Heavy ion accelerator facility for the rare isotope beam productions

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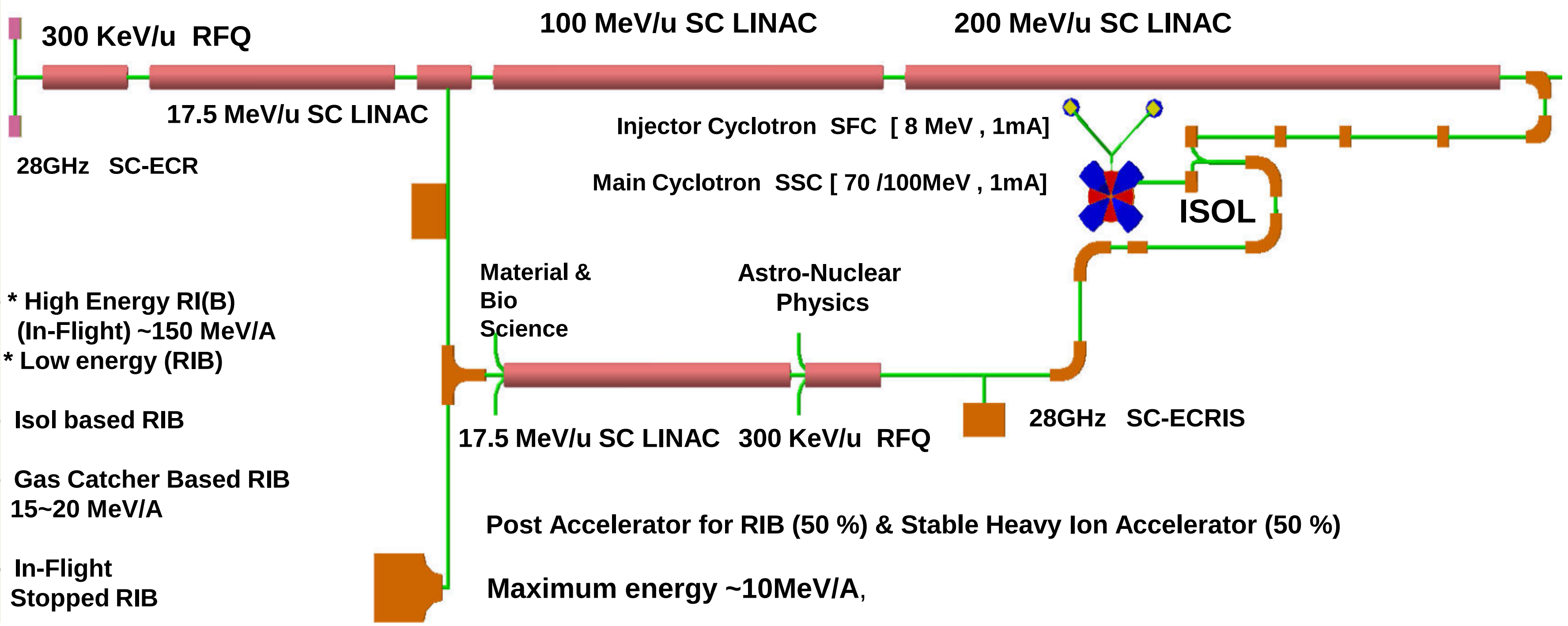
Overview

- Basic Concept of KoRIA Facitlity
- Technical issues in the accelerator design
  - Cyclotron
  - ISOL
  - Ion sources
  - RFQ
  - Low Energy SC LINAC
  - High Energy SC LINAC
  - Beam Instrumentation and Control System
- Summary

Basic Concept KoRIA facility



① * High Energy RI(B)
(In-Flight) ~150 MeV/A
* Low energy (RIB)

② Isol based RIB

③ Gas Catcher Based RIB
15~20 MeV/A

④ In-Flight
Stopped RIB

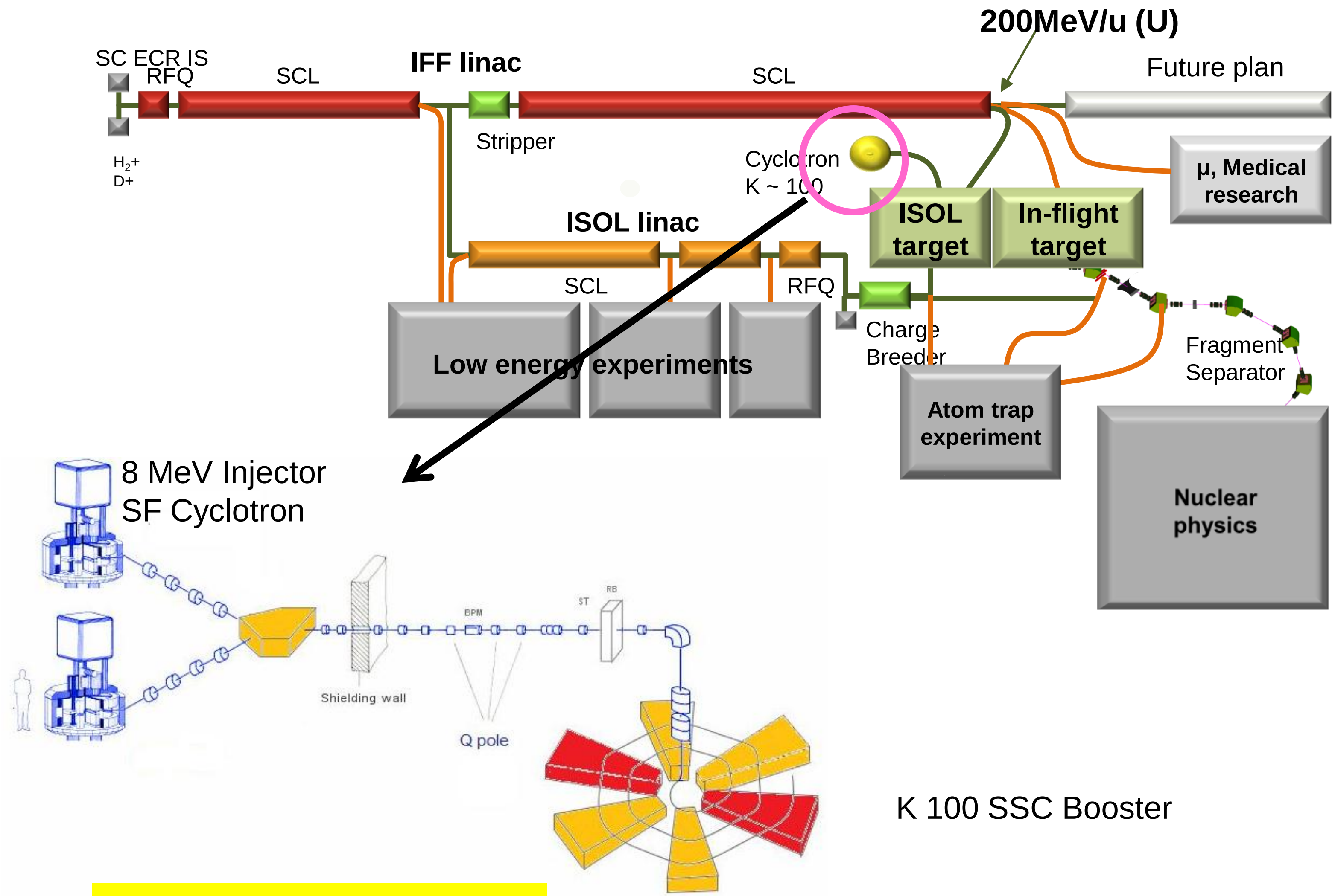
→ Laser spectroscopy
(Mass measurement)

Post Accelerator for RIB (50 %) & Stable Heavy Ion Accelerator (50 %)

Maximum energy ~10MeV/A,

Cyclotron

Cyclotron

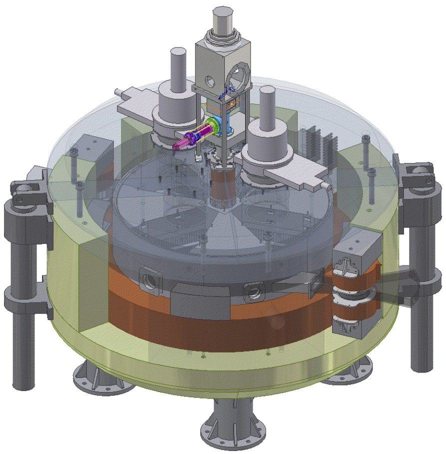


Cyclotron layout of ISOL

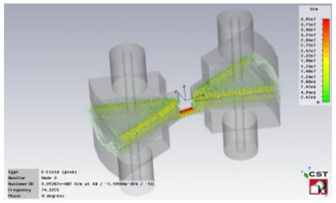
Cyclotron

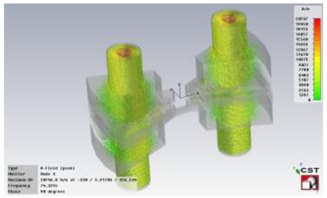
Injector SF Cyclotron

- 8 MeV SF Cyclotron
- 4 Sector Magnet
- Deep Valley
- 4 th Harmonics
- Expected Beam Intensity : 500uA ~ 1 mA



Layout

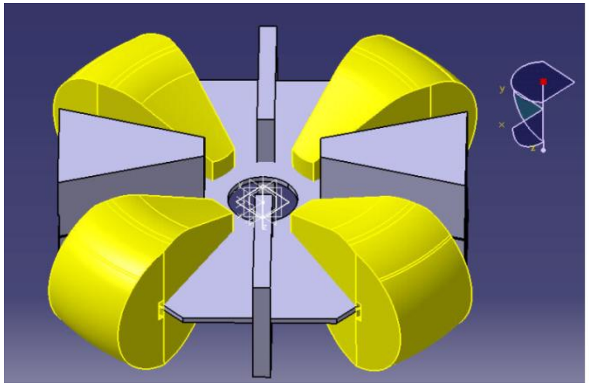


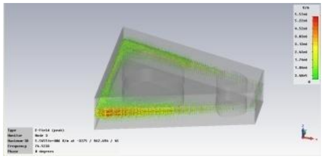


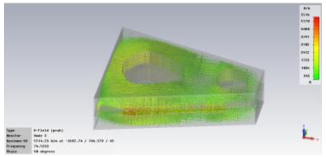
Field analysis

K100 SSC Cyclotron

Injection Energy	8 MeV
Extraction Energy	70/100 MeV
Beam intensity	1 mA
RF- Frequency	60 MHz
External diameter	6 m







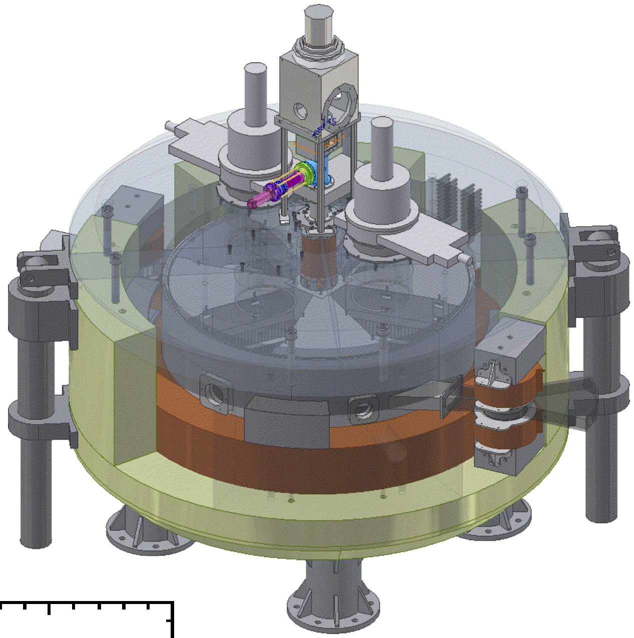
Specifications of SF and SS Cyclotron

	Parameters	Values
Ion source	Multi-cusp DC Type	
	Max. Extracted Beam Current	15mA
	Max. Arc Volt.	150V
	Type of Extracted Ion	proton, deuteron
Injector System	Buncher Max. E-potential	200 V
	Solenoid-Q doublet OP. power	35W
	Inflector electrode potential	10 kV
Magnet	Pole/Extraction Radius	0.4m / 0.35m
	Diameter	0.8 m
	Hill Angle	48°
	Center field	1.15T
	Max./Min B field	0.3T / 1.95T
RF System	Frequency/ Harmonics Number	74.3MHz/4th
	Dee Number/Dee angles	2 /40°
	Dee Voltage/Q-value	50kV/5981

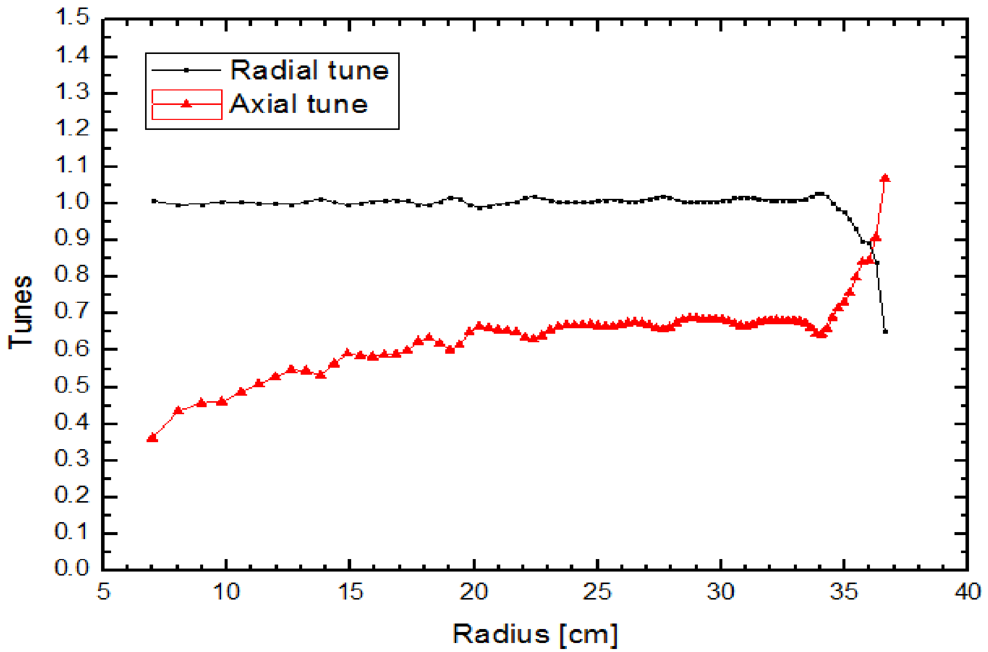
	Parameters	Values
Beams	Extraction Energy	70 MeV/100 MeV
	Estimated maximum beam intensity with 1 injector	1mA
	emittance	4mm mπrad
	Type of Extracted Ion	proton, deuteron
Magnet	Pole radii – r_{min}/r_{max}	1 m / 4.3 m
	External radius	2.4 m
	Number of magnet sectors	4
	Magnetic gap	3 cm
	Sector angle on injection radius	30 deg.
	Approx. total iron weight	300 Tons
	Average field	0.565 T
	Relative Field variation	0.54-0.59 T
RF System	Frequency/ Harmonics Number	74.3MHz/6th
	Type of resonator	Double
	Dee Number/Dee angles	2/ 28 degree
	Q-value	14292
	Peak Voltage (Inj./Ext.)	150 /200 KVolts
	Peak radial gain/ turn (Inj./Ext.)	50 / 20 mm
	Estimated total accelerator efficiency	22 %

Injector SF Cyclotron

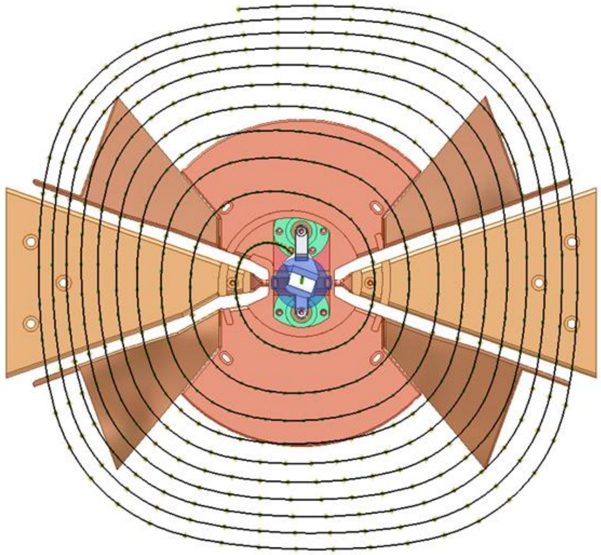
8 MeV SF Cyclotron
4 Sector Magnet
Deep Valley
4 th Harmonics
Expected Beam Intensity
500uA ~ 1 mA

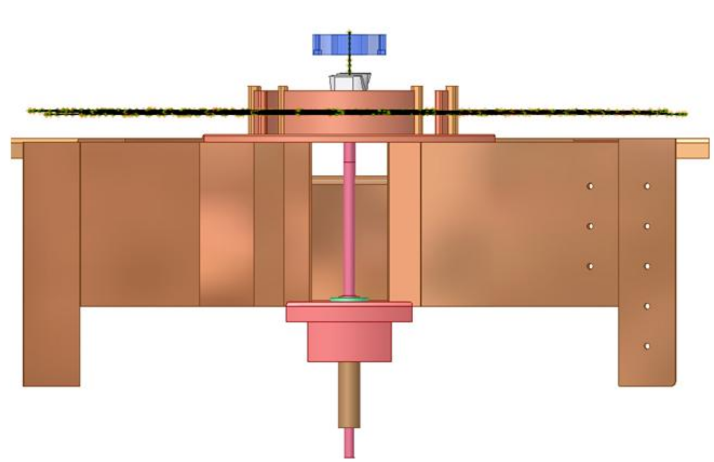


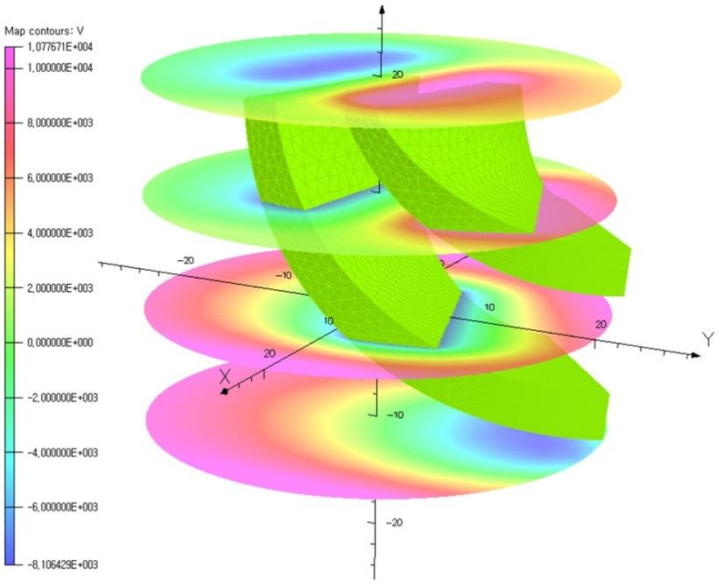
Radial and axial beam tunes

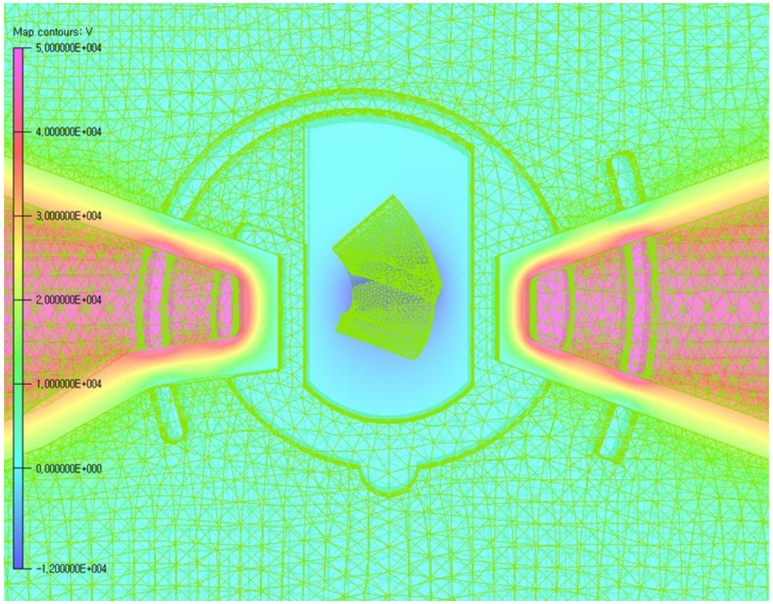


Central Region and Inflectors

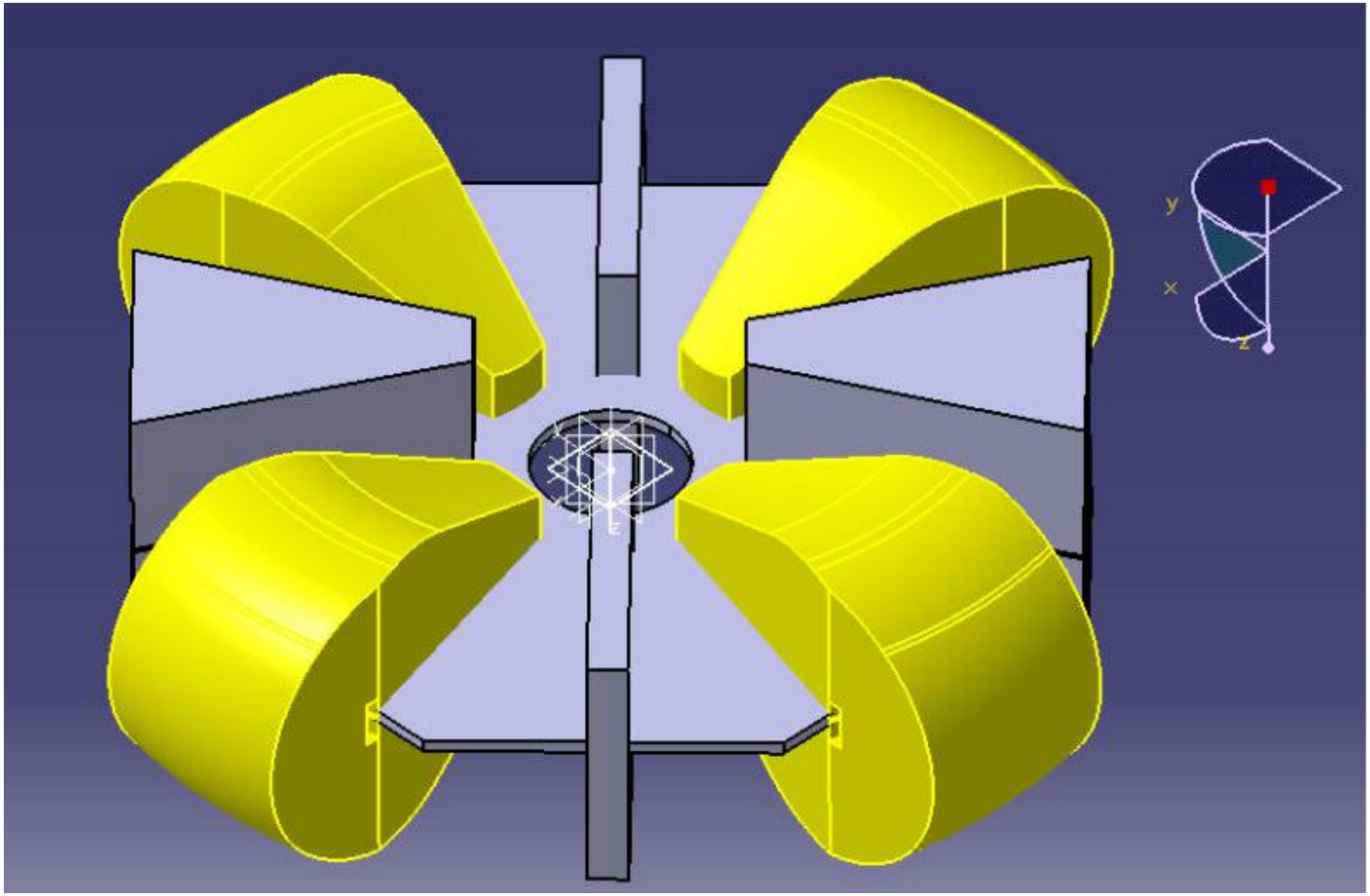




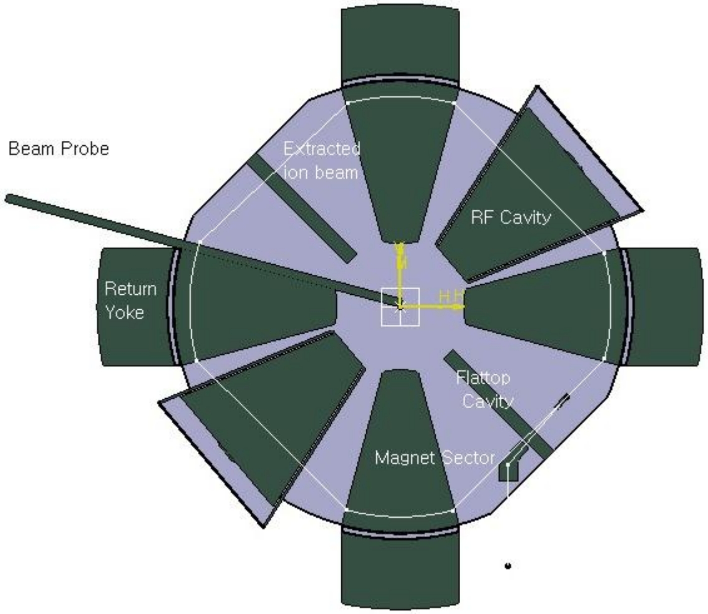




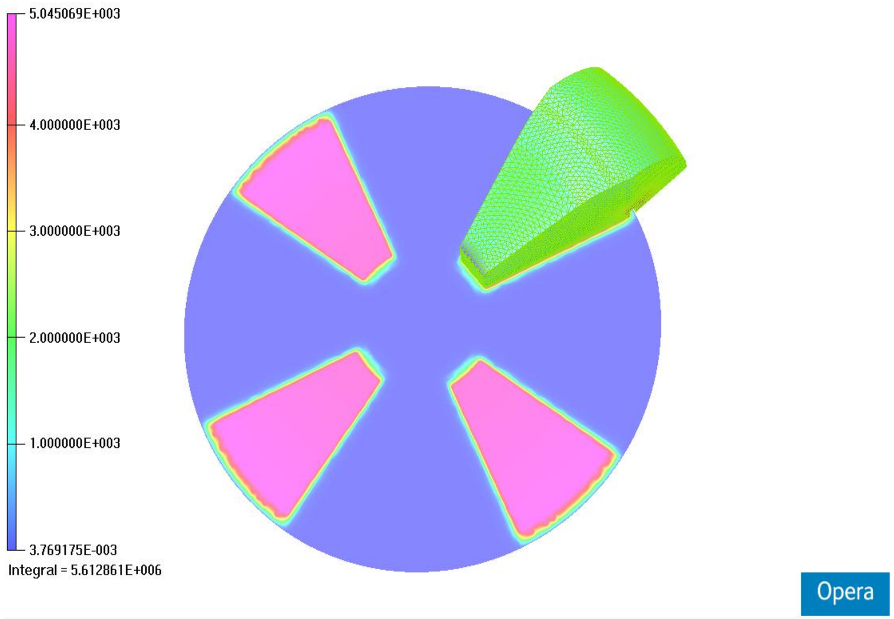
K100 Separated Sector Cyclotron

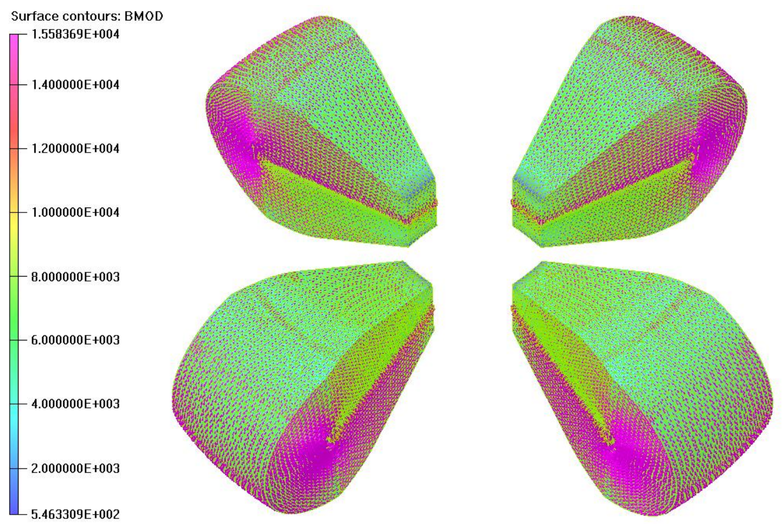


Layout of SSC

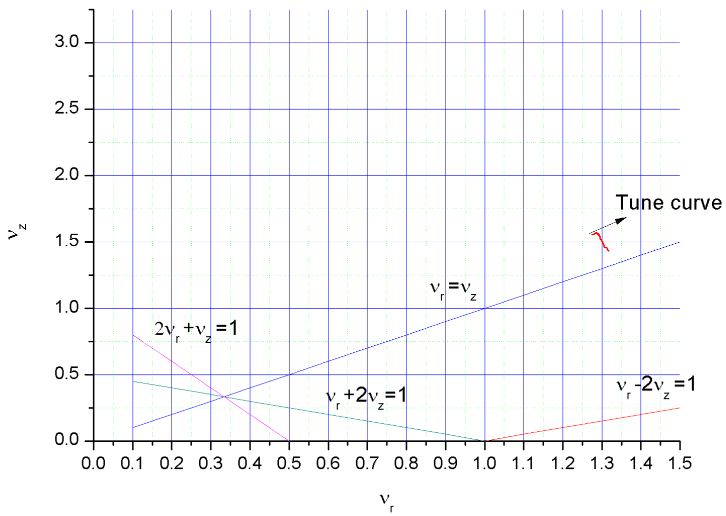


TOSCA magnet simulation

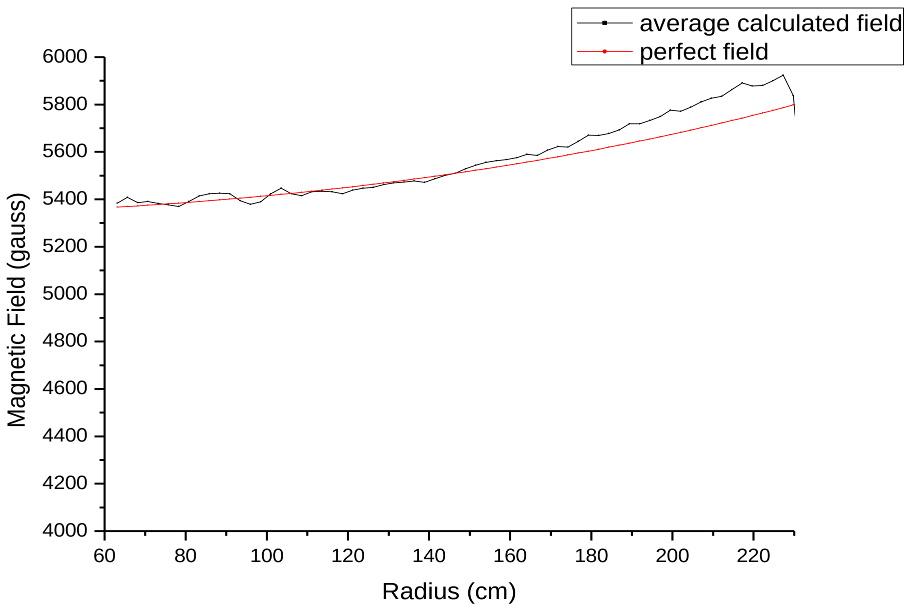




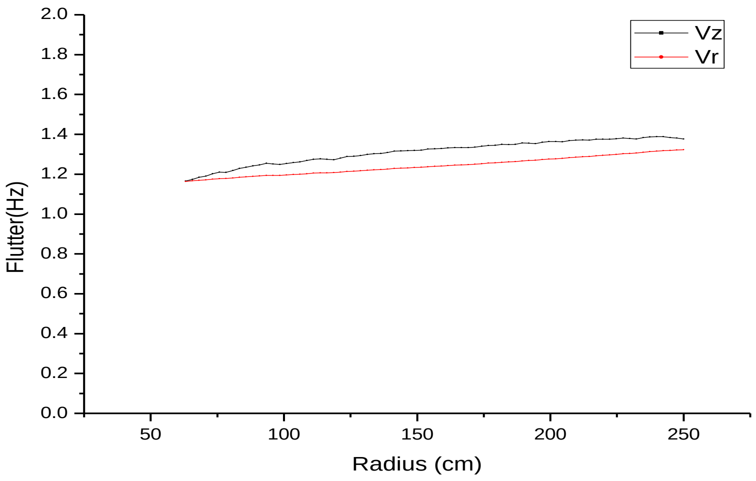
Tune diagram



Isochronous magnetic field



Flutters diagram



ISOL

Task

ISOL Target TASK

70 kW high power target

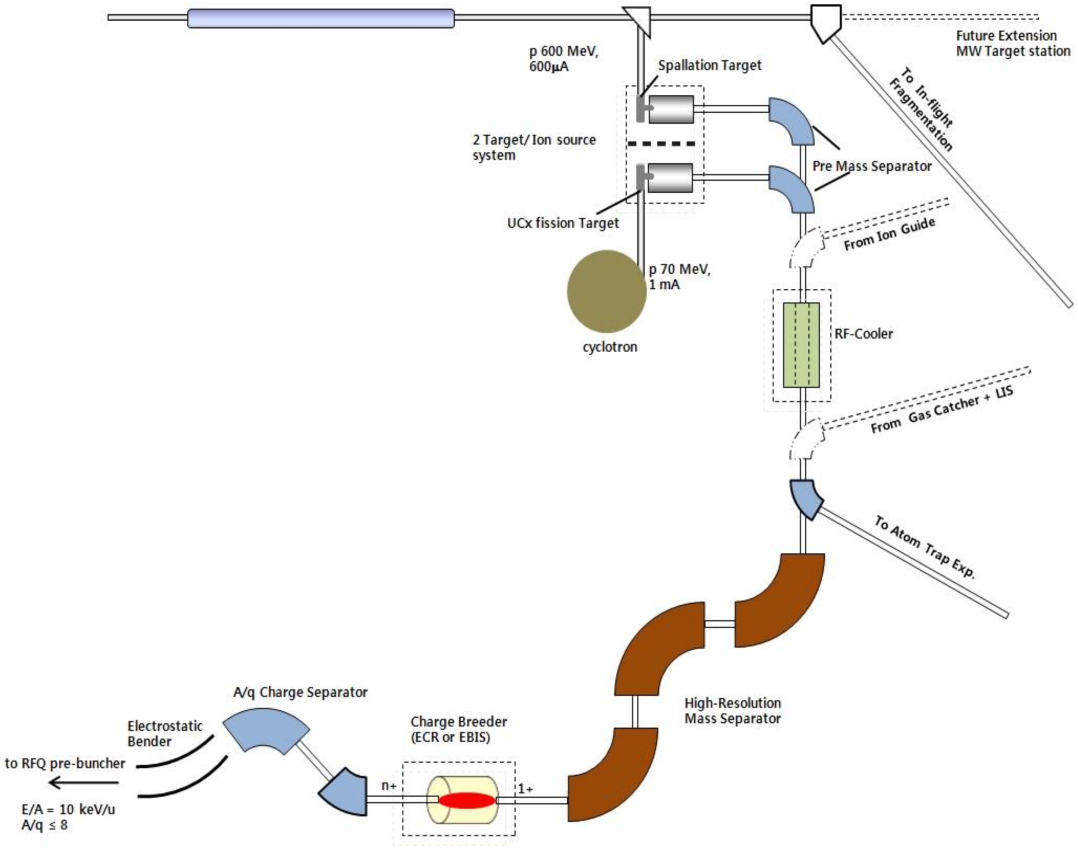
- 70 kW high power target
- Shielding
- Vacuum, cooling, venting
- Handling system
- Target area, etc

Scheme of RI Beam Extraction

- Pre separator
- RFQ cooler
- High resolution mass separator
- Charge breeder
- A/q separator, electric bender
- Transport system

The conceptual designs are/were studied to satisfy user’s requirement that is to provide high intensity and high quality of neutron-rich beams to experimental hall.

