Review of Accelerators for Radioactive Beams

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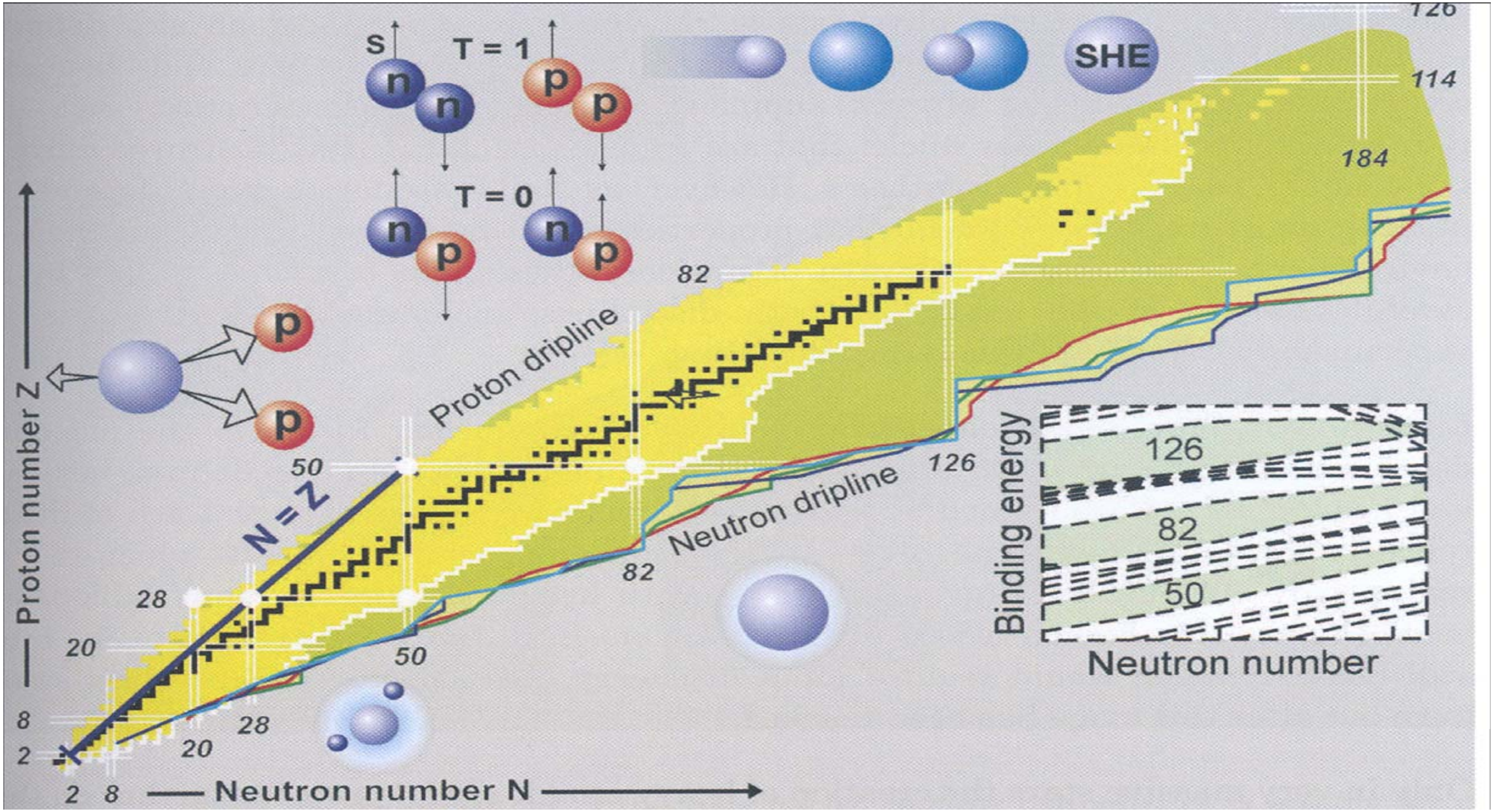
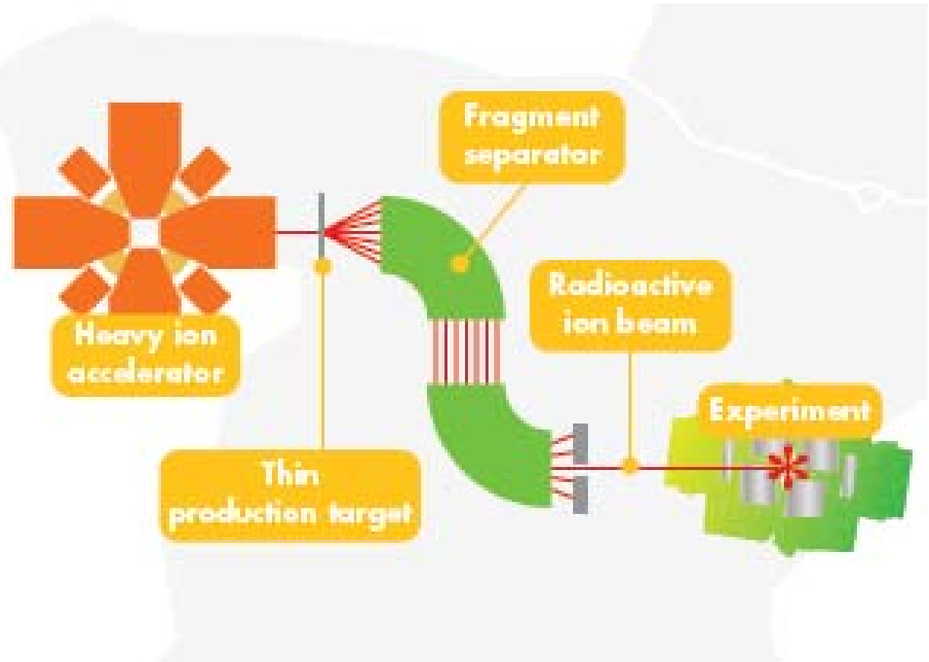
The Nuclear Chart and Challenges



