Summary ERL22, WG4 Superconducting RF

Nilanjan Banerjee (University of Chicago)
Matthias Liepe (Cornell University)
Peter McIntosh (STFC)
Hiroshi Sakai (KEK)

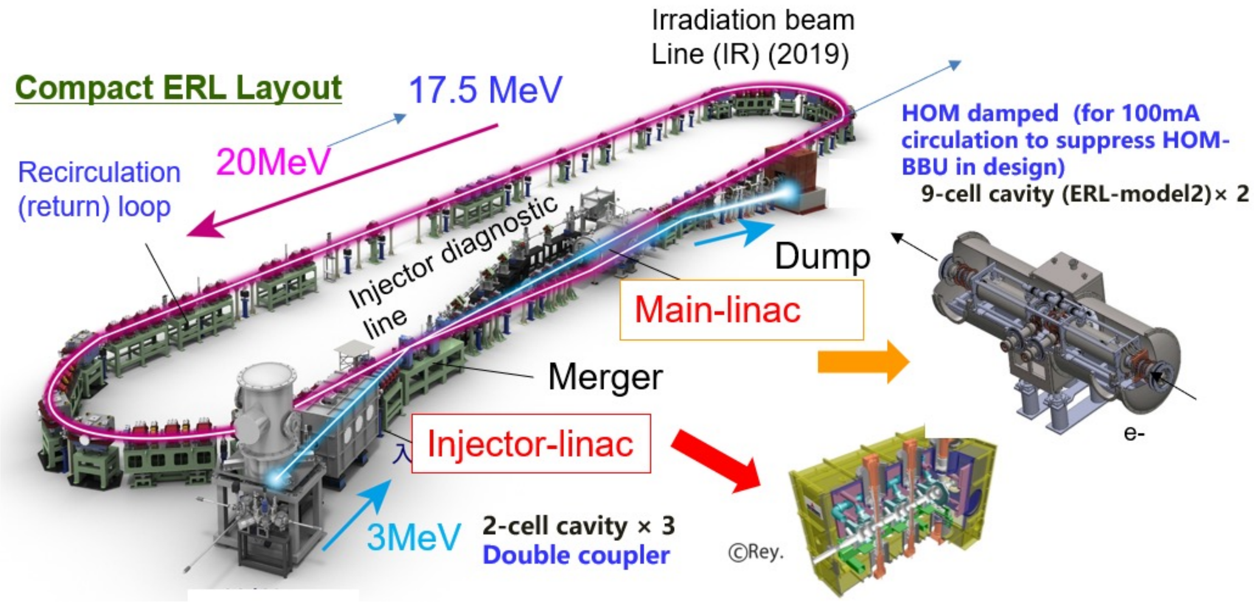
SRF WG4 Themes

1. **SRF Systems and Operations**
   - A. SRF performance on the CERL at KEK – H Sakai (KEK)
   - B. High gradient "turn key" SRF systems for small scale ERLs like MESA – F Hug (U Mainz)
   - C. SRF systems for the EIC hadron cooling – R Rimmer (Jlab)
2. **Injectors**
   - A. KEK SRF Gun development – T Konomi (KEK)
   - B. SRF photo-injector and Booster modules at bERLinPro – A Neumann (HZB)
3. **Cavities, Couplers and Tuners**
   - A. Overview Nb3Sn cavity progress (for CW machine) – L Shpani (Cornell U)
   - B. SRF R&D for EUV-FEL – T Konomi (KEK)
   - C. Fast Reactive Tuner developments at CERN - N Shipman (CERN)
4. **RF Control and HOM damping**
   - A. SRF operations, microphonic control etc at CBETA – N Banerjee (U Chicago)
   - B. Achieving stable cw operation in vector sum – R Leewe (TRIUMF)
   - C. Iterative Learning Control for Beam Loading Compensation – R Leewe (TRIUMF)
   - D. HOM-Damping Studies in a Multi-Cell Elliptical Superconducting RF Cavity for the Multi-Turn Energy Recovery Linac PERLE – C Barbagallo (IJCLab)

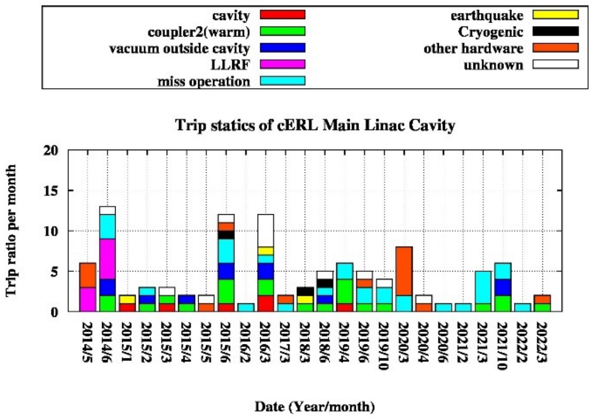
12 x 15+5min talks, over 3 x WG4 sessions

SRF Systems and Operations

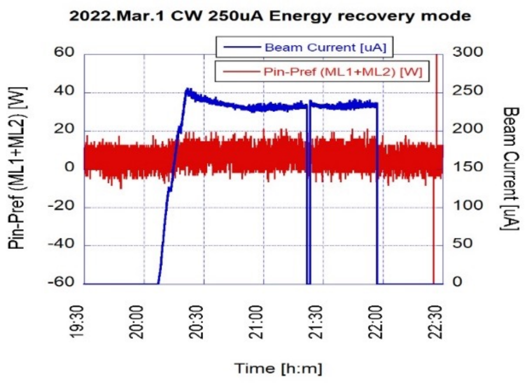
SRF performance on the cERL at KEK – Hiroshi Sakai (KEK)



KEK cERL cryomodule are operating from 2012 until now for almost 10 years.



Small trip ratio for 10 years



We could stable CW beam operation with 0.3mA energy recovery mode in 2022

- **SRF performance of cERL cryomodules** under cERL beam operation in **the latest three years**
  - For injector, one we met the severe degradation in 2020. But we could recover the normal radiation onset level by the pulse processing.
  - For Main iinac we met the cavity degradation under beam operation after the unknown burst event of ML1. But for the latest 3 years, we did not see more degradation. Main issues are field emission for ML2 and thermal breakdown for ML1.
  - Finally, **by applying the pulse processing for both cryomodule before the beam operation, we kept the stable beam operation under LLRF optimization.**
  - For higher energy operation, we applied pulsed operation to escape the HOM quench of injector. We could increase the energy from 17.5 MeV to 23.0 MeV for irradiation beam line.
- **SRF R&D** for future EUV-FEL and so on from cERL operation in KEK
  - More reliable operation, we design the **F.E suppression and HOM suppression cavity for EUV-FEL** and develop the **F.E reduction approaches (clean assembly , HOM damper)**
  - SRF Gun is under developing for CW high current beam generation in KEK. (now FRIB)
  - **Higher-Q R&D and Nb3Sn cavity R&D** also tried to reduce CW heat load.

