Baseline Design of the RISP Accelerator Facility

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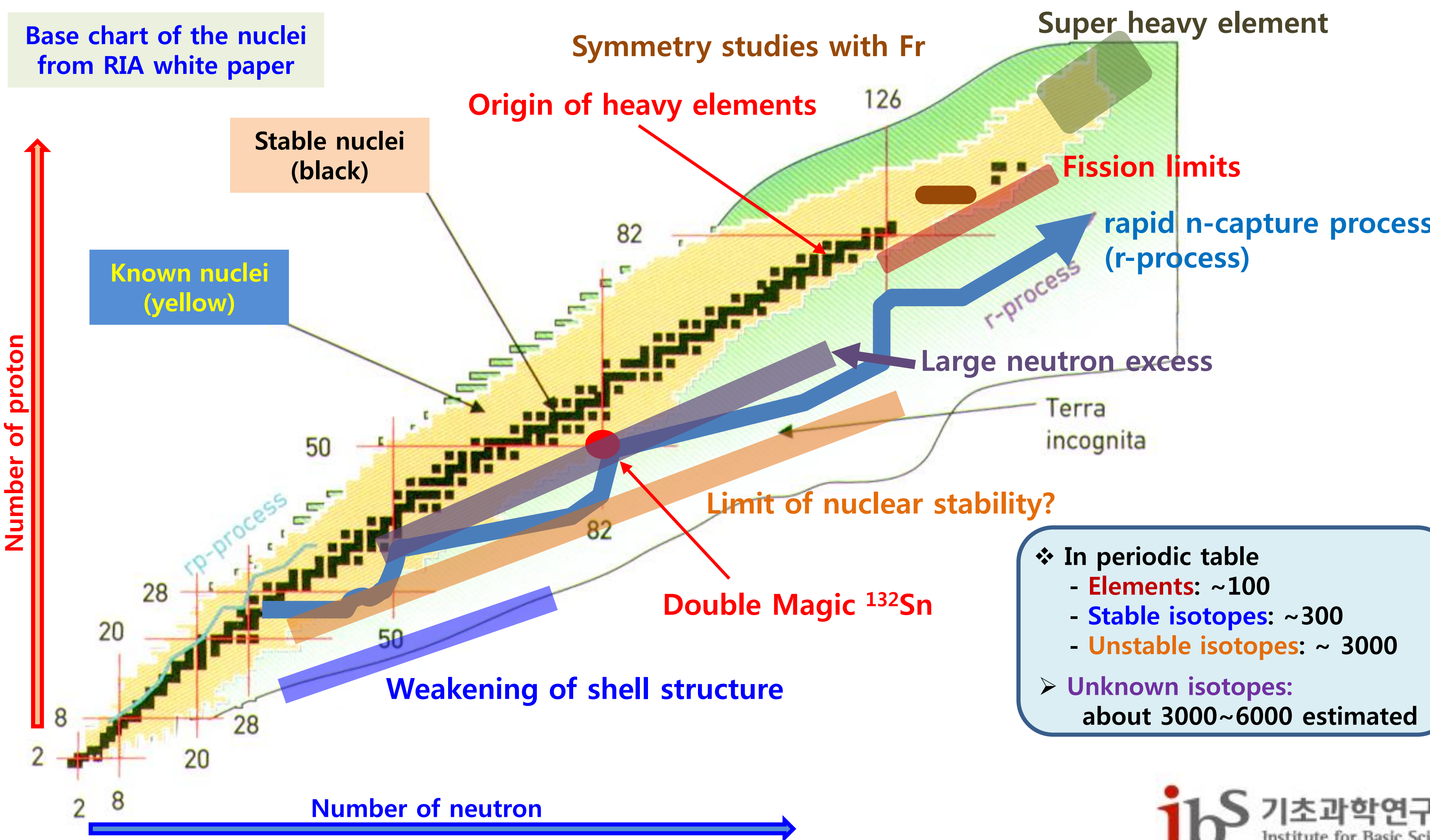
RISP Status and Plan

- Conceptual Design report (Mar. 2010 - Feb. 2011)
- IAC review (Jul. 2011 – Oct. 2011)
- Rare Isotope Science Project started in IBS (Dec. 2011) Director Prof. Sunkee Kim
- RISP Workshop on accelerator systems (May 6 – 9, 2012)
- TAC (May 10, 2012)
- Conceptual Design of the Building and Conventional Facilities (May 2012)
- Baseline Design Summary (by July 2012) – Base line parameters
- RISP Workshop on Advanced Experimental Techniques using RI Beams – Today 16, July
- IAC (July 26-27, 2012)
- Technical Design Report (by Jun. 2013)
- Ground Breaking (2014)

Rare Isotope Science

"Nuclear science is entering a new era of discovery in understanding how nature works at the most basic level and in applying that knowledge in useful ways". - National Academy 2007 RISAC Report -



- In periodic table
  - Elements: ~100
  - Stable isotopes: ~300
  - Unstable isotopes: ~ 3000
- Unknown isotopes: about 3000~6000 estimated

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Key Science Drivers of RISP

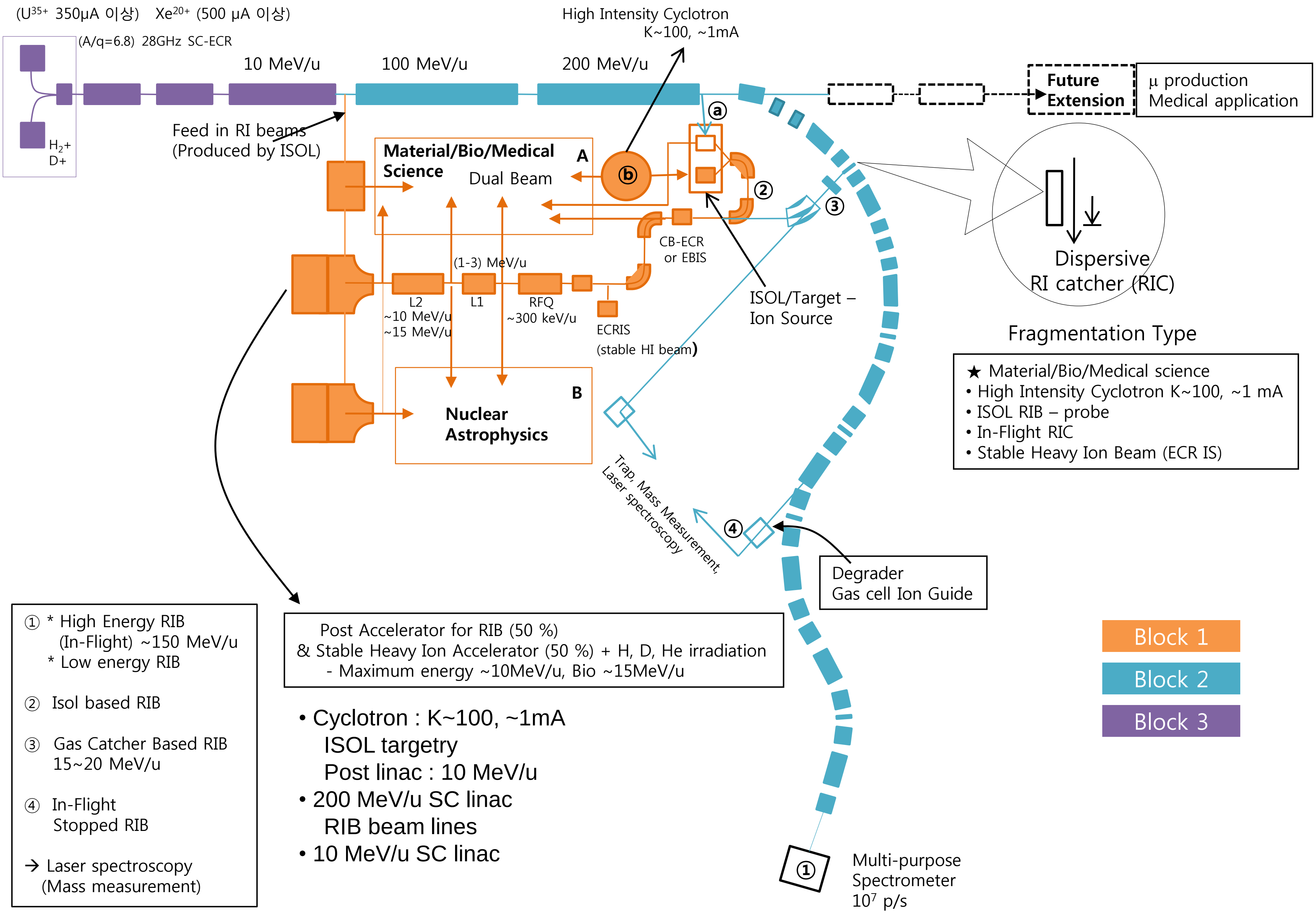
- **Highest priority research subjects**
  - Nuclear reaction experiments important to nuclear-astrophysics : e.g. $^{15}O(a,\gamma)^{19}Ne$, $^{45}V(p,\gamma)^{46}Cr$
  - Search for super heavy elements : $Z > 113$
  - Nuclear structure of n-rich RI near $N=126$, $80<A<140$
  - Nuclear symmetry energy at sub-saturation density

- **Important scientific applications**
  - Precision mass measurement & Laser spectroscopy
  - Material science : β-NMR, μ-SR
  - Medical and bio-science
  - Nuclear data for Gen-IV NPP and nuclear waste transmutation

