What field performance can we expect from the gun

Jacek Sekutowicz

1. *Niobium Limit and Cavity Shapes*
2. *SC Cavity Performance*
3. *Tests of SRF guns*
4. *Final Remarks*

1. Niobium limit and Cavity Shapes

Assumption: SRF guns will be made of bulk Niobium (at least for the next decade)

The limits in the performance of a SRF-gun cavity are due:

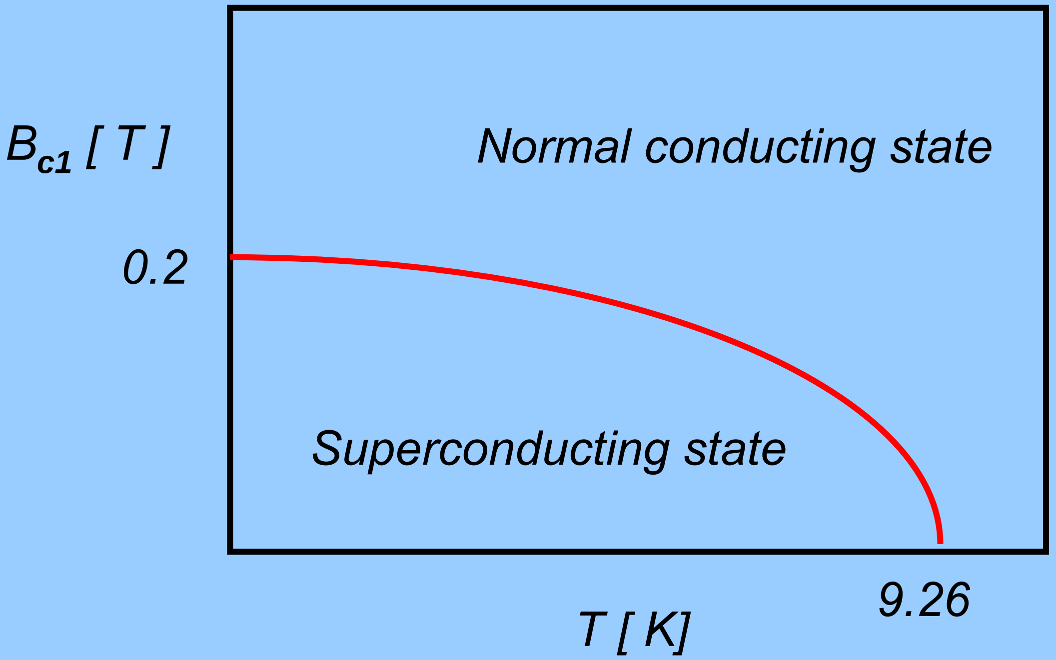
- *superconducting properties of niobium*
- *geometry of the cavity*
- *crystallographic structure of Nb and roughness of the surface*
- *quality of the surface preparation*
- *performance of auxiliaries (FPC, HOM couplers…)*

1. Niobium limit and Cavity Shapes

- *Superconducting properties of niobium*

B_{c1} = 180-190 mT

T_c = 9.26 K



1. Niobium limit and Cavity Shapes

- Cavity Shape

The limit in maximum E_{peak} on the wall is simply:

$$E_{max} = \frac{B_{c1}}{(\frac{B_{peak}}{E_{acc}})} \cdot (\frac{E_{peak}}{E_{acc}})$$

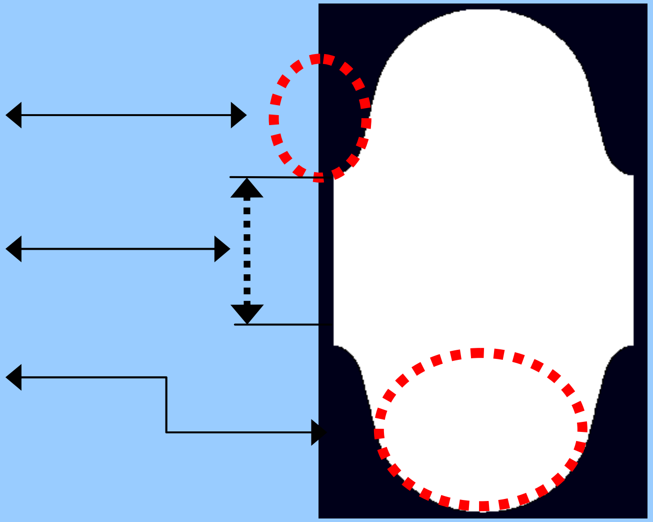
These are geometric factors

Geometry :

iris ellipsis : half-axis h_r, h_z

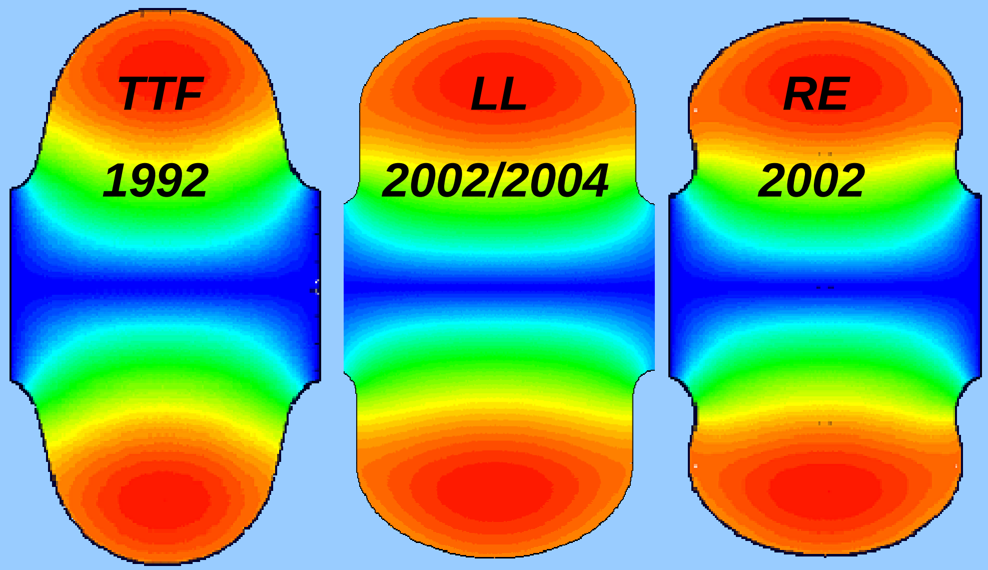
iris radius : r_i

equator ellipsis : half-axis h_r, h_z



1. Niobium limit and Cavity Shapes

Various shapes on the market (can be scaled to meet F requirements).