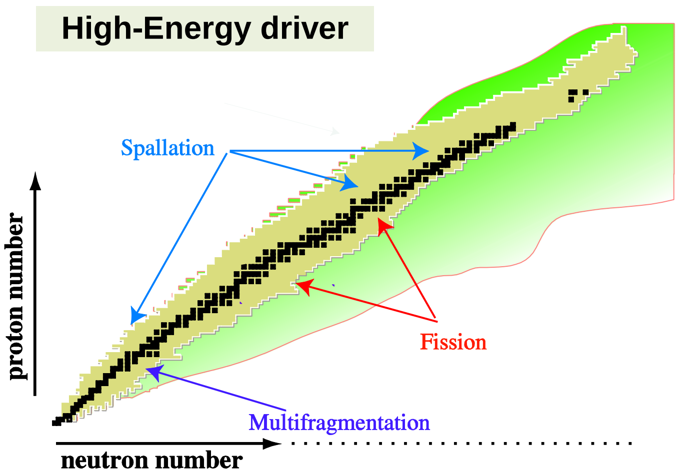
ISOL System

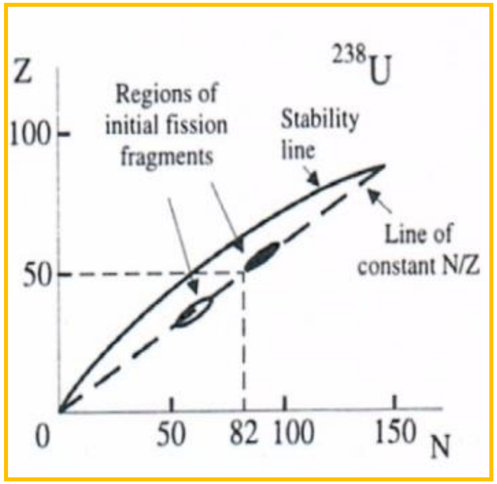


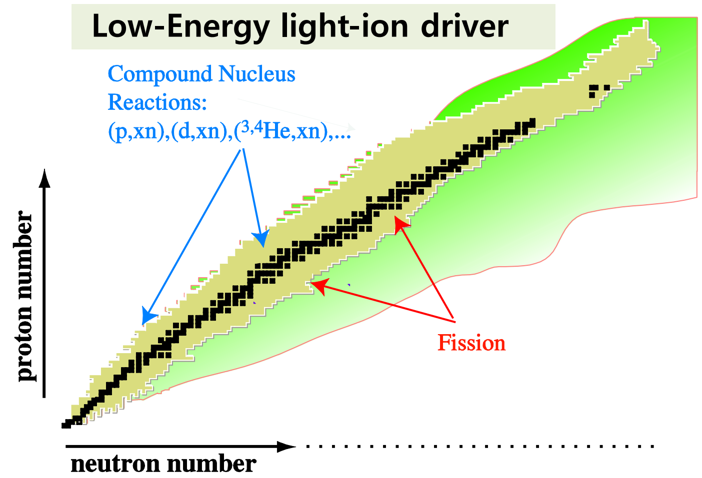
ISOL RIB Extraction system layout

Primary Beam	**70 MeV, p, 1mA**
Production Target	**70kW, direct multi-layered Disk UC_x ,2 .5 g/cm^3**
Yield on Target	**1.2 x 10^{14} fission/s, neutron-rich, 4 x 10^{11} /s for ^{132}Sn**
ISOL IS	**FEBIAD, Surface Ionization both RI except for refractory element**
ISOL system	**attach/detach system of IS/Target mo dule**
pre mass selector	**M/ΔM ~ 100 to increase beam quality**
RFQ-Cooler	**Energy spread < 4eV, Emittance ~3 π mm mrad Online transmission >60 %**
High Resolution M ass Separator	**M/ΔM ~45000**
Charge Breeder	**ECR and/or EBIS**
A/q separator	**(a/q)/Δa/q) >~3000**
beam injection on RFQ	**A/q < 8 for ECR, mostly 4<A/q<8 E/A = 10 keV/u ^{132}Sn ~10^8 /s, ^{138}Xe ~10^{11} /s**
Typical beam on experimental targe t	**^{132}Sn ~10^8 /s**

For n-rich RI Production







Fission reaction is best way to produce neutron-rich RIs, especially medium-mass region.

n-rich production rates w.r.t fission reaction and fragmentation reaction

TABLE I. Predicted NSCL secondary beam intensities for several nuclides, produced via fission of ^{238}U or fragmentation. See the main text for a discussion.

Nuclide	^{238}U Fission			Fragmentation			
	Yield (pps/pnA)	0.087 pnA Rate (pps)	5 pnA Rate (pps)	Primary Beam	Intensity (pnA)	Yield (pps/pnA)	Rate (pps)
^{134}Sn	4.0	0.35	20	^{136}Xe	2.0	3.3×10^{-5}	7.2×10^{-5}
^{114}Tc	2.6	0.23	13	^{124}Sn	1.5	0.019	0.028
^{105}Y	0.23	0.020	1.2	^{124}Sn	1.5	0.0030	0.0045
^{78}Zn	63	5.5	320	^{86}Kr	10	4.7	94
^{55}Sc	0.47	0.041	2.4	^{86}Kr	10	0.38	7.6

ISOL method using fissile material is more effective than In-Flight method to produce n-rich beams.

direct vs. converter target – SPES TDR

1-step: p 40 MeV 0.2 mA on multi-slice direct target (25 g UCx)

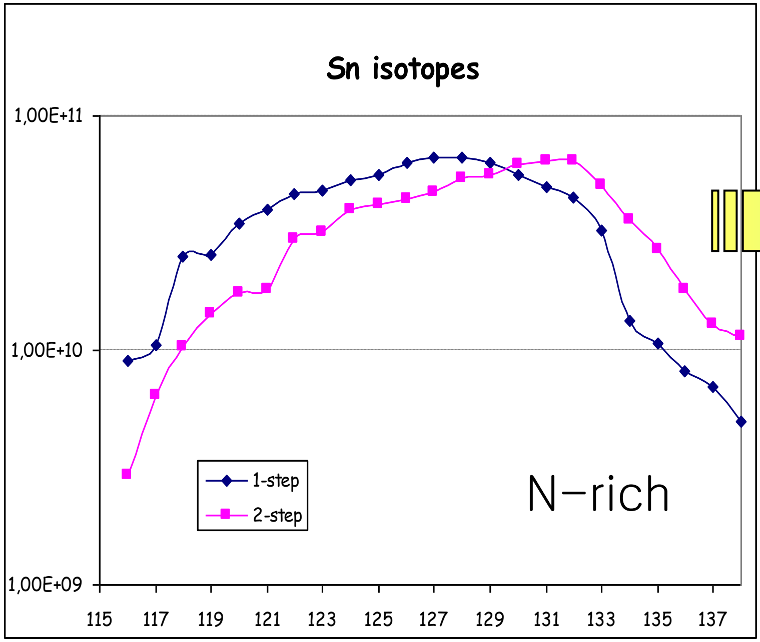
2-step: d 40 MeV 2mA on thick ^{12}C converter + UCx target (800 g)

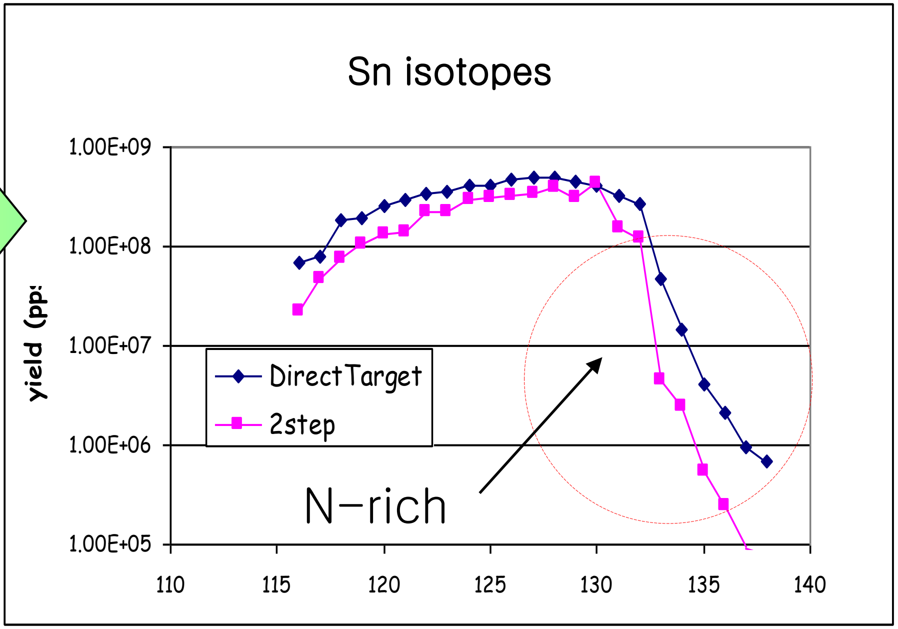
10^{13} fissions/sec

Release times considered:
1-step 2 s, 2-step 40 s

In-target production from M.C.

Beam intensities evaluated considering release, ionization and reacceleration efficiencies





Direct target have advantages to provide neutron-rich beams

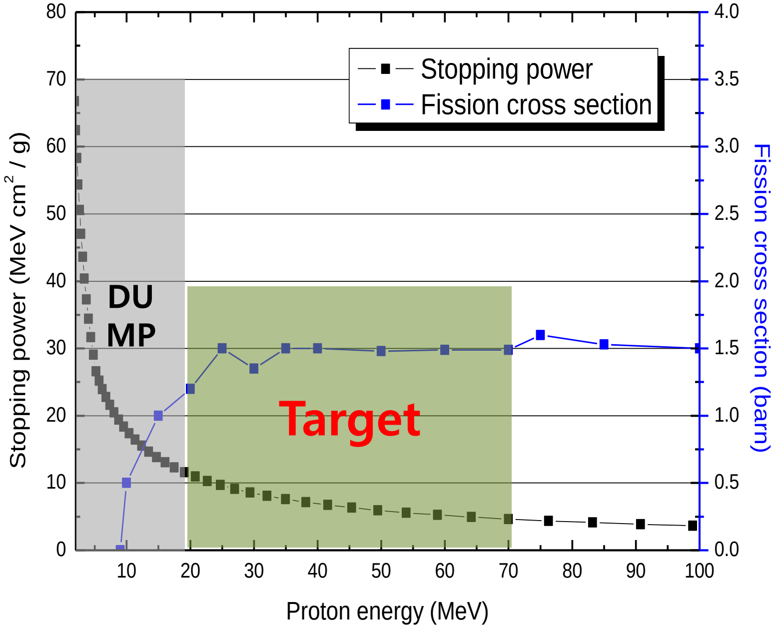
Design of ISOL Target

Requirement of ISOL target Optimization

- **high rate of fission reaction**
- **low power deposition in target materials**
- **Fast isotope release time to increase efficiency**

→ depends on mass, density, material, geometry

target Optimization →difficult task !!



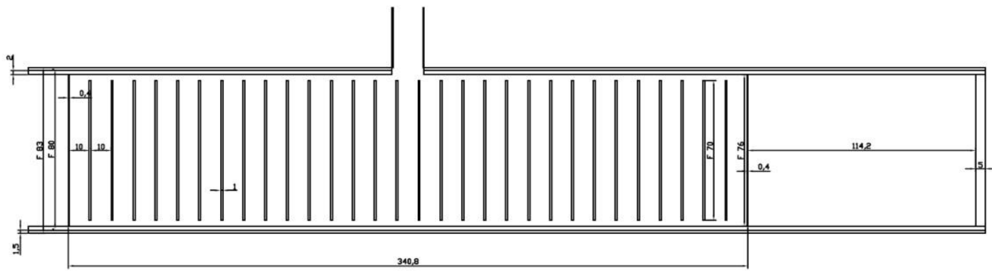
Fission cross-section vs. stopping power on proton

Critical Problem: how to dissipate the Power deposited in Target?

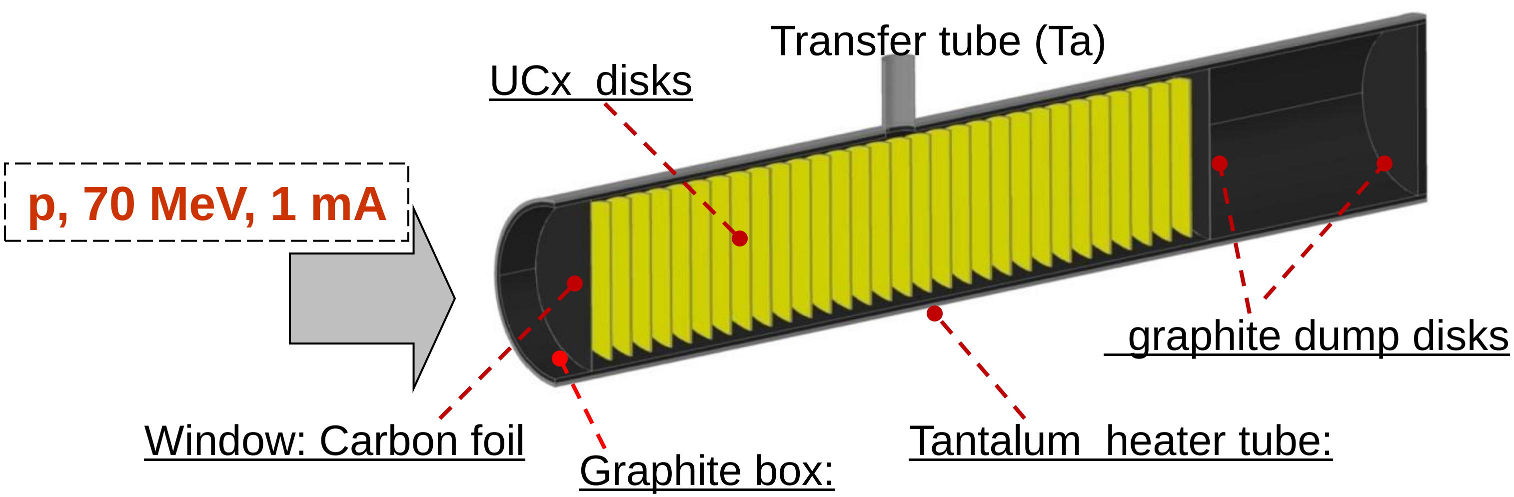
1) **MULTIPLE Layered** : increase the radiation surface area $P \propto ST^4$

2) **DUMP** : send the proton with low fission rate & high stopping power value

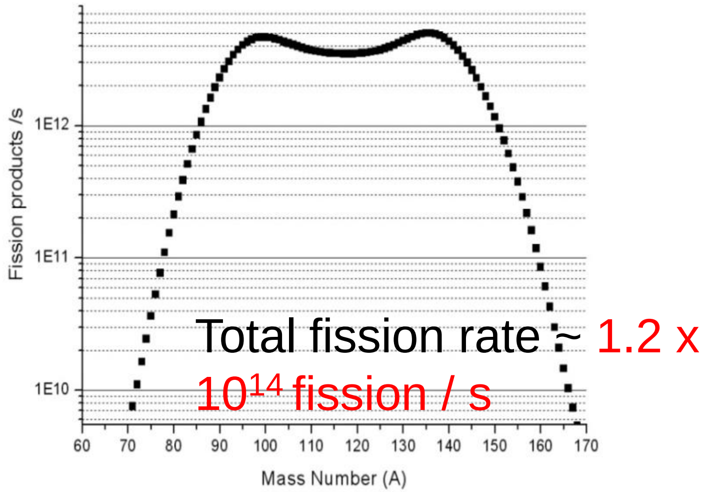
Design of High Power Direct Target



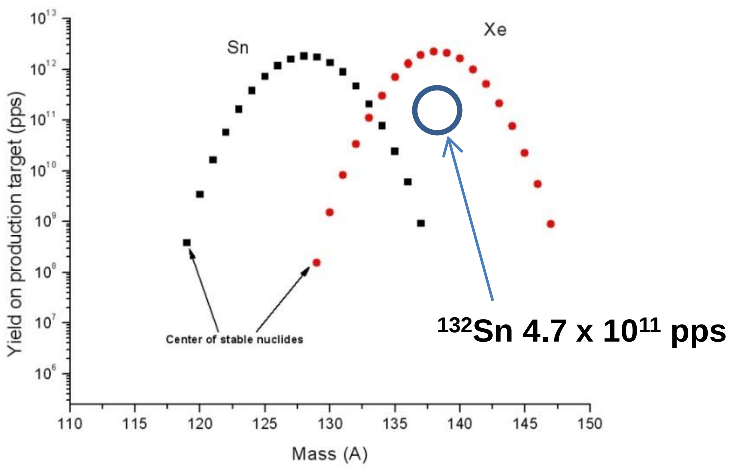
Target : UCx, 2.5g/cm^3
Disk diameter :Φ 7cm, 30 disk
Disk thickness : ~ 1 mm
effective length : ~ 30 cm
Deposit power : 33.3 W/cm^3
Power density : 130 W/g
Total deposit power on target : 36 kW
Beam Dump : graphite
Window : carbon foil
Tube: tantalum , Box : graphite
Total amount of U-238 : ~260g



Fragment mass distribution on production target



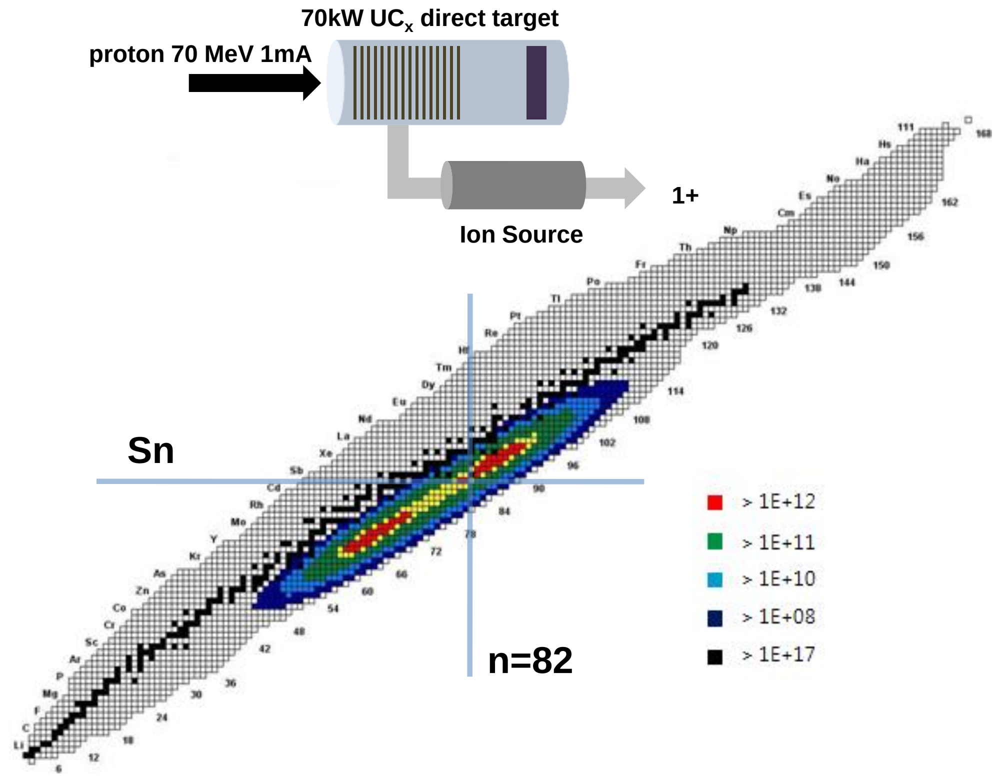
Expected fission mass spectra yields



Yields of Sn and Xe on production target

Simulation of p(^{238}U, f)

- Model: MCNPX and ETFSI fission model
- Driver: k=100 cyclotron
- Beam: 70 MeV, 1mA proton
- Target: UC_2 of 2.5 g/cm^3 and 3 cm thickness

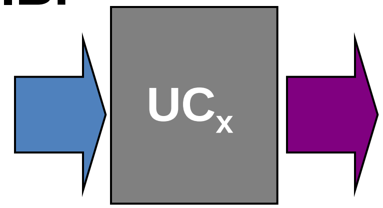


Fission product Mass Distribution KoRIA-ISOL

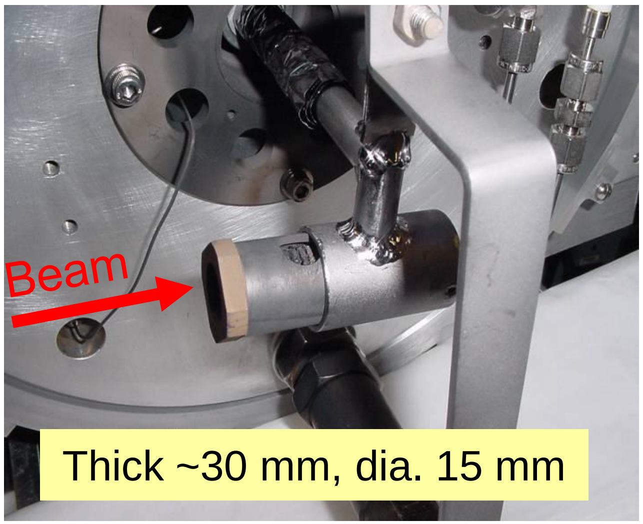
Expected yield of RIBs on Experimental target

-HRIBF

HRIBF-ORNL p, 40 MeV, 10 μA



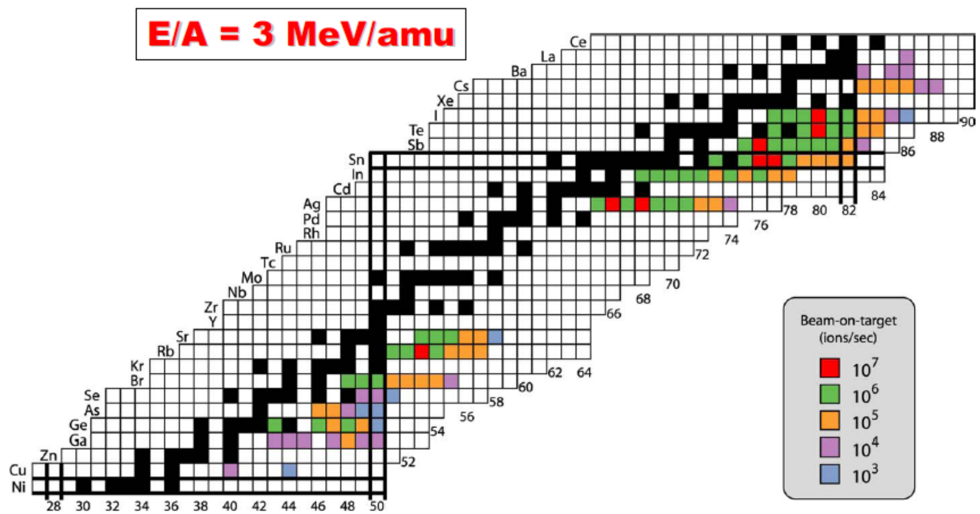
Fiss./s ~ 4 x 10^{11}



- Total of 1200 hours operation with 10 μA of 40 MeV protons
- More than 120 different RIBs extracted

Available Neutron-rich Radioactive Ion Beams

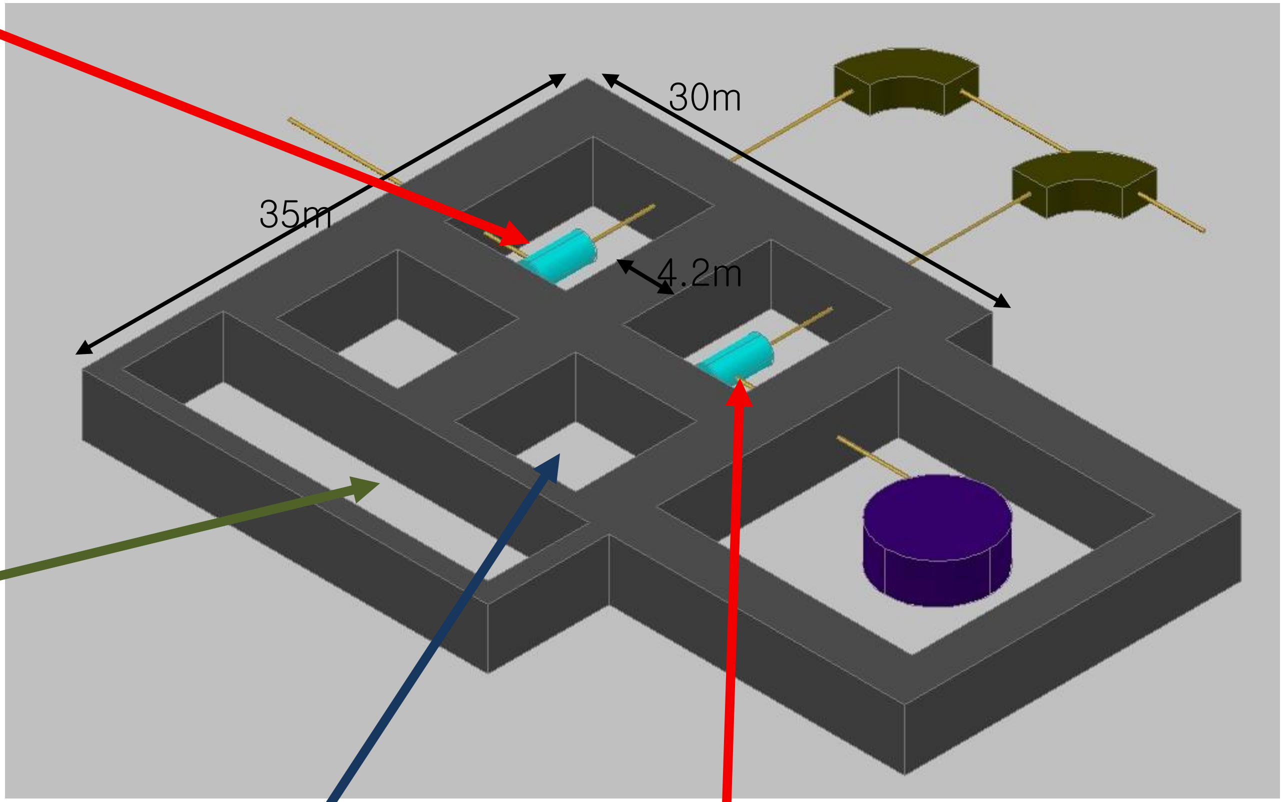
(over 100 beams with intensities ≥10^3 ions/sec)



We expect that more than 2 order of intensity isotopes could be provided on KoRIA Exp. hall than HRIBF.

