ERL beam instrumentation

ERL beam instrumentation group

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Developments of monitors
Developments of control including fs technology

Beam instrumentation for the ELR

1. Profile measurement

   Fluorescence screen

   Optical profile monitor by OTR or SR

   Wire scanner SEM or Compton scattering

   High speed gated camera

2. Position measurement

   BPM electronic

   BPM SR or OTR

3. Intensity measurement

   DCCT,   Differential DCCT

   Photocathode, Faraday cup

   SR or OTR intensity monitor

4. Emittance measurement

   Fluorescence screen with slit

   Wire scanner

   Interferometer SR or OTR

5. **Temporal structure**

   Streak camera   SR or OTR

   Incoherent intensity interferometer SR or OTR

   CSR interferometer   CSR

   BLM opto-electric

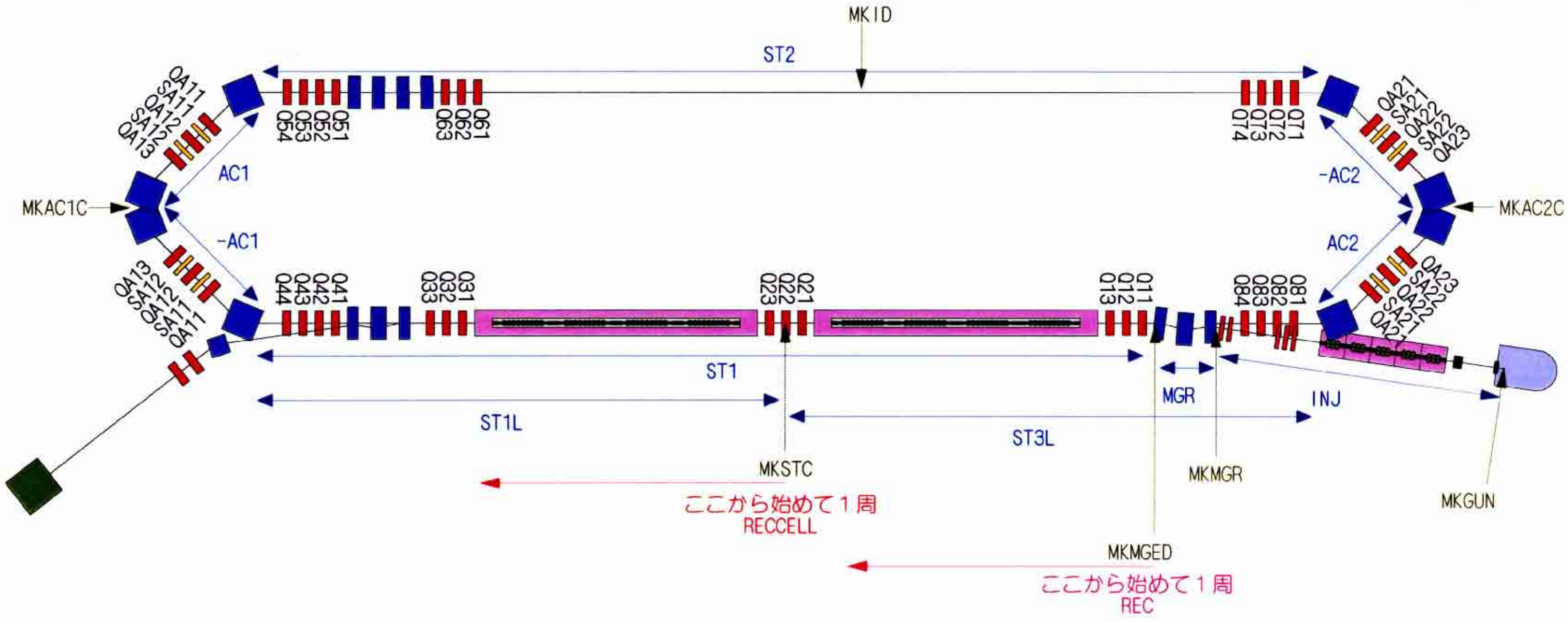
6. **Halo**

   Wire scanner

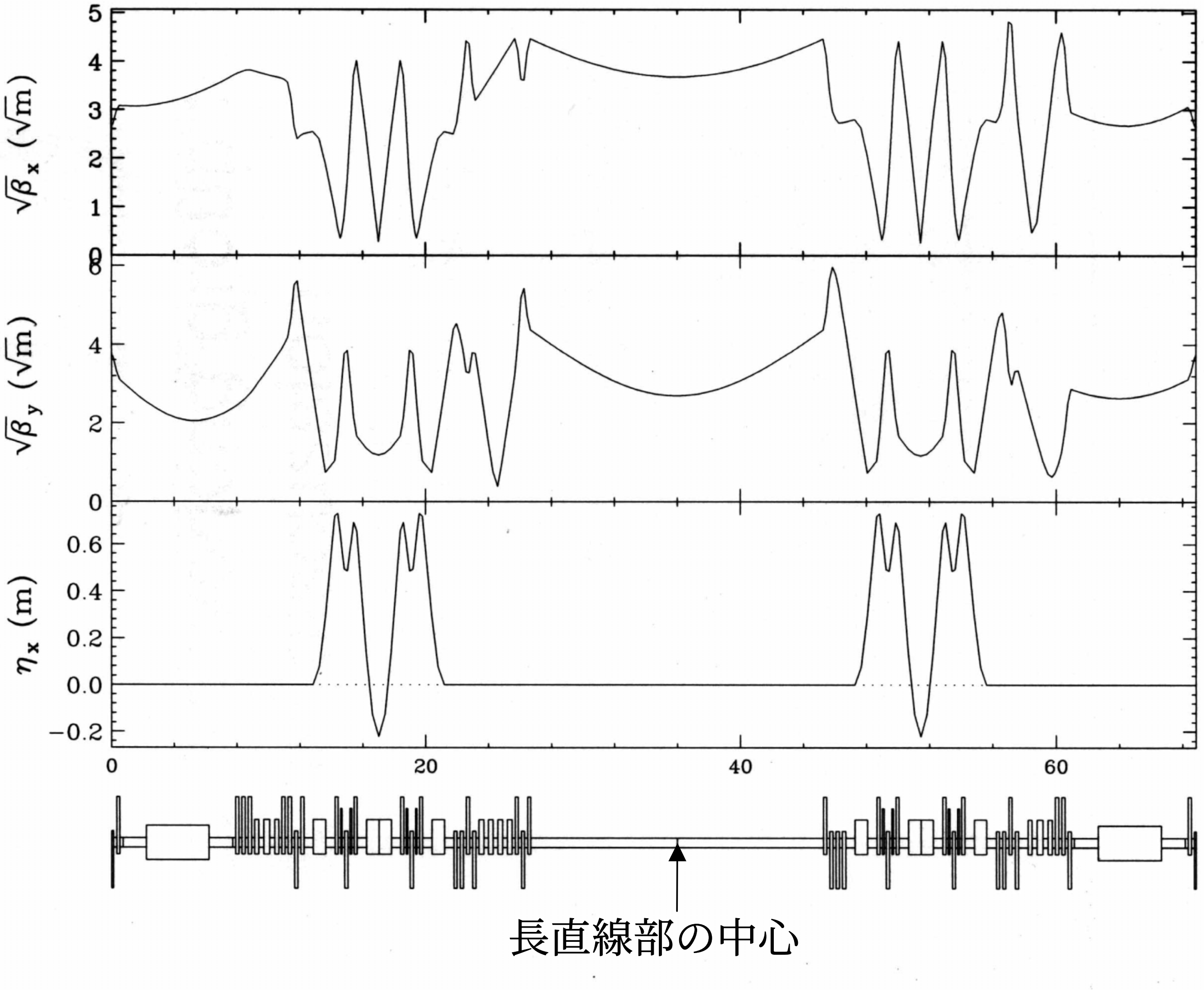
   Coronagraph SR or OTR

7. **Beam loss**

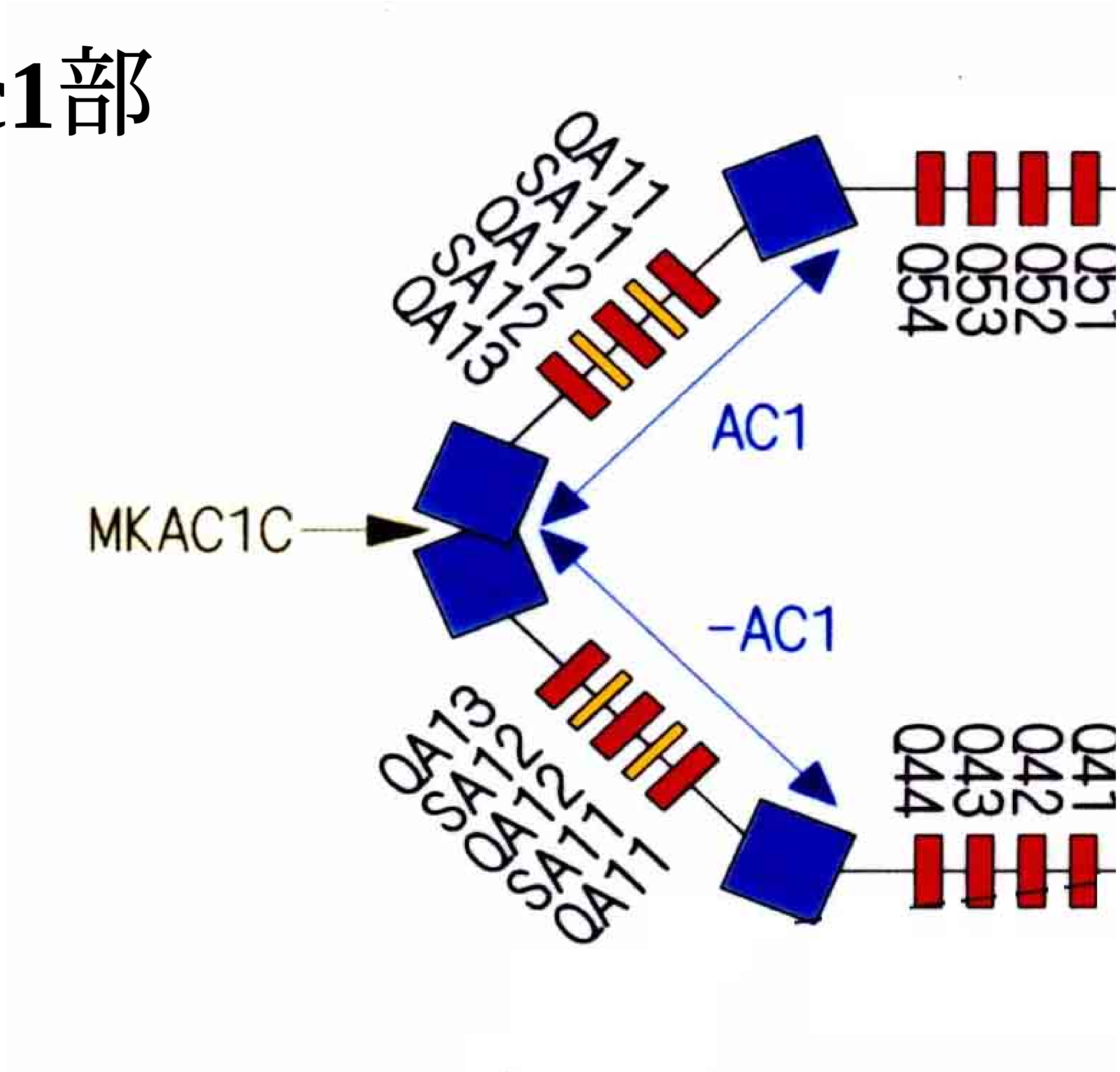
ERL試験機のレイアウト



現在提案されている周回部のOptics案（原田）



Arc1部

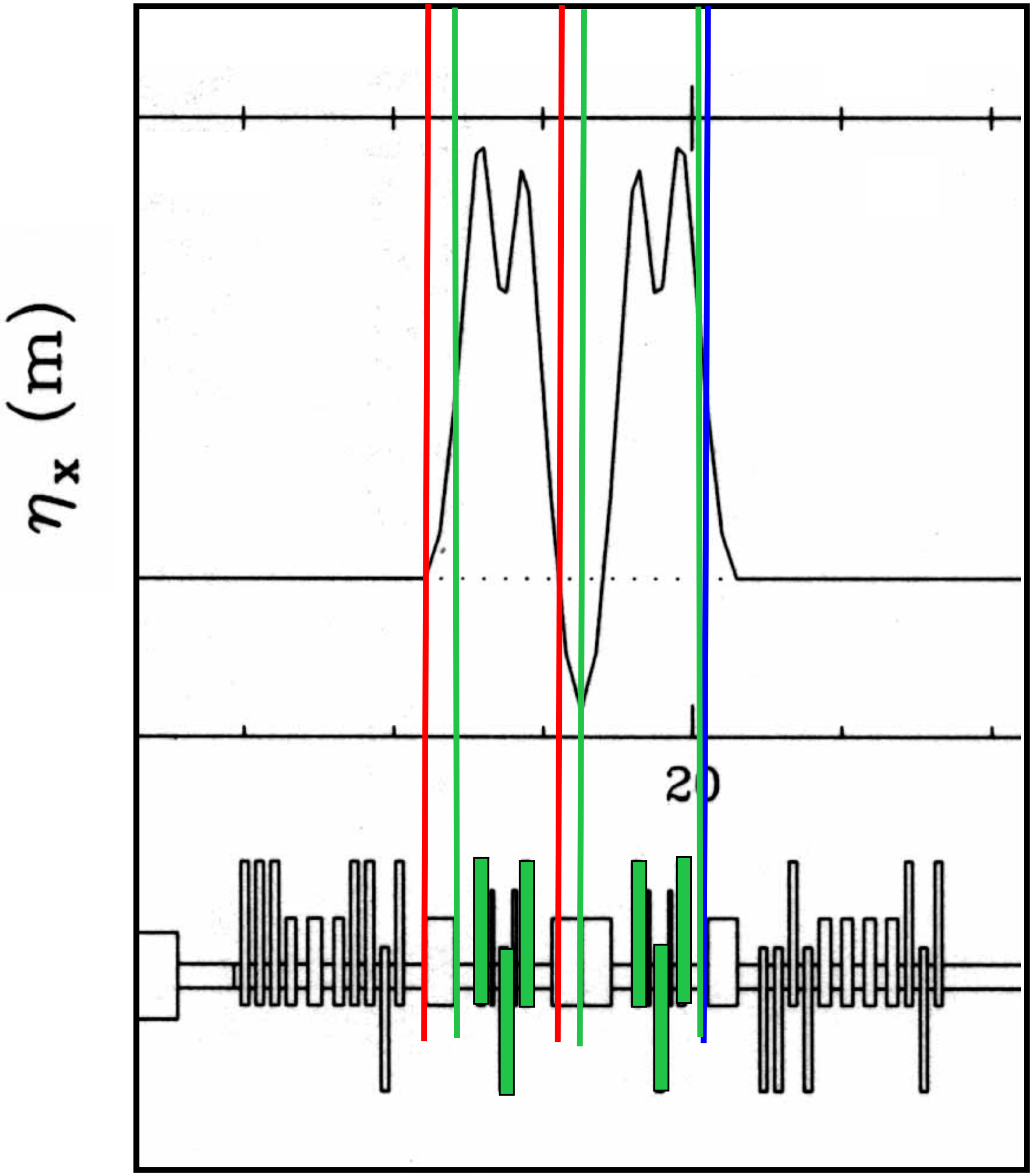


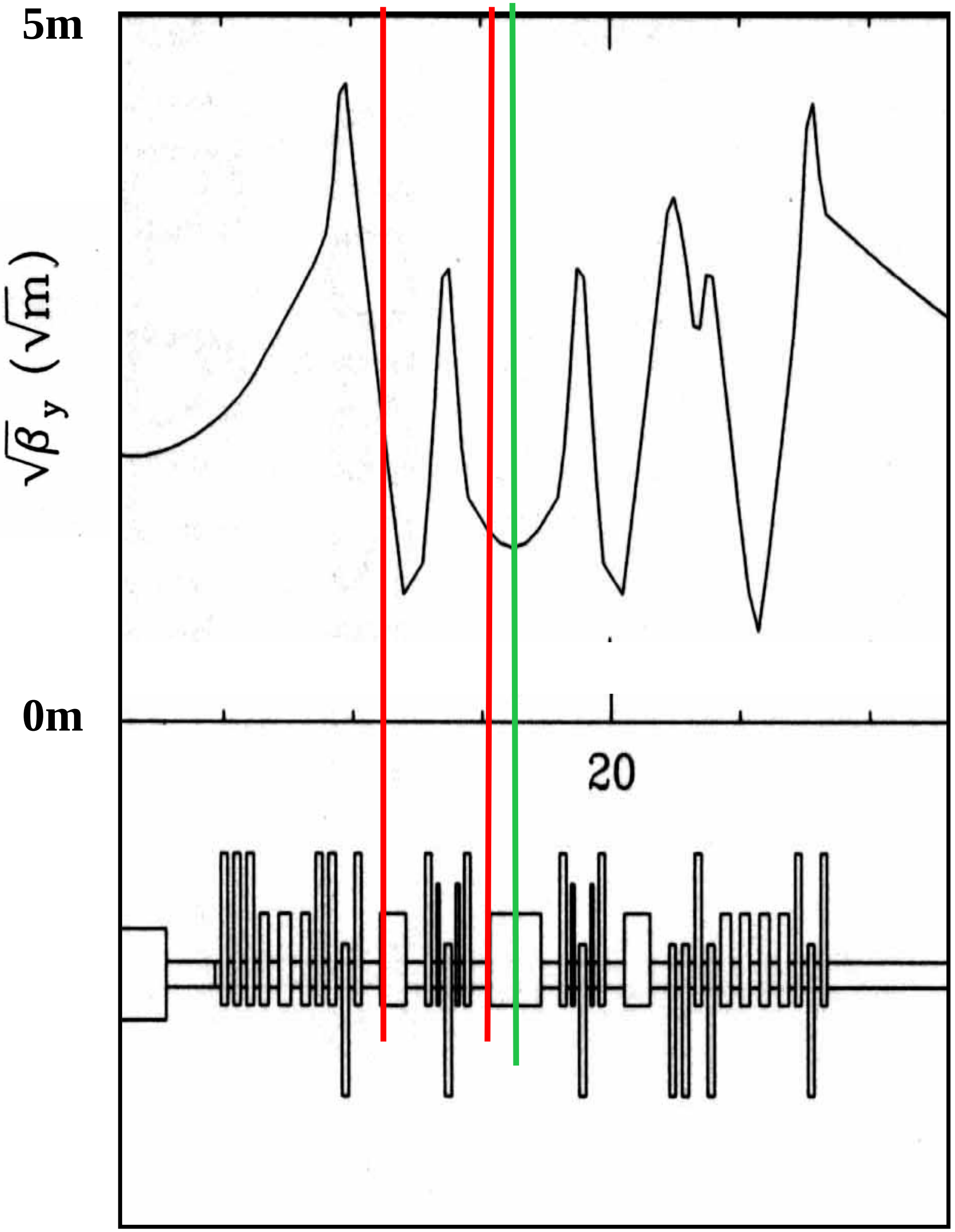
QA11
SA11
QA12
SA12
QA13
Q51
Q52
Q53
Q54
AC1
MKAC1C
-AC1
QA13
SA12
QA12
SA11
QA11
Q41
Q42
Q43
Q44

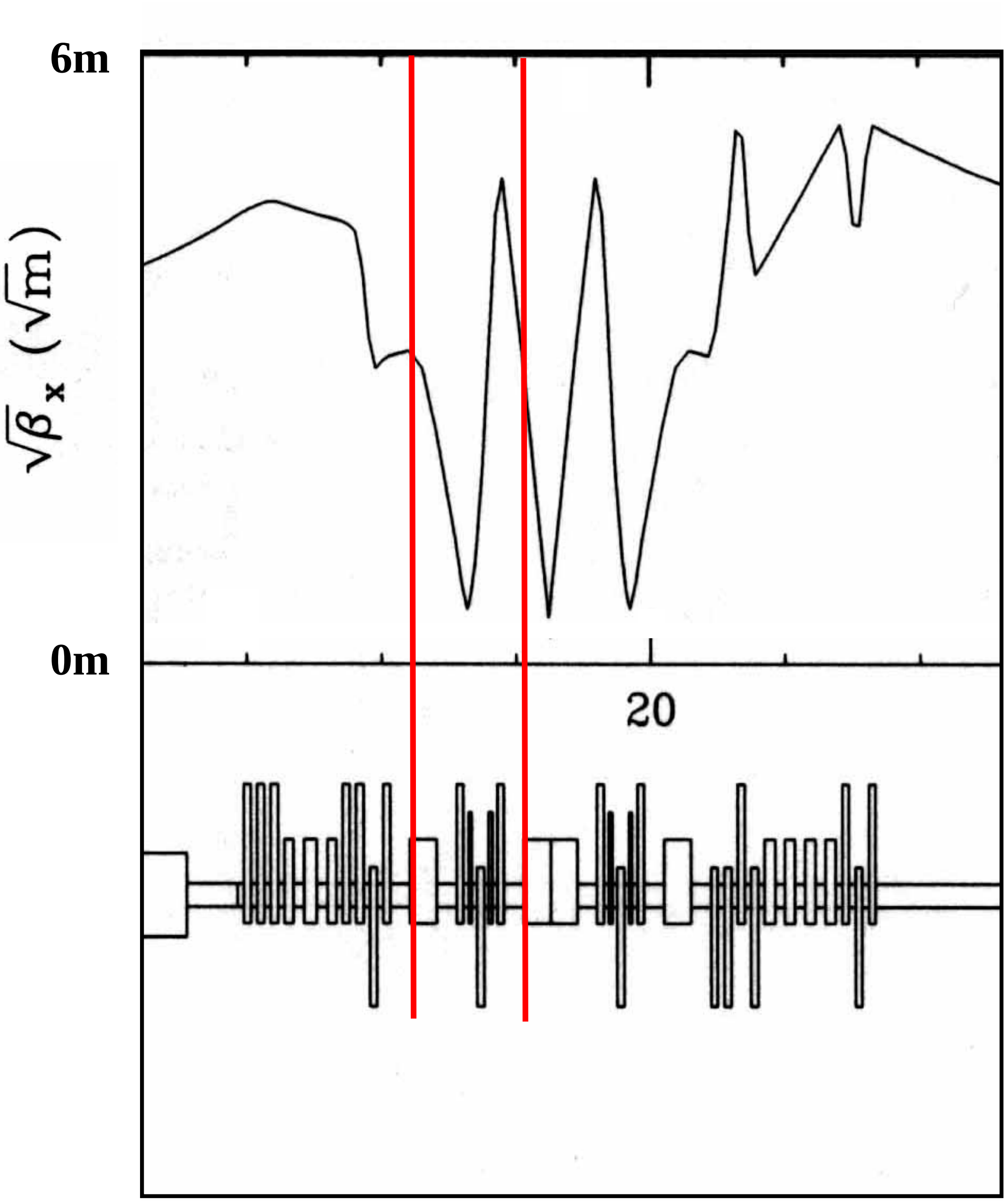
Dispersion

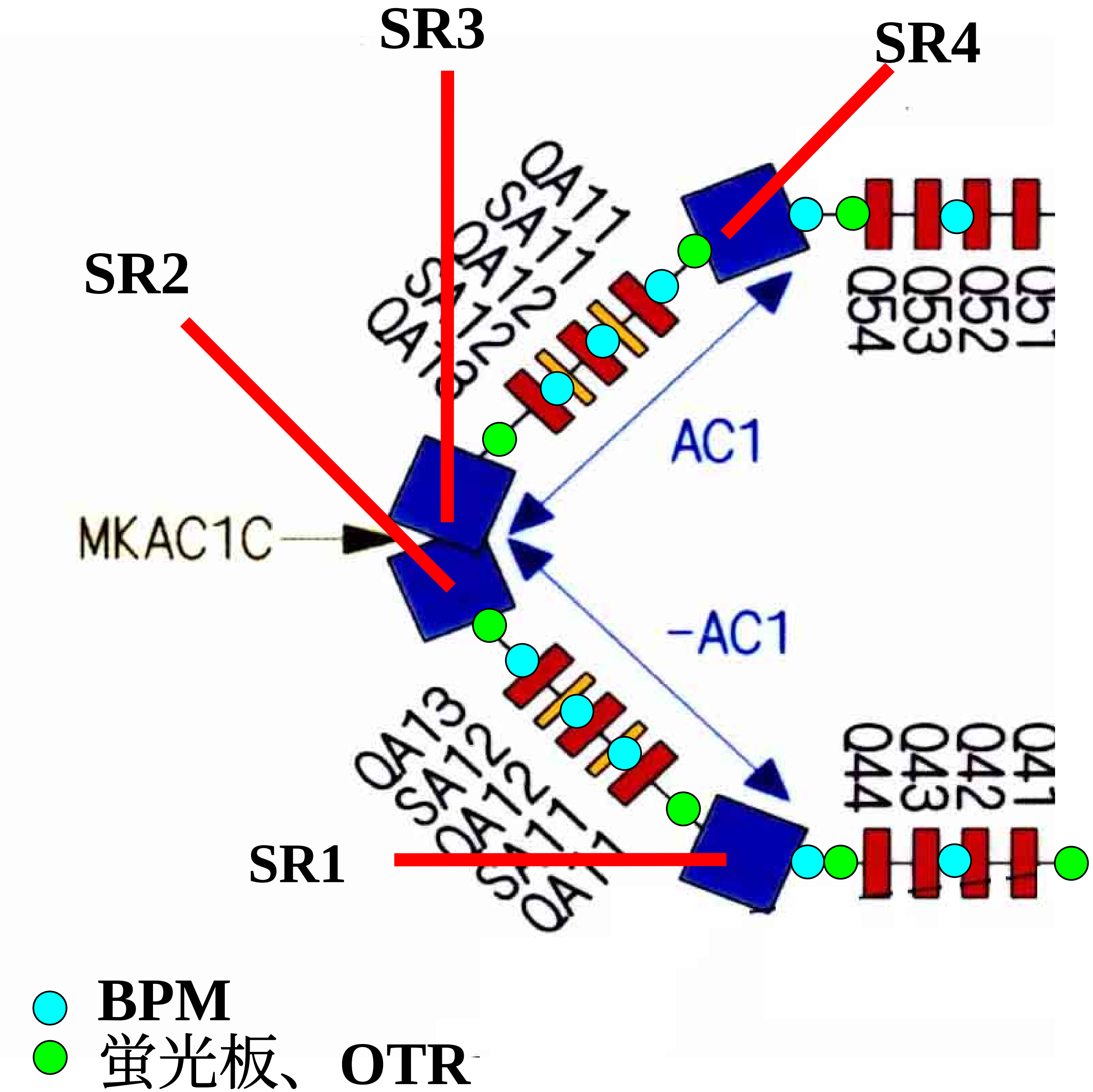
赤：ビームサイズ測定
Emittance評価
Halo測定
Dispersionなし
緑：ビームサイズ測定
Dispersion評価
光学的ビーム位置
測定PBPM
青：Halo測定
Dispersionあり