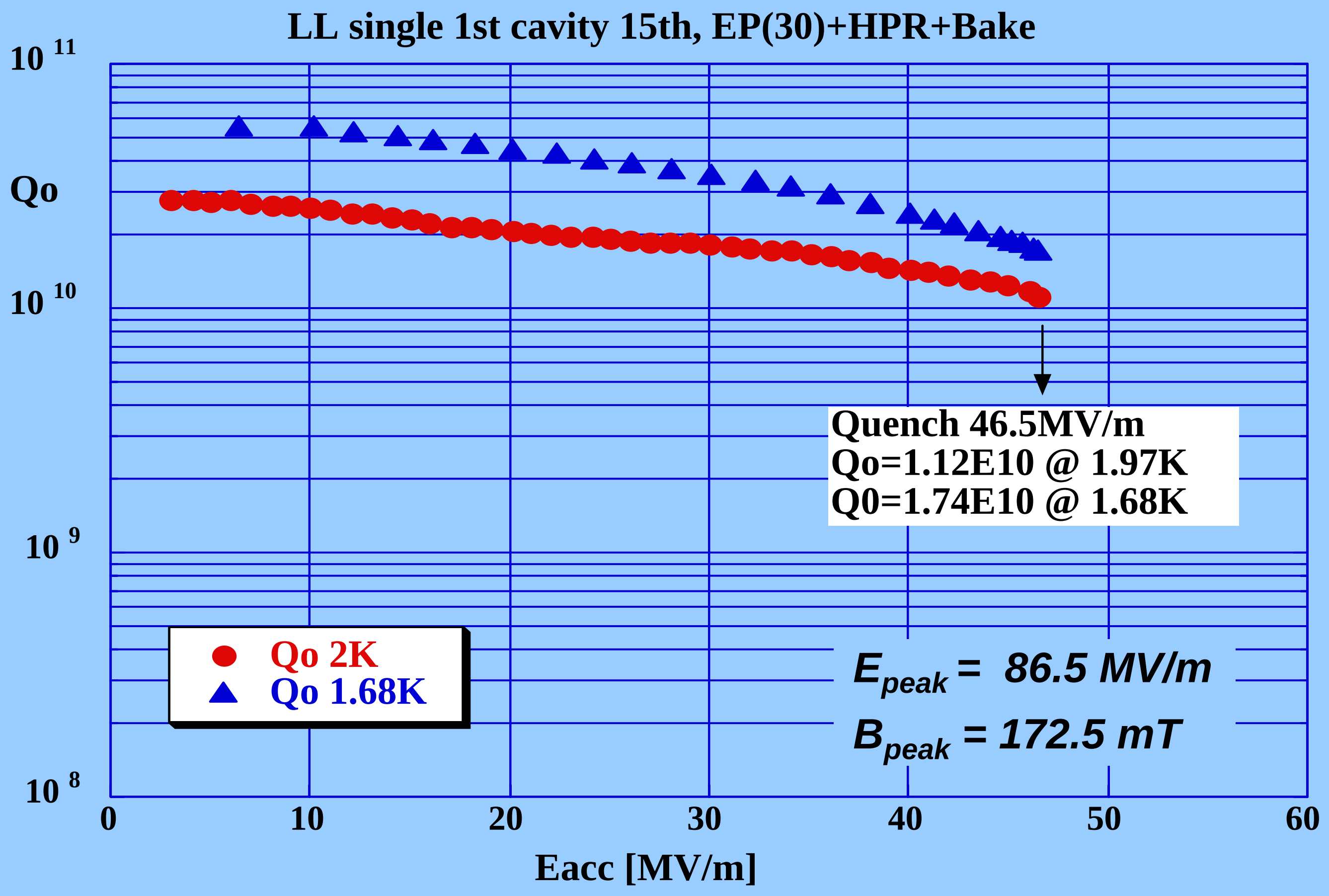


r_{iris}	[mm]	35	30	33
k_{cc}	[%]	1.9	1.52	1.8
E_{peak}/E_{acc}	-	1.98	2.36	2.21
B_{peak}/E_{acc}	[mT/(MV/m)]	4.15	3.61	3.76
Max E_{peak}	[MV/m]	**90.7**	**124.2**	**111.7**

1.3 GHz

2. SC Cavity Performance

KEK single-cell tests in September 2005 !!!!!!!



LL single 1st cavity 15th, EP(30)+HPR+Bake

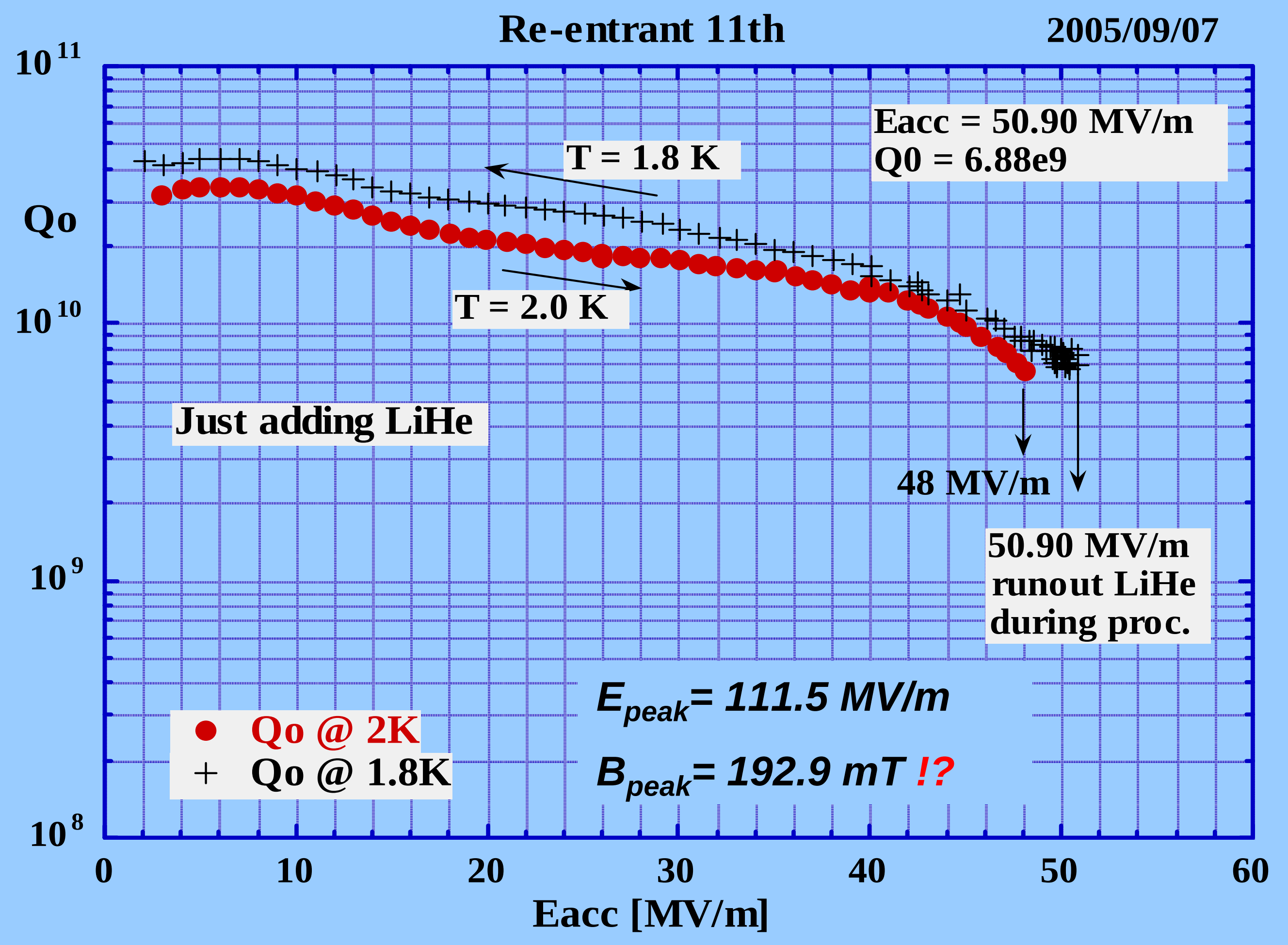
Quench 46.5MV/m
Qo=1.12E10 @ 1.97K
Q0=1.74E10 @ 1.68K

E_{peak} = 86.5 MV/m
B_{peak} = 172.5 mT

Courtesy K. Saito

2. SC Cavity Performance

KEK single-cell tests in September 2005 !!!!!!!



E_{peak}= 111.5 MV/m

B_{peak}= 192.9 mT !?

Courtesy K. Saito

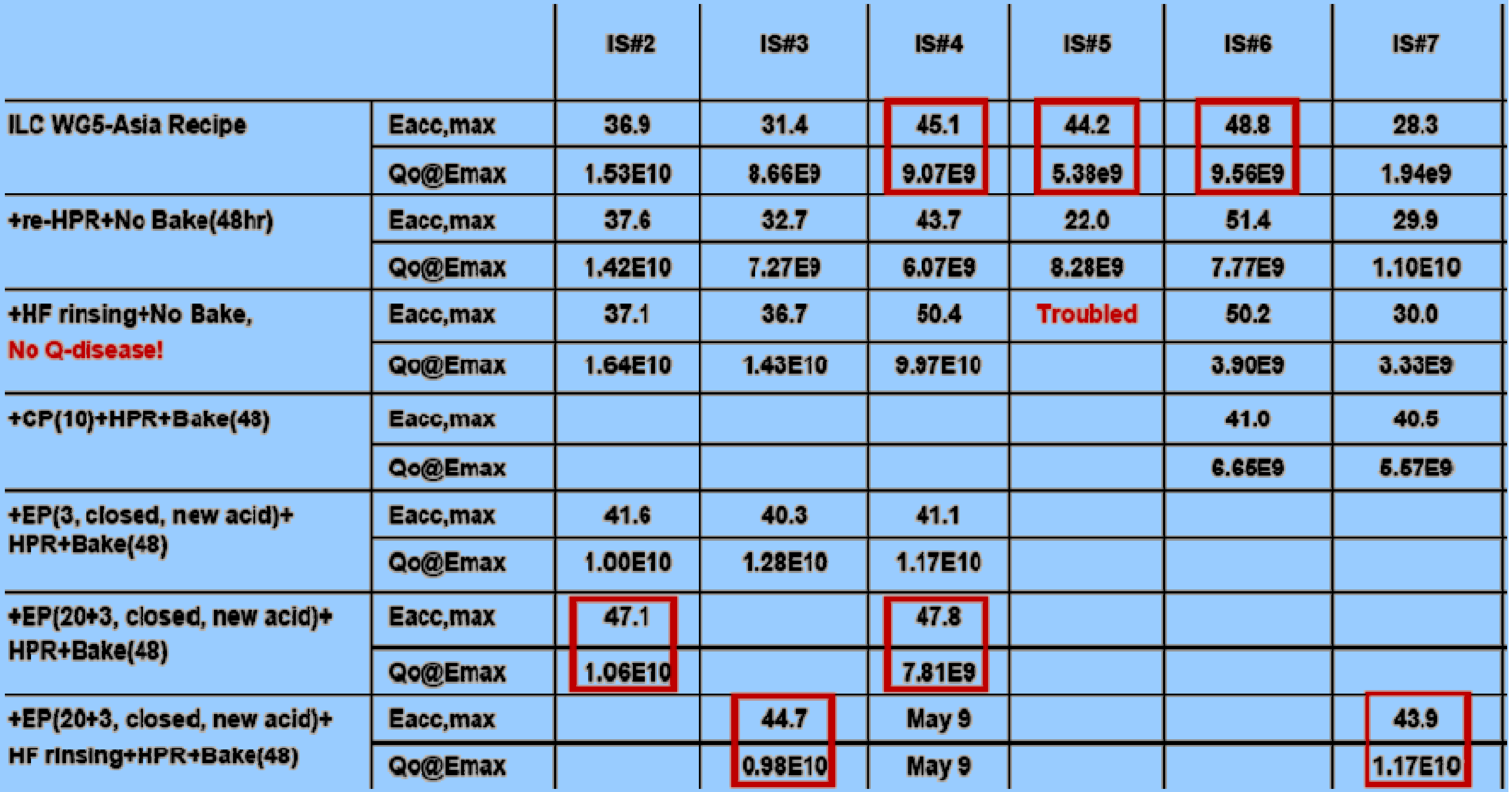
2. SC Cavity Performance

Recent KEK results (ICHIRO ≈ LL shape)

$E_{peak} = E_{acc}*1.9$

$\mathbf{E}_{\mathbf{peak}} = < 83.4\ , 92.7> @\ \mathbf{Q} = < 5.4E9\ , 1.2\ E10>$

Courtesy Kenji Saito



		IS#2	IS#3	IS#4	IS#5	IS#6	IS#7
ILC WG5-Asia Recipe	**Eacc,max**	**36.9**	**31.4**	**45.1**	**44.2**	**48.8**	**28.3**
	Qo@Emax	**1.53E10**	**8.66E9**	**9.07E9**	**5.38e9**	**9.56E9**	**1.94e9**
+re-HPR+No Bake(48hr)	**Eacc,max**	**37.6**	**32.7**	**43.7**	**22.0**	**51.4**	**29.9**
	Qo@Emax	**1.42E10**	**7.27E9**	**6.07E9**	**8.28E9**	**7.77E9**	**1.10E10**
+HF rinsing+No Bake, **No Q-disease!**	**Eacc,max**	**37.1**	**36.7**	**50.4**	**Troubled**	**50.2**	**30.0**
	Qo@Emax	**1.64E10**	**1.43E10**	**9.97E10**		**3.90E9**	**3.33E9**
+CP(10)+HPR+Bake(48)	**Eacc,max**					**41.0**	**40.5**
	Qo@Emax					**6.65E9**	**5.57E9**
+EP(3, closed, new acid)+ HPR+Bake(48)	**Eacc,max**	**41.6**	**40.3**	**41.1**			
	Qo@Emax	**1.00E10**	**1.28E10**	**1.17E10**			
+EP(20+3, closed, new acid)+ HPR+Bake(48)	**Eacc,max**	**47.1**		**47.8**			
	Qo@Emax	**1.06E10**		**7.81E9**			
+EP(20+3, closed, new acid)+ HF rinsing+HPR+Bake(48)	**Eacc,max**		**44.7**	**May 9**			**43.9**
	Qo@Emax		**0.98E10**	**May 9**			**1.17E10**

2. SC Cavity Performance

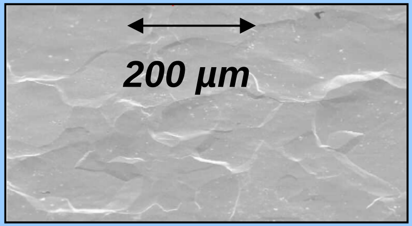
Generally speaking we are approaching with $\mathbf{E_{peak}}$ ***=> 100 MV/m***

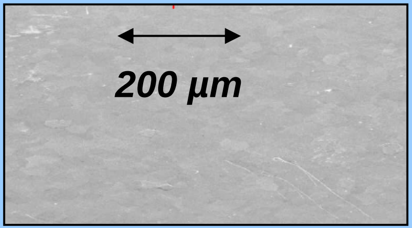
What about ***Q****, can make it higher than >* ***1. E10*** *at that field level* ***?***

- *Crystallographic structure of Nb and roughness of the surface*

First improvement : use EP instead of BCP

roughness ~10 µm





roughness ~1 µm

The standard (BCP) procedure is with an acid mixture containing ***1 part HF, 1 part*** $\mathbf{HNO_3}$ ***and 2 parts*** $\mathbf{H_3PO_4}$ *in volume.*

The standard EP procedure is with electrolyte ***HF*** *and* $\mathbf{H_2SO_4}$ *in volume ratio of* ***1:9.***

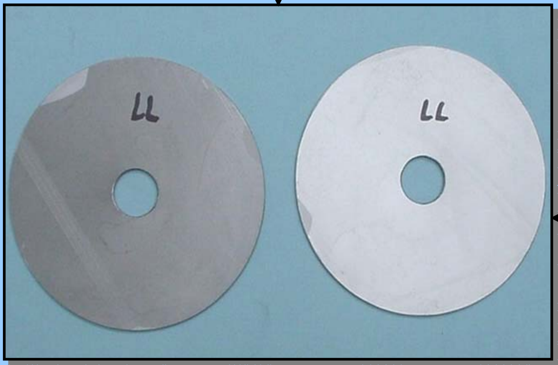
2. SC Cavity Performance

Second improvement : use single crystal material instead of poly-crystal

The most effective "knob" to lower the cryogenic load.

Courtesy P. Kneisel

$$\textbf{Cryogenic Load} = \frac{R_{BCS} + R_{residual}}{\underbrace{(R/Q)\cdot G}_{\text{Geometry of cavity}}} \cdot V^2$$

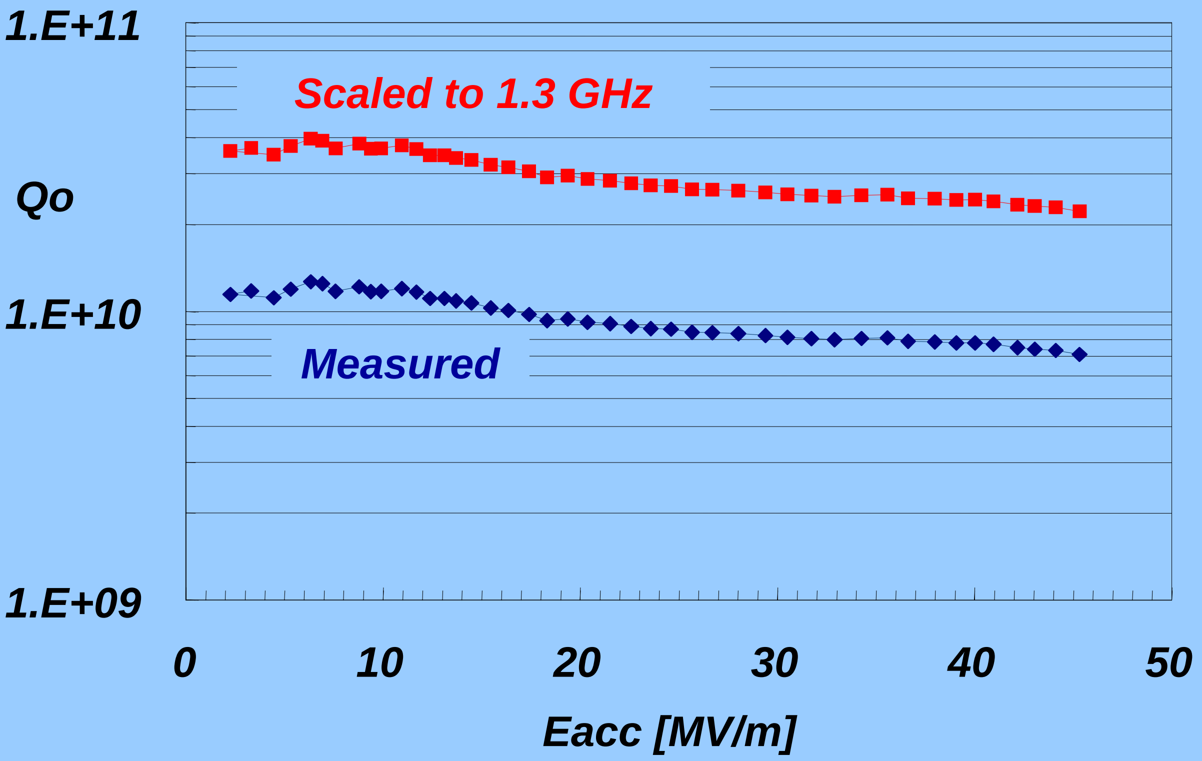


Single crystal material

- *Very smooth surface (roughness 30 nm)*
- *Much less grain boundaries*
- *Less inclusions*

2. SC Cavity Performance

LL 2.3 GHz

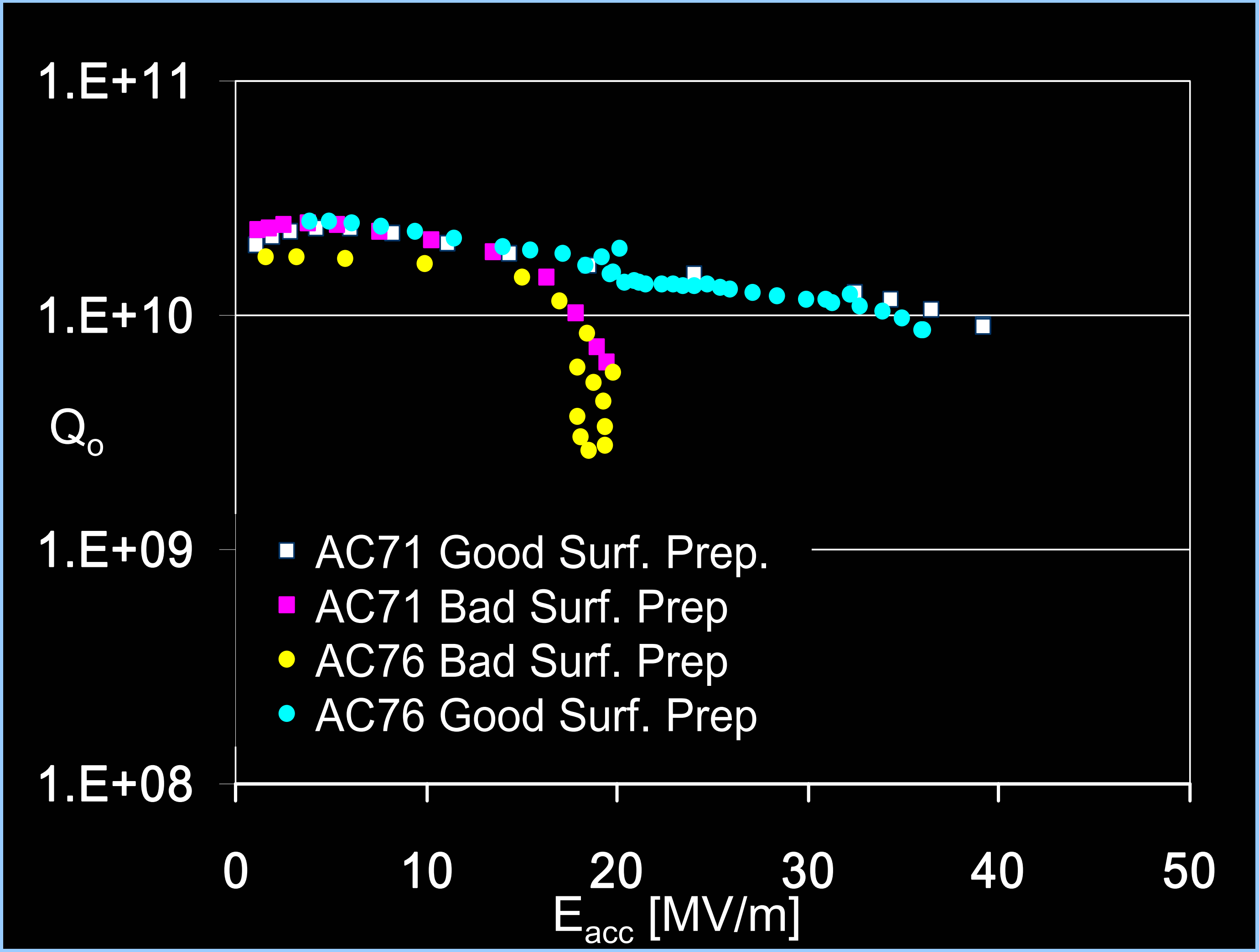


Courtesy P. Kneisel, JLab

Qo ~ **$2\cdot10^{10}$** *for 1.3 GHz at* E_{peak} **= 85.5 MV/m** *if* R_s *dominated by BCS*

2. SC Cavity Performance

- *Quality of the surface preparation*



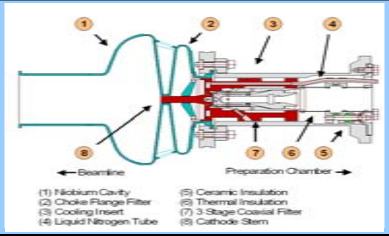
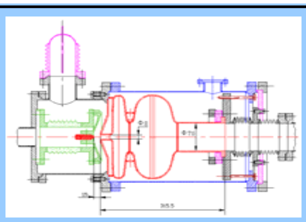
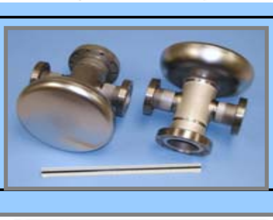
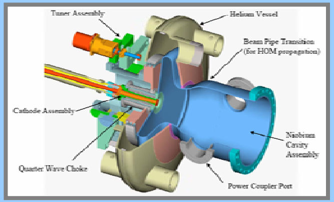
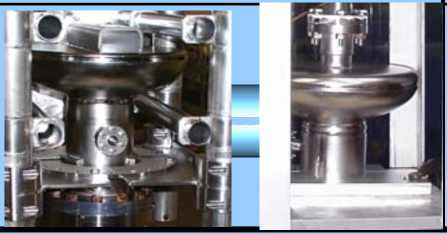
2. SC Cavity Performance

- *Performance of auxiliaries (FPC, HOM couplers, chokes…)*

Many problems may arise from the auxiliaries:

1. *FPC: Multipacting and heating*
2. *HOM: Thermal instability of the output antenna and feedthrough in cw mode*
3. *Choke: Multipacting*

3. Tests of the SRF guns

Projects	*Cavity*	*F [GHZ]*	*E_{cath} [MV/m]*
FZ Rossendorf		*1.3*	*S: 25* *M: 22 (4K) / 46 (2K)*
IHIP *Peking University*		*1.3*	*M: 2.7 (4K)*
BNL		*1.3*	*M: 48 (2K)*
BNL/AES		*0.704*	*S: 30*
DESY, BNL, JLab, *INS, SUNY, SLAC*		*1.3*	*S: 60* *M: 25*