Summary MESA Modules – Florian Hug (U Mainz)

Cryomodule production:

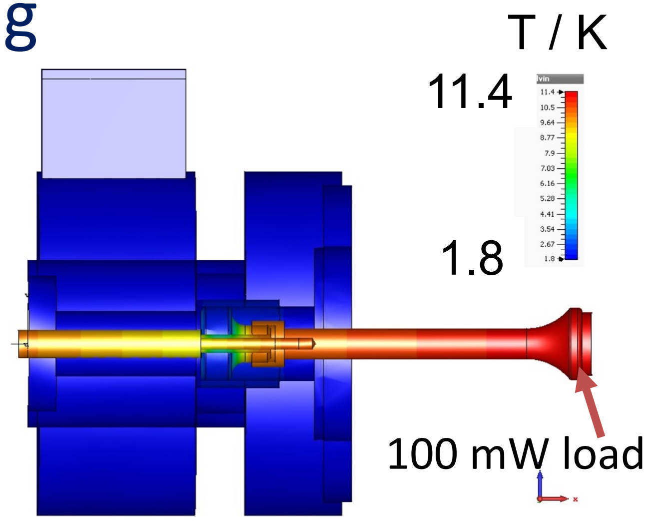
- Successful „turn key“ CM production by industry
- 2 modules with 2x 12.5 MV/m @ $Q_0 = 1.2 \cdot 10^{10}$

Cryomodule future:

- Refurbishment of a spare module (from ALICE) ongoing
  → future maintenance, hands on experience, tests on coated HOM antennas for higher beam loading

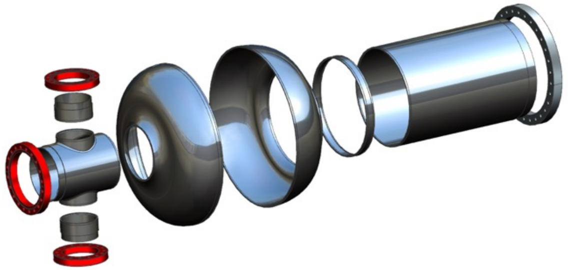
„Turn key“ experience:

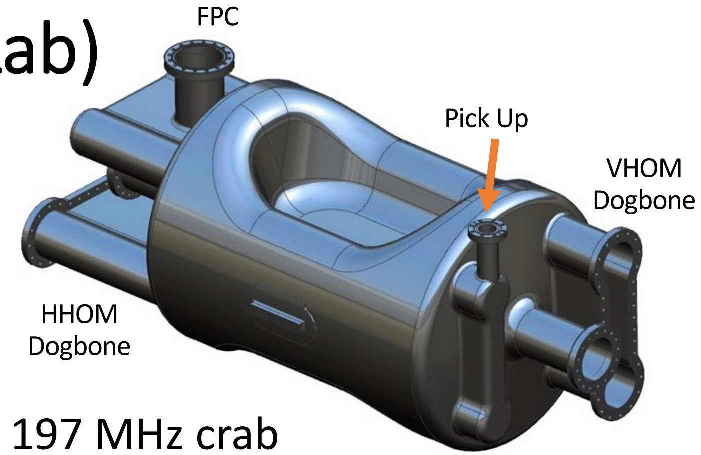
- Urgent need of close contact to vendor during project
- Successful in the MESA case



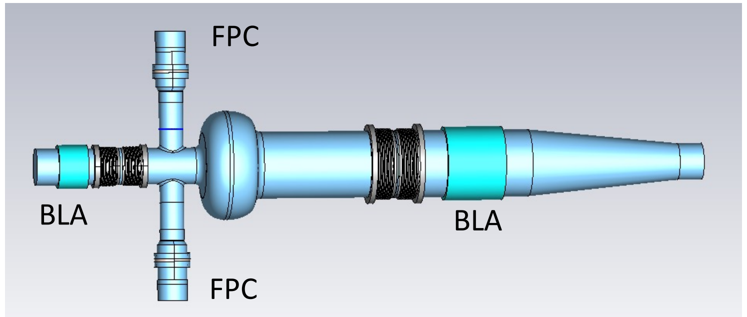
SRF Systems for the EIC Hadron Cooling – Rob Rimmer (JLab)

- ESR and crab Prototypes coming soon!
- ERL cavity may be developed from ESR
  - Baseline HOM damping scheme using BLA's
  - Other options can be considered

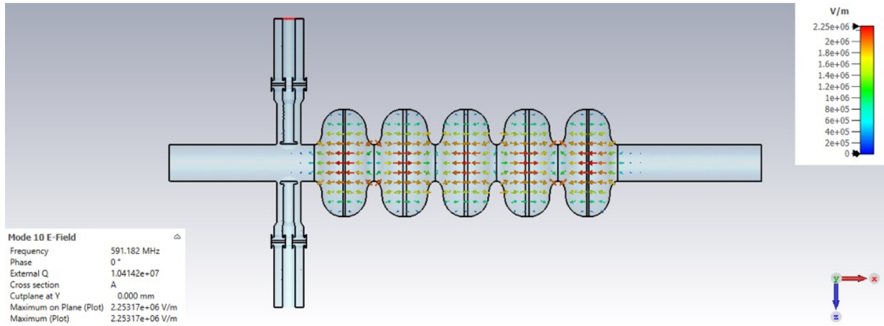




HSR 197 MHz crab

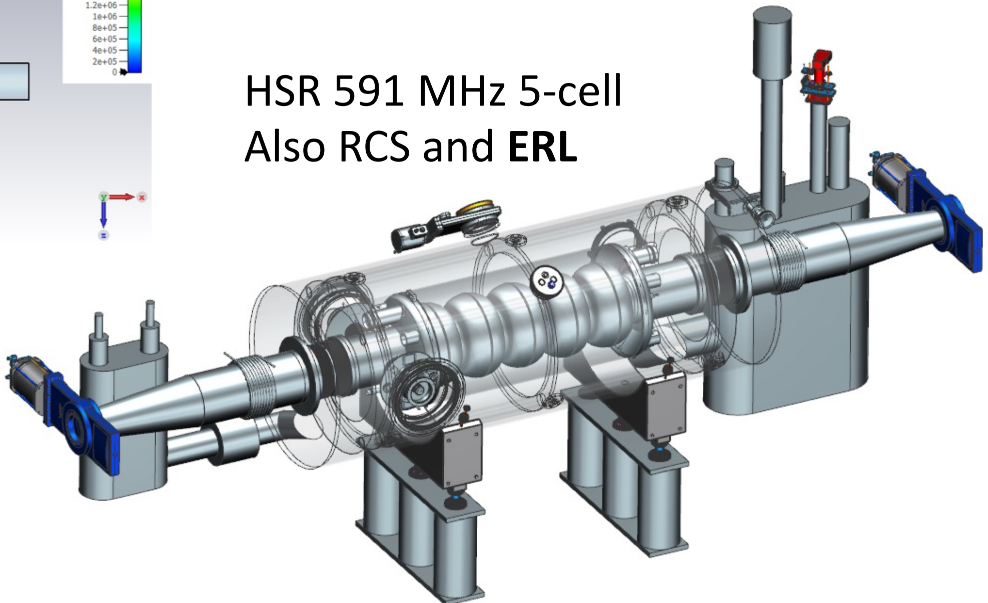


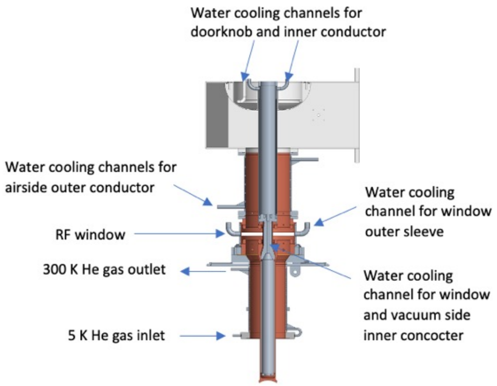
ESR 591 MHz 1-cell



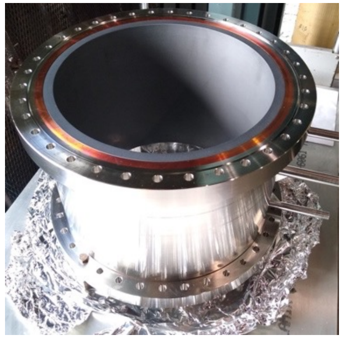
591 MHz 5-cell (w/o HOMs)

