RF Acceleration

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CEA-FNAL

Outline

1. Superconducting RF: high gradients
2. Superconducting RF: CW operation
3. Warm RF: higher gradients

Back Up Material

- List of the 23 past and present SRF accelerators built in Europe
- The European Spallation Source SRF LINAC
- Movie of Robotization in the ISO4 Clean Room at CEA
- Xband infrastructure overview 2018-11-8

Superconducting RF: High Gradients

TESLA Technology Collaboration (http://tesla-new.desy.de/)

e.g. https://ribf.riken.jp/TTC2018/

SRF Conferences

e.g. http://srf2017.csp.escience.cn/dct/page/70002

The European XFEL

The most recent and longest superconducting linac in the world is in operation

Currently

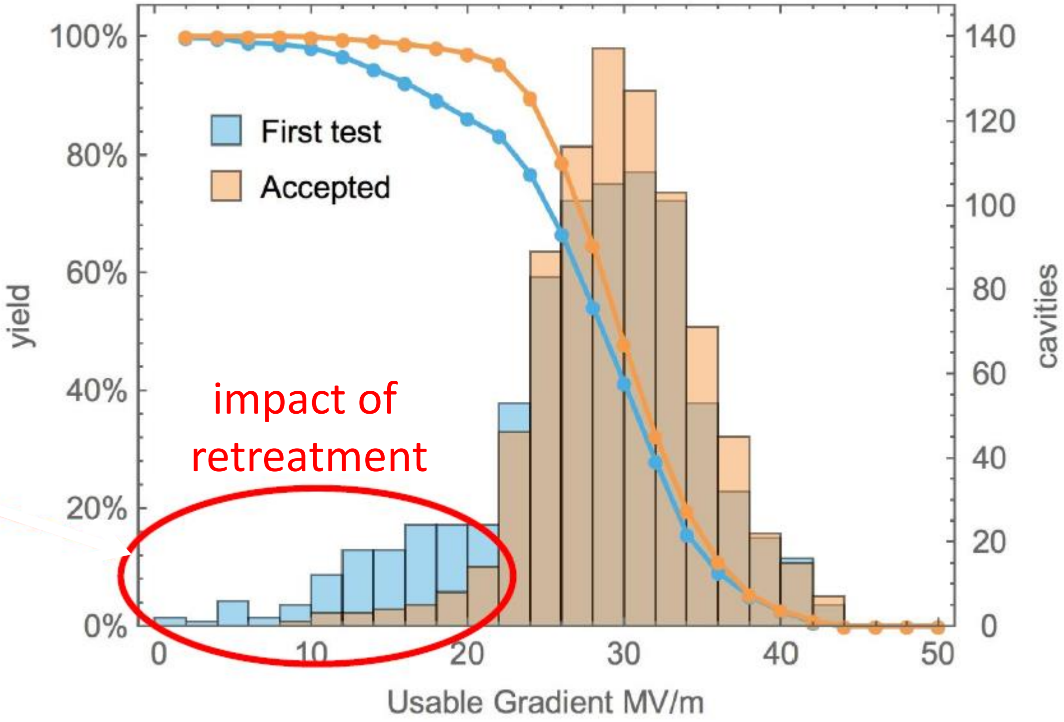
- 96 superconducting modules (1.3 GHz) in a single cryostat in the main tunnel
- plus 2 injector modules (1.3 GHZ + 3.9 GHz)
- RF components and electronics rack are located below the accelerator.

Eu-XFEL Cavity Production and Performance

Final Performance at Acceptance Tests (sent for module assembly)

- $\langle E_{usable} \rangle = 29.8 \pm 5.1$ MV/m over 816 cavities production.

Vertical Test (VT)



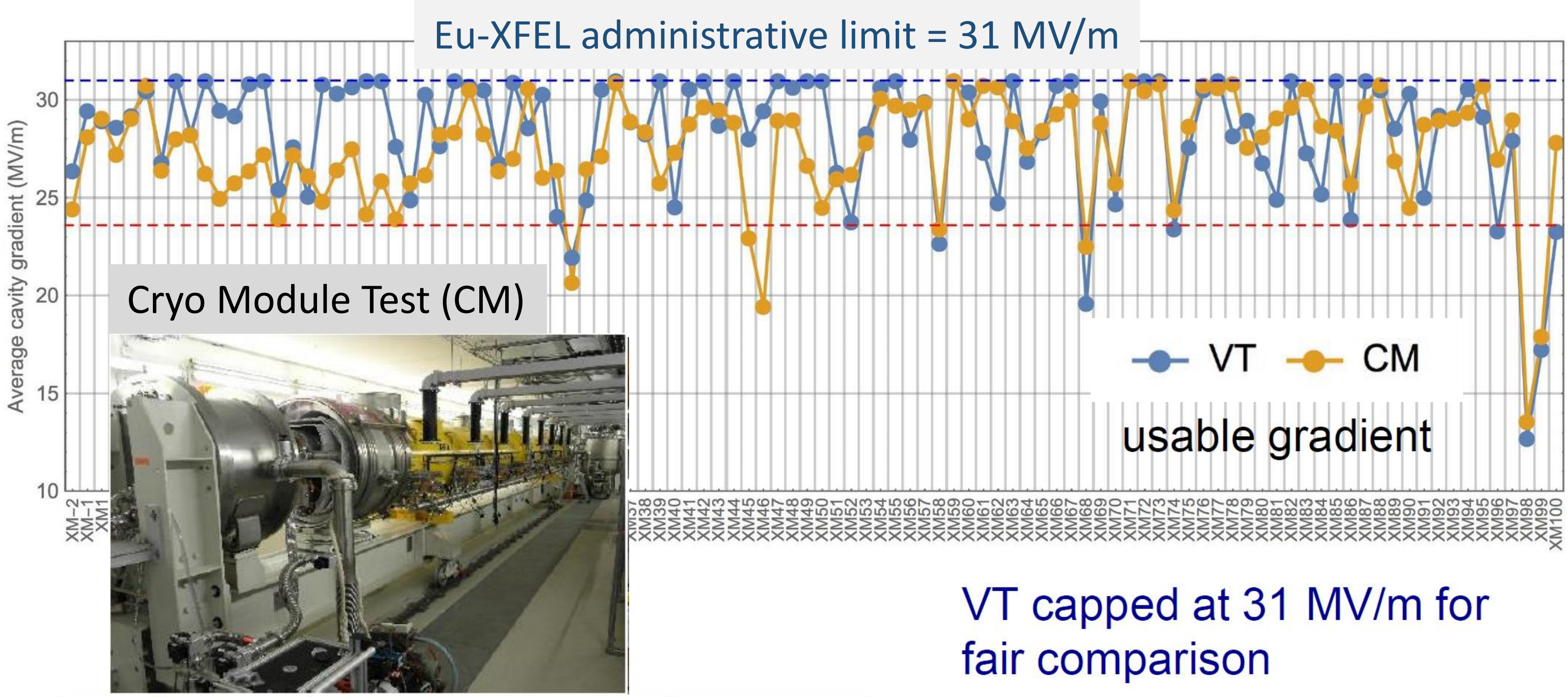
Note:

1) the [20 – 40] MV/m ‘Gaussian’ spread of usable gradients, surprisingly large for an industrial production based on a ‘single’ process !

2) Reducing the spread to [30 – 40] MV/m would yield the ILC goal of 35 MV/m.

Eu-XFEL Module Performance

Final Performance at Acceptance Tests over 102 module assemblies


Eu-XFEL administrative limit = 31 MV/m

Cryo Module Test (CM)

VT capped at 31 MV/m for fair comparison

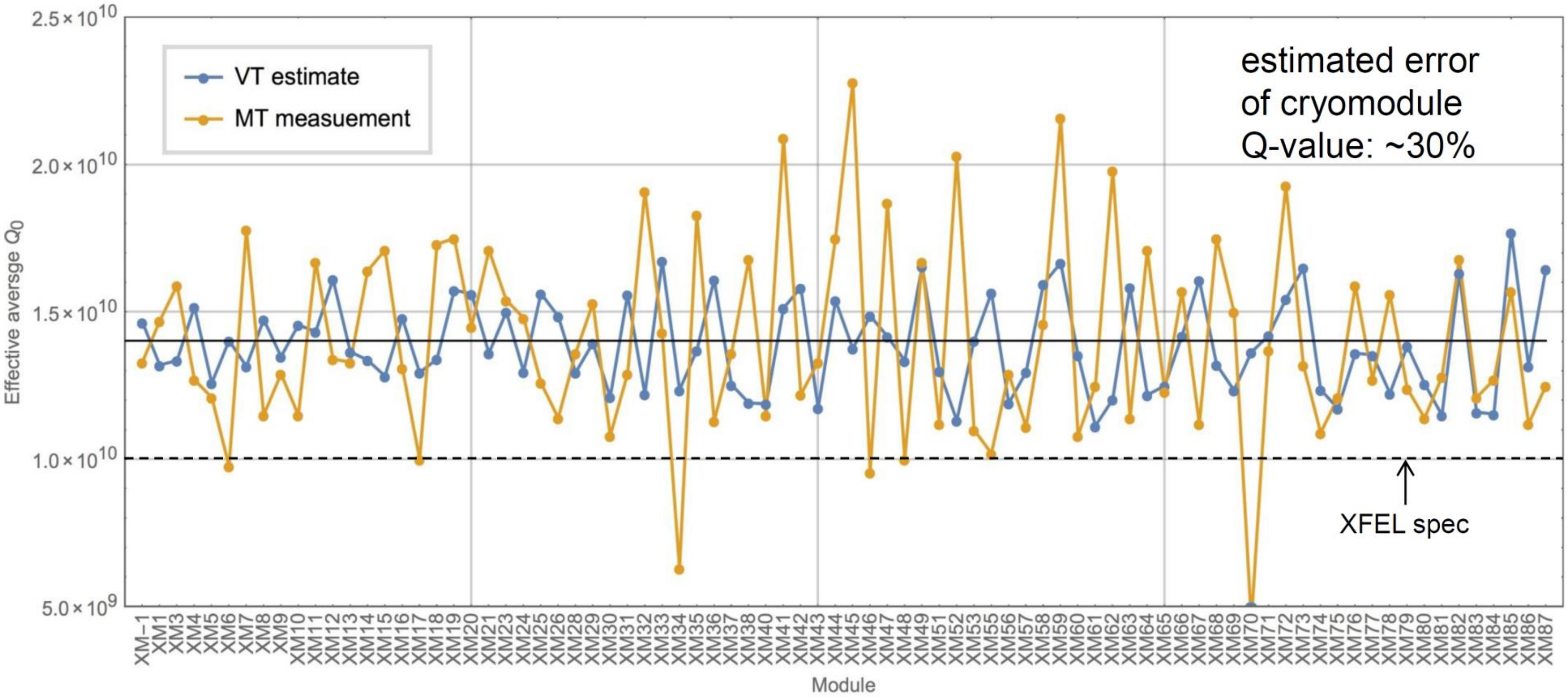
	N_{cavs}	Average	RMS
VT	815	28.3 MV/m	3.5
CM	815	27.5 MV/m	4.8

