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

HIGHER ORDER MODE ABSORBERS FOR HIGH CURRENT SRF APPLICATIONS

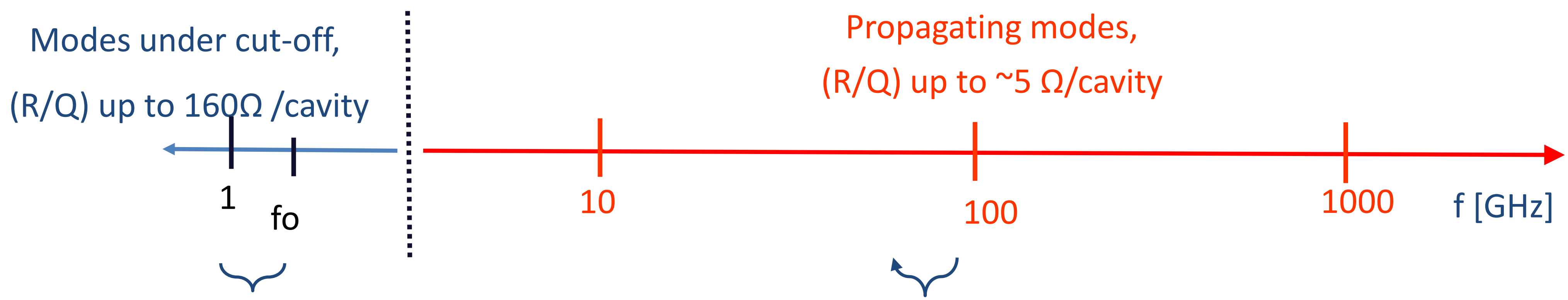
R. EICHHORN, CORNELL

Outline

- Motivation
- Cornell HOM absorber designs and results
- Overview over different absorber concepts
  - XFEL
  - BNL-ERL
  - Ariel
  - JLAB
  - APS upgrade
  - Berlin Pro
  - KEK-cERL
- Summary

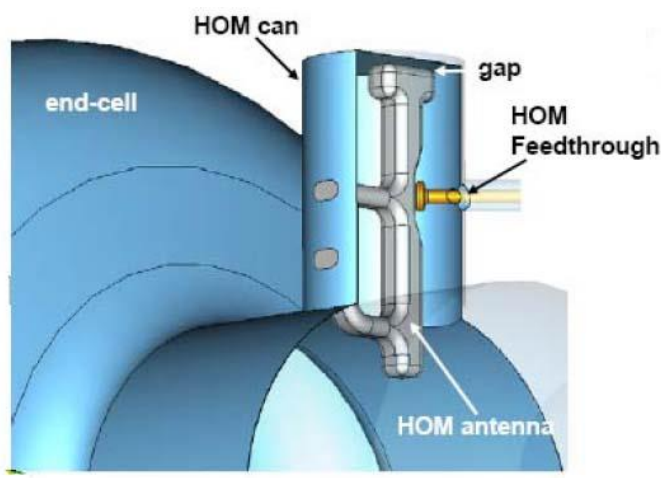
Motivation

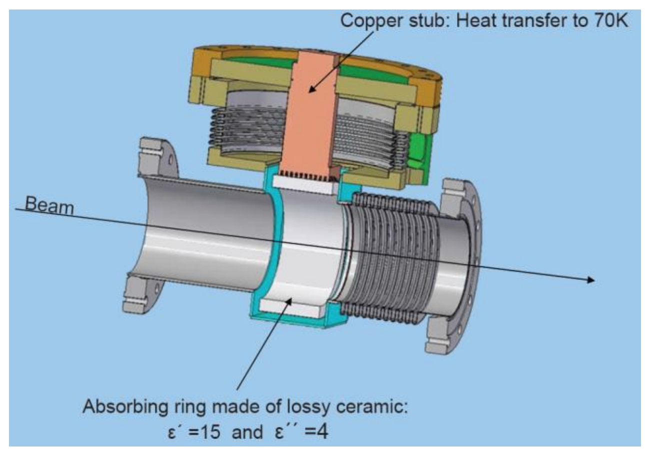
HOM power in the TESLA cavity:



HOM couplers

Beam Line Absorber

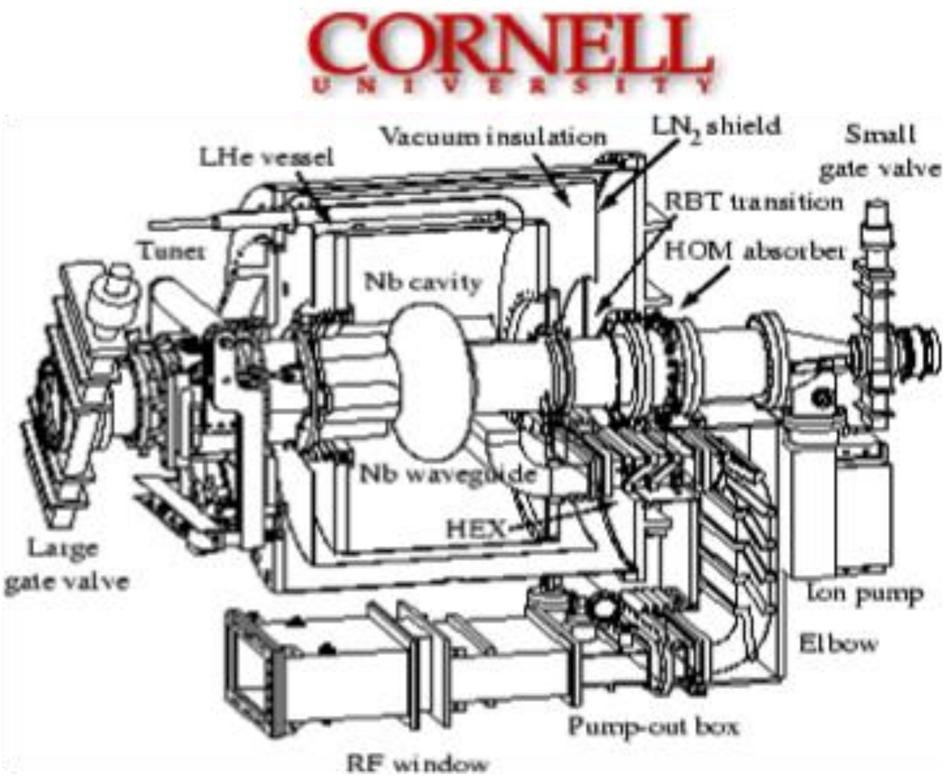


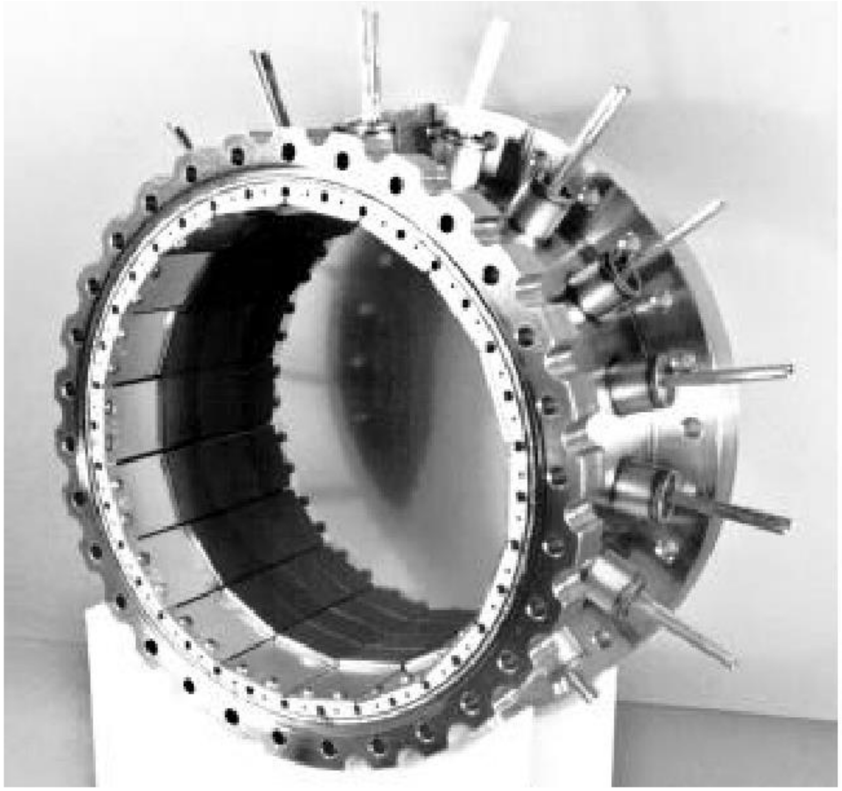


CW mode: XFEL beam (200 pC @ 0.1 MHz @ σ_z = 25 μm @ 100%DF): **0.6 W/CM**

Courtesy: Jacek Secutowicz

Cornell's History on Absorbers





- During physics runs it supported 750 mA

- Ferrite absorber tiles
- Water cooled

[D. Moffat, et al., PAC 1993]

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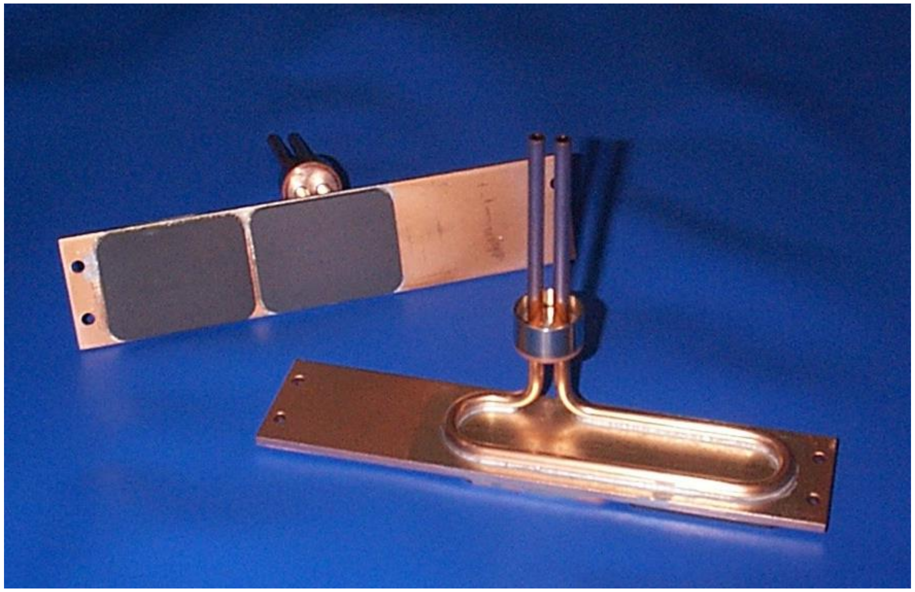
Todays B-Cell absorbers



3 layers are sputtered to the ferrite

- titanium layer,
- a mixture out of titanium/copper
- copper layer

Total thickness: 1 µm

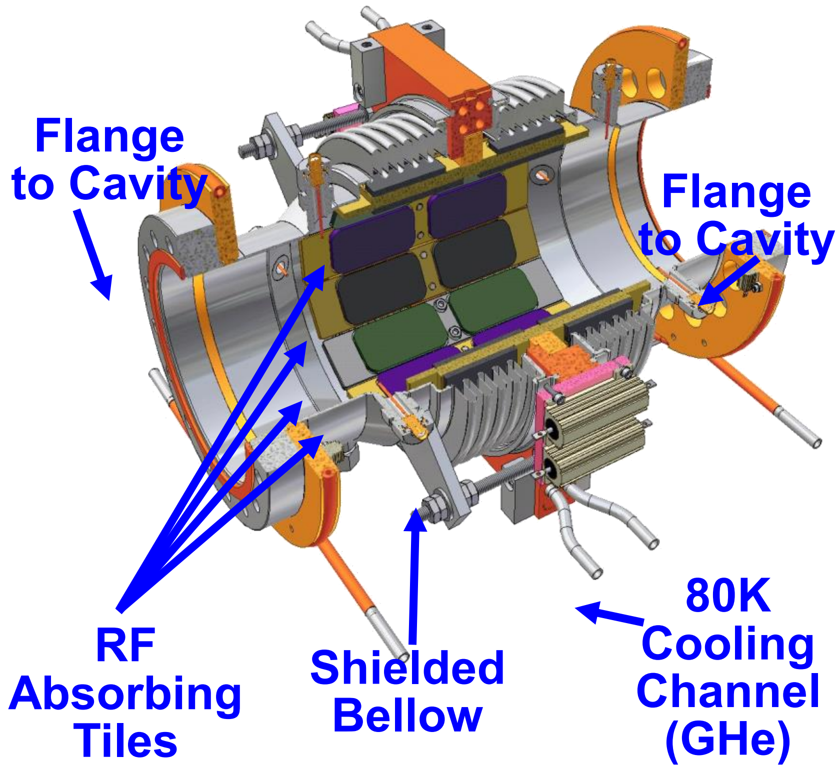
The ferrite tiles are soldered then to a copper plated Elkonite (Copper-Tungsten sinter metal that fits the thermal expansion of the ferrites) plate.

