Cyclotron Option for betabeams

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Plan

- Facts on cyclotrons
- Cyclotron solutions for EURISOL postaccelerator (feasibility study)
- hints for betabeams cyclotron solution

Facts on Cyclotrons (I)

- $E/u \approx Kb\,(q/A)^2$
- $Kb \approx 48.3\,(B.\rho)^2$ (B : T, R: m)
- EURISOL feasibility study :

100 MeV/u $^{132}Sn^{25+}$ $\Rightarrow Kb \approx 2800$ $B\rho = 7.8$ T.m

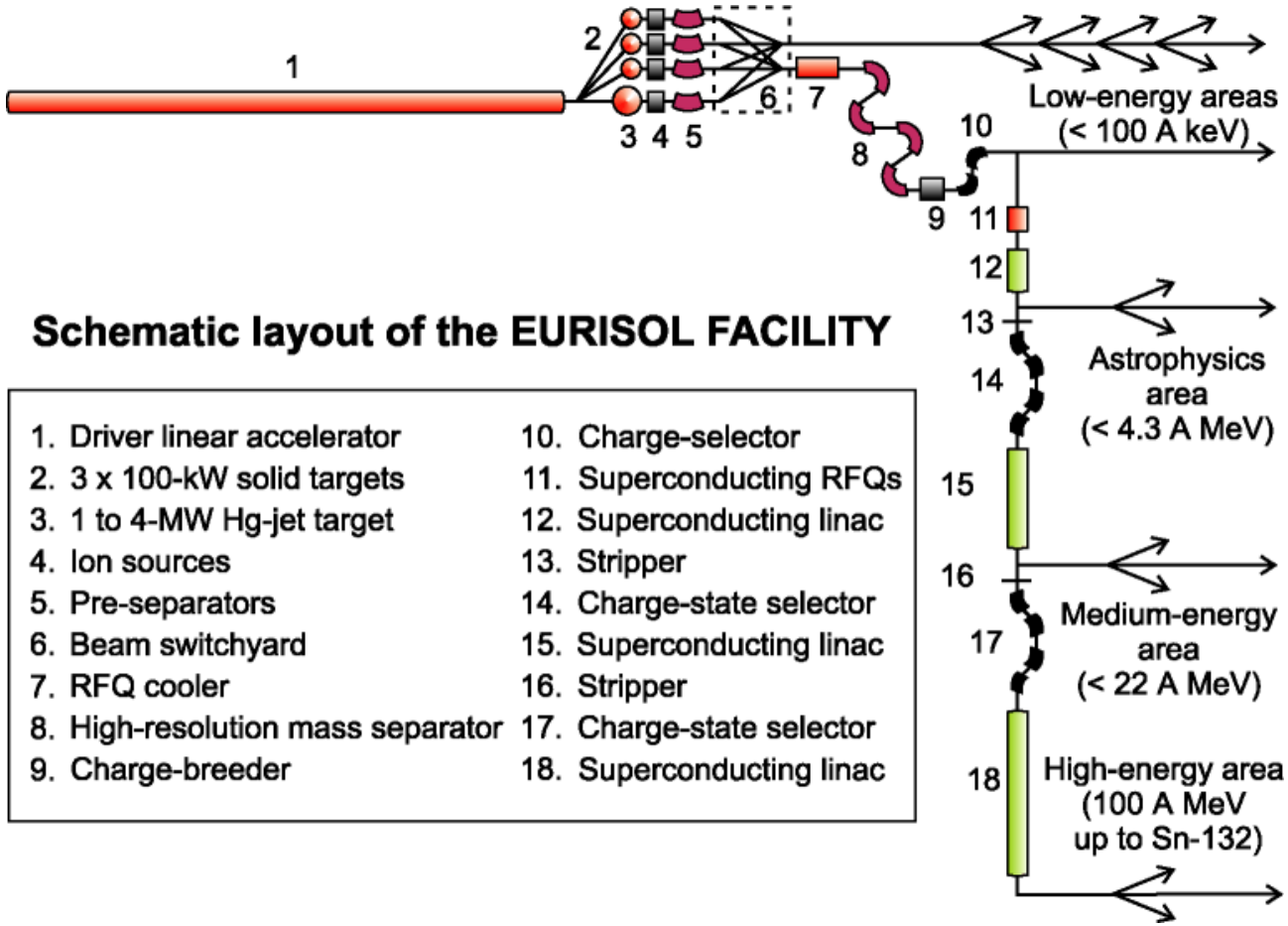
$\Rightarrow$ without stripping, leads to very large cyclotron

Facts on Cyclotrons (II)

- « compact » machines
- less costly
- high mass separation
- CW machine (isochronous cyclotron)
- experience on RIB post acceleration (LLN, GANIL, Dubna)

- restricted operating range (compact SC)
- energy change not straightforward
- lower transmission (intrinsic or by stripping)