~3% difference measured this way

Note: *the small degradation is only an average effect. Individual module degradation can be much larger, up to 30%.*

Eu-XFEL Module Performance

Final Performance at Acceptance Tests over 102 module assemblies



Average Q_0-value at ~ 23 MV/m: vertical 1.4 x 10^{10}

cryomodules **1.4 x 10^{10}**

Note: $Q_0 = \omega_{RF} W / P_{\Omega}$ = 1.4 x 10^{10} *leads to 360 W of peak 2K heat load per cryomodule at 25 MV/m.*

ROBOTIZATION

Robotization should reduced assembly mistakes

Robotization could be implemented for, e.g. in order of complexity:

  - Ionized N2 cleaning (cf. movie in Back-Up Material),
  - Coupler assembly,
  - String assembly,

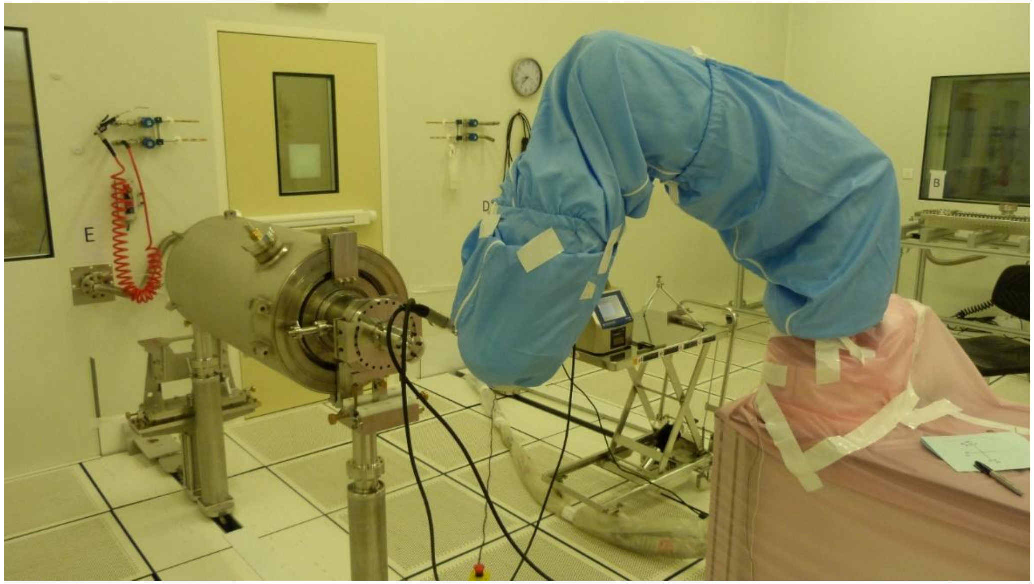
Robotization will be beneficial with respect to :

- Reducing labour cost
- Uniformization of assembly procedures across several regional assembly plants
- Introducing ‘plug-compatible’ component design variations

‘COBOT’-IZATION

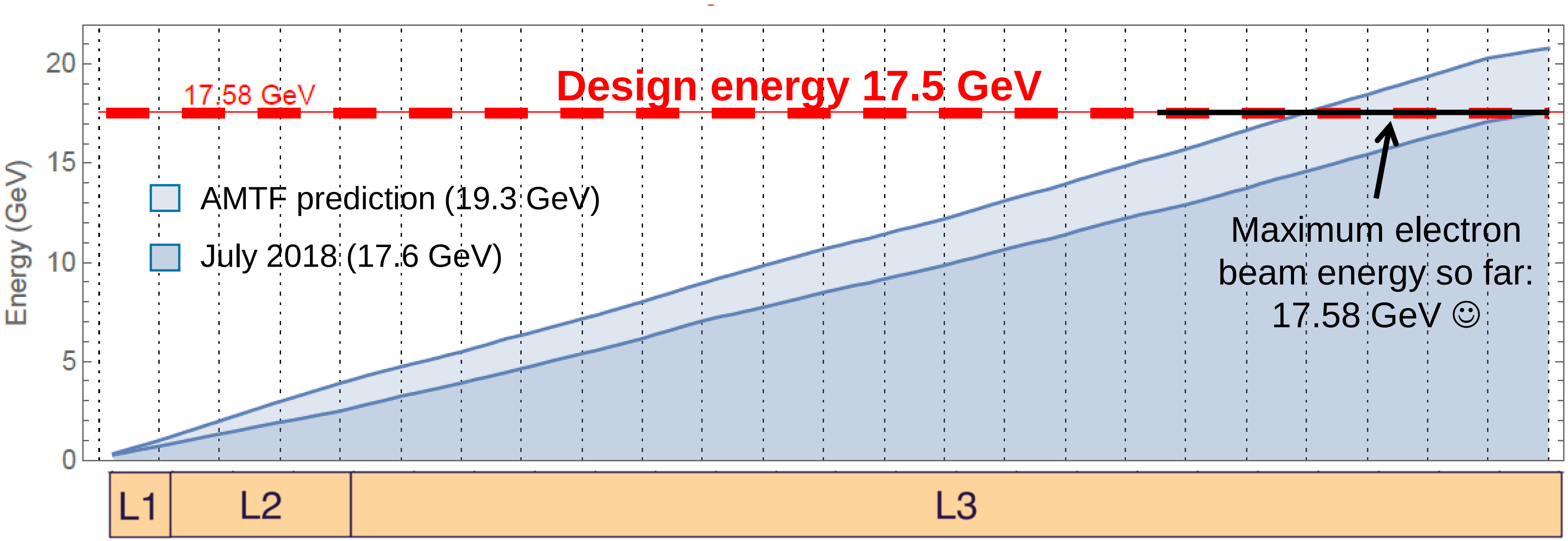
A first ‘proof of principle’ experiment has been implemented at Saclay, in the Eu-XFEL/ESS Clean Room with a ‘collaborative’ robot, a.k.a ‘Cobot’, for the Ionized-N2 cleaning of the blind holes ESS cavity flange .

Cobot



Cobot in Saclay ISO4 Clean Room

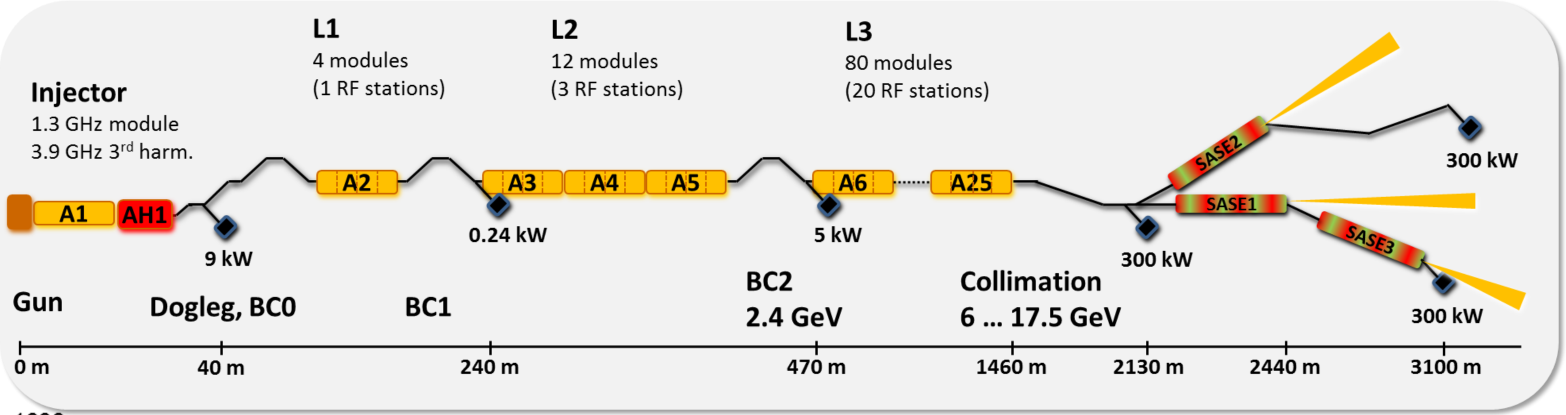
European XFEL Commissioning: Energy

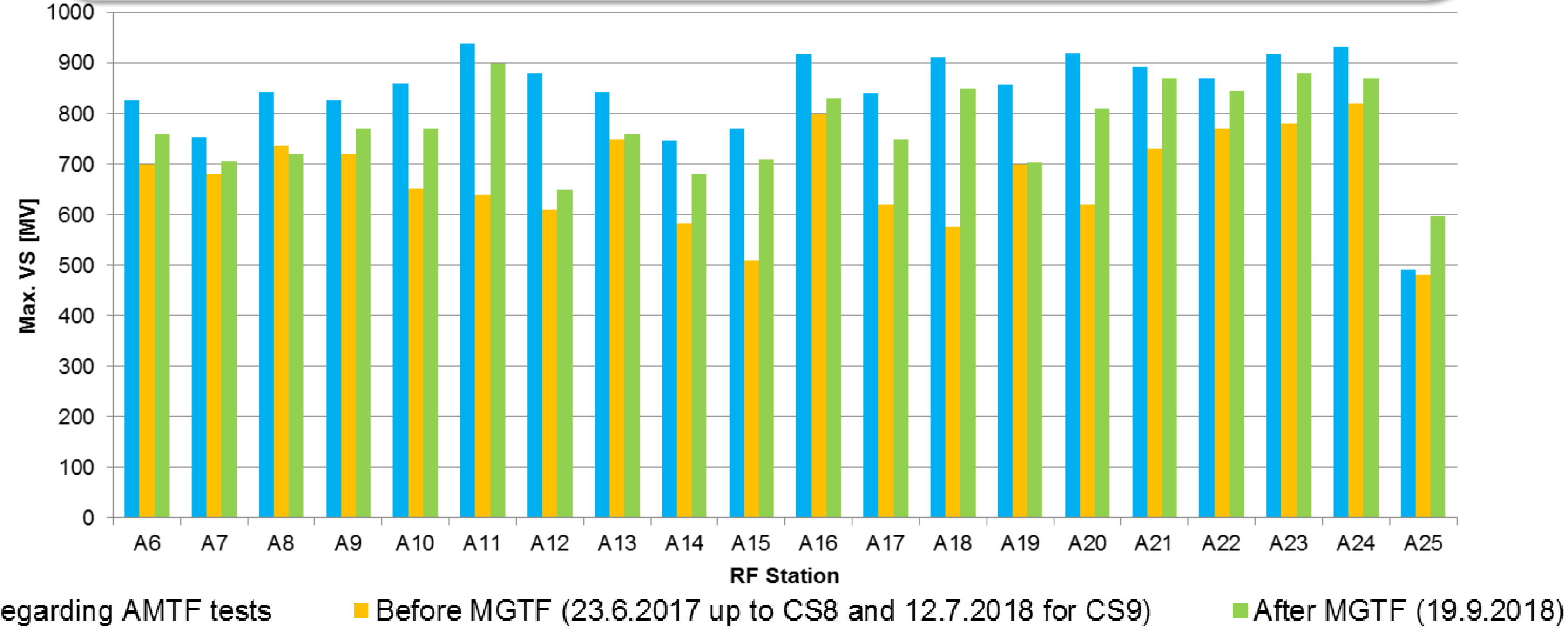


- The accelerator is commissioned according to schedule and towards expected parameters.
- All 25 RF stations (4 modules powered by one klystron) are in operation
- The maximum electron beam energy so far is **17.6 GeV, 92% of AMTF prediction**
- There is still potential to increase the accelerating performance.

