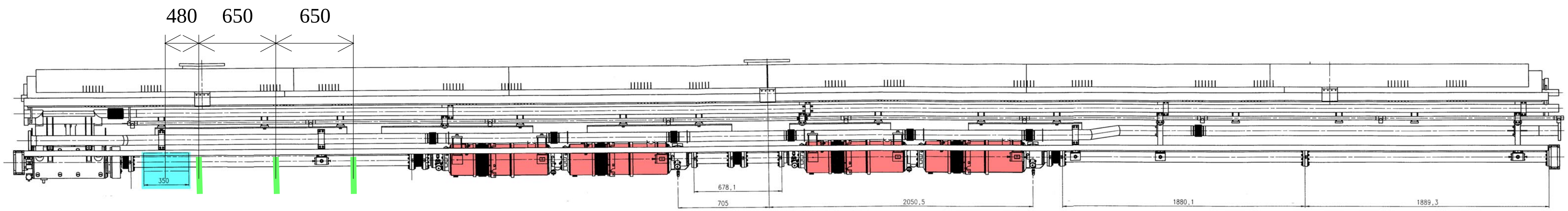
XFEL HOM absorber

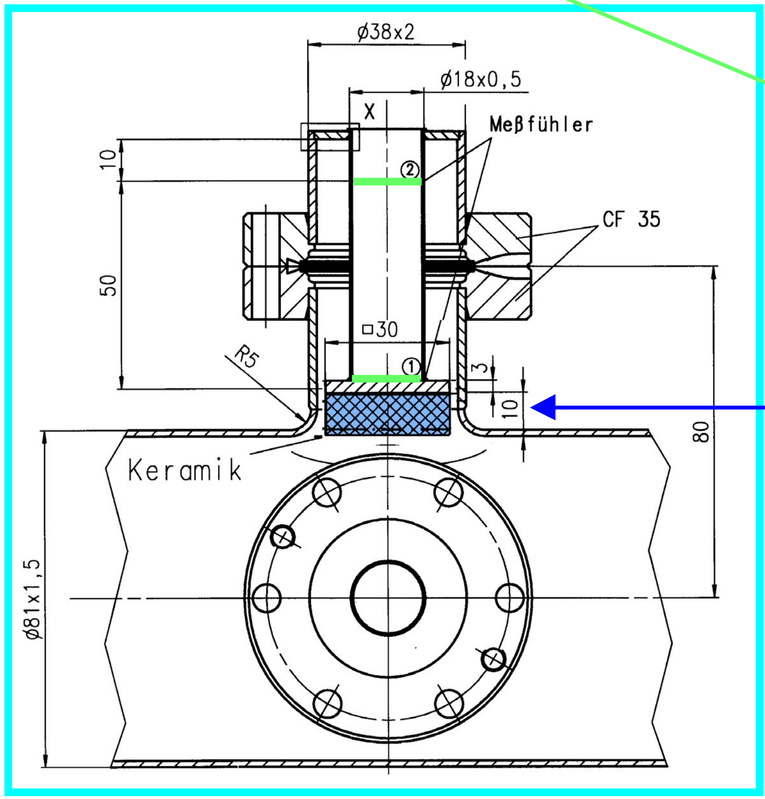
- HOM absorber in cryo module (sept 2002)
- monopole losses
- HOM absorber / coupler
- absorber design
- absorber materials
- some questions

Sep. 2002: HOM Absorbers in Cryo Module



cavities

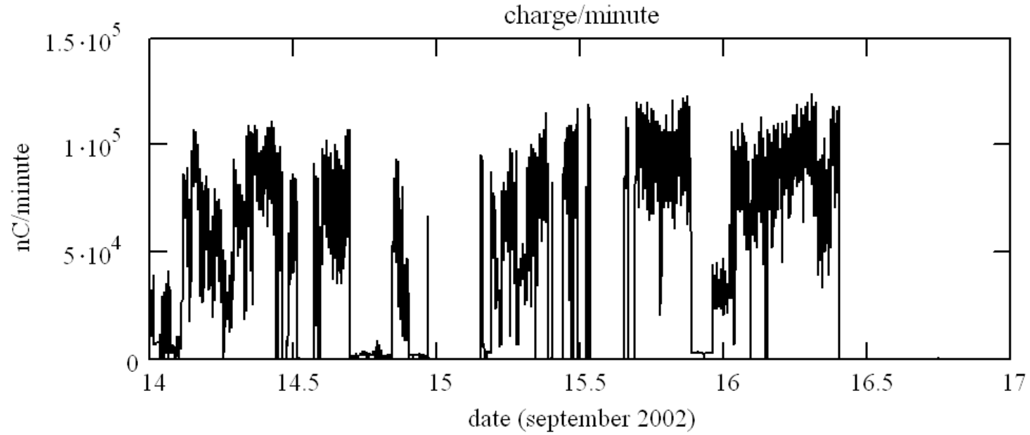
steel beam pipes !