EURISOL lay-out



Schematic layout of the EURISOL FACILITY

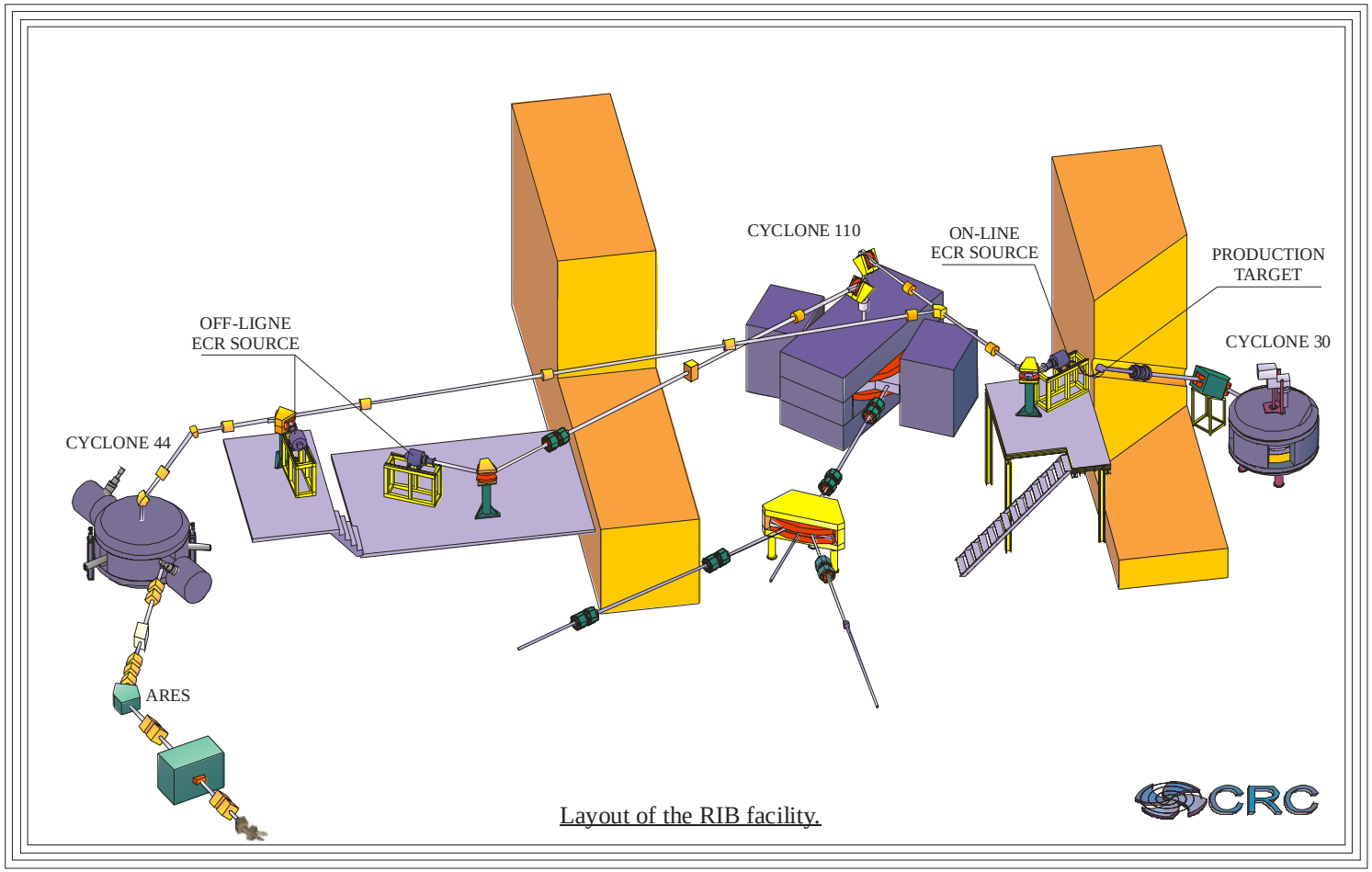
1. Driver linear accelerator
2. 3 x 100-kW solid targets
3. 1 to 4-MW Hg-jet target
4. Ion sources
5. Pre-separators
6. Beam switchyard
7. RFQ cooler
8. High-resolution mass separator
9. Charge-breeder
10. Charge-selector
11. Superconducting RFQs
12. Superconducting linac
13. Stripper
14. Charge-state selector
15. Superconducting linac
16. Stripper
17. Charge-state selector
18. Superconducting linac

Cyclotrons options for EURISOL feasibility study

- Two room temperature cyclotrons and stripper (GANIL like)
- Superconducting compact cyclotron (MSU/NSCL, AGOR…)
- Superconducting separated sector cyclotron (RIKEN SRC)

o larger room temperature SSC : IRC K980 RIKEN (2006)
o larger SC compact cyclotron : K1200 MSU/NSCL (1988)
o larger SC SSC : SRC K2500 RIKEN (2006)

First postacceleration of RIB by a cyclotron
CRC Louvain-la-Neuve Belgium

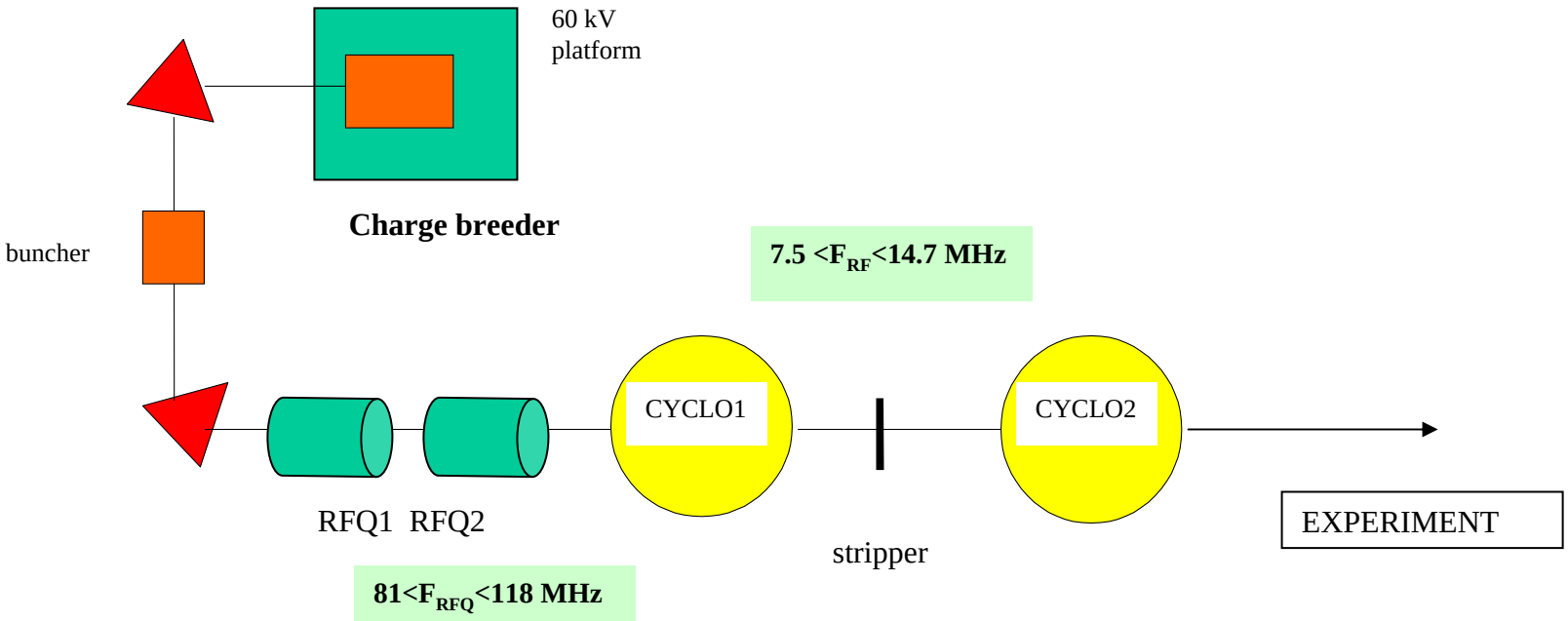


Layout of the RIB facility.

