

WG3: Mass Production & Quality Assurance for Accelerator Modules

Takeshi Dohmae – Laura Monaco – Mattia Parise

Convener's session summary

4 sessions

6 topics

31 Presentations

Session 1

Experience from
completed/ongoing
projects

Session 2

HPGS
HOMs

Session 3

Couplers
CMs

Session 4

CMs
Cavities

Mass Production & Quality Assurance for Accelerator Modules

Convener's session summary — ten facilities, one common questionnaire

● OPERATING - COMPLETE

EuXFEL (DESY)

FRIB (MSU)

● PRODUCTION DONE COMMISSIONING

LCLS-II-HE (SLAC) - ESS - SHINE

RAON - HIAF (IMP)

● EARLY PRODUCTION

HL-LHC (CERN) - PIP-II (FNAL)

S3FEL

Every facility prepared the project's summary table and answered the same six questions:

1. **Yield vs Spec:** What were final yield rates for cavities, couplers, and cryomodule components, and how did actual performance compare to design specs?
2. **VT-to-CM Transfer:** What performance degradation was observed from Vertical Test to cryomodule operation, and how were the design margins defined to account for it?
3. **Industrialization & Repeatability:** Which assembly tools, cleanroom equipment, or standardized procedures were most critical for repeatability and throughput during production?
4. **Supply Chain & Material Quality:** How did material selection and supplier QA affect the production timeline, and were there notable performance variations across niobium batches or vendors?
5. **Transport & Logistics:** What technical challenges arose during cryomodule transportation, and what monitoring criteria (vacuum, shock, alignment) were used to verify hardware integrity on arrival?
6. **Spare Parts Strategy:** What was the ratio of spare parts to installed components, and did that buffer adequately cover non-conforming parts throughout production?

What we heard: quality, performance & production

FINDINGS 1–3 OF 6



Q1 High final yields — but reprocessing is the norm

- Final cavity yields is around 95–100%, couplers ~87–100%, CM components 94–100%.
- First-pass yields are far lower: ~25% (HL-LHC), 65% (LCLS-II-HE), 85% (S3FEL).
- Field emission is the dominant cause of failure and rework across projects.

65% → 95%

*first-pass → final
(LCLS-II-HE)*



Q2 Gradient mostly transfers; field emission does not

- Quench gradient largely preserved VT→CM; Q0 occasionally degraded (trapped flux).
- FE appears in the module even when absent in vertical test (LCLS-II-HE: 0→32 cavities).
- Margins set empirically (~15–20%); admin power limits mask true CM performance.

0 → 32

*cavities with FE for
LCLS-II HE
VT → CM*



Q3 Vendor partnership + in-house control + standard tooling

- Recurring recipe: deep vendor oversight, critical steps in-house, standardized cleanroom procedures.
- Qualified tooling with spare sets prevents production bottlenecks.
- Throughput gains: HL-LHC 5→20 cold tests/yr; HIAF 50→26 days per module.

5 → 20

*cold tests / year
(HL-LHC)*

Supply chain, logistics & the road to operations

FINDINGS 4–6 + TAKEAWAYS



Q4 Supply & material

- Procure niobium early to protect the schedule.
- Batch-to-batch variation seen (mechanics, flux-expulsion temp) — rarely an RF driver.
- 100% ECS of sheets; PED compliance a recurring EU theme.



Q5 Logistics & transport

- Standard kit: accelerometers + shock & vacuum logging, alignment on arrival.
- Mostly no degradation, but rare hard events (coupler bellows, vacuum leaks, a cavity lost in a crash).
- Customs & tariffs now a real schedule risk.



Q6 Spare-parts strategy

- ~10–20% buffer is typical and generally sufficient.
- Most non-conformances are reworked into conformance.
- Couplers increasingly treated as 'slow-burning consumables'.

⚡ CONVENER'S TAKEAWAYS

1

Define “yield” consistently. First-pass vs. after-reprocessing differ 2 – 3×. Reprocessing is planned, not exceptional.

3

The repeatable recipe is organizational. Deep vendor partnership + in-house critical steps + qualified, spare-backed tooling.

