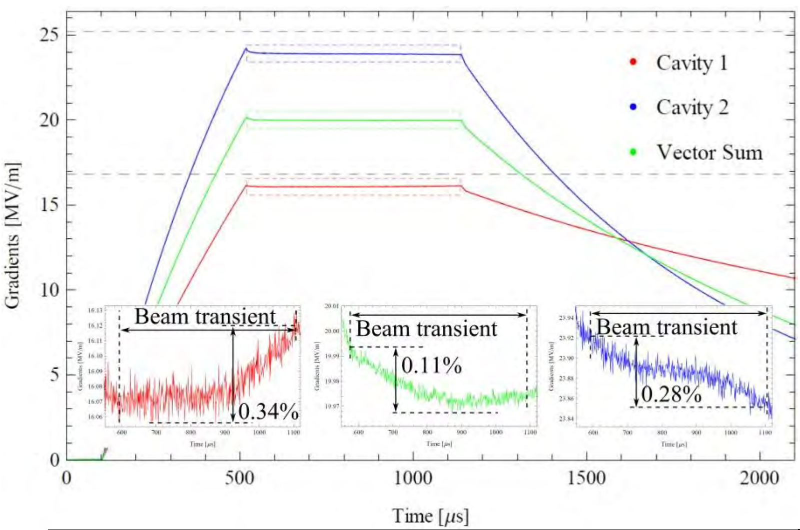
P_kQ_L Operation Stabilities

RF Parameter

V_{Cav1} = 16 MV/m
V_{Cav2} = 24 MV/m
Q_{L1} = 9e6
Q_{L2} = 3e6
Filling time = 410 µs
*Beam compensation active

Beam Parameter

Pulse Length = 615 µs
Average current = 6.4 mA



	P_kQ_L	QB nominal	
Beam	6.4 mA* (60 mins)	6.6 mA* (60 mins)	Off (20 mins)
ΔA/A (cav1)	0.041%rms	-	0.042%rms
ΔA/A (cav2)	0.031%rms	-	0.045%rms
ΔA/A (vector sum)	0.009%rms	0.009%rms	0.008%rms
Δϕ (cav1)	0.042°rms	-	0.027°rms
Δϕ (cav2)	0.031°rms	-	0.021°rms
Δϕ (vector sum)	0.009°rms	0.009°rms	0.008°rms

All stabilities are estimated for the beam transient time.

- **First actual P_kQ_L operation**
- **Fulfills ILC stability requirements (ΔA/A = 0.07%, Δϕ = 0.32°)**
- **Procedure applicable for ILC (39 cavities)**

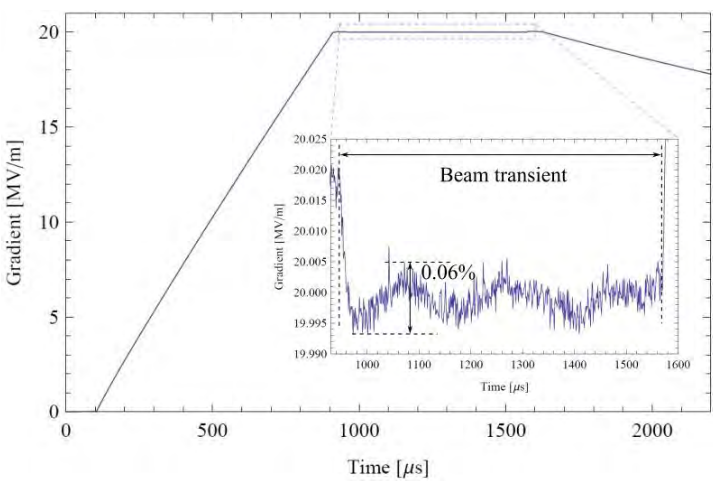
High Q_L Operation

RF Parameter

- V_{Cav1} = 20 MV/m
- V_{Cav2} = 20 MV/m
- Q_{L1} = 2e7
- Q_{L2} = 2e7
- Filling time = 800 µs
- *Beam compensation active