Selected RI beams for BDS

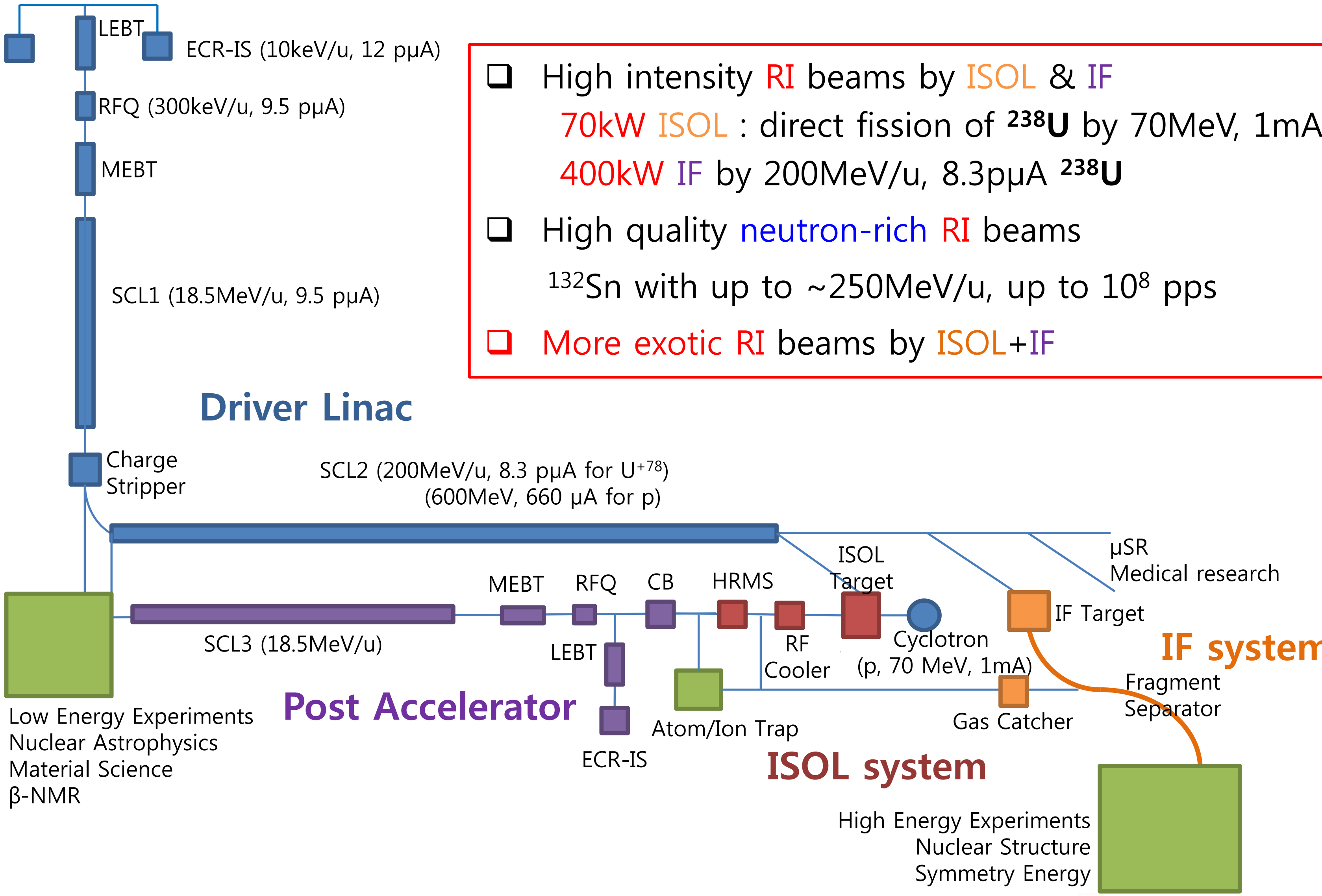
RI Beam species	Energy Range	Desired Intensity [pps]	Research fields
^{132}Sn, ^{144}Xe	> 100 A MeV	10^8, 10^6	Nuclear structure
^{15}O	< 10 A MeV < 30 keV	10^{10} 10^8	Nuclear astrophysics Material Science
^{26m}Al	< 15 A MeV	10^7	Nuclear astrophysics
^{45}V	0.6-2.25 A MeV	$10^7 – 10^9$	Nuclear astrophysics
^{68}Ni, ^{106}Sn, ^{132}Sn, $^{140, 142}Xe$	10-250 A MeV	10^9	Symmetry energy
$^{6,8}He$, ^{12}Be, $^{24-30}O$	50-100 A MeV	10^9	Nuclear Study with Polarized target
^{17}N, ^{17}B, ^{12}B, $^{14-15}B$, $^{31-32}Al$, ^{34}K	50-100 A MeV	10^9	Nuclear Study with Polarized RI beam
^{64}Ni, ^{58}Fe (stable)	A few A MeV	10^{12}	SHE
^{8}Li, ^{11}Be, ^{17}Ne	< 30 keV	10^8	Material science
$^{133-140}Sn$	< 60 keV	1	Atomic physics
^{8}B, ^{9-11}C, ^{15}O	≥ 200 A MeV	$10^7 – 10^9$	Medical and Bio science

Birth of RISP : KoRIA (April, 2009)



RAON: RISP Accelerator Complex

- ❑ High intensity RI beams by ISOL & IF
  - 70kW ISOL : direct fission of **^{238}U** by 70MeV, 1mA p
  - 400kW IF by 200MeV/u, 8.3pμA **^{238}U**
- ❑ High quality neutron-rich RI beams
  - ^{132}Sn with up to ~250MeV/u, up to 10^8 pps
- ❑ More exotic RI beams by ISOL+IF



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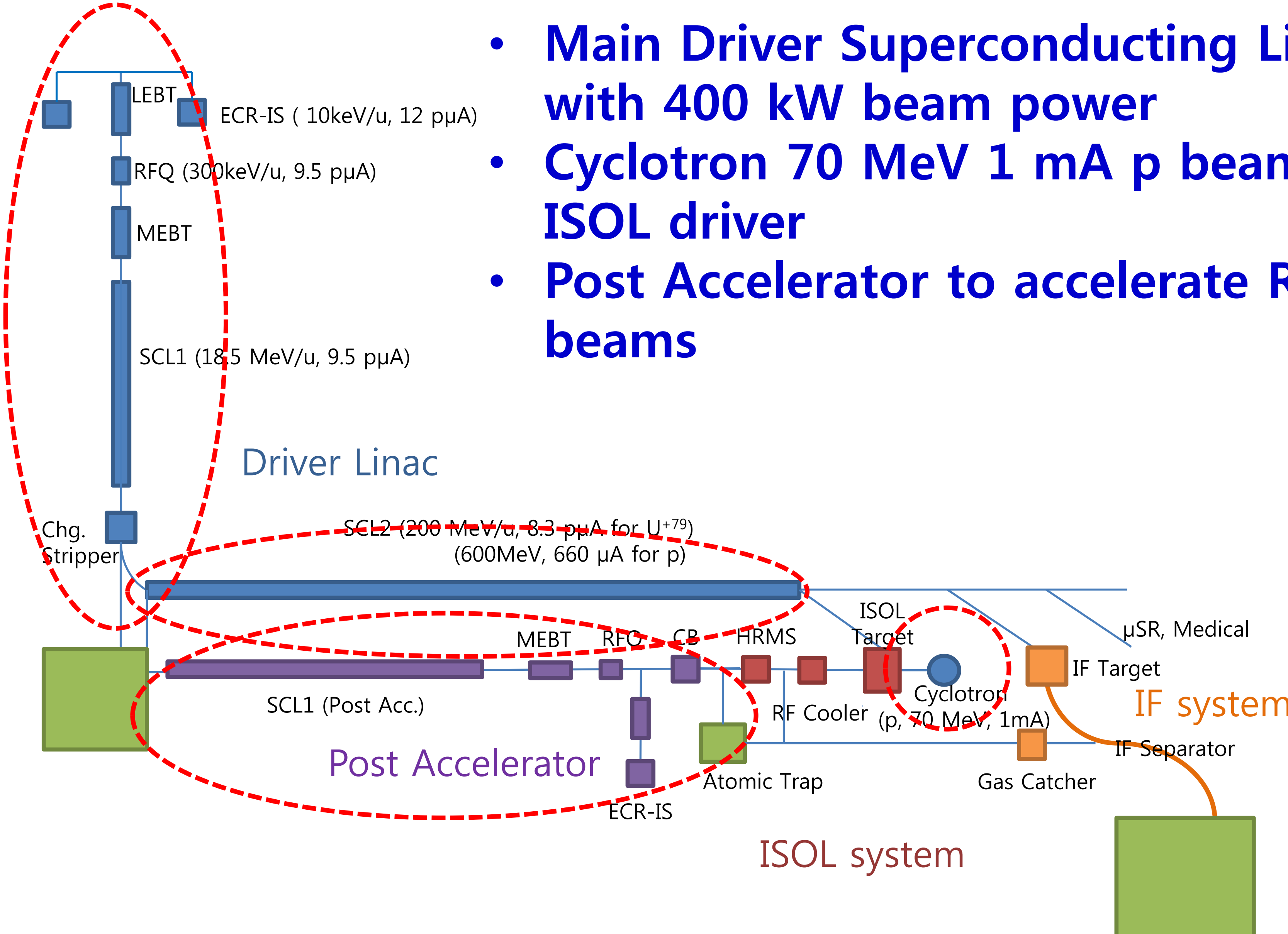
Accelerator System

- **Main Driver Superconducting Linac with 400 kW beam power**
- **Cyclotron 70 MeV 1 mA p beam as ISOL driver**
- **Post Accelerator to accelerate RI beams**



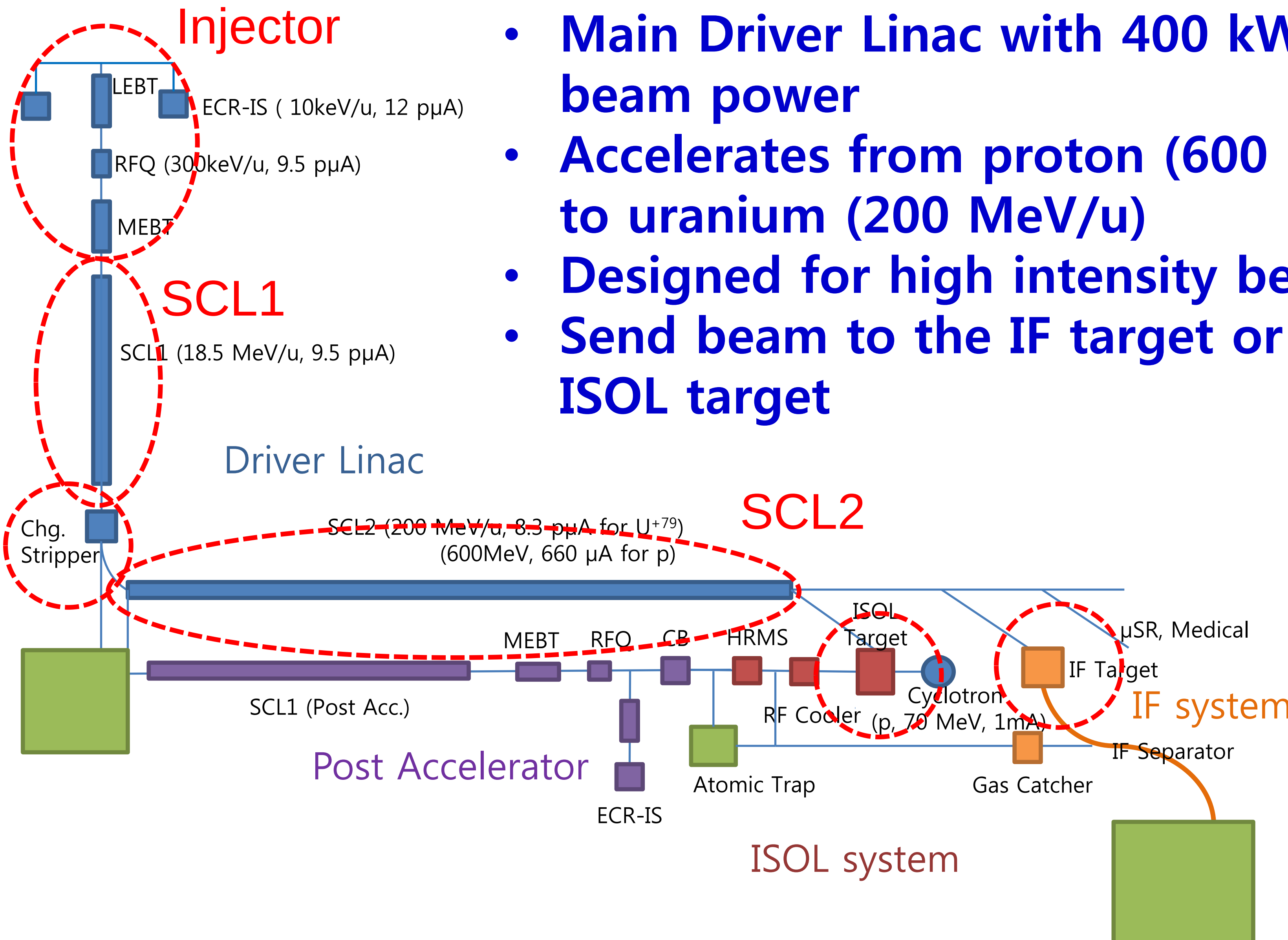
Accelerator System

Beam Requirement of Accelerator System

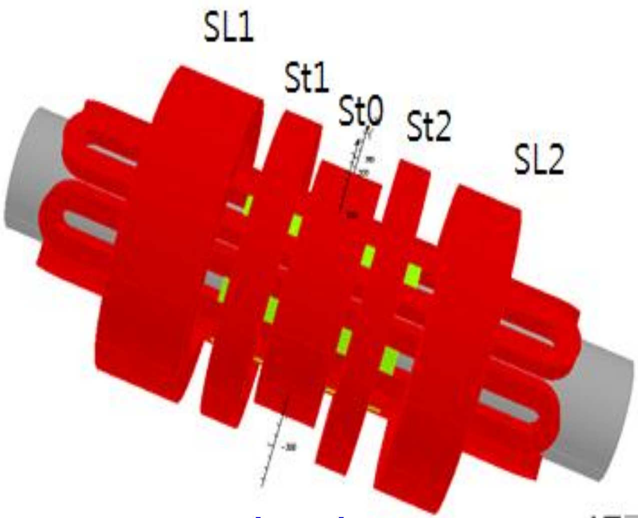
Accelerator	Driver Linac		Post Acc.	Cyclotron
Particle	proton	U^{+79}	RI beam	proton
Beam energy	600 MeV	200 MeV/u	18.5 MeV/u	70 MeV
Beam current	660μA	8.3 pμA	-	1 mA
Power on target	400 kW	400 kW	-	70 kW

