Conceptual Design of Storage Ring Vacuum System for the SPring-8 upgrade project (SPring-8-II)

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Overview of SPring-8-II (1)

Critical Boundary Conditions

1. Reuse of the existing machine tunnel.
2. Preserving of all the existing ID beamlines axes.
3. Minimized blackout period.

⇨ Practical targeted emittance to be *around 100 pmrad* with the IDs in operation and the targeted stored current to be *100 mA*.

Overview of SPring-8-II (2)

	Upgraded	Current
Beam Energy (GeV)	6	8
Ring Current (mA)	100	100
Unit-cell Structure	5-Bend Achromat	Double-Bend
Length of ID straight (m)	4.68	6.65
Emittance (nmrad)	0.15 (AC, w/o und) ~ 0.1 (AC, w und)	2.4 (NA, w/o und) ~ 6 (AC, w/o und)
Coupling ratio (%)	10	0.2
Beam Lifetime (h)	~ 10	10 ~ 100
Beam filling pattern	Multi-bunch only	Hybrid w intense bunches

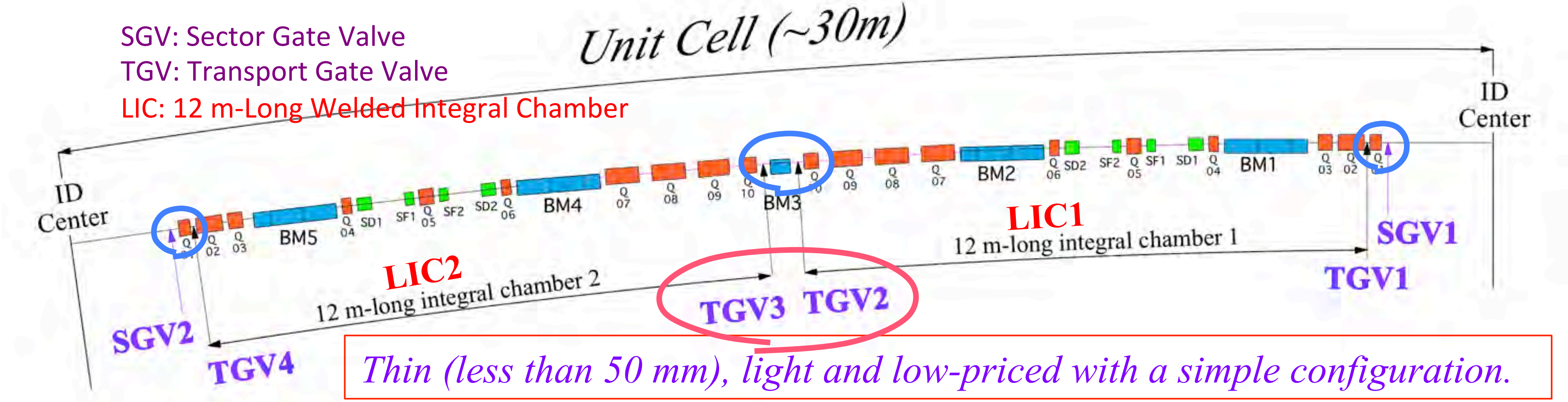
- ✓ Five bend achromat composed of four longer longitudinal gradient bends and one shorter homogeneous bend, which provides BM radiation to reduce the emittance.
- ✓ Lower stored beam energy from 8 to 6 GeV, which will offer additional emittance reduction and an increase in space for magnets resulting from shortening the ID straight sections.
- ✓ Determine the filling pattern to be multi-bunch filling with vacant gaps only in order to keep the beam lifetime longer than 10 hours.

http://rsc.riken.jp/pdf/SPring-8-II.pdf

SR Vacuum System – Design Strategy (1)

1. *Exclude "in-situ baking" including NEG activation from consideration*
   - Time constraint issue (1-year blackout for replacement of ***1.5 km storage ring***)
   - Space constraint issue (Increase in number of multi-pole magnets and MBA)

We plan to establish a highly-performed procedure to realize the UHV system in the tunnel within a limited amount of time without exposing the vacuum surface to the air.



Thin (less than 50 mm), light and low-priced with a simple configuration.

- ✓ LIC will be evacuated to UHV by ex-situ baking, followed by the NEG activation in advance.
- ✓ Then, it will be moved under vacuum to the tunnel and aligned inside the magnets.
- ✓ Remaining 3 short connection chambers will be attached to the LICs through the TGVs.
- ✓ The connection chambers will be baked in-situ when necessary.
- ✓ Then, by opening the TGVs, the total vacuum system for a unit cell will be ready.
- ✓ After once opened, the TGVs probably never close again without maintenance for a serious vacuum trouble.

SR Vacuum System – Design Strategy (2)

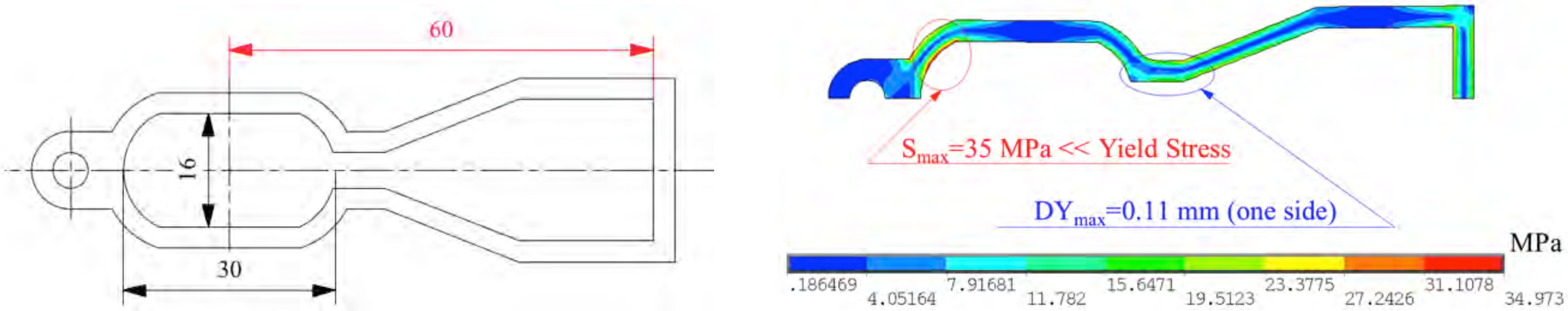
2. Start with a proven system design with discrete absorbers and NEG cartridges

