Technical Challenge of Cavity Mass Production in LCLS-II

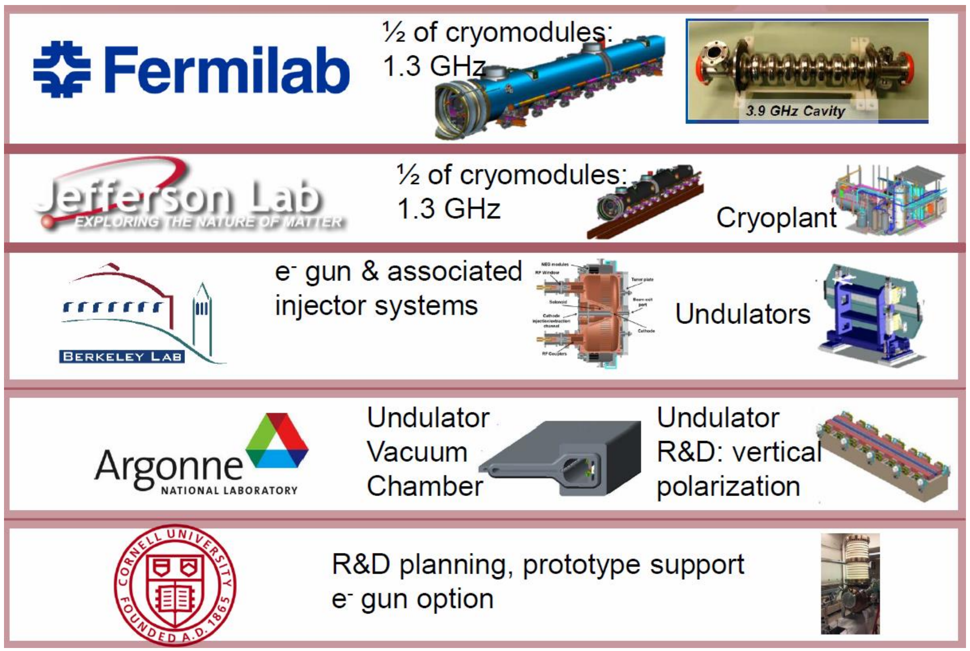
F. Marhauser

TESLA Technology Collaboration Meeting

1-4. Dec. 2015

LCLS-II Cavity Mass Production

- Industrial fabrication of 266 LCLS-II accelerating cavities (+ optional units)
- ~⅓ of quantity required for European X-Ray FEL ('XFEL')
- Cavities sufficient for 33 cryomodules (CMs) adding to the 2 prototype CMs (sums up to 35 CMs in baseline design to achieve 4 GeV energy gain)
- All CMs assembled at FNAL and JLab concurrently and shipped to SLAC
- JLab leads all cavity procurement activities with industry
  → long history in industrial procurement of SRF cavities (CEBAF and SNS)



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  → long history in industrial procurement of SRF cavities (CEBAF and SNS)
- Yet too early in the procurement to relate to production issues
  - Cavity production has not started yet
  - Still in Phase I – Vendor Qualification
  - Challenges are still to come

Industrial Vendors for LCLS-II Cavity Mass Fabrication

- **Ettore Zanon, S.p.A.**
  Schio, Italy

www.zanon.com

- **RI Research Instruments GmbH**
  Bergisch-Gladbach, Germany

www.research-instruments.de

- Production quantity shared equally among vendors (2 x 133 cavities)

Cavity Procurement Strategy

- JLab leads LCLS-II cavity procurement

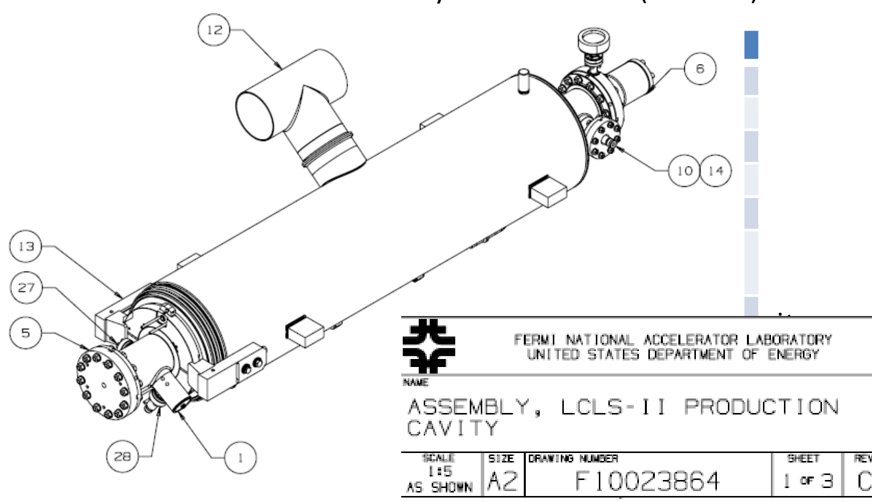
Jefferson Lab
Thomas Jefferson National Accelerator Facility

Manages all procurement activities

Fermilab

Cavity design and technical drawings and material procurement

Released to vendors early Oct. 2015 (Rev. C)

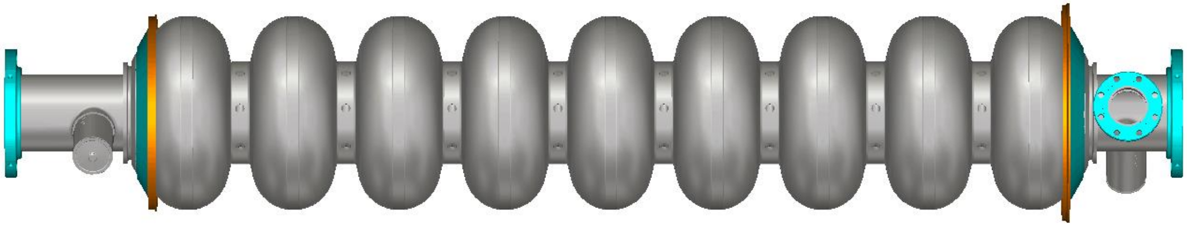


research instruments

E. ZANON

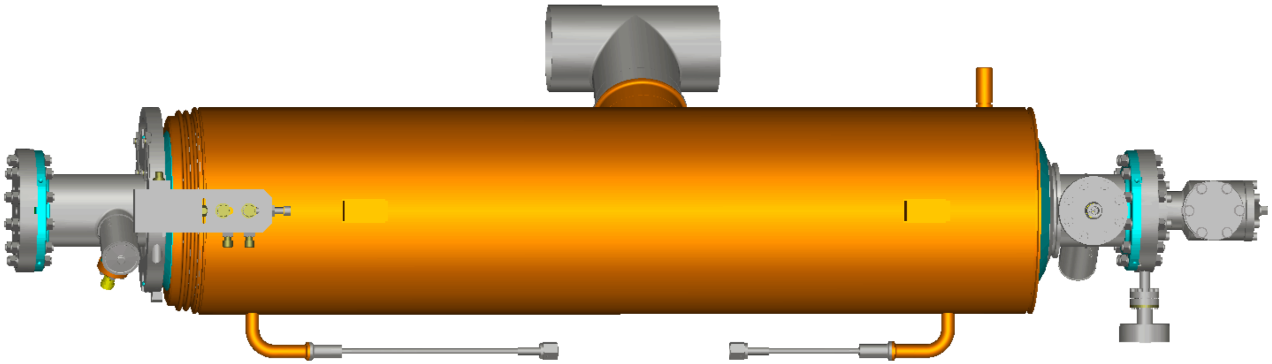
Cavity Design

- Cavity design: based on TESLA-type 1.3 GHz nine-cell cavities
  - Bare cavity (almost) identical to XFEL design



Cavity Design

- Cavity design: based on TESLA-type 1.3 GHz nine-cell cavities
  - Bare cavity (almost) identical to XFEL design
  - Main alteration: Helium vessel design (FNAL instead of XFEL design), e.g. two He fill lines
    - Little cost or schedule impact according to vendor quotes/responses

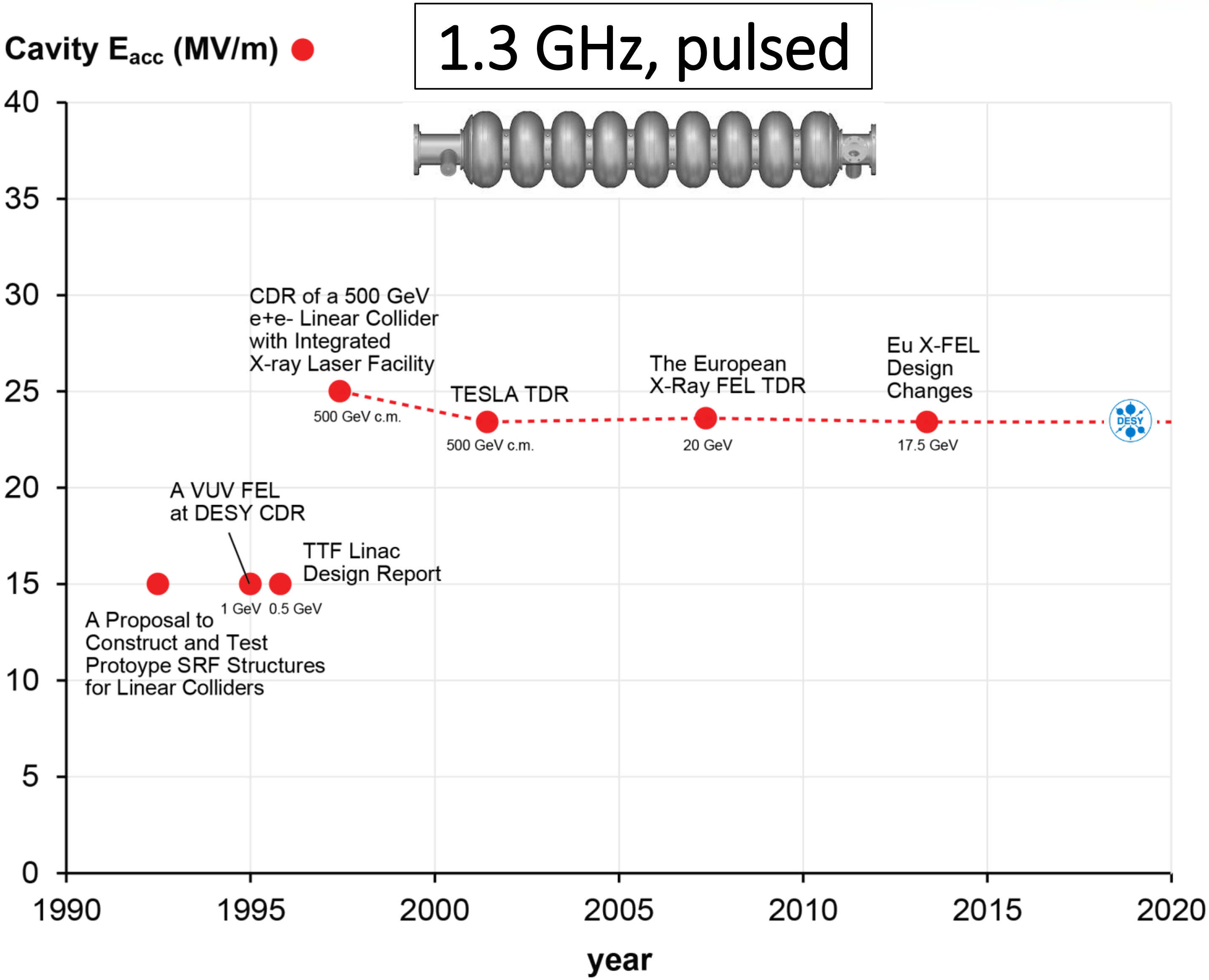


- Build-to-Print also means that cavities have to be delivered…
  - welded into Helium vessel,
  - under vacuum, and
  - with vertical qualification hardware attached → ready to test vertically

What are the Challenges?