Driver Linac

- **Main Driver Linac with 400 kW beam power**
- **Accelerates from proton (600 MeV) to uranium (200 MeV/u)**
- **Designed for high intensity beams**
- **Send beam to the IF target or ISOL target**



ECR Ion Source



Superconducting Magnet

- Consists of 28 GHz RF system and superconducting magnets for high current ion beam generation
- X-ray shielding required
- High temp oven under design
- Generating 12 pμA (U beam)

ECR-IS	
Ion Beam	Proton to Uranium beam
Extraction Energy	10 keV/u
RF power	10 kW
Extraction Emittance	0.1π mm-mrad
Beam Current	12 puA ($^{238}U^{33+}$, $^{238}U^{34+}$)
RF Frequence	28GHz

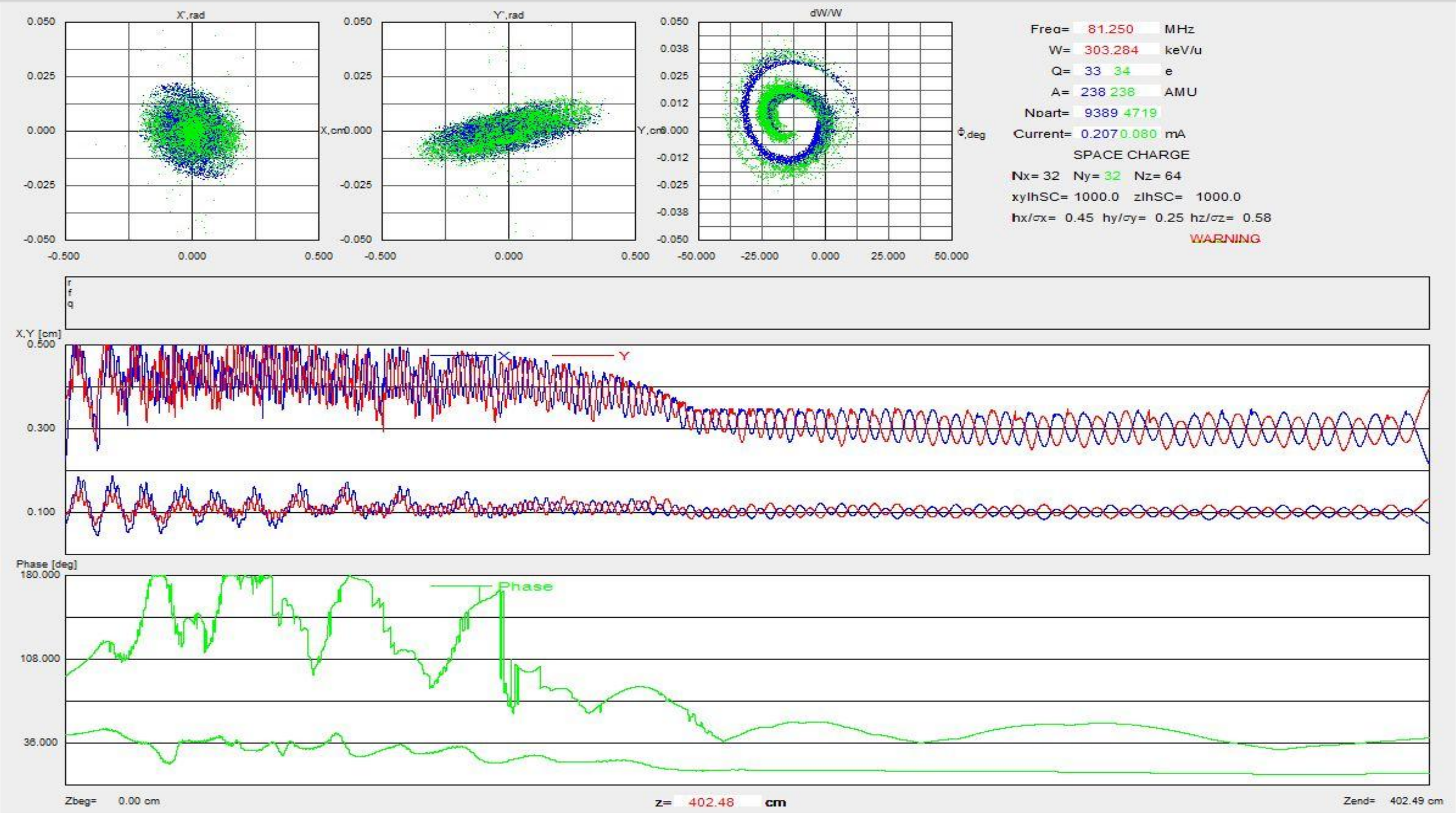
RFQ

RFQ is

- **To accelerate ion beams from 10 keV/u to 300 keV/u**
- **4 m long, 81.25 MHz**

RFQ	
Input Energy	10 keV/u
Output Energy	300 keV/u
Input Emittance (rms)	0.12π mm-rad
Frequency	81.25 MHz
Input charge	33, 34 (Uranium-238)
Input current	12 pμA
Output current	9.5 pμA

RFQ



- ε_x=0.12 mm-mrad, ε_y=0.18 mm-mrad, ε_z=8.2 MeV-deg @ exit of RFQ
- With LEBT bunchers (TRACK code)
- Accelerate ion beams 10 keV/u to 300 keV/u

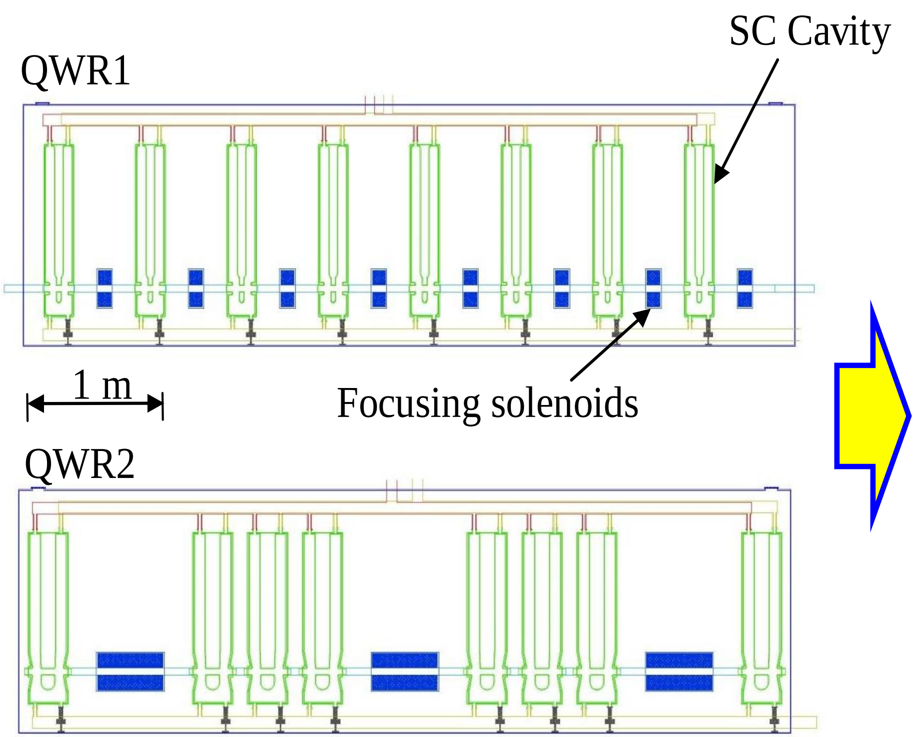
Driver SCL

SCL is designed

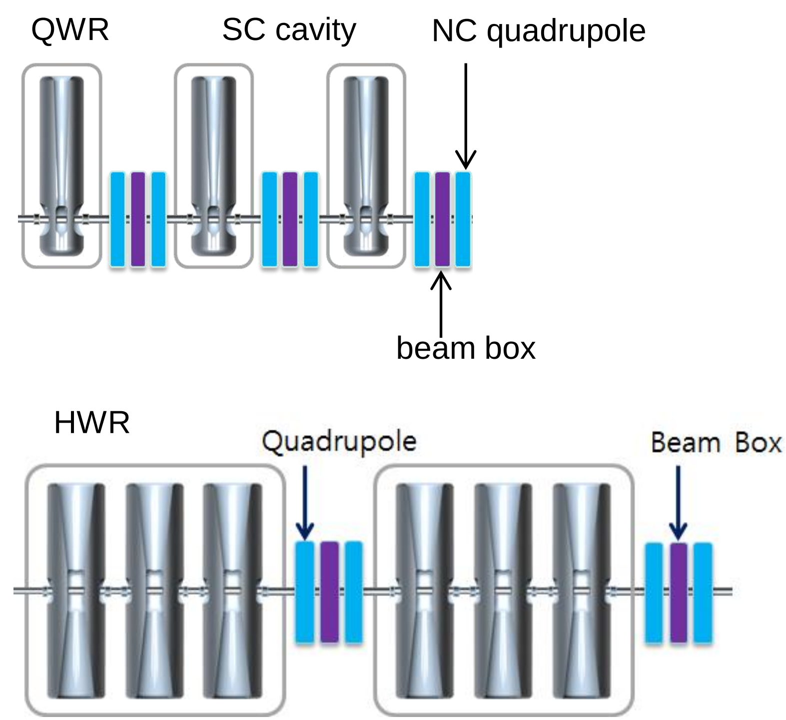
- To accommodate the needs of various user groups
- To accelerate high intensity beams
- Nb Cavities operating at 2K
- Focusing by normal conducting quad doublets
- Optimized geometric beta of SC cavities (0.047, 0.12, 0.30, 0.53)
- Employs larger aperture to reduce beam loss (4cm and 5 cm aperture)
- Cryogenic load estimated 1.9 kW [Driver Linac 2K] + 0.35 kW [Post Acc]
- Cavity geometry optimized for Epeak/Eacc, Bpeak/Eacc, R/Q, QR_s

SCL Layout

- **Linac base frequency = 81.25 MHz**
- **Design to accelerate high intensity ion beams**
- **Flexile operation to meet the needs of various user groups**



