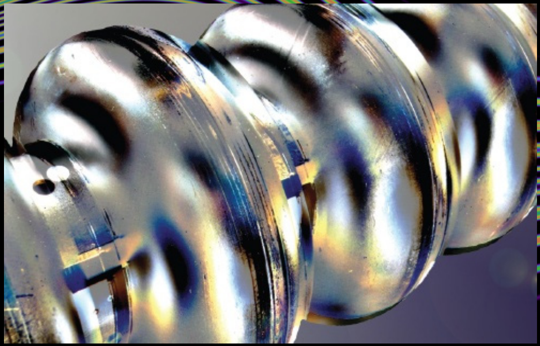
NITROGEN INFUSION R&D FOR CW OPERATION AT DESY



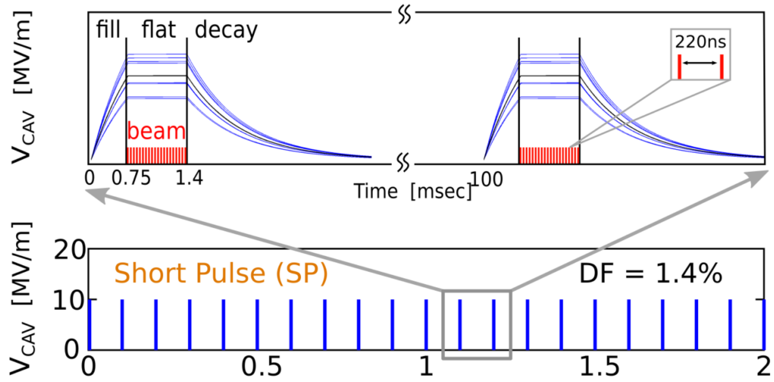
Marc Wenskat on behalf of the SRF team at DESY
LINAC 2018, Beijing – 20.9.2018

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

DESY.

European XFEL

Motivation



E = 17.5 GeV

N_{bunch}/s = 27k

European XFEL

Motivation

Benefits of Continuous Wave (CW) operation

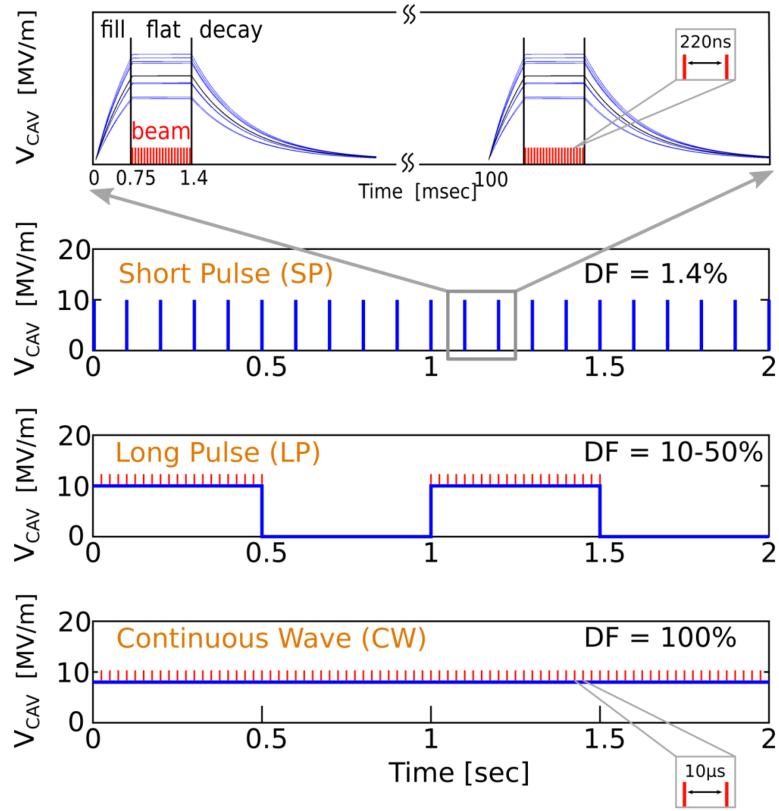
- Flexible beam patterns for detectors

Almost any macro pulse structure can be offered

- Slower repetition rate lasers
- Fill-transients no longer an issue

Benefits of Long Pulse (LP) operation

- Still high duty factor (DF = 10-50%)
- Higher gradients than CW with same heat load



$E = 17.5$ GeV

$N_{bunch}/s = 27k$

$E = 10$ GeV

$N_{bunch}/s = 50k^*$

*up to 500 kHz for 20pC

$E = 8$ GeV

$N_{bunch}/s = 100k^*$

*up to 1 MHz for 20pC

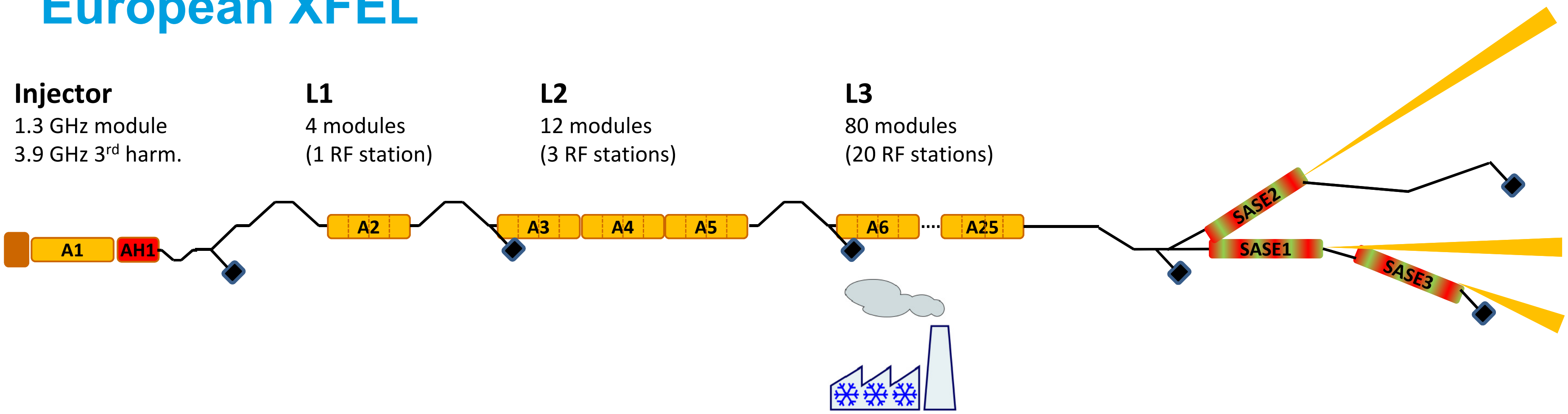
European XFEL

Injector
1.3 GHz module
3.9 GHz 3rd harm.

L1
4 modules
(1 RF station)

L2
12 modules
(3 RF stations)

L3
80 modules
(20 RF stations)



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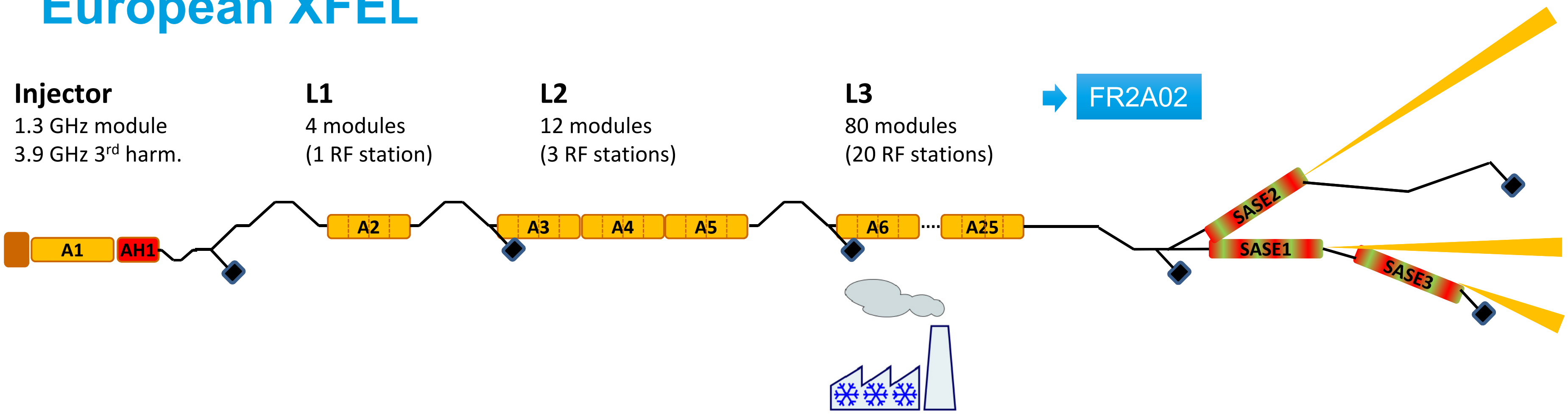
FR2A02



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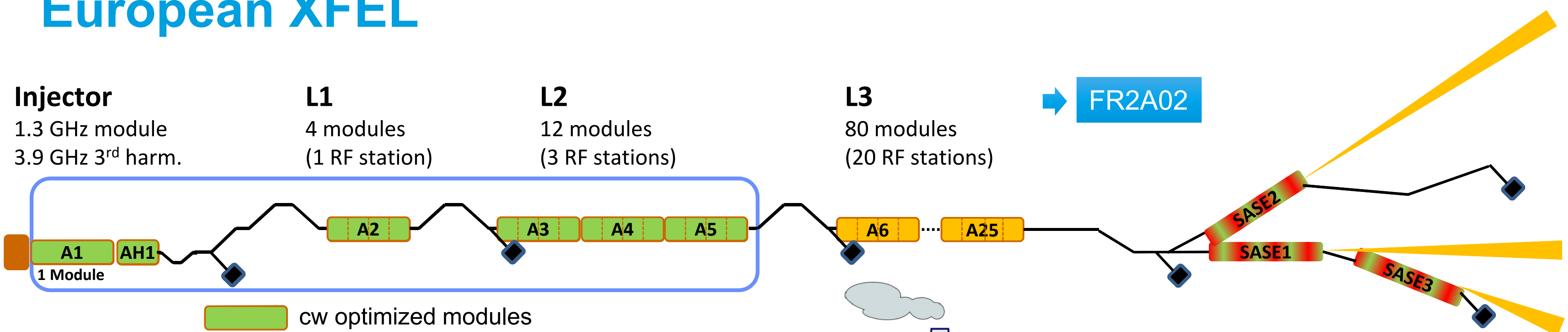
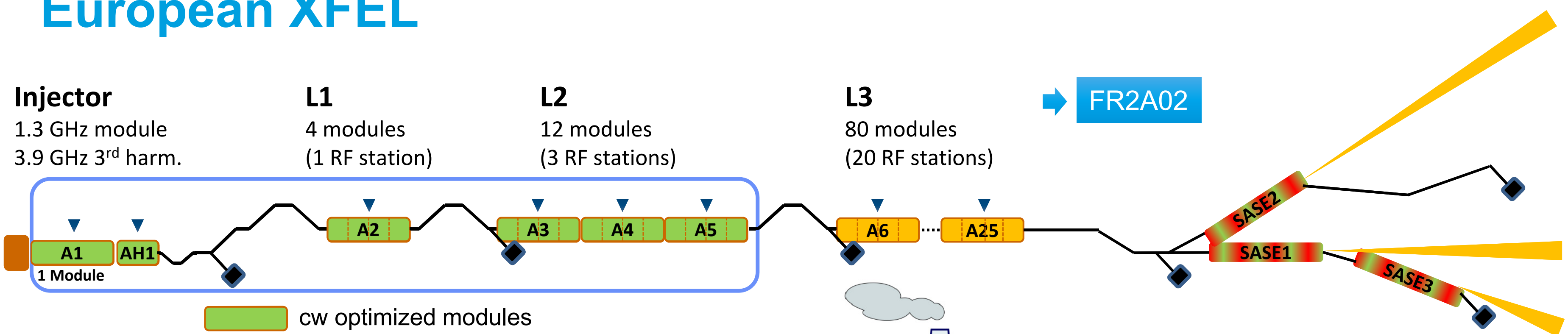
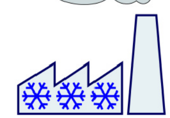