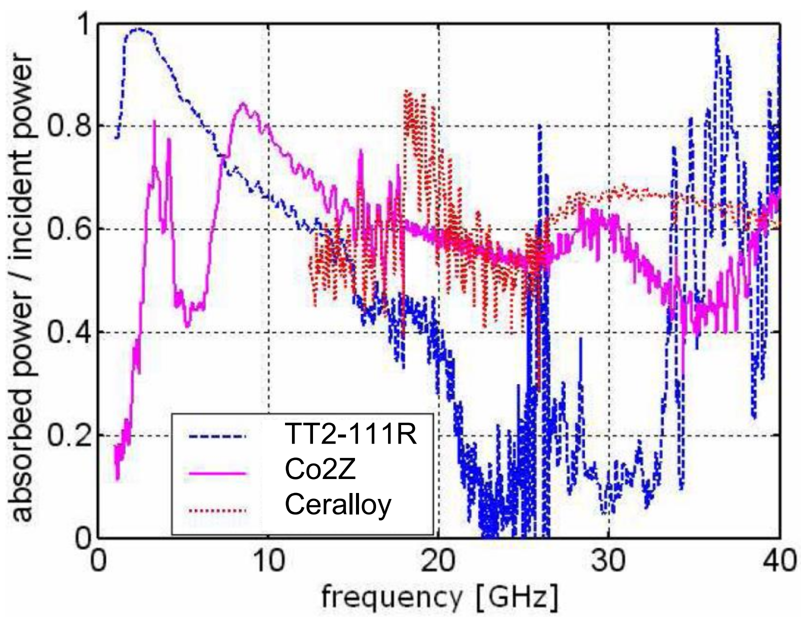
On the backside of the Elkonite plate the water cooling tubes are soldered. Each HOM panel is designed to absorb up to 600 W RF power. For the delicate soldering of the ferrites to the Elkonite plate inductive brazing under Argon atmosphere is used.

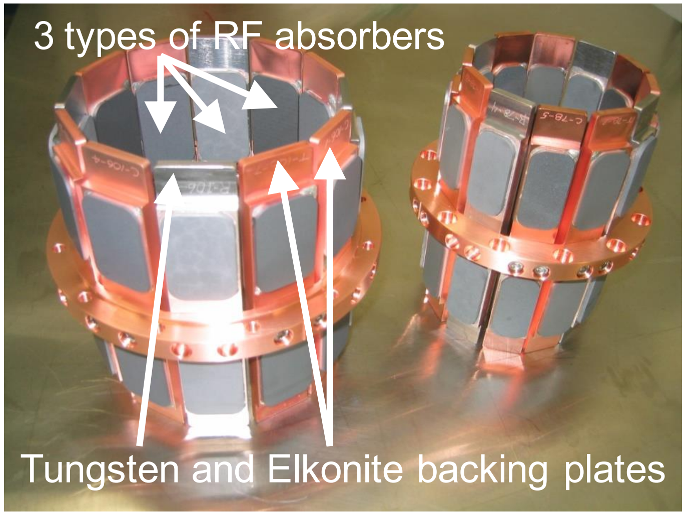
Courtesy: Michael Pekeler

Cornell ERL Absorber V1

- Based on three absorbing materials to ensure broad band absorption up to high frequencies

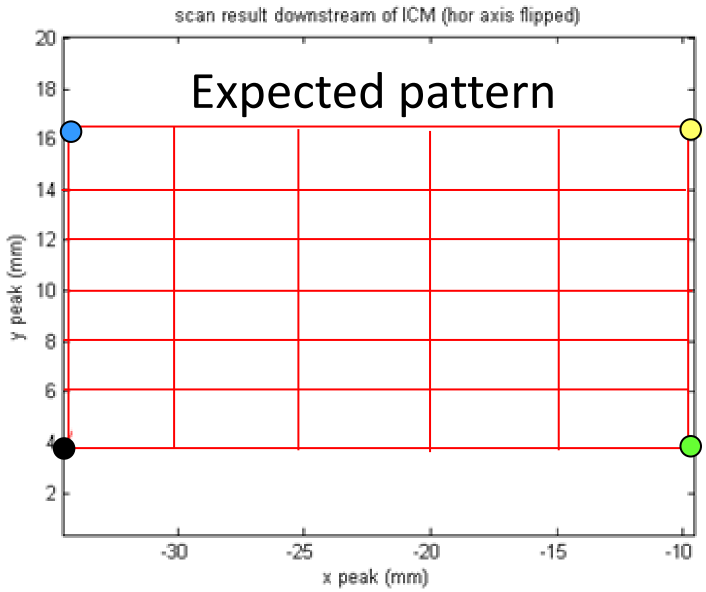


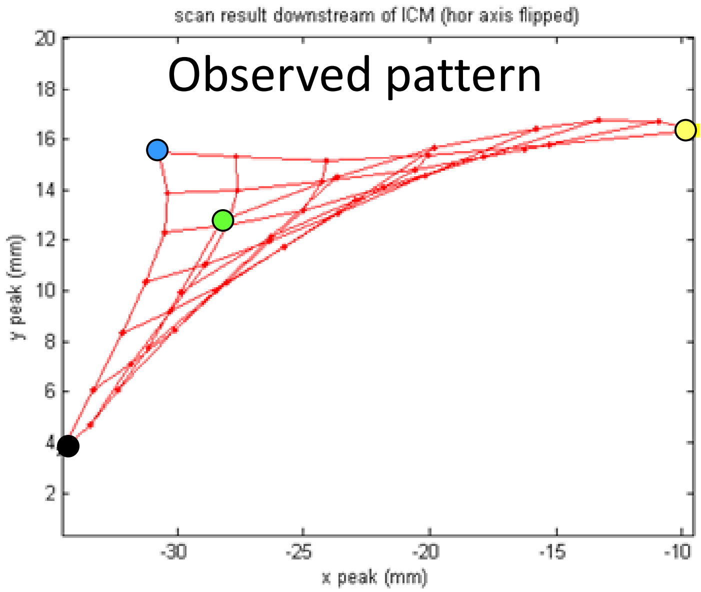




Experience with V1

- Delamination because of mismatch in the CTE
- Even more serious:
  Beam deflection as material charges up





- Dielectric lossy ceramic (137ZR10) had to be removed, requiring a full rebuild of the cryomodule

DC conductivity

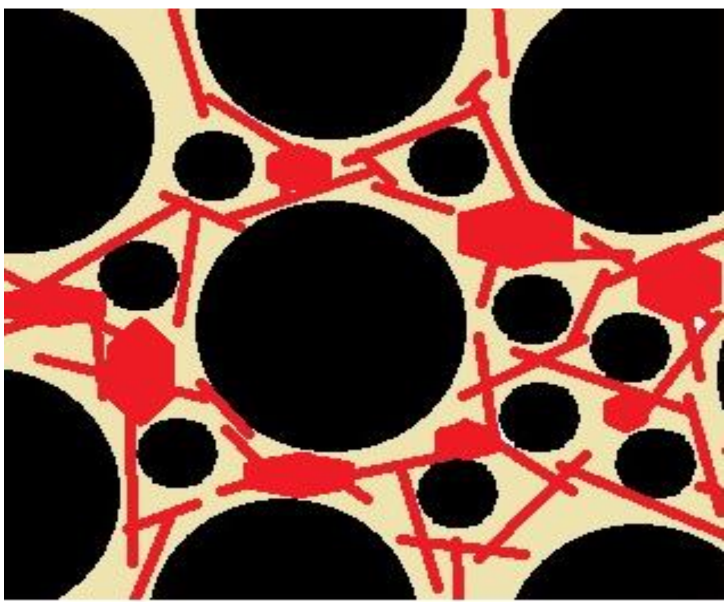
Material	300 K	77 K
Coorstek SiC SC-2	49 Ω	59 Ω
Coorstek SiC SC-35	~100 kΩ	Infinite
Ceradyne AlN CS-137	5.7kΩ	7 kΩ

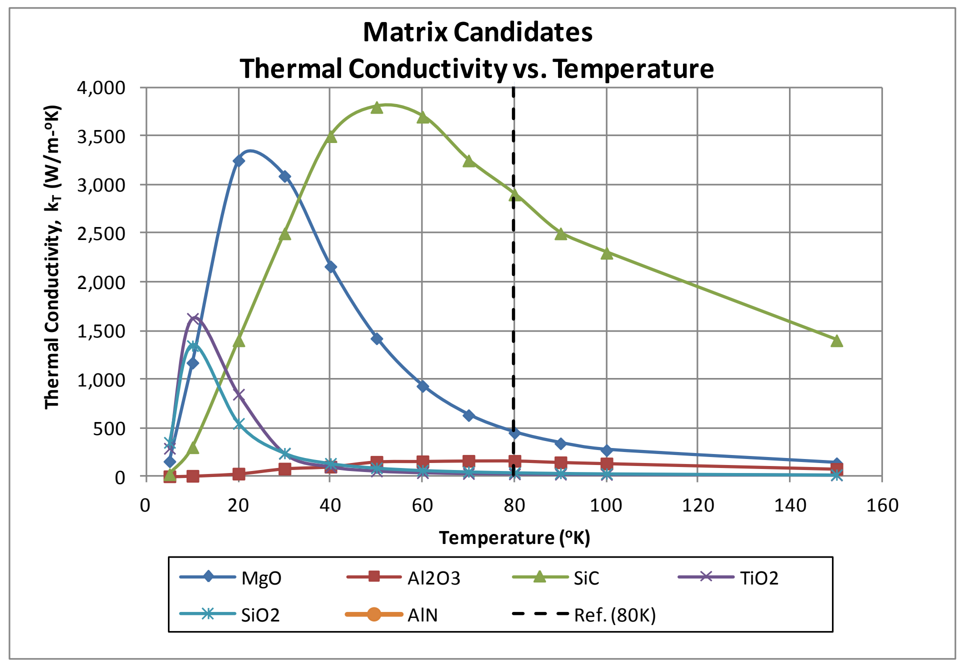
Too conductive-> no absorption

Is infinite low enough ?