- Cavity production follows “Build-to-Print” approach adapted from XFEL
- Main Challenges:
  - Vendors must keep schedule for on-time delivery → cryomodule assembly
  - Vendors must follow precise technical specification and meet all requirements
  - Quality Assurance and Quality Control must be in place
  - Rework/repair should be minimized
- What is not guaranteed: Cavity performance
  - Project bears all risks
- What’s New/Different to Previous Projects? **Nitrogen-Doping**
  - Goal and challenge: Achieve unprecedented high Q_0–values for cavities
- What is confidence level to obtain high-Q_0 cavities from vendors?

What is the Confidence Level for Cavity Performance ?
E.g. DESY over the recent decades



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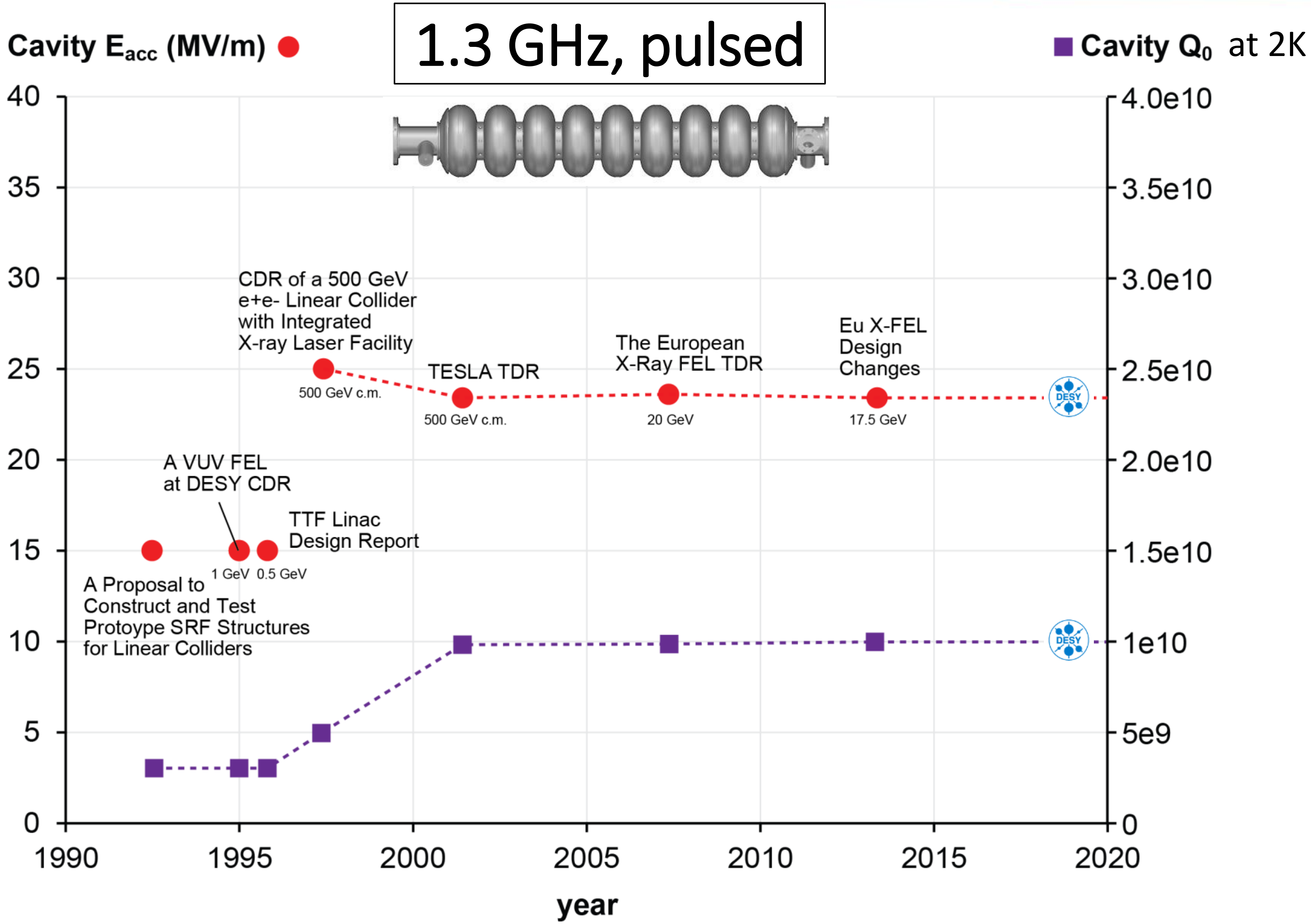
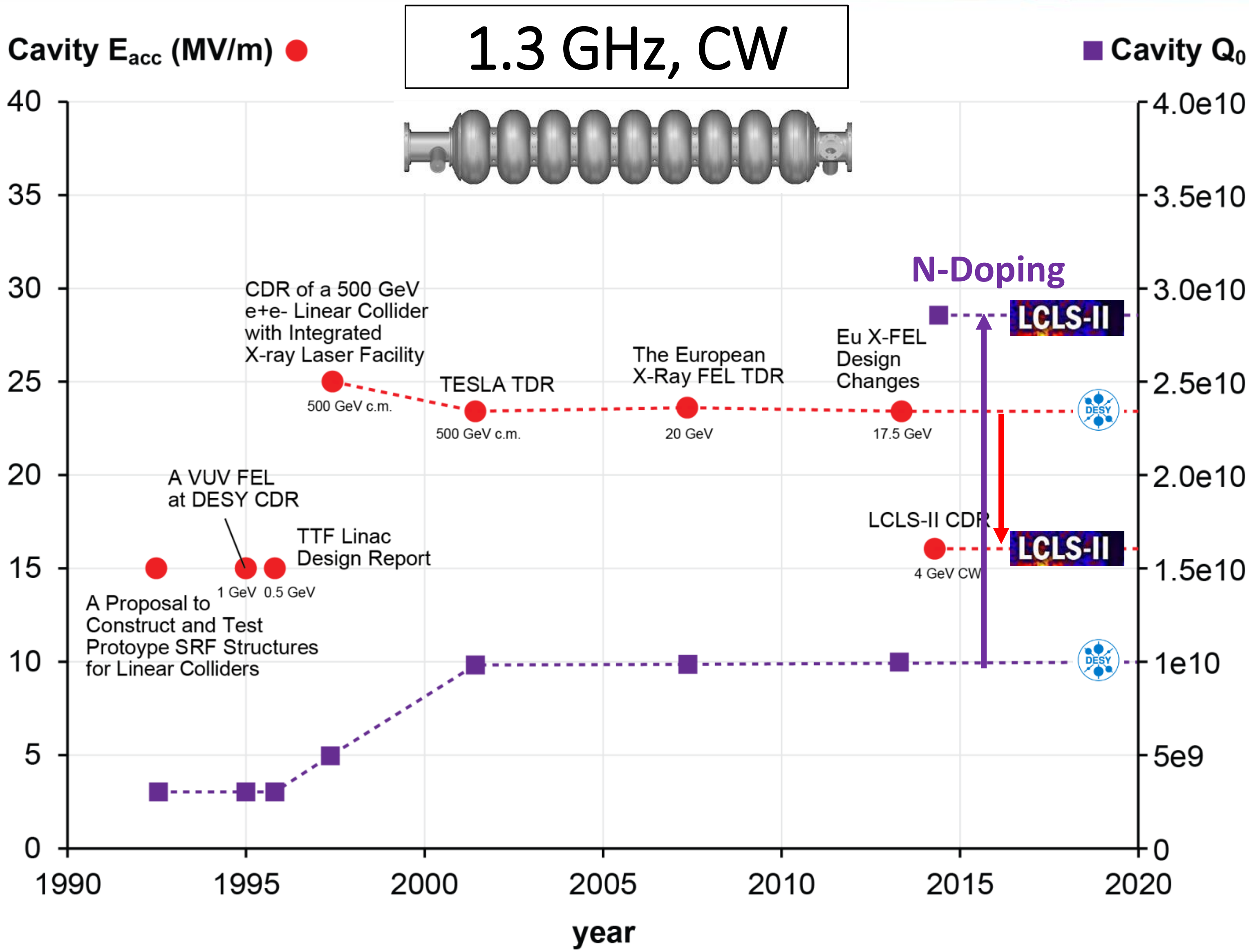
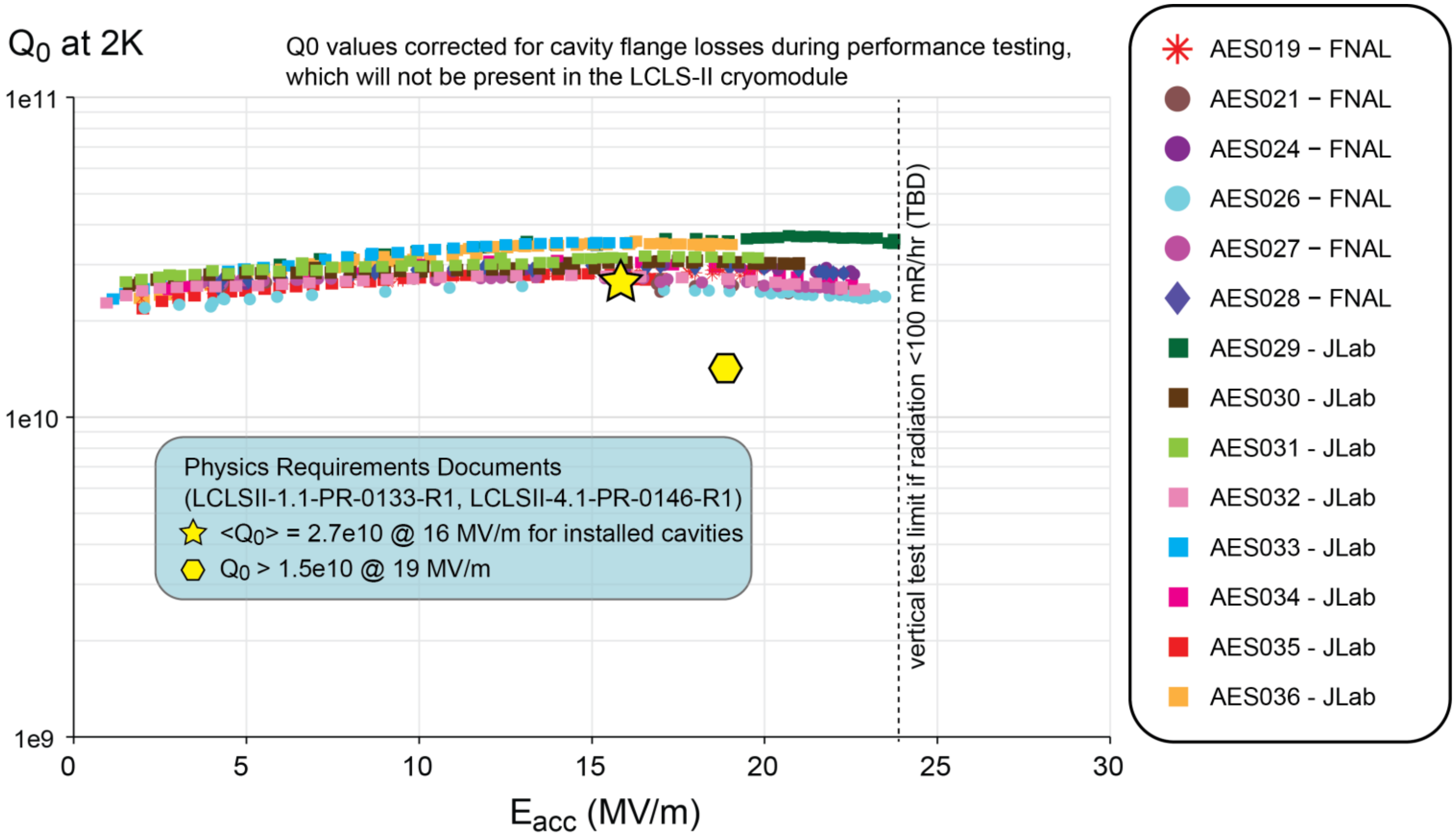