Previous Driver SCL Design
with SC solenoids



Driver SCL
with NC doublets

SCL Layout

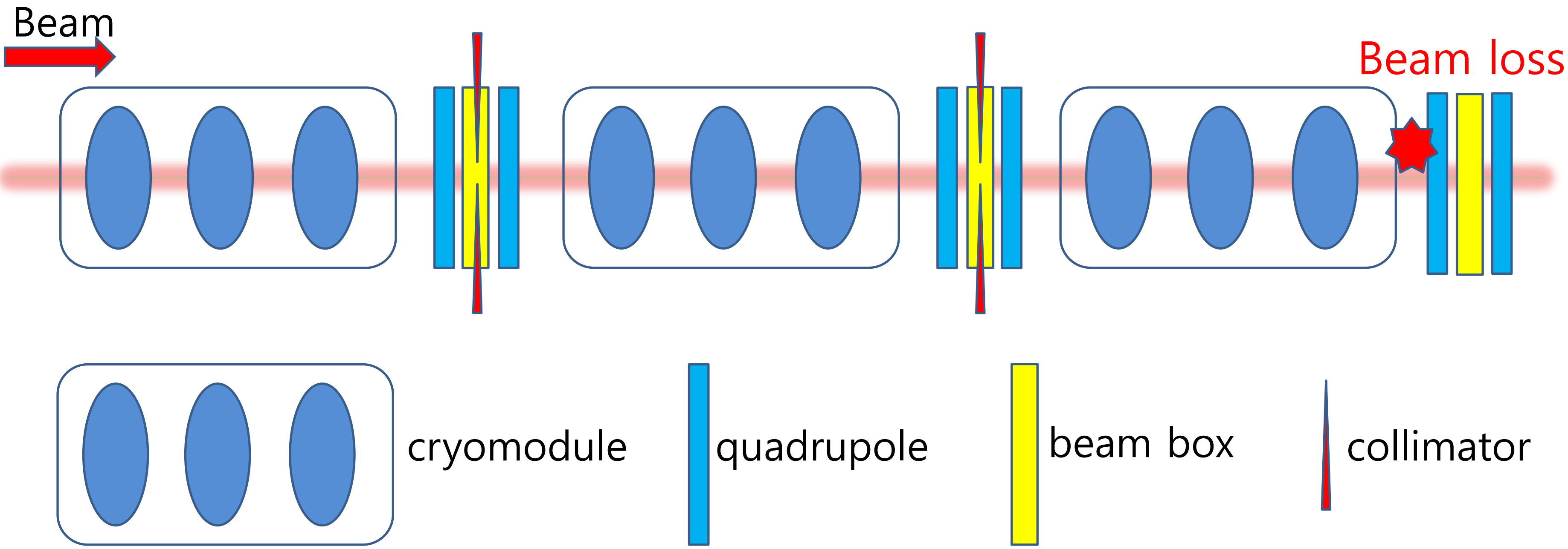
- NC quadrupole lattice option has the following merits:

1. Accurate alignment < 150 mm of NC quadrupoles is straightforward.
2. Beam quality control is straightforward and design is more adequate for high power beam operation.
3. Advantages in beam diagnostics and collimation through beam boxes.

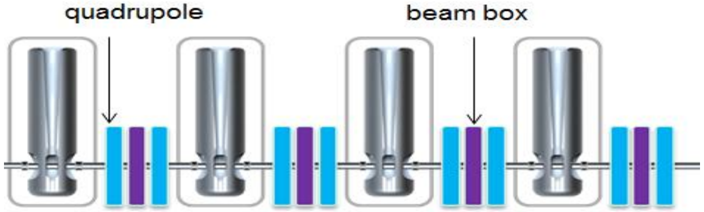
4. The linac cost seems to be in error range compared with the SC solenoid option. (← removal of costly SC solenoids)
5. Preliminary cryo-load comparison suggests that overall cryo-load difference is small compared with the dynamic load.

SCL Layout

- Present SCL layout provides good beam diagnostics configuration for machine tuning.
- Necessary beam diagnostics can be installed at beam boxes.
- Also provides good beam loss collimation, improving beam quality for users, reducing beam loss.

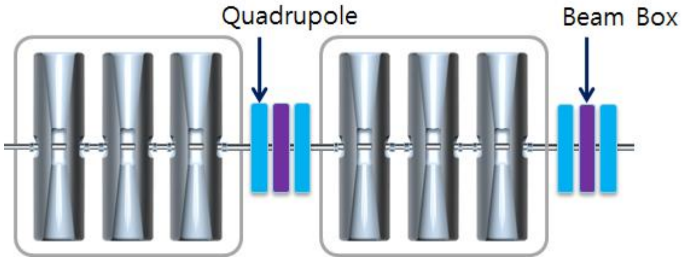


SCL Layout

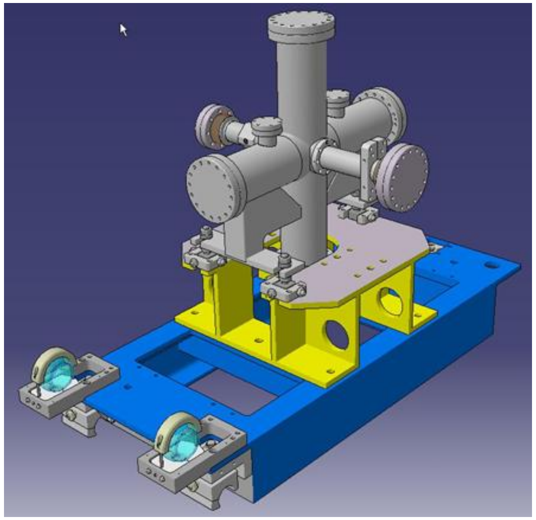


[1 QWR + 1 QD] x 24

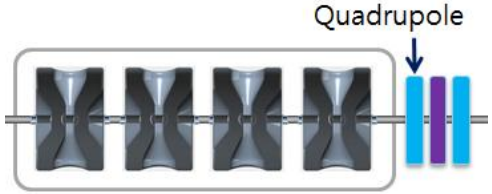
SCL1



[3 HWR + 1 QD] x 14
[6 HWR + 1 QD] x 16

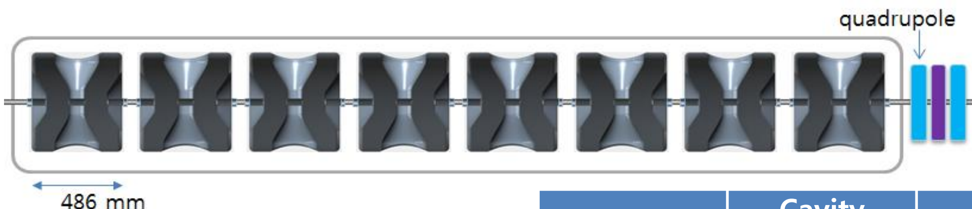


beam box example
(courtesy of SPIRAL2)



[4 SSR + 1 QD] x 22

SCL2



[8 SSR + 1 QD] x 17

SCL	Cavity structure	Frequency	β_g	Number of cavities	Output energy
SCL1	QWR	81.25 MHz	0.047	24	2.5 MeV/u (U^{+33})
	HWR	162.5 MHz	0.12	138	18.6 MeV/u (U^{+33})
SCL2	SSR	325 MHz	0.30	88	71 MeV/u (U^{+79})
	SSR	325 MHz	0.53	136	200 MeV/u (U^{+79})

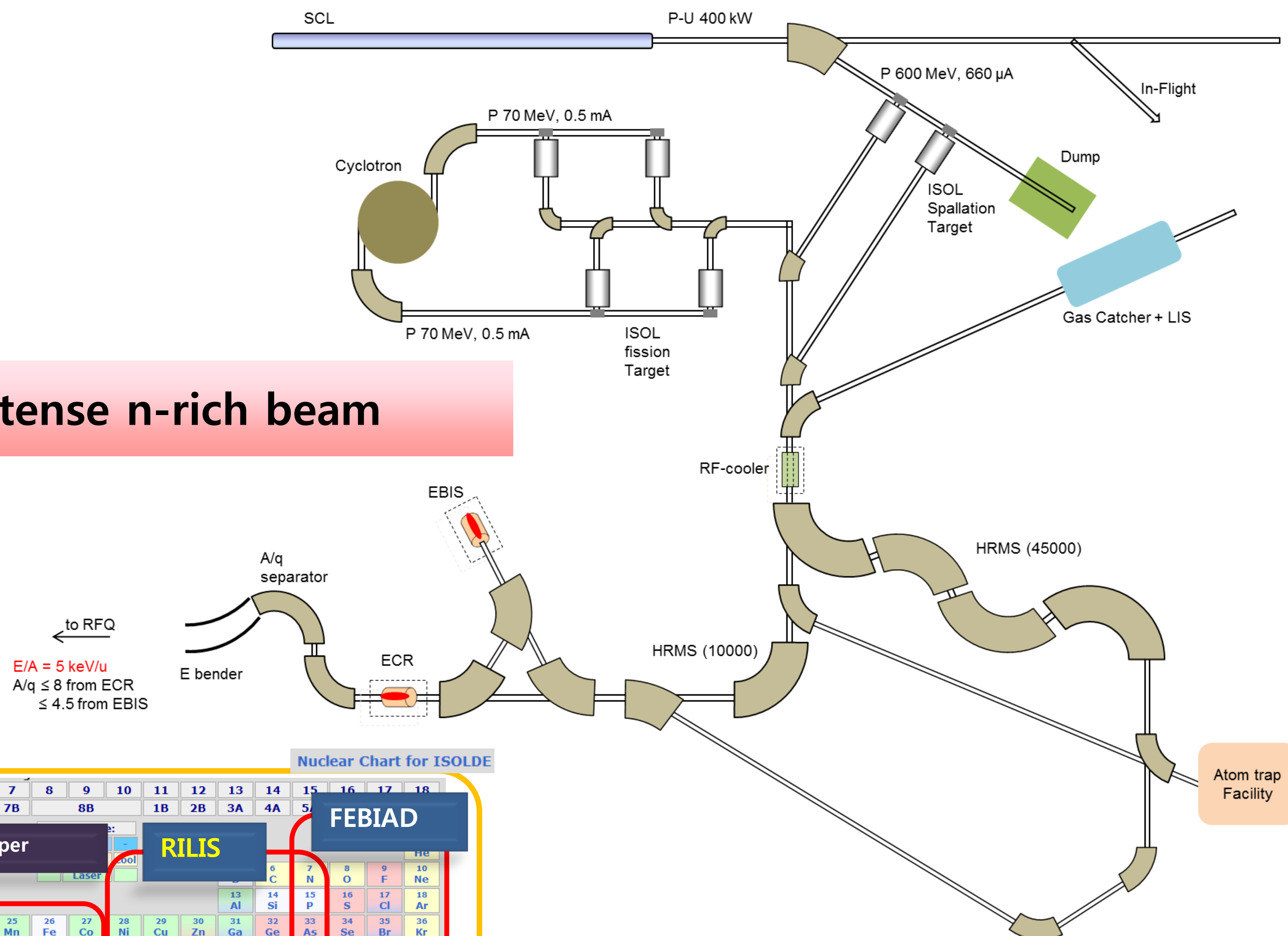
SCL machine tolerance
(Driver SCL, Post SCL)

Machine imperfections for actual accelerator

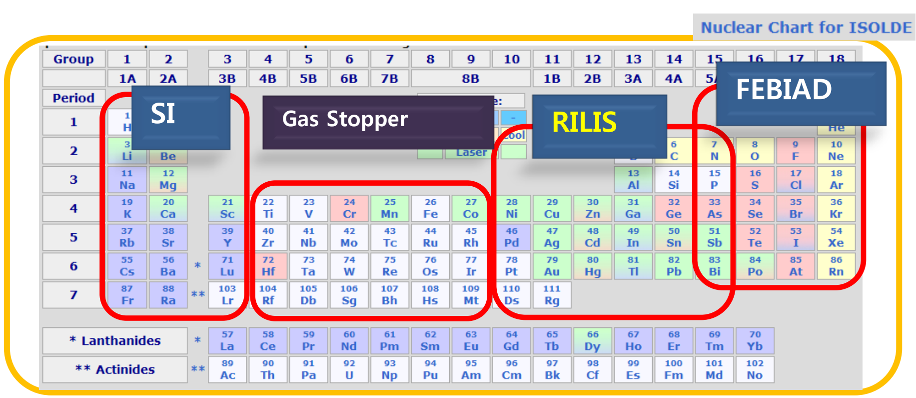
Parameters	SCRF Cavity	Warm Quadrupole	SC Solenoid	Distribution
Displacement (mm)	±1	±0.15	±0.5	Uniform
Rotation (mrad)	-	±5	-	Uniform
Phase (deg)	±1	-	-	3σ Gaussian
Amplitude (%)	±1	-	-	3σ Gaussian

- **Preliminary study is done.**
- **Further studies on machine tolerances will be done.**

