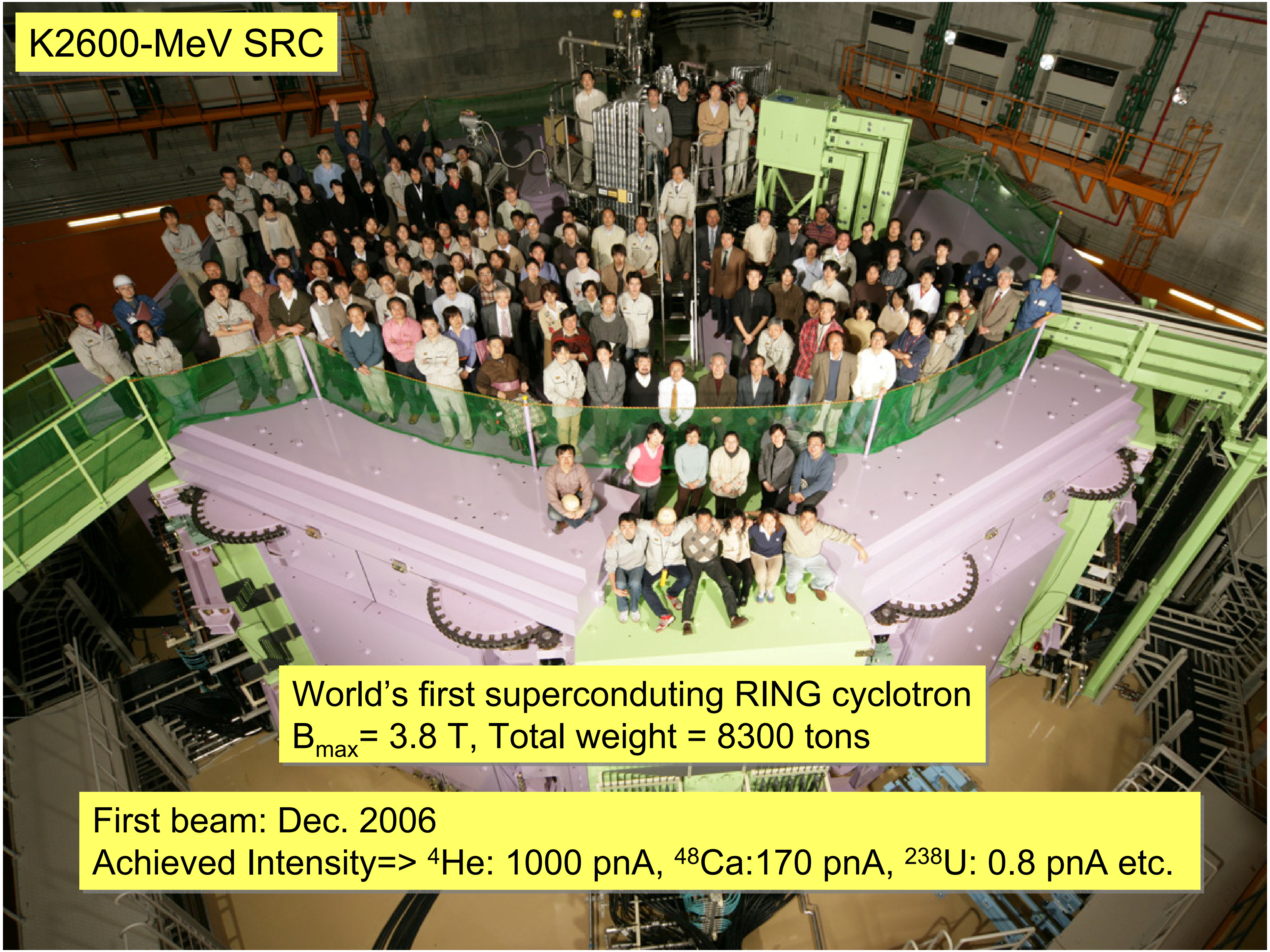
(RIBF = RI Beam Factory)

Two injectors: RILAC & AVF

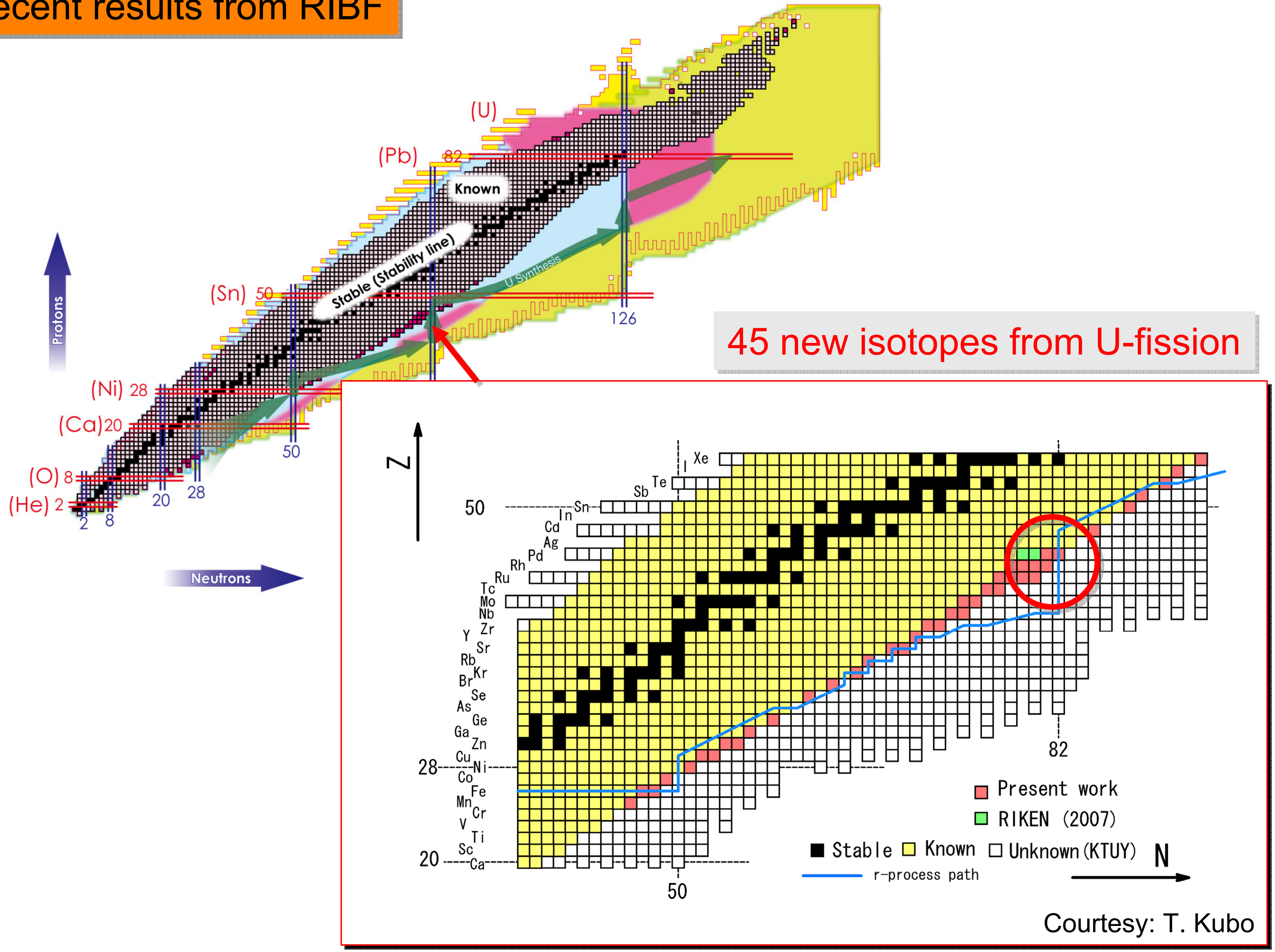
Four booster cyclotrons: RRC, fRC, IRC, SRC

=> p to U: E > 345MeV/u, cw-mode acceleration




K2600-MeV SRC
World's first superconduting RING cyclotron
B_{max}= 3.8 T, Total weight = 8300 tons
First beam: Dec. 2006
Achieved Intensity=> ^{4}He: 1000 pnA, ^{48}Ca:170 pnA, ^{238}U: 0.8 pnA etc.

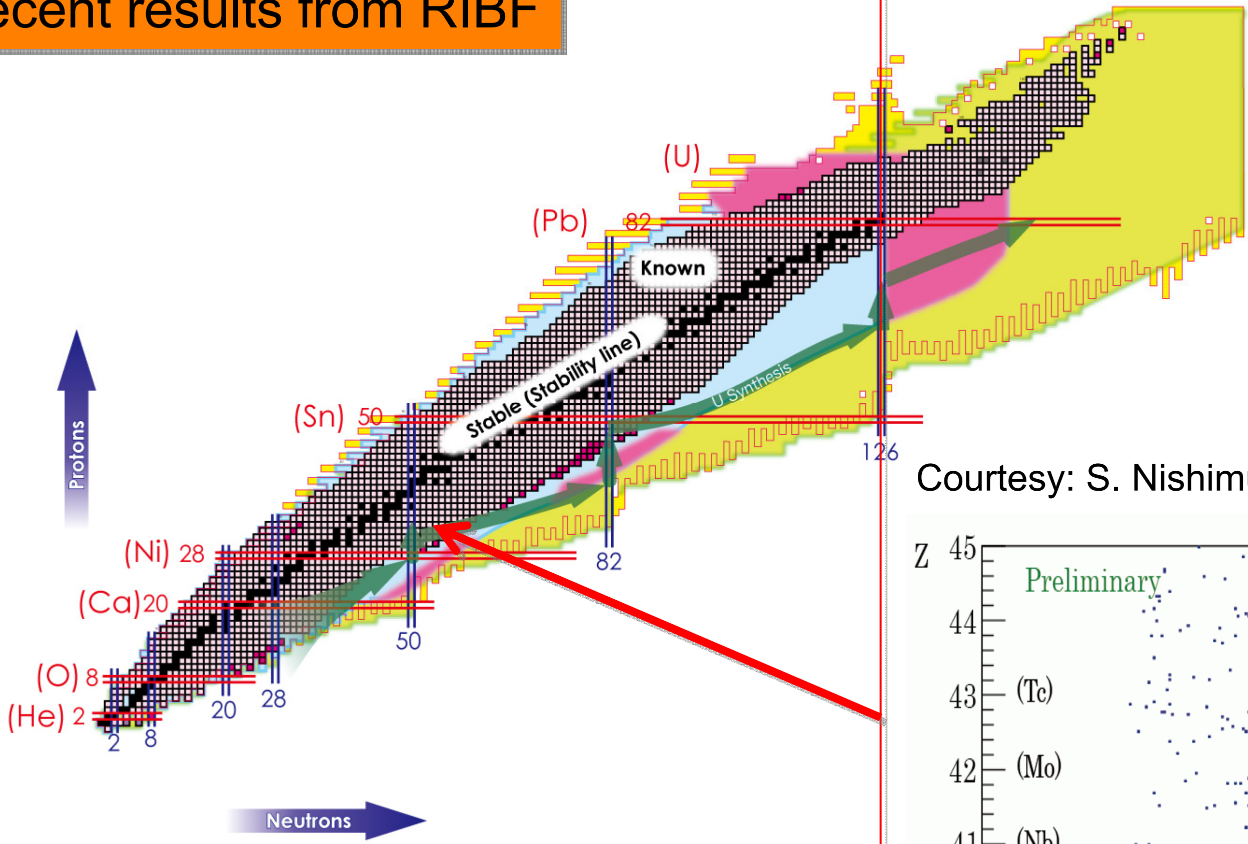
Recent results from RIBF

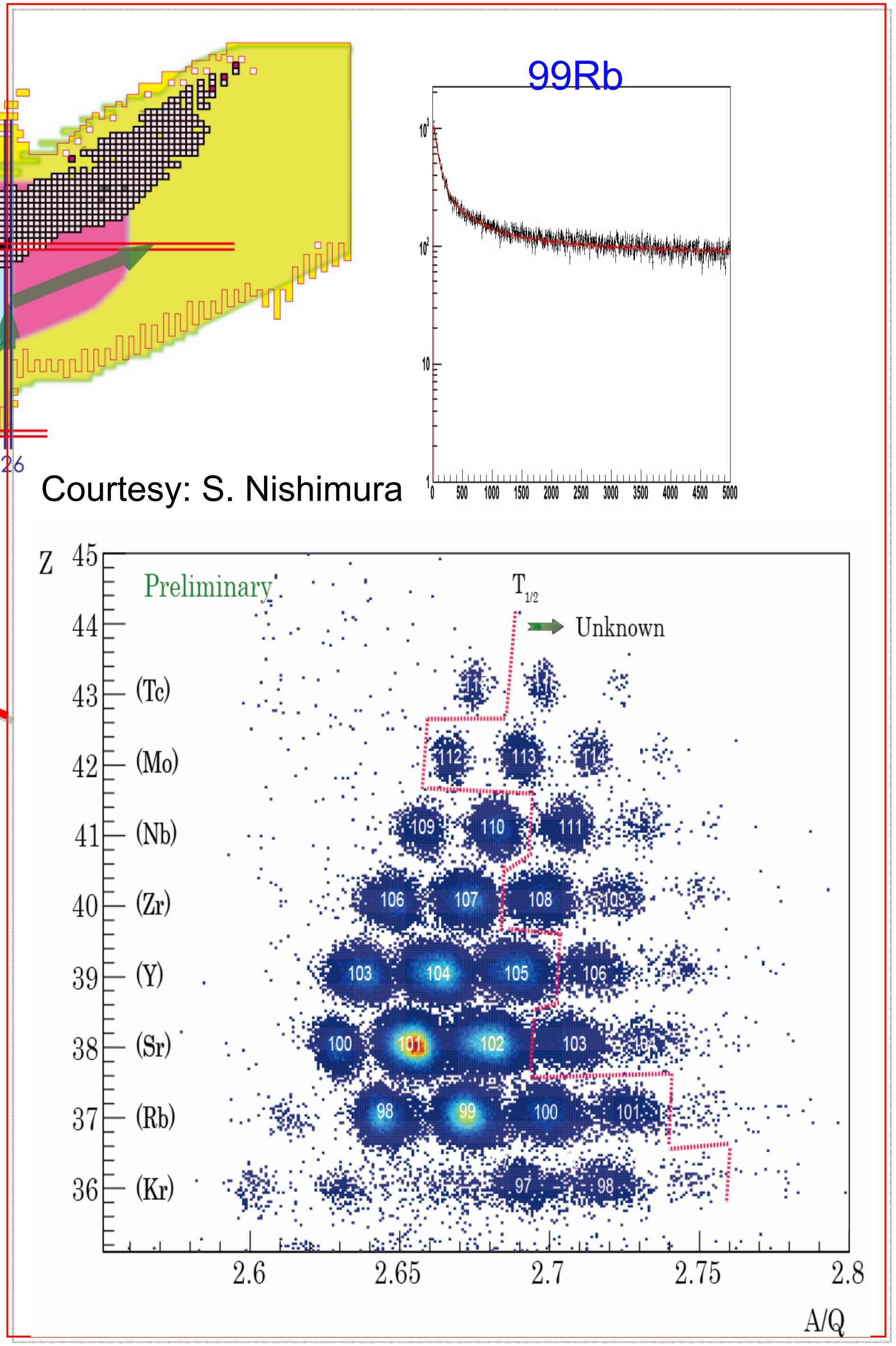


45 new isotopes from U-fission

Courtesy: T. Kubo

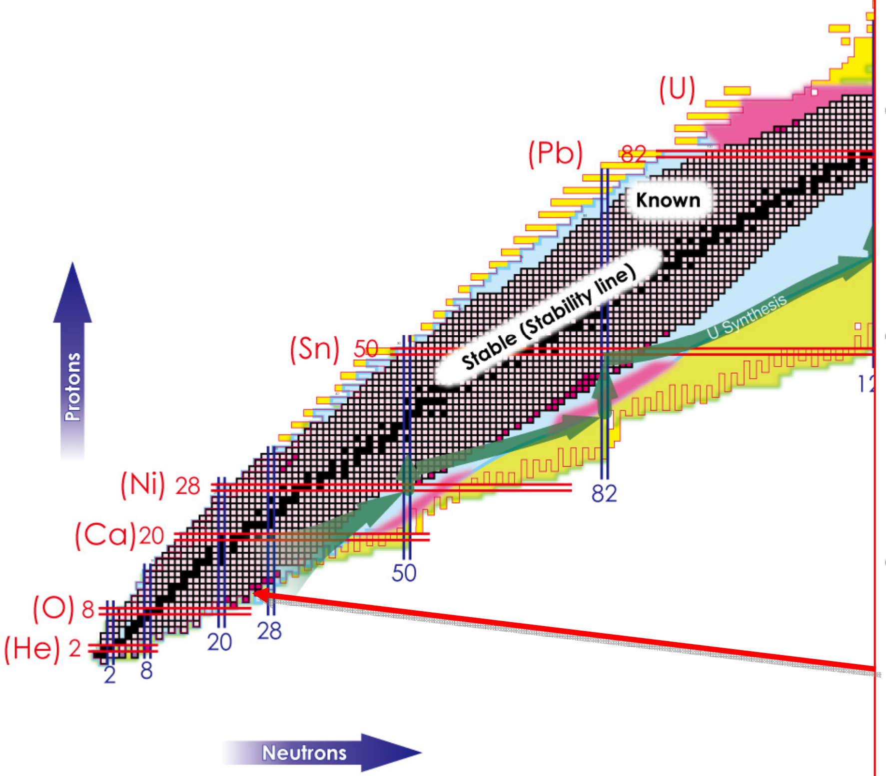
Recent results from RIBF

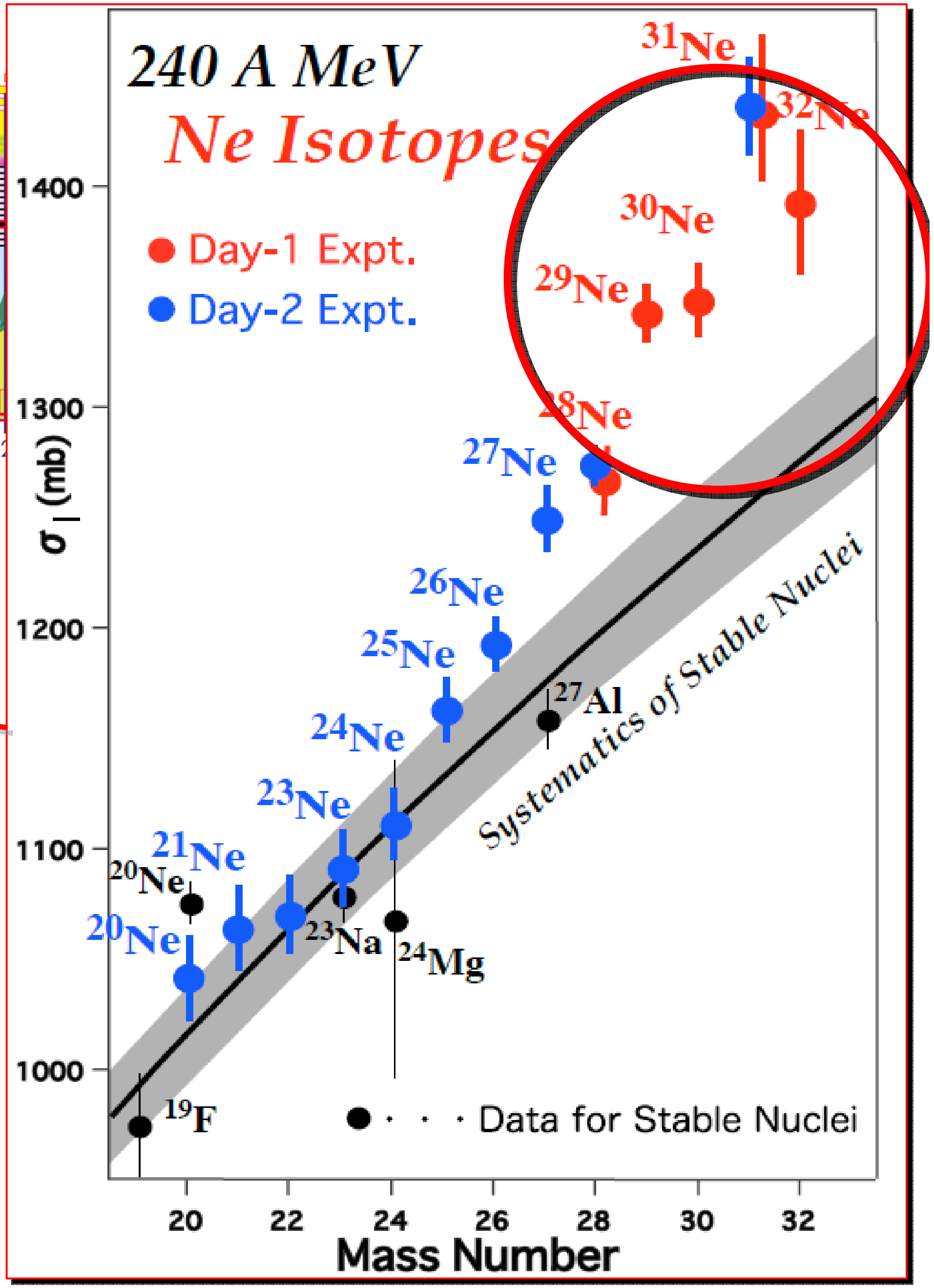




14 ~ 18 new $T_{1/2}$ measured !