This is what the vendor says…

So we partnered with Alfred University to develop our own material





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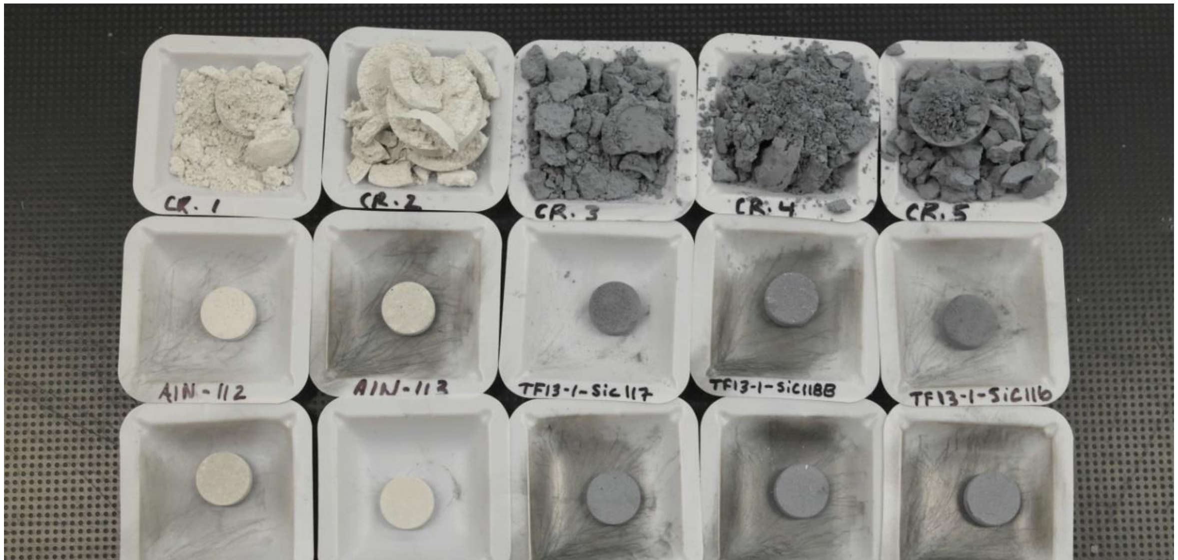
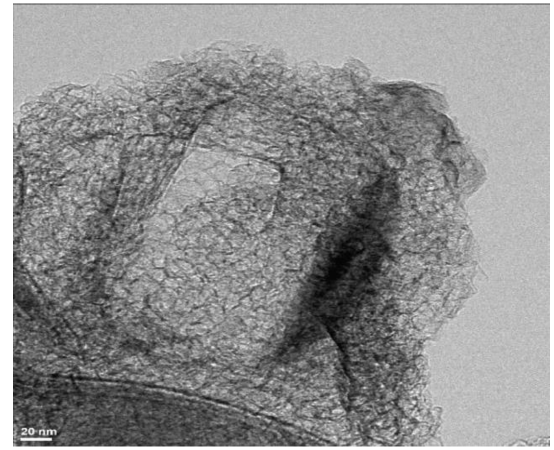
A new absorber material?

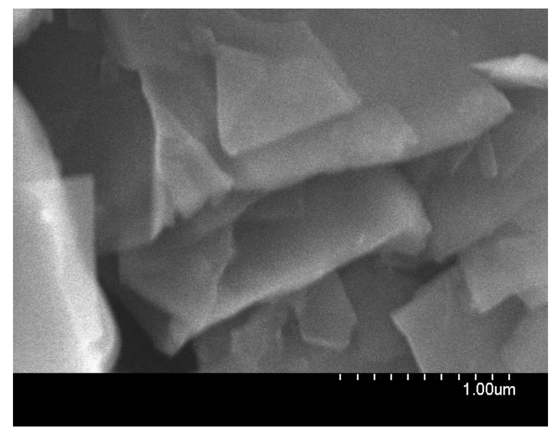


Summary - Pre & Post Processing (TF-13):

Sample / Composition	Green Pellet Mass (g)	mass Post-Fire (g)	Green Volume (cm^3)	Volume (cm^3) Post-Fire	Green Density (g/cm^3)	Density (g/cm^3) Post-Fire	Density Change (%)
TF13-1-AlN112	1.0046	0.9034	0.4328	0.4126	2.3213	2.1893	-5.7%
TF13-3-AlN112	1.0012	0.9421	0.4303	0.4126	2.3265	2.1893	-5.9%
TF13-3-AlN113	0.9950	0.9445	0.4585	0.4211	2.1701	2.2429	3.4%
TF13-1-AlN113	0.9986	0.9448	0.4625	0.4283	2.1590	2.2057	2.2%
TF13-1-SiC117	0.9961	0.9217	0.4951	0.4661	2.0119	1.9773	-1.7%
TF13-1-SiC114	0.9889	0.9480	0.4875	0.4605	2.0287	2.0585	1.5%
TF13-1-SiC118B	0.9970	0.9917	0.4999	0.4698	1.9943	2.1110	5.9%
TF13-2-SiC118B	0.9982	1.0021	0.5015	0.4625	1.9903	2.1666	8.9%
TF13-1-SiC116	1.0030	0.8997	0.5743	0.5381	1.7464	1.6719	-4.3%
TF13-1-SiC115	0.9936	0.9835	0.4899	0.4657	2.0283	2.1117	4.1%
TF13-1-SiC113	0.9971	0.9468	0.4959	0.4621	2.0106	2.0488	1.9%



Graphene (vendor 1) showing hollow imprint (above), compared with vendor 2, (below).

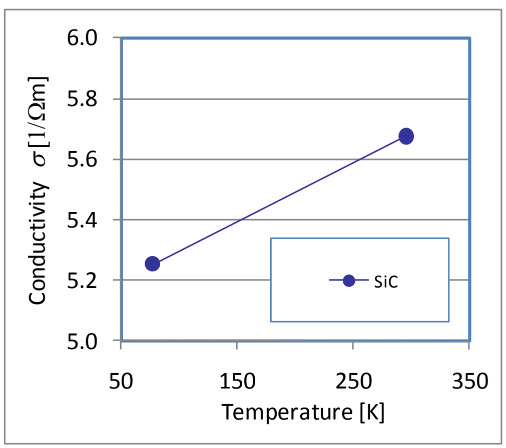


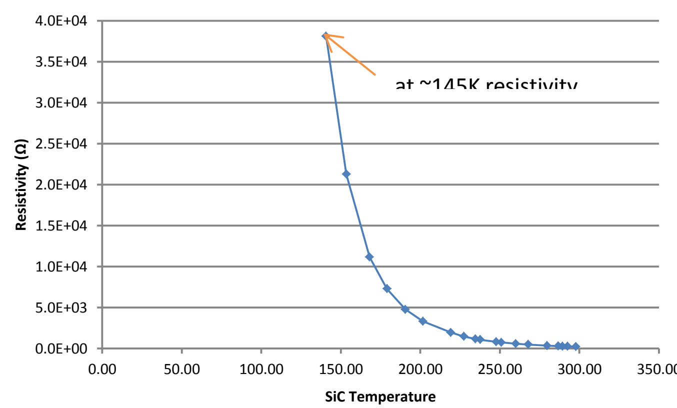
R. Eichhorn et al., IPAC 2014

CLASSE facilities are operated by the Cornell Laboratory for Elementary Particle Physics (LEPP) and the Cornell High Energy Synchrotron Source (CHESS) with major support from the National Science Foundation.

So, what we had to accept

- Don’t try to fabricate your own ceramics
- Ceradyne 137 (AlN) seemed the best fit…..
  …. until we learned the vendor does not guarantee parameters
- So we took SC-35 (SiC):
  - Large batch to batch variations
  - Difficult to match CTE
  - Rather strong outgasing
  - High particulation and chipping





Measured on a sample

Finding on a full cylinder

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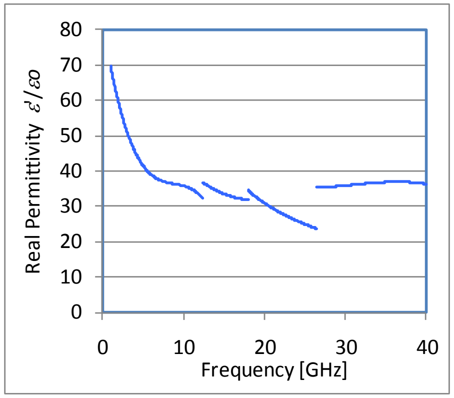
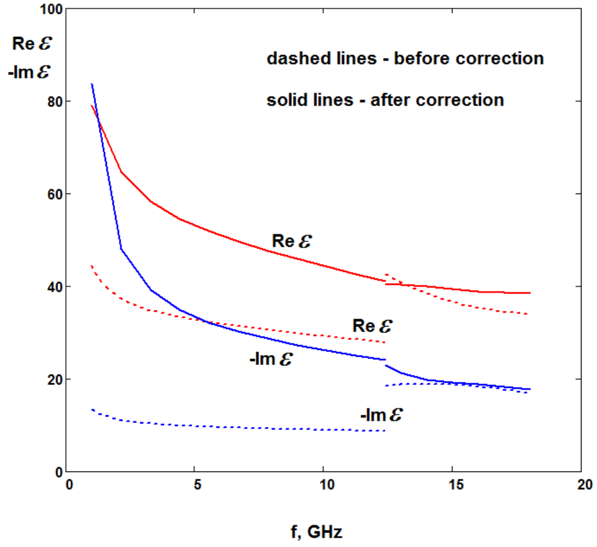
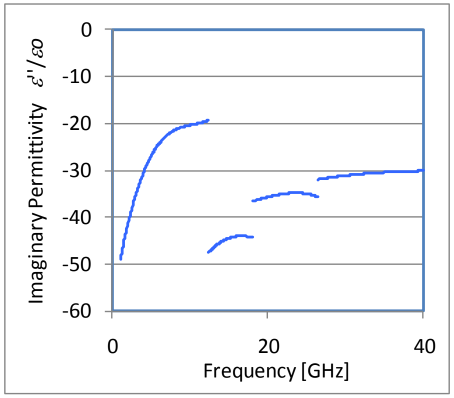
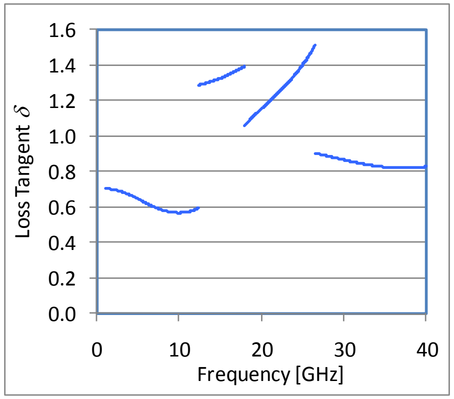
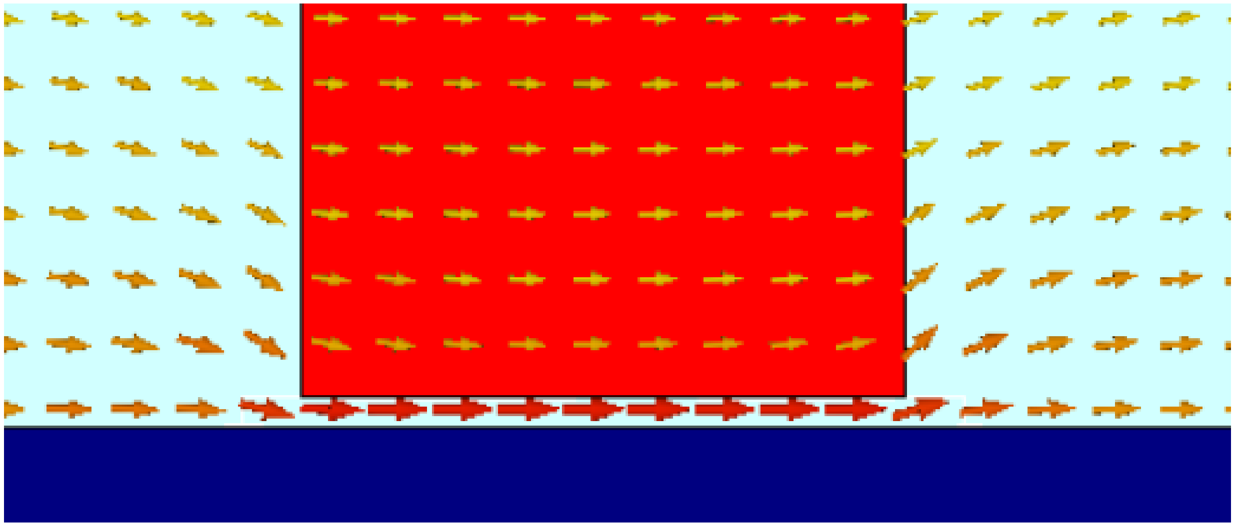
Measuring ε and μ