2

Field emission is our shared, unsolved limiter. It dominates VT→CM transfer and worsens in operation; HPR, pulse & plasma processing only partly help.

4

Production is largely solved, sustaining 20–40 yr operation is the frontier. Spares, couplers-as-consumables, and knowledge transfer to the host lab.

Session2a:Pressure Vessel Code in Accelerator Projects

Convener's session summary — three regions

Questions

1. What is the request for materials which will be used for high pressure vessel?
2. What kind of pressure test are required? And how much is the pressure?
3. How to harmonize each regions/country (how industries comply to foreign pressure vessel codes)?
4. Which kind welding test requested?
5. What kind of tests are required for the completed high pressure vessel?

Respondent

Daniele Sertore (INFN) / Henry Przybilski (ESS)

Experience applying PED and ASME was summarized, and the presentation highlighted how different regulatory frameworks influence material qualification, welding, and pressure testing. How to build proper cryogenic lines to fulfill PED requirements was also presented from ESS experiment.

Yawei HUANG (SHINE)

The presentation provides a clear, comprehensive overview of China's pressure piping and vessel codes, structured around materials, testing, welding, and regulatory alignment.

Takeshi Dohmae (Kensei Umemori) (KEK/ITN)

This presentation outlines KEK's practical approach to applying Japan's High Pressure Gas Safety (HPGS) regulations to SRF cavities, detailing material requirements, welding tests, and multi-step pressure testing.

1. What is the request for materials which will be used for high pressure vessel?

- The requested mechanical property for Nb300 used in XFEL, ESS, and PIP-II were shown.
- China's legal definitions and classification criteria for pressure piping, pressure vessels were shown.
- Different requests for each material (hi-RRR/lo-RRR Nb, NbTi, Ti) are shown. Charpy impact test in cryogenic temperature is also requested.

2. What kind of pressure test are required? And how much is the pressure?

- PED requests $1.43 \cdot \text{MAWP}$ (maximum allowable working pressure), ASME/FNAL requests $1.15 \cdot \text{MAWP}$ with nitrogen.
- In SHINE, test pressure will be 1.1 - 1.33 times the design pressure while design pressure is defined as $\text{MAWP} \cdot 1.05$.

3. How to harmonize each regions/country (how industries comply to foreign pressure vessel codes)?

- In case of 3.9 GHz cavity, external notify body "TUEV Nord" was required by Category IV. Vendor takes care of the whole qualification process in PED art. 4.3 for ESS and ASME for PIP-II.
- In China, pressure piping code and pressure vessel code are defined. SHINE also refers ASME code.
- Deep communication with vendor is very important. Necessary tests/inspections were written in technical specification document.

4. Which kind welding test requested?

- 3.9 GHz and ESS: PED, DESY qualification process with PMA (Particular Material Appraisal), TUEV-Nord. PIP-II: ASME Boiler and Pressure Vessel Code, and/or the ASME B31.3-2014 piping code.
- SHINE follows general Chinese code (GB/T).
- Need bending test and tensile test from welding samples in Japan.

5. What kind of tests are required for the completed high pressure vessel?

- Welding test, pressure test (PED), X-ray (ASME) are required.
- Pressure test, leak test and vacuum test are required in Chinese code.
- Three steps of pressure tests (bare cavity, He jacket, jacketed cavity) are required at KEK.

Fabrication challenges and processes for HOMs

Convener's session summary — three presentations



Investigation of Nb material for HOM housing

Takeshi DOHMAE (KEK)
Alexey Ermakov, Andrea Muhs, Jens Iversen (DESY)
Hiroaki Umezawa (Tokyo Denkaï Co., Ltd.)
Shinohara Press Service Co., Ltd.
Katagiri Seisakusho Co., Ltd.