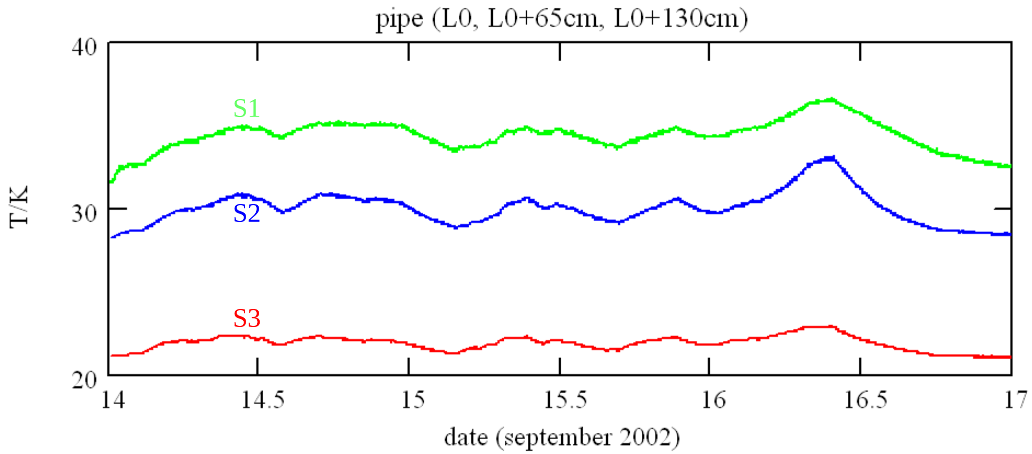


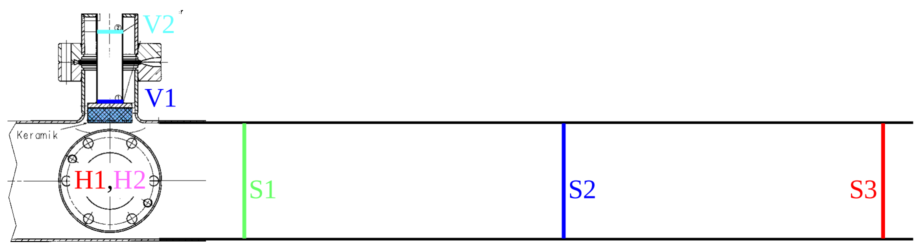
T sensors @ absorber & beam pipe

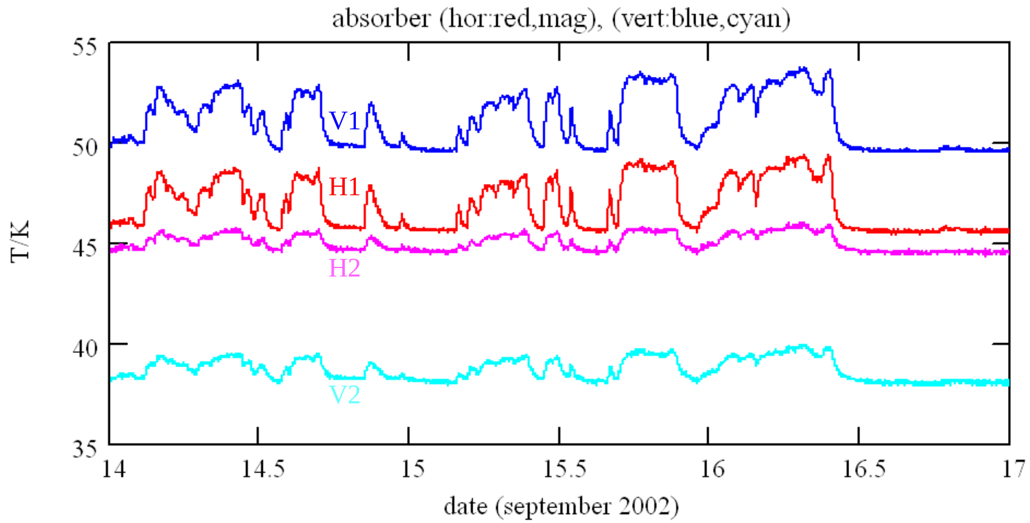
absorber material
ZR10CB5
d = 30 mm
h = 10 mm

Measurements (500µs bunch train)



