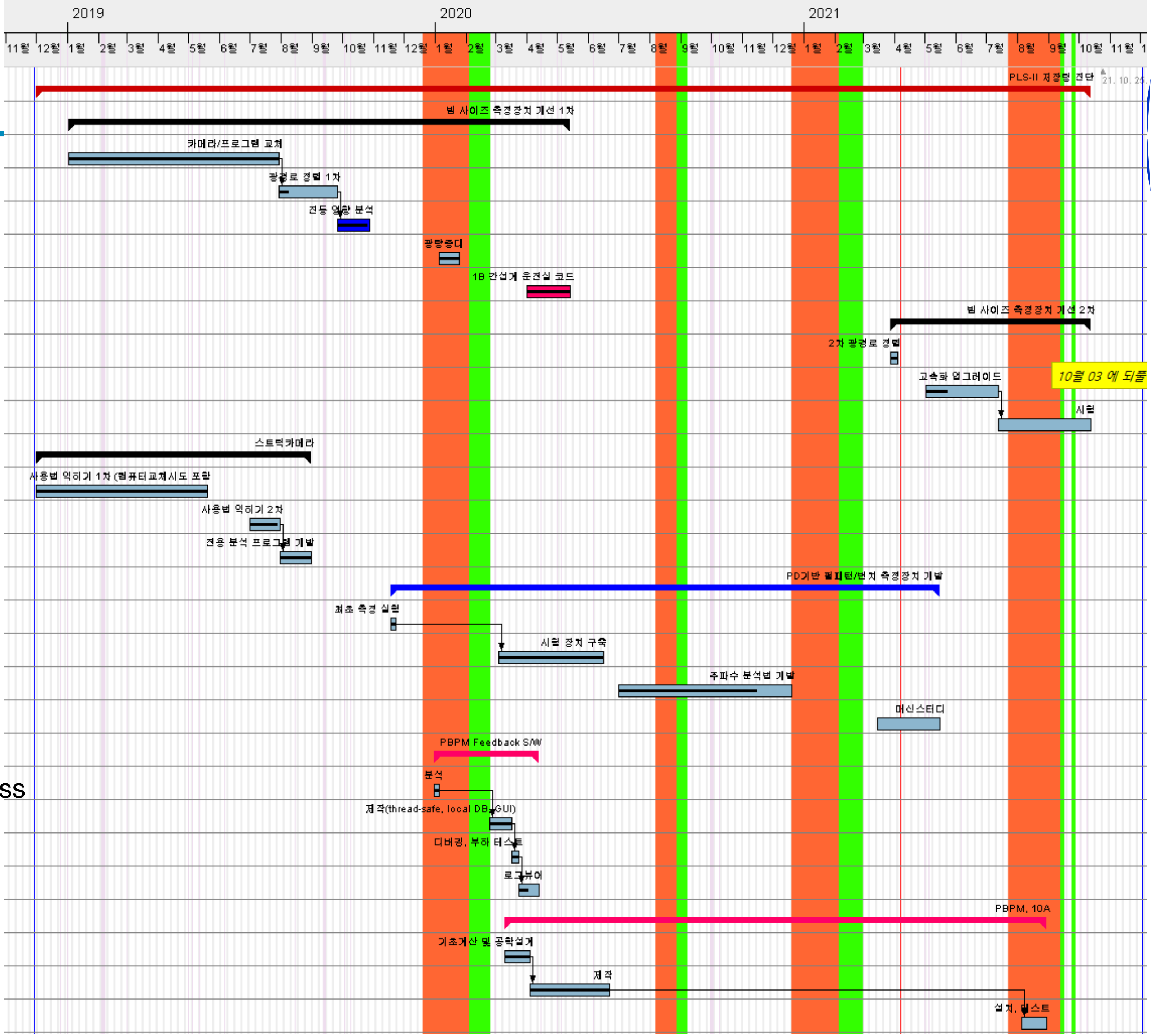
Beam Diagnostics R&D 일부 소개

한가람

13/May/2022

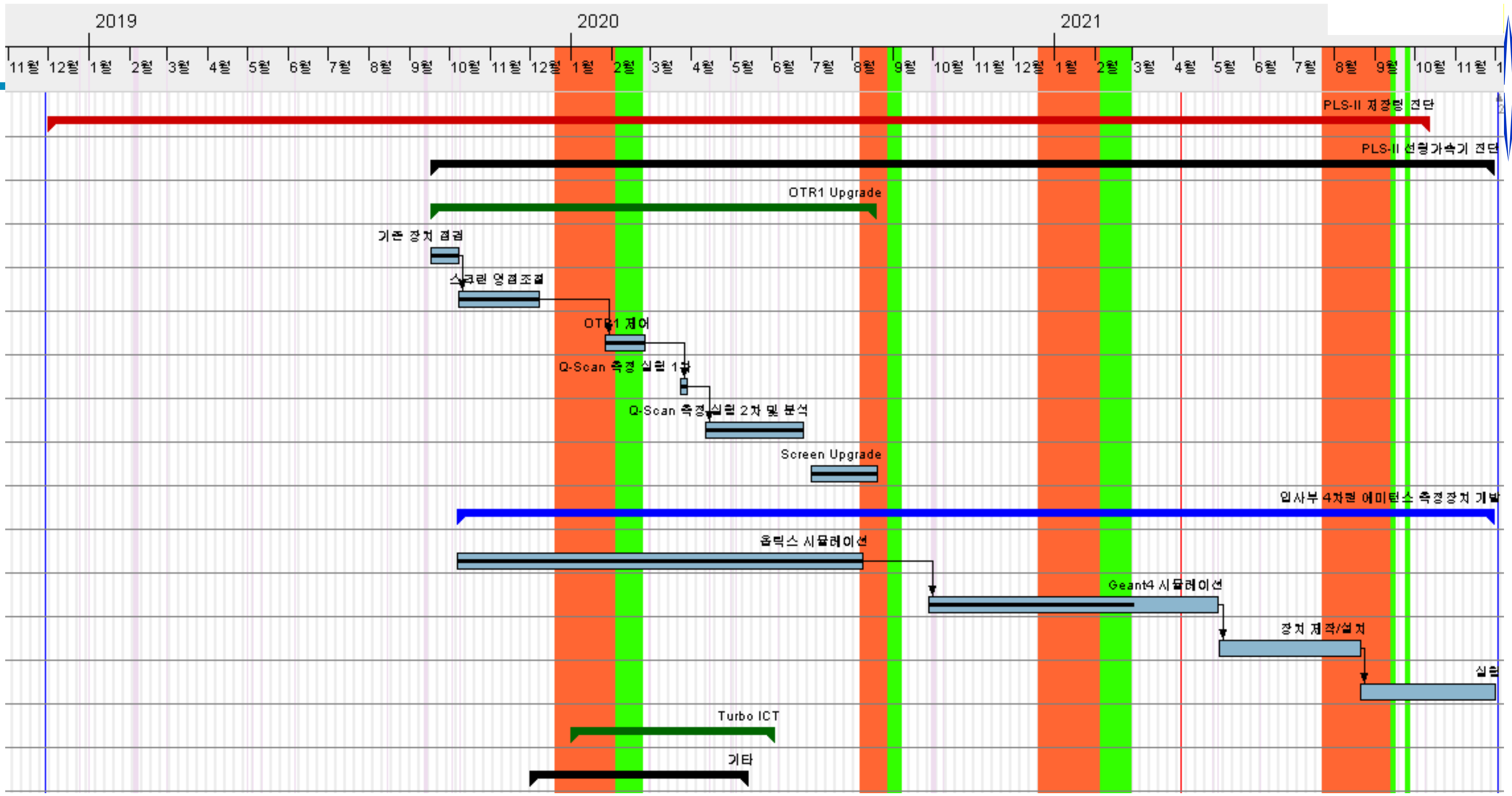
저장링

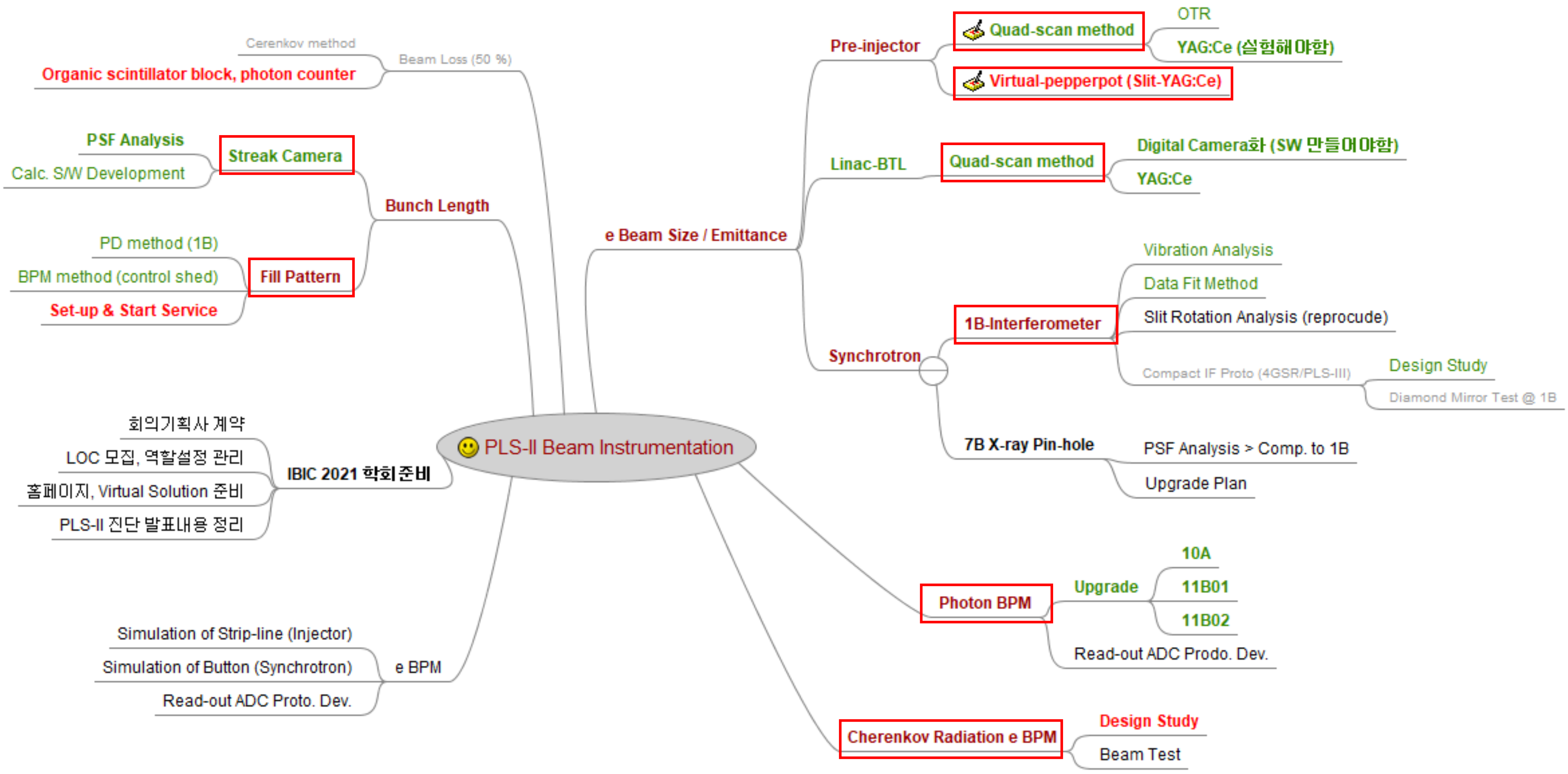
- 저장링 빔사이즈, 에미턴스
  - 분석 개선 (저속 단순계산 -> 고속 핏팅)
    관련 HW/SW 재구성
  - 광량 개선 (거울, 필터, 진동 등)
    30 Hz -> 130 Hz 측정
    기계 진동 성분 분리
  - 2차 고속화 (~4 kHz)
    느린 빔 불안정 모니터용
- 저장링 빔 번치 길이
  - 기존 Streak-camera (일시 측정용)동작
  - 신규 PD 상시측정장치 개발
    - 24시간 번치별 길이/전하량/시간 관측
- PBPM 개선
  - Tungsten blades -> Diamond blades
    Lower total crossection -> almost no E-loss
  - Blades 위치 차 -> decoupling cross-talk
  - Control SW 개선 (미반영)

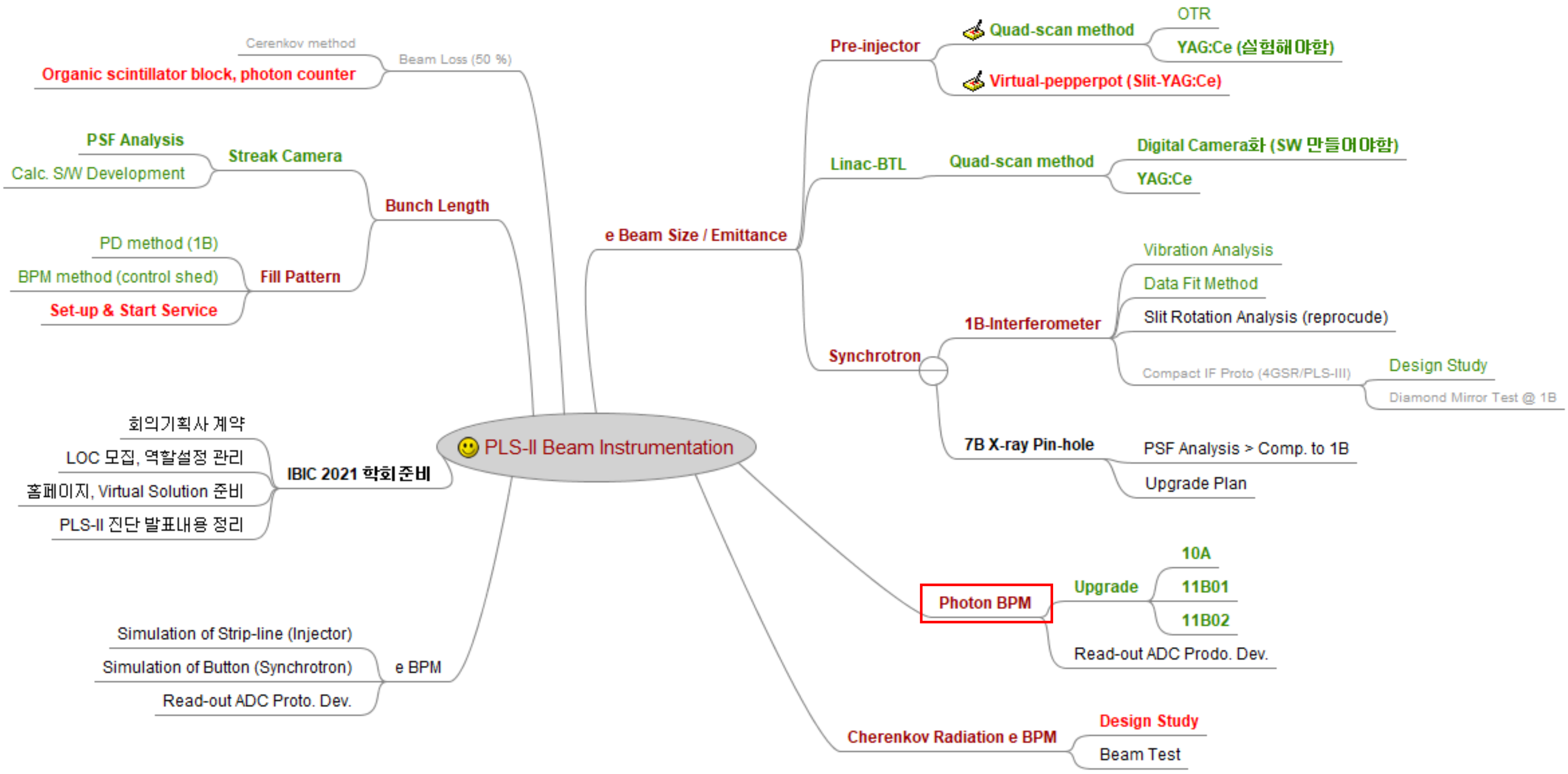


입사기

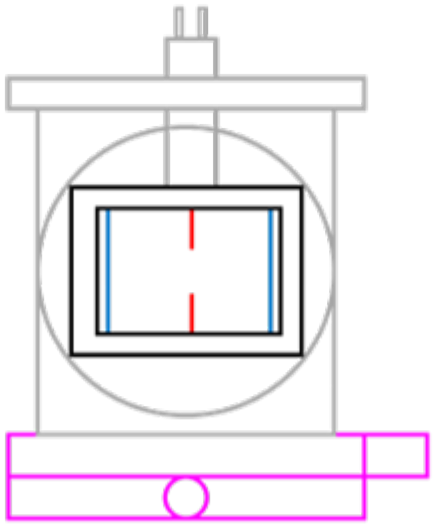
- 입사기 에미턴스 측정
  - Screen monitor 기능 개선
    광량 개선 : OTR -> YAG
    분해능 개선
    시간 : 3 s -> 0.1 s
    30 -> 1 macro-pulse/shot
    공간 : 104 um/px -> 25 um/px
  - 에미턴스 측정
    기존 시공간 분해능 제약을 극복
    115, 150 -> 14, 16 pi.mm.mrad
    현재 정상적 측정, e-gun 교체 대비 완료
  - 4차원 에미턴스 측정
    100 MeV 급 전자빔 4차원 에미턴스
    측정장치 개발(진행/시도중)



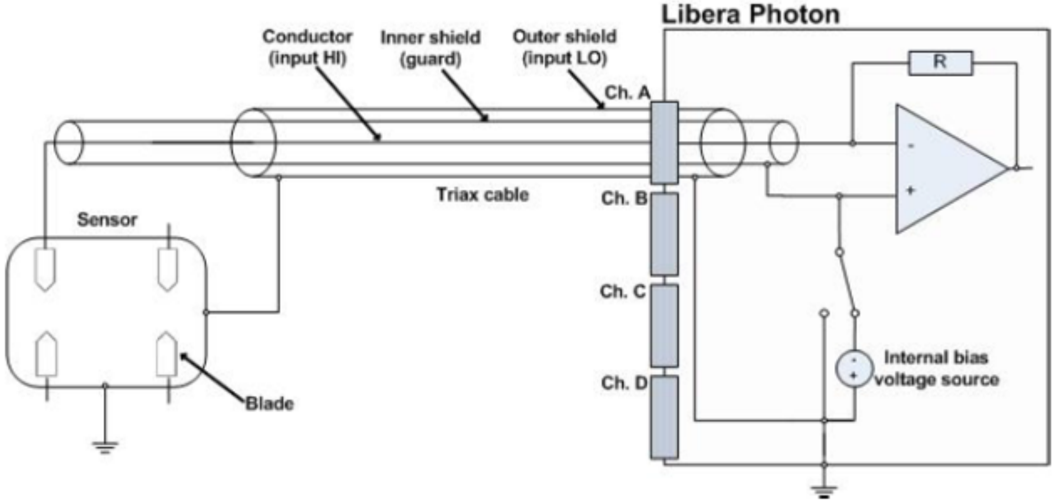

PLS-II Beam Instrumentation
Beam Loss (50 %)
Cerenkov method
Organic scintillator block, photon counter
Bunch Length
Streak Camera
PSF Analysis
Calc. S/W Development
Fill Pattern
PD method (1B)
BPM method (control shed)
Set-up & Start Service
IBIC 2021 학회준비
회의기획사 계약
LOC 모집, 역할설정 관리
홈페이지, Virtual Solution 준비
PLS-II 진단 발표내용 정리
e BPM
Simulation of Strip-line (Injector)
Simulation of Button (Synchrotron)
Read-out ADC Proto. Dev.
e Beam Size / Emittance
Pre-injector
Quad-scan method
OTR
YAG:Ce (실험해야함)
Virtual-pepperpot (Slit-YAG:Ce)
Linac-BTL
Quad-scan method
Digital Camera화 (SW 만들어야함)
YAG:Ce
Synchrotron
1B-Interferometer
Vibration Analysis
Data Fit Method
Slit Rotation Analysis (reprocude)
Compact IF Proto (4GSR/PLS-III)
Design Study
Diamond Mirror Test @ 1B
7B X-ray Pin-hole
PSF Analysis > Comp. to 1B
Upgrade Plan
Photon BPM
Upgrade
10A
11B01
11B02
Read-out ADC Prodo. Dev.
Cherenkov Radiation e BPM
Design Study
Beam Test


PLS-II Beam Instrumentation
Beam Loss (50 %)
Cerenkov method
Organic scintillator block, photon counter
Bunch Length
Streak Camera
PSF Analysis
Calc. S/W Development
Fill Pattern
PD method (1B)
BPM method (control shed)
Set-up & Start Service
IBIC 2021 학회준비
회의기획사 계약
LOC 모집, 역할설정 관리
홈페이지, Virtual Solution 준비
PLS-II 진단 발표내용 정리
e BPM
Simulation of Strip-line (Injector)
Simulation of Button (Synchrotron)
Read-out ADC Proto. Dev.
e Beam Size / Emittance
Pre-injector
Quad-scan method
OTR
YAG:Ce (실험해야함)
Virtual-pepperpot (Slit-YAG:Ce)
Linac-BTL
Quad-scan method
Digital Camera화 (SW 만들어야함)
YAG:Ce
Synchrotron
1B-Interferometer
Vibration Analysis
Data Fit Method
Slit Rotation Analysis (reprocude)
Compact IF Proto (4GSR/PLS-III)
Design Study
Diamond Mirror Test @ 1B
7B X-ray Pin-hole
PSF Analysis > Comp. to 1B
Upgrade Plan
Photon BPM
Upgrade
10A
11B01
11B02
Read-out ADC Prodo. Dev.
Cherenkov Radiation e BPM
Design Study
Beam Test

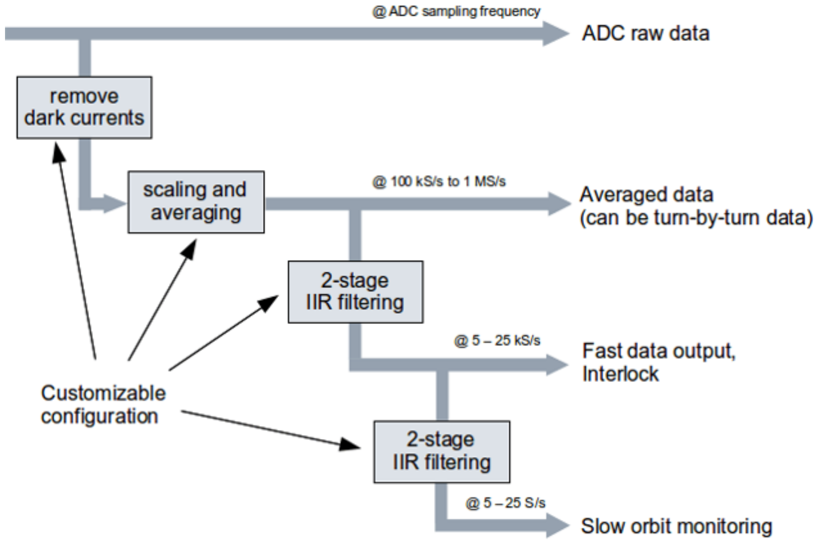
PBPM : Basic



- Copper body
  - 80 x 60 mm
- Tungsten blades
  - 0.5 mm thickness
- High voltage electrode
- Water cooling system
- Translation stage
  - Horizontal, vertical



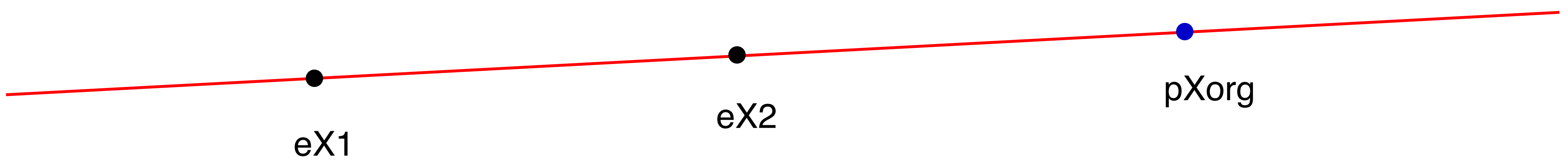
10 Hz Sampling



PBPM : Feedback Algorithm

- **최초 실행 시 Photon Beam (PB) position 기록, pXorg**
- **While True (2초 마다 반복)**
  - 현재 PB position N회 반복 읽음, 평균 구함 <pXnow>
  - dX = <pXnow> - pXorg 계산
  - 현재 eX1, eX2 위치 읽고 아래의 계산 수행
    - eX1_new = eX1 + dX / dL * G
    - eX2_new = eX2 - dX / dL * G

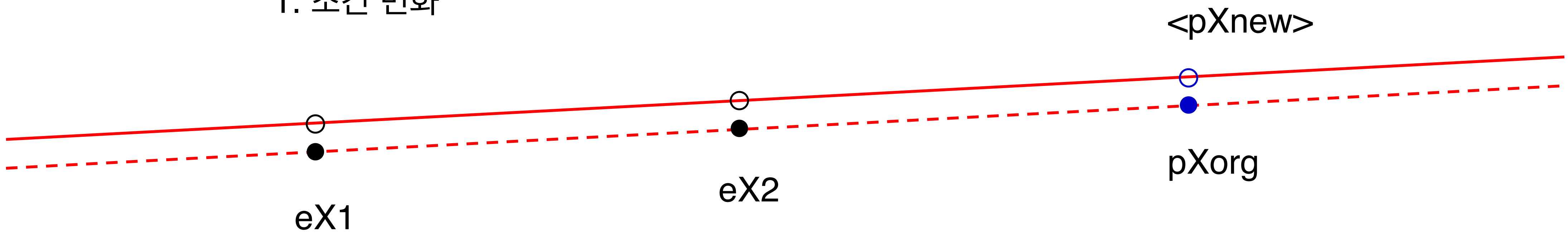
초기 조건



PBPM : Feedback Algorithm

- **최초 실행 시 Photon Beam (PB) position 기록, pXorg**
- **While True (2초 마다 반복)**
  - 현재 PB position N회 반복 읽음, 평균 구함 <pXnow>
  - dX = <pXnow> - pXorg 계산
  - 현재 eX1, eX2 위치 읽고 아래의 계산 수행
    - eX1_new = eX1 + dX / dL * G
    - eX2_new = eX2 - dX / dL * G

1. 조건 변화

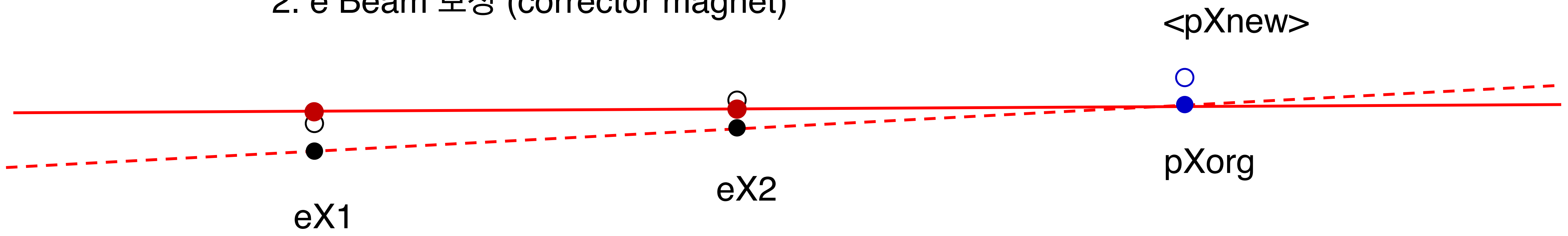


예) eBPM 자체의 위치가 열 변형, 지반 변형 등에 의해 틀어진 경우,
eBPM은 자신이 아직도 변한 위치가 아닌 원래 위치라고 측정함.

PBPM : Feedback Algorithm

- **최초 실행 시 Photon Beam (PB) position 기록, pXorg**
- **While True (2초 마다 반복)**
  - 현재 PB position N회 반복 읽음, 평균 구함 <pXnow>
  - dX = <pXnow> - pXorg 계산
  - 현재 eX1, eX2 위치 읽고 아래의 계산 수행
    - eX1_new = eX1 + dX / dL * G
    - eX2_new = eX2 - dX / dL * G

2. e Beam 보정 (corrector magnet)

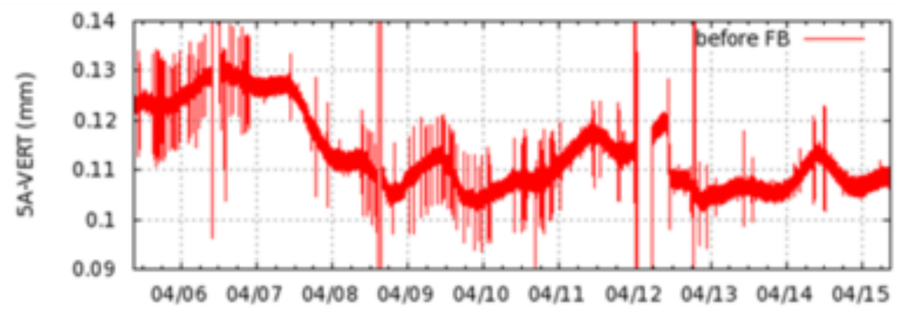


예) eBPM 자체의 위치가 열 변형, 지반 변형 등에 의해 틀어진 경우,
eBPM은 자신이 아직도 변한 위치가 아닌 원래 위치라고 착각함.

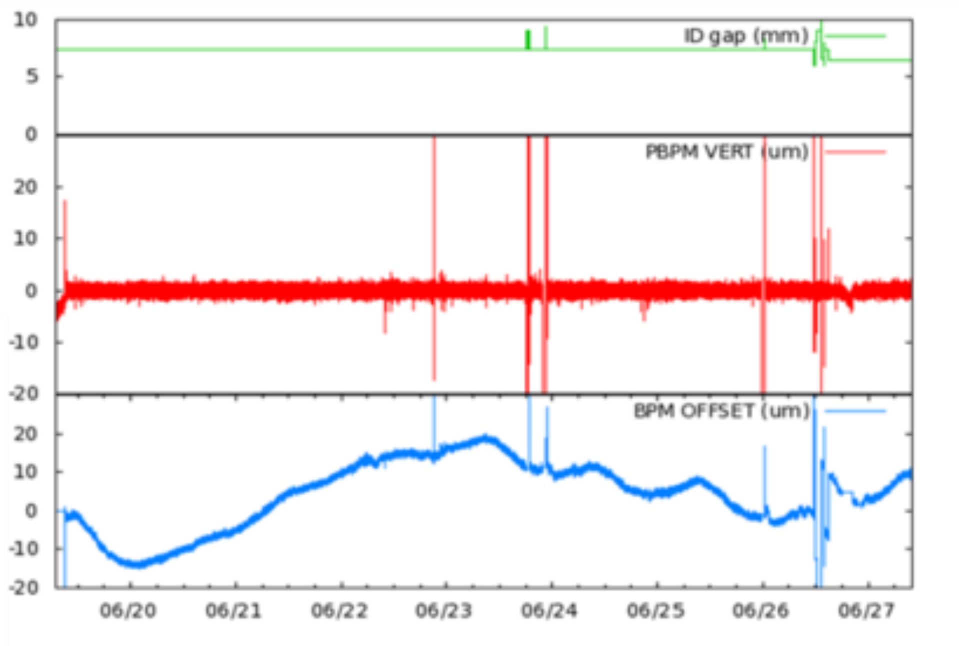
PBPM : Feedback Algorithm

- **Remarks**
  - 장점 : PBPM 위치에서 항상 photon 빔의 위치 유지
  - 단점 : photon beam 각도 변화 가능 --> 7B 각도 까지 보정 가능한 PBPM 스터디 중
- **장기적 대안 :**
  - 절대 위치 eBPM, pBPM 개발 --> 견고한 support + BPM chamber 위치 트랙킹 장치
    - 그래도 BL station 지반이 변화하면 답 없음...

