TUOBC02

Small-Beta Collimation at SuperKEKB to Stop Beam-Gas Scattered Particles and to Avoid Transverse Mode Coupling Instability

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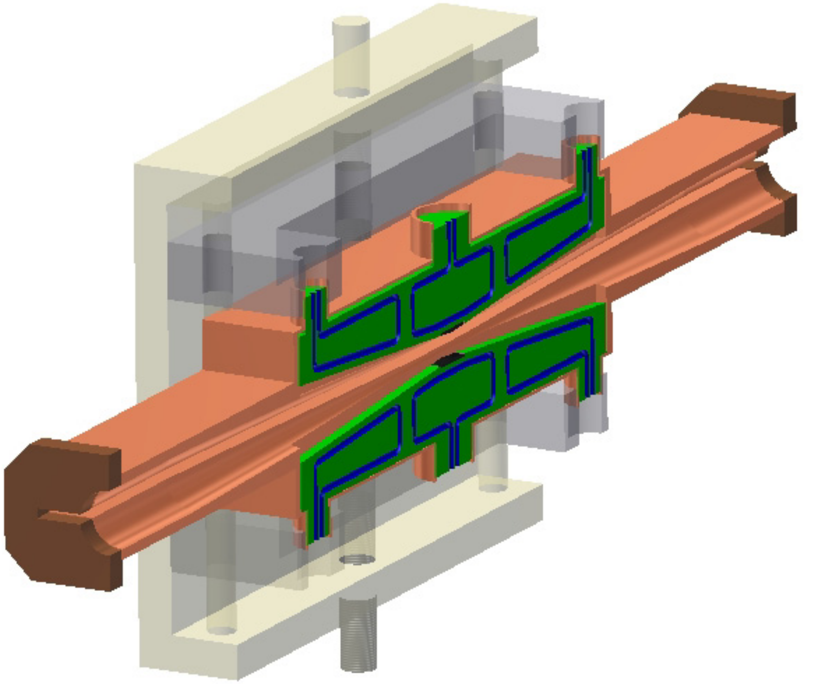
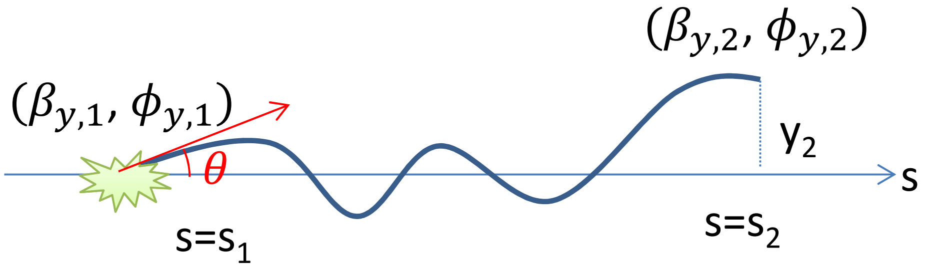


Introduction

- At SuperKEKB, beam particle scattered elastically (Coulomb-scattered) by remaining gas molecules are one of dangerous sources of detector background.
- Scattered particles are lost inside the detector, since beam pipe physical aperture(r/sqrt(β_y)) is the narrowest inside the detector. We need collimators outside interaction region(IR) to stop those particles.
- Collimator width should be very narrow (few mm), so we should be careful not to lose beam stability.

K. Kanazawa

Beam-gas Coulomb scattering



θ: Coulomb scattering angle

$$y_2 = \theta \sqrt{\beta_{y,1} \cdot \beta_{y,2}} \sin(\phi_{y,2} - \phi_{y,1})$$

Horizontal deviation by Coulomb scattering is negligible

The critical scattering angle θ_c to hit IR beam pipe

$$\theta_{c,1} = r_{IR} / \sqrt{\beta_{y,1} \cdot \beta_{y,IR}}$$

Coulomb beam lifetime τ_R is proportional to θ_c^2

$$\frac{1}{\tau_R} = c n_G \frac{4\pi \sum Z^2 r_e^2}{\gamma^2} \left\langle \frac{1}{\theta_c^2} \right\rangle \propto \langle \beta_y \rangle \cdot \beta_{y,IR} / r_{IR}^2$$

	KEKB e+ ring	SuperKEKB e+ ring
IR beam pipe radius: r_{IR}	35mm	13.5mm
Max. vertical beta: $\beta_{y,IR}$	600m	2900m
Averaged vertical beta: $\langle\beta_y\rangle$	23m	50m
Min. scattering angle: θ_c	0.3mrad	0.036mrad
Beam-gas Coulomb lifetime	>10 hours	~35 min.

