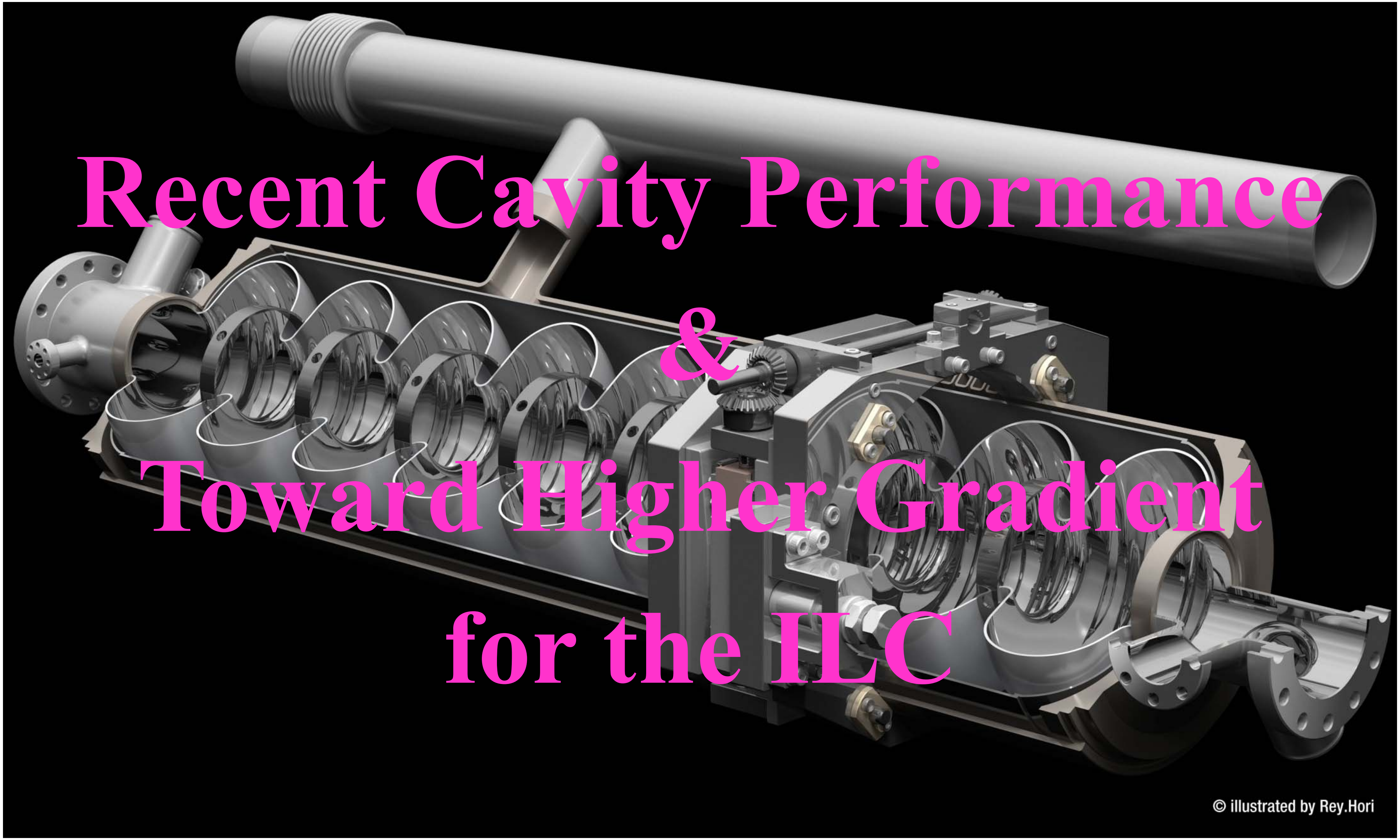
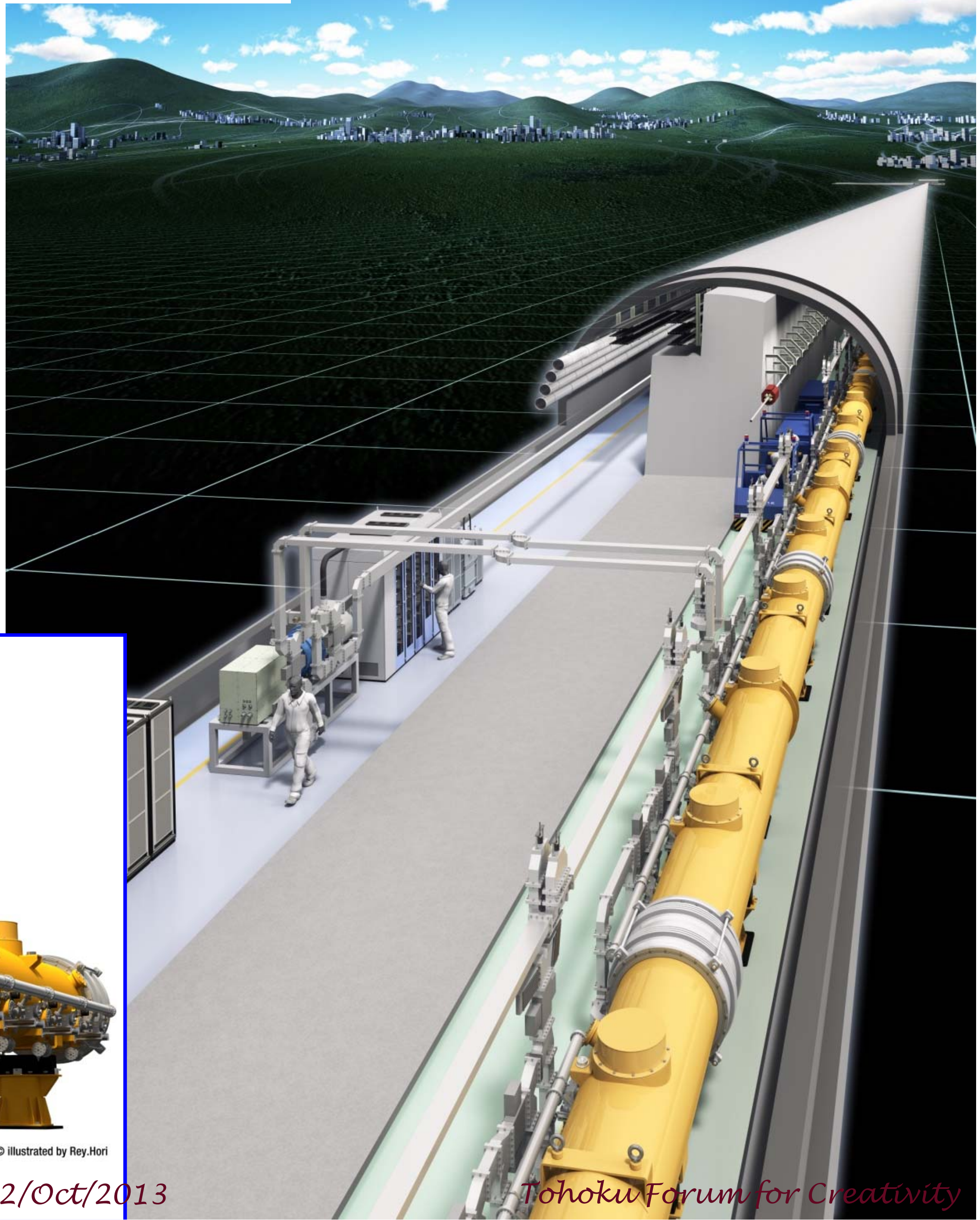
Recent Cavity Performance & Toward Higher Gradient for the ILC



Kirk

Outline

- ✓Cavity Package for ILC
- ✓Worldwide R&D Laboratory
- ✓Recent Cavity Performance
- ✓Toward Higher Gradient
- ✓Summary

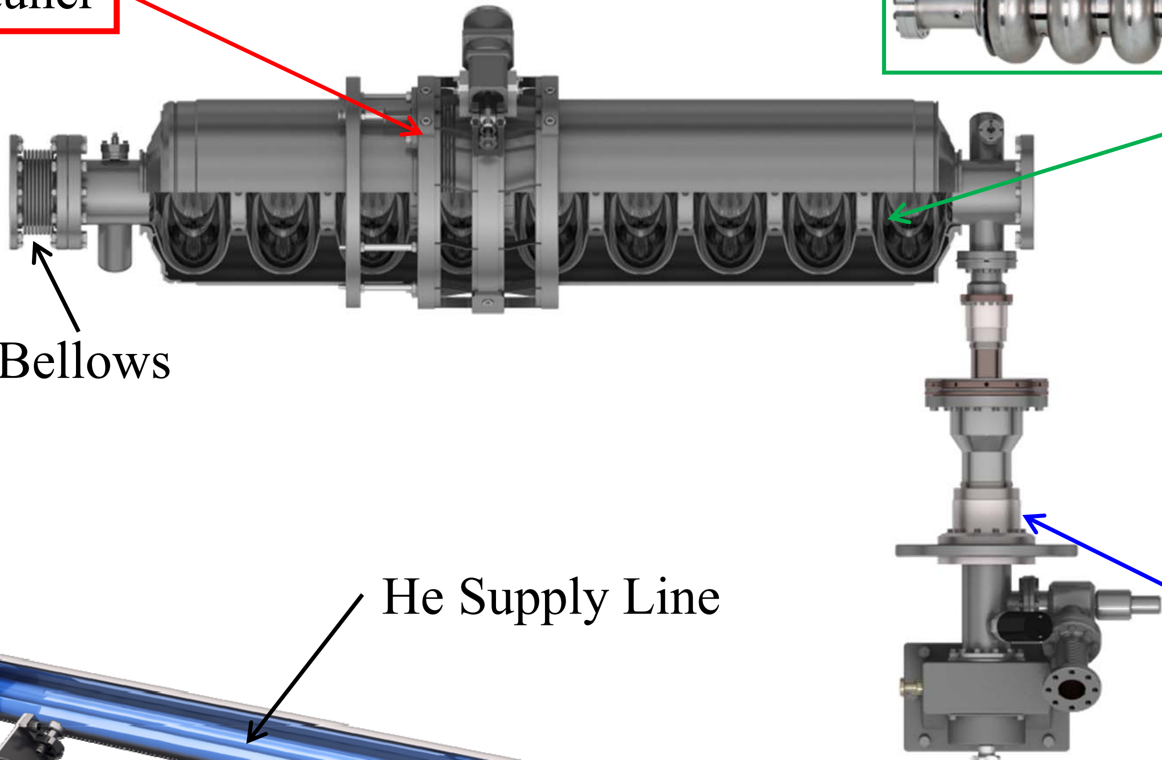


Cavity Package & Performance Specification for the ILC

Cavity Package in TDR

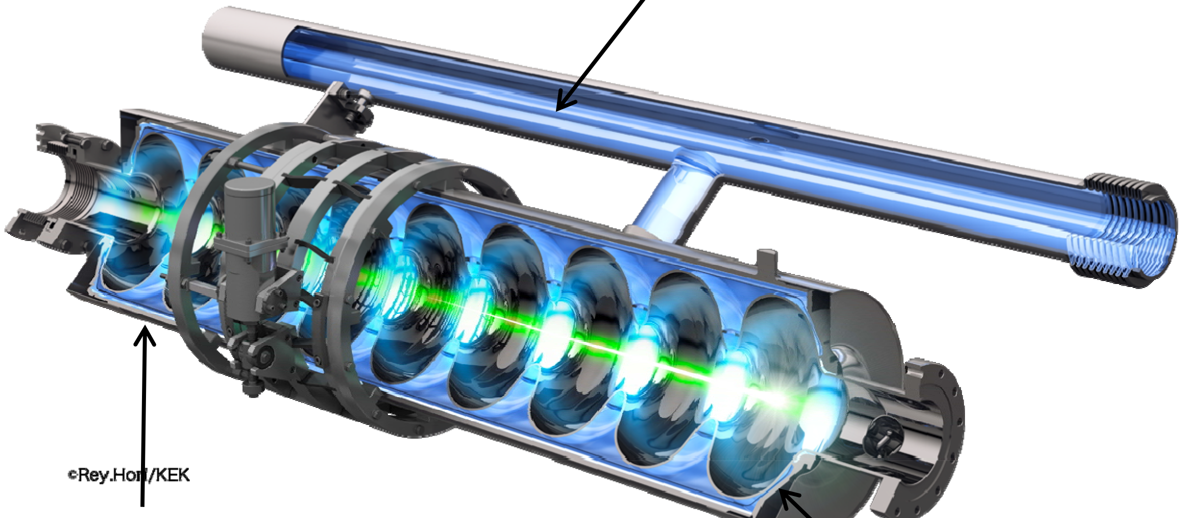
Blade tuner

TESLA cavity



Bellows

He Supply Line



TTF-III coupler

He Jacket (Titanium)

Magnetic Shield

ILC Specification

- Performance test for Cavity only
  - $Q_0 = 0.8 \times 10^{10}$ @35 MV/m (28 – 42 MV/m)
  - Should be passed in twice V.T.s
  - Only EP/BCP as Surface Process

10% ↓

- Cryomodule Operation with Beam
  - $Q_0 = 1.0 \times 10^{10}$ @31.5 MV/m (25 – 38 MV/m)
  - Average Gradient in one Cryomodule

Random gradient spread of ±20% is acceptable!