PUBLIC CAO HALL 222

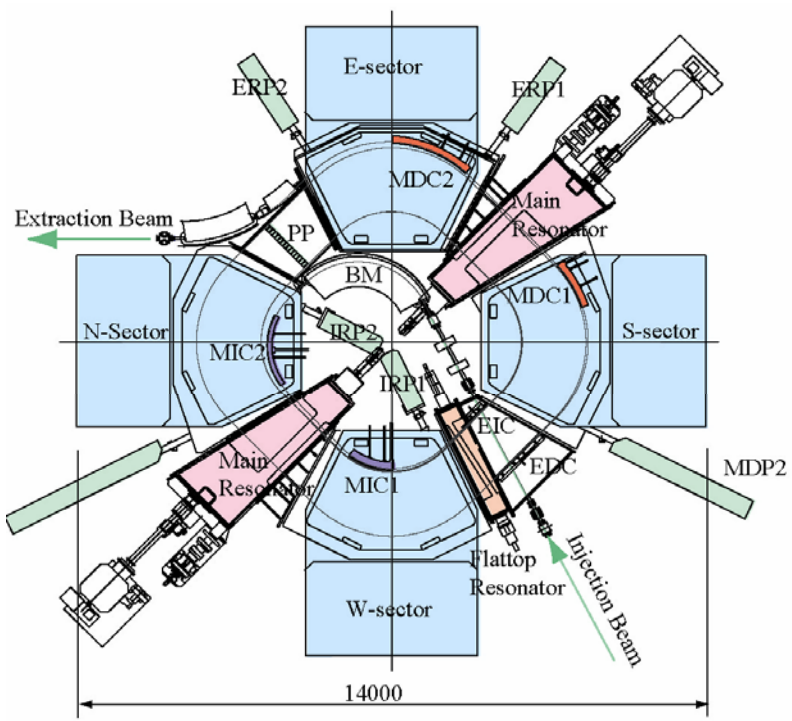
First Meeting Eurisol Betabeams Task RAL 17-01-2004

Room temperature cyclotrons



Specification of RIKEN IRC

Plan view

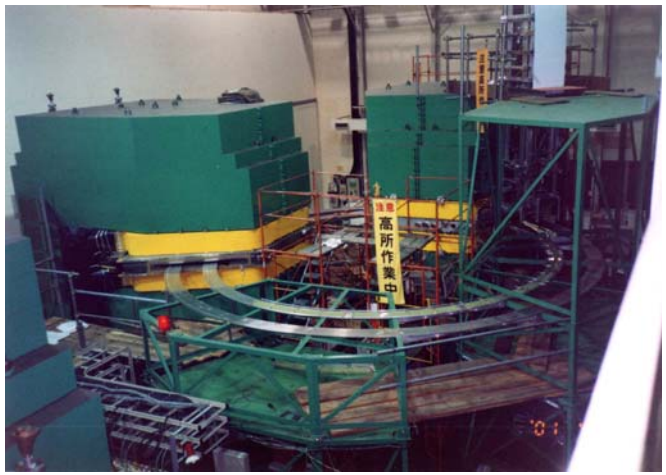


MDP: Main Differetial Probe PP: Phase Probe
IRP: Injection Radial Probe ERP: Extraction Radial Probe