HSR 591 MHz 5-cell
Also RCS and **ERL**

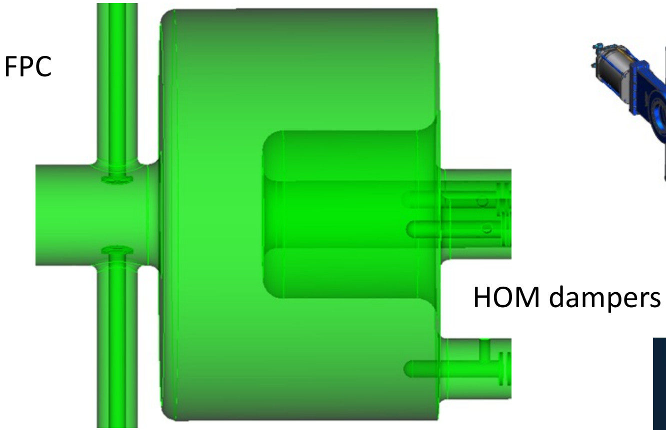




400 kW FPC



BLA



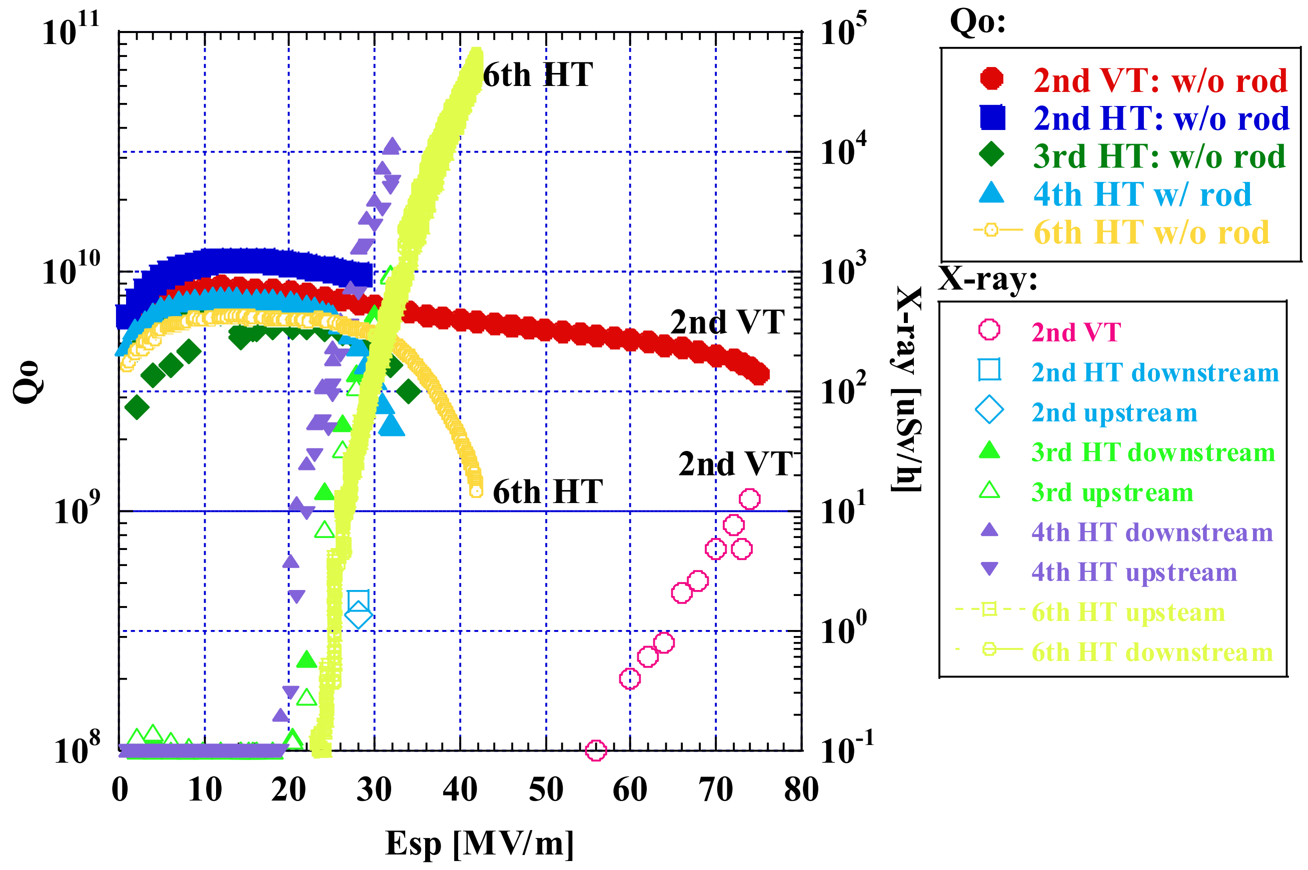
Pre-cooler 197 MHz QWR

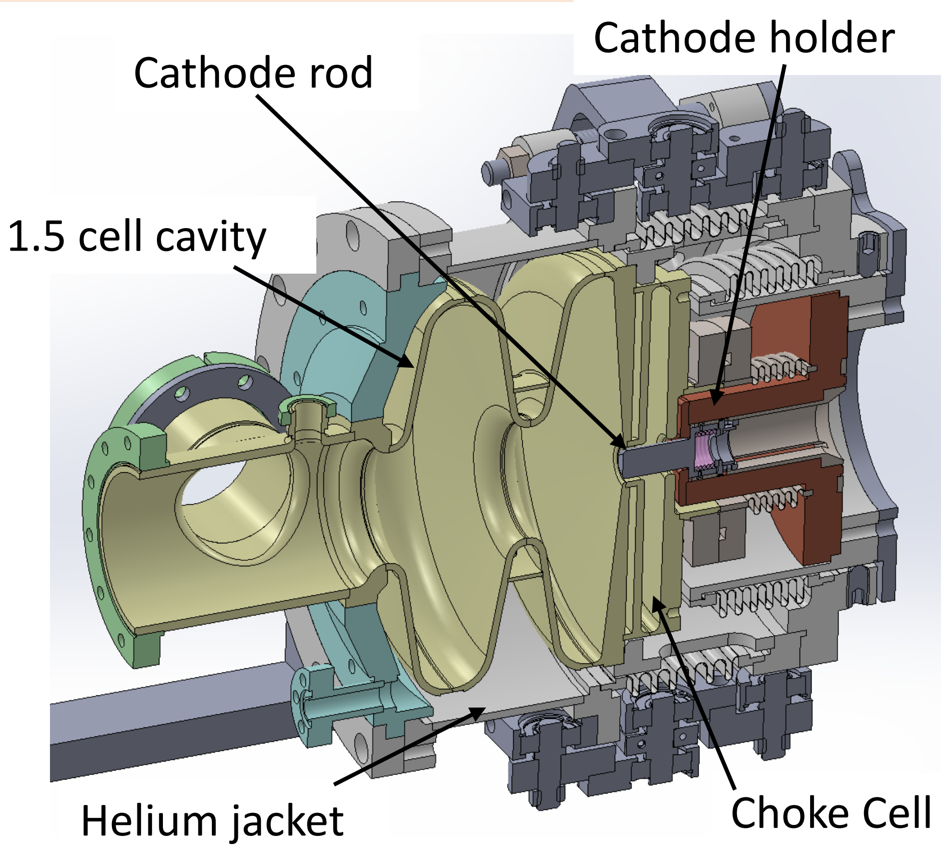

ERL 2022
66th ICFA Advanced Beam Dynamics Workshop on Energy Recovery Linacs
Cornell
October 3-6, 2022
In-Person at Clark Hall on Cornell Campus
More details on Indico

Injectors

Horizontal test of SRF gun #2 at KEK – Taro Konomi (KEK/MSU)

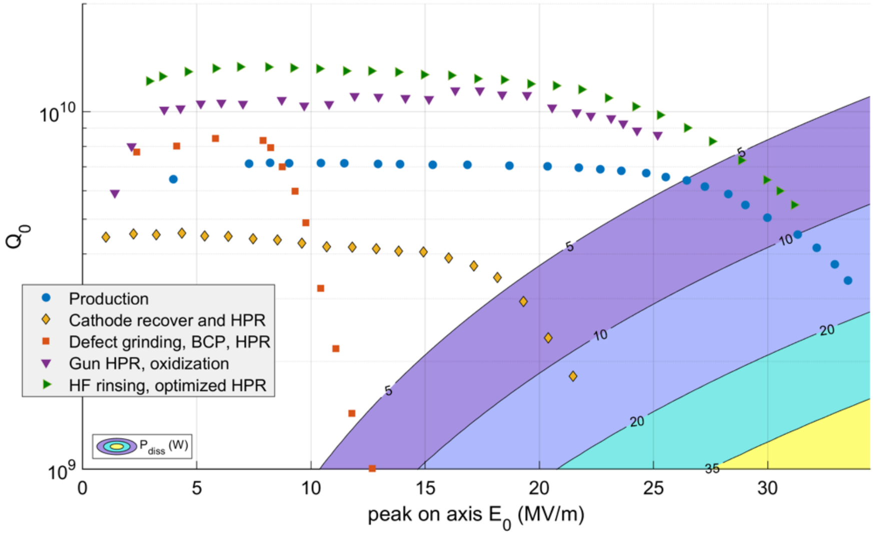
- Esp reach the target value by applying EP and HPR in VT because assembly procedure is well established.
  - ➢Esp= 76 MV/m w/o cathode, Esp=61.5 MV/m w/ cathode (target Esp=41.9 MV/m)
- The gradient was significantly lower in HT. This was due to the complicated procedure.
  - ➢Esp=42 MV/m (6th HT)

