

2026 가속기 여름학교

IRIS Beam Diagnostics

Jangwon Kwon

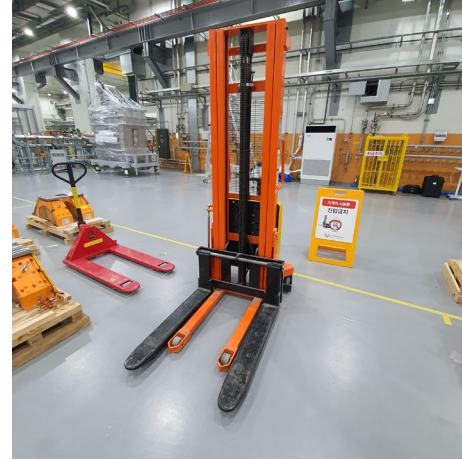
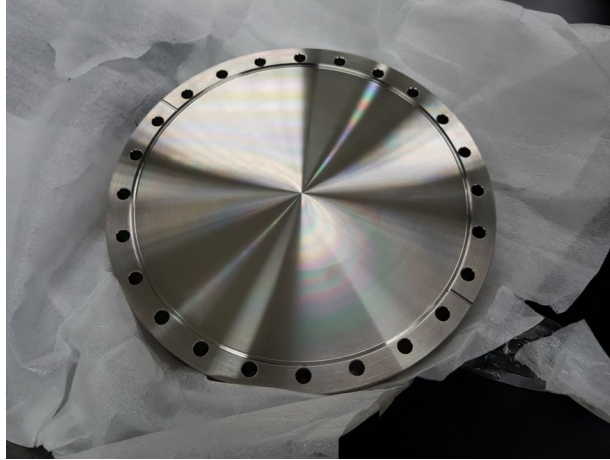


2026.07.09

Beam ?



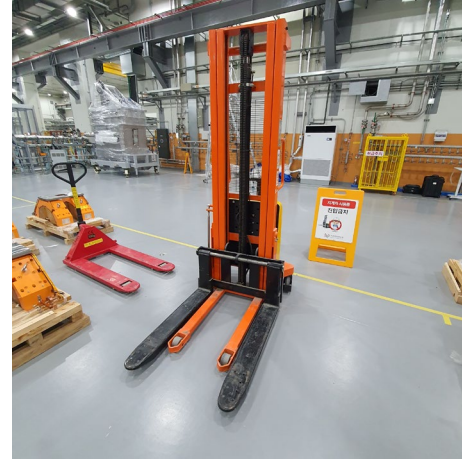
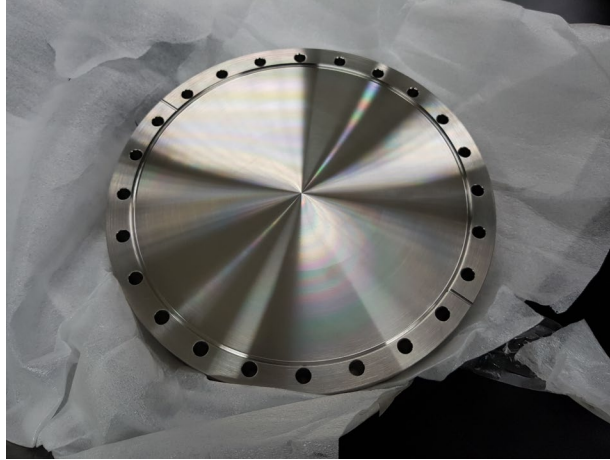
무언가의 특성을 이해 - 육안 관찰 - 형태, 윤곽, 색 인지



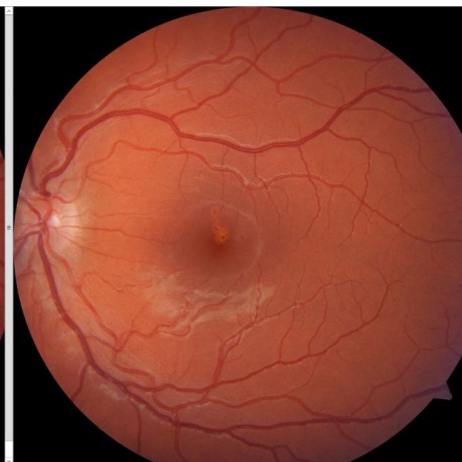
Beam ?



무언가의 특성을 이해 - 육안 관찰 - 형태, 윤곽, 색 인지



Beam의 특성을 이해 - 육안 관찰 - 형태, 윤곽...



Beam ?



터널에는 사람이 머물 수 없다

빔 운전 중에는 **방사선 안전**을 위해 터널 출입이 통제되므로, 사람이 머문 상태로 빔을 켤 수 없다.



빔은 어두운 금속관 속을 지난다

고진공을 유지하기 위한 금속 빔파이프 내부로 빔이 지나가며, 그 안은 빛이 들어오지 않는 어두운 공간이다.



빛이 발생하는 순간은 극히 드물다

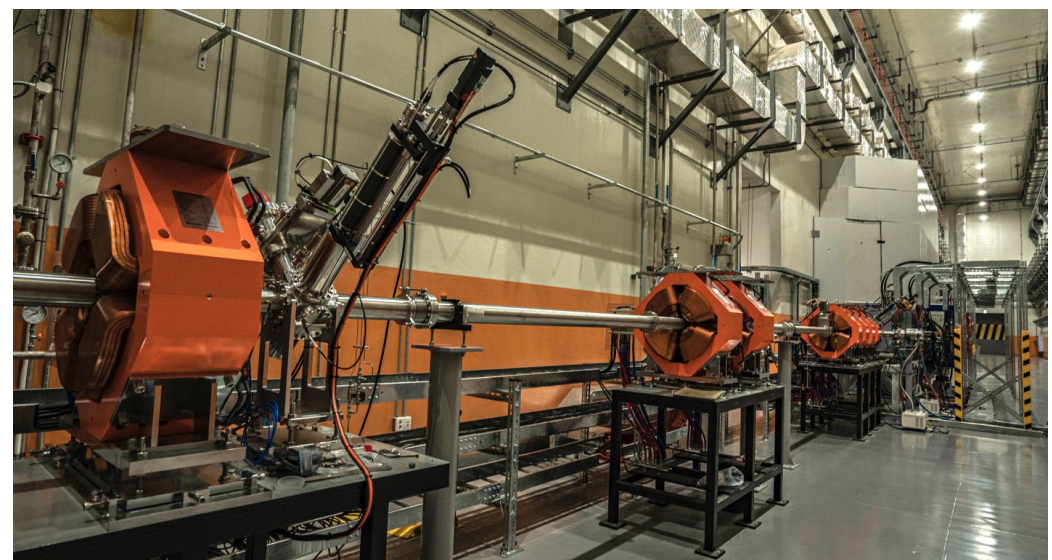
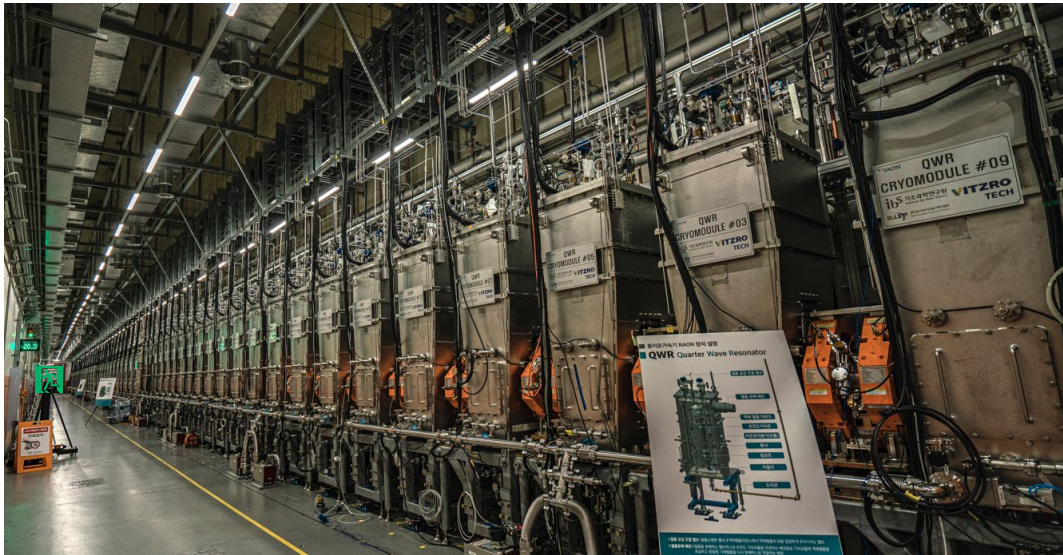
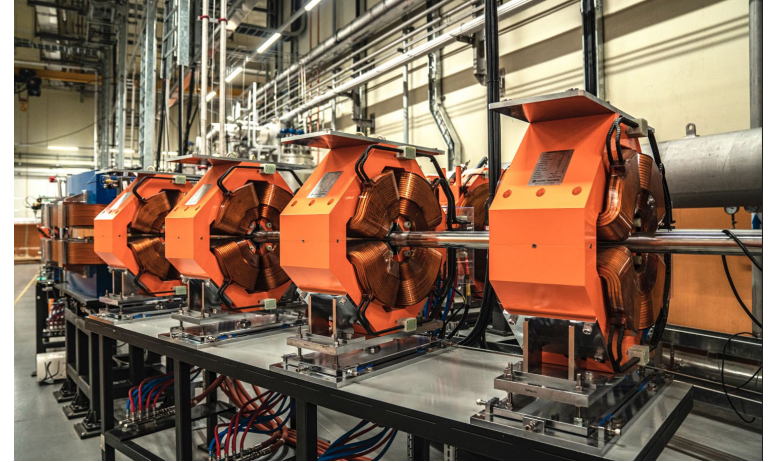
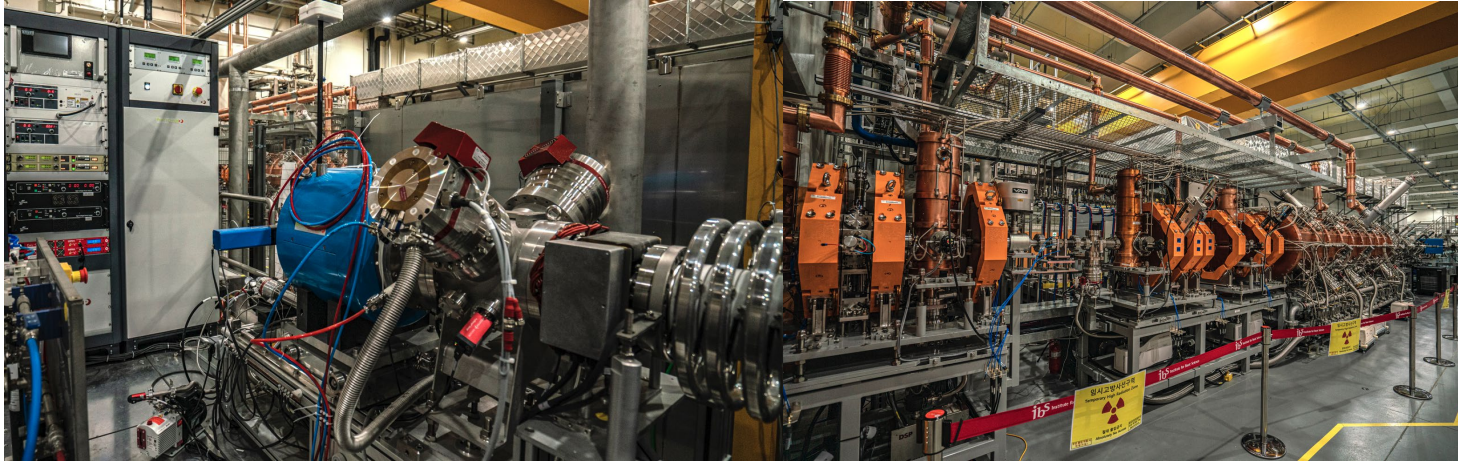
빔이 스스로 빛을 내는 현상은 매우 예외적인 경우에만 일어나므로, 눈으로 '보려' 해도 사실상 불가능하다.



RAON 가속기



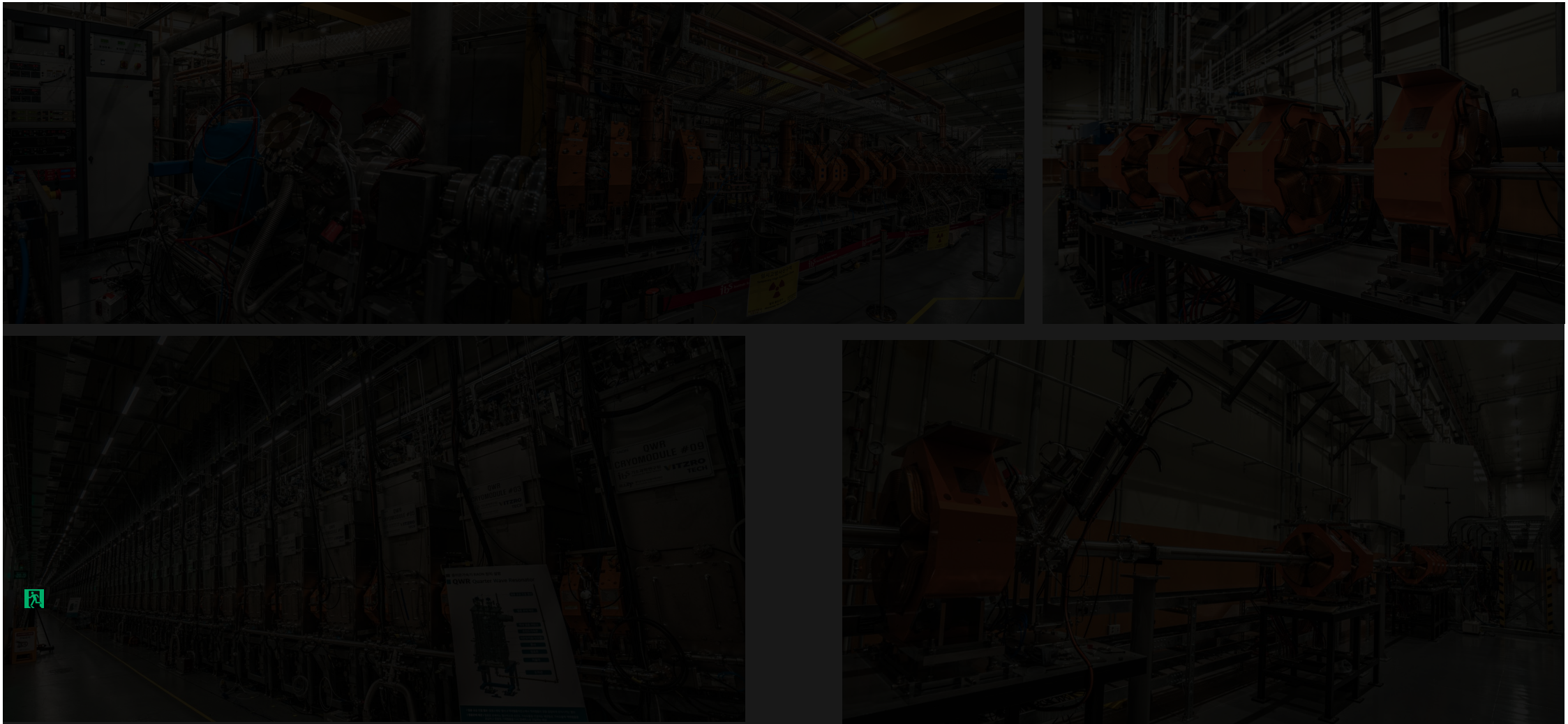
■ 중이온가속기 연구소



RAON 가속기



■ 중이온가속기 연구소



Beam ?



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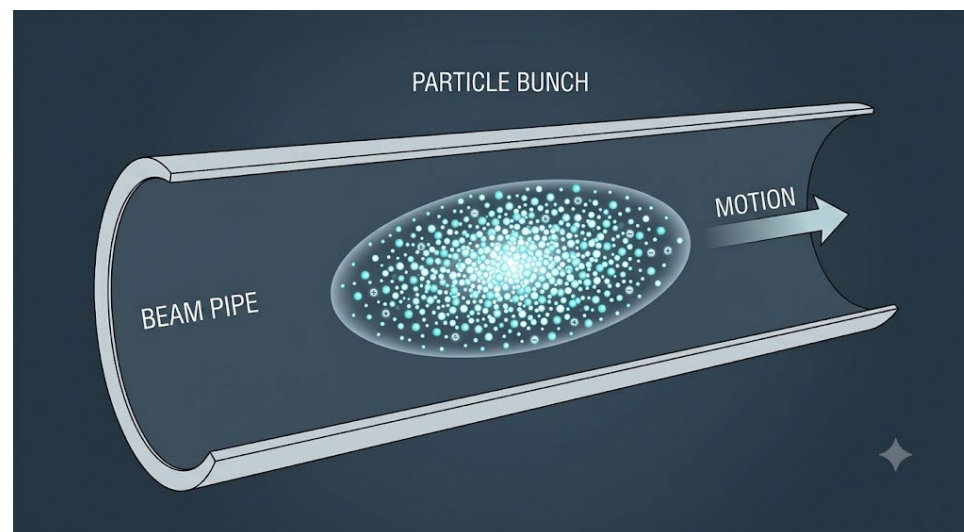
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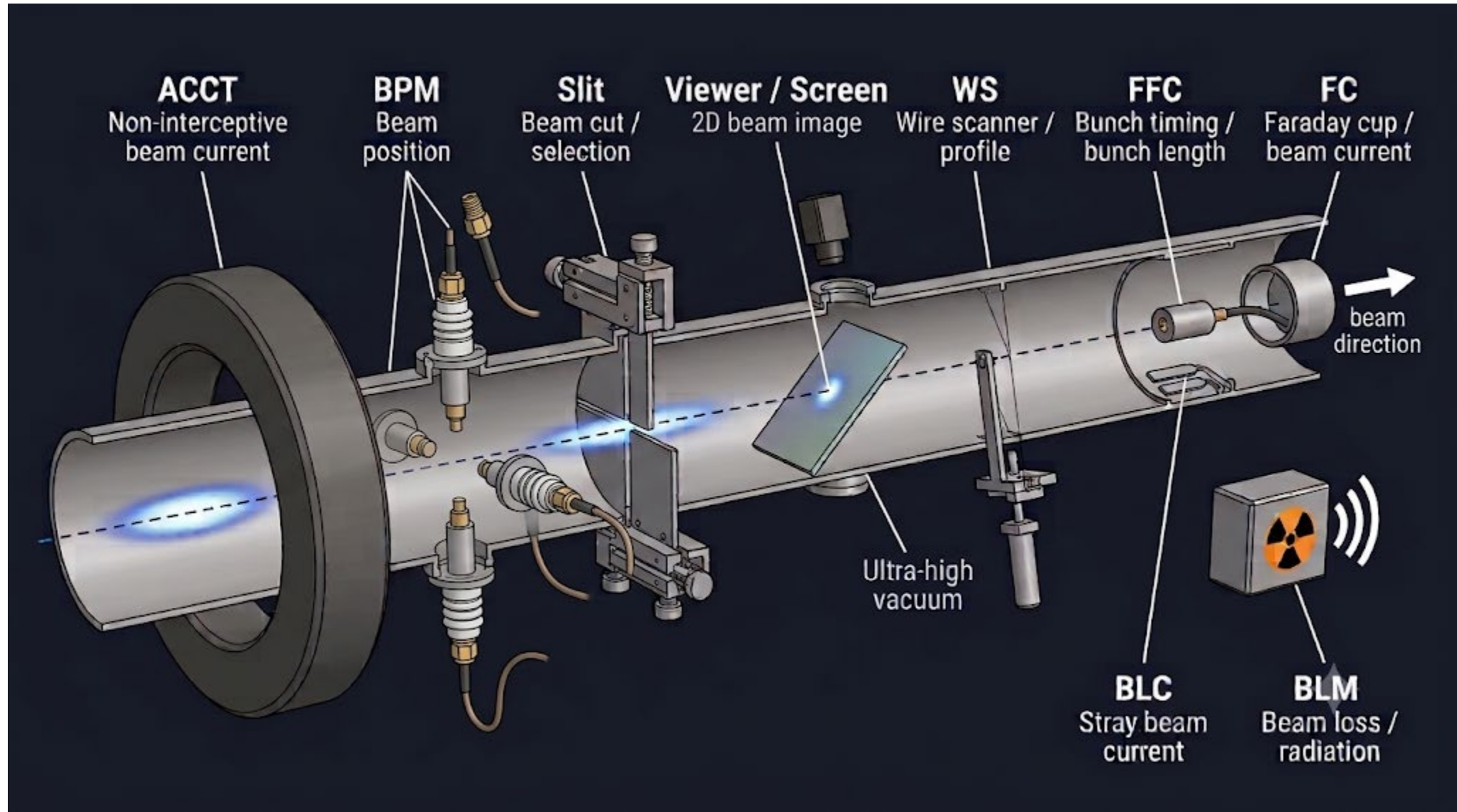


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Beam ?



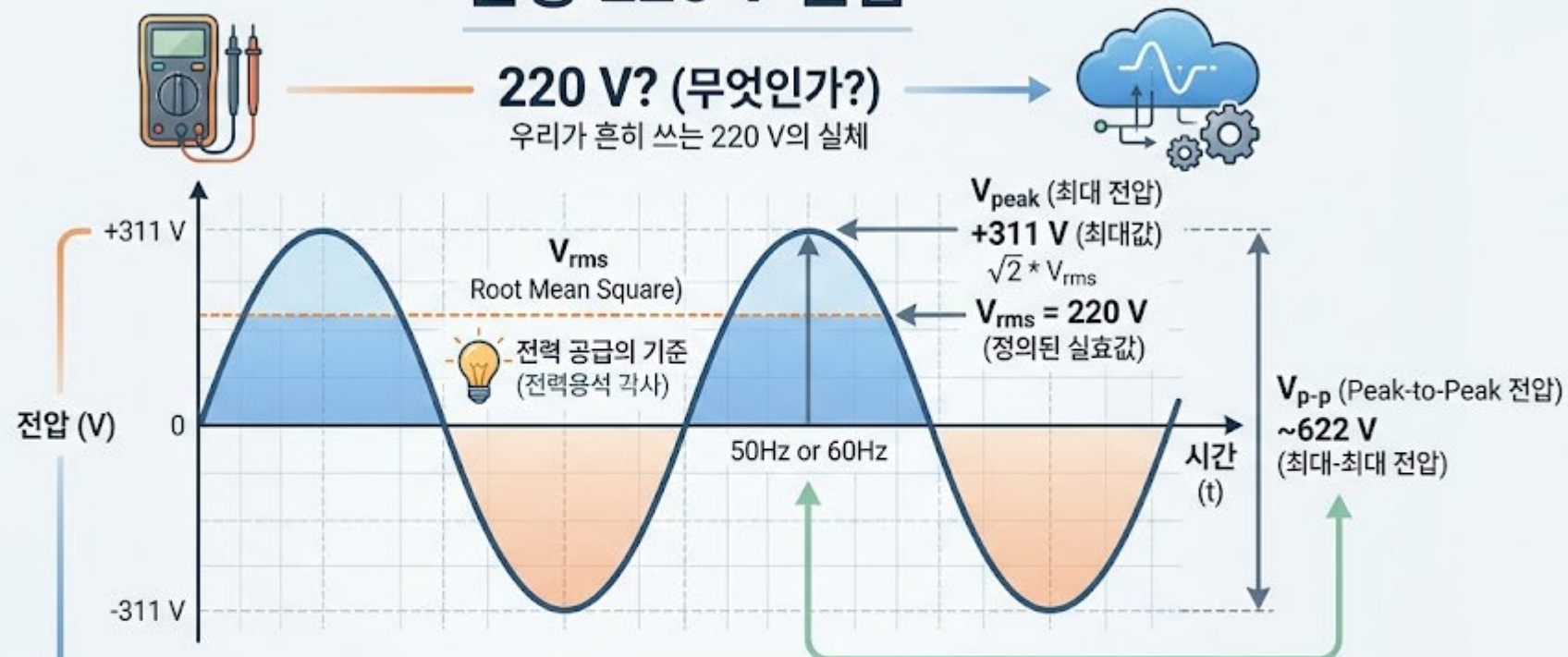
Unit – definition



단상 220 V 전압

220 V? (무엇인가?)

우리가 흔히 쓰는 220 V의 실체



데이터/신호
(Data/Signal)

?

무엇을 기준으로
정의할 것인가?

데이터 전송이나 처리
시 서에는 경인가?

최대값 (Peak)

RMS값 (RMS)

평균값
(Average)

명확한 정의가
필요함!

데이터 전송이나 처리
시에는 RMS, Peak, P-P 등
정확한 정의가 필수적입니다.

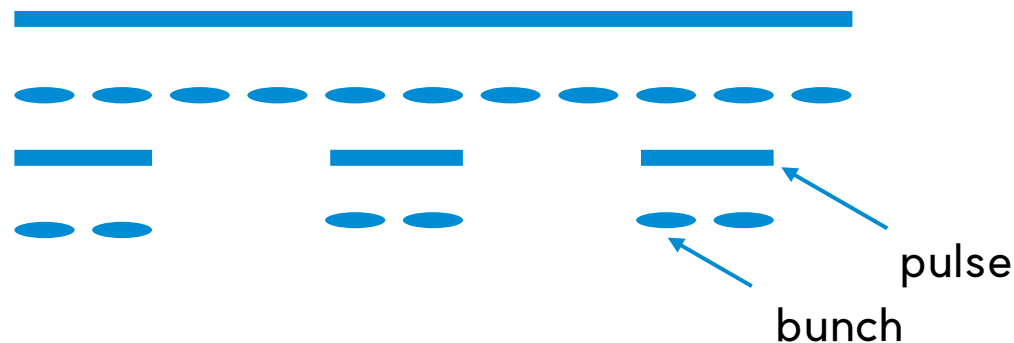
Basic of ACCELERATOR



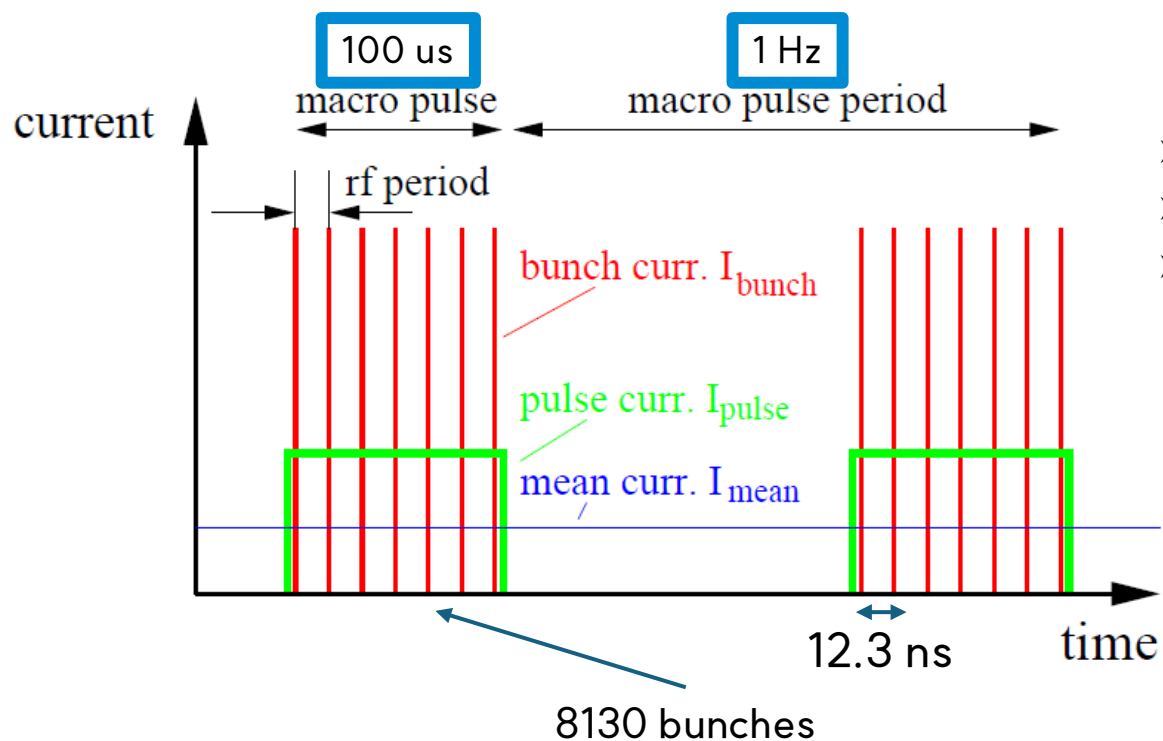
■ Beam structure

structure

- DC beam
- CW beam
- Pulse beam
- ~ Pulse



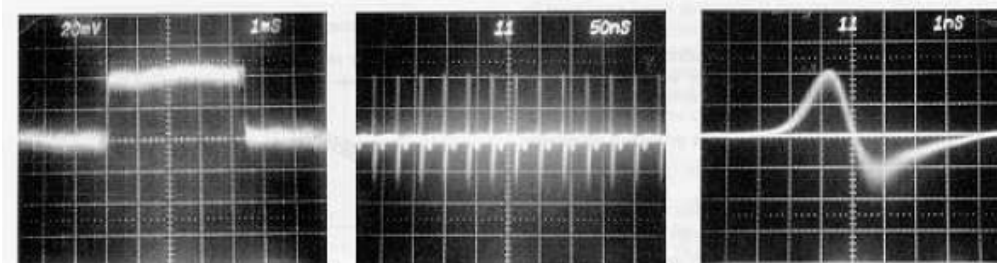
IRIS case @ commissioning beam pulse



$$I = \frac{dQ}{dt}, 1 A = 1 \frac{C}{s}$$

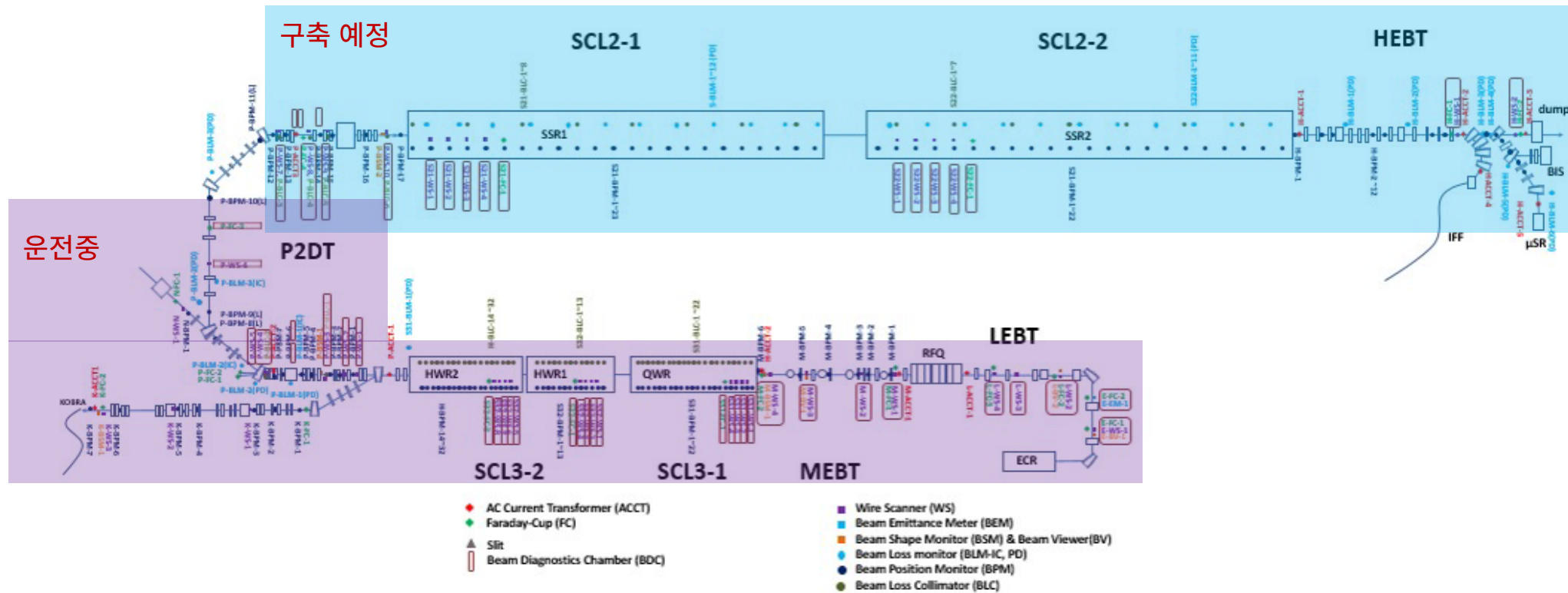
- Mean current I_{mean} [A]
- Pulse current I_{pulse} [A]
- Bunch current I_{bunch} [C/bunch]

