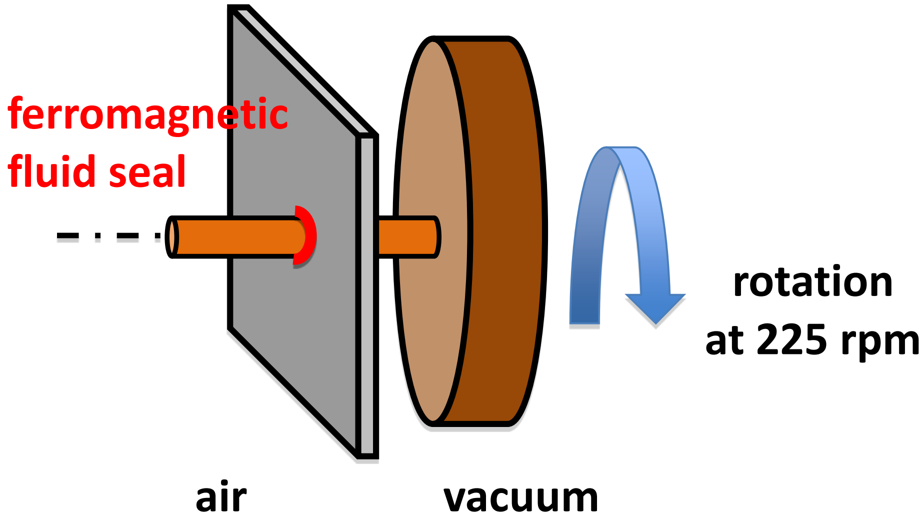
ILC E-driven e+ source
Rotation Target design and R&D

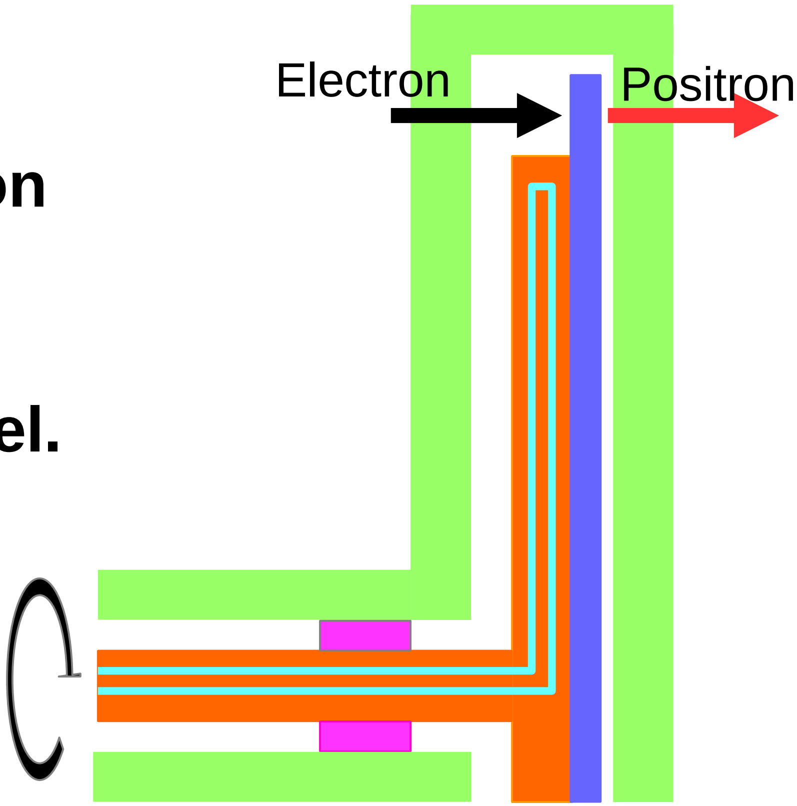


T. Omori, 23-Oct-2018

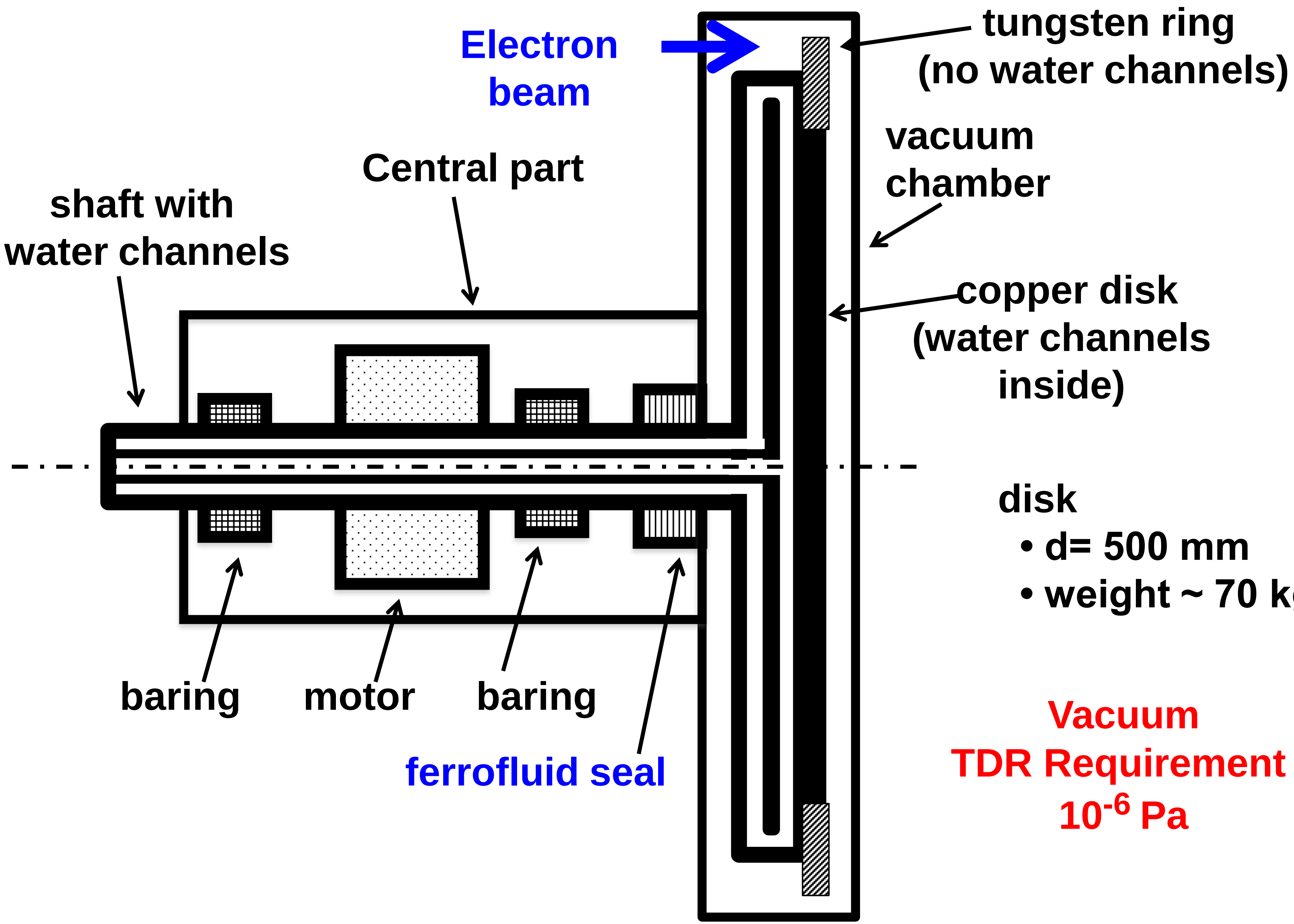
LCWS 2018, Oct 22nd - 26th, 2018
University of Texas at Arlington, USA

Target

- W-Re 16mm thick.
- 5 m/s tangential speed rotation (225 rpm, 0.5m diameter) in vacuum.
- Water cooling through channel.
- Vacuum seal with ferro-fluid.



Rotation Target (E-driven)

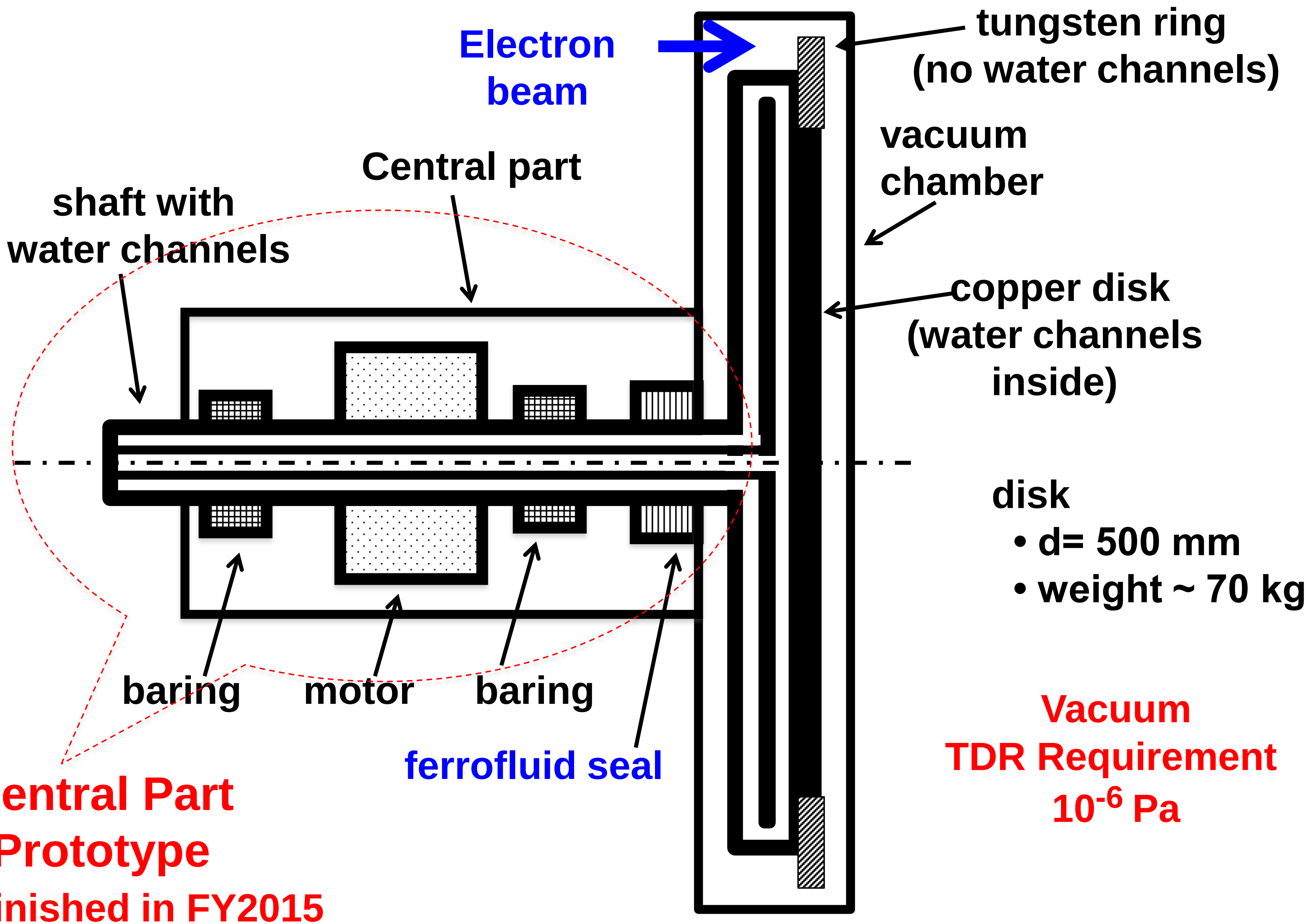


disk

- d= 500 mm
- weight ~ 70 kg

Vacuum
TDR Requirement
10^{-6} Pa

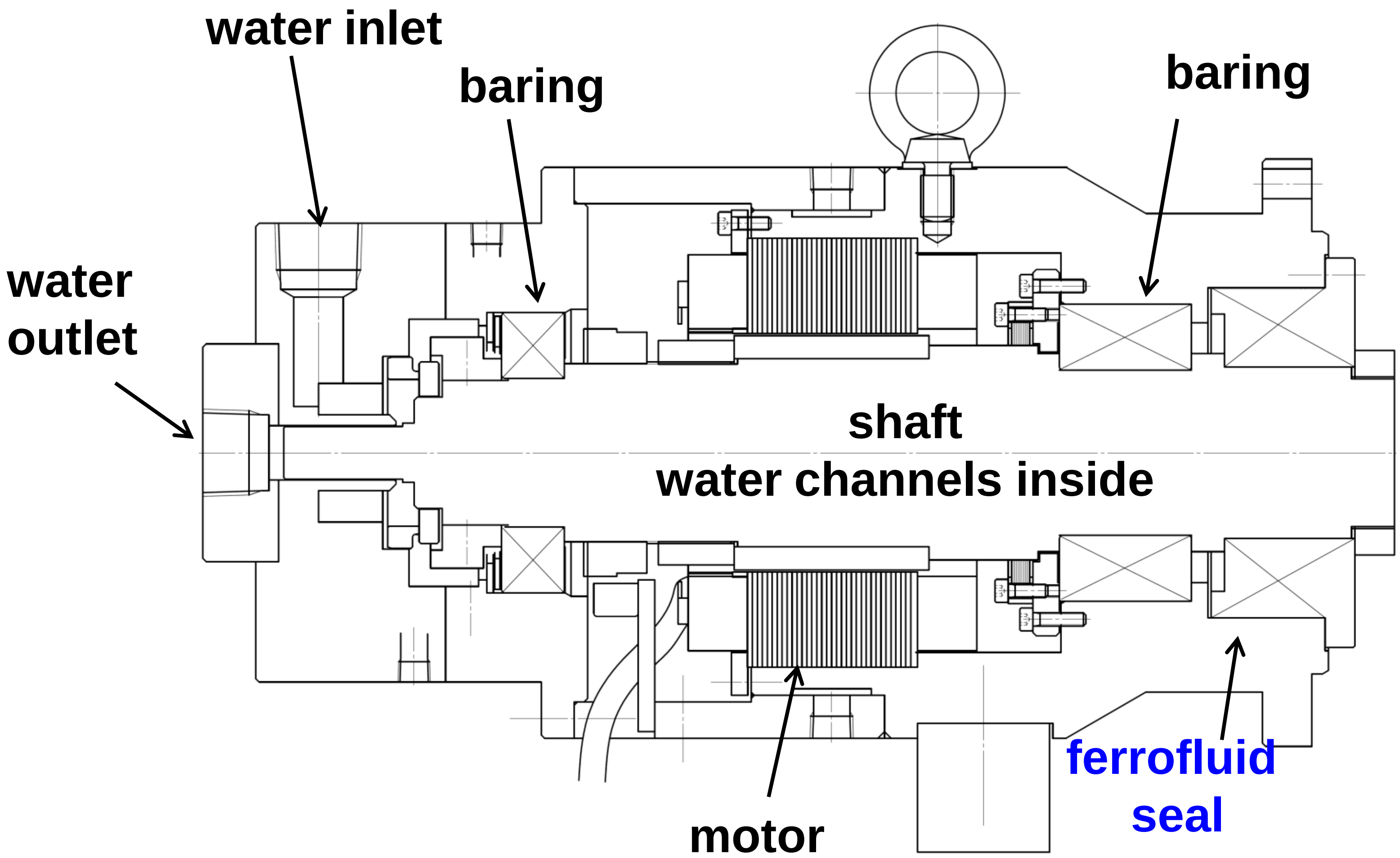
Rotation Target (E-driven)