Worldwide R&D Laboratory

Worldwide Laboratory for SCRF R&D

FLASH@DESY

STF@KEK

ILCTA@FNAL

FLASH(TTF) @DESY

FLASH (TTF) tunnel

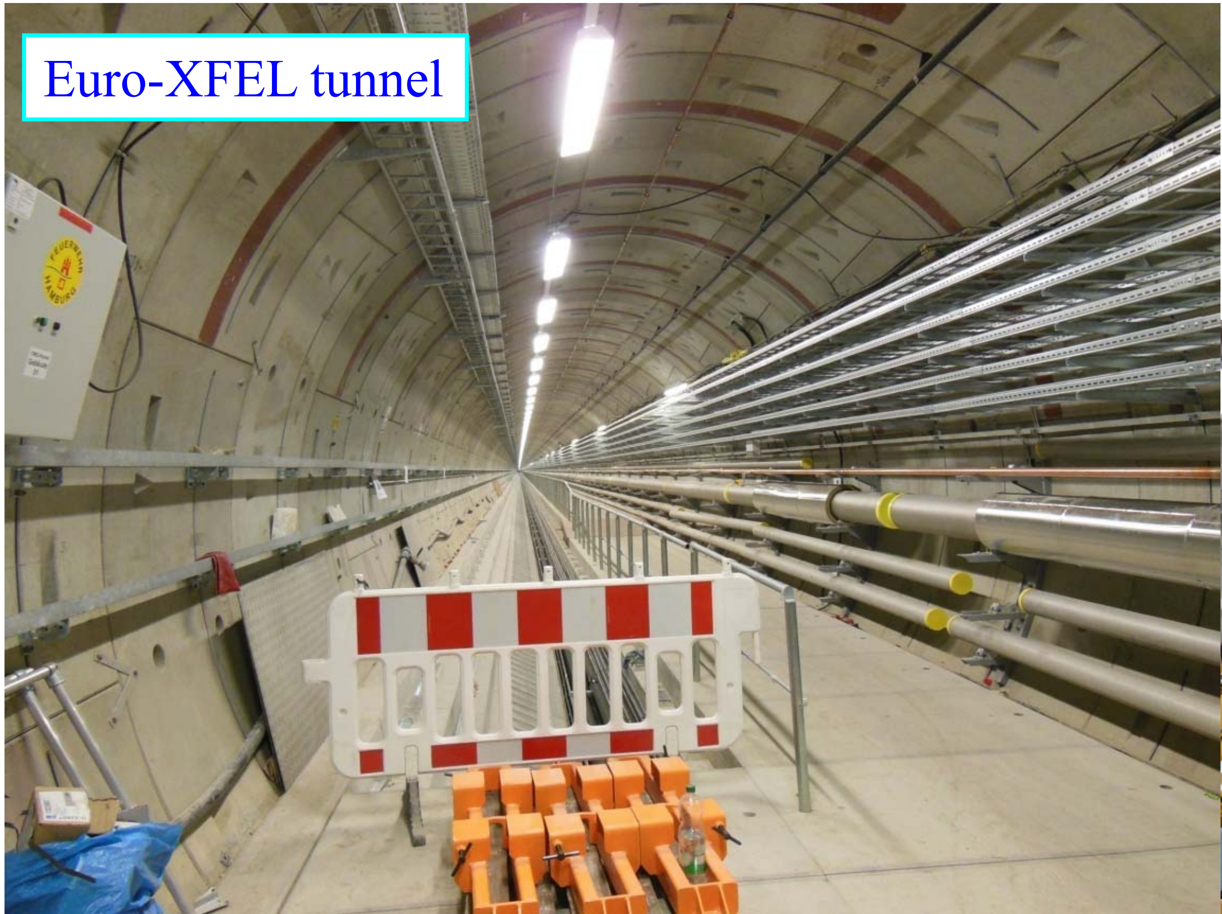
Cleanroom

Assembly hall

Euro-XFEL @DESY

800 Cavities and 100 Cryomodules will be fabricated and tested!

Euro-XFEL tunnel



1/20 scale for ILC ! !

Accelerator Module Test Facility

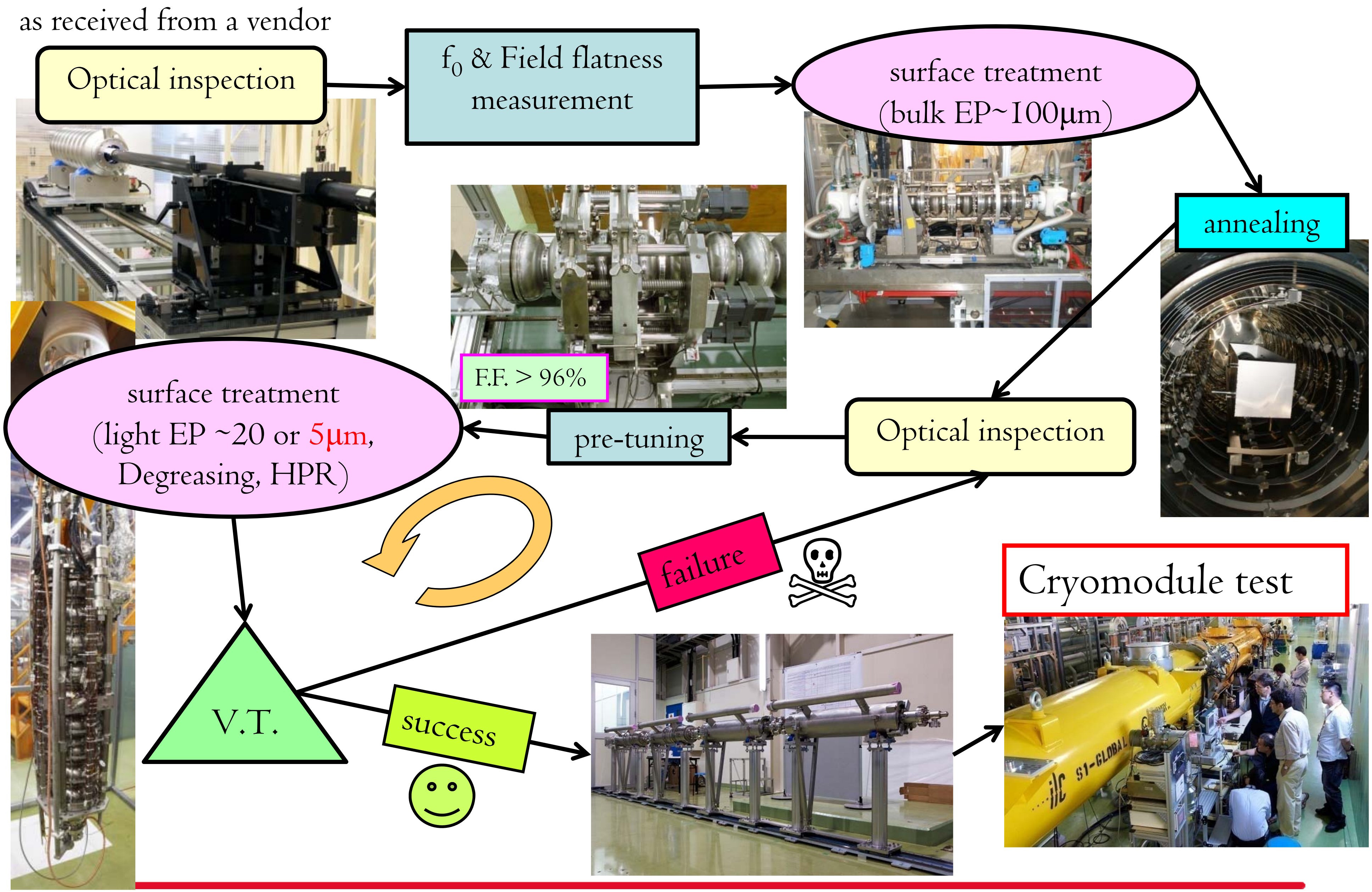
Recent Cavity Performance in KEK

Measured/Fabricating Cavities

- MHI-01~04 Phase-1 (already done)
- MHI-05~09 S1-Global (already done, except for MHI-08)
- MHI-10, 11 S0 plan (already done)
- MHI-12, 13 Quantum Beam (under beam operation)
- MHI-14~22 Phase-2 (for CM-1)
- MHI-23~26 Vertical testing (for CM-2a)
- MHI-27~30 Under fabrication
- MHI-A, B, C New fabrication method study @MHI
- HIT-01, 02 New vendor
- TOS-01, 02 New vendor
- KEK-00, 01 In house / Under fabrication
- AES-001 International Collaboration (commissioning)
- IHEP-01 International Collaboration (Large Grain)
- PKU-04 International Collaboration (Large Grain)

Totally, 40 cavities!

Sequence of cavity process



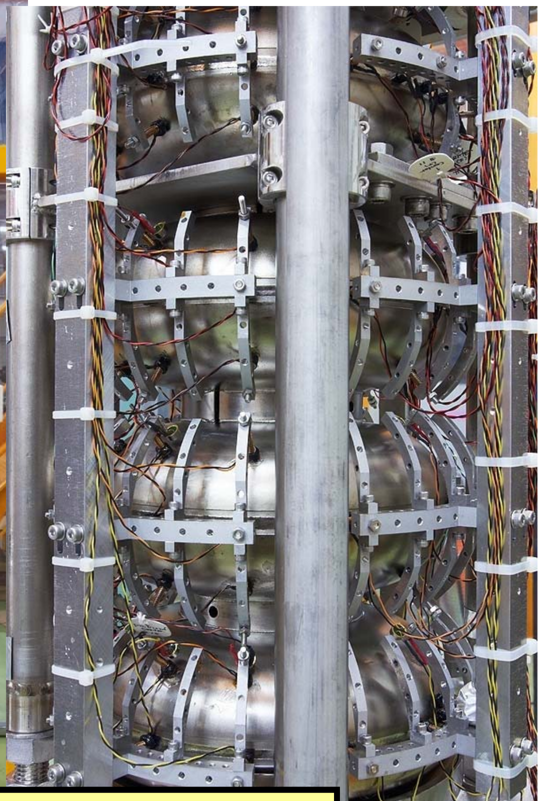
Useful Tools @KEK-STF

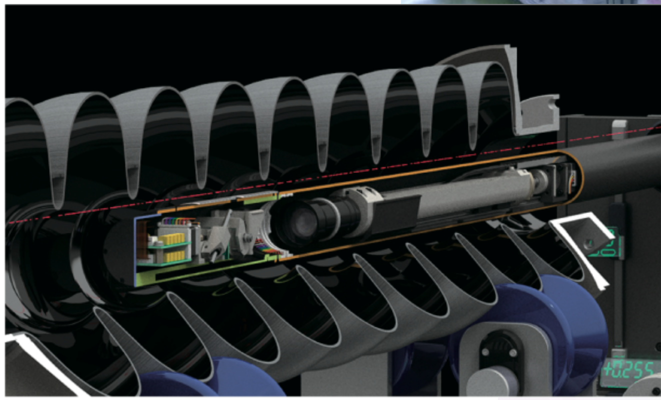
1) T-mapping/X-ray-mapping

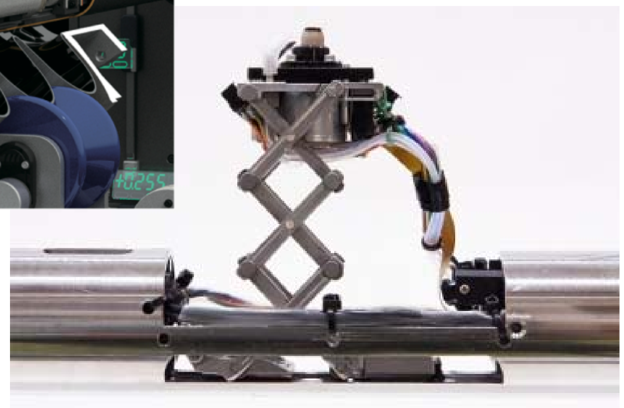
2) Optical inspection (Kyoto Camera)

3) Local Grinding Machine

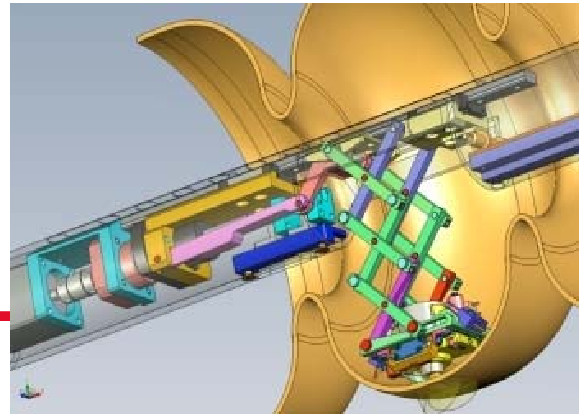
Collaboration with Kyoto Univ.



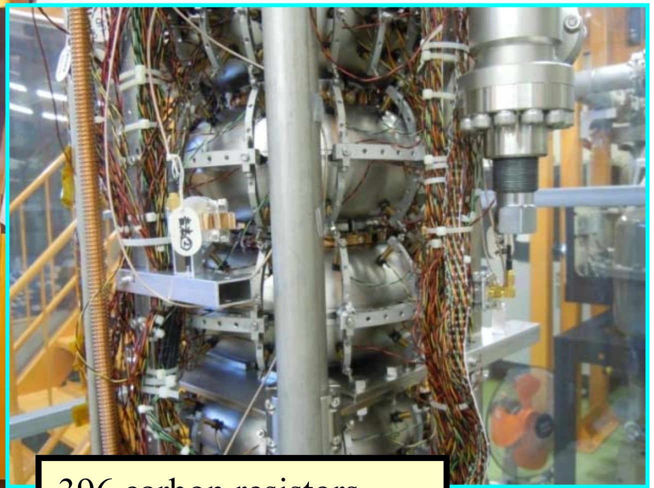




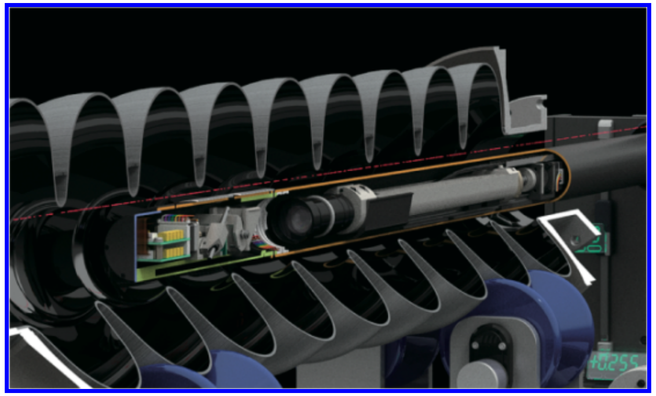
396 carbon resistors
182 PIN photo diodes
Radiation monitor



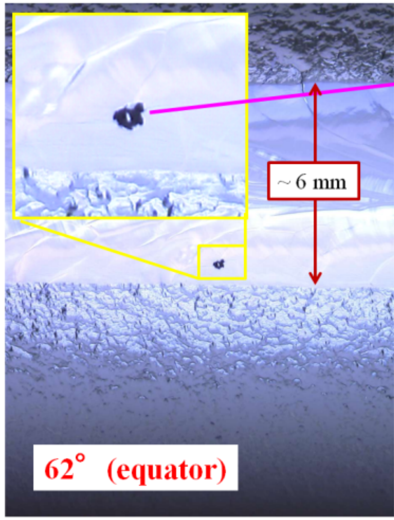
Defect Identification by Inspection tools

