SuperKEKB (KEKB upgrade) status

K. Ohmi (KEK-ACCEL)

XI SuperB workshop

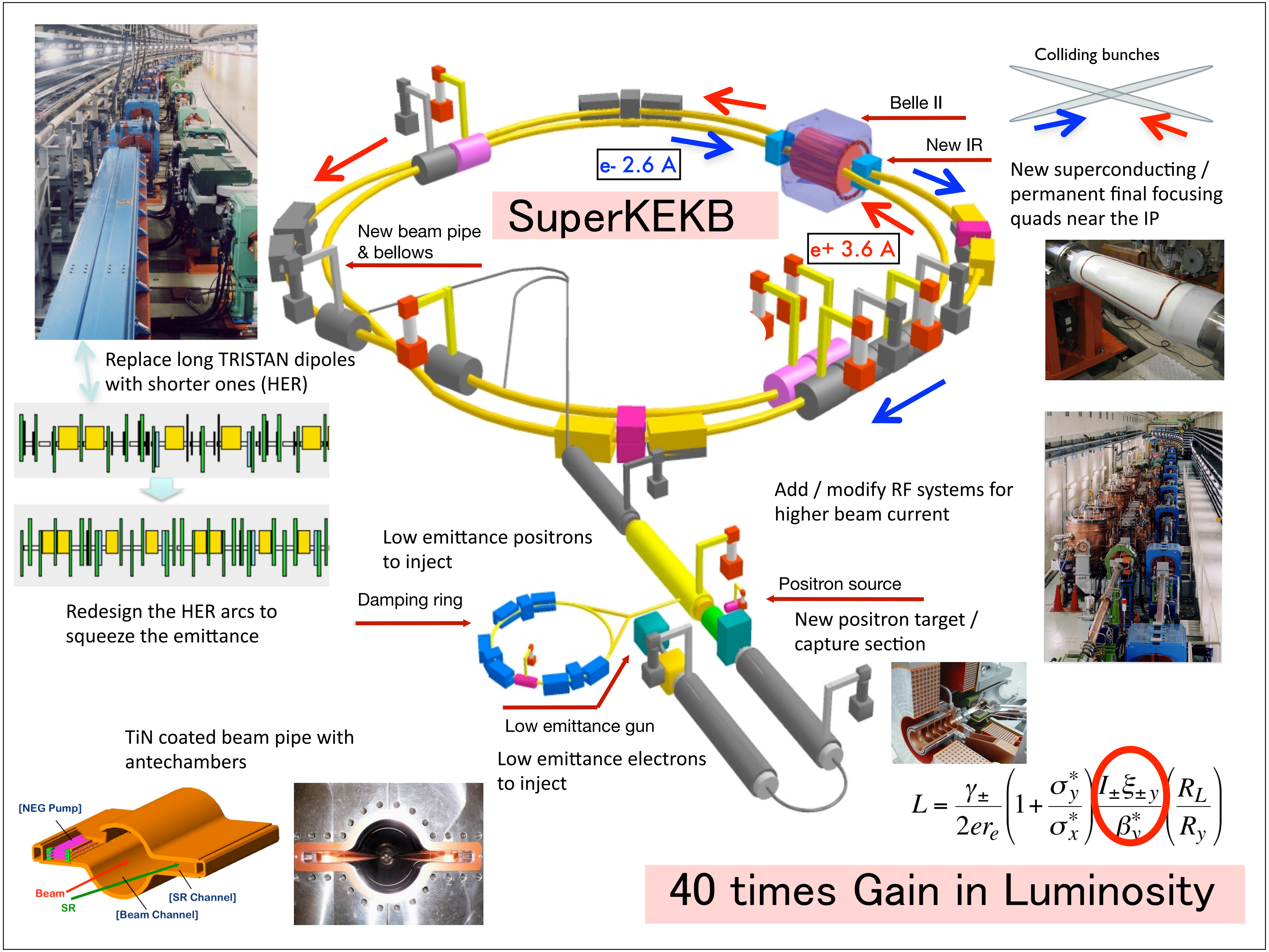
1-4 Dec. 2009, INFN-LNF

Crab crossing

- Maximum beam-beam parameter 0.091 ($\xi_n=2r_e\beta_y L/\gamma N f_0=0.06$).
- Luminosity increases 1.65 to 2.11×10^{34} $cm^{-2}s^{-1}$ due to correction of chromatic aberrations of IR optics parameters, especially x-y coupling.
- Optics parameters at IP are still ambiguous. Good luminosity is given at nonzero coupling parameters (R3 and R4). R1 and R2 are not measurable in enough accuracy.
- First beam noise is also doubtful.

Change the strategy

- Anyway, we could not achieve the high beam-beam parameter >>0.1.
- It is the time to go another direction, low emittance and low beta.
- In this scheme, the beam-beam parameter is mild, while optics design and technical implementation with a high accuracy are required.



Colliding bunches
Belle II
New IR
e- 2.6 A
e+ 3.6 A
SuperKEKB
New beam pipe & bellows
New superconducting / permanent final focusing quads near the IP
Replace long TRISTAN dipoles with shorter ones (HER)
Redesign the HER arcs to squeeze the emittance
Add / modify RF systems for higher beam current
Low emittance positrons to inject
Damping ring
Positron source
New positron target / capture section
Low emittance gun
Low emittance electrons to inject
TiN coated beam pipe with antechambers
[NEG Pump]
Beam
SR
[SR Channel]
[Beam Channel]
$L = \frac{\gamma_\pm}{2 e r_e} \left(1 + \frac{\sigma_y^*}{\sigma_x^*}\right) \left(\frac{I_\pm \xi_{\pm y}}{\beta_y^*}\right) \left(\frac{R_L}{R_y}\right)$
40 times Gain in Luminosity

Design parameters

	KEKB Design	KEKB Achieved : with crab	SuperKEKB High-Current	SuperKEKB Nano-Beam
Energy (GeV) (LER/HER)	3.5/8.0	3.5/8.0	3.5/8.0	4.0/7.0
β_x^* (cm)	100/100	120/120	20/20	3.2/2.5
β_y^* (mm)	10/10	5.9/5.9	3/6	0.27/0.42
ε_x (nm)	18/18	18/24	24/18	3.2/1.7
σ_y(μm)	1.9	0.94	0.85/0.73	0.059
ξ_y	0.052	0.129/0.090	0.3/0.51	0.09/0.09
σ_z (mm)	4	~ 6	5/3	6/5
I_{beam} (A)	2.6/1.1	1.64/1.19	9.4/4.1	3.6/2.6
$N_{bunches}$	5000	1584	5000	2500
Luminosity (10^{34} cm^{-2} s^{-1})	1	2.11	53	80

Design parameters

Y. Ohnishi

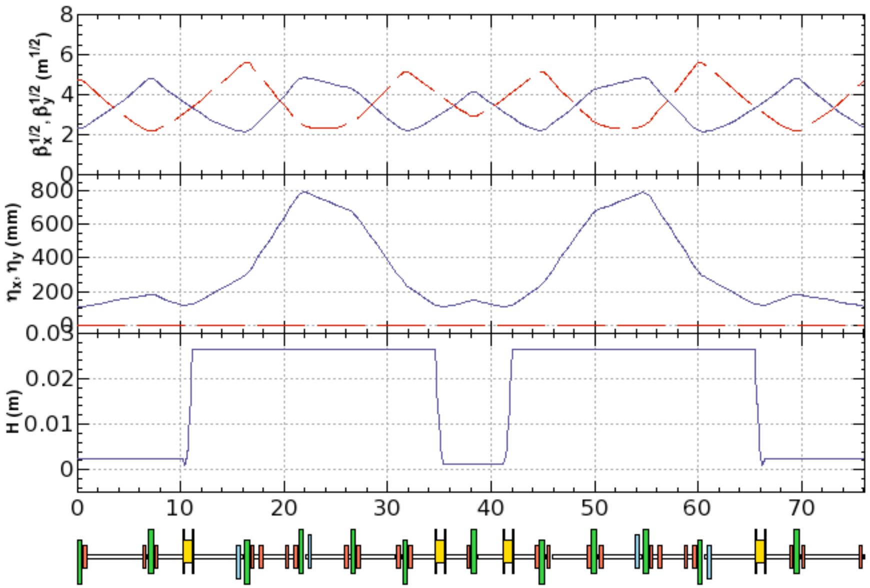
		LER	HER	
Emittance	ε_x	3.2	1.7	nm
Coupling	$\varepsilon_y/\varepsilon_x$	0.40	0.48	%
Beta Function at IP	β_x^* / β_y^*	32 / 0.27	25 / 0.42	mm
Beam Size	σ_x^* / σ_y^*	10.1 / 0.059	6.5 / 0.059	μm
Bunch Length	σ_z	6	5	mm
Half Crossing Angle	ϕ	41.3		mrad
Beam Energy	E	4	7	GeV
Beam Current	I	3.6	2.6	A
Number of Bunches	n_b	2500		
Energy Loss / turn	U_0	2.28	2.15	MeV
Total Cavity Voltage	V_c	6.3	6.3	MV
Energy Spread	σ_δ	7.92×10^{-4}	5.91×10^{-4}	
Synchrotron Tune	ν_s	-0.0185	-0.0114	
Momentum Compaction	α_p	2.85×10^{-4}	1.90×10^{-4}	
Beam-Beam Parameter	ξ_y	0.09	0.09	
Luminosity	L	8×10^{35}		$cm^{-2}s^{-1}$

LER arc cell

A. Morita

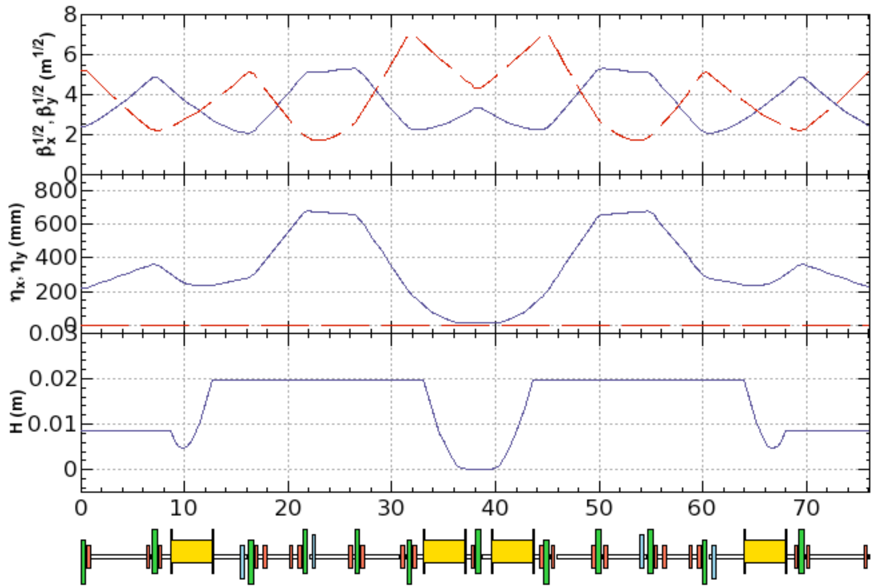
Longer bending magnet to achieve the low emittance

L_{bend} = 0.89 m → 4 m



KEKB

ε_x = 8.8 nm α_p = 3.3x10^{-4}



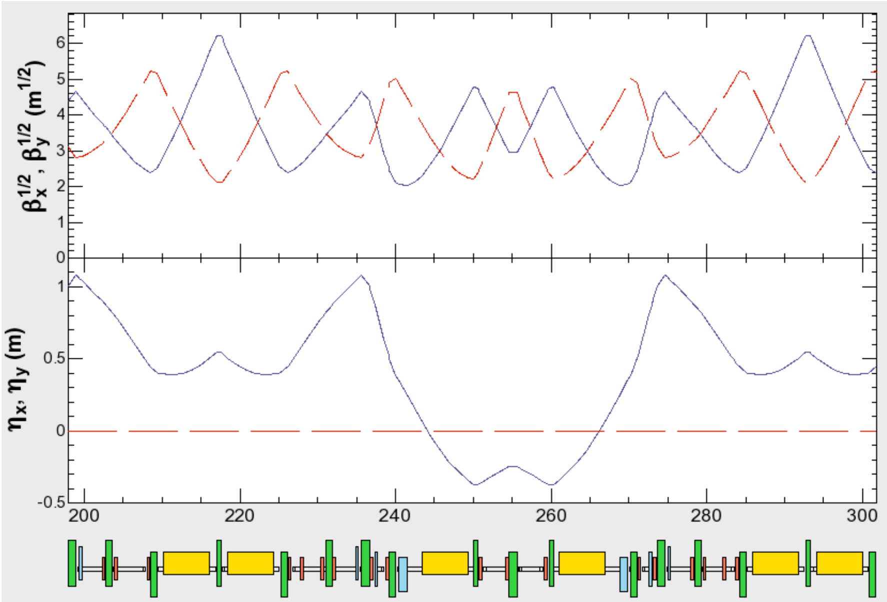
SuperKEKB

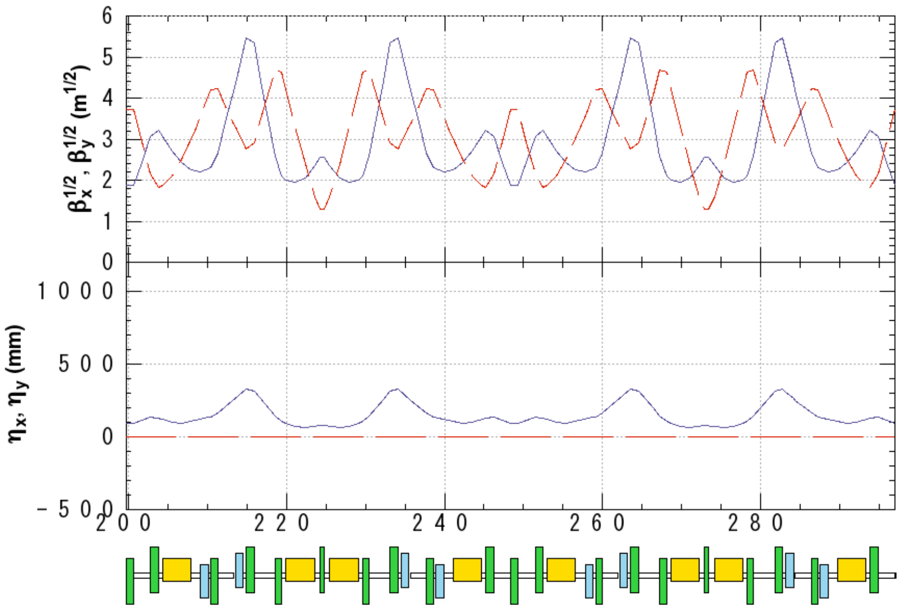
ε_x = 3.2 nm α_p = 4.4x10^{-4}

HER arc cell

Y. Ohnishi

Increase number of arc cell





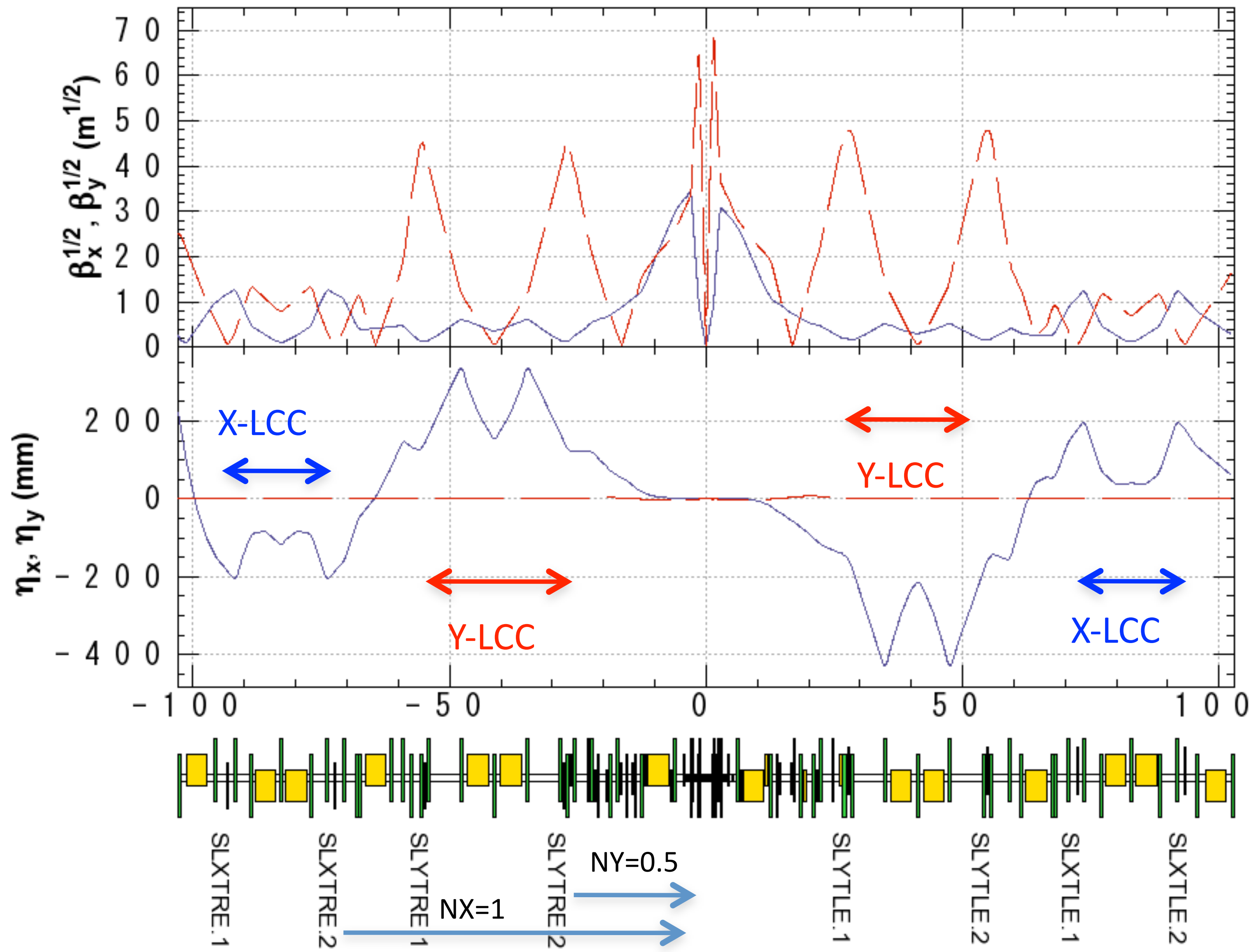
KEKB
24 nm

SuperKEKB
1.7 nm

Replace long dipole magnets with shorter ones.
All magnets of the arc section must be taken out and re-installed.

