Field Emission: recent update and what we can do

J. Mammosser, S. Kim, ORNL

G. Wu, J. Ozelis, C. Ginsburg, D. Bice, Fermilab

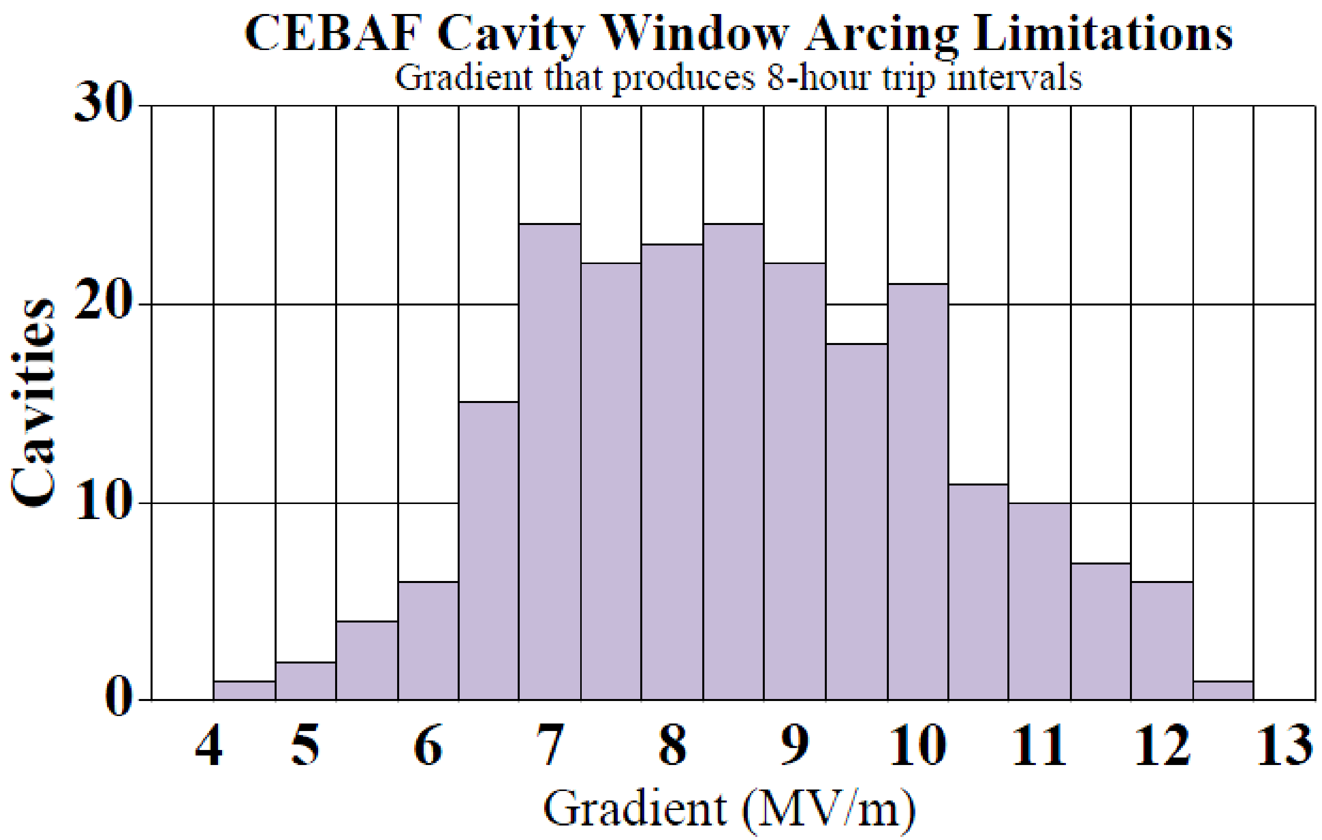
Integrated, Process-centric and Empirical Field Emission Studies

- Identify process elements responsible for Field Emission and evaluate improvements using single cell cavities
- Identify the Field Emission source through sample collection throughout module production process
- Utilize high electric field cavity to characterize the field emission strength and composition
- Evaluate process improvements to prevent emission source
- Explore methods to reduce the emission current

A collaboration between ORNL and Fermilab

Examples of Field Emission and its effects on CM Performance

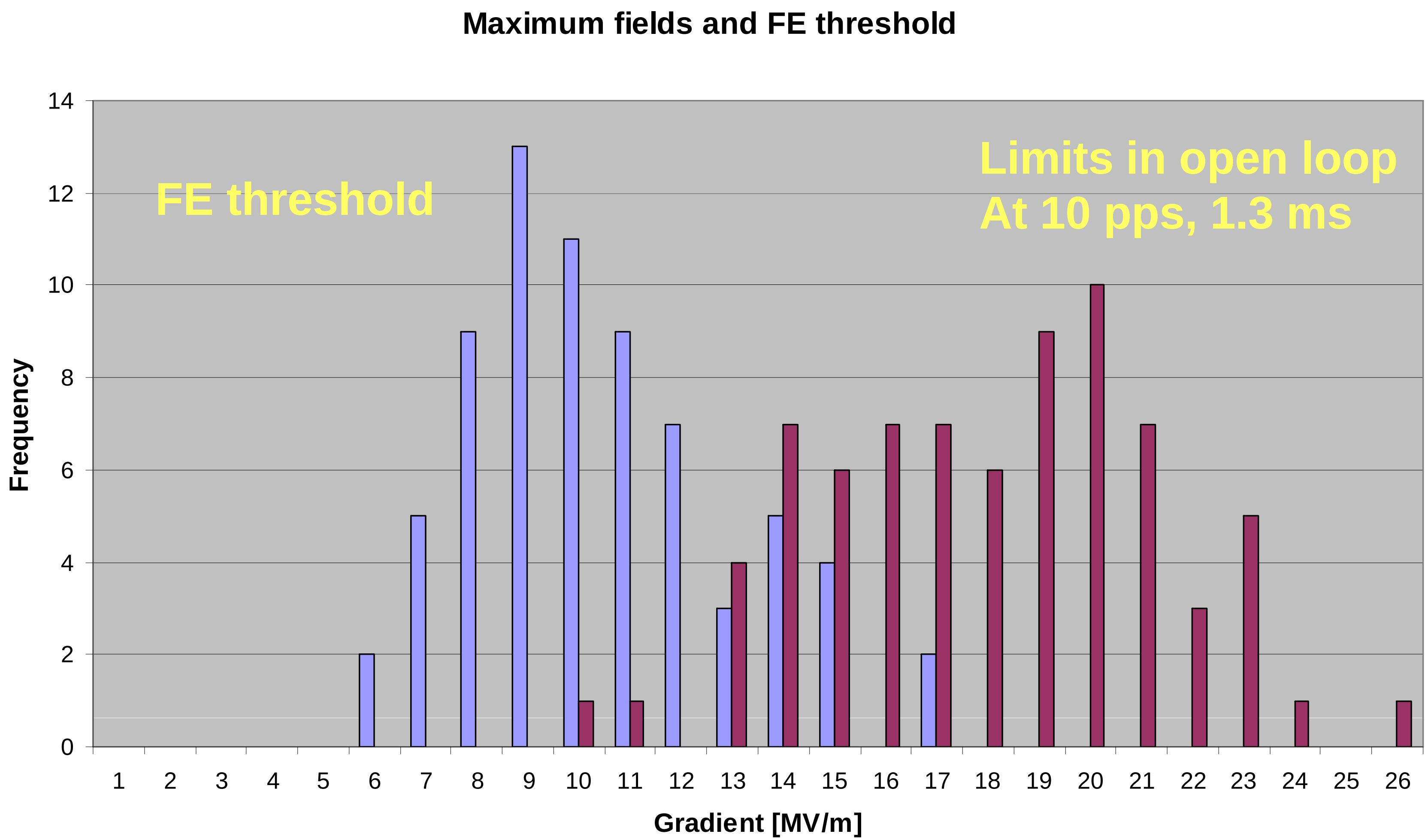
CEBAF SRF Cryomodule



CEBAF cavity window arcing is mostly caused by Field emission current

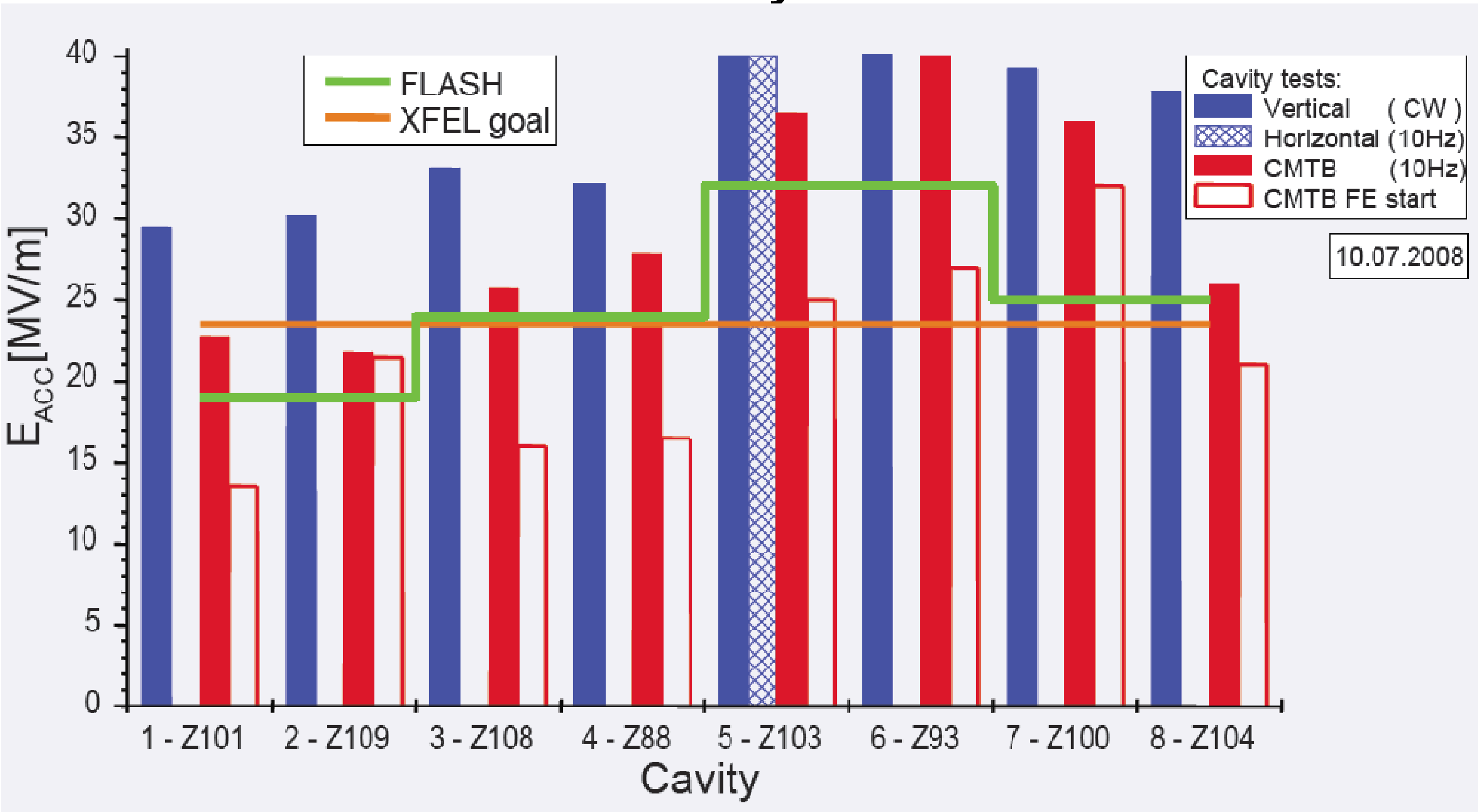
C. Reece, J. Benesch, and J. Preble, PAC2001, p1186

