TTC CW SRF workshop Highlight

2013/7/17

ERL検討会

Hiroshi Sakai

6/12(Wed)～6/14(Fri)の3日間Cornell大学で行われた。
このworkshopはTTC meetingの番外編で
主にCWのSRF cavityやcryomoduleにtopicを
絞った会議であり、CEBAFやERLやその他のCWやhigh
dutyマシンについて色々発表があり、議論を行った。

詳しくは http://www.lepp.cornell.edu/Events/TTCWorkshop/
発表資料も載っております。

Scope of the CW SRF workshop

George Hoffstaetter (Cornell Univ.)

- Cornell mainly works for the SRF for ERL

  → it works CW condition and need high Q and high Eacc.
- Topics of this workshop

  (1) Cavity design (KEK, Jlab, Cornell, Berkeley, Fermilab)

  (2) SRF Gun (HZDR, HZB) & low beta (Fermi, IHEP, IMP) & transversal cavities (APS).

  (3) CW cavity operation (Cornell, JLAB, HZB, Fermi)

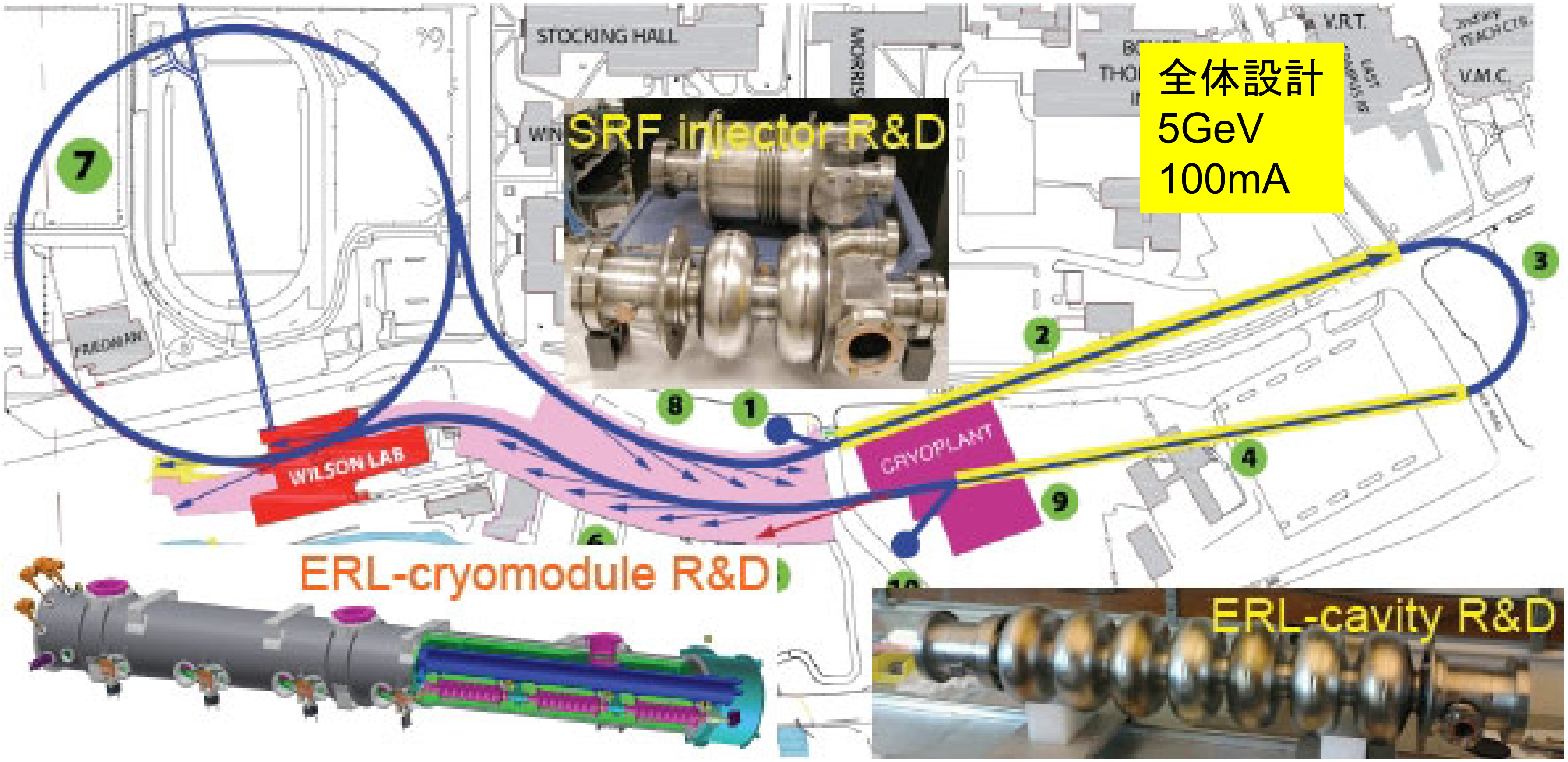
  (4) High Q performance and treatment procedure (Fermi, Jlab, Cornell, HZB)

  (5) CW couplers (Cornell , KEK, Fermi)

  (6) HOM absorbers (Cornell, KEK, Jlab, DESY, APS)

  (7) CW cryomodule (Daresbury, Berkeley, Cornell, Fermi, Jlab, KEK)
- ERL activities at Cornell Univ.
  - ERL apply for light sources, high energy physics, Nuclear physics
  - Low loss SRF cavities for CW linacs bulk BCP 650C final BCP bake 120C → Q0=1*10^11 @ 1.6K
  - 75mA with NaKSb / 52mA of GaAs and 80pC/bunch : 0.3mm.mrad (core)

Cornell ERL project



ERL injector test beam lineが現在稼働中。100mAのDC Gunと5MeVまでの超伝導空洞入射器によるビーム評価を行っている。
また ERL main linac用のcavityを1つ入れたcryomoduleを作成しhigh power testを行った。

(Cornell) ERL milestone

Cornell Laboratory for Accelerator-based Sciences and Education (CLASSE)

ERL-readiness milestones

Many milestones, some world records, have been achieved:

Peak bunched-beam current: → (CW operation session) Bruce Dunham on Wednesday

75mA with NaKSb / 52mA with GaAs, **65mA stable for 8h, 1/e = 2.6 days.**
(2013.6.12現在)

Smallest normalized thermal emittance: 0.25 mm mrad/mm radius

Smallest normalized emittance after injector at 80pC: 0.5 / 0.3 mm mrad
with normalized bunch core emittance **: 0.3 mm mrad**

This bunch in a 5GeV ERL would produce X-rays brighter than any ring today.
(a 25pmX25pm ERL/USR or a 0.3nmX3pm storage ring, 20 * Petra III)

SRF-cavity: Q of 3.E10 at 16MV/m → (High Q session) Nick valles on Thursday

Construction of a prototype ERL cryomodule and an improved DC electron source are ongoing.

> The injector prototype has already achieved beam sufficient for an ultra-bright x-ray ERL. And further improvements are yet possible.
> Now is the time to prepare for construction of an X-ray ERL !

(1) Cavity design

- KEK main linac cavity (Kensei Umemori)
- JLAB upgrade cavity (Gigi Ciovati)
- Cornell main linac cavity RF design (Nick Valles)
- NGLS and Project-X HOM calculations for coupler needs (Alexander Sukhanov)

  → calc HOM effect with project X(162.5MHz) & NGLS(1MHz)
- Cornell main linac cavity mechanical optimization (Sam Posen: Cornell)

  →calc cavity structure and pressure dependence

まずは各空洞の設計思想についてCW対応として設計や縦測定、cryomoduleテストが進んでいるKEK,Jlab,Cornellについて主に紹介する。

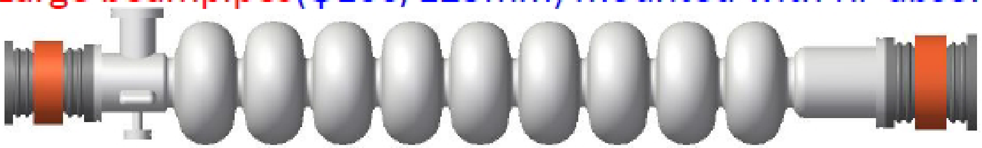
KEK main linac cavity (K.Umemori)

KEK-ERL design
3GeV & 100mA
Qo=1*10^10@15MV/m

HOM Strategy and cavity design

- Dipole mode: Lower impedance of (R/Q)Qext/f
- Monopole mode: Avoid frequency around 2.6GHz, 5.2GHz ...
- Quadrupole mode: Eccentric fluted beampipe
- Packing factor: Select 9cell structure

1) Iris diameter 80mm, elliptical shape at equator
2) Large beampipes(ϕ100/123mm) mounted with RF absorber

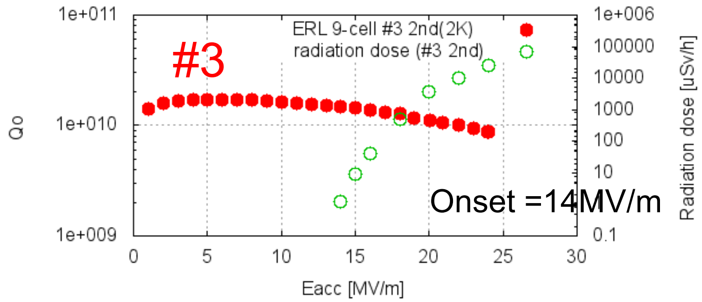


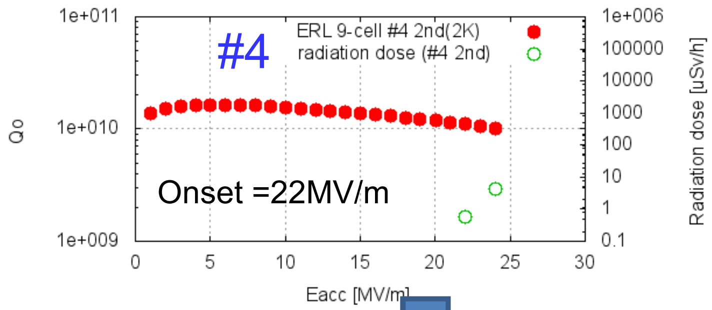
Main parameters for the acceleration mode

Frequency	1300 MHz	Coupling	3.8 %
Rsh/Q	897 Ω	Qo x Rs	289 Ω
Ep/Eacc	3.0	Hp/Eacc	42.5 Oe/(MV/m)

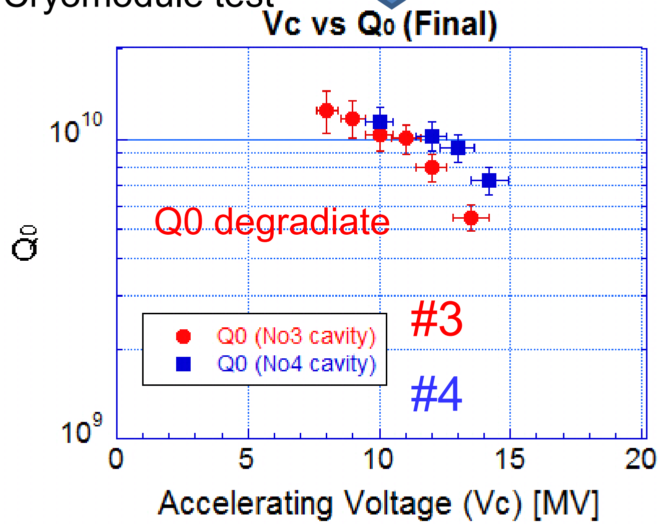
- focus HOM damping
  → 600mAのHOM-BBU thresholdまで確保。
  → monopoleも±40MHzで避けた計算(<6GHz)
- Epk/Eaccがdesign上TESLAの1.5倍
  V.Tでは問題なかったが cryomodule testでfield emissionが増大 。運転のfield emissionが今後の課題
  → CW運転ではfield emissionが最大の問題点(提言)

Vertical test



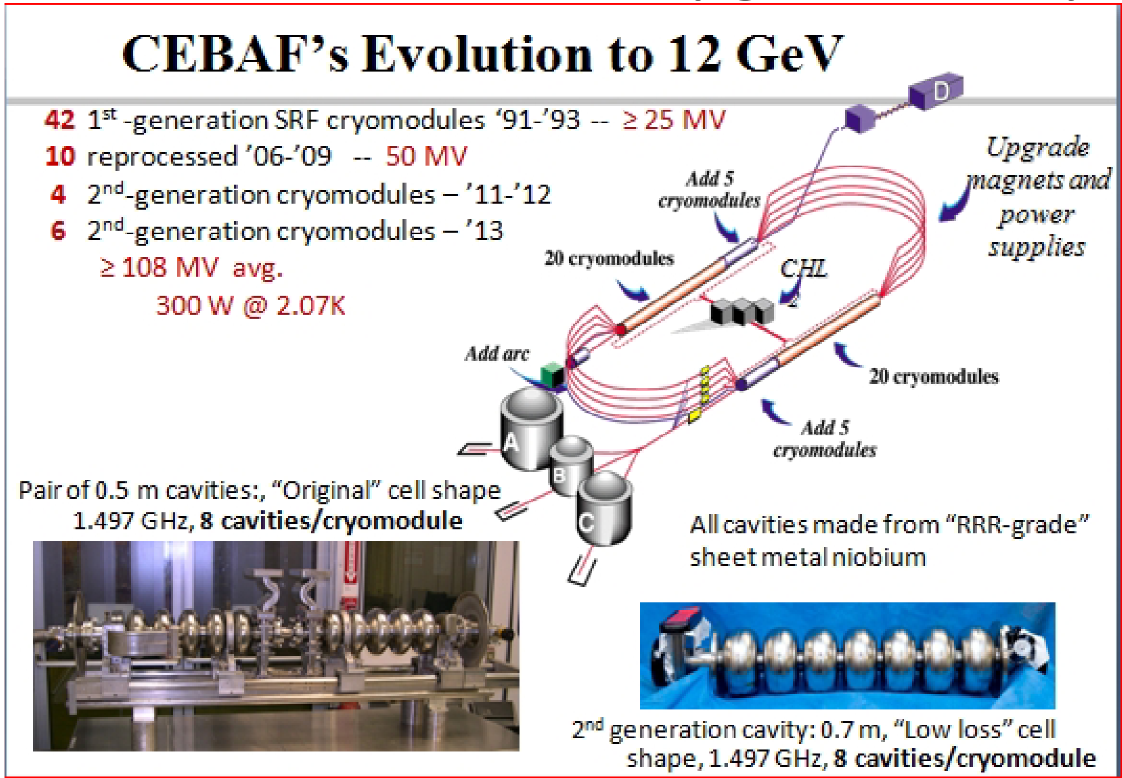


Cryomodule test



Field emission onset starts 8-9MV/m

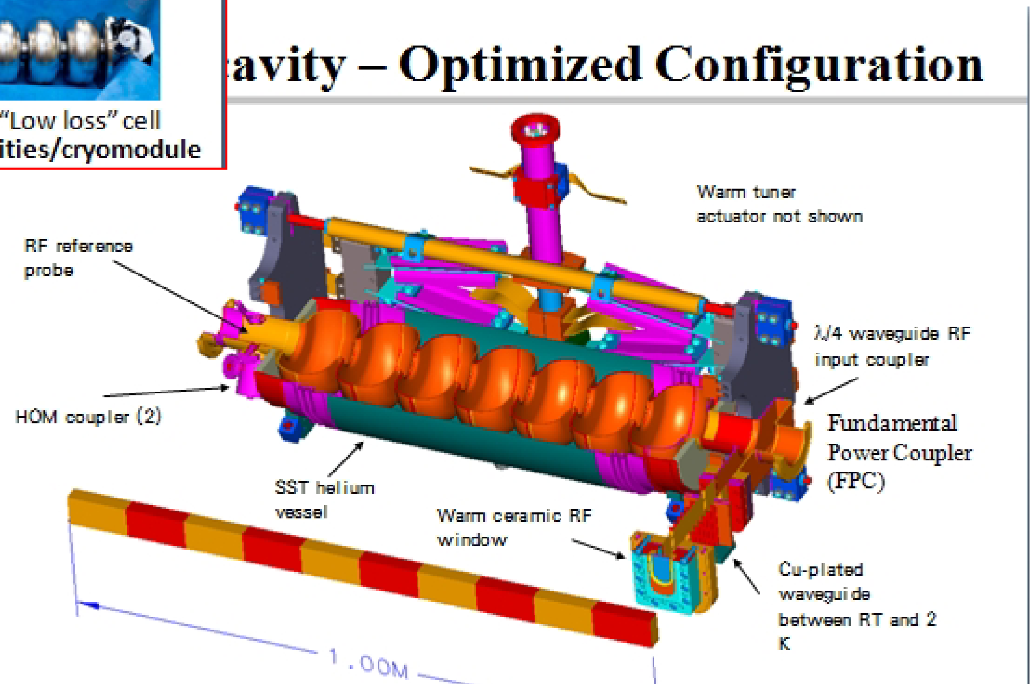
CEBAF upgrade cavity (Gigi Ciovati)



- The LL-shape was chosen because of ~20% lower P_{wall} than HG-shape

E_{acc}=19.2 MV/m with **$Q_0 \geq 8 \times 10^9$** at **2.07 K** in **CW operation**

- No stiffening rings, to increase tunability
- New helium vessel design, to replace titanium with stainless steel for cost and joint reliability
- Optimized waveguide input coupler geometry for $Q_{ext} = 3.2 \times 10^7$
- Nb HOM coupler probes confidently cooled
- Optimized position and orientation of HOM couplers (now only on "field probe" side) for HOM damping
- Pressure sensitivity: ~220 Hz/Torr

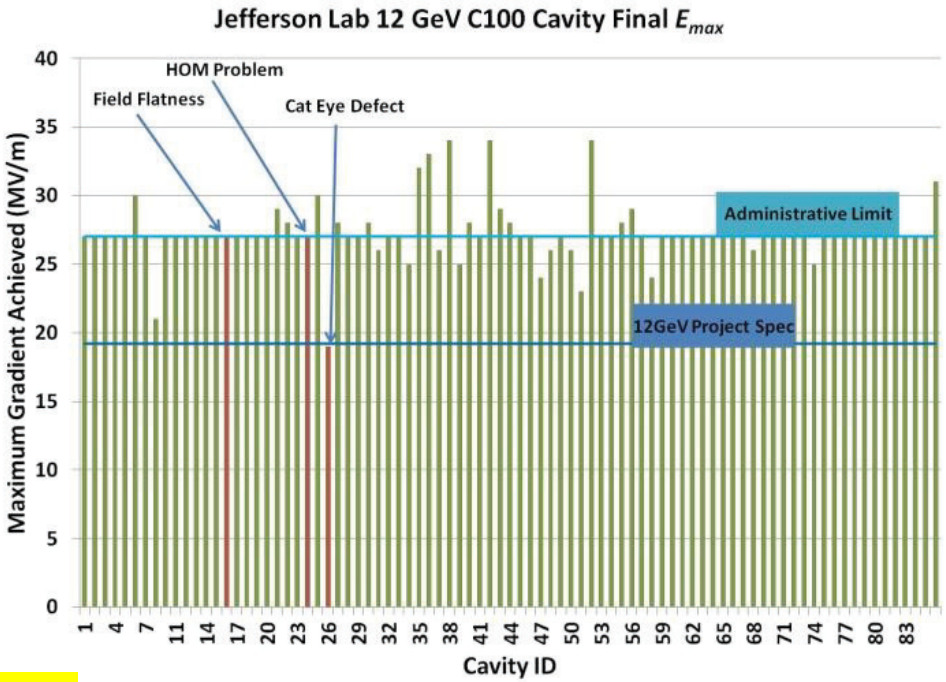


C100 cavity

CEBAF C100 Cavity treatments – Production process

- **160 µm BCP** and pre-tuned **by vendor**
- Receipt inspection – mechanical and rf
- US >> Bake: 600 C, 10 hrs
- US >> EP: **30 µm, @20°C** regulated by external water spray
- US >> Tune
- Helium vessel welding
- Flange lapping
- HPR
- Partial assembly
- HPR >> dry in Class 10 cleanroom
- Final assembly, leak check
- Bake: **120° C, 24 hrs**
- Vertical test @ 2.07 K
- HPR >> dry in Class 10
- String assembly

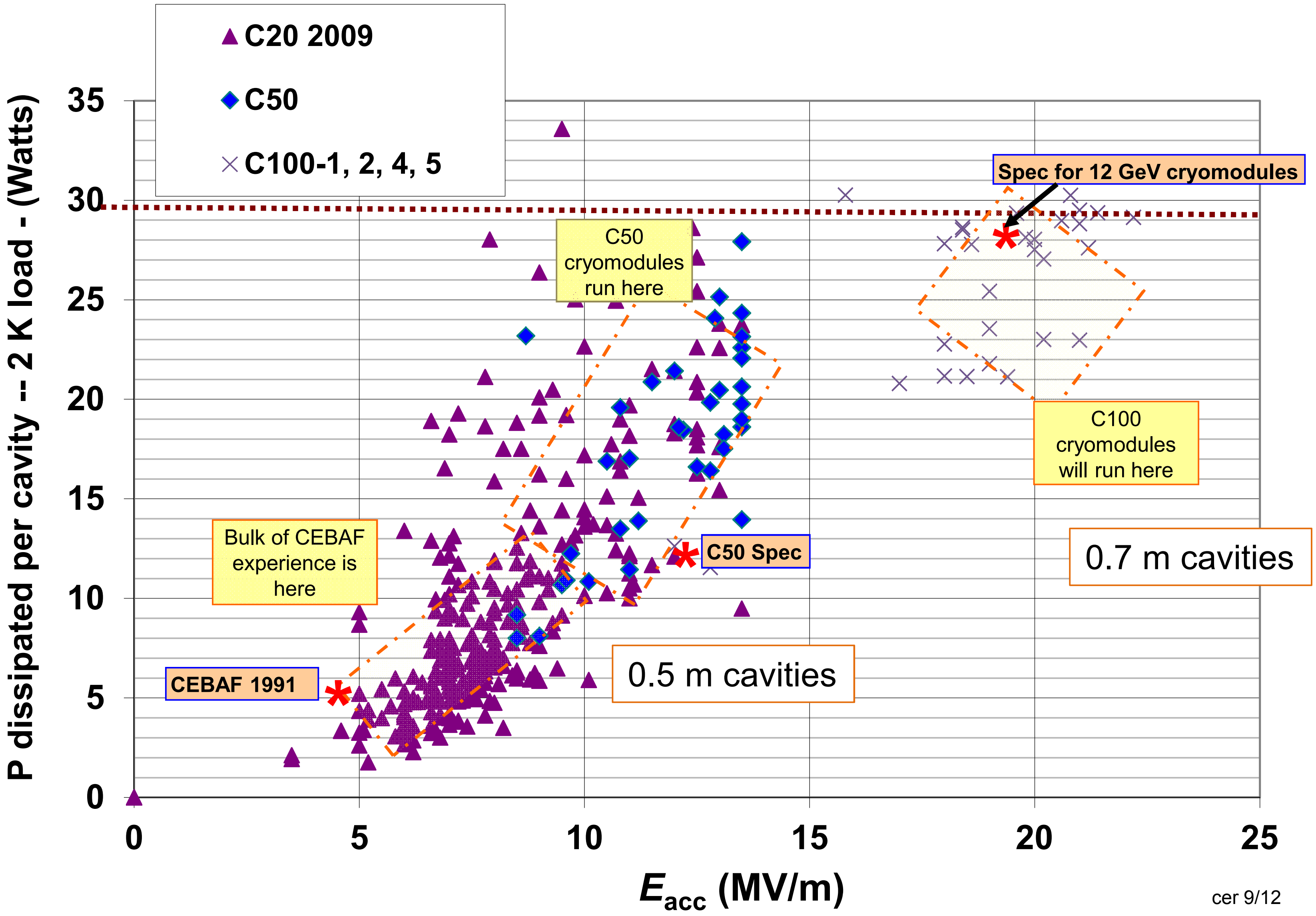
縦測定後にHPRを
行っている。



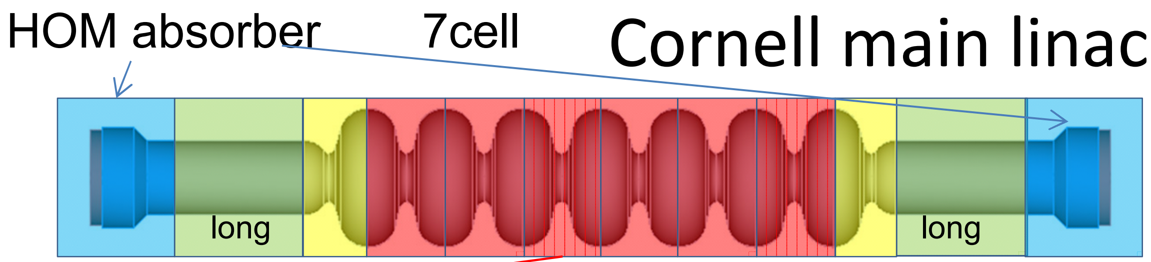
- Add additional surface treatment
  - 30 µm EP: increase gradient
  - HPR (High Pressure Rinse)
  - 120°C bake: increase Q_0

A. Reilly et al., SRF'11, TUPO061.

2 K Dynamic Heat Load vs. Cavity Gradients in CEBAF

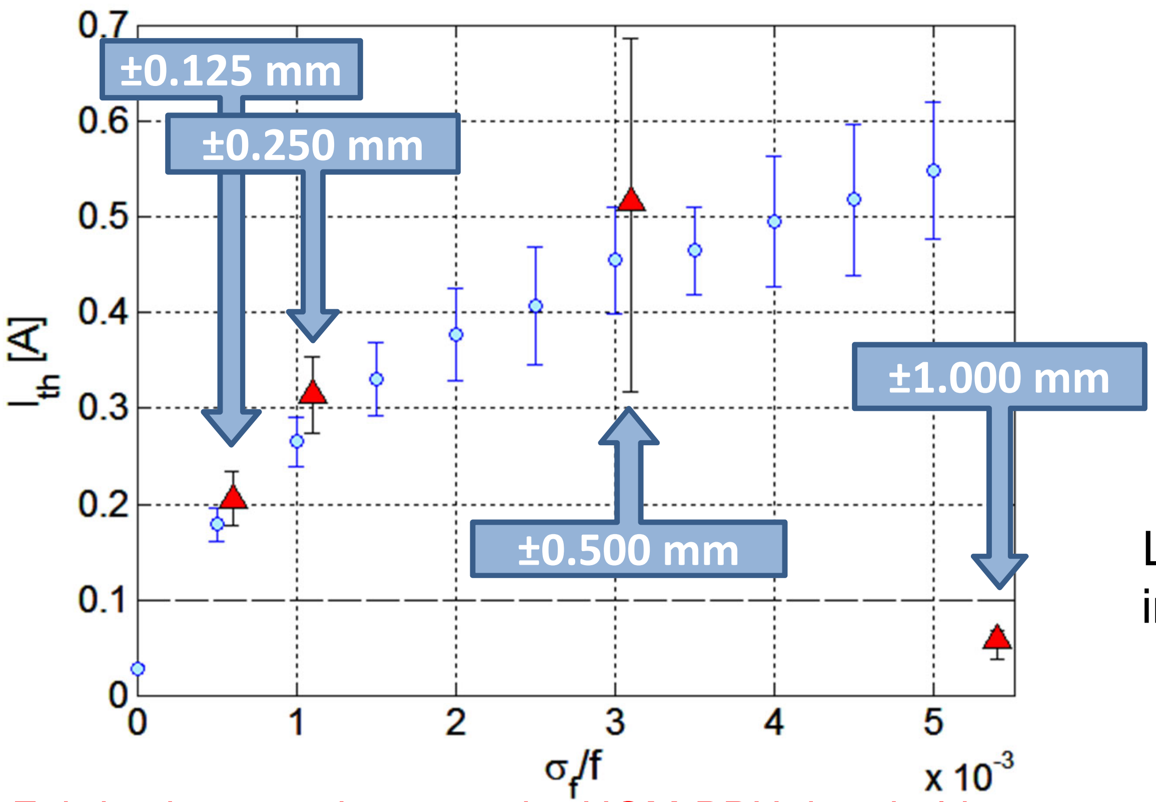


Cornell main linac cavity design (N.Valles)

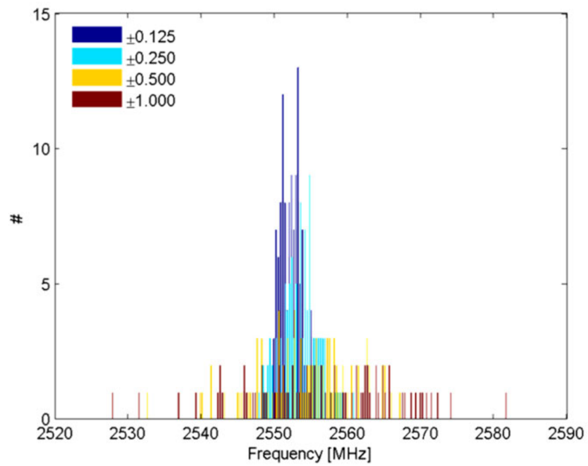


Goal: Maximize I_{th} > 100 mA (under constraints)

Optimize Cavity W.R.T. BBU parameter → Introduce realistic shape variations (x400/error) → Compute dipole HOMs to 10 GHz (1692 modes /cavity) → Generate realistic ERL (x100) → Compute BBU current



Fabrication error increase the HOM-BBU threshold current



Loosened machining tolerances increase relative cavity-to-cavity HOM frequency spread (good!)

