Challenges in ILC SCRF Technology

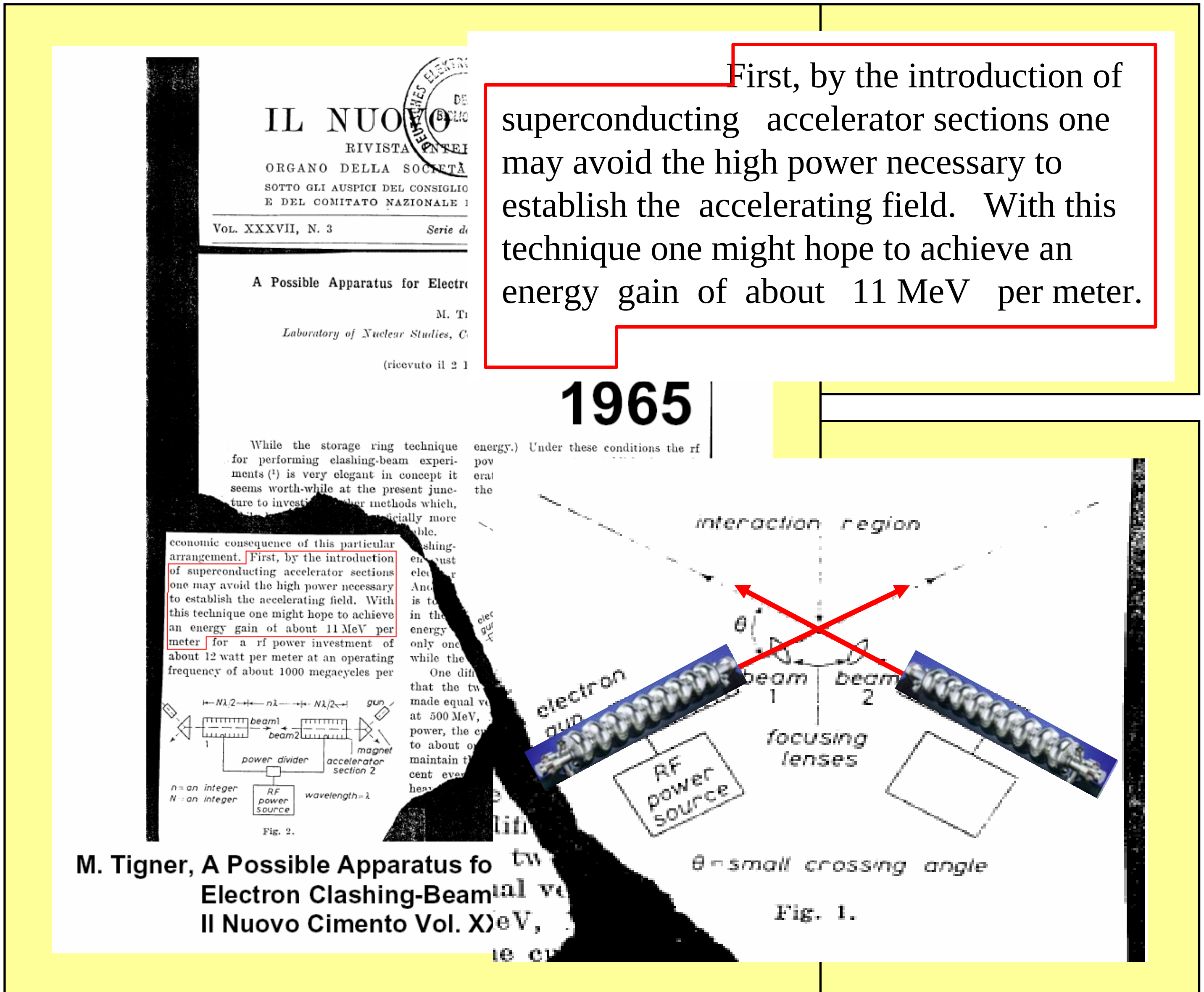
Detlef Reschke

DESY

APAC 07, January 29 – February 02, 2007

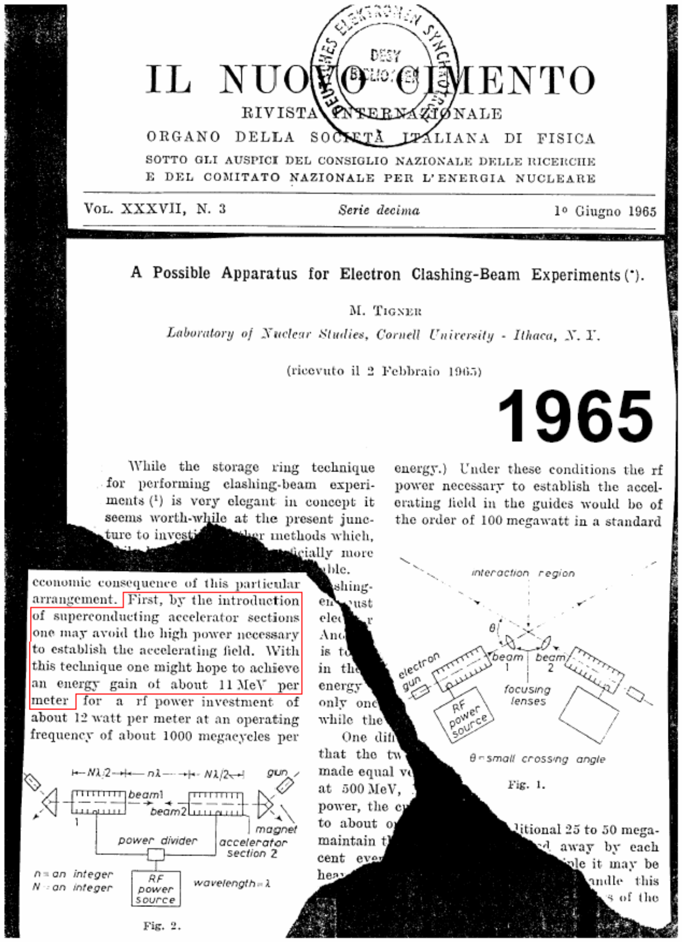
- Introduction
- Reminder: Some SCRF Basics + limitations
- S0 / S1 activities
  - Cavities
  - Module

An old idea – The cold linear collider



(courtesy of H. Weise)

An old idea – The ILC



IL NUOVO CIMENTO
RIVISTA INTERNAZIONALE
ORGANO DELLA SOCIETÀ ITALIANA DI FISICA
SOTTO GLI AUSPICI DEL CONSIGLIO NAZIONALE DELLE RICERCHE
E DEL COMITATO NAZIONALE PER L'ENERGIA NUCLEARE

VOL. XXXVII, N. 3 — *Serie decima* — 1° Giugno 1965

A Possible Apparatus for Electron Clashing-Beam Experiments (*).

M. TIGNER
Laboratory of Nuclear Studies, Cornell University - Ithaca, N. Y.

(ricevuto il 2 Febbraio 1965)

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Fig. 1.

Fig. 2.

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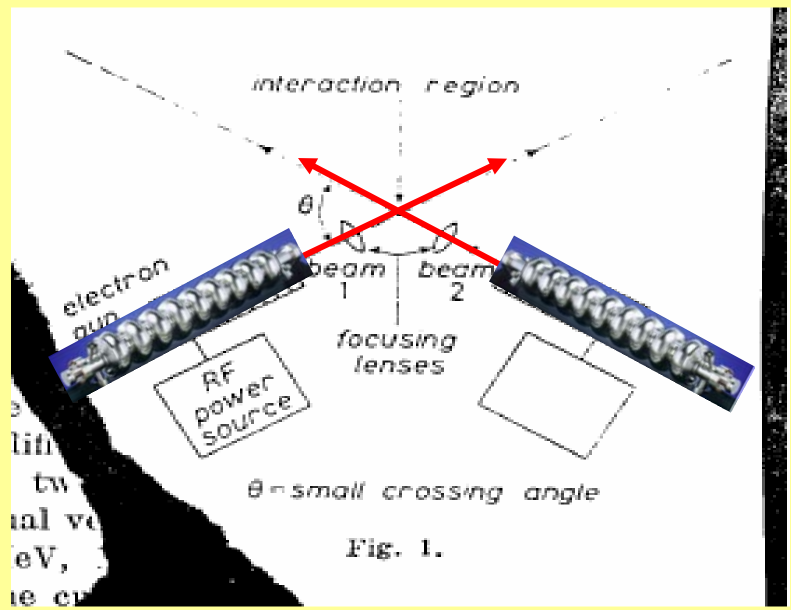
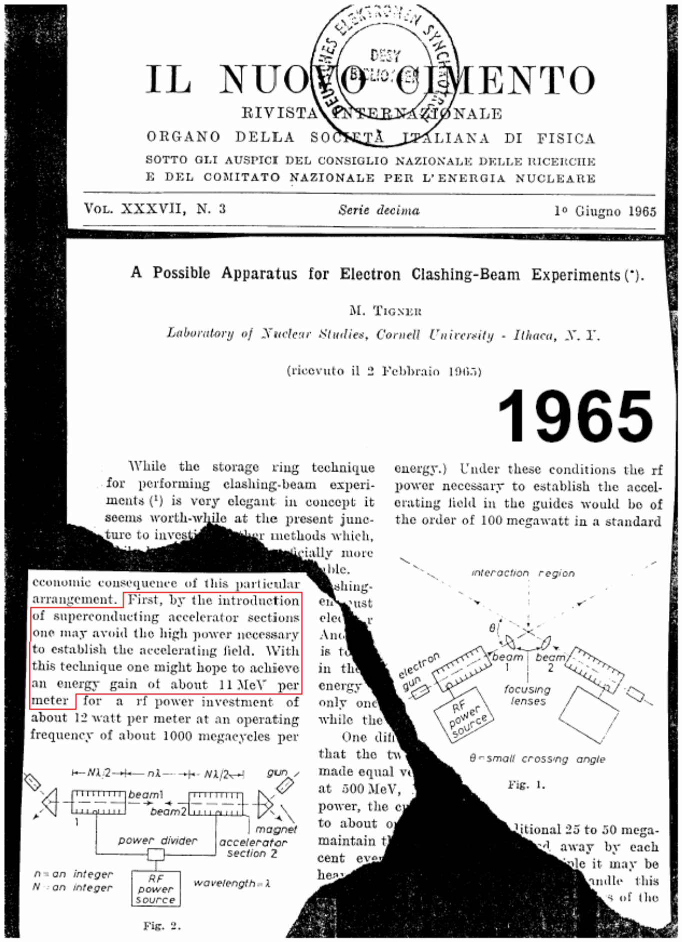


Fig. 1.

The TESLA Collaboration's TDR



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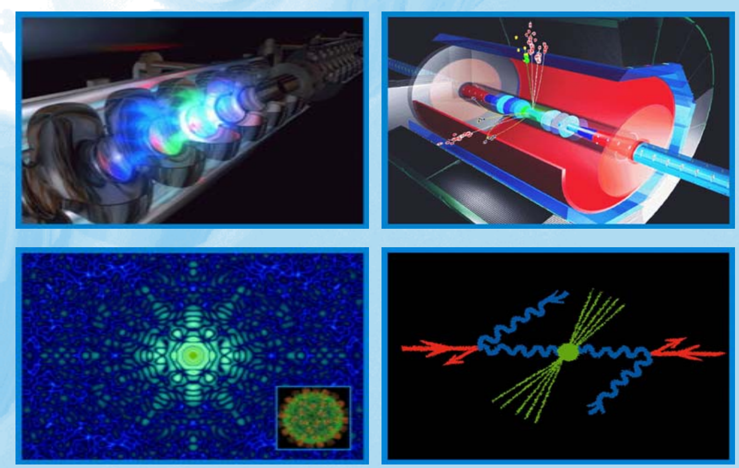
TESLA

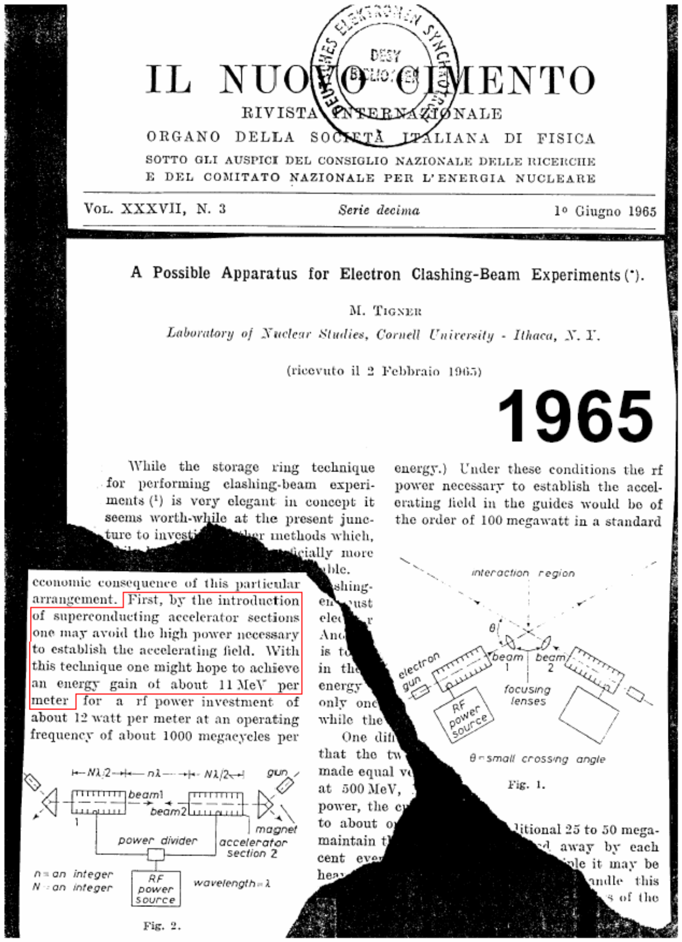
The Superconducting Electron-Positron Linear Collider with an Integrated X-Ray Laser Laboratory

