Conventional e+ Source Rotation Target R/D

T. Omori (KEK)

On behalf of the Truly Conventional Collaboration

ANL, IHEP, Hiroshima U, U of Tokyo, KEK, DESY, U of Hamburg, CERN

Rotation target design study: ongoing with Rigaku

3-Nov-2015

LCWS 2015, The Fairmont Chateau Whistler, Whistler, CANADA

Today's Talk

R/D of the Slow Rotation Target of the Conventional e+ Source for ILC

(1)Summary of the R/D in 2013-2014, and
the first half of 2015.

(2) Plan of the R/D in 2015-2016.

Conventional e+ Source for ILC

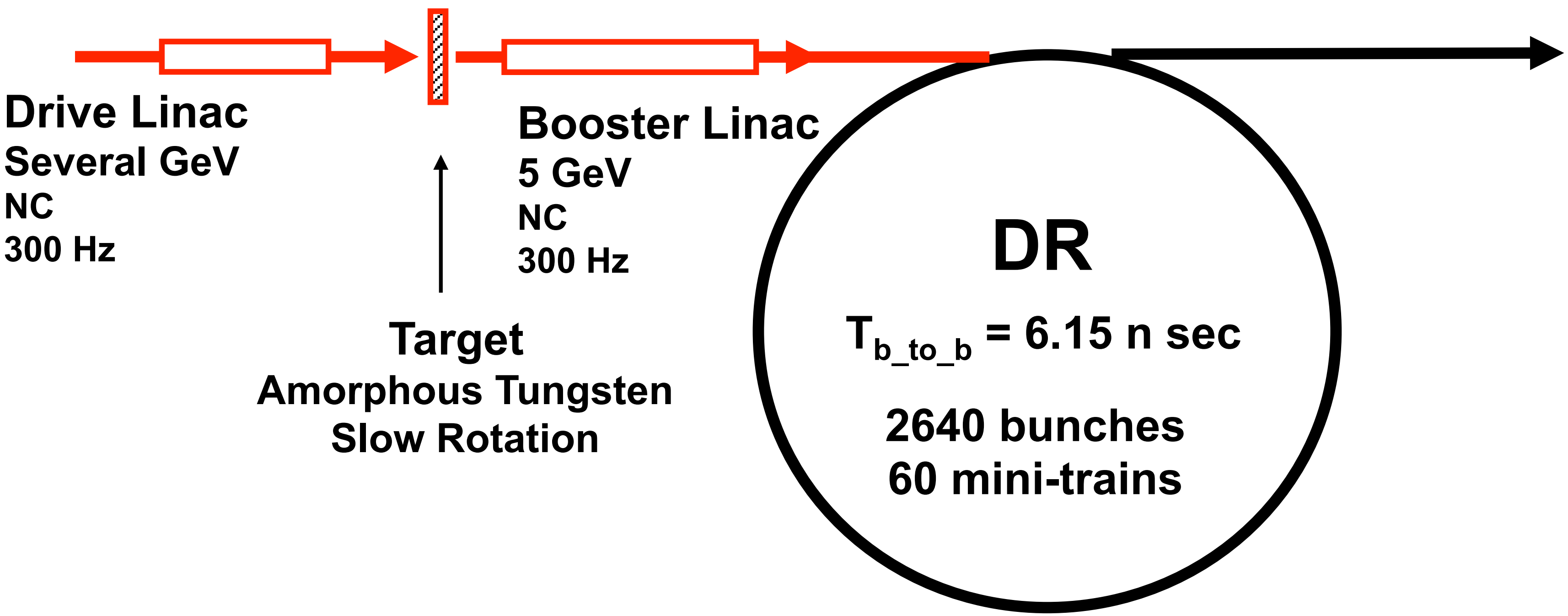
Normal Conducting Drive and Booster Linacs in 300 Hz operation

e+ creation

20 triplets, rep. = 300 Hz
- **triplet = 3 mini-trains with gaps**
- **44 bunches/mini-train, $T_{b\_to\_b}$ = 6.15 n sec**

go to main linac

2640 bunches/train, rep. = 5 Hz
- **$T_{b\_to\_b}$ = 369 n sec**



Time remaining for damping = 137 m sec

We create 2640 bunches in 63 m sec ⇐ **Stretching**

NIM A672 (2012) 52—56

Conventional e+ Source for ILC

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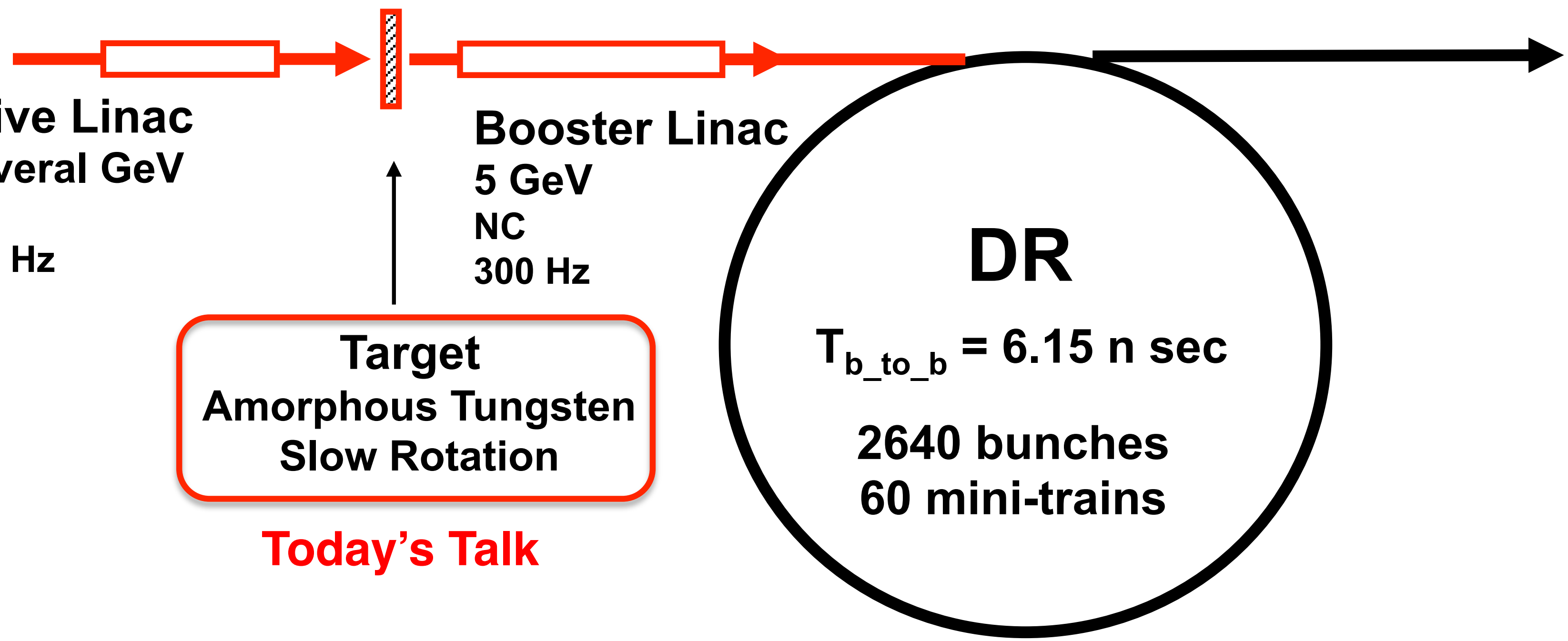

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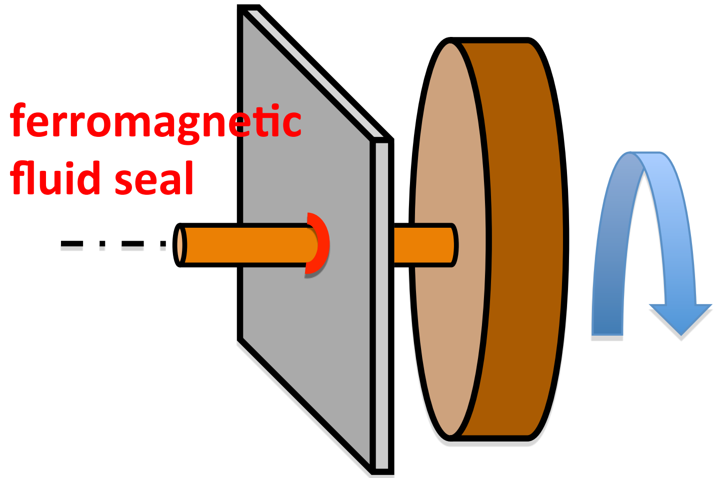
We create 2640 bunches
in 63 m sec ⇦ Stretching

NIM A672 (2012) 52—56

Moving Target

- ~5m/sec required (1/20 of undulator scheme)

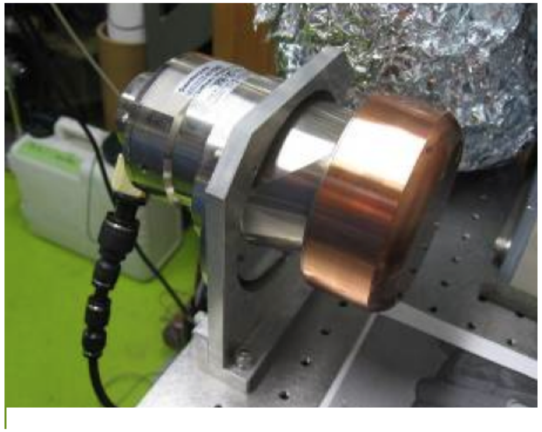
rotating target with ferromagnetic seal



main issue: vacuum

The target R/D in 2013-2014, and the first half of 2015.

TEST: Vacuum Leak Rate FY2013


Small (d=10 cm) off-the-shelf rotation target

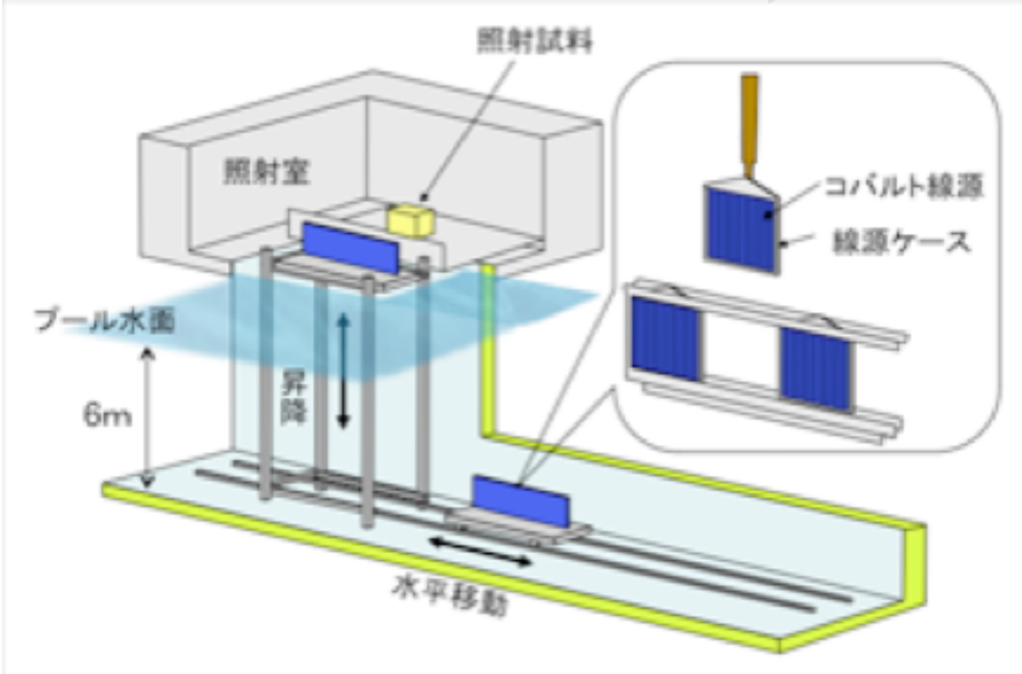
Conclusion: No problem

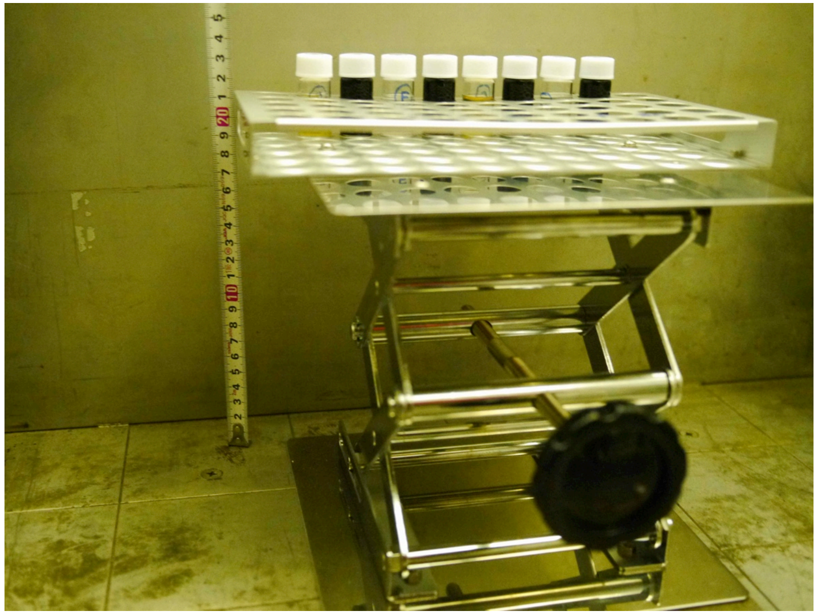
Leak Rate Measurement:
various speed, various temperature
no problem (both CN-oil and F-oil)

Lake rate was small enough.
We can get P< $1x10^{-7}$ Pa, if we put reasonable pumps (several 1000 letters/s) at the upstream of the target.

Radiation Tolerance Test FY2013

Takasaki Advanced Radiation Research Institute, JAEA





Gamma-ray source: Co 60

1.1×10^4 Gy/h

Photo: Dec/2013

TEST: Radiation Tolerance

FY2013: Conclusion

F-oil

Dissociation/degradation occurred at low dose, 0.27 MGy. No hope.

CN-oil

Viscosity increased, but NO dissociation/ degradation occurred.

-->

We planed more systematic study.

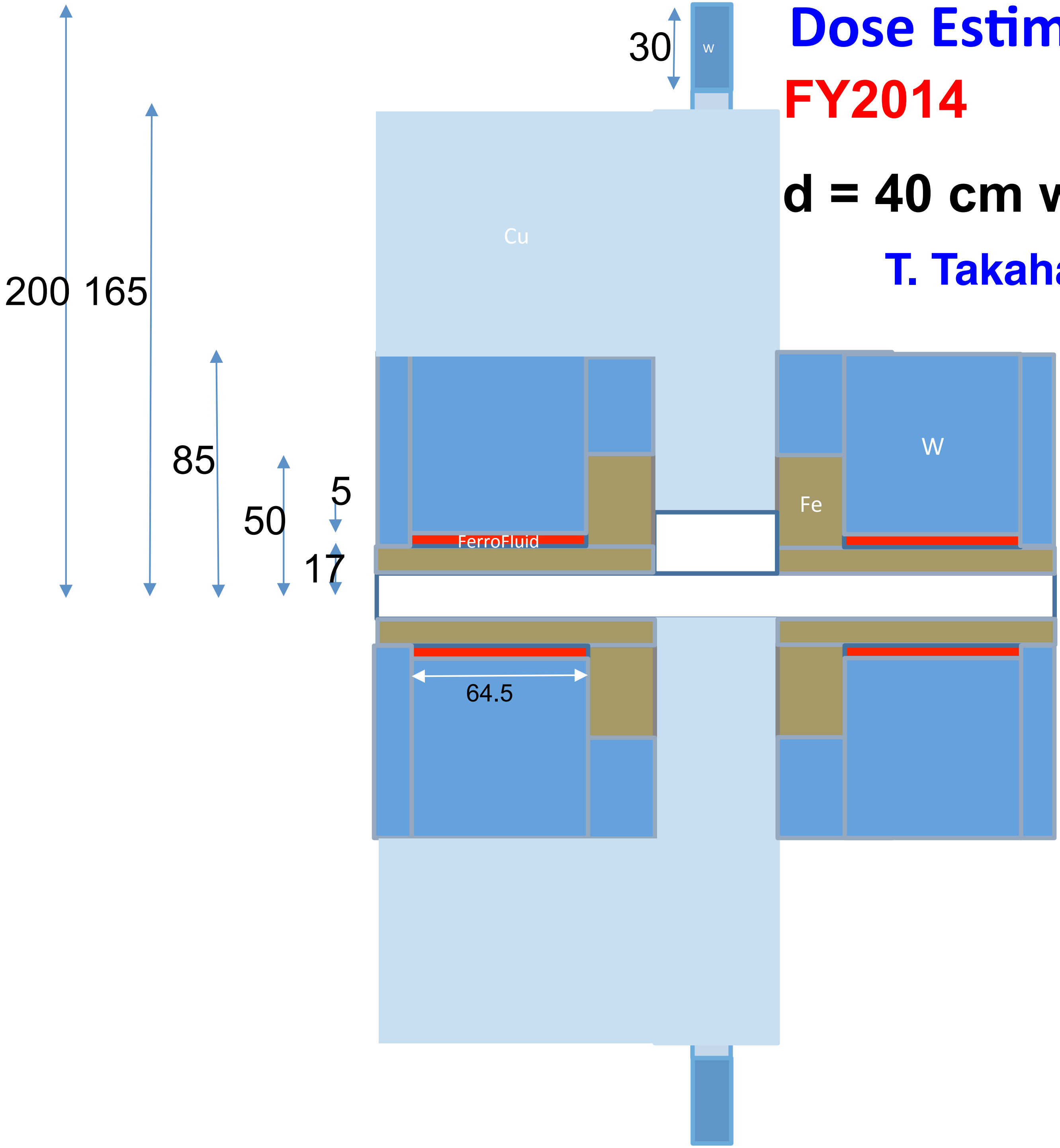
- **Viscosity change as a function of dose.**
- **Use irradiated fluid in vacuum seal.**