ISOL Facility @ RISP



for providing intense n-rich beam

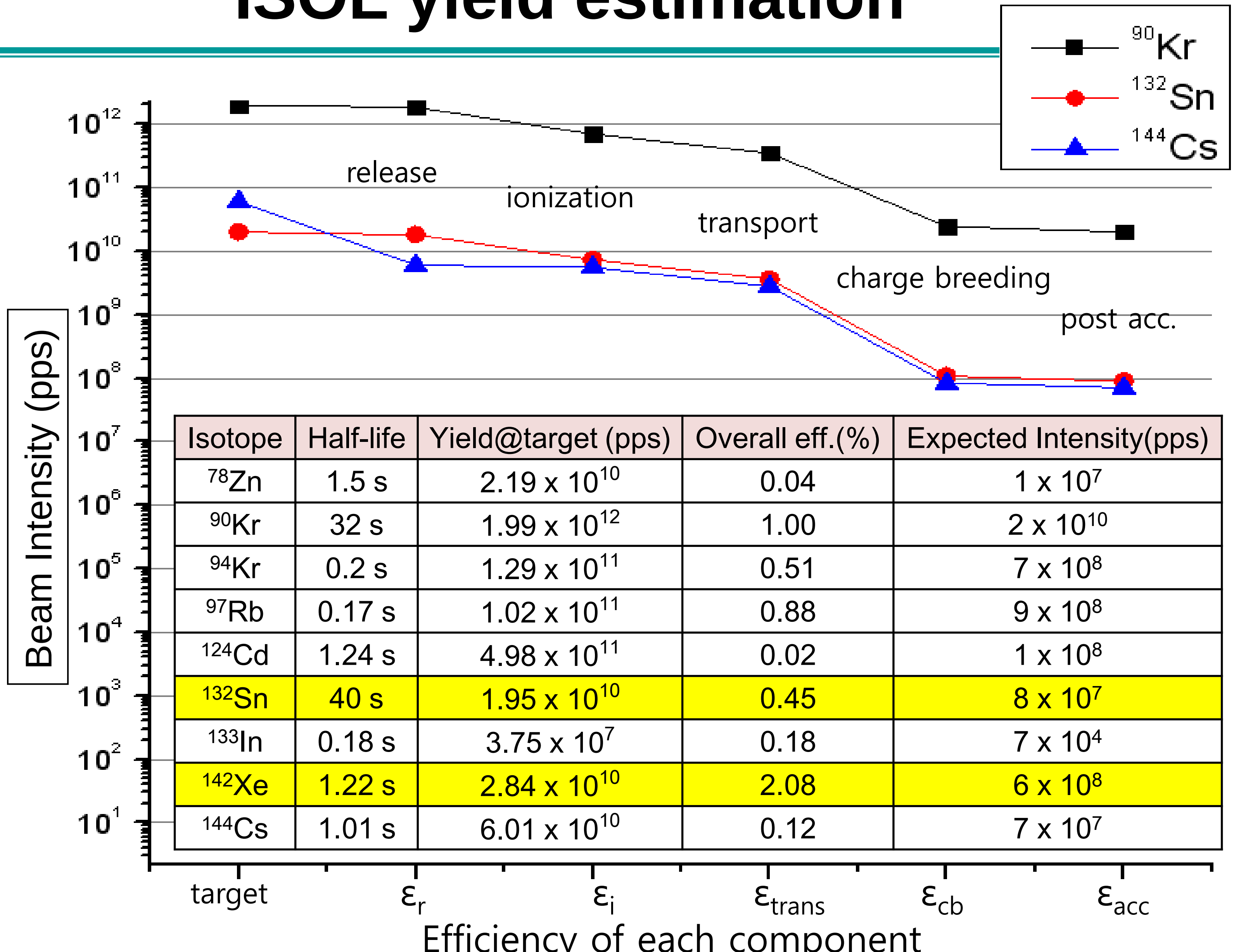


ISOL Facility @ RISP

Development of ISOL System Components

System	Component	Development Goal/Challenging
Target	High Power fission Target	10^{14} fission/s (UC_x)
	400 kW Spallation Target	Various Target materials (Ta, SiC)
RI Ion Source Gas Stopper	SI, FEBIAD, RILIS Gas Catcher + RILIS	High vapor pressure elements Low vapor pressure elements
RF-Cooler	CW and Pulsed	Emitt. ~ 3 π , $\Delta E < 10$ eV $\varepsilon_{trans.} > 60$ %
HRMS	R_m ~10000 and R_m ~45000	D > 40 cm/% for R_m ~45000
Charge Breeder	ECR and/or EBIS	BG < 1 nA for ECR, E = 5 keV/u
A/q Selector	E + B Combination	$R_m > 3000$
Expected yield @ Low E exp. hall		~ 10^8 pps for ^{132}Sn

ISOL yield estimation

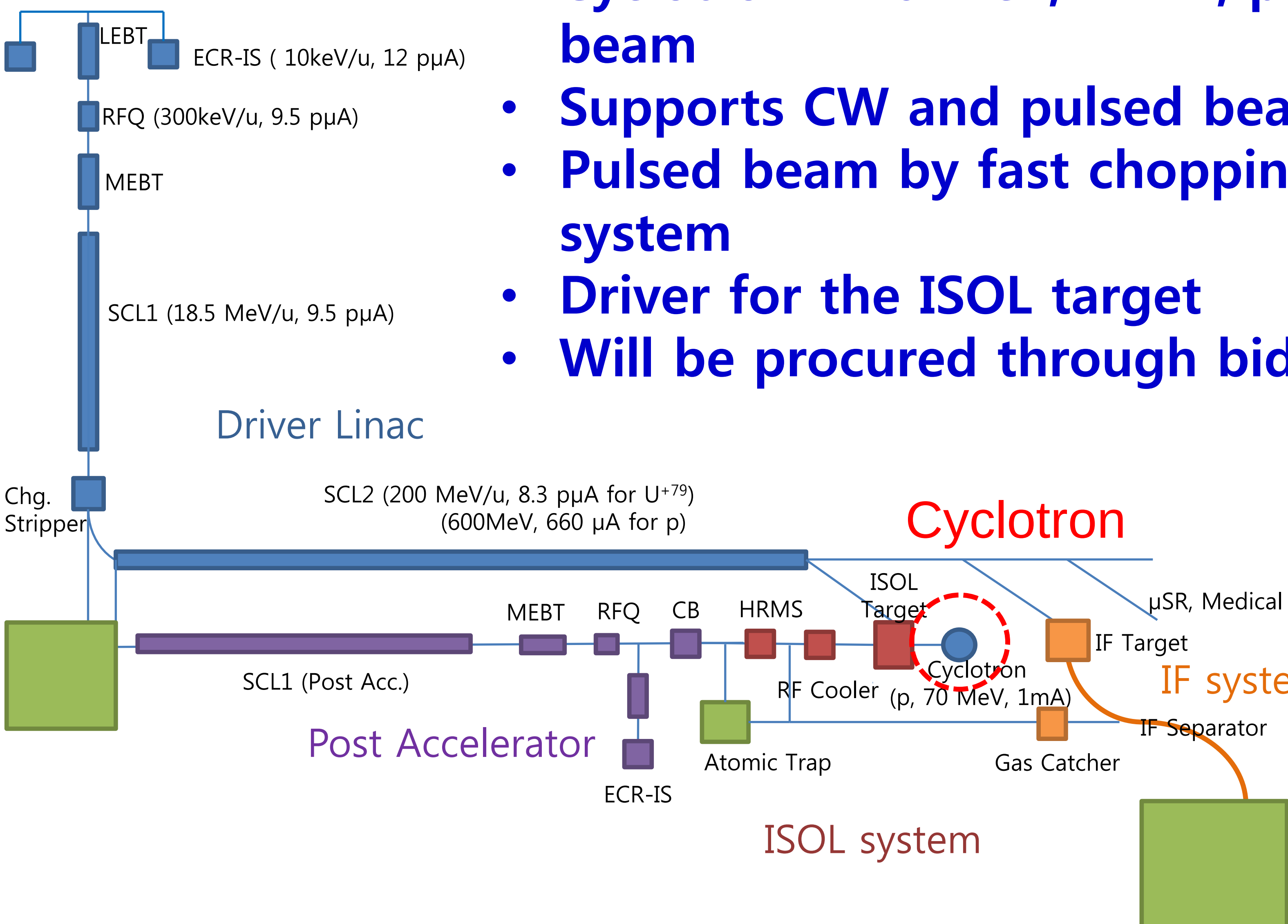


Isotope	Half-life	Yield@target (pps)	Overall eff.(%)	Expected Intensity(pps)
^{78}Zn	1.5 s	2.19×10^{10}	0.04	1×10^{7}
^{90}Kr	32 s	1.99×10^{12}	1.00	2×10^{10}
^{94}Kr	0.2 s	1.29×10^{11}	0.51	7×10^{8}
^{97}Rb	0.17 s	1.02×10^{11}	0.88	9×10^{8}
^{124}Cd	1.24 s	4.98×10^{11}	0.02	1×10^{8}
^{132}Sn	40 s	1.95×10^{10}	0.45	8×10^{7}
^{133}In	0.18 s	3.75×10^{7}	0.18	7×10^{4}
^{142}Xe	1.22 s	2.84×10^{10}	2.08	6×10^{8}
^{144}Cs	1.01 s	6.01×10^{10}	0.12	7×10^{7}

* Overall efficiency is estimated under consideration of previous ISOL system
(HRIBF, CERN-ISOLDE, KEK-ISOL etc.)

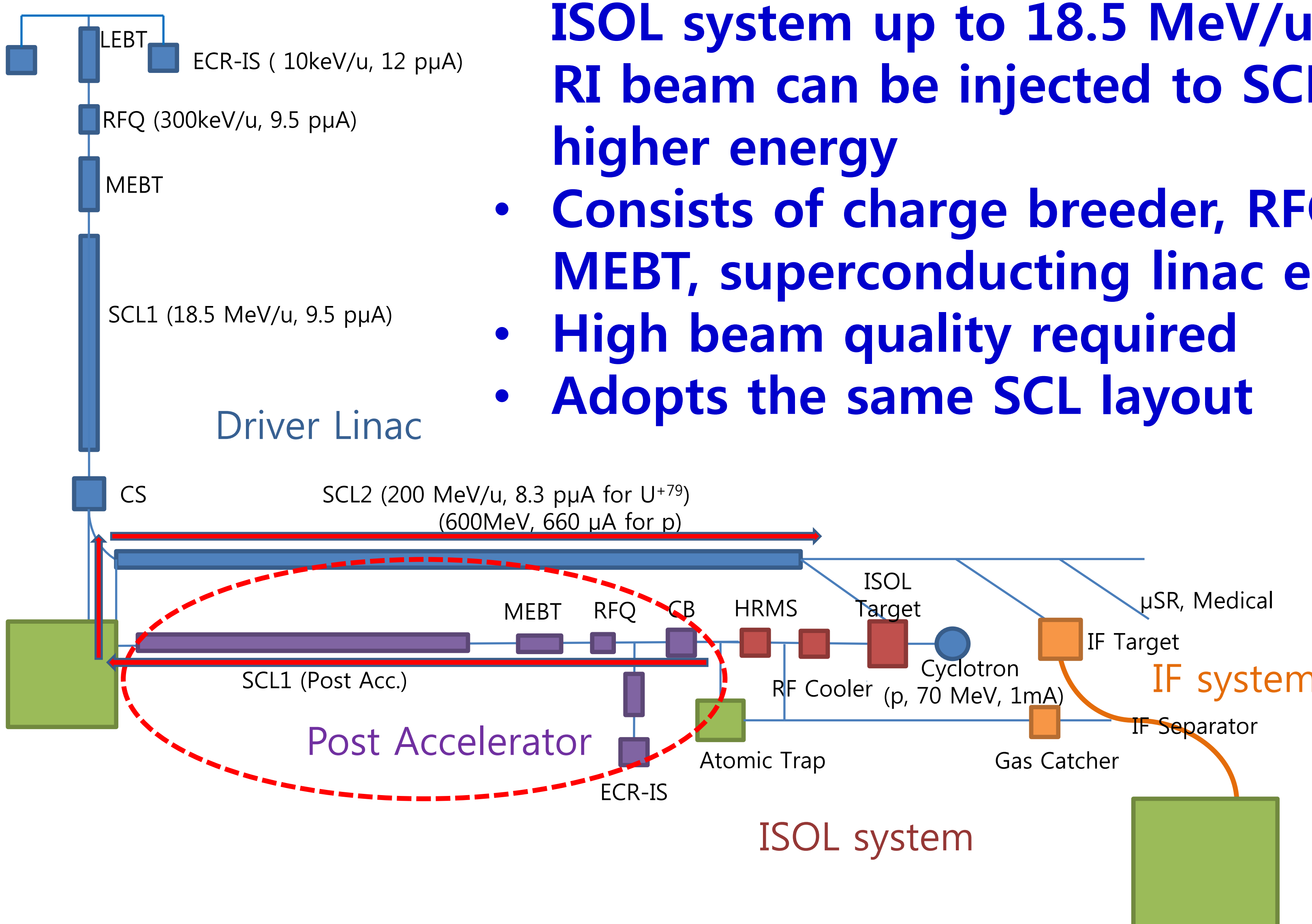
Cyclotron

- Cyclotron – 70 MeV, 1 mA, proton beam
- Supports CW and pulsed beam
- Pulsed beam by fast chopping system
- Driver for the ISOL target
- Will be procured through bidding