SNS SRF Cryomodule



S. Kim, LINAC2008

FLASH SRF Cryomodule M8

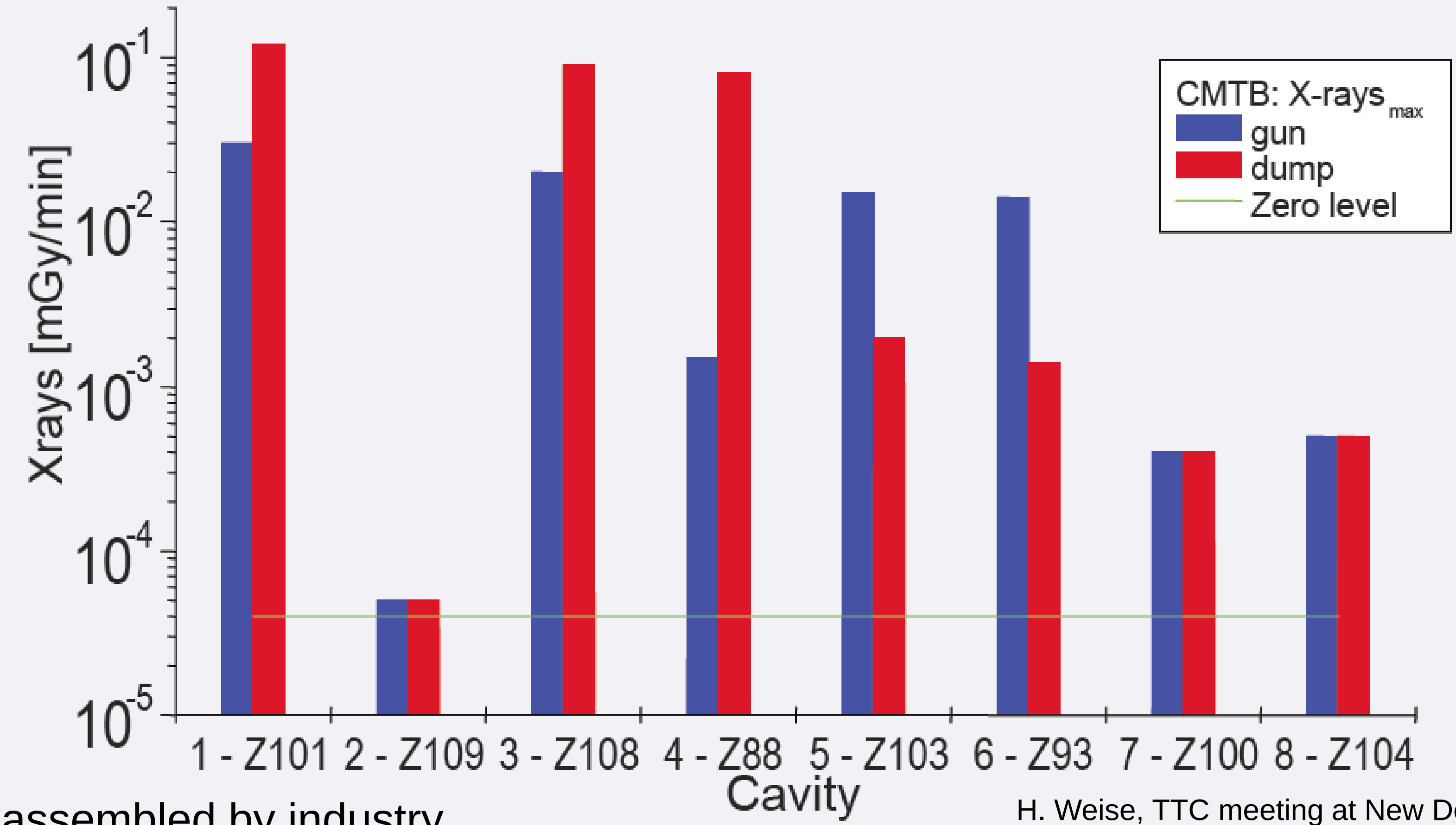


M8 is assembled by industry

H. Weise, TTC meeting New Delhi, 2008

FLASH SRF Cryomodule M8

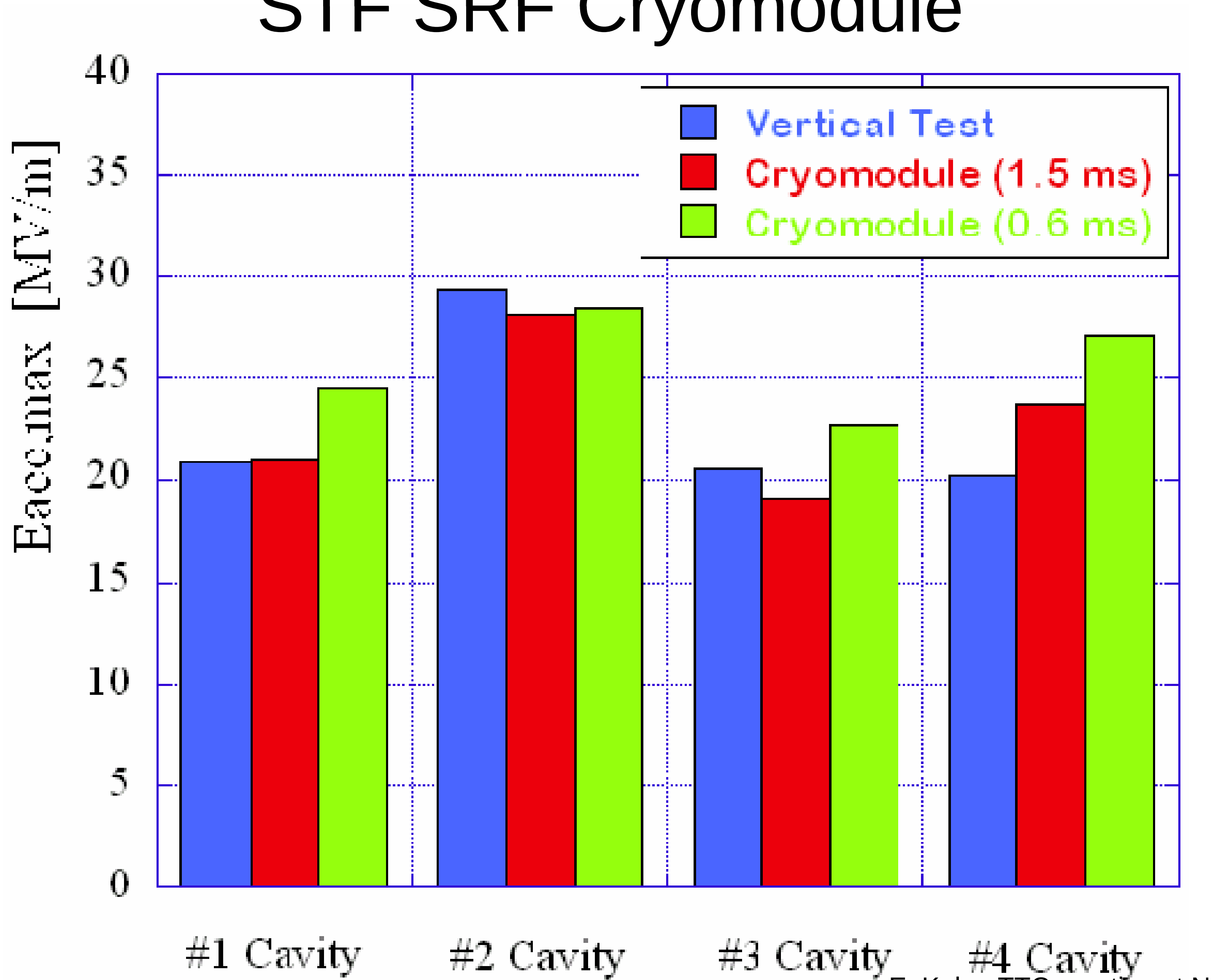
Module 8: X-rays



M8 is assembled by industry

H. Weise, TTC meeting at New Delhi, 2008

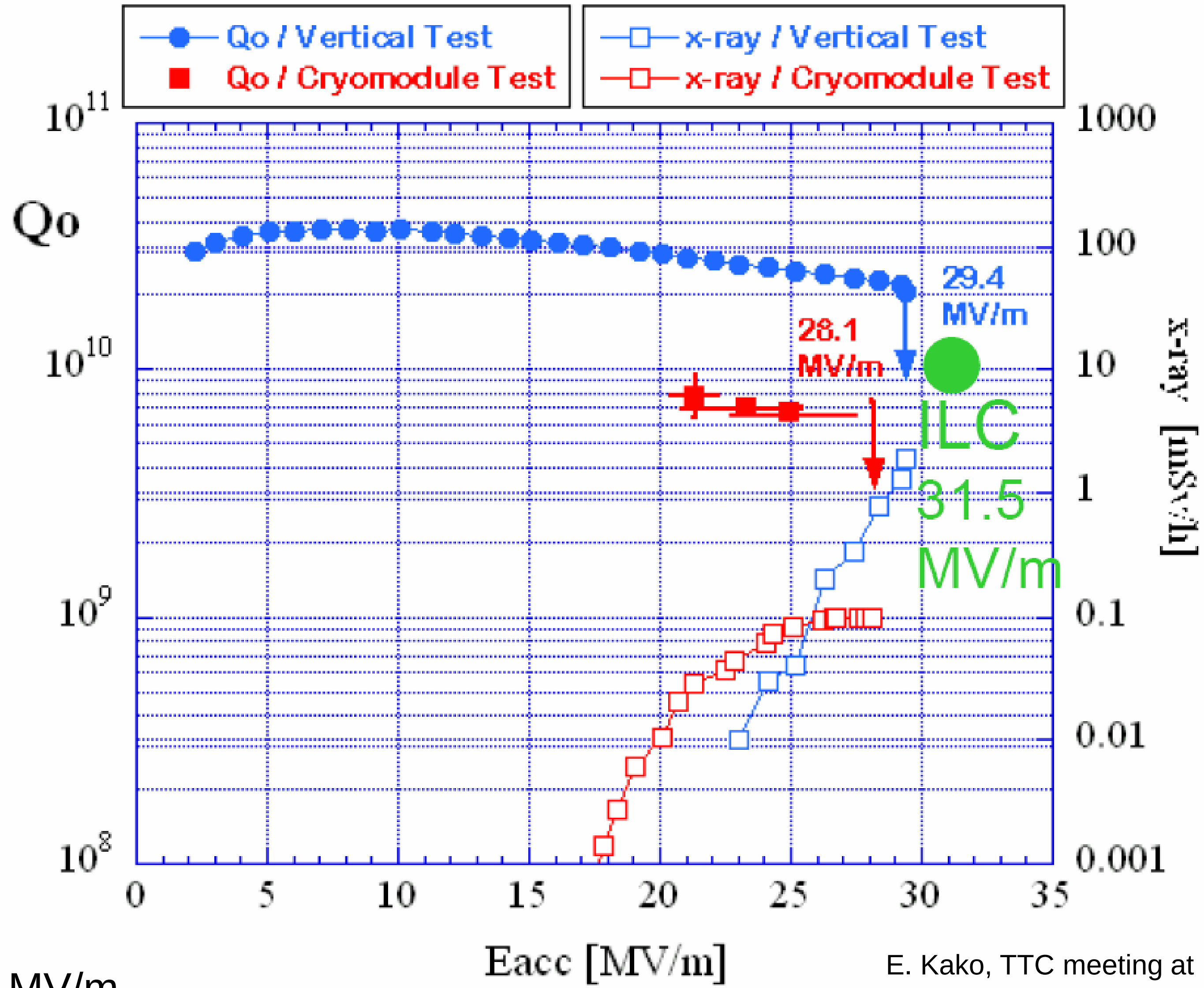
STF SRF Cryomodule



E. Kako, TTC meeting at New Delhi, 2008

Eacc = 23 MV/m

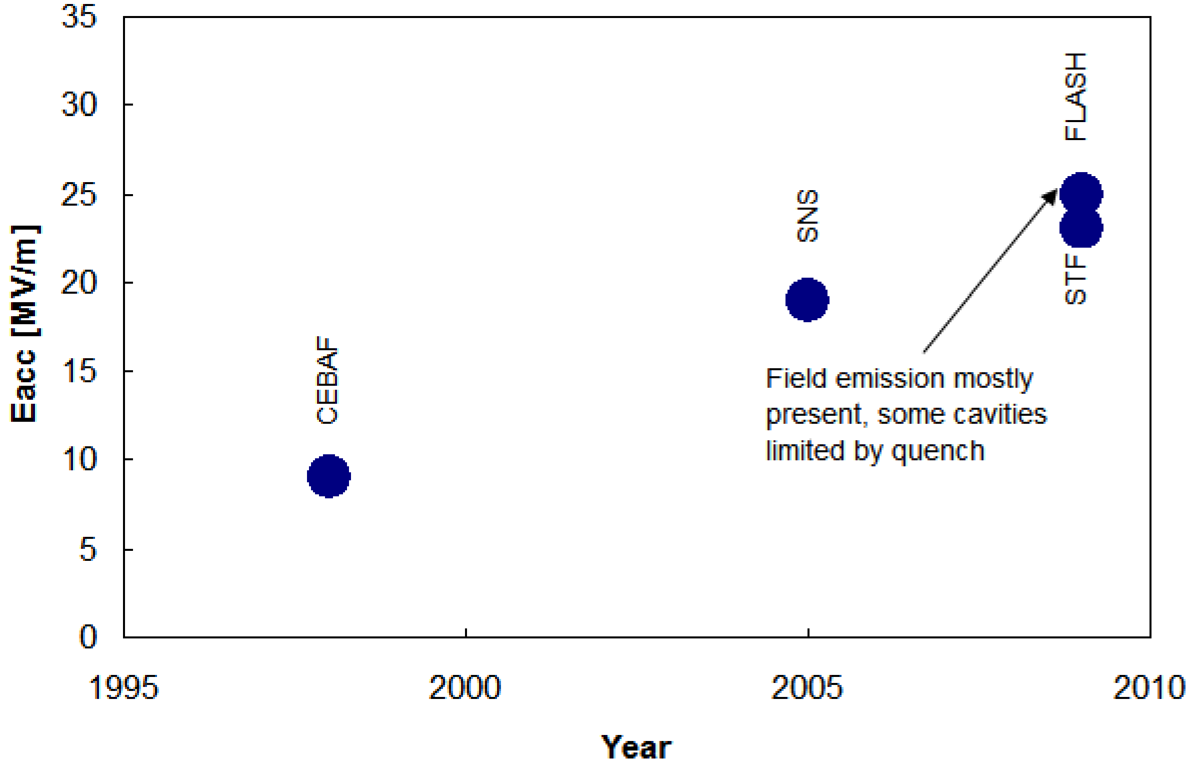
STF SRF Cryomodule



Eacc = 23 MV/m

E. Kako, TTC meeting at New Delhi, 2008

Field Emission: the dominating limitation of usable gradient in SRF Cryomodule



FLASH: M8 used modern EP cavities, but was assembled by industries. M7, M6 was mixed with EP and BCP cavities.

Review of the recent FE sample studies

Review of the latest FE studies* :

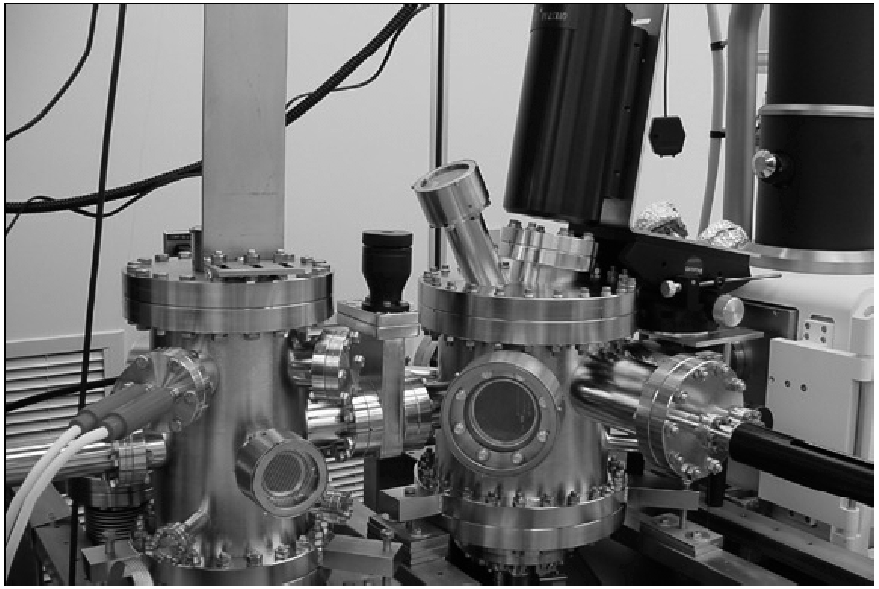
- Contrary to the common notation, “no inherent difference in emitter nature, or significant difference in emission density is observed up to 140 MV/m (DC)” for samples after BCP or EP
- Bulk impurities do not contribute to FE. (After removing the inclusions caused by machining)
- Virtually “All emitters are foreign macro-particles”
- “Natural emitters are generally micron or submicron particles & geometrical defects.”
- Ultrasonic rinsing is very effective

* T. Wang, Ph.D. dissertation, Virginia Tech, 2002

Review of the recent FE sample studies

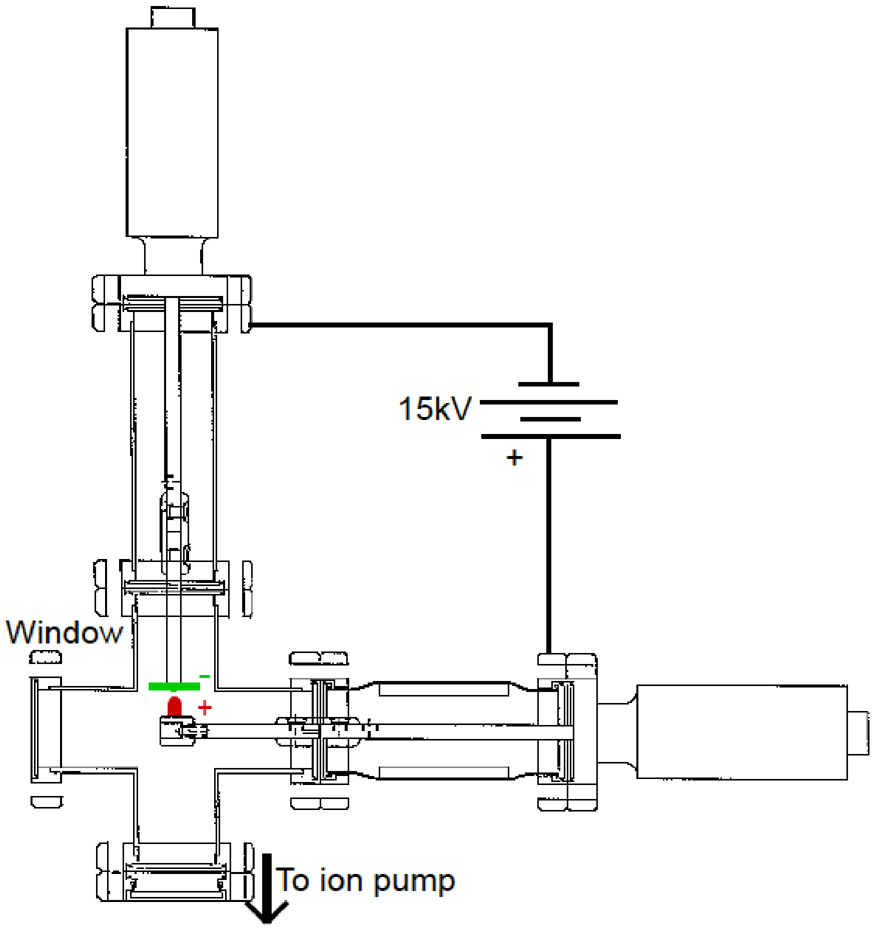
Field emitter viewer - not a fundamental research tool, but a **process monitor**

- In-situ contamination monitor
- High sensitivity (replacing particle counter)