15 November 2018

RF Performance as of 19th of September 2018

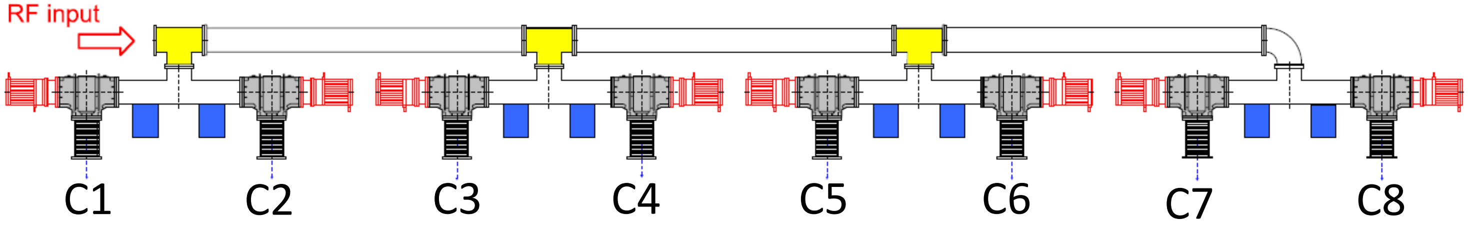




Note: *the voltage calibrations at AMTF and XFEL are different (power-based vs beam-based)*

Eu-XFEL RF Distribution

Waveguide Distribution (WD) for one module (8 cavities)



- 1 10-MW klystron drives four modules (32 cavities)
- WD for cryomodules tailored for MT results
  - maximising voltage
  - up to 3dB difference between cavity pairs
- Allow up to 3dB split between adjacent cryomodule pairs
- Equal power output from two klystron arms

Note: *single cavity powering would be ideal but it is not YET economically feasible:*

- *one 10 MW RF unit ~ 2 M€, hence ~ 60 k€ per cavity for 300 kW.*
- *one 300 kW klystron (only) costs ~150 k€*
- *one 4 kW Solid State Amplifier @ 1.3 GHz costs ~50 k€*

SRF High Gradients: personal conclusions

EU-XFEL results	Gradient	Ratio	Ratio’	Mitigations/Solutions
Cavities Vertical Test	29.8 MV/m	100%		Massive industrialisation studies
Idem, capped @ 31 MV/m	28.3 MV/m	95%	100%	N.A.
Modules in AMTF	27.5 MV/m	92%	97%	Robotization
Modules with beam	25.3 MV/m	85%	89%	Improved RF distribution

Mitigations:

1) Review the cavity production industrial process and understand the root cause for the large gradient spread in acceptance tests.

2) Eliminate the contamination during assembly and tunnel installation.

3) Consider other RF power distribution schemes, if possible.

Superconducting RF: Continuous Wave (CW) Operation

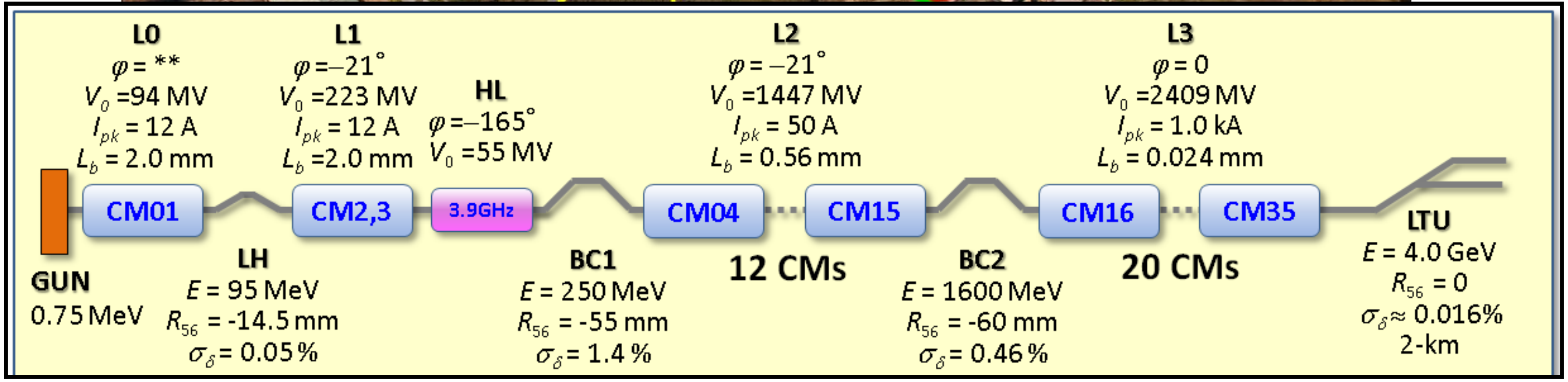
TESLA Technology Collaboration (http://tesla-new.desy.de/)

TTC/ARIES topical workshop on flux trapping and magnetic shielding
https://indico.cern.ch/event/741615/

SRF Conferences
e.g. http://srf2017.csp.escience.cn/dct/page/70002

LCLS-II 4 GeV Linac at SLAC
35 modules @ 1.3 GHz, 100% duty cycle

4 GeV Linac



L0
φ = **
V_0 =94 MV
I_{pk} = 12 A
L_b = 2.0 mm

L1
φ =–21°
V_0 =223 MV
I_{pk} = 12 A
L_b =2.0 mm

HL
φ =–165°
V_0 =55 MV

L2
φ = –21°
V_0 =1447 MV
I_{pk} = 50 A
L_b = 0.56 mm

L3
φ = 0
V_0 =2409 MV
I_{pk} = 1.0 kA
L_b = 0.024 mm

CM01 CM2,3 3.9GHz CM04 … CM15 CM16 … CM35

GUN
0.75 MeV

LH
E = 95 MeV
R_{56} = -14.5 mm
σ_δ = 0.05 %

BC1
E = 250 MeV
R_{56} = -55 mm
σ_δ = 1.4 %

12 CMs

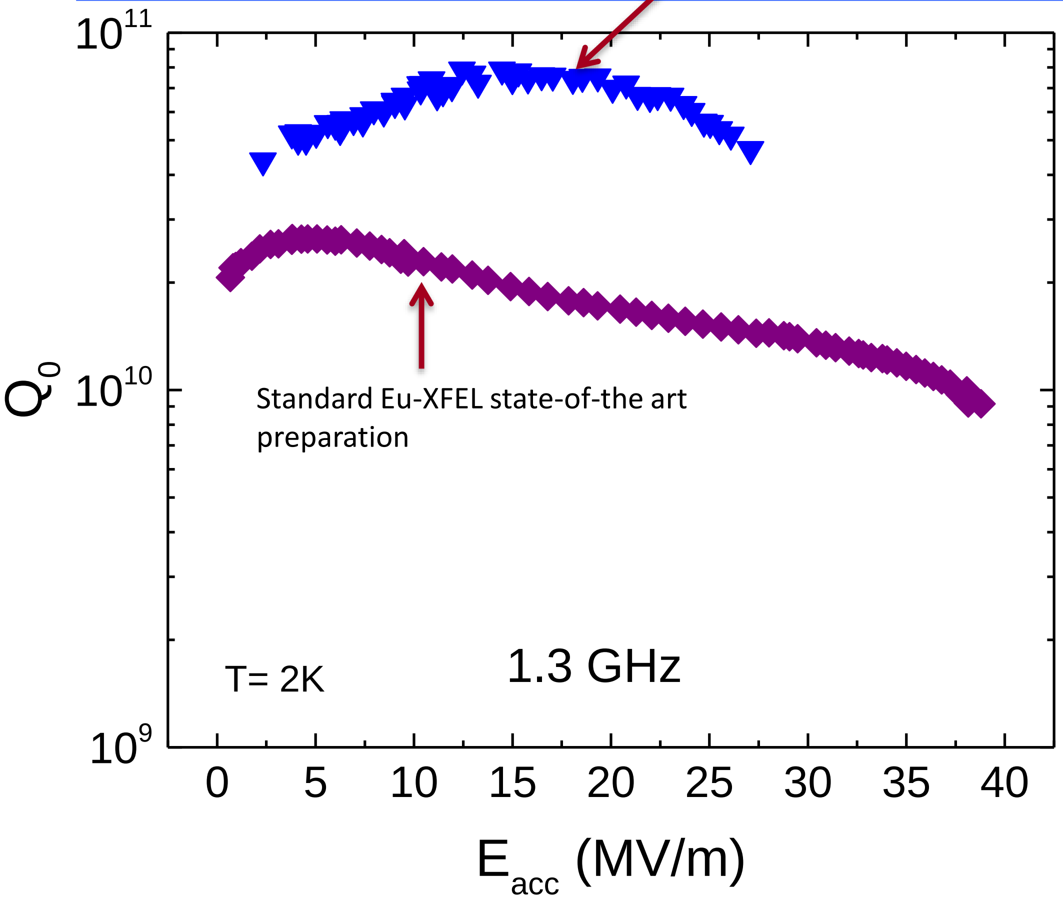
BC2
E = 1600 MeV
R_{56} = -60 mm
σ_δ = 0.46 %

20 CMs

LTU
E = 4.0 GeV
R_{56} = 0
$\sigma_\delta \approx$ 0.016%
2-km

LCLS-II Cavity Production: N2 Doping High-Temperature Treatment

Record after nitrogen doping – up to 4 times higher Q0!