LCLS-II High-Q_0 Cavity Approach



Vertical Testing of Dressed Prototype Cavities at FNAL and JLab

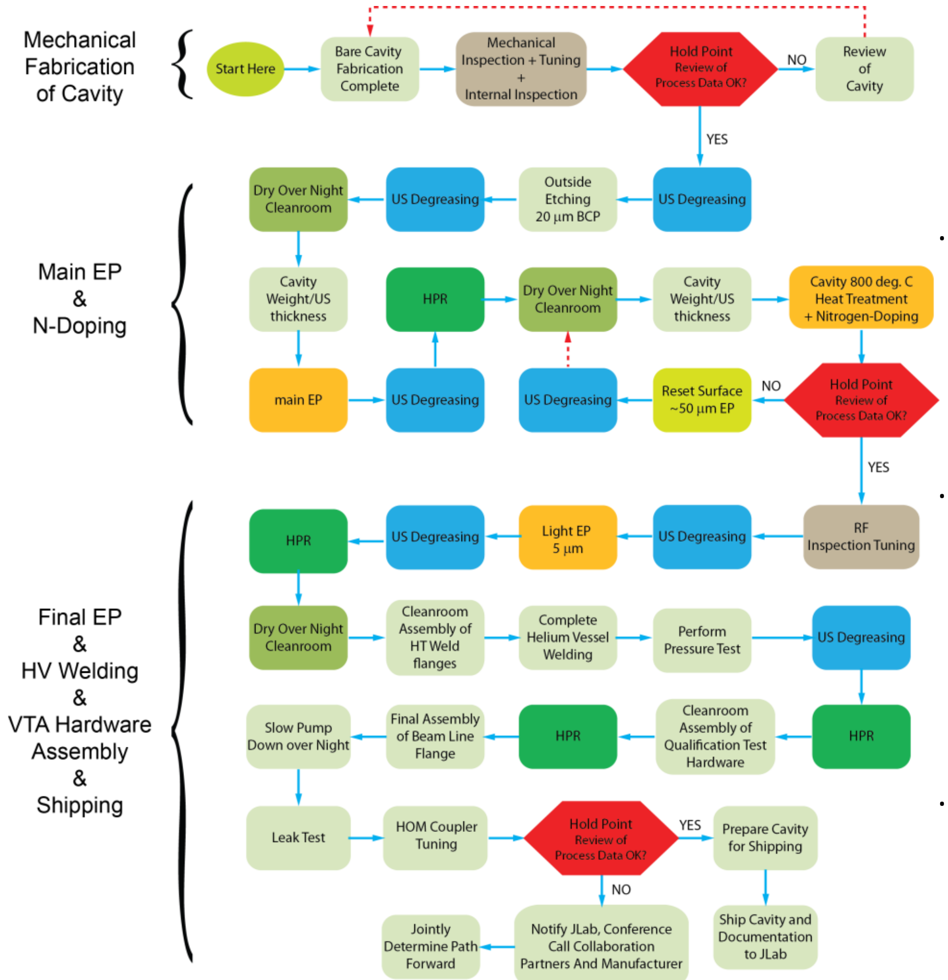


LCLS-II prototype cavities with helium vessel (status Oct. 2015)

Cavity Procurement Phases

Phase	Purpose	Cavity Count	Duration (months)
	Prototype CMs	16	in progress
I	Vendor Qualification	4	6 months May - Nov 2015
II	1st Articles	16	7 months Nov 2015 - June 2016
III	Full Production	250	15 months June 2016 - Sep. 2017
II + III	Procurement Units	266	22 months Nov 2015 - Sept. 2017
IV	Optional Units	32	-

Quality Assurance and Quality Control



After cavity mechanical fabrication

- Check of all fabrication and inspection data prior to release for chemical/heat treatment processing

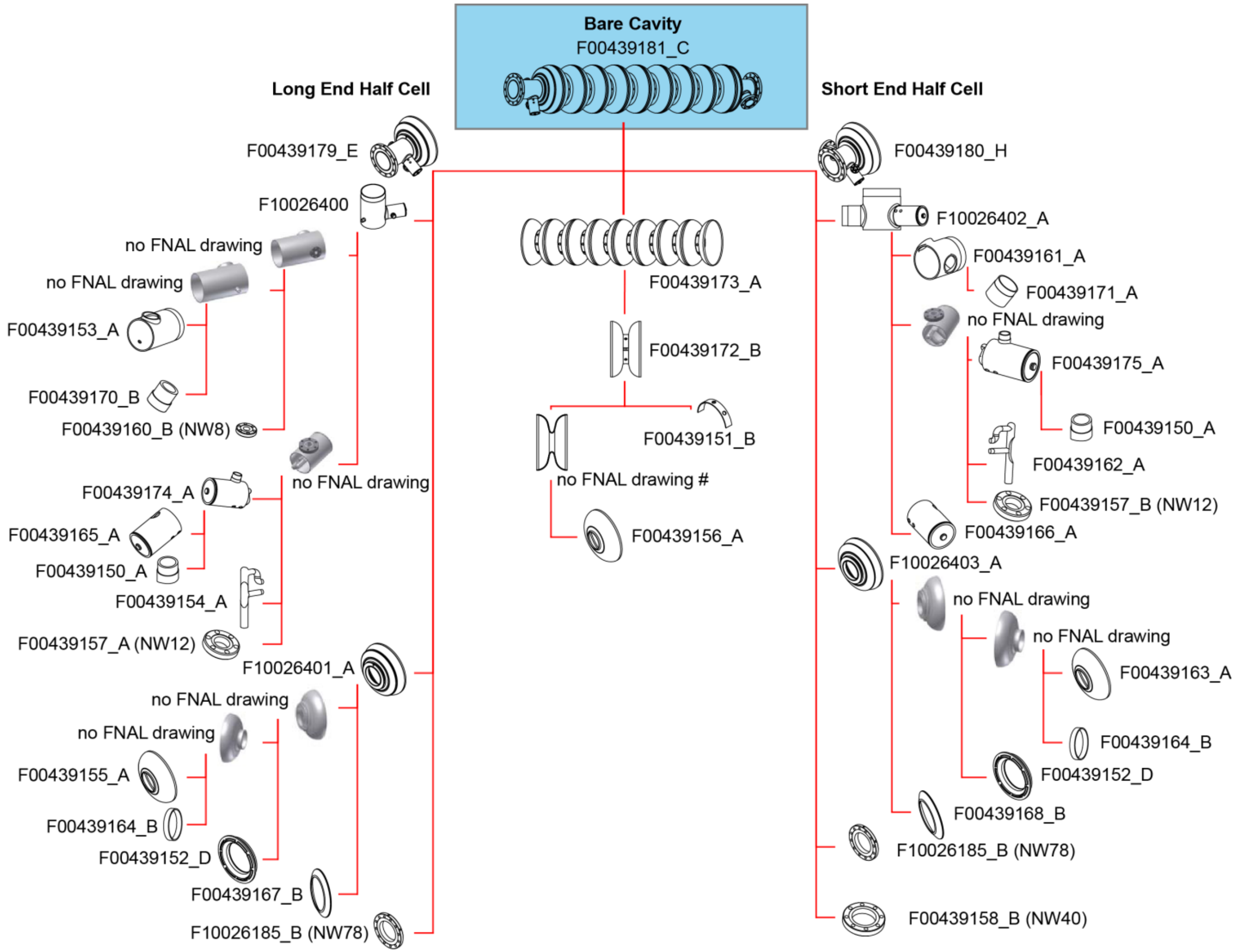
After chemical/heat treatment processing

- Check of all process and inspection data prior to release for final chemistry, welding of helium vessel and assembly for vertical test qualification