Beam Parameter

- Pulse Length = 615 µs
- Current = 6.1 mA



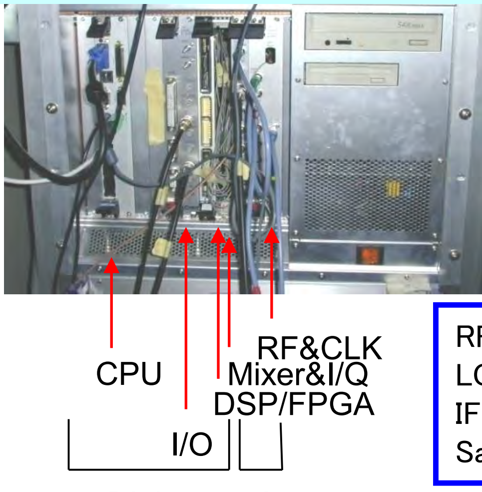
	High Q_L		QB Nominal	
Beam	6.1 mA* (60 mins)	Off (20 mins)	6.6 mA* (60 mins)	Off (20 mins)
ΔA/A (cav1)	0.121%rms	0.030%rms	-	0.042%rms
ΔA/A (cav2)	0.160%rms	0.032%rms	-	0.045%rms
ΔA/A (vector sum)	0.011%rms	0.008%rms	0.009%rms	0.008%rms
Δϕ (cav1)	0.033°rms	0.027°rms	-	0.027°rms
Δϕ (cav2)	0.028°rms	0.027°rms	-	0.017°rms
Δϕ (vector sum)	0.015°rms	0.014°rms	0.009°rms	0.008°rms

All stabilities are estimated for the beam transient time.

- **Detuning stayed constant during 1h operation**
  → Microphonics are not severe
- **Fulfills ILC stability requirements (ΔA/A = 0.07%, Δϕ = 0.32°)**