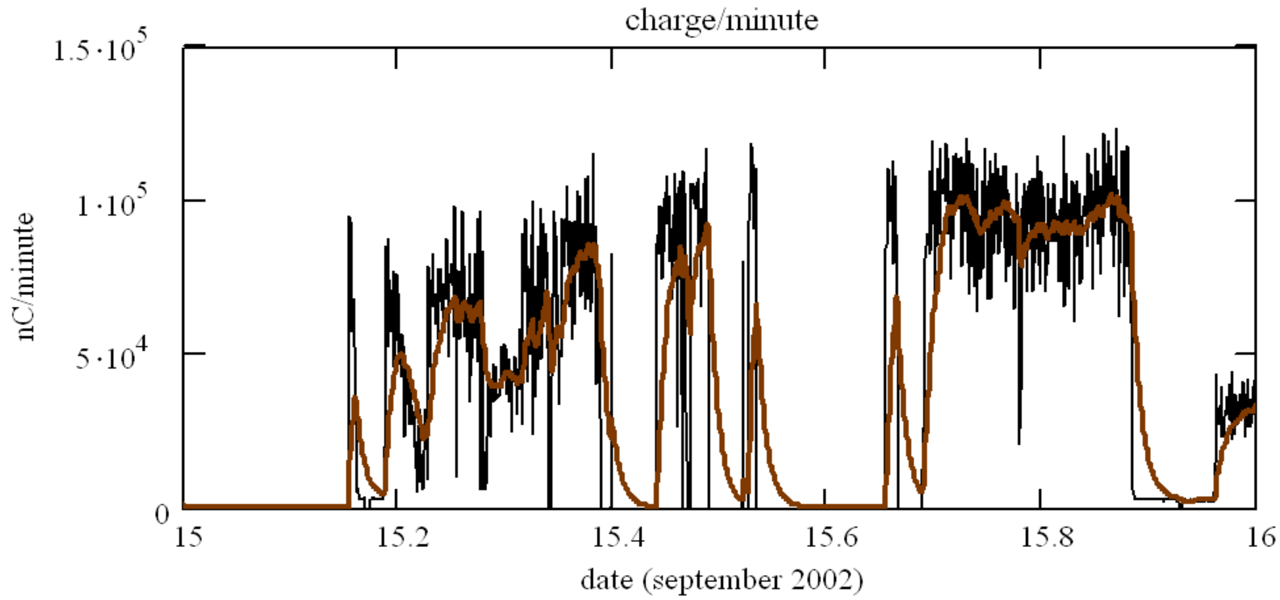






charge/min

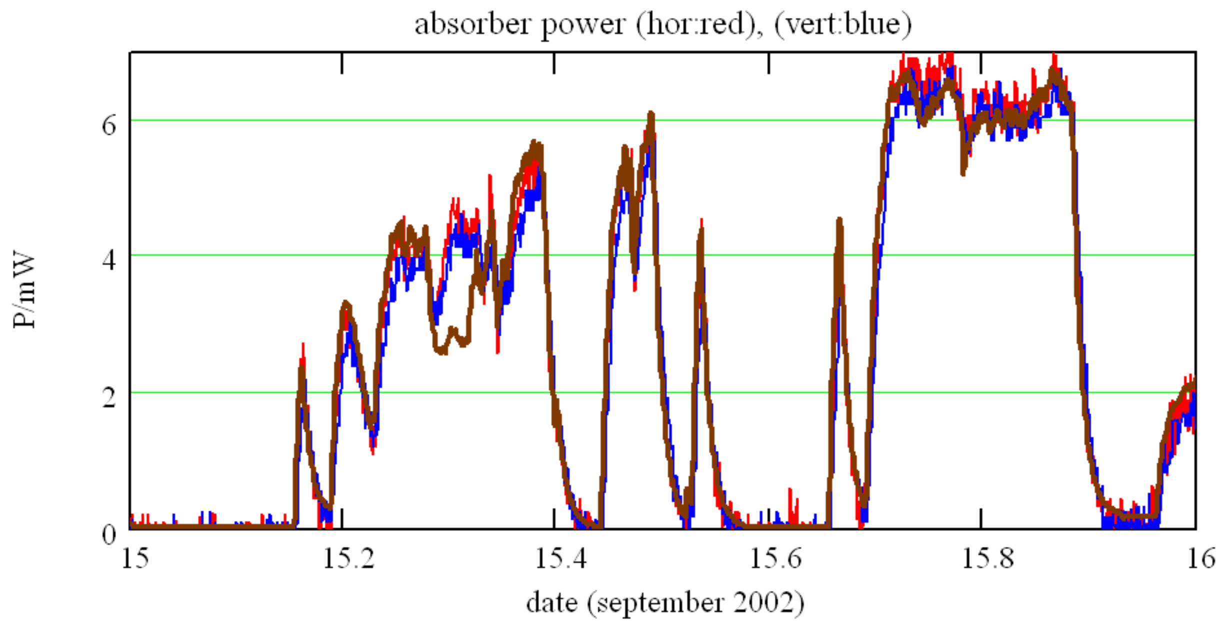
low pass filtered charge/min
τ = 12min



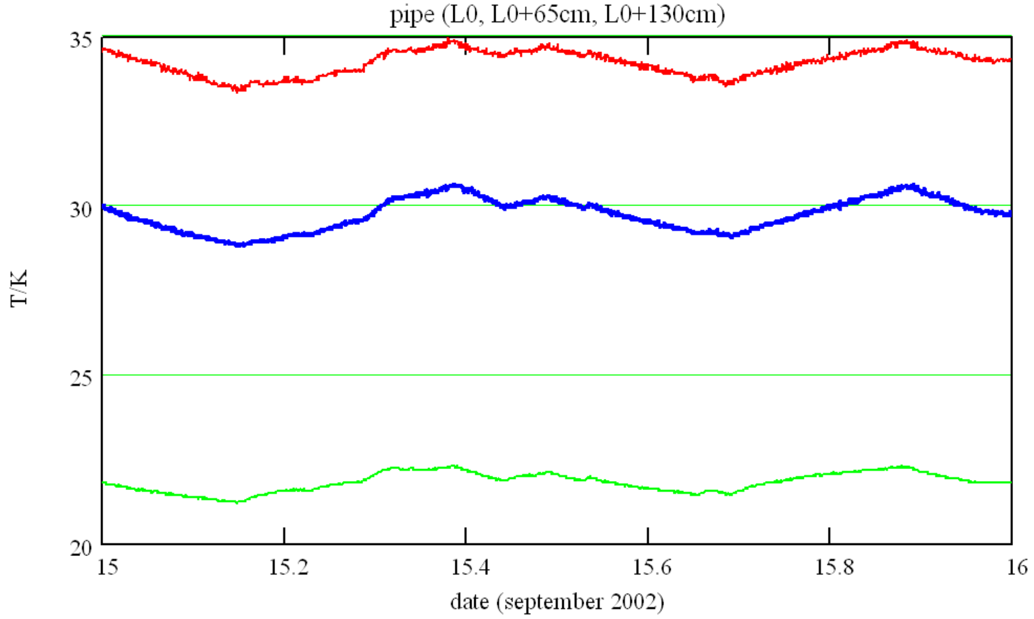
HOM absorber, absorbed power:
horizontal, vertical

scaled and low pass filtered
charge/min τ = 12min

$$P_{abs} \approx \langle I \rangle_{DC} \frac{4\ \text{mW}}{\mu\text{A}}$$



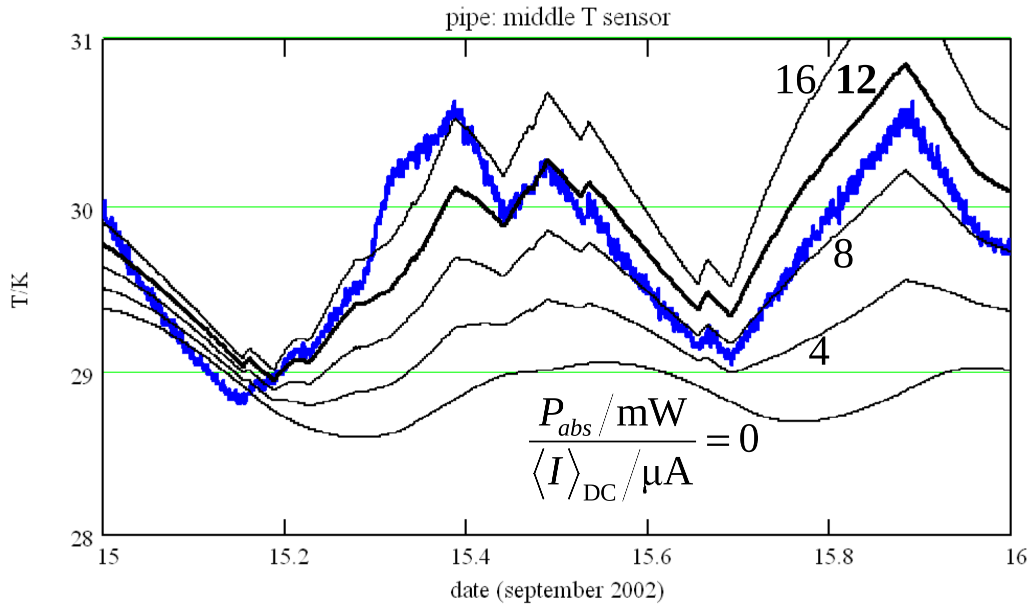
measured beampipe temperatures
(S1, S2, S3)

