RAON Beam Diagnostics System

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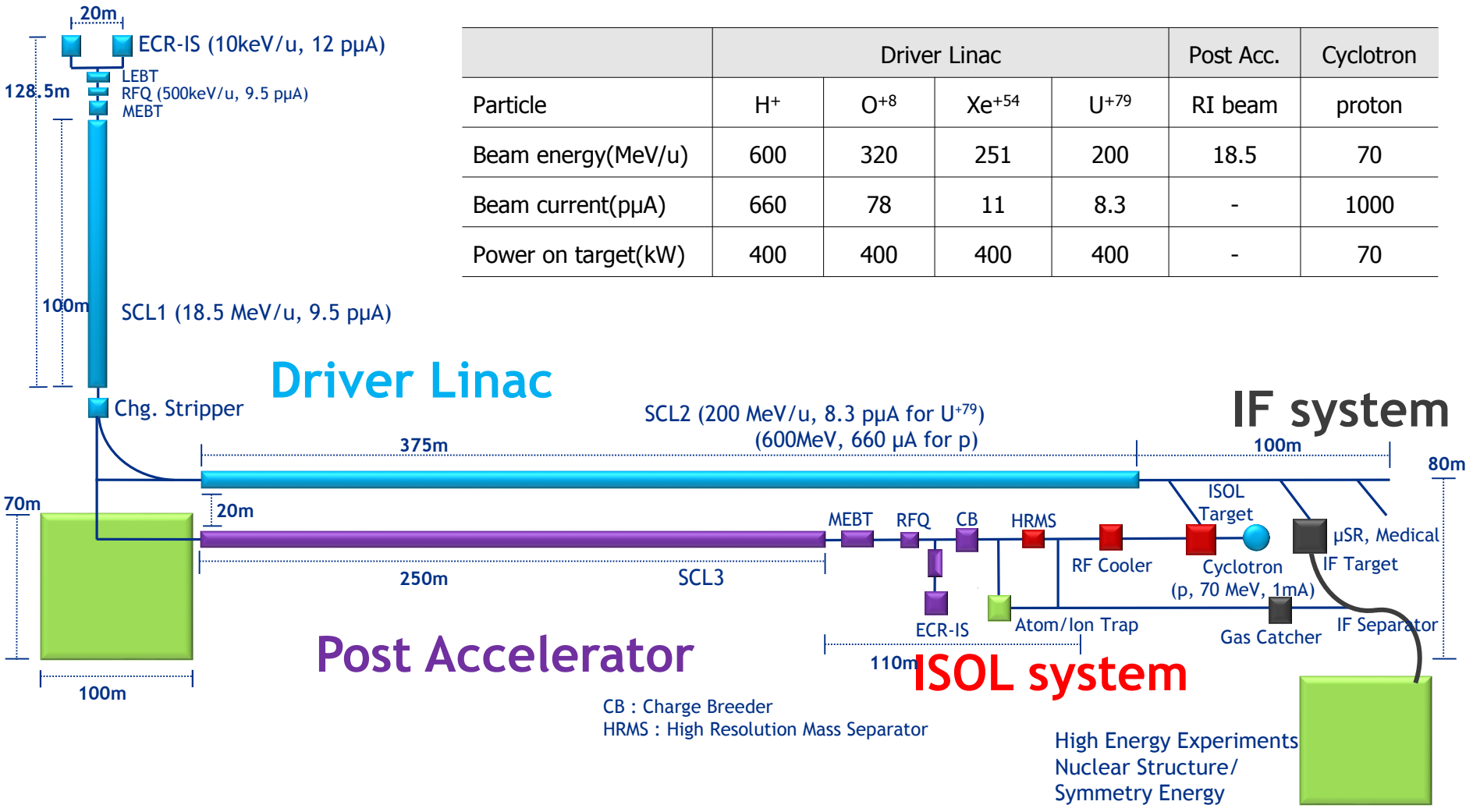
Concept of RAON

	Driver Linac				Post Acc.	Cyclotron
Particle	H^{+}	O^{+8}	Xe^{+54}	U^{+79}	RI beam	proton
Beam energy(MeV/u)	600	320	251	200	18.5	70
Beam current(pμA)	660	78	11	8.3	-	1000
Power on target(kW)	400	400	400	400	-	70



RAON Beam Parameters

	Driver Linac				Post Acc.	Cyclotron
Particle	H^{+}	O^{+8}	Xe^{+54}	U^{+79}	RI beam	proton
A/Q	1	16/8 (2)	131/54 (2.4)	238/79 (3.0)	-	1
Beam energy per nucleon (MeV/u)	600	320	251	200	18.5	70
Beta (v/c)	0.79	0.67	0.62	0.57	-	0.37
Total beam energy (MeV) = Beam energy per nucleon * A	600	5,120	3,3012	47,600	-	70
Particle current (pμA)	660	78	11	8.3	-	1000
Charge current (eμA) = Particle current * Q	660	624	594	655.7	-	1000
pps (#/s) = Particle current / e = Charge current / (Q*e)	4.1×10^{15}	4.9×10^{14}	6.9×10^{13}	5.2×10^{13}	-	6.3×10^{15}
Power on target (kW) = Beam energy per nucleon * A * Particle current = Total beam energy * Charge current / Q	400	400	400	400	-	70

ISOL Beam Parameters(Example)

Section (exit)	Ion mass range		Intensity range	Beam energy	Example of RIB
Cyclotron	1		max. 1.0 mA	35~70 MeV	
Target/Ion S.	6~160		10^{11}~10^{12} pps	10~80 keV	$^{132}Sn^{1+}$, 20 keV
Pre-Separator	RI	6~160	10^{10}~10^{11} pps	"	$^{132}Sn^{1+}$, 20 keV
	test*		10^{9}~10^{11} pps	"	
HRMS	RI	6~160	10^{3}~10^{10} pps	"	$^{132}Sn^{1+}$, 20 keV
	test		10^{8}~10^{10} pps	"	
Charge Breeder	RI	6~160	**10^{2}~10^{9} pps**	10 keV/u	$^{132}Sn^{(20\sim33)+}$, 1320 keV
	Test		10^{8}~10^{10} pps	"	

* test ions (stable) : ^{133}Cs, ^{87}Rb, ^{39}K, ^{23}Na, ^{132}Xe, ^{84}Kr
** 1 nA=6.24x10^{9} pps

Beam Diagnostics Functions

➢ Initial commissioning & Component tuning

- FC, WS, BV, CT, BPMs(position, phase, TOF), etc

❖ Beam specification; ex. Ar(9+), 30eμA, 50μs, 1Hz, …

➢ During operation(On-line)

- Monitor beam transport and acceleration function

✓ BPM : Beam position and phase

✓ BCM : Beam current and transmission(RFQ, SCL3(1), P2DT, SCL2, etc.)

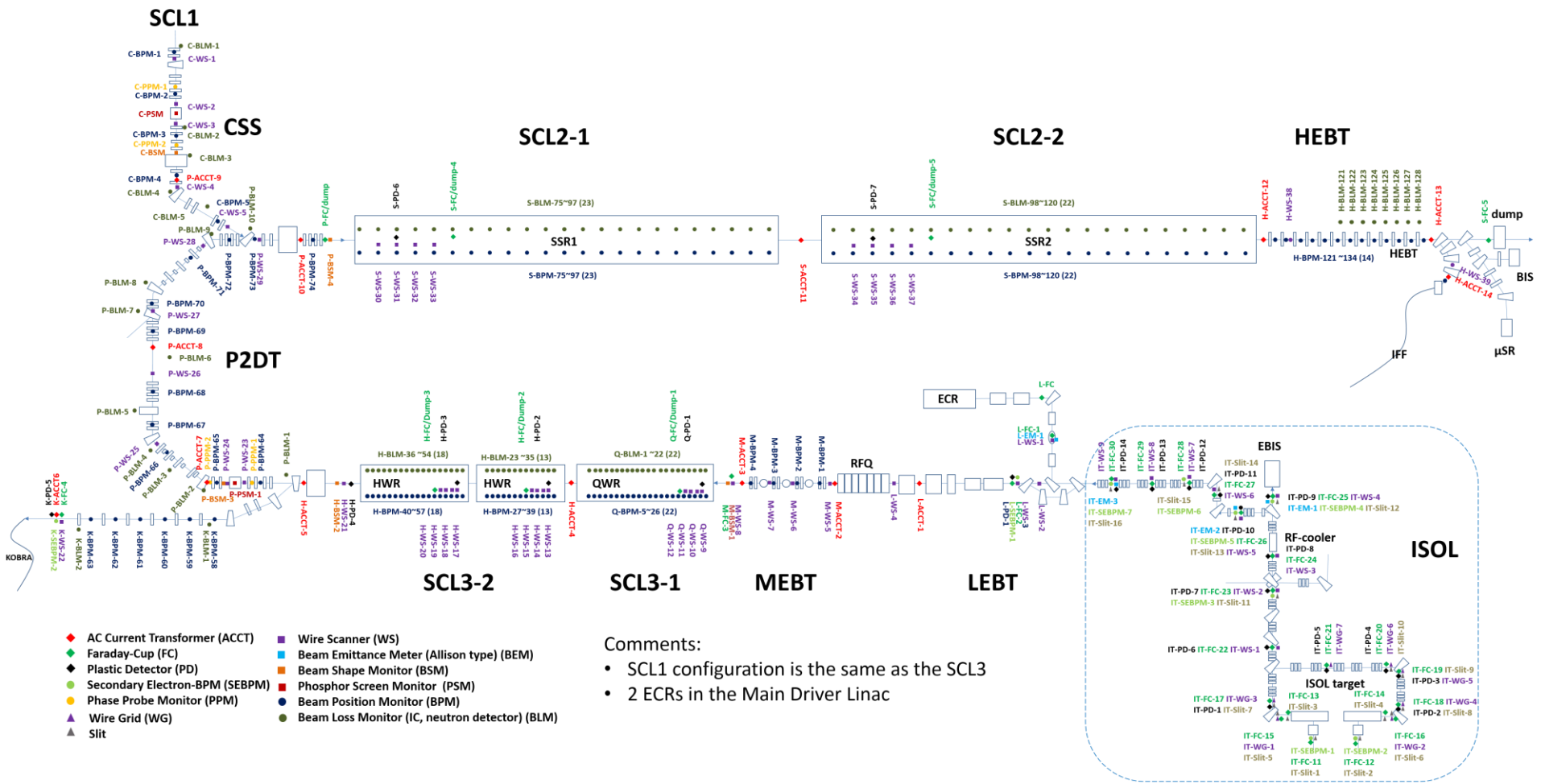
✓ BLM : Beam Loss and link to Machine Protection

❖ Beam current is 1mA ~ 1μA

➢ Commissioning and during operation(On-demand)

- 1-D, 2-D profile distribution (WS, EM)
- Bunch length (FFC)

Layout of RAON Beam Diagnostics



Comments:

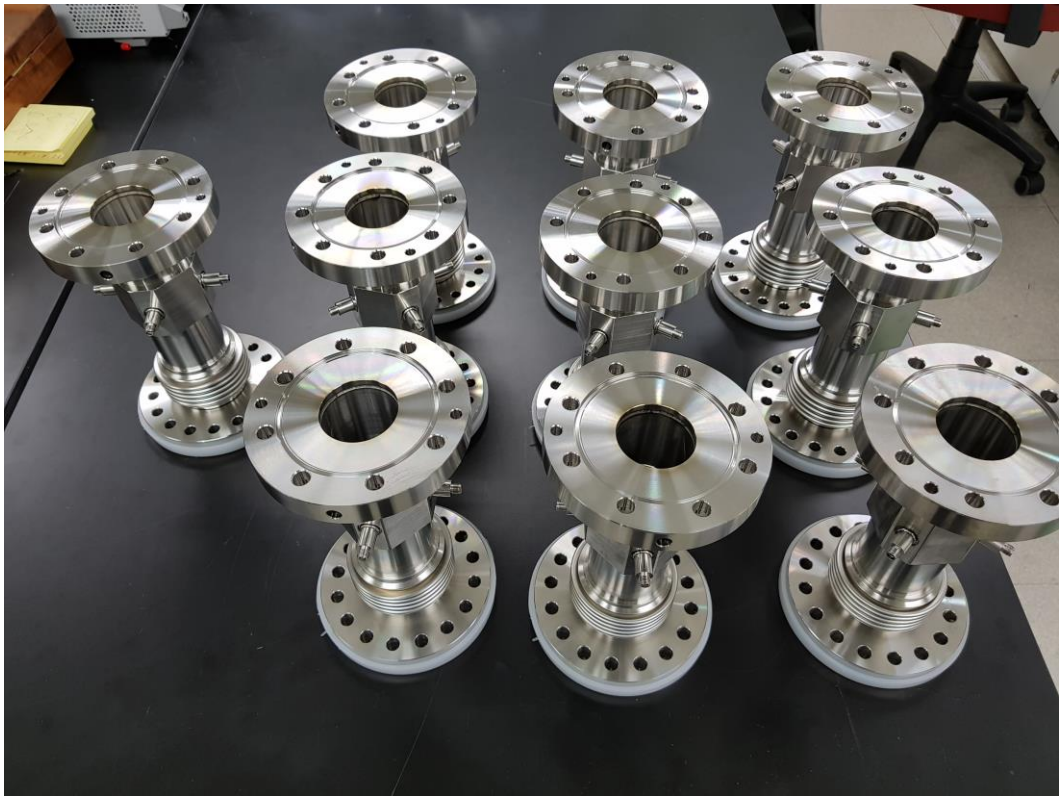
- SCL1 configuration is the same as the SCL3
- 2 ECRs in the Main Driver Linac

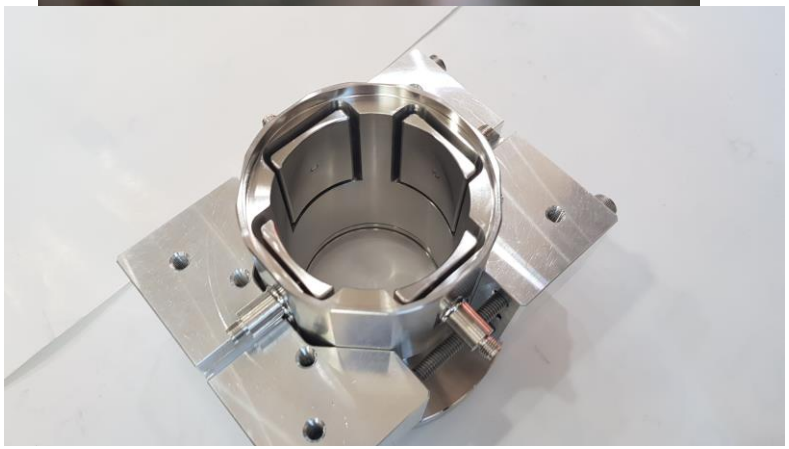
SCL1 configuration is the same as the SCL3

Beam Position Monitor(BPM)

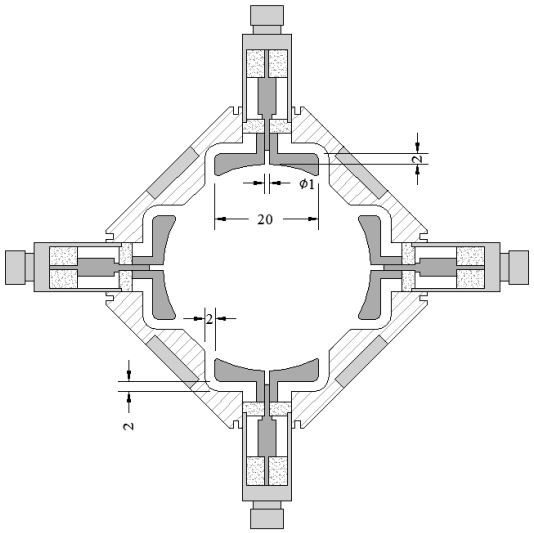
- Measurements : Beam Position, Phase, relative Intensity
- Button-type BPM; Kyocera-SMA feedthrough
- Curved type, Size: 20mmx30mm, Capacitance(each Button) ~ 8pF

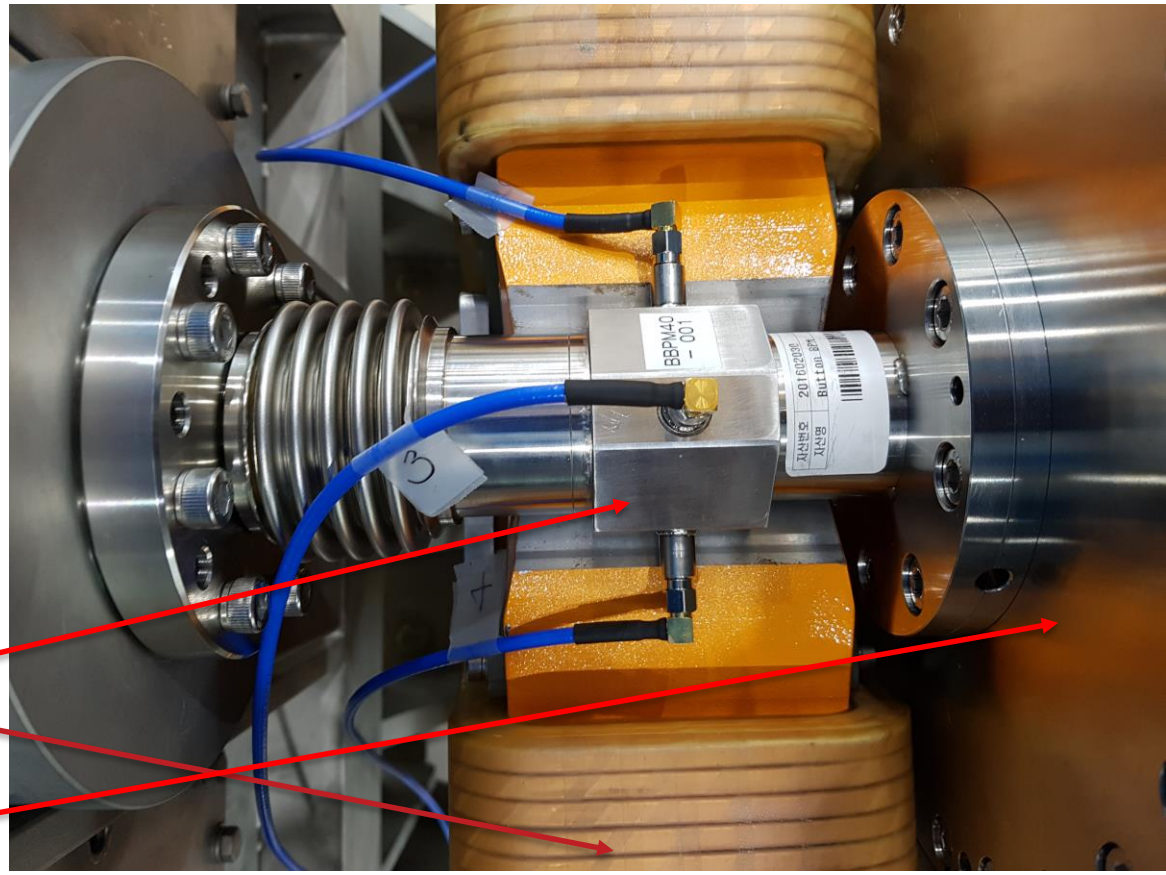
❖ 60 BBPMs for SCL3: Designed(RISP), Fabricated(Domestic Company)





BPM in the SCL Warm section





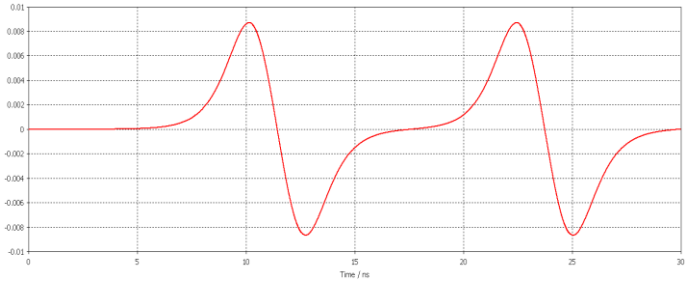
Quadrupole Magnet

BPM

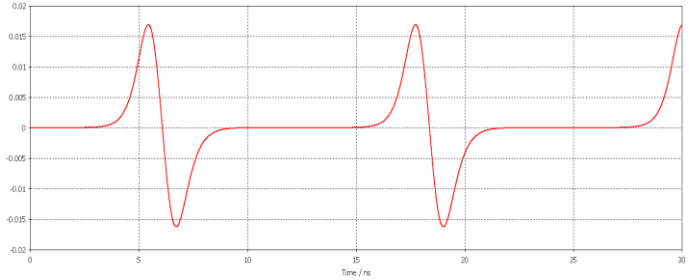
Beam Diagnostics Chamber

BPM Simulation

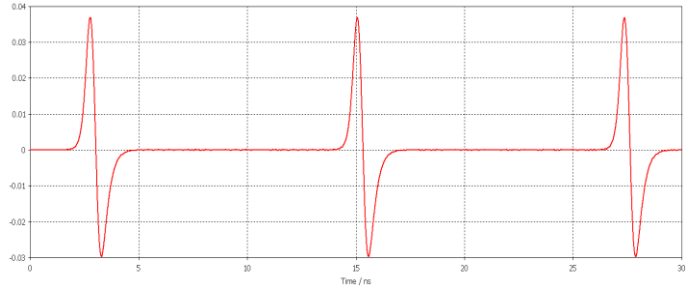
MEBT



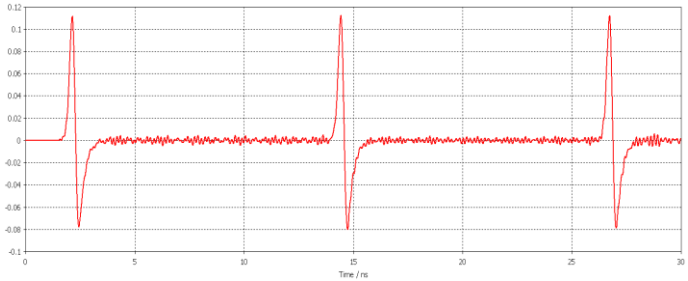
SCL11 exit



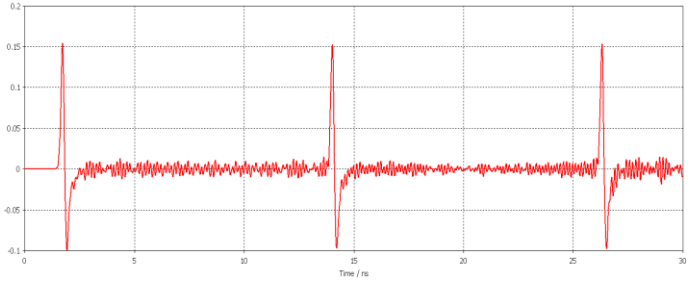
SCL12 exit



SCL21 exit



SCL22 exit

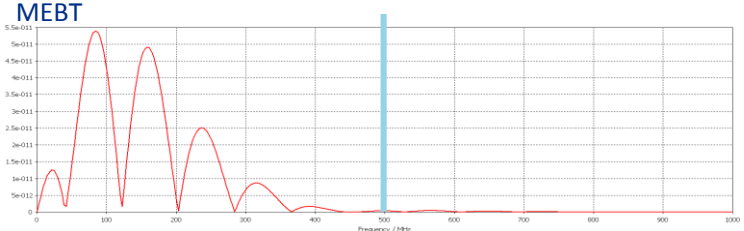


CST Particle Studio

Repetition: 81.25MHz, ~ 12.3ns

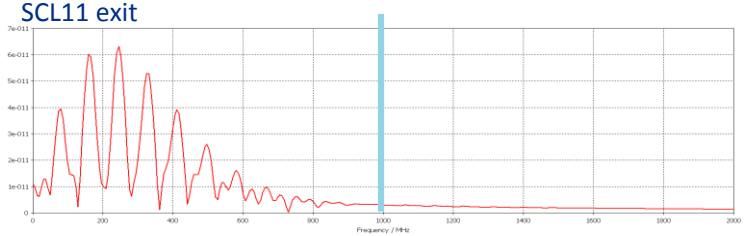
BPM Signals in Frequency Domain

MEBT



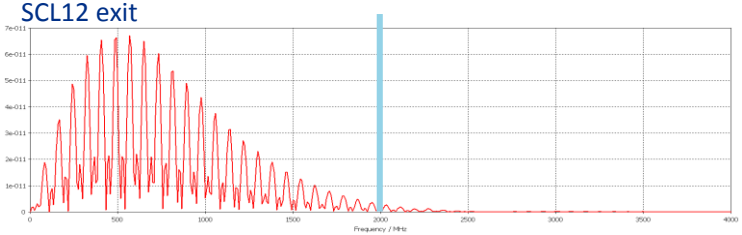
500 MHz

SCL11 exit



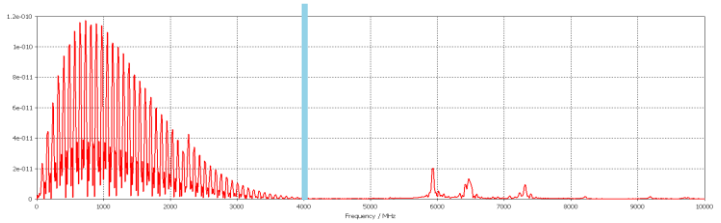
1000MHz

SCL12 exit



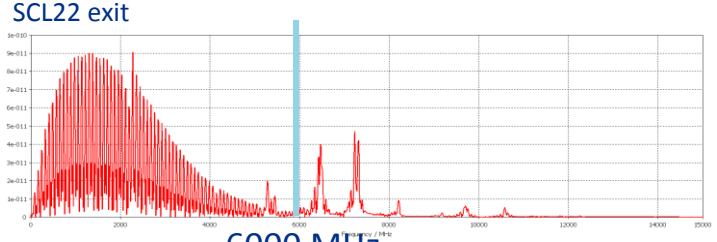
2000MHz

SCL21 exit



4000 MHz

SCL22 exit

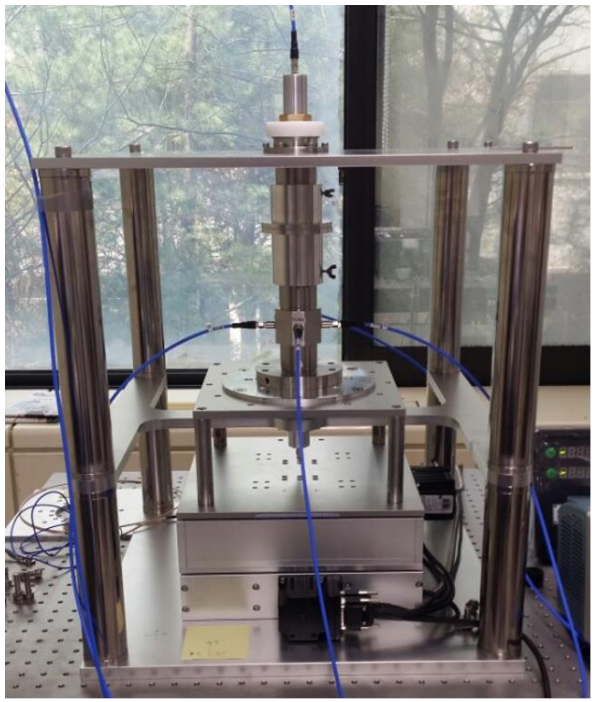


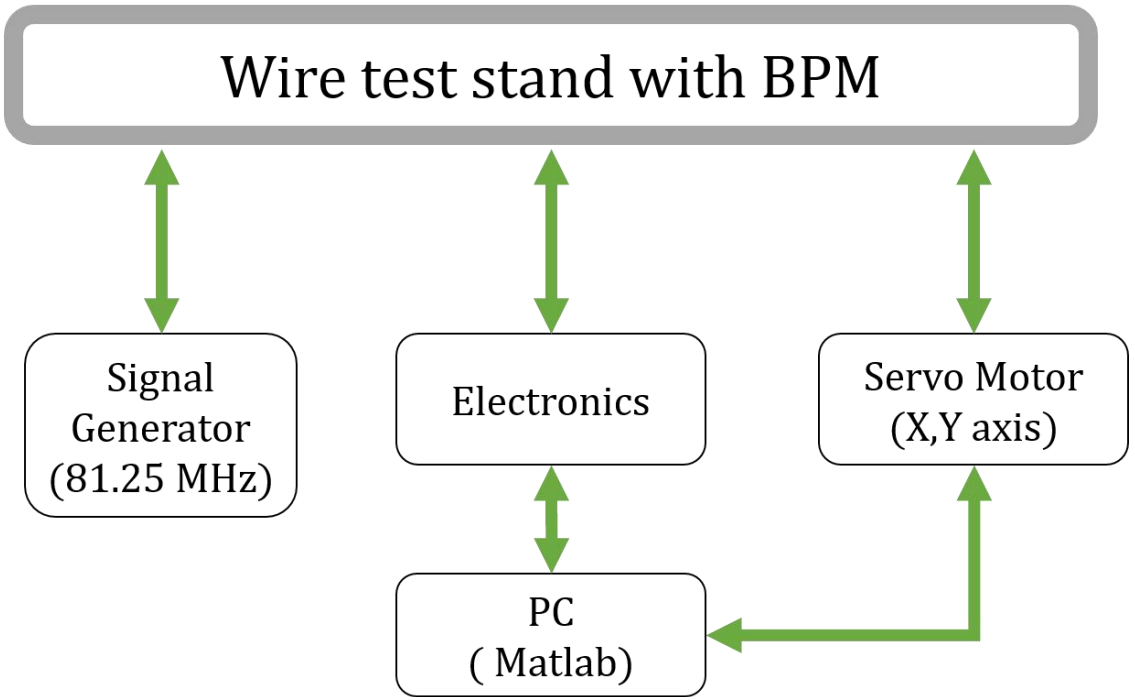
6000 MHz

CST Particle Studio
Repetition: 81.25MHz, ~ 12.3ns

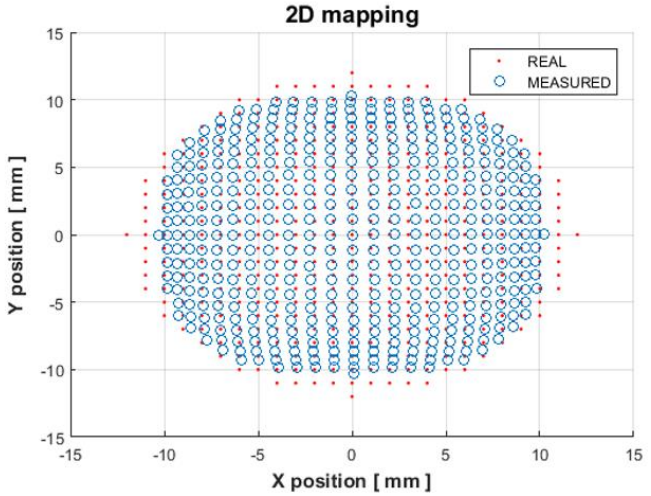
- Higher Harmonics(>2nd) signal is dominant after SCL11(SCL31)
- Signal Processing with 1st, 2nd harmonics for MEBT & SCL11(SCL31)
  1st, 3rd harmonics for SCL12(SCL32)
- 60 BPM modules; being fabricated by a domestic company “mobiis”

BPM Wire Test





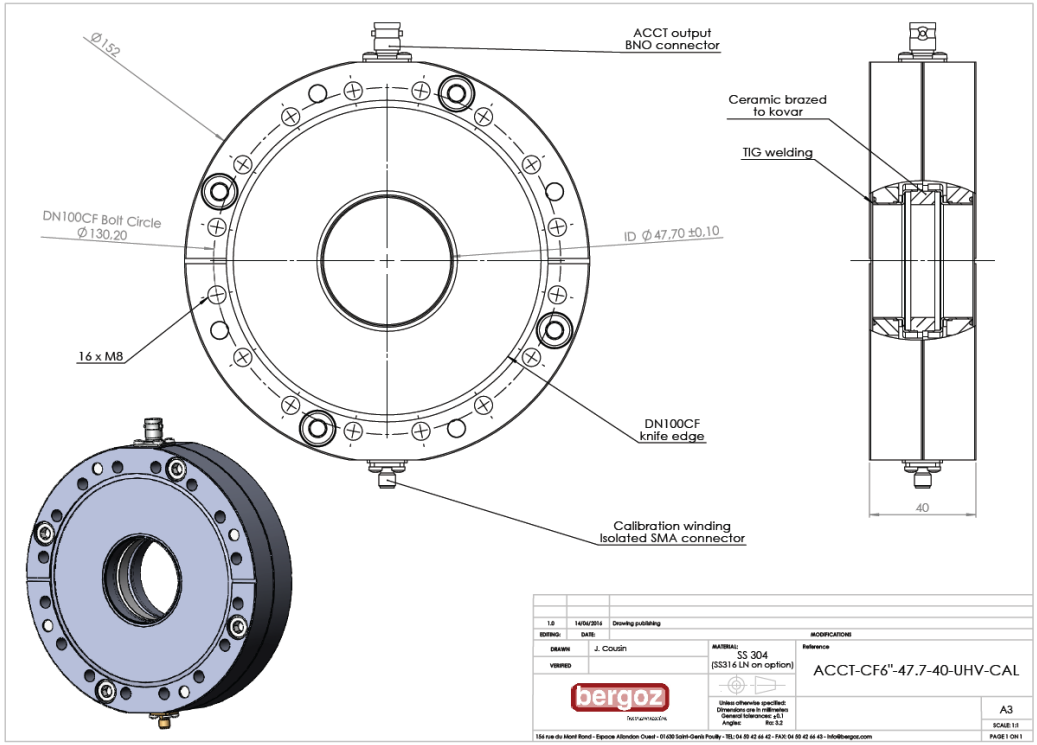
- Fixed Wire(0.5mm music wire)
- BPM on stage is moving(x,y)
- Test each BPM, 2D(x,y) Field Mapping
- Electronics : I-tech, Libera Single-Pass H