ISOL Target Area

600 MeV proton
Spallation target Front end area

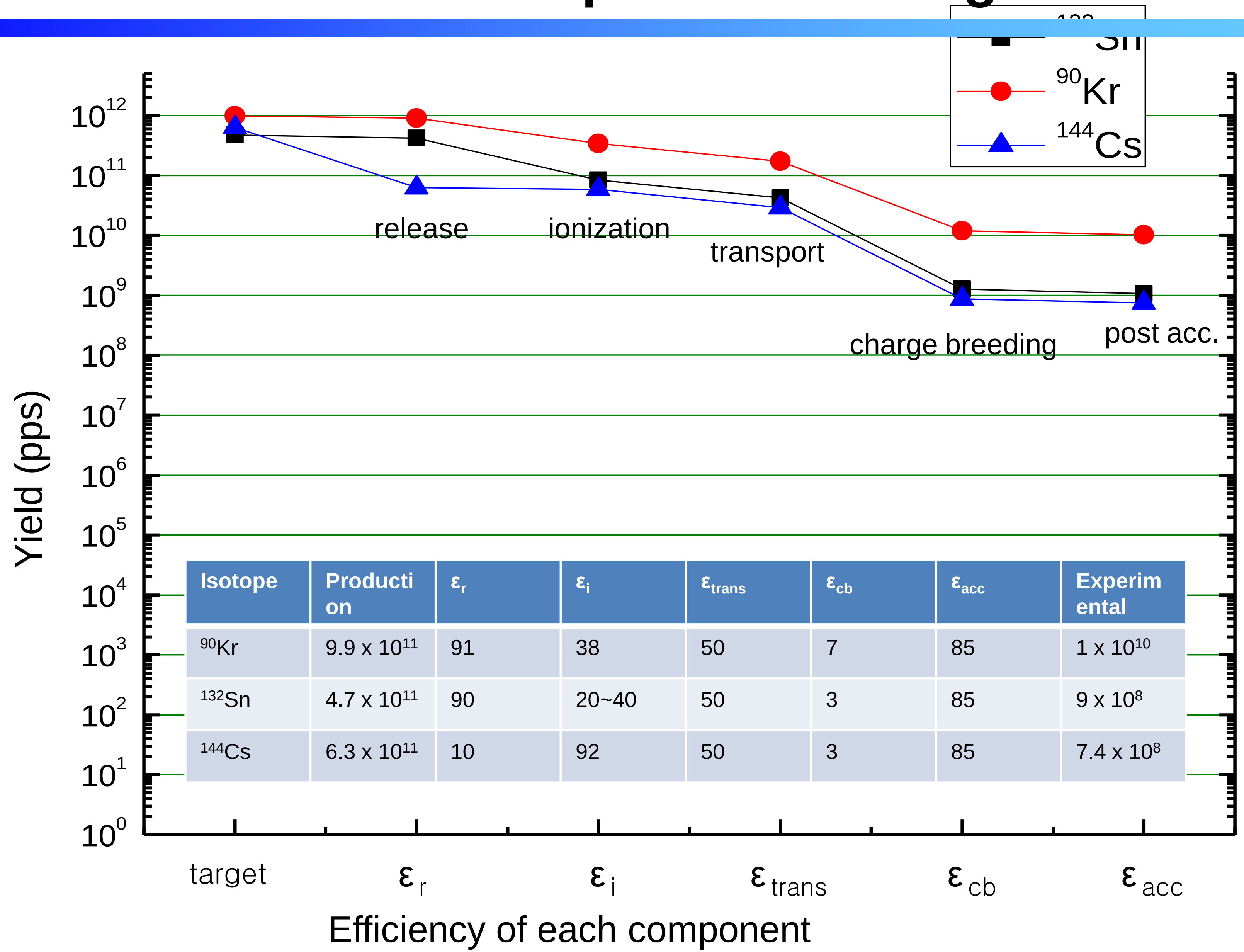


Services Zone

Handling Zone

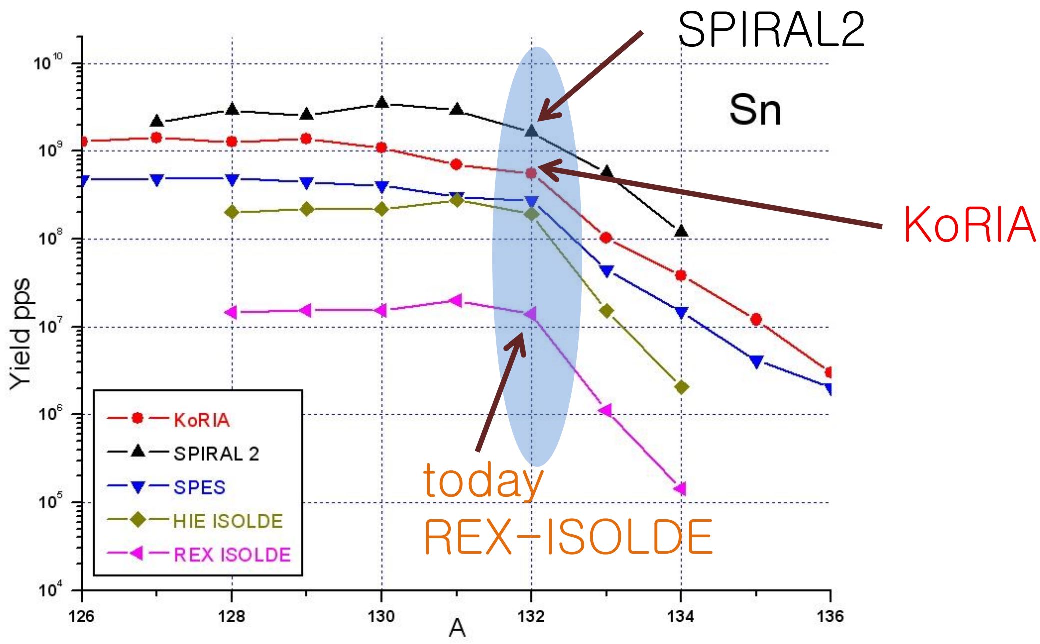
Fission target Front end area

Yield estimation on experimental target



Isotope	Production	ε_r	ε_i	ε_{trans}	ε_{cb}	ε_{acc}	Experimental
^{90}Kr	9.9×10^{11}	91	38	50	7	85	1×10^{10}
^{132}Sn	4.7×10^{11}	90	20~40	50	3	85	9×10^{8}
^{144}Cs	6.3×10^{11}	10	92	50	3	85	7.4×10^{8}

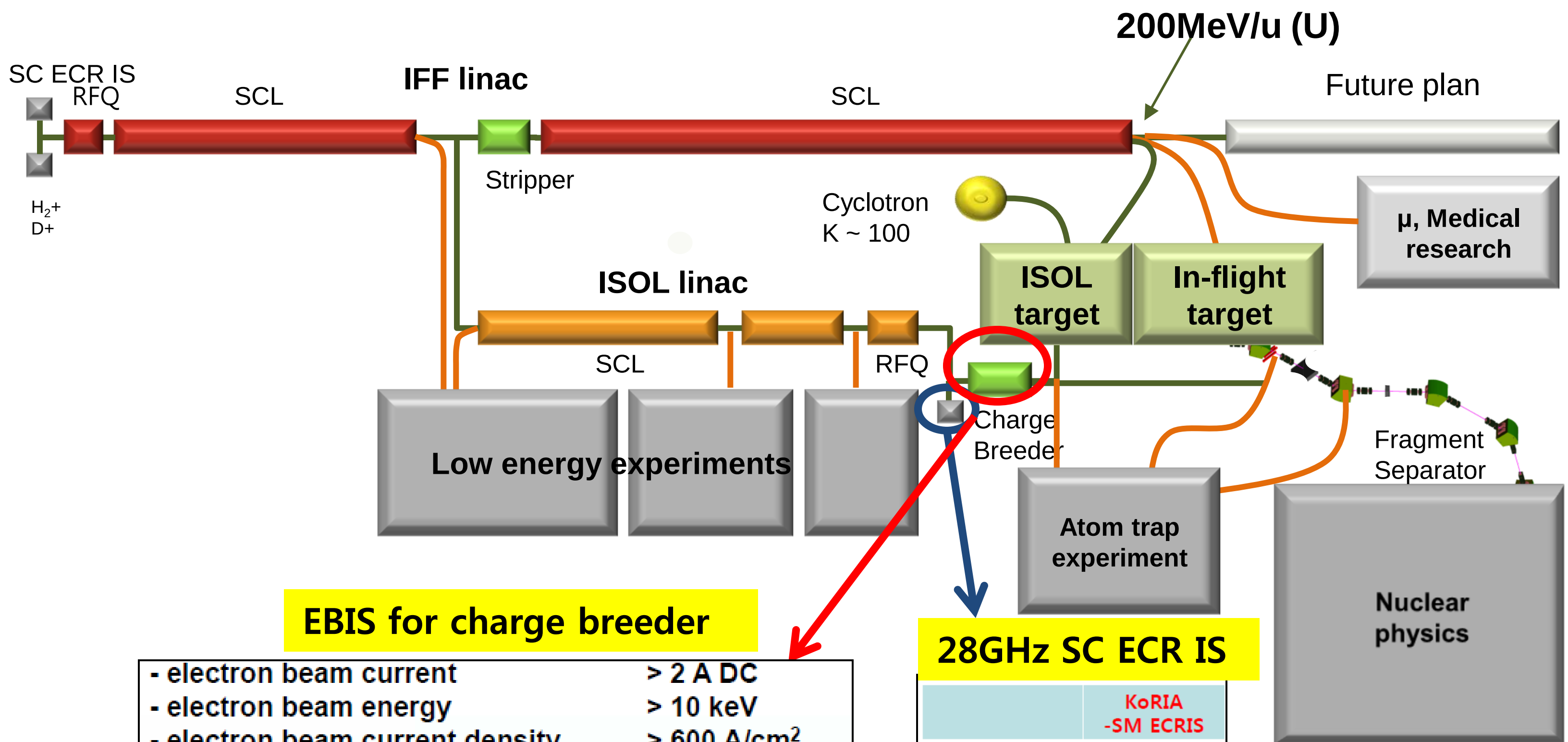
Sn yield comparison from world ISOL facilities



	Primary Beam	Power on target	target	Fission/s	^{132}Sn rate
KoRIA	P 70 MeV 1 mA	70 kW	Direct	10^{14}	$9 \cdot 10^8$
SPIRAL2 GANIL	d 40 MeV 5mA	200 kW	Convert.	10^{14}	$2 \cdot 10^9$
HRIBF	p 40 MeV 10 µA	0.4 kW	Direct	$4 \cdot 10^{11}$	$2 \cdot 10^5$
SPES LNL	p 40 MeV 200 µA	8 kW	Direct	10^{13}	3.10^8

Ion Source

Ion Source



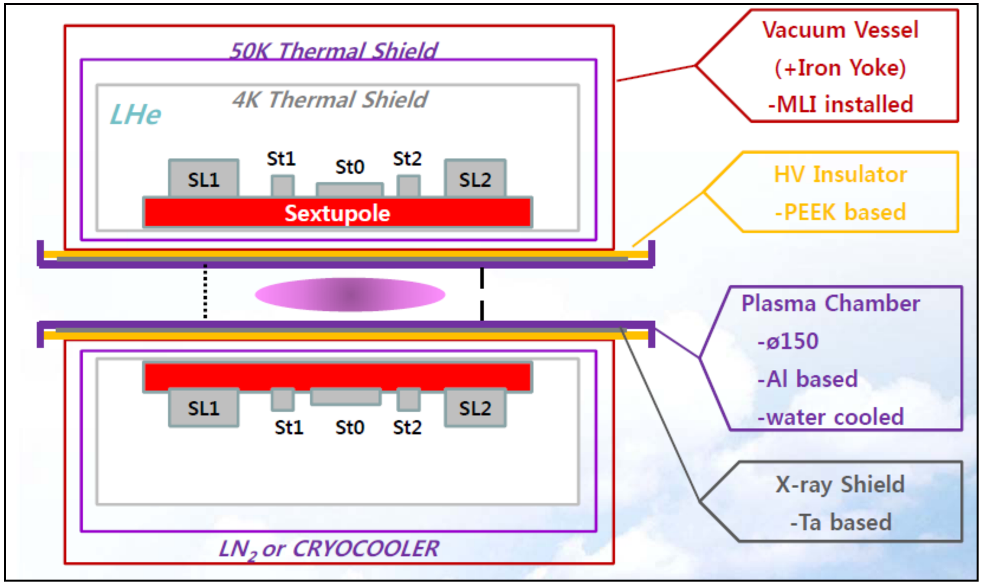
EBIS for charge breeder

- electron beam current	> 2 A DC
- electron beam energy	> 10 keV
- electron beam current density	> 600 A/cm^2
- breeding time	30 ~ 40 ms
- efficiency	> 15 %
- solenoid field strength	> 5 T
- solenoid bore diameter	> 155 mm
- trap length	> 700 mm
- drift tube diameter	> 31 mm
- cathode material/ life	LaB_6 or CeB_6
- vacuum	~10^{-9} torr

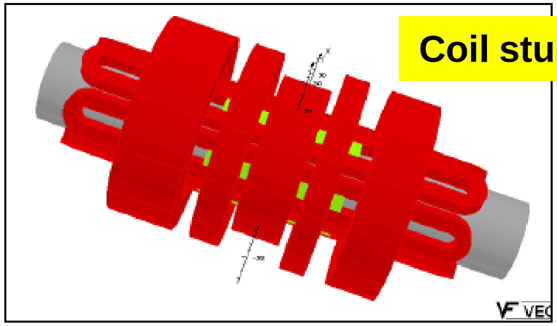
28GHz SC ECR IS

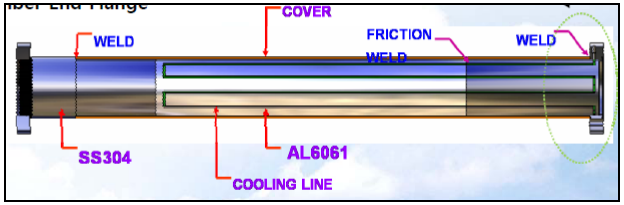
	KoRIA -SM ECRIS
f [GHz]	28
P [kW]	10
$Ø_{chamber}$[mm]	150
L_{plasma}[mm]	500
V_{ext} [kV]	30
B_{RES} [T]	1
B_{inj}	> 4
B_{ext}	> 2.5
B_{rad}	2.2
B_{min}	0.3~0.8

Ion Source

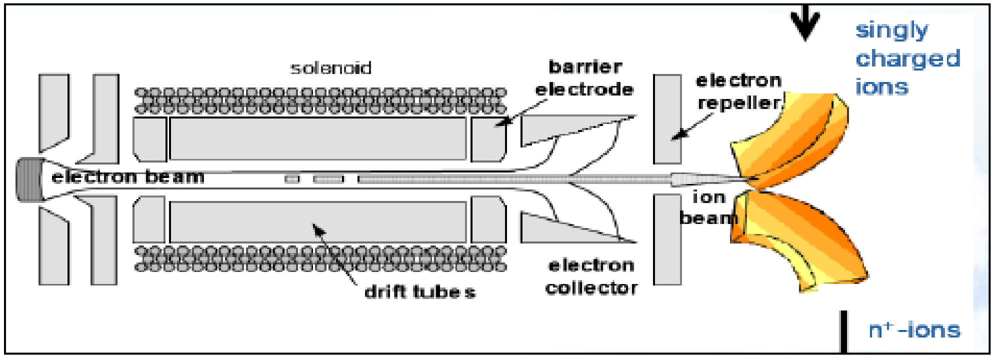


SM magnet system for 28GHz SC ECR IS

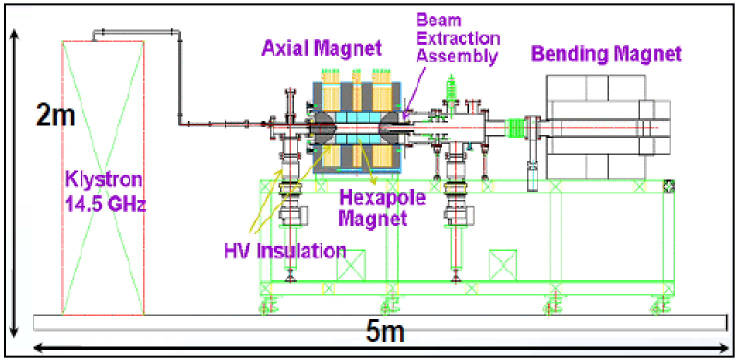




Plasma chamber for 28GHz SC ECR IS



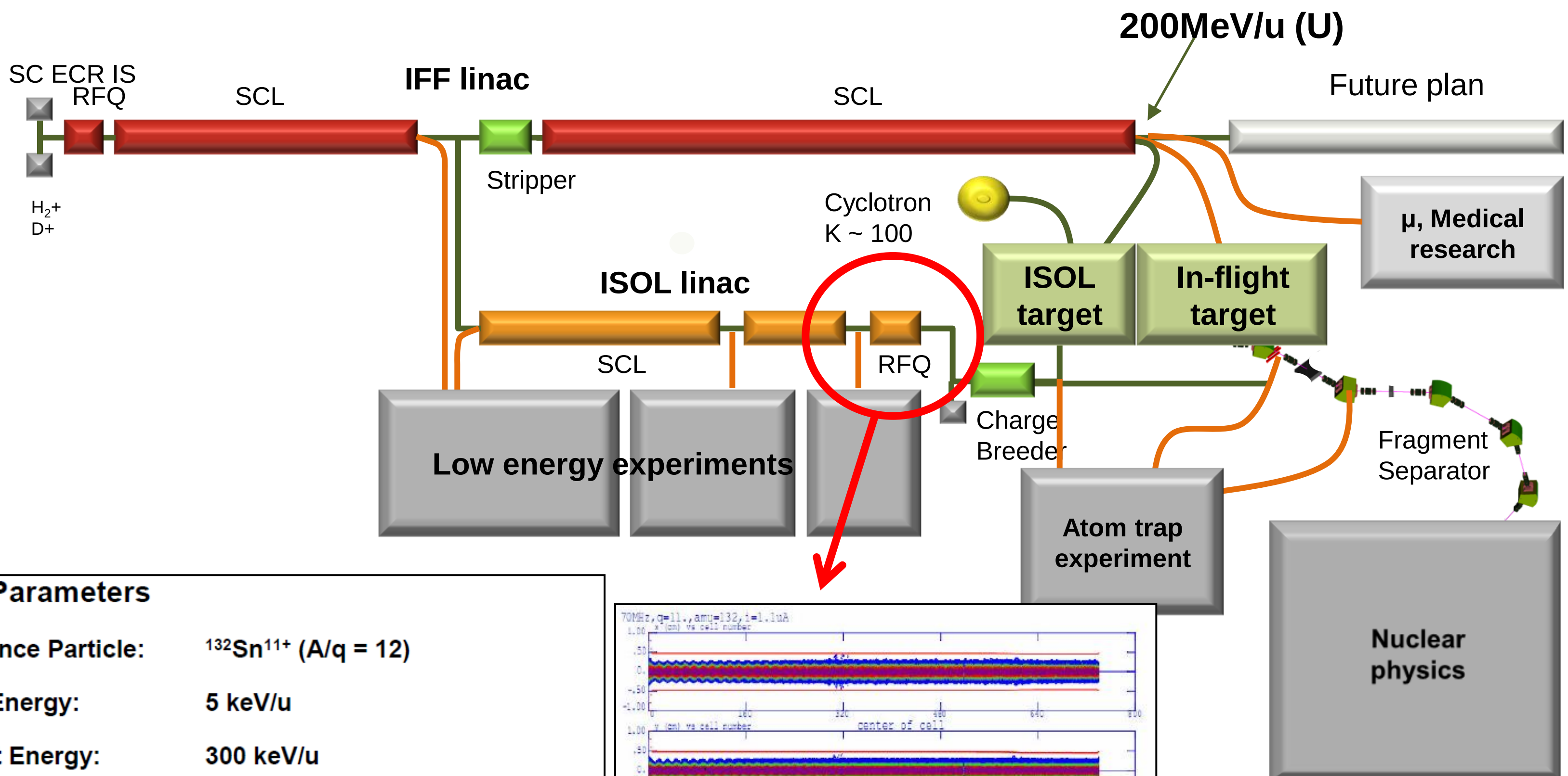
EBIS layout



14.5GHz SC ECR IS layout

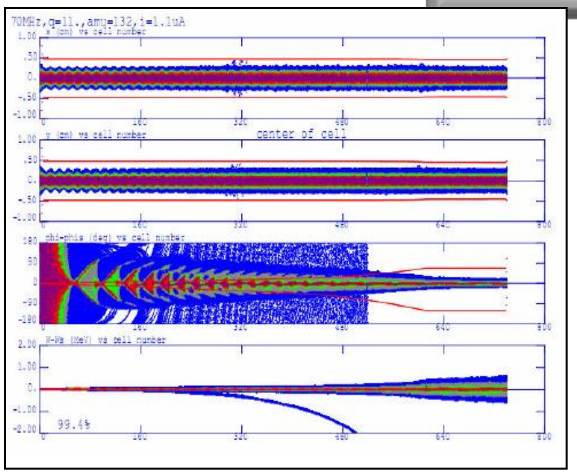
RFQ

RFQ



❑ **Design Parameters**

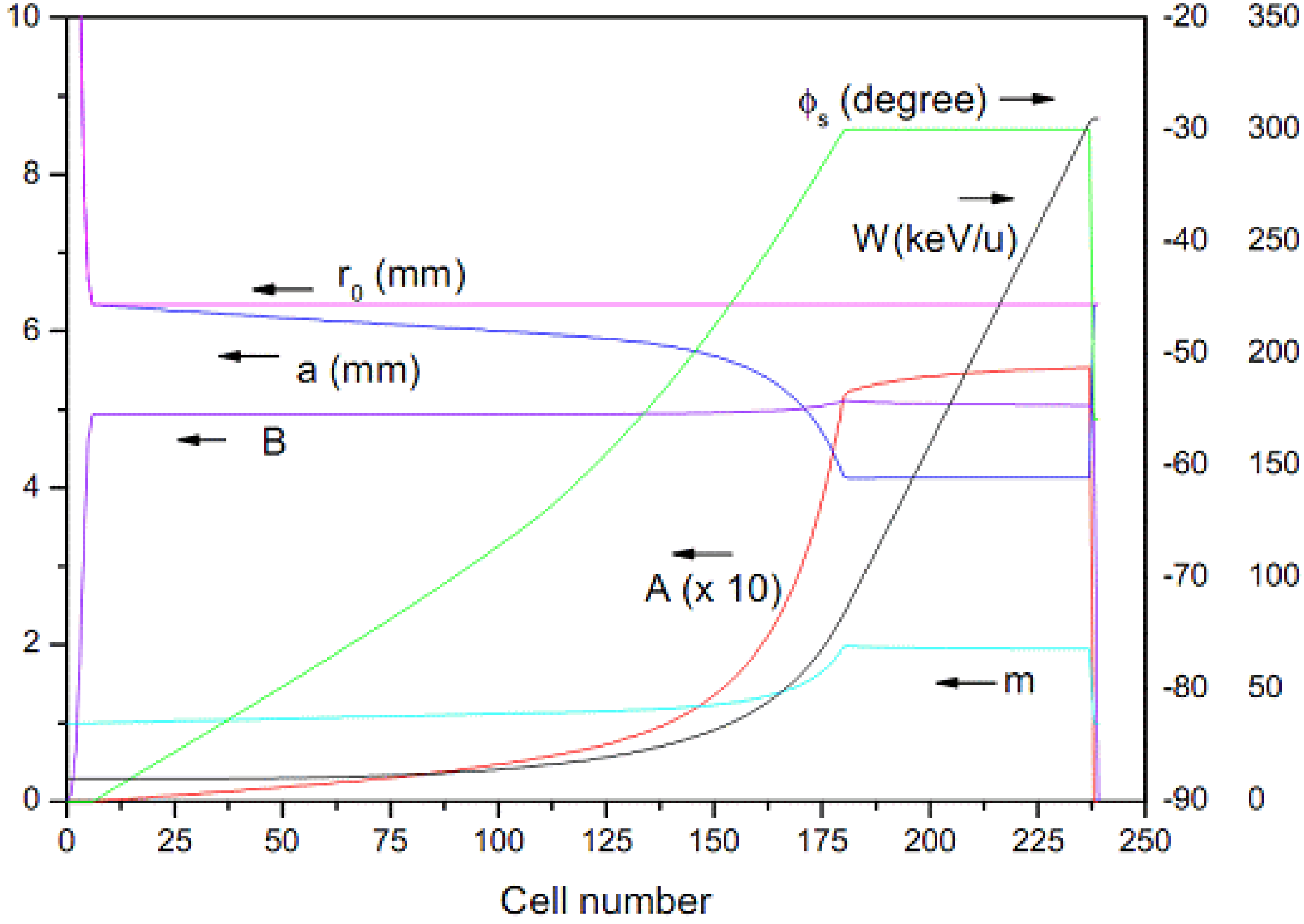
- **Reference Particle:** $^{132}Sn^{11+}$ **(A/q = 12)**
- **Input Energy:** **5 keV/u**
- **Output Energy:** **300 keV/u**
- **Beam Current:** **0.1 pμA (assumption)**
- **Input Emittance:** **0.1 π mm-mrad (normalized rms)**
- **Duty:** **100% (CW)**
- **Frequency:** **70MHz**
- **Kilpatrick:** **< 1.6**



Design specification for the RFQ

Reference Particle (multi charge state)	$^{238}U^{33+}$ ($^{238}U^{32+}$, $^{238}U^{34+}$)
A/q	< 7.5
RF frequency	70MHz
input energy	10 keV/u
output energy	300 keV/u
Beam Current (reference particle)	10 pμA
Beam Duty	100 % (CW)
Beam Power	214 kW
input transverse emittance	0.1 π mm-mrad (normalized rms)
peak surface electric field	1.6 Kilpatrick

Determination of the design parameters of RFQ

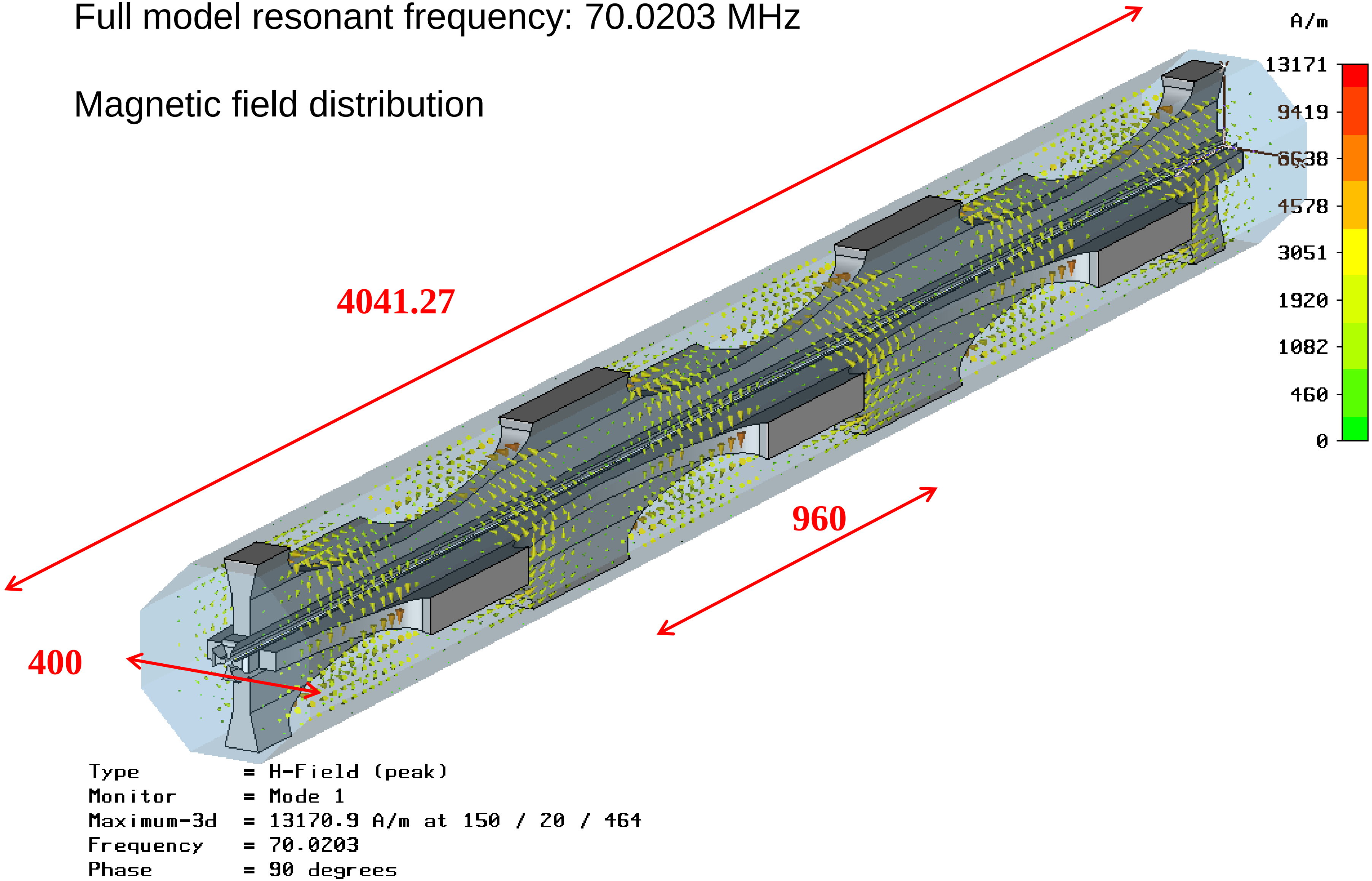


a(aperture radius), r_0 (average aperture radius), m(modulation), A(accelerating efficiency), B(focusing efficiency), ϕ_s (synchronous phase), W(energy).

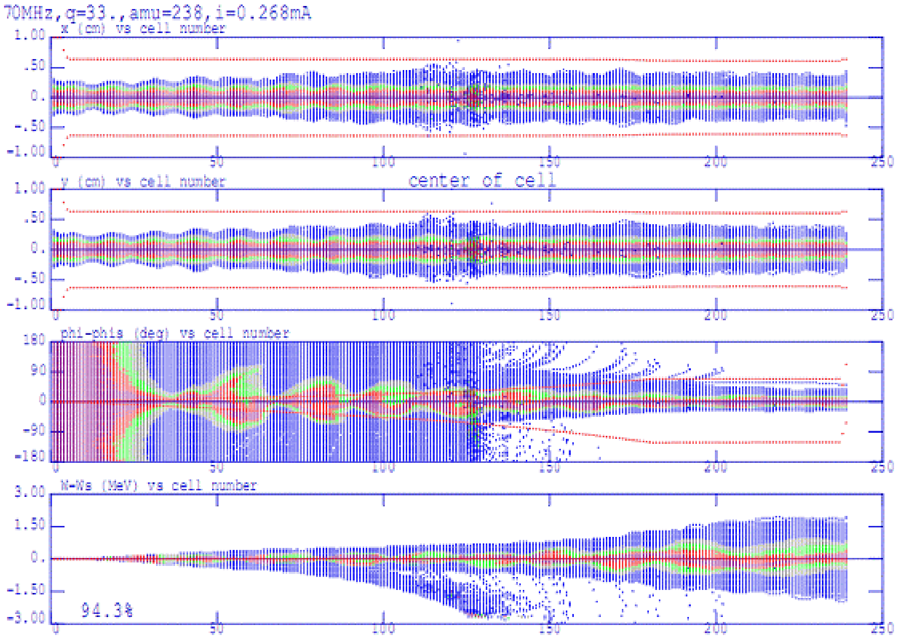
Geometry of the RFQ for simulation

Full model resonant frequency: 70.0203 MHz

Magnetic field distribution



Particle distribution through RFQ

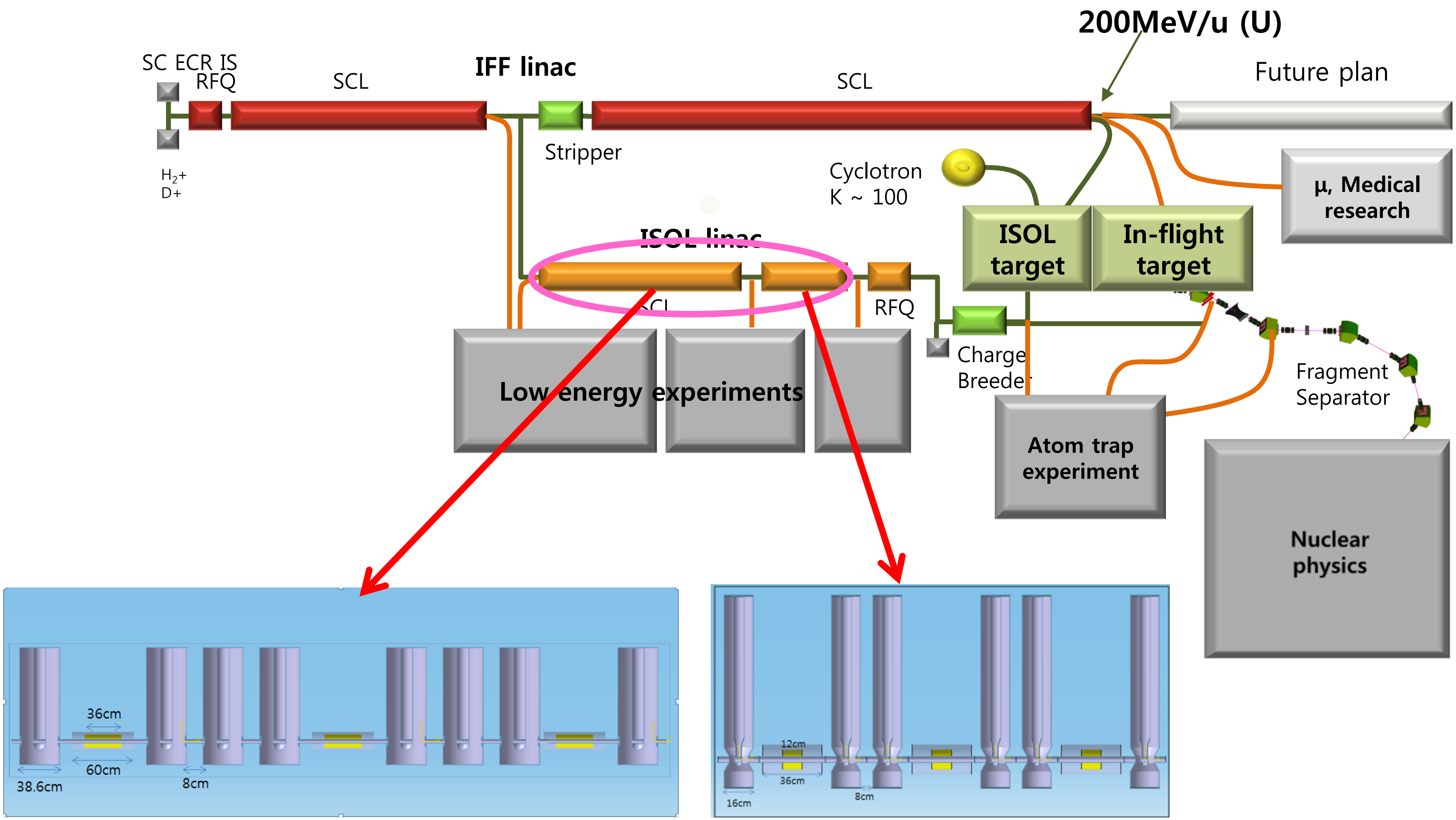


Kinetic energy and transmission characteristics of uranium beams in RFQ

Charge State	Kinetic Energy(keV/u)	Transmission Rate (%)
32	303.5	86.8
33	305.4	94.3
34	303.8	91.3