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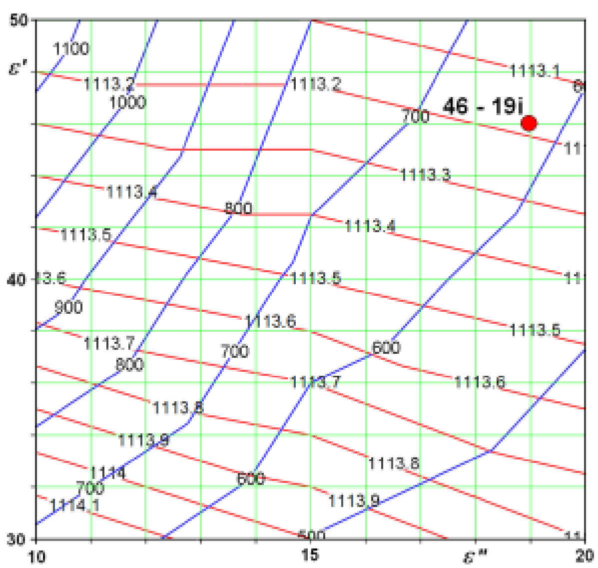
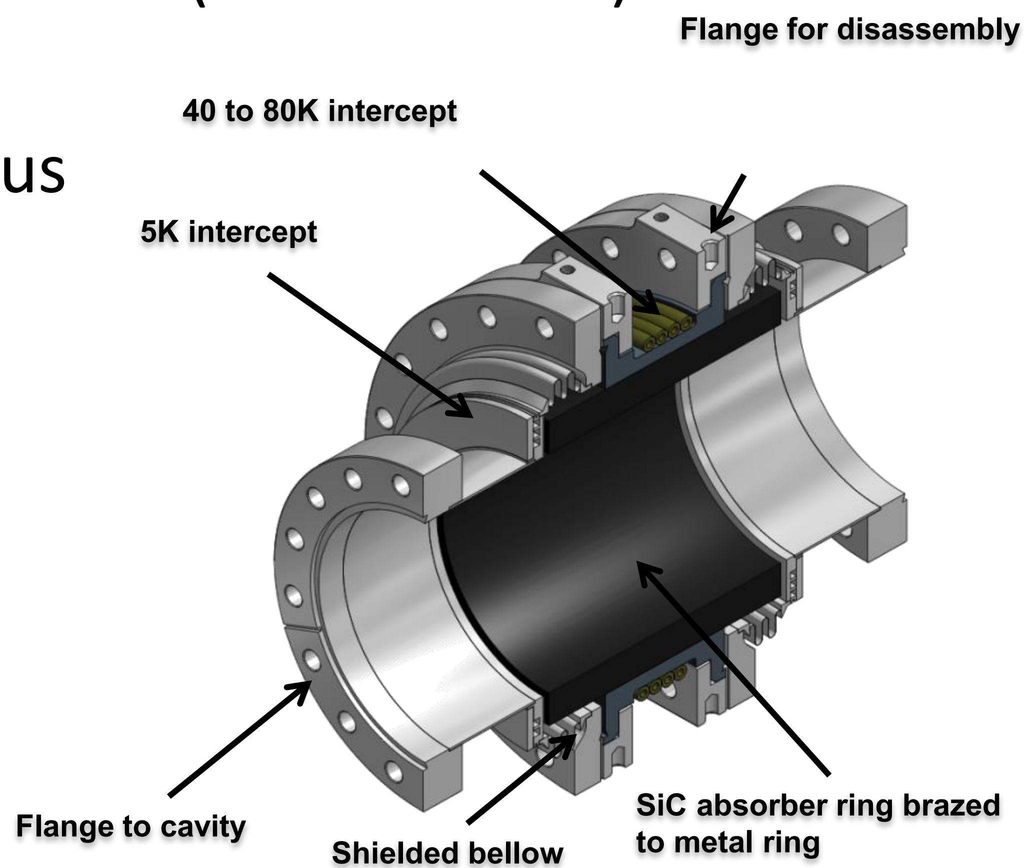
Absorber V2.0

- Broad band absorption using a SiC (Coorsteck SC-35) cylinder
- Brazed into a Tungsten shelve (to match CTE)
- But what we learned: Tungsten becomes porous under brazing cycle





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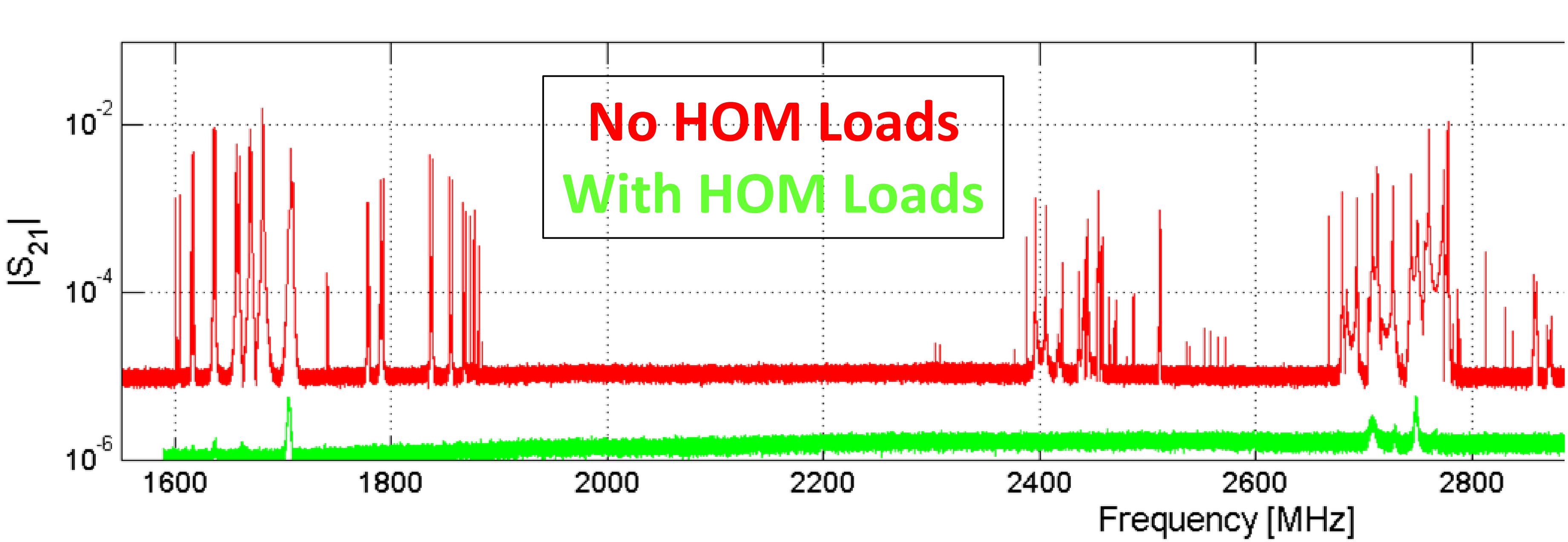
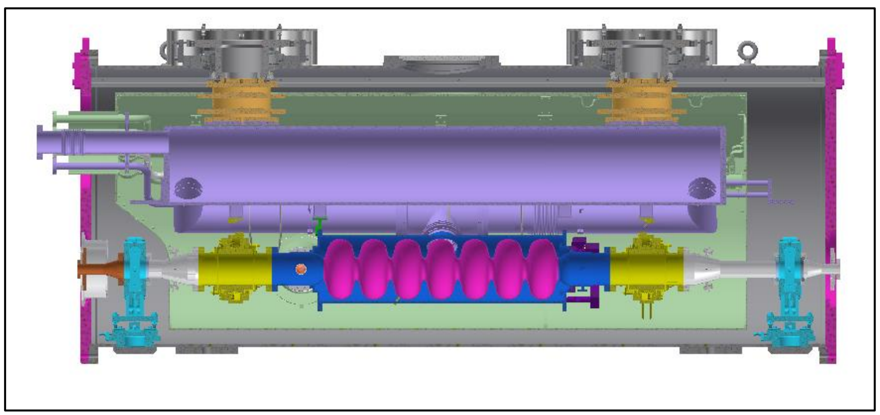
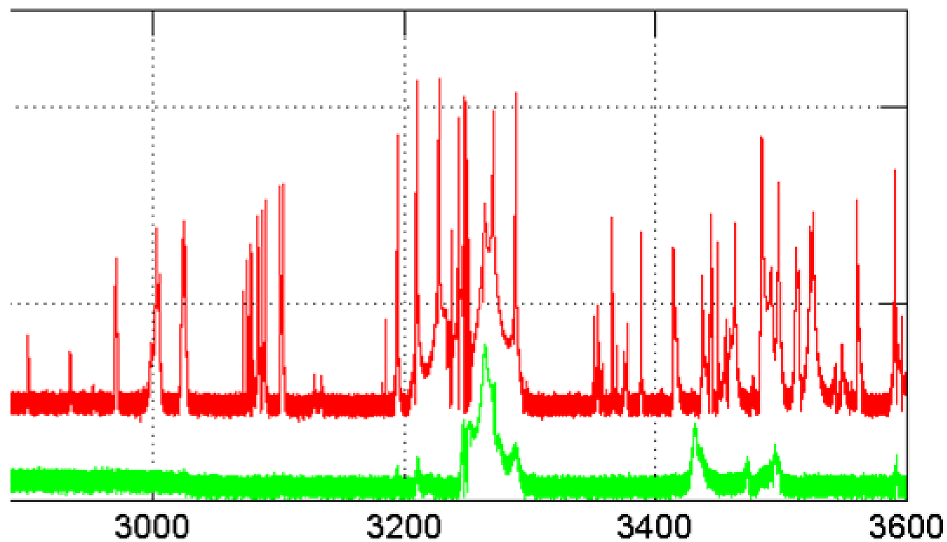
V2.0 performance







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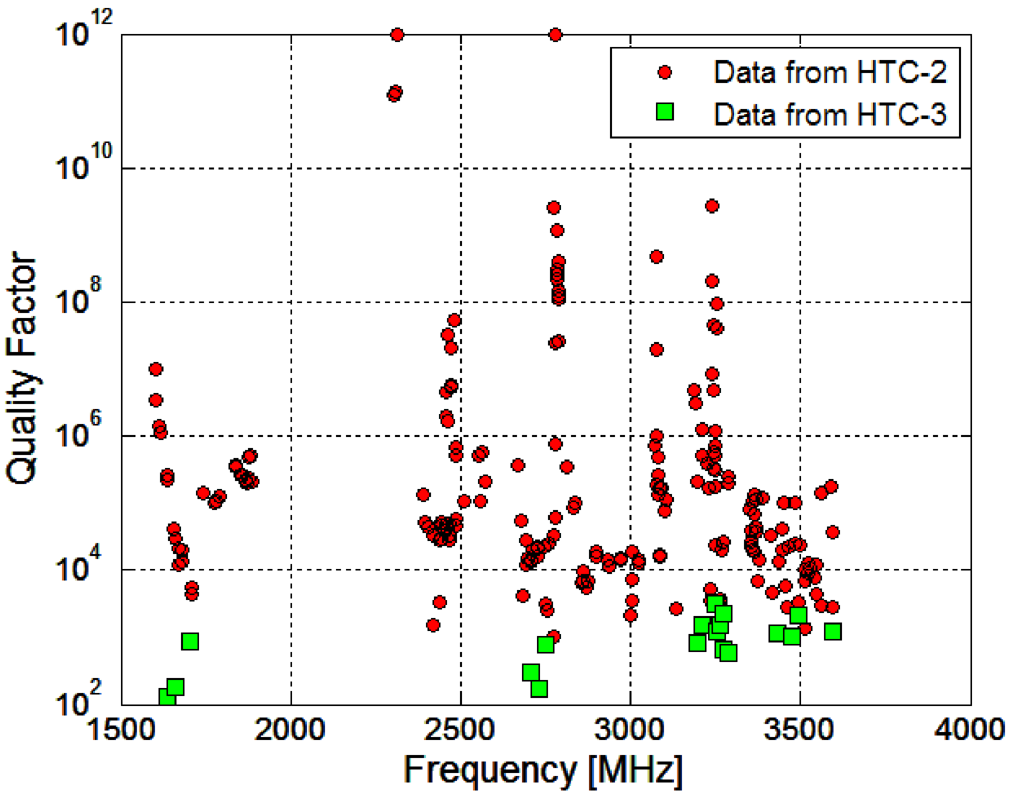
V2.0 performance

