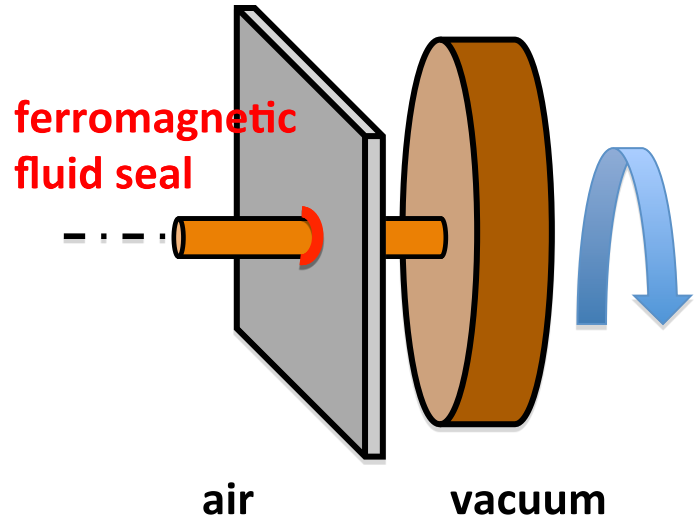
Rotation Target R and D of ILC E-driven source

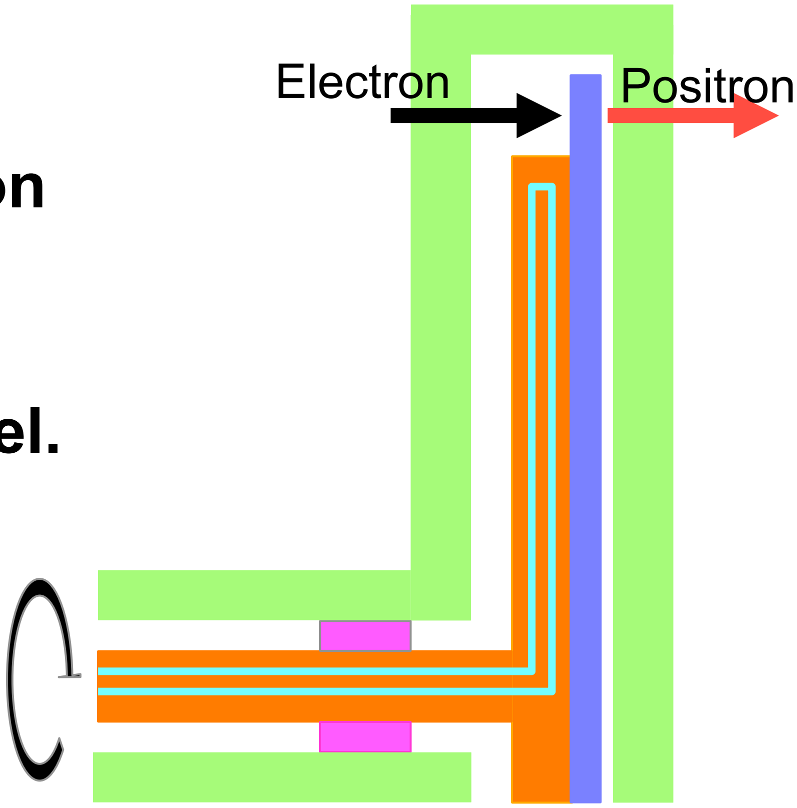


T. Omori (KEK), 20-September-2017

2017 POSIPOL 2017
September 18-21, 2017, BINP, Novosibirsk, Russia

Target

- W-Re 14mm thick.
- 5 m/s tangential speed rotation (225 rpm, 0.5m diameter) in vacuum.
- Water cooling through channel.
- Vacuum seal with ferro-fluid.



Today's Talk

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

- Target R/D (1): Heat&Stress Simulations, and Radiation Test
- Target R/D (2): Vacuum Test of the Prototype
- Summary

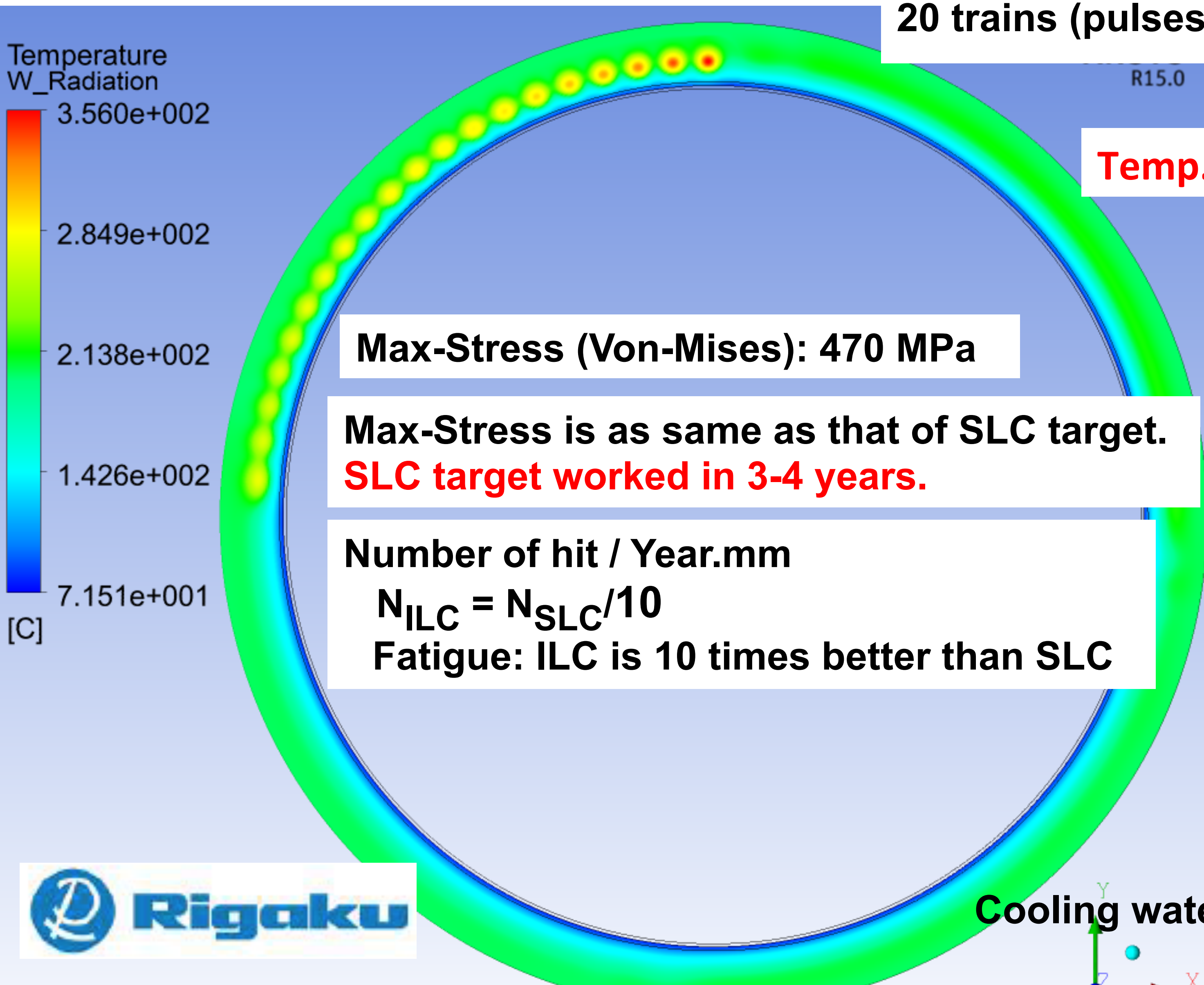
Heat&Stress Simulations
and
Radiation Test

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.

Number of hit / Year.mm

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

Fatigue: ILC is 10 times better than SLC

Stress: OK
Cooling: OK

$N_b = 2600$

Cooling water: 60 ℓ /min

TEST: Radiation Tolerance   FY2014

Takasaki Advanced Radiation Research Institute, JAEA

November 2014

10-Nov-2014

TEST: Radiation Tolerance

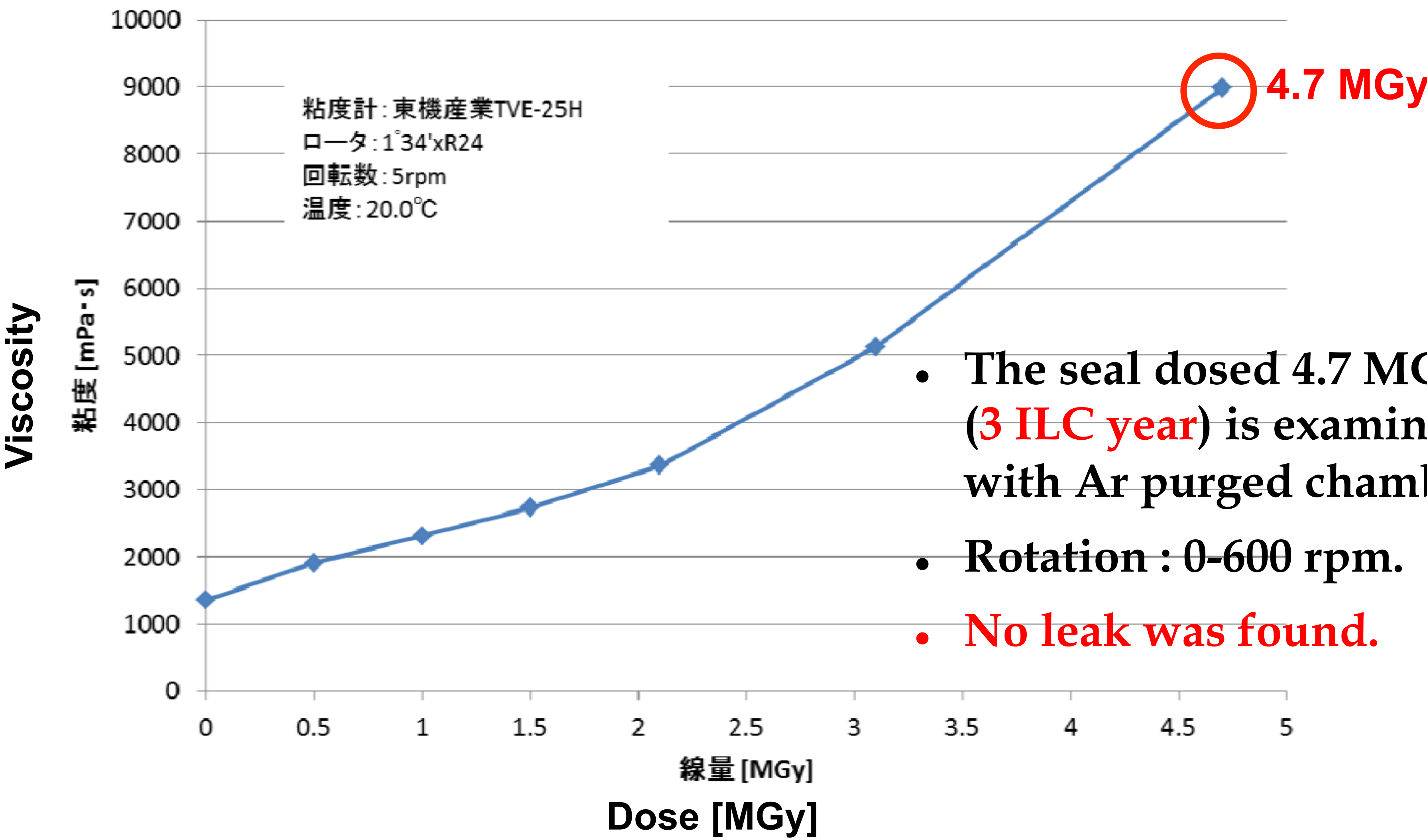
November 2014

More systematic study for CN oil

FY2014

Viscosity as a function of dose

放射線量と磁性流体の粘度の関係



- The seal dosed 4.7 MGy (3 ILC year) is examined with Ar purged chamber.
- Rotation : 0-600 rpm.
- No leak was found.

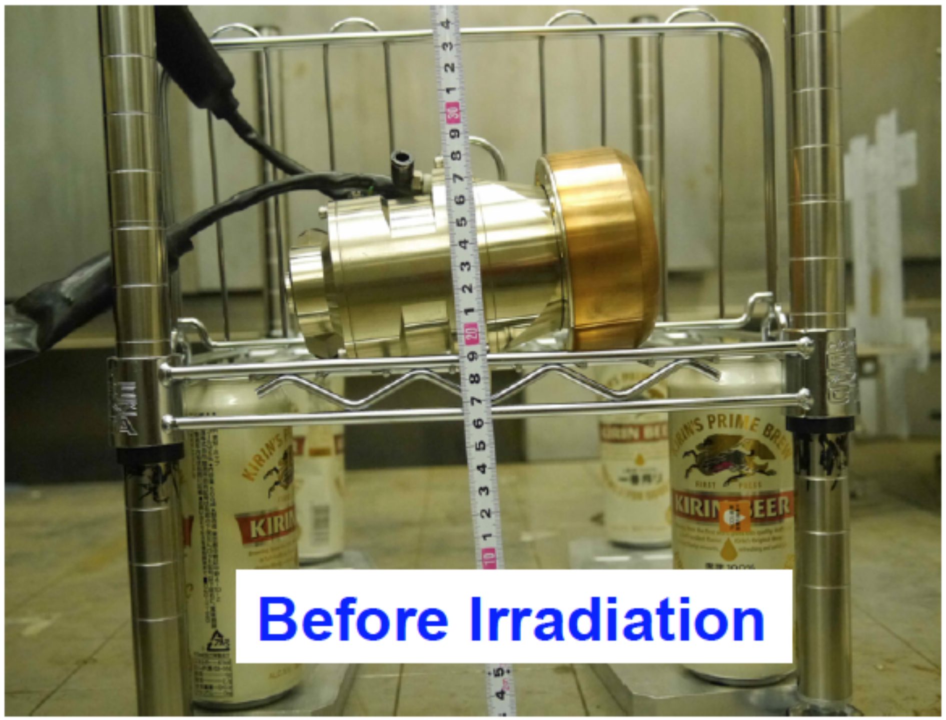
Conventional (E-driven): Target

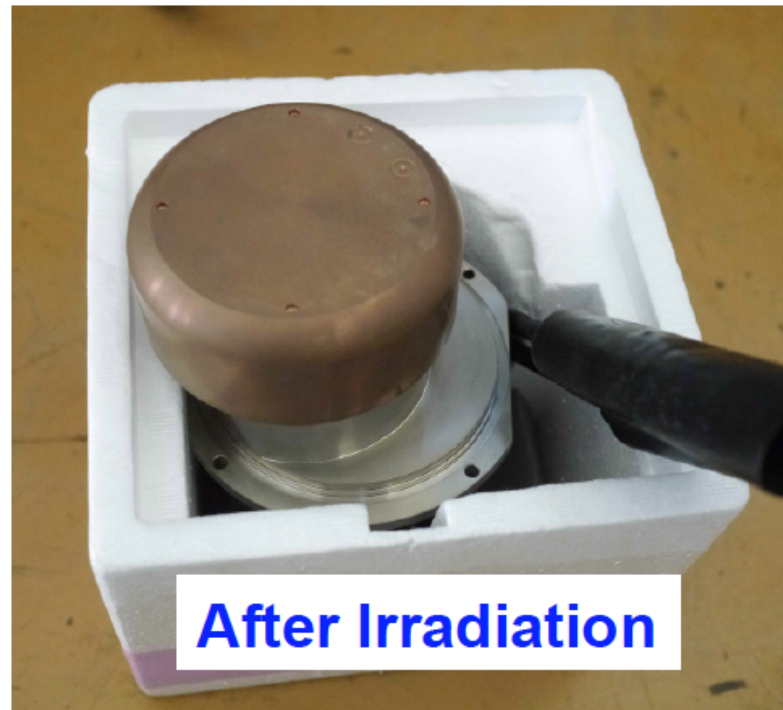
TEST: Radiation Tolerance Mar 2015

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





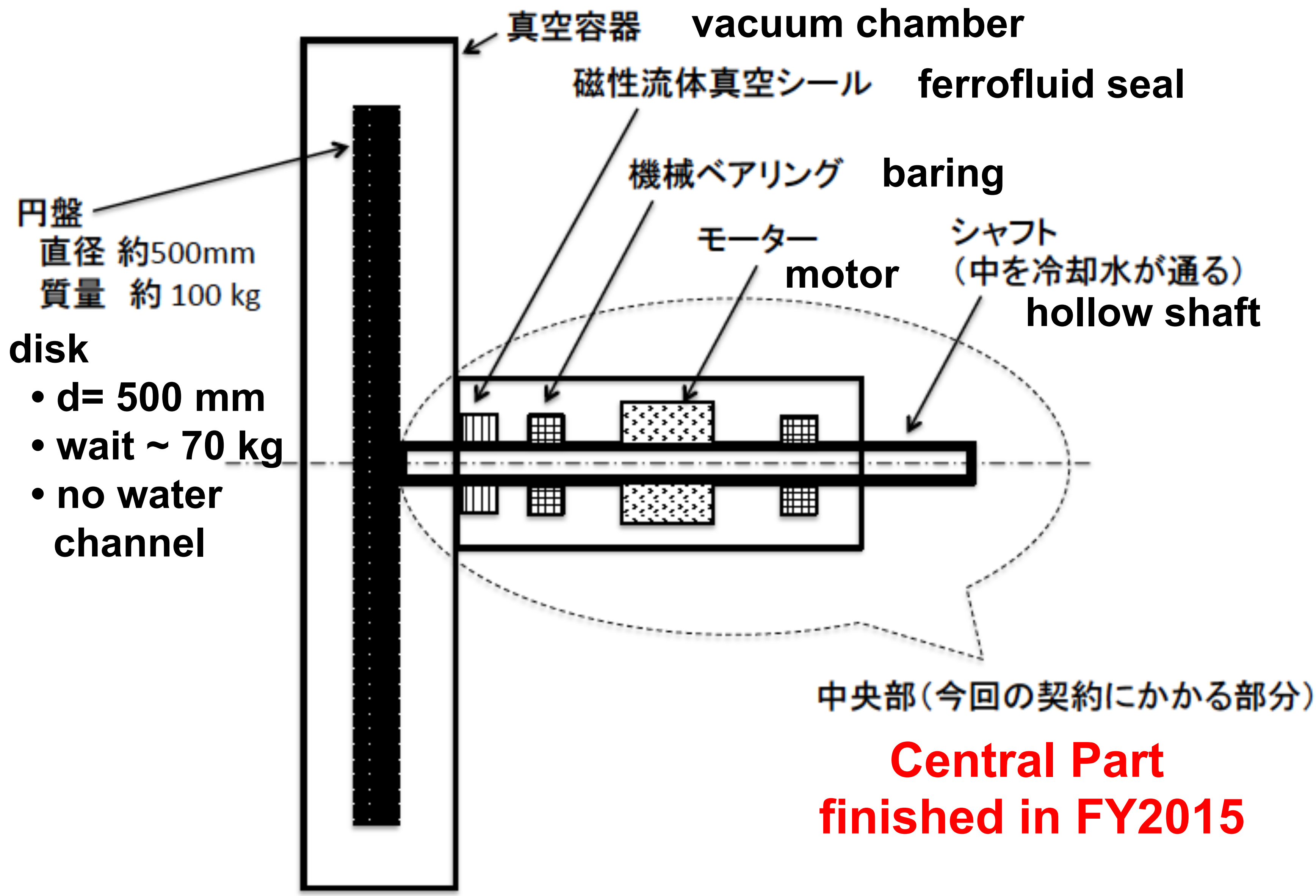
After irradiation, we made rotation and vacuum test.

We found NO problem

T. Omori

Vacuum Test
of
the Prototpe

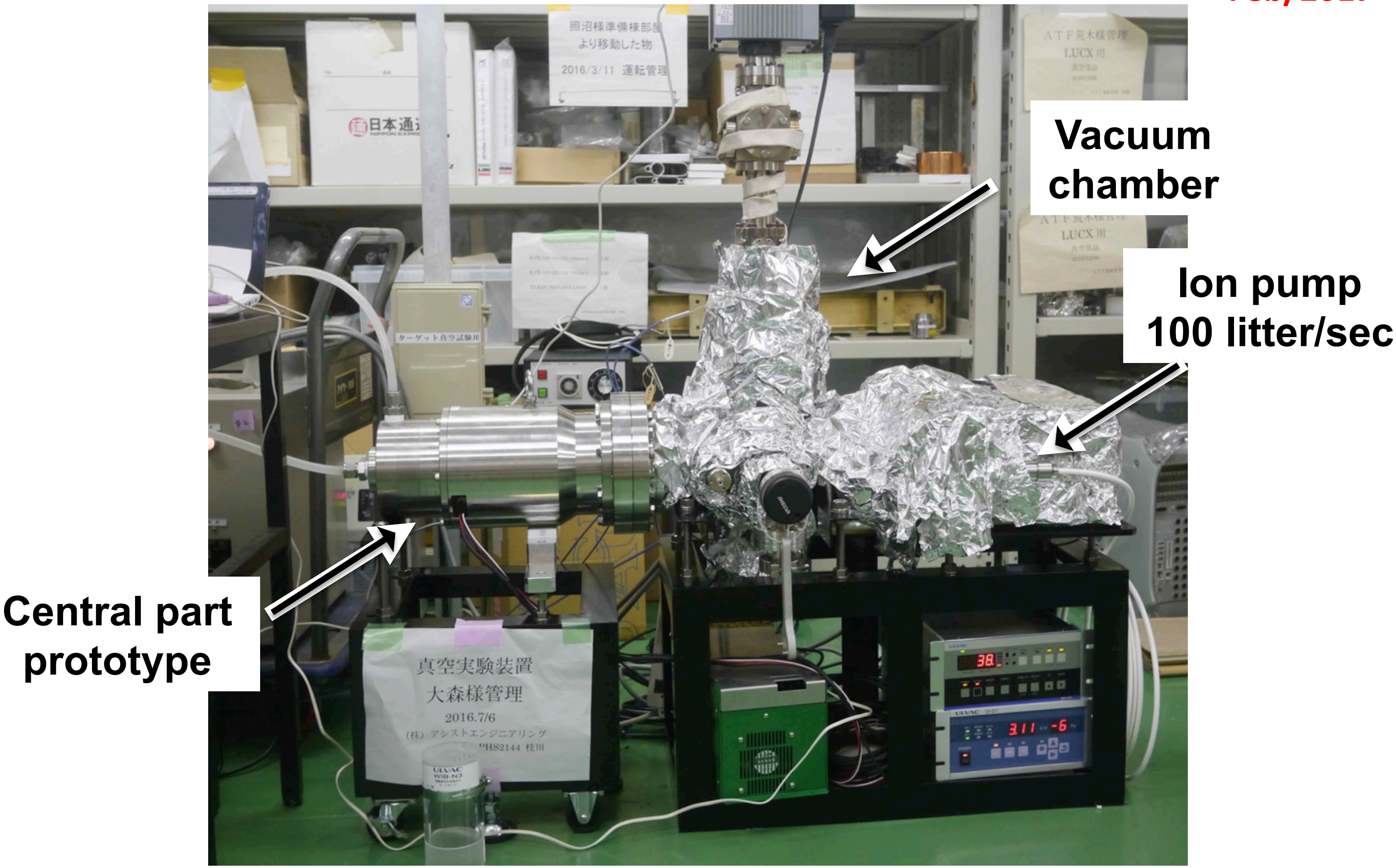
Prototype of the Rotation Target (E-driven)



回転ターゲットプロトタイプ概略断面図

Central Part Prototype Vacuum Test

Feb/2017



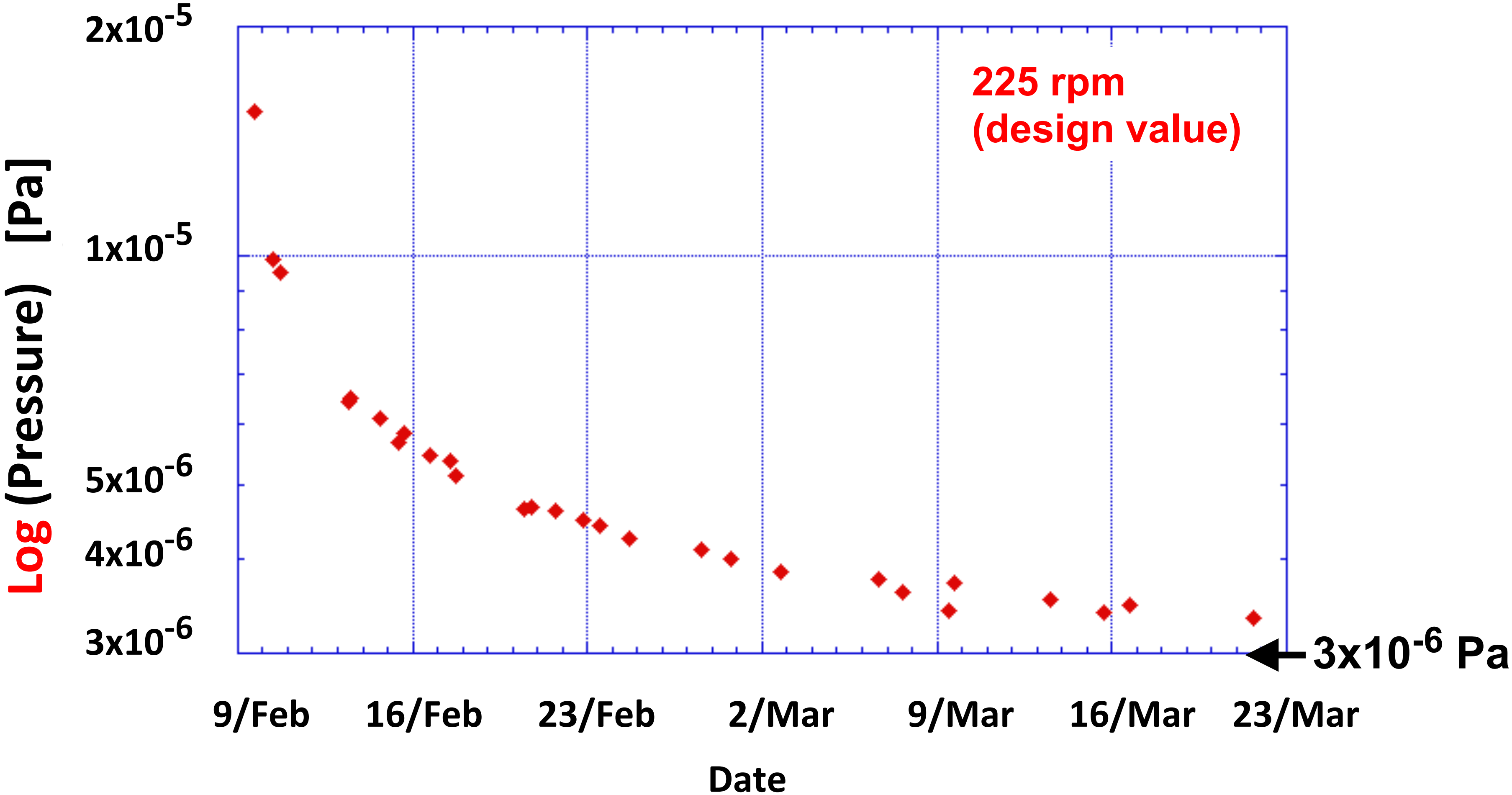
Central Part Prototype: Funded by KEK
Vacuum Test: Funded mostly by Hiroshima Univ.