Before



After



Feedback 운전 상황

총 16개 PBPM 중 feedback 적용 된 13개 빔라인에서 모두 운영 중

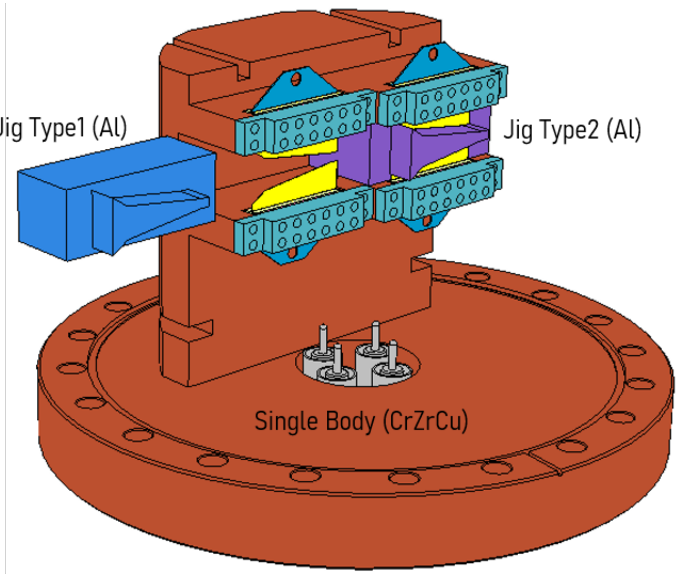
No	Beamline	Calibration (250mA)	Feedback
1	1C	X: 789000, Y: 769000 (ID gap 6.5mm)	미적용
2	3C	X: 2870000, Y: 624000 (ID gap 6.5mm)	O
3	4C	X: 1730000, Y: 890000 (ID gap 7.0mm)	O
4	5A	Y: 1.05 (ID gap 7.4mm)	O
5	5C	X: 2570000, Y: 930000 (ID gap 6.0mm)	O
6	6D	Y: 450000	O
7	7A	X: 2100000, Y: 1070000 (ID gap 6.0mm)	O
8	7C	X: 1210000, Y: 107000 (ID gap 7.1mm)	O
9	8A	Y: 1.31, ID gap table (22~60mm)	O
10	8C	X: 1750000, Y: 1160000 (ID gap 7.6mm)	O
11	**9A**	X: 1500000, Y: 1500000 (ID gap 6.7mm)	O
12	**9B**	Y: 850000	O
13	**9C**	X: 1130000, Y: 940000 (ID gap 7.4mm)	O
14	9D	Y : 0.75	미적용
15	10D	Y : 0.76	미적용
16	11C	X: 1360000, Y: 870000 (ID gap 7.3mm)	O

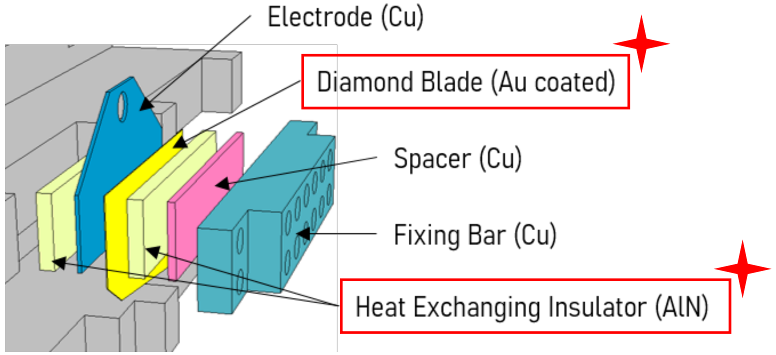
1C : user service 이전
9D : old pbpm
10D : old pbpm

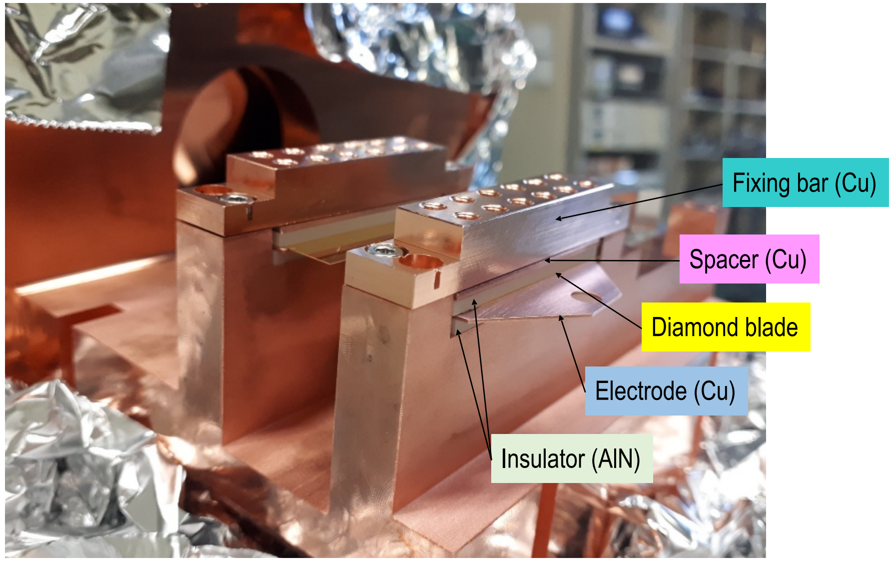
PBPM : Upgrade

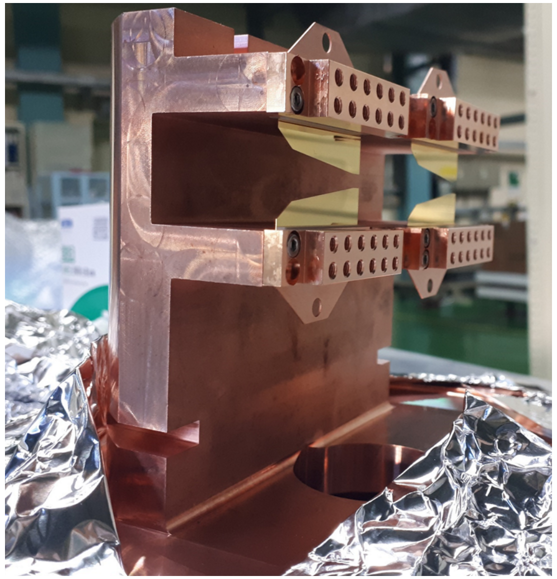
- **Hardware [2020/05~12]**
  - 기존 : Tungsten Blades
  - 신규 : Diamond Blades + Metal Coat
  - 차이 1 : 밀도
    - 낮은 X-ray Crossection -> 낮은 Linear Energy Transfer -> 높은 pBeam power 에도 견딤
  - 차이 2 : 구조
    - Horizontal 방향 Scattering을 Decouple 시킴 -> Cross-talk 효과 감소 -> 정밀도 증가
- **Feedback Software [2020/05~07]**
  - 기존 : Bash Script
  - 신규 : Python Deamon
  - 차이 1 : 기능
    - 빔라인별 로그 제공, 주변 제어기에 적게 데이터 호출, 낮은 부하, 안정적 동작

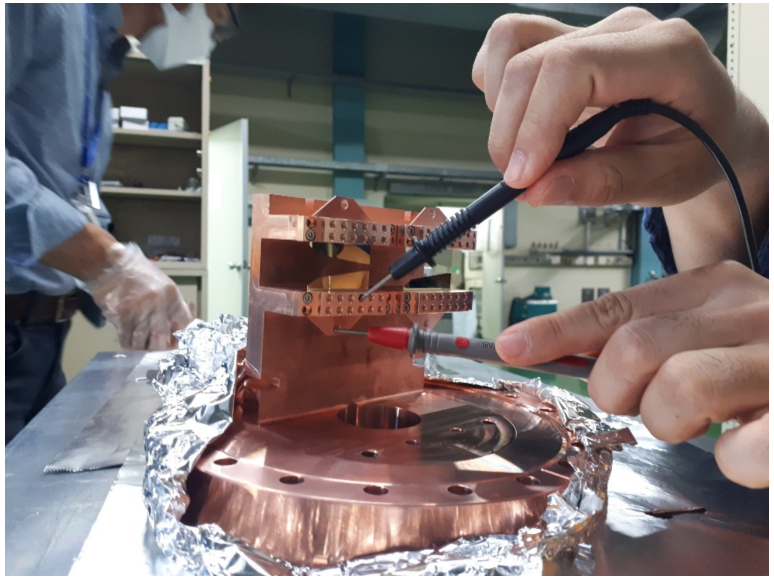
※ 10 PBPM 조립 중

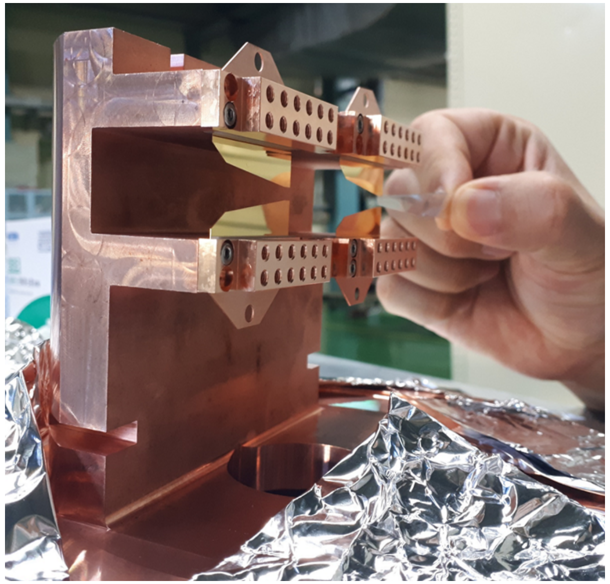







1차 조립 완성


절연시험

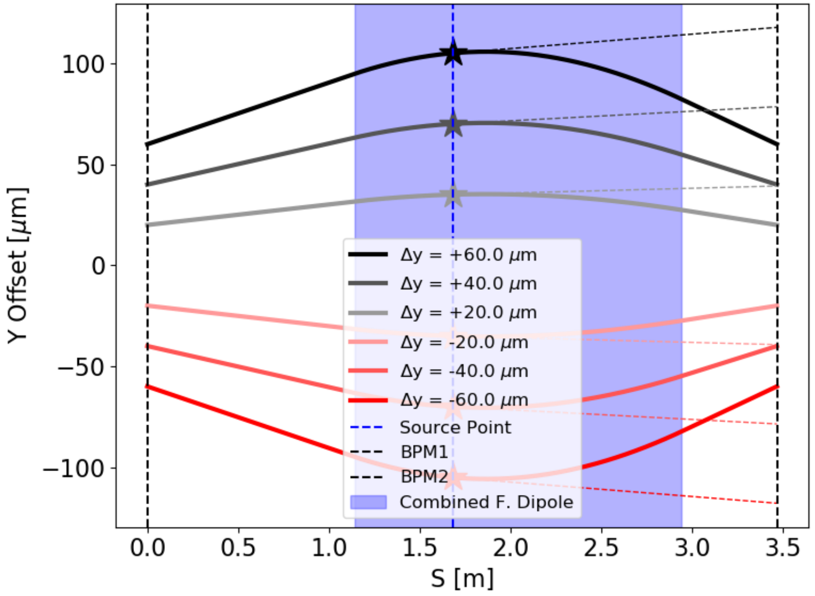

간극(3 mm) 측정

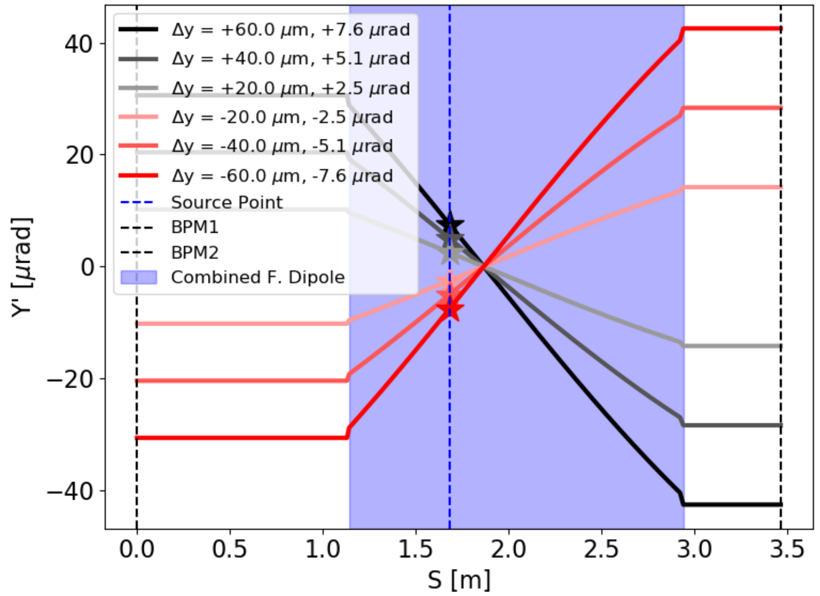
계산을 통한 7B Offset 실험 결과의 재현

문제 : 7B 에서 PBPM 2개로 재 보니, e beam의 vertical offse을 조절하면, 수직 각도가 바뀜을 발견

분석 : 시뮬레이션

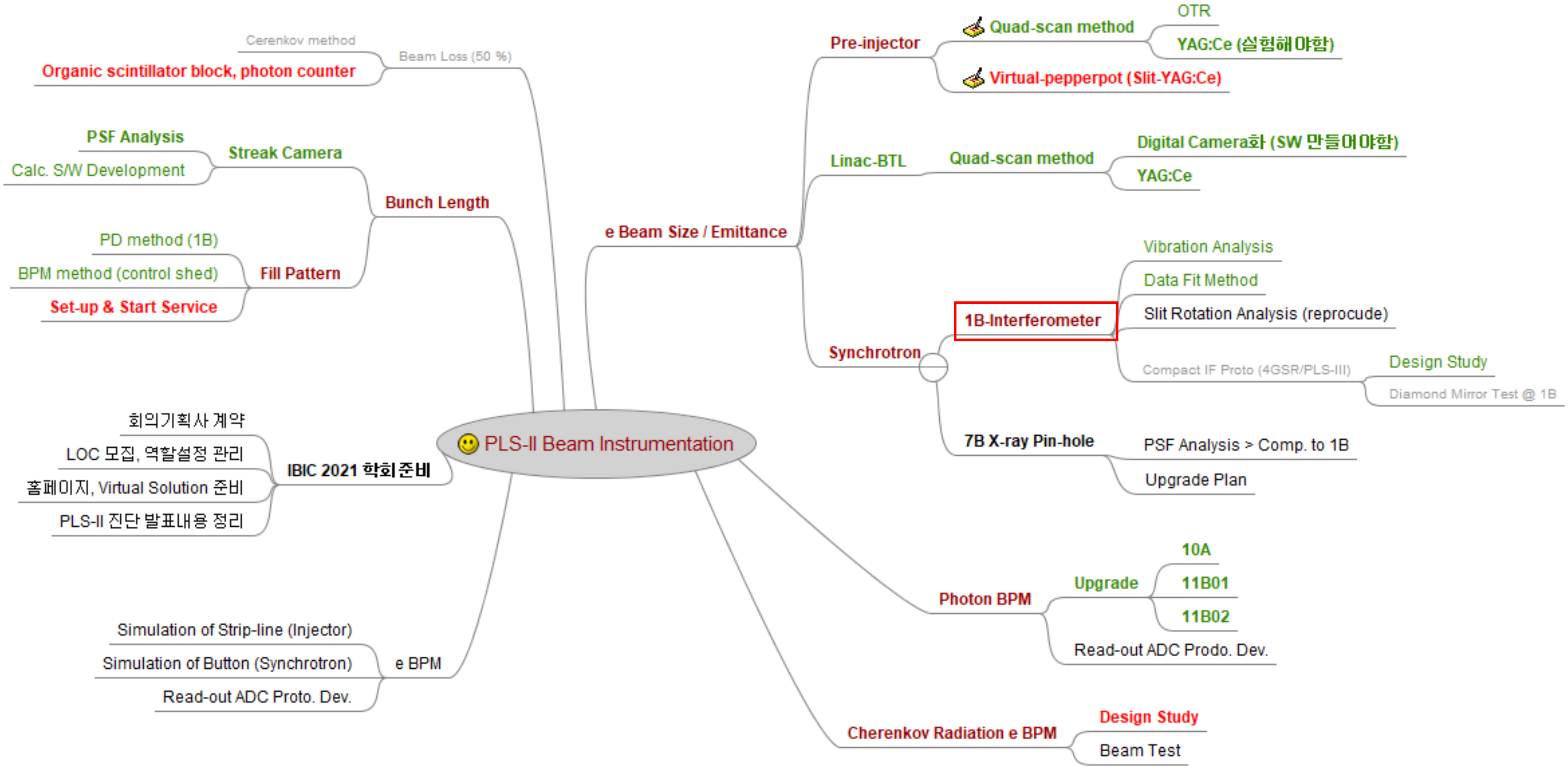
- 60, 40, 20 urad 에 대해서 해를 다 찾아보면, 실험과 비슷하게 나옴
- 따라서, 이 실험 결과는 Combined Function (B+Q)의 Q 성분 kicking 기여 때문으로 추정됨





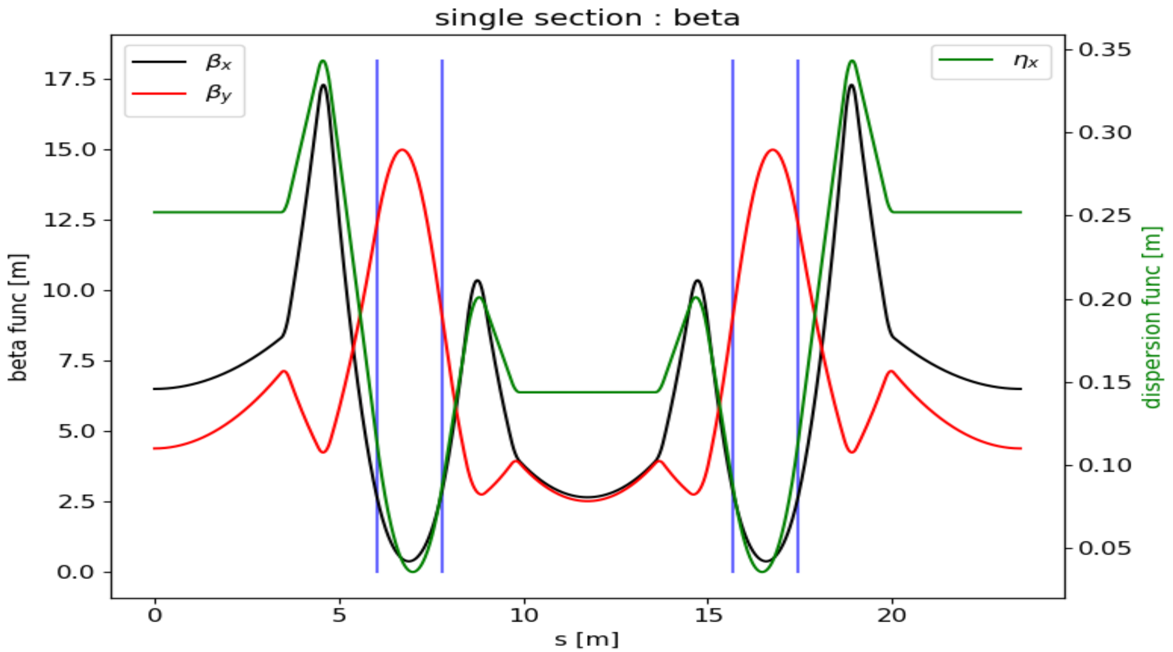
ds= 7.53 [m]

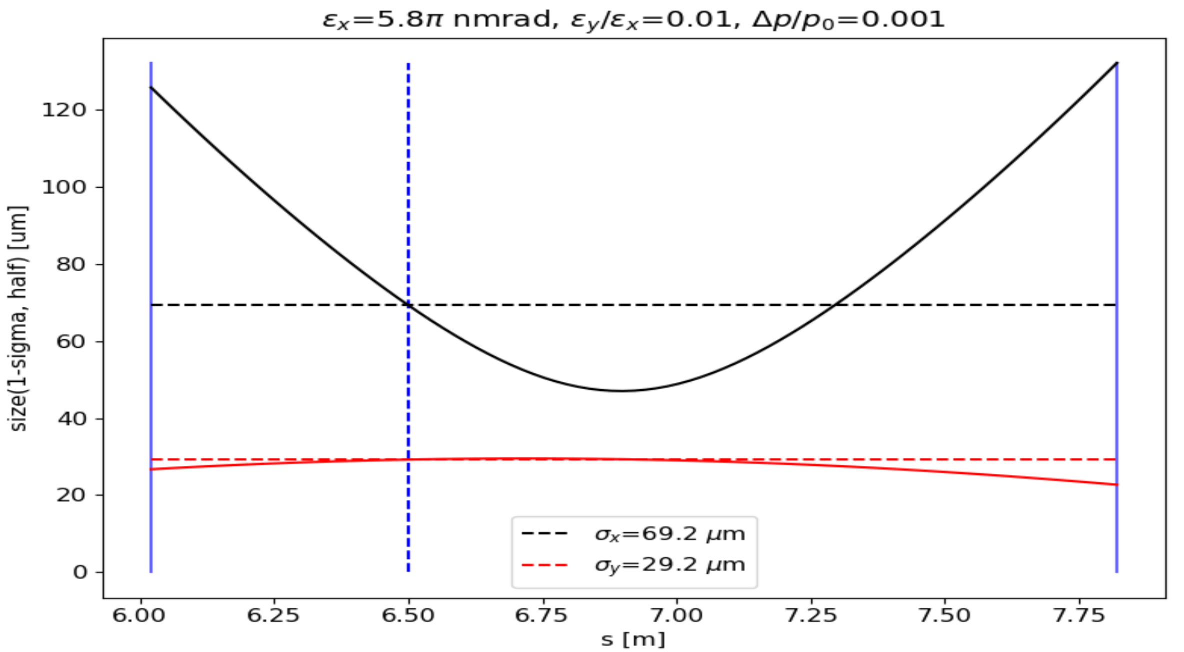
y_offset	dy/ds [urad]	(dy/ds)-y'$_0$ [urad]
0	0.954	0.000
20	3.831	2.877
40	6.348	5.394
60	8.579	7.625
0	0.421	0.000
-20	-1.899	-2.320
-40	-4.568	-4.989
-60	-6.826	-7.247



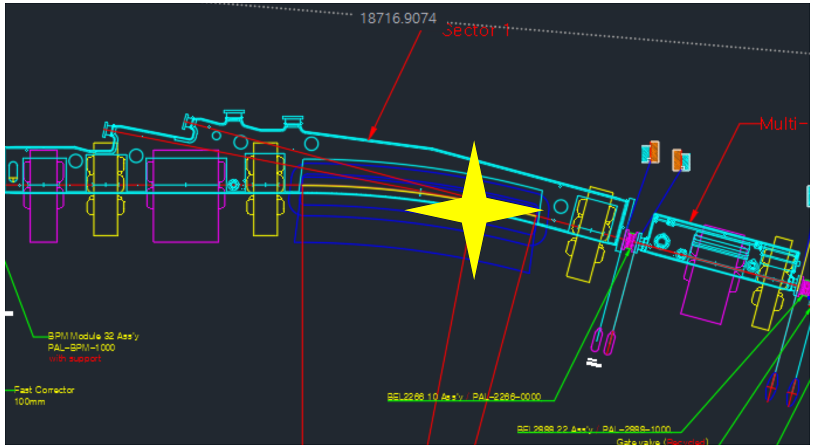
PLS-II Beam Instrumentation
Beam Loss (50 %)
Cerenkov method
Organic scintillator block, photon counter
Bunch Length
Streak Camera
PSF Analysis
Calc. S/W Development
Fill Pattern
PD method (1B)
BPM method (control shed)
Set-up & Start Service
IBIC 2021 학회준비
회의기획사 계약
LOC 모집, 역할설정 관리
홈페이지, Virtual Solution 준비
PLS-II 진단 발표내용 정리
e BPM
Simulation of Strip-line (Injector)
Simulation of Button (Synchrotron)
Read-out ADC Proto. Dev.
e Beam Size / Emittance
Pre-injector
Quad-scan method
OTR
YAG:Ce (실험해야함)
Virtual-pepperpot (Slit-YAG:Ce)
Linac-BTL
Quad-scan method
Digital Camera화 (SW 만들어야함)
YAG:Ce
Synchrotron
1B-Interferometer
Vibration Analysis
Data Fit Method
Slit Rotation Analysis (reprocude)
Compact IF Proto (4GSR/PLS-III)
Design Study
Diamond Mirror Test @ 1B
7B X-ray Pin-hole
PSF Analysis > Comp. to 1B
Upgrade Plan
Photon BPM
Upgrade
10A
11B01
11B02
Read-out ADC Prodo. Dev.
Cherenkov Radiation e BPM
Design Study
Beam Test

1B Interferometer : Design Value

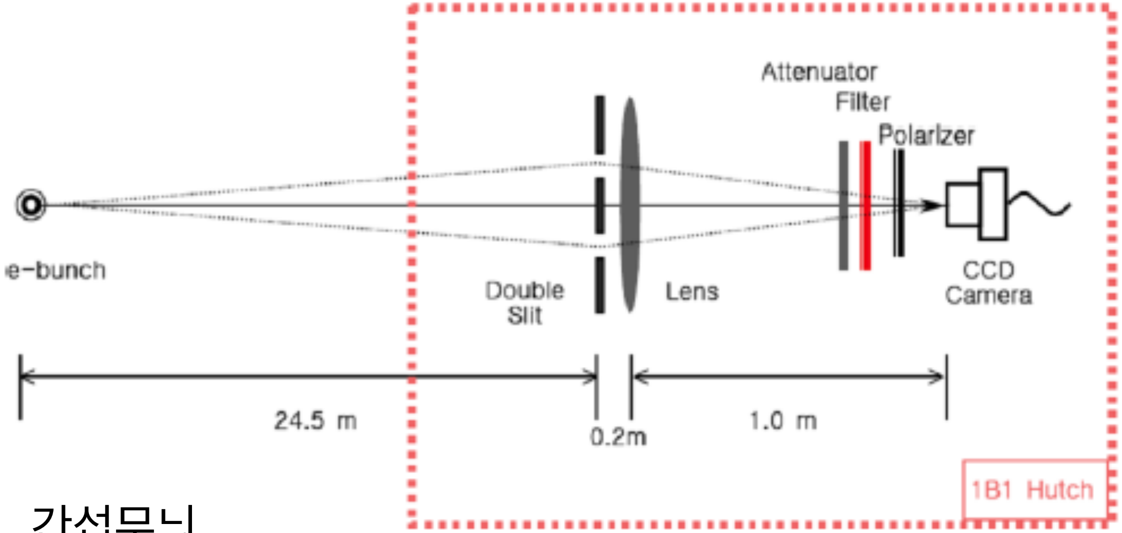




- **Based on PLS-II Lattice Design**
  - SR generated 4 deg in BM



1B Interferometer : Theory



간섭무늬

$$I(y) = I_0 \left[\mathrm{sinc}\left(\frac{2\pi a}{\lambda R} y \right) \right]^2 \left[1 + \gamma \cos\left(\frac{2\pi D}{\lambda R} y + \varphi \right) \right]$$

가우시안 분포일때, visibility 와 빔사이즈 관계

$$\gamma = \exp\left[-\frac{1}{2} \left(\frac{2\pi D}{\lambda L} \right)^2 \sigma^2 \right] \rightarrow \sigma = \frac{\lambda L}{\pi D} \sqrt{\frac{1}{2} \ln\left(\frac{1}{\gamma} \right)}$$

Visibility는 간섭무늬에서 구할 수 있으므로 사이즈 계산 가능

$$\gamma = \frac{I_{max} - I_{min}}{I_{max} + I_{min}}.$$

$$I = I_0 \left\{ \frac{\sin(u)}{u} \right\}^2 \left\{ 1 + \left| \frac{2J_1(\upsilon)}{\upsilon} \gamma \right| \cos(\delta) \right\}$$

$$u = \frac{kax}{R}, \ v = \frac{k\xi d}{L}, \ \delta = \frac{kdx}{R}$$

k: Wave number
a: Silt width
ξ: Source size
d: Slit separation

$$\gamma = \exp\left[-\frac{1}{2} v^2 \right] = \frac{I_{max} - I_{min}}{I_{max} + I_{min}}$$

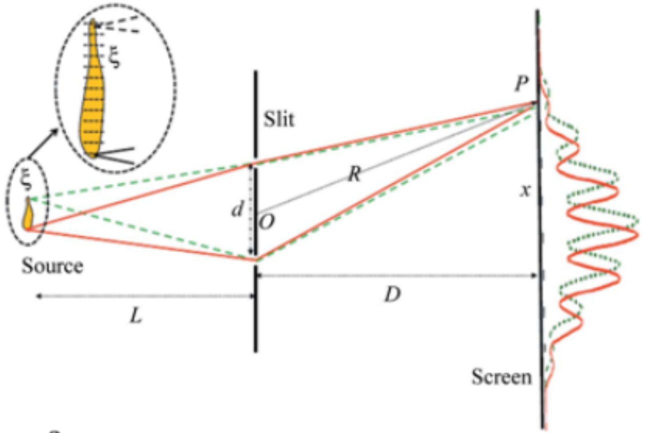


Figure 2
Configuration of the interference with a finite light source. The point *O* is defined as the centre of the slits. *d* is the distance between the two square apertures. *R* is the distance between points *O* and *P* on the screen. *L* is the distance between the source and the diffracting mask. *D* is the distance from the diffracting mask to the detection screen.