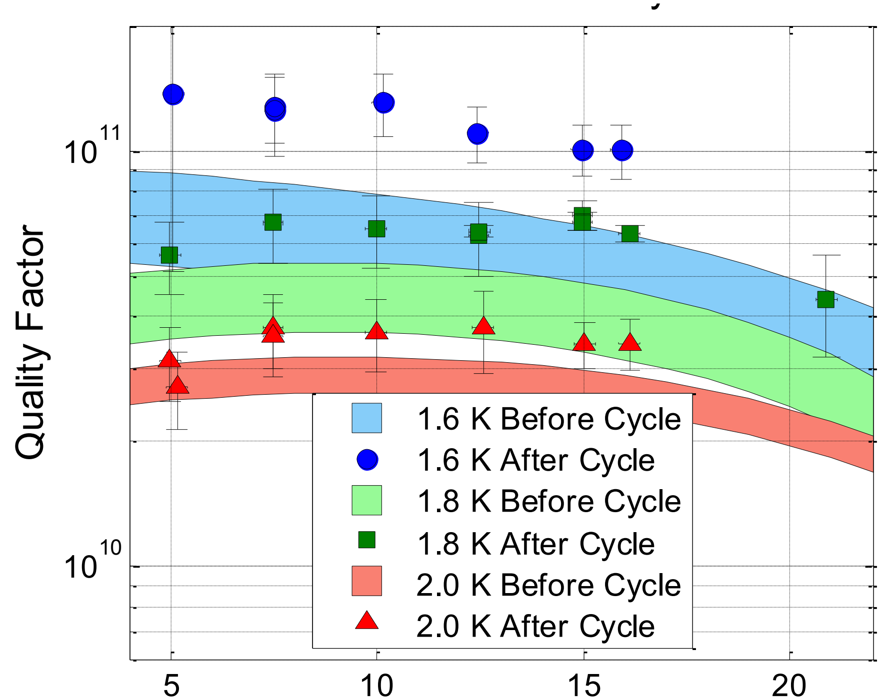
HTC-2: No HOM Absorbers

HTC-3: With HOM Absorbers



Beamline HOM absorbers strongly damp dipole HOMs to under Q ~ 10^4

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



At 16.2 MV/m

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

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

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

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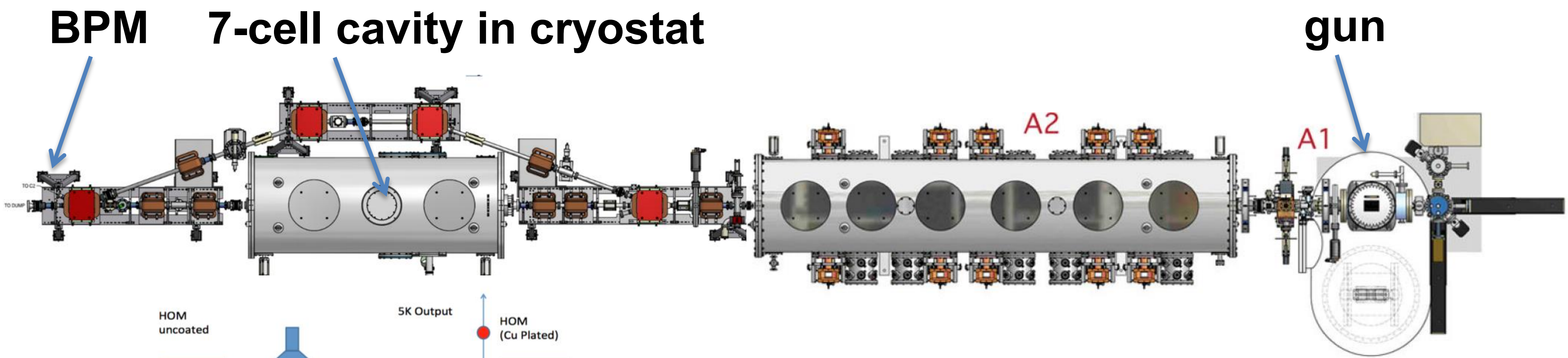
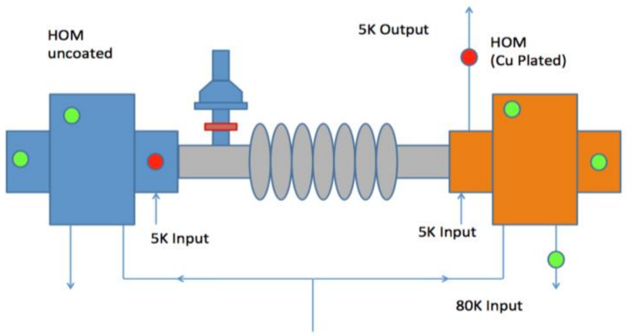
V2.0 beam test





Current, bunch length	ΔT (beam pipe behind Abs.) coated/uncoated	ΔT (80K gas temp) coated/uncoated	ΔT (80K absorber temp) coated/uncoated	ΔT (5K flange next to cavity) coated	ΔT, beam pipe to cavity coated/uncoated
25 mA, 3.0 ps	0.075/0.075	1.14/0.82	1.02/0.975	0.007	0.076/-.005
40 mA, 3.4 ps	0.2475/0.335	2.95/2.16	2.72/2.53	0.021	0.179/0.009
40 mA, 2.7 ps	0.2975/0.425	3.00/2.22	2.772/2.63	0.027	0.203/0.014

- No charge-up of the HOM ceramics observed

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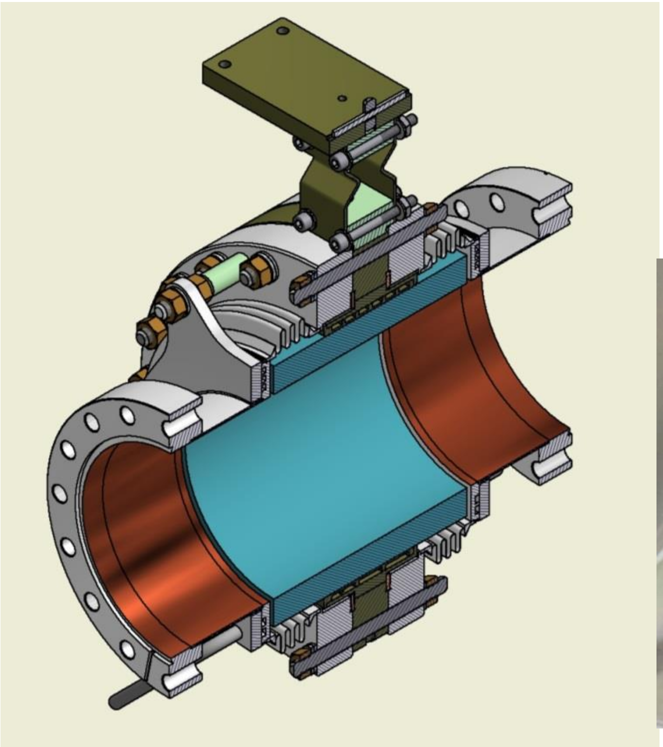
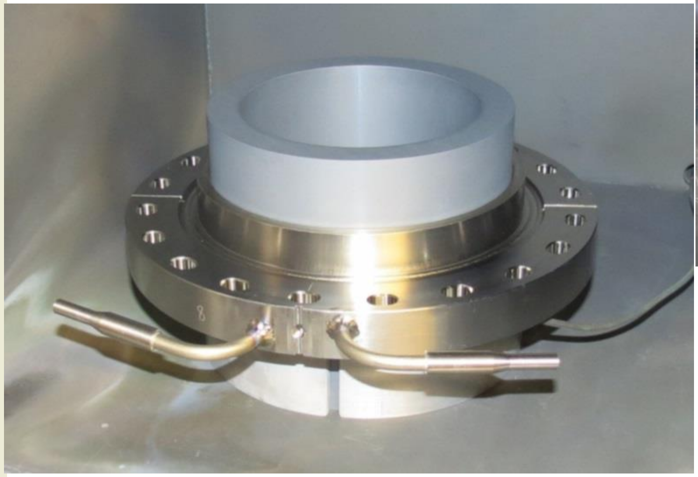
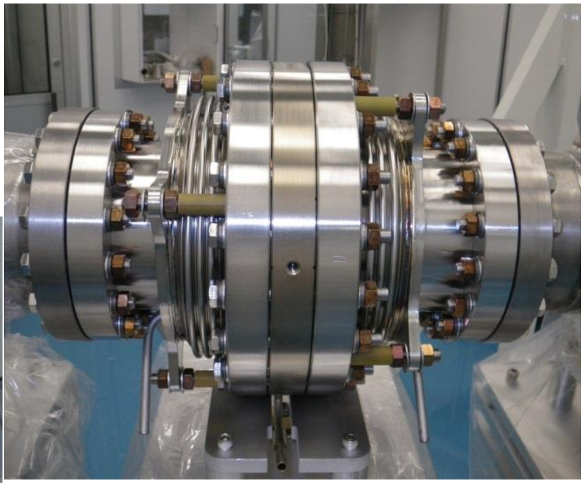
V2.1