Dose Estimation

FY2014

d = 40 cm with radiation shield

T. Takahashi (Hiroshima)

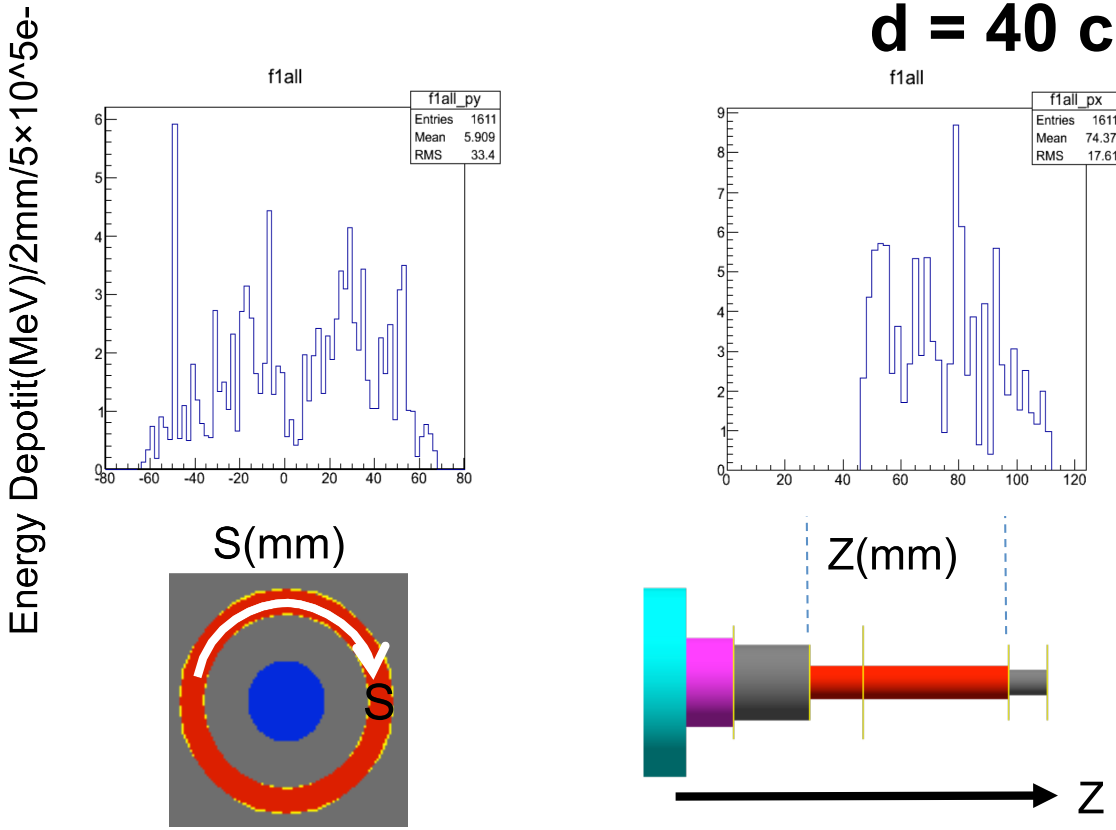


Results

Dose Estimation

FY2014

d = 40 cm with radiation shield



T. Takahashi (Hiroshima)

Peak 1.5MGy/year

(**2630 bunches/pulse**, 5Hz 2e10/bunch 1 year = 10^7s)

TEST: Radiation Tolerance   FY2014

Takasaki Advanced Radiation Research Institute, JAEA

November 2014

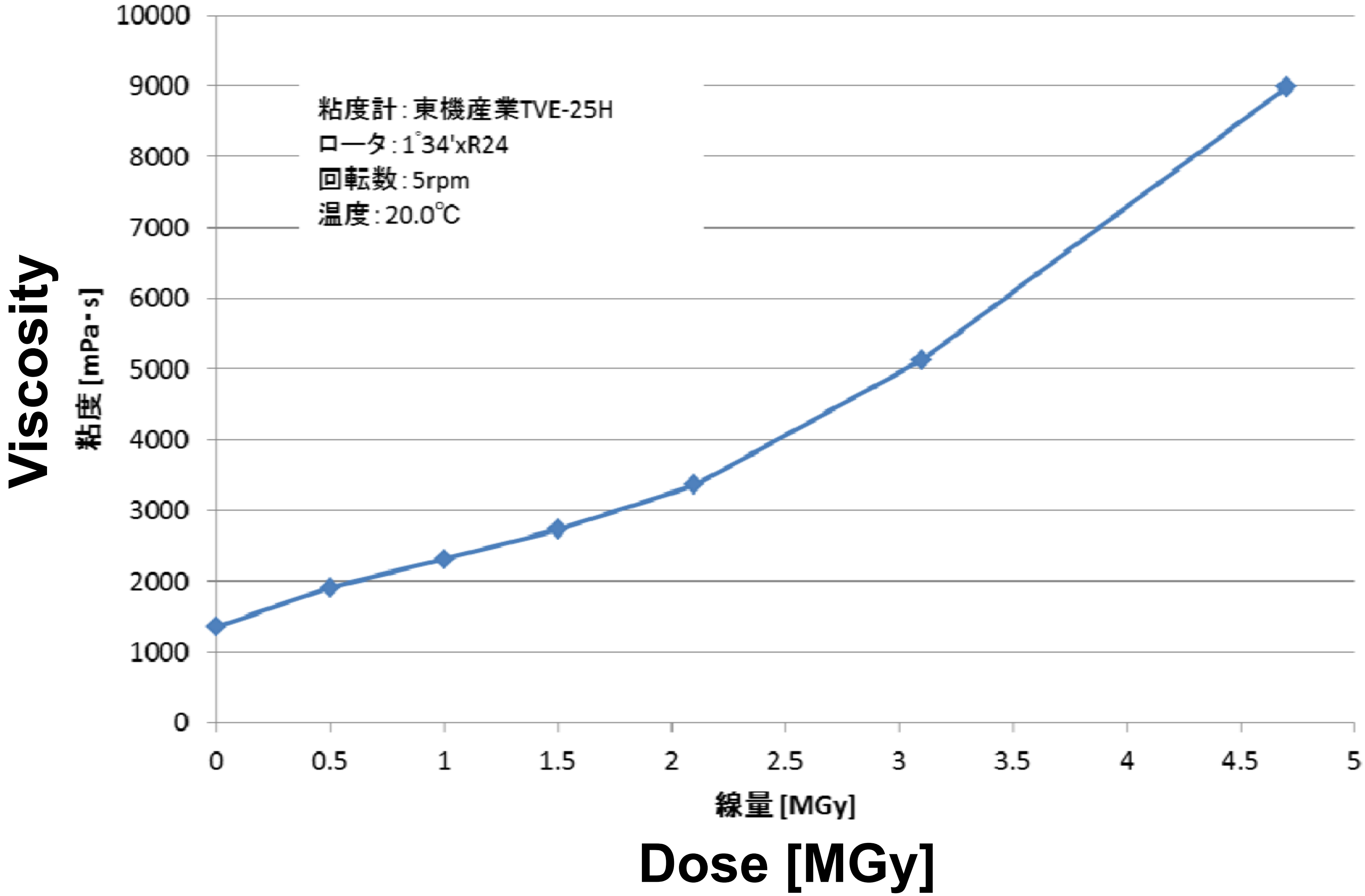
10-Nov-2014

TEST: Radiation Tolerance FY2014 November 2014

More systematic study for CN oil

Viscosity as a function of dose

放射線量と磁性流体の粘度の関係



TEST: Radiation Tolerance FY2014 November 2014

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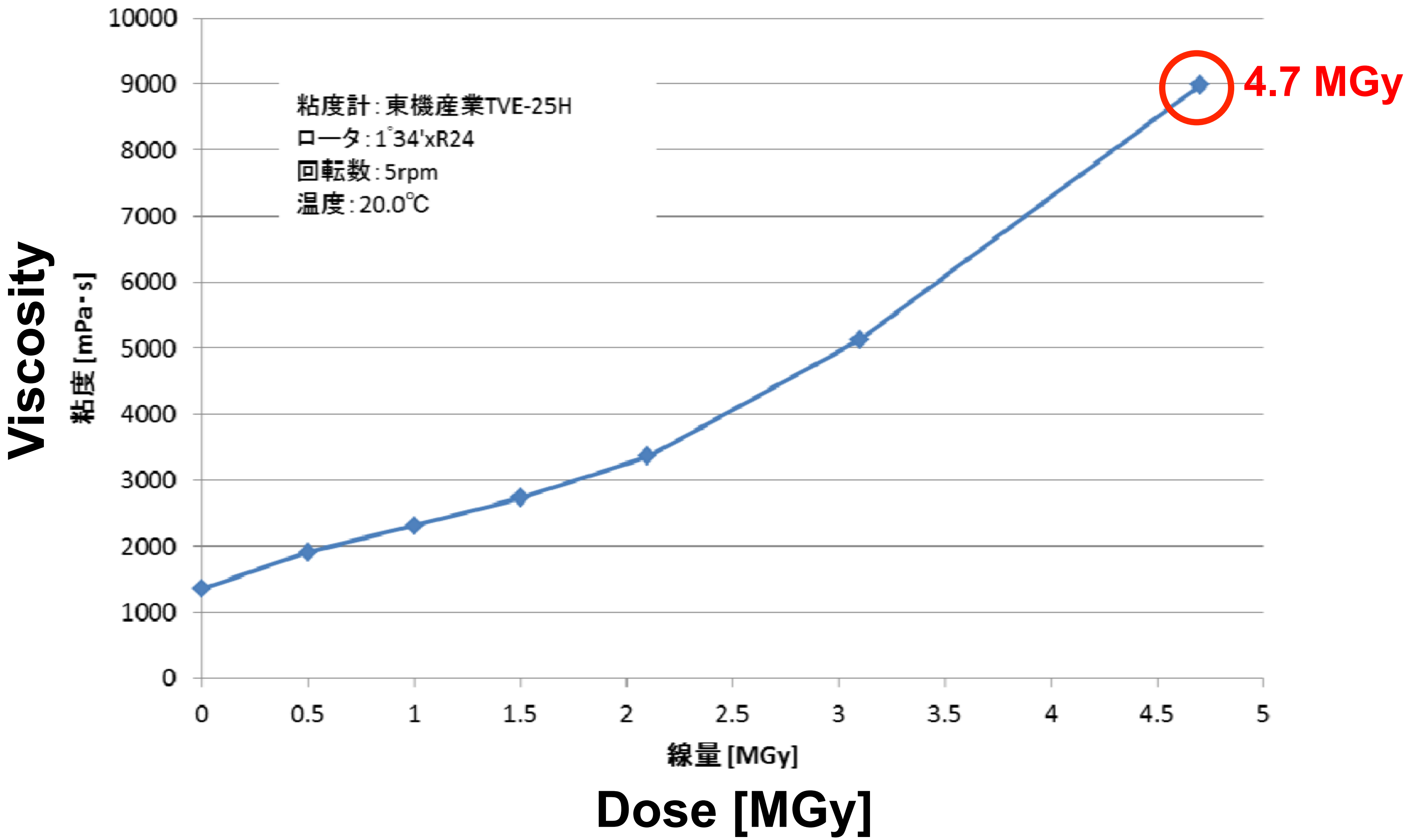
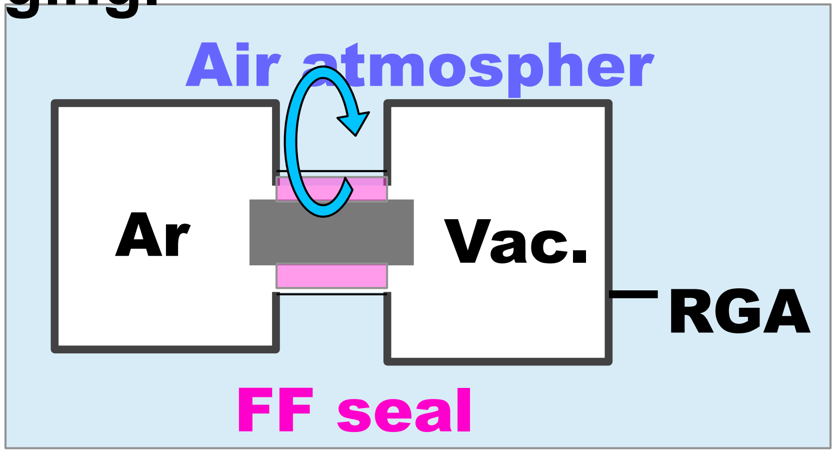


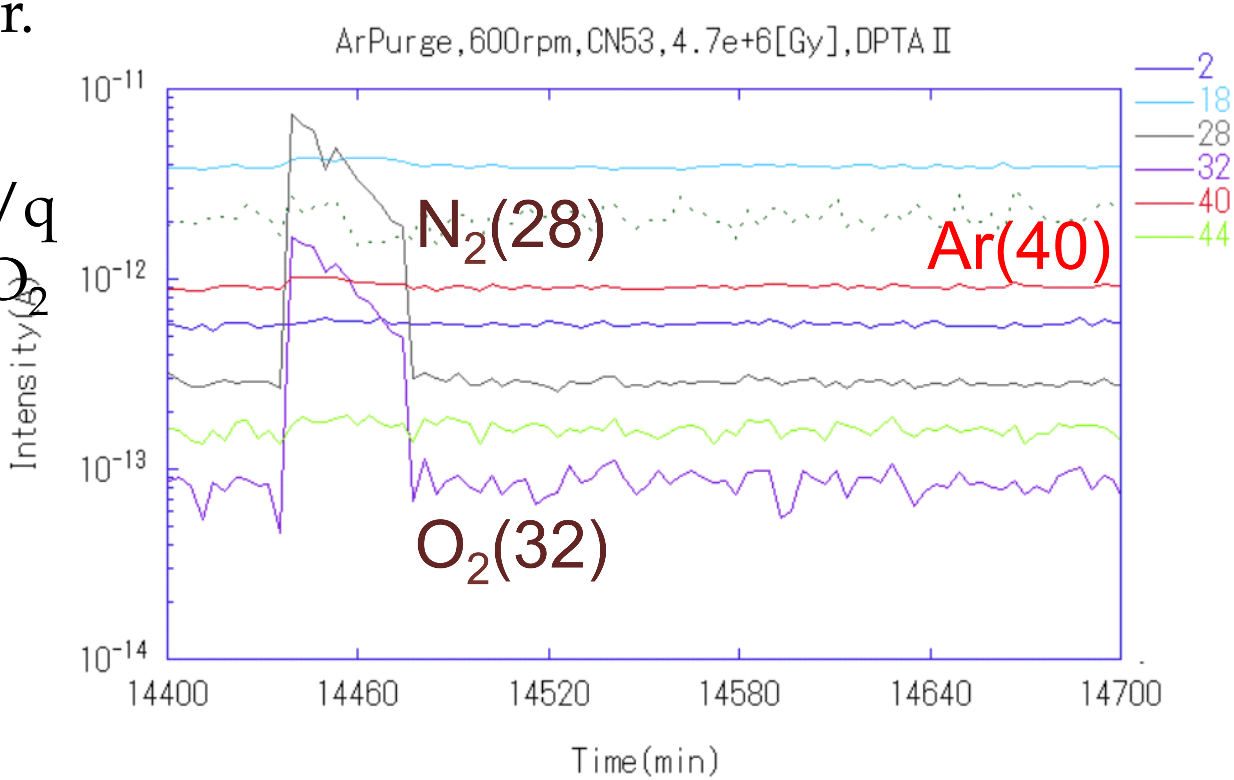
PY2014: Radiation Test:

- **We used irradiated CN-oil (4.7 MGy) in a small rotation target.**
- **Made vacuum test after Ar-purging.**



Ar purge seal test

- The seal dosed 4.7 MGy (3 ILC year) is examined with Ar purged chamber.
- Rotation : 0-600 rpm.
- **No leak was found.** (m/q = 28 and 32 are N_2 and O_2 from air)



Rotation target design study: ongoing with Rigaku

FY2014-2015

Points:

Diameter, material, shape, rotation speed, cooling,,,

B-filed on the target disk (Hiroshima),

Flux concentrator (IHEP, BINP)

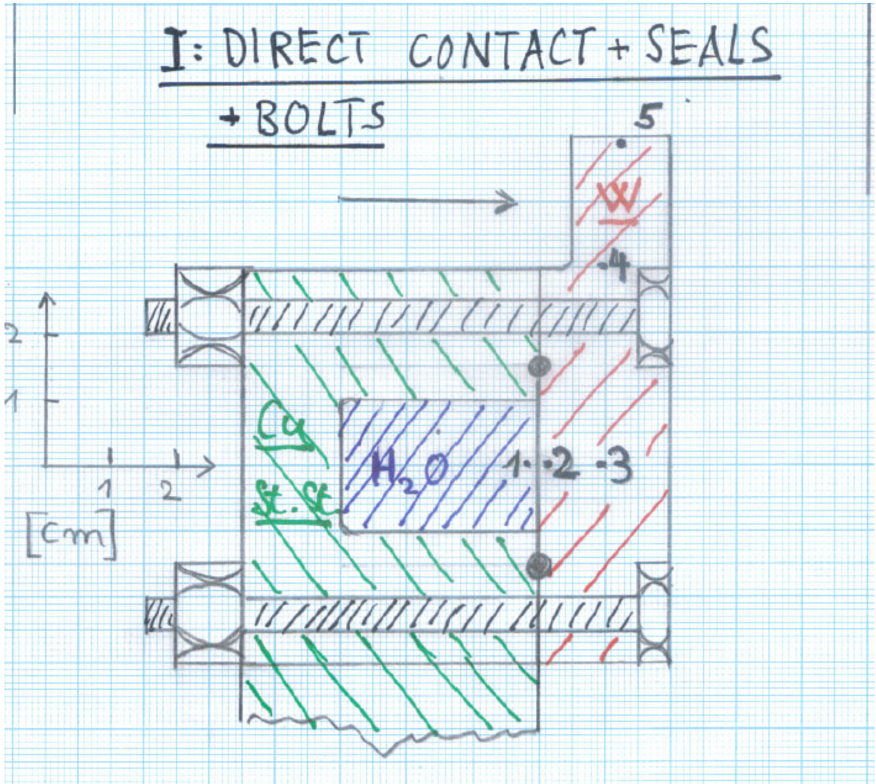
Peter SIEVERS (CERN)

Rotation target design study

FY2014

I Direct Cooling

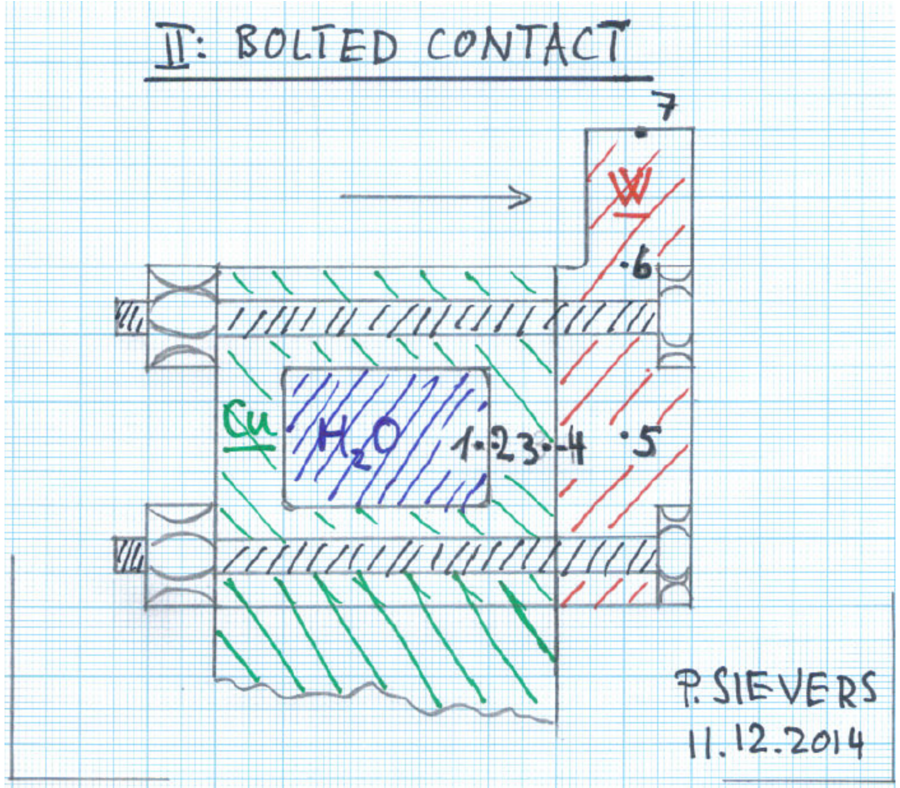
I 直接冷却



W-Cu joint
metal gaskets
remain UHV leak tight?

II Indirect Cooling

II 間接冷却



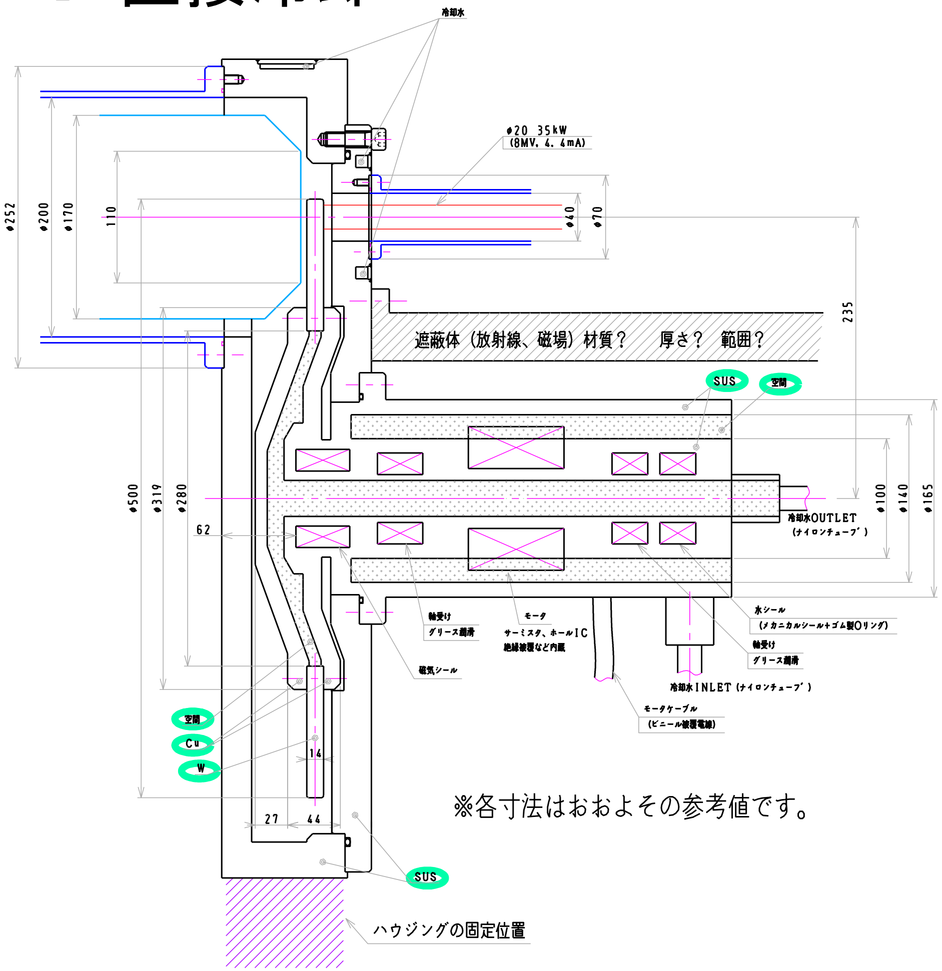
"monolithic welded water circuit
entirely of the same material (Cu)"

Rigaku

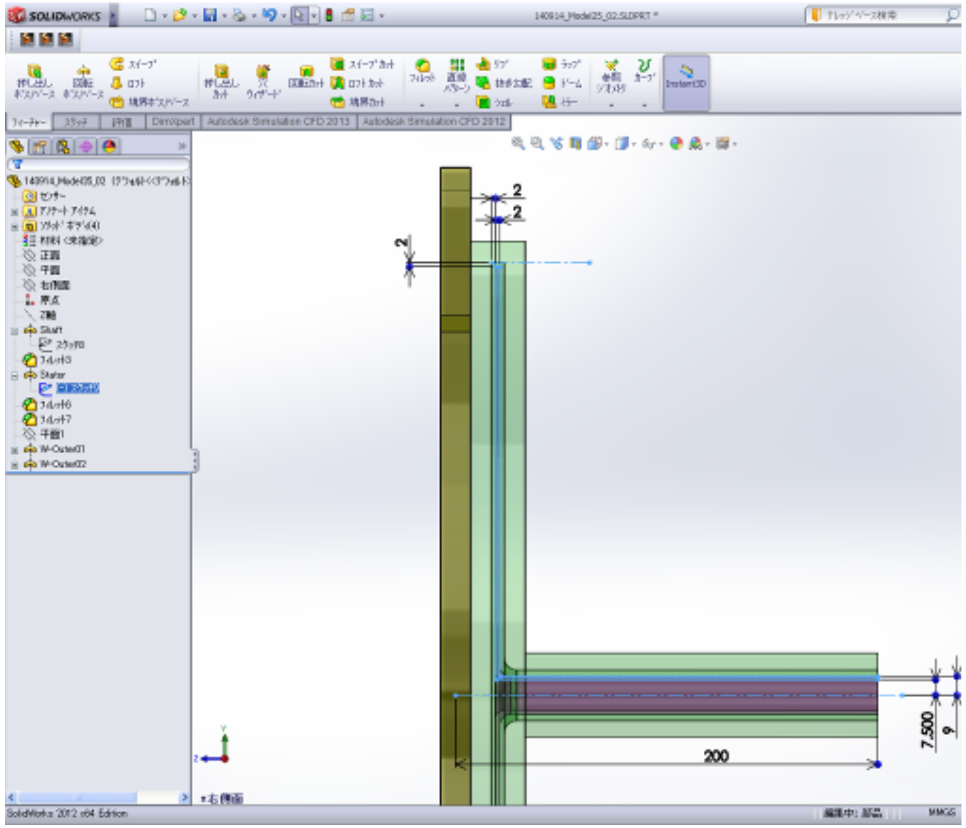
Rotation target design study

FY2014

Ⅰ Direct Cooling
Ⅰ 直接冷却

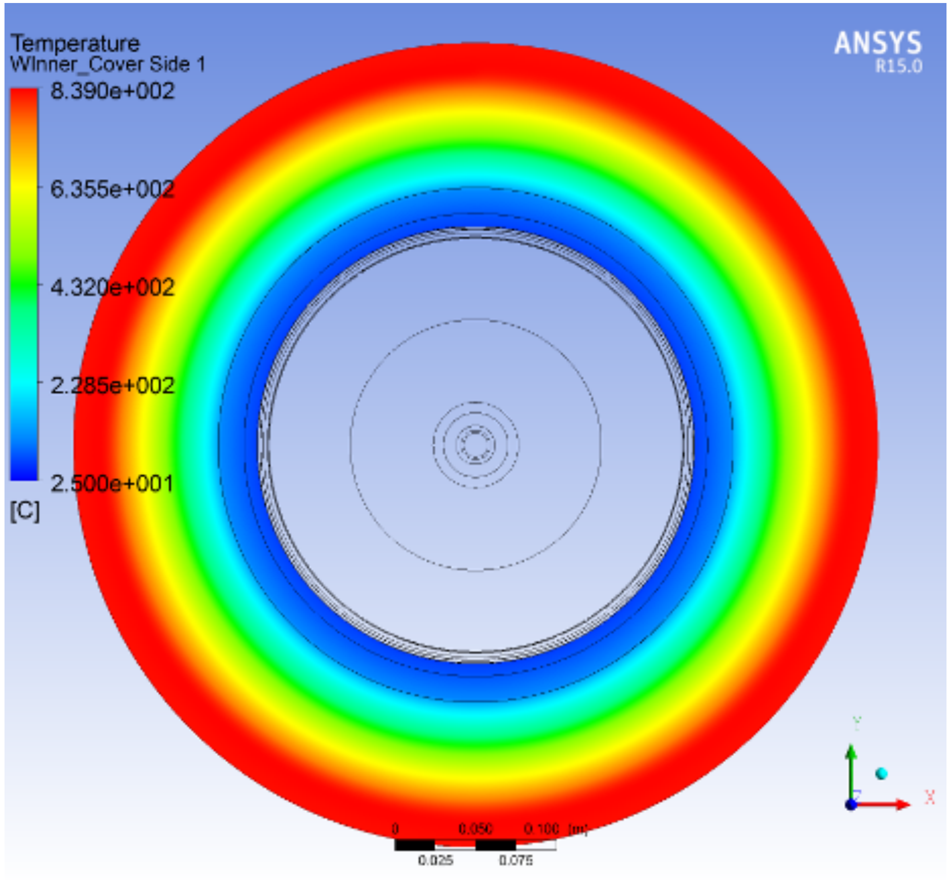


Ⅱ Indirect Cooling
Ⅱ 間接冷却



Rigaku FY2014 **Rotation target design study**

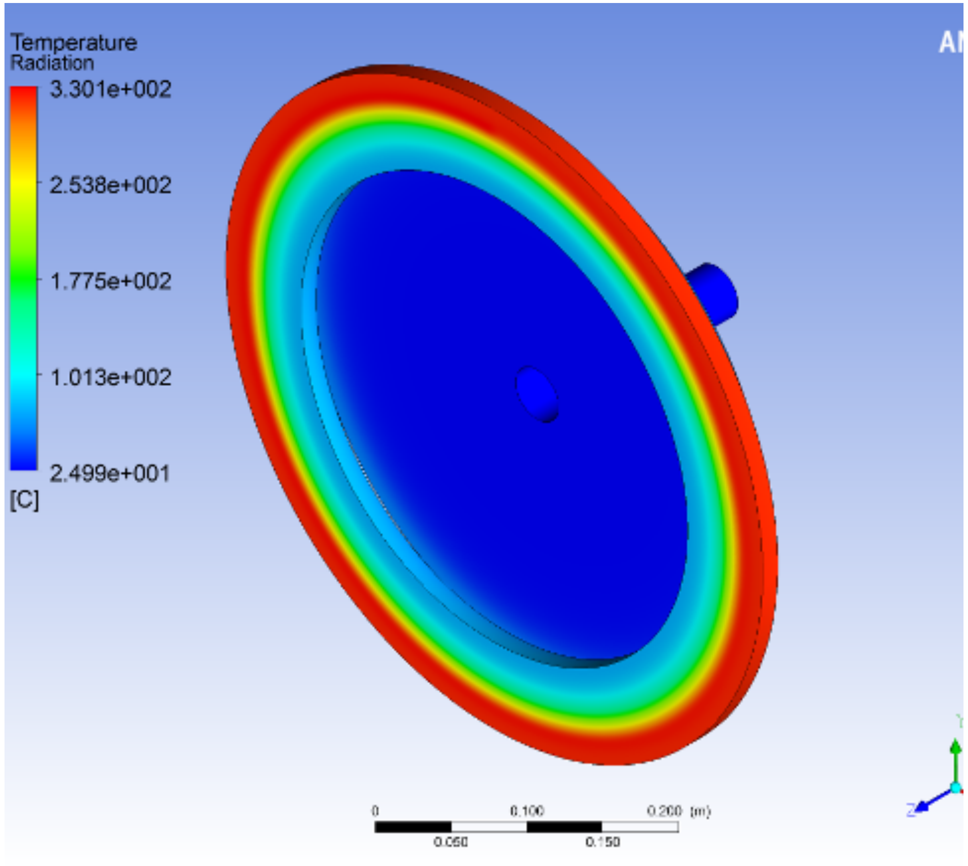
Ⅰ Direct Cooling



Temperature Distribution

Max. 840℃

Ⅱ Indirect Cooling



Temperature Distribution

Max. 330℃

600rpm

CW Beam

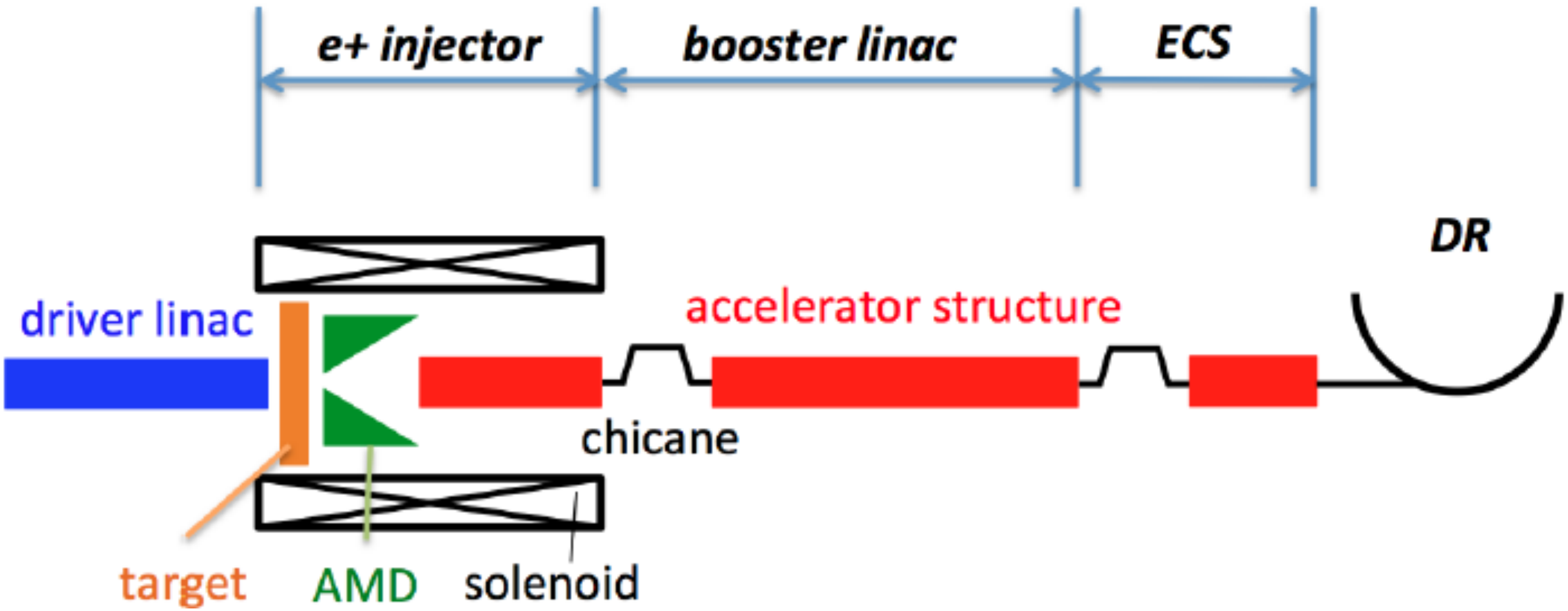
Conclusion: Indirect cooling is better.

Seimiya & Kuriki
(Hirosima U.)

FY2014 Rotation target design study

AMD is employed is a capture section.
The AMD will be a pulse Flux Concentrator.

Seimiya, Kuriki (Hirosima U.), et al.
Submitted to PTEP



Need to consider the effect of the Flux Concentrator leakage field on the target disk.

FY2014 Rotation target design study

The effect of the FC leakage field on the target.

(1) The FC B-field is pulse.

The pulse is fast.

half cycle ~12 micro second (roughly sinusoidal)

Dominant

(2) The target is rotating.