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.**

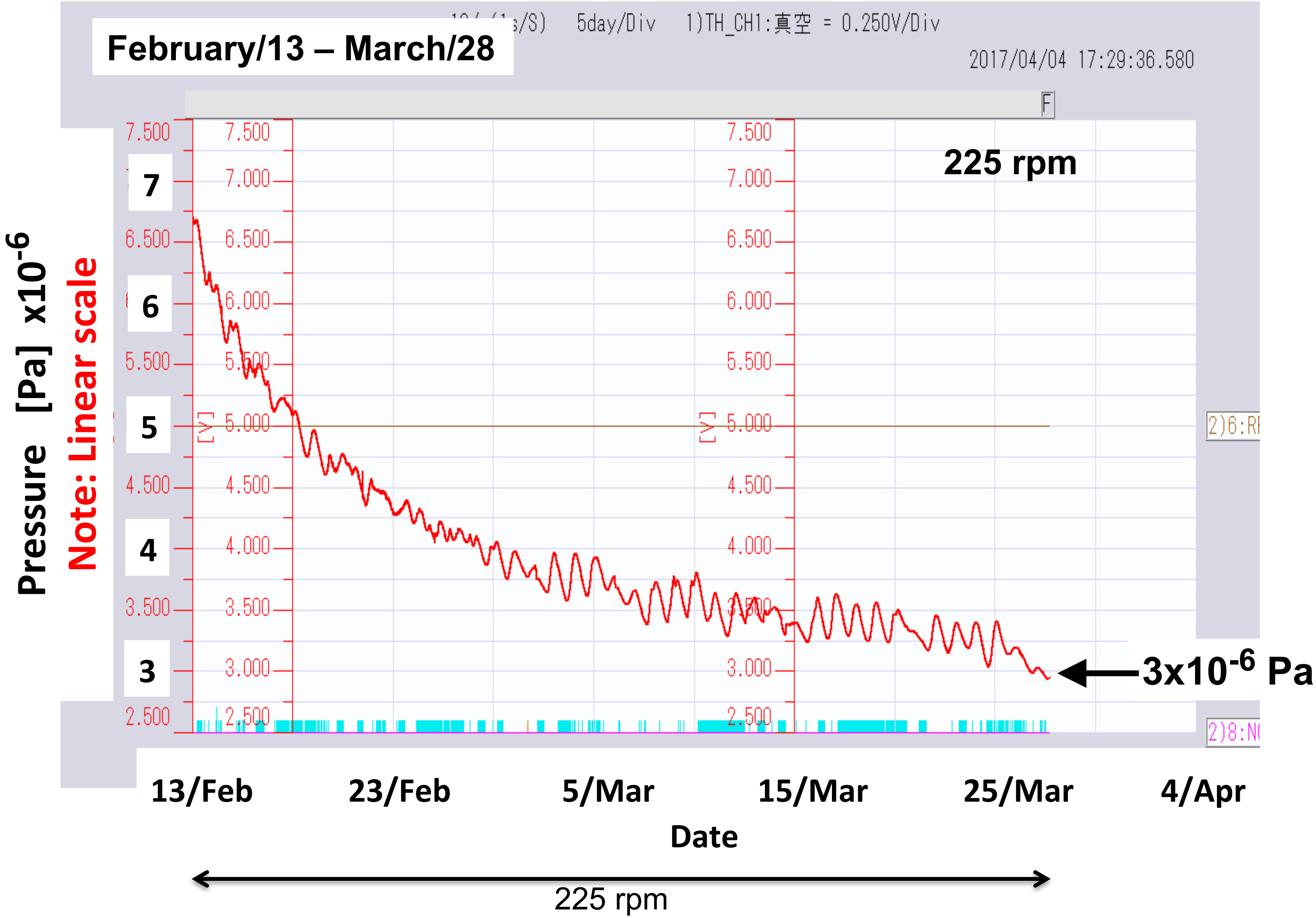
Central Part Prototype Vacuum Test

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



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.

Central Part Prototype Vacuum Test

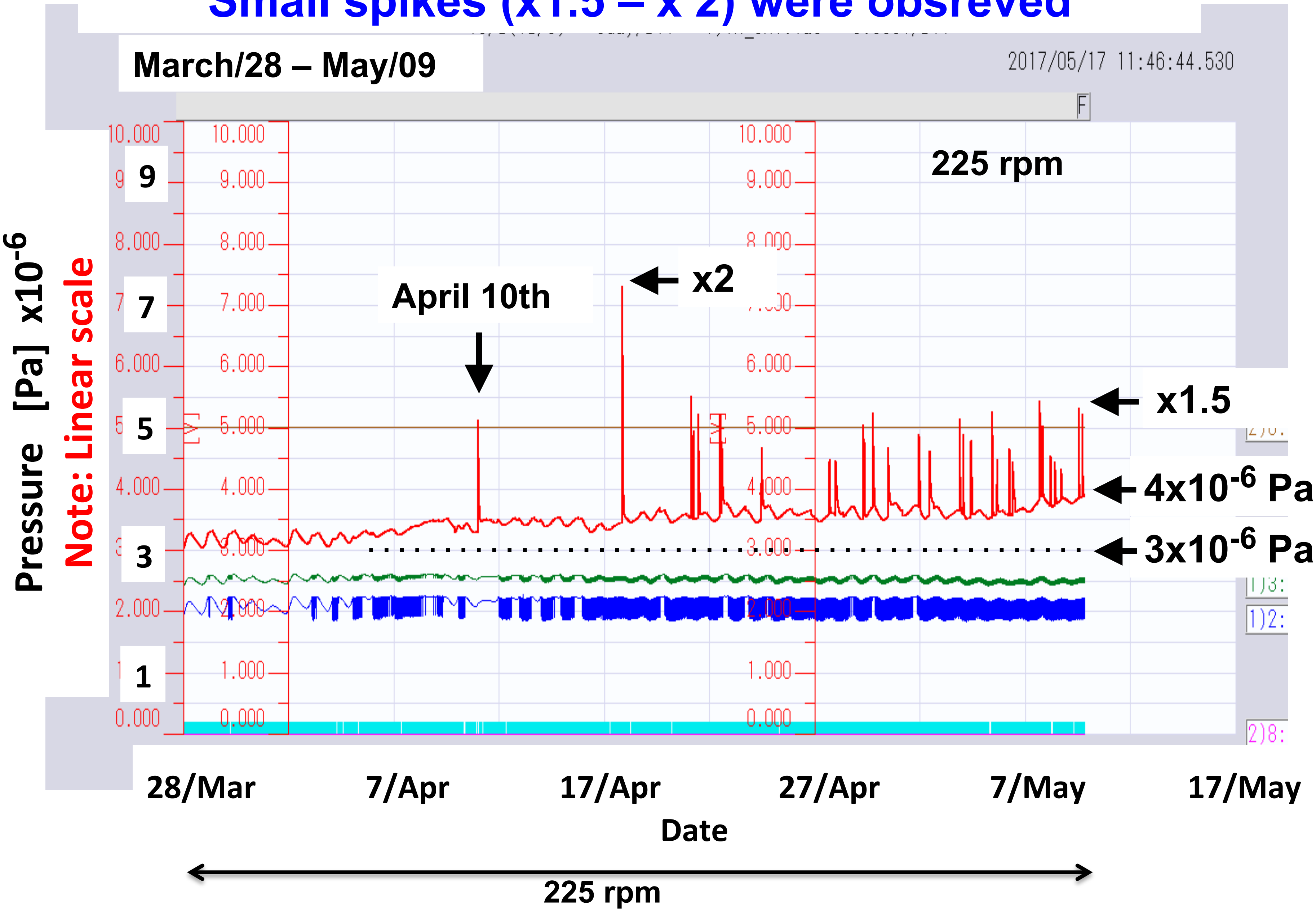


Central Part Prototype Vacuum Test
Facts and What happened (1)

- Ion pump 100 litter/sec.
- Rotation at 225 rpm (design value).
- We started the experiment on February 9th.
- Vacuum level went good monotonically.
- And reached ~ $3x10^{-6}$ Pa at the end of March.

Central Part Prototype Vacuum Test

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

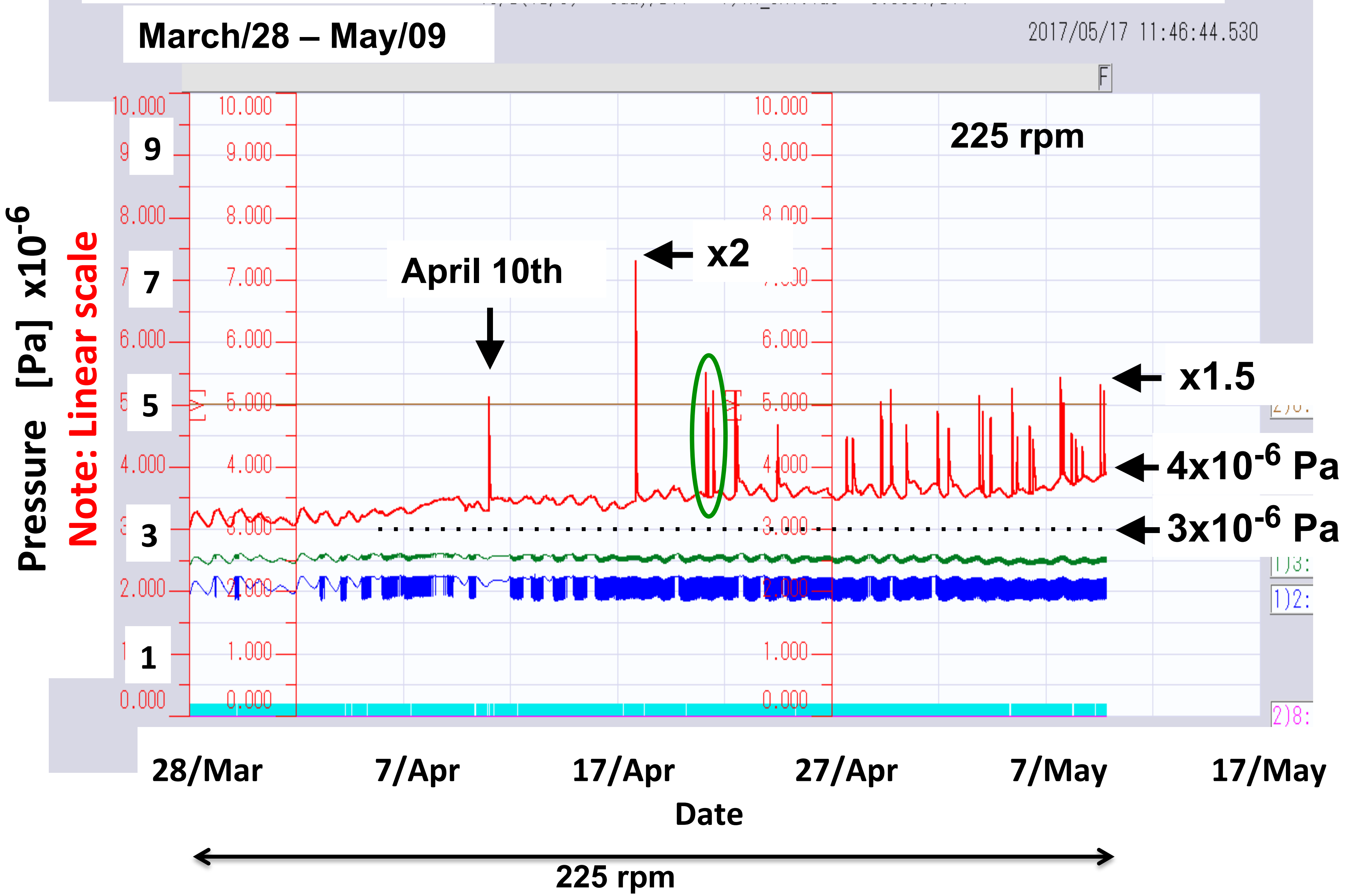


Central Part Prototype Vacuum Test
Facts and What happened (1)

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

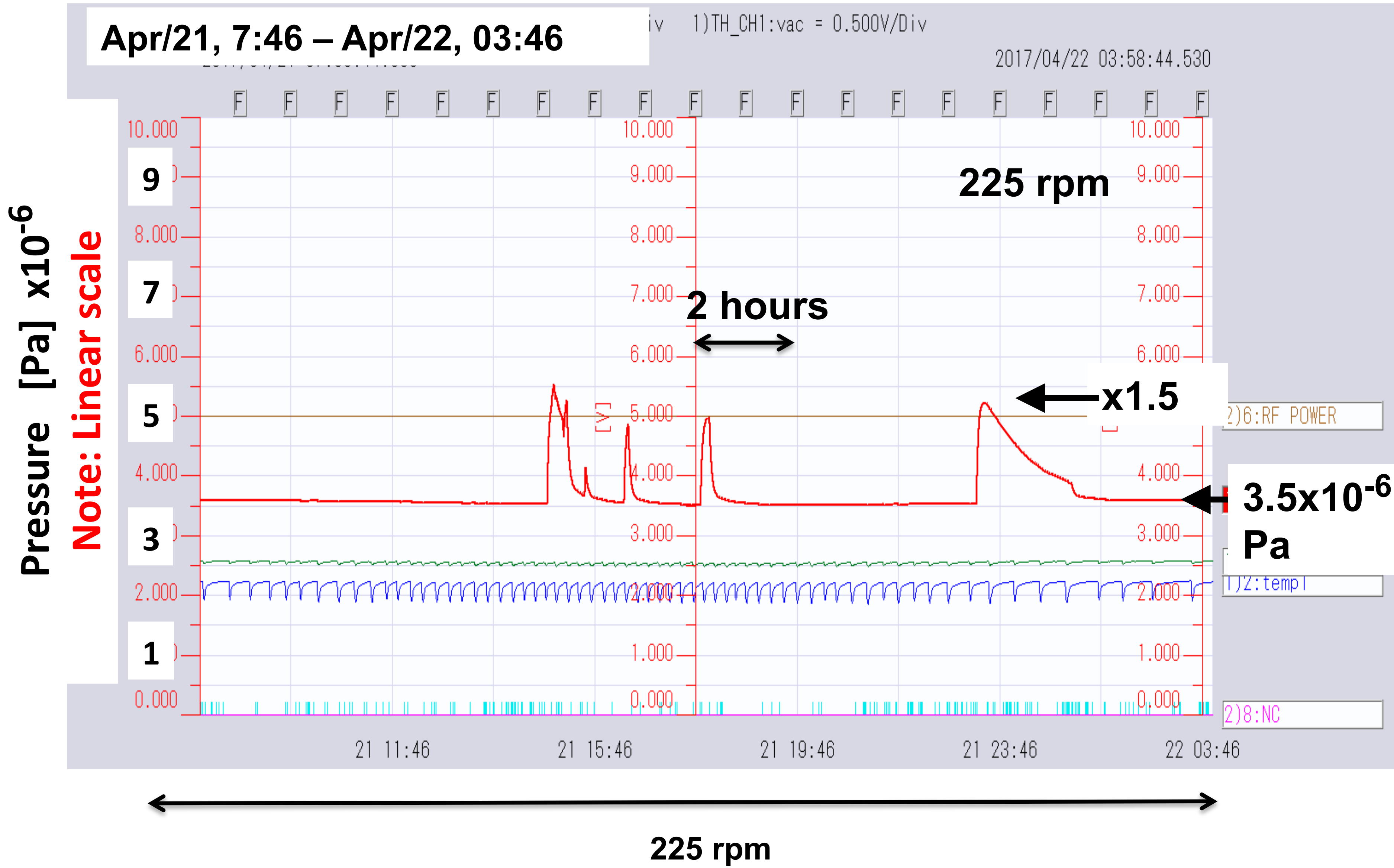
Central Part Prototype Vacuum Test

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



Central Part Prototype Vacuum Test

Close-up of the small spikes



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

Facts

Vacuum 3×10^{-6} Pa (measurement results)

Keep good vacuum over five months

Sikes

Vacuum level slowly went worse.

Concerns

Sikes

Aging

Contamination of the accelerator tube

Estimation in ILC e+ source system

＊Data measured by the central part prototype (experiment)

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

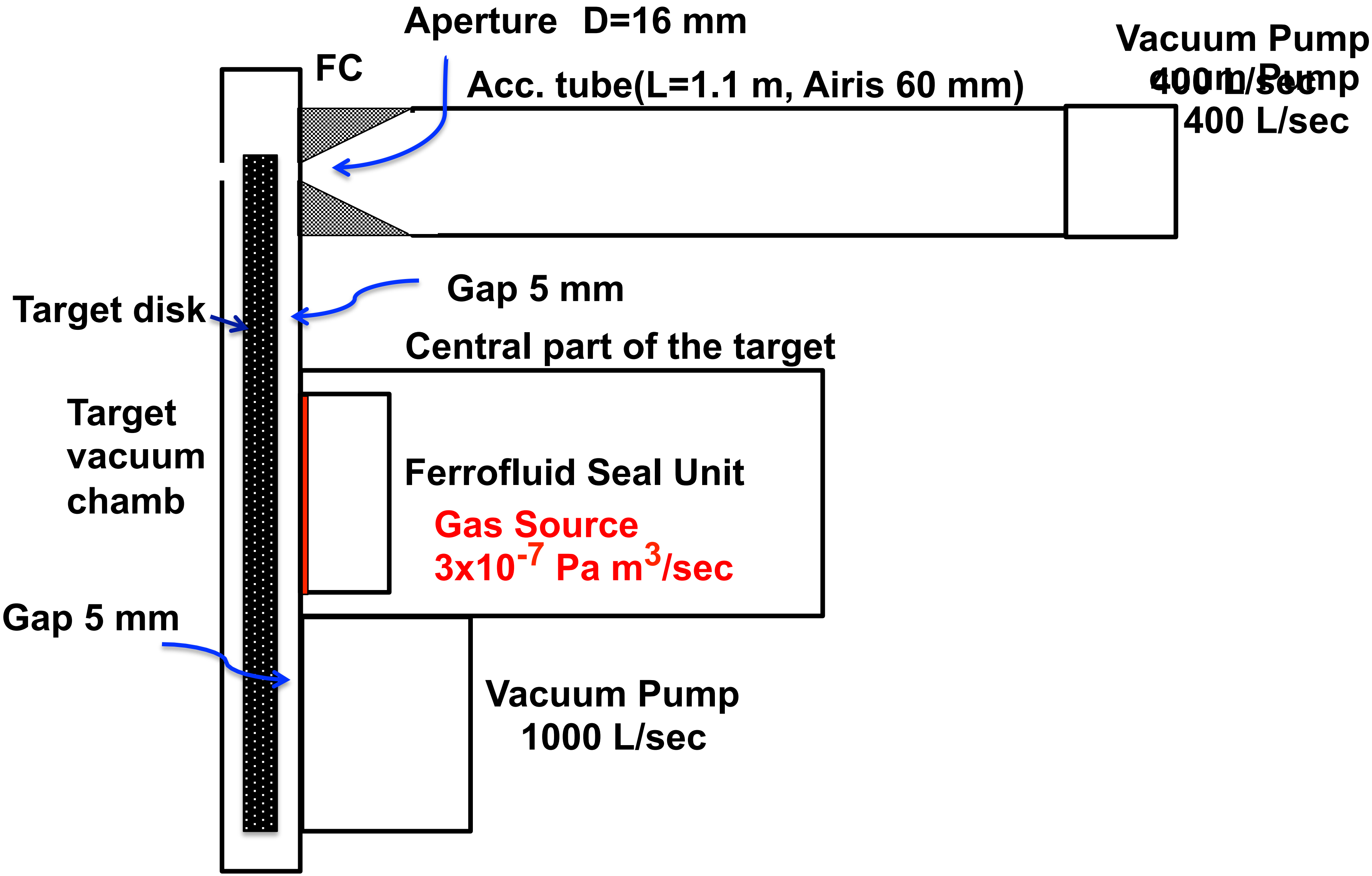
Vacumm pump used 100 L/s (=$100x10^{-3}$ m^3/sec)(Ion pump)

＊Leak rate （calculated from the above）

($3x10^{-6}$ Pa) x ($100x10^{-3}$ m^3/sec) = $3x10^{-7}$ Pa m^3/sec

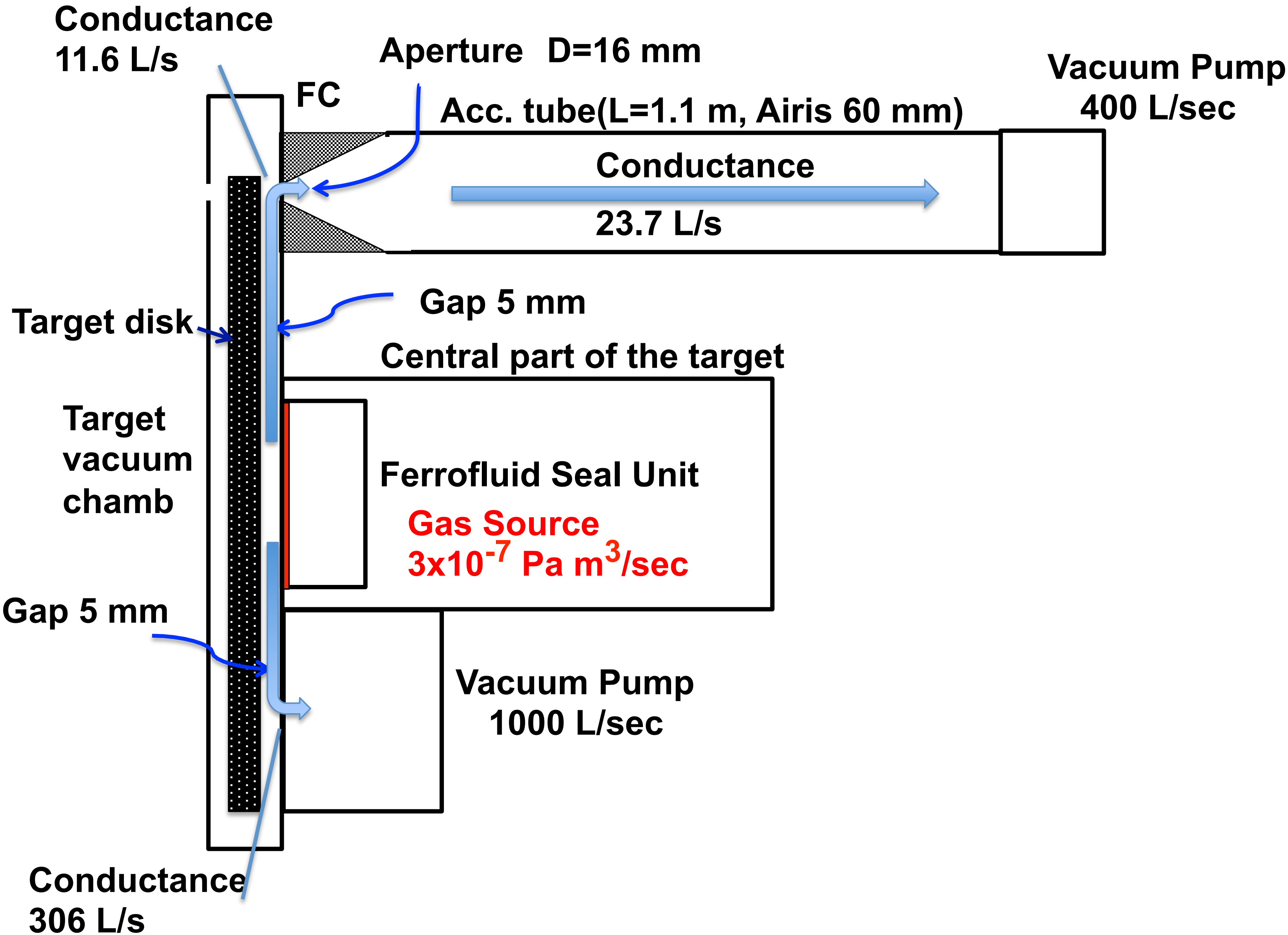
＊Estimate expected vacuum levels and gas flows in ILC e+ source system by using the leak rate