- Keep what seems to work… and replace what failed



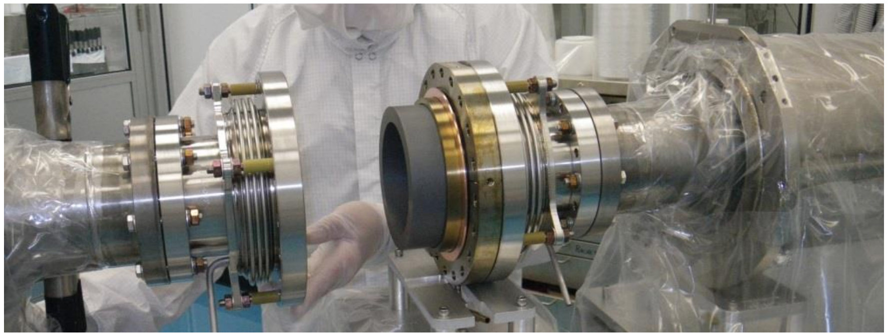
Absorbing Material:
Doped SiC





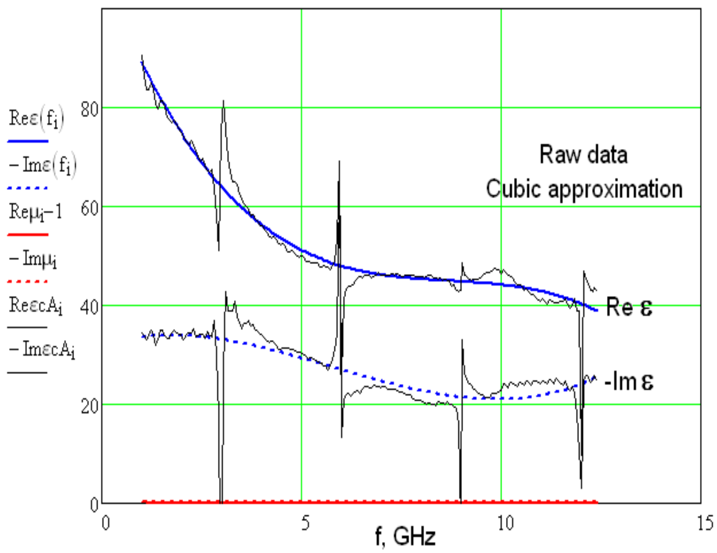
SiC shrink-fitted into
Ti shelve

Cooling Passage
Configuration of 80K
Cooling Jacket

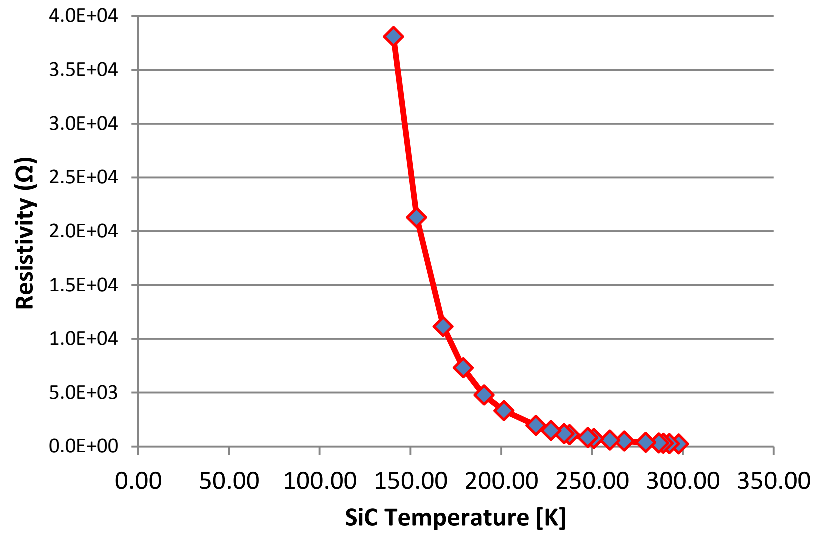


V2.1 properties

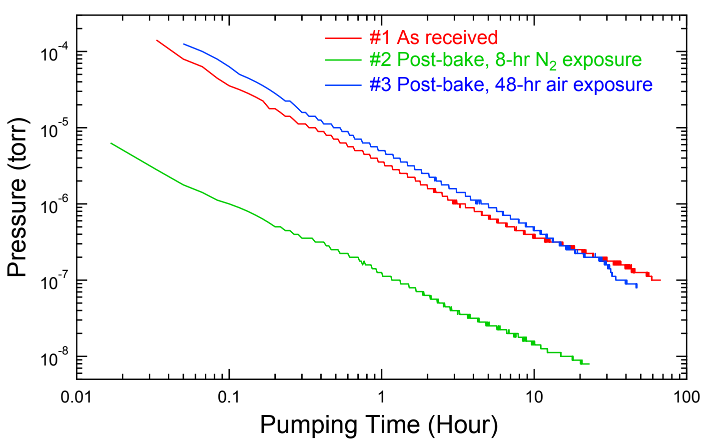
RF absorption



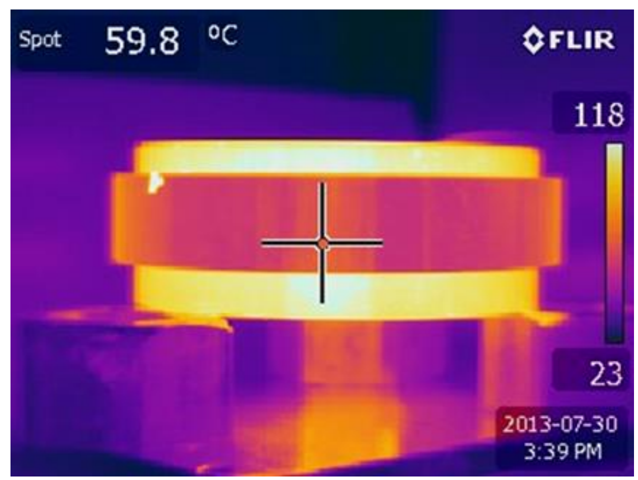
DC resistifity



outgasing



Heat transfer



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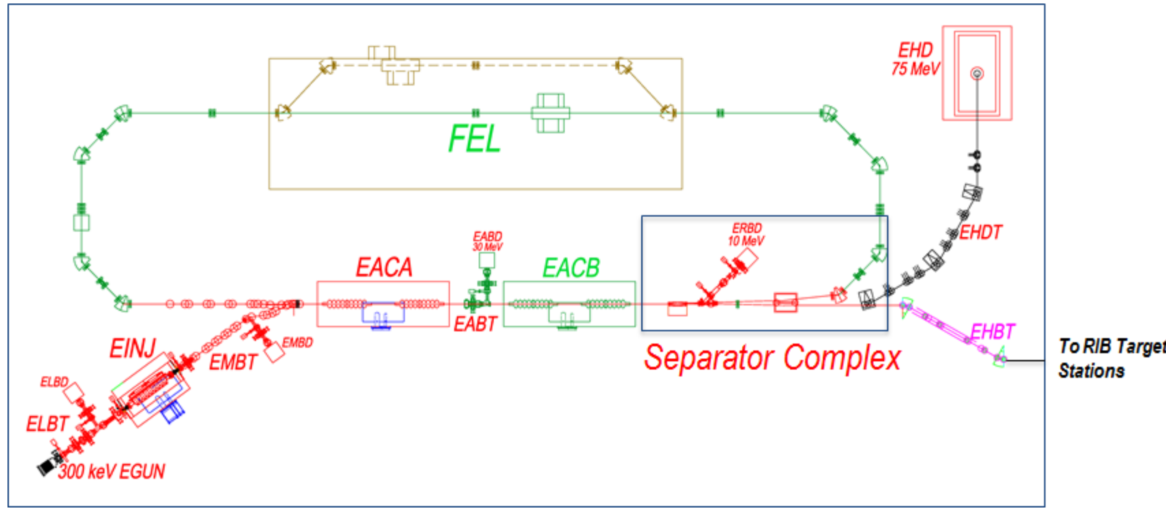
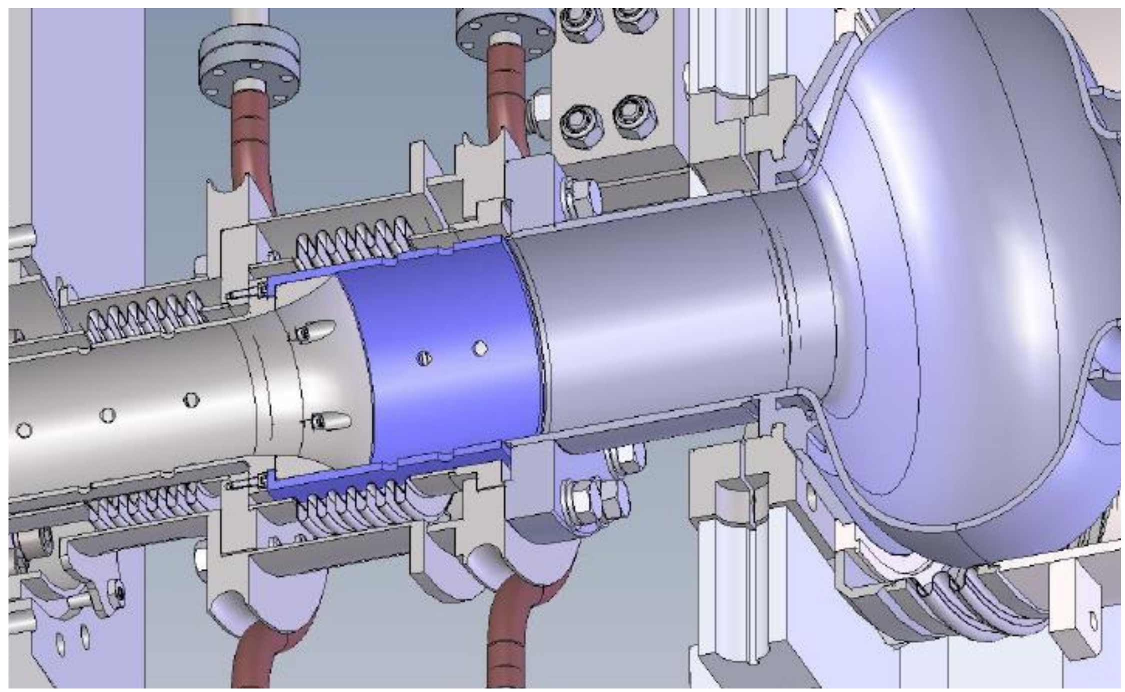
ABSORBER CONCEPTS FROM OTHER LABS

ARIEL e-Linac - TRIUMF

- ARIEL e-Linac 50MeV 10mA driver for radioactive ion beam production
- Upgrade plans for ERL operation
- BBU Shunt-impedance limit < 10MΩ (Goal ≤ 1MΩ)
- Resistive beam line absorbers reduce Q_L of HOMs
  - SS on coupler side
  - CESIC on pick-up side
  - cooled with LN_2





P. Kolb et al: MOPB088

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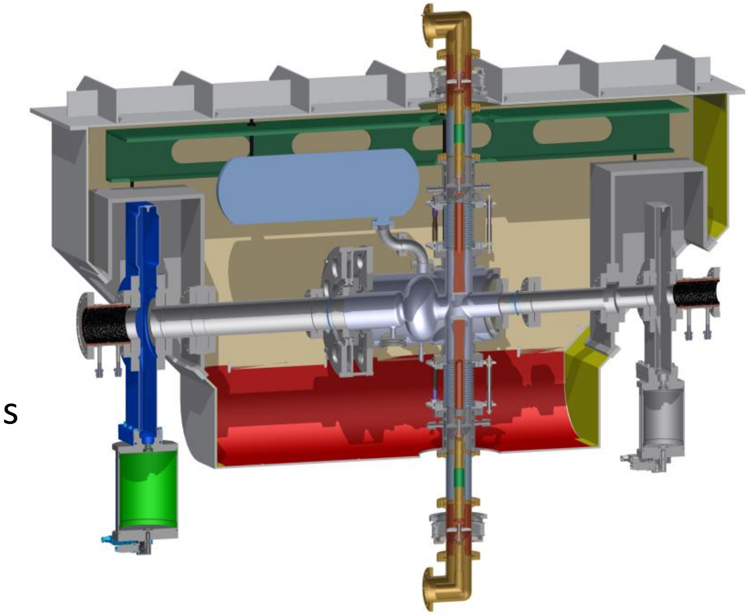
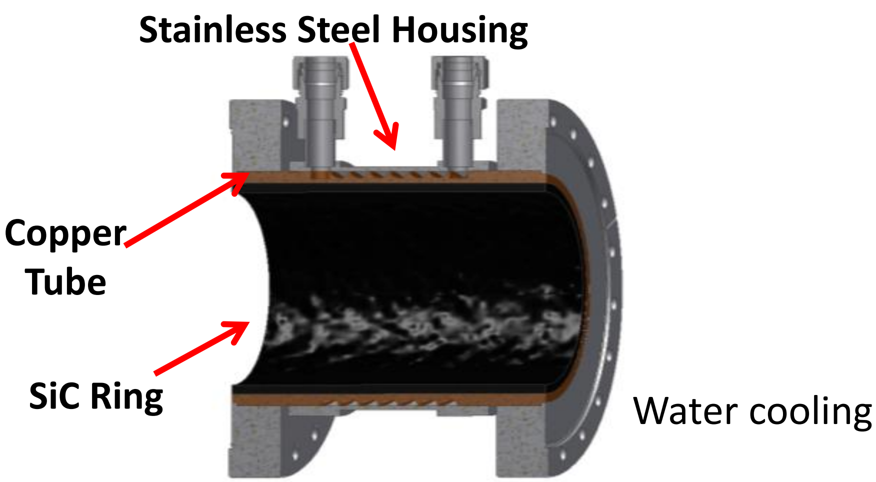
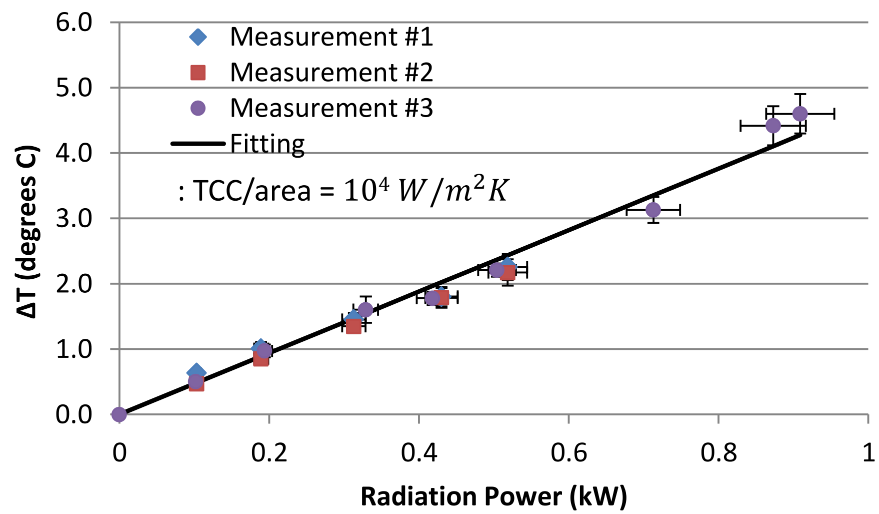
Higher Harmonic Cavity for the APS-U