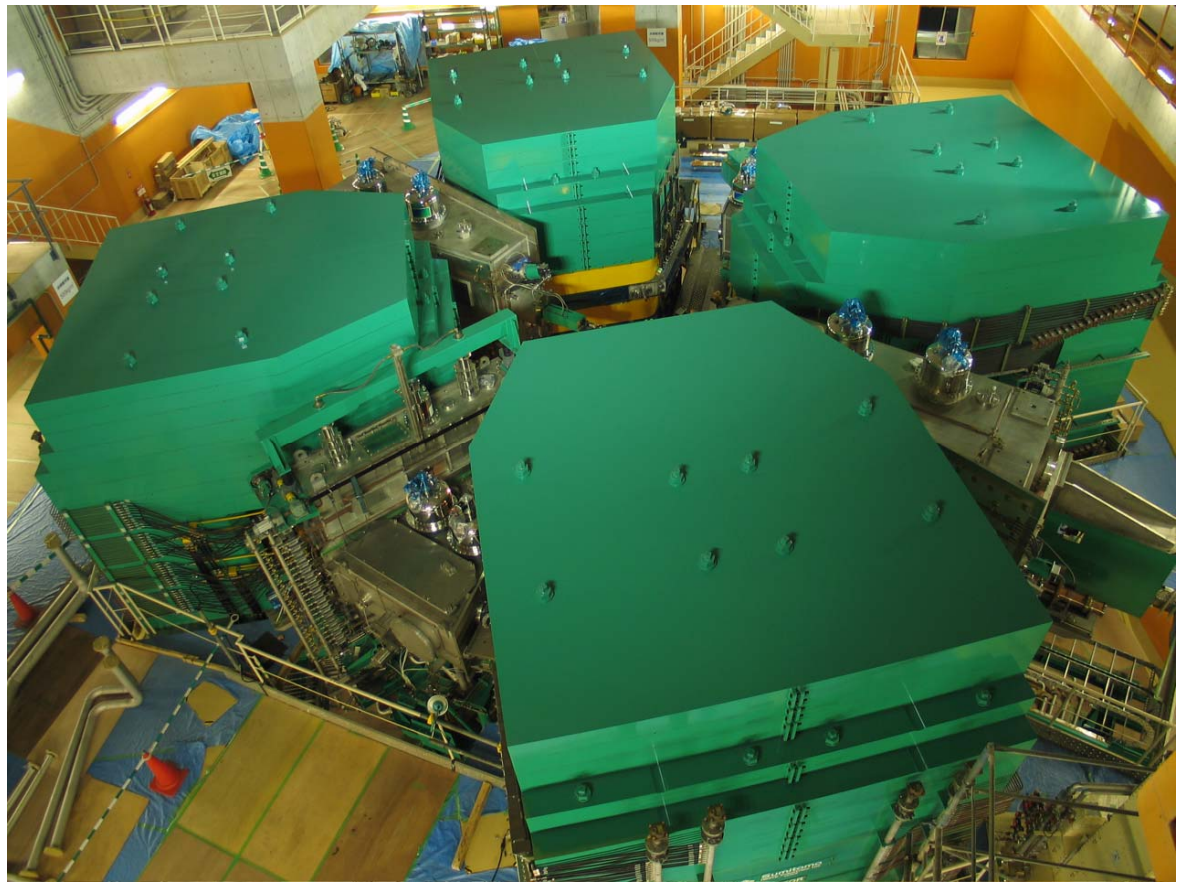
Specifications

K-value	980 MeV
No. of sector magnets	4
Sector angle	53 deg
Mean injection radius	2.77 m
Mean extraction radius	4.15 m
Maximum magnetic field	1.9 T
Total weight of magnets	2,720 t
No. of RF resonators	2 +1 (Flattop)
RF frequency	18 - 38 MHz
Acceleration harmonics	7