Fabrication Variation (2D)

Design topic

- Many cavity design meet requirement of especially HOM-BBU threshold current.
- HOM randomization can increase HOM-BBU threshold. → Cornell make fabrication variation and calculate by separate cavities

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- How much can be calculate more than 10GHz HOMs ?
- Coupler kick
- Program for experimental study for HOM effects on existing CW linacs.
- How to suppress field emission (Epk/Eacc) ?

(2) SRF Guns & low beta & Transversal cavities

- Selected experiences of 6 years Rossendorf SRF-Gun (Andre Arnold)
- CW SRF Photoinjector experience at HZB (Andrew Burril)
- Project-X cavities (Timergali Khabibouline)
- APS crab cavities (Jim Kerby)
- Progresses on China ADS Superconducting cavity (Peng Sha)
- IMP’s low beta cavities (Yuan He)

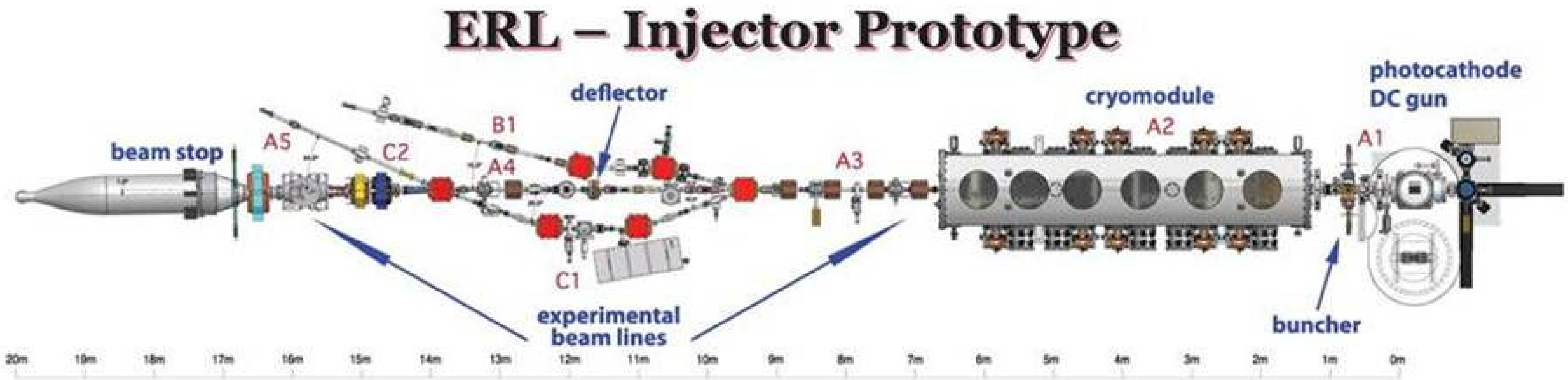
SRF Gunの今までの運転経験や現状が前半のtopic。後半はいろんなlow beta & crab cavityについて。APSのCrab cavityは空洞横からLOMを取るというアイデアで斬新。(時間ないので省略)

(3) CW cavity operation

- Experience with CW caity operation with high beam loading at Cornell (Bruce Dunham)
- Experience with high loaded Q cavity operation at JLAB (Tomasz Plawski)
- Experimece with high loaded Q operation at HZB (Axel Neumann)
- CW aspects of microphinics compensation (Yuriy Pischalnkov) → LFD compensation(みなさんの方が良く知っているので、省略)
- Experience with high loaded Q cavity operation at Cornell (Mathias Liepe) →まとめ

Michrophonics を以下に抑えるかがtopicだった。

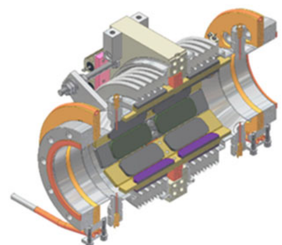
Experience with CW caity operation with high beam loading at Cornell (Bruce Dunham) (Cornell Injector)



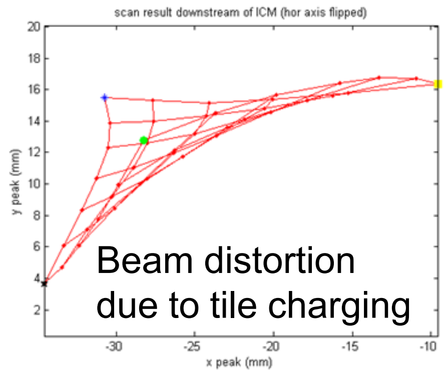
Requirements:
- 5-15 MeV
- 77 pC per bunch
- 100 mA average current
- 0.3 um emittance
  (normalized rms)

- Issues
  Coupler conditioning (with beam)
  Coupler quadrupole fields –> beam
  asymmetry
  HOM RF absorbing tiles*
  Coupler cooling*
  Spurious trips, machine protection*

Status:
- Emittance goals met, simulations verified
- 75 mA maximum average current
  63 hour 1/e cathode lifetime at 65 mA
- Max energy 13 MeV

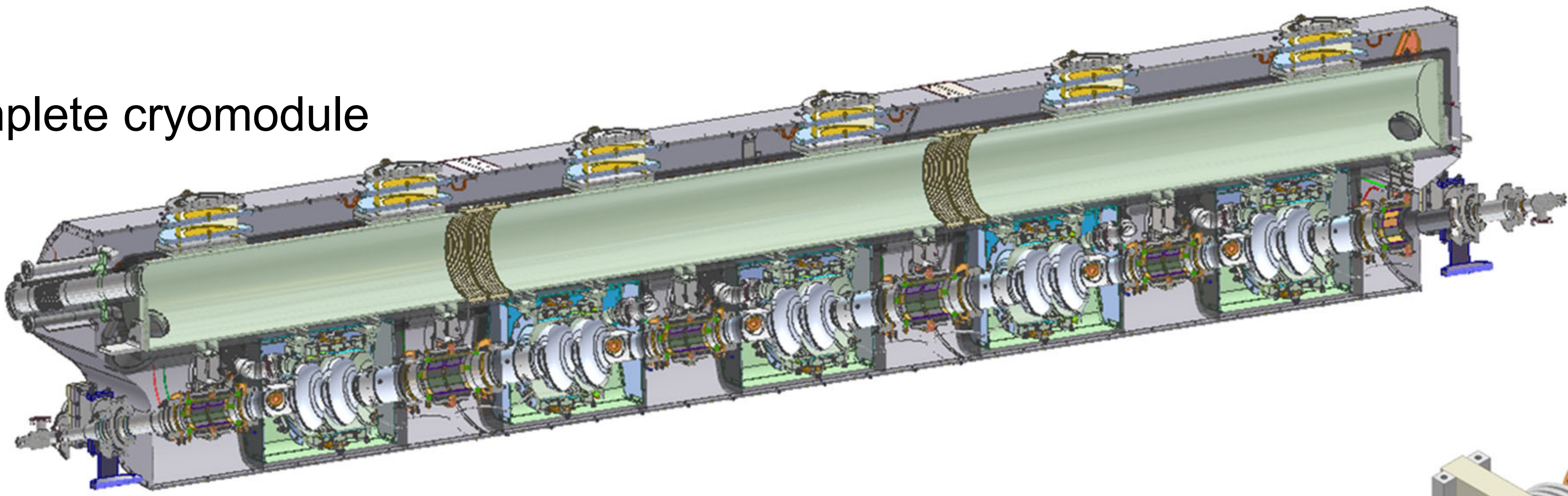


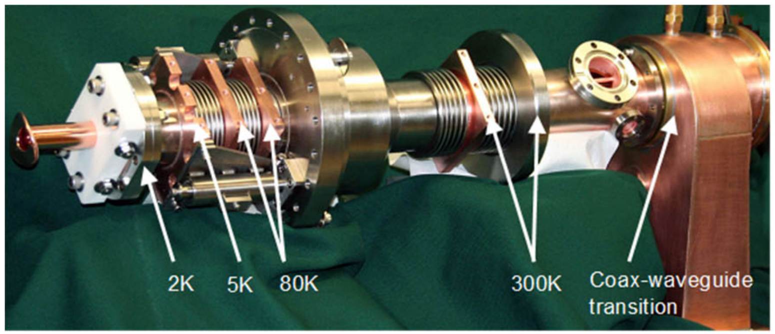
Some of the RF absorbing tiles facing the beam became insulating at 80 K and distorted the beam. We removed half of the tiles, which still provides adequate HOM damping.



Cornell ERL Injector cryomodule

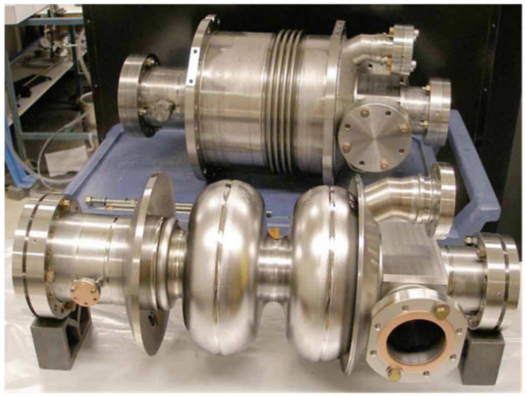
Complete cryomodule

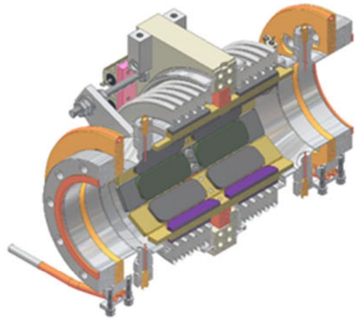




Couplers (made by industry)

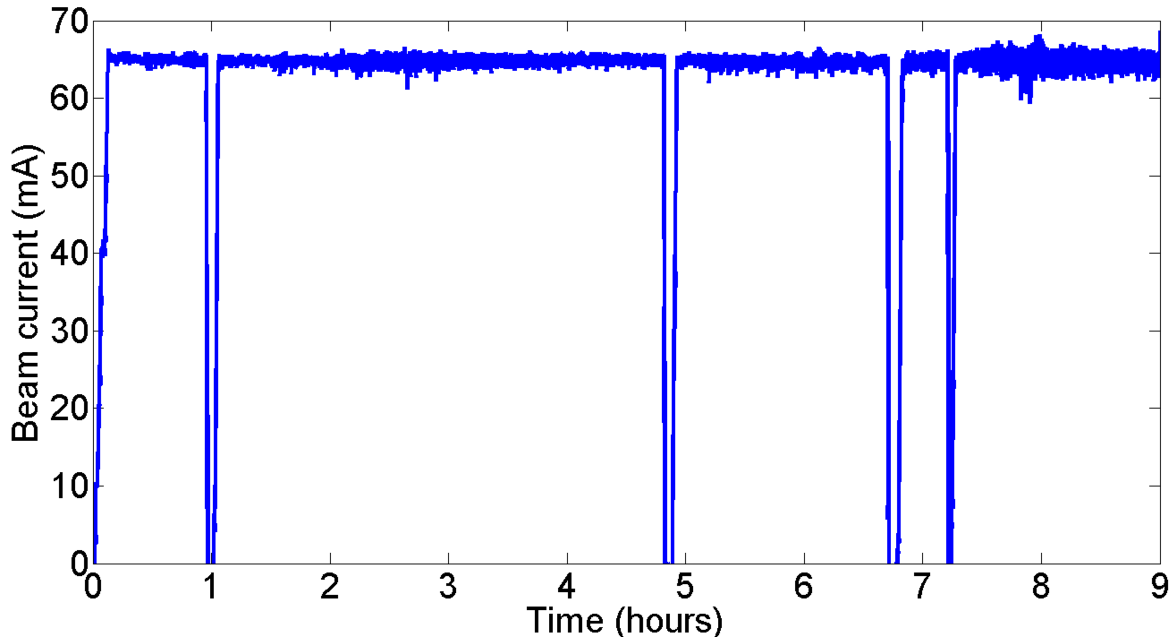
5X 2-cell cavities (made in house)





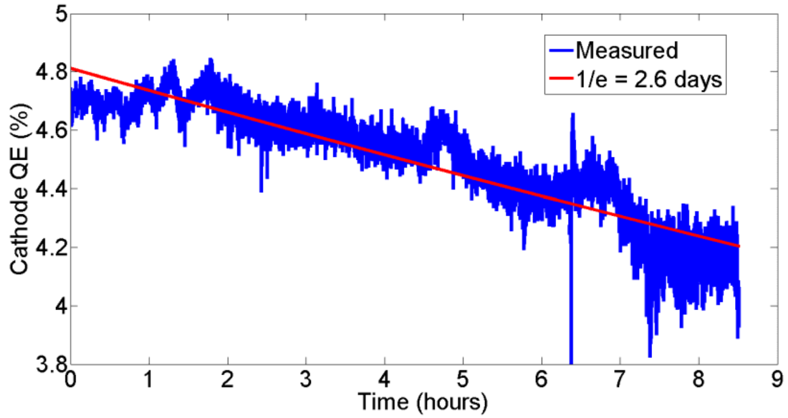
HOM loads with RF absorbing tiles

Recent results (Cornell injector)



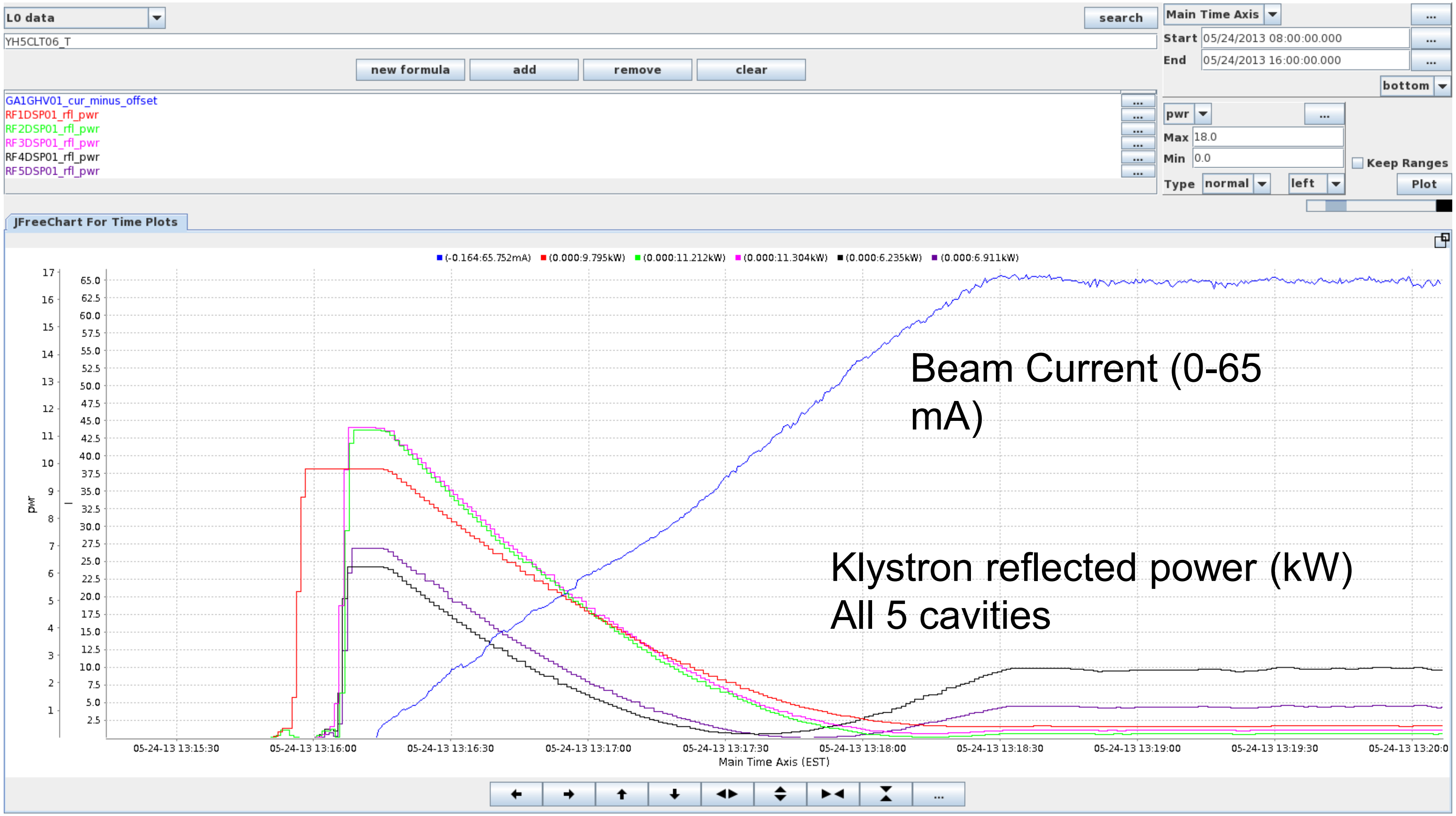
Ran 65 mA average current at 4 MeV for 8 hours – 2000 Coulombs of charge. Had 2 RF coupler trips and 2 spurious trips.

Cathode lifetime (NaK_2Sb cathode) of 63 hours (1/e). With the available laser power, 1 week of uninterrupted operation is possible

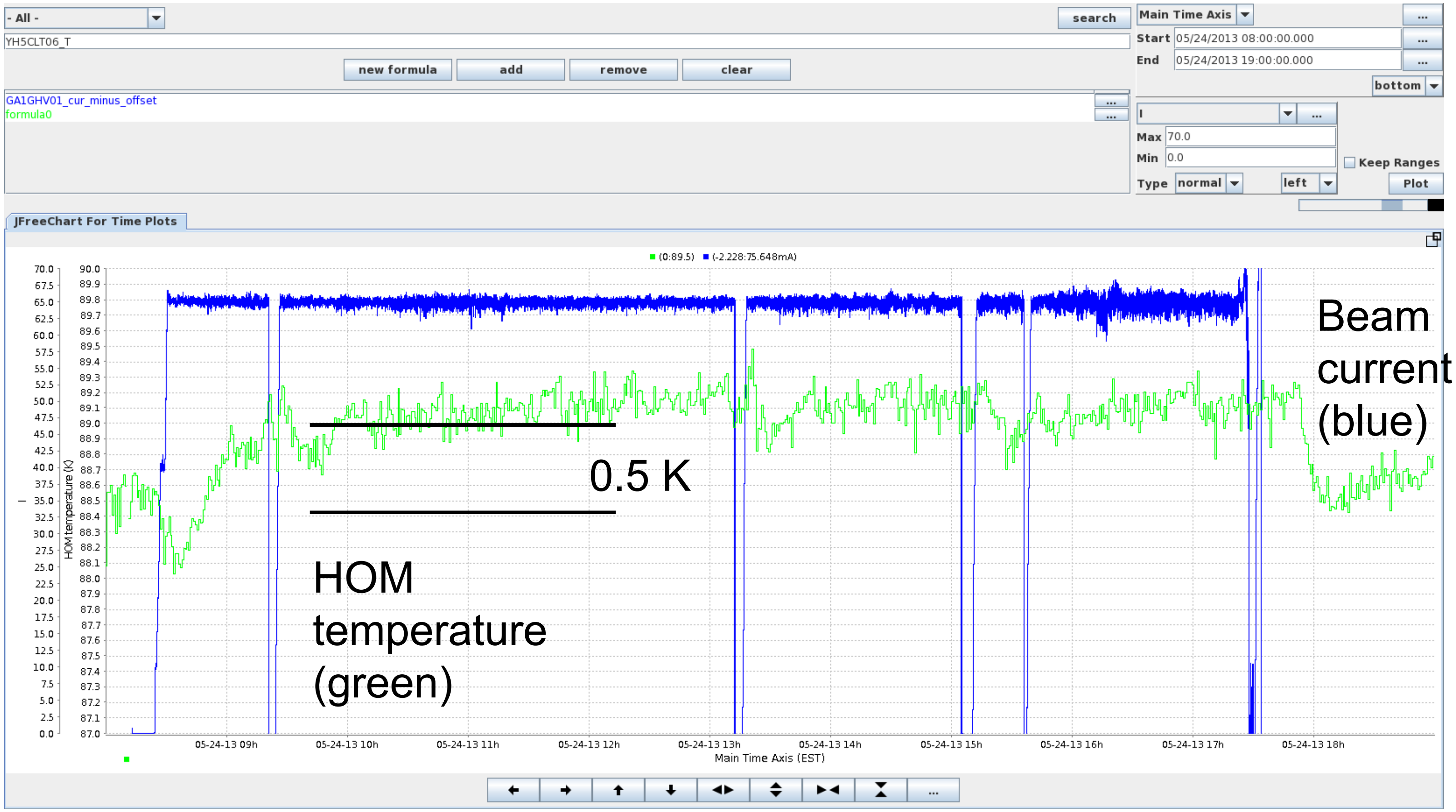


Coupler adjustment (Cornell injector)

Couplers are adjusted to provide ~0 reflection at the desired current.