TTC 2026 meeting
2026. 9. June

Challenges with production of HOM Couplers for Hi-Lumi

June 9th, 2026
Naeem Huque

Jefferson Lab U.S. DEPARTMENT of ENERGY

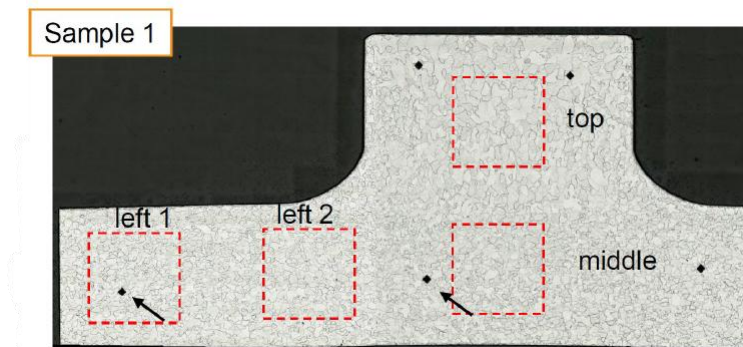


Fabrication Challenges and Process Optimization of HOM Absorber for the S³FEL

Huizhong Pang
Institute of Advanced Light Source Facilities, Shenzhen
June 9, 2026, TTC Meeting, Paris, France

Each presenter discussed fabrication challenges related to HOMs

Takeshi DOHMAE (KEK) developed a novel forming technique in collaboration with Japanese industry to reduce material and fabrication costs while simultaneously improving quality. The team successfully fabricated HOM cans directly from stock material via forming, achieving superior microstructure (grain size) and dimensional accuracy.

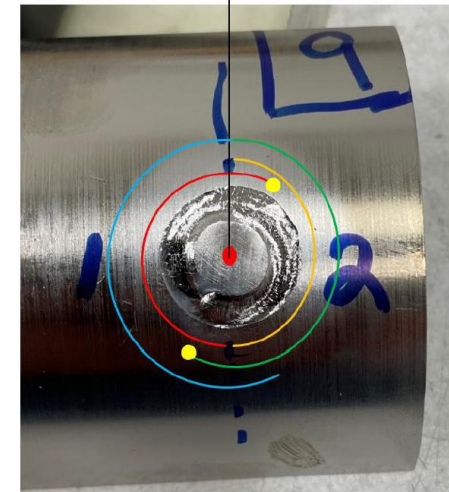
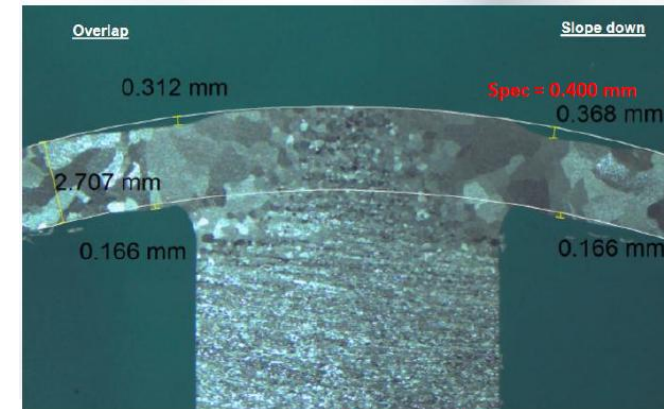


Fabrication challenges and processes for HOMs

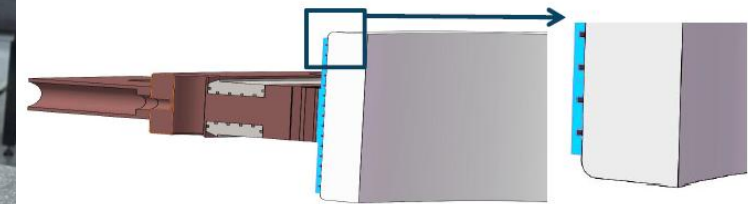
Convener's session summary — three presentations

Each presenter discussed fabrication challenges related to HOMs

Naheem Huque (JLab) presented the complete fabrication process for HL-LHC crab cavity HOMs, highlighting key lessons across the full production chain: raw material quality control, machining, antenna electron beam welding (EBW) and its qualification, brazing, and final acceptance testing. The overarching takeaway: allocate sufficient development time when tackling new, complex HOM assemblies.