Vacuum
TDR Requirement
10^{-6} Pa

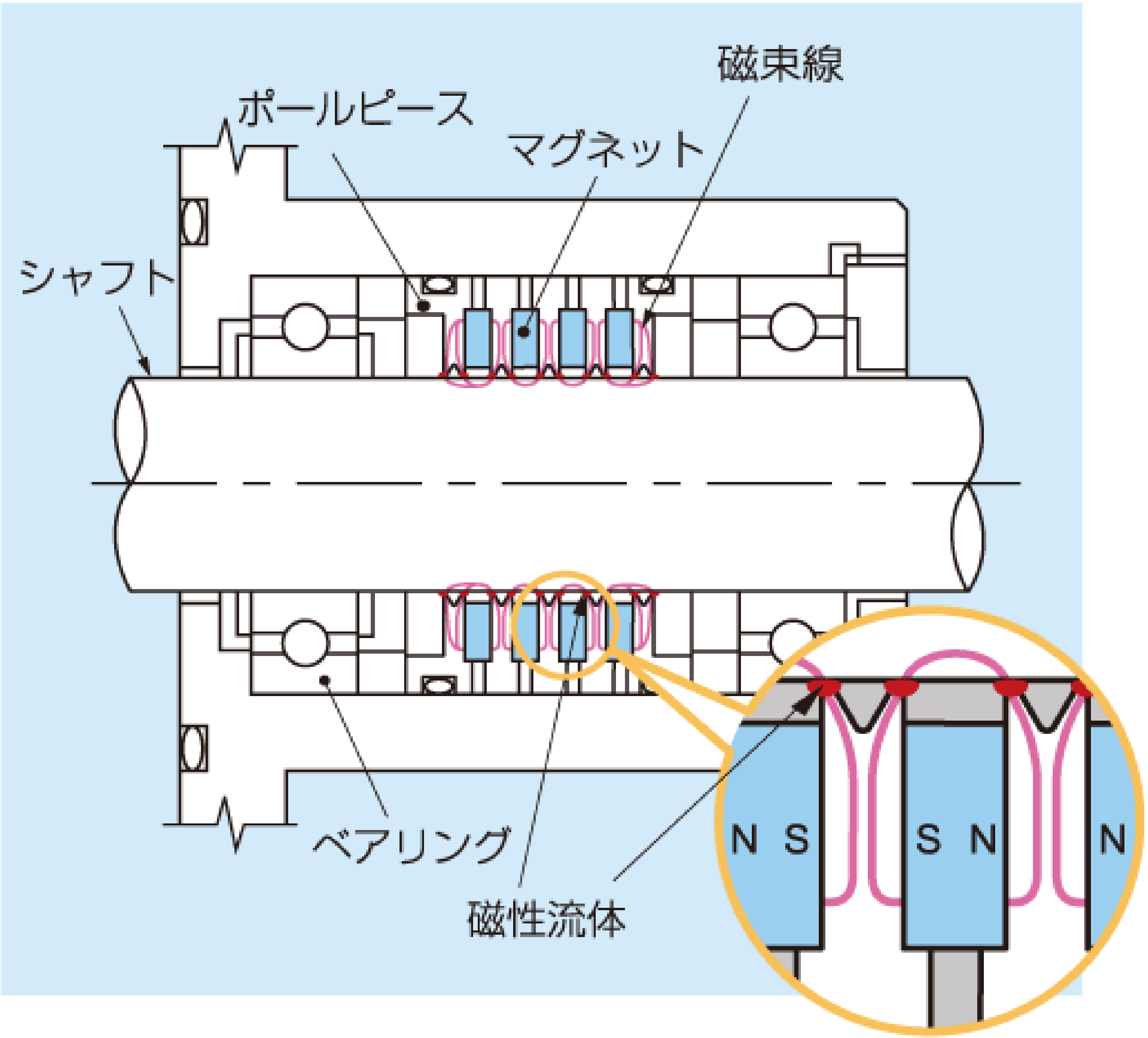
Central Part
Prototype
finished in FY2015

Central Part Prototype

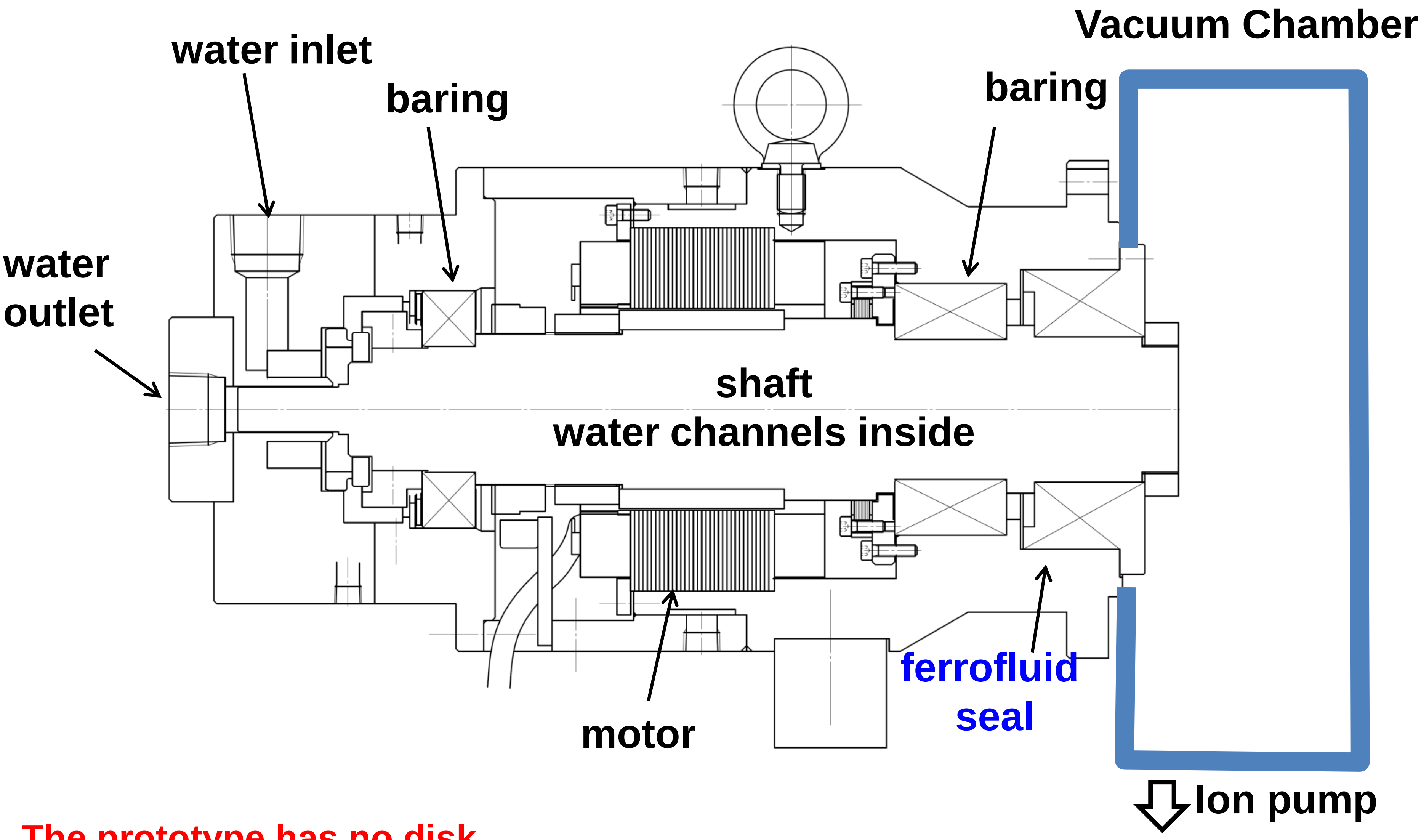


The prototype has no disk.

Schematic of ferrofluid seal



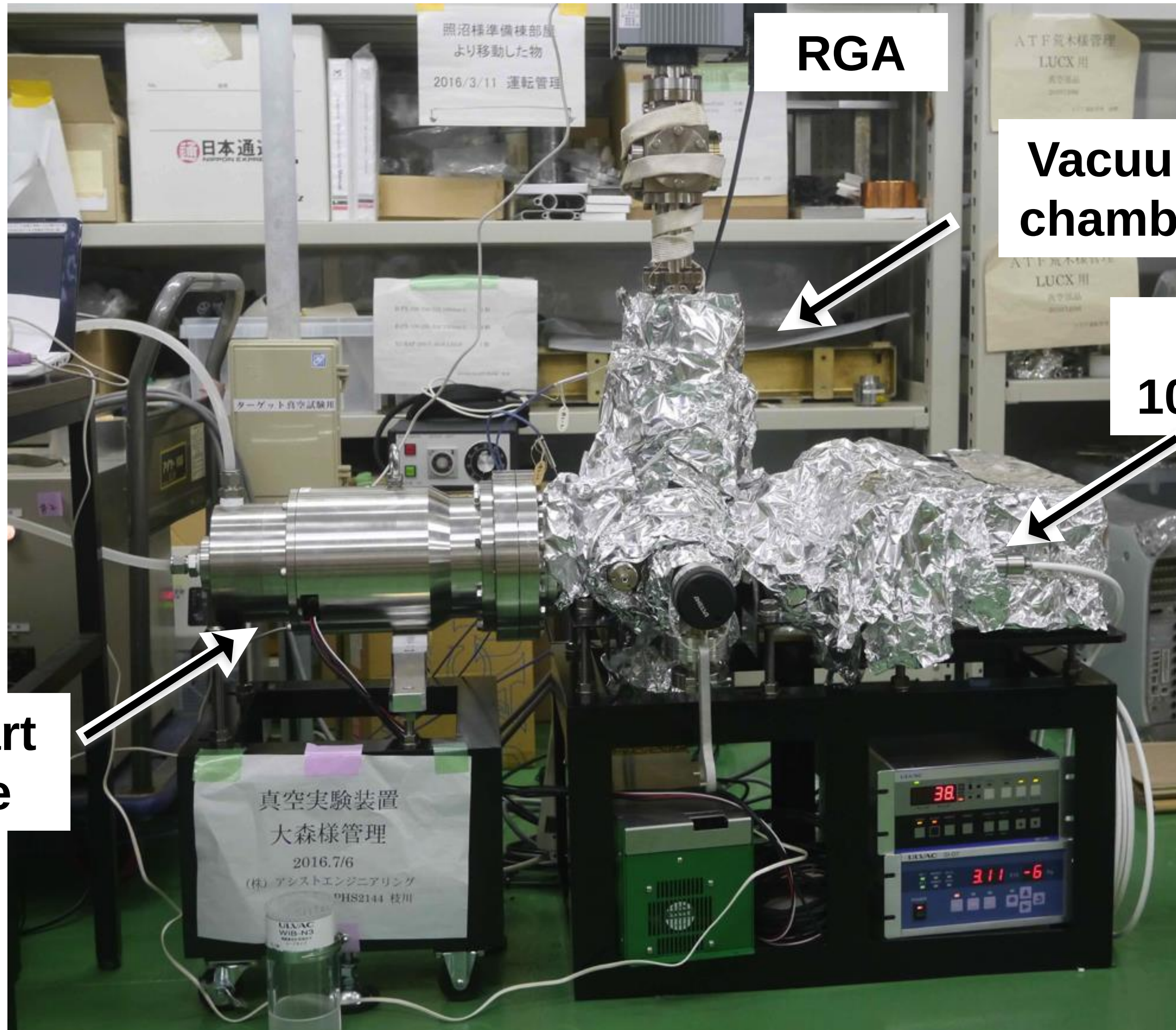
Central Part Prototype Vacuum Test



The prototype has no disk.