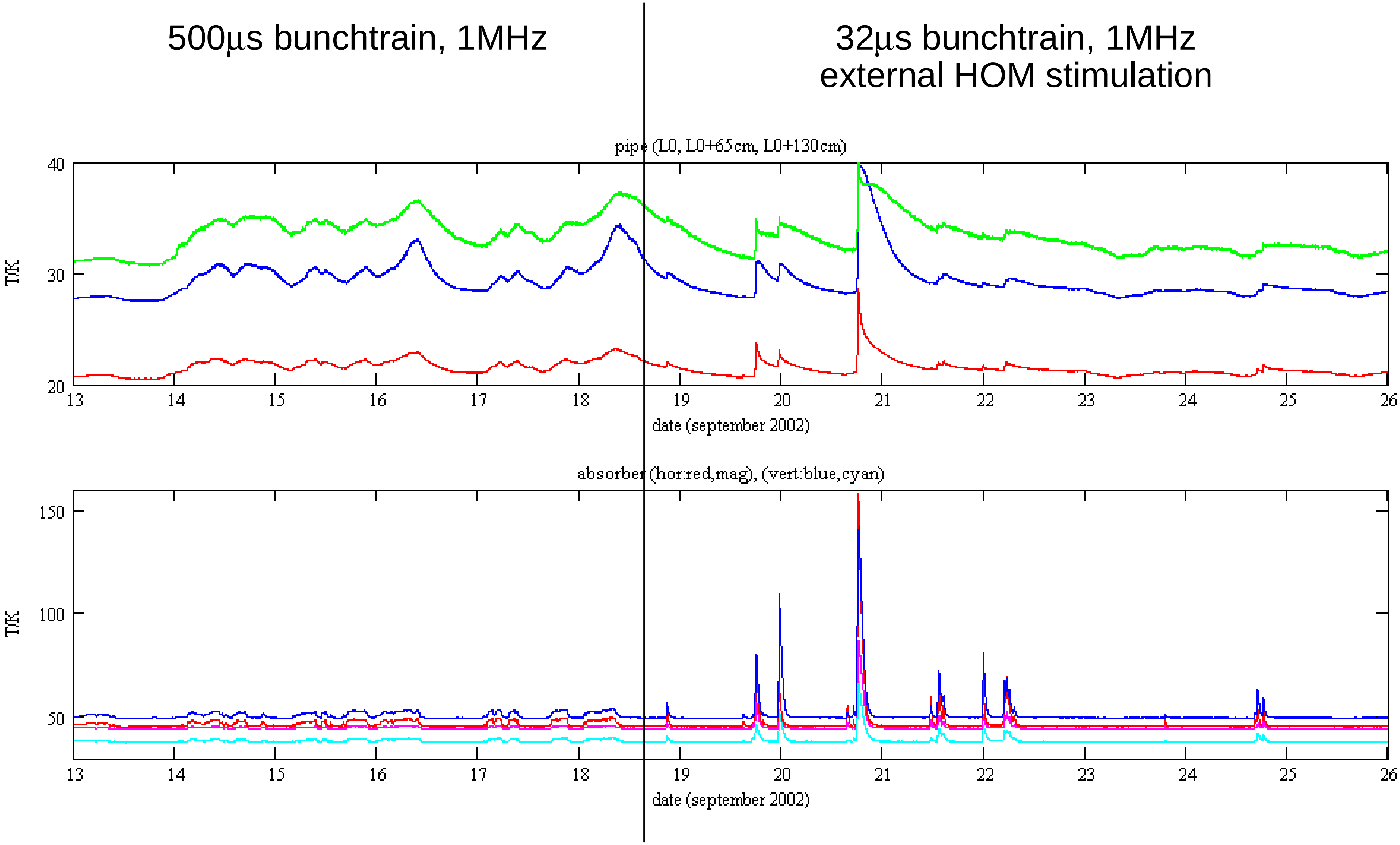


measured beampipe temperature S2

solution of transient heat equation with boundary conditions S1,S3 and $P_{abs} \sim \langle I \rangle_{\mathrm{DC}}$

$$P_{abs} = P'_{abs} L_{pipe}$$





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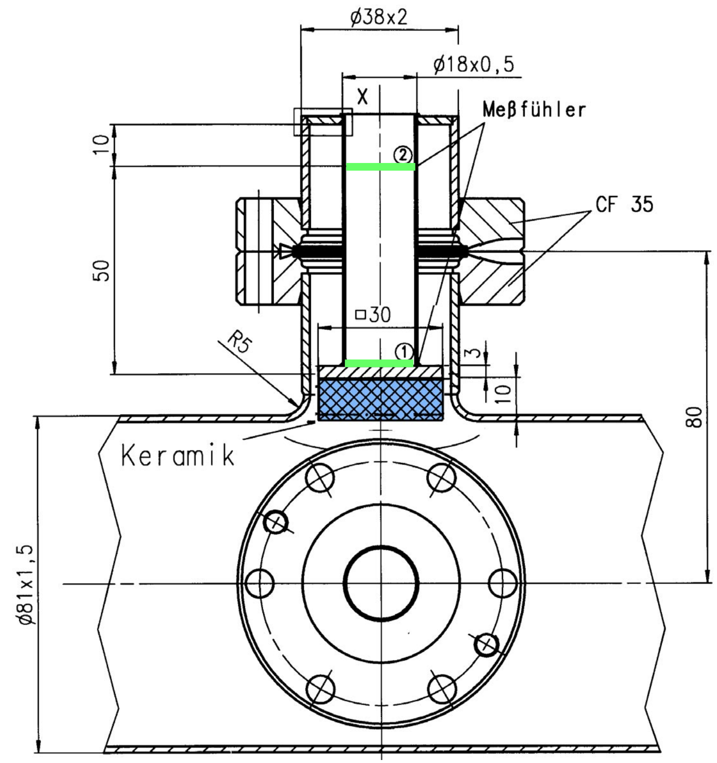
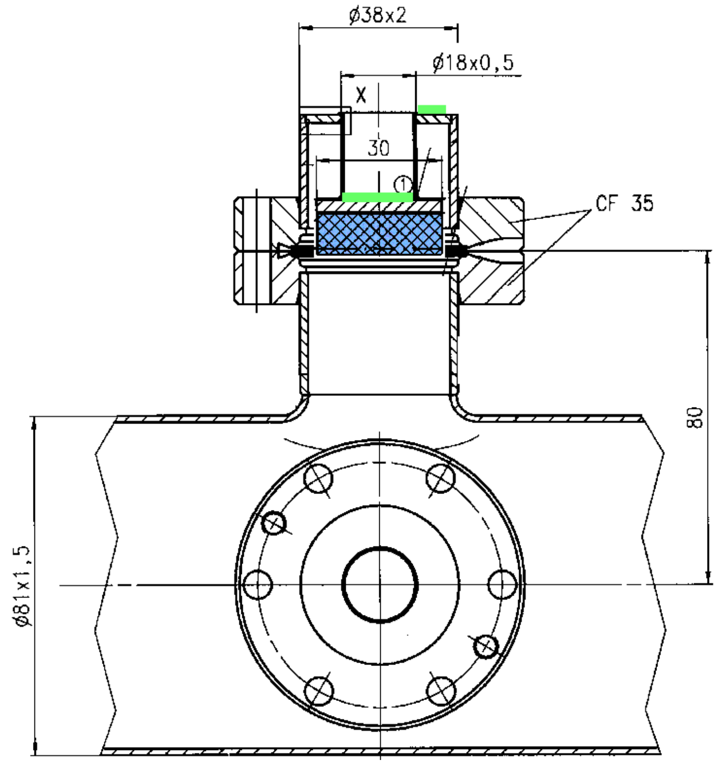
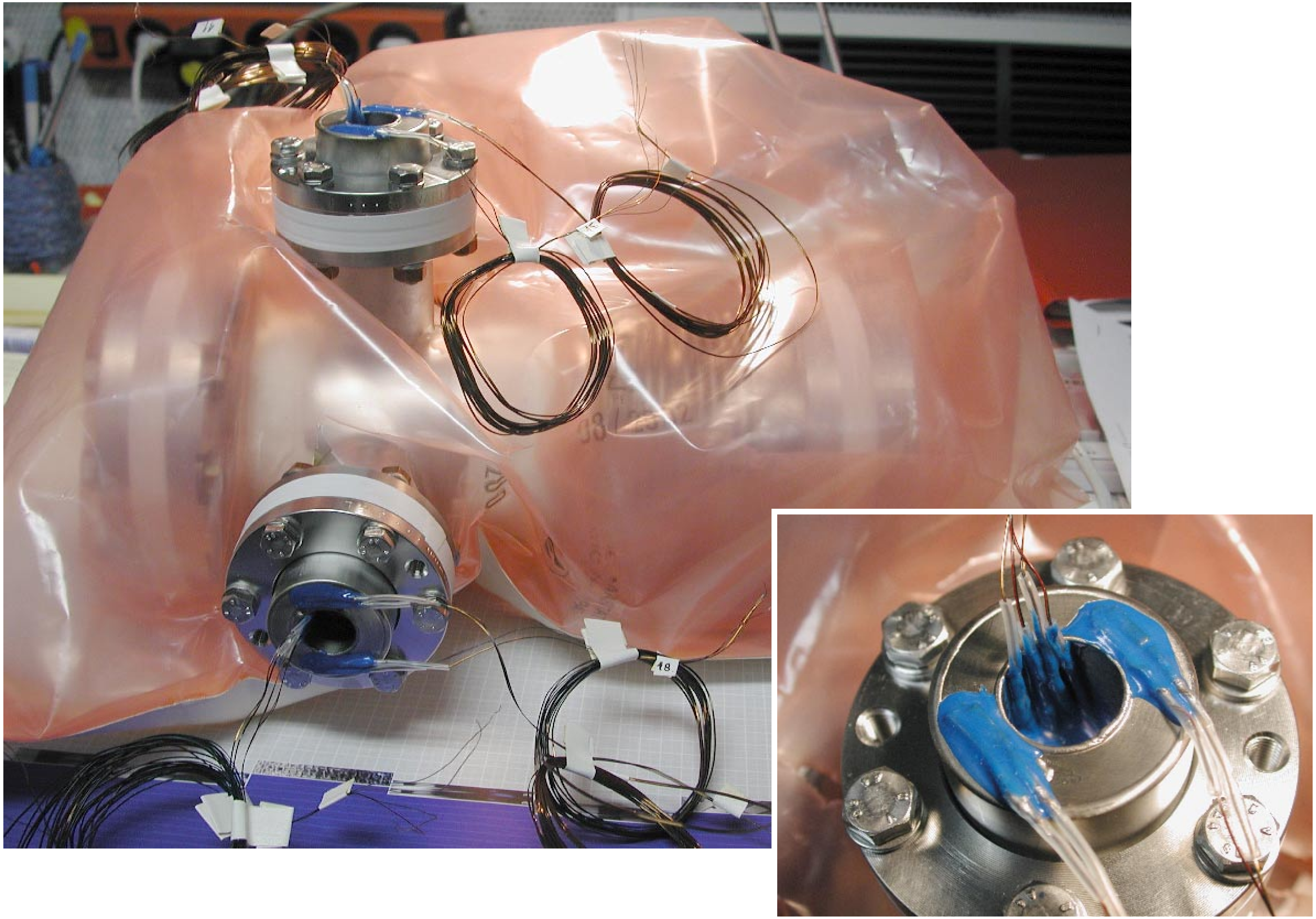
TTF2: test absorber between module 2 & 3