- CW : 100 % duty
- IRIS 99.5% duty, CW like beam
- Current = charge / time



Example:
Pulse and bunch
structure at
GSI LINAC:

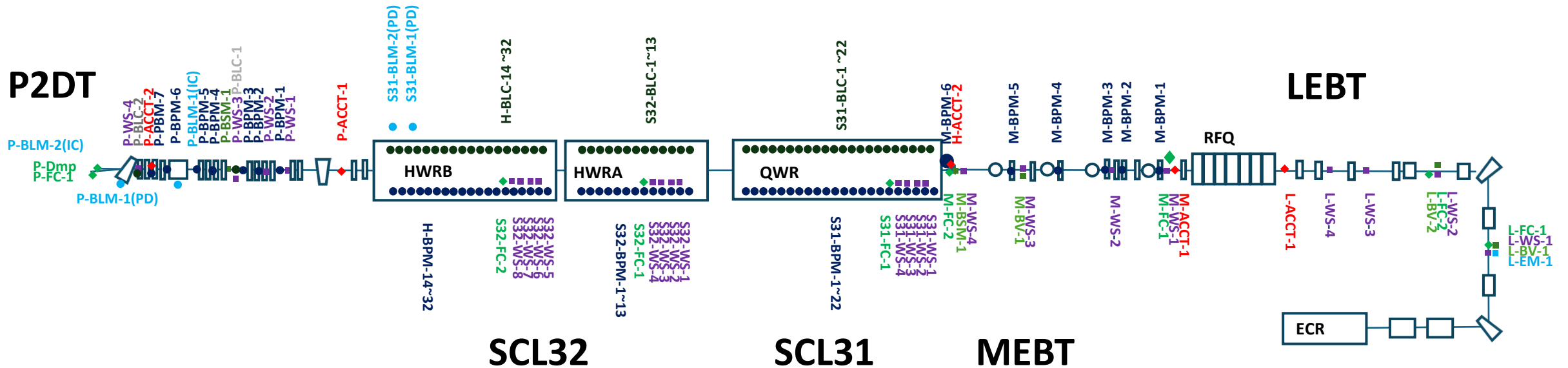
RAON 가속기 빔진단장치



Device	Injector	SCL3	P2DT	KoBRA
Faraday cup	6 ea	3 ea	3 ea	2 ea
ACCT	3 ea	1 ea	2 ea	-
Wire scanner	8 ea	12 ea	10 ea	3 ea
Beam Position Monitor	6 ea	54 ea	17 ea	7 ea

Device	Injector	SCL3	P2DT	KoBRA
Allison scanner	X, Y	-	-	-
Beam viewer	2 ea	-	-	-
Plastic Detector	-	1 ea	2 ea	-
Beam loss collector	-	53 ea	10 ea	3 ea

RAON 가속기 빔진단장치



Installation

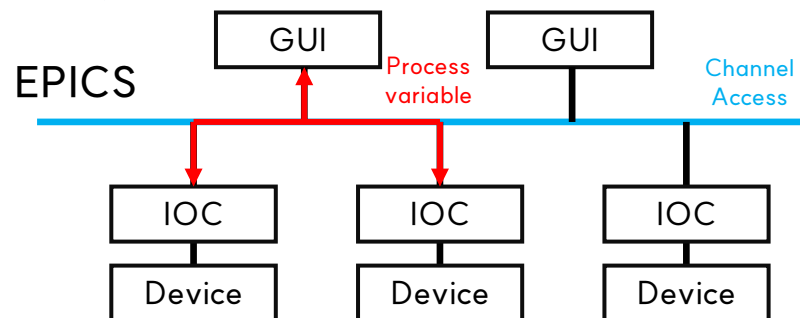
- Wire scanner – 24 sets
- Beam Viewer – 3 sets
- Bergoz ACCT – 5 set
- Faraday Cup – 9 sets
- Beam Attenuator – 2 sets
- 2-D Allison Scanner – 2sets
- Stripline FFC – 2 set
- BPM – 67 sets
- BLM – 4 sets
- BLC – 56 sets

◆ AC Current Transformer (ACCT)
◆ Faraday-Cup (FC)
◆ Plastic Detector (PD)
◆ Secondary Electron-BPM (SEBPM)
◆ Phase Probe Monitor (PPM)
◆ Wire Grid (WG)
◆ Slit
◆ Beam Diagnostics Chamber (BDC)

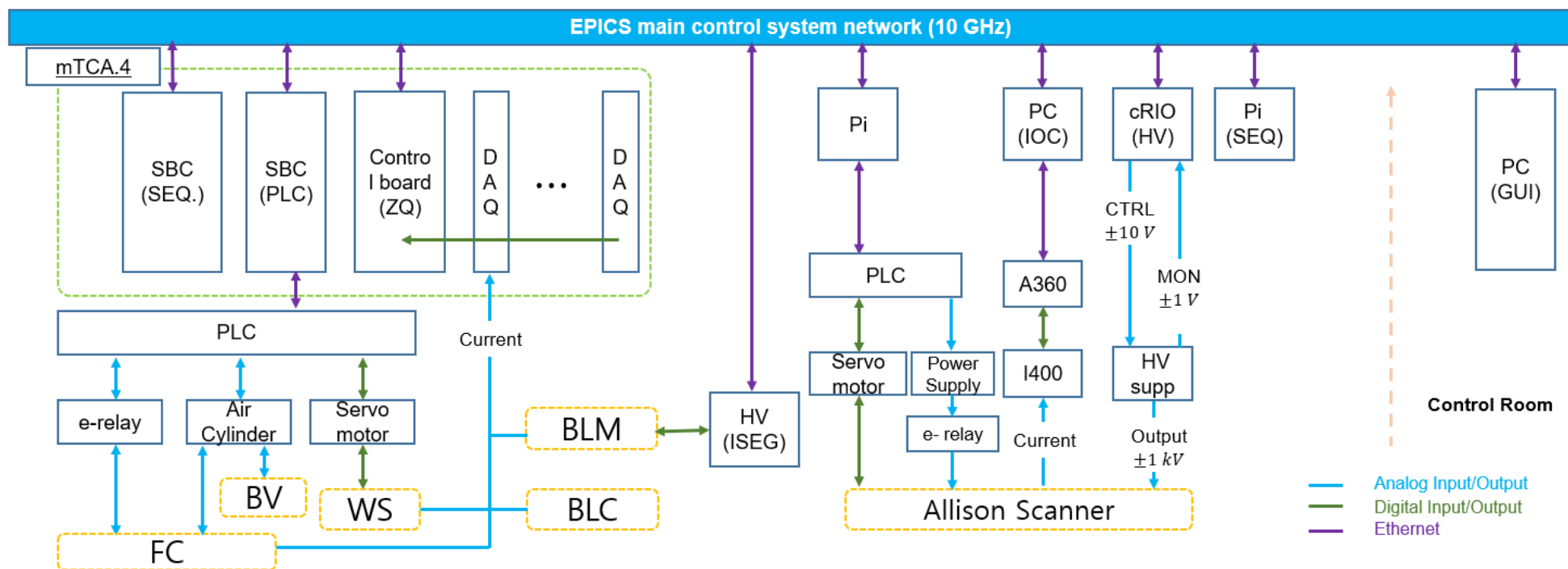
◆ Wire Scanner (WS)
◆ Beam Emittance Meter (BEM)
◆ Beam Shape Monitor (BSM) & Beam Viewer(BV)
◆ Beam Loss monitor (BLM-IC, PD)
◆ Beam Position Monitor (BPM)
◆ Beam Loss Collimator (BLC)

ACCT : 10uA<
 WS : 10uA<, spatial range $\pm 20\text{mm}$
 BPM : 100uA<, resolution <100um
 FC : 0.1uA~1mA, 5%
 BLM : 0.1 W/m~100W/m

- Diagnostics Control System



- Input/Output Controller(IOC) : Data transceiver
- Graphical User Interface(GUI) : Data display
- Channel Access(CA) : Protocol for data distribution(IP/TCP)
- Process Variable(PV) : Data Item

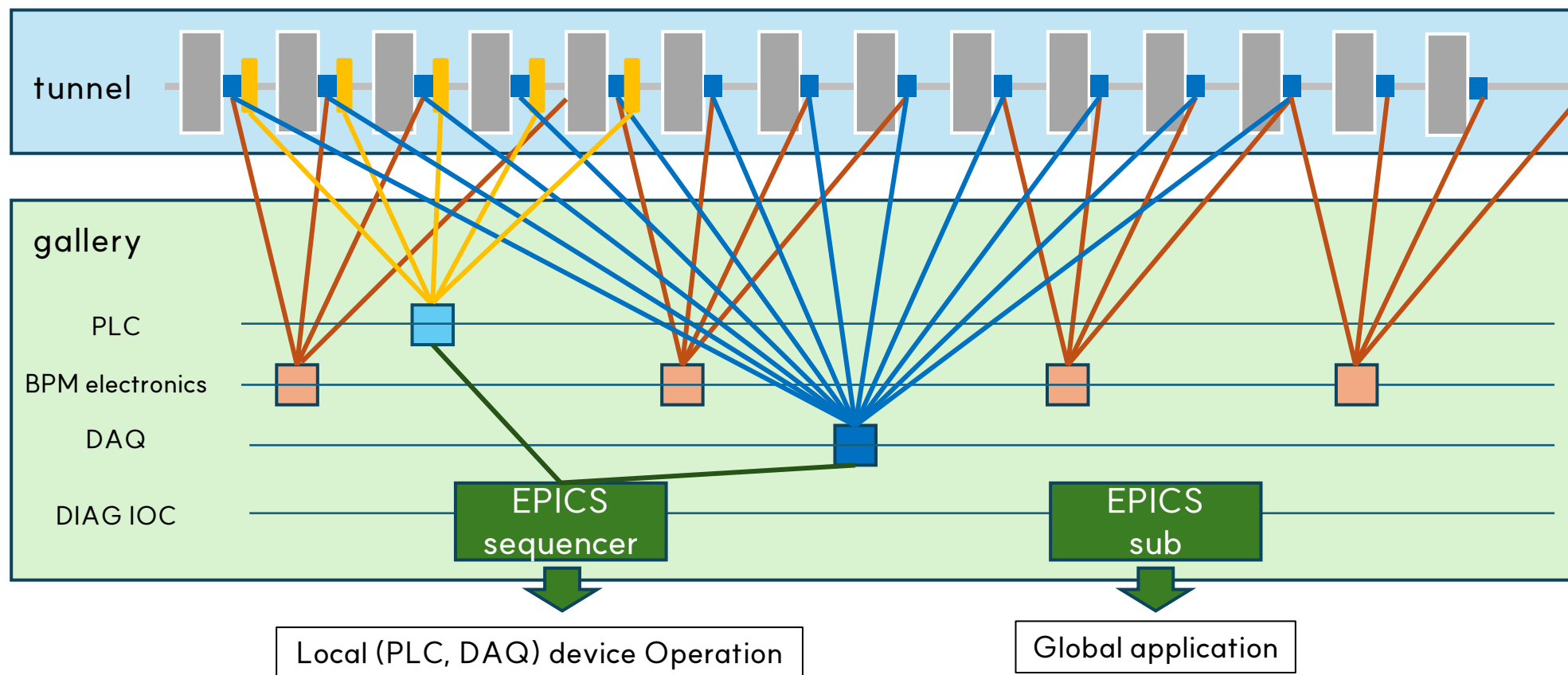


Beam Diagnostics



■ Diagnostics Control System

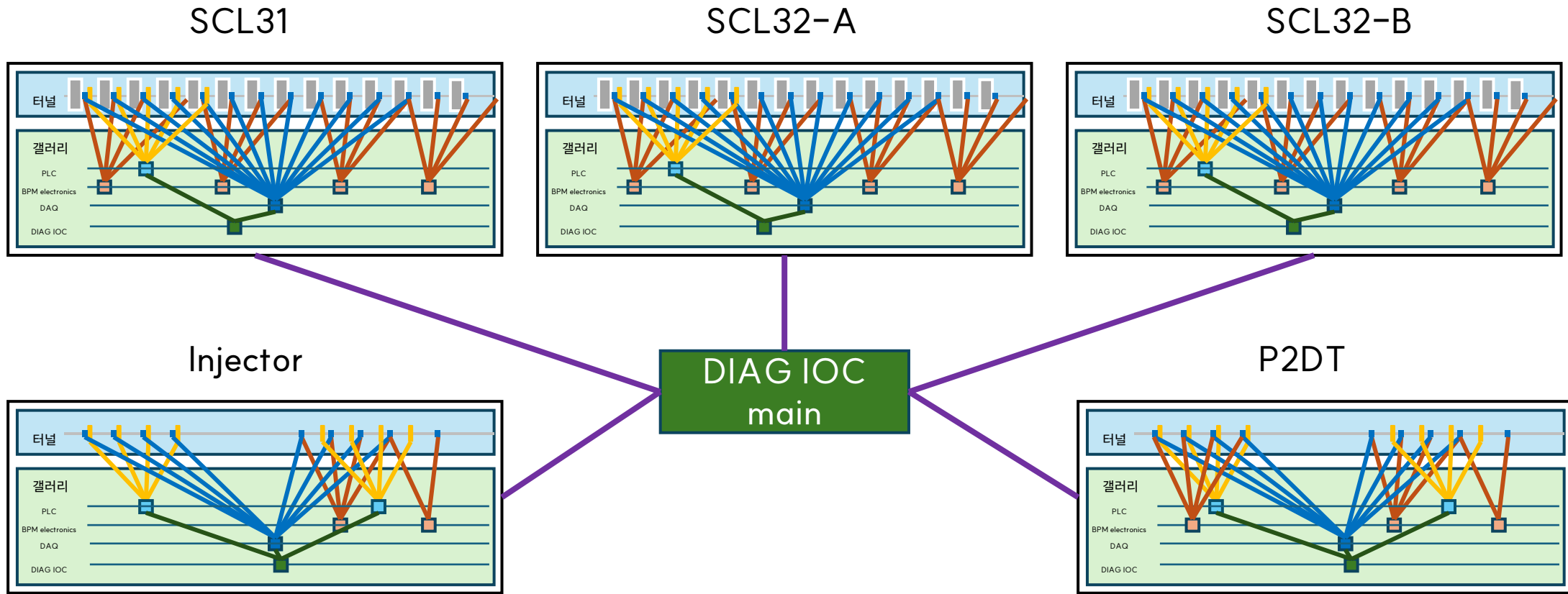
- 빔-계측-개별 electronics
- 빔-구동-계측-분석
- 빔-계측-통합 분석



RAON 가속기 빔진단장치



■ Diagnostics Control System



RAON 가속기 빔진단장치

■ Diagnostics Control system

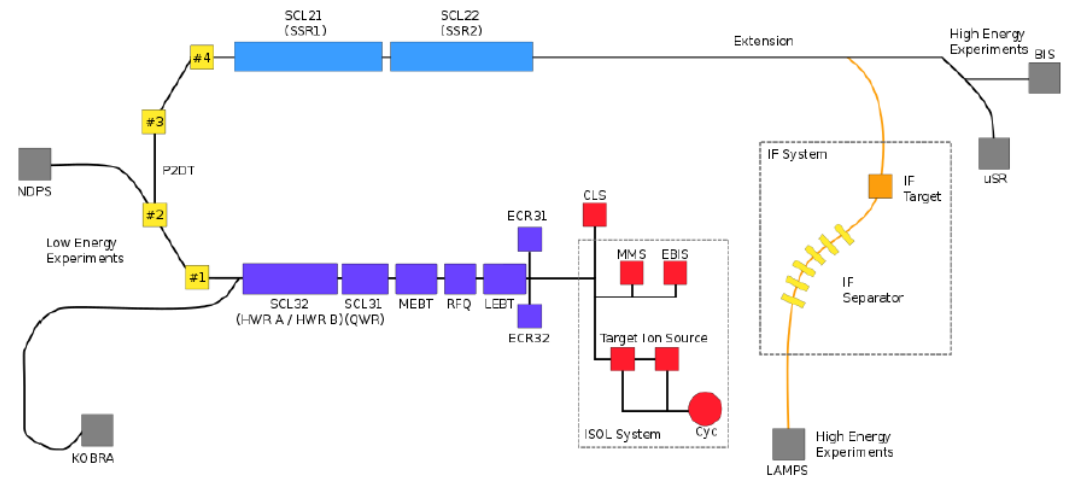
- Channel list (714 ea)

section	RACK	Device	넘버	슬롯	channel	장치	넘버	name
ECR32	LBD-1	CAM	1			BV-CAM	1	ECR32-DIAG:BV001
ECR32	LBD-1	cRIO	1			EM-HV	1	LEBT-DIAG:EM001
ECR32	LBD-1	cRIO	1			EM-HV	1	LEBT-DIAG:EM001
ECR32	LBD-1	I200	1		1	EM-current	1	LEBT-DIAG:EM001
ECR32	LBD-1	I200	1		2	EM-current	1	LEBT-DIAG:EM001
ECR32	LBD-1	PLC	0	DO		FC-actuator	1	ECR32-DIAG:FC001
ECR32	LBD-1	PLC	0	DO		FC-actuator	2	ECR32-DIAG:FC002
ECR32	LBD-1	PLC	0	driver1		BV-motor	1	ECR32-DIAG:BV001
ECR32	LBD-1	PLC	0	driver2		ws-motor	1	ECR32-DIAG:WS001

- Device IP (131 ea)

Section	Rack	Device	IOC	IP	Program
LEBT	LBD-1	PLC		192.168.83.120	
LEBT	LBD-1	F460		192.168.83.121	
LEBT	LBD-1	A360		192.168.83.122	
LEBT	LBD-1	cRIO	EM	192.168.83.123	
LEBT	LBD-1	PC	M-ACCT	192.168.83.124	
LEBT	LBD-1	cRIO	EPICS API test	192.168.83.125	
LEBT	LBD-2	mTCA	MCH	192.168.83.130	
LEBT	LBD-2	HV-crate	LEBT-HV001	192.168.83.195	EPICS3
LEBT	LBD-2	SBC	LEBT-SEQ001	192.168.83.140	EPICS3
LEBT	LBD-2	SBC	LEBT-PLC001	192.168.83.141	EPICS3
LEBT	LBD-2	mTCA	LEBT-ZQ001	192.168.83.150	EPICS3
LEBT	LBD-1	Camera		192.168.83.160	
LEBT	LBD-1	Camera		192.168.83.161	

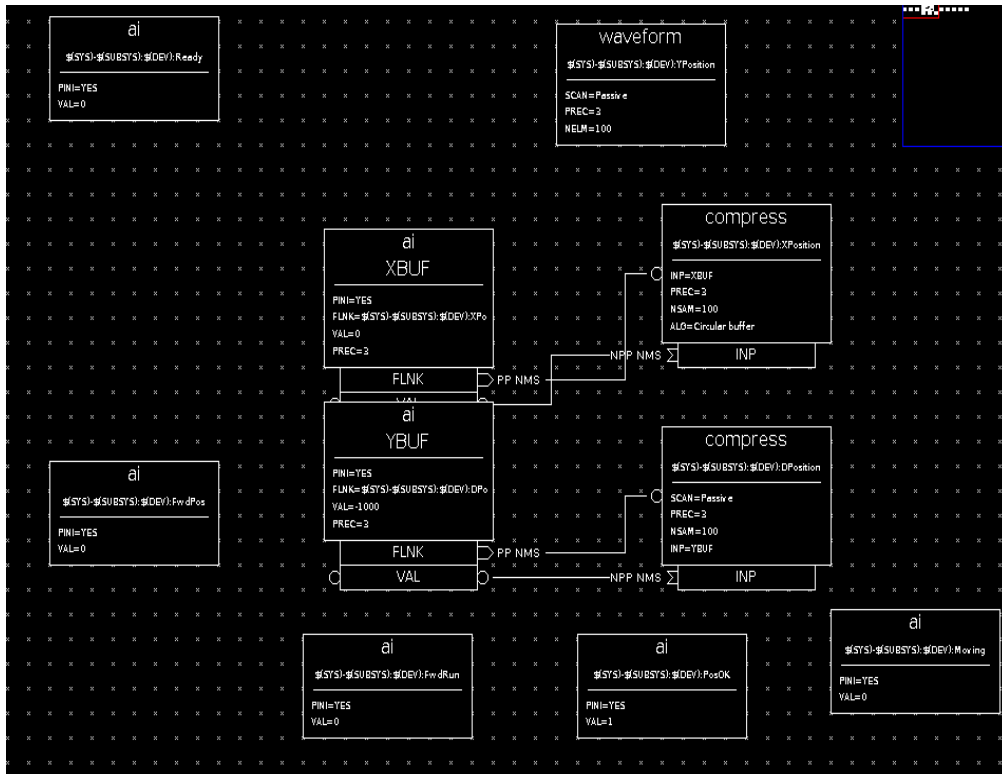
PV Naming convention



SEC/SYS	SUBSYS	:DEV	-SUBDEV	:Signal
ECR32	DIAG	EM	X	Current
LEBT	TFc	CM	AN	Count
MEBT	MPS	Cav	CST	State
SCL31	TS	TUN	Dump	Energy
SCL32	BL	Chop	Fan	Volt
:	:	:	:	:

RAON 가속기 빔진단장치

- Diagnostics Control system
- EPICS Database



Load record instances

```
dbLoadRecords("db/dbAirCylinder.vdb", "SYS=LEBT, SUBSYS=-DIAG:, DEV=BV002, SUBDEV=:")
dbLoadRecords("db/dbAirCylinder.vdb", "SYS=LEBT, SUBSYS=-DIAG:, DEV=AT001, SUBDEV=:")
```

- Autosave

autosave R5.3

Automatically generated – DO NOT MODIFY –
211217-111607

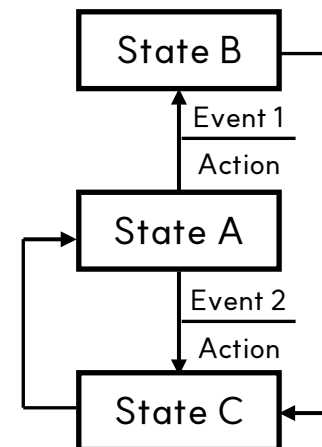
LEBT-DIAG:WS002:XCenter 136.4

LEBT-DIAG:WS002:YCenter 65.4

LEBT-DIAG:WS002:DCenter 100.9

LEBT-DIAG:WS002:Width 20

- Sequencer



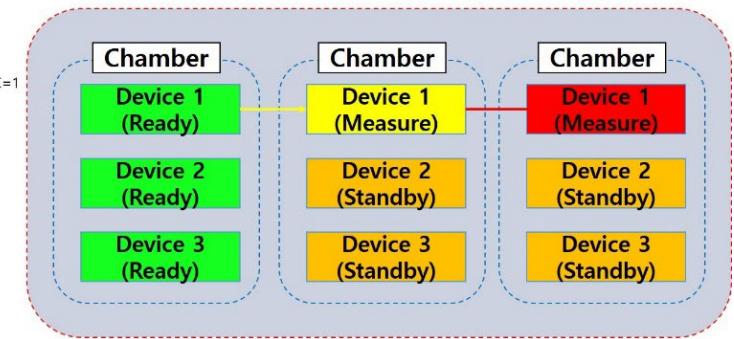
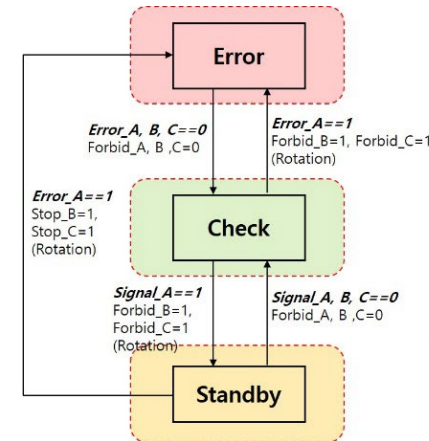
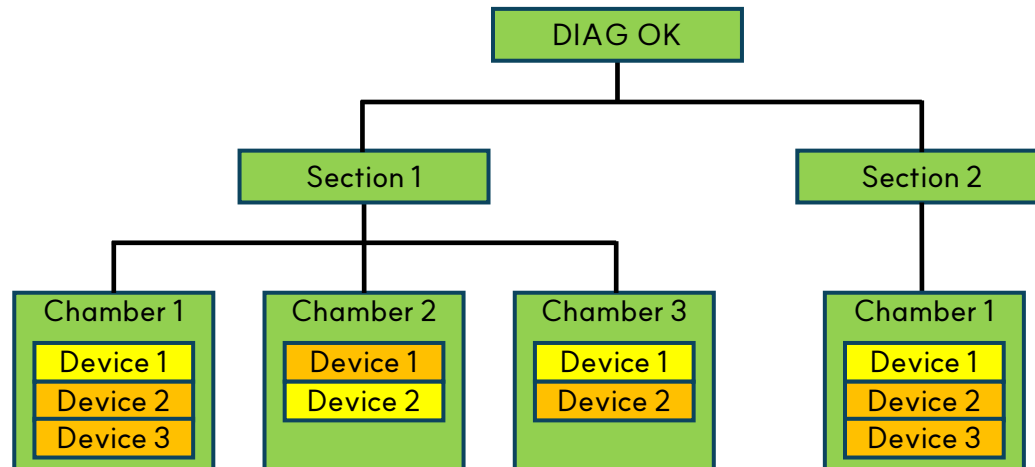
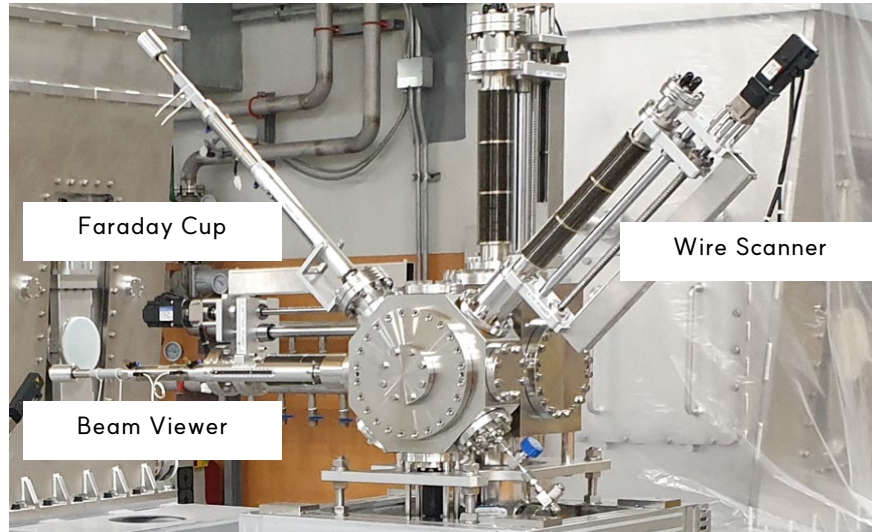
```
int variable1; double variable2;
assign variable1 to "process variable1";
assign variable2 to "process variable2";
monitor variable1;
```

```
ss programName {
state stateA {
when(event1) {
pvGet(variable2);
variable1=value1;
} state stateB
pvPut(variable1);
```

```
when(event2) {
variable1=value2;
} state stateC
pvPut(variable1);
}
```