J-PARCリニアックLLRFの性能

安価で高速バスを持つcPCIを採用



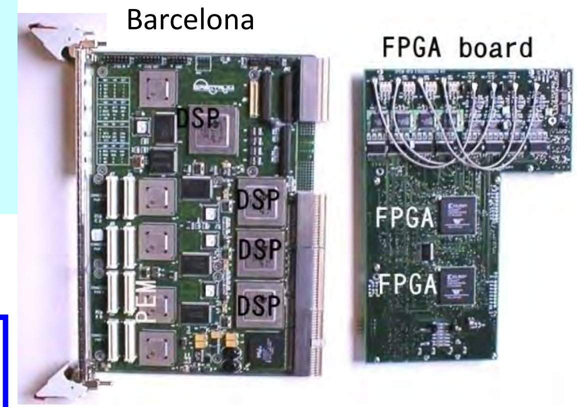
世界最初にRFのFBにFPGAを採用

FPGAはDSPボードのメザニンカード

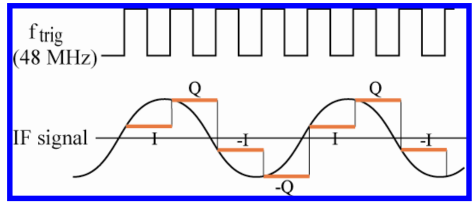
FPGAは高速のFBに専念

データ解析、パラメータの変更はDSPボード

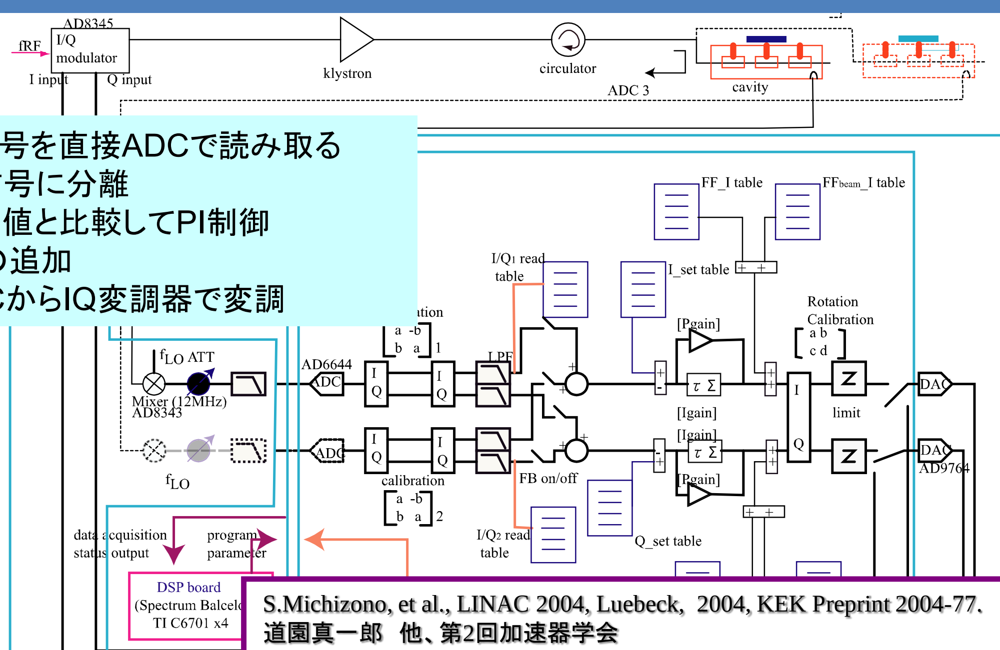
（DSPボードからFPGAは高速アクセス可能）



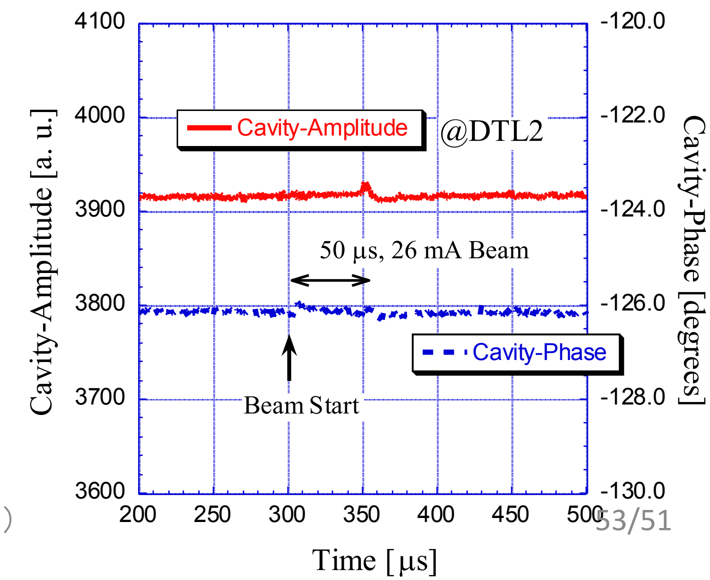
RF : 324MHz
LO : 312MHz
IF : 12MHz
Sampling:48MHz



空洞安定度は振幅±0.2%，位相±0.2度．常伝導運転マシンとしては世界最高水準.



IF信号を直接ADCで読み取る
IQ信号に分離
設定値と比較してPI制御
FFの追加
DACからIQ変調器で変調



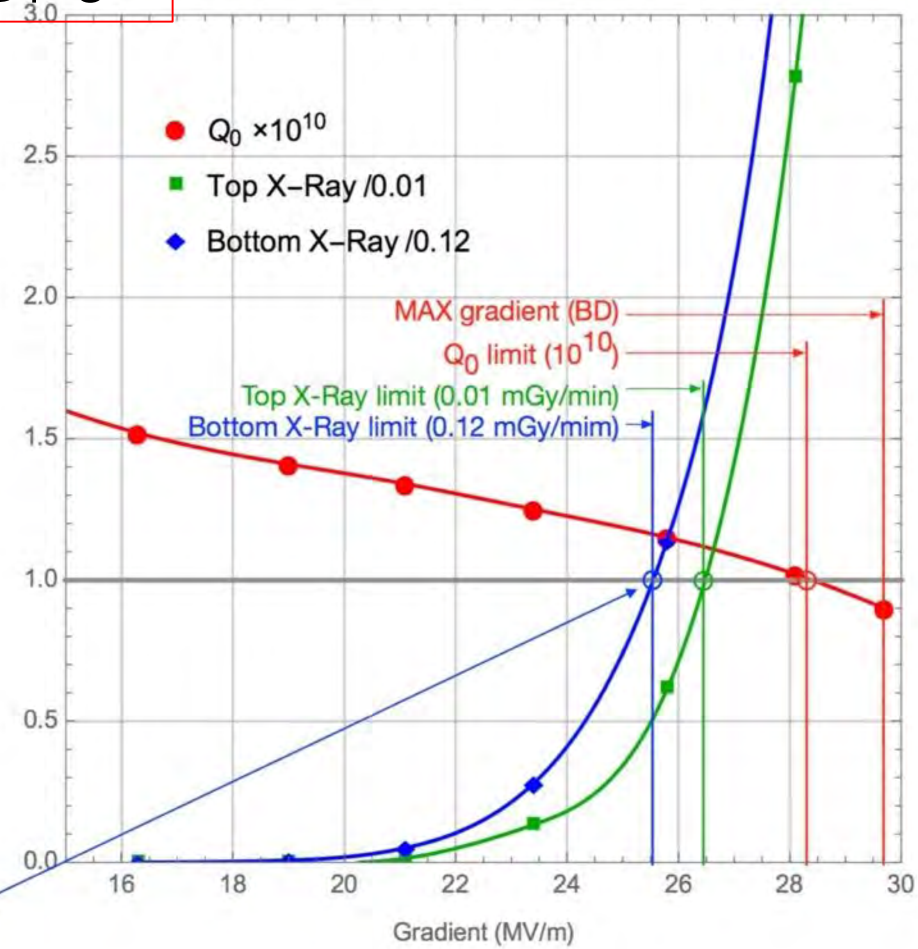
S.Michizono, et al., LINAC 2004, Luebeck, 2004, KEK Preprint 2004-77.
道園真一郎　他、第2回加速器学会