Low Energy SC LINAC

Low Energy SC Linac

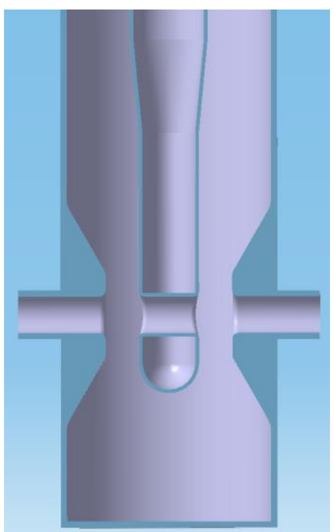
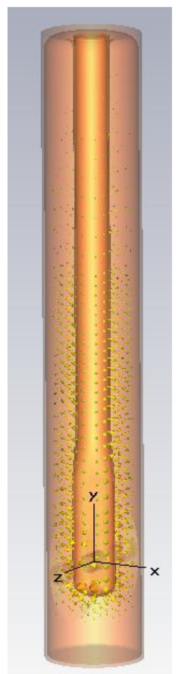
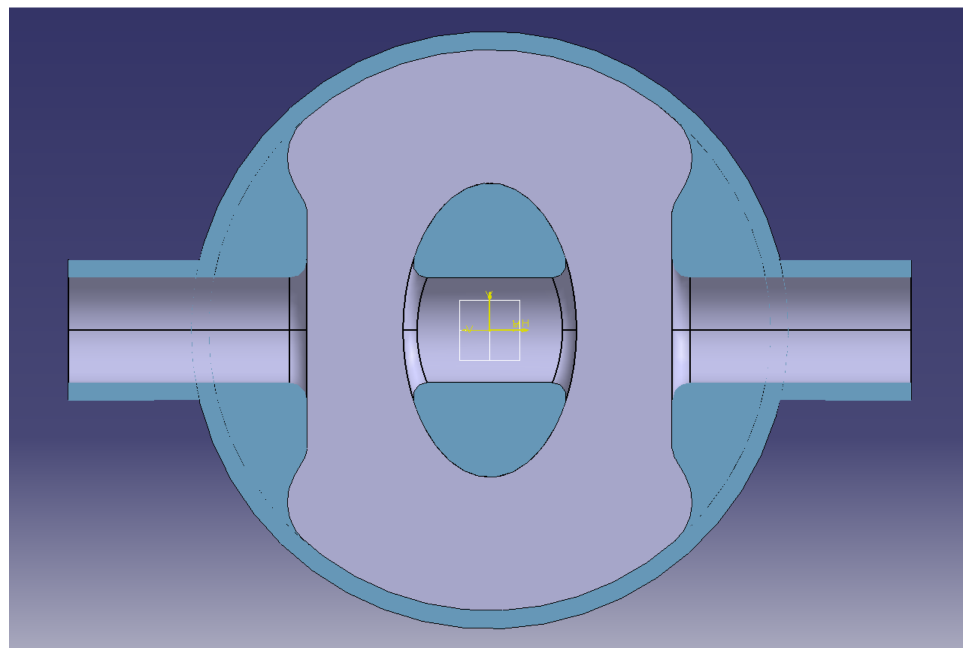


SC QWR (2.0-17.5 MeV/u]

SC QWR (0.3-2 MeV/u]

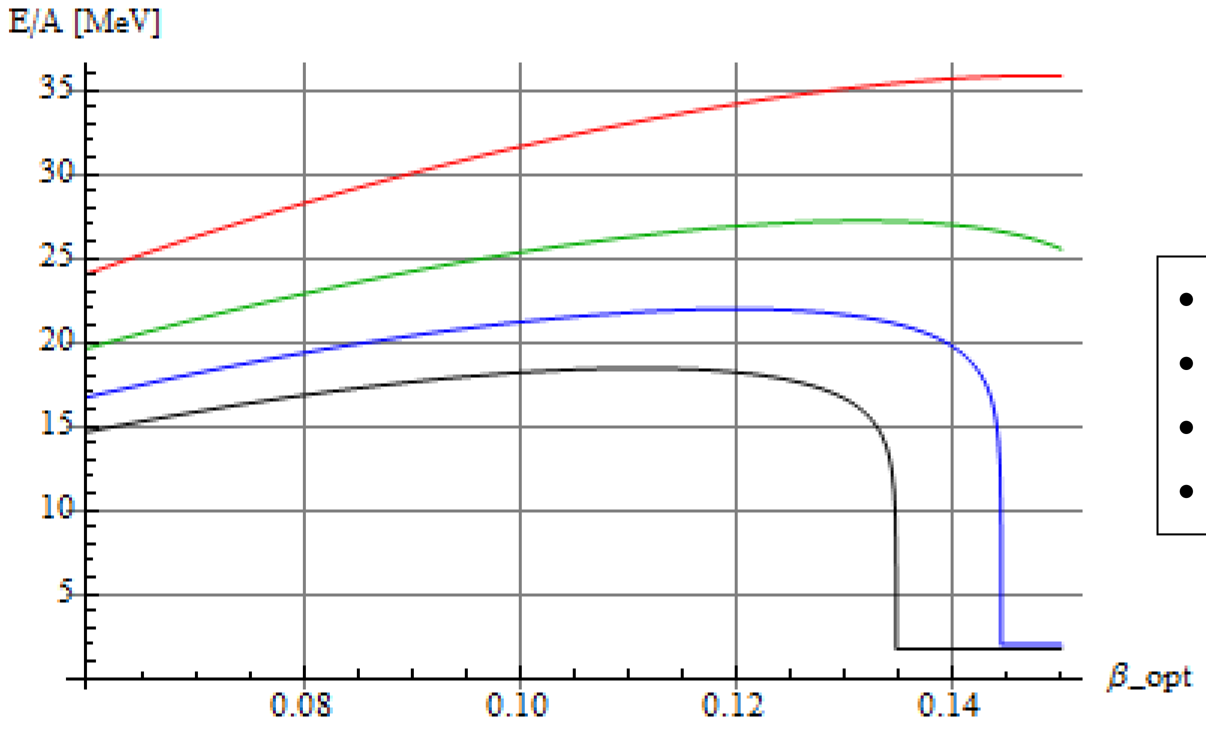
Low-β SC QWRs

- To accelerate RIBs from 0.3 MeV/u (v=0.0254 c),
  - β_{opt} ~ 0.04
    - Smaller β_{opt} : smaller dipole steering & better beam quality
    - Higher β_{opt} : better efficiency in acceleration, more cost-effective
  - Our current choice: β_{opt} = 0.040 (subject to change)

β_{opt} of high-β QWRs ?

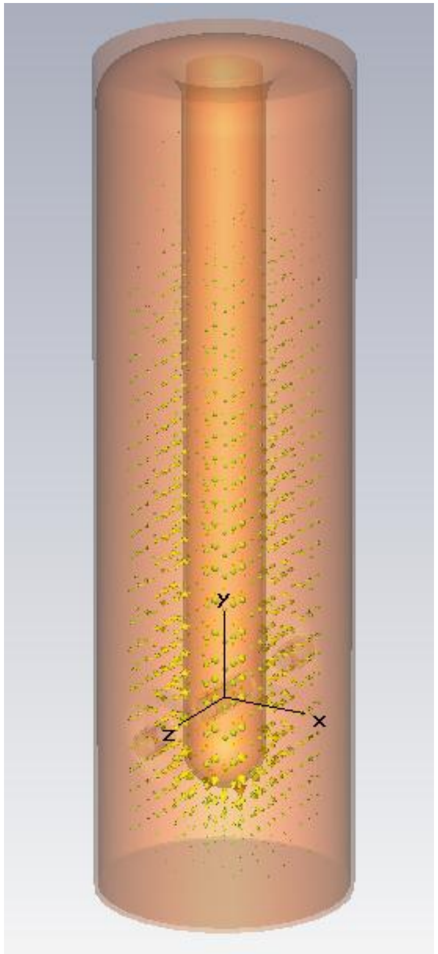
Achievable energy w.r.t. β_{opt} of the high-β QWRs, for the given low-β section

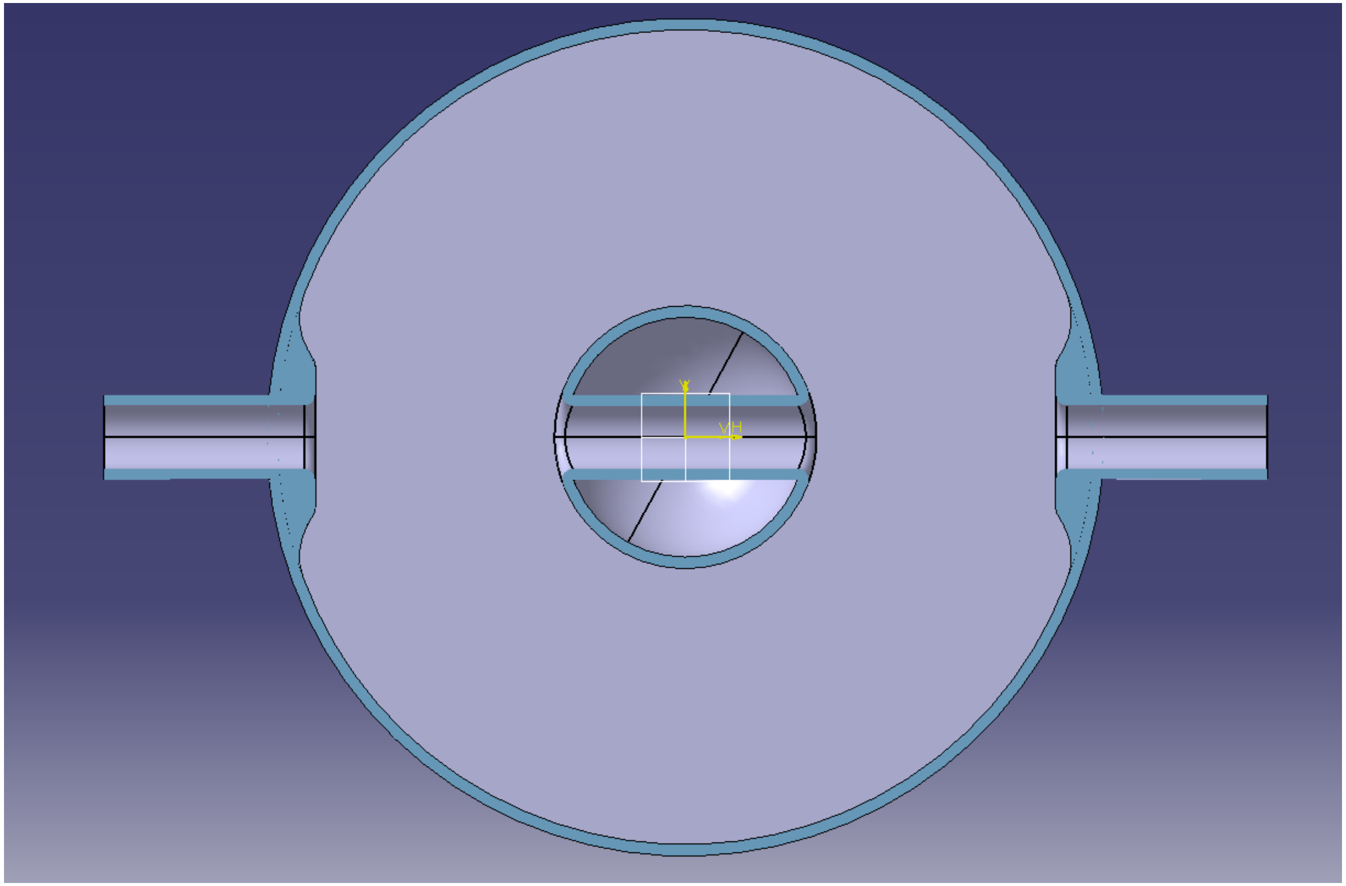


- Red: A/q=6
- Green: A/q=8
- Blue: A/q=10
- Black: A/q=12

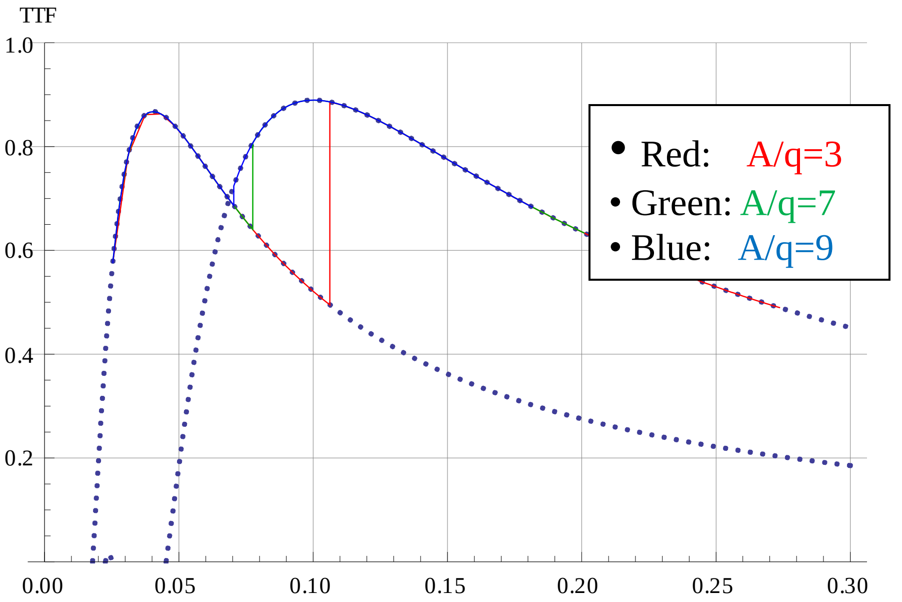
Our current choice: β_{opt} = 10

High-β SC QWRs

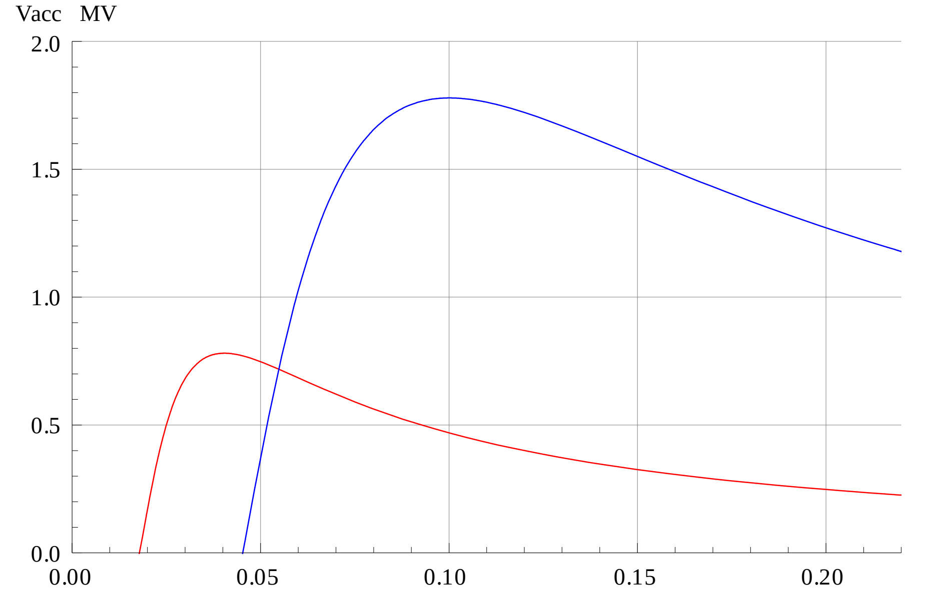




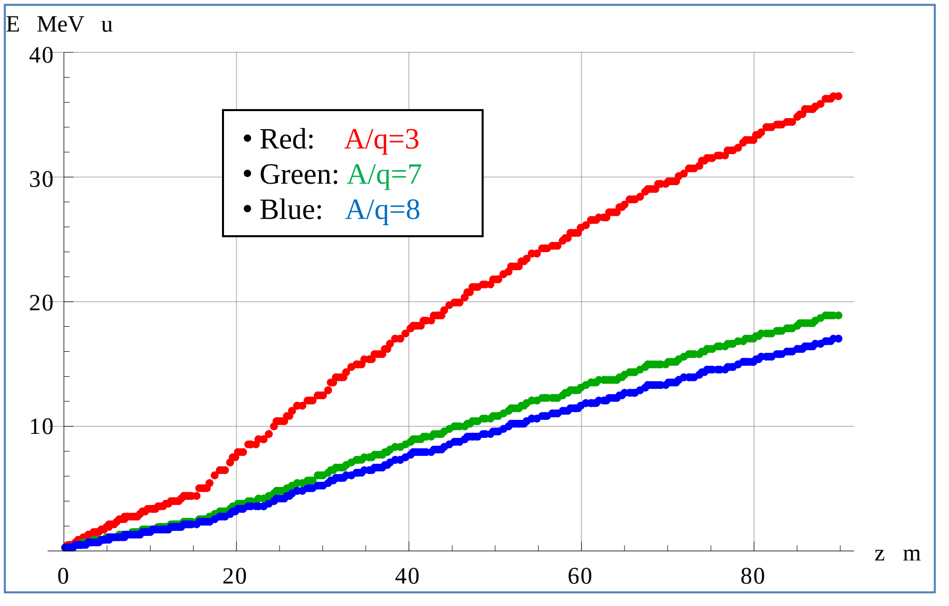
TTF curve w.r.t.β



Voltage gain curve w.r.t.β



Beam energy w.r.t. z [m]

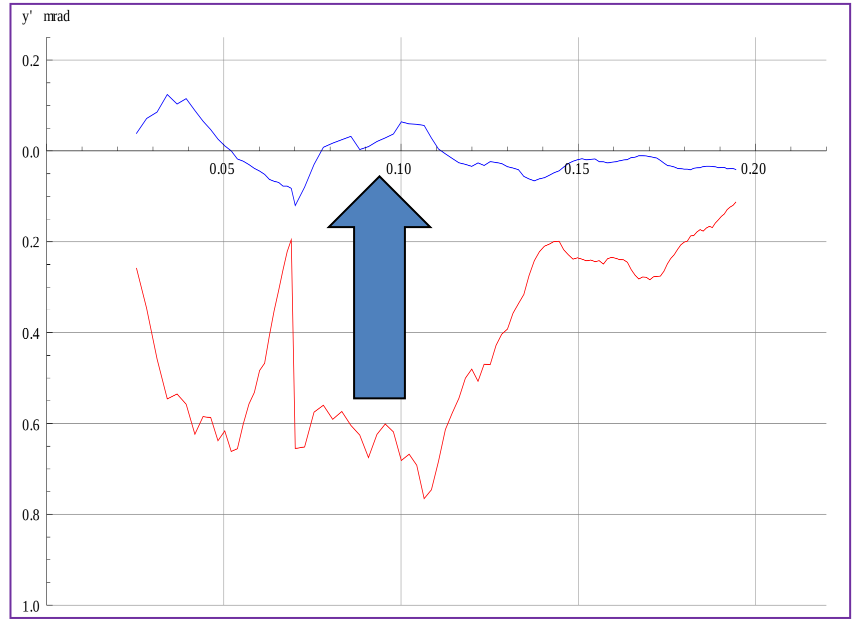


Specs of QWRs

	low-β	high-β
β_{opt}	4.0%	10.0%
f_0 (frequency)	70 MHz	70 MHz
a_0 (bore radius)	15 mm	15 mm
L (diameter of O.C)	172 mm	340 mm
V_0 (Input)	0.9 MV	2.0 MV
E_p	30 MV/m	33 MV/m
$E_0 = V_0 / L$	5.23 MV/m	5.88 MV/m
T_{opt}	0.87	0.89
Q_0 (@ R=20 nΩ)	0.7×10^9	1.4×10^9
P_{diss}(@ R=20 nΩ)	2.2 Watt	4.4 Watt
R/Q (with TTF include)	412 Ω	510 Ω

Dipole steering of QWRs

Steering: Δy’ [mrad]



By shifting beam axis 0.024 mm and 0.26 mm upward, steering (~0.7 mrad) reduced to ≤ 0.1 mrad

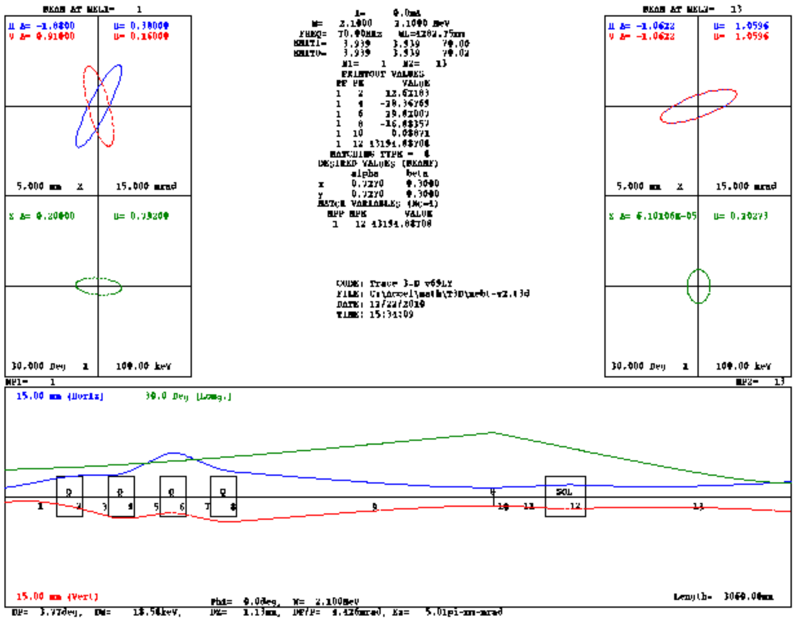
SC Solenoids

- Two SC (Nb-Ti) solenoids (44 cm and 68 cm long) will be used.
- XY-correcting coils will be employed
- Design parameters

	1^{st} kind	2^{nd} kind
Operating temperature	4.5 K	4.5 K
Coil material	Nb-Ti	Nb-Ti
Mechanical length	44 cm	68 cm
Max field strength	9 Tesla	9 Tesla
$\int B^2 dz$	9.7 $T^2 \cdot m$	29.2 $T^2 \cdot m$
Fringe field at neighboring cavity wall	≤ 0.2 Gauss	≤ 0.2 Gauss
Number of solenoids	12	33

MEBT (from RFQ to ISOL Linac)

- There are many possible different options
- One example: 3-m long 1-rebuncher system

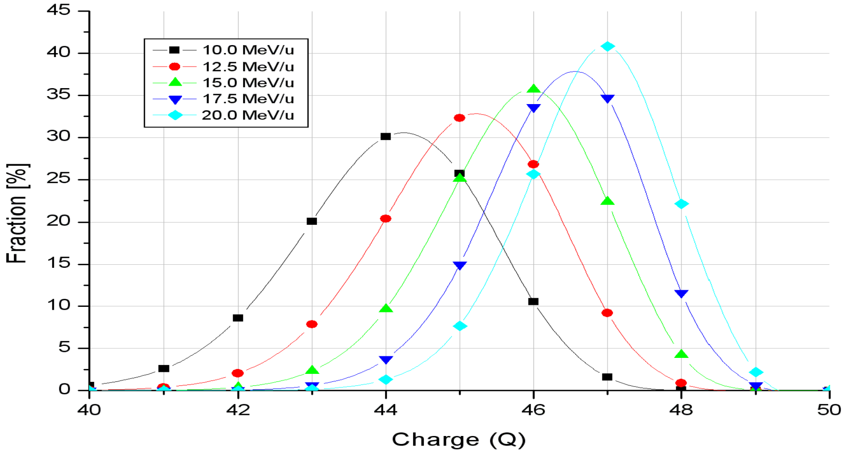


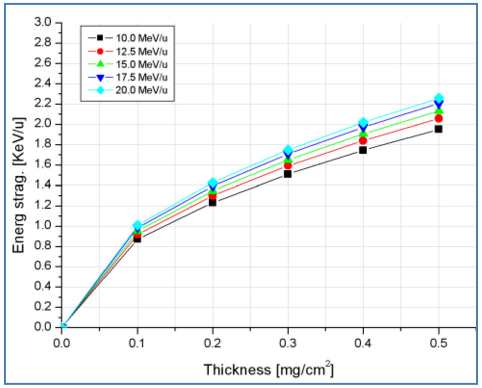
- Design of more flexible 2-rebuncher MEBT is under progress

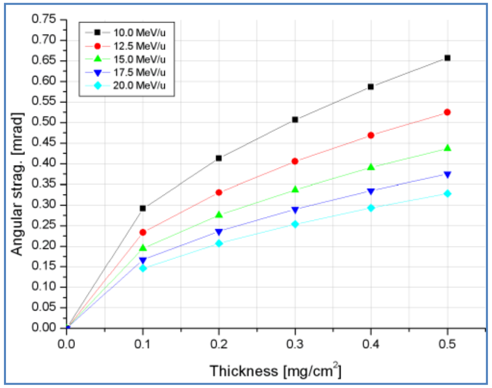
Charge stripping section

- Charge stripping section is located at the end of ISOL Linac, just before the bending section, with a carbon-foil of thickness 0.3 mg/cm^2
- Lise++ code has been used for simulation for ^{132}Sn isotope

- Charge distribution w.r.t. beam energy
- Energy [KeV/u] and angular [mrad] struggling w.r.t. foil-thickness

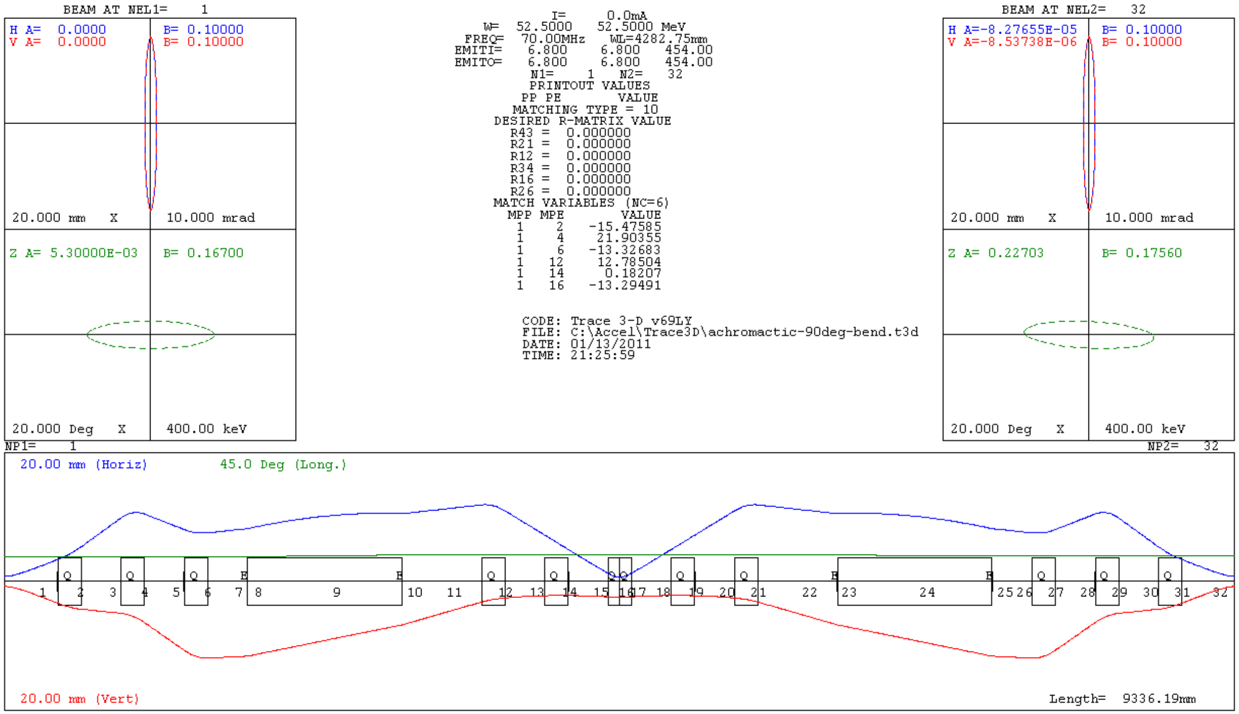




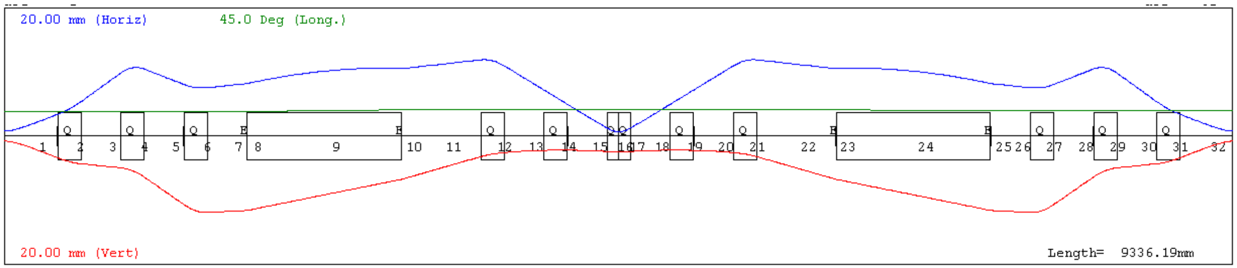


- At E=17.5 MeV/u, 98 % of beams will be captured (with $\Delta q/q \leq 5$ %)

- Trace3D simulation for on-momentum

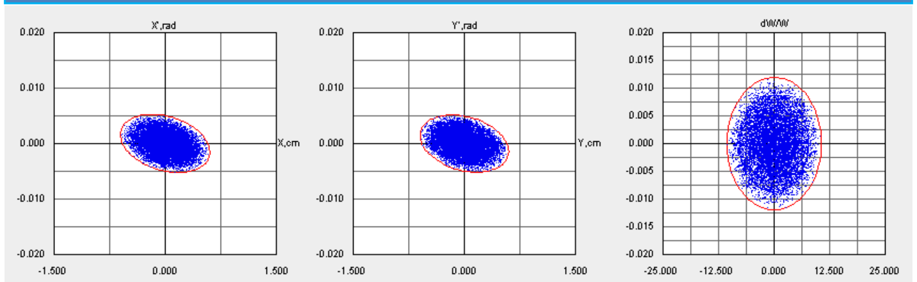


- Trace3D simulation for off-momentum (Δp/p= 5 %)

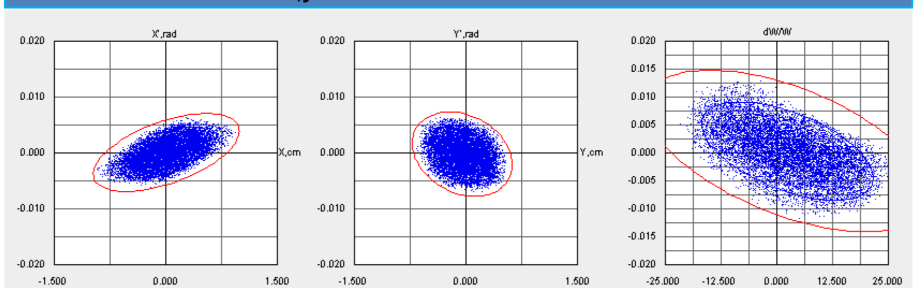


De-acceleration with $^{132}Sn^{18+}$

E= 0.3 MeV/u, $\varepsilon_{nx,y}$ = 0.10 mm mrad, ε_{nz} = 5.1 deg/KeV/u

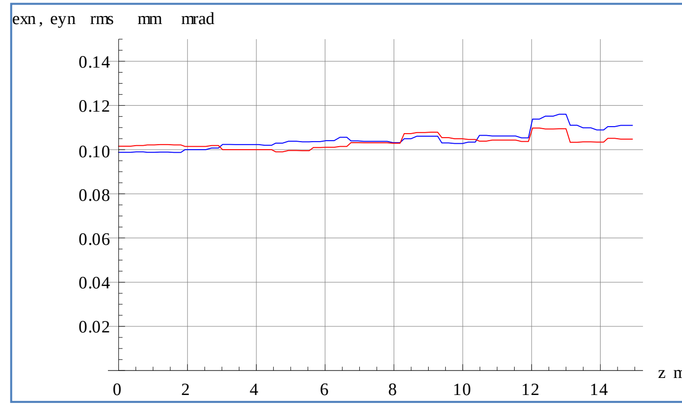


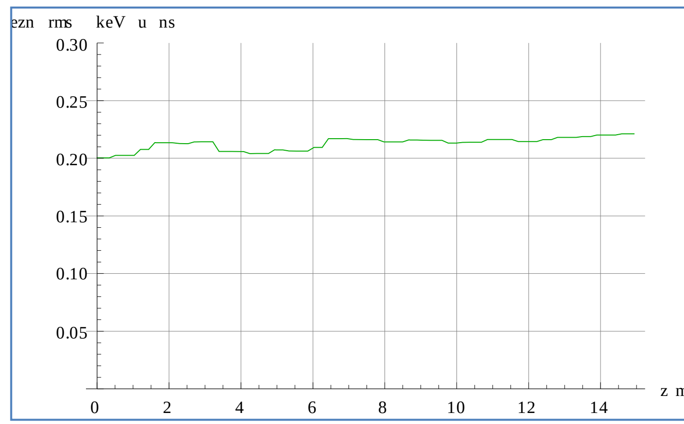
E= 0.16 MeV/u, $\varepsilon_{nx,y}$ = 0.11 mm mrad, ε_{nz} = 5.6 deg/KeV/u