Huizhong Pang (IASF) presented the design and development of a new HOM absorber, along with optimization of its fabrication process. Manufacturing requires AlN metallization and brazing, with strict requirements for a crack-free final product. A prototype was successfully produced, validating the optimized fabrication approach.



Added brazing filler grooves

Fundamental Power Couplers: Development, Fabrication and Challenges

Convener's session summary — four presentations



Zhenyu Ma

Shanghai Advanced Research Institute(SARI), Chinese Academy of Sciences

9 June, 20246

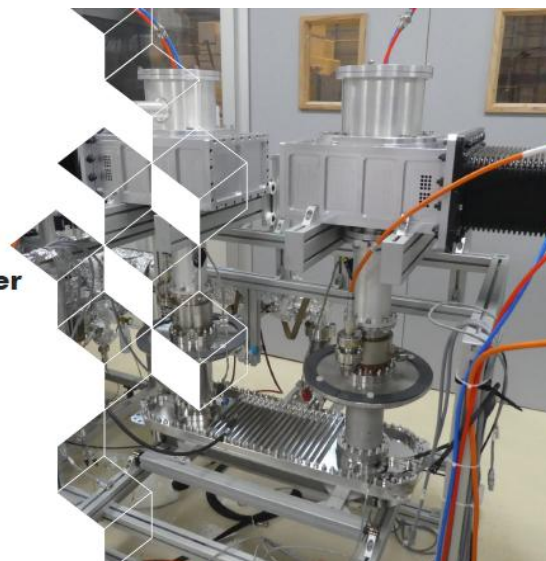
SHINE

TTC2026 Meeting, Paris, France



Fundamental Power coupler for ESS, experience from series production and conditioning

Thibault Hamelin



Issues and mitigation methods with FPC during 1.3GHz Cryomodule assembly

Wei Chen, Yonghu Yun

Institute of Advanced Light Source Facilities, Shenzhen

09-12 June, TTC'2026 Meeting, Paris Saclay

Fundamental Power Couplers: Development, Fabrication and Challenges

Convener's session summary — four presentations

Each presenter discussed development, fabrication experience and some challenges related to FPCs

Zhenyu Ma (SARI) presented development of 3.9 GHz Fundamental Power Couplers for SHINE. A design is presented as well as measurements and tests performed on two prototypes.

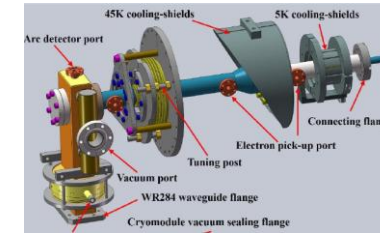


FIG. 3.9 GHz couplers test bench.

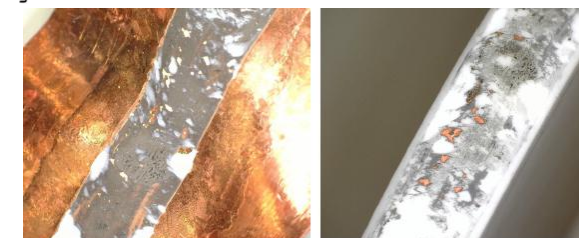
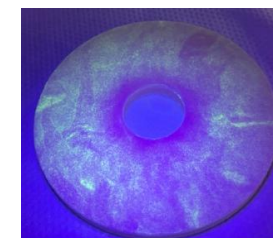
Wei Chen (IASF) presented issues and their mitigation on 1.3 GHz Fundamental Power Couplers for S3FEL. This included coupler bellows excessive deformation solved by optimizing the torque applied on the 5K thermal intercept and damage to the tuning rod bellows solved by swapping the connector from brass to PEEK and by process changes.



Thibault Hamelin (CEA) presented the experience from the series production related to the couplers for ESS. Technical issues such as cracks in the ceramic, brazing overflow, ceramic fragments are presented, TiN and copper coating. Importance of diagnostic during RF conditioning and inspection are highlighted.



Tommaso Aiazzi (FNAL) presented the fabrication status of PIP-II couplers and recent challenges related to ceramic windows brazing. Ceramics from 2 different vendors leak after brazing of the ceramic window. Possible causes are highlighted as well as QC inspection process. Root cause is still to be established but most probable cause is powder quality.