全ての四極にはBPMをつける
Arcの中心にはBPMがつけられるか？



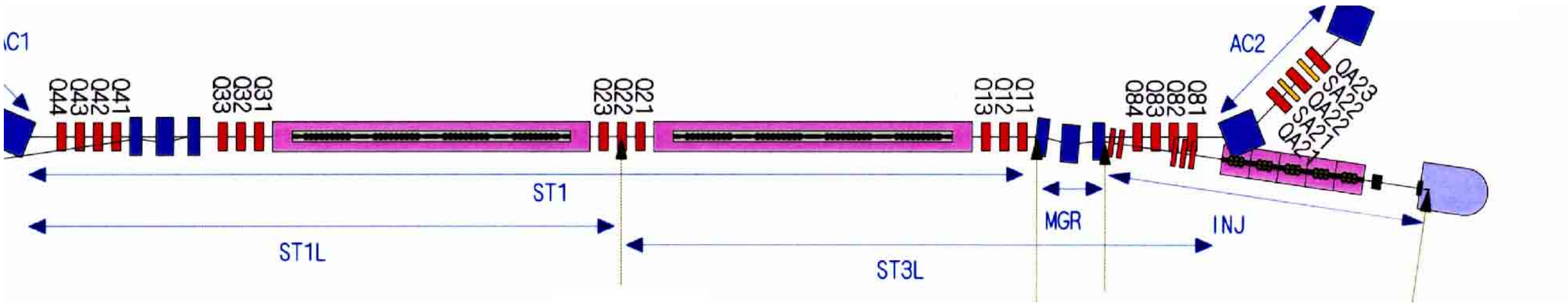

5m
0m
√β y (√m)
20


6m
$\sqrt{\beta_x}$ ($\sqrt{m}$)
0m
20

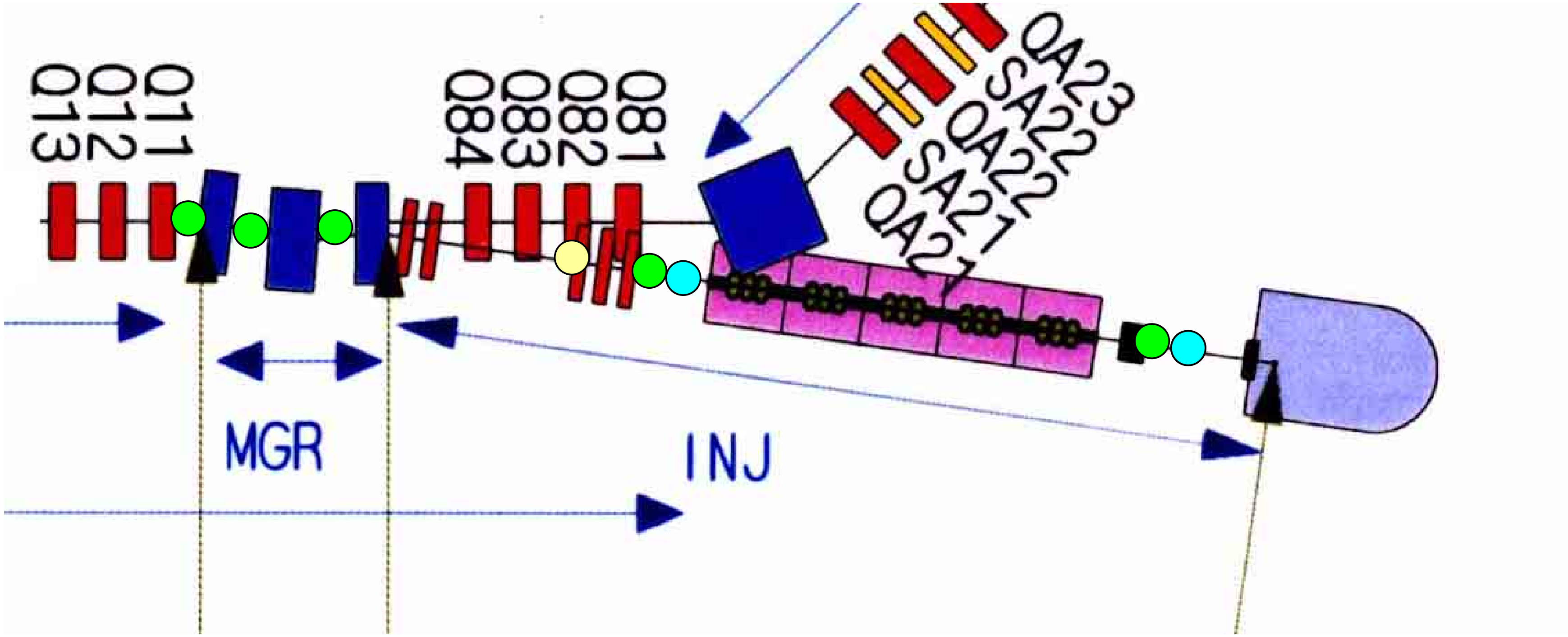


SR3
SR4
SR2
QA11
SA11
QA12
SA12
QA13
Q51
Q52
Q53
Q54
AC1
MKAC1C
-AC1
QA13
SA12
QA12
SA11
QA11
Q41
Q42
Q43
Q44
SR1
BPM
蛍光板、OTR

入射部および加速空洞直線部



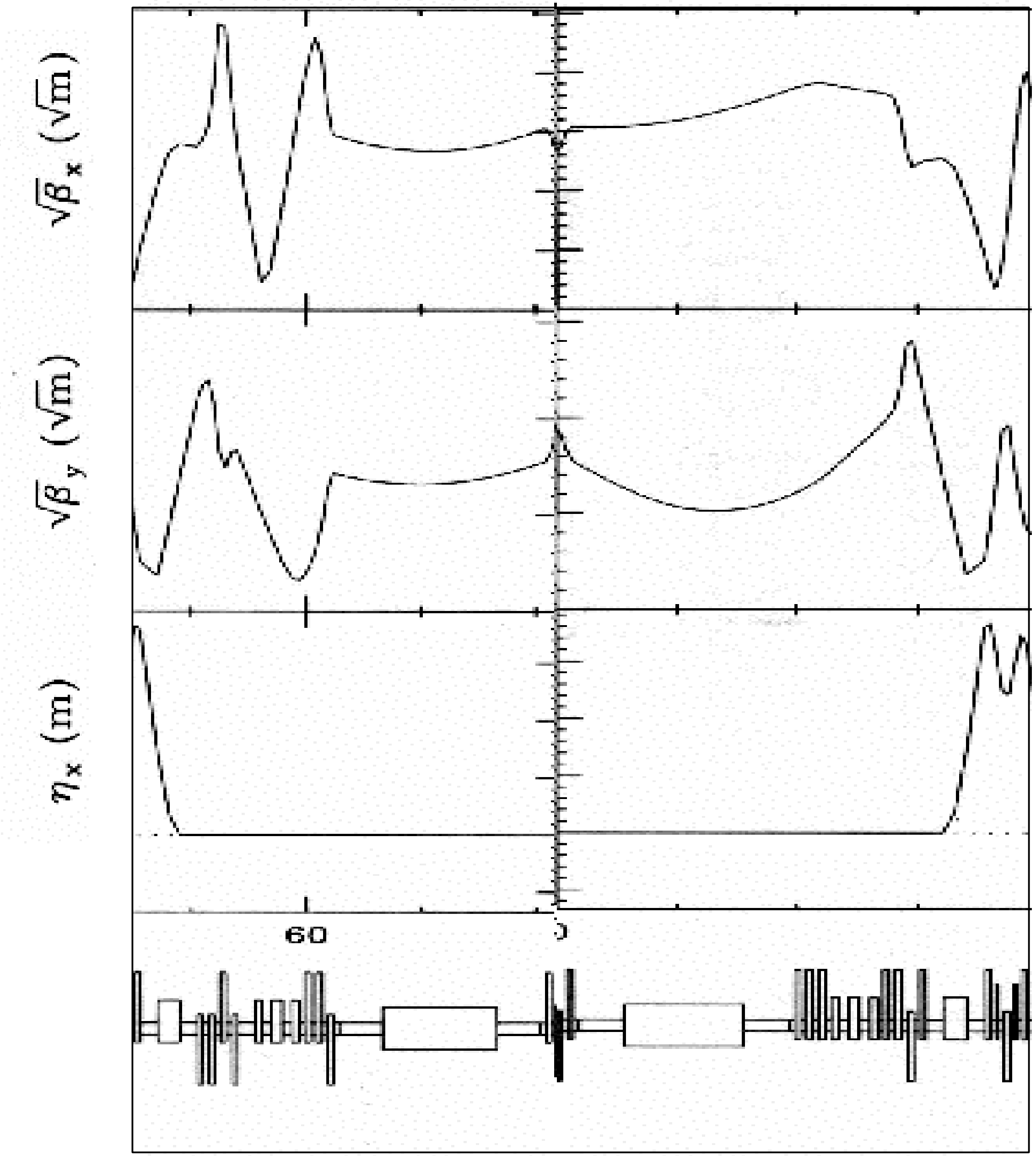
入射部



● 蛍光板またはスリット付蛍光板(emittance 評価)

● BPMストリップライン

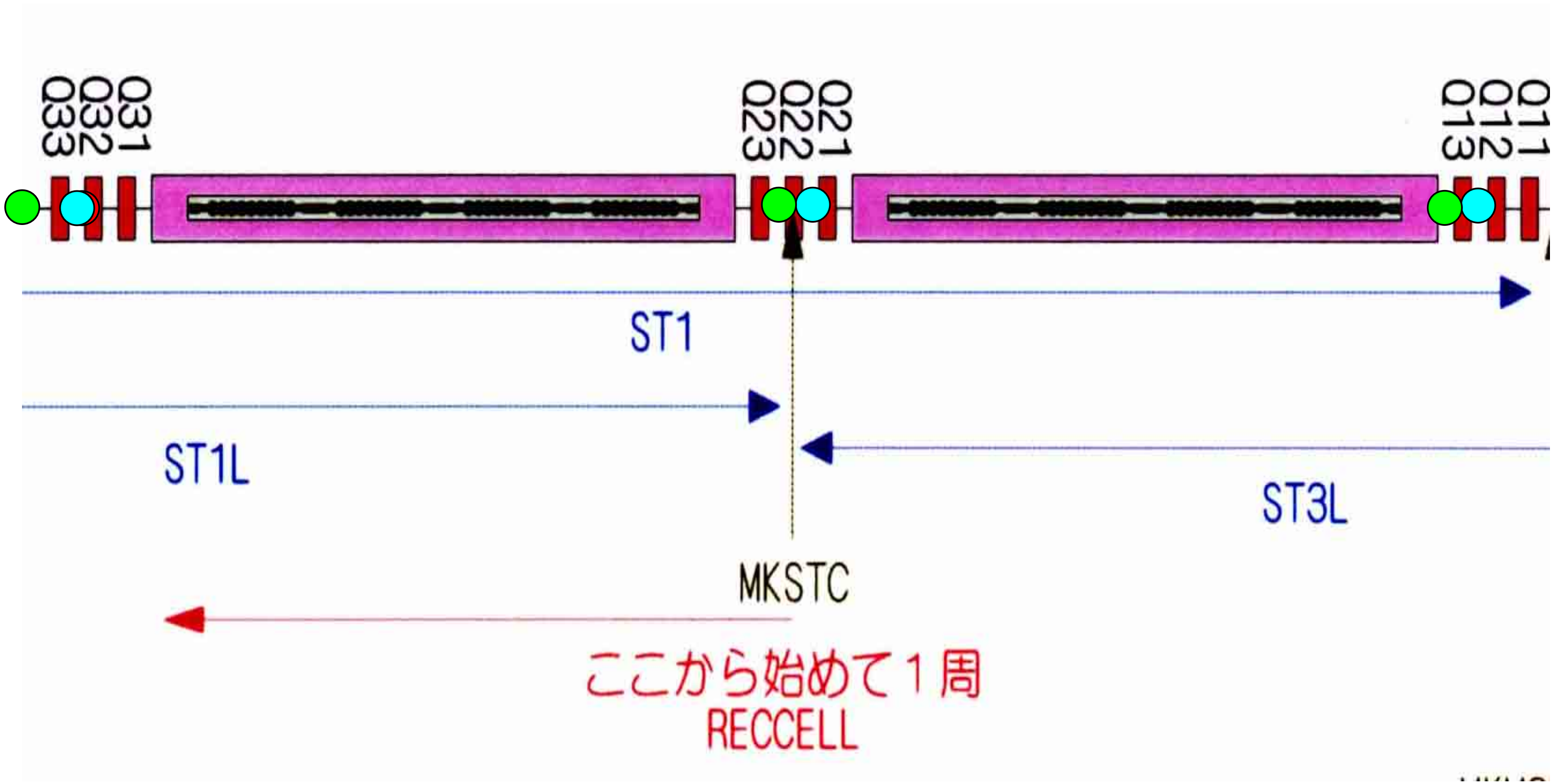
● ワイヤースキャナーまたはSEM

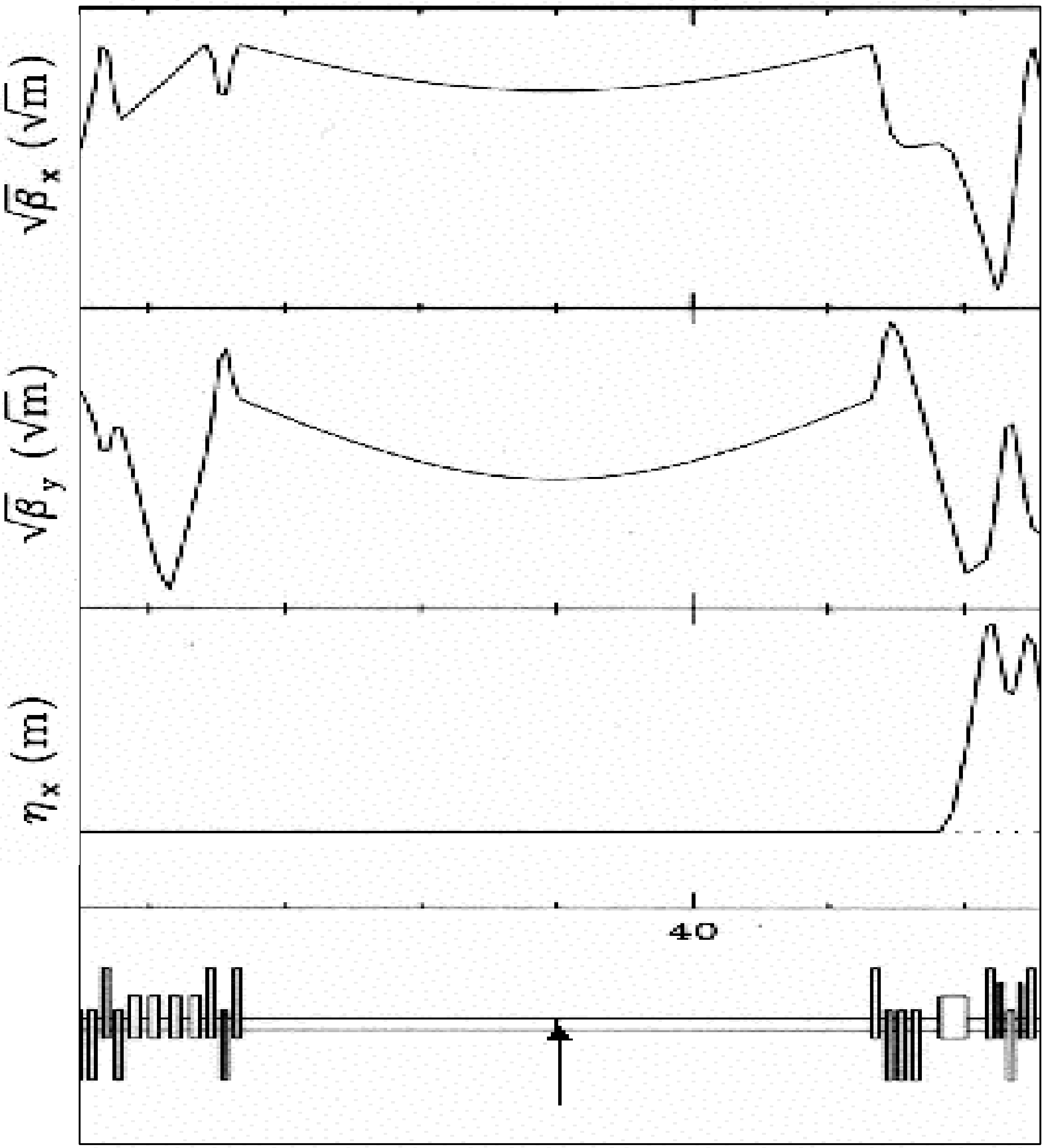


$\sqrt{\beta_x}$ ($\sqrt{\text{m}}$)
$\sqrt{\beta_y}$ ($\sqrt{\text{m}}$)
η_x (m)
60