P = 10^{-7}Pa is assumed

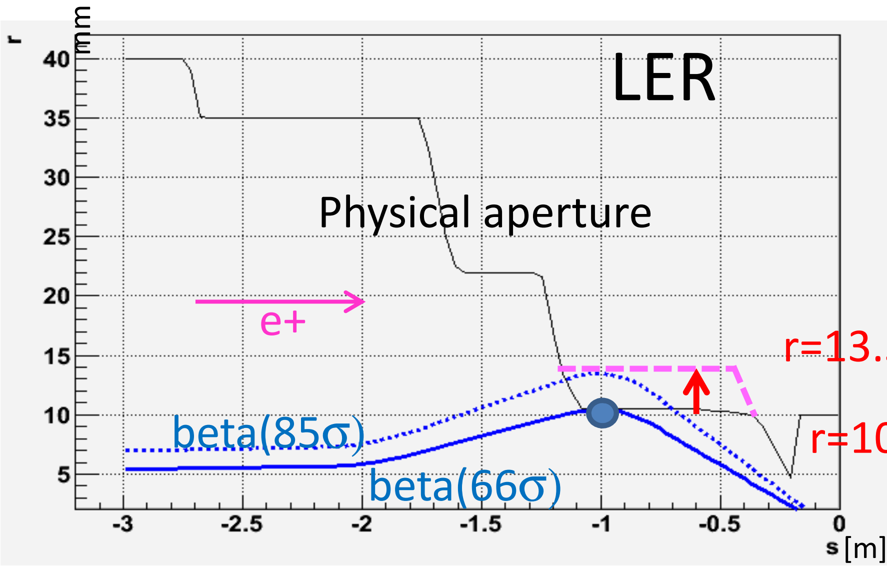
Beam-gas lifetime is only x1/90 of KEKB, due to larger vertical beta and narrower physical aperture

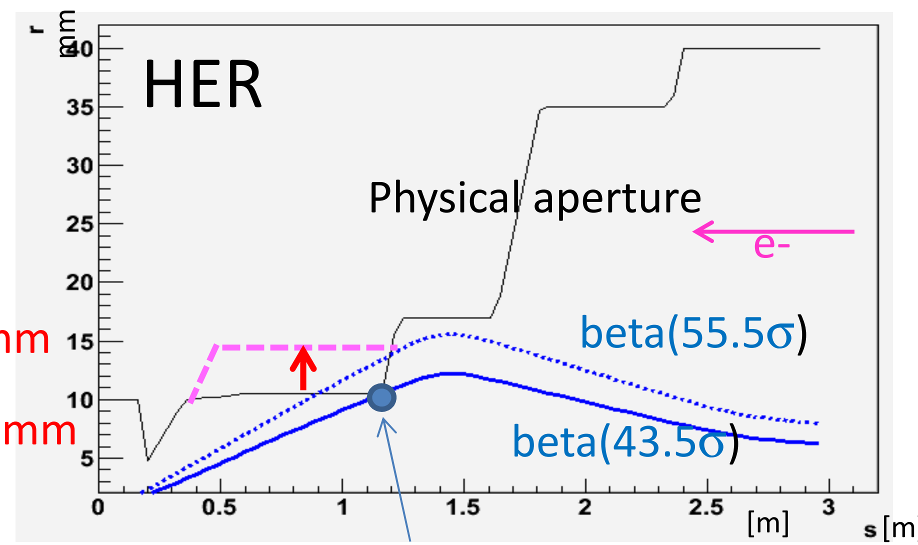
Loss Rate $\propto$ P x I x $\langle\beta\rangle$ x β_{IR} / r_{IR}^2

Strategy to reduce Coulomb BG

$\tau \propto r^2$

- Larger QC1 physical aperture (r=10.5mm→13.5mm)