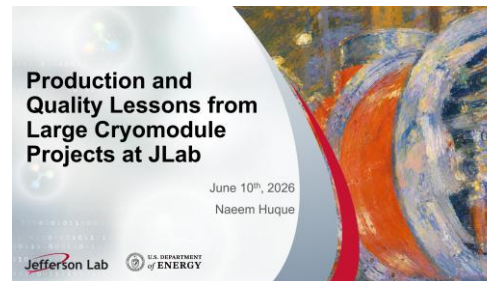
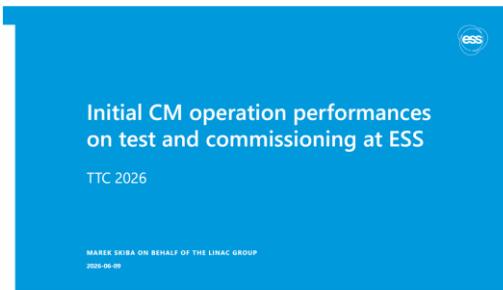


fail

Peel tests

Session3/4: Mass Production and QA/QC: String and CM

Convener's session summary — Five presentations



Marek Skiba (ESS) presented performance of initial CM operation on test and commissioning at ESS. Preparation status of LINAC for commissioning, cryogenic status are reported. Some issues on tuner motor, FE, performance degradation and cold compressor bearing failure were also reported.



Commisioning of Accelerator Cryogenic

Timeline

- 1st Cooldown of the ACCP and CDS:** Dec-2022 (8K)
 - + identification of some issues (high HL, TAO, valves tightness)
- 2nd Cooldown of the ACCP and CDS:** Jun-2023 (2K)
 - + 2 cryomodules (Spokes **SPK-110** and Elliptical **MBL-020**).
- 1st Cooldown of the LINAC:** Nov-2024 (2K) BOD1
 - + 27 cryomodules (up to **HLB-050**).
- 2nd Cooldown of the LINAC:** Feb-2025 (2K) BOD1 (unplanned)
 - + 27 cryomodules (up to **HLB-050**).
- 3rd Cooldown of the LINAC:** Nov-2025 (2K) BOD2
 - + 33 cryomodules (up to **HLB-110**).

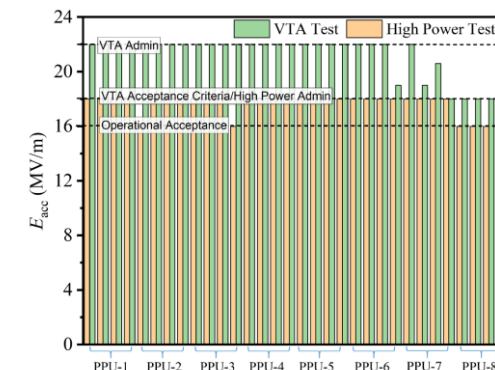
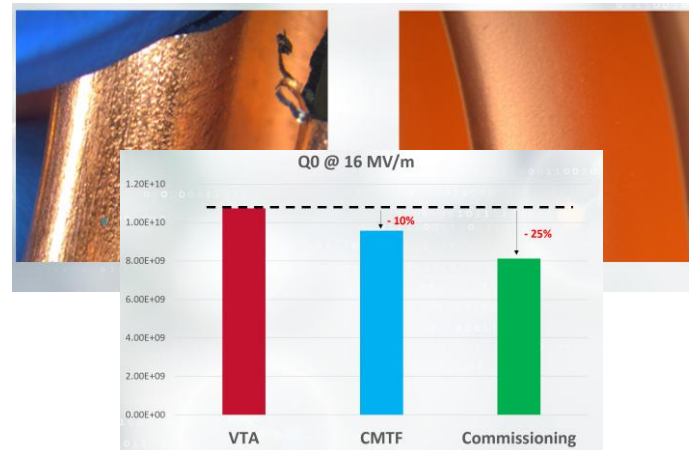
Yawei Huang (SHINE): SHINE measured the 2 K static heat load of 32 cryomodules and found values systematically higher than the 20 W design target. Detailed analysis shows that conduction is the dominant contributor, while radiation and convection are secondary. Study of heat in-leak from RF cables are on going. The final 20 prod. cryomodules measurement will give a full analysis for SHINE.