1 – Replace the front-end cryomodules (17x)

- Larger cooling capability
- CW cavities

European XFEL





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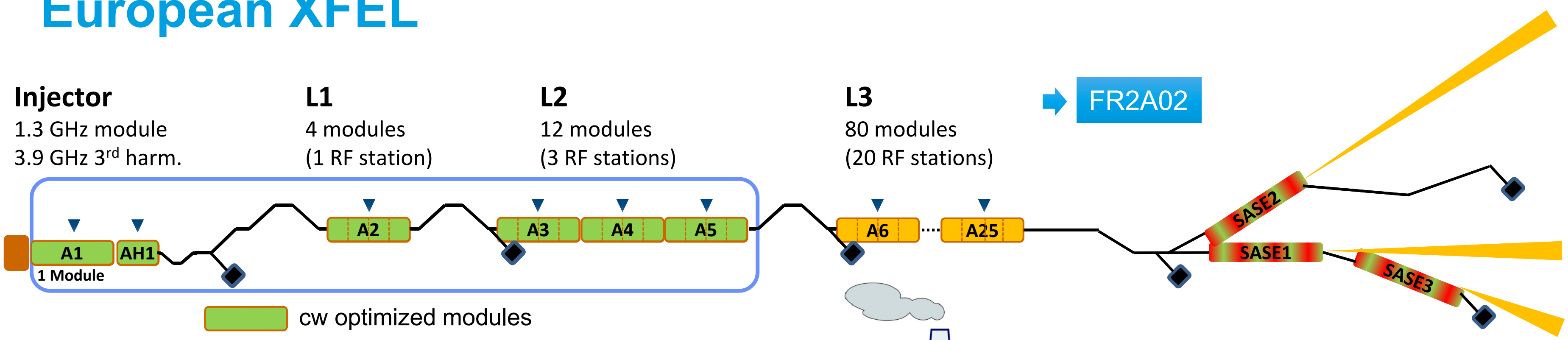
2 – Install CW capable RF sources

- 1x IOT per RF station

European XFEL



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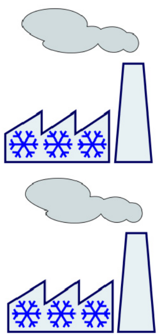
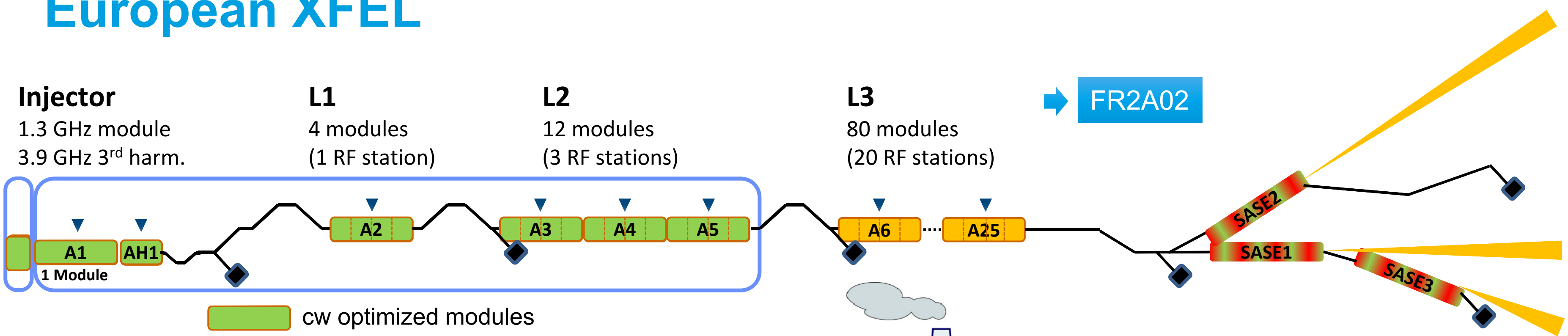
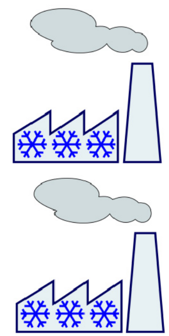


3 – Double the cryo plant (cost driver)

- 2.5 → 5kW

European XFEL





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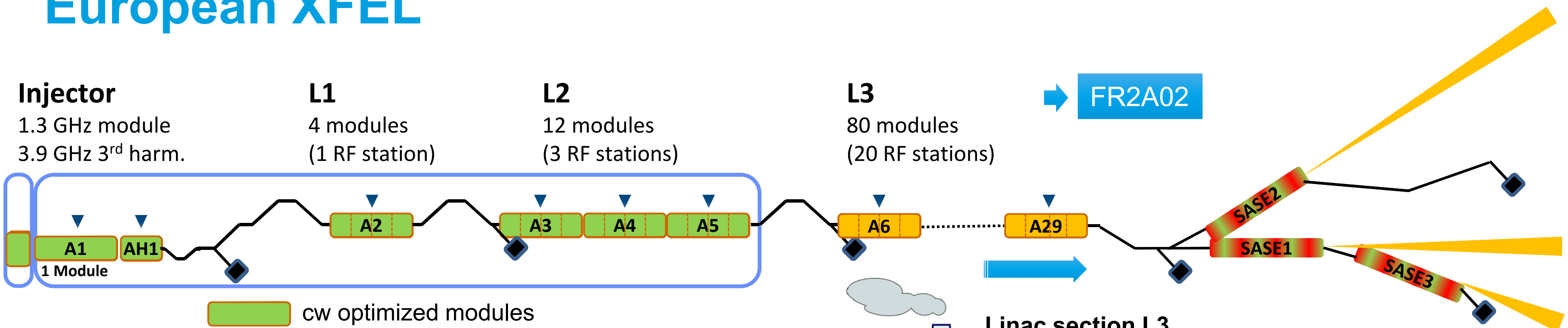
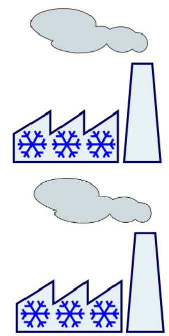
European XFEL





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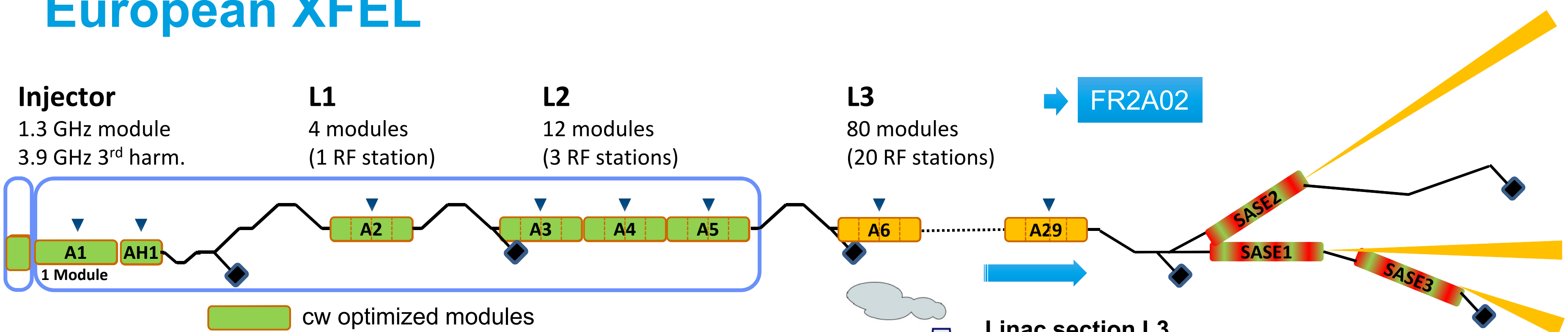
Linac section L3

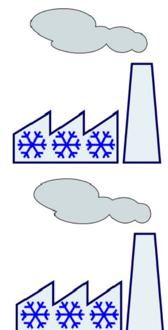
- operated at moderate CW gradients
- lengthened by former A2 … A5
  80 + 12 modules
  24 RF stations

➡ **Expected energy 8 GeV !**

- **The former front-end cryomodules can be installed at the end of the linac to lengthen L3 (+4 RF stations)**
- **No further action required in L3 (>1km)**
- **The upgraded XFEL would be capable of short pulse long pulse <u>AND</u> continuous wave operation**

European XFEL





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➡ **Expected energy 8 GeV !**

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- Larger cooling capability
- CW cavities ➡ TUPO028, TUPO029

2 – Install CW capable RF sources

- 1x IOT per RF station ➡ WE1A04, MOPO104, MOPO38, TUPO132, MOPO36

3 – Double the cryo plant (cost driver)

- 2.5 → 5kW

4 – Install CW capable gun:

- RF gun upgrade ➡ MOP037

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New surface preparations

Modifications of the European XFEL surface preparation process

- The proven European XFEL surface treatment (**final EP**) resulted in
  - Average usable gradient: 29 MV/m
  - Average low field quality factor: $2.1 \cdot 10^{10}$
  - Average Q-value at 23.6 MV/m: $1.3 \cdot 10^{10}$ (Spec: > $1.0 \cdot 10^{10}$)