We widened IR beam pipe radius without major change in final Q design.
Coulomb lifetime improved (LER: 1360→2240sec, HER: 2100→3260sec)

- Vertical collimators!
  - IR aperture should not be narrowest over the ring
  - – Collimator aperture should be narrower than IR aperture
  - – Beam instability? (collimators should be very close(few mm) to the beam)

<< TODAY'S MAIN TOPIC >>

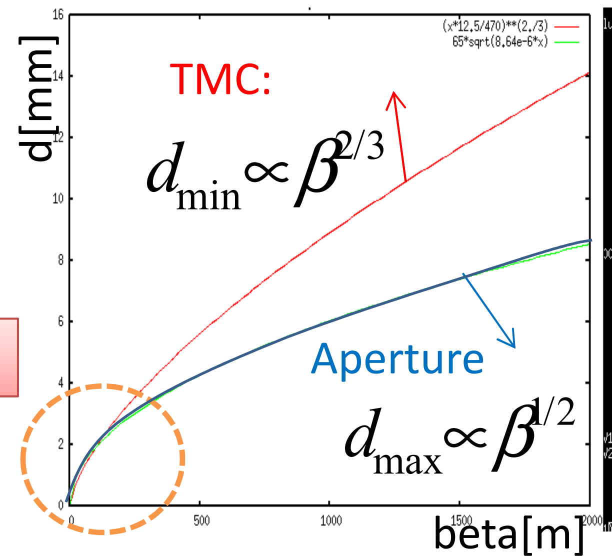
Where we should put vertical collimator?

Collimator aperture should be narrower than IR aperture.

$$d/\sqrt{\varepsilon\beta} < r_{IR}/\sqrt{\varepsilon\beta_{IR}} \quad \Rightarrow \quad d_{\max} \propto \beta^{1/2}$$

d: collimator (half) width, from beam center to collimator head

Collimator position



Transverse Mode Coupling Instability (TMCI) should be avoided.

also called "fast head-tail instability"

Assuming following two formulae:

$$I_{thresh} = \frac{C_1 f_s E/e}{\sum_i \beta_i k_{\perp i}(\sigma_z)} > 1.44\ \text{mA/bunch (LER)}$$

taken from "Handbook of accelerator physics and engineering, p.121"

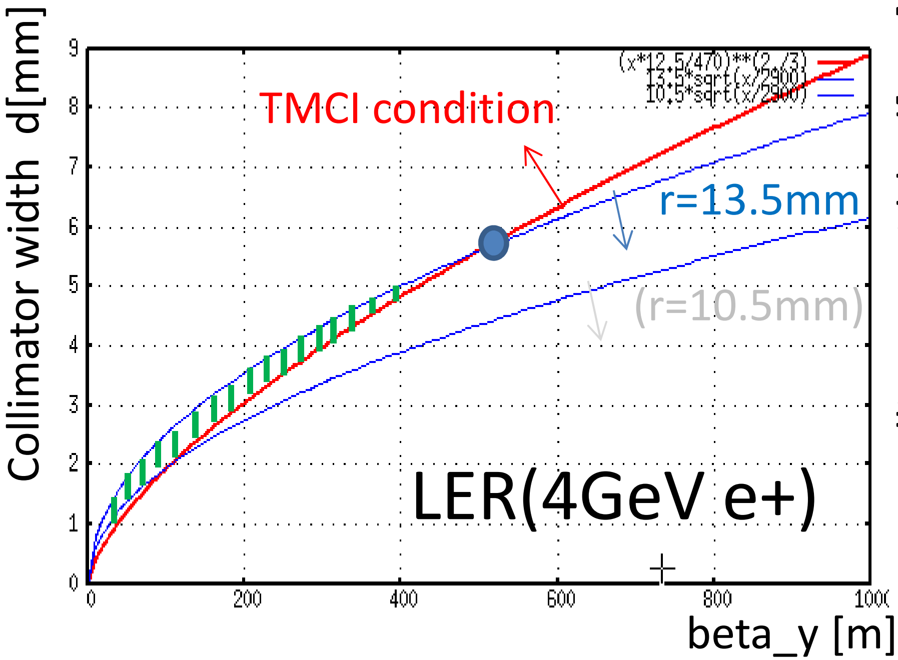
Kick factor $k_\perp = 0.215 A Z_0 c \sqrt{\dfrac{\theta_{\text{slope}}}{\sigma_z d^3}}$