3. Tests of the SRF guns

FZR

4 K-test

$2.5 \cdot 10^8$ @ E_{peak}=22 MV/m

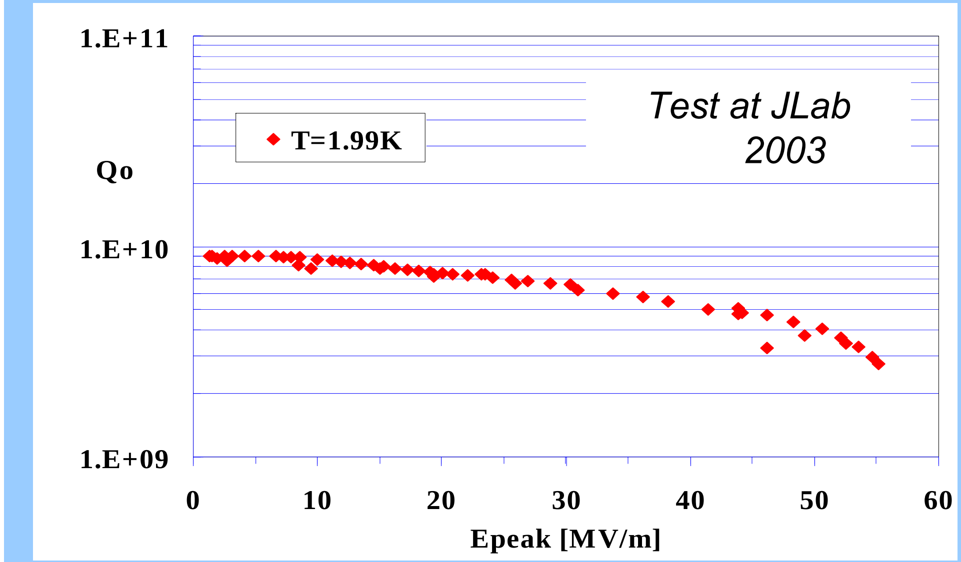
2 K-test

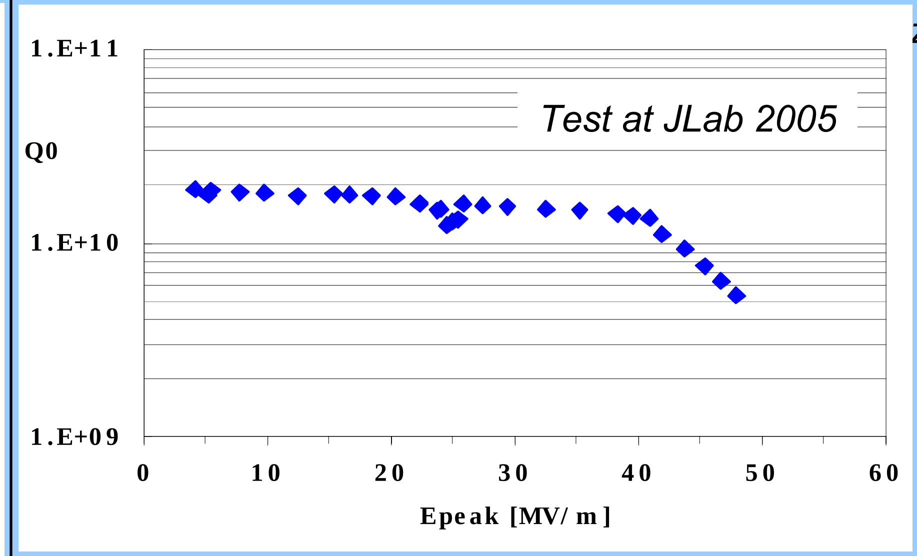
$5 \cdot 10^9$ @ E_{peak}=46 MV/m

IHIP-Peking

4.2 K- test

10^8 @ Eacc= 5 MV/m

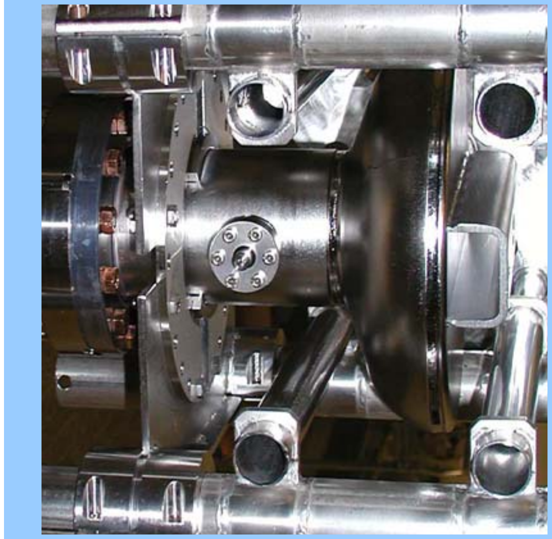


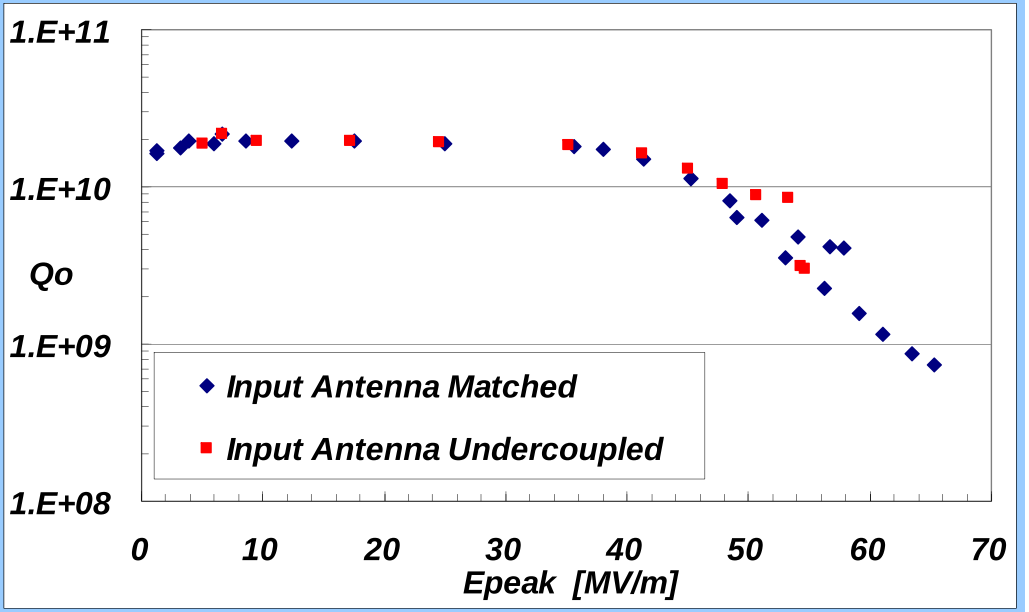


3. Tests of the SRF guns

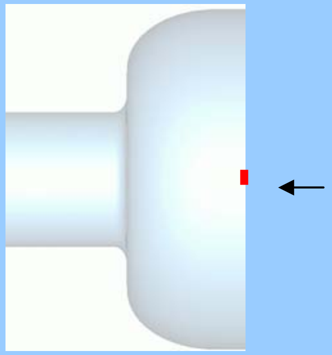
DESY Half-cell

No Lead coating

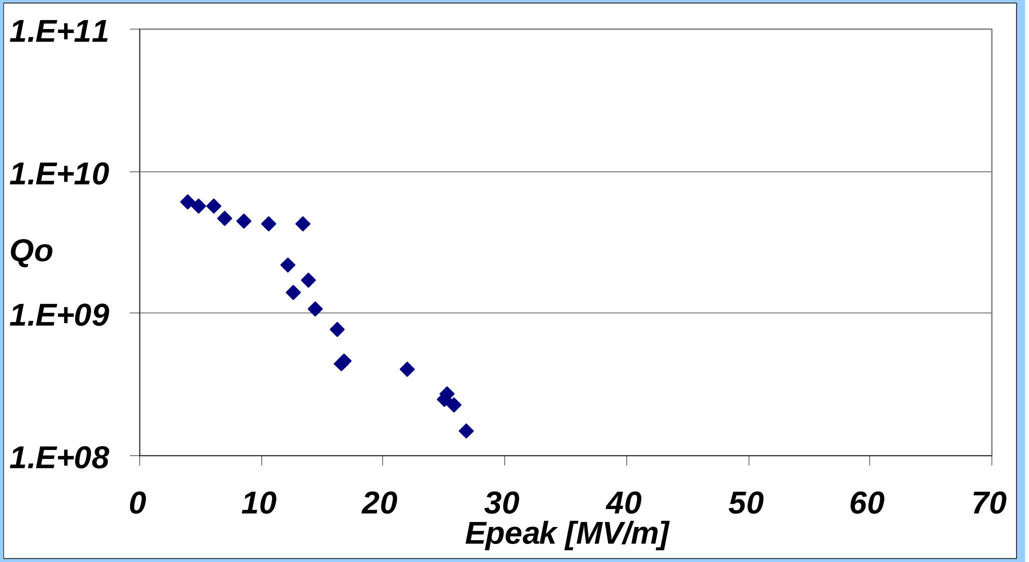




With Lead coating



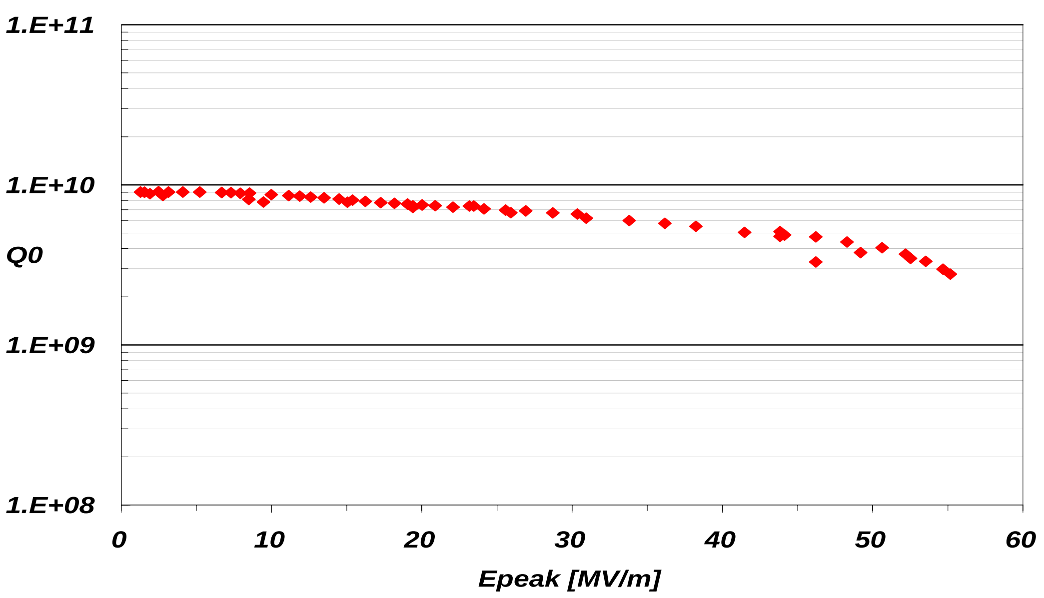
Pb spot Ø 4mm,
Thickness ~ 50 nm



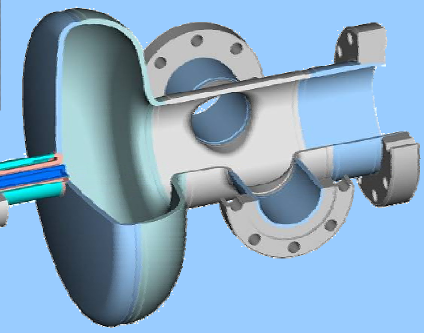
3. Tests of the SRF guns

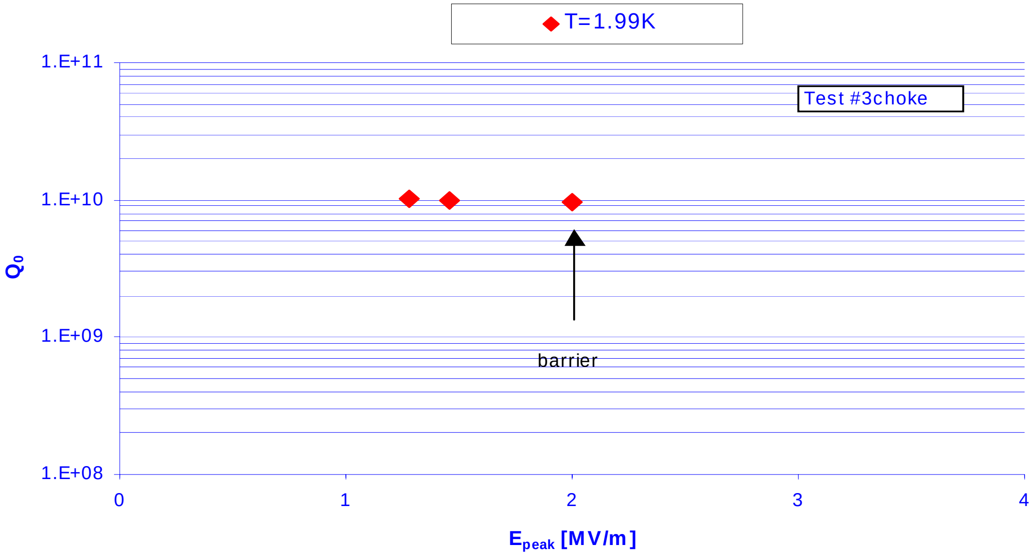
BNL/AES 1.3 GHz

Without choke



With choke

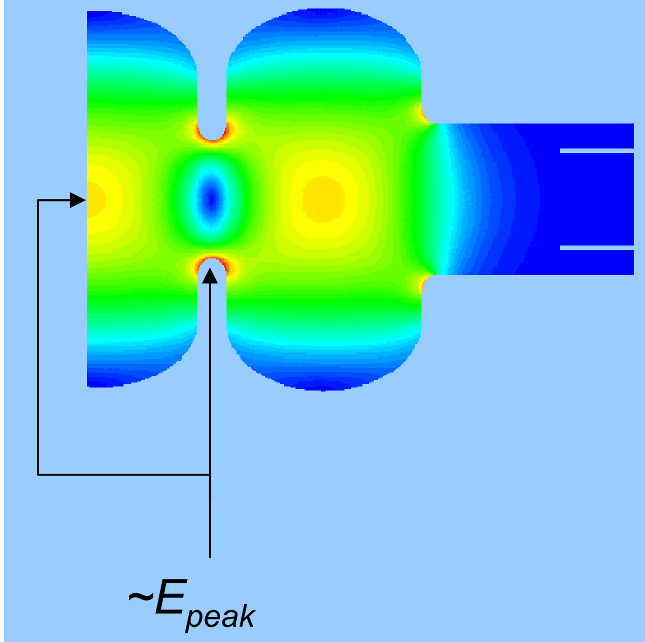


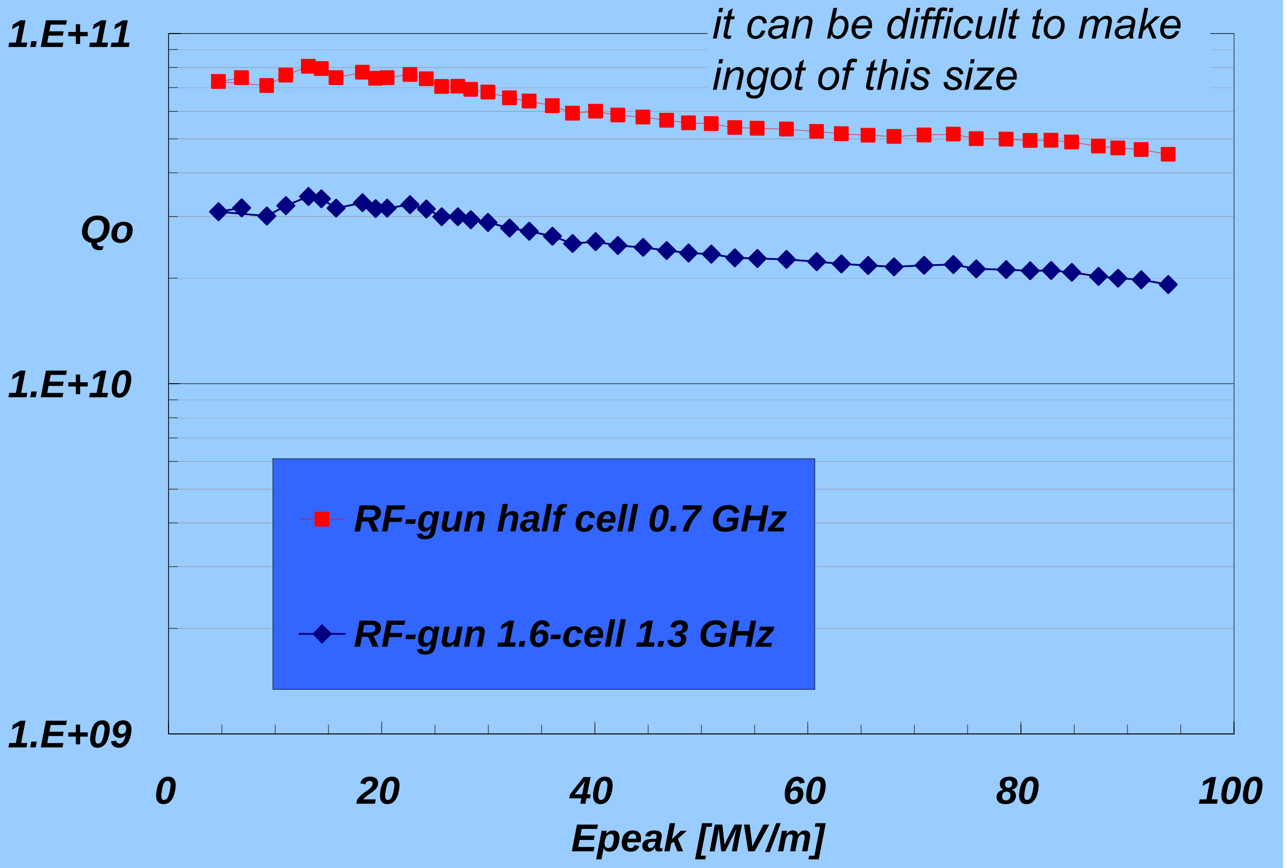


4. Final Remarks

Ultimate performance: ***the shape and material if Rs is BCS dominated***

single crystal niobium *(scaled from the JLab result on 2.3 GHz full-cell)*





it can be difficult to make ingot of this size

High ***Q*** *means: low cryogenic losses, low (or no) dark current, very low radiation*

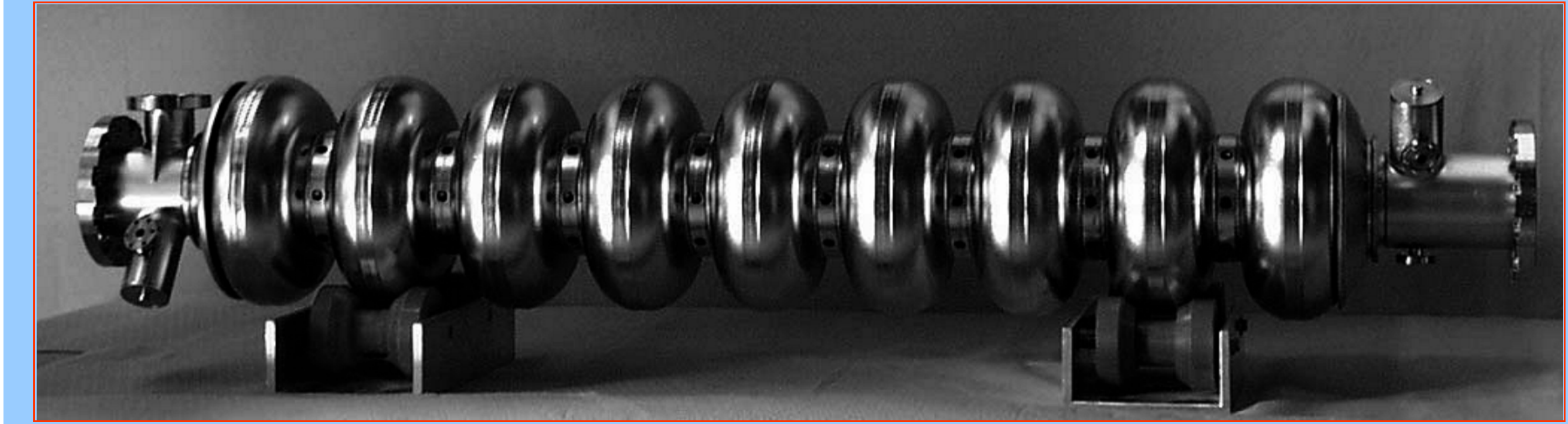
4. Final Remarks

Ultimate performance due to HOM couplers

Auxiliaries of TESLA cavity has been designed for pulse operation with duty factor of the order of 1%.

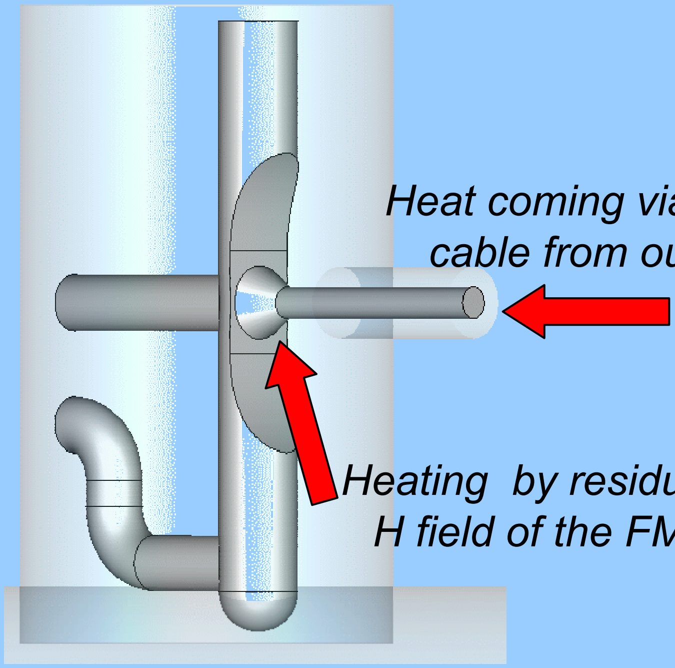
One of feature of that design is that HOM couplers are placed outside the LHe vessel.