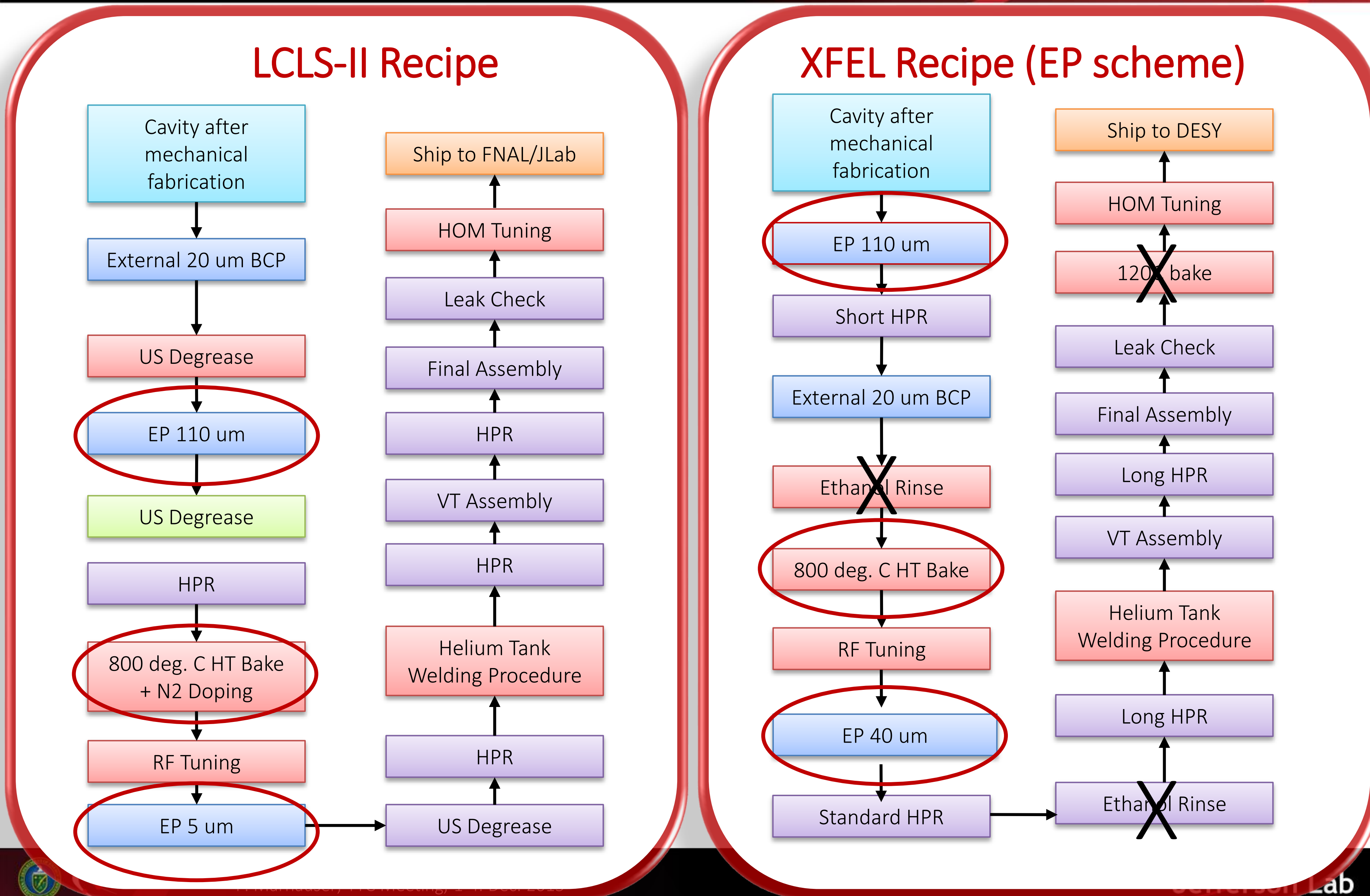
After all cavity steps are complete

- Check of all data prior to release for shipping to FNAL & JLab

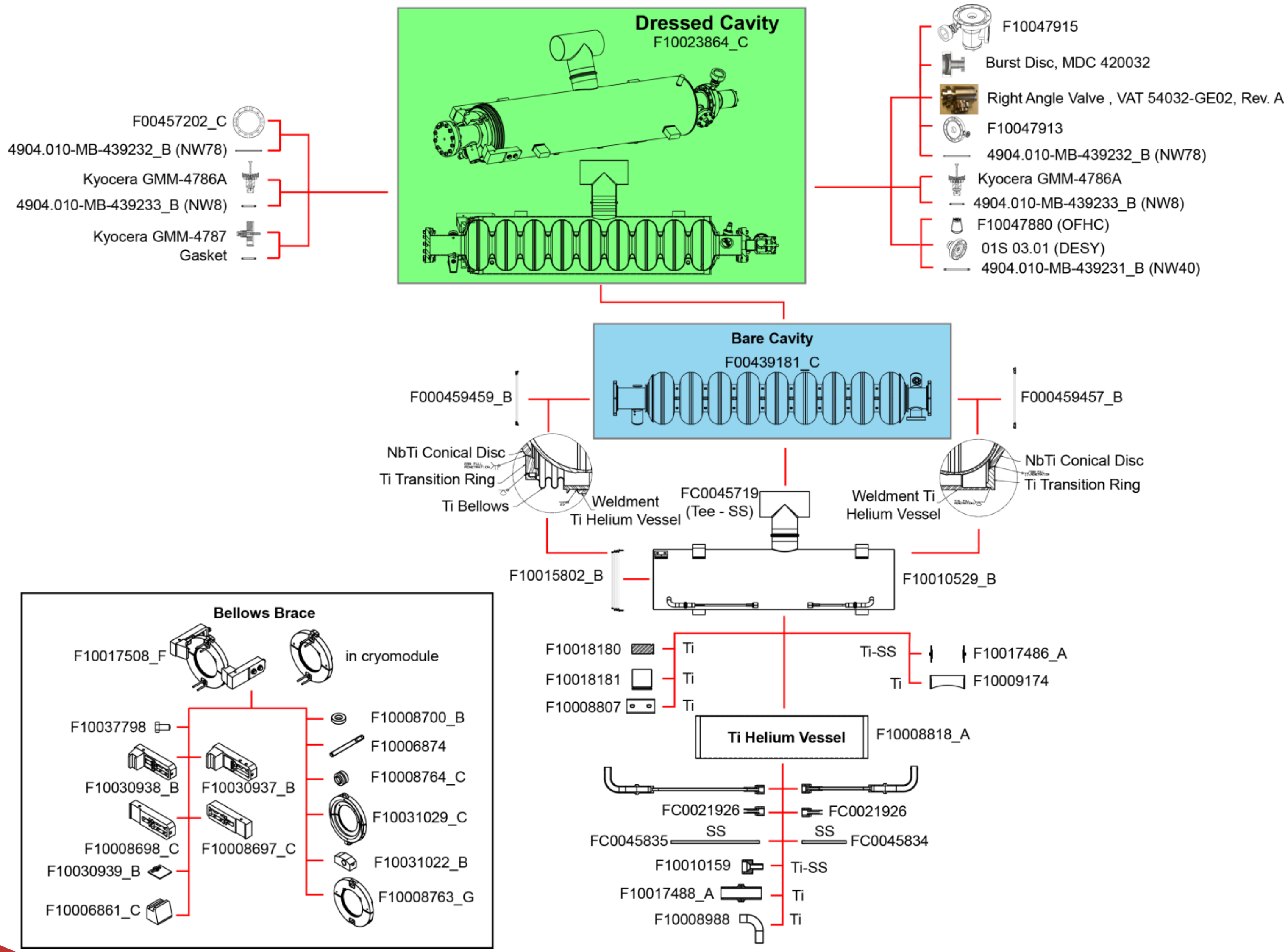
1) Mechanical Fabrication of Bare Cavity



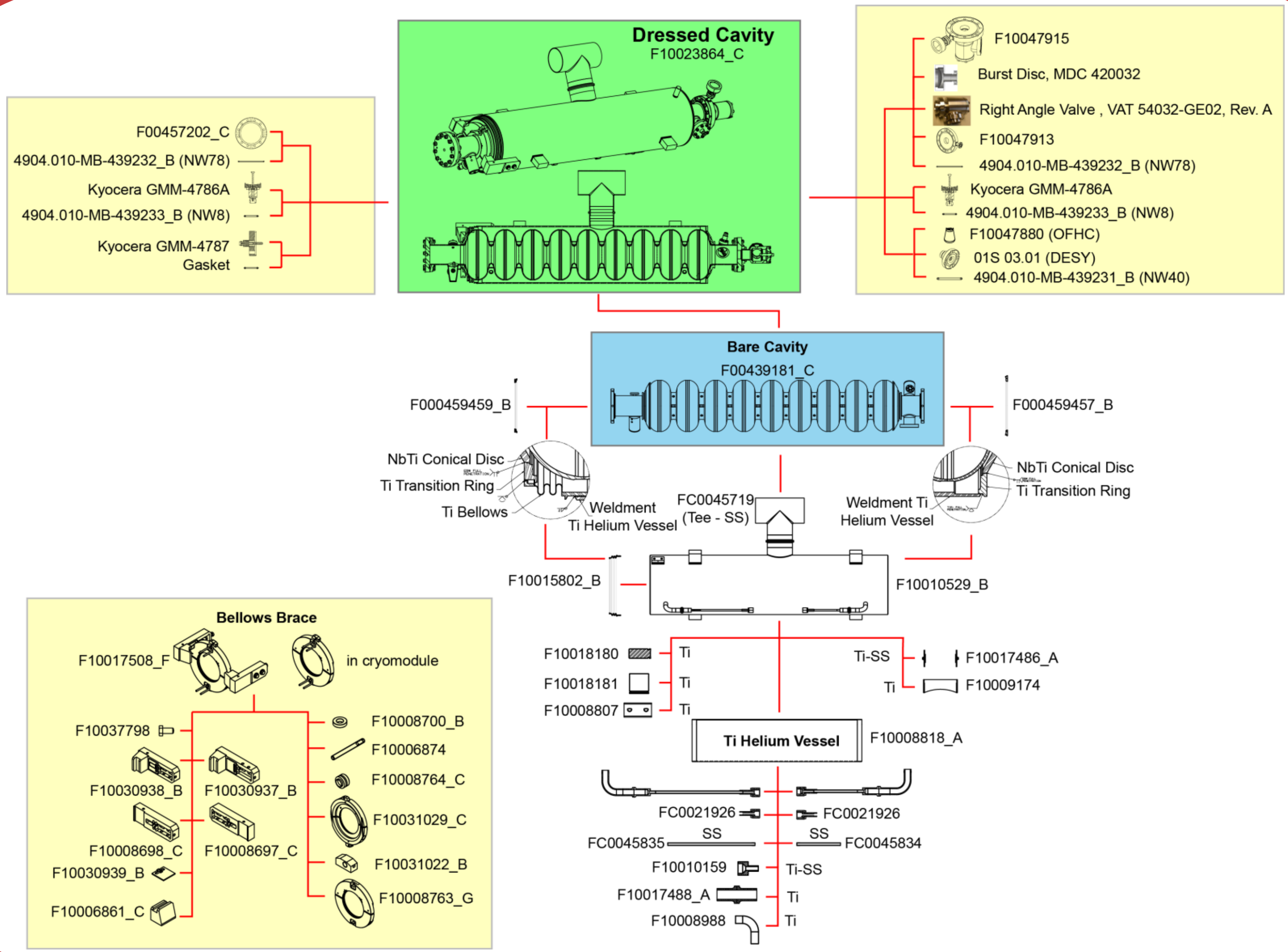
2) Post-Processing Flow Chart (LCLS-II vs. XFEL Recipes)