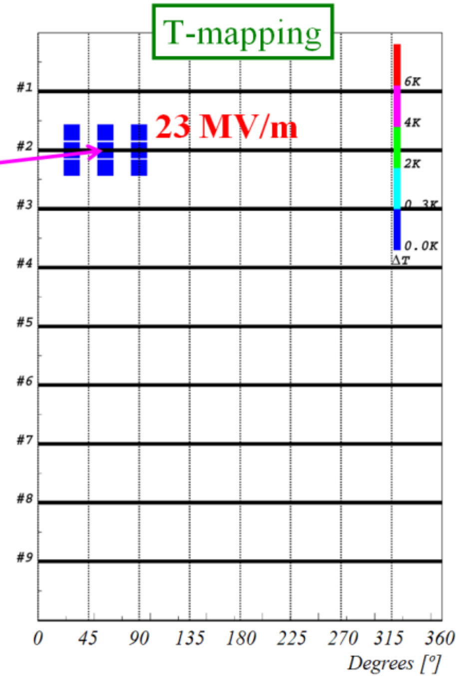


396 carbon resistors
182 PIN photo diodes
Radiation monitor

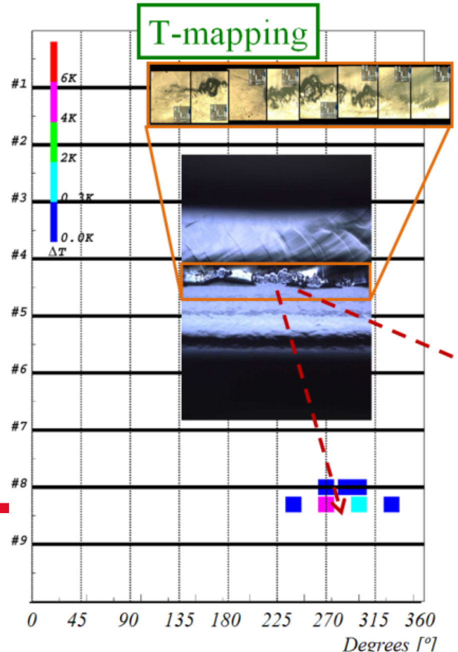


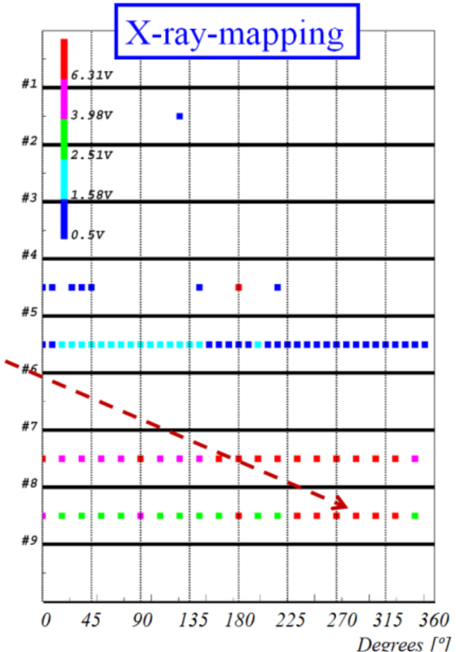
Thermal Quench





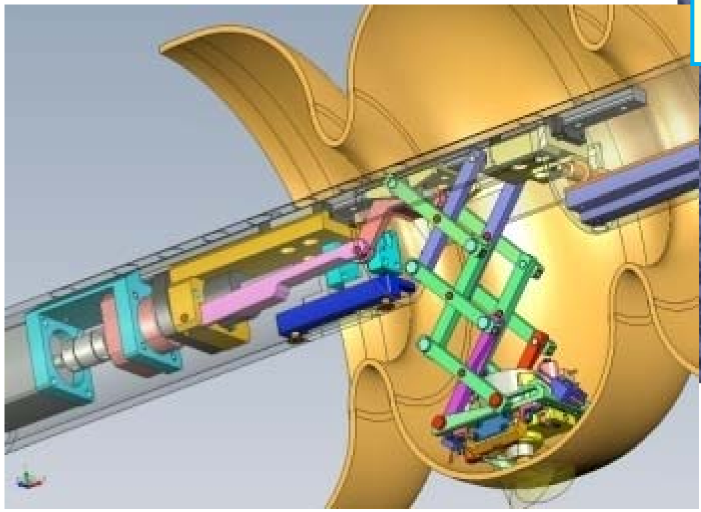
Field emission

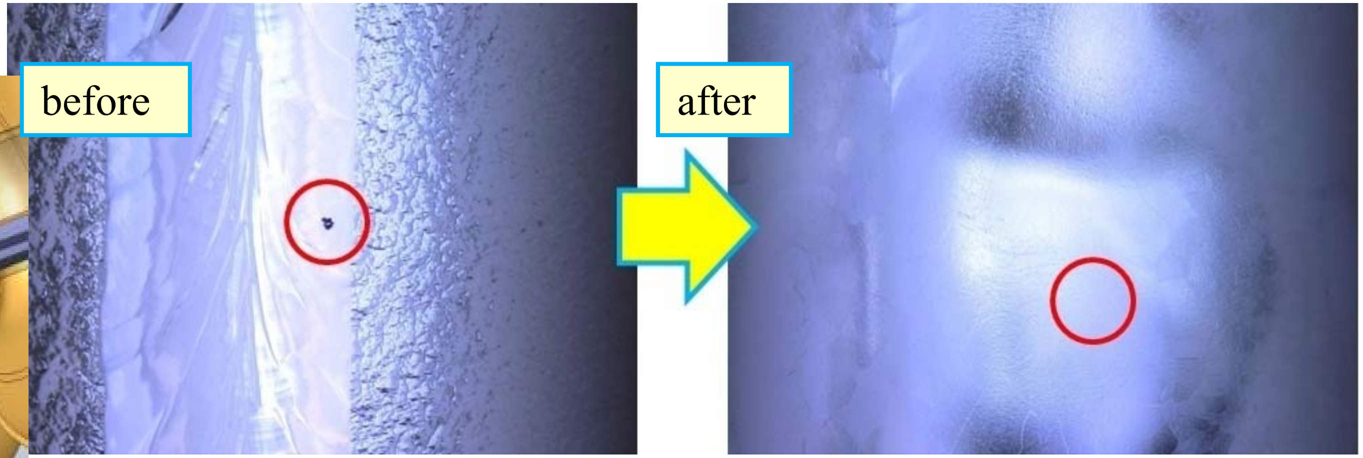




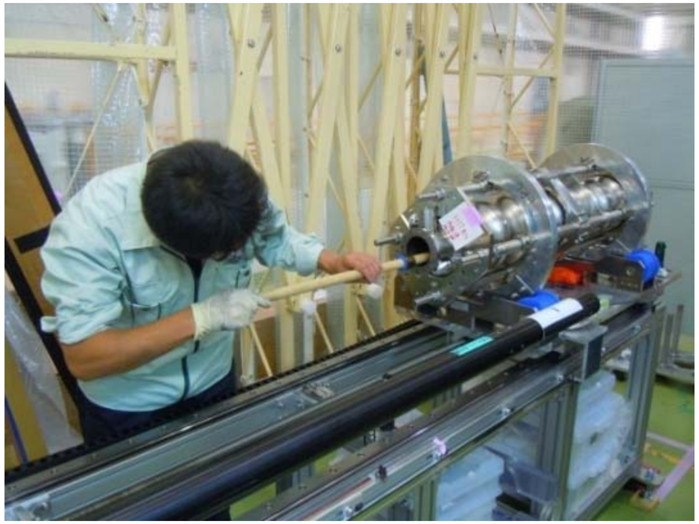
Example of Local Grind at STF

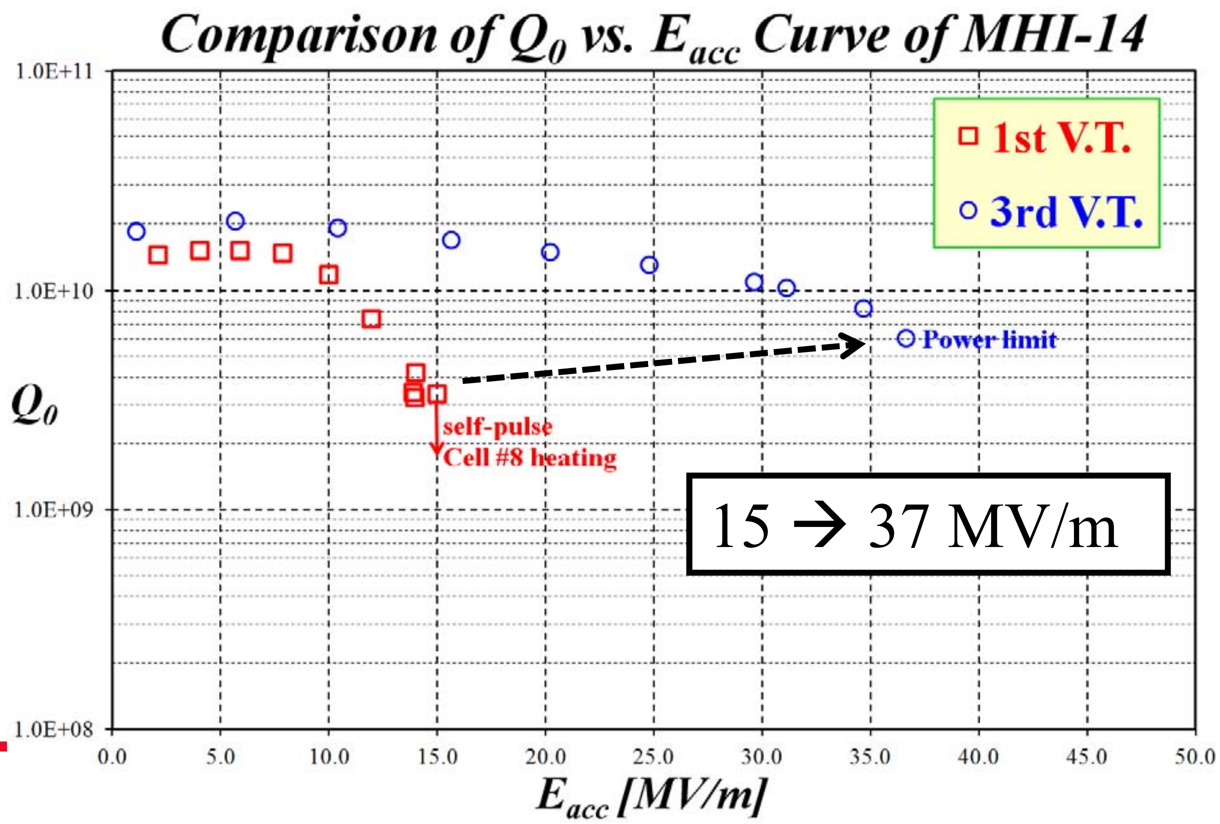
For equator



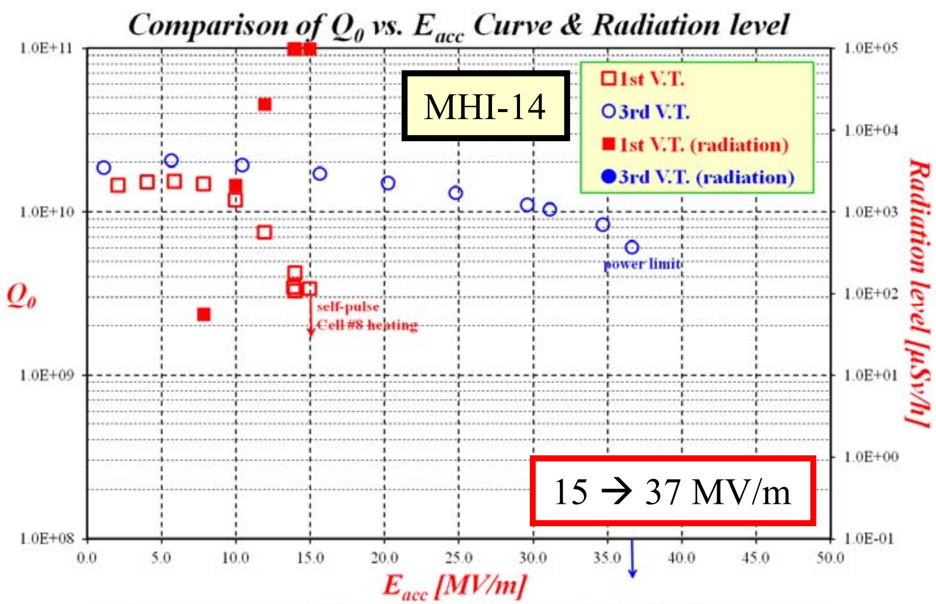


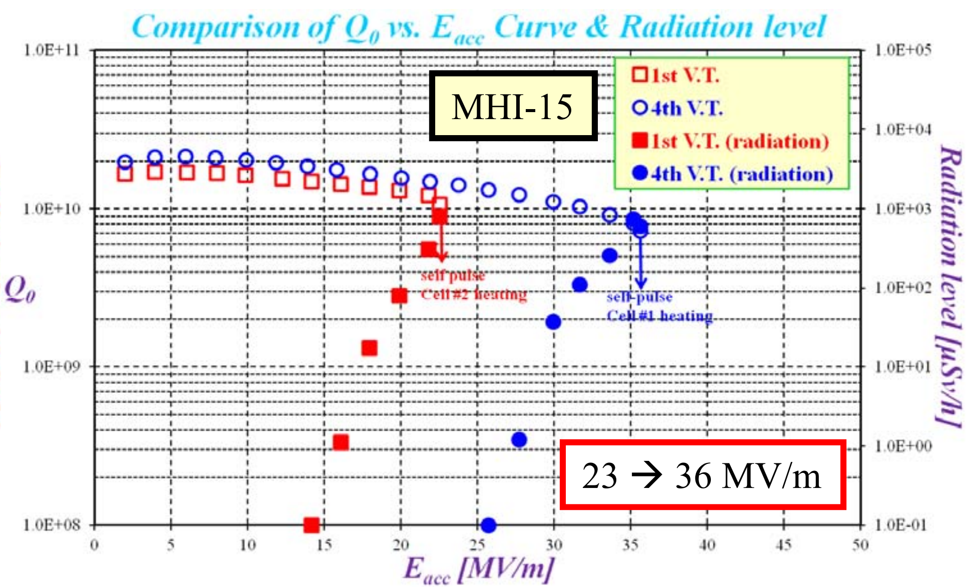
For iris & beampipe

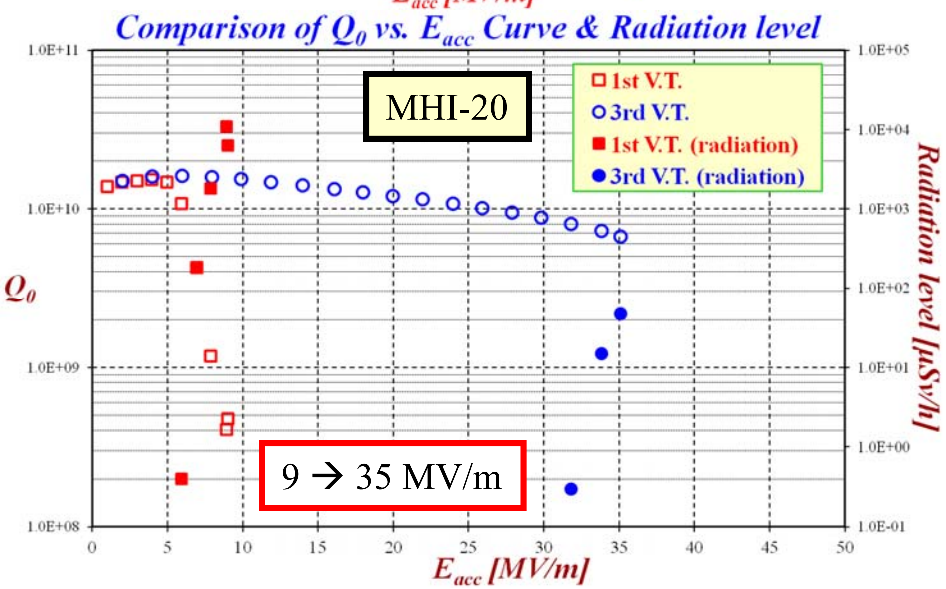


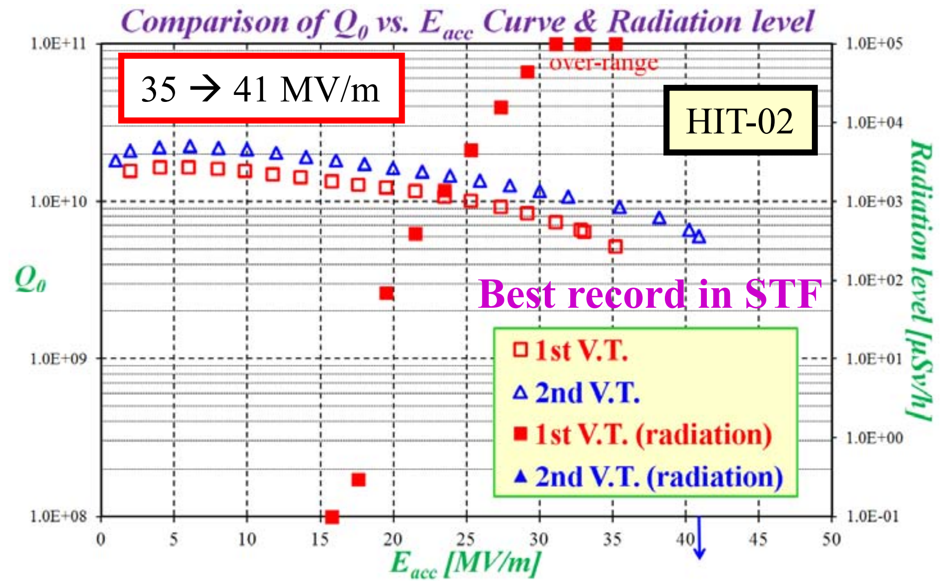


Performance Improvement by Local Grind





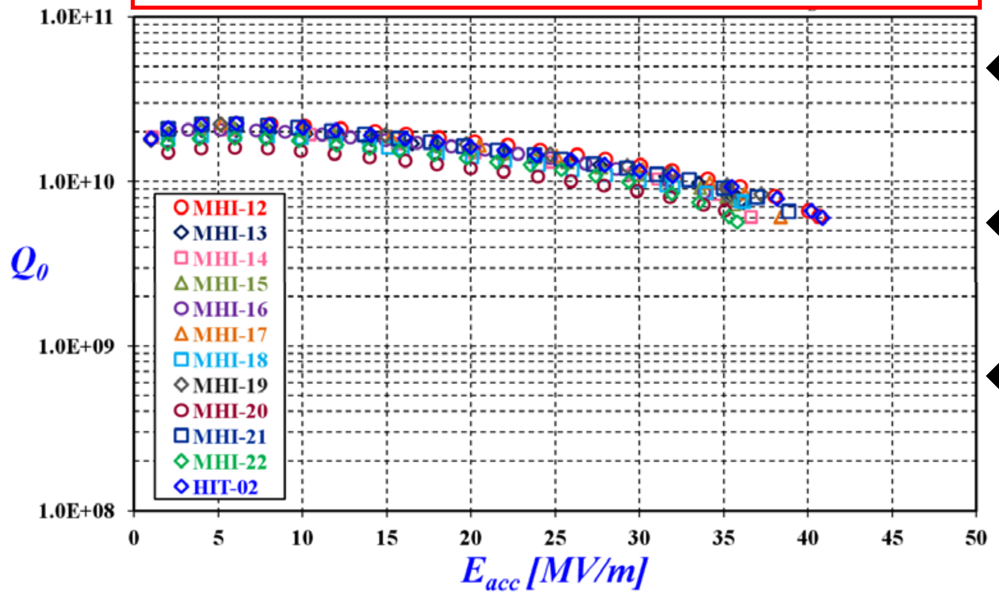




The radiation level also decreased drastically!

Recent Cavity Performance in KEK

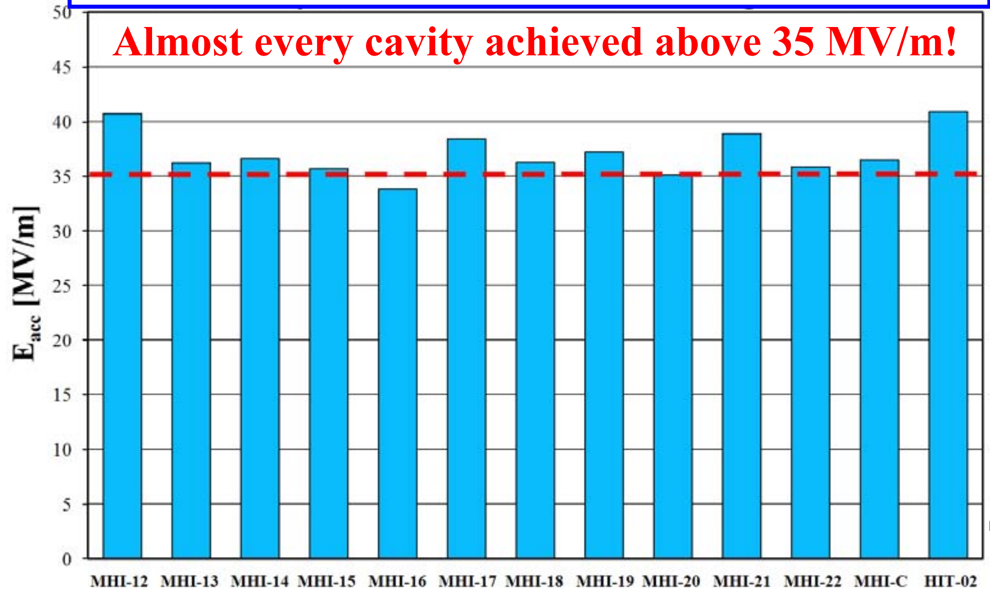
Q_0 – Eacc Curve for Recent Cavities



- All cavities achieved above 35 MV/m.
- Averaging gradient 37.1±2.0 MV/m.
- HIT-02 achieved 41 MV/m (Japan record)

ILC spec.: 35 MV/m ± 20%

Maximum Gradient for Recent Cavities



Almost all cavities were limited by administration limit.
Typically, that is the RF power limitation.

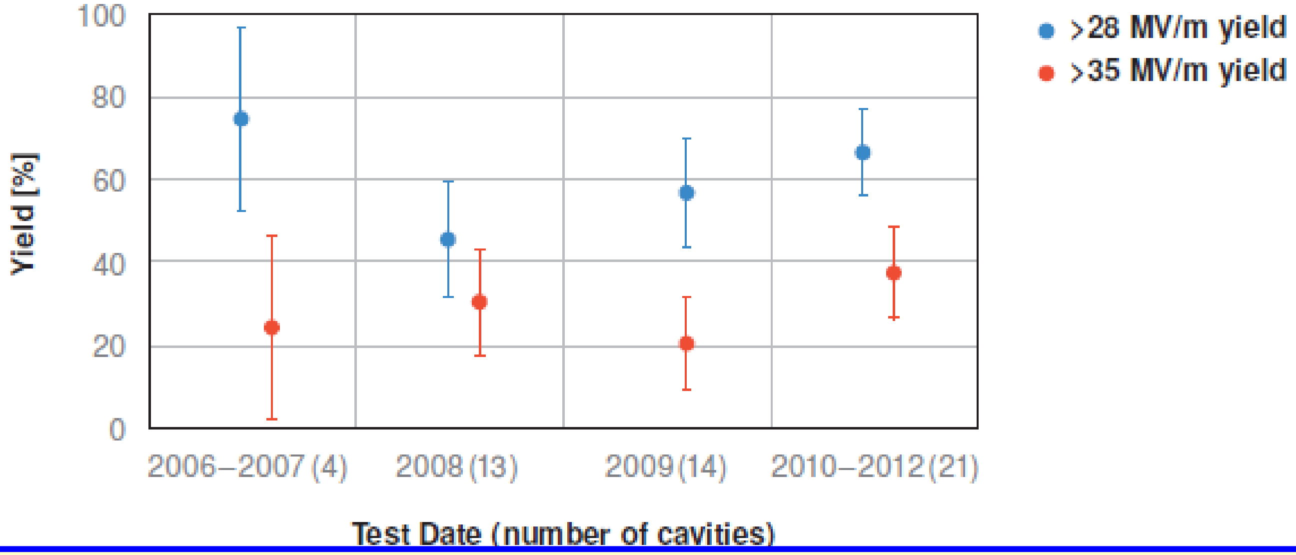
This means the cavity performance becomes higher possibly.

We can achieve around 40 MV/m possibly!

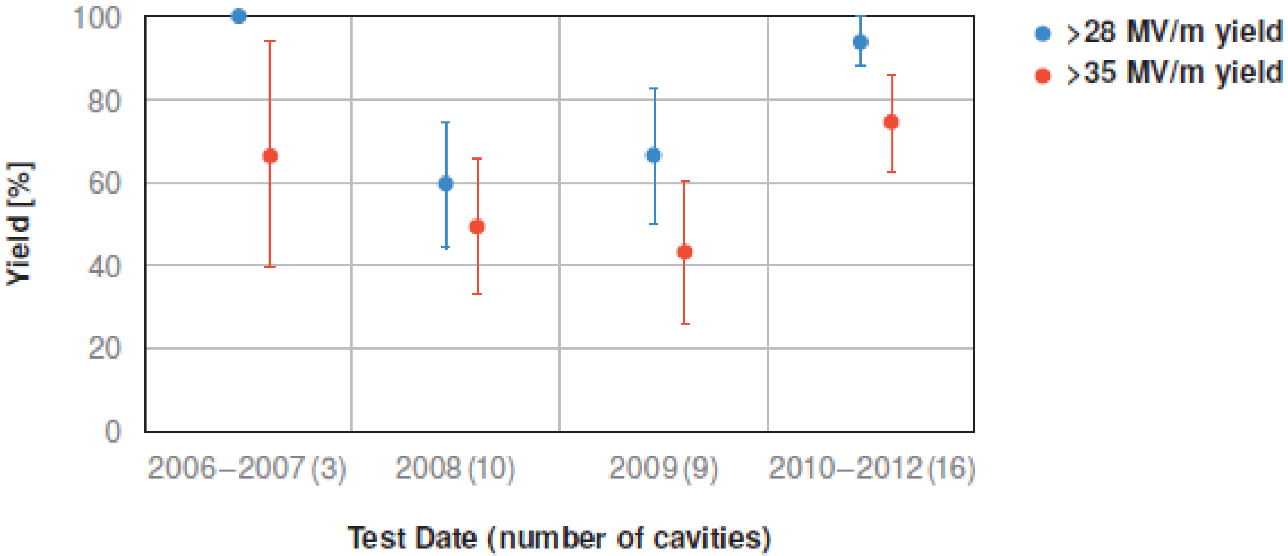
Toward Higher Gradient for 1 TeV Upgrade

Cavity Yield Plot in TDR

Figure 2.19
Cavity yield for two gradient thresholds as a function of years, based on the global ILC cavity database updated as of October 2012 [67, 68]. Numbers in parentheses refer to cavity sample size. The cavities received standard treatment and were provided by established vendors.



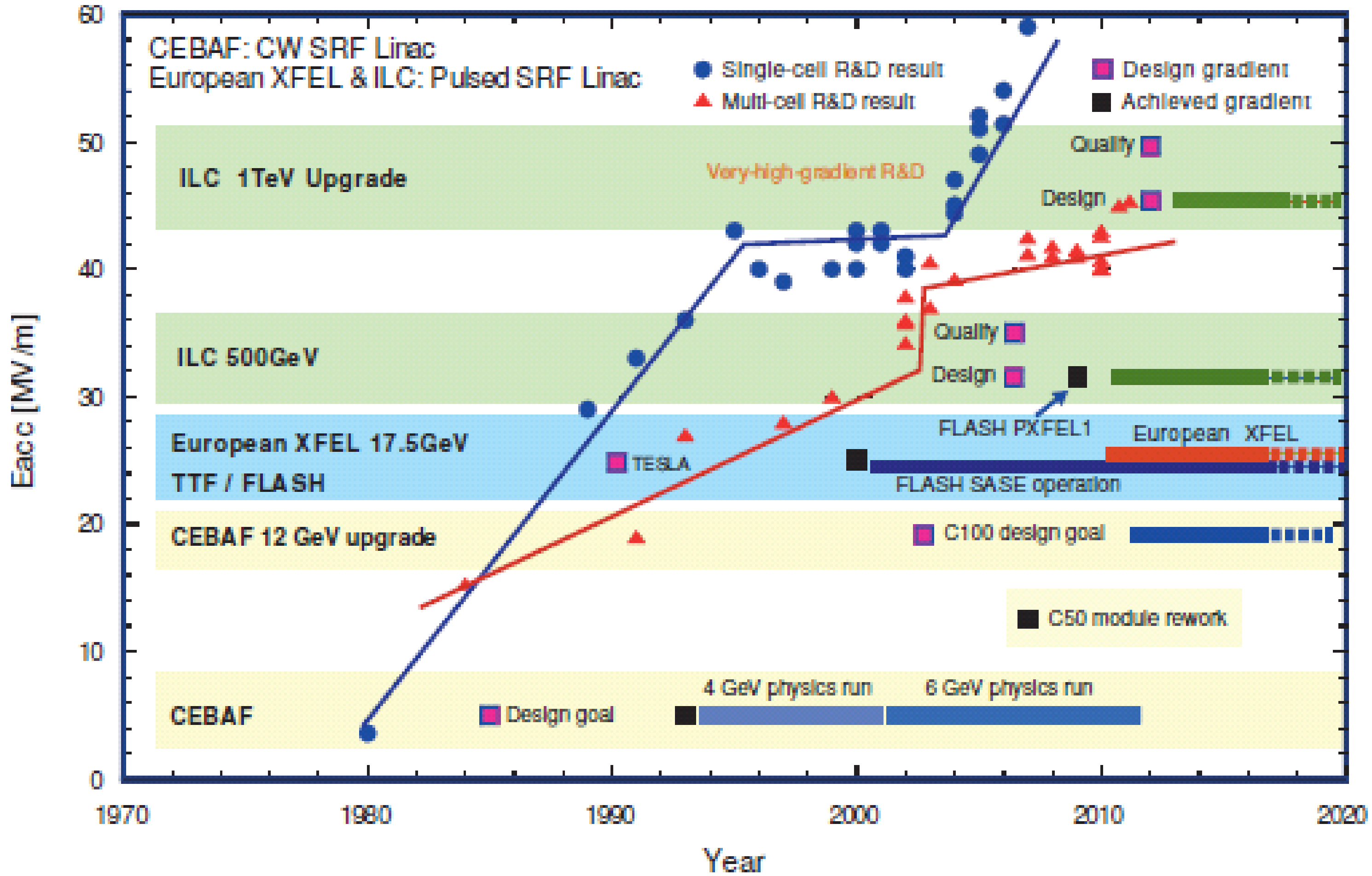
We already achieved 37 MV/m in averaging gradient!



Comparison of 1- and 9-cell performance

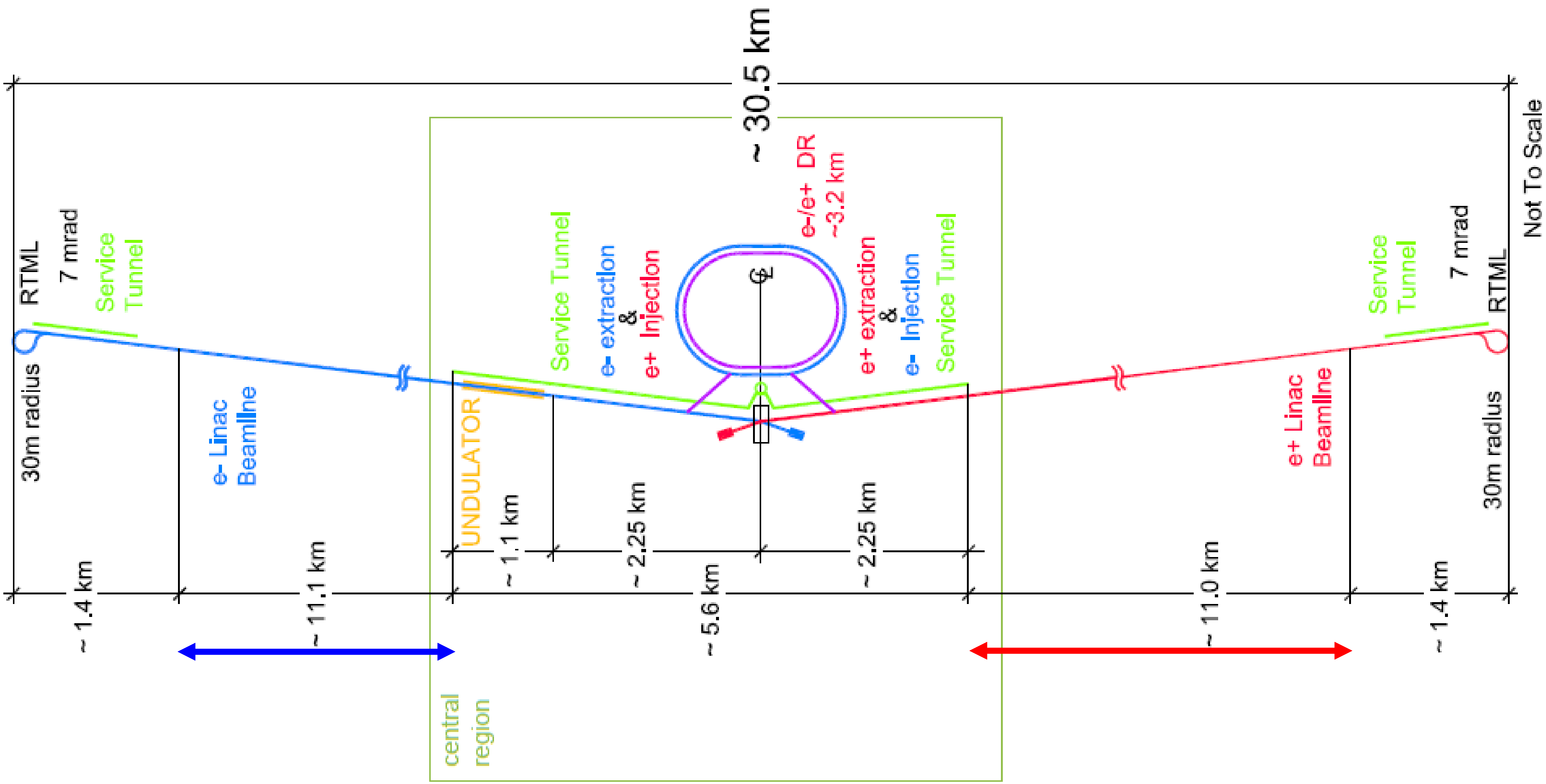
There is large gap between 1-cell and 9-cell cavity performance!

Figure 2.20
L-band SCRF niobium-cavity-gradient envelope and gradient R&D impact on SCRF linacs.