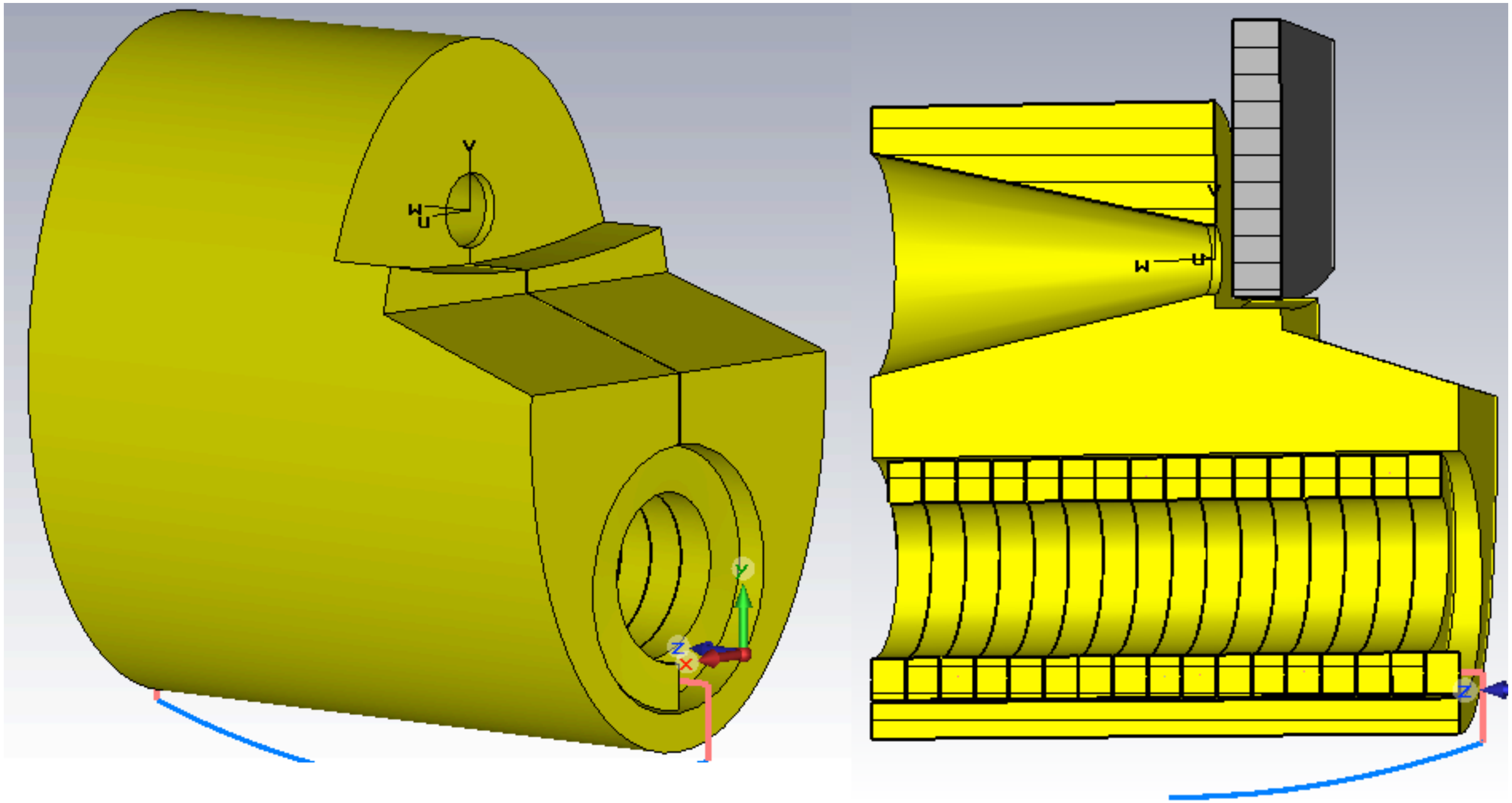
Rotation is slow. ~5 m/s.

Small, Negligible (2)/(1) ~ 1/1000

Pavel Martyshkin (BINP) FY2015 Rotation target design study

Flux Concentrator (FC) leakage field on the target disk.

Cone diameter is 16 mm (Nose FC)



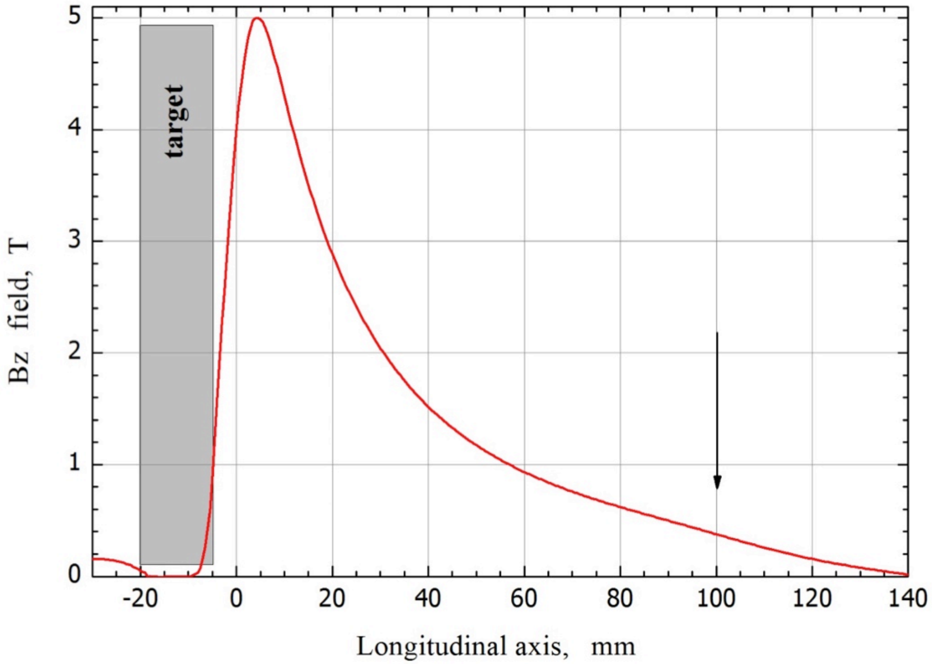
Sun Xianjin (IHEP) also made a study too, based on another design (2014-2015).

Pavel Martyshkin (BINP) FY2015 Rotation target design study

Flux Concentrator (FC) leakage field on the target disk.

Cone diameter is 16 mm (Nose FC)

B = 1 Tesla at Target Disk



	Nose FC type D 16 mm
Peak current	25 kA
Peak field	5 Tesla
Peak transverse field	50-60 mTesla
Current shape	half of sine
Current pulse length	25 μs
Target ohmic loss	≈ 10 J/pulse
FC ohmic loss	≈ 140 J/pulse
Repetition rate 300 pps *	
Target losses *	3.2 kW
FC losses *	**41 kW**

* When we calculate real average, we need to divide the numbers by three.

Sun Xianjin (IHEP) also made a study too, based on another design.

FY2014-2015 **Rotation target design study**

The effect of the FC leakage field on the target.

Heating:

1 kW (3.2 kW in 63 msec). It is 1/30 of the heat by beam.

Conclusion: No problem.

Note:
At LCWS2015 (Tsukuba), Omori reported heating is 190kW. It was rough estimate by hand.
Omori reported that we need cure.
But new conclusion based on detail simulation is NO PROBLEM.

Forces:

Small in both braking and attractive/repulsive forces.

Conclusion: No problem.

Thermal Analysis: Target Model and Cooling Condition

FY2014-2015

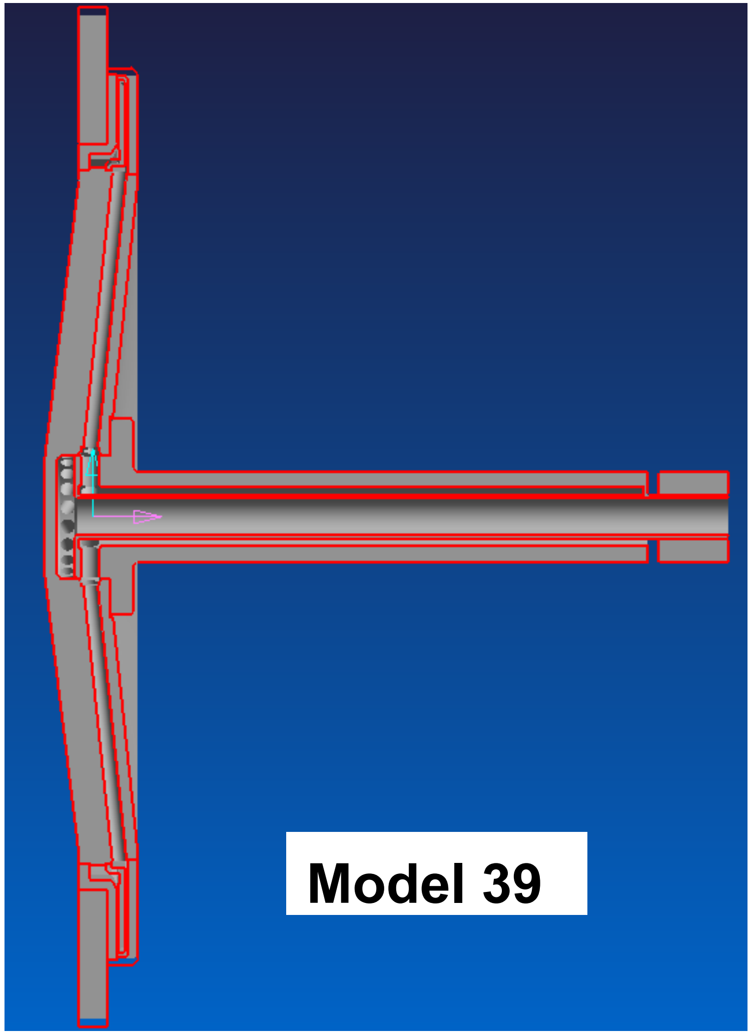
Model : 500 mm diameter rotation target

Rim (φ500-φ366×14t) W + Central Cu Disk (water flow inside)

Rotation: 200 - 600rpm

Water temperature at inlet: 25 °C

Software; ANSYS CFX



Thermal Analysis:

We did both CW beam analysis (for simplicity) and pulse beam analysis (more realistic).

We assume 2600 bunches in all analysis.

- CW beam analysis

  38kW (35kW+3kW(*)) CW

  ↑ beam ↑ FC

FY2014-2015

* Note
3 kW is not correct
should be 1 kW

- Pulse beam analysis: step 1

  114.1 kW(111.1kW+3kW) 63 ms

  0 kW (0kW+0kW) 137 ms

  ↑ beam ↑ FC

FY2015 New
Reported in Posipol 2015

- Pulse beam analysis: step 2

  20 trains (pulses) in 63 ms

New^2

- Common condition

  Cooling water: 30 ℓ/min, T at inlet: 25℃

Rigaku

Thermal Analysis:

We did both CW beam analysis (for simplicity) and pulse beam analysis (more realistic).

We assume 2600 bunches in all analysis.

- CW beam analysis

  38kW (35kW+3kW(*)) CW

  (35kW: beam, 3kW: FC)

FY2014-2015

* Note
3 kW is not correct
should be 1 kW

- Pulse beam analysis: step 1

  114.1 kW(111.1kW+3kW) 63 ms

  0 kW (0kW+0kW) 137 ms

  (first term: beam, second term: FC)

