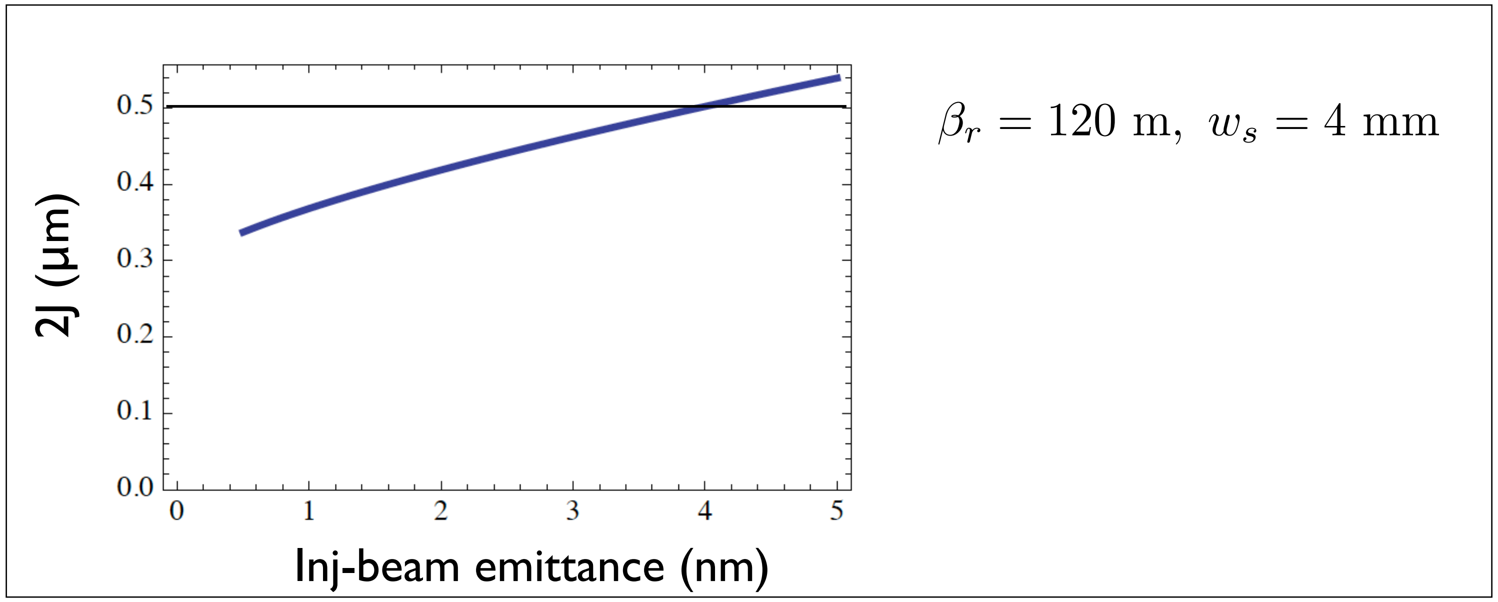
Design of Damping Ring

Kikuchi, M., MAC2010, 16Feb'10

Requirements

a) Injection aperture of LER

$$2J = 0.5\ \mu\text{m}$$



$\beta_r = 120\ \text{m},\ w_s = 4\ \text{mm}$

- Emittance of Injected beam

$$\epsilon_i \lesssim 4\ \text{nm}$$

b) Lifetime of LER

$$\tau \lesssim 600\ \text{sec}$$

- Intensity of Injected beam

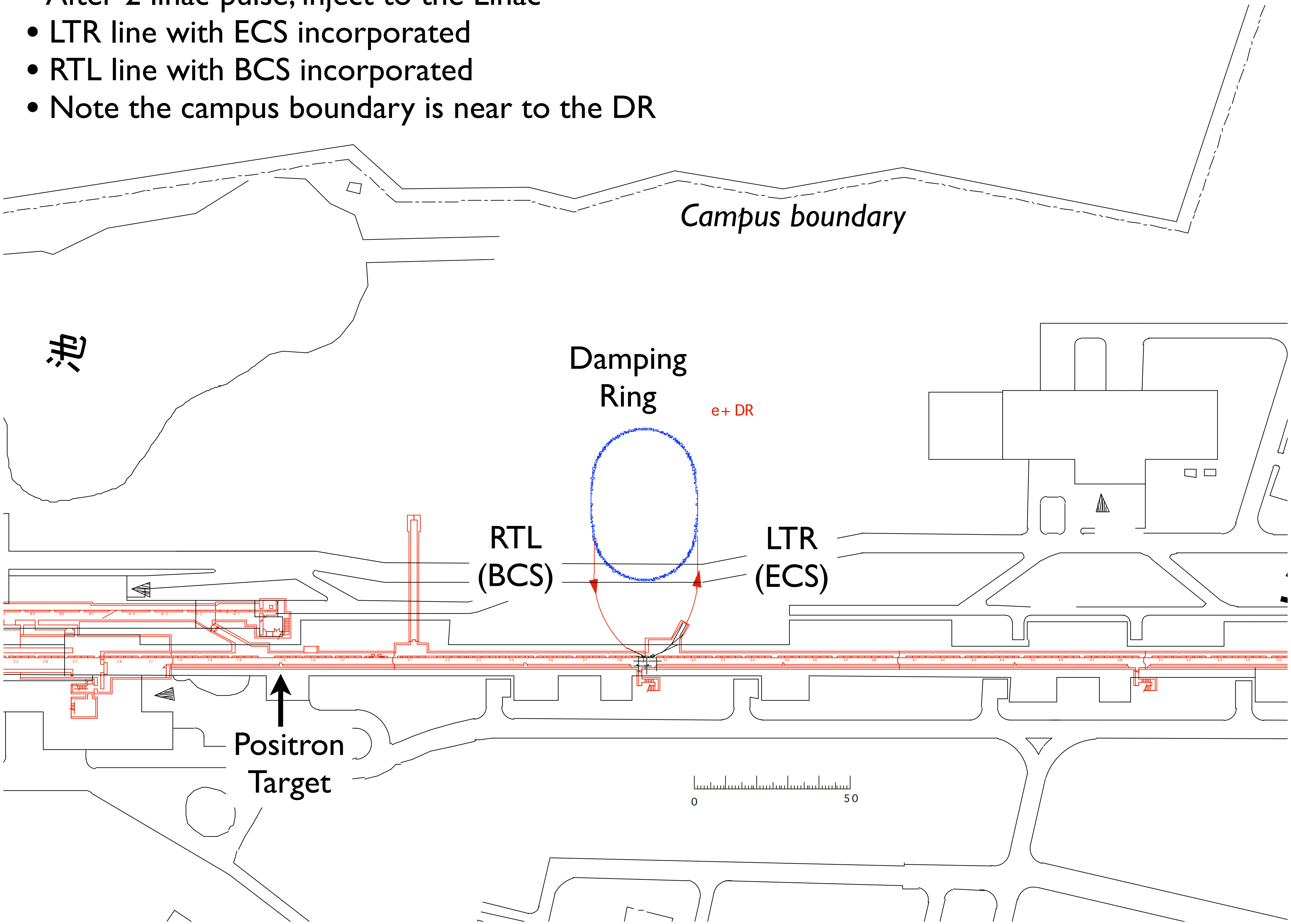
$$q \simeq 8\ \text{nC/pulse}$$

The Damping Ring has

- to accept high intensity beams with high emittance
- to reduce the emittance down to 16 nm (at 1GeV)

Layout of the System

- Positron target at sector1-5
- Capture + acceleration with L-band
- Extract from Linac at 1GeV
- After 2 linac-pulse, inject to the Linac
- LTR line with ECS incorporated
- RTL line with BCS incorporated
- Note the campus boundary is near to the DR



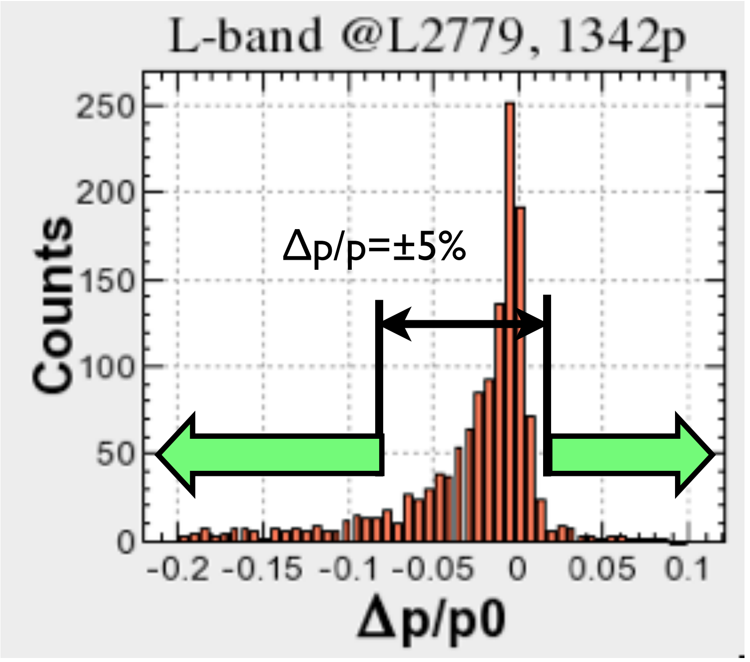
Beam Parameters

Parameters of the injected beam

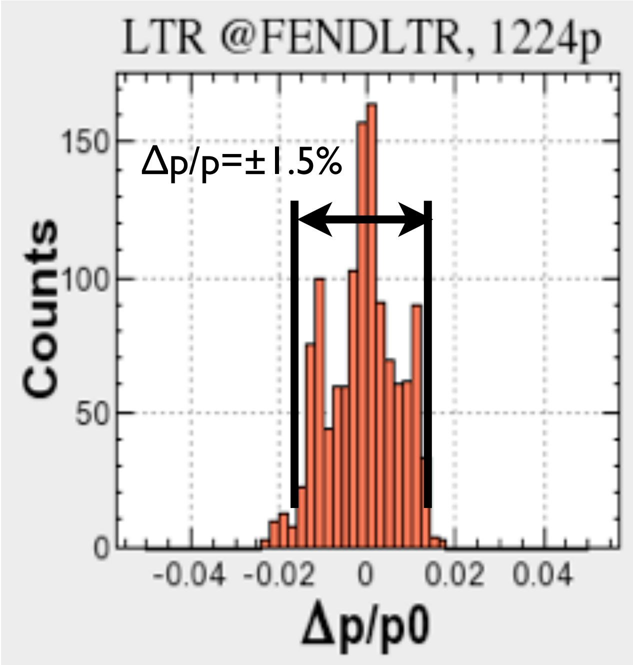
	before ECS	after ECS
Energy (GeV)	1.0	
Repetition frequency (Hz)	50	
Emittance (μm)	2.1	
Energy spread *) (%)	± 5	± 1.5
Bunch length *) (mm)	± 8.7	± 28.2
Number of bunches per pulse	2	
Bunch spacing (ns)	98	
Bunch charge (nC)	8	