Technical Design Report



March 2001

… has to be converted into the ILC TDR



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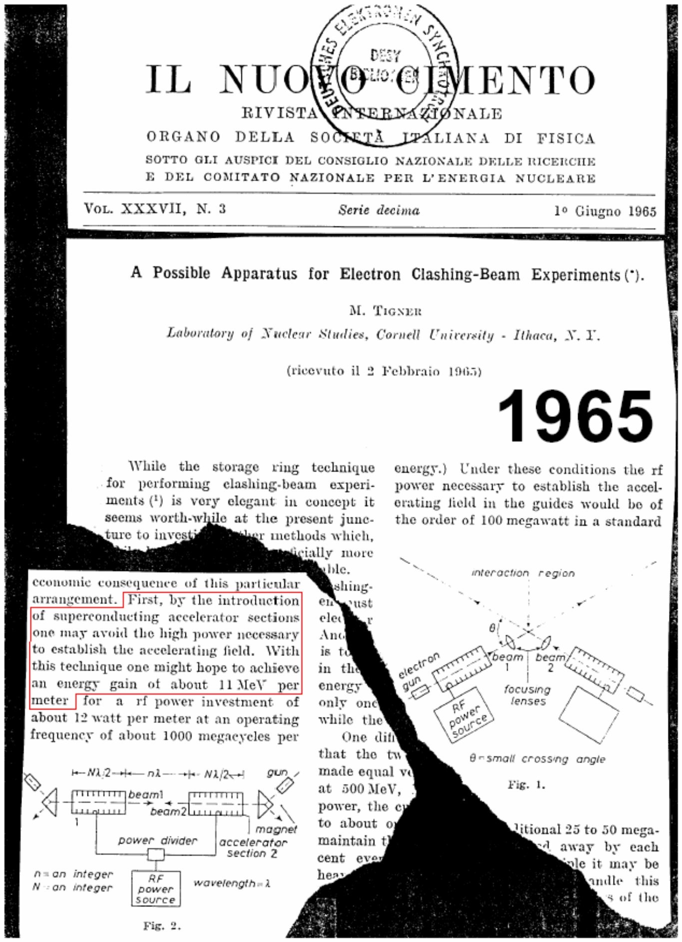

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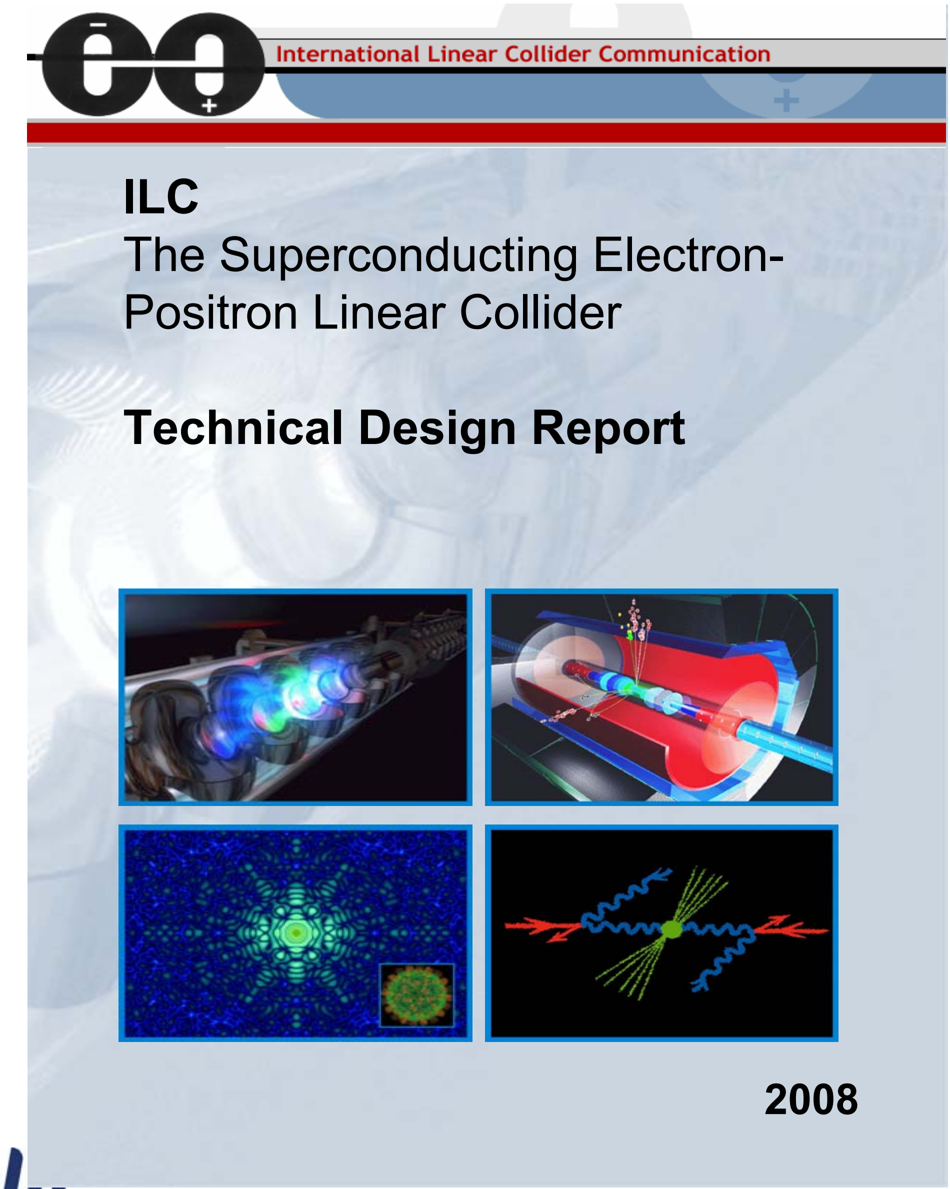


ILC Cavity Parameters

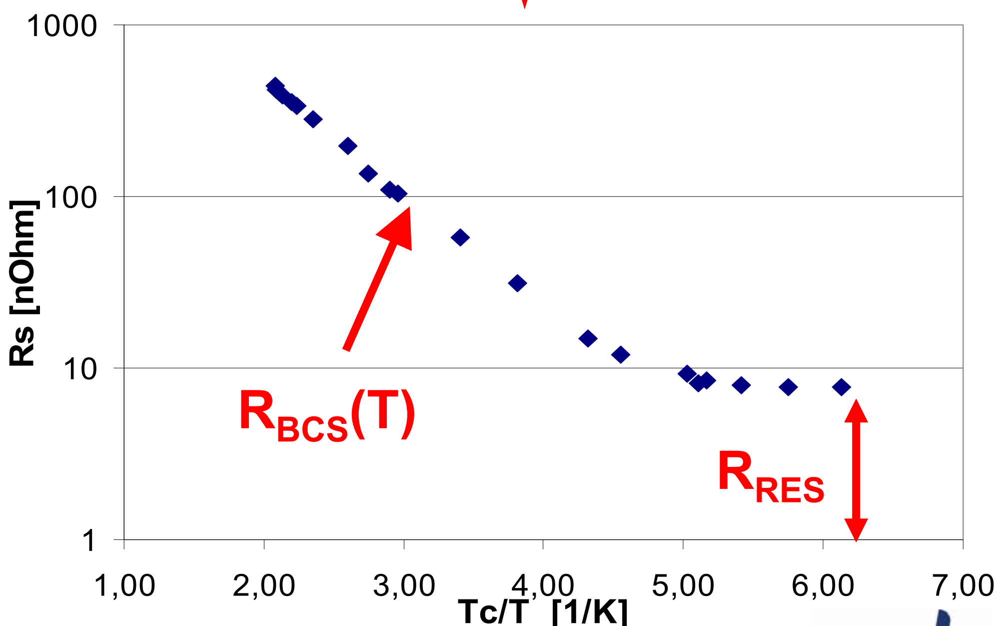
- Nine-cell Nb structures at 1.3 GHz:

ILC parameters:		**BCD (baseline)**	**ACD (alternative)**
Cavity shape		TESLA	Low Loss or Reentrant
Cavity Acceptance Performance	E_{acc} [MV/m]	35	40
	Q_0	$0,8 \cdot 10^{10}$	$0,8 \cdot 10^{10}$
Cavity Operation Performance	E_{acc} [MV/m]	31,5	36
	Q_0	$1,0 \cdot 10^{10}$	$1,0 \cdot 10^{10}$
Coupler		„TTF type III“	
Cryomodule		„Type IV”	
		8(9) cav. /module	8(9) cav. /module

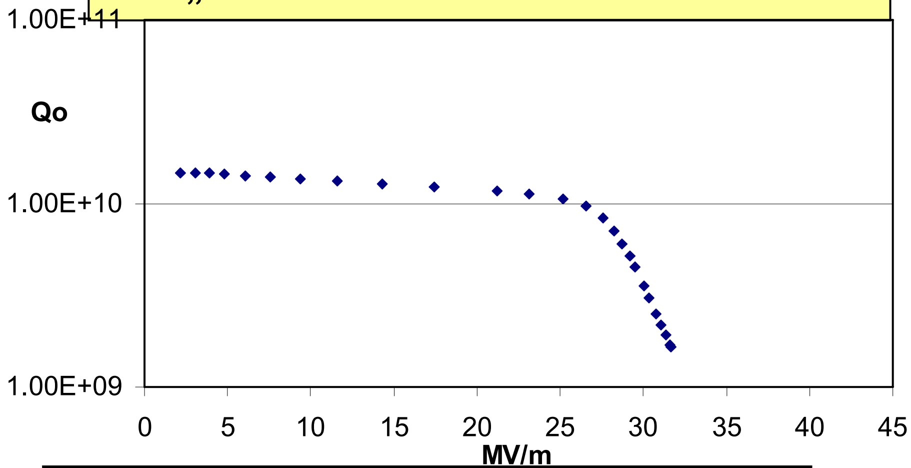
SCRF Basics: Surface Resistance $R_s(T)$

- SCRF: Surface resistance $R_s > 0$ for $T > 0K$!
- For Nb: R_s (T, ω, H) = (R_{BCS}(T, ω) + R_{res}) + R_s (H)

$$R_s = \frac{A}{T}\omega^2 e^{-\frac{\Delta}{k_B T_C}\frac{T_C}{T}} + R_{res}$$



e.g. „Q-slope w/o field emission“ => „120C bake“ for EP-cavities



Geometry factor:

G = 270 Ohm

$$Q_o = \frac{G}{R_s}$$

Typical Quality factor:

$Q_0 \sim 2 \cdot 10^{10}$ at 2K

SCRF basics (ctd.)

- Critical magnetical field of Niobium at 1.3 GHz ?
  - RF field penetrates for less than 10^{-9} s => Delayed penetration in the fluxons (superheating)

Property	Experimental data [mT] at 4.2 K	Calculated field [mT] at 0 K	Calculated field [mT] at 2 K	E_{acc} [MV/m] at 2 K
B_{c1}	130	164	156	37
B_c	158	200	190	45
B_{sh}	190	240	230	54
B_{c2}	248	312	297	62

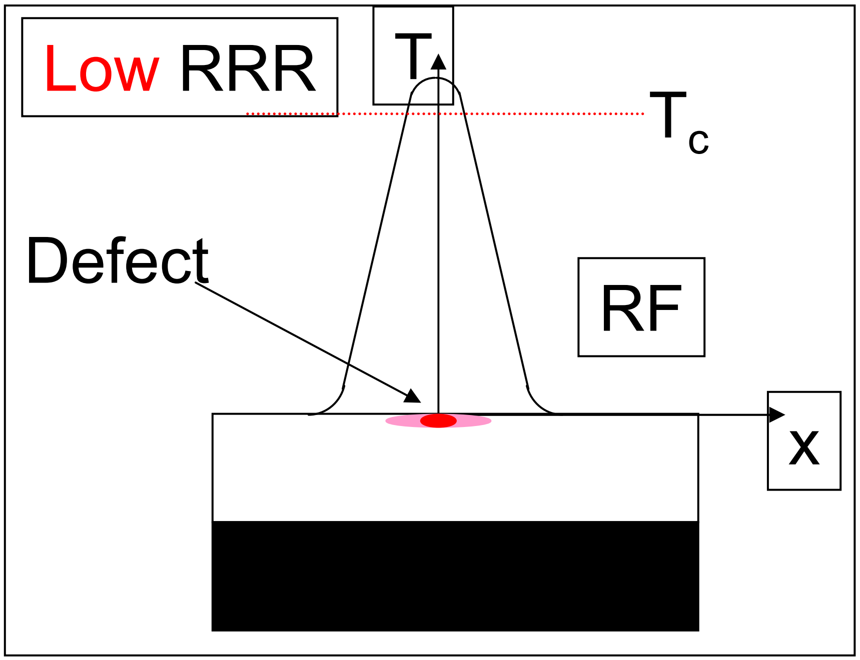
What is really the fundamental limit for RF cavities?

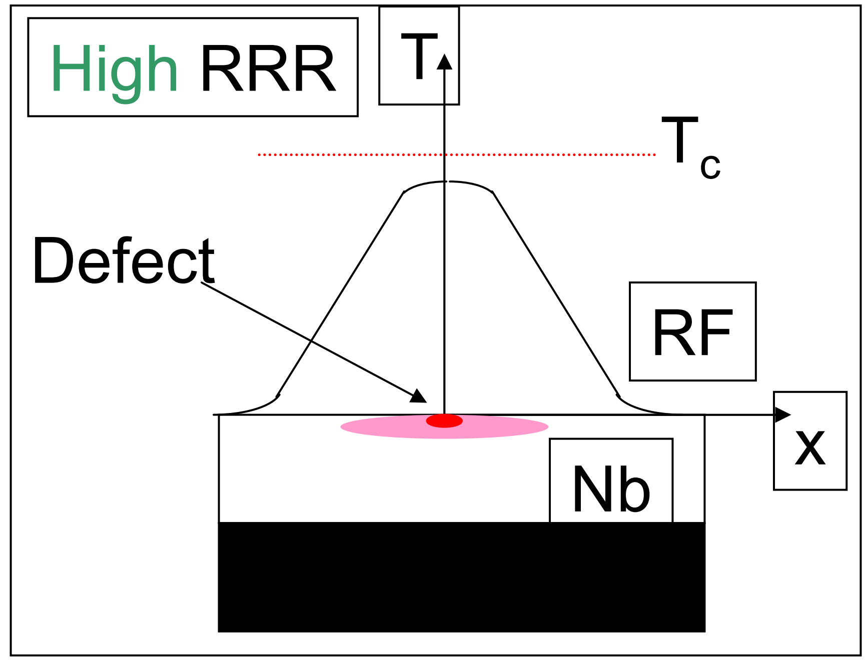
K. Saito, 2001: H_c^{rf} is 180 mT at <2K ! => end of discussion ???

- Experimental:
  - (180-190) mT achieved in single-cell cavities
  - 170 mT achieved in nine-cell cavities

Limitations: Thermal breakdown

- Experimental field limitation by thermal breakdown (Quench)
  - T of part (or all) of surface exceeds T_c, dissipating all stored energy
  - Quench: surrounding material cannot transport the increased thermal load to the helium





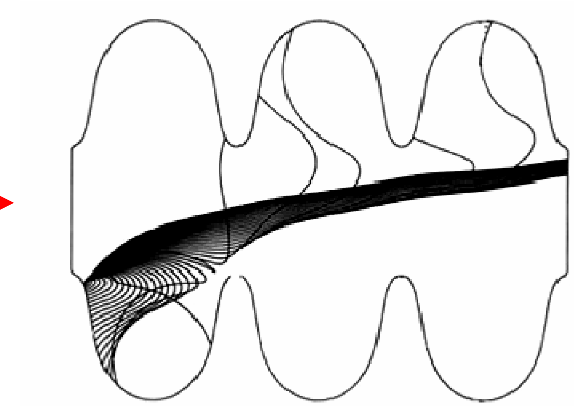
=> high purity Nb with high thermal conductivity (RRR > 300) required

=> ILC Industrialization: large amounts of reproducable high quality Nb

Limitations: Field emission

- Major limitation of the last years in multi-cell cavities:

- **Field Emission!!**

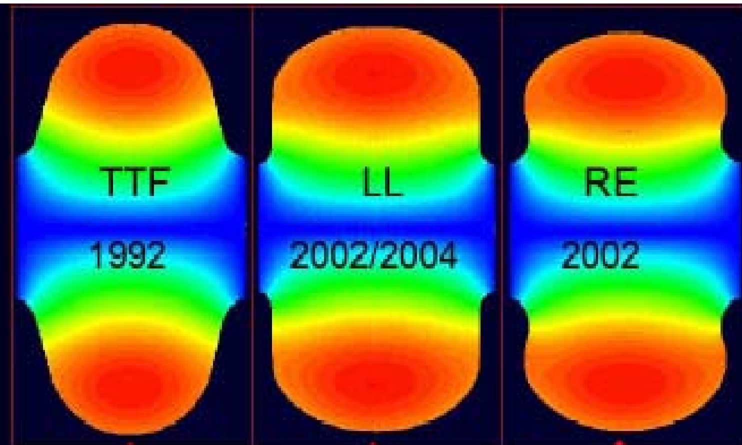


- Typical (good) onset of field emission at 1.3 GHz
  - single-cell cavities: $E_{acc,onset} > 30$ MV/m
  - multi-cell cavities (vertical + horizontal): $E_{acc,onset} \approx (20 - 25)$ MV/m
- Origin of field emission (FE) in SRF cavities:
  - Metallic (conducting) particles of irregular shape; typical size: 0,5 - 20 µm
  - hydrocarbon contamination of the vacuum system

=> Quality of final cleaning & dustfree assembly is crucial
for field emission free cavities !!

Cavity shape

- Relation of magnetic surface field and gradient E_{acc} depends on the cell shape:



r_{irisb}	[mm]	35	30	33	
k_{cc}	[%]	1.9	1.52	1.8	field flatness
E_{peak}/E_{acc}	-	1.98	2.36	2.21	max gradient (E limit)
B_{peak}/E_{acc}	[mT/(MV/m)]	4.15	3.61	3.76	max gradient (B limit)
R/Q	[Ω]	113.8	133.7	126.8	stored energy
G	[Ω]	271	284	277	dissipation
R/Q*G	[Ω*Ω]	30840	37970	35123	dissipation (Cryo limit)

- TTF shape (BCD): Lower E_s + tilted iris area, but higher H_p/E_{acc} (~15%)
  => good wet cleaning, optimized for FE, stronger cell-to-cell coupling
- Low Loss (ACD): Lower H_p/E_{acc} , but reduced iris diameter + higher E_p/E_{acc}
- Reentrant (ACD): Compromise for rf parameters, but difficult cleaning

ILC Cavities

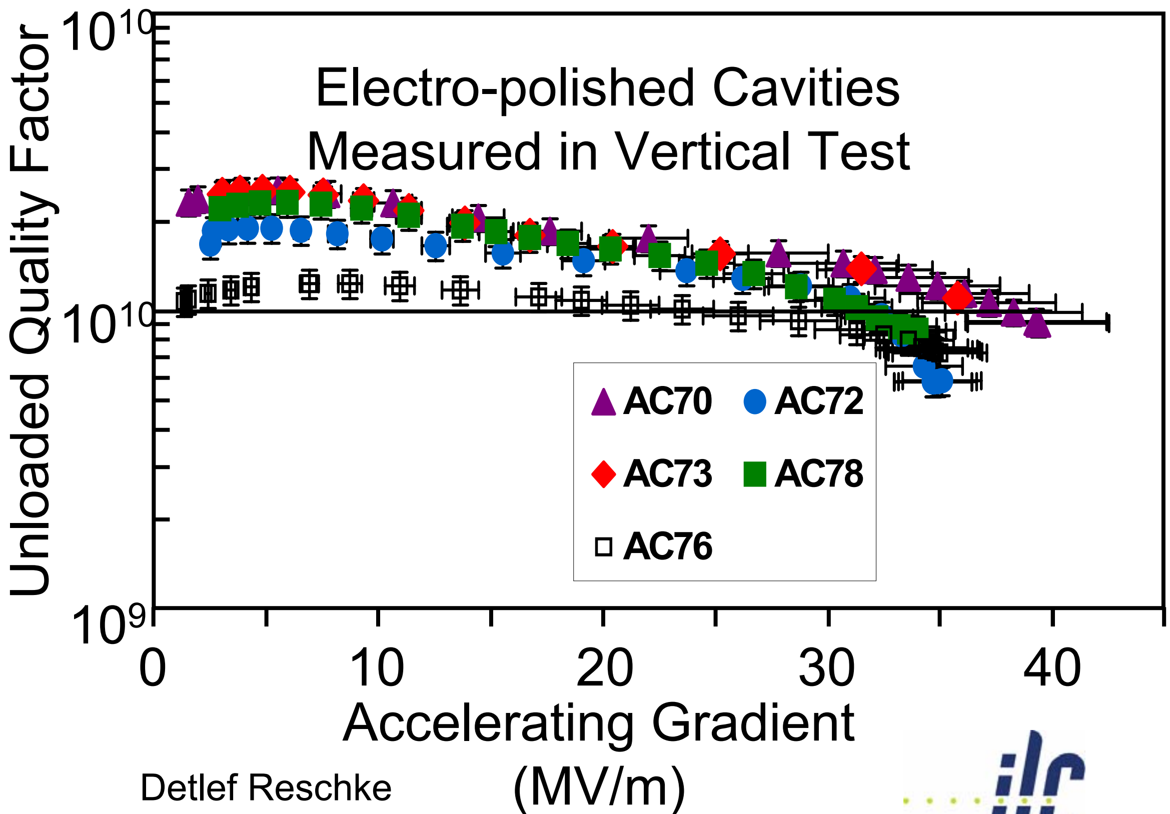
TESLA – Cavity

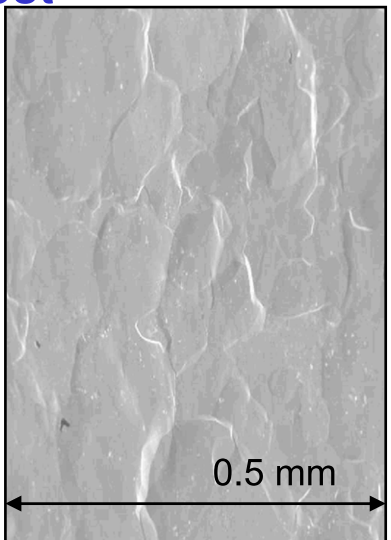
← TESLA-like cavities at KEK

Low Loss cavities at KEK →

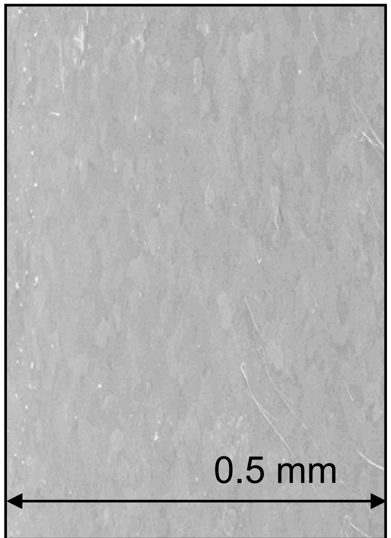
Cavity preparation

- BCD cavity preparation scheme:
  - Cleaning after fabrication, entrance-check + 1. tuning
  - Electropolishing (EP) of (120-150) µm for removal of damage layer
  - 800C firing for mechanical stress release & H-degassing
  - Electropolishing for final preparation (20-50)µm
  - HPR + Assembly + Vertical acceptance test



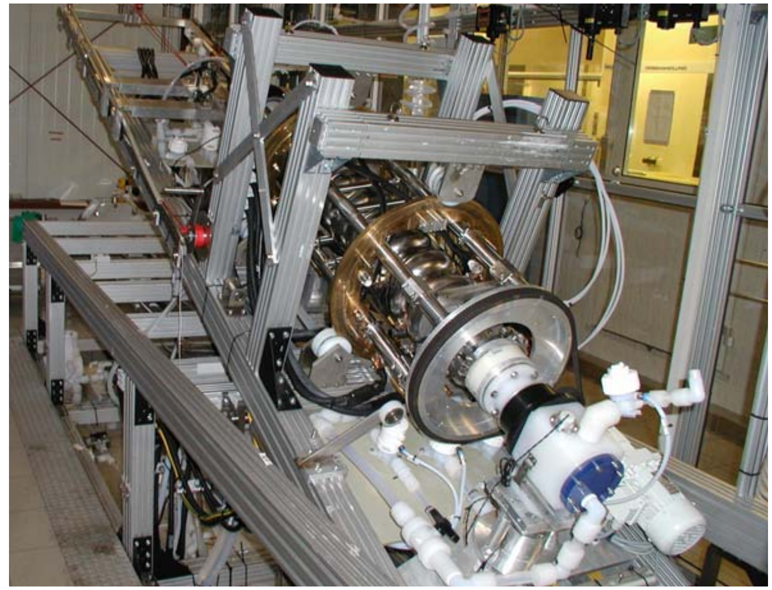
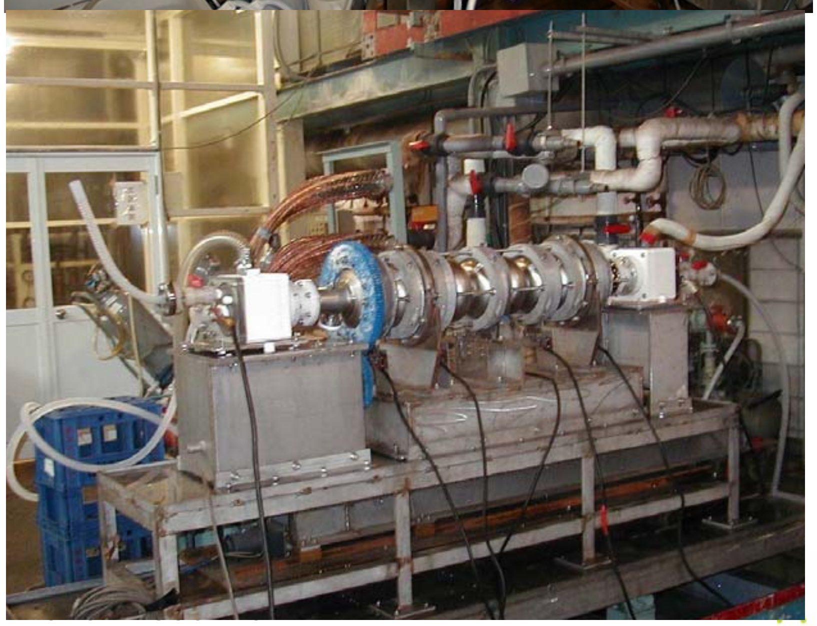
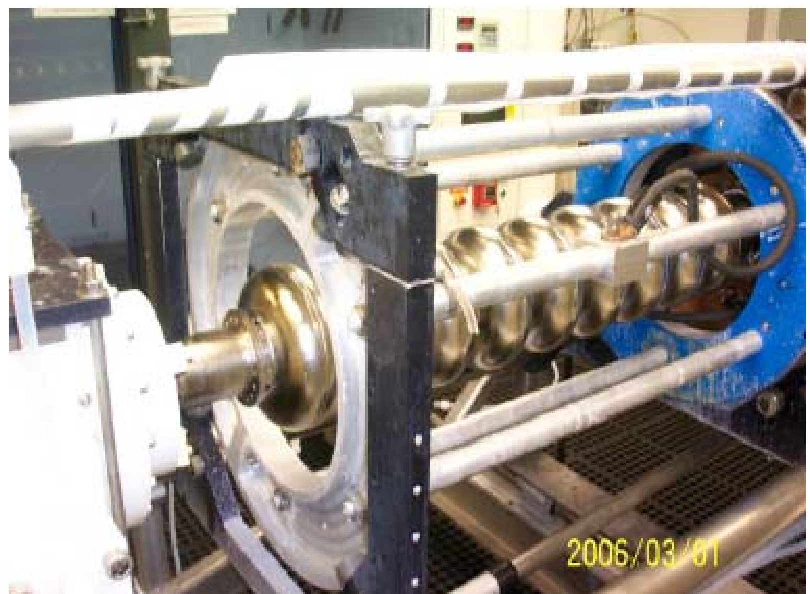


BCP Surface
(1µm roughness)



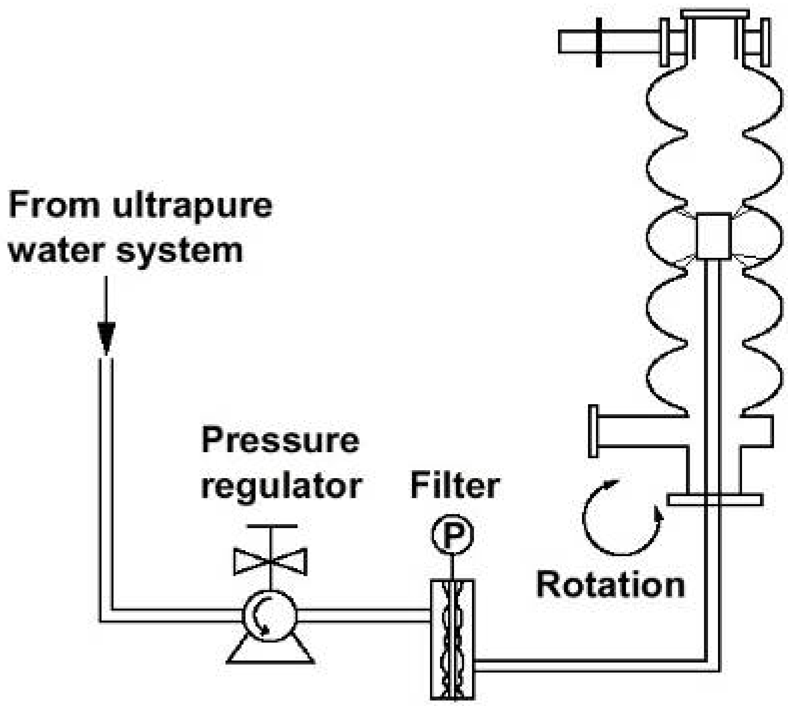
EP Surface
(0.1µm roughness)

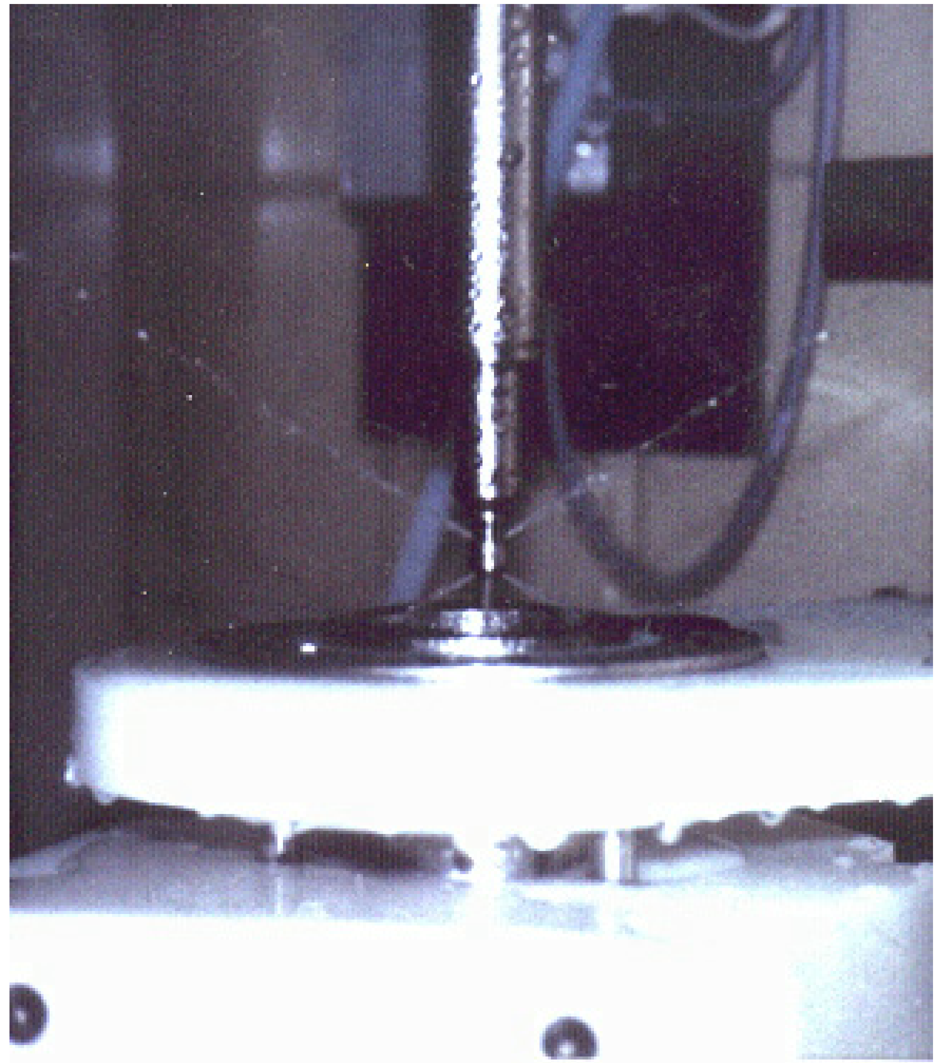
EP facilities all over the world

Cavity preparation: High Pressure Rinsing

- Advanced cleaning techniques





100 atm jet water rinsing

ILC R&D: S0/1 task force

- S0: Cavities & S1: Cryomodule

=> Mission of task forces:

- Provide the information needed for gradient choice
- Time scales: mid 08 / end 09
  with a phased approach to match design /cost effort

- S0/S1 task force:
  - Hitoshi Hayano (KEK)
  - Toshiyasu Higo (KEK)
  - John Mammosser (JLab)
  - Hasan Padamsee (Cornell)
  - Marc Ross (FNAL)
  - Kenji Saito (KEK)
  - Lutz Lilje (DESY)

S0 (cavity) situation + task:

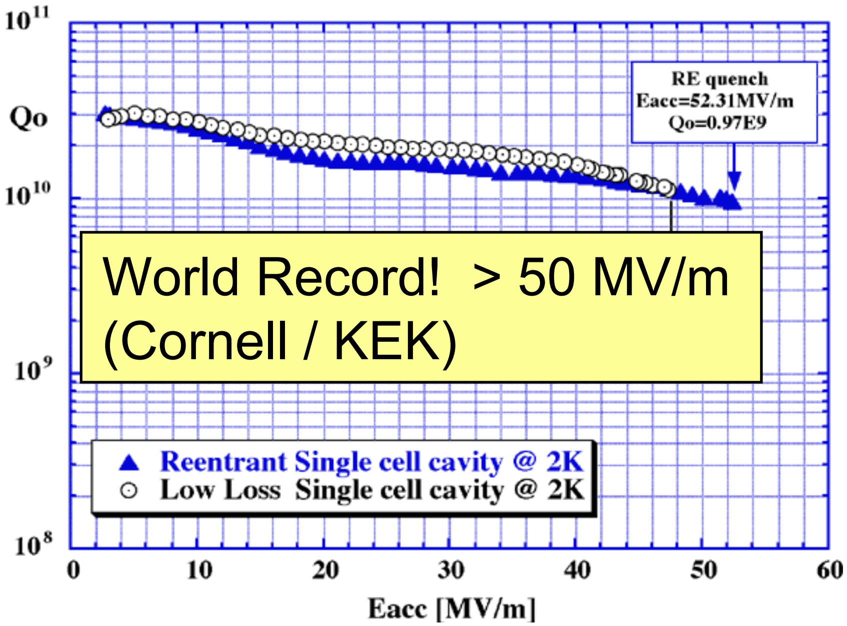
- **Improve the yield for cavity gradients !**
- The situation before us :
  - Proof of principle for 35- 40 MV/m exist
  - Single cell results (40 - 50 MV/m) show that baseline preparation procedures are in hand
  - But low yield for 35 MV/m in 9-cells

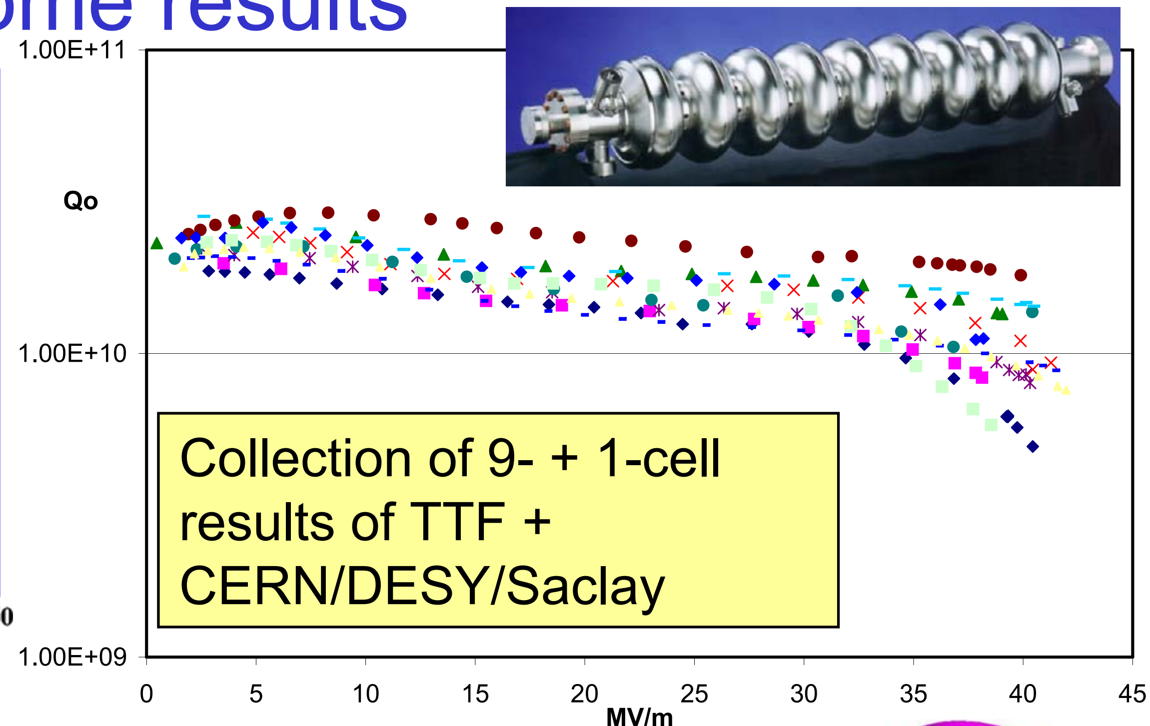
=> many tests limited by field emission, some by quench, few by H–Q-disease

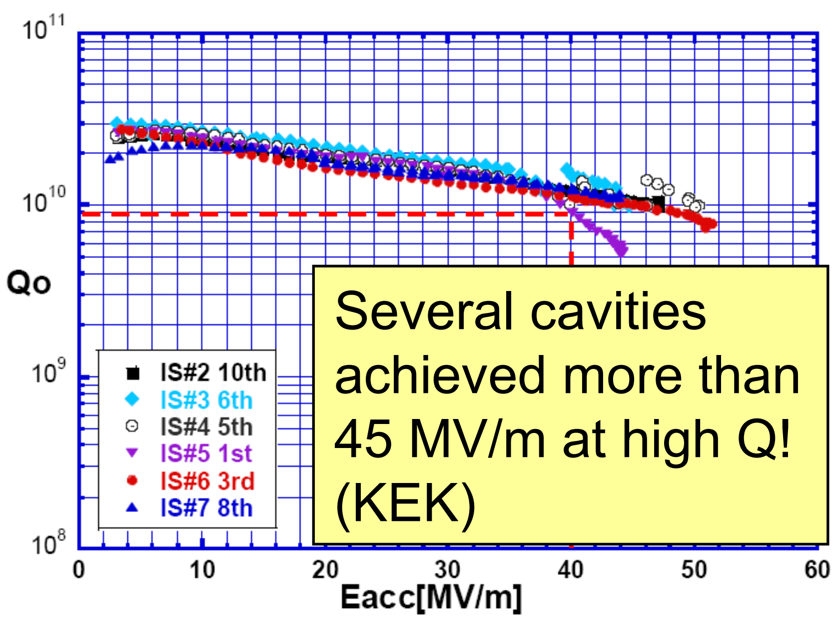
=> Examples of Variables to address:

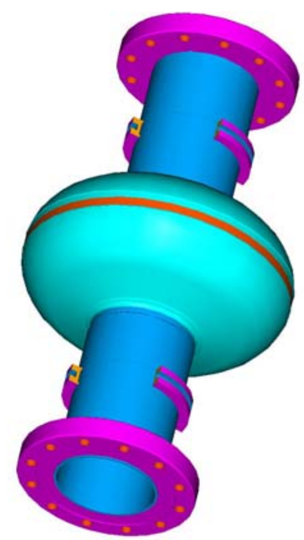
Preparation:	EP parameters (electrolyte, operation mode, Sulphur, H, .)
	Rinsing parameters (water quality, time, pressure, …)
	Particulate contamination (assembly procedures)
	Quality control !!
Fabrication:	Cavity production (e-beam welds, quality control, …)
	Nb material (RRR, grain size, defects, quality control…)

Some results

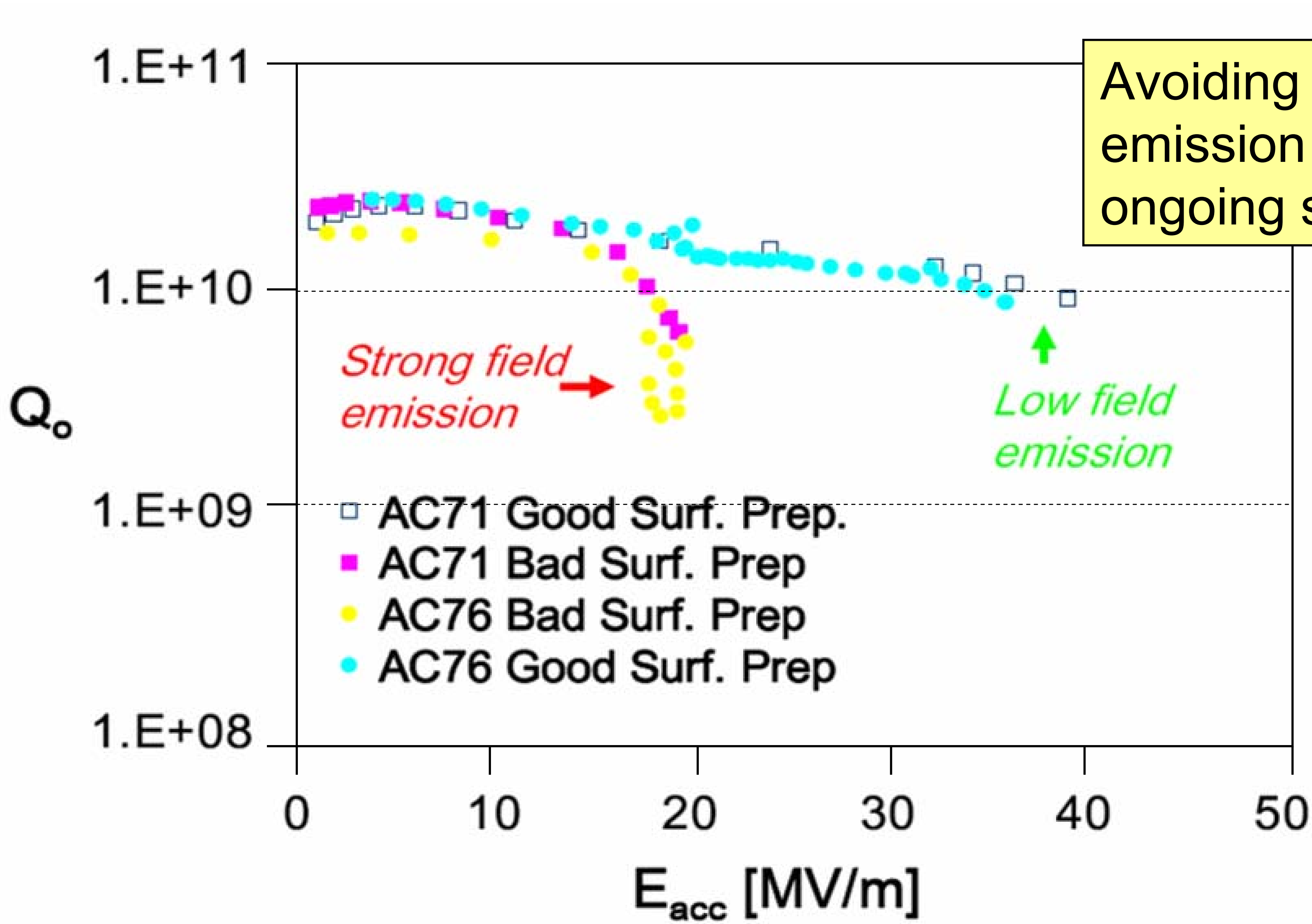








But Work needed: Reproducibility in Preparation



Avoiding field emission is an ongoing struggle !

Program for S0:

- Several tasks before us
  - Improve reproducibility of cavity processing => 80% yield in first test
  - Carry out coupled R&D programs in parallel to improve processes
    - multi-cell tests with diagnostics, single cells prep/tests, preparation R&D, materials R&D, diagnostics and QA on EP, HPR…systems
  - Valuable input from TTC community on R&D
  - Results from R&D programs feed into 9-cell activities
  - Establish final best recipe to use for subsequent productions applied at all institutions
- S0, Part 1: i) "tight-loop" experiments
  => define baseline yield in all regions
  => interregional exchange of qualified nine-cell cavities
  ii) inject process improvements from parallel R&D program
  => repeat exchange as necessary
- S0, Part 2: Cavity production: order staged batches of 50 nine-cells each
  => "final production" batch mid of 2009 with 35 MV/m in 1-2 tests

R & D activities (program under discussion)

- Focus on
  i) single-cell prep + tests
  - Rinsing studies (ethanol, US, H_2O_2, HF-rinse, …)
  - investigation + removal of sulphur contamination after EP

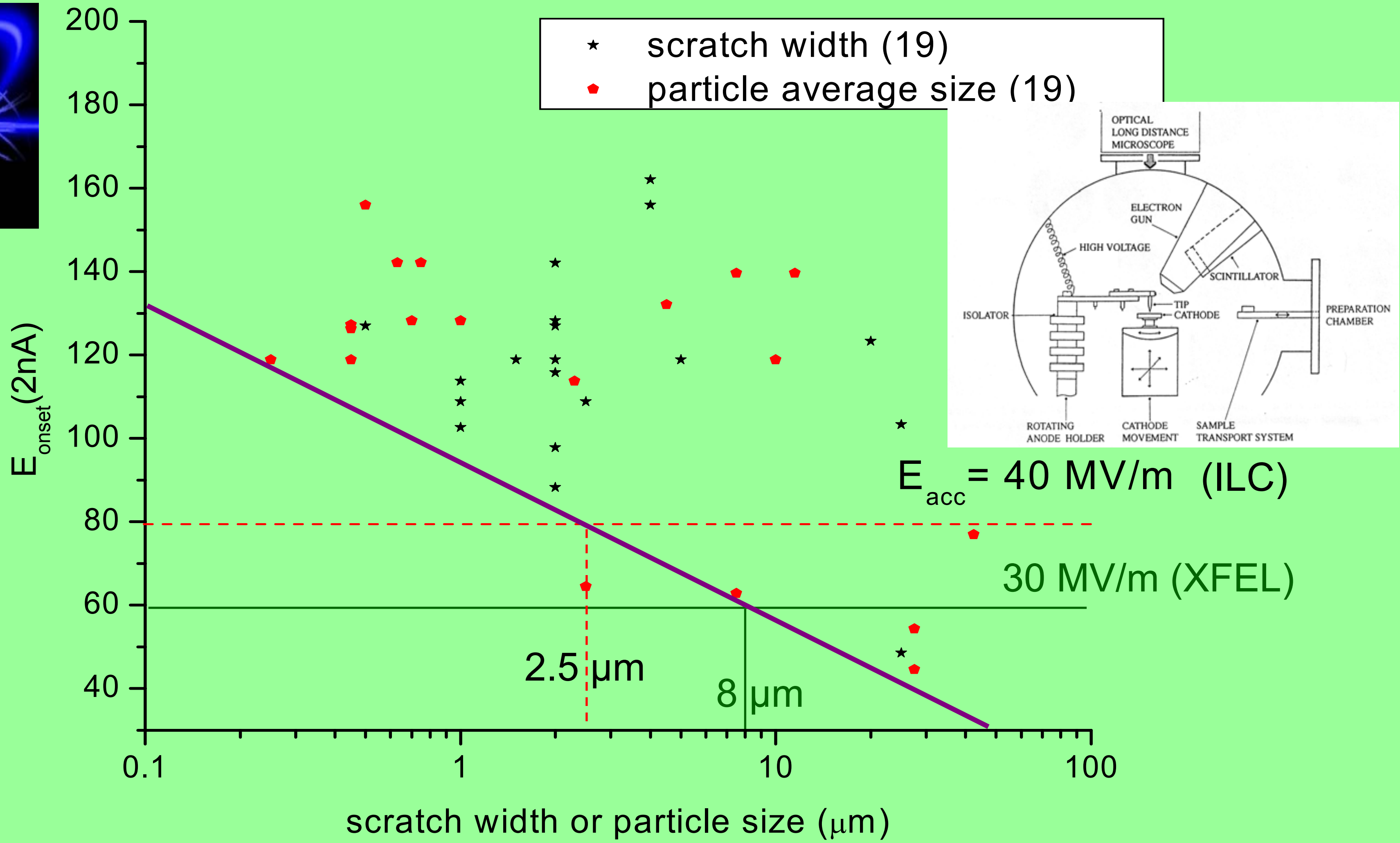
  ii) improved quality control
  - Process monitoring (acids, water,…)
  - Qualify HPR systems with force sensor system by INFN Milano

- Activities at CARE, TTC, SMTF and individual labs (KEK, Cornell, CEA Saclay,…)
- Additional studies ongoing (S-deposition, field emission, etc.)

- Use synergy effects with European XFEL

University of Wuppertal: Correlation of FE onset field and emitter size ?

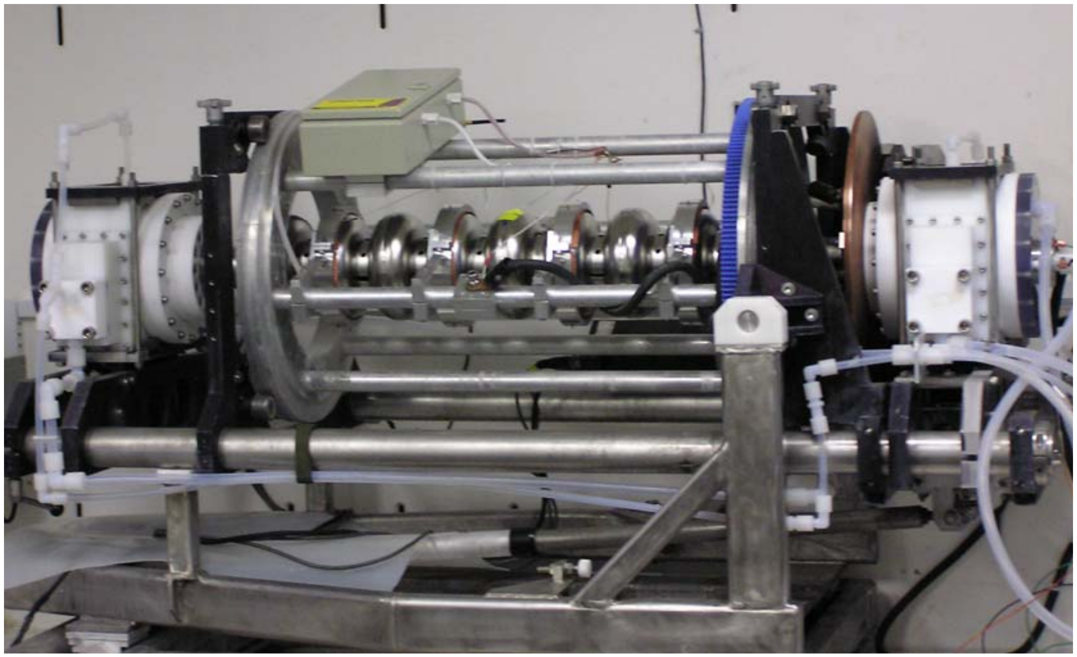
Field emission scanning microscope and SEM analysis of 38 field emitters

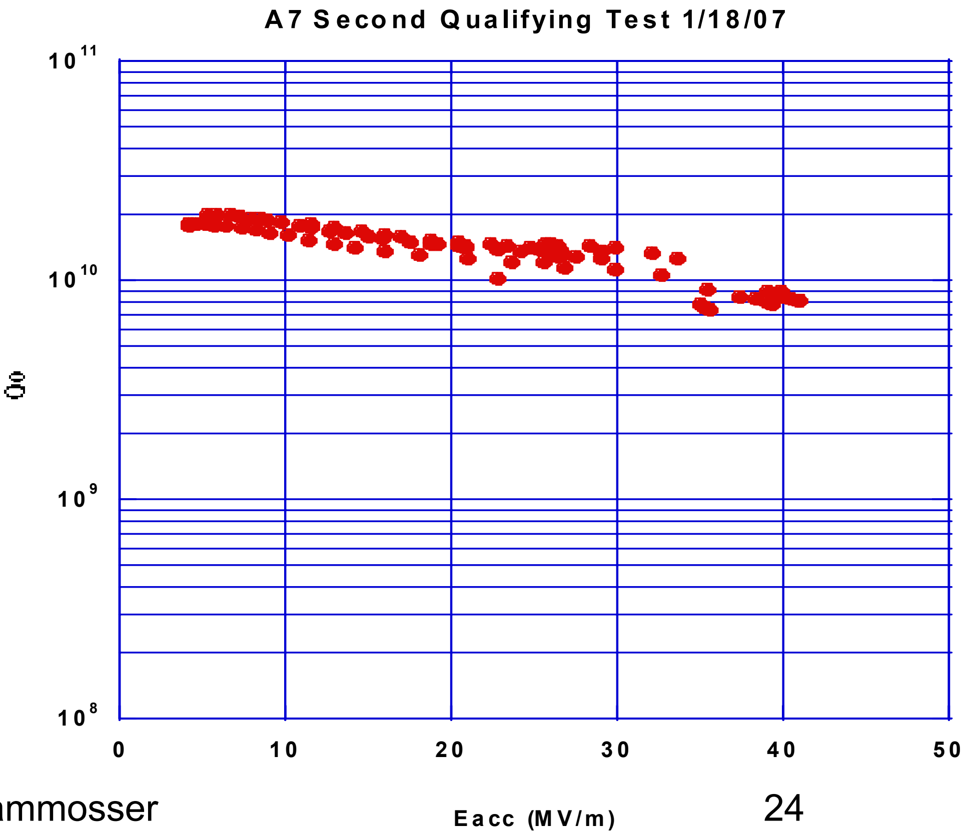


Evidence for correlation ⇒ fast FE quality control by emitter size

EP and Vertical Testing at Jlab

- Jlab has commissioned the EP, HPR, Bake and Vertical Testing for the 1.3 GHz cavities.
- Jlab will be the center of the S0-1 “Tight Loop” actives in USA.

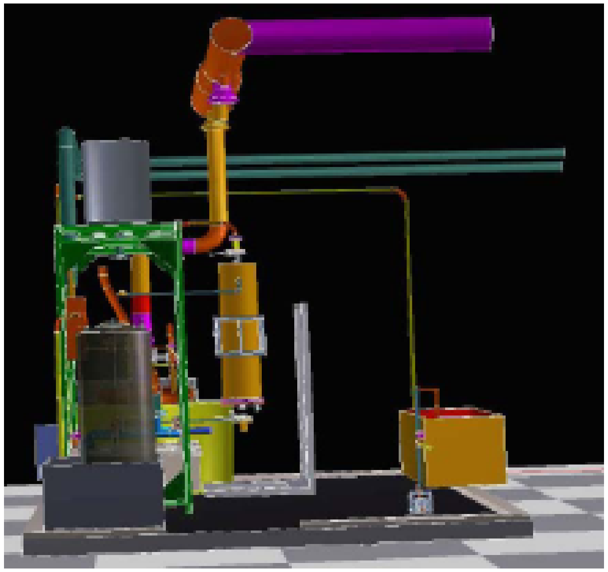


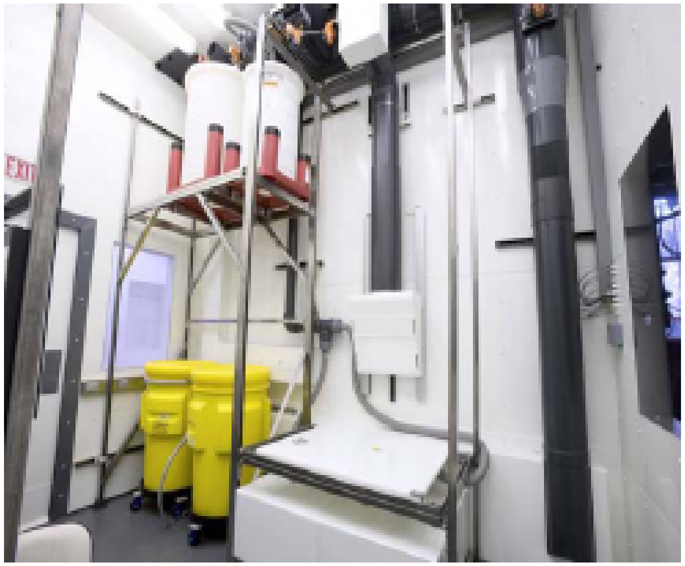


courtesy of J. Mammosser

Surface Processing Facility at ANL/FNAL

- Fermilab and Argonne are jointly building a surface processing facility for ILC Cavity R&D.
- The facility will have capability to perform BCP, EP and HPR.
- The BCP Facility is under final phase of construction and will be safety reviewed by Spring of 07.
- Design of the EP facility is progressing with plans to be commission with 9 Cell 1.3 GHz Cavities by the end of FY07.

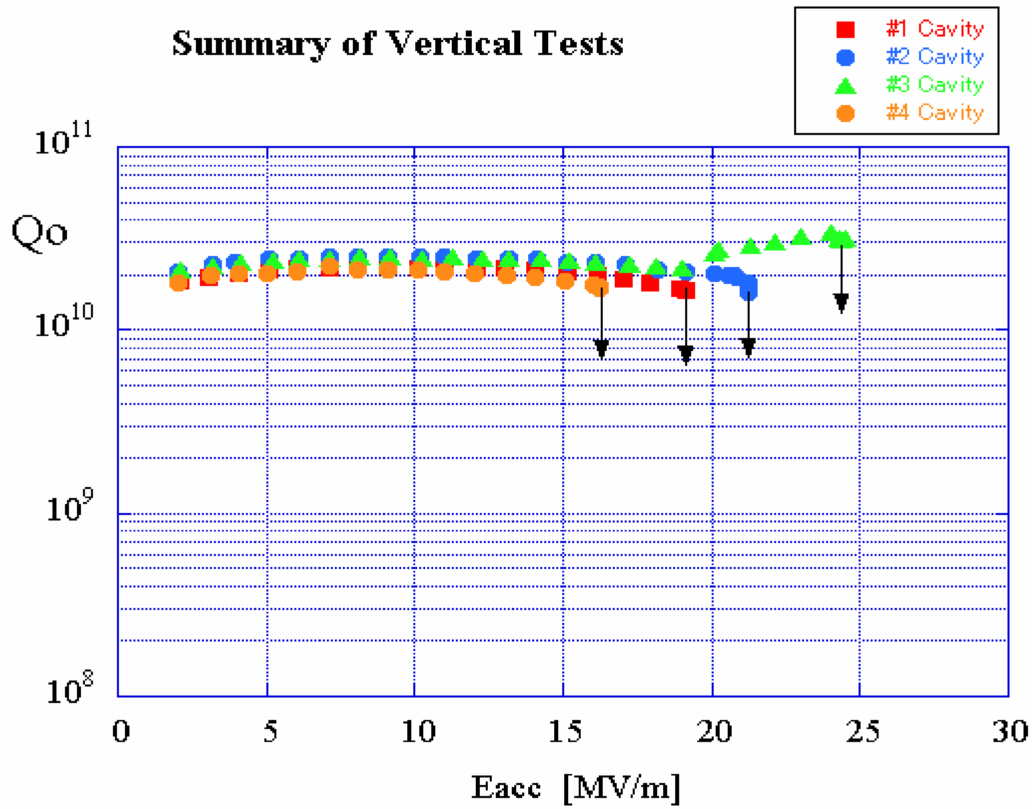




KEK: Vertical Tests of TESLA style Cavities

Up to now, 9 tests for 4 cavities.

#1 cavity : 3 tests (max 19.2MV/m)
#2 cavity : 2 tests (max 20.3MV/m)
#3 cavity : 3 tests (max 24.5MV/m)
#4 cavity : 1 test (max 17.1MV/m)



S1 - Modules

- Goals:
- Achieve 31,5 MV/m at $Q_0=10^{10}$ as operational gradient as specified in the BCD in more than one module of 8 cavities
  - including e.g. fast tuner operation and other features that could affect gradient performance
- At least 3 modules should achieve this performance.

  - Re-assemblies (exchange of cavities) can be included.

  - Not necessarily final module design.

  - Each module should be operated a few weeks under realistic conditions.
- Intermediate goal:

  One module with 31,5 MV/m average gradient as proof-of-existence

  (If necessary with adapted rf distribution)

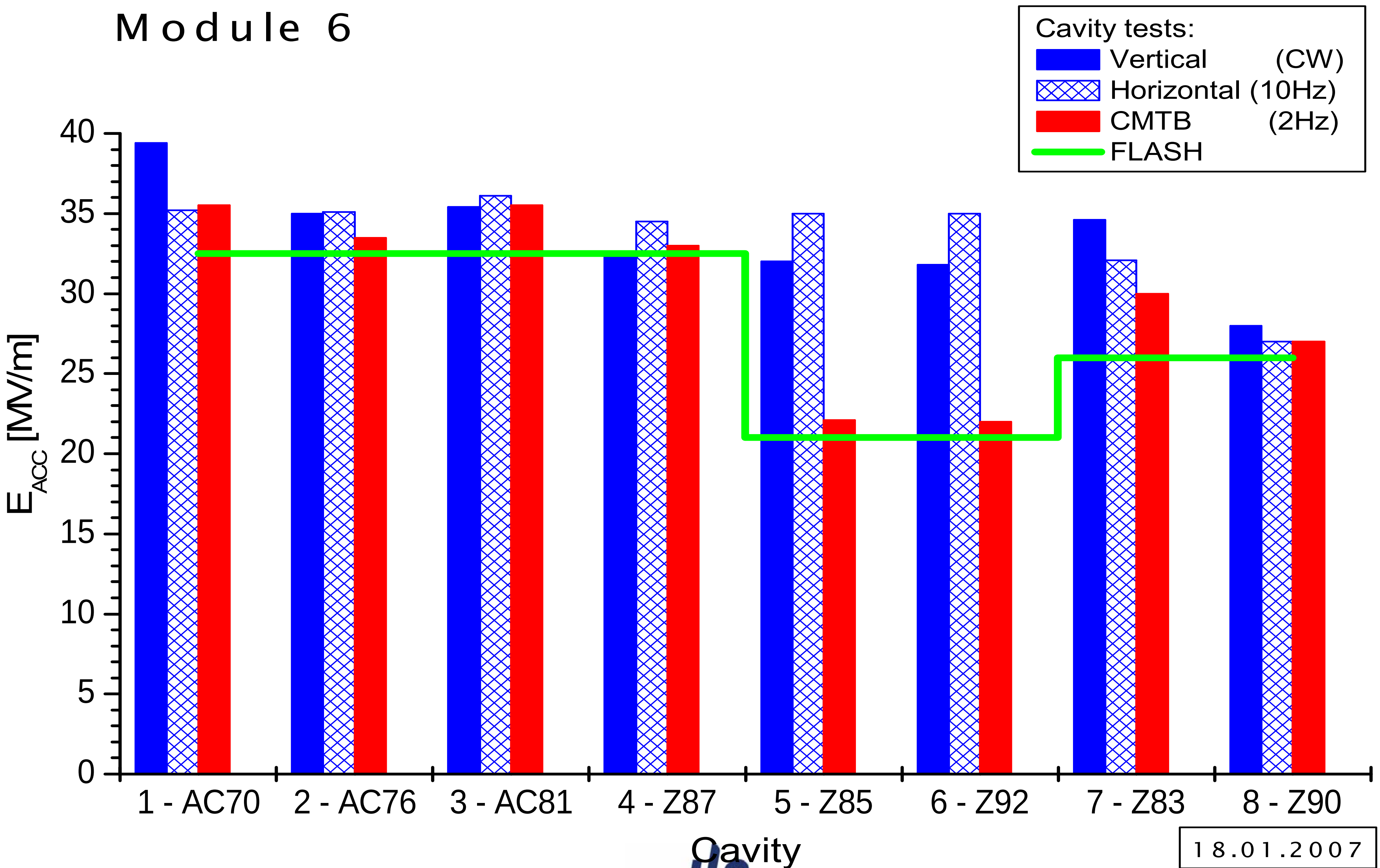
DESY **C**ryo **M**odule **T**est **B**ench (CMTB)

- CMTB: Test facility for 12m modules independant FLASH operation
- Test of module 6 ongoing (goal 35 MV/m)

CMTB under full operation

Module 6 rf tested

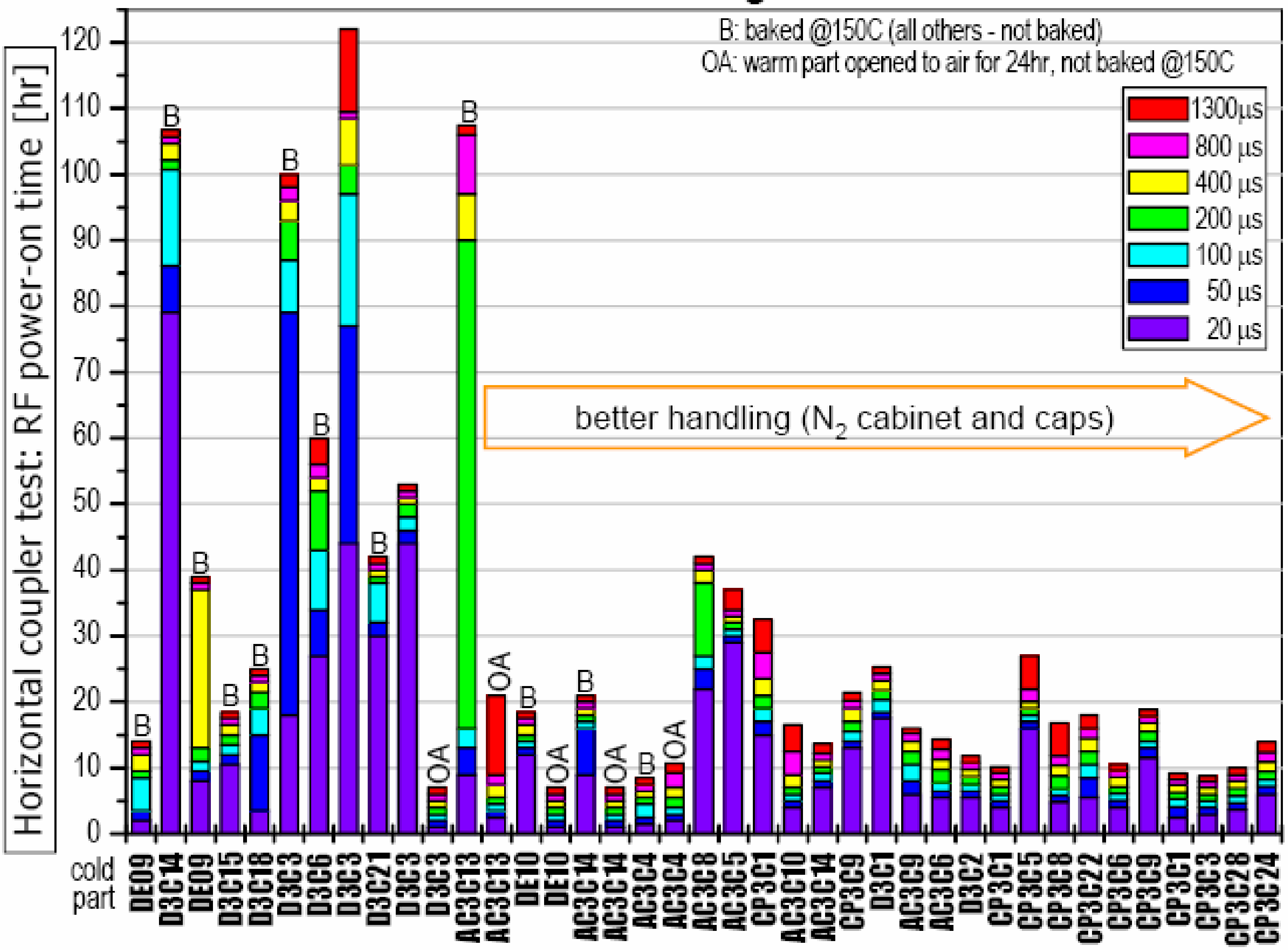
Now: Cryogenic cycling of module 6 + final rf checks



(courtesy of D. Kostin)

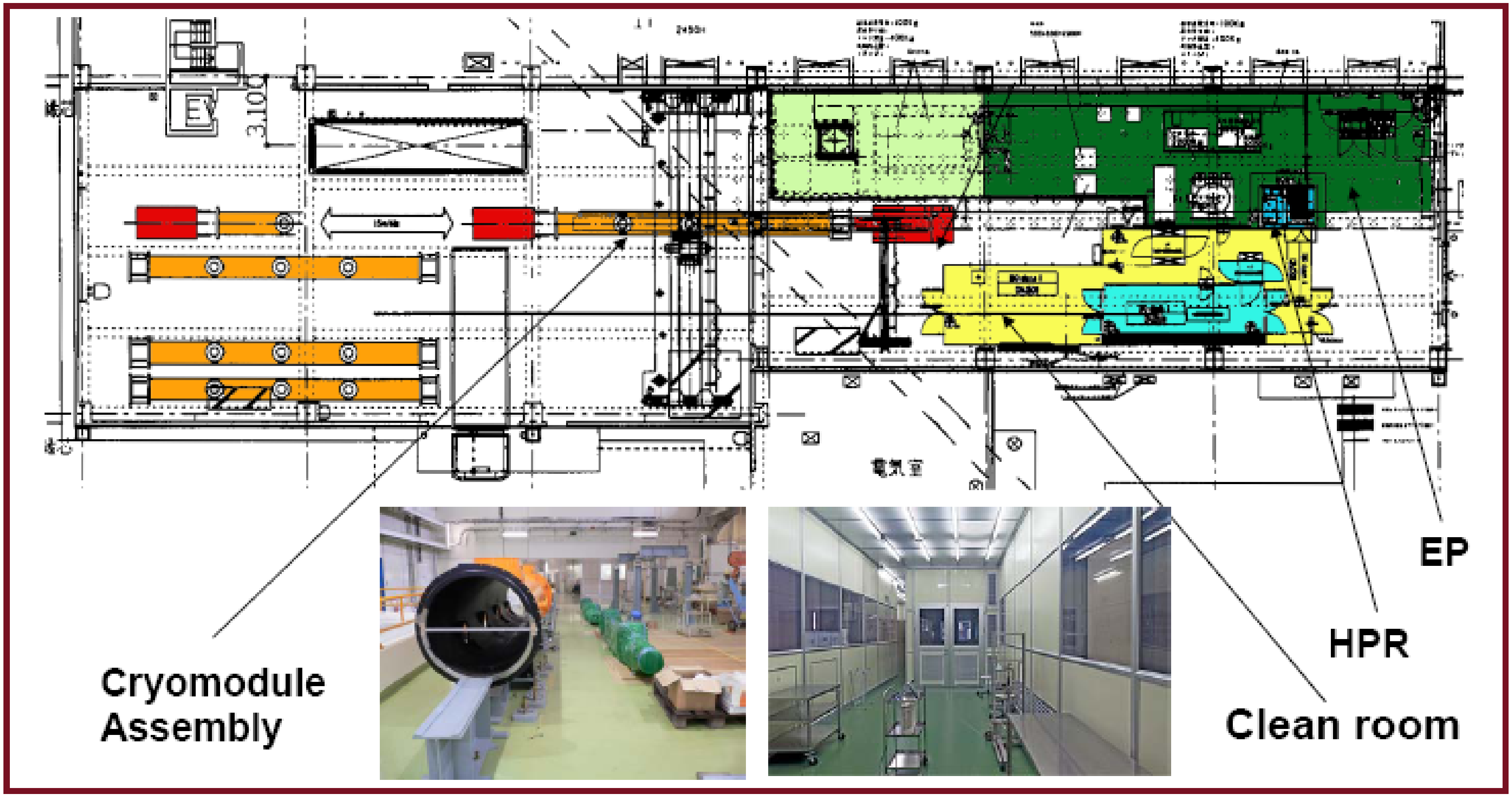
Coupler conditioning for FLASH

Horizontal test stand conditioning:



KEK: STF SC infrastructure

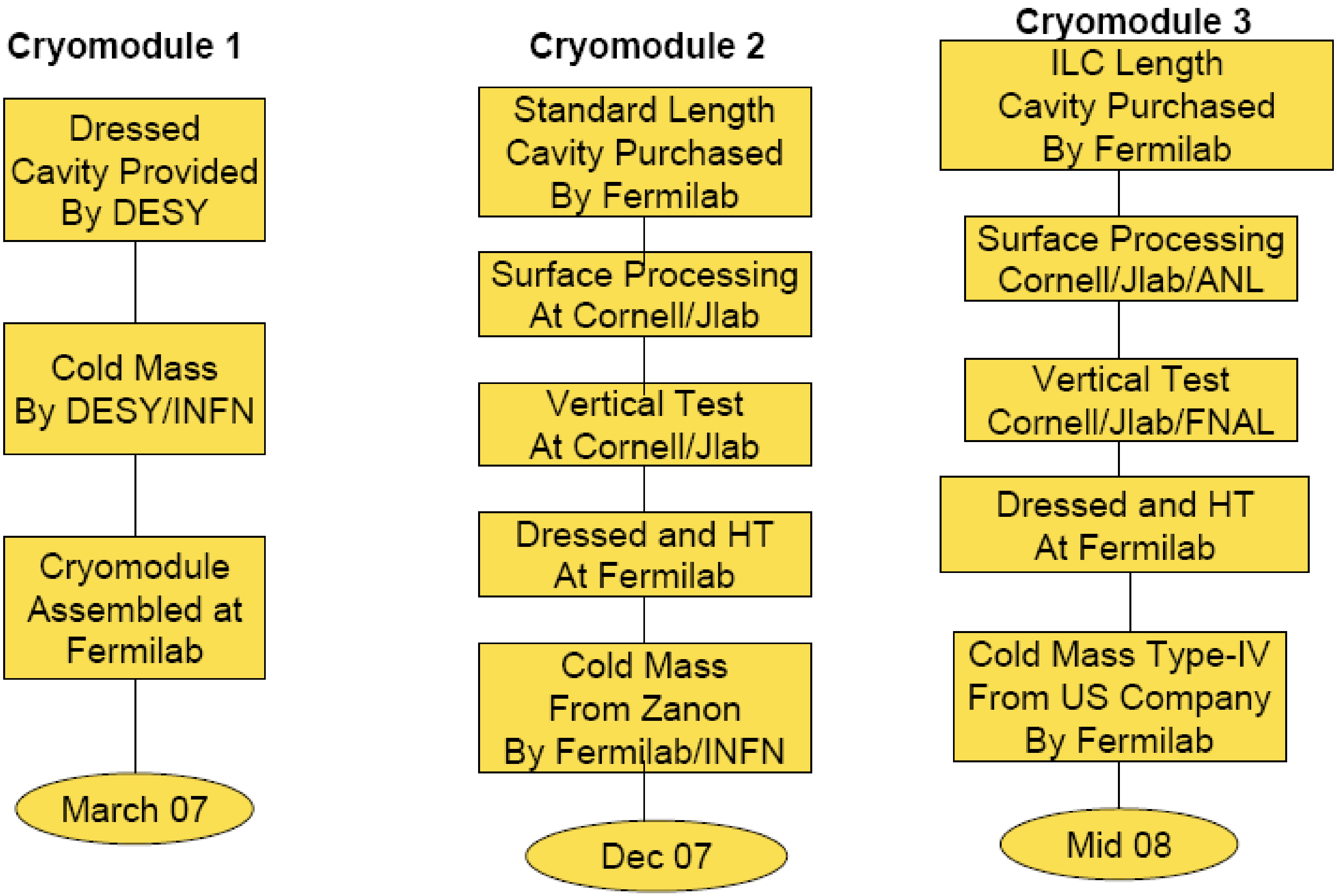
EP: under construction. will be completed in Mar. 2007
HPR:under construction. will be completed in Dec. 2006
Clean room: under use of short cryomodule assembly.



Cavity Dressing and Cryomodule Assembly Facility

- Fermilab has finished the construction of the Cavity Dressing and Cryomodule Assembly Facility.
    - The design is based on input and recommendations from DESY.
- Detailed development and check out of the tooling is in progress.
    - DESY is sending two dressed cavities to debug this facility.
- FNAL is awaiting the delivery of Cryomodule Kit from DESY.