FY2015 New
Reported in Posipol 2015

- Pulse beam analysis: step 2

  20 trains (pulses) in 63 ms

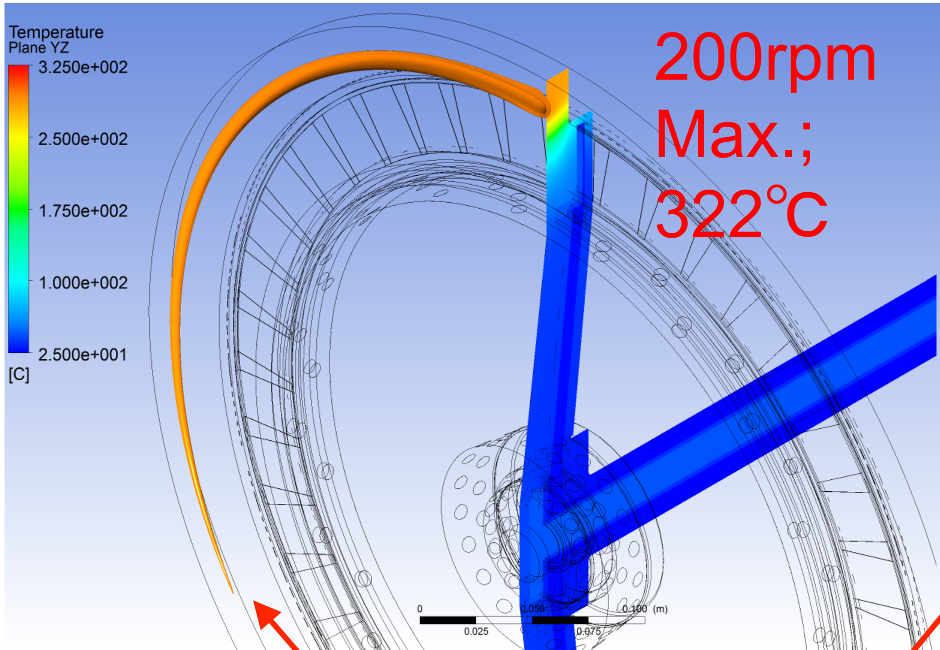
New^2

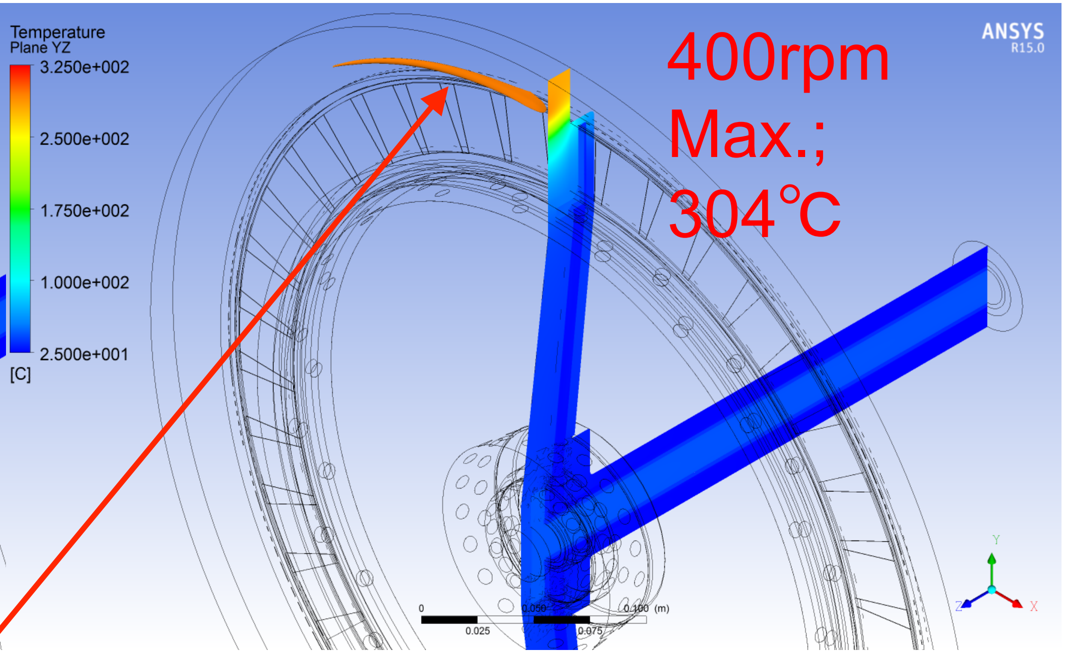
- Common condition

  Cooling water: 30 ℓ/min, T at inlet: 25℃

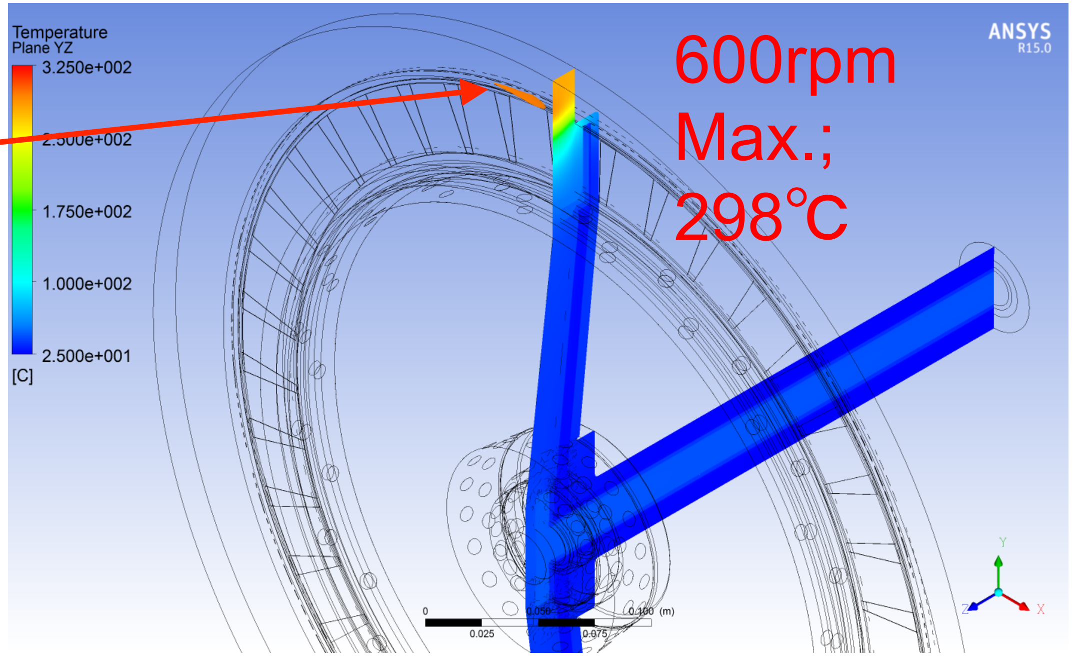
Rigaku

Temperature in various rotation speeds: CW beam analysis





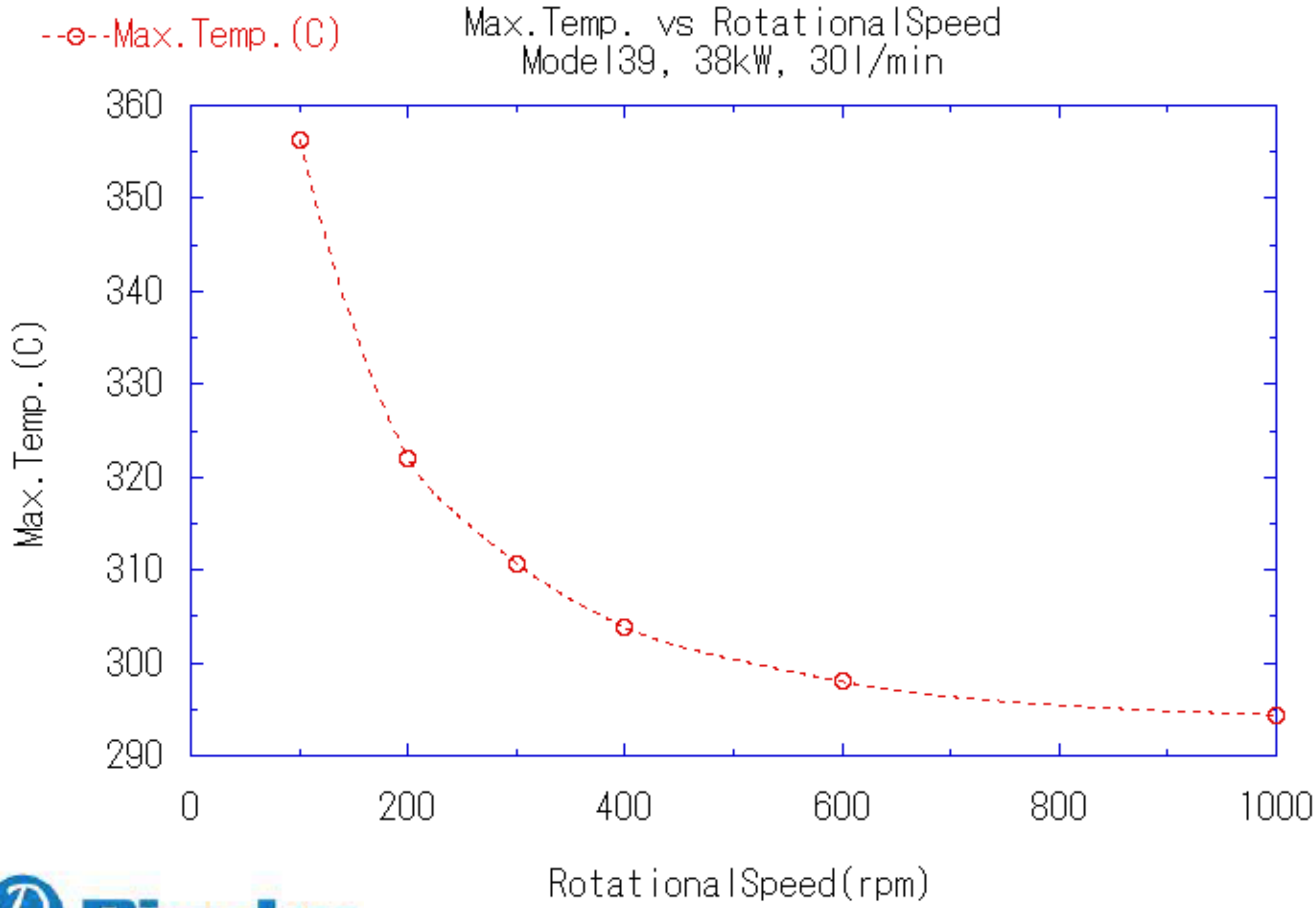
等温度平面;
295°C



Rigaku

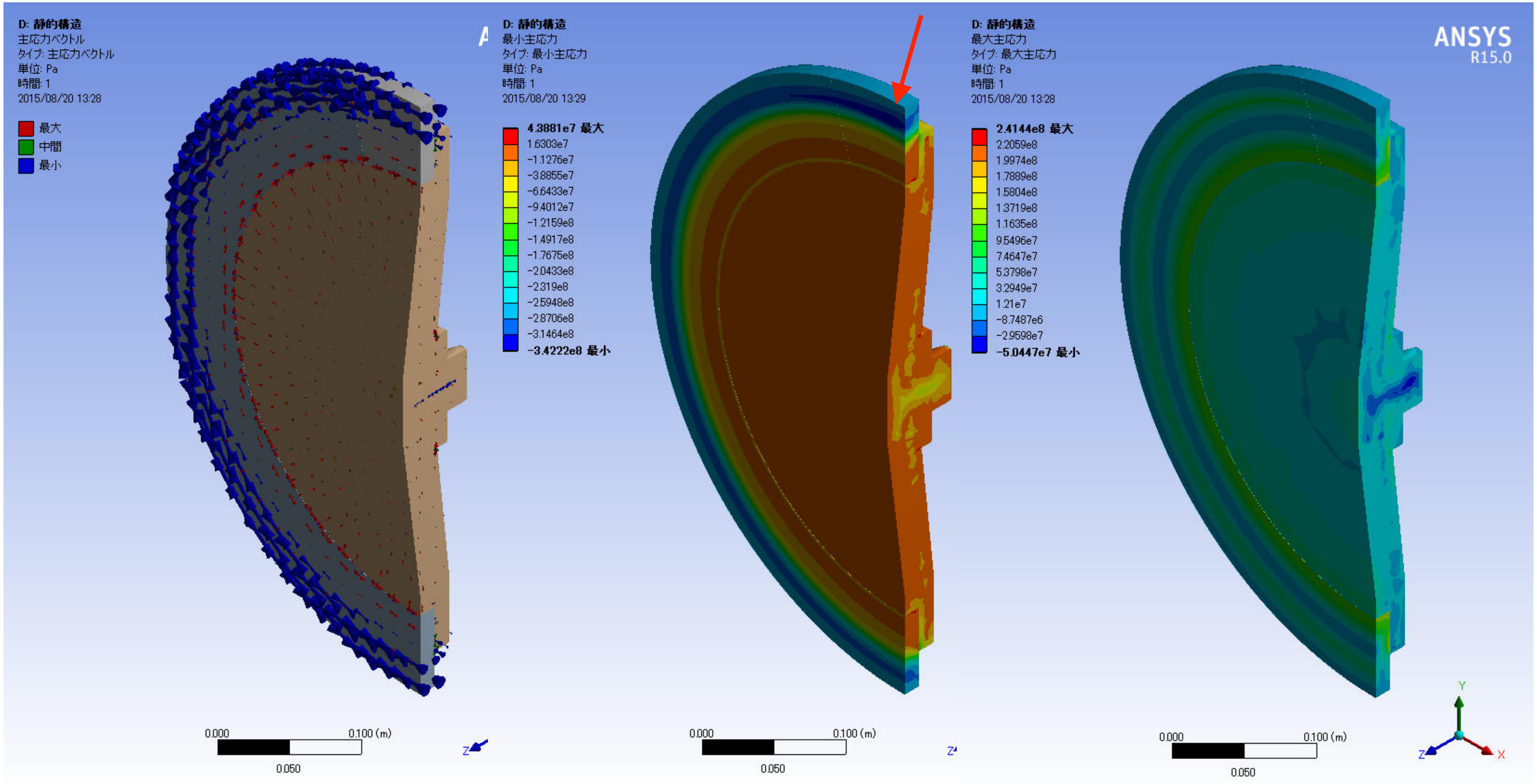
Nb=2600

Temperature in various rotation speeds: CW beam analysis



Nb=2600

Stress: rotation speed 200 rpm, CW Beam analysis



Direction (arrows)

Min Principal Stress (Compression) → - 3e+8Pa

Max Principal Stress (Expansion) → 2e+8Pa

Rigaku

Nb=2600

高温部の応力を正確に得る為に非定常解析が必要

Thermal Analysis:

We did both **CW beam** analysis (for simplicity) and **pulse beam** analysis (more realistic).

We assume **2600 bunches** in all analysis.

- CW beam analysis

  38kW (35kW+3kW$^{(*)}$) CW

  ↑ beam ↑ FC

FY2014-2015

* Note
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should be 1 kW

- Pulse beam analysis: **step 1**

  114.1 kW(111.1kW+3kW) 63 ms

  0 kW (0kW+0kW) 137 ms

  ↑ beam ↑ FC

FY2015 New
Reported in
Posipol 2015

- Pulse beam analysis: **step 2**

  20 trains (pulses) in 63 ms

New^2

- Common condition

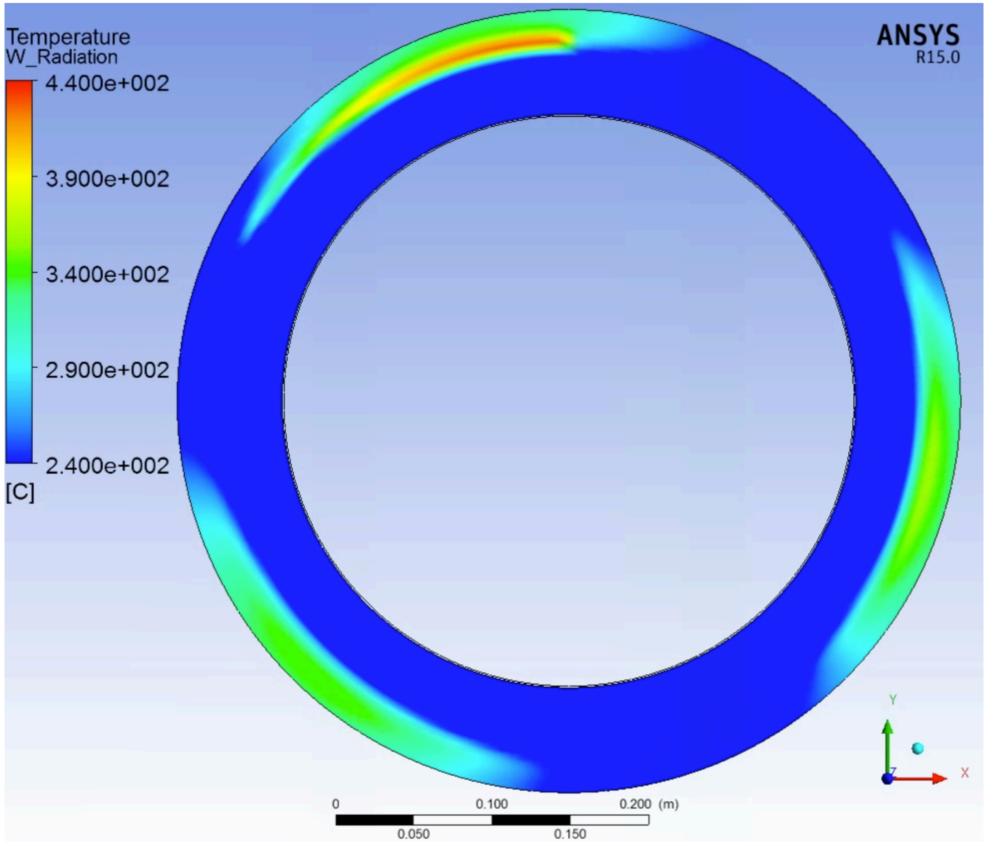
  Cooling water: 30 ℓ/min, T at inlet: 25℃

Rigaku

Pulse beam analysis: Comparison of 200 rpm and 220 rpm

step 1

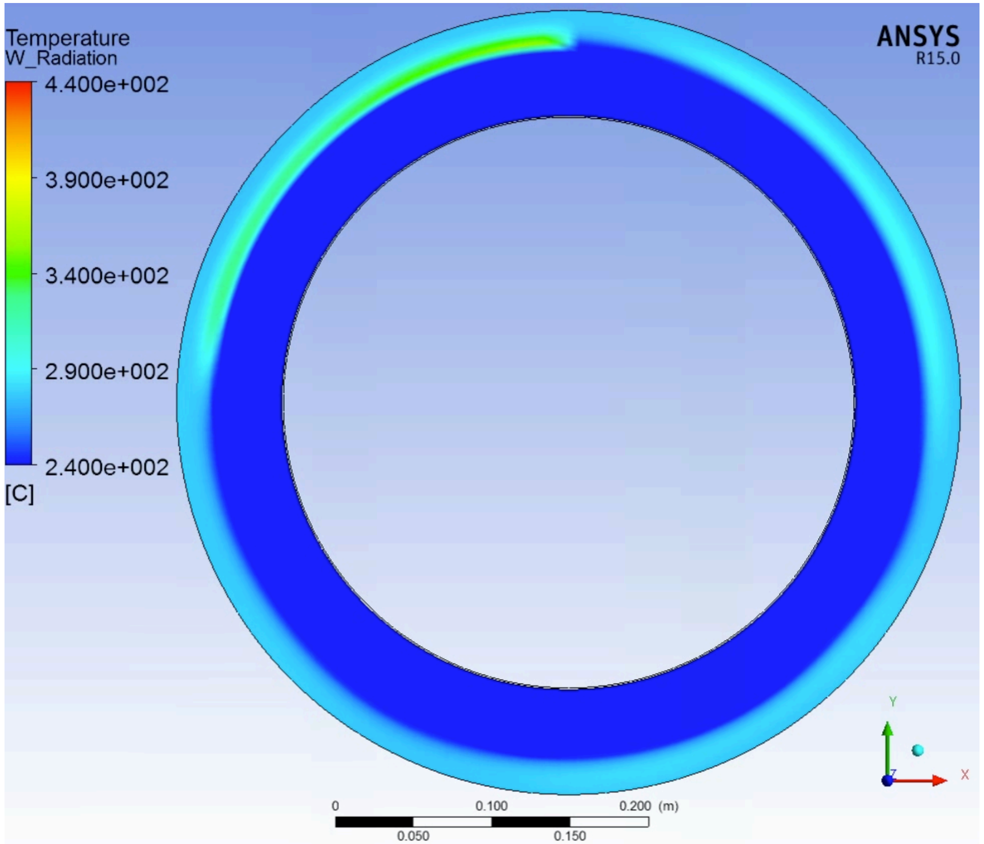
200 rpm



After reaching steady state

Max Temp = 441 °C

220 rpm



After reaching steady state

Max Temp = 373°C

220 rpm is BETTER than 200 rpm.

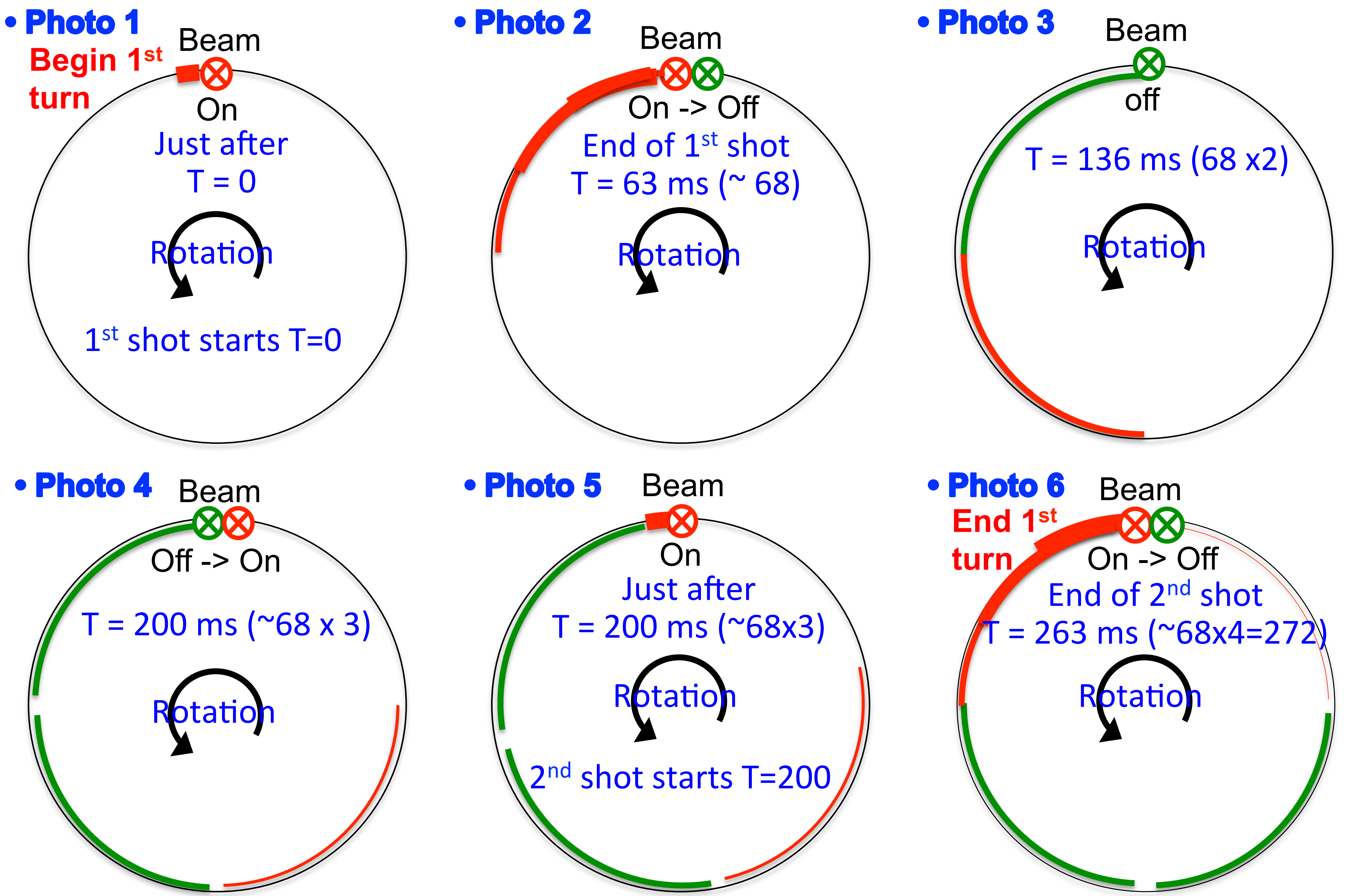
At 220 rpm: Temperature more UNIFORM and LOWER maximum value.