HER IR

Y. Ohnishi

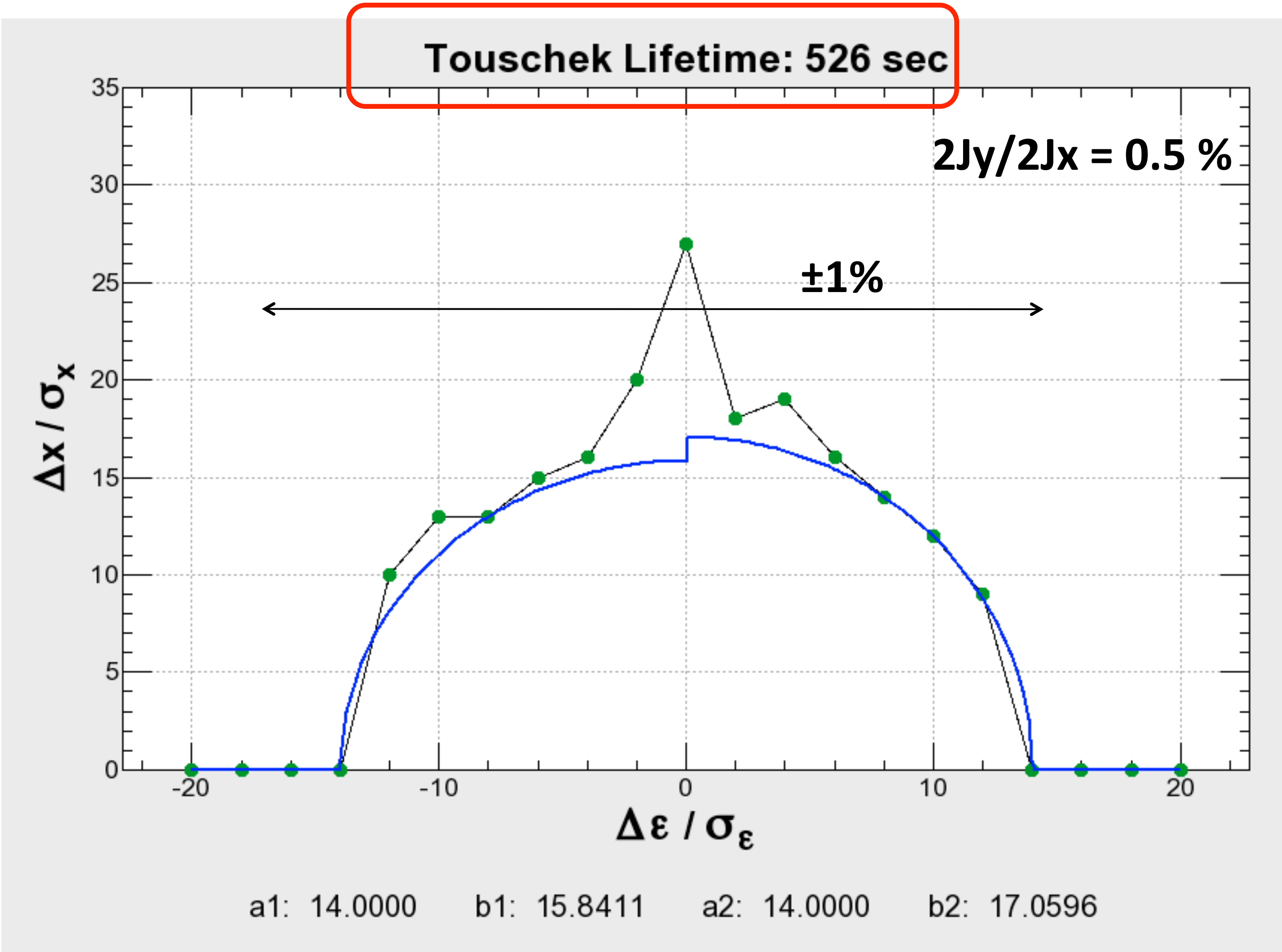


2-family local correction is used

HER Dynamic Aperture

Y. Ohnishi

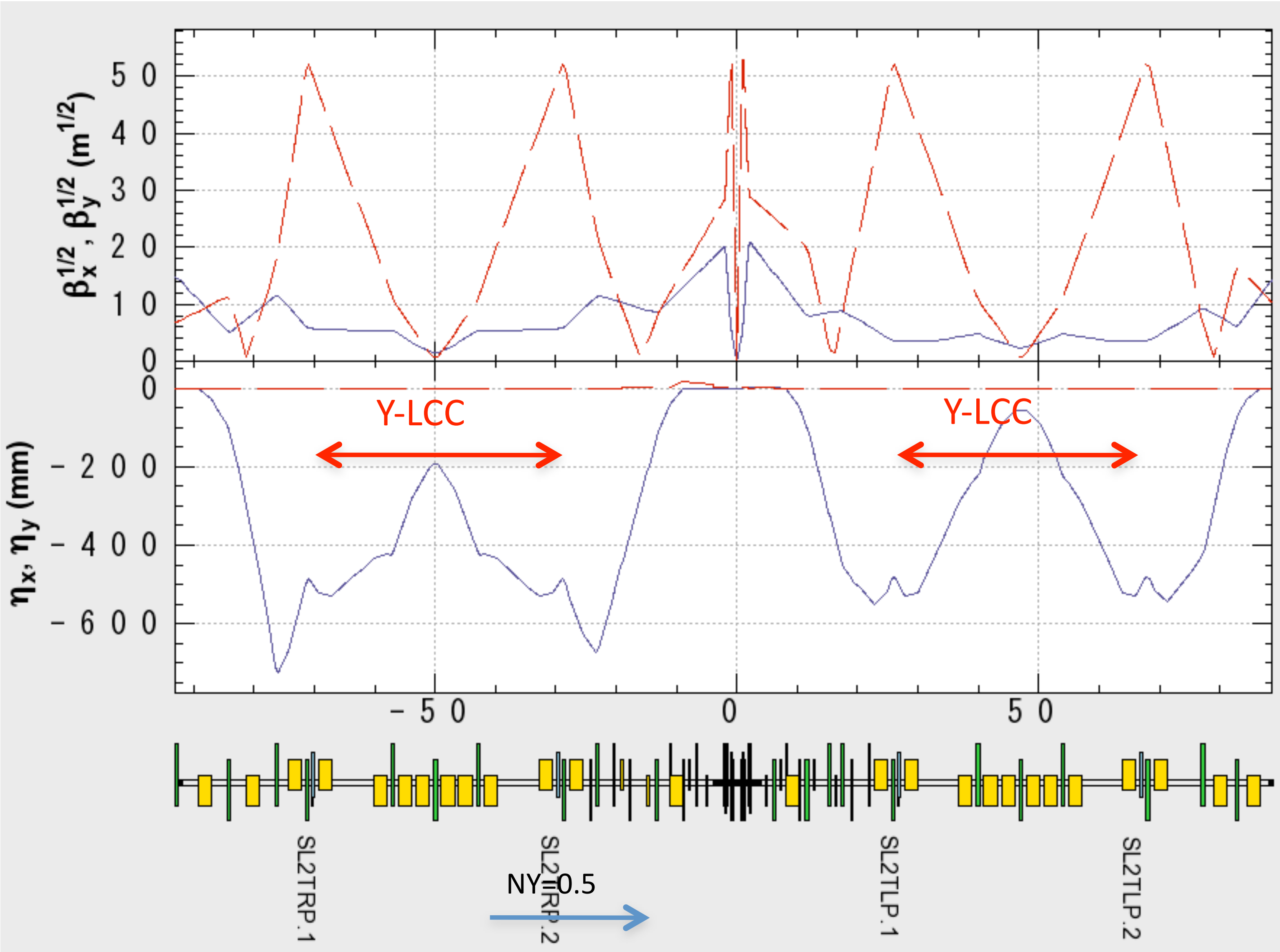
w/ solenoid field



The optimization work to achieve longer lifetime is in progress.

LER IR

A. Morita

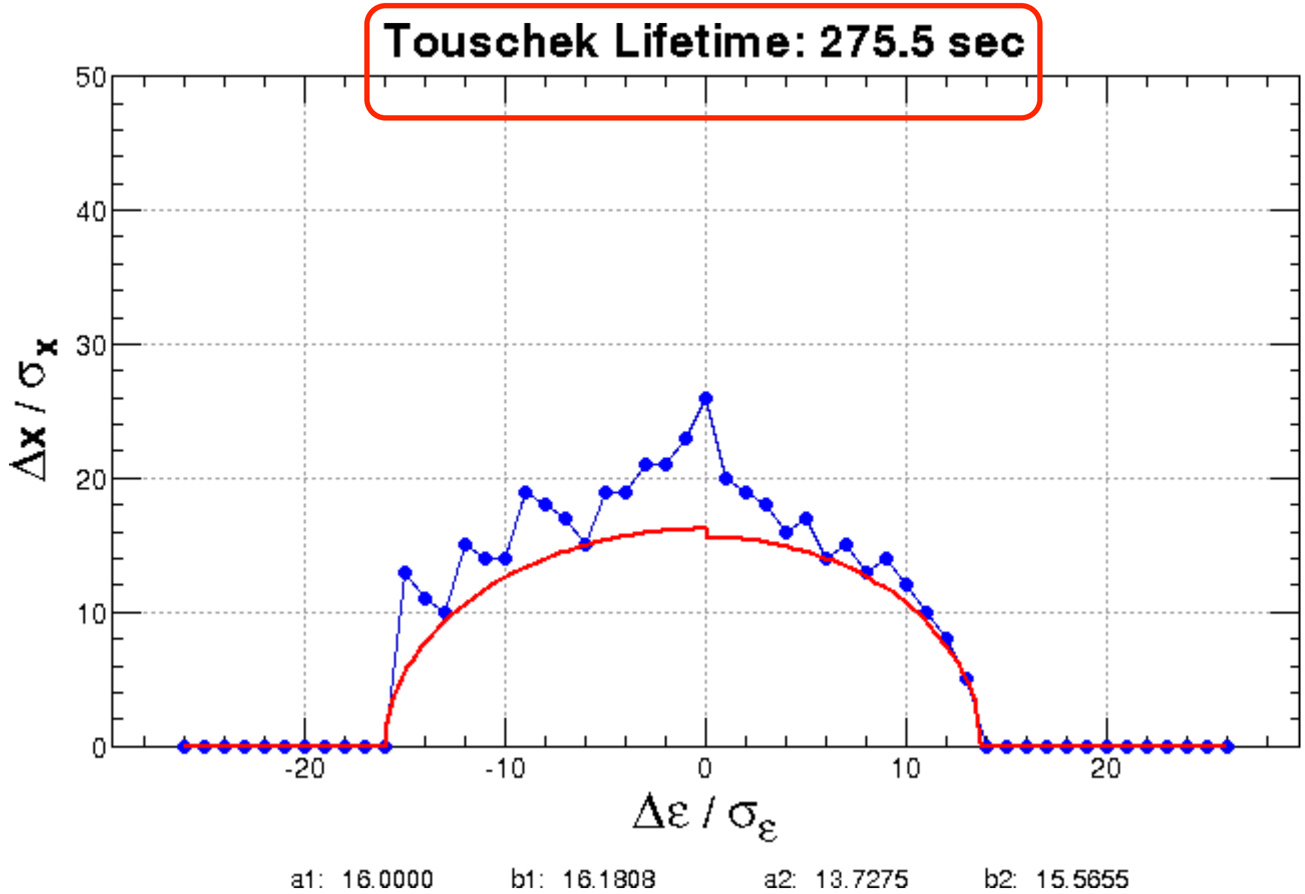


1-family local correction is used

LER Dynamic Aperture

A. Morita

Energy is 4 GeV to get longer Touschek life. **w/ solenoid field**



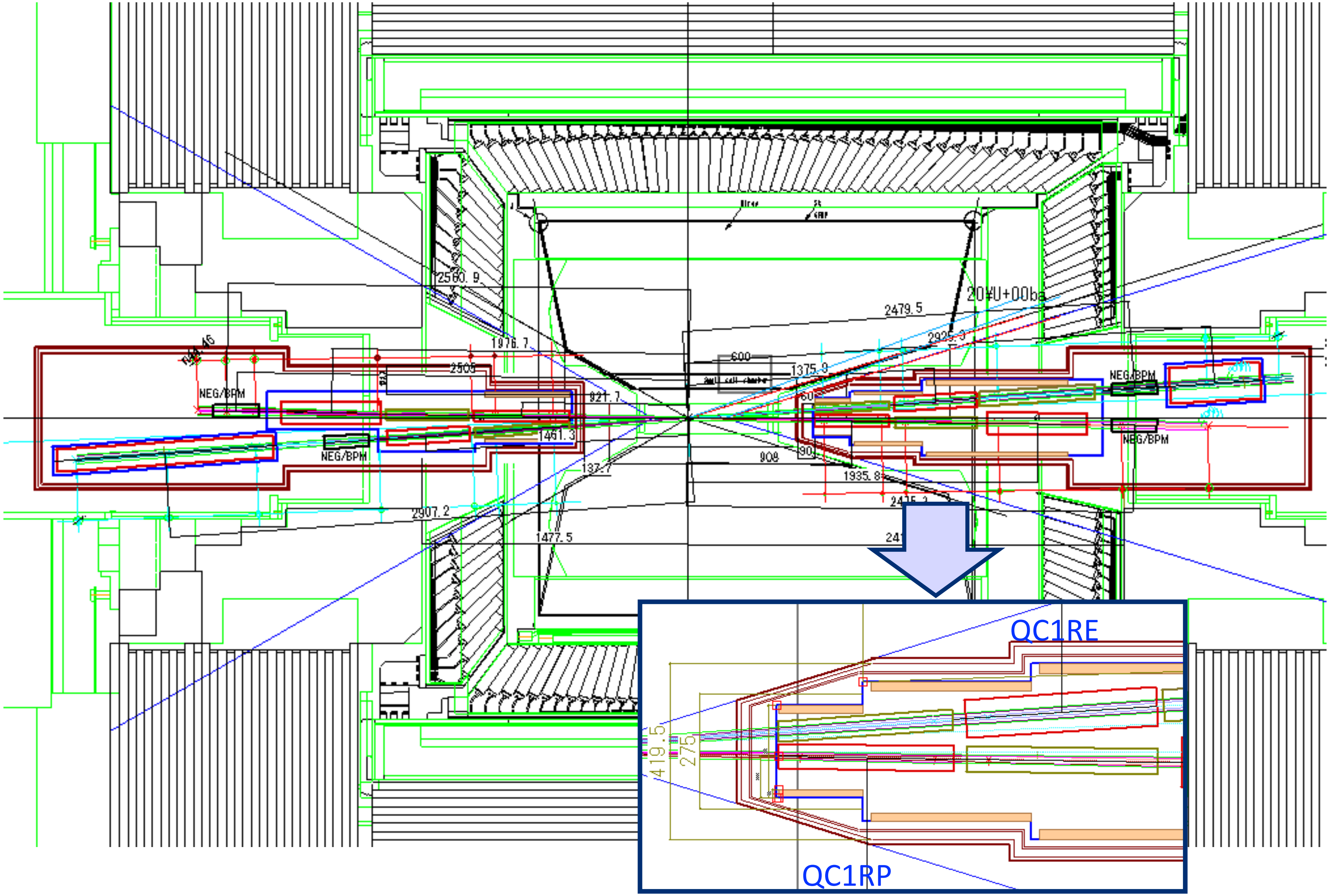
The lifetime is not enough.