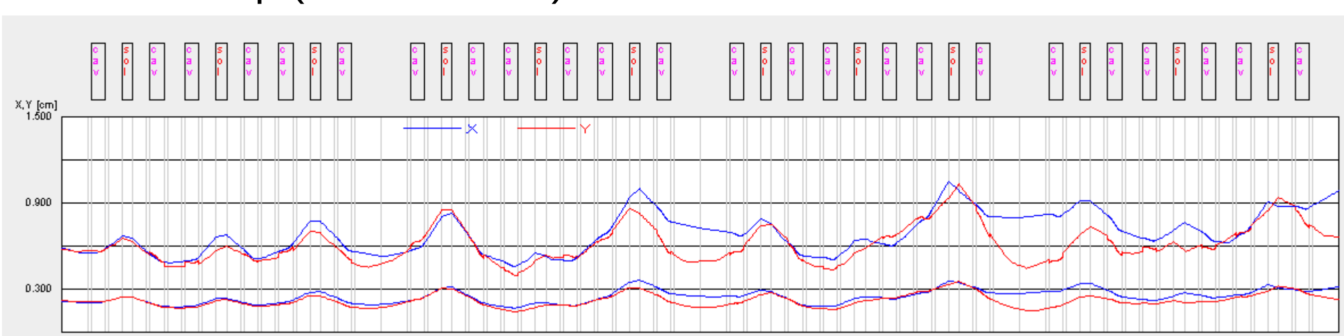
- ❖ Synchronous phase φ_s is set to be - 160°
- ❖ Field level cavities are adjusted

Transverse & longitudinal emittance



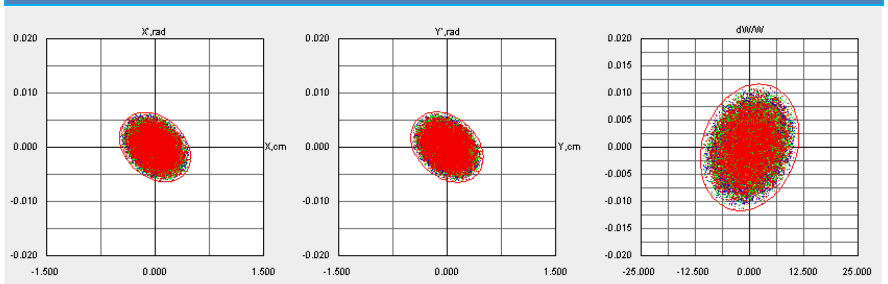


Beam envelop (max and rms)

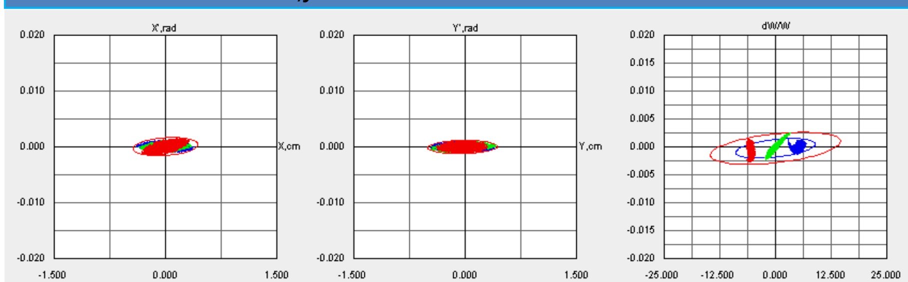


Multi-charge case with $^{132}Sn^{17+,18+,19+}$

E= 0.3 MeV/u, $\varepsilon_{nx,y}$ = 0.10 mm mrad, ε_{nz} = 5.1 deg/KeV/u

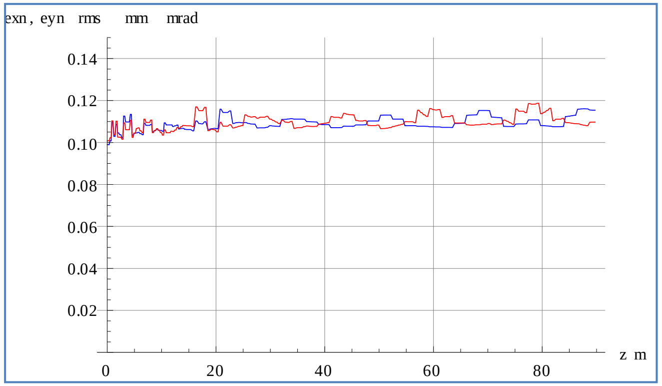


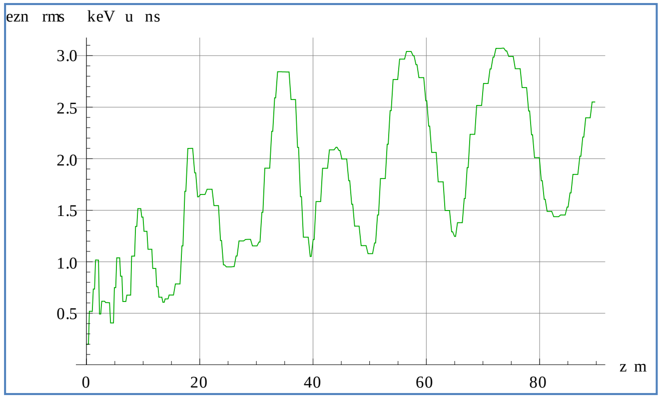
E= 18.3 MeV/u, $\varepsilon_{nx,y}$ = 0.11 mm mrad, ε_{nz} = 64.3 deg/KeV/u



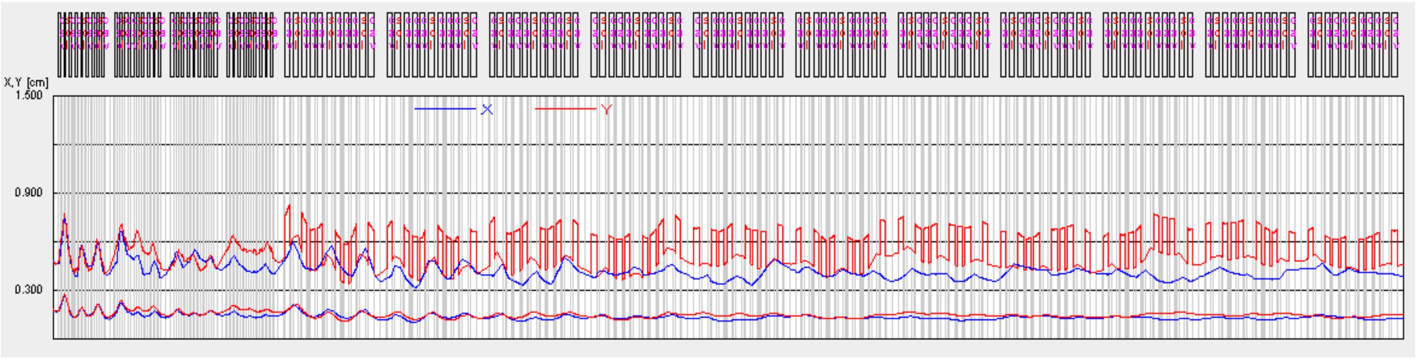
- Synchronous phase φ_s is set to be - 30°

Transverse & longitudinal emittance



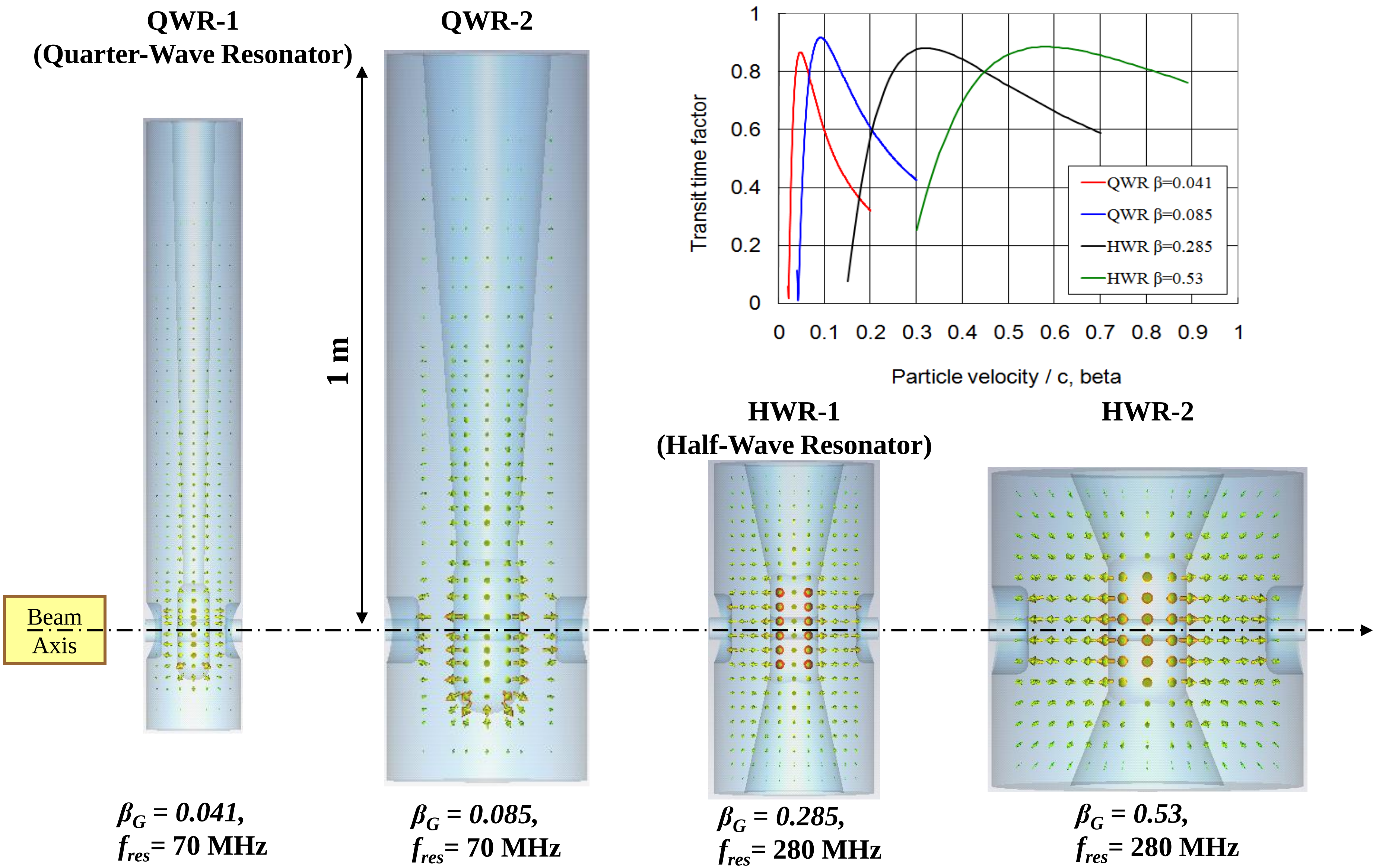


Beam envelop (max and rms)



High Energy SC LINAC

Optimized design of SCRF Cavities



SCRF Cavity Parameters

Parameters	Unit	Low-energy section		High-energy section	
Cavity type	-	QWR-1	QWR-2	HWR-1	HWR-2
β_G	-	0.041	0.085	0.285	0.53
β_{opt}	-	0.047	0.091	0.32	0.58
Resonant frequency	MHz	70	70	280	280
Number of cavities	EA.	**24**	**96**	**78**	**160**
Operating temperature	K	4.5	4.5	2	2
Unloaded Q-factor / 10^{9}*	-	0.7	1.3	5.9	9.8
Accelerating voltage at $\beta = \beta_{opt}$	MV	**0.72**	**1.7**	**1.7**	**3.7**
Peak surface electric field	MV/m	**25**	**25**	**25**	**25**
Peak surface magnetic field	mT	**43**	**39**	**49**	**61**
Average charge state (for U)	C	33	33	79	79
Beam current (for U)	pμA	9.5	9.5	8	8
Wall dissipation power	W	**2.1**	**4.8**	**2.9**	**10.1**
Input RF power per cavity	W	**400**	**920**	**1900**	**4000**
Loaded Q-factor / 10^{6}	-	2.5	4.6	6.1	16
Cavity bandwidth	Hz	18	8	29	14

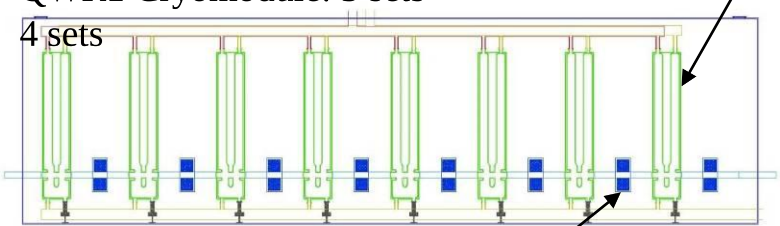
* Surface resistances are assumed to be 10 nΩ.

Cryomodules and the Energy Gain along SC Linac

QWR1 Cryomodule: 3 sets

4 sets

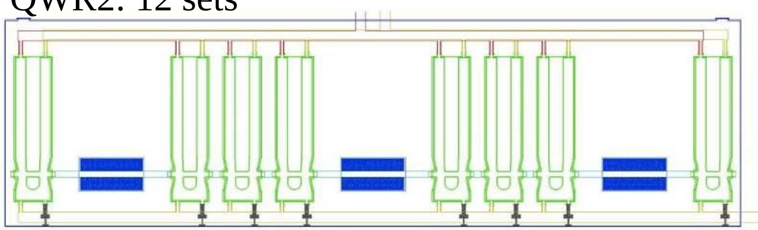
SC Cavity



1 m

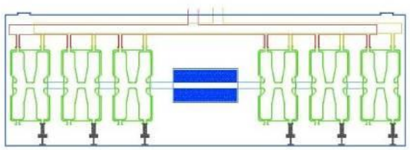
Focusing solenoids (SC): 5.5 – 7 T

QWR2: 12 sets



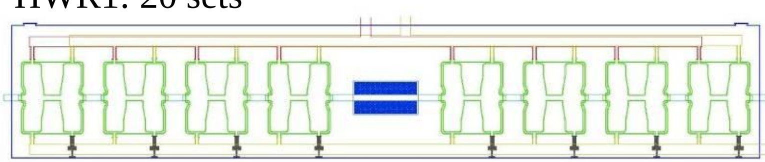
5 – 6.3 T

HWR1: 13 sets

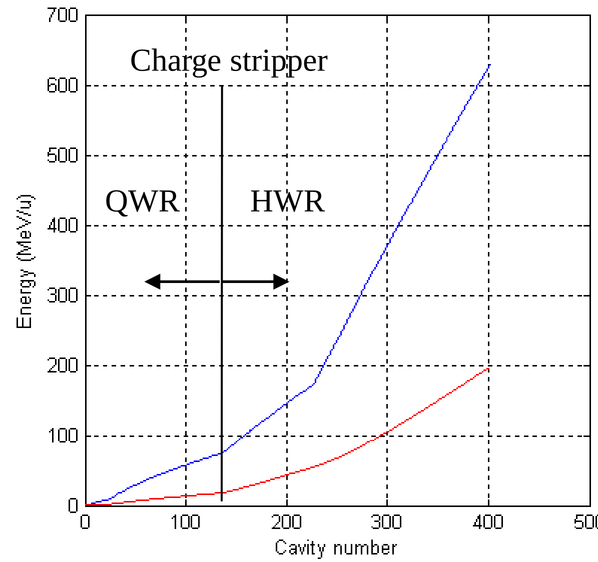


4.5 – 5.5 T

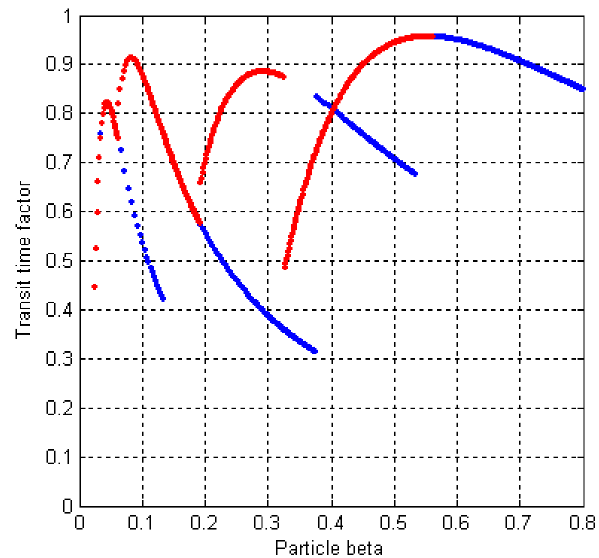
HWR1: 20 sets



6 – 7 T

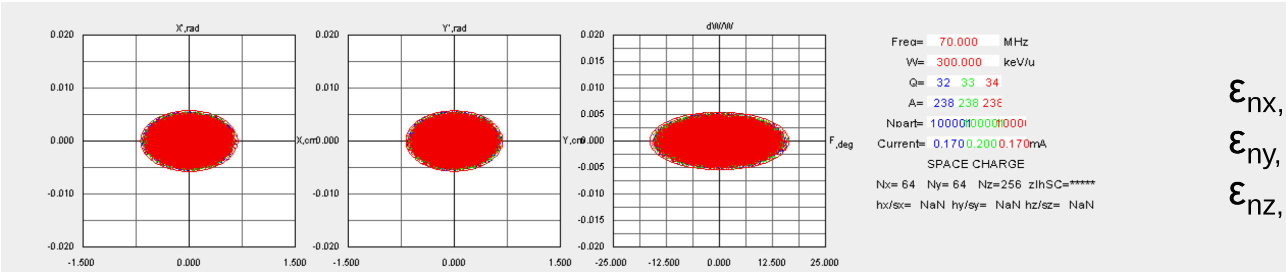


Blue: Proton / **Red: Uranium ion**



SC Linac - Low Energy Section

Low-E section IN



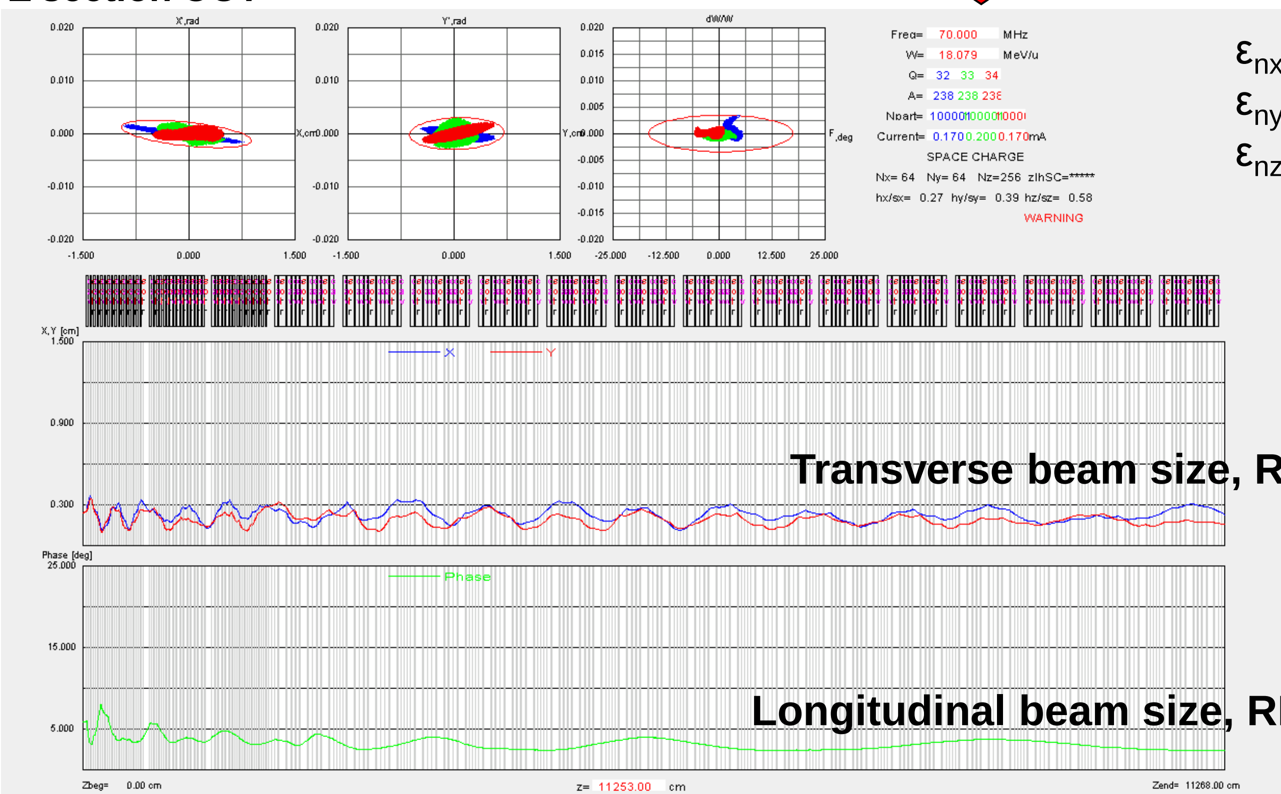
$\varepsilon_{nx,\ rms}$ = 0.13 mm·mrad

$\varepsilon_{ny,\ rms}$ = 0.13 mm·mrad

$\varepsilon_{nz,\ rms}$ = 0.14 keV/u·ns

Transmission: 100%

Low-E section OUT



$\varepsilon_{nx,\ rms}$ = 0.25 mm·mrad

$\varepsilon_{ny,\ rms}$ = 0.23 mm·mrad

$\varepsilon_{nz,\ rms}$ = 0.85 keV/u·ns

- $\Phi_{RF} = -28^{o}$

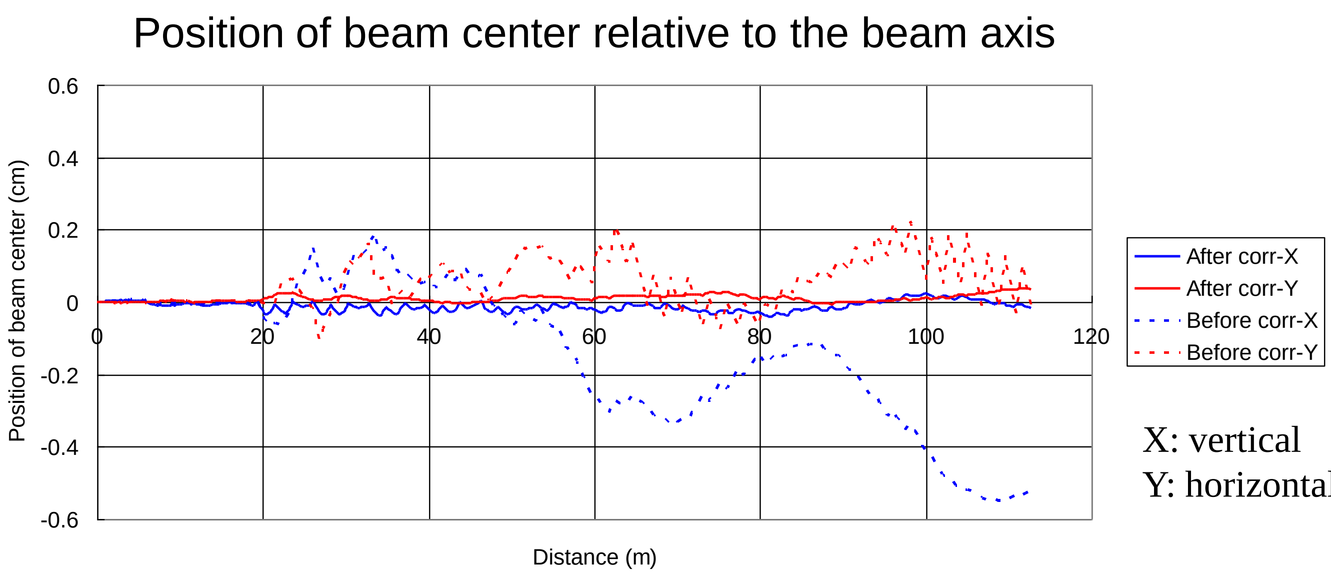
Transverse beam size, RMS

Longitudinal beam size, RMS

Length: ~ 110 m

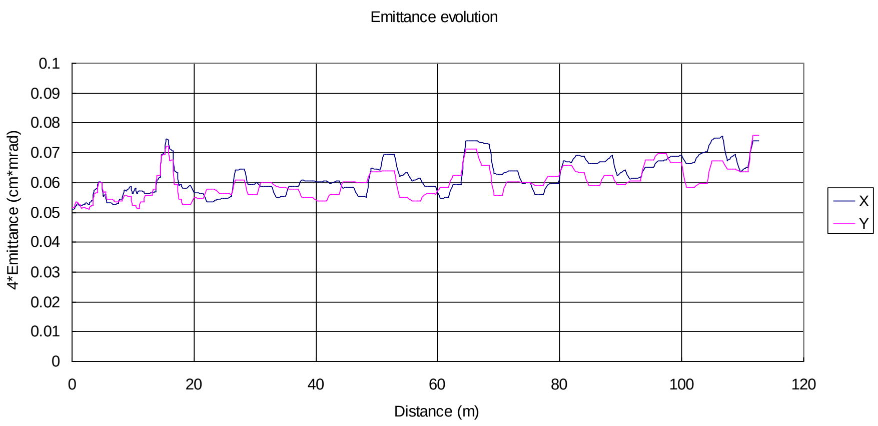
using TRACK code with 100k particles/charge state

Correction of Dipole Deflection in QWR

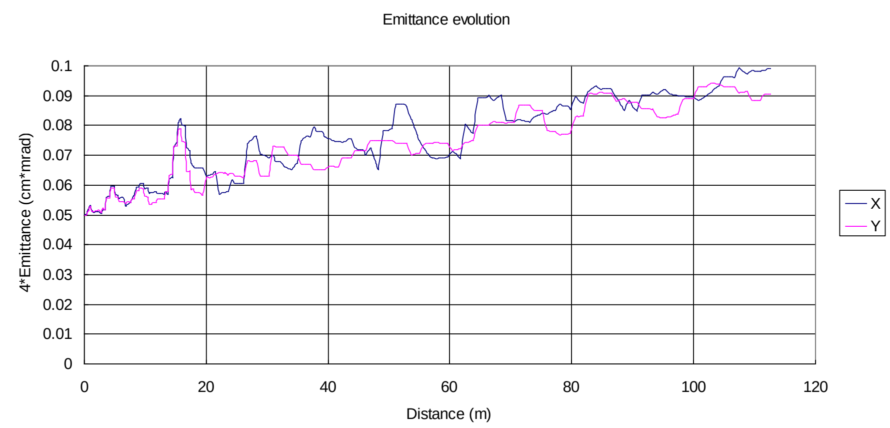


X: vertical
Y: horizontal

Single charge-state acceleration (33)

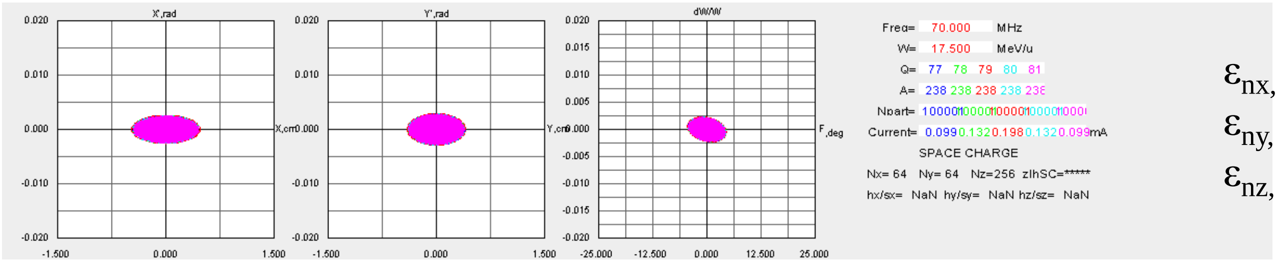


Multiple charge-state acceleration (32 – 34)



SC Linac – High Energy Section

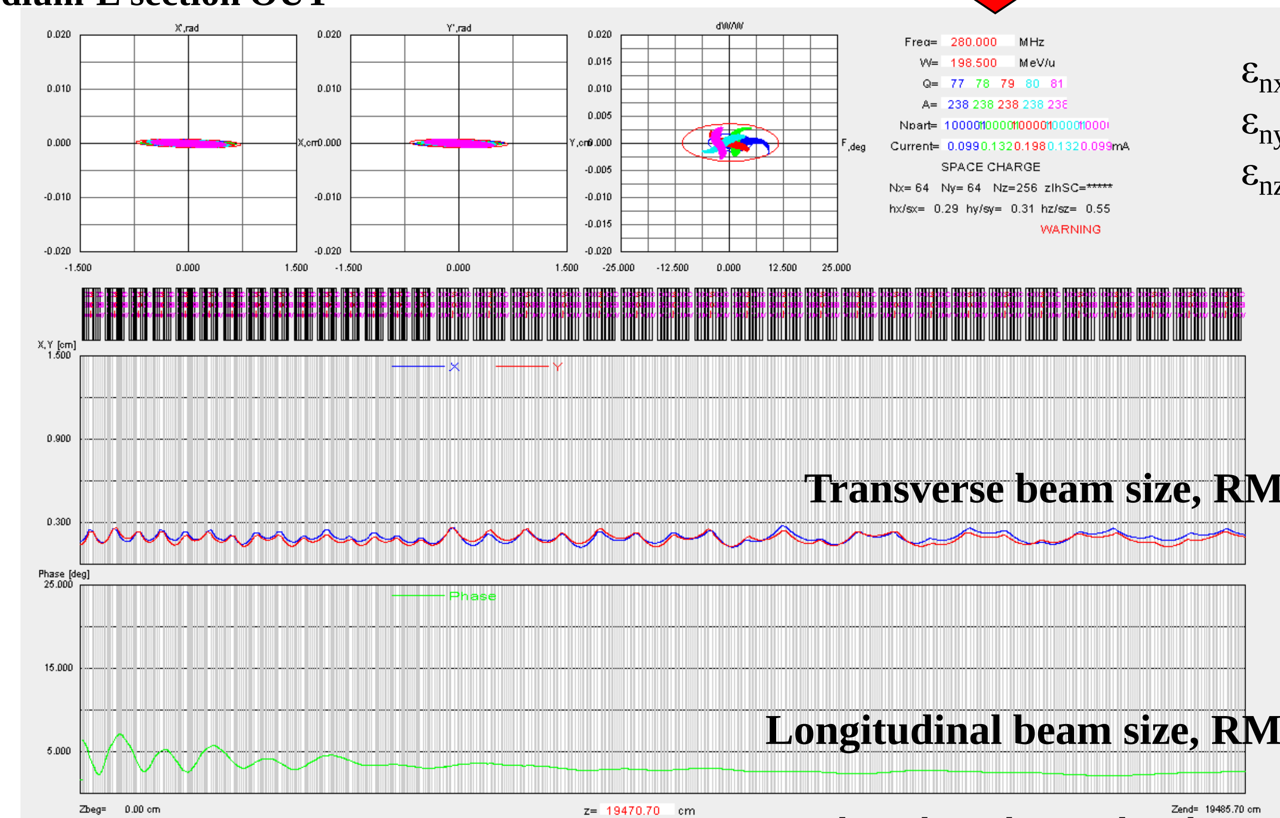
Medium-E section IN



$\varepsilon_{nx,\ rms}$ = 0.30 mm·mrad
$\varepsilon_{ny,\ rms}$ = 0.28 mm·mrad
$\varepsilon_{nz,\ rms}$ = 0.87 keV/u·ns

Transmission: 100%

Medium-E section OUT



$\varepsilon_{nx,\ rms}$ = 0.30 mm·mrad
$\varepsilon_{ny,\ rms}$ = 0.28 mm·mrad
$\varepsilon_{nz,\ rms}$ = 3.3 keV/u·ns