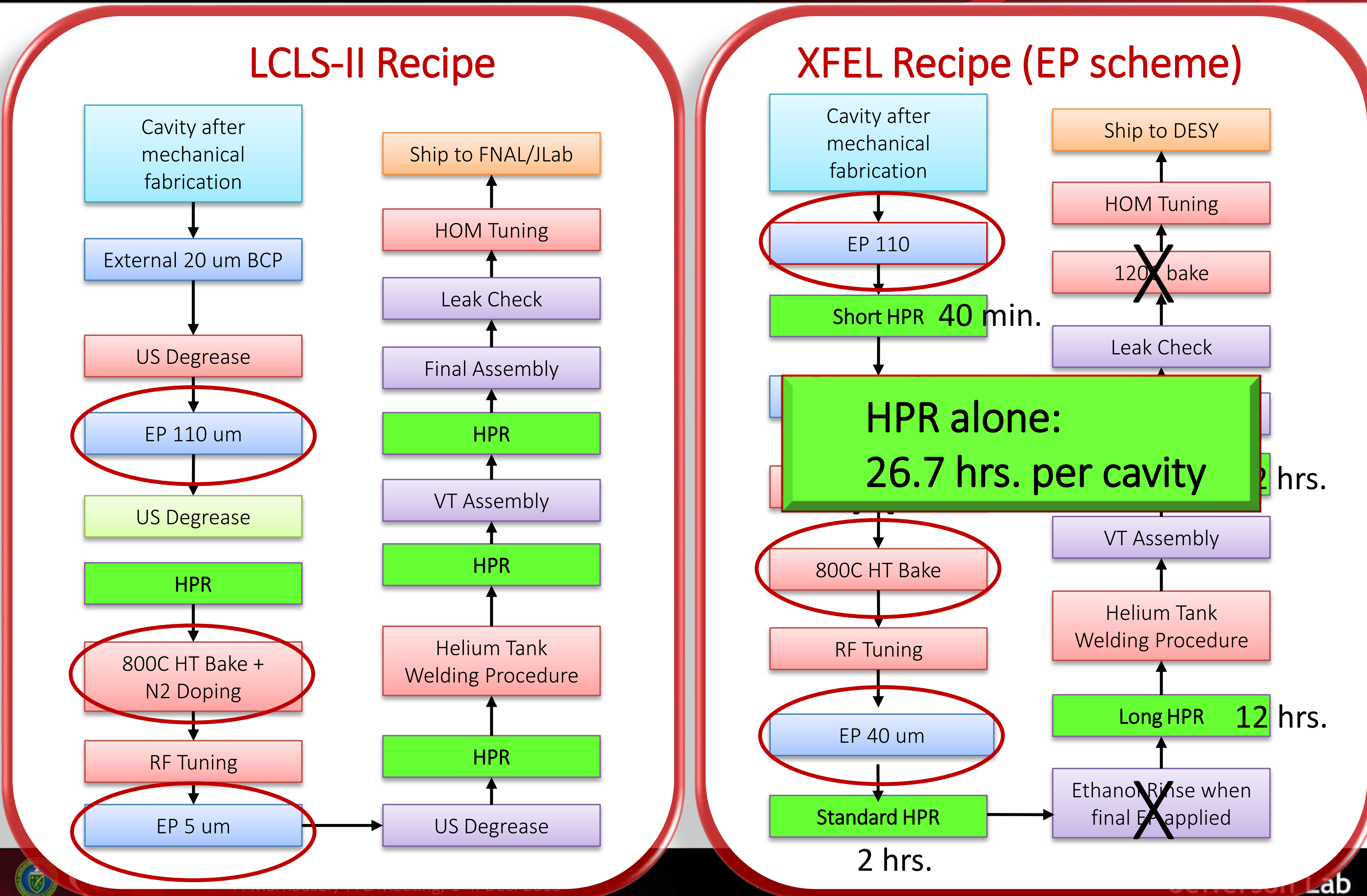
3) Helium Vessel Integration and Hardware Assembly



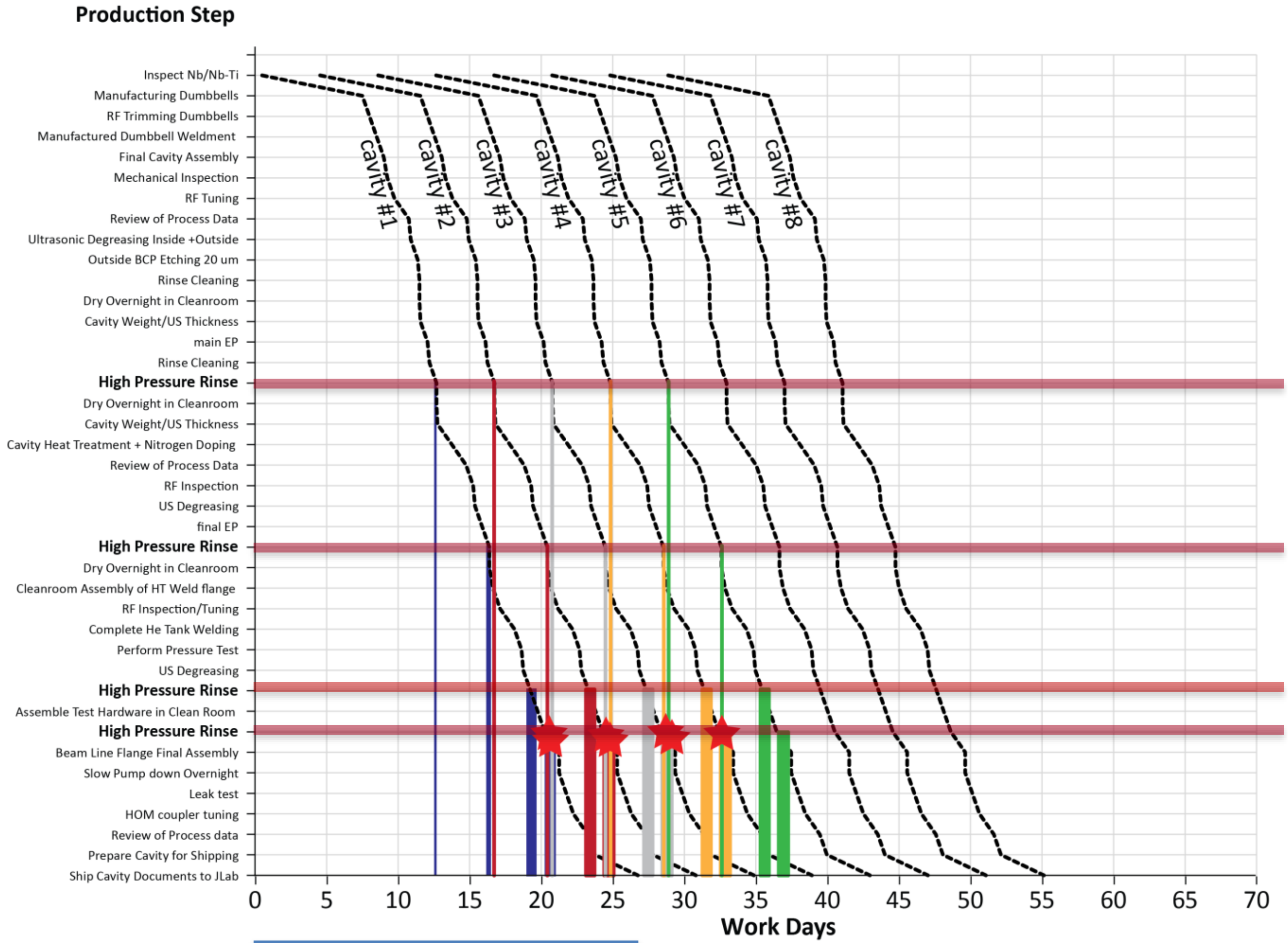
Parts required for Vertical Qualification Tests



E.g. High Pressure Water Rinsing



Example: Fabrication and Post-Processing Timeline

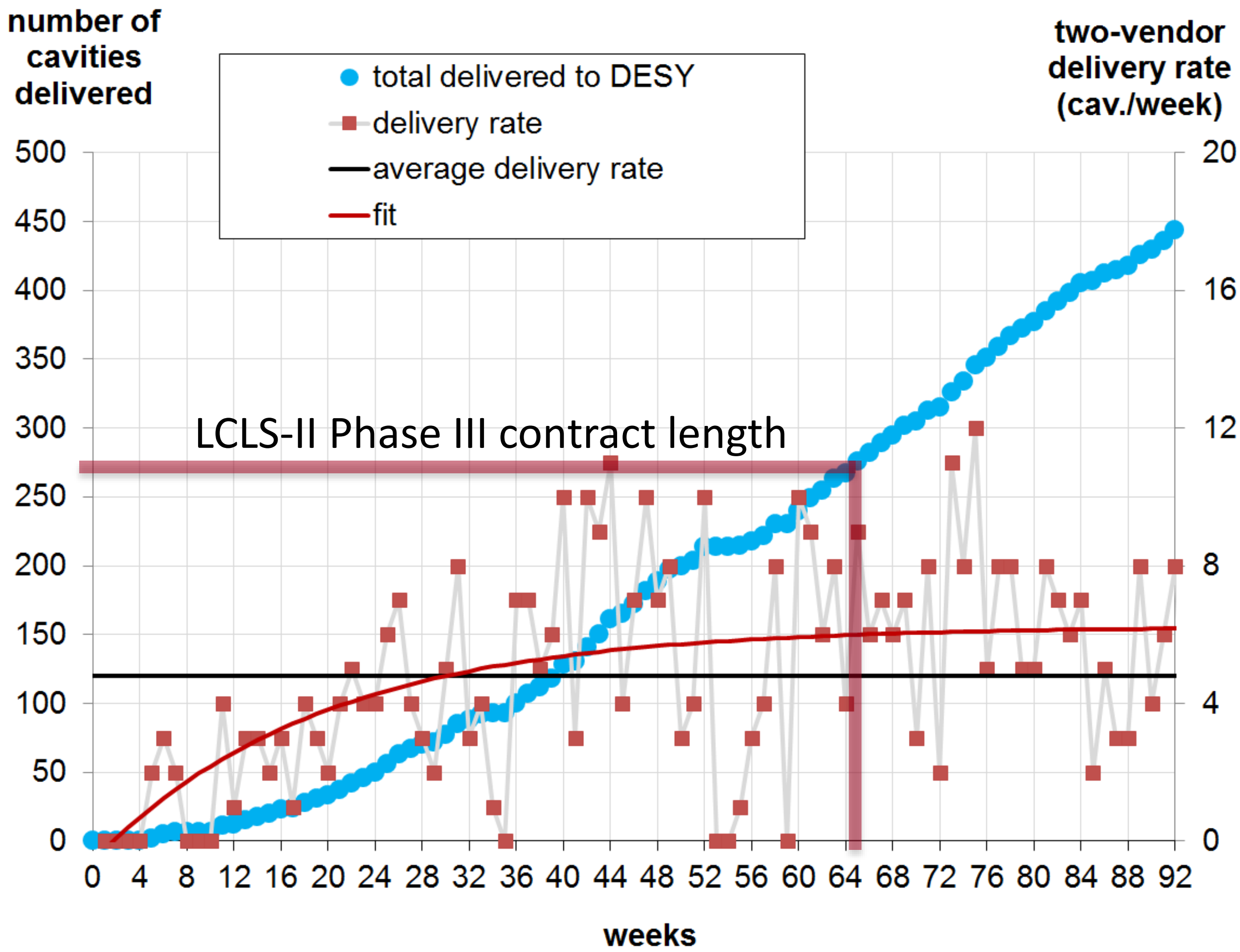


~ 1 month lead time
for 1st cavity

Challenging Schedule, e.g. impact of High Pressure Rinses (HPR)

- Phase III: 250 cavities in 450 calendar days → ~4 cavities/week
  - Highest SRF cavity delivery rate after CEBAF upgrade (~1 cavity/week) and before XFEL
  - 'Industrialization' for XFEL has shown this is feasible
- 450 calendar days or **~330 net work days** assuming 5 work days per week
- Assuming work is done in three work (24 hrs. day)
- With **1 HPR cabinet**: 250 * 26.7 hrs. = **278 work days for HPR alone**
- With **2 HPR cabinets**: **139 days HPR alone** - consider that other processes require a lot of time as well, e.g. electropolishing and high-temperature bake-out
- LCLS-II required 2 vendors to meet schedule (each with 2 HPR cabinets)

Realistic Schedule XFEL (Status 10/2014)

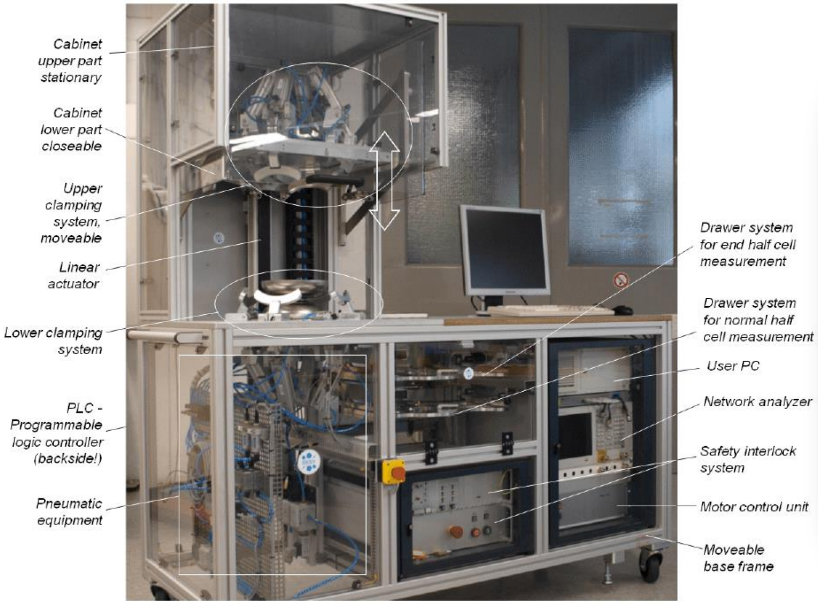


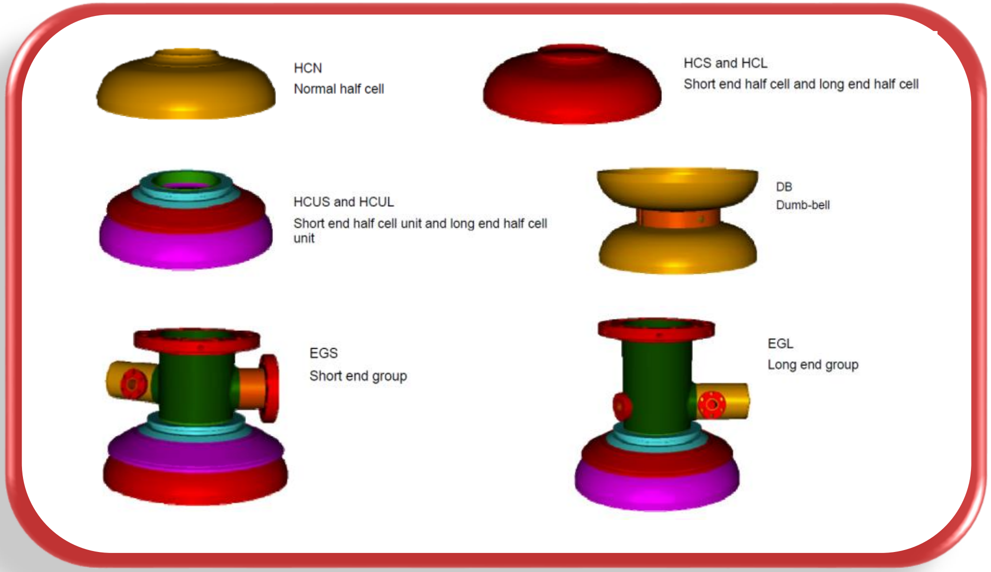
> 4 cavities/week on average

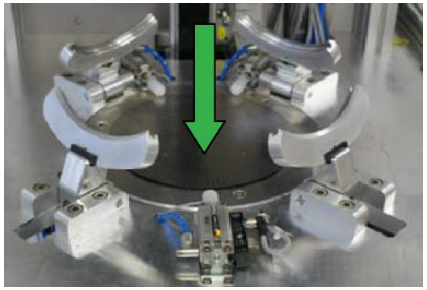
LCWS 14, Oct 6-10 2014, Belgrade
Hans Weise, DESY

DESY-owned machines

- Semi-automated HAZEMEMA - tuning of half cells, dumbbells and end-groups







J. Iversen et al., Proceedings of SRF2009, Berlin, Germany, THPPO071

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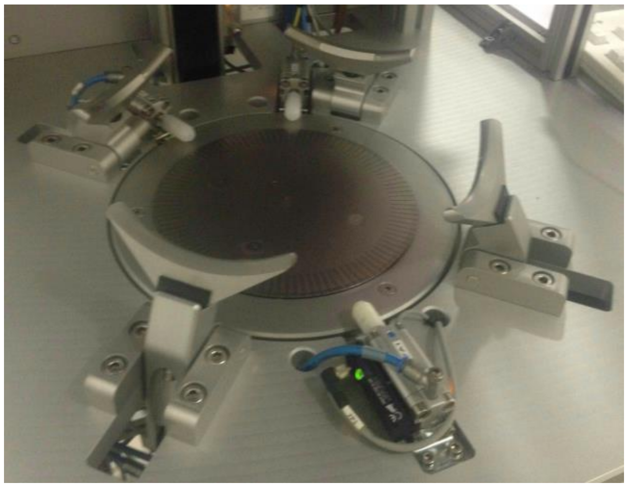


	Clamping	Test duration for dumb-bell	Required manpower
Simple device	manual	5 min	2
New machine	automated	2 min	1

	Parts per cavity	**Measurements done for 41 cavities**
Normal half cell	16	656
Short half cell Long half cell	2	82
Dumb-bell	8	656
End half cell unit	2	82
Short end group Long end group	2	164
Summary	**30**	**1640**

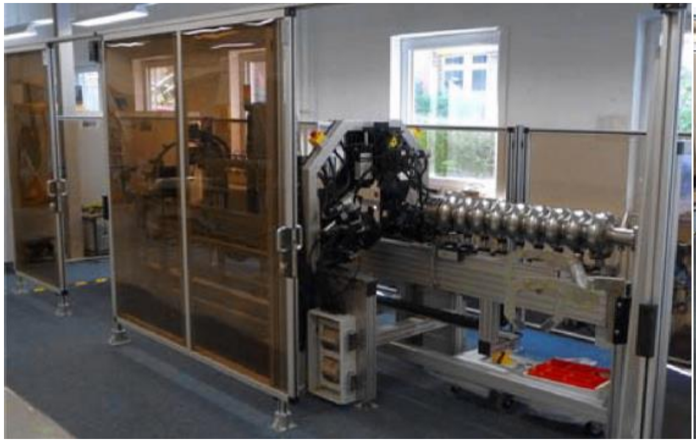
Table 2) Experiences (amount of measurements done during the fabrication of 41 cavities)

Test object	**Decreased test duration**	**Realized test duration (min)**
Half cell	67%	1
Dumb-bell	80%	2
End half cell unit	67%	1
End group	67%	1

J. Iversen et al., Proceedings of SRF2009, Berlin, Germany, THPPO071

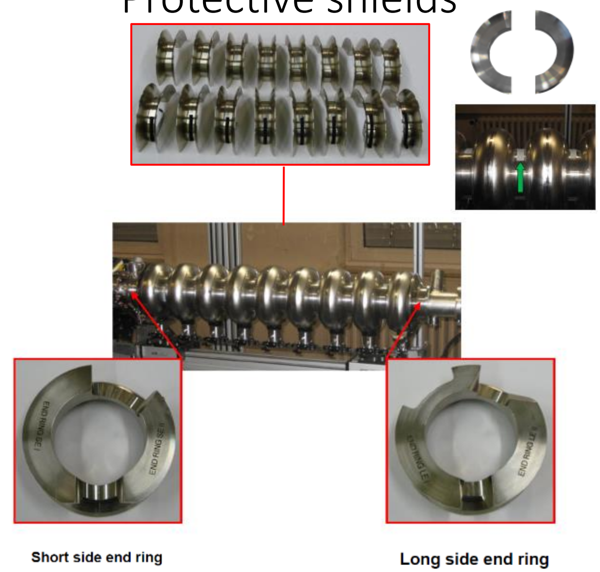
DESY-owned machines

- High-level automated Cavity Tuning Machine (CTM) - tuning of welded cavity



- Developed within collaboration of DESY, FNAL and KEK
- For use at industry by non-RF experts
- Also allows eccentricity measurements of each cell
- Cavity length and straightness

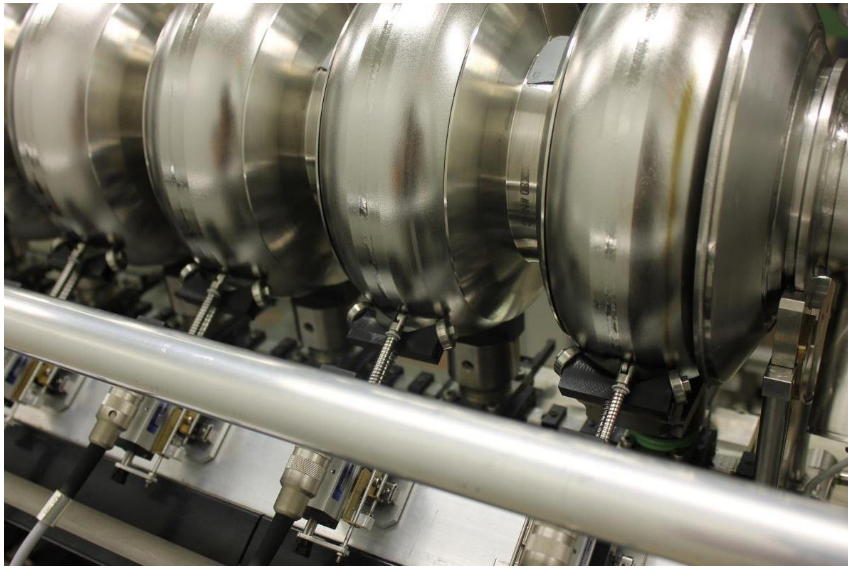
Protective shields

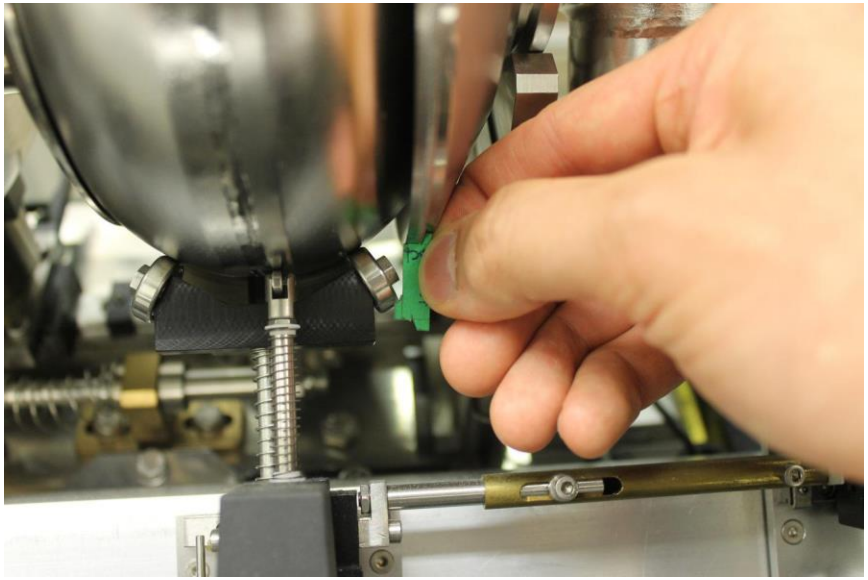


D. Reschke et al., Phys, Rev. ST Accel. Beams 13, 071001 (2010)

Technical issues due to modifications to XFEL design

- Technical issues encountered with FNAL cavity design (due to old TESLA drawing versions used) and with the new FNAL helium vessel
- Discussion between JLab, DESY and vendors to find resolutions
- Collision studies done by DESY especially concerning the use of the CTM
  - Special thanks to Jens Iversen, Jan-Hendrik Thie

