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FREIA Laboratory

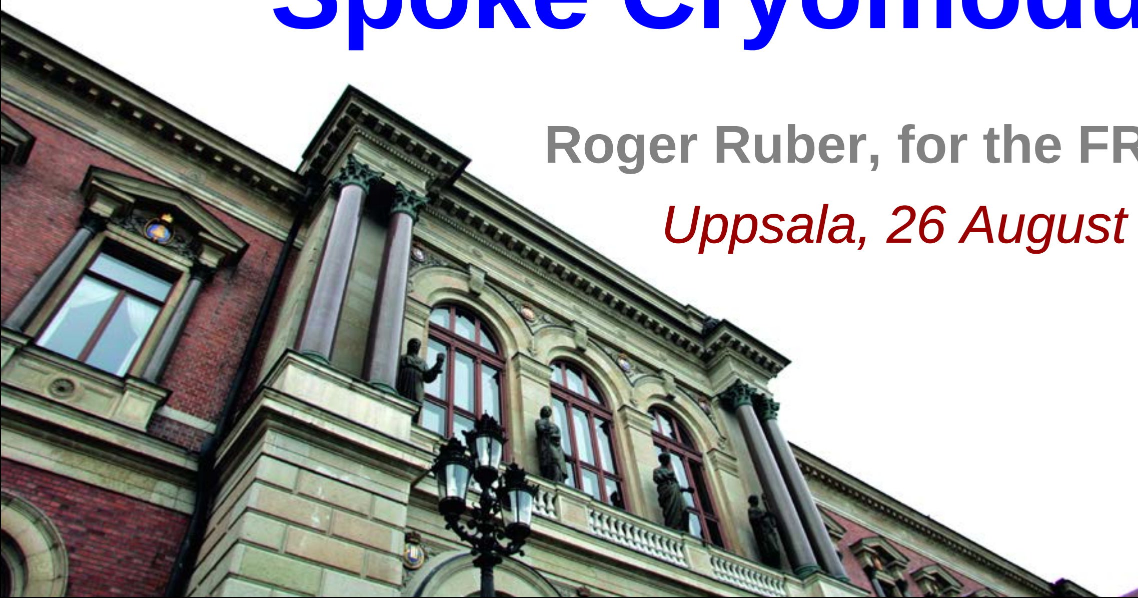
Facility for Research Instrumentation and Accelerator Development

EUROPEAN SPALLATION SOURCE

Spoke Cryomodule Testing

Roger Ruber, for the FREIA team

Uppsala, 26 August 2019



Overview of Infrastructure for Cryomodule Testing

FREIA INFRASTRUCTURE

FREIA Laboratory

Facility for Research Instrumentation and Accelerator Development

Funded by
KAWS, Government,
Uppsala Univ.