HOM damper heat load with beam (Cornell injector)

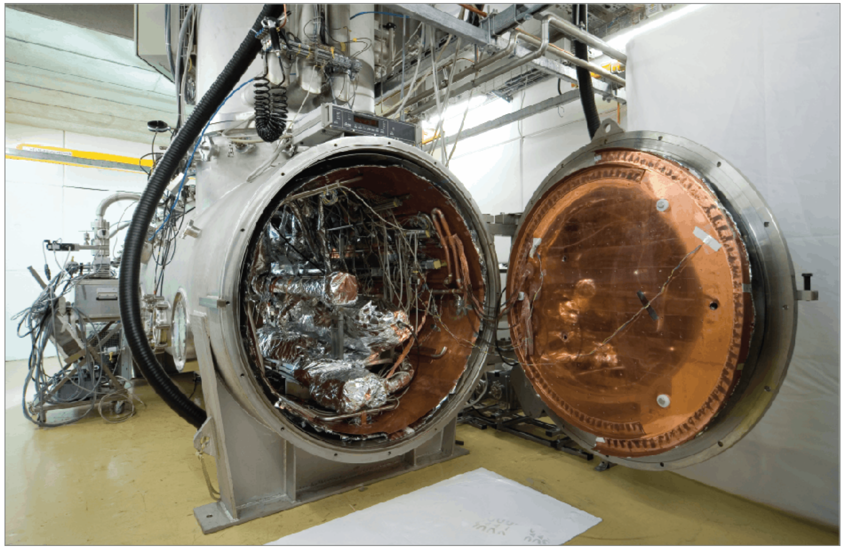


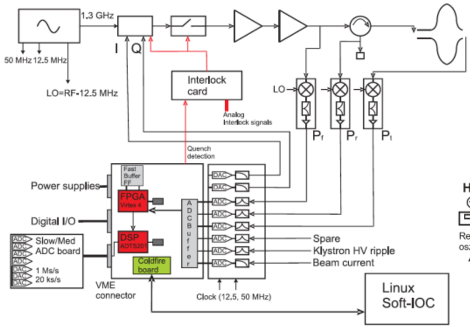
At most 0.5K temperature rise (65 mA, 4 MeV, 2-3 ps rms bunch length)

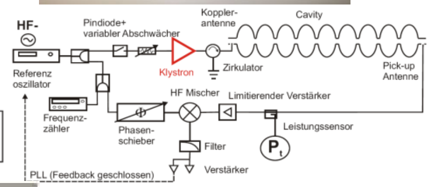
Experimece with high loaded Q operation at HZB (Axel Neumann)

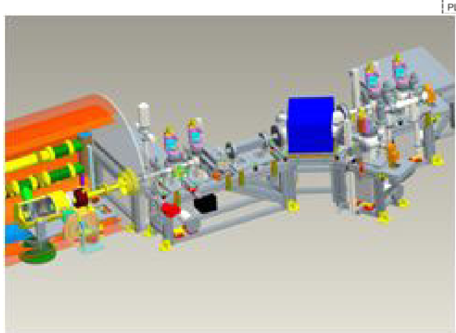
•Test set up: Horizontal test facility HoBiCaT

- **Testing fully equipped cavities including helium vessel, motor- and piezo tuner, CW modified TTF couplers, magnetic shielding, etc.**
- **Temperature range down to 1.5 K, typically 1.8 K with 100 W @ 1.8 K: 16 mbar ±30 μbar rms**
- **Coupling variable, installations down to β_c=1 possible**
- **RF set up: 19 kW IOT, 400 W solid state amplifier driven by PLL or Cornell's LLRF system**
- **Two cavities tested in parallel or sample studies**
- **Gun cavity tested with diagnostic beam-line**





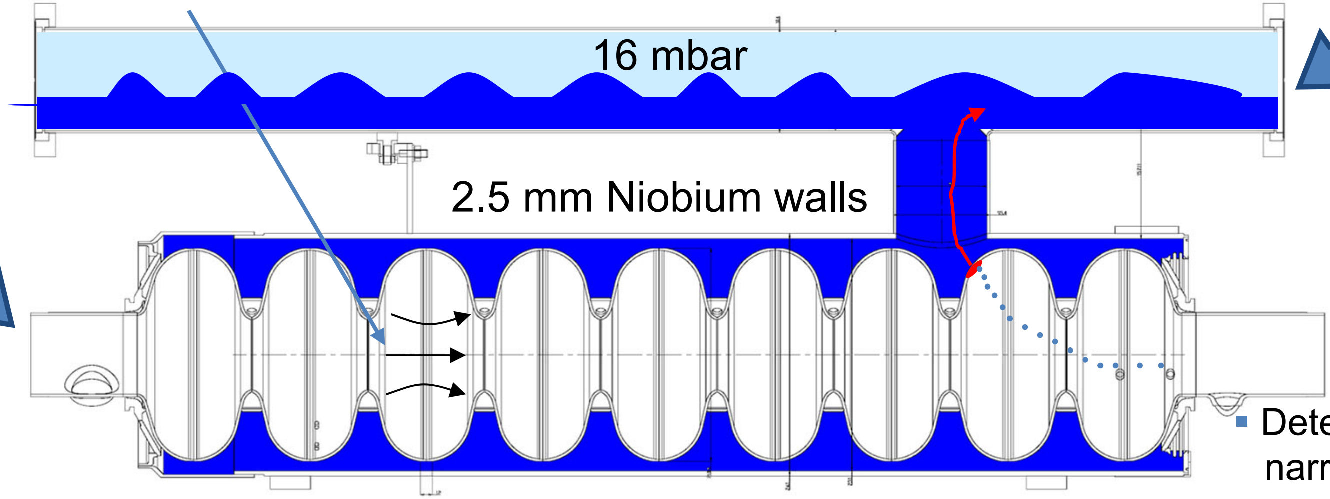




CW operation: Field stability determined by Microphonics (HZB)

- Helium pressure fluctuations
  $\Delta f/\Delta p$ = 50-60 Hz/mbar,
  Gun:100 Hz/mbar

- Field amplitude variation:
  Dynamic Lorentz force, $\Delta f/\Delta E_{acc}^2$ = 1Hz/(MV/m)²



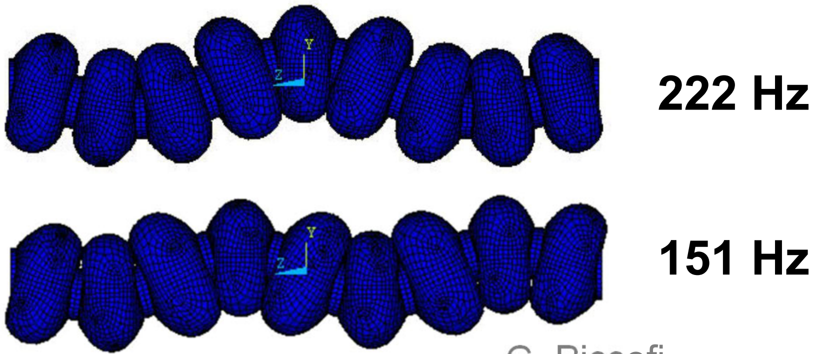
Heat transport dynamics

- Stochastic background noise

- Deterministic, narrow-band sources: Vacuum pumps

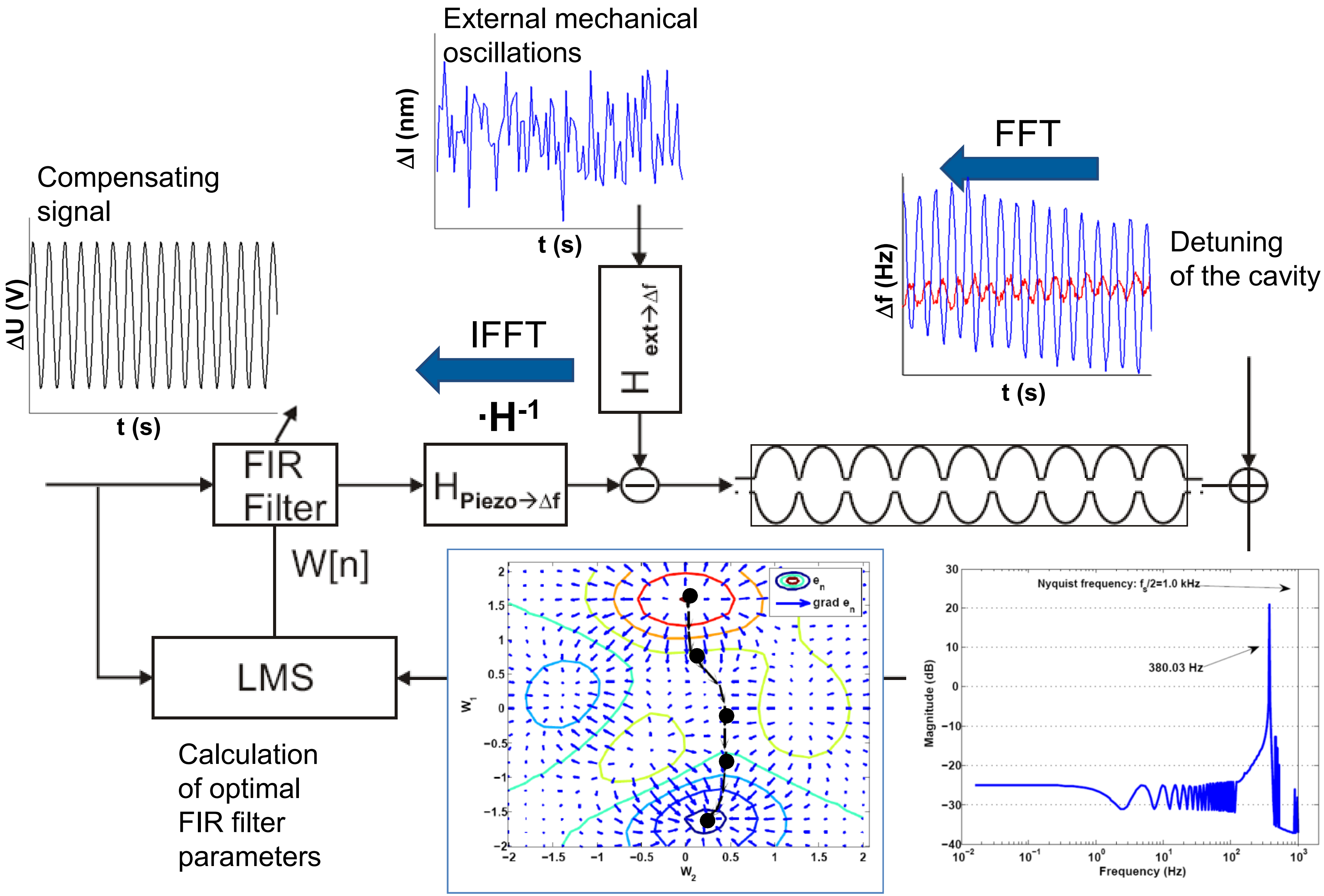
Mechanical oscillations of the Cavity: Microphonics

Response of the Cavity-Helium vessel-Tuner system:
(FEM simulations, e.g.: *Devanz et al. EPAC 2002*)



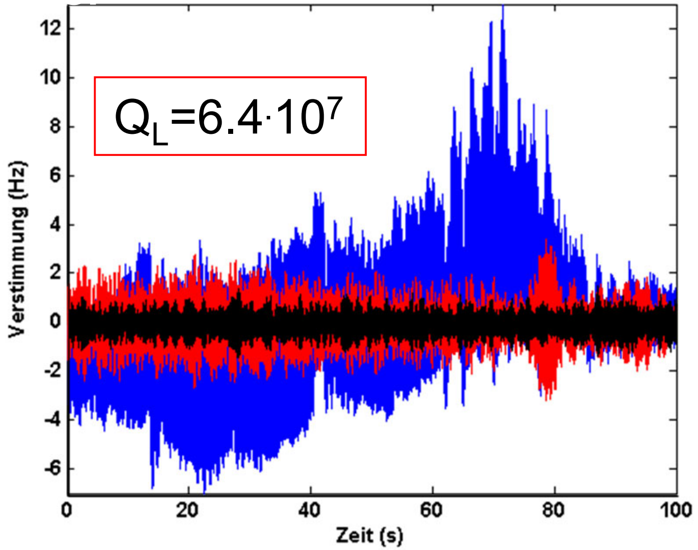
G. Bissofi

A tested scheme: Least-mean-square based adaptive feedforward (HZB)



Compensation results (HZB)

Single-resonance control:

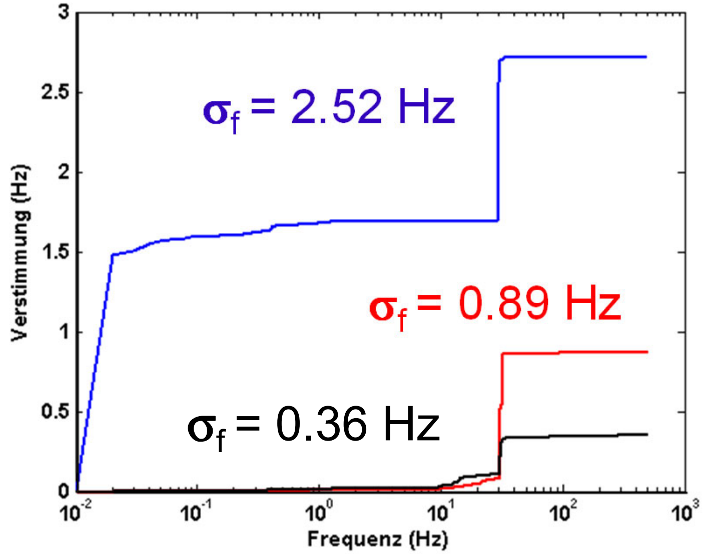


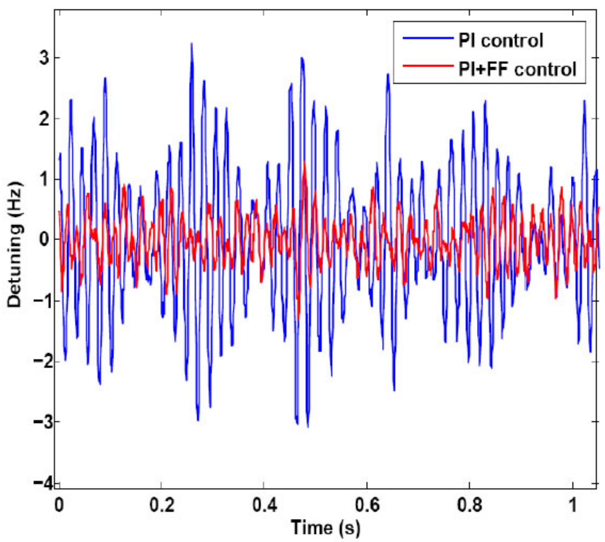
ΣFFT

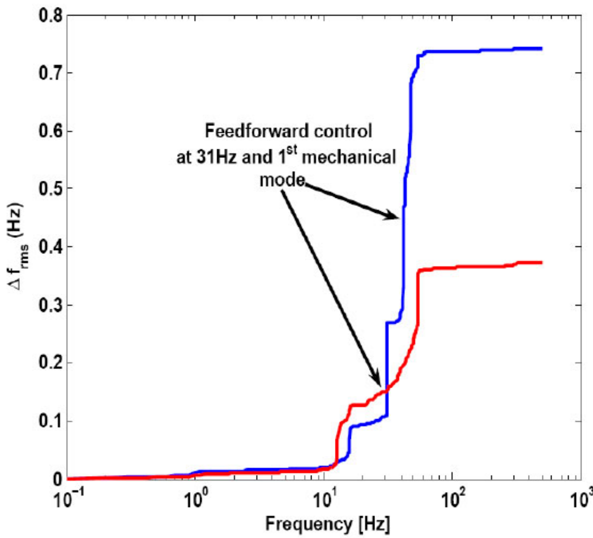
Open loop

Feedback only

Feedback and Feed-forward



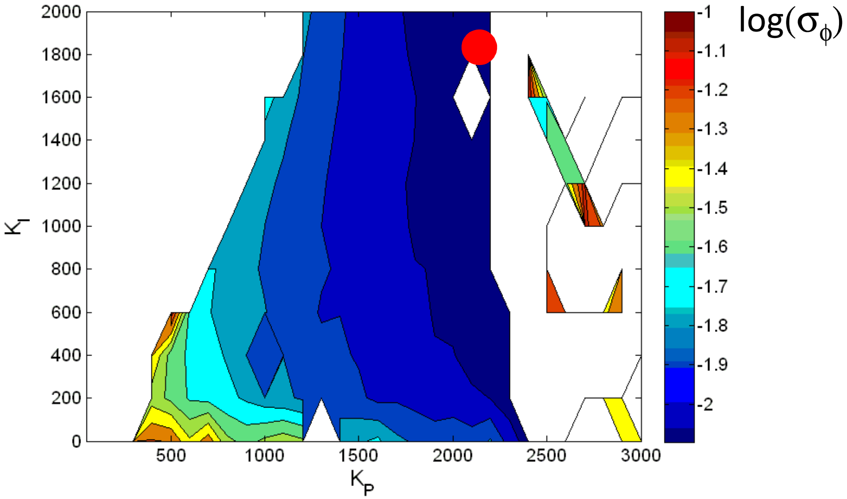




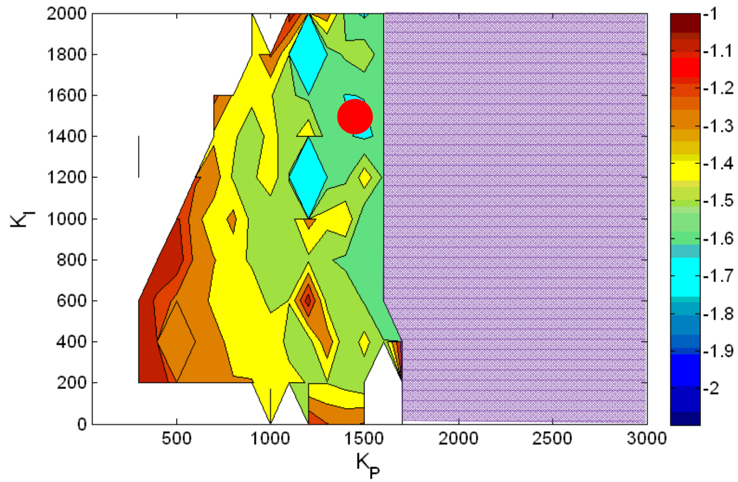
Multi-resonance control:

Piezo resolution seems to limit control of neighboring modes

LLRF studies with U Cornell: Limits of Q_L (HZB & Cornell)

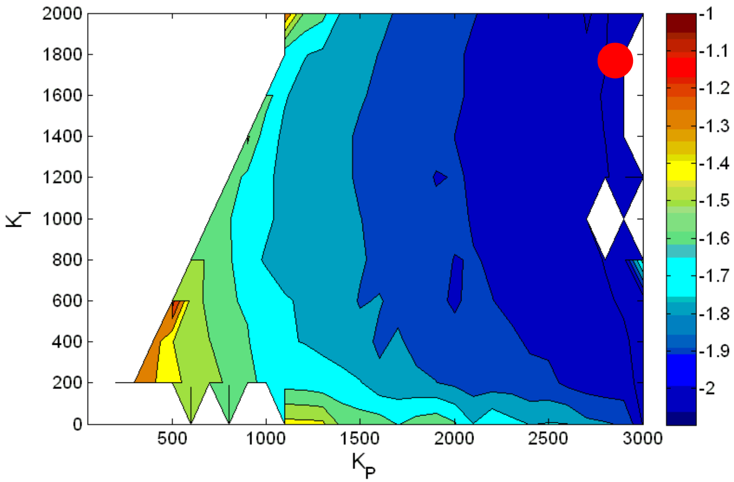


Q_L=5·10^7, $f_{1/2}$=13 Hz



Q_L=2·10^8 , $f_{1/2}$=3.25 Hz

Q_L=1·10^8, $f_{1/2}$=6.5 Hz



Best results: ●
5·10^7 0.008°
1·10^8 0.0093°
2·10^8 0.0236°

9 cell TESLA cavity
E_{acc}= 10-12 MV/m
T_{bath}= 1.8 K
PI piezo loop
8/9-π filter optimized

LF detuning → IOT beam instable

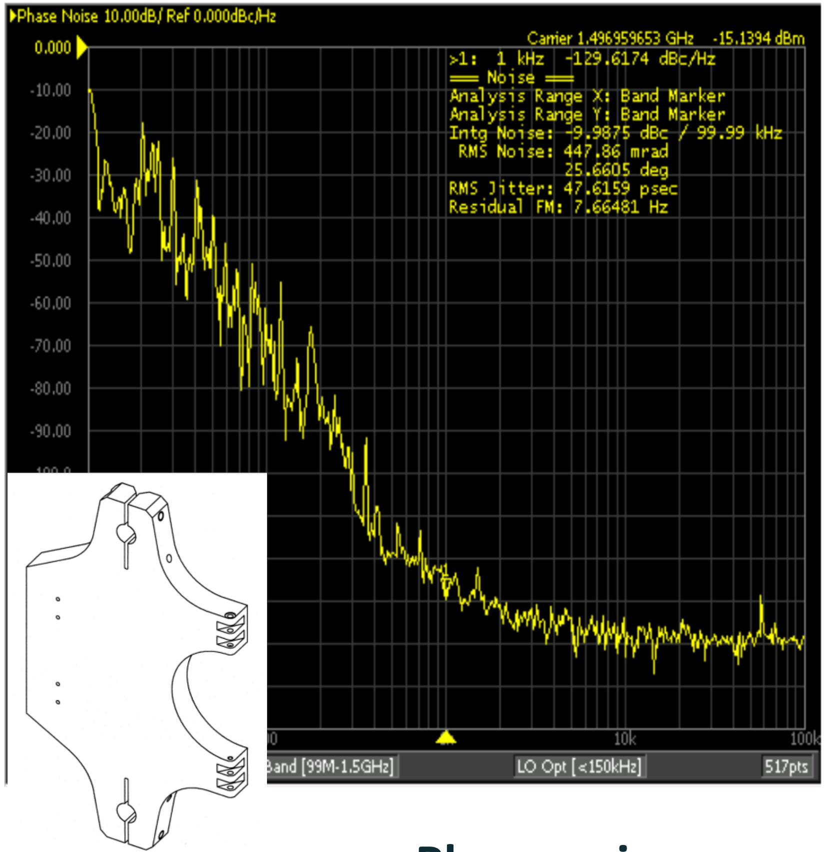
Cavity field trip

Areas with σ_ϕ>0.1 were blanked out

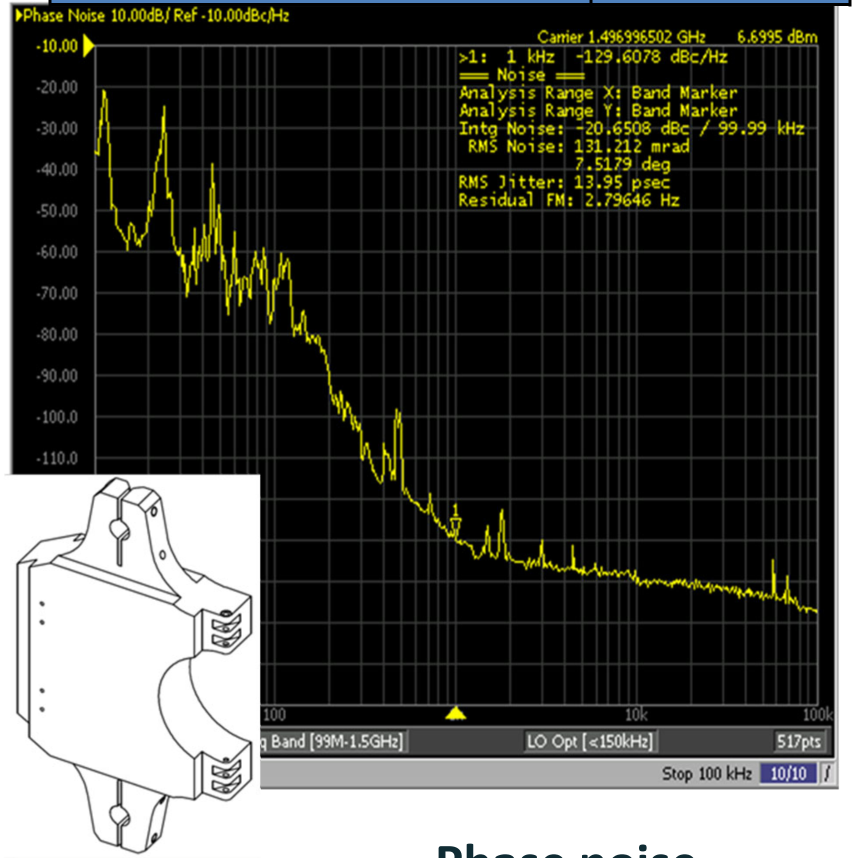
High QL challenge (JLAB) (Tomasz Plawski)

Fundamental frequency f_0	1497 MHz
Accelerating gradient E_{acc}	> 20 MV/m
Input coupler Q_{ext}	3.2 x 10^7
Active length	0.7 m
r/Q	1300 Ω/m
Tunning sensitivity	0.3 Hz/nm
Pressure sensitivity	420 Hz/torr
Lorenz force frequency sensitivity K_L	~2 Hz/(MV/m)^2

C100 GDR mode – Original/Modified Tuner

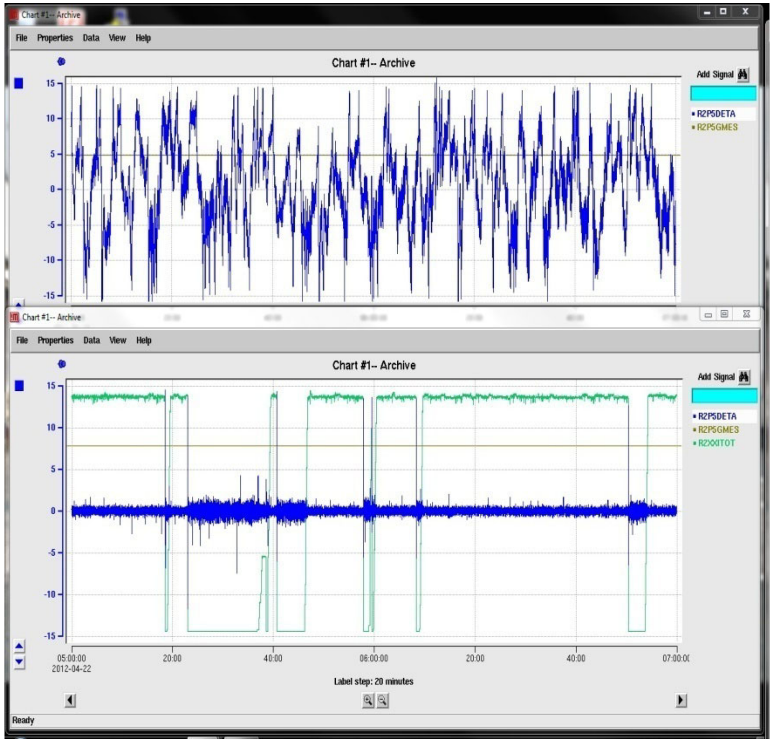


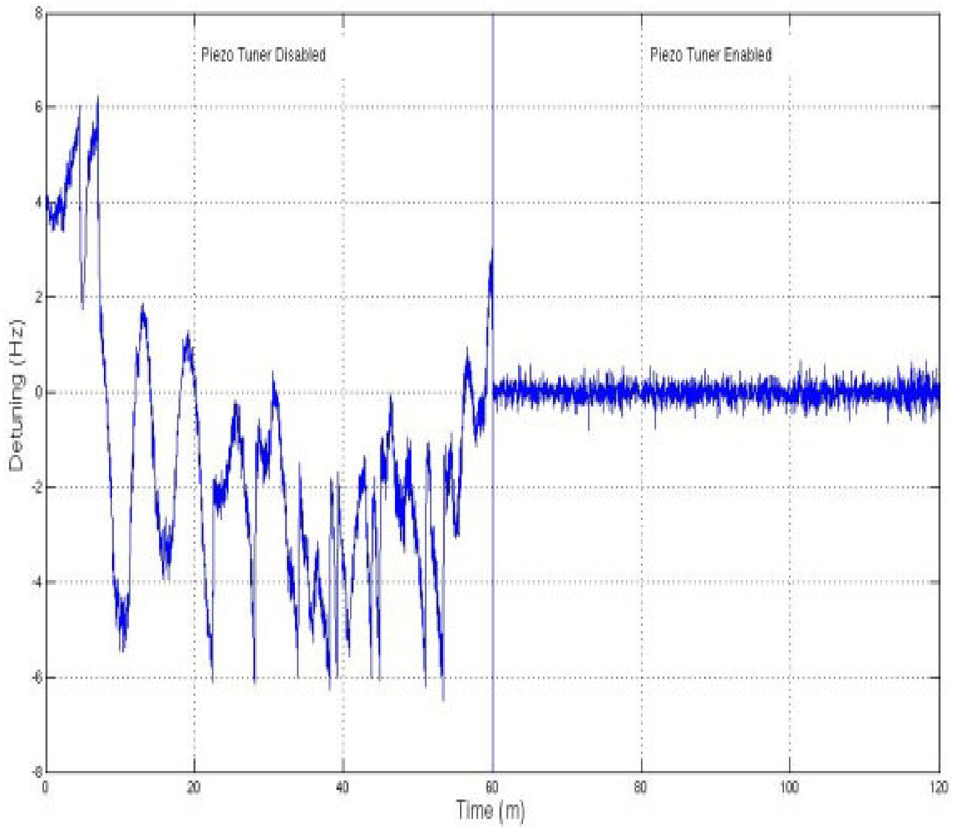
Phase noise
25.6 deg rms /14 Hz rms



Phase noise
7.5 deg rms /4 Hz rms

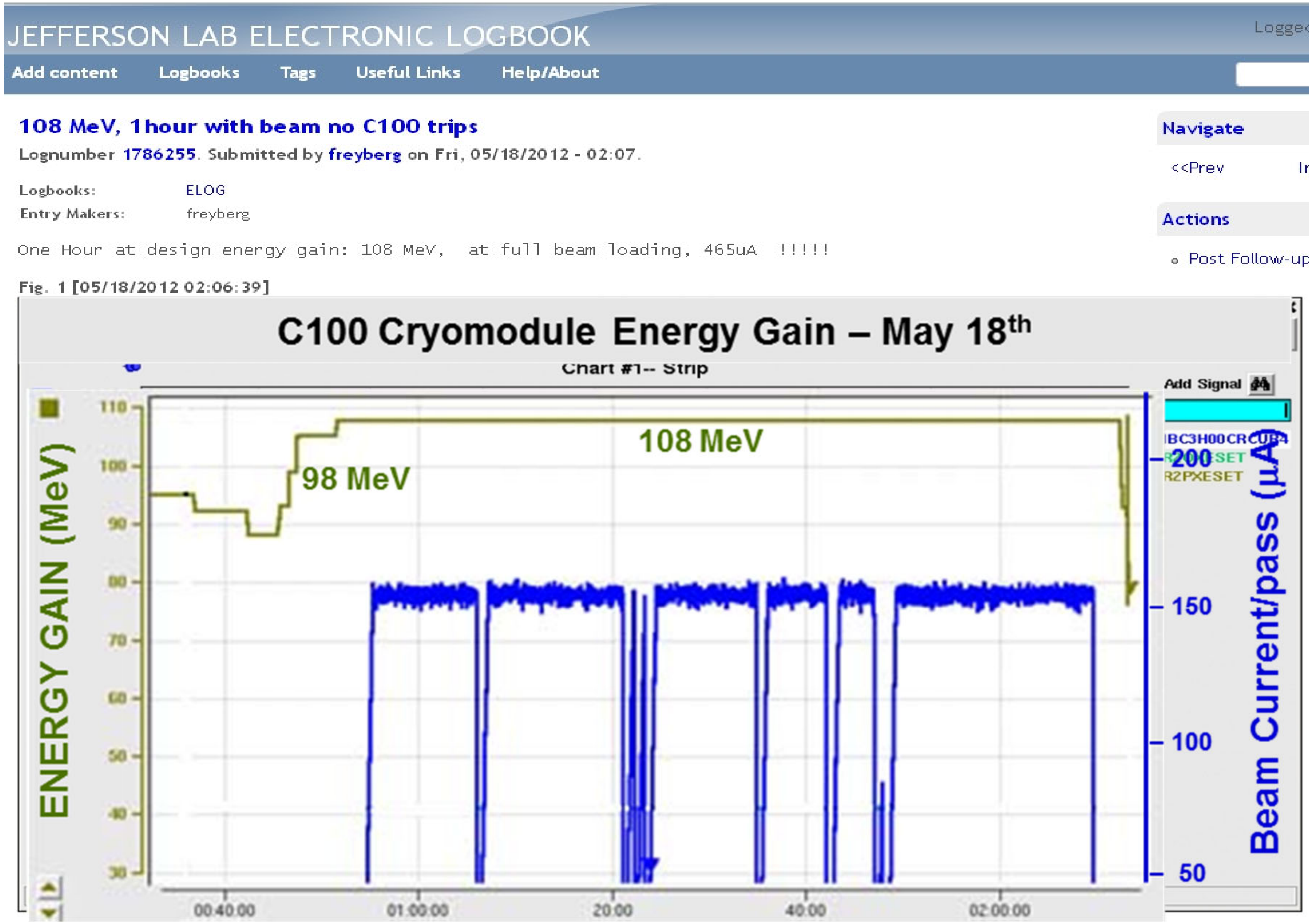
CEBAF C100 PZT Control (JLAB)