T. Wang, Ph.D. dissertation, Virginia Tech

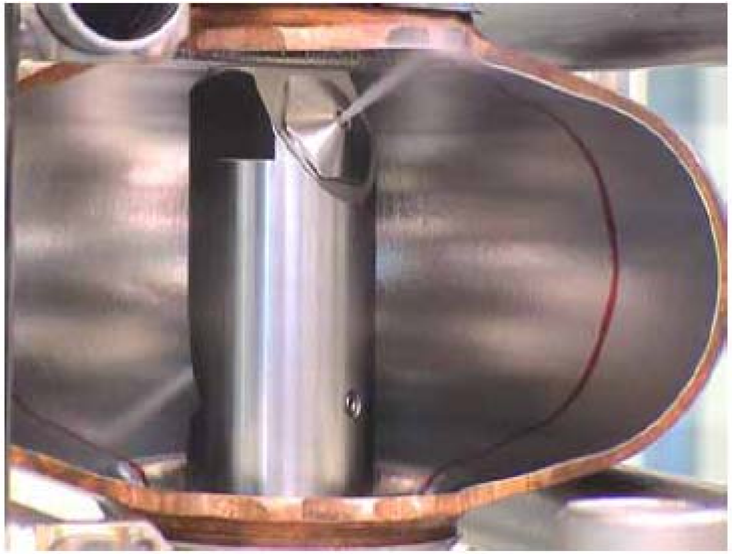
Review of the recent FE sample studies

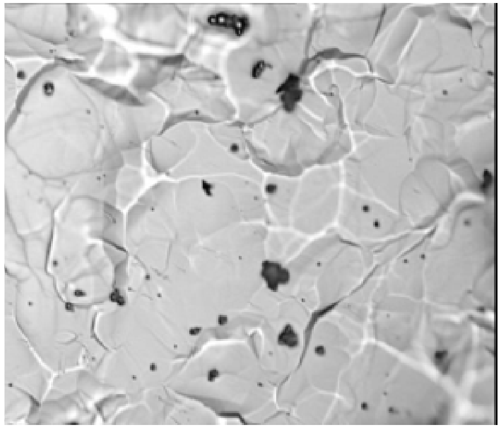


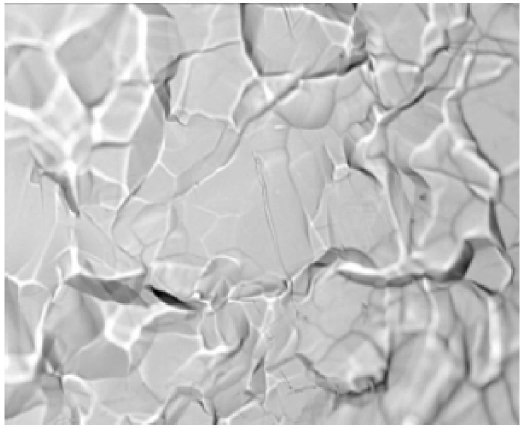
- Highly conductive plasma during high voltage breakdown
- Voltage breakdown can cure Field emission
- DC and RF voltage break down follows same mechanism

G. Werner, Ph.D. dissertation, Cornell university, 2004

Review of the recent FE sample studies







Fe, Cu particles clean away by DIC

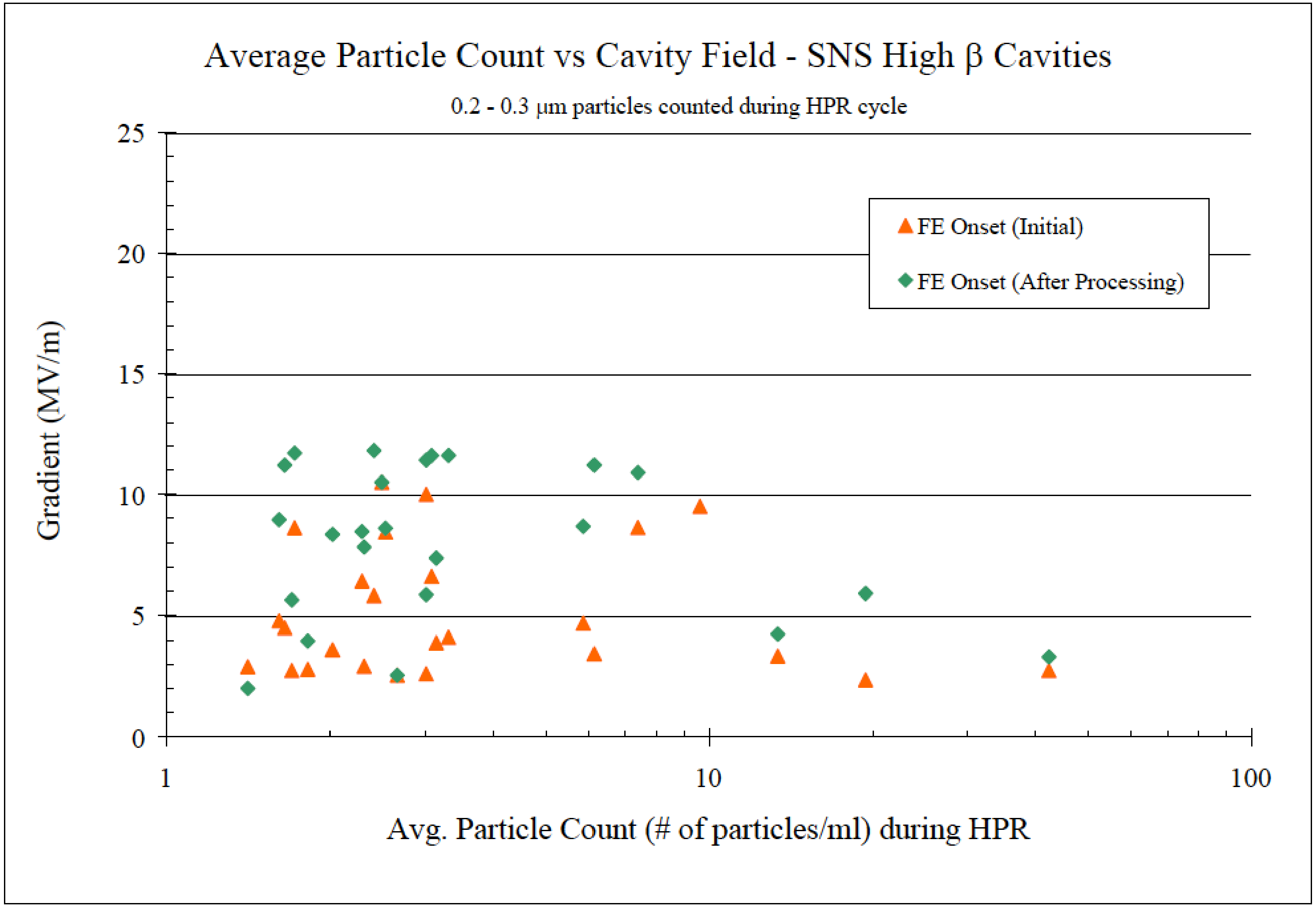
- Only HPR resistant emitter turned out to be a thin conductive object with a folded edge and submicron protrusions, which mainly consists of Nb.