The Model



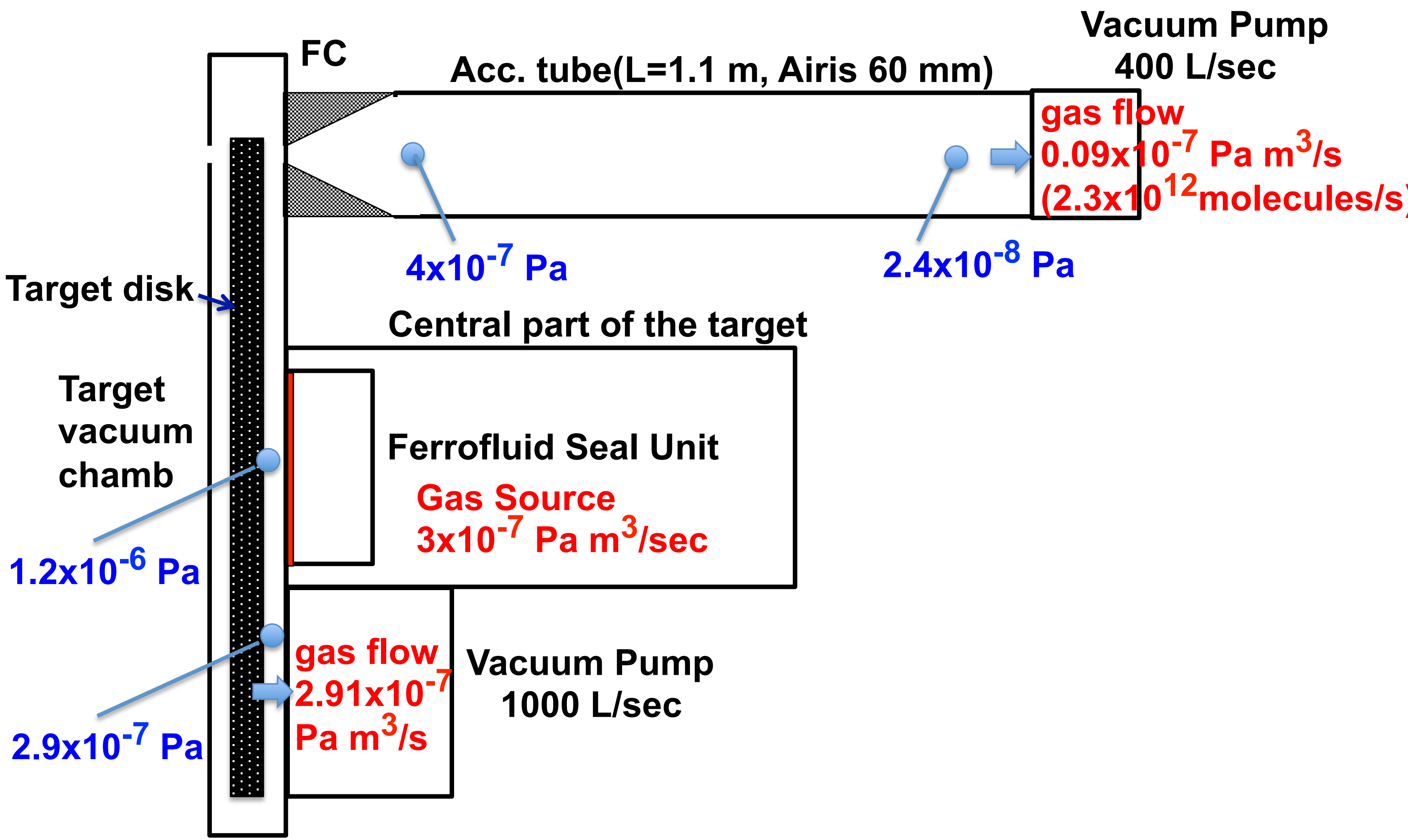
Aperture D=16 mm
FC
Acc. tube(L=1.1 m, Airis 60 mm)
Vacuum Pump
400 L/sec
Gap 5 mm
Target disk
Central part of the target
Target vacuum chamb
Ferrofluid Seal Unit
Gas Source
3x10-7 Pa m3/sec
Gap 5 mm
Vacuum Pump
1000 L/sec

The Model



Conductance
11.6 L/s
Aperture D=16 mm
FC
Acc. tube(L=1.1 m, Airis 60 mm)
Vacuum Pump
400 L/sec
Conductance
23.7 L/s
Target disk
Gap 5 mm
Central part of the target
Target
vacuum
chamb
Ferrofluid Seal Unit
Gas Source
3x10-7 Pa m3/sec
Gap 5 mm
Vacuum Pump
1000 L/sec
Conductance
306 L/s

The Results


Vacuum Pump
400 L/sec
FC
Acc. tube(L=1.1 m, Airis 60 mm)
gas flow
0.09x10-7 Pa m3/s
(2.3x1012molecules/s)
4x10-7 Pa
2.4x10-8 Pa
Target disk
Central part of the target
Target
vacuum
chamb
Ferrofluid Seal Unit
Gas Source
3x10-7 Pa m3/sec
1.2x10-6 Pa
gas flow
2.91x10-7
Pa m3/s
Vacuum Pump
1000 L/sec
2.9x10-7 Pa

Estimation in ILC e+ source system

* Data measured by the central part prototype **(experiment)**
  - Vacuum 3×10^{-6} Pa (mesurement results)
  - Vacumm pump used 100 L/s (=100×10^{-3} m^3/sec)(Ion pump)
* Leak rate （calculated from the above）
  - (3×10^{-6} Pa) x (100×10^{-3} m^3/sec) = 3×10^{-7} Pa m^3/sec
* Estimate expected vacuum levels and gas flows by using the leak rate
* Estimate **contamination by the ferrofluid**.
  - **Assumption: All "leak" is due to evaporation of the fluid.**
  - **→We assume the worst case.**

  In reality, there are three possible causes for the "leak".
  - (a) evaporation of the seal fluid.
  - (b) air leak via the seal
  - (c) Degassing from the surface

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

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

2.29x 10^{12} molecules s^{-1}

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

1.19 x 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

v = 10^{13} frequency factor

β = 3.85x10^{-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 $\eta(t=\infty) = 2.7\text{x}10^{-3}$ (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.

Evaporation of the Fluid?

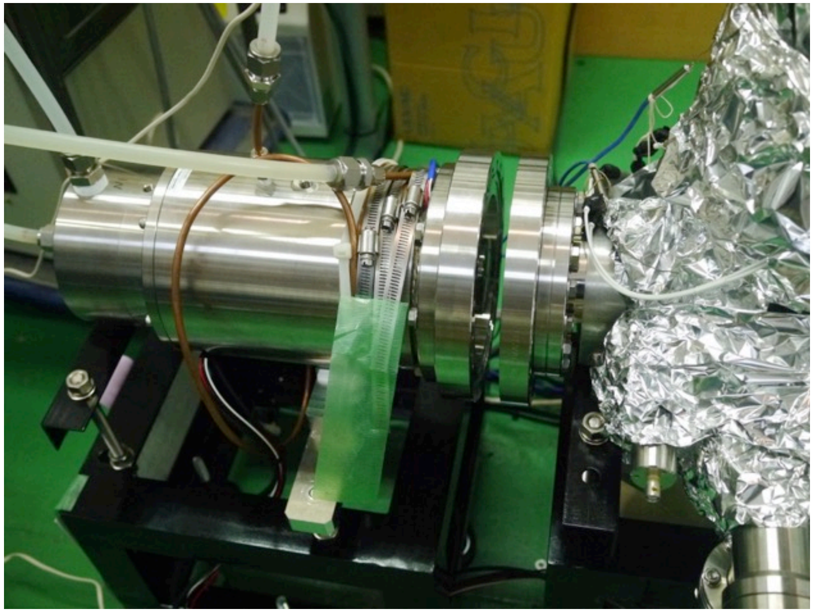
The dominant cause of the "leak" is NOT the evaporation.

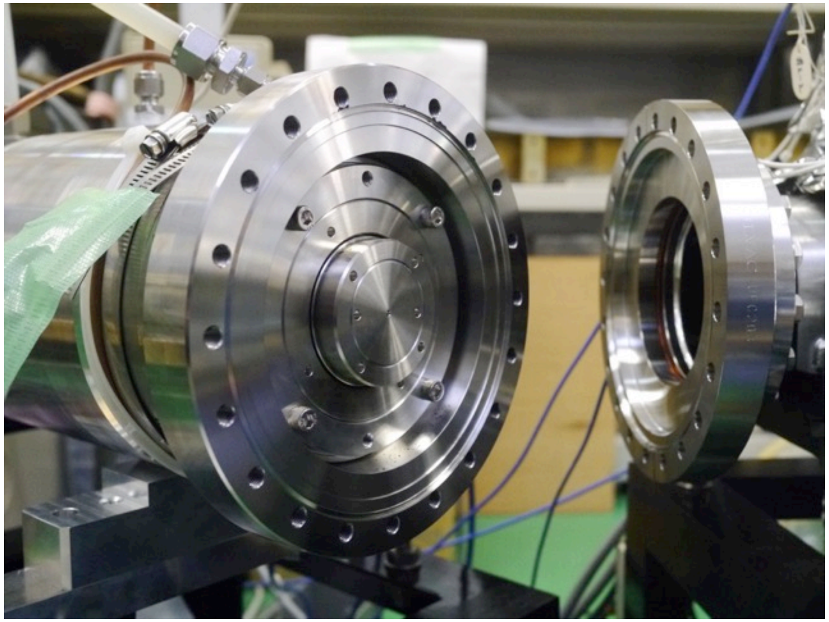
∗ Evidence 1:

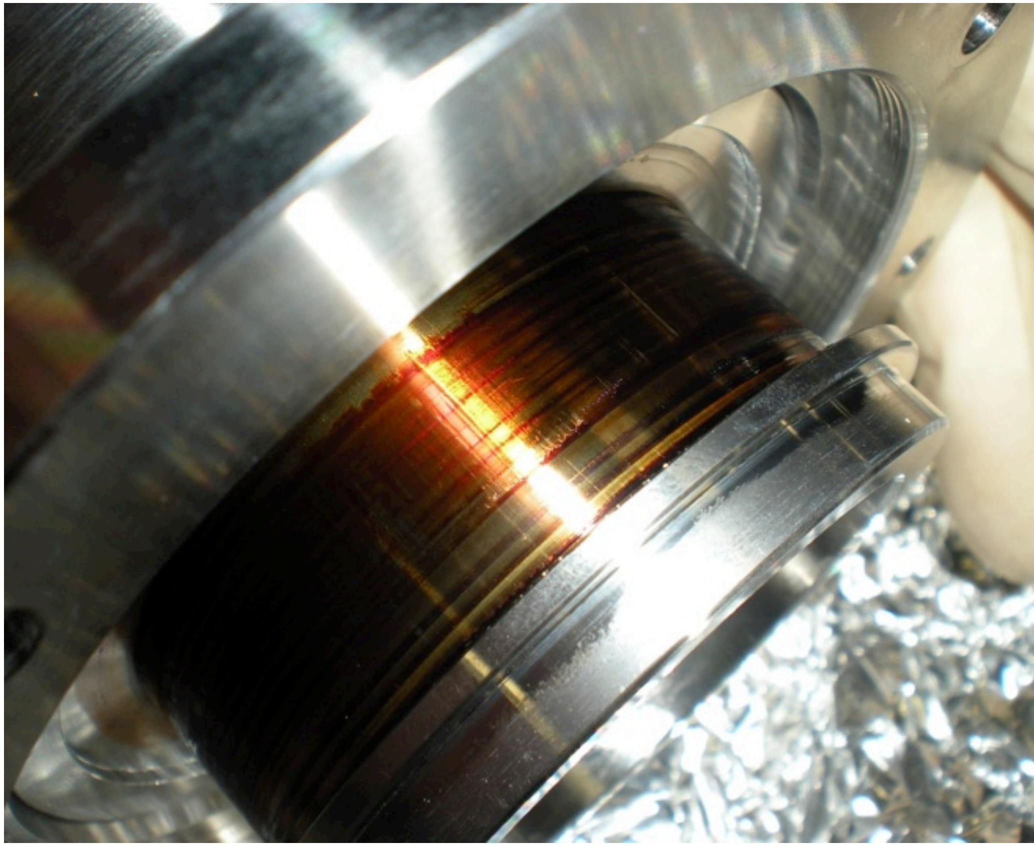
- If the leak rate "$3x10^{-7}$ Pa m^3/sec" (measured value) is dominantly caused by the evaporation, the evaporation speed is estimated to be 1.2×10^{-10} mol./sec
- Since very small amount of the fluid (less than m*l*) is used in the prototype, if evaporation proceeds at the rate all the fluid gone in two months.
- However, the seal keeps good vacuum over five months.
  - -> The evaporation speed is much more slower than the estimated vale.

We Opened the prototype and made observation

July 19th







Evaporation of the Fluid?

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

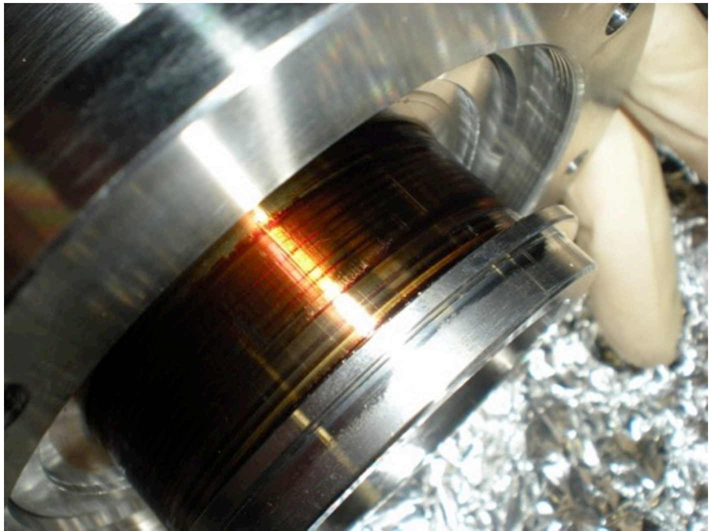
∗ Evidence 2:

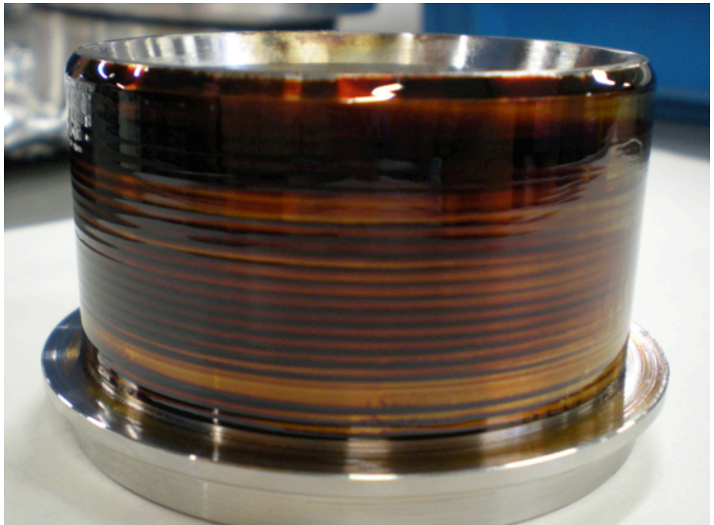
- We opened the chamber of the prototype on 19th July.
  And observed inside by eyes.

- 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.



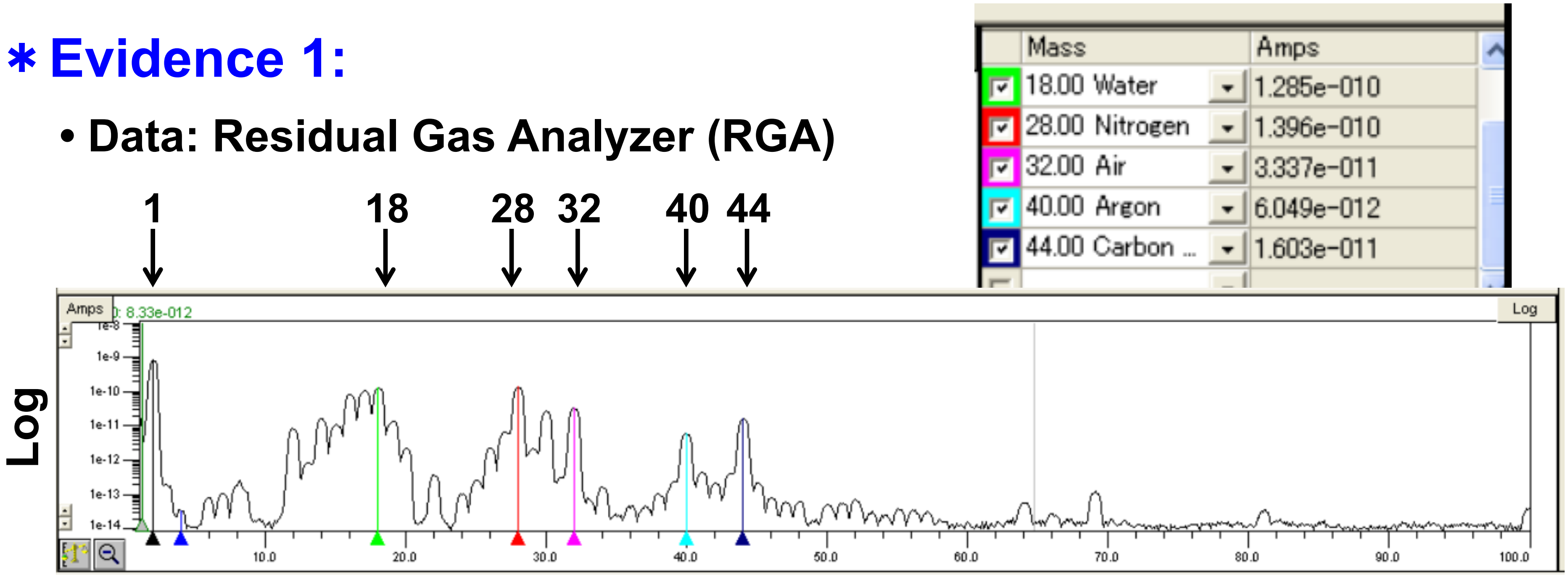


Evaporation of the Fluid?

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

∗ Evidence 1:

- Data: Residual Gas Analyzer (RGA)



- If the fluid (macromolecule) is evaporated, it is expected to observe the fragments of the macromolecules of the fluid.

- However NO such objects were observed at high mass rang in the RGA data.

Contamination by the ferrofluid?
Conclusion:

(1) Estimation with worst case assumption (#) shows that covering by the fluid is 0.27%

#All "leak" measured in the test is due to evaporation of the fluid.

(2) The assumption is NOT true. We did not observe an indication of the evaporation.

(3) We do not worry about the contamination by the ferrofluid.

(4) It seams that the "leak" is mostly leak of the air. Continuous leak of air may cause contamination?

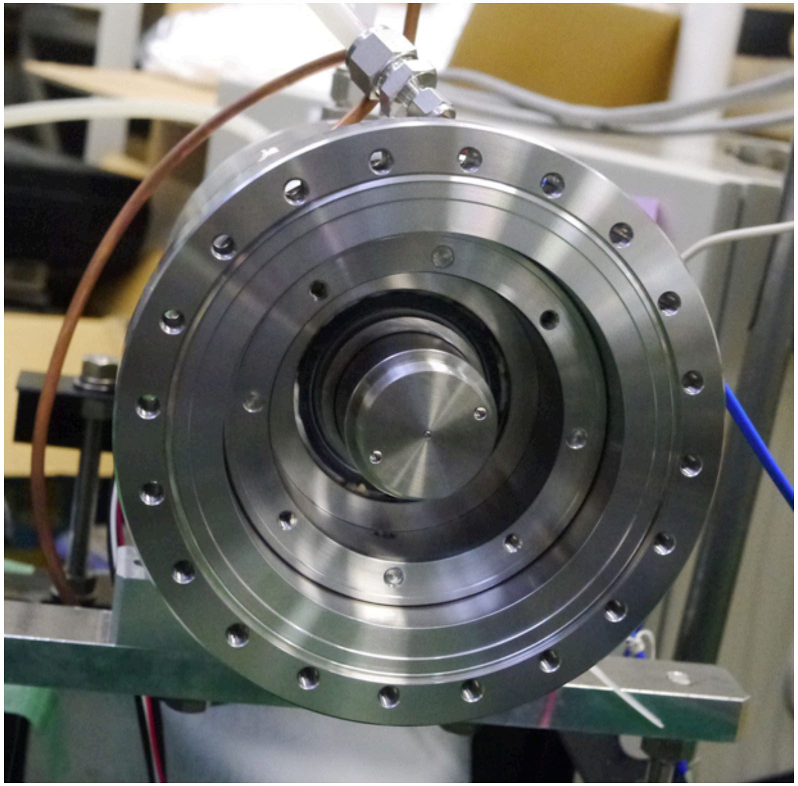
Reinstallation of the Seal Unit

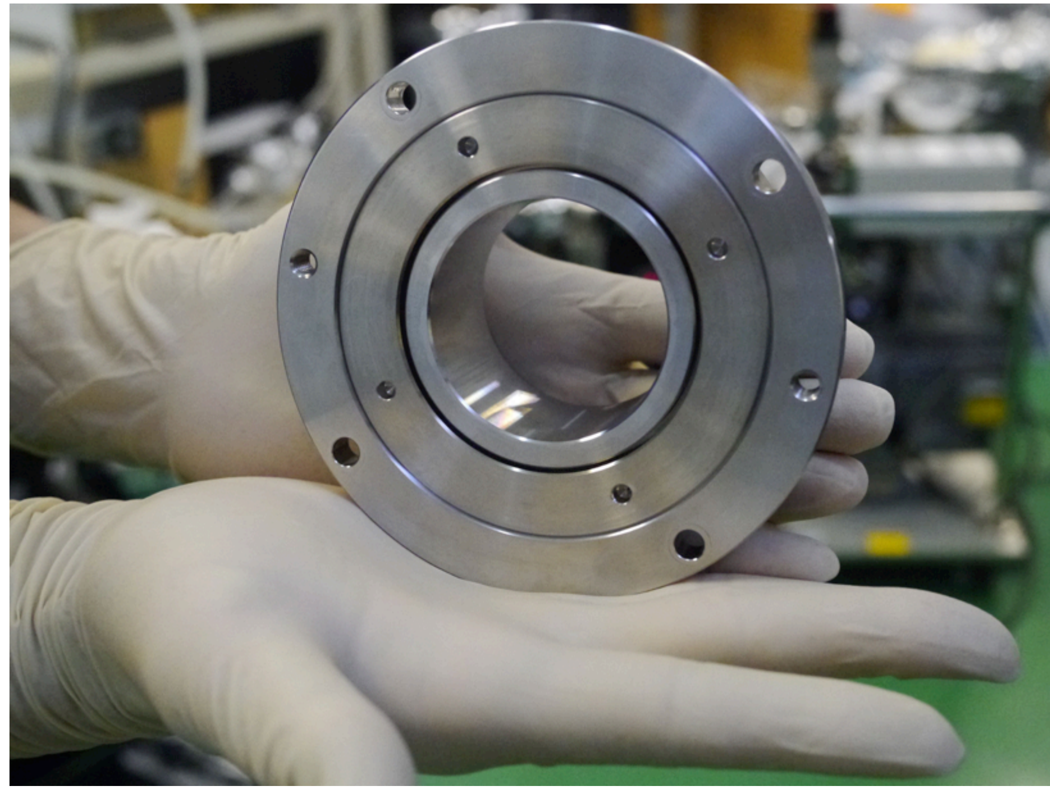
(1) We opened the chamber 19th July.

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

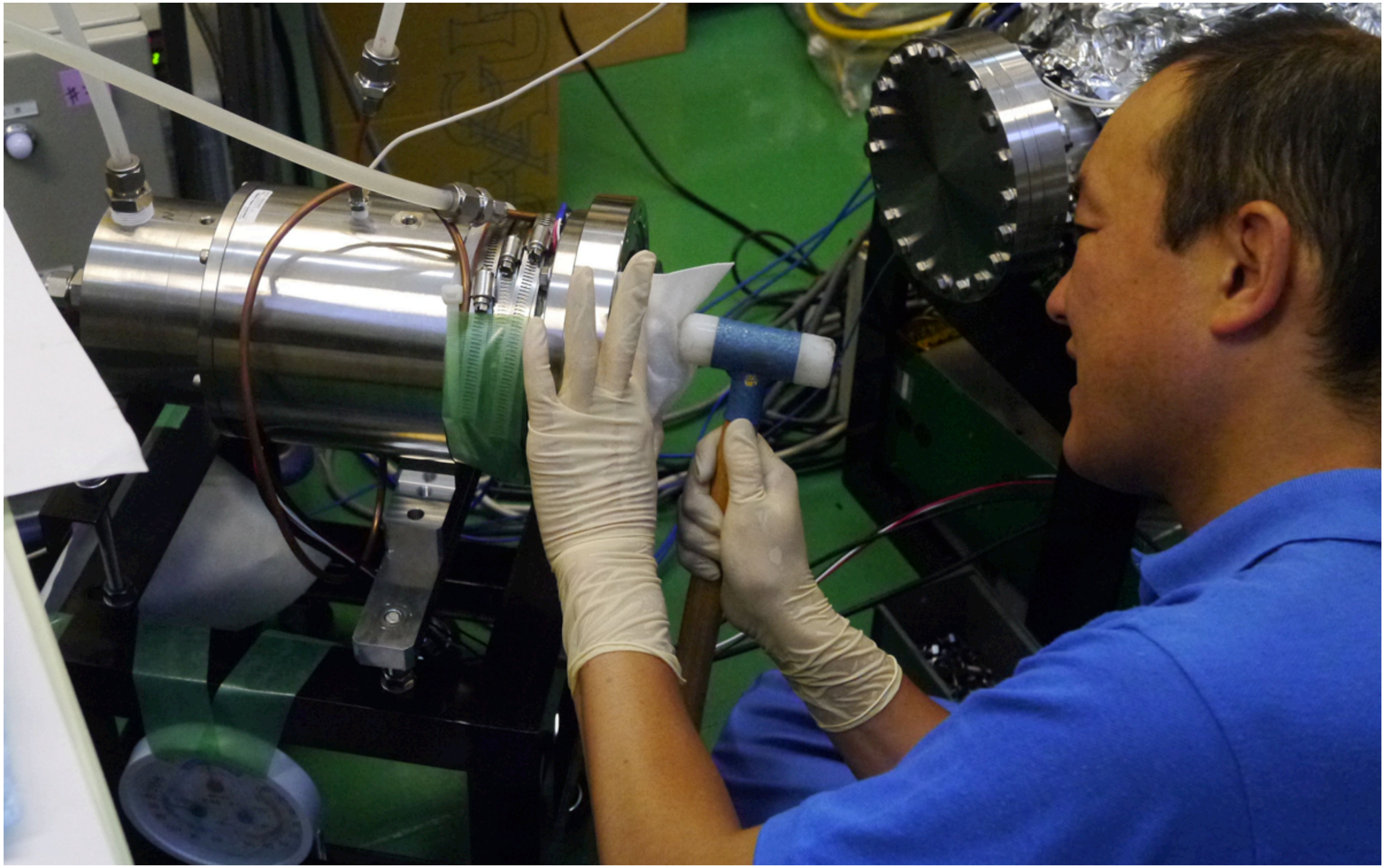
(3) We reinstalled the unit on 31st July.