RAON 가속기 빔진단장치

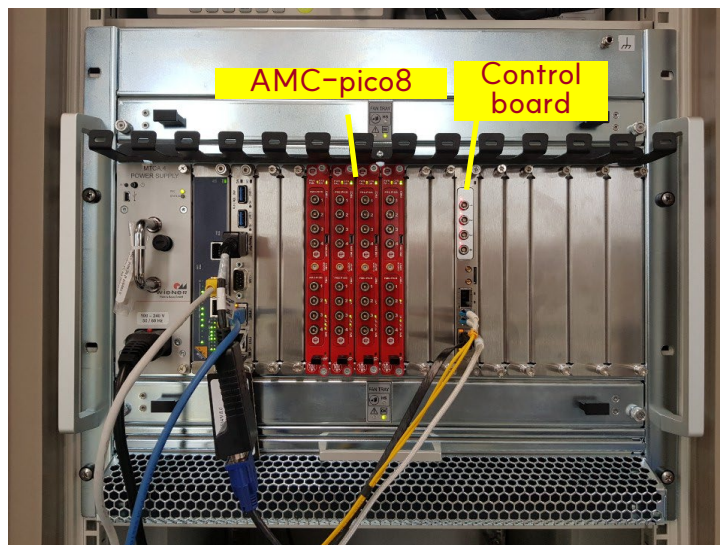
Chamber Interlock



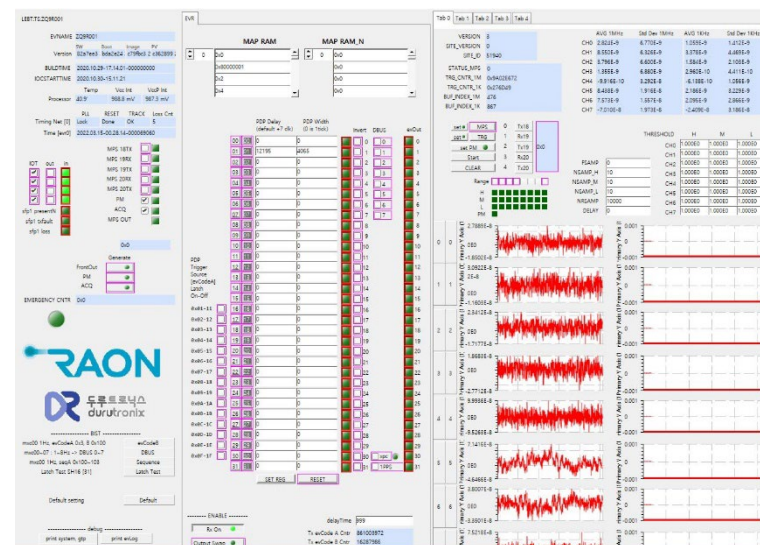
ECR32	WS001	☐ Start	☐ Stop	☐ Reset	☒	EM001-X	☐ Start	☐ Stop	☐ Reset	☒
	BV001	☐ Start	☐ Stop	☐ Reset	☐	EM001-Y	☐ Start	☐ Stop	☐ Reset	☐
	FC001	☐ IN	☐ OUT	☐ Reset	☐	FC002	☐ IN	☐ OUT	☐ Reset	☐
LEBT	WS002	☐ Start	☐ Stop	☐ Reset	☐	WS003	☐ Start	☐ Stop	☐ Reset	☐
	FC002	☐ IN	☐ OUT	☐ Reset	☐	AT001	☐ IN	☐ OUT	☐ Reset	☐
	BV002	☐ IN	☐ OUT	☐ Reset	☐					
MEBT	WS001	☐ Start	☐ Stop	☐ Reset	☐	WS002	☐ Start	☐ Stop	☐ Reset	☐
	FC001	☐ IN	☐ OUT	☐ Reset	☐	CM001	☐ IN	☐ OUT	☐ Reset	☐
SCL31	WS001	☐ Start	☐ Stop	☐ Reset	☐	WS002	☐ Start	☐ Stop	☐ Reset	☐
SCL32A	WS001	☐ Start	☐ Stop	☐ Reset	☐	WS002	☐ Start	☐ Stop	☐ Reset	☐
SCL32B	WS005	☐ Start	☐ Stop	☐ Reset	☐	WS006	☐ Start	☐ Stop	☐ Reset	☐
P2DT	WS001	☐ Start	☐ Stop	☐ Reset	☐	WS002	☐ Start	☐ Stop	☐ Reset	☐
KoBRA	FC001	☐ IN	☐ OUT	☐ Reset	☐	WS001	☐ Start	☐ Stop	☐ Reset	☐

Beam Diagnostics

■ Diagnostics Control system



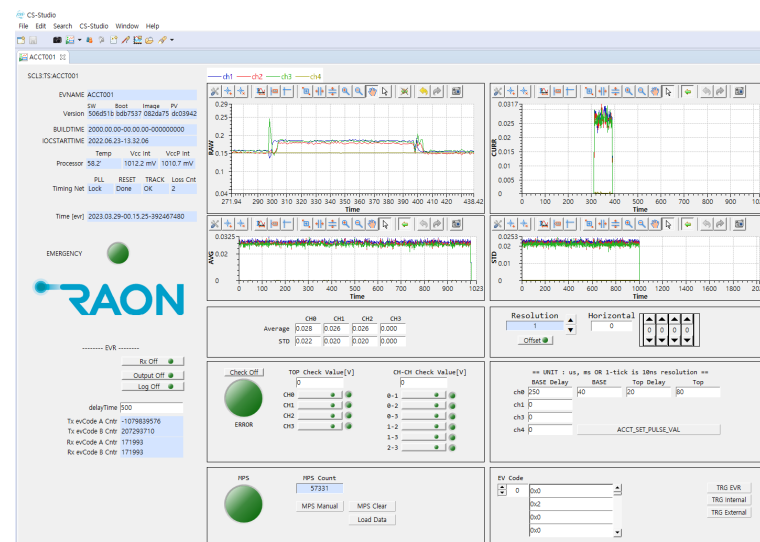
mTCA based DAQ



- Current (WS, FC, BLM, BLC) – μ TCA system
 - CAENels AMC-pico: 42 boards, 8 ch/20 bit/pA range
 - Modification of firmware for trigger with RAON timing system
 - Embedded EVR, PM trigger
 - MPS trigger from each channel



ACCT electronics



- Current (ACCT electronics)
 - 4 ch / 16 bit / 1 mA range
 - Modification of firmware for trigger with RAON timing system
 - Embedded EVR, PM trigger
 - MPS trigger from each channel

RAON 가속기 빔진단장치



■ Diagnostics Control system

Alias at python

```
# File Input
List='진단장치 관리목록(20230318).xlsx'
PV='ZQAlias.xlsx'

# option
DataSelection=13 # [1]LEBT [2]SCL31 [3][4]SCL32 [5][6]P2DT [7]SCL21 [8]SCL22
[9][10]HEBT [11]KoBRA [12][13]NDPS

Database=pd.read_excel(List, sheet_name='Device') # Data Load
Database.fillna(0, inplace=True) # Replace NaN with 0

BDDData=pd.read_excel(PV, sheet_name='Board') # Data Load
ZQData=pd.read_excel(PV, sheet_name='ZQ') # Data Load
DVDData=pd.read_excel(PV, sheet_name='Device') # Data Load

Board='001' #ZQ Number Setting
if (DataSelection==4 or DataSelection==6 or DataSelection==13) :
    Board='002'

Data=Database[(Database.넘버==DataSelection) & (Database.장비=='mTCA')] # Data input
```

Local PV

Device PV

PV Archiving (~ 20,000 PVs)

```
# File Input
List='진단장치 관리목록(20230807).xlsx'
Device='Device(20231006).xlsx'

# Data Load
SECDATA=pd.read_excel(List, sheet_name='Section')
IPDATA=pd.read_excel(List, sheet_name='IP')

# Data Set
Date=time.strftime('%Y%m%d', time.localtime(time.time()))
```

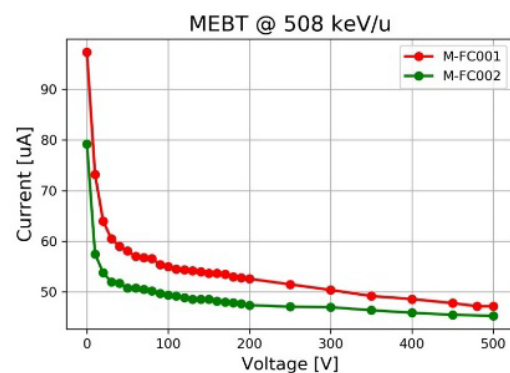
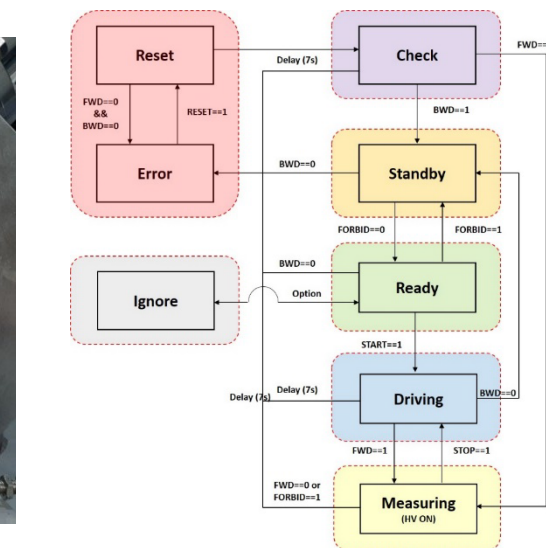
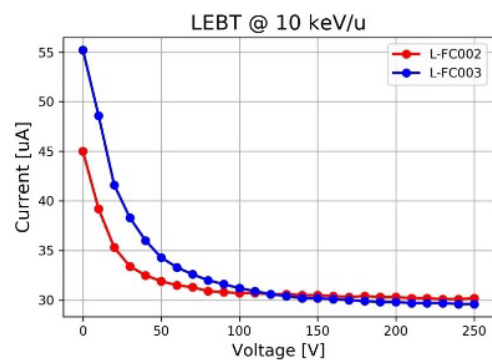


Section	Process Variable	Analog/Digital	Record Type	Description	Unit	Setting(Off/On)	Archiving(Off/On)	Archiving Mode	IP	IOC Device	IOC Rack	Autosave
LEBT	LEBT-DIAG:AT001:Start	Analog	Analog Input	BV 측정 시작	0(Off), 1(On)	X	O	Event	192.168.83.140	LEBT-SEQ001	LBD-2	X
LEBT	LEBT-DIAG:AT001:Stop	Analog	Analog Input	BV 측정 정지	0(Off), 1(On)	X	O	Event	192.168.83.140	LEBT-SEQ001	LBD-2	X
LEBT	LEBT-DIAG:AT001:Forbid	Analog	Analog Input	Interlock 여부		X	O	Event	192.168.83.140	LEBT-SEQ001	LBD-2	X
LEBT	LEBT-DIAG:AT001:State	Analog	Analog Input	BV 상태	0 ~ 5	X	O	Event	192.168.83.140	LEBT-SEQ001	LBD-2	X
LEBT	LEBT-DIAG:AT001:Signal	Analog	Analog Input	Interlock 신호		X	O	Event	192.168.83.140	LEBT-SEQ001	LBD-2	X
LEBT	LEBT-DIAG:AT001:FwdStatus	Digital	Digital Input	전진 구동 상태 확인		X	O	Event	192.168.83.141	LEBT-PLC001	LBD-2	X
LEBT	LEBT-DIAG:AT001:BwdStatus	Digital	Digital Input	후진 구동 상태 확인		X	O	Event	192.168.83.141	LEBT-PLC001	LBD-2	X
LEBT	LEBT-DIAG:AT001:FwdOn	Digital	Digital Input	전진 상태 확인		X	O	Event	192.168.83.141	LEBT-PLC001	LBD-2	X
LEBT	LEBT-DIAG:AT001:BwdOn	Digital	Digital Input	후진 상태 확인		X	O	Event	192.168.83.141	LEBT-PLC001	LBD-2	X
LEBT	LEBT-DIAG:AT001:FwdSW	Digital	Digital Output	전진 스위치		X	O	Event	192.168.83.141	LEBT-PLC001	LBD-2	X
LEBT	LEBT-DIAG:AT001:BwdSW	Digital	Digital Output	후진 스위치		X	O	Event	192.168.83.141	LEBT-PLC001	LBD-2	X
LEBT	LEBT-DIAG:AT002:Start	Analog	Analog Input	BV 측정 시작	0(Off), 1(On)	X	O	Event	192.168.83.140	LEBT-SEQ001	LBD-2	X
LEBT	LEBT-DIAG:AT002:Stop	Analog	Analog Input	BV 측정 정지	0(Off), 1(On)	X	O	Event	192.168.83.140	LEBT-SEQ001	LBD-2	X
LEBT	LEBT-DIAG:AT002:Forbid	Analog	Analog Input	Interlock 여부		X	O	Event	192.168.83.140	LEBT-SEQ001	LBD-2	X
LEBT	LEBT-DIAG:AT002:State	Analog	Analog Input	BV 상태	0 ~ 5	X	O	Event	192.168.83.140	LEBT-SEQ001	LBD-2	X
LEBT	LEBT-DIAG:AT002:Signal	Analog	Analog Input	Interlock 신호		X	O	Event	192.168.83.140	LEBT-SEQ001	LBD-2	X
LEBT	LEBT-DIAG:AT002:FwdStatus	Digital	Digital Input	전진 구동 상태 확인		X	O	Event	192.168.83.141	LEBT-PLC001	LBD-2	X
LEBT	LEBT-DIAG:AT002:BwdStatus	Digital	Digital Input	후진 구동 상태 확인		X	O	Event	192.168.83.141	LEBT-PLC001	LBD-2	X

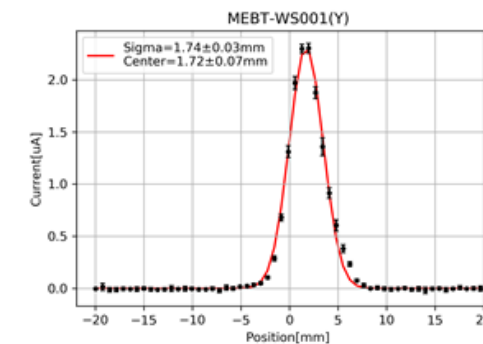
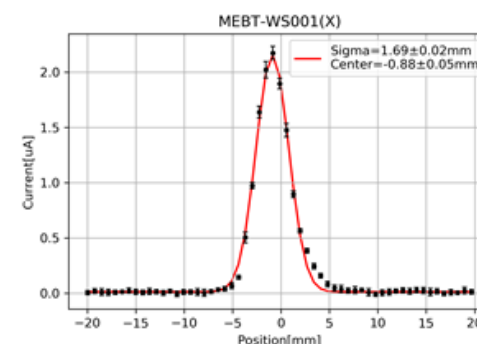
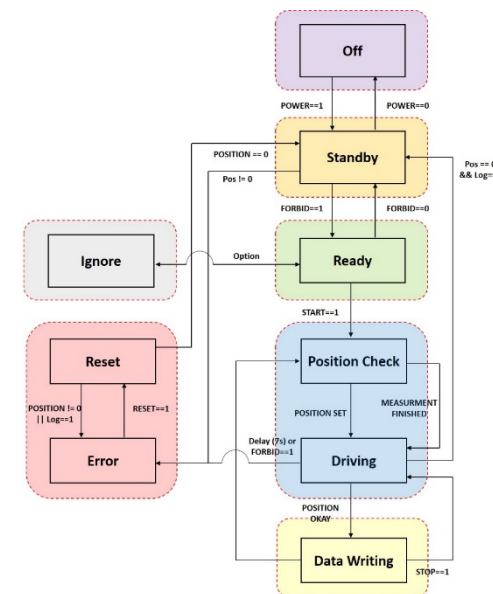
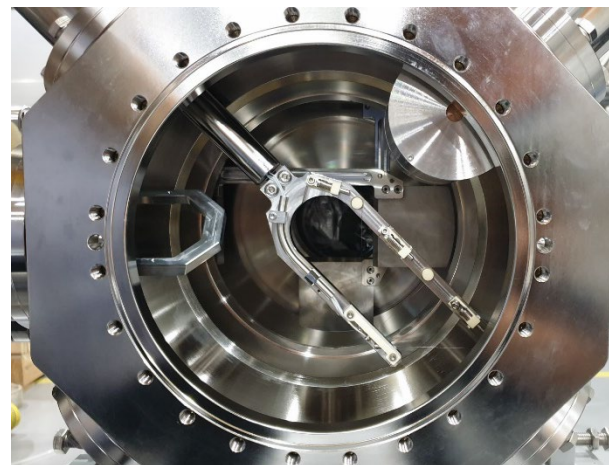
Beam Diagnostics

■ Integrated control

Faraday Cup

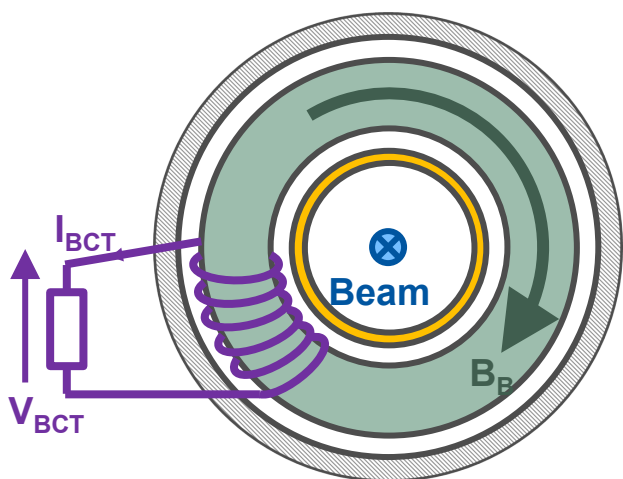
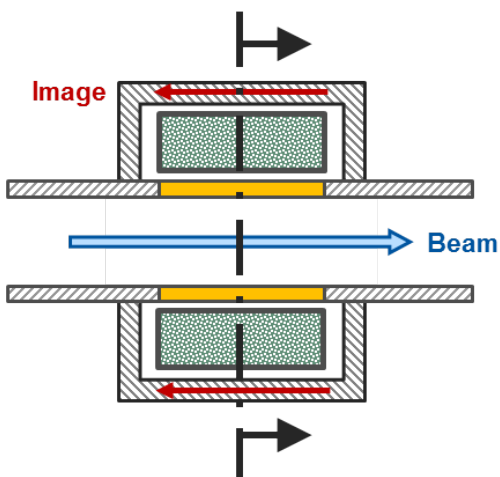


Wire scanner



Beam Instruments

AC Current Transformer



Time domain description:

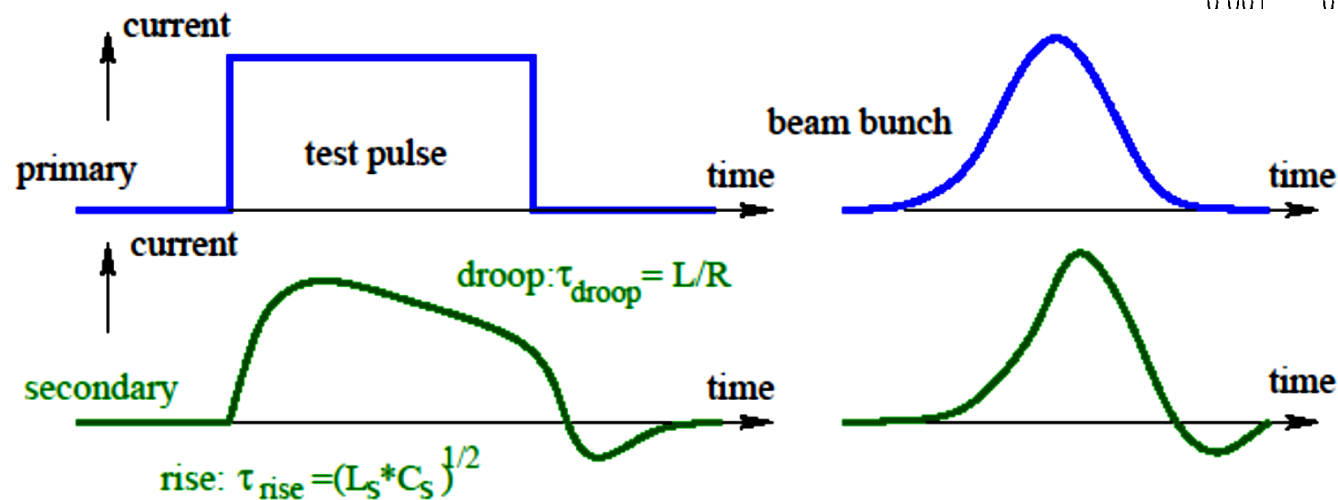
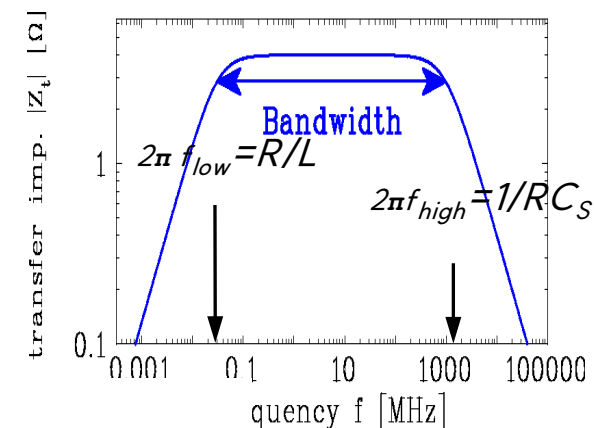
Droop time: $\tau_{droop} = 1/(2\pi f_{low}) = L/R$

Rise time: $\tau_{rise} = 1/(2\pi f_{high}) = 1/RC_S$ (ideal without cables)

Rise time: $\tau_{rise} = 1/(2\pi f_{high}) = \sqrt{L_S C_S}$ (with cables)

For the working region the voltage output is

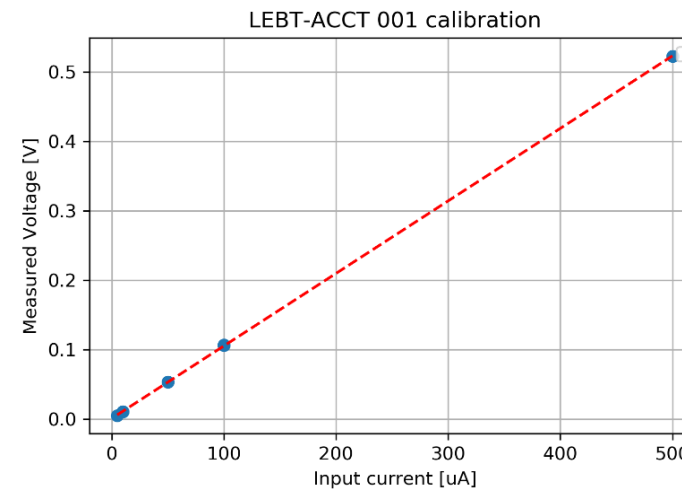
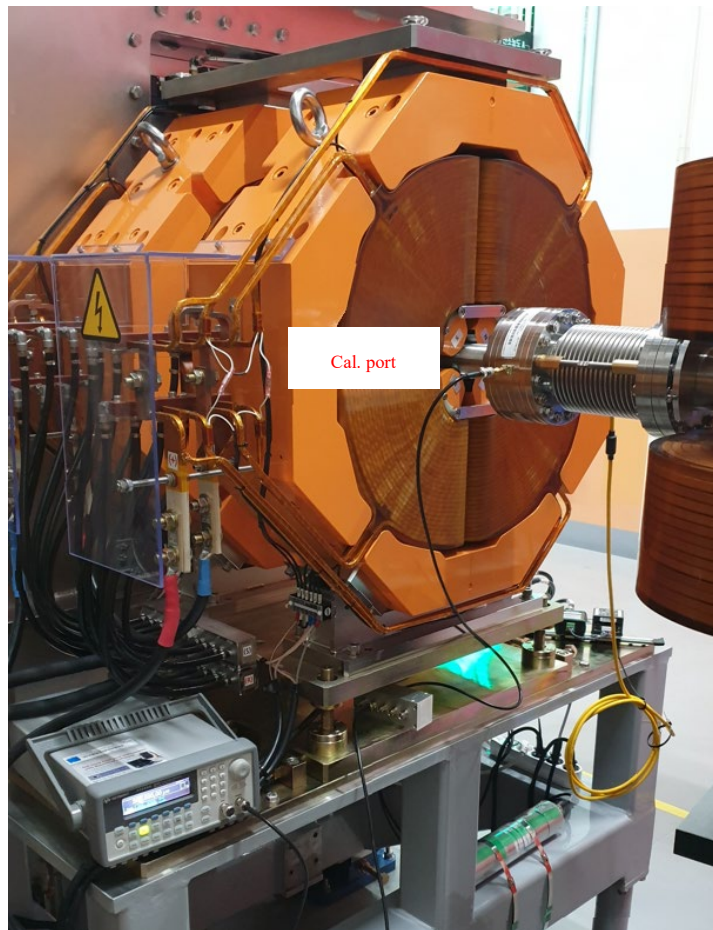
$$U(t) = \frac{R}{N} \cdot e^{-t/\tau_{droop}} \cdot I_{beam}$$



Beam Instruments



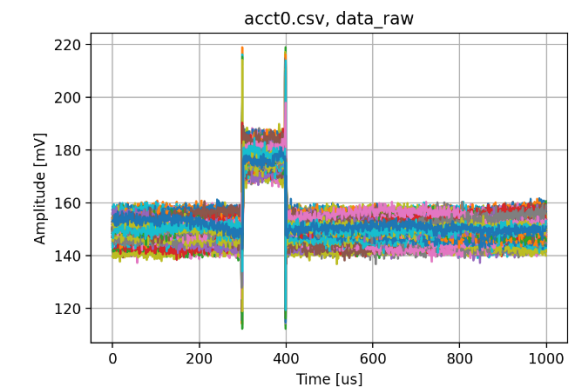
■ AC Current Transformer



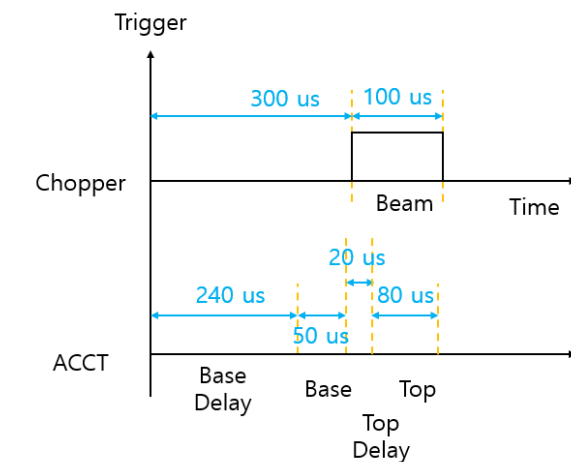
$$I_{cal} = V_{mea} * A + B$$

Device	Factor A	Factor B
L-ACCT001	9.5797e-4	-9.3431e-7
M-ACCT001	9.5732e-4	8.7103e-7
M-ACCT002	9.5732e-4	8.7103e-7
P-ACCT001	9.3548e-4	1.5883e-8

Trigger mode beam

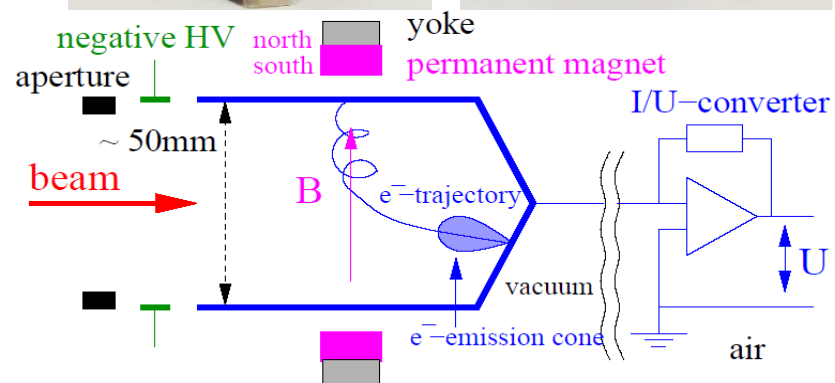
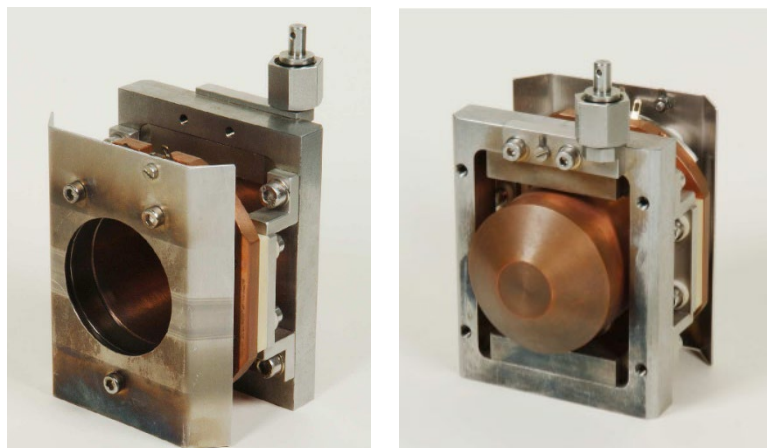


Timing structure



Beam Instruments

Faraday Cup

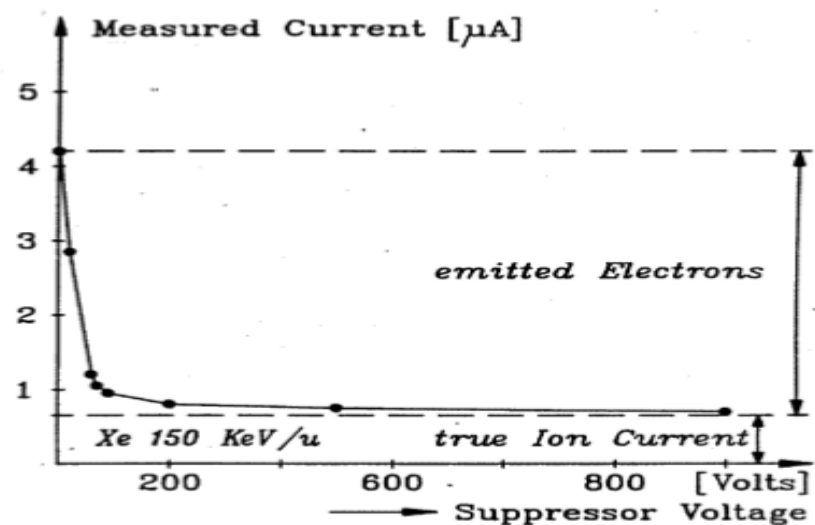
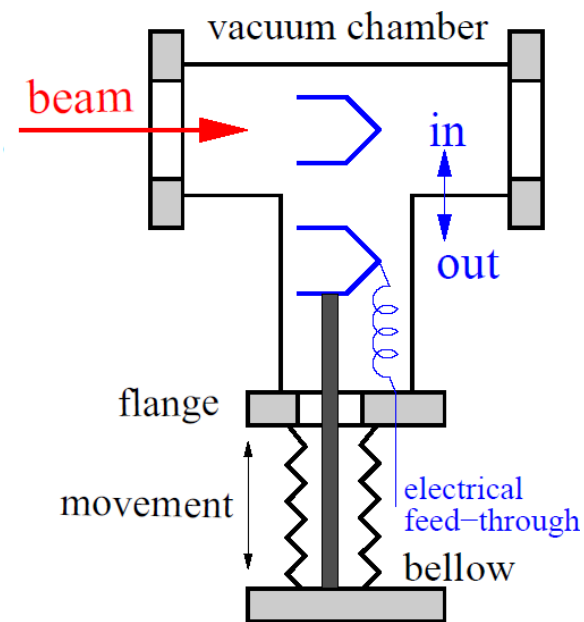