D. Reschke, G. Mueller, DESY and Wuppertal university, 2007

A. Dangwal, D. Reschke, G. Müller, SRF2005

Examples of Field Emission and its effects on Vertical Cavity Performance

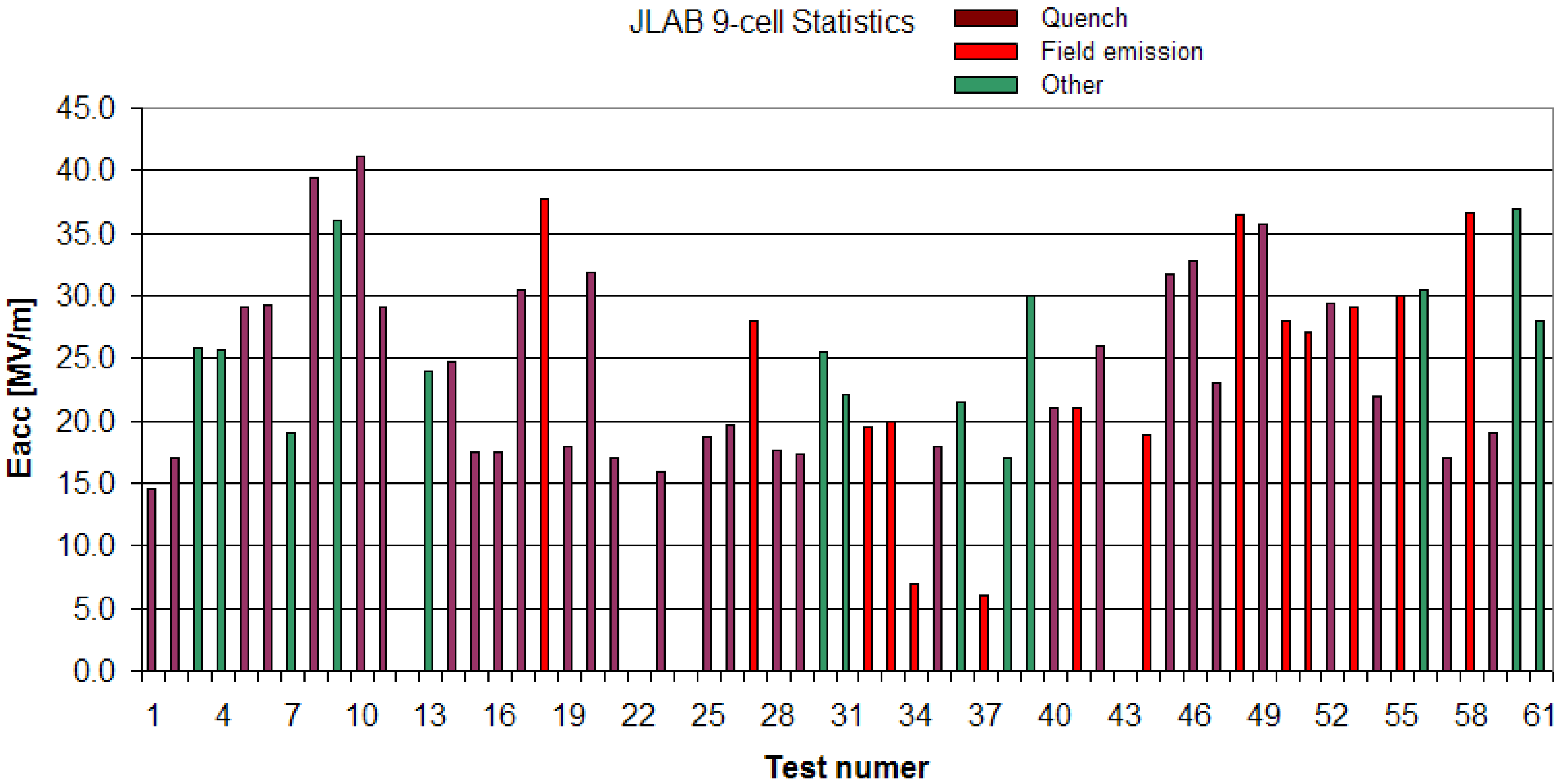
Field Emission: JLAB SNS experience



JLAB SNS cavity experience

J. Ozelis, SNS production, 2005

Field Emission: JLAB experience

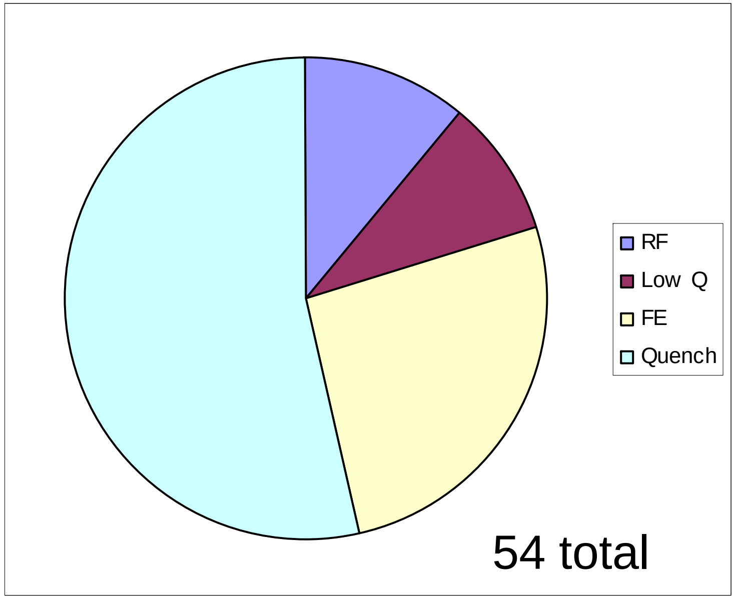


JLAB cavity experience

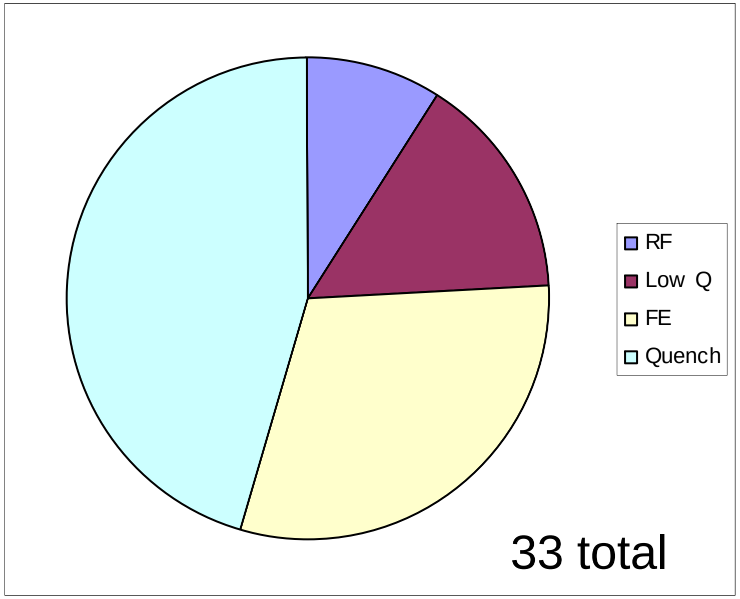
R.Geng et al, http://srf.jlab.org/JLabILCinfo/JLabILC.html, 2008

Field Emission: JLAB experience

All the cavities



Without AES cavities



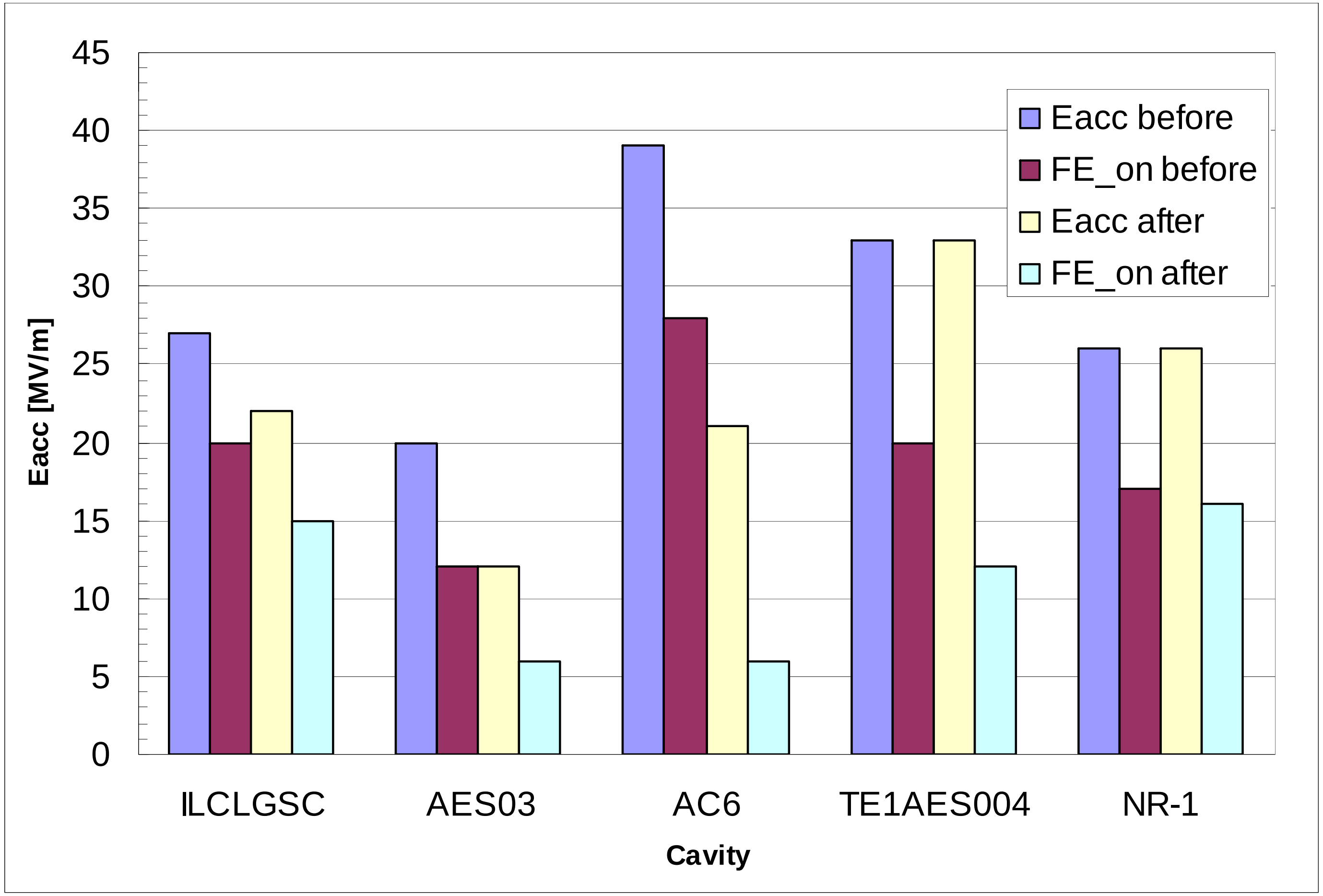
JLAB cavity experience

R.Geng et al, http://srf.jlab.org/JLabILCinfo/JLabILC.html, 2008

Data based on RF cycles

FE is the hard real limit which drops Q

Field Emission: Fermilab experience



All FE limited except NR-1 pending quench investigation

Before: assembled/tested else where
After: assembled/tested at Fermilab

J. Ozelis, VTS data

Summary and views

- Pro-active is important to deal with Field Emission
- “Being careful” has been practiced for the past decades
- QA is vital during cavity work flow
- Field emission is persistent like your “shadows”.