TTF1, Sept 2002



TTF2

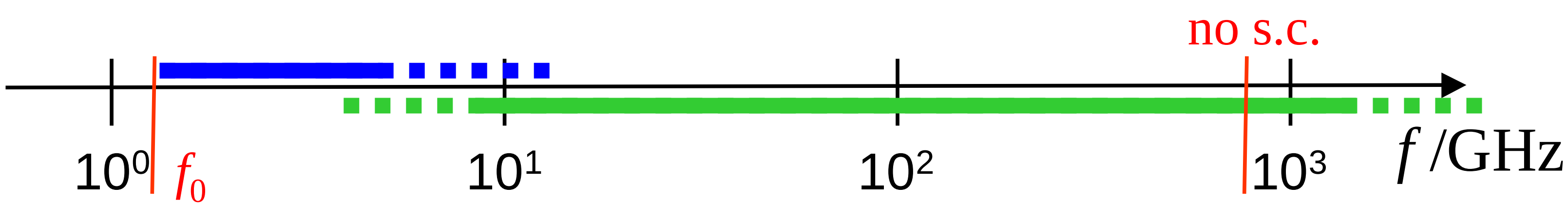




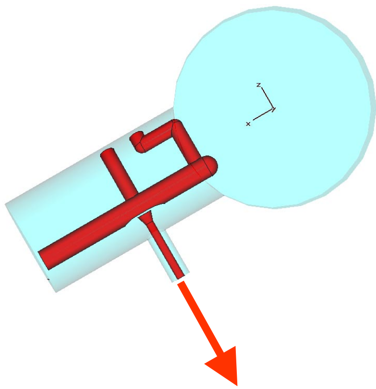
what is a hom absorber ?

trapped &
quasi trapped modes:
resonant
effects

propagating modes

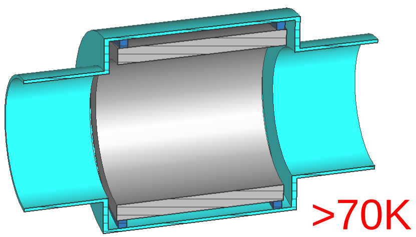


HOM couplers



coax to warm load

HOM absorbers



no transmission lines or waveguides
⇒ absorber at temperature level with
good cryo efficiency

absorbers in interconnections between modules
T > 70K

monopole single passage losses
TESLA-TDR

f_{rep} = 5 Hz
T_{HF} = 0.95 ms

a) Collider (500GeV)

σ_{bunch} = 400 μm
N_{bunch} = 2820
q_{bunch} = 3.2 nC (9.5 mA)

losses per module (12x9cells):

P = 23.3 W
$P(f >$ 5 GHz) = 17.4 W
$P'(f >$ 10 GHz) = 12.7 W
$P'(f >$ 20 GHz) = 8.1 W
$P'(f >$ 50 GHz) = 3.0 W
$P'(f >$100 GHz) = 0 .7 W

b) FEL

σ_{bunch} = 25 μm
N_{bunch} = 11315
q_{bunch} = 1.0 nC (12 mA)

losses per module (12x9cells):

P' = 14.2 W
$P'(f >$ 5 GHz) = 11.5 W
$P'(f >$ 10 GHz) = 9.3 W
$P'(f >$ 20 GHz) = 7.1 W
$P'(f >$ 50 GHz) = 4.7 W
$P'(f >$100 GHz) = 3.1 W

monopole single passage losses
TDR supplement

TDR supplement:

	Unit	Value
Final energy	GeV	10...**15**...20
Injection energy	GeV	0.5
Accelerating gradient*) E_{acc}	MV/m	10...**17**...23.5
Total length (incl. BC-III)	m	1380
Active length	m	859.4
Modules	#	78
Cavities	#	936
Klystrons	#	26
Bunch charge Q_b	nC	1
Bunch spacing Δt_b	ns	200
Bunch train length (max.)	μs	800
Repetition rate	Hz	10
Average beam power	kW	600
AC power (RF and cryogenics)	MW	3.5

* In the first linac section, the gradient is fixed at 18 MV/m for a constant beam energy of 2.5 GeV in the bunch compressor III.