2 K Thermal Performance Analysis

- Summary for 2K static heat load contribution from three heat transfer ways
 - All measurement for analysis are based on the Mass Flow Method

NO.	Heat Transfer	CM component	2K static heat load Estim. (W)	2K static heat load Mes. (W)	Note
1	Conduction	Post support	0.12	0.52	
2		MPC	0.44	0.40	Suspect: 0.049W/MPC=f(Cu coating)
3		CryoValvel	1.14	~1.0	0.57W/CryoValve
4		Others (e.g Cables)	~1.0	?	Unknown: 24.1W - 10.5W = 13.6W (RF cable, Tuner cable, Cryocable)
6	Convection	Insulating Vacuum	0	0	~5.0E-4Pa
7	Radiation	45K Shield	1.5	5.0	Estim. vs Mes.: 0.05W/m2 vs 0.15W/m2
8	Test stand	Entire	~1.0	3.5	Faraday Cup not included
9		Faraday Cup	—	0.05	
10	Total		5.2	24.1	26 CMs with Single Shield

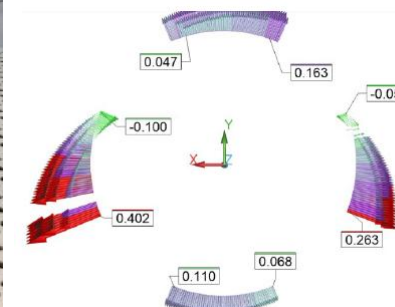
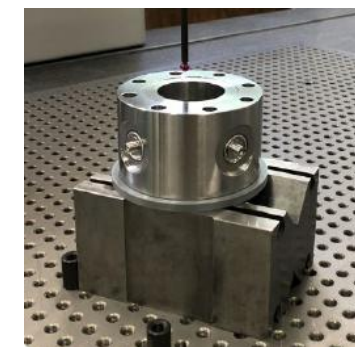
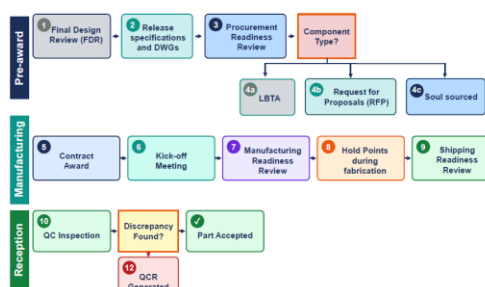
Naeem Haque (JLab) summarized brief overview of CM production including production strategies, copper plating, cavity performance, non-conformance report dispositions at JLab. Copper plating technique on bellows improved after several iterations. Few percent of cavity performance degradation between VT-CM were reported for CEBAF, LCLS-II and SNS-PPU CM.



Jacopo Bernardini (FNAL)

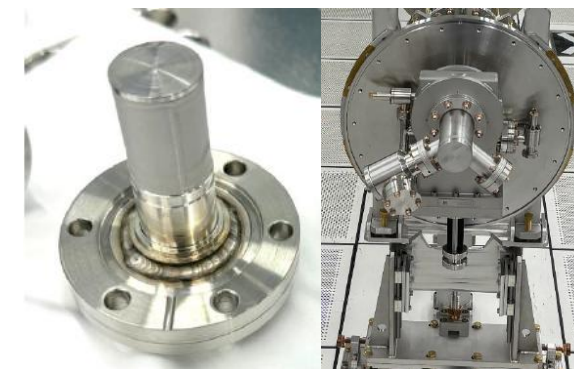
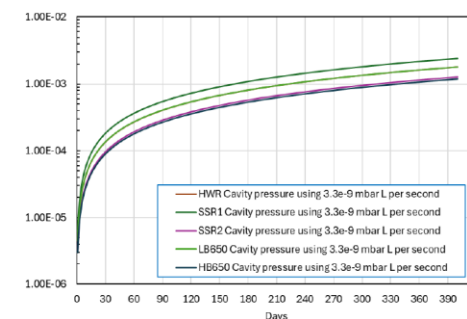
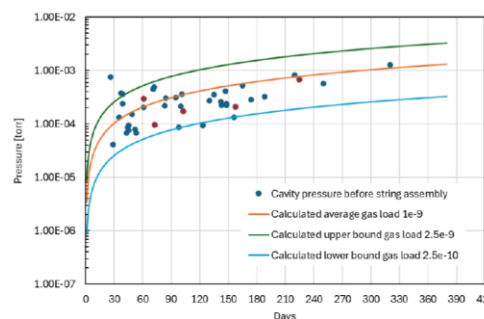
An overview of the procurement lifecycle for PIP-II's CM components is presented. Focus is on custom components (BPMs, Beamline Bellows, Support Posts and Vacuum Vessels). Lessons learned are clear: vendor engagement prior to award, strong technical team involvement, continuity between prototyping and production and tackling of NCs as soon as possible prior to final shipment are imperative for success.