Recent results from RIBF





Interaction cross section (~ nuclear radii) measured for Ne isotopes

=> Neutron skin & Halo

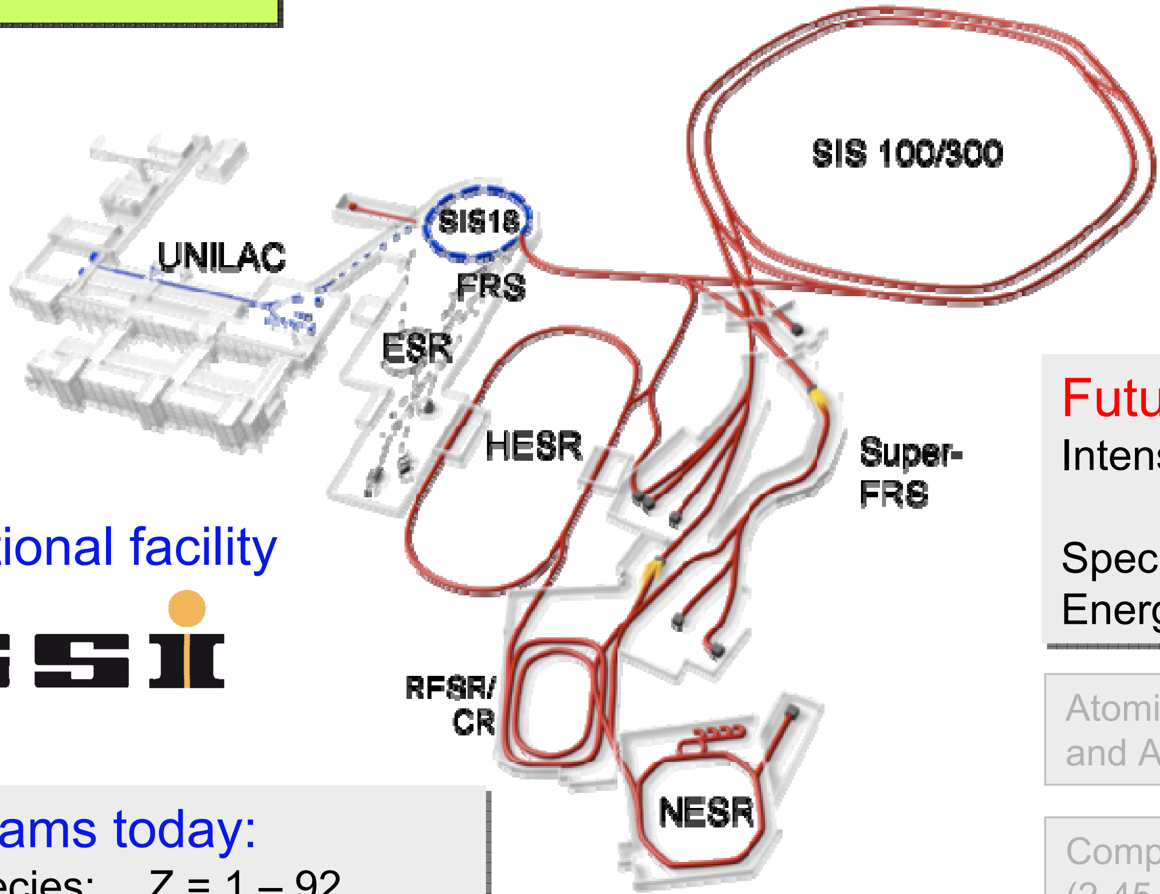
Courtesy: M. Takechi

2) GSI & FAIR

(FAIR= Facility for Antiproton and Ion Research)

International project

National facility



Beams today:
Species: Z = 1 – 92
Energies: up to 2 GeV/u

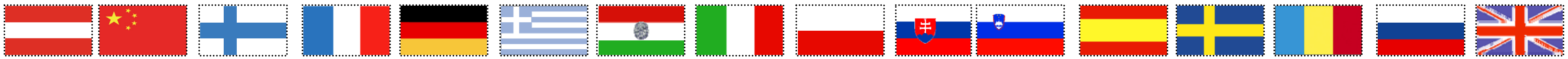
Future beams
Intensities: primary x 100
secondary x 10000 fold
Species: Z = -1 – 92
Energies: Ions up to 35-45 GeV/u

Atomic Physics, Plasma Physics and Applications (APPA) (0 to AGeV)

Compressed Baryonic Matter (CBM) (2-45 A GeV)

Antiproton Physics (PANDA) (0 t0 15GeV)

Nuclear Structure and Astrophysics Reactions (NUSTAR) (0 to 1 GeV/u)

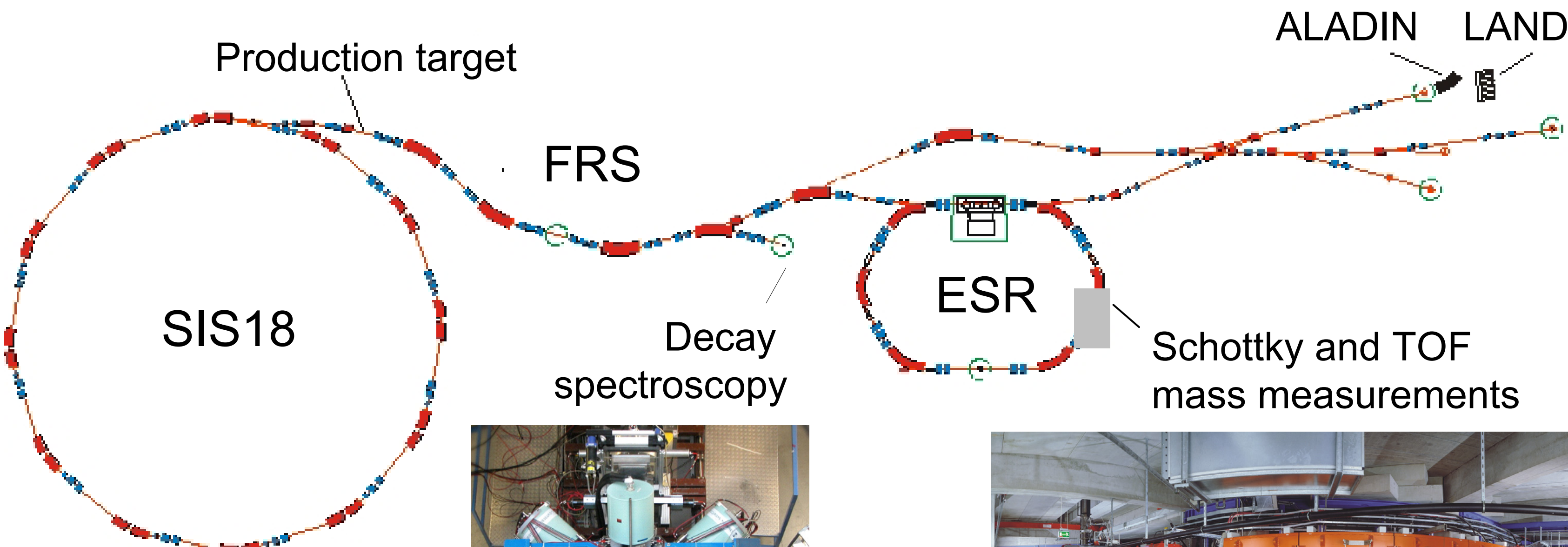


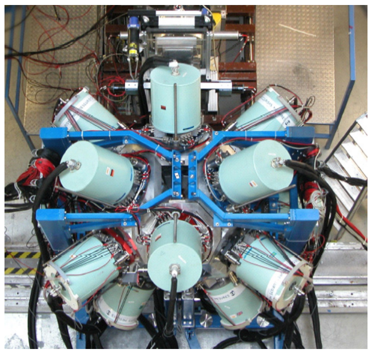
Austria China Finnland France Germany Greece India Italy Poland Slovakia Slovenia Spain Sweden Romania Russia UK

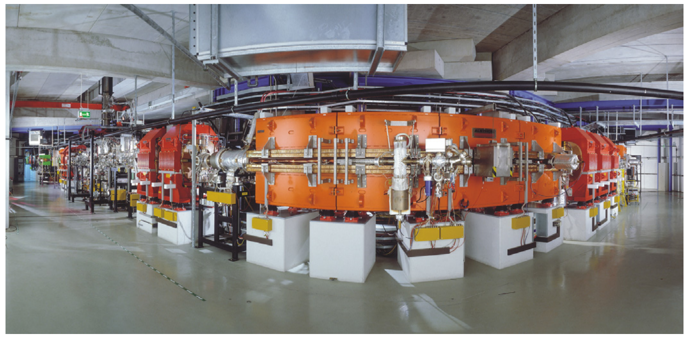
GSI SIS18 – FRS - ESR

Production technique:
Fragmentation and photo-fission

Complete kinematic reactions







Courtesy: W. Henning

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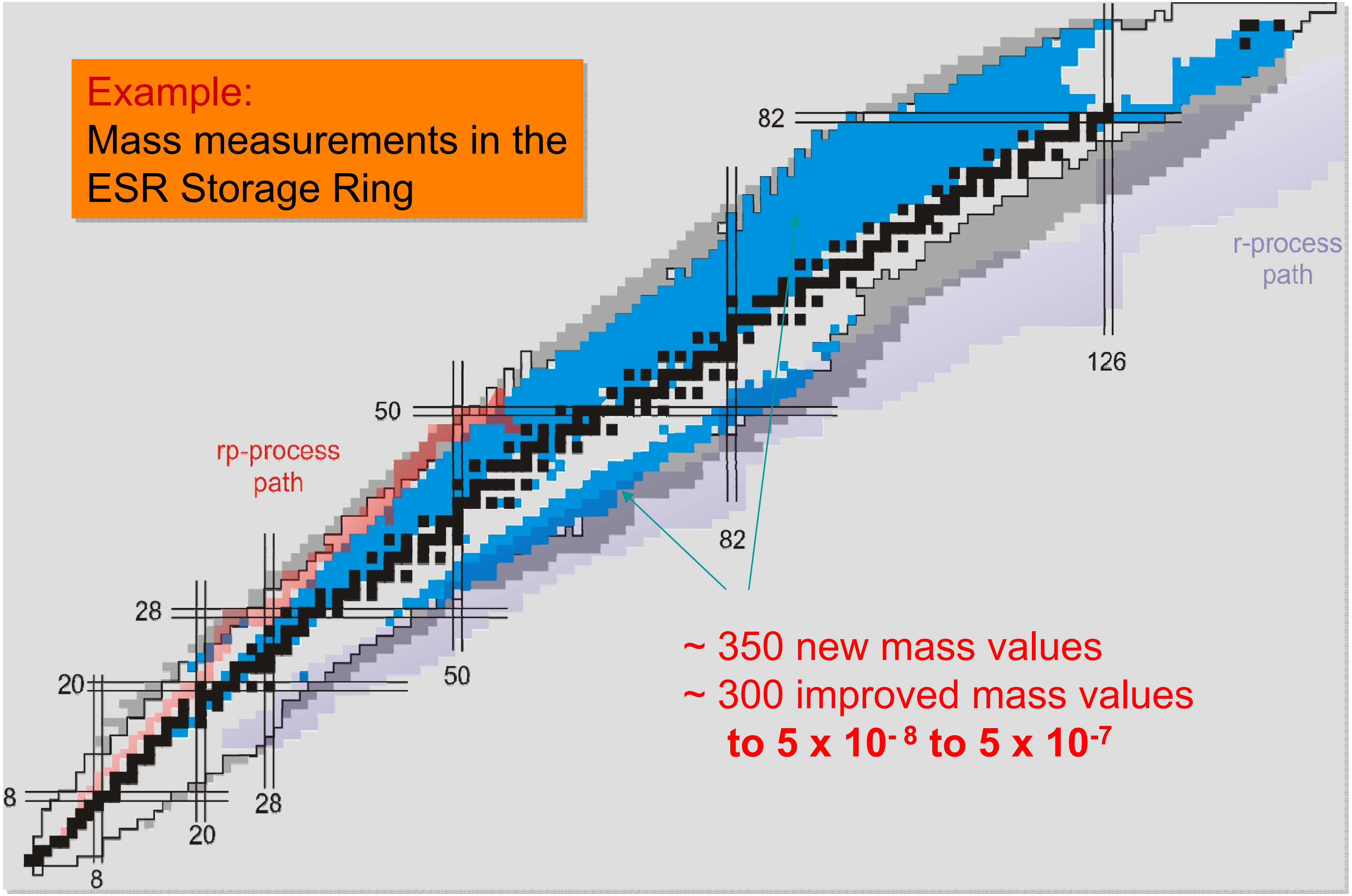
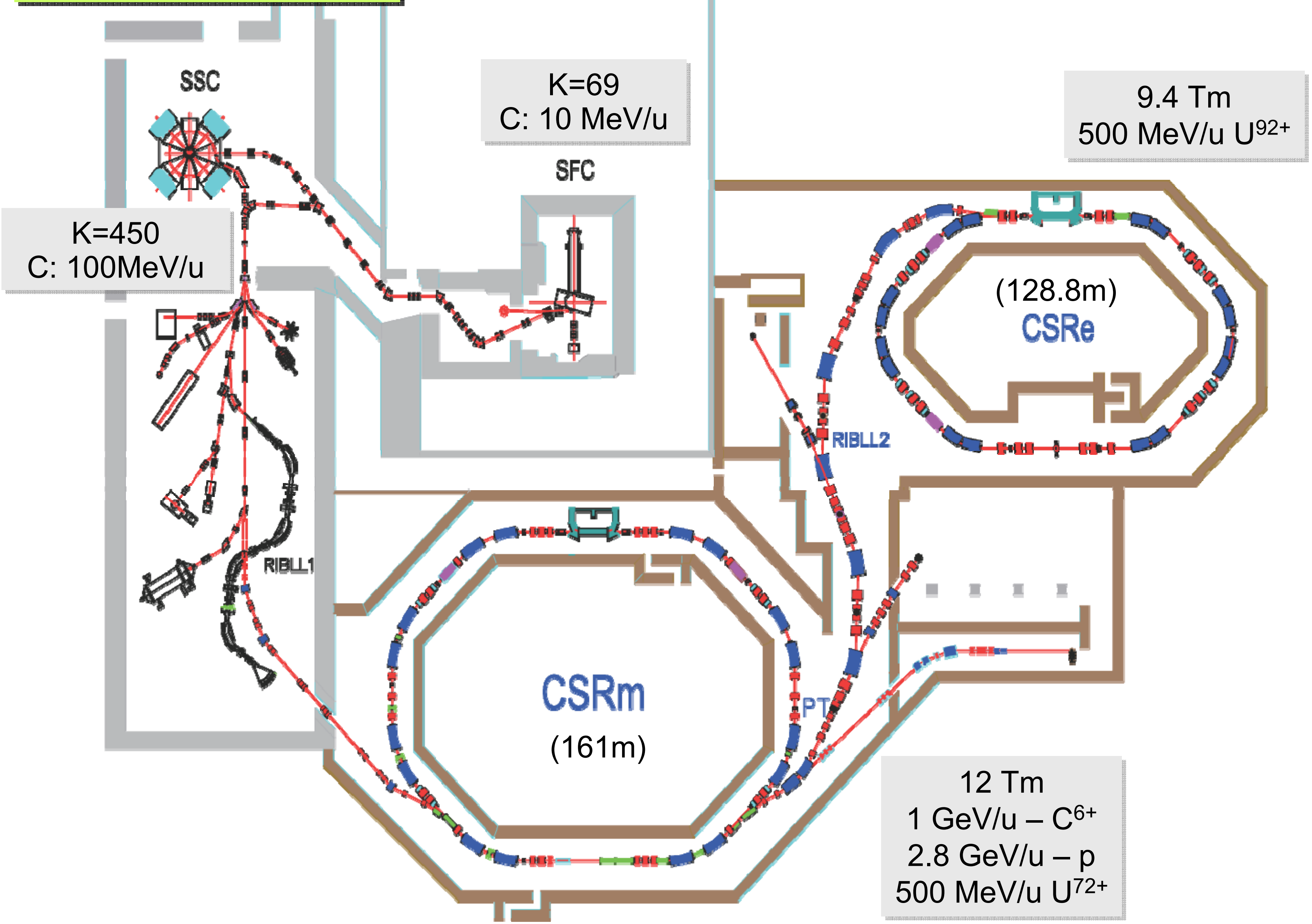