Magnetic field:

To prevent for secondary electrons leaving the cup

Electric field:

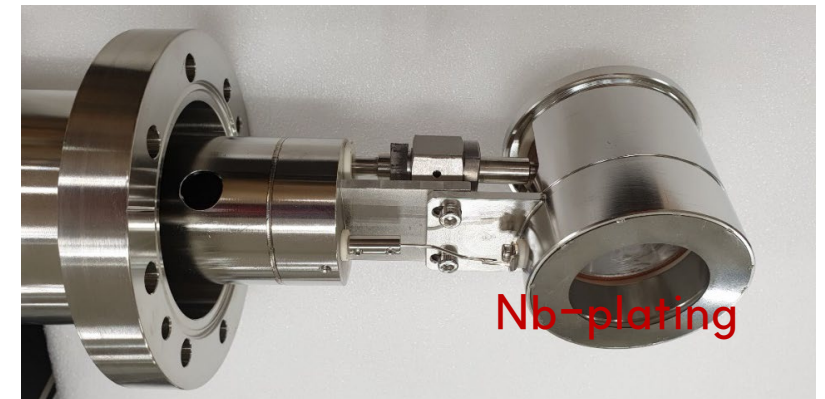
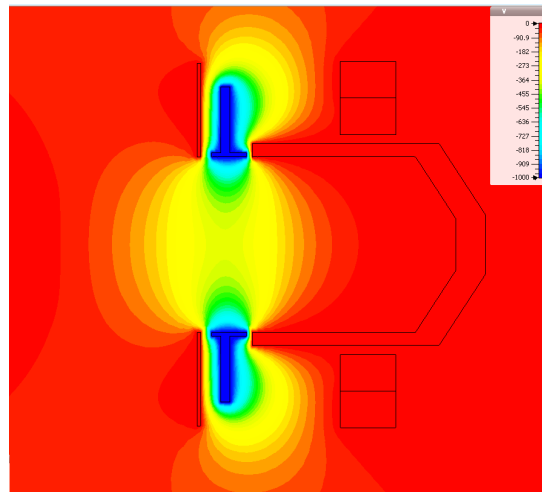
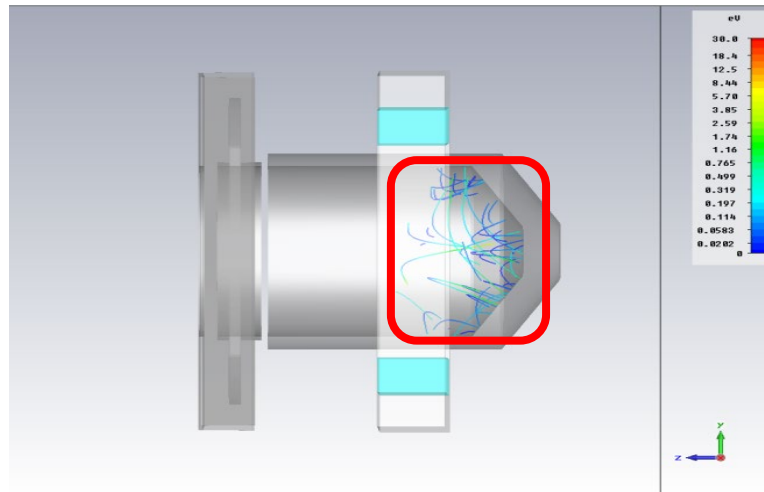
Potential barrier at the cup entrance.



Beam Instruments



■ Faraday Cup



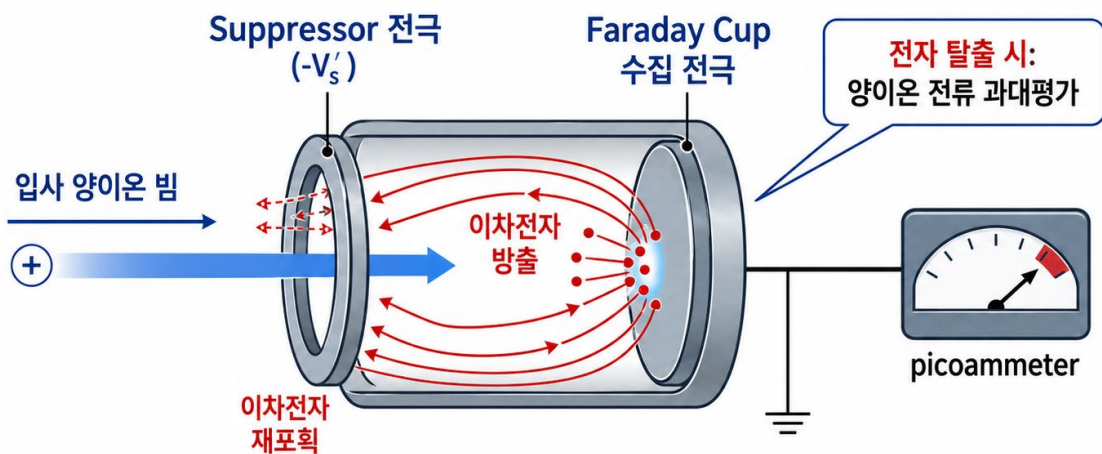
- Compare transformer and faraday cup

	Transformer	Faraday cup
Measurement	Magnetic field	Electrical Charges
Method	Non-destructive	destructive
Current limit	About $1\text{ }\mu\text{A}$ (for most cases)	About 10 pA

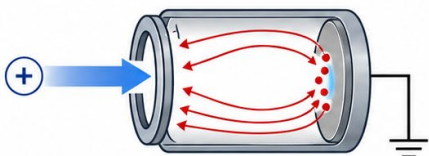
Beam Instruments

Faraday Cup (secondary electron)

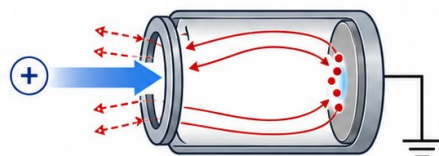
Faraday Cup 전류 측정 원리



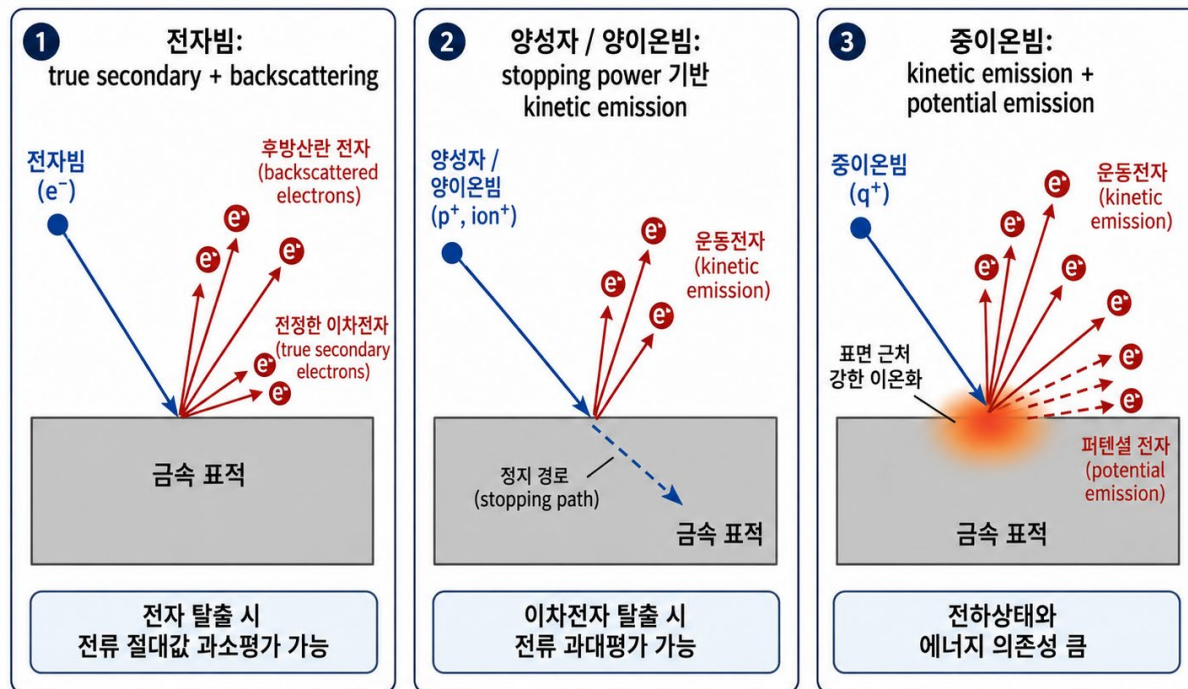
Case A 전자 재포획 → 정확한 전류



Case B 전자 탈출 → 측정 전류 증가



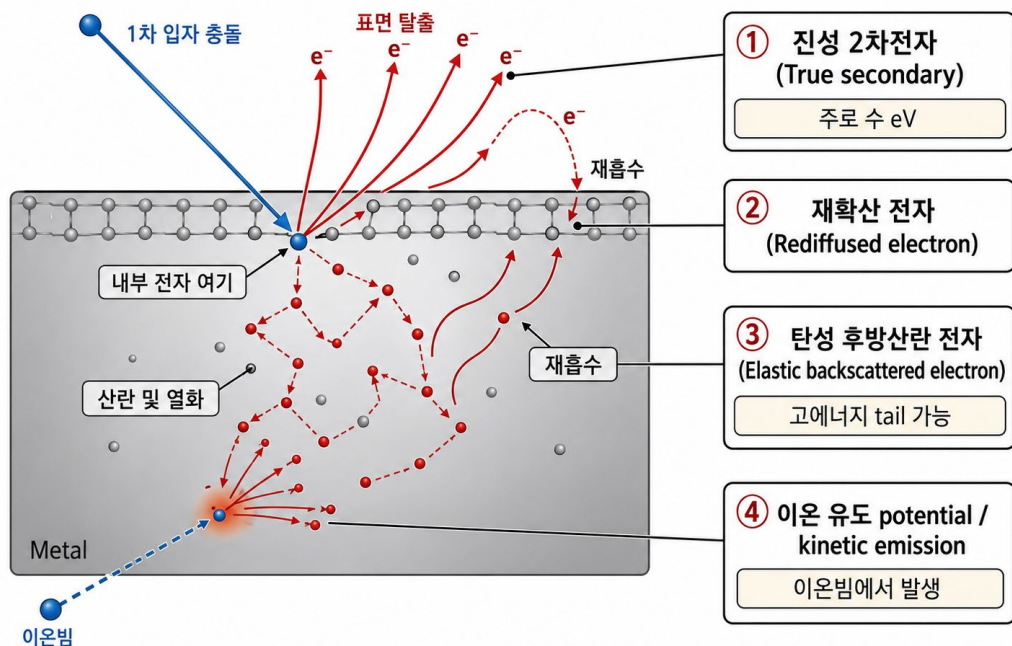
입자 종류별 이차전자 발생 특성



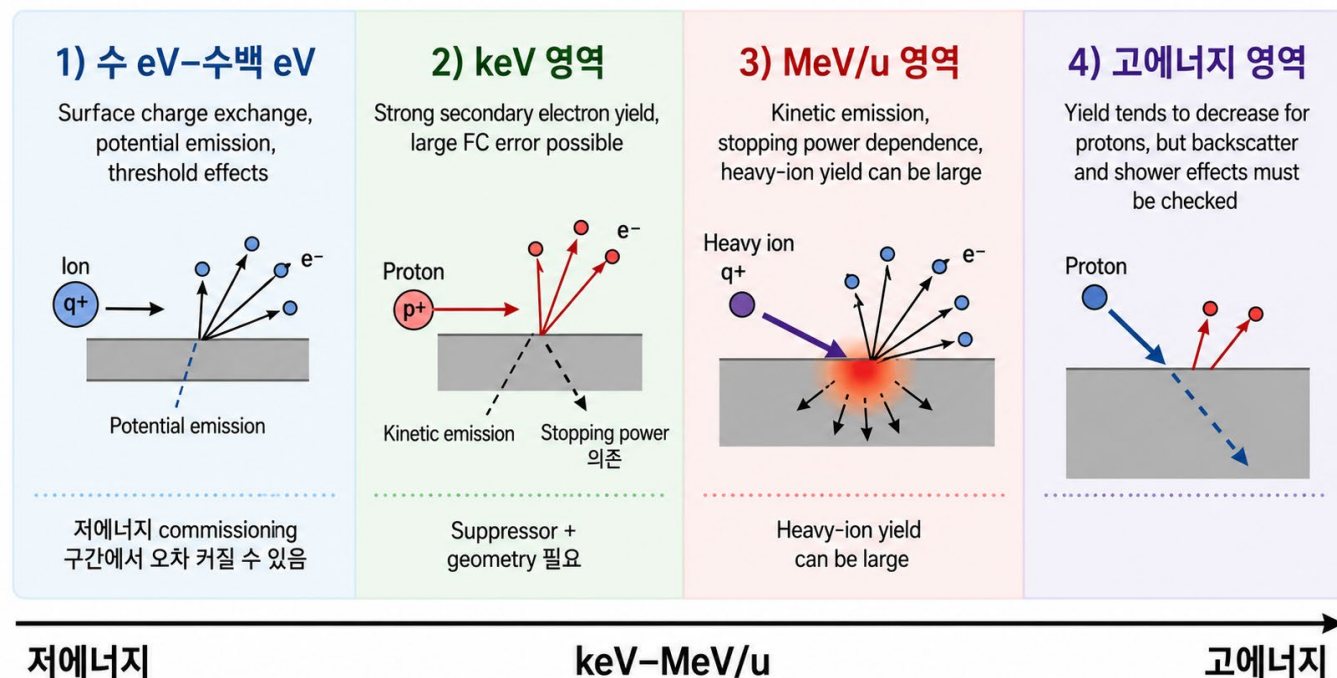
요약: 전자빔(과소평가), 양성자/양이온/중이온빔(과대평가 가능)

Faraday Cup (secondary electron)

이차전자 발생 메커니즘



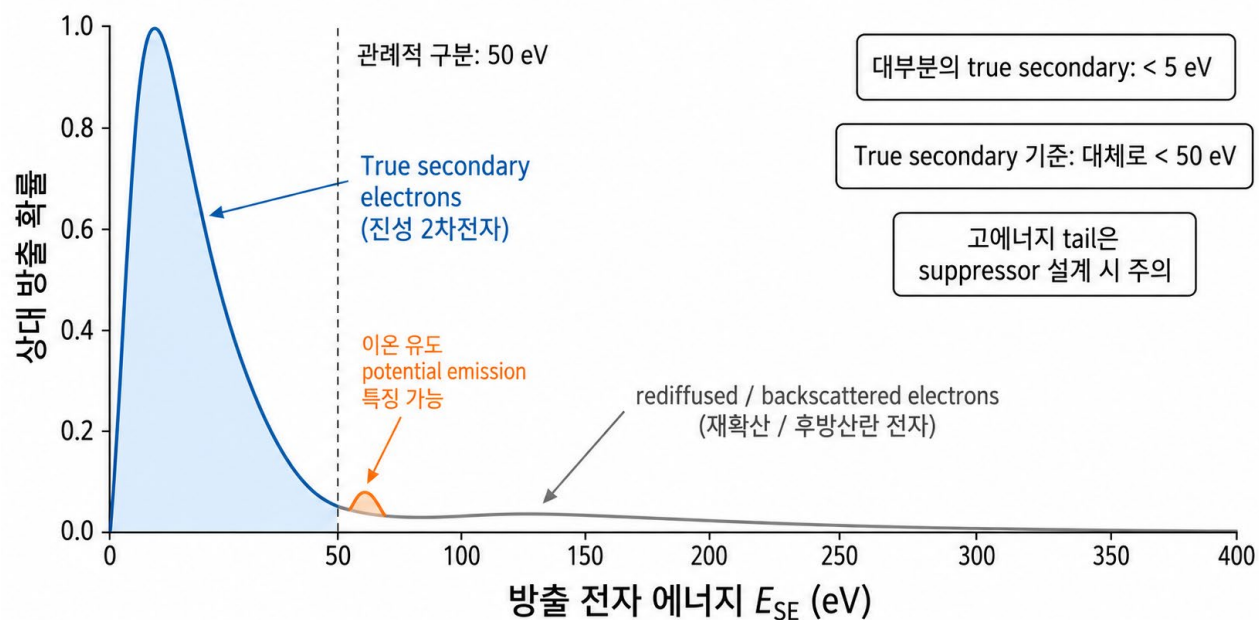
빔 에너지에 따른 주요 현상



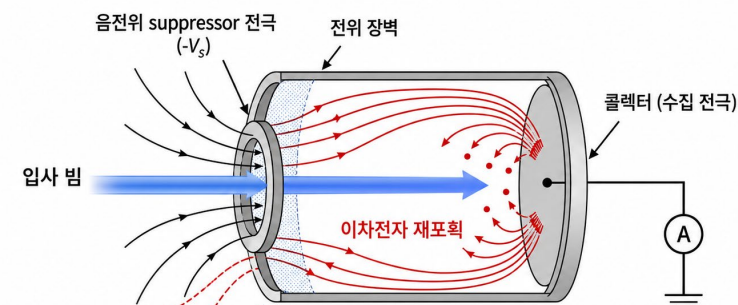
Beam Instruments

Faraday Cup (secondary electron)

이차전자 에너지 분포

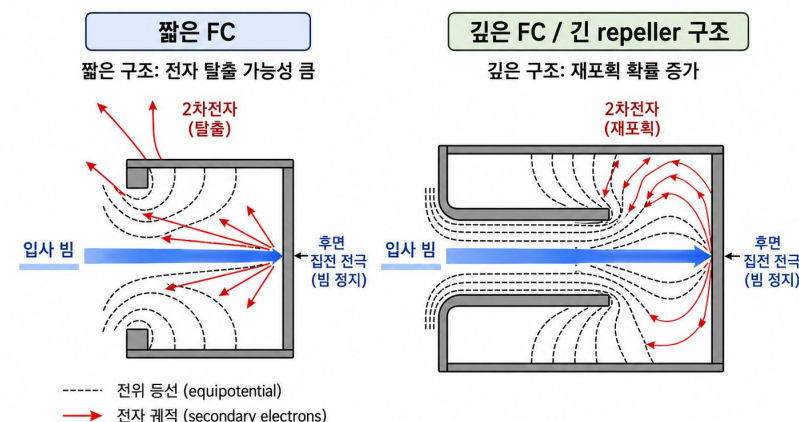


Suppressor 전극에 의한 억제 원리



- true secondary는 수십 V 장벽으로 대부분 억제 가능
- 고에너지 backscattered 전자는 더 큰 장벽 또는 깊은 구조 필요

짧은 FC와 깊은 FC 구조 비교

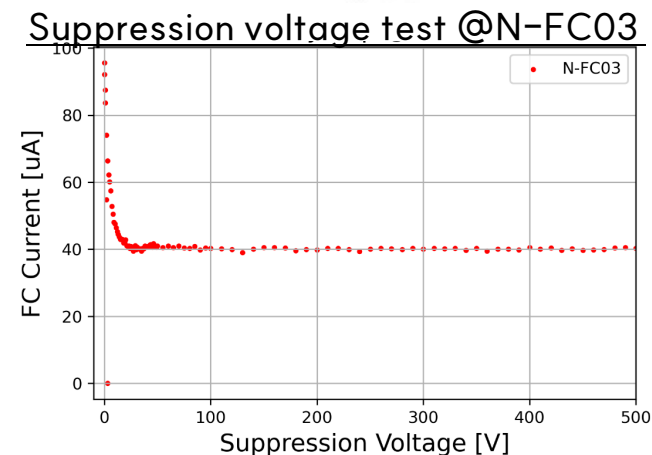
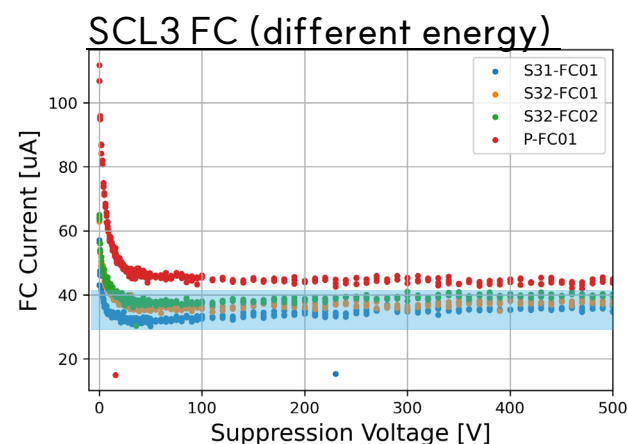
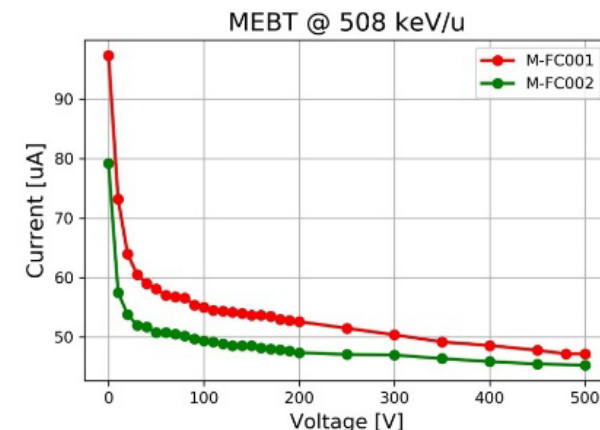
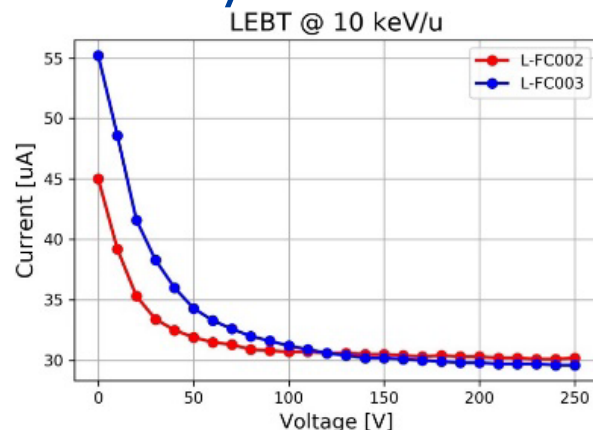


같은 전압이라도 축방향 전위장벽은 형상에 의존
L/D 비, aperture, repeller 길이 중요

Beam Instruments



■ Faraday Cup (secondary electron)



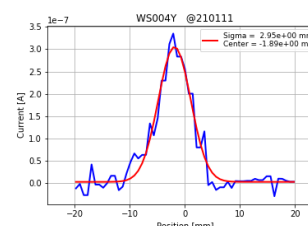
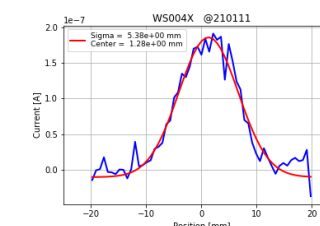
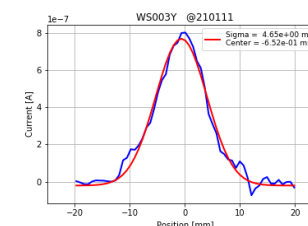
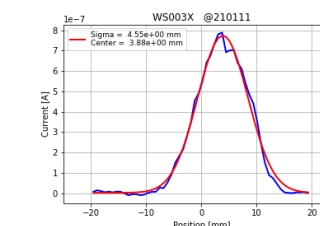
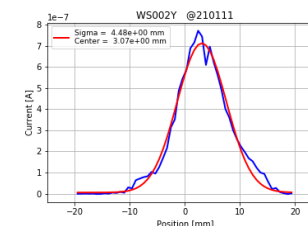
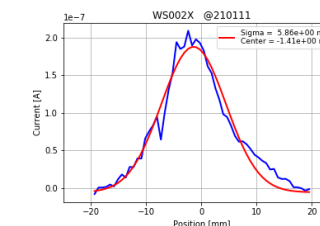
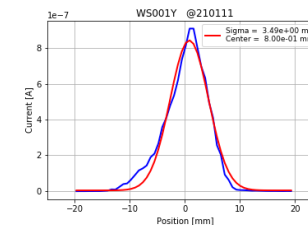
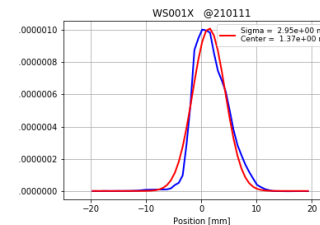
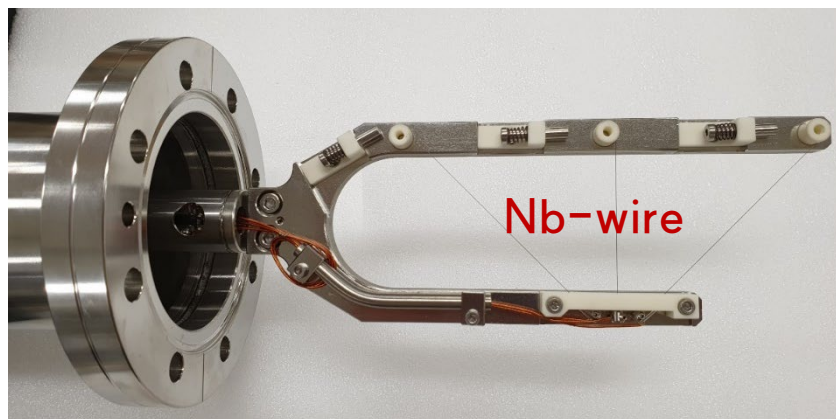
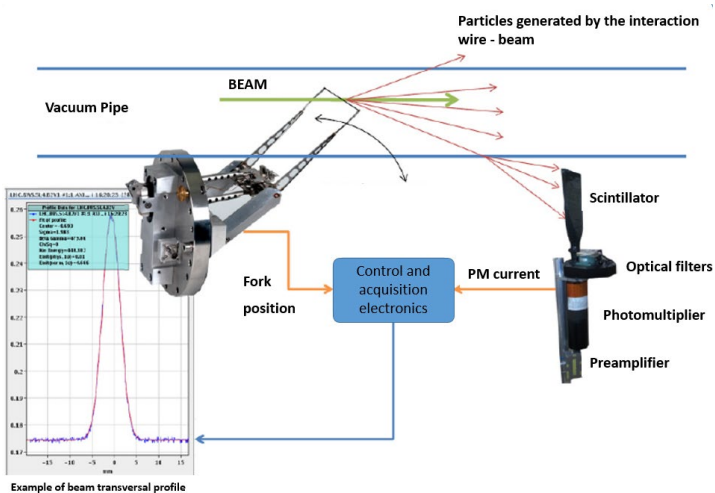
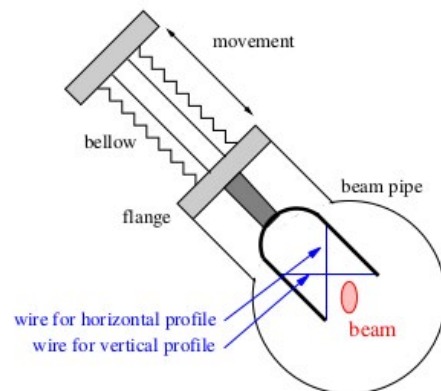
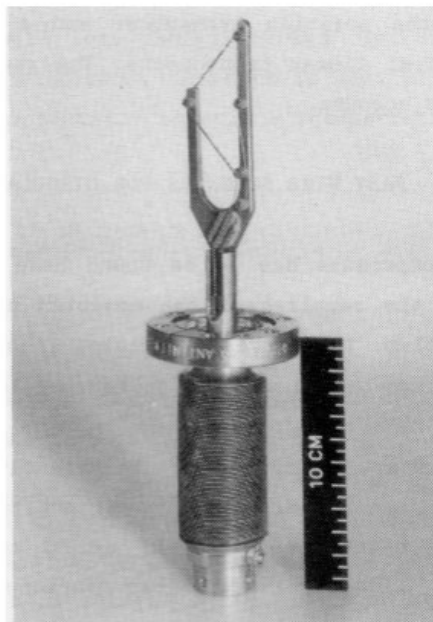
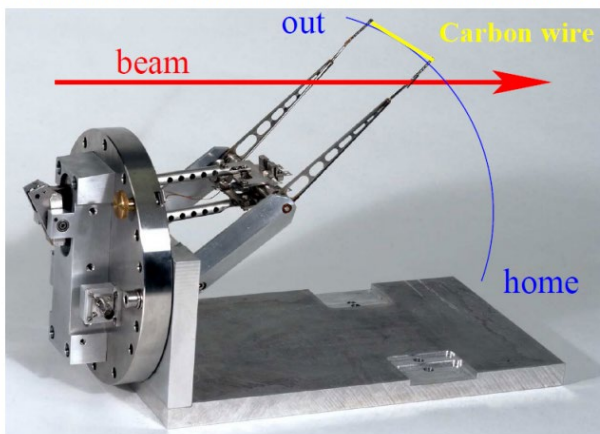
- There is a region where the suppression voltage trend deviates (50–100V).
- P2DT FC does not show this trend.