Central Part Prototype Vacuum Test

Feb/2017

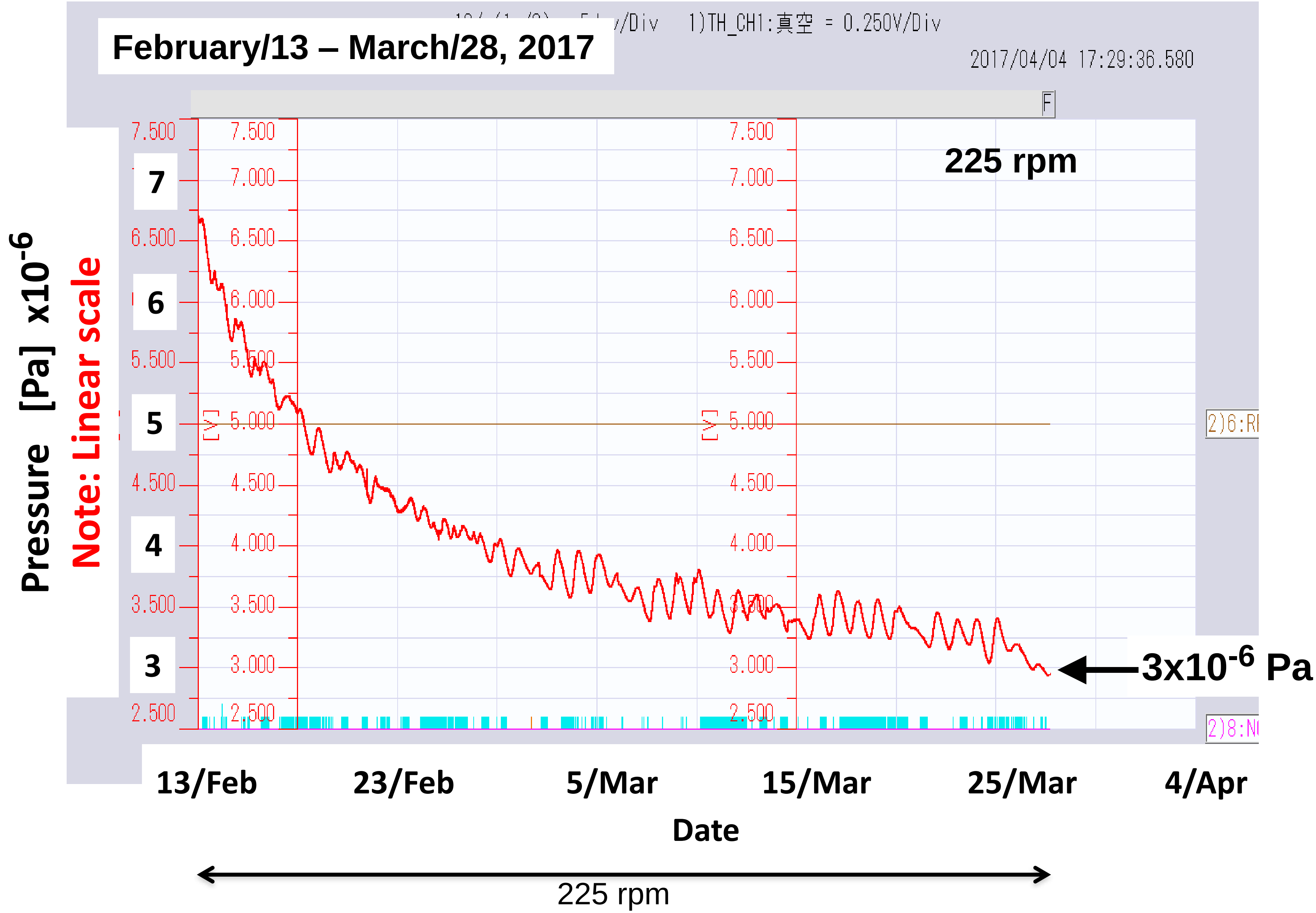


Central Part Prototype: Funded by KEK
Vacuum Test: Funded mostly by Hiroshima Univ.

Central Part Prototype Vacuum Test
Facts and What happened (1)

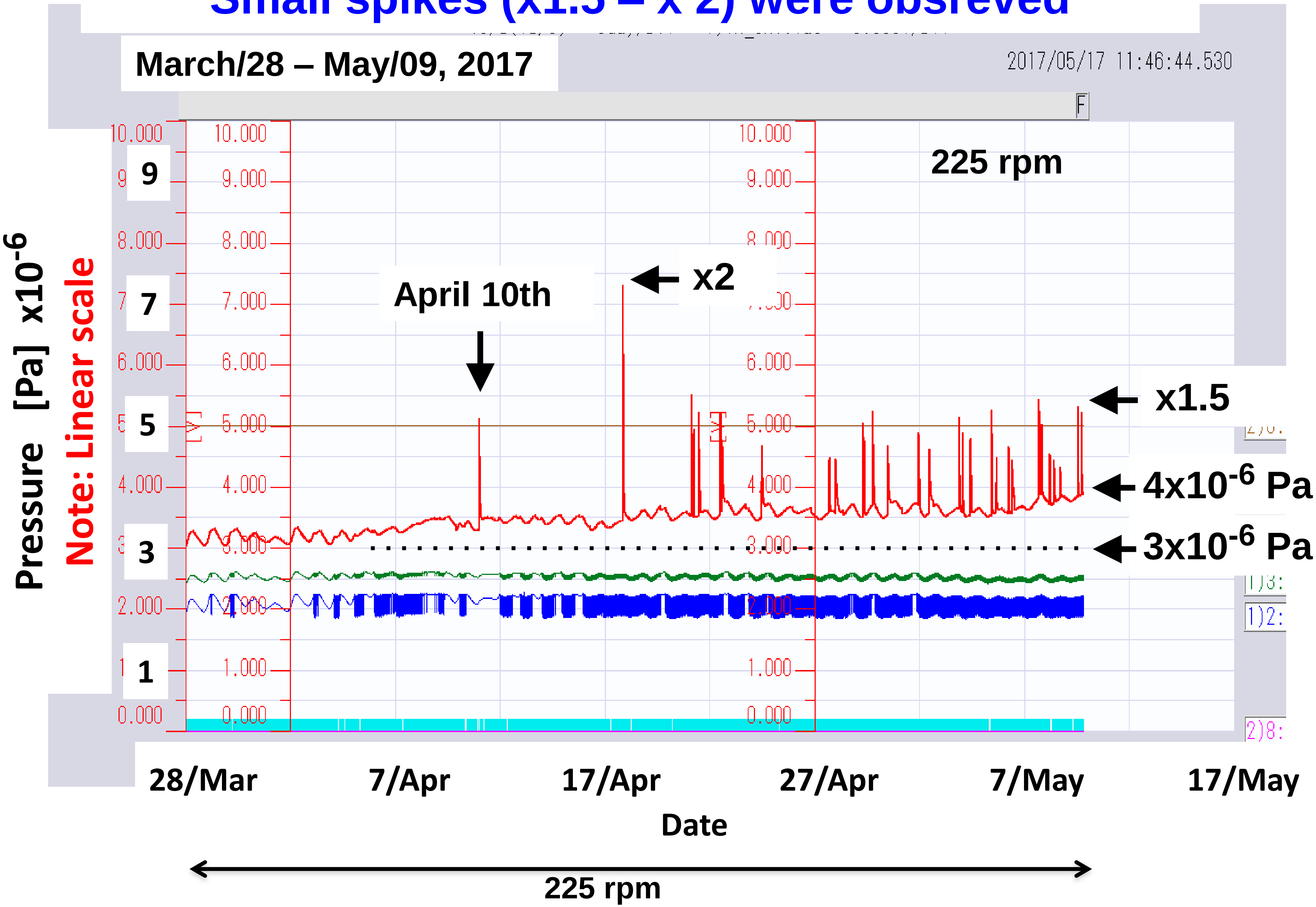
- **Ion pump 100 litter/sec.**
- **Rotation at 225 rpm (design value).**
- **We started the experiment on February 9th, 2017.**

Central Part Prototype Vacuum Test



Central Part Prototype Vacuum Test

Small spikes (x1.5 – x 2) were obsreved



Central Part Prototype Vacuum Test
Facts and What happened

- Ion pump 100 litter/sec.
- Rotation at 225 rpm (value).
- We started the experiment on February 9th, 2017.
- Vacuum level went good monotonically.
- And reached ~ 3×10^{-6} Pa at the end of March.
- Vacuum level was stable at ~ 3×10^{-6} until April 10th.
- Then, we observed small spikes.
  - Height of a spike ~x1.5.

Vacuum Test: ILC Rotation Target
Facts and Concerns at the Prototype

Facts

Vacuum **$3x10^{-6}$ Pa (measurement results)**

Keep good vacuum over five months

Sikes

Vacuum level slowly went worse.

Concerns

Sikes

Aging

Contamination of the accelerator tube

Reinstallation of the Seal Unit

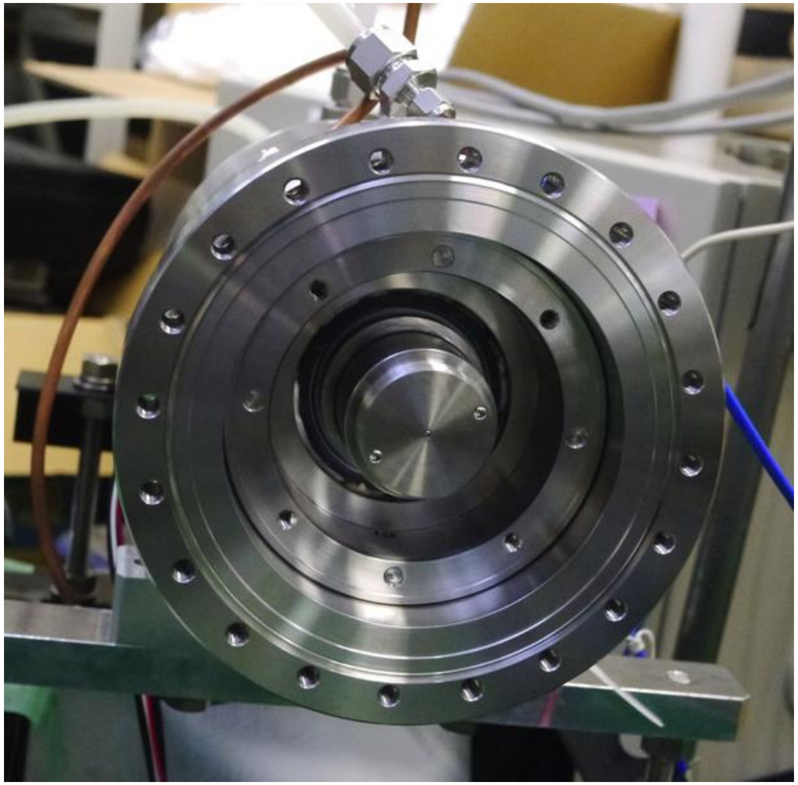
(1) We opened the chamber 19th July 2017.

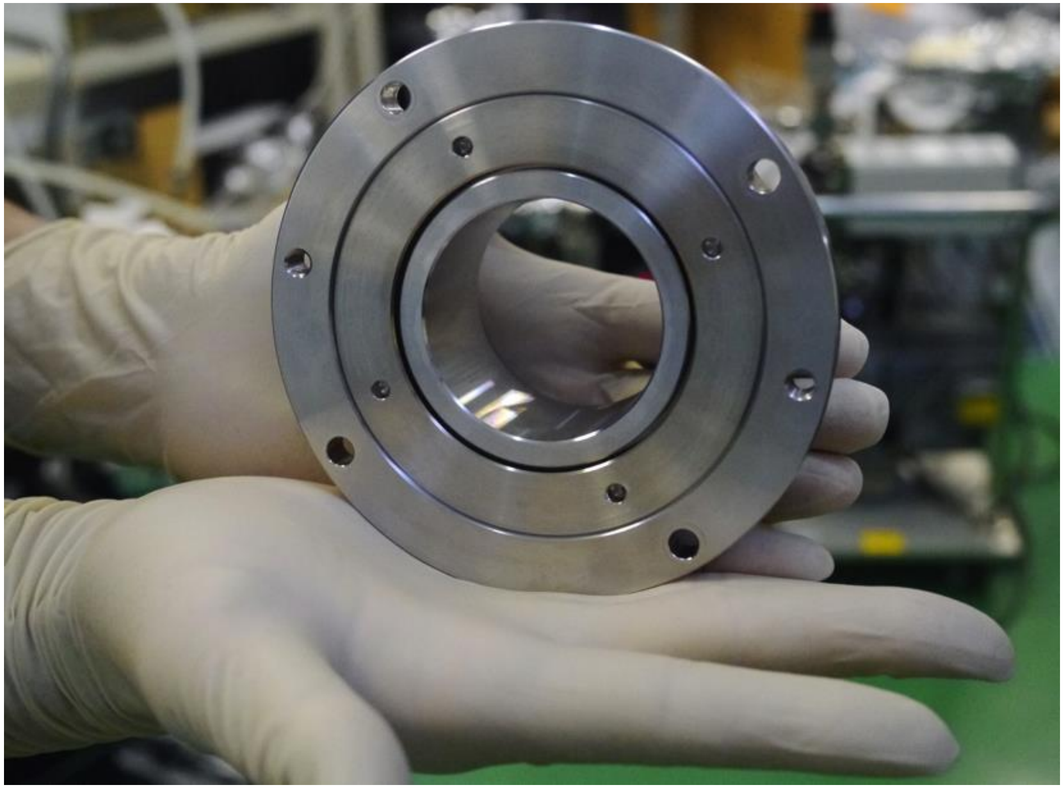
(2) The seal unit was sent back to the company (RIGAKU). The company checked the unit, washed the unit, and applied fresh ferrofluid.

(3) We reinstalled the unit on 31st July 2017.

