ReA Operation Experience over Several Years

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FRIB

NSCL

Outline

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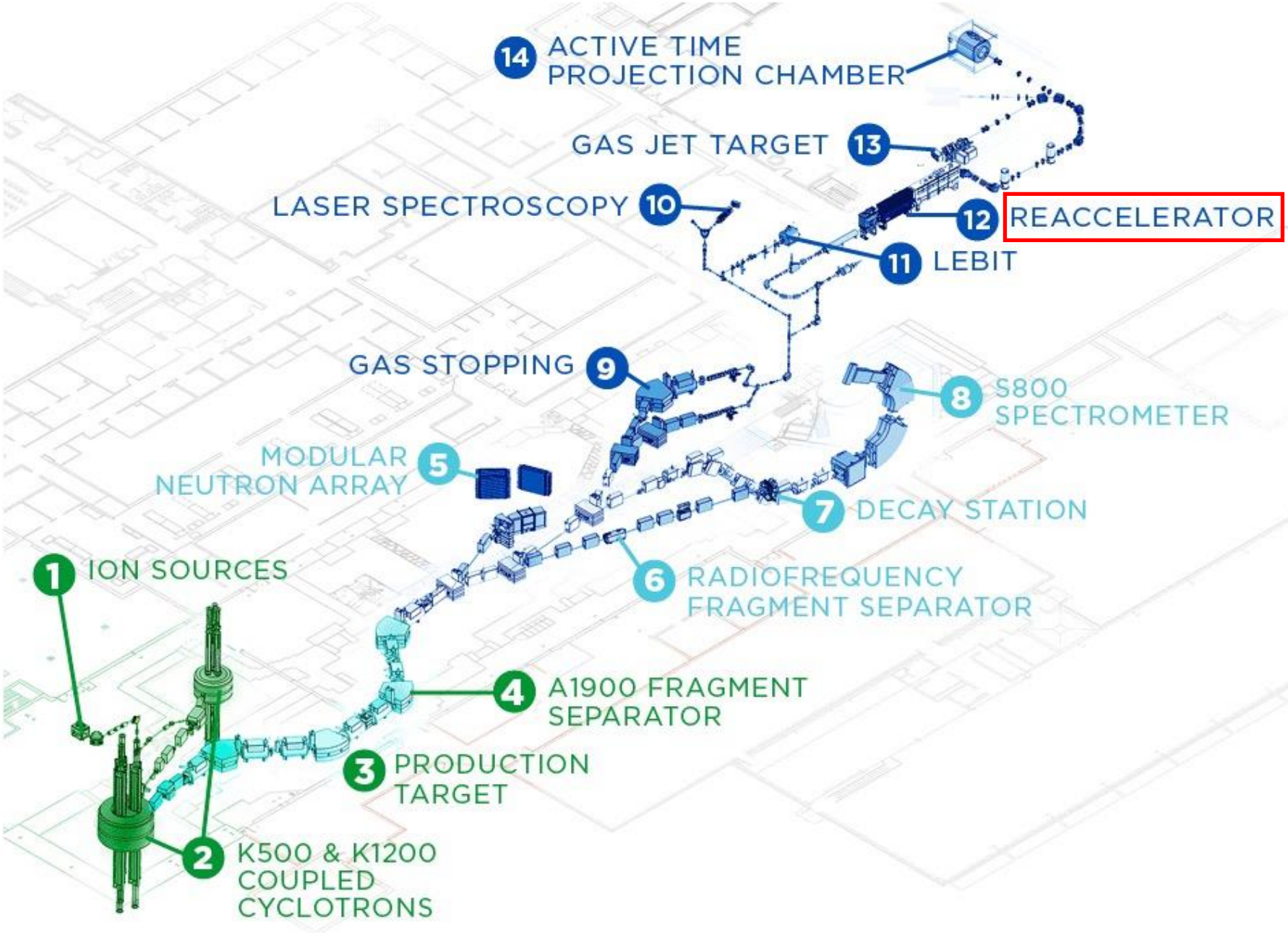
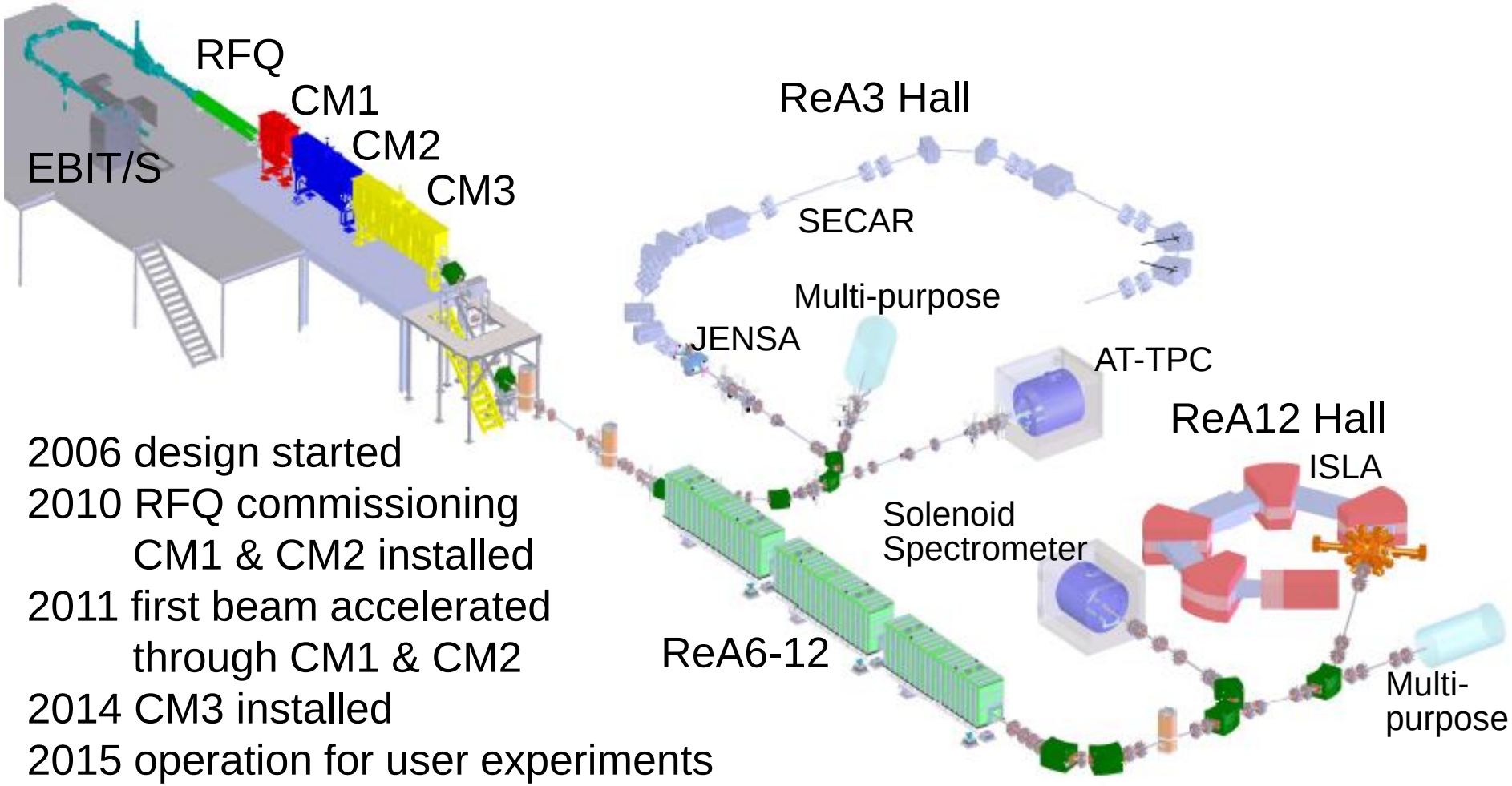
  - ReAccelerator (ReA)
  - ReA3 features
    - 7 β=0.041 QWRs, two cryomodules
    - 8 β=0.085 QWRs, one cryomodules
- Resonator operation experience
  - Resonator field gradient setup
  - Turn on problems and solutions
  - Stable operation issues and resolutions
  - Recent improvements
- Summary