- Well saturated current value with suppress voltage over 50V
- NDPS – FC03 : 40.2 uA
- KoBRA-FC01 : 40.6 uA
- P2DT-ACCT01 : 35 uA

Beam Instruments

■ Wire scanner

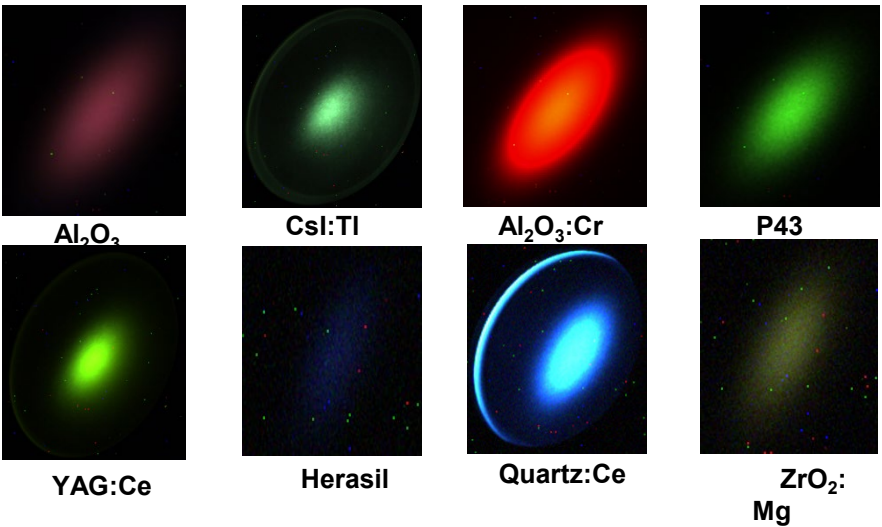
Fast pendulum scanner for synchrotrons; sometimes it is called '*flying wire*':



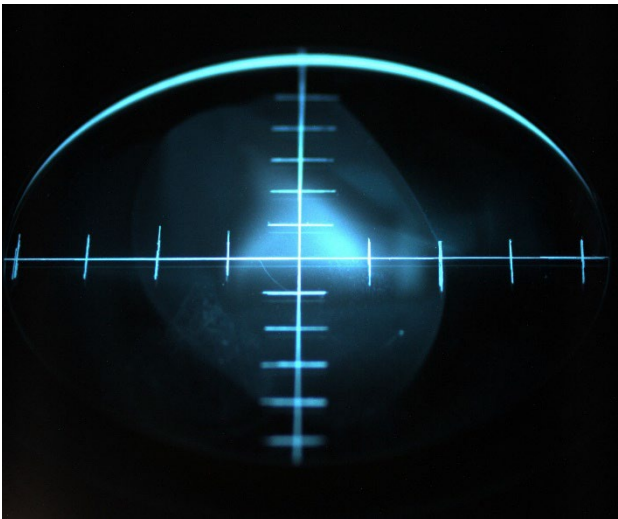
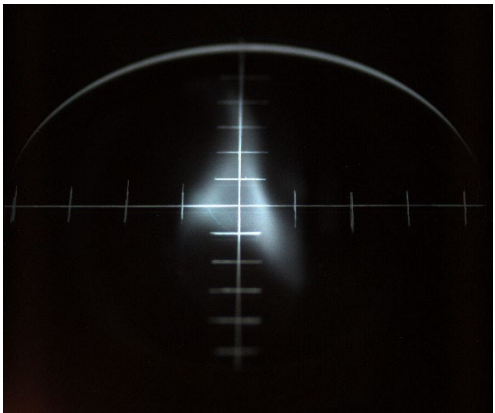
Beam Instruments



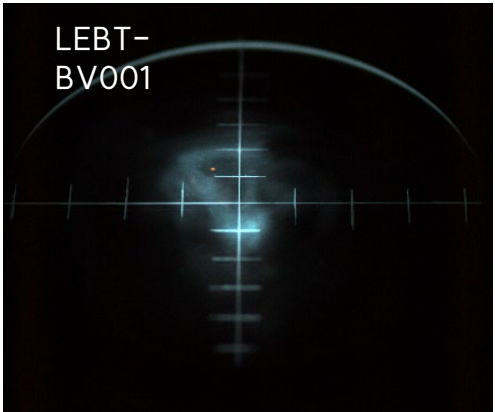
- Beam viewer(phosphor screen)



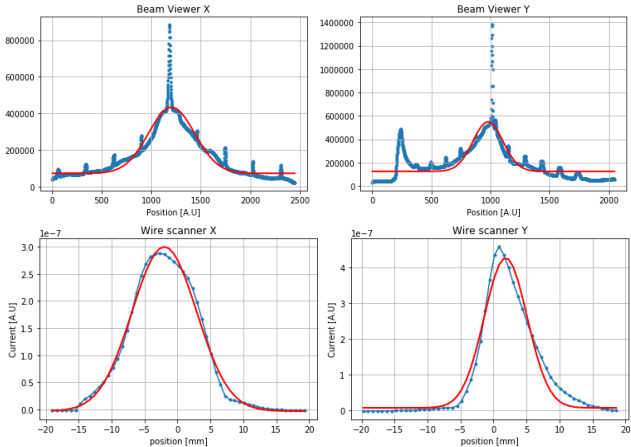
Ar 8+ 14.1 uA @ LEBT-FC001



Ar 9+ 22.9 uA @ LEBT-FC001

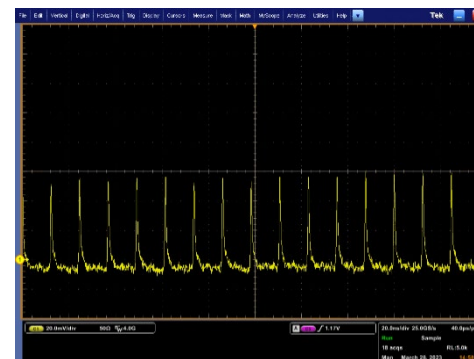
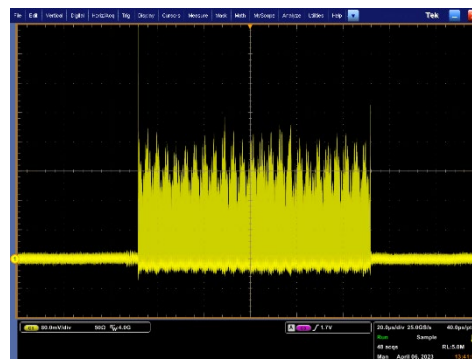


Type	Material	Supplier
Single Crystal	YAG:Ce CsI:Tl	Saint Gobain Crystals
Powder on Al	P43 (Gd ₂ O ₂ S:Tb) (layer of 50 μm)	Proxitronic
Ceramics	Al ₂ O ₃ Al ₂ O ₃ :Cr (Chromox) ZrO ₂ :Y(Z700 20 A) ZrO ₂ :Mg (Z507)	BCE Special Ceramics
Quartzglass	Pure (Herasil 102) Ce doped (M382)	Heraeus Quartzglass

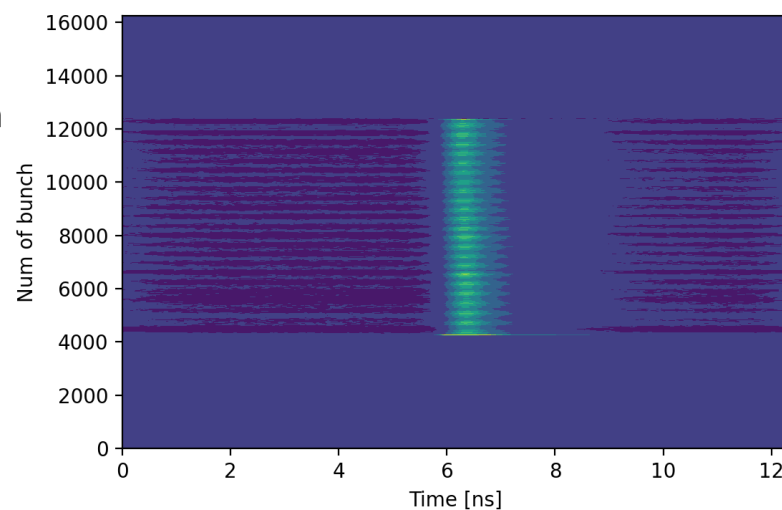


Beam Instruments

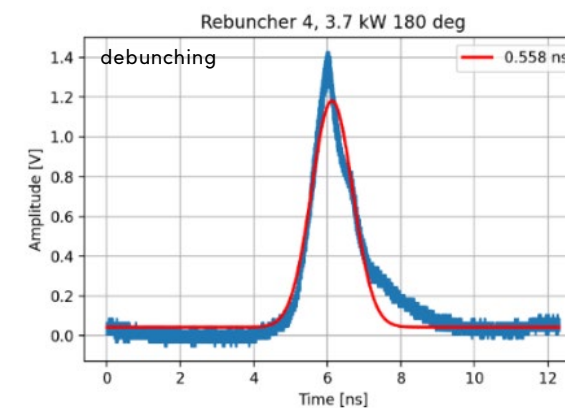
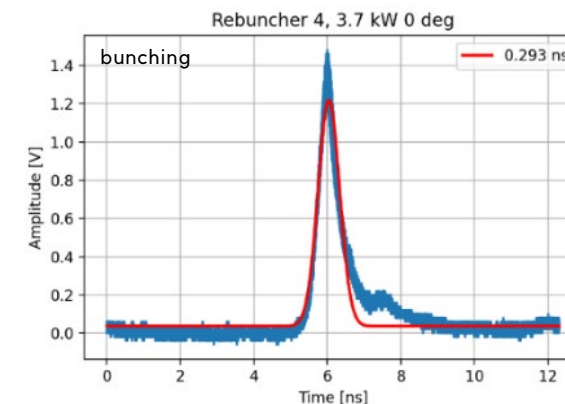
■ Stripline type Fast Faraday Cup



Oscilloscope (4 GHz, 25 GSPS)



- Semi-rigid SMA cable in vacuum
- PEEK insulator
- Ta plate in front of FFC
- Bolting at irregular position



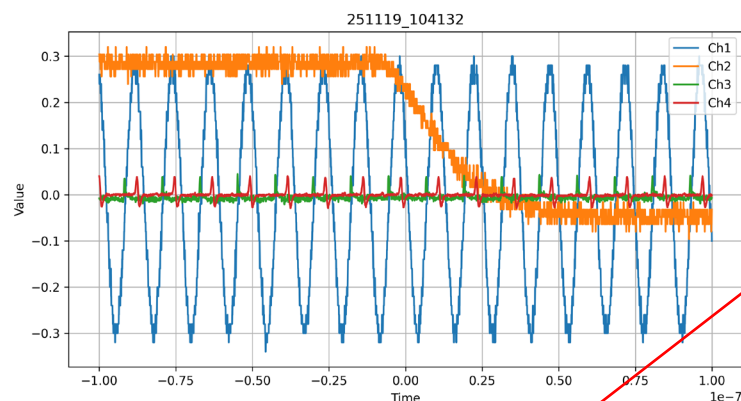
- Ar 8+, 50 uA, at the end of MEFT (4 bunchers)
- 100 μ s macro pulse commissioning beam

Beam Instruments



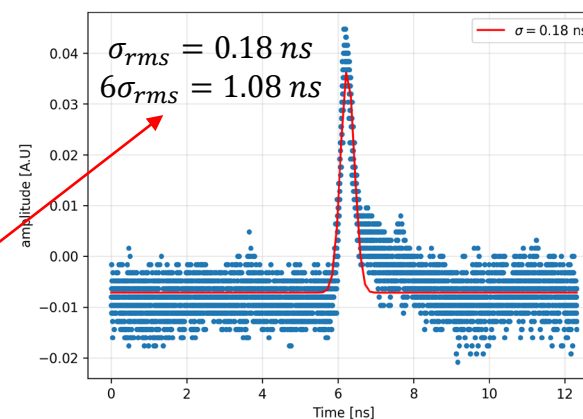
FFC & BPM data

ex) 18.5 MeV/u @ P2DT

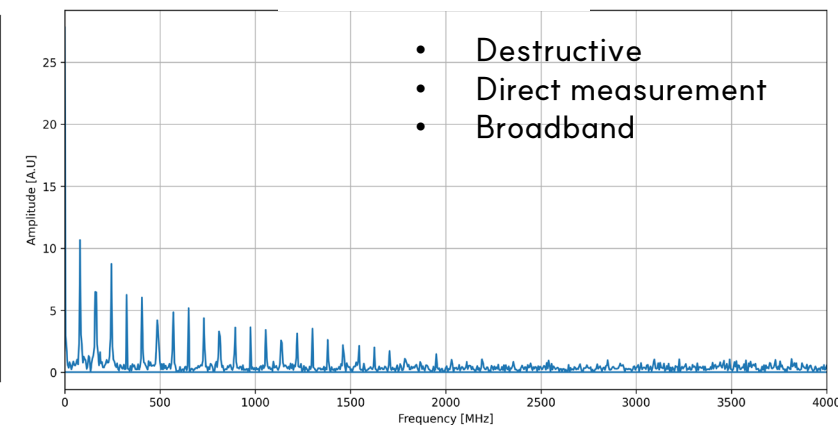


FFC

Time domain

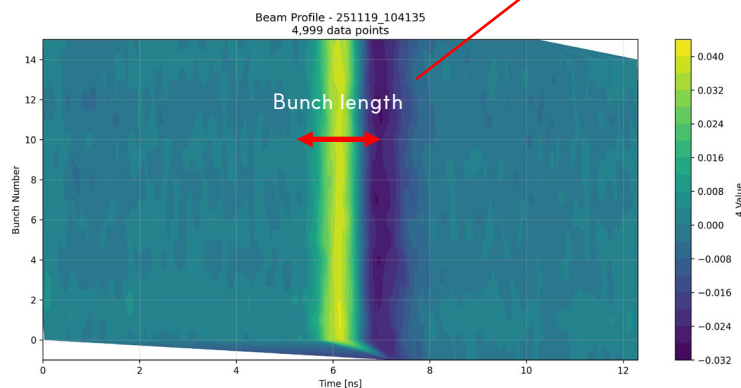


Frequency domain



- Destructive
- Direct measurement
- Broadband

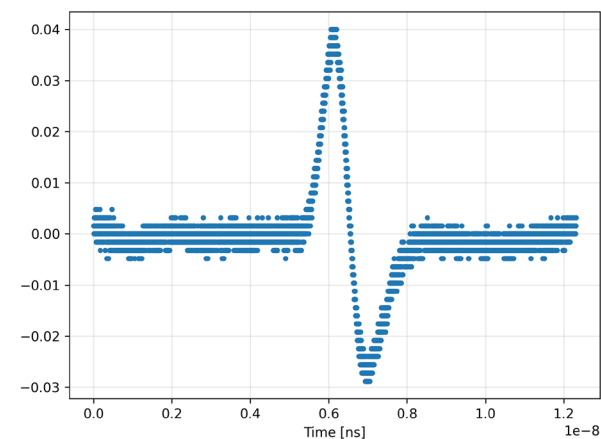
14 bunches, ~200 ns



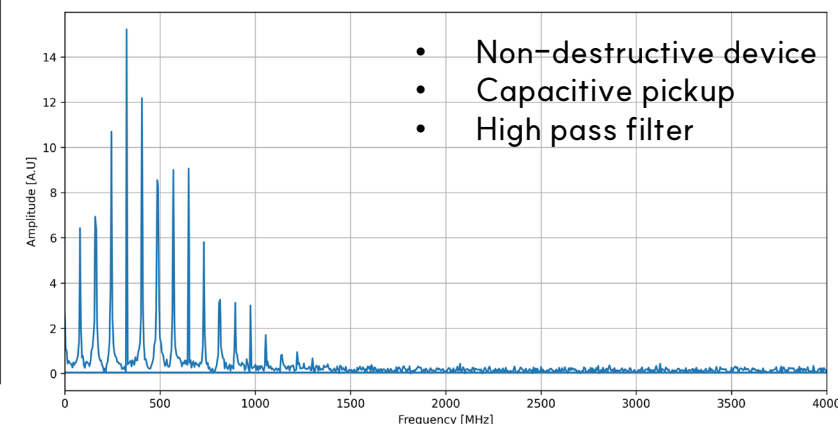
Period, ~12.3 ns

BPM

Time domain



Frequency domain

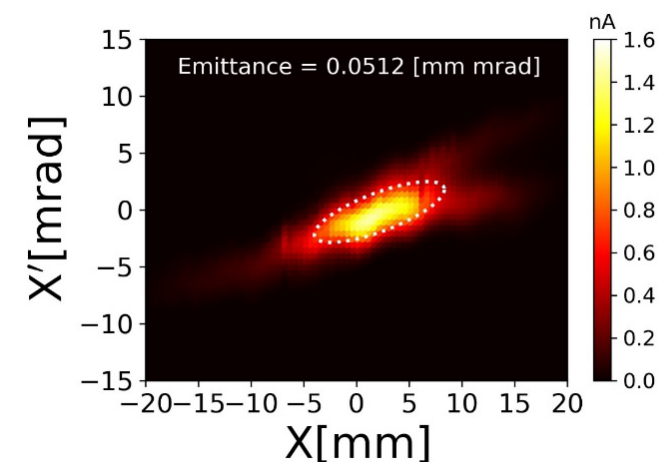
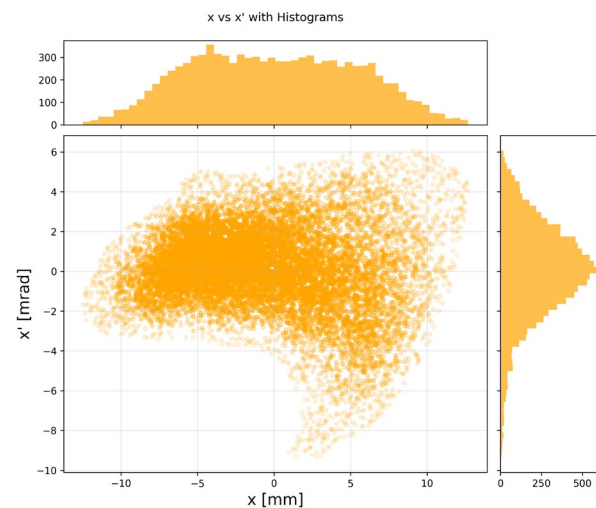
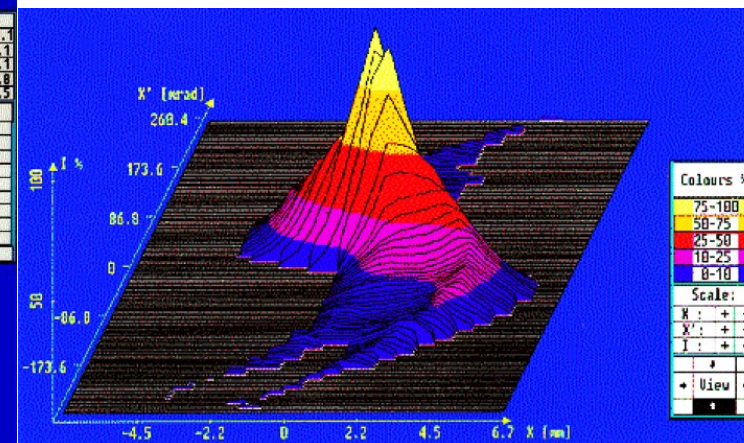
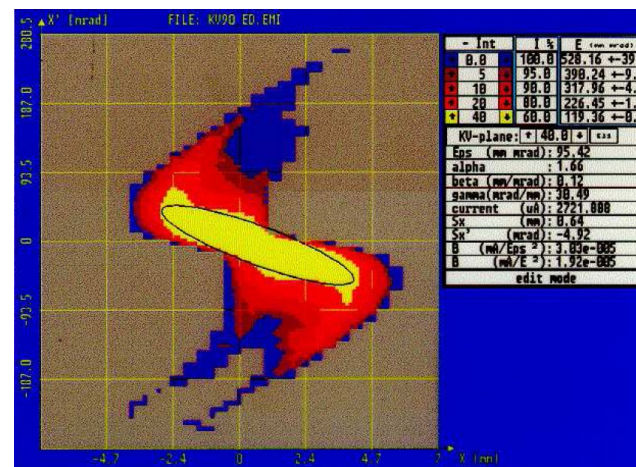
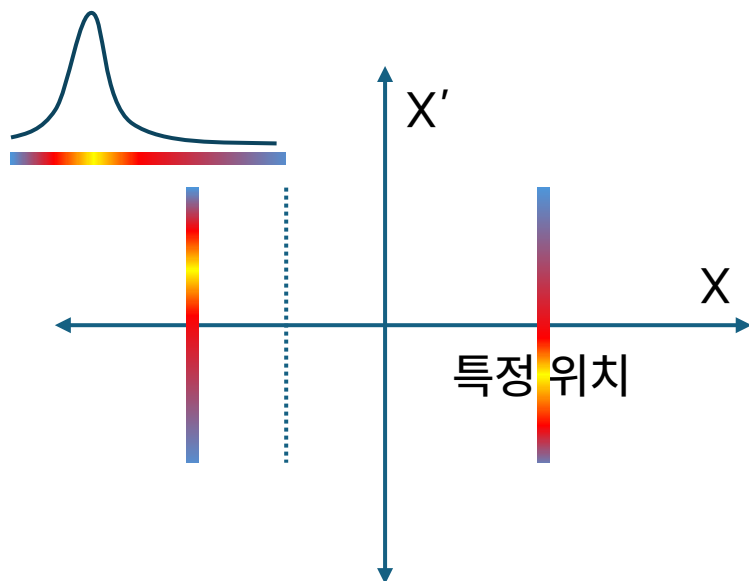


- Non-destructive device
- Capacitive pickup
- High pass filter

Beam Instruments

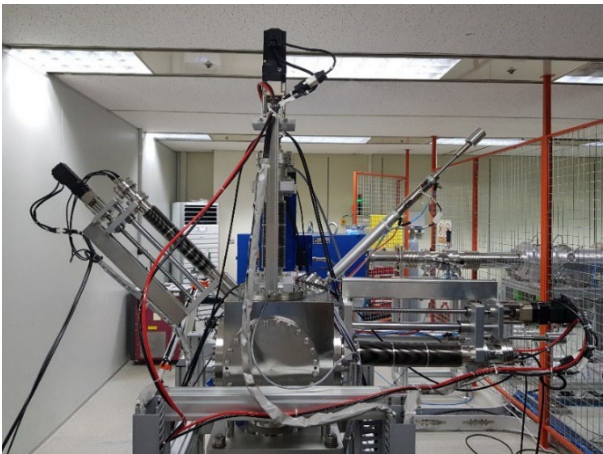
■ Phase space

1. Slit – profile(grid, wire scanner)
2. Allison scanner
3. pepper pot
4. Quadrupole magnet scan
5. Multi wire method



Beam Instruments

- Allison scanner

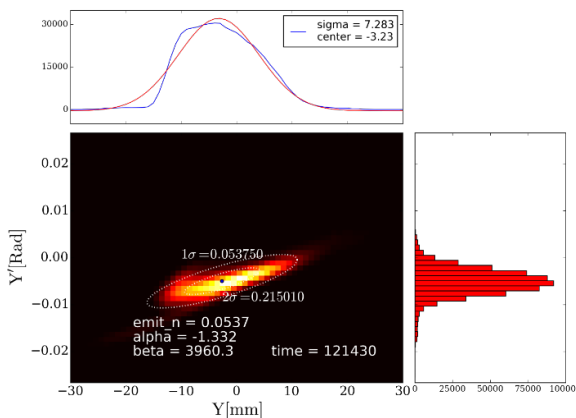
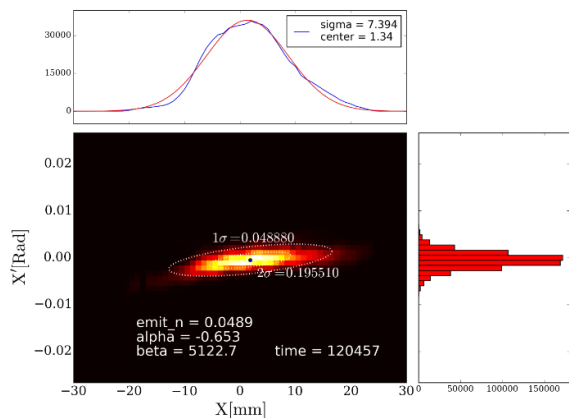
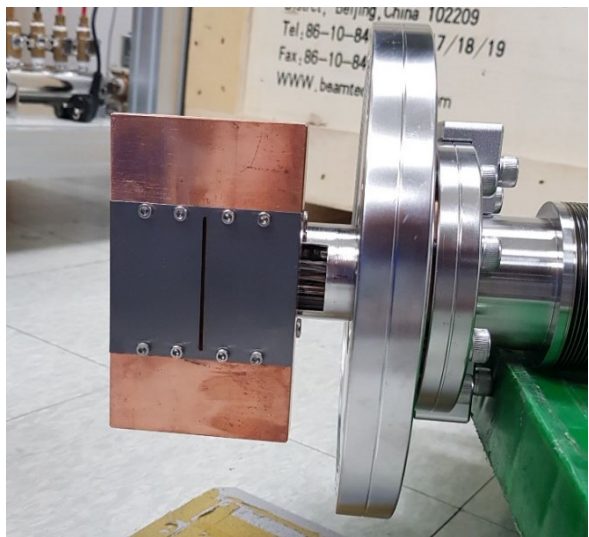
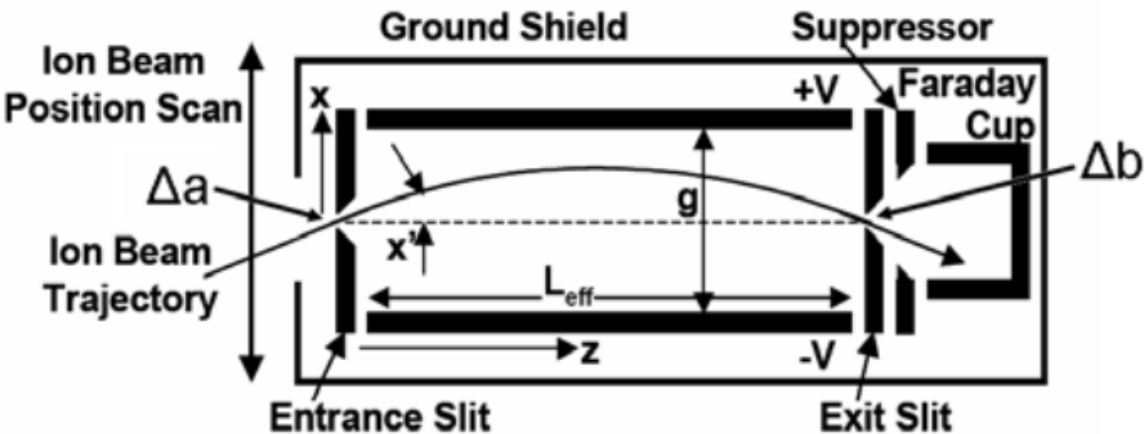


$$X'_{max} = \pm \frac{2g}{(L + 4\delta)}$$

$$V_{max} = \pm \frac{8g^2U}{L(L + 4\delta)}$$

Table. Parameter of Allison scanner scanner

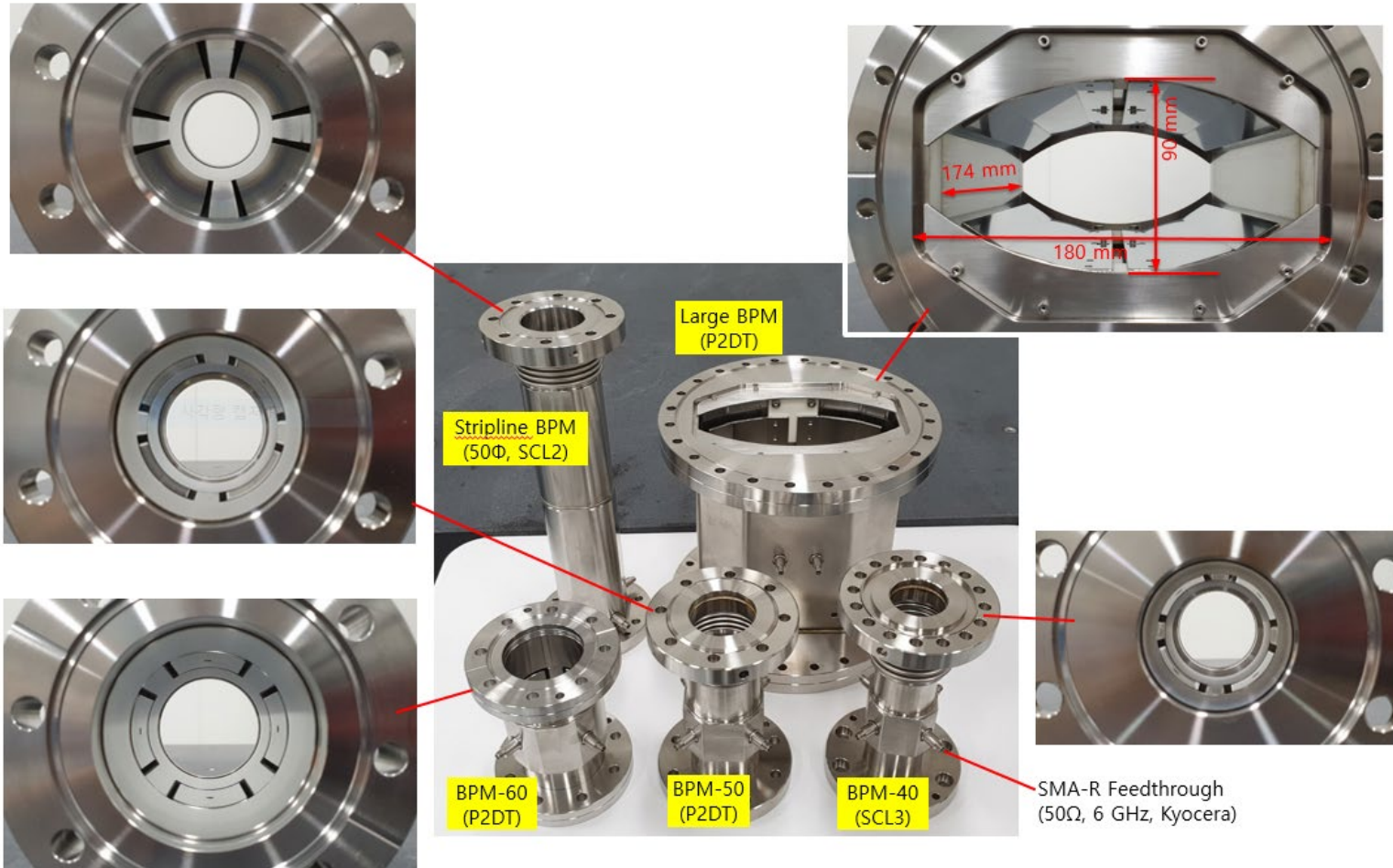
Device	Factor A
Plate Voltage	$\pm 1\text{ kV}$
Supp. Voltage	-500 V
Slit Gap	0.1 mm
Plate Length	75.8 mm
Plate Gap	4 mm
Gap δ	1.7 mm
X'_{max}	$101\text{ mrad (50.5 mard)}$
A/Q	$< 4.89\text{ (9.78)}$