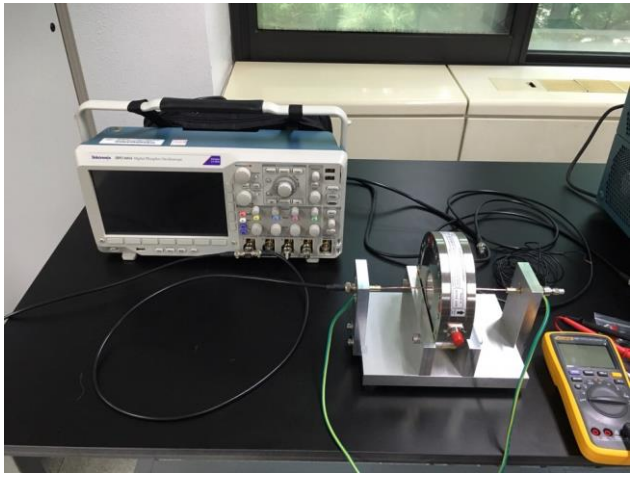
Beam Current Monitor(ACCT)

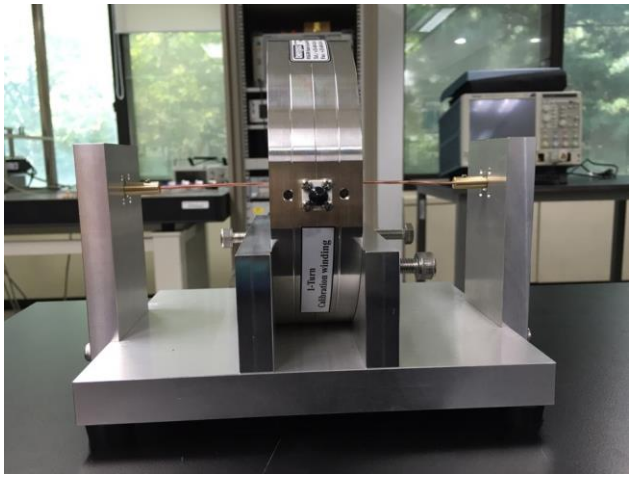
Bergoz ACCT

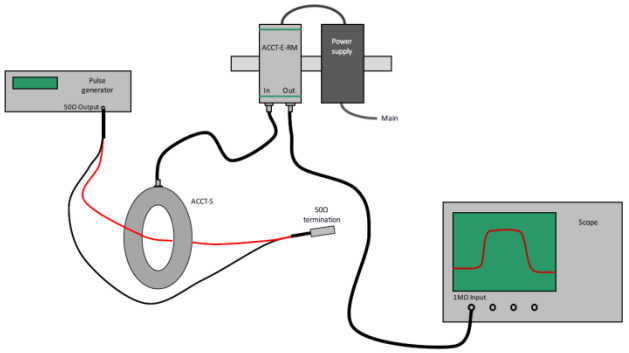
- RAON Beam Current < 1mA
- 3Hz(Lower Cutoff, -3dB) ~ 300kHz(Upper cutoff, -3dB)
- t(droop) = 0.35/f(low, 3db) = 117ms
- t(rise) = 0.35/f(high, 3db) = 1.17μs
- V(output)/A(input) = 1000



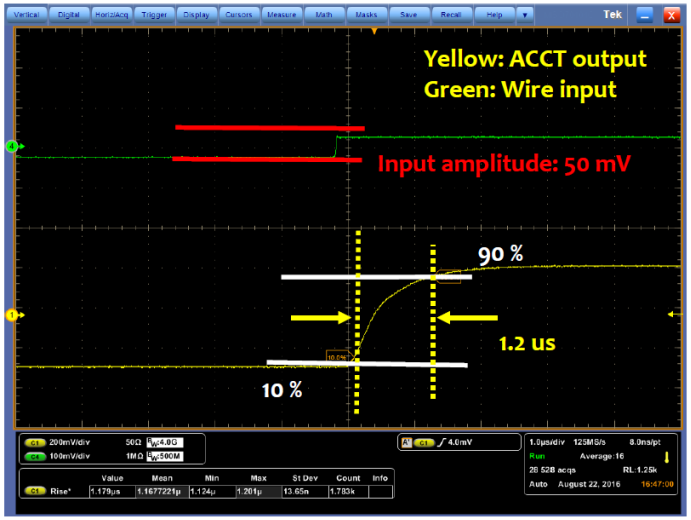
ACCT Wire Test

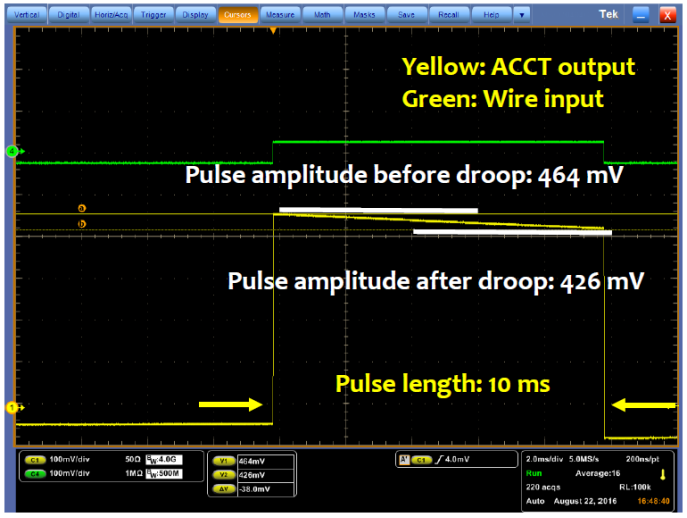






- Rise time, Droop time





❖ 6 Bergoz ACCT(ID=48mm): Purchased & ready to be installed

Beam Loss Monitor(BLM)

◆ Beam Loss Monitor

➢ Monitor Regular(slow) losses and Irregular(fast) losses

➢ Radiation Sources

- Radiation : neutron, proton, gamma, electron, ion for >~7MeV/u
  gamma, electron <~7MeV/u
- Outside of Vacuum Chamber(secondary) : gamma, neutron
- At Low energy region(ex. SCL11 or SCL31)

  - No or very low radiation level is expected
- X-ray from SC Cavity & RF source is background source to BLM

❖ Source term simulation(MCNPX) has been conducted throughout Linac Tunnel

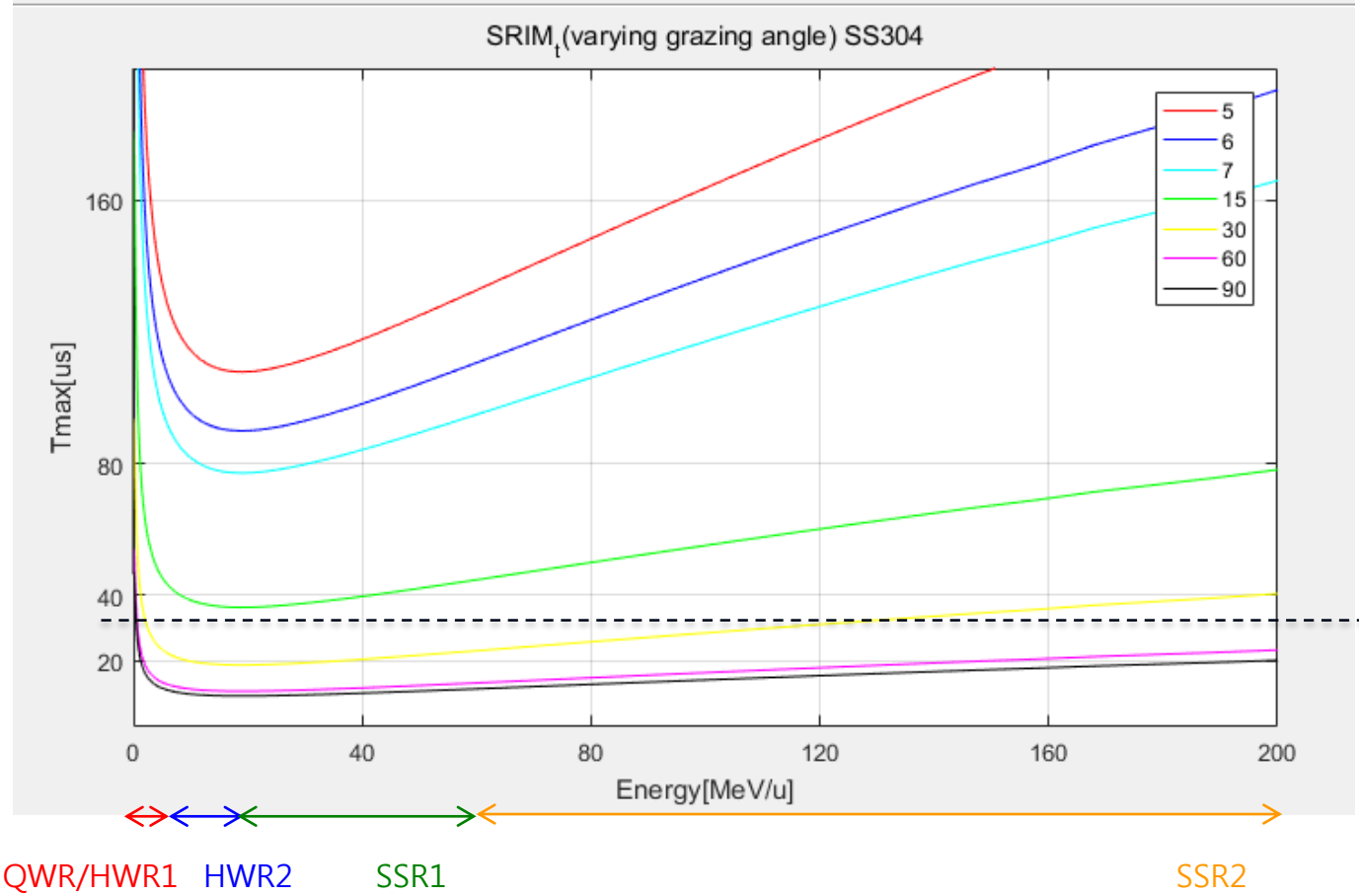
◆ MPS(Machine Protection System) requirements are checked

- DBCM(Differential Beam Current Monitor) with ACCT networks is considered for primary fast loss detection

  * CT networks : ACCT1 – RFQ – ACCT2 – MEBT- ACCT3 – SCL1(3) – ACCT4 ….)

➢ Plastic Scintillator, Proportional Counter, Halo Monitor Ring are being considered

Machine Protection System requirements



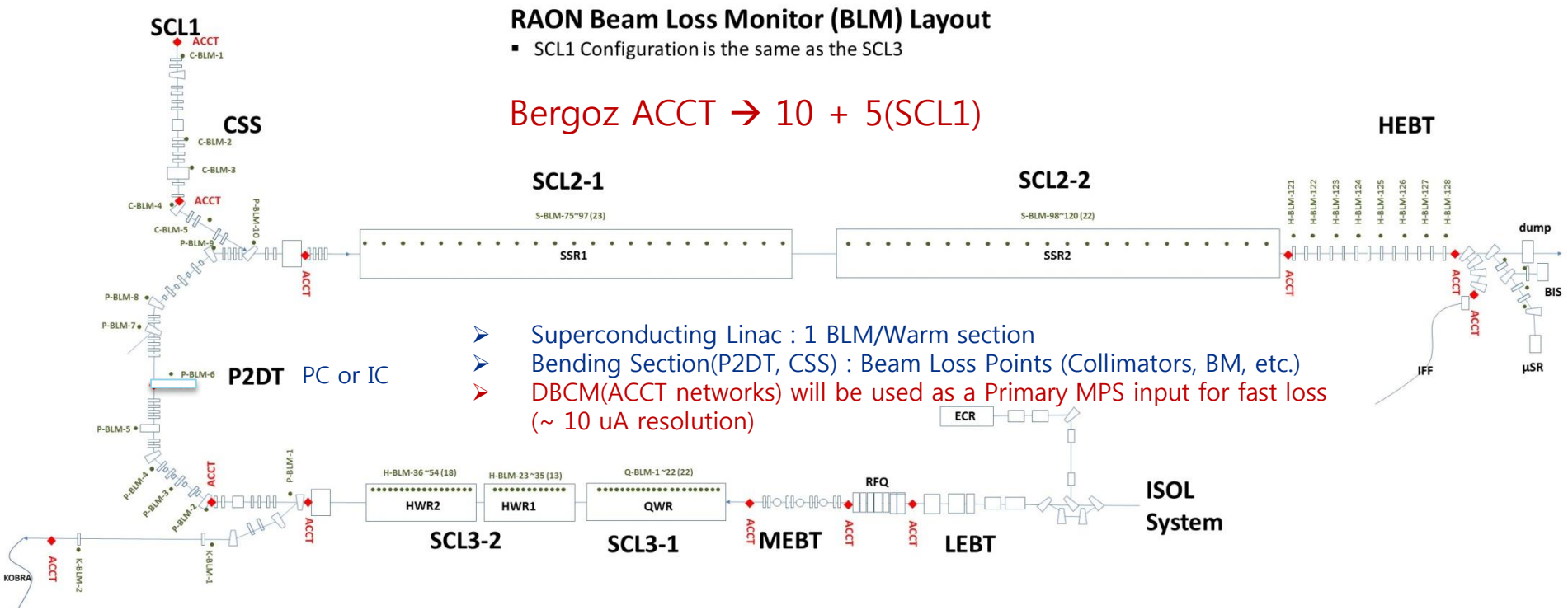
θ=90° : the worst case scenario with full beam at perpendicular incidence; is expected only when objects(e.g., valve) in the beam line.

RISP design goal
(~ 35 us)

35 us = 15 us (sense) + 10 us (respond) + 10 us (latent beam in pipe)

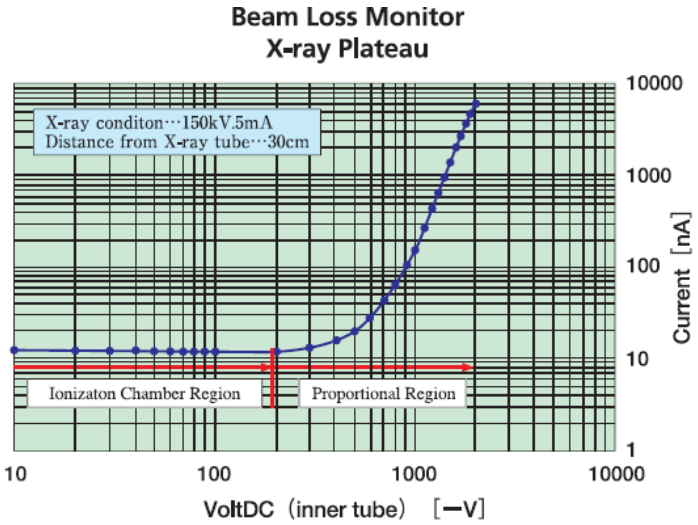
*Slow loss (1W/m) ~100 ms (?)

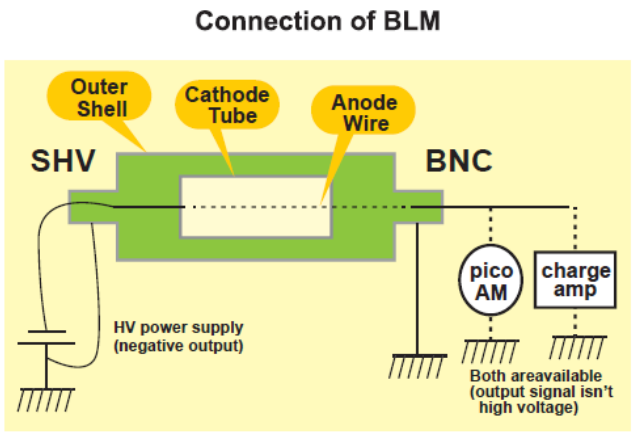
RAON BLM Layout(Preliminary)

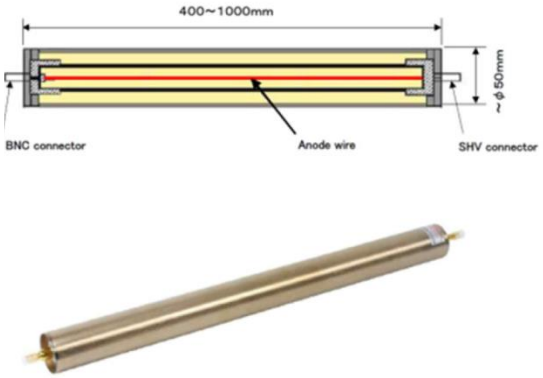


	PC(IC)	PD	HMR	DBCM(ACCT)
QWR	-	-	X	X
HWR1	-	X	X	X
HWR2	-	X	X	X
SSR1	X	-	X	X
SSR2	X	-	X	X

BLM, Proportional Counter







Volume ~ 245 cm^3

Benchmarking:
(J-PARC, KOMAC)

Model	E6876-600
Manufacturer	Toshiba (Japan)
Gas	Ar + Co_2
Response time	0.1 usec
Typical gain	1000 (at 2000 V)

BLM, Plastic Detector

Model	R2083A(Hamamatsu, ϕ46mm)
Gain (PMT_{gain})	2.5E6 (@ 3.0 kV)
Scintillator material	**BC408 (EJ-200)**
Density ρ_{BC408} of BC408	1.032g/cm^3
Scintillator size	ϕ50.8mm, 300 mm
Light output R_s of BC408	0.1 $photon/eV$
Scintillator volume (V_{BC408})	193 cm^3
ε_{cath}(420nm photon 기준)	23.6%
Supply voltage of PMT	3.5 kV (Max.)
Sensitivity (Scintillator+PMT)	**117.5 C/rad $\cdot \varepsilon_{coll}$**

→ This organic plastic is less sensitive to low energy X-ray, and interacts with fast neutrons (>50 keV) through (n,p) scattering.

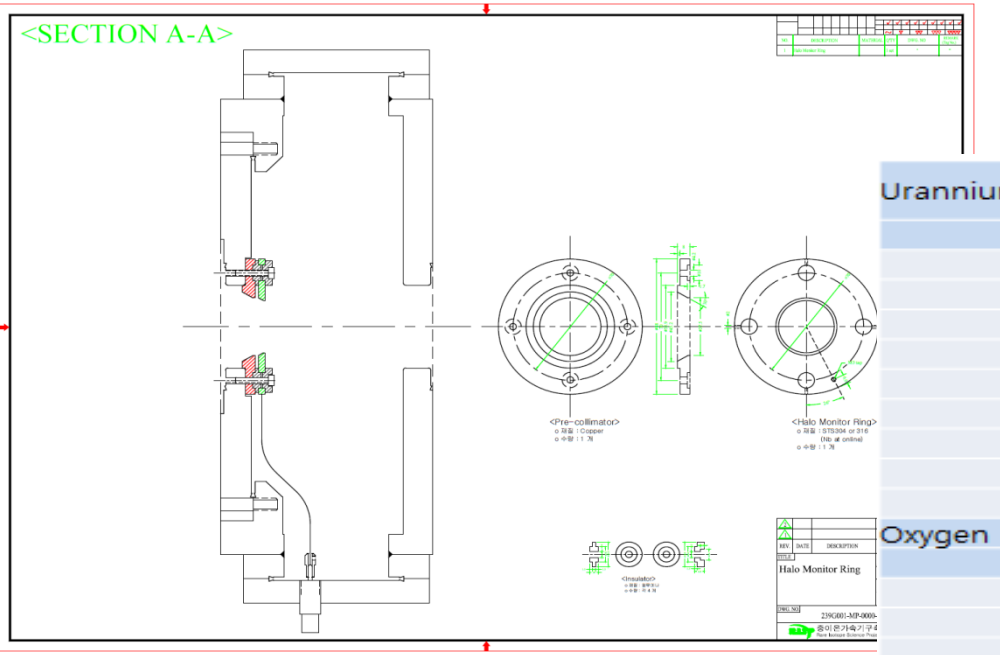
→32.6 mA/($\frac{\text{rad}}{\text{h}}$) $\cdot \varepsilon_{coll}$

$$S_{PD} = \frac{100\ erg}{g \cdot rad} \cdot \rho_{BC408} \cdot V_{BC408} \cdot \frac{1\ eV}{1.6 \cdot 10^{-12}\ erg} \cdot R_s(BC408) \cdot \varepsilon_{coll} \cdot \varepsilon_{cath} \left[\frac{electron}{photon}\right] \cdot \frac{1.6 \cdot 10^{-19}}{electron} \cdot PMT_{gain}$$

* ε_{coll}: collection efficiency to photocathode (50%~70%)

* ε_{cath}: efficiency of photon →photoelectron

BLM, Halo Monitor Ring

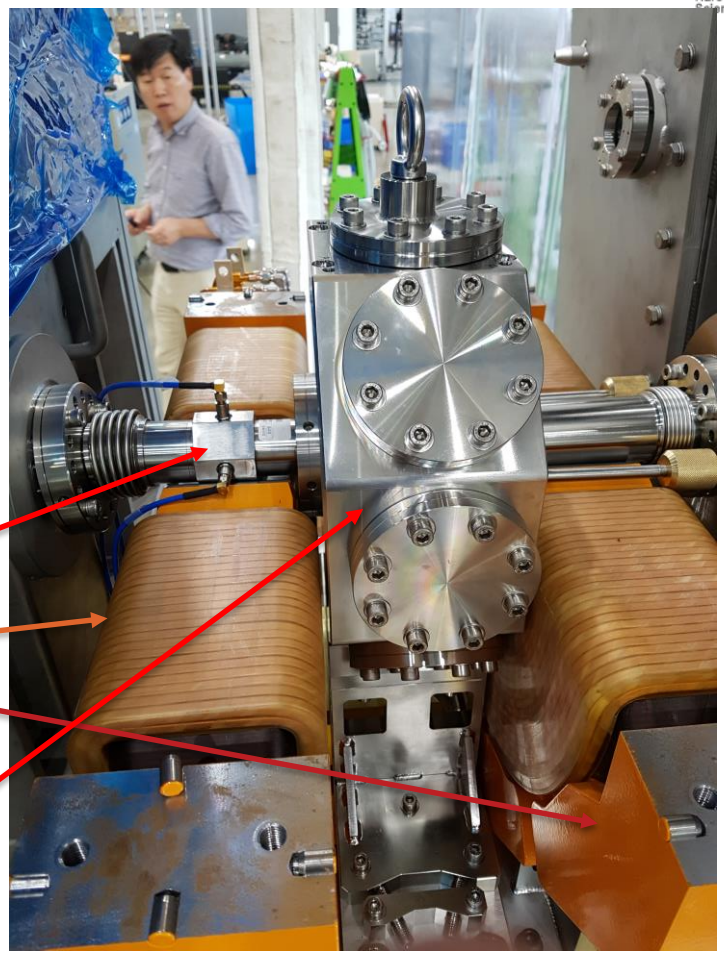


Urannium 238	Output	E(MeV/u)	Warm section period m	Intercepted current nA
	ECR-IS	0.01		
	RFQ	0.5		
	QWR	2.6	1.21	65.51
	HWR1	6	1.8	42.23
	HWR2	18.5	2.68	20.39
	CSS	18		
	SSR1	56.3	2.672	15.75
	SSR2	210	5.21	8.24
Oxygen 16	Output	E(MeV/u)		
	ECR-IS	0.01		
	RFQ	0.5		
	QWR	4	1.21	94.53
	HWR1	10.1	1.8	55.69
	HWR2	34.1	2.68	24.56
	CSS	34		
	SSR1	90.8	2.672	14.71
	SSR2	325.7	5.21	8.00
Proton 1	Output	E(MeV)		
	ECR-IS	0.01		
	RFQ	0.5		
	QWR	6.1	1.21	198.36
	HWR1	20.8	1.8	86.54
	HWR2	80.9	2.68	33.13
	CSS	80.9		
	SSR1	187.1	2.672	14.28
	SSR2	600	5.21	8.68

- Radiation level outside vacuum chamber at low energy region is very small

- HMR intercepts the beam loss directly, and the intercepted current will be enough to be readout, especially at low energy region

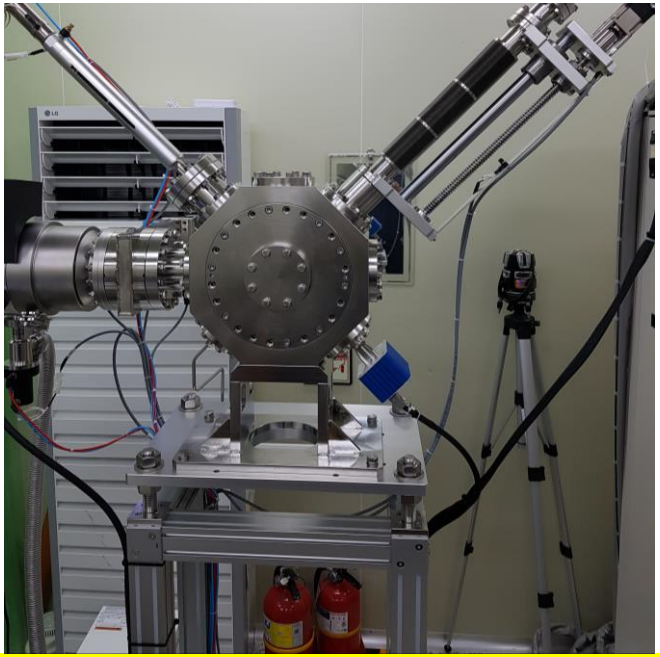
SCL3 Warm Section



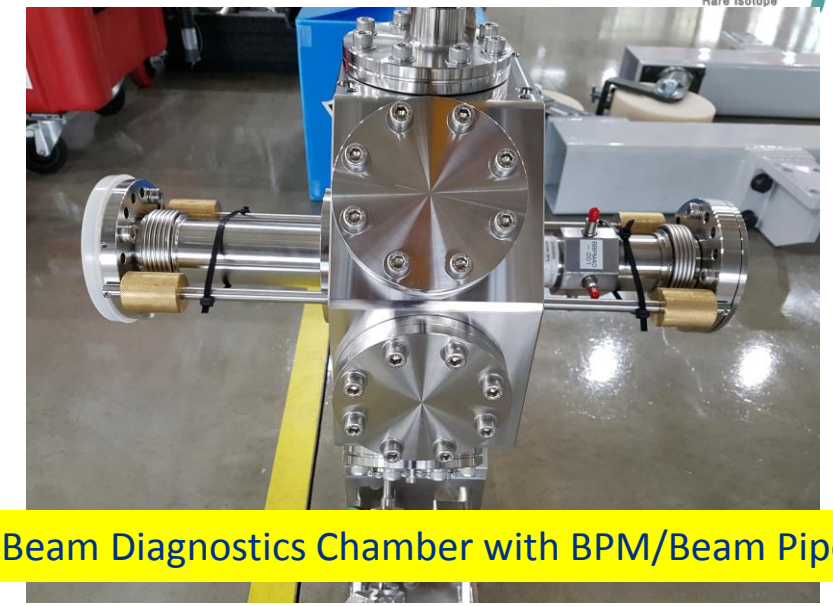
Quadrupole Magnet(130mm)
QWR Cryomodule
BPM
Beam Diagnostics Chamber(138mm)
Beam Pipe

- BPM inside(Center) of Quadrupole Magnet
- Installation(&align) procedures are prepared, tested

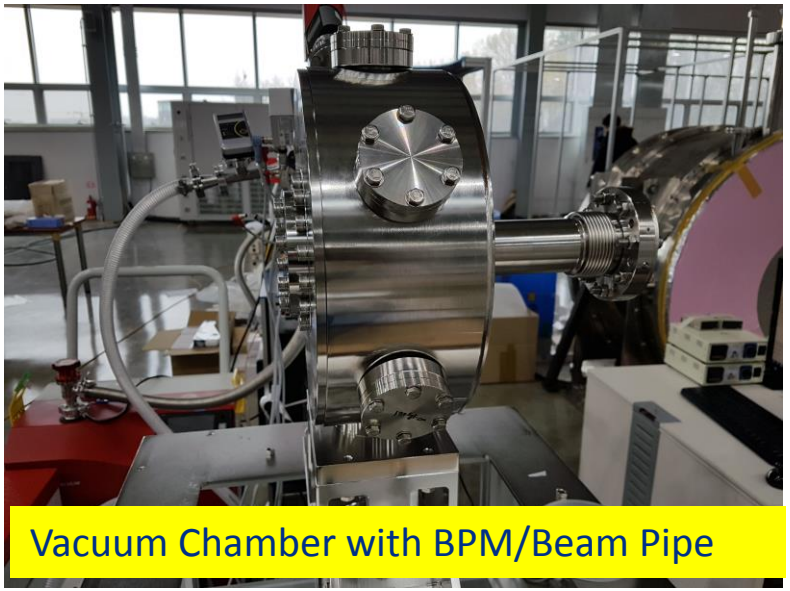
Beam Diagnostics System, Vacuum Chamber for SCL3 Warm Section



Prototype installed at SCL Demo
- WS, FC, Vacuum



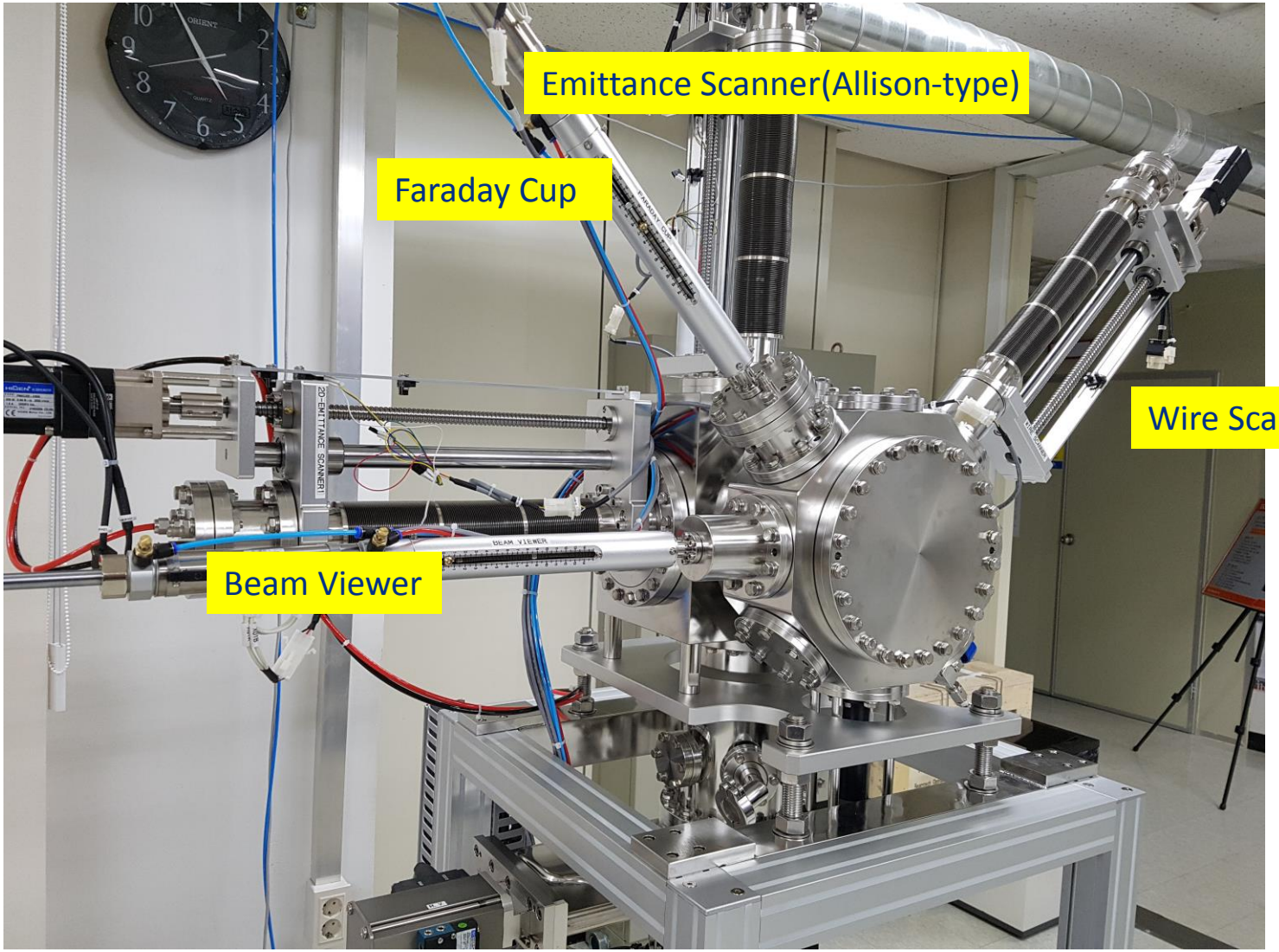
Beam Diagnostics Chamber with BPM/Beam Pipe



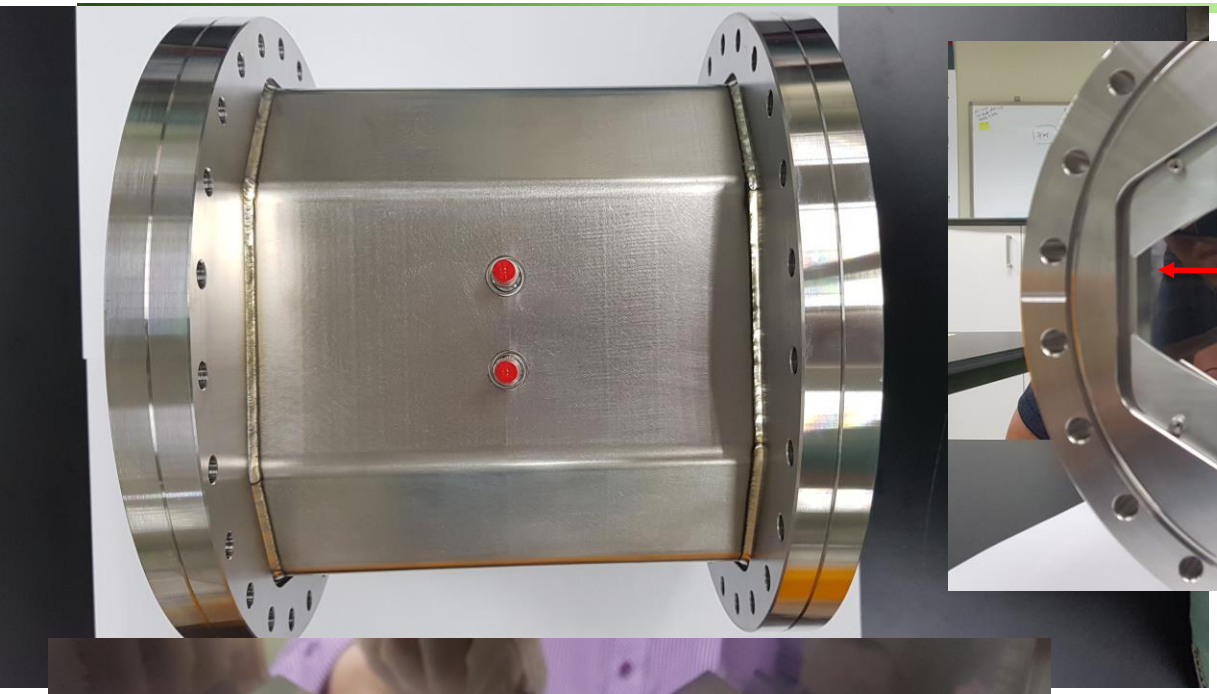
Vacuum Chamber with BPM/Beam Pipe

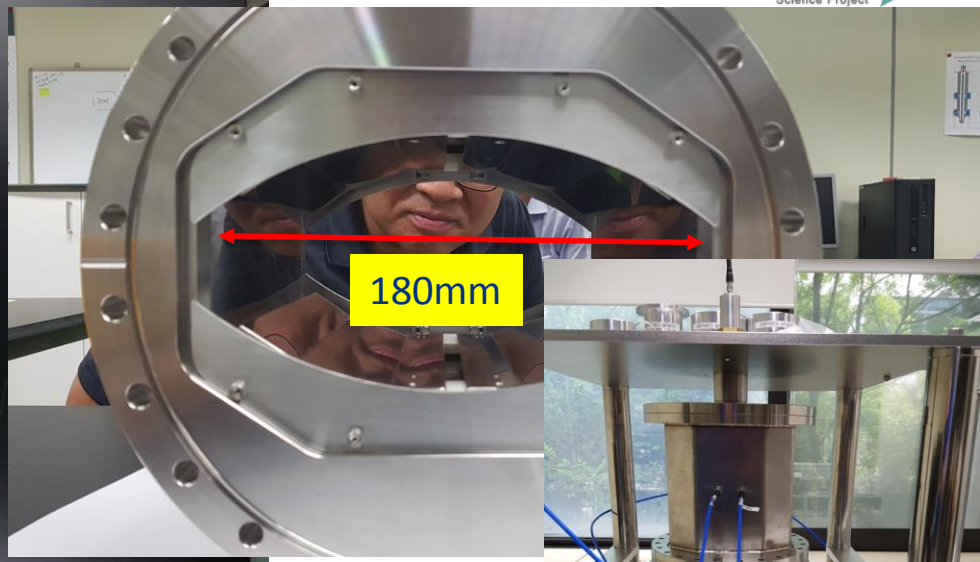
- Up to 8 ports available
- 3 Diagnostics Device(FC, WS, PD)
- Vacuum System