Table 3.6.1: *Overview of main parameters for the first stage XFEL linac.*

bunch length ~ 25 µm

short range wake / length
(I. Zagorodnov, TESLA 2003-19)

$$w_{\|}(s) = 41.5 e^{-\sqrt{\frac{s}{1.74\cdot 10^{-3}}}} \quad \left[\frac{V}{pC\cdot m}\right]$$

→ longitudinal loss parameter (25 µm):

$$k_{\|}' = 18.5\cdot 10^{12}\,\frac{\mathrm{V}}{\mathrm{Cm}}$$

→ “single passage” losses (12 cavities):

$$P_{sp} = q^2 k_{\|}' L_{\mathrm{length}}\, f_{\mathrm{rep}} N_{\mathrm{particles/pulse}} = 9.21\,\mathrm{W}$$

per module

for comparison Q_0 losses:

$$E = 23.5\,\frac{\mathrm{MV}}{\mathrm{m}} \qquad Q_0 = 10^{10} \qquad T_{\mathrm{rf}} = 1.37\,\mu\mathrm{sec}$$

$P_0 = 7.4\,\mathrm{W}$ per module

monopole single passage losses (TDR supplement)

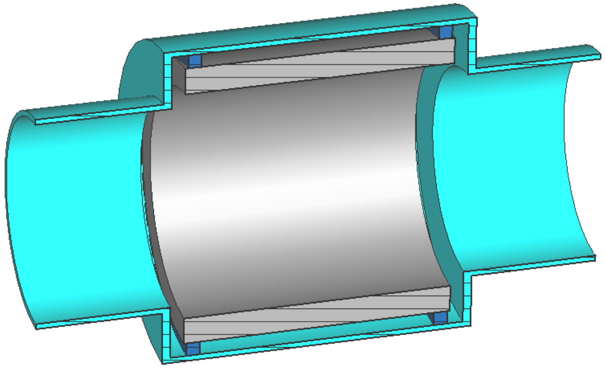
$$P_{sp} = q^2 k'_{\|} L_{\text{length}} f_{\text{rep}} N_{\text{particles/pulse}} = 9.21\,\text{W}$$ per module

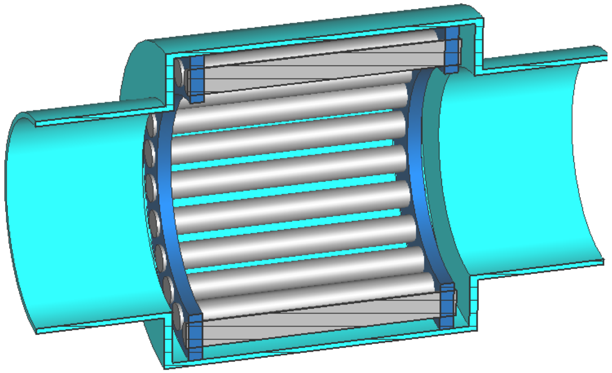
losses above f:

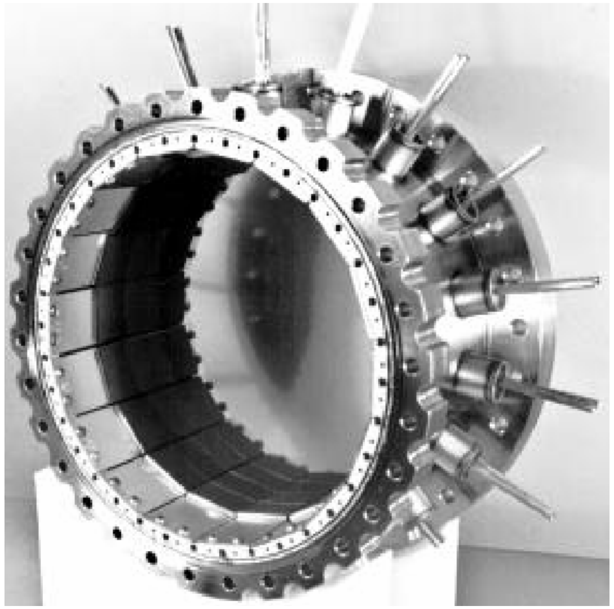
8.17 W	f > 1.3 GHz	~ 45 monopole modes (R. Wanzenberg, TESLA 2001-33)
7.55 W	2.45 GHz	
7.54 W	2.76 GHz	
7.50 W	3.67 GHz	
7.48 W	3.83 GHz	
7.3 W	5 GHz	
6.3 W	10 GHz	
5.0 W	20 GHz	
3.4 W	50 GHz	
2.4 W	100 GHz	
0.4 W	750 GHz	to cavity walls

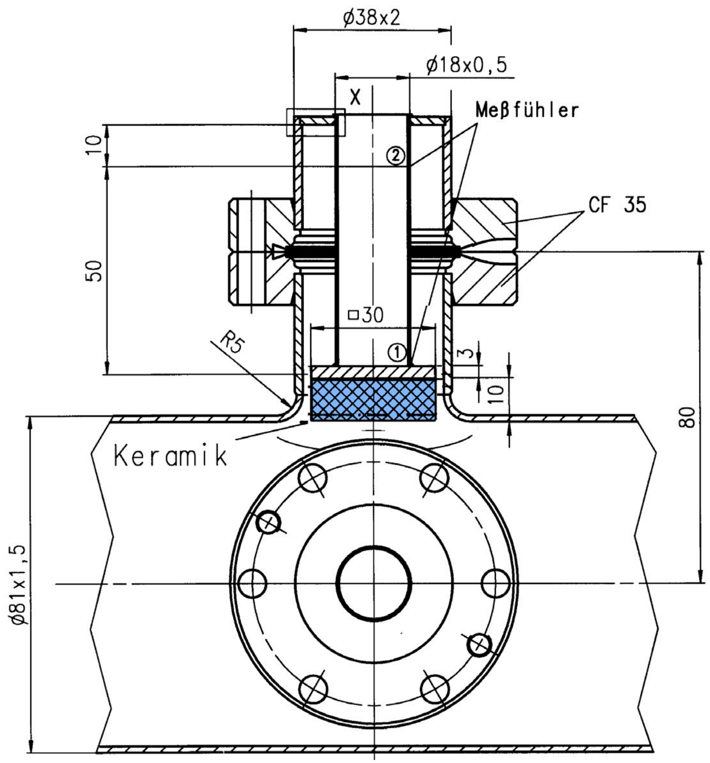
approximately (7.3 – 0.4) W can reach the absorber