Beam Instruments



- Beam Position Monitor



Index



- Background



- Beam Position Monitor



- BPM electronics



Beam Instruments

■ Beam Position Monitor

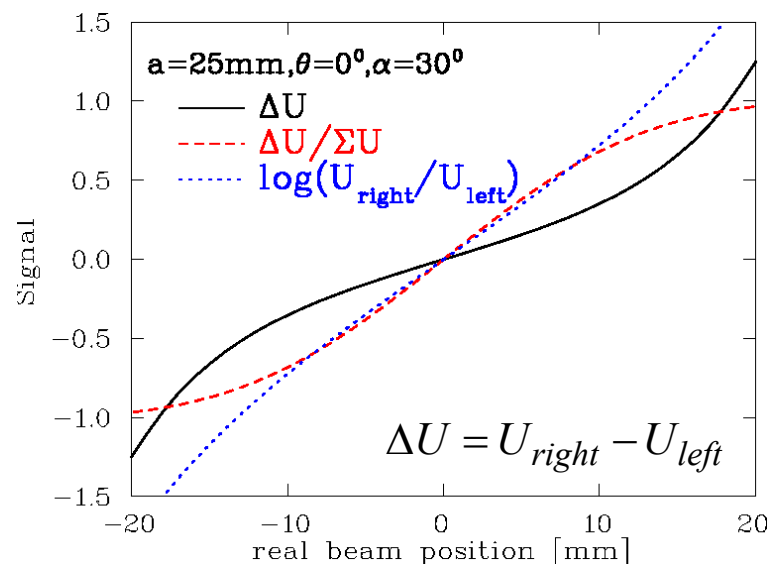
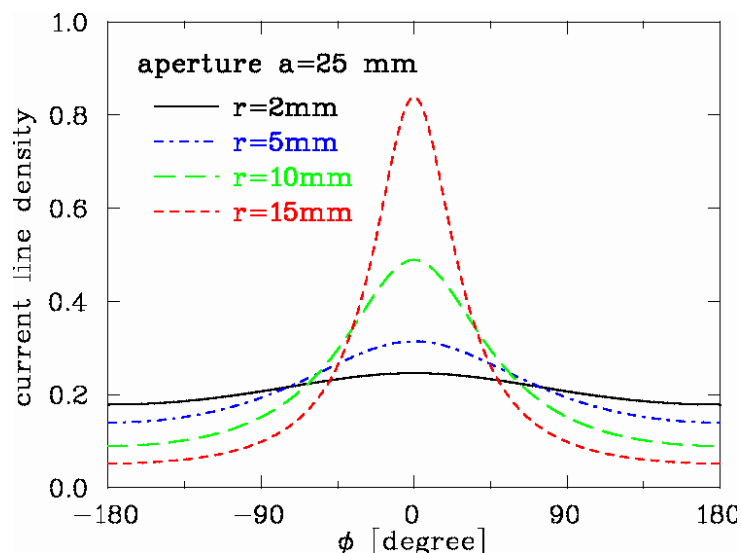
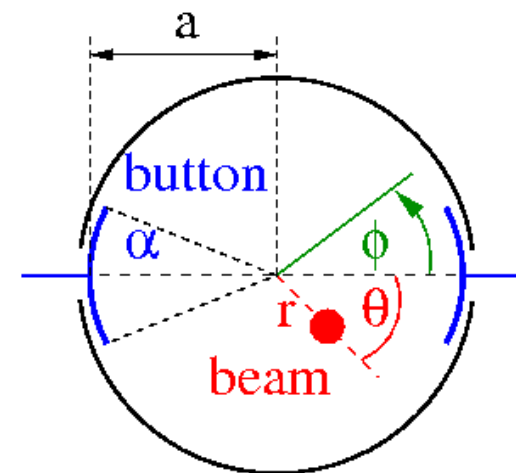
'Proximity effect': larger signal for closer plate

Ideal 2-dim model: Cylindrical pipe → image current density via 'image charge method' for 'pencil' beam:

$$j_{im}(\phi) = \frac{I_{beam}}{2\pi a} \cdot \left(\frac{a^2 - r^2}{a^2 + r^2 - 2ar \cdot \cos(\phi - \theta)} \right)$$

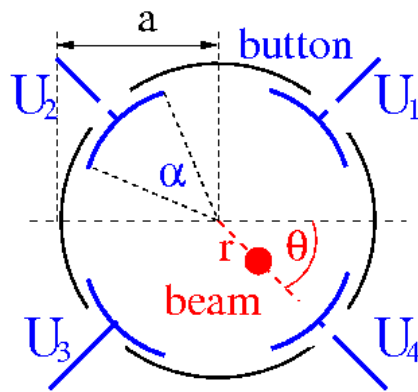
Image current: Integration of finite BPM size:

$$I_{im} = a \cdot \int_{-\alpha/2}^{\alpha/2} j_{im}(\phi) d\phi$$



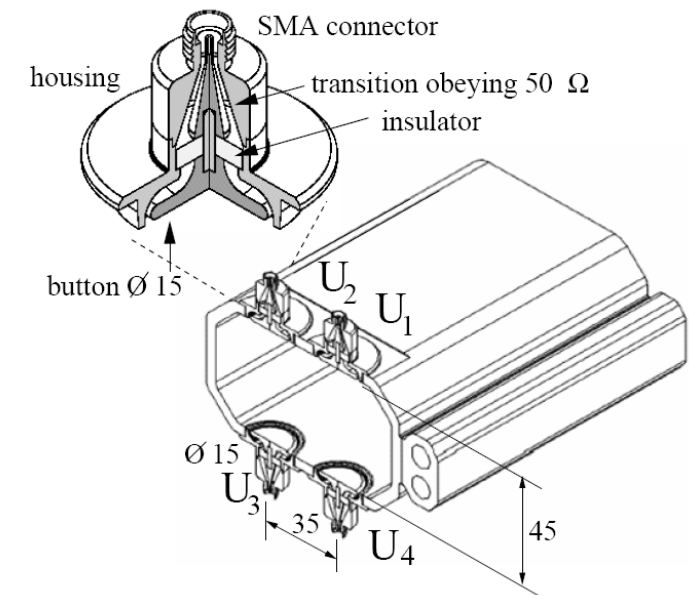
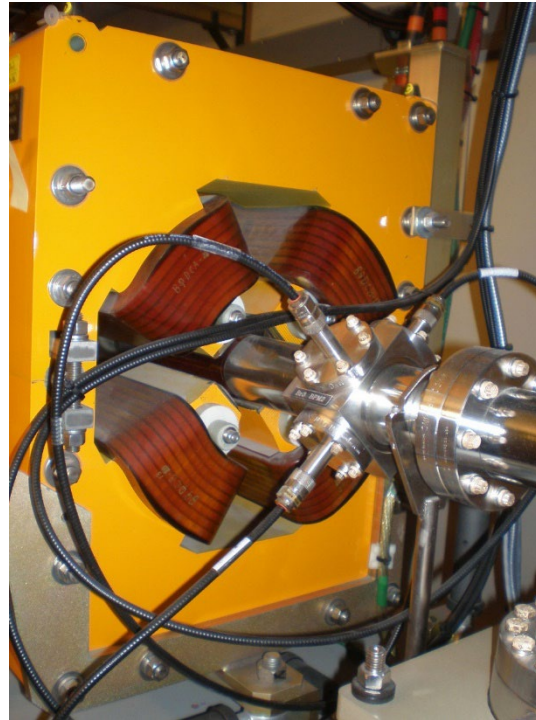
Beam Instruments

- Beam Position Monitor



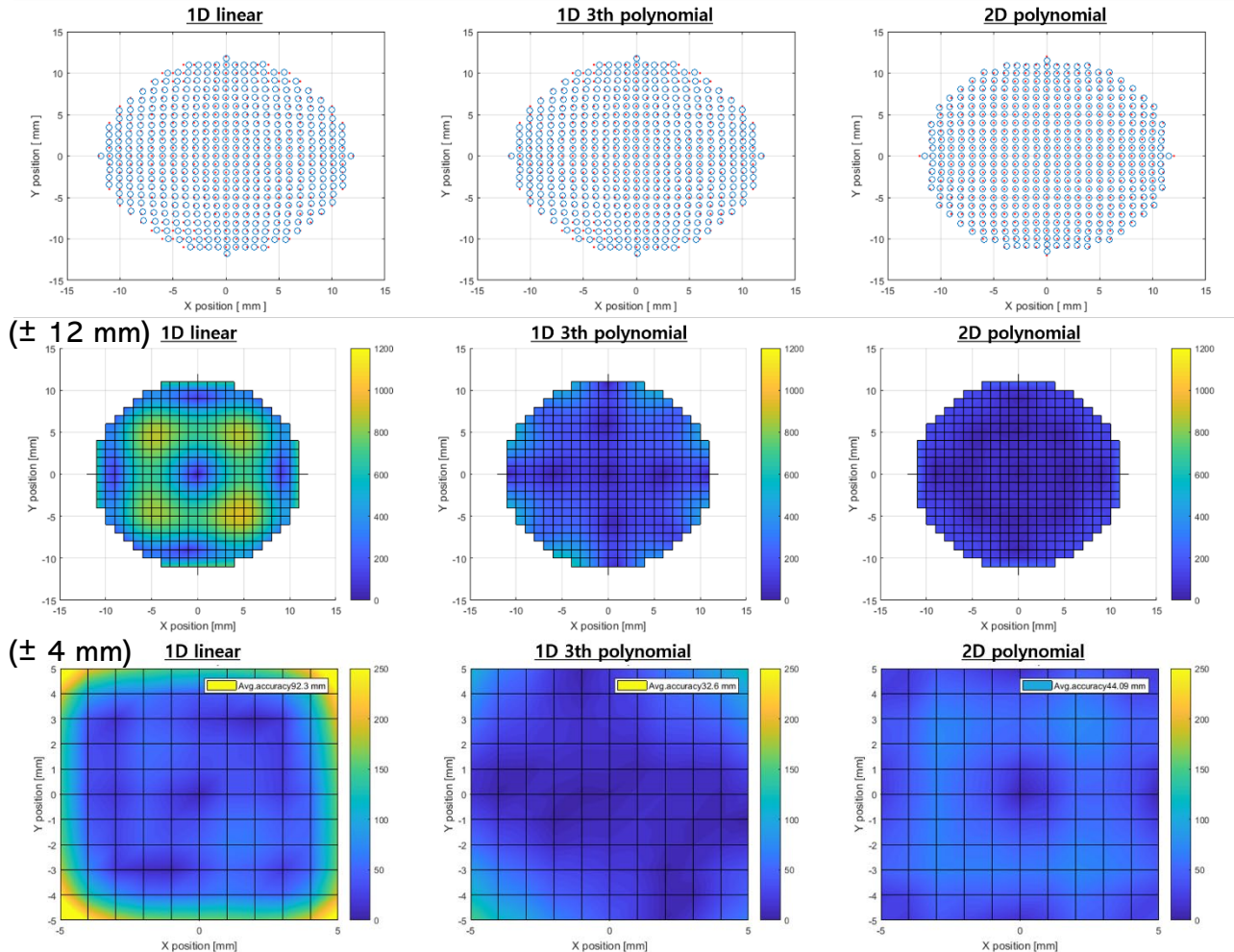
$$\text{horizontal : } x = \frac{1}{S} \cdot \frac{(U_1 + U_4) - (U_2 + U_3)}{U_1 + U_2 + U_3 + U_4}$$

$$\text{vertical : } y = \frac{1}{S} \cdot \frac{(U_1 + U_2) - (U_3 + U_4)}{U_1 + U_2 + U_3 + U_4}$$



Beam Instruments

■ Beam Position Monitor



• Position calculation

- Delta-over-sigma, $x = \frac{V_{\text{right}} - V_{\text{left}}}{V_{\text{right}} + V_{\text{left}}} \equiv \frac{\Delta}{\Sigma}$
- Log, $x = \text{Log}(V_{\text{right}}/V_{\text{left}}) = \text{Log}(V_{\text{right}}) - \text{Log}(V_{\text{left}})$
- Arctan, $x = \arctan(\frac{V_{\text{right}}}{V_{\text{left}}})$

• Position calibration

1) 1-D linear

$$X = K_x X_0 + \text{Offset}_x$$

$$Y = K_y Y_0 + \text{Offset}_y$$

2) 1-D polynomial

$$X = K_1 X_0^3 + K_2 X_0^2 + K_3 X_0 + K_4$$

$$Y = L_1 Y_0^3 + L_2 Y_0^2 + L_3 Y_0 + L_4$$

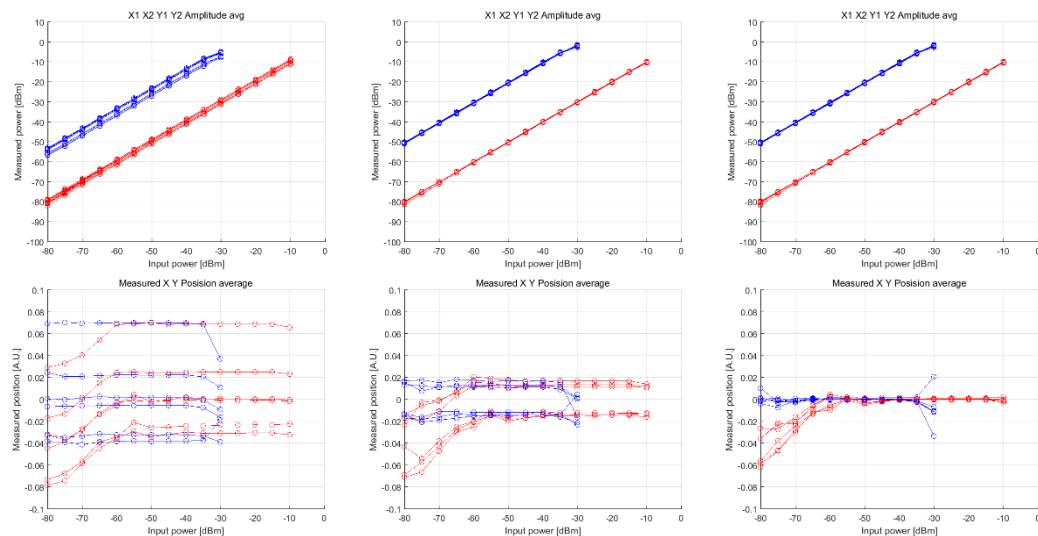
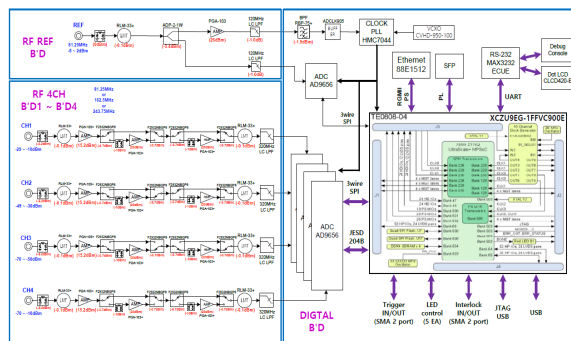
3) 2-D polynomial

$$X = \sum_{n=0}^3 \sum_{m=0}^3 K_{nm} X_0^n Y_0^m$$

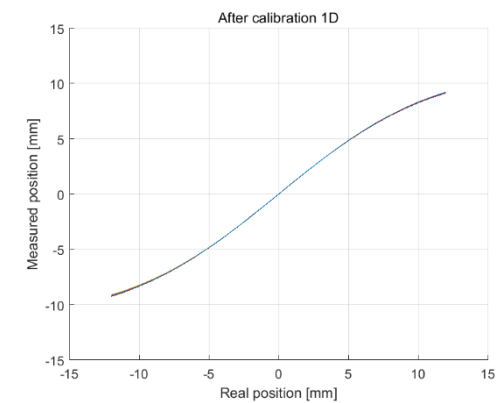
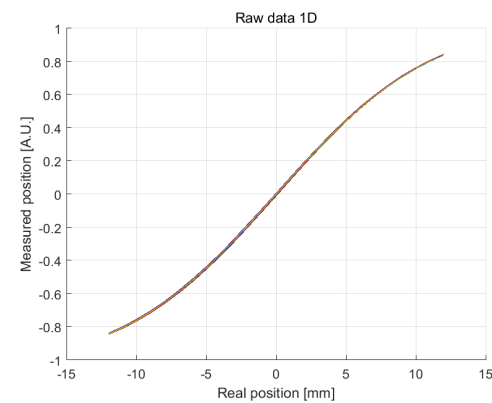
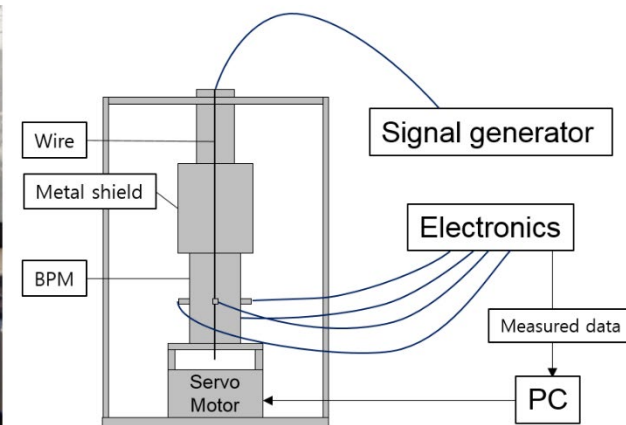
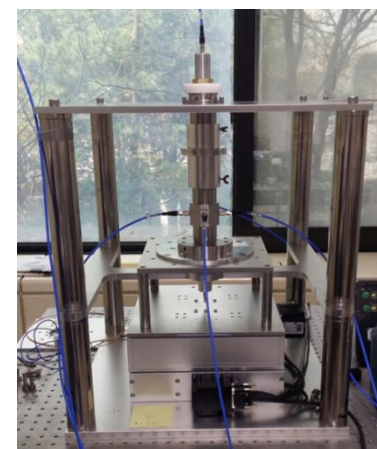
$$Y = \sum_{n=0}^3 \sum_{m=0}^3 L_{nm} X_0^n Y_0^m$$

Beam Instruments

■ Beam Position Monitor

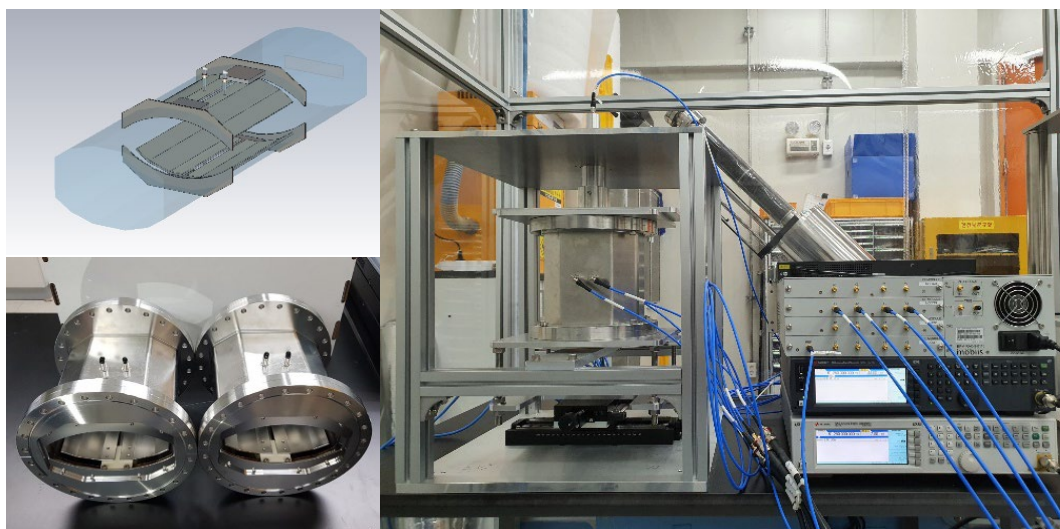
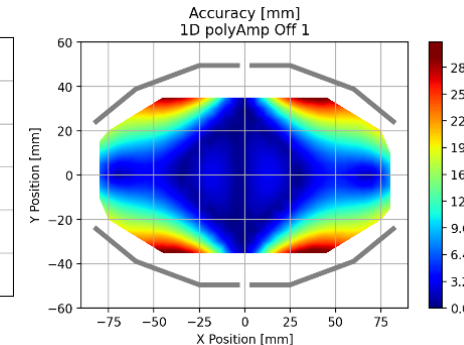
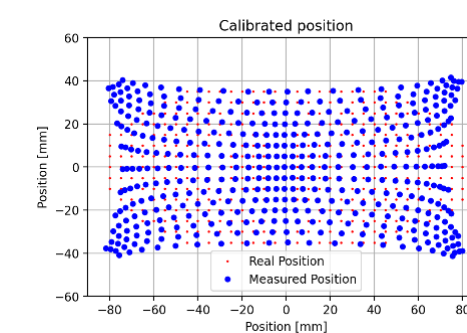
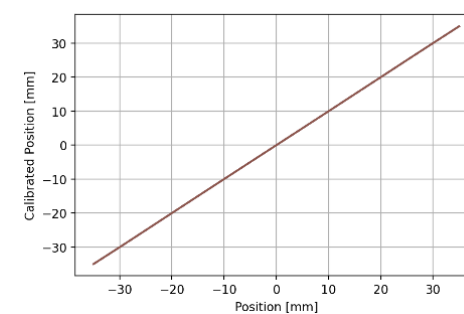
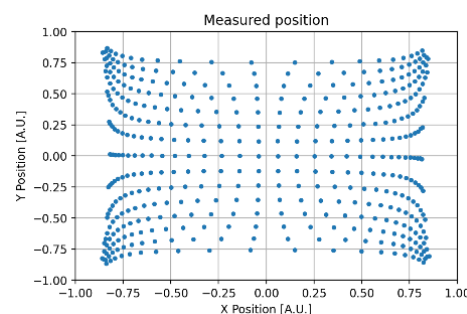
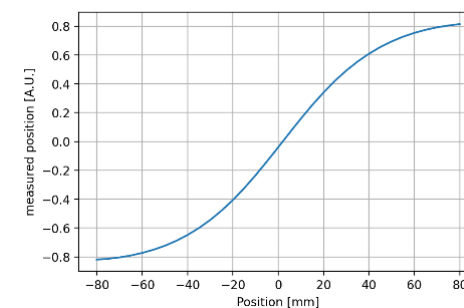
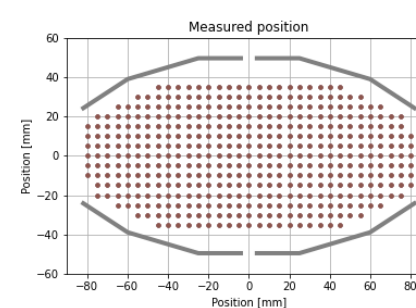
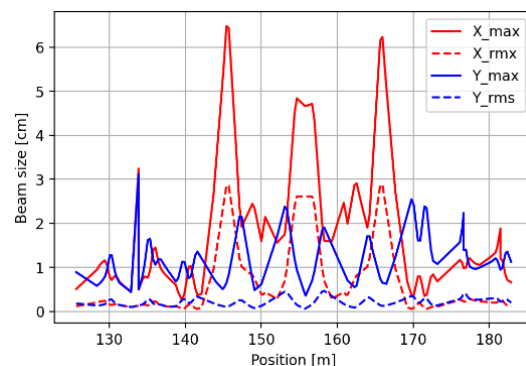
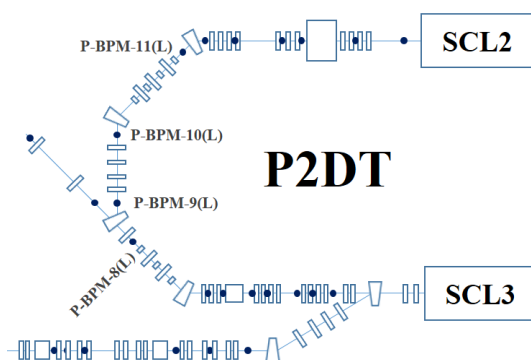


■ Wire test



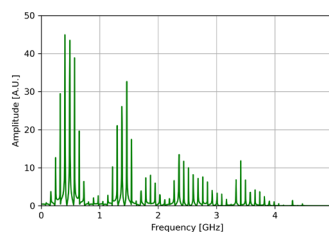
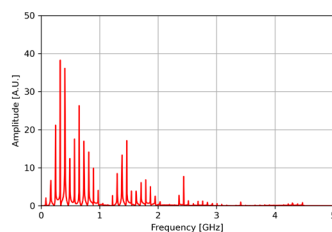
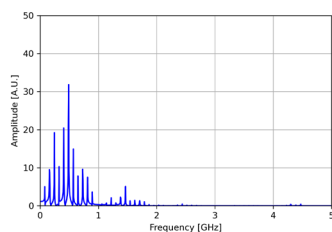
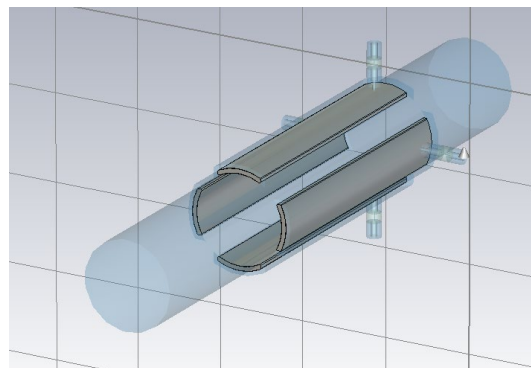
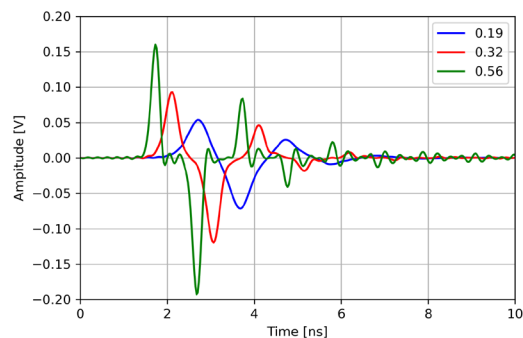
Beam Instruments

■ Beam Position Monitor

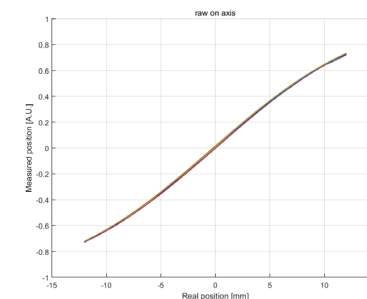
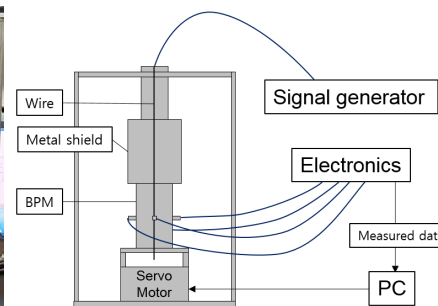


Beam Instruments

■ Beam Position Monitor

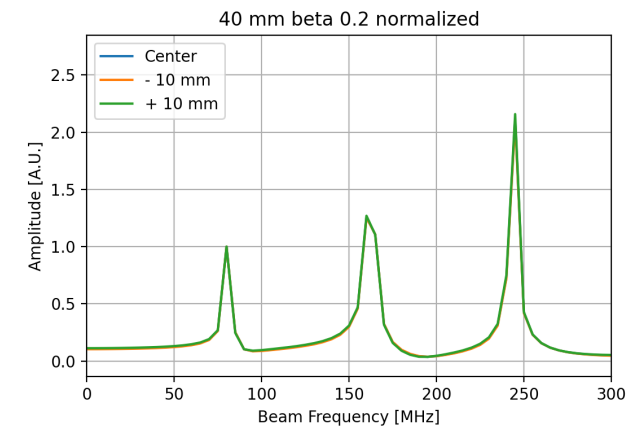
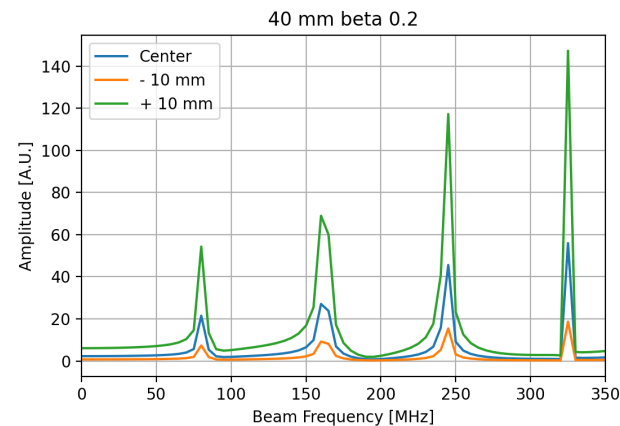
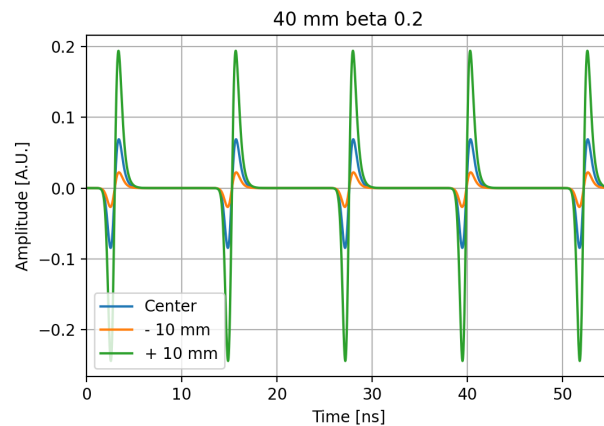
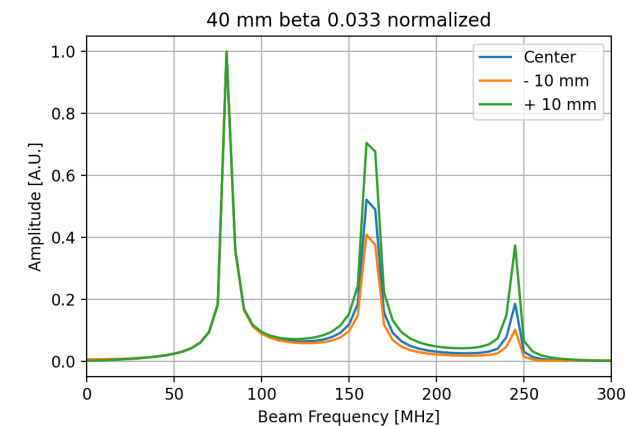
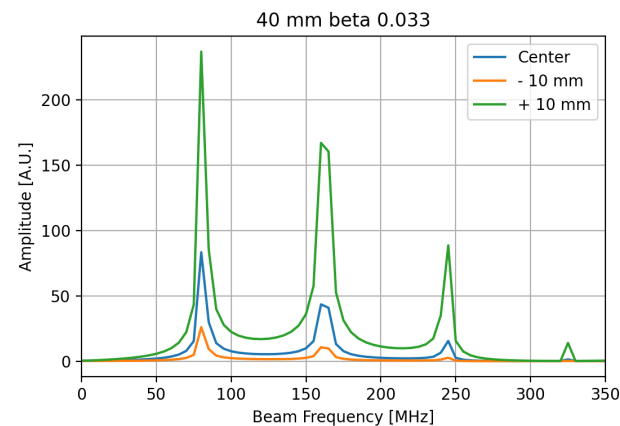
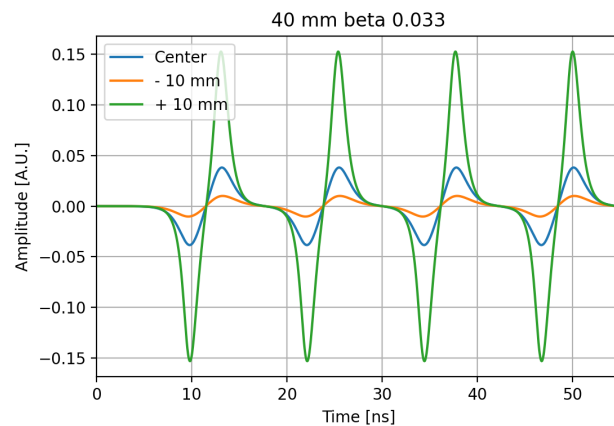


1mA [dBm]	At center of BPM		
	1 st	2 nd	3 rd
S32	-43.98	-37.68	-33.74
S21	-43.86	-37.43	-33.15
S22	-43.88	-37.31	-32.92



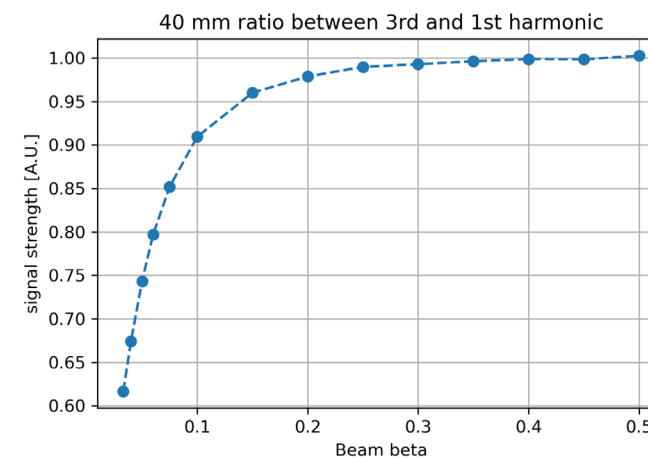
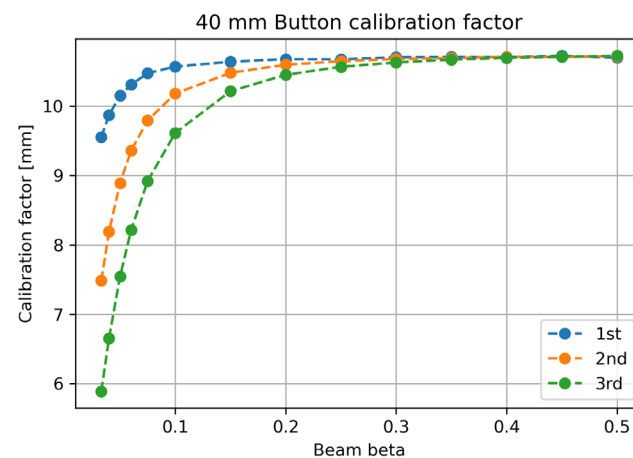
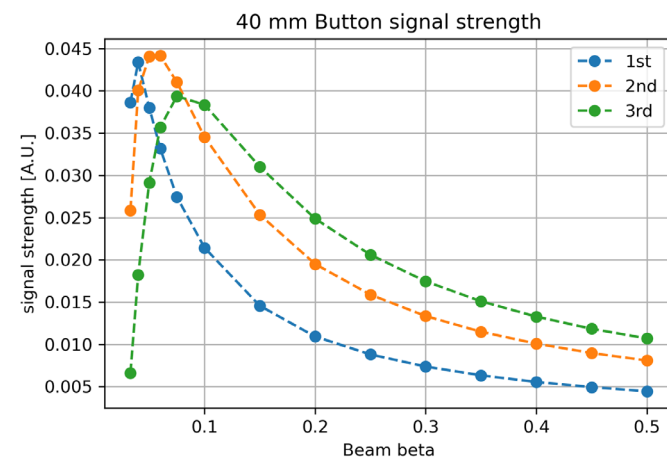
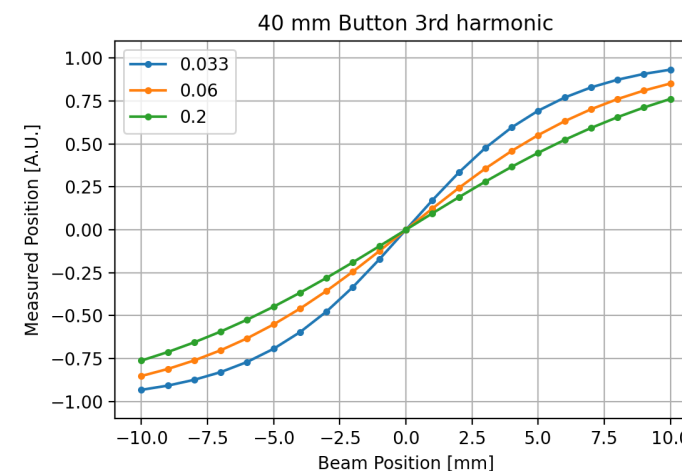
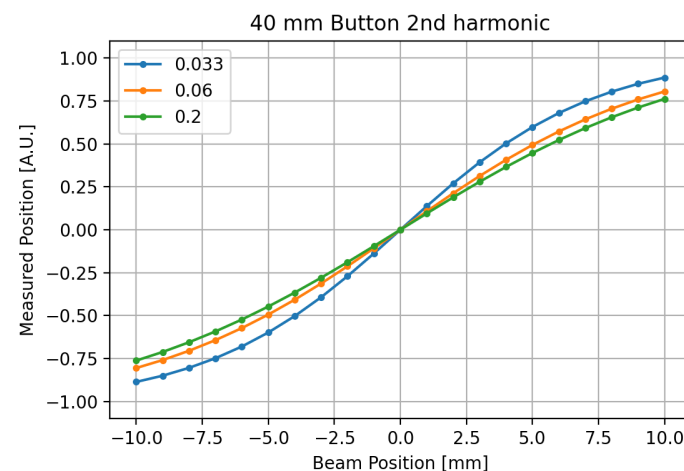
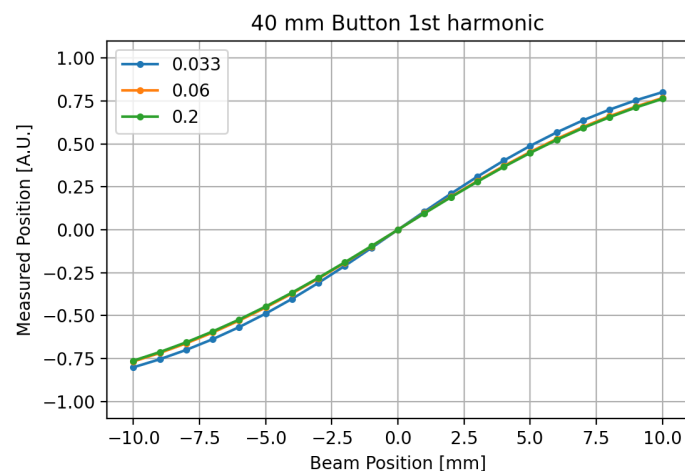
Beam Instruments

- Beam Position Monitor
- Beta dependency of beam position measurement



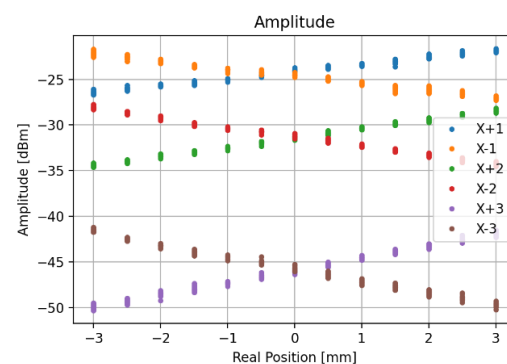
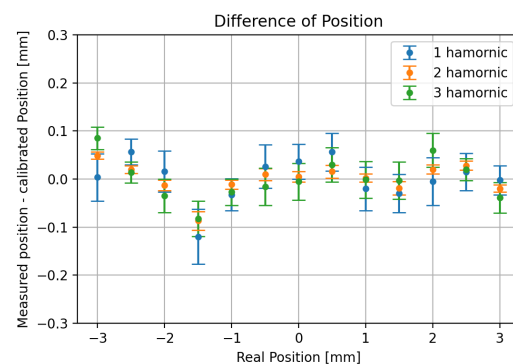
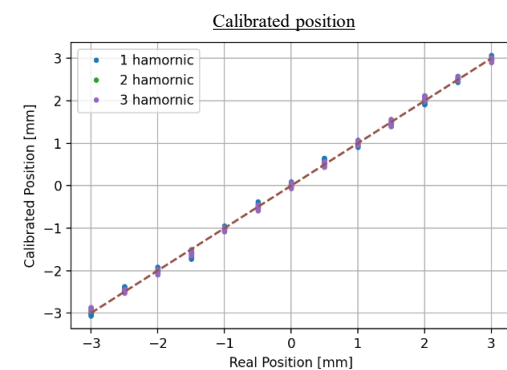
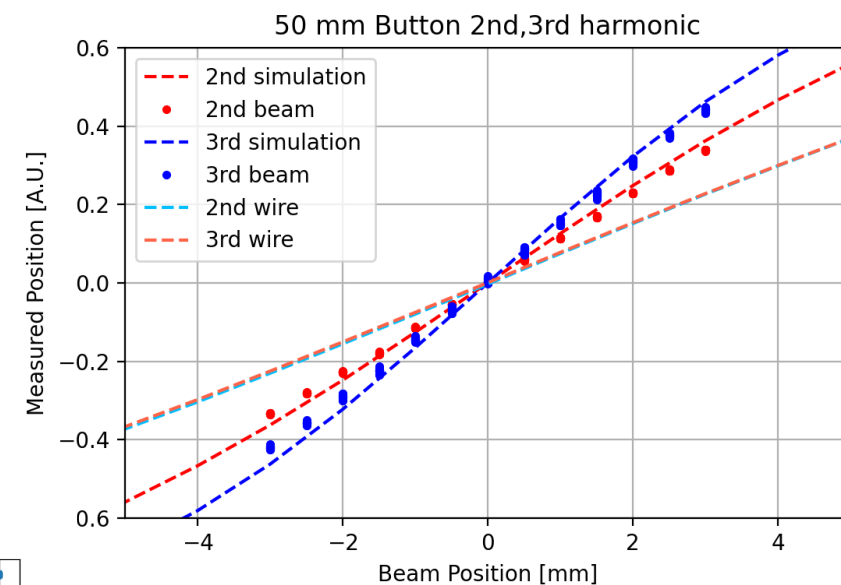
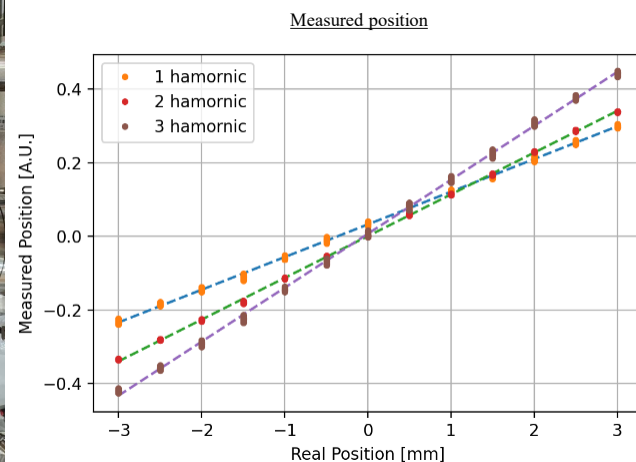
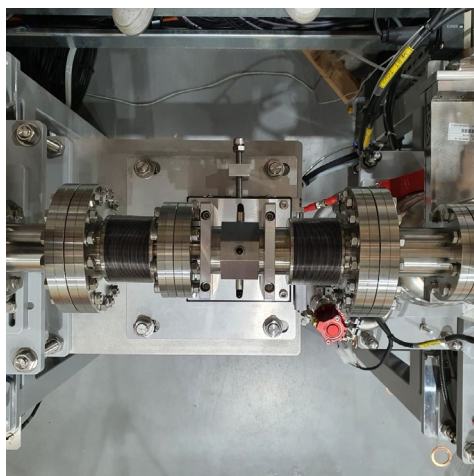
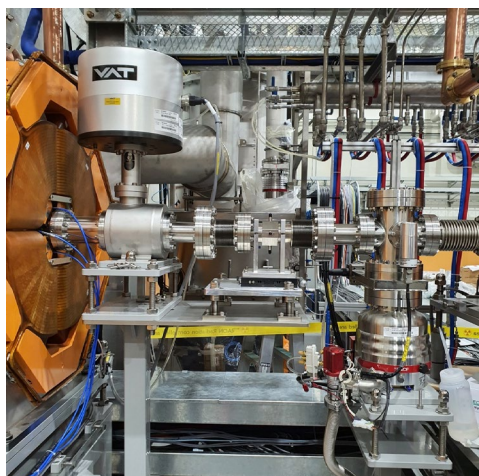
Beam Instruments

- Beam Position Monitor
- Beta dependency of beam position measurement



Beam Instruments

- Beam Position Monitor
- Beta dependency of beam position measurement



Wire test bench

1st : 13.45
2nd : 13.56
3rd : 13.61

Simulation

1st : 11.401
2nd : 8.384
3rd : 6.622

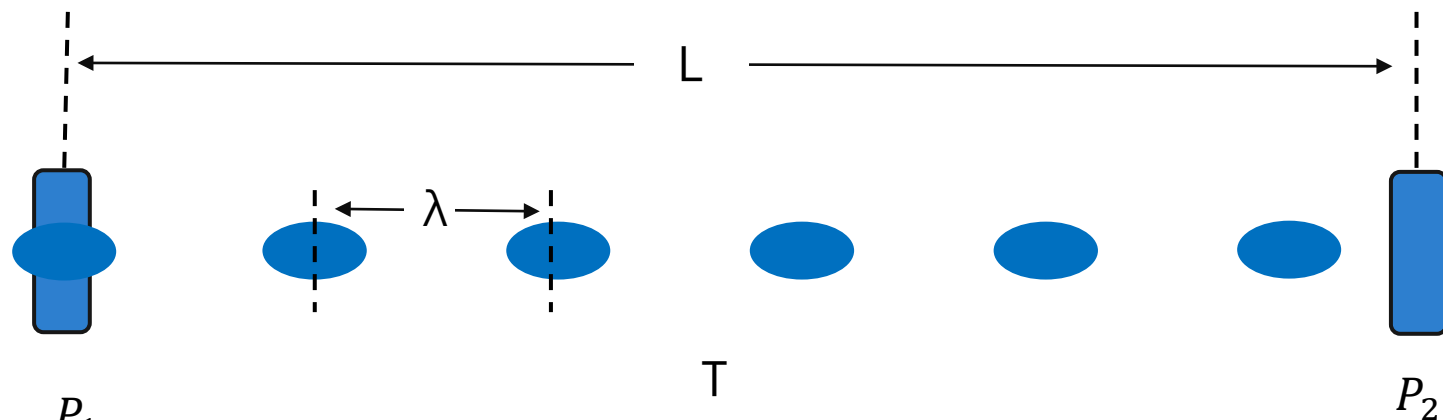
Beam based cal.

1st : 11.25
2nd : 8.817
3rd : 6.818

Beam Instruments

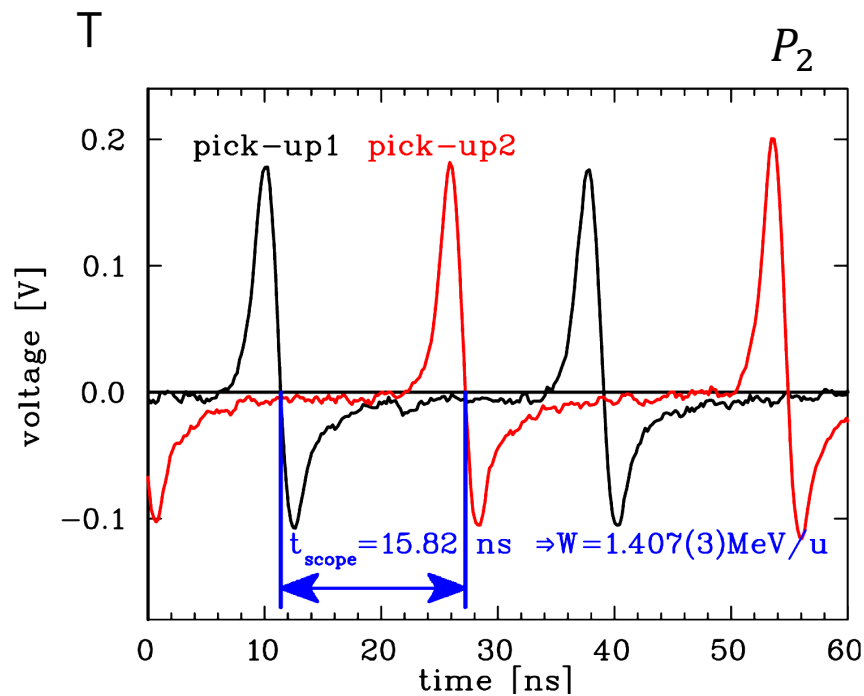


- Phase, time measurement → Energy measurement



$$\beta c = \frac{L}{NT + t_{\text{scope}}}$$

→ the velocity β is measured.



measurement : T, L

$$E = \frac{1}{2}mv^2$$

$$\frac{dE}{dt} = -mL^2t^{-3}$$

$$\frac{dE}{E} = 2 \frac{dt}{t}$$

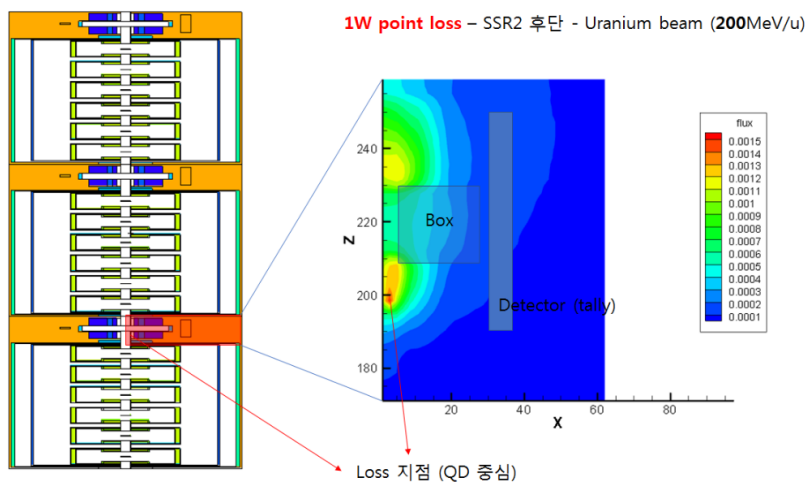
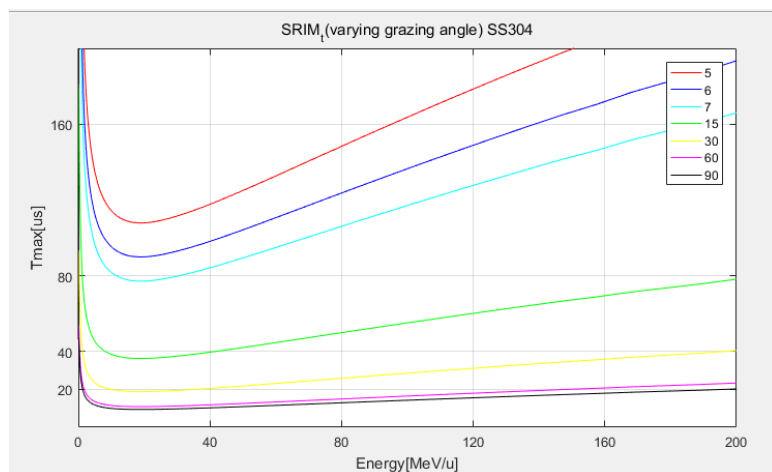
Phase(energy) resolution : 1°

Time resolution : ~ 17 ps

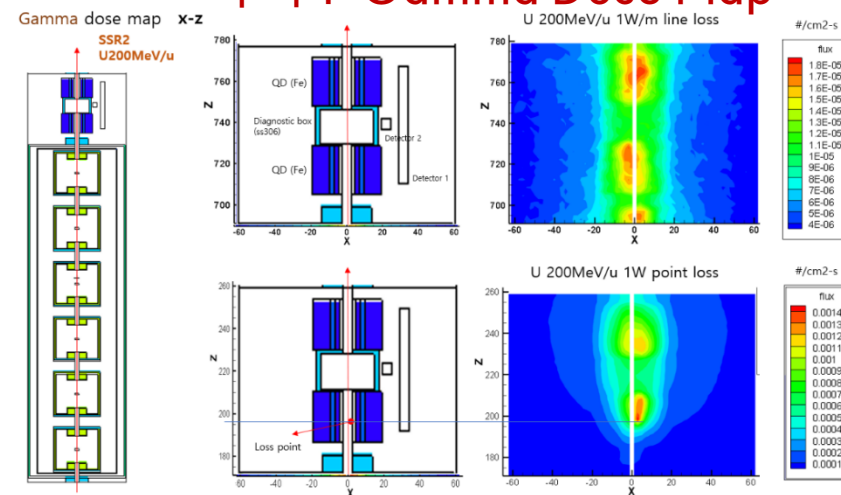
(81.25MHz)