Coupled Cyclotron Facility at NSCL



ReAccelerator (ReA)

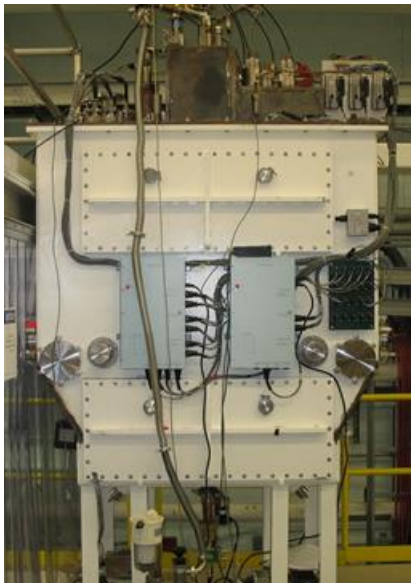


2006 design started
2010 RFQ commissioning
CM1 & CM2 installed
2011 first beam accelerated
through CM1 & CM2
2014 CM3 installed
2015 operation for user experiments

ReA6 under construction
ReA12 under design

ReA3 β=0.041 Cryomodules

CM1:
one β=0.041 QWR
two solenoids



CM2:
six β=0.041 QWRs
three solenoids

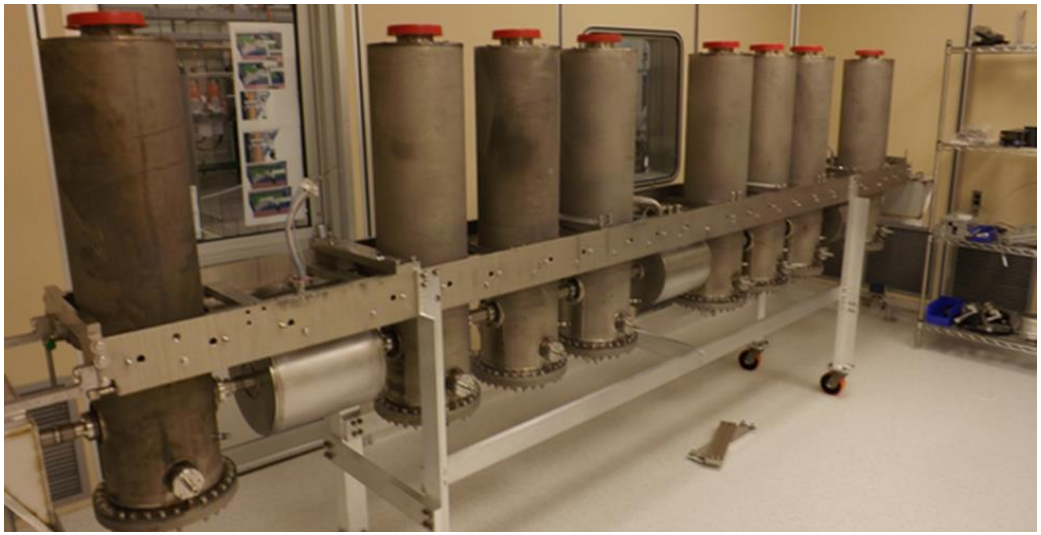
A total of 7 β=0.041 QWRs

ReA3 β=0.085 Cryomodule

CM3:

eight β=0.085 QWRs

three solenoids



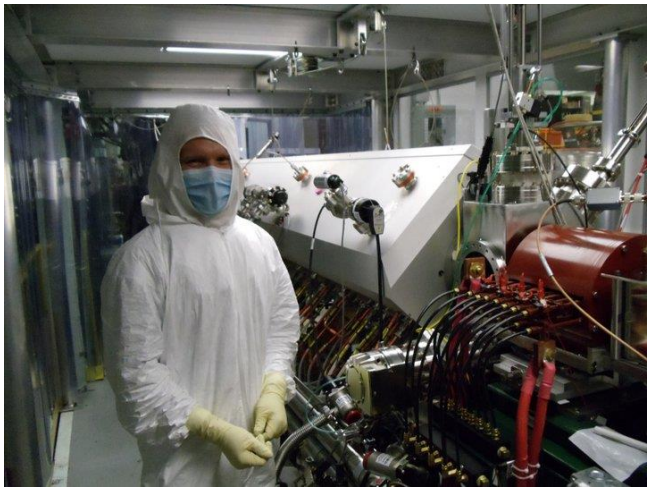
A total of 8 β=0.085 QWRs

Some Facts on ReA3 (1)

- A total of 15 superconducting resonators
  - 7 β=0.041 QWRs and 8 β=0.085 QWRs
- ReA3 linac installed on a mezzanine
  - 3-4 times large vibration than that on the floor
- Improved LLRF controllers
  - ADRC (Active Disturbance Rejection Control) algorithm is more effective than traditional PID
  - Digital self-excited loop employed for automatic cavity tuning and start-up
- Tuners driven by both piezo and stepper motor
  - piezo not working on three resonators
- Beam line vacuum separated from insulating vacuum
- Cryogenics transfer line shared with FRIB resonator tests
  - Large helium bath pressure when cooldown or warmup

Some Facts on ReA3 (2)

- Clean rooms established
  - All warm areas are enclosed by clean rooms
  - Portable clean rooms are used on beam lines
  - Follow regular clean room procedures
- No cold traps adjacent cryomdules



Resonator Field Gradient Setup

- Resonator field gradients calibrated with beam energy measurements
  - Beam energy gain measured with Si detectors and dipole magnets
  - Higher operation gradient for most β=0.041 resonators
- Different criterion to set the maximum operation gradients
  - Reliable and stable operation is essential
  - Limit of X-ray emission for β=0.041 resonators
  - Limit of forward power for β=0.085 resonators
- Scaling of field amplitude works very well to keep same velocity profile (resonator phases not changed) to accelerate ion beams with different q/A
  - Gradient scaled as large as 15%

Turn on Problems and Solutions (1)

- Multipacting
  - Multipacting was a major problem during CM2 commissioning
    - Multipacting barrier at very low field
    - Pulsed conditioning on and off for 2 months
    - Reliable operation was achieved since then
    - Except CM2R1, multipacting back in 2 years
    - Full warm up with pumping for several days, it recovered
  - CM3R1 also suffered multipacting barrier at low field
    - Prevented operational use for some experiments
    - Recovered after a warm-up during shutdown
  - Mild multipacting
    - Continue conditioning (high or low power) seems not work well
    - Turn off rf power and wait about 10 min, usually works

Turn on Problems and Solutions (2)

- Cