European XFEL & ILC-HiGrade cavities

- European XFEL cavities: fabrication strategy and test results
- ILC HiGrade program and actual test results
- Goal of the ILC related R&D program @ DESY
- Typical cavity surface defects
- CBP polishing of Nb cavities

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A Total of ~830 s.c. Cavities Ordered in Industry

Based on DESY's **long time experience** the two companies Research Instruments and E. Zanon were contracted to produce each

- 4+4 **pre-series cavities**
- 280 XFEL type **series cavities**
- 12 HiGrade cavities, first used for quality assurance, later available for further investigations & treatments (high gradient R&D towards ILC)
- Additional 120 cavities each were ordered as an option to be placed after the evaluation of the successful start of the series production

- **No performance guaranty given by the two vendors**, i.e. the risk of unexpected low gradient or field emission is with DESY
- **Production precisely following the specifications** which also include the exact definition of infrastructure to be used

- **Nb / NbTi to be supplied by DESY**

European ILC-HiGrade programme

24 cavities are added to the ***EXFEL*** order as a part of the ILC-HiGrade program:

- Initially, serve as **quality control (QC)** sample for the ***EXFEL***
  - extracted regularly, ~**one cavity/month:** **first half of cavities arrived!**
  - after the **normal acceptance test** will be **taken out** of the production flow --> **R&D**

- Delivered with **full treatment** but **no helium tank**
  -> **maximize** the data output from the test

- Further handling within **ILC-HiGrade** **as feasibility study** for **ILC goal**:
  - "Second sound" and T-mapping from the 2^{nd} cold RF test
  - optical inspection (OBACHT) and replica

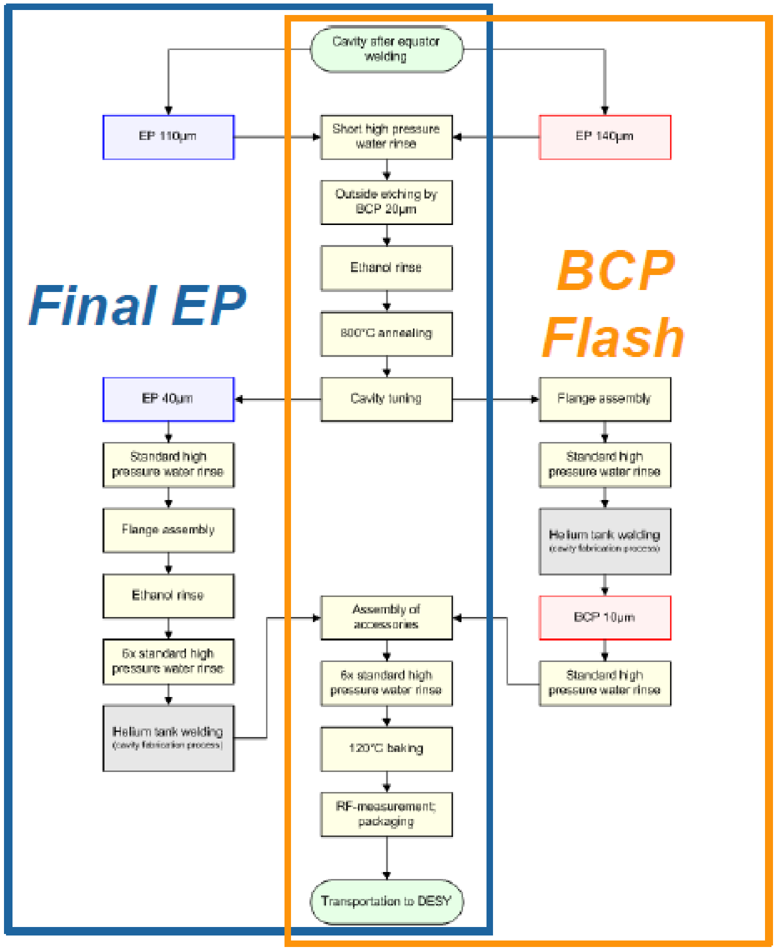
  Further treatment options:
  - Centrifugal Barrel Polishing (CBP)
  - Local Grinding repair
  - additional EP polishing

- Eventually aim **3 world record modules** from the **24 ILC-HiGrade cavities**

Cavity Surface Treatment

- **Two schemes** for the final surface treatment:
  - E. Zanon (Italy)**: BCP Flash**
  - Research Instruments (Germany)**: Final EP**

ILC recipe



- At each company:
  - 4 Cav for set-up of infrastructure
  - 4 Cav for qualification of infrastructure
  => Reference Cavities (RCV)
- Close **supervision** of infrastructure, processes, procedures and handling by DESY + INFN Milano required
- **No performance guarantee** results in:
  - the risk of unexpected low gradient or field emission is with DESY
  - **responsibility for re-treatment at DESY**

Vertical Acceptance Test at 2K

"Standard" cavity test at 2K

- Measurement of **$Q_0(E_{acc})$ in π-mode**
- Measurement of **fundamental mode frequencies**
- **X-ray** control on top and bottom of each cryostat
- Remark: no $Q_0(T)$,
  no $Q_0(E_{acc})$ in fundamental modes,
  no $Q_0(E_{acc})$ at various bath temperatures
- Remark II: RF measurement one by one

> **Cavity "full equipped"**

- Dressed with He-tank (except HiGrade cavities)
- Equipped with fixed High Q-antenna pick-up and two HOM-antennas
- All cavities checked for Q-disease by parking at 100K

> **Measurement with fix coupling**
=> overcoupled at low and medium gradients
=> larger error than at $\beta \approx 1$

> "Long pulse" operation (few sec RF on) not full cw (protection of HOM feedthroughs)

Acceptance criteria

- **Acceptance criteria:** “Usable gradient” >26 MV/m with either
  - Quench or
  - Unloaded Q_0 of $\geq 1\text{x}10^{10}$ or
  - X-ray level: upper detector < $1\text{x}10^{-2}$ mGy/min;
    lower detector < 0.12 mGy/min
- with 26 MV/m to give 10% margin compared to 23.6 MV/m design gradient
- **Definition of usable gradient:**
  - Gradient of Quench or
  - Gradient of Unloaded Q_0 of = $1\text{x}10^{10}$ or
  - Gradient of X-ray level: upper detector = $1\text{x}10^{-2}$ mGy/min; lower detector = 0.12 mGy/min

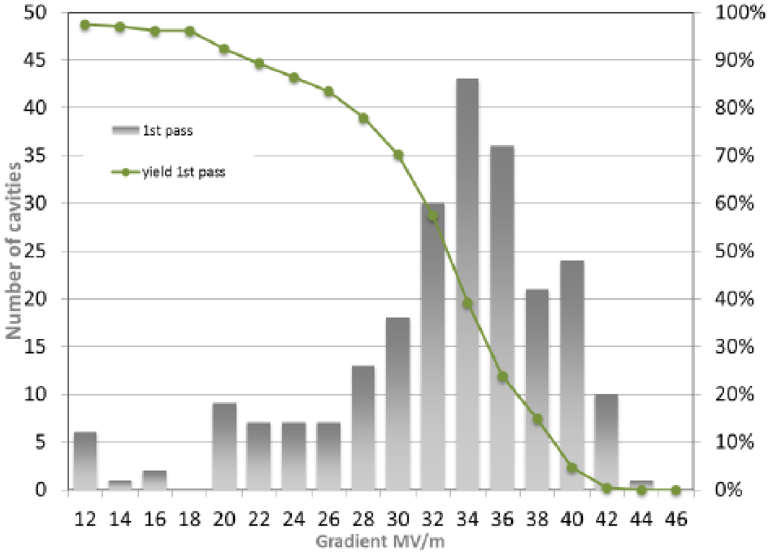
Yield of gradients for EXFEL: Status March 14, 2014