Simulated by Rigaku Nb=2600

At Posipol 2015, Omori presented 200 vs 180.

Rotation = 220 rpm : Photos of 1st turn.

Photos = Lab. Frame Views

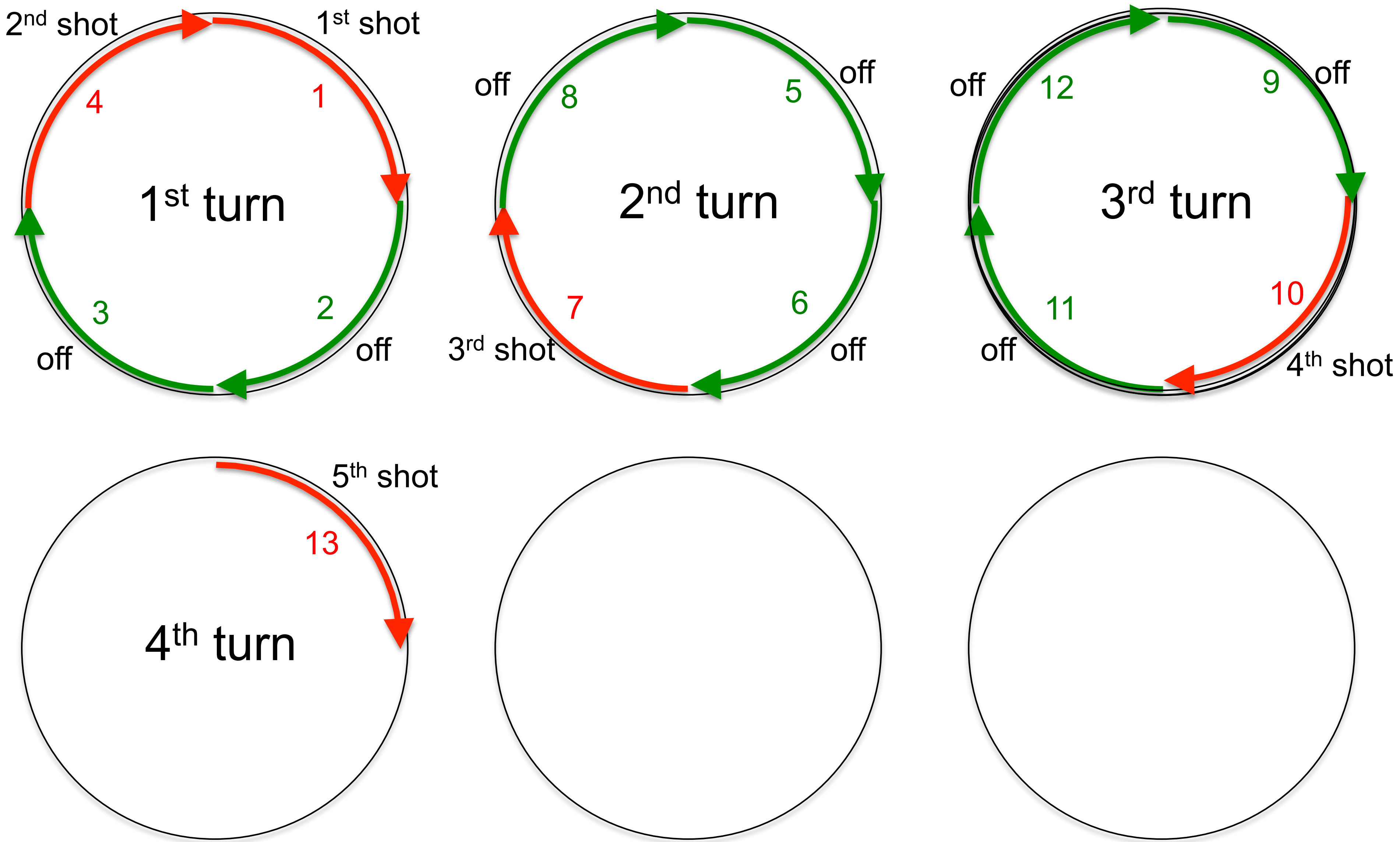


One turn takes 272 m sec. 272 m sec / 4 = 68 ms 68 ms ~ 63 ms (duration of beam on)

68 ms x 2 ~ 137 ms (duration of beam off) 68 ms x 3 = 200 ms (one cycle of ILC)

Rotation = 220 rpm

Target Rest Frame Views



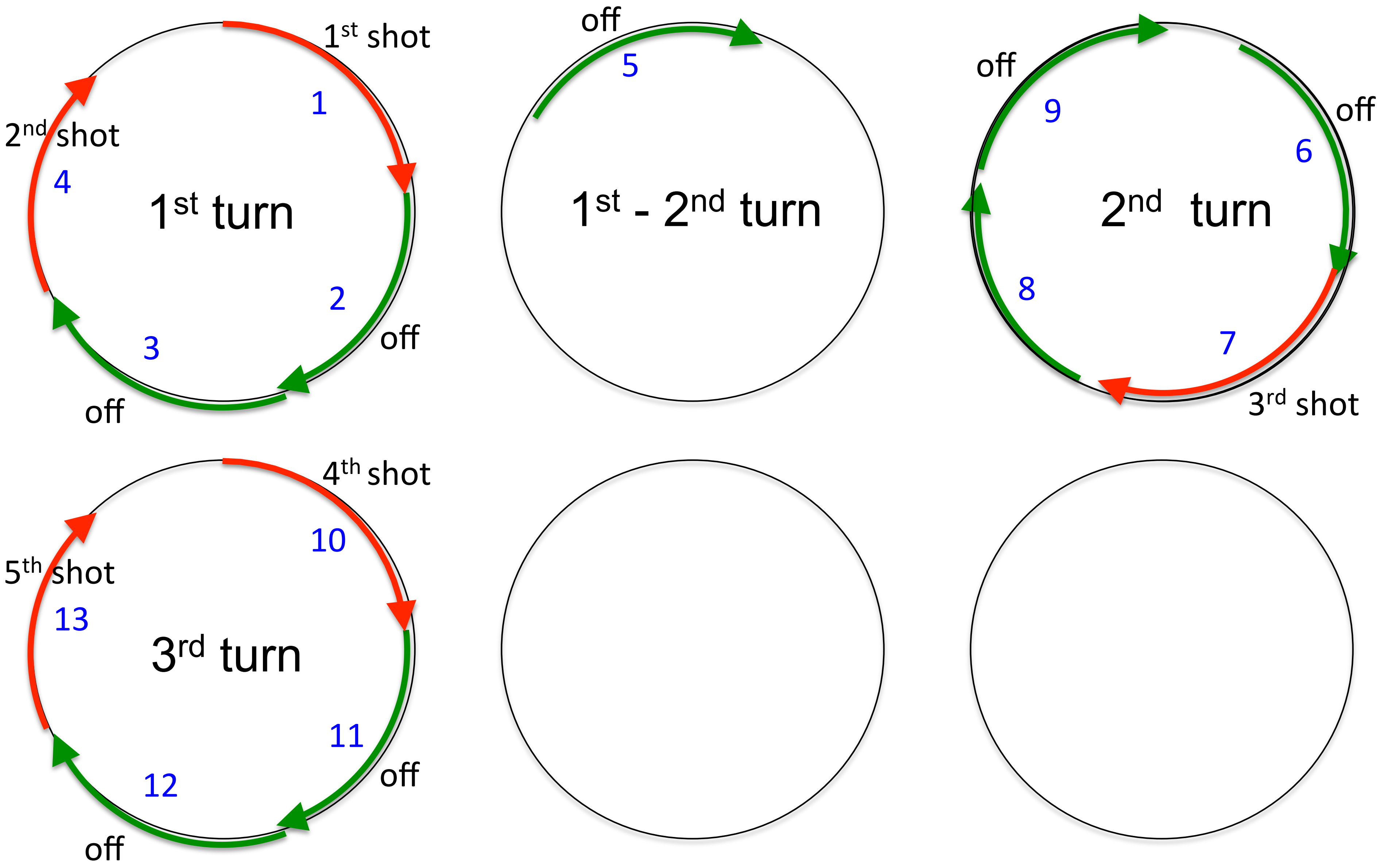
One turn takes about 272 m sec.

Each Red number (1, 4, 7, 10, 13) corresponds 63 m sec.

Each Green number (2,3, 5,6, 8,9, 11,12) corresponds 68.5 m sec.

63ms + 68.5ms + 68.5ms = 200ms

Rotation = 200 rpm **Target Rest Frame Views**



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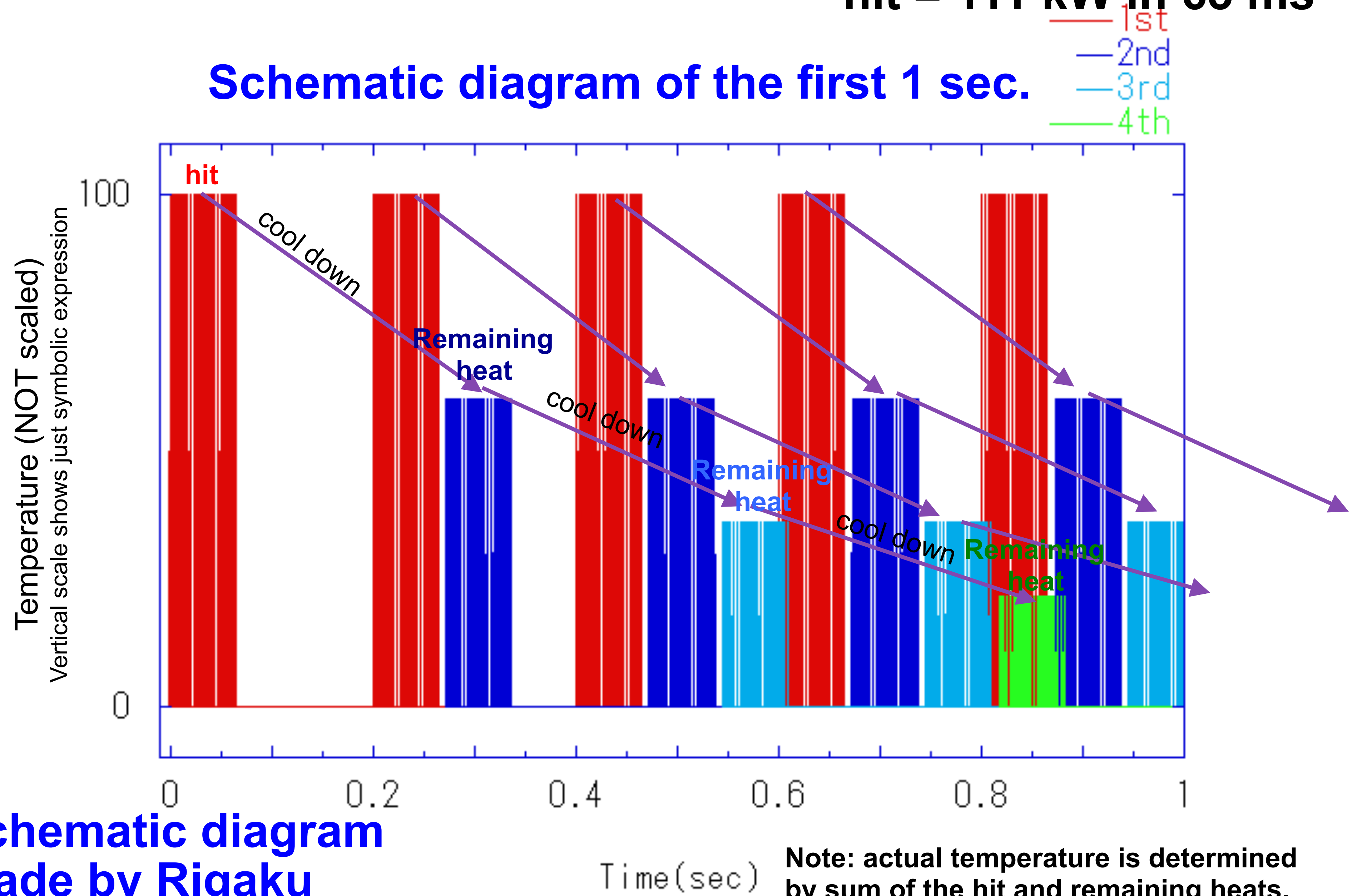
Each Green number (2,3, 5,6, 8,9, 11,12) corresponds 68.5 m sec.
63ms + 68.5ms + 68.5ms = 200ms

Pulse Beam Diagram

Rotation speed = 220rpm

hit = 111 kW in 63 ms

Schematic diagram of the first 1 sec.



Schematic diagram made by Rigaku

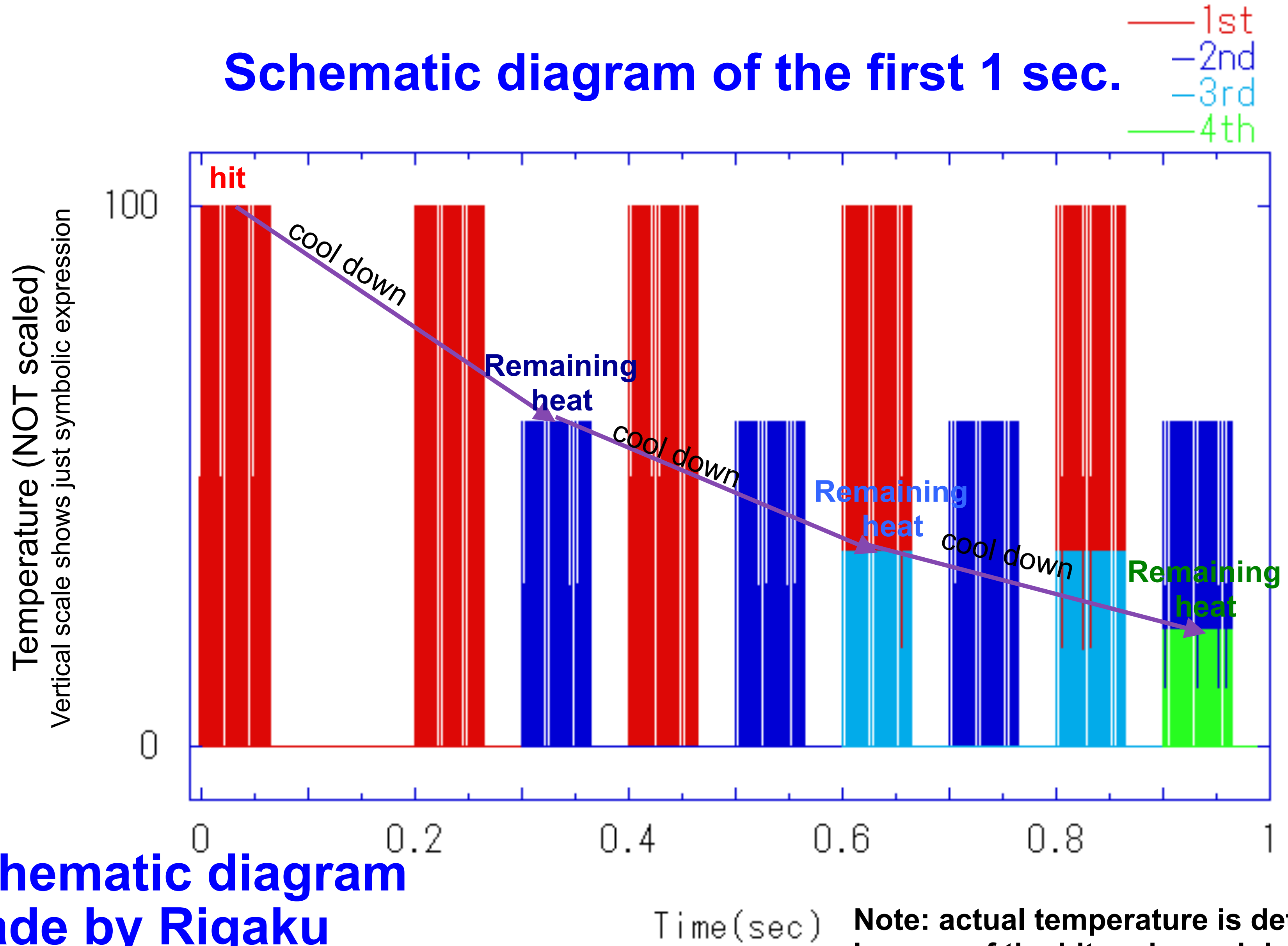
Note: actual temperature is determined by sum of the hit and remaining heats.

Pulse Beam Diagram

Rotation speed = 200rpm

hit = 111 kW in 63 ms

Schematic diagram of the first 1 sec.



Schematic diagram made by Rigaku

Note: actual temperature is determined by sum of the hit and remaining heats.

Thermal Analysis:

We did both CW beam analysis (for simplicity) and pulse beam analysis (more realistic).

We assume 2600 bunches in all analysis.