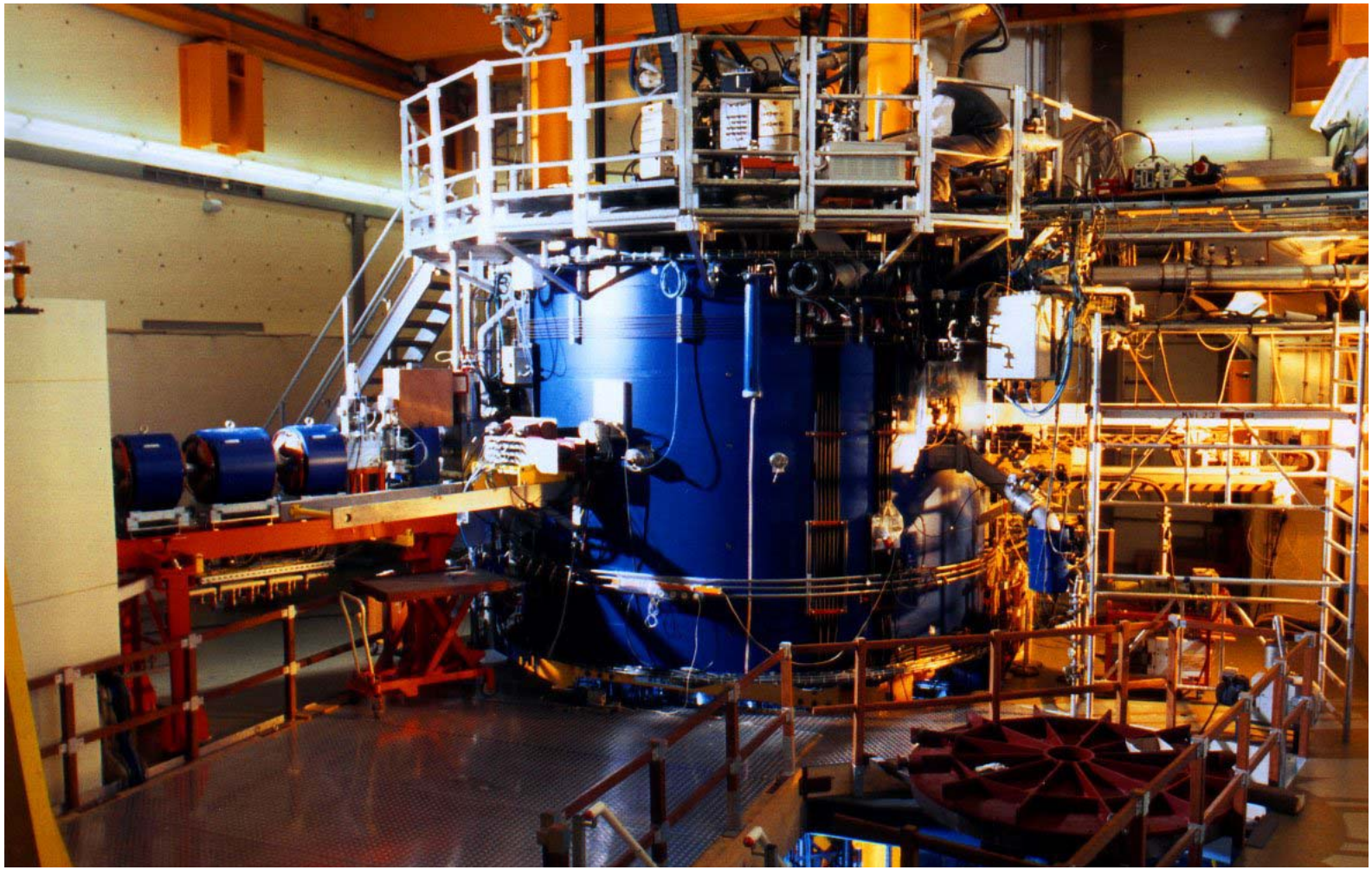
Magnetic field mapping at the factory



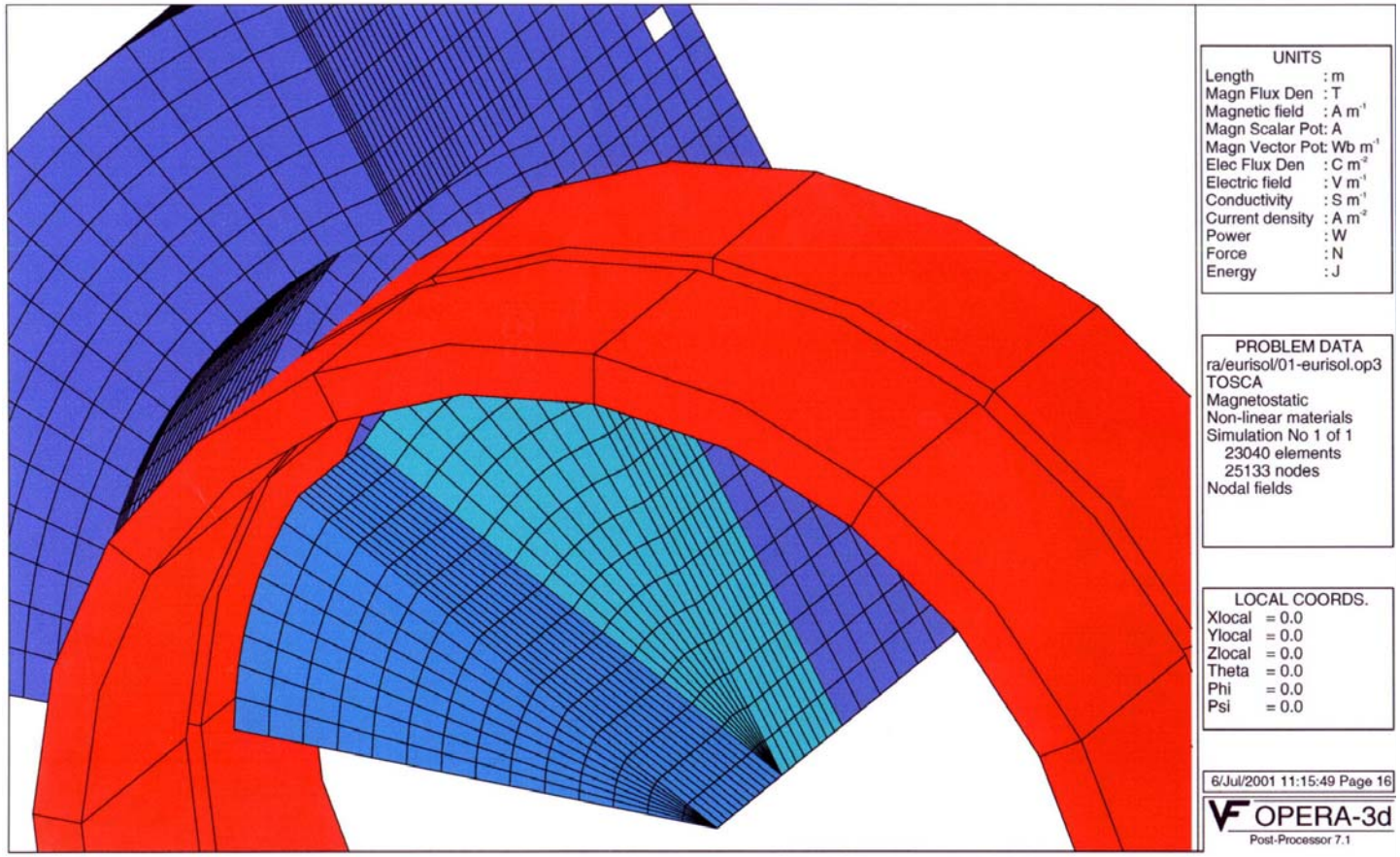
Assembled IRC at RIKEN

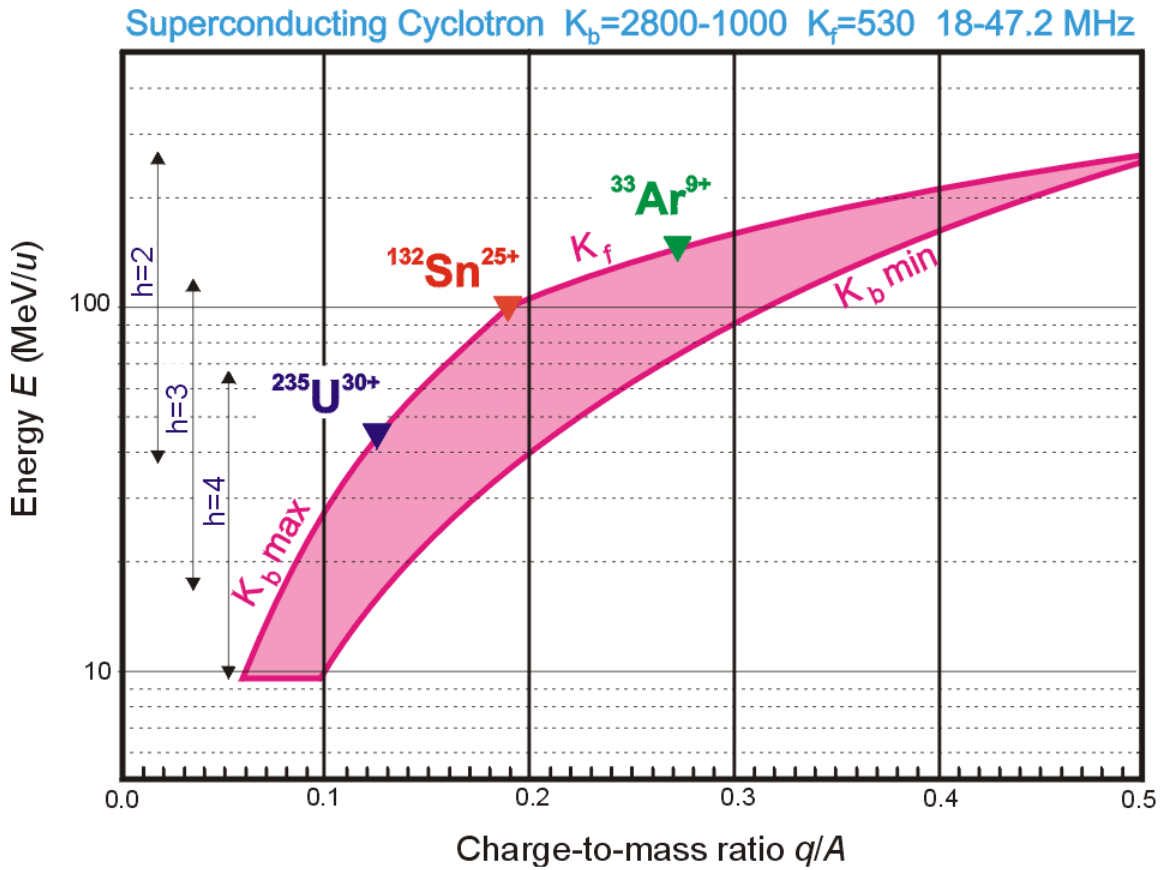