Production Methods

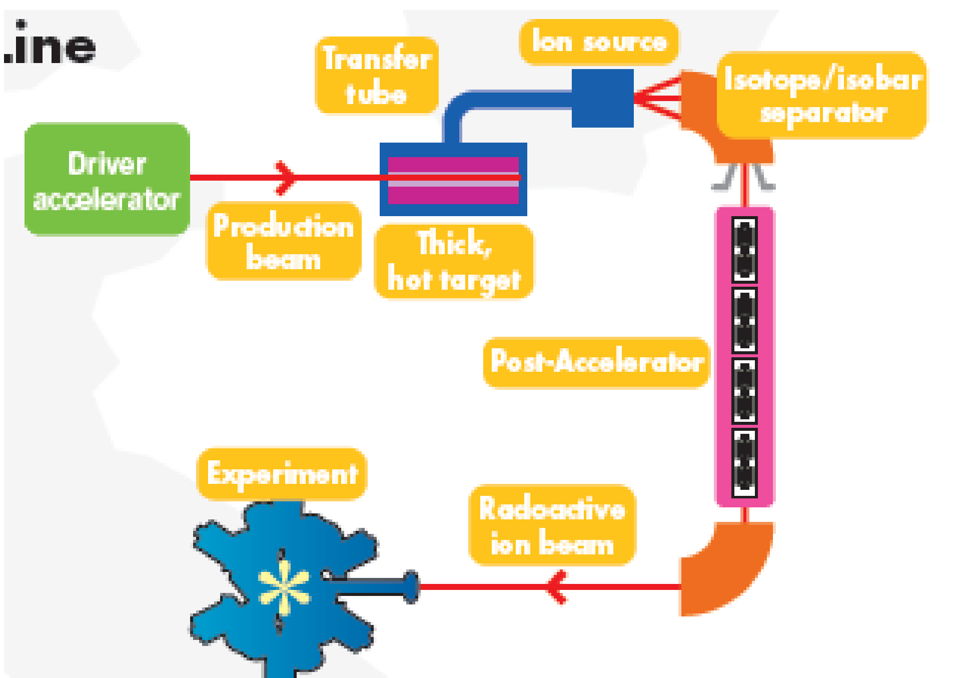


In-Flight Fragmentation

High Energy, all species,
low intensity, poor beam qualities

ISOL : Isotope Separation On-Line

High intensity, good optical quality,
Low energy, diffusion and effusion



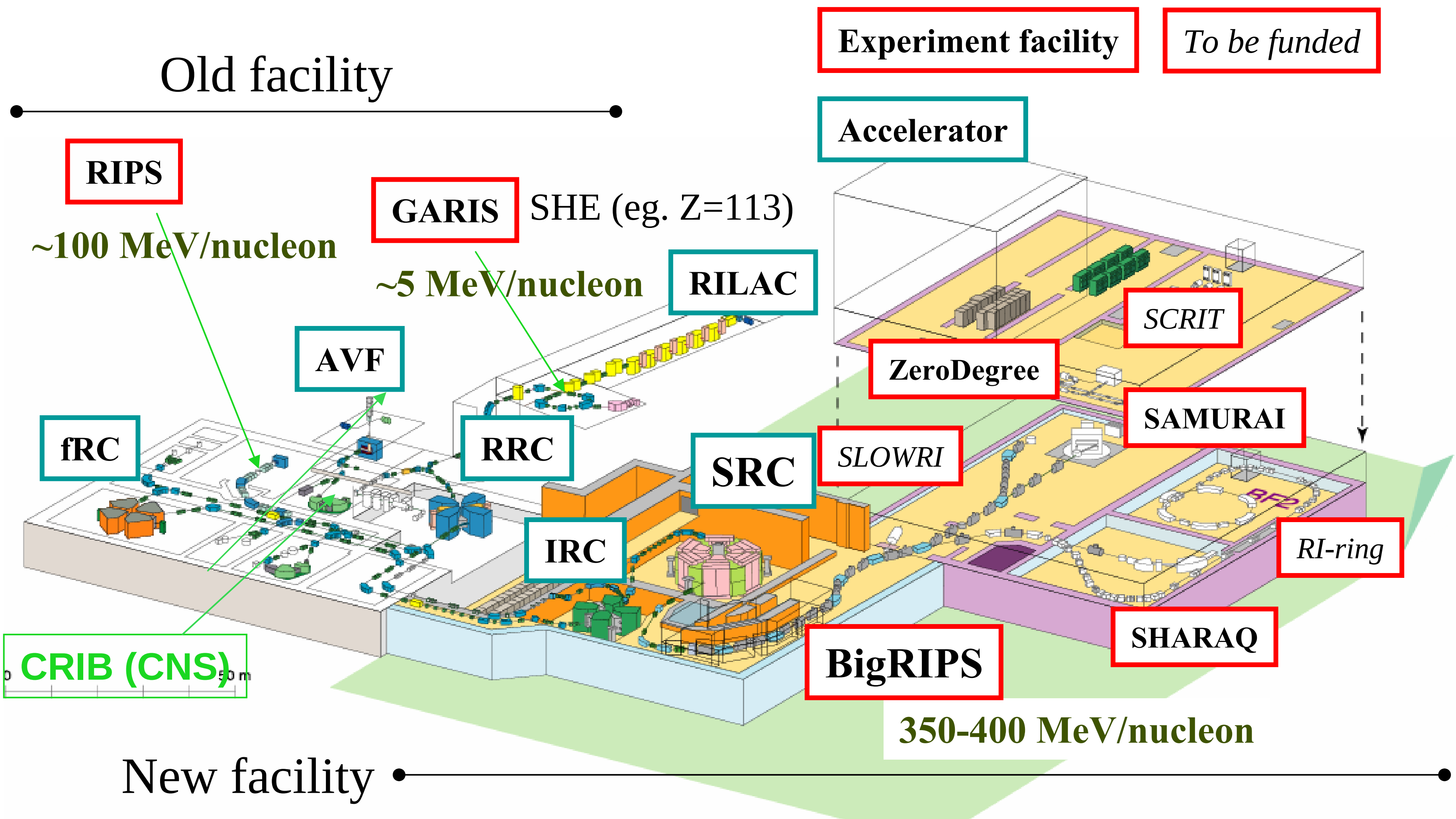
THE EUROPEAN PLAN for the LONG TERM FUTURE

NuPECC recommends the construction of 2 'next generation' RIB infrastructures in Europe, i.e. one ISOL and one in-flight facility. The in-flight machine, FAIR, would arise from a major upgrade of the current GSI facility, while EURISOL would constitute the new ISOL facility

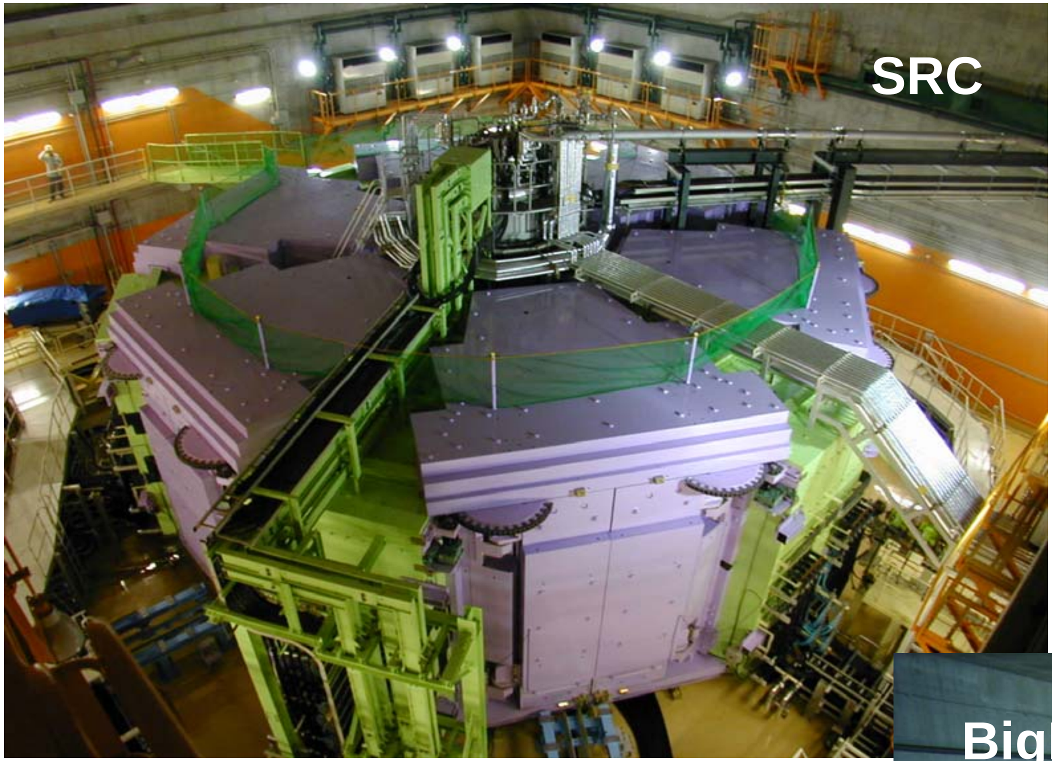
Current Fragmentation Facilities

Facility	Location	Driver	Primary Energy	Typical intensity	Fragment separator
GANIL	Caen, France	2 separated sector cyclotrons	Up to 100A MeV	^{36}S 10^{13} pps ^{48}Ca 2 10^{12} pps	SISSI + ALPHA
GSI	Darmstadt, Germany	Linac + Synchrotron	Up to 2A GeV	10^{10} ppspill	FRS
NSCL	East Lansing, USA	2 coupled superconducting cyclotrons	Up to 200A MeV	^{40}Ar 5 10^{11} pps	A1900
RARF RIKEN	Tokyo, Japan	Ring cyclotron	Up to 100A MeV	^{40}Ar 5 10^{11} pps	RIPS

RIKEN RI Beam Factory (RIBF)



Intense (80 kW max.) H.I. beams (up to U) of 345*A*MeV at SRC
Fast RI beams by projectile fragmentation and U-fission at BigRIPS
Operation since 2007