The optimization work to achieve longer lifetime is in progress.

2 family local correction will be tried.

IR Overview

N. Ohuchi



The magnet design of QC1R/L-P

N. Ohuchi

Separated final quadrupole magnets

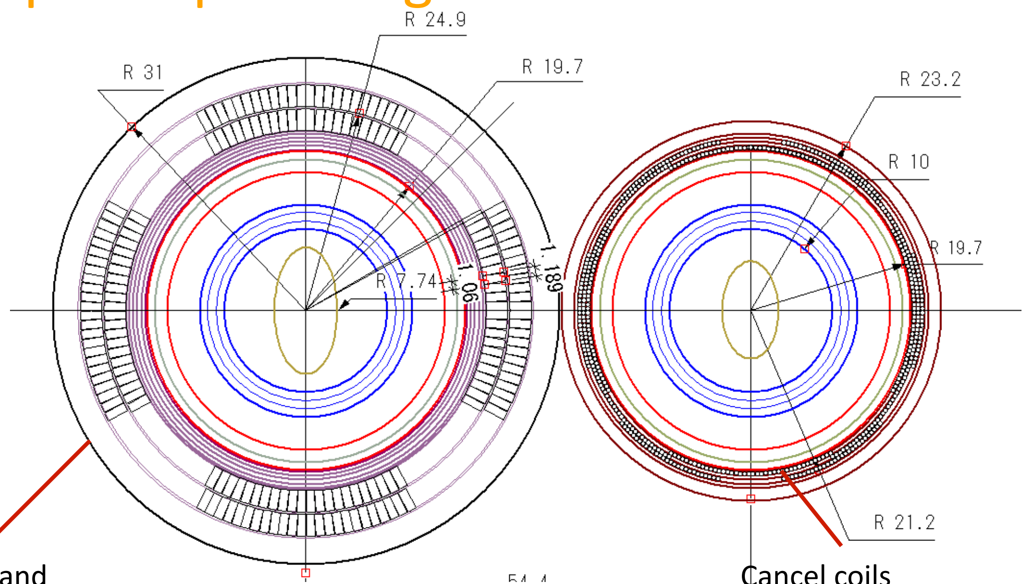
Magnet Parameters

- Magnet inner radius=22 mm, outer radius=27.86 mm
- Magnet current=1622 A
- Field gradient=80.63 T/m
- Current density, J_{SC}= 2314 A/mm^2
- Magnetic length L_{eff} = 0.278 m
- Peak field w/o solenoids = 1.9 T
- Operation temperature = 4.4 K

Cable Parameters

- Size =2.5mm × 0.93mm
- Number of SC strand=10
- Diameter of the strand=0.5mm
- Cu ratio=1.8
- I_c= 2000 A @ 5T and 4.2 K

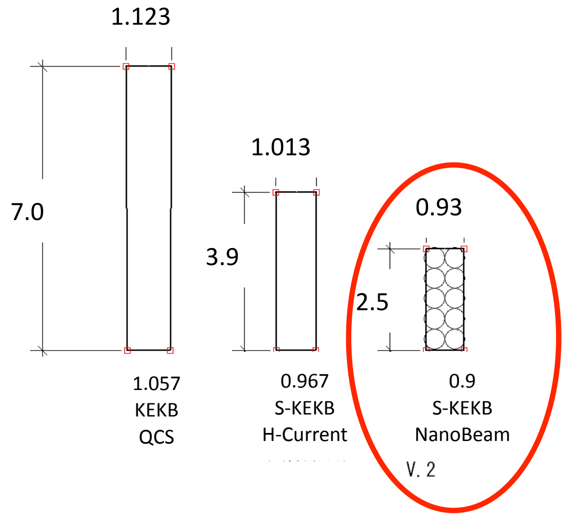
→ Ohnishi's talk @IR session



Main quads and SC correctors:
Normal Octupole
Skew Quadrupole
Normal Dipole
Skew Dipole

Cancel coils
SC correctors:
Normal Sextupole
Normal Quadrupole
Normal Dipole

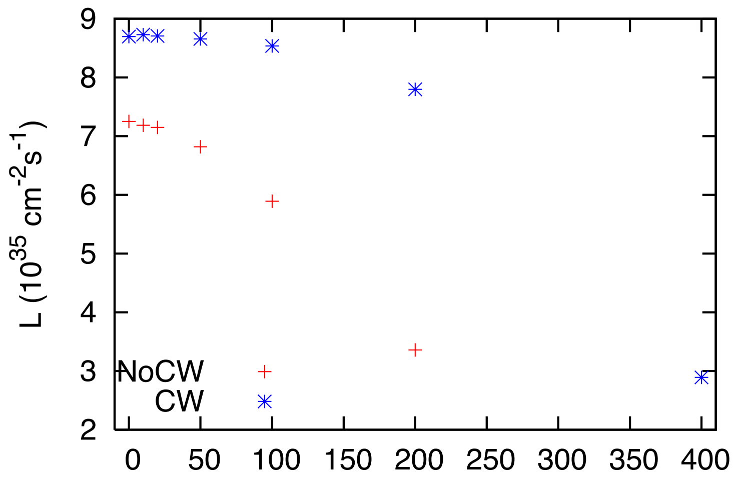
Cross section of QC1 RP

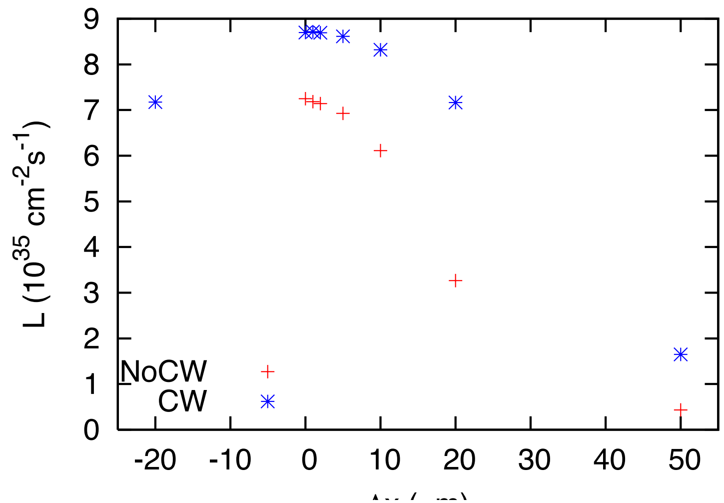


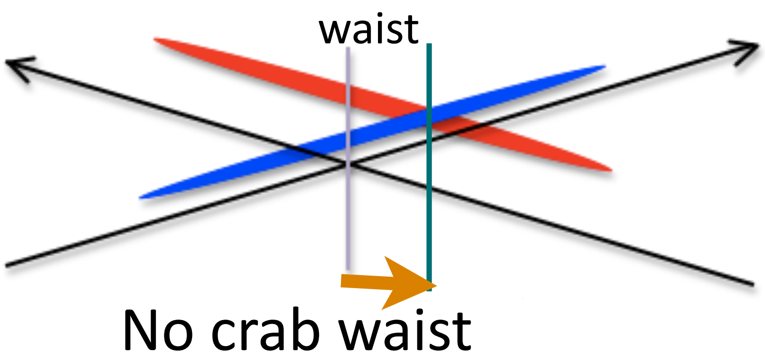
Designed new SC cable for main quadrupole

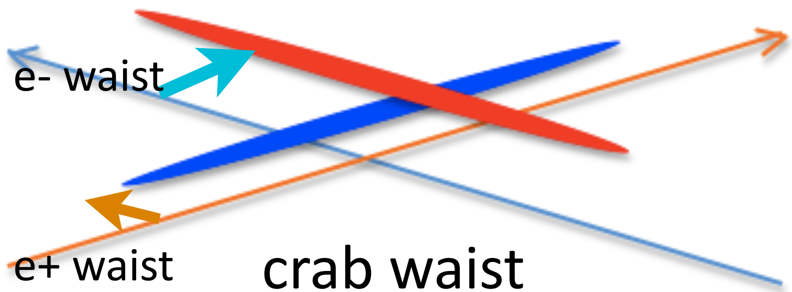
Tolerance of collision condition
Horizontal collision offset and waist

- Horizontal offset and waist are related to each other.
- The cross point of the waist is only one in x-z plane for the crab waist scheme.