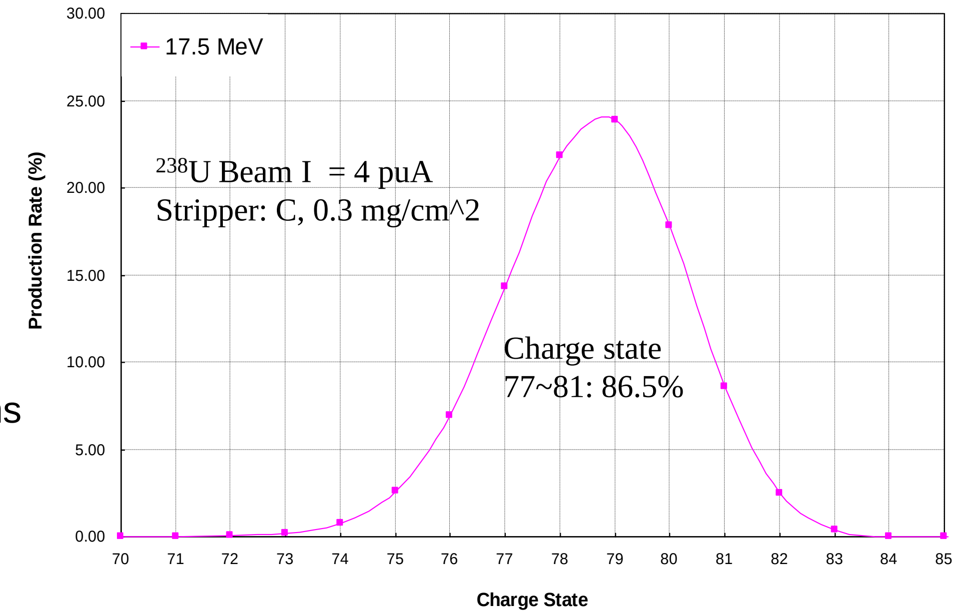
- Φ_{RF} = -30°

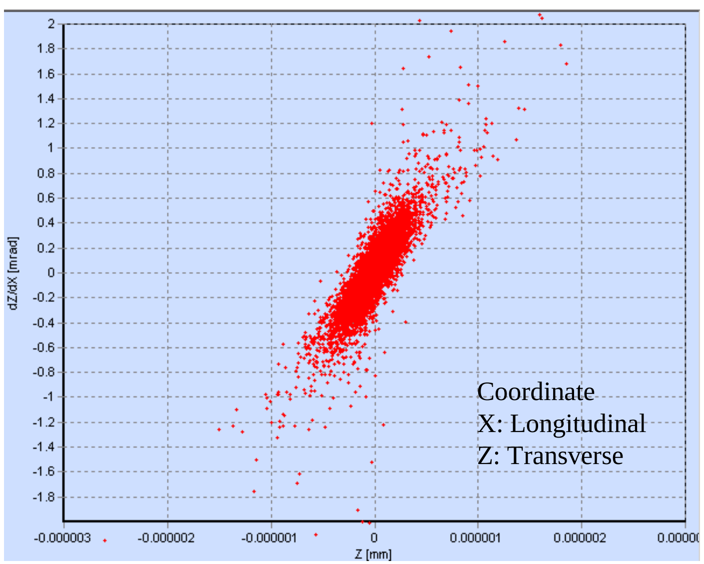
Length: ~ 200 m

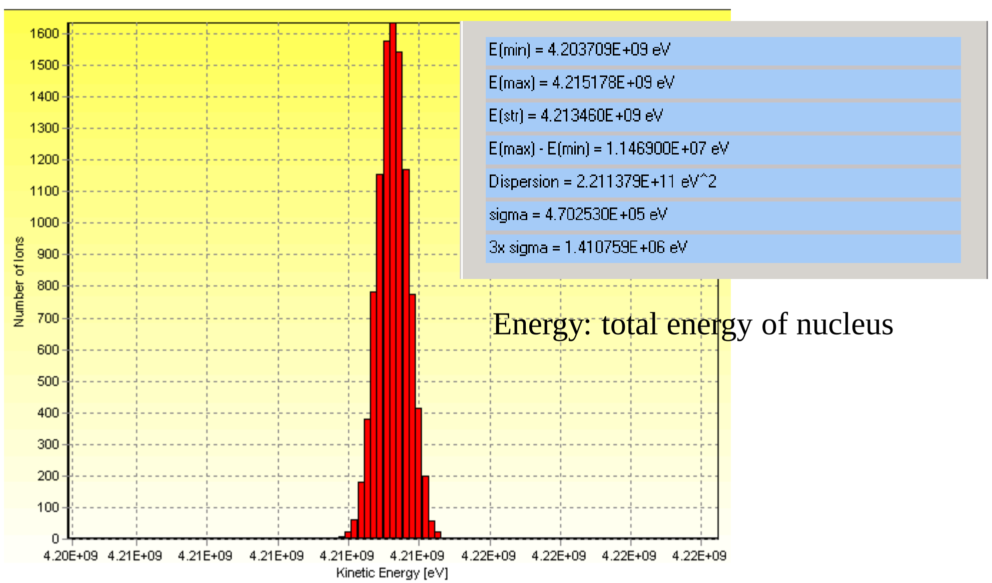
using TRACK code with 100k particles/charge state

Charge Stripper

- **17.5-MeV/u** uranium ion penetrated through **300-μg/cm² carbon**
- Charge distribution: 85% within charge state of 77 – 81 (using LISE++ code).
- Beam quality simulated by using SRIM code
  Transverse momentum spread: ± 0.4 mrad (rms
  Energy spread: less than 0.04%

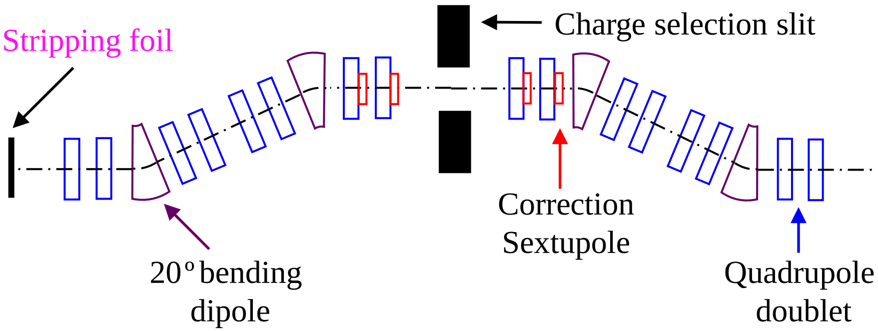




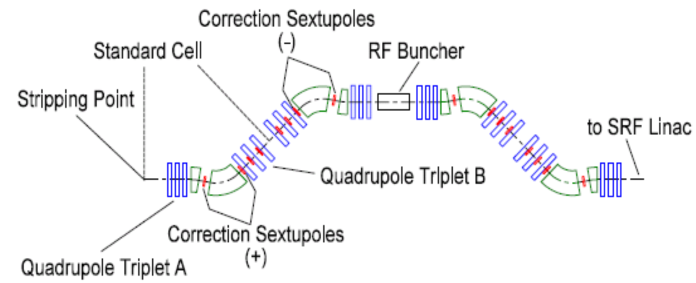


Charge Stripping Section – Chicane

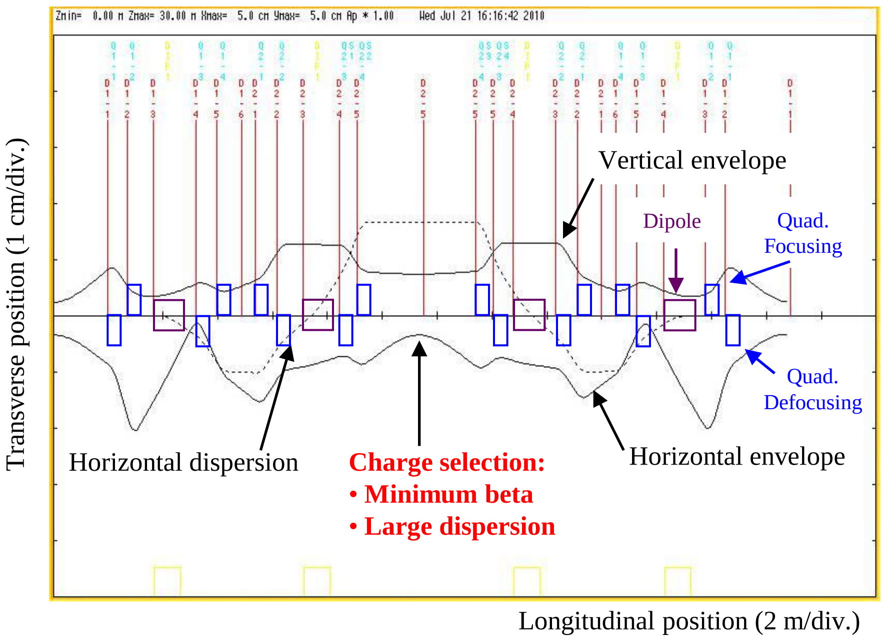
Chicane structure for charge selection (length: ~ 27 m)



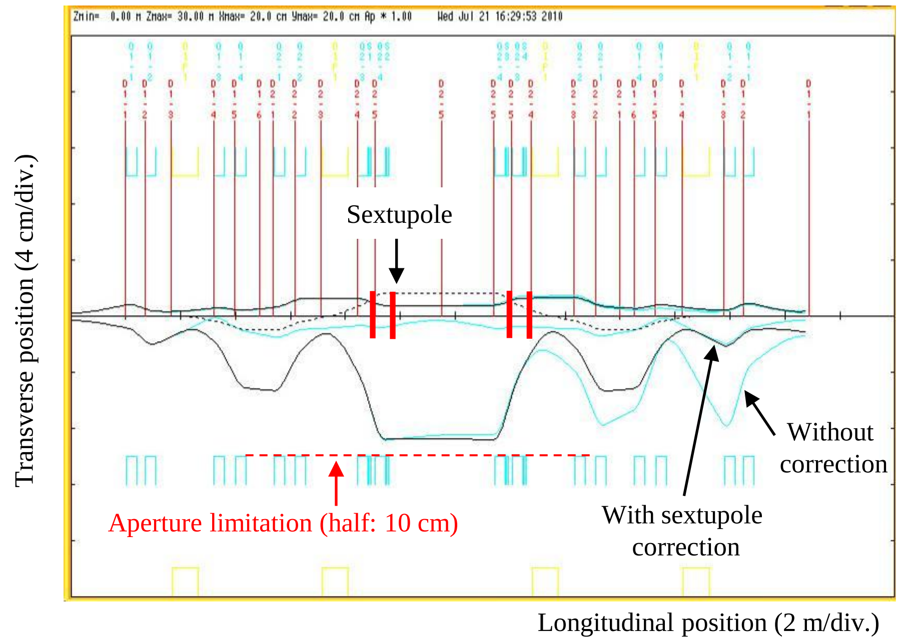
Cf. FRIB design (length: ~ 40 m)



Beam optics with on-momentum



Beam optics with off-momentum, $\Delta p/p = 5\%$ $\Leftrightarrow$ $Q=79\pm2$

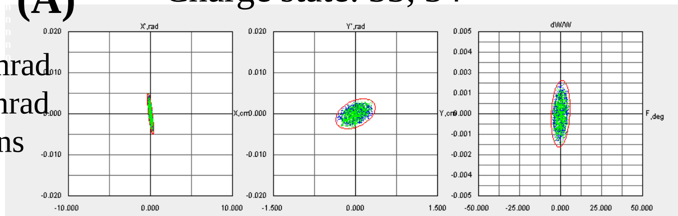


using TRANSPORT code

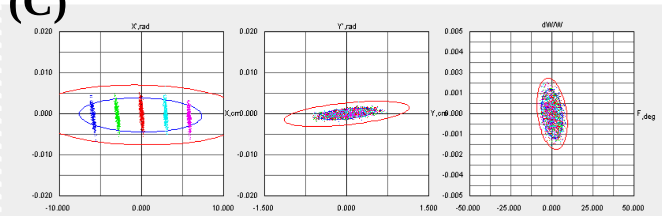
Charge Stripping Section

$\varepsilon_{nx,\,rms}$ = 0.22 mm·mrad
$\varepsilon_{ny,\,rms}$ = 0.20 mm·mrad
$\varepsilon_{nz,\,rms}$ = 1.1 keV/u·ns

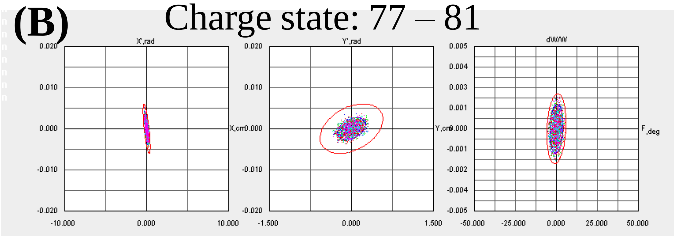
(A) Charge state: 33, 34



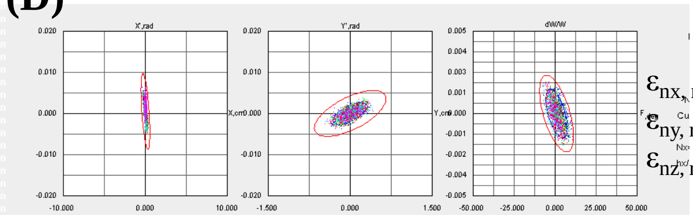
(C)



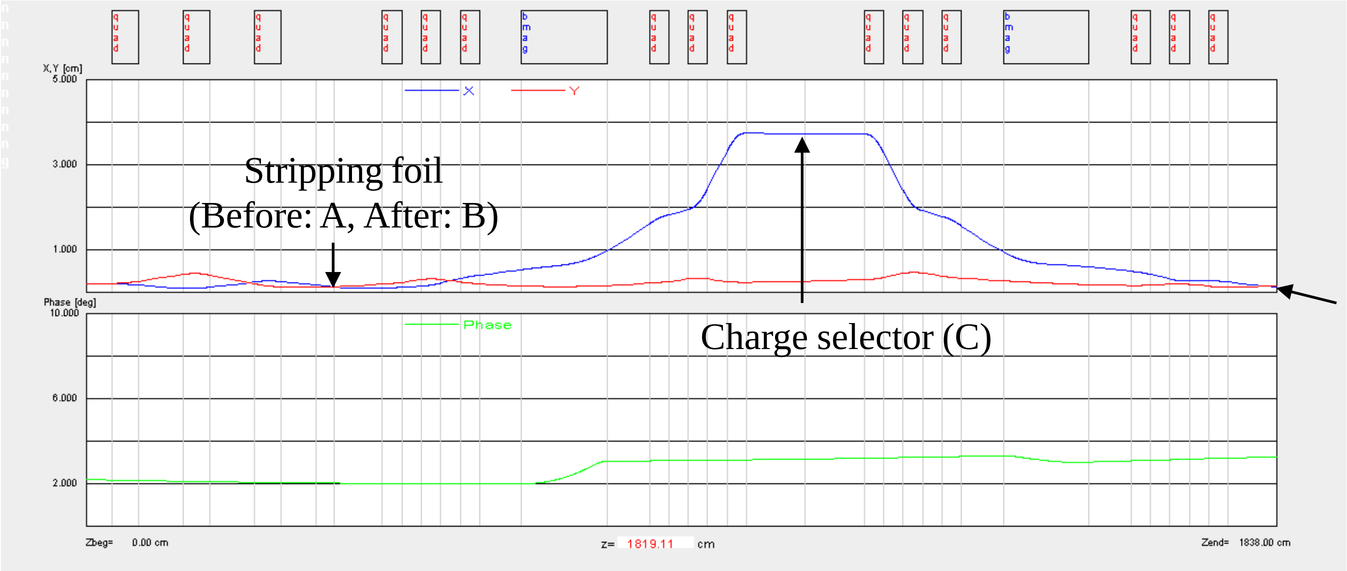
(B) Charge state: 77 – 81



(D)



$\varepsilon_{nx,\,rms}$ = 0.30 mm·mrad
$\varepsilon_{ny,\,rms}$ = 0.22 mm·mrad
$\varepsilon_{nz,\,rms}$ = 1.4 keV/u·ns



Out (D)

Length: ~ 20 m

using TRACK code

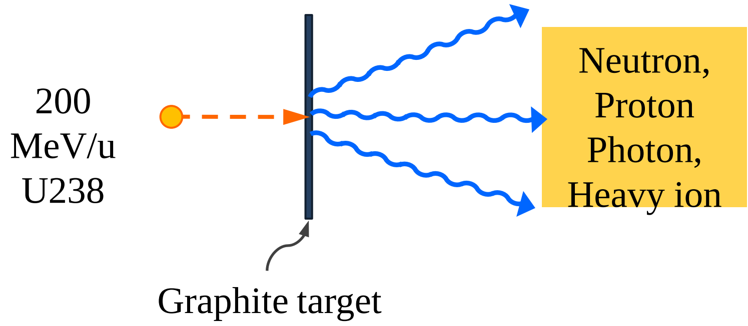
200 MeV/u(U) SC Linac

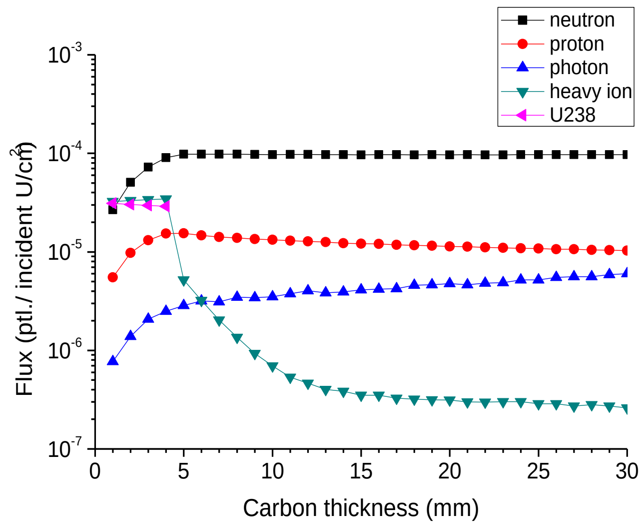
Beam Parameters

Ion Species	Z/ A	Ion source output		SC linac output			
		Charge	Current (pμA)	Charge	Current (pμA)	Energy (MeV/u)	Power (kW)
Proton	1/ 1	1	660	1	660	610	400
Ar	18/ 40	8	42.1	18	33.7	300	400
Kr	36/ 86	14	22.1	34-36	17.5	265	400
Xe	54/ 136	18	18.6	47-51	12.5	235	400
U(1)	92/ 238	33-34	11.7	77-81	7.9	210	400
U(2)	92/ 238	34	5.9	77-81	4.3	210	216

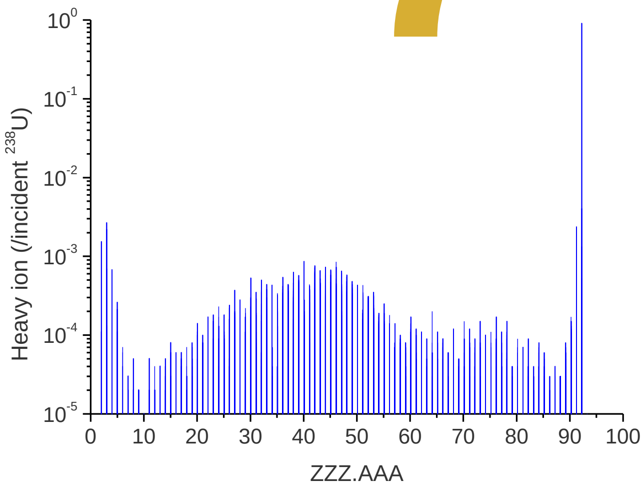
(1) Double charges from U ion source
(2) Single charge from U ion source

Particle Flux by U^{238} Source

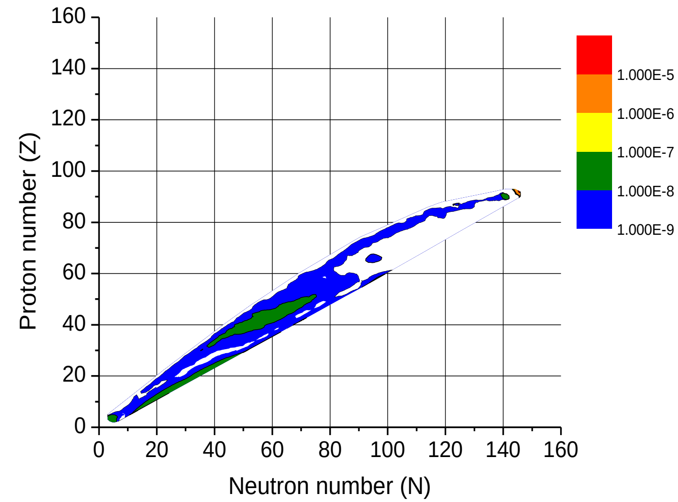




Flux of the output elements with the variation of carbon target thickness

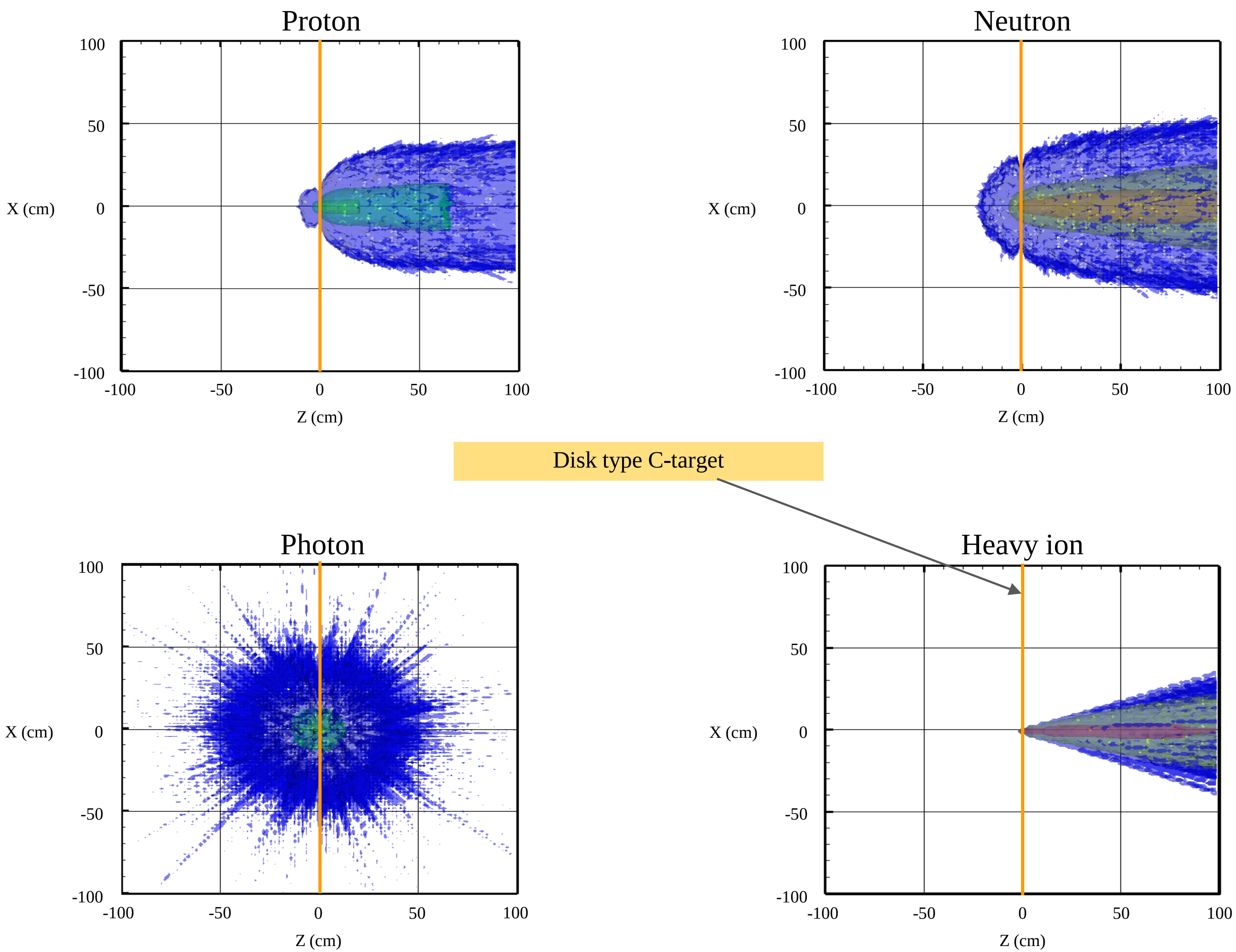


- Heavy ion distribution produced in 4mm-thick Target
- Why 4 mm? → Largest flux of heavy ion
- ZZZ.AAA on X axis => atomic number.atomic mass
  eg.) U^{238} is written as 92.238 on the X axis.



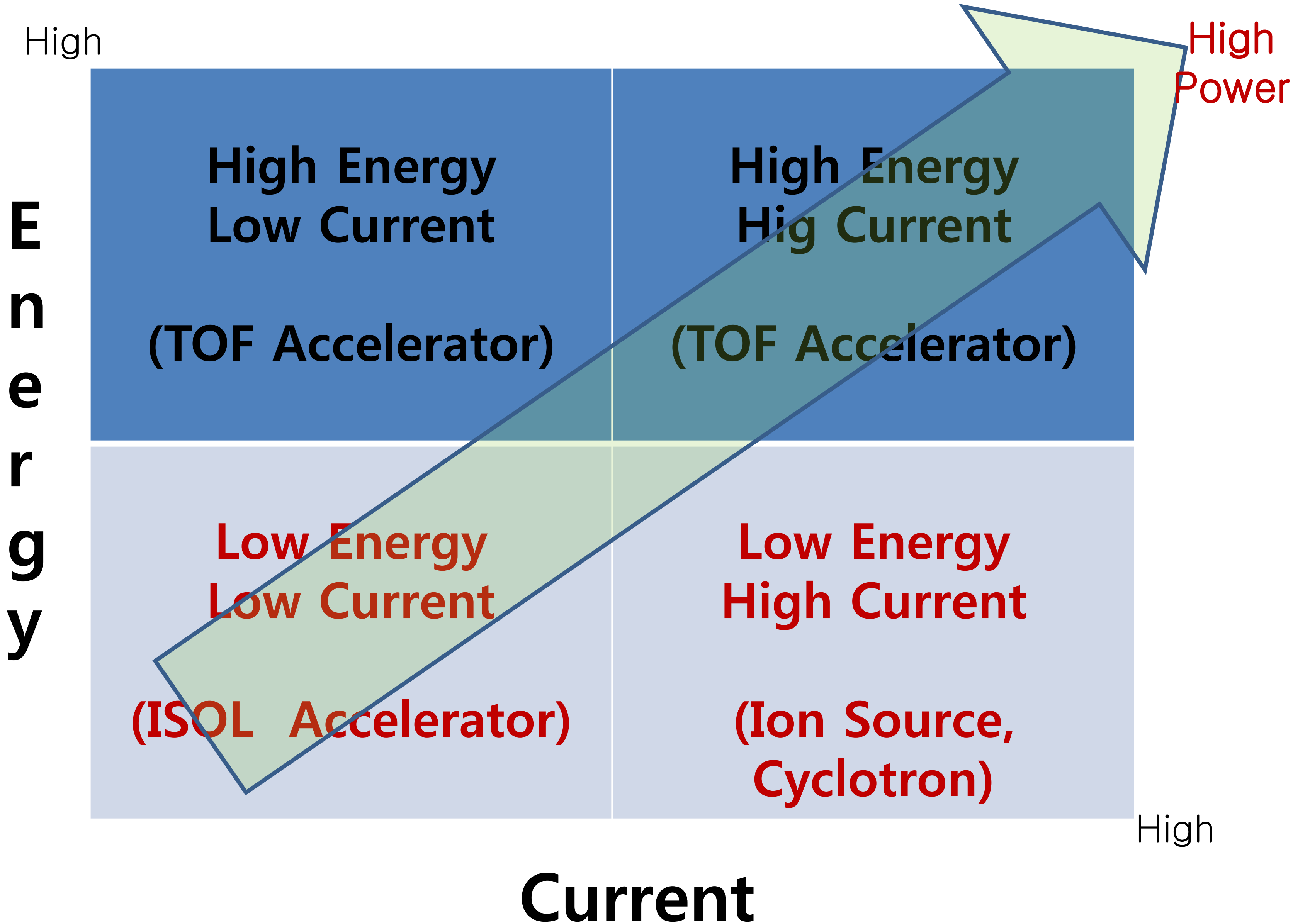
Z vs. N plot of heavy ions produced in 4mm-thick target

Ray Tracing for U^{238} (200 MeV/u) & Carbon (2 mm)

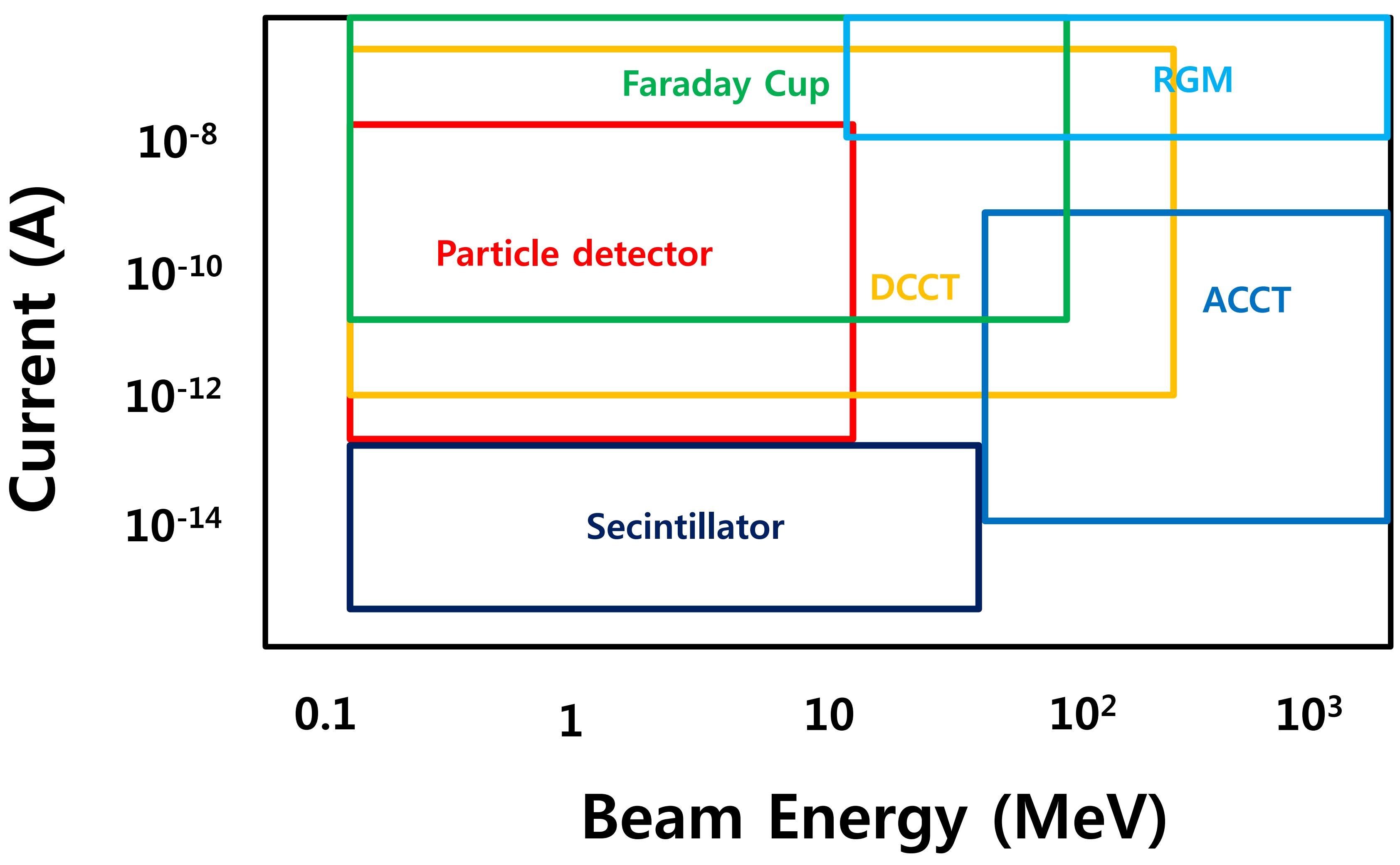


Beam Instrumentation

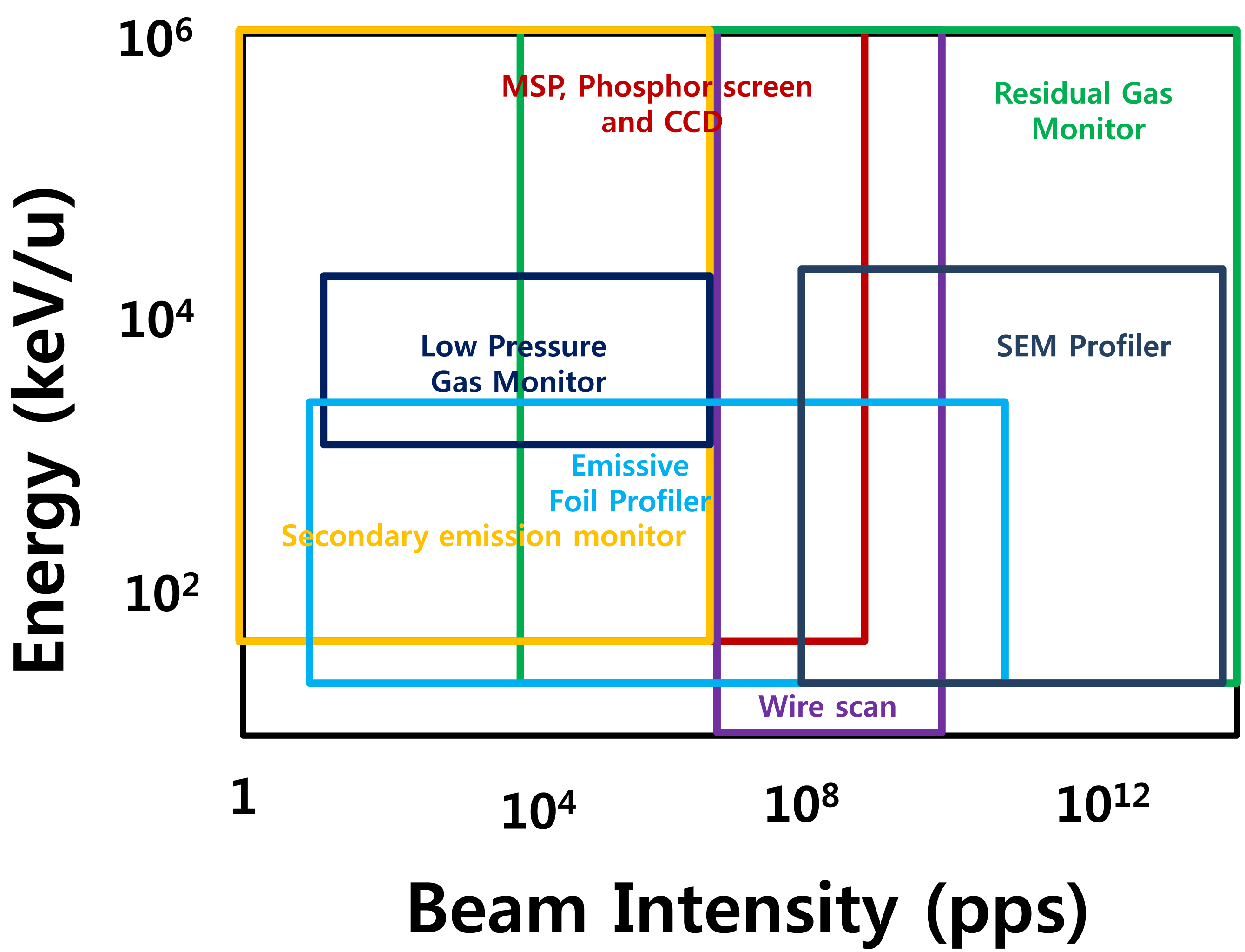
Beam Diagnosis System



Beam Current Monitors



Beam Profile Monitors



Beam Profile Monitors

Profiler type	Energy range	Intensity range	facility
Phosphor screen and CCD	1 MeV/u <	10^4 pps ~ 10^{10} pps	ISOLDE
MSP, Phosphor screen and CCD	60 keV/u ~ 460 MeV/u	1 pps ~ 10^9 pps	REX-ISOLDE
Rotation wire	1 keV/u <	10^7 pps ~ 10^{10} pps	
Scintillator	1 MeV/u <	1 pps ~ 10^{10} pps	
Scintillator fibre	1 MeV/u <	1 pps ~ 10^7pps	
Gas detector	1 MeV/u <	1 pps ~ 10^5 pps	
Residual Gas Monitor	100 keV/u <	10^4 pps ~ 10^{13} pps	
Secondary Electron emission	100 keV/u <	1 pps ~ 10^7 pps	
Low Pressure Gas Monitor	0.5 MeV/u ~ 25 MeV/u	10 pps ~ 10^7 pps	GANIL
Secondary Emission Foil Profiler	20 keV/u ~ 5 MeV/u	10 pps ~ 10^{11} pps	GANIL
Secondary Emission multiwire profiler	20 keV/u ~ 25 MeV/u	10^8 pps ~ 10^{13} pps	GANIL