AGOR K600



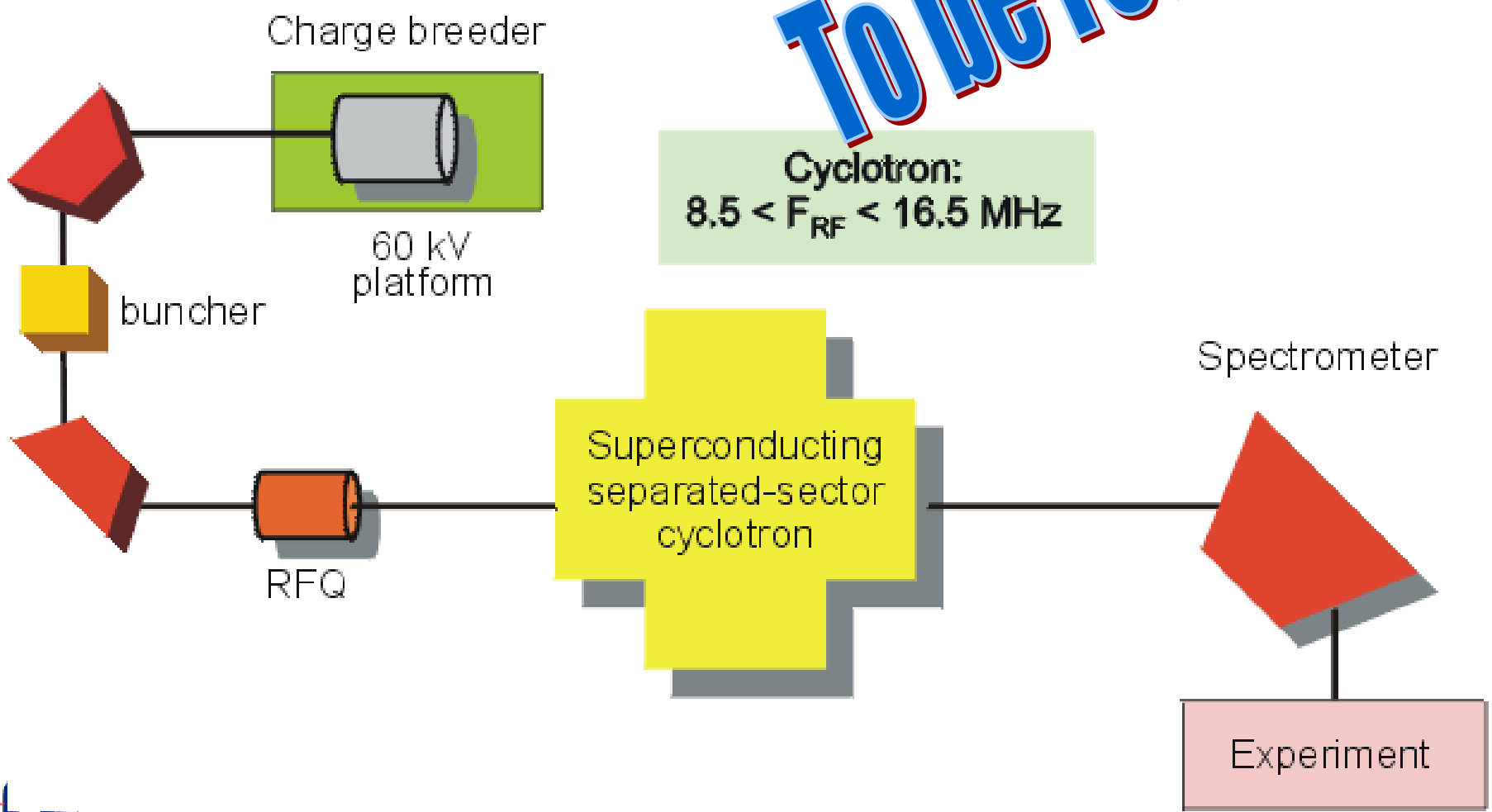
Compact superconducting cyclotron



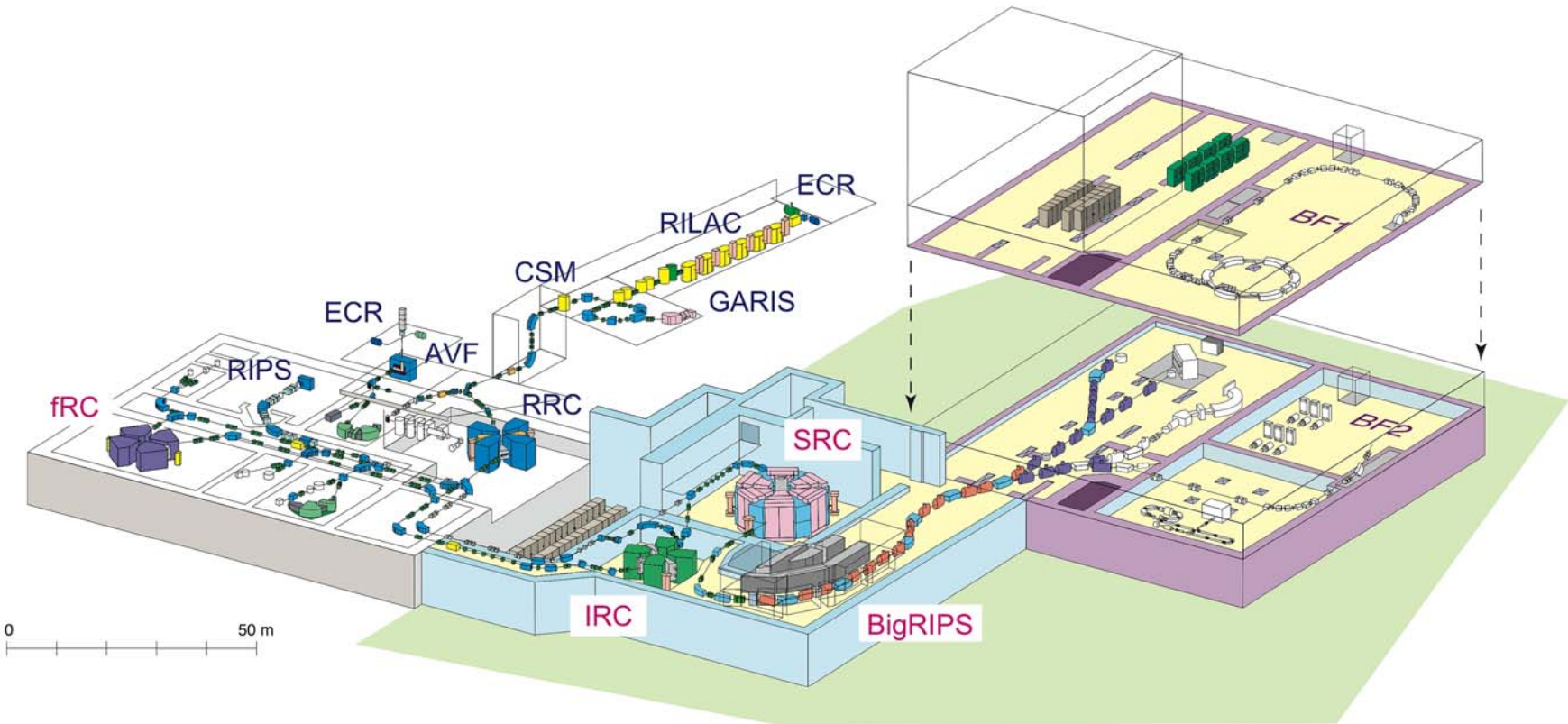

Superconducting Cyclotron K_b=2800-1000 K_f=530 18-47.2 MHz
Energy E (MeV/u)
Charge-to-mass ratio q/A
100
10
0.0
0.1
0.2
0.3
0.4
0.5
h=2
h=3
h=4
$^{33}Ar^{9+}$
$^{132}Sn^{25+}$
$^{235}U^{30+}$
K_f
K_b min
K_b max