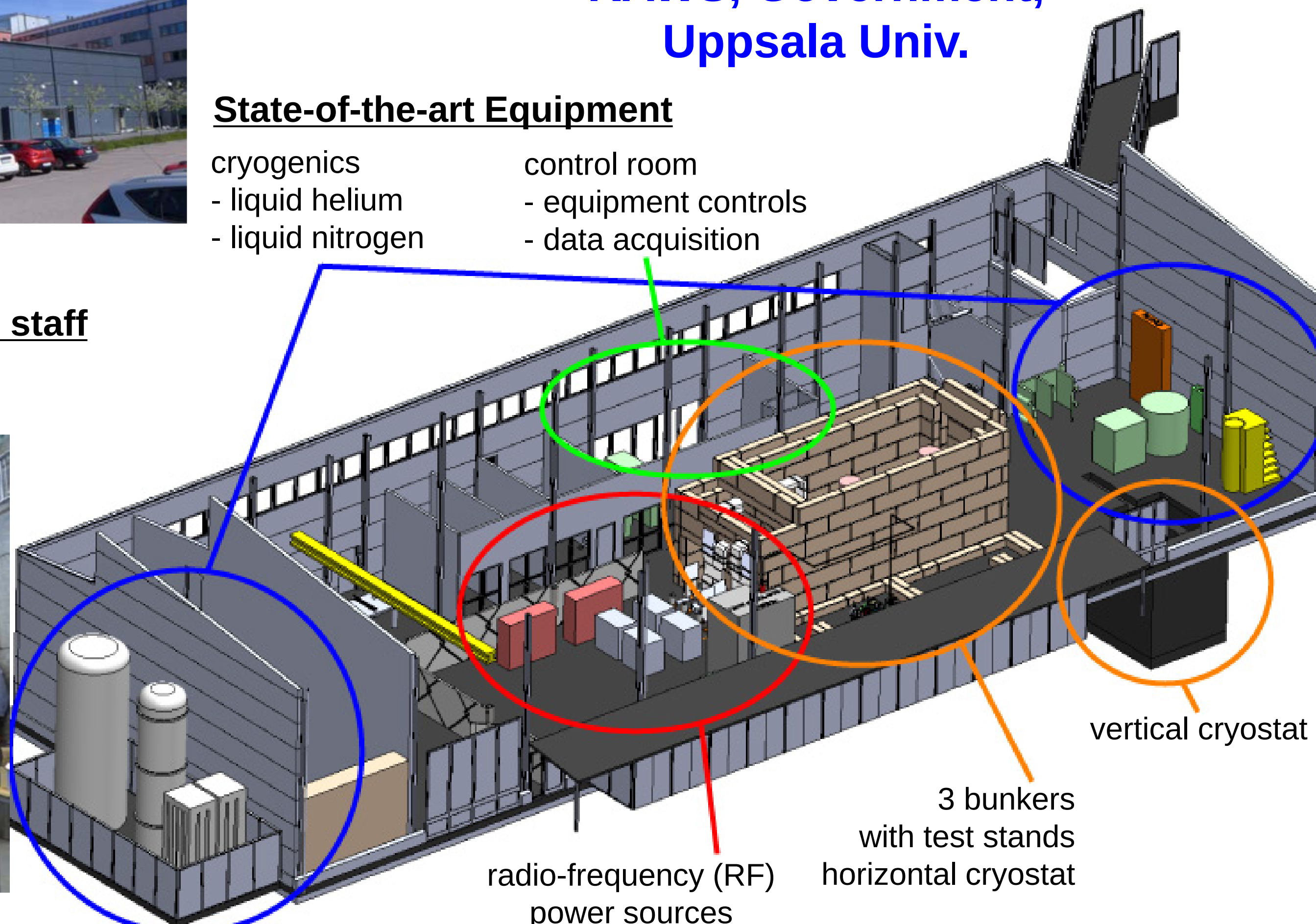
State-of-the-art Equipment

cryogenics
- liquid helium
- liquid nitrogen

control room
- equipment controls
- data acquisition

Competent and motivated staff

collaboration of physics (IFA)
and engineering (Teknikum).



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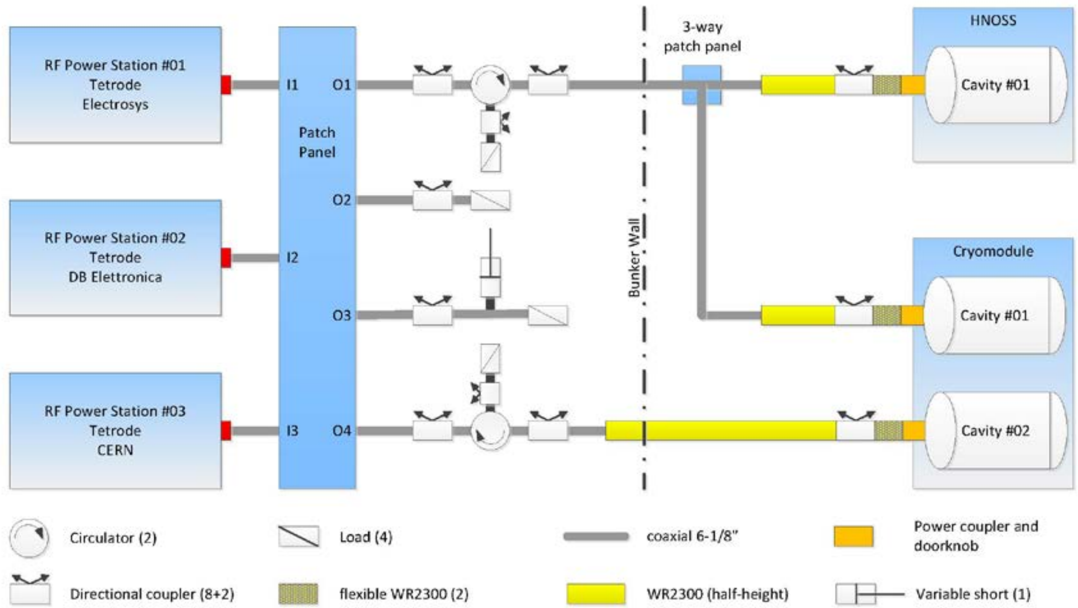
Cryogenics

- **Helium liquefaction**
  - 150 l/h at 4.5K (LN2 pre-cooling)
  - 2000 l LHe dewar/buffer, 3+1 outlets
  - cryostats connected in closed loop
- **Gas recovery**
  - 100 m^3 gasbag
  - 3x 25 m^3/h compressor
  - 10 m^3 200 bar storage
- **2K Pumping**
  - ~3.2 g/s at 10 mbar
  - ~4.3 g/s at 15 mbar
  - 110(90)W at 2.0(1.8)K
- **Liquid nitrogen**
  - 20 m^3 LN2 tank

