Main linac module development for compact ERL at KEK

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Contents

installed

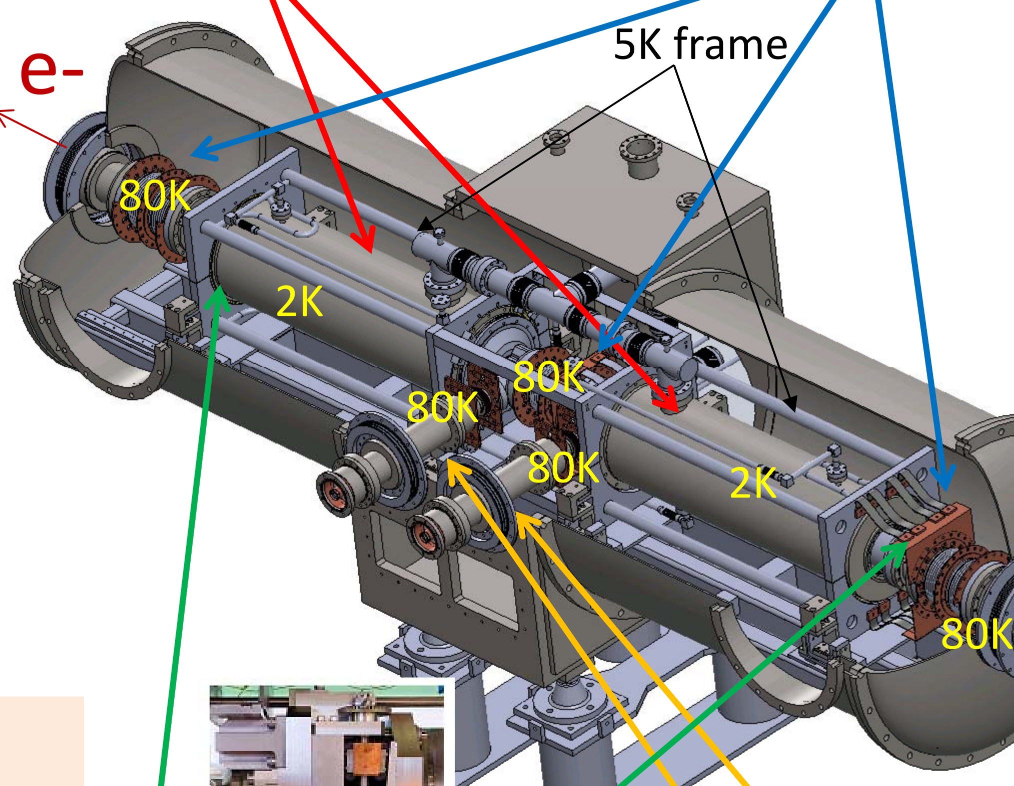
Compact ERL(cERL) @KEK

TTC CW SRF workshop @Cornell Univ. (2013.June.12-June.14)

Compact ERL main linac cryomodule configuration

9cell superconducting cavity
Max 25MV/m at V.T
Q0 > 1*10^10 @15MV/m

HOM absorber
- HIP ferrite on Copper beampipe
- Operation at 80K. (expected 150W HOM power)
- Check enough absorption ability of ferrite at 80K



(Compact) ERL target

Frequency : 1.3 GHz
Input power : 20kW CW (SW)
Gradient: 15MV/m
Q0: >1*10^10
Beam current : max 100mA (against HOM-BBU instability)

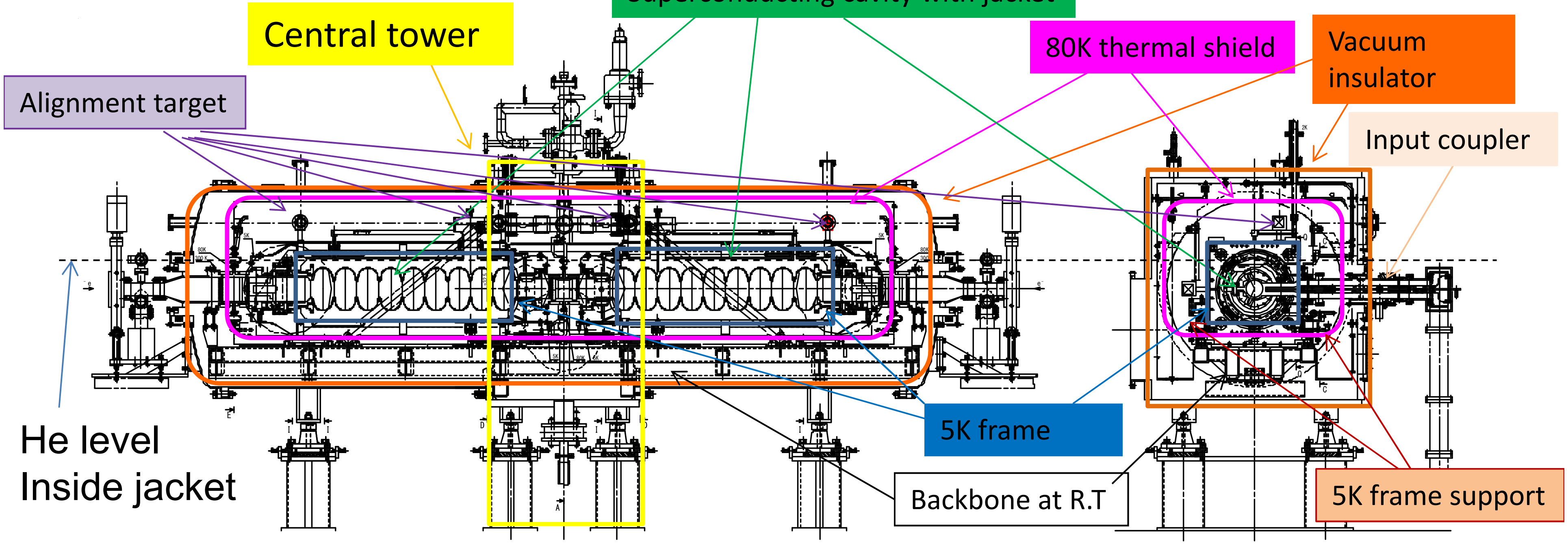
2-cavity cryomodule was developed for compact ERL main linac to demonstrate the high current ERL operation at cERL. We have done the high power test by using this cryomodule in 2012.

Frequency Tuner
Slide jack tuner (mechanical)
piezo tuner(fine tuning)

Input coupler
- 20kW CW (standing wave)
- Cold and warm window
- HA997 ceramic is used
- QL=(1-4)*10^7(variable)

Detailed design of Cryomodule of cERL main linac

Magnetic shield equipped just outside 5K frame with 1.5t thickness



Requirements

Dynamic loss (**need margin 80W @ 2K of cooling ability**)

Cavity : 25 W (for 2K) / cavity(@15MV/m)

Input coupler : 1.5 W (for 5K) / coupler

HOM absorber : 150W (for 80K)/ cavity (100mA)

Alignment

±1 mm from beam line

Support

Cavity(2K) – 5K frame– backbone(300K) – Central tower(300K) （supported from bottom side）

Method

Against CW operation

- Enlarge ϕ300mm diameter of jacket and make enough surface of He level in jacket .
- Gas He outlet = ϕ54mm
- 5K frame is used to suppress heat leak into 2K.

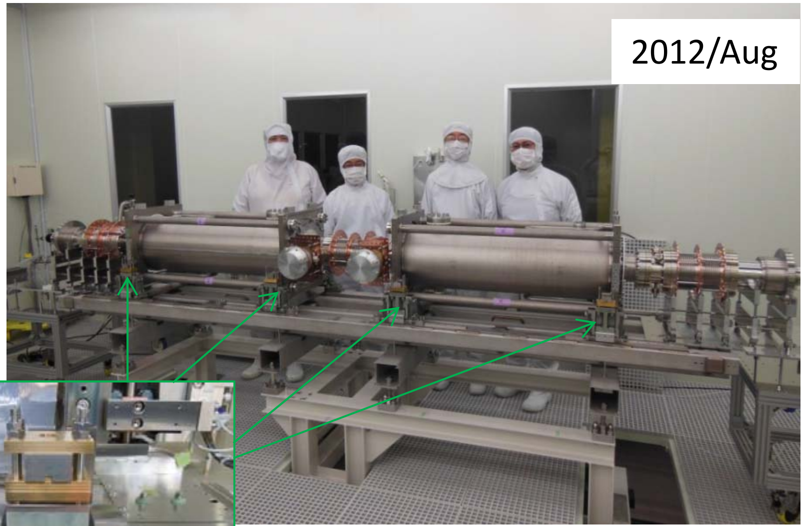
Structure

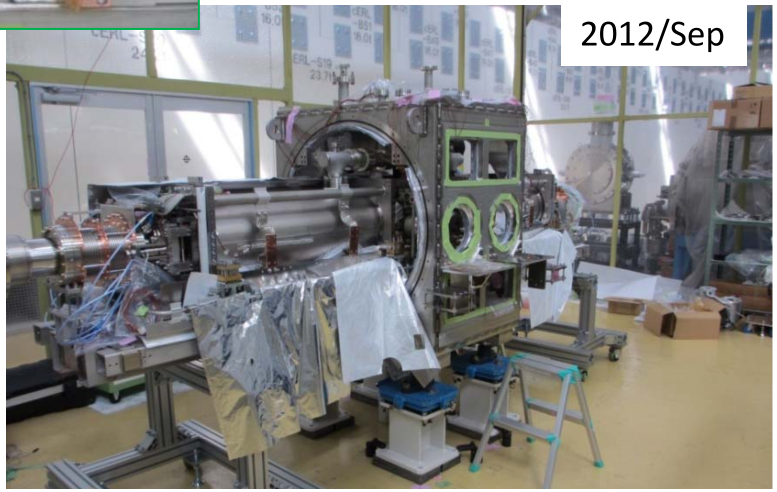
- 5K frame support cavity and alignment target set on frame. By using target, we trace the cavity position under cooling.
- 5K frame was supported from fixed backbone set at 300K via 5K frame supports which reduce the heat leak to 5K frame and thermal shrink .

Module Assembly after V.T

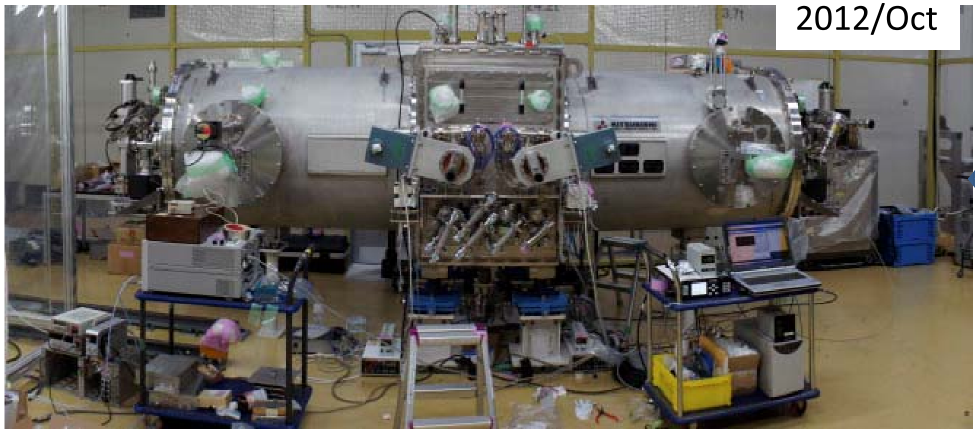
After Ar gas purging into cavities,He jacket were welded on cavities

Cavities, HOM absorbers and cold window of input couplers were assembled in class 4 clean room supported by backbone through 5K frame support





Assemble He line, magnetic shield, thermal Insulator, sensor and so on



After fixing alignment, warm window set and vacuum vessel were mounted. Gate valves were set on both sides

Cryomodule Cooling to 2K

Strategy of cooling

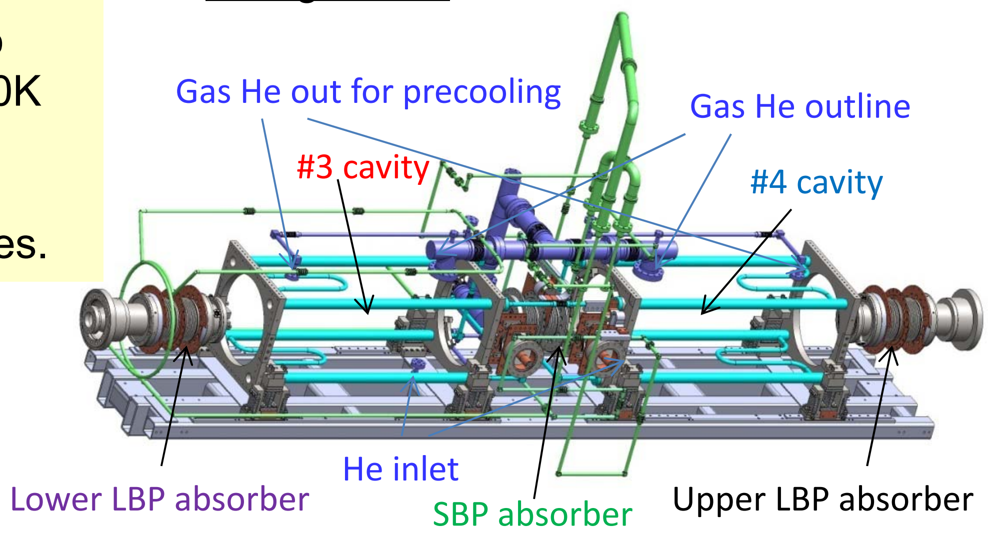
・HOM damper should be cooled down slowly, to avoid cracking of ferrite.3K/h was required for 80K line, which cool the HOM dampers.

・Relatively large temperature difference was avoided within each 2K, 5K(He) and 80K(N_2) lines.

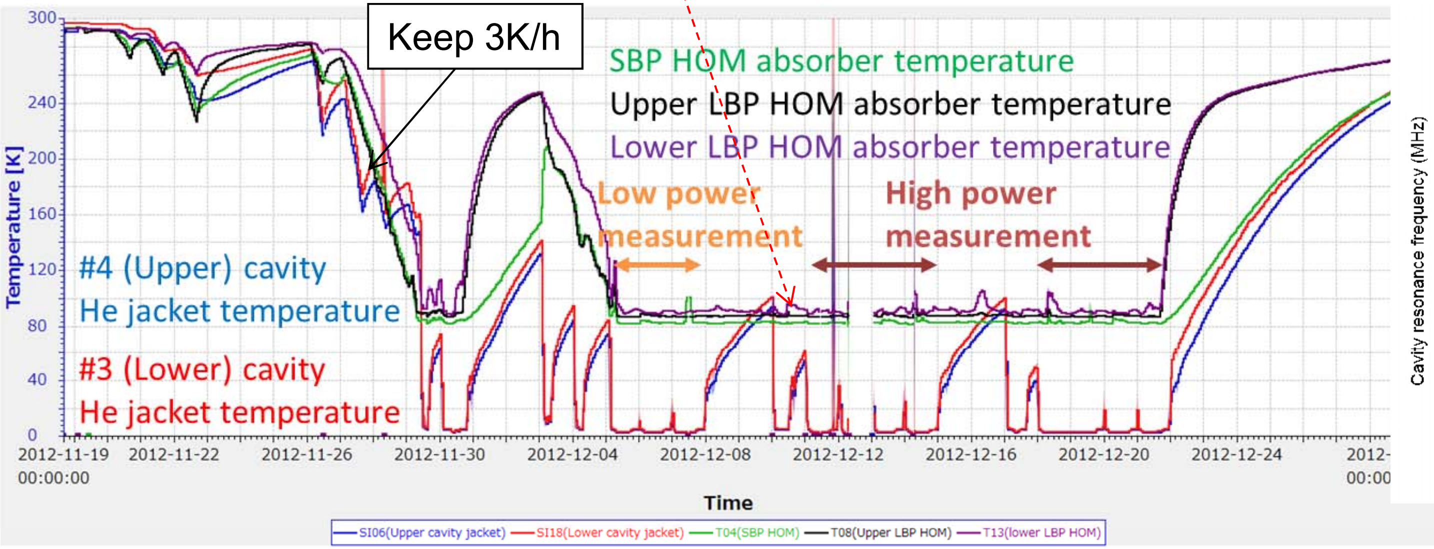
From Dec. 4th, 80K lines were always cooled down to 2K.While 2K line operation was only stopped, during midnight and weekend.