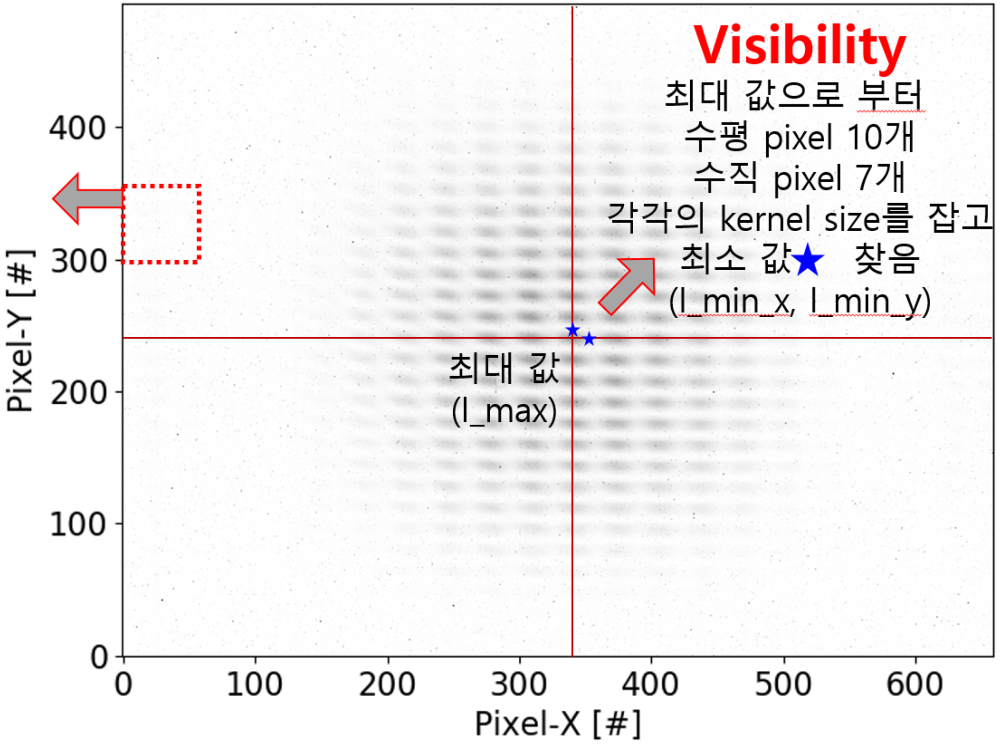
1B Interferometer : 2019/05 이전

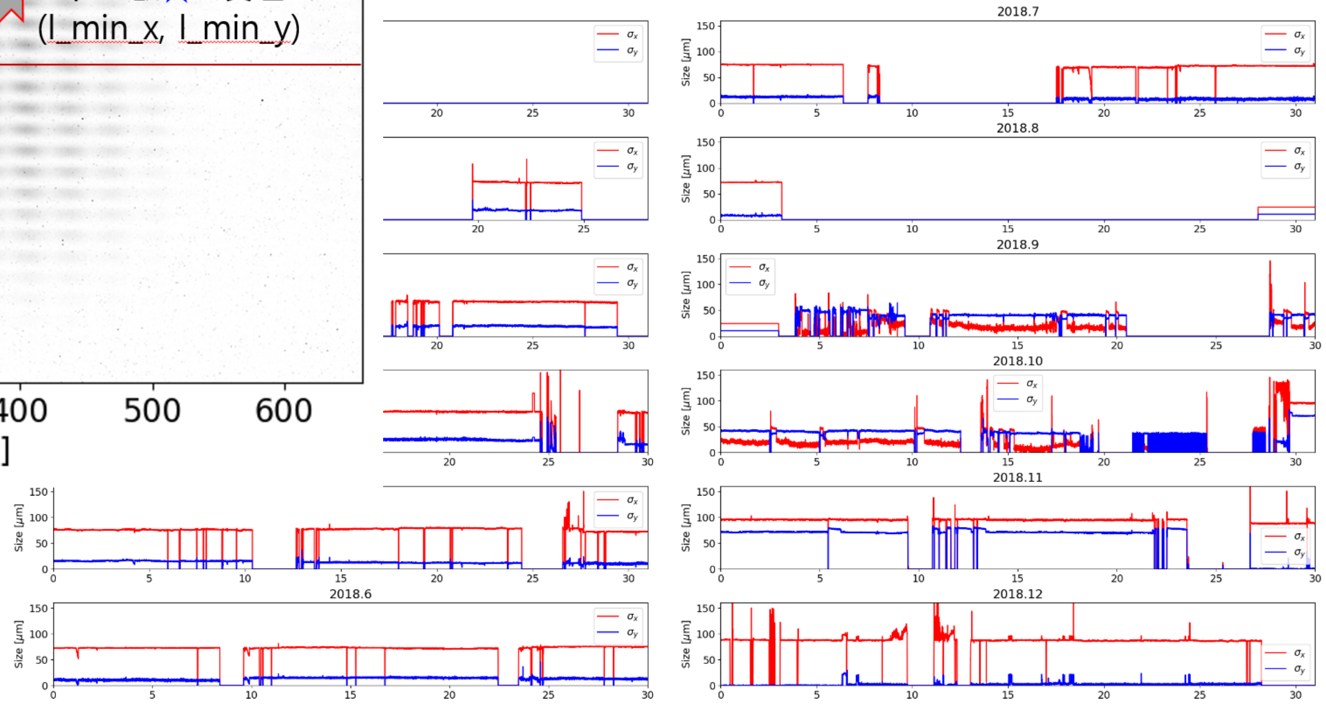
Background
50 px X 50 px
2500 pixels 평균을
전체에서 뺌

Statistics
100 frame 평균치를
1 frame 분석시 마다
윈도우를 shift 해 가며 출력

delay 없이 초당 8 frame 수준
12.5 초간 빔 크기 평균

Exp. Time Control
노출시간 조절 없음





1B Interferometer : 2019/05 이후 SW 개선

$$f(x, a_i) = a_0\left(\frac{\sin a_1(x-a_2)}{a_1(x-a_2)}\right)^2\left(1 + a_3\cos(K_0 x + \Phi_0)\right) + a_4$$

where,

a_1 : 그래프 최대치의 ± 5 %

a_2 : CCD 축 너비의 0.25 ~ 0.5

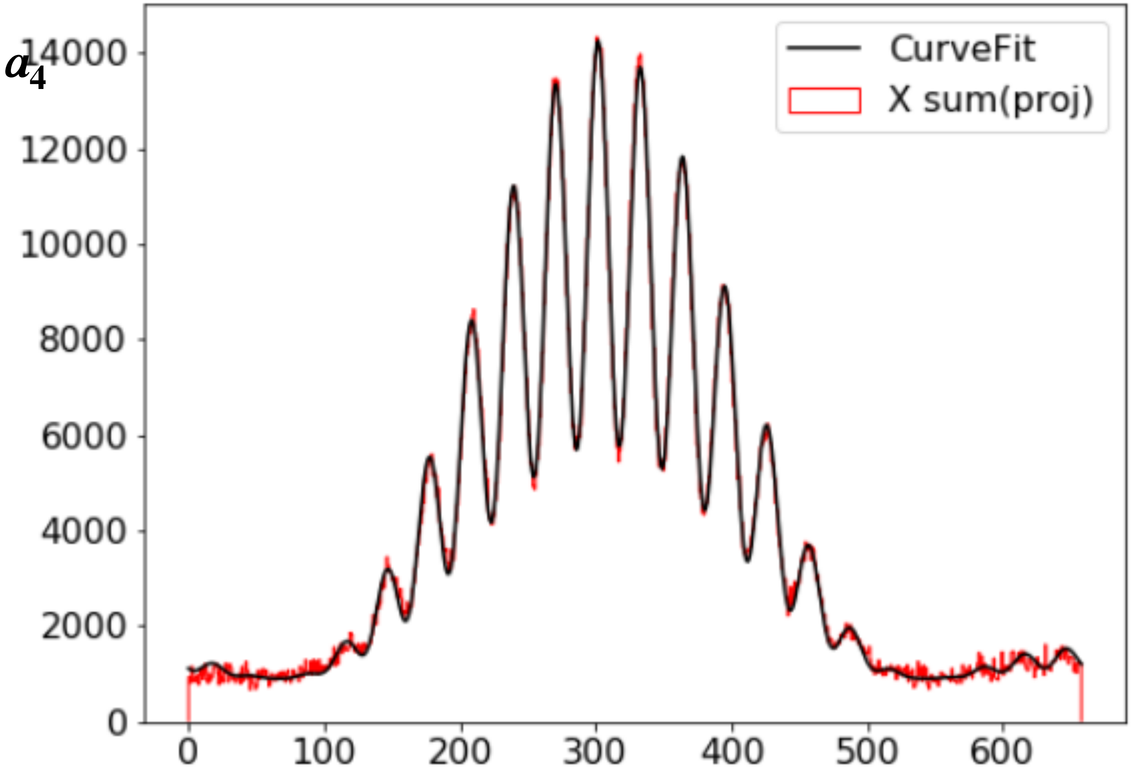
a_3 : peak 최대점 기준 인접한 peak 사이

a_4 : 0~1

a_5 : Spectrum 분석치의 ± 10 %

$$I_x(x) = \left[\frac{\sin\left(\frac{\pi\omega_x}{\lambda R}x\right)}{\frac{\pi\omega_x}{\lambda R}}\right]^2\left[1 + \gamma_x \cos\left(\frac{2\pi D_x}{\lambda R}x + \phi_x\right)\right],$$

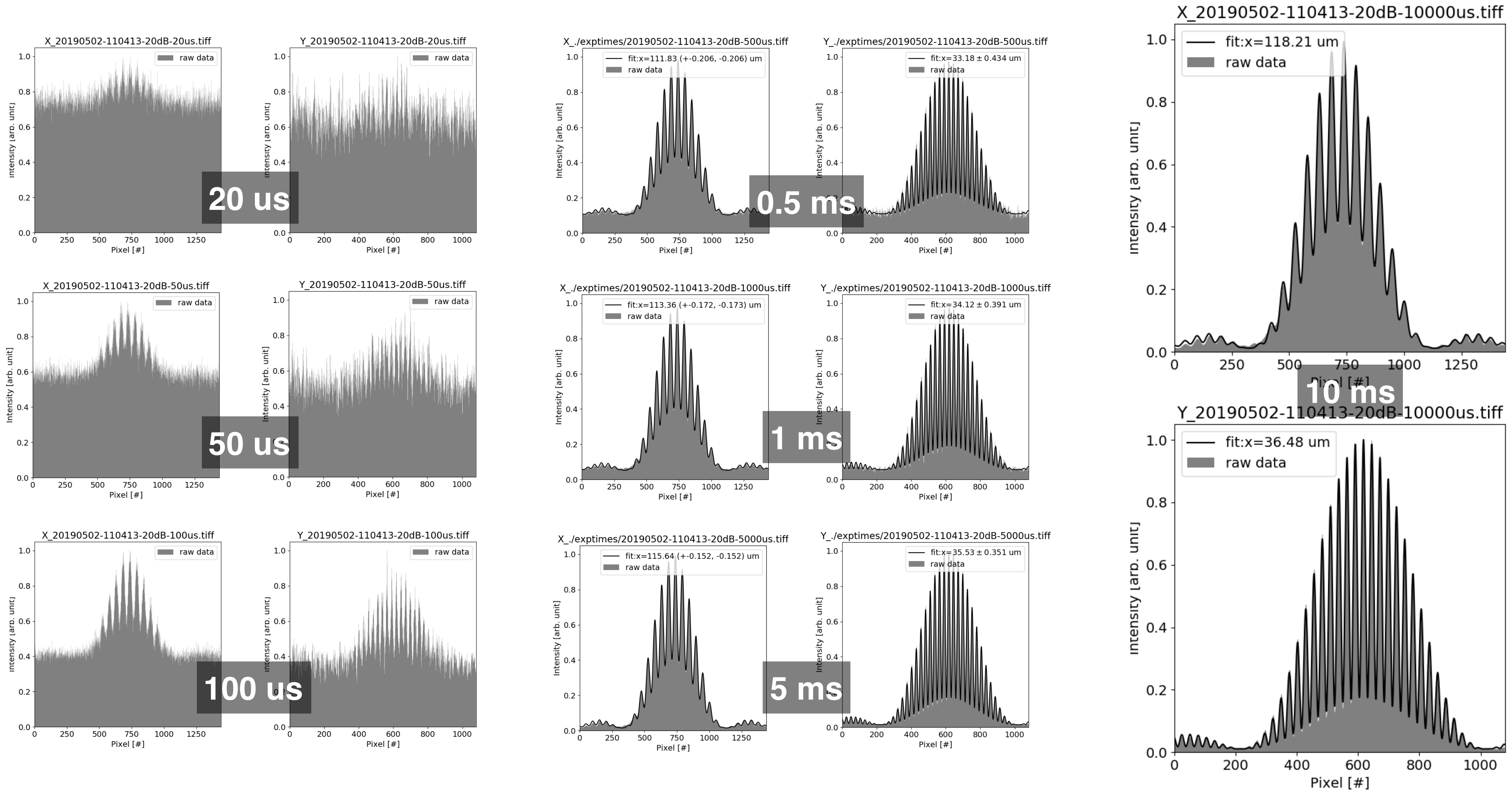
$$\sigma_{x,y} = \frac{\lambda}{\pi}\frac{s}{D_{x,y}}\sqrt{\frac{1}{2}\ln\frac{1}{\gamma_{x,y}}}$$



Camera Candidates

Model Name [Basler]		avA1000-100gm	acA1300-200um	**acA1440-220um**	daA1600-60um	**acA720-520um**
Price [10,000 KRW]		235	64	**63**	63	**63**
Sensor	Vendor	ON Semi.	ON Semi.	Sony	e2v	Sony
	Name	KAI-1050	PYTHON 1300	IMX273	EV76C570	IMX287
	Type	CCD	CMOS	CMOS	CMOS	CMOS
	Size [mm]	5.6 x 5.6	6.1 x 4.9	5.0 x 3.7	7.2 x 5.4	5.0 x 3.7
	Resolution [px]	1024 x 1024	1280 x 1024	1440 x 1080	1600 x 1200	720 x 540
	Resolution [MP]	1	1.3	1.6	2	0.38
	Pixel Size [um]	5.5 x 5.5	4.8 x 4.8	3.45 x 3.45	4.5 x 4.5	6.9 x 6.9
	Frame Rate [fps]	101	203	227	60	520
EMVA data	EMVA Quantum Efficiency [%]	39.2	53.0	62.7	?	63.2
	Dark Noise [-]	11.7	10.6	2.8	?	2.9
	Saturation Capacity [-]	17.9	6.9	10.5	?	20.7
	Dynamic Range [dB]	63.7	56.3	71.5	?	74.2
	Signal-to-Noise Ratio [dB]	42.5	38.4	40.2	?	43.2
Camera Data	Interface	GigE	USB 3.0	USB 3.0	USB 3.0	USB 3.0
	Pixel Bit Depth [bits]	8, 12	8, 10	8, 12	8, 12	8, 12
	Power Requirements	12Vdc / PoE	USB 3.0	USB 3.0	USB 3.0	USB 3.0
	Power Consumption [W]	5	3	3.3	1.3	3

1B Interferometer : 시분해능 증가



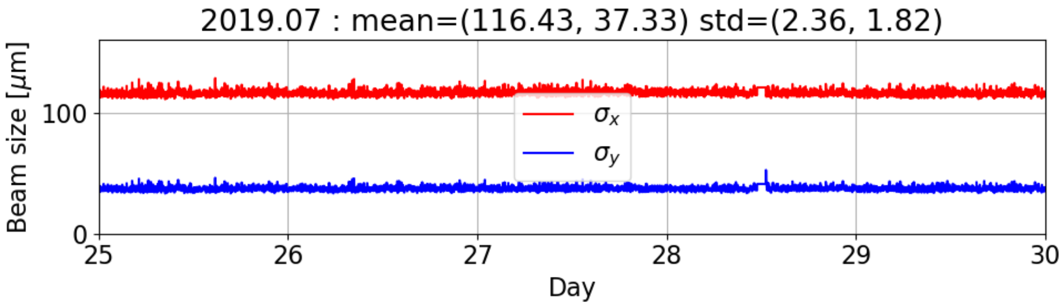
Multi-core Analysis, Ultra-fast Interferometer

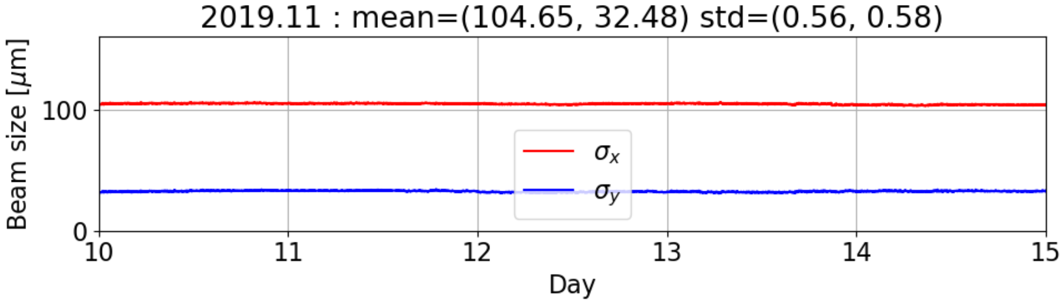
```
top - 19:16:44 up 2 days,  7:46,  4 users,  load average: 20.77, 7.53, 2.76
Tasks: 528 total,  27 running, 332 sleeping,   0 stopped,   0 zombie
%Cpu(s): 81.8 us,  0.7 sy,  0.0 ni, 16.8 id,  0.0 wa,  0.0 hi,  0.7 si,  0.0 st
KiB Mem : 65909832 total, 50175952 free,  2019272 used, 13714608 buff/cache
KiB Swap:  2097148 total,  2097148 free,        0 used. 63108872 avail Mem

  PID USER      PR  NI    VIRT    RES    SHR S  %CPU %MEM     TIME+ COMMAND
28486 garam     20   0 1370440  52204   9100 R  87.7  0.1   0:26.03 python
28498 garam     20   0 1370452  52228   9100 R  87.4  0.1   0:25.69 python
28487 garam     20   0 1370440  52208   9100 R  87.1  0.1   0:26.08 python
28469 garam     20   0 1370428  52176   9100 R  85.8  0.1   0:26.60 python
28489 garam     20   0 1370444  52212   9100 R  85.8  0.1   0:26.34 python
28468 garam     20   0 1370424  52172   9100 R  85.4  0.1   0:26.57 python
28492 garam     20   0 1370448  52216   9100 R  85.4  0.1   0:25.61 python
28472 garam     20   0 1370428  52176   9100 R  84.8  0.1   0:26.79 python
28480 garam     20   0 1370436  52192   9100 R  84.8  0.1   0:25.84 python
28495 garam     20   0 1361336  43248   9100 S  84.8  0.1   0:25.81 python
28483 garam     20   0 1370436  52196   9100 R  84.4  0.1   0:26.35 python
28494 garam     20   0 1370448  52220   9100 R  84.4  0.1   0:25.70 python
28490 garam     20   0 1370444  52212   9100 R  84.1  0.1   0:26.07 python
28467 garam     20   0 1370428  52172   9100 R  82.8  0.1   0:26.20 python
28496 garam     20   0 1370452  52224   9100 R  82.5  0.1   0:24.87 python
28491 garam     20   0 1361332  43240   9100 S  82.1  0.1   0:25.58 python
28470 garam     20   0 1361316  43204   9100 S  81.5  0.1   0:26.58 python
28473 garam     20   0 1361316  43208   9100 S  81.5  0.1   0:26.74 python
28474 garam     20   0 1370432  52180   9100 R  81.5  0.1   0:26.29 python
28484 garam     20   0 1361324  43228   9100 S  81.5  0.1   0:25.61 python
28477 garam     20   0 1370436  52188   9100 R  80.8  0.1   0:26.18 python
28488 garam     20   0 1361328  43236   9100 S  80.8  0.1   0:26.27 python
28471 garam     20   0 1370428  52176   9100 R  79.8  0.1   0:26.60 python
28497 garam     20   0 1370452  52224   9100 R  78.8  0.1   0:24.80 python
28493 garam     20   0 1361336  43244   9100 S  78.5  0.1   0:25.43 python
28478 garam     20   0 1370436  52188   9100 R  77.8  0.1   0:26.09 python
28485 garam     20   0 1361328  43232   9100 S  77.5  0.1   0:25.71 python
28482 garam     20   0 1370436  52196   9100 R  76.5  0.1   0:25.98 python
28476 garam     20   0 1370432  52188   9100 R  75.8  0.1   0:26.33 python
28481 garam     20   0 1370436  52196   9100 R  75.8  0.1   0:26.03 python
28475 garam     20   0 1370432  52188   9100 R  71.9  0.1   0:26.02 python
28479 garam     20   0 1370436  52188   9100 R  69.2  0.1   0:25.78 python
28435 garam     20   0 1570868  77272  24316 R  35.4  0.1   0:13.96 python
  982 message+  20   0   51668   5964   3996 S   2.6  0.0  22:51.27 dbus-daemon
 1001 avahi     20   0   48560   5184   3344 S   1.7  0.0  15:44.16 avahi-daemon
22099 root      20   0  308520  14396   9956 S   1.0  0.0   3:49.16 cups-browsed
28013 garam     20   0   53060   4368   3252 R   0.7  0.0   0:02.21 top
24024 root      20   0       0      0      0 I   0.3  0.0   0:00.08 kworker/15:2-ev
27889 root      20   0       0      0      0 I   0.3  0.0   0:00.66 kworker/26:1-ev
```

```
top - 19:16:58 up 2 days,  7:46,  4 users,  load average: 22.15, 8.48, 3.15
Tasks: 527 total,  29 running, 330 sleeping,   0 stopped,   0 zombie
%Cpu0  : 62.0 us,  0.5 sy,  0.0 ni, 26.8 id,  0.0 wa,  0.0 hi, 10.7 si,  0.0 st
%Cpu1  : 83.9 us,  0.5 sy,  0.0 ni, 14.0 id,  0.0 wa,  0.0 hi,  1.6 si,  0.0 st
%Cpu2  : 52.9 us,  0.5 sy,  0.0 ni, 42.4 id,  0.0 wa,  0.0 hi,  4.2 si,  0.0 st
%Cpu3  : 95.6 us,  1.1 sy,  0.0 ni,  3.3 id,  0.0 wa,  0.0 hi,  0.0 si,  0.0 st
%Cpu4  : 96.7 us,  0.5 sy,  0.0 ni,  2.7 id,  0.0 wa,  0.0 hi,  0.0 si,  0.0 st
%Cpu5  : 86.6 us,  0.5 sy,  0.0 ni, 10.7 id,  0.0 wa,  0.0 hi,  2.1 si,  0.0 st
%Cpu6  :100.0 us,  0.0 sy,  0.0 ni,  0.0 id,  0.0 wa,  0.0 hi,  0.0 si,  0.0 st
%Cpu7  :100.0 us,  0.0 sy,  0.0 ni,  0.0 id,  0.0 wa,  0.0 hi,  0.0 si,  0.0 st
%Cpu8  : 95.6 us,  1.1 sy,  0.0 ni,  2.7 id,  0.0 wa,  0.0 hi,  0.5 si,  0.0 st
%Cpu9  : 95.1 us,  1.6 sy,  0.0 ni,  3.3 id,  0.0 wa,  0.0 hi,  0.0 si,  0.0 st
%Cpu10 : 88.0 us,  1.1 sy,  0.0 ni, 10.9 id,  0.0 wa,  0.0 hi,  0.0 si,  0.0 st
%Cpu11 : 85.8 us,  0.0 sy,  0.0 ni, 14.2 id,  0.0 wa,  0.0 hi,  0.0 si,  0.0 st
%Cpu12 : 71.4 us,  3.3 sy,  0.0 ni, 25.3 id,  0.0 wa,  0.0 hi,  0.0 si,  0.0 st
%Cpu13 : 99.5 us,  0.0 sy,  0.0 ni,  0.5 id,  0.0 wa,  0.0 hi,  0.0 si,  0.0 st
%Cpu14 : 97.8 us,  0.0 sy,  0.0 ni,  2.2 id,  0.0 wa,  0.0 hi,  0.0 si,  0.0 st
%Cpu15 : 79.8 us,  2.2 sy,  0.0 ni, 18.0 id,  0.0 wa,  0.0 hi,  0.0 si,  0.0 st
%Cpu16 : 88.5 us,  2.7 sy,  0.0 ni,  8.7 id,  0.0 wa,  0.0 hi,  0.0 si,  0.0 st
%Cpu17 : 99.5 us,  0.5 sy,  0.0 ni,  0.0 id,  0.0 wa,  0.0 hi,  0.0 si,  0.0 st
%Cpu18 : 82.4 us,  0.0 sy,  0.0 ni, 17.6 id,  0.0 wa,  0.0 hi,  0.0 si,  0.0 st
%Cpu19 : 94.0 us,  0.0 sy,  0.0 ni,  6.0 id,  0.0 wa,  0.0 hi,  0.0 si,  0.0 st
%Cpu20 : 74.3 us,  0.5 sy,  0.0 ni, 25.1 id,  0.0 wa,  0.0 hi,  0.0 si,  0.0 st
%Cpu21 : 98.4 us,  0.0 sy,  0.0 ni,  1.6 id,  0.0 wa,  0.0 hi,  0.0 si,  0.0 st
%Cpu22 : 88.5 us,  0.5 sy,  0.0 ni, 10.9 id,  0.0 wa,  0.0 hi,  0.0 si,  0.0 st
%Cpu23 : 75.5 us,  0.5 sy,  0.0 ni, 23.9 id,  0.0 wa,  0.0 hi,  0.0 si,  0.0 st
%Cpu24 : 74.7 us,  1.6 sy,  0.0 ni, 23.6 id,  0.0 wa,  0.0 hi,  0.0 si,  0.0 st
%Cpu25 : 45.2 us,  1.6 sy,  0.0 ni, 50.0 id,  0.0 wa,  0.0 hi,  3.2 si,  0.0 st
%Cpu26 : 67.2 us,  0.5 sy,  0.0 ni, 32.2 id,  0.0 wa,  0.0 hi,  0.0 si,  0.0 st
%Cpu27 : 69.9 us,  0.0 sy,  0.0 ni, 30.1 id,  0.0 wa,  0.0 hi,  0.0 si,  0.0 st
%Cpu28 : 92.9 us,  0.0 sy,  0.0 ni,  7.1 id,  0.0 wa,  0.0 hi,  0.0 si,  0.0 st
%Cpu29 : 41.0 us,  0.0 sy,  0.0 ni, 58.5 id,  0.0 wa,  0.0 hi,  0.5 si,  0.0 st
%Cpu30 : 65.6 us,  1.1 sy,  0.0 ni, 33.3 id,  0.0 wa,  0.0 hi,  0.0 si,  0.0 st
%Cpu31 : 36.8 us,  1.6 sy,  0.0 ni, 61.5 id,  0.0 wa,  0.0 hi,  0.0 si,  0.0 st
KiB Mem : 65909832 total, 50140208 free,  2053980 used, 13715644 buff/cache
KiB Swap:  2097148 total,  2097148 free,        0 used. 63074164 avail Mem

  PID USER      PR  NI    VIRT    RES    SHR S  %CPU %MEM     TIME+ COMMAND
28476 garam     20   0 1370432  52192   9100 R  99.5  0.1   0:38.02 python
28484 garam     20   0 1370440  52200   9100 R  99.5  0.1   0:36.93 python
28474 garam     20   0 1361316  43212   9100 S  98.4  0.1   0:37.81 python
28491 garam     20   0 1370448  52212   9100 R  95.1  0.1   0:36.78 python
28494 garam     20   0 1370448  52220   9100 R  91.3  0.1   0:36.89 python
28467 garam     20   0 1361312  43200   9100 S  90.2  0.1   0:37.49 python
28490 garam     20   0 1370444  52212   9100 R  88.0  0.1   0:37.49 python
28488 garam     20   0 1361328  43236   9100 S  85.2  0.1   0:37.59 python
```

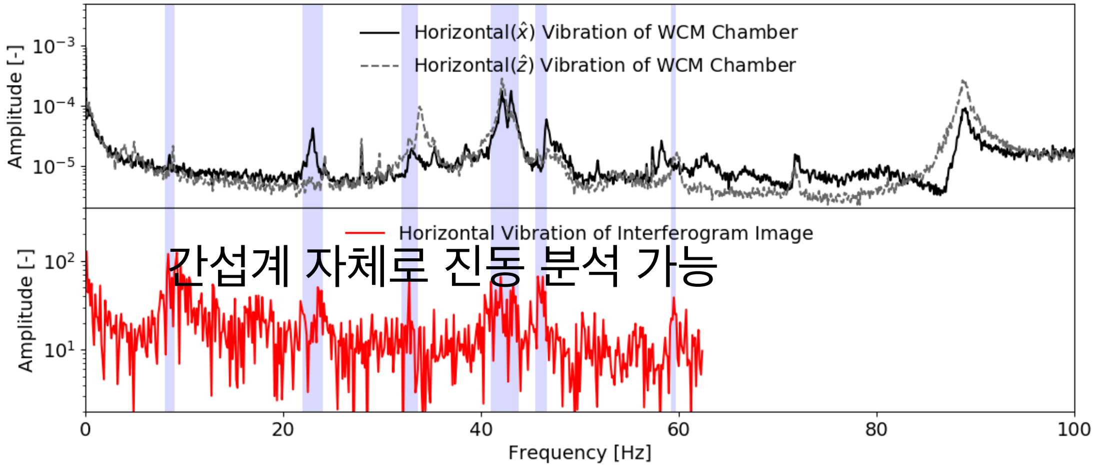
1B Interferometer : WCM 개선, CAMSW 개선 이후 결과

알골 개선 후, WCM 진동 존재



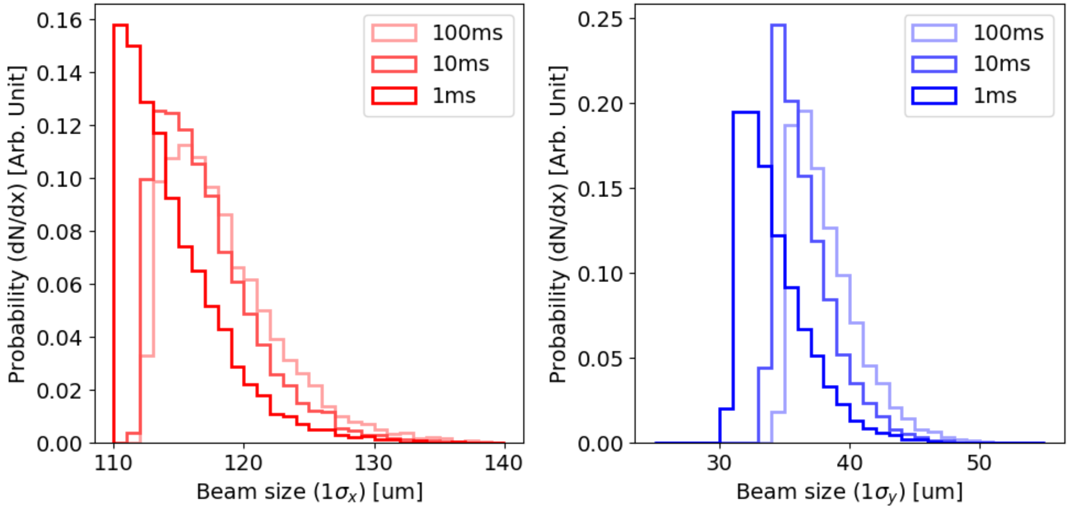


WCM 저진동 쿨러 설치 후(이채순)