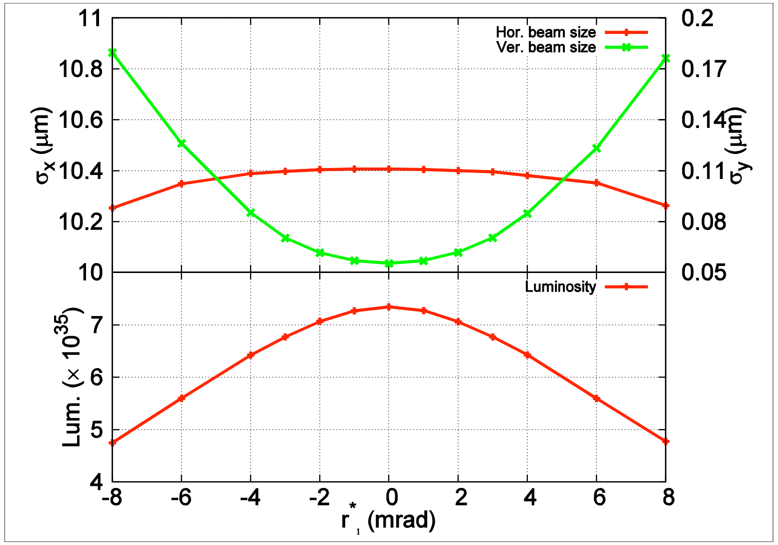


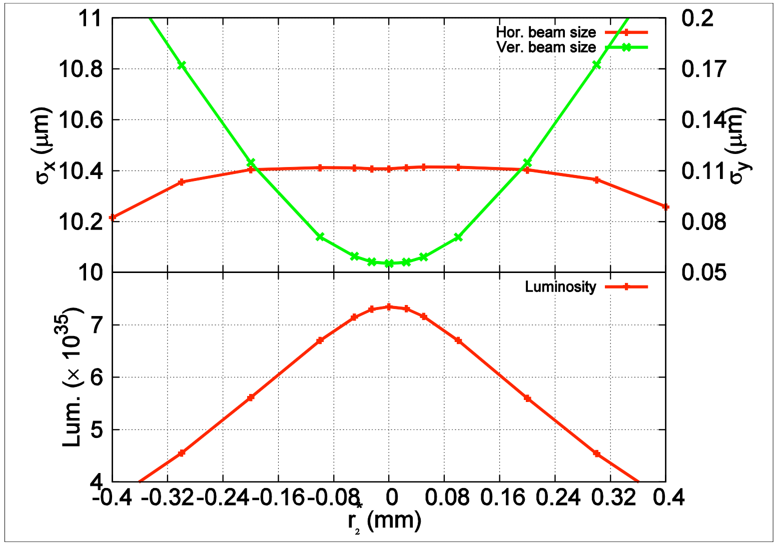


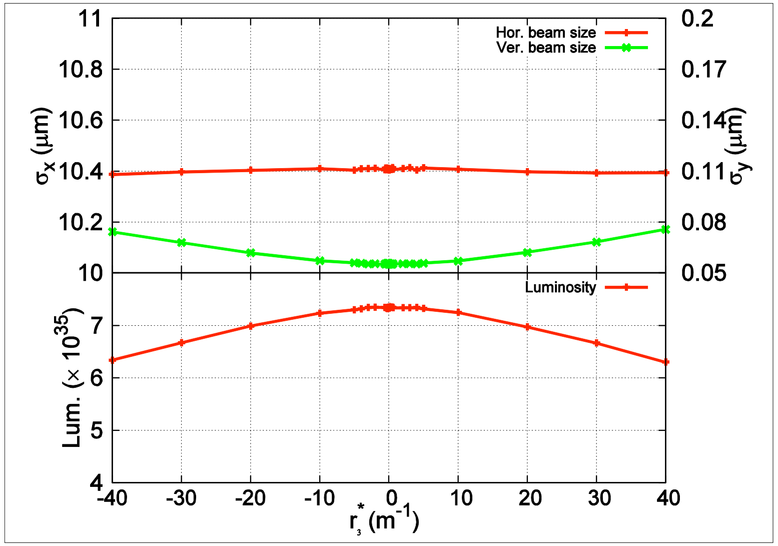


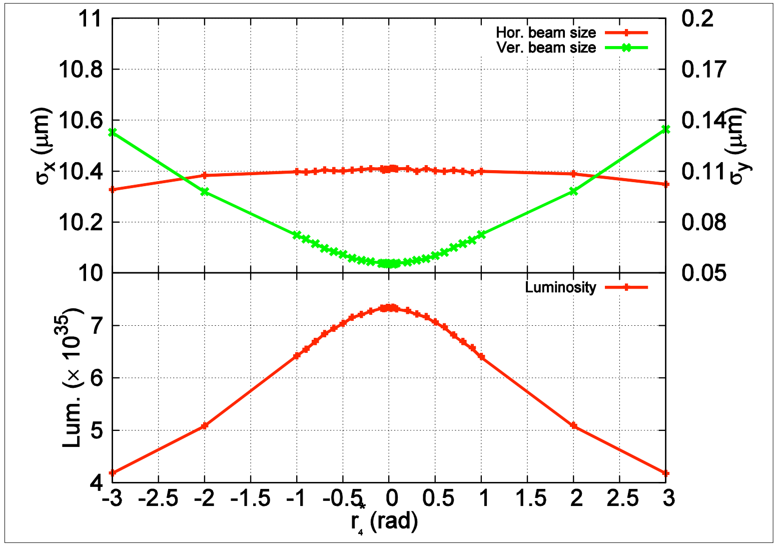


X-Y coupling w/ crab waist

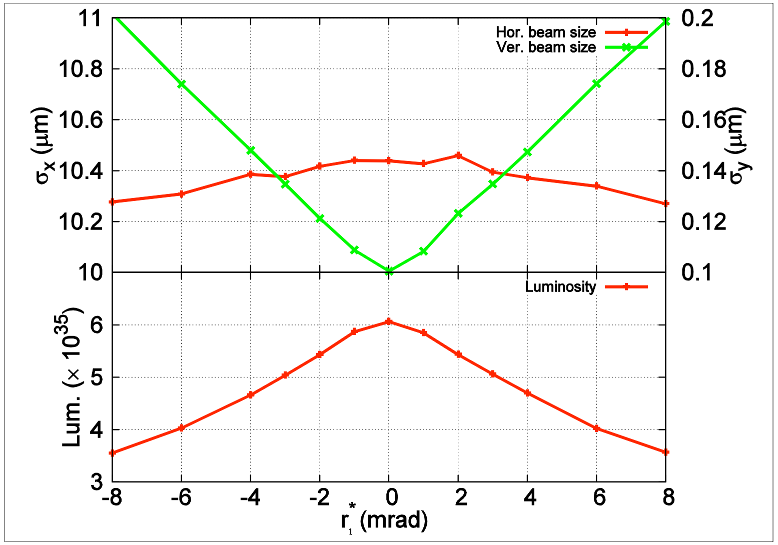


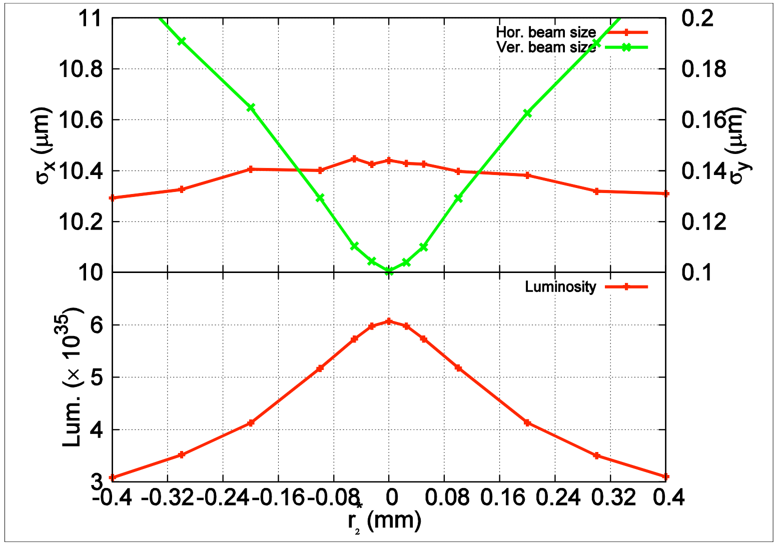


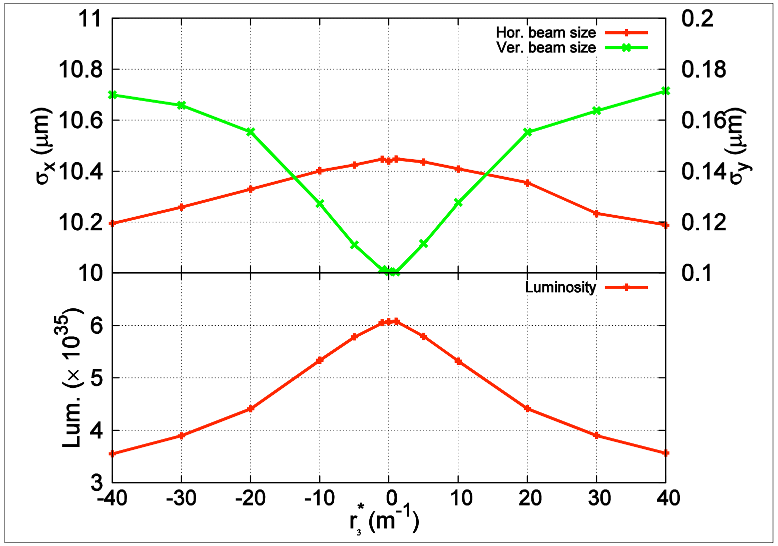


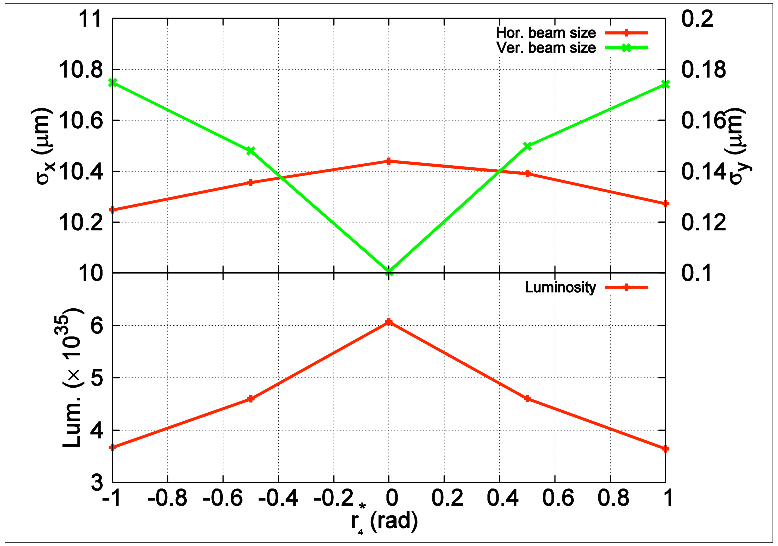


X-Y coupling w/o crab waist

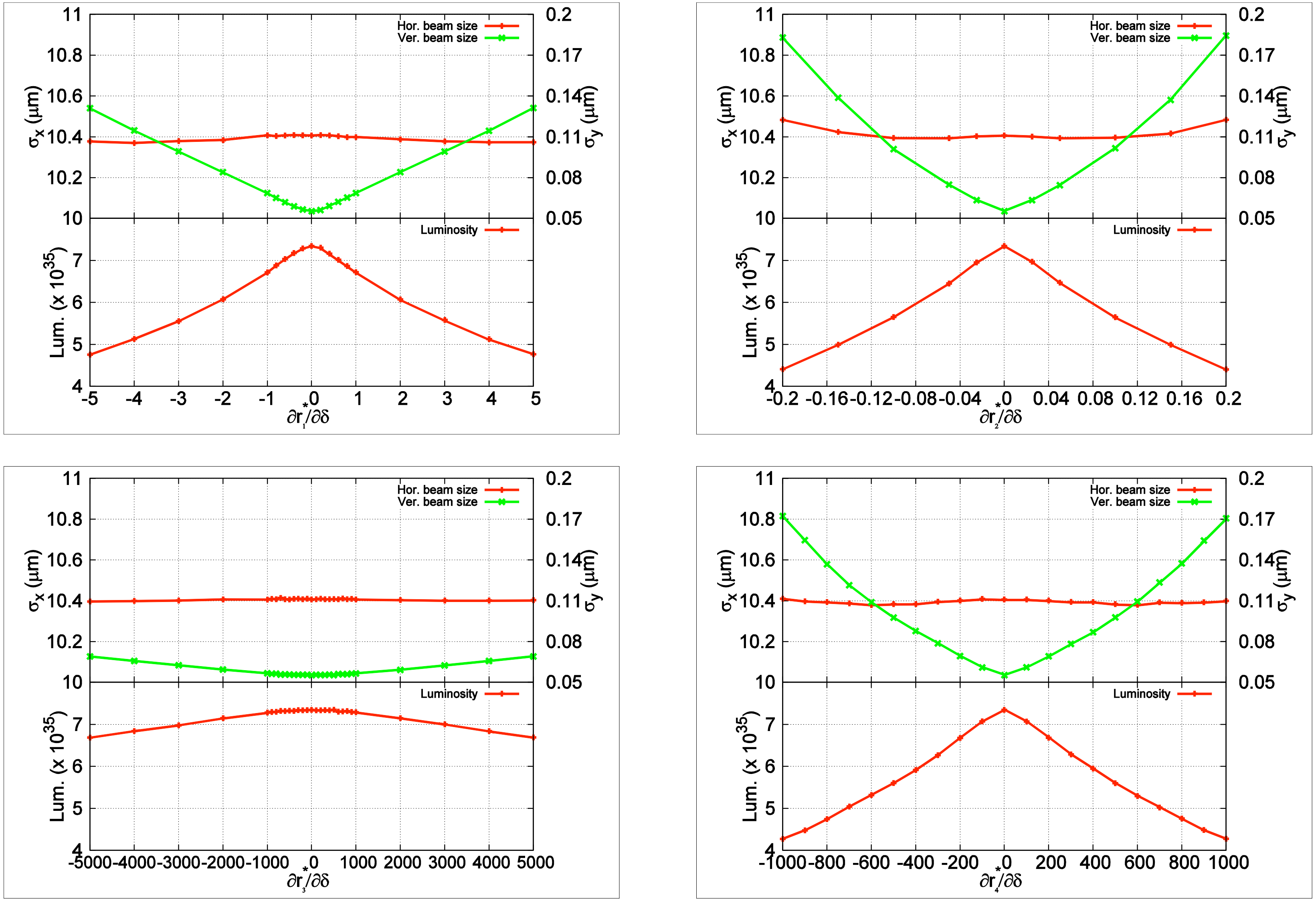




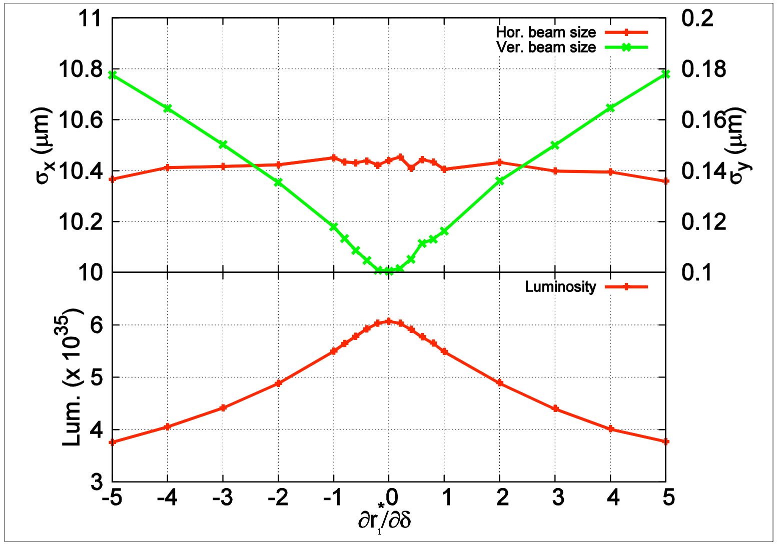


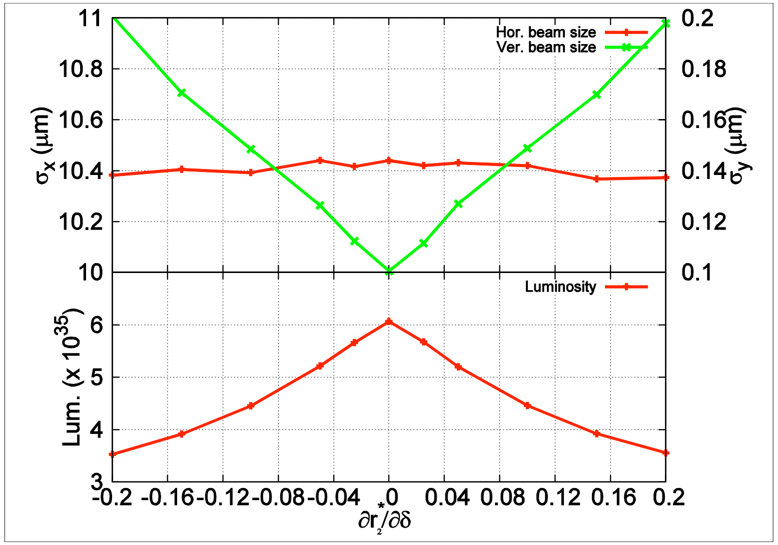


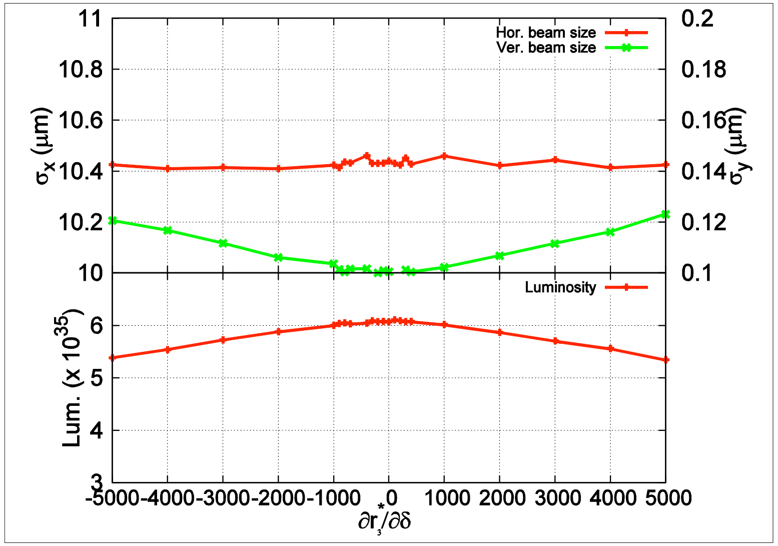
Chromatic X-Y w/ crab waist

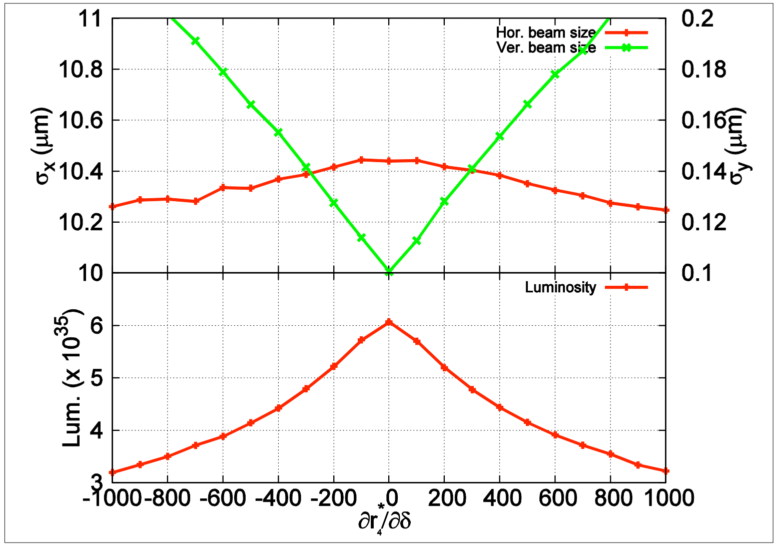


Chromatic X-Y w/o crab waist

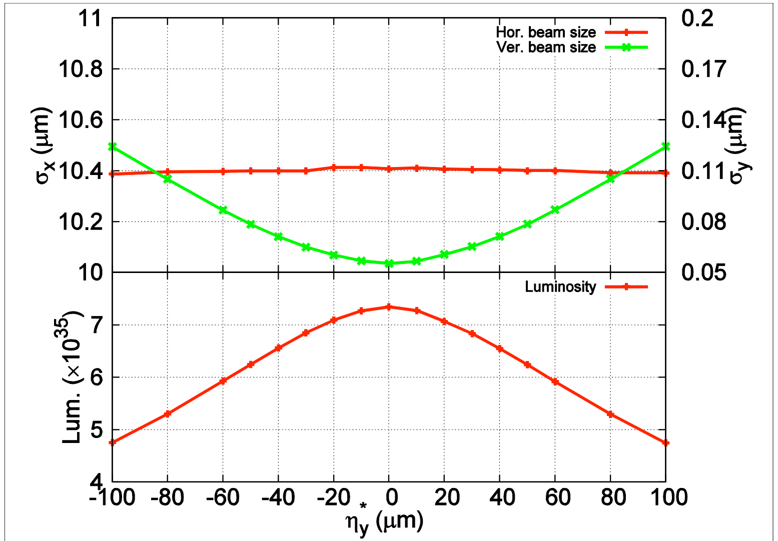


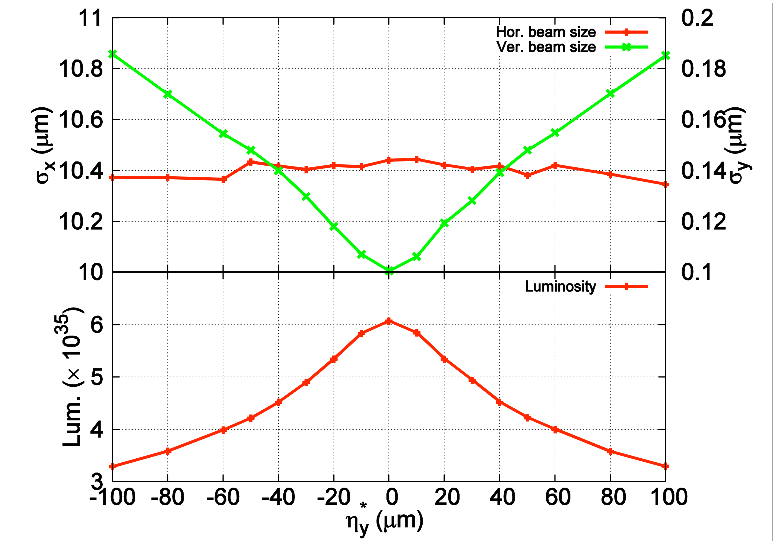






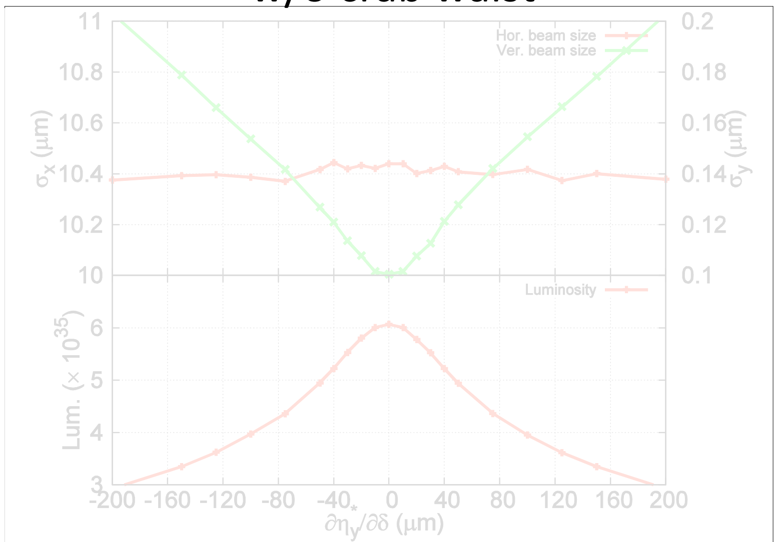
Vertical dispersion and it’s chromaticity