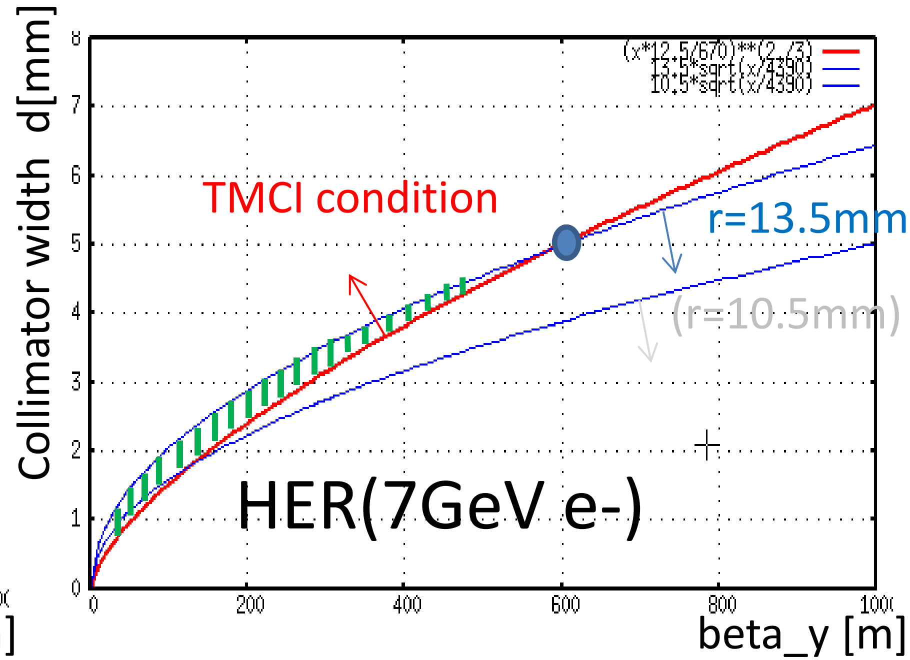
(in case of rectangular collimator window)

$$\Rightarrow \quad d_{\min} \propto \beta^{2/3}$$

We should put collimator where beta_y is SMALL!

Candidate collimator locations





Collimator position should satisfy not only above beta_y condition,
but also need space(at least 1.5m), and the phase should be close to IR phase

V collimator @ LLB3R (downstream)
(s=-90→-82m, βy=30→146m)
βy=125m, 2.23mm<d<2.81mm

Ny(Vcol)= 42.82, Ny(IR)= 44.32

V collimator @ LTLB2 (downstream)
(s=-63→-61m, βy=81→187m)
βy=123m, 1.74mm<d<2.26mm

Ny(Vcol)= 1.25, Ny(IR)= 0.25

Vertical collimator width vs. Coulomb loss rate, Coulomb life time

LER (e+)

Vcol width[mm]	IR loss [GHz]	Total loss[GHz]	Coulomb life[sec]
2.40	0.04	153.9	1469.8
2.50	0.05	141.8	1594.8
2.60	0.09	131.0	1724.9
2.70	0.24	121.4	1860.2
2.80	1.65	111.4	2000.5
2.90	11.48	100.8	2014.3
3.00	21.98	90.3	2014.3

Based on element-by-element simulation considering causality the phase difference

Summed up to 100turns

HER(e-)

Vcol width[mm]	IR loss [GHz]	Total loss[GHz]	Coulomb life[sec]
2.10	0.0007	49.6	3294.0
2.20	0.001	45.2	3615.2
2.30	0.357	41.0	3951.3
2.40	7.99	33.0	3985.9
2.50	13.1	27.9	3985.9