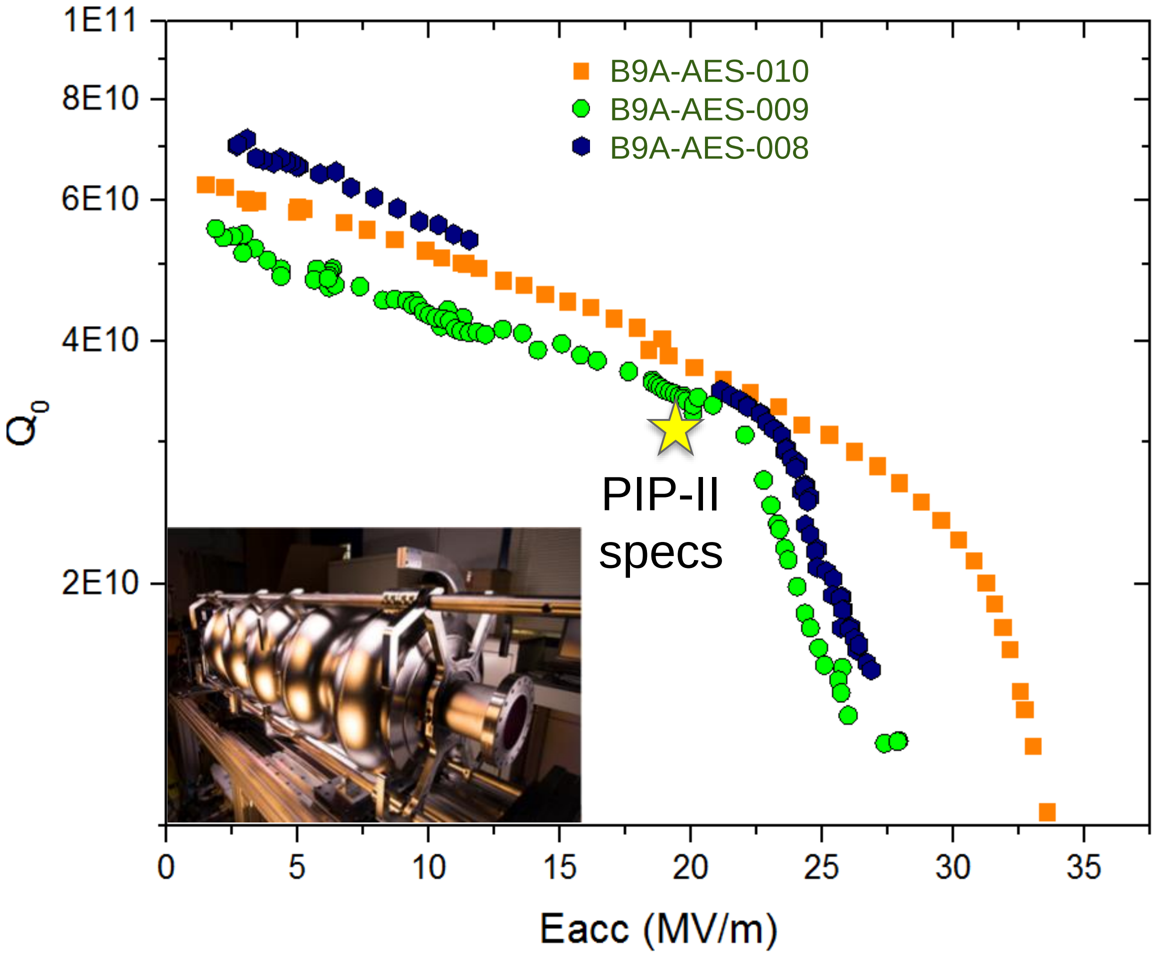
Result obtained at Fermilab on one 1.3 GHz cavity.

Note: *How much of this and of the following LCLS-II achievements apply to circular colliders SRF at lower frequencies, around 400 MHz, is a question under investigation.*

cf. ARIES/TTC topical meeting

LCLS-II Cavity Production: N2 Doping High-Temperature Treatment

Note: *no rising Q_0 vs. Eacc slope at low field*



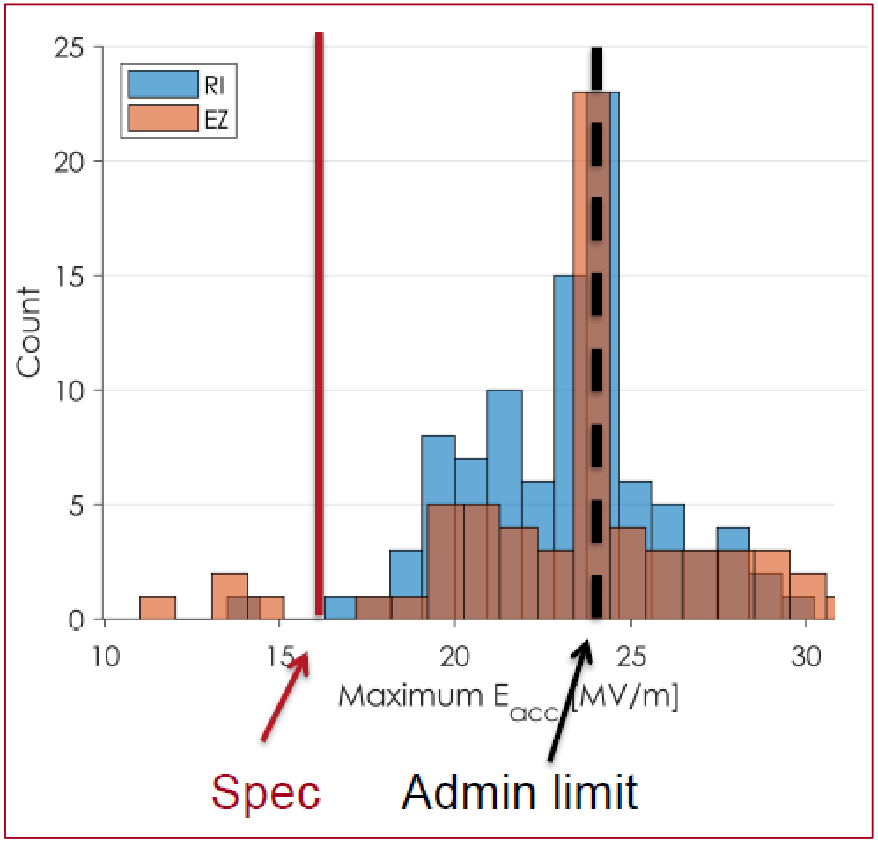
Result obtained at Fermilab on three 5-cell 650 PIP-II cavities.

Note: *How much of this and of the following LCLS-II achievements apply to circular colliders SRF at lower frequencies, around 400 MHz, is a question under investigation.*

cf. ARIES/TTC topical meeting

LCLS-II Cavity Production for CW operation

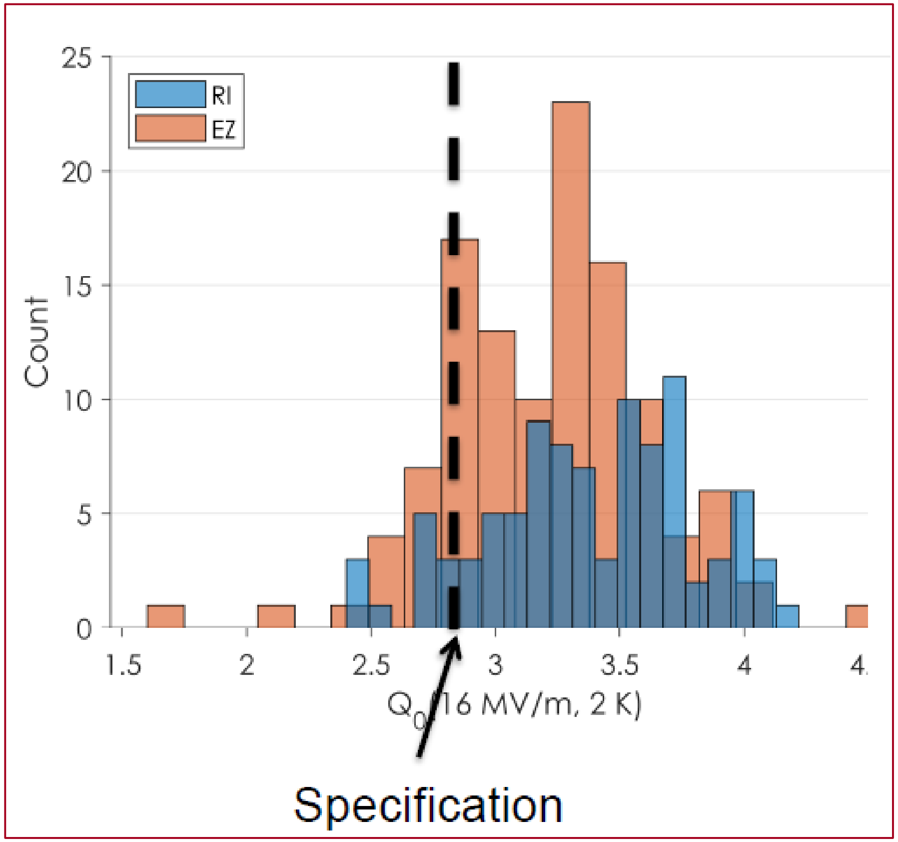
Gradient specification = 16 MV/m



Spec

Admin limit

Q_0 specification = 2.7 x 10^{10}

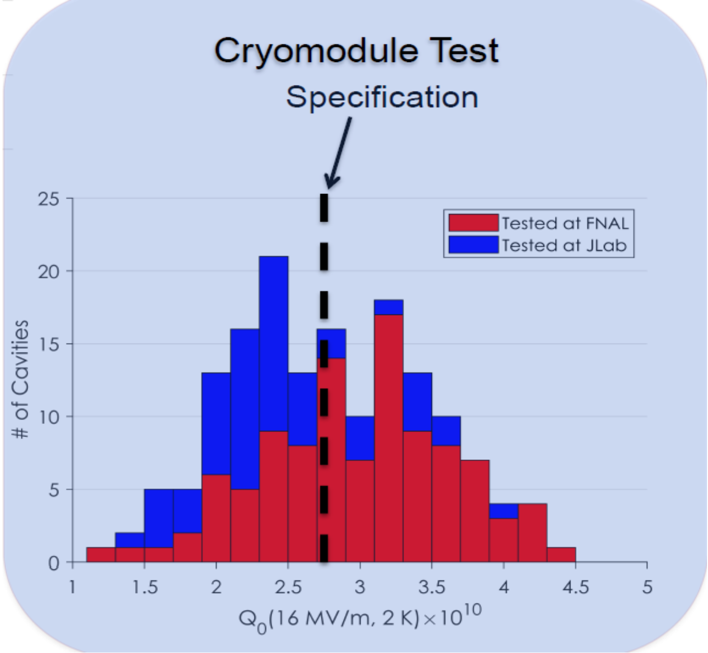


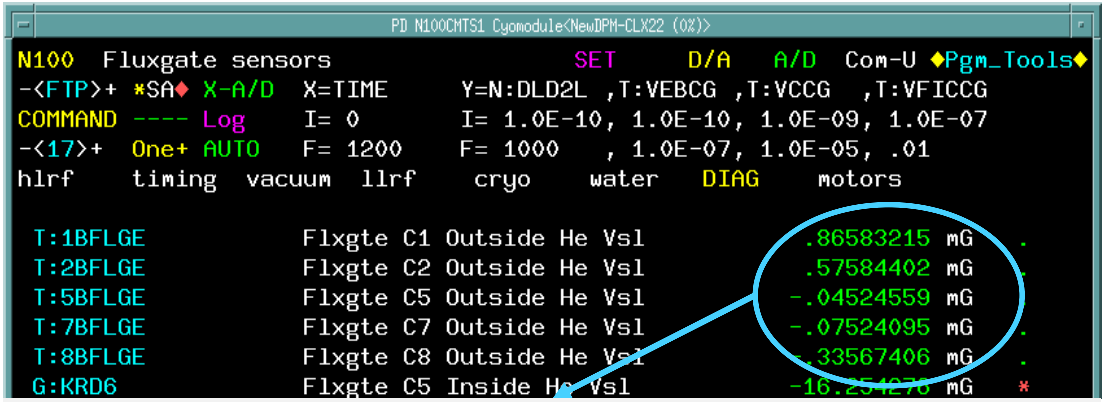
Specification

Note: *the transfer to industry of cavity fabrication process has been successful and fast.*