*) Full width

before ECS



after ECS



truncate the beam by ~20 % at
the entrance of LTR

Beam Parameters 2

Parameters of the Damping Ring

Energy		1.0		GeV
Number of bunch trains		2		
Number of bunches/train		2		
Maximum stored current*		70.8		mA
Energy loss per turn		0.0714		MV
Horizontal damping time		12.66		ms
Injected-beam emittance		2100		nm
Stored current	0	35.4	70.8	mA
Equilibrium emittance	11.7	13.0	14.0	nm
Coupling		10		%
Emittance at extraction(hor.)	15.3	16.6	17.6	nm
Emittance at extraction(ver.)	4.8	5.0	5.1	nm
Energy band-width of injected beam		± 1.5		%
Energy spread	0.0526	0.0535	0.0542	%
Bunch length	5.2	5.3	5.4	mm
Momentum compaction factor		0.00191		
Number of normal cells		32		
Cavity voltage for 1.5 % bucket-height		0.257		MV
RF frequency		509		MHz
Inner diameter of chamber		32		mm
Bore diameter of magnets		44		mm

* 8 nC/bunch

- We take
  8 nC/bunch (16 nC/pulse)
  as a design value of maximum intensity

Magnetic parameters

	No.	Field		Length	
Bend B1	32	1.267	T	0.729	m
B2	38			0.255	m
B3	6			0.355	m
B4	2			0.392	m
Quad	84	16.4	T/m	0.25	m
Sext	74	427	T/m^2	0.1	m

Lattice Design

a) Normal Cell

FODO with Reverse bend

- easy to get low momentum compaction
- shorter damping time
- large dynamic aperture
- ◆ not very small emittance

b) Dispersion Suppressor

- 4 free quads + 2 “half” bends

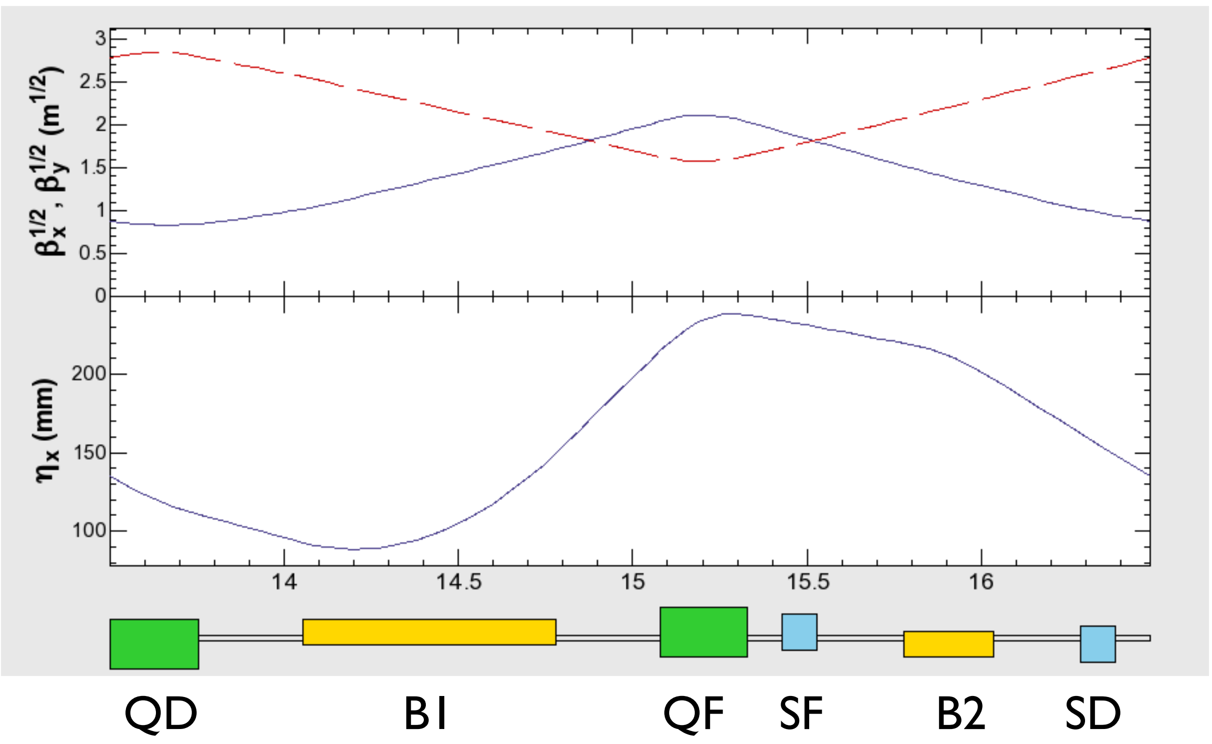
c) Straight

- 4 free quads
- For RF and Injection/extraction
- Large aperture (inner dia. Φ40 mm)