Courtesy: W. Henning

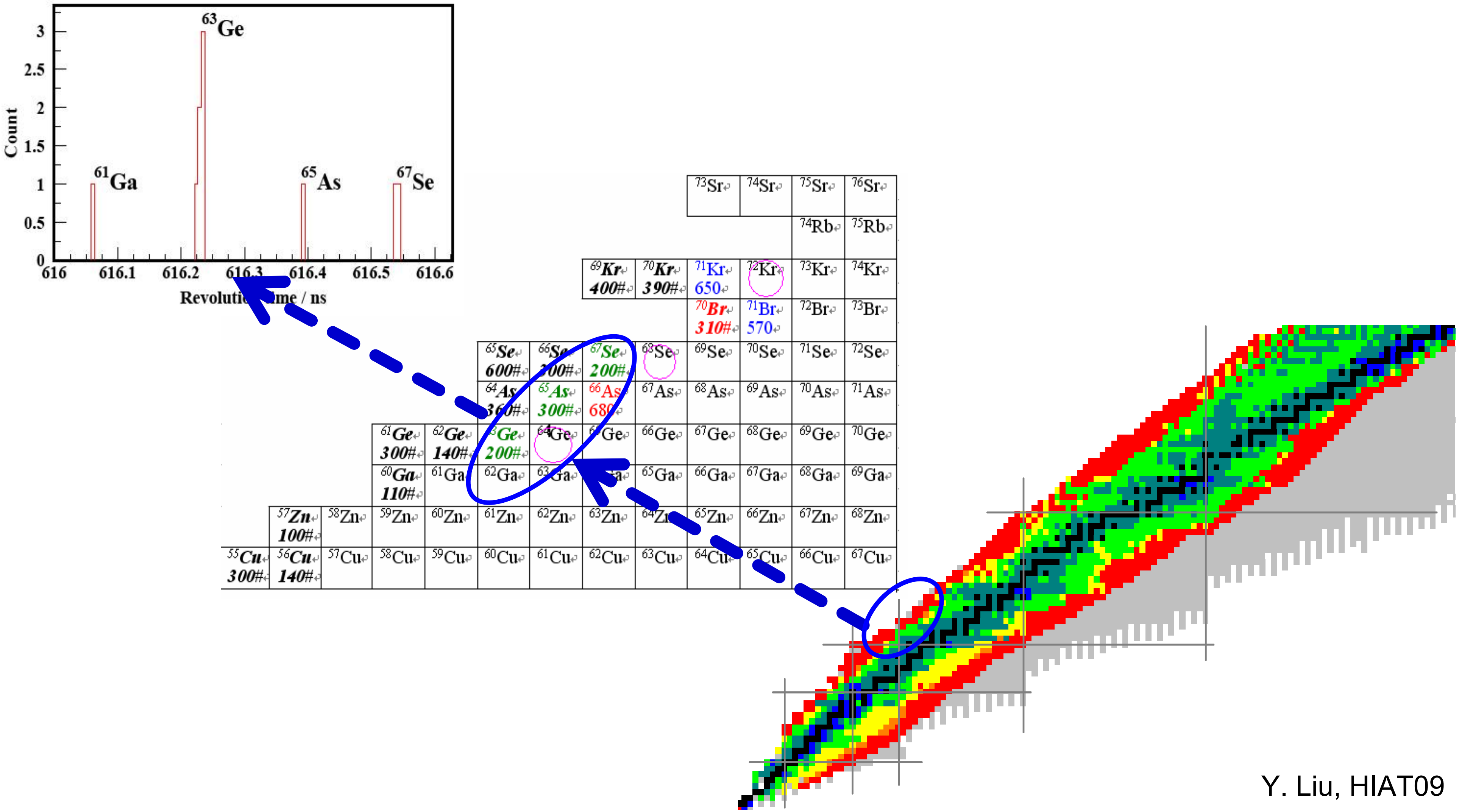
3) IMP HIRFL-CSR

(HIRFL = Heavy Ion Research Facility in Lanzhou)



Recent results from IMP HIRFL

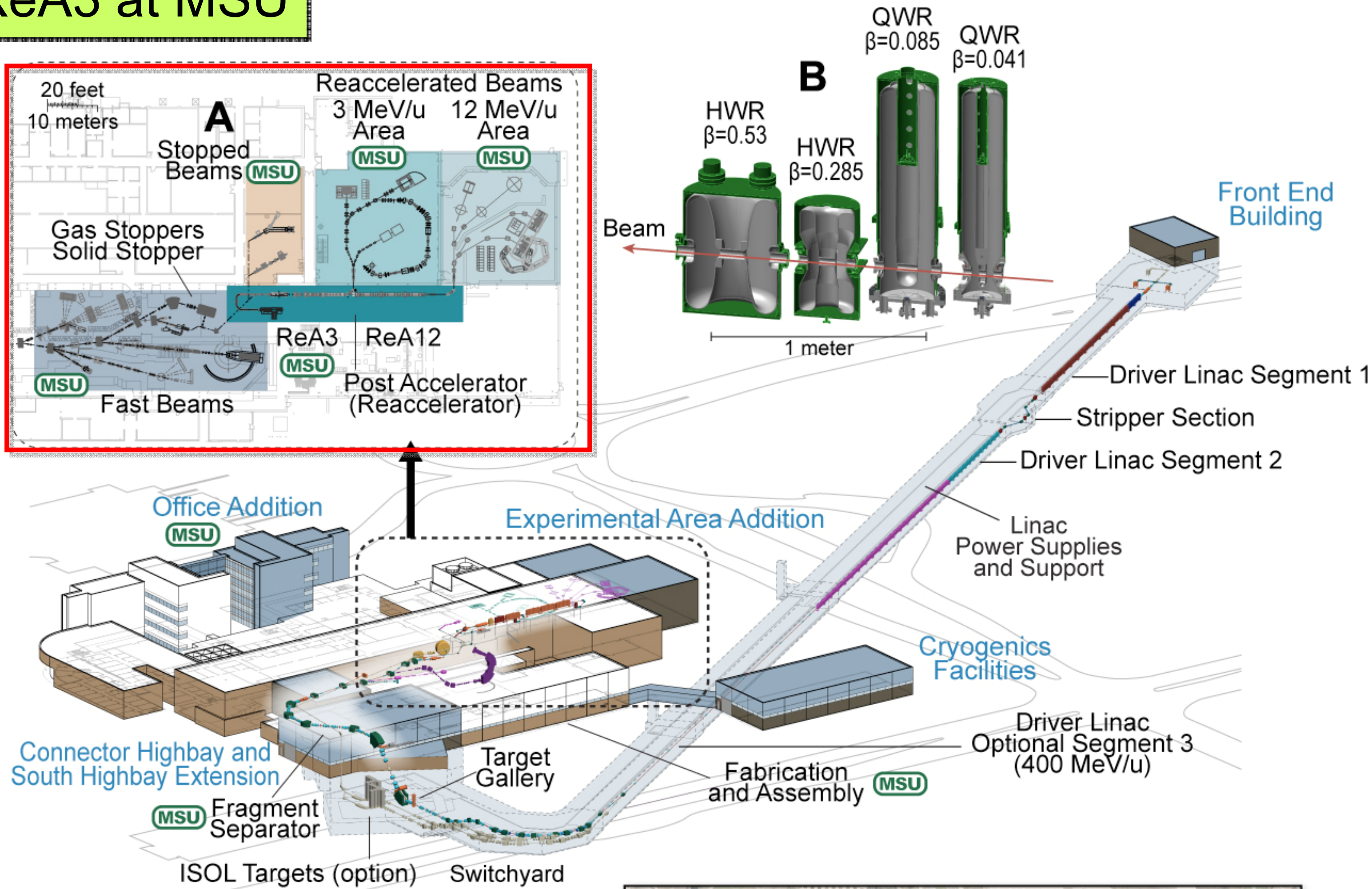
Mass measured for the 3 drip-line nuclei ^{63}Ge, ^{65}As, ^{67}Se with the life-time of 100ms

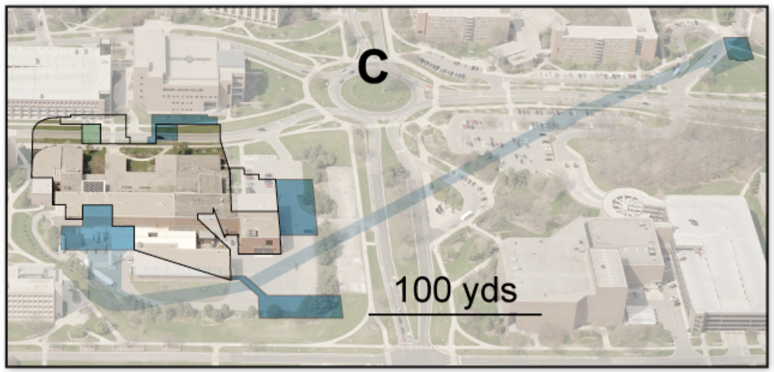


Y. Liu, HIAT09

4) FRIB & ReA3 at MSU

(FRIB= Facility for Rare Isotope Beams)





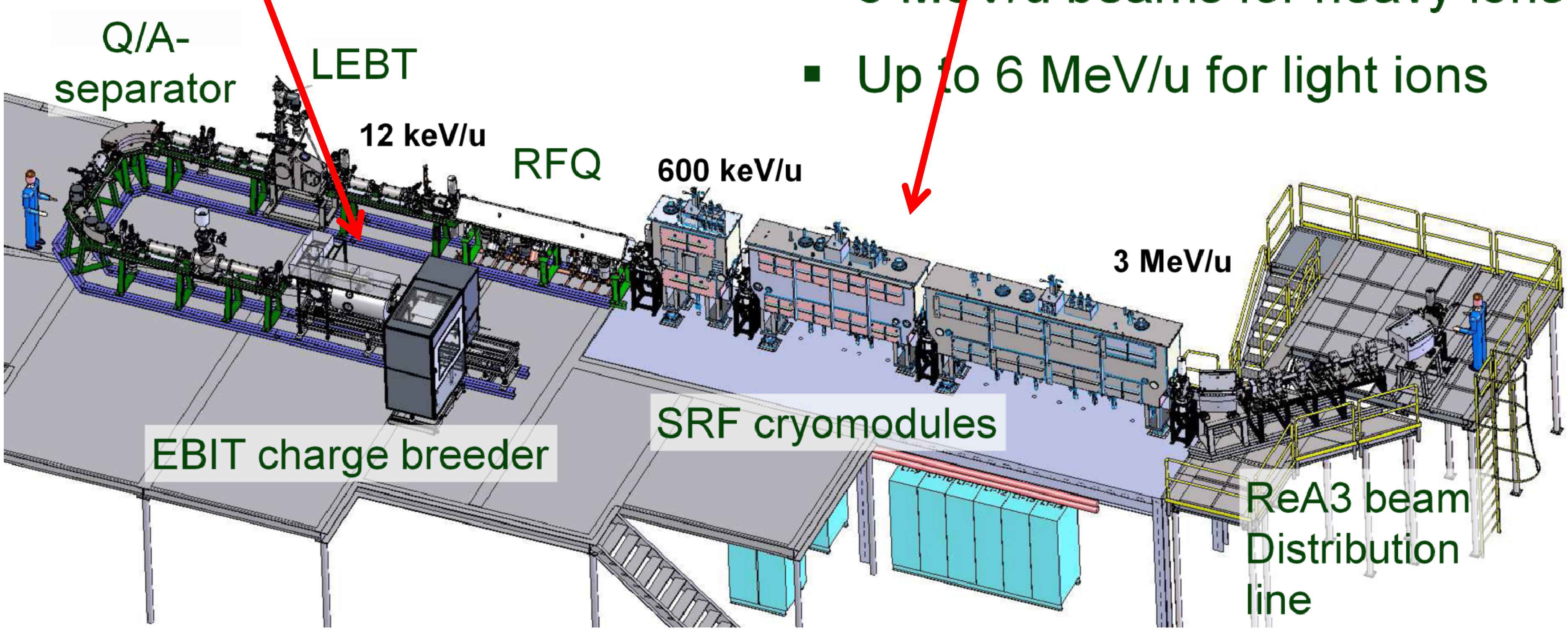
- 200 MeV/u – 400 kW U beam provided with SRF driver linac
- Three stopping stations
- SRF reaccelerator up to 12 MeV/u

ReA3 at NSCL

Ion sources development: charge state breeder

SRF development: ReA3 linac modules

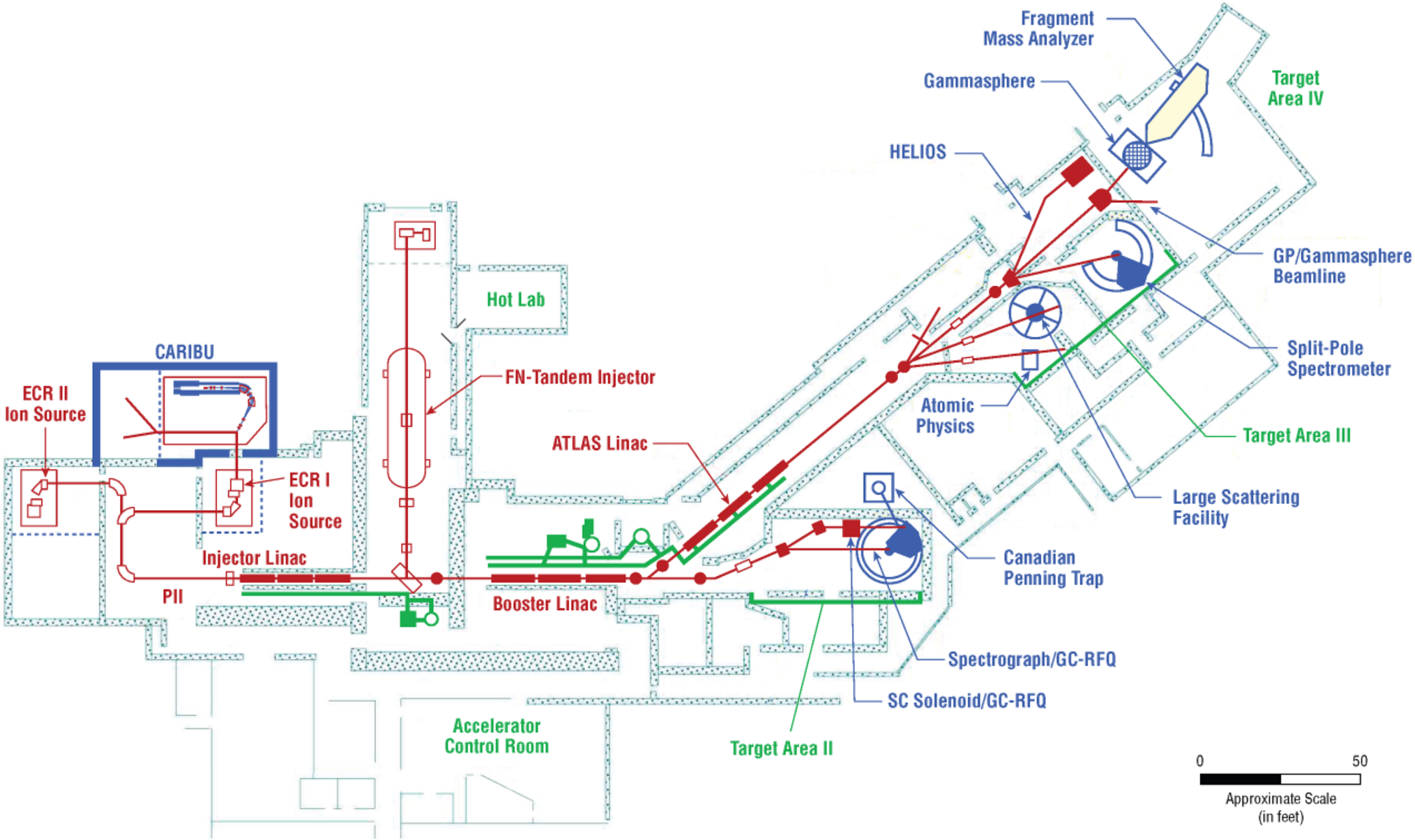
- 3 MeV/u beams for heavy ions
- Up to 6 MeV/u for light ions



Courtesy: O. Kester

5) CARIBU at Argonne ATLAS Facility

(CARIBU= CAlifornium Rare Isotope Breeder Upgrade)



5) CARIBU at Argonne ATLAS Facility

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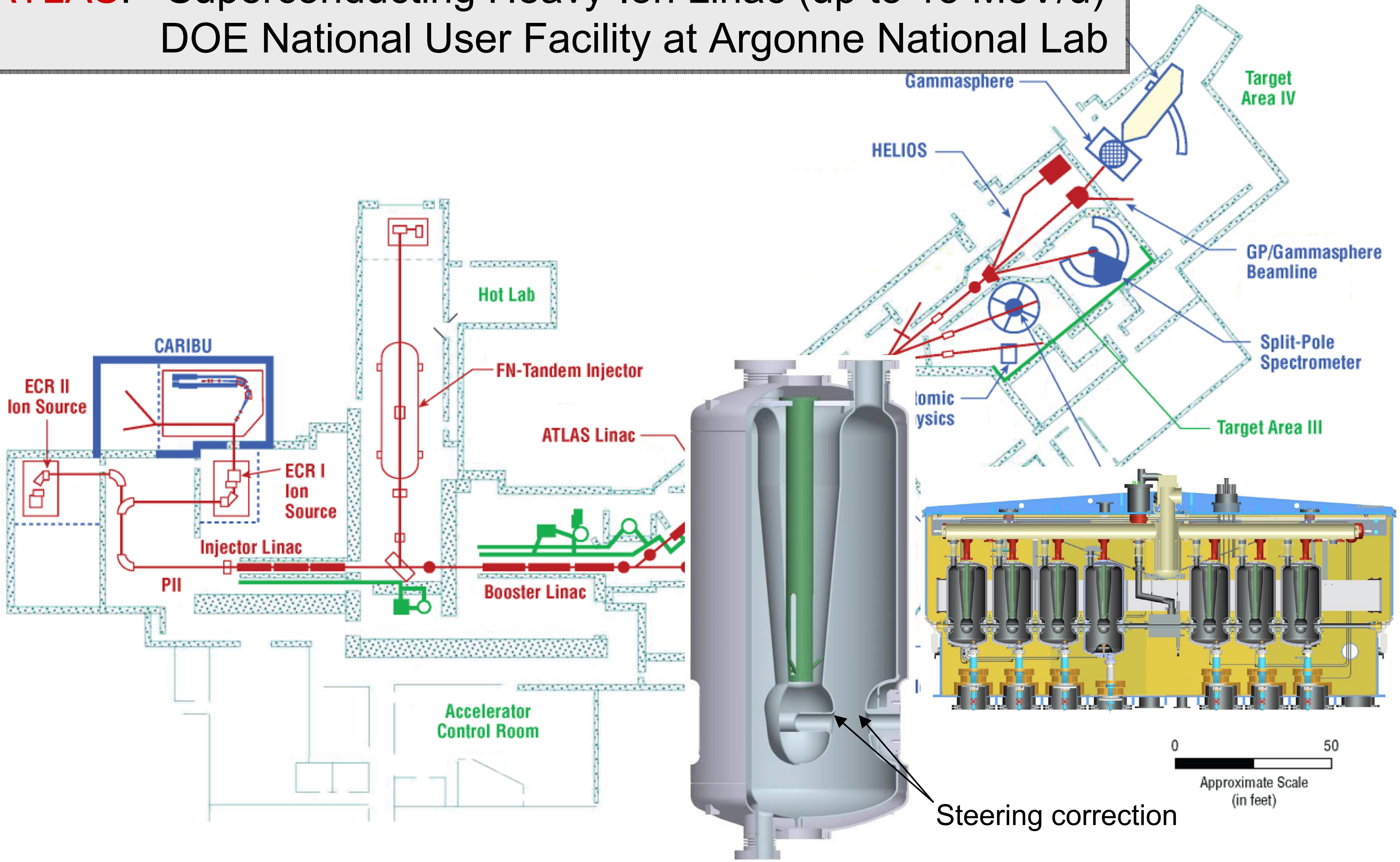
ATLAS: Superconducting Heavy-Ion Linac (up to 15 MeV/u)
DOE National User Facility at Argonne National Lab