LCLS-II Cryomodule Production

Preservation of High-Q_0 in cryomodule requires careful ‘**magnetic hygiene**’ and ‘**fast cooldown**’: both have been remarkably achieved for LCLSII cryomodules:





```
N100  Fluxgate sensors                   SET     D/A    A/D   Com-U ♦Pgm_Tools♦
-<FTP>+ *SA♦ X-A/D  X=TIME     Y=N:DLD2L ,T:VEBCG ,T:VCCG  ,T:VFICCG
COMMAND ---- Log    I= 0       I= 1.0E-10, 1.0E-10, 1.0E-09, 1.0E-07
-<17>+  One+ AUTO   F= 1200    F= 1000   , 1.0E-07, 1.0E-05, .01
hlrf    timing  vacuum  llrf    cryo    water   DIAG    motors

 T:1BFLGE           Flxgte C1 Outside He Vsl           .86583215 mG   .
 T:2BFLGE           Flxgte C2 Outside He Vsl           .57584402 mG   .
 T:5BFLGE           Flxgte C5 Outside He Vsl          -.04524559 mG   .
 T:7BFLGE           Flxgte C7 Outside He Vsl          -.07524095 mG   .
 T:8BFLGE           Flxgte C8 Outside He Vsl          -.33567406 mG   .
 G:KRD6             Flxgte C5 Inside He Vsl           -16.254276 mG   *
```

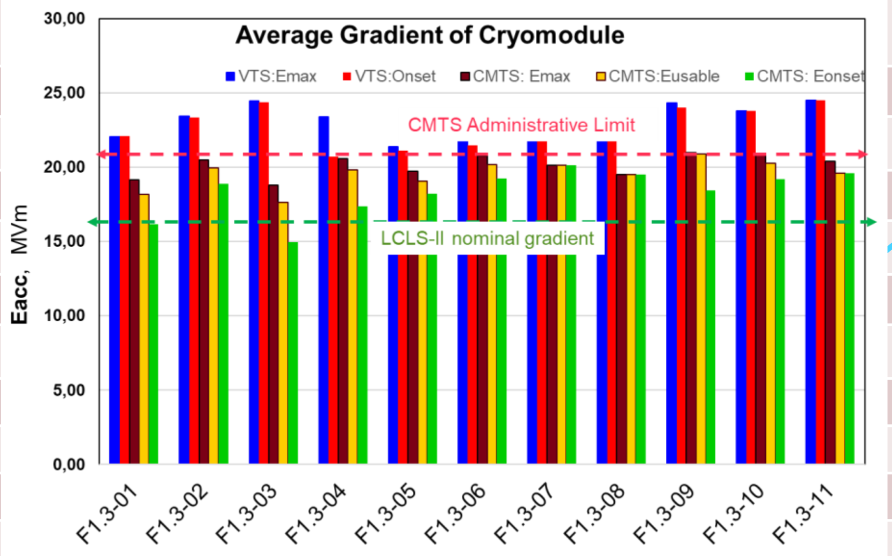
The 5 active fluxgate sensors record less that 0.1 µT magnetic field along the 8-cavity string, 500 times smaller that earth magnetic field.

Notes:

- *fast cool-down (30 g/s supercritical Helium from 50 K down) has only recently been implemented at JLab.*
- *Flux trapping Nb material problem was unraveled and solved by higher T treatment.*

LCLS-II cryomodules performance at FNAL

	VTS		CMTF Test				
Cryomodule	Total Voltage [MV]	Q0@16MV/m	Maximum Voltage [MV]	Usable Voltage [MV]	Q0 @16MV/m	Cavities not meeting FE onset spec (14 MV/m)	Cavities with FE limiting the usable gradient to <16 MV/m
F1.3-01						#5, #7	none
F1.3-02						#5	none
F.13-03						#3, #4, #7	#3, #4
F1.3-04						#3, #6	#3
F1.3-06						#2	none
F1.3-05						#2	none
F1.3-07						none	none
F1.3-09						#5, #6	none
F1.3-08						none	none
F1.3-10						#2	none
F1.3-11						none	none
F1.3-12	207.2	3.49E+10	170.7	164	3.1E+10	none	none
F1.3-13							
Average	**197.1**	**3.1E+10**	**166.9**	**161.7 ~19 MV/m**	**2.90E+10**		



Note: *Most modules are Field Emission (FE) free, or are not limited by FE (12 X-Ray detectors)*
→ *LCLS-II module assembly demonstrated a step forward against contamination*

SRF CW Operation: personal comments

1) Extrapolation to 400-500 MHz cavities and cryomodules is a question under work.

2) LCLS-II throughput is about 1 month: not fit for large scale production.

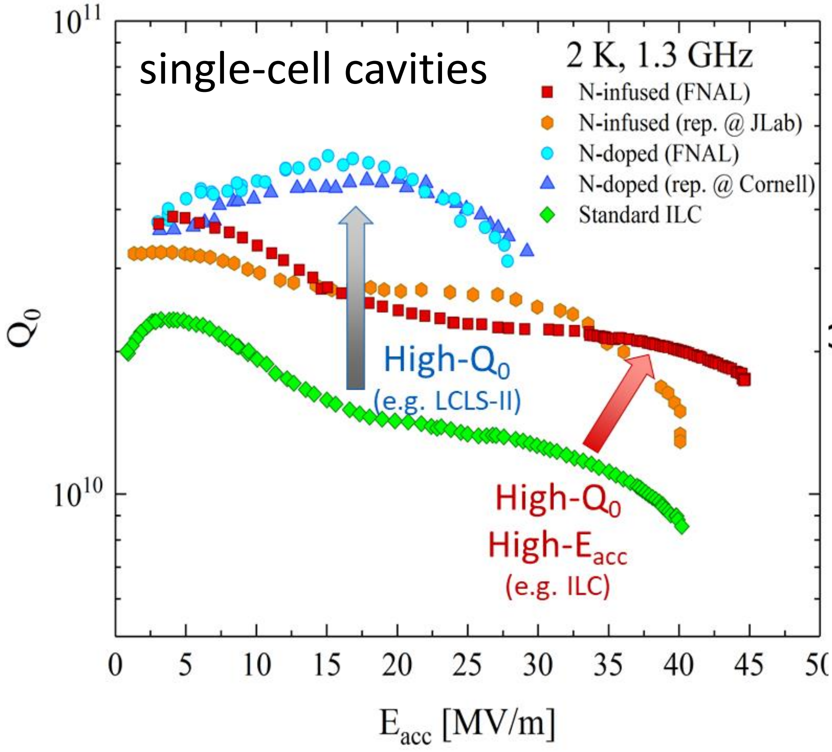
3) LCLS-II disclosed the critically of cryomodule transport over long distances.

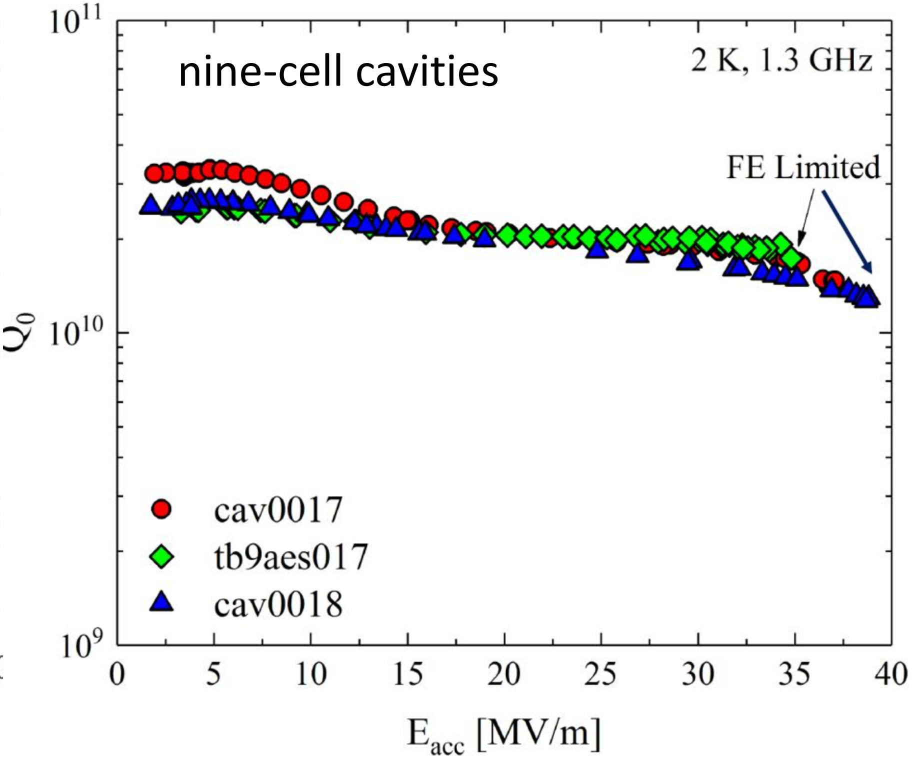
4) PIP-II will cope with the problem of cryomodule transport over the ocean.