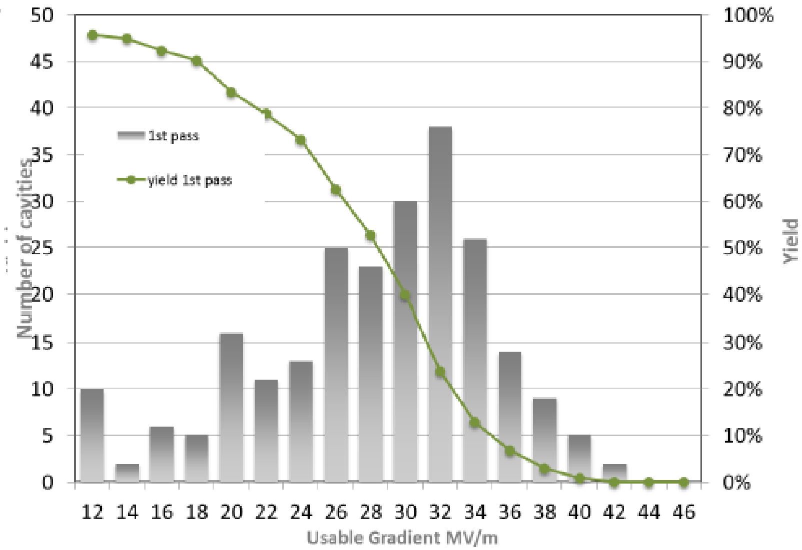
Test Results for the Testing of 800 Series Cavities for the European XFEL

European XFEL

Yield of gradients: As received / 1. Pass

- Yield of usable and maximum gradient of **237 cavities as received => 66 % (156 cavities) passed**





Average **maximum** gradient: **(31.0 ± 6.9) MV/m**

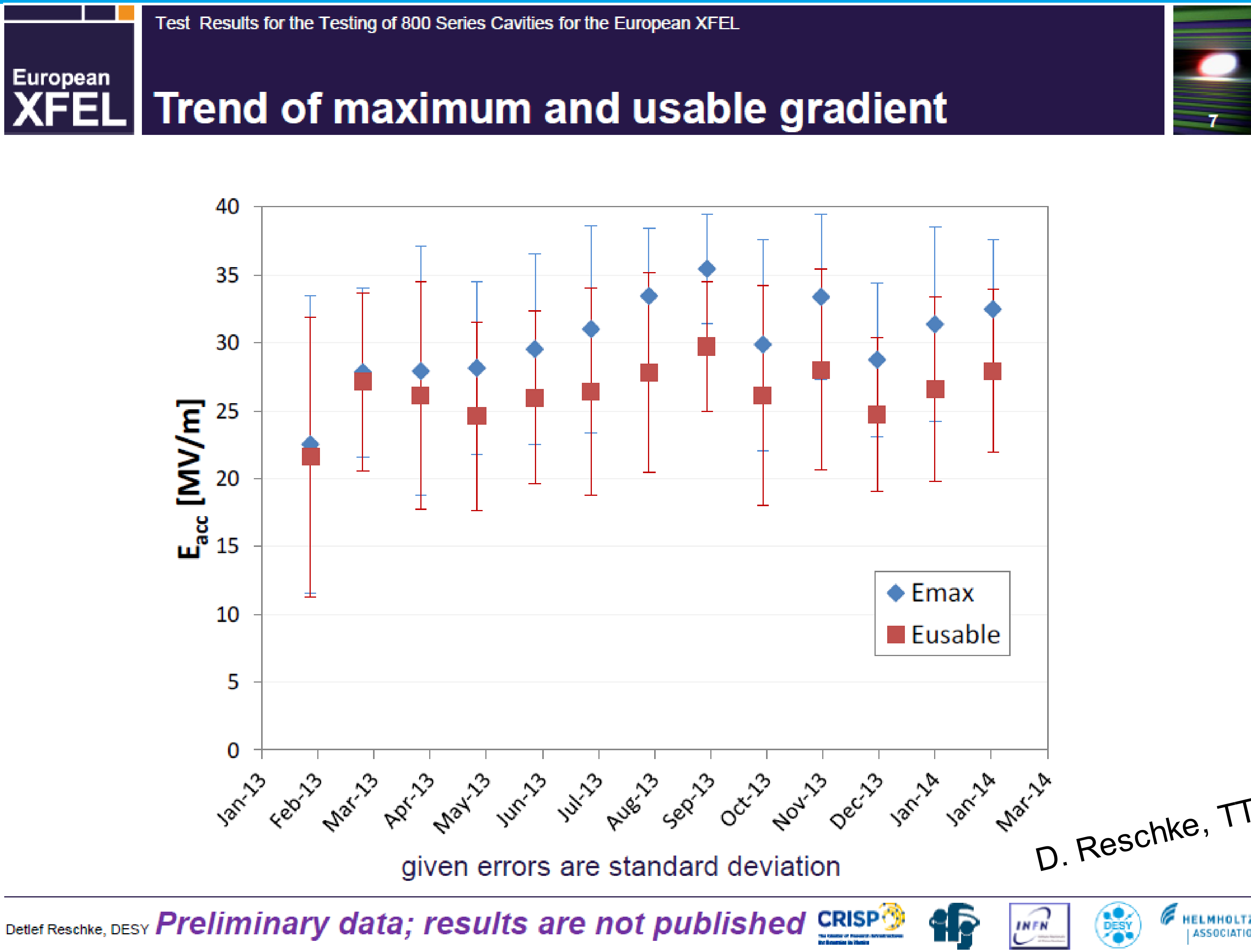
Average **usable** gradient: **(26.6 ± 7.1) MV/m**

given errors are standard deviation

D. Reschke, TTC 2014

Detlef Reschke, DESY *Preliminary data; results are not published*

Trend of gradients: Status March 14, 2014



D. Reschke, TTC 2014

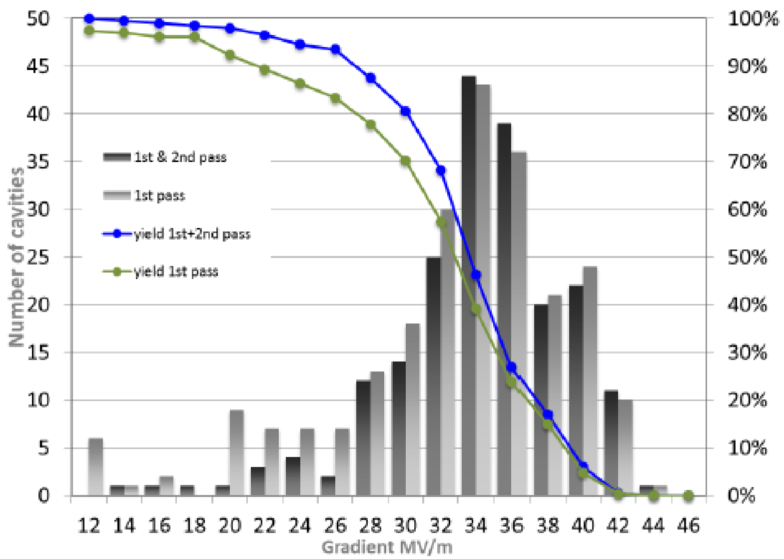
Retreatment: Status March 14, 2014

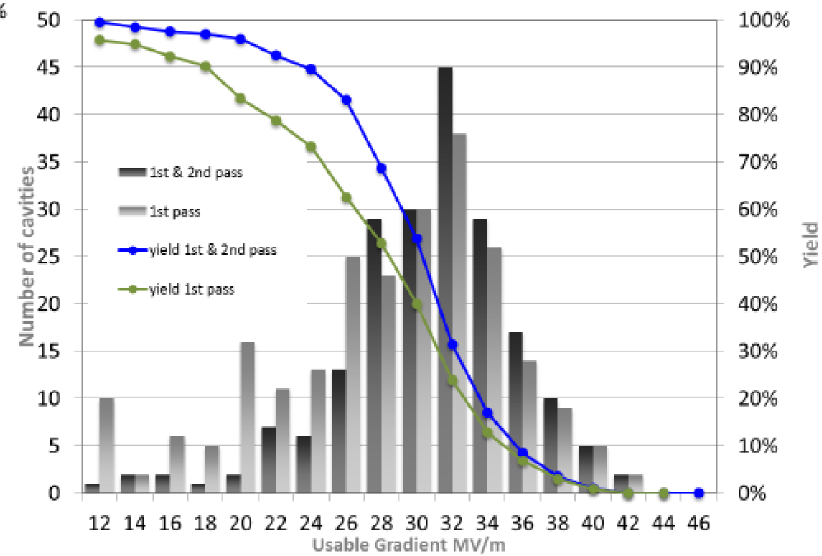
Test Results for the Testing of 800 Series Cavities for the European XFEL

European XFEL

Yield of gradients: After 1. re-treatment (2. pass)

- Yield of usable and maximum gradient of ~207 cavities (2.pass) **=> 85%** (cavities that passed in 1. pass + results of cavities after re-treatment)
- **Average** gradients **increased + spread reduced**





Average **maximum** gradient: **(32.8 ± 4.9) MV/m**

Average **usable** gradient: **(29.3 ± 5.1) MV/m**

given errors are standard deviation

D. Reschke, TTC 2014

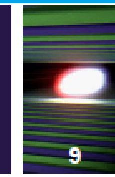
Detlef Reschke, DESY *Preliminary data; results are not published*

Q-values: Status March 14, 2014

Test Results for the Testing of 800 Series Cavities for the European XFEL

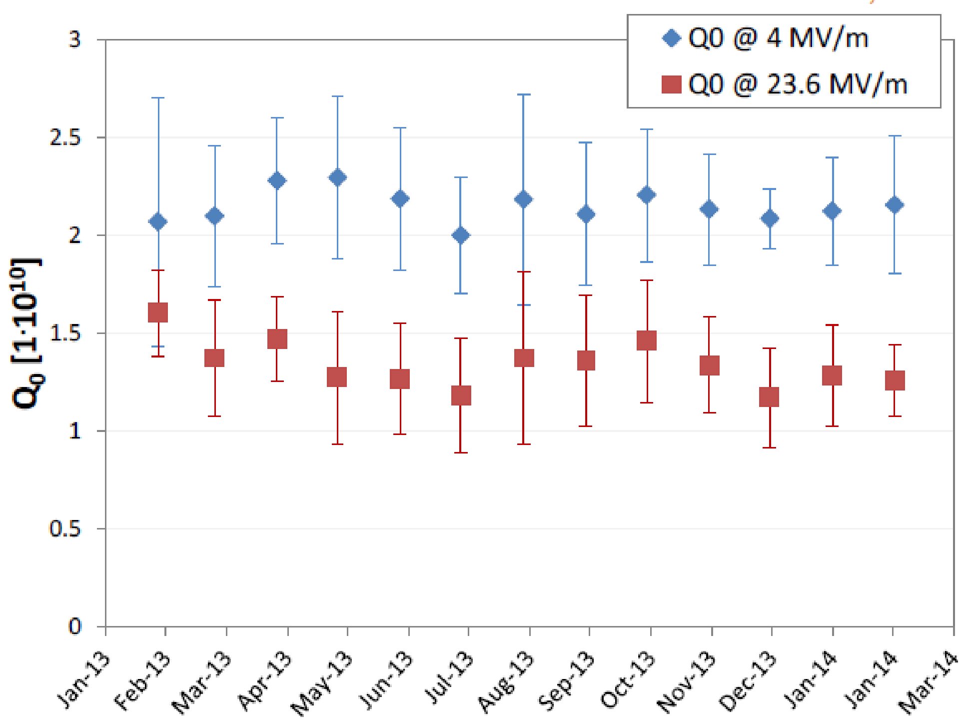
European XFEL

Q-Values



- Low field Q_0-value „As received“

$Q_{0,max} = (2.2 \pm 0.4) \cdot 10^{10}$
(standard deviation)



- Few cavities show Q-value < $2 \cdot 10^{10}$ at low gradient even w/o FE
  => feedback and quality control to companies
  => reason not clear

D. Reschke, TTC 2014

Detlef Reschke, DESY *Preliminary data; results are not published*

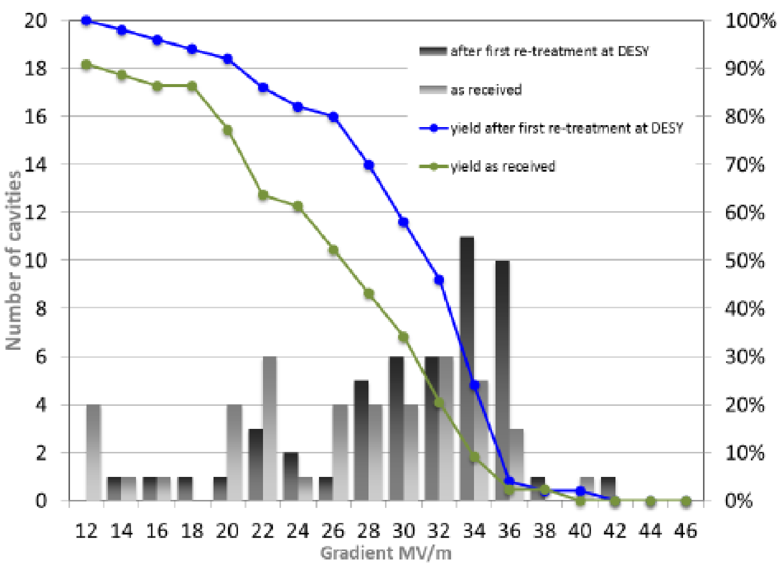
Retreatment I: Status March 14, 2014

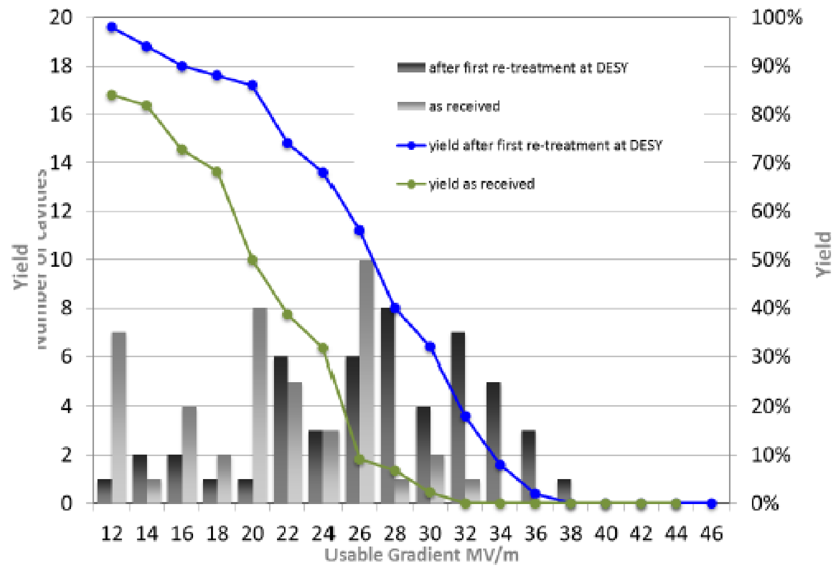
Test Results for the Testing of 800 Series Cavities for the European XFEL

European XFEL

Re-Treatment I

- Analysis of 50(45) cavities after **first** re-treatment => **typically HPR**
- Reason for re-treatment is typically **field emission**





Average **maximum** gradient	before re-treatment: (24.4 ± 8.2) MV/m
	after re-treatment: **(29.2 ±5.9) MV/m**
Average **usable** gradient	before re-treatment: (18.8 ± 6.8) MV/m
	after re-treatment: **(25.5 ±6.4) MV/m**

D. Reschke, TTC 2014

Detlef Reschke, DESY *Preliminary data; results are not published*

Retreatment II: Status March 14, 2014

Test Results for the Testing of 800 Series Cavities for the European XFEL

European XFEL

Re-Treatment II

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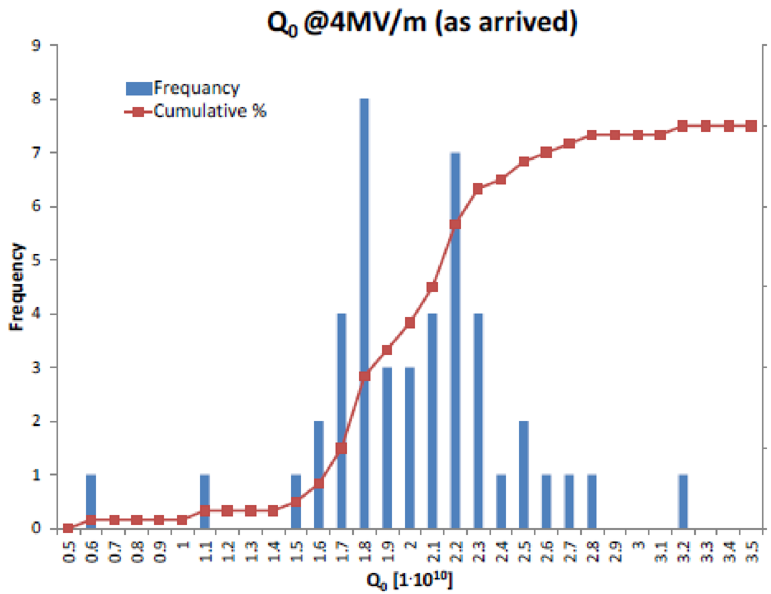
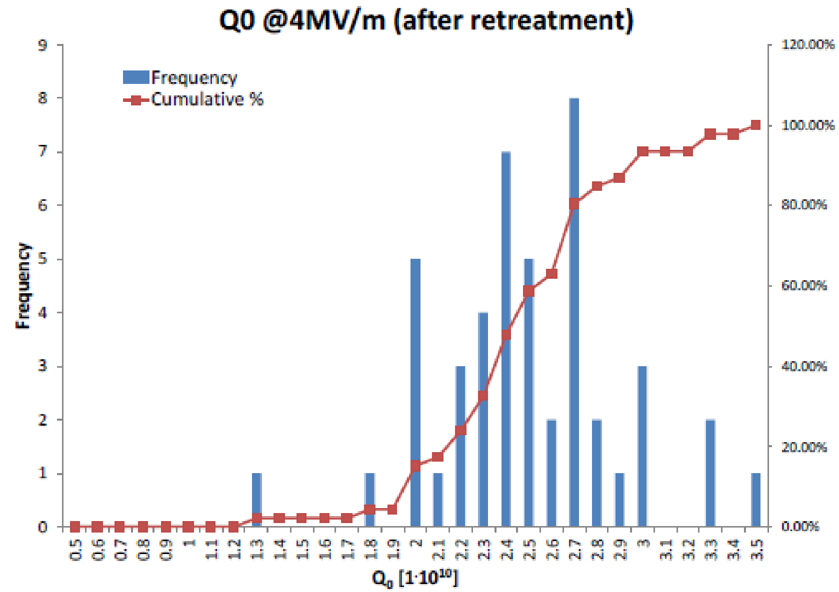
- Improvement of **Q-value**: **Q_0 @ 4 MV/m = 2.0 · 10^{10} -> 2.5 · 10^{10}**

  Q_0 @ 23.6 MV/m = 1.1 ·10^{10} -> 1.5 ·10^{10}





- **Second Re-Treatment** (6 cavities so far)**:**
  typically short 5-10µm BCP + HPR + 120C bake
  => NOT in this analysis

D. Reschke, TTC 2014

Detlef Reschke, DESY *Preliminary data; results are not published*

BCP Flash vs. Final EP: Status September 2013

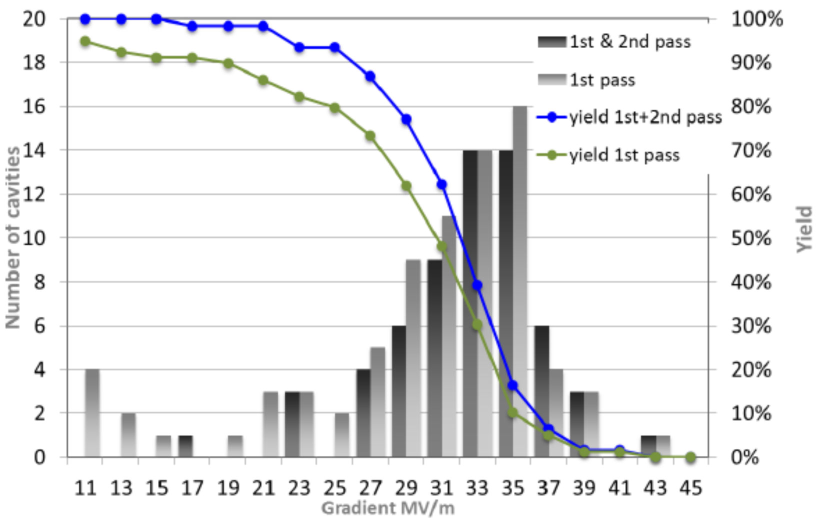
Infrastructure, Methods and Test Results for the Testing of 800 Series Cavities for the European XFEL

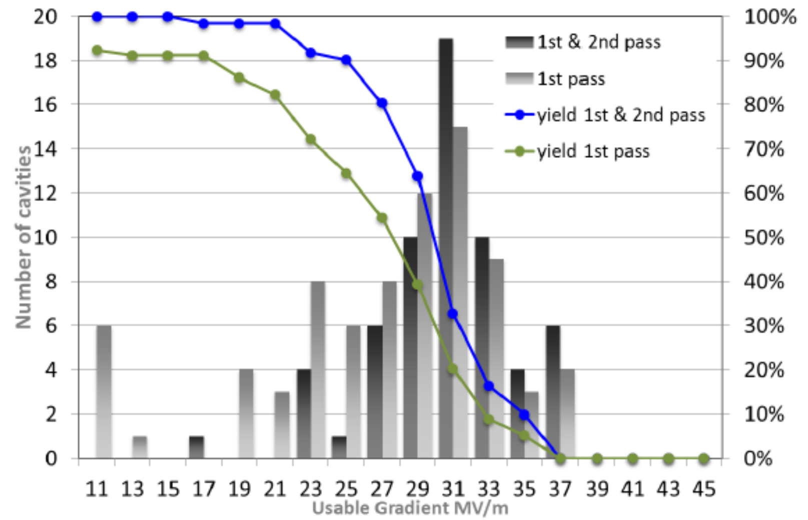
European XFEL

Yield of gradients: After re-treatment (2. pass)

15

- Yield of usable and maximum gradient of 64 cavities (2.pass):
  50 cavities passed in 1.pass + 14 cavities after re-treatment
- **Average gradients increased + spread reduced** (standard deviation)





Average **maximum** gradient:

(30.9 ± 4.4) MV/m

EZ: (30.4 ± 4.5) MV/m

RI: (32.3 ± 4.1) MV/m

ILC recipe

Average **usable** gradient:

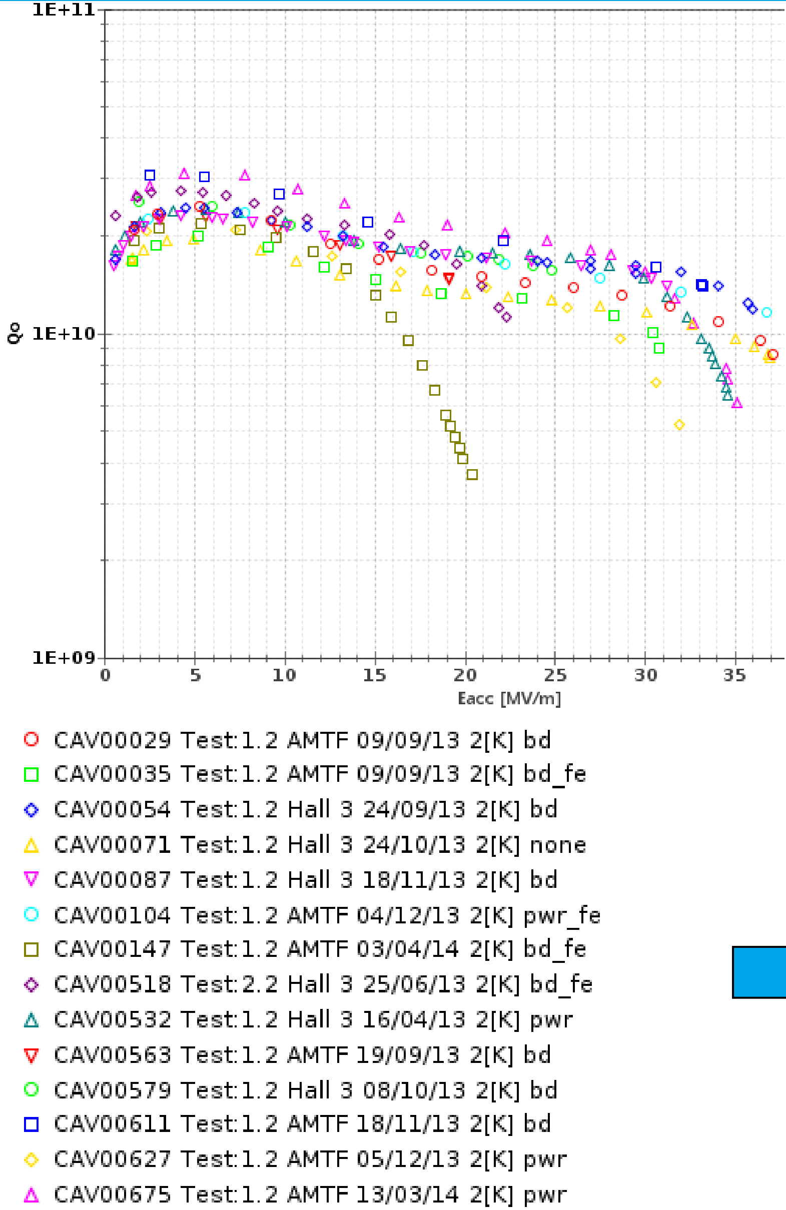
(29.0 ± 3.9) MV/m

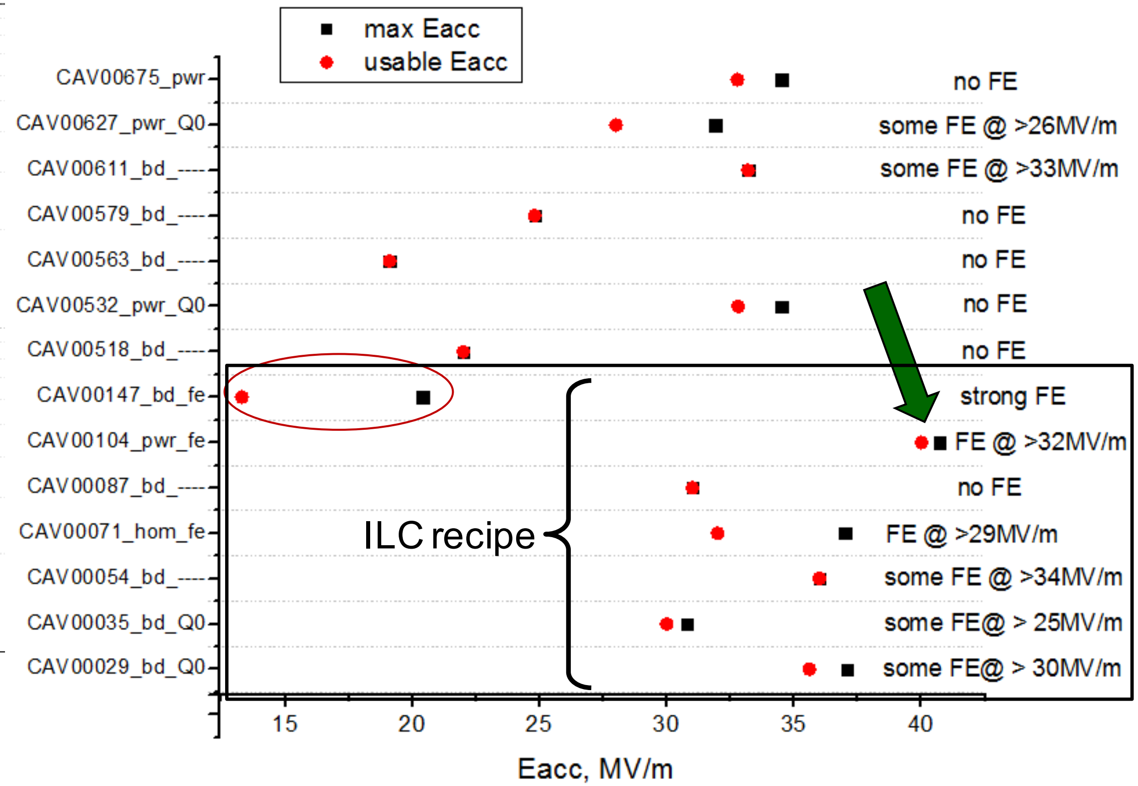
EZ: (28.4 ± 4.0) MV/m

RI: (30.6 ± 3.1) MV/m

D. Reschke, SRF2013

Cold RF tests ILC-HiGrade cavities (14 out of 24)





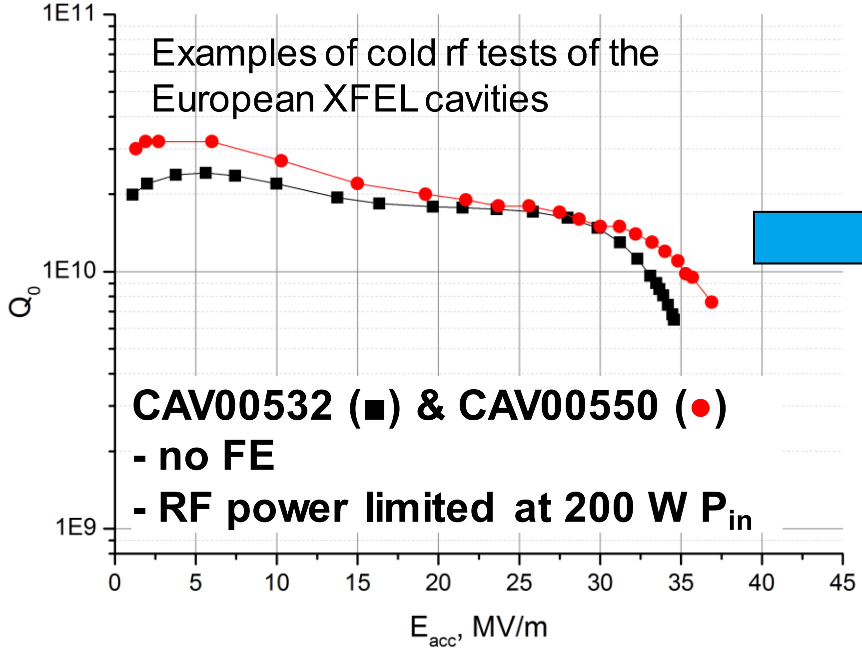
- "ILC recipe" provides cavities with maximum usable gradient of ~31 (34) MV/m, some achieve >40 MV/m

- Main limitation is FE

Goal of the ILC related R&D program @ DESY

- Solid understanding/control of the industrial mass-production process (with 800 EXFEL +24 ILC-HiGrade cavities

- Clear **identification** of the **gradient limiting factors**
- **Elaboration** of cavity treatment providing at least **E_{acc} > 35 MV/m** @ **>90% yield**



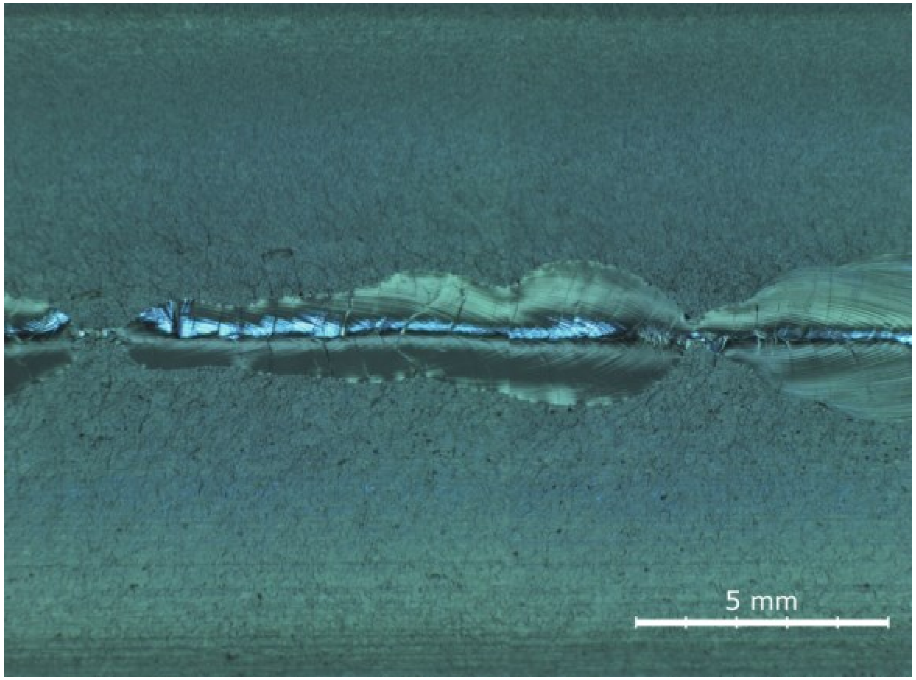
The EXFEL production process has **provided** cavities with **35 MV/m** gradient

Goal: establish **high yield** at high field

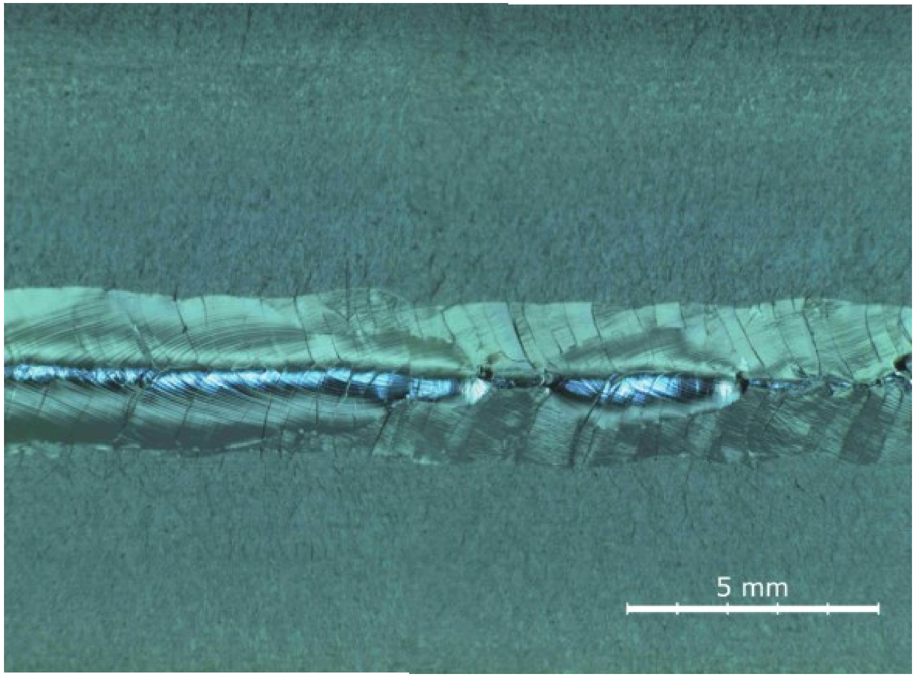
R&D program @ DESY derived from global effort for ILC and well in phase with effort elsewhere

Typical surface defects: irregular welding

> **Optimization** of equator welding parameters:



Initial, **not optimized**
→ **e$^-$ -beam not penetrated everywhere**
→ **strong variation of the seem- width**



Final, **optimized**
→ **e$^-$ -beam fully penetrated**
→ **homogeneous welding seem**

> **OBACHT** provides much **better resolution and image quality** as compared to the conventional **endoscopes**

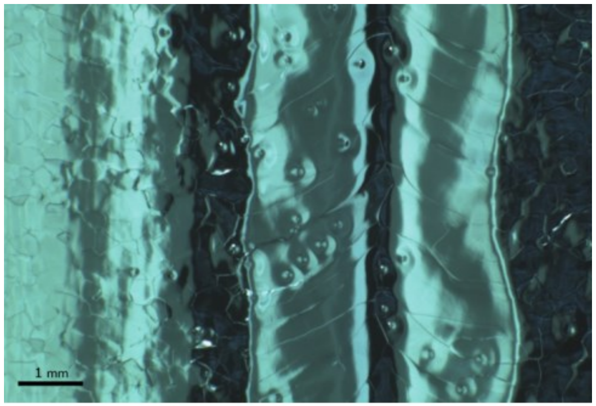
Cold RF tests vs. surface quality

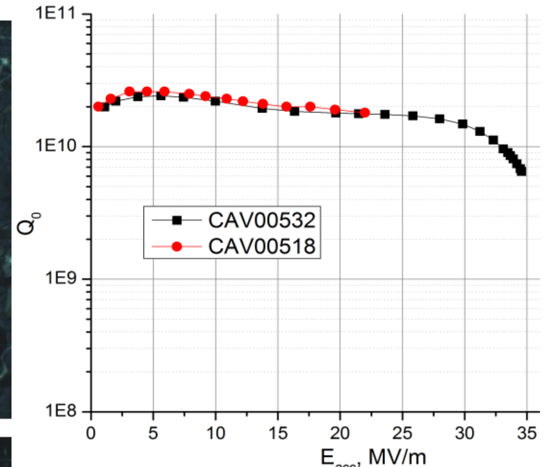
CAV00532:

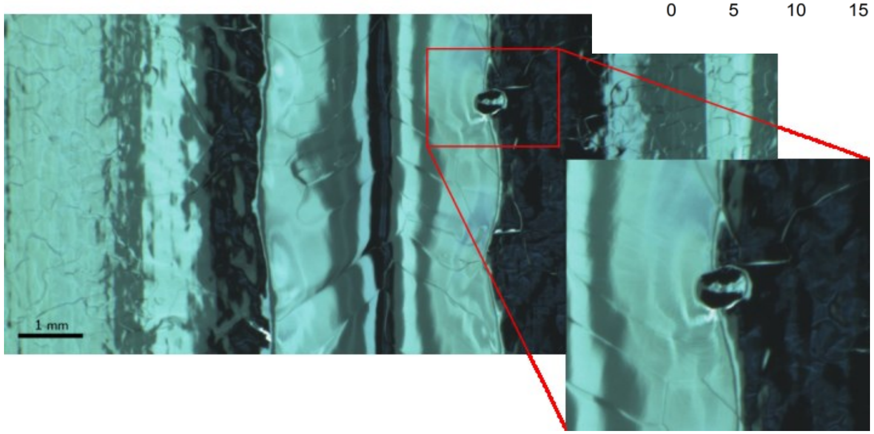
→ **Successful** cold RF test result with **no FE**, RF power limited at 200W P_{in})

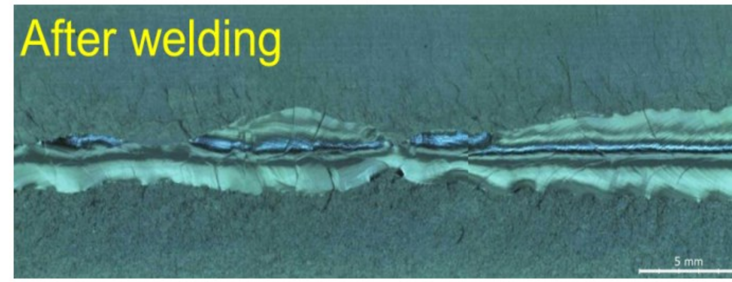
CAV00518:

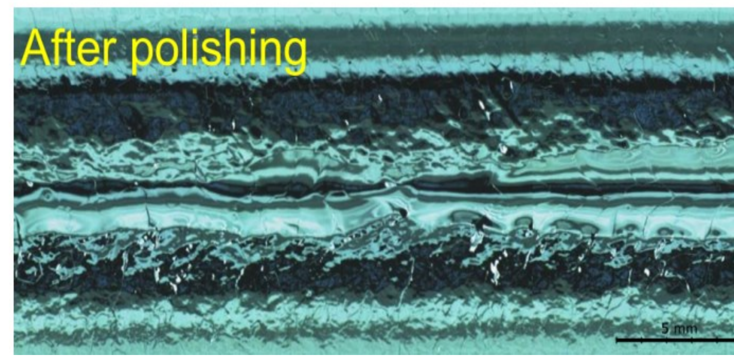
→ Unsuccessful cold RF test result with quench at **22 MV/m**, **no FE**











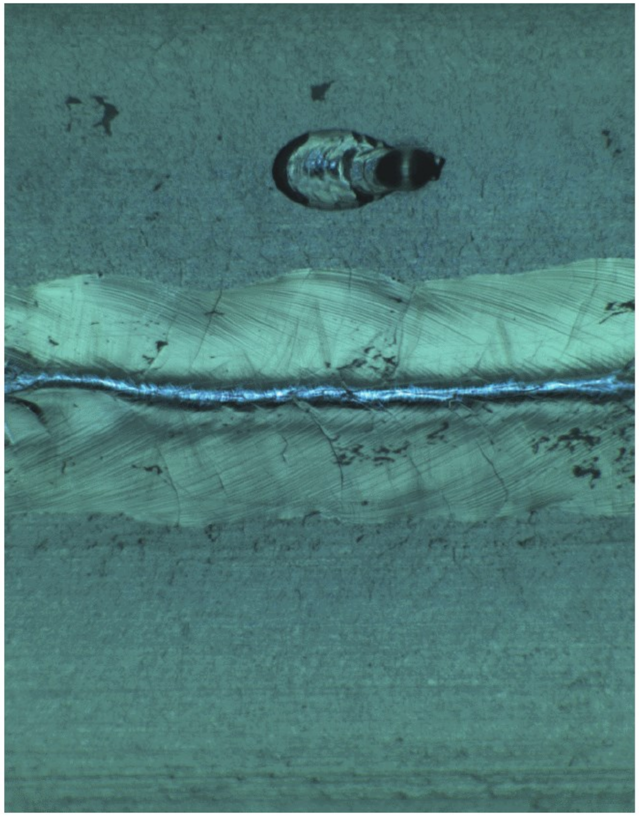
-> **Nice** RF result despite of “pits” and “cat-eyes” on the surface

-> OBACHT indicates defective welding as a possible quench reason

→ **Second Sound** & **T-mapping** will be applied for the quench localization and further studies

Typical surface defects: welding spatters

Endoscopes & **OBACHT** (shown here) inspections discover some **"spatters"** occasional occurring during the welding:



After final polishing:

→ max E_{acc} **= 30.5 MV/m**
→ **no FE**

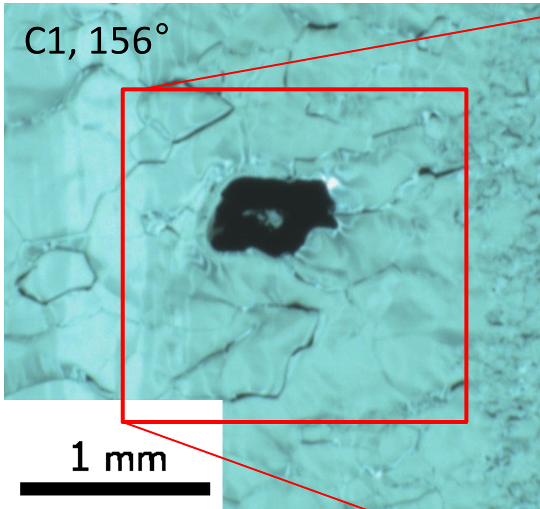
→ reason is under investigation

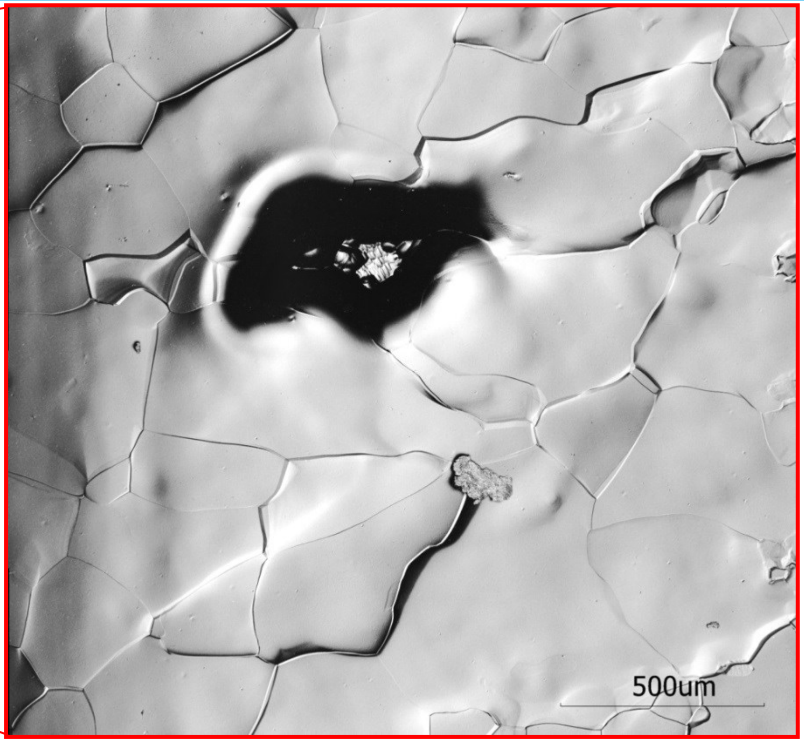
→ an **additional grinding/repair** is required

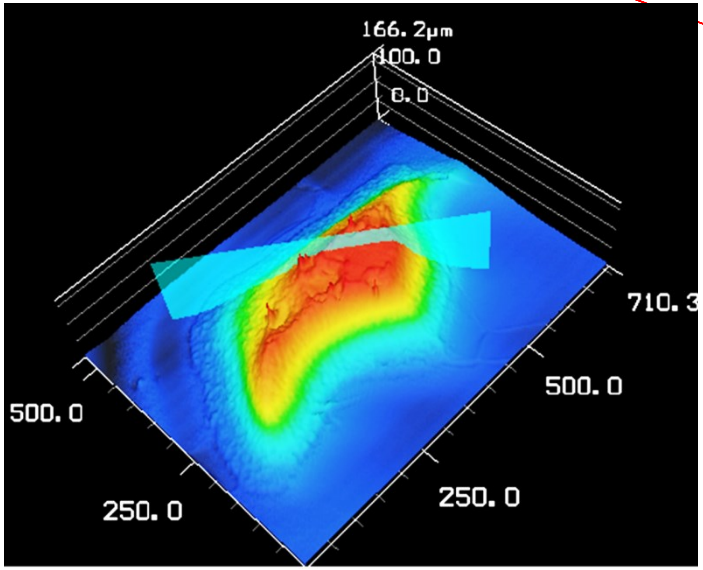
→ optimum repair procedure (here shown a manual one) is under study

Typical surface defects: foreign inclusions

OBACHT image







- E_{max} = 16 MV/m at low Q-value of 1.6e10 limited by Quench
- height of the defect is ~124 µm
- Most probably a foreign inclusion not affected by polishing
- No inclusion was seen by Eddy current scans

Centrifugal Barrel Polishing (CBP) of Nb cavities

How to repair cavities?

- Which kind of defects can be removed by CBP?
- How does CBP influence on cavities performance?

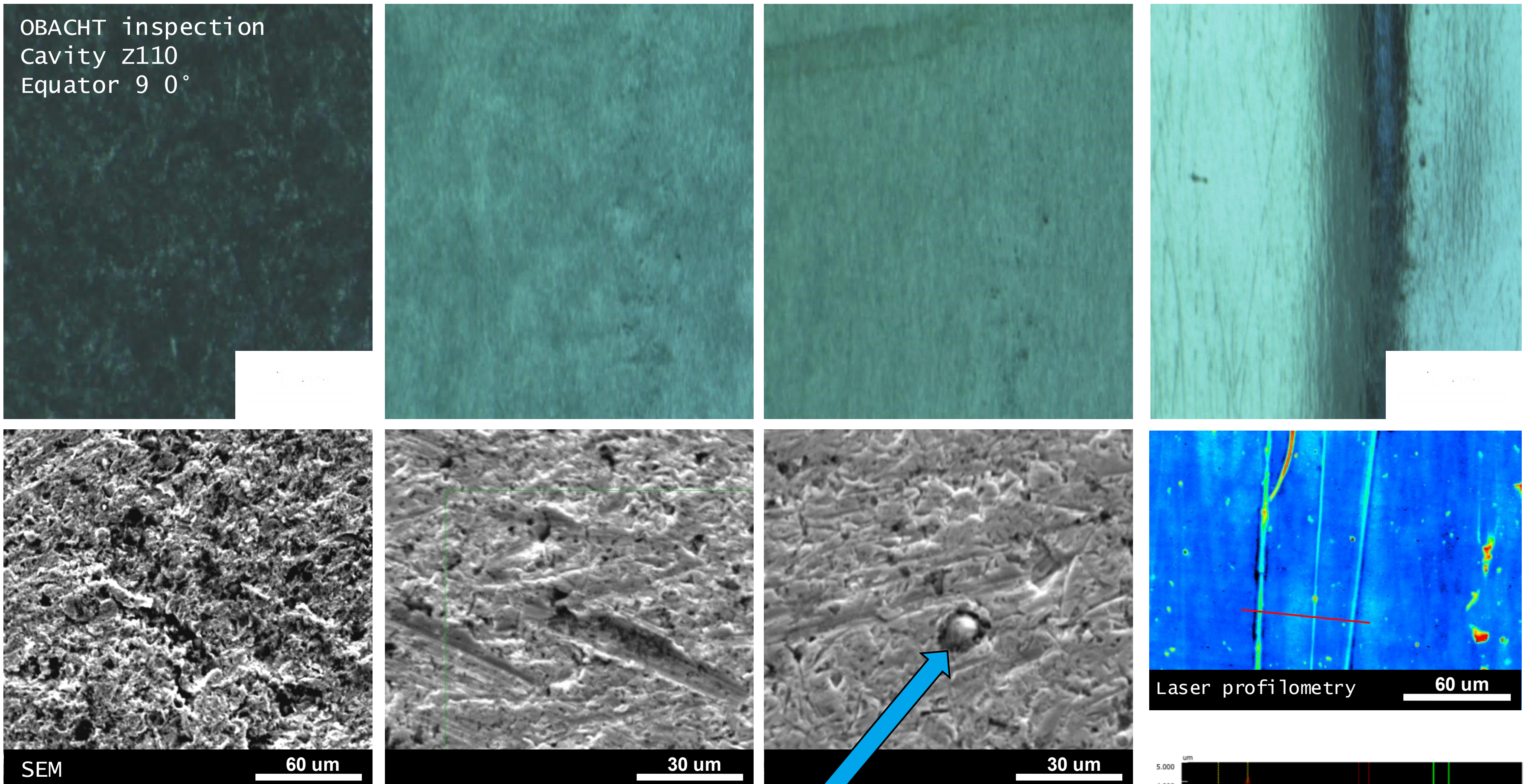
Can we replace bulk EP?

- Can CBP be used to remove Nb damaged layer (~150 μm) instead of bulk EP?
  (reduced sulphur contamination?)
- Can CBP be integrated in the existing production flow?

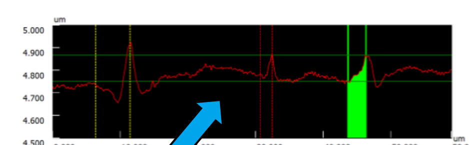
The CBP machine is being commissioned based on the polishing recipes derived from best FNAL, JLAB, and previous DESY experience

CBP of Nb cavities: OBACHT+SEM+EDX+ Replica/3D Laser profilometer analysis

Step 1 | Step 2 | Step 3 | Step 4

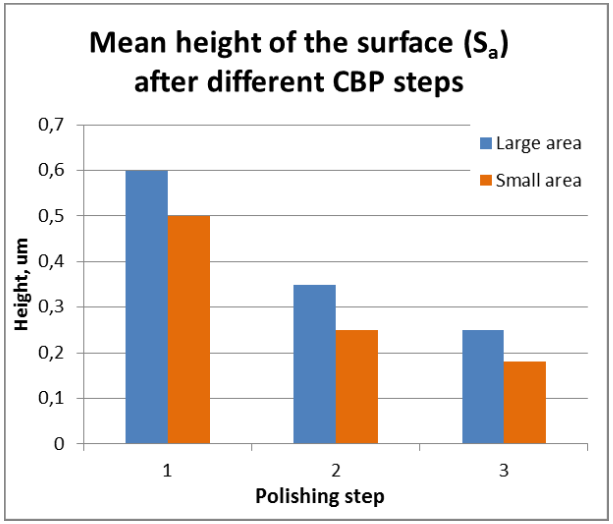


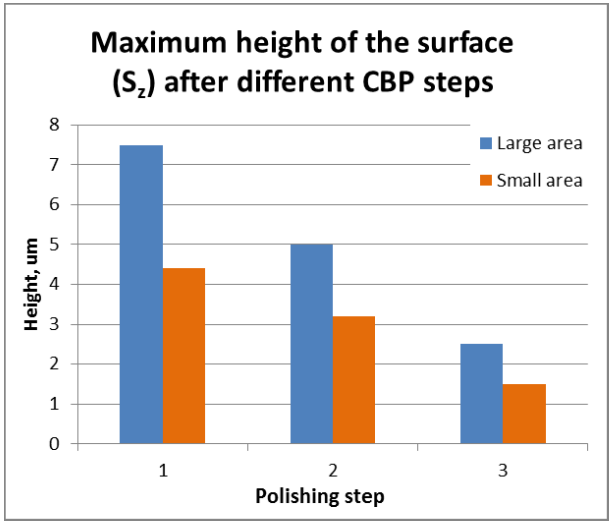
Embedded particle of polishing media (Al_2O_3)



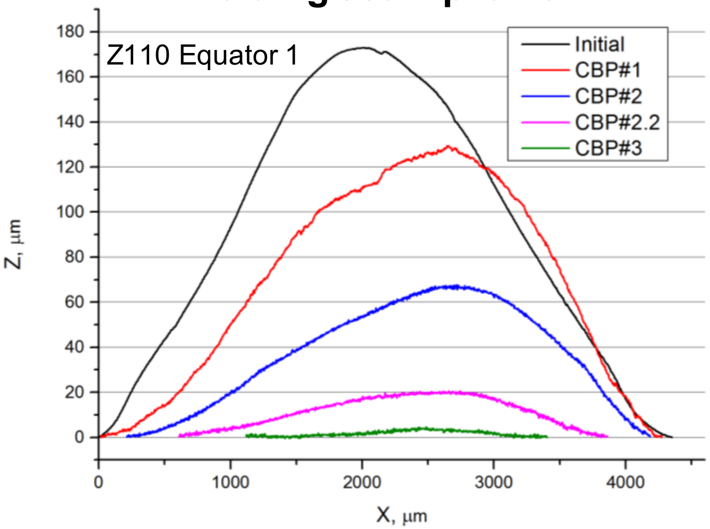
Welding seam profile

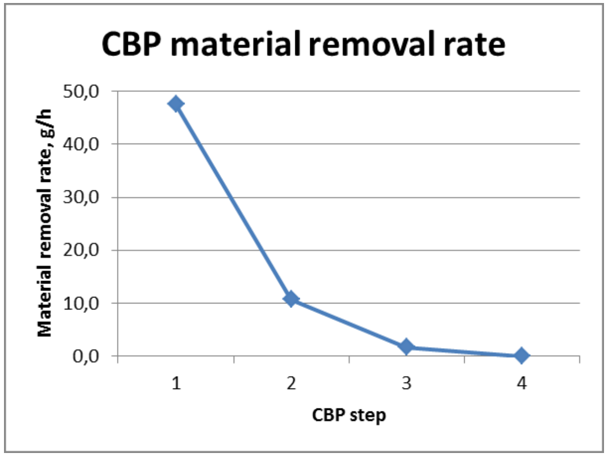
CBP of Nb cavities: roughness and removal analysis





Welding seam profile





Thank you for your attention !

Acknowledgements:
- **FLA/ILC group** (Eckhard Elsen, Brian Foster, Yegor Tamashevich, Alena Prudnikava, Ricarda Laasch, Marc Wenskat, Lea Steder, Sebastian Aderhold, Jörn Schaffran, Uwe Cornett, Gert Falley, Agnessa Guddat), Nicholas John Walker
- **all DESY and INFN colleagues** involved in the XFEL cavity fabrication, treatment and tests.

Some slides/information is taken from SRF2013 and TTC2014 talks of D. Reschke

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