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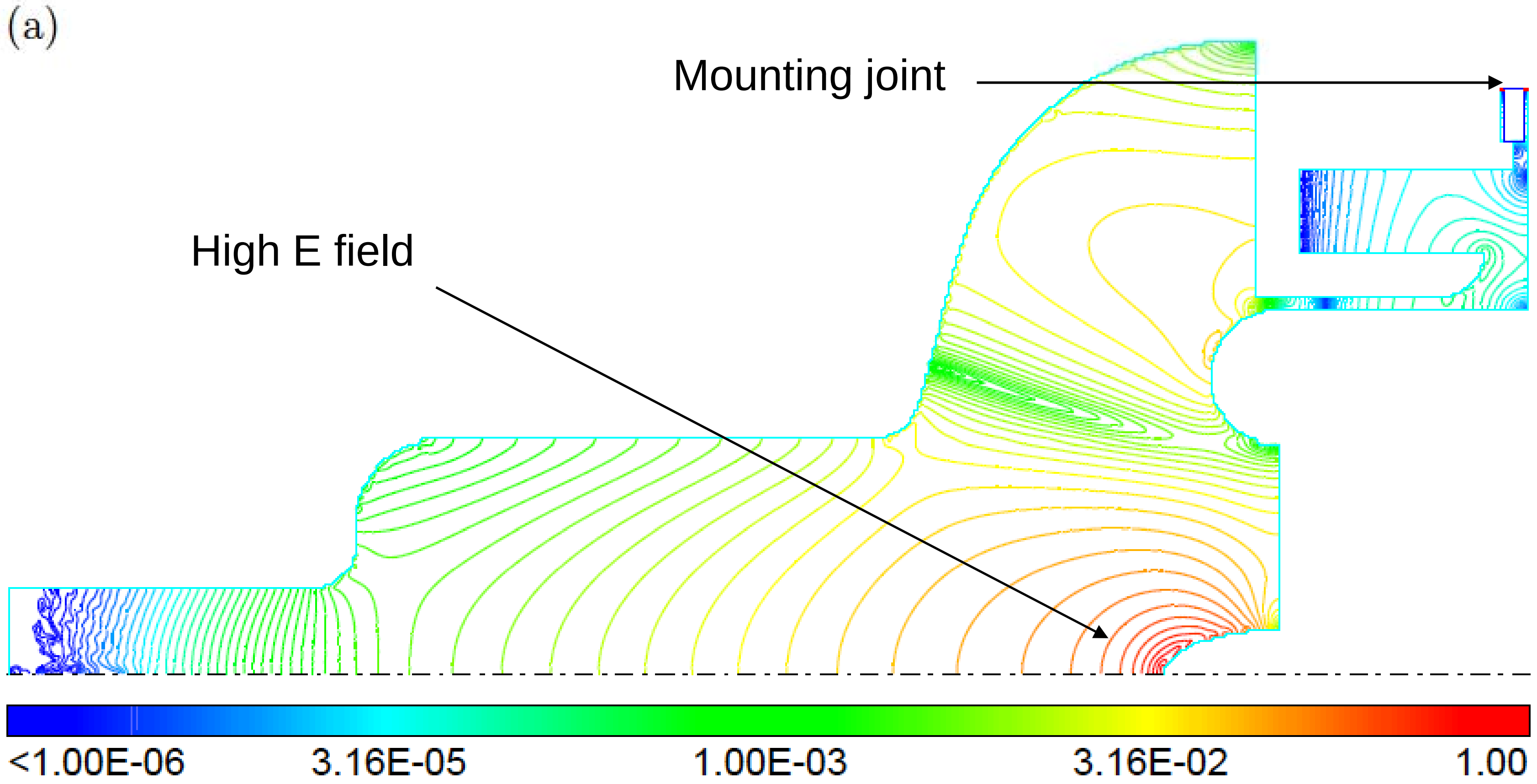
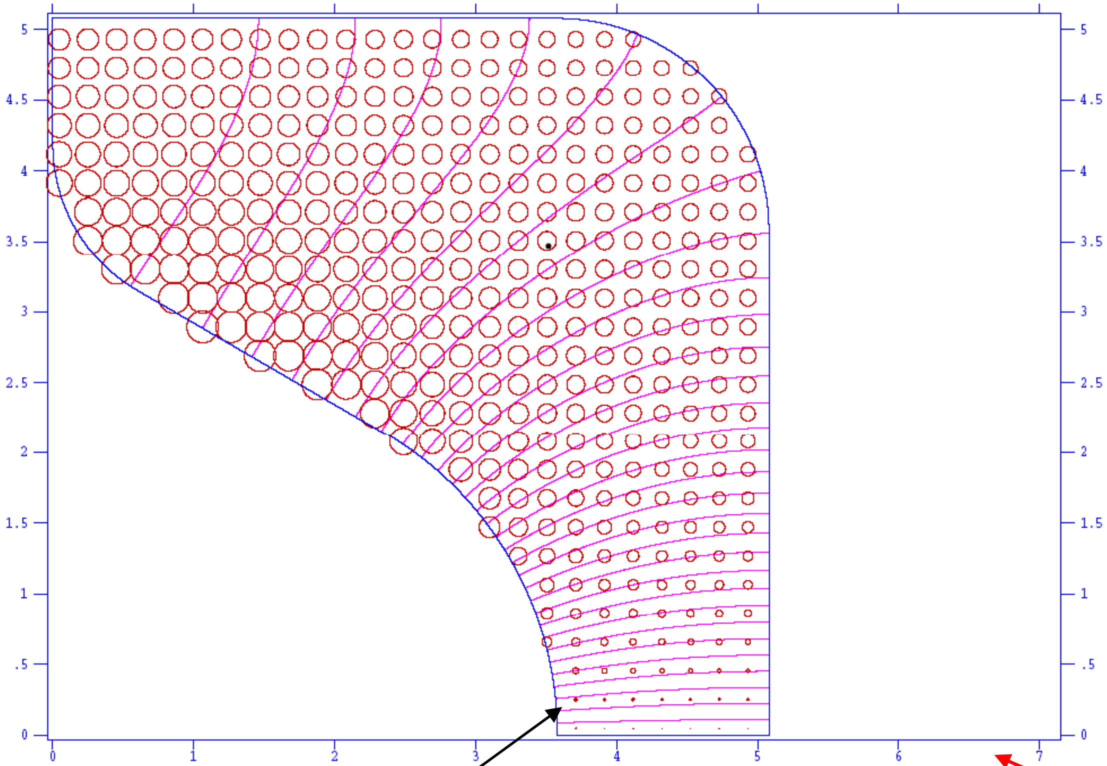
High electrical field cavity



Conceptual design of Cornell new mushroom cavity

G. Werner, Ph.D. dissertation, Cornell university, 2004

High electrical field cavity



Demountable end part

Electrical and magnetic field profile of HE cavity by Superfish code. Circles represents H field

Cavity	Freq. f_0 [MHz]	B_{peak}/E_{pk} [mT/(MV/m)]
APT-med β [7]	700	2.4
APT-hi β [7]	700	2.5
SNS-med β [8]	805	2.1
SNS-hi β [8]	805	2.2
RIA [9]	805	2.0
TRASCO [10]	700	1.85
TESLA [11]	1300	2.1
JLab-OC [12]	1497	1.8
JLab-HG [13]	1497	2.25
JLab-LL [14]	1497	1.72
BNL-AES [15]	704	2.9
ILC-RE [16]	1300	1.7
ILC-LL [17]	1300	1.4
Rounded Pillbox	750	1.8
Re-entrant	750	1.7
HE cavity	1300	1.13

80MV/m Epk, ~ 90 mT Hpk

Courtesy of S. Kim, ORNL

Preliminary, please contact S. Kim for permission to use

Sample collection

- Look for FE viewer in extra slide section

- Details of ORNL HE cavity is mostly missing, pending update from Sang-ho

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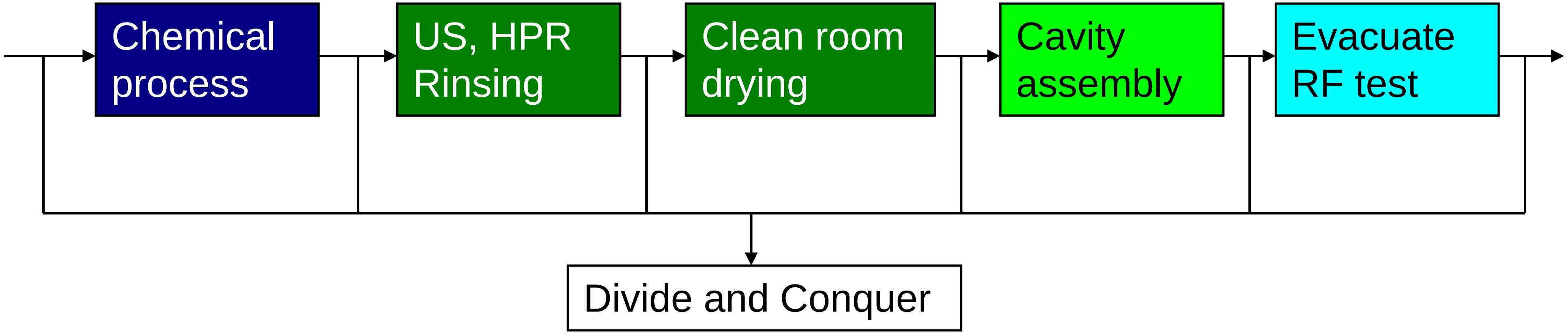
Single cell process evaluation



FNAL/ANL does one part, JLAB/Cornell completes the other

4 TE1ACC00x, 2 NR-x and 2 TE1AES00x available

Single cell interlaced between 9-cell queue

Process improvement for FNAL/ANL production line

Post processing evaluation

Field emitter conditioning

- RF conditioning
- Helium processing
- Plasma cleaning
- High power pulsed processing

Collaborating tasks

- ORNL
  - Develop HE cavity, analyze samples, plasma processing (Kim, Mammosser)
- FNAL
  - Single cell process evaluation
  - Collect coupons, test HE cavity samples, X-ray detection, plasma processing (Ginsburg, Ozelis, Wu, Bice)
- Both explore the post-processing using HE cavity and single cells.
- Re-start semi-automatic cleanroom assembly process

Activities designed for cavity EP, HPR, assembly, string assembly

FNAL effort is small addition to our normal business. No change of normal scheduling is foreseen.

Goals and milestones

- HE cavity development (12-month)
- Sample collection (3-month, 20 samples)
- Processing optimization (6-month)
- Post processing such as plasma (6-month)

Preliminary

Goals and milestones

- Develop on-line witness samples methods for FNAL/ANL Processes (12-month)
- Collect and Analyze Witness Samples From FNAL/ANL Processes(10-month)
- Processing optimization (6-month)
- Develop high field test cavity for plasma cleaning development (6-month)

Preliminary

Goals and milestones

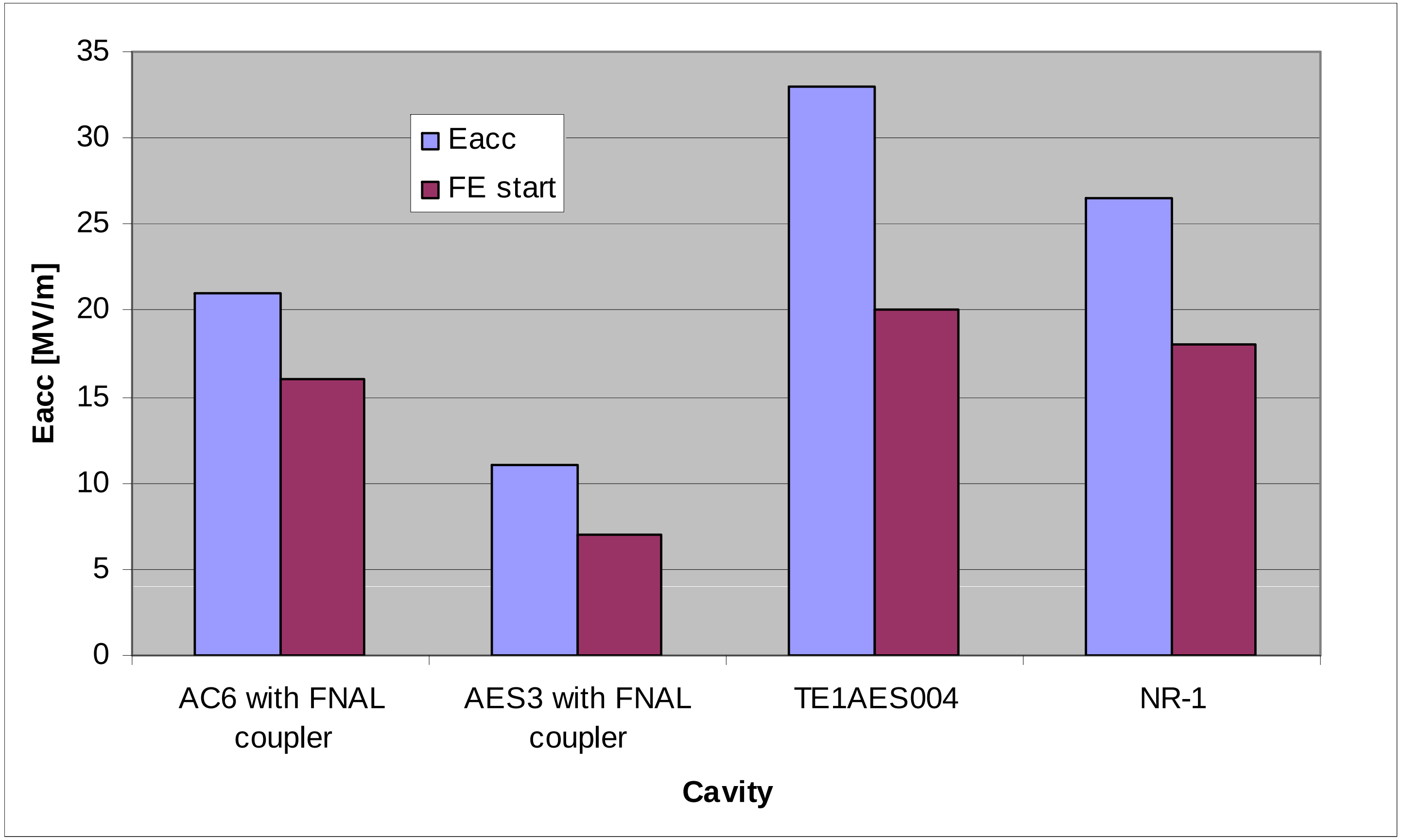
Activity	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
samples methods								
Processing optimization								
Collect and Analyze Witness Samples								
high field test cavity								