- CW beam analysis

  38kW (35kW+3kW(*)) CW

  ↑ beam ↑ FC

FY2014-2015

* Note
3 kW is not correct
should be 1 kW

- Pulse beam analysis: step 1

  114.1 kW(111.1kW+3kW) 63 ms

  0 kW (0kW+0kW) 137 ms

  ↑ beam ↑ FC

FY2015 New
Reported in Posipol 2015

- Pulse beam analysis: step 2

  20 trains (pulses) in 63 ms

New^2

- Common condition

  Cooling water: 30 ℓ/min, T at inlet: 25℃

Rigaku

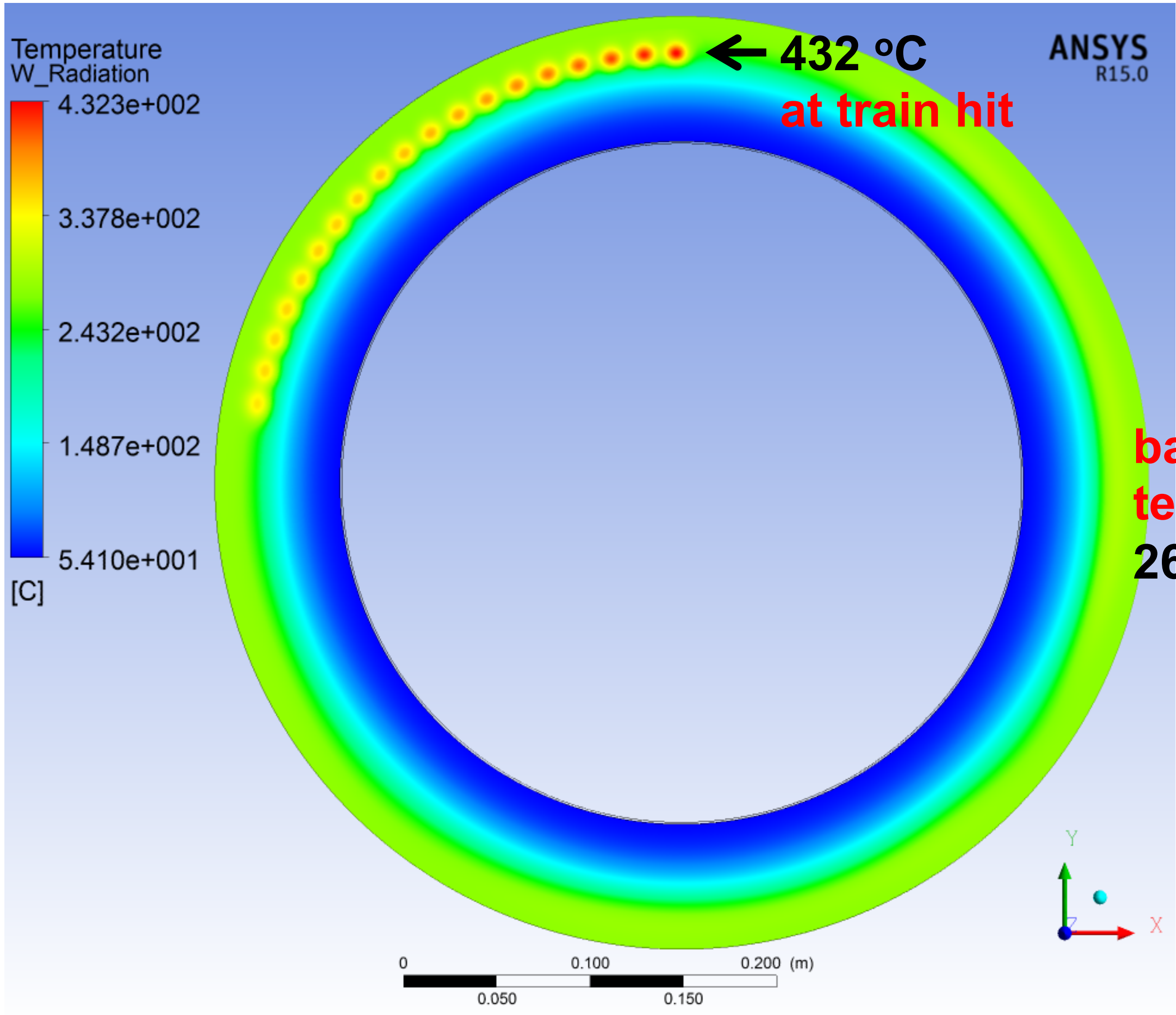
Pulse Beam Analysis step 2:

20 trains in 63 ms

Rotation speed = 220rpm

1 train = 373 kW(**) in 0.99 m sec (*)

train to train separation: 3.3 m sec



* Note: 1
One train corresponds 132 bunches, but time structure in a train is ignored.

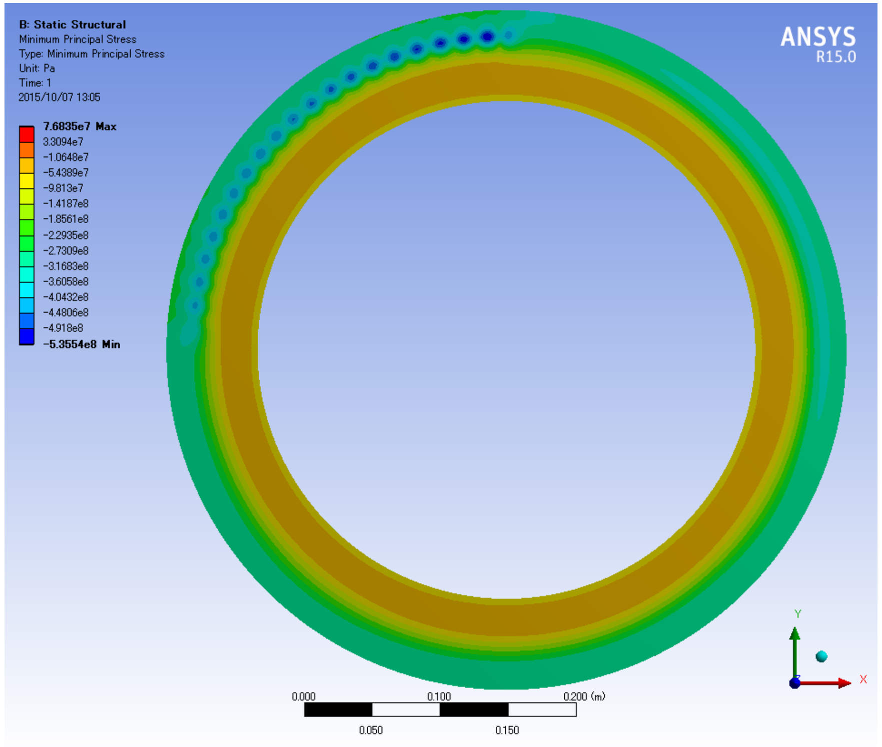
* Note: 2
This is NOT totally correct.
Pulse width of a train is NOT 0.99 m sec. It is 0.99 micro sec.
But difference in the results are small.

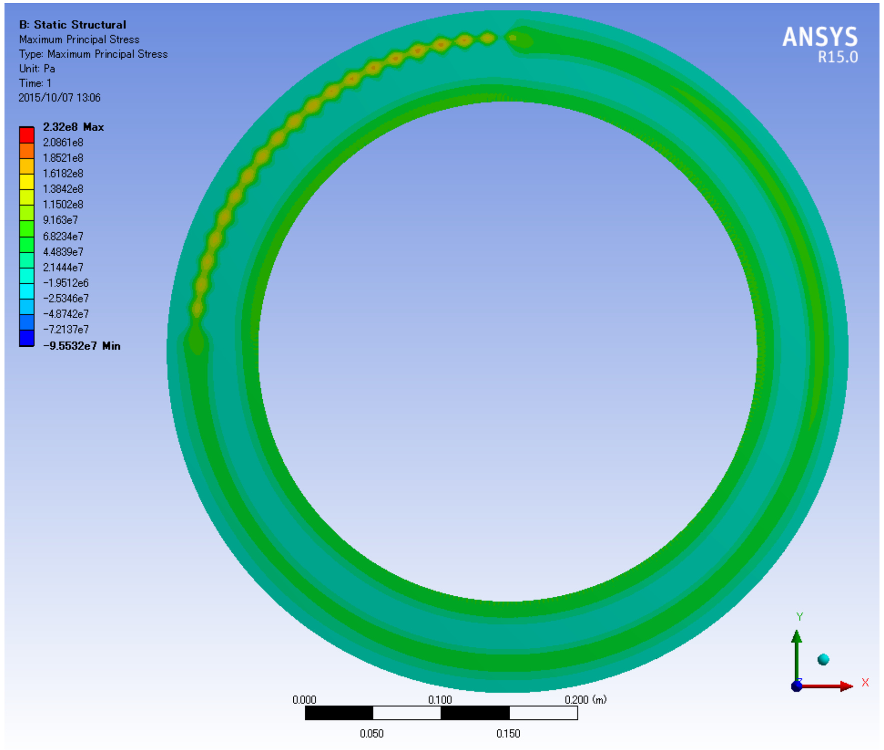
** Note: 3
This value is NOT accurate.
This is 5% larger than correct value.

Simulated by Rigaku Nb=2600

Stress: rotation speed 220 rpm, Pulse Beam Analysis, Step 2

20 trains in 63 ms





最小主応力
→ -5.4e+8Pa(圧縮)

Min Principal Stress
(Compression)
→ - 5.4e+8Pa

最大主応力
→ 2.3e+8(引張り)

Max Principal Stress
(Expansion)
→ 2.3e+8Pa

Simulated by Rigaku

Pulse Beam Analysis step 2:

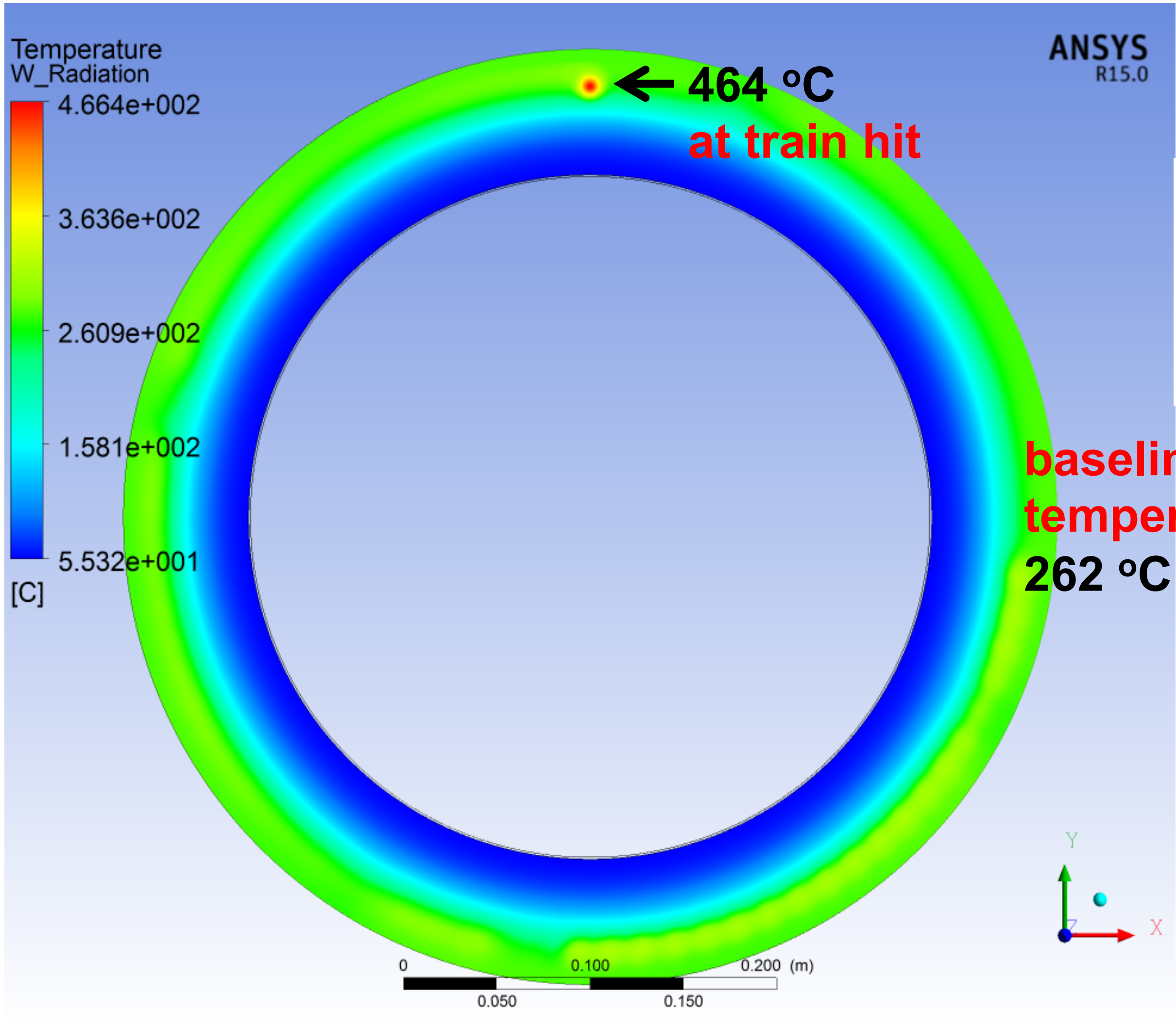
20 trains in 63 ms

1 train simulated

Rotation speed = 220rpm

1 train = 373000 kW(**) in 0.99 micro s (*)

train to train separation: 3.3 m sec



baseline temperature 262 °C

* Note: 1
One train corresponds 132 bunches, but time structure in a train is ignored.

- Note: 2
  Pulse width of a train is NOT 0.99 m sec. It is 0.99 micro sec.
  We made correction
  But difference in the results are small.

Corrected.

** Note: 3
This value is NOT accurate.
This is 5% larger than correct value.

Simulated by Rigaku Nb=2600

Summary of the R/D in Past 2.5 Years: FY2013-mid.FY2015

FY2013: Leak Rate measurement

We took leak rate data by using a small (d=10cm) rotation target off the shelf.

Conclusion: Leak Rate is small enough.

FY2013-2014: Radiation Test:

We made radiation test of ferrofluid at Takasaki Lab.

Conclusion:

F-oil: No hope.

CN-oil: No problem up to 4.7 MGy (about 3 ILC years).

FY2014-2015: Target Design Study.

We made design study with the company, Rigaku.
Study included both mechanical design and thermal stress analysis.

We now have a nearly final mechanical design.
Thermal stress study is ongoing.

Plan of the R/D in FY2015-FY2016

Outline of the Plan in Next Two Years

(1) We will make a prototype in two years (FY2015-2016).

(2) The prototype is full-size, d=500 mm.

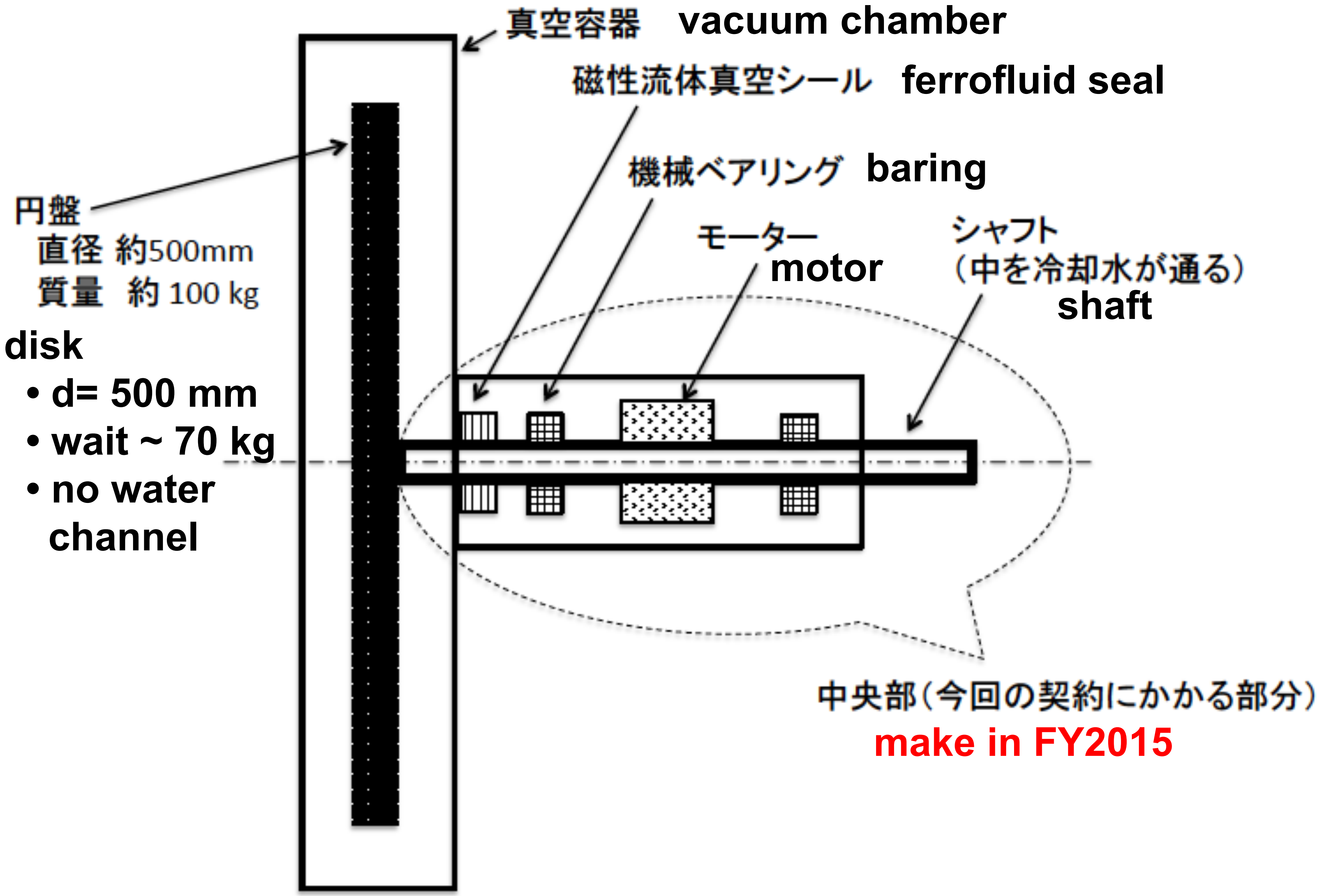
(3) Full-size means that target wheel has the same radius, the same weight, the same moment as those of the real target. The locations of the vacuum seal and bearing in the prototype are as same as those in the real one.

(4) The prototype is not totally as same as the real one.
- The prototype has no water channels in the disk.
- We don't use W for disk.