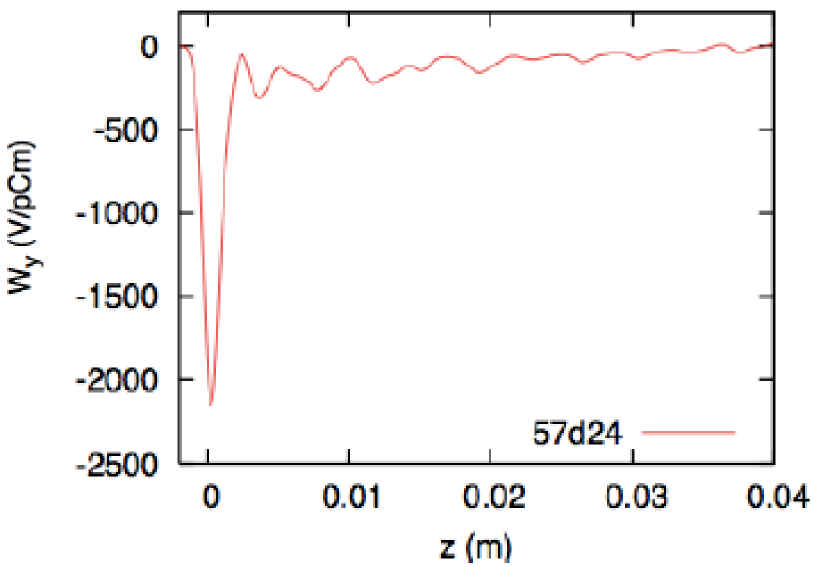
IR loss rate is VERY sensitive to the collimator width.
(Once Vcol aperture>QC1 aperture, all beam loss goes from Vcol to IR

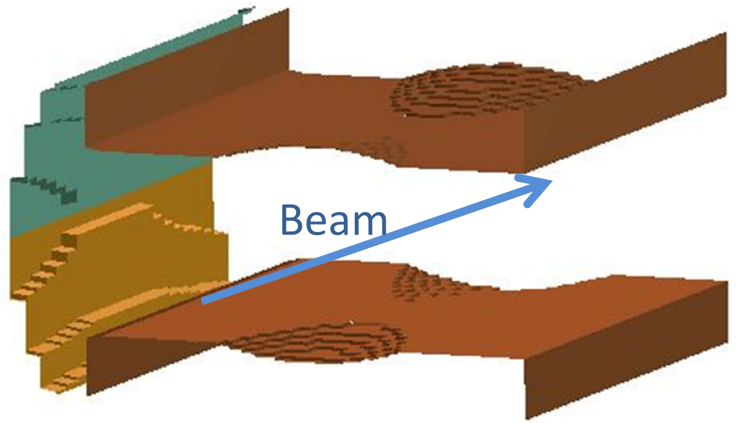
Typical orbit deviation at Vcol : +-0.12mm (by iBump V-angle: +-0.5mrad@IP)

Y. Suetsugu

Impedance of realistic collimator

d=2.4mm mask for LER



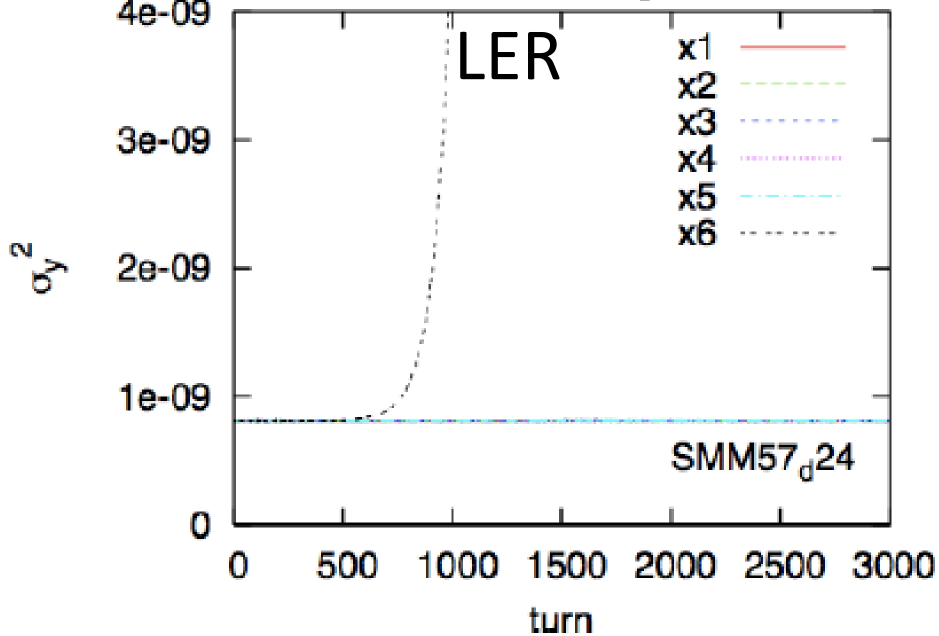


Dedicated design for low impedance "round-flat-round"