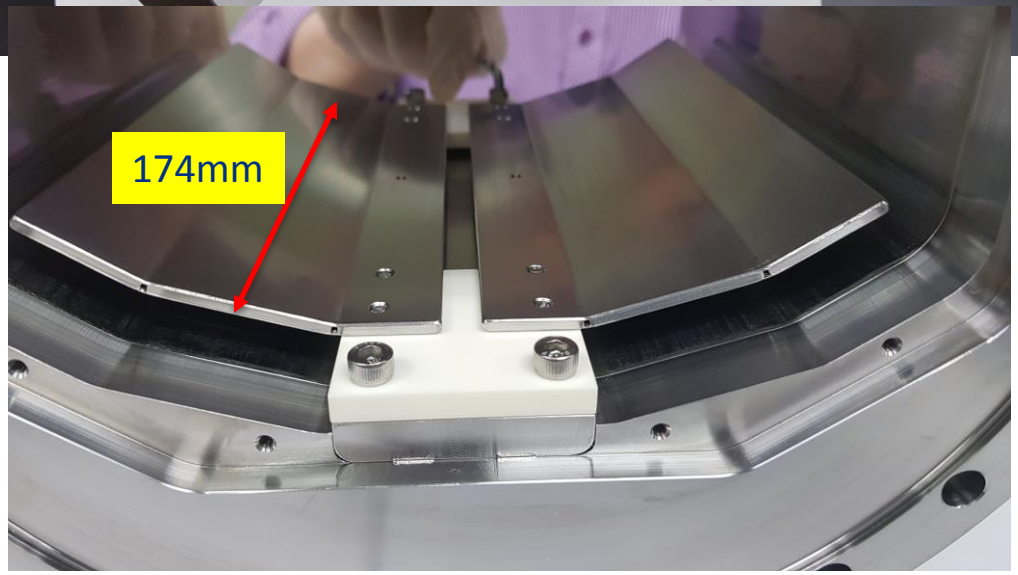
LEBT Beam Diagnostics



Large BPM @ P2DT

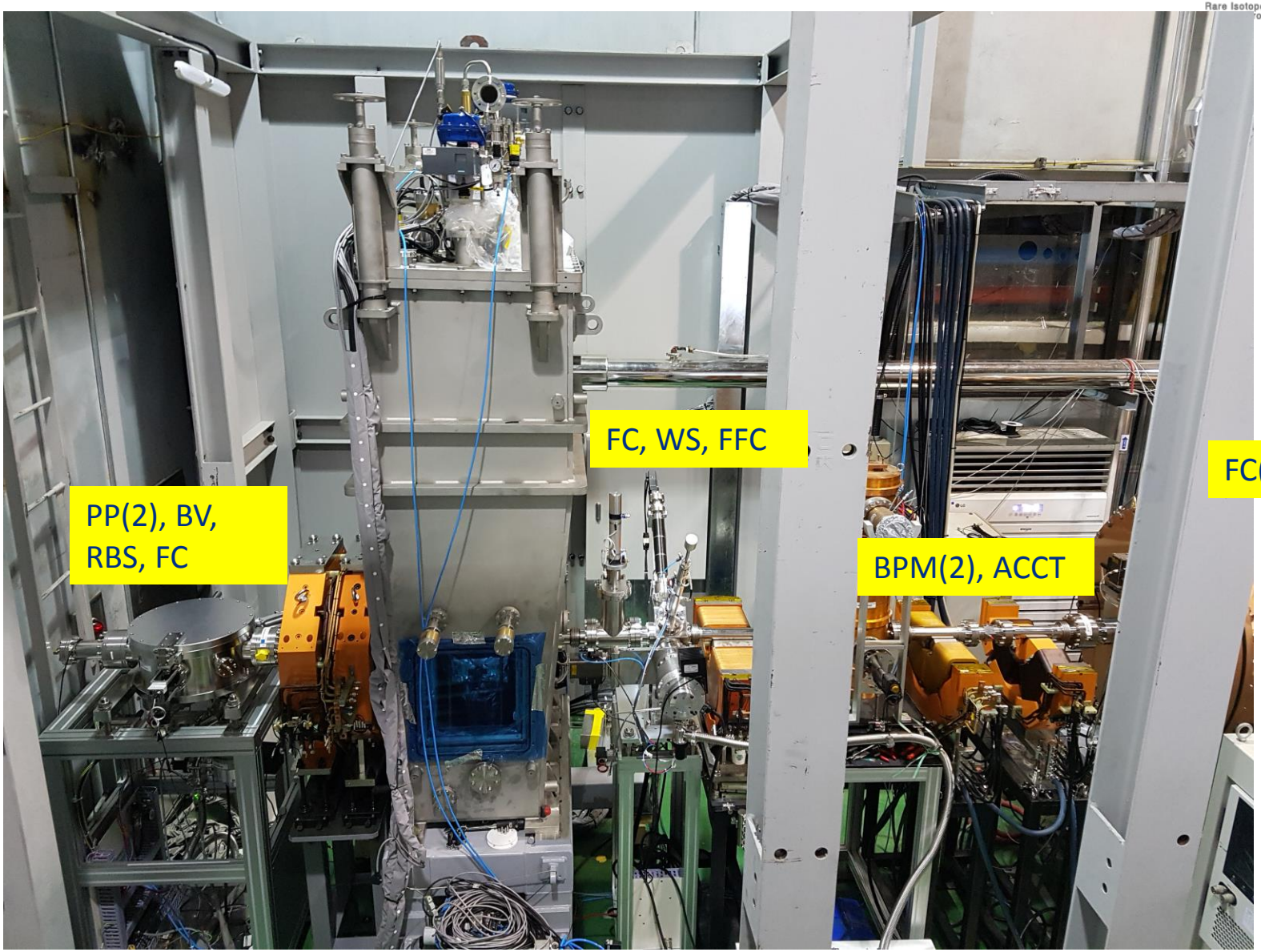




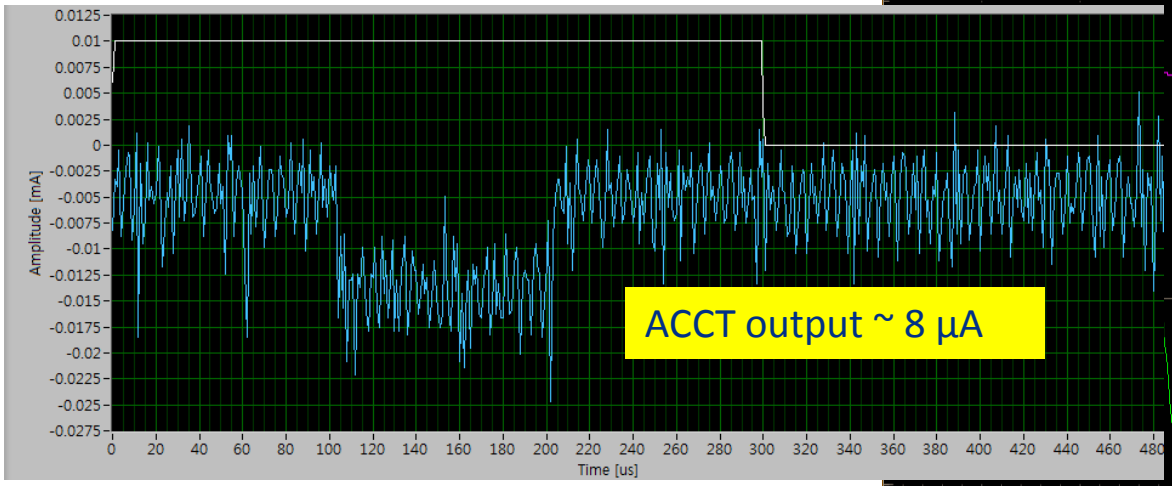


- Intensive CST Simulation
- Just Fabricated (Still Prototype)
- Vacuum check done
- Ready for wire test

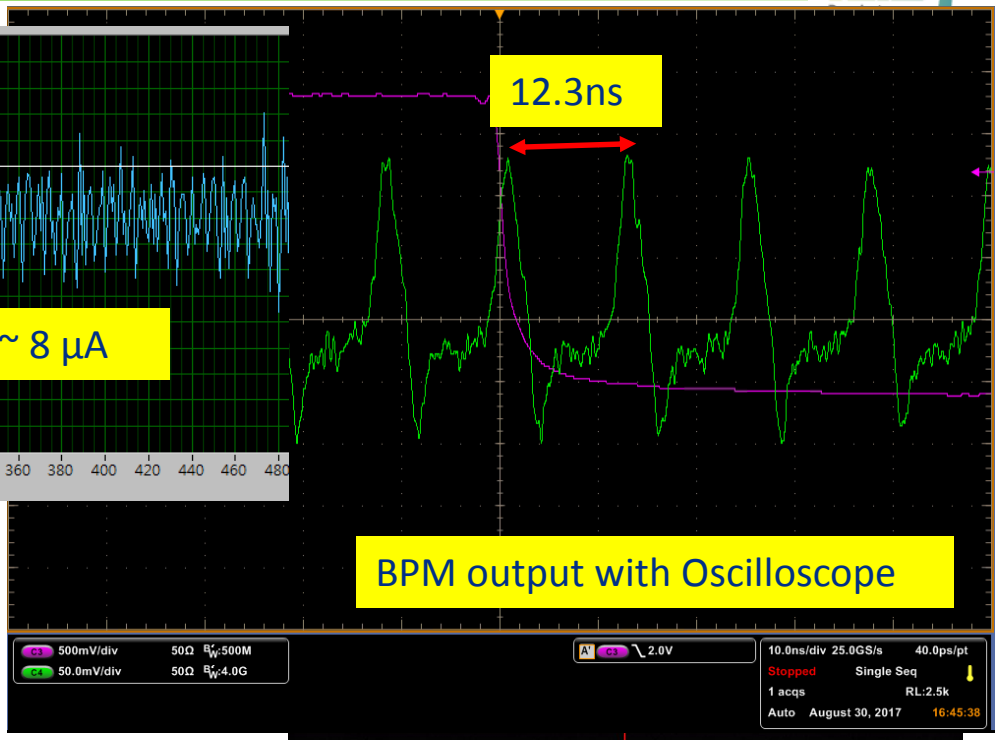
At SCL Demo



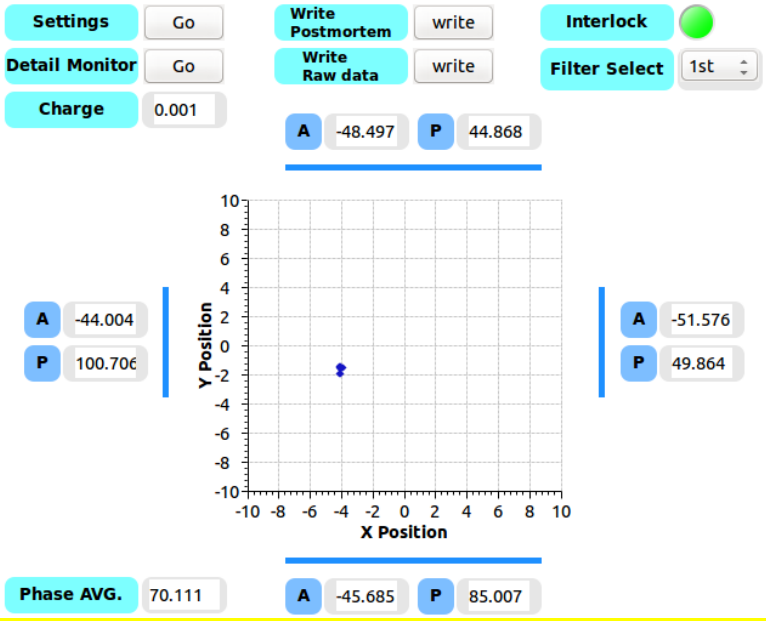
At SCL Demo



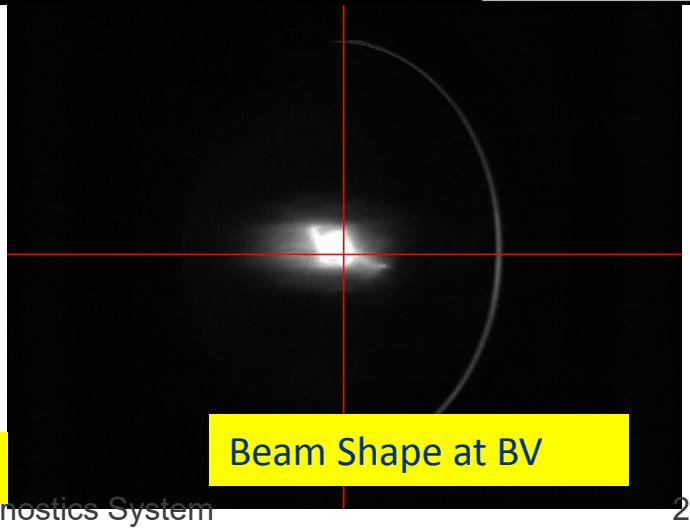
ACCT output ~ 8 μA



BPM output with Oscilloscope



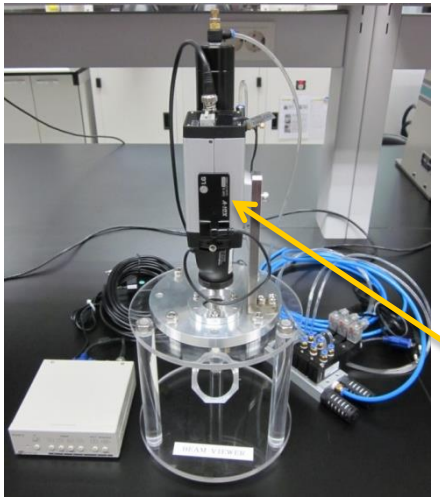
Position & Phase monitoring with BPM Controller(Prototype)



Beam Shape at BV

ISOL Test Facility

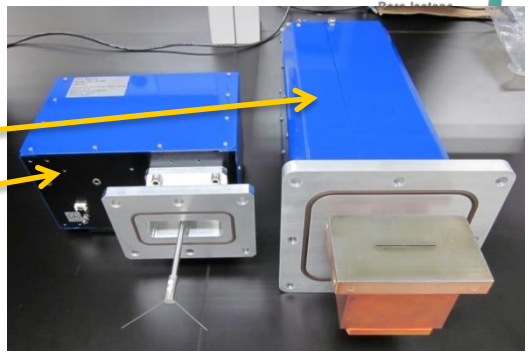
Beam diagnostics @ISOL Test Facility



Beam viewer

Wire grid (NTG) at high-rad area

Beam diagnostics chamber at the end of the off-line ISOL facility



Oscillating wire scanner & Allison-type emittance scanner (D-Pace)

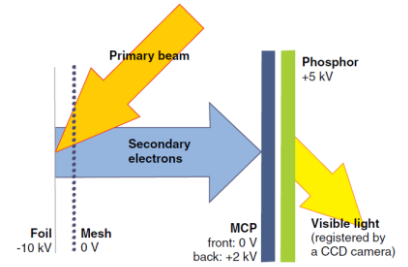


FIG. 3. Operation principle of a foil-based secondary emission monitor.

SE-BPM

DAQ System

- ➢ **BPM – standalone (with Timing, Trigger, Interlock, etc.)**
- ✓ Preproduction version will be ready(Oct. 2018) for evaluation test
- ➢ **Others(WS, FC, CT, BLM, etc.) with µTCA system**
- ✓ CAENels AMC-pico; 8ch 20bit Picoammeter
- ✓ Vadatech DAQ523; 12ch 16bit voltagemeter

Summary and Plan

- BPM(Beam Position Monitor)
  - Fabricated 60 Button-type BPM for SCL3
  - BPM controller for 60 BPMs are being produced by domestic vendor
  - A prototype of Large(P2DT section) BPM is being tested
- BCM(ACCT)
  - Tested at SCL Demo and showed a good sensitivity to measure ~ few μA
  - 6 Bergoz ACCT are ready for installation
- BLM(Beam Loss Monitor)
  - Plastic Scintillator+PMT, Proportional Counter, HMR are being considered
  - 3 PC(Toshiba BLM) are in our test lab., will be calibrated
  - DBCM(ACCT networks) will be used for primary MPS
- FC, WS, PD, FFC, Phase Probe, EM, etc.
  - 1 each(at least) has been fabricated and tested
  - Readout and control systems are being designed


감사합니다
RAON