ISOL Accelerator Beam Parameters

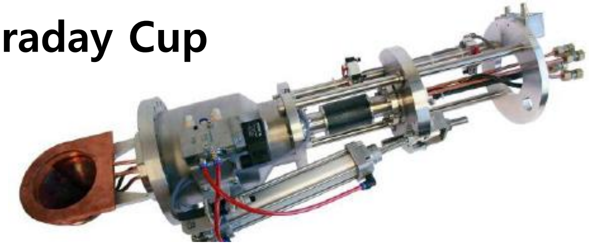
Section	Energy	Current	Power	Ø (mm)	$\varepsilon_{r \cdot rms \cdot norm}$ (π·mm·mrad)	Ion	A/Q
1	70 MeV	1 mA	70 kW	2	0.2	$^{1}H^{1+}$	1
2	10 keV/u	10^7 ~ 10^8 pps	-	2	0.4	$^{132}Sn^{22+}$	6~7
3	10 keV/u	10^7 ~ 10^8 pps	-	2	0.4	$^{132}Sn^{22+}$	6~7
4	10 keV/u	10^7 ~ 10^8 pps	-	2	0.4	$^{132}Sn^{22+}$	6~7
5	15 MeV/u	10^7 ~ 10^8 pps	-	2	0.4	$^{132}Sn^{22+}$	6~7

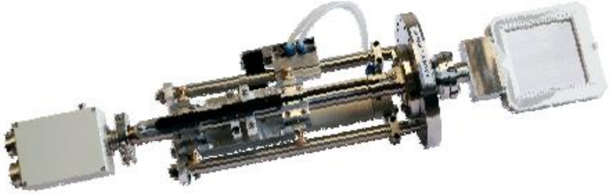
Low Energy Beam Diagnosis System (<10MeV/u)

Beam quantity		Diagnosis system(Suggestion)
Low Energy Beam (<10 MeV/u)	Current	Faraday Cup, DC Current Transformer, Second Emission Monitor
	Position	Pick-up, using profile measurement
	Profile	Second Emission Monitor, Low Pressure Gas Monitor, Wire scanner, Beam induced Fluorescence
	Transverse Emittance	Slit + Second Emission Monitor, quadrupole scan
	Longitudinal Emittance	Wire scanner, TOF application
	Beam Loss	Semiconductor detector

GANIL SPIRAL2

Faraday Cup

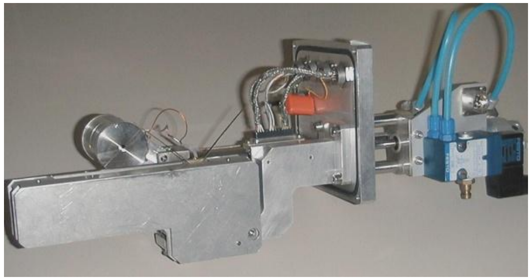


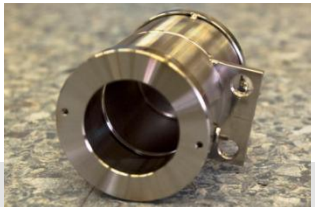


Secondary electron emission (SEM) grid

CERN ISOLDE

Wire Scanner and Faraday cup





High Energy Beam Diagnosis System (<200MeV/u)

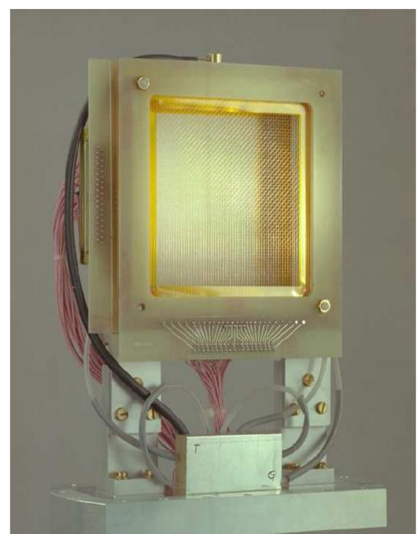
Beam quantity		Diagnosis system(Suggestion)
High Energy Beam (<200 MeV/u)	Current	DC Current Transformer, AC Current Transformer
	Position	Pick-up, using profile measurement
	Profile	MWPC, Beam induced Fluorescence
	Transverse Emittance	quadrupole scan
	Longitudinal Emittance	Wire scanner, TOF application
	Beam Loss	Semiconductor detector

GANIL SPIRAL2

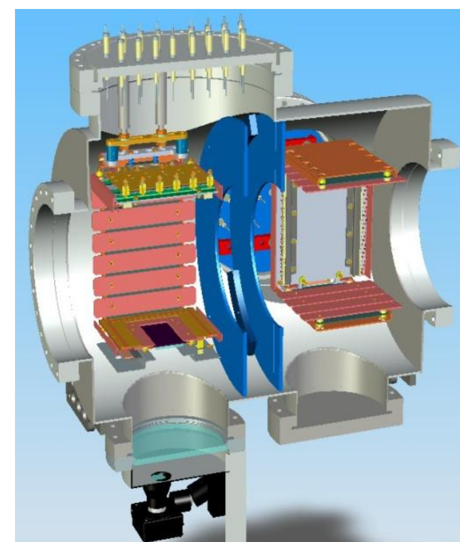
GSI FAIR

Position monitor

DC Transformer



MWPC



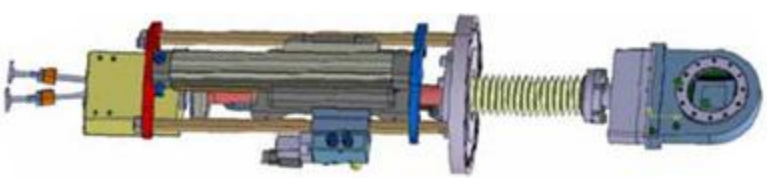
Residual Gas Monitor

RI Low Current Beam Diagnosis System

Beam quantity		Diagnosis system
RI Beam	Current	Faraday cup, DC Current transformer
	Position	using profile measurement
	Profile	Second Emission Monitor, Wire scanner
	Transverse Emittance	Slit + Second Emission Monitor
	Longitudinal Emittance	Wire scanner, TOF application
	Beam Loss	Semiconductor, Gas-type detector

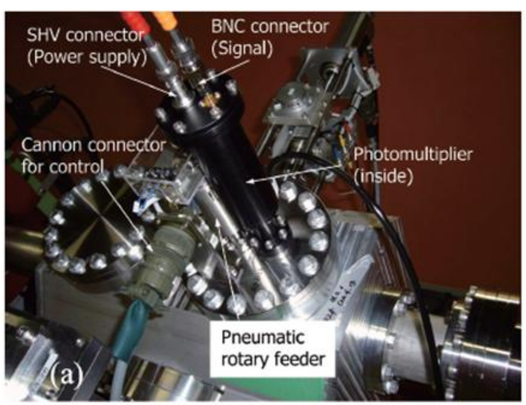
GANIL SPIRAL2

Emissive Foil Monitor

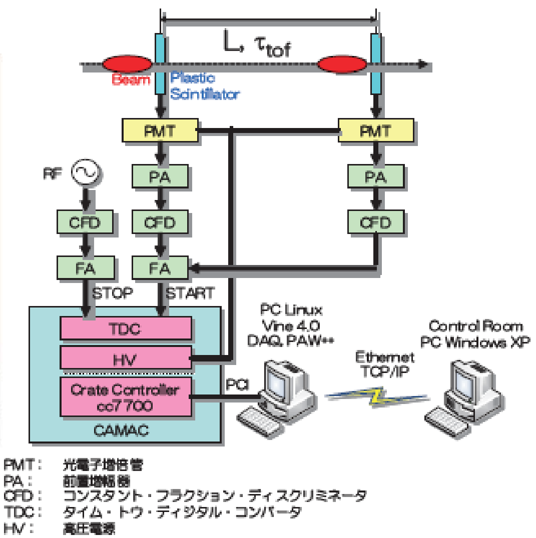


Low Pressure Gas Monitor

RIKEN RIB

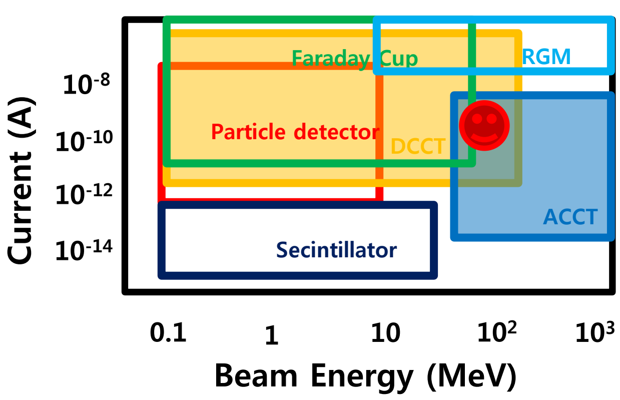


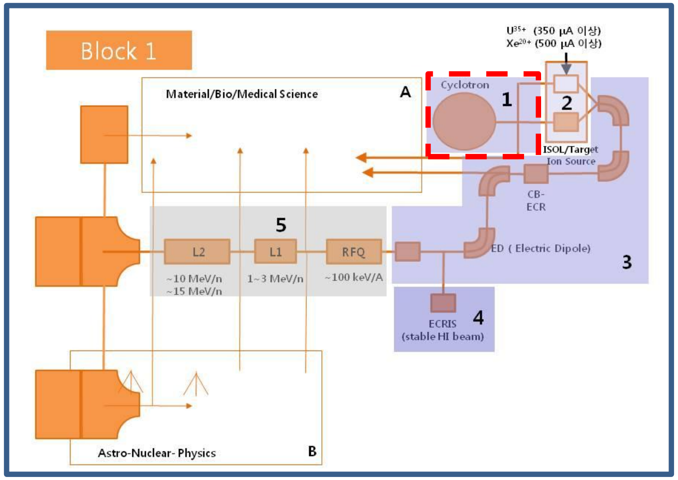
Energy Monitor

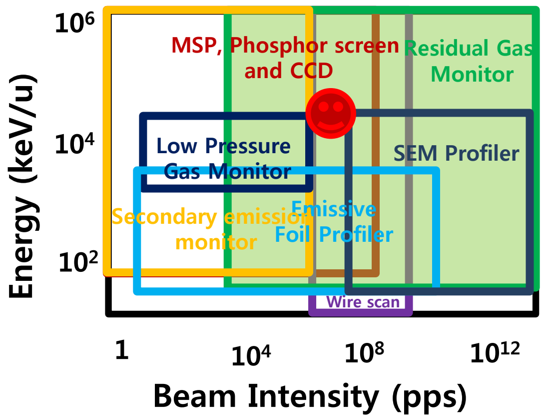


Section 1 : Cyclotron exit and ISOL/Target Ion source

Current	DC Current transformer, A.C. Current transformer
Position	Pick-up electrodes
Profile	Residual Gas Monitor, Proton Beam Residual Gas Fluorescence Analysis
Transverse Emittance	Using profile measurement
Longitudinal Emittance	Pick-up electrodes by using the time-of-flight
Beam Loss	Semiconductor radiation detector

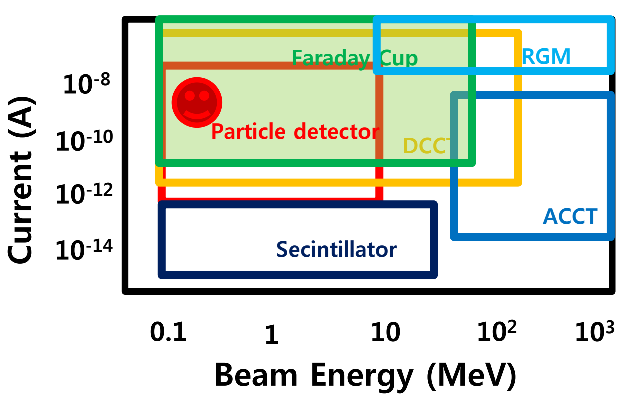


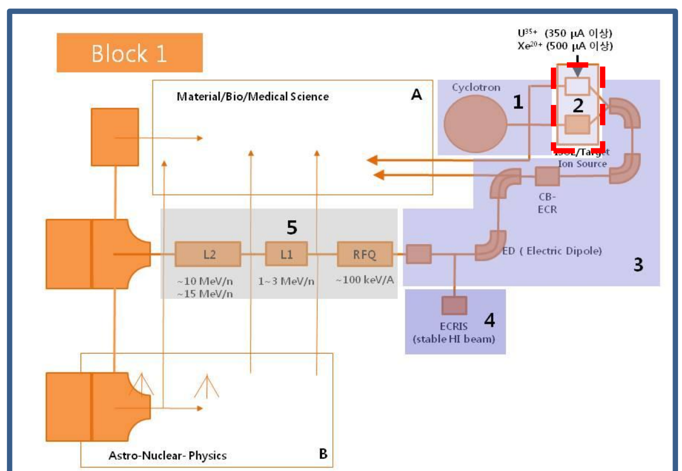


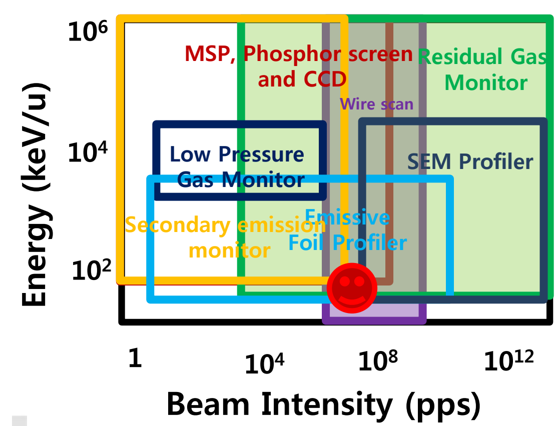


Section 2 : ISOL/Target Ion Source

Current	Faraday cup
Position	Using profile measurement
Profile	Wire scanner, Residual Gas Monitor
Transverse Emittance	Using profile measurement
Longitudinal Emittance	Using profile measurement
Beam Loss	Gas type gamma-ray detector

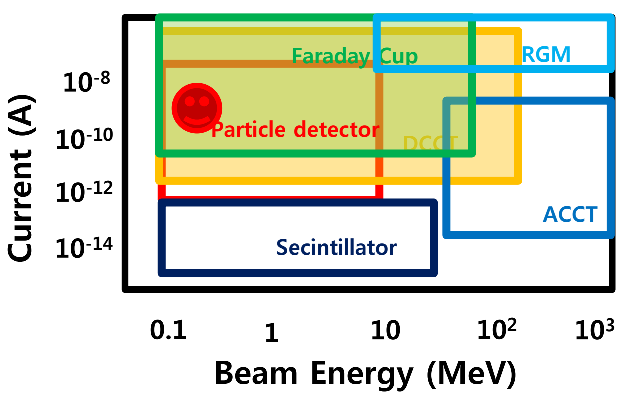


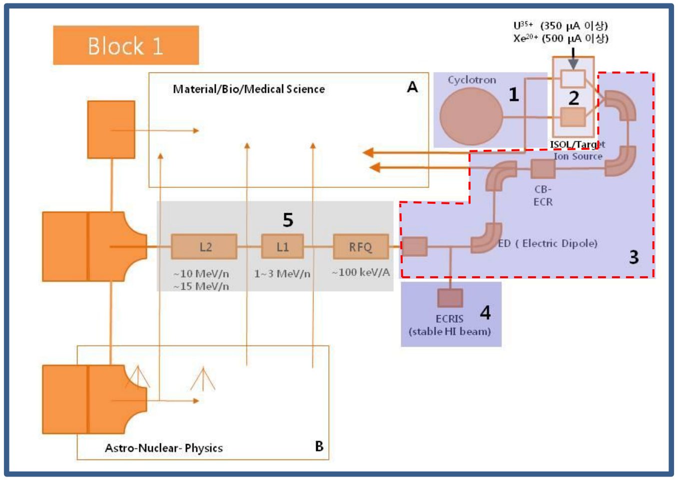


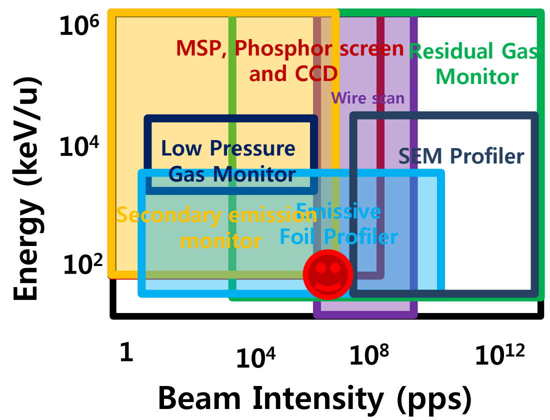


Section 3 : ISOL/Target Ion Source exit

Current	Faraday cups, DC Current transformer
Position	Using profile measurement
Profile	Emissive Foil Profiler, Second Emission Monitor, Wire scanner
Transverse Emittance	Alloson scanner, Slit + Second Emission Monitor, Using profile measurement
Longitudinal Emittance	Wire scanner, Pick-up electrodes by using the time-of-flight
Beam Loss	Semiconductor radiation detector
Charge/Mass State	Magnetic Mass Spectrometer, Electric Dipole Scanner

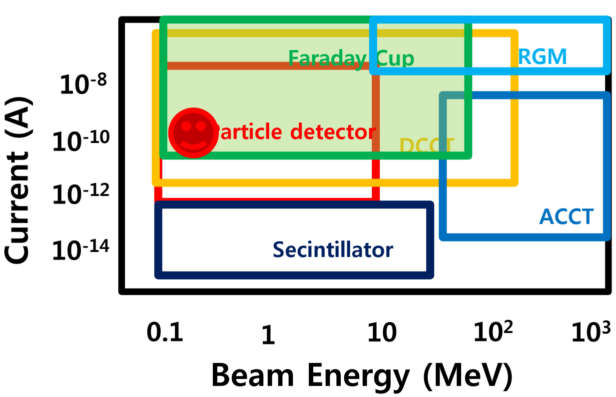


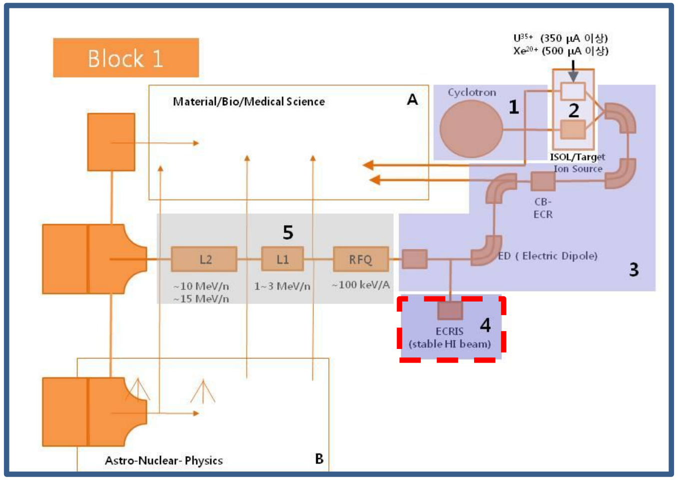


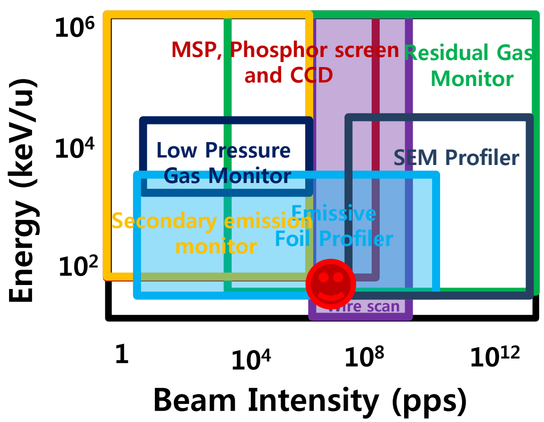


Section 4 : ECRIS exit

Current	Faraday cups
Position	Using profile measurement
Profile	Emissive Foil Profiler, Wire Scanner
Transverse Emittance	Using profile measurement
Longitudinal Emittance	Using profile measurement
Beam Loass	semiconductor detector

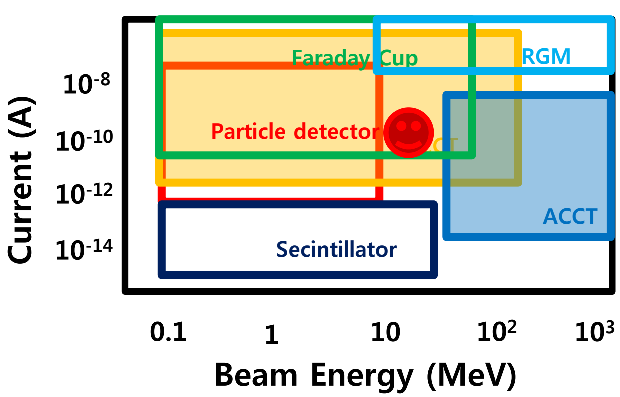


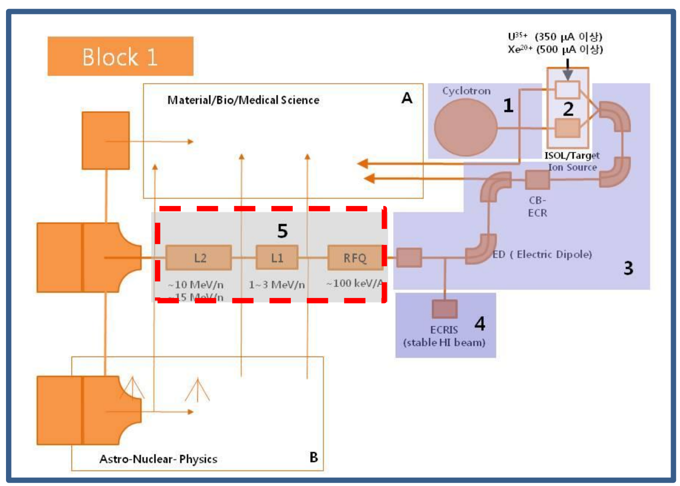


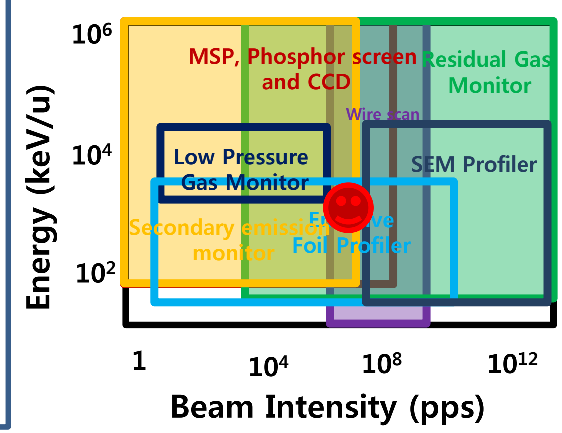


Section 5 : From RFQ to SC Linac exit

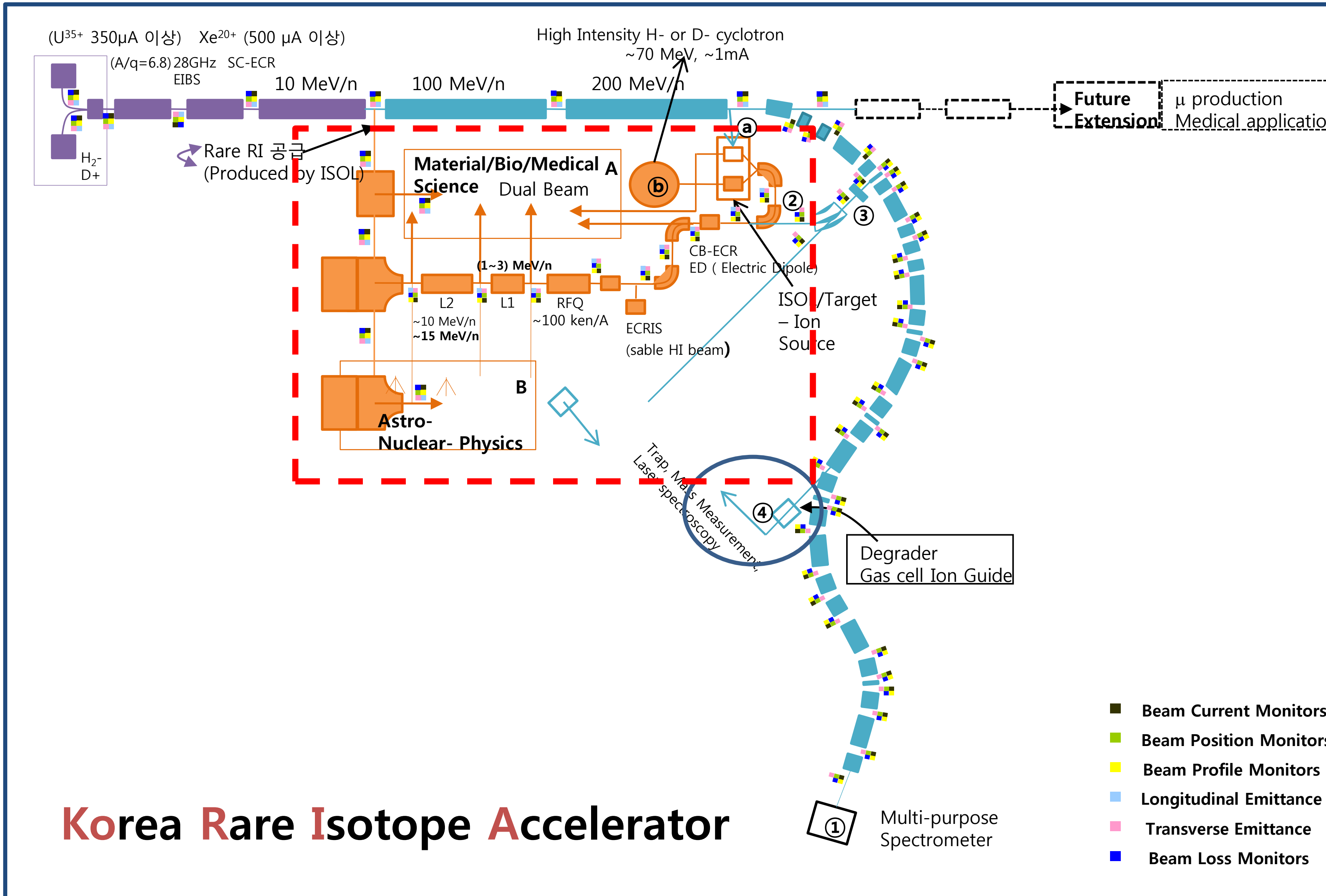
Current	D.C. current transformer, A.C. current transformer
Position	Pick-up electrodes
Profile	Second Emission Monitor, Wire scanner, Residual Gas monitor
Transverse Emittance	Alloson scanner, Slit + Second Emission Monitor, quadrupole scan
Longitudinal Emittance	Wire scanner, Pick-up electrodes by using the time-of-flight, Residual Gas Ionization monitor, 2 Slits + dipole magnet + Faraday cup
Beam Loass	Semiconductor radiation detector





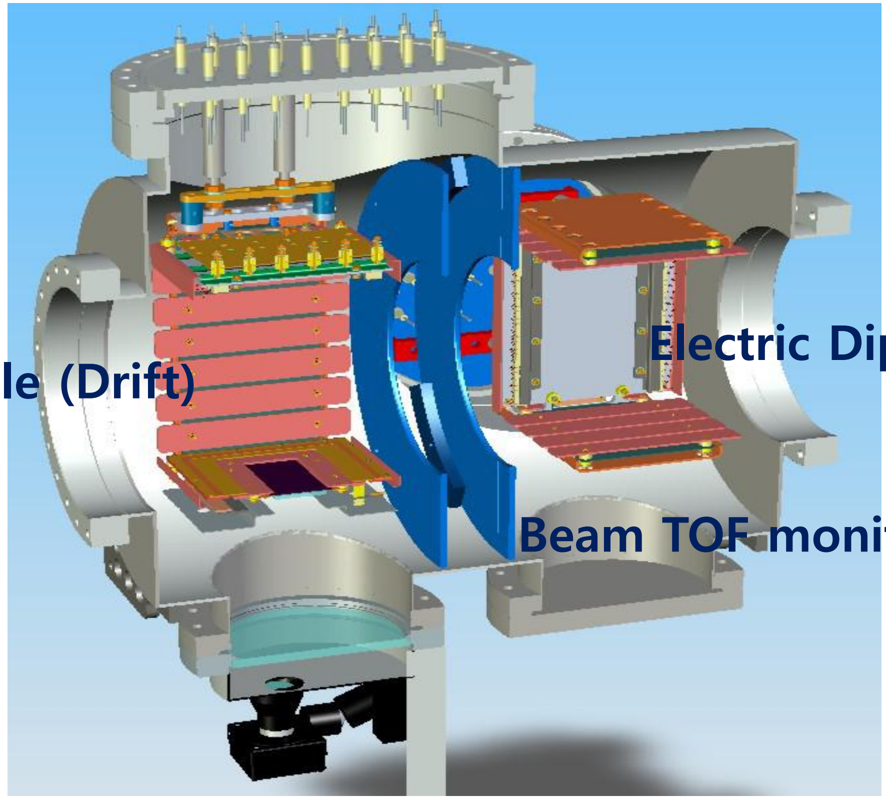


Beam Diagnostics System Installation Position (Preliminary)