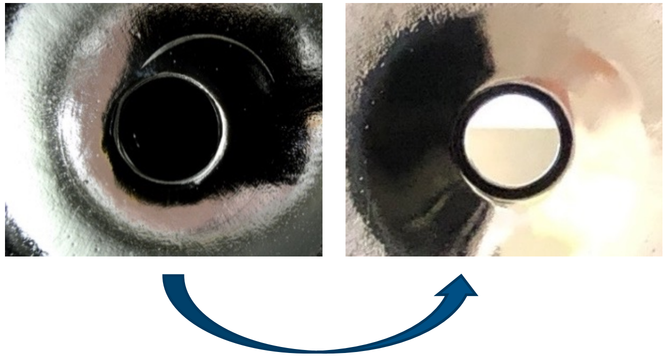




Status of SRF systems for bERLinPro – Axel Neumann (HZB)

- Focus on finalizing cryo-modules for the injector line of SRF gun and booster
- Currently, after a two years long refurbishment program to recover the SRF gun cavities from damages during the production process, cavities are back on performance level.





- During coldstring acceptance test, a field emitter was activated, currently the gun string is back in the cleanroom for cavity and couplers exchange
- The booster will follow-up, once the gun is completely assembled in the accelerator hall.
- As preparatory work, the couplers were conditioned up to 60 kW CW in traveling wave at 1.3 GHz
- All cold string parts are in house and several booster cavity tests demonstrated the cavities being twice in field above the specs required for bERLinPro
- In total, first beam from the gun will take place about in summer 2023
- Comment: Built at least 3-4 SRF gun cavities for such a program

Cavities, Couplers and Tuners

Overview of Nb_3Sn Cavity Progress (for CW machines)

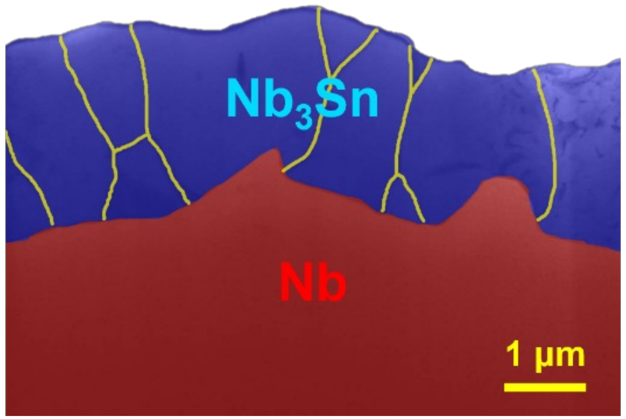
Presented by Liana Shpani*, Cornell University

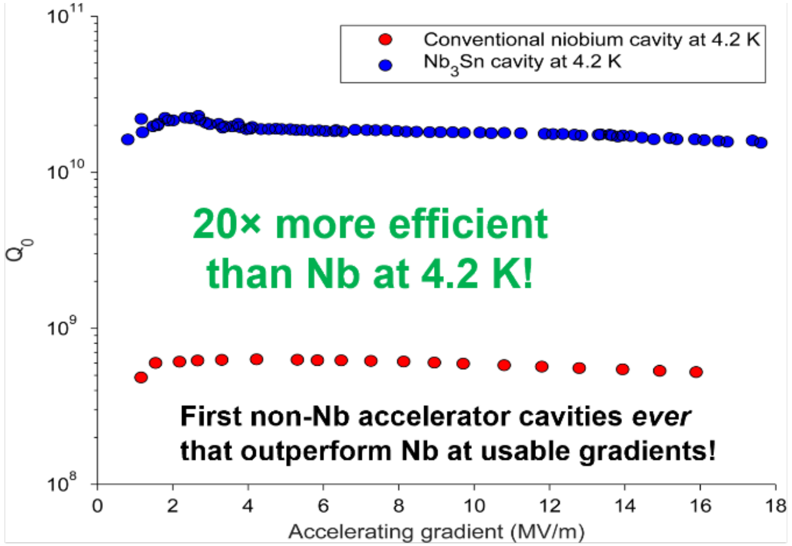
- Nb_3Sn is a **high-potential material** for next-generation SRF cavities
  - → **Higher energy gain**
  - → **Lower cooling cost and complexity**

- Nb_3Sn **coating facilities are established** around the World (Cornell, FNAL, JLab, KEK, etc.)

- Ongoing R&D will **improve Nb_3Sn performance** of Nb_3Sn films
  - → **Thinner films**
  - → **Reduced surface roughness**

- **Applications** are at **early stages**
  - → Multicell Nb_3Sn cavities
  - → Prototype cryomodule testing
  - → Turn-key compact cryomodules





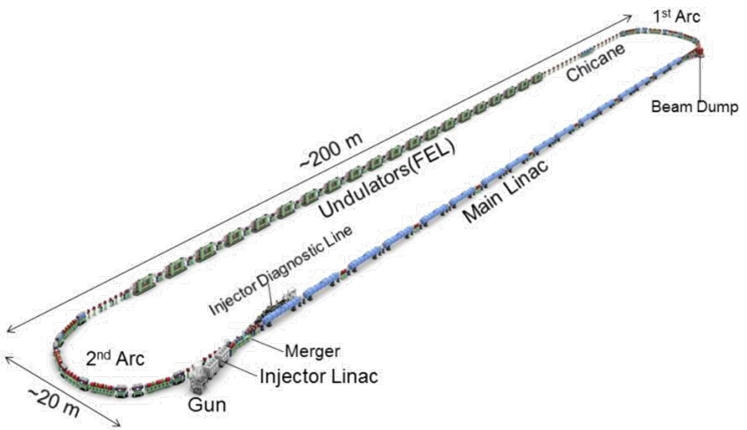
S. Posen et al., Applied Physics Letters 106, Issue 8 (2015).

Design of the 9-cell superconducting cavity for EUV light source accelerator

Taro Konomu (KEK/MSU)

Center for Applied Superconducting Accelerator
応用超伝導加速器センター

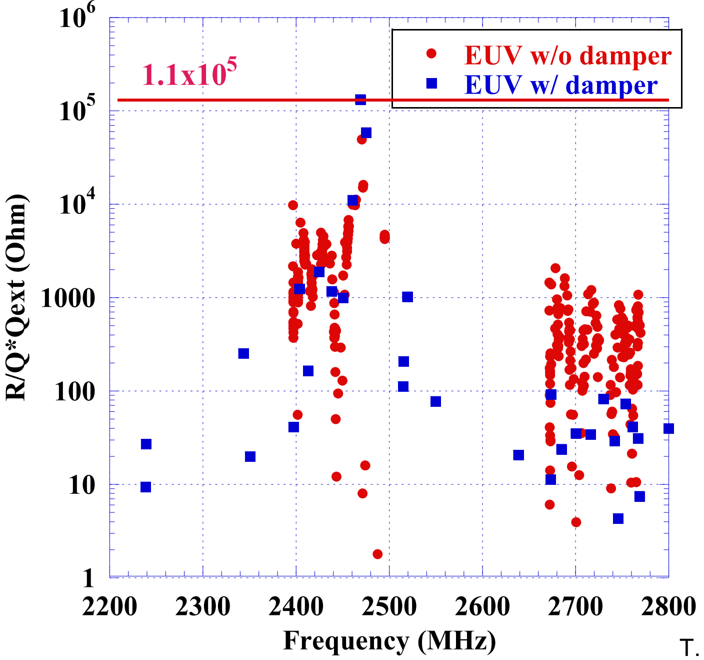
Cavity Parameters	KEK-EUV	TESLA
Frequency (MHz)	1300	1300
Iris diameter (mm)	**70**	**70**
R/Q (Ω)	1009	1036
G (Ω)	269	270
Ep/Eacc	**2.0**	**2.0**
Hp/Eacc (mT/(MV/m))	4.23	4.26
BBU limit	>190 mA	~80 mA