World's First and Strongest
K2600MeV
Superconducting Ring Cyclotron

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

World's Largest Acceptance
9 Tm
Superconducting RI beam Separator

~250-300 MeV/nucleon RIB

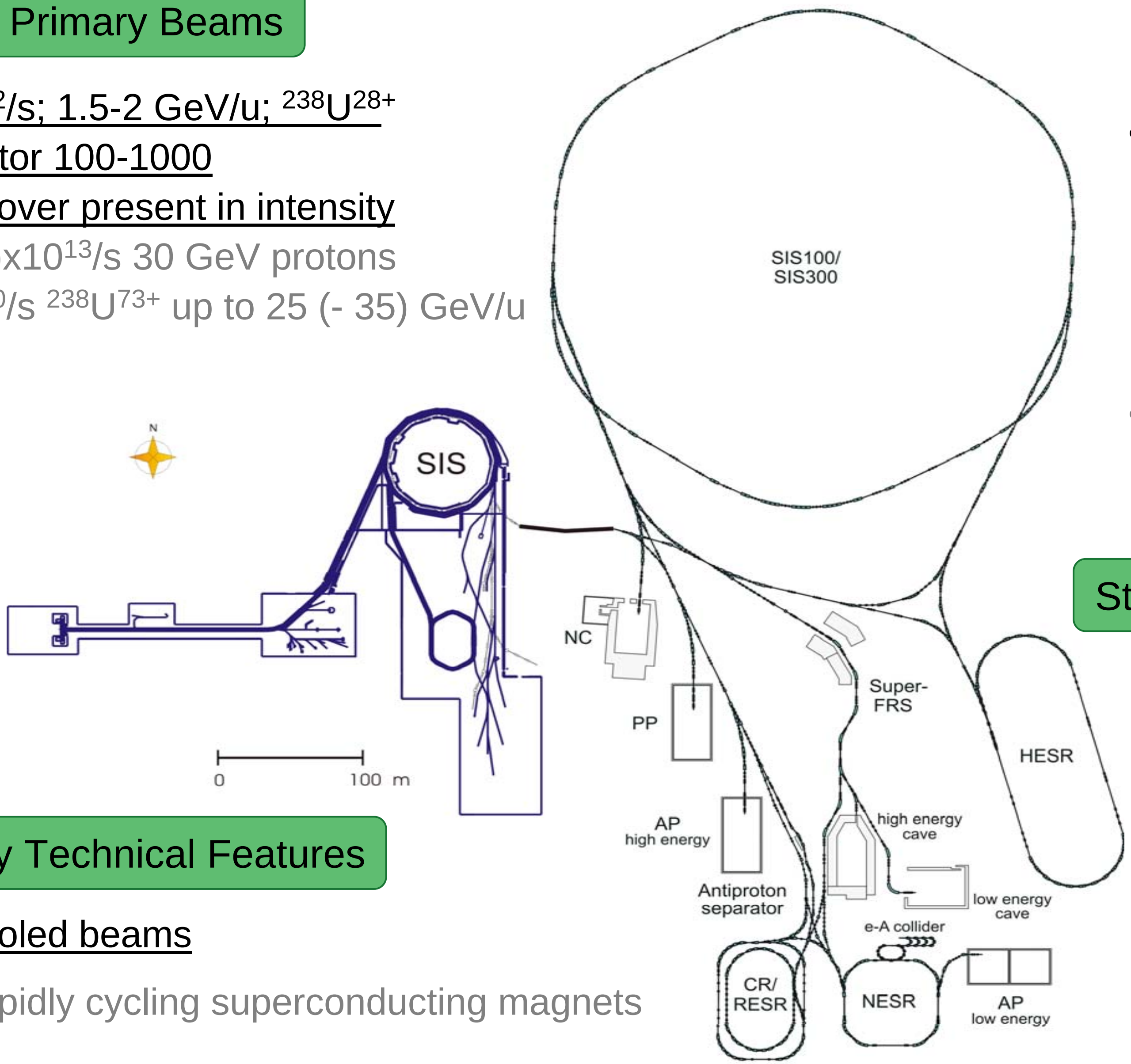
Next Generation Facility: FAIR at GSI

Primary Beams

- 10^{12}/s; 1.5-2 GeV/u; $^{238}U^{28+}$
- Factor 100-1000 over present in intensity
- 2(4)x10^{13}/s 30 GeV protons
- 10^{10}/s $^{238}U^{73+}$ up to 25 (- 35) GeV/u

Secondary Beams

- Broad range of radioactive beams up to 1.5 - 2 GeV/u; up to factor 10 000 in intensity over present
- Antiprotons 3 - 30 GeV



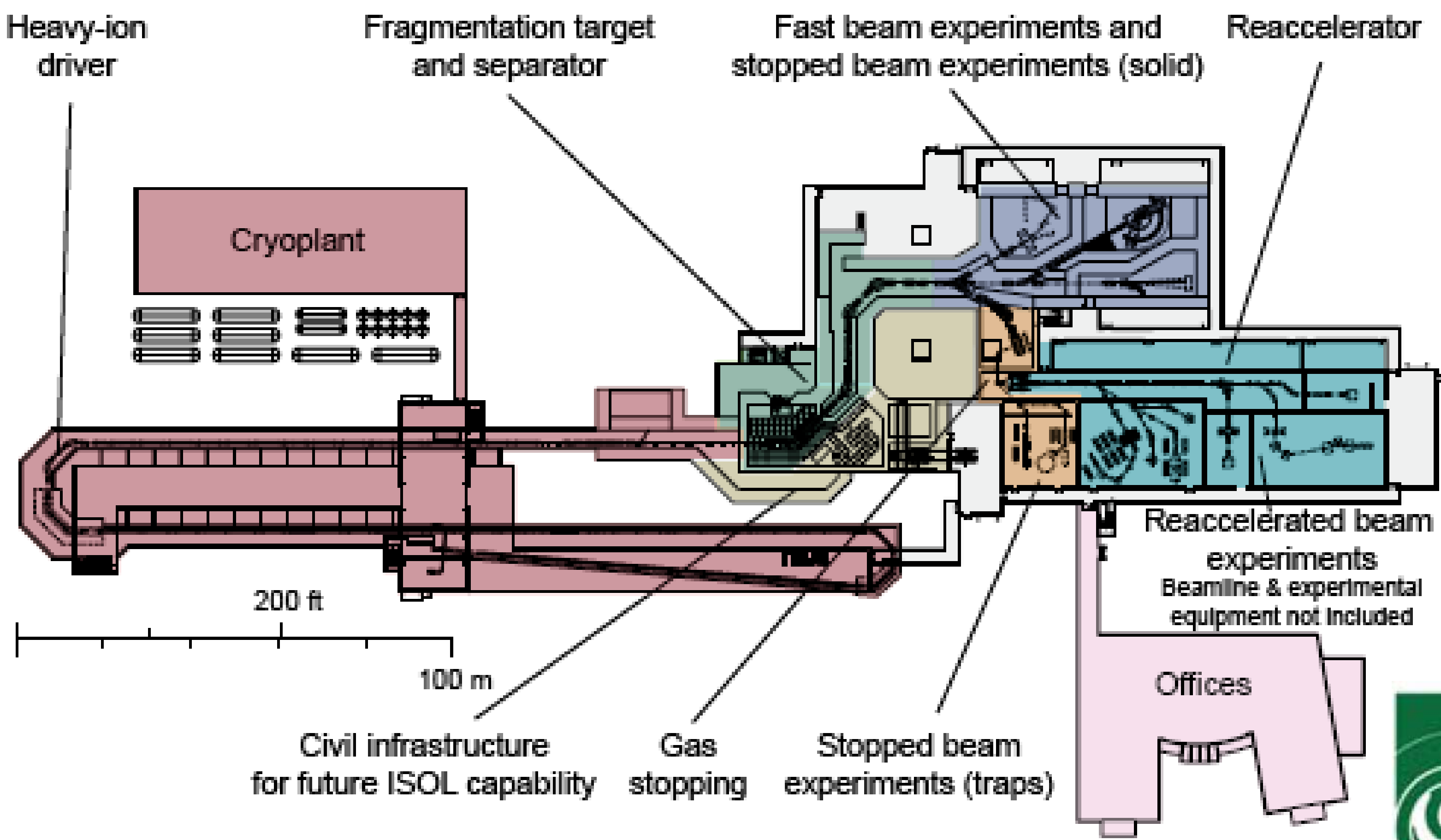
Storage and Cooler Rings

- Radioactive beams
- e – A collider
- 10^{11} antiprotons stored and cooled at 0.8 - 14.5 GeV

Key Technical Features

- Cooled beams
- Rapidly cycling superconducting magnets

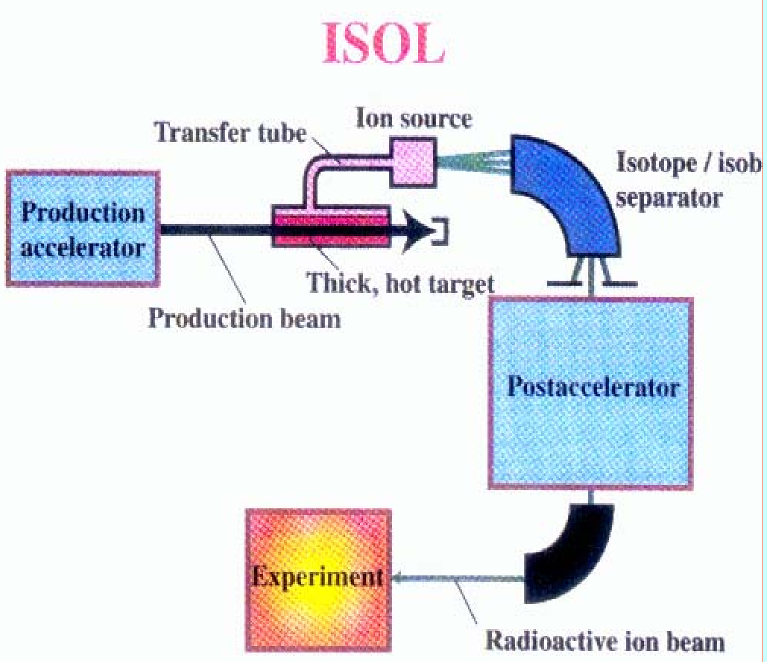
FRIB/ISF : The US project at the NSCL/MSU



Today's ISOL facilities

Facility	Location	Driver	Post accelerator	Final energy	Main beams available
REX-ISOLDE	CERN, Geneva	PS booster; 1.4 GeV protons	REX LINAC	0.3A-3A MeV	Large variety including fission frag.
SPIRAL	Caen, France	GANIL coupled cyclotrons	CIME cyclotron	2.7A-25A MeV	He, Ne, Ar, Kr, N, O, F
TRIUMF/ISAC	Vancouver, Canada	500 MeV proton cyclotron	RFQ + SC LINAC	0.2 – 5A MeV	Large variety up to Lu
ORNL/HRIBF	Oak Ridge, Tn	ORIC 50 MeV protons	25 MV Tandem	~10A MeV	Light ions and fission frag.