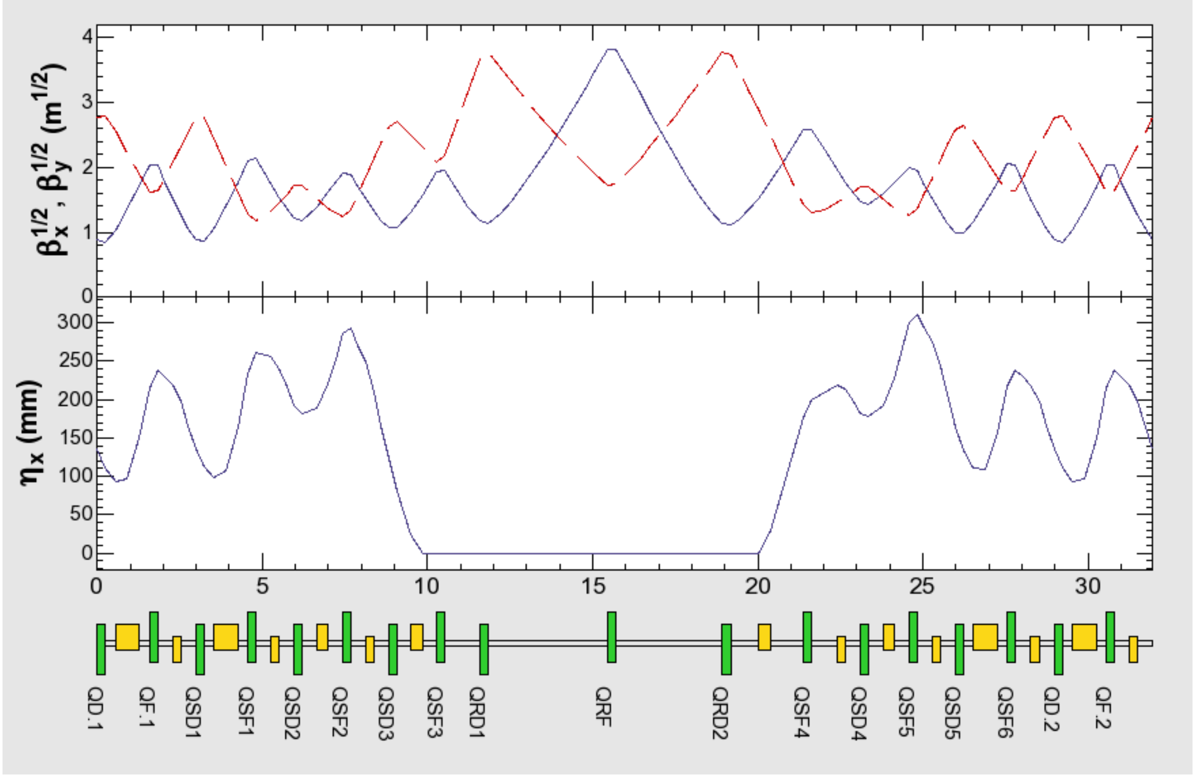
d) Chromaticity correction

- 9 family sextupoles

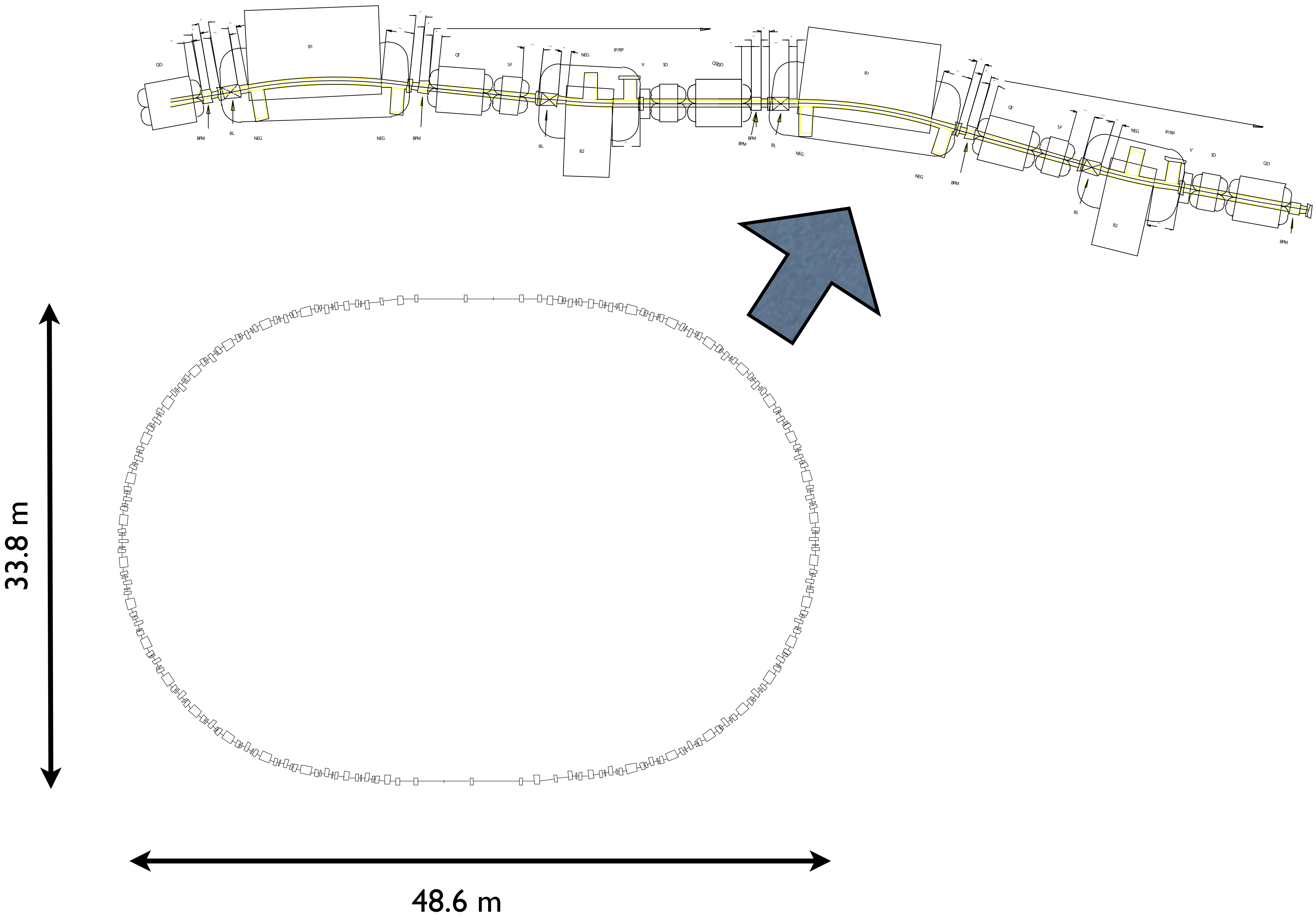
Normal cell



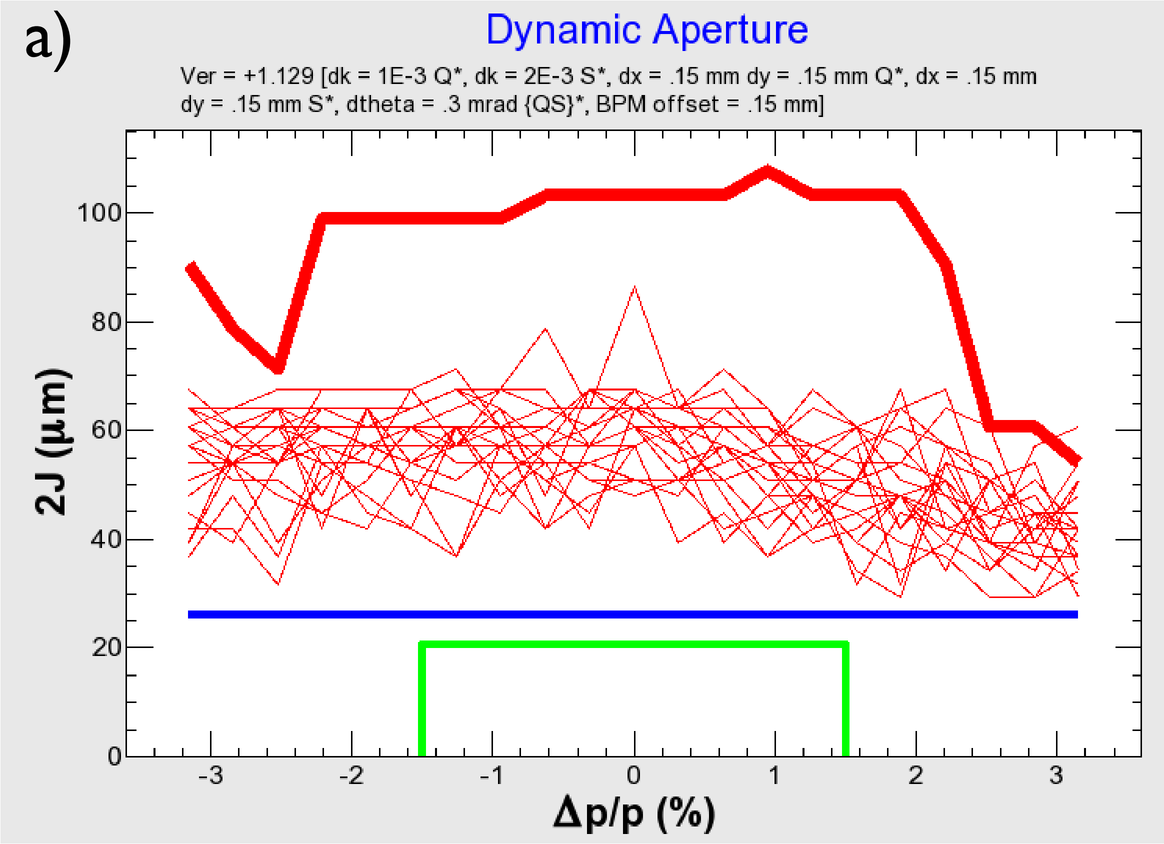
Dispersion suppressor and straight



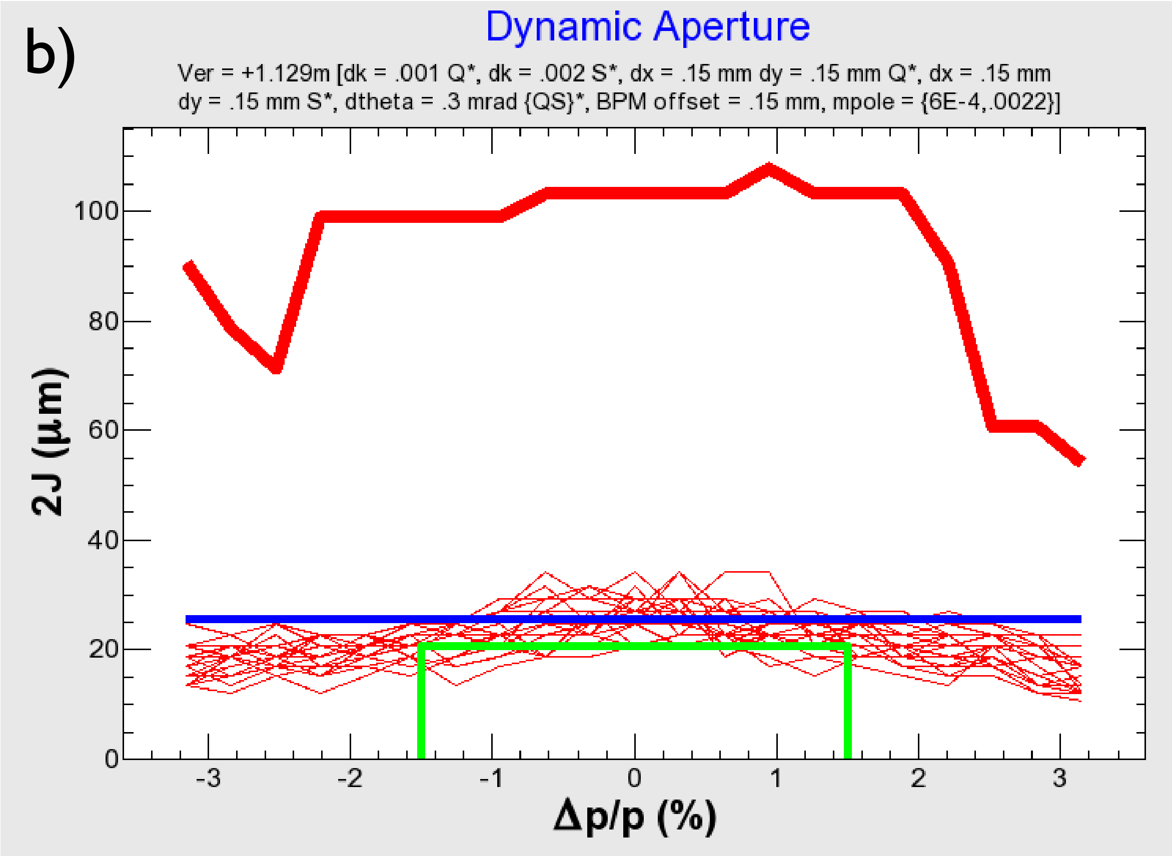
Beam line is occupied with magnets



Dynamic Aperture



- Thick **red** line: No machine errors
- Thin red lines: With machine errors(20 seeds)
  - strength error for quads 1e-3
  - strength error for sexts 2e-3
  - misalignments for quads/sexts 0.15 mm
  - rotation errors for quads/sexts 0.3 mrad
  - BPM offsets 0.15 mm
- Blue line: Physical aperture
- Green line: Injected beam
  - 2J = 3-sigma of injected beam emittance with 10% margin