High Power RF Amplifiers



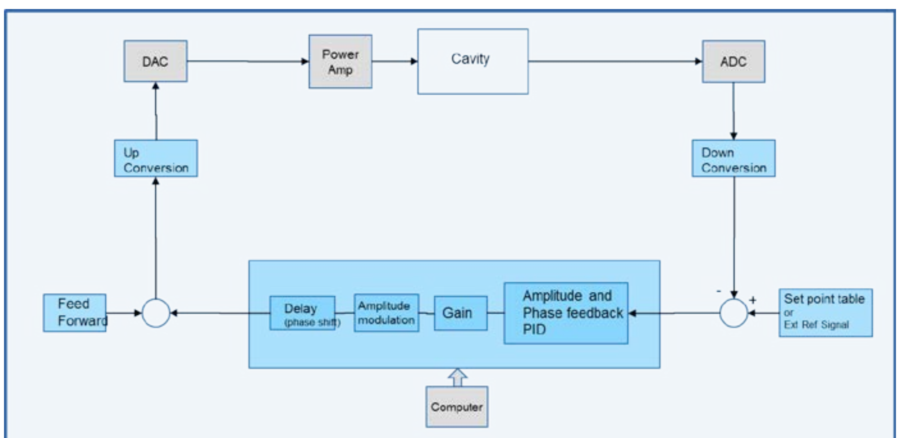

- **400 kW pulsed (352 MHz)**
  - 2 stations, each 2 tetrodes TH595(A)
  - 3.5 ms, 14-28 Hz
- **50 kW CW (352/400 MHz)**
  - single tetrode TH571b
- **RF Switch Board (coax)**
  - ~15 min switch time



FPGA Based Digital LLRF

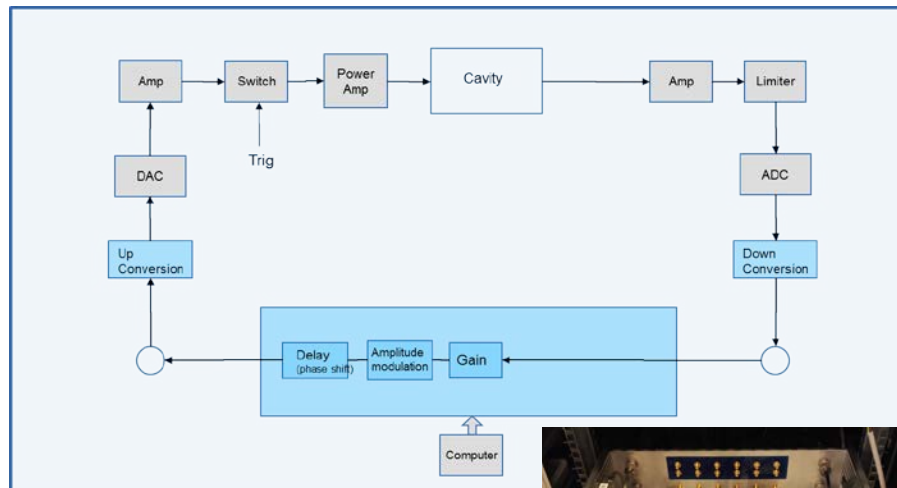
Signal Driven

- 2 ADC inputs at 250 Msps
  - (*) analogue bandwidth of 750 MHz
- 2 DAC outputs at 500 Msps
- Digital downconversion to baseband 0 Hz, no analog mixers
  - downconverted signal at 10 Msps or 1 Msps, selectable
- undersampling to operate at any frequency from 10 to 750 MHz*

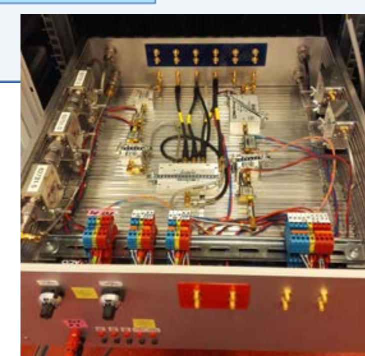


Self-excited Loop

- CW or
- pulsed mode
  - switch closes the loop for a duration of 3.2 ms, repetition rate of 14 Hz.