Cooling pipe configuration

Green : 80K line
Blue : 2K line
Light bule : 5K line

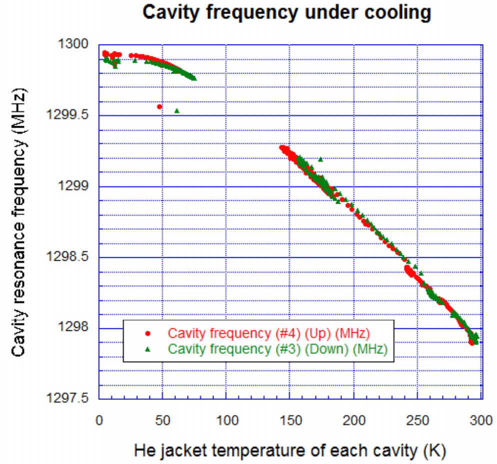


History of 2k cooling



3 weeks keep 2K cooling (1 weeks for Low level measurement and 2 weeks for High power test)

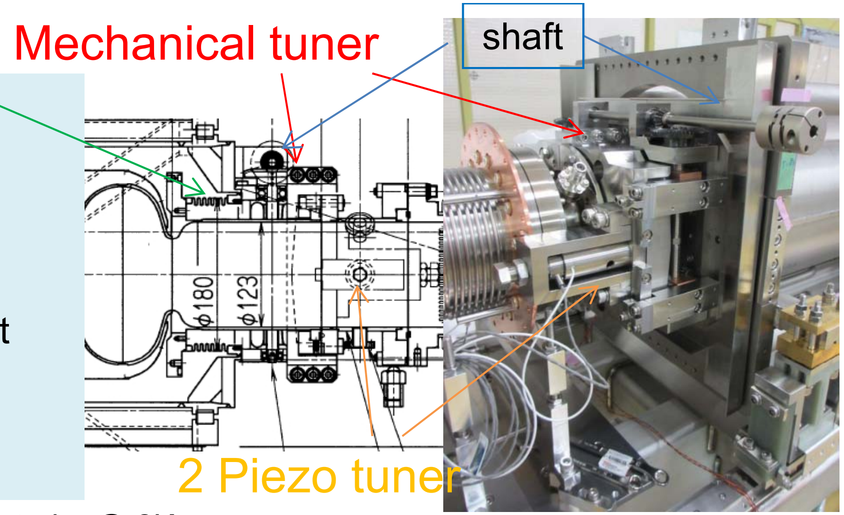
Cavity frequency



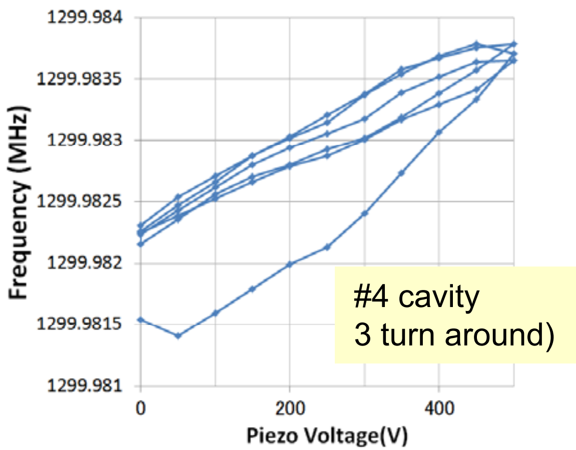
Cavity frequency was changed to +2MHz (1299.9MHz with tuner 0.5mm keep) from 300K to 2K, which agree well with V.T measurements

Frequency tuner

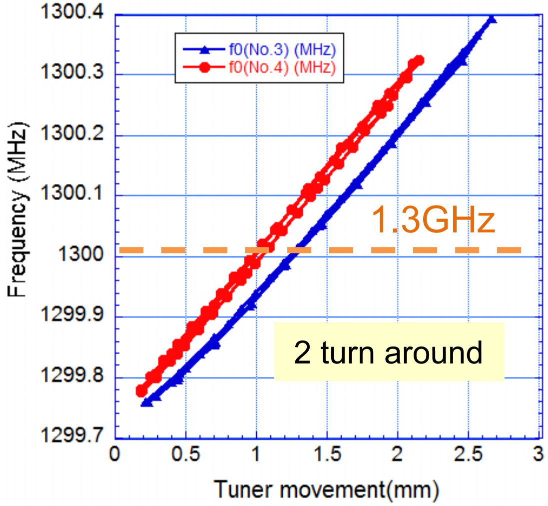
- Cavity frequency could be tuned to 1.3GHz.
- Coarse mechanical tuners smoothly moved and enough stroke (more than 2mm) was obtained.
- Fine piezo tuners also worked smoothly and has enough stroke under 2K cooling.
- 200Hz backlash was observed by using coarse tuner. But we did not observe sudden frequency change due to this backlash. Piezo can make this backlash cancel out smoothly.
- Tuner temperature is 30K (too big) at 2K condition.



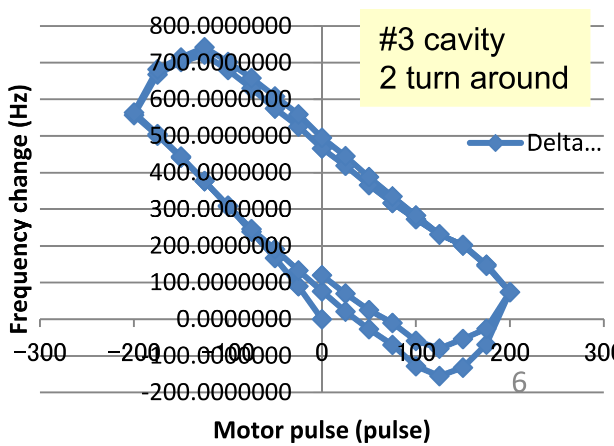
Piezo performance @ 2K



Coarse mechanical tuner stroke @ 2K



Coarse tuner fine tune by motor@ 2K



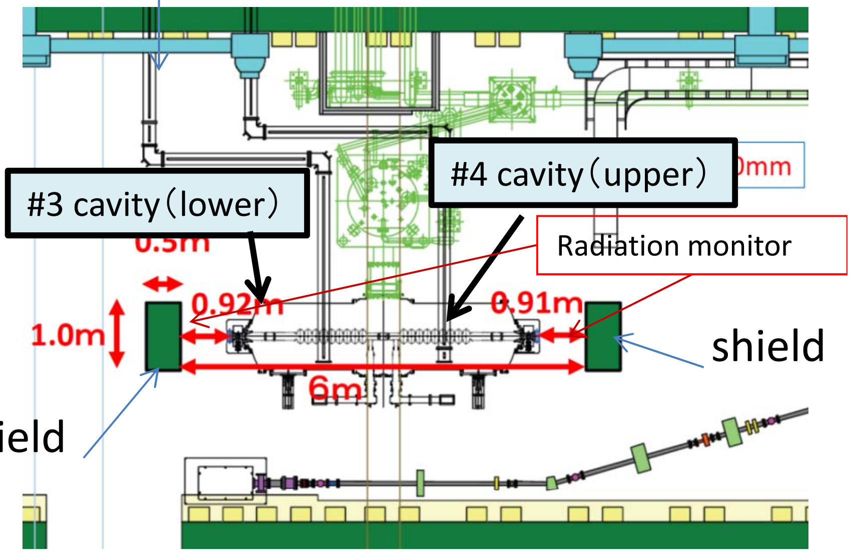
Performance @ 2K		Upper cavity (#4)		Lower cavity (#3)	
Coarse tuner (Slide jack tuner)	Stroke&slope	272kHz/mm (0-2mm)		265kHz/mm (0.5-2.5mm)	
	Max backlash	< 50Hz		About 200Hz	
	Torque of shaft	< 3N m @ 2mm position		< 3N m @ 2.5mm position	
Piezo (0-500V)		1.4kHz(500V)	1.1kHz(500V)	1.4kHz (500V)	1.2kHz (500V)

Results of high power test

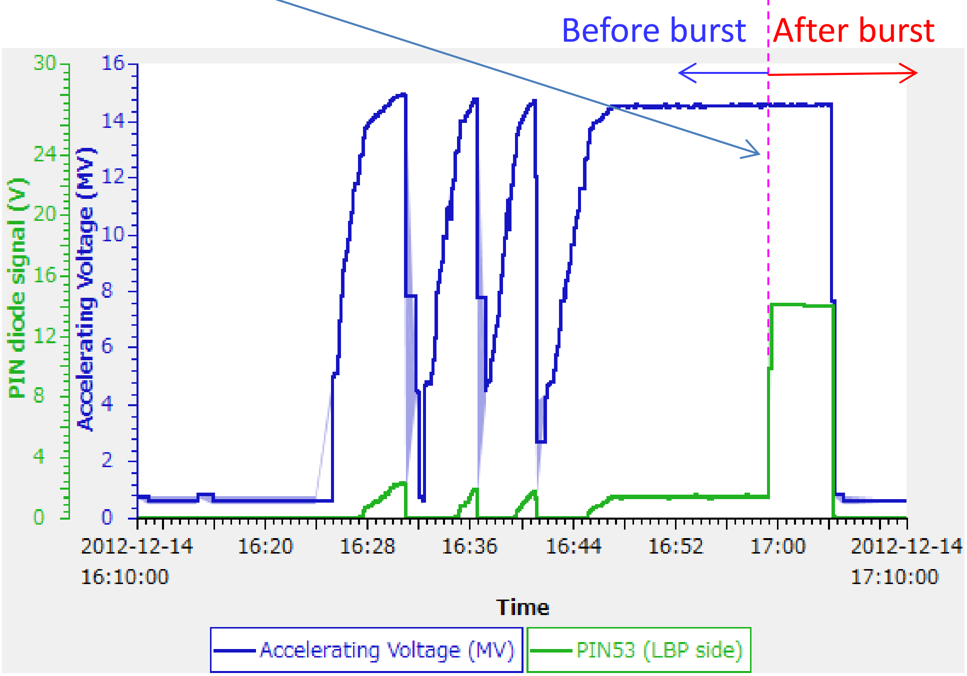
- Both cavities reached to Vc = 16MV.
- X-ray of #4 cavity increased during processing.
- Field emission on-set was 8-9 MV for both cavities

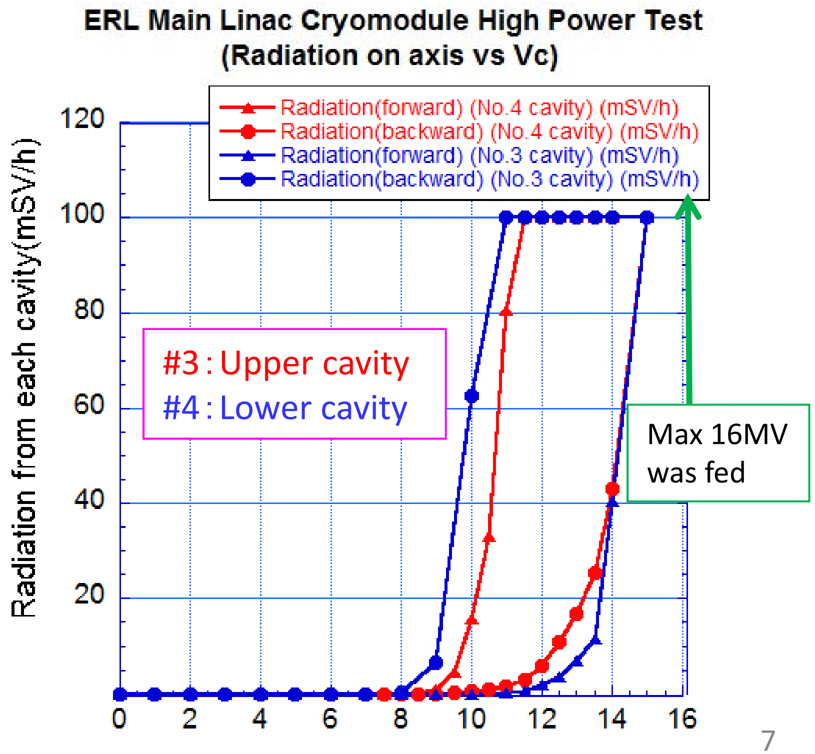
Upper QL : 1.54*10^7
Lower QL : 1.15*10^7

Max input power (Pin) is 5kW



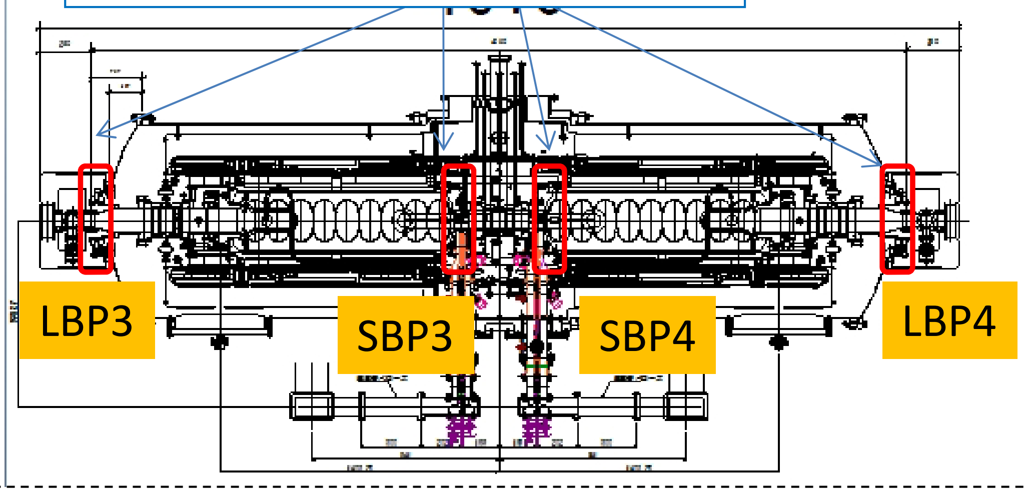
X-ray burst happened, and X-ray was suddenly increased while keeping field



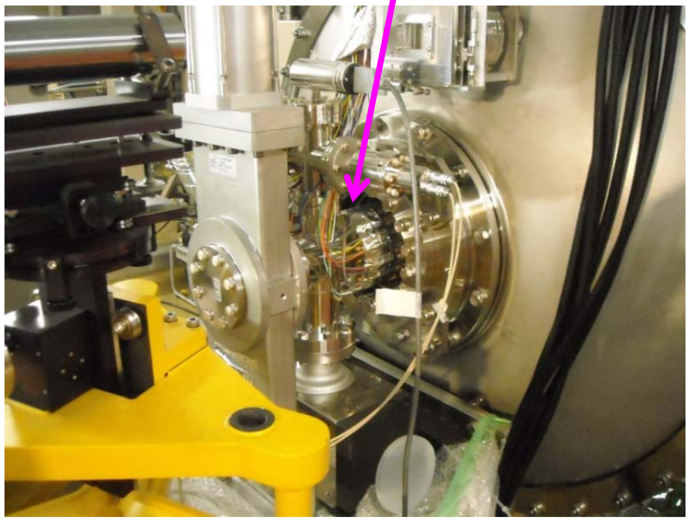


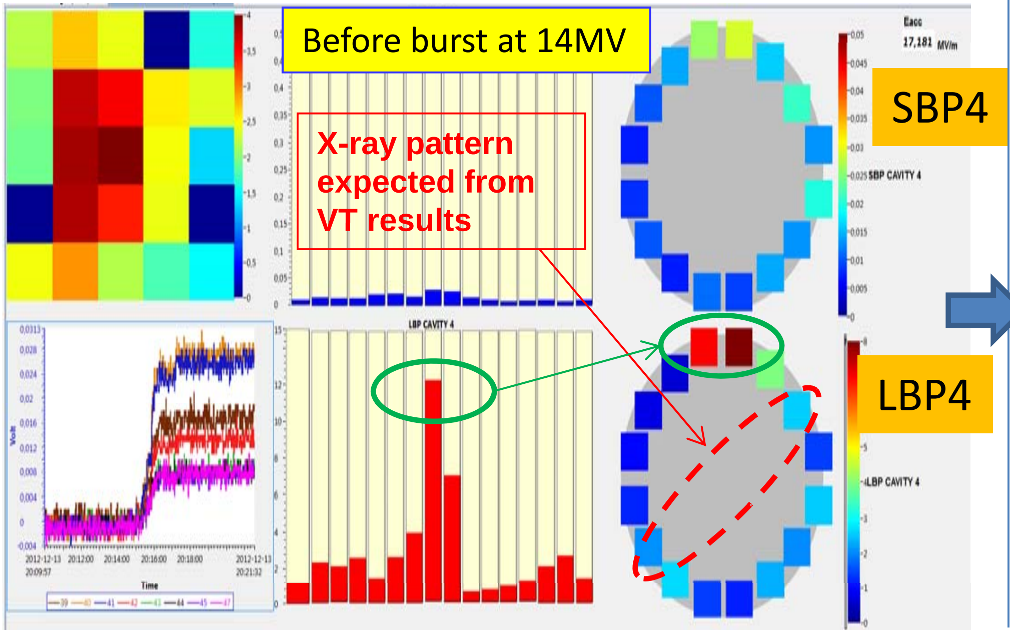
Accelerating voltage vs Radiation

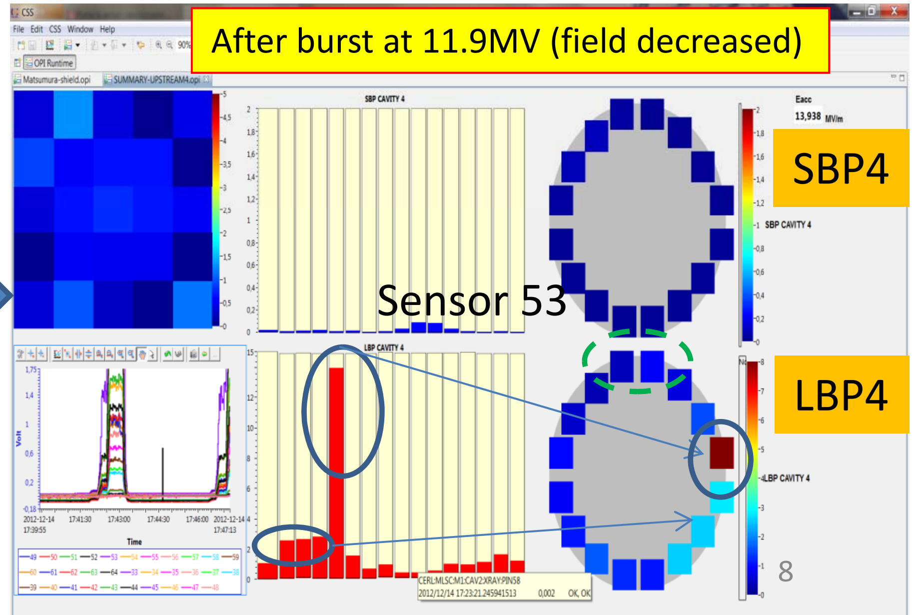
Detail radiation distribution measurement