- a) + Systematic high order multipoles

Allowed-order multipoles

				$\Delta B/B$ at 22 mm
dipole	K_2/K_0	2.48	m^{-2}	6×10^{-4}
	K_4/K_0	2.31×10^5	m^{-4}	2.3×10^{-3}
quadrupole	K_5/K_1	3.07×10^5	m^{-4}	6×10^{-4}
	K_9/K_1	1.49×10^{16}	m^{-8}	2.3×10^{-3}
sextupole	K_8/K_2	1.07×10^{11}	m^{-6}	6×10^{-4}
	K_{14}/K_2	7.63×10^{27}	m^{-12}	2.3×10^{-3}

Dynamic Aperture 2

- Errors in the case a) is tolerable.
- Systematic high-order multipoles has to be much less than those of the case b)
  - ΔB/B errors in KEKB : (0.12 %, 0.45 %) at 50 mm
  - Assumed ΔB/B errors of (0.06 %, 0.23 %) at 22 mm is scaled down from KEKB error in ΔB/B: Actually it means larger multipole field because nth-pole field behaves as r^n.
- Systematic high-order multipoles can be tuned by end-shimming technique(K. Egawa)

Beam loss scenario

- The beam keeps the same level as the Linac, because of groundwater issue as well as cost saving,
- Radiation safety is then an issue.

Strategy: cut tails prior to entering the DR

- Two mask system is prepared in the Linac
  - Longitudinal mask at the entrance of LTR line; 20 % loss is expected
  - Transverse mask in the Linac to cut the emittance tail if necessary
  - Linac tunnel is very tolerant of a beam-loss because of its thick concrete wall

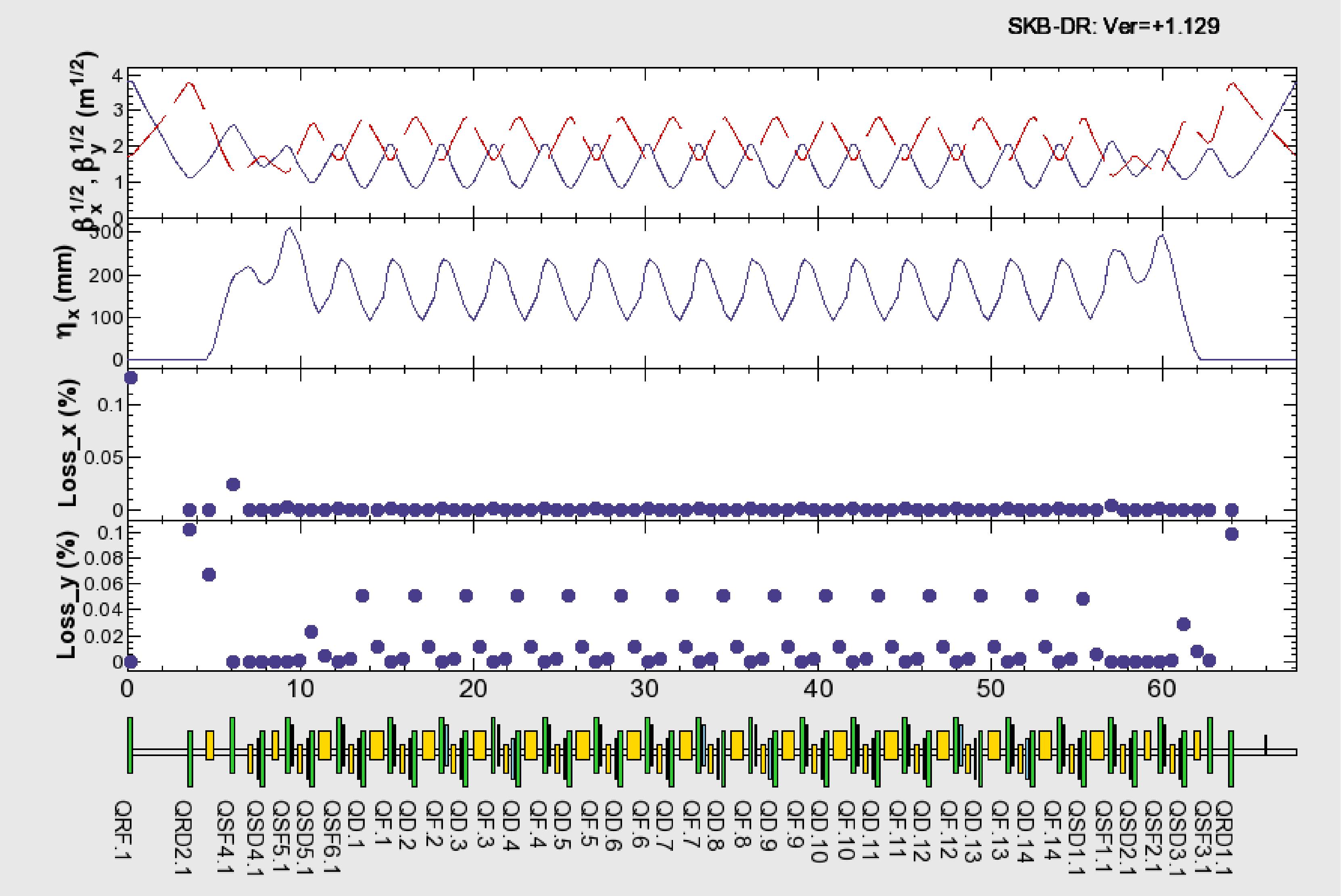
Beam loss in the DR

(1) Physical aperture in capture process (assuming DA > Physical apert.)

- Allow 10% increase of injected emittance for beta-beat and emittance mismatch
- 1 mm for COD and chamber misalignment

BL = 0.15 % (at straight), 0.07 % (at arc)

Beam loss rate



(2) Beam-gas scattering

- Assume physical aperture and momentum acceptance Δp/p=±1.5 %
- Assume P = 1e-5 Pa

BL = 0.1 %

(3) Intra-beam scattering

nC/bunch	Hor. Emittance (nm)	Coupling(%)	Touschek lifetime (sec)
0	11.7		
4	13.0	10	~600
8	14.0	10	~350

$$\frac{1}{\tau} \propto \frac{1}{\sigma_x \sigma_y \sigma_z}$$

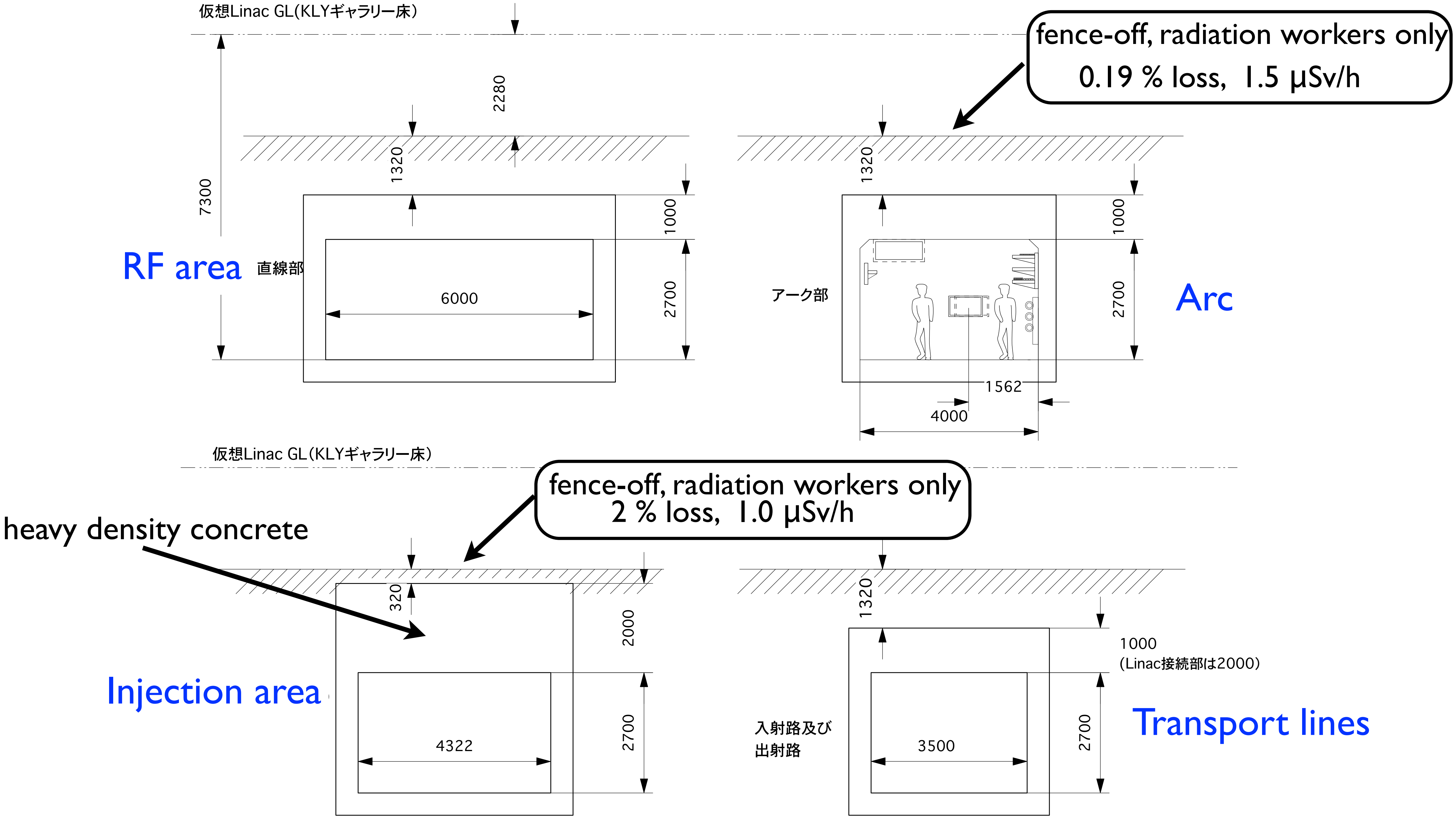
Beam loss occurs just before extraction

For (8 nC/bunch, 10%) case

$$-\frac{\Delta N}{N} = -\int_0^T \frac{1}{N}\frac{dN}{dt}dt = \int_0^T \frac{dt}{\tau(t)} = 2.45 \times 10^{-5}$$