Code in the FPGA



Controls and Measurement

- **Slow Controls & Safety Interlock**
  - quench detection
  - connecting different sub-systems: cryogenics, cryostats, powering, ...
  - Siemens PLC + Nat.Instr. cRIO
  - LabVIEW
    - power coupler auto conditioning
      - pulse length, power level, (rep rate=14 Hz)
    - SEL control and data acquisition
    - monitor cavity profile (IQ)
    - cavity frequency shift tracing
    - dynamic Lorentz force detuning
  - EPICS
    - user interface
    - data archiver

Ongoing Maintenance Work

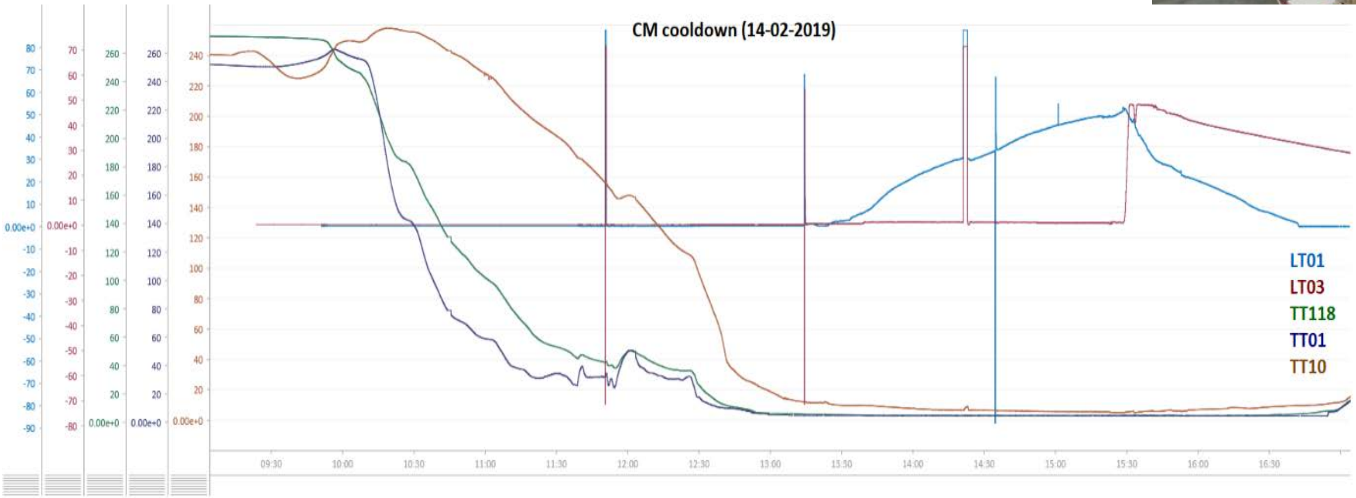
- Cryomodule
  - water flow meters
    - added filter, installed new meters → seems ok for the moment
- Cryogenic system
  - loosing small amount of helium gas during operation
    - suspect leak in the recovery compressors
  - recovery compressors run below capacity
    - looking for replacement compressor
- Control system
  - implementing the valve box and cryomodule in EPICS
  - LLRF implementation (new system version)
- Improving software
  - automatic conditioning and measurement software

Prototype Spoke Cryomodule Testing

CRYOMODULE EXPERIENCE SO FAR

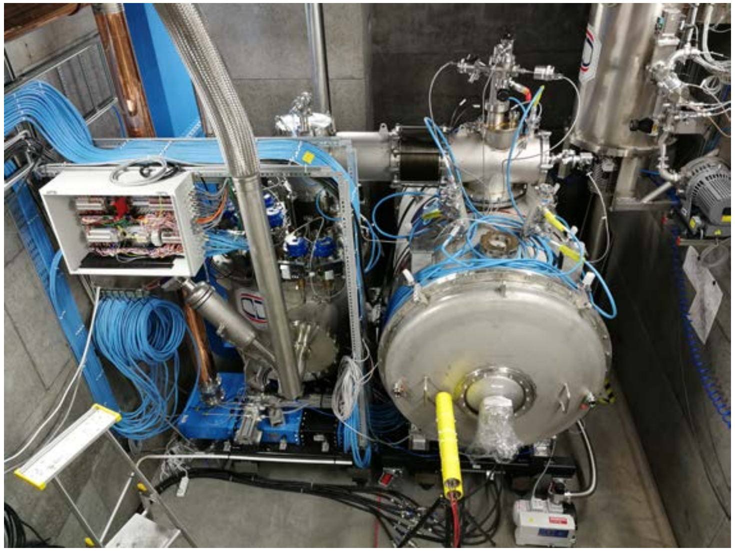
Spoke Valve Box Prototype

- Cryo test run with simulator (Dec + Jan)
  – commissioning controls & functionality test
- Thermo-acoustic oscillations
  – installed RLC-circuit to damp the oscillations

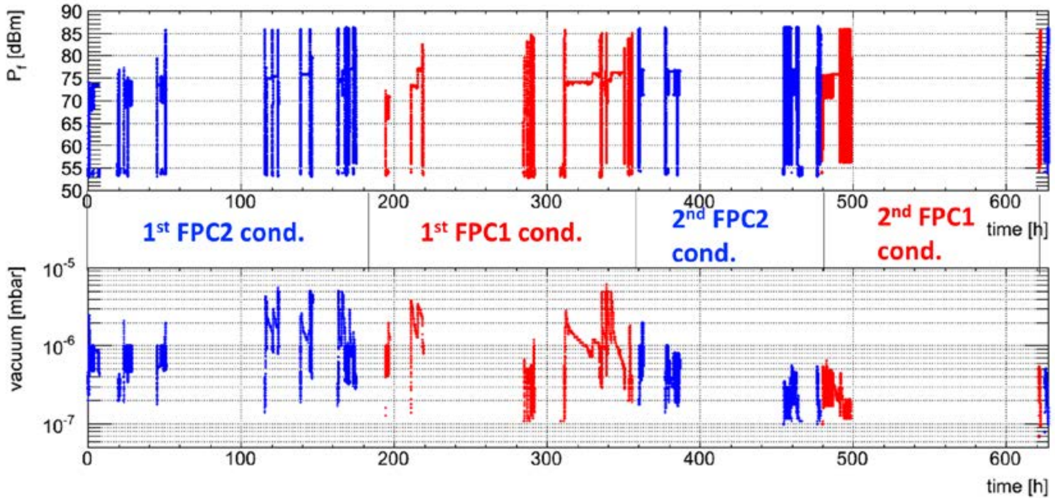


Warm RF Conditioning

- ~3 days/cavity
  - 1st conditioning ~50 hours
  - 2nd conditioning ~20 h (cross-contamination)

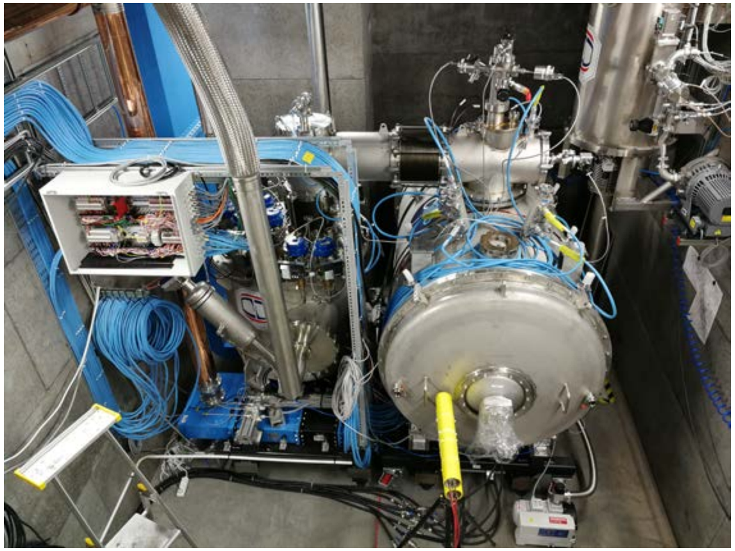


- fully automatic system conditioning system
  - commissioned and implemented to run 24h/day
- MP bands consistent with HNOSS test
  - strength depends on pulse length,
  - 1st/2nd conditioning…



Cool Down

- Cool Down
  - 4h 15min to 4.5 K
    - 2h 30 min for shield
  - ~1/2 day to 2 K
    - including stabilization