July 31st, 2017:

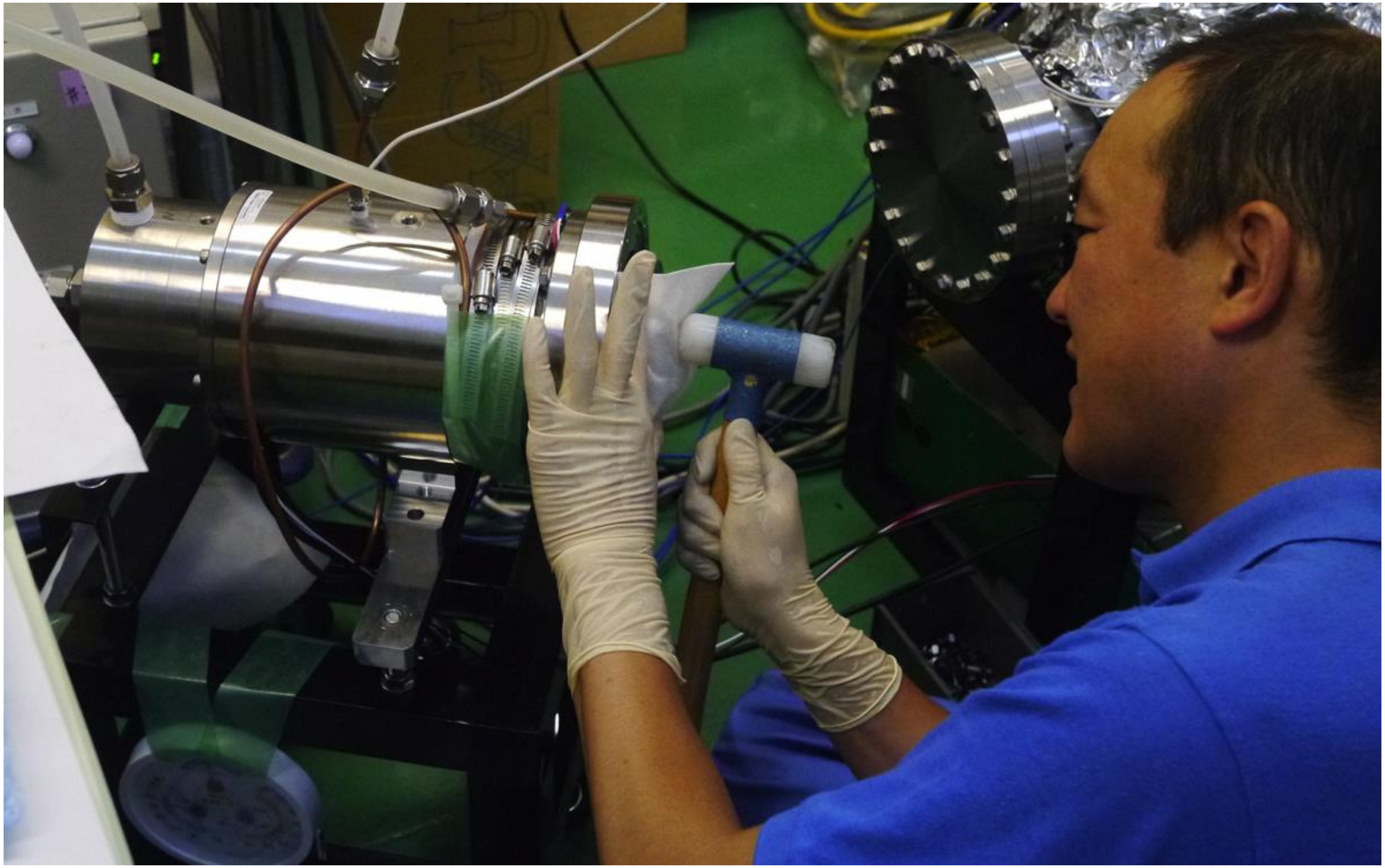
We reinstalled the seal unit and closed the chamber again



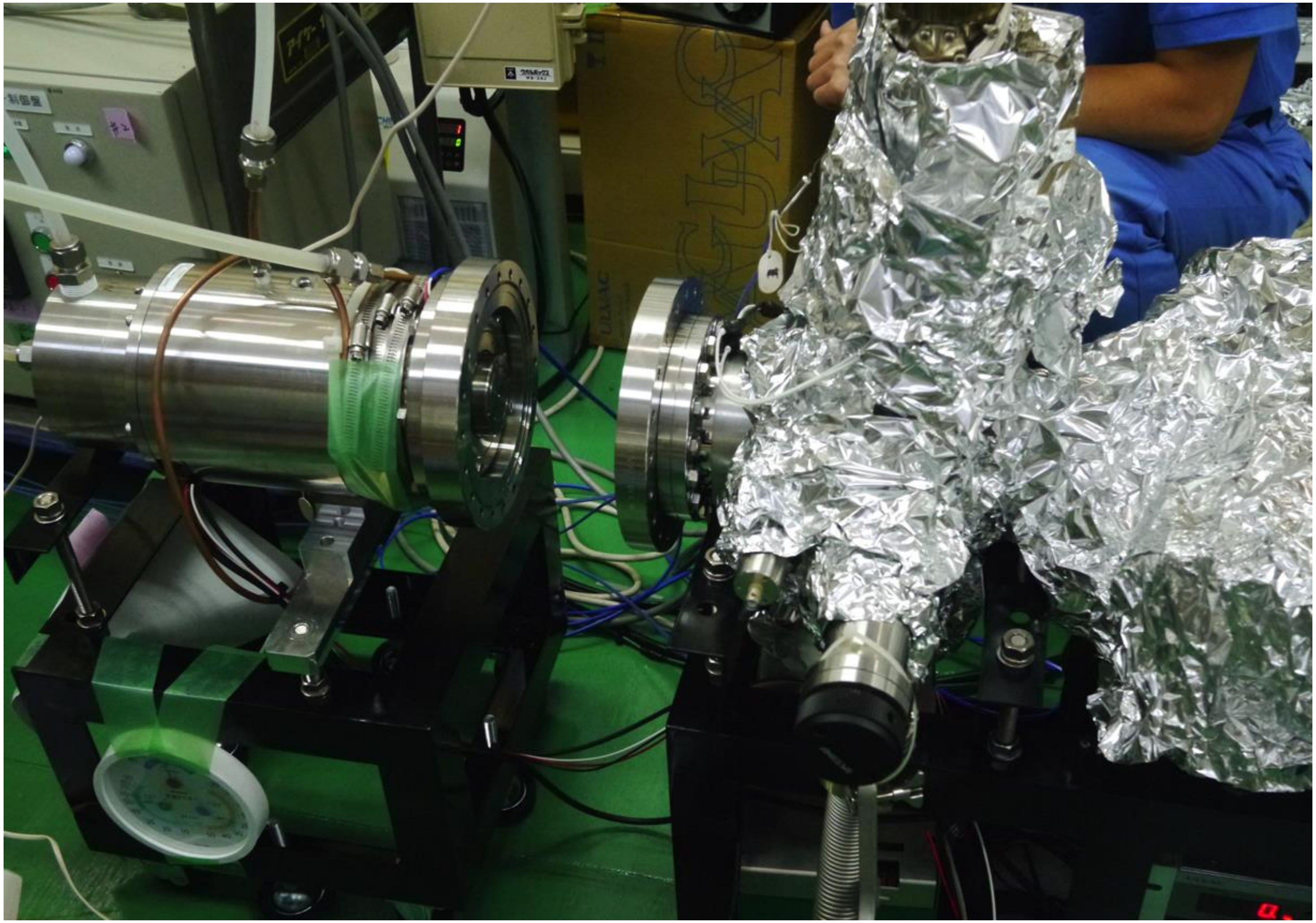


July 31st, 2017:

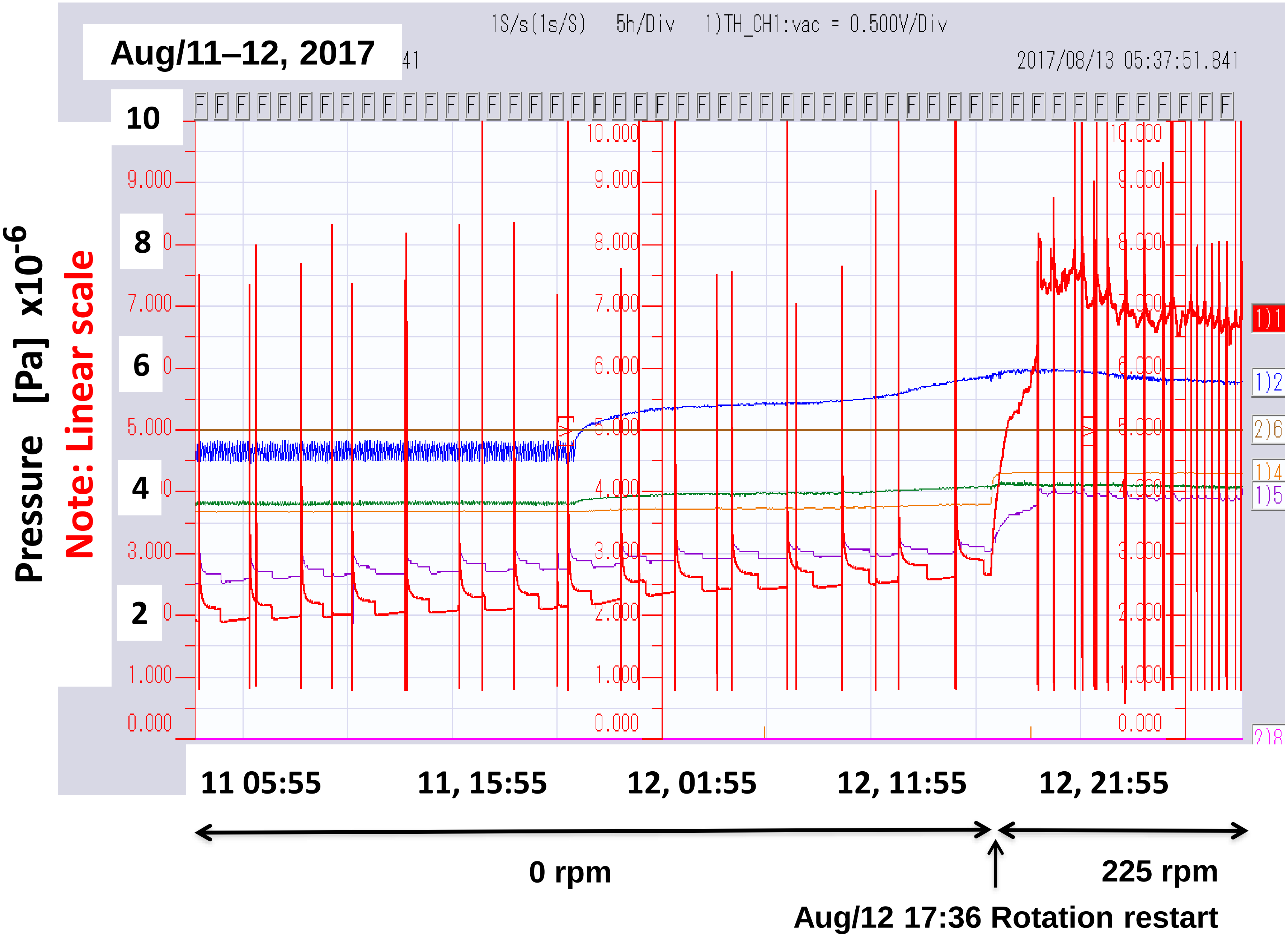
We reinstalled the seal unit and closed the chamber again



July 31st, 2017:
We reinstalled the seal unit and closed the chamber again



Vacuum Test: After reinstallation



Spikes in August 2017

- We observed spikes again in the operation in August after the reinstallation (the second experiment).

- The frequency of spikes was rather high. Every 10-20 minutes.

- Spikes appeared immediately after restart of operation.

  cf. Spikes appeared after 3 months of operation in the first experiment in Febuary-July).

- In the first experiment, we suspected the aging of the ferrofluid was the cause of the spikes. But in the second experiment we observed spikes immediately.

- Quality control is the cause?.

- **An Event on August (2017)**

  The air conditioner of the room was broken in early August.

- **September (2017):**

  The air conditioner of the room was broken in early August. Rotation in bad environment may give bad affect on the seal fluid. So we stopped the rotation at the end of August and suspended the experiment.

- **Begging of of October (2017):**

  We restarted the experiment at the begging of October.

  Vaccum: 4-5x10^{-6} Pa at 225rpm

  Spikes: every 10-30 min (height ~x20)

October-November (2017) : New Tests

- **Fast speed rotation**

We intentionally change the rotation speed to much faster than the rated speed to change the state (condition) of the fluid.