Overview of procurement life-cycle



Mattia Parise (FNAL)

Standardization of string assembly procedures for PIP-II is presented. Four topics are standardized: RGA criteria, Venting, Purging, Particle Counter and Blowing. Efforts are still ongoing for purging and particle counting/blowing due to the different facilities and partners involved in the project.



Cavities: Development, Fabrication and Testing

Convener's session summary — five presentations



RF Testing and Performance Analysis of Low Beta Superconducting Cavities for HIAF Facility

Shihui WEI, Feng QIU, Yuan HE, Lijuan YANG, Zheng GAO, Jiayi PENG, Liepeng SUN, Tiancai JIANG (IMP), Rihua ZENG (Dongjiang Lab)
On behalf of IMP SRF team Institute of Modern Physics (IMP)



Progress about CSNS-II superconducting cavities

Wenzhong Zhou, Cong Zhang
Institute of High Energy Physics of Chinese Academy of Sciences

TTC 2026 Meeting, CEA-CNRS-Universit  Paris Saclay, 9-12 June 2026, Gif sur Yvette, France



Development of 1.3 GHz Cavity for S³FEL project



Yuchao FANG
On behalf of IASF SRFC team
Institute of Advanced Light Source Facilities, Shenzhen

10th Jun. TTC'2026 Meeting, Paris French



June 10, 2026

PIP-II Cavities Qualification Challenges

Jacopo Bernardini, Mattia Parise
TTC 2026 Meeting, CEA-CNRS-Universit  Paris Saclay, 9-12 June 2026, Gif sur Yvette, France



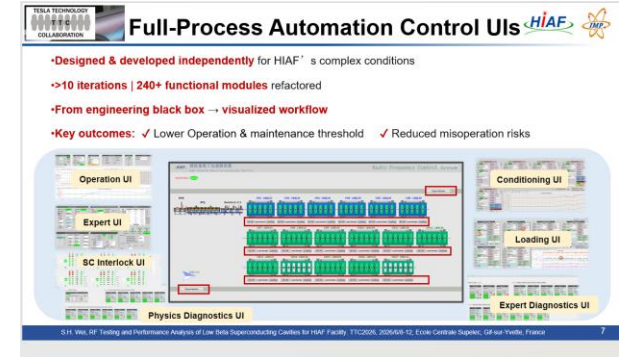
Production of RFD crab cavities for the U.S. in-kind contribution to the HL-LHC upgrade

Leonardo Ristori - FNAL
HL-LHC AUP L2 Manager

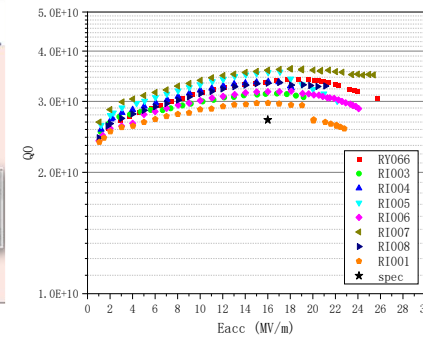
TTC 2026 Meeting, CEA-CNRS-Universit  Paris Saclay, 9-12 June 2026