June 31st: We reinstalled the seal unit and closed the chamber again

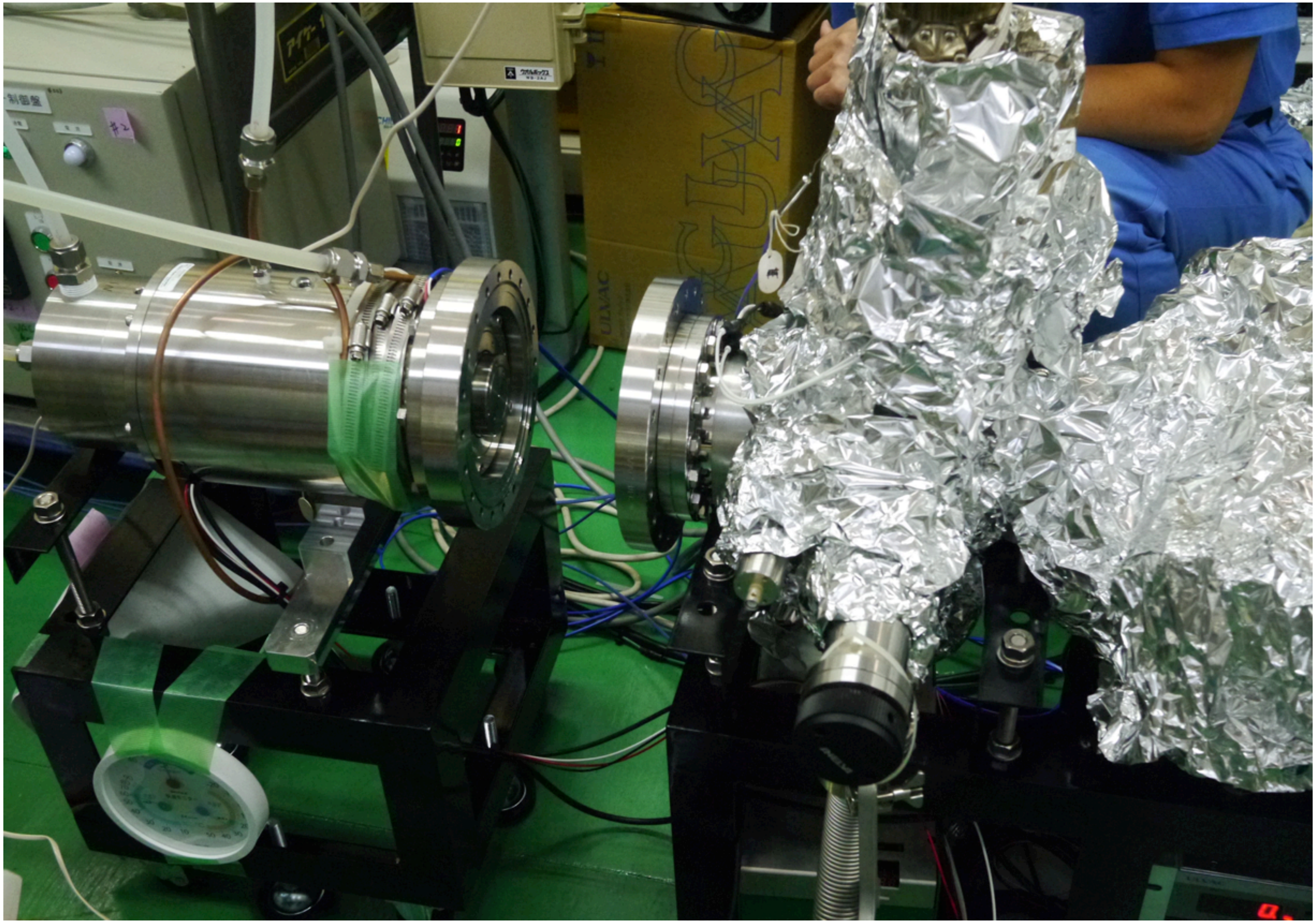




June 31st: We reinstalled the seal unit and closed the chamber again



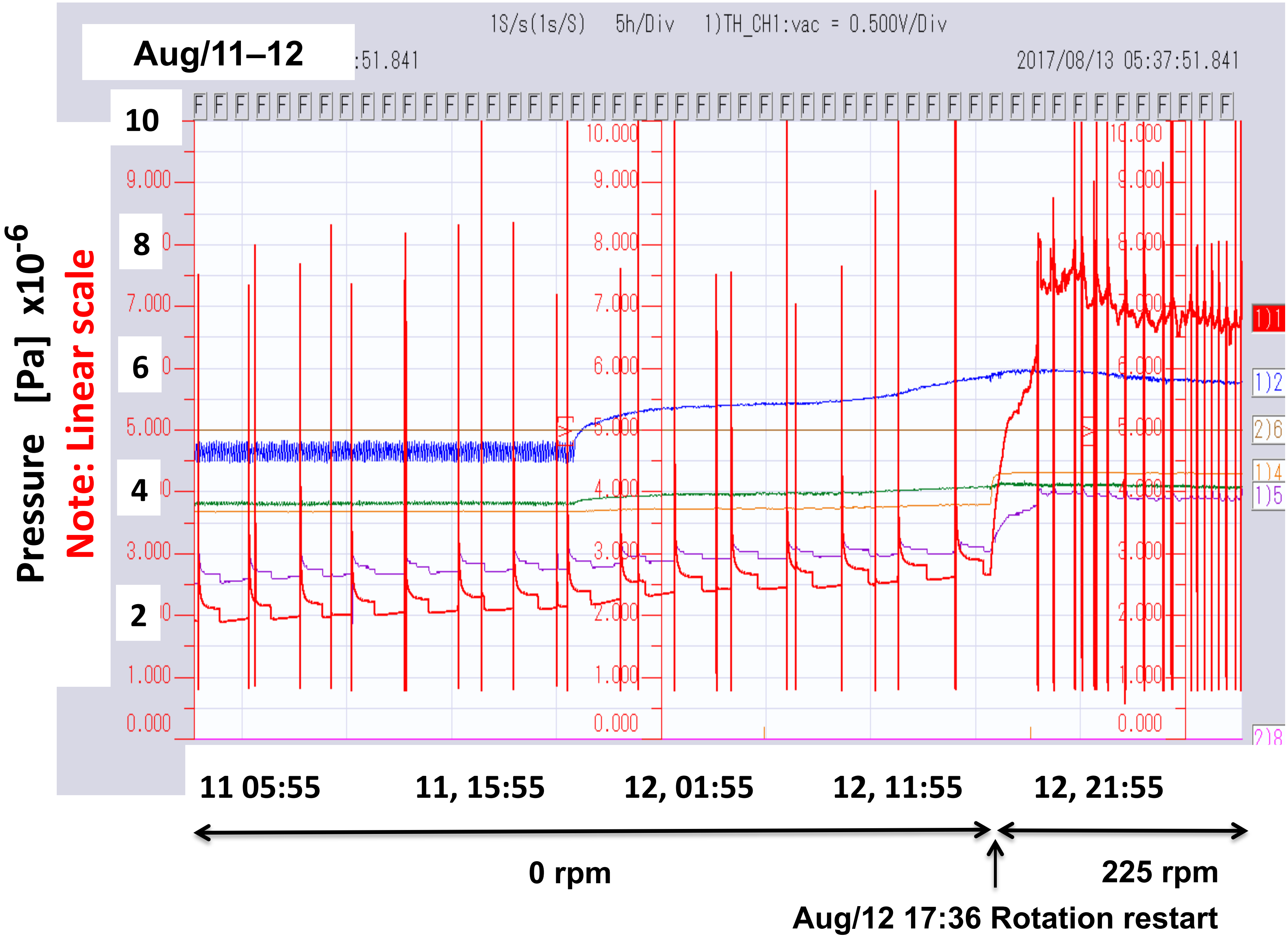
June 31st: We reinstalled the seal unit and closed the chamber again



Reinstallation of the seal unit

- **Reinstallation**
  31st July AM：reinstallation, pumping(turbo), baking start
  PM: baking
  2nd Aug. AM：stop baking
  4th Aug. Evening: all instruments stop
- **KEK scheduled power shut down**：5th-6th Aug.
- **8th Aug. Moring**：pumping(turbo) restart
  Evening: baking start
- **9th Aug. Air Conditioner in the room Broken**
- **10th Aug 16:31 Baking stop**
  19:15 pumping stsrt by the ion pump
- **KEK Summer Holidays**：
  11th(Fri), 12nd(Sat), 13rd(Sun), 14th(Mon), 15th(Tue), 16th(Wed), Aug.
  ↑
  17:36 restart rotation

Vacuum Test: Afer reinstallation



Facts, obstacles, and concerns

- Reinstallation of the seal unit: 31st July
- KEK scheduled power shut down：5th-6th, Aug.
- Air-conditioner of the room broken: 9th Aug.
  - NOT scheduled.
  - New air-conditioner was installed in the middle of September.
  - Experiment after the reinstallation was performed in no good environment
- KEK Summer Holidays：11th-16th, Aug.
- We observed spikes again in the operation after the reinstallation.

Spikes

- We observed spikes again in the operation after the reinstallation.
- Spikes appeared immediately after restart of operation.

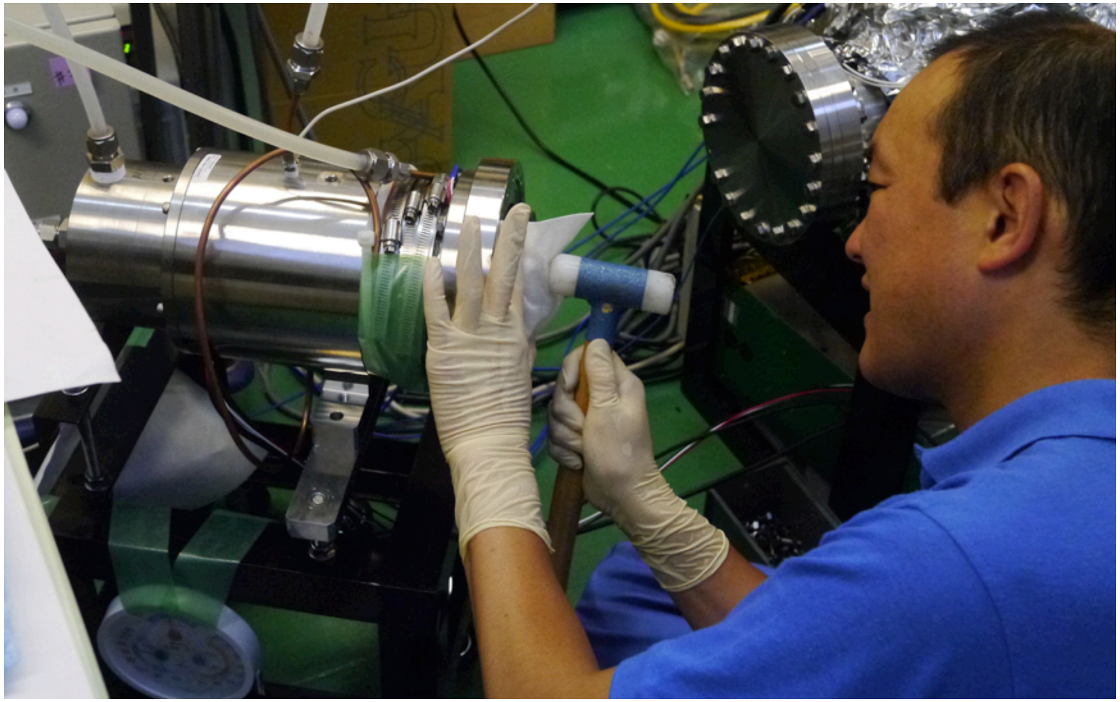
  cf. Spikes appeared after 3 months of operation in the first experiment in Febuary-July).

- 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?.

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?



Summary

Summary (1)

Heat, Cooling, Stress

- Detailed simulation study of heat, cooling, stress, was done. →OK (OK even for 2600 bunches)

Radiation trelance

- The radiation test of the ferrofluid was already done. The ferrofluid is vital against 3-year ILC operation.
- The irraidation test of the whole system (motor, bearing,,,) was done. No problem was found.

Central Part Prototype Vacuum Test (1)

- Long term test was performed (Feb. 9th – July 19th).
- 3-5x10^{-6} Pa is kept with 225 rpm rotation with 100 l/s ion pump.

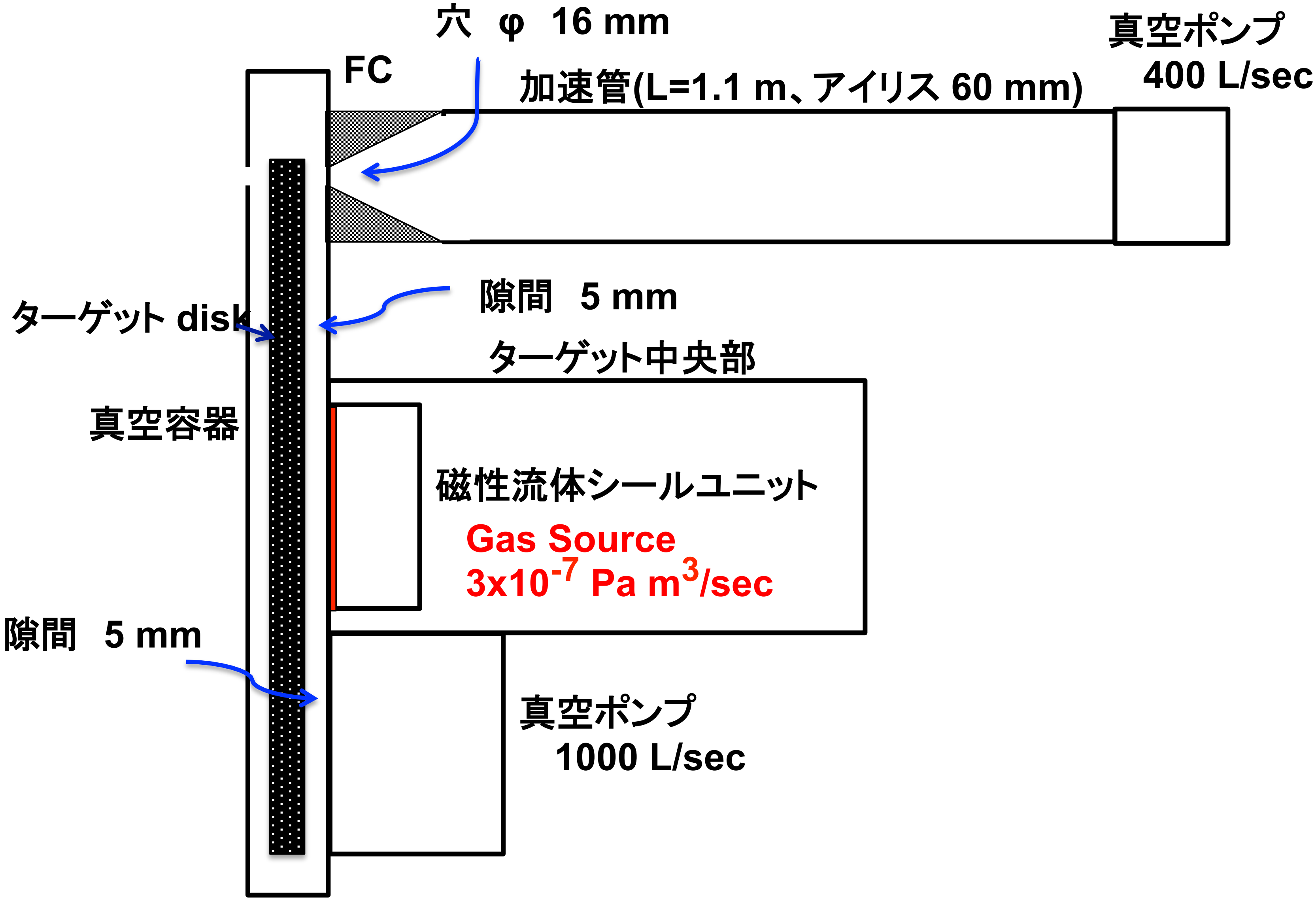
Summary (2)

Central Part Prototype Vacuum Test (2)

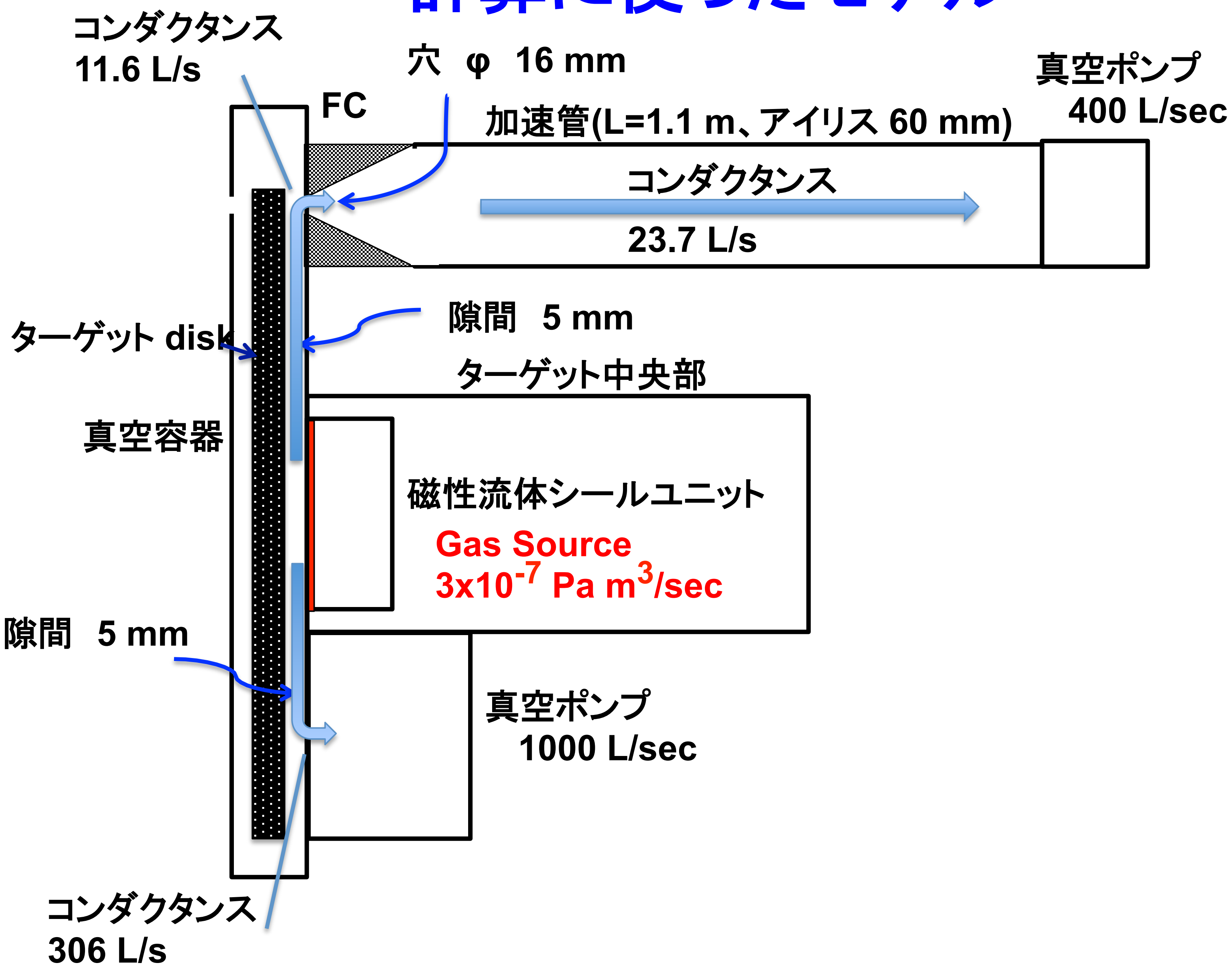
- The vacuum level is the same as expected.
- It seams promising.
- However we still have some concerns.
  - Spikes.
  - Aging of the ferrofluid.
  - Quality contorol.
- Now the test was suspended due to the air-conditioner break down. (Now we can restart.)
- We are planning a gas flow system at the air-side of the seal unit. Gas = (dry air?, N_2? Ar?, Ne?,,)
  This may prevent water in air goes into ferrofluid.
  The controlled gas (not air in the room) leaks into vacuum

Backups

計算に使ったモデル

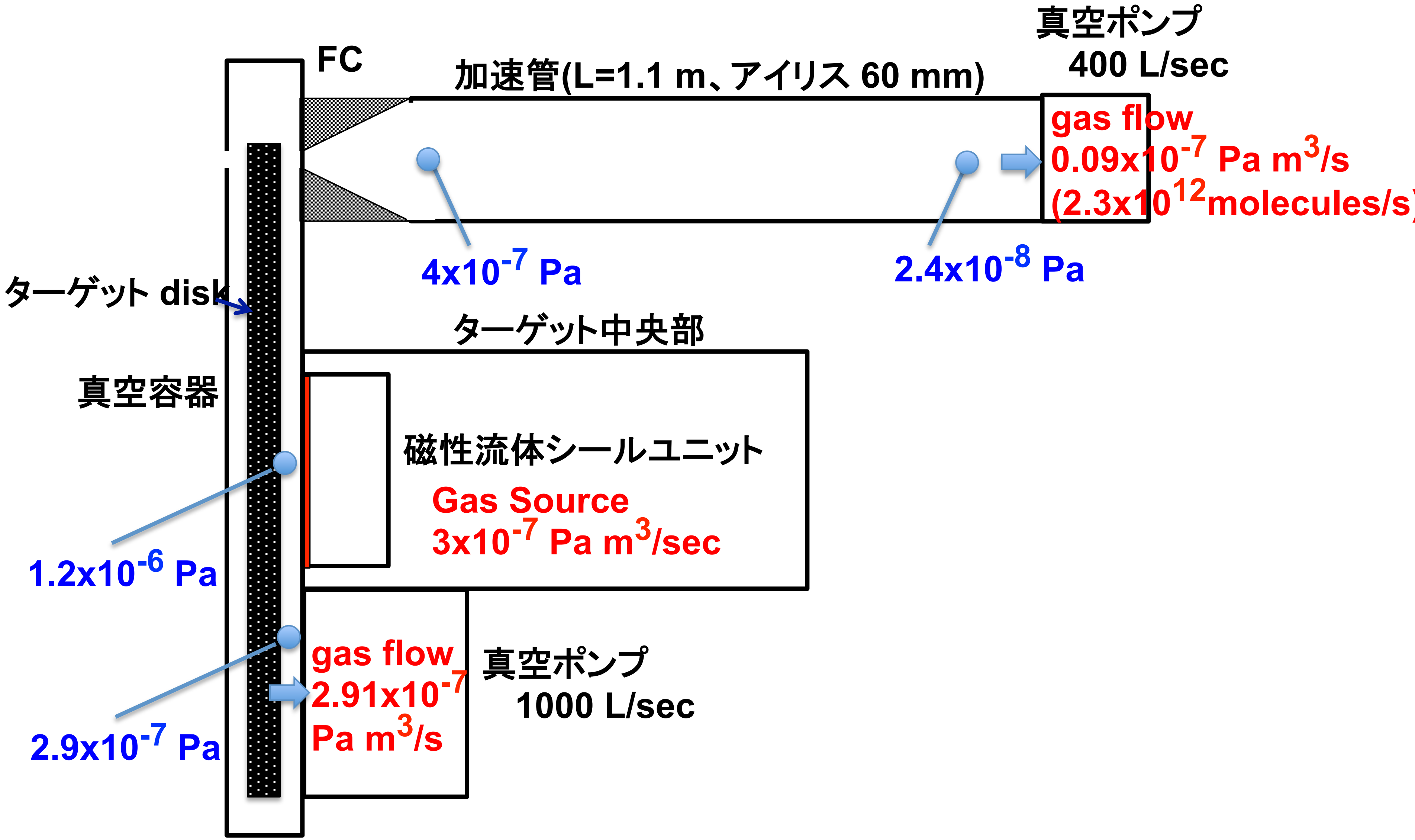

穴 φ 16 mm
真空ポンプ
400 L/sec
FC
加速管(L=1.1 m、アイリス 60 mm)
隙間 5 mm
ターゲット disk
ターゲット中央部
真空容器
磁性流体シールユニット
Gas Source
3x10-7 Pa m3/sec
隙間 5 mm
真空ポンプ
1000 L/sec

計算に使ったモデル



コンダクタンス
11.6 L/s
穴　φ　16 mm
FC
加速管(L=1.1 m、アイリス 60 mm)
真空ポンプ
400 L/sec
コンダクタンス
23.7 L/s
ターゲット disk
隙間　5 mm
ターゲット中央部
真空容器
磁性流体シールユニット
Gas Source
3x10^-7 Pa m^3/sec
隙間　5 mm
真空ポンプ
1000 L/sec
コンダクタンス
306 L/s

計算結果



真空ポンプ
400 L/sec
FC
加速管(L=1.1 m、アイリス 60 mm)
gas flow
0.09x10-7 Pa m3/s
(2.3x1012molecules/s)
4x10-7 Pa
2.4x10-8 Pa
ターゲット disk
ターゲット中央部
真空容器
磁性流体シールユニット
Gas Source
3x10-7 Pa m3/sec
1.2x10-6 Pa
gas flow
2.91x10-7
Pa m3/s
真空ポンプ
1000 L/sec
2.9x10-7 Pa

ILC Rotation Target

＊中央部プロトタイプにより測定された data (実測)

到達真空度 $3x10^{-6}$ Pa

真空ポンプ 100 L/s (=$100x10^{-3}$ m^3/sec)　　（イオンポンプ）

＊リークレート （上記より計算）

($3x10^{-6}$ Pa) x ($100x10^{-3}$ m^3/sec) = $3x10^{-7}$ Pa m^3/sec

＊リークレートに基づいて、各部の到達圧力、ガスフローを計算してみる。

＊加速管内面のコンタミの危険性を推定する

仮定 (以下の計算では下記を仮定する)

上記の「リーク」が全て磁性流体のベースオイル蒸発によるとする。

注）実際には下記のような要因があるが、まずは全て (a) として計算してみる（最悪を仮定）

(a) ベースオイル蒸発

(b) 真空シールを通しての大気側からの漏れ

(c) 真空容器内面からの脱ガス

加速管(Cu) 内面への吸着

加速管内のガスフロー　(前々ページ)

2.29×10^{12}　molecules s^{-1}

加速管内面の Cu 原子の面密度(個／m^2)

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

加速管1本の内部の表面積

$1.09\ m^2$

加速管内への吸着率　α

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

注:加速管に流れたベースオイルは全て壁面で吸着されると仮定(安全サイド)

Cu 表面からの吸着分子の脱離係数　β

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

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

Ea=100 keV　activation energy

$v = 10^{13}$　frequency factor

加速管(Cu) 内面への吸着

表面被覆率 η を表す微分方程式とその解

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

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

答え

平衡状態の表面被覆率 $\eta(t=\infty) = 2.7\times10^{-3}$ (0.27%)

平衡状態に達する時間の目安 $1/\beta$ = 110 days

結論

加速管表面の吸着分子は一分子層に遠く及ばない(被覆率 0.27%)

注

上記は、実測された「リークレート」が全てベースオイルの蒸発に起因するとの仮定にもとずく計算。したがって上限値。実際には蒸発はもっと小さいと考えられる。

ベースオイルの蒸発

＊リークレートの主な原因はベースオイルの蒸発では無い：傍証1

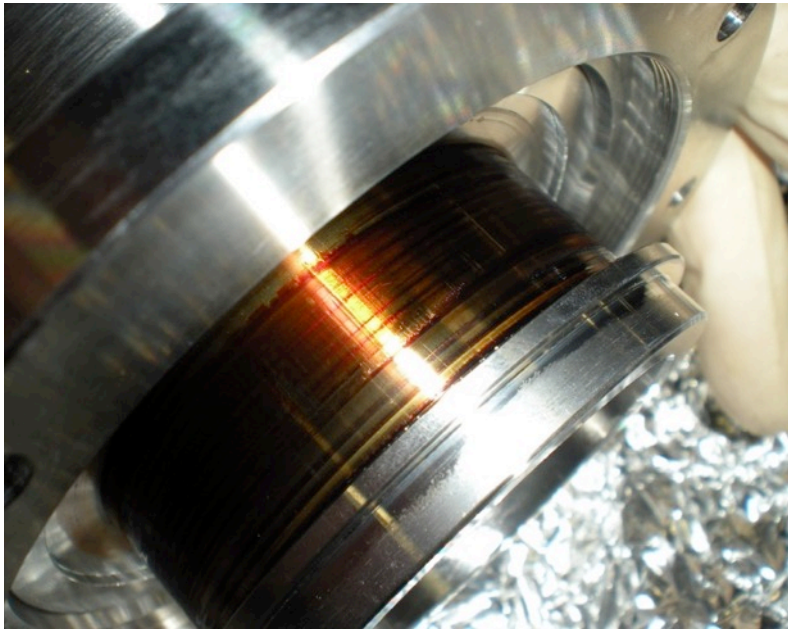
- リークレート $3x10^{-7}$ Pa m^3/sec (実測に基づく計算) が全てベースオイルの蒸発に起因すると仮定すると、オイルの蒸発率は 1.2 x 10^{-10} mol/sec
- prototype に使われている磁性流体の量は極めてわずかなので、

この仮定によると、2ケ月でベースオイルは全て蒸発して無くなる（リガク）。

- 実際には5ヶ月強 (2/9 -> 7/19) の連続運転の後も、10^{-6} Pa 台の真空を保っているので、ベースオイルの蒸発は限定的。

＊リークレートの主な原因はベースオイルの蒸発では無い：傍証2

- 7/19(水) に 5 月強にわたる実験を中断し、大気開放して調べてみた。
- 目視では異常な点は、何も確認できなかった。オイルは減っていなかった。
  異常の例→ 磁性流体が蒸発・乾燥して、ポロポロとした粉になる。
- ２０段のシールのうち、真空に近い側の段は劣化しているかと予想していたが、まったく変化は無かった。



Evaporation of the Fluid?