Piezo compensation bandwidth: 1 Hz
PI regulator
Wider bandwidth causes mechanical mode excitation/ instabilities
Substantial improvement for slow detuning (helium pressure drift or slow microphonics)

C100 One Hour Run (JLAB)現状



2013年11月から本格的にビームoperationがstart

(4) Cavity high Q performance & treatment procedures

- High Q R&D at FNAL (Anna Grasselino)
- High Q0 preservation (Andy Hocker) →FNALでモジュール用の磁気シールドを作成＆測定。磁気シールドは重要という結論。。。
- High Q0 R&D at JLAB (Gigi Ciovati)
- High Q R&D at Cornell (Fumio Furuta) → BCPとEPのに比較(BCPはHGに適さない)。7cell-Tmapの紹介など。
- Experience with cavity operation in cryomodules test at JLAB (Tom Powers)
- High Q cavity operation in cryomodule at Cornell (Nick Valles)
- HZB High-Q0 Optimization by thermal cycling (Axel Neumann) →HoBiCaTでの冷却thermal cycleの結果。これらの測定からThermocurrents due to temperature gradientsという仮定をし、その影響を調べた。温度をゆっくり均一に冷やすのが重要。

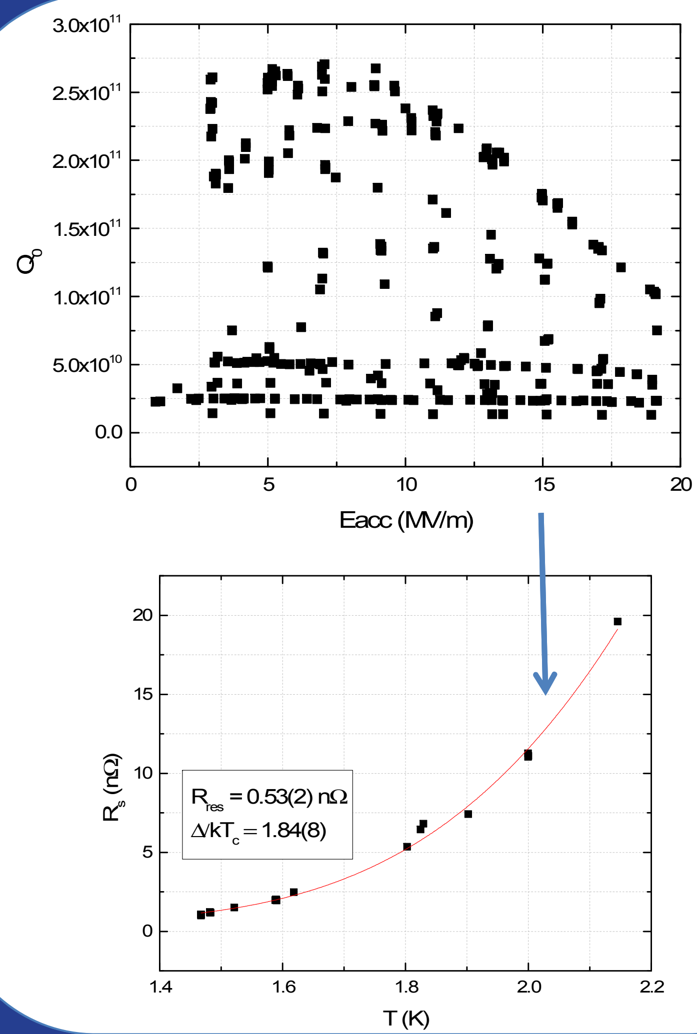
このsessionは結構盛り上がった。特にCW運転にはQ0を上げるのはdesirableなのでQ0を上げるためにはどれが効くのかなど議論が行われた。

Approach for RBCS(B,T) (FNAL)

Approach

A. Romanenko and A.Grassellino
http://arxiv.org/abs/1304.4516

- Obtain as many Q(B,T) measurements as practical at *ALL fields* (not only at a single low field as is customary)
- At each fixed field fit corresponding Q(T) to extract Rres
  - Also gives Rbcs(T) = Rs(T)-Rres



Bath temperature

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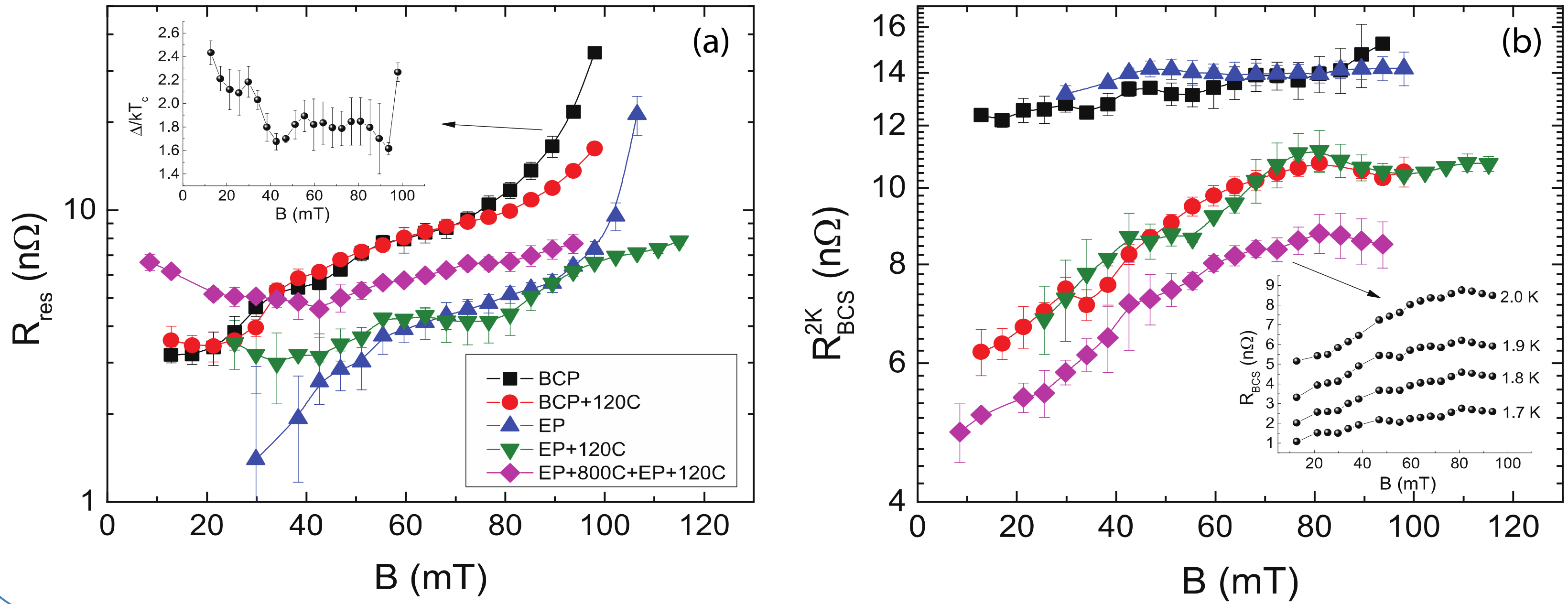
Fermilab

High Q R&D at FNAL (Anna Grasselino)

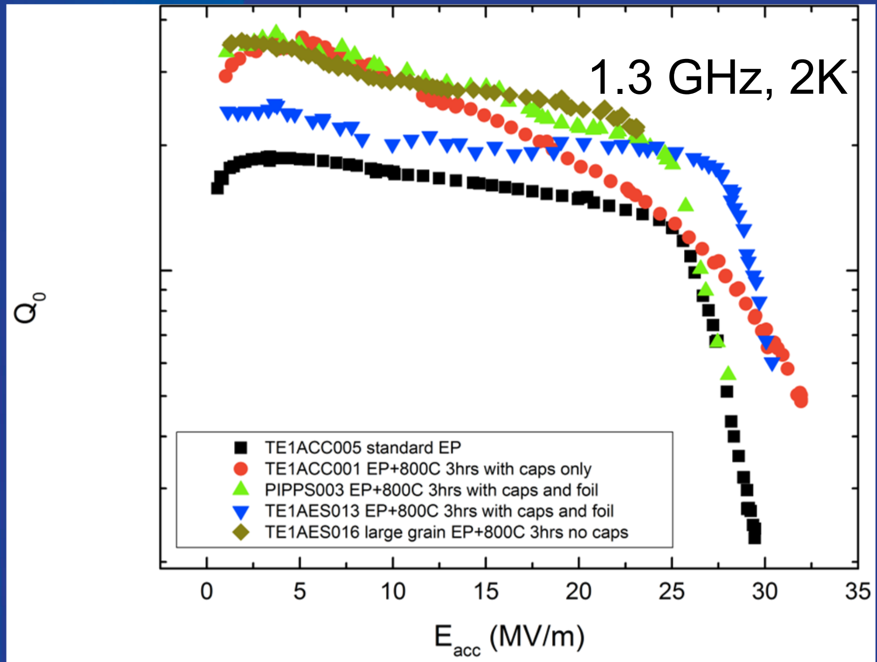
Field Dependence of Surface Resistance for typical treatments

- Obtain as many Q(B,T) measurements as practical at *ALL fields* (not only at a single low field as is customary)
- At each fixed field fit corresponding Q(T) to extract Rres
  - Also gives Rbcs(T) = Rs(T)-Rres → see backup slide in detail



- Medium field Q slope is a combination of both $R_0(B)$ and $R_{BCS}(B)$
- R_{BCS} decreases but becomes *strongly field dependent after 120C*
- Medium field Q slope is *NOT due to thermal feedback*
- Stronger $R_0(B)$ for *BCP vs EP*

ここらへんは私の勉強不足でちゃんとした結論は言いません。



Annealing with caps+ no chemistry produces extra-low residual resistance (FNAL)

A.Grassellino et al, http://arxiv.org/abs/1305.2182

- *Systematically low R_0*
- *Extra cost savings from skipping the post furnace chemical processing*
- *See also* G. Ciovati, Phys. Rev. ST Accel. Beams 13, 022002 (2010)

CAVITY ID	Type	Treatment	Q at 5 MV/m, T = 2K	Residual Resistance at 5 MV/m (nΩ)
TE1AES016	Large grain	EP + 800°C 3 hrs no caps, argon venting	3.5e10	1.47±0.44
TE1AES013	Fine grain	EP + 800°C 3 hrs with caps plus foil, dry air venting	2.4e10	<1.09
PIPPS003	Fine grain	CBP + EP + 800°C 3 hrs with caps plus foil, nitrogen venting	3.5e10	1.45±0.84
TE1ACC001	Fine grain	EP + 800°C 3 hrs with caps only, nitrogen venting	3.5e10	0.85±0.67

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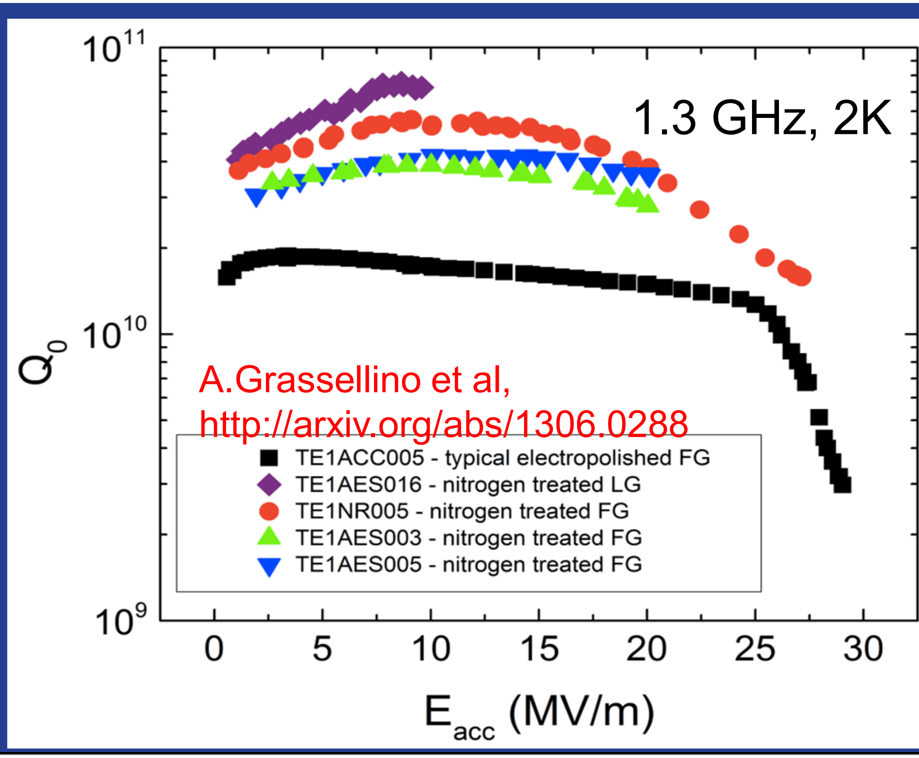
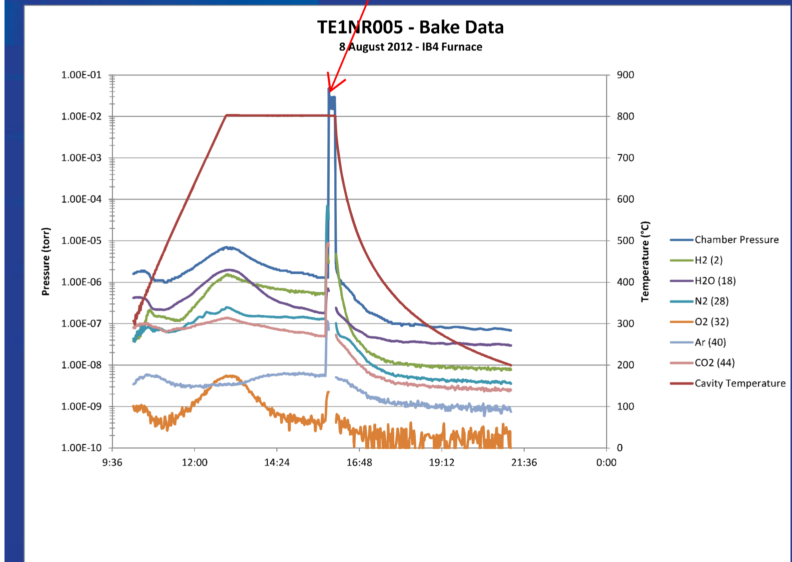
New surface processing techniques for Q maximization (2) (FNAL)

Heat treatmentの最後にN2gasを10分くらい流すとQが良くなったという結果が得られている？NbNを最初に作っておき、強い表面を作っておくということか？



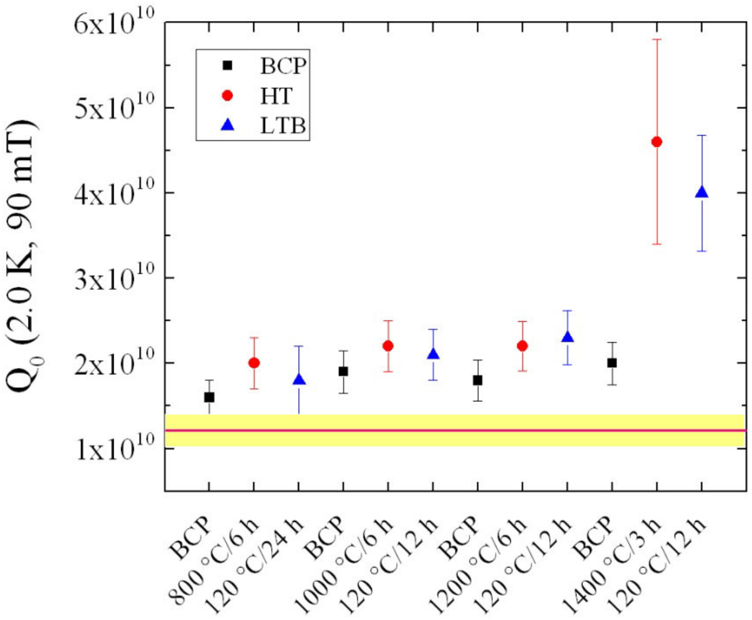
Heat treatments in nitrogen produce unprecedented values of $R_{BCS}(B)$

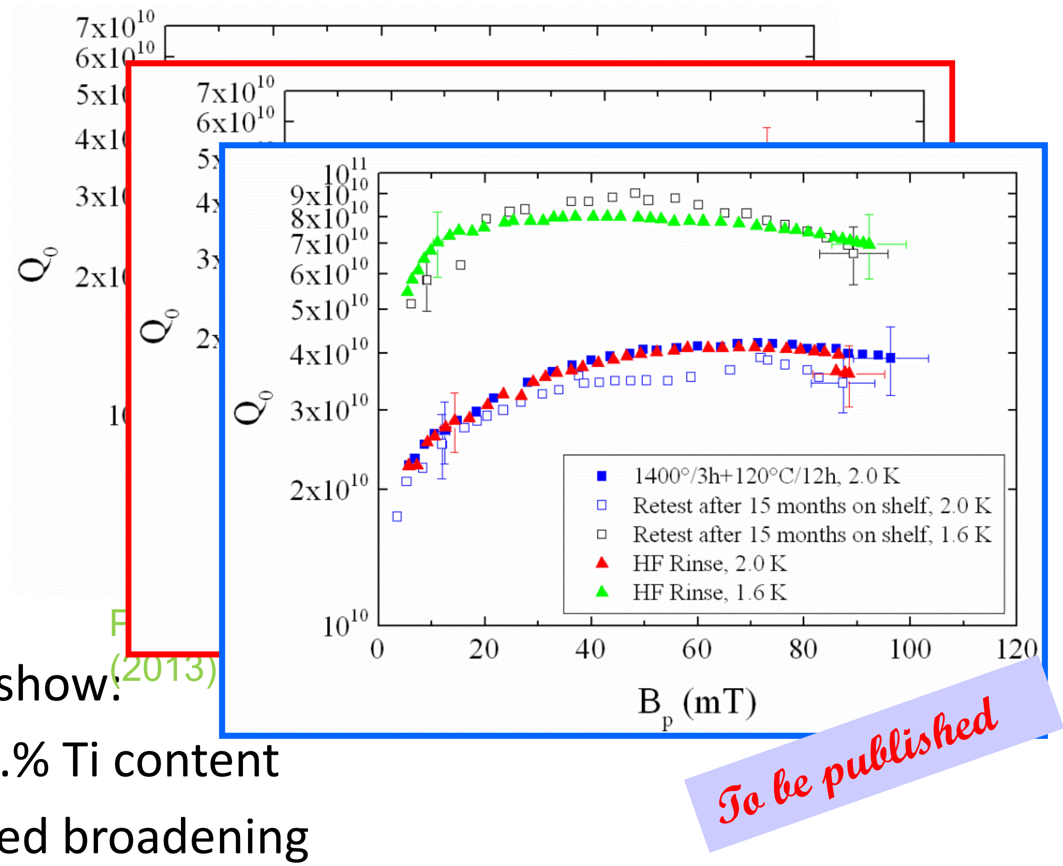


CAVITY ID	Type	Treatment	Subsequent cumulative material removal via EP for each RF test [μm]	Highest Q measured at T=2K (correspondent to material removal in red); max Q value located at ~ B_{pk} [mT]
TE1AES016	Large grain EP	1000°C 1 hour with ~ 2×10^{-2} Torr p.p. nitrogen	80	$(7.4\pm1.4)\times10^{10}$, 40 mT
TE1AES003	Fine grain BCP	1000°C 10 min with ~ 2×10^{-2} Torr p.p. nitrogen	10, 60	$(4.1\pm0.6)\times10^{10}$, 50 mT
TE1AES005	Fine grain EP	1000°C 1 hour with ~ 2×10^{-2} Torr p.p. nitrogen	20, 40, 80	$(4.2\pm0.13)\times10^{10}$, 70 mT
TE1NR005	Fine grain EP	800°C 3 hours in UHV, followed by 800°C 10 min with ~ 2×10^{-2} Torr p.p. nitrogen	5, 15	$(5.3\pm0.85)\times10^{10}$, 70 mT

High Q0 R&D at JLAB (Gigi Ciovati)
HT extended up to 1400° C with new furnace

- Ingot Nb cavity (RRR~200, Ta~1375 wt.ppm), treatment sequence after fabrication: CBP, BCP, HT, HPR

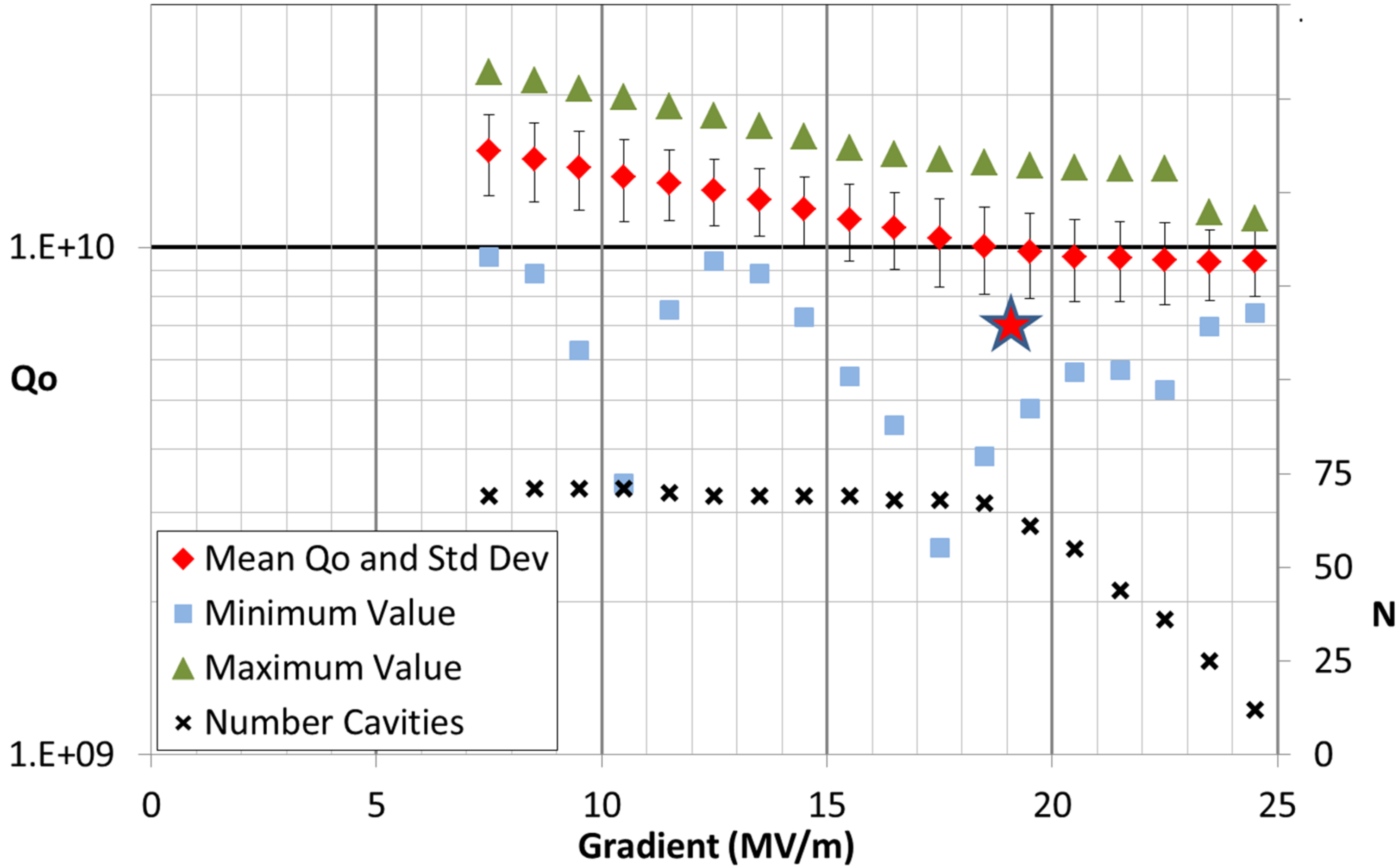




- Samples' analysis after 1400° C show:
  - Reduced H content and ~1 at.% Ti content
  - Higher energy gap and reduced broadening parameter
  - Unchanged mechanical properties

ここらへんは私の勉強不足でちゃんとした結論は言いません。

Experience with cavity operation in cryomodules test at JLAB
Q vs E results 1 (JLAB) (Tom)

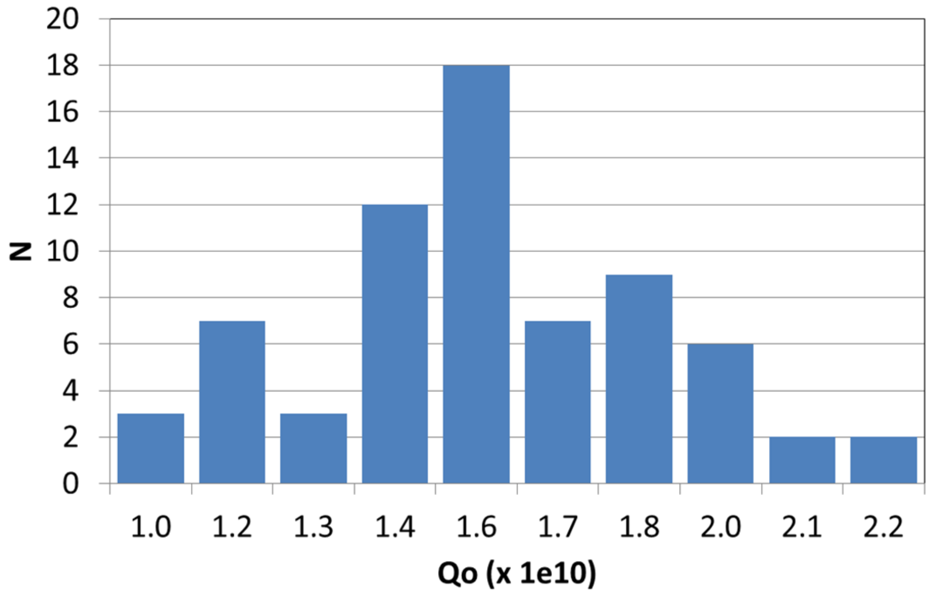


Qo at Emax* for the Cavities in 9 of the C100 Cryomodules

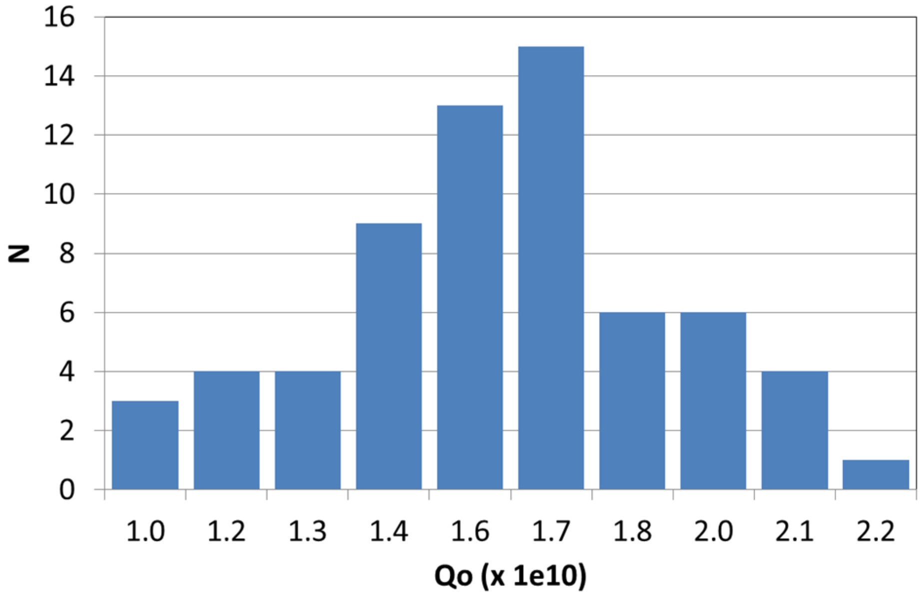
*This data is the highest gradients for which Qo measurements were made. Higher gradients were acheived on a number of the cavities.

Jlab C100 moduleでのcryomodule測定の結果。80空洞　- 8空洞 =72空洞

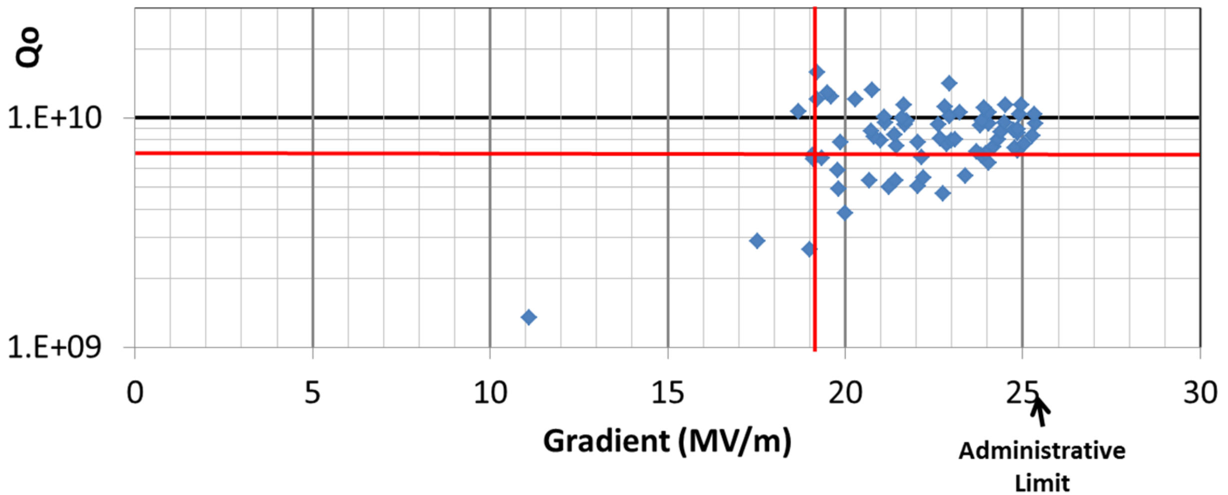
Qo vs E Statistics (JLAB) (Tom)



Distribution of Qo for 9 - C100 Cryomodules Operated at 7.5 MV/m



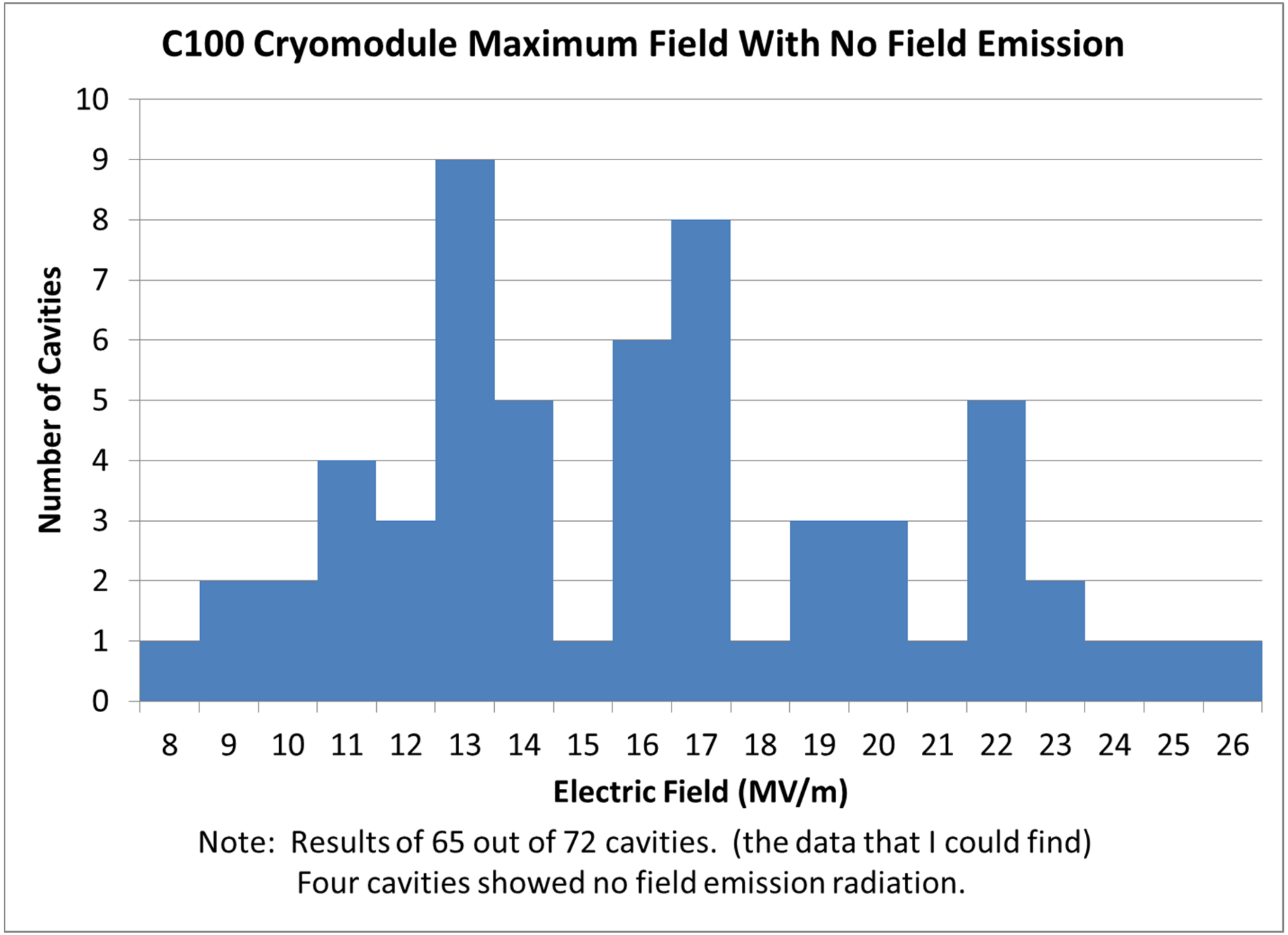
Distribution of Qo for 65 of 72 Cavities Operated at 19 MV/m



Jlab C100 moduleでのcryomodule測定の結果。割とrequirementに近い値を達成。

Radiation onset (JLAB) (Tom)

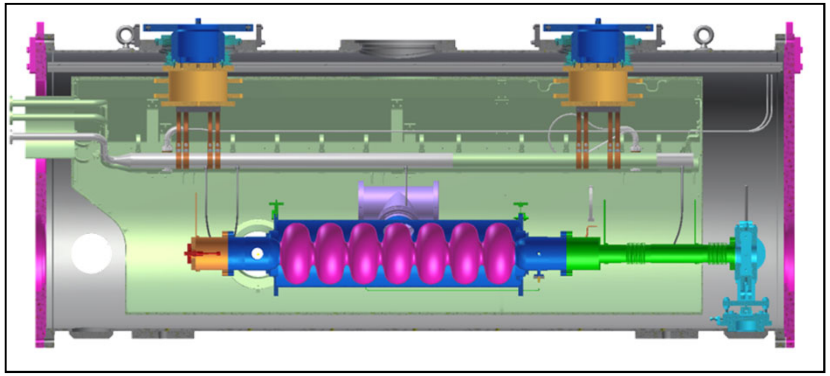
但し、

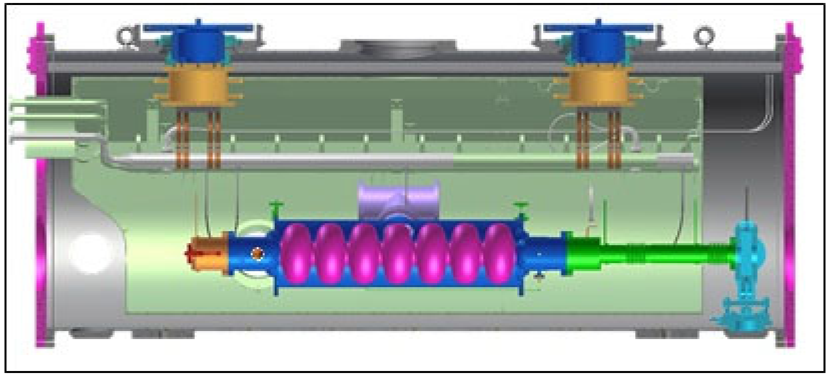


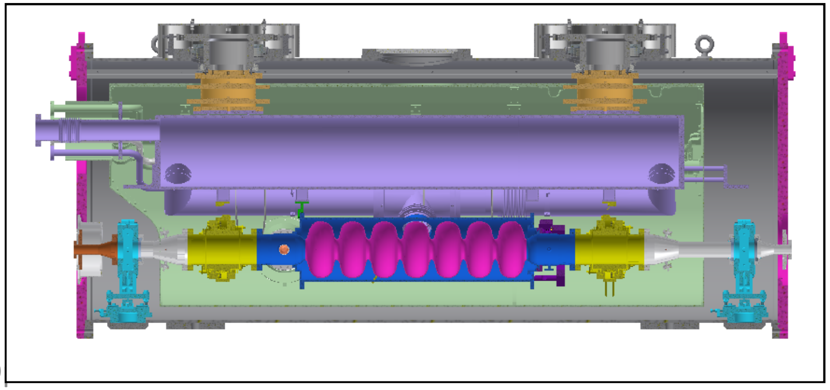
Jlab C100 moduleでのcryomodule測定の結果。Field emission onsetの分布は幅広い。

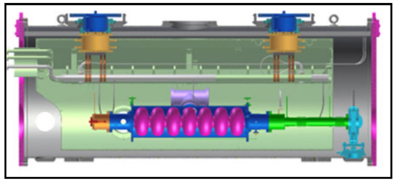
High Q cavity operation in cryomodule at Cornell (Nick Valles)

- HTC-1: Follow vertical assembly procedure as closely as possible
- HTC-2: Include side mounted, **high power RF input coupler**
- HTC-3: Full cryomodule assembly-high power RF input coupler and **beam line HOM loads**



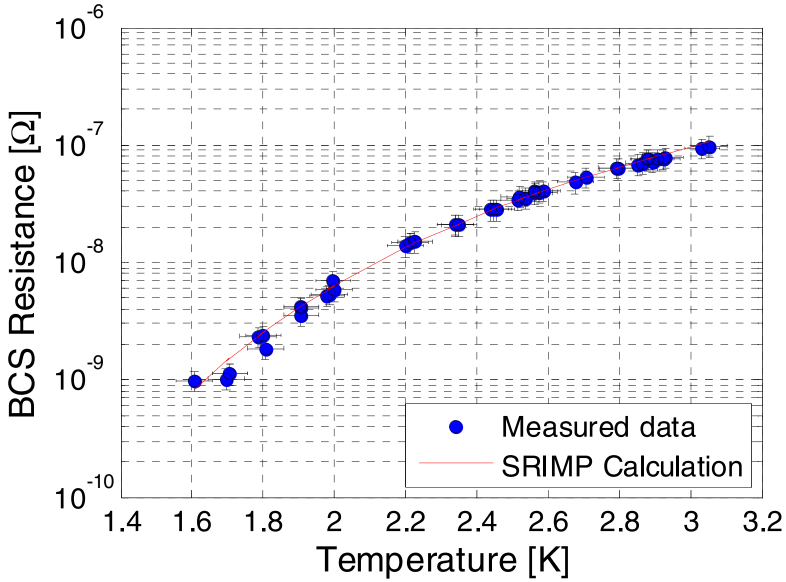






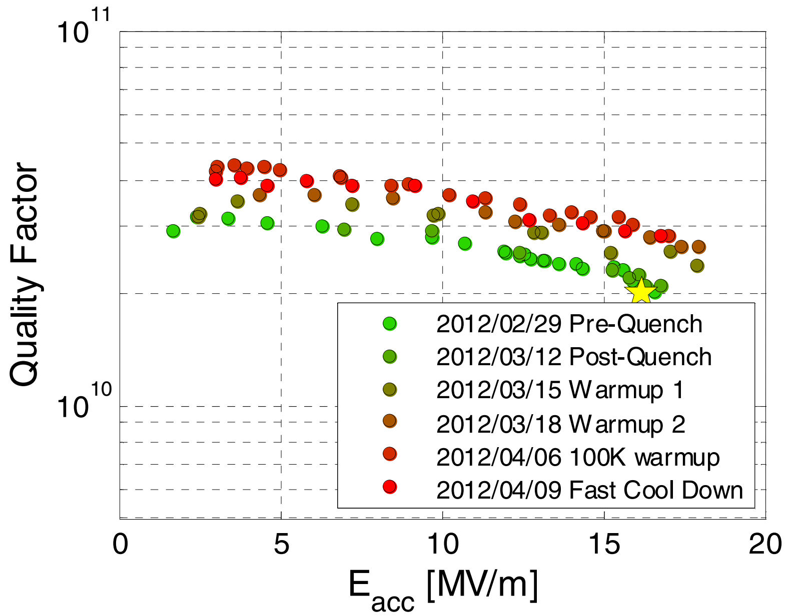
HTC-1 (Cornell, Nick)

Superconductor properties



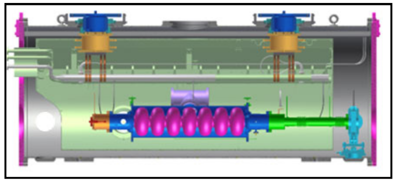
- $T_c = 9.15$ K
- Resid. resistance = 6.5 nΩ
- RRR of RF layer = 11.8

Thermal Cycling Investigation



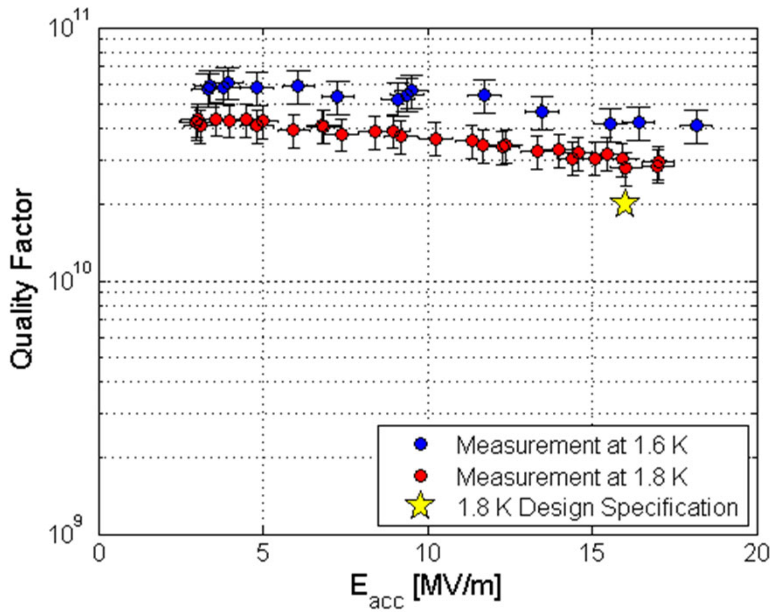
Temperature Cycling

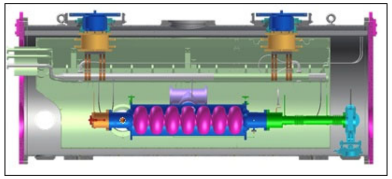
- First cycle > 10 K
- Second cycle > 15 K
- Final cycle > 100 K



HTC-1: Results (Cornell, Nick)

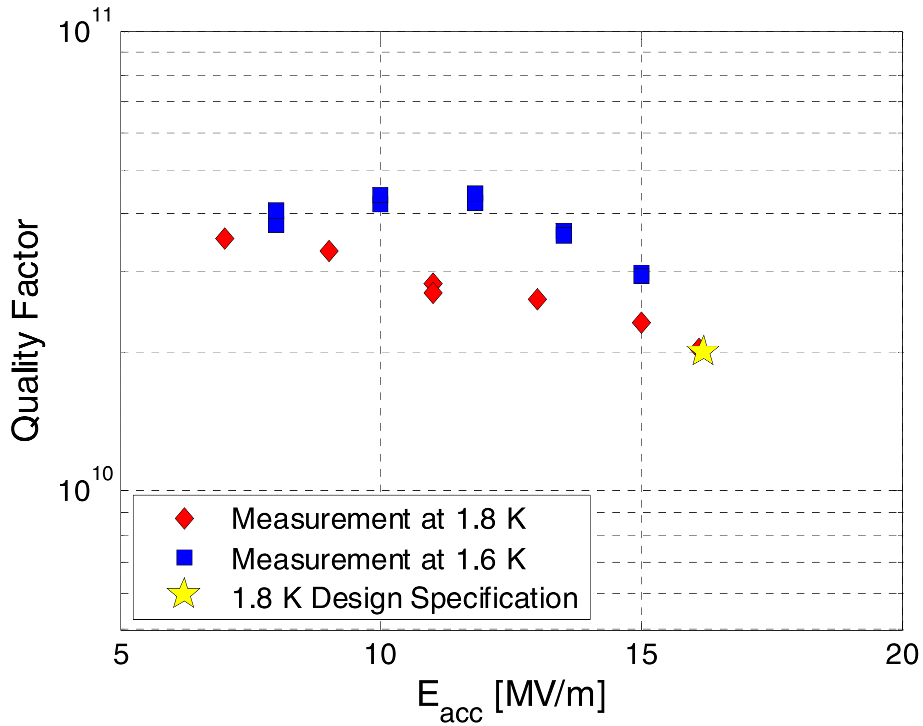
- Cavity exceeded Q specification at 1.8 K by 50%, reaching $3x10^{10}$
- Q(1.6 K, 5 MV/m) = $6x10^{10}$
- Exceeded gradient specifications
- RF-based and calorimetric-based Q measurements yielded consistent values

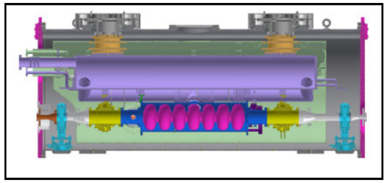




HTC-2: Results (Cornell, Nick)

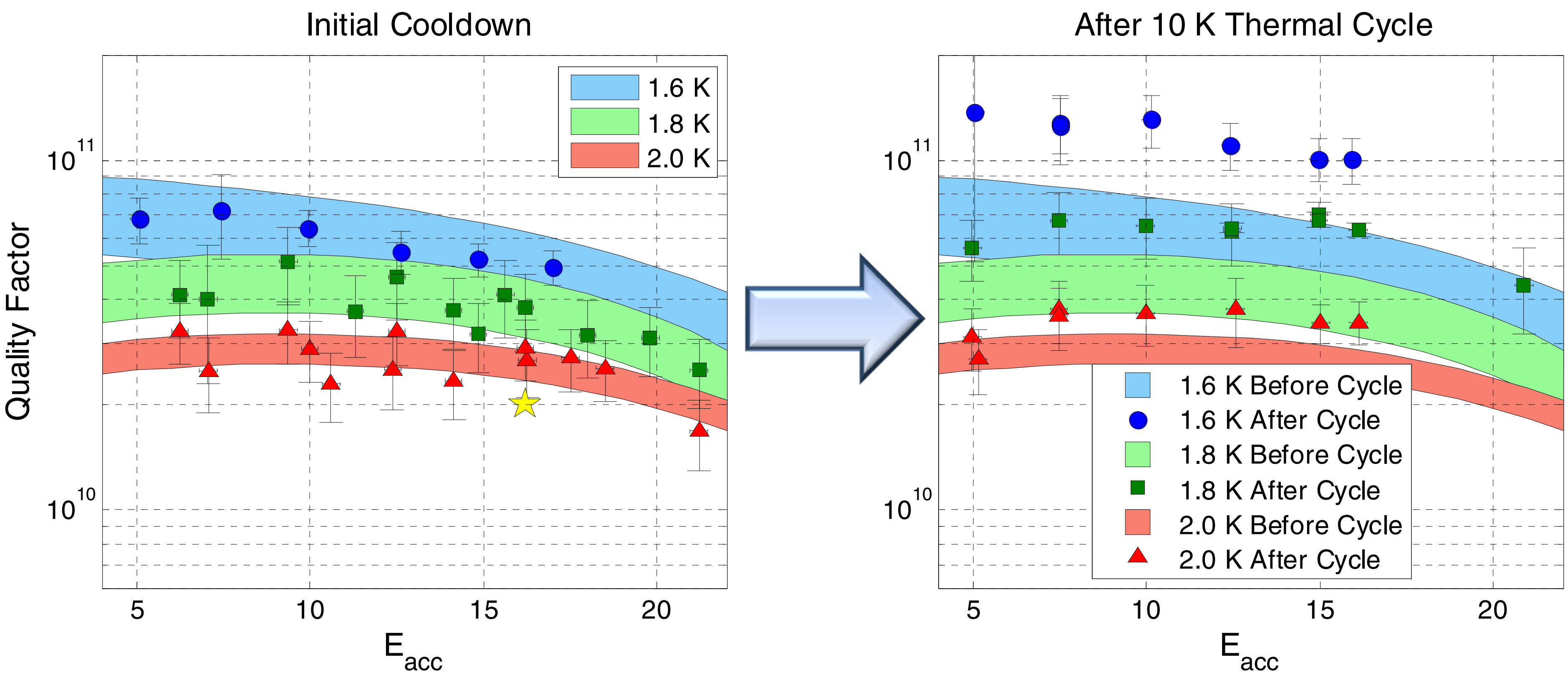
- Quality factor, gradient specifications achieved
- Administrative limits prevented higher field measurements (not limited by quench)
- Lower Q (than HTC-1) due to high radiation levels





Q0>1*10^11 (??) ほんまか？

HTC-3: Results (Cornell, Nick)