Preliminary

Extra slides

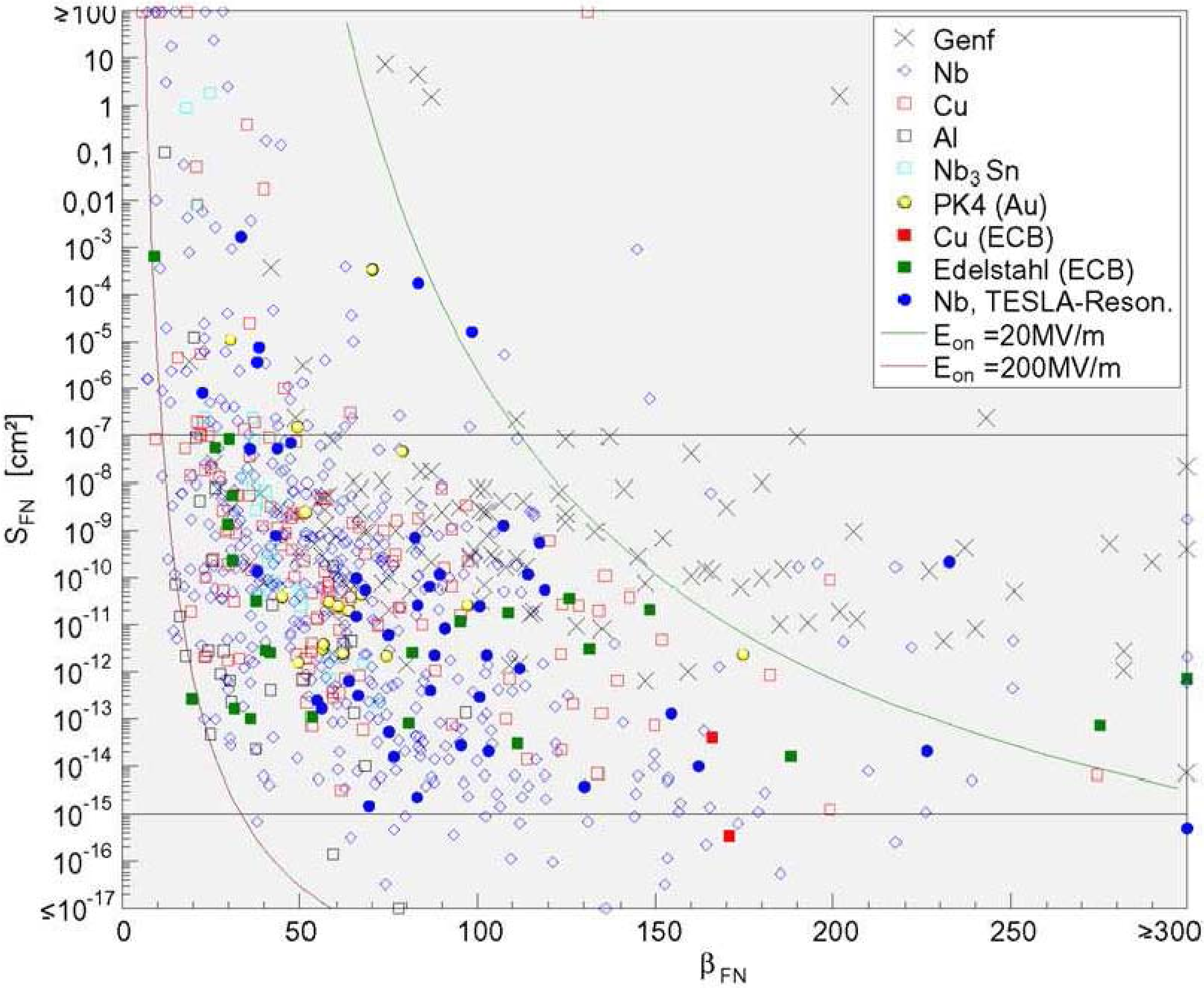
Add in slide w/HPR prt ct. vs FE onset

Field Emission: Fermilab experience

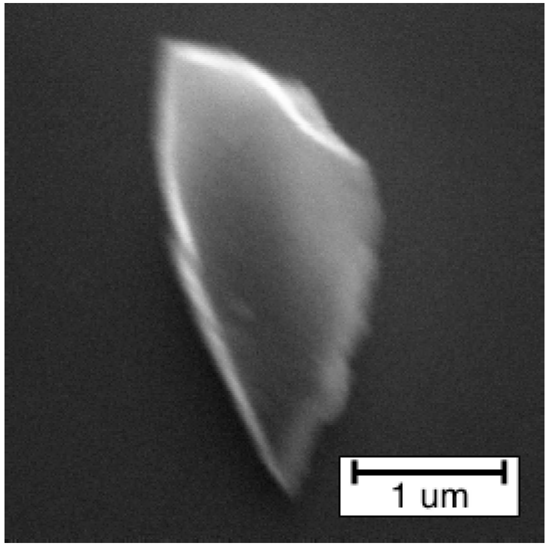


Without before-Fermilab result

All FE limited except NR-1 pending quench investigation



β and S parameters for various individual field emitters, T. Habermann, Ph.D thesis, Univ. of Wuppertal



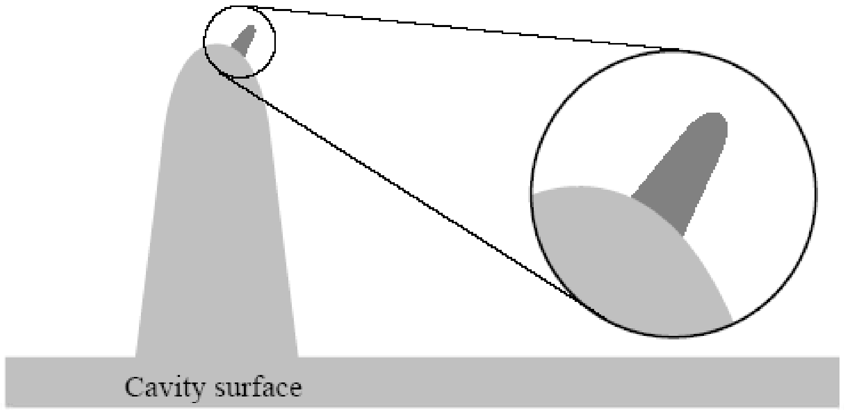


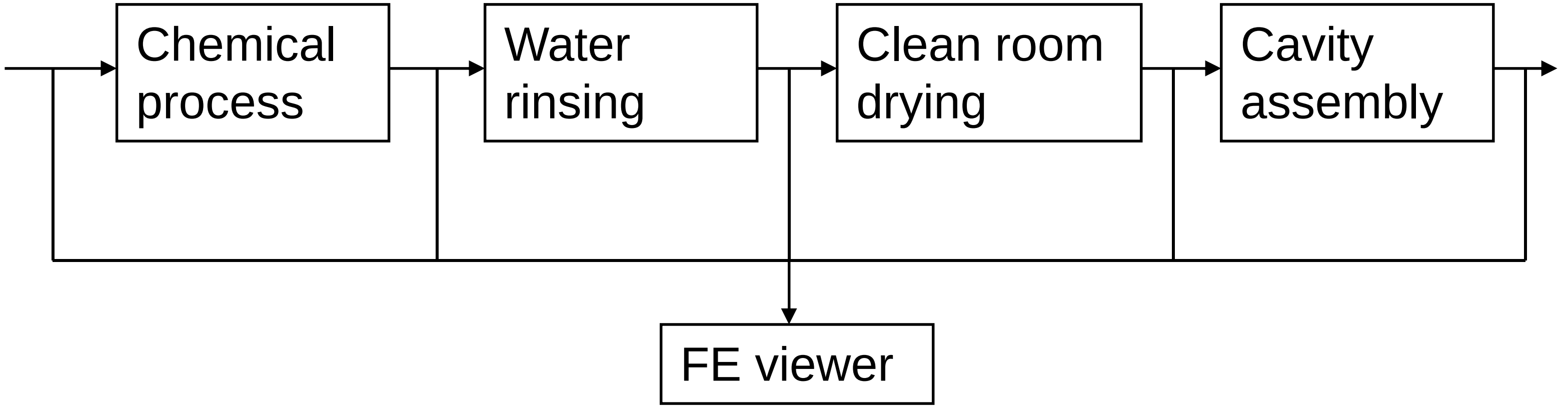
Figure 3.4: Substantial field enhancement up to several hundred can be achieved if a small whisker sits on a large one (tip-on-tip model).

J. Knobloch, Ph.D. dissertation, Cornell university, 2004

Figure 4.3: A contaminant particle (carbon) before breakdown (left, magnified view above), and the starburst after breakdown (right), centered exactly where the particle was.