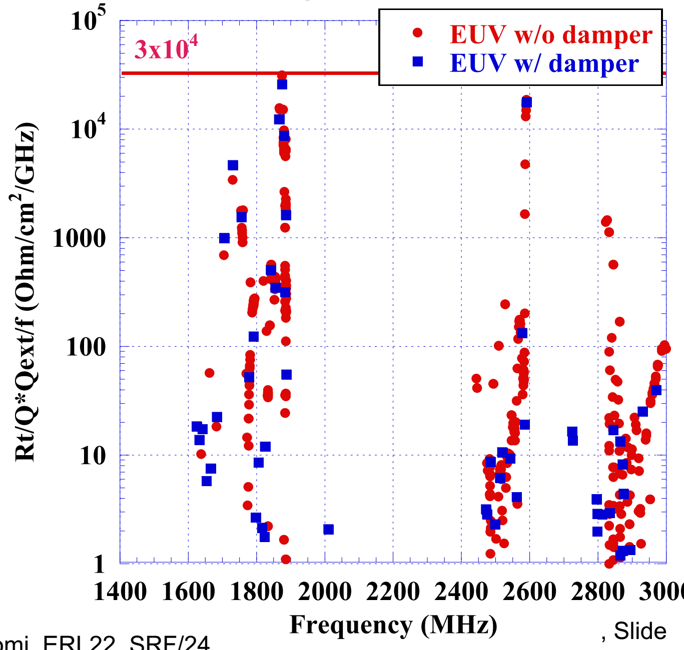
- EUV cavity has been designing for EUV-ERL/FEL accelerator.
- 9 cell cavity was optimized by tuning End cell shape.
- HOM damper was designed with AlN data taken by ourselves.

Parameters	Target value
Wavelength	13.5 nm
EUV Power	10 kW
Bunch charge	60 pC
Beam energy	800 MeV
Repetition frequency	162.5 MHz
Average current	**9.75 mA**
Accelerating gradient	**12.5 MV/m**
Number of cavities	64

Monopole HOM



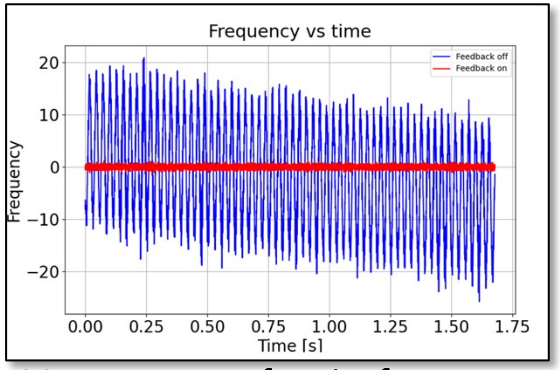
Dipole HOM



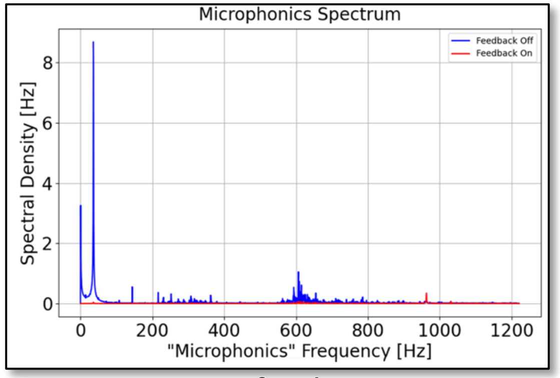
FRT Developments at CERN

N. Shipman et al.

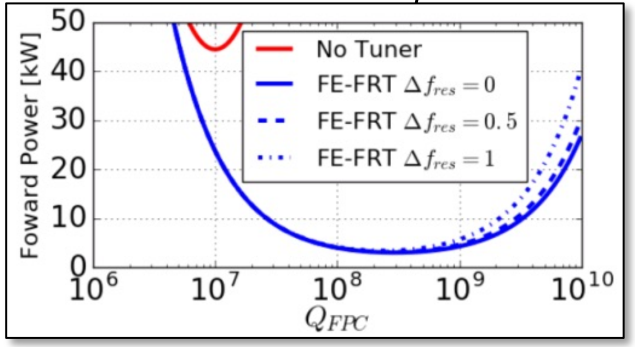
Brookhaven National Laboratory | euclid TECHLABS | Lancaster University | CERN



Measurement of cavity frequency with and without FRT.



Measurement of µphonics spectrum with and without FRT compensation.



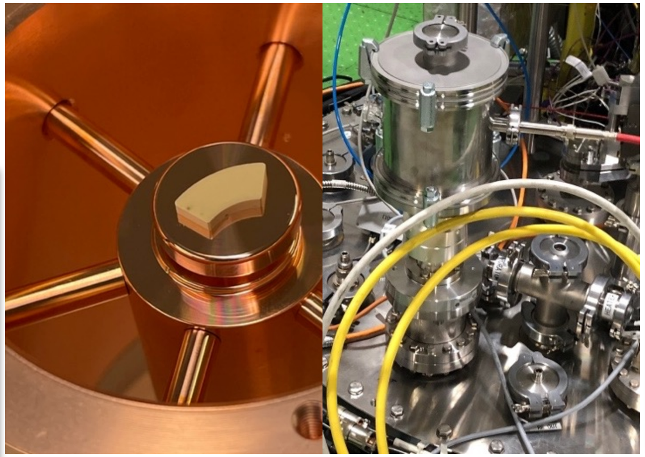
Estimated power reduction for PERLE with and without FRT.

Microphonics:

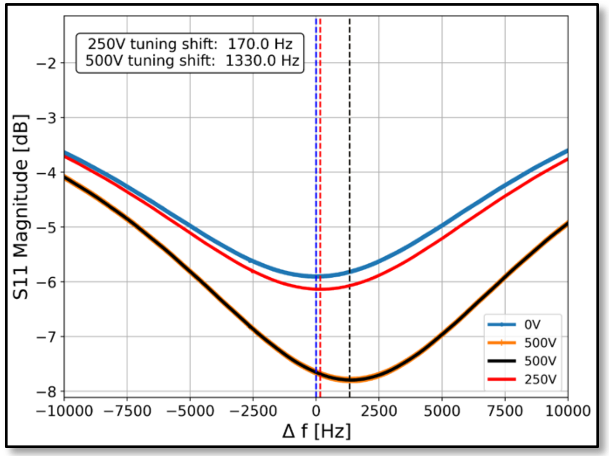
- FRTs perfectly suited to compensating microphonics in low beam loading machines
- Can reduce RF power demands by order of magnitude
- Excellent microphonics compensation already demonstrated experimentally
- Should be developed for real application, EIC, bERLinPro, PERLE, CEBAF, HIE-ISOLDE, other?

Transient detuning:

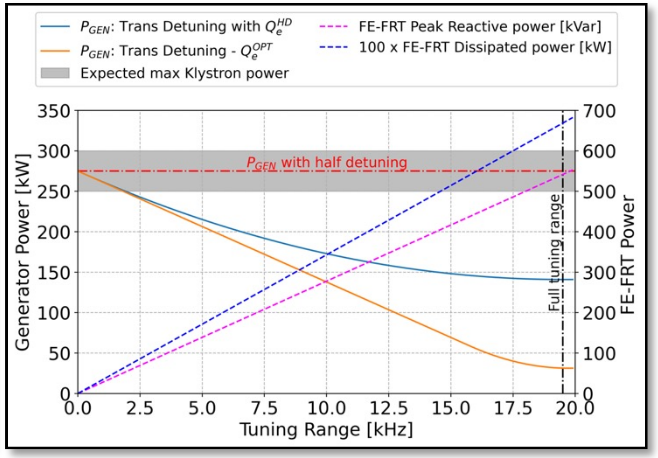
- CERN FRT research now focussed on transient detuning
- Could reduce RF power demand at injection by up to order of magnitude
- Significantly more challenging due to higher reactive power
- New prototype TDD0 designed, built and tested
- Tuning of LHC cavity demonstrated
- Targeting transient beam loading demonstration with “TDD1” in new year



“TDD0” prototype FRT during assembly and installed on cryostat top plate.



Measured frequency shift of LHC cavity with FRT.

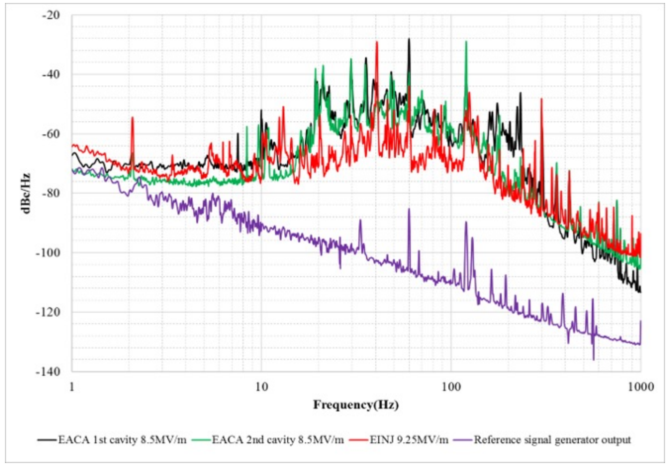


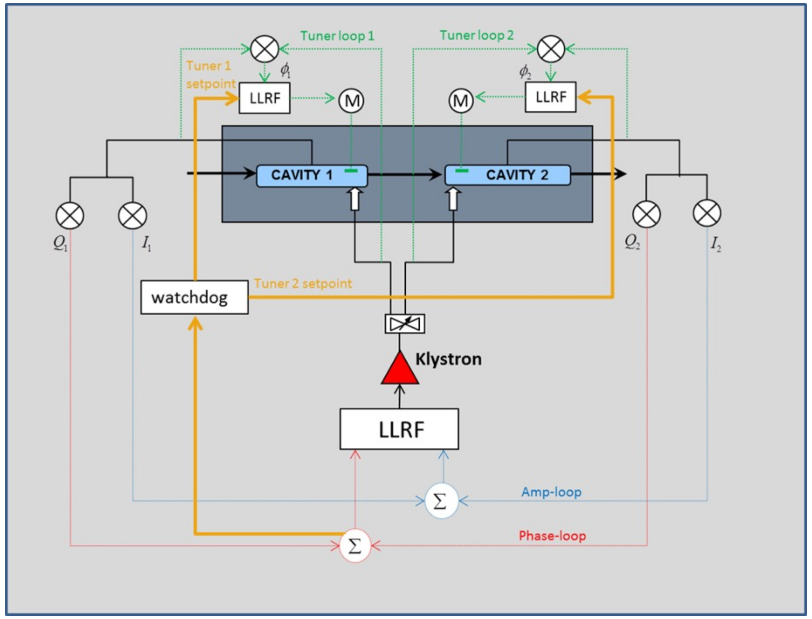
Estimated RF power reduction vs tuning range for HL-LHC with FRT (orange).

RF Control and HOM Damping

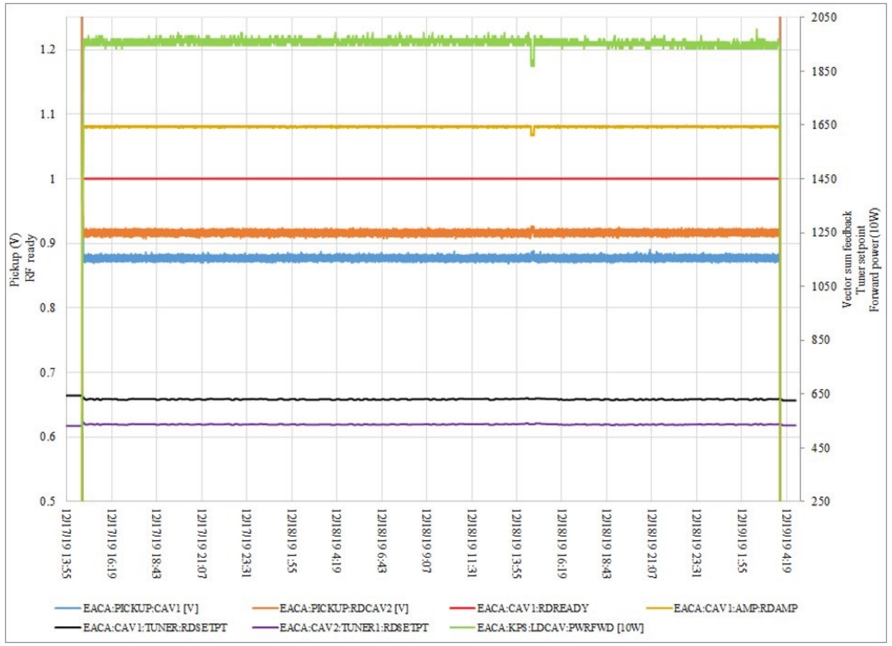
Achieving stable CW operation in vector sum at TRIUMF - Ramona Leewe at al.

- Operating two cavities in vector sum and CW – starting conditions
- Challenges and Issues and Solutions
  - Microphonics
    - Solution: system damping +piezo
  - Lorentz force driven oscillations
    - Solution: additional control loop





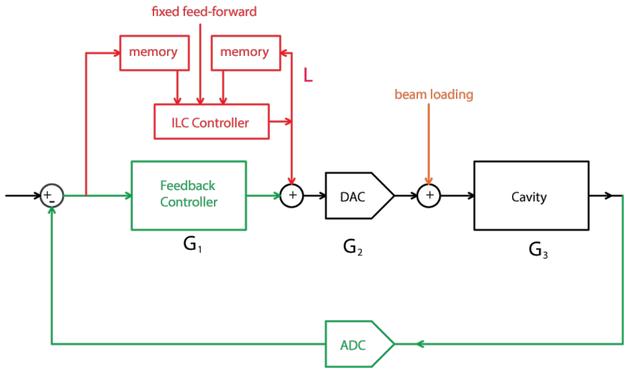
Stable operation



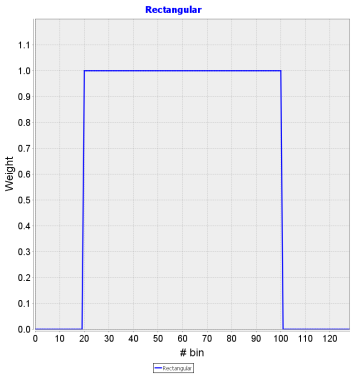
Ramona Leewe, Ken Fong

Iterative learning controller for beam loading compensation at TRIUMF – Ramona Leewe et al.

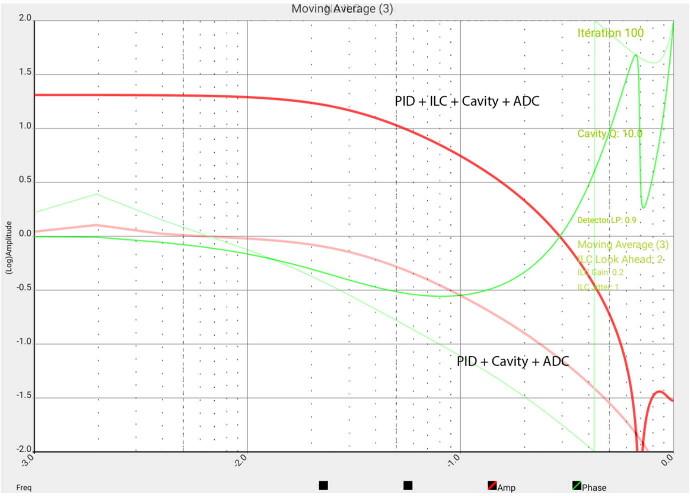
Block diagram



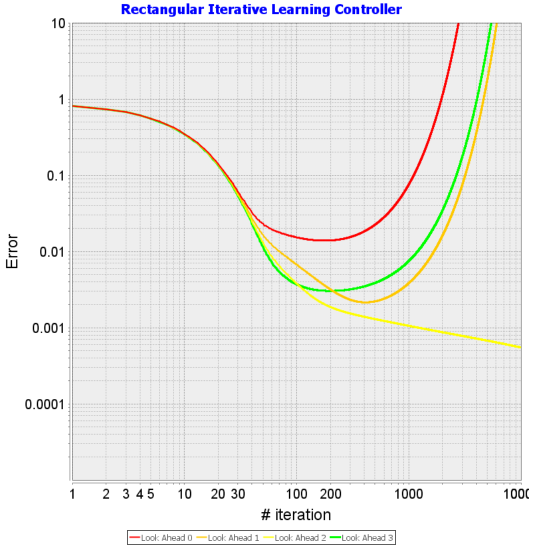
Window function



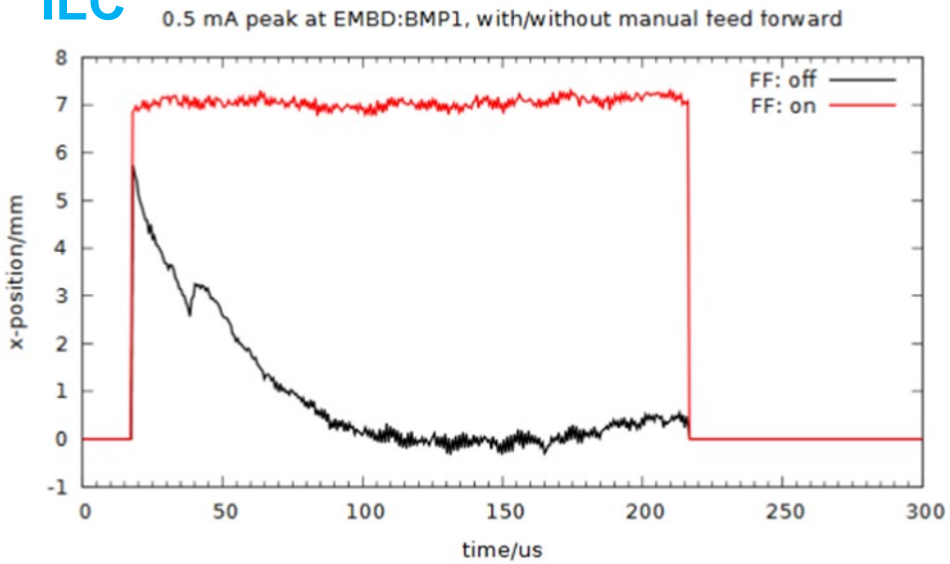
Bode diagram



Rate of convergence



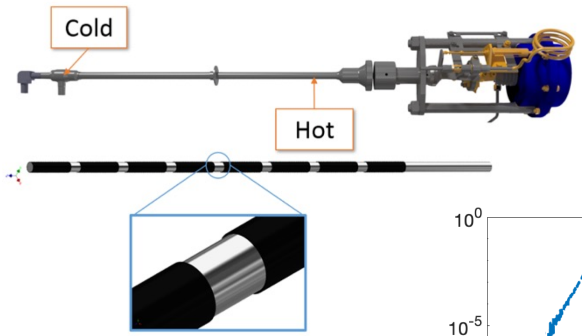
BPM measurement with and without ILC

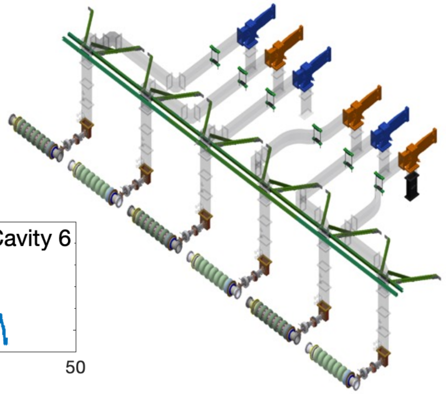


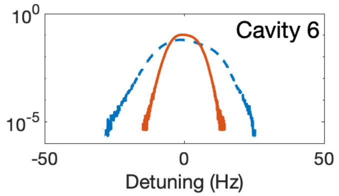
Summary

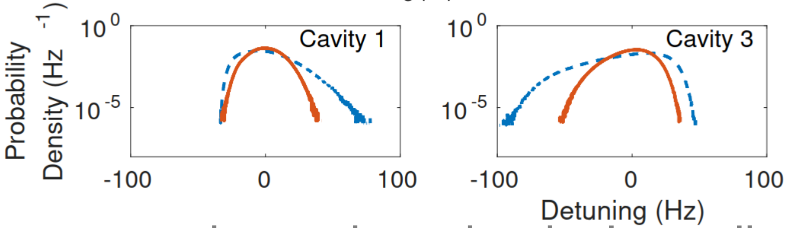
- Frequency domain analysis allows different window function evaluation
- Stability depends mainly on the phase which depends on the look ahead in the window function
- BPM measurements show great results with a good choice of window function and look ahead

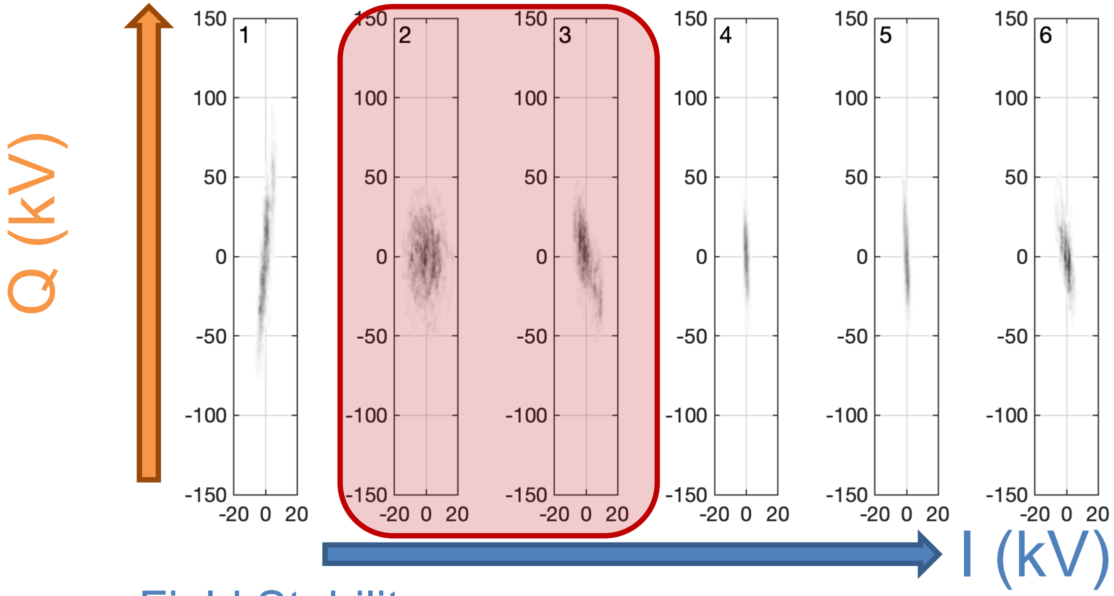
SRF Operations, microphonic control at CBETA – Nilanjan Banerjee (UChicago/Cornell)











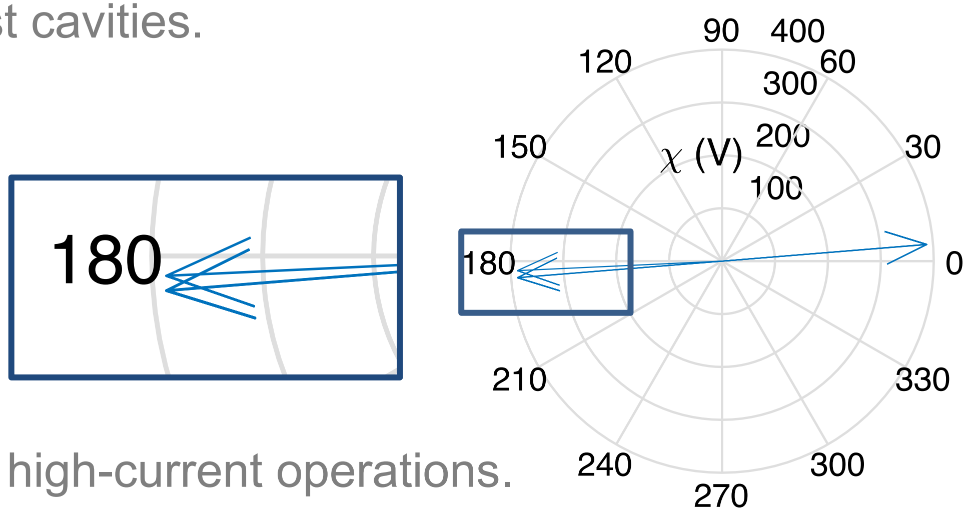
Vibrations

Chiefly from cryogenics and mechanical coupling which we mitigated. Further suppressed using a modified narrowband Active Noise Control (ANC) algorithm.