Post-Accelerator System

- Accelerates RI beams from the ISOL system up to 18.5 MeV/u and RI beam can be injected to SCL2 to higher energy
- Consists of charge breeder, RFQ, MEBT, superconducting linac etc.
- High beam quality required
- Adopts the same SCL layout



Main Research Subjects

Nuclear Science	Nuclear Astrophysics & Nucleosynthesis	- Direct measurements of proton and alpha capture reactions - Search for Super Heavy Elements beyond Z=113
	Nuclear Structure & Matter	- RI nuclear structure of neutron rich nuclei near N=126, 80<A<140 - Symmetry energies at sub-saturation density
	Nuclear Data	- Neutron capture cross section measurements by using n-TOF
	Nuclear Theory	- Development of RI nuclear theories
Atomic & Molecular Science	Precision Mass Measurement & Laser Spectroscopy	- Hyperfine structure and characteristics of element and nuclei
Material Science	RI Material Research	- Search for new material and its properties with β-NMR/μSR and RI beam
Medical & Bio Science	Medical & Bio application	- Development of new cancer therapy - Biological effect of tissue and DNA by RI beam

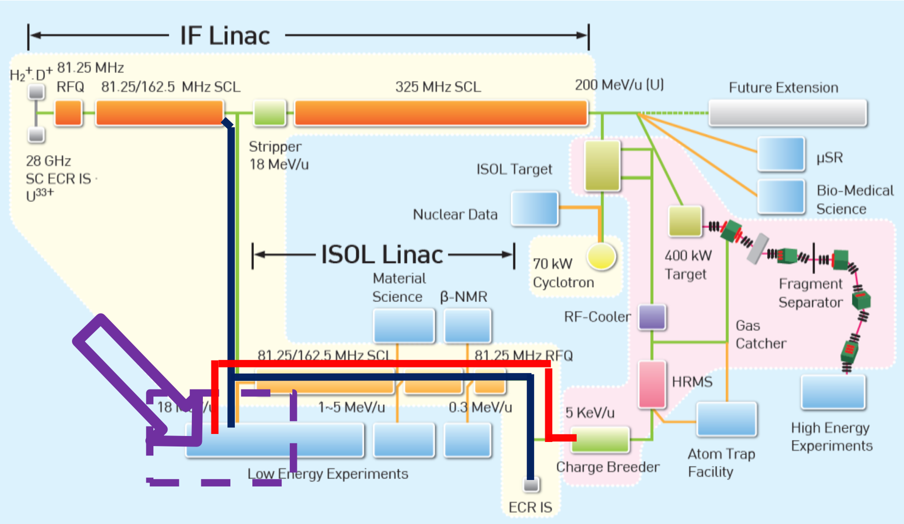
Essential experimental systems

- Study the preliminary researches
- Develop the experimental systems in parallel with the accelerator
- Make user program with the international collaboration

Nuclear Physics	Large Acceptance Spectrometer
Nuclear Astrophysics	Korea Recoil Spectrometer (KRS) Gas filled Separator for SHE
Atomic physics	Atom & Ion Trap System
Nuclear data by fast neutrons	neutron Time-of-Flight (n-ToF)
Material science	β-NMR/NQR, mu-SR Laser Selective Ionizer
Medical and Bio sciences	Heavy Ion Therapy research Irradiation Facility

Recoil Spectrometer (KRS)

Main facility for nuclear and nuclear astrophysics exp with low E beams



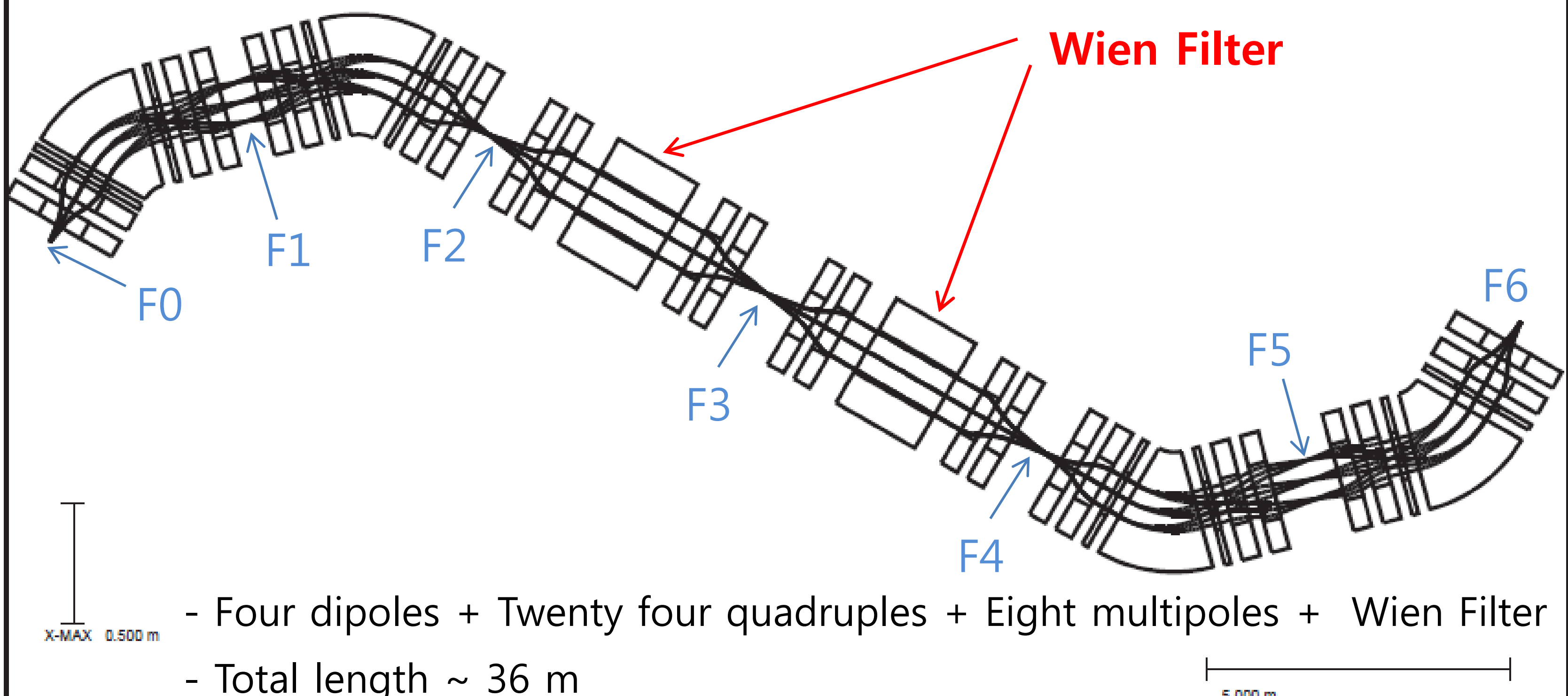
▪ **Spec. of the RISP Recoil spectrometer**

Maximum magnetic rigidity (T·m)	~ 1.5
Mass resolution (ΔM/M)	< 0.5 %
Momentum resolution (Δp/p)	~ 0.05 %
Angular acceptance (mrad)	< ± 100
Background reduction	< 10^{-15}

▪ **Available experiments at the RISP Recoil Spectrometer**

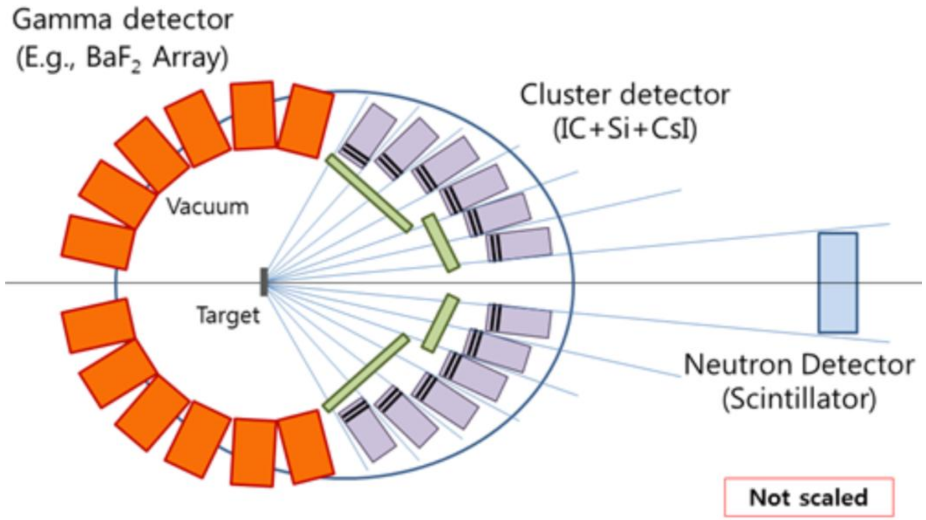
Physics topics	Measurements
rp-process	radiative capture, transfer reaction, elastic/inelastic scattering
s- & r-process	transfer reaction (d,p), decay measurement
neutron drip line studies, halo nuclei	transfer reaction, scattering
proton drip line studies	transfer reaction, fusion-evaporation reaction

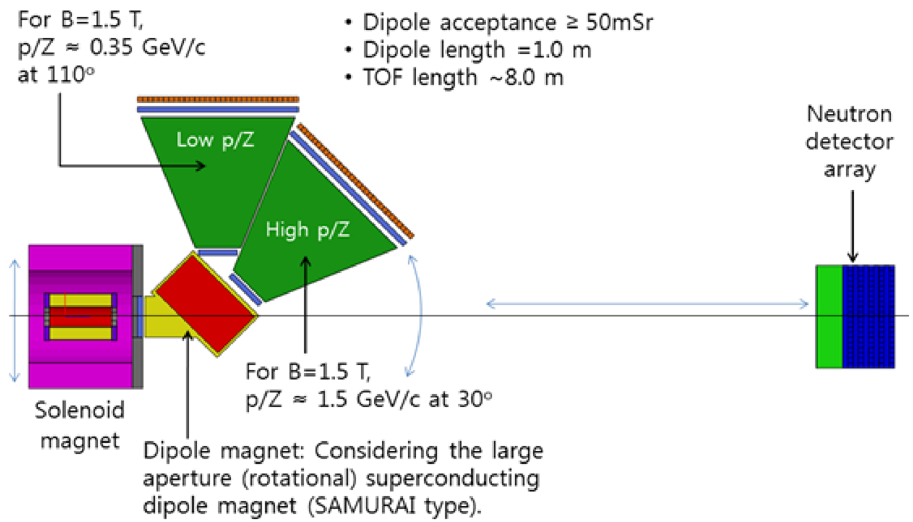
- **Variable operation modes**
  - RI beam production via in-flight method
  - Recoil separation
- **Double achromatic with electrostatic component**