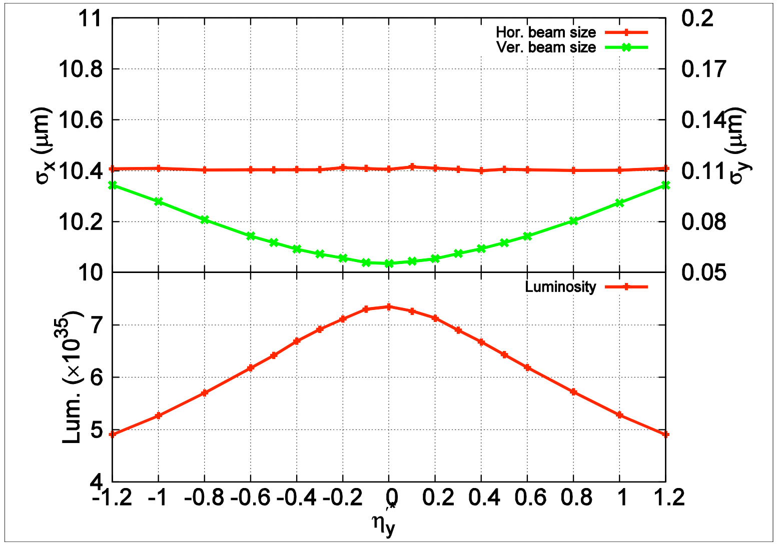


w/ crab waist

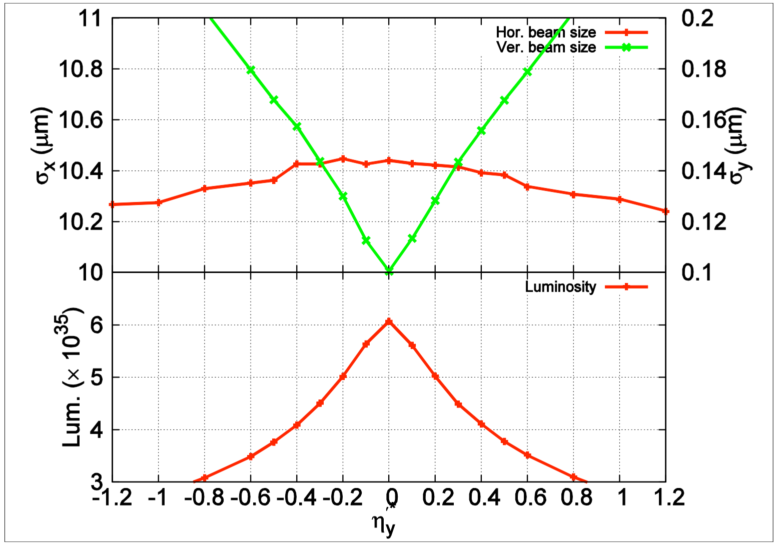
w/o crab waist



Vertical momentum dispersion, η_y'



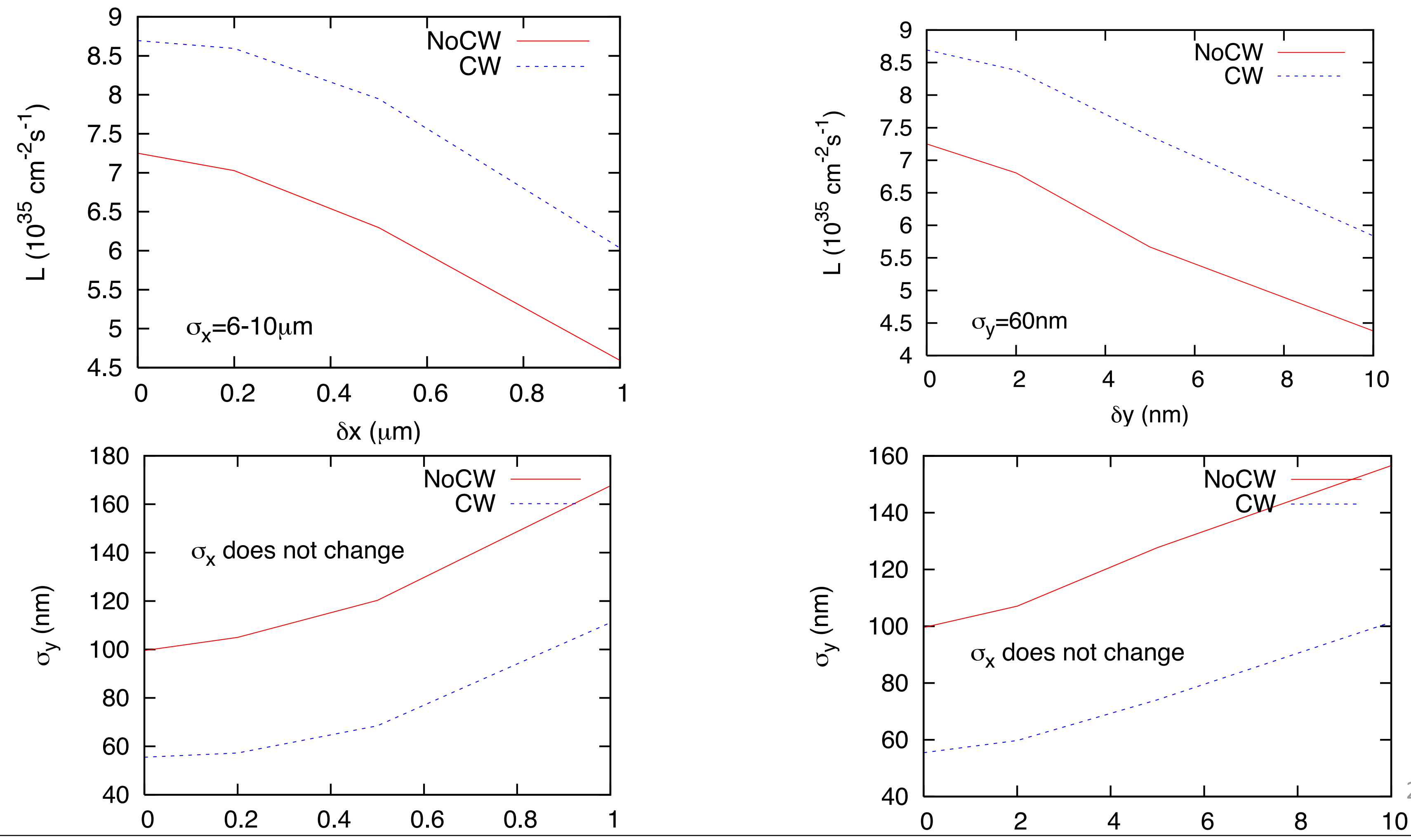
w/ crab waist



w/o crab waist

Beam noise

- Turn by turn noise



Summary – tolerance for parameters with 20% luminosity degradation

Parameter	w/ crab waist	w/o crab waist
r_1^* (mrad)	±5.3	±3.5
r_2^* (mm)	±0.18	±0.13
r_3^* (m^{-1})	±44	±15
r_4^* (rad)	±1.4	±0.4
$\partial r_1^* / \partial\delta$ (rad)	±2.4	±2.1
$\partial r_2^* / \partial\delta$ (m)	±0.086	±0.074
$\partial r_3^* / \partial\delta$ (m^{-1})	$\pm 1.0\times 10^4$	±8400
$\partial r_4^* / \partial\delta$ (rad)	±400	±290
η_y^* (μm)	±62	±31
$\eta_y'^*$	±0.73	±0.23

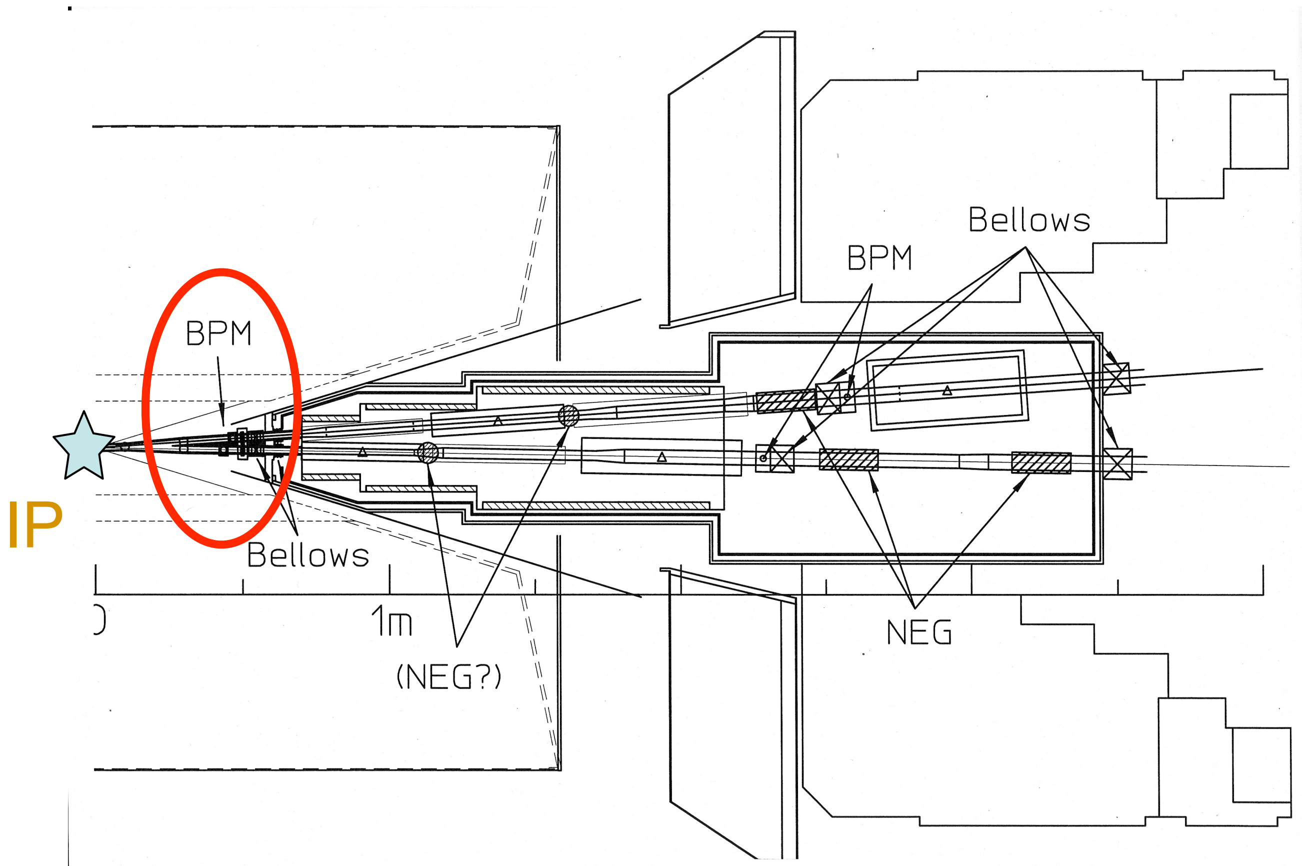
Δx (μm) collision offset	10	10
Δs (μm) waist error	100	100
δx (μm) turn by turn noise	0.5	0.5
δy (nm)	4	4

Measure x-y coupling and its chromatic aberrations

- Two monitors are located at both sides of IP.
- Phase space reconstruction using turn by turn position measurement.
- Correlation matrix <$\mathbf{x}\mathbf{x}^t$> of 4 position data $\mathbf{x}$= (x_L,y_L,x_R,y_R), which contain 10 parameters, gives 2 amplitude(normalization), α_{xy}, β_{xy}, r1-r4.

IR vacuum chamber

K. Kanazawa



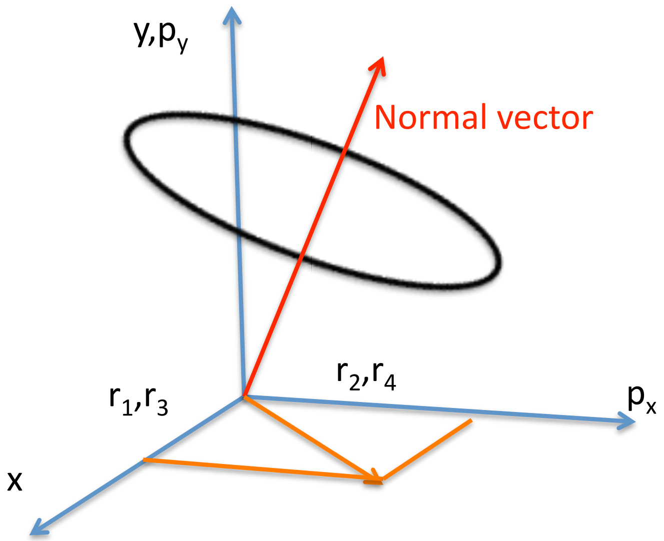
- Two monitors located at the both side of IP.
- Only solenoid field exist between the two monitors. The transfer matrix is simple and clear.

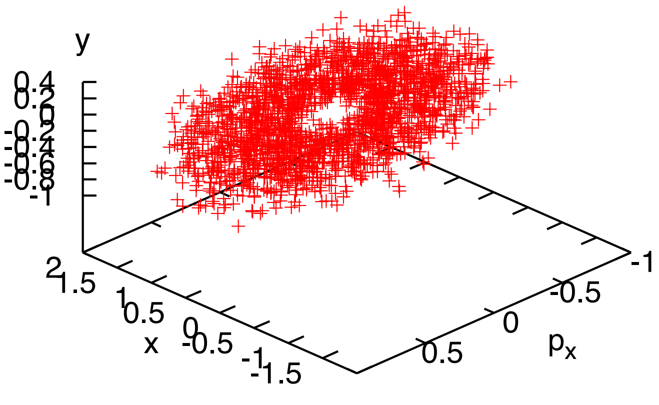
x-y coupling

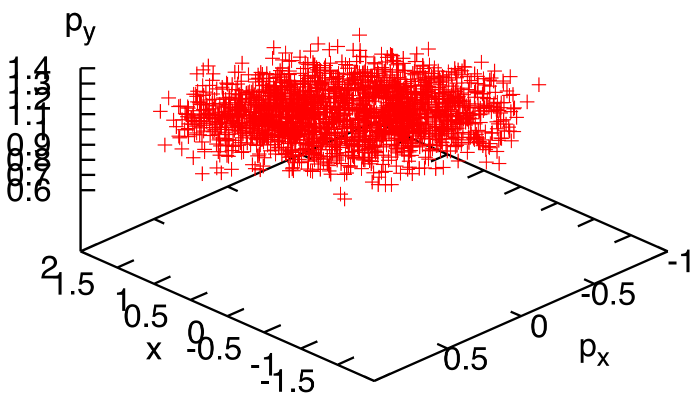
- r1 and r2 are seen.