Initial Cooldown at 16.2 MV/m

$Q(2.0\ K) = 2.5 \times 10^{10}$

$Q(1.8\ K) = 3.5 \times 10^{10}$

$Q(1.6\ K) = 5.0 \times 10^{10}$

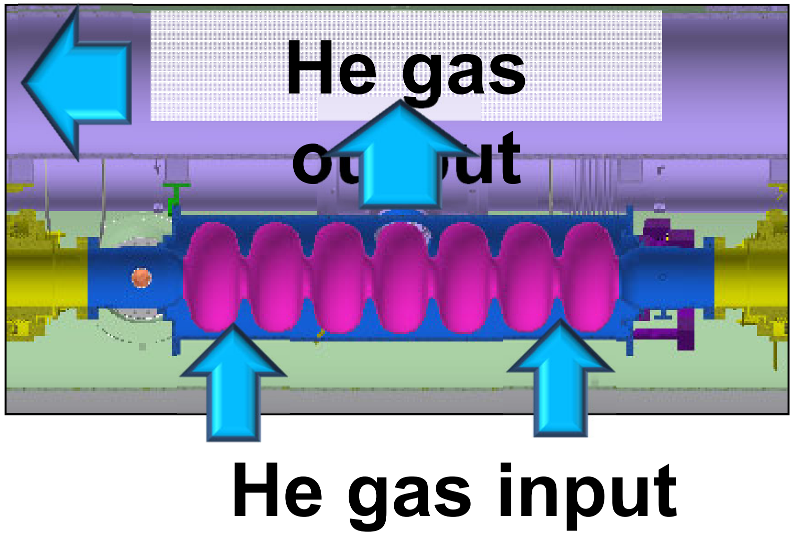
10 K thermal cycle at 16.2 MV/m

$Q(2.0\ K) = 3.5 \times 10^{10}$

$Q(1.8\ K) = 6.0 \times 10^{10}$

$Q(1.6\ K) = 10.0 \times 10^{10}$

High Q Cryomodules (Cornell, Nick)



- Magnetic shielding is essential
- Thermal gradients across cavity should be minimized to get high Qs
- Cavity temperature gradient ~0.2 K
- Cool down rate through T_c: ~ 0.4 K/hr

6 Cernox temperature sensors mounted on top and bottom of end cells and center cell

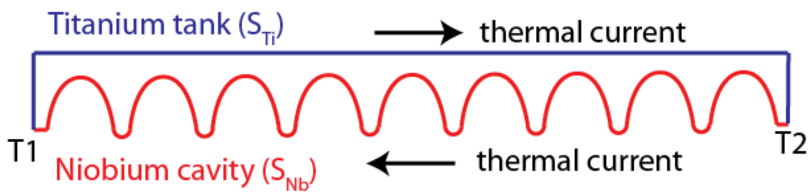
Thermal currentをなくしながら冷やせばQ0は上がるはずという結論。難しいか？？

Thermocurrents (HZB, Axel Neumann)

Thermoelectric effect:
Voltage due to material and temperature dependent charge carrier velocity

$$U_{thermo} = (S_{Niobium} - S_{Titanium}) \cdot \Delta T$$

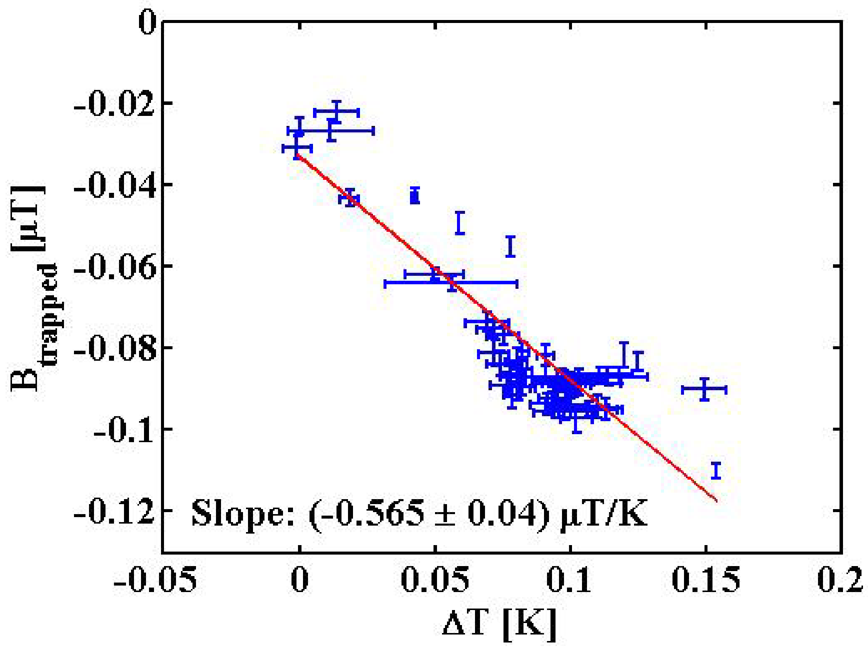
S are Seebeck coefficients

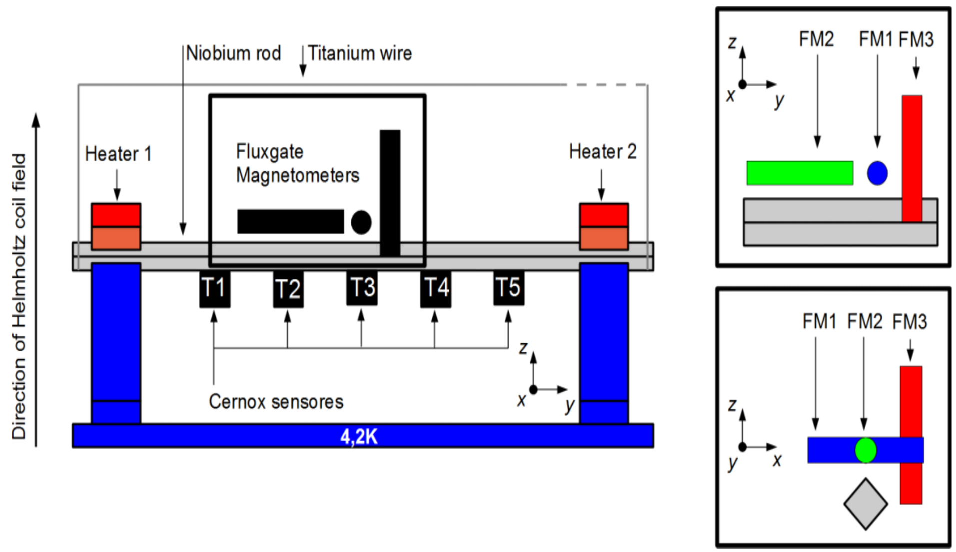


Cavity-tank system as „thermoelement“
Close circuit to obtain thermocurrent.

Master thesis Julia Vogt, see poster WEPWO004 for further details

Set up model experiment





High Q0 Topic

- What is the good material and treatment for High Q0 ?
  - Furnace temperture (with N2 gas)
  - BCP or EP ?
  - HF rinse for finalization
  - Large grain / fine grain
  - Baking 120C ?
- Magnetic shield is essential for High Q0
- Thermal cycle near Tc is effective for high Q0
- How to suppress field emission on string assembly

(5) CW couplers

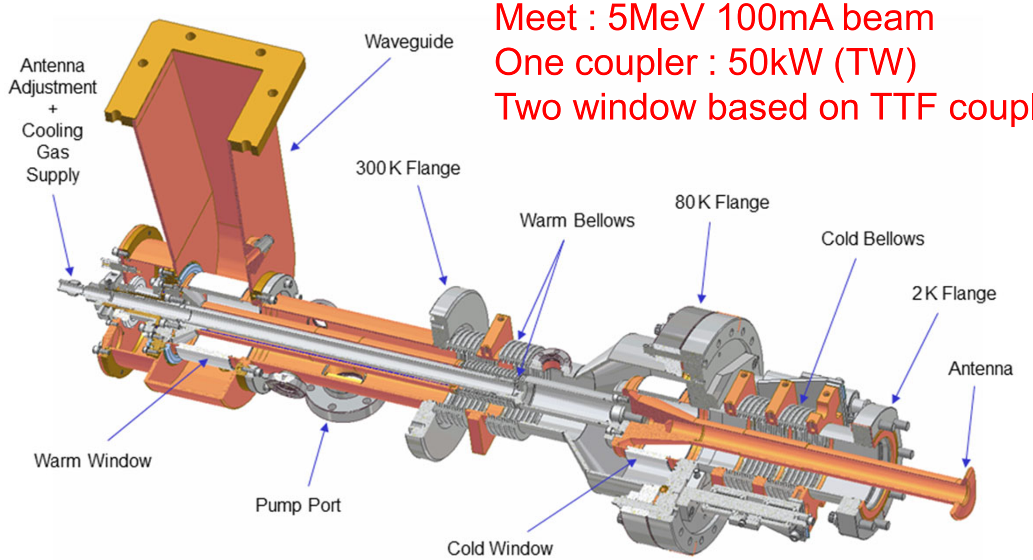
- Cornell main linac coupler (Vadim Veshcherevich)
- KEK ERL main linac coupler (Hiroshi Sakai)
- Project-X couplers (Timergali Khabiboulline)

  → chokeを使った形、ほんまにできるのか？
- JLAB waveguide couplers (Gigi Ciovati)
- Cornell injector coupler (Vadim Veshcherevich)
- KEK ERL injector coupler (Eiji Kako)

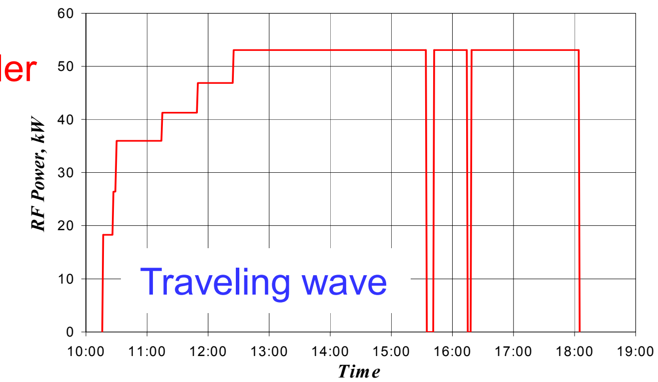
CW対応した各入力カプラーの状況報告がメイン。やはりコーネルのinjectorのカプラーが60kW程度のCWまで対応して、さらにbeam運転しているというのがすごいなという印象。あとJlabのwaveguide couplerの現状などが知れたのが良かったか？KEKからも加古さんと阪井でcERL カプラーの現状報告。Jlabでは常温agingをしないというのは少し驚き。

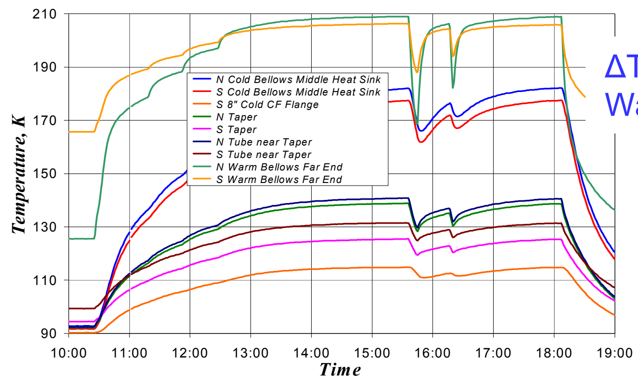
Cornell ERL injector coupler (Vadim)

Variable :QL=9.2*10^4 – 8.5*10^5
Meet : 5MeV 100mA beam
One coupler : 50kW (TW)
Two window based on TTF coupler

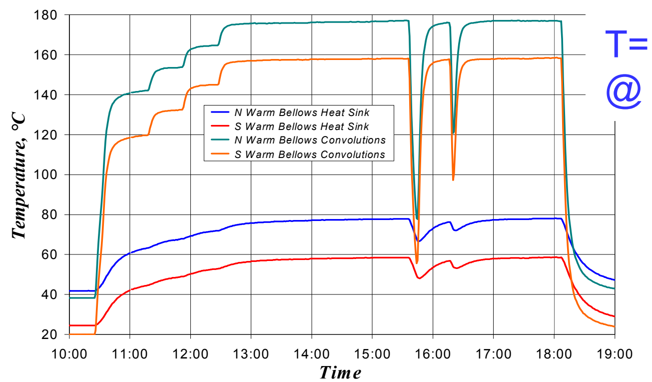


Results of test stand





ΔT= 80K
Warm bellows

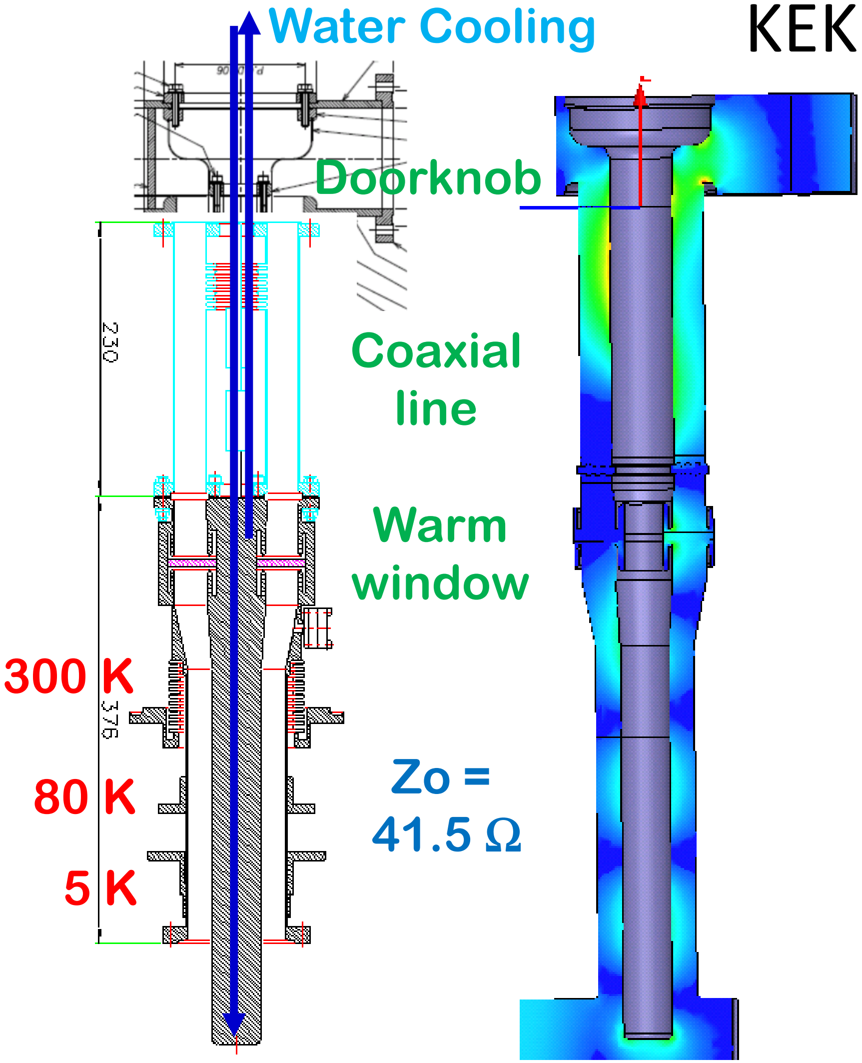


T= 180°C
@ bellows

Present status

- Two of ten couplers were tested on the test stand up to 61 kW CW.
- In the cryomodule, couplers were processed in pulse and CW modes w/o beam; finally processing is going on during high current beam operation.
- RF power up to 40 kW CW per coupler was applied so far during beam operation.
- Beam current up to 75 mA was accelerated in the ERL Injector.
- High current beam operation will be continued.

KEK ERL injector coupler (Kako)



Inner/outer conductor of warm parts were added water cooling

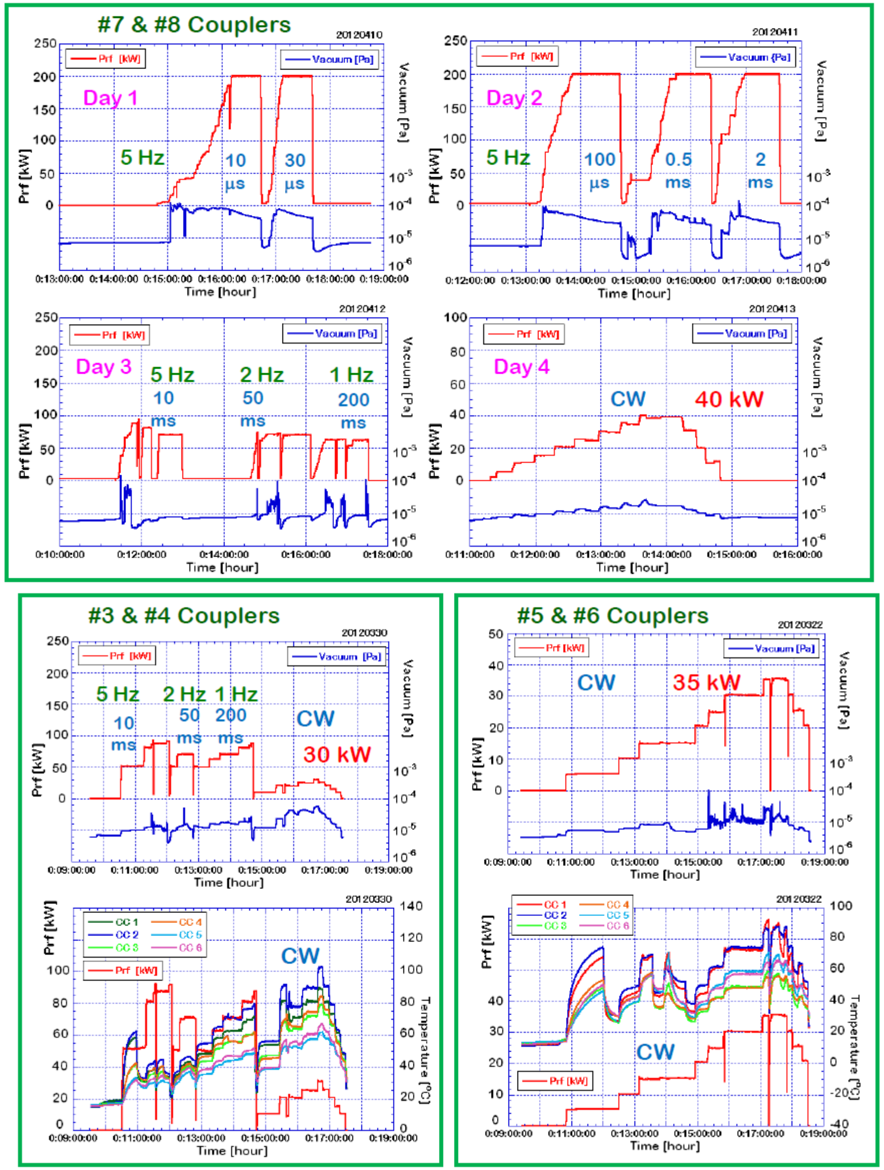
Now Beam operation of cERL started with

Eacc = 7.2, 7.3, 6.9 MV/m

P_{RF} = 3.0, 8.9, 8.1 kW /2

Q_L = 12.0, 5.8, 4.8 x 10^5

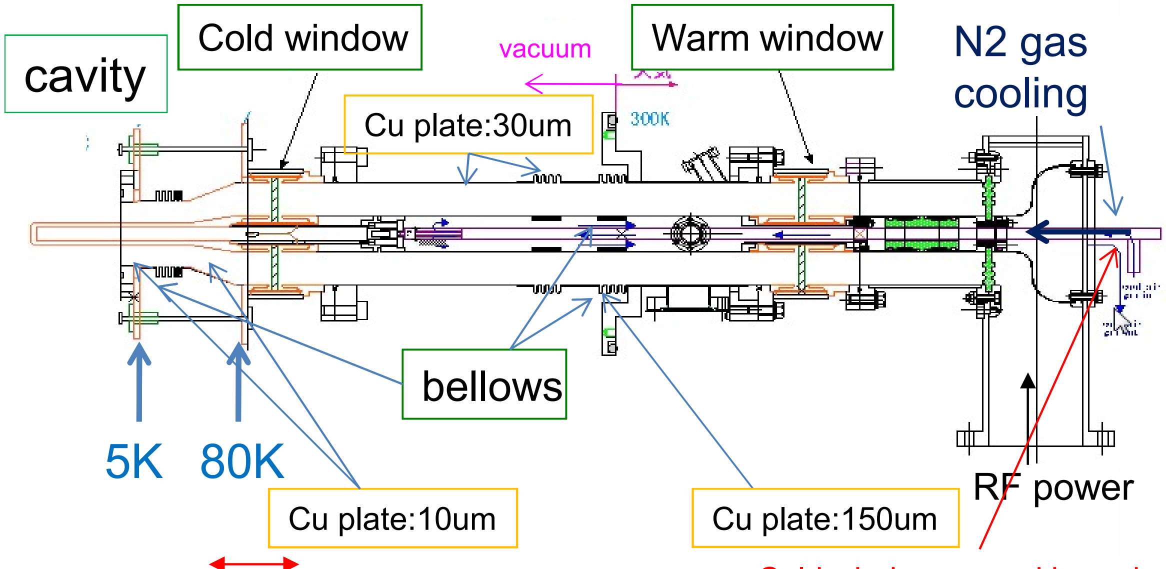
Test stand results

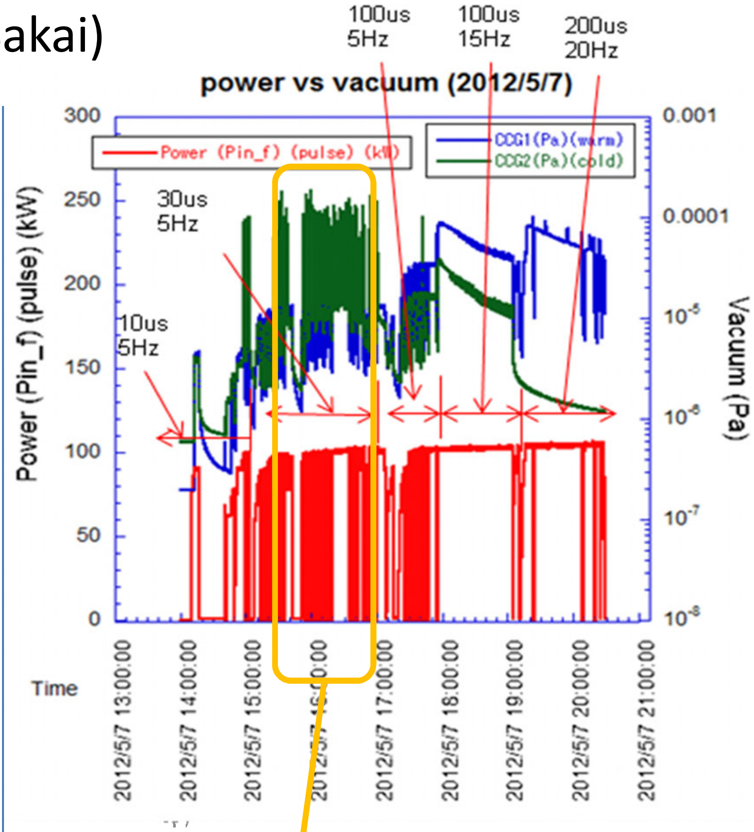


200 kW, <2ms, 5Hz (1%), 30~40 kW, CW

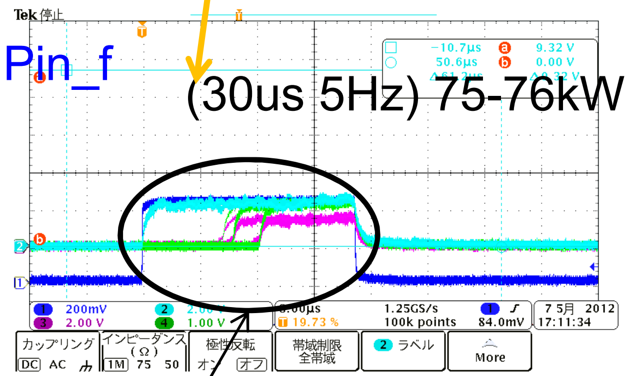
Basic design

KEK ERL main linac coupler (H.Sakai)





Power test @ test stand



Arc signal was delayed when we processessed –> arc sensor works well

•Basic parameters

frequency : **CW, 1.3GHz**

Accelerating gradient : **Max 20MV/m (First)**

input power : **max 20kW** , standing wave (michrophincs Δf=50Hz)

loaded Q(Q_L) : **(1-4) * 10^7 (variable coupling)**

- Present status

  105kW(20Hz,200us), 43kW CW power with traveling wave @ test stand

  Fiber arc sensor works effectively for ITL within 10us and see processing.

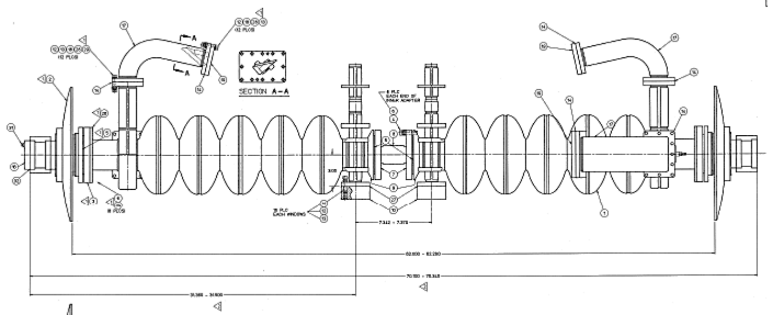
  cryomodule test of 2K condition up to 15kW SW on detune condition.

  We can keep 14MV with 4.5kW power feeding with QL=1.5*10^7 @2K

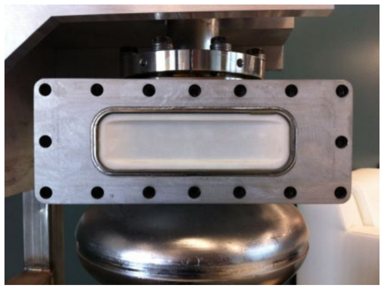
  Michrophonics of Δf=7Hz of pk-pk. This is much smaller than expected.

  No significant temperature rise was observed under 15kW power feeding.