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

＊Evidence 1:

- If the leak rate "3x10^{-7} Pa m^3/sec" (measured value) is dominantly caused by the evaporation, the evaporation speed is estimated to be 1.2 x 10^{-10} mol./sec
- Only very small amount of the fluid (less than mL) is used in the prototype に使われている磁性流体の量は極めてわずかなので、

この仮定によると1ヶ月でベースオイルは蒸発して無くなる(はず)

- 実際には5ヶ月強(2/9 - 7/19)の連続運転で10^{-6} Pa 台の真空を保っているので、ベースオイルの蒸発は限定

＊リークレートの主な原因はベースオイルの蒸発では無い：傍証2

- 7/19(水) に 5 月強にわたる実験を中断し、大気開放して調べてみた。
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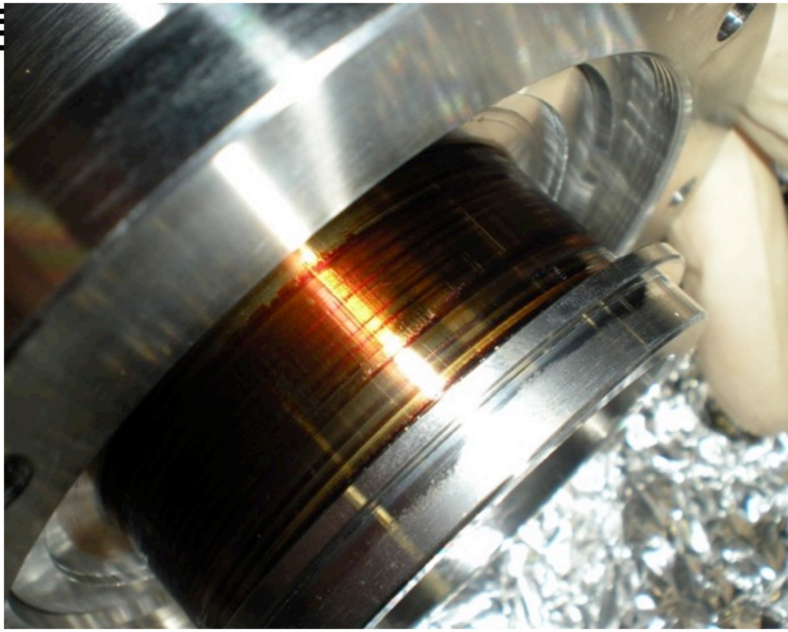
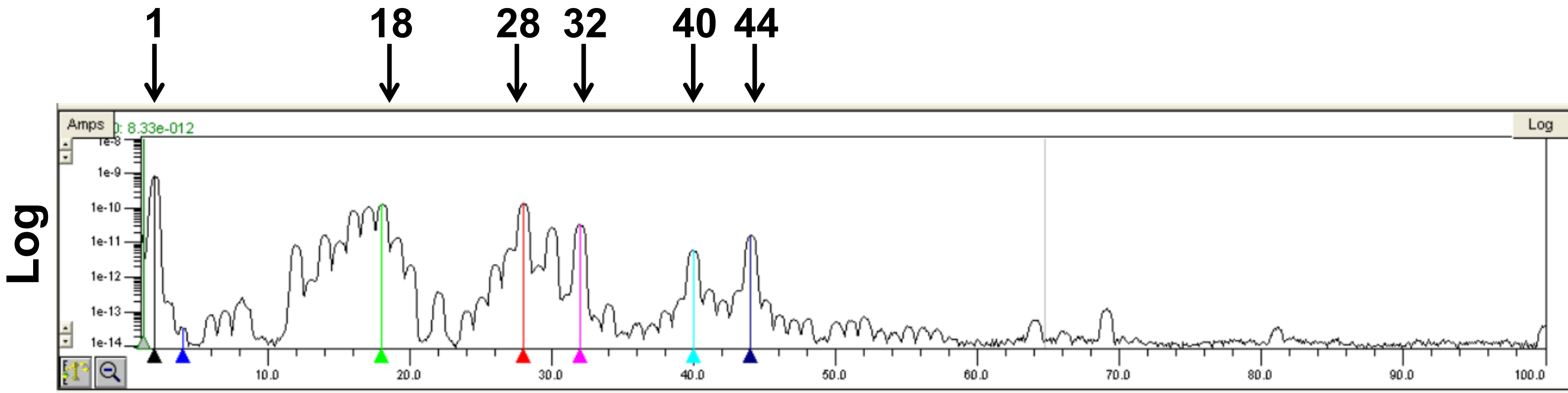
- 20段のシールのうち、真空に近い側の段は劣化しているかと予想していたが、まったく変化は無かった。



ベースオイルの蒸発？

＊リークレートの主な原因はベースオイルの蒸発では無い:傍証3

- 残留ガス分析器の data



	Mass	Amps
☑	18.00 Water	1.285e-010
☑	28.00 Nitrogen	1.396e-010
☑	32.00 Air	3.337e-011
☑	40.00 Argon	6.049e-012
☑	44.00 Carbon ...	1.603e-011

Qマスではイオン化時に、分子の乖離物が発生する。
ベースオイル（高分子）が雰囲気中に存在すれば、炭化水素の乖離物が必ず観測されるが、主要な成分としては観測されていない。
ベースオイルは、発生ガスの主要成分ではない。

磁性流体シールユニット再インストール

再インストール:

7/31(月) 午前:再インストール、冷却水17.5C、粗排気、ベーキング開始

午後:ベーキング継続

8/2 (水) 朝:　ベーキング停止

8/4 (木) 夕方:全ての機器を停止

KEK停電:8/5 (金)、8/6(土)

8/8 (火)　朝:運転再開、粗排気　　　夕方:ベーキング開始

8/10(木) 16:31 ベーキング停止

19:15 イオンポンプON

19:31　電離真空計　1.79×E-5Pa (IPカレント259μA)

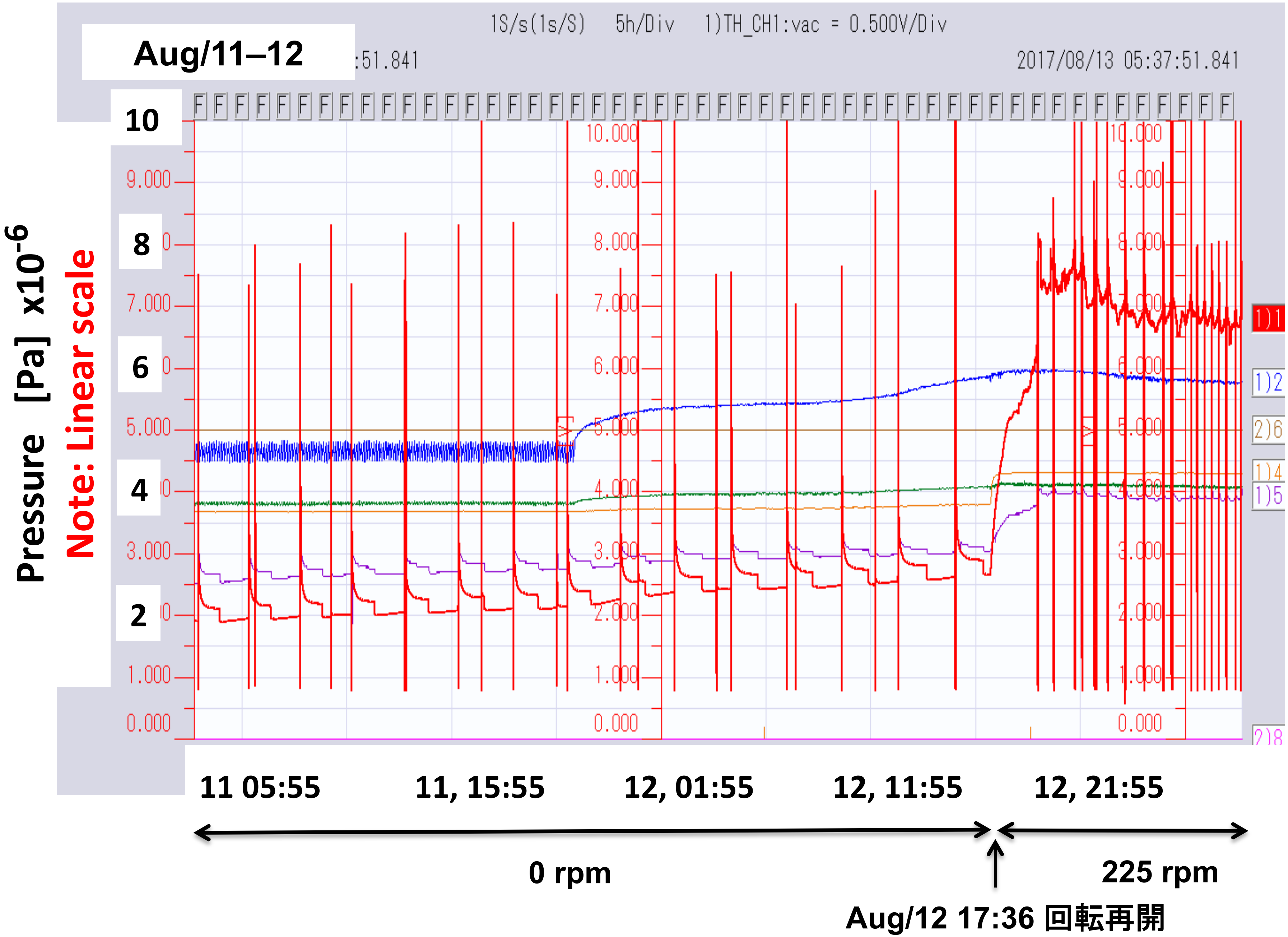
KEK夏休み:

8/11(金)、8/12(土)、8/13(日)、8/14(月)、8/15(火)、8/16(水)