Handling Bending Radiation

Intercepted by discrete photon absorbers only without directly irradiated any inner wall of vacuum chambers in spite of severe space constraints.

Vacuum Chamber

Main chambers, made from extruded aluminum alloy, need antechamber.



Cross-sectional view (Left) and structural analysis of straight vacuum chamber

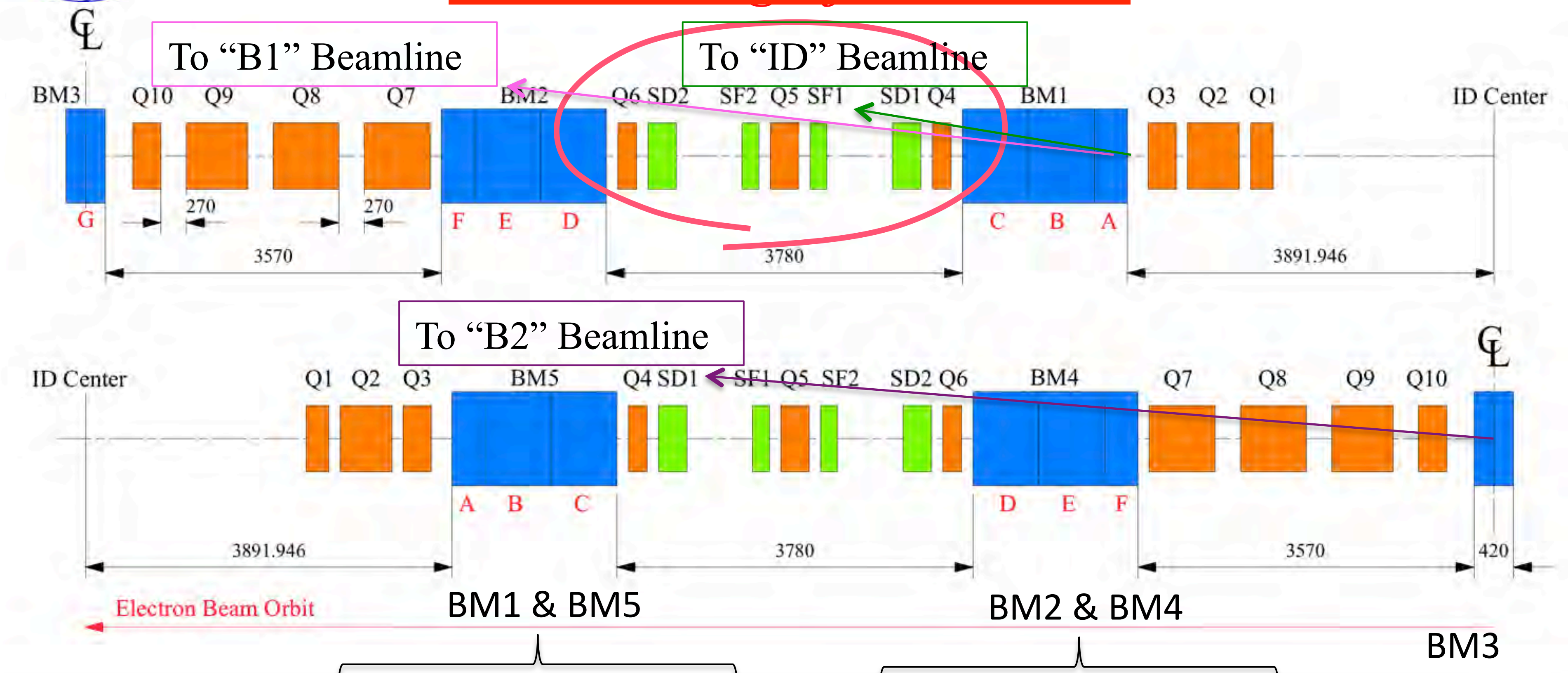
Vacuum Pumping

Mainly provided by discrete NEG cartridges, some of which combine a SIP in spite of low vacuum conductance.

- *Arrangement of photon absorbers by ray-tracing*
- *Arrangement of vacuum pumping system by pressure calculation*

→ Ascertain whether this strategy is practical or not.