- rotation at 900 rpm
- rotation at 1150 rpm
- change speed every 3 minutes, (225 <-> 900)x20 times

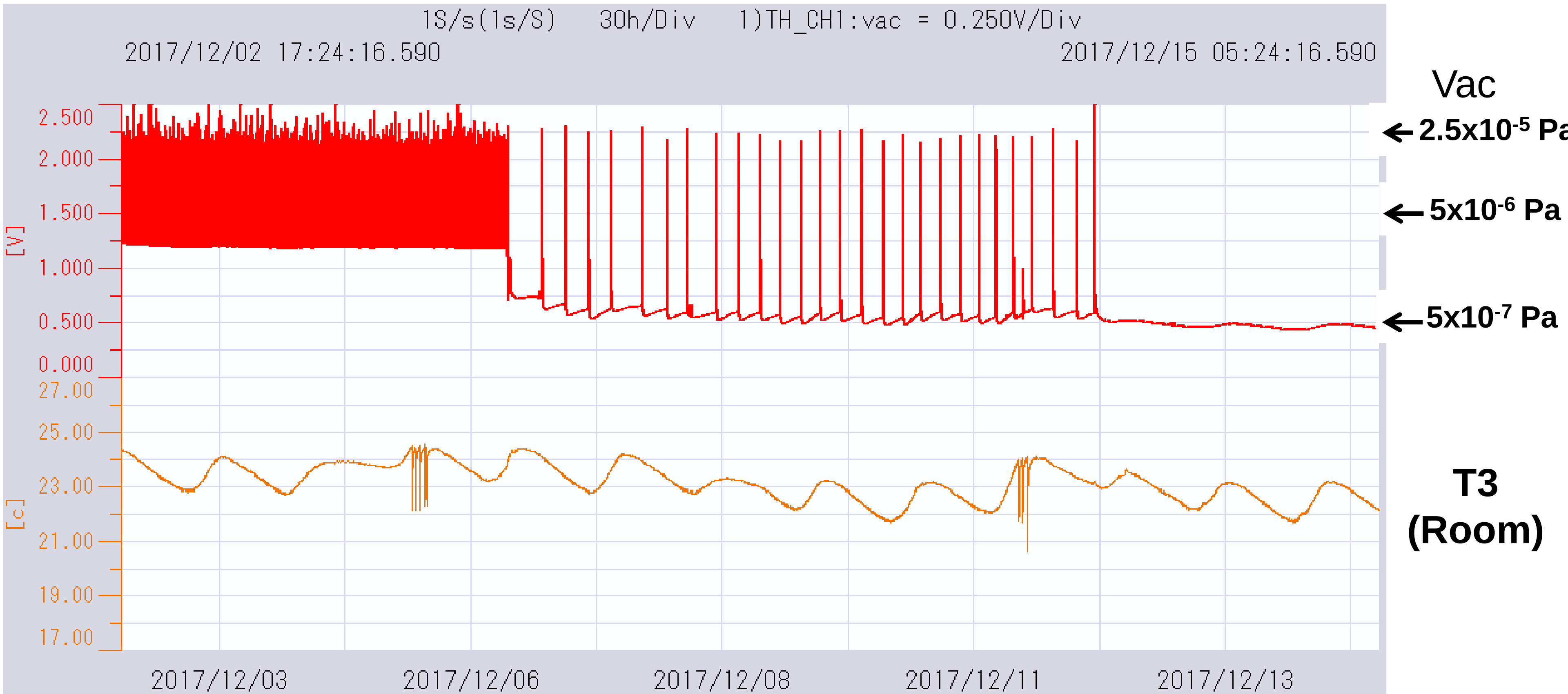
- **End of October**

Situation at the end of October.

Vaccum: 3.3×10^{-6} Pa at 225rpm

Spikes: every 2-3 hours (height ~x20)

2017, Dec. 02nd - Dec. 15th



1150 rpm
Spikes: every 20 min

225 rpm

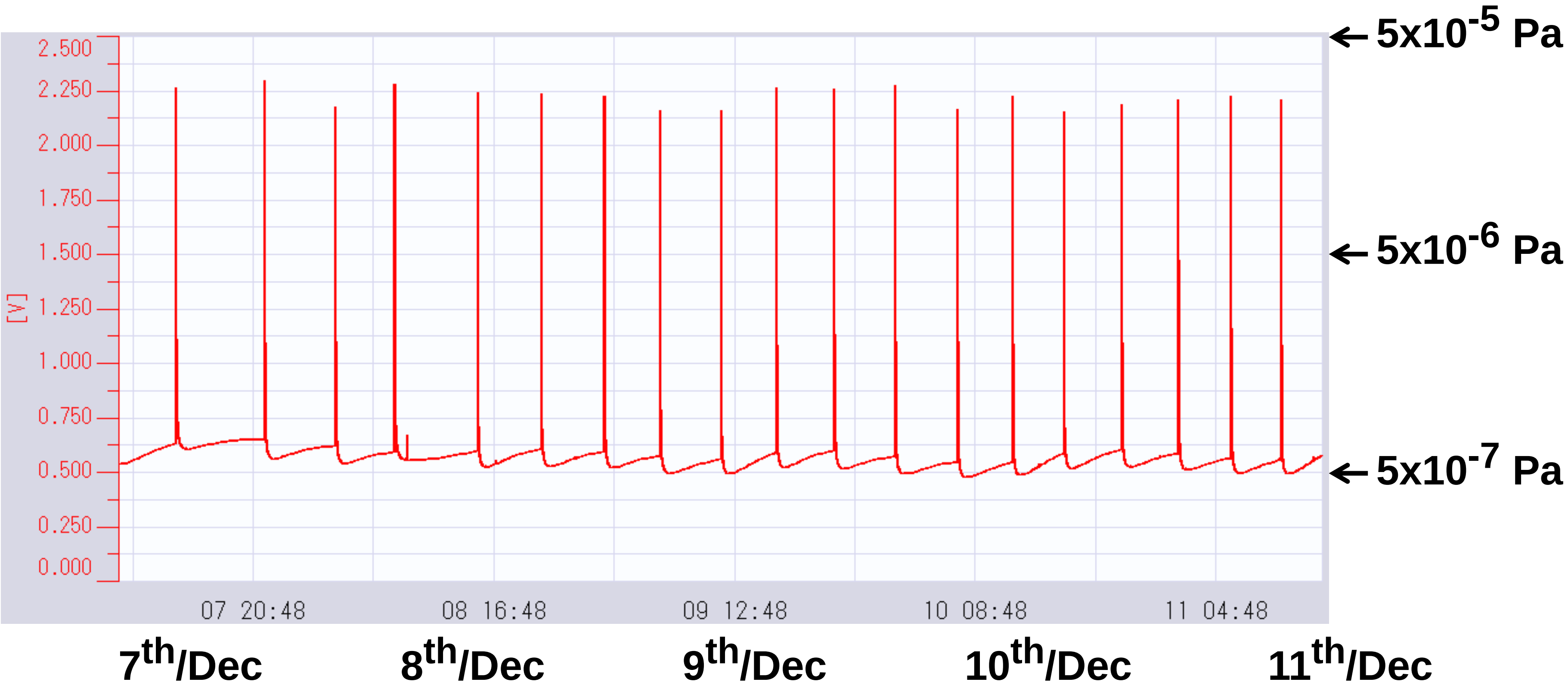
Spikes: every 6 hours

0 rpm

Dec. 06th 13:40
1150 rpm -> 225 rpm

Dec. 12nd 09:32
225 rpm -> 0 rpm
the last spike at the moment of the stop

Vacuum at 225 rpm



base	~ 5×10^{-7} Pa
peak of spikes	~ 2×10^{-5} Pa

Vacuum TDR Requirement 10^{-6} Pa

Results of Gas flow Experiment

Gas flow gave better results

3×10^{-6} Pa → 5×10^{-7} Pa

We guess less humidity gave good result.

But we still have spikes

Estimation in ILC e+ source system

∗ Data measured by the central part prototype (experiment)

Vacuum (result exp.) 5×10^{-7} Pa (base (NO spike))

Vacumm pump used 100 L/s $(=100 \times 10^{-3}\ m^3/sec)$ (Ion pump)

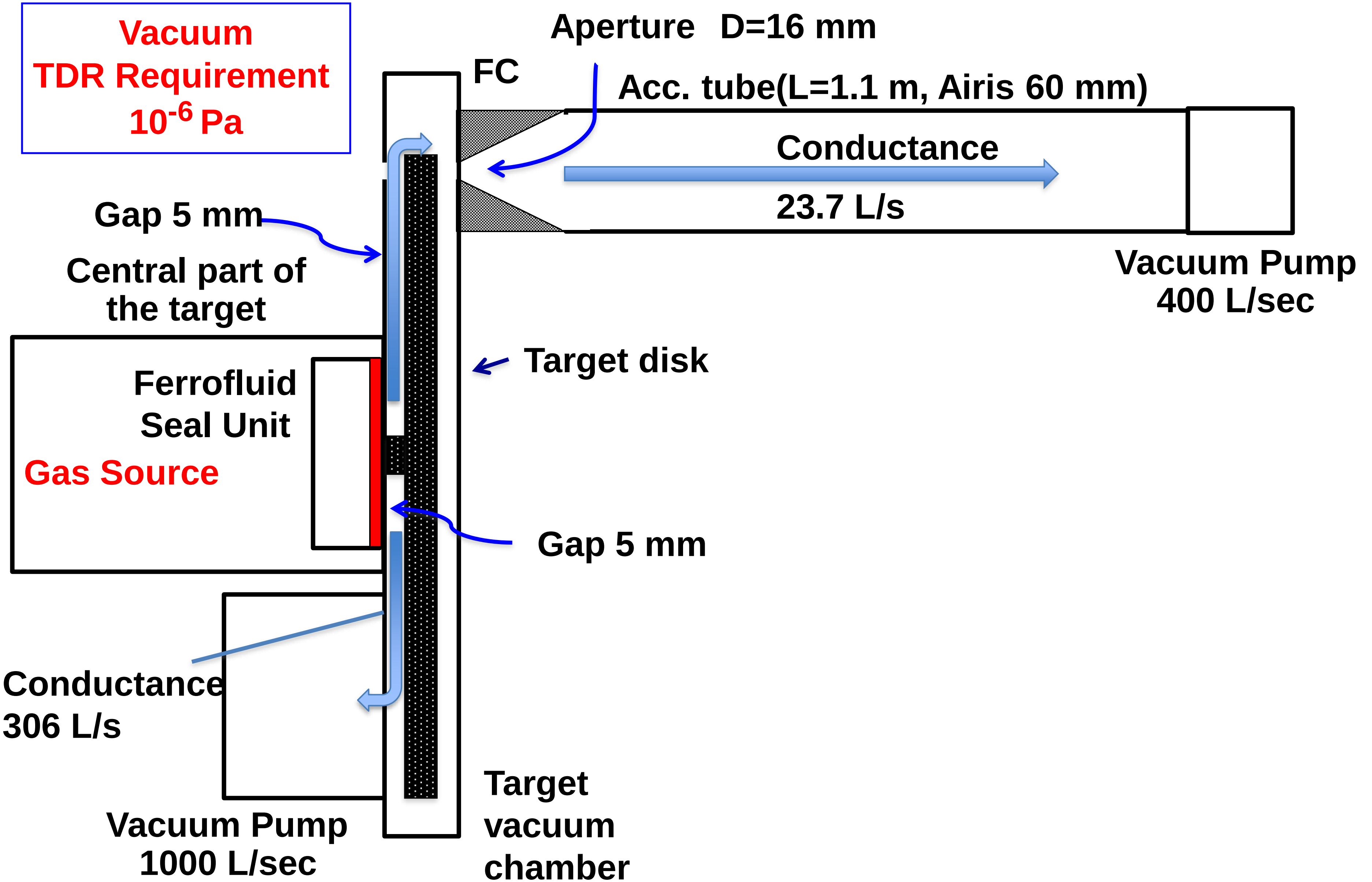
∗ Leak rate （calculated from the above）

$(5 \times 10^{-7}\ Pa) \times (100 \times 10^{-3}\ m^3/sec) = 5 \times 10^{-8}\ Pa\ m^3/sec$

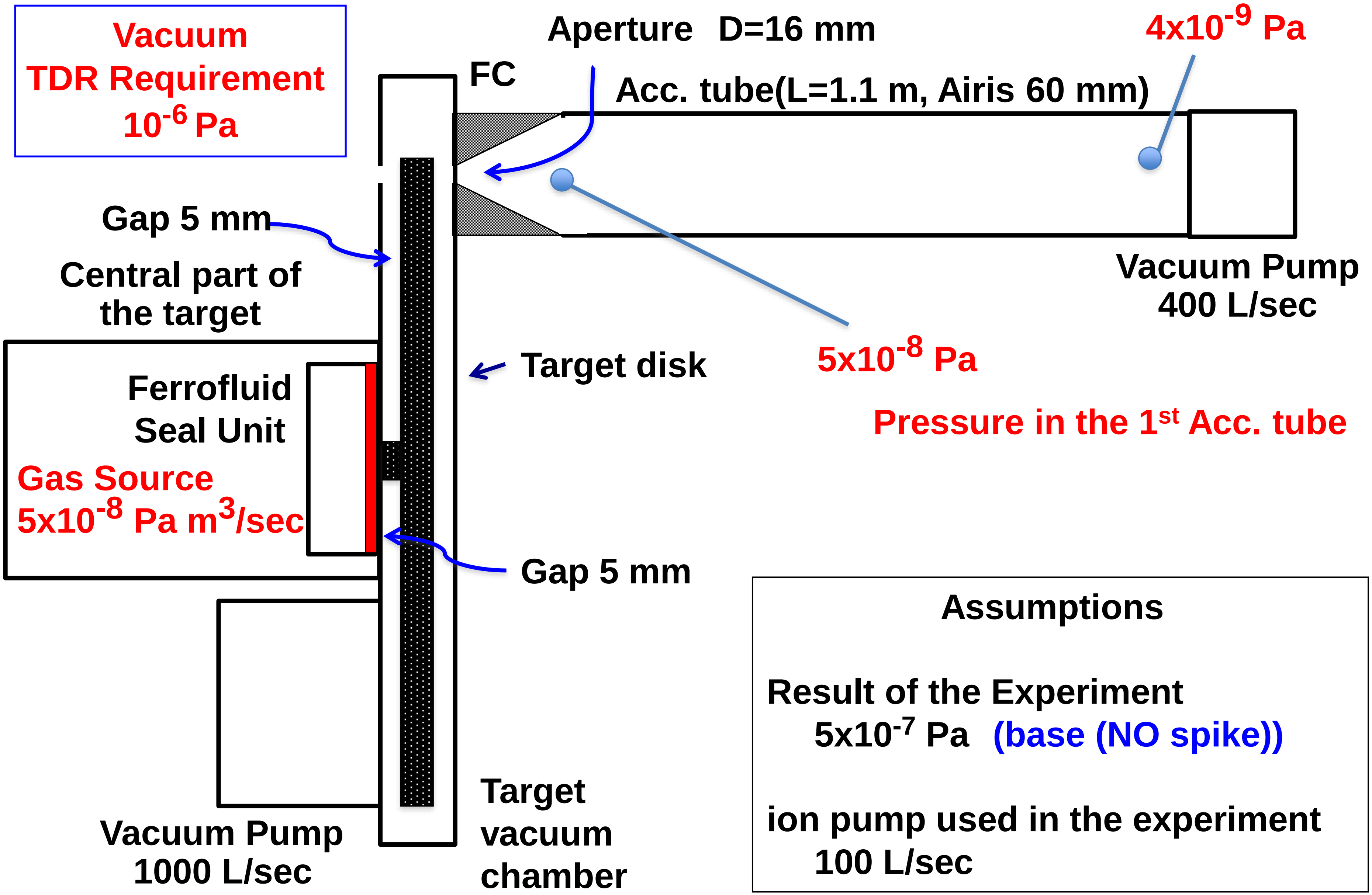
∗ Estimate expected vacuum levels and gas flows at 1st acc-tube in ILC e+ source system by using the leak rate.