Cross section of the tunnel

8 nC/bunch = 100 %



fence-off, radiation workers only
0.19 % loss, 1.5 μSv/h

fence-off, radiation workers only
2 % loss, 1.0 μSv/h

heavy density concrete

RF area

Arc

Injection area

Transport lines

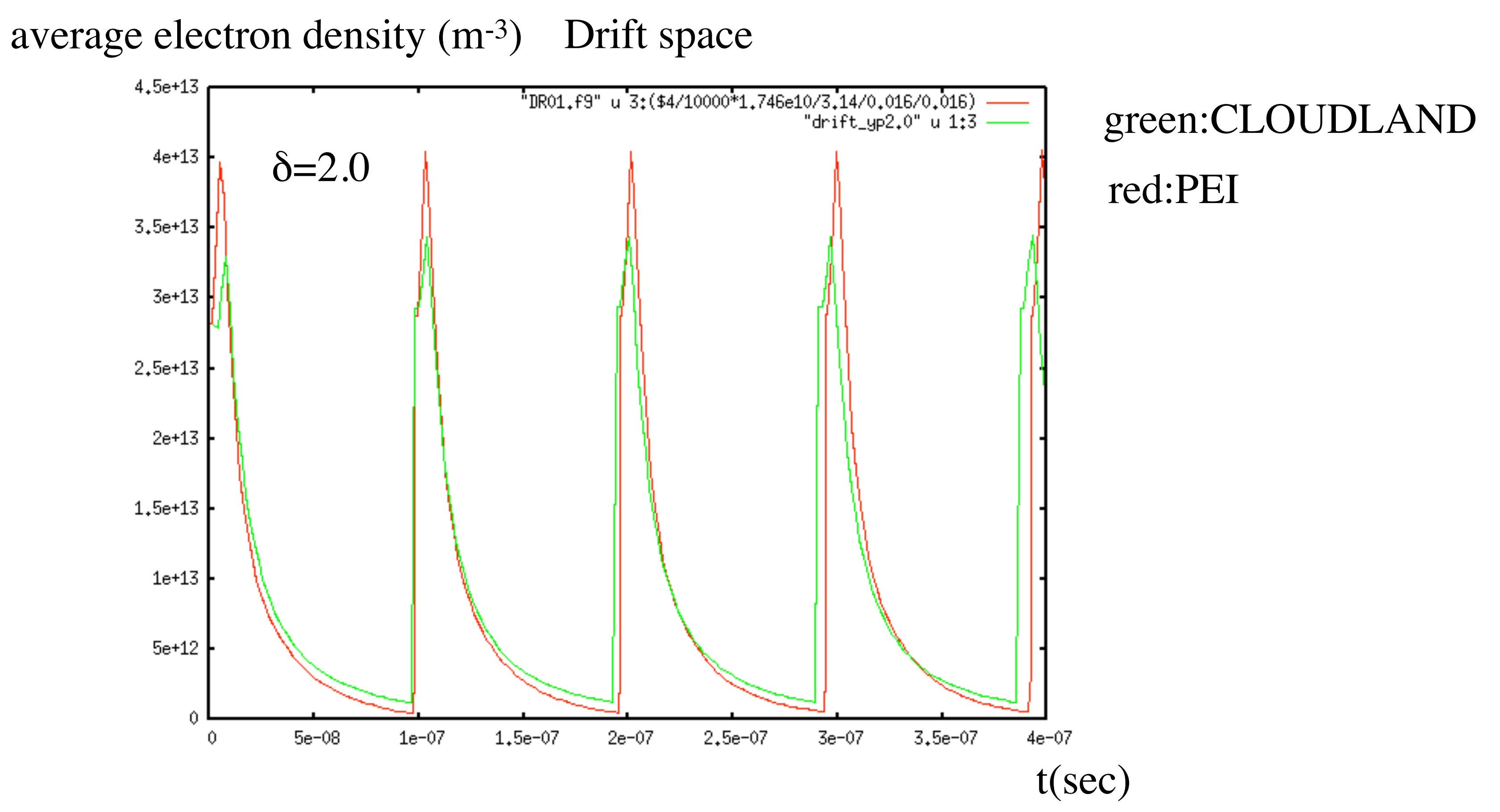
Instability

Electron Cloud Instability

At first sight, not seems an issue because of longer bunch spacing(98 ns) *but....*

- Simulation of cloud formation (8 nC/bunch)

by H. Fukuma



photoelectron line density on a chamber wall : $2.27\ 10^{10}\ m^{-1}$

Instability 2

(CLOUDLAND)

		drift	bend	quad
	length(m)* L	79	36	21
$\delta = 2.0$	central density(m^{-3}) ρ_e	1.3×10^{12}	0.6×10^{12}	0.5×10^{12}
	$\rho_e L$	103×10^{12}	22×10^{12}	11×10^{12}
	$\sum \rho_e L$	1.35×10^{14}		
$\delta = 1.2$	central density(m^{-3}) ρ_e	0.5×10^{12}	0.6×10^{12}	0.4×10^{12}
	$\rho_e L$	40×10^{12}	22×10^{12}	8×10^{12}
	$\sum \rho_e L$	0.7×10^{14}		

* Sextupoles and correctors are counted as "drift".

- Photo electrons are comparable to the theoretical threshold

$$(\rho_e L)_{\mathrm{th}} = 1.57 \times 10^{14}\ \mathrm{m}^{-2}$$

- Tracking simulation (8 nC/bunch)

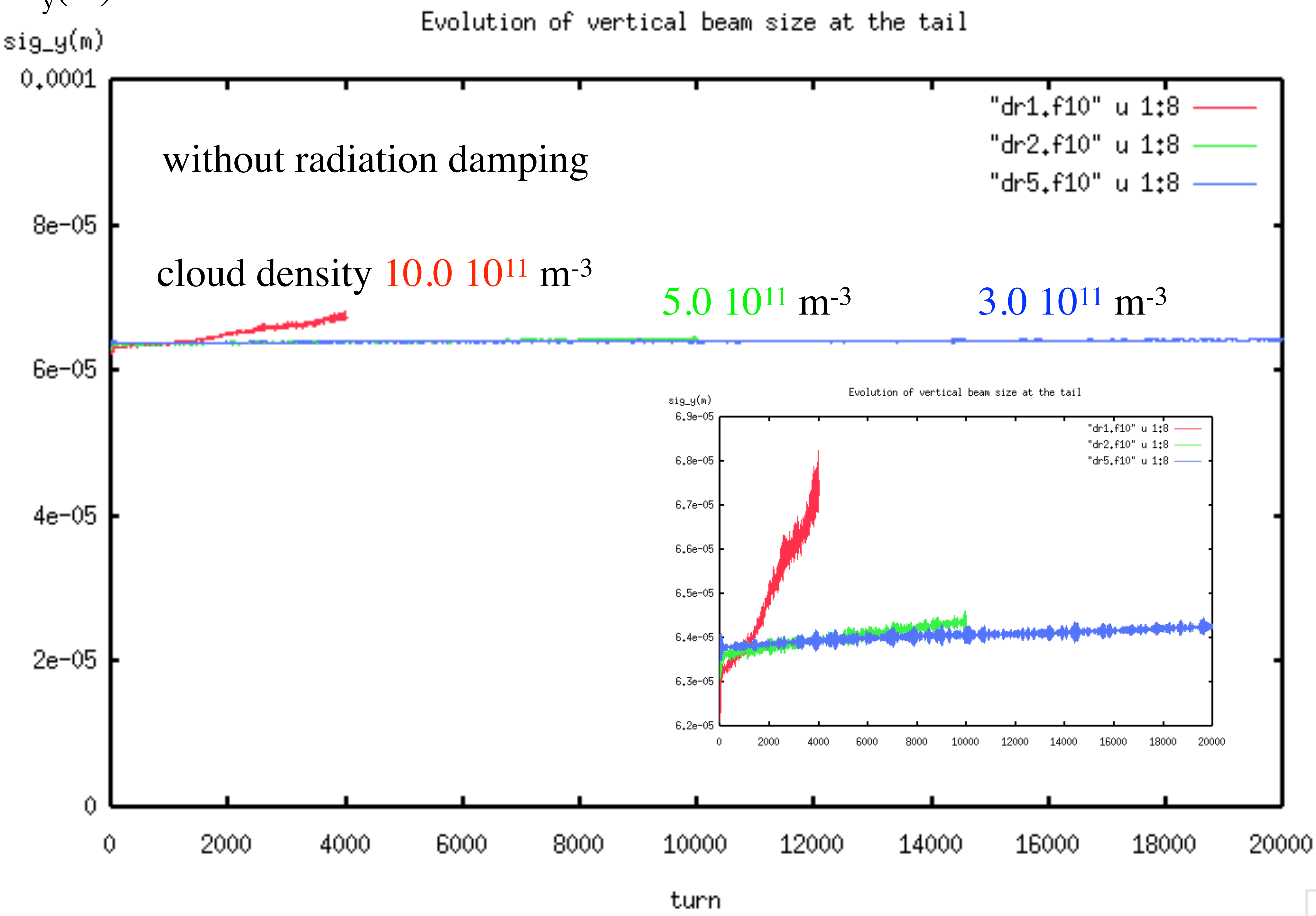
Instability 3

- Evolution of beam size of the last slice

by H. Fukuma

Emittance 12.6 nm, coupling 5%

σ_y(m)