Lattice Design for unit cell

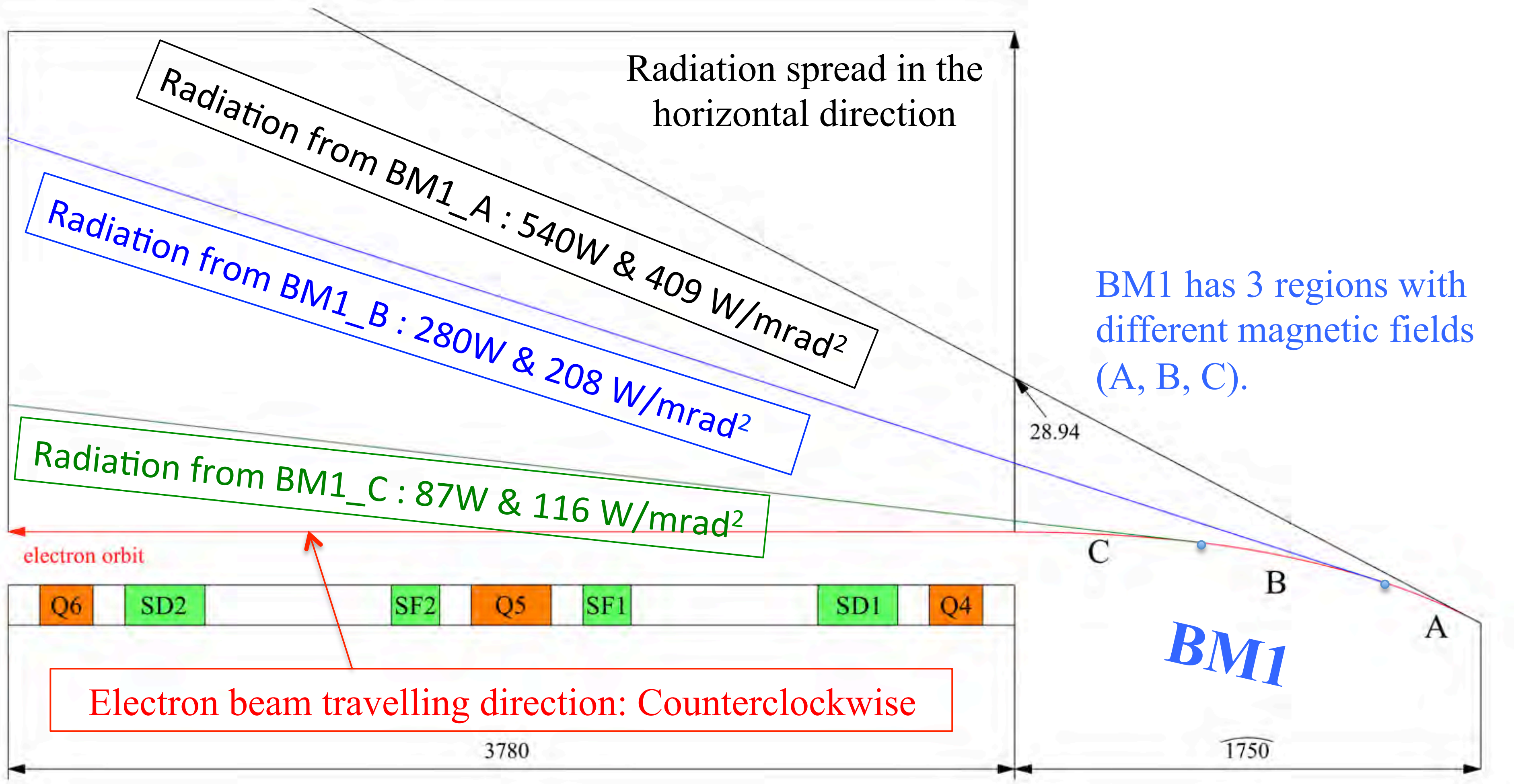


	A	B	C	D	E	F	G
B (T)	0.58	0.30	0.17	0.22	0.39	0.78	0.95
Power (W/mrad)	53.0	27.0	15.1	20.1	36.0	70.7	86.9
Power Density (W/mrad^2)	408.7	208.1	116.3	154.9	277.2	544.5	669.4

Specification of Bending Magnets at 6 GeV and 100 mA

Ray Tracing for BM1 (1)

- There are 3 different regions which have different power density.
- Photon absorbers should be arranged in position between the multi-pole magnets so that the radiation may not irradiate unwanted vacuum chamber walls.



BM1 has 3 regions with different magnetic fields (A, B, C).

Ray Tracing for BM1 (2)