超伝導加速器

Definition of "Usable Gradient" in VT

以下のどれかの原因で使用可能勾配が決められる

- Minimum of the following gradient values:
  - MAX (i.e. quench)
  - $Q_0 = 10^{10}$
  - X-ray 1 (top) threshold
  - X-ray 2 (bottom) threshold



In this example, usable gradient is limited by FE (bottom X-ray) to ~25.5 MV/m

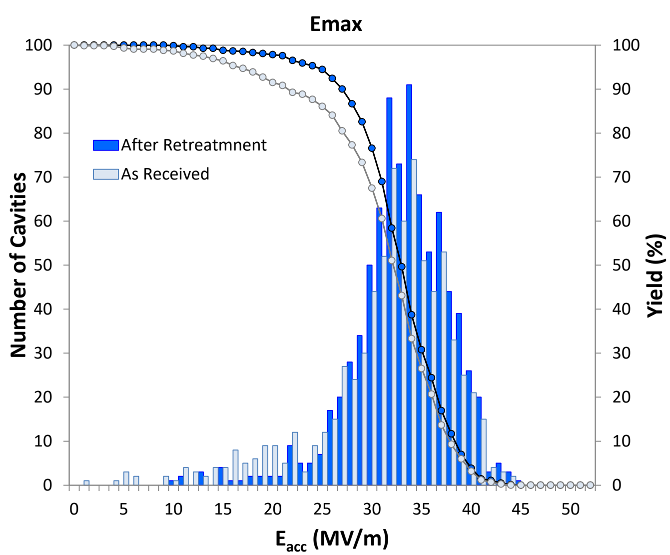
EXFELでの空洞性能とTDR31.5MV/m運転

EXFELでの空洞の性能と、現在のILC-TDRでの31.5MV/m運転の現実性

【回答】

- 2007年から空洞性能向上のためのR&Dを進め、空洞性能は飛躍的に向上してきた。
- 欧州XFEL での実績として、表面処理を3回まで認めることにより、33 MV/m, Q 値>10^{10}の達成率が90%を超えている。
- 電界、Q値を総合し、ILCが求める技術レベルの90%レベルを達成している。

- **欧州XFEL超伝導加速空洞実績:**
  - 量産実績2 x 400台
  - 最高電界 (A社: 400) : 34.7 MV/m
    (B社: 400) : 31.5MV/m
    (全体) : 33.0 MV/m



空洞製造 内面研磨 回数	E-XFEL-A 実績 電界: [MV/m] 率: [%] (Q値達成含）	ILC 計画 電界: [MV/m] 率: [%] (Q値達成含）
1回目	33 MV/m 63%	35 MV/m 75%
2,3 回目	**33 MV/m** 82%, **91%** **(2, 3 回表面処理)**	**35 MV/m** **90%**
・E-XFEL実績: ILC 計画目標に対して、電界、Q値を総合し、**約90%の技術レベルを達成。**		

Extrapolation to ILC - VT

- ILC TDR assumed VT acceptance > 28MV/m (XFEL >20 MV/m)
  - Average of 35 MV/m (XFEL 26 MV/m)
  - Assumed first-pass yield: 75%
  - 25% cavities retreated to give final yield of 90% >28 MV/m (35 MV/m average)
    - ➡ 10% over-production assumed in value estimate

RI results only (ILC recipe)

		ILC TDR (assumed)	XFEL max	XFEL usable
First-pass	Yield >28 MV/m	75%	86%	53%
	Average >28 MV/m	35 MV/m	36 MV/m	33.5 MV/m
First+Second pass	Yield >28 MV/m	90%	92%	80% *
	Average >28 MV/m	35 MV/m	36 MV/m ✔	33 MV/m ✘

* based on re-treatment model using XFEL data

but close!

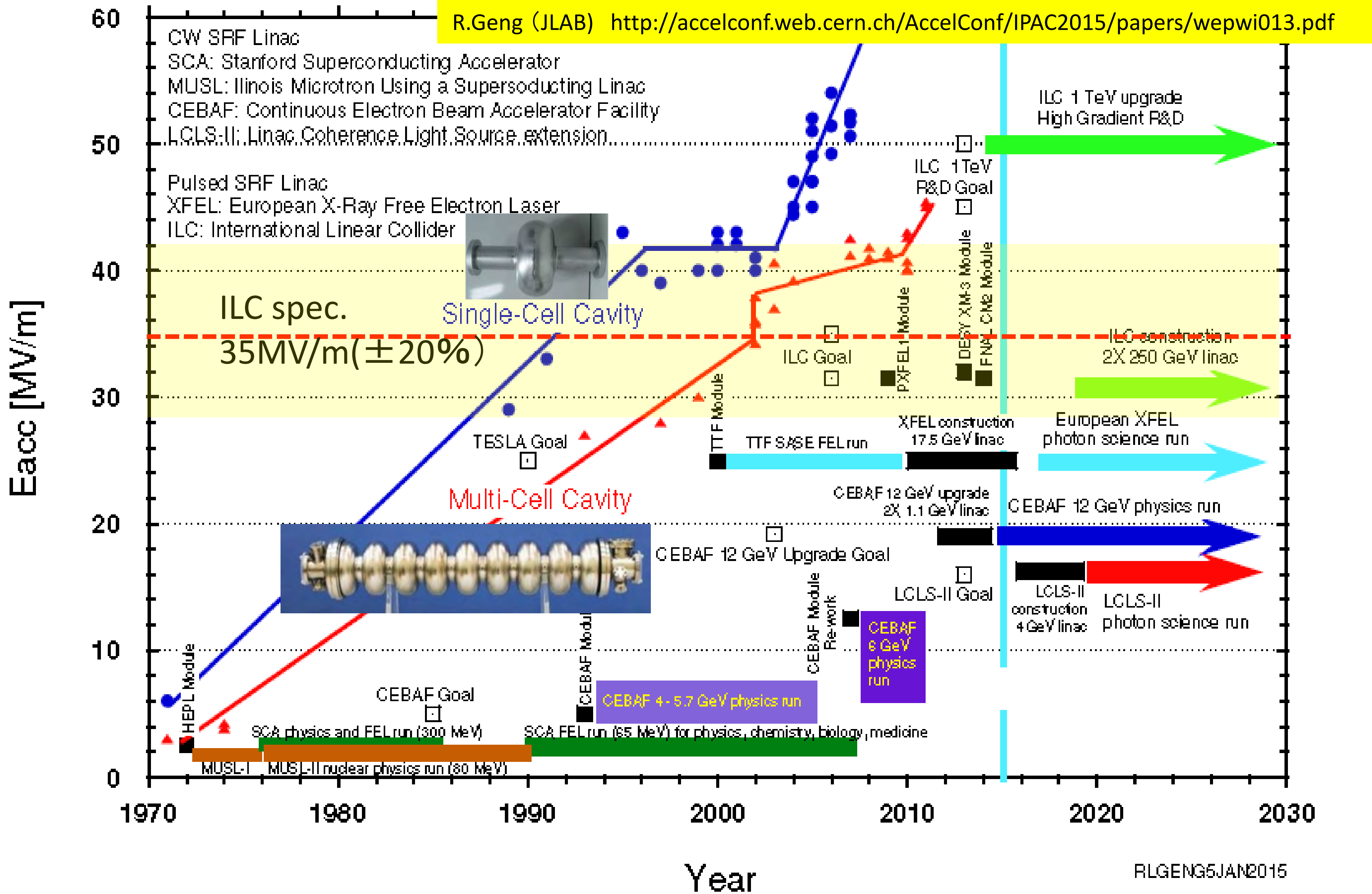
More re-treatments - but only HPR
Number of average tests/cavity increases from 1.25 to 1.46
20% over-production or additional re-treat/test cycles

➡ ILC 性能まで
~ 90 % のレベル

Nicholas Walker ● DESY ● nicholas.walker@desy.de

Lバンド(~1.3GHz) 空洞の性能向上（世界）

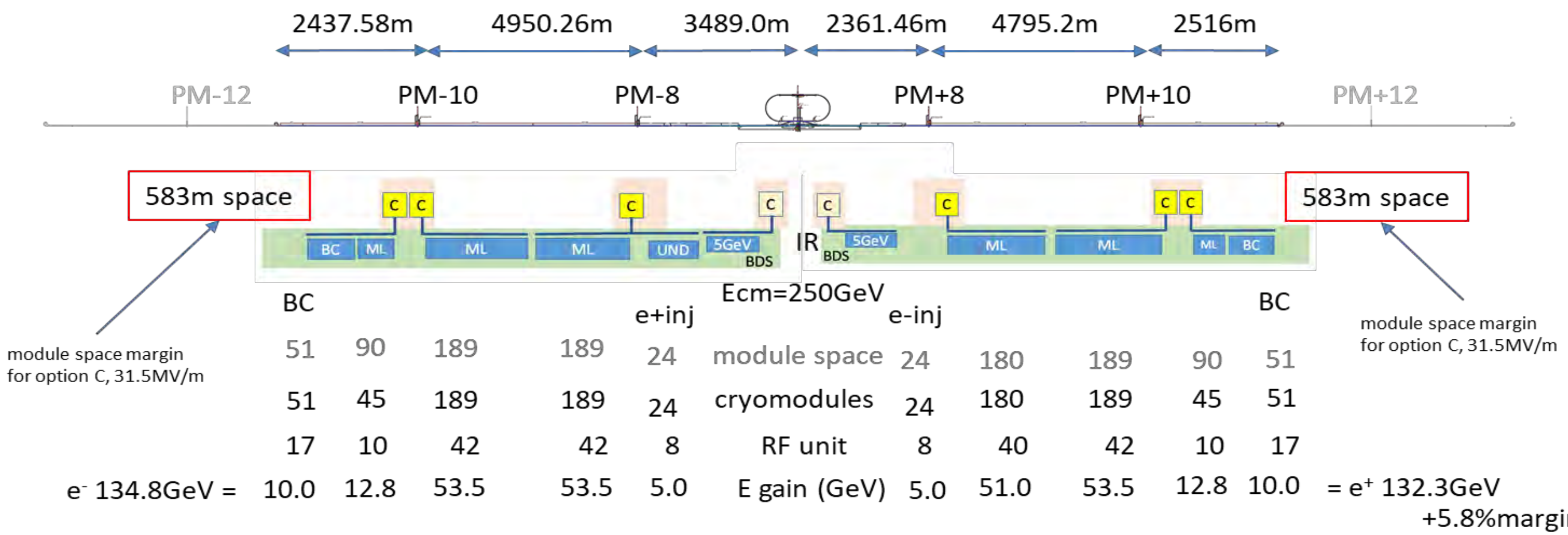
R.Geng（JLAB） http://accelconf.web.cern.ch/AccelConf/IPAC2015/papers/wepwi013.pdf



超伝導空洞のマージン

空洞の性能が達成されない場合の対応

【回答】
250GeV ILCでは新たに2.5%(8000台の空洞のうち200台に相当)の余裕(全体で6%)で設計されている。また、電子側、陽電子側に600m程度の空きトンネルがあり、(予算は別途必要であるが)400台程度の空洞の追加が可能である。



クライオモジュール加速勾配

DESY-XFEL(TDR vol-3 part-I, p43)

2.5.2 Cryomodule

The cryostat design for the European XFEL is based on the first cryostats developed and built by INFN Milano within the TESLA R&D effort. Although the ILC module has developed several differences, it remains very close to the European XFEL design. Figure 2.36 shows a comparison of the ILC and XFEL cryomodule designs.

From the perspective of production, the cryomodule can be separated into three parts:

- the string assembly which comprises of the eight cavities and their associated auxiliary components (high-power input coupler, HOM couplers, helium tank, mechanical tuner etc.), the superconducting quadrupole package including a beam position monitor and a HOM absorber;
- the so-called cold-mass of the cryostat, which includes the 300 mm gas-return pipe, support fixtures (for the cavity string), thermal shields, cryogenic piping etc.;
- the outer (insulating) vacuum vessel.

The original type-I cryostat design was improved for FLASH at DESY (type-II); the further improved type-III design was finally shared with the worldwide community and forms the basis of the ILC type-IV module. Only minor modifications have been made to the type-III for the European XFEL. The procurement of the 100 cryostats (cold-mass and outer vessel) is organised by DESY; in total four vendors were qualified, and two finally contracted for the series production.