BPM

OTR,蛍光板

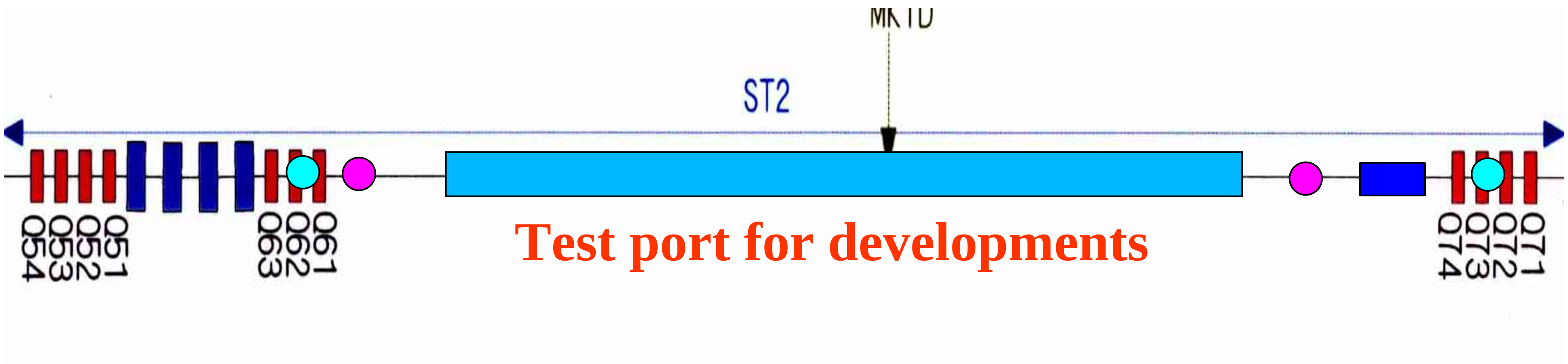

Q33
Q32
Q31
Q23
Q22
Q21
Q13
Q12
Q11
ST1
ST1L
ST3L
MKSTC
ここから始めて1周
RECCELL



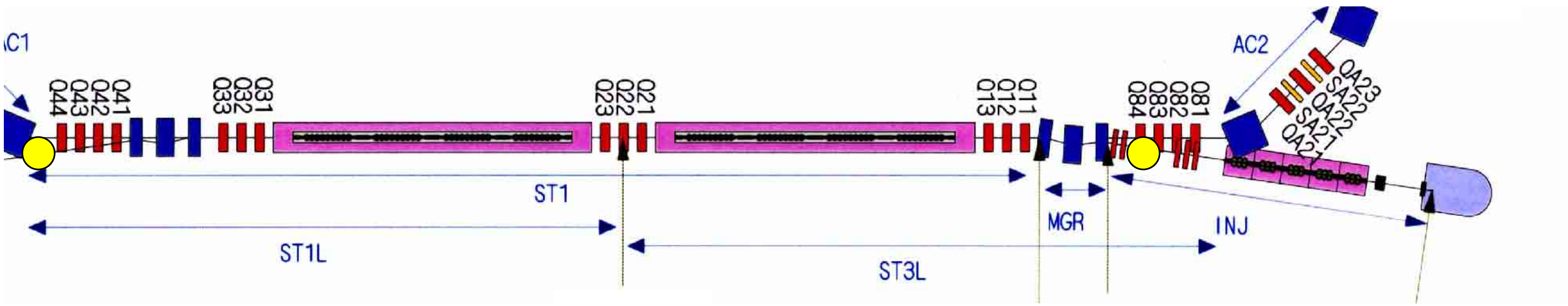
$\sqrt{\beta_x}$ ($\sqrt{m}$)
$\sqrt{\beta_y}$ ($\sqrt{m}$)
η_x (m)
40

cavity BPM

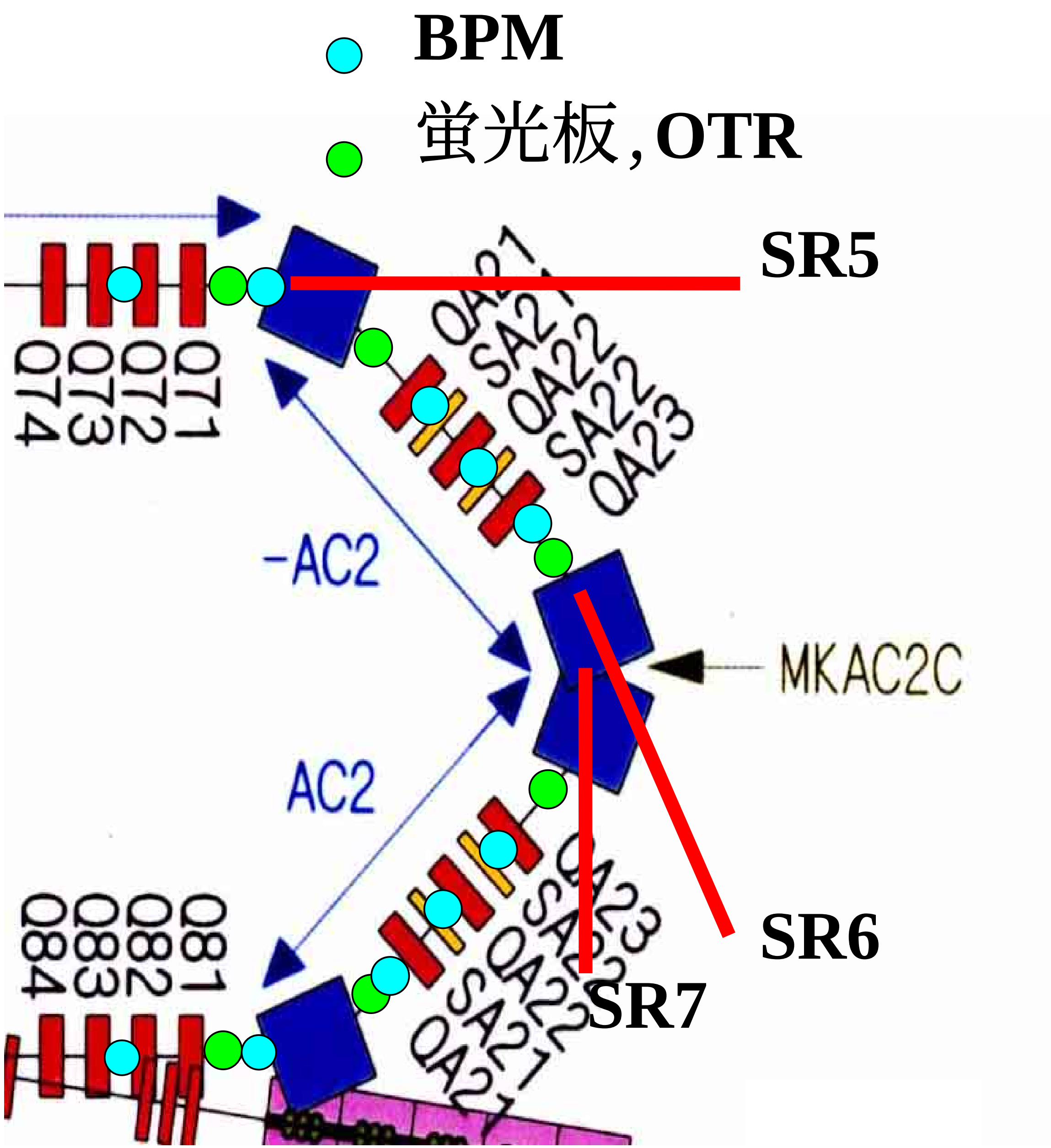
BLM (one pass, Opto-electric type)