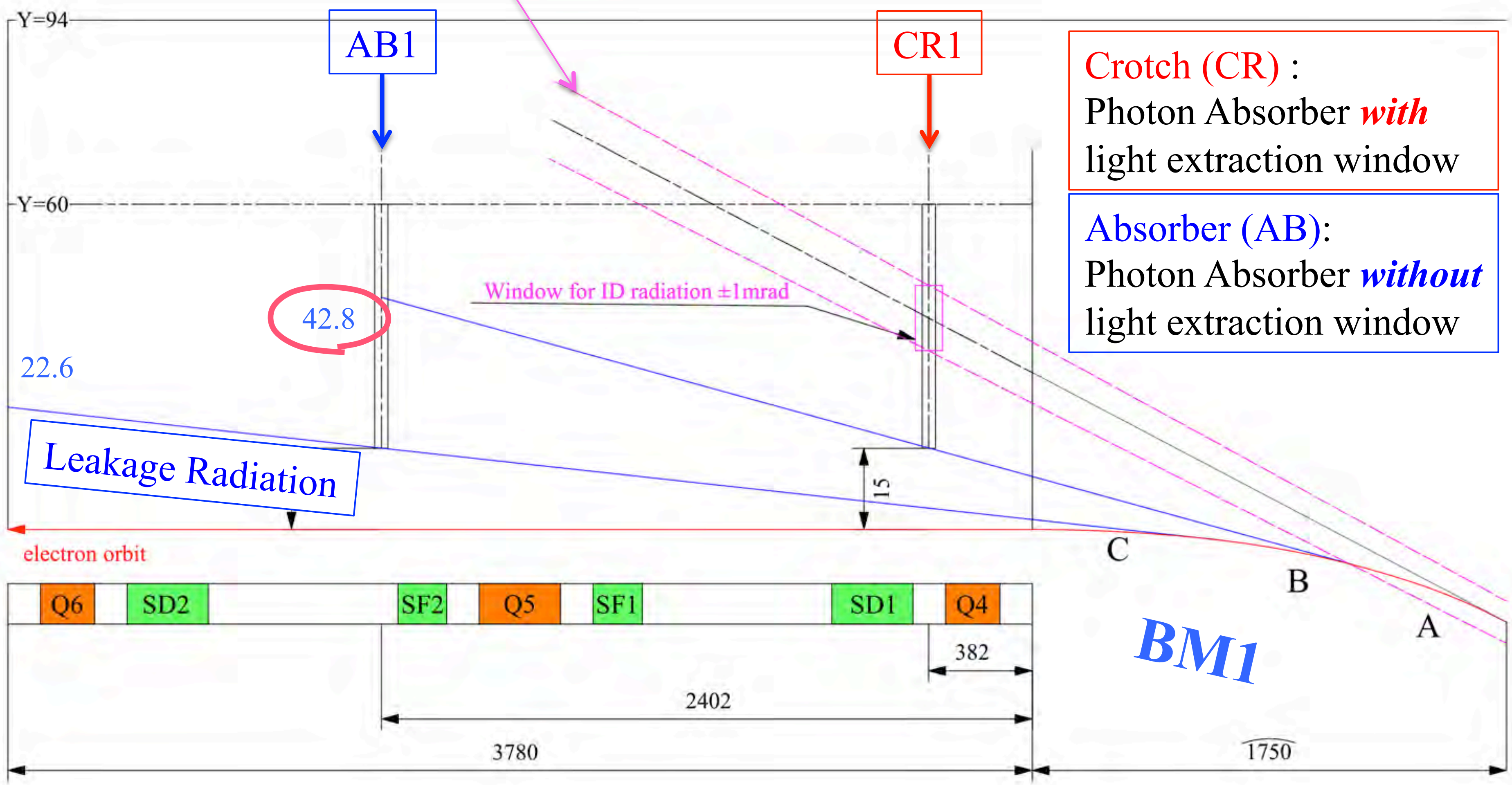
ID radiation with a divergence angle of ±1 mrad

- *CR1 should be laid out at the space between Q4 and SD1 and it has a window for extraction of ID radiation.*
- *Radiation cut by CR1 will spread to be 42.8 mm from the electron orbit at AB1 position.*

Radiation spread in the horizontal direction

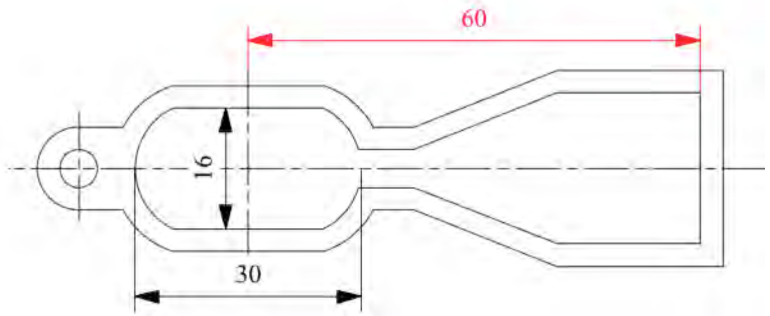
Crotch (CR) : Photon Absorber ***with*** light extraction window

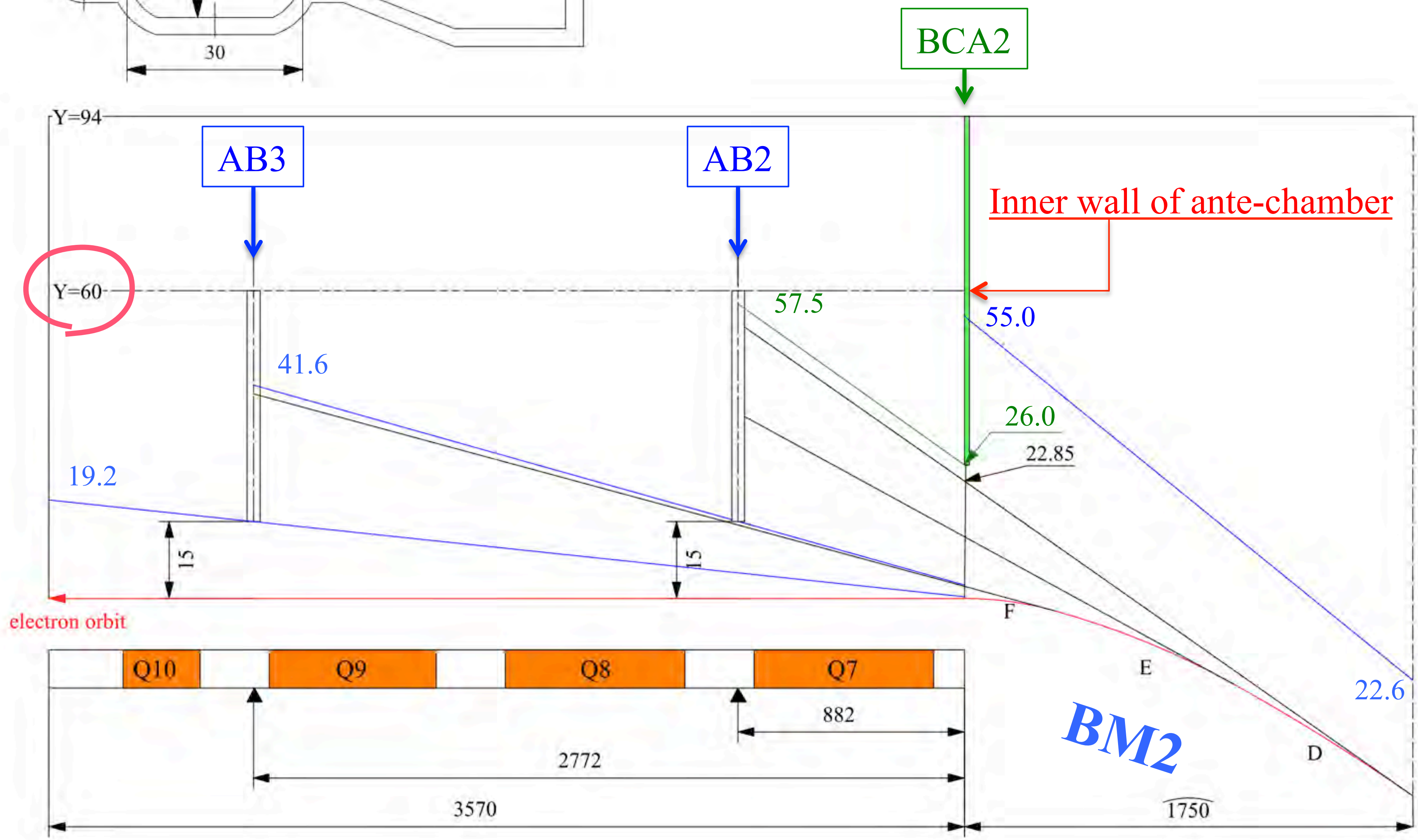
Absorber (AB): Photon Absorber ***without*** light extraction window