$$y = -r_1 X - r_2 X'$$

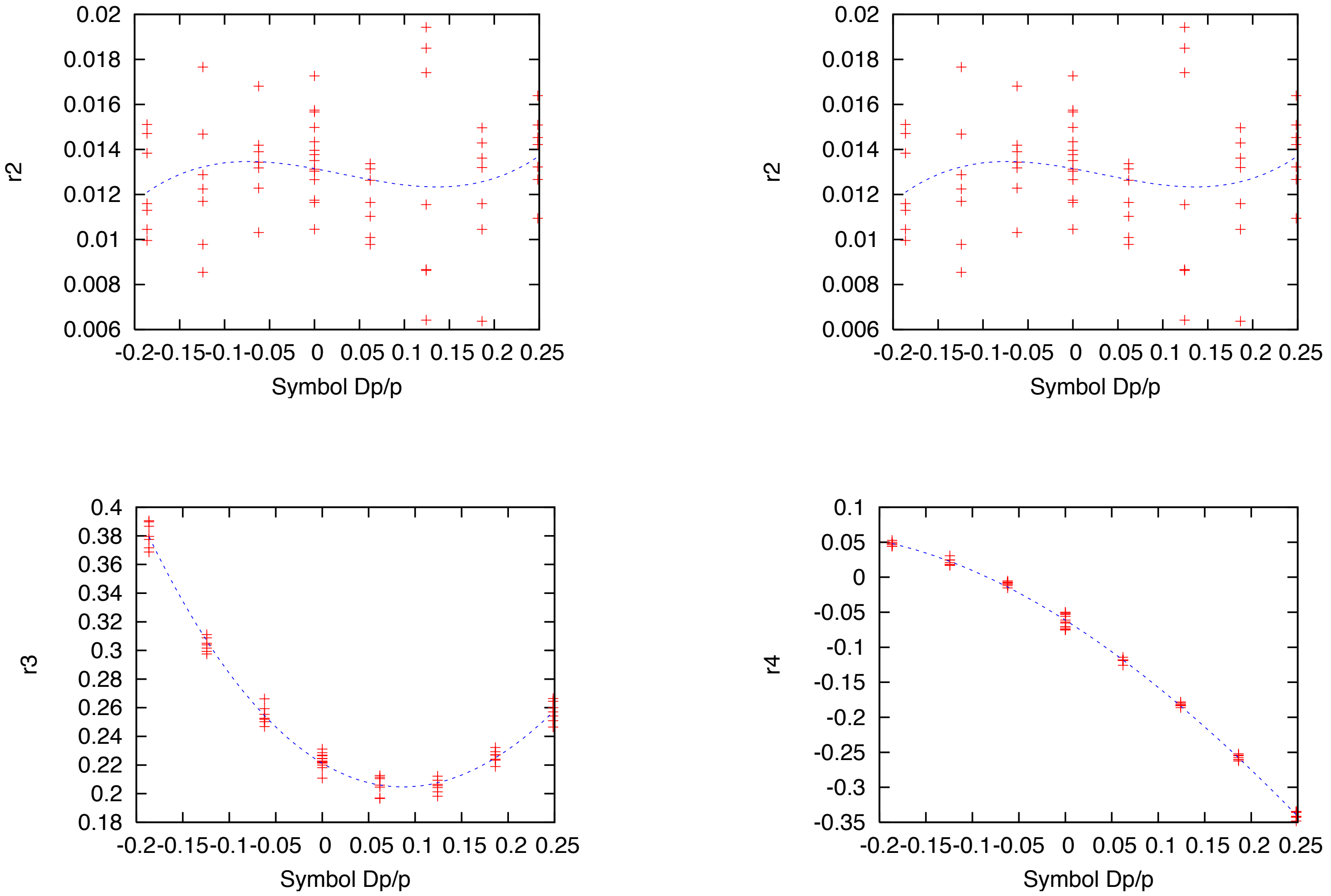
$$p_y = -r_3 X - r_4 X'$$







Measurement of the chromatic X-Y in KEKB-LER



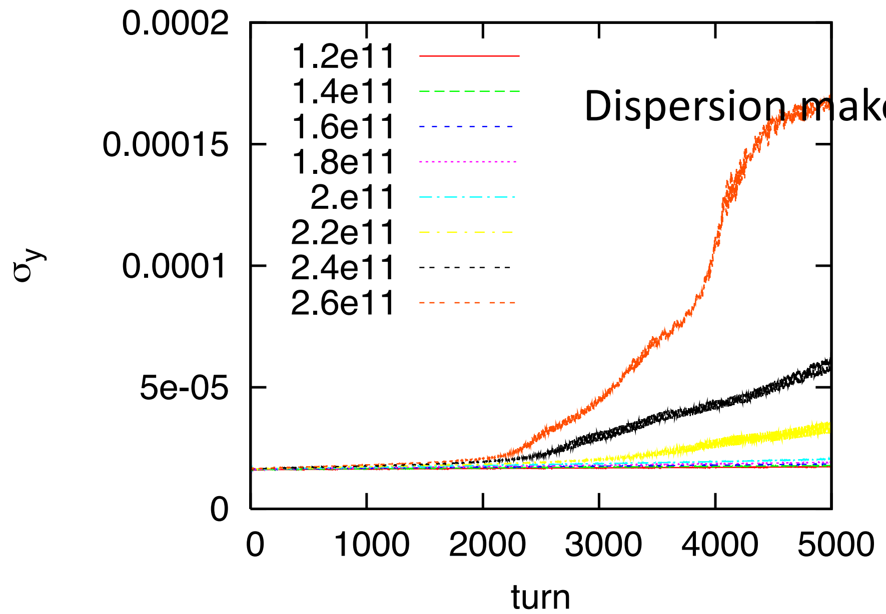
- R1, R2, which are related to y not p_y, are hard to measure.

Monitor and feedback

- BPM with the diameter of 6mm. Three types of readout, turn by turn (500MHz), orbit feedback and IP feedback (5kHz).
- Bunch by bunch feedback using iGP. Damping time is 0.4/0.7ms for LER/HER in the transverse, and 11.4ms in the longitudinal.
- Gated Tune and IP optics parameter (β, X-Y) measurement using PLL.
- Synchrotron light monitors, visual light, Xray, Bremsstrahlung.

Electron cloud issue

- Threshold of the fast head-tail instability, ρ_e=1-2x10^{11} cm^{-3}.



Dispersion makes to degrade the 1/2 density.

- Ante-chamber, Solenoid, coating and grove. The density is reduced 3-6x10^{10} cm^{-3}. (M. Suetsugu)

Injector

M. Kikuchi

- Requirement for the injection rate

LER: $\Delta N = I/f_{rev}\tau \quad I = 4\text{ A} \quad \tau = 400\text{sec} \longrightarrow \Delta N = 100\text{ nC/sec}$

4 nC/pulse @25Hz

HER: $2.5\text{ nC/pulse @25Hz}$

- Damping ring for LER injection,

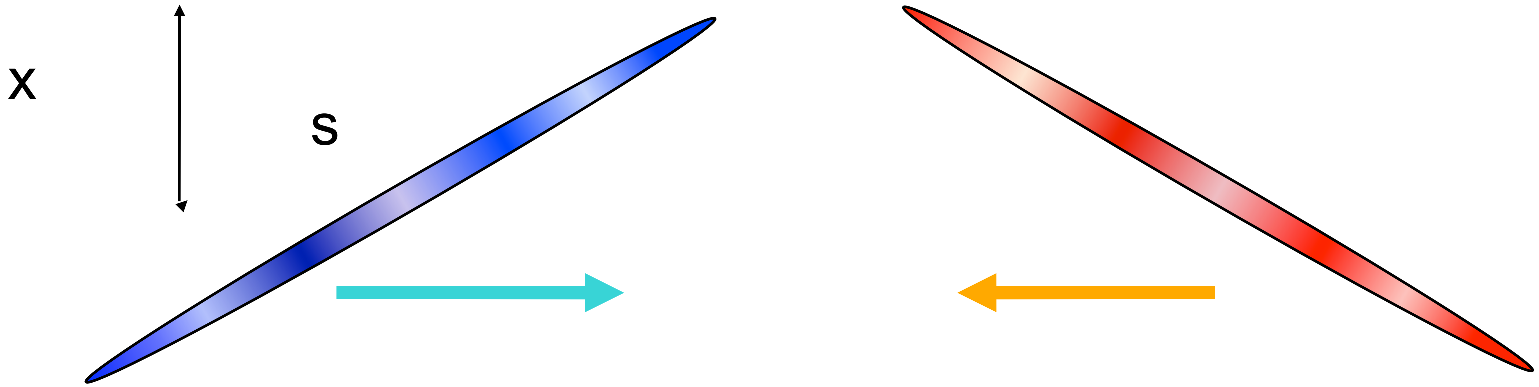
$$\gamma\varepsilon = 4.2 \times 10^{-3}\text{m} \Rightarrow 2.6 \times 10^{-5}\text{m}$$

- Development of Photo-cathode RF Gun.

ATF type Gun can be used.

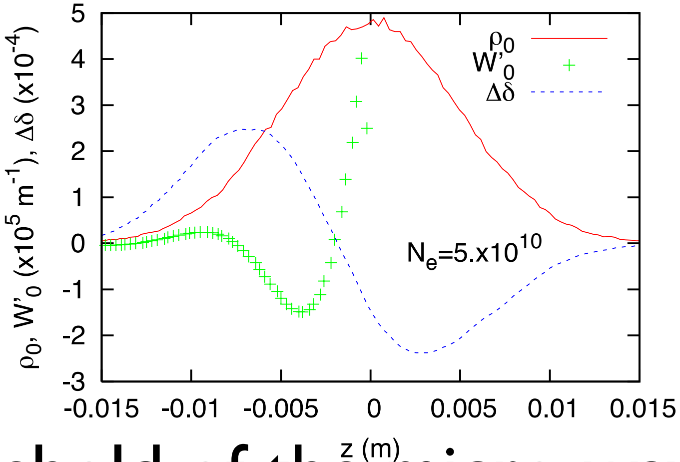
Microwave instability in Nano beam Collision

- Integrated horizontal beam-beam force along bunch length is Bassetti-Erskine type for tri-Gaussian distribution in x-y-z plane.
- When Micro-wave instability arises, transverse beam-beam force is distorted and fluctuated.

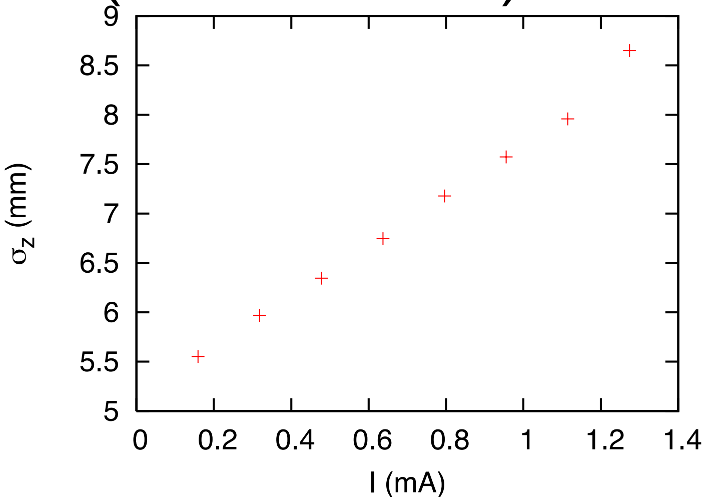


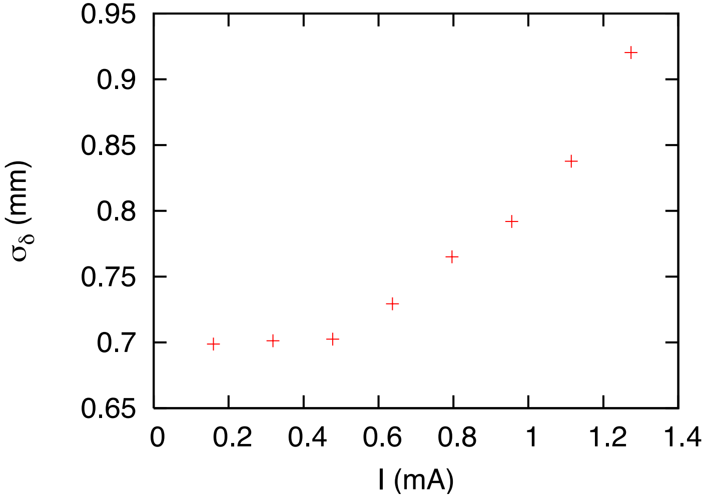
Model wake field

- Low Q resonator model (Y. Cai)



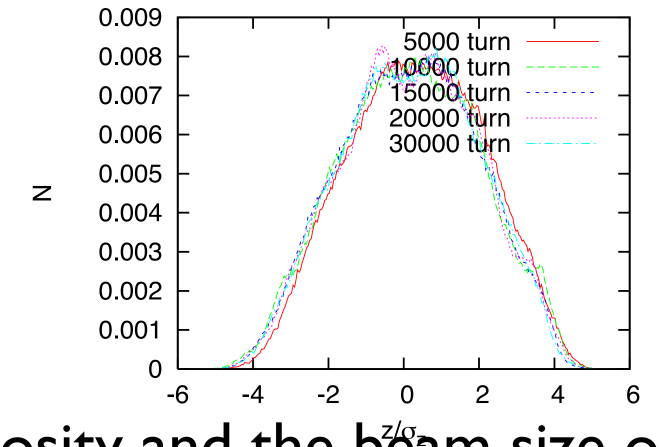
- Threshold of the micro-wave instability is 0.5mA (N_b=3.3x10^{10})





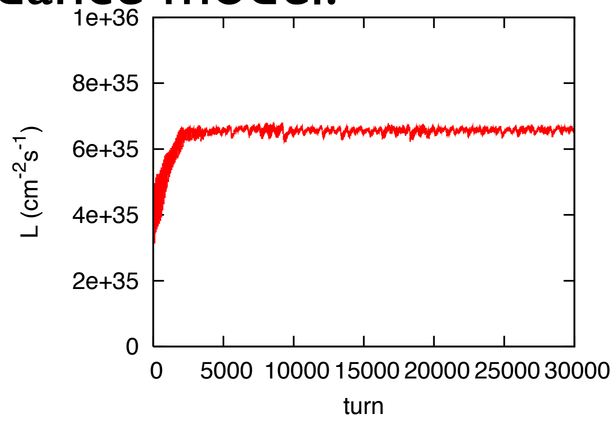
Simulation result of collision under micro-wave instability

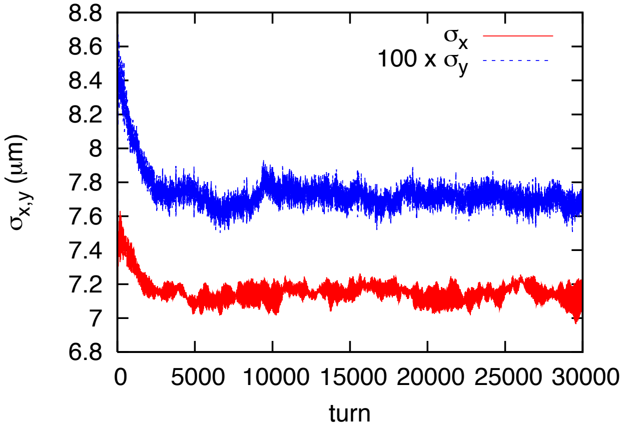
- Longitudinal profile of the strong beam.



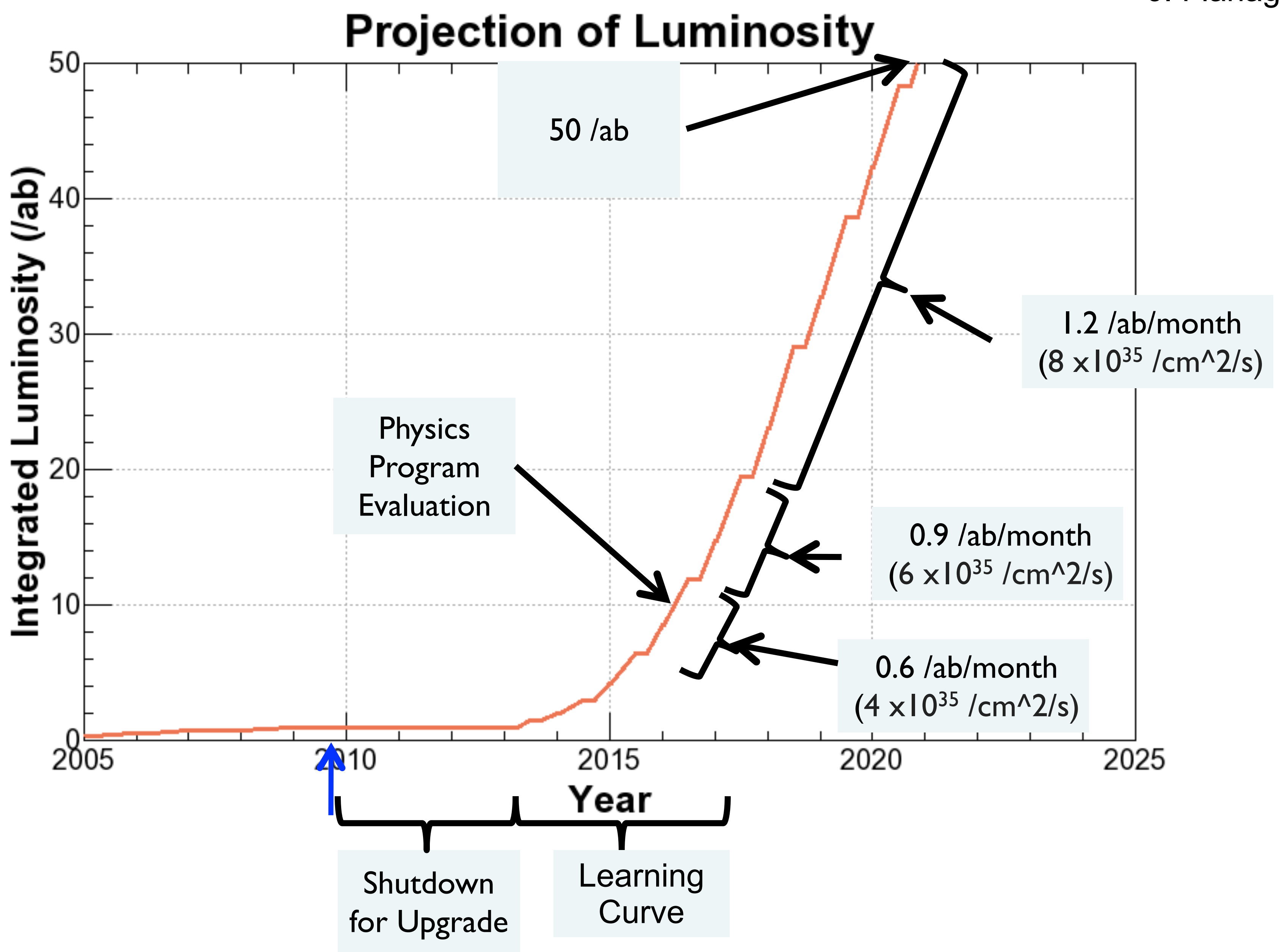
The resonator model is mild for instability.