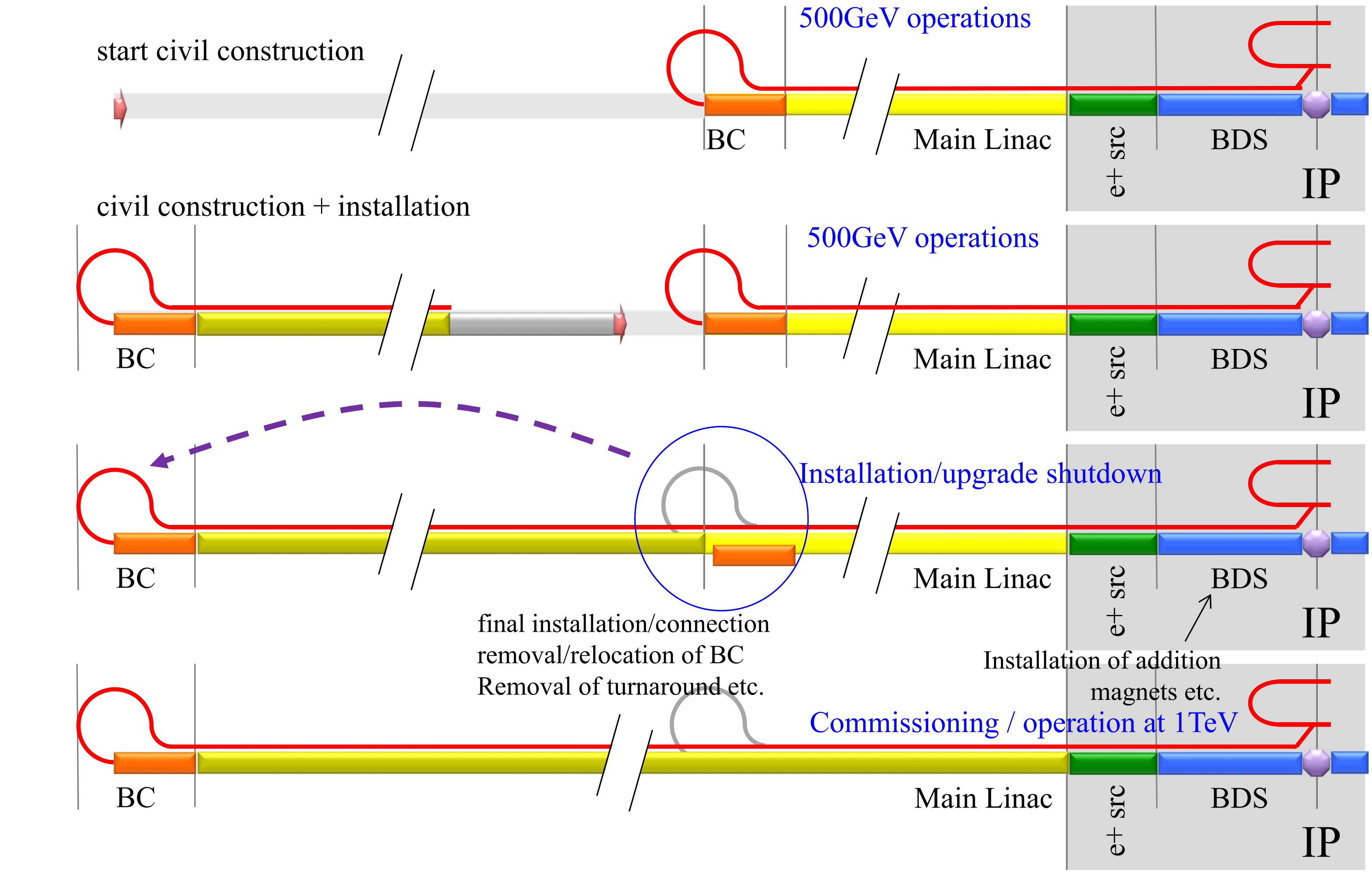
9-cell performance is almost saturated?!

500 GeV ILC Accelerator Layout



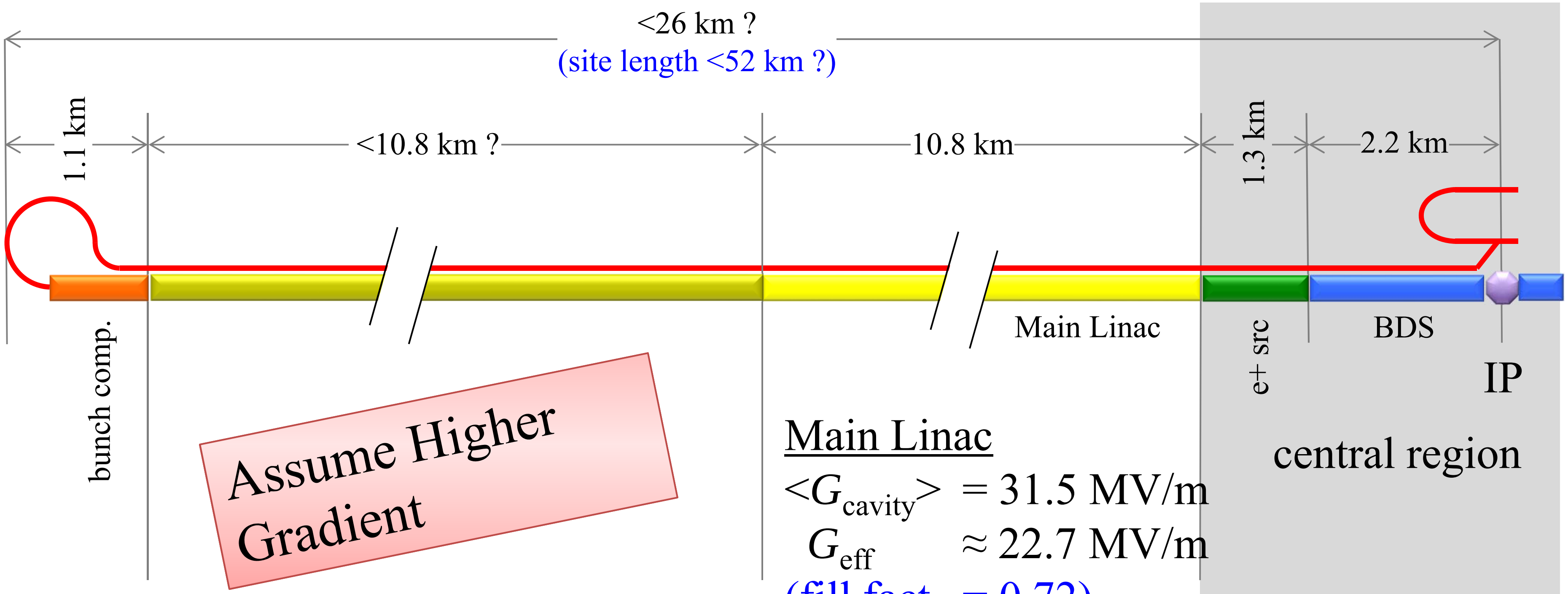
Main Linac section is 11 km for each beam in Phase-1.

Staging Scenario(s)



N.Walker @Granada

TeV Upgrade : From 500 to 1000 GeV



Main Linac

$\langle G_{cavity} \rangle = 31.5$ MV/m

$G_{eff} \approx 22.7$ MV/m

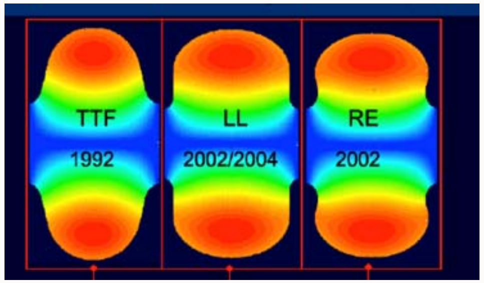
(fill fact. = 0.72)

Snowmass 2005 baseline recommendation for TeV upgrade:

$G_{cavity} = 36$ MV/m $\Rightarrow$ 9.6 km

(VT ≥ 40 MV/m)

New Goal!



Based on use of low-loss or re-entrant cavity shapes

N.Walker @Granada

What approach can we take?

According to TDR (Volume 3, Part 1, Page 28)...

① Cavity Shape
- Low Loss, Re-Entrant, Low Surface Field

② Material
- Large Grain, Seam-less

③ Surface Treatment
- Recently, new idea trying

④ Packing Factor of Cryomodule
- Exchanging Q-mag to Cavity

① Cavity Shape

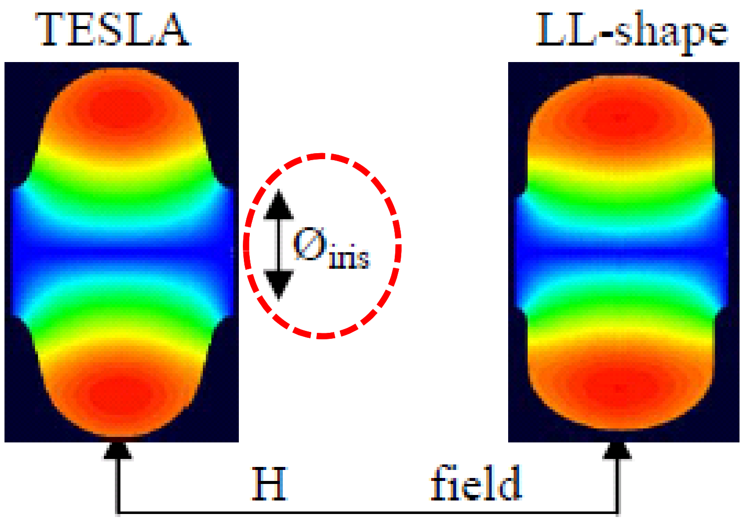
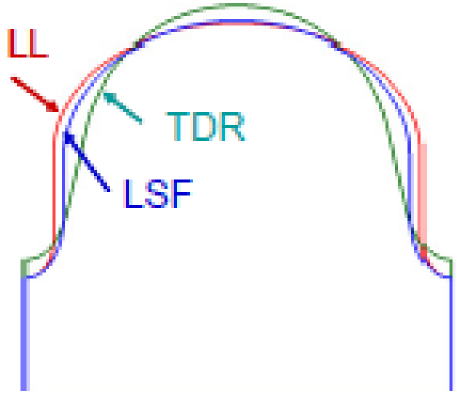


Figure 1: H contour in two shapes of inner cell.



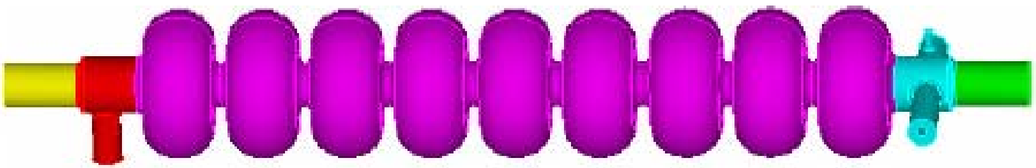


Figure 6: The 9-cell LSF cavity with coupler end-groups.

Table 2.11
Comparison of RF parameters of alternate-shape cavities with the baseline

		TESLA	Low-loss/ ICHIRO	Re-entrant	Low-surface field
frequency	GHz	1.3	1.3	1.3	1.3
Aperture	mm	70	60	60	60
E_{peak}/E_{acc}	–	1.98	2.36	2.28	1.98
H_{peak}/E_{acc}	mT/(MV/m)	4.15	3.61	3.54	3.71
Cell-cell coupling	%	1.90	1.52	1.57	1.27
G*R/Q	Ω^2	30840	37970	41208	36995

① Cavity Shape

LINEAR COLLIDER COLLABORATION

Table 2.11
Comparison of RF parameters of alternate-shape cavities with the baseline

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G*R/Q	Ω^2	30840	37970	41208	36995

The most different point is “aperture”.

→ Beam Instability
→ HOM Damping
→ Need to re-design End Group (?)