Field Stability

Mostly dominated by microphonics detuning on most cavities.

Measured an energy recovery efficiency of 99.4±0.1% for 1-turn operations at 70 μA.



Beam Loading

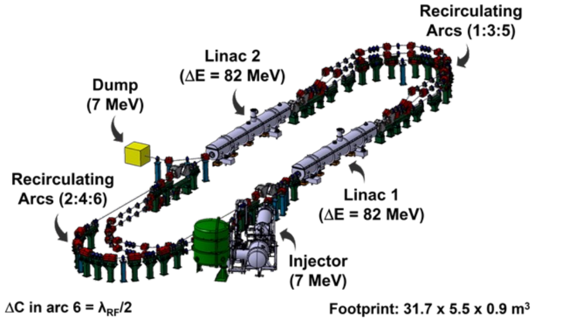
Reactive beam loading due to relativistic effects will be important for high-current operations.

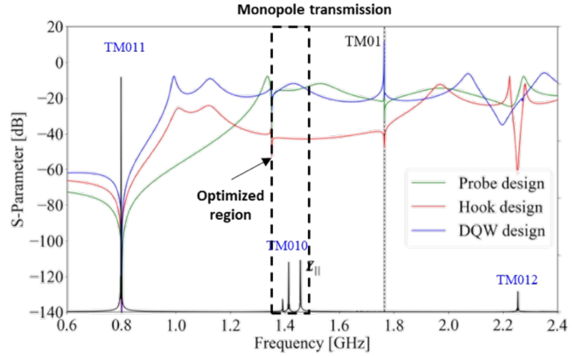
International Workshop on Energy Recovery Linacs (ERL 22), October. 3-6 October 2022

HOM-Damping Studies in a Multi-Cell Elliptical Superconducting RF Cavity for the Multi-Turn Energy Recovery Linac PERLE

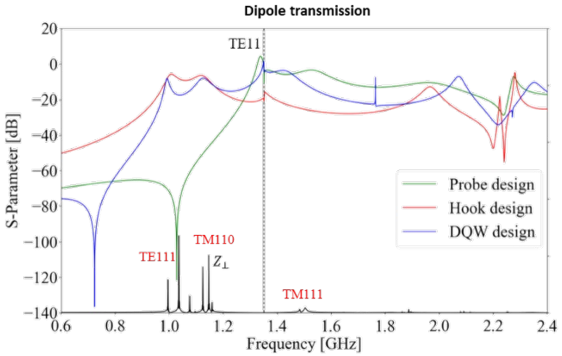
C. Barbagallo[1,2], P. Duchesne[1], W. Kaabi[1], G. Olry[1], F. Zomer[1,2] ([1]IJCLab - CNRS, [2]Université Paris-Saclay)
R. A. Rimmer[3], H. Wang[3]

Our study focuses on the HOM-damping studies in the 5-cell SRF cavity designed for the Multi-Turn Energy Recovery Linac PERLE



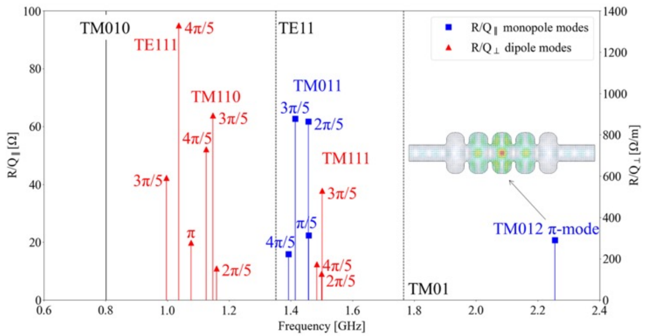


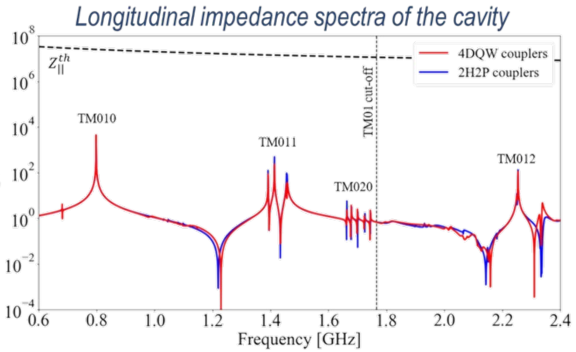
The DQW coupler exhibits a better monopole coupling for TM010 mode than the probe design.

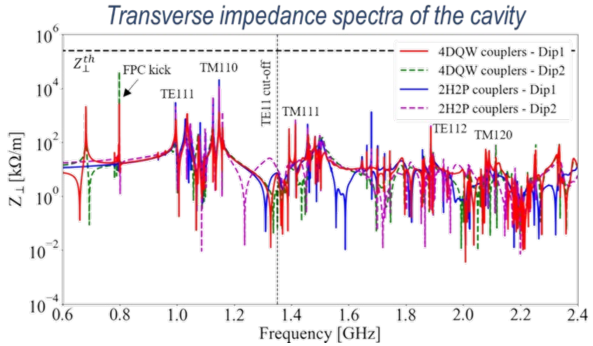


The hook coupler provides higher damping of the first two dipole passbands (TE111 and TM110)

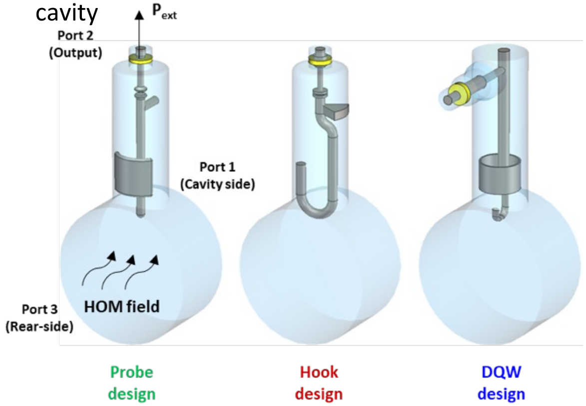
Potentially dangerous HOMs were identified and classified until 2.4 GHz. A trapped monopole mode was found at around 2.25 GHZ

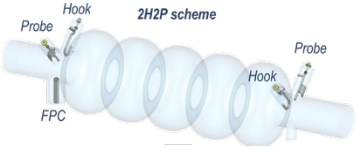


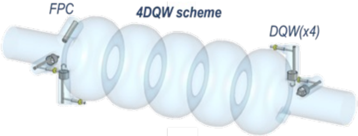




Three possible HOM coupler designs were optimized to damp monopole and dipole HOMs of the PERLE cavity







The damping scheme with four DQW couplers shows promising results in damping both monopole and dipole HOMs

Computed impedance levels are below the analytically-computed beam-stability limits

Recent SRF progress of each lab since 2019

- Cavity & module design for ERL
  - Design for high current or high energy machine
  - Or compact, turn-key?
- High Q R&D, Nb3Sn and more
  - Nb3Sn is promising for open a new era for CW ERL machine
- Supporting components
  - High-power and HOM couplers, tuners and controls.
  - Careful not to duplicate efforts.
- SRF guns
  - Cathode dissipation and mechanical manipulation.

Incorporating advances in SRF technologies to further improve the wall-plug efficiency of ERLs: Nb3Sn, FRTs, RF control

Improved Collaboration?