● differential DCCT for current valance

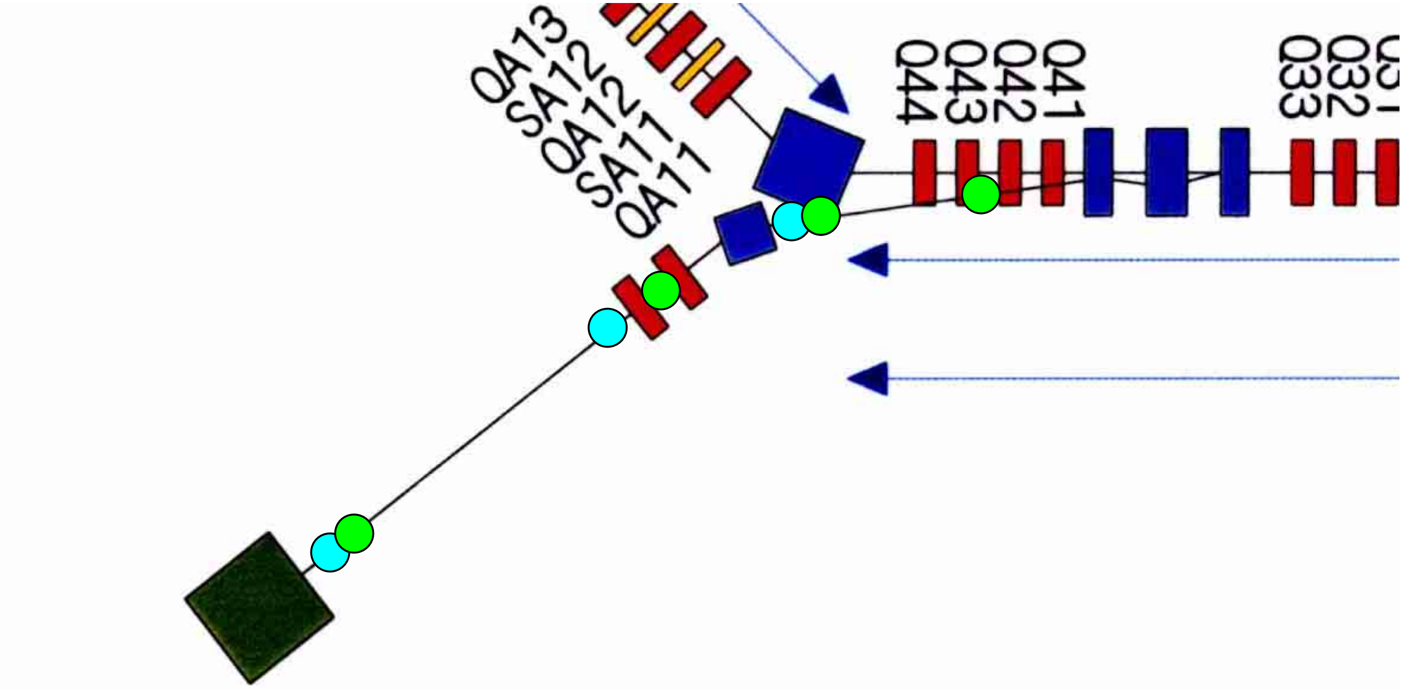


Arc2部



BPM
蛍光板,OTR
SR5
SR6
SR7
MKAC2C
-AC2
AC2
QT1
QT2
QT3
QT4
QA21
SA21
QA22
SA22
QA23
Q81
Q82
Q83
Q84

Dump line



BPM

蛍光板

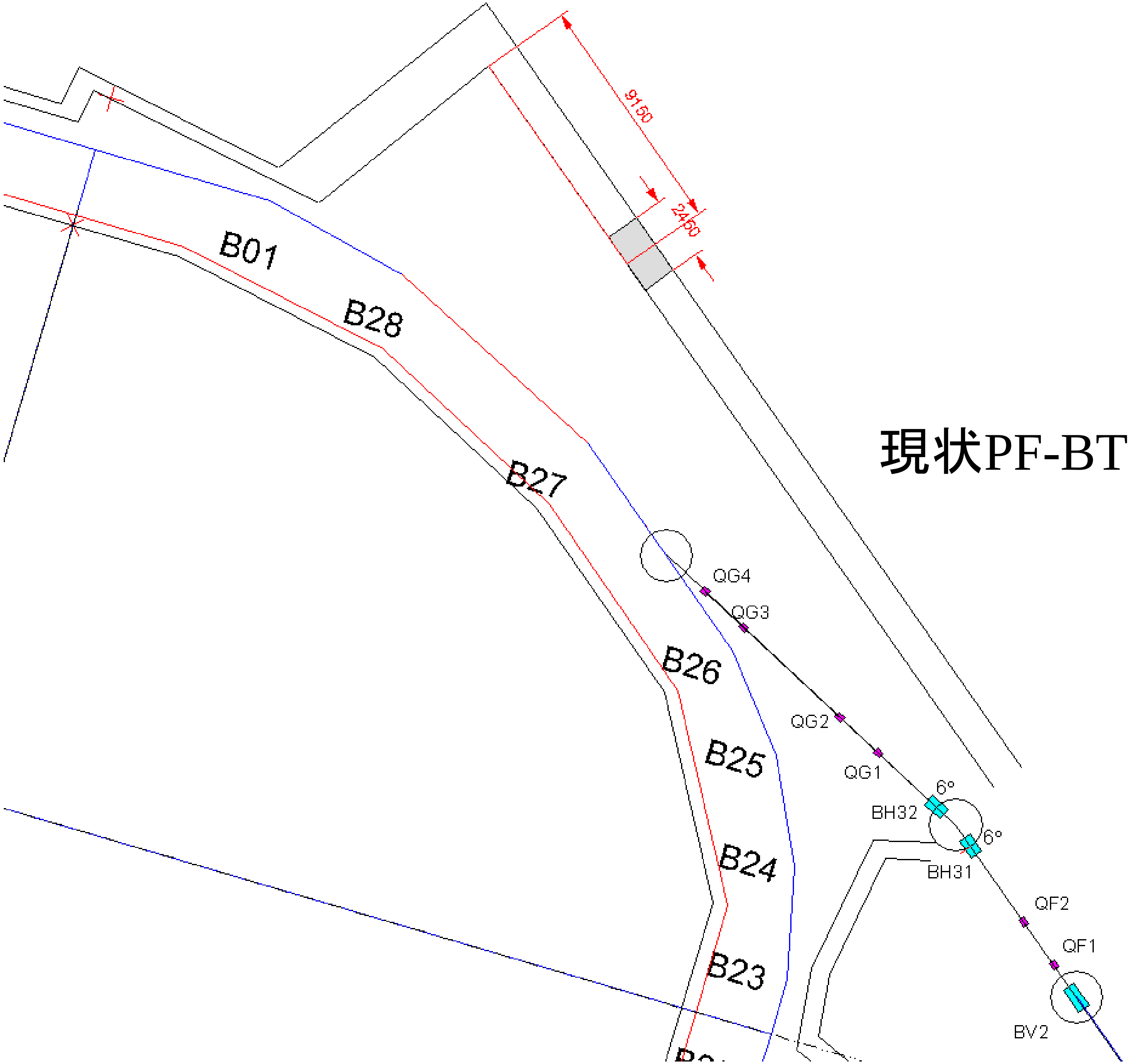
	Device		Accuracy	Resolution	Comment
Injector	BPM(strip line)	2			Position, timing
	Fluorescence screen	2			Position, profile
	Fluorescence screen (with slit)	2			Emittance
	Wire scanner SEM mode	1			Emittance, Halo
Merger	Fluorescence screen	4			Position, profile
Straight1 cavity	BPM	3			Position, timing, phase
	Fluorescence screen	3			Position, profile
	OTR	1			Position, profile
Arc1	BPM	8			Position, timing, phase
	BPMSR	1			Position
	Fluorescence screen	6			or OTR Position, profile
	SR	3			SRI, Streak camera Halo, profile

Straight 2	BPM	2			Position, timing, phase
	Cavity BPM	2			Accurate Position
	Test section				development
	BLM (Opto-electric)				Bunch length
Arc2	BPM	8			Position,timing, phase
	BPMSR	1			Position
	Fluorescence screen	6			or OTR Position, profile
	SR	3			SRI, Streak camera Halo, profile
Others	Differential DCCT	1			Current difference
	DCCT	1			DC current
	WCM	1			Bunch by bunch Current
Dump line	Fluorescence screen	4			Position, profile
	BPM	3			Position

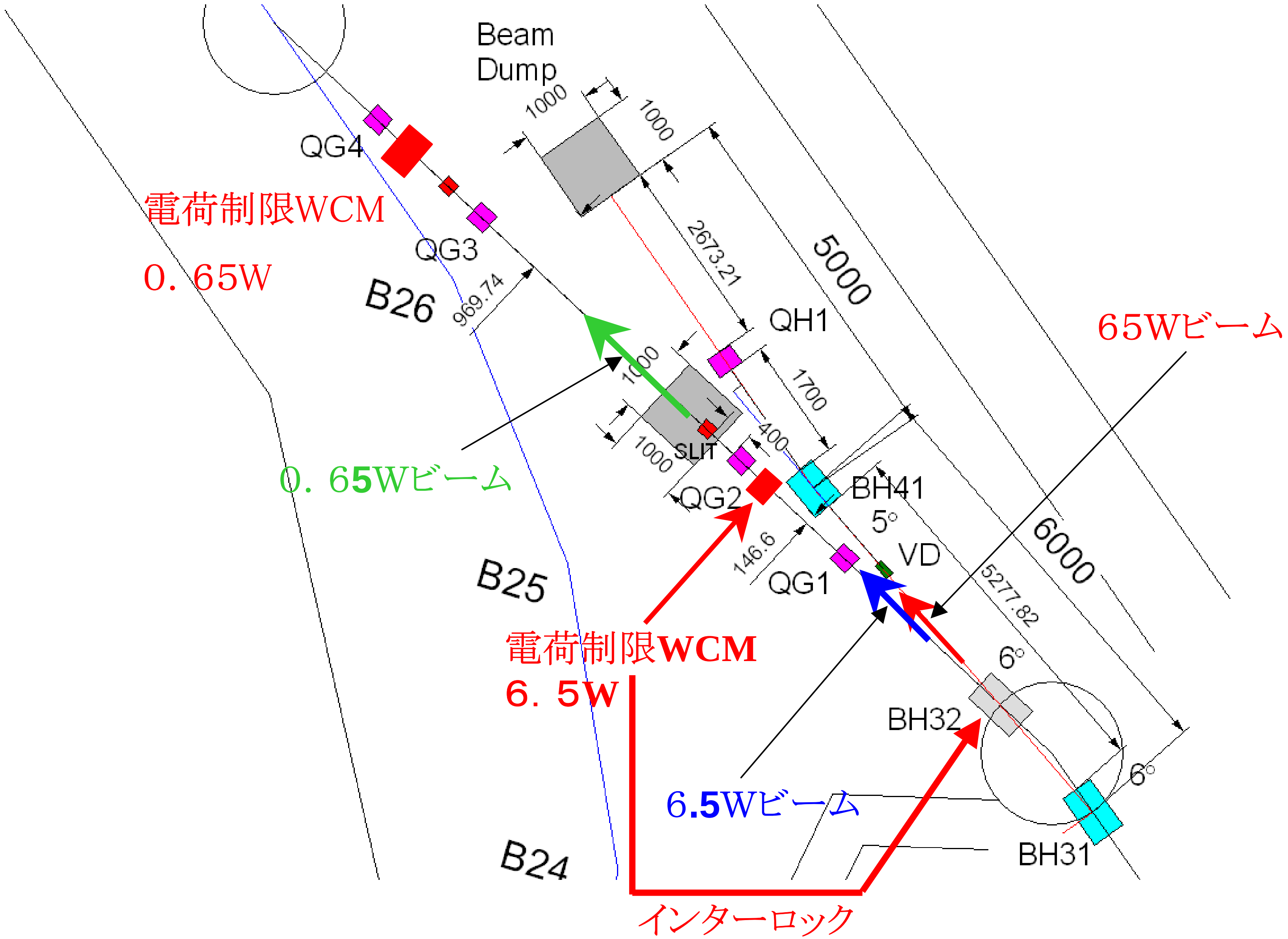
Test facility for short pulse beam at PFBT

Development of beam monitors
Development of fs technology

現状PF-BT

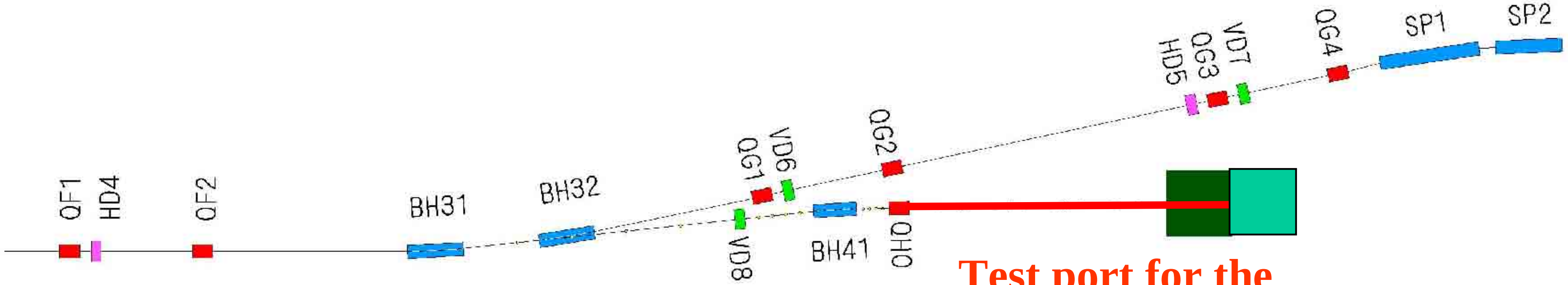


9150
2450
B01
B28
B27
B26
B25
B24
B23
QG4
QG3
QG2
QG1
6°
BH32
6°
BH31
QF2
QF1
BV2



Beam
Dump
1000
1000
2673.21
5000
QG4
電荷制限WCM
0. 65W
QG3
B26
969.74
QH1
65Wビーム
1000
1700
0. 65Wビーム
1000
SLIT
400
QG2
BH41
5°
VD
6000
146.6
QG1
5277.82
B25
電荷制限WCM
6. 5W
6°
BH32
6°
6.5Wビーム
BH31
B24
インターロック

0.6ps to 4psec   60W (2.5GeV,1nc, 25pps)



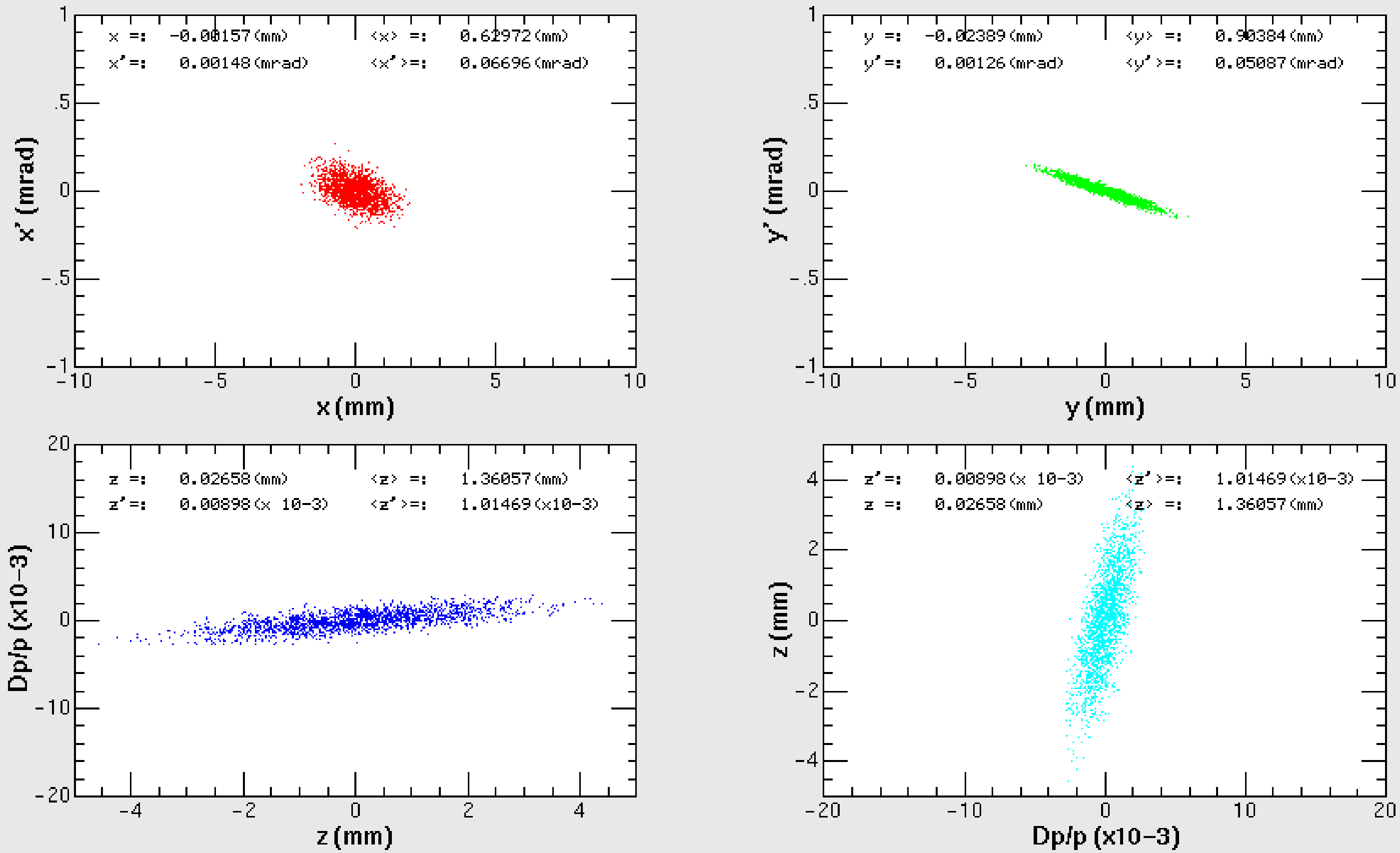
Test port for the development of beam monitors

ε_x=40 (nm*rad)
ε_y=13 (nm*rad)