Original CEBAF pairs (Gigi Ciovati)



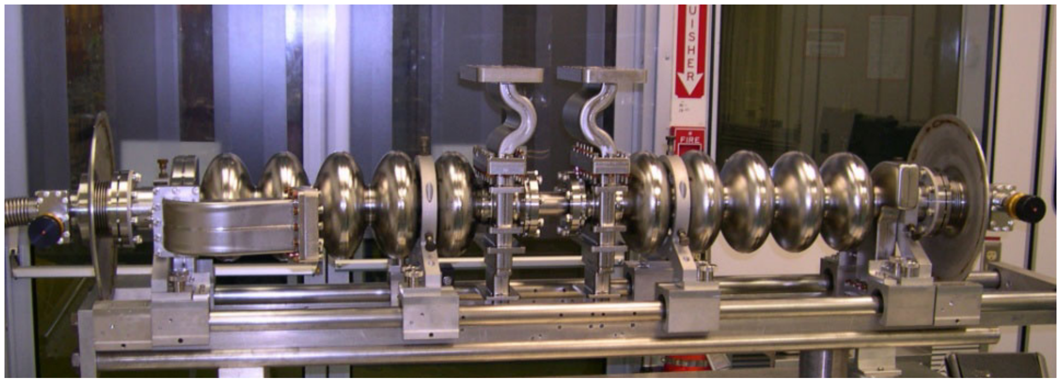
- Two 5-cell cavities back to back
- Waveguide FPC's with "stub on stub"
- 6 kW CW at full power (later 8 kW)
- Ceramic cold windows close to beam line, inside helium vessel
  - Cold window charging by field emission and arcing was a major cause of downtime
  - Managed by developing trip rate models for each cavity based on Fowler Nordheim field emission
- Waveguide HOM dampers cooled by helium (except for FEL)
- Polyethylene warm windows (later changed for ceramic)



Reworked "C50" pairs (Gigi Ciovati)

- Reprocessed 10 weakest modules
  - Reworked original cavities (BCP + HPR)
  - Gradients improved from ~5 MV/m to ~12MV/m
- 8 kW CW maximum power
- Added dogleg to shield cold window
  - Eliminated cold window arcing
- Rework of tuners to reduce backlash
- Next module will be the same except EP and remove some magnetized components from the tuner

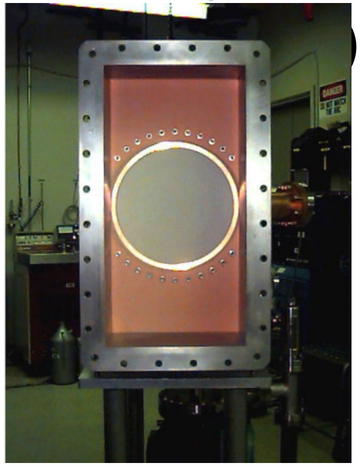
Dogleg waveguide



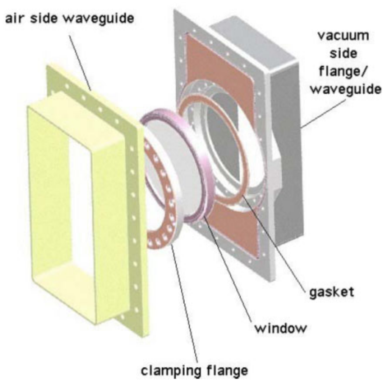
JLAB HC Cryomodule RF High Power Window (Gigi Ciovati)

High power capability required.

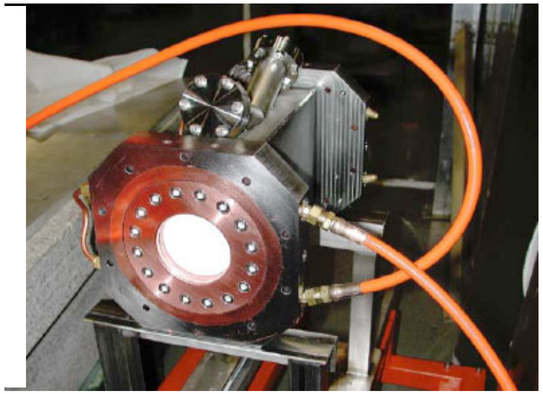
- A waveguide RF window was preferred to a co-axial design
- Design is based on water cooled scaled PEP-II type window design, (tested near 1 MW CW at 700 MHz for LEDA)
- 1497 MHz prototypes have been built, window ceramic thickness optimized in test fixture
- High power tested to 60 kW CW at JLab FEL (limited by



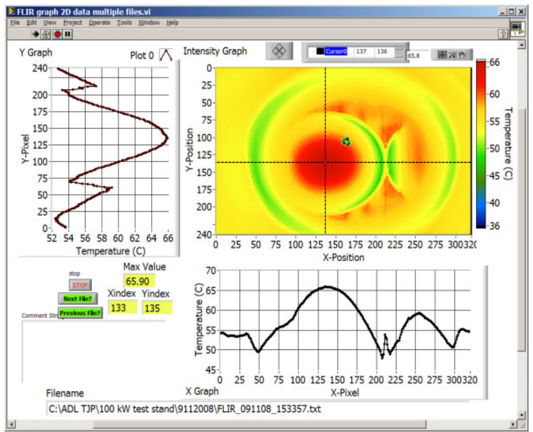
PEP-II 476 MHz waveguide window assembly



LEDA 700 MHz waveguide window assembly



JLab 1497 MHz window on test box



High power IR image

Rimmer, Elliott, Marhauser, Powers, Stirbet

CW coupler topic

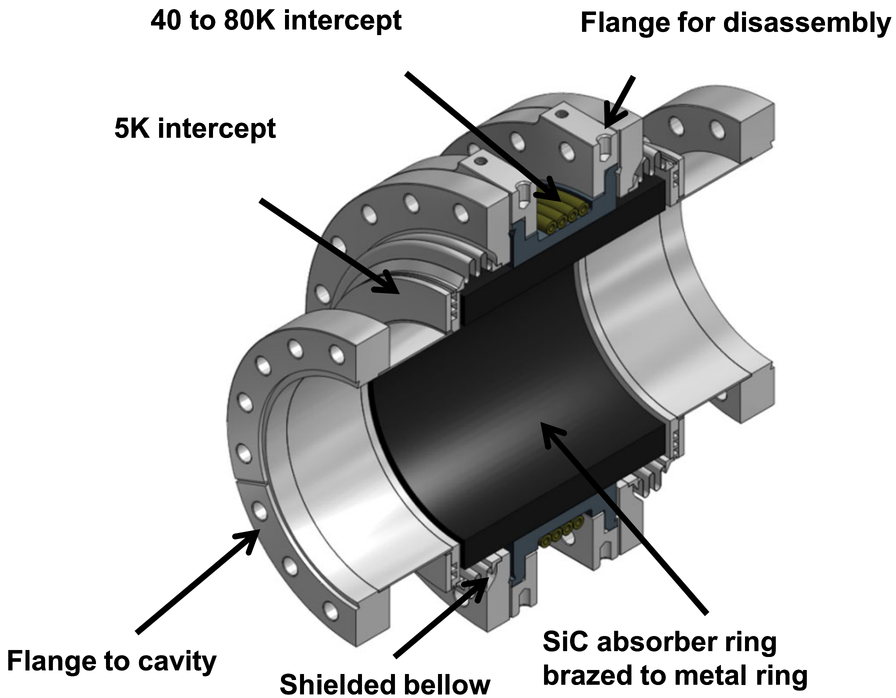
- Cold窓は必要か？ →割れない実績があるならCold窓なしでもいいというのはJLABの主張。Mollerは反対していたようだが？？
- 窓が割れた時や運転でビームに対してITLを如何に早く落とすか？ → arc sensor や Electron probeなど、使えるのかと聞かれたので私からはCold窓でfiberを使って a few usでITLが可能であると主張しておいた。
- Wavegude とcoaxialどちらがいいか？→結論はでなかった。Wave guideのCold窓は無い方がいいが、それをwarmに置いて運転する分には今のところ問題なし。static入熱に関してはメラーはwavegudeの方がcoaxialより4倍大きいと主張。またvariableができないのは難点などの主張あり。Jlabからは内導体の発熱をどう抑えるかなどの反論あり。

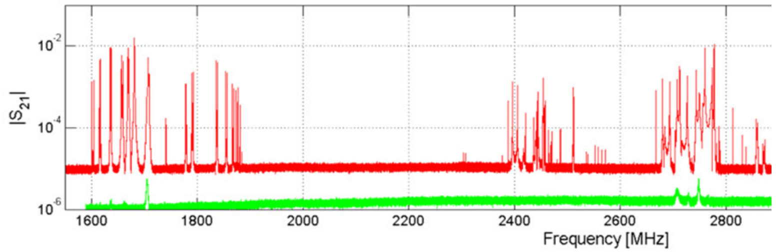
(6) HOM absorbers

- Cornell HOM beamline loads (Ralf Eichhorn)
- KEK HOM couplers (Eiji Kako)
- KEK HOM beamline loads (Kensei Umemori)
- CEBAF waveguide absorbers (Gigi Ciovati)
- XFEL beamline loads and HOM couplers for CW (Denis Kostin)
- HOM dampers development for the APS upgrade short pulse X-ray (Geoff Waldschmitt)

このsessionも盛り上がったsessionの一つ。特にCW運転にはコーネルなどでSiCを使ったHom absorberをテストしているが、leakに悩まされている。KEKからはHOM couplerは現在発熱が問題であると加古さんが発表。HOM absorberはcERLに組み込んで動作的には問題ないが、ferrite with HIPでクラックが入るとの報告を梅森さんから報告。CW用のHOM absorber開発が難しいと再認識。ここらへんで、CW用ではないが、DenisがXFEL用に設置したHOM coupler &HOM absorber (AlN)がうまく動いているとの報告。これとは別にCEBAFのwaveguide absorberはこれからが期待か？

Cornell Main Linac HOM Absorbers (Ralf)

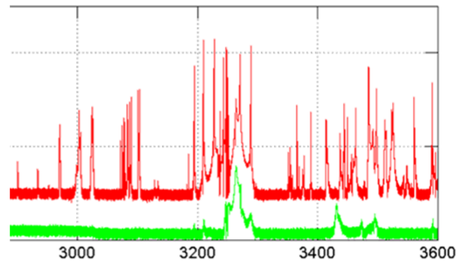




No HOM Loads

With HOM Loads

$Q_0 > 2*10^{10}$ for the fundamental mode

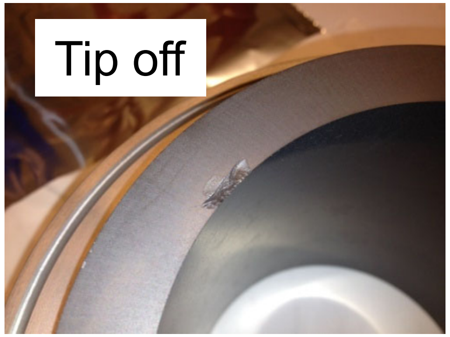


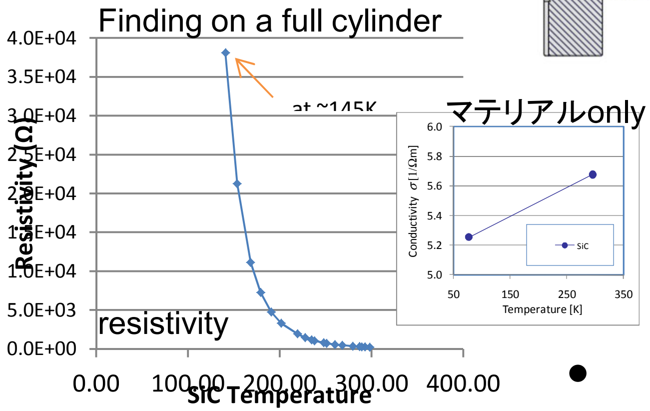
Cavity for HTC3

- Full-circumference heat sink to allow >500W dissipation @ 80K
- Broadband SiC absorber ring
- Includes bellow sections
- Flanges allow easy cleaning
- Zero-impedance beamline flanges

Issues for cornell SiC absorber (Ralf)

- We have a vacuum to vacuum leak in HTC 3
- Tungsten becomes porous under brazing cycle
- SiC is not a nice material
  - Strong outgasing
  - High particle contamination
  - Tends to chip
- How reliable is the material?

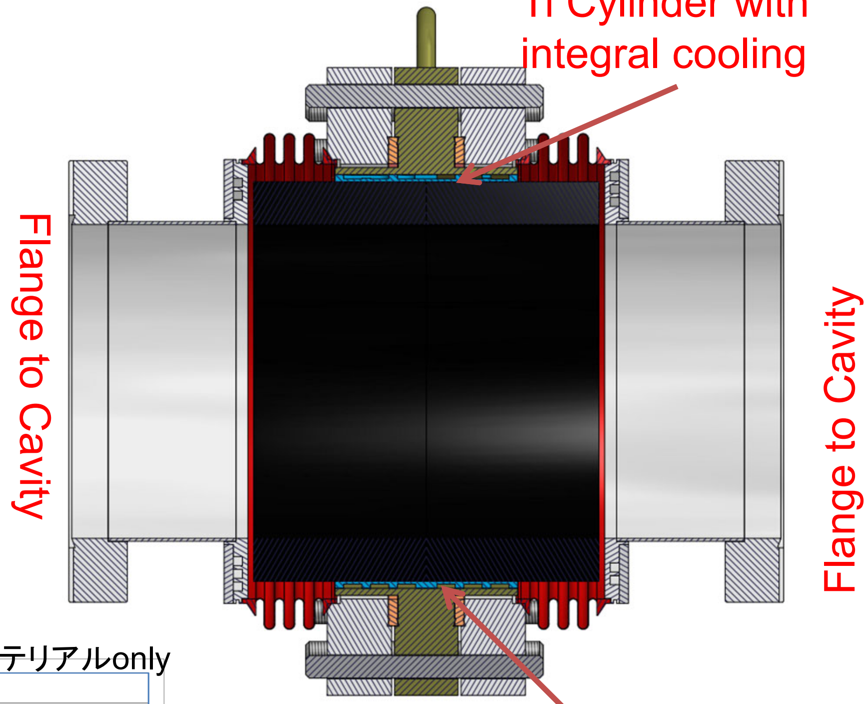




今回のダンパーに関してもかなり自信がなさそう。

Next Version

Shrink-fitting SiC to Ti-5



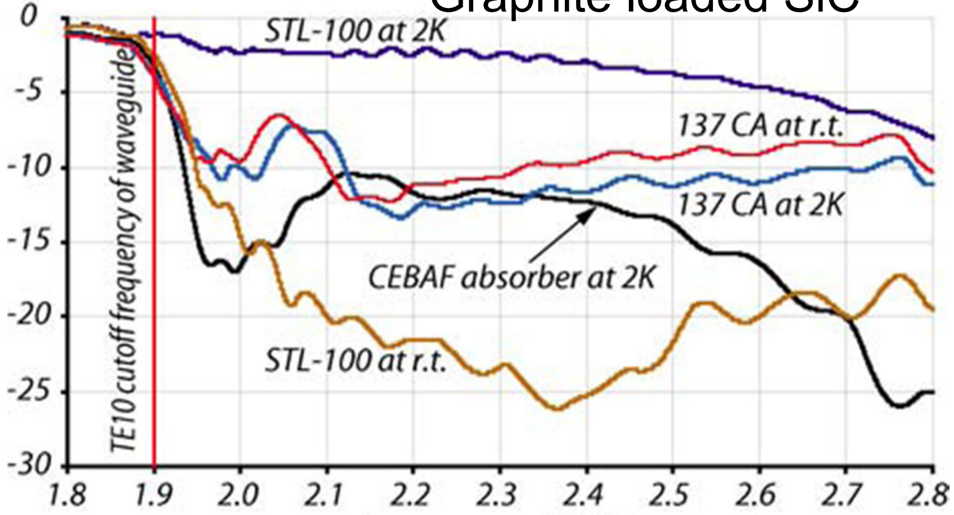
- Use AlN instead of SiC?

Jlabのマテリアルを使うのか？？

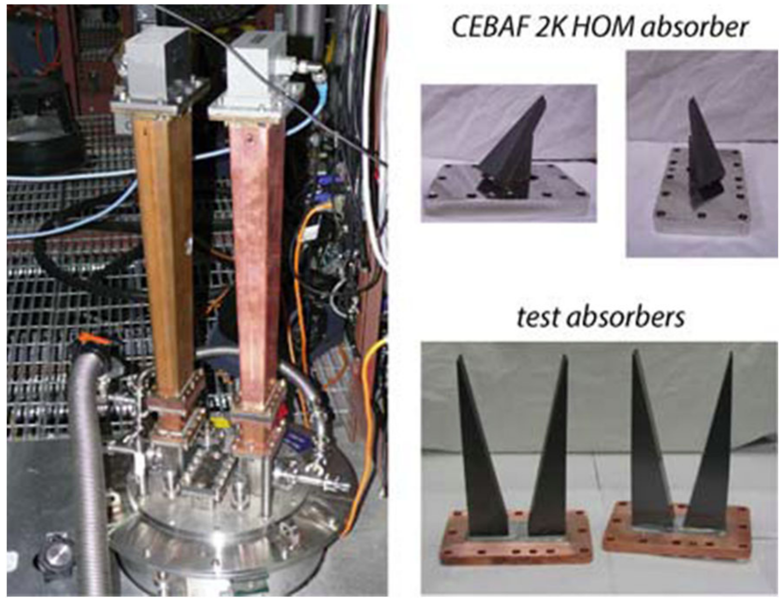
(CEBAF) Cold measurement of new materials

- Special waveguide test insert allows cryogenic RF measurements of test loads and material samples

Graphite loaded SiC



Example: Reflection response of different AIN-based composites measured at room temperature (r.t.) and 2 K, compared to original CEBAF load.



Test setup in the vertical Dewar (left), CEBAF absorber (top right) and two different wedge absorber assemblies (bottom right) made of ceramic AIN-based composites.

MARHAUSER PAC09

KEK ERL HOM absorber (K.Umemori)

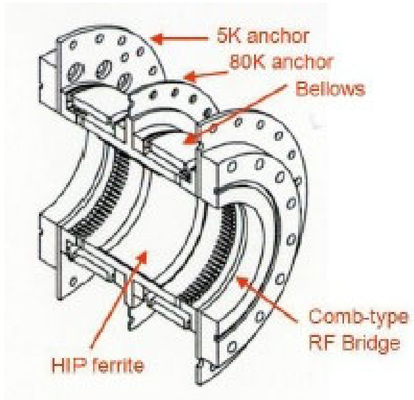
HOM absorber (SBP 1つ, LBP 2つ)

・HIP ferrite (IB004) on Copper beampipe

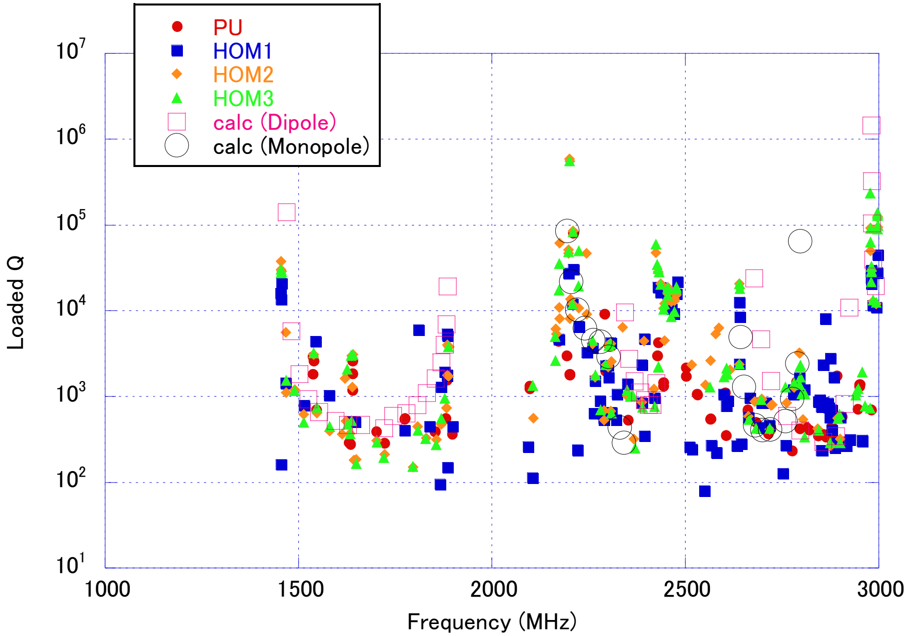
・Outside: bellows, Inside Comb-type RF bridge

・Operation at 80K. (expected 150W HOM power 3ps bunch length)

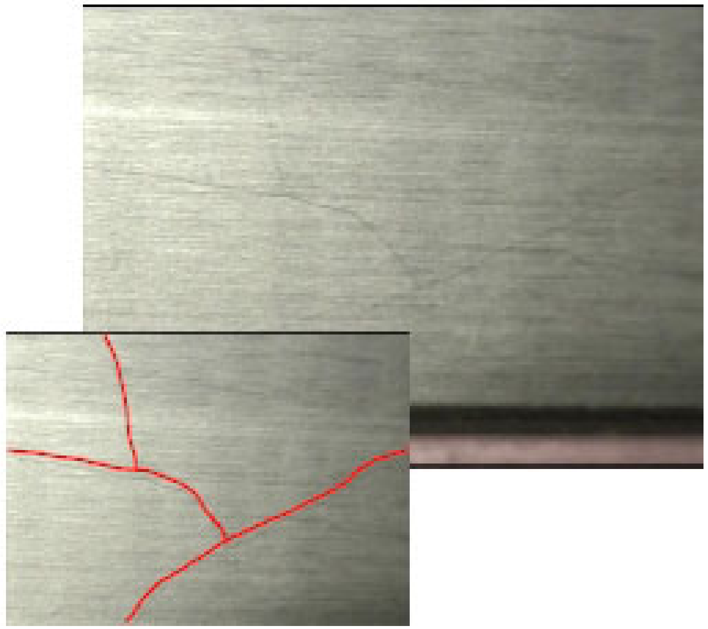
・Check enough absorption ability of ferrite at 80K



Their behavior, frequency and loaded Q values, were generally agreed with calculation results on cryomodule test



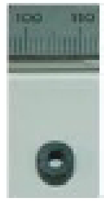
- Under thermal cycle between 300K and 80K, we observed some crack around edge of ferrite damper.

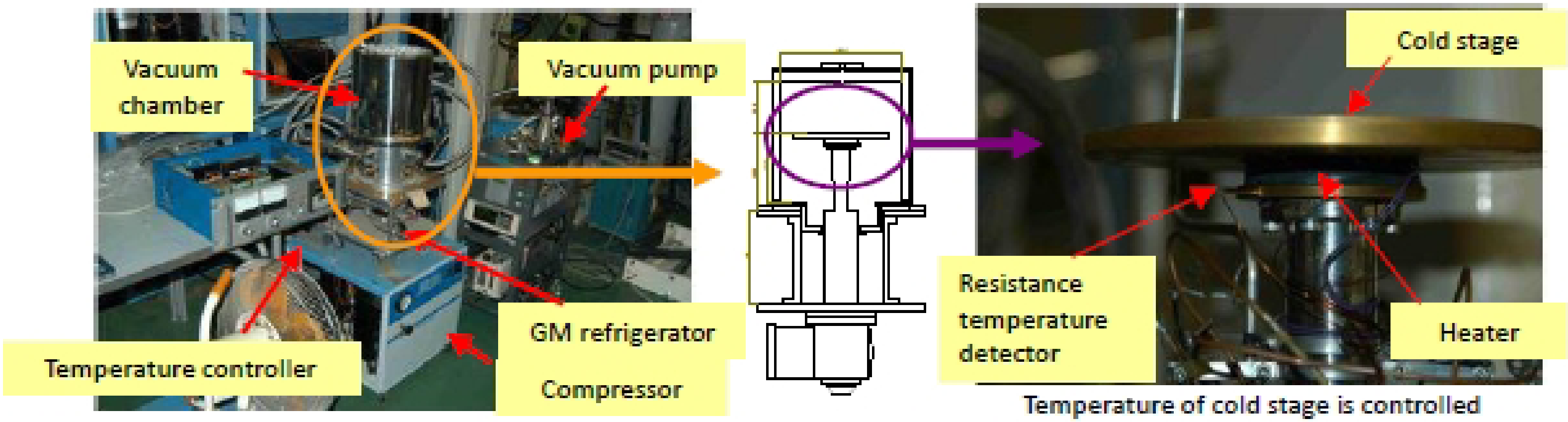


Low temperature RF character (Umemori)

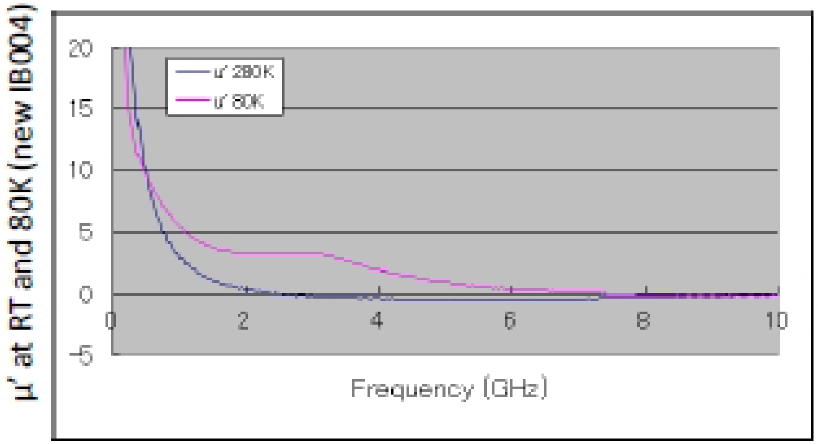
Low temperature measurement of RF absorber's characteristics

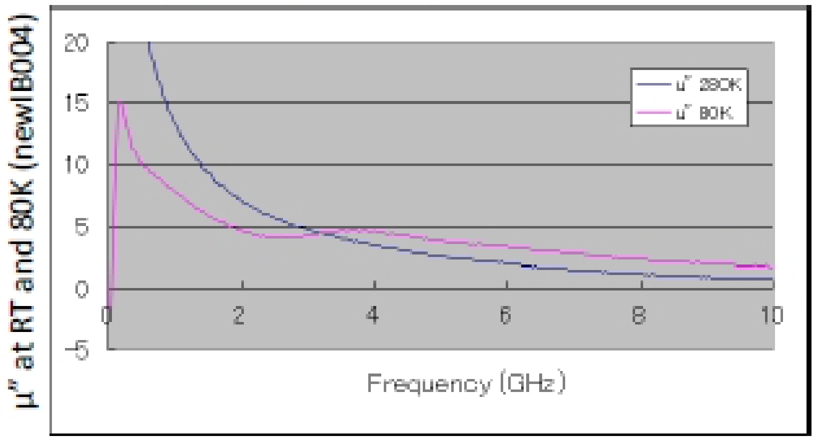
- RF absorber should work at 80K
- Temperature dependence was measured while cooling with refrigerator





Temperature of cold stage is controlled



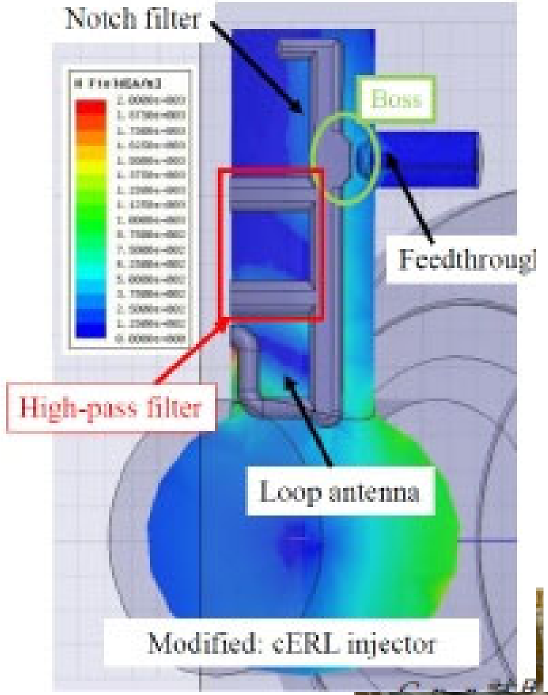


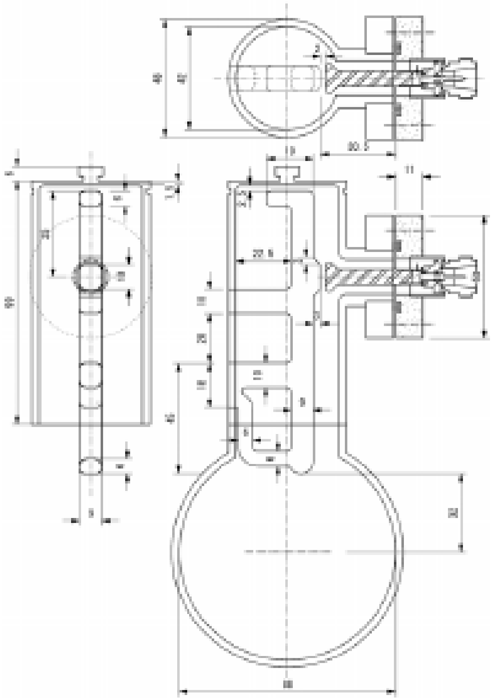
Good absorption at low temperature. In cryomodule test , this damper works well.
But under HIP condition some crack was observed.
And we also see the high resisitivity on 80K → charge up. And no-bakable.