- cw operation requires highest possible Q-values
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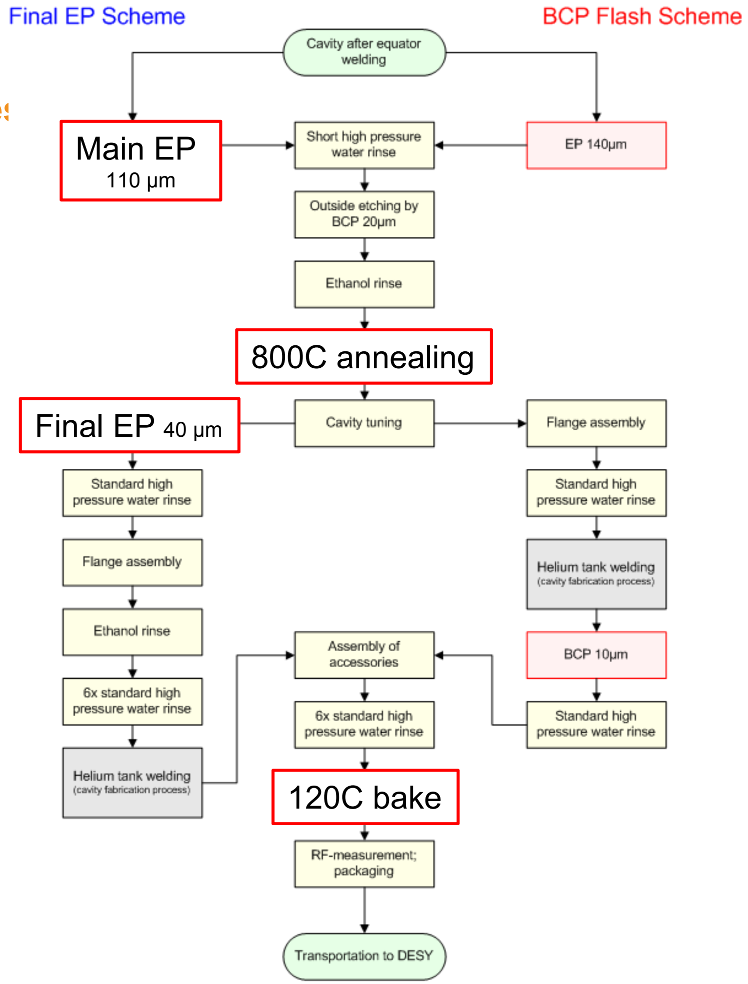

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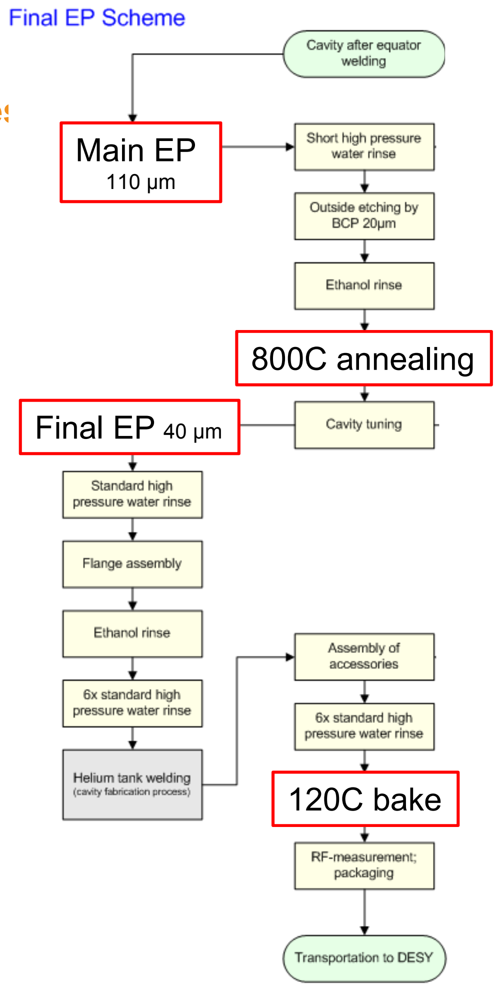

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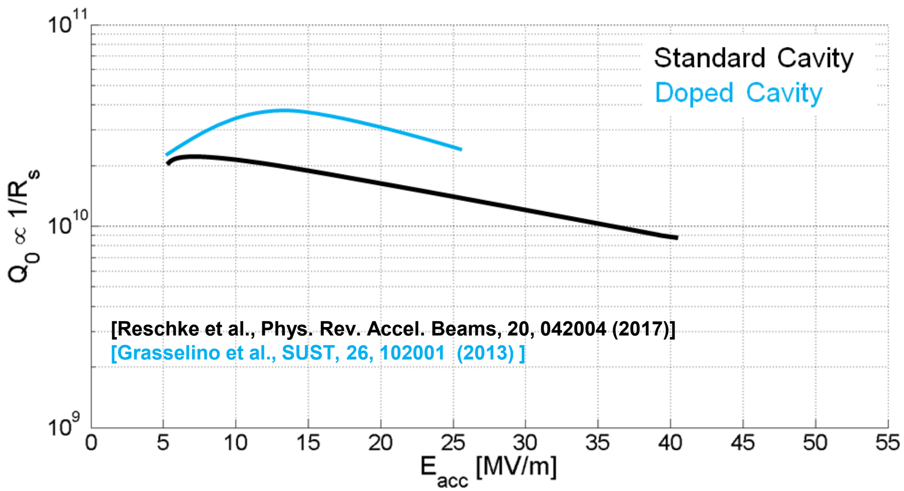
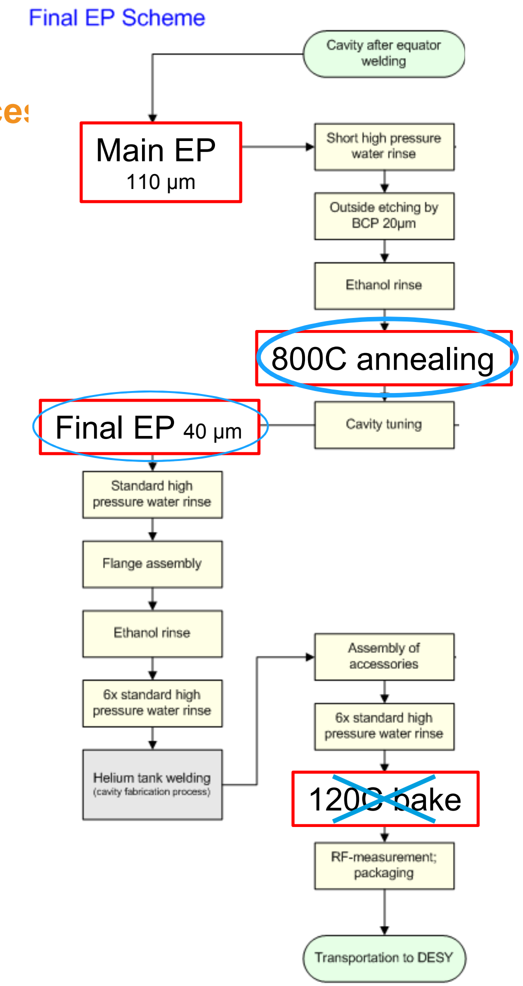
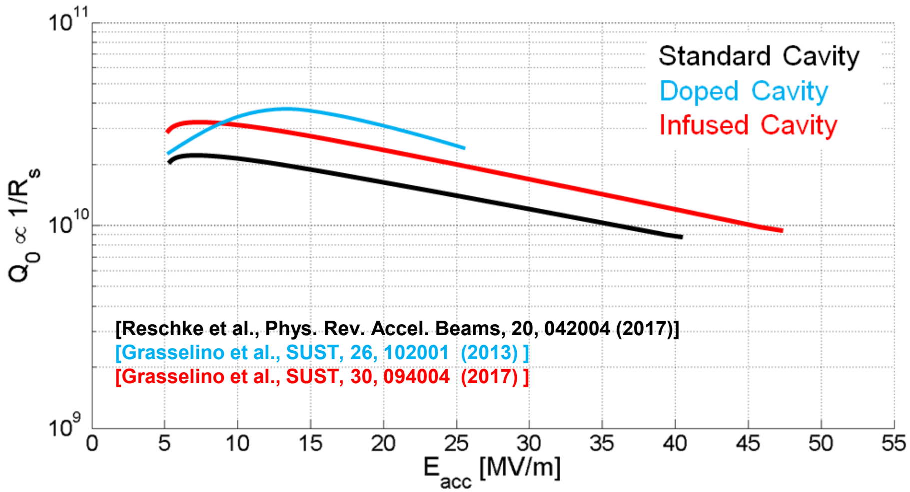


- **"Nitrogen doping":**
  Novel surface treatments applying a **partial pressure of nitrogen during heat treatment** (developed at Fermilab) result in higher Q-values
  - "Nitrogen doping" industrialized for LCLSII cavity production => high Q-values, but limited at medium gradients

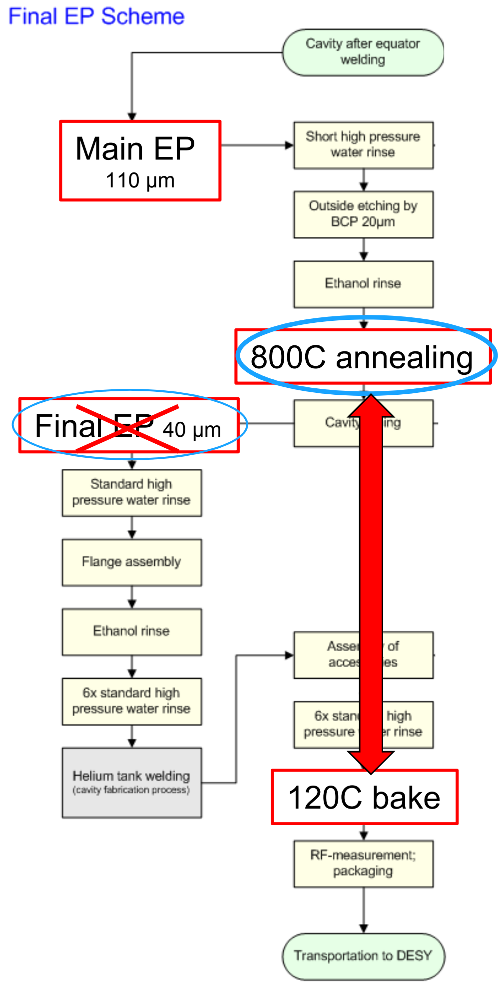


New surface preparations

Nitrogen Treatment: doping vs. infusion

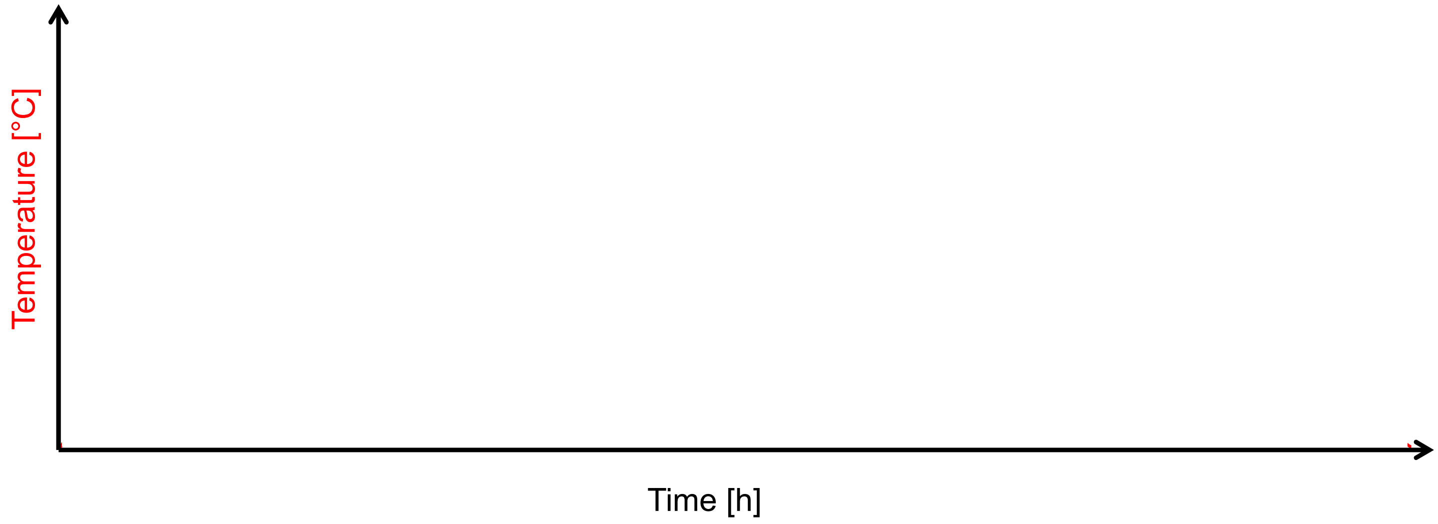


- **"Nitrogen infusion"** still in R&D phase
- Allows higher Q-values and higher gradient



The Recipe

N-Infusion



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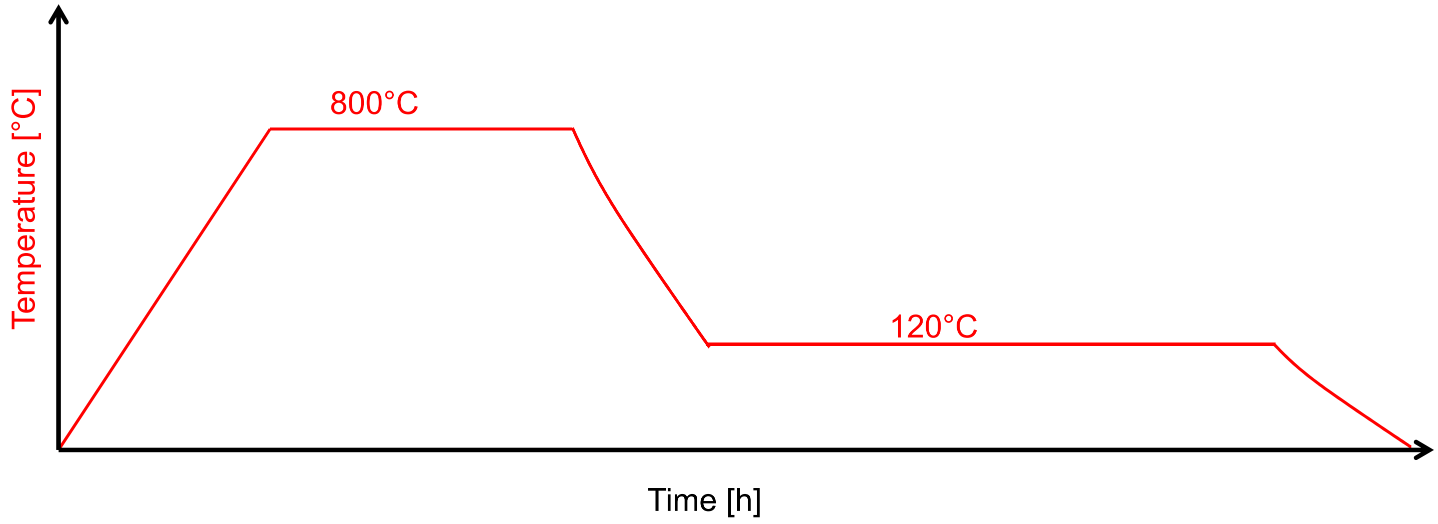

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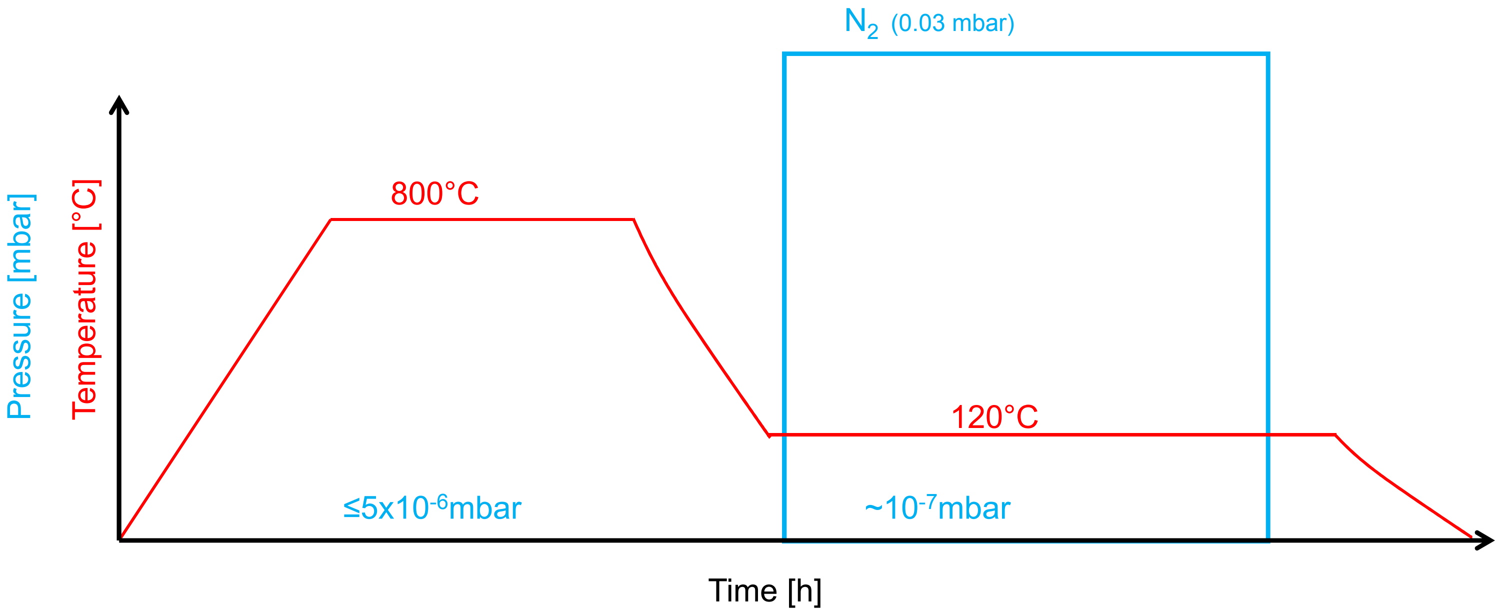

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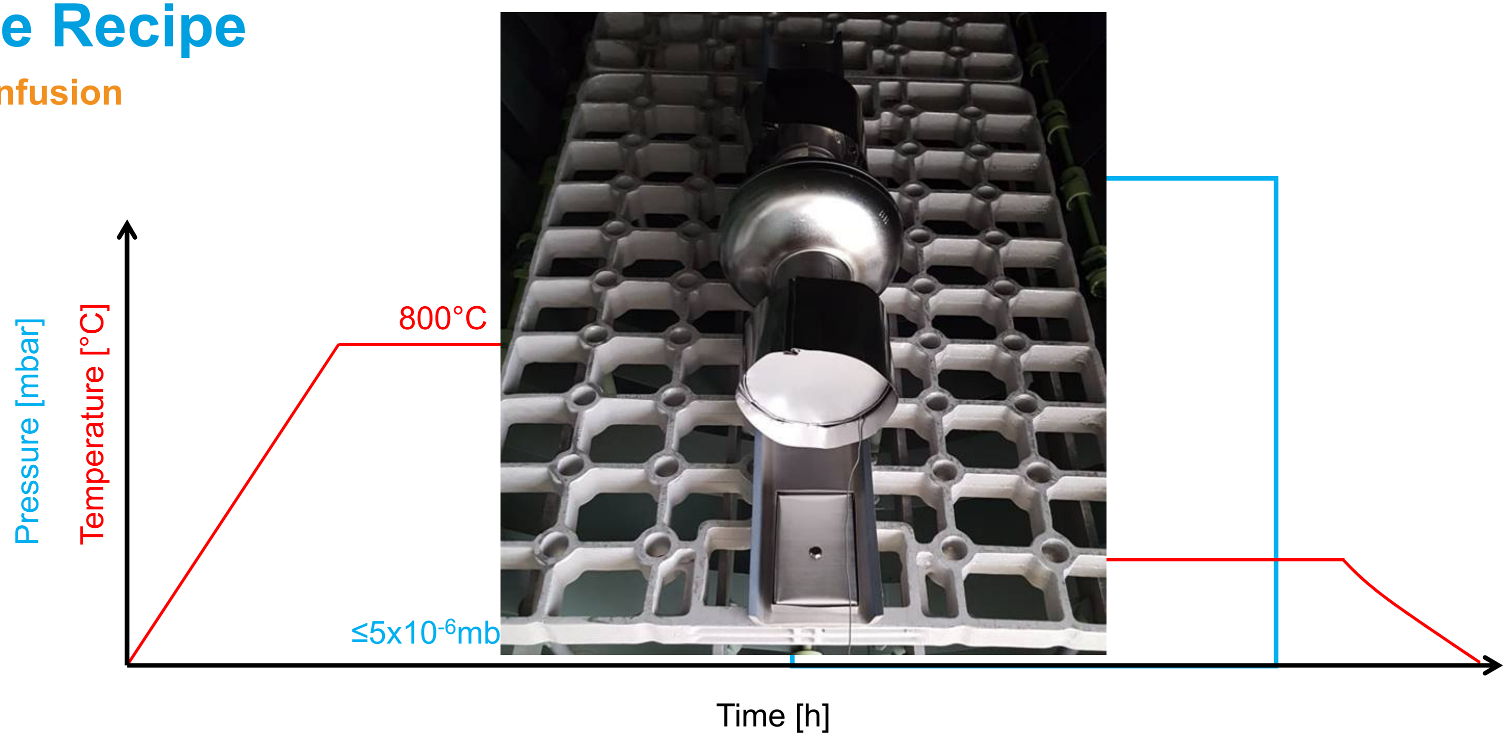

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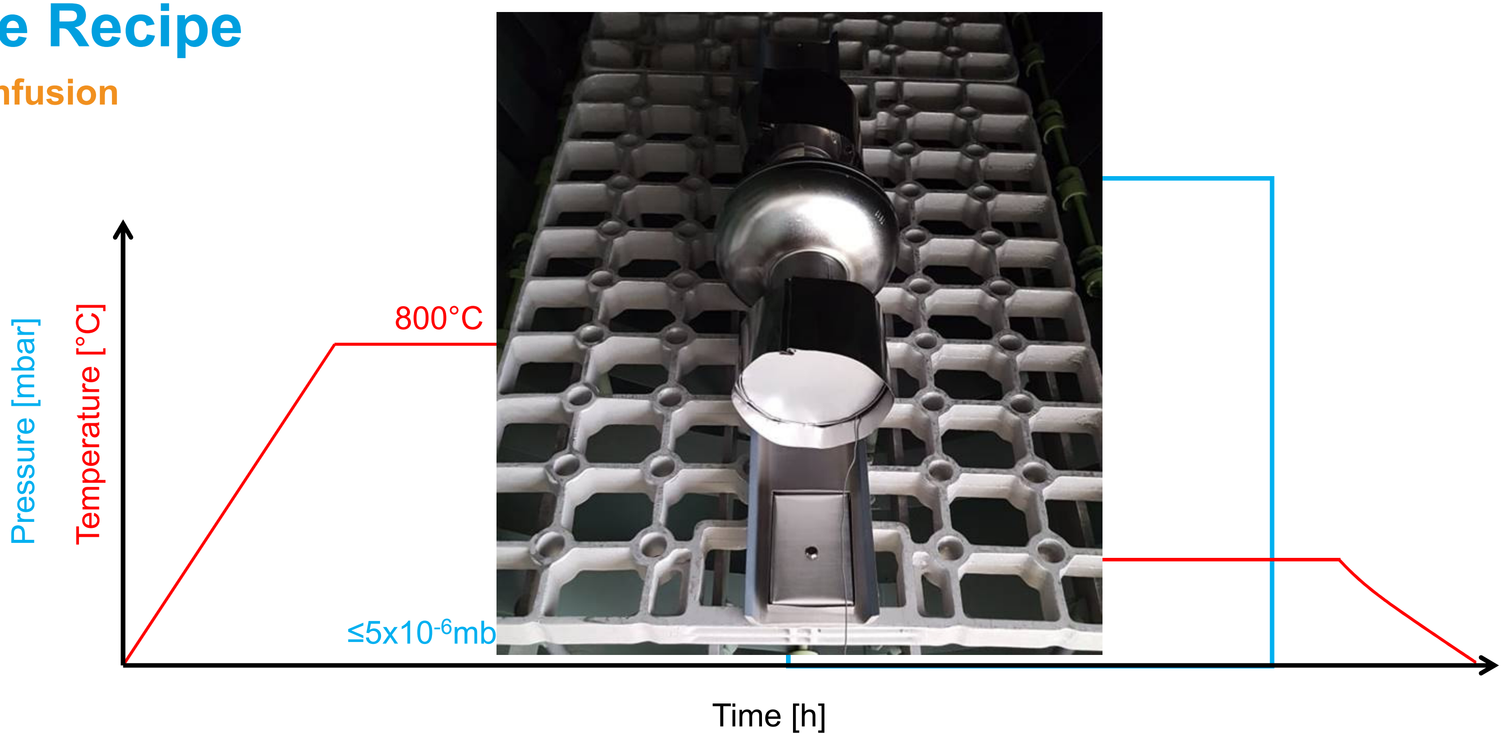
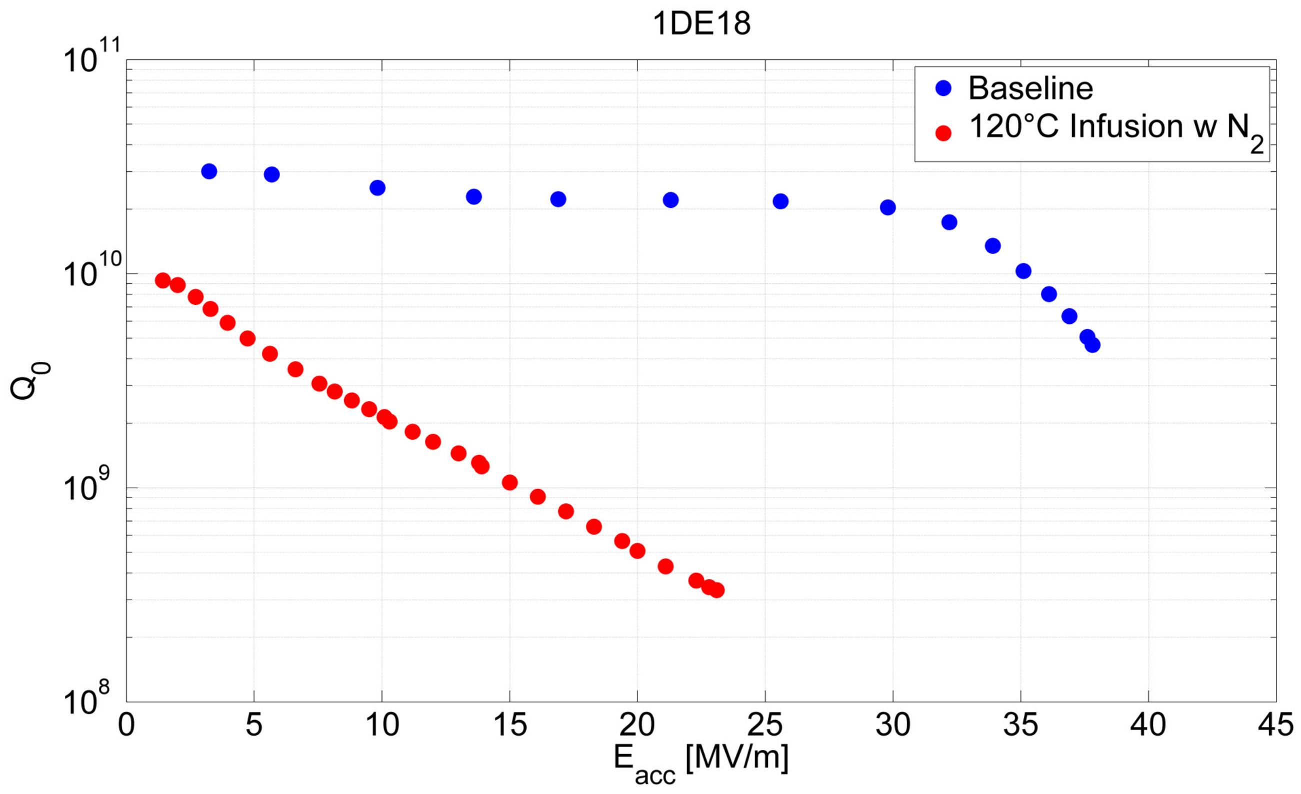


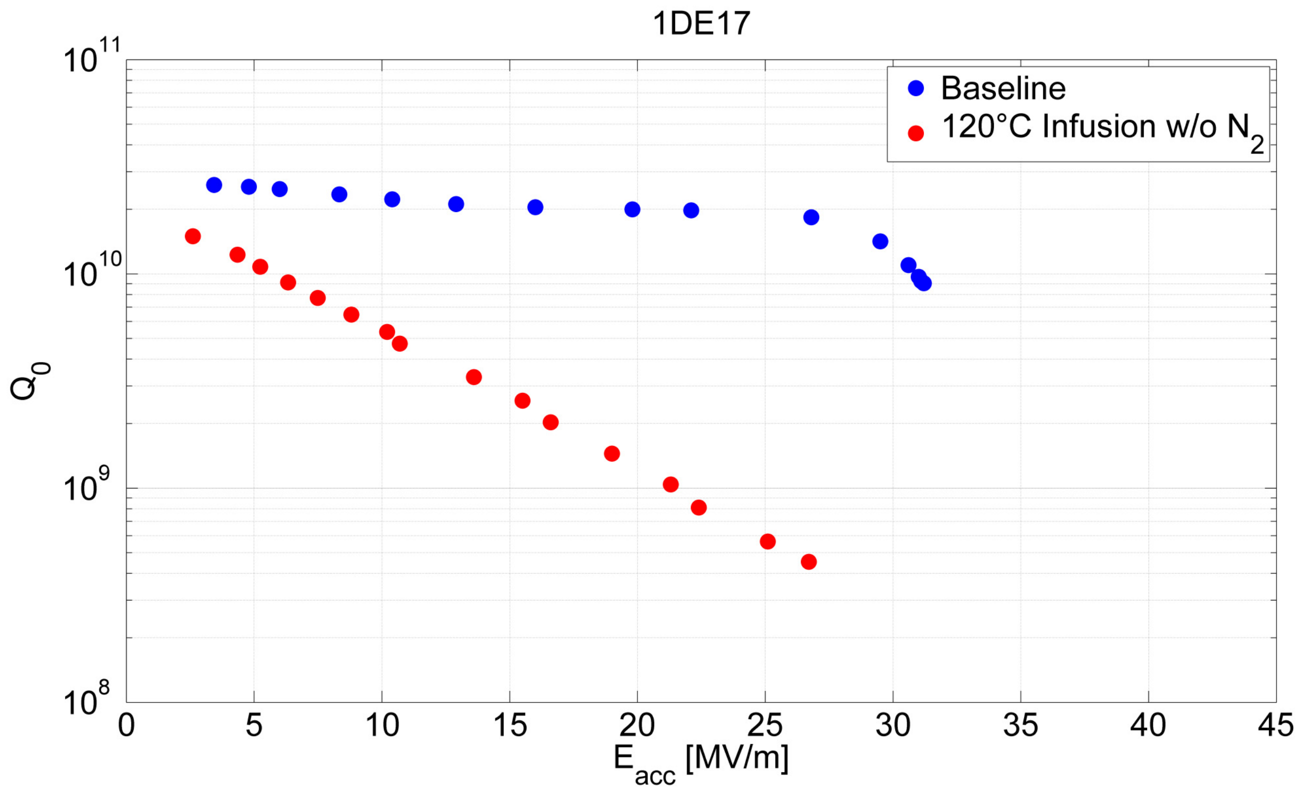
Problem: No one cooks like Grandma

First Infusion Run



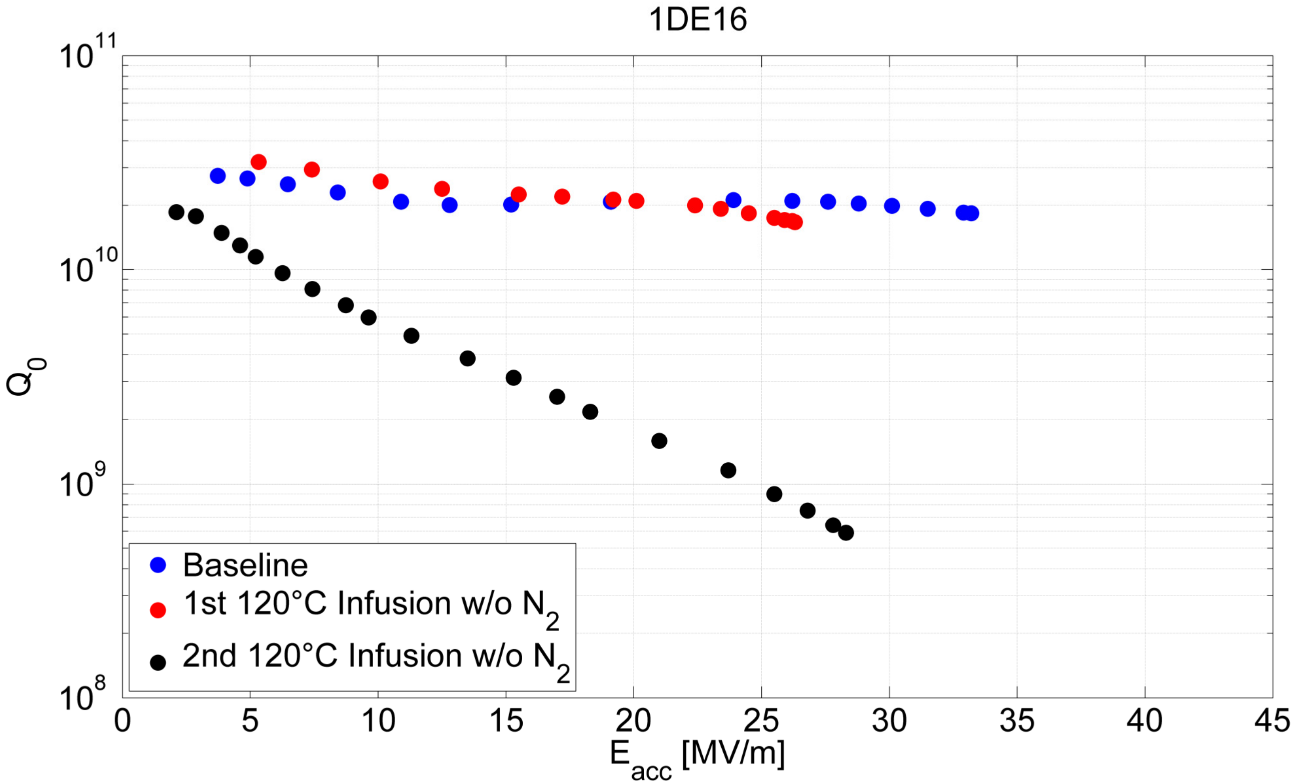
Second Infusion Run

w/o Nitrogen – just temperature cycle

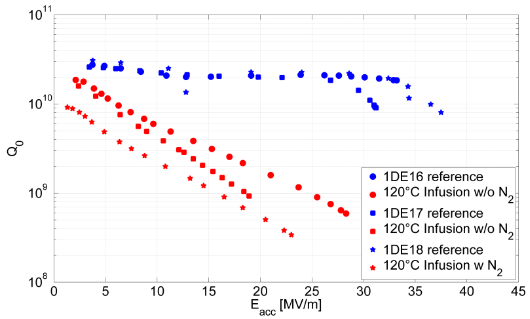


Third & Fourth Infusion Run

w/o Nitrogen – just temperature cycle



Whats going on?



	1DE18	1DE17	1DE16
Material	Ningxia fine grain	Ningxia fine grain	Plansee fine grain
Reference @ 2K			
$E_{acc,max}[\frac{MV}{m}]$	37.7 - BD	31.2 - BD	32.2 - BD
Q_0(4 MV/m)[$\times 10^{10}$]	2.8	2.5	2.7
Baking Parameters			
p @ 800°C [mbar]	2×10^{-5}	1.1×10^{-5}	5.5×10^{-6}
P_{N_2} @ 120°C[mbar]	$7 - 300 \times 10^{-5}$	w/o	w/o
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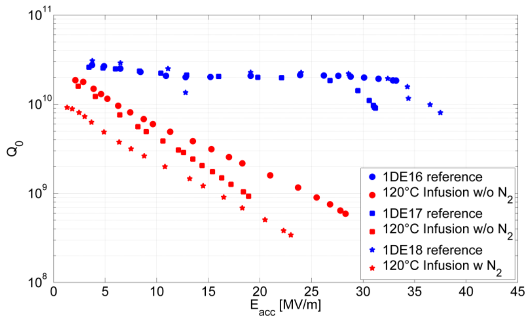

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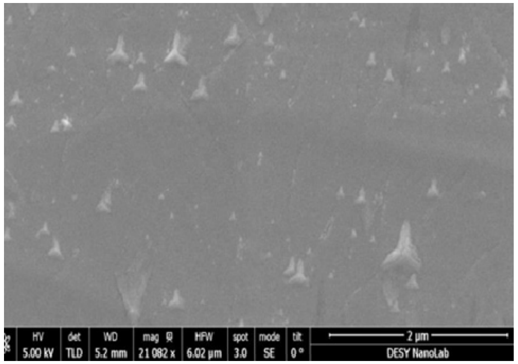

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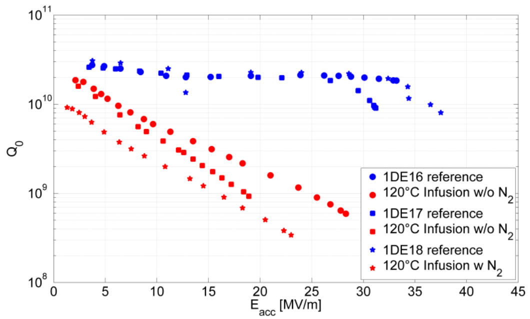

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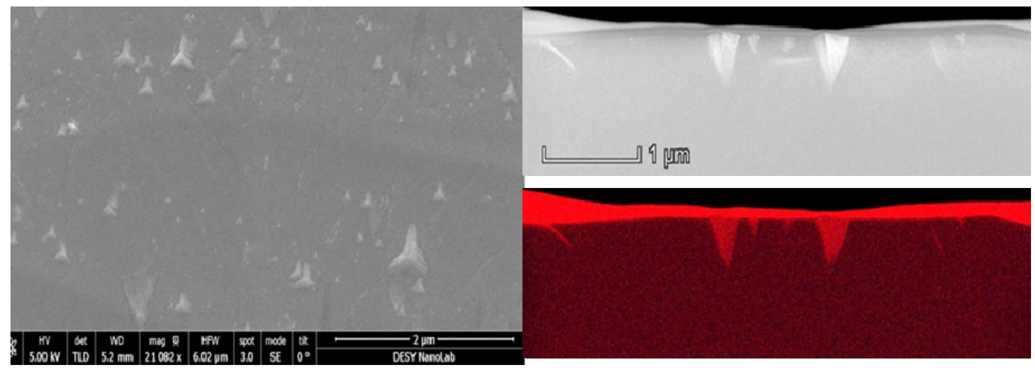

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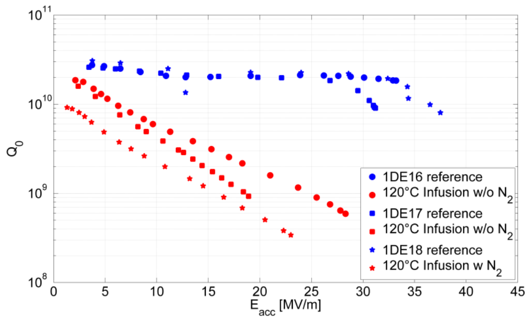

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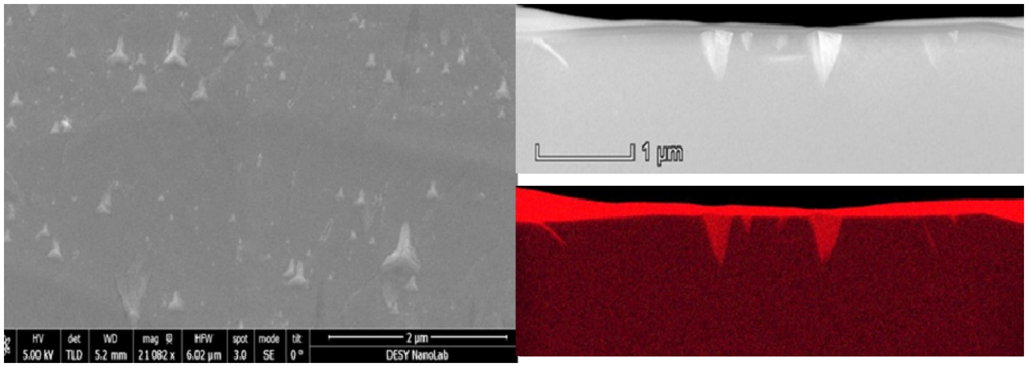

RGA during 800°C bake showed high mass contributions (Hydrocarbons)

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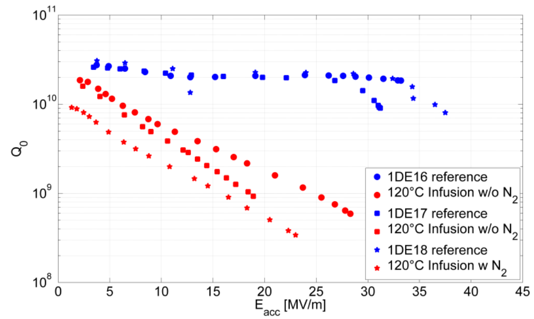

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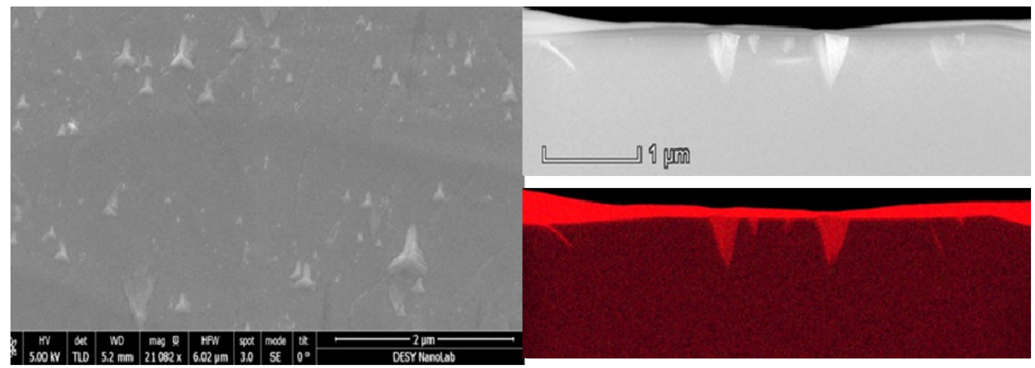
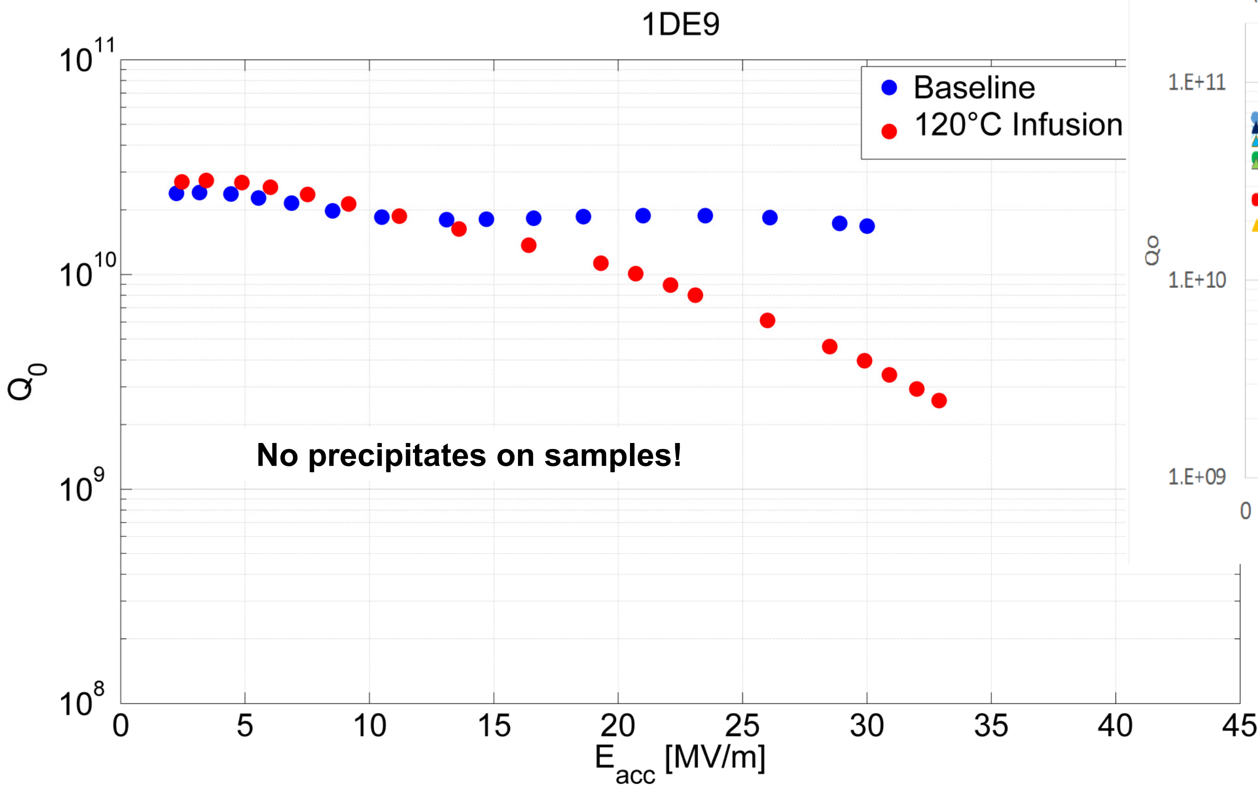


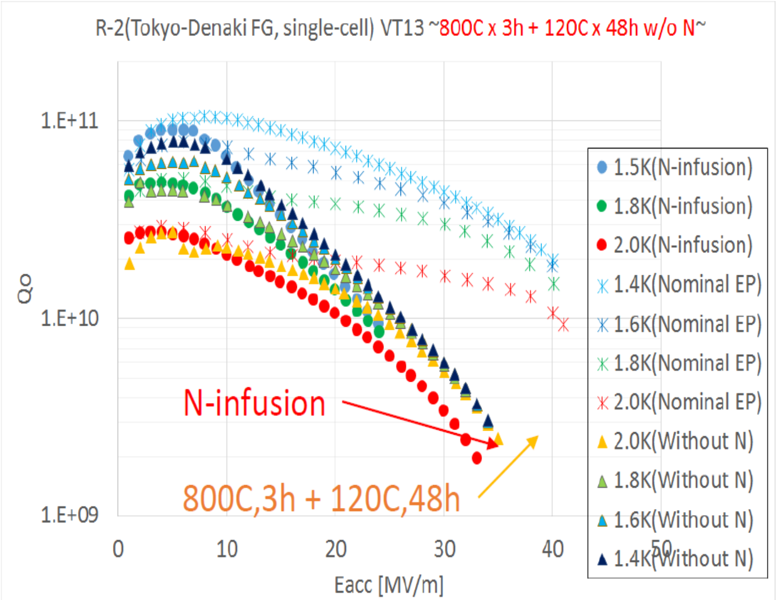
RGA during 800°C bake showed high mass contributions (Hydrocarbons)

Samples within a standard 800°C bake showed precipitates as well

Fifth Infusion Run

w/o Nitrogen – just temperature cycle





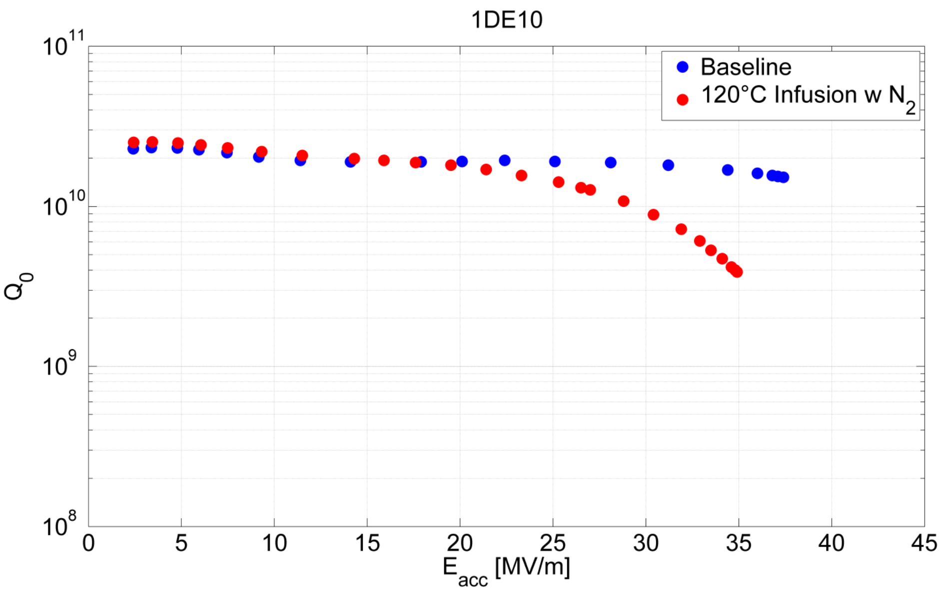
[K. Umemori et al., „Trial of Nitrogen Infusion and Nitrogen Doping by using JPARC Furnace“, THPB021@SRF2017]

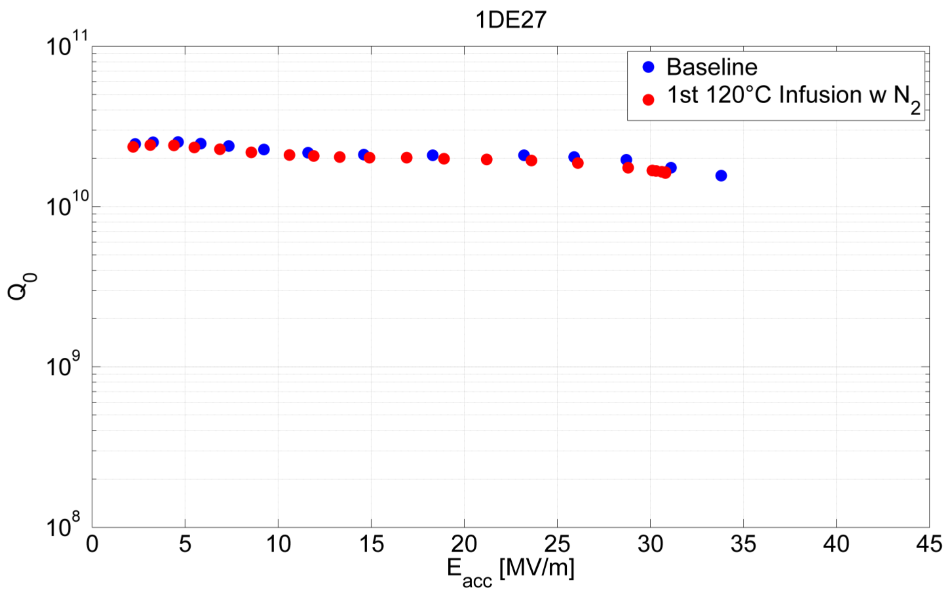
KEK identified 120°C part of bake as origin of deterioation.

Did we solve our 800°C problem and moved on to another?

Sixth and Seventh Infusion Run

With Nitrogen!