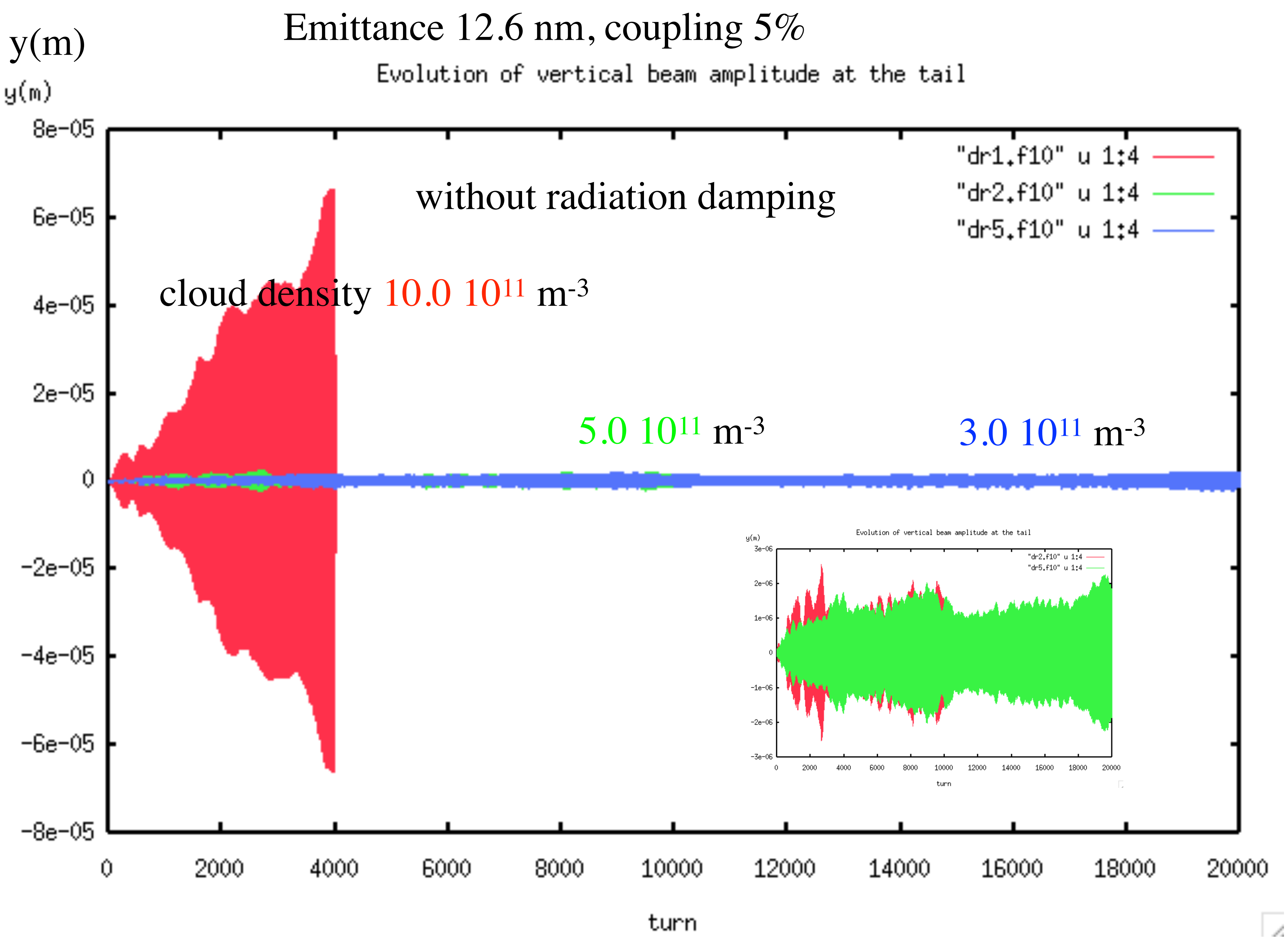


without radiation damping

cloud density 10.0 10^{11} m^{-3} 5.0 10^{11} m^{-3} 3.0 10^{11} m^{-3}

Instability 4

- Evolution of barycenter motion of last slice



Emittance 12.6 nm, coupling 5%

y(m)

without radiation damping

cloud density 10.0 10^{11} m^{-3}

5.0 10^{11} m^{-3}

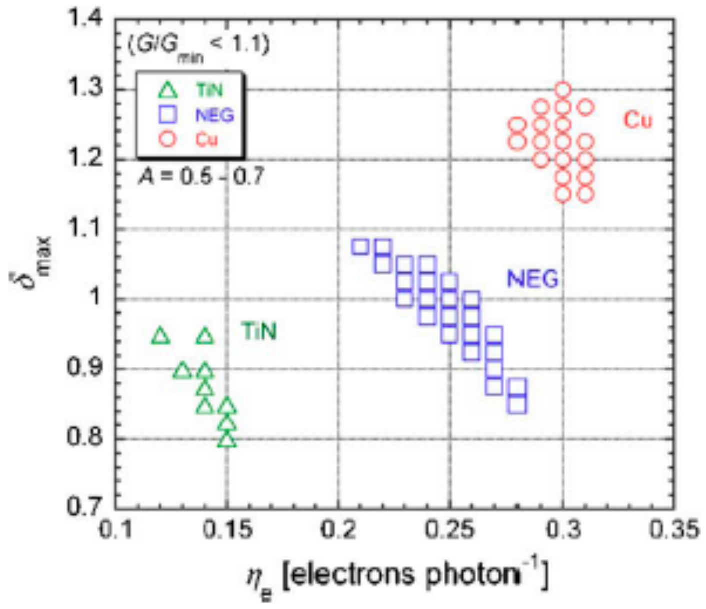
3.0 10^{11} m^{-3}

Instability 5

- $\rho_e \leq 3 \times 10^{11}\ \mathrm{m}^{-3}$ or $\rho_e L \leq 0.4 \times 10^{14}\ \mathrm{m}^{-2}$

- Mitigation is necessary to reduce SEY much less than 1.2
  - TiN coating
  - Groove (Vacuum people favors)

SEY (measured at KEKB)



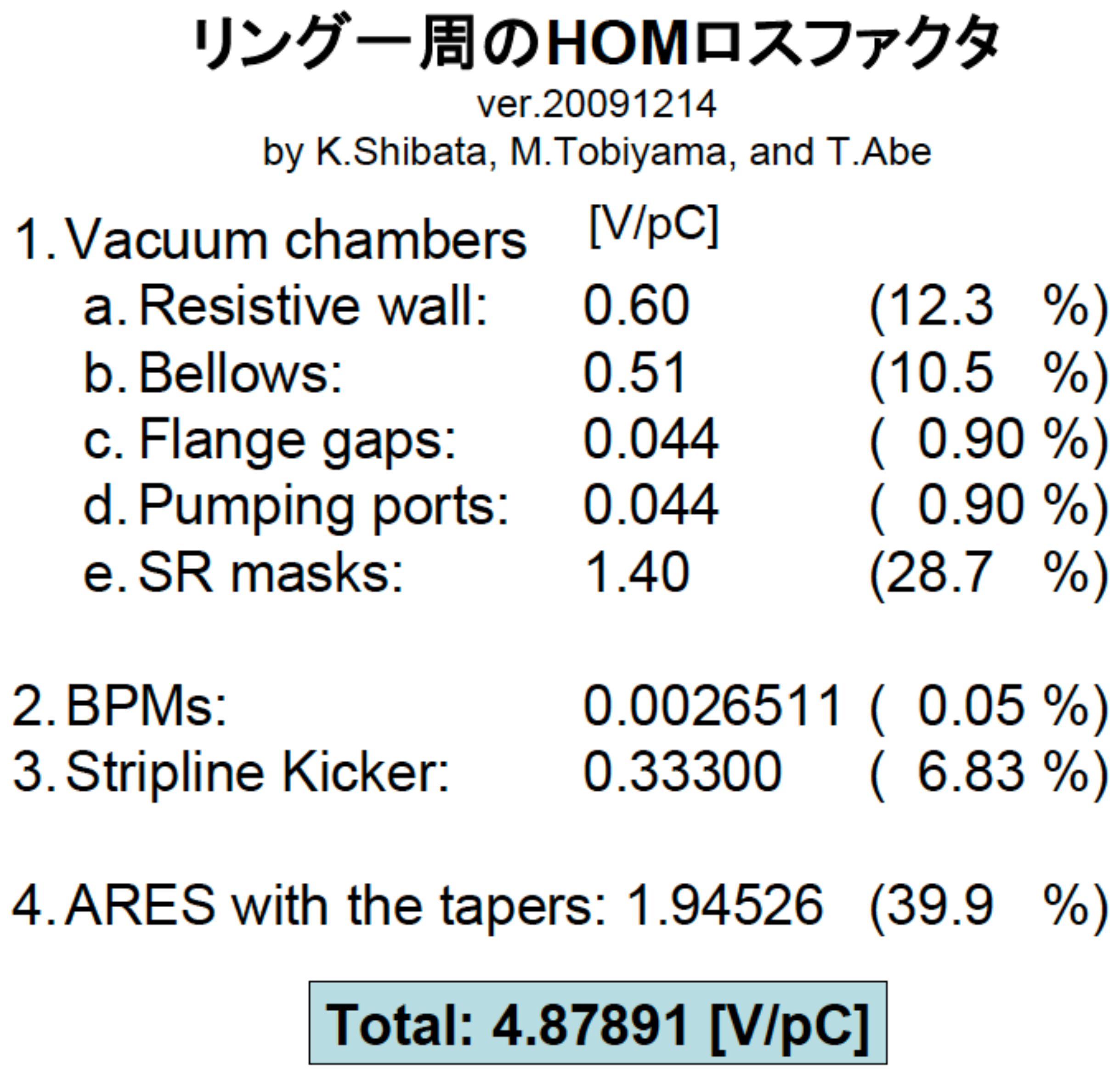
Y. Suetsugu et al. , NIM A 556 (2006)