absorber design



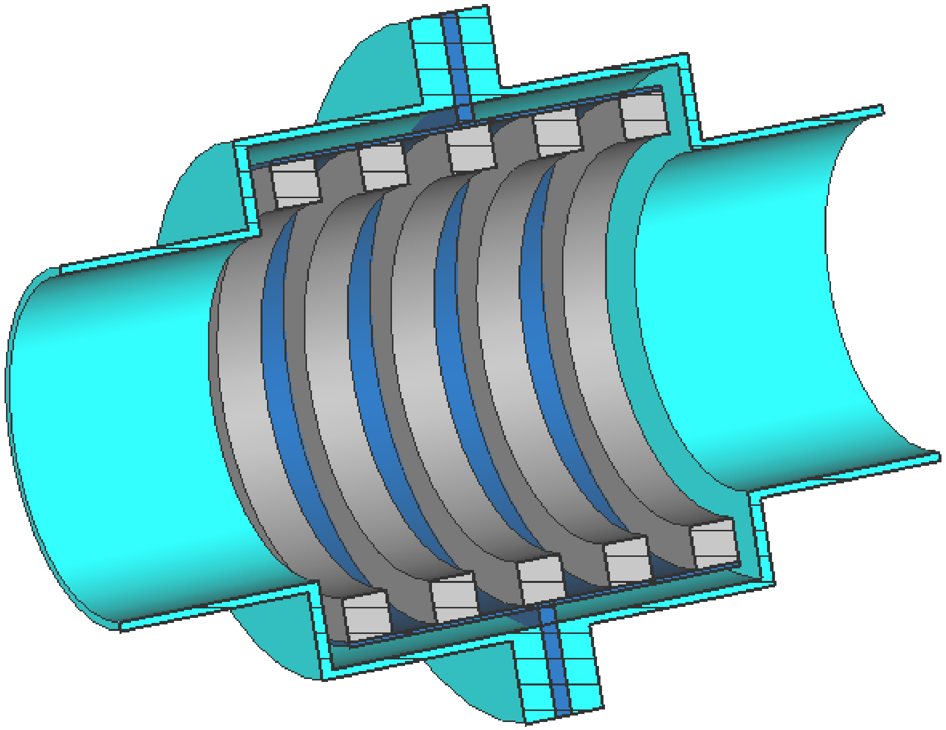


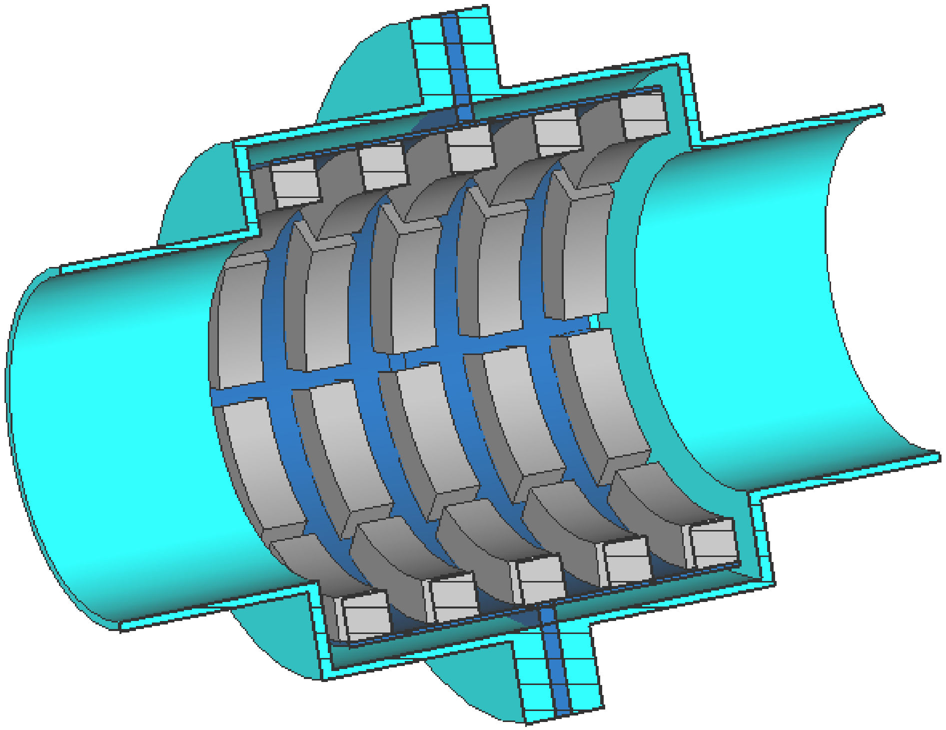




- thermal isolation to T < 70K
- thermal contact (cooling) to T = 70K
- electrical contact
- mechanical contact
- protection ?

it is not possible to design an absorber without boundary conditions !!!
the material is probably not (the big) problem;





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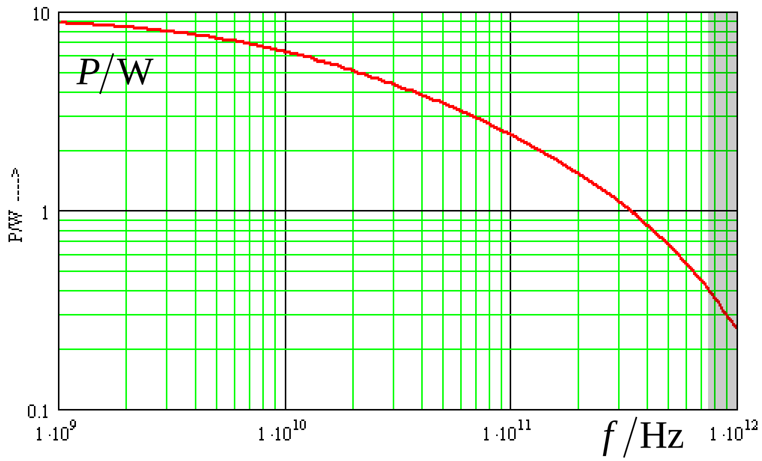
	requirements	$Al_2 0_3$&Mo UNIPRESS	AlN & carbon CERADYNE	ferrite
comment		collaboration; reproducibility ? furnace for large probes ?	used @ 2K in CEBAF; what material? large probes ?	used @ 300K In CESR
rf propperties	$P^{(t)}/P^{(inc)} > 0.5$ $\alpha(10\mathrm{GHz}) > 1/(1\mathrm{cm})$	ok for some materials 80 K test @ X-band (early probes)	ok for some materials 80 K test @ X-band	absorption mechanism for f > 10 GHz unclear;
dc conductivity @ 80 K !!!	depends strongly on geometry & holder $>10^{-12}$ S/m cylinder type $>10^{-9}$ S/m rod type		$2 \cdot 10^{-9}$ S/m @ 300K	
thermal conductivity @ 80 K !!!	depends strongly on geometry & holder >100 W/(m·K) should be ok	≈ 150 W/(m·K) @ 86K		
radiation resistivity	no definition, so far			
vacuum		probes rejected	ZR10CB5 tested	
handling (mechanical prop., brazing, ...)		density & porisity measured; SEM photographs	ZR10CB5 used in module 1*	