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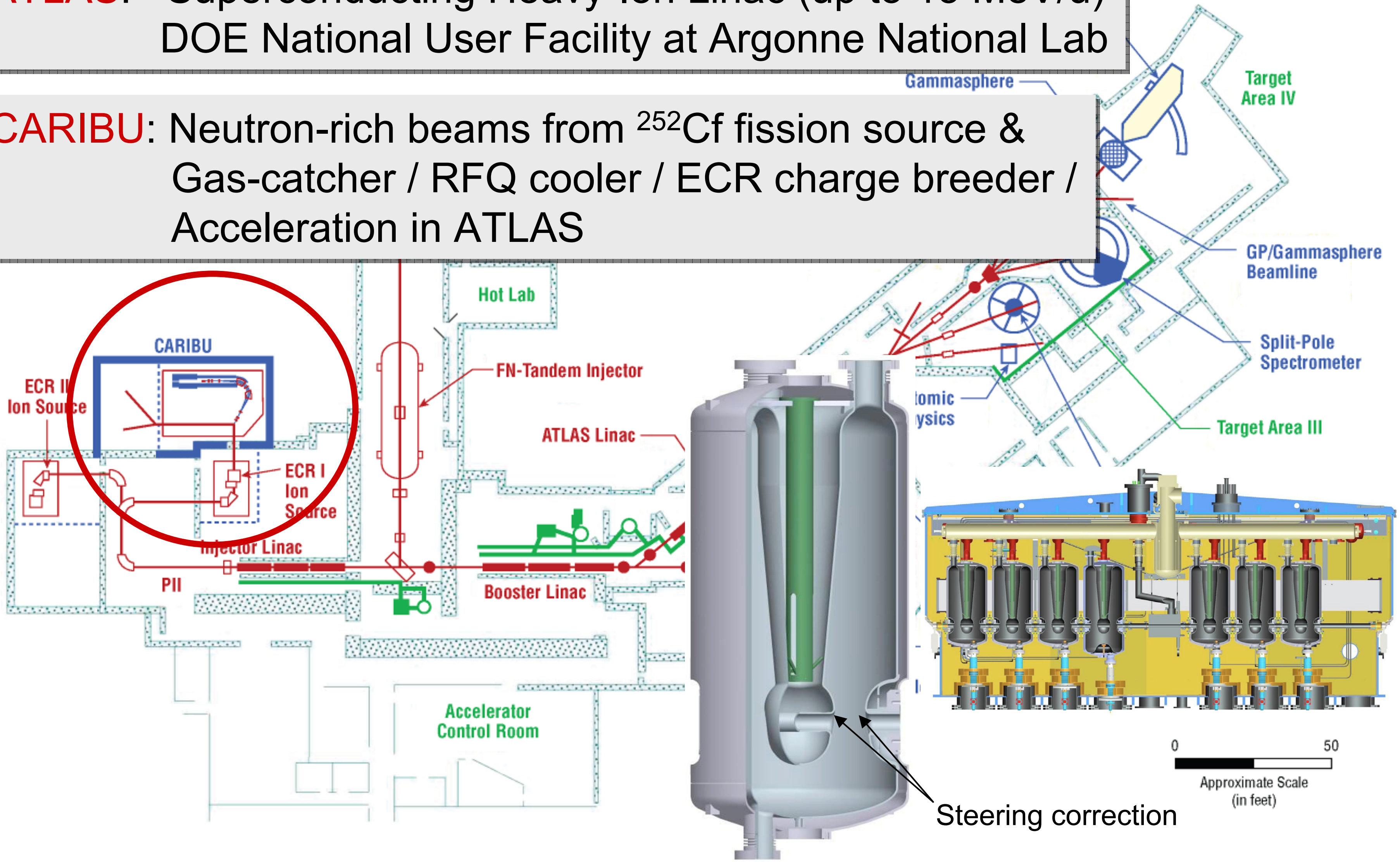
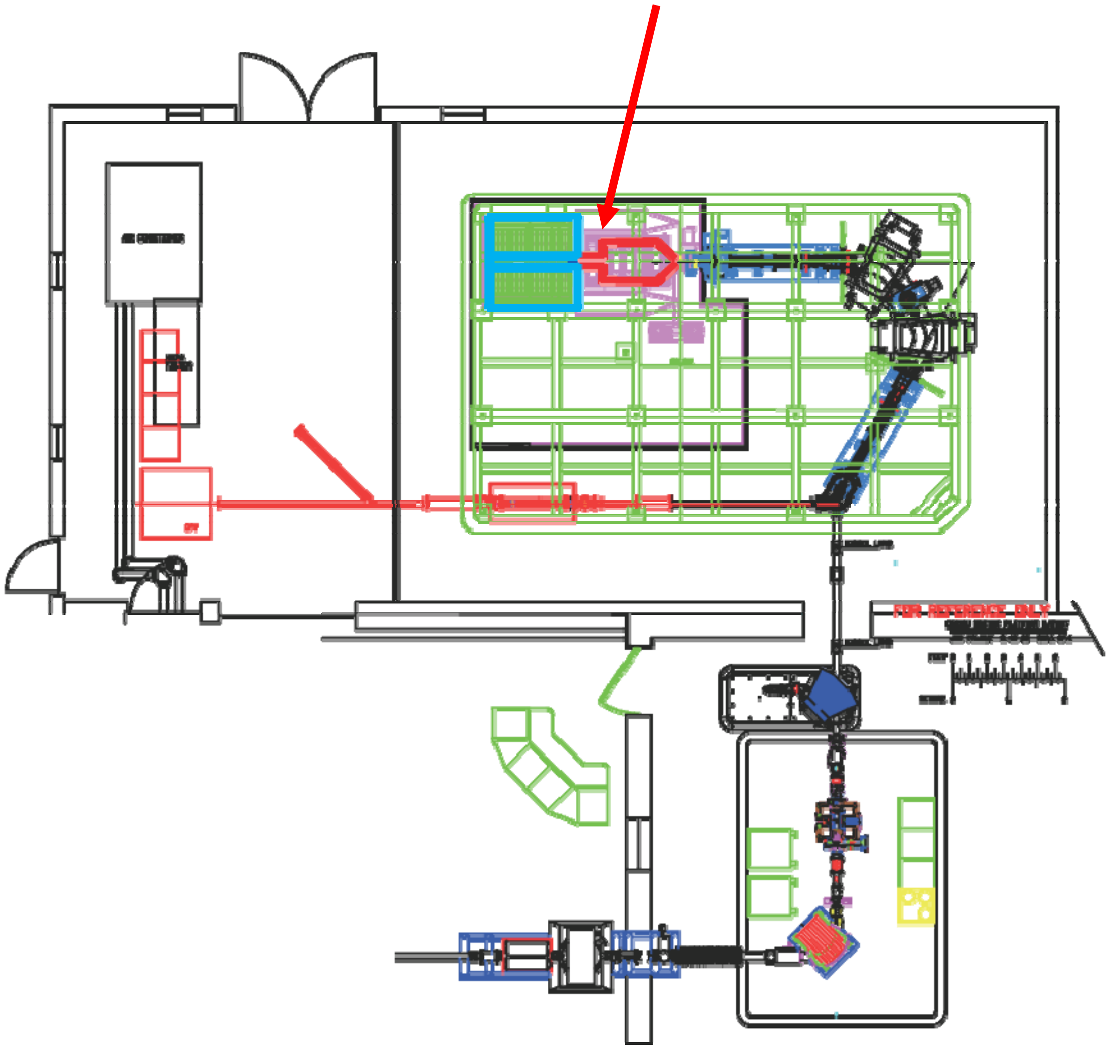
ATLAS: Superconducting Heavy-Ion Linac (up to 15 MeV/u)
DOE National User Facility at Argonne National Lab

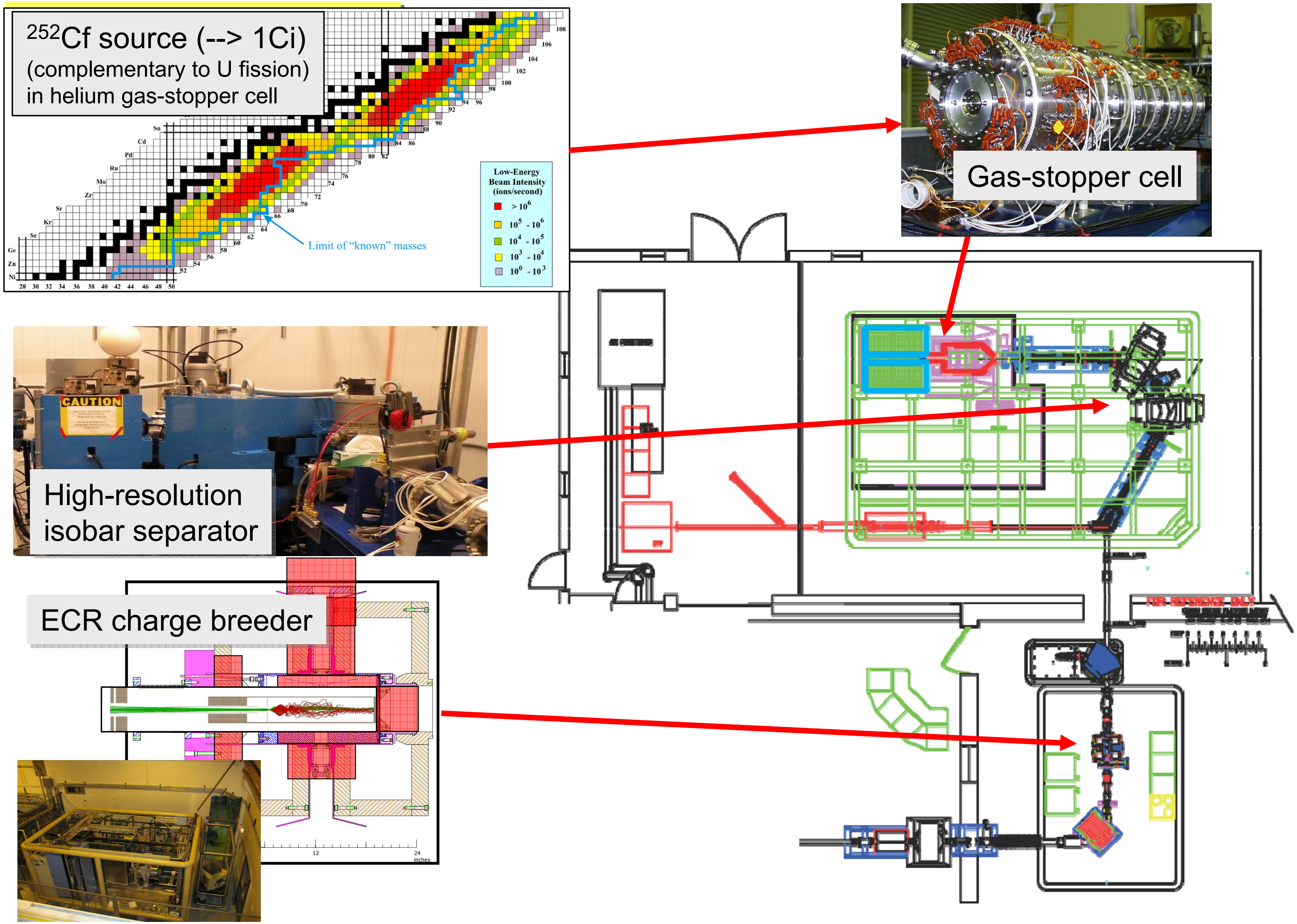
CARIBU: Neutron-rich beams from ^{252}Cf fission source &
Gas-catcher / RFQ cooler / ECR charge breeder /
Acceleration in ATLAS



CARIBU at ATLAS



Courtesy: W. Henning



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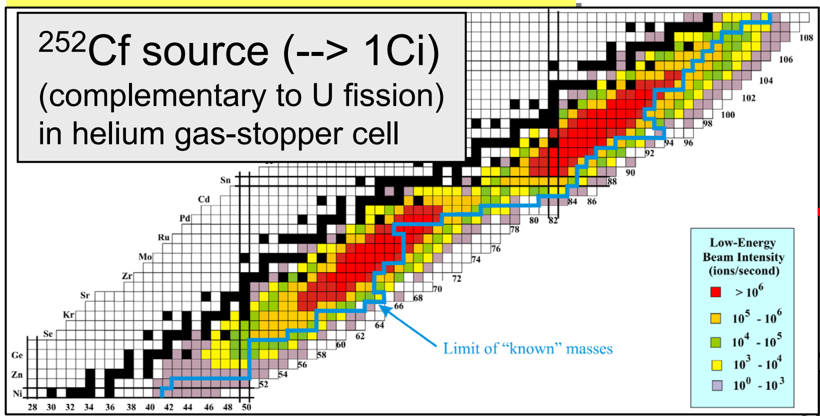
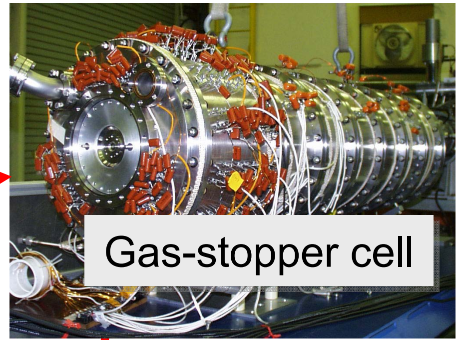
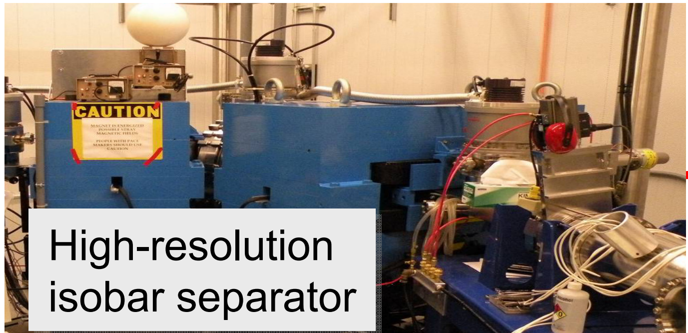


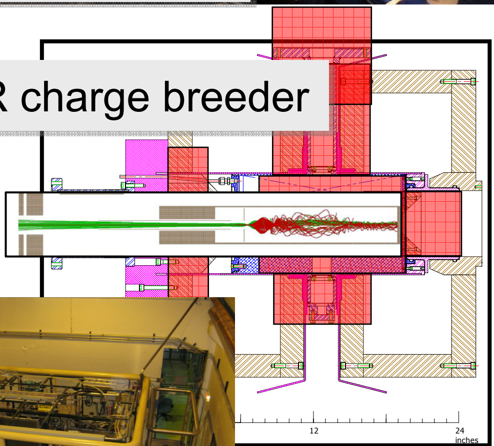
^{252}Cf source (--> 1Ci)
(complementary to U fission)
in helium gas-stopper cell



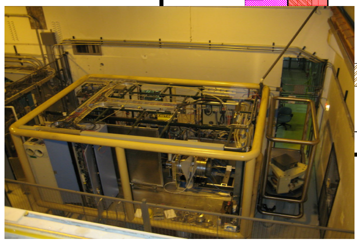
Gas-stopper cell

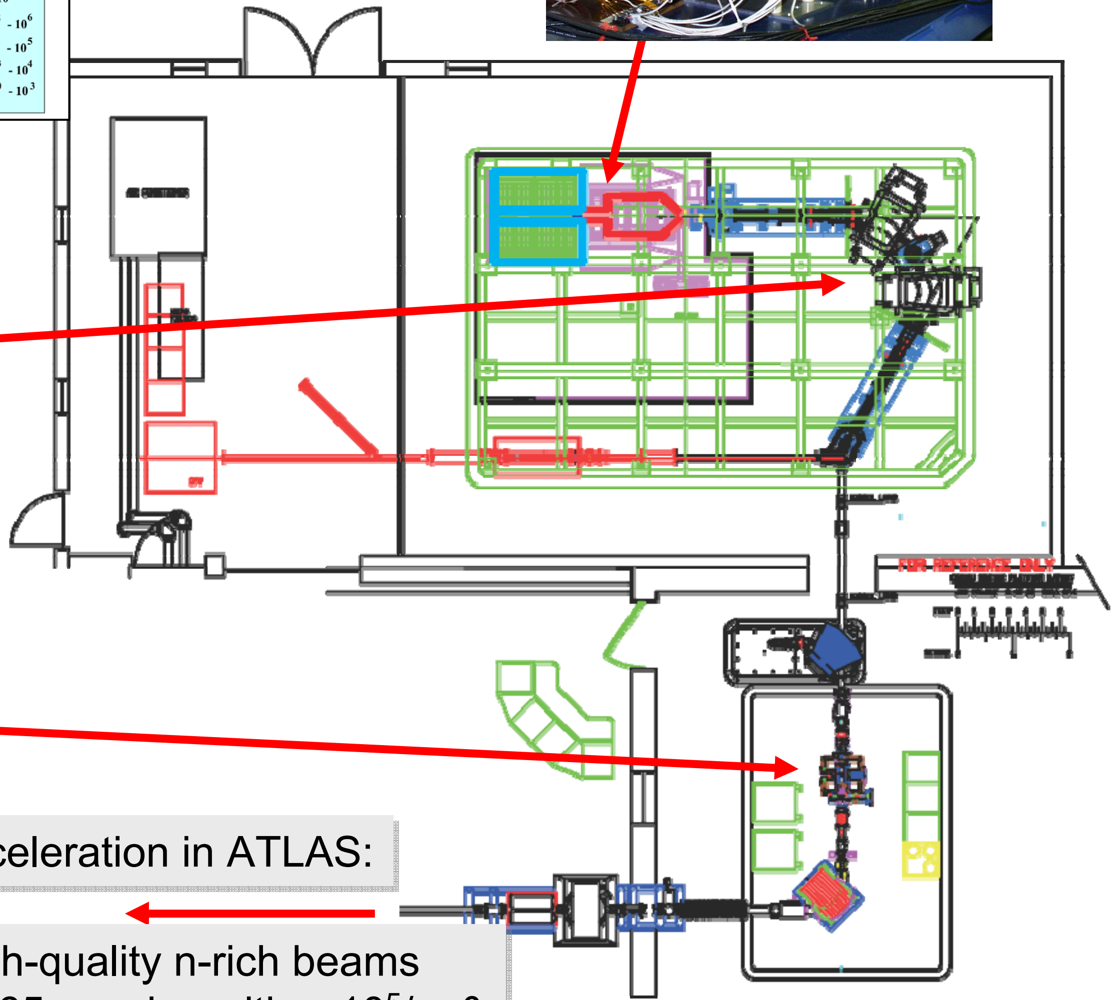


High-resolution isobar separator



ECR charge breeder

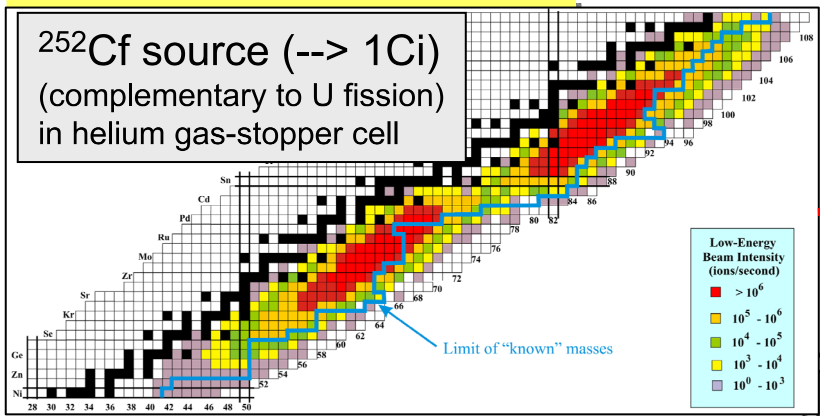




Acceleration in ATLAS:

High-quality n-rich beams
~ 65 species with > 10^5/s &
> 150 species with > 10^4/s

Courtesy: W. Henning



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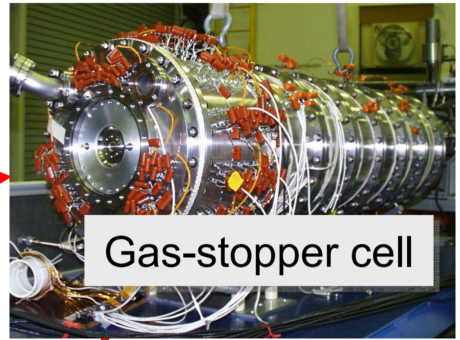
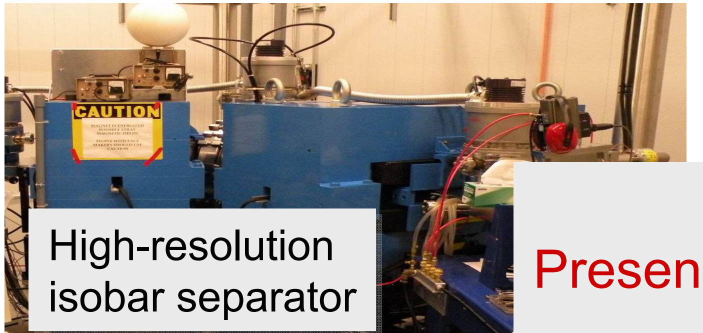


Gas-stopper cell



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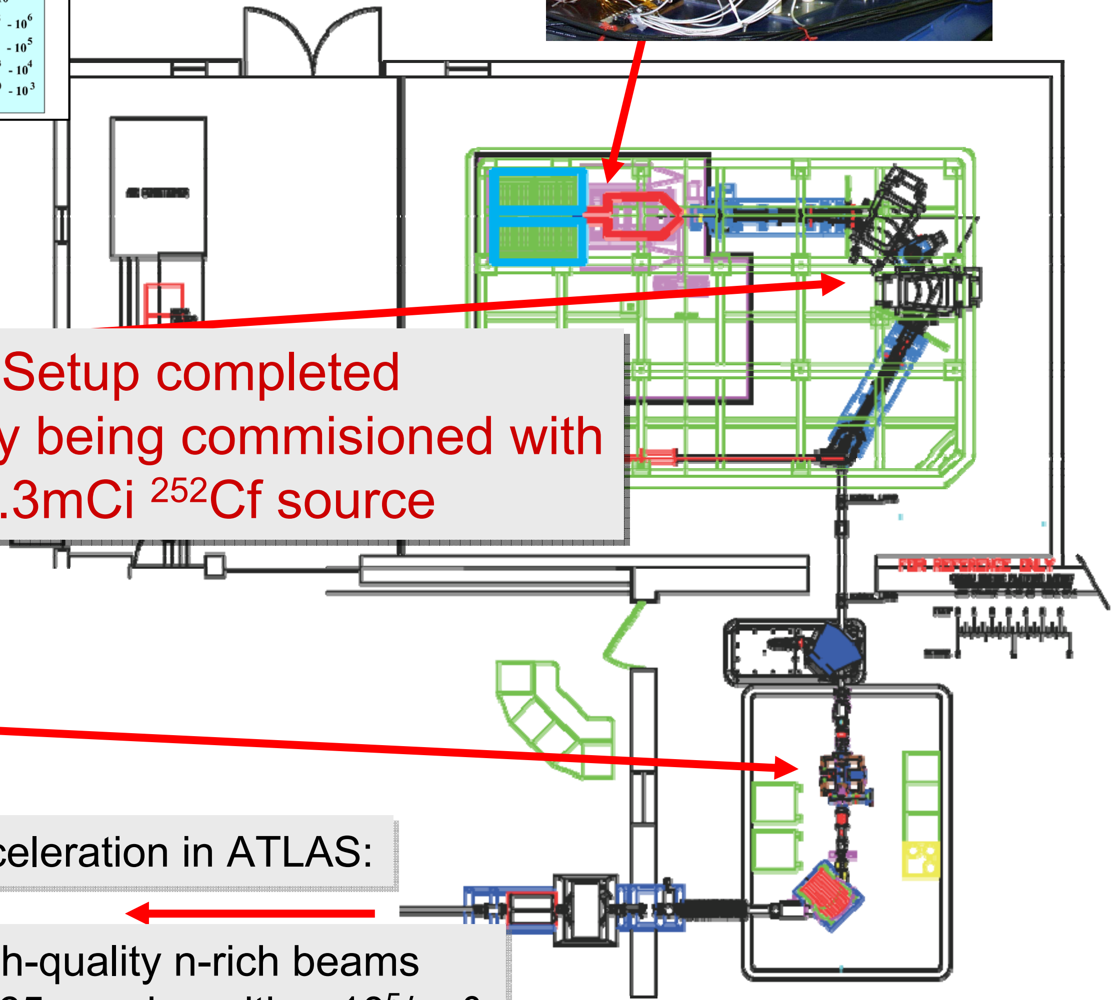
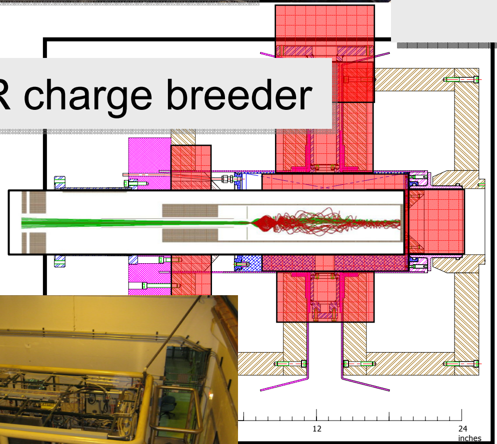
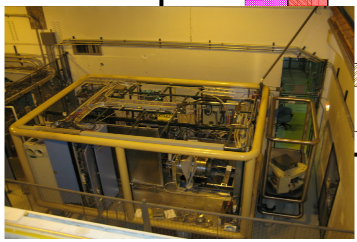


Setup completed
Presently being commisioned with
2.3mCi ^{252}Cf source



ECR charge breeder



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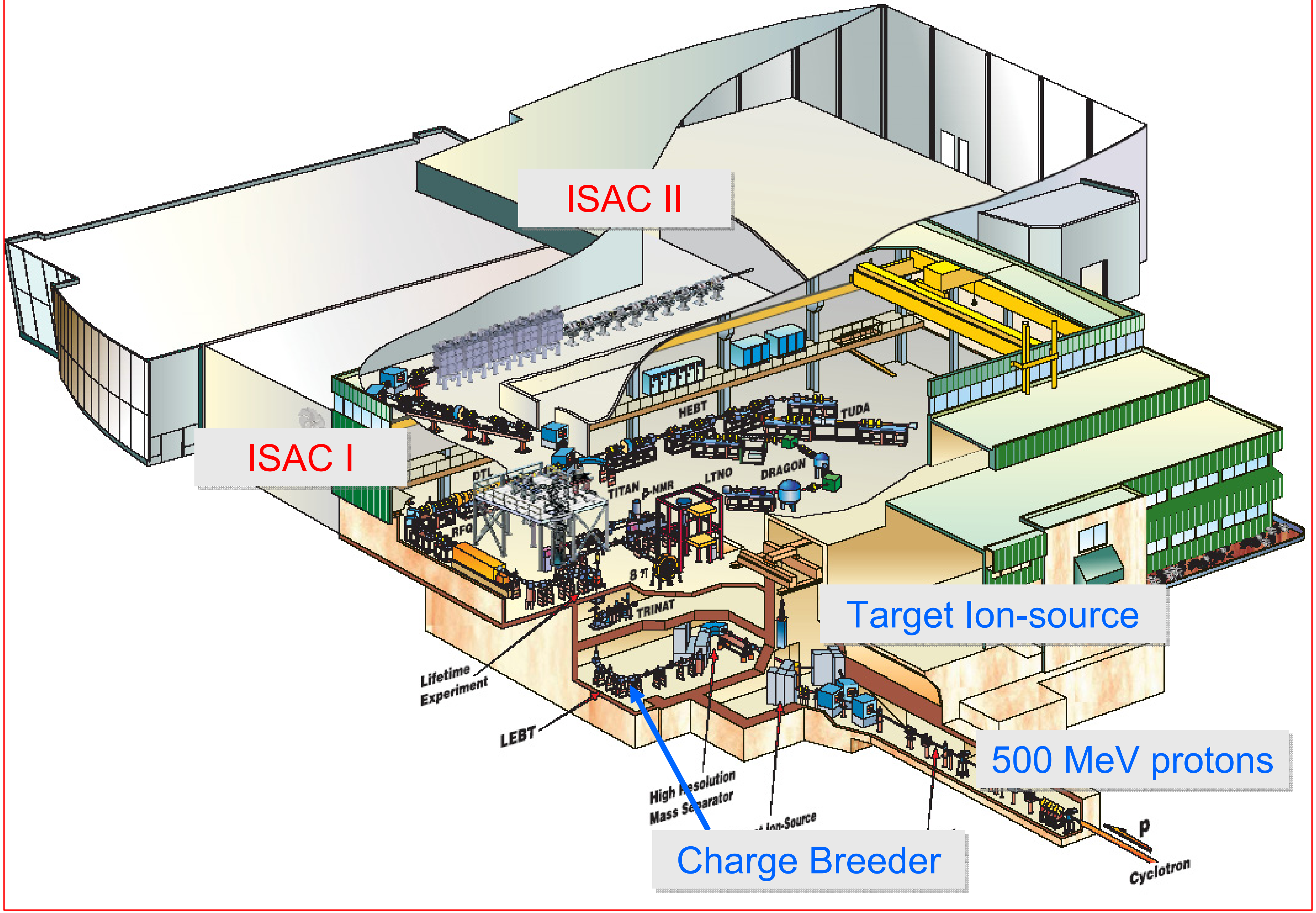
6) TRIUMF ISAC

(ISAC = Isotope Separator and ACcelerator)



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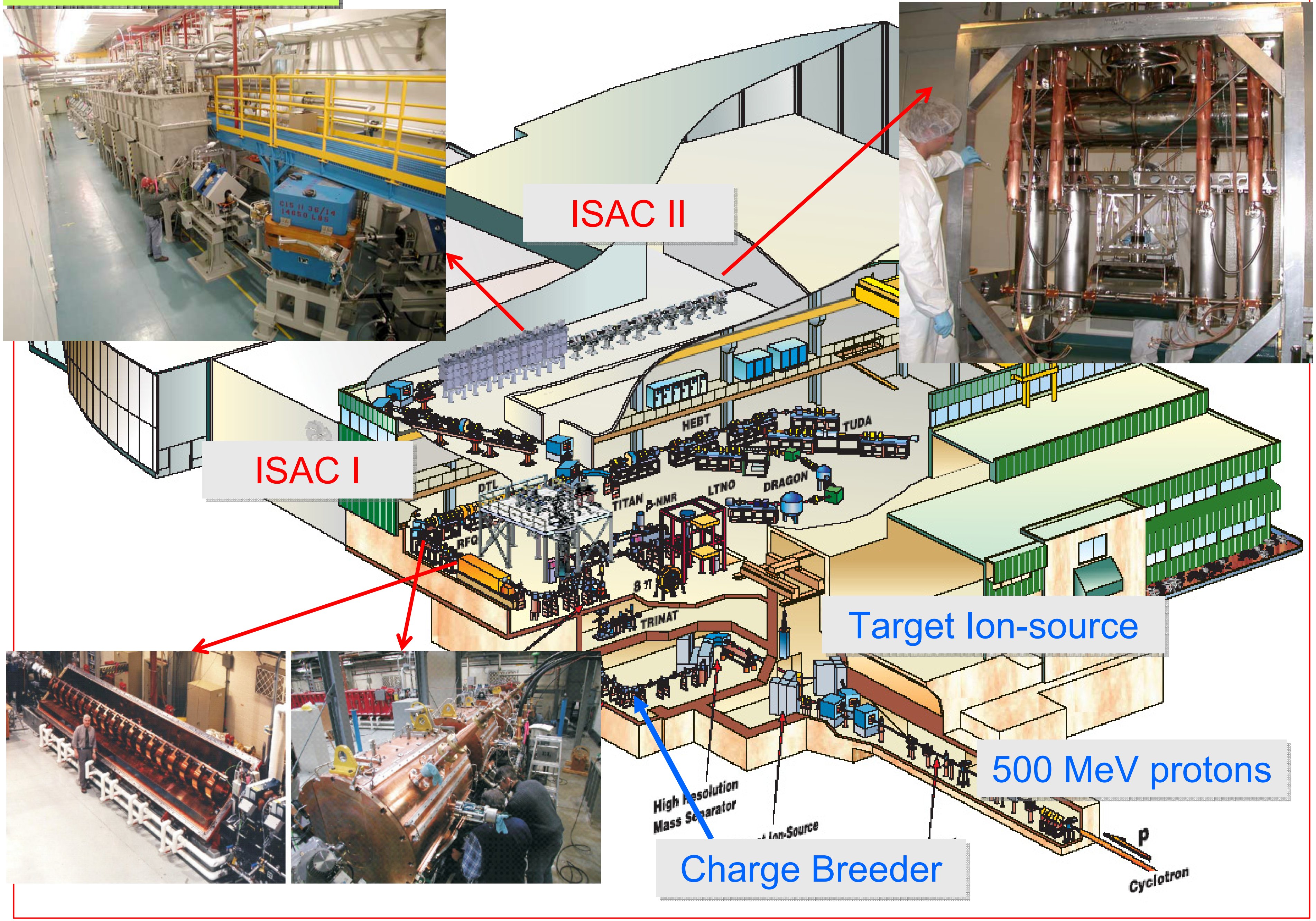

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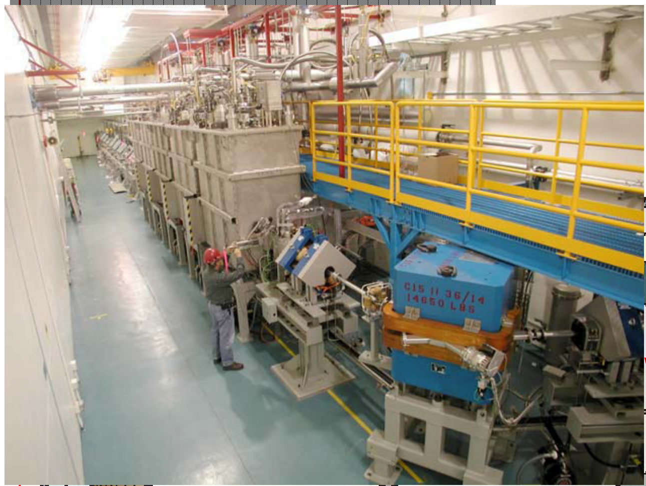
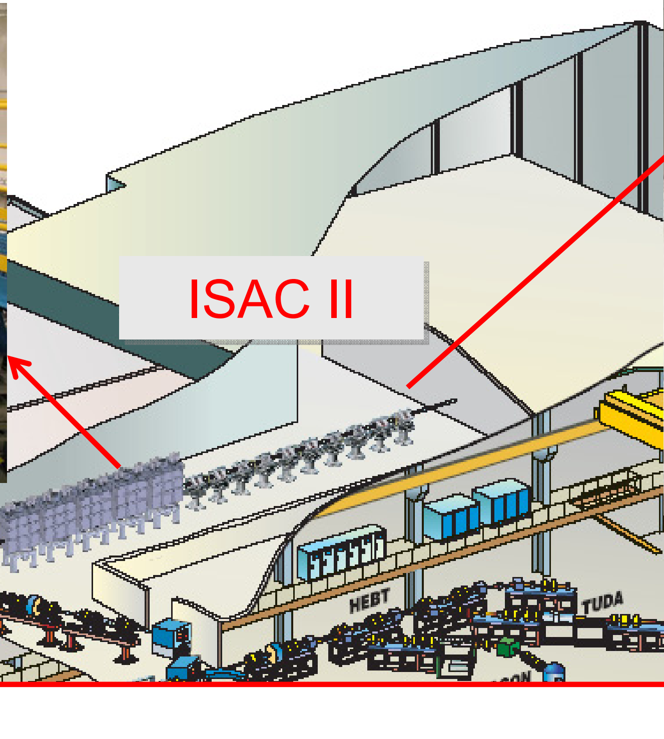
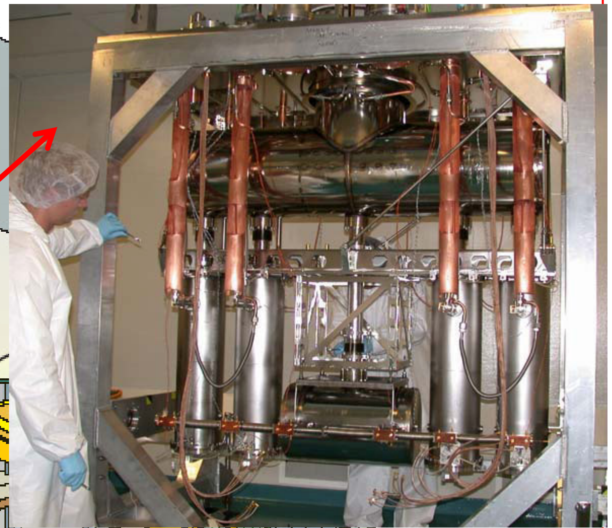
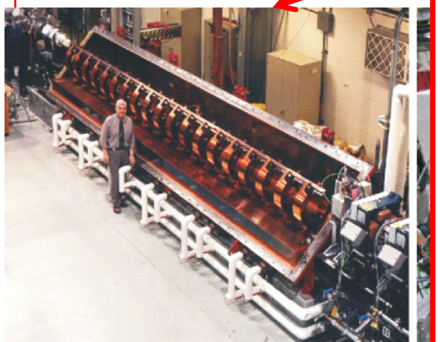
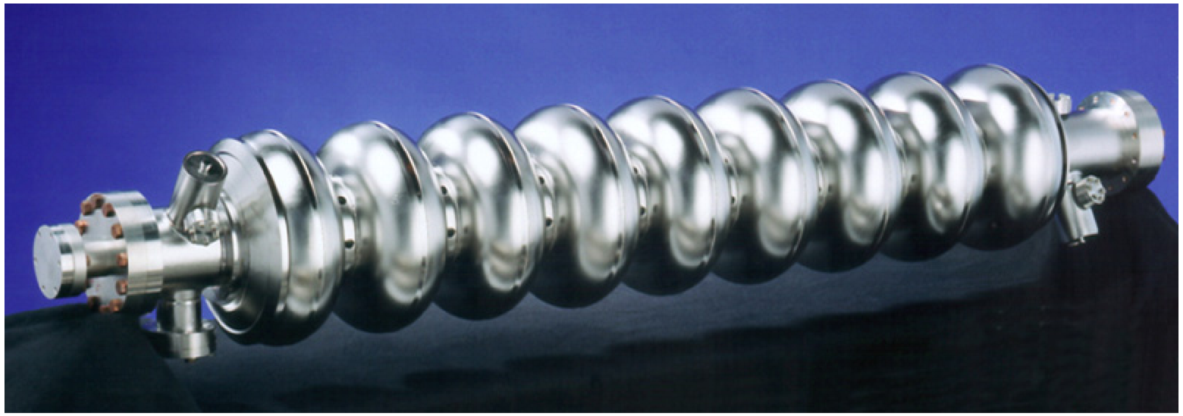