Beam Instruments

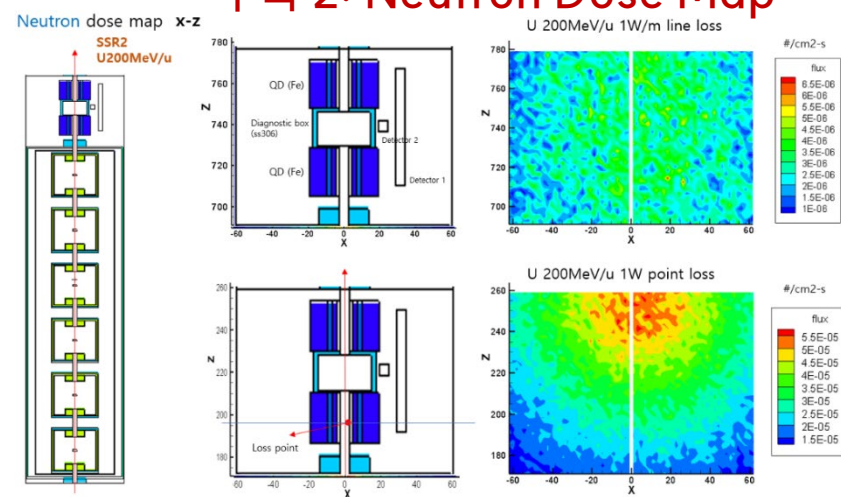
■ Beam Loss Monitor



부록 1: Gamma Dose Map



부록 2: Neutron Dose Map

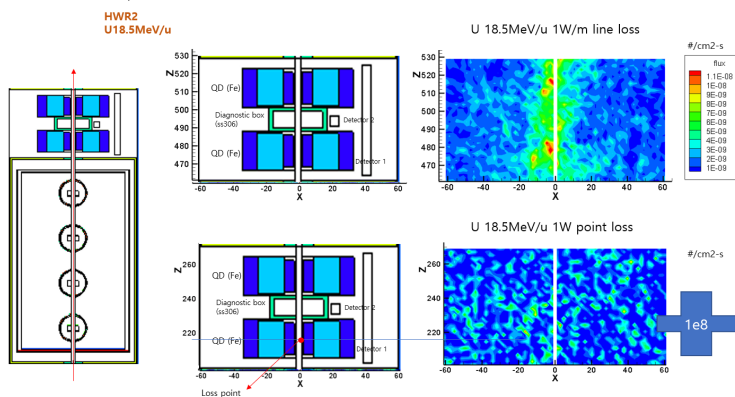


Beam Instruments

■ Beam Loss Monitor

Gamma dose map

Gamma dose map x-z

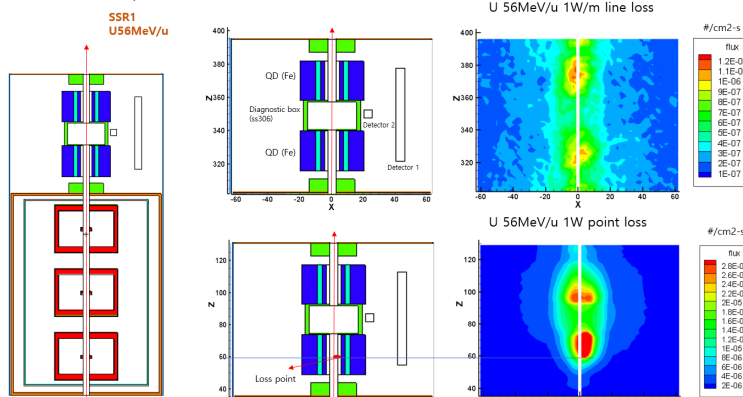


MCNPX simulation

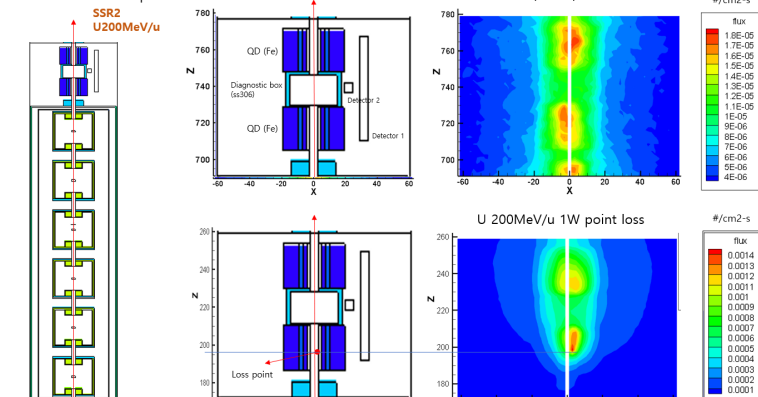
1W/m

1W point loss

Gamma dose map x-z



Gamma dose map x-z

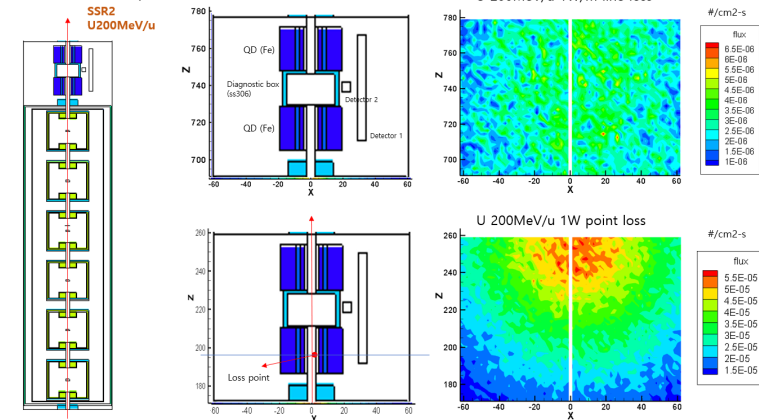


Low beam energy

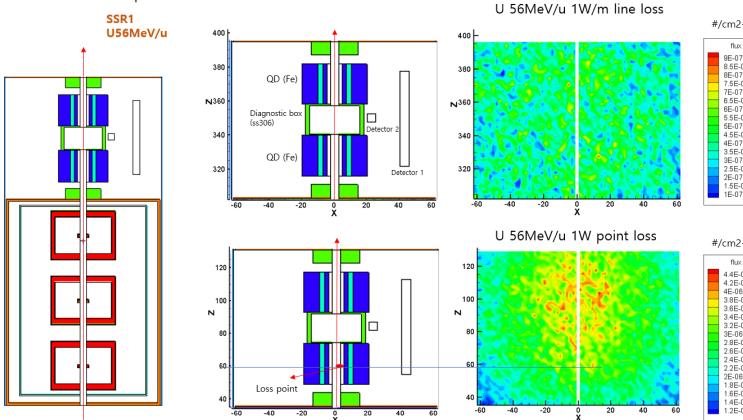
high beam energy

Neutron dose map

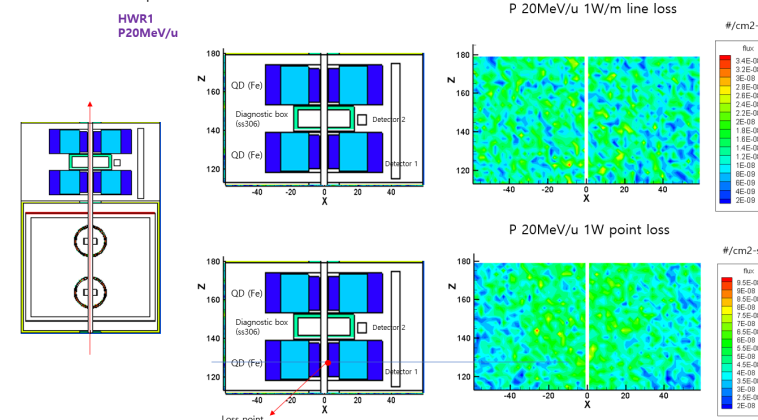
Neutron dose map x-z



Neutron dose map x-z

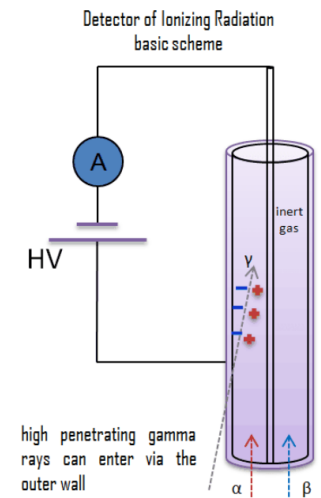
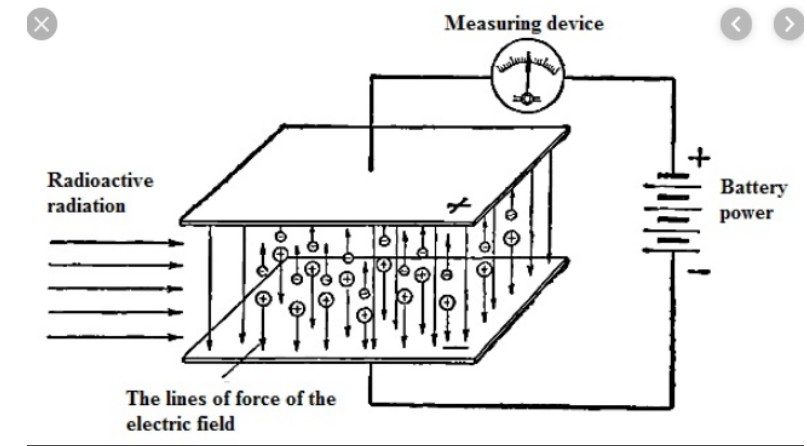
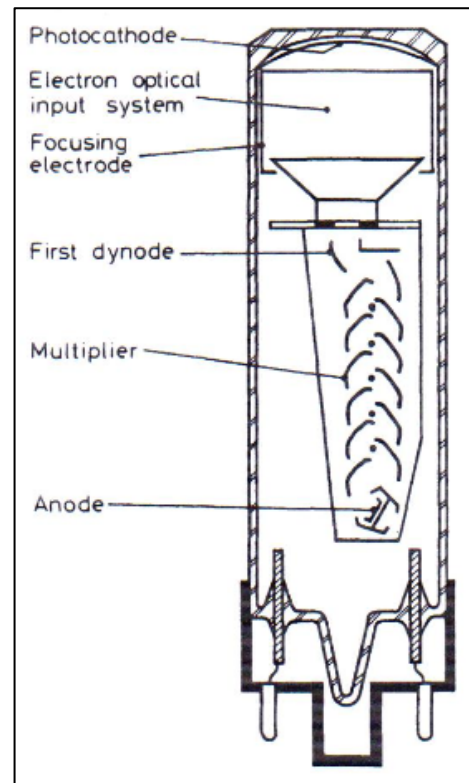
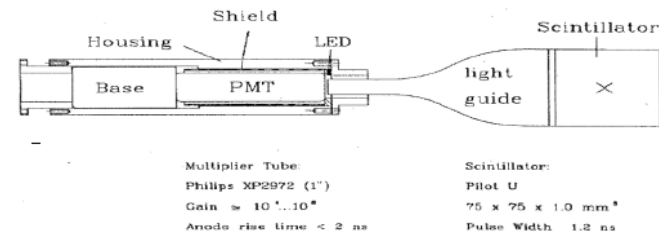
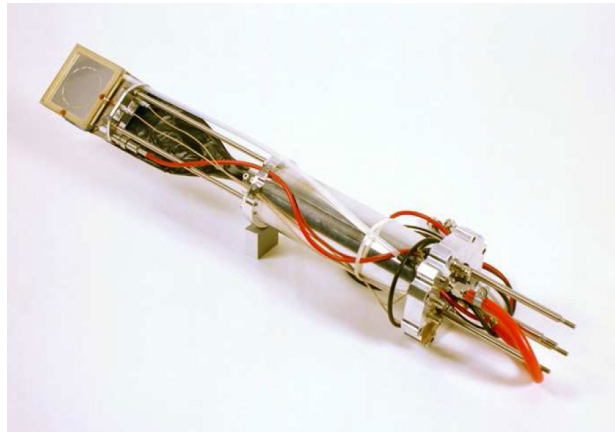


Neutron dose map x-z



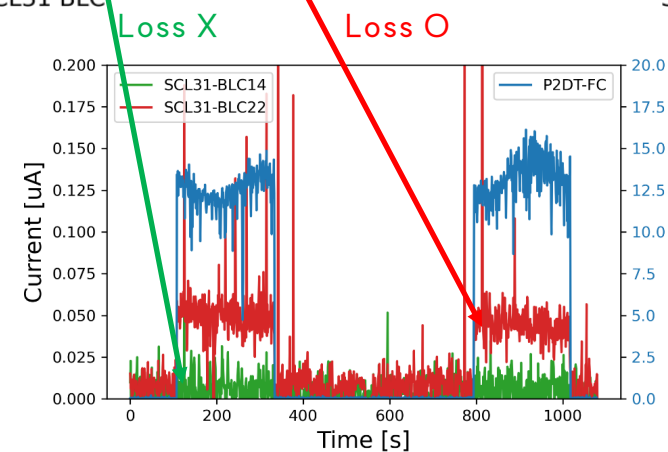
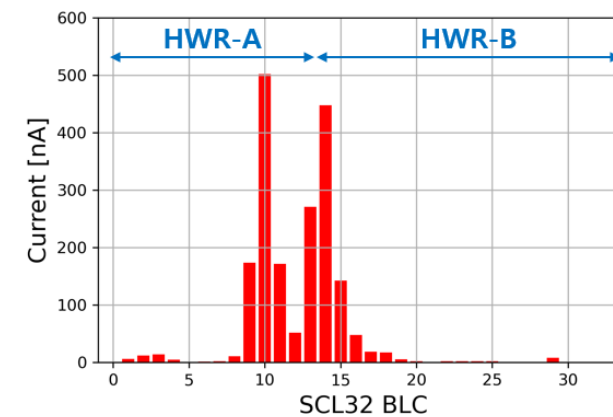
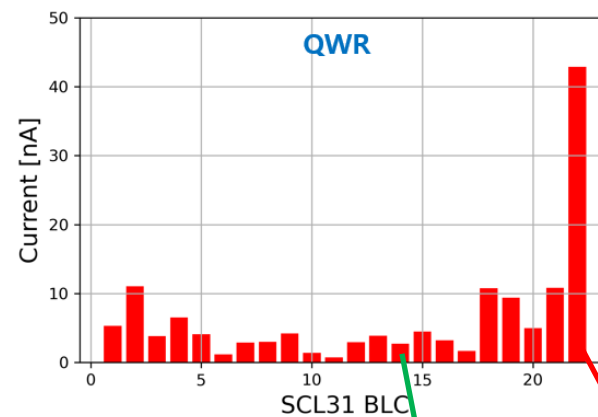
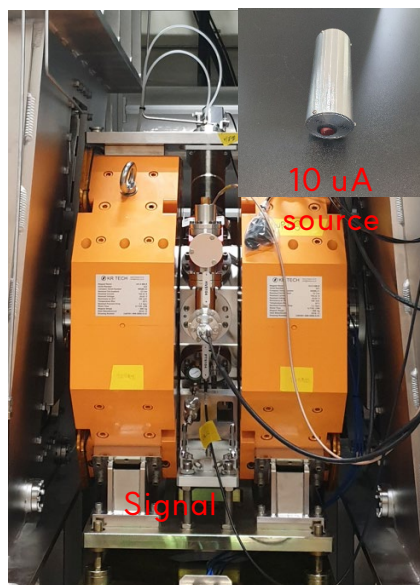
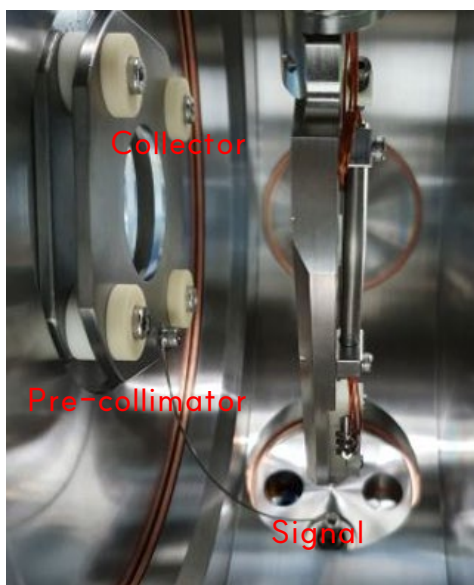
Beam Instruments

■ Beam Loss Monitor



Beam Instruments

- Beam Loss Monitor
- SCL3 BLC, <20 MeV/u



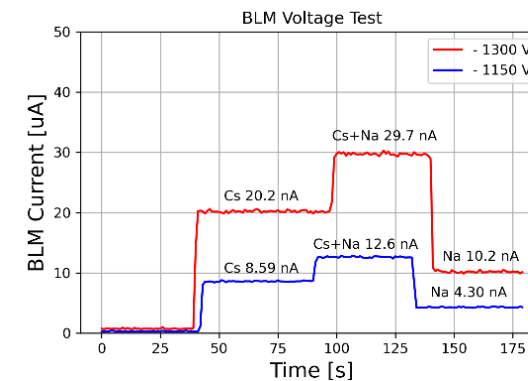
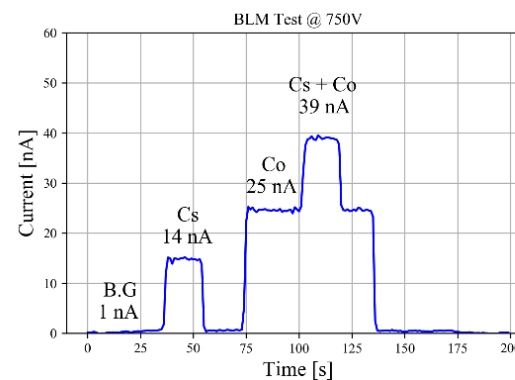
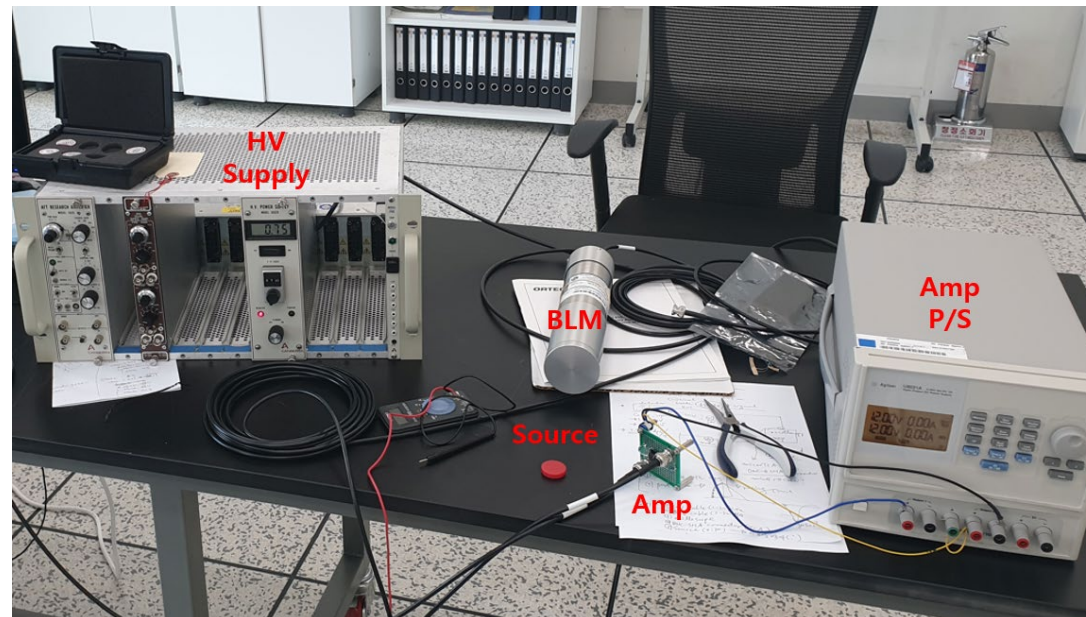
Beam Instruments

- Beam Loss Monitor
- Plastic detector



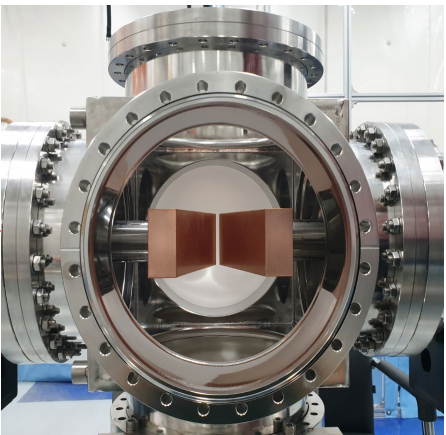
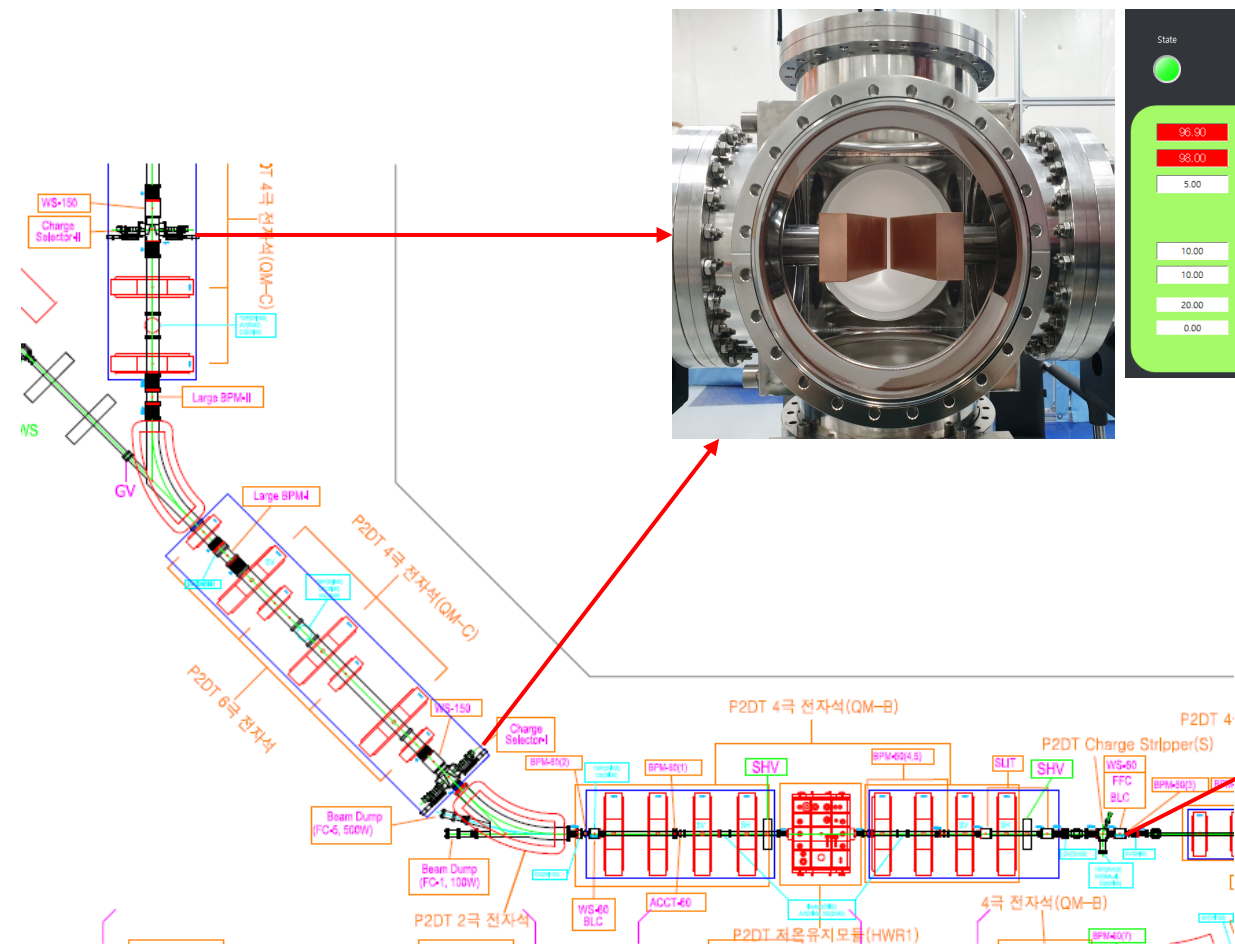
Device Specification

Rise time	0.35 ns
Decay time	1.4 ns
Operation HV	Negative
Scintillator dia.	5 cm
Scintillator thick	10 cm

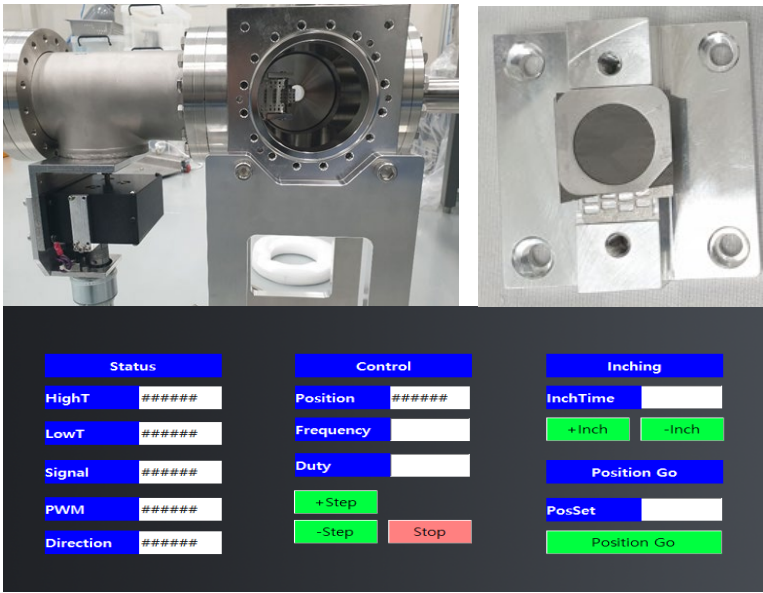


Beam Instruments

- Charge Stripper & selector

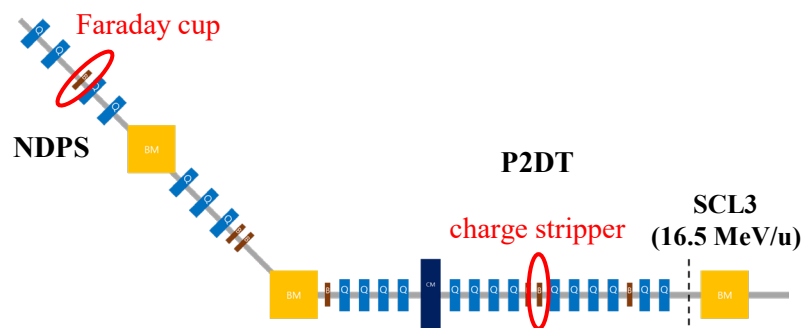


Charge Stripper

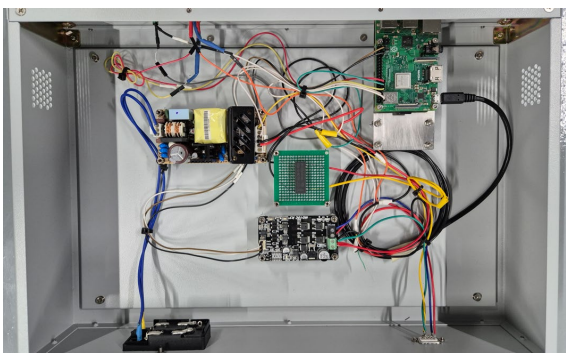


Beam Instruments

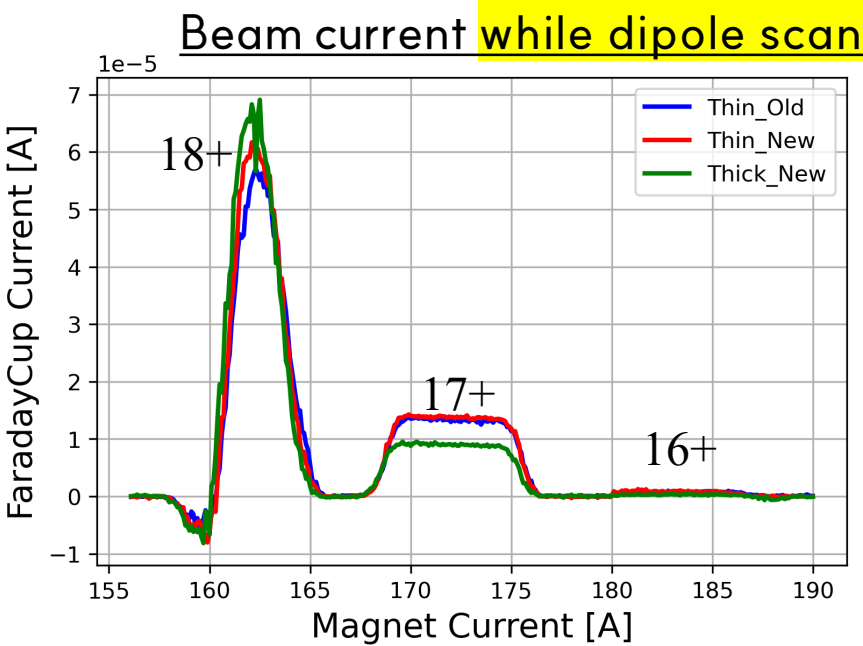
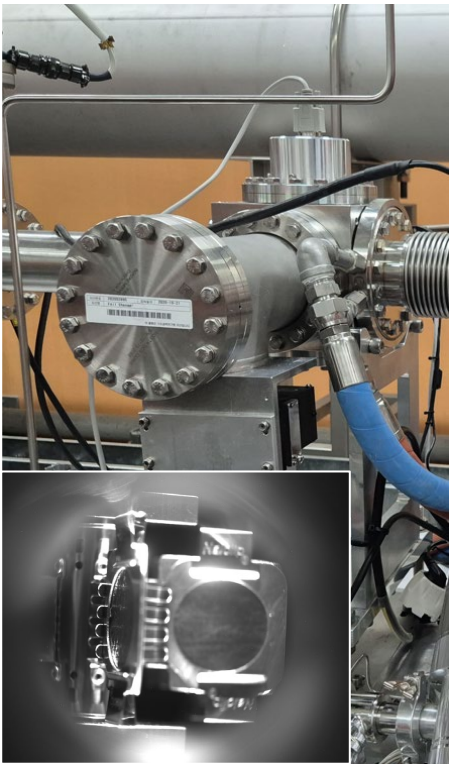
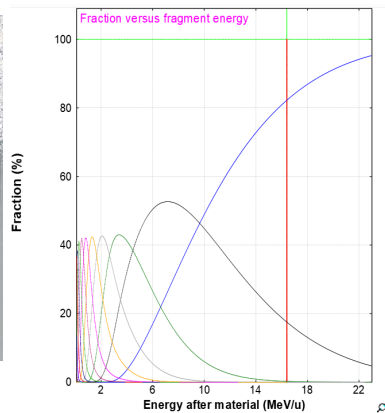
Charge Stripper & selector



Control box



Simulation result

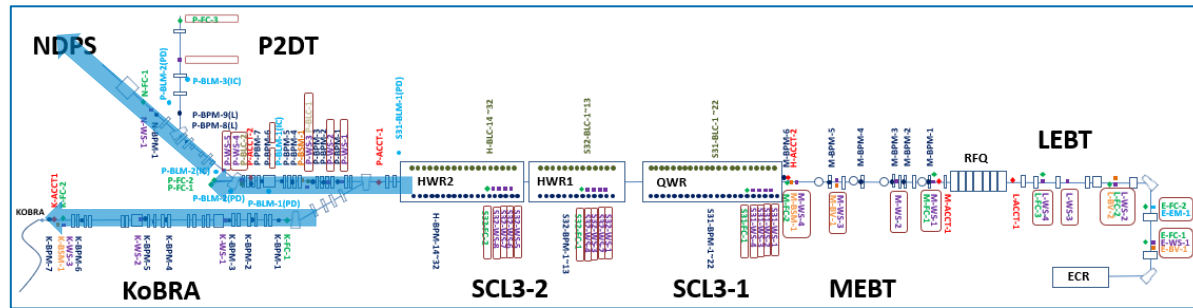


- EPICS based motor control program on Raspberry pi is running
- Two different thicknesses of carbon foil were installed.
- Charge stripping was performed at a rate similar to the simulation.

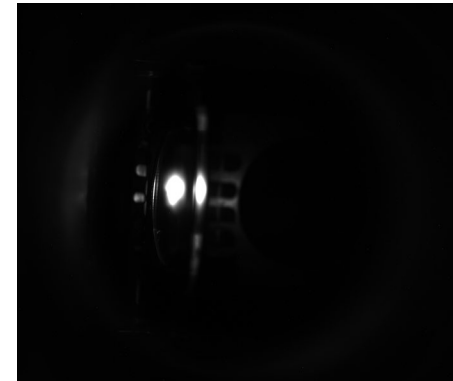
Foil type	Ar 16+	Ar 17+	Ar 18+
Thin_old	1.35 %	19.43 %	73.22 %
Thin_new	1.63 %	18.47 %	79.90 %
Thick_new	0.57 %	12.05 %	87.38 %
simulation	0.22 %	17.53 %	82.21 %

Beam loss monitor

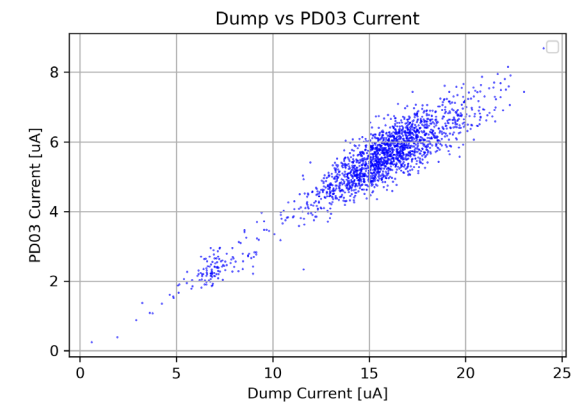
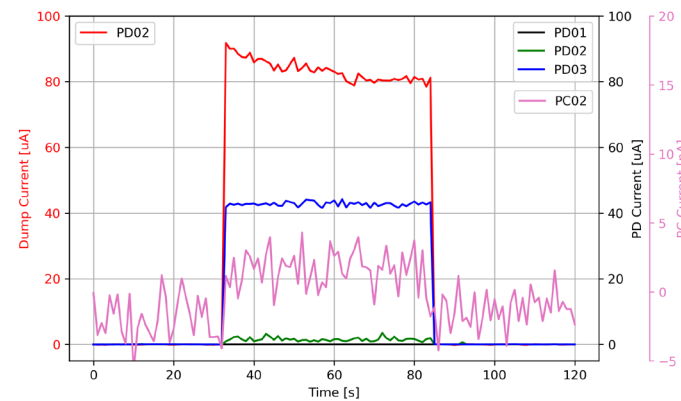
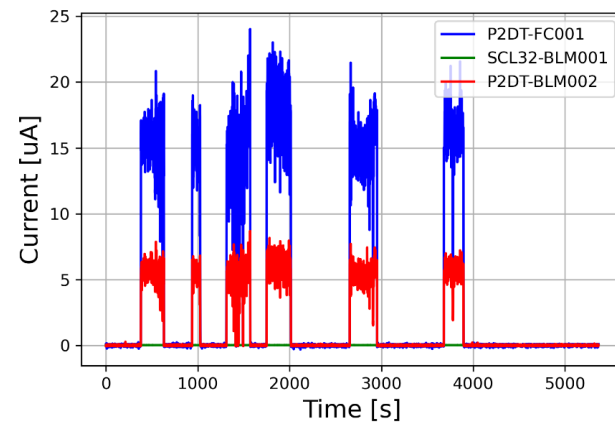
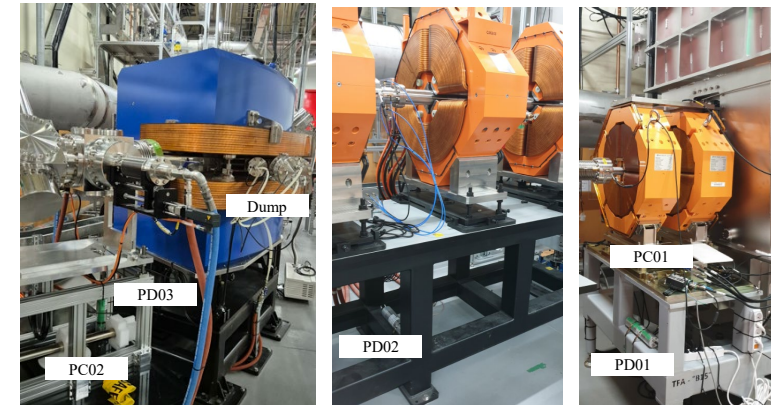
- Plastic detector and proportional counter



P2DT BV



P2DT BLM



감사합니다.