This made the design cheaper but: it may lead to warming up of the HOM coupler



4. Final Remarks

The main problem is heating of the output line.



Heat coming via. output cable from outside.

Heating by residual H field of the FM

Nb antenna loses superconductivity,

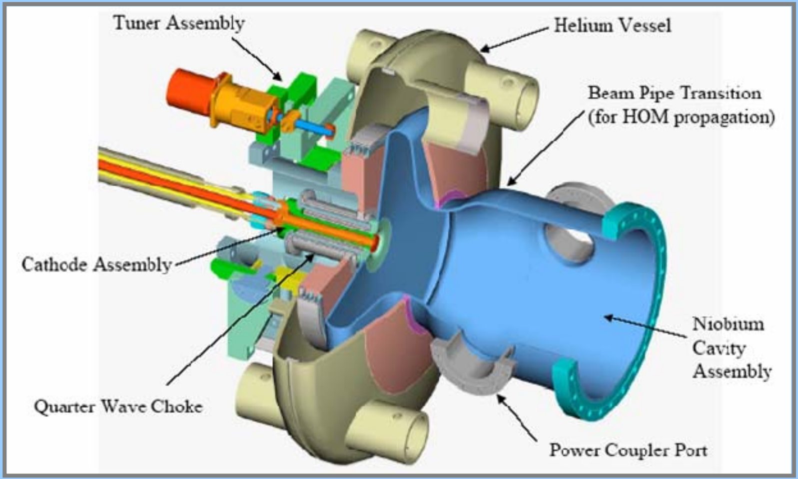
Nb, Cu antennae will warm when the RF on

Additional cryogenic losses at higher duty factor (and cw) operations

4. Final Remarks

Limit in performance due to FPC:

FPC: high current RF-guns of a 1 A class for cw operation



With design energy of 2 MeV

- *E_{cath} is ~ 30 MV/m (Eacc ~ 20 MV/m)*
- *Power transferred to the beam is 2 MW (1MW/FPC)*

Limit (with high probability) will be due to the FPC performance