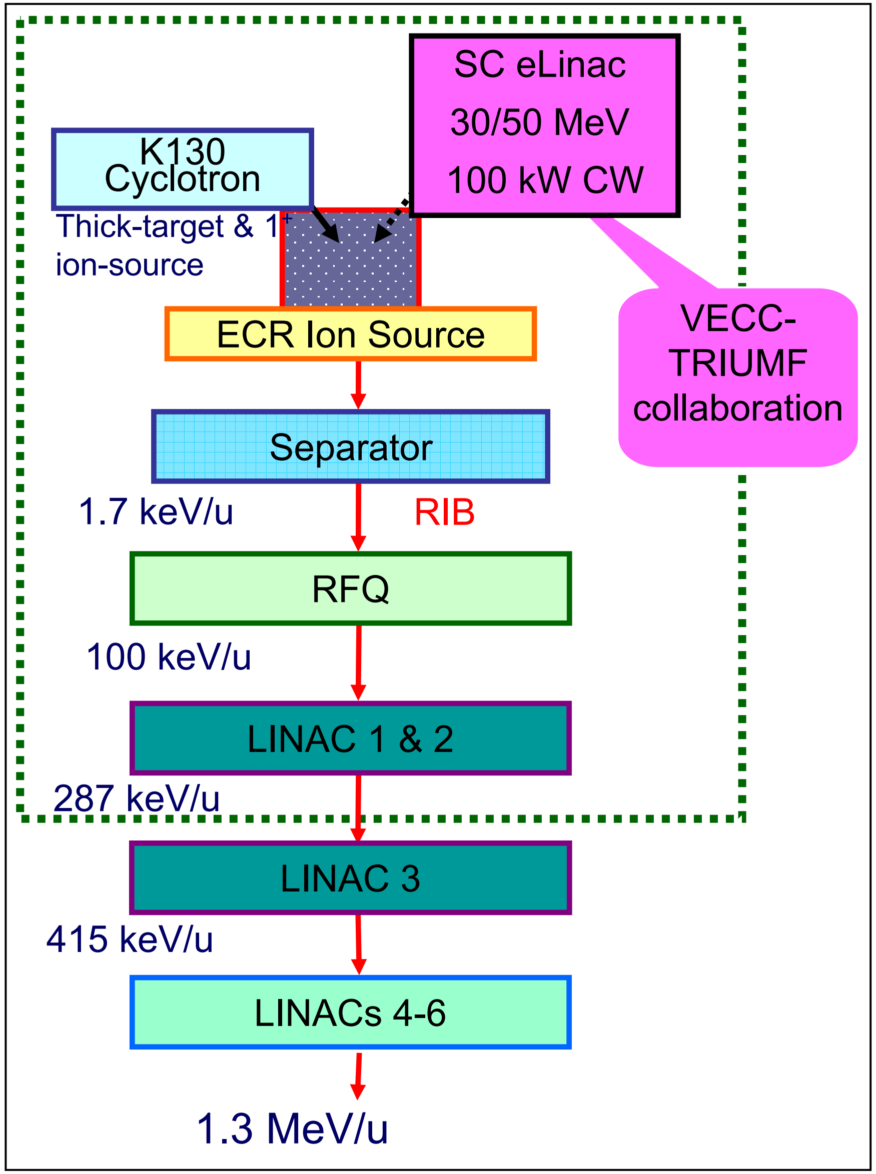


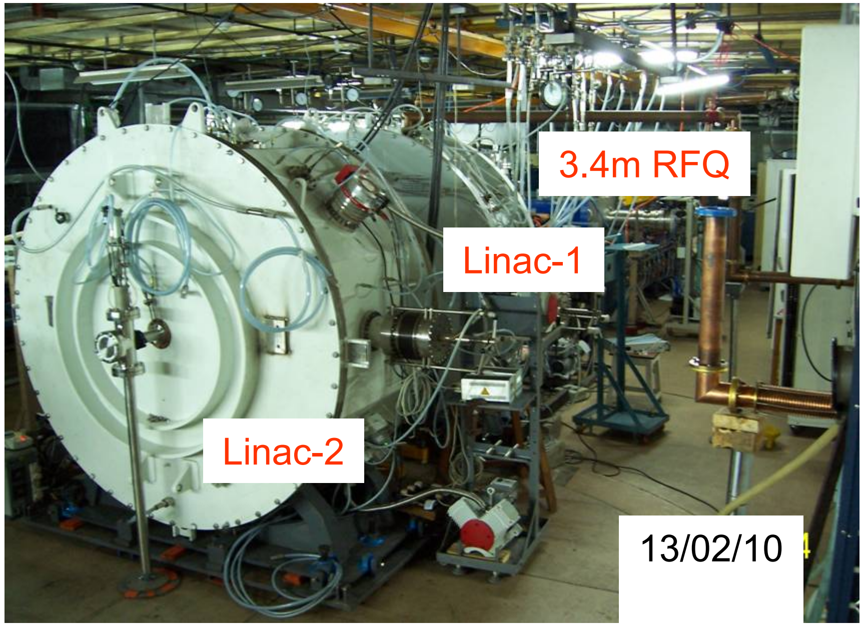
e-driver (1.3 GHz/50 MeV/10 mA) for 10^{14} f/s

7) VECC RIB project

(VECC = Variable Energy Cyclotron Center)

Schematic Layout

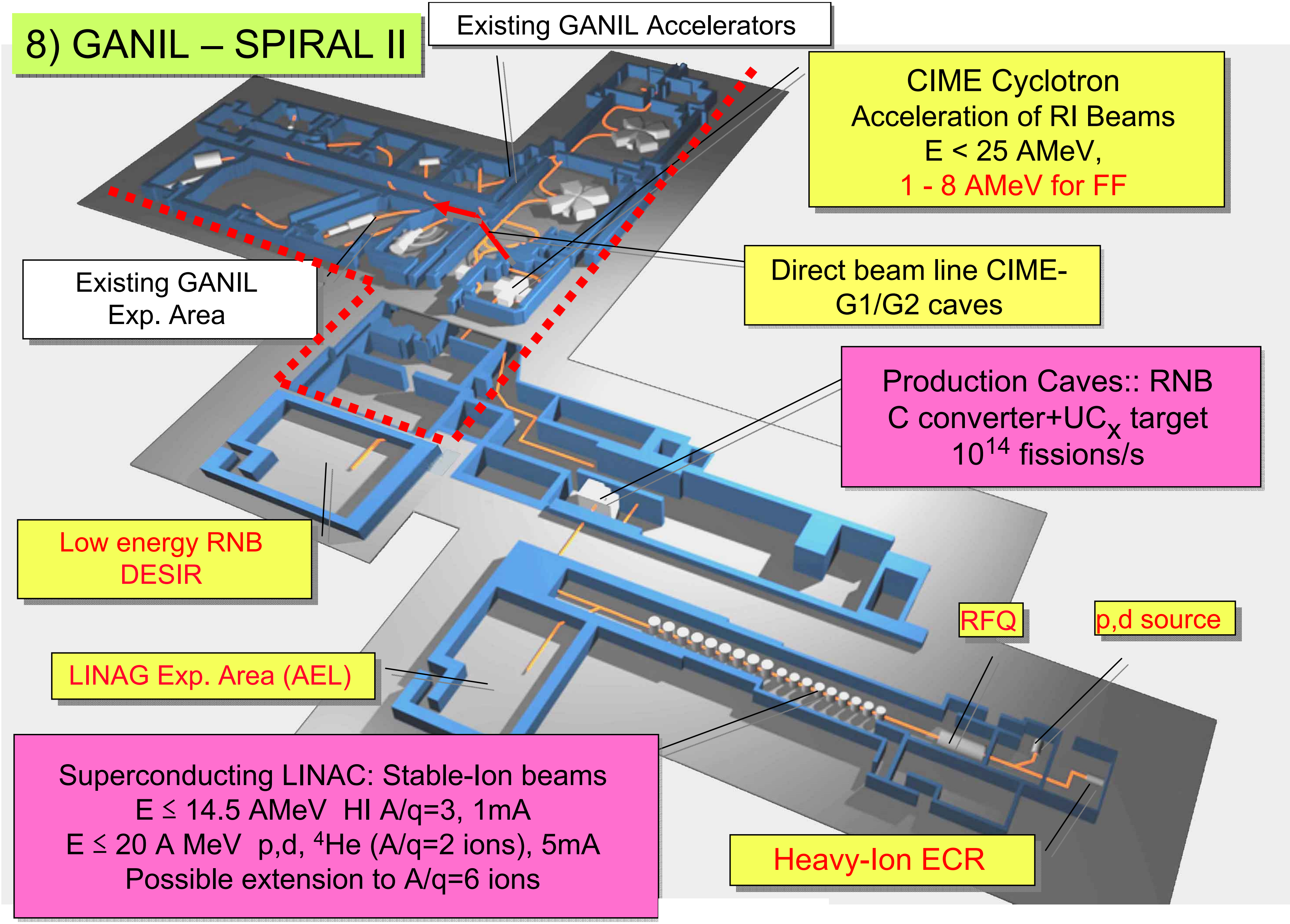




- RFQ (3.4 m, 100 keV/u) commissioned in June 2008.
- Linac-1 & Linac-2 commissioned, Linac-3 under installation. Linac 4-6 designed & being ordered.
- SC e-Linac development started. 1st phase : 10 MeV Injector Cryomodule being developed in collaboration with TRIUMF.

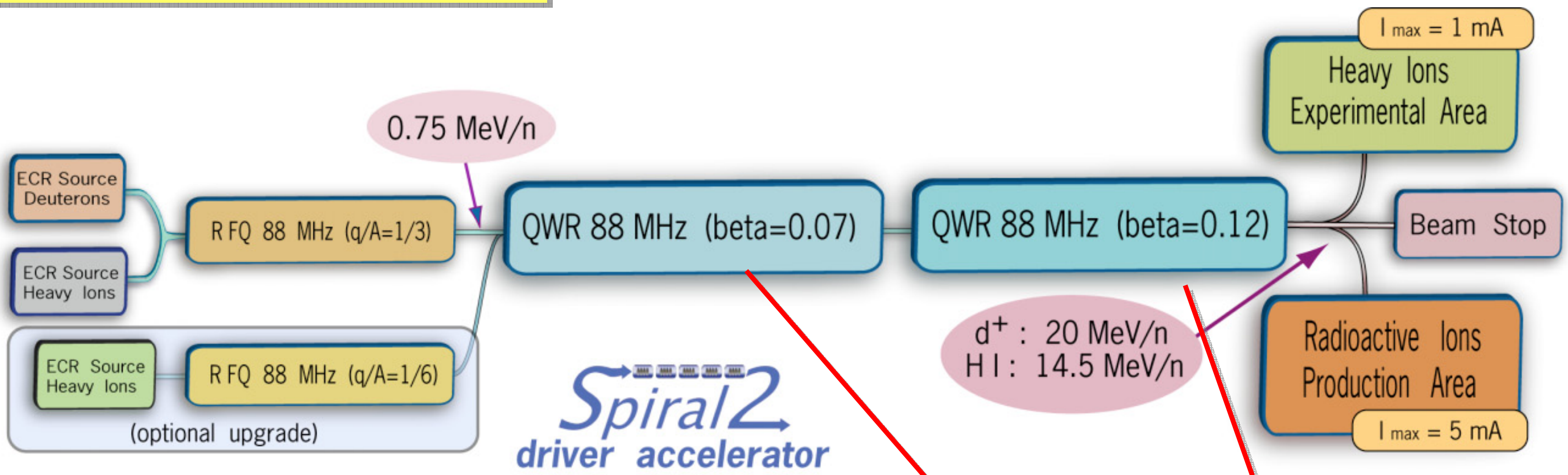
Courtesy: A. Chakrabarti

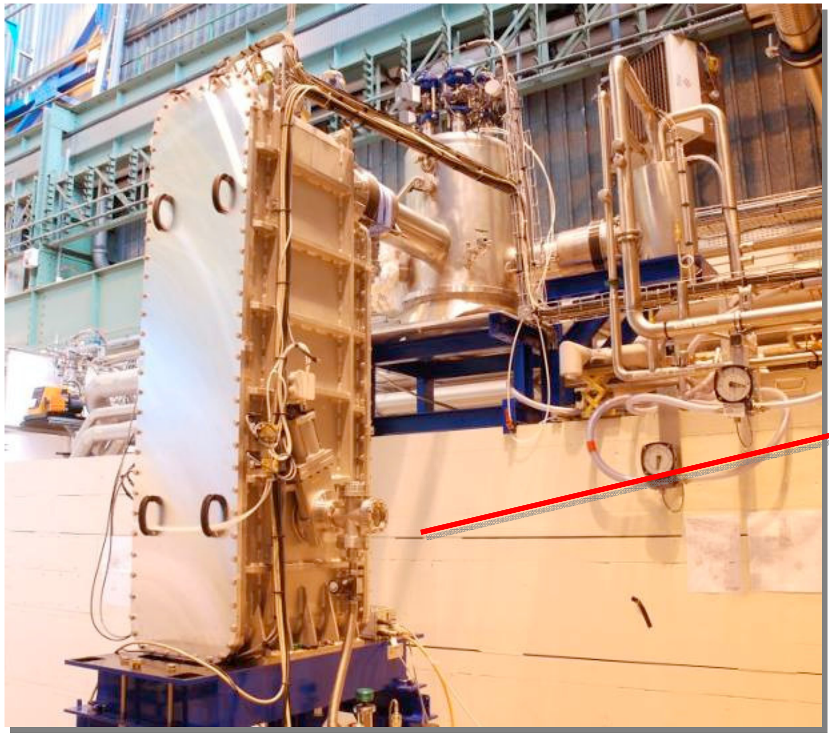
8) GANIL – SPIRAL II



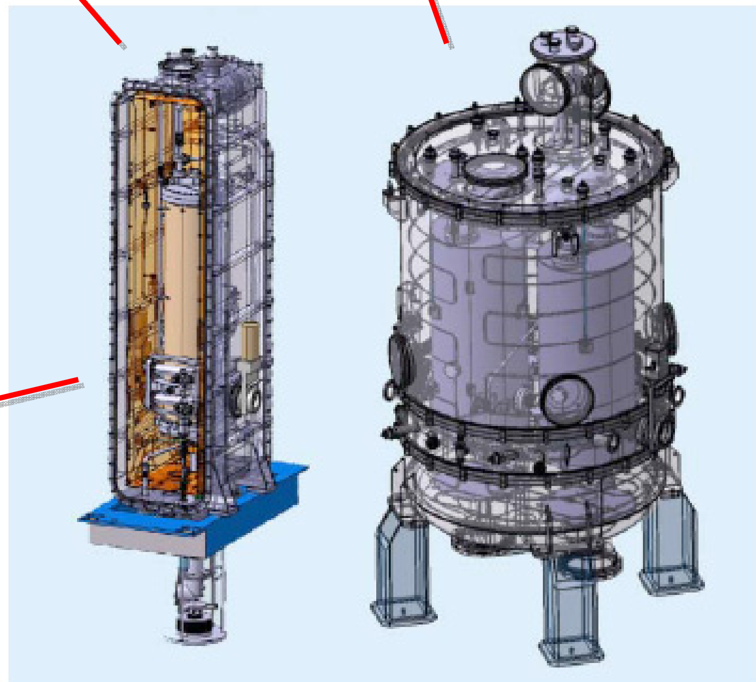
(SPIRAL= Systeme de Production d'Ions Radioactifs Acceleres en Ligne)