- Four dipoles + Twenty four quadruples + Eight multipoles + Wien Filter
- Total length ~ 36 m

Large Acceptance Spectrometer





E < 20*A* MeV **E > 20*A* MeV**

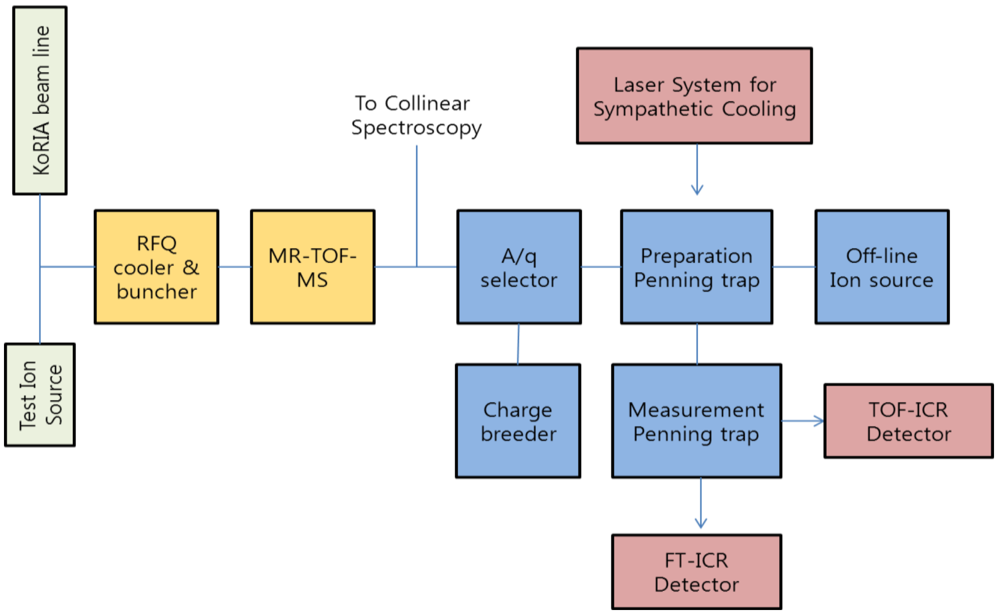
Physics goal

➢ Sensitivity of observables for symmetry energy
- Pygmy Dipole Resonance
- Flow
- Particle yield and ratio
- Etc.

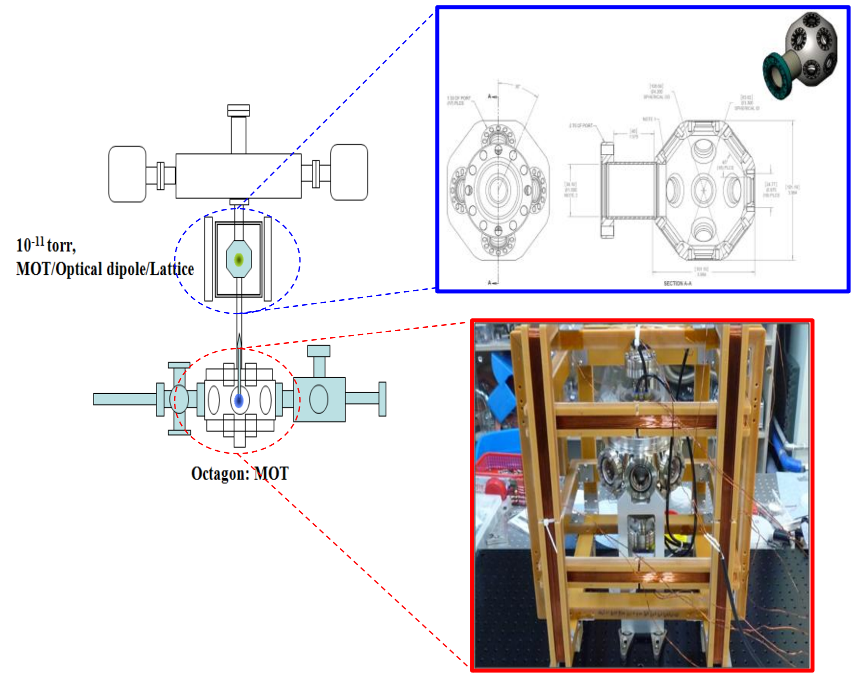
With state beam (^{238}U up to 200A MeV) &
unstable beam ^{132}Sn up to 250A MeV