Si PIN diode set around beam axis





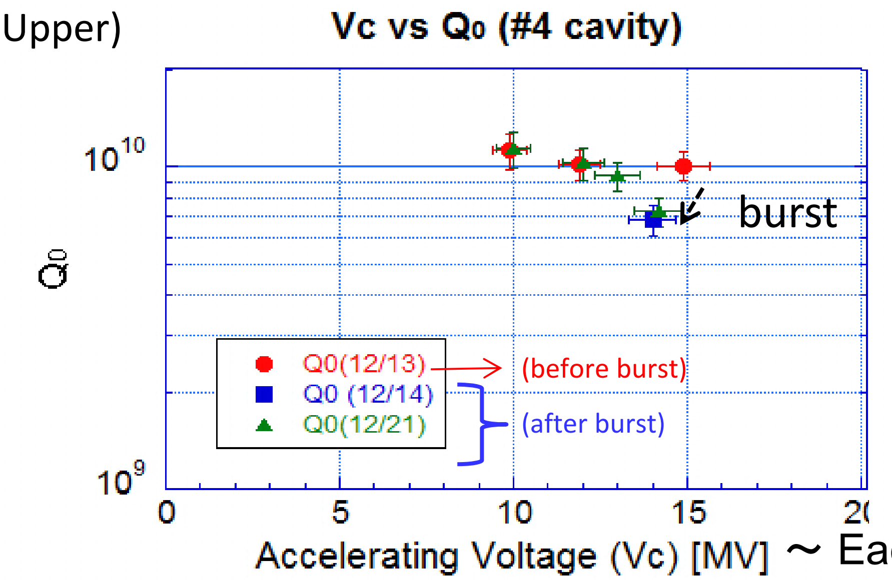


・Radiation pattern was changed from V.T
・Radiation pattern also changed after X-ray burst

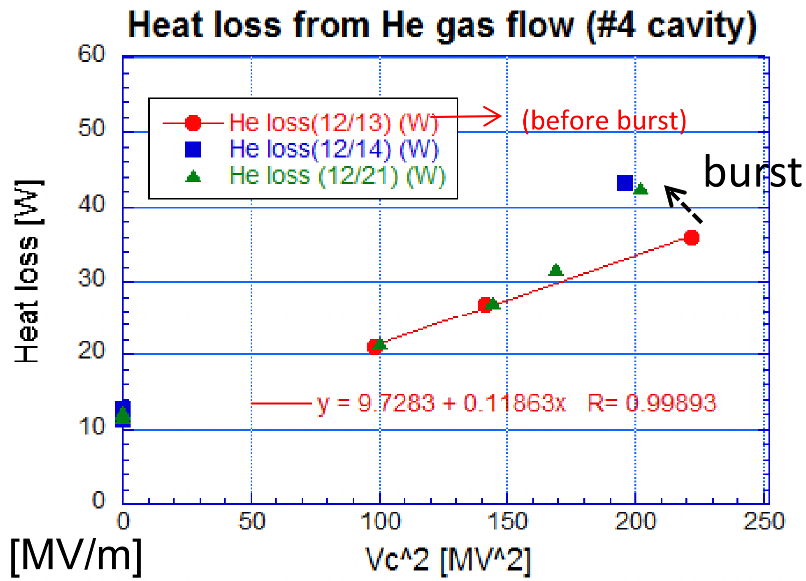
・Another new radiation sources were produced during assembly work and high power test.

Dynamic loss measurements

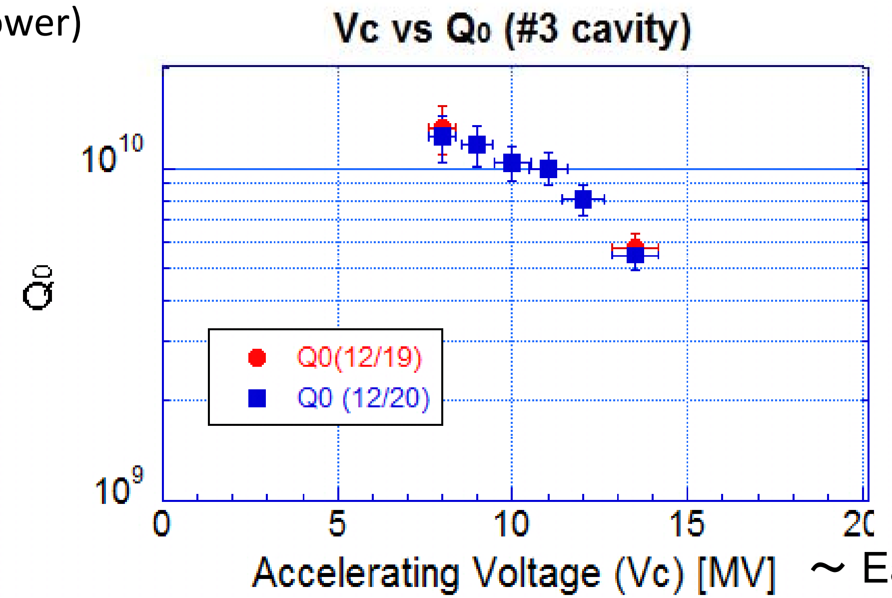
#4 (Upper)



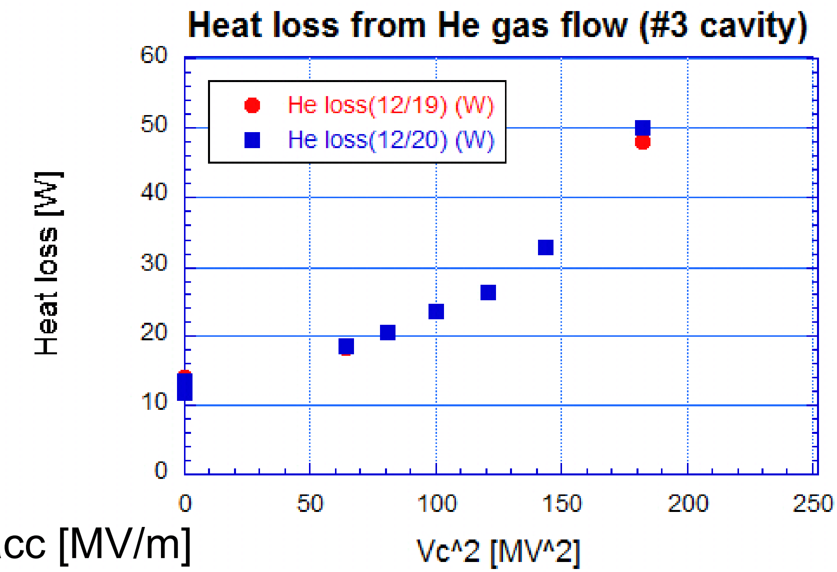
～ Eacc [MV/m]



#4(Lower)



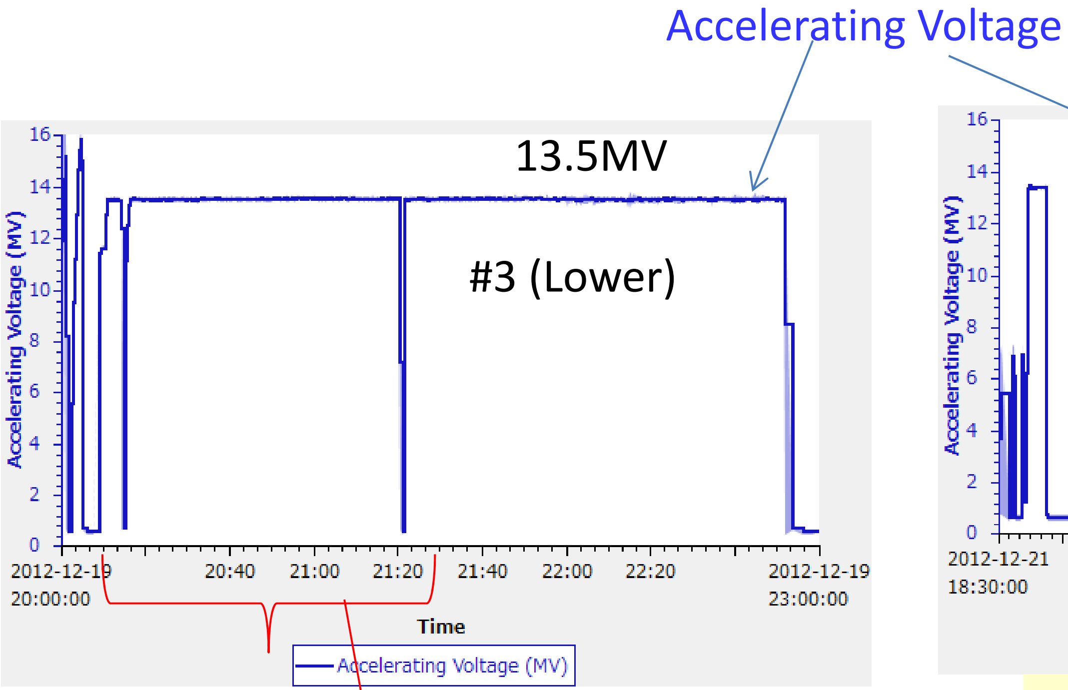
～ Eacc [MV/m]

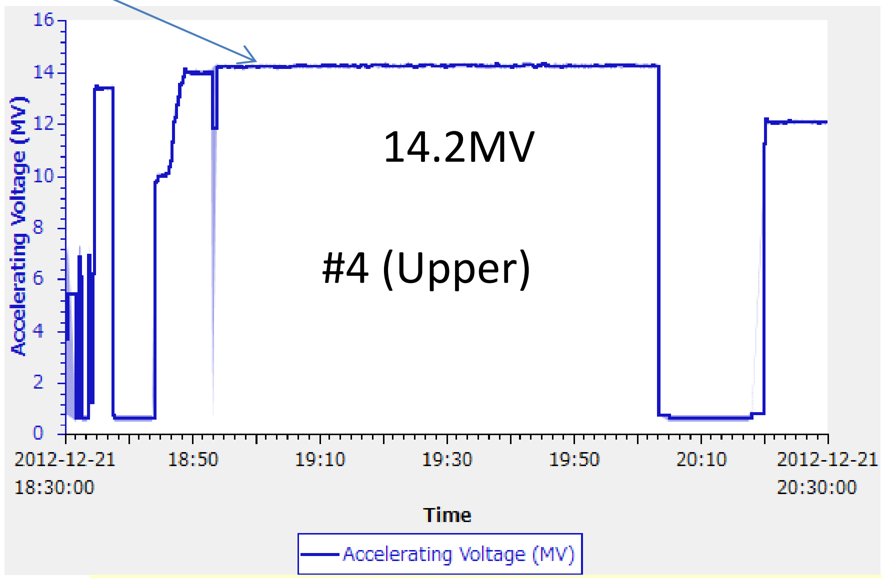


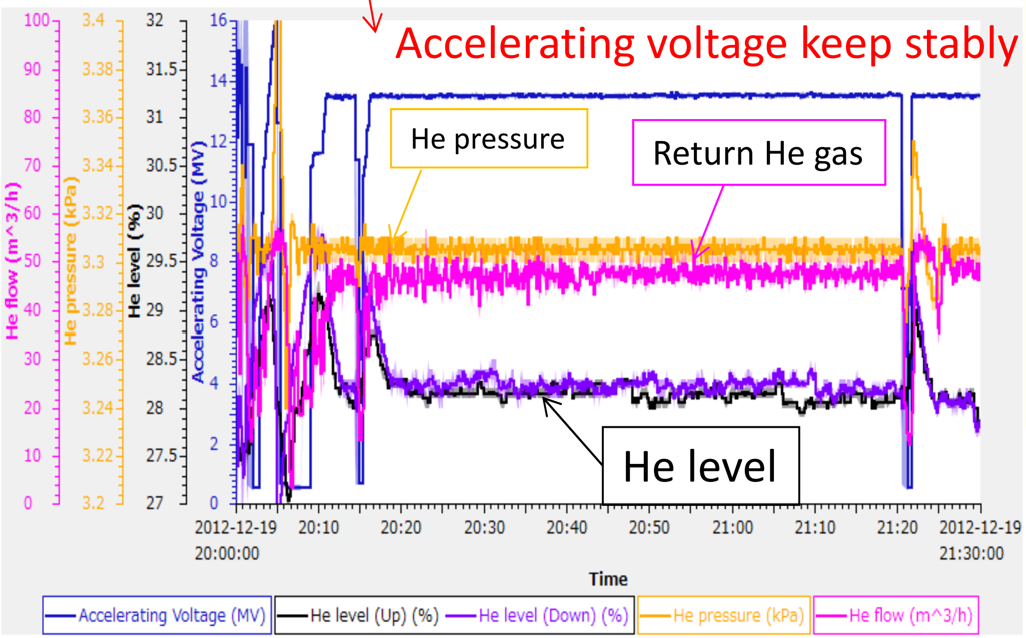
Q-value was dropped by field emission ← Cryogenic loss drastically increased.
Q-value is higher than 1*10^10 at low field of less than 10MV of Vc.
Magnetic shield works well .

2K Static loss :
11W at final (little large)

Vc keep test





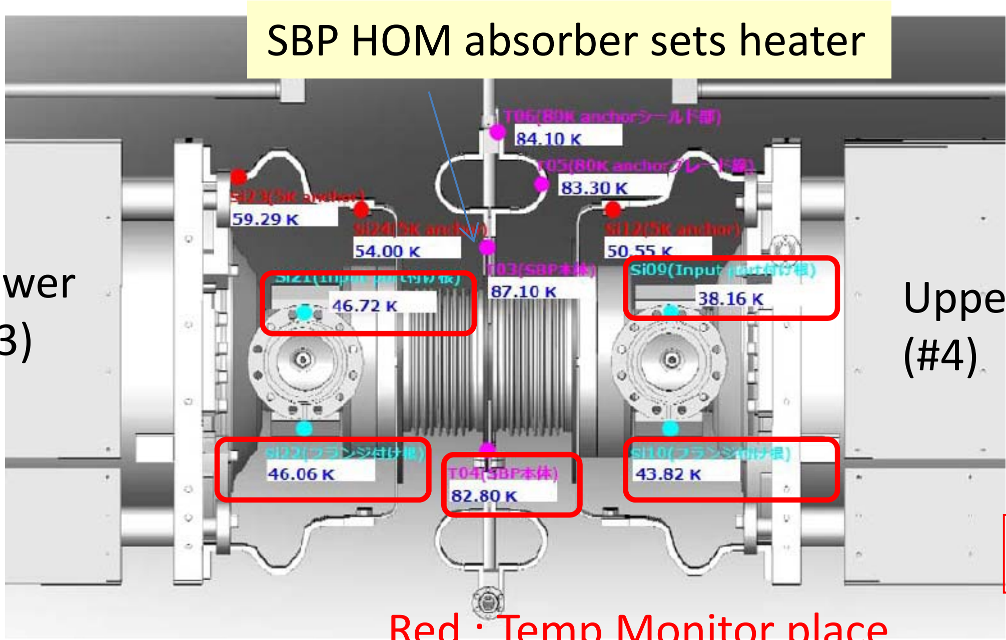


・We can keep the following voltages of
Upper cavity : 14.2MV
Lower cavity : 13.5MV
for more than 1 hour. (40-45W heat @2K)
・We cannot keep more than 14.5MV field because of the lack of the cryogenic power (>50m^3/h ～50W)
・Now we prepare twice bigger cryogenic power for cERL beam operation.

We note that He gas return, He level and He pressure were also stable. Especially He pressure keep stable within 10Pa (measured), which contributed the microphonics suppression (<3Hz/10Pa is expected from 4.2K → 2K Δf=28kHz)

Temperature rise around cavity on high power feeding & SBP HOM heater test

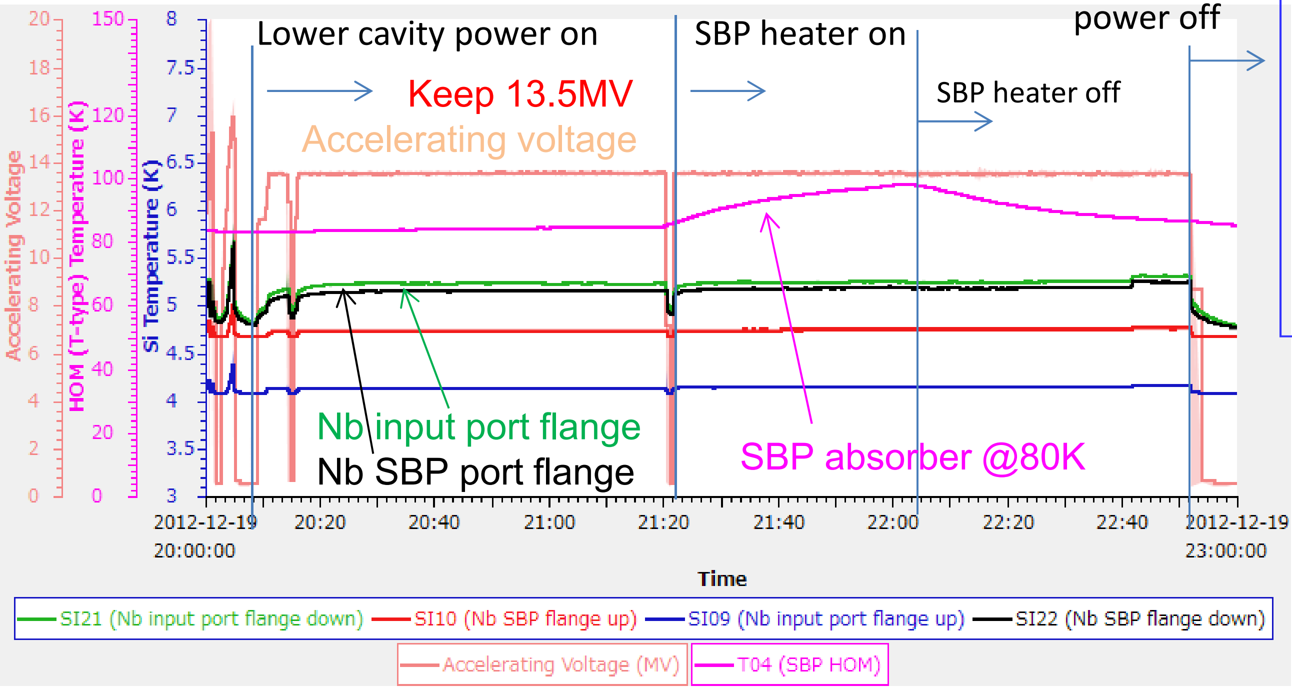
Lower (#3)



Upper (#4)

Measure the temperature rise on cavity flange when the accelerating voltage of lower cavity was kept at 13.5MV .Furthermore, we add 30W (equal to the 50mA beam current HOM power)to SBP absorber by Heater to estimate the heat leak to 2K cavity and Nb flange.

4.5kW of Pin power fed into lower cavity

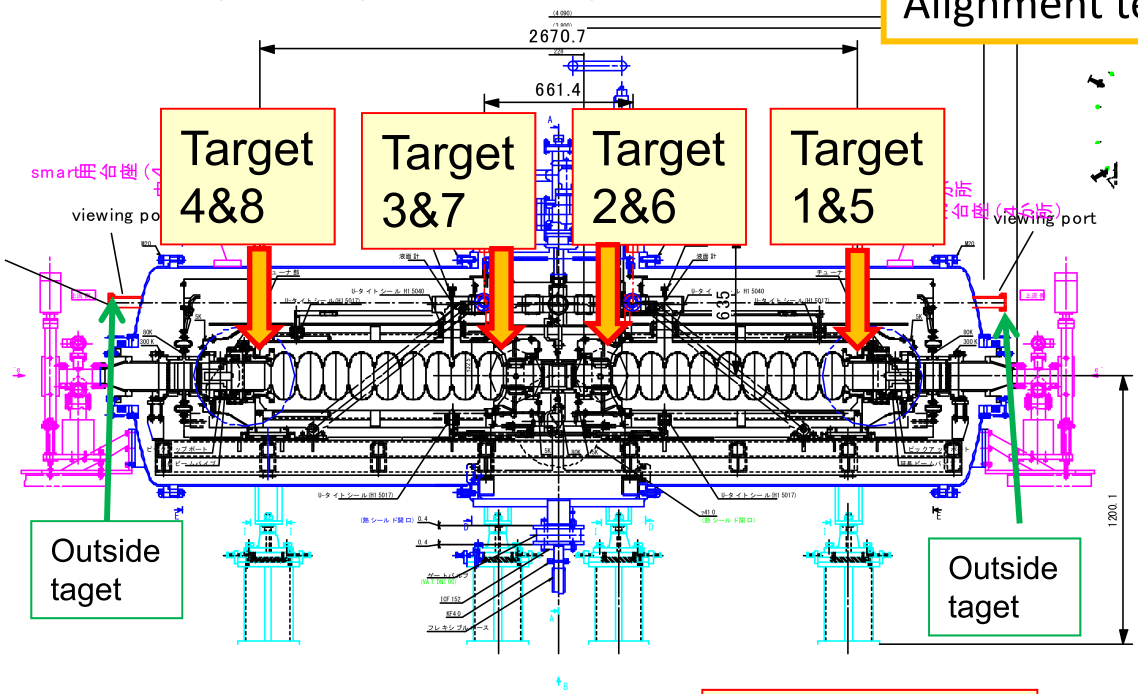


- Temperature rise of Nb input and SBP flange is from 4.8K to 5.2K (ΔT =0.4K) by power feeding of 4kW
- 30W of SBP HOM heater did not contribute the temperature rise of the Nb flange of cavity.

•Heat leak to 2K was absorbed by 80K & 5K anchor and isolated by bellows of SBP HOM absorber as expected by design of cryomodule.

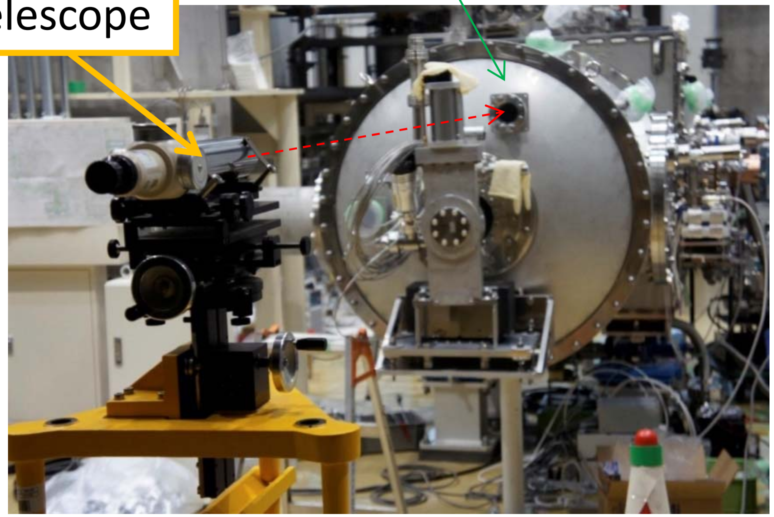
Cavity alignment setting under cooling

Setting of alignment targets

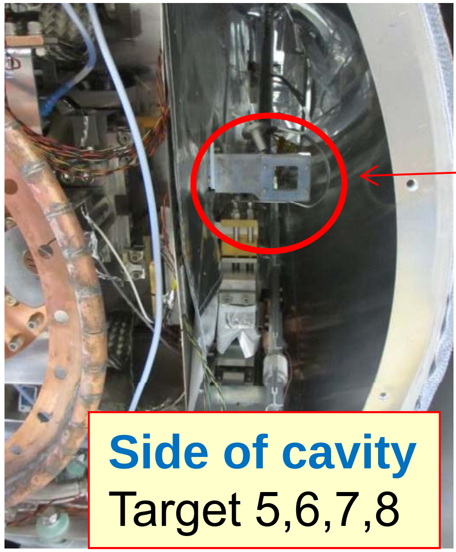


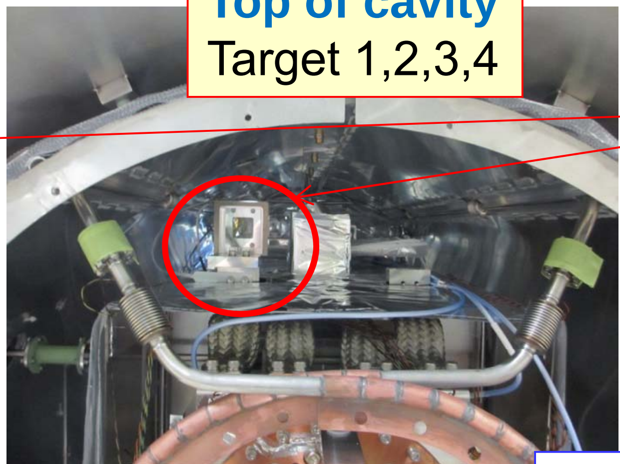
4 outside targets on R.T to make base lines of telescope

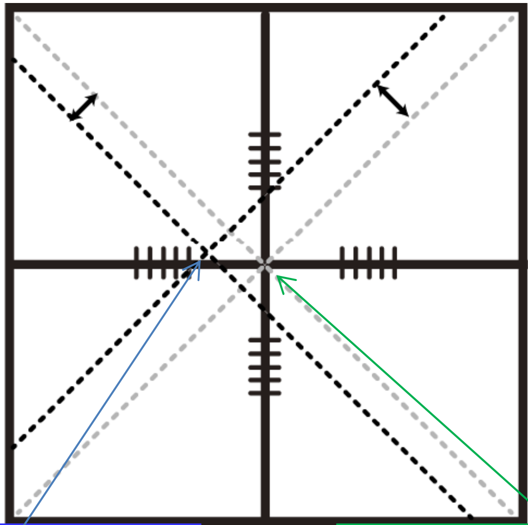
Alignment telescope



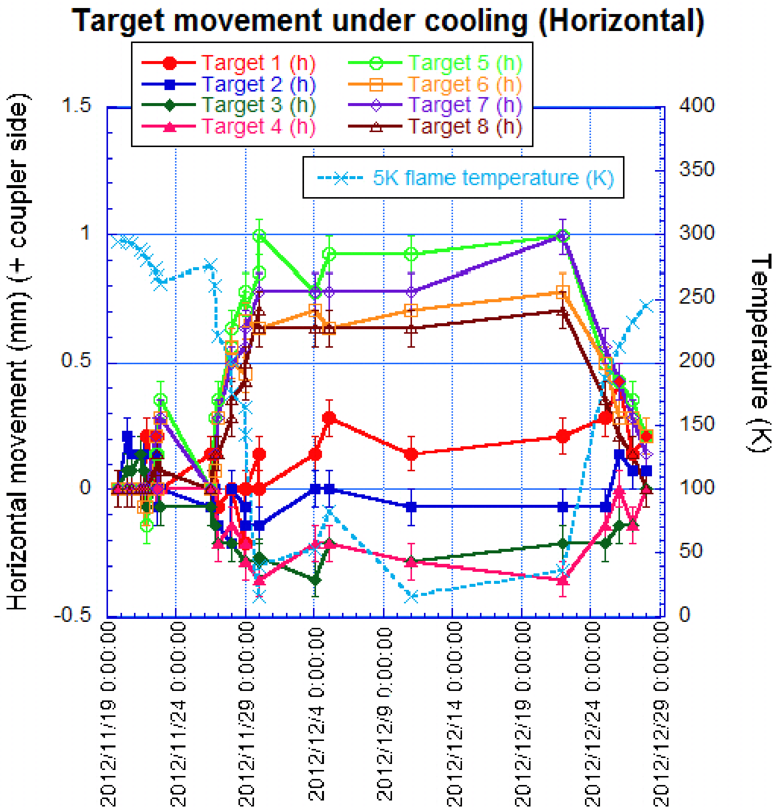
8 Qurtz targets with markers were set around 5K frame at known position from caity centor mechanically along cavity axis

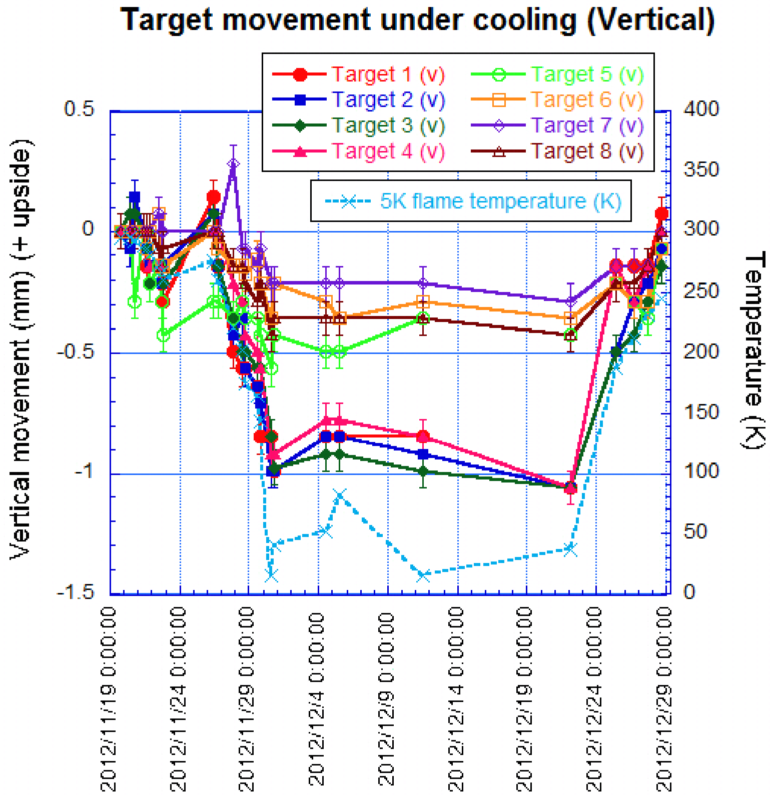






Cavity movement during cool down to 2K



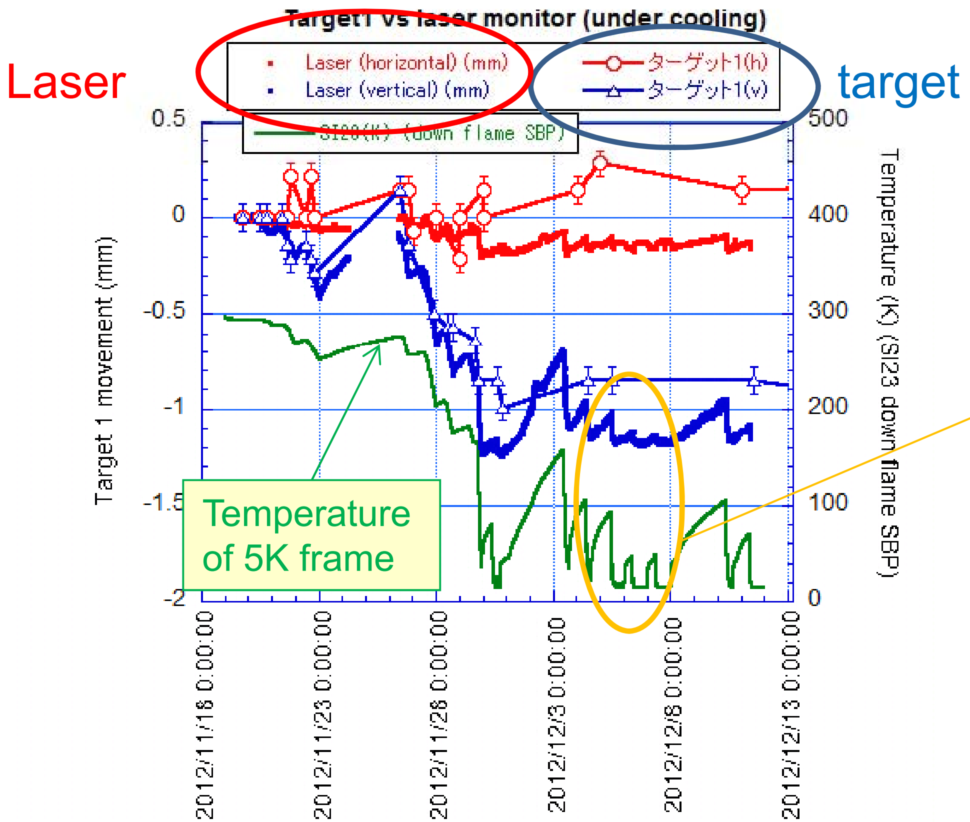


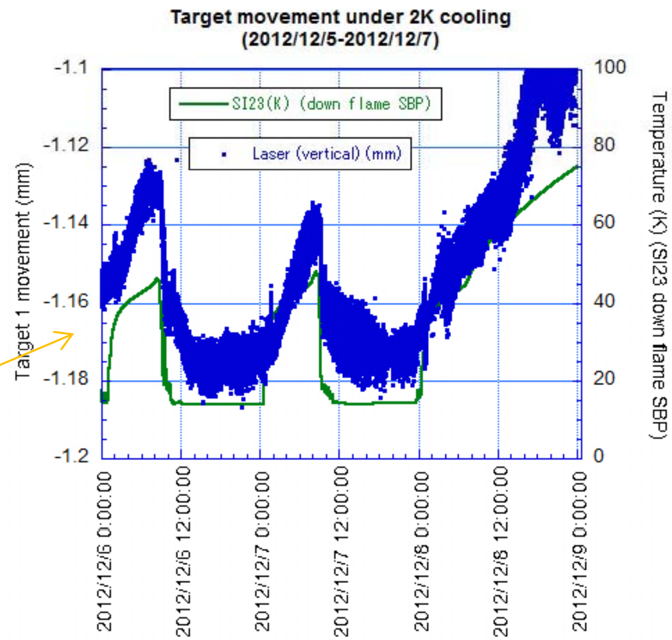
Movement of targets and cavities between RT to 2K	Horizontal (mm)	Vertical(mm)
Target 1-4 (Average)	-0.11	-1.06
Target 5-8 (Average)	0.87	-0.37
Average movement of cavity center (from target 5-8)	0.39	-0.37

- Upper targets (1-4) and side target (5-8) moved same direction and had almost same movements.
- By using this measurements, about 0.4mm of cavity center movement was expected horizontally and vertically , which almost agreed well with expected values of thermal shrink of 5K supports
- Measured target values come back to same position by warming up to 300K

Precise measurement of cavity movement by laser position monitor

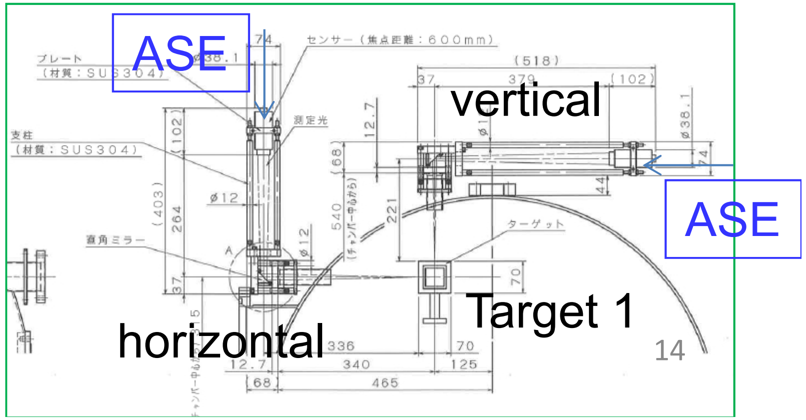
To confirm the measurement accuracy of target, we also measure the movement by newly developed laser position monitor with 10um level accuracy by setting one target.



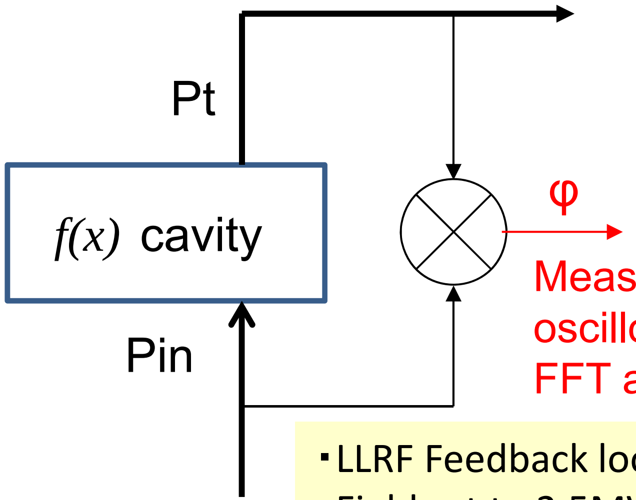


This monitor based on interference of ASE light between target and reference position. By measuring reference position movement we know the target position movement

- Laser monitor roughly agree with target measurement by telescope with ±0.1mm
- While keeping 2K , target movement was stable within 10um → cavity was stable within 10um
- Temperature of 5K frame is sensitive for 5K frame movements by laser position monitor.



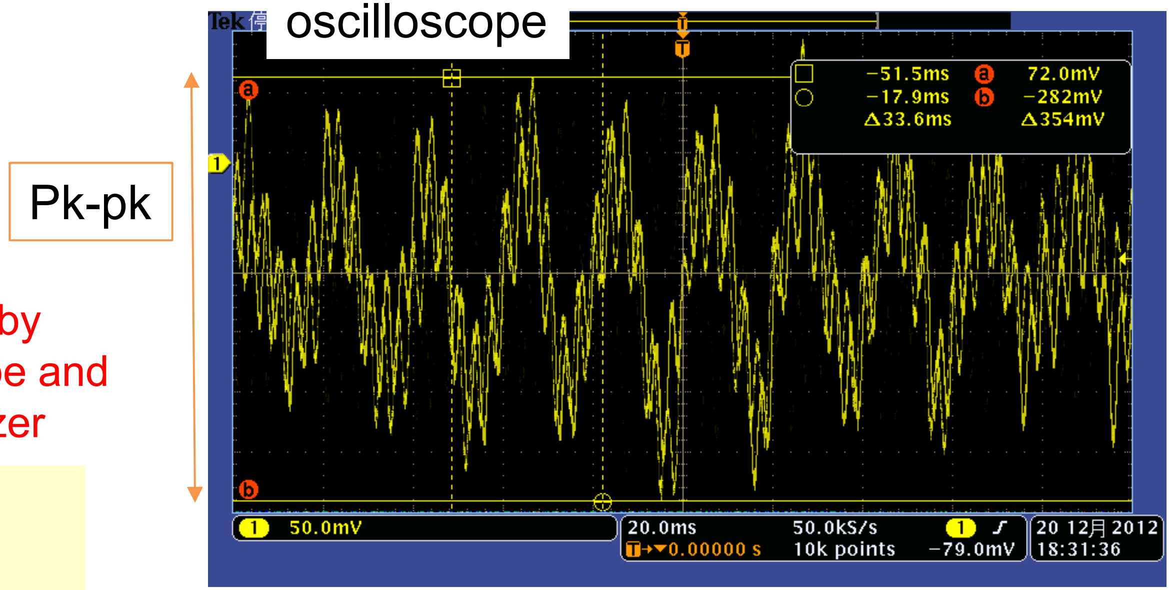
2K microphonics measurements



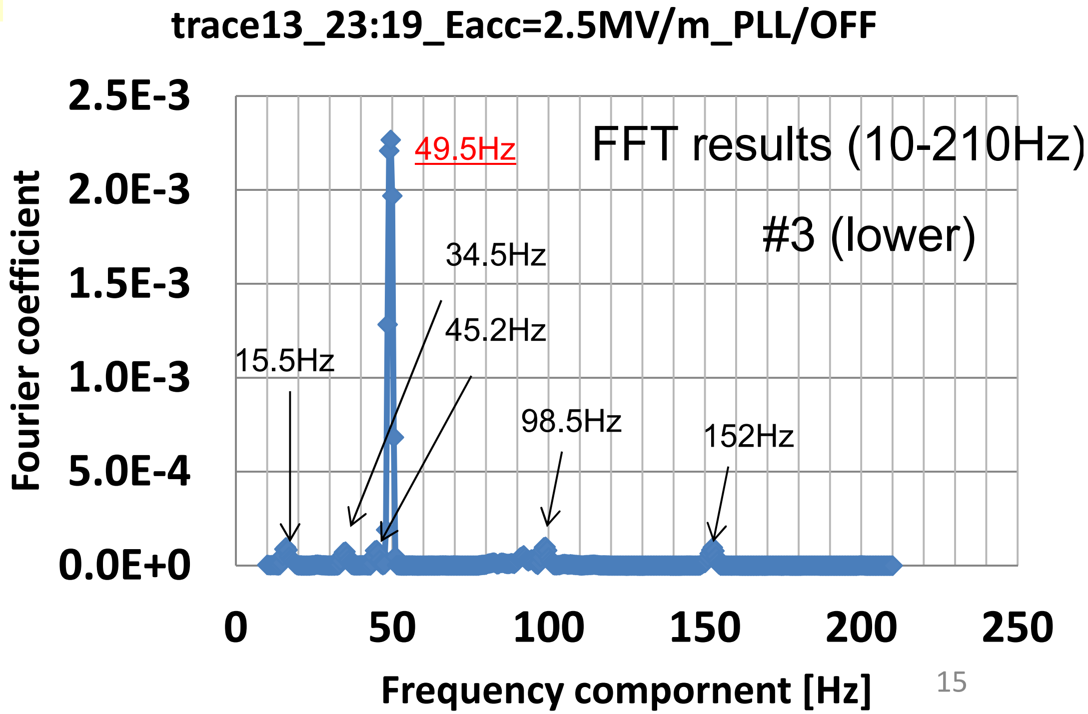
Measured by oscilloscope and FFT analyzer

- LLRF Feedback loop off
- Field set to 2.5MV/m
- Measured by #3 cavity

#3 (lower)



- Pk-pk = 7Hz by oscilloscope. It allow us to increase the QL higher than several *10^7 → lower power
- Main peak was observed at 49.5Hz (not 50Hz of electrical noise) by FFT analyzer ,which was not come from cavity resonance frequency.
- It might come from backbone and/or 5K flame resonance frequency??



We need to continue measuring michrophinics on next cERL operation

Summary

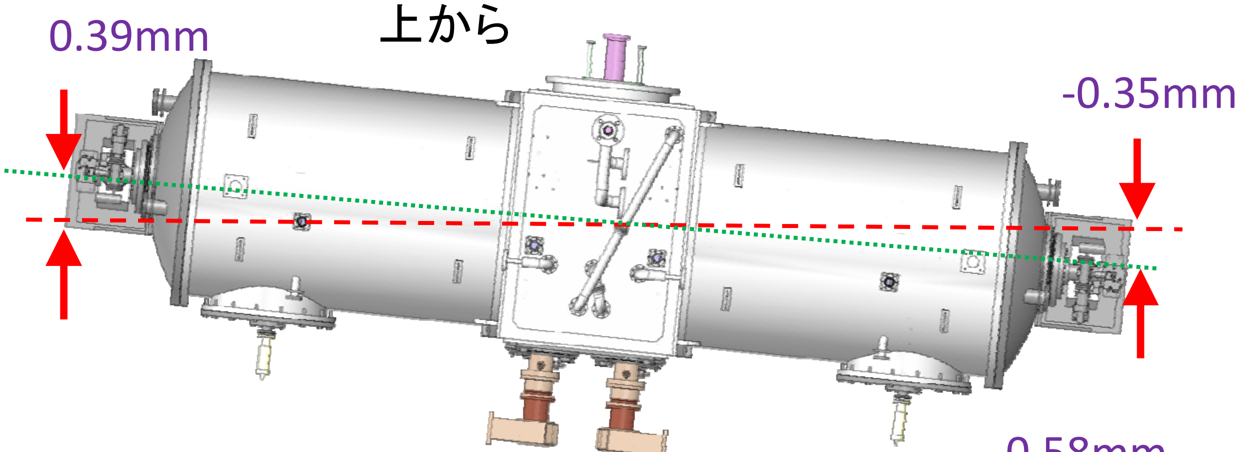
- After performing the 25MV/m and Q0>1*10^10 @15MV/m on V.T, we prepared the main linac cryomodule with two 9cell ERL cavities and installed it into cERL beam line on 2012/Oct.
- Main linac cryomodule was able to cooled down to 2K by controlling the cooling condition including 3K/h speed at HOM absorber.
- Tuner works well under 2K condition and can tune 1.3GHz of fo.
- Both cavities reached 16MV by feeding CW power. But we met the severe field emission by newly produced emitter which come from the cryomodule assembly work and during high power test.
- We can keep 13.5-14MV of accelerating voltage for more than 1 hour with enough cryogenic power.
- Heat leak come from SBP HOM absorber would be neglected to Nb cavity.
- Cavity movement was 0.4mm under 2K cooling. It is allowable for beam operation. After warming up, cavity center come back original position.
- Michrophinics was expected to 7Hz of Pk-Pk. We need to measure more.

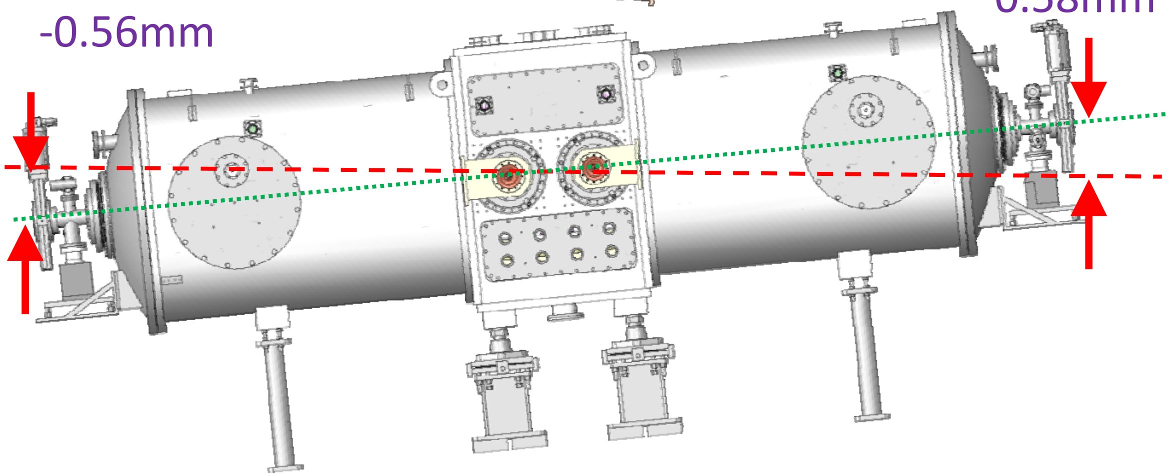
In 2013, beam operation of injector was started. After summer shutdown we will install round loop of cERL and start the beam operation with energy recovery on cERL.
Main linac stable operation of cERL is next issues for our module by Digital LLRF.
We also plan to install a cryomodule with 4 9cell-cavites to cERL for energy upgrade.

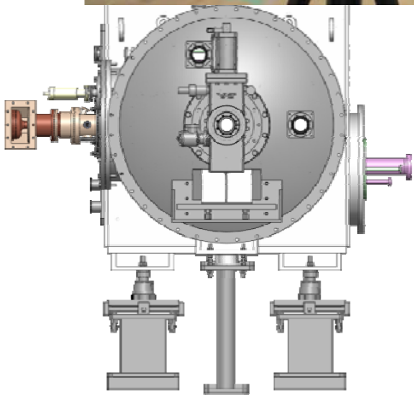
Backup

設置時のアライメント

- まずオートレベル、下げ振り、水準器で位置合わせ
- 中央タワー部を冷凍機接続場所へ設置する
- レーザートラッカーによる微調整





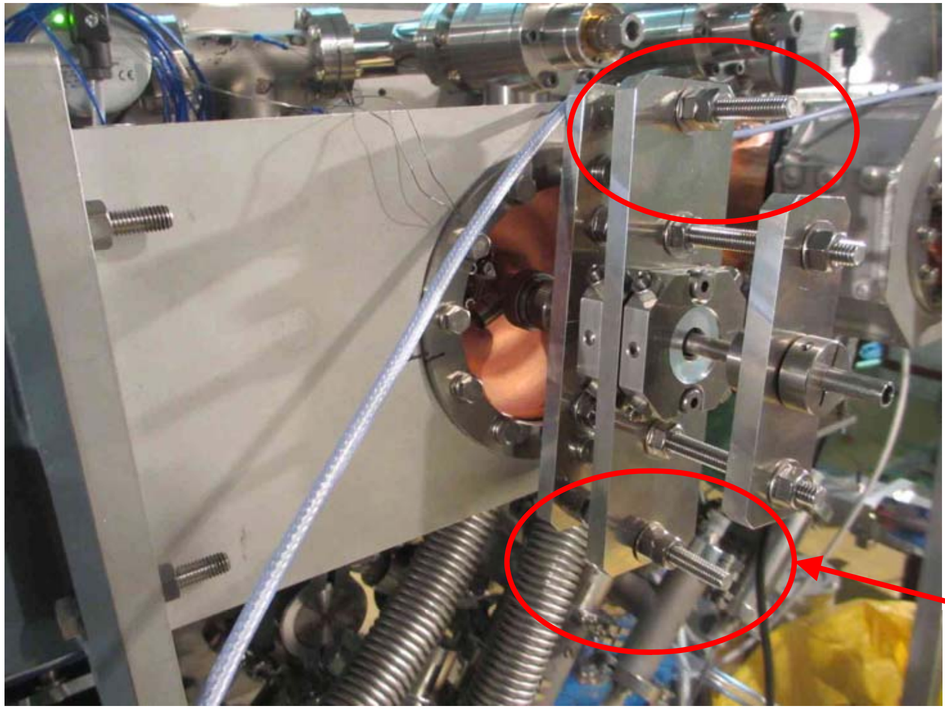


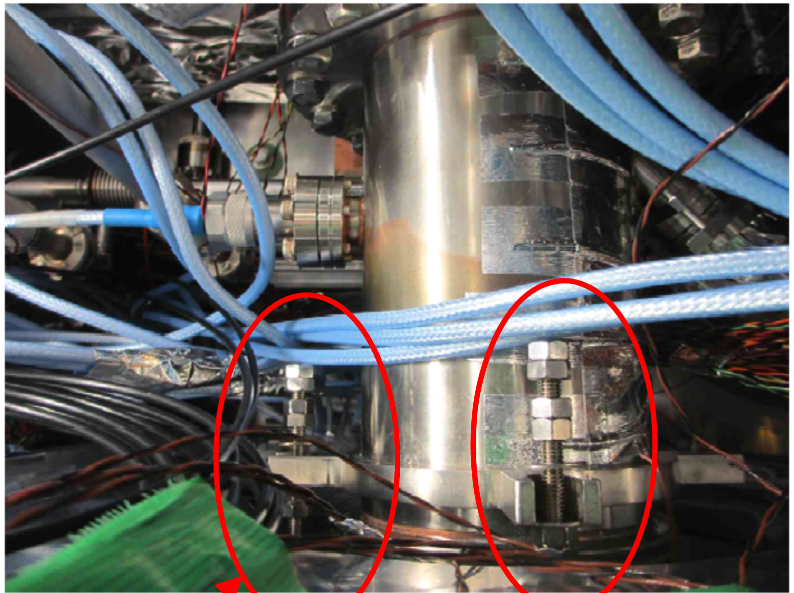
カップラー調整

- 挿入長(±5mm)の調整
- Q_{load}=1.5～5.3×10^7　上流
  8.7×10^6～3.3×10^7 下流

1～4×10^7　(2×10^{7}が中心)　設計値

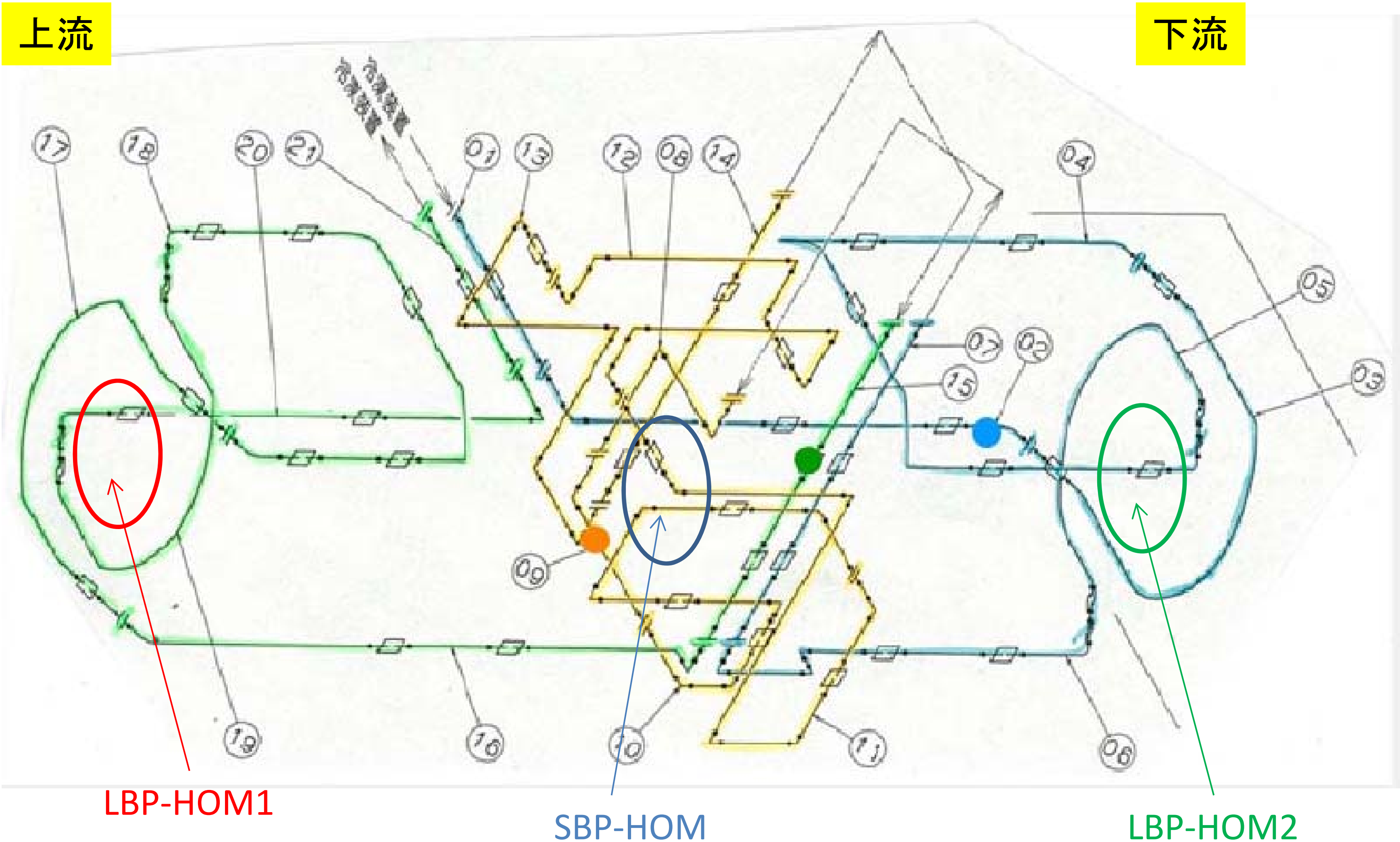
断熱槽内部



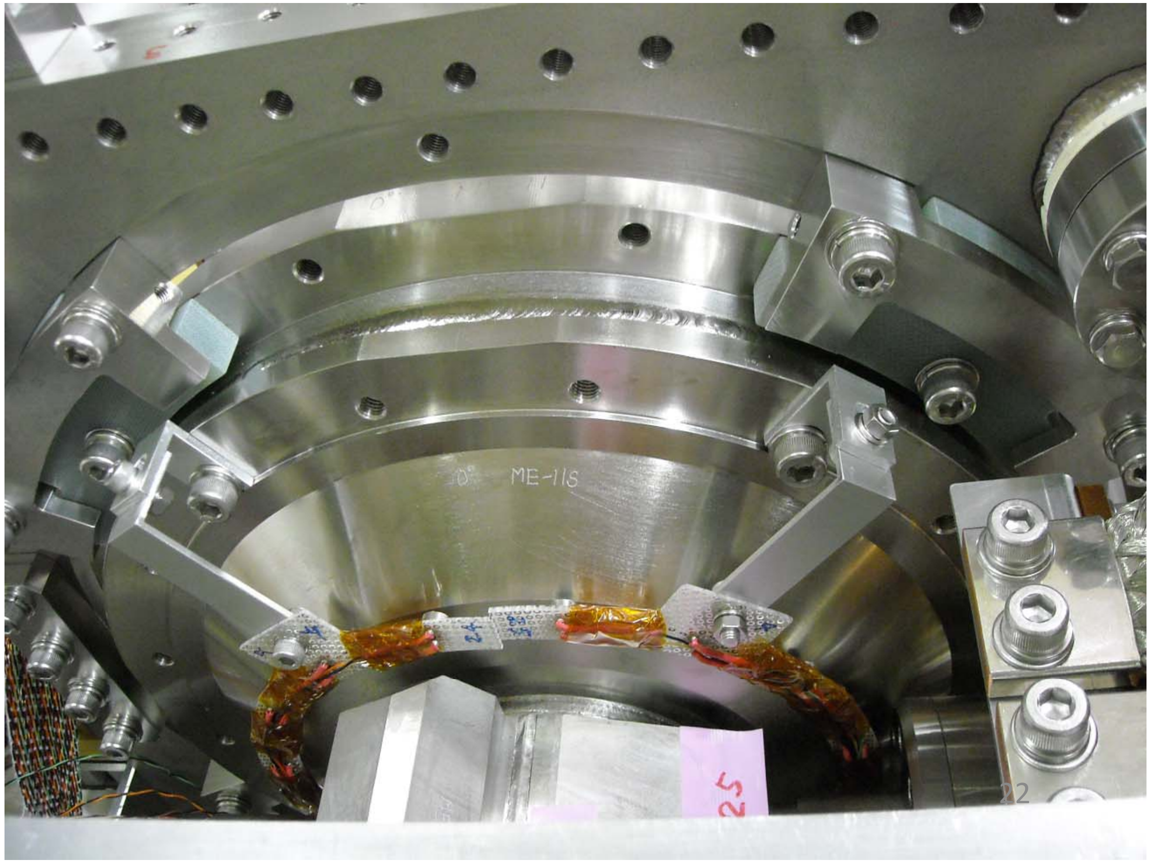


位置ストッパー

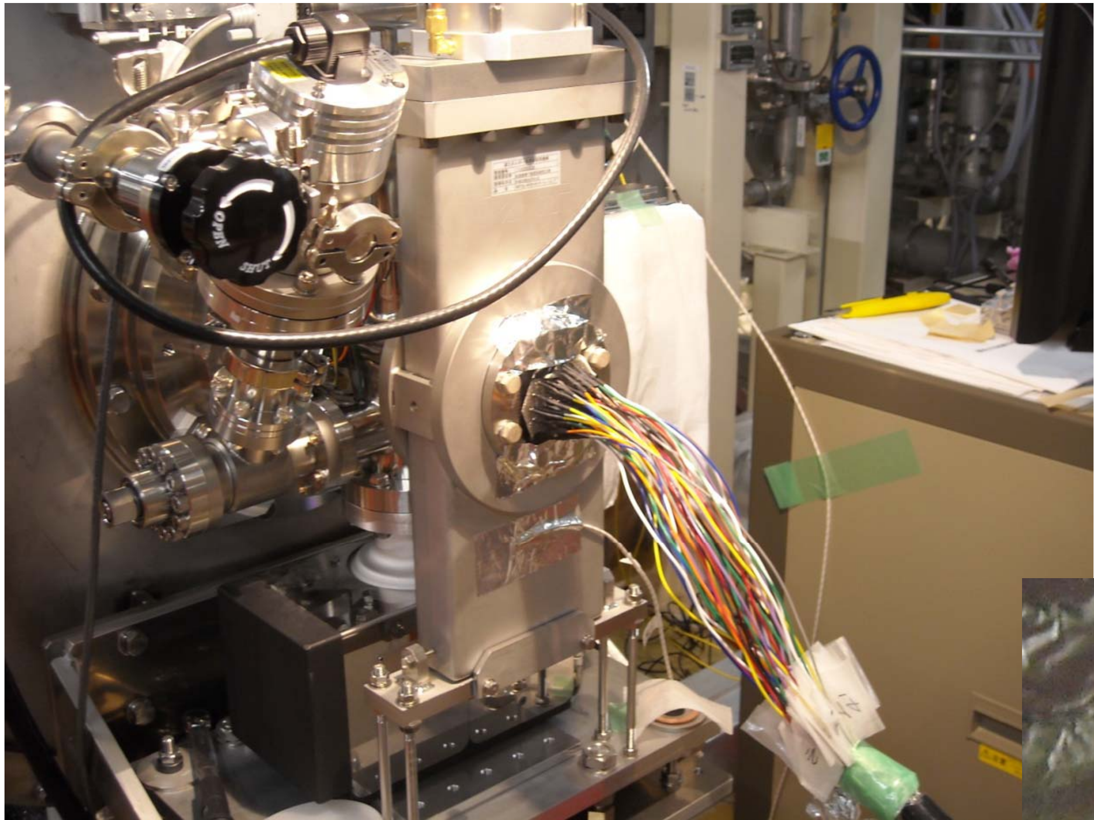
80K配管とりまわし

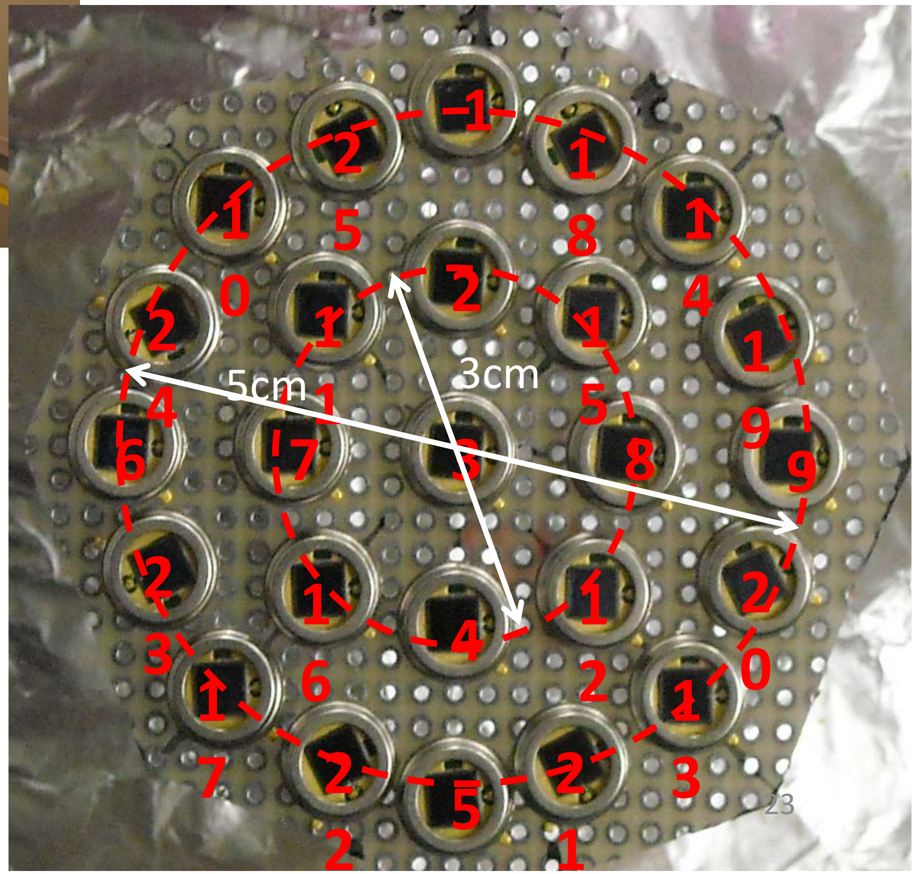


SBP PIN DIODES

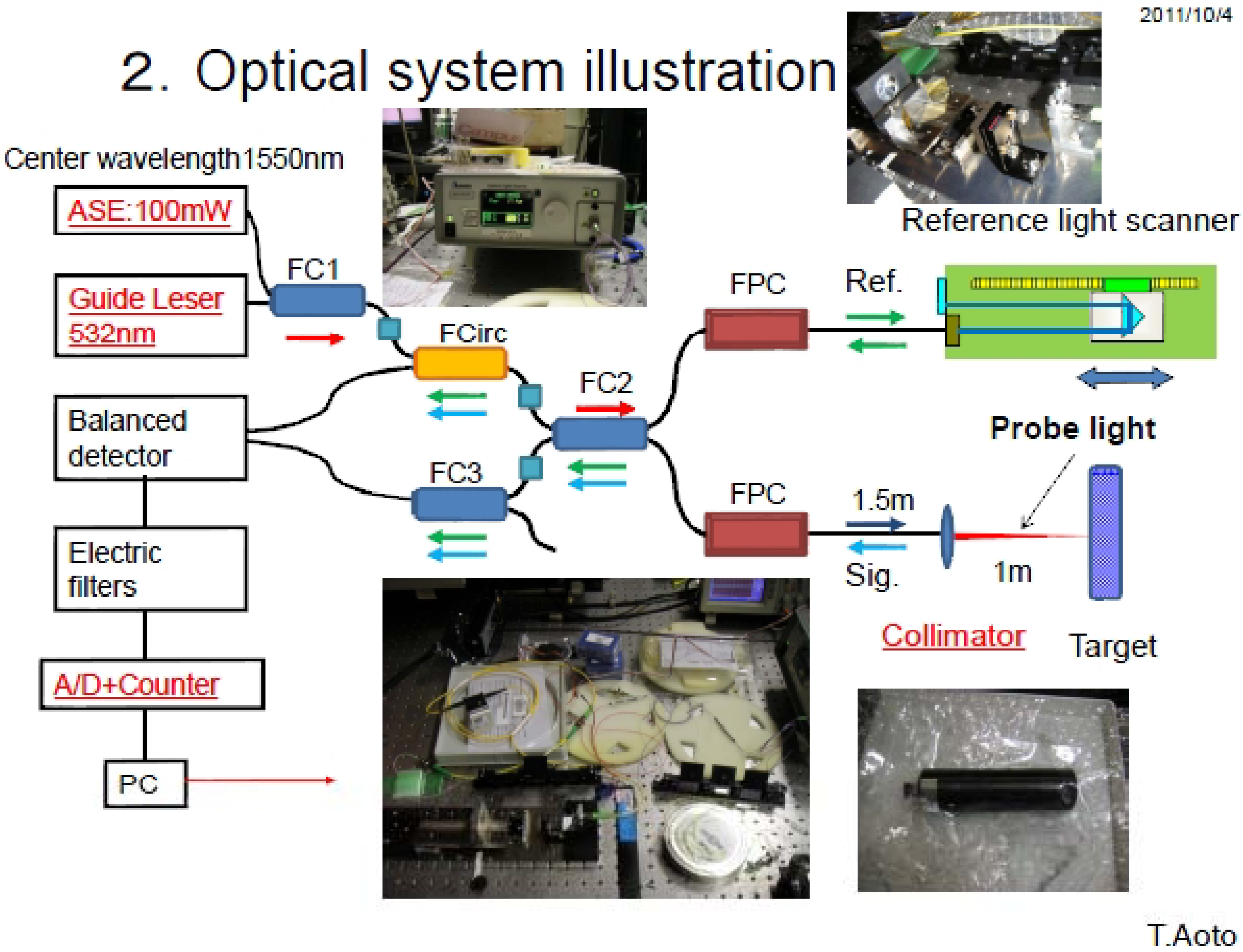


Profile monitor





Laserを用いた精密位置測定装置

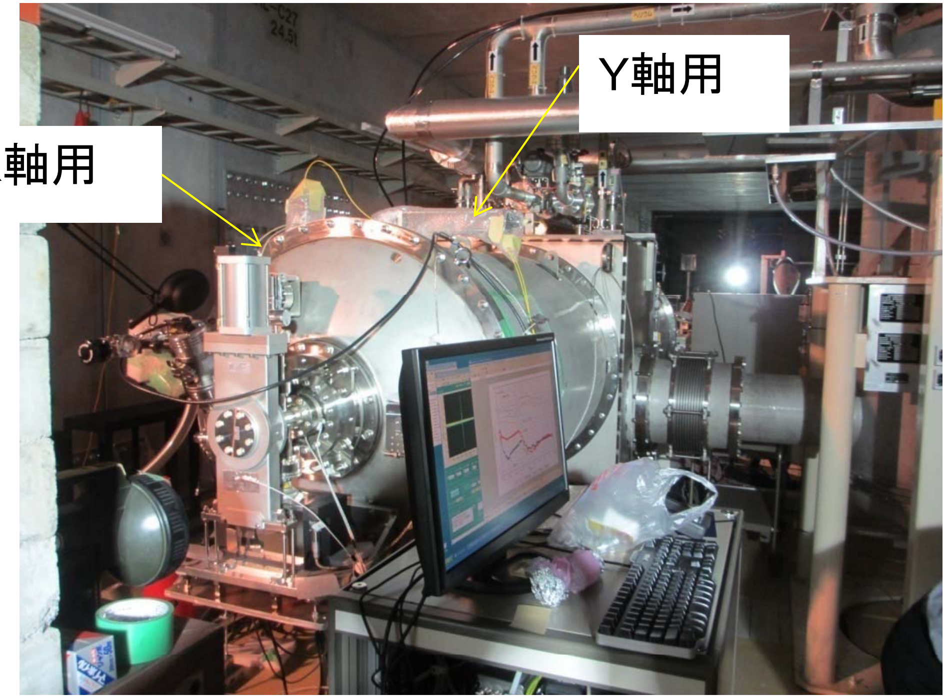


10umの精度が目標

Laser変位計 Setup(写真)

X軸用

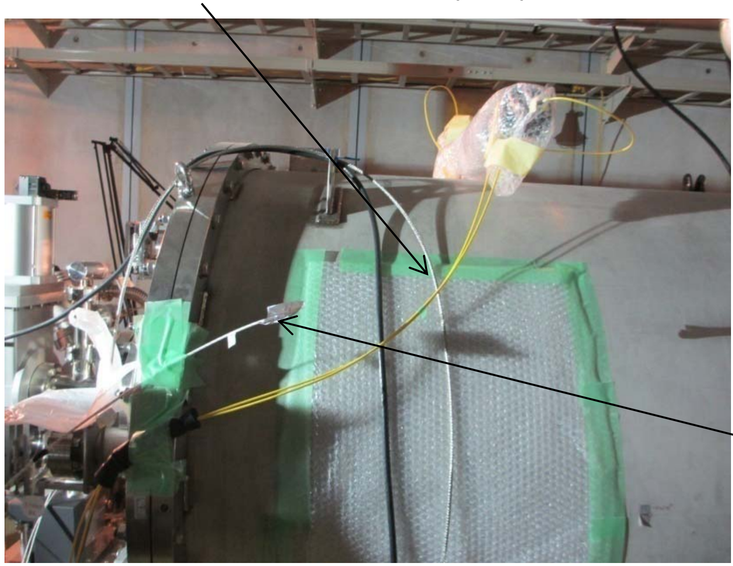
Y軸用



ASE光源

参照光用ファイバー（熱電対も入っている。）

モニター用ファイバー(3m)



断熱槽上部熱電対

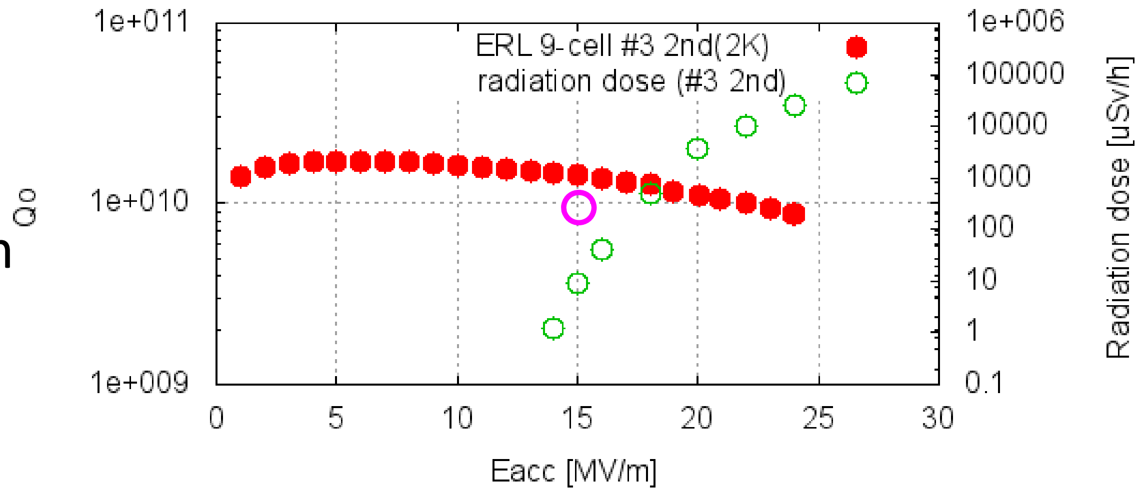
ファイバーは温度補償用ファイバーを使用

Results of vertical tests(2011年度)

昨年度はcERL用に2台の空洞を作成し、縦測定で性能評価を行った。
それぞれの空洞は2回の縦測定を行い、最終的に25MV/mの加速勾配の達成。
また、cERLの要求である15MV/mでQ0>1*10^10を達成した。

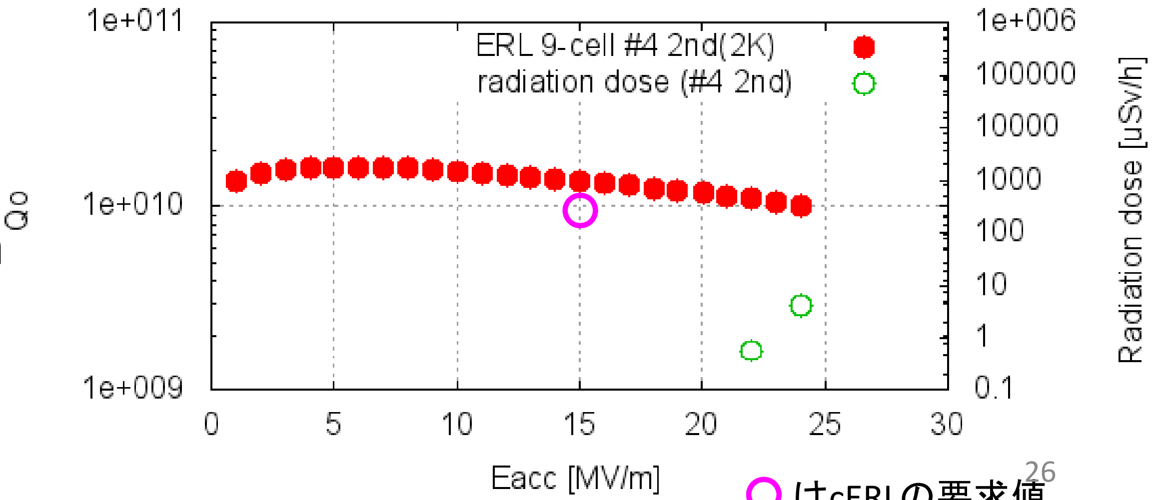
ERL 9-cell #3 cavity

- Field reached to 25 MV/m
- No limitation up to 25 MV/m
- Q > 1e10@15MV/m
- Satisfied cERL specification
- X-ray onset around 14 MV/m



ERL 9-cell #4 cavity

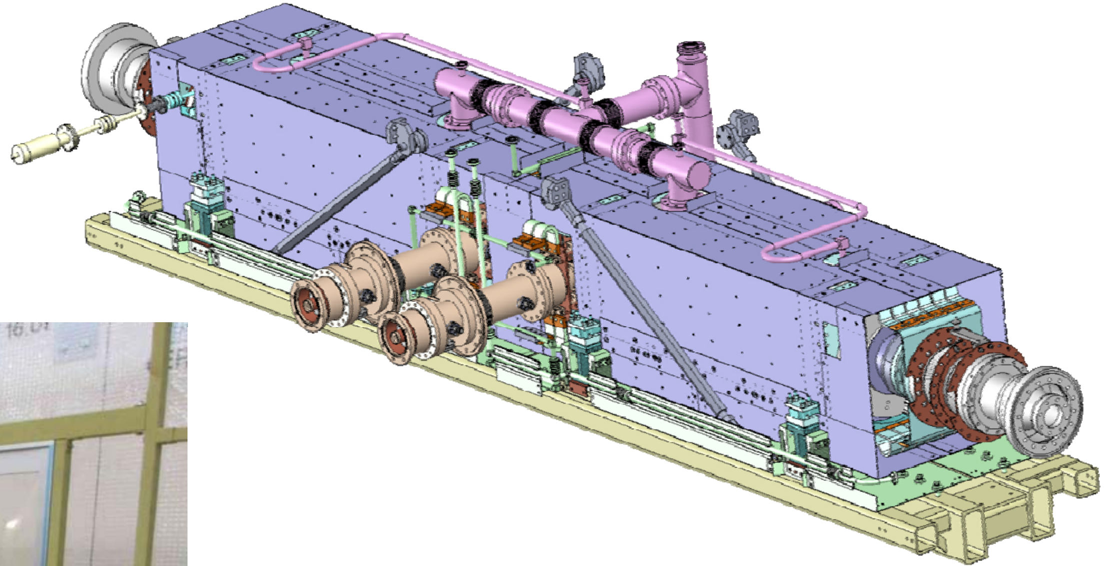
- Field reached to 25 MV/m
- No limitation up to 25 MV/m
- Q > 1e10@15MV/m
- Satisfied cERL specification
- X-ray onset around 22 MV/m

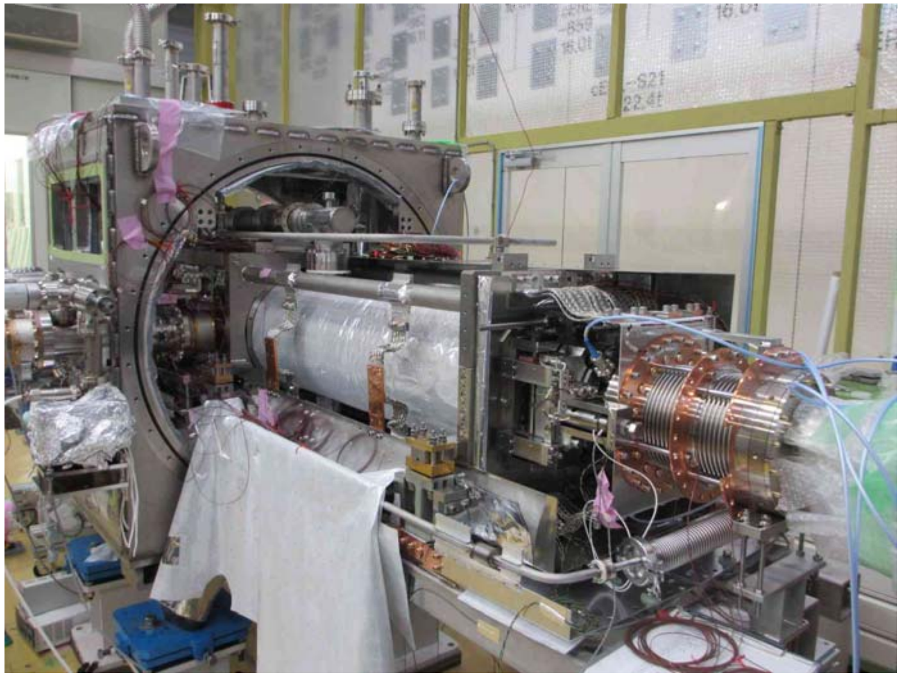


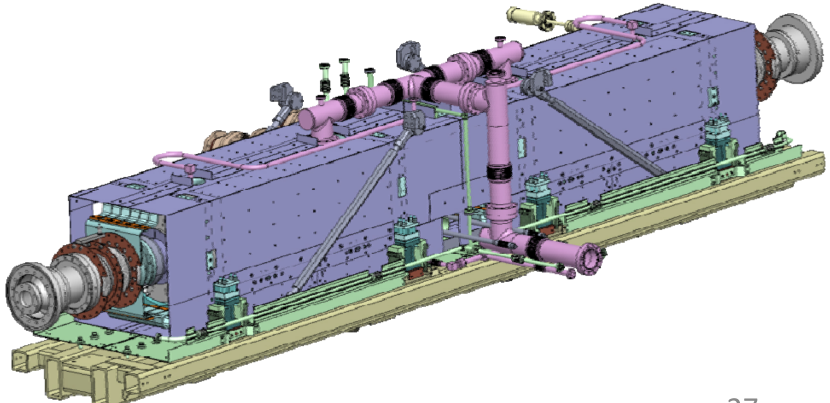
○ はcERLの要求値

磁気シールド

- 残留磁場　10mGauss以下
  （一部30mG　カップラー付近　地磁気方向に広い開口部）



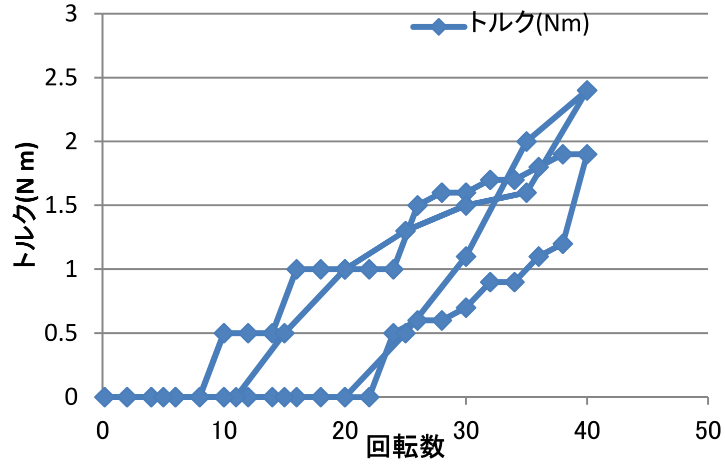




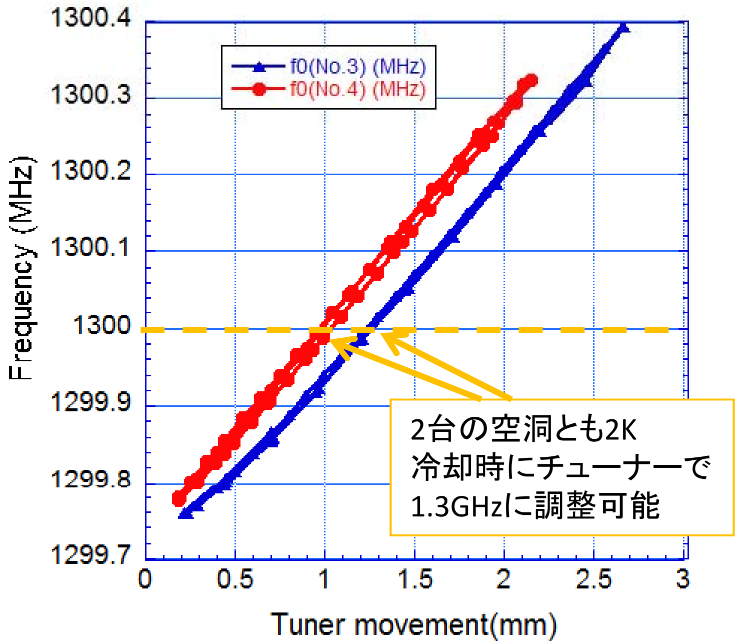
2Kでのチューナーテスト
(チューナーperformance)

チューナーを2K冷却下で動かす。20回転/1mm
上流(#4):1299.781MHz -- 1300.325MHz (0-40回転)
下流(#3):1299.795MHz – 1300.393MHz (0-50回転)
1.3GHzに両方とも調整可能であることがわかった。
上流、下流ともトルクは3Nm以内で収まっていた。
ロードは900kg以下で抑えた所で回転を止めた。

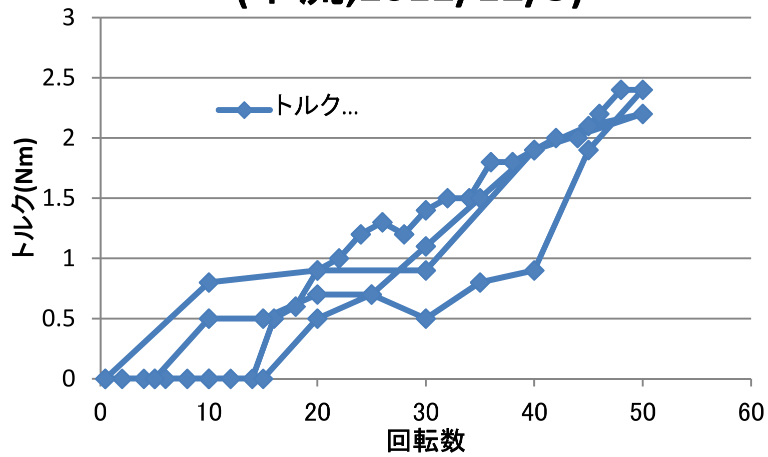
トルク(Nm) vs 回転数
(上流,2012/12/5)



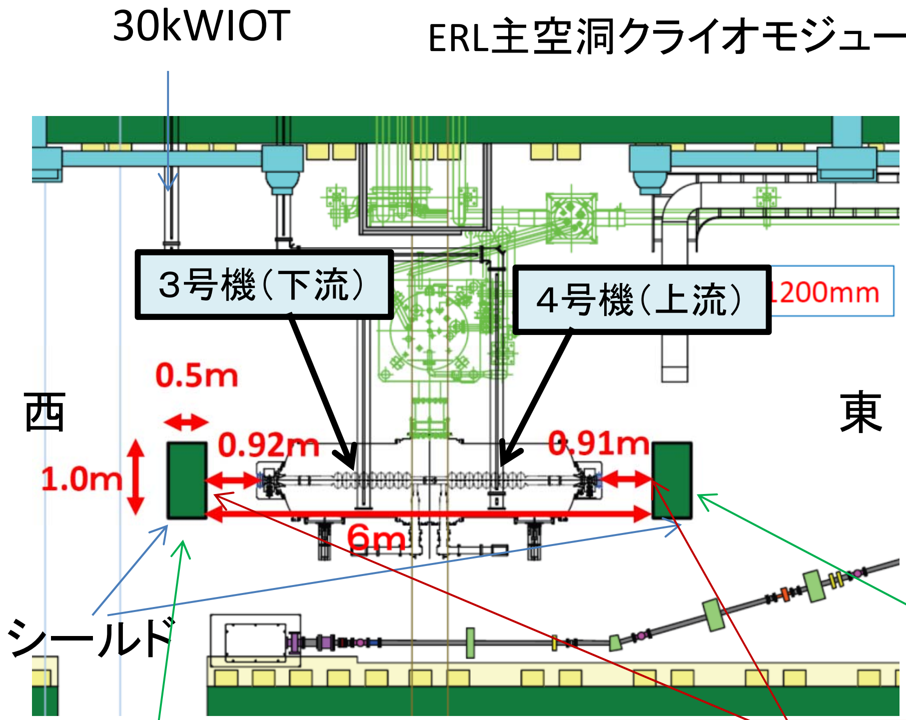
2K冷却時のtunerでの周波数変化



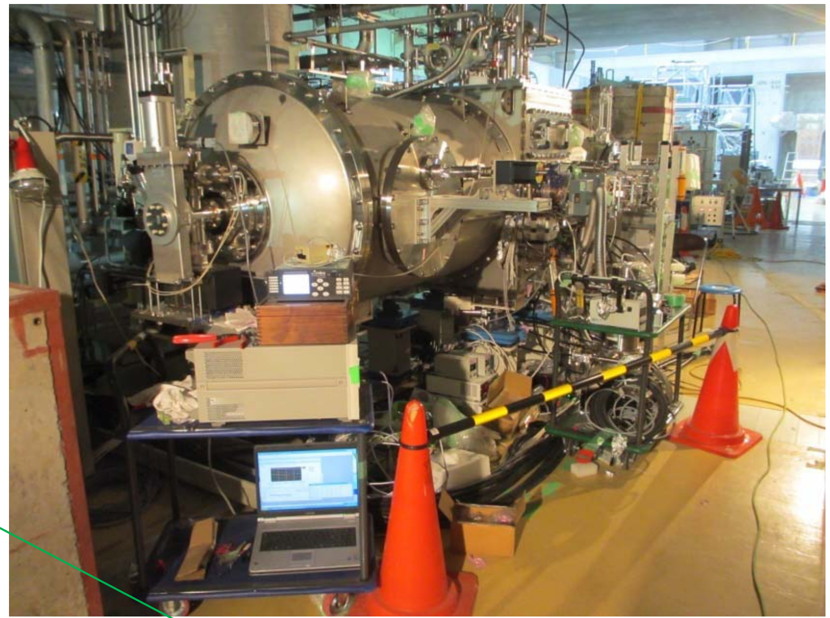
トルク vs 回転数
(下流,2012/12/5)



ERL主空洞クライオモジュールパワーテスト(setup)

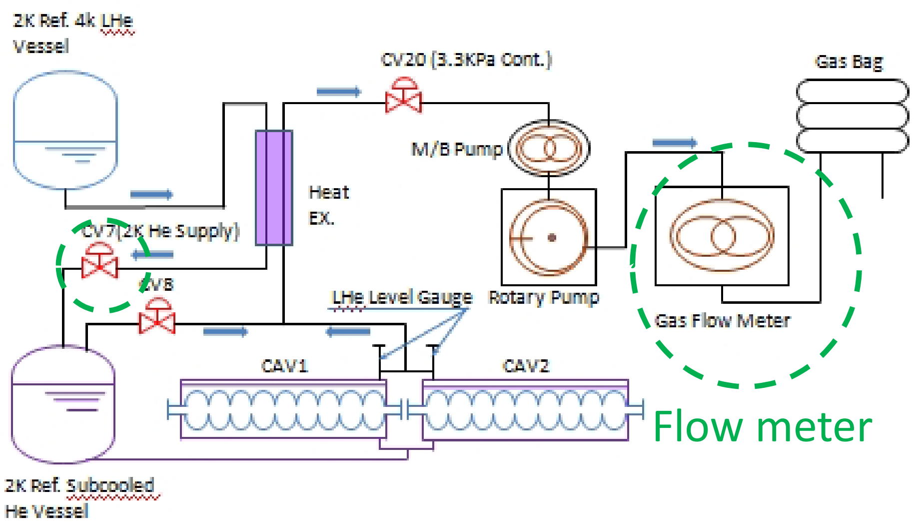


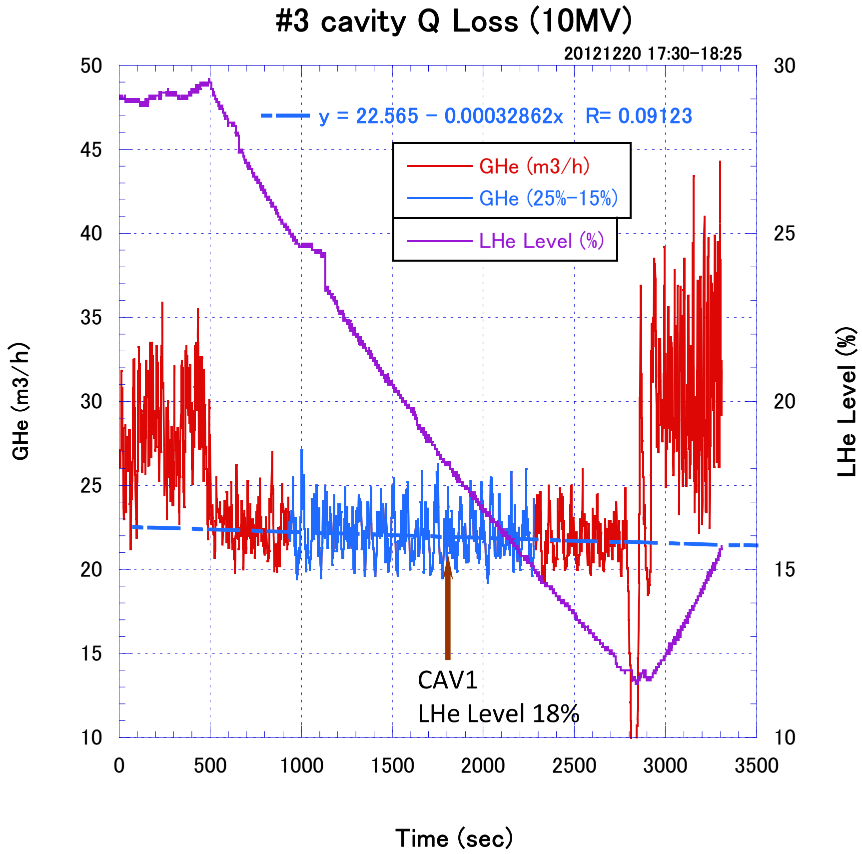
モジュール全体像



エリアモニターをシールドの内側に設置。

冷凍負荷測定(Return He Gas 測定方法)





バルブ、液面操作

- RF入力してCAV1 LHe液面計で28%以上を一定時間維持する。
- CV7のバルブを閉じ2K LHeの供給を停止する。
- Gas flow meterでReturn He Gasを計測。
- CAV1 LHe Levelが14%以下になったらRF入力を停止し次の測定に備えてCV7バルブで2K LHeを供給する。

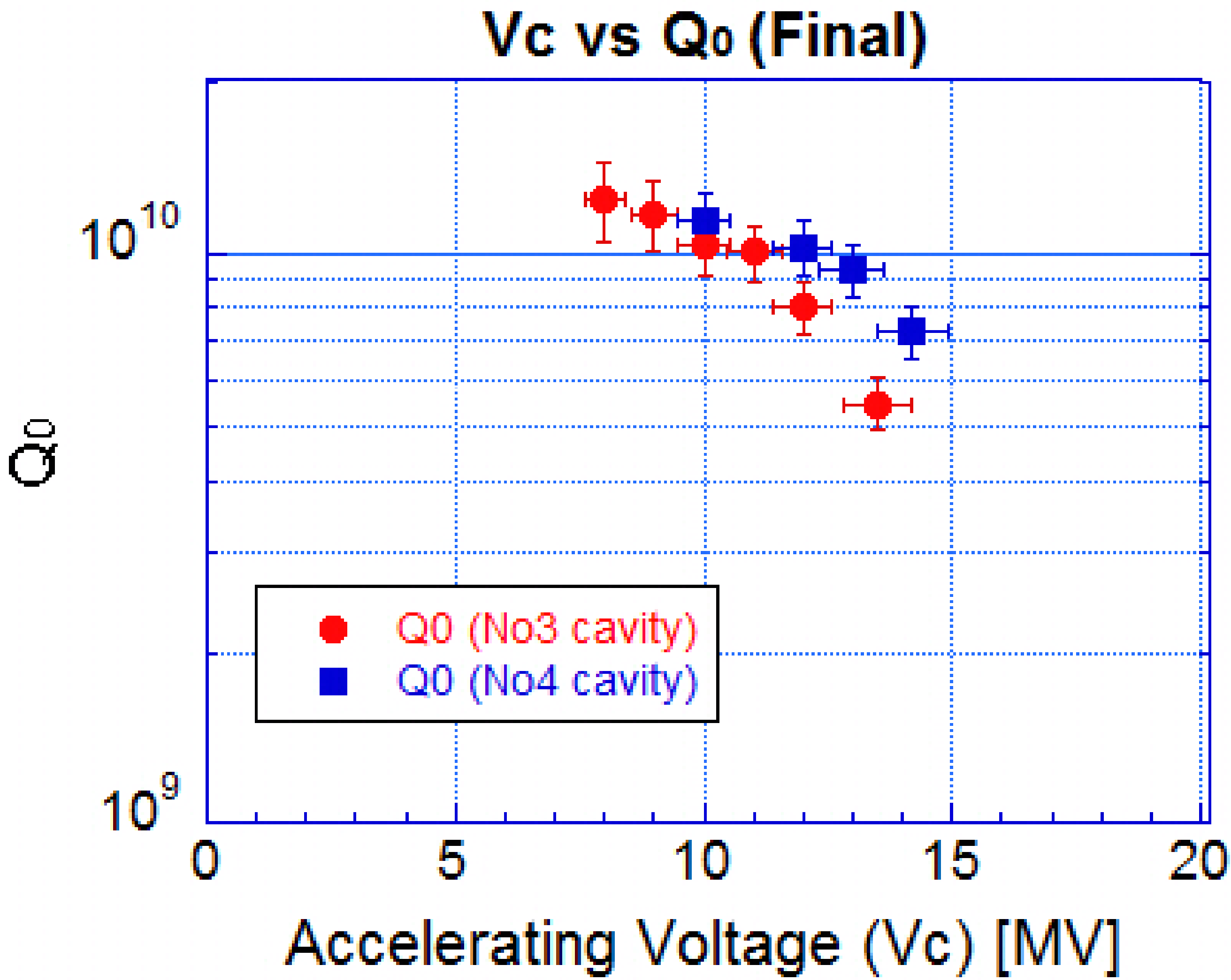
He Gas量の求め方

- 決まった液面高さ間(25%-15%)での傾きを求める。
- 定めた(18%)液面高さのReturn He Gas流量を求める。
- その18%時のStatic loss(detuneのdynamic lossとほぼ同じ)を除したものをHe Gas量とする。

Heat loss (W) = 1.076*He流量(m^3/h)

By K.Hara

Final Vc vs Q0



FinalのVc vs Q0の状況。上流のNo4の方が性能が良い。