Driver linac of SPIRAL II



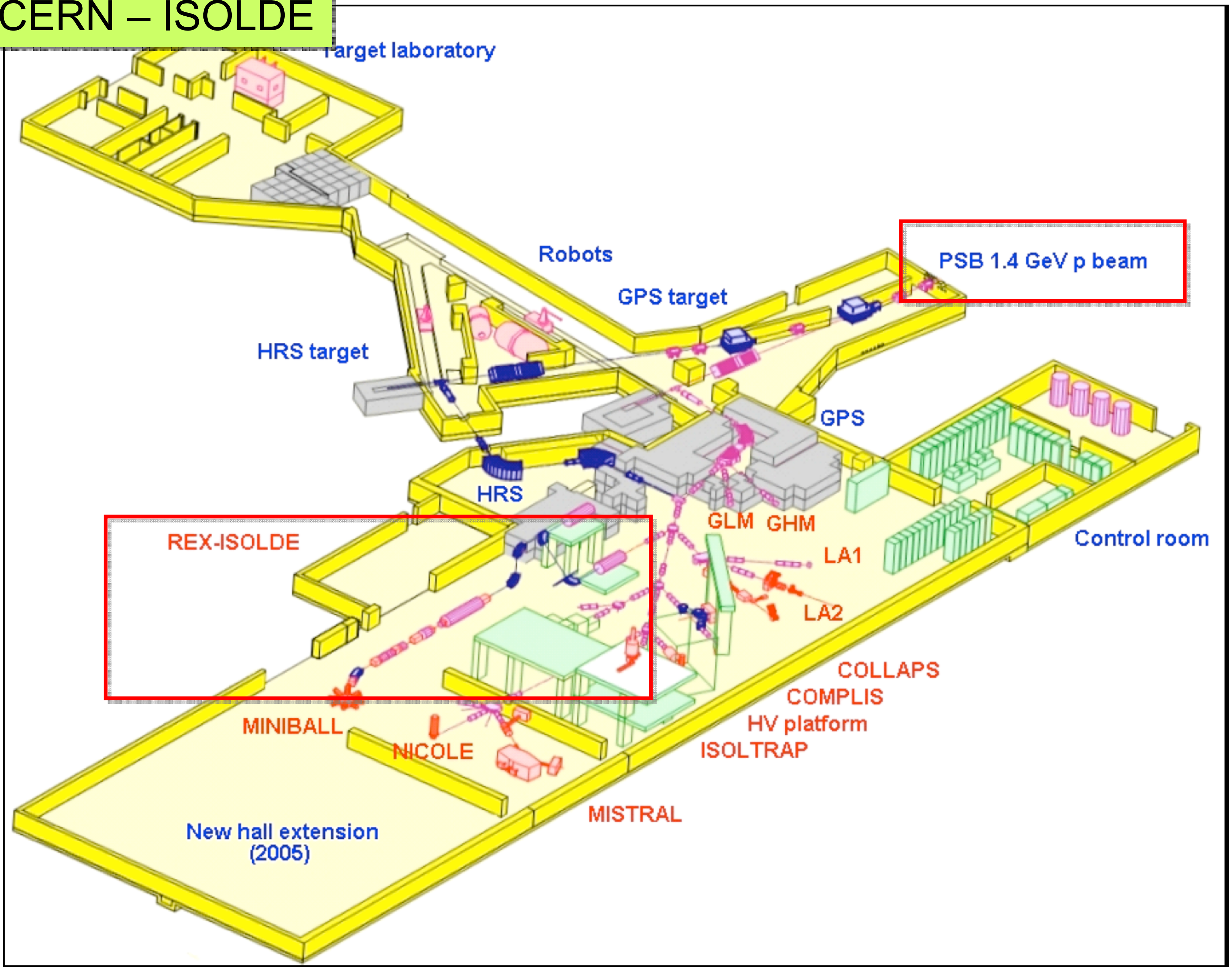


P. Bernaudin et al., SRF2009



T. Junquera et al., LINAC2006

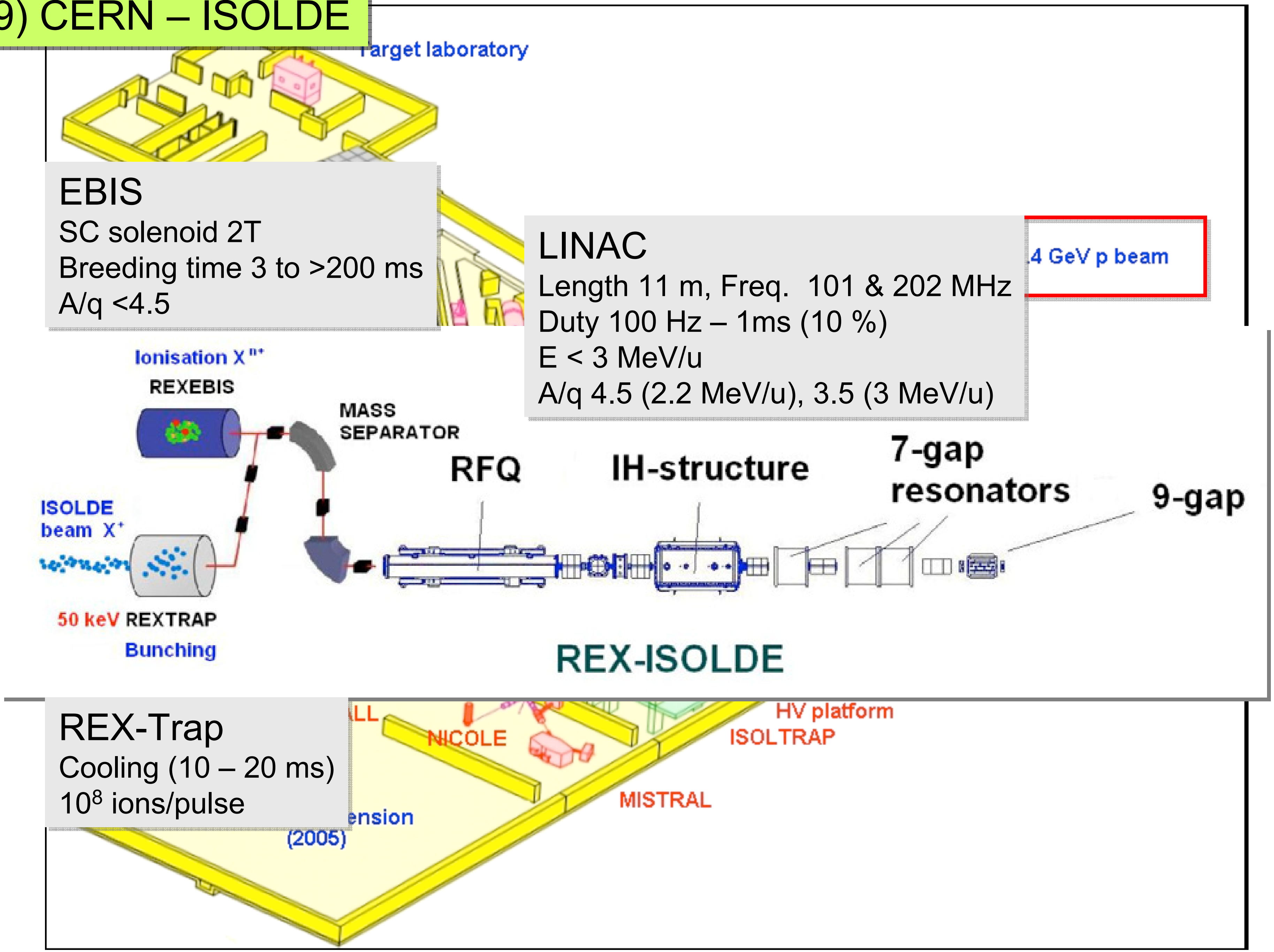
9) CERN – ISOLDE



9) CERN – ISOLDE

EBIS
SC solenoid 2T
Breeding time 3 to >200 ms
A/q <4.5

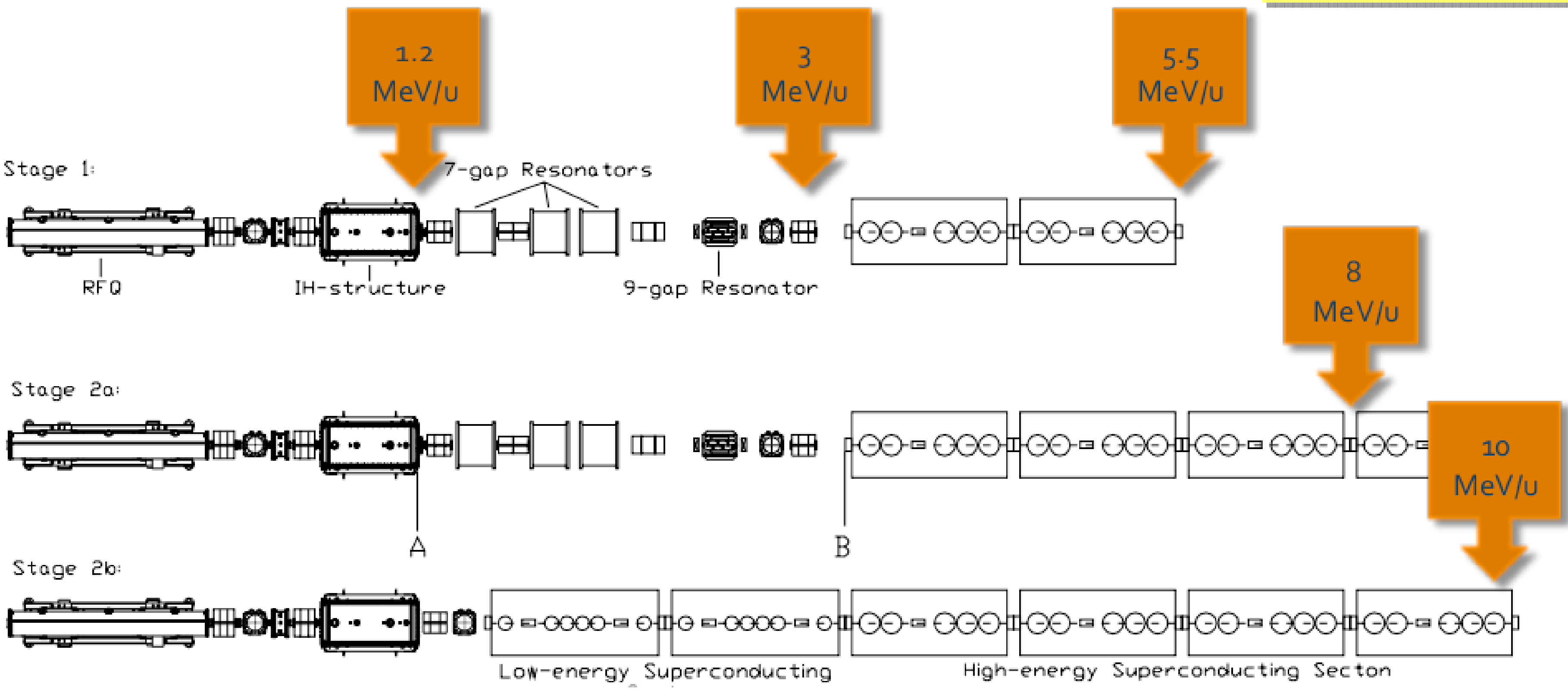
LINAC
Length 11 m, Freq. 101 & 202 MHz
Duty 100 Hz – 1ms (10 %)
E < 3 MeV/u
A/q 4.5 (2.2 MeV/u), 3.5 (3 MeV/u)



REX-Trap
Cooling (10 – 20 ms)
10^8 ions/pulse

HIE-ISOLDE

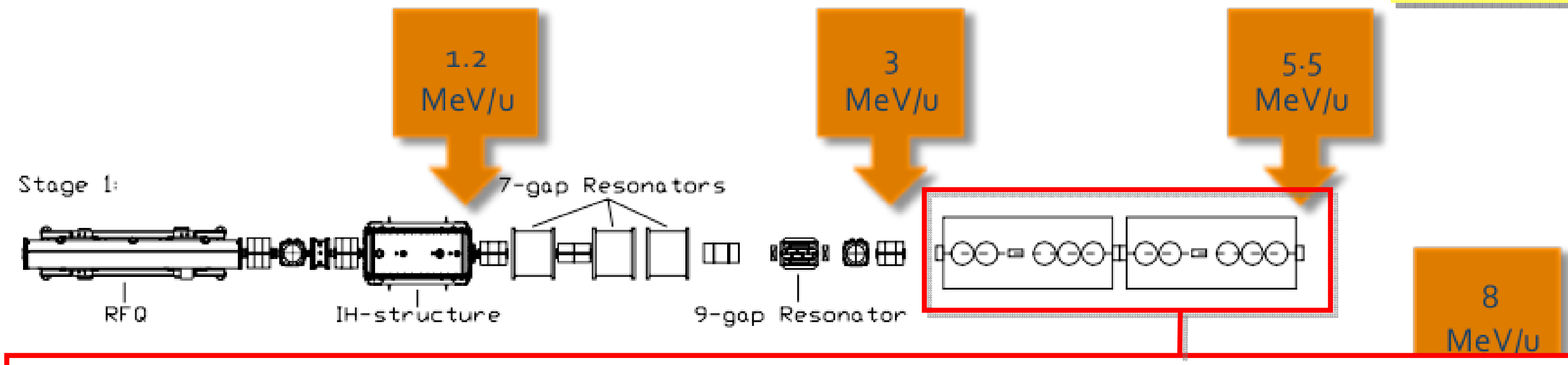
3 stages installation

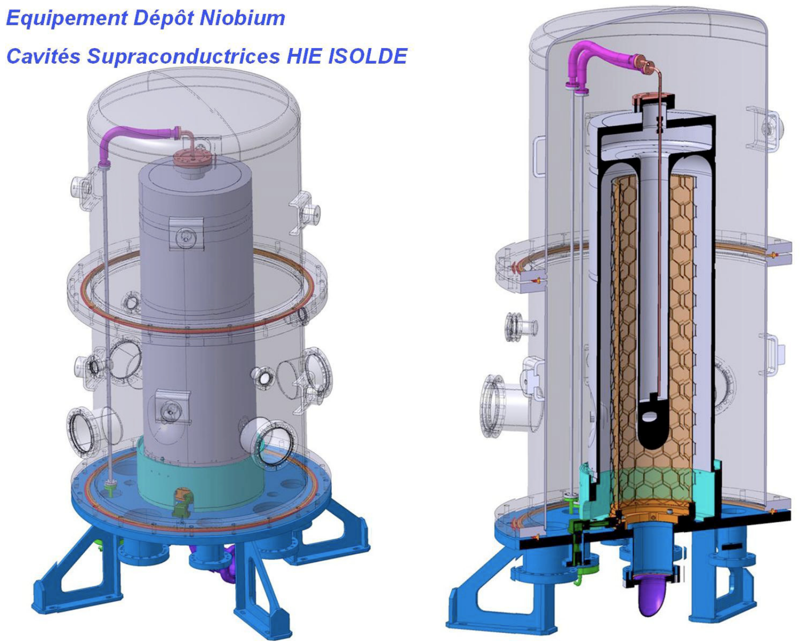


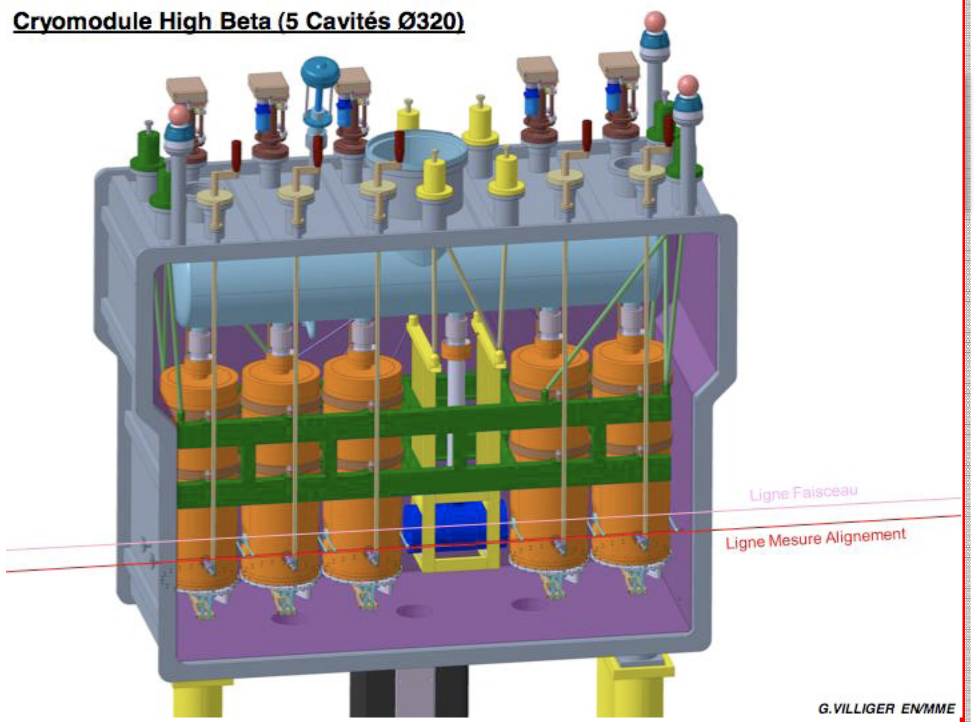
M. Pasini et al., HIAT2009

3 stages installation

HIE-ISOLDE







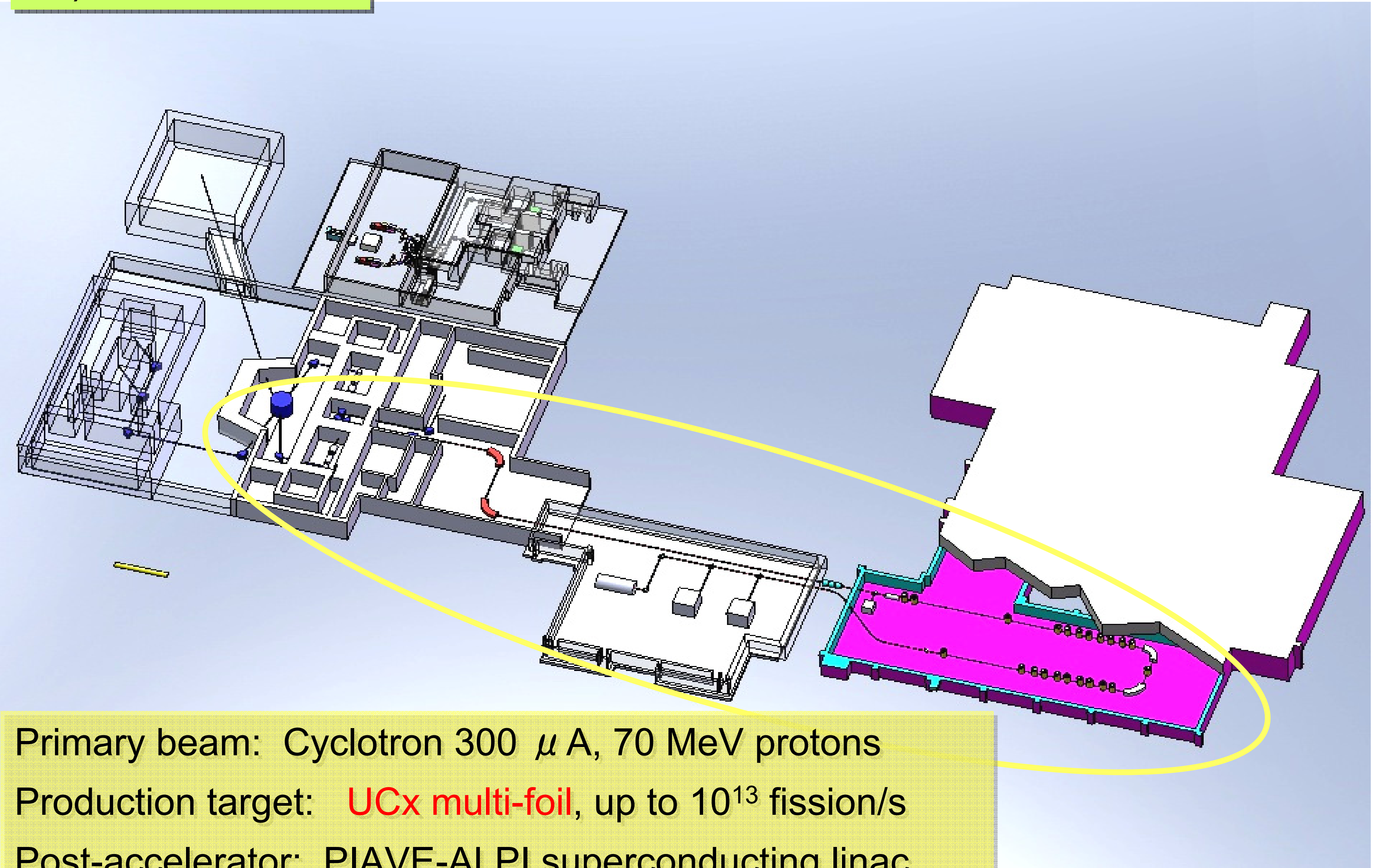
Nb sputtered cavity

Cryomodule

M. Pasini et al., HIAT2009

10) INFN – SPES

(SPES = Selective Production of Exotic Species)