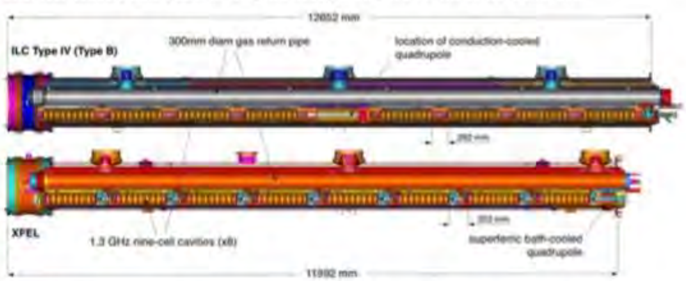
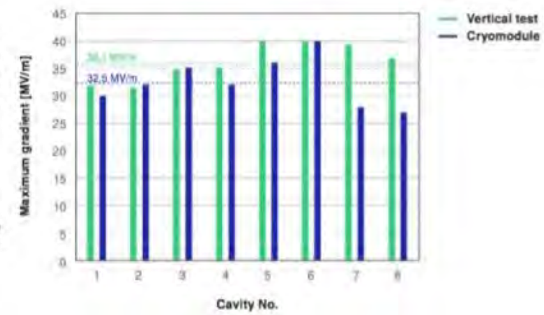


Figure 2.36. A comparison of the ILC (top) and XFEL (bottom) cryomodules. For the ILC the Type-IV module design with 8 cavities and one quadrupole package is shown. The most obvious difference is the longer length of the ILC module, driven primarily by the larger centrally located quadrupole (the longer quadrupole is required for the higher beam energy). The XFEL uses a superferric bath-cooled quadrupole located at the end of the module, while the ILC baseline locates the conduction-cooled magnet at the more stable central location. The reduced inter-cavity spacing is also indicated (ILC being 6 cm less than XFEL).

The cavity string and module assembly for the European XFEL is the responsibility of CEA Saclay / IRFU (France). A new dedicated infrastructure has been set-up for this purpose. Construction of the infrastructure started in 2009 and major parts were commissioned in 2010. An intense two-phase training period was used to transfer the assembly procedures from DESY to the IRFU supervisors and then to a sub-contracted company who will provide the approximately 30 personnel required to assemble the cryomodules at a rate of one per week. All major components required for the assembly are supplied by European XFEL collaboration partners as shown in Table 2.17. The work done at IRFU starts with the reception of already tested components (cavities, couplers, etc.) and ends with the shipping of completed accelerator modules ready for testing at DESY. As with the cavity production, the detailed specifications for the module assembly have been made available to the GDE and have been used as the basis for the industrial studies for ILC module assembly and cost estimation (see Section 2.9). Furthermore, the similarity in cryomodule designs has provided important technical information such as cryogenic heat loads, which can easily be scaled to the ILC

The first XFEL prototype module (PXFEL-1) achieved an average gradient on the module test stand of 32.5 MV/m when each cavity was driven independently (see Fig. 2.37), and represents the best performing module to date. The module average reflects a 10 % performance drop from the average of the individual cavity measurements achieved in the low-powered vertical tests (36.1 MV/m), mainly due to the large degradation observed in the last two cavities in the string (cavities No. 7 and 8). Such degradation in one or two cavities is not atypical and is an indication of contamination during string assembly. The XFEL series production will provide significantly larger statistics to help mitigate such assembly errors. PXFEL-1 is now installed in the FLASH linac, where it routinely accelerates beam, albeit at a reduced average gradient due to the limitations of the RF power distribution system. With its high-gradient cavities, it has been a focus of the ILC experimental programme at FLASH (see Section 3.2).