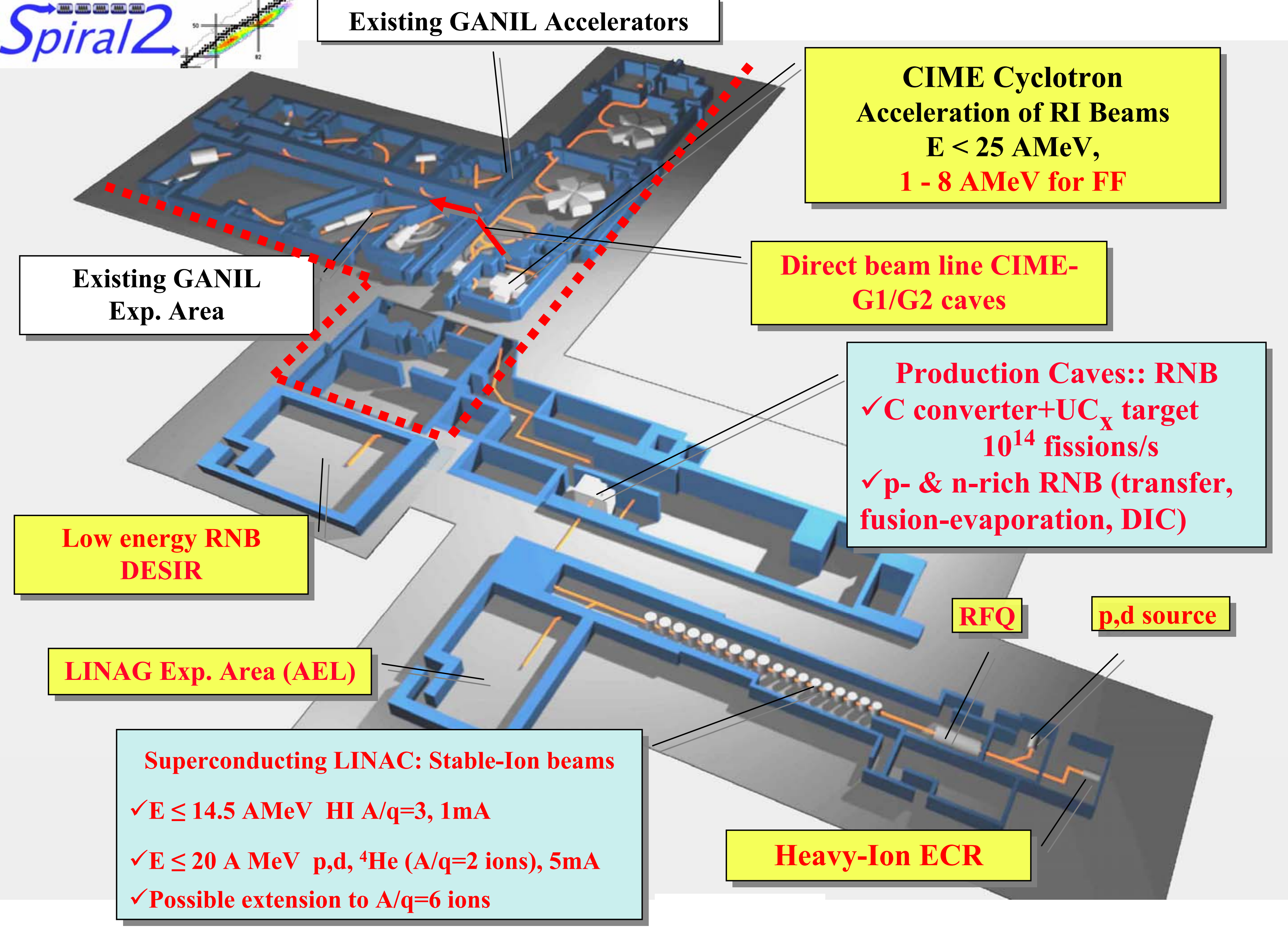
The European ISOL Road Map



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

European ISOL Facilities

Facility	Driver	Beam Power	Number of fissions	Post-accelerator	Energy
SPIRAL-II GANIL	LINAC Deuterons 40 MeV HI 15A MeV	200 kW	>5 10^{13}	Cyclotron CIME	2A-25A MeV
HIE-ISOLDE	PS booster Protons 1.4 GeV	10 kW	10^{13} + spallation	Linac REX	0.8A–10A MeV
SPES Legnaro	Commercial cyclotron p 40 MeV	8kW	10^{13}	Linac ALPI	10A MeV
EURISOL	Superconducting CW LINAC p 1GeV	5 MW	>10^{15} + spallation	Superconducting LINAC	150A MeV


Spiral2
Existing GANIL Accelerators
CIME Cyclotron
Acceleration of RI Beams
E < 25 AMeV,
1 - 8 AMeV for FF
Existing GANIL Exp. Area
Direct beam line CIME-G1/G2 caves
Production Caves:: RNB
✓C converter+UC_x target
10^{14} fissions/s
✓p- & n-rich RNB (transfer, fusion-evaporation, DIC)
Low energy RNB DESIR
RFQ
p,d source
LINAG Exp. Area (AEL)
Superconducting LINAC: Stable-Ion beams
✓E ≤ 14.5 AMeV HI A/q=3, 1mA
✓E ≤ 20 A MeV p,d, ^{4}He (A/q=2 ions), 5mA
✓Possible extension to A/q=6 ions
Heavy-Ion ECR

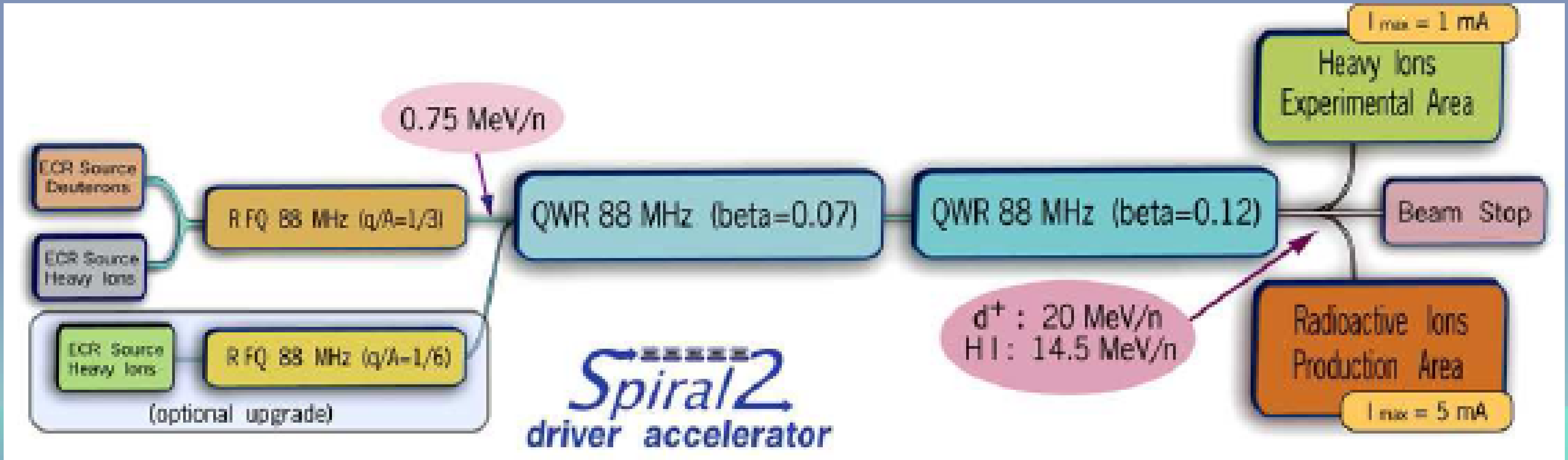
SPIRAL2 DRIVER ACCELERATOR Baseline Configuration: October 2006

beam	p+	D*	ions	ions
Q/A	1	1/2	1/3	1/6
I (mA) max.	5	5	1	1
W_O min. (Mev/A)	2	2	2	2
W_O max. (Mev/A)	33	20	14.5	8.5
CW max. beam power (KW)	165	200	44	48

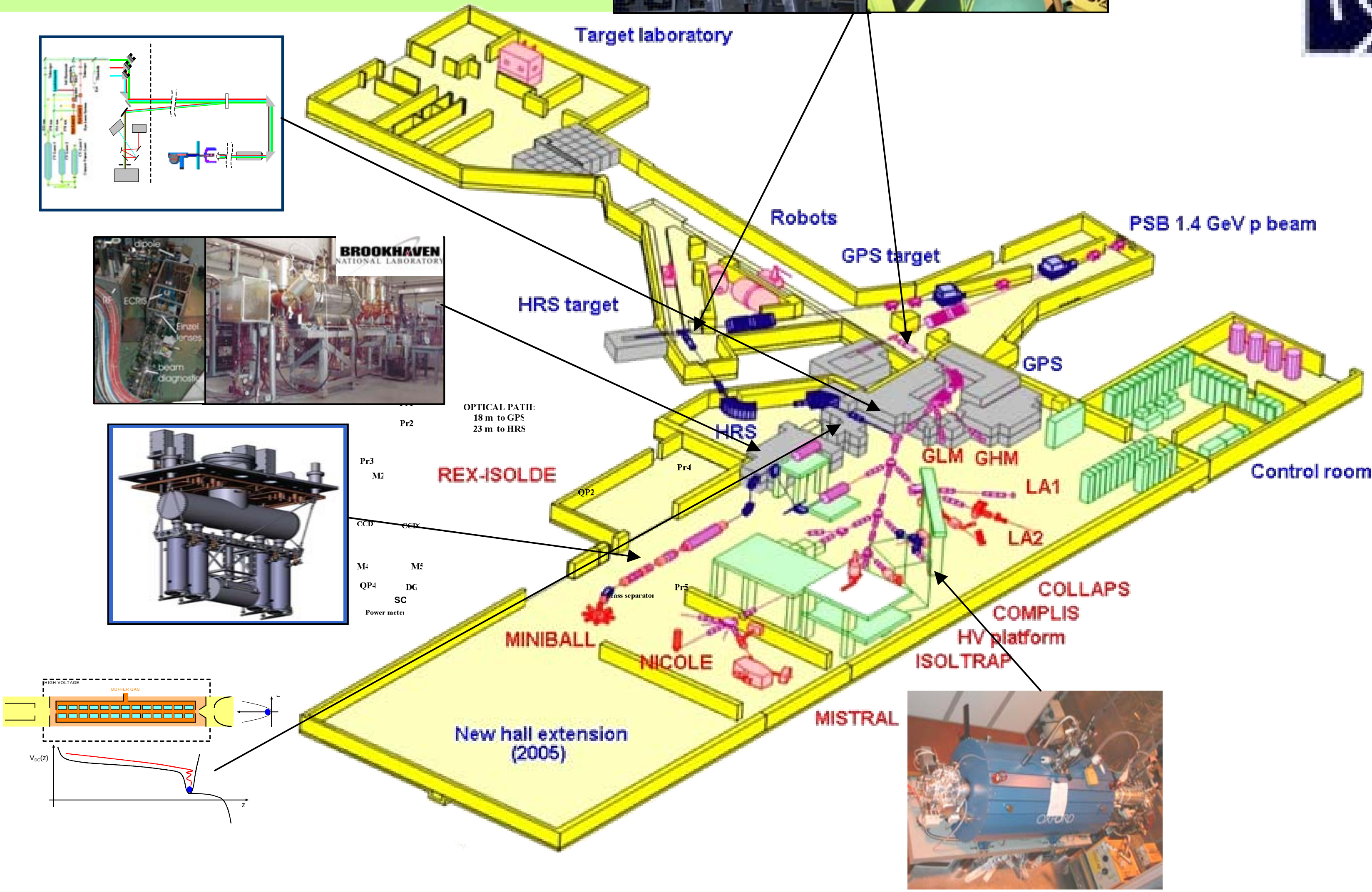
Total length: 65 m (without HE lines)