↑

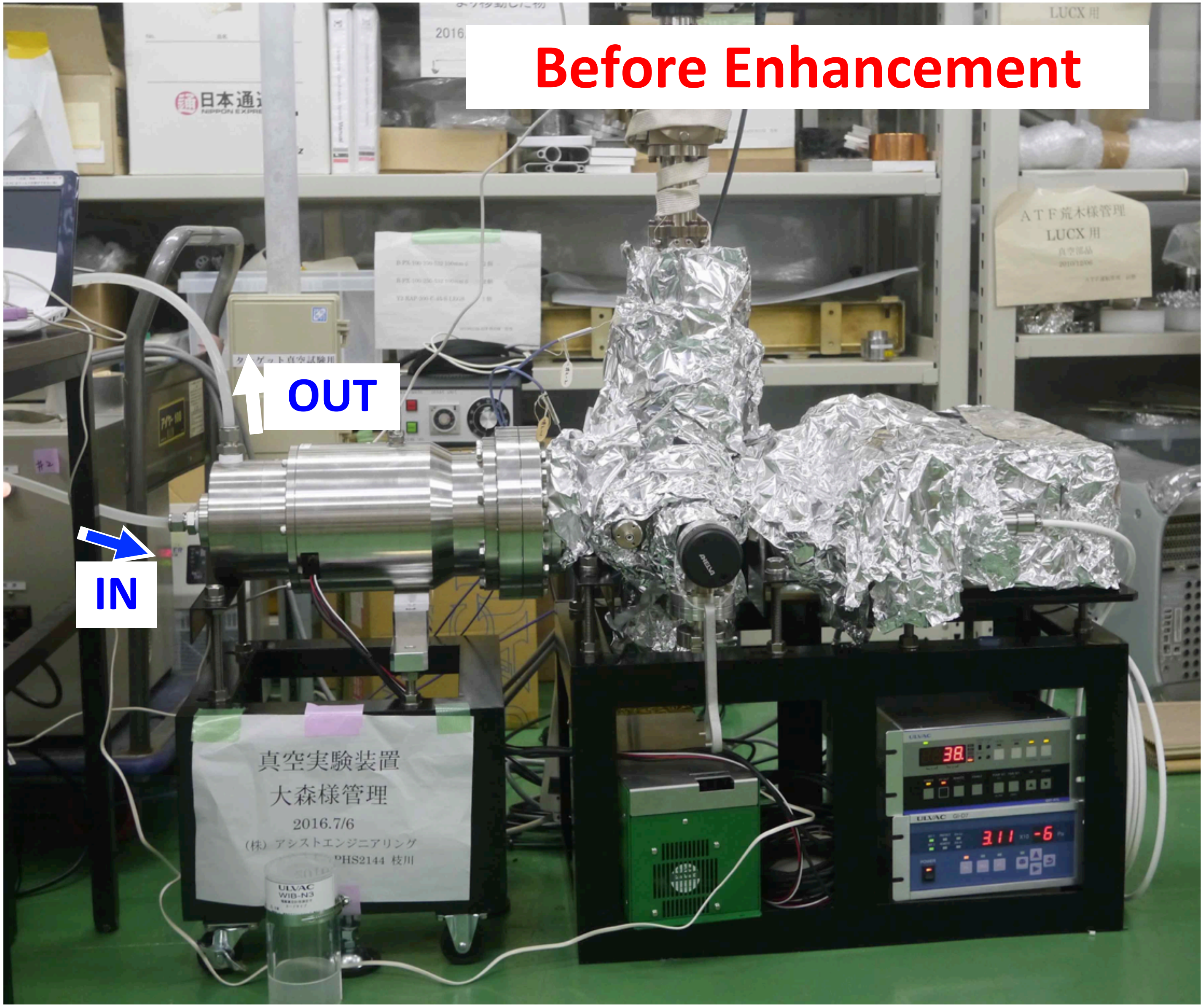
夕方17:36 回転再開

再インストール後：Vacuum Test

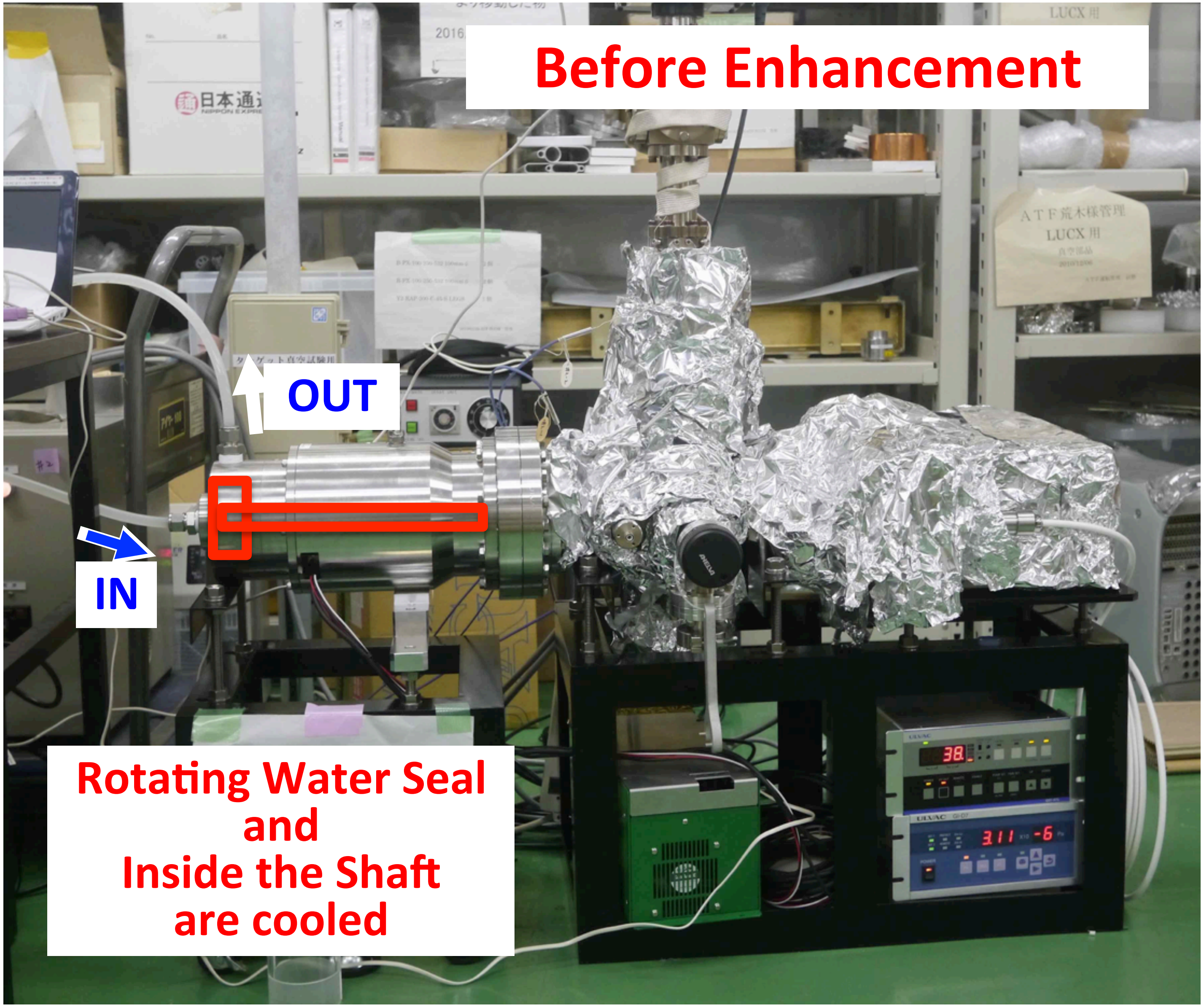


Central Part Prototype Vacuum Test

Enhancement of the Water Cooling Channel

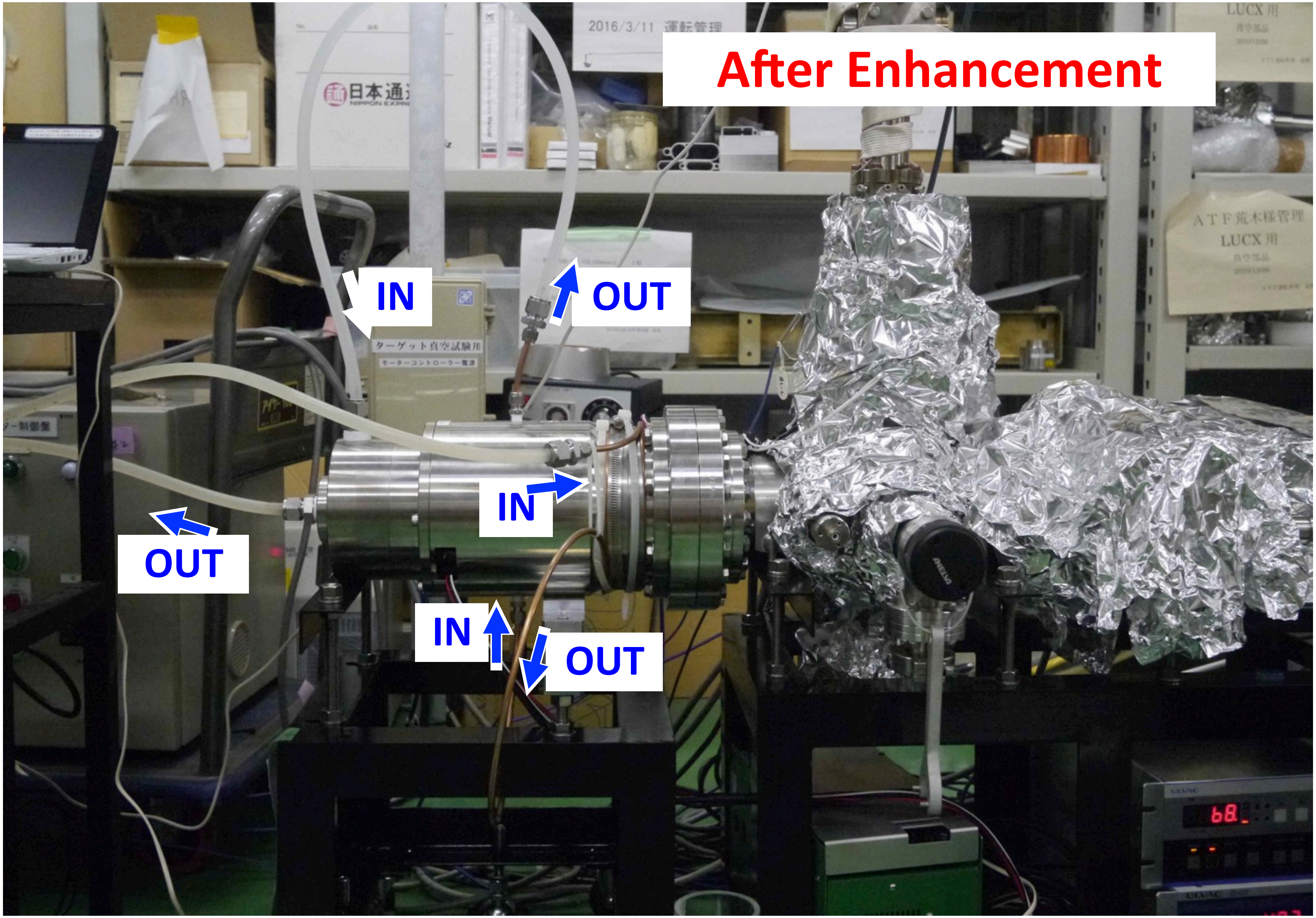


Central Part Prototype Vacuum Test
Enhancement of the Water Cooling Channel



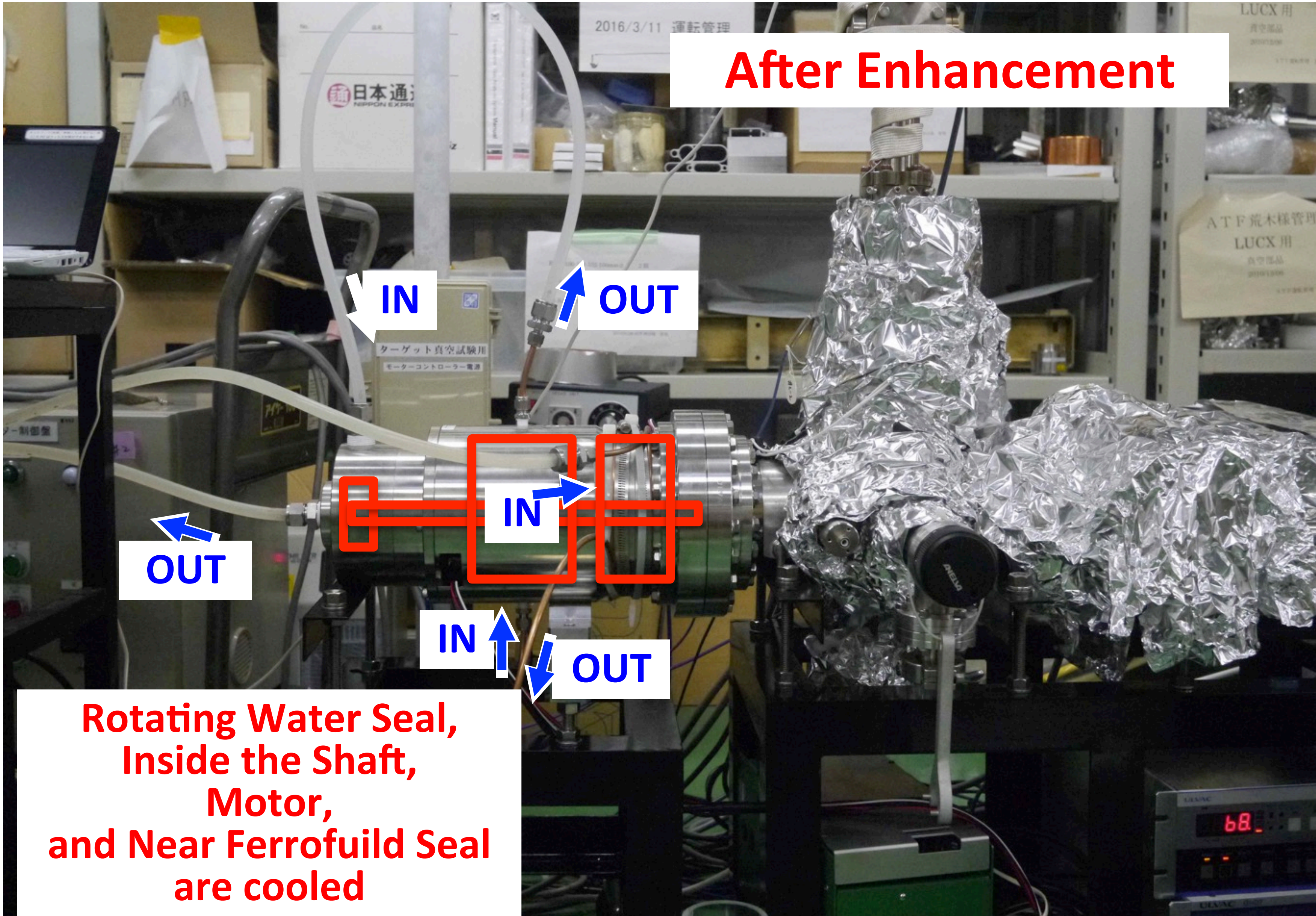
Central Part Prototype Vacuum Test

Enhancement of the Water Cooling Channel

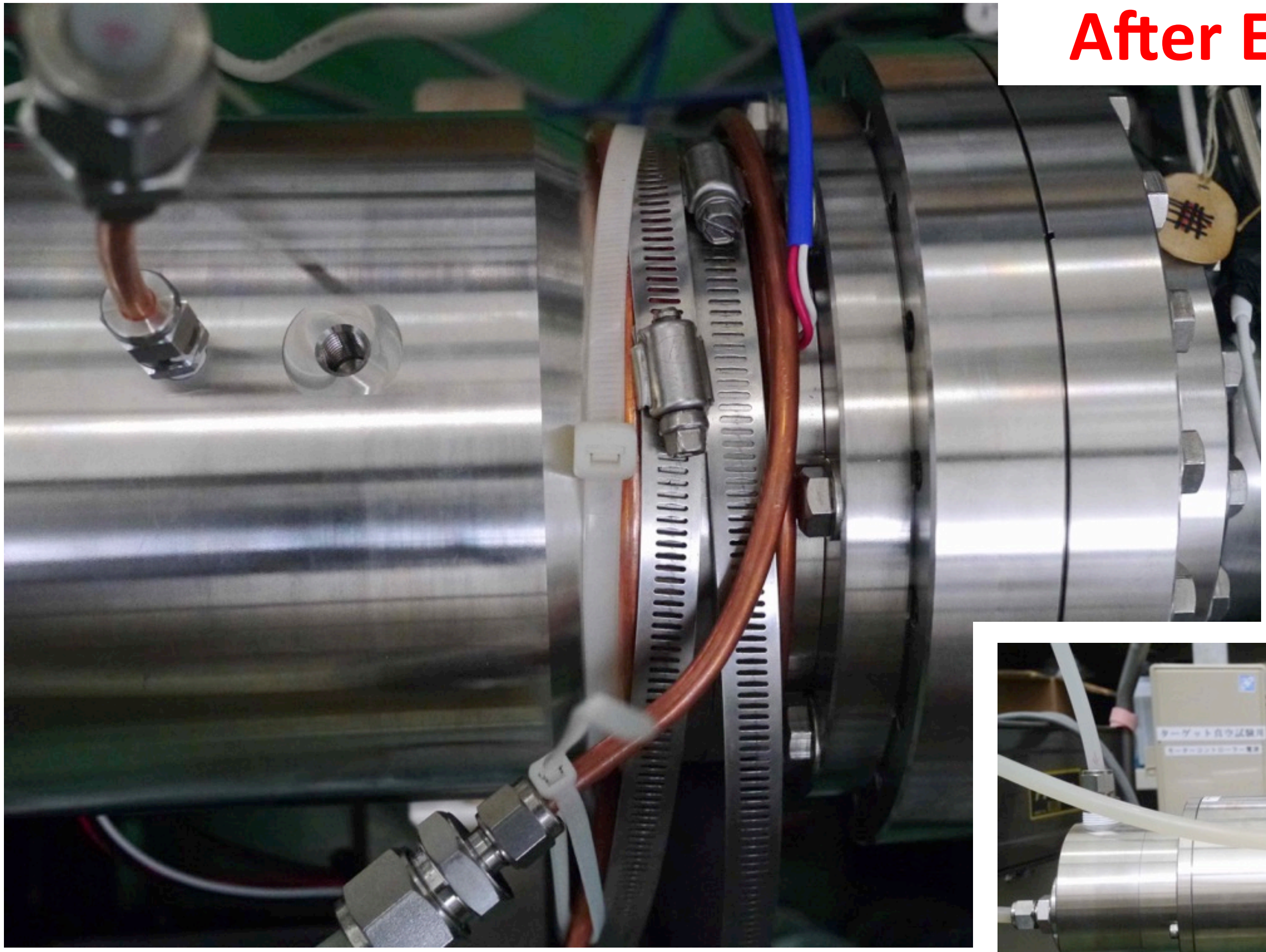


Central Part Prototype Vacuum Test

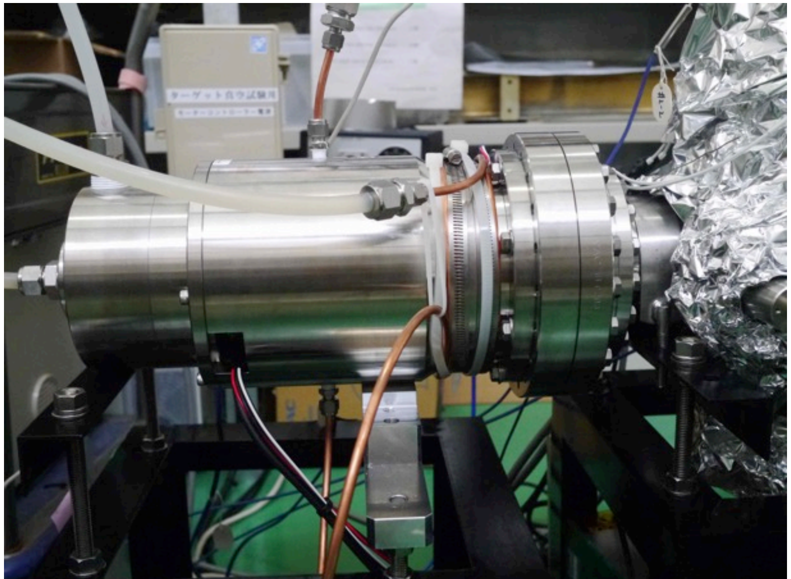
Enhancement of the Water Cooling Channel



Central Part Prototype Vacuum Test
Enhancement of the Water Cooling Channel

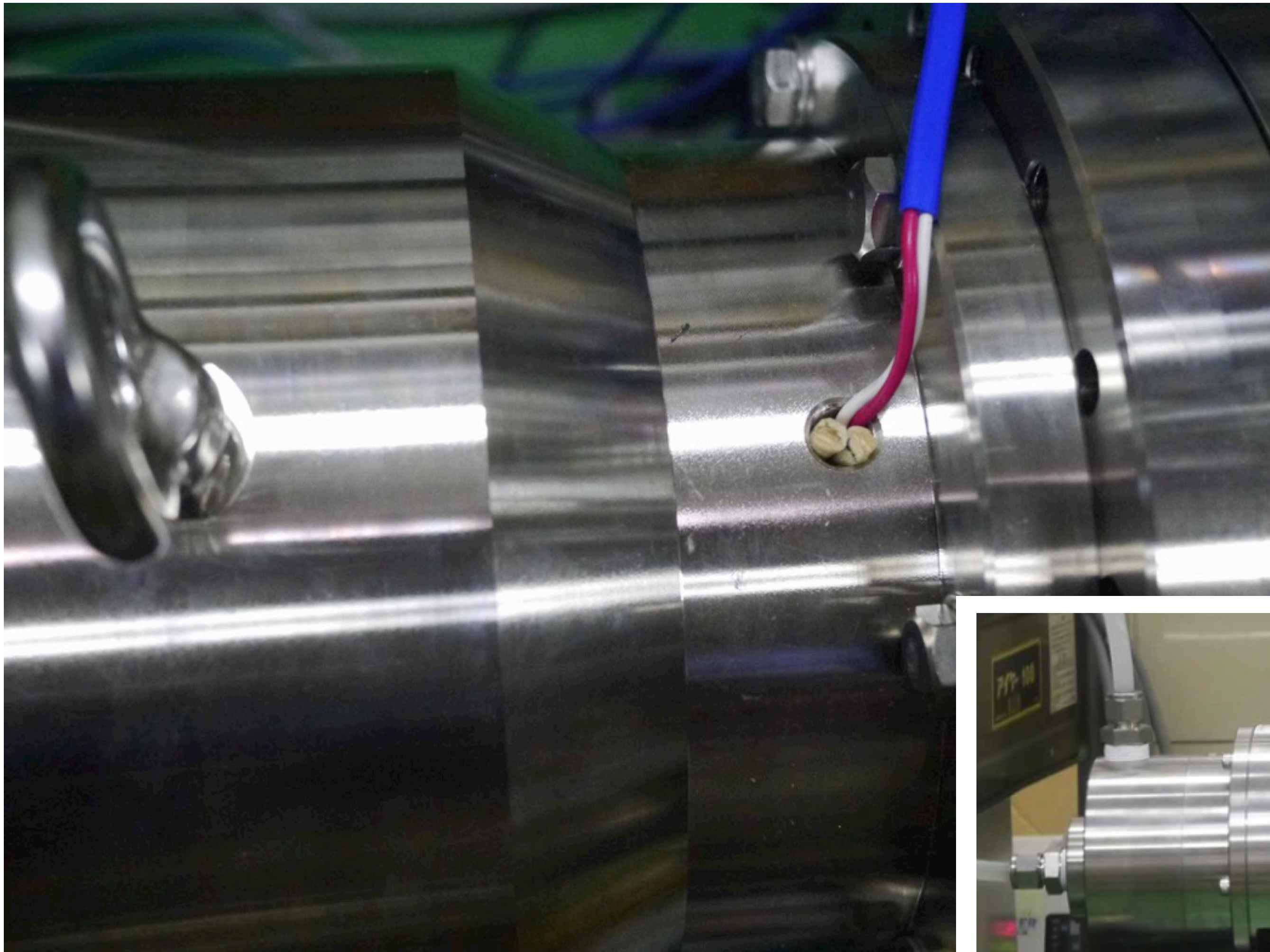


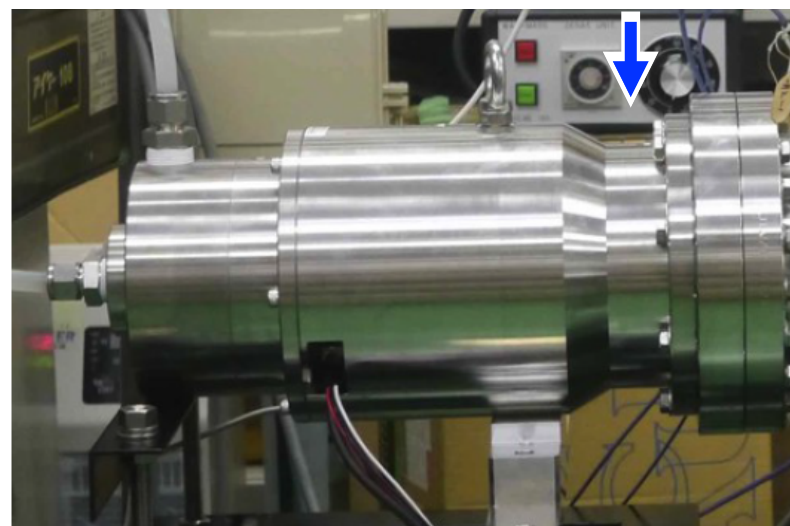
After Enhancement



Central Part Prototype Vacuum Test

We added thermocouple at near the ferrofluid seal



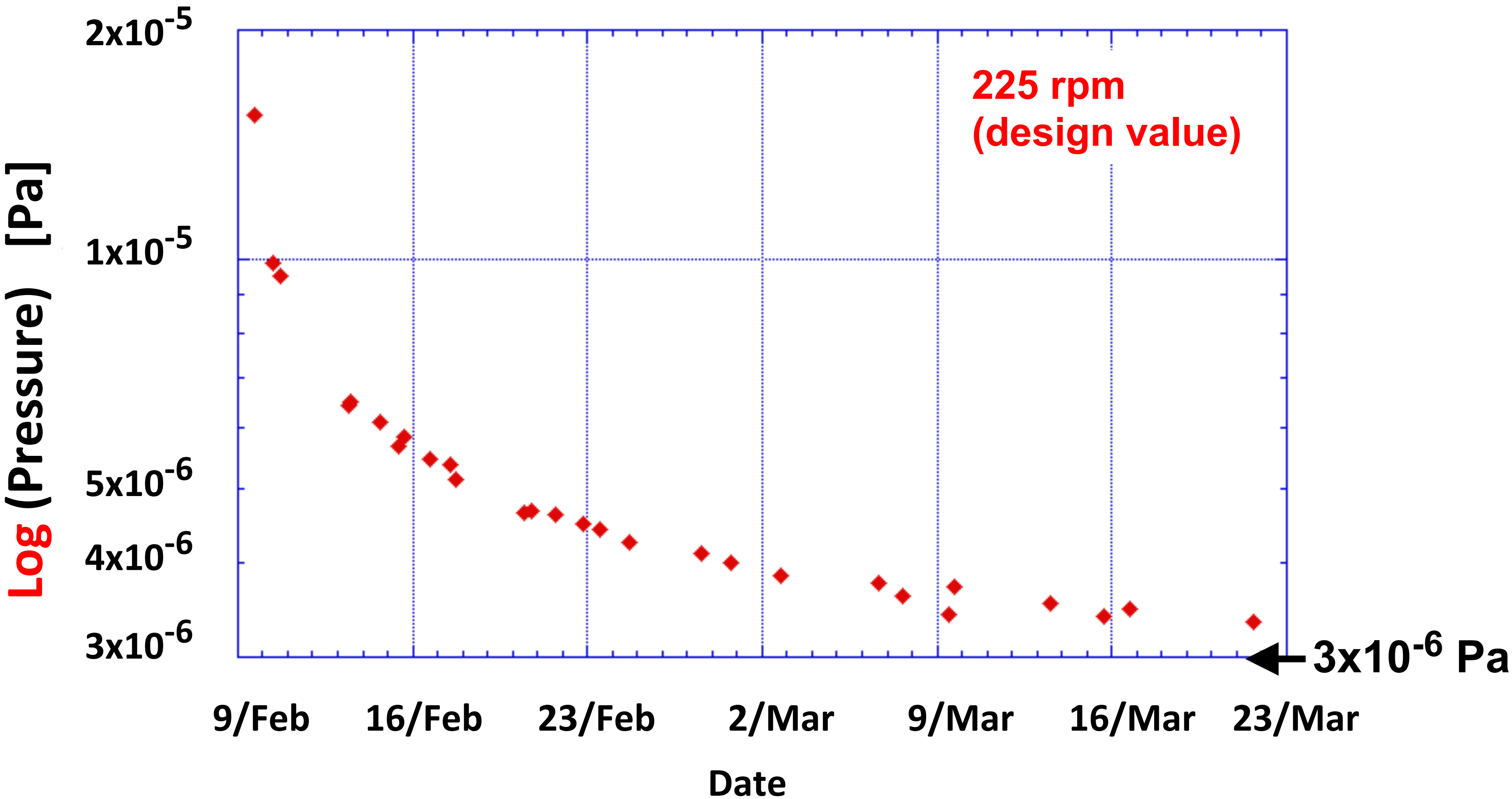


Central Part Prototype Vacuum Test
Facts and What happened (1)

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

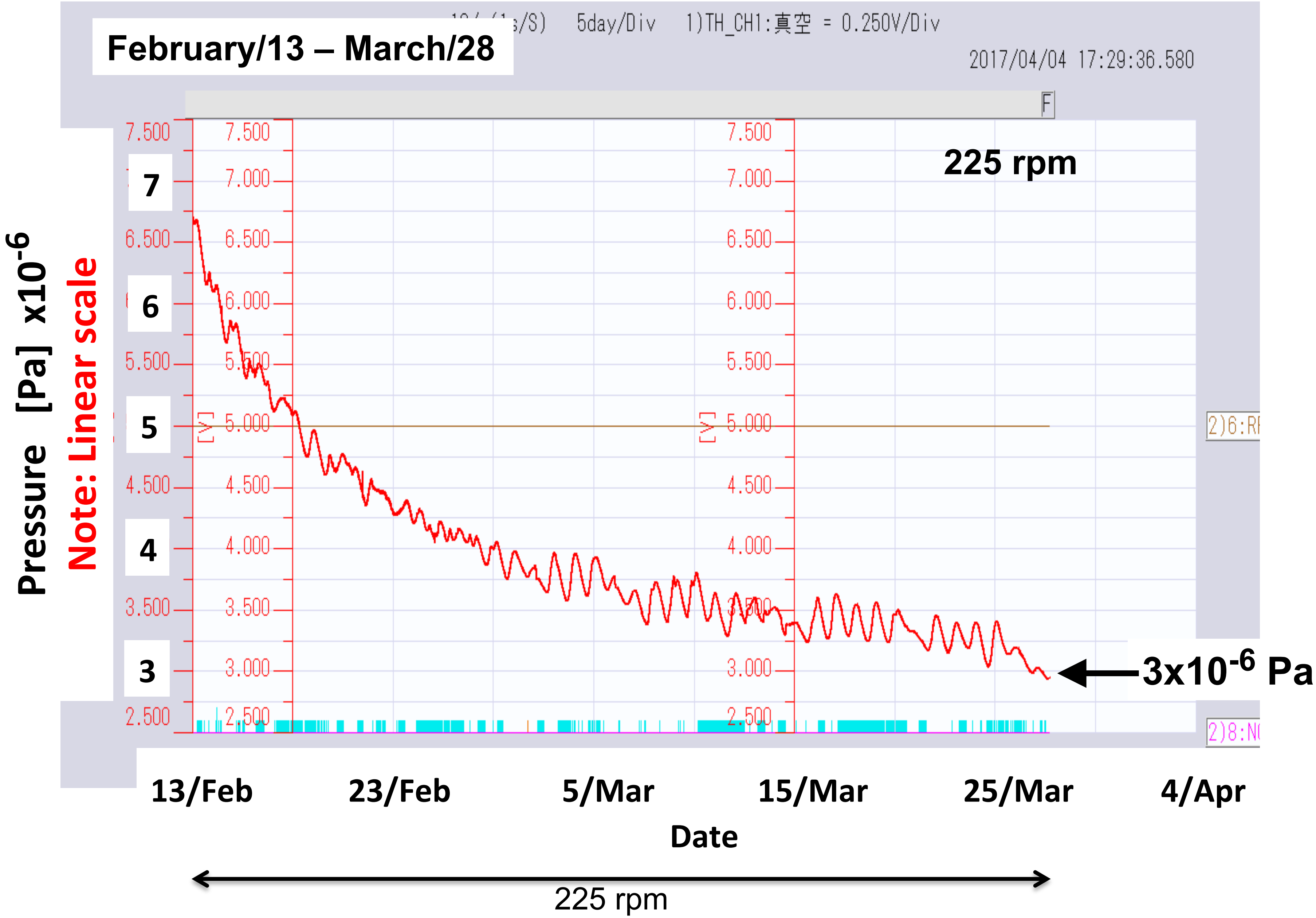
Central Part Prototype Vacuum Test

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



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.

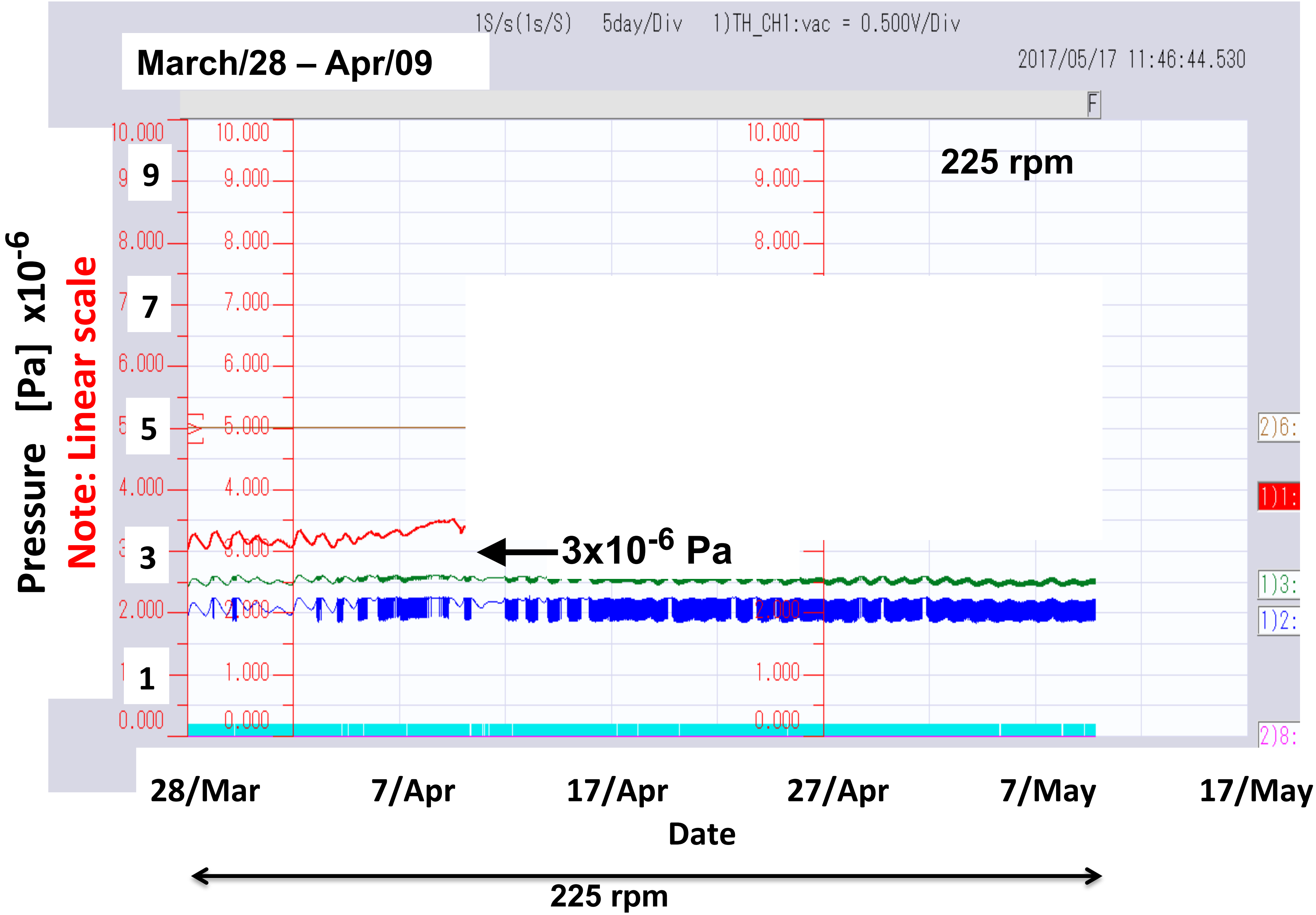
Central Part Prototype Vacuum Test



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.**
- **Vacuum level went good monotonically.**
- **And reached ~ $3x10^{-6}$ Pa at the end of March.**