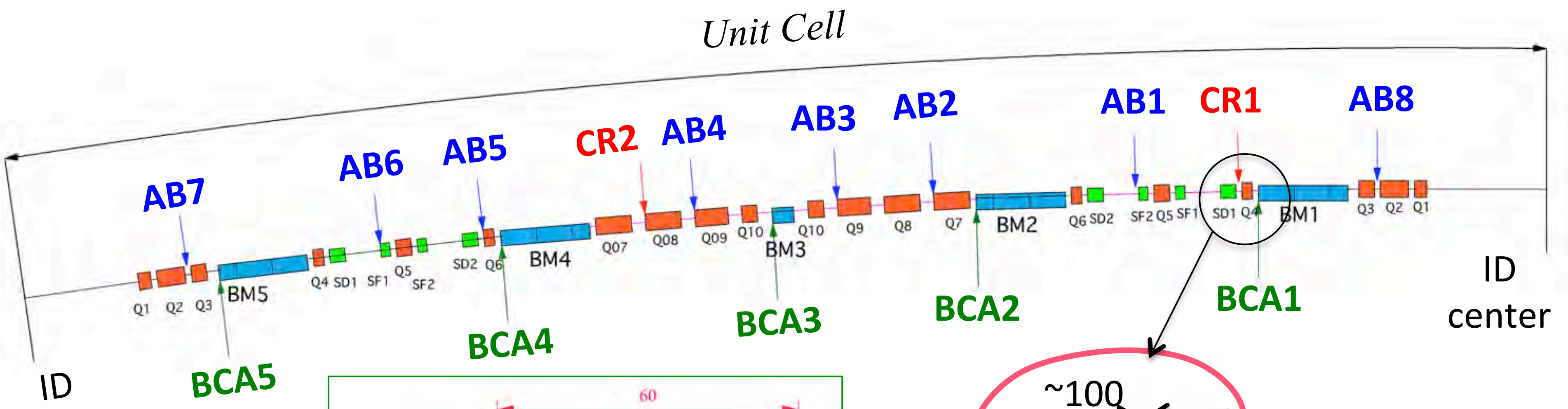
Ray Tracing for BM2

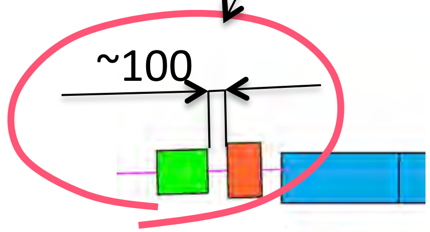
We can keep the distance between the electron beam orbit and the inside wall of the ante-chamber to be about 60 mm.

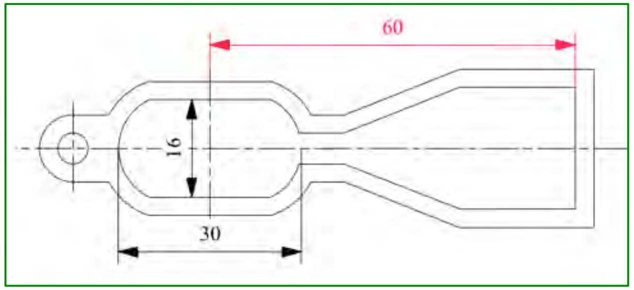




Distribution Map of Photon Absorbers







- *Arrangement of a pair of photon absorbers in each straight section will be able to deal with the new lattice design.*
- *By adding supplementary absorbers of BCA, we are optimistic about the miniaturization of the ante-chamber.*
- *Because there is a very narrow space between magnets where CR or AB will be inserted, designing a compact heat-absorbing body is our new task.*

Power Distribution on Photon Absorbers for unit cell

	CR1	AB1	BCA2	AB2	AB3	BCA3	AB4	CR2	BCA4
Absorbed Power (kW)	0.649	0.223	0.071	0.641	0.604	0.184	0.439	0.987	0.461
Radiation Sweep Angle (mrad)	13.41	8.27	4.92	21.55	8.81	2.60	5.56	11.36	5.31
*1) Peak Power Density (W/mm^2)	128.7	21.6	3.7	174.8	64.4	33.0	179.4	94.4	23.6