D^+ : ECR ion source
Heavy Ions: ECR Ion Source
Slow and Fast Chopper
RFQ (1/1, 1/2, 1/3) & 3 re-bunchers

12 QWR beta 0.07 (12 cryomodules)
14 QWR beta 0.12 (7 cryomodules)
1 KW Helium Liquifier (4.2 K)
Room Temperature Q-poles
30 Solid State RF amplifiers (10 & 20 KW)

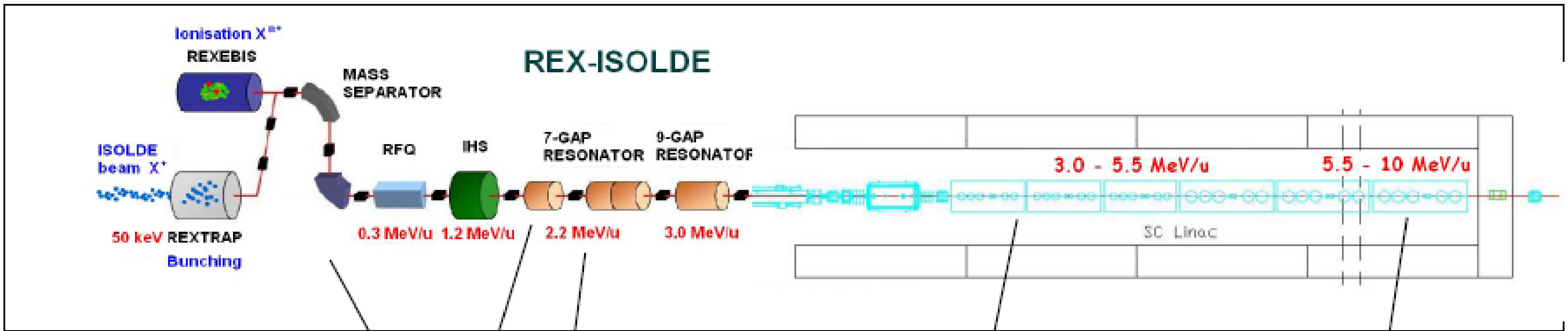


HIE-ISOLDE



Target laboratory
Robots
GPS target
PSB 1.4 GeV p beam
HRS target
GPS
HRS
BROOKHAVEN
NATIONAL LABORATORY
dipole
RF
ECRIS
Einzel lenses
beam diagnostics
OPTICAL PATH:
18 m to GPS
23 m to HRS
Pr2
Pr3
M2
Pr4
QP2
CCD
M4
M5
QP4
DG
SC
Power meter
Mass separator
Pr5
REX-ISOLDE
GLM
GHM
LA1
LA2
Control room
COLLAPS
COMPLIS
HV platform
ISOLTRAP
MINIBALL
NICOLE
MISTRAL
New hall extension
(2005)
HIGH VOLTAGE
BUFFER GAS
z