Further R&D on High Gradient Doping

‘Nitrogen infusion’ process

- High Q_0 ~$2x10^{10}$ at 2 K for accelerating fields larger than 35 MV/m
- High accelerating gradients ~45 MV/m repeatedly reached on 9 cell cavities





Note: /*The lower surface resistance and higher* Q_0 *can be used to reduce the cost of cryogenics consumption, but also to open the parameter space of ILC, e.g. towards higher energy or towards longer pulses.*

Warm RF: Higher Gradients

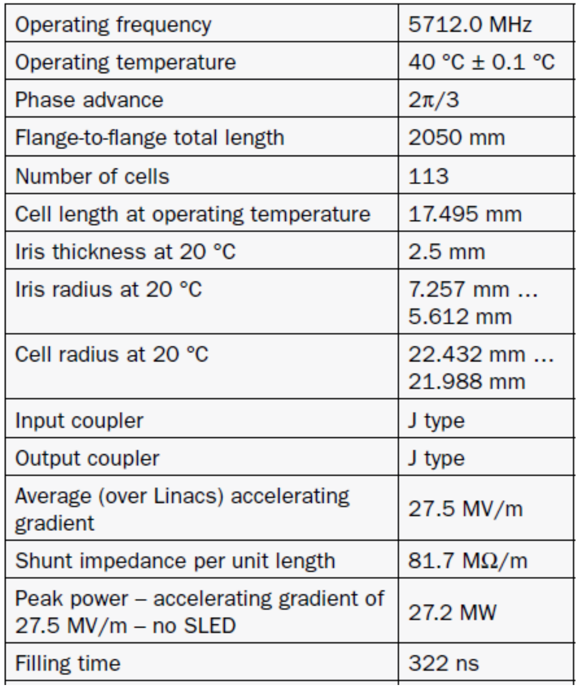
International Workshop on High Gradient Acceleration, HG2018 https://indico.cern.ch/event/675785/overview

Linear Collider Workshop LCWS

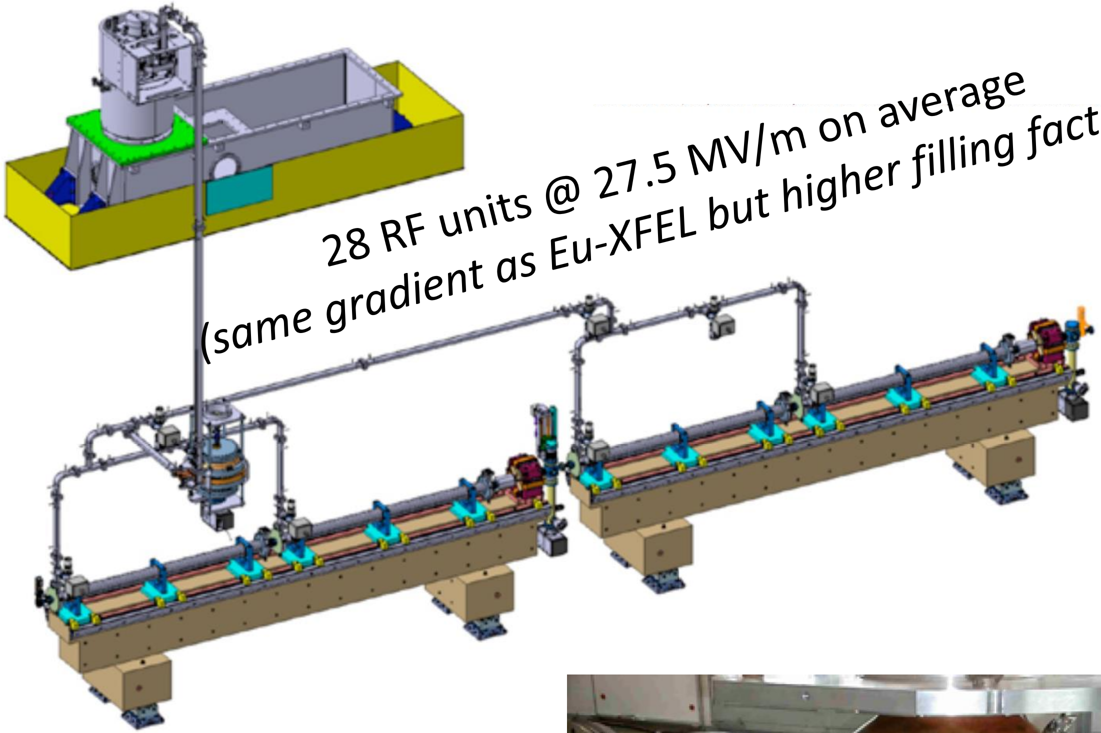
https://agenda.linearcollider.org/event/7889/

The SwissFEL LINAC: 5.8 GeV, 6 GHz, 3 µs, 100 Hz

Table 3.2.4.1: Main parameters for the C-band structures.



Operating frequency	5712.0 MHz
Operating temperature	40 °C ± 0.1 °C
Phase advance	2π/3
Flange-to-flange total length	2050 mm
Number of cells	113
Cell length at operating temperature	17.495 mm
Iris thickness at 20 °C	2.5 mm
Iris radius at 20 °C	7.257 mm … 5.612 mm
Cell radius at 20 °C	22.432 mm … 21.988 mm
Input coupler	J type
Output coupler	J type
Average (over Linacs) accelerating gradient	27.5 MV/m
Shunt impedance per unit length	81.7 MΩ/m
Peak power – accelerating gradient of 27.5 MV/m – no SLED	27.2 MW
Filling time	322 ns



28 RF units @ 27.5 MV/m on average
(same gradient as Eu-XFEL but higher filling factor !)

Notes: *The RF technology of SwissFEL (PSI) and SACLA FEL (Japan) is very close to that of CLIC, with Cu travelling wave warm RF structure, and RF pulse compression.*

Three main differences *SwissFEL vs. CLIC:*

1) *Lower RF frequency: 6 GHz vs. 12 GHz*
2) *Lower gradient: 27.5 MV/m vs. 100 MV/m*
3) *Longer RF module: 2 m vs. 0.25 m*

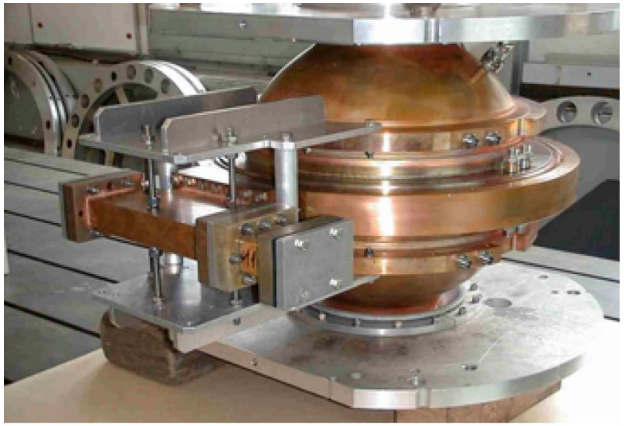


Fig. 3.2.4.11: 3 GHz BOC used at the CLIC Test Facility (CERN).

Most recent structure – PSI T24 N2

Specifications:

- 11.994 GHz
- **T**apered with **24**(2) accelerating cells.
- 120° Phase advance/cell.
- Iris aperture diameter 6.3mm (input) -4.7mm (output)
- Iris thickness 1.67mm (in) – 1mm (out)
- Length about 25 cm
- Fill time 59ns.

Manufactured by The Paul Scherrer Institute (PSI) using the same production line as SwissFEL.

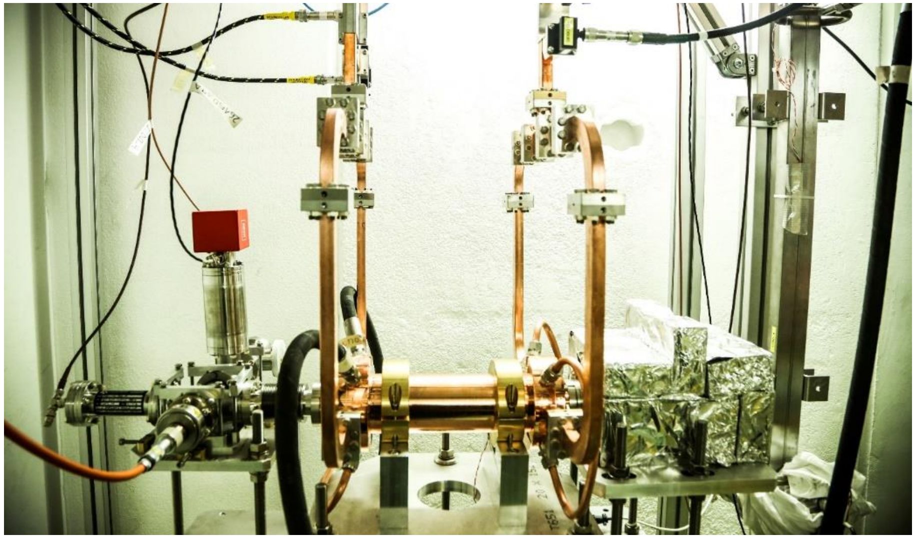


Figure: PSI T24 in X-box 2

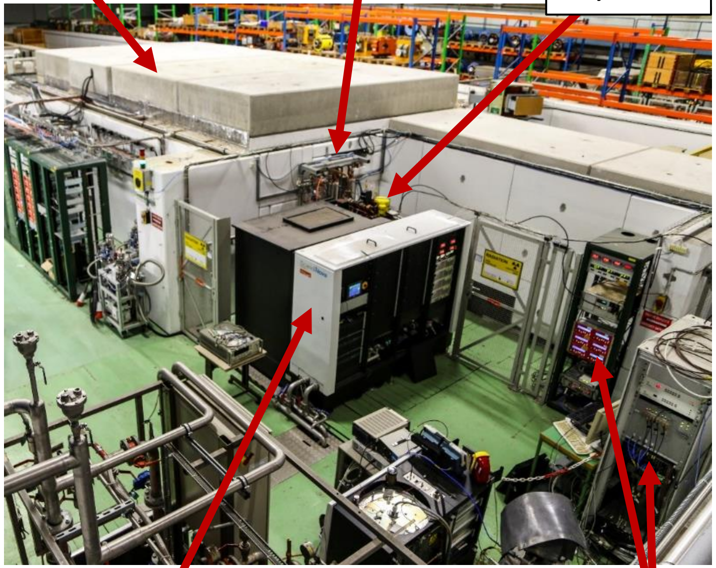
R&D Test Infrastructures

X-Box 2

Radiation Bunker

Pulse Compressor

50 MW Klystron

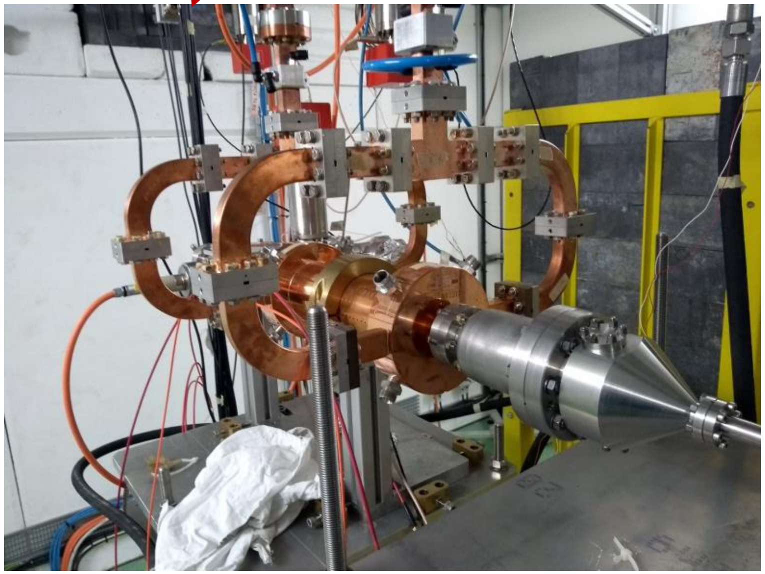


ScandiNova Modulator

SSA and LLRF/PXI Racks

Feeds this structure

Waveguide entry here



‘PSI T24 N2’ structure test-stand:

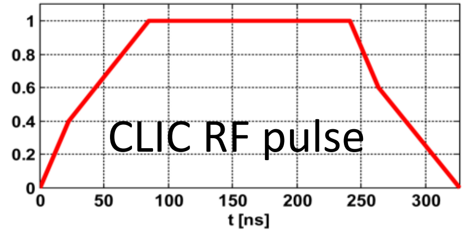
- 1.5µs pulse length
- 50Hz rep rate.