Primary beam: Cyclotron 300 μA, 70 MeV protons

Production target: UCx multi-foil, up to 10^{13} fission/s

Post-accelerator: PIAVE-ALPI superconducting linac

10^7-10^9 rare ions/s A = 80-160 up to 11 MeV/u

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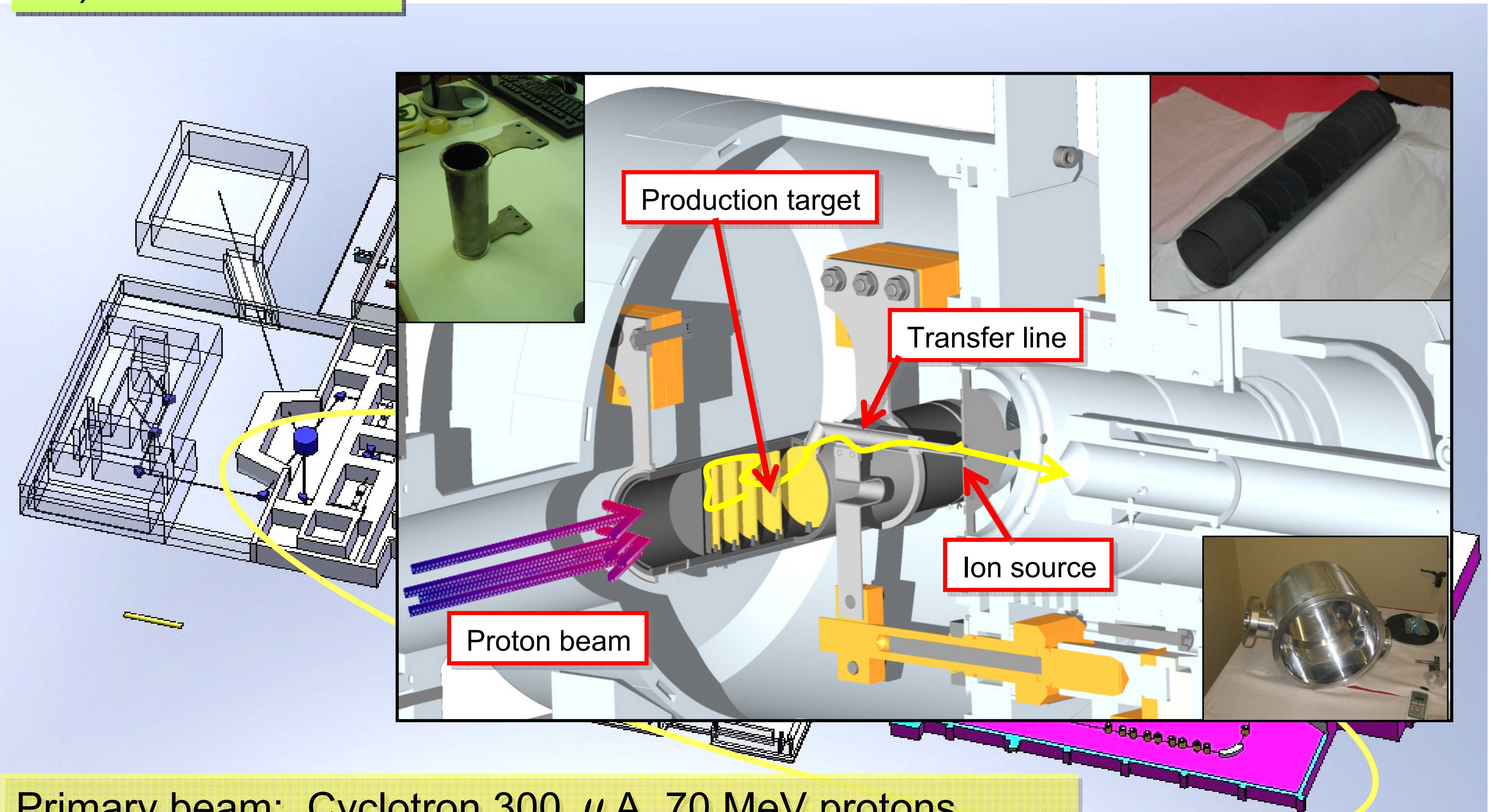

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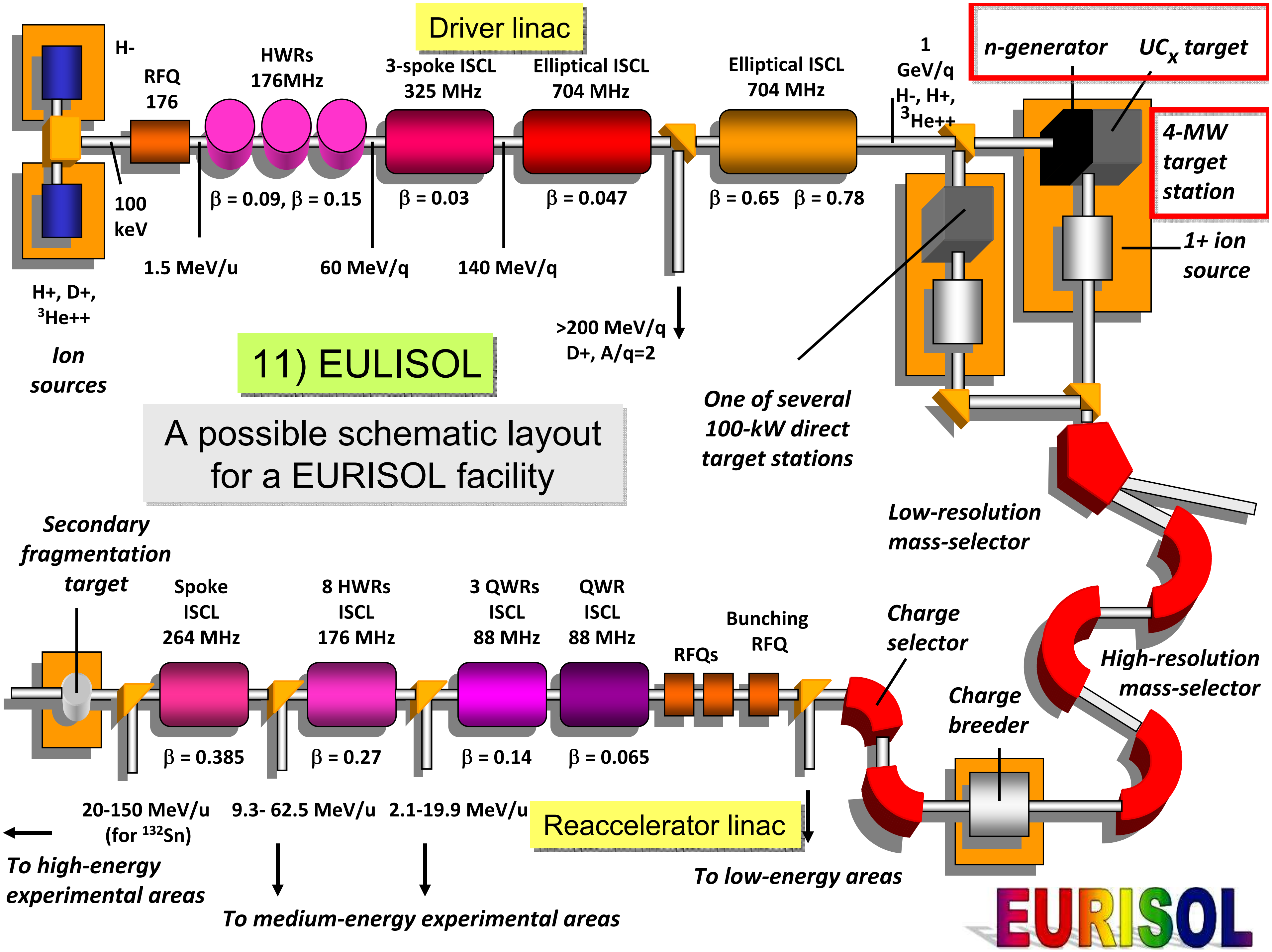
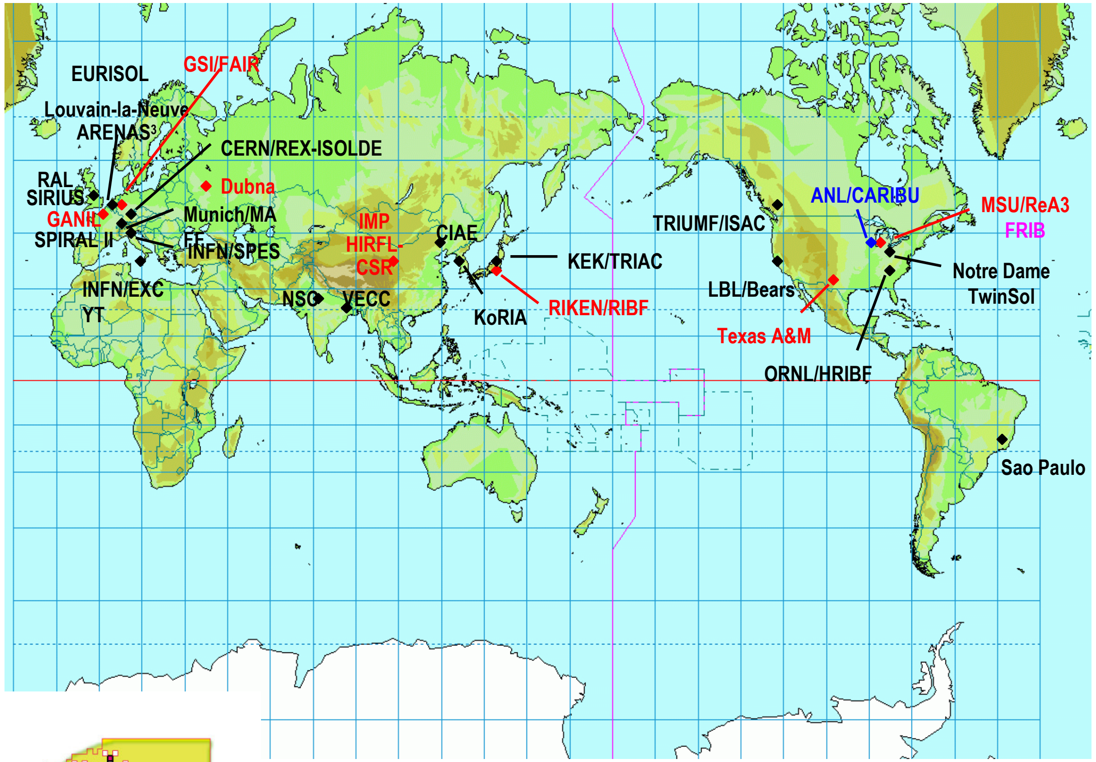
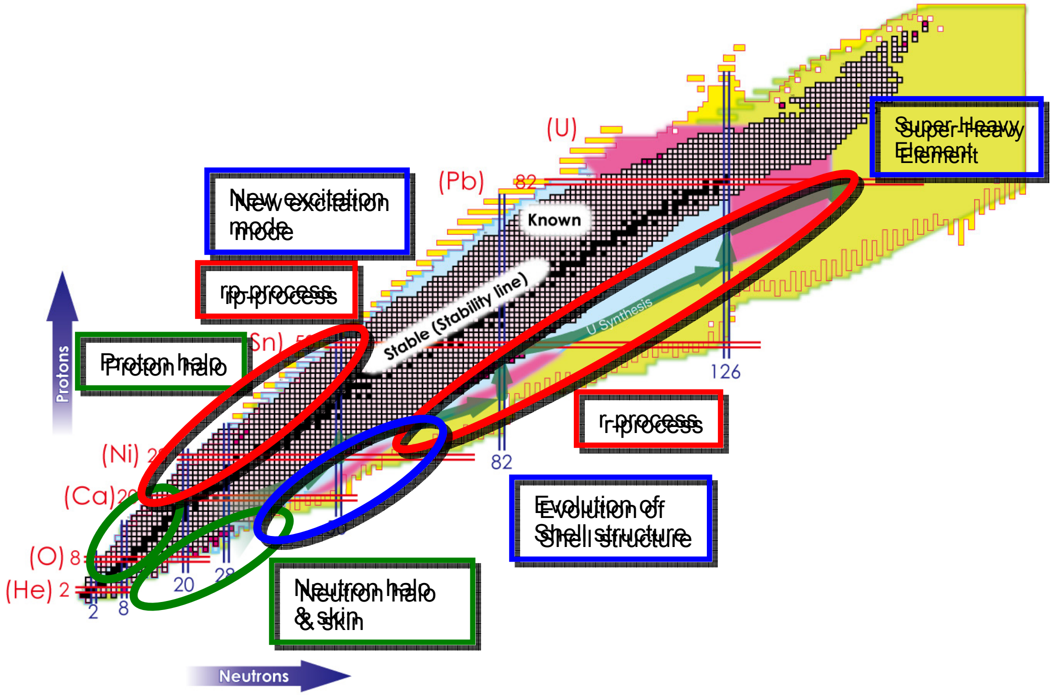


Driver linac
H-
RFQ
176
HWRs
176MHz
3-spoke ISCL
325 MHz
Elliptical ISCL
704 MHz
Elliptical ISCL
704 MHz
1
GeV/q
H-, H+,
$^3He^{++}$
n-generator
UC_x target
4-MW
target
station
1+ ion
source
100
keV
β = 0.09, β = 0.15
β = 0.03
β = 0.047
β = 0.65 β = 0.78
1.5 MeV/u
60 MeV/q
140 MeV/q
H+, D+,
$^3He^{++}$
Ion
sources
11) EULISOL
>200 MeV/q
D+, A/q=2
A possible schematic layout
for a EURISOL facility
One of several
100-kW direct
target stations
Low-resolution
mass-selector
Secondary
fragmentation
target
Spoke
ISCL
264 MHz
8 HWRs
ISCL
176 MHz
3 QWRs
ISCL
88 MHz
QWR
ISCL
88 MHz
RFQs
Bunching
RFQ
Charge
selector
High-resolution
mass-selector
Charge
breeder
β = 0.385
β = 0.27
β = 0.14
β = 0.065
20-150 MeV/u
(for ^{132}Sn)
9.3- 62.5 MeV/u
2.1-19.9 MeV/u
Reaccelerator linac
To high-energy
experimental areas
To medium-energy experimental areas
To low-energy areas
EURISOL


EURISOL
GSI/FAIR
Louvain-la-Neuve
ARENAS3
CERN/REX-ISOLDE
RAL
SIRIUS
Dubna
GANIL
SPIRAL II
Munich/MA
FF
INFN/SPES
IMP
HIRFL-CSR
CIAE
KEK/TRIAC
INFN/EXC
YT
NSC
VECC
KoRIA
RIKEN/RIBF
TRIUMF/ISAC
ANL/CARIBU
MSU/ReA3
FRIB
Notre Dame
TwinSol
LBL/Bears
Texas A&M
ORNL/HRIBF
Sao Paulo

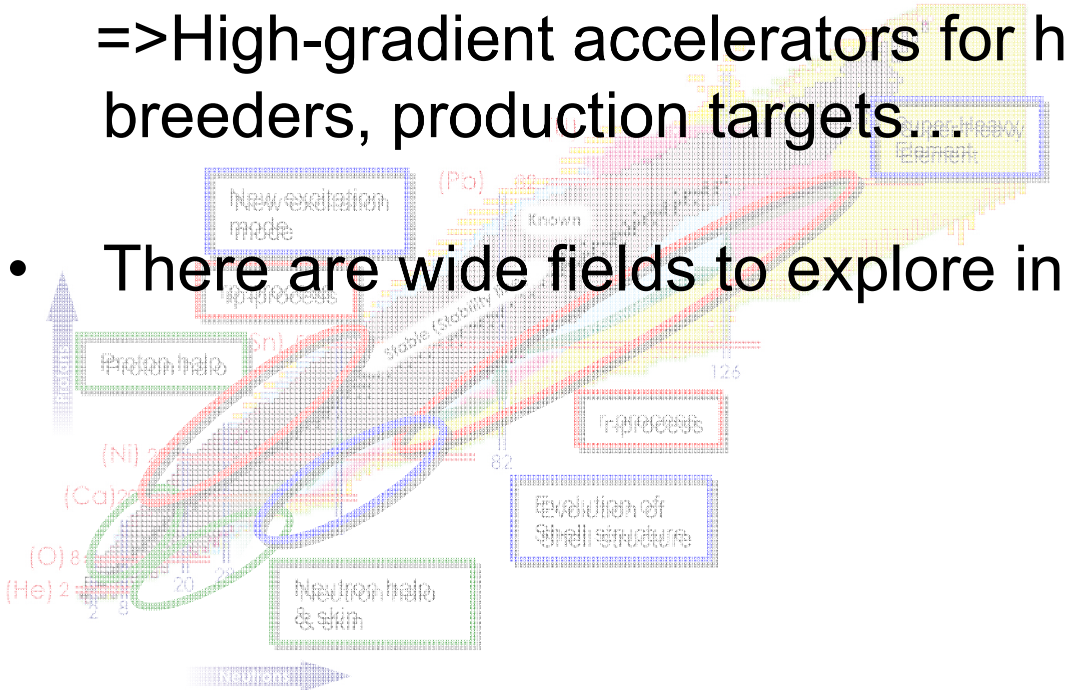

(U)
(Pb)
82
Known
Super Heavy Element
New excitation mode
rp-process
Stable (Stability line)
U Synthesis
Protons
Proton halo
(Sn)
126
r-process
(Ni)
(Ca)
82
Evolution of Shell structure
(O) 8
(He) 2
20
28
2
8
Neutron halo & skin
Neutrons

4. Summary

- New RI-Beam facilities are starting, under construction and planned in the world.

- A wide variety of technologies is required for modern RI-Beam facilities. They are rapidly moving ahead:
  =>High-gradient accelerators for high beam power, charge breeders, production targets…

- There are wide fields to explore in the nuclear world!



IPAC'10
The 1st International Particle Accelerator Conference

Many thanks to

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Yasushige Yano

HIAT09 HP (http://hiat09.lnl.infn.it)
Spiral2 HP (http://www.ganil-spiral2.eu/spiral2)
ANPhA HP (http://ribf.riken.jp/ANPhA/)
SRF09 & SRF07 Proc. (JACoW)

Members of the Accelerator Group, RIKEN Nishina Center

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