Staging of SC linac



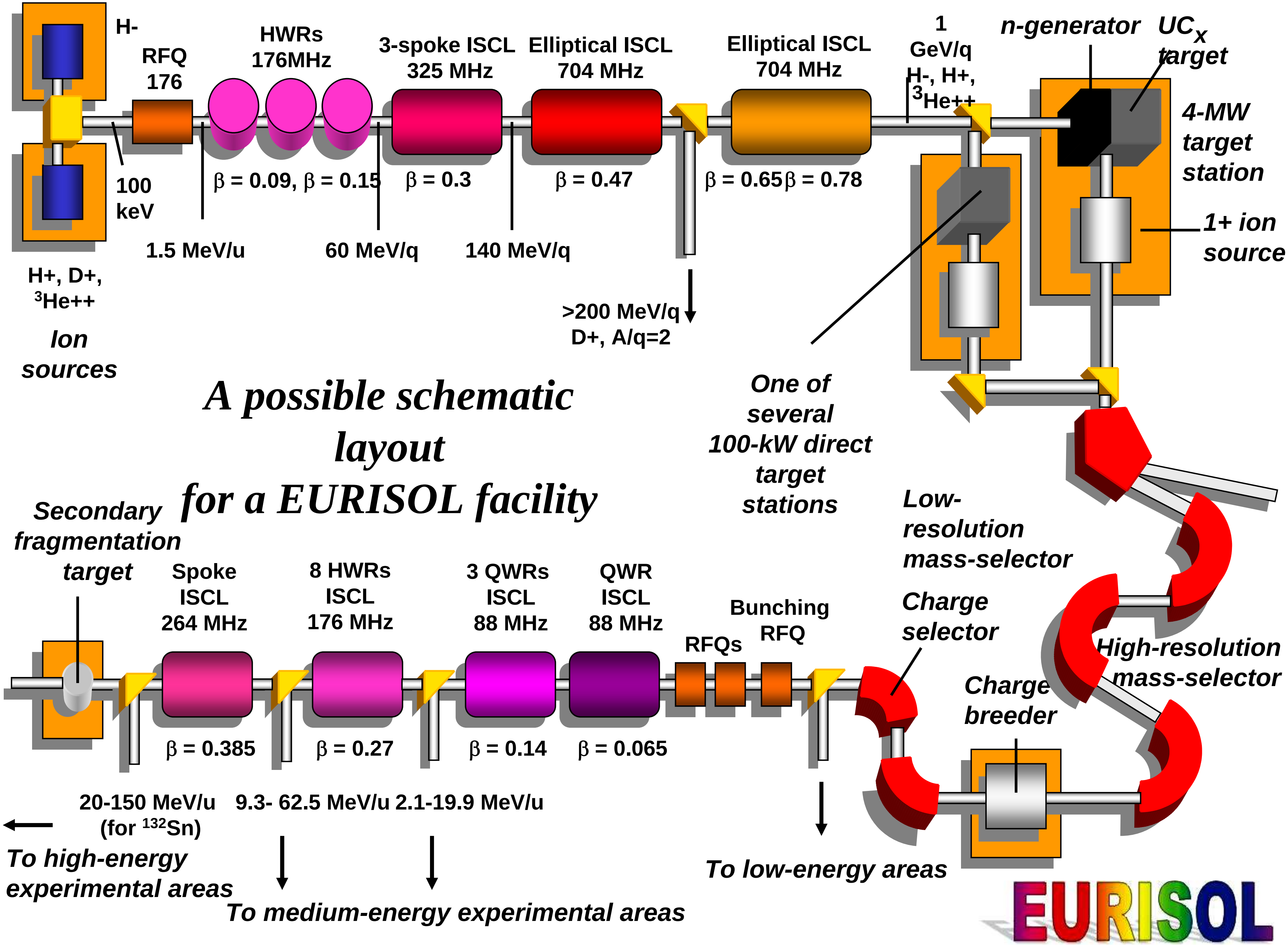
Existing NC REX-LINAC to 3 MeV/u

Phase 1: SC 3-5.5 MeV/u

Phase 2: SC5.5 -10 MeV/u

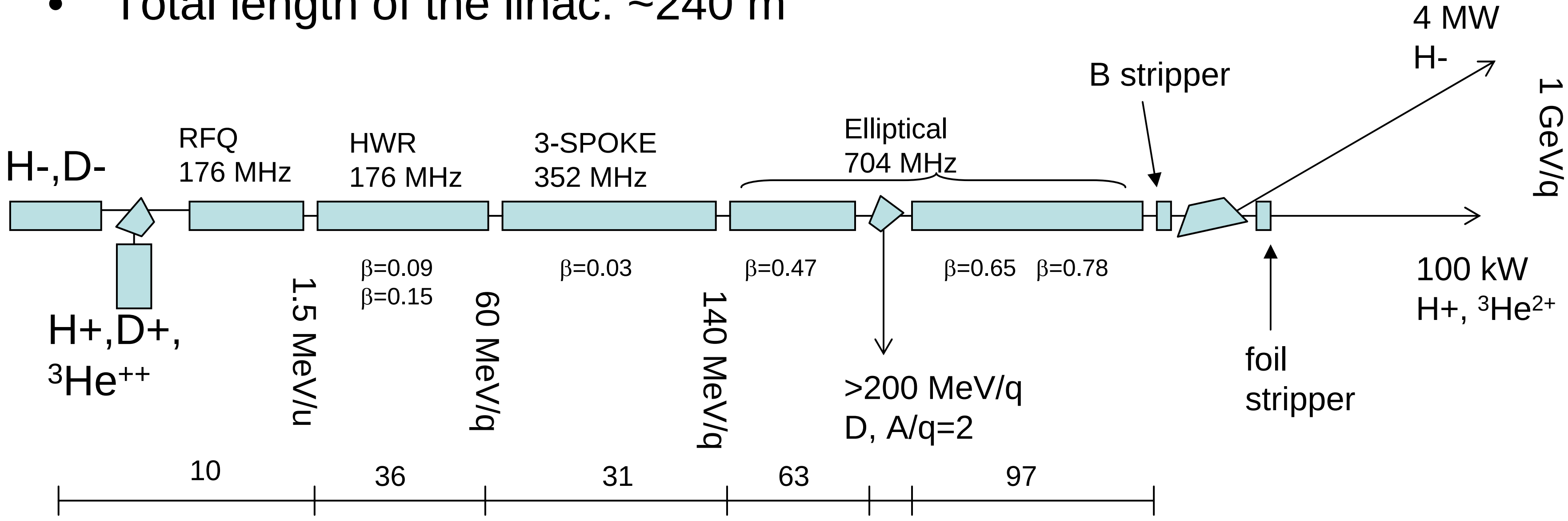
Phase 3: SC 1.2-3 MeV/u

Phase 4: SC low energy stage for CW operation (ECR?)


H-
RFQ 176
HWRs 176MHz
3-spoke ISCL 325 MHz
Elliptical ISCL 704 MHz
Elliptical ISCL 704 MHz
1 GeV/q H-, H+, $^{3}He^{++}$
n-generator
UC_x target
4-MW target station
1+ ion source
100 keV
β = 0.09, β = 0.15
β = 0.3
β = 0.47
β = 0.65β = 0.78
1.5 MeV/u
60 MeV/q
140 MeV/q
H+, D+, $^{3}He^{++}$
Ion sources
>200 MeV/q D+, A/q=2
One of several 100-kW direct target stations
A possible schematic layout for a EURISOL facility
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
Bunching RFQ
RFQs
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
To high-energy experimental areas
To medium-energy experimental areas
To low-energy areas
EURISOL

New baseline scheme with extended capabilities

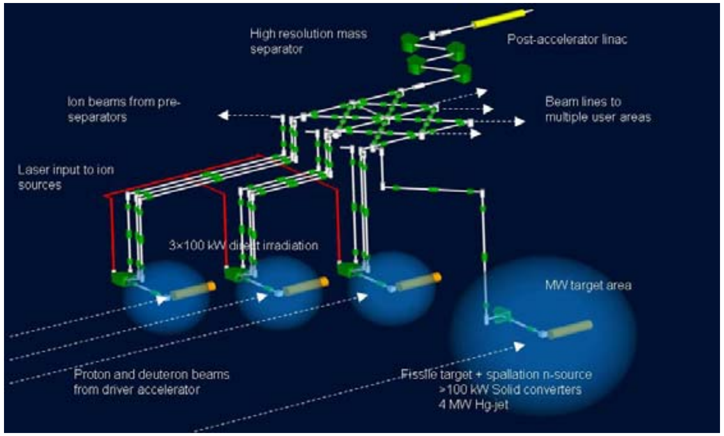
- 2 injection lines for H,D, He and A/q=2 ions
- SARAF scheme up to 60 MeV/q
- IPNO scheme from 60 to 140 MeV/q
- CEA scheme from 140 to 1000 MeV/u
- cw beam splitting at 1 GeV (1 line 4 MW + 3 lines 100 kW)
- Total length of the linac: ~240 m

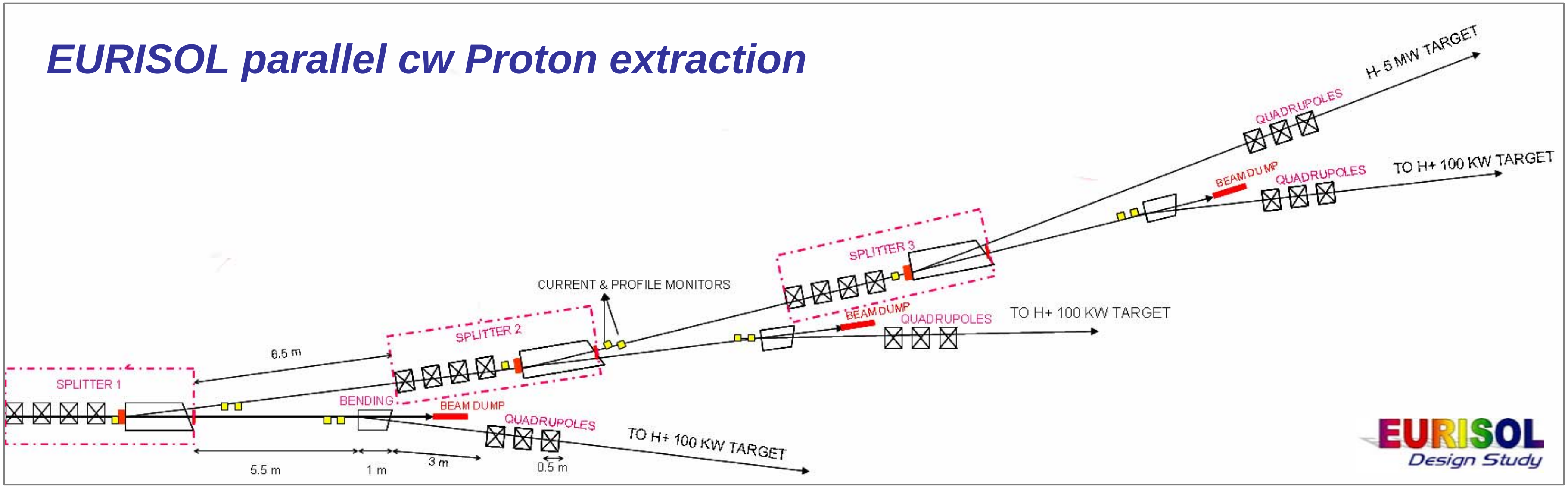


EURISOL task 7 : Alberto Facco LNL-Legnaro

1 GeV Multiple Extraction

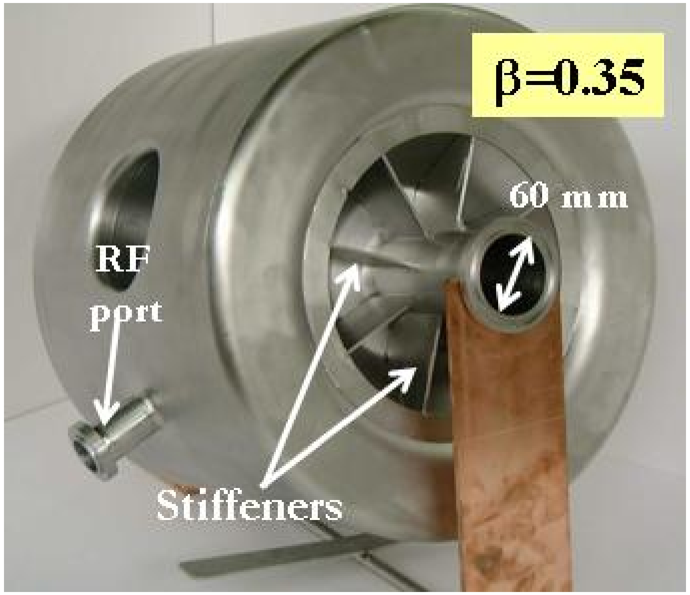
- 3 splitting stations
- 4 simultaneous users for cw proton beams:
  - 1 × 4 MW
  - 3 × 0÷100 kW (continuously adjustable)
- Unique ability of EURISOL at present



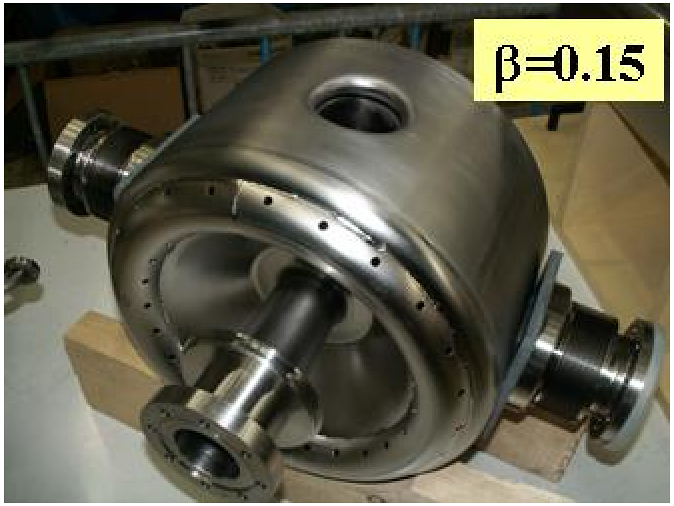


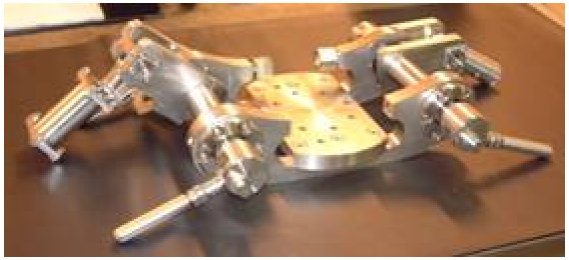
Spoke cavities development @ IPN Orsay

- 2 prototypes at $\beta=0.15$ and $\beta=0.35$ fabricated and successfully tested at 4.2 K.
- This technology is the basis for the 3-Spoke required by the Driver linac