	AB5	AB6	BCA5	AB7	(ID absorber)	AB8	BCA1	Total	SPring-8
Absorbed Power (kW)	***1.229***	0.307	0.103	0.206	(0.585)	0.017	0.065	6.770	Max. 5.40
Radiation Income Angle (mrad)	20.45	9.44	5.13	10.30	(14.15)	0.32	1.23	142.8	—
*1) Peak Power Density (W/mm^2)	***171.4***	18.2	5.0	112.2	—	7.7	4.5	—	Max. 340

*1) Normal incidence angle

Target of Gas Scattering Lifetime (1)

<Ultra-Low Emittance Ring>

Not the *Gas Scattering Lifetime* (τ_g) but the *Touschek Lifetime* (τ_T) by intrabeam scattering naturally dominates the *Beam Lifetime* (τ_{total}).

$$\frac{1}{\tau_{total}} = \frac{1}{\tau_g} + \frac{1}{\tau_T}$$

10 h   12 h

Targeted τ_g => 60 h

Möller Scattering

$$1/\tau_m = cN\sum_i Z_i\sigma_m \qquad \sigma_m = Max\left\{\frac{2\pi r_e^2}{\gamma}\times\frac{1}{(\Delta p/p)_c}, \frac{4\pi r_e^2}{\gamma^2}\times\frac{1}{\theta_c^2}\right\}$$

Rutherford Scattering

$$1/\tau_r = cN\sum_i \sigma_r \qquad \sigma_r = \frac{4\pi Z_i^2 r_e^2}{\gamma^2}\times\frac{1}{\theta_c^2}$$

Bremsstrahlung

$$1/\tau_b = cN\sum_i \sigma_b \qquad \sigma_b = 4\alpha r_e^2 Z_i(Z_i+1)\left\{\frac{4}{3}\ln\frac{1}{(\Delta p/p)} - \frac{5}{6}\right\}\ln\left[183\cdot Z_i^{-\frac{1}{3}}\right]$$

$$\frac{1}{\tau_g} = \frac{1}{\tau_m} + \frac{1}{\tau_r} + \frac{1}{\tau_b} = cN\left[\sum_i Z_i\sigma_m + \sum_i \sigma_r(Z_i) + \sum_i \sigma_b(Z_i)\right]$$

σ: scattering cross-section
c: speed of light
N: number of molecules
Z_i: atomic number of molecules species *i*
P_i: partial pressure for species *i*

Target of Gas Scattering Lifetime (2)

$$\frac{1}{\tau_g} = 7.26\times10^{28}\left[2.50\times10^{-30}\sum_i Z_i + 2.50\times10^{-30}\sum_i Z_i^2 + 1.02\times10^{-30}\sum_i Z_i(Z_i+1)\ln\left\{183\cdot Z_i^{-1/3}\right\}\right]\times P_i$$

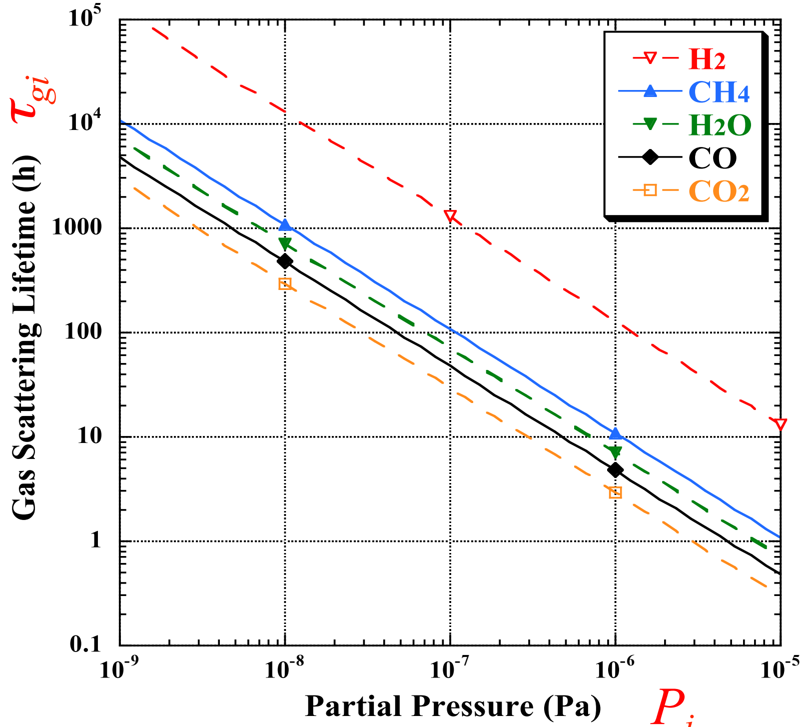
ID gap: GFO

GFO: ID gap is fully opened.

	ID gap: GFO	ID gap: 5 mm
Min. vertical aperture (half-size); a_y [m]	*0.008*	*0.0025*
Min. horizontal aperture (half-size); a_x [m]	0.015	0.015
$\beta^m{}_y$ [m] at a_y	*27*	*4.08*
$\beta^m{}_x$ [m] at a_x	30	30
Average $\langle\beta_y\rangle$ [m]	14	14
Average $\langle\beta_x\rangle$ [m]	7	7
γ_c/γ [−]	0.02	0.02

Parameters of SPring-8-II

➢ Some parameters naturally vary depending on the in-vacuum ID gap.