Cryomodule Fabrication Plans for an RF Unit Test at ILCTA@Fermilab



A (Alternative)CD: Continous R&D

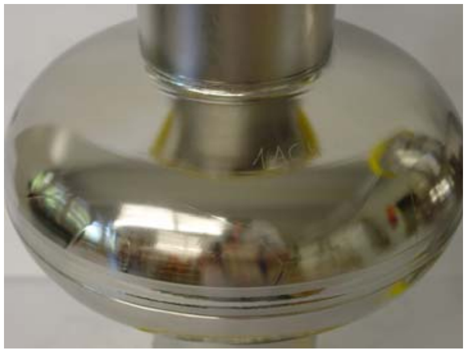
- "ACD is part of the BCD":

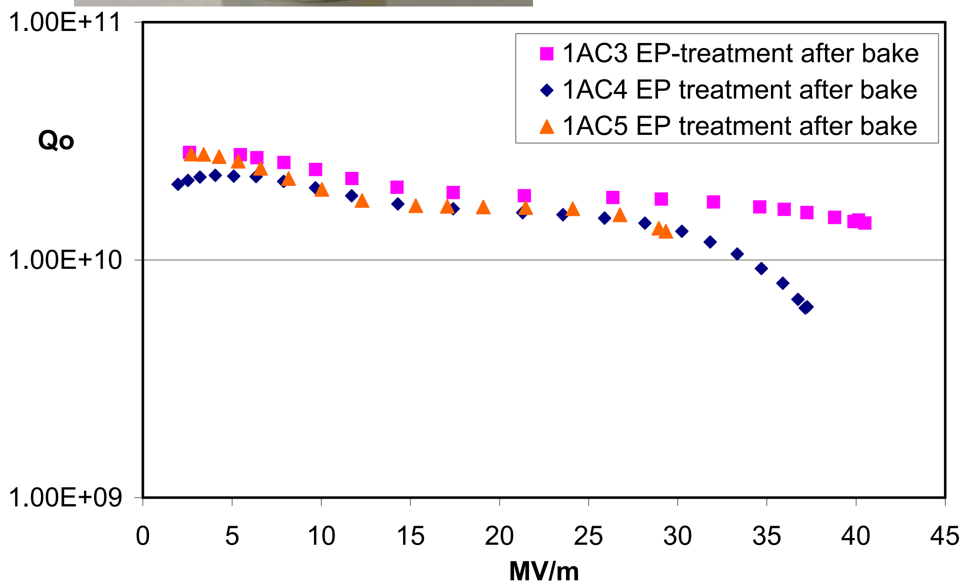
- ACD Examples from BCD document:
  - Large grain Nb material and cavities
  - Alternate shape cavities: Low Loss & Re-Entrant

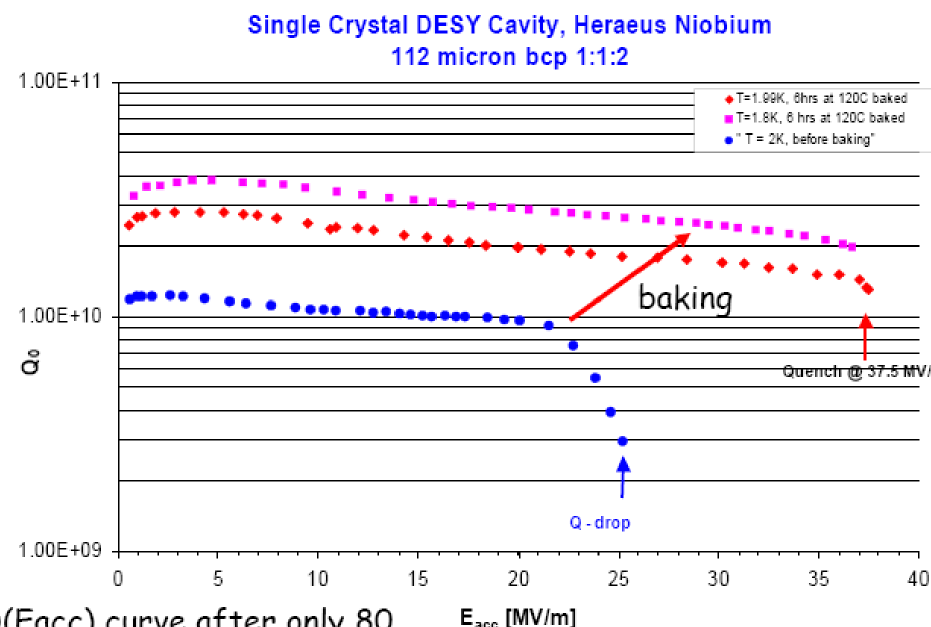
- Important Long-Range R&D:
  - Address field emission as a long-range issue
  - Aggressive quality control for EP, rinsing, assembly
  - In-situ processing of emitters
  - Re-visit : High Pulsed Power processing
  - Other Cost reduction ideas

ACD: Large-grain + mono-crystal cavities

- Activities on large-grain + single-crystal single-cell cavities at JLab, KEK, DESY, …
- 3 nine-cell cavities at DESY after BCP treatment only: E_{acc} = 28 MV/m



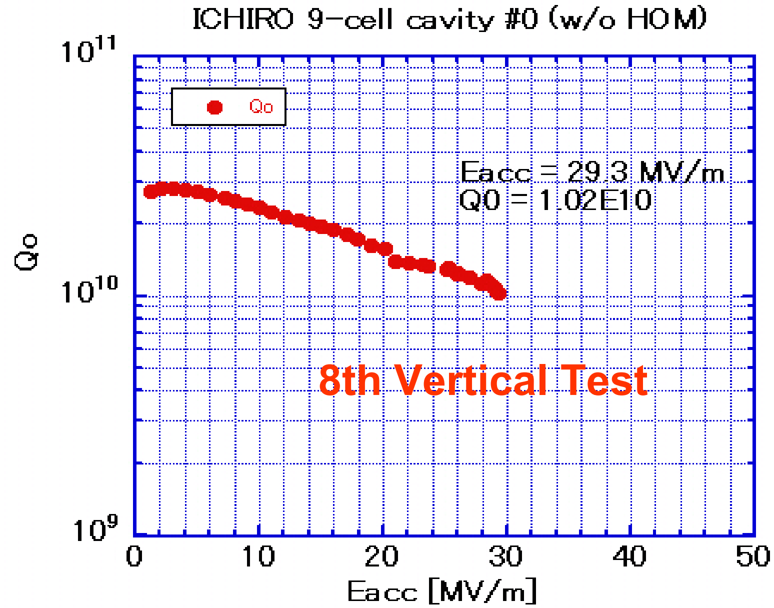




Q(Eacc) curve after only 80 µm BCP and in situ baking 120°C for 12 hrs.

ACD: LL-type Ichiro 9-cell Cavity Vertical Test

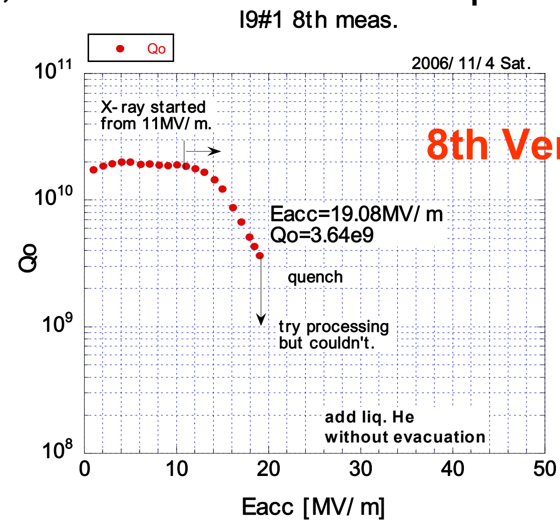
#0 : without HOM /input port



4 EP, 16 measurement -> reached to 30MV/m,
Now under modification of end-group.

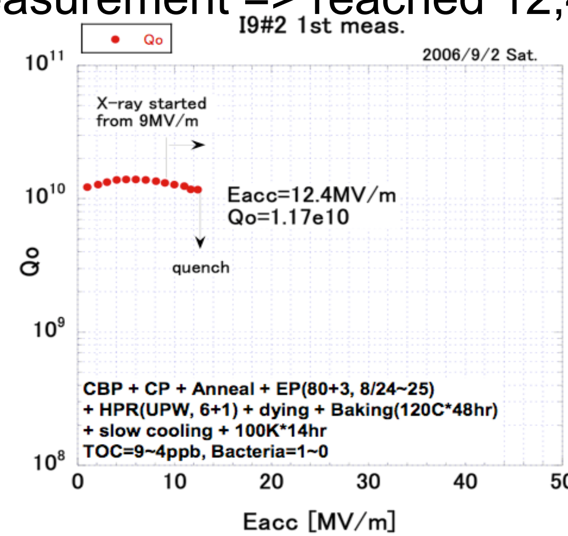
#1 : with HOM /input port

4 EP, 8 measurement => up to 19 MV/m



#2 : with HOM /input port

1st measurement => reached 12,4 MV/m

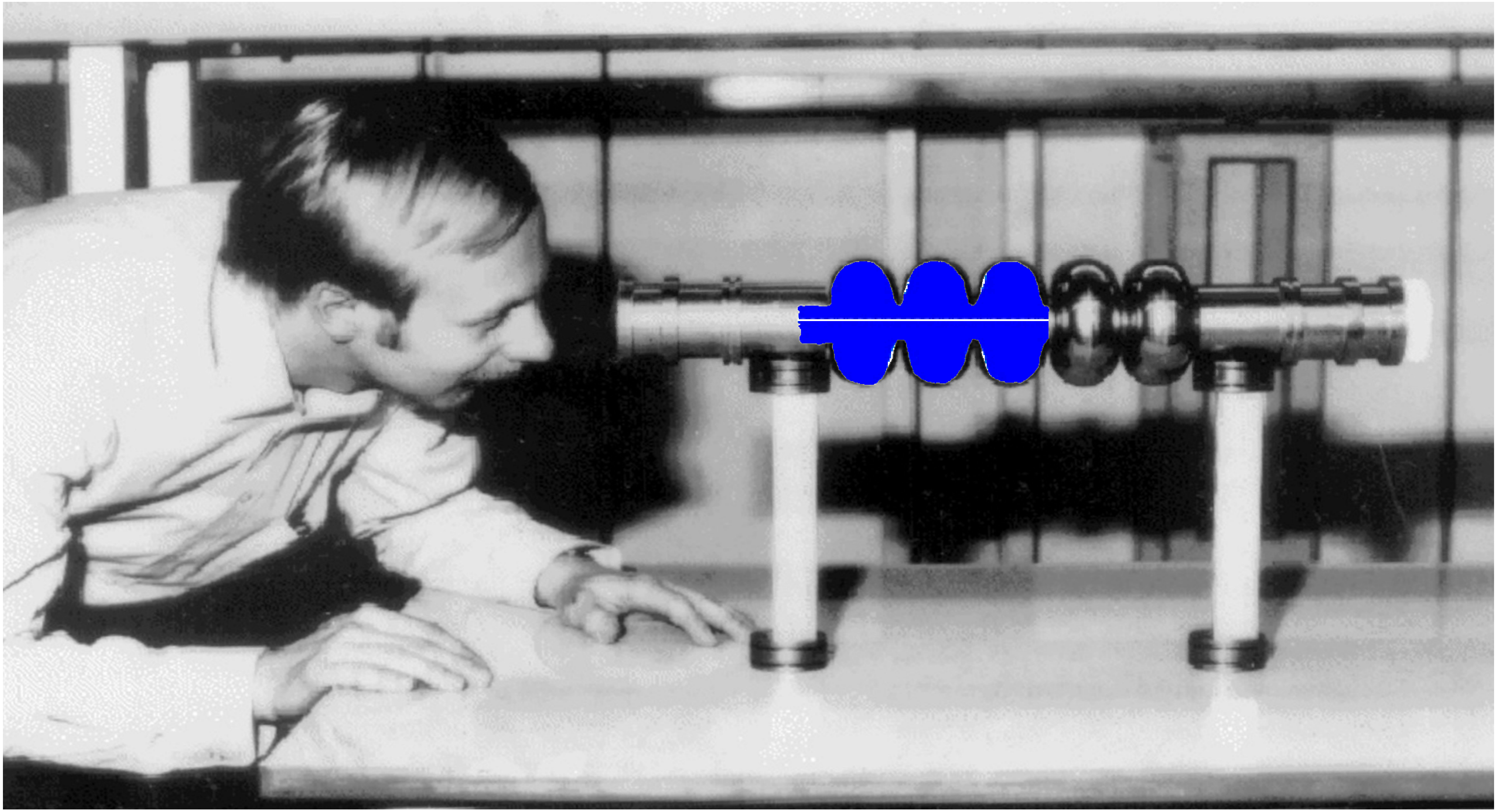


Thanks !

- Thanks to all colleagues who provided me information, especially

  H. Hayano, D. Kostin, L. Lilje, J. Mammosser, H. Padamsee, D. Proch, H. Weise

The end !!



(courtesy of H. Weise)