Impedance Budget

K. Shibata et al.

H. Fukuma

- Loss factor



リング一周のHOMロスファクタ

ver.20091214

by K.Shibata, M.Tobiyama, and T.Abe

	[V/pC]	
1. Vacuum chambers		
a. Resistive wall:	0.60	(12.3 %)
b. Bellows:	0.51	(10.5 %)
c. Flange gaps:	0.044	(0.90 %)
d. Pumping ports:	0.044	(0.90 %)
e. SR masks:	1.40	(28.7 %)
2. BPMs:	0.0026511	(0.05 %)
3. Stripline Kicker:	0.33300	(6.83 %)
4. ARES with the tapers:	1.94526	(39.9 %)

Total: 4.87891 [V/pC]

- Resistive wall instability

$$\text{growth rate } g = \frac{cI}{4\pi\nu_\beta E}\sum_{p=-\infty}^{\infty}\mathrm{Re}\,Z((pM+\mu)\omega_0+\omega_\beta)$$

$$\mathrm{Re}Z = sign(\omega)\cdot\frac{Z_0\cdot R}{b^3}\cdot\delta$$

$$\delta = \sqrt{\frac{2c}{Z_0\sigma|\omega|}}$$

I = 70.8 mA, E = 1 GeV, M = 4, R = 21.6 m, b = 0.016 m , σ(Al) = 4 10^7 1/ohm/m at 0 C

ν_β=12.24 / 4.265 (H/V)

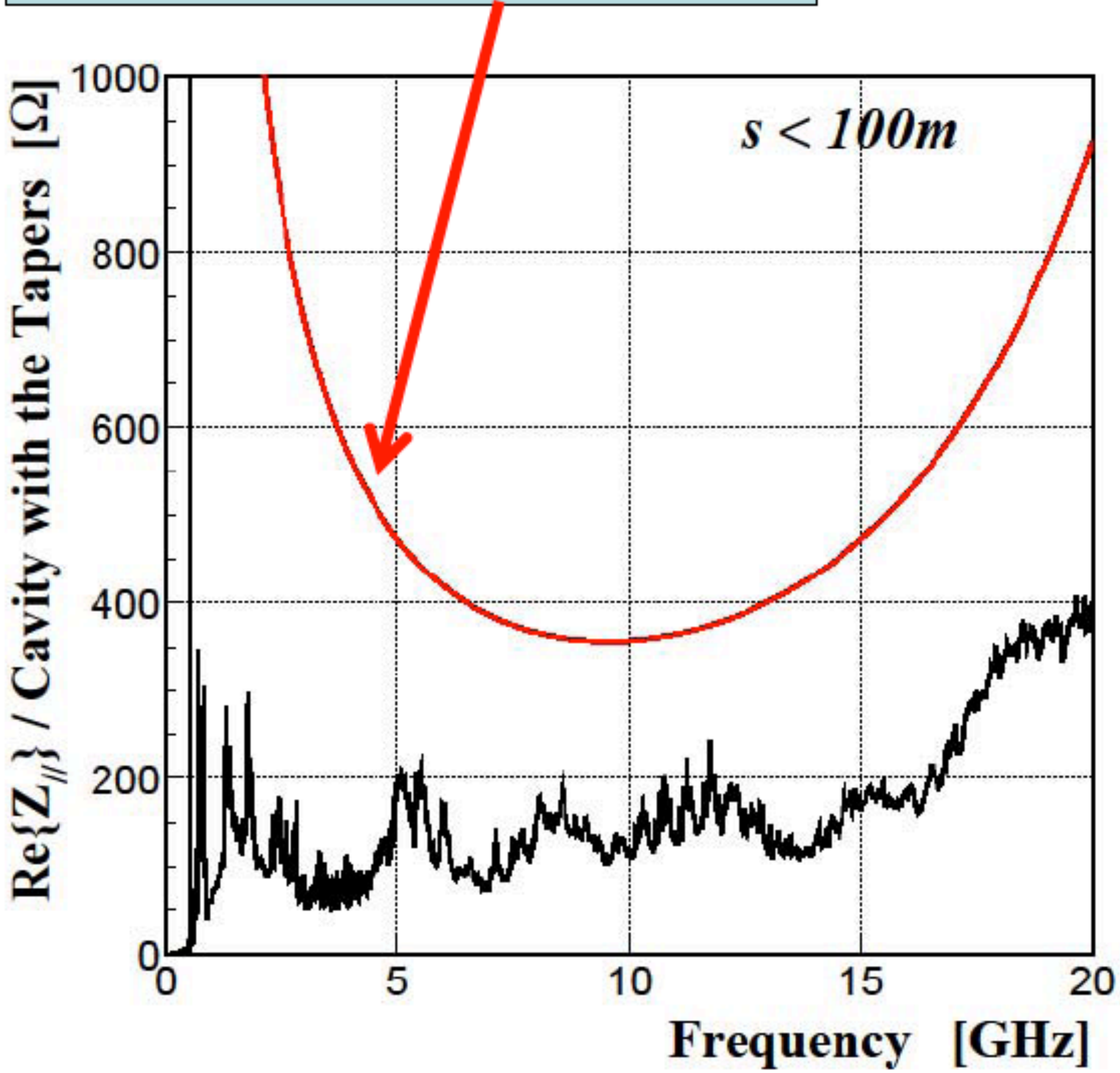
growth time : 77 / 26 ms (H/V) > transverse damping time 12.7 ms

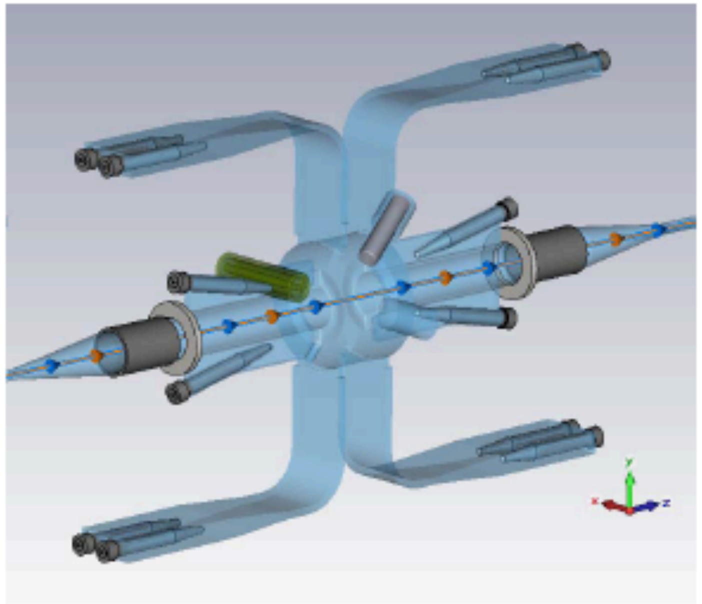
- Threshold of longitudinal coupled bunch instability

T. Abe

＜進行方向結合バンチ不安定性の閾値＞

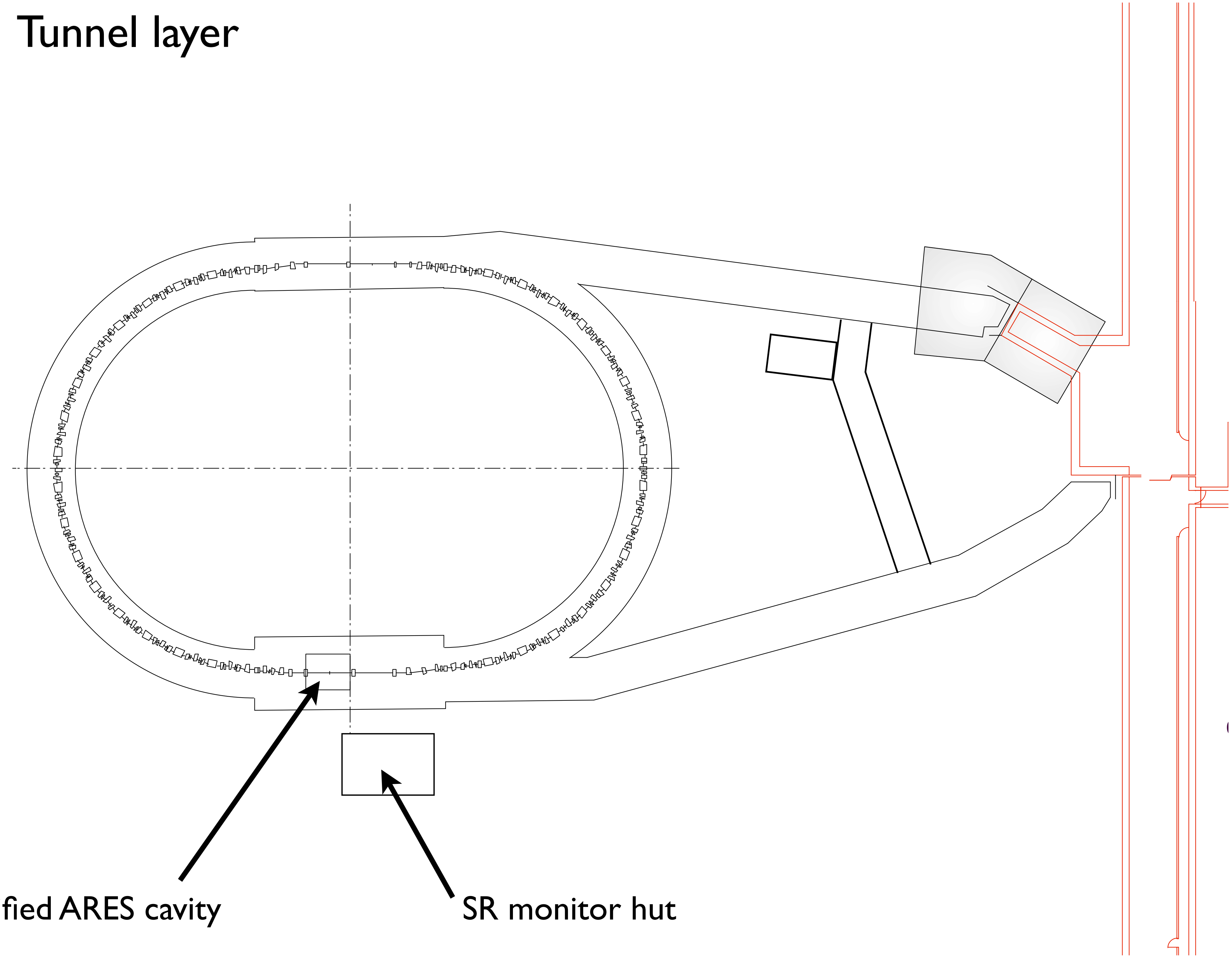
●Growth Time: 20[msec]
●LossFactor(HOM): 4.87891[V/pC]
●parameterlist_091026