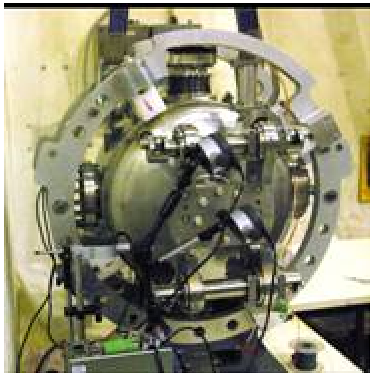


IPN Orsay Division Accélérateurs



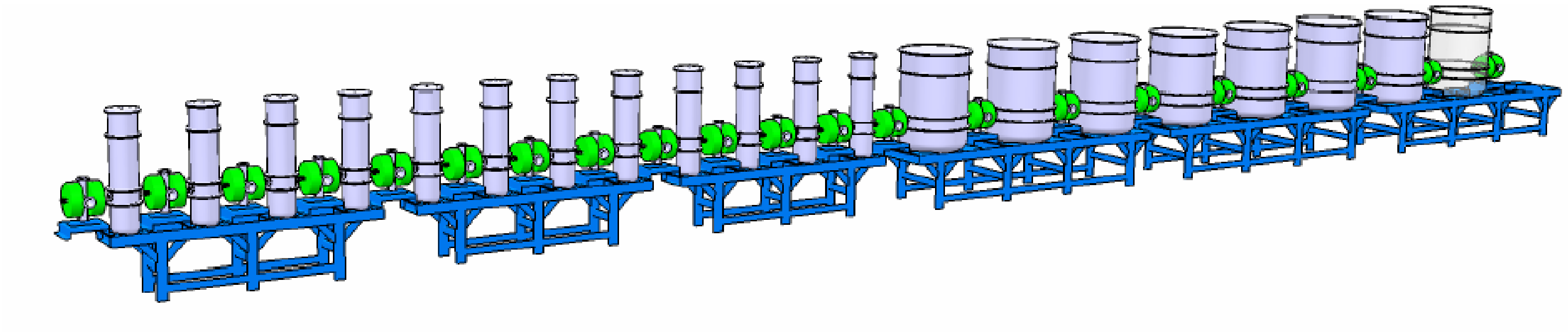


Spoke cavity tuner



EURISOL Task 8: Sébastien Bousson – IPN Orsay

Design of the post-accelerator



SPIRAL-2 philosophy : Smoothest beam dynamics (regular FDO lattice, low number of β-sections), Modular solution and simple cryostats, Separated vacuum (safety with FP), Warm focusing (easier for alignement), Possibility to insert diagnostics at each period, ease of tuning

Main technical requirements:

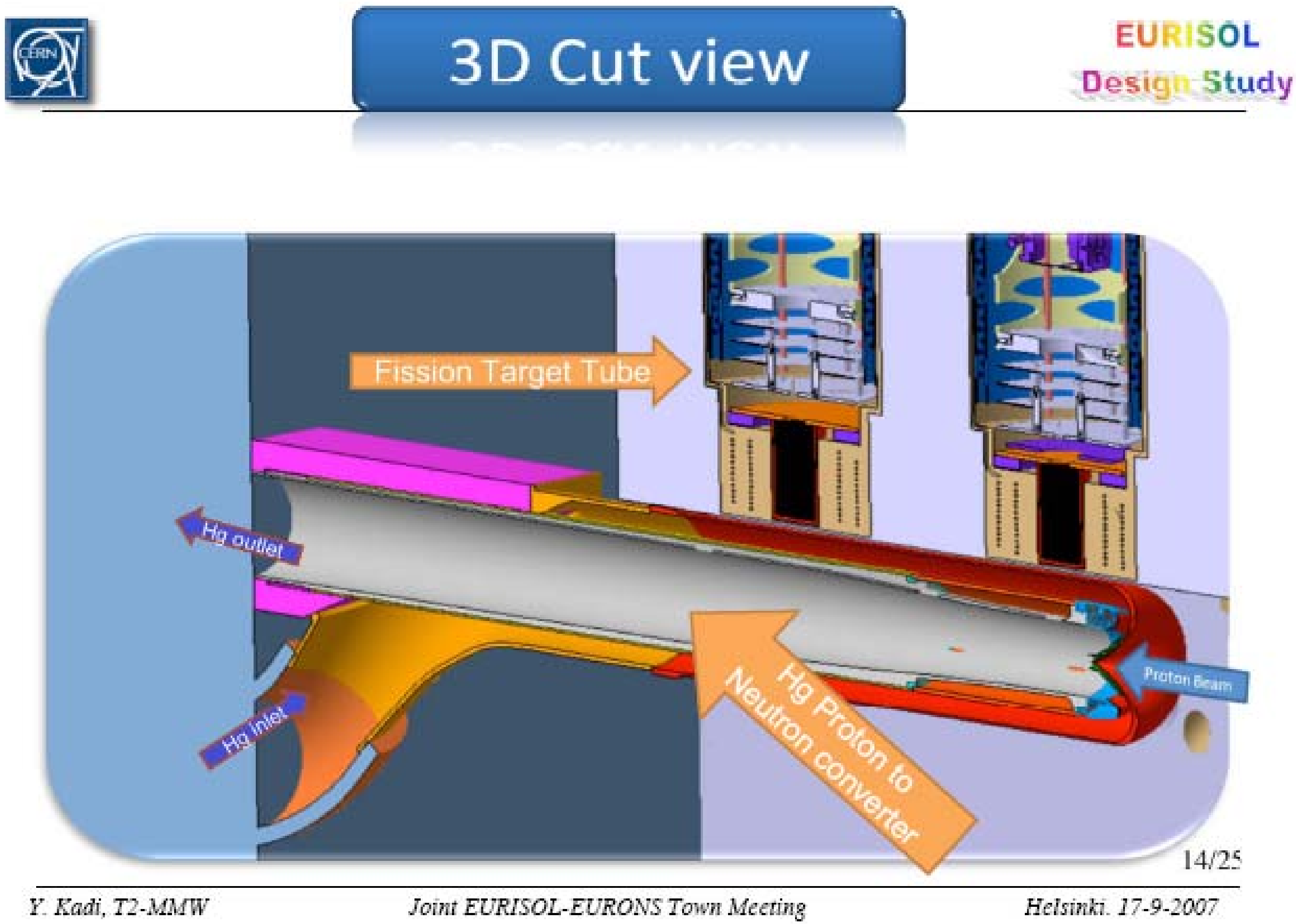
Only 2-gap cavities (high q/A acceptance)

Max. accelerating fields 7.8 MV/m

Nominal operation for A/Q between 4 and 8

$^{132}Sn^{25+}$	Section 1	Section 2	Section 3	Section 4	TOTAL
Cavity Freq.	88.05 MHz	88.05 MHz	176.1 MHz	264.15 MHz	-
Cavity β	0.065	0.14	0.27	0.385	-
# cav./ cryo	1 QWR	3 QWR	8 HWR	14 SPOKE	-
# cavities	15 cav	27 cav	80 cav	154 cav	**276 cav**
Length	17.9 m	26.1 m	59.0 m	103.8 m	**206.8 m**
Ouput energy range	-	2.1 – 19.9 MeV/A	9.3 – 62.5 MeV/A	20.0 – 150.0 MeV/A	**2.1 – 150.0 MeV/A**