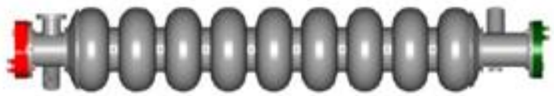




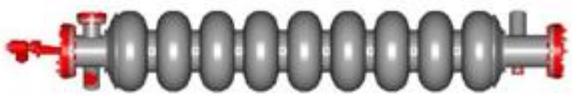
Courtesy of Ambra Gresele (E. ZANON)

Configuration of cavity on CTM - Design

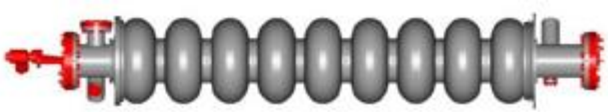
1) Open Cavity with Conical Discs



2) Closed Cavity with Field Measurement System (FMS) installed

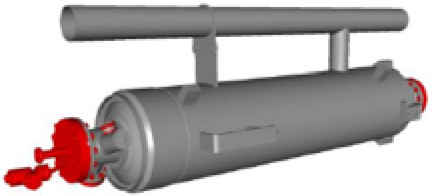


3) Closed Cavity with Transition Rings and Bellows (FMS installed)



Final eccentricity measurement before Helium vessel welding

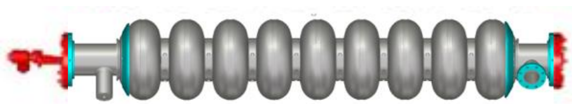
4) Closed Cavity welded into Helium vessel (FMS installed)



Configuration of cavity on CTM Fermilab - Design

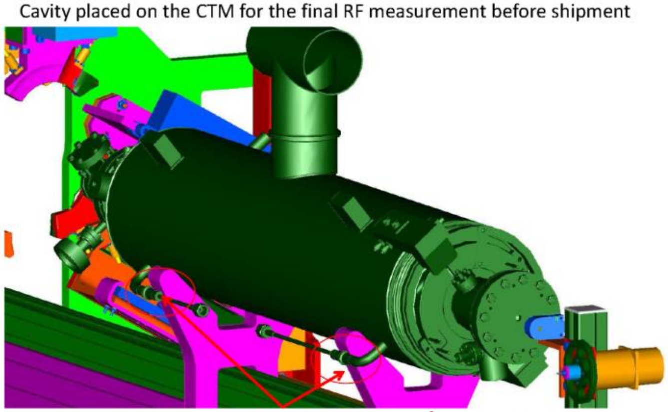
1) Open Cavity with Conical Discs

2) Closed Cavity with Field Measurement System (FMS) installed

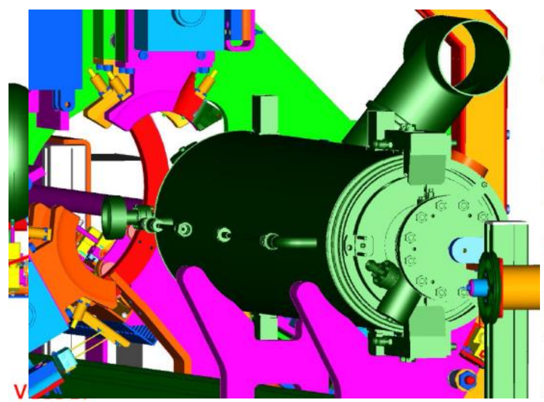


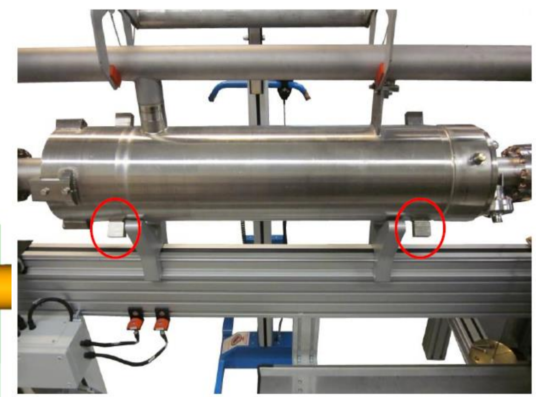
3) Closed Cavity with Transition Rings and Bellows (FMS installed)

Cavity placed on the CTM for the final RF measurement before shipment



Collision "bellow"/"transition rings"!



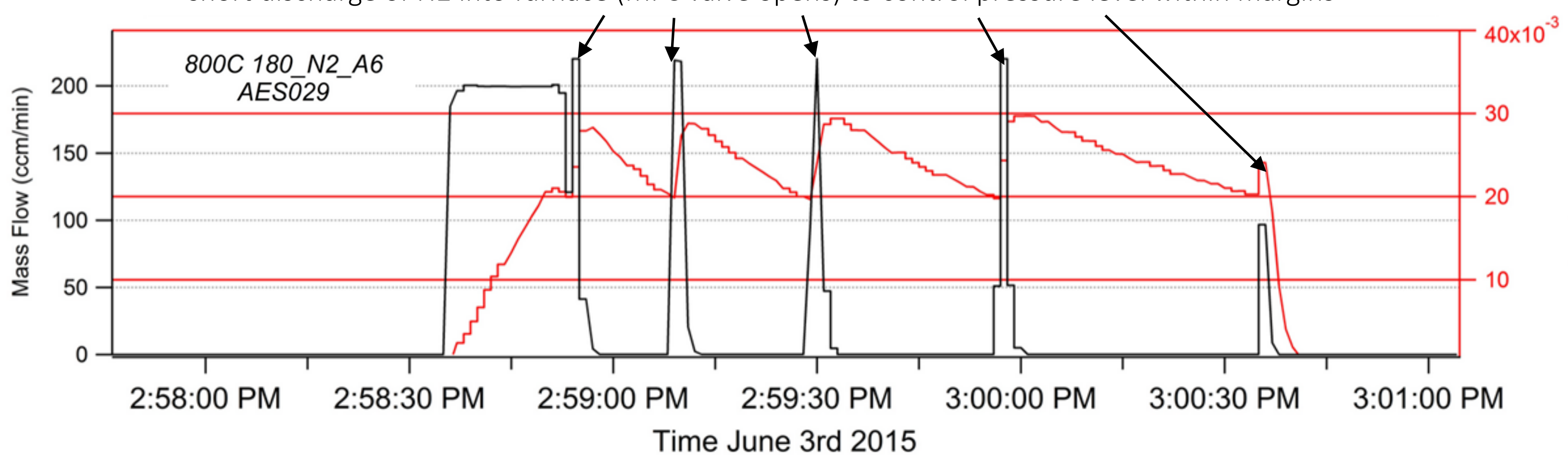


Simple Solution: Modify supports (and cavity lifter to carry cavity into CTM)

What's New/Different to Previous Projects? – Nitrogen-Doping

- Nitrogen-Doping is part of routine 800 deg. C vacuum furnace bake-out
  - 2 minutes doping make a difference in performance

Step	Temperature (°C)	Duration	N-Pressure (mTorr)
H degassing	800 ± 10	180 ± 5 min	0
N-Doping	800 ± 10	2 min ± 6 sec	26 ± 4
Annealing	800 ± 10	6 min ± 6 sec	0



Typical N-doping run at JLab (without active pumping)

Vendor Qualification (VQ) – N-Doping Technology Transfer

- Technology transfer to industry successful
  → pressure control well demonstrated by both vendors within required limits
- 3 of 4 VQ cavities N-doped, last cavity in preparation, 1 cavity shipped to JLab
- Vertical RF acceptance tests pending

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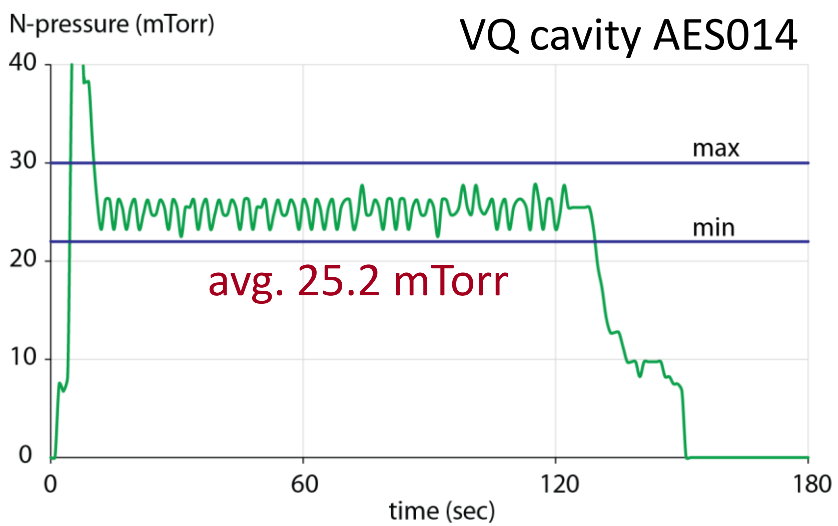
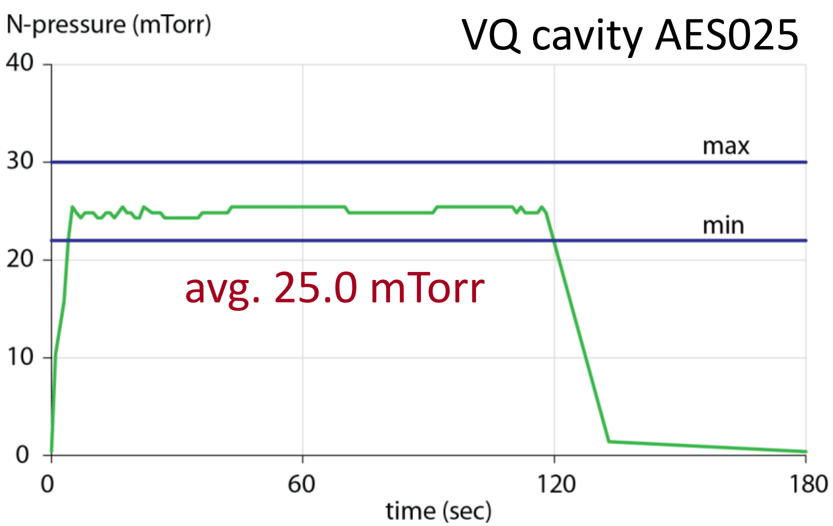
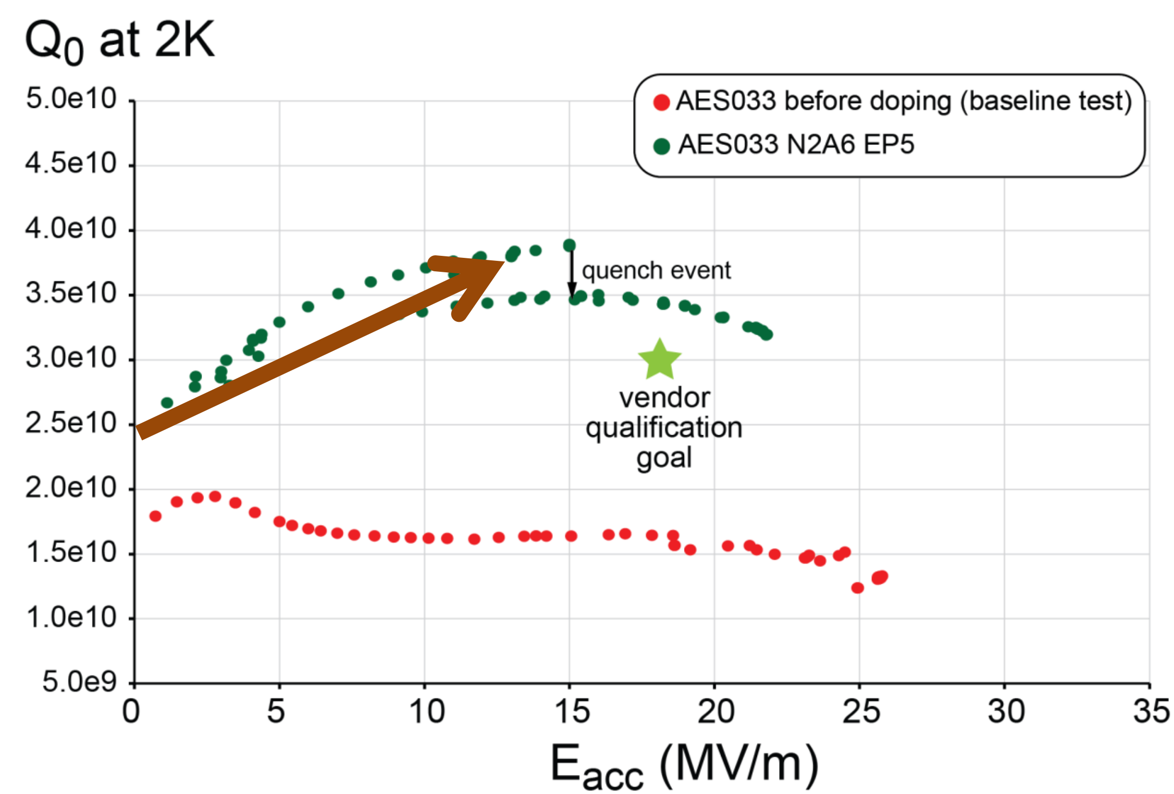