간섭계 자체로 진동 분석 가능

노출시간 감소에 따른 빔 사이즈 변화

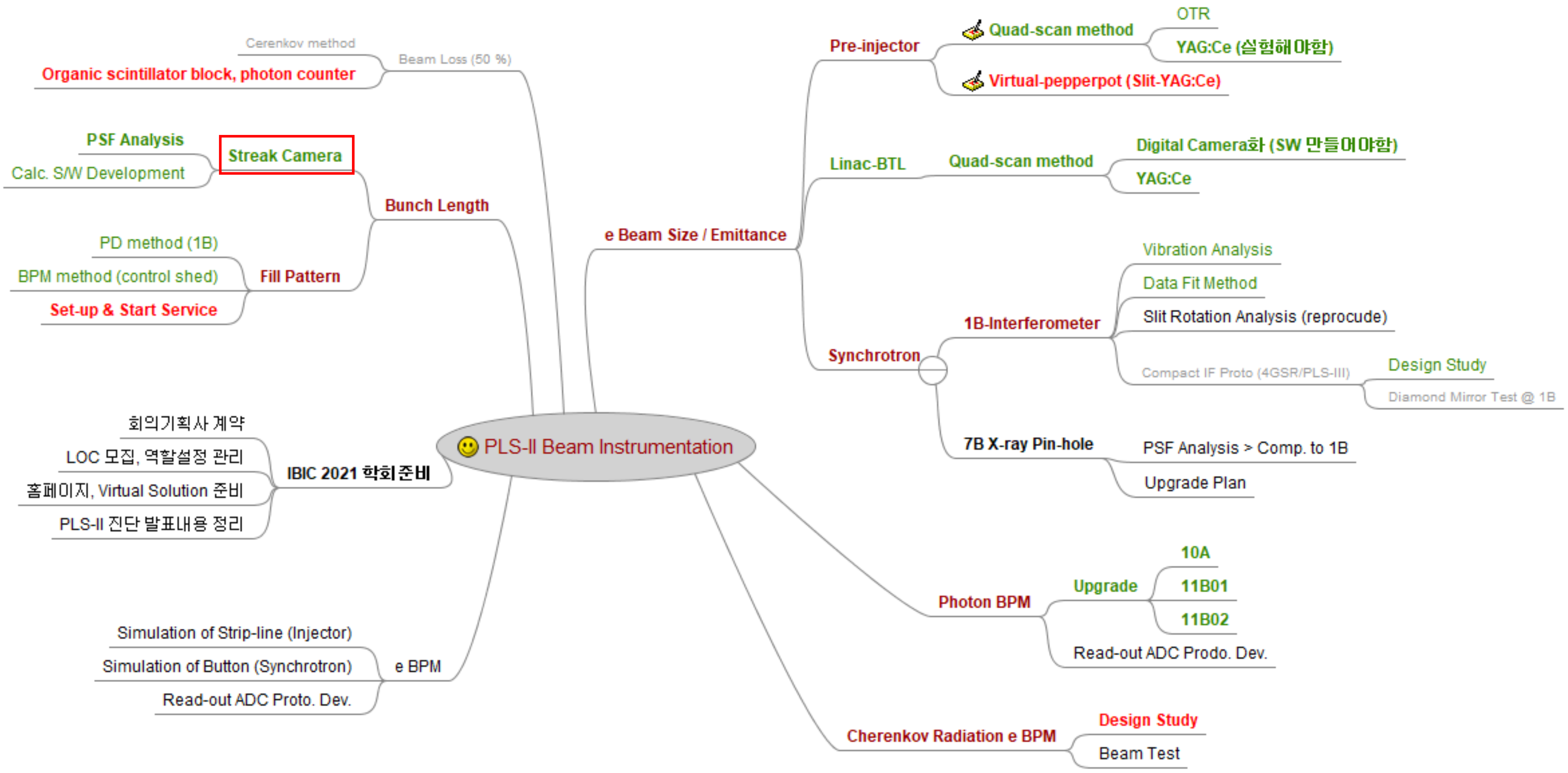


현재 노출 100-200 us, 빔사이즈 90, 22 um 수준

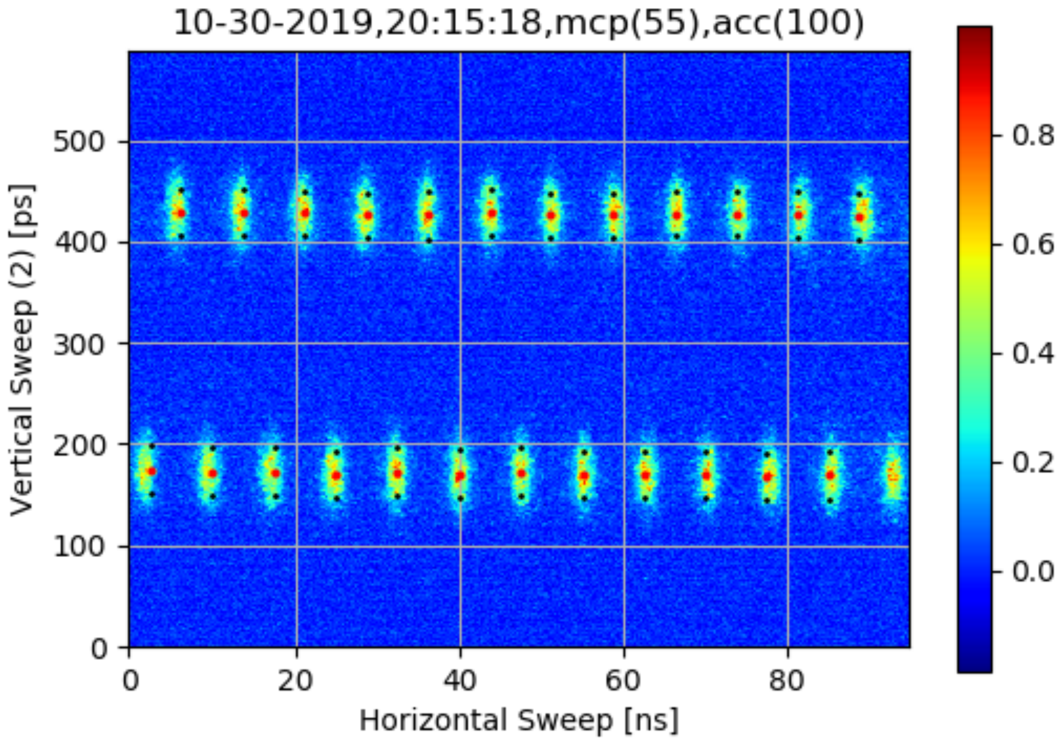
1B Interferometer : SR Emittance

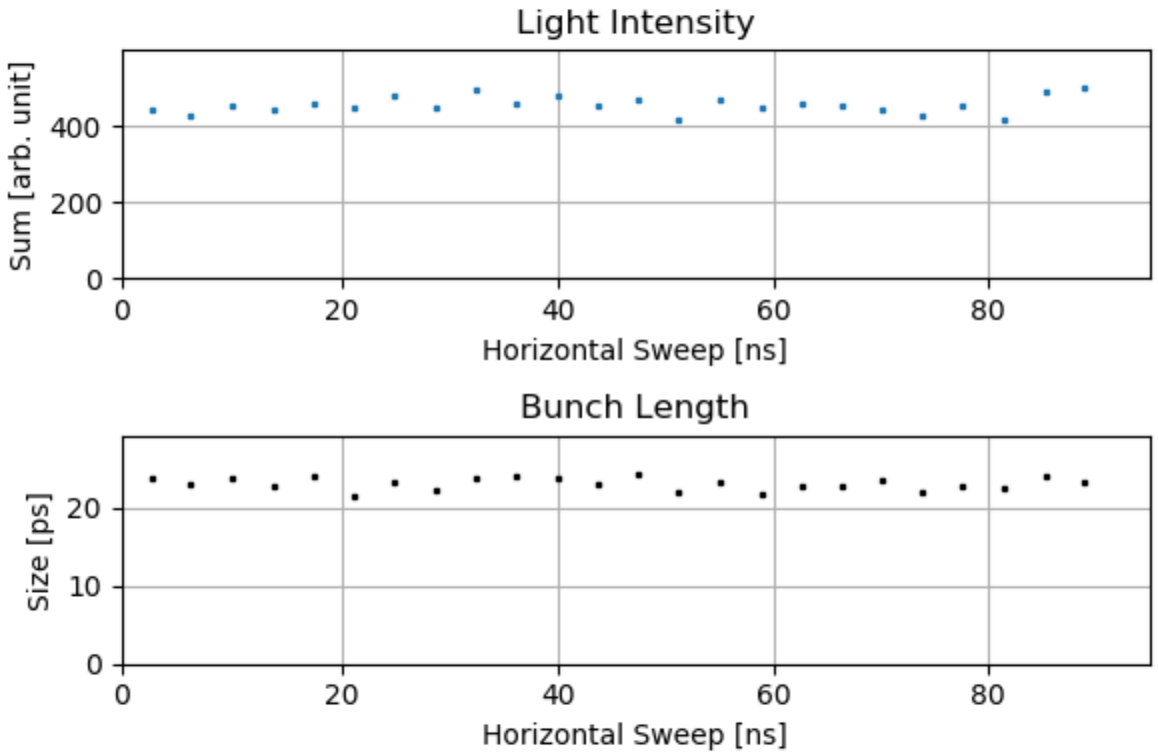
```
In [12]: SIGx = 89 * um      #var
         SIGy = 22 * um      #var

         BETA_X = 0.825      #const
         BETA_Y = 14.711     #const
         ETA_X = 0.056       #const
         DPOP = 0.001        #const

         # 커플링이 작을때만 유효함
         emitx = (SIGx**2 - (ETA_X * DPOP)**2 )/BETA_X
         emity = SIGy**2/BETA_Y

         emit0 = emitx + emity
         coup0 = emity/emitx

         print(f'beta(designed)\t= ({BETA_X:.2f}, {BETA_Y:.2f}) [m]')
         print(f'Dx(designed)   \t= {ETA_X:.2f} [m]')
         print(f'dp/p(designed)\t= {DPOP*100:.2f} [%]\n')

         print(f'size(measured)\t= ({SIGx/um:.1f}, {SIGy/um:.1f}) [um]\n')

         print(f'emit(calc.)    \t= {emit0*1000.0:.2f} ({emitx*1000:.2f}, {emity*1000:.2f}) pi [nm.rad]')
         print(f'coup(calc.)    \t= {100.0*coup0:.2f} [%]')

beta(designed)   = (0.82, 14.71) [m]
Dx(designed)     = 0.06 [m]
dp/p(designed)   = 0.10 [%]

size(measured)   = (89.0, 22.0) [um]

emit(calc.)      = 9.63 (9.60, 0.03) pi [nm.rad]
coup(calc.)      = 0.34 [%]
```

우리 저장링 에미턴스는 약 9.6 pi[nm.rad]입니다
평상시에도 측정 가능하지만, 아직 몇 가지 더 검증 중입니다.
설계치는 ID 없을 경우, 있는 경우는 8-9 pi nm rad 예상


PLS-II Beam Instrumentation
Beam Loss (50 %)
Cerenkov method
Organic scintillator block, photon counter
Bunch Length
Streak Camera
PSF Analysis
Calc. S/W Development
Fill Pattern
PD method (1B)
BPM method (control shed)
Set-up & Start Service
IBIC 2021 학회준비
회의기획사 계약
LOC 모집, 역할설정 관리
홈페이지, Virtual Solution 준비
PLS-II 진단 발표내용 정리
e BPM
Simulation of Strip-line (Injector)
Simulation of Button (Synchrotron)
Read-out ADC Proto. Dev.
e Beam Size / Emittance
Pre-injector
Quad-scan method
OTR
YAG:Ce (실험해야함)
Virtual-pepperpot (Slit-YAG:Ce)
Linac-BTL
Quad-scan method
Digital Camera화 (SW 만들어야함)
YAG:Ce
Synchrotron
1B-Interferometer
Vibration Analysis
Data Fit Method
Slit Rotation Analysis (reprocude)
Compact IF Proto (4GSR/PLS-III)
Design Study
Diamond Mirror Test @ 1B
7B X-ray Pin-hole
PSF Analysis > Comp. to 1B
Upgrade Plan
Photon BPM
Upgrade
10A
11B01
11B02
Read-out ADC Prodo. Dev.
Cherenkov Radiation e BPM
Design Study
Beam Test

Filling Pattern : Streak Camera 필요시 측정

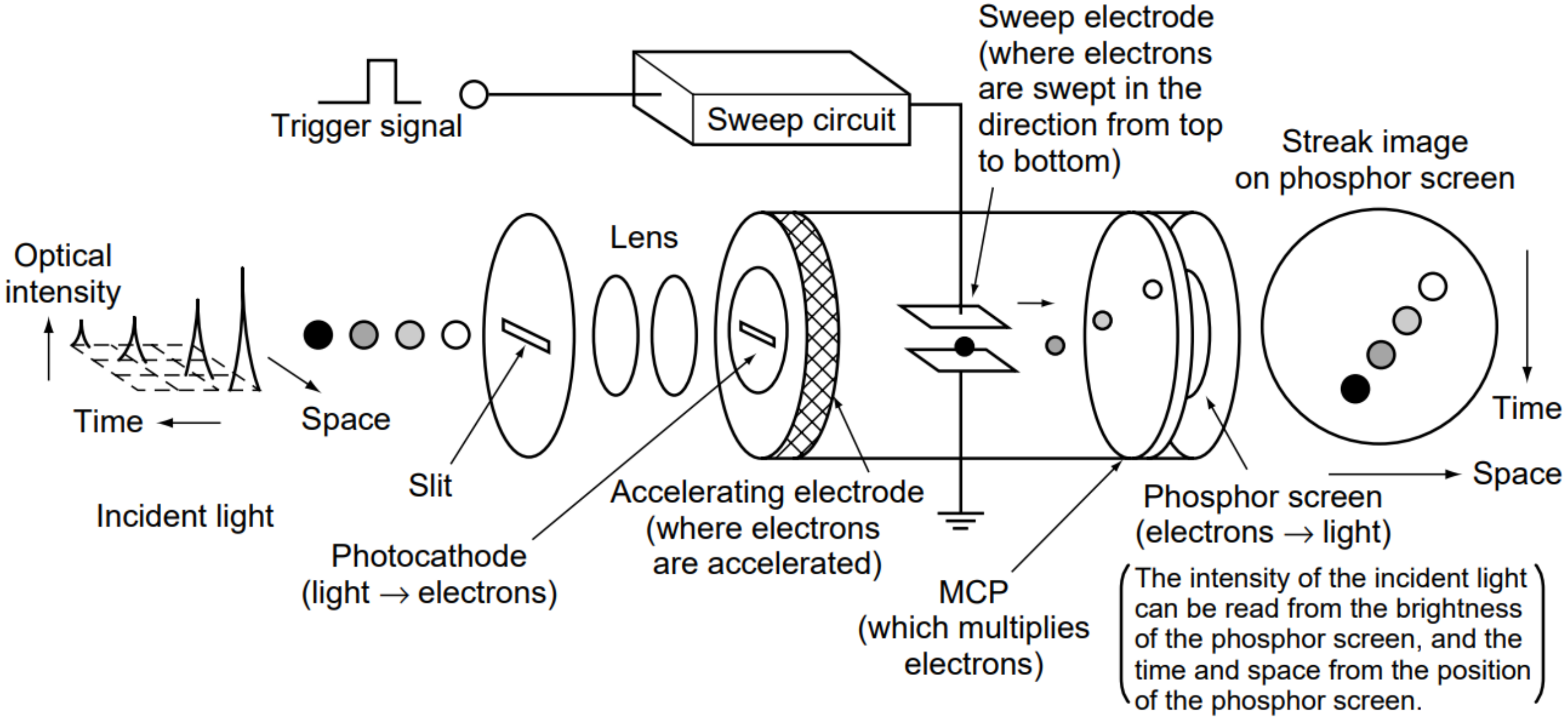




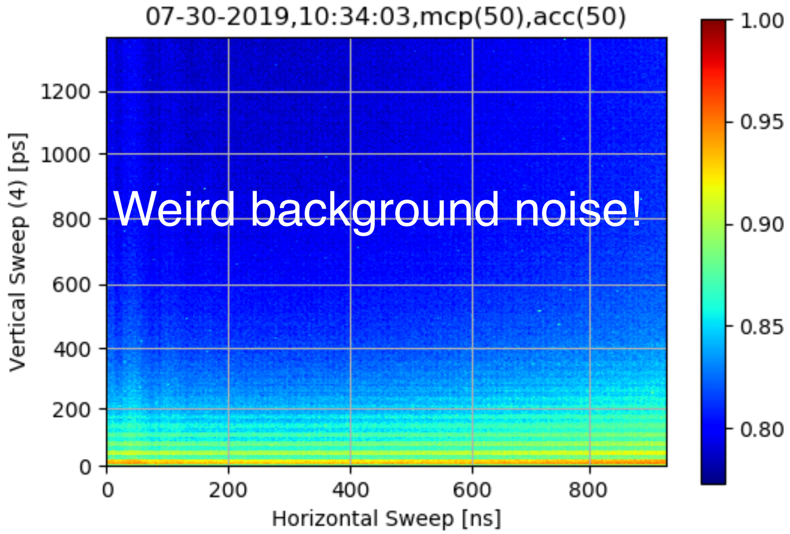
우리 빔 평균 번치 길이는 약 21~23 ps (1-sigma) 입니다
언제든 이상하다 싶을 때 1B에서 정교하게 측정이 가능합니다

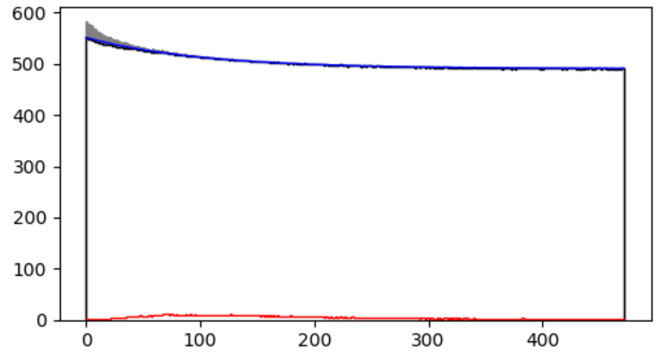
Streak Camera

- **Streak camera c5680, (1997년 구매)**
  - 1.25 ps/px (T2), 0.3 ps/px (T1)
  - 125 MHz Vertical Sweep
  - Typical PSF rms = 2.1 px, (현재 우리는 약 4-7 px)

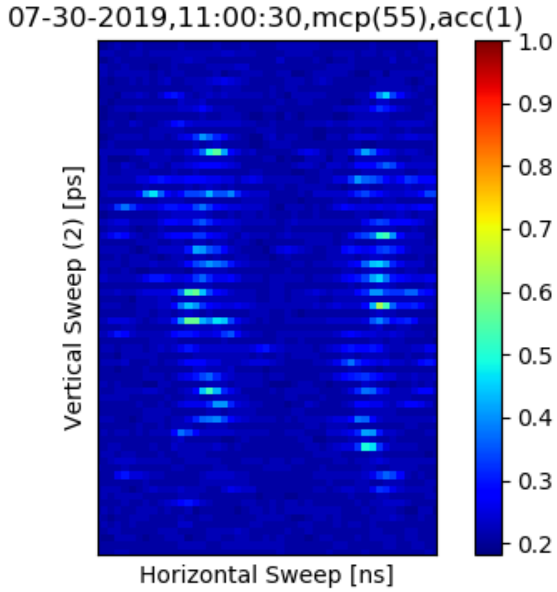


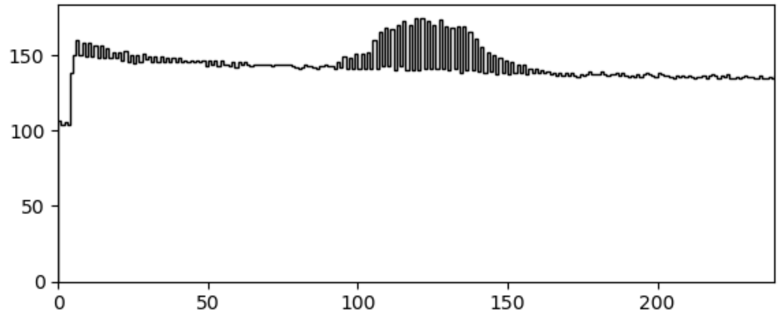
Old Streak Camera



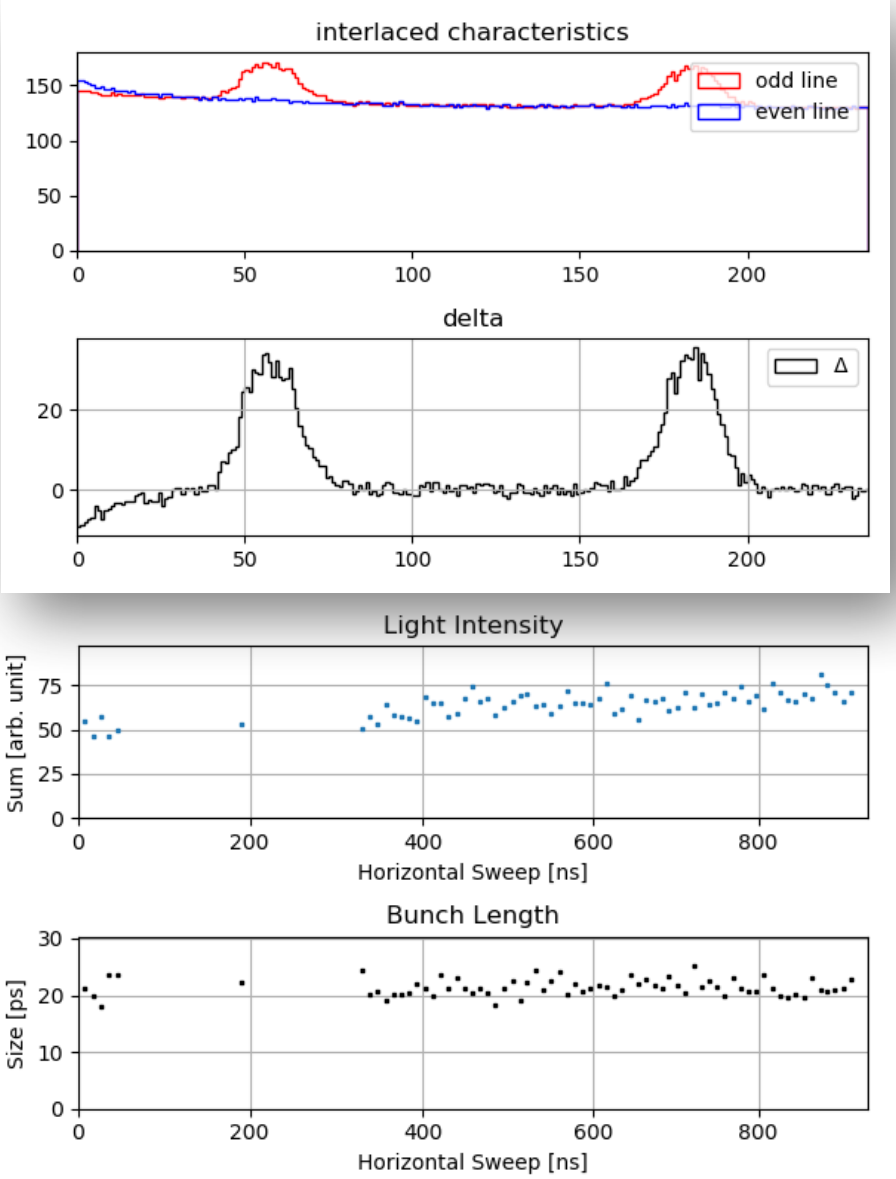


interlacing effect ?

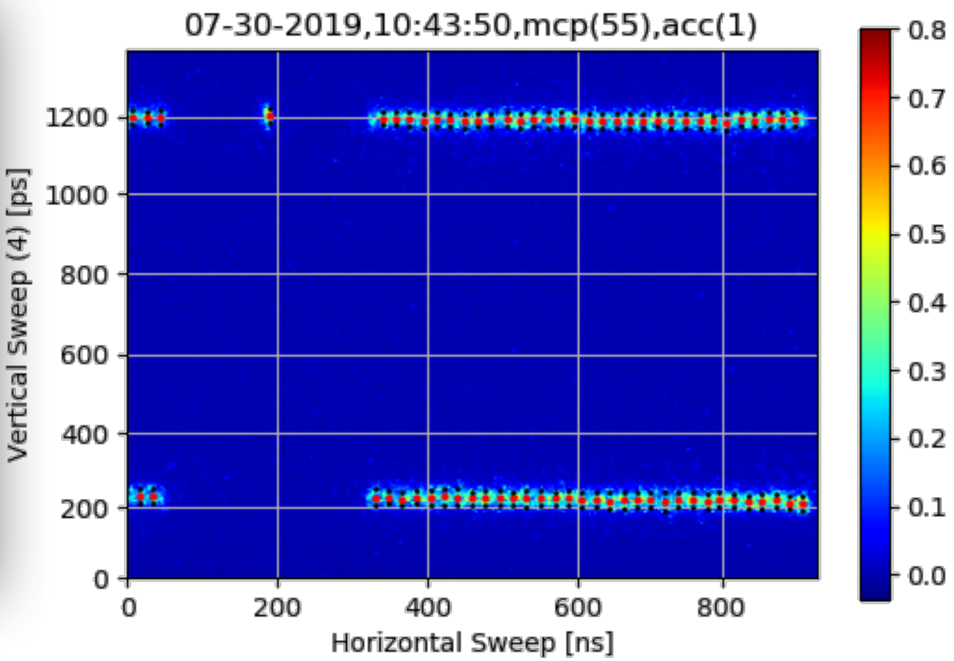




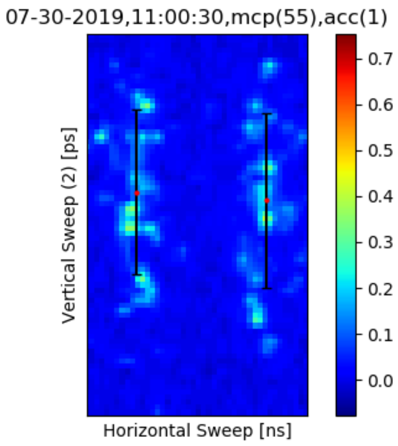
Solution



interlaced characteristics
odd line
even line
delta
Δ
Light Intensity
Sum [arb. unit]
Horizontal Sweep [ns]
Bunch Length
Size [ps]
Horizontal Sweep [ns]

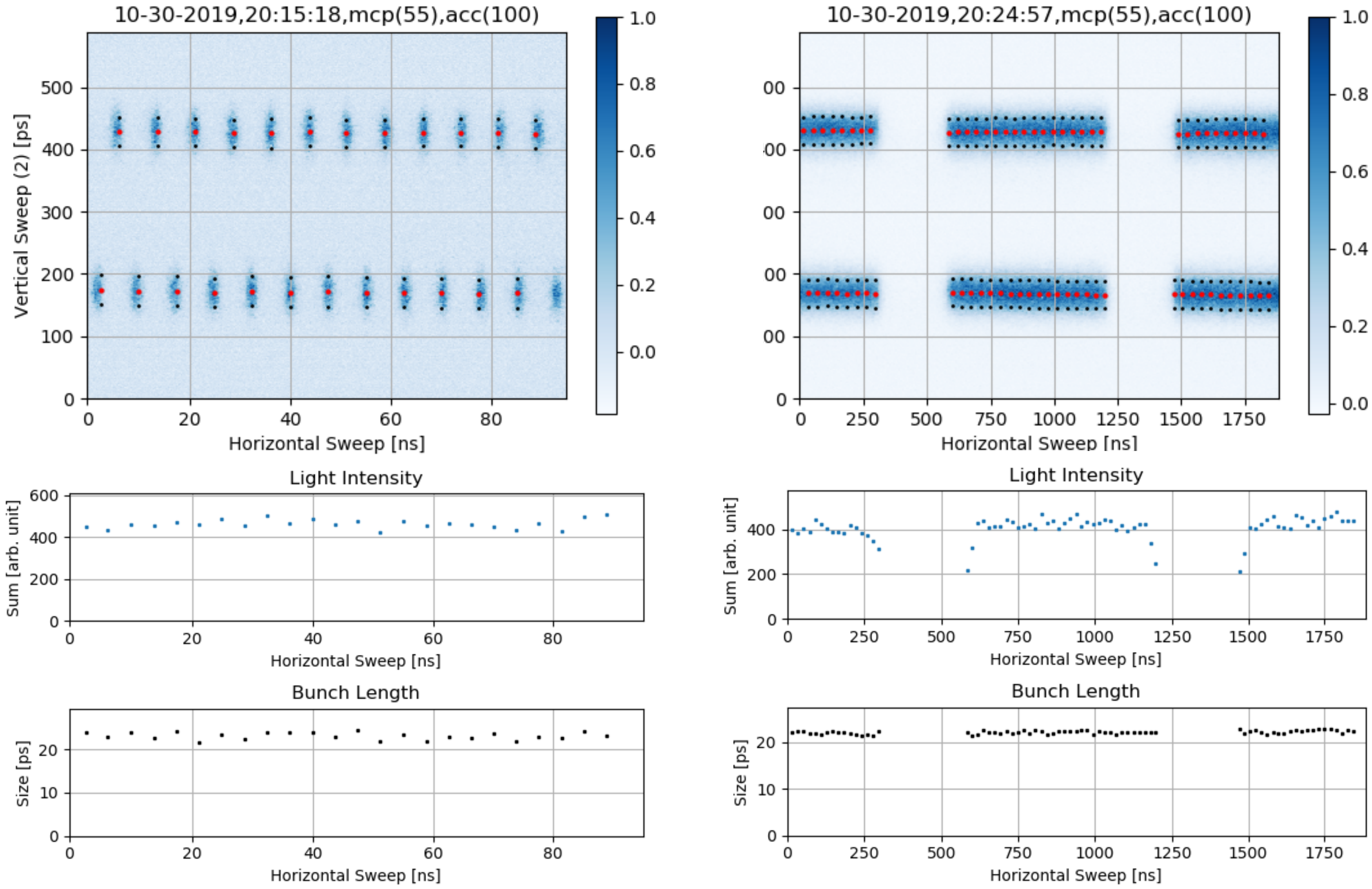


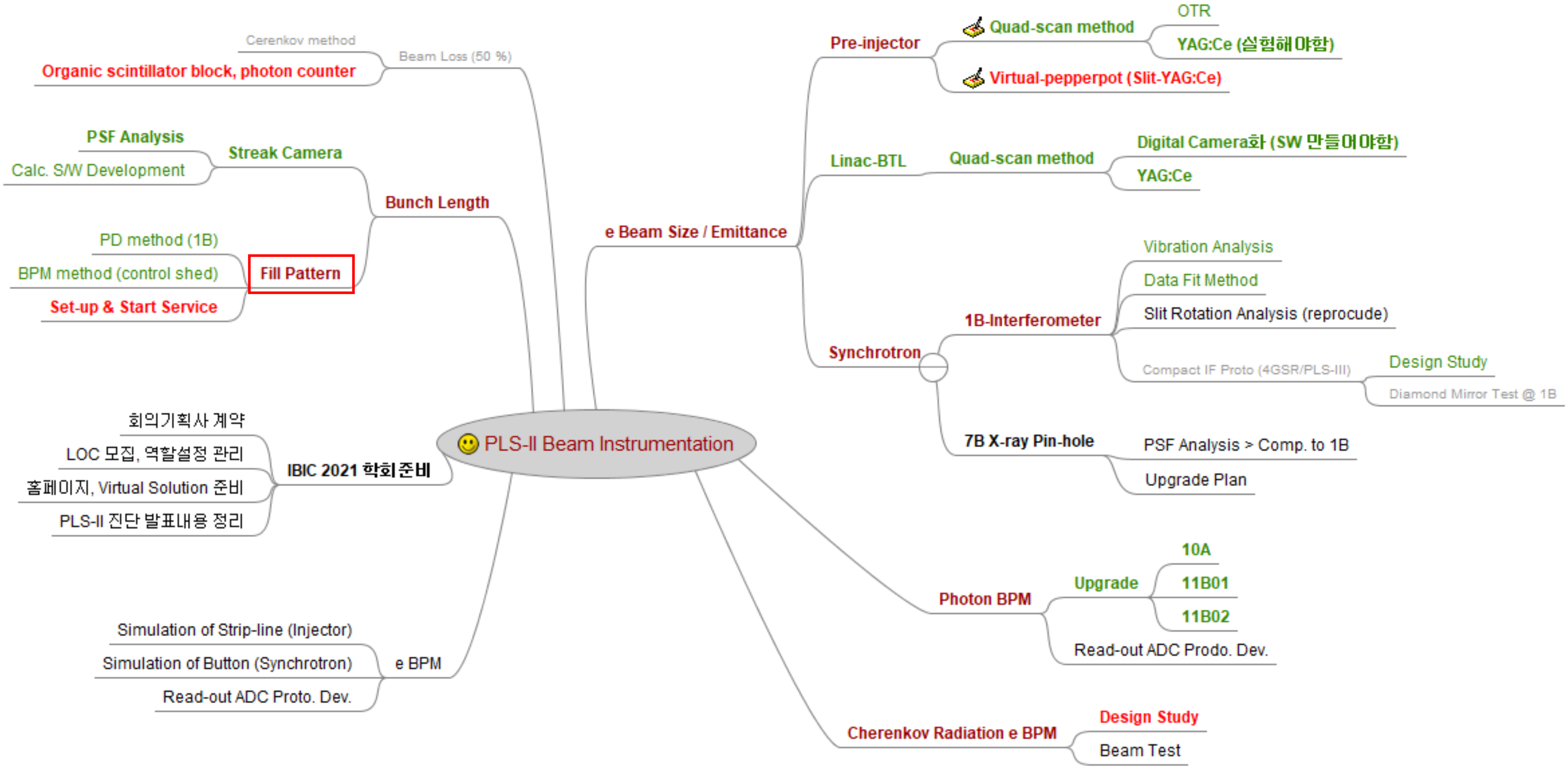
07-30-2019,10:43:50,mcp(55),acc(1)
Vertical Sweep (4) [ps]
Horizontal Sweep [ns]