Expected relationship between τ_{gi} and P_i at GFO

Gas Species	$\tau_{gi}\times P_i$ (Pa·h)
H_2	1.29×10^{-4}
CH_4	1.08×10^{-5}
CO	4.78×10^{-6}
CO_2	2.95×10^{-6}

➢ *The products of τ_{gi} and P_i are to be utilized later for the calculation of the beam lifetime.*

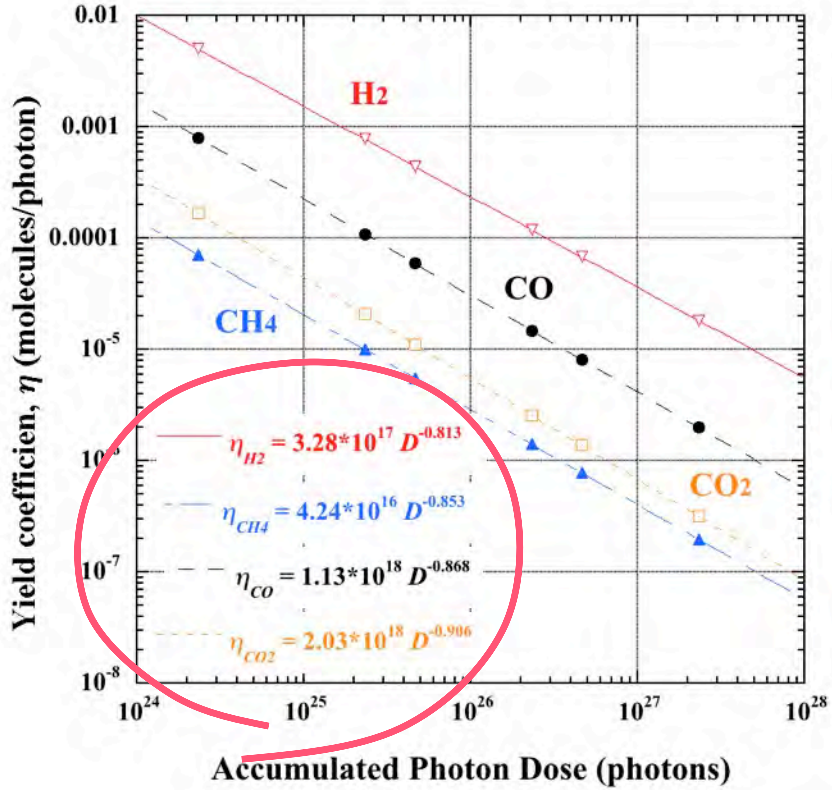
Evaluation of Outgassing Rate

1. Photon Stimulated Desorption (PSD)

- Yield coefficient (η) depends on the material and the accumulated photon dose.
- Since the main materials of the new ring nearly equal to the existing ones.

Measurement results at the SPring-8 are applicable to pressure calculation of the new ring with a consideration of the conversion of 8 GeV into 6 GeV.

H_2, CO	: large outgassing rate
CO_2	: short gas scattering lifetime
CH_4	: NOT evacuated by NEG



PSD yield coefficients (η_i: i=H_2, CH_4, CO, CO_2) as a function of accumulated photon dose.

2. Thermal Desorption (TD)

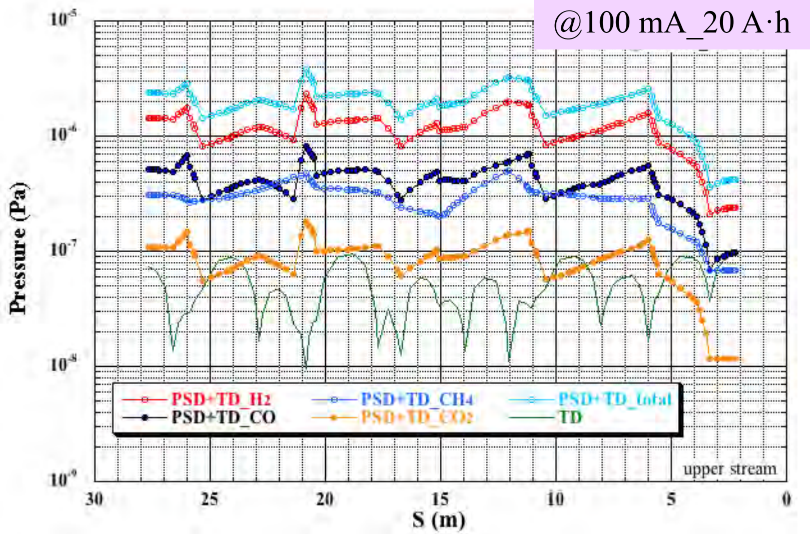
- TD was set to 6.7×10^{-9} ($Pa \cdot m^3/s/m^2$) , which is same as the design value for the SPring-8.
- Composition ratios of H_2 and CO are assumed to be 80% and 20%, respectively.

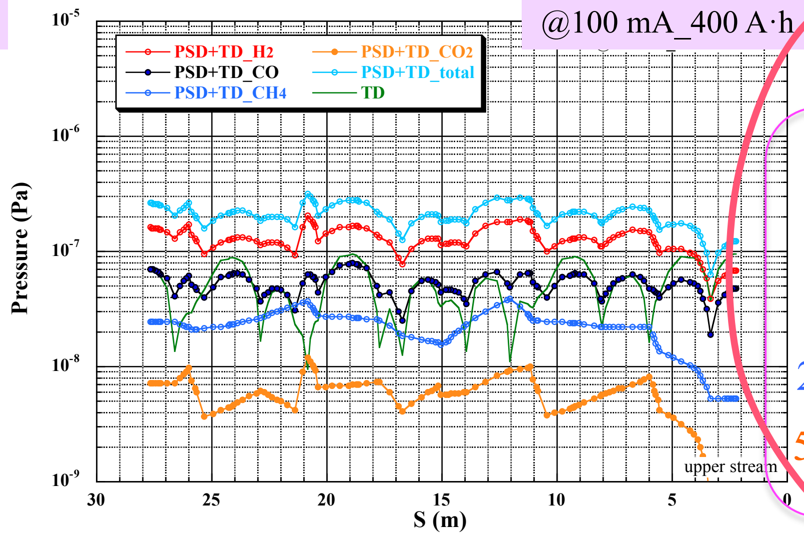
Arrangement of Vacuum Pumps

Targeted beam dose is 400 A·h, when the targeted τ_g is established.