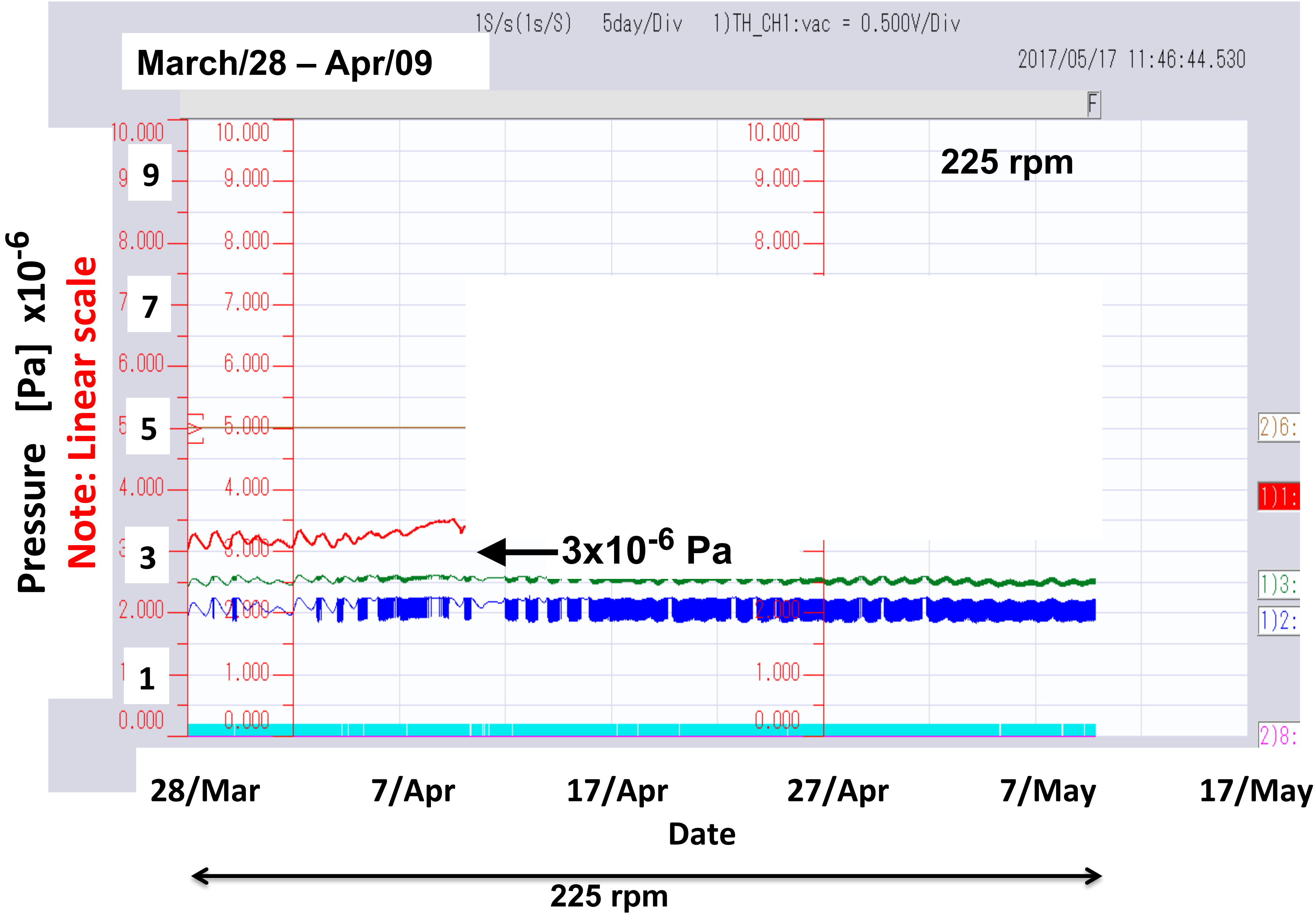
Central Part Prototype Vacuum Test



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

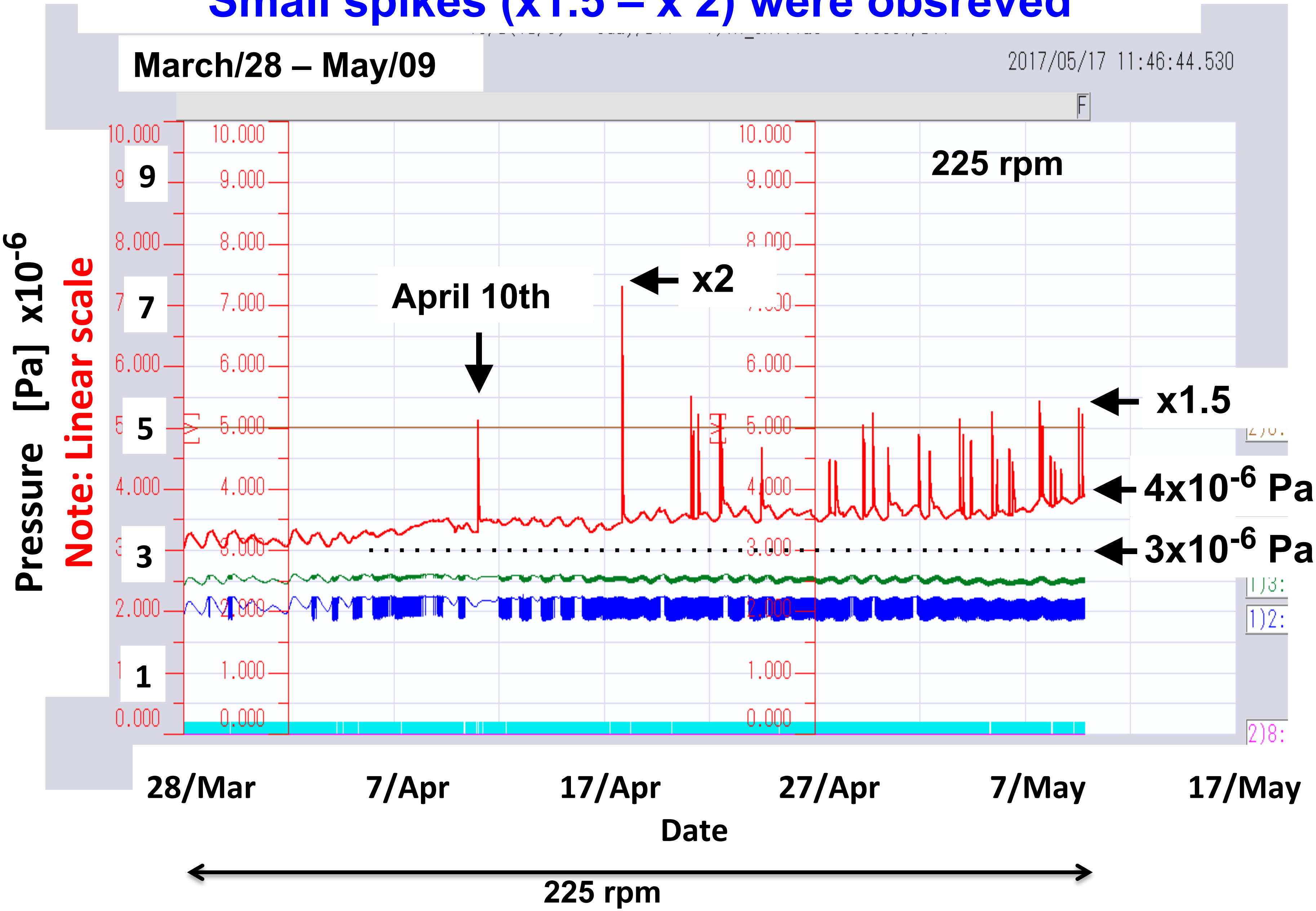
- Ion pump 100 litter/sec.
- Rotation at 225 rpm (design value).
- We started the experiment on February 9th.
- Vacuum level went good monotonically.
- And reached ~ $3x10^{-6}$ Pa at the end of March.
- Vacuum level was stable at ~ $3x10^{-6}$ until April 10th.

Central Part Prototype Vacuum Test



Central Part Prototype Vacuum Test

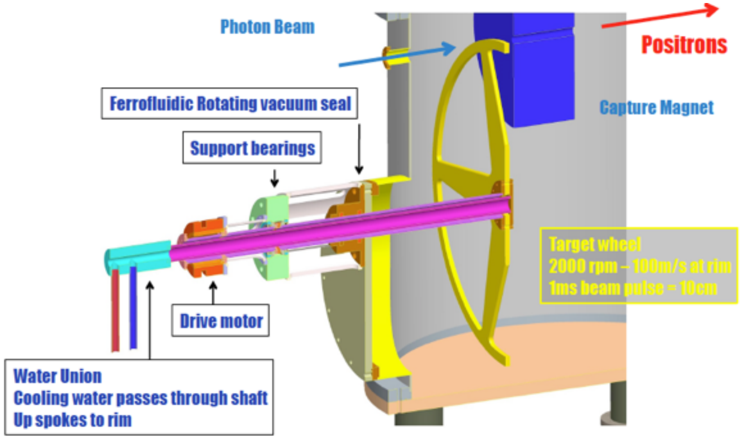
Small spikes (x1.5 – x 2) were obsreved

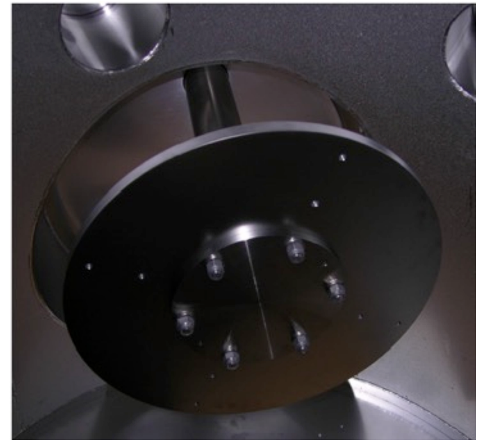


Central Part Prototype Vacuum Test
Facts and What happened (1)

- Ion pump 100 litter/sec.
- Rotation at 225 rpm (value).
- We started the experiment on February 9th.
- Vacuum level went good monotonically.
- And reached ~ $3x10^{-6}$ Pa at the end of March.
- Vacuum level was stable at ~ $3x10^{-6}$ until April 10th.
- Then, we observed small spikes.
  - High of a spike ~x1.5.

Prototype test (not full size yet) of the unduraor target at LLNL was not fully successful (2010-2012)

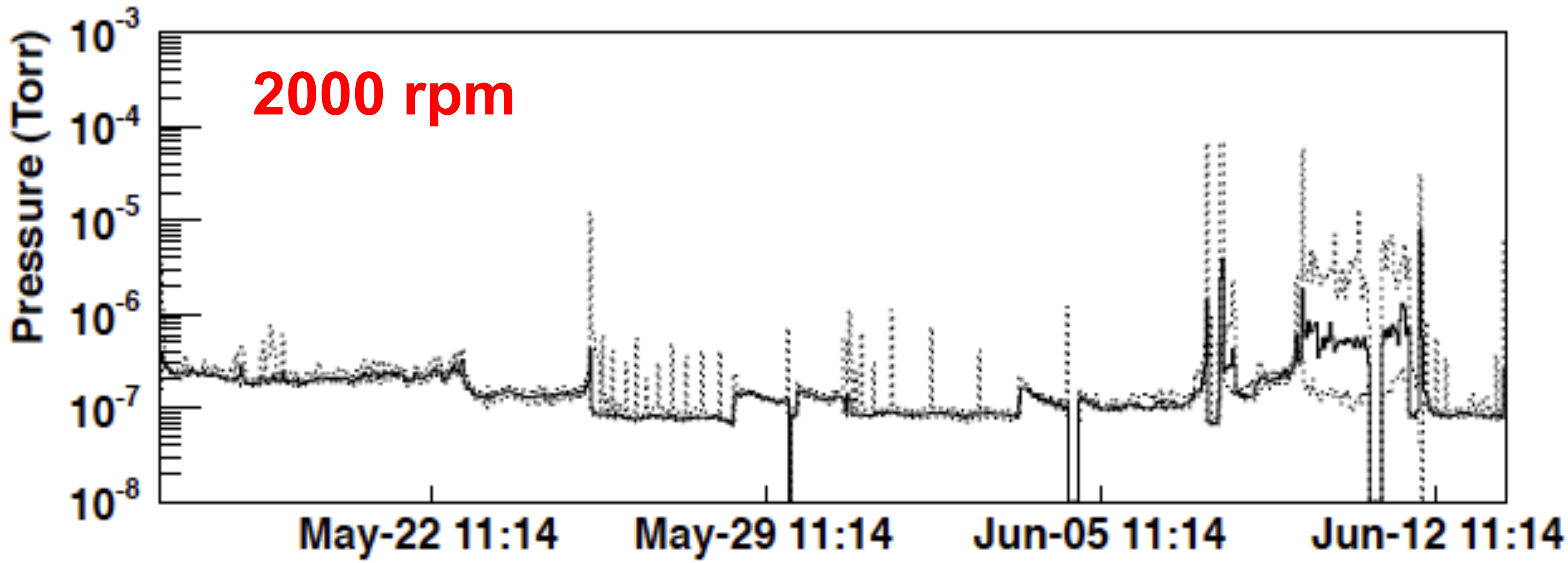




Same weight as real wheel. Smaller diameter.

Note: Logarithmic scale

Note: Torr



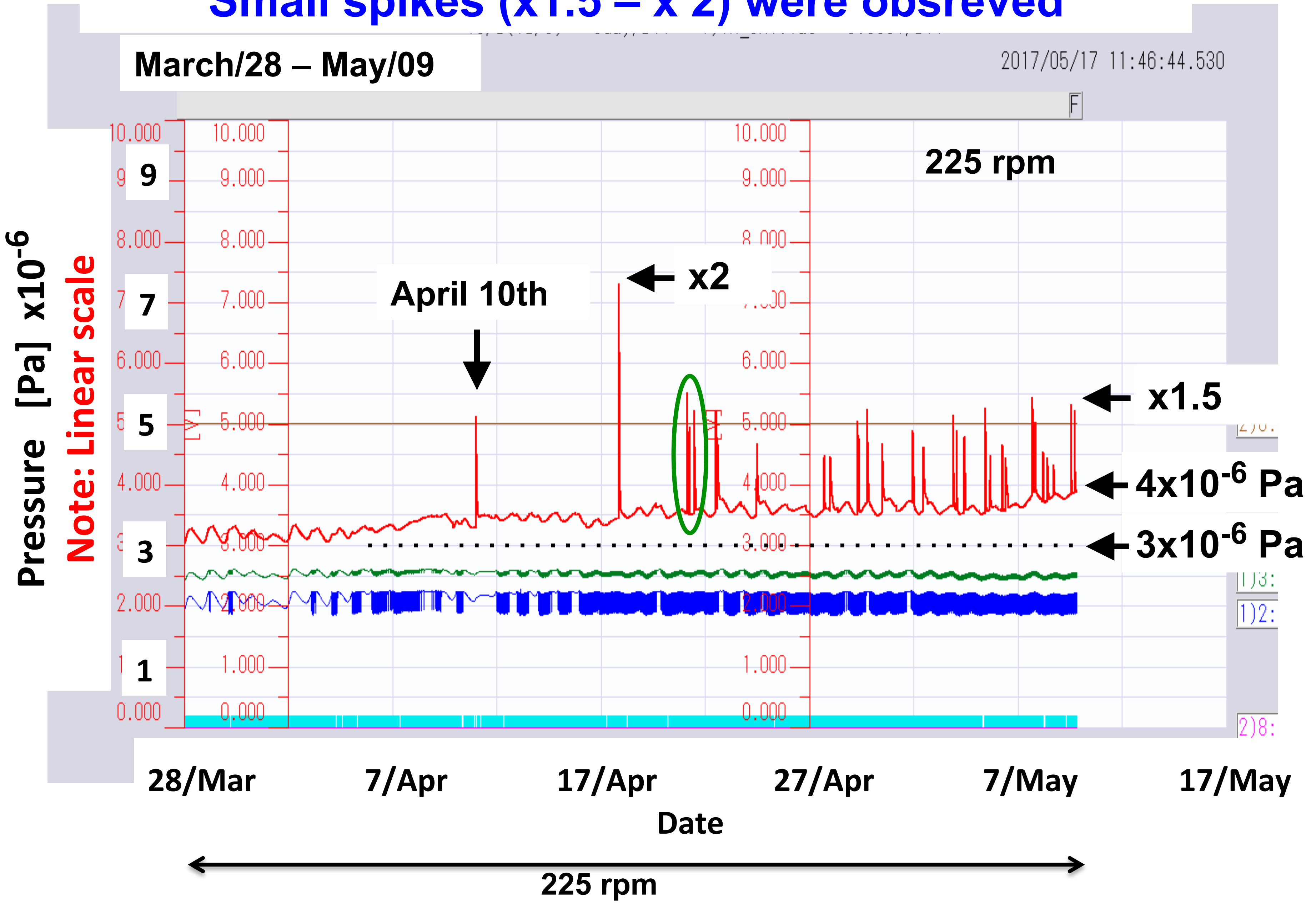
- They all have outgassing spikes
- Off-the-shelf models do not seem to be well designed for this.

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.**
- **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.**
  - **High of a spike ~x1.5.**
    (cf. Undulator target at LLNL, spikes ~x100- x1000)

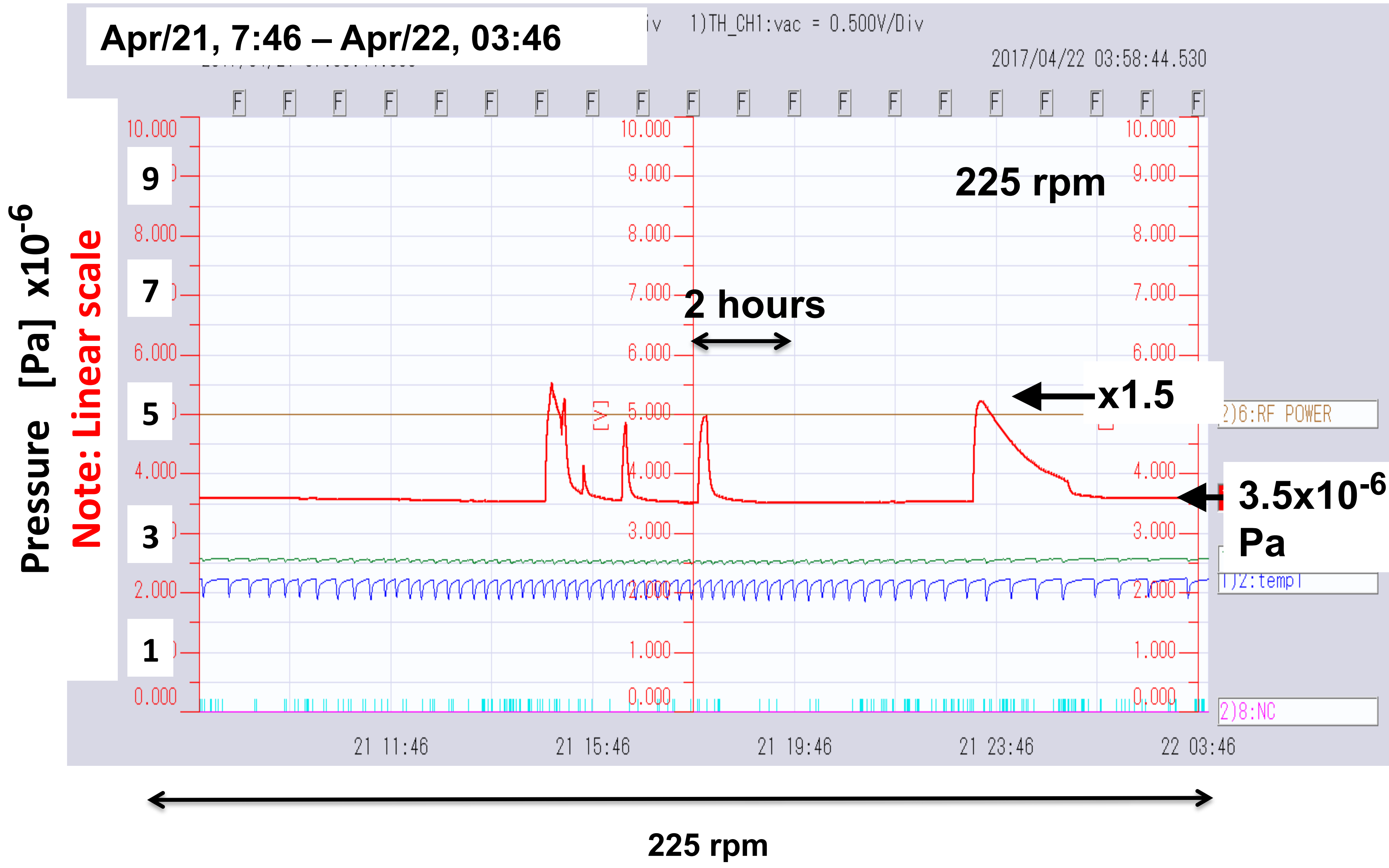
Central Part Prototype Vacuum Test

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



Central Part Prototype Vacuum Test

Close-up of the small spikes

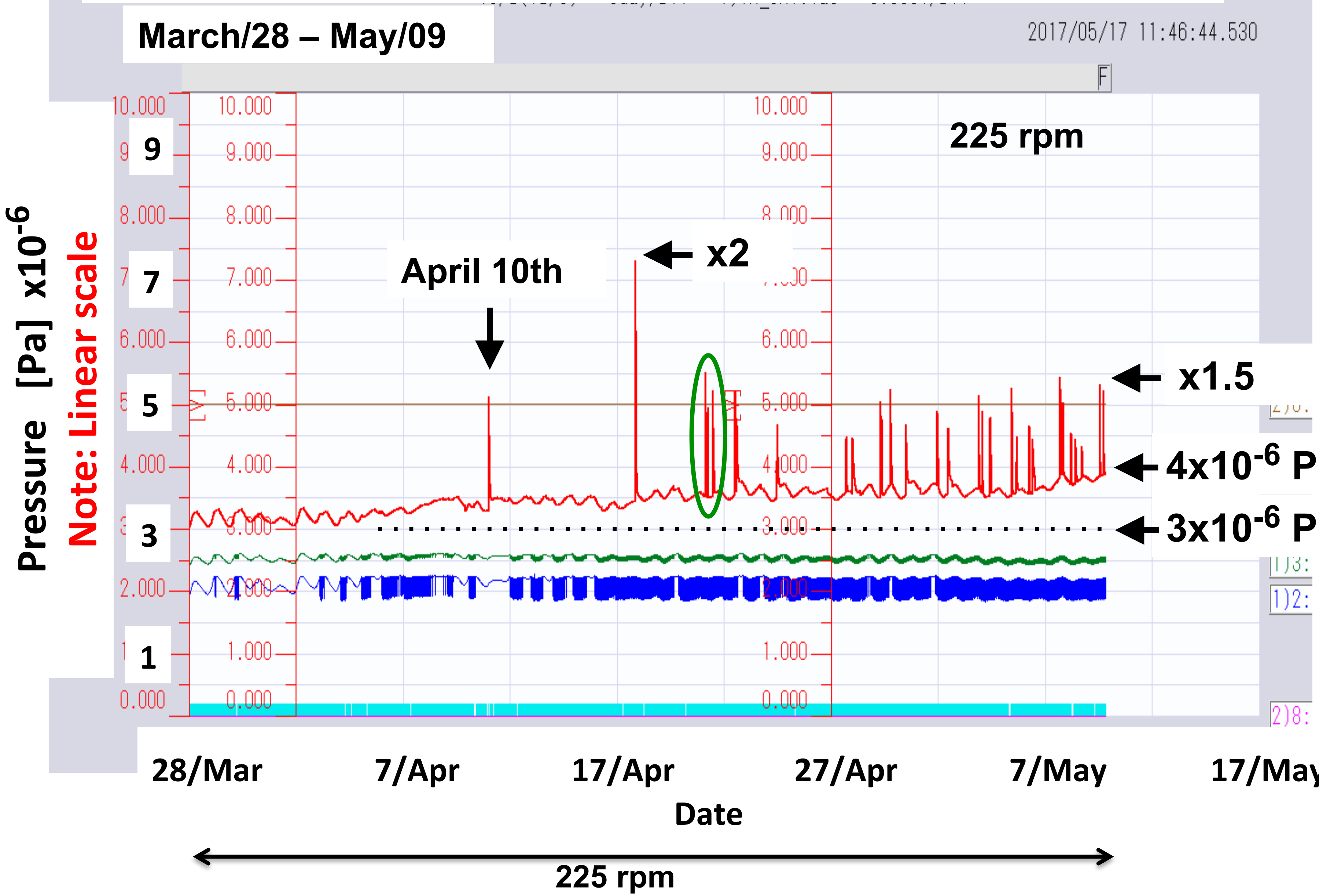


Central Part Prototype Vacuum Test
Facts and What happened (1)

- Ion pump   100 litter/sec.
- Rotation at 225 rpm (design value).
- We started the experiment on February 9th.
- Vacuum level went good monotonically.
- And reached ~ $3x10^{-6}$ Pa at the end of March.
- Vacuum level was stable at ~ $3x10^{-6}$ until April 10th.
- Then, we observed small spikes.
  - High of a spike ~x1.5.
    (cf. Undulator target at LLNL, spikes ~x100- x1000)
  - The time constant was 10-60 minutes.

Central Part Prototype Vacuum Test

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



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

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- Vacuum level was stable at ~ 3×10^{-6} until April 10th.
- Then, we observed small spikes.
  - High of a spike ~x1.5.
    (cf. Undulator target at LLNL, spikes ~x100- x1000)
  - The time constant was 10-60 minutes.
- Vacuum went gradually bad, it was ~4×10^{-6} on May 10th.
- Something seemed to be aging. Ferrofluid?

Central Part Prototype Vacuum Test Conclusion (1)

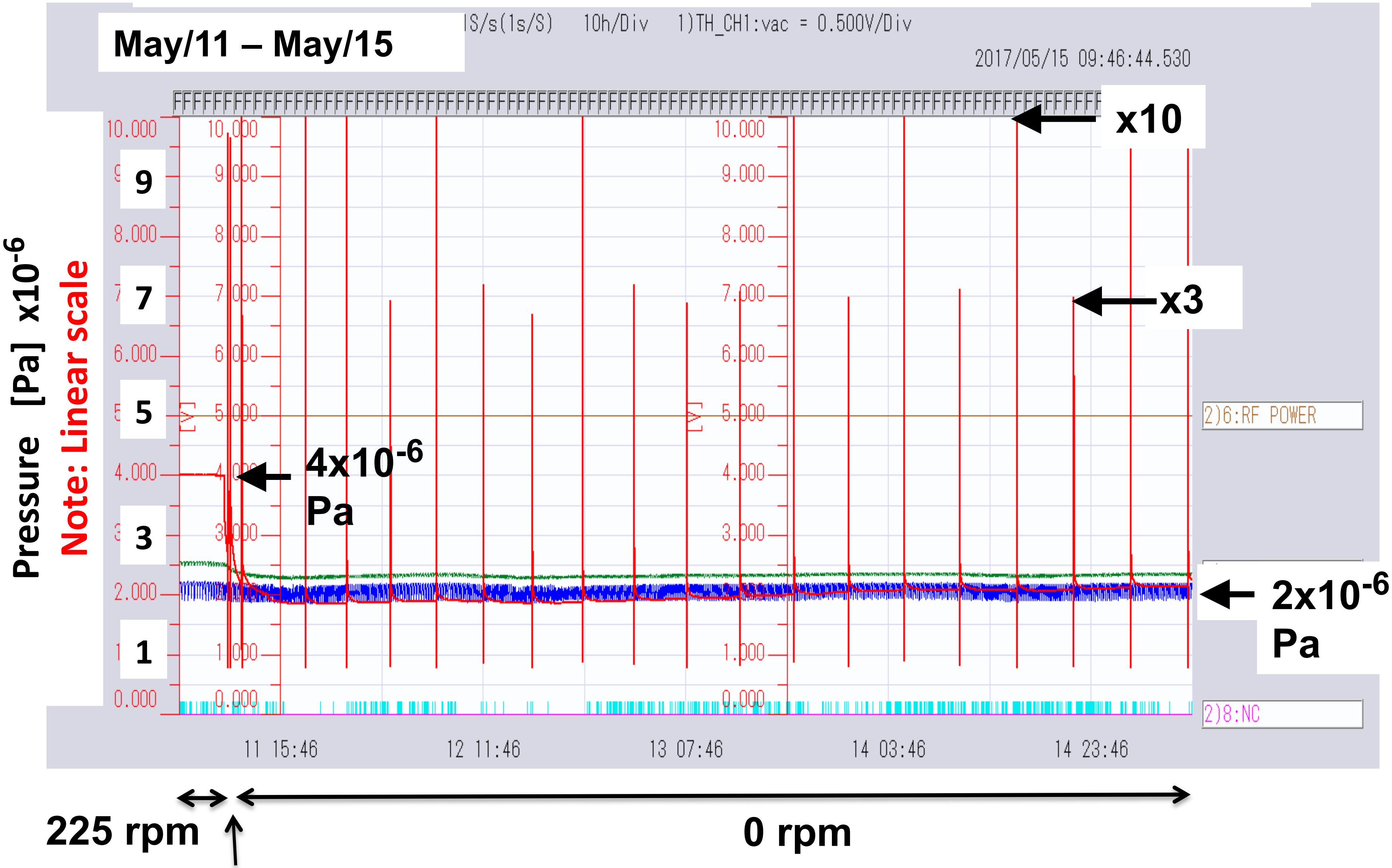
- 3-5x10^{-6} Pa is kept with 225 rpm rotation with 100 l/s ion pump.
- The vacuum level is the same as expected.
- It is promising.
- However we have concern for lifetime of the system.