K. Ohmi

I_{th} calculated by tracking simulation

σ_z = 6mm

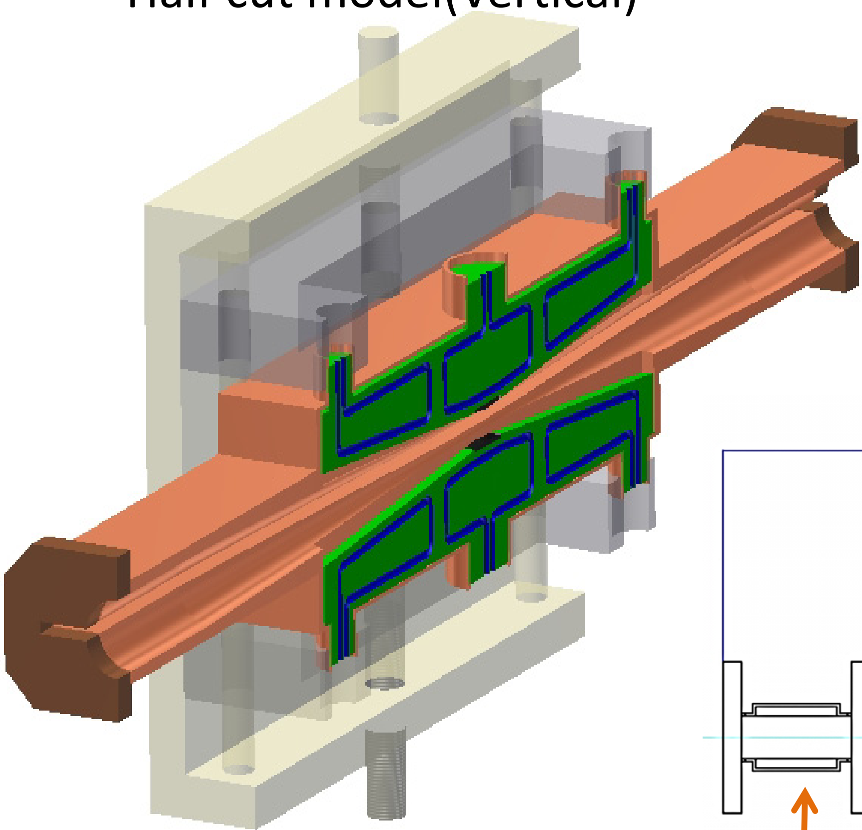


I_{th}=1.44mAx5~6=7.2~8.6mA

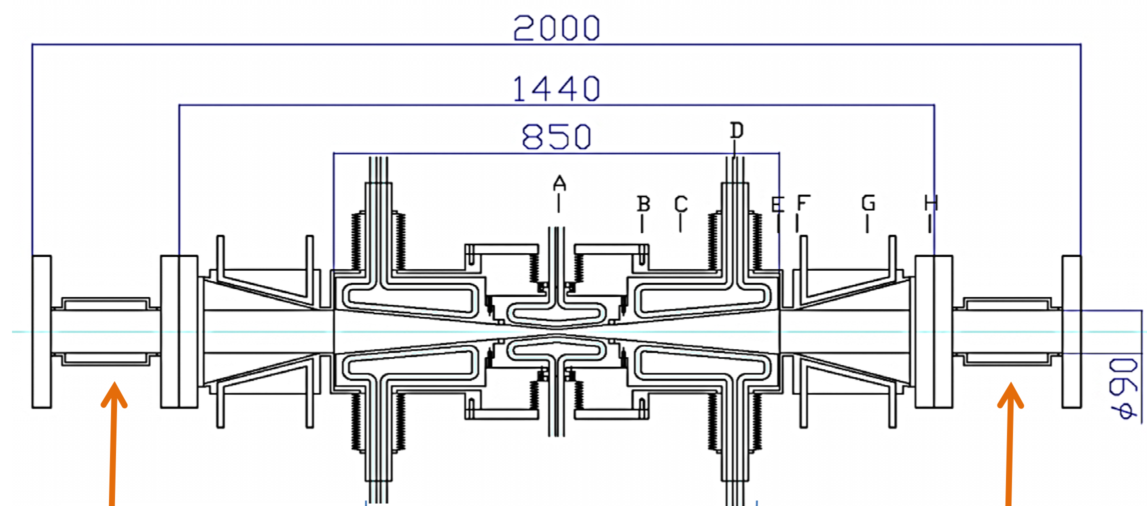
TMC instability caused by the LER vertical collimators are tolerable.