07-30-2019,11:00:30,mcp(55),acc(1)
Vertical Sweep (2) [ps]
Horizontal Sweep [ns]

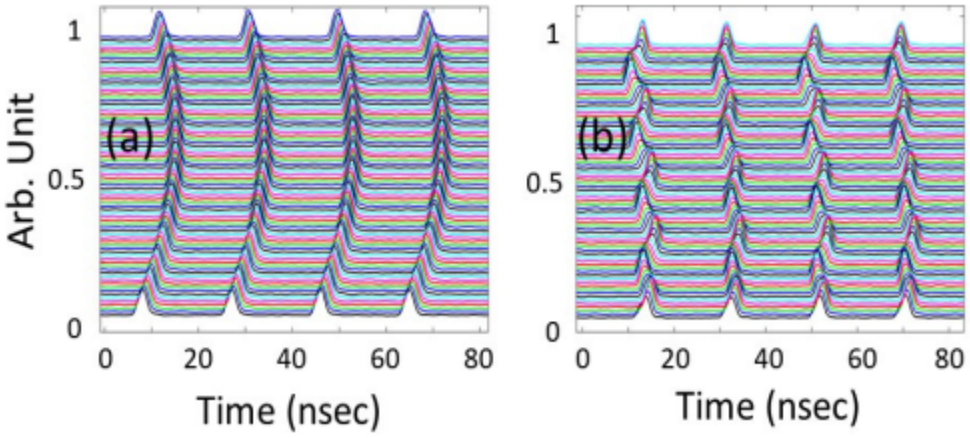
Measurement Results




PLS-II Beam Instrumentation
Beam Loss (50 %)
Cerenkov method
Organic scintillator block, photon counter
Bunch Length
Streak Camera
PSF Analysis
Calc. S/W Development
Fill Pattern
PD method (1B)
BPM method (control shed)
Set-up & Start Service
IBIC 2021 학회준비
회의기획사 계약
LOC 모집, 역할설정 관리
홈페이지, Virtual Solution 준비
PLS-II 진단 발표내용 정리
e BPM
Simulation of Strip-line (Injector)
Simulation of Button (Synchrotron)
Read-out ADC Proto. Dev.
e Beam Size / Emittance
Pre-injector
Quad-scan method
OTR
YAG:Ce (실험해야함)
Virtual-pepperpot (Slit-YAG:Ce)
Linac-BTL
Quad-scan method
Digital Camera화 (SW 만들어야함)
YAG:Ce
Synchrotron
1B-Interferometer
Vibration Analysis
Data Fit Method
Slit Rotation Analysis (reprocude)
Compact IF Proto (4GSR/PLS-III)
Design Study
Diamond Mirror Test @ 1B
7B X-ray Pin-hole
PSF Analysis > Comp. to 1B
Upgrade Plan
Photon BPM
Upgrade
10A
11B01
11B02
Read-out ADC Prodo. Dev.
Cherenkov Radiation e BPM
Design Study
Beam Test

Filling Pattern : Photo-diode 상시 측정

- **목표 : 아래 그림과 같은 번치 길이 정보 상시 제공**



1) Filling pattern (낮은 수준의 purity 분별 포함)

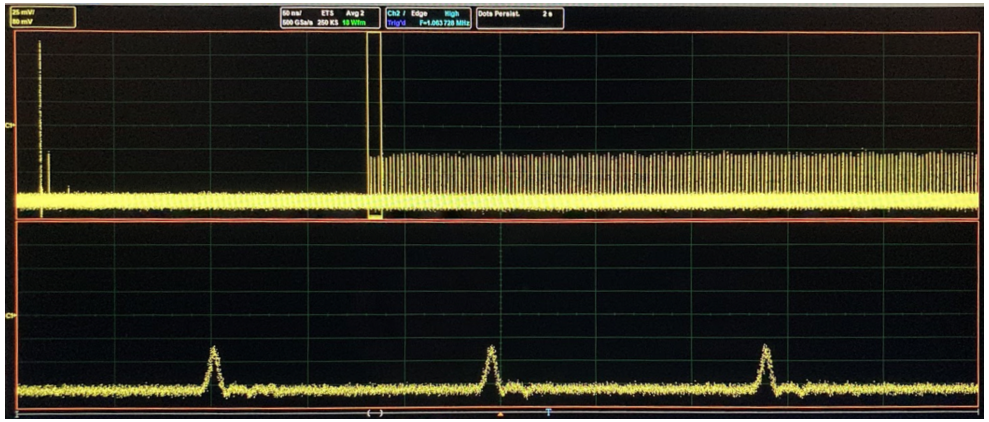
2) 개별 Bunch length 추적

3) 번치 위치 안정성

4) FP feedback

등 실시간 확인 가능

- **현재 상황 (2020/12/17), 장치 셋업/테스트 완료**



Fill Pattern Monitor (현재 운영중)

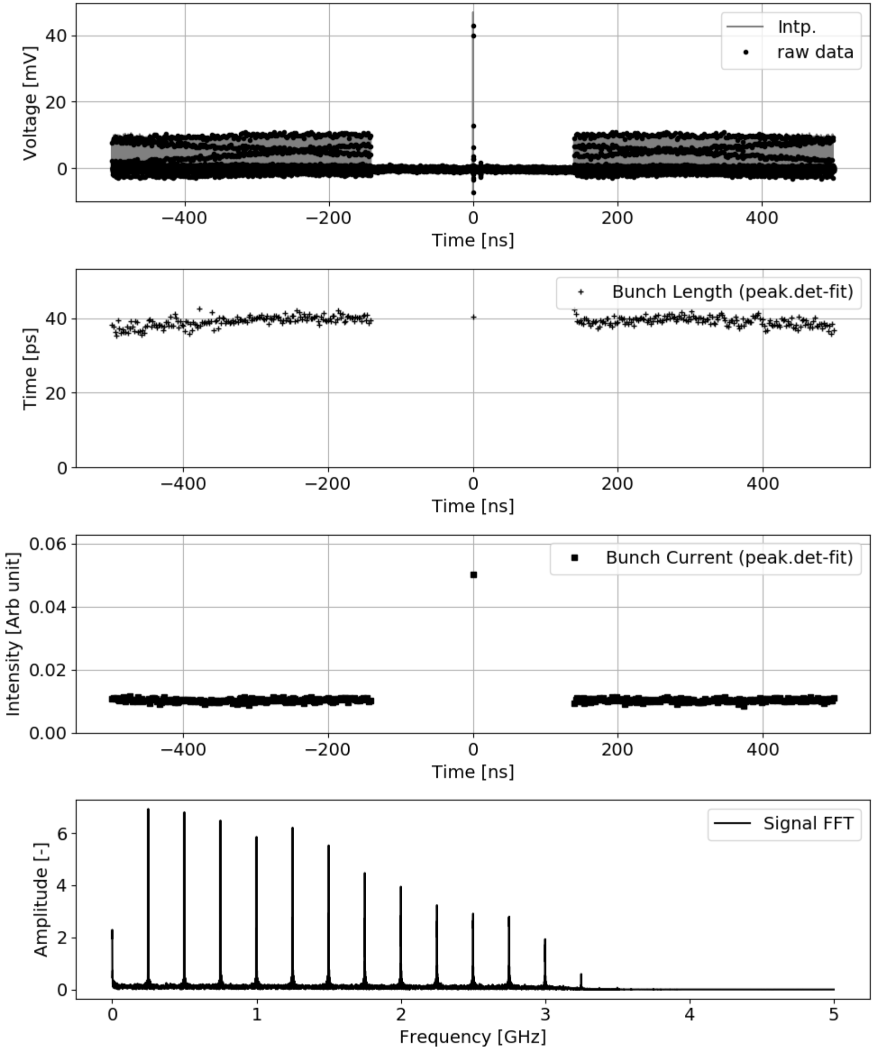
- 구성

1. Sec12-unused BPM - 1 button @ tunnel
2. Digitizer System @ control shed
   - Crate - U1091AC30 - 300 W, cPCI Bus
   - ADC - U1065A (10 bit ADC, 1-ch, 2-3 GHz ABW, 8 GS/s Sampling Speed, 1 MS Memory)
   - PC interface - U1092A (250 MB/s, 5M Cable)
3. PC @ where?
   - Acquires S/W + EPICS IoC
4. PV - `SR:FPM:Wf:L0`

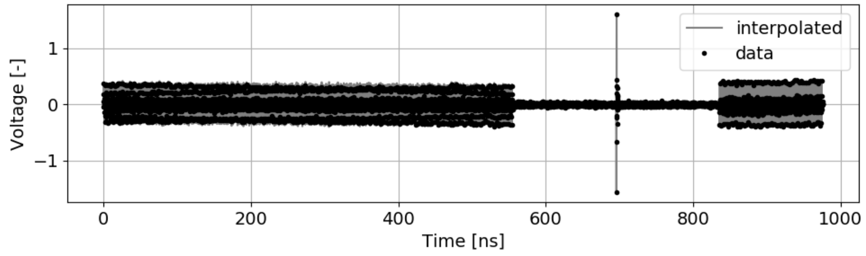
- 1B PD 방법 시도, 신호 미약, 측정 불가 --> BPM으로 개발
- 2019.11 - 1B PD 방법 성공

PD 방법과 BPM 방법 비교

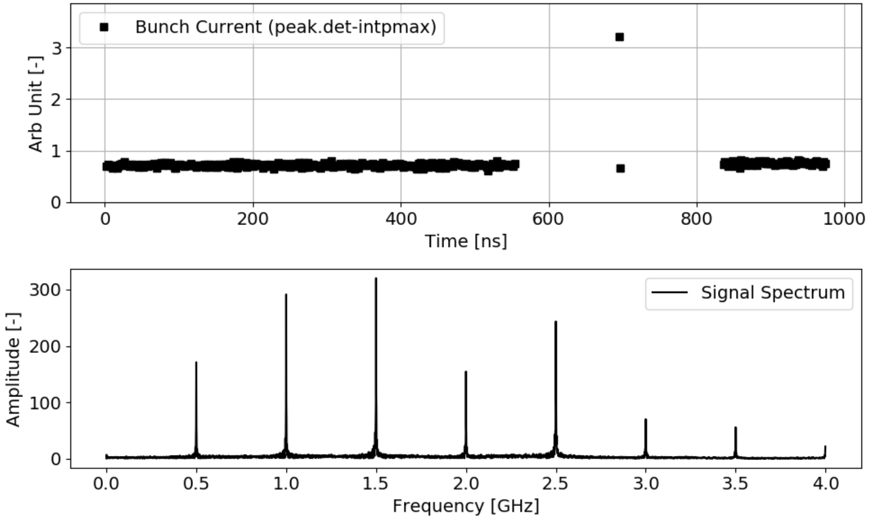
PD 방법



BPM 방법(현재)

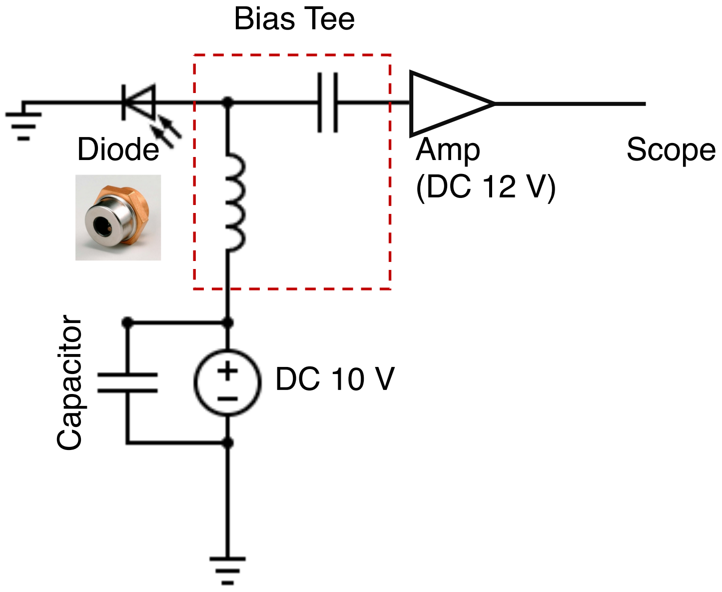


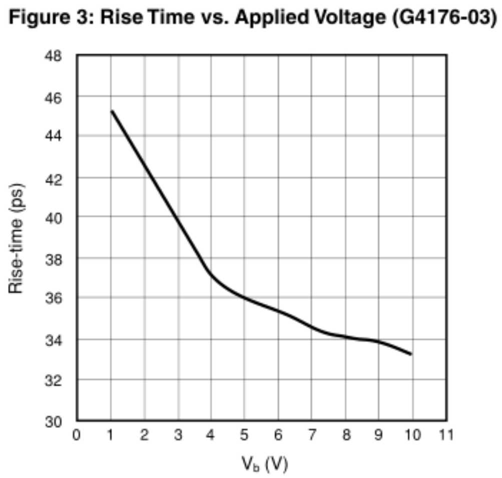
길이 측정 불가

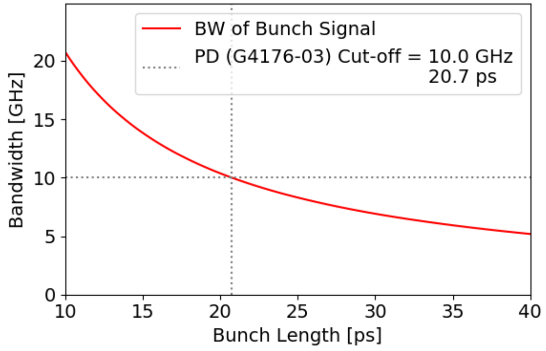


Filling Pattern : Photo-diode 상시 측정

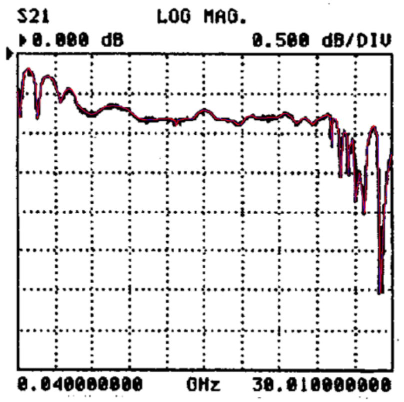
- **Photo diode**
  - rise time(t) ~ 35 ps @ 7 V (bias)
  - Eq. bandwidth = 0.35/t = 10 GHz
  - Eq. bunch length = 20.7 ps
    - less than 21 ps --> impossible



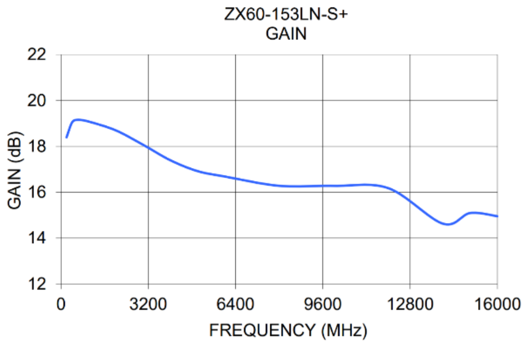




- **Bias Tee**
  - Tr. Ratio -> Gain으로 취급

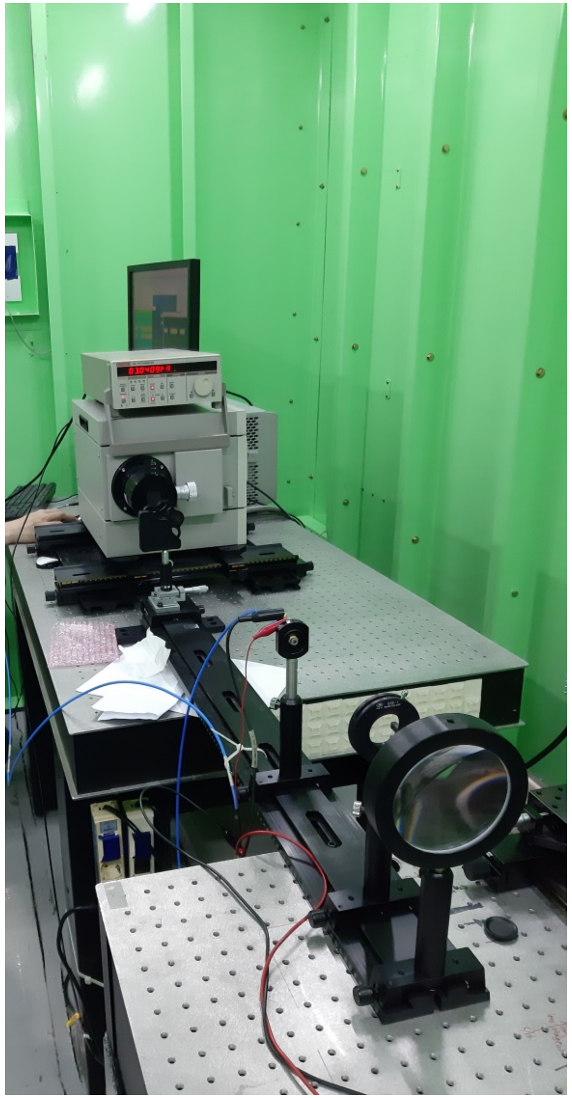


- **Pre-amp**
  - Gain

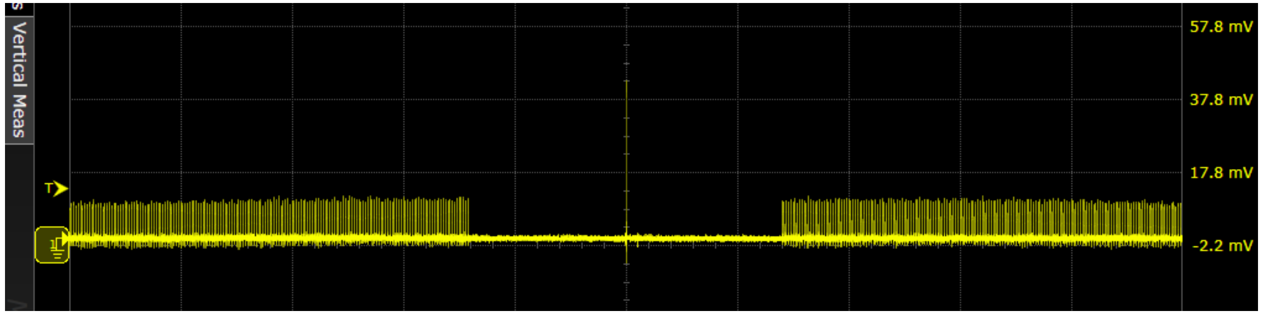


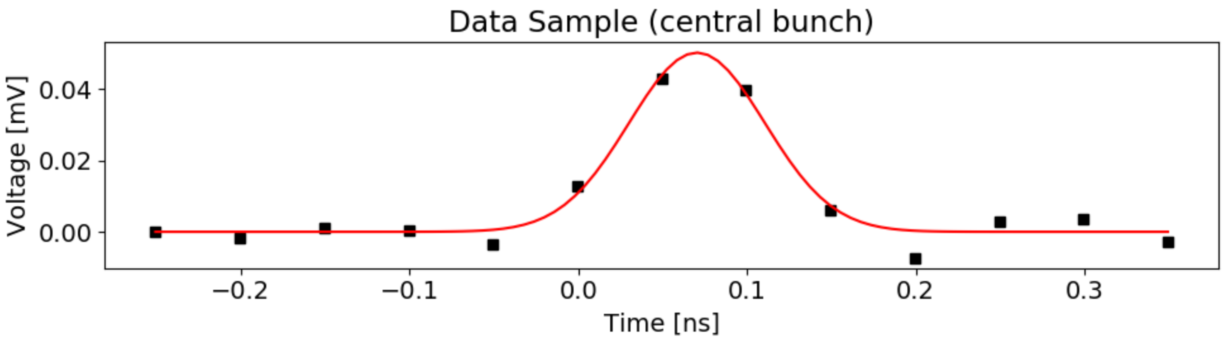
PD의 rise time을 35 ps로 잡으면, 21 ps 정도는 잴 수 있음

PD FPM 1차 실험, 2019/11/11



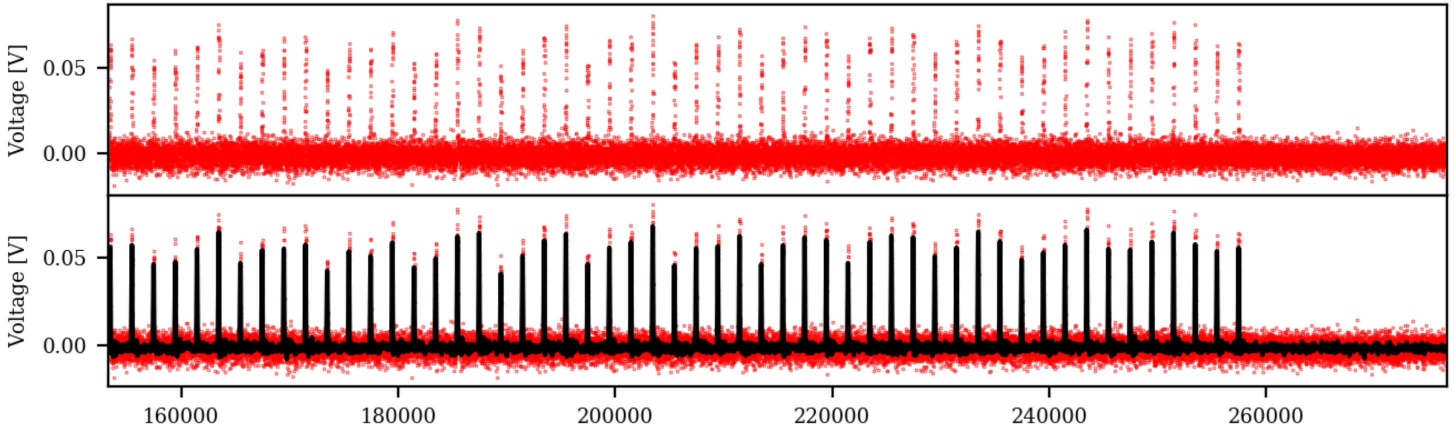
- Photodiode + Bias Tee + Amplifier
- Fast digitizer (10GBW, 40GS)
- (opt) Pico-ampere-meter

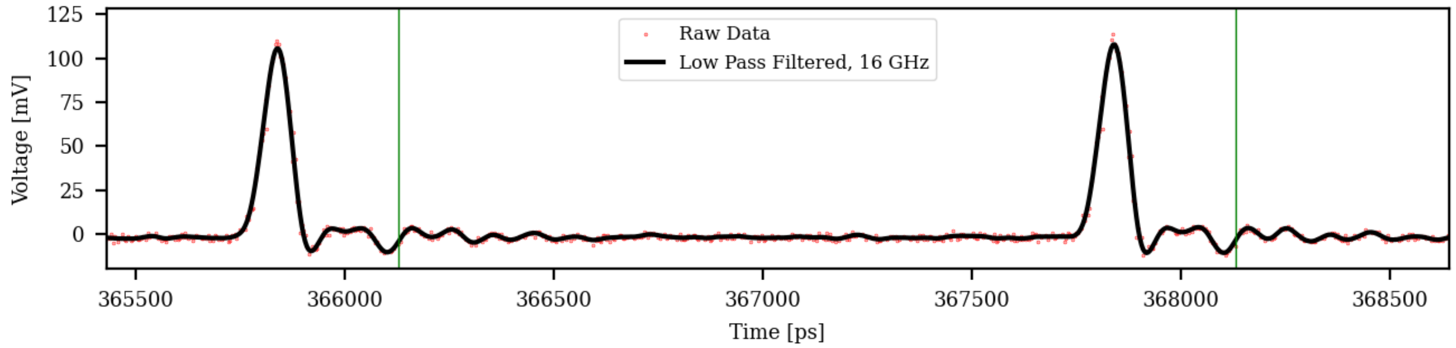




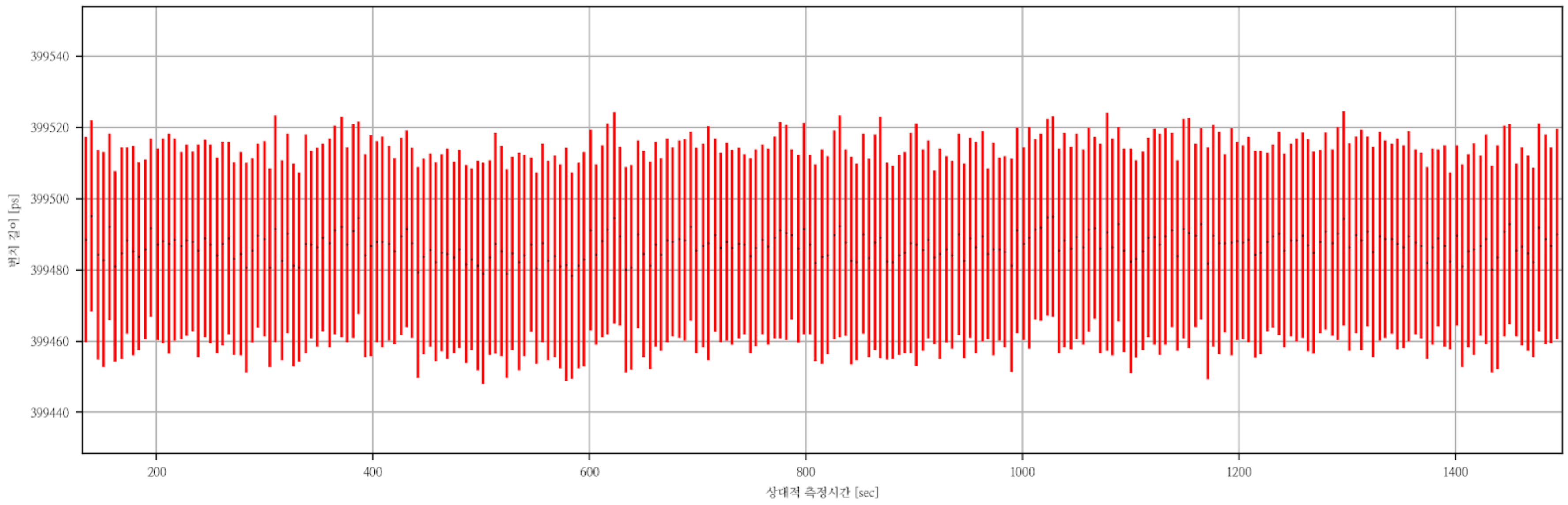
Filling Pattern : Control SW

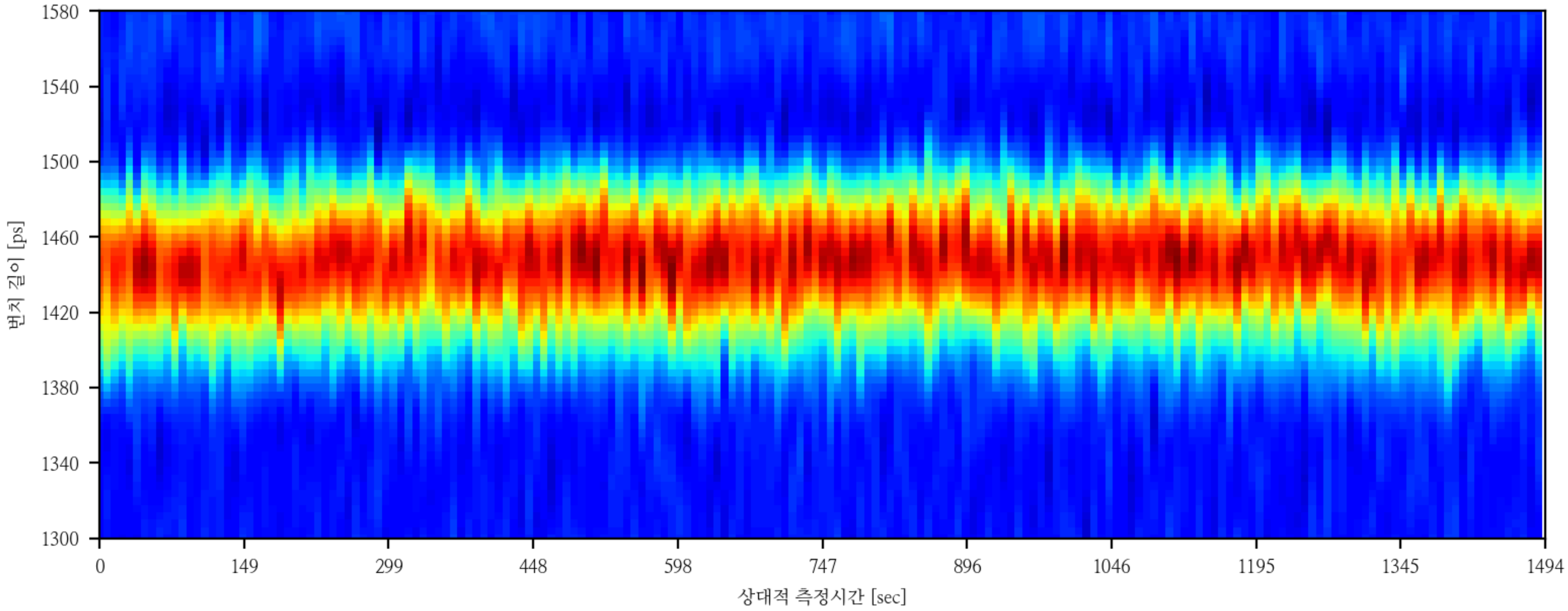
- 현재는 자동화 제어/계측 코드 제작중
  - [250k points/second -> FFT -> Filter -> Compensation -> IFFT -> Gaussian Fit (500 times) -> DB Access](repeat)
  - Auto Analysis -> Inform
- 검증을 위한 머신 스터디중 (Mar/2021 ~)