- A suitable arrangement of the pumping system was examined so as to keep the τ_g at 60 h after a beam dose of 400 A·h, when the new vacuum system is supposed to reach steady condition.
- We arranged NEG and SIP at all the discrete photon absorbers where the PSD should be excited.

Pumping System	Pumping Speed (m^3/s)				Position
	H_2	CH_4	CO	CO_2	
1	0.36	0.01	0.17	0.10	CR1, 2; AB1, 2, 3, 4, 6, 7; BCA4
2	0.12	0.01	0.05	0.03	AB8; BCA1, 3
3	0.47	0.01	0.22	0.13	AB5
4	0.23	0.01	0.10	0.06	BCA2, 5





P_i

1.3×10^{-7} (H_2)

5.3×10^{-8} (CO)

2.3×10^{-8} (CH_4)

5.8×10^{-9} (CO_2)

Expected partial pressure distribution in a unit cell except ID section at 20 A·h (Left) and 400 A·h (Right).

Partial Pressure and Beam Lifetime

ID Gap: GFO, 400 A·h

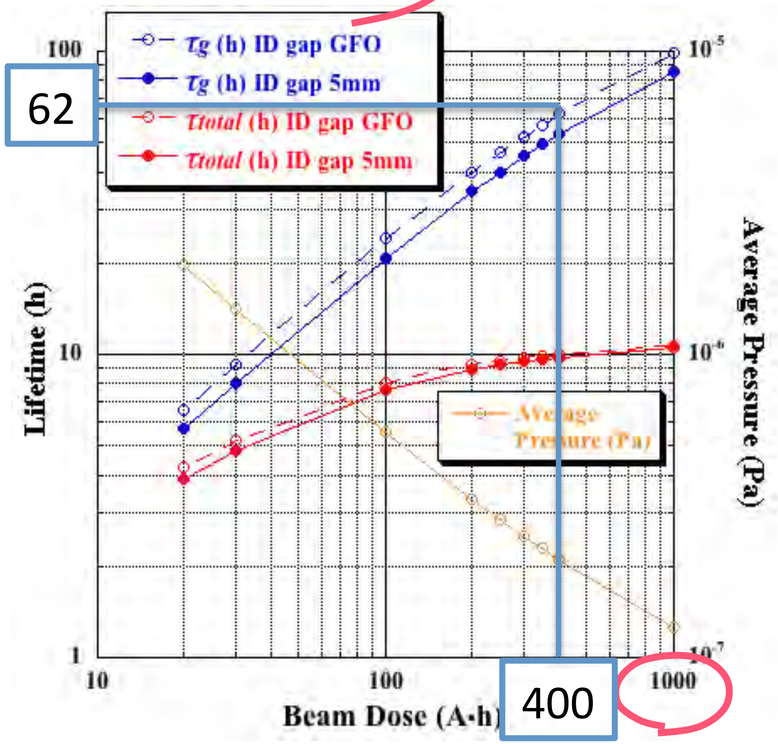
Residual Gas	$\tau_{gi} \times P_i$ (Pa·h)	P_i (Pa)	τ_{gi} (h)
H_2	1.29×10^{-4}	1.3×10^{-7}	992
CH_4	1.08×10^{-5}	2.3×10^{-8}	470
CO	4.78×10^{-6}	5.3×10^{-8}	90
CO_2	2.95×10^{-6}	5.8×10^{-9}	509

$$\frac{1}{\tau_g} = \sum_i \frac{1}{\tau_{gi}}$$

i=H_2, CH_4, CO, CO_2

τ_g=62 h @400 A·h

Average pressure : 2.12×10^{-7} Pa



Gas scattering lifetime and overall beam lifetime at 100 mA as a function of the beam dose.

- At a beam dose of 400 A·h, τ_g will reach 62 h, which exceeds our target of 60 h.
- When beam dose reaches 1,000 A·h, τ_g will reach about 100 h even at ID gap of 5 mm, which is more than seven times the *Touschek*.
- This means that τ_g has no impact on the beam lifetime.

Enough ultimate pressure for the new ring with the top-up operation can be achieved by arranging local pumping systems effectively nearby all the photon absorbers.

Summary and Future Plans

1. **We have started a conceptual design of the storage ring vacuum system for SPring-8-II based on the two significant strategies, namely 1) Exclude in-situ baking including NEG activation from consideration, 2) Start with a proven system design with discrete absorbers and NEG cartridges.**

2. **Judging from the results of ray tracing, it became clear that an arrangement of a pair of photon absorbers in each straight section and a supplementary absorber in each bending chamber would be able to deal with the new lattice design.**

3. **As a result of pressure calculation, it was confirmed that the targeted gas scattering lifetime would be able to be achieved by arranging local pumping system effectively nearby all the photon absorbers.**

4. ***We are mainly focusing on developing 1) thin, light and low-priced TGV with a simple configuration, 2) compact heat-absorbing body with high cooling ability and low vibration, and 3) thin bellows and flanges.***

5. ***In parallel, we are preparing for a prior performance test for a unit vacuum cell, with a view to starting the mass production in the middle of FY2017.***