Facility Plan

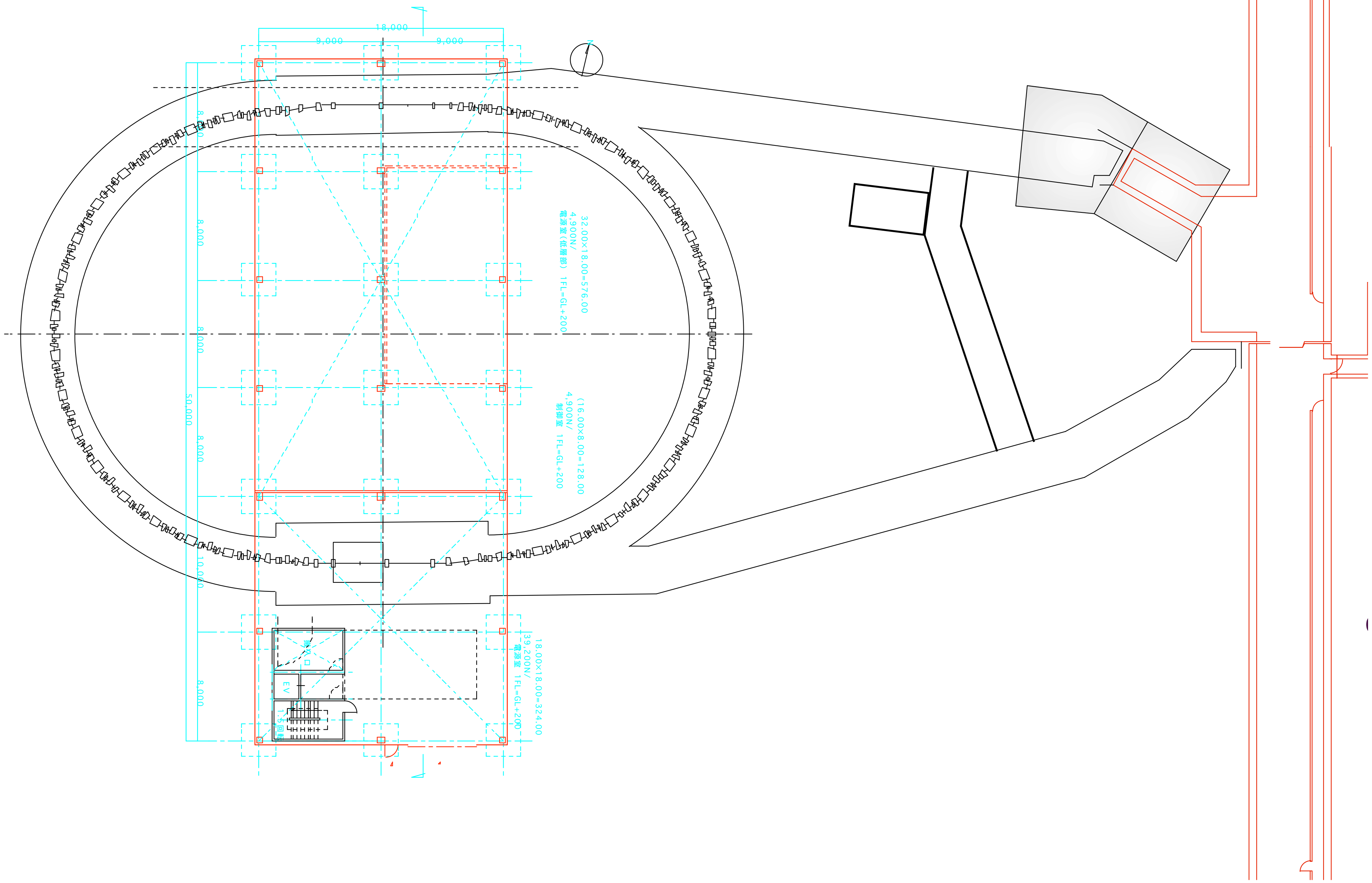
Tunnel layer



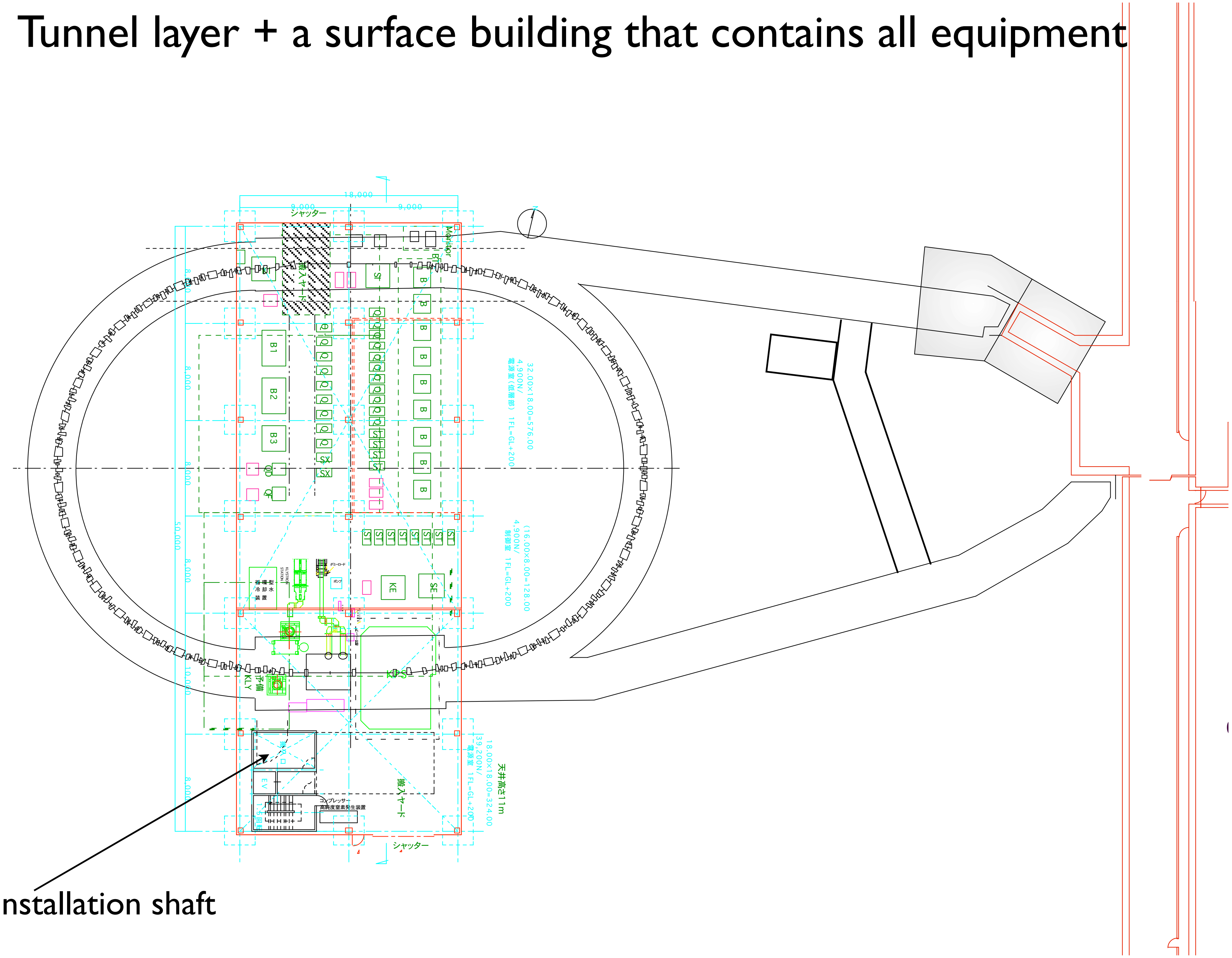
Modified ARES cavity

SR monitor hut

Tunnel layer + a surface building



Tunnel layer + a surface building that contains all equipment



Installation shaft

Summary

- Lattice design is almost frozen
- Systematic high-order multipoles should be cared
- Beam loss scenario has been investigated
  - Tails are cut in the Linac tunnel
  - Loss in DR is tolerable for the present tunnel design
- Electron cloud density is larger than the threshold of PEI if SEY=1.2
  - mitigation should be made
- Facility plan is on-going