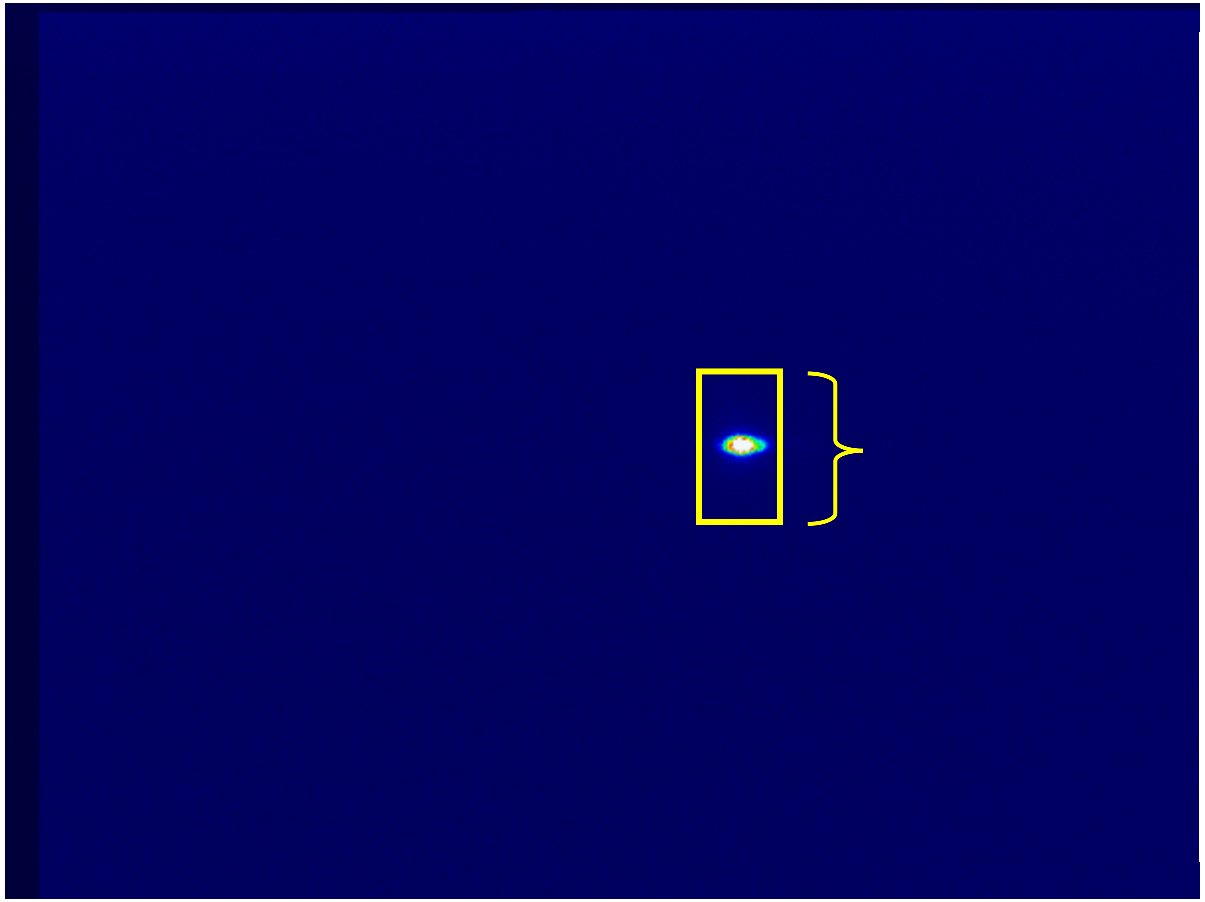


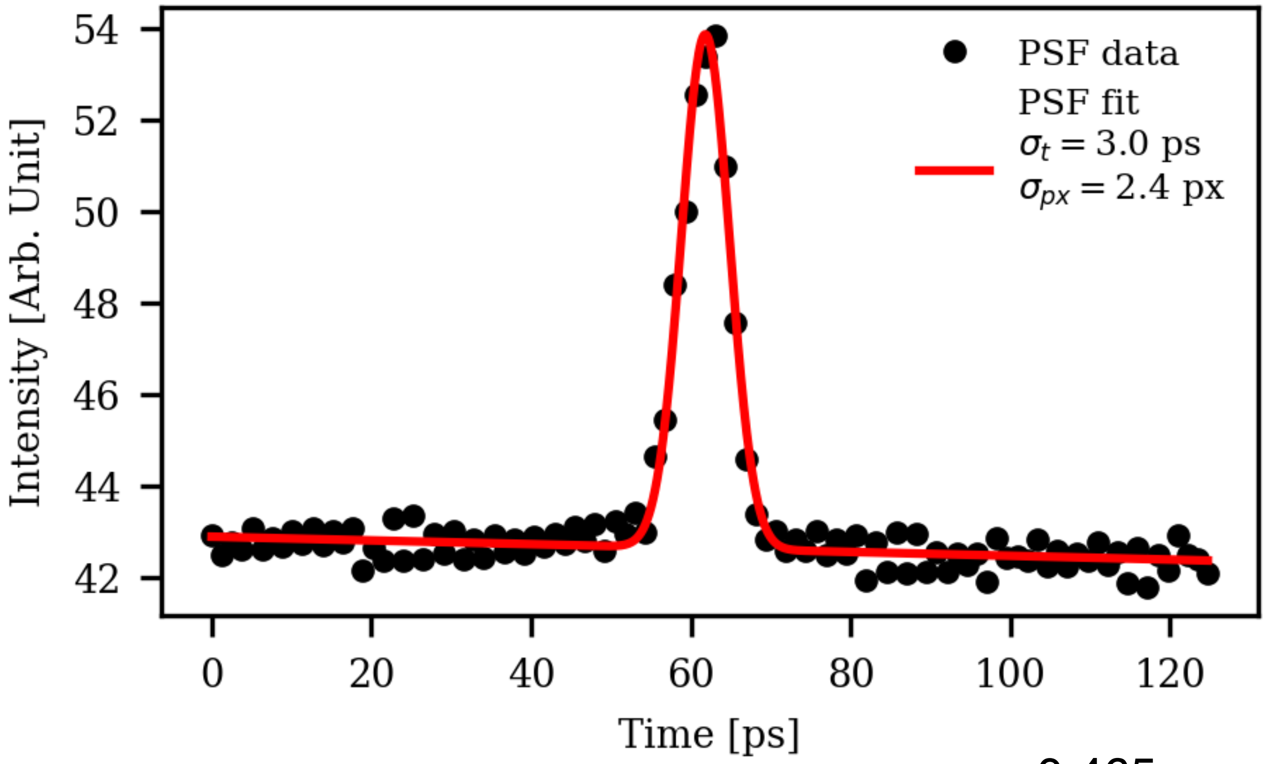
8-avg


399540
399520
399500
399480
399460
399440
번치 길이 [ps]
200
400
600
800
1000
1200
1400
상대적 측정시간 [sec]


1580
1540
1500
1460
1420
1380
1340
1300
번치 길이 [ps]
0
149
299
448
598
747
896
1046
1195
1345
1494
상대적 측정시간 [sec]

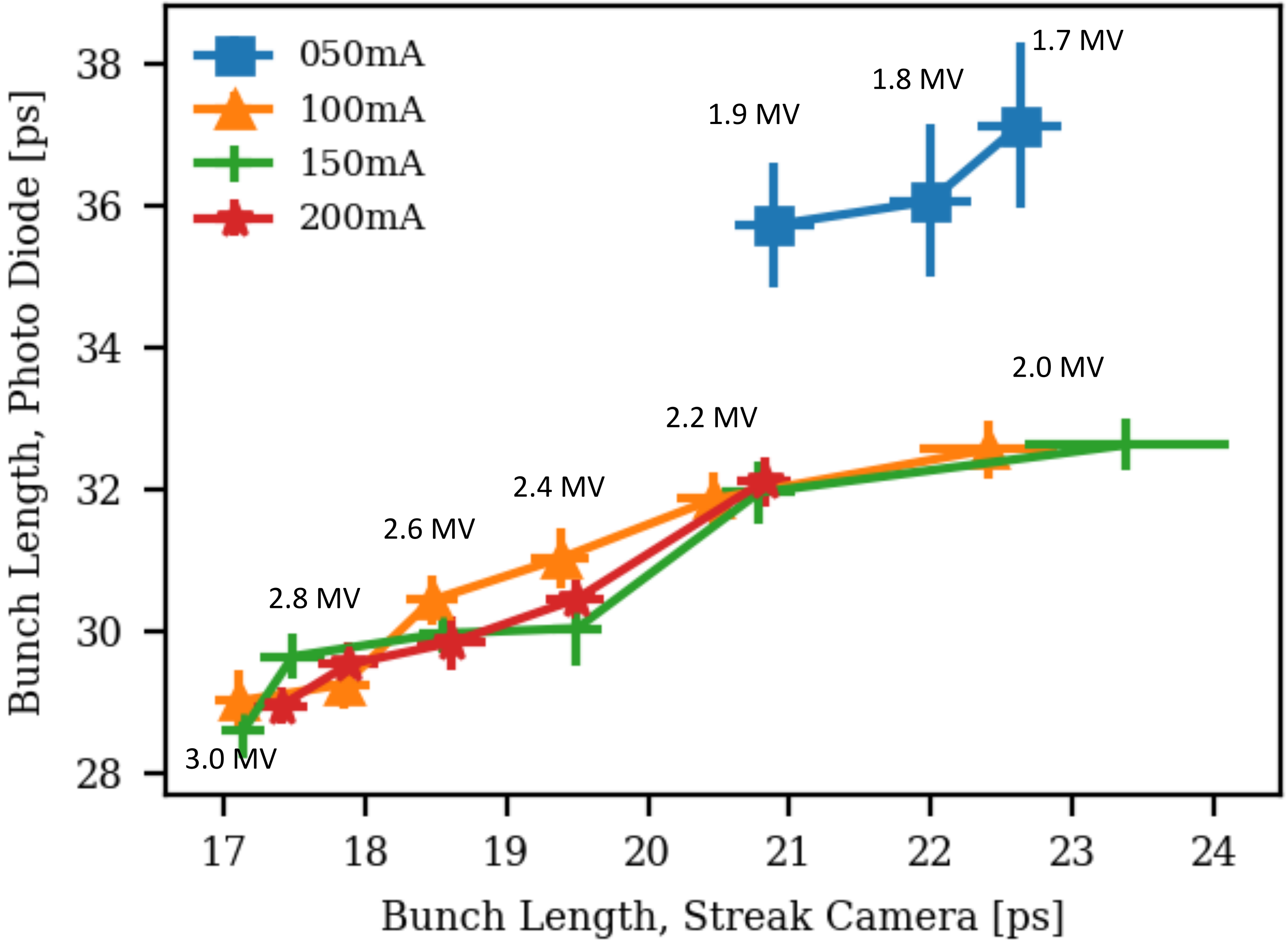
Point Spread Function + Jitter



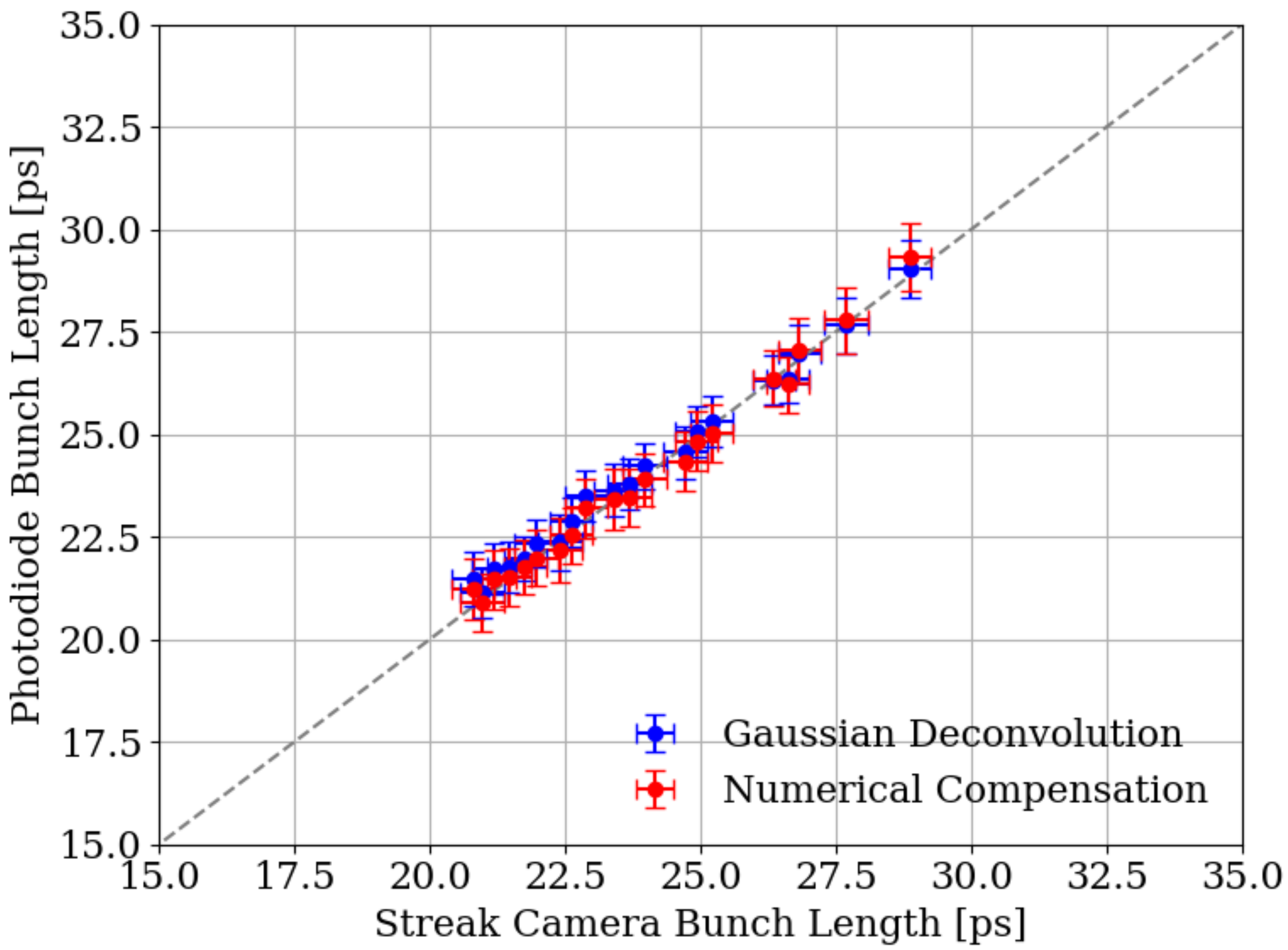


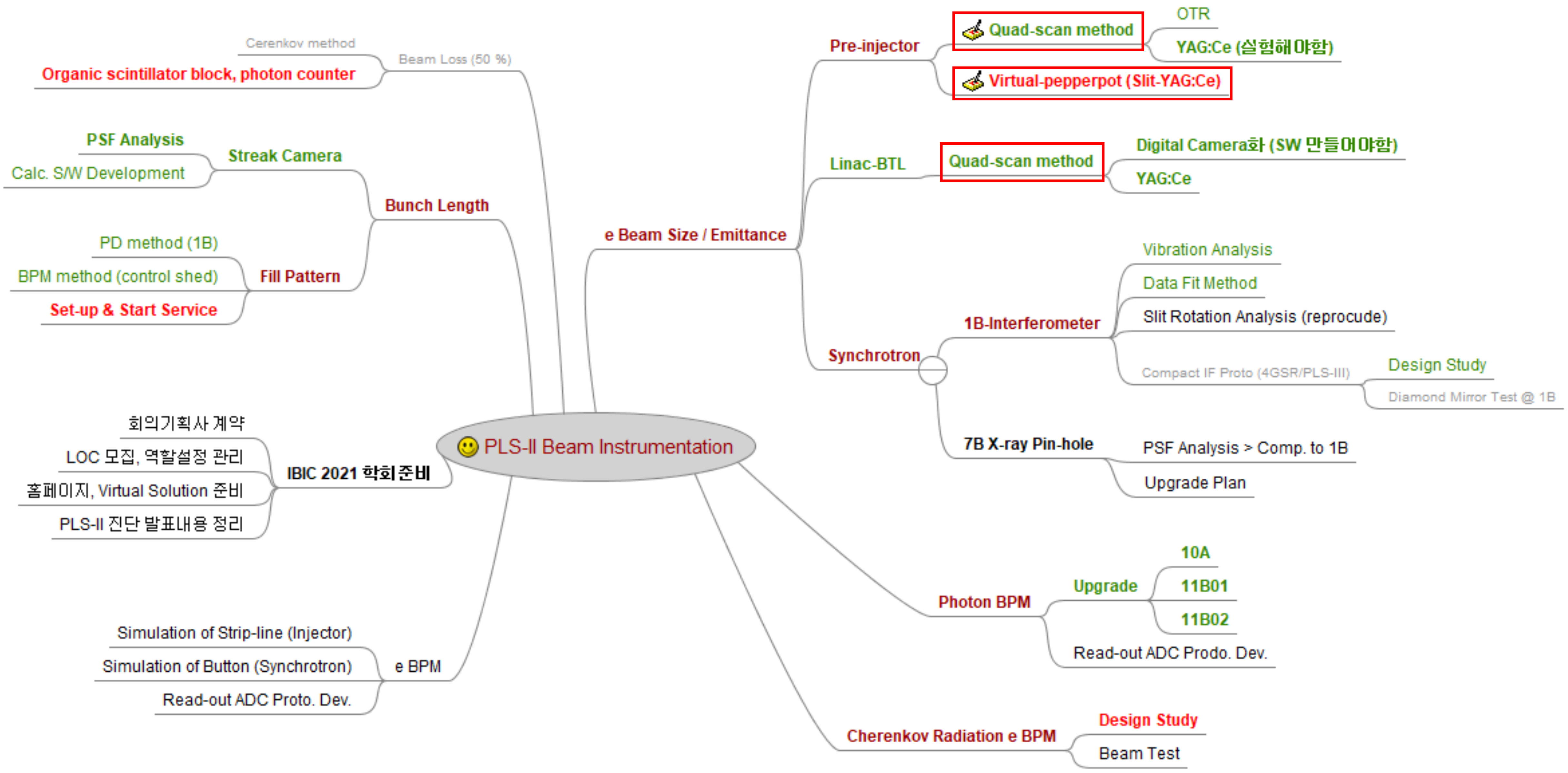
σ_{jitter} = 0.465 ps

MS 1 Result (Comparison btw ST and PD)

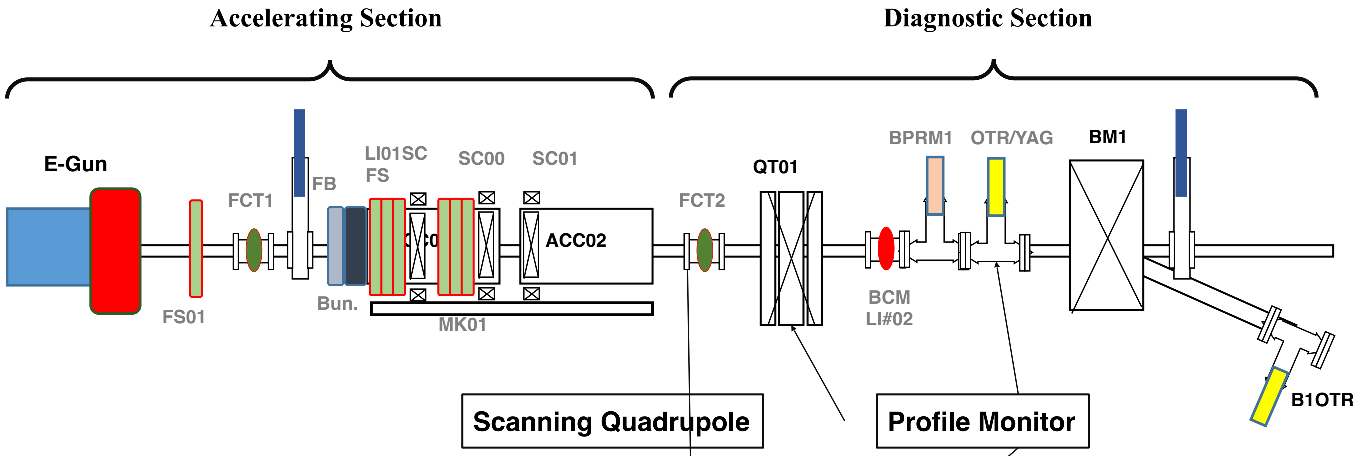


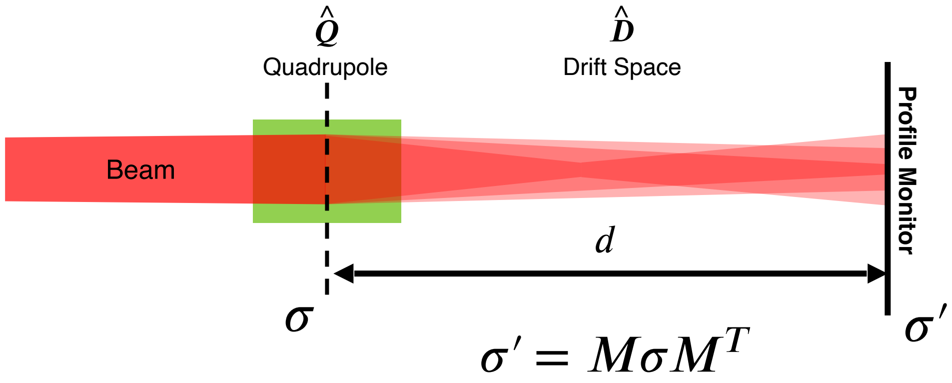
MS 2 Result (Comparison btw ST and PD)

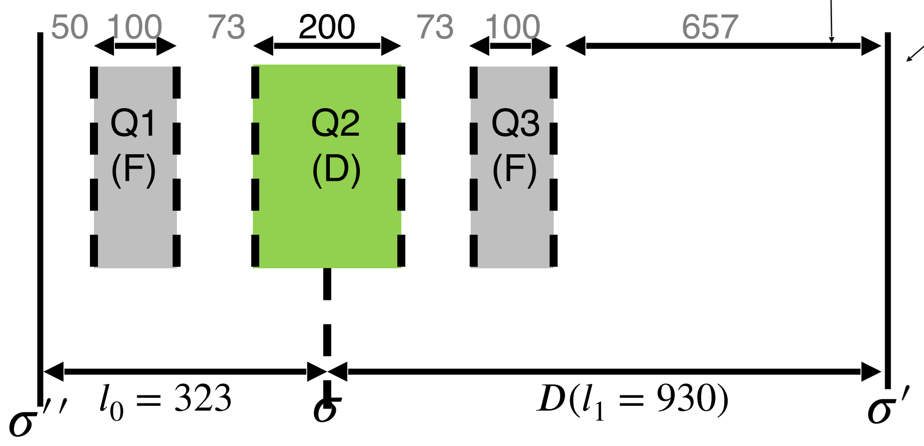



PLS-II Beam Instrumentation
Beam Loss (50 %)
Cerenkov method
Organic scintillator block, photon counter
Bunch Length
Streak Camera
PSF Analysis
Calc. S/W Development
Fill Pattern
PD method (1B)
BPM method (control shed)
Set-up & Start Service
IBIC 2021 학회준비
회의기획사 계약
LOC 모집, 역할설정 관리
홈페이지, Virtual Solution 준비
PLS-II 진단 발표내용 정리
e BPM
Simulation of Strip-line (Injector)
Simulation of Button (Synchrotron)
Read-out ADC Proto. Dev.
e Beam Size / Emittance
Pre-injector
Quad-scan method
OTR
YAG:Ce (실험해야함)
Virtual-pepperpot (Slit-YAG:Ce)
Linac-BTL
Quad-scan method
Digital Camera화 (SW 만들어야함)
YAG:Ce
Synchrotron
1B-Interferometer
Vibration Analysis
Data Fit Method
Slit Rotation Analysis (reprocude)
Compact IF Proto (4GSR/PLS-III)
Design Study
Diamond Mirror Test @ 1B
7B X-ray Pin-hole
PSF Analysis > Comp. to 1B
Upgrade Plan
Photon BPM
Upgrade
10A
11B01
11B02
Read-out ADC Prodo. Dev.
Cherenkov Radiation e BPM
Design Study
Beam Test

Pre-injector Emittance Measurement (Quad-scan Method)







Electron kinetic energy = 98.16 MeV

----> p = 98.66 (MeV/c)

B. Lee, JKPS 2016

Thin lens approx.   kl = ql/p G(I),

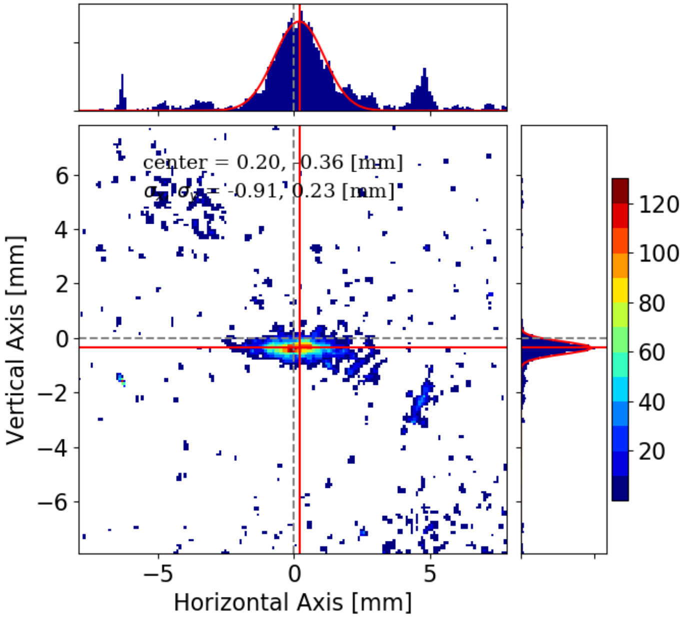
$G(I) = A_n I$

A_{Q1} or A_{Q3} = (+0.288 T/m)/(1.32 A) ... x 방향 기준 부호

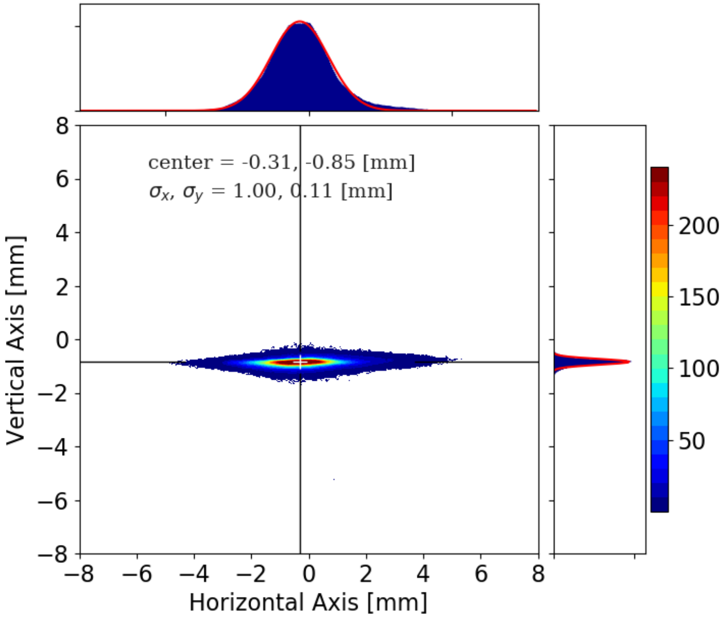
A_{Q2} = (-0.284 T/m)/(1.31 A) ... x 방향 기준 부호