The Model

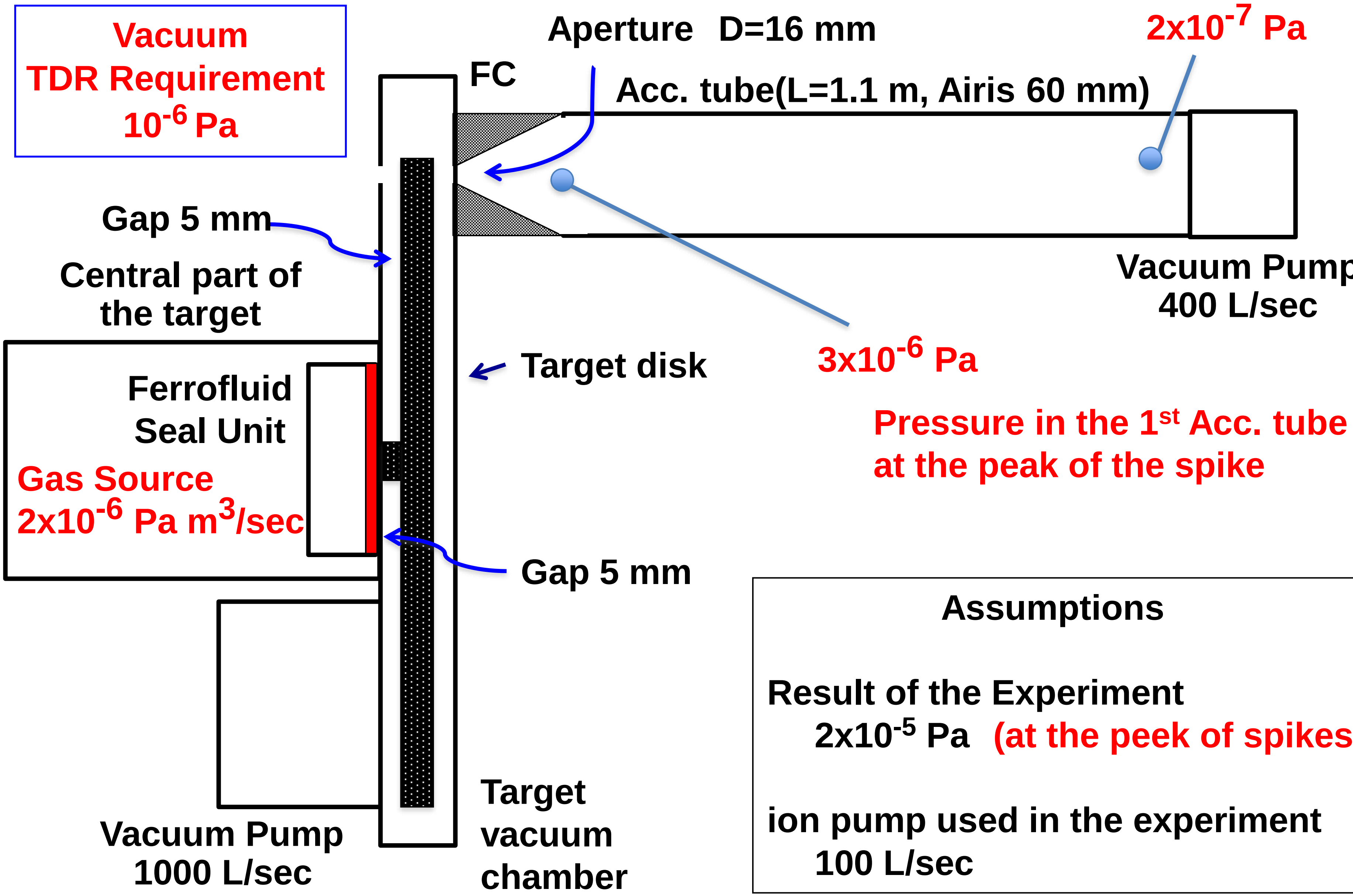
Vacuum
TDR Requirement
10^{-6} Pa



The Calculation based on the Model: 1



The Calculation based on the Model: 2



Assumptions

Result of the Experiment
2×10^{-5} Pa (at the peek of spikes)

ion pump used in the experiment
100 L/sec

Plan on improvements

Vacuum
TDR Requirement
10^{-6} Pa

Result of experiment is promising

Pressure at Base

- 5×10^{-7} Pa at 225 rpm (experiment)

  Calculation at first Acc. tube :
  from 7×10^{-8} to 4×10^{-9} Pa

Pressure at Peaks of Spike

- 2×10^{-5} Pa at 225 rpm (experiment)

  Calculation at first Acc. tube :
  from 3×10^{-6} to 2×10^{-7} Pa

Bur we still have spikes

We are planning to make improvements.

Summary

Summary of Target Vacuum Test

(1) Results of the experiments (so far)

- 5×10^{-7} Pa at 225 rpm (dry N2 gas flowing in the "air" side)
- 3×10^{-6} Pa at 225 rpm (NO gas flow)

  gradual degradation of vacuum 1×10^{-6} Pa/month
- Spikes

  5×10^{-7} Pa → 2×10^{-5} Pa (every 6 hours, duration 2 min)

(2) Calculations of Vac. at First Acc. tube(inputs: (1))

- from 7×10^{-8} to 4×10^{-9} Pa

  (when 5×10^{-7} Pa at near seal (base))
- from 3×10^{-6} to 2×10^{-7} Pa

  (when 2×10^{-5} Pa at near seal (peak of spikes))

TDR Requirement
10^{-6} Pa

(3) Plans of Improvements

Try Super Seal (in 2018)

Try two-stage seal (when we get increased budget)

Backups

Radiation Test

Tests of Ferrofluid

November 2014

TEST was done: Radiation Tolerance

Takasaki Advanced Radiation Research Institute, JAEA

- The seal dosed up to 4.7 MGy (3 ILC year , 2600 bunch) is examined.
- Rotation : 0-600 rpm.
- No leak was found. GOOD!
- But, viscosity increased.

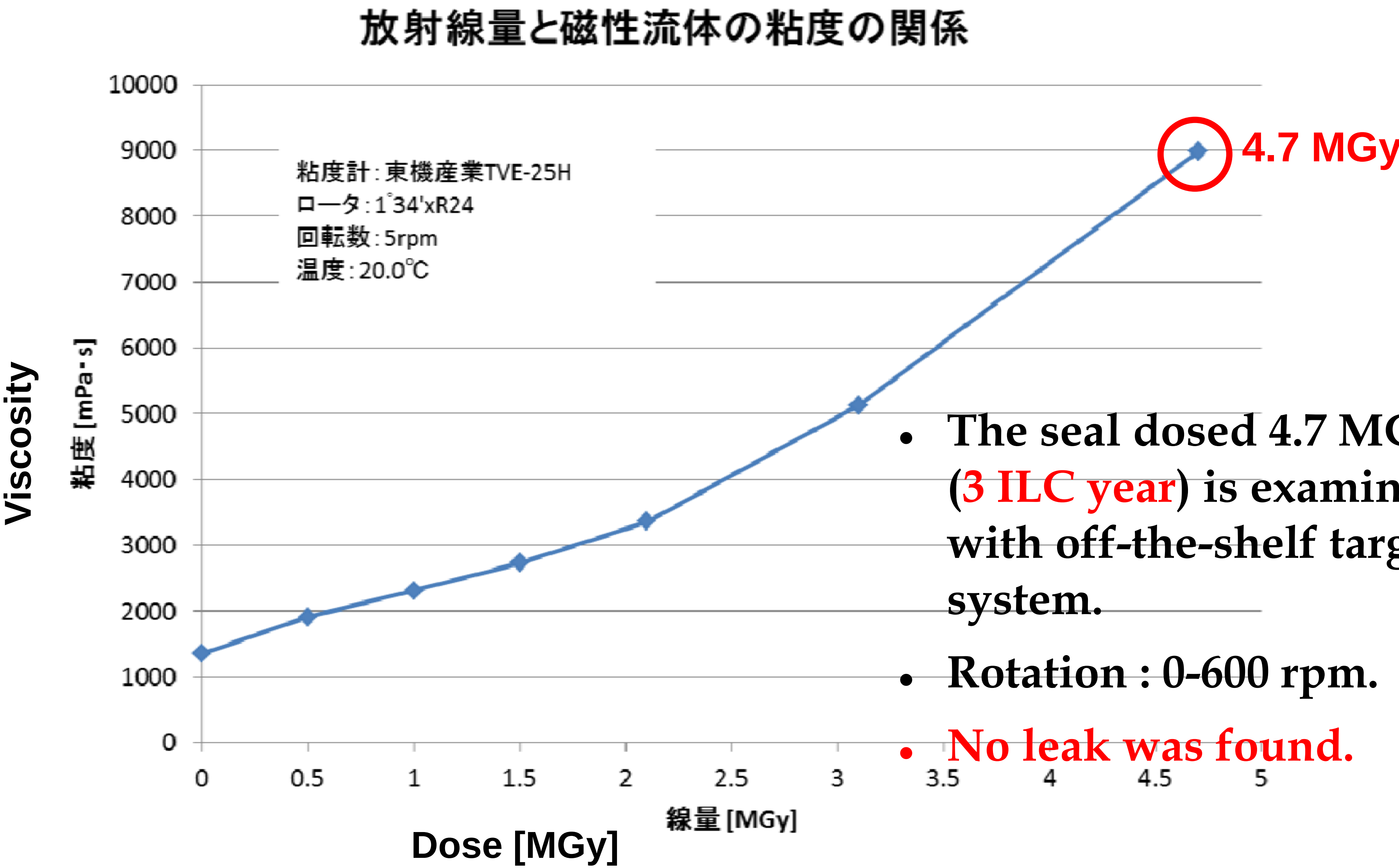
TEST: Radiation Tolerance

November 2014

More systematic study for CN oil

FY2014

Viscosity as a function of dose



- The seal dosed 4.7 MGy (3 ILC year) is examined with off-the-shelf target system.
- Rotation : 0-600 rpm.
- No leak was found.

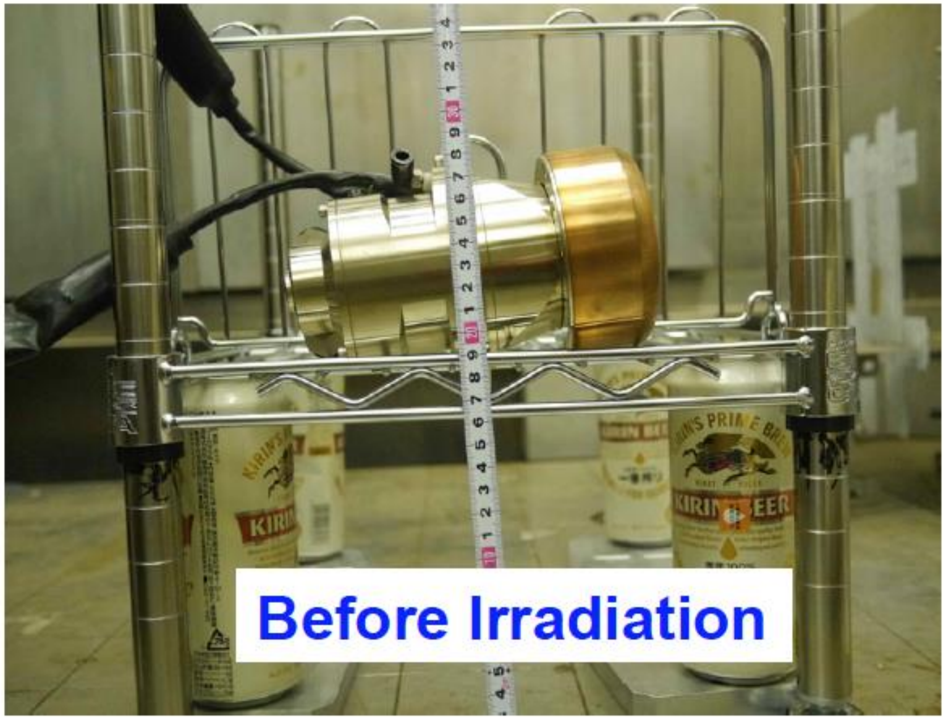
Radiation Test: Entire Target

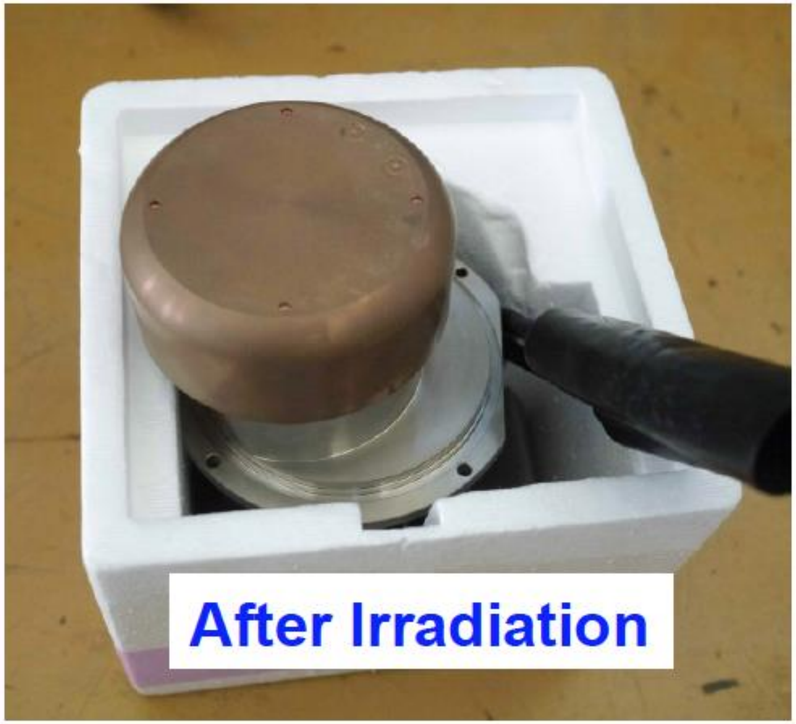
TEST: Radiation Tolerance Mar 2015

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

Radiation test of the whole system: motor, bearing, ferrofluid,,,

0.6 M Gy irradiation on the motor.
corresponds 1 ILC year





After irradiation, we made rotation and vacuum test.