- APS-U Beam Parameters
  - Beam current: 200 mA
  - Bunch repetition rate: 13/88 MHz
  - Bunch charge: 15.3/2.2 nC
  - Bunch length: >50 ps
- HOM Absorber
  - Two SiC cylinders matched to both beam pipes: one of them is enlarged to extract monopole and dipole HOMs
  - Coorstek SC-35, shrink-fitted into Cu (0.1 mm diameter interference fit)
  - Calculated HOM power is ~1.7 kW

2 RT SiC absorbers







Courtesy: Sang-Hoon Kim, Michael P. Kelly

THPB072, THPB073, THPB088

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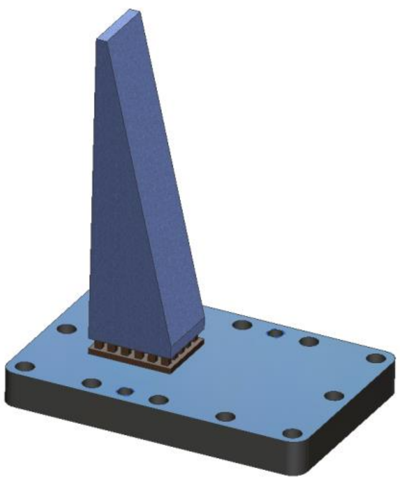
New HOM Waveguide Load Design for CEBAF Cryomodule (C50)

Original design

- Material: Graphite loaded SiC from Coorstek working at 2K.
- Simpler load shape. One wedge is good enough for the <=10W HOM power in C50.
- Improved brazing to reduce stress and enhance thermal conduction.



New conceptual design

- Mock up room temperature NWA test (no brazing, wedge not precisely positioned) showed agreement with simulation.
- Will use similar design with two wedges for high power HOM load.

Courtesy: Robbert Rimmer

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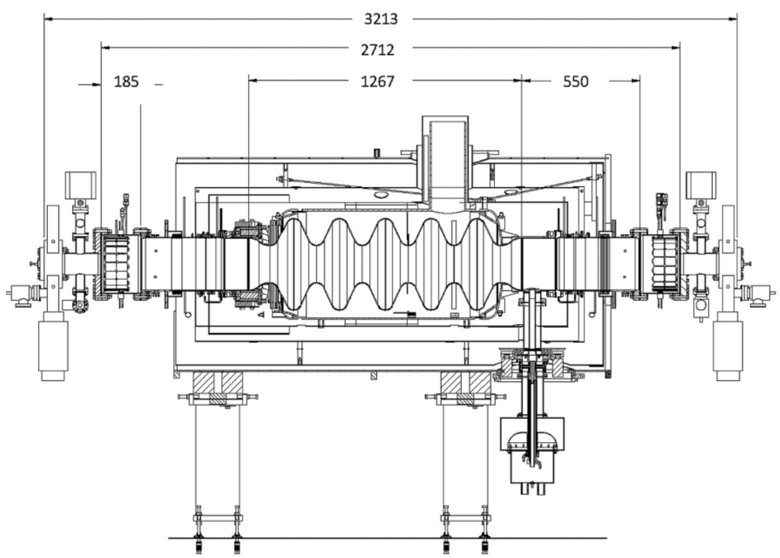
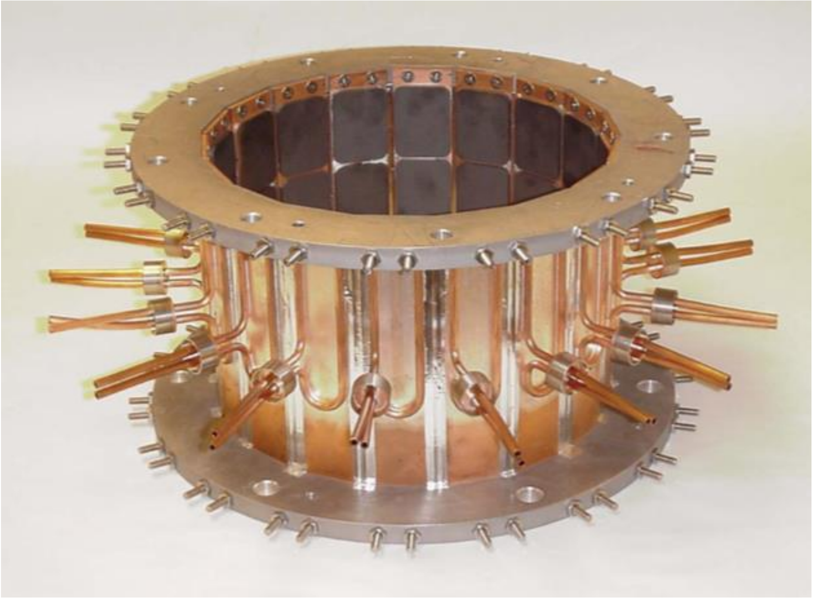
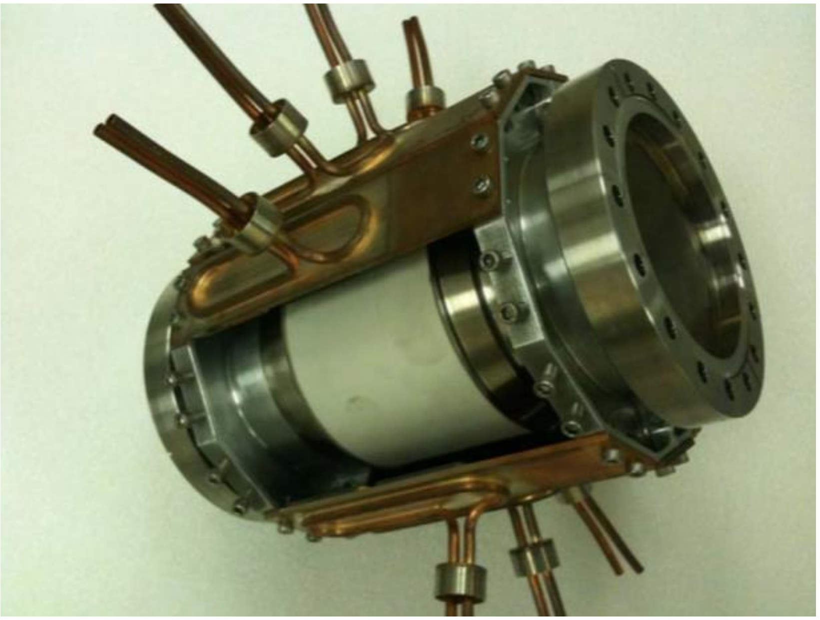
BNL ECX cavity absorber





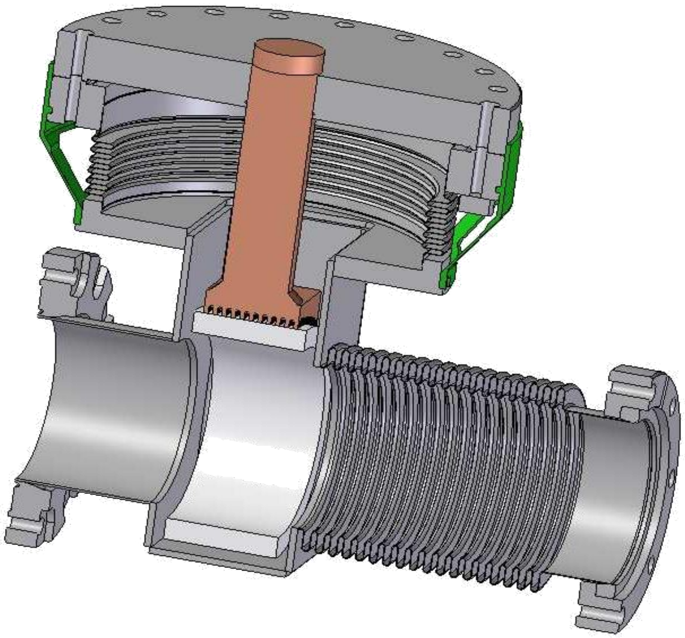


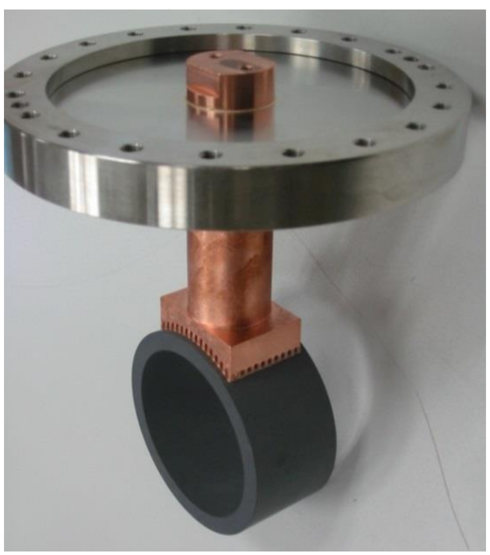
Ceramic must be sputter coated with 321 stainless steel, about 1~ nm thick

Phys. Rev. ST Accel. Beams 13, 121002 (2010)

Courtesy: Sergey Belomestnykh

XFEL beam line absorbers





Spec for the ceramics:

- Heat conductivity at 40K > 50 W/(m*K)
- DC resistivity(across the cylinder) < 200MΩ at 70K

Measured absorption properties:

Ceradyne CA137

$\varepsilon<30$ @ $tg\delta > 0.1$ for 5 GHz < f < 40 GHz

Sienna Technologies AlN STL-150D

$\varepsilon<30$ @ $tg\delta > 0.4$ for 5 GHz < f < 12 GHz

Courtesy: Jacek Secutowicz

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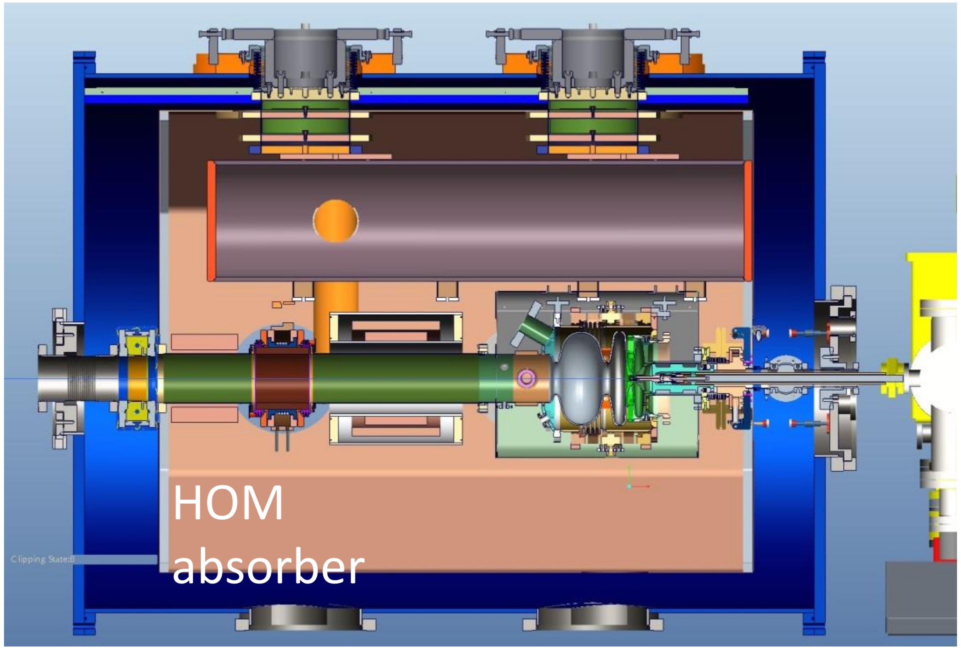
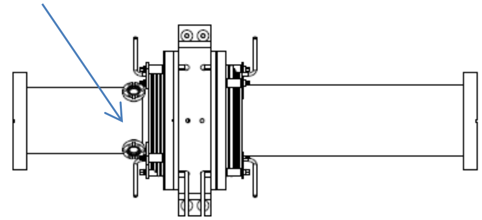
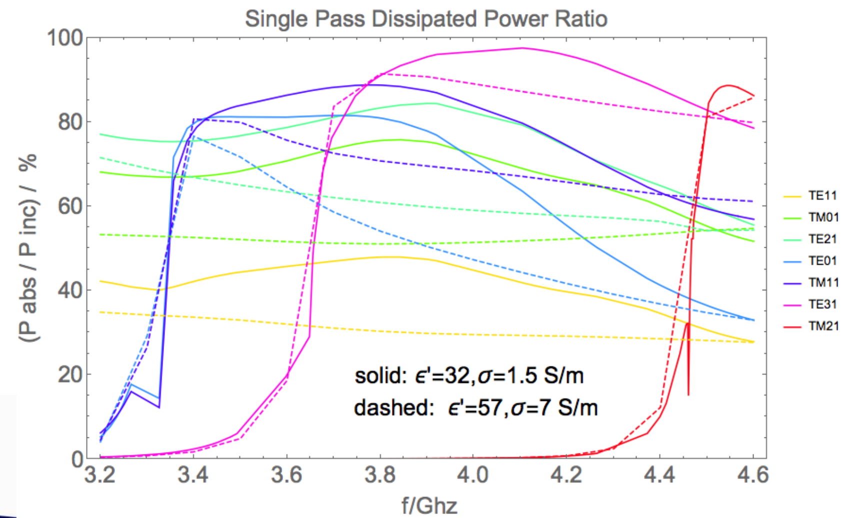
bERLinPro absorbers



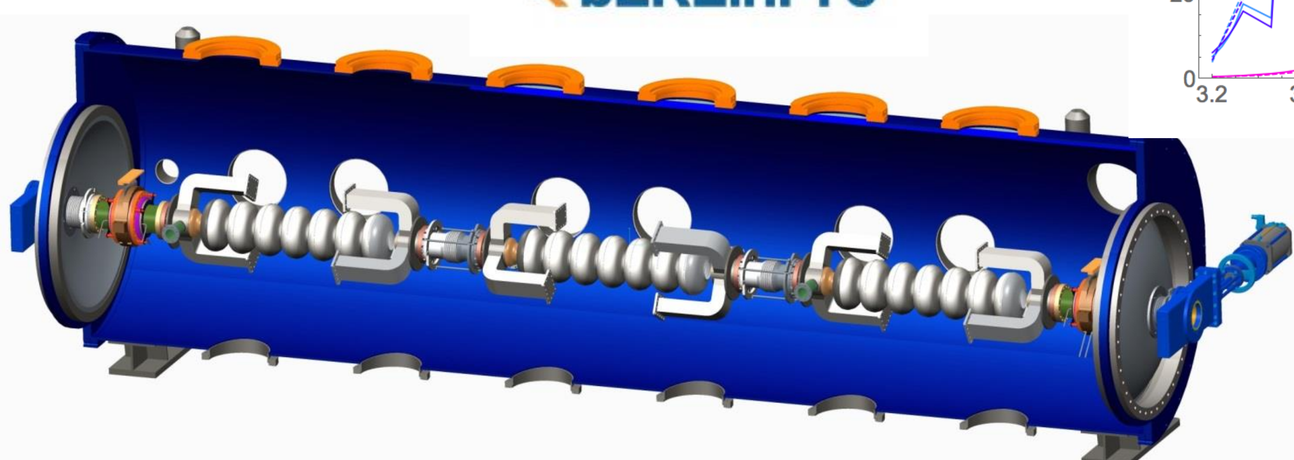
3 pick-up ports for HOM damping characterization

Cornell style + made HOM absorber SiC





bERLinPro



WG based HOM damping (Jlab)

Courtesy: Axel Neumann, Hans-Walter Glock

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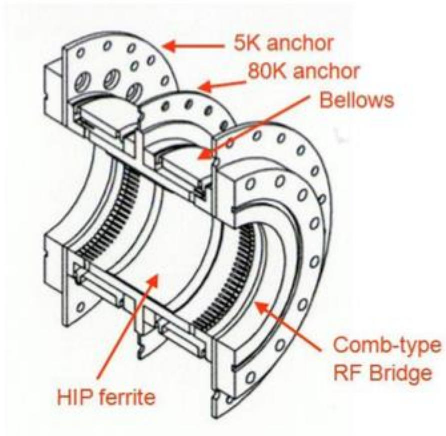
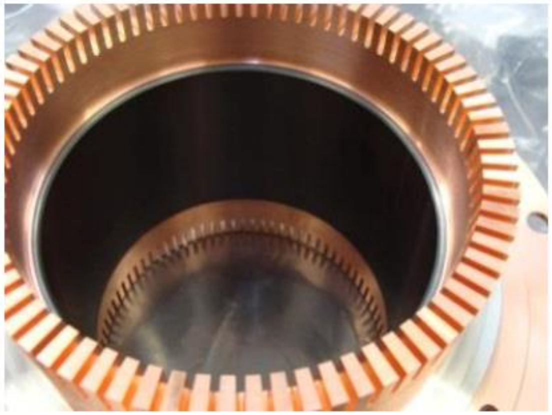
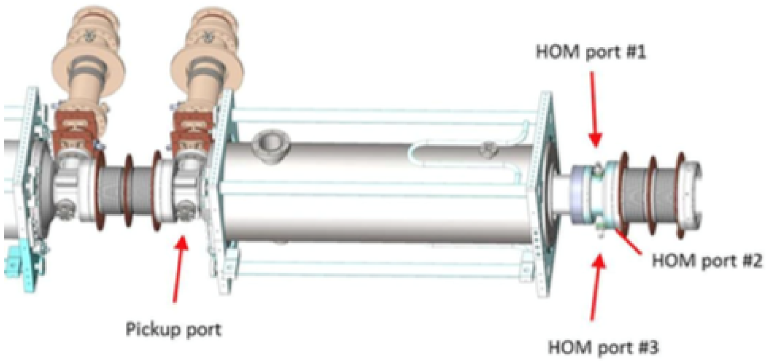
KEK-ERL main linac

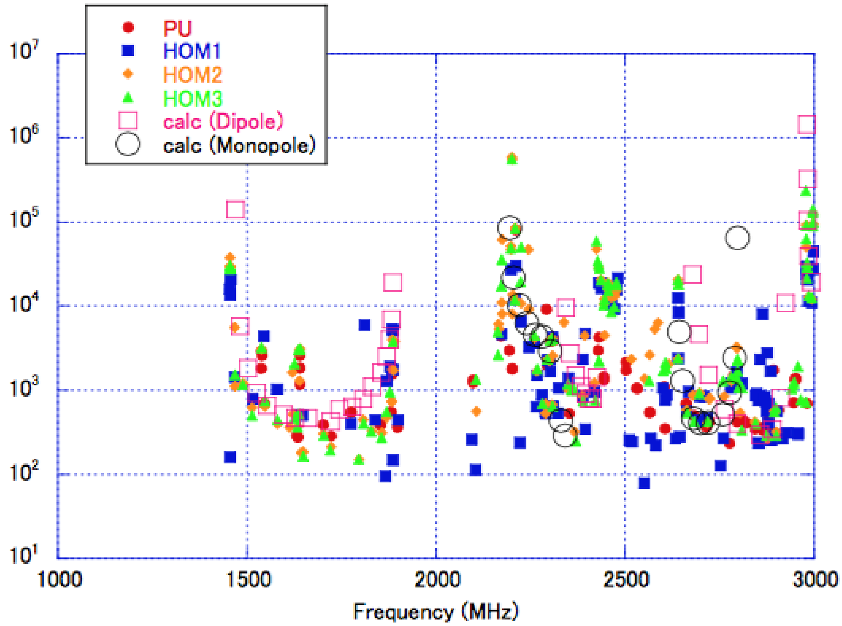
- 2 * 100 mA beam, expected HOM power is 150W per cavity (3ps bunch length)
- Absorber is IB004 ferrite, bonded to Cu pipe





Cryomodule measurements:
in good agreement with expectations





Courtesy: Hiroshi Sakai

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Summary

- Various concepts to absorb HOM power exist
- The absorbing material is still an issue
  - Unreliable RF parameters
  - Unreliable DC conductivity
  - Low thermal conductivity
  - Small thermal expansion
  - Bonding techniques
  - Particulation and cleaning
  - Outgasing
  - ……

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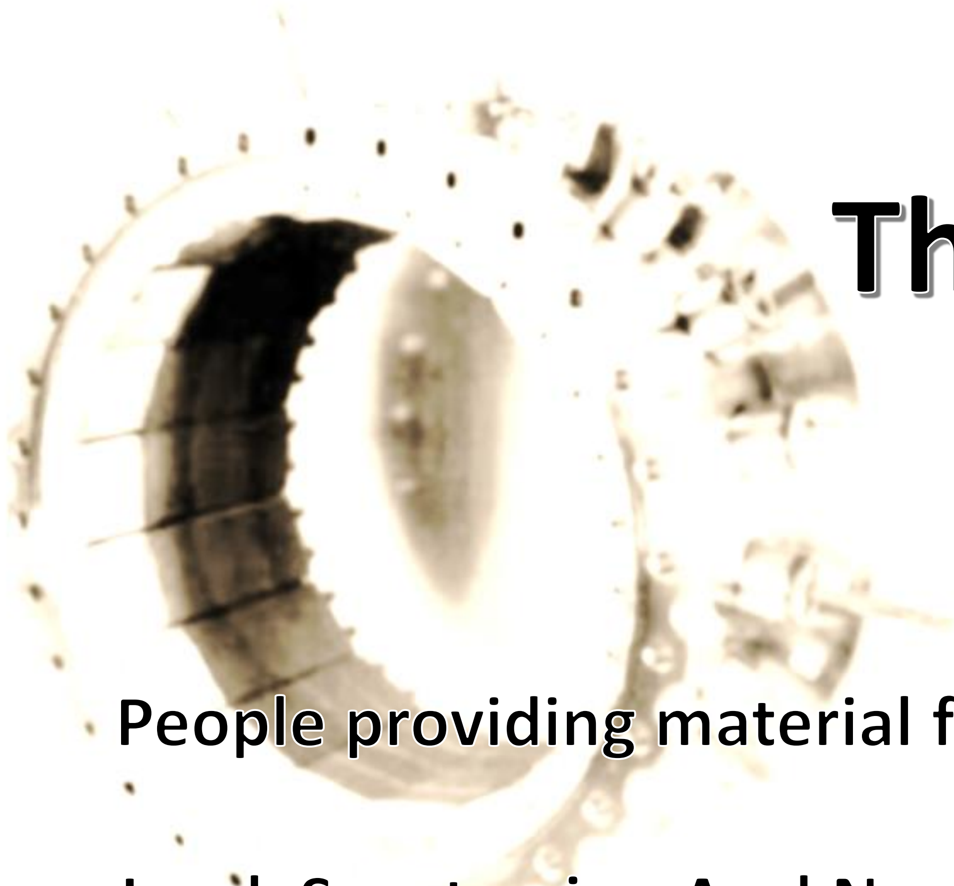

Thanks

People providing material for this talk:

Jacek Secutowicz, Axel Neumann, Hans-Walter Glock, Hiroshi Sakai, Philipp Kolb, Sergey Belomestnykh, Robbert Rimmer, Sang-Hoon Kim, Michael P. Kelly and Michael Pekeler

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