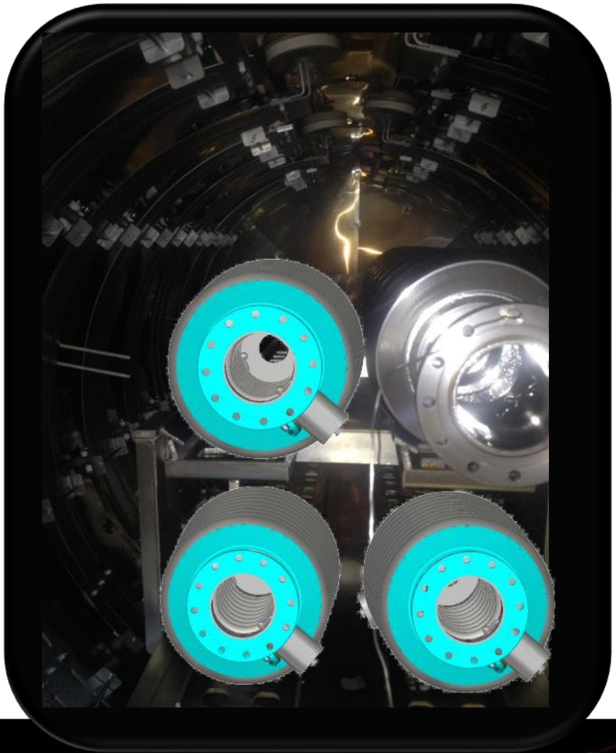
Vendor Qualification (VQ) – N-Doping Technology Transfer

- Characteristic of N-doped TESLA cavity compared to un-doped cavity: initial Q_0 rise, which is used as criteria for vendor qualification
- Desired goal is Q_0 = 3e10 at 18 MV/m



Not yet demonstrated: Multiple cavity N-doping

- LCLS-II schedule demands that several cavities to be doped at once
- Consider occupancy time of furnace (only 1 furnace per vendors): ~2-3 days (~1 day pumping, bake-out + ~15 hrs. cool down)
  - → at least 133*2=266 days per vendor occupancy ! → need to stack cavities
- Mass flow regulation capability at vendors indicates that this is possible though not demonstrated yet → not enough cavities



Vendor Qualification (VQ) – Temperature-Controlled Electropolishing

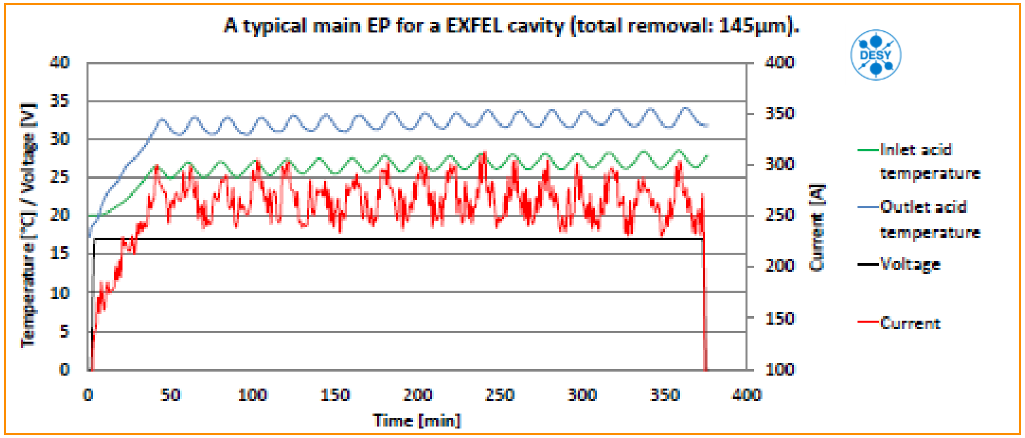
- **Aim:** Lower EP process temperatures ≤ 25 deg. C at cavity walls to:
  1) Eliminate solid sulfur precipitation (thus Ethanol rinsing)
  2) Provide better control of overall removal amount, particularly for fine 5 µm EP after doping
  3) Mitigate volatility of removal rates from cavity to cavity → therefore frequency change especially after EP (e.g. better control of frequency change after bulk EP)

- **But:** Longer EP occupancy (~3x) → two shifts for 1 bulk EP

The facility can perform **five bulk treatments per week** (140 µm each) over a long period.

M. Rizzi et al, Proceedings of SRF2015, Whistler, Canada, MOPB102

Vendor Qualification (VQ) – Temperature-Controlled Electropolishing



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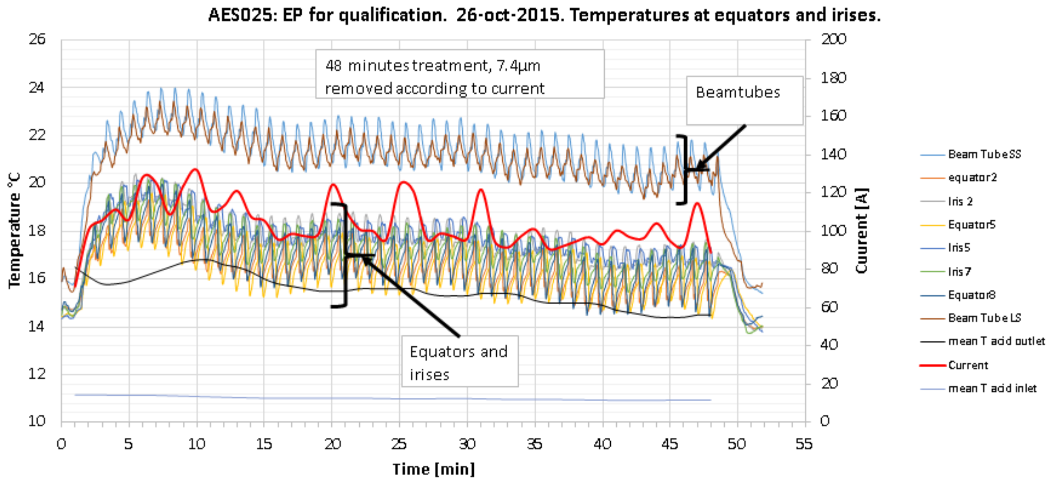
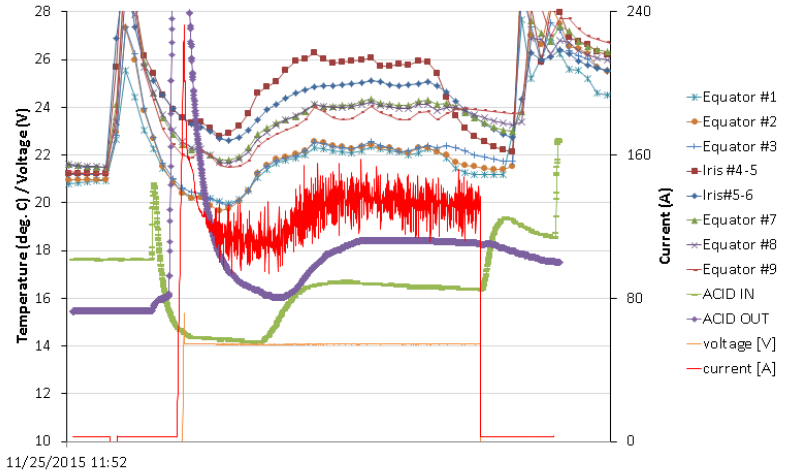


research instruments



Courtesy of M. Rizzi

Courtesy of D. Trompeter

Challenge with Dual Vendor Award

- How to best provide consistency among vendors?
  - Different facilities, e.g. furnace and electropolishing facility
  - It may require different approaches to provide similar results
  - Experience and expertise may differ
  - As long as requirements are met, different approaches may be accepted
- So far both vendors are doing well
- Main Challenges are still ahead for LCLS-II

Acknowledgements

Jefferson Lab (Thomas Jefferson National Accelerator Facility)

E. Daly
J. Fitzpatrick
J. Leung
A. Palczewski
J. Preble
C. Reece

Fermilab

A. Grassellino
C. Grimm
M. Merio
A. Rowe

SLAC National Accelerator Laboratory

B. Miller
M. Ross

research instruments

S. Bauer
A. Gottschling
M. Knaak
M. Pekeler
D. Trompeter

E. ZANON

G. Corniani
A. Gresele
D. Rizzetto
M. Rizzi

DESY

J. Iversen
J. Sekutowicz
A. Matheisen
D. Reschke
W. Singer
J.-H. Thie
H. Weise