Phase Space Plot of Injected Beam

Beam : at the position of BH31

BH31 入口



σ_z=1.4 (mm)=4.2(psec)
σ_ε=1.0 x 10^{-3}

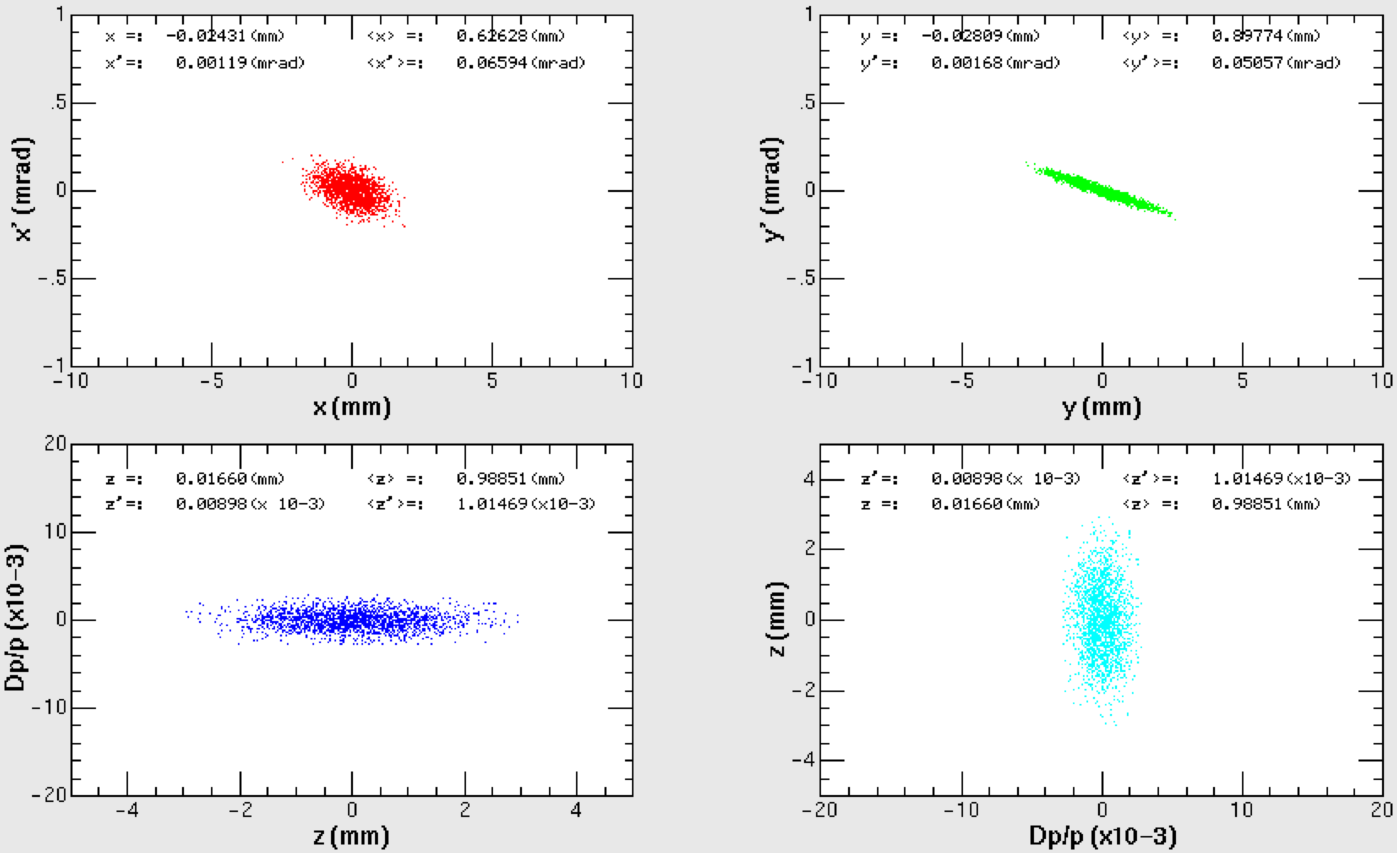
R56=1.0 (m)
Normal : BK-BH31間

ε_x=40 (nm*rad)
ε_y=13 (nm*rad)

Phase Space Plot of Injected Beam

Beam : at the position of BH31

BH31 入口



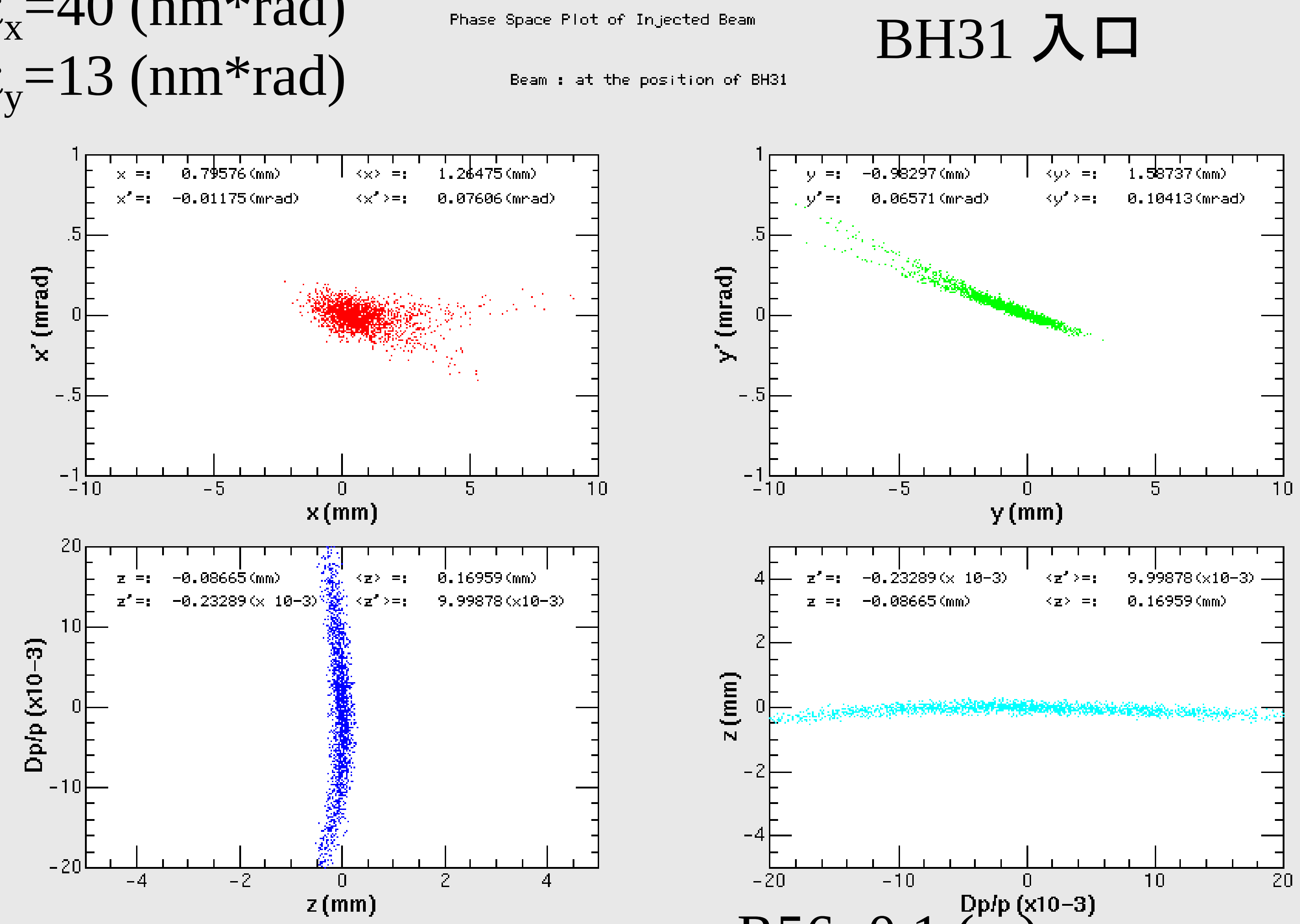
σ_z=0.99 (mm)=3.3(psec)
σ_ε=1.0 x 10^{-3}

R56=0.0 (m)
Isochronous: BK-BH31間

ε_x=40 (nm*rad)

ε_y=13 (nm*rad)

BH31 入口



σ_z=0.17 (mm)=0.57(psec)

σ_ε=10.0 x 10^{-3}

R56=0.1 (m)

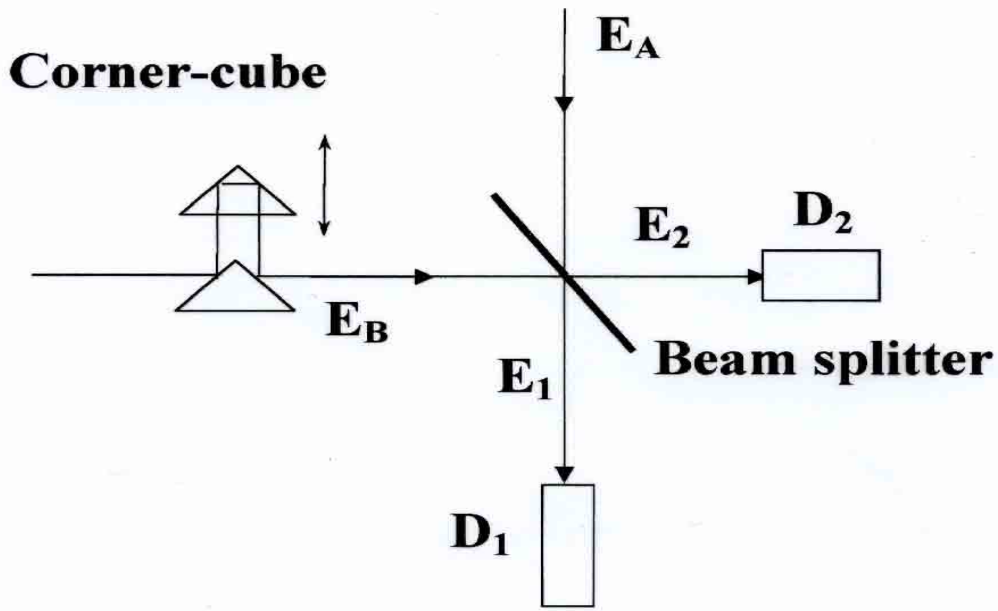
T566 = -0.11 (m)

Bunch Compress: BK-BH31間

Beam instrumentation based on Optical and opto-electric method

Incoherent SR intensity
Interferometry
for
Short bunch mesurement

Bunch length measurement by intensity interferometry



Input fields for a beam splitter in intensity interferometry.

Let us represent the incident optical field by the complex field ,

$$E_A(t) = C_A(t) A_A(t)$$
$$E_B(t) = C_B(t) A_B(t) \,. \quad -(3)$$

Here C(t) is the pulse envelope having a pulse width (bunch length) σ_p, and A(t) is a stationary random variable having coherence time τ_c.

We assume the correlation function of A(t) and C(t) have Gaussian shape. We also assume that E_A and E_B of two photons have no first order coherence. We thus obtain from Eq. (2), remormalizing the proportional constant K,

$$\mathrm{Count}_{12}(\delta\tau) = K{\sigma_p}^2\left(1+\frac{\tau^*}{\sigma_p}\left[1-\frac{1}{2}\exp\left(-\frac{\delta\tau^2}{4{\sigma_p}^2}\right)\right]\right),$$

$$\frac{1}{{\tau^*}^2} = \frac{1}{{\sigma_p}^2} + \frac{1}{{\tau_c}^2} \,.$$

Let us represent the incident optical field by the complex field ,

$$E_A(t) = C_A(t)A_A(t)$$
$$E_B(t) = C_B(t)A_B(t) \; .$$

Here C(t) is the pulse envelope having a pulse width (bunch length) σ_p, and A(t) is a stationary random variable having coherence time τ_c.

We assume the correlation function of A(t) and C(t) have Gaussian shape.

We thus obtain coincidence count;

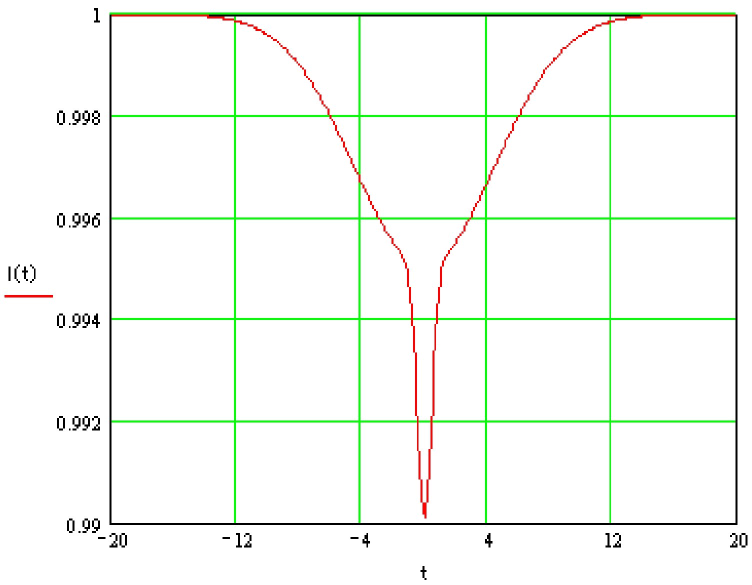
$$\mathrm{count}_{12}(\delta\tau) = K\sigma_p^{\ 2}\left[1-\frac{1}{2}\exp\left(-\frac{\delta\tau^2}{4\tau_c^{\ 2}}\right)+\frac{\tau^*}{\sigma_p}\left(1-\frac{1}{2}\exp\left(-\frac{\delta\tau^2}{4\sigma_p^{\ 2}}\right)\right)\right]$$

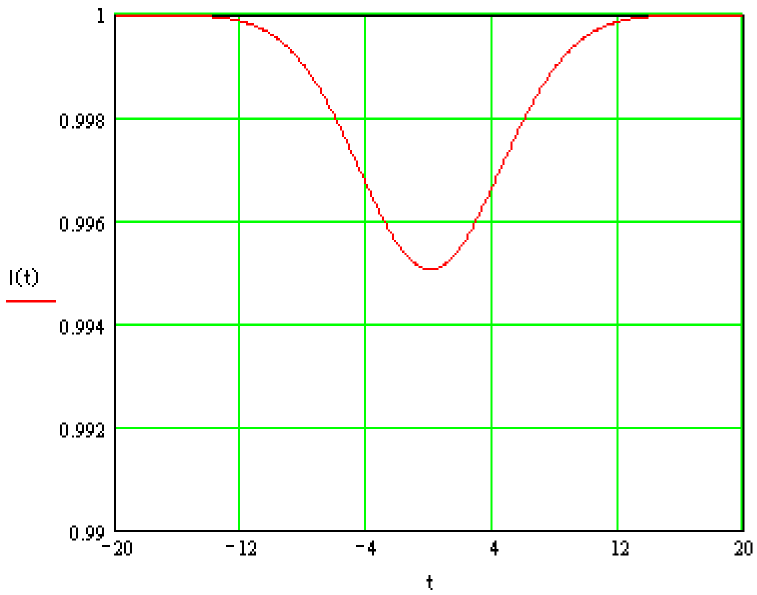
$$\frac{1}{\tau^{*2}} = \frac{1}{\sigma_p^{\ 2}} + \frac{1}{\tau_c^{\ 2}} \; .$$

Illustration of intensity interference pattern with coherent light pulse.