RF Test Results

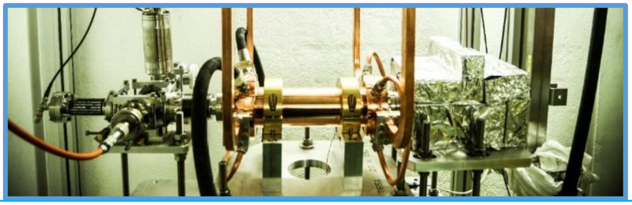
It has been proposed empirically that surface electric field, pulse length and BDR are related:

$$BDR = K.E_a^{30}.\ t_p^{5}$$

BDR = Break Down Rates per pulse and per meter.



CLIC BDR criterion of 3e-7 → holds for tens thousand structure. It requires months running with a single structure for sufficient statistics.



Mean Time Between Breakdowns = 1 h

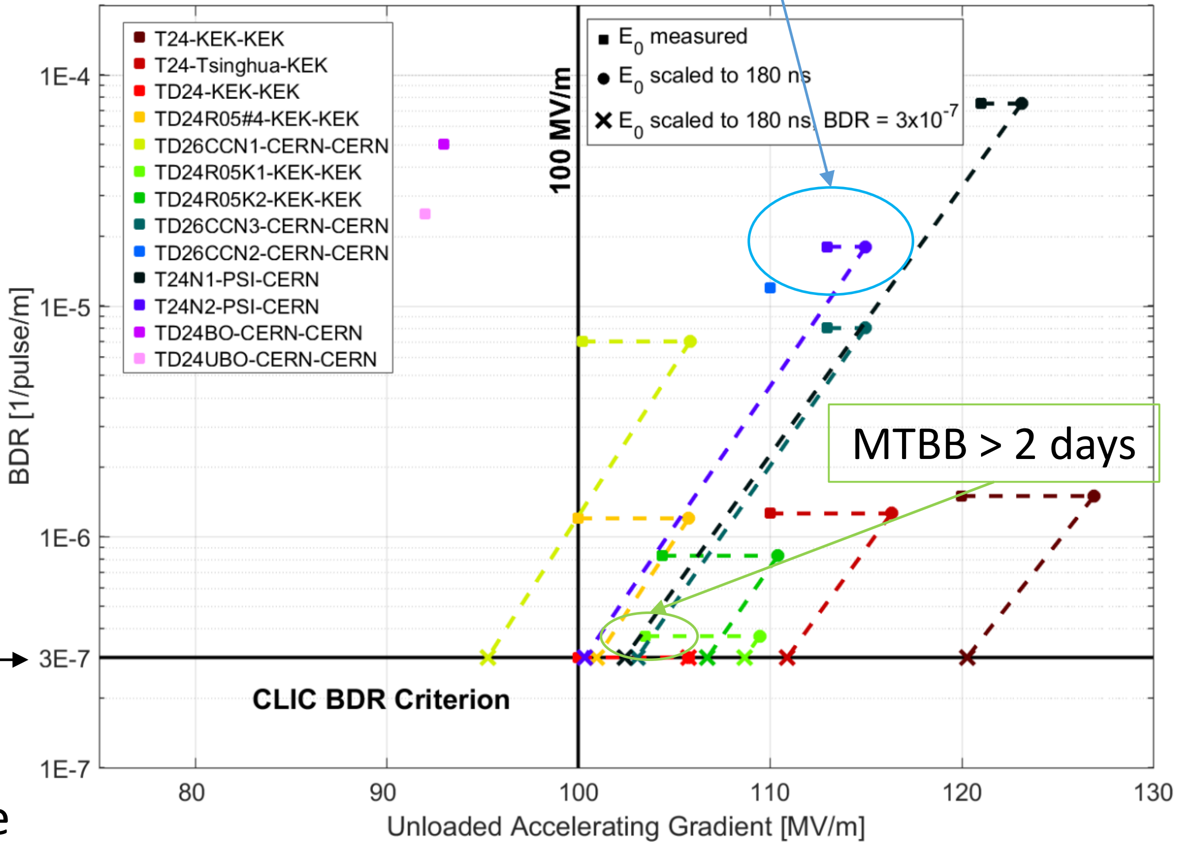
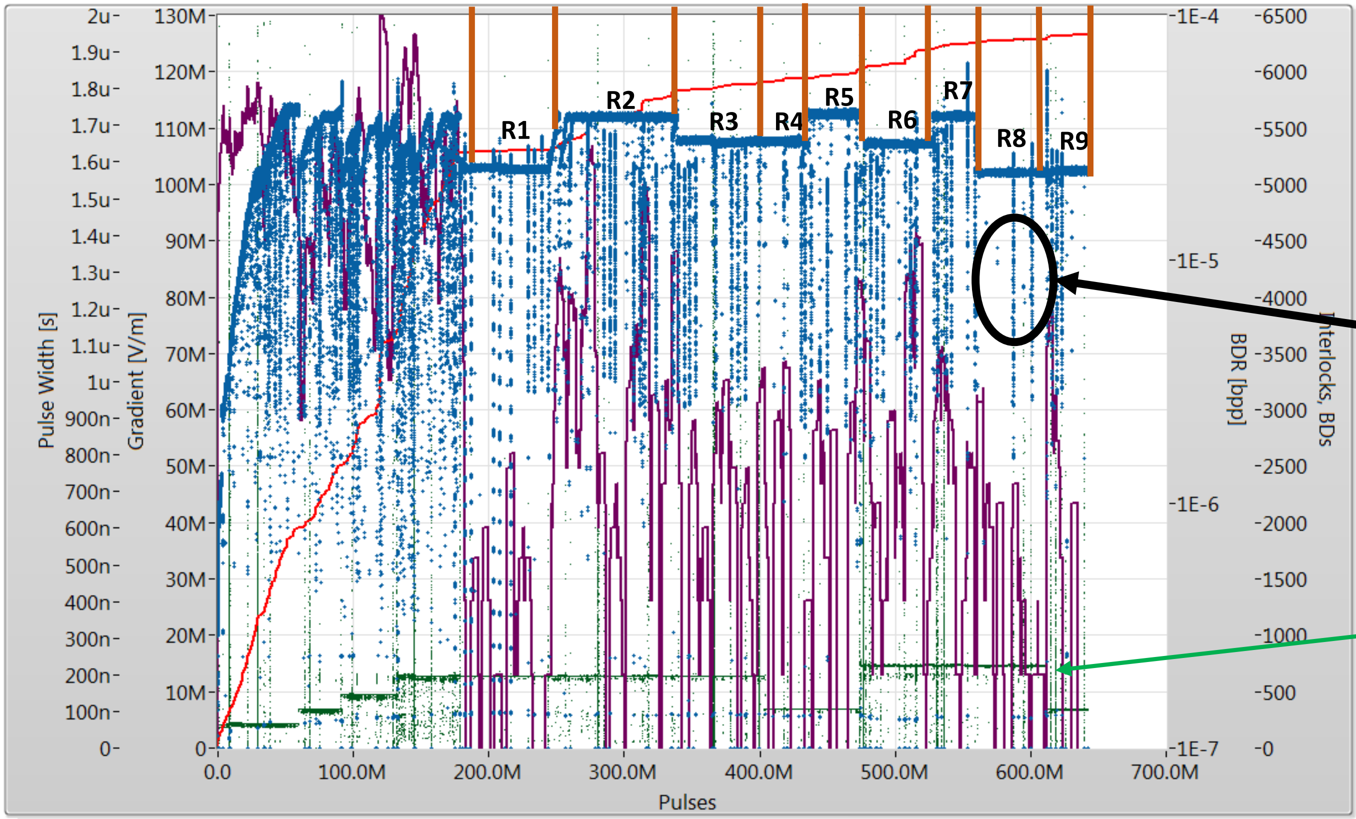


Figure: Prototype structure performances scaled to CLIC specs.

RF Conditioning

Conditioning Summary – PSI T24 N2

pulse width = 2 μs



☑ Gradient
☑ BDs
☑ BDR
☑ Pulse width

NB: Regular power drops due to dark current measurements

Run	Gradient (MV/m)	Pulse Length (ns)	Pulses (millions)
1	103	200	68
2	108	200	64
3	112	200	91
4	108	100	32
5	112	100	41
6	108	CLIC	54
7	112	CLIC	34
8	103	CLIC	37
9	103	100	31

CLIC RF pulse

700 Millions RF pulses = 160 days at 50 Hz repetition rate

Conclusions

- RF acceleration is currently THE main technology to (longitudinally and sometimes transversely) accelerate charged particles.
- SRF acceleration underwent large progress in the last two decades (from LEP200) :
  - ×5 in accelerating fields
  - ×3 in Ohmic losses.
- SRF acceleration is still an active field of R&D with Niobium showing unexpected resourcefulness.
- Warm RF acceleration demonstrates very high gradients, with more 'system' test demonstration needed.

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- M. Ross (SLAC)
- Lee Millar*, W. Wuensch (CERN)