We found NO problem

T. Omori

New Radiation Test:
Feb 2018 and Summer 2018

Radiation tests with monocular structure analysis by GPC and UV-Vis methods are on going.

GPC: Gel Permeation Chromatography

UV-Vis: Ultraviolet Visible Spectrophotometer

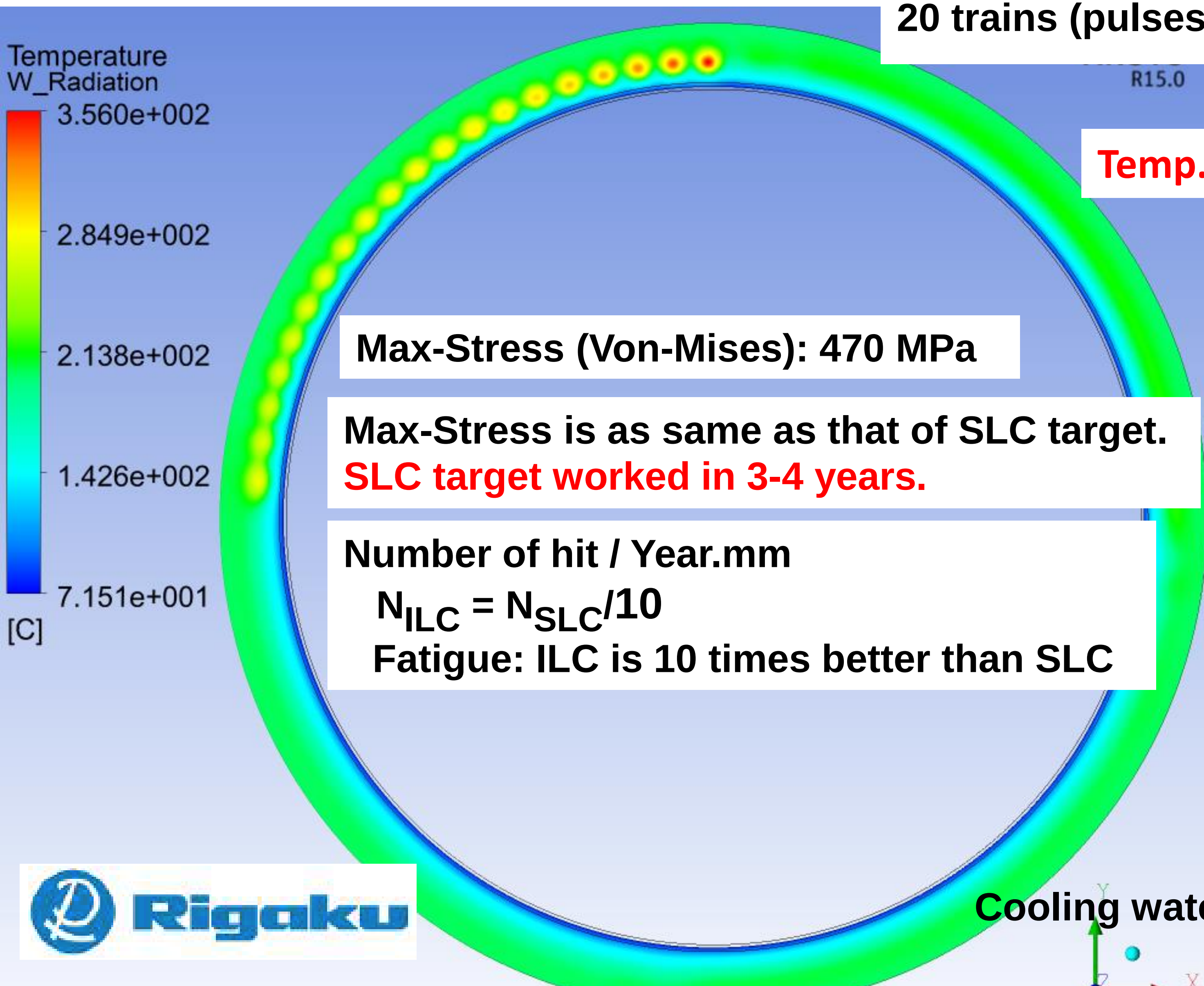
Heat&Stress Simulations

Simulation : target stress and cooling

Pulse#02 225rpm

Pulse beam analysis: step 2

20 trains (pulses) in 63 ms



Temp.Max.; 356.0℃

Max-Stress (Von-Mises): 470 MPa

Max-Stress is as same as that of SLC target.
SLC target worked in 3-4 years.

Stress: OK
Cooling: OK

Number of hit / Year.mm

$N_{ILC} = N_{SLC}/10$

Fatigue: ILC is 10 times better than SLC

$N_b = 2600$

Cooling water: 60 ℓ /min

Summary of the Radiation Test

(1) The ferrofluid dosed 4.7 MGy (3 ILC year, 2600b)

We used the ferrofluid in a small target. Rotation : 0-600rpm.

No leak was found. GOOD!

But, viscosity increased, and we need to know the cause.

(2) Test of entire target system

A small target was dosed 0.6 MGy at the motor.

It corresponds 1 ILC year (2600b).

No problem was found in rotation and in vacuum.

(3) Radiation tests with monocular structure analysis

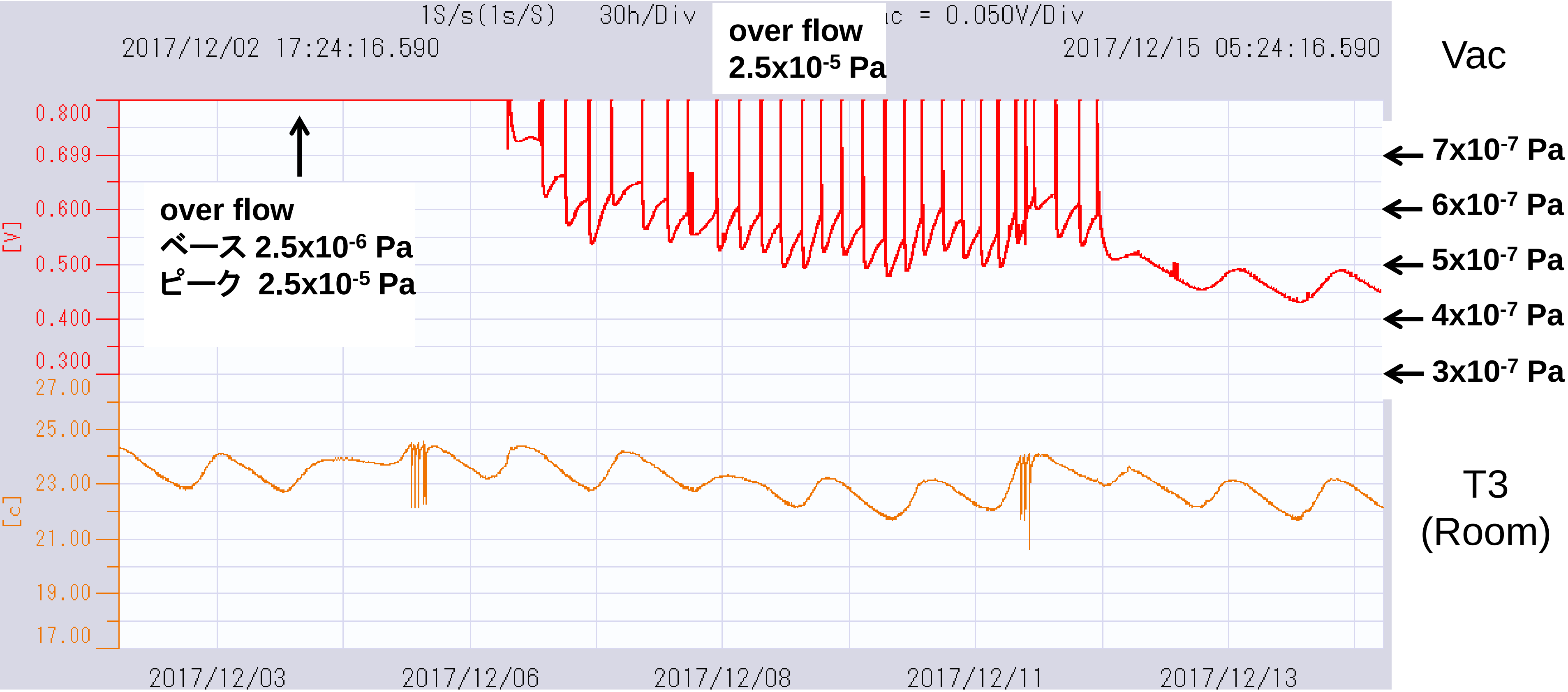
The test is on going

Summary of the Heat&Stress Simulations

- **Stress of the ILC target is as same as that of the SLC target.**
- **Compare Number of hit / Year.mm**

  $N_{ILC} = N_{SLC}/10$

2017, Dec. 02nd - Dec. 15th



1150 rpm
Spikes: every 20 min

225 rpm

Spikes: every 6 hours

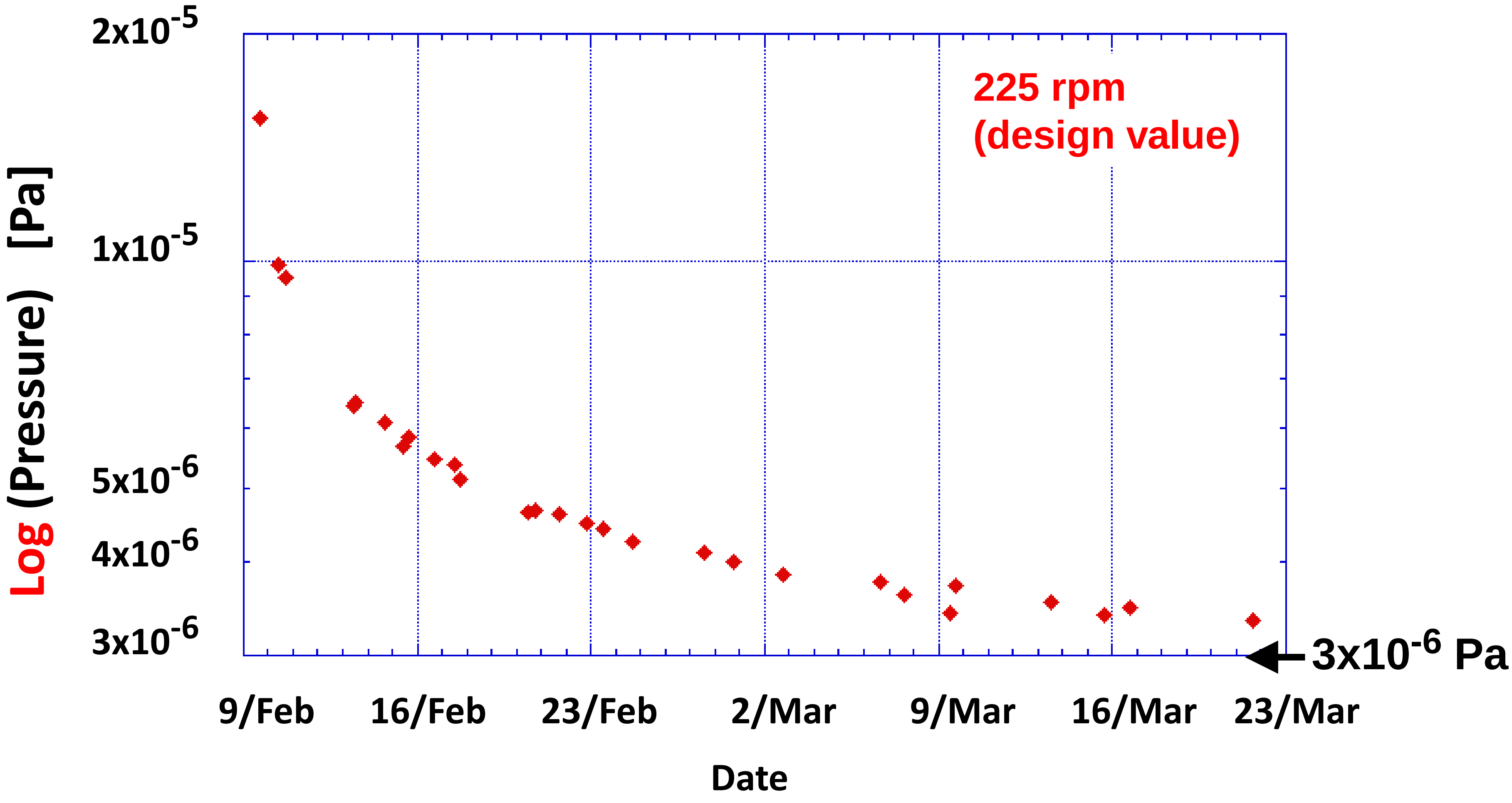
0 rpm

Dec. 06th 13:40
1150 rpm -> 225 rpm

Dec. 12nd 09:32
225 rpm -> 0 rpm
the last spike at the moment of the stop

Central Part Prototype Vacuum Test

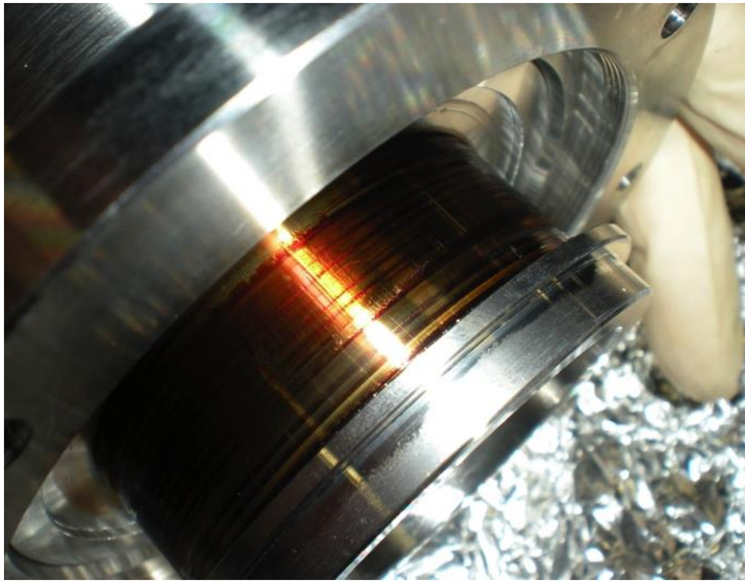
The test started on February 9th, 2017 with continuous rotation at 225rpm



The vacuum test started on February 9th with continuous rotation at 225 rpm (design value). The vacuum level seems to be reasonable in comparison with the expectation. The vacuum level is as good as the ILC TDR requirement. It seems promising. But the prototype has no disk. We will make further study.