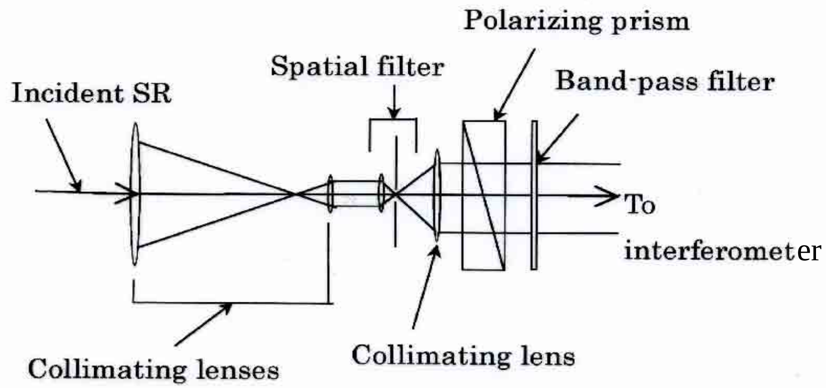
Phase correlation peak in the center.

Illustration of intensity interference pattern with chaotic light pulse.

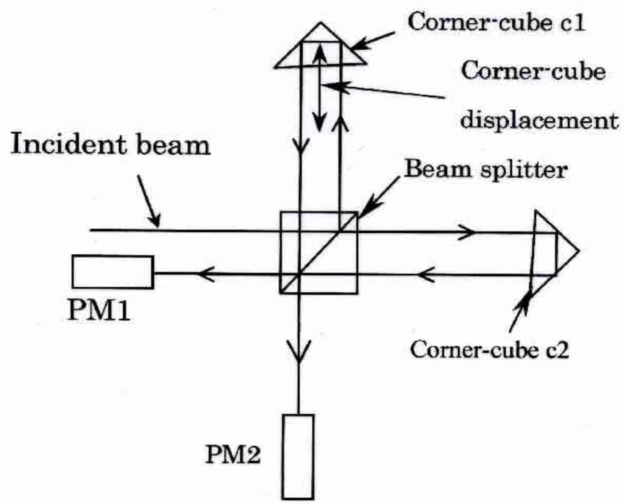




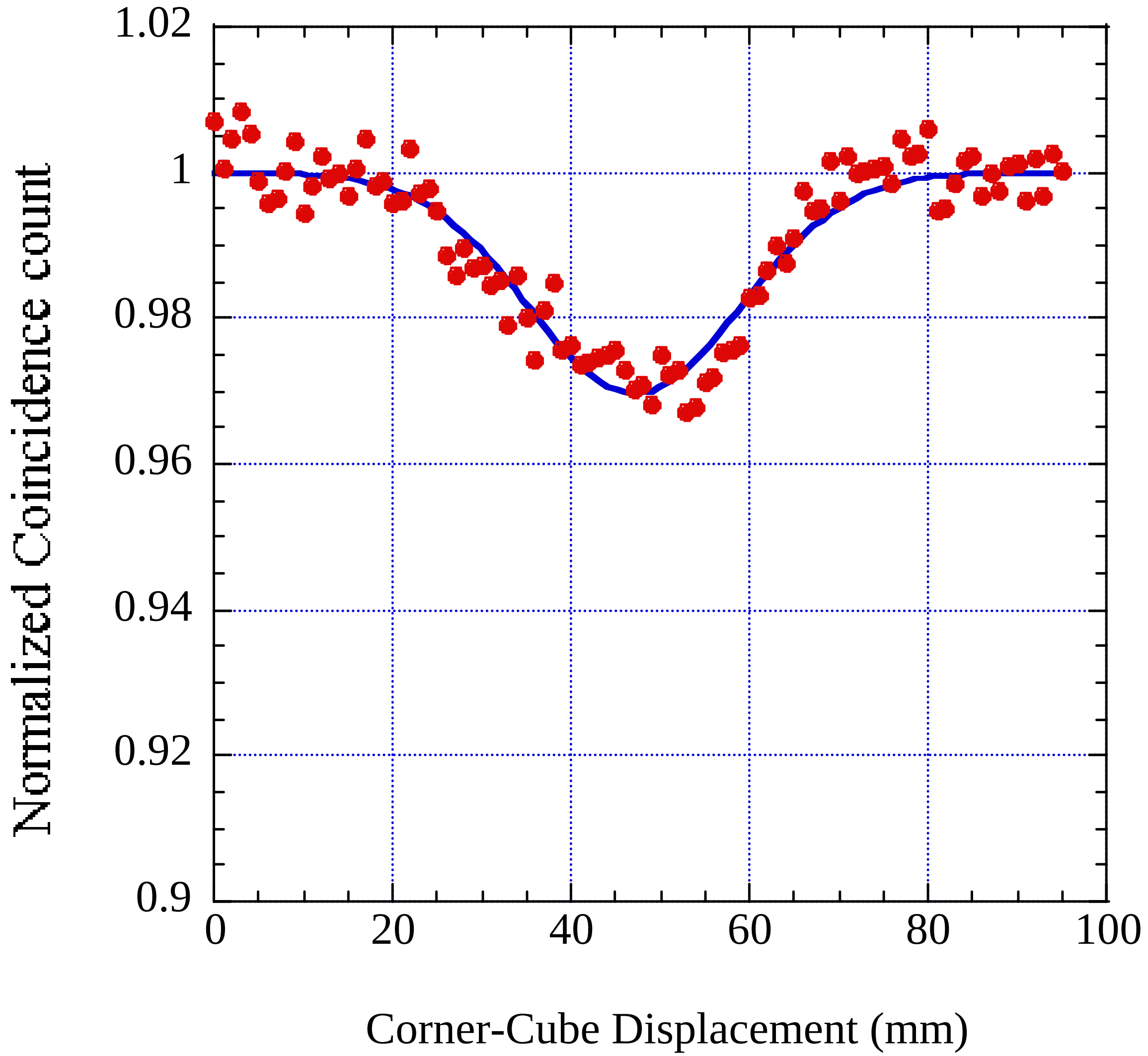
Experimental setup of the intensity interferometer



(a) Set up of first-stage system to produce an incidence beam for the interferometer



(b): Set-up of intensity interferometer.

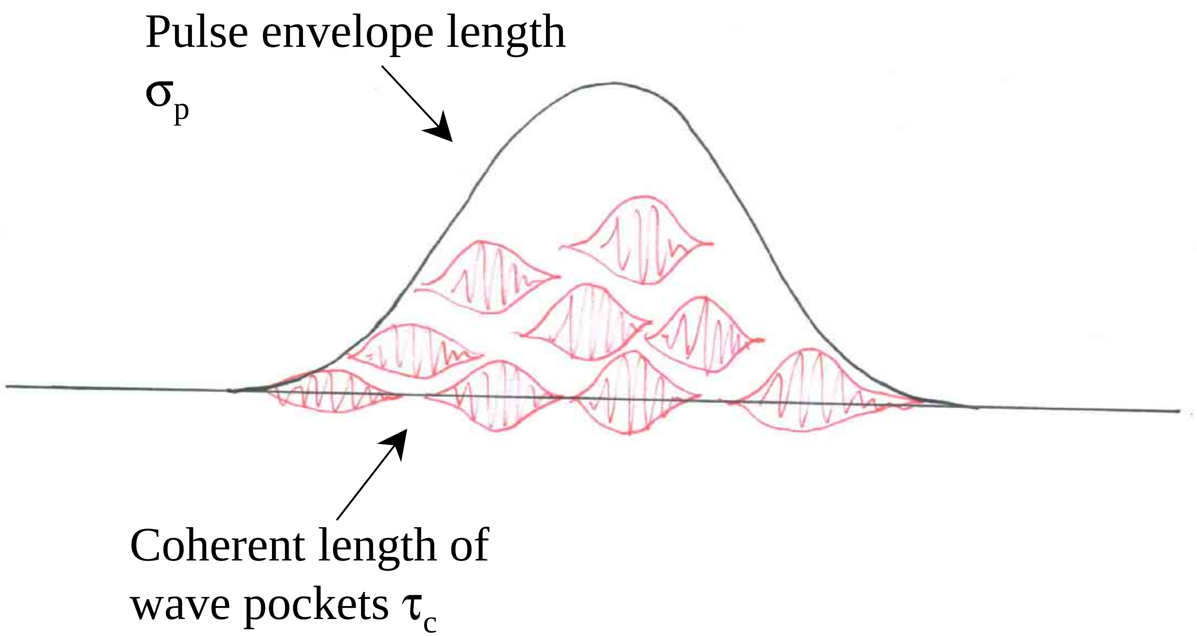


Normalized Coincidence count
1.02
1
0.98
0.96
0.94
0.92
0.9
0
20
40
60
80
100
Corner-Cube Displacement (mm)

Pulse envelope length σ_p is always longer than Coherent length of wave pockets τ_c.

$$\sigma_p \geq \tau_c$$

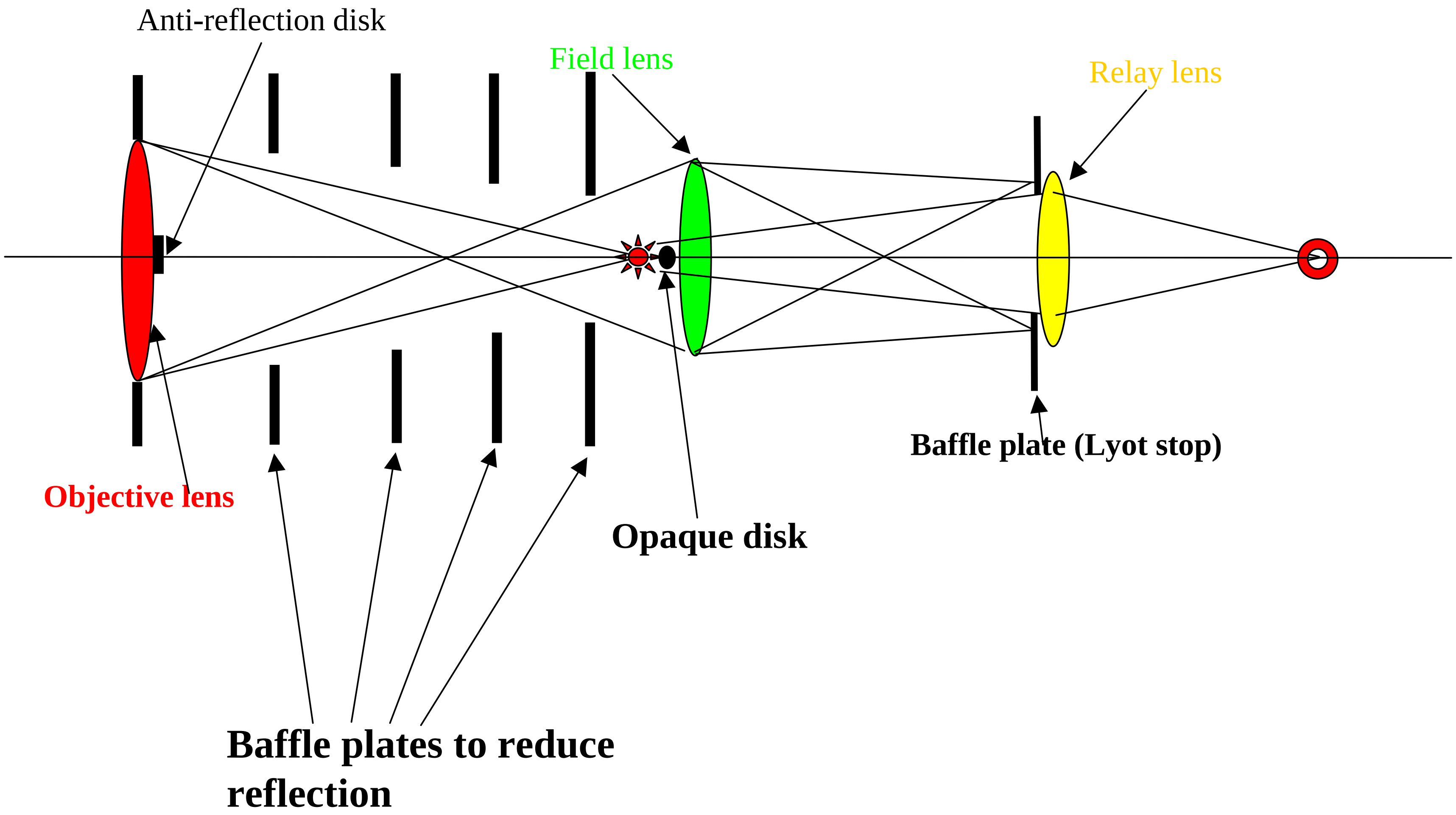
We can measure the very short pulse length with intensity interferometry with nearly no theoretical limit on temporal resolution.



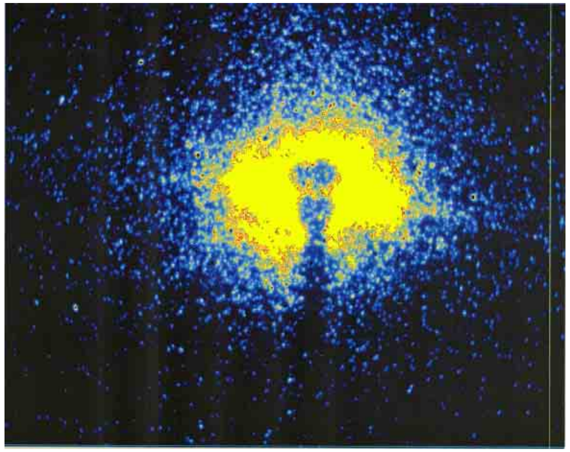
Actual resolution will be limited by dispersion of the glass.