* Lancaster University

Back-Up Material

SRF Accelerators in Europe: past & present

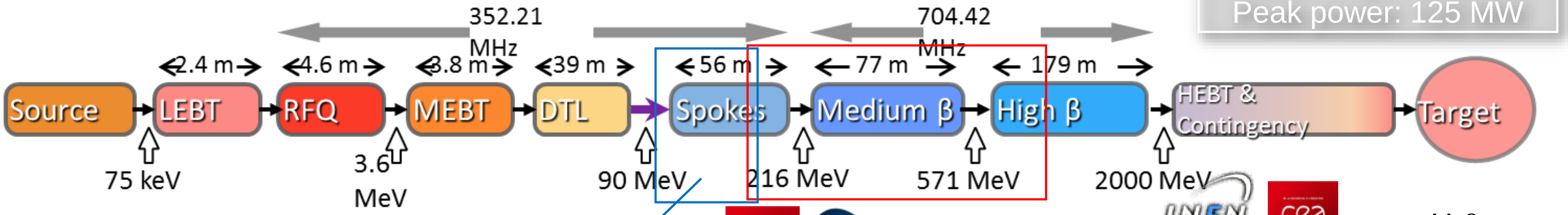
Name	Particles	# cavities		Type	Material	Gradient	Mode	T	Status	Location
HERA	electrons, positrons	16	500 MHz	β=1 elliptical 4-cell	Nb	4.0 MV/m	CW	4.2 K	de-commissioned	DESY
LEP200	electrons, positrons	16 272	352 MHz	β=1 elliptical 4-cell	Nb Nb/Cu	5 MV/m 7 MV/m	CW	4.5 K	de-commissioned	CERN
LISA	electrons	4	500 MHz	β=1 elliptical 4-cell	Nb	6 MV/m	pulsed	4.2 K	de-commissioned	LN Frascati
MACSE	electrons	5	1.5 GHz	β=1 elliptical 5-cell	Nb	10 MV/m	CW	1.8 K	de-commissioned	CEA-Saclay
Tandem PA	ions	16 34	81 MHz 135 MHz	β=0.085 helix λ/2 β=0.085 helix λ	Nb	2.2 MV/m	CW	4.2 K	de-commissioned	CEA-Saclay
Tandem PA	ions								de-commissioned	Daresbury
ALICE	electrons	2 2	1.3 GHz	β=1 elliptical 9-cell β=1 elliptical 9-cell	Nb	3-5 MV/m 13.5 MV/m	pulsed	2 K	operation	Daresbury
ALPI	ions	2 12 50 58	80 MHz 80 MHz 160 MHz 160 MHz	β=0.0255 RFQ β=0.055 QW β=0.13 QW β=0.13 QW	Nb Nb Pb/Cu Nb/Cu	2-3 MV/m 4 MV/m 2.7 MV/m 4.8 MV/m	CW	4.5 K	operation de-commissioned	LN Legnaro
DIAMOND	electrons	2	500 MHz	β=1 elliptical 1-cell	Nb	6.5 MV/m	CW	4.5 K	operation	Oxford
ELBE	electrons	1 4	1.3 GHz	β=1 elliptical 3½-cell β=1 elliptical 9-cell	Nb	8 MV/m 9 MV/m	CW	2 K	operation	HZDR
ELETTRA	electrons	1	1.5 GHz	β=1 elliptical 2-cell	Nb	5 MV/m	CW	4.5 K	operation	Trieste
FLASH	electrons	56 4	1.3 GHz 3.9 GHz	β=1 elliptical 9-cell	Nb	20-30 MV/m 14.5 MV/m	pulsed	2 K	operation	DESY
ISOLDE	ions	12 20	101 MHz	β=0.063 QW β=0.103 QW	Nb/Cu	6 MV/m	CW	4.5 K	operation	CERN
LHC	protons, ions	16	400 MHz	β=1 elliptical 1-cell	Nb/Cu	6 MV/m	CW	4.5 K	operation	CERN
S-DALINAC	electrons	1 1 10	3 GHz	β=0.85 elliptical 2-cell β=1 elliptical 5-cell β=1 elliptical 20-cell	Nb	5 MV/m 5 MV/m 5 MV/m	CW	2 K	operation	Darmstadt
SLS	electrons	1	1.5 GHz	β=1 elliptical 2-cell	Nb	5 MV/m	CW	4.5 K	operation	PSI
SOLEIL	electrons	4	352 MHz	β=1 elliptical 1-cell	Nb/Cu	6 MV/m	CW	4.2 K	operation	SOLEIL
E-XFEL	electrons	808 8	1.3 GHz 3.9 GHz	β=1 elliptical 9-cell	Nb	24 MV/m 15 MV/m	pulsed	2 K	operation	Hamburg
SPIRAL2	D+, ions A/Q = 3	12 14	88 MHz	β=0.07 QW β=0.12 QW	Nb	6.5 MV/m 6.5 MV/m	CW	4.2 K	operation	GANIL
BERLinPro	electrons	1 3 3	1.3 GHz	β=1 elliptical 1½-cell β=1 elliptical 2-cell β=1 elliptical 7-cell	Nb	20 MV/m 18 MV/m	CW	2 K	construction	HZB
IFMIF-EVEDA	D+	8	176 MHz	β=0.094 HW	Nb	4.5 MV/m	CW	4.5 K	construction	Rokkasho
SARAF	D+	12 14	176 MHz	β=0.091 HW β=0.181 HW	Nb	6.5 MV/m 7.5 MV/m	CW	4.5 K	construction	SOREQ
ESS	protons	26 36 84	352 MHz 704 MHz 704 MHz	β=0.5 double spoke β=0.67 elliptical 6-cell β=0.86 elliptical 5-cell	Nb	8 MV/m 15.5 MV/m 18.2 MV/m	pulsed	4.5 K	construction	Lund

European Spallation Source (ESS)

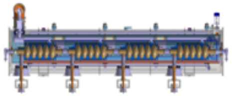

April 2018

- ❑ The European Spallation Source is under construction in Lund, Sweden
- ❑ ESS will offer neutron beams of unparalleled brightness for cold neutrons, delivering more neutrons than the world’s most powerful reactor-based neutron sources today, and with higher peak intensity than any other spallation source

High Power Accelerator
Ultimate energy: 2 GeV
Repetition rate: 14 Hz
Pulse length: 2.89 ms
Peak power: 125 MW



UPPSALA UNIVERSITET



M-β

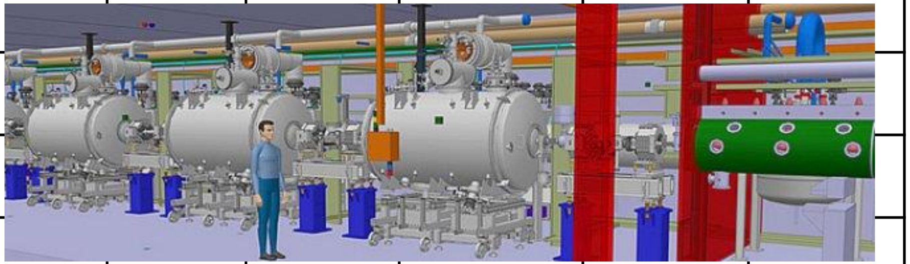
H-β

- ❑ ESS Cold Linac:

a collaborative project

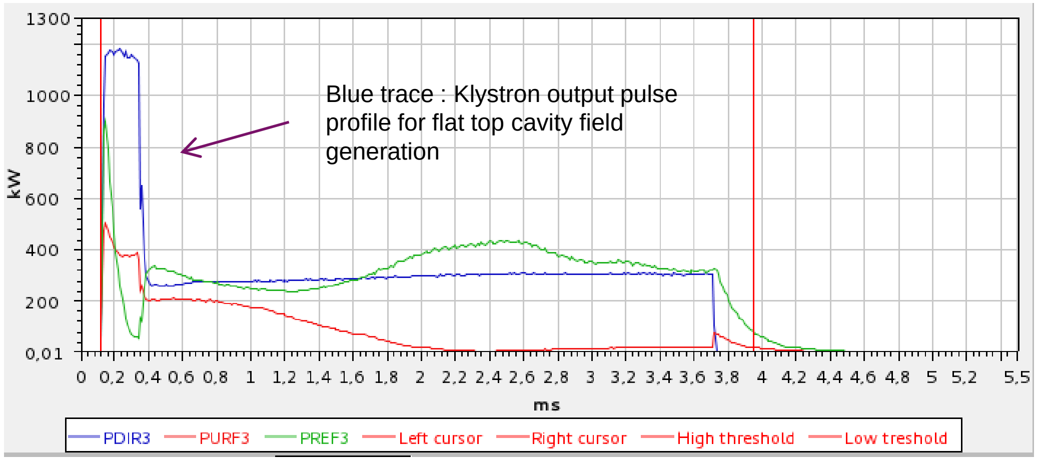
ESS LINAC Work Matrix

	EU	Germany	France		Italy		Poland	Spain	Sweden	UK
	ESS-Lund	DESY	CEA	CNRS	Elettra	INFN	IFJ-PAN	ESS-Bilbao	Uppsala	STFC
Linac Components										
RF systems	✓				✓			✓		
LLRF									✓	
Cryomodules			✓	✓						
SRF cavities			✓	✓		✓				✓
Powers Couplers			✓	✓						
Frequency Tuners			✓	✓						
Cold vacuum	✓		✓	✓						
Module Assembly			✓	✓						
Test Infrastructures										
Cavities/couplers		✓	✓	✓						✓
Cryomodules	✓		✓	✓			✓		✓	



ON-GOING HIGH POWER TEST OF ESS MEDIUM β=0.67 CRYOMODULE AT CEA-SACLAY : PRELIMINARY RESULTS

- Operated at 2K
- All four cavities connected to RF source
- 3 CEA cavities, 1 INFN cavity
- Only single cavity high power operation is possible with the current setup
- Fundamental Power Couplers (FPC) are conditionned at room temperature first, then at 2K up to 1.2 MW peak power



Blue trace : Klystron output pulse profile for flat top cavity field generation

Up to now:

- 4 FPCs conditioned at room temperature, 3 FPCs conditioned with cryogenic operation
- All cavities tuned to nominal frequency at 704.42 MHz
- 2 cavities operated at 2K above nominal gradient of 16.7 MV/m , RF pulse of 3.6 ms total, @14 Hz, with LFD piezo compensation

‘COBOT’-IZATION

Xband infrastructure overview 2018-11-8

High-gradient test infrastructure

CERN	XBox-1	50 MW, 12 GHz	Operational (later to CLEAR)
	Xbox-2	50 MW, 12 GHz	Operational
	XBox-3	4x6 MW, 12 GHz	Operational
KEK	NEXTEF	2x50 MW	Operational
Tsinghua	Later energy upgrade for Thompson	50 MW, 12 GHz	Operational
Trieste	CTF	45 MW, 3 GHz	Operational
Valencia		2x10 MW, 3 GHz	Commissioning
Frascati		50 MW, 12 GHz	Procurement
Shanghai		50 MW, 12 GHz	Installation
Melbourne, ALS		2x6 MW, 12 GHz	Planning
SLAC	NLCTA+XTA	2x50 MW, 11 GHz	Operational
	Klystron Test Lab	2x50 MW, 11 GHz	Operational

X-band linearizers and deflectors

Trieste	Linearizer for Fermi	50 MW	Operational
PSI	Linearizer for SwissFEL	50 MW	Operational
	Deflector for SwissFEL	50 MW	Procurement
DESY	Deflector for FLASHforward	6 MW	Procurement
	Deflector for FLASH2	6 MW	Procurement
	Deflector for Sinbad	tbd	Procurement
SINAP	Linearizer for soft X-ray FEL	6 MW	Operational
	Deflectors for soft X-ray FEL	2x50 MW	Procurement
Daresbury	Linearizer	6 MW	Procurement
Tsinghua	Linearizer for Compton source	6 MW	Planning
SLAC	LCWS linearizer	50 MW	Operational
	LCWS deflector	50 MW	Operational

X-band linacs

SLAC	NLCTA+XTA	2x50 MW, 11 GHz	Operational
Eindhoven	Compact Compton source - 25 MeV	6 MW	Procurement
CERN	CLEAR – 50 MeV (from Xbox-1)	50 MW	Preparation
Tsinghua	Thompson source upgrade – 50 MeV	50 MW	Design
Frascati	XFEL, injector to plasma - 1 GeV	8x50 MW	CDR
Collaboration	CompactLight – 6 GeV	30x50 MW	Design Study
CERN	LDMX – 3.5 GeV	24x50 MW	Letter of intent submitted
Groningen	1.4 GEV XFEL Accelerator - 1.4 GeV		NL roadmap
CERN	CLIC – 380 GeV	5800x50 MW	CDR