No evidence of the seal solvent evaporation

- **No evidence of the seal solvent evaporation: fact 1**
  - **If the leak late 3x10^{-7} Pa m^3/sec (measurement) is dominantly caused by the solvent evaporation, the evaporation rate should be 1.2 x 10^{-10} mol/sec.**
  - **Amount of the fluid of the prototype is very little, we can measure by a earpick, all the fluid should be gone in 2 months. But the fact is that the fluid kept good vacuum more than 5 months (from Feb. to July).**
- **No evidence of the seal solvent evaporation: fact 2**
  - **We opened the chamber on 19th July. No abnormal trace was observed.**
  - **No decrease of the fluid was observed. No black powder (leftover of evaporated solvent) was found.**

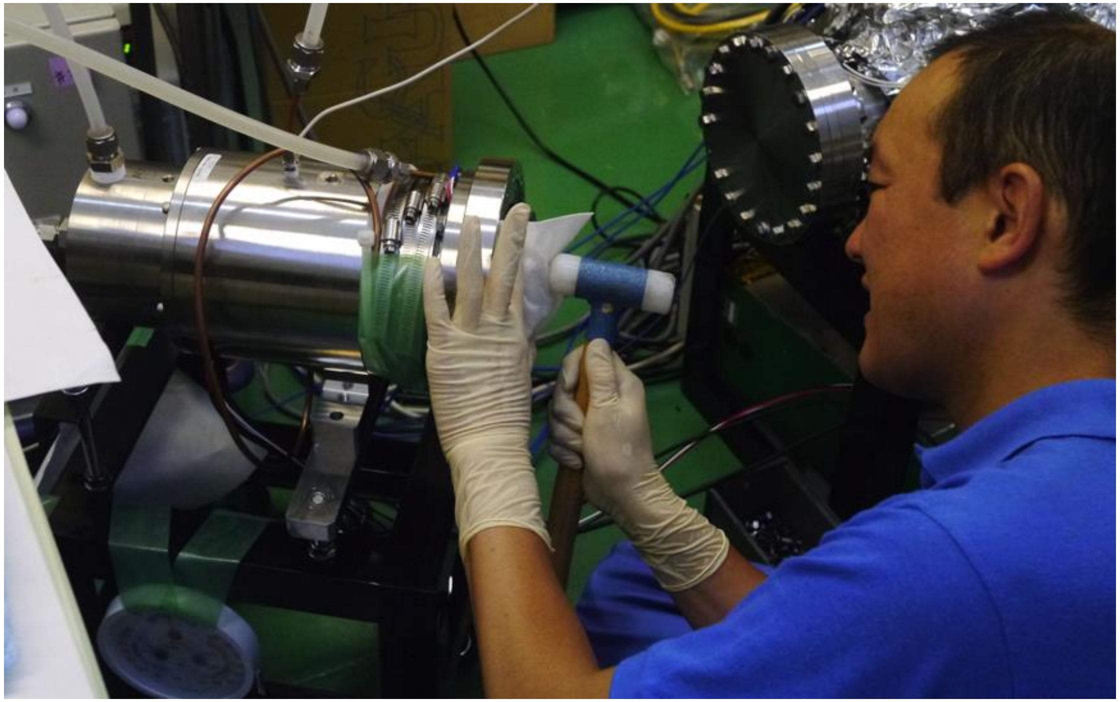


- **No evidence of the seal solvent evaporation: fact 3**
  - **Residuals gas in the chamber was constantly observed of the gas analyzer (Q-mass). We found NO or VERY LITTLE of macromolecules which are considered fragment of the solvent.**

Quality Control?

(1) The seal unit was carried from the company to KEK with no protection to atmoshere in mid-summer in Japan. Maybe the ferrofluid absorbed water in the atmosphere?

(2) Maybe reinstallation work in KEK (NOT in the company) caused an issue in the quality control?



Absorption of the gas on the surface (Cu) of the accelerator tube

Gas flow in the accelerator tube (see the previous page)

2.29×10^{12} molecules s^{-1}

Cu atom surface density ($1/m^2$)

$1.19 \times 10^{12}\ m^{-2}$

Total inner surface area of the accelerator tube

$1.09\ m^2$

Gas absorption rate on the surface α

$$\alpha = \frac{2.29 \times 10^{12}}{1.92 \times 10^{19} \times 1.09} = 1.03 \times 10^{-7}\ 1/\mathrm{s}$$

Note: We assume all gas comes to the accelerator tube are absorbed on the surface. -> We assume the worst case.

Gas removal rate from the surface β

$$\beta = \nu \exp\left(-\frac{E_a}{RT}\right)$$

Ea=100 keV activation energy

$\nu = 10^{13}$ frequency factor

$\beta = 3.85 \times 10^{-5}$

Absorption of the gas on the surface (Cu) of the accelerator tube

Covering rate η :Differencial Eq. and the Solution:

$$\frac{d\eta}{dt} = \alpha - \beta\eta$$

$$\eta = \frac{\alpha}{\beta}\left(1 - e^{-\beta t}\right)$$

Answer

Covering rate at Equilibrium $\eta(t=\infty) = 2.7\times10^{-3}$ **(0.27%)**

Days to reach equilibrium $1/\beta = 110$ **days**

Conclusion

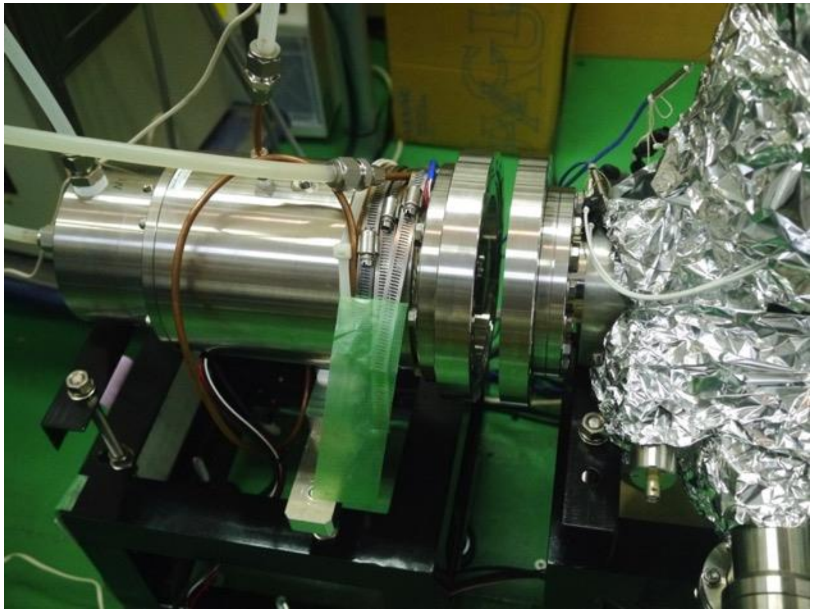
The covering is far smaller than single molecule layer (Covering rate 0.27%)

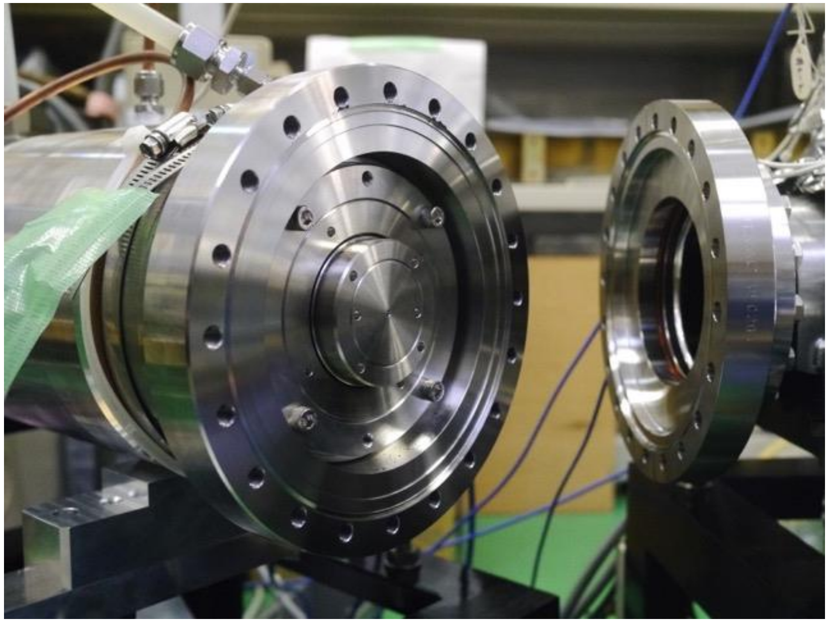
Note:

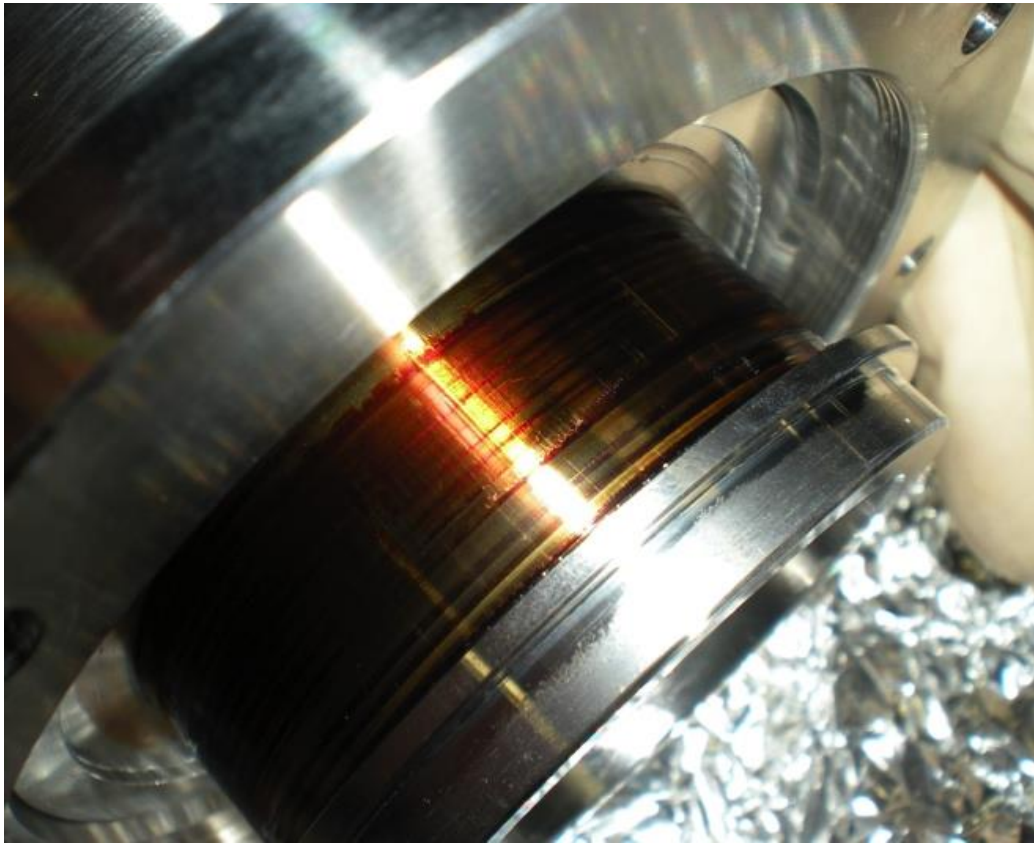
The answer and the conclusion are based on the assumption that the measured "leak" rate is fully due to the evaporation of the seal fluid. But this is NOT true. The evaporation is only a very small part of the "leak". The actual situation should be much better.

We Opened the prototype and made observation

July 19th







Evaporation of the Fluid?

The dominant cause of the "leak" is NOT the evaporation.

∗ Evidence 2:

- We opened the chamber of the prototype on 19th July.
  And observed inside by eyes.

- No damage of the fluid was observed by eyes.
  Even small amount of disappearance of the fluid was observed.

  If there is evaporation, we will see powders of dried fluid.

- Before the opening, we expected to see the powders at some stages of the seal (seal has 20 stages in total) near the vacuum.
  But we observed healthy fluid even at the inner most stage.