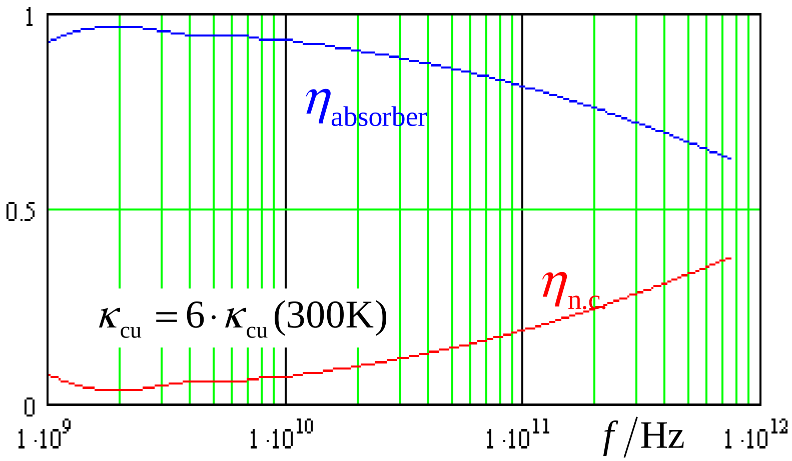
absorption efficiency

(example)

losses above frequency



absorption efficiency



$$\int \eta_{\text{absorber}}(\omega)dP = 5.86\ \text{W}$$

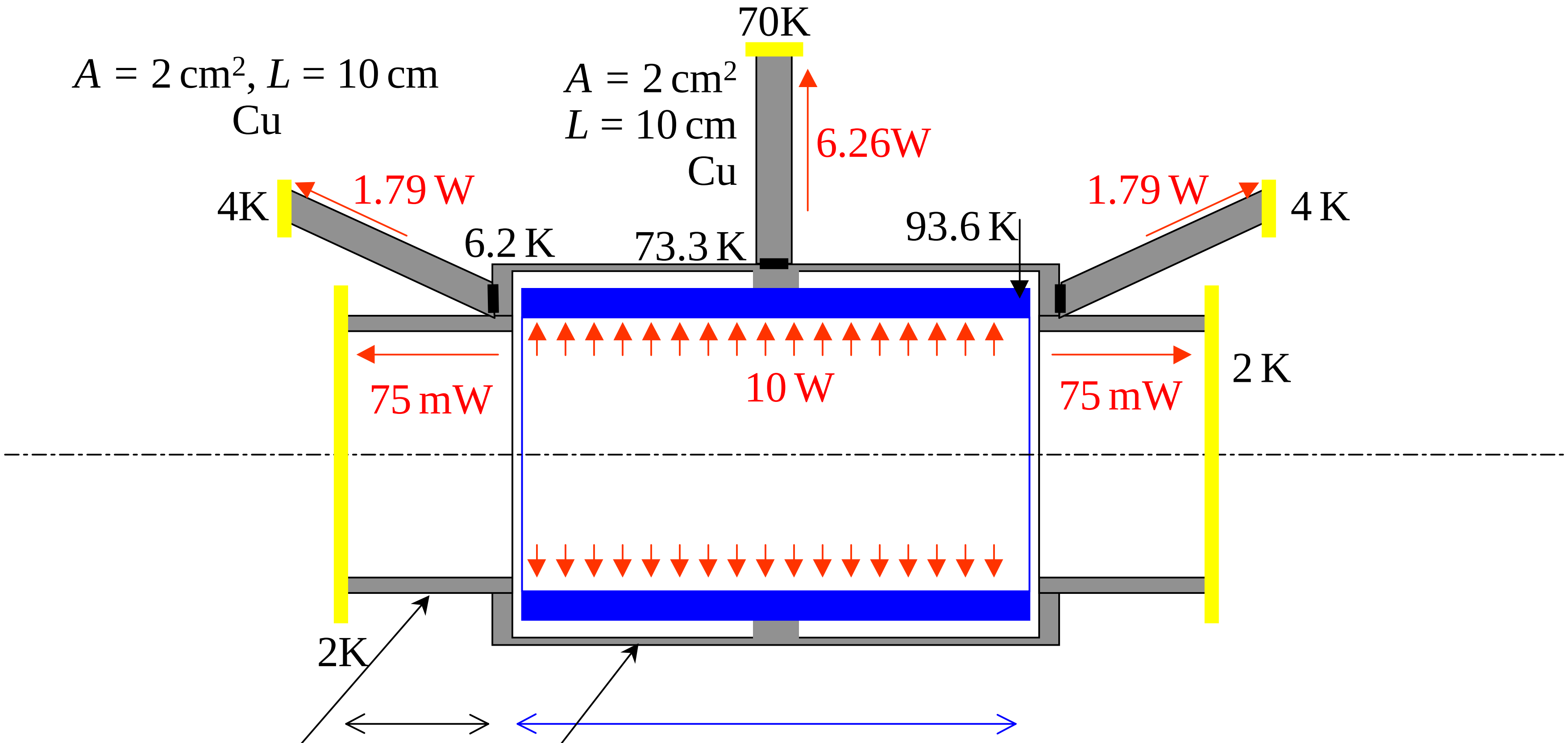
safty factor: $S = 0.9$

$$\int \eta_{\text{absorber}}(\omega)dP \cdot S = 5.27\ \text{W}$$

losses in n.c. surfaces:

$$6.9\ \text{W} - 5.27\ \text{W} = 1.63\ \text{W}$$

thermal isolation (example)



r = 39 mm
d = 2 mm steel
10 µm Cu (RRR=10)

r = 60 mm, d = 1 mm
steel + stiffening

10 cm
r_1 = 44 mm
r_2 = 54 mm

2 K and 4 K losses
are
nearly static !

single passage losses > 5 GHz (example)

dynamic losses @ 2K

total: 7.3 W

to cavity walls: 0.4 W

to normal conducting walls: 1.63 W (safty margin + anomalous skin effect)

2.03 W

+ static losses depend on available space!

@ 2K: ~ 0.15 W

@ 4K: ~ 3.58 W

some questions

- absorber per module or per two modules
- positon, space (boundary conditions)
- material
- dc conductivity (measurement setup?)