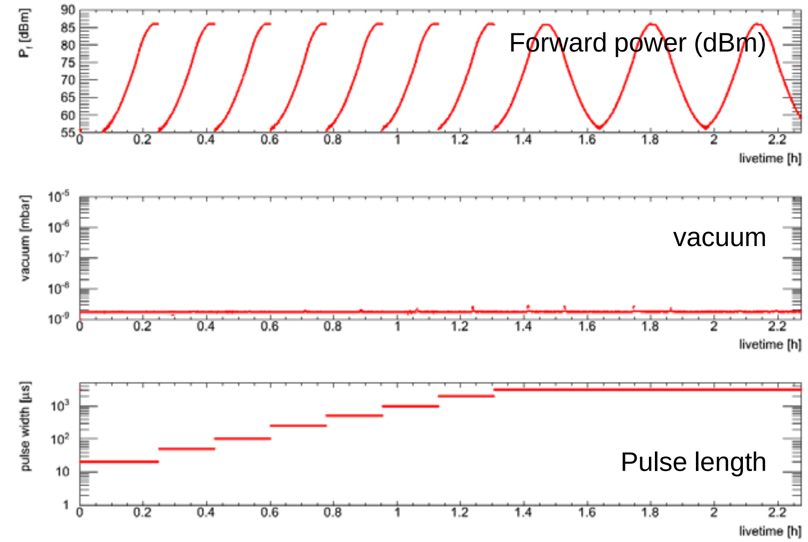


Cold RF Conditioning

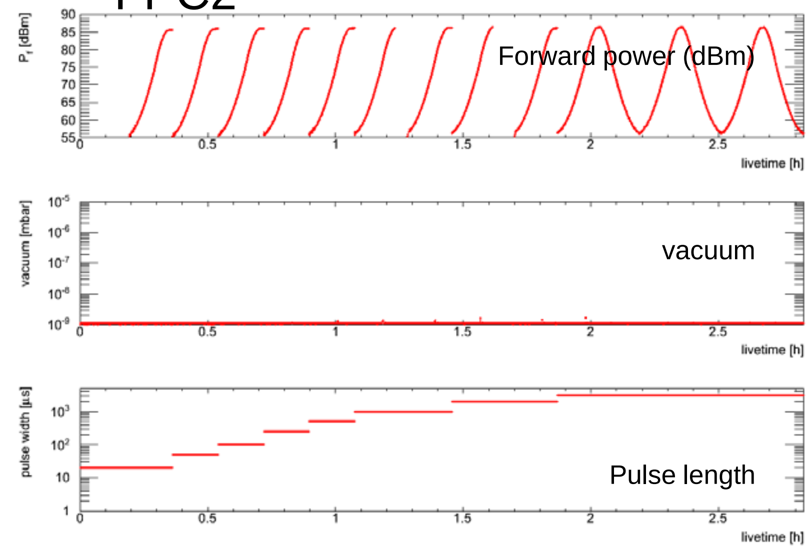
- FPC conditioning (4K)
  - no coupler activity
  - Quench during cavity conditioning at 4 K
    - burst disc rupture → thermal cycling
    - implemented quench detection
    - from now on always at 2 K

- FPC conditioning (2K)
  - ~1/2 day/cavity

FPC1



FPC2



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Overview FPC Conditioning

FPC1	Warm	Cold
Real time [h]	304	4.1
Intervention #	17	2
Live time [h]	76	2.3
Dead time [h]	228	1.8

FPC2	Warm	Cold
Real time [h]	297	2.9
Intervention #	23	1
Live time [h]	78	2.8
Dead time [h]	219	0.1

- Re-conditioning is required due to cross contamination
- Total conditioning timing was
  - about 4 weeks (real time),
  - can be improved to 7 days (based on live time) or
  - 3 days if conditioning two couplers simultaneously

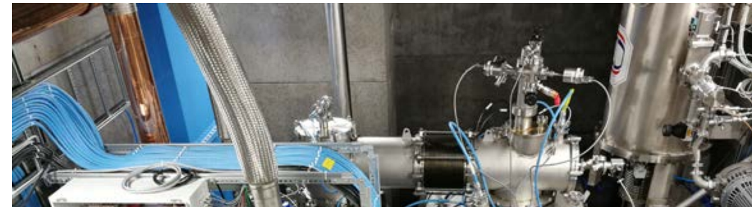
Cavity Conditioning

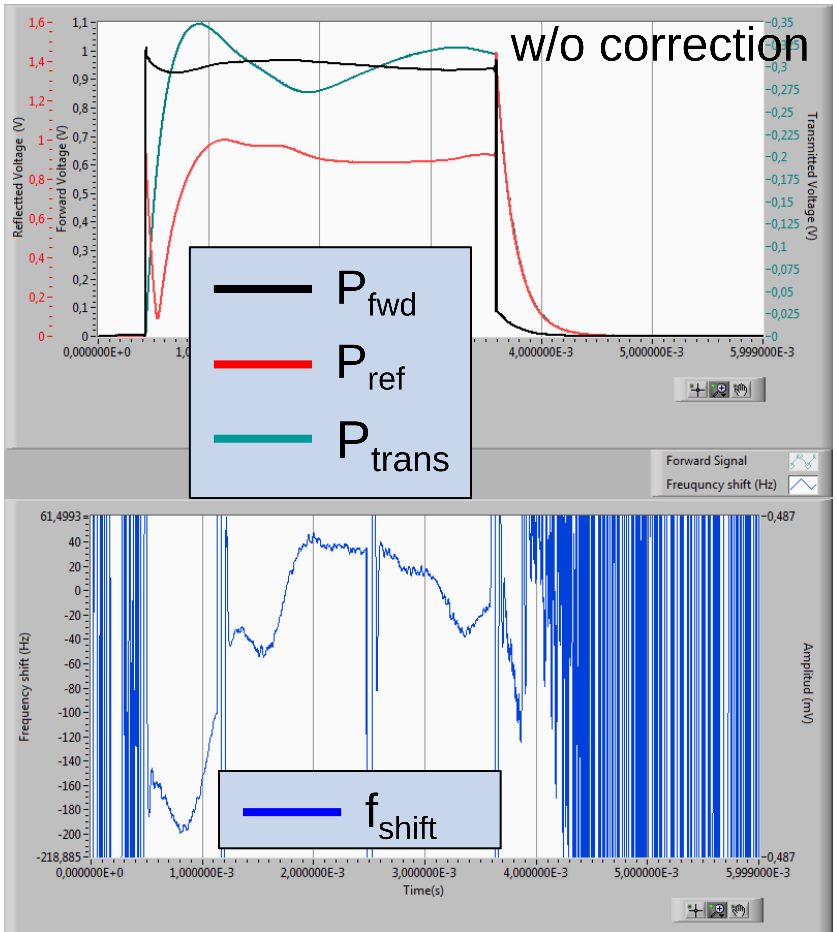
	Cav1	Cav2 1st run	Cav2 2nd run	Cav2 3rd run
live time [h]	6	6.7	7.3	7.4
Loop	Open loop	SEL	SEL	SEL
Conditioning strategy	1ms@ 14Hz 3.2ms@14Hz	1ms@ 14Hz 3.2ms@14Hz	3.2ms@ 1Hz 3.2ms@14Hz	1ms@ 14Hz 3.2ms@14Hz