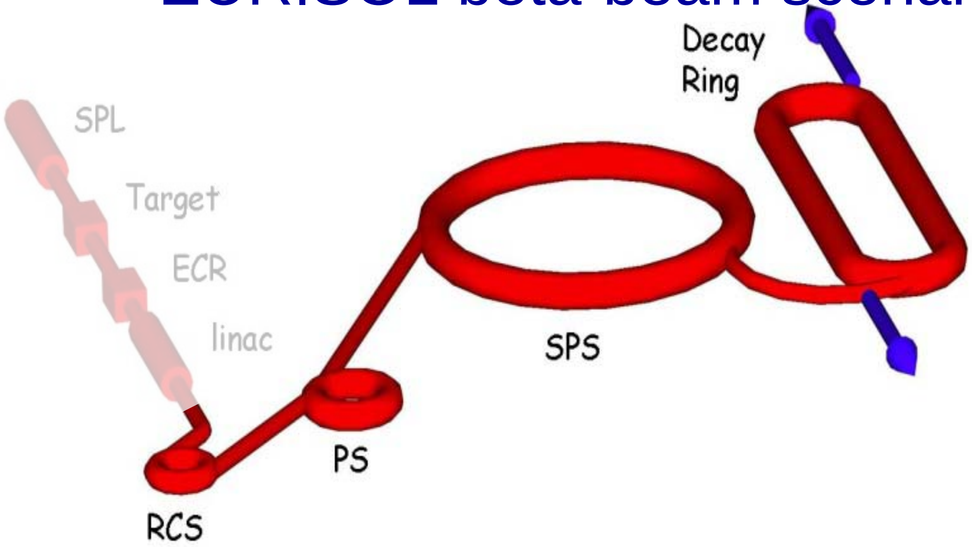
New Target Concept



L. Tecchio Task 4

Beta Beam Study

EURISOL beta-beam scenario

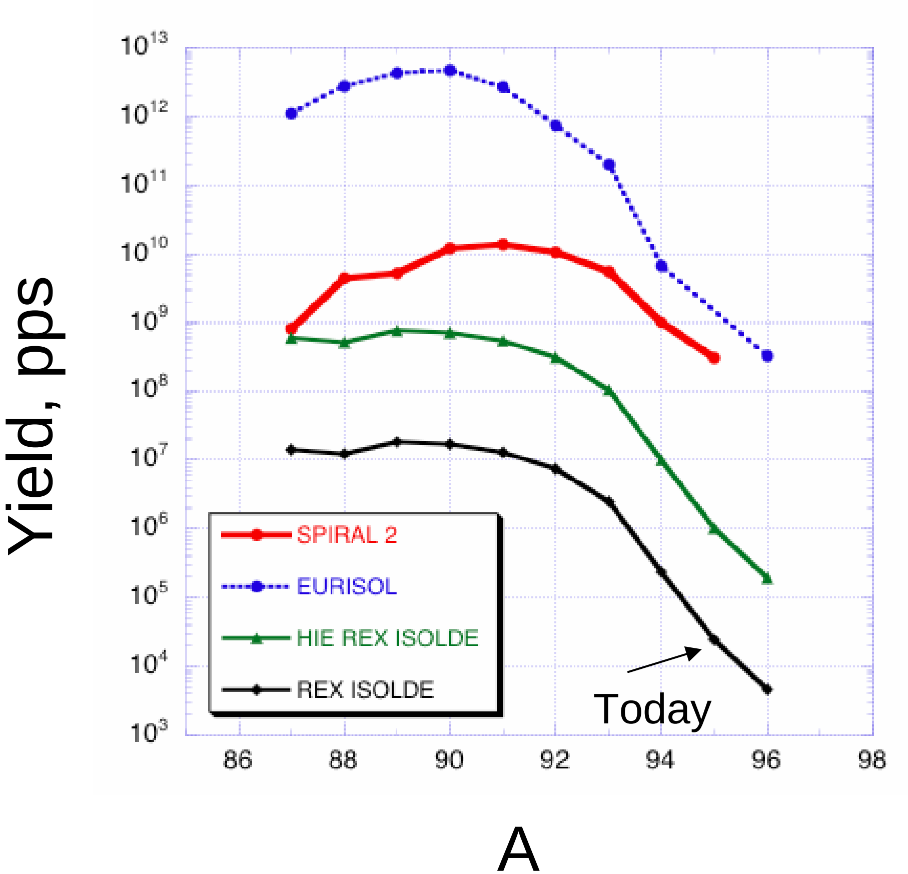


Ion choice: ^{6}He and ^{18}Ne
Based on existing technology and machines
Study of a beta-beam implementation at CERN

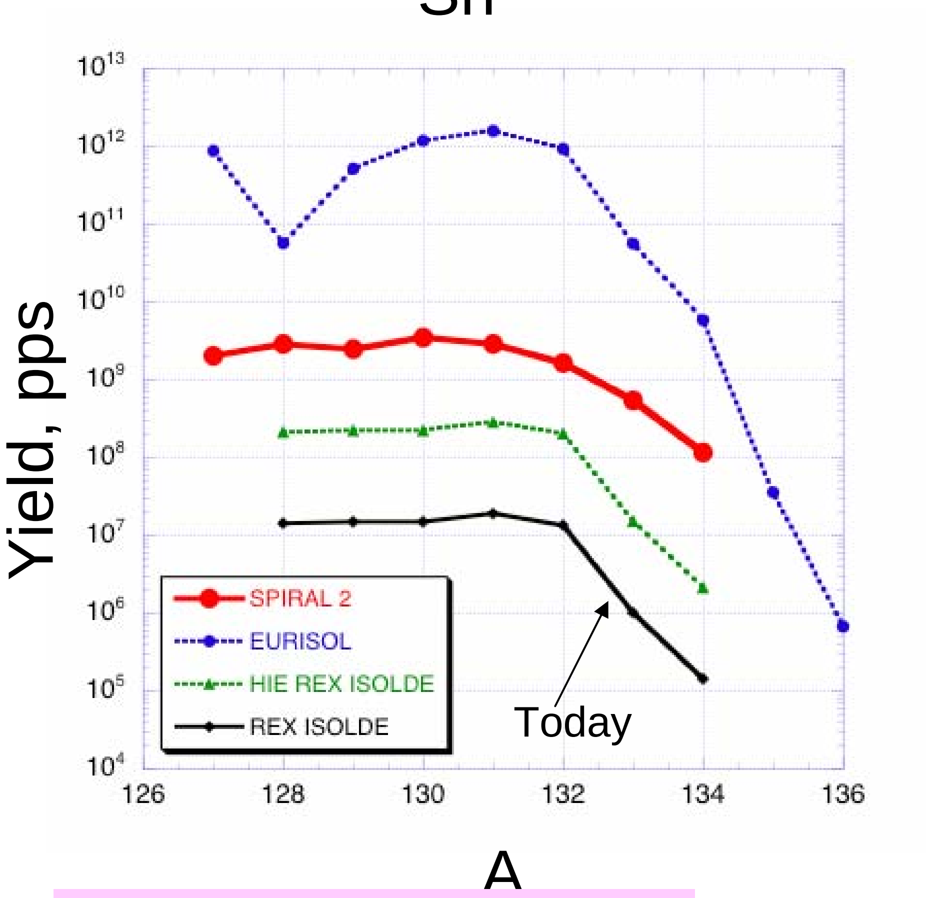
Once we have thoroughly studied the EURISOL scenario, we can “easily” extrapolate to other cases. EURISOL study could serve as a reference.

Yields of fission fragment after acceleration (best numbers for all)

Kr



Sn



Thanks to Marek Lewitowicz

Possible Locations?

The Design Study will investigate the implementation and cost of EURISOL in these 3 hypotheses

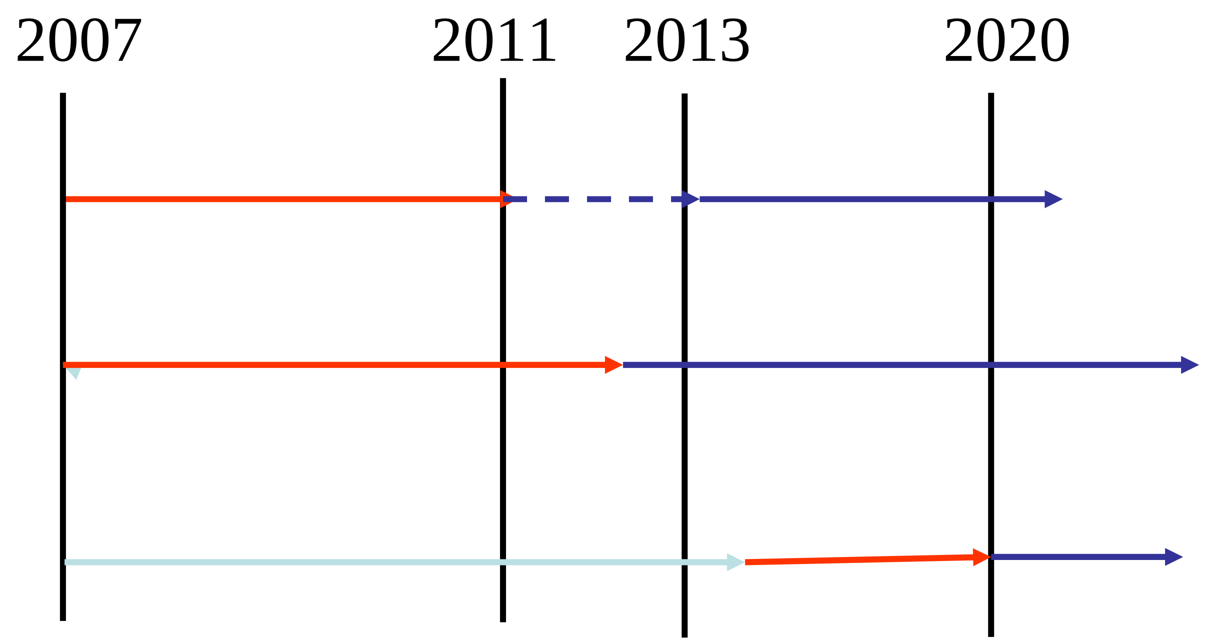
Time scales

Spiral2

HIE-ISOLDE, SPES

GSI FAIR

EURISOL



Project definition

Construction

Exploitation

To be taken with caution

Summary and Conclusions

- We are today at a turning point in RIB science with the study and construction of a new generation of dedicated facilities offering higher intensities and more exotic nuclei.
- There is a coherent plan for future development :
  - Fragmentation with RIBF and FAIR (and FRIB in USA?)
  - Intermediate generation ISOL facilities: SPIRAL2, HIE-ISOLDE, SPES
  - EURISOL
- Superconducting LINACs are the cornerstones of the ISOL projects due to their flexibility, modularity and small beam losses
- Cyclotrons and synchrotrons are necessary to reach the high energies needed for in-flight facilities.

RIB Physics Reach