- Luminosity and the beam size of the weak beam. No remarkable effect except for the bunch lengthening in this impedance model.





J. Flanagan



Projection of Luminosity
Integrated Luminosity (/ab)
Year
0
10
20
30
40
50
2005
2010
2015
2020
2025
50 /ab
1.2 /ab/month
(8 x10^35 /cm^2/s)
0.9 /ab/month
(6 x10^35 /cm^2/s)
0.6 /ab/month
(4 x10^35 /cm^2/s)
Physics Program Evaluation
Shutdown for Upgrade
Learning Curve

Cost

	Oku yen (~M$)
Linac and damping ring	31
Vacuum	135
Magnets	93
IR	20
RF system	25
Monitor, control	32
Belle detector	14.7
Summation	350.7

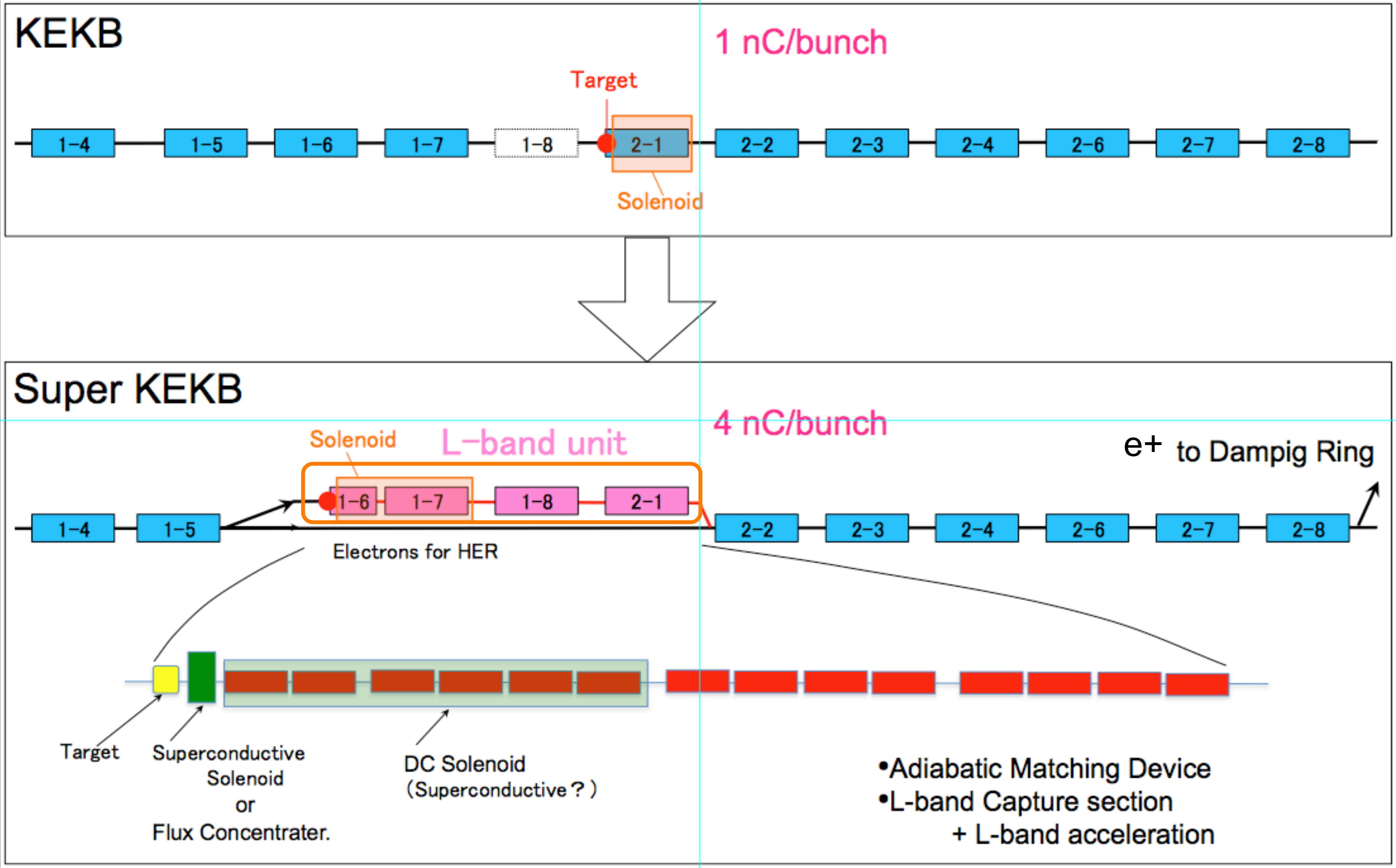
Summary

- Optics design is going. First design has finished without crab waist.
- Optics study with Crab waist sextupole is begun in 2010 with the help of E. Levichev and P. Piminov.
- Wide momentum aperture is required to get enough Touschek life time.

- Fine tuning of IP parameters is necessary.
- Strong-strong code with the shifted Green function is under construction.

Linac upgrade for the positron generation

M. Kikuchi

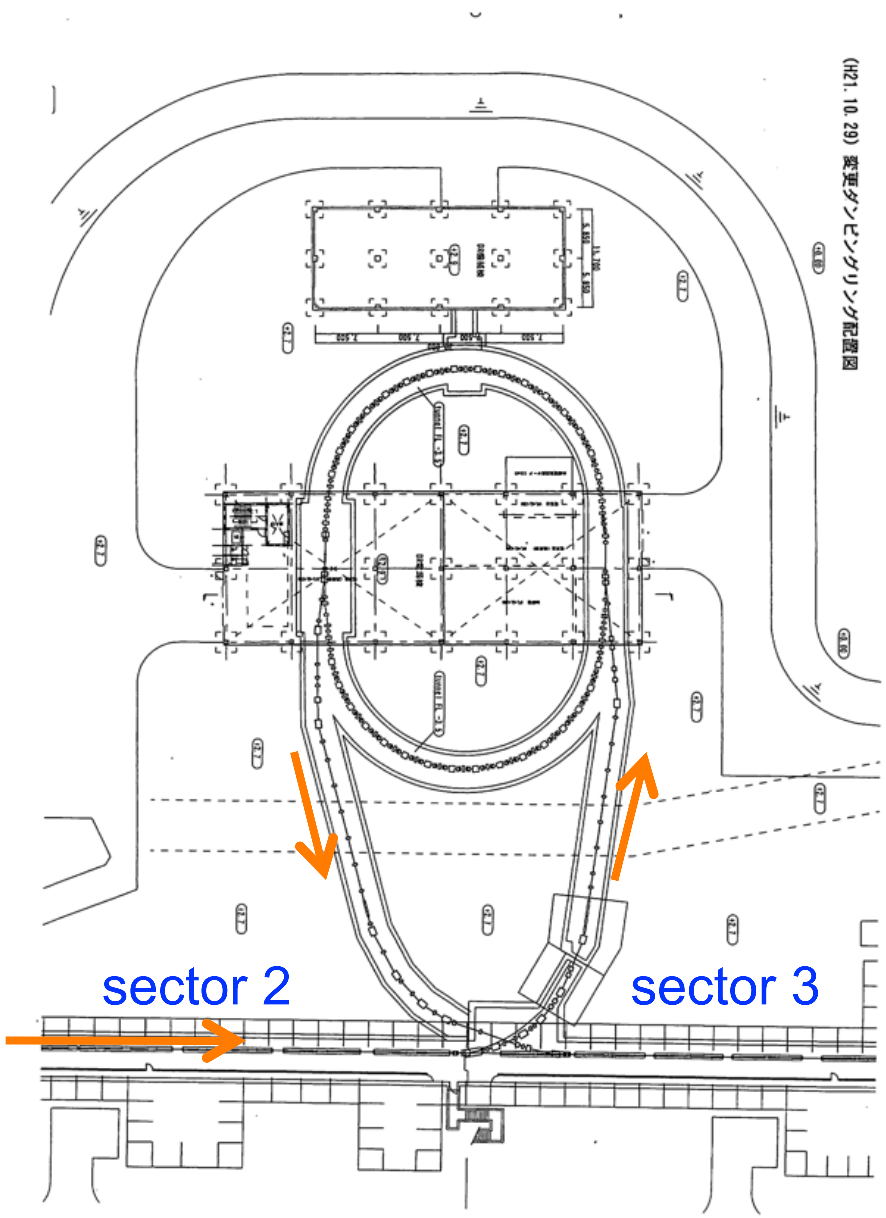


Damping ring for e+

M. Kikuchi

Parameters

- Circumference: 135 m
- Energy: 1 GeV
- Maximum current 71 mA
- Cavity voltage 0.26 MV
- RF frequency 509 MHz



Electron gun

KEK ATF RF gun（Urakawa）

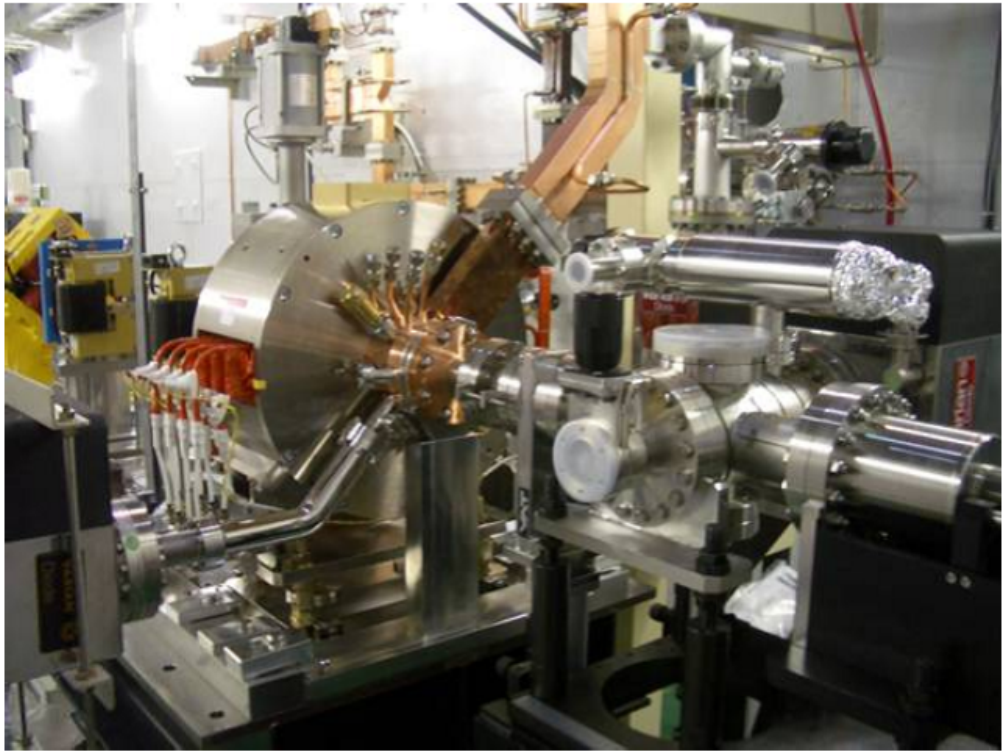


図 2.20: テストベンチビームライン全景

最大ビームエネルギー	7MeV
最大電荷量	5nC/bunch
バンチ数	100
繰り返し	12.5Hz
運転周波数	2856MHz
モードロックレーザー周波数	357MHz
バンチ間隔	2.8ns
フォトカソード	CsTe
量子効率（目標）	>3 %
レーザーエネルギー（目標）	>3 μ J/bunch
レーザー波長	266nm
レーザーパルス長 (FWHM)	10ps
高周波パルス幅	2.05μs
高周波空洞入力電力	15.7MW
ソレノイド電磁石最大磁場	3.2kGauss
シケイン部矩形電磁石最大磁場	500Gauss

表 2.1: テストベンチの主な最大定格値

山崎良雄　博士論文（2006）

Electron gun

	Specifications	SCSS	ATF	LCLS
Charge (nC/bunch)	5 nC	1 nC	1~5 nC	1 nC
Bunch/pulse	2	1	1~100	1
Pulse /second	50 Hz	10 Hz	12.5 Hz	120 Hz
Emittance (mm mrad)	20	< 3	<10	1
Laser	-	-	~10μJ/bunch 266nm	~2mJ/pulse 253nm
Q.E.	-	-	0.5%~数% Cs_2Te	$5x10^{-5}$ Cu

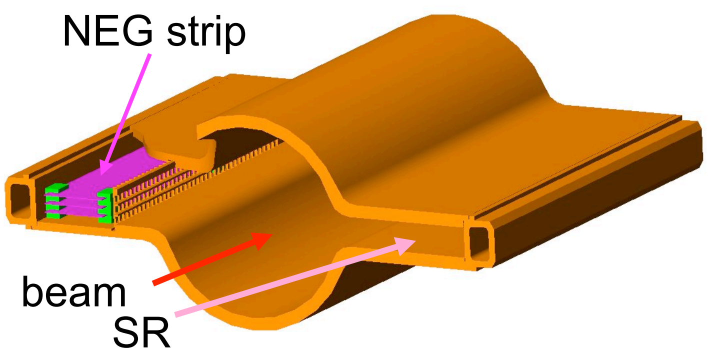
Photocathode RF gun will be developed.

Y. Suetsugu

Beam duct

- LER
  - Beam duct with ante-chamber
    - SR power was reduced since bending radius for LER was increased.
    - Alminum can be used as duct material in arc sections instead of cooper (?) (It can reduce costs)
    - In wiggler section, copper duct must be used.
  - Distributed NEG pump
    - Low beam impeadance
  - To suppress electron cloud
    - Ante-chamber
    - TiN coating
    - grooved surface
    - Clearing electrode
- HER
  - Copper beam duct

Concept



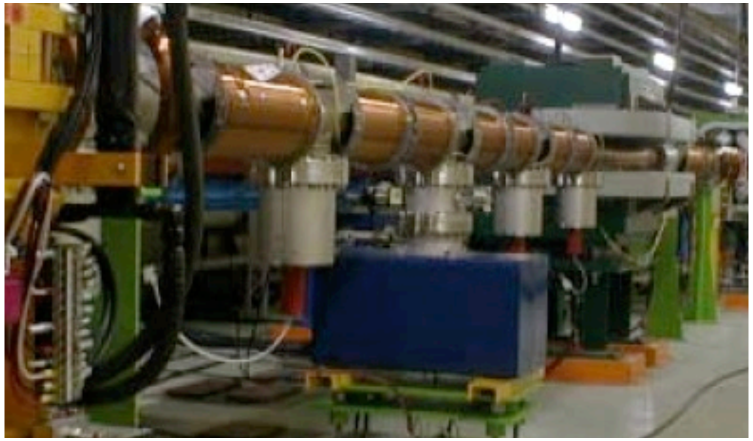
>2000 beam ducts must be fabricated and installed only in only ∼3 yrs.
It would be very tight schedule.