Again precipitates on samples! ☹

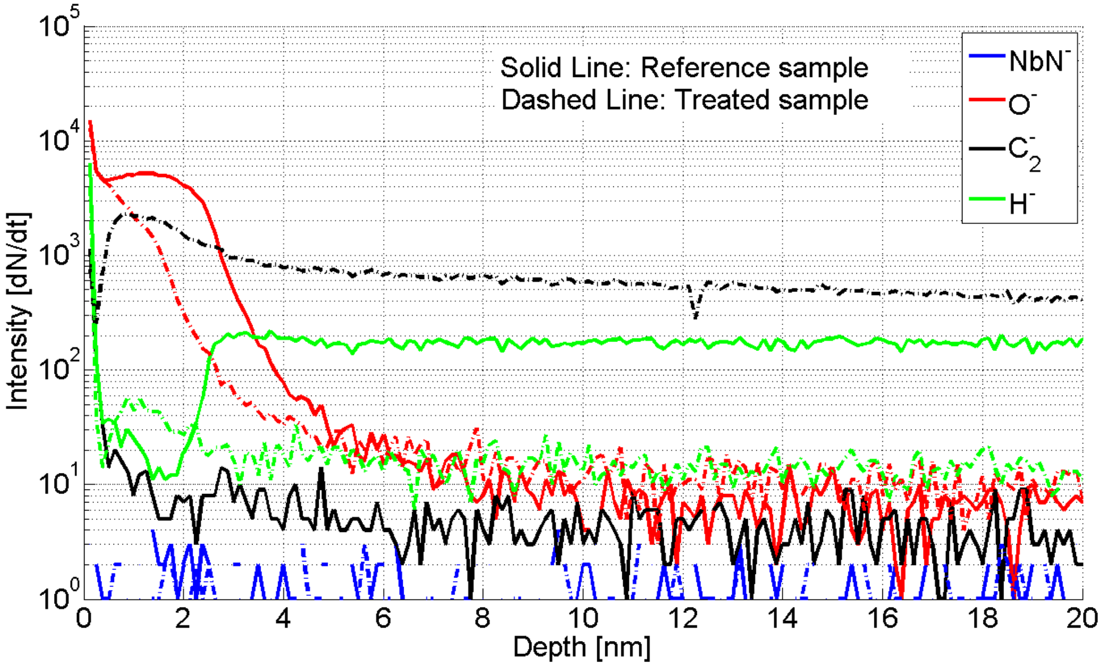
BUT…

TOF-SIMS Analysis

Treated vs. Reference and „Inner vs. Outside Atmosphere“

TOF-SIMS Analysis

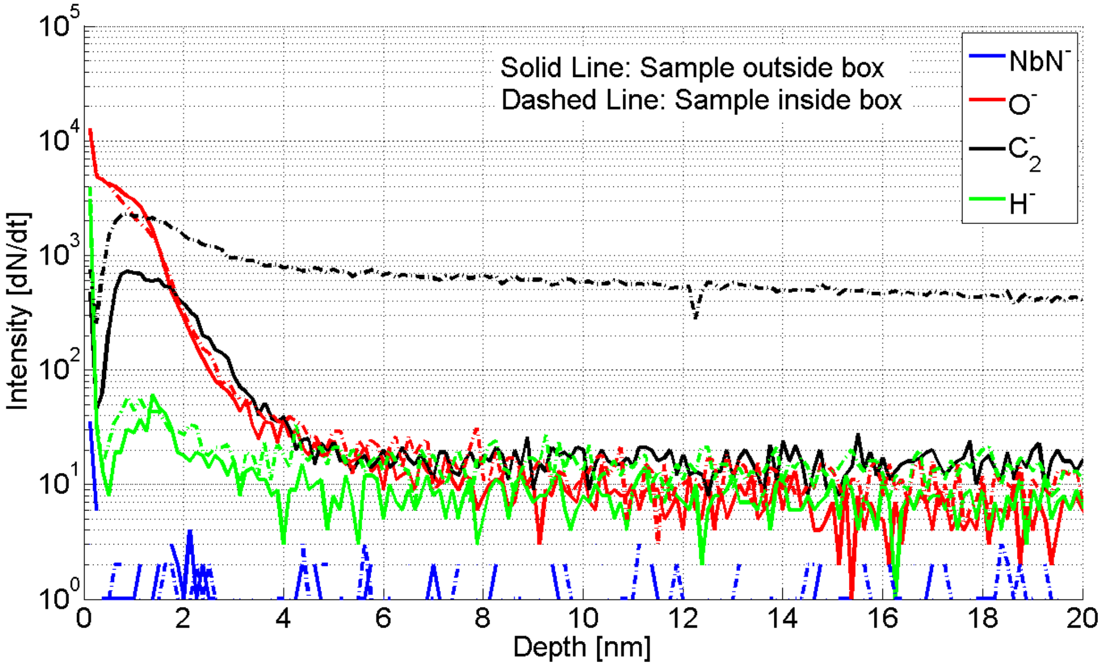
Treated vs. Reference and „Inner vs. Outside Atmosphere“



TOF-SIMS Analysis

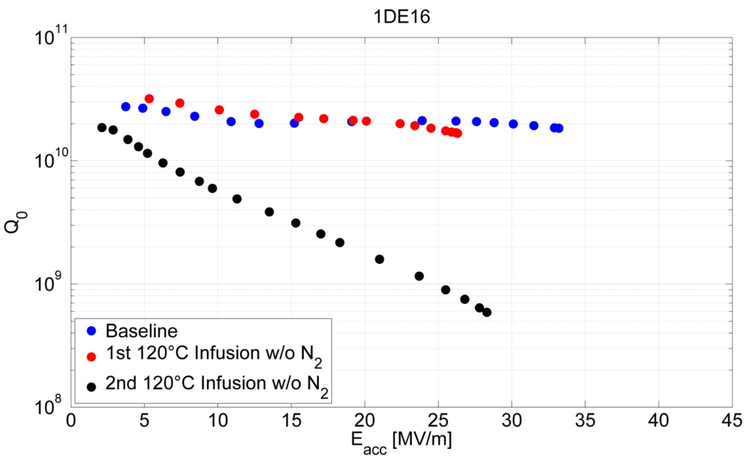
Treated vs. Reference and „Inner vs. Outside Atmosphere“

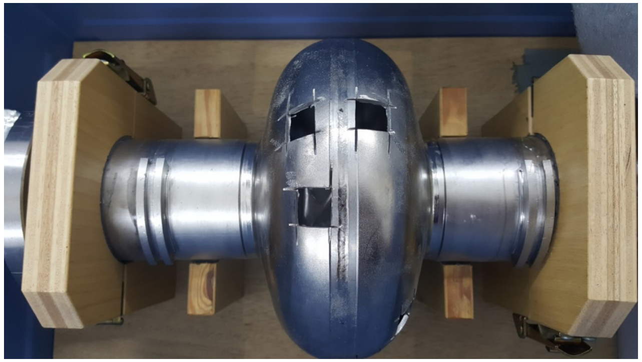
No precipitates on outside samples
Precipitates on inside samples

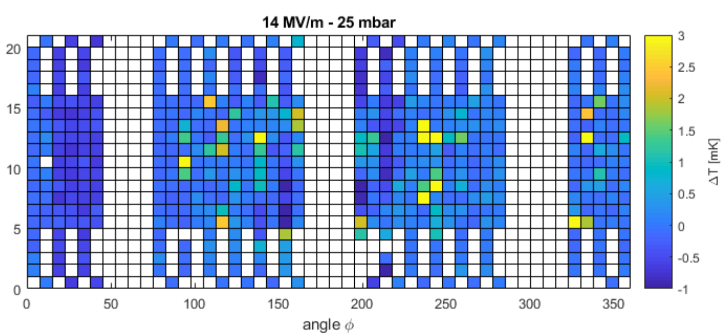


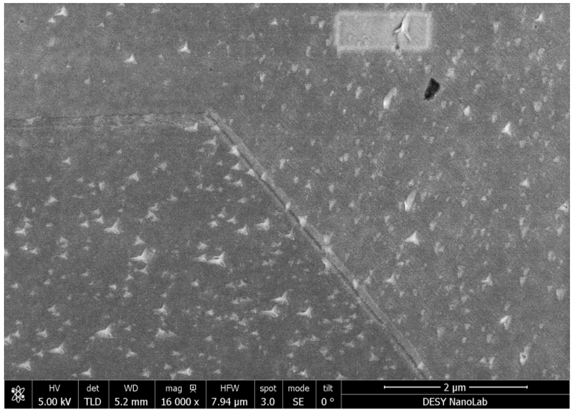
Sample Surface = Cavity Surface?

Origin of deterioration?









One more puzzle…

In-situ sample R&D

- UHV-mobile chamber with in-situ surface characterization

- Two samples, both single crystals [100]:
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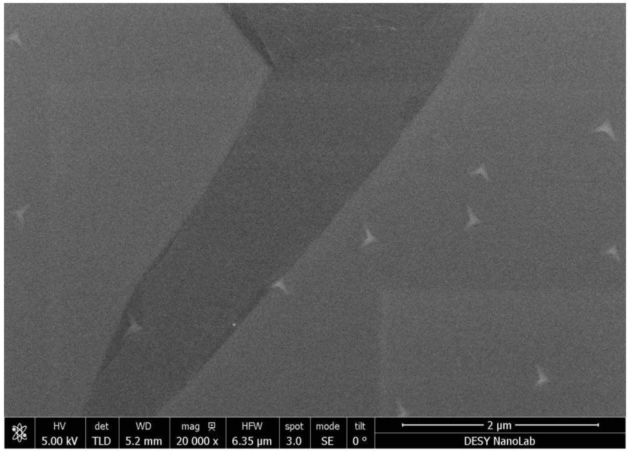

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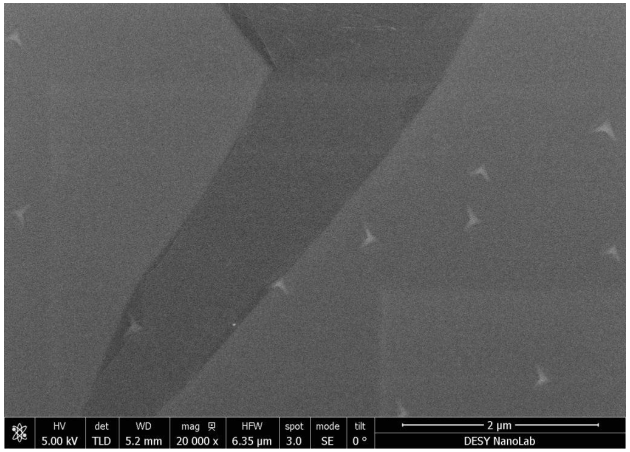
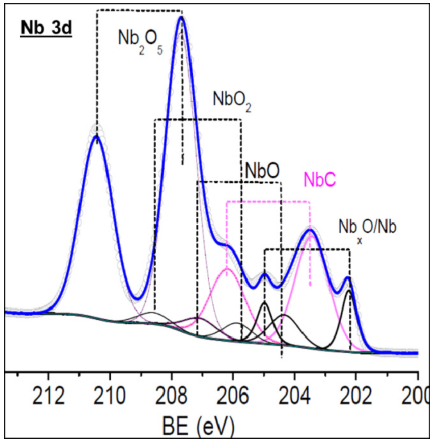
  - XPS confirmed Nb-C phase, no Nb-N





Conclusions

- „Atmosphere“ inside cavity and niobium box different than furnace – no data!
- Need of caps will be investigated
- New set of caps with defined „leak“ will be fabricated

- Lack of nitrogen in samples is puzzling
- Origin of Nb-C precipitates
- And relation to rf performance not obvious