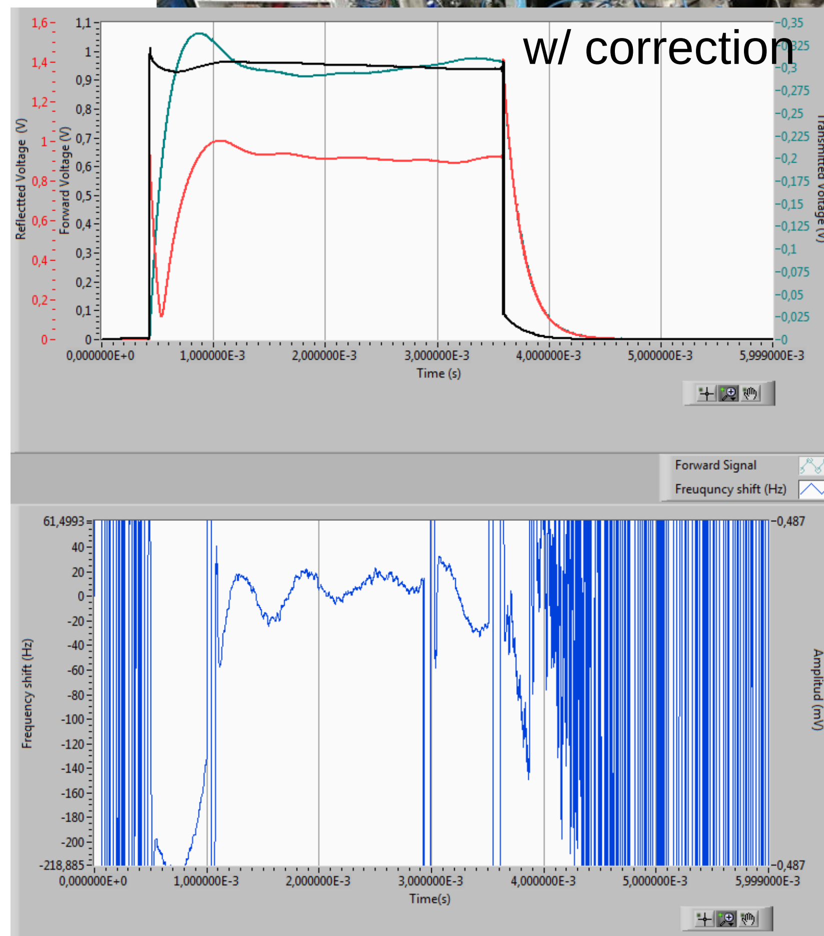
- Different loop setting and conditioning strategies were studied
  - no significant difference was found in the time variation of cavity conditioning.
- Open loop with a fixed repetition rate of 14 Hz would be an optimal option
- Total cavity conditioning timing is about 2 days

Spoke Cryomodule Prototype (2019)

- Fast tuner performance
  - Lorenz force detuning compensation (piezo)