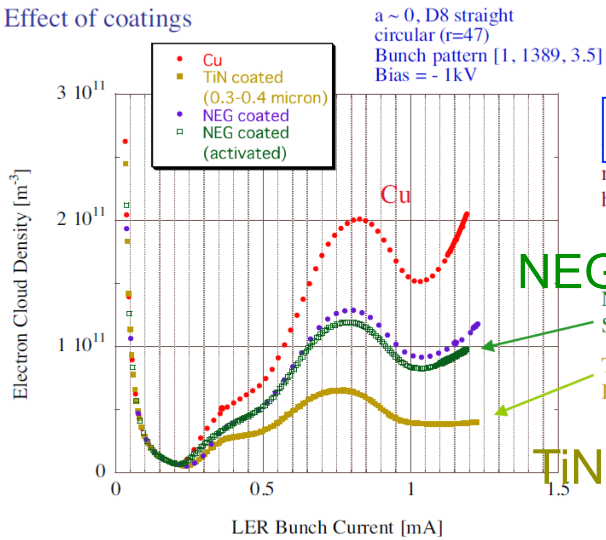
Y. Suetsugu

R&D to suppress electron cloud

- Cures for electron cloud instability
  - Issues for positron ring
- Established cures
  - Drift section: ～50 Gauss solenoid fields (measured and used at KEKB)
  - Ante-chamber (PEP-II)
  - TiN-coating

Solenoid





Measured e- density

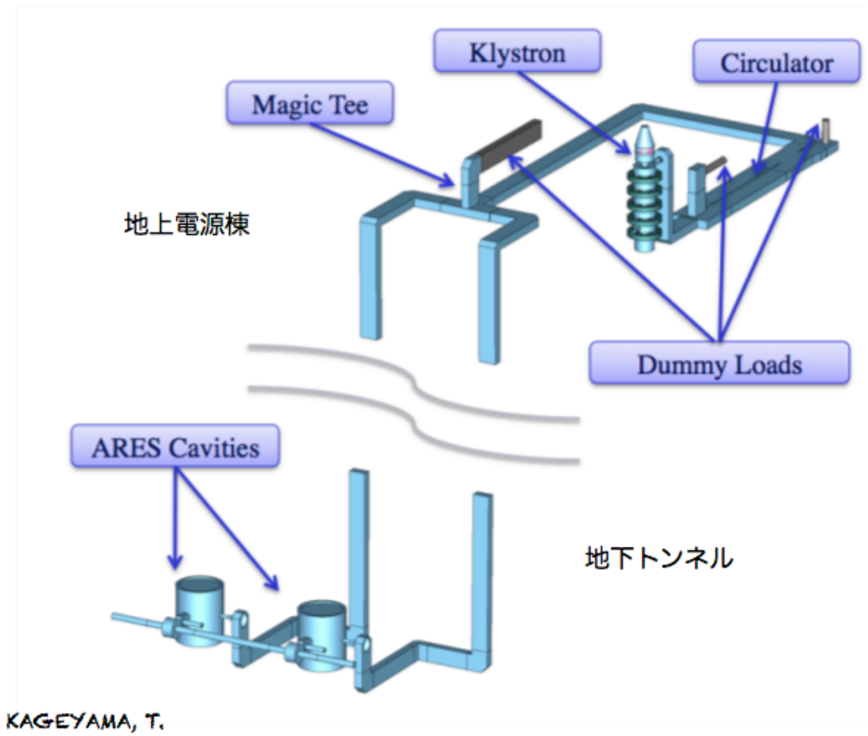
K. Kanazawa

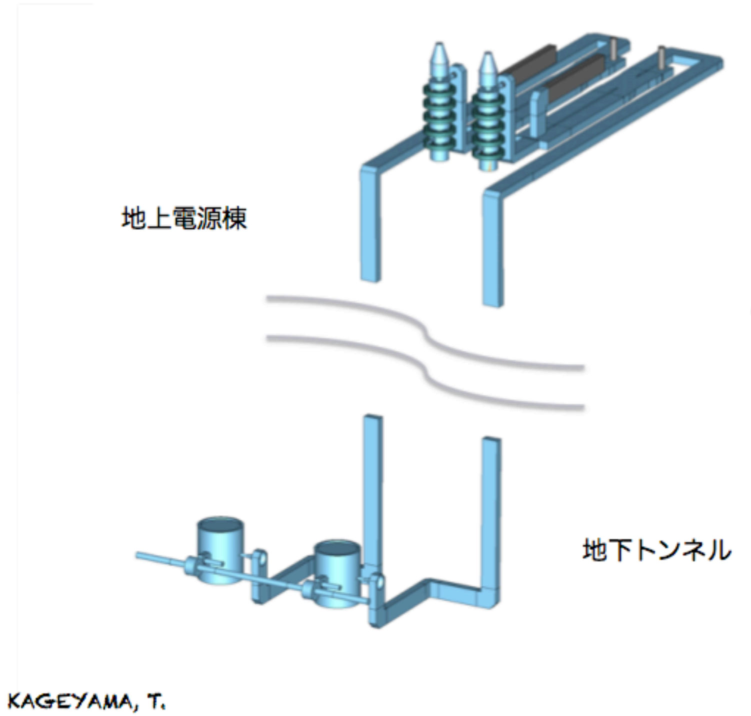
NEG coating

TiN coating

RF systems

T. Kageyama





KEKB
1:2

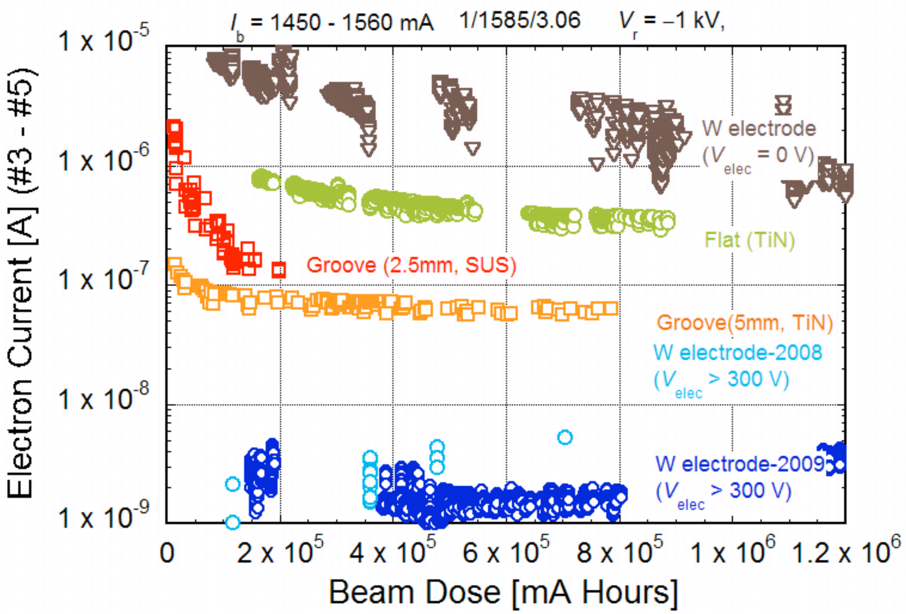
SuperKEKB
1:1

Input power will be twice (400 → 800 kW)

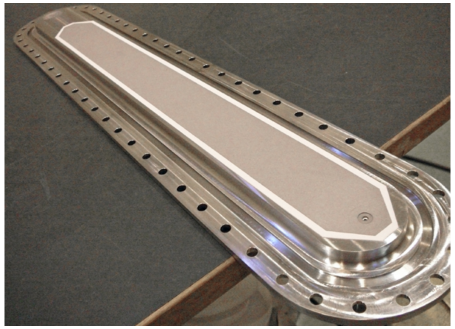
R&D to suppress electron cloud

Y. Suetsugu

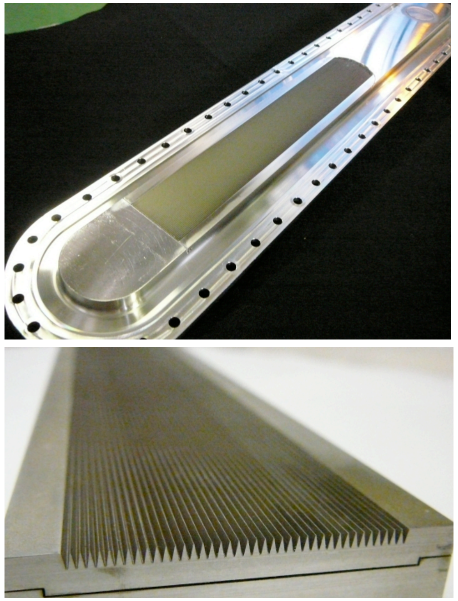
- Clearing electrode
  - Apply bias voltage
  - Measured electron density is 1/100 smaller than that for TiN-coating surface.
- Grooved surface
  - Reduce SEY, small impedance
  - Measured electron density is 1/10 smaller than that for TiN-coating surface



Electrode



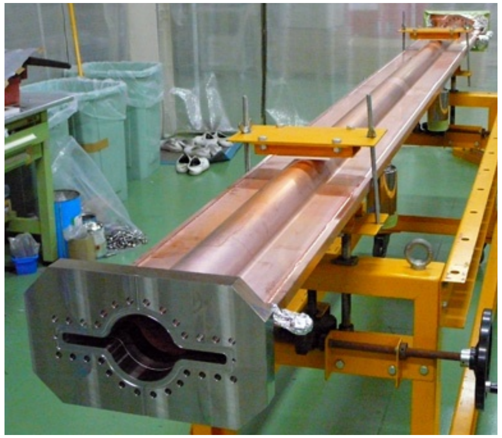
Groove



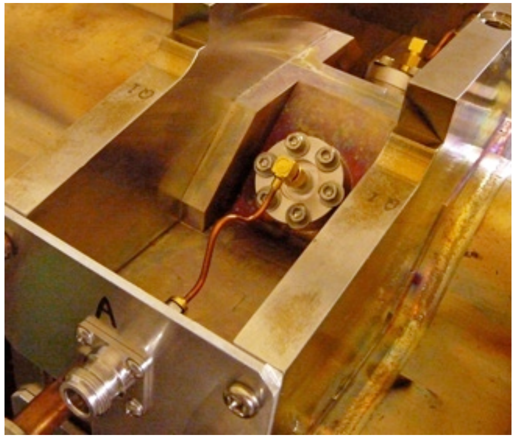
Developed vacuum components

Y. Suetsugu

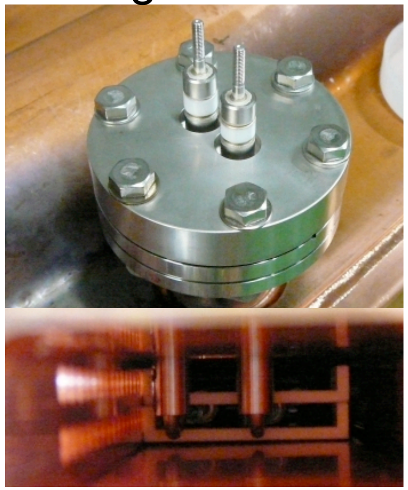
Straight duct



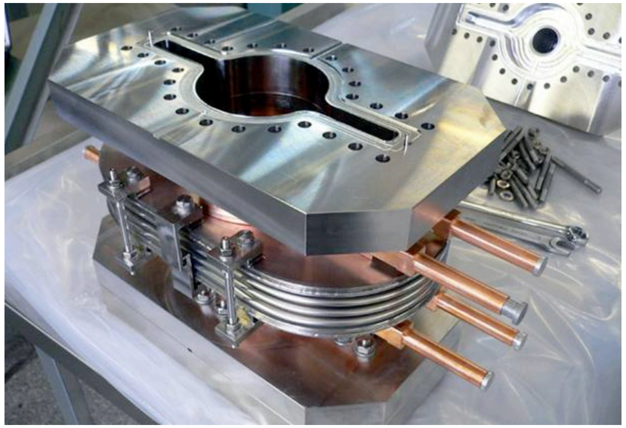
BPM



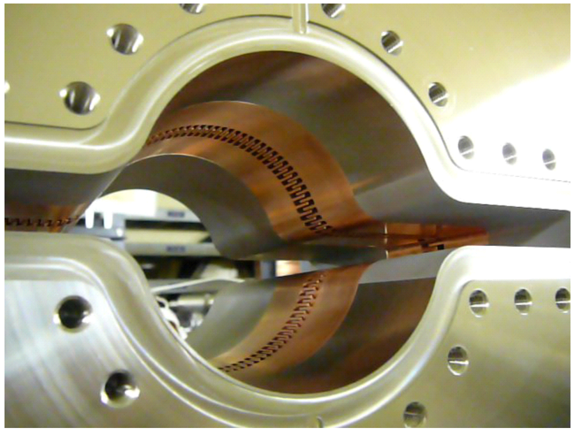
Feed through for NEG



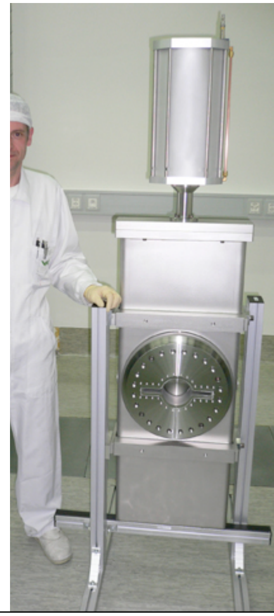
Bellows chamber



RF-shield (gate valve)



Gate valve



Transfer matrix in Solenoid magnet

$$x' = p_x - by/2 \qquad y' = p_y + bx/2 \qquad b = eB_s/p_0$$

- Transfer matrix for (x,p_x,y,p_y)

$$M_{sol} = \begin{pmatrix} \frac{1+\cos bs}{2} & \frac{\sin bs}{b} & -\frac{\sin bs}{2} & -\frac{1-\cos bs}{b} \\ -\frac{b\sin bs}{4} & \frac{1+\cos bs}{2} & \frac{b(1-\cos bs)}{4} & -\frac{\sin bs}{2} \\ \frac{\sin bs}{2} & \frac{1-\cos bs}{b} & \frac{1+\cos bs}{2} & \frac{\sin bs}{b} \\ -\frac{b(1-\cos bs)}{4} & \frac{\sin bs}{2} & -\frac{b\sin bs}{4} & \frac{1+\cos bs}{2} \end{pmatrix}$$

Beam-beam simulation in solenoid magnet

- Slice-particle collision in weak-strong simulation.
- Transfer collision point of slice-particle, s=(z-z_{sl})/2, then collision and return to s=0.

$$
\begin{aligned}
\bar{p}_x &= \frac{1}{1+b^2s^2}\left(-\frac{b^2s}{4}x + p_x + \frac{b^3s^2}{8}y - \frac{bs}{2}p_y\right) \\
\bar{p}_y &= \frac{bs}{2} + \bar{p}_y - \frac{b^2s}{4}y = \frac{1}{1+b^2s^2}\left(-\frac{b^3s^2}{8}x + \frac{bs}{2}p_x - \frac{b^2s}{4}y + p_y\right) \\
\bar{x} &= x + \bar{p}_x s - \frac{bs}{2}y \\
\bar{y} &= y + \bar{p}_y s + \frac{bs}{2}x \\
\bar{\delta} &= \delta - \frac{(\bar{p}_x - by/2)^2 + (\bar{p}_y + bx/2)^2}{4}
\end{aligned}
$$

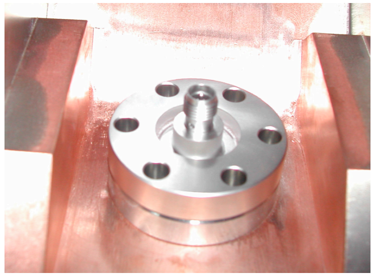
- There are no difference in simulation result with/without solenoid.

Solenoid gives x-y coupling dependent on z

$$R = D^{-1} M_{sol} \approx \begin{pmatrix} 1 & 0 & -bs/2 & -b^2s^2/4 \\ 0 & 1 & b^3s^2/8 & -bs/2 \\ bs/2 & b^2s^2/4 & 1 & 0 \\ -b^3s^2/8 & bs/2 & 0 & 1 \end{pmatrix}$$

- R1=R4~bs/2~0.001 for b=0.124 and s=0.015. R2, R3~0.
- R1は1unit位、R4は小さい。シミュレーションでも効果は見えない。

Instrumentation upgrade



1. Beam position monitor (BPM)

•A button of a diameter of 6 mm was developed in order to reduce the signal power at the button electrode and is being tested by beam.

•Three types of a detector are being developed.

(1)A narrowband detector is similar to that of KEKB, but the detection frequency is 500MHz taking into account of low cut-off frequency of an ante-chamber.

(2) A medium-band detector will be used for the feedback system of orbit stabilization. It will also has a capability to measure turn by turn position of beam for the optics measurement during physics run.

(3)A special detector aiming at the resolution of 0.5 micron and the repetition rate of 5kHz will be used for collision feedback.

Final specification for the BPM system will be determined after the requirements of beam optics are fixed.

2. Bunch feedback system

iGp

•Transverse feedback system will use two kickers in each ring to get shorter damping time (0.4/0.7ms in LER/HER) than that of KEKB.

•Longitudinal feedback system will use two DAFNE type kickers per ring. Expected damping times is 11.4 ms for LER.

•Digital filter (iGp) which was developed at INFN, KEK and SLAC will be used for both systems.

H. Fukuma

H. Fukuma

3. Synchrotron radiation monitor

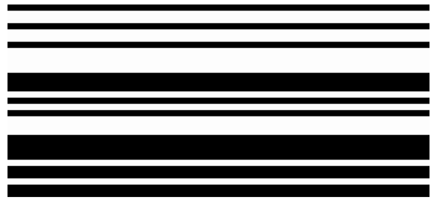
A. Visible light monitor

•A bending radius of a light source bend in LER will be doubled to reduce the heat load in a extraction mirror to a level of KEKB. A resolution of size measurement is marginal in HER.

B. X ray monitor

•Purpose of the monitor is to provide high-resolution bunch-by-bunch measurement capability, with low beam current dependence.

•In collaboration with Cornell U. and U. Hawaii we are investigating and developing an x-ray monitor system featuring coded aperture imaging and STRUM high-speed readout.



Uniformly Redundant Array (URA) mask

C. Beamstrahlung Monitor

•The monitor was developed by G. Bonvicini (Belle, Wayne State U.) originally for use at CESR. It uses relative strengths of x- and y-polarization of wide-angle beamstrahlung to diagnose quality of collision, e.g. beam separation and beam size.

•Monitor and Vacuum groups are assisting Prof. Bonvicini with design of system for use at the upgraded KEKB.

4. Gated Measurement for Bunch-Tune, -Orbit and -Phase

•A fast gate module is being developed for a fast gate to measure the tune, orbit and longitudinal phase of each bunch separated by 2ns. Beam test shows good separation of BPM signal by the gate.