PLS-2 Design Handbook

Screen 모니터 HW 업그레이드

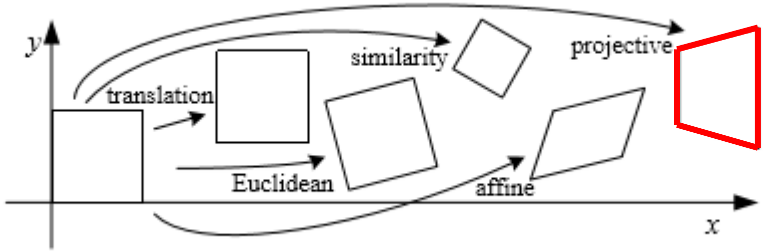


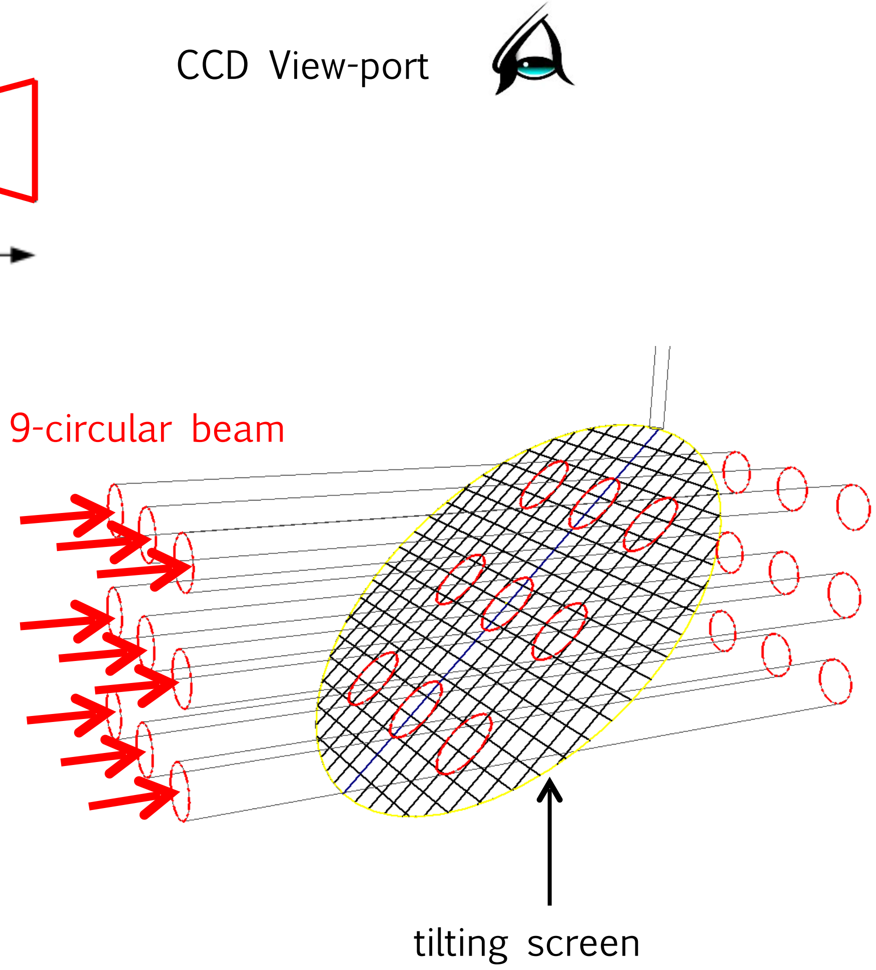
전

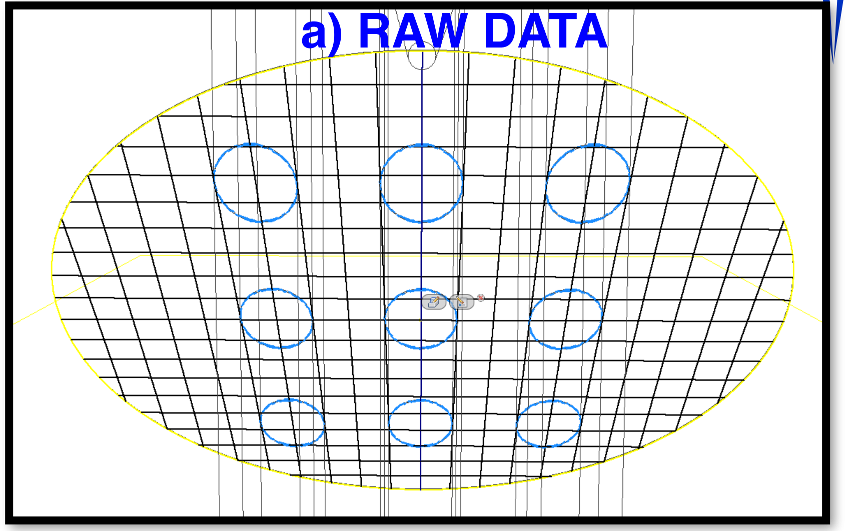


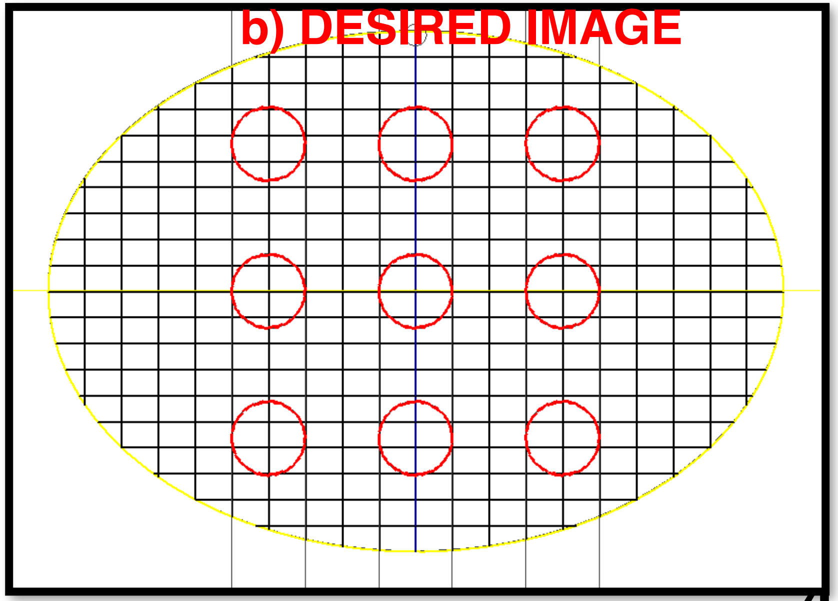
후

동기 : perspective projection









스크린모니터를 이용해 빔을 측정할 때,

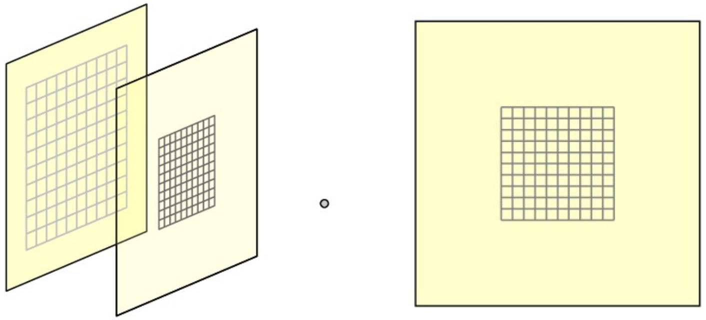
문제 1
우측 그림의 b) 를 예상하고 screen을 달지만,
실제로는 a) 처럼 보임.

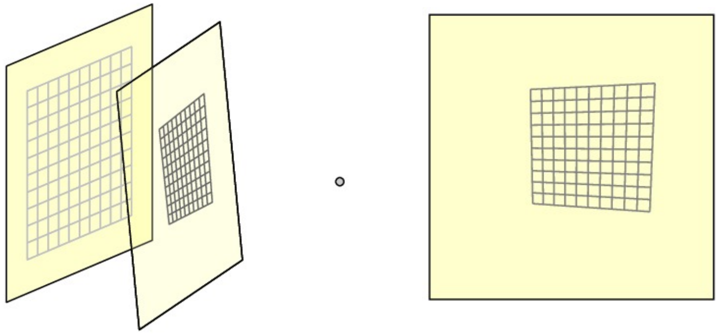
문제 2
어디가 로컬 좌표계의 0인지 모름.

해결책:
a) 를 b) 로 만들어주기 위한 Map을 만들어
calibration 해야 함.

cali. 이후에는 정량적 모양/크기 측정가능.

이론 : perspective transformation





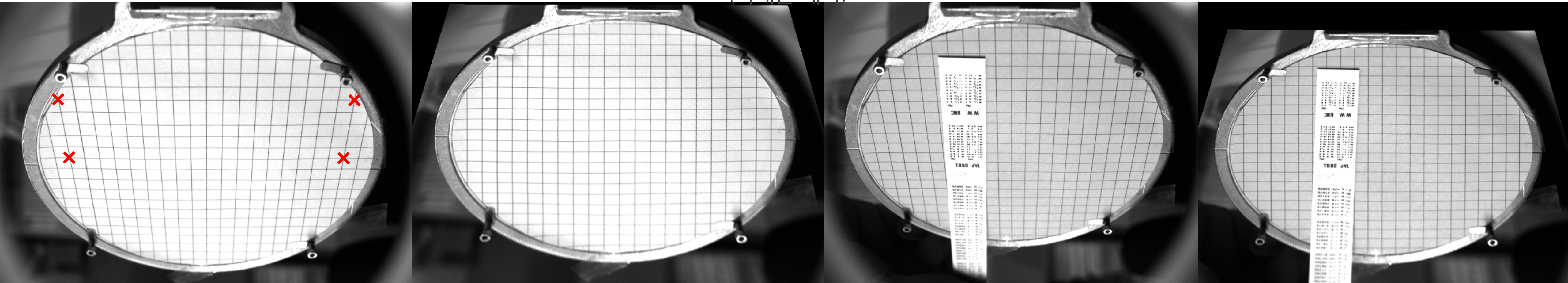
$$w_0 \begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \begin{bmatrix} a & b & c \\ d & e & f \\ g & h & j \end{bmatrix} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix}$$

$$(x, y) \mapsto (u, v) = \left(\frac{ax + by + c}{gx + hy + j}, \frac{dx + ey + f}{gx + hy + j} \right).$$

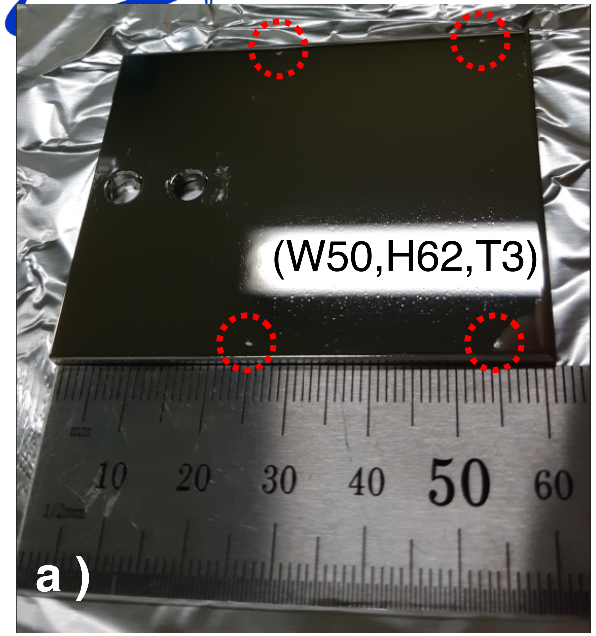
뷰 포인트가 주어지고, 프로젝션 면이 보여지는 normal vector와 임의의 각으로 배치될 때, 좌표 변환 하는 방법

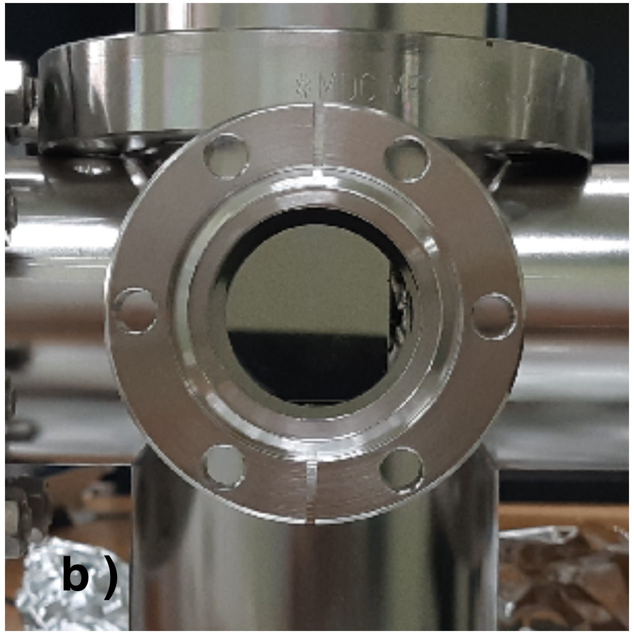
3x3 matrix (calibration matrix) 를 풀어내려면, Boundary Condition 4 쌍을 구해야 함 (빔 좌표 4쌍, 카메라 좌표 4 쌍)

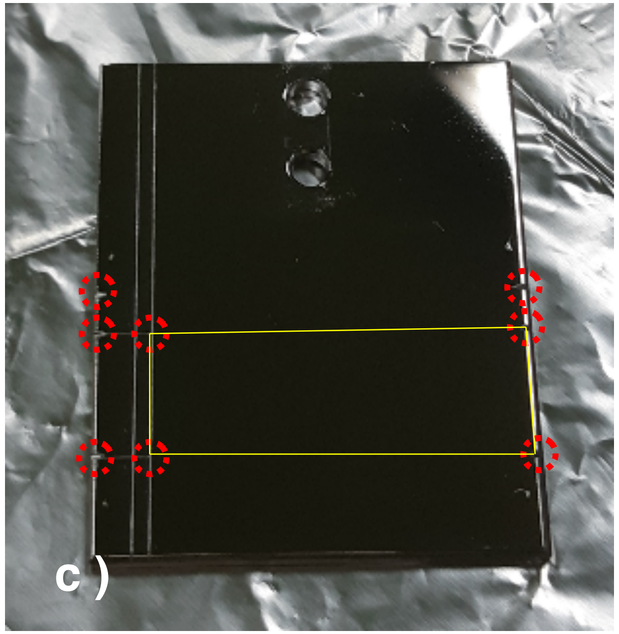
(아래는 예시)

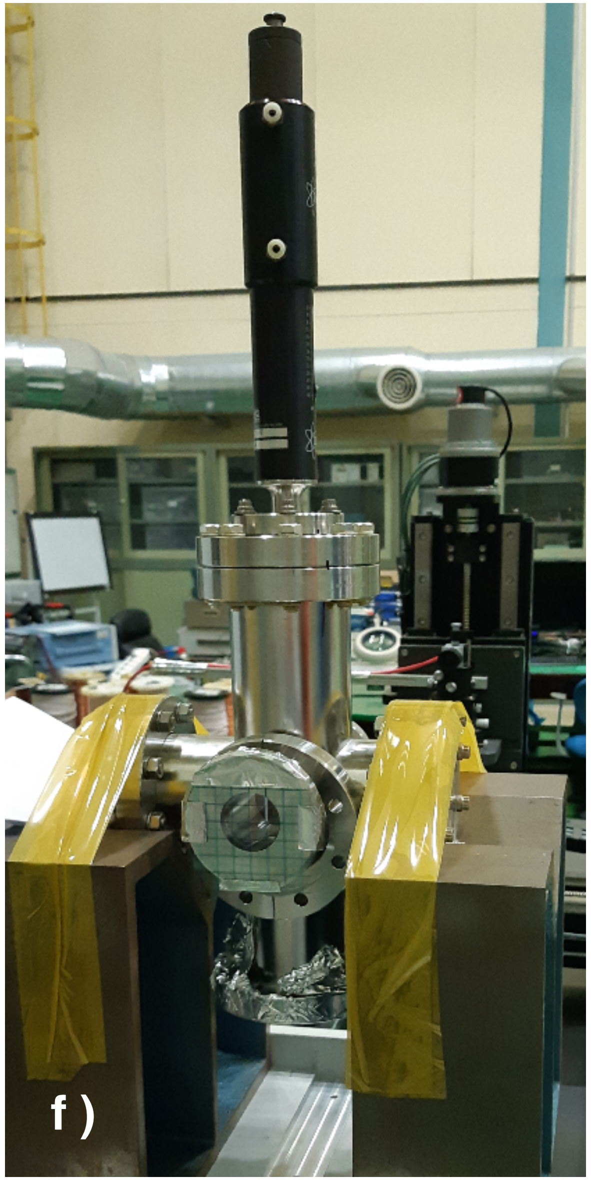


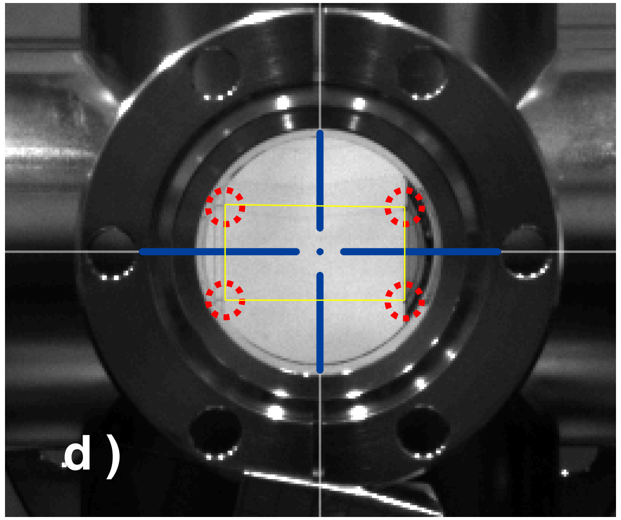
작업내역 1: OTR 캘리브레이션 작업의 (2/2) 진행, OTR 챔버로 실제 정렬

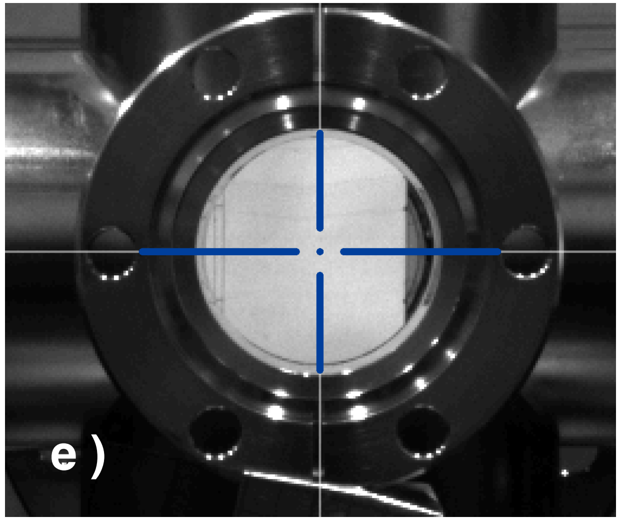






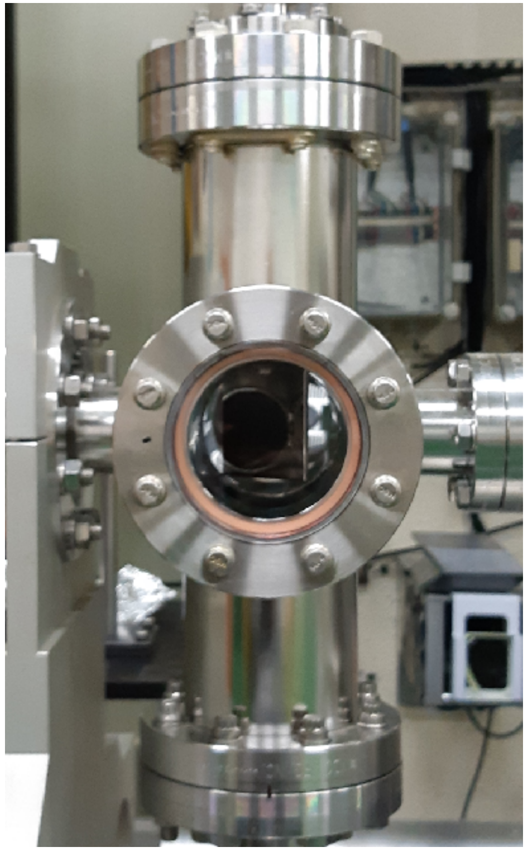




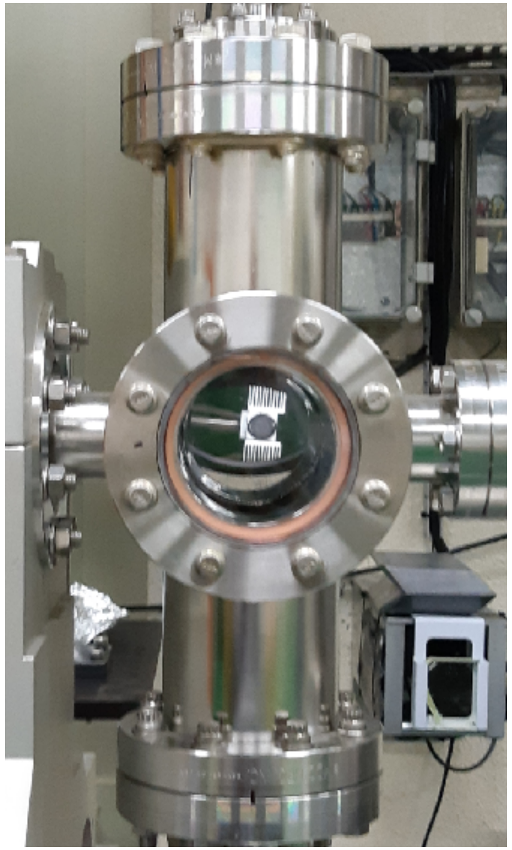


a) 사이즈 계측, 스크래치 내서 마킹
b) 조립하고 확인해보니 안보임
c) 몇 차례 a)-b) 반복하며 여러 군데 스크래치 (홈파기, 줄긋기 등)
d) 결국 보임 (위치 표기)
e) 결국 보임 (중심만 표기)
f) 연습용 챔버 제거 후 OTR 챔버 설치, 정렬

작업내역 2: 다시 조립, 진공 배기

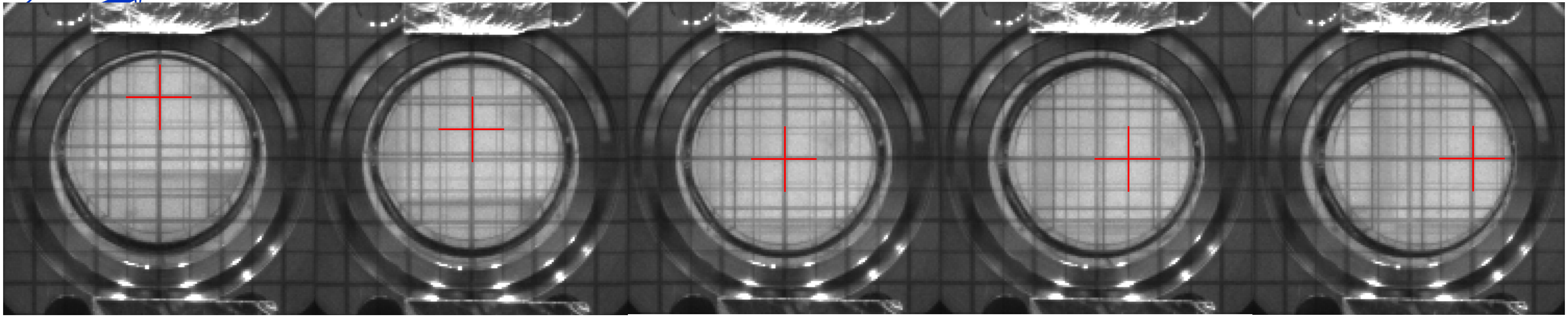


스크린 내렸을 때

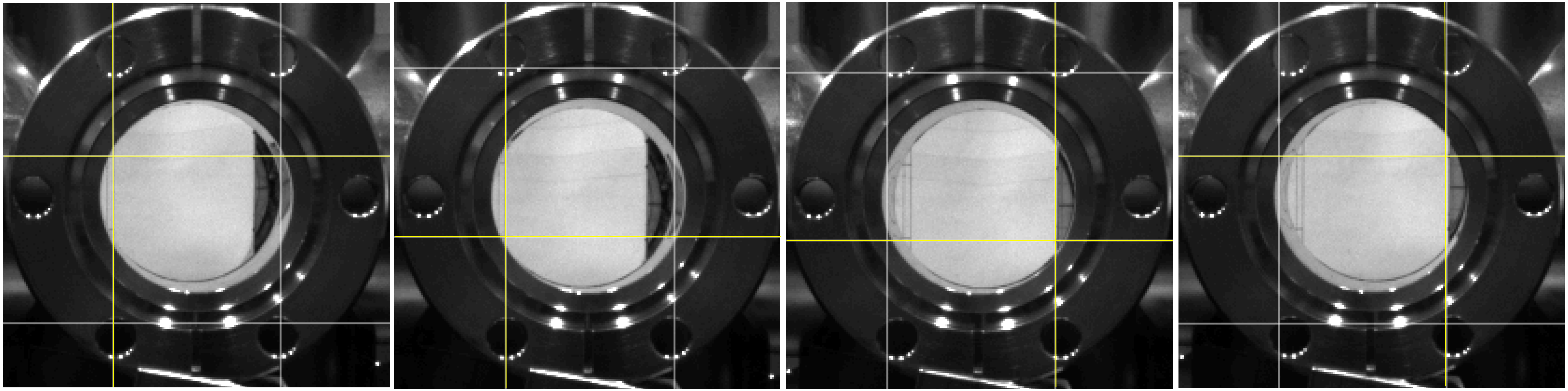


스크린 올렸을 때

Calibration 내역

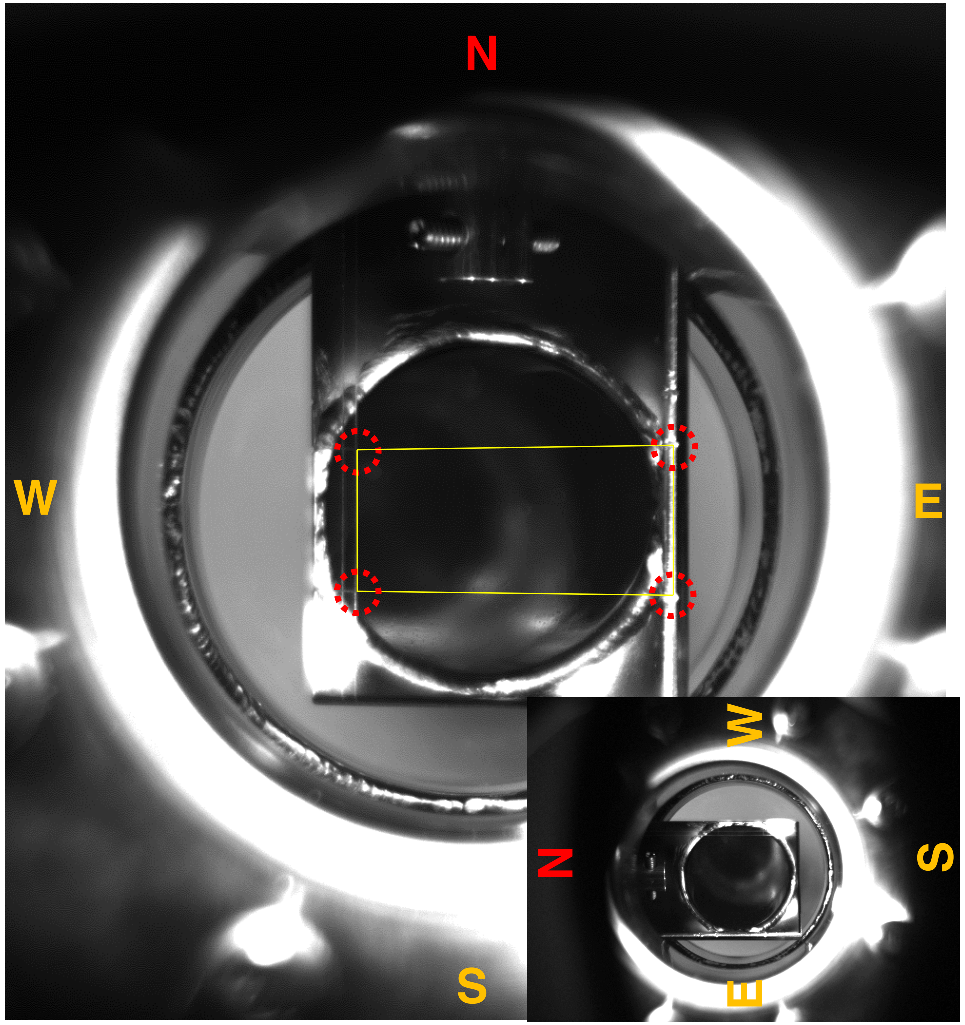


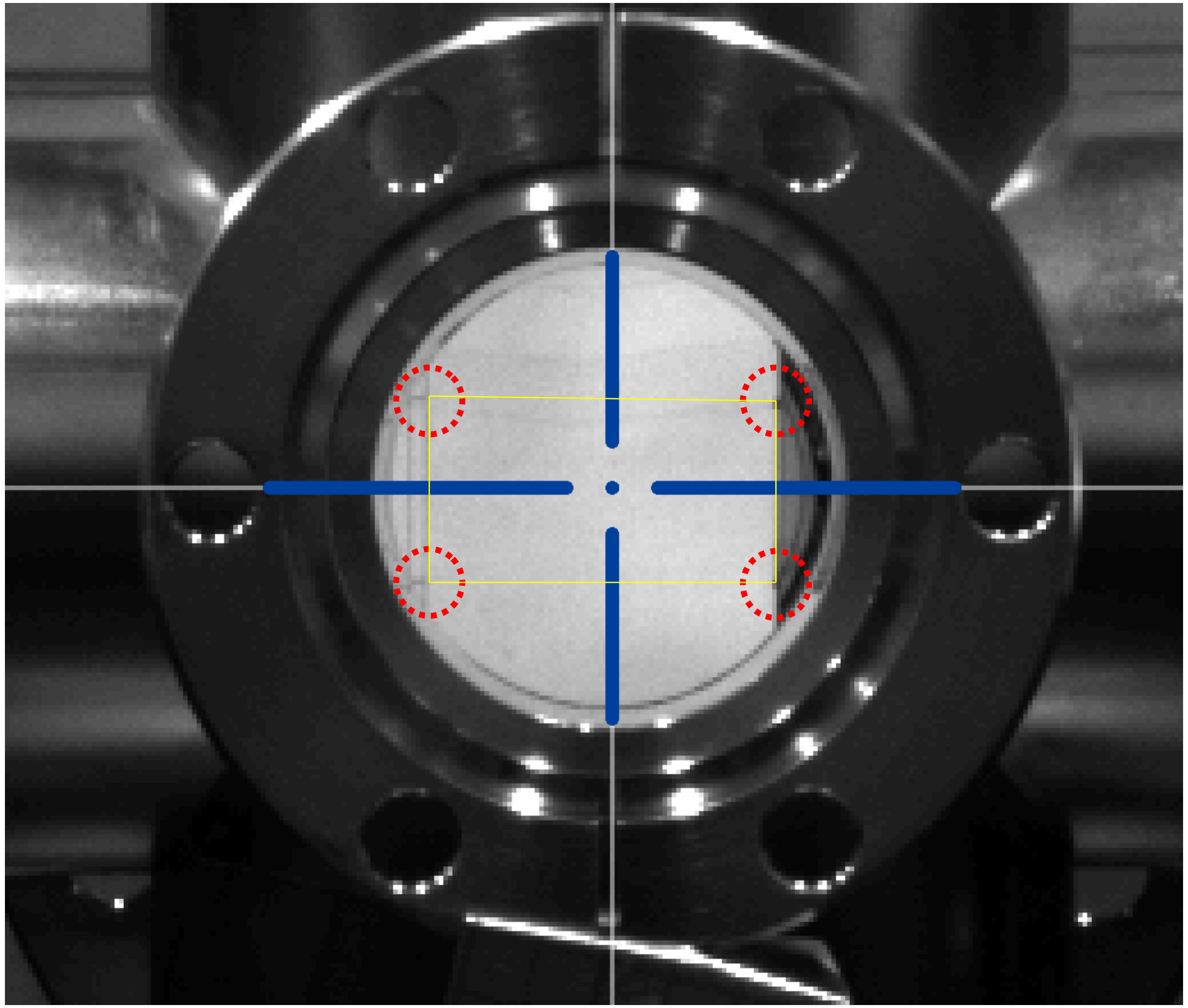
1. Local Coord. 의 Tr. Plane 상의 표기된 좌표 추출 (-15.1, 7.4) (-15.1, -7.2), (13.5, -7.9), (13.5, 7.0) in mm.