① Cavity Shape

Table 2.11
Comparison of RF parameters of alternate-shape cavities with the baseline

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Cell-cell coupling	%	1.90	1.52	1.57	1.27
G*R/Q	Ω^2	30840	37970	41208	36995

Higher risk in field emission for higher E_{peak} / E_{acc}

Fowler-Nordheim law:

$$J(r,t) = 1.54\times10^{\left(-6+\frac{4.52}{\sqrt{\varphi}}\right)}\frac{(\beta E)^2}{\varphi}e^{\left(\frac{-6.53\times10^9\varphi^{1.5}}{\beta E}\right)}$$

$$v_0 = \sqrt{\frac{2|e|\varphi}{m}}$$

φ - Work function of the metal (i.e., 4.4 for Cu)

β - Field enhancement factor (300 typical)

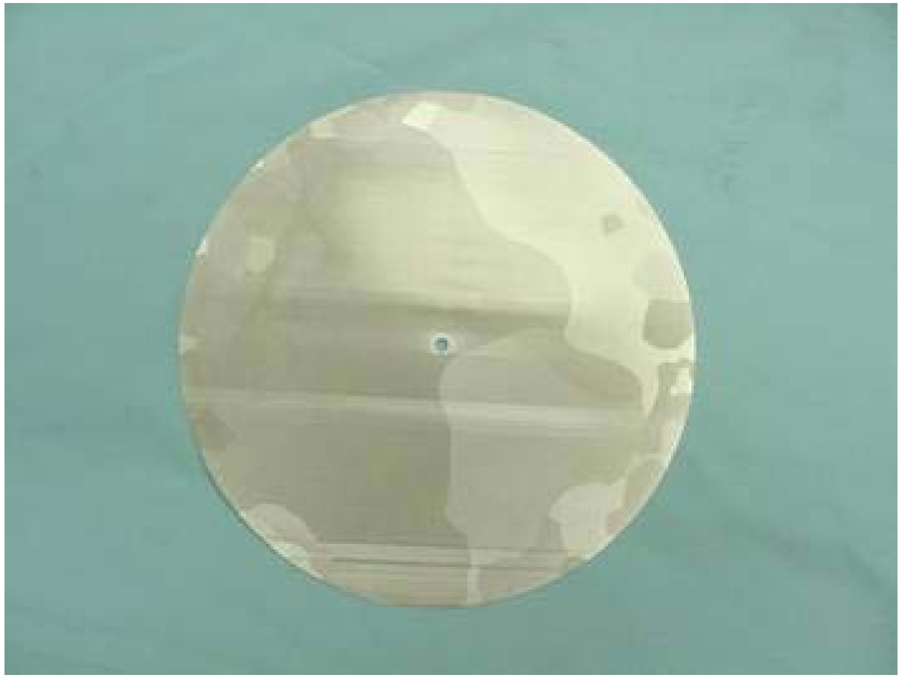
E – Magnitude of external electric field

m – Mass of an individual particle

② Material

Fine Grain

Large Grain



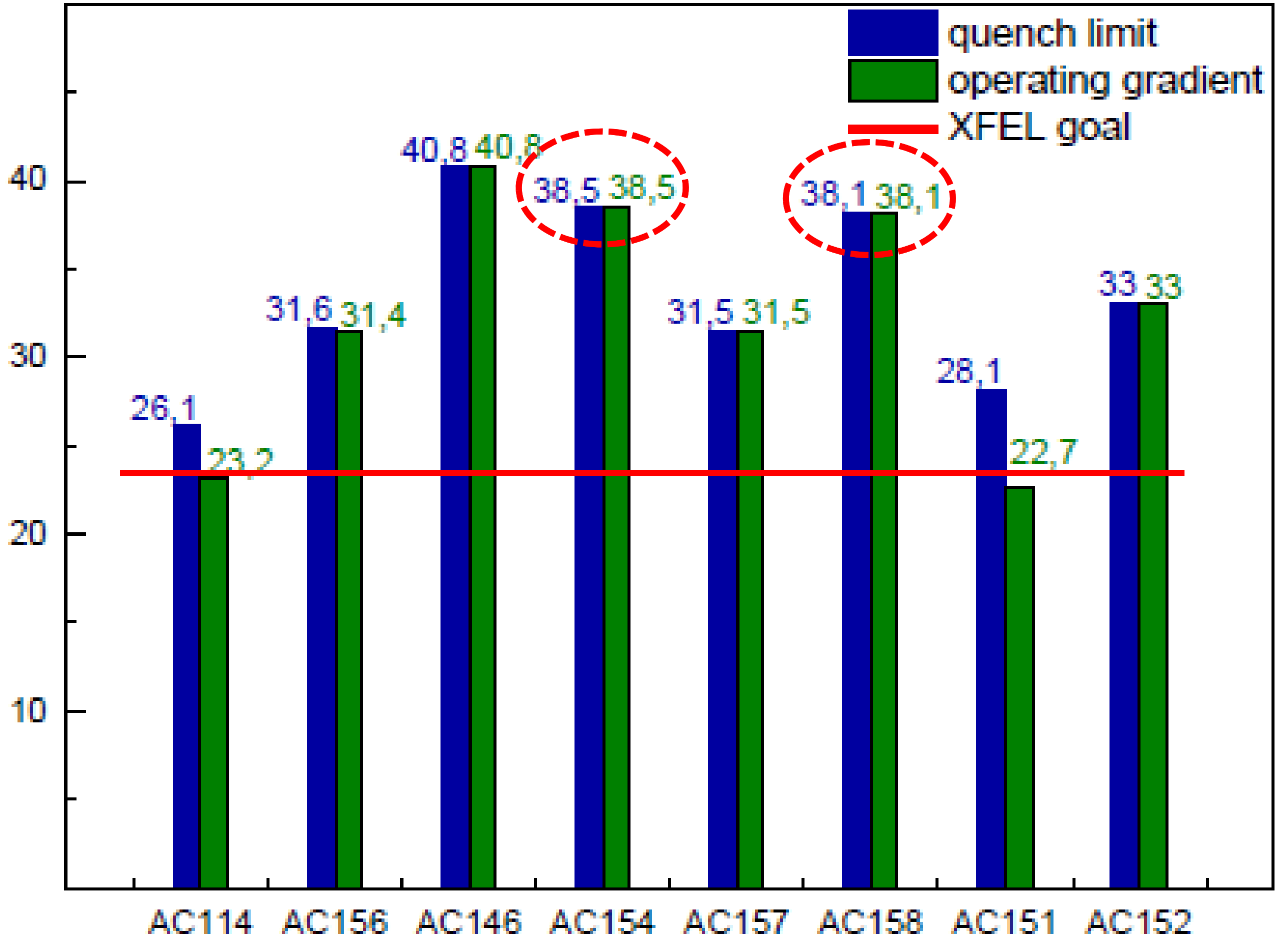
The remarkable merit is higher Q_0 at lower gradient.

↓

lower residual resistance

② Material

Test result of XM-3 Cryomodule for Euro XFEL at DESY



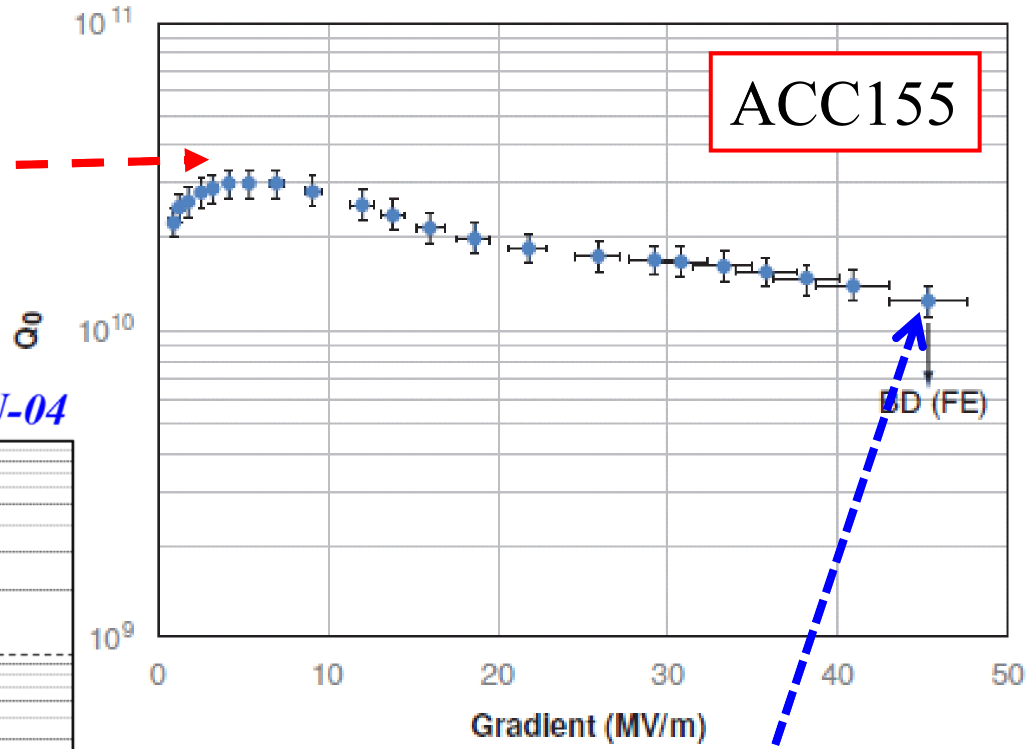
L.G. L.G. F.G. L.G. L.G. L.G. L.G. L.G.

Cryogenic loss is 60% lower than only F.G. cavities!

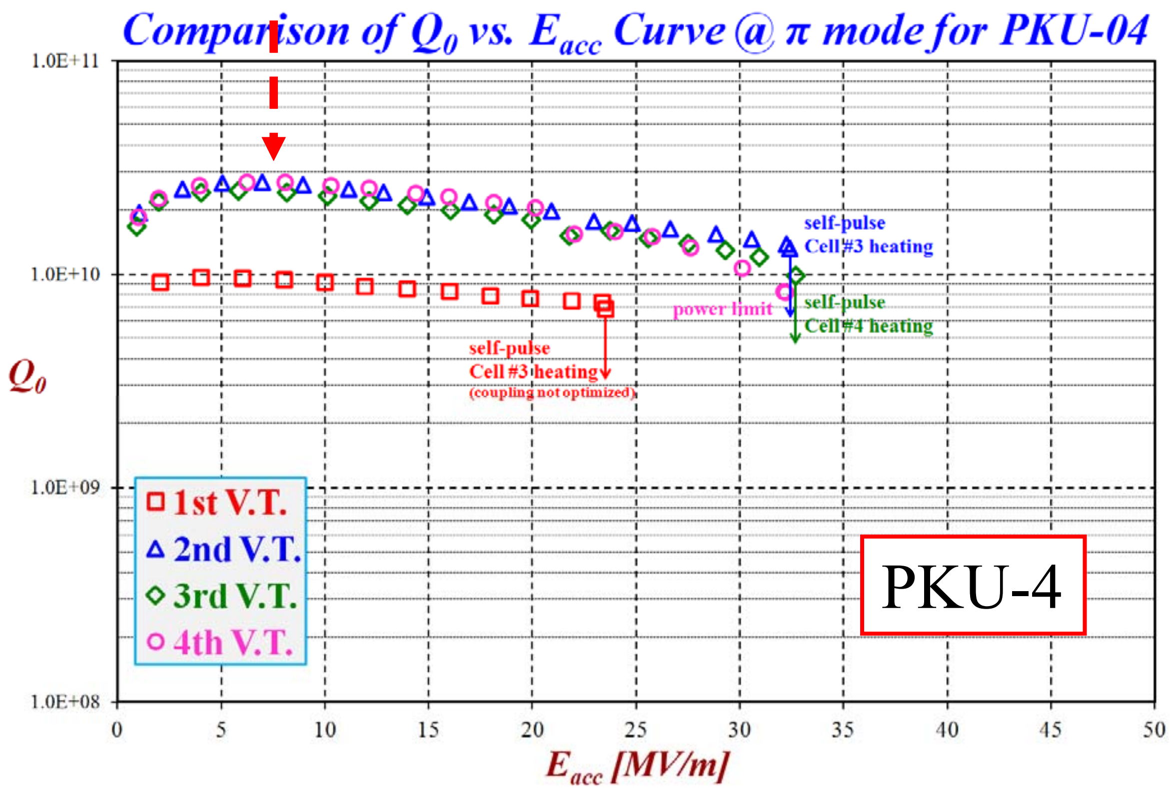
② Material

Vertical test results for ACC155 and PKU-4 made by L.G.

Figure 2.22
Demonstration of 45 MV/m by a 9-cell large-grain niobium TESLA shape cavity (AC155) at DESY.



Higher Q_0



DESY's cavity still has higher Q_0 than 10^{10} at maximum gradient!

Big margin!