G. Werner, Ph.D. dissertation, Cornell university, 2004

Field emission viewer

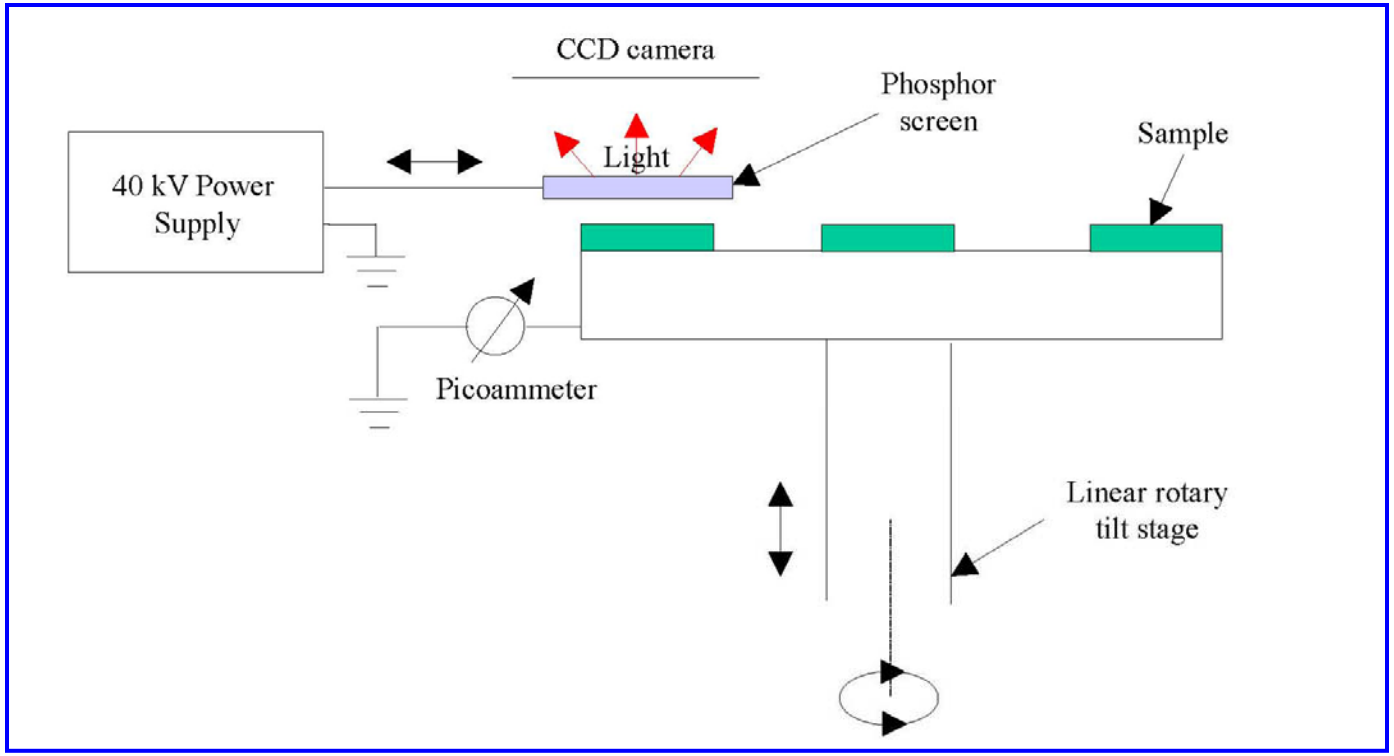


Process monitoring to maintain the process integrity :

- Dummy cavity with flat samples (Process pre-qualification, in-process monitoring: one dummy cavity between every N cavities)
- Cavity ride-on samples (flat sample inside FPC port for every cavity *)

* W-D. Moeller, DESY

Field emission viewer



Multiple sample stage with load-lock port

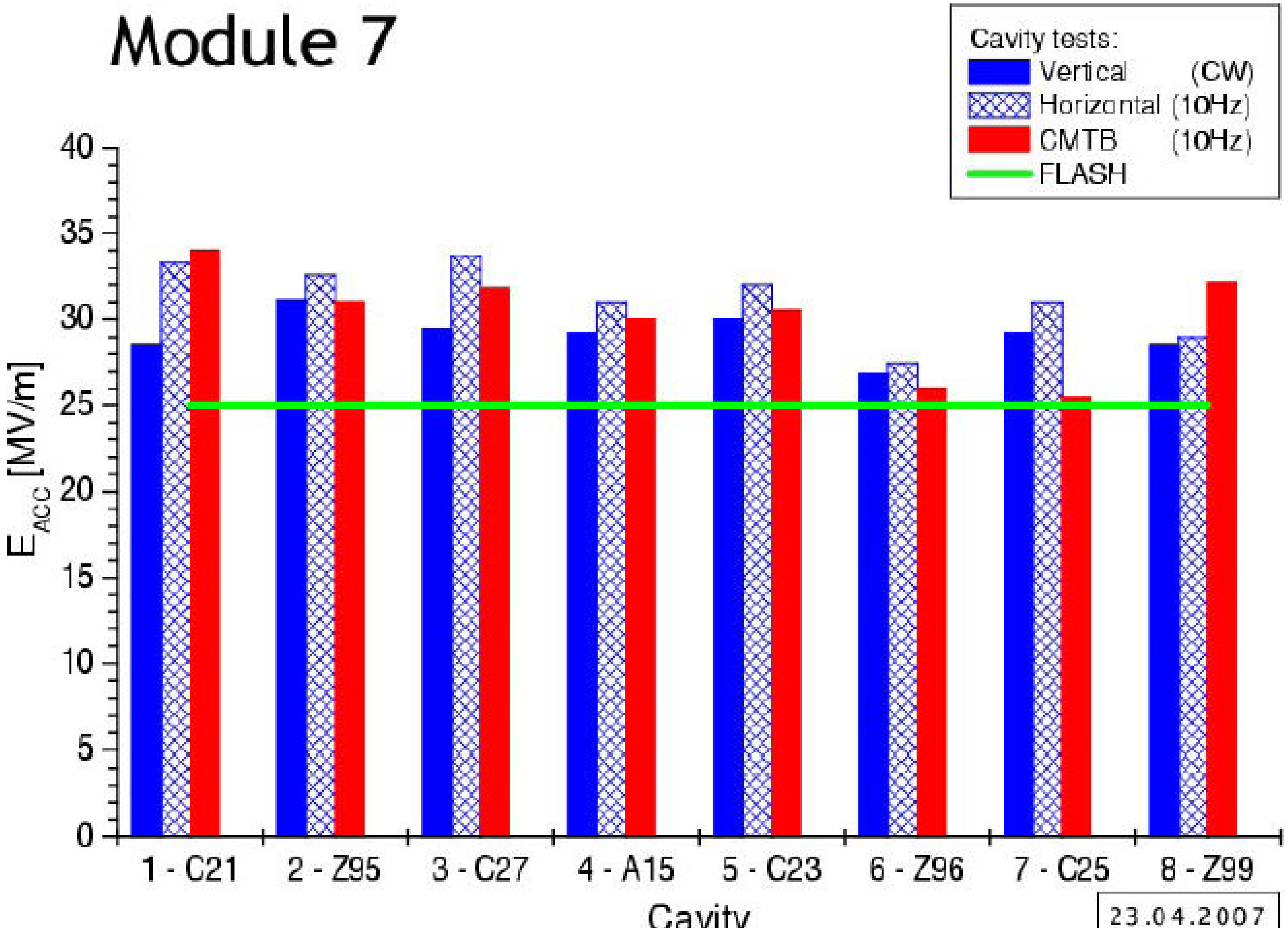
With possibility to load to SEM,SIMS if necessary

Courtesy of A-M. Valente-Feliciano, JLAB

2006 FNAL

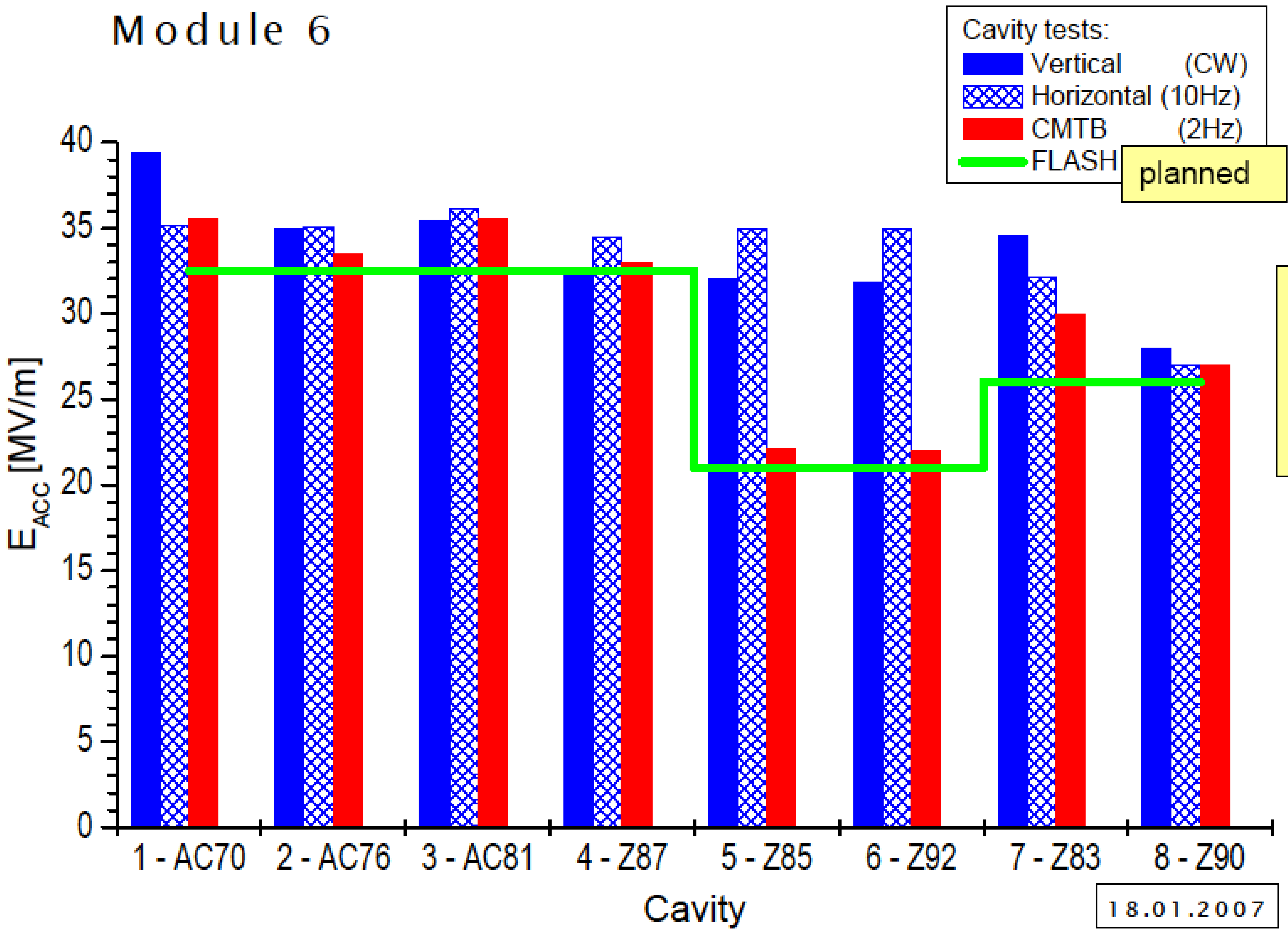
Module 7 limits on CMTB

10Hz 500/800us 23-April-07



Cavity Performance

(courtesy D. Kostin – DESY)



Average gradient: 28 MV/m