Central Part Prototype Vacuum Test
Facts and What happened (2)

- **Something seemed to be aging. Ferrofluid?**
- **When ferrofluid aged, small air void penetrate via ferrofluid?**
- **We stopped rotation on May 11th**

Central Part Prototype Vacuum Test

On May/11, we stopped rotation

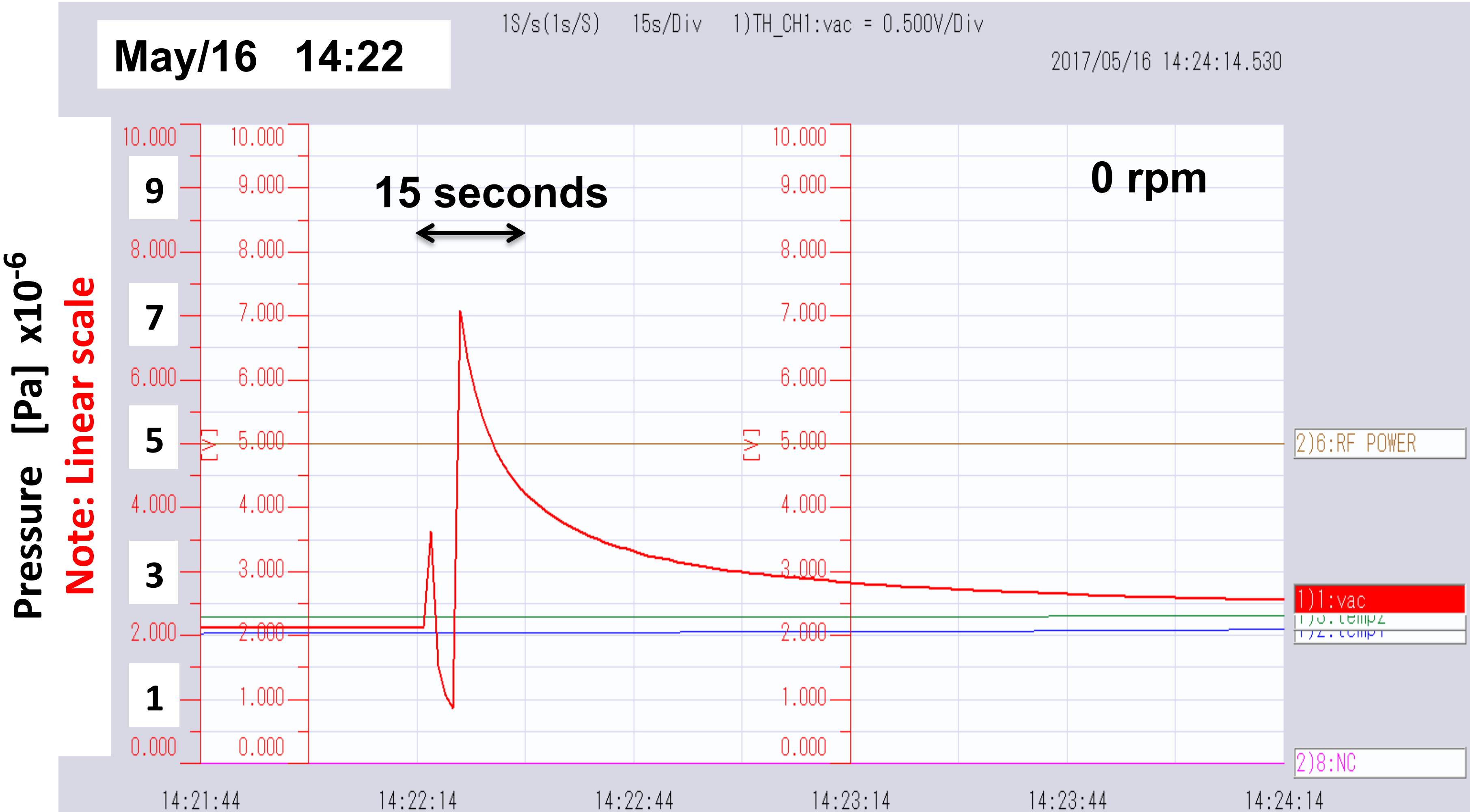


May/11 10:15, Stop Rotation

Central Part Prototype Vacuum Test
Facts and What happened (2)

- **Something seemed to be aging. Ferrofluid?**
- **When ferrofluid aged, small air void penetrate via ferrofluid?**
- **We stopped rotation on May 11th**
  - **Vacuum level got better $4x10^{-6} \rightarrow 2x10^{-6}$.**
  - **We observed larger spikes. The height was x3 – x10.**
  - **Sikes were rather periodic.   T = 5 hours 50 minutes.**

Central Part Prototype Vacuum Test



Central Part Prototype Vacuum Test
Facts and What happened (2)

- Something seemed to be aging. Ferrofluid?
- When ferrofluid aged, small air void penetrate via ferrofluid?
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    - Vacuum level got better $4x10^{-6} \rightarrow 2x10^{-6}$.
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    - Sikes were very short term.

Central Part Prototype Vacuum Test
Facts and What happened (2)

- Something seemed to be aging. Ferrofluid?
- When ferrofluid aged, small air void penetrate via ferrofluid?
- We stopped rotation on May 11th
  - Vacuum level got better $4\times10^{-6} \rightarrow 2\times10^{-6}$.
  - We observed larger spikes. The height was x3 – x10.
  - Sikes were rather periodic.   T = 5 hours 50 minutes.
  - Sikes were very short term.

Conclusion (2)

- We don't quit understand the phenomena yet.
  But, since situation changed when we stopped rotation, we judged the aging of ferrofluid caused the deterioration of the vacuum quality.

Central Part Prototype Vacuum Test
Next steps (1)

Our guesses

- We suspected aging of the ferrofluid caused the deterioration of the vacuum quality.
- We suspected temperature rise of the ferrofluid by rotation may affect the aging.

Central Part Prototype Vacuum Test
Next steps (1)

Our guesses

- We suspected aging of the ferrofluid caused the deterioration of the vacuum quality.
- We suspected temperature rise of the ferrofluid by rotation may affect the aging.

Next steps (1)

- We are going to enhance the cooling water channel.
- We added temperature monitor (thermocouple) at near the ferrofluid seal (unfortunately not really near).

Central Part Prototype Vacuum Test

Enhancement of the Water Cooling Channel

Before Enhancement

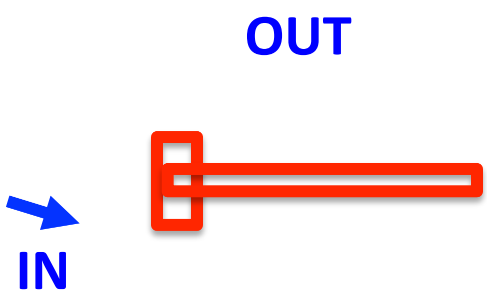
OUT

IN

Central Part Prototype Vacuum Test

Enhancement of the Water Cooling Channel

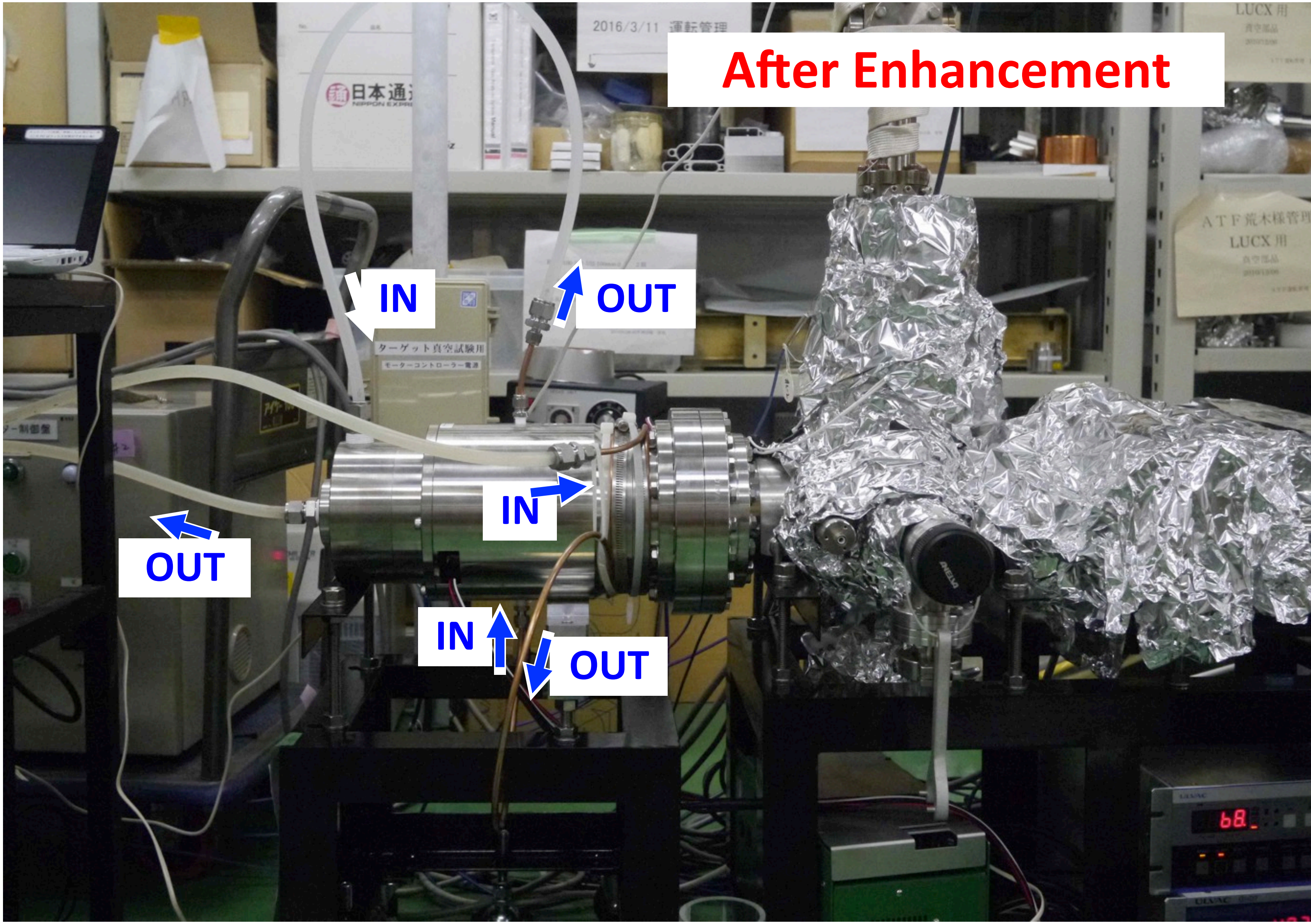
Before Enhancement



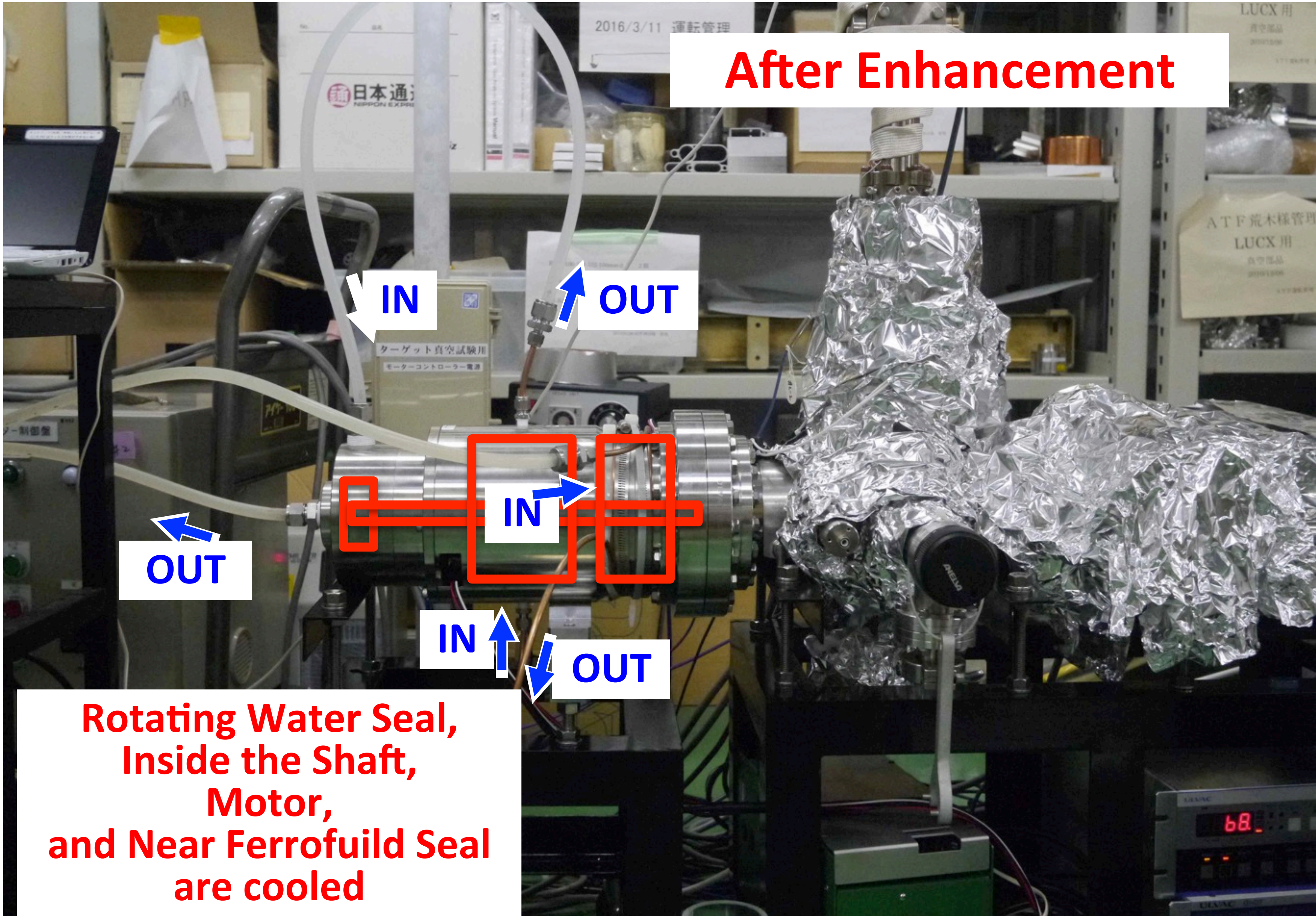
**Rotating Water Seal
and
Inside the Shaft
are cooled**

Central Part Prototype Vacuum Test

Enhancement of the Water Cooling Channel

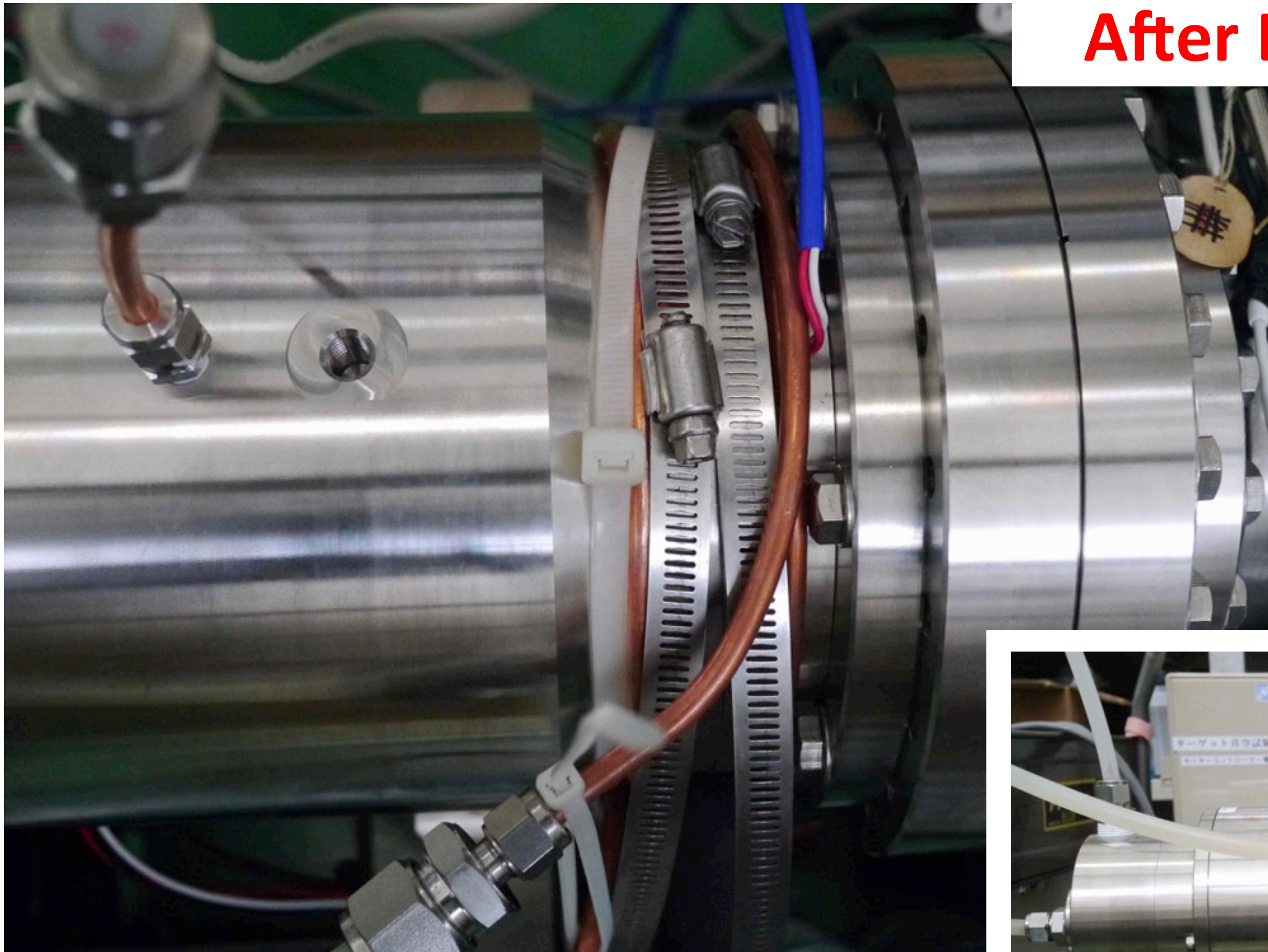


Central Part Prototype Vacuum Test
Enhancement of the Water Cooling Channel

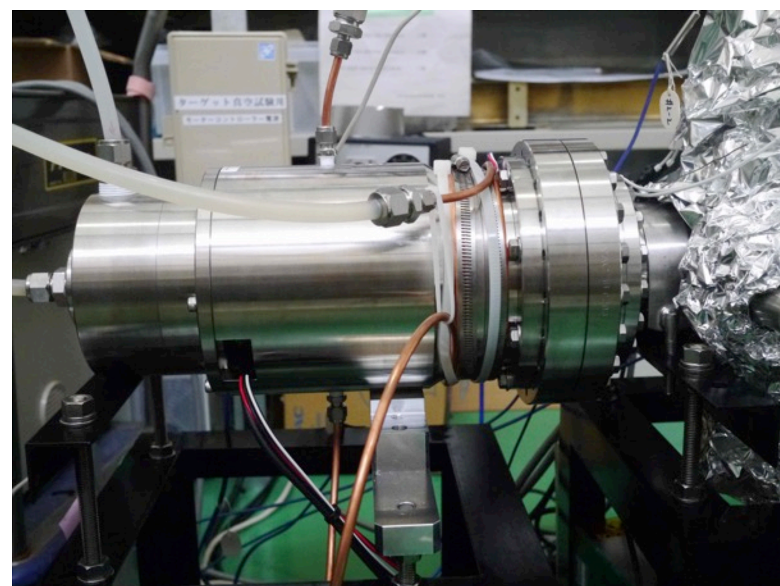


Central Part Prototype Vacuum Test

Enhancement of the Water Cooling Channel

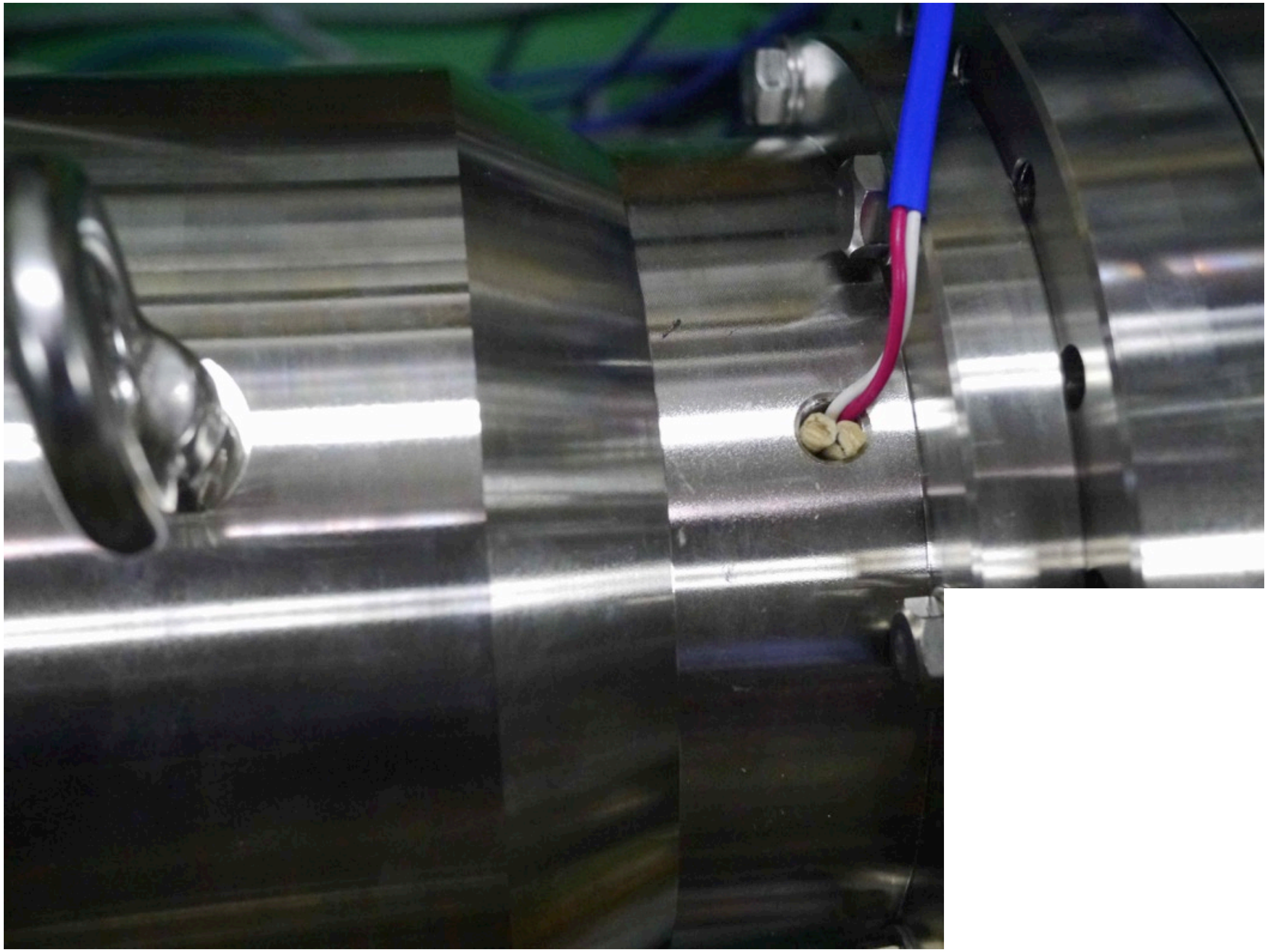


After Enhancement



Central Part Prototype Vacuum Test

We added thermocouple at near the ferrofluid seal



Central Part Prototype Vacuum Test
Next steps (1)

Our guesses

- We suspected aging of the ferrofluid caused the deterioration of the vacuum quality.
- We suspected temperature rise of the ferrofluid by rotation may affect the aging.

Next steps (1)

- We are going to enhance the cooling water channel.
- We added temperature monitor (thermocouple) at near the ferrofluid seal (unfortunately not really near).
- We are going to change water temperature.
  25 C (now) → 20 C → 15 C. We will do it begging of July.
- We will check lower limit of the temperature which doesn't make condensation of the water in air.

Central Part Prototype Vacuum Test
Next steps (2)

Next steps (2)

- We will break vacuum on July 19th.
- The vacuum seal will be send back to Rigaku. Rigaku exchange ferrofluid.
- We will reinstall the vacuum seal end of July.
- Then we will restart vacuum test with:
  - fresh ferrofluid,
  - enhanced cooling water channel,
  - lower water temperature,
  - and, improved temperature monitor.