Latest collimator design

- Half cut model(Vertical)



Details not fixed yet



SiC?
(HOM absorber)

This part
replaceable?

SiC?

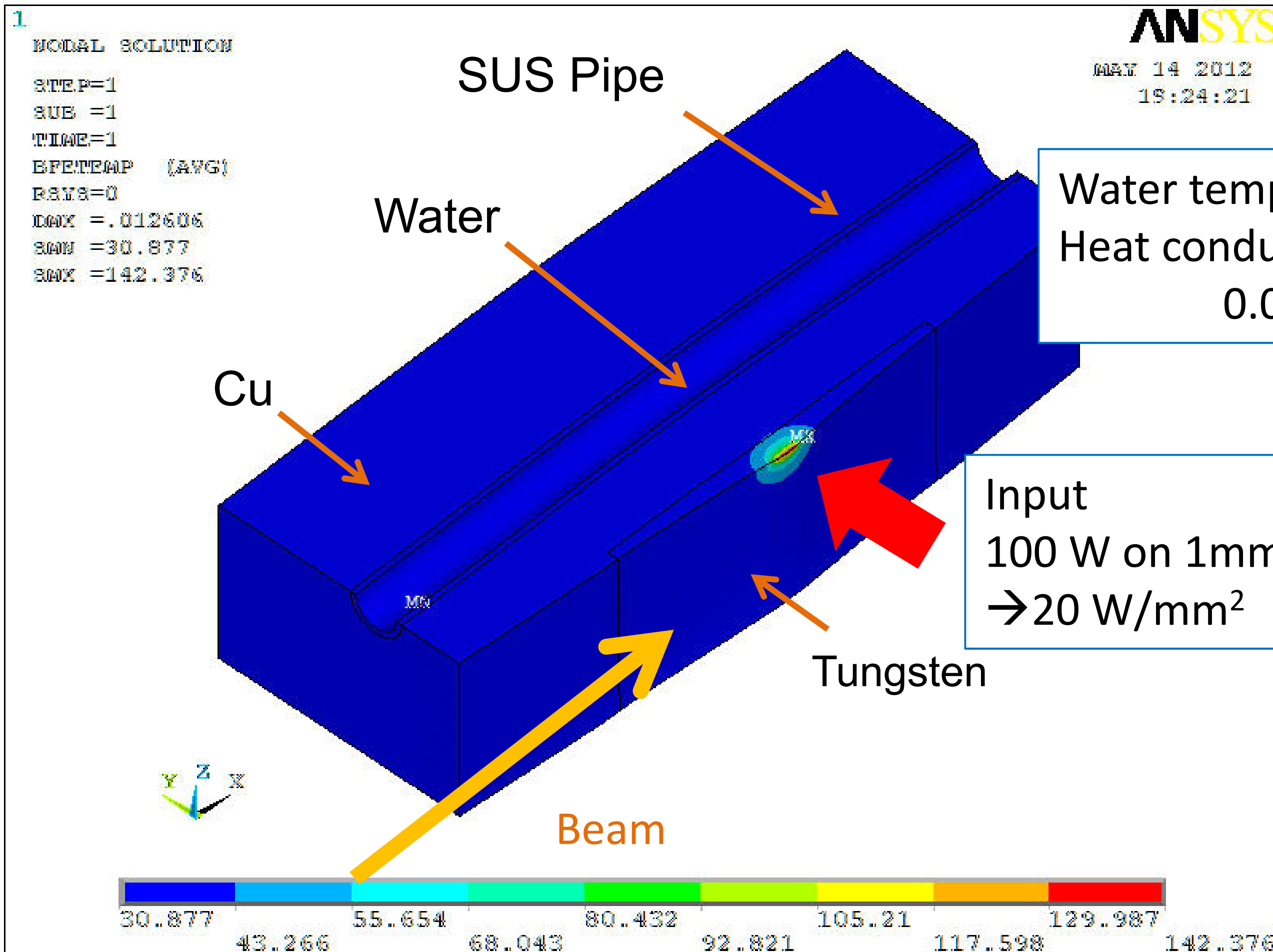
Y. Suetsugu

Head load on collimator

- Temperature with 100W input

100W = ~100GHz loss of 7GeV electrons

Water cooling
10mm from surface



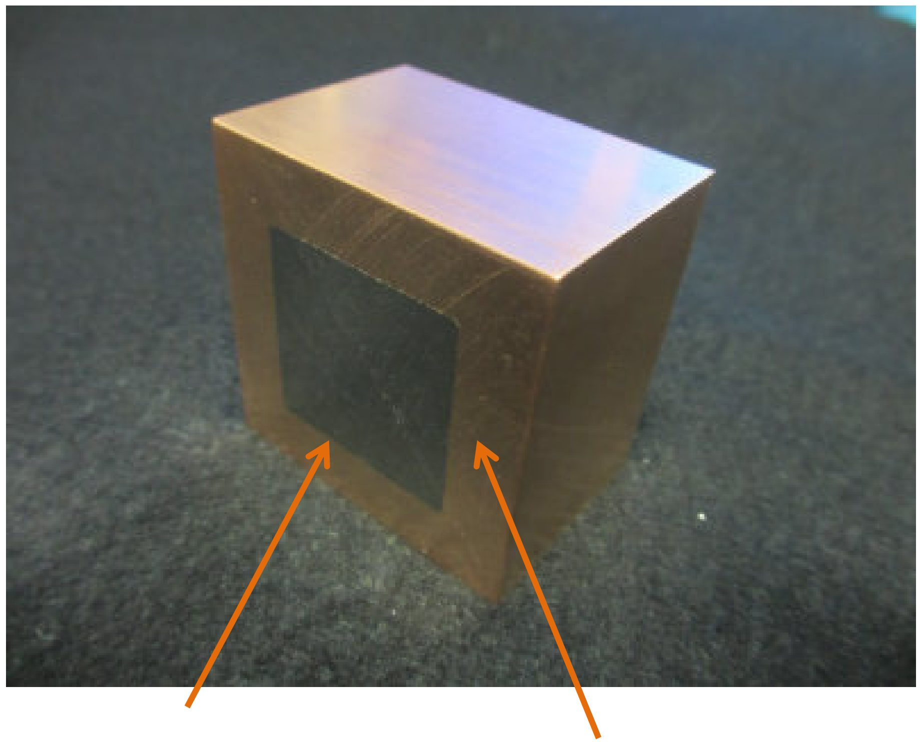
Water temperature 25°C
Heat conductivity
0.005 W/mm^2

Input
100 W on 1mm(y)x5mm(s)
→20 W/mm^2

No problem.
Displacement, Von Mises stress are also torelable

Collimator head (HIP process)

- Demonstration with test sample was successful



Summary

- Larger <β_y> and narrower IR aperture make Beam-gas Coulomb BG much severer at SuperKEKB than at KEKB
- Vertical collimators , placed at small beta_y, can reduce beam-gas loss in IR down to ~0.1GHz for both rings (not including secondary showers)
- Beam instability for such collimators is confirmed to be tolerable both by theoretical equation and tracking simulation with realistic collimator shape
- Vacuum level at large beta_y affects beam-gas lifetime.
- Collimator design R&D is ongoing which can resist ~100GHz loss

Related talks and posters:
"Beam background and MDI design for SuperKEKB/Belle-II" (**TUPPR007)**
"Design Progress and Construction Status of SuperKEKB" by K. Oide (**TUPPR006)**
"Overview of SuperB factories" by M. Biagini(**WEYA03**)