Multi Parameter Measuring System(Concept)

Residual Gas Monitor(RGM) for multi-parameter measurement with Beam Dynamic Image



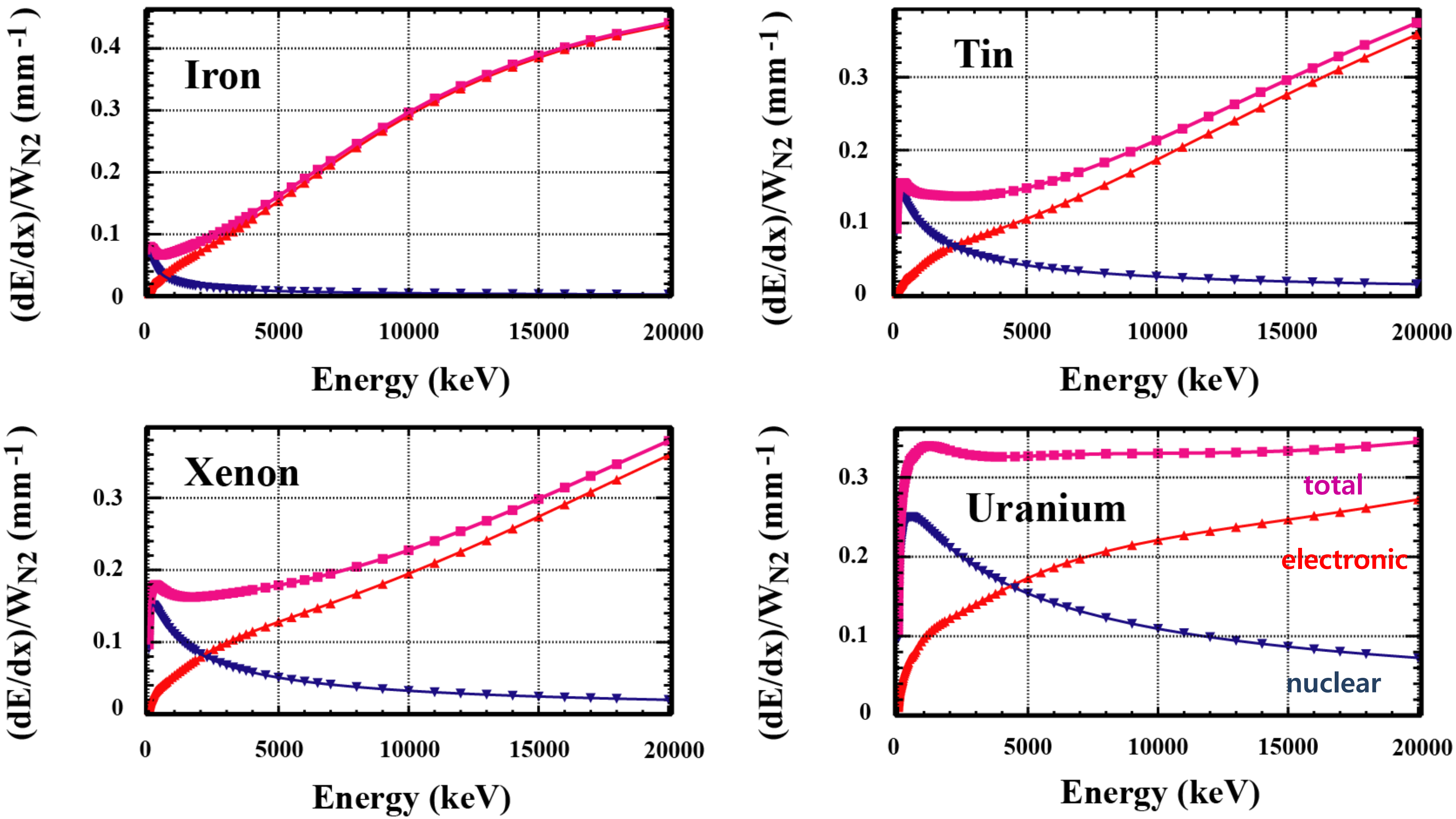
Electron/ion pair creation simulation

$$n = (dE/dx)/W_{N2}$$

$$(dE/dx)_{total} = (dE/dx)_{electronic} + (dE/dx)_{nuclear}$$

Pressure = 4.2 X 10^{-6} mbar

Air Density = 5.0 X 10^{-9} g/cm^3
= 2.0 X 10^{14} atoms/cm^3

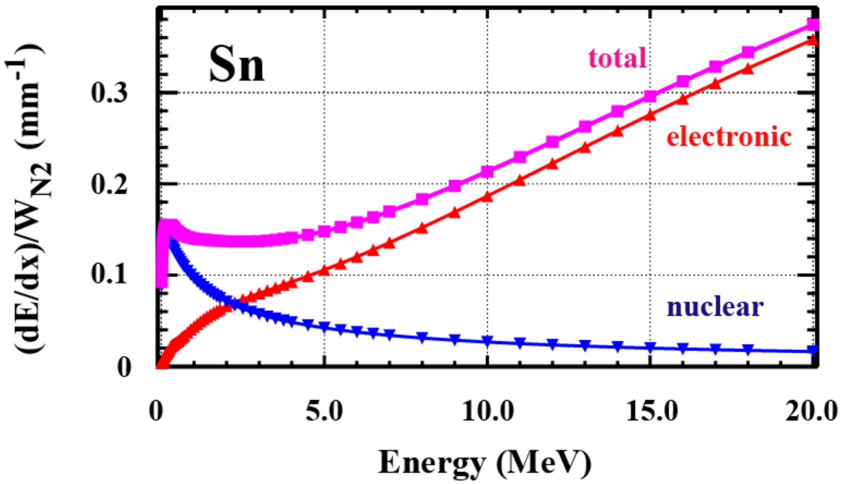


Perfomance simulation of Mutiparameter measuring system

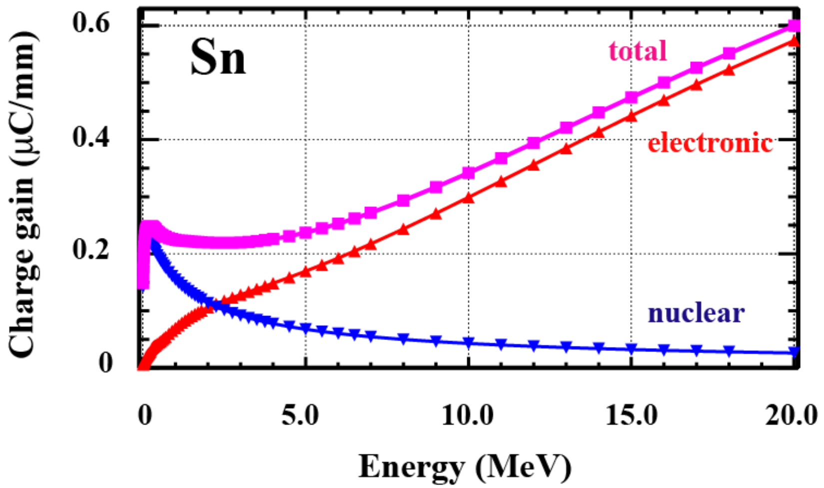
(unit : #/mm)

$$n = (dE/dx)/W_{N2}$$

$$(dE/dx)_{total} = (dE/dx)_{electronic} + (dE/dx)_{nuclear}$$



W_{N2} = 36.4 eV
Pressure = 4.2 X 10^{-6} mbar
Air Density = 5.0 X 10^{-9} g/cm^3
= 2.0 X 10^{14} atoms/cm^3



Beam Intensity = 10^7 pps
MCP Gain = 10^6

Control system

Control System

Two important topics in control system :

1) To guarantee reliable controllability for all the sub systems and equipments over the accelerator facility,

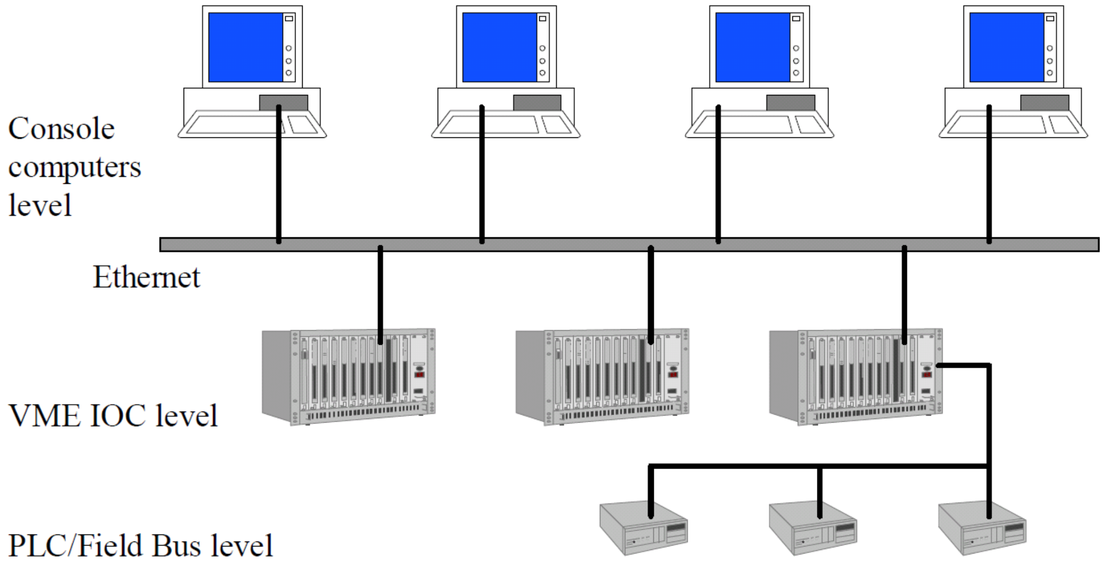
2) Be capable of collection and service for all data and information that came from accelerator machine or experiments.

EPICS Toolkit

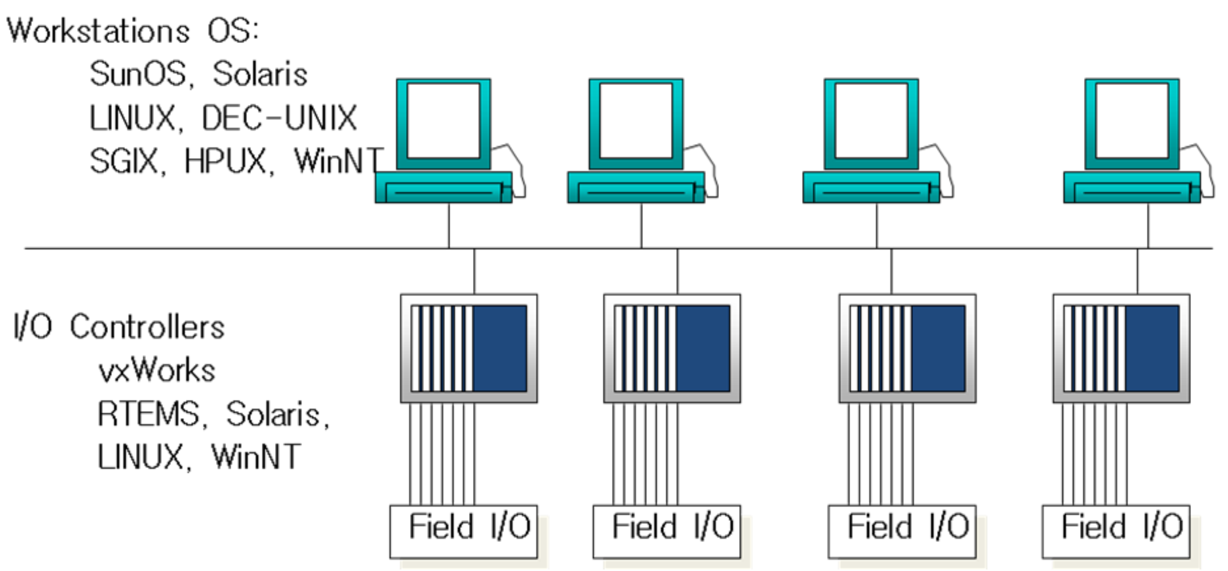
The EPICS for :

- data acquisition
- supervisory control
- close-loop control
- sequential control
- operation optimization
- etc.

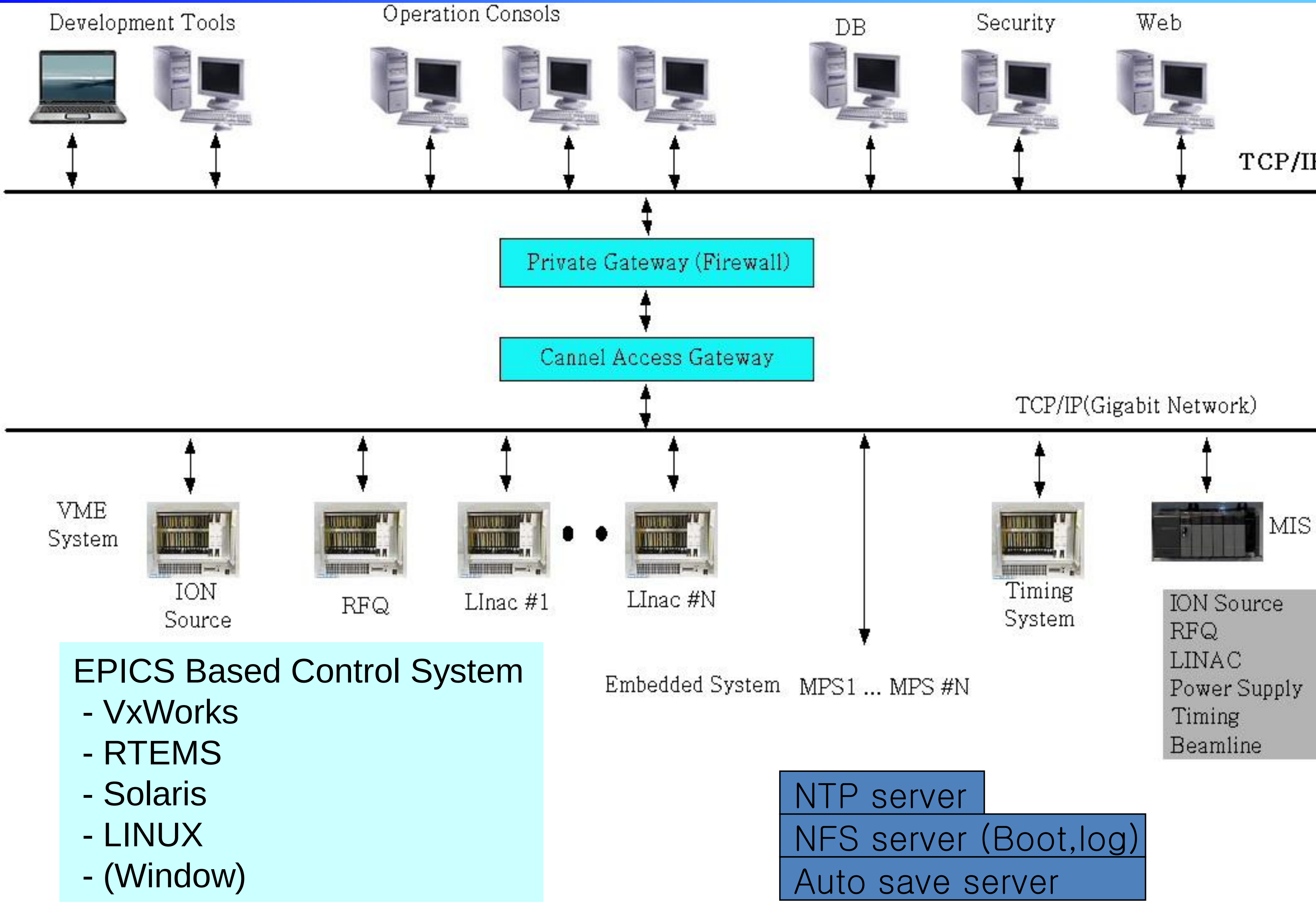
General EPICS
hardware architecture



General EPICS
server/client OS
architecture



Control System Architecture



High level control system

Machine Operation and Surveillance System

- Computer hardware : SUN / HP Workstation and many desktop computers
- OS : Soraris / HPUX / Linux(RHEL5.5 64Bit) / WinNT
- Application software : Control System Studio (CSS), EDM, MEDM, Matlab, Qt, LabView, Probe, Alarm Handler, Python, IDL

Data Management Server System

- Computer hardware : SUN / HP Workstation and many desktop computers
- OS : Soraris / HPUX / Linux(RHEL5.5 64Bit) / WinNT
- Application software : Web, database, nfs, backup system, e-log system, RDBS, Archive

Physics Application Support System

- Computer hardware : SUN / HP Workstation and many desktop computers
- OS : Soraris / HPUX / Linux(RHEL5.5 64Bit) / WinNT
- Application software : MML, SDDS, Elegant, Control System Studio (CSS),IDL

Sub-system IOC hardware and software

IOC hardware :

- VME : MVME6100 VME of PowerPC architecture (68K) CPU.
- Compact-PCI(cPCI) : Intel® Pentium® M/Celeron® M Universal CompactPCI®, CPCI-7808(GE-Ganuc)
- ARM CPU based embedded board.

Sub-system IOC OS :

- Real-time OS : vxWorks 6.6, RTEMS4.9 (Real-Time Executive for Multiprocessor Systems)
- Linux : RHEL5.5(Read Hat Enterprise Linux) (64Bit)

The sub-system satisfies the following conditions

- Sub-systems must include more than one EPICS IOC
- Sub-system can be modified or monitored by the HLCS (high level control system)
- Sub-system can be operated and tested independently.
- The software code of IOC can be modified by a remote system.
- Execution of the IOC is able to start by the image file
- Generate and receive the software event through control network
- Accept the software event signal from the timing system
- Self-protection ability, and offer local status to the machine protection system (MPS).
- Protect itself on receiving signal from the MPS.
- Input the hardwiring protection signal from MPS and vice versa.
- Accept the data from the MPS and take proper measures to protect itself.

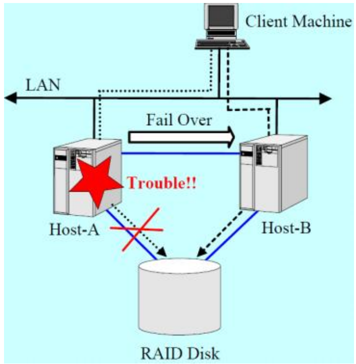
Planned Field Bus

- Serial(RS-232, RS-422, RS-485)
- GPIB
- CAN Bus
- Ethernet I/O (GPIB LAN Boxes, Ether IP Modules, Oscillator, Oscilloscope, etc)

Database System

The database system should respond to the various requirements of the clients.
- To store in safety
- To access in promptitude.
- Be able to access through web

1) All information of the sub-system,
2) Calibration data
3) Image of IOC
4) The various components such as *.db, *.template, start script of IOC, node information and so on.



The RAID (redundant array of independent disks) :
- Duplicated against computer failure

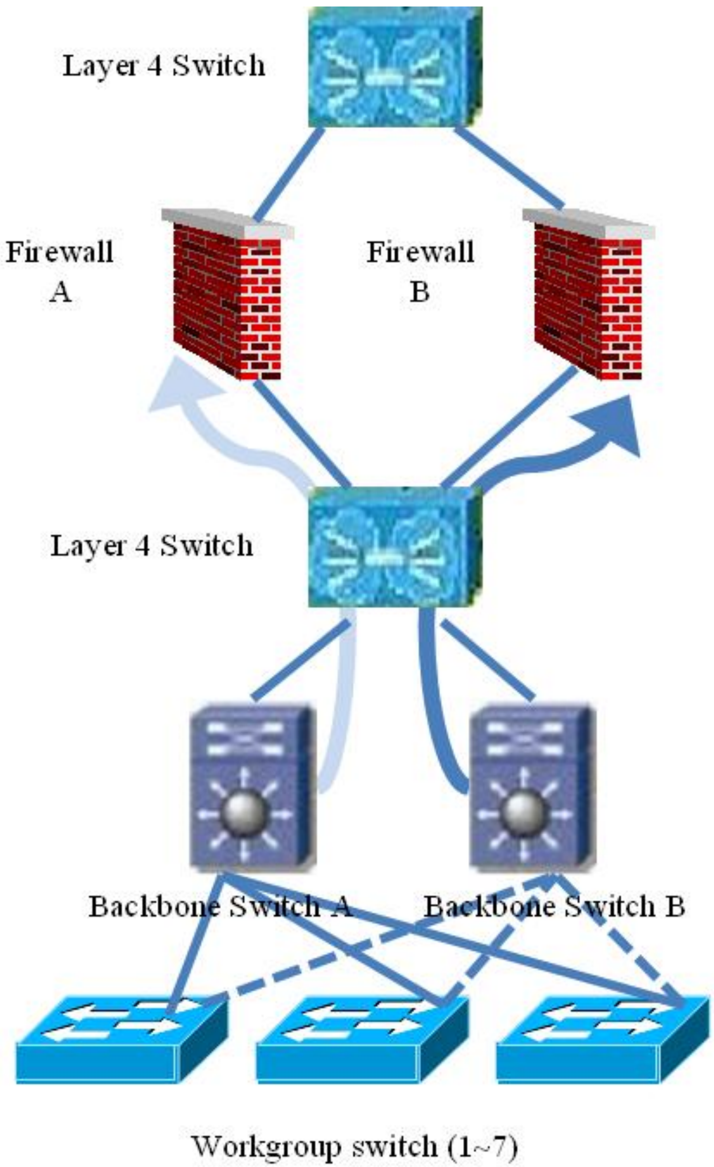
The database management system was commercially available as ORACLE, my-SQL etc.

Machine Protection System (MPS)

The MPS is indispensible system to protect the accelerator machines

- Generate the signal responding to whether system operation is going on or not.
- Integrate all the ready statuses of the sub-systems.
- Easy expandable in I/O and program depending on the sub-system.
- Possible to modify the protection sequence without interrupting accelerator operation.
- The MPS should have three levels responding for warning, alarm and protection.
- Record both the origin of cause and following-up measures at each level.
- Offer the MPS status to the High Level Control System
- Some important I/Os of MPS was duplicated.
- The UPS was installed for 24-hour operation, etc.

Network Failure



Conceptual drawing for network failure

Backbone duplication

- The network doesn't top the service while equipments repair is going on o trouble occurs by the duplication of the major facility.

Network Configuration (1)

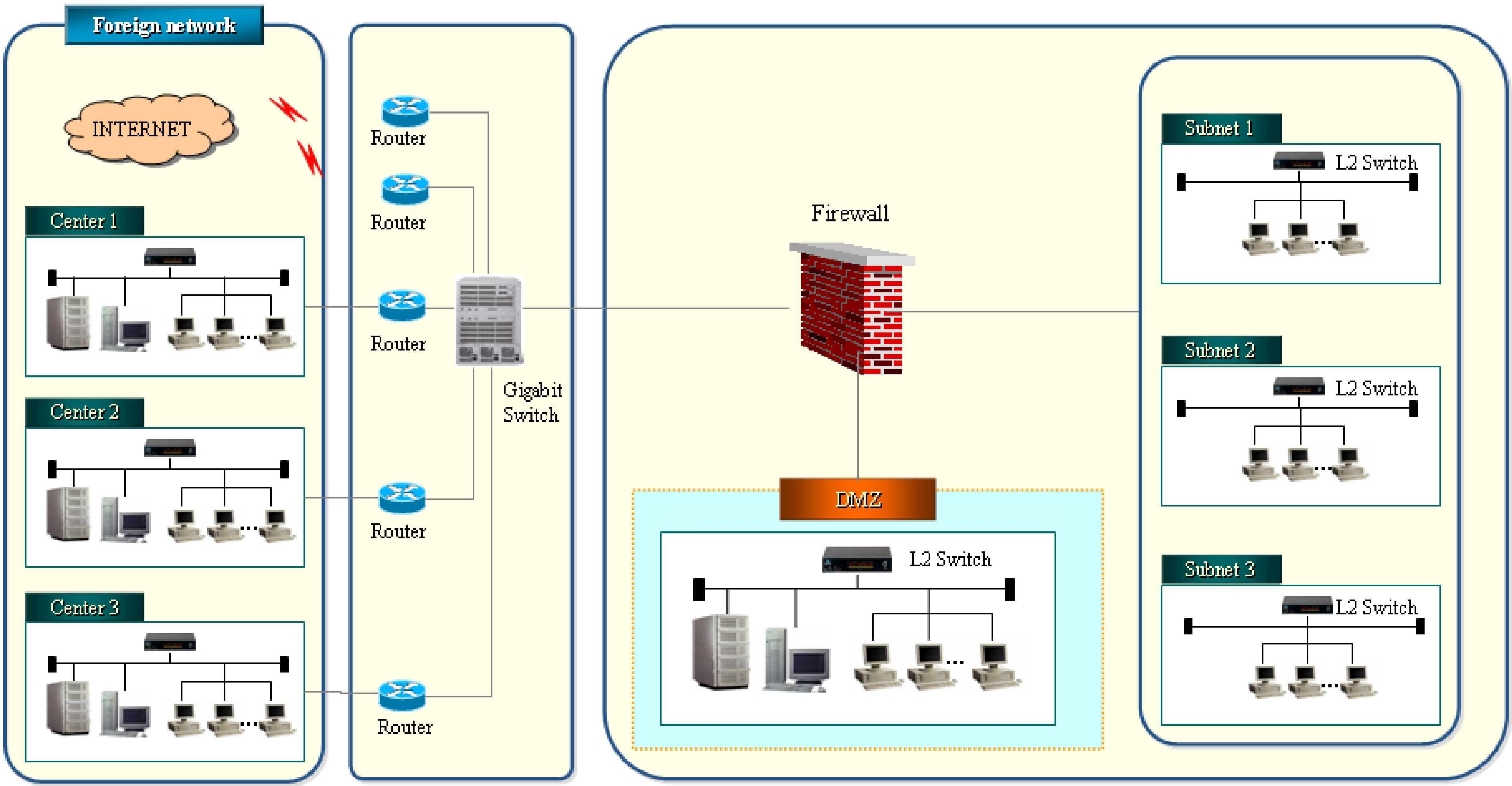
1. Office network :

To consider system expansion and integration with growing number of buildings and users, try to keep the open architecture and standard protocol when the network equipments chose.

2. Control Network

- Device control network : Sub-system control & monitoring
- Diagnosis network : webcam or digital camera equipped with Ethernet
- Event timing network : Network for the event timing system
- Interlock network : To secure the reliability of the interlock signal handling
- Beam line network : Beam line control

Network Configuration(2)



Timing System

The purposes of a timing system are summarized as followings:

1) To synchronize all the accelerator sub-systems over the accelerator complex,

2) To trigger the devices at right time by a pulse or several sequential pulses,

3) To provide exact time for diagnostic components and data acquisition devices

4) To match the delays between devices

5) To provide timestamps of collected data or executed actions.

The timing system should be :

▪ Receives the parameters and commands from the EPICS IOC, and transmits the status of the timing system.

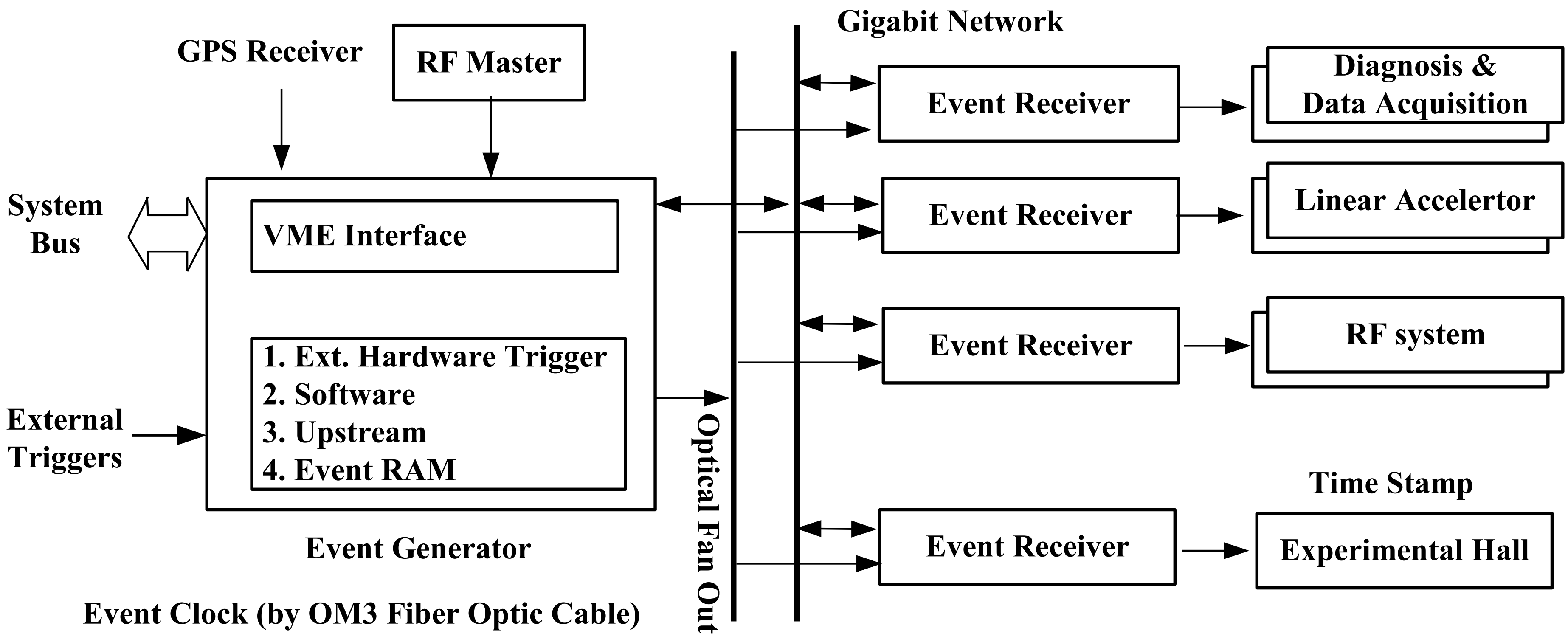
▪ Easy expandable to meet increasing applications.

▪ Accept the AC line frequency to synchronize to the event generation.

Event Timing System

Events	8-bit code -256 event
Distributed bus byte	8-bit
Event Clock Ratio	50 - 125MHz
Transmitted bit rate	1.0 - 2.5Gbps
Event Generator (EVG)	- Hardware trigger input - Software event - Event sequencer - Upstream EVG. etc.
Event Receiver (EVR)	- Fixed width pulses - Programmable delay & width pulses - Delay output - Set-reset output, - Software interrupts, etc.
Transmission media	Multi-mode or single-mode fiber optic
Time precision	less than 10ps

Conceptual timing system



Summary

Cyclotron

Conceptual design of K8 SFC and K100 SSC

ISOL

Conceptual design of 70kW direct fission target

- Fission rate ~ 10^{14}fission/s
- Provide high intensity and high-quality beams of neutron-rich nuclei

Conceptual design of ISOL RI Beam transport system

-Yield on experiment of ^{132}Sn ~ 9 x 108

Ion source

- Conceptual design 28 GHz SM ECRIS as a driver ion source in.
- Both of EBIS and ECRIS will be developed as a charge breeder to complement each other for the differently needed beam condition

RFQ

•Structure

The choice of the "window-type" RFQ : correct at the CW duty factor and no significant problems in thermal analysis.

•Frequency

The choice of the 70 MHz fundamental frequency :

Use a lower frequency.

The original RFQ frequency was 50MHz.

Now, ANL 57&60 < KoRIA 70 < FRIB 80, SPIRAL2 88 MHz

Low Energy SC LINAC

- We could meet all the design goals, that is, no beam loss is observed, no significant parametric resonance is observed.
- Beam quality is well preserved: emittance growth of any charge states is only a few per cents, even for de-acceleration case.
- Solenoid strength is less than 8 Tesla

High Energy SC LINAC

Beam loss tolerance : 1 W/m

End of RFQ : $1.7 * 10^{-3}$

End of SC linac1 : $2.9 * 10^{-5}$ (beam power ~ 35 kW)

Beam Instrumentation

Specific beam parameters need to determine beam diagnosis system design with a consideration of beam dynamic ranges.

Beam diagnosis system needs to have wide dynamic range design for covering planed beam values.

Control System

Control system : EPICS adapted

Machine Protection System : To protect accelerator devices

Database system – Redundancy

Network System – backbone duplication, Dedicated network, Security

Event timing system – Time stamp, Trigger signal, Delay etc.

Digitally Controlled Magnet Power Supply (EPICS embedded)

Digitally controlled LLRF system (Amplitude 1 % , Phase 1 Degree)