Cavities: Development, Fabrication and Testing

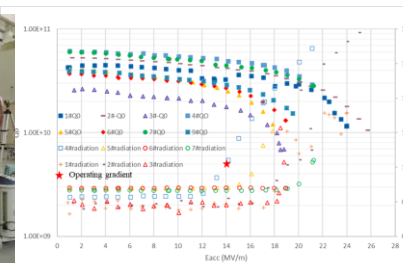
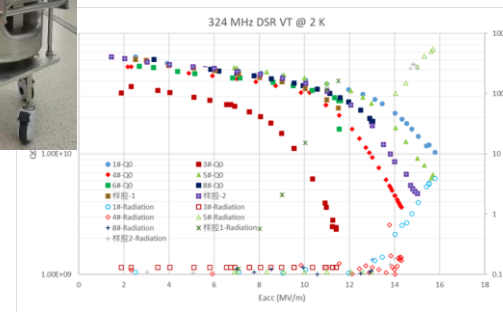
Shihui Wei (IMP) presented the HIAF status (6 QWR CMs, 30 cavs; 11 HWR CMs, 66 cavs), showing the completion and commissioning of 96 superconducting cavs using an automated control interface. This innovative parallelized measurement architecture enables standardized, rapid online batch testing of key cavity parameters. The resulting portable intelligent framework effectively reduces operational risks and will be reused for CiADS and IP-SAFE.



Yuchao Fang (IASF) presented the production and qualification of the first 8 1.3 GHz cav: from factory acceptance → on-site inspection → vertical test. S3FEL project will have in total 1.3GHz cav (24 CMs, 192 1.3 GHz cavs, $3.0 \cdot 10^{10}$ @ 20 MV/m) and their production will be done partially in industry (full cycle), partially shared between industry and lab (surface treatment done in the collaborative platform), and all VT are done at Dalian platform.



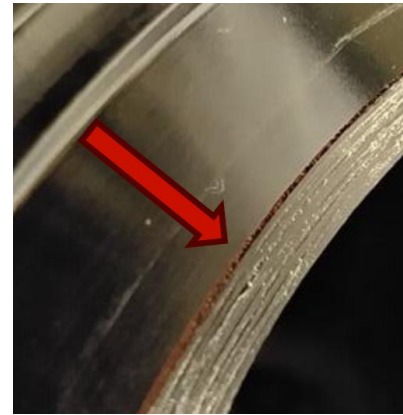
Wenzhong Zhou (SNS) summarized the current status of cav activities for CSNS-II. CSNS-II uses 20 double-spoke cavities in 10 CMs and 24 of 6-cell elliptical cavs in 8 CMs. 3 CMs with double spoke cavity were completed and tested, also performing CMs transportation test. For the elliptical cavities, 12 cavs have been completed, and 8 did the VT. Moreover, 1 CM (3 cavs) has been assembled and tested.



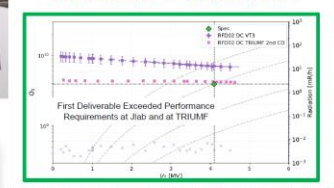
Cavities: Development, Fabrication and Testing

Leonardo Ristori (FNAL)

Manufacturing and Processing Challenges related to crab cavities for HL-LHC are presented. This includes manufacturing and brazing challenges with resolved non-conformances. Processing and final rinsing is driving the cavities performance with multiple facilities (both in industry and laboratories) involved resulting in overall test successes, but final path forward still need to be defined.



Cold Tests 1st Deliverable



N. Huque, A. Castilla (Jlab) - B. Laxdal, Z. Yao (TRIUMF)

Mattia Parise & Jacopo Bernardini (FNAL)

PIP-II cavities performance challenges are presented. SSR1 and SSR2 cavities processing recipe yielding ~80% FE free cavities has been established using MSU robotic HPR and Cobotic coupler assembly. 650 MHz cavities have been affected by internal surface defects that were resolved with optimized EP process and manual grinding. Cobotic flange assembly was also employed at Fermilab yielding good results.