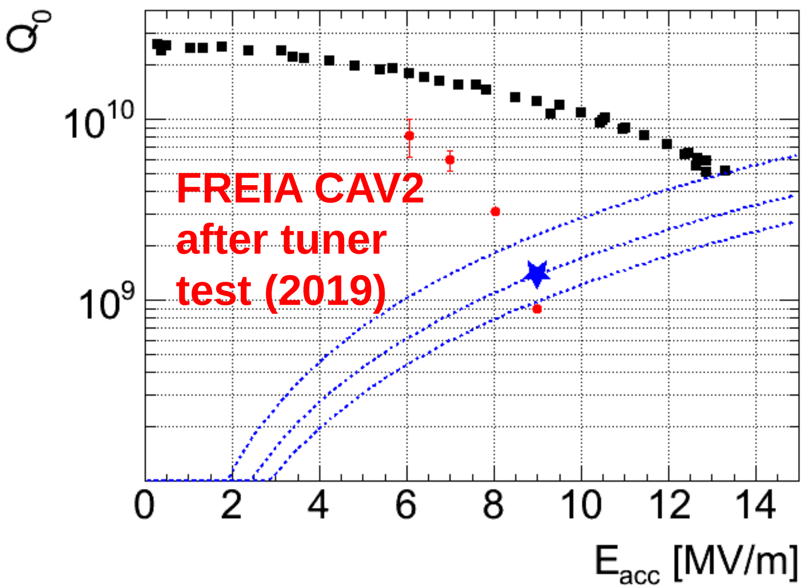






Spoke Cryomodule Prototype (2019)

- Cavity #2 performance
  - multipacting regions similar as prototype
    - 2-3; 4-5; 7-8 MV/m
  - field emission sensitive to tuner motion or position (under investigation)



  - thermal cycle cryomodule up to 40 K
    - outgassing up to 10-4 mbar observed around 20 K,
      - implying that hydrogen is vaporized from the cavity surface.
    - field emission almost back as before the CTS activities
  - maximum E_{acc} improved from 9 MV/m to 10 MV/m after thermal cycle

  - **Q_0 performance of cavity2 recovered as before the CTS activities**

Series Spoke Cryomodule Testing

- how to keep testing to 4 weeks, and
- which additional resources required to achieve that?

OUTLOOK

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There Will Be Differences ...

- Prototype to 1st series cryomodule
  - 5 people from IPNO did the prototype installation
    - none of FREIA was unfortunately able to follow up all the details
  - we should learn when removing the prototype
  - support frame / trolley is different
  - doorknob is different
  - instrumentation connectors are different
    - have to redo connectors on local cabling (and commission)

- 1st to following series cryomodules
  - pumping ports
    - trade-off between speed and safety
    - 1st cryomodule can/will be tested with 2 pumps

Testing and Operation

- 2 hours for moving the tuner (1 hour for one direction)
  - thus there is an advantage to prolong the daily operation time
- need & accuracy of the Q_0 value
  - measurement time depends on required accuracy
  - is it enough to give the upper limit of the power dissipation?
- RF stations reliability and maintenance is a problem
  - need a good high power RF engineer
    - previous announcements did not result in a good candidate → try again
- LLRF: waiting for a new system (replacing an old version)
  - hardware available, but no working system yet
    - integrated control system part needs more work

- Documentation and test results
  - report should be ready before completing test next module/installation at ESS
  - also: agree on what & how to test (on reception, cold test, ...)

Critical Personnel Resources

- **During installation**
  - 1st cryomodule:
    - Patxi and Matthieu from IPNO, to teach us and check our work
  - 1st + following
    - 1 or 2 mechanics, to help us, and (if from ESS) for their training
- **During testing**
  - on-site: 3 operators in CR for cryo, SRF, LLRF/controls
    - 1 or 2 operators, to off-load Rocio/Lars + help extend daily operation time
  - on-call: high power RF
    - 1 engineer, to assist Rolf & co
  - remote: LLRF
    - ICS/uTCA-LLRF expert from ESS (have no expertise at FREIA)

Critical Spare Parts

- **RF stations**
  - extra RF station as back up, and/or
  - preferably same amount of spare tetrode tubes as in use
    - 2 ordered: 1 to arrive end August, 1 in Feb 2020 (10 months delivery time!)
    - order more from Thales and/or can we rely on ESS stock?

- **LLRF**
  - spare FPGA cards for Uppsala NI/LabVIEW system
  - spare µTCA cards in Uppsala, as delivery from Lund takes a few days

- **Other**
  - cooling water flow meters (FPC)
    - preparing Eletta flow switches as back-up
  - RF power meters
    - want to keep the ESS power meters to speed up calibration procedures

Summary

Uppsala University & FREIA Laboratory doing their best efforts to make this project a success and on-time

Most critical resources

- operator/technician
  - mechanic during installation
  - operator during testing
  - ICS remote support for LLRF
- high power RF engineer
- spare parts
  - tetrodes
  - LLRF
- acceptance criteria