Calibration 내역

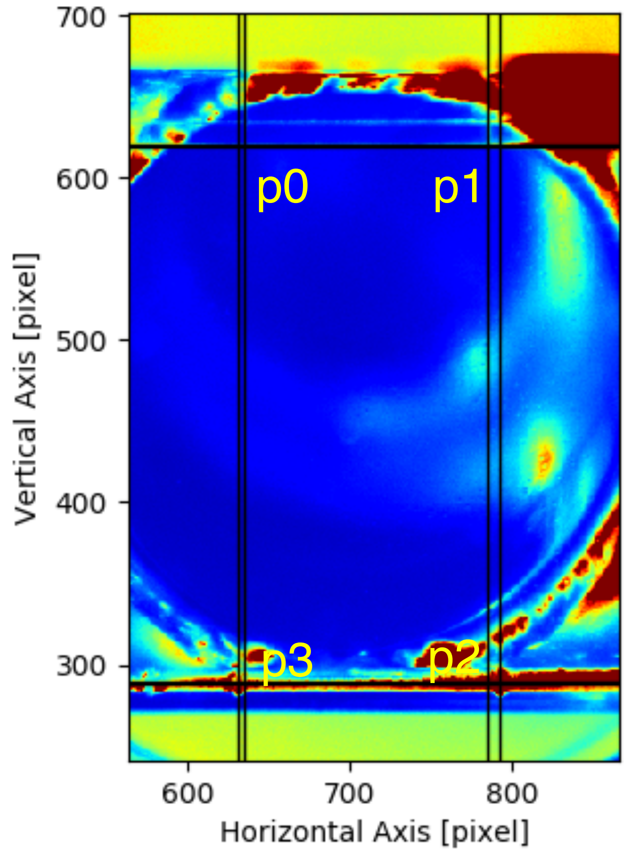
2. Camera 축 좌표 따고

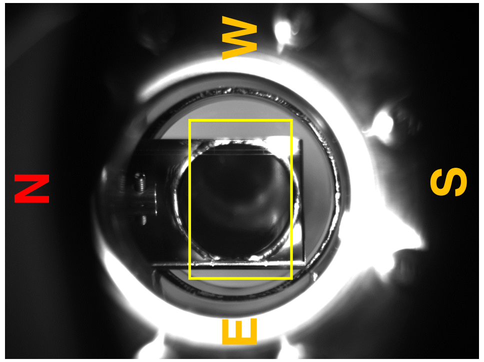


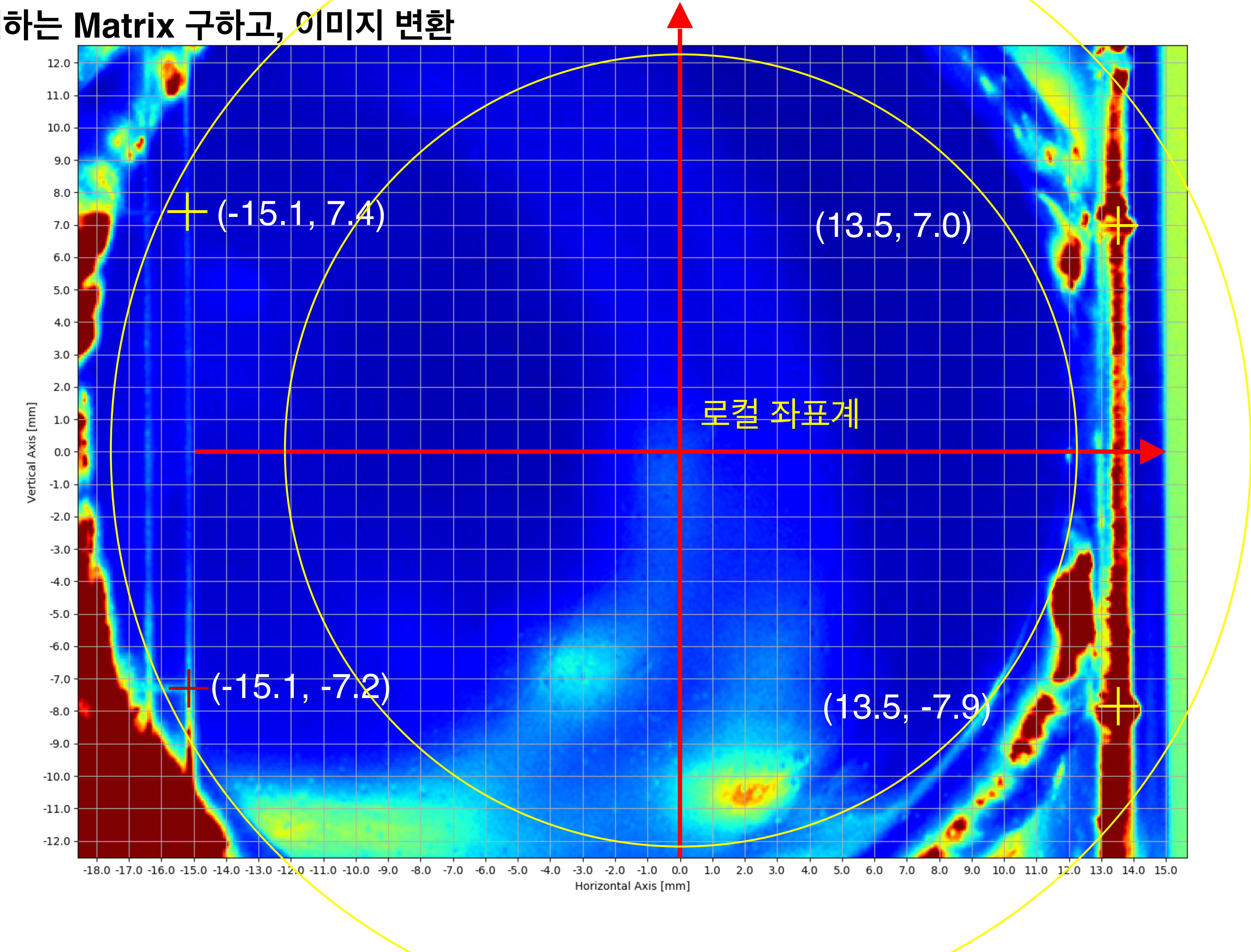


Calibration 내역

3. 두 측정을 매개하는 Matrix 구하고, 이미지 변환

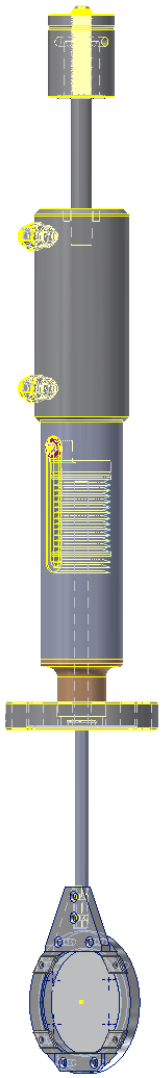


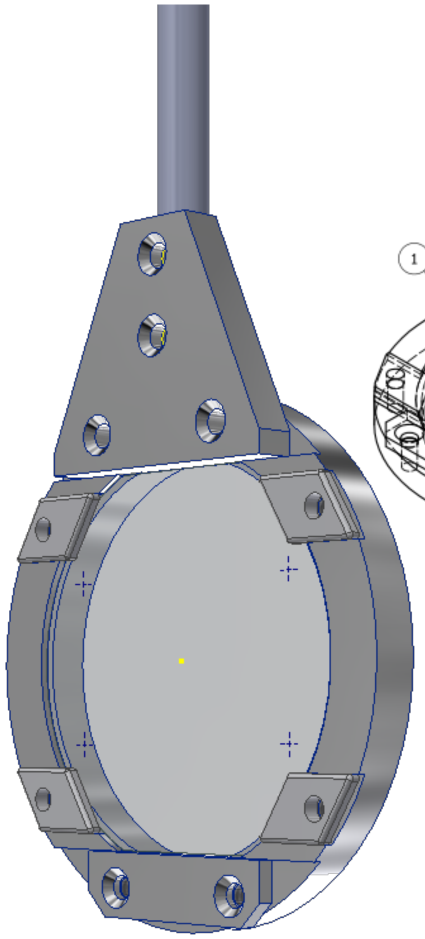


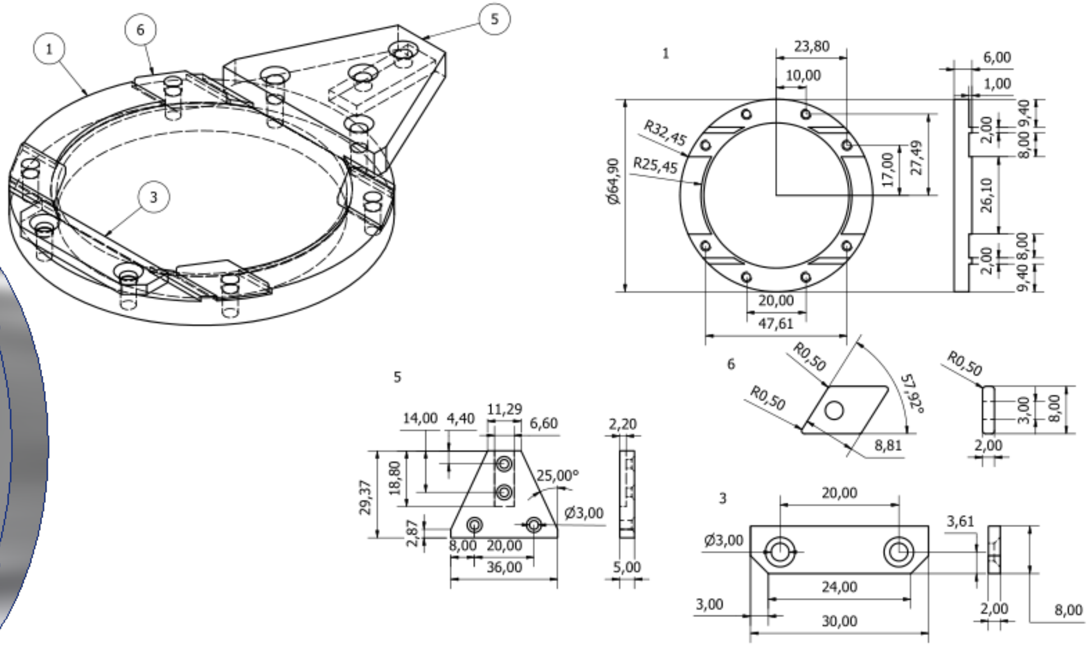


OTR -> YAG

1, 3, 5 - AL6061,
6 - Peek

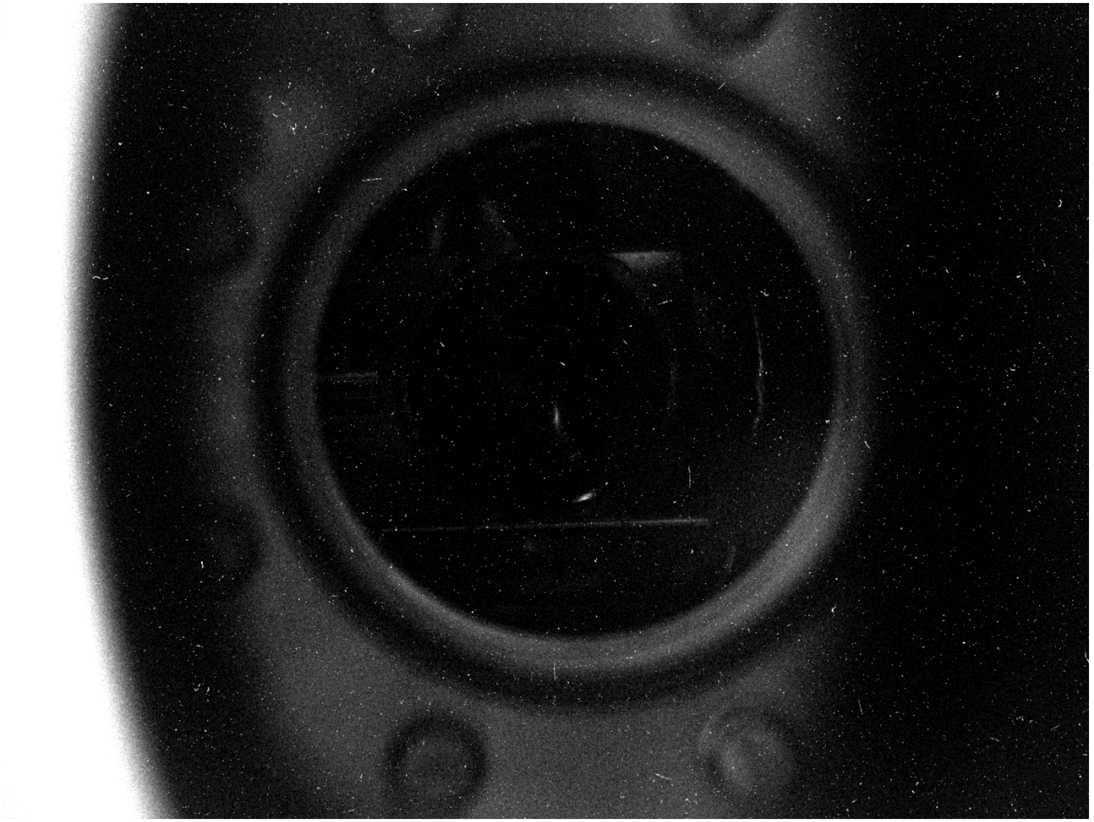




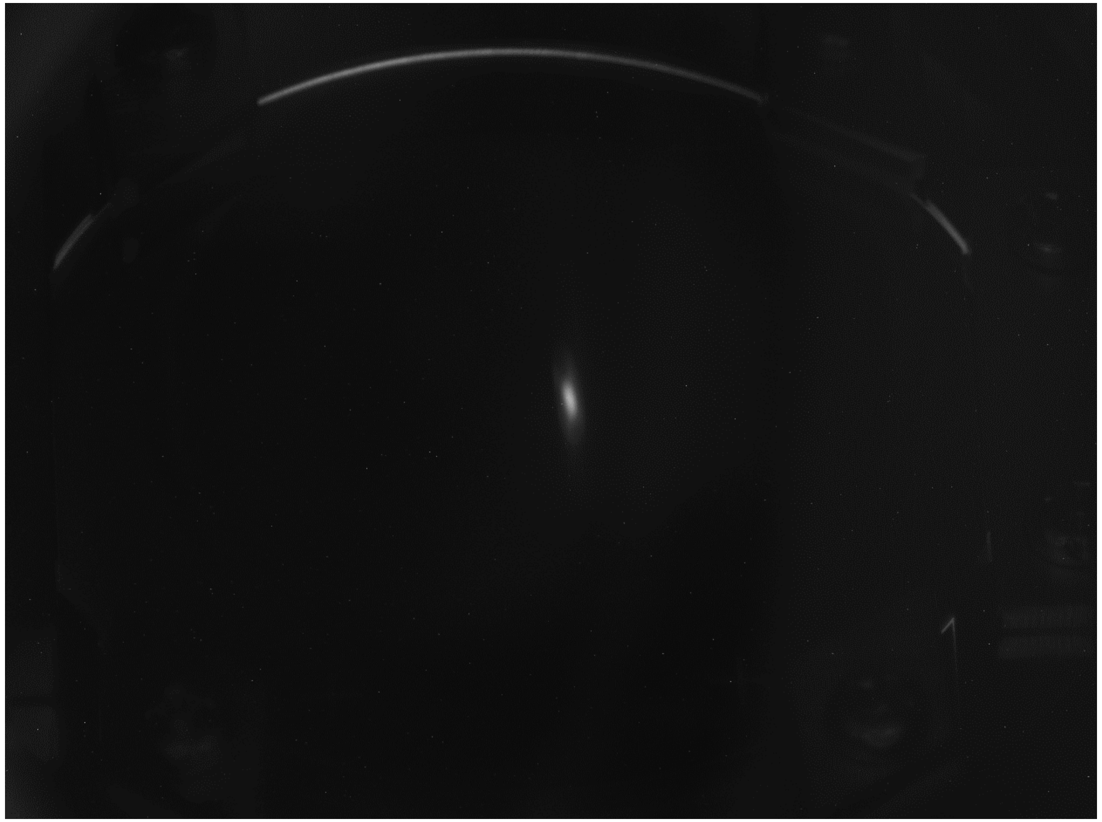


OTR -> YAG Raw Data Comparison

업그레이드 된 LIOTR1 은, 빔을 선명하게 pulse by pulse 로 관측 가능
(과거에는 30 pulse를 누적하고, 최대 증폭을 해야 겨우 빔이 보였음)



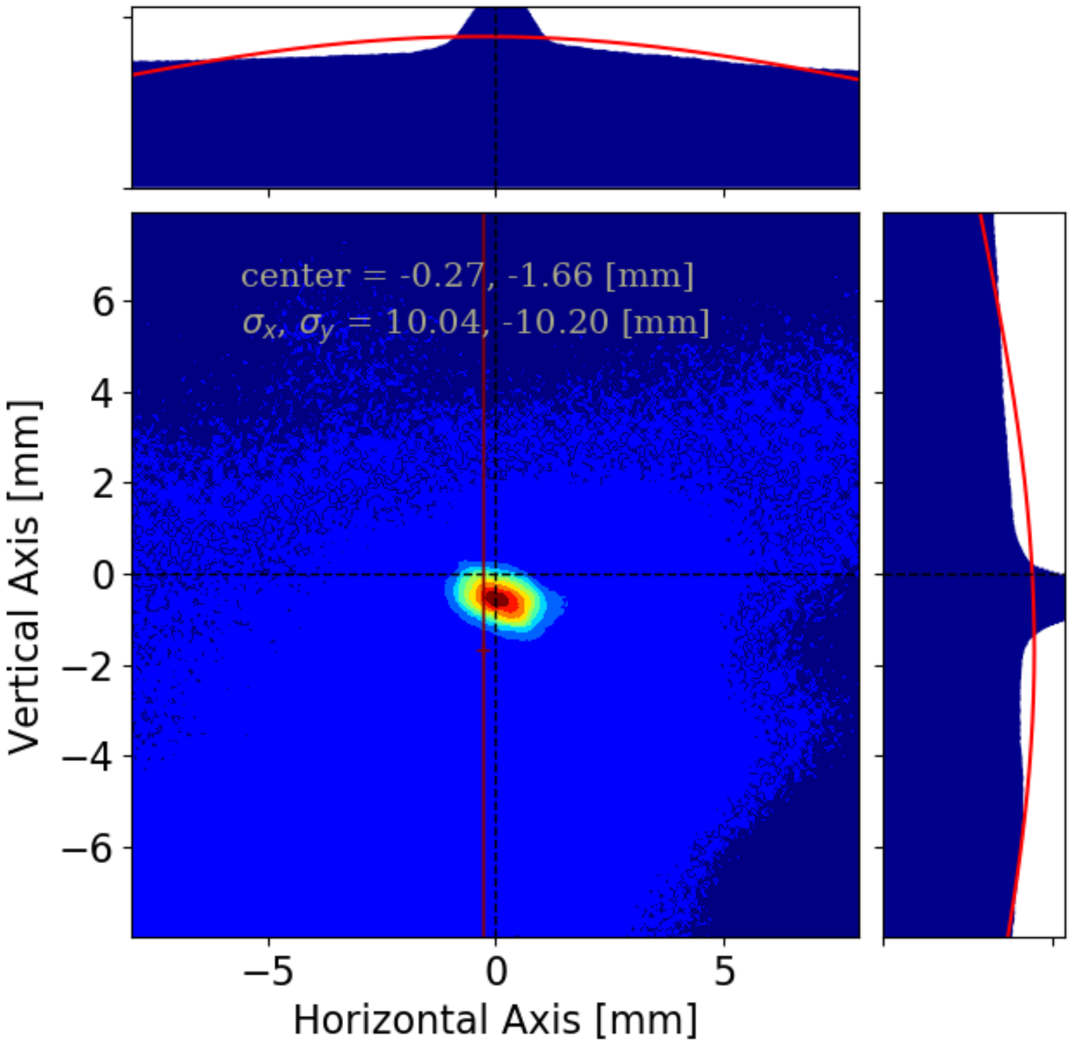
노출시간 : 3초 (30 beam pulse/shot)
증폭(단위 없음) : 최대
25 mm 단렌즈, 조리개 최대



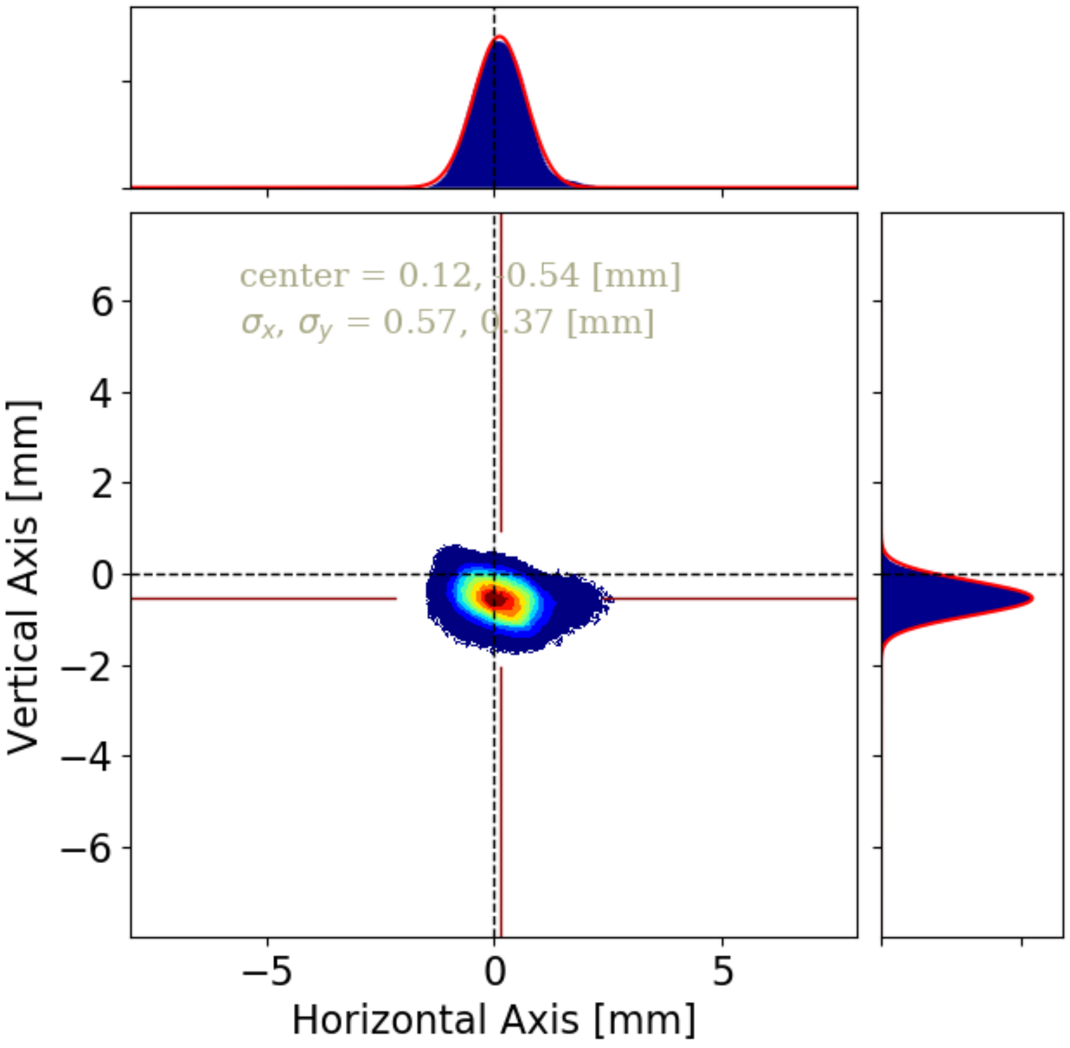
노출시간 : 0.1초 (1 beam pulse/shot)
증폭 : 0
75 mm 단렌즈, 조리개 최대

Image Processing

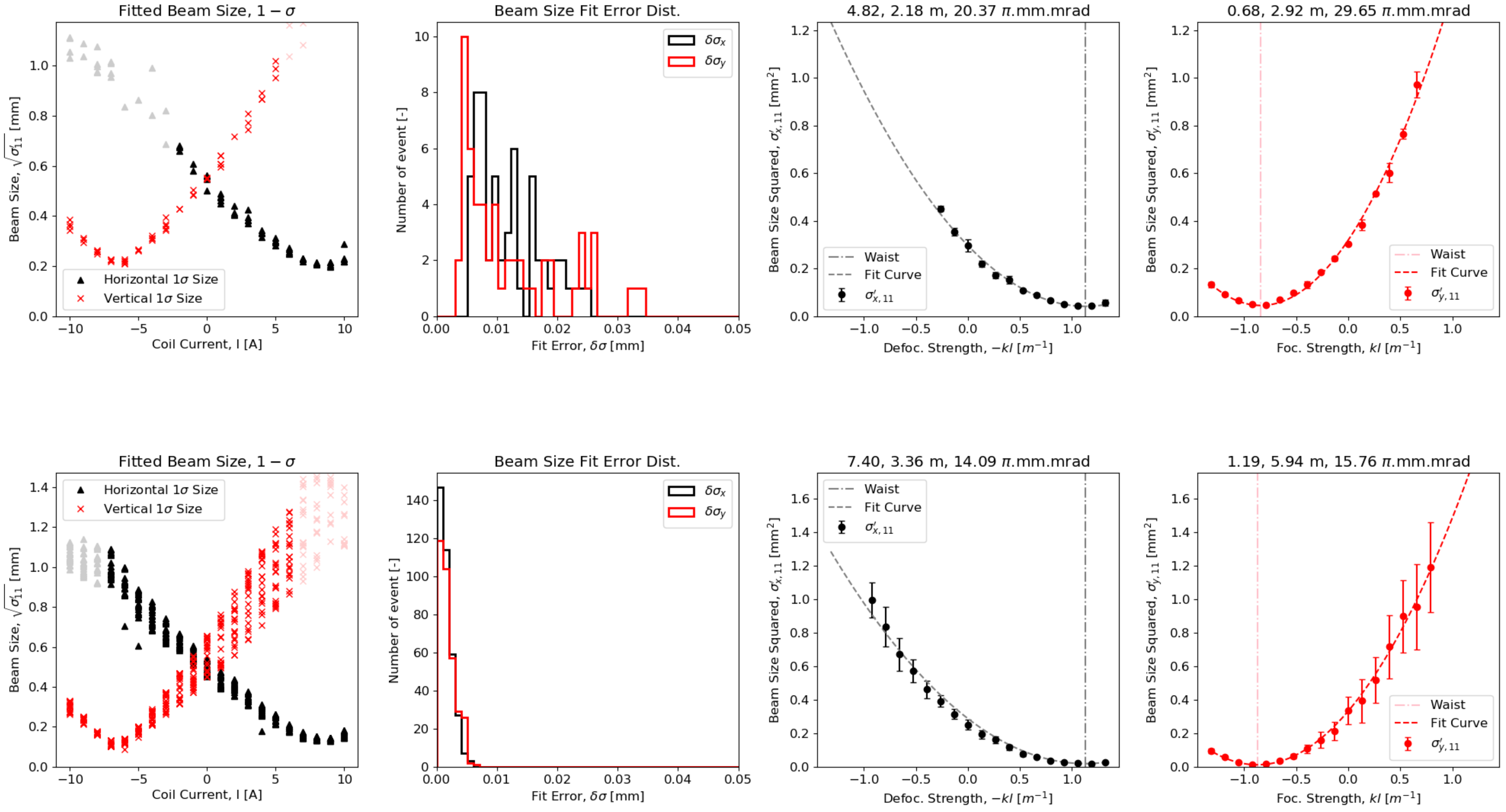
적용 전



자동 적용 후



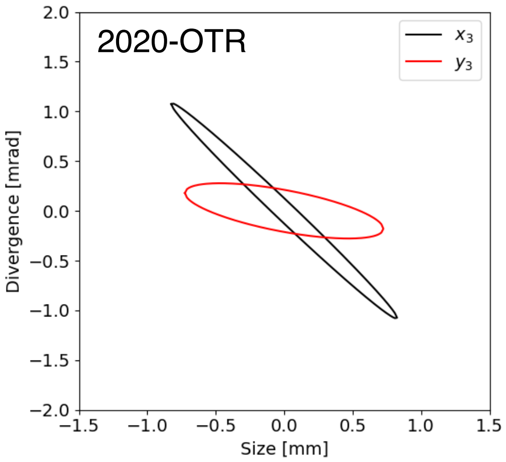
측정

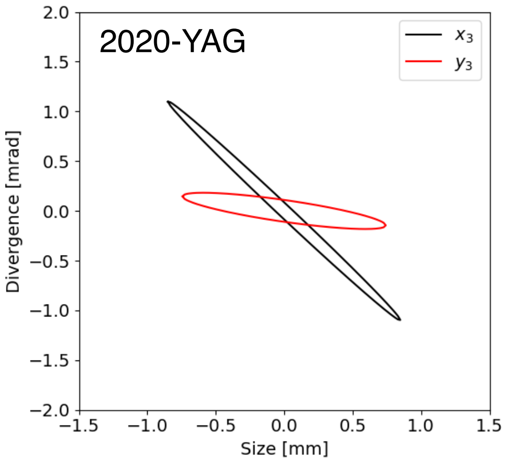


Fitted Beam Size, 1 − σ
Beam Size, $\sqrt{\sigma_{11}}$ [mm]
Coil Current, I [A]
Horizontal 1σ Size
Vertical 1σ Size
Beam Size Fit Error Dist.
Number of event [-]
Fit Error, δσ [mm]
$\delta\sigma_x$
$\delta\sigma_y$
4.82, 2.18 m, 20.37 π.mm.mrad
Beam Size Squared, $\sigma'_{x,11}$ [mm^2]
Defoc. Strength, $-kl$ [m^{-1}]
Waist
Fit Curve
$\sigma'_{x,11}$
0.68, 2.92 m, 29.65 π.mm.mrad
Beam Size Squared, $\sigma'_{y,11}$ [mm^2]
Foc. Strength, kl [m^{-1}]
Waist
Fit Curve
$\sigma'_{y,11}$
Fitted Beam Size, 1 − σ
Beam Size, $\sqrt{\sigma_{11}}$ [mm]
Coil Current, I [A]
Horizontal 1σ Size
Vertical 1σ Size
Beam Size Fit Error Dist.
Number of event [-]
Fit Error, δσ [mm]
$\delta\sigma_x$
$\delta\sigma_y$
7.40, 3.36 m, 14.09 π.mm.mrad
Beam Size Squared, $\sigma'_{x,11}$ [mm^2]
Defoc. Strength, $-kl$ [m^{-1}]
Waist
Fit Curve
$\sigma'_{x,11}$
1.19, 5.94 m, 15.76 π.mm.mrad
Beam Size Squared, $\sigma'_{y,11}$ [mm^2]
Foc. Strength, kl [m^{-1}]
Waist
Fit Curve
$\sigma'_{y,11}$

결과

?





Emittance Measurement	2011-OTR	2020-OTR	2020-YAG
[	115.1	18.5	**13.9**
[	150.7	28.9	**15.9**

신형 e-gun 으로 교체, cathod 단면적 1/4 됨

Pre-injector의 빔 에너지를 신뢰할 수 없는 경우, 에너지 편차에 대한 에미턴스 차이 추정

dE/E0	-2 %	0 %	+2 %
[	13.3	**13.9**	14.4
[	15.2	**15.9**	16.5

Summary

- **PBPM**
  - 13기 Feedback 가동 중, 7B 2-pbpm 효과 스터디 중
- **Interferometer**
  - Beam Size 130 Hz 측정 중, Emittance 측정 중
- **Streak Camera**
  - Bunch Purity, Bunch Length, Filling Pattern 요청시 측정 가능
- **Photo Diode Filling Pattern Monitor**
  - 시분해 실험 빔라인을 위해 Streak Camera의 기능을 상시 서비스 하는 장치 구성 완료
    2021년 1분기 부터 서비스 예정
- **Etc**
  - 4D Emittance - 저장링 빔 입사 효율 등을 증대하기 위해 고차원 에미턴스 미터 개발 중