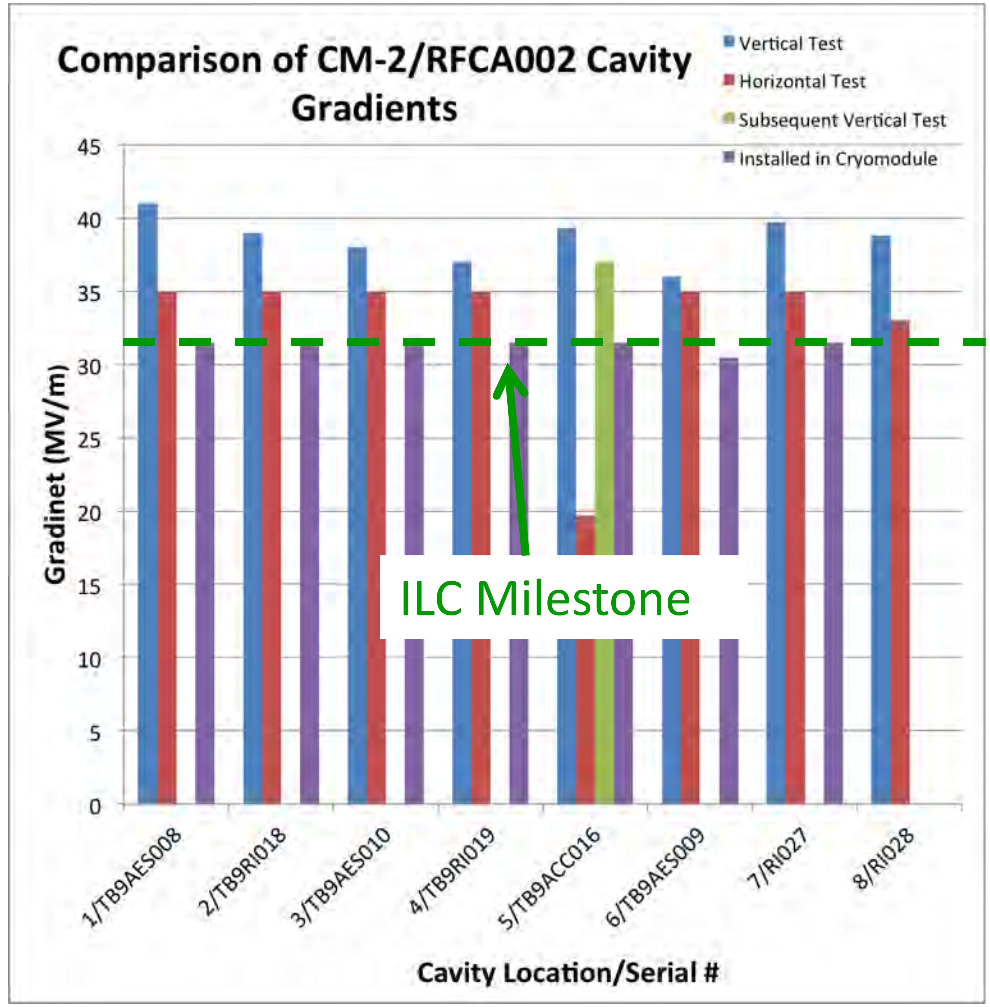
Figure 2.37 Maximum gradient results for the XFEL prototype module PXFEL-1, where an average of 32.5 MV/m was sucessfully demonstrated (without beam) [89]. The individual cavity performance results from the low-power vertical tests are also shown for comparison. The observed 10 % degradation is primarily due to cavities 7 and 8.



2.5.3 RF Power System

The RF system includes all components required to convert AC line power to pulsed RF power and to distribute it to the superconducting cavities of the accelerator. The main components have been developed, constructed and tested for several years since the early 1990s, when DESY started to host the TESLA test facility (later converted to FLASH). The RF power source has now had nearly two decades of operational experience at TTF/FLASH, and more recently at the RF gun test-stand PITZ at DESY, Zeuthen. The European XFEL will use altogether 29 complete RF stations. The stations are split into the modulator installed outside the accelerator tunnel, and the pulse transformer / 10 MW multi-beam-klystron units inside the tunnel, close to the accelerator modules. Pulse cables of a length up to approximately 1 km connect both parts of the RF station. The 10 MW multi-beam klystron technology is shared by the European XFEL and ILC (Section 2.8). The many years of development of this klystron have lead to a mature design and the qualification of three vendors, from which two were contracted for the production of European XFEL klystrons. Modulator development started with the Fermilab bouncer-type modulator originally provided for the TESLA Test Facility in the mid 1990ies. A second generation of bouncer-type modulator was built by a German company. After further R&D, the European XFEL has finally adopted a pulse-step modulator — a solid-state modulator not unlike the ILC baseline Marx modulator. Beyond the klystron and modulator, further development of the RF system was required for the European XFEL. Due to the limited space inside the European XFEL tunnel, a compact waveguide distribution system has been developed. The waveguide distribution is based on a binary cell which consists of two circulators connected to a shunt tee with integrated phase shifters. Four binary cells are combined by three asymmetric pre-coupled

Performance to Date - Gradient



Recent Accomplishments – CM-2

- CM-2 has achieved an average cavity gradient of 31.5 MV/m with all 8 cavities powered simultaneously
- 1.6 millisecond pulse width, 5 Hz repetition rate
- Lorentz Force Detuning Compensation (LFDC) on and 'adapting'
- LLRF operated in 'closed loop'
- Peak accelerating voltage = 252 MV
- Cavity 8 Warm coupler vacuum problem repaired in situ
  - required warm-up to room temperature
- Successful cool down and resumption of operation