(5) We will use irradiated ferromagnetic fluid in the prototype.

(6) We will make continuous running test (~1 year?) and will prove that vacuum always stay good level.

Prototype: We have made a contract with Rigaku.



回転ターゲットプロトタイプ概略断面図

Points of the prototype

The loads on the vacuum seal and the bearing are determined by the weight and the moment of the target disk. So we will make full size prototype.

The purpose is vacuum test.
It is not necessary to use W for the disk.
We don’t use W for cost saving.

Water channels will be unimplemented. It is cost saving. Target rotation is slow, water circulation is within the past experience of the company. We have no need to demonstrate.

Backup

TEST: Radiation Tolerance FY2014
More systematic study for CN oil

November 2014

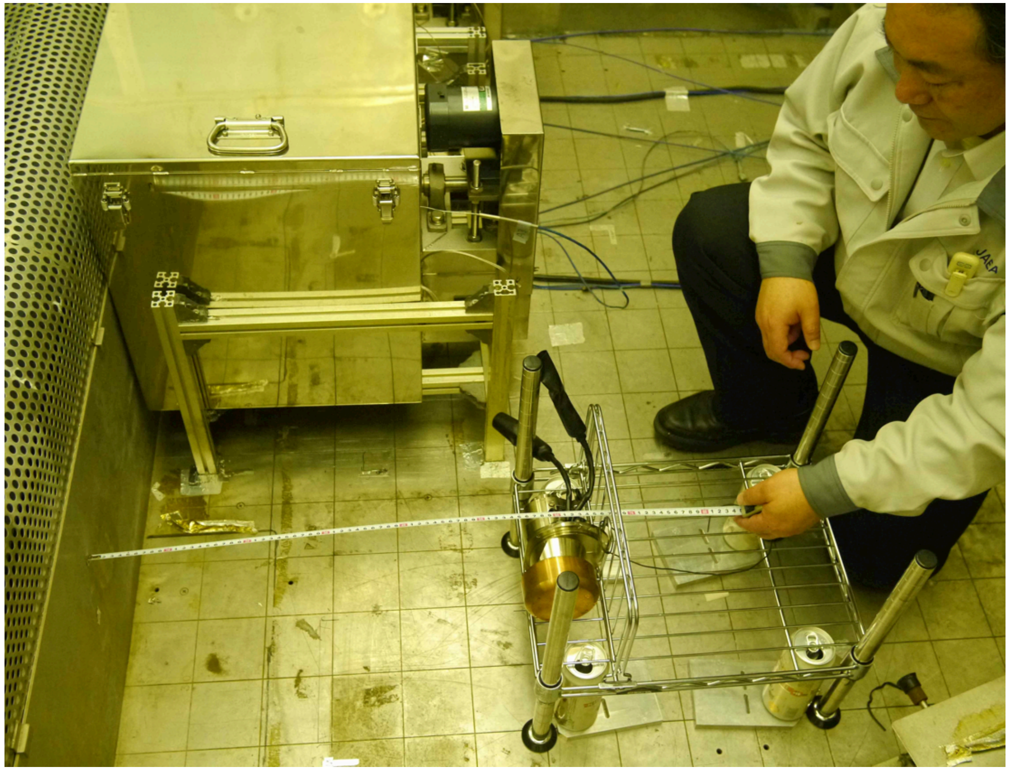
Leading With Innovation

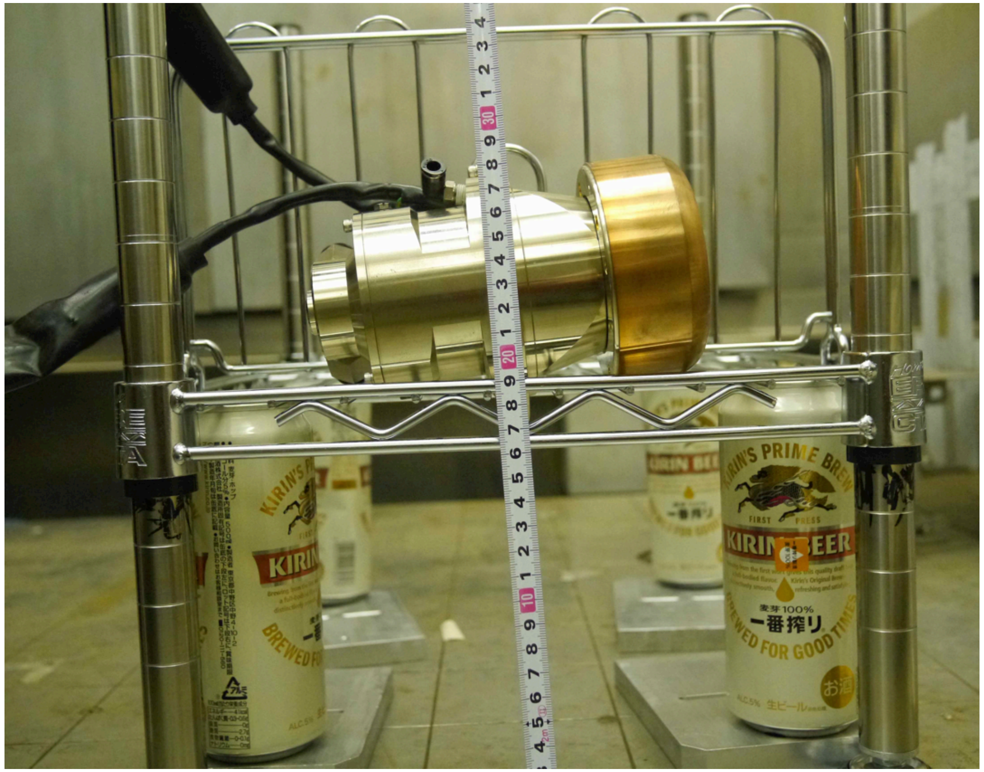
粘度の違いは見られるが、外見に異常なし

TEST: Radiation Tolerance FY2014 Mar 2015

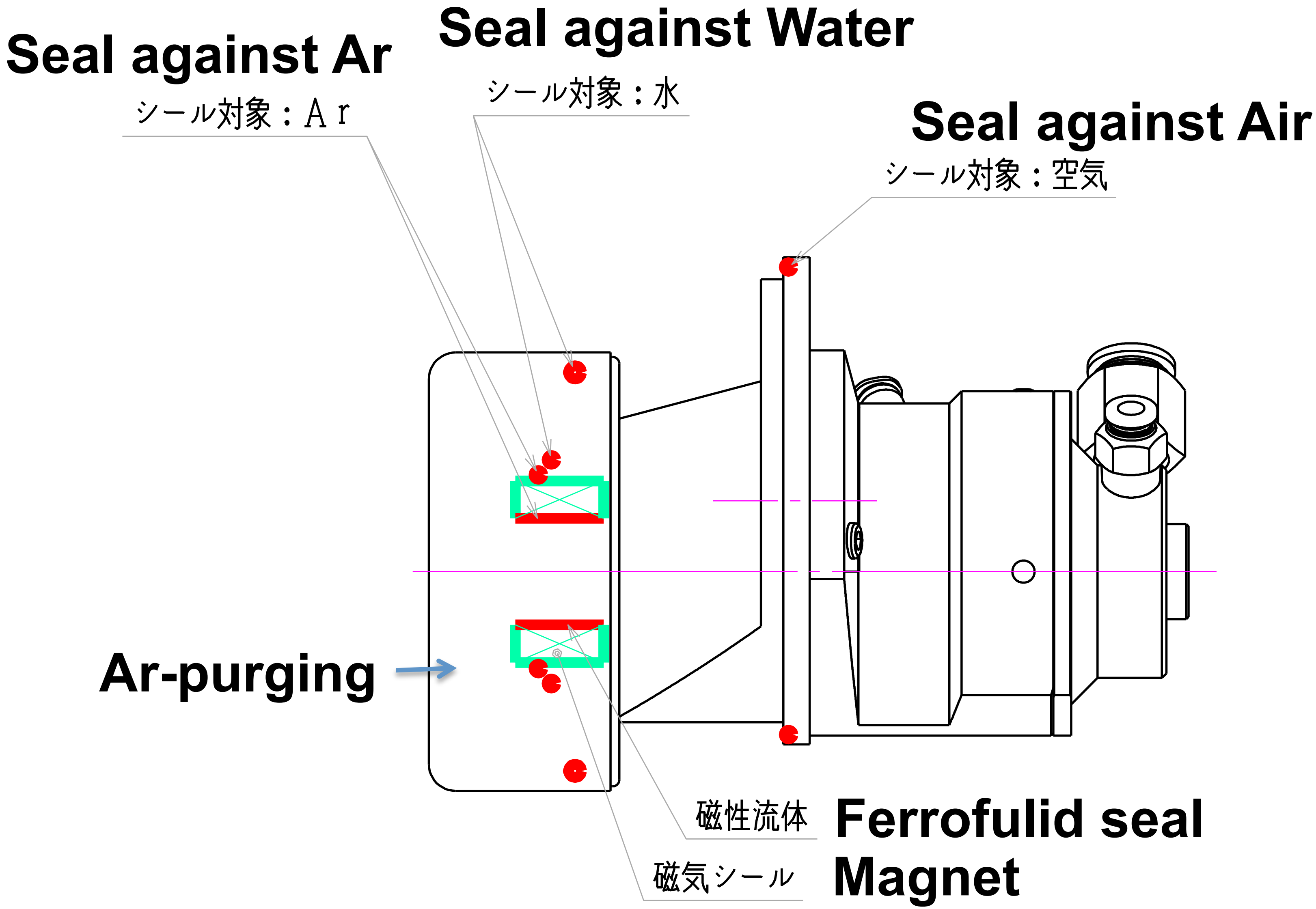
Irradiation to the small (d=10 cm) off-the-shelf rotation target

Radiation test fo the moter: 0.6 M Gy irradiation on the motor.
corresponds 1 ILC year





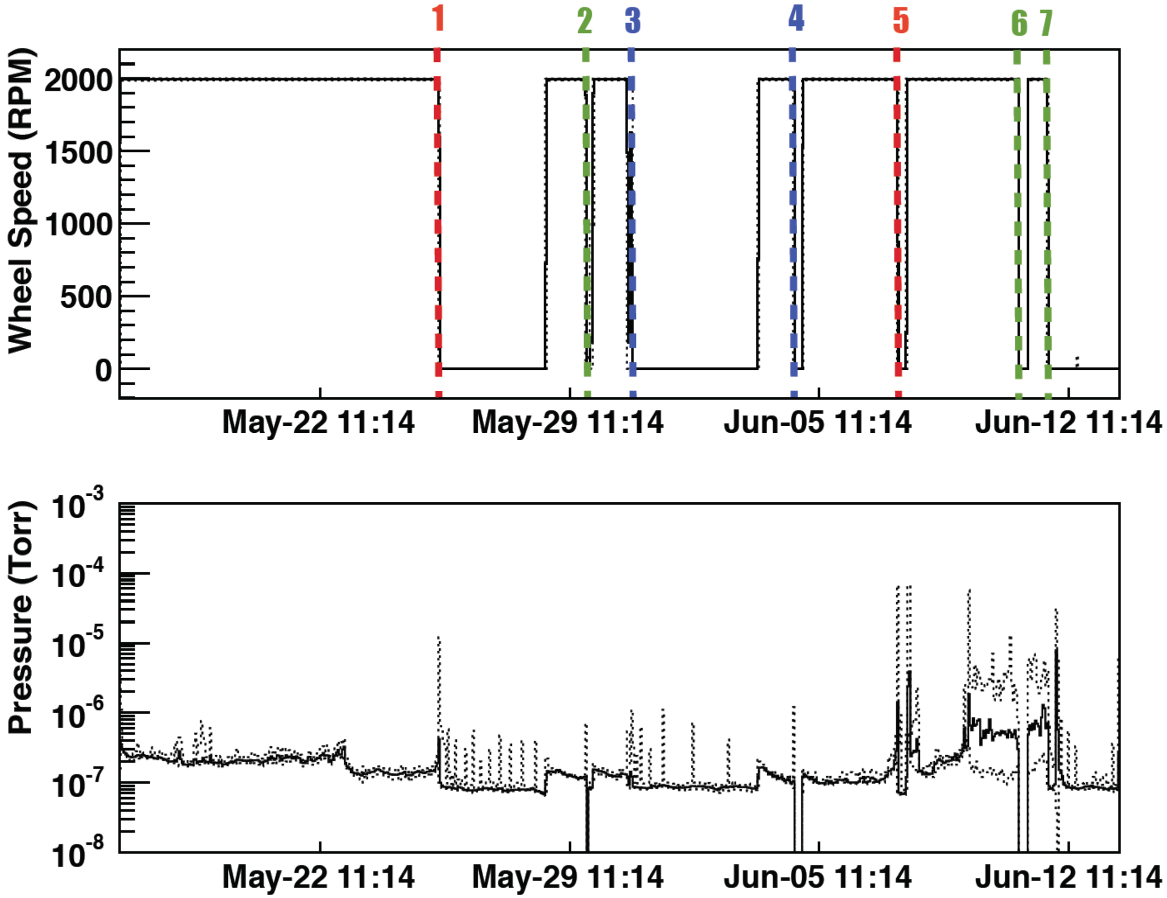
After irradiation, we made rotation and vacuum test.
NO problem



その他チャンバー内十数ヶ所にメタルパッキング使用　　シール対象：空気

undulator source : Vacuum test of rotation seal

FerroTec Seal #1 ran for 1 month (450 hours up)



Pressure Trip

System Trip

Planned Down

1 - Pressure Spike

2 - DAQ software change

3 - Cooling water flow

4 - Vibration Limit

5 - Pressure Spike

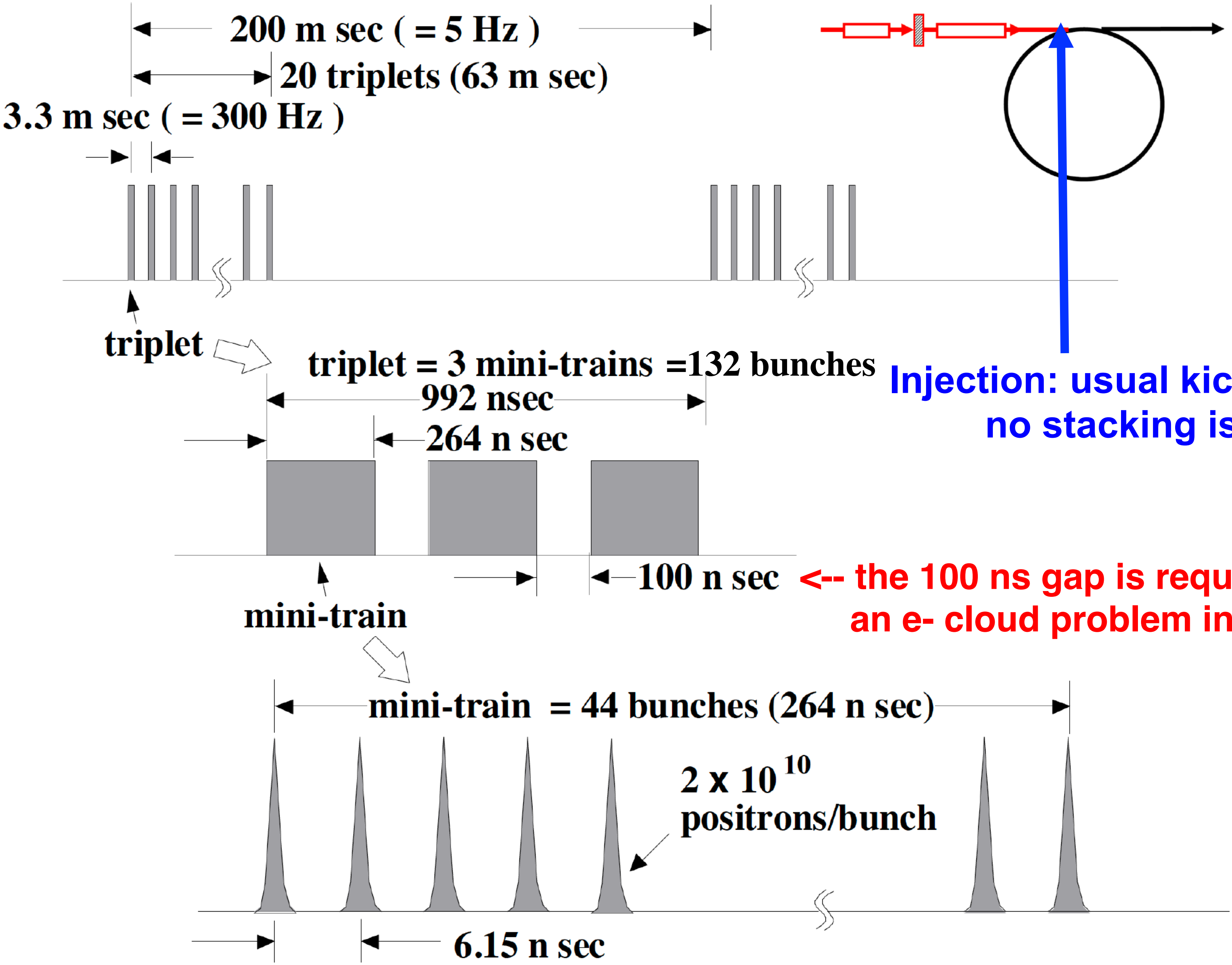
6 - Wheel stopped for pressure test

7 - System down for rework

Lessons Learned

- Ferrofluidic seals are not boring, each one has its own individual personality
  - We would prefer them to be anonymously interchangeable and predictable
- They all have outgassing spikes
  - A differential pumping region just after the seal would be a useful modification
- We are pushing them to speeds at which there is significant heat dissipation
  - Off-the-shelf models do not seem to be well designed for this.
  - Improved cooling design is a must for any future system

Beam before DR



Injection: usual kicker (~ 1 us)
no stacking is necessary

<-- the 100 ns gap is required to cure
an e- cloud problem in e+ DR.