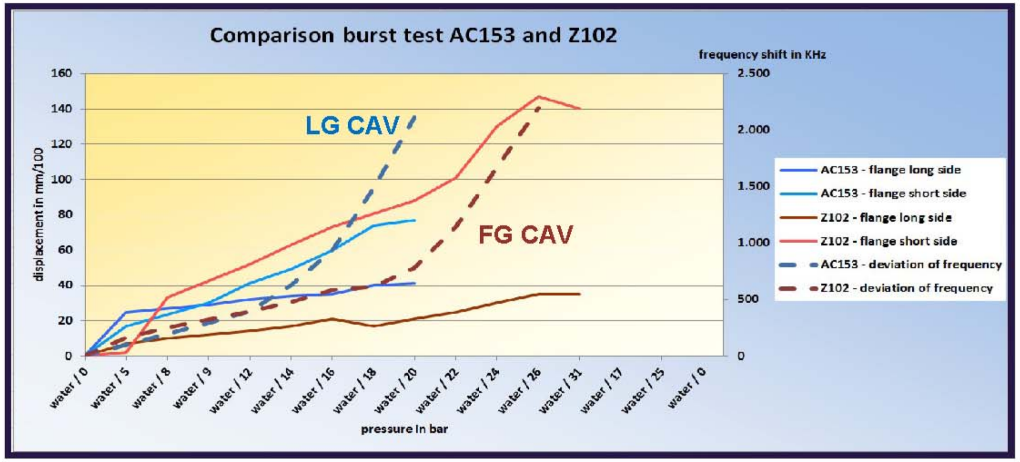
② Material

European XFEL

Cavity burst test. LG Cavity and Fine Grain Cavity. Poster MOP048, A. Schmidt et al

LG cavity after burst test. **How painful for us was to look on this.**

Burst happened at the connection of stiffening ring to half cell



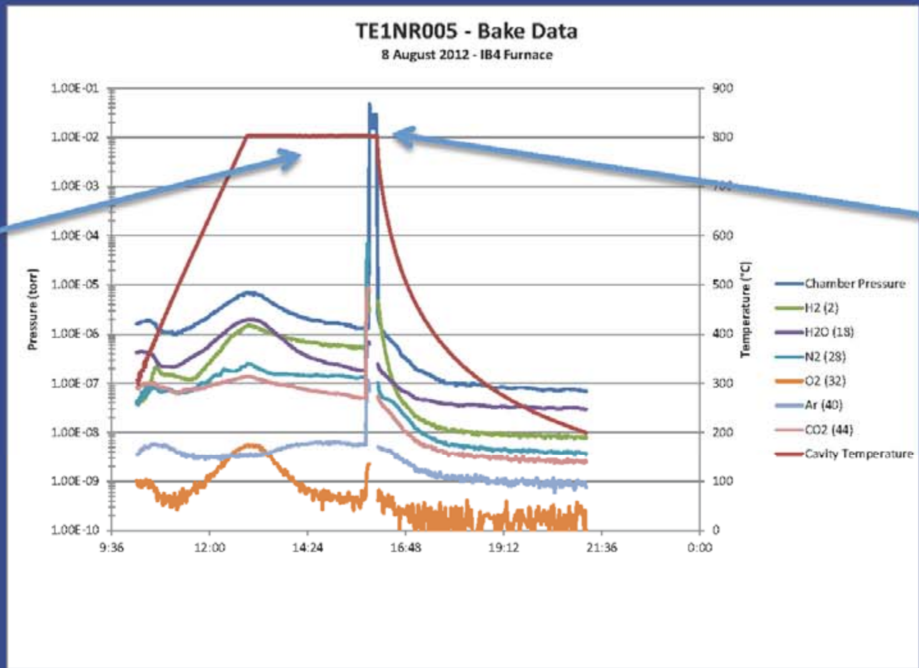
The burst test on a Fine Grain and Large Grain cavity could approve the sufficient stability of both types for European XFEL Linac

W. Singer

③ Surface Treatment

High T bake in nitrogen gas

Standard 800C degassing cycle



Gas injection, ~10 min

- Several cavities treated with nitrogen at different T: 600C, 800C and 1000C for different duration
- Q all extremely poor after treatment ~ 10^7-10^9
- Then, we removed a certain amount of material via electropolishing

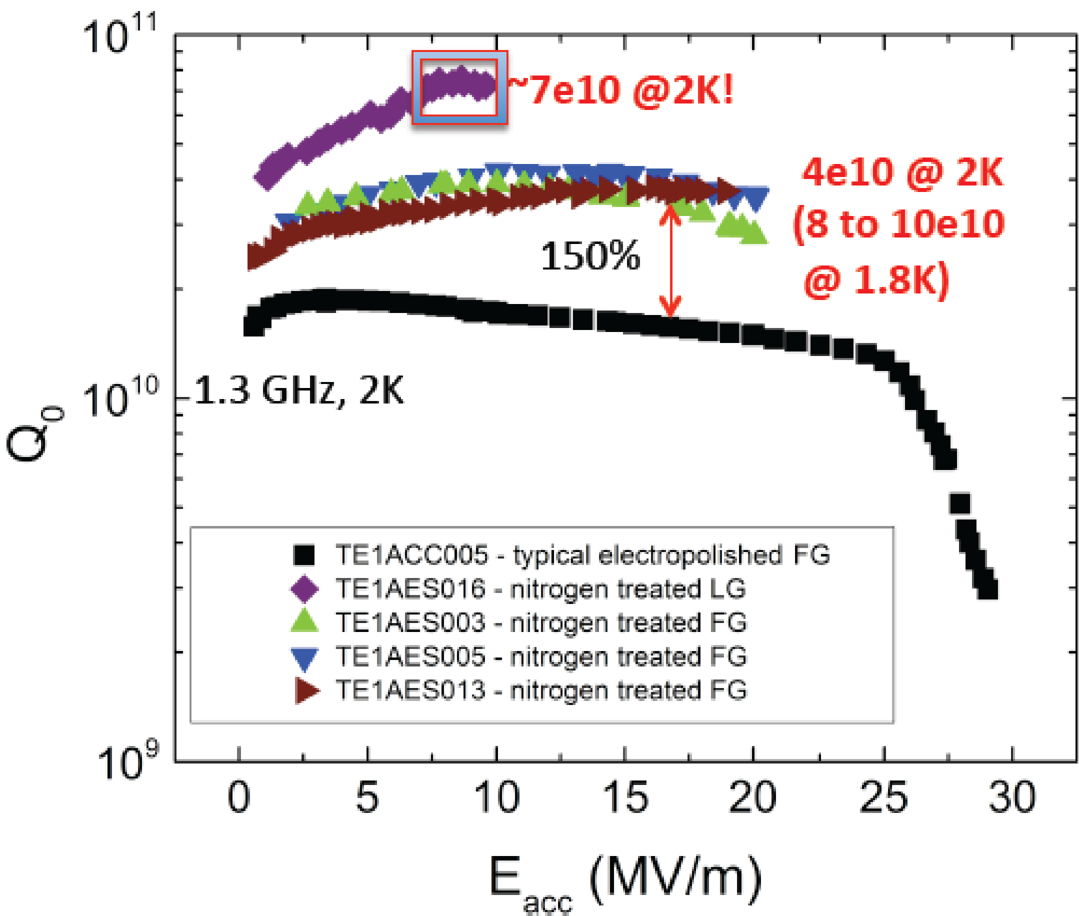
U.S. DEPARTMENT OF ENERGY

8

Fermilab

③ Surface Treatment

Comparing nitrogen treated cavities to standard EP



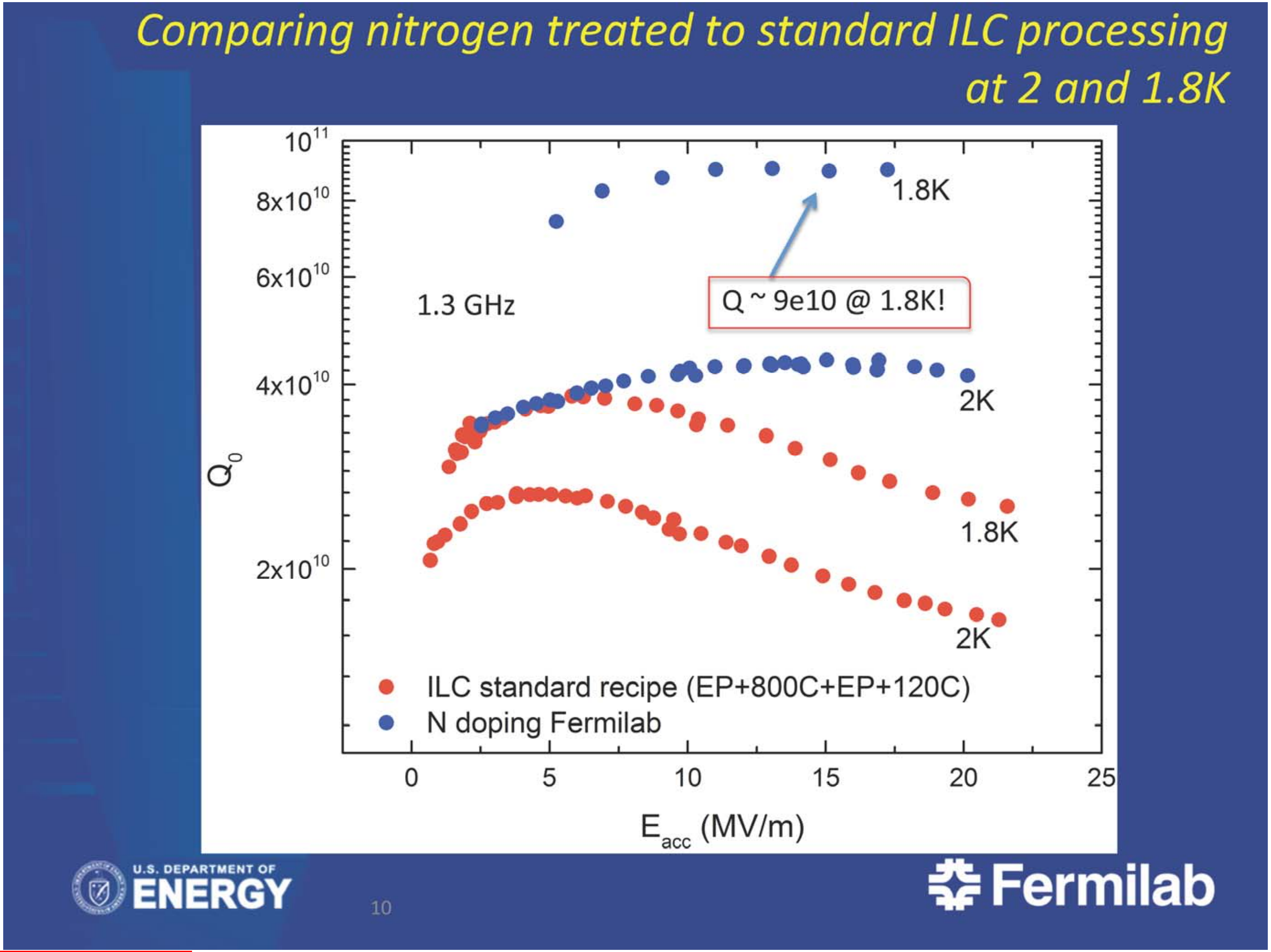
A.Grassellino et al, 2013 *Supercond. Sci. Technol.* 26 102001

Quench field systematically at 20.5 MV/m (~ 86 mT magnetic peak field) for all nitrogen treated cavities (except the LG which was limited to low quench even before treatment). This has been verified in a different geometry (650 MHz) where the quench appeared at 23MV/m, corresponding again to exactly 86 mT Bpk.

U.S. DEPARTMENT OF ENERGY

Fermilab

③ Surface Treatment

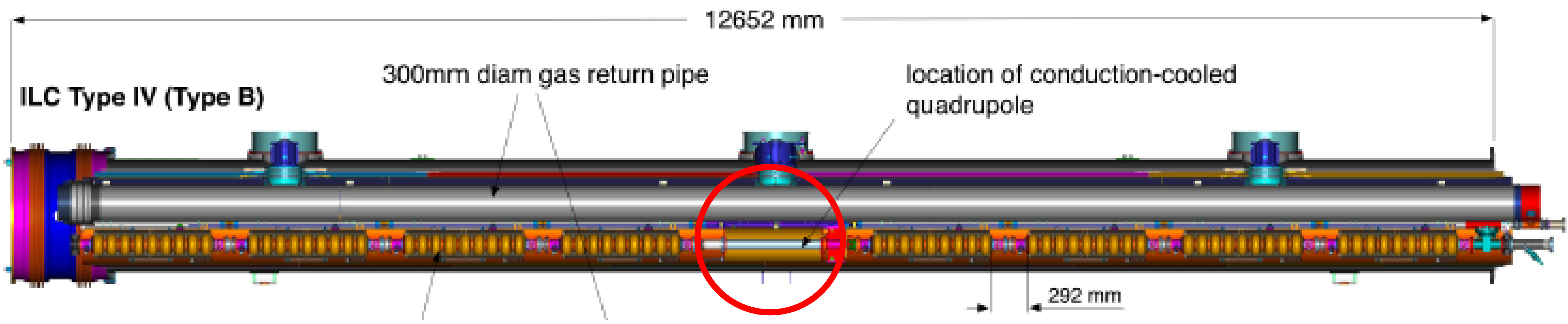


A. Grassellino

④ Packing Factor of CM

Type A CM: 9 Cavities

Type B CM: 8 Cavities



How (at least) many Q-magnets are necessary for Main Linac?

Is it possible to exchange from Q-magnet to Cavity?

In my opinion,
the development of the Large Grain Cavity
is the most probable for the higher gradient option.

Summary & Future Plan

Summary & Future Plan

- ✓ Cavity performance is already around **37 MV/m**!
- ✓ New shape study is not done enough.
- ✓ Many large grain cavities are fabricated in DESY.
  - ✓ In KEK, single cell cavity study is just started.
- ✓ New surface treatment method is starting.
- ✓ Packing factor of CM should be discussed.


Thank you for your attention