Superconducting SSC

To be revisited



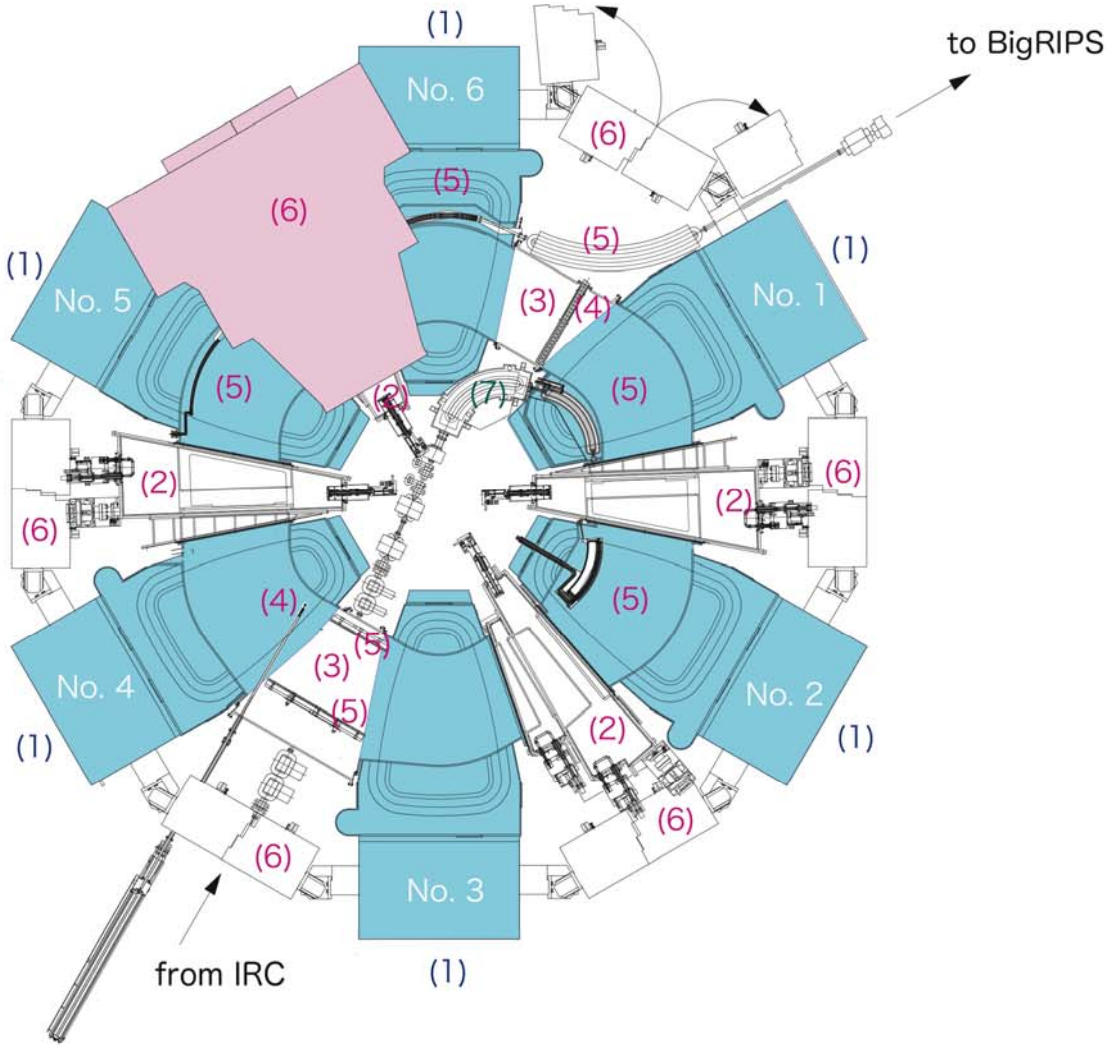
RIKEN


ECR
RILAC
CSM
GARIS
ECR
AVF
RIPS
fRC
RRC
SRC
IRC
BigRIPS
BF1
BF2
0
50 m

RIKEN SRC

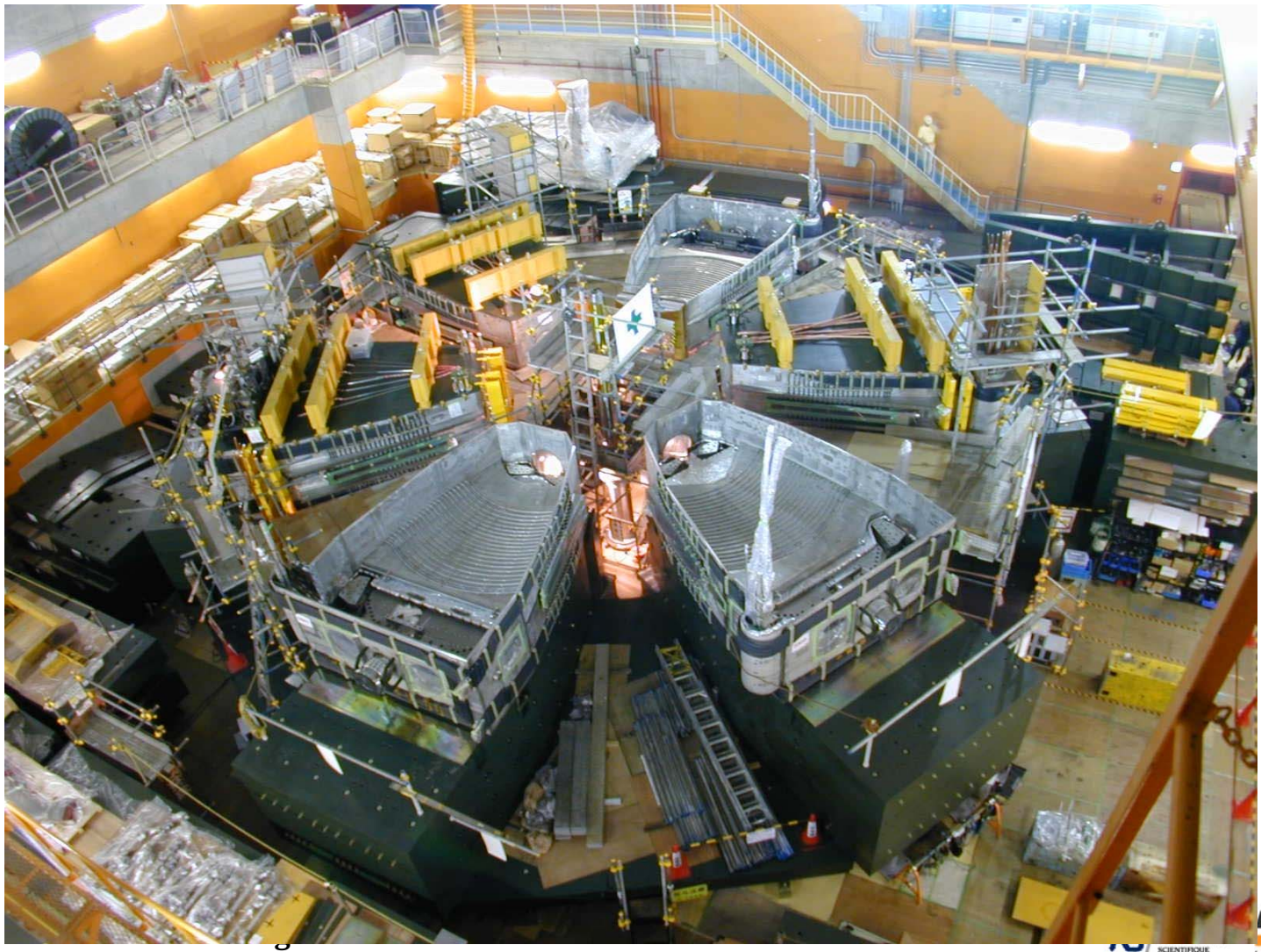
Superconducting Ring Cyclotron (SRC) Plan View

(1) Superconducting Sector Magnet
(2) rf-Resonator
(3) Vacuum chamber in the valley region
(4) Beam Monitoring System
(5) Beam Injection and Extraction System
(6) Magnetic and Radiation Shield
(7) Superconducting Bending Magnet



3.8T (240 MJ)
RF : 18-38 MHz
Weight: 8,300 tons
Diameter : 19 m
Height : 8 m

RIKEN SRC



Comparison

	2 RT Cyclotron	SC compact cyclotron	SC SSC	SC Linac
Energy range (MeV/n)	2.9 –11.2 23 -106	10-250	24-250	continuous
independent linac for low-energy beams (10 MeV/n)	To be discussed	YES	YES	NO
Bunch time length (ps)	500 -1000	500 - 1000	500 - 1000	100
Overall transmission	10%	10 to 15 %	50%	
Total cost (M€) Including 10 MeV/u	83 M€	69 M€	102 M€	78 M€
Cost/'1%	8 M€/%	7 M€/%	2 M€/%	1.1 M€/%
Separation of RIB*	YES :<1,2.10^{-4}	YES : 1.10^{-4}	YES : 5 10^{-5}	NO
Comments	RFQ to be developed	Restricted Range	RFQ to be dev'ed,Injector?	

Conclusion of Eurisol feasibility study

- 2 RT SSC cyclotrons with stripping
- 1 SC SSC without stripping (cyclotron injector probably necessary)
- 1 SC compact cyclotron

- **LINAC selected :**

- Energy range
- Flexibility
- Efficiency (X-charge state acceleration)
- Bunch length properties

Betabeams Cyclotron option

- Injection into PS : $^{10+}Ne^{18}$ and $^{6}He^{2+}$ 300 MeV/u

  $B\rho$ = 4.9 and 8.1 T.m resp.

  $\Rightarrow$ in the state-of-the-art range

- production of lower charge state, necessity to pre-accelerate for efficient full stripping (10 MeV/u minimum, then 22 MeV/u?)

  $\Rightarrow$ Superconducting SSC

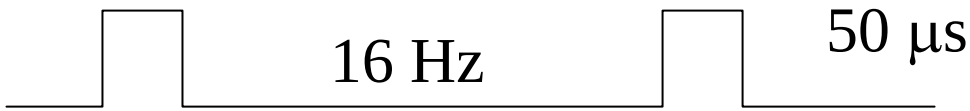
- Cyclotron 20 to 300 MeV/u?

Cyclotron 20 to 300 MeV/u

- Emax/Emin ≈ 15, Rmax/Rmin ≈ 4, too large
- Intermediate stage necessary : cyclotron or higher in EURISOL linac energy?
- check : matching, cost, tuning
- Time structure : assuming 30 MHz RF frequency

  ⇒ 0.5 – 1 ns bunch length

  cyclotron keeps time structure (CW) but debunching?
- Intensity required :
  - Average : 2.7 μA (He) 3.2 μA (Ne)
  - Peak : 3.4 mA (He) 4. mA (Ne) Space charge regime!



Conclusion

- Cyclotron option seems possible

However :

- String of machines : linac +cyclotron(s)
- Seems close to limits : bending, space charge?
- Cost, complexity, tuning?
- interest @ 50 MeV/u ?

$^{18}Ne^{3+}$ and $^{6}He^{1+}$ $B\rho = 6.2$ T.m Kb ≈ 1800
$^{18}Ne^{10+}$ and $^{6}He^{2+}$ $B\rho = 3.4$ T.m Kb ≈ 550

Discuss in details the requirements and issues!