Coronagraph for halo measurement

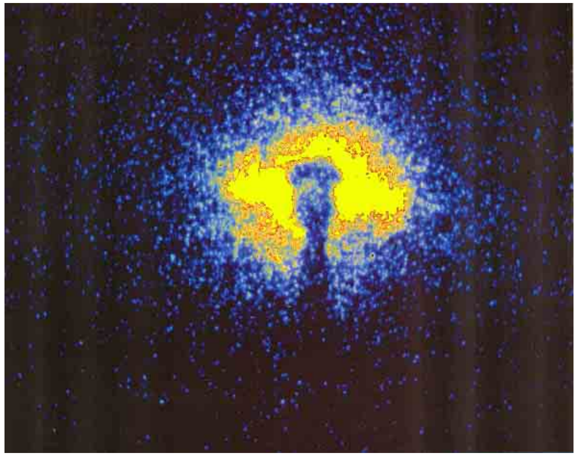
Optical layout of the coronagraph



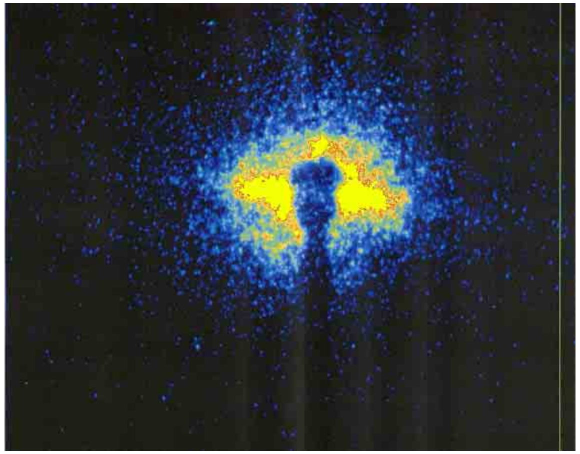
Beam tail images in the single bunch operation at the KEK PF measured at different current



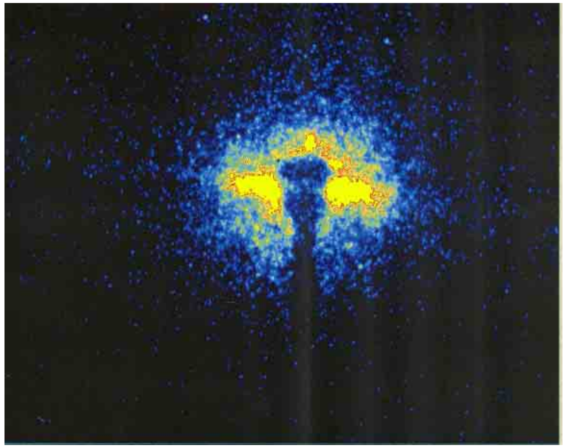
65.8mA



61.4mA

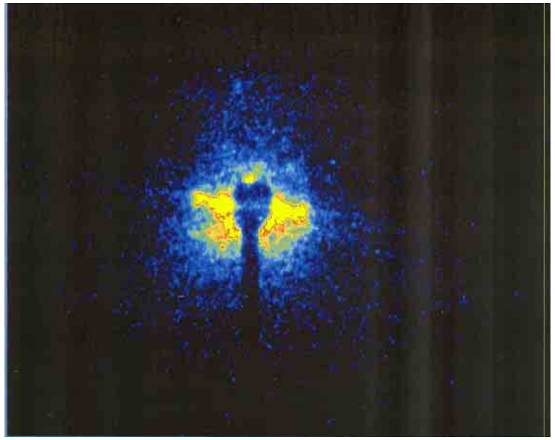


54.3mA



45.5mA

35.5mA

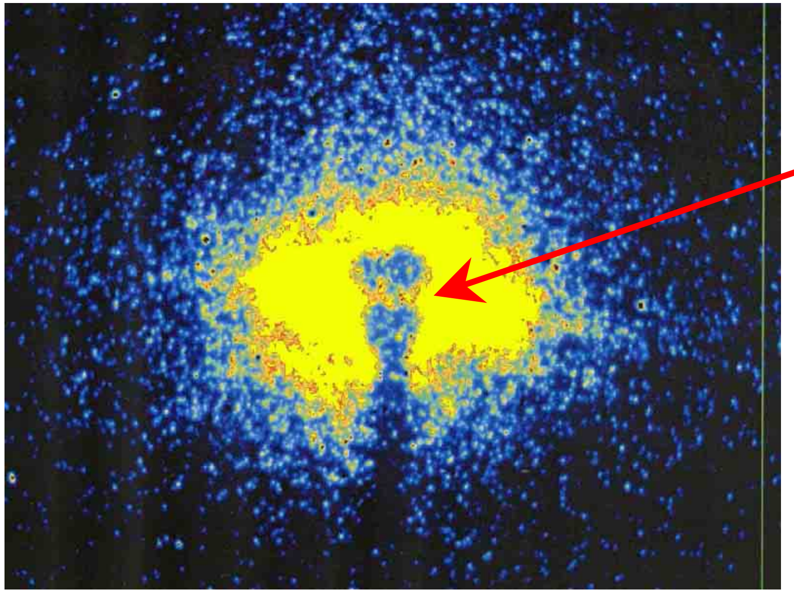


396.8mA
Multi-bunch
bunch current 1.42mA

Observation for the more out side

Single bunch
65.8mA

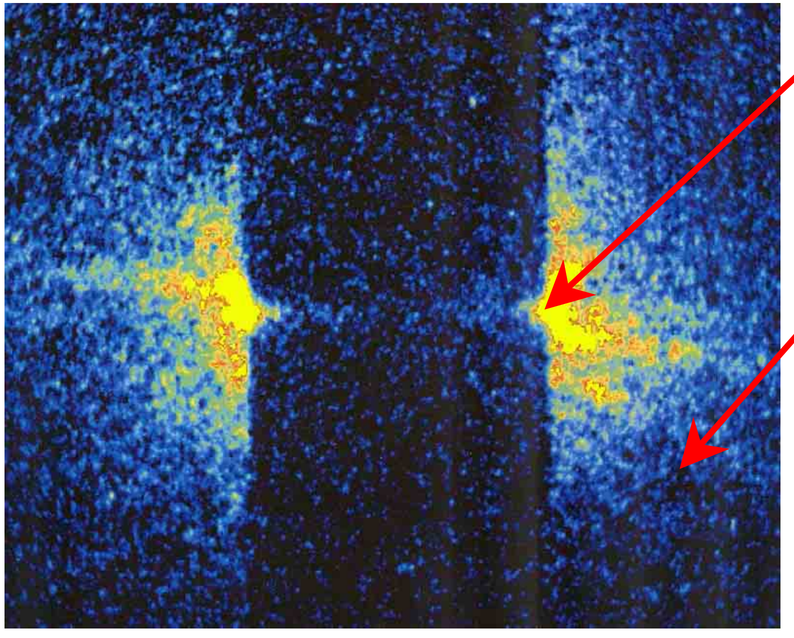
Exposure time of CCD : 3msec



Intensity in here : $2.05x10^{-4}$ of peak intensity

Far tail

Exposure time of CCD : 100msec



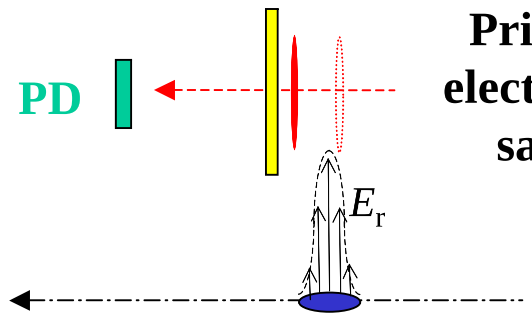
$2.55x10^{-6}$

Background leavel : about $6x10^{-7}$

Bunch length monitoring
by Opto-electric method

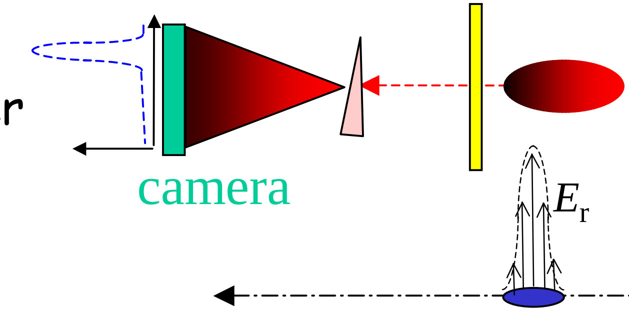
Electro-Optical Sampling

1. Sampling:
- simple analysis
- balanced detector allows high sensitivity
- good synchronization required
- multi-shot method
- arbitrary time window possible



Principal of electro-optical sampling

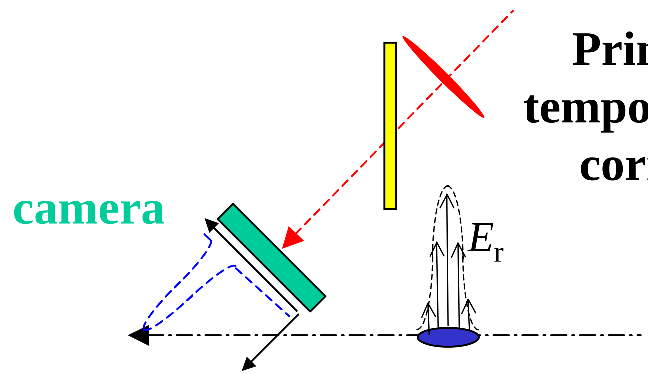
2. Chirp laser method:
- single shot method
- some more effort for laser and laser diagnostics required
- resolution due to laser ~ $\sqrt{t_0 \cdot t_{chirp}}$
- time window ~ 1-20ps



Principal of temporal-wavelength correlation

TTF2 @ 140m

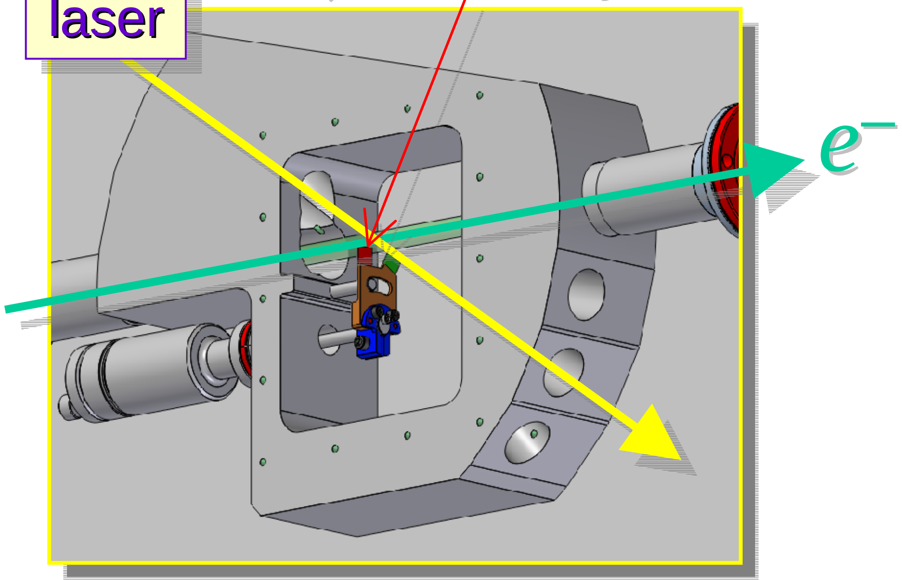
3. Spatial method:
- single shot method
- imaging optics is critical
- resolution due to geometry > $t_0/\cos(\alpha)$
- time window ~ 1-20ps



Principal of temporal-spatial correlation

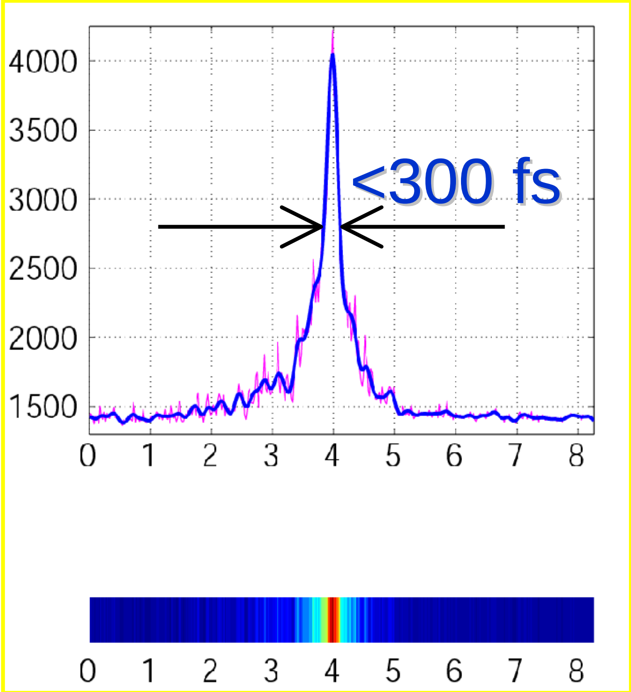
TTF2: Methods 1&2 installed at 140 m, method 3 will be used at 190 m

Electro-Optical Sampling

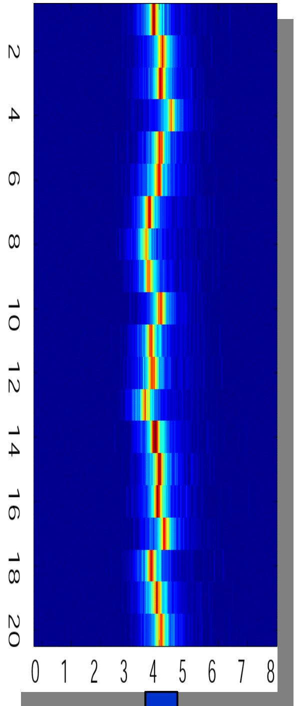


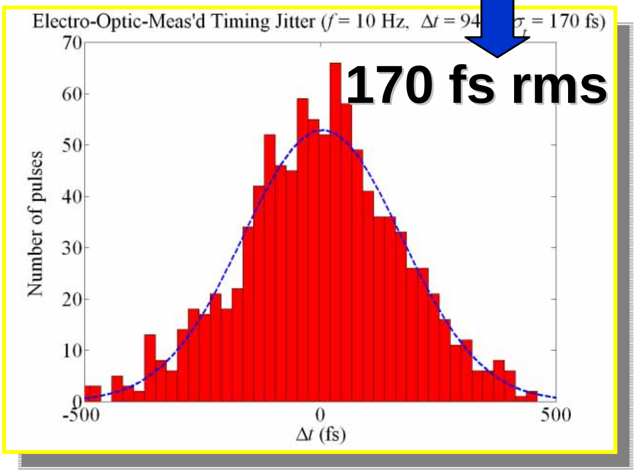
e^- temporal information is encoded on transverse profile of laser beam

Single-Shot



Timing Jitter (20 Shots)





Sub-Picosecond Pulse Source

PPS

Adrian Cavalieri et al., *U. Mich.*

Courtesy of J. Hastings