Atomic and nuclear physics

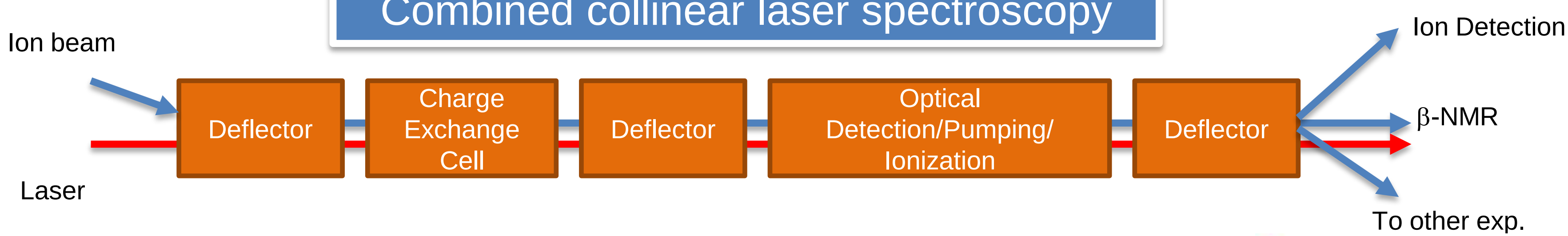
Precision mass measurement



Double MOT system for Standard Model test



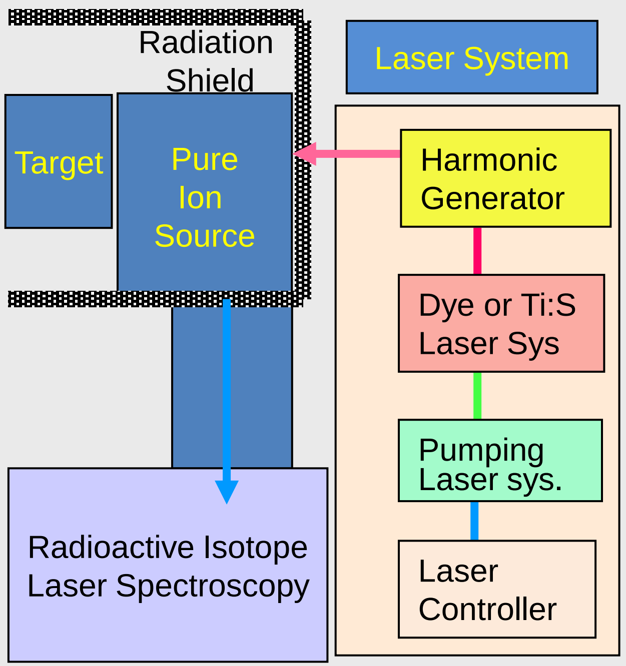
Combined collinear laser spectroscopy

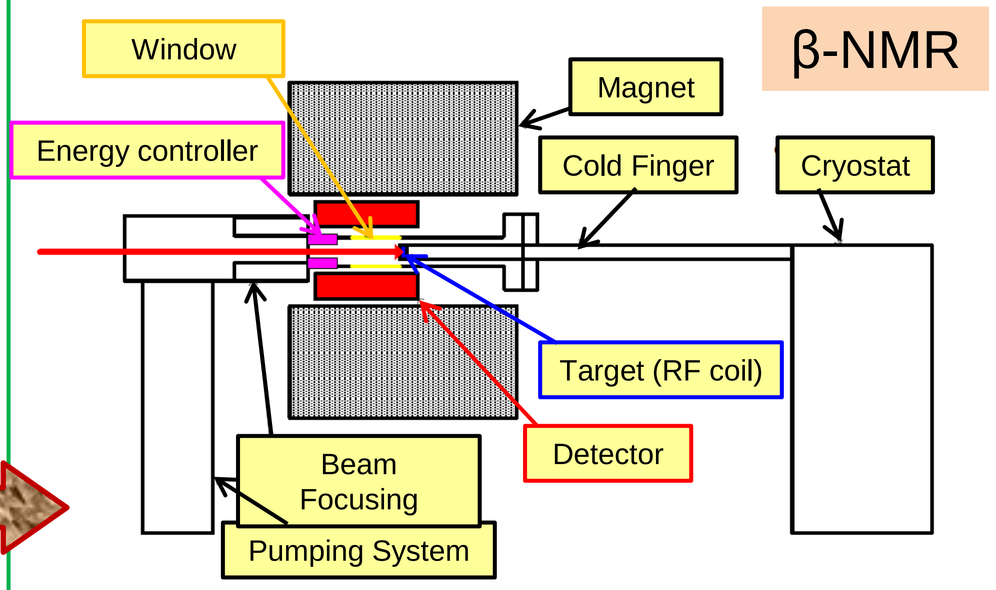


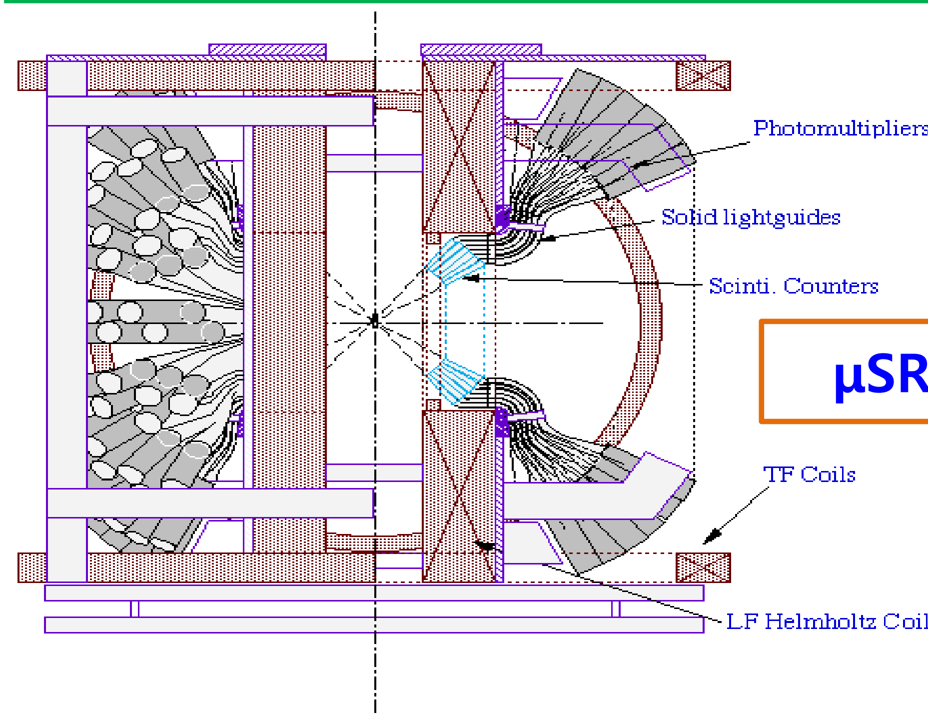
Material Science

β-NMR/NQR and μSR
High purity laser ion source

High purity laser ion source





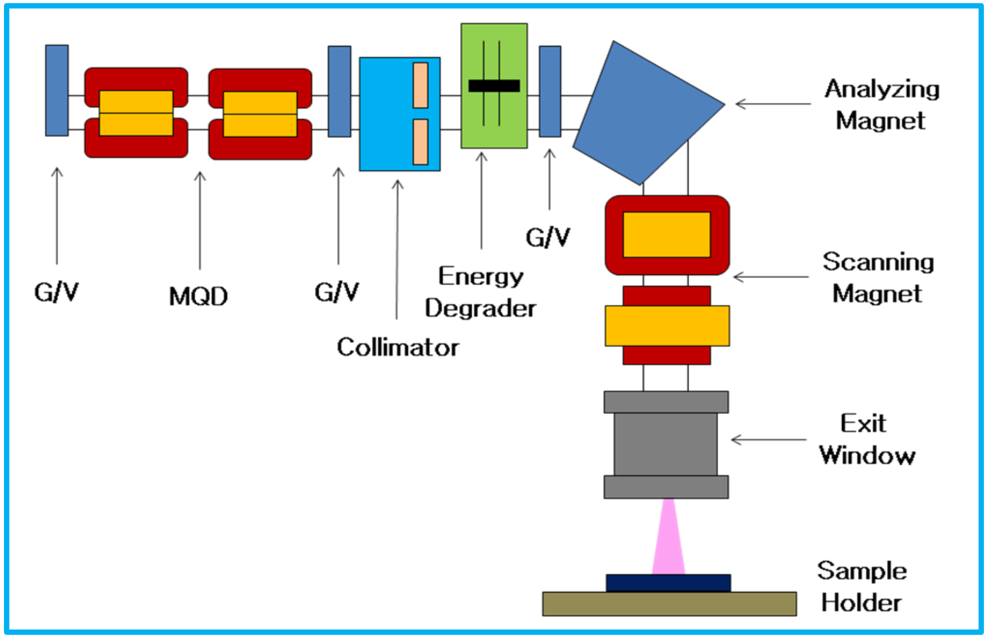


μSR

Bio-Medical Science

Beam line design
- Electromagnet and power supply system
- Beam diagnostics system
- Vacuum system
- Cooling system
- Sample target system
- Control system

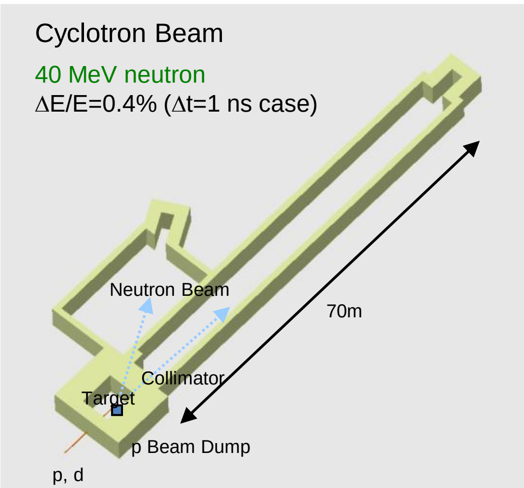
Applied beam line

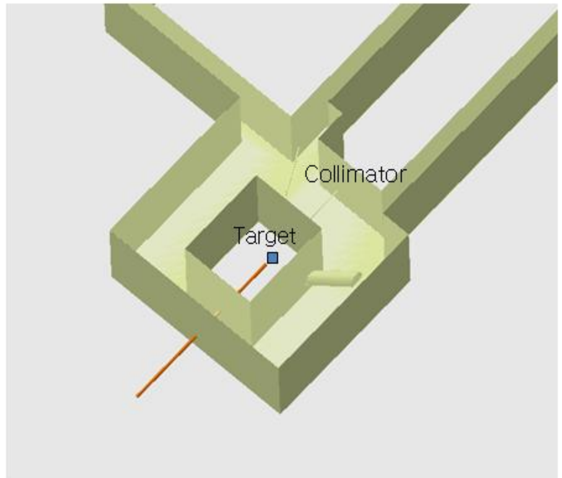


Specification
- Irradiation from perpendicular beam line
- Beam irradiation size : 5~20 cm
- Beam window for atmosphere irradiation
- Cooling system to prevent heat
- Beam energy degrader for control

Nuclear Data

Beam line for fast neutron facility

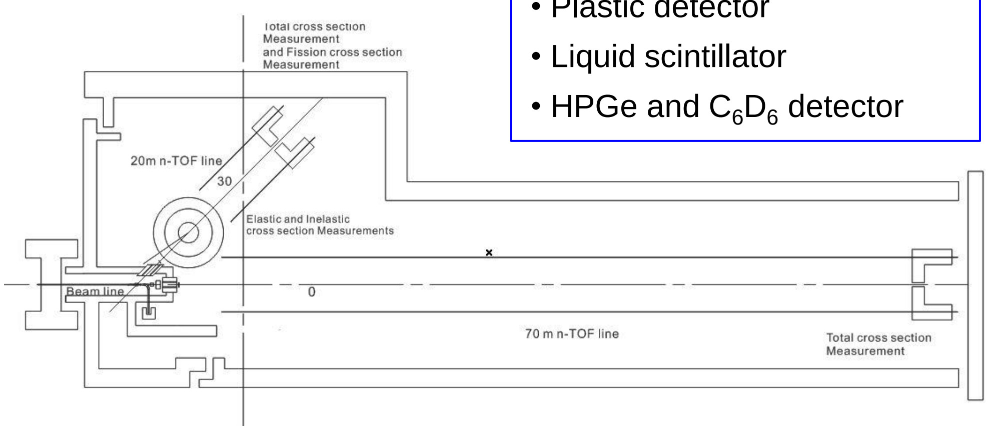




Component
- Accelerated p beam line
- 2 neutron beam line
  : angle 0˚, 30 ˚

Neutron production
- Beam energy : 70 MeV proton (p,n)
- Target : Light element targets such as Li, Be and C
- Production the fast neutrons, up to a few tens of MeV

Detection system



Detector
- Plastic detector
- Liquid scintillator
- HPGe and C_6D_6 detector

Measurement of cross-section (total, capture, etc)
- Measurement of neutron total cross section at 0^o degree with respective to neutron beam
- Measurement of different cross section at 30^o coincidently
- 160 BaF_2 ball detector to increase the detection efficiency of gamma-ray
  - Decay time : 0.6 ns
- C_6D_6 detector : ~ 2 ns decay time

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Development Plan

2009

LoIs from domestic users

- **Science program** with RI beams up to 200 AMeV
- **83 LoI's** (nuclear/astrophysics, nuclear data, standard model, biomedical, mass measurement, material science, ERD analysis)

2010 ~ 2011

Science classification

- Nuclear science
- Atomic & Molecular science
- Material science
- Medical & Bio science

2011 ~ 2013

Facility specifications

- Beam specifications (energy, intensity, pulse width …)
- Specifications of experimental facilities

We are here!!!

2013 ~ 2017

R&D and Installation

- Spectrometer
- Detection system
- Beam line
- Apparatus for applied sciences

2017

Day-1 experiments

Upgrade and extension

2012 ~ 2013

Refinement

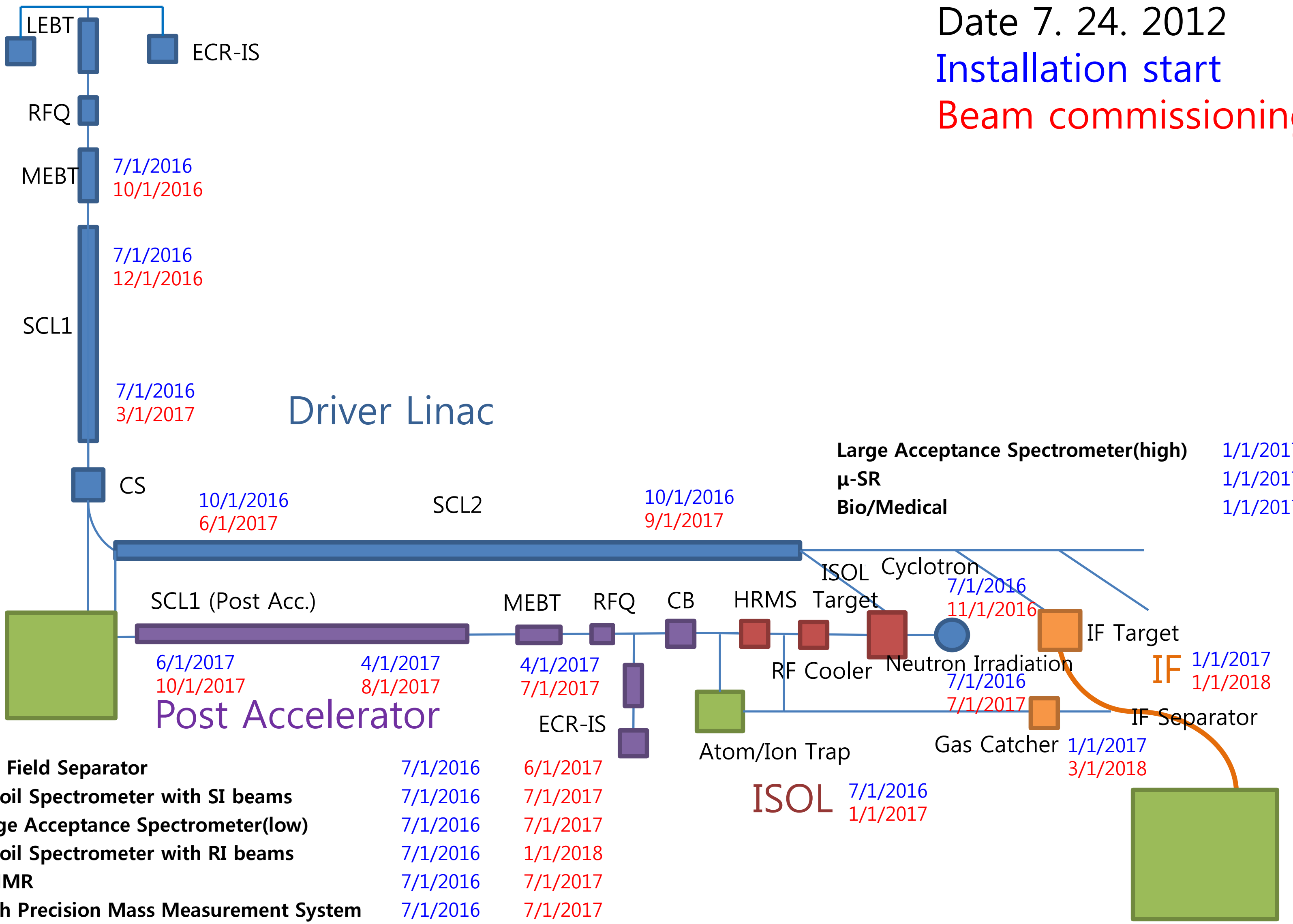
- Based on Realistic modification of specifications
- **LoIs for specified experiments (domestic + foreign)**

Schedule

Date 7. 24. 2012

Installation start

Beam commissioning start



Large Acceptance Spectrometer(high)	1/1/2017	3/1/2018
μ-SR	1/1/2017	1/1/2018
Bio/Medical	1/1/2017	1/1/2018

Gas Field Separator	7/1/2016	6/1/2017
Recoil Spectrometer with SI beams	7/1/2016	7/1/2017
Large Acceptance Spectrometer(low)	7/1/2016	7/1/2017
Recoil Spectrometer with RI beams	7/1/2016	1/1/2018
β-NMR	7/1/2016	7/1/2017
High Precision Mass Measurement System	7/1/2016	7/1/2017
High Precision Laser Spectrometer	7/1/2016	7/1/2017

Bird's Eye View

Thank you for attention !

Question or comment ?