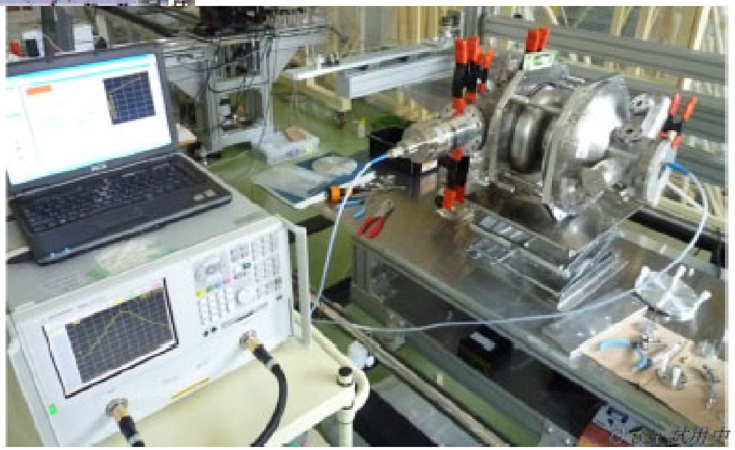
We also would like to search another material like SiC and/or AlN.

KEK ERL HOM coupler (Kako)

Design and Measurement







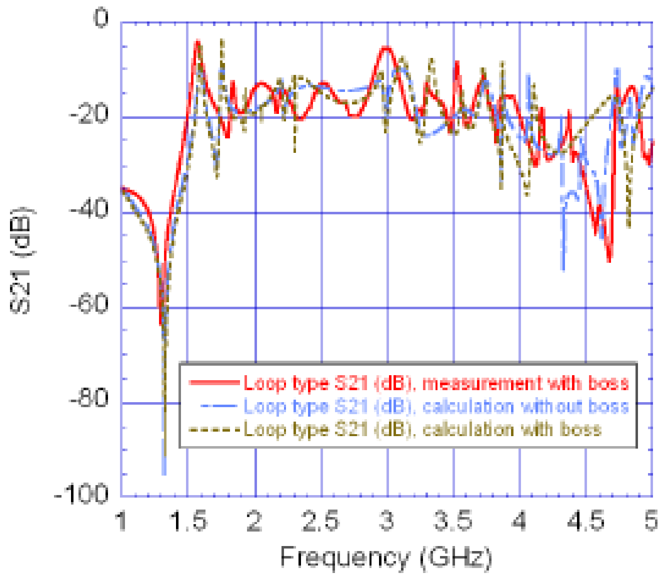
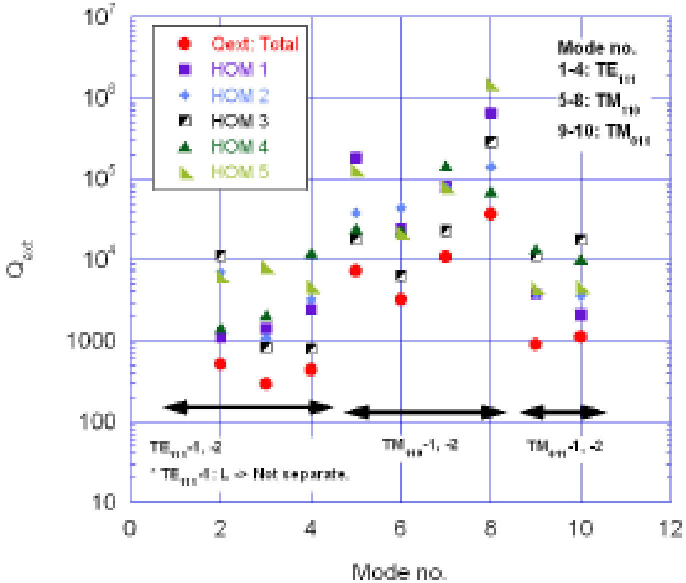


fig13a_rivise.tif



By K. Watanabe

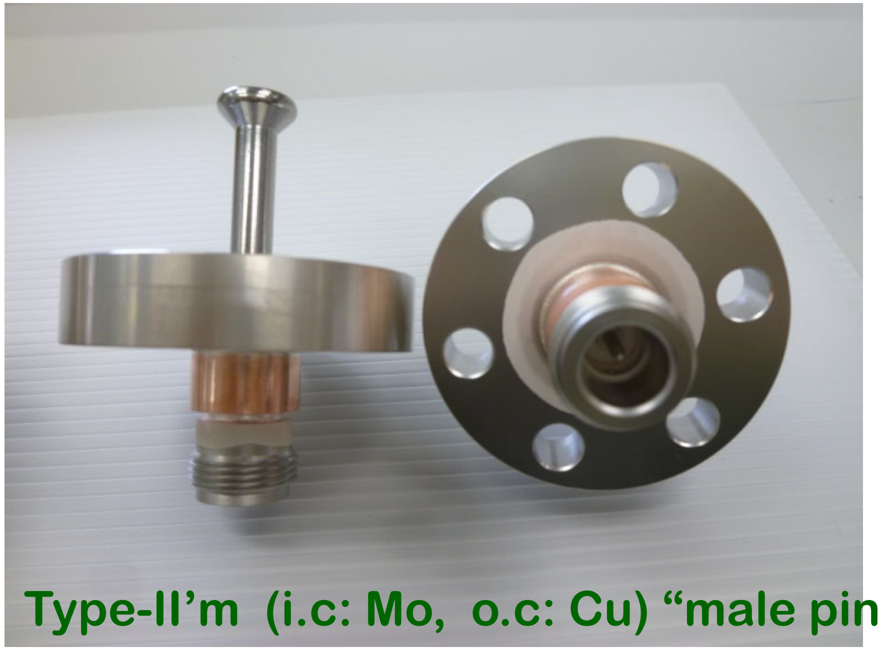
Qextは問題なし。

RF Feedthroughs (Kako)

Type-0 (i.c: Kovar, o.c: Kovar)

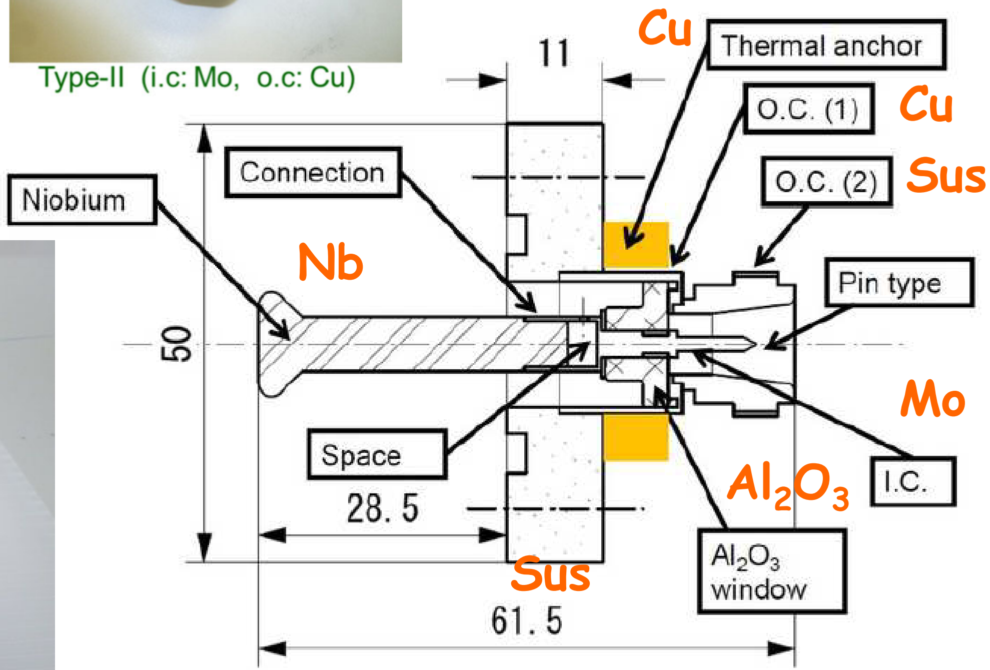
Type-I (i.c: Mo, o.c: Kovar)

Type-II (i.c: Mo, o.c: Cu)



Type-II'm (i.c: Mo, o.c: Cu) "male pin"

By K. Watanabe



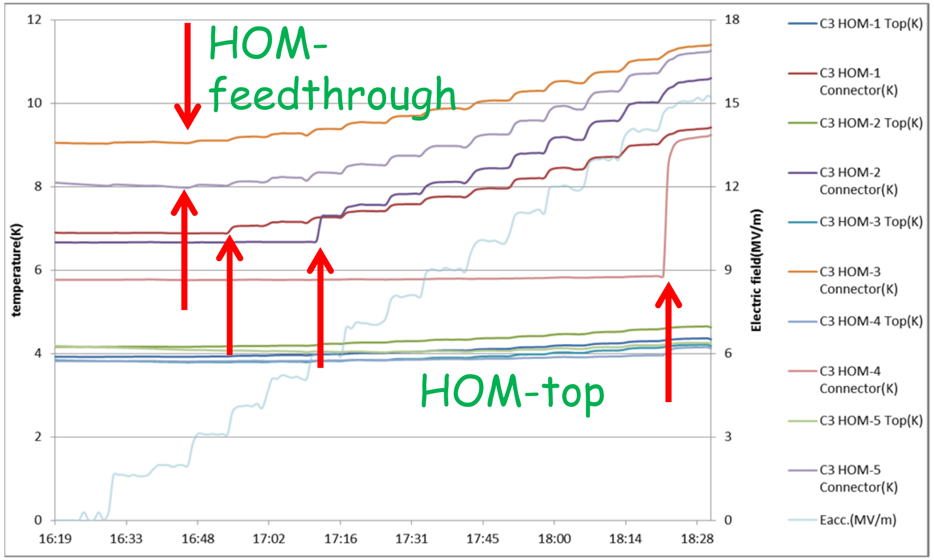
Order for next,

Type-III ; Al_2O_3 → Sapphire

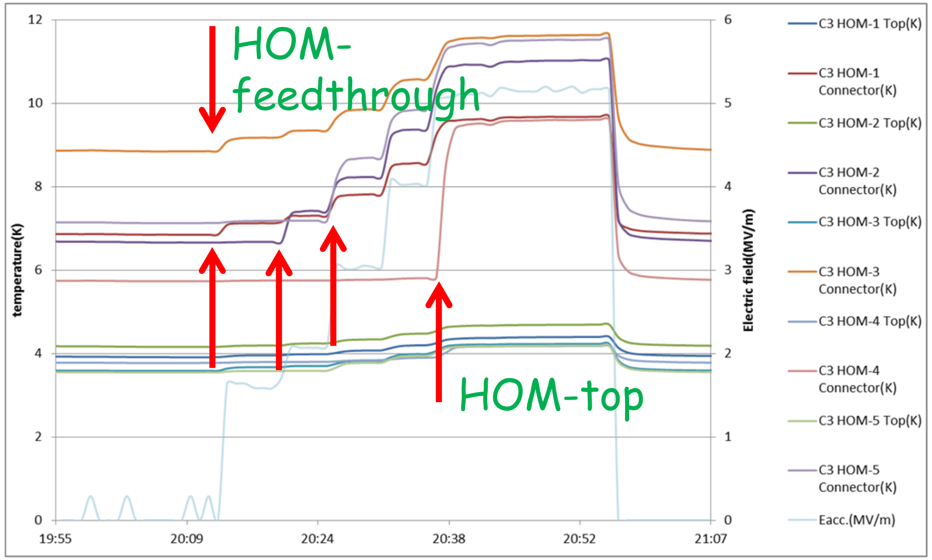
Sus flange → Ti

Dynamic Temperature around HOM Couplers (No.3 cav in module) (Kako)

No.3 Cavity (50 ms, 2 Hz, 10%)



No.3 Cavity (CW)



Eacc at antenna quench

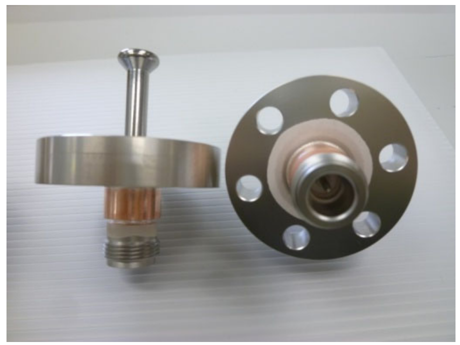
現状の問題点
低い電圧で
HOMのprobeが
クエンチしている。

No.3 Cavity (10% Duty)

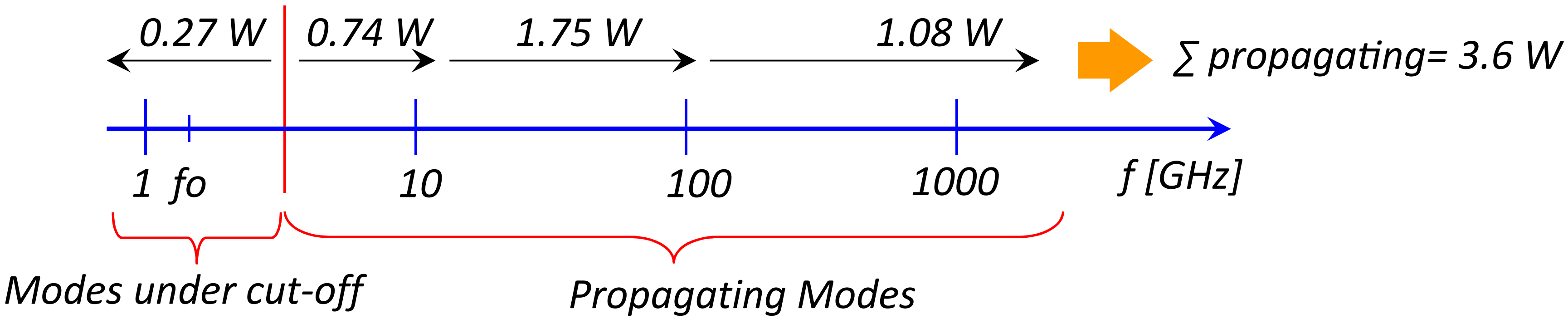
HOM-1: 4 MV/m
HOM-2: 6 MV/m
HOM-3: 3 MV/m
HOM-4: 15 MV/m
HOM-5: 3 MV/m

No.3 Cavity (CW)

HOM-1: 1.7 MV/m
HOM-2: 2 MV/m
HOM-3: 1.7 MV/m
HOM-4: 5 MV/m
HOM-5: 3 MV/m

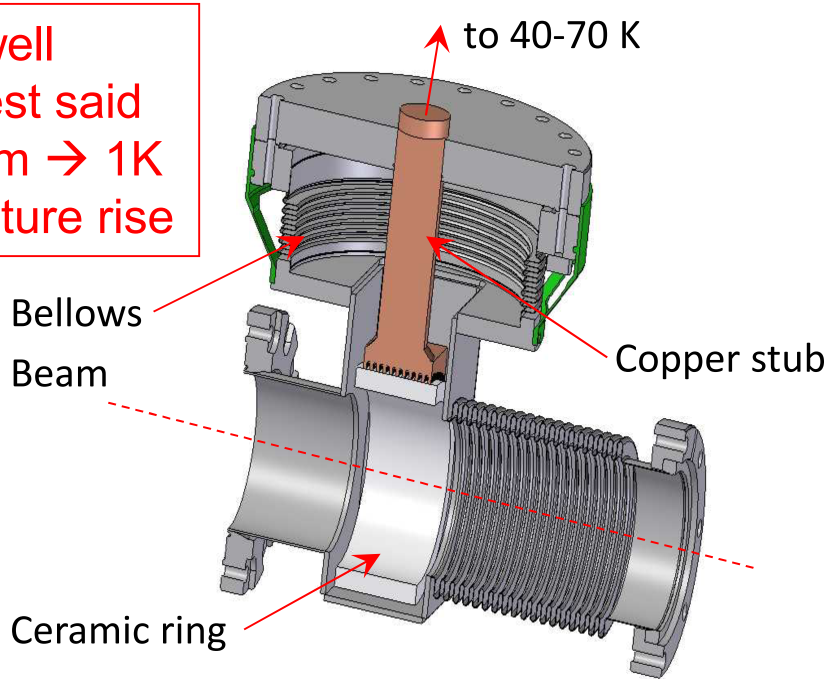


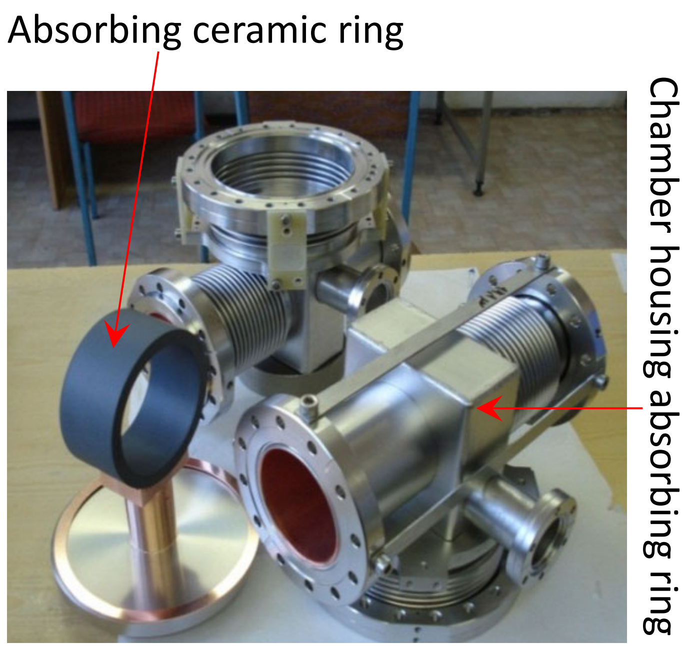
XFEL beamline loads and HOM couplers for CW (Denis)



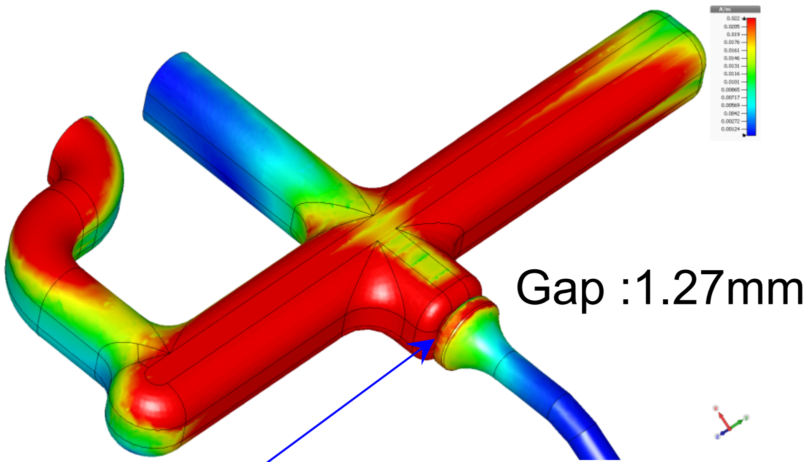
The XFEL beam line absorbers suppressing propagating modes have capacity of 100 W, which makes them suitable for large DF operations .

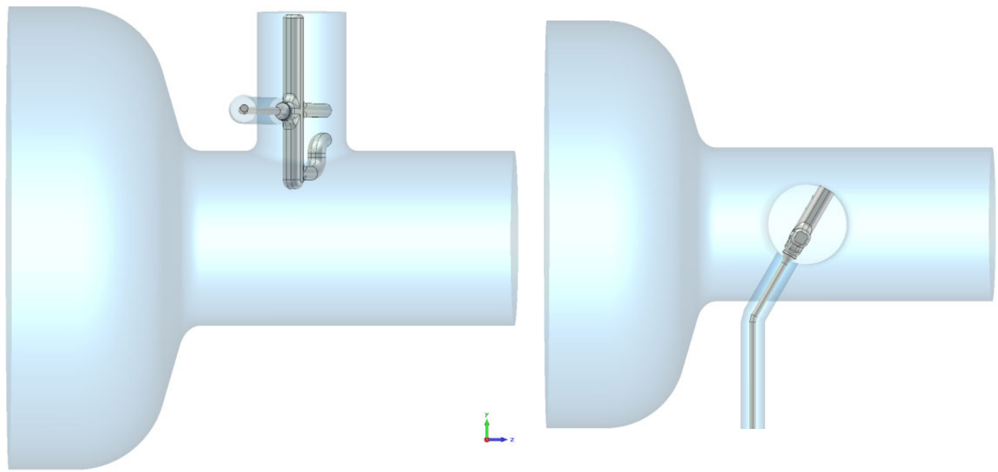
Works well
Beam test said
1.5 Phom → 1K
temperature rise

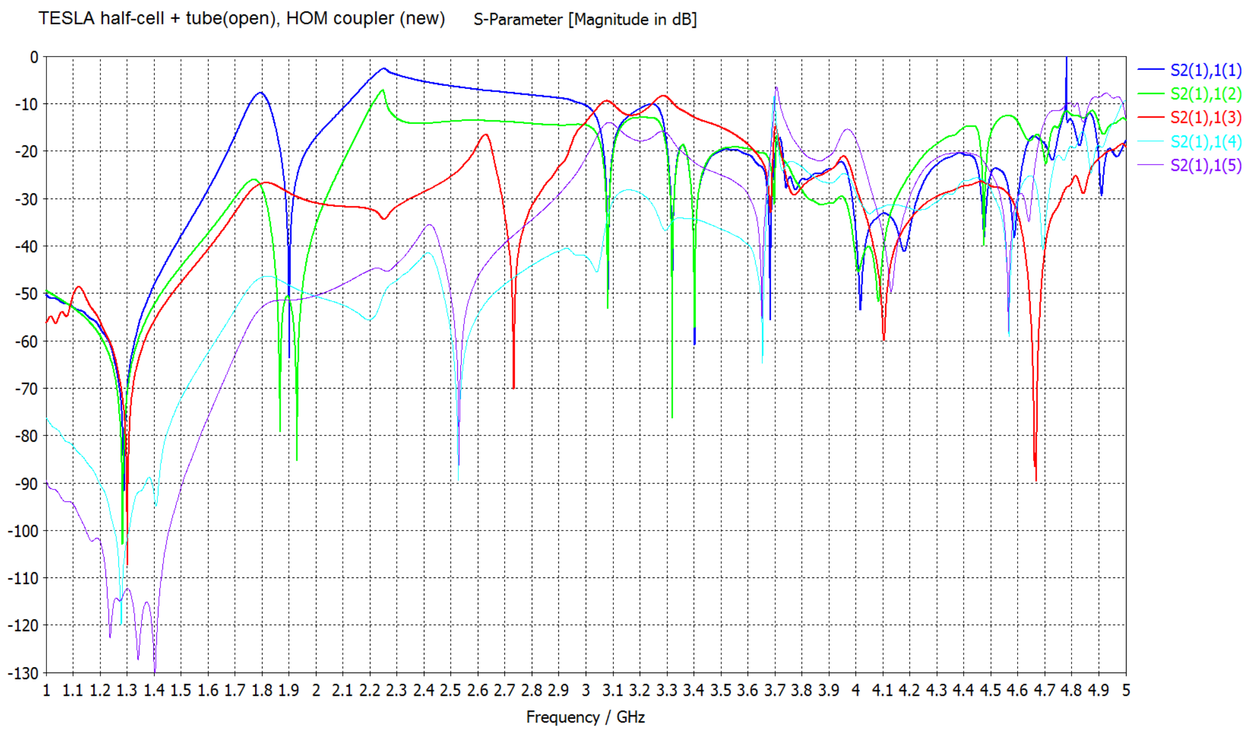




XFEL HOM coupler simulation work (Denis)







plot max. 0.022 A/m with 1 W input tube power

HOM absorbers topics

- Are we happy? (Cornell case → no)
- Maybe not! (cornell ,KEK, Jlab , DESY)
  - What is the best broad-band absorbing material?
  - How reliable is it? (blasing ? , HIP bonding)
  - How to realize the vacuum barrier?
  - How much should we care about cleaning issues?
- HOM coupler or HOM damper ? → damper can absorb the large heat load.
- Waveguide or beamline load ?

→waveguide is better than beamline load on the view points of packing factor.

(7) CW cryomodule

- International ERL module (Alan Wheelhouse)
- NGLS modules (John Corlett)
- Cornell MLC (Ralf Eichhorn)
- CW cryomodule design for Project X (Yuriy Oriov)
- JLAB upgrade module cost and optimization (Tom Powers)
- KEK ERL injector module (Eiji Kako)
- CW operation of XFEL module (Wolf-Dietrich Moeller)
- KEK ERL main linac module (Hiroshi Sakai)

今まで色々出てきたので、詳細は割愛。Daresburyでinternational ERL moduleがようやく冷却試験を開始。Cornellなどは6個入り空洞の1 moduleを検討しており、曲がりやmichrophonicsなどを検討。あと、XFELはHOMの改善が課題 CWの熱負荷テストも行った。KEKではcERLに組み込んだinjectorはビーム運転開始を報告。Main linacはパワーテスト。

TTC next special topicsの提案(G.Hoffstatter) &次回

- Next special topics agenda
  - High Q (Fermiが主催でやるか？)
  - Michrophonics suppression (Cornell , HZB ??)
  - Field emission (KEK ??)
  - Power source (Solid state ampなど)
  - LLRF (これは別でやっている)
  - HOM absorbers (potential for collaboration)
  - Couplers and copper coating
  - Warm cold transition (?)

非常に好評だったので、次回も色々テーマを絞ってspecial topicをやっていければとのこと。

TTC general meeting：次回は2014年3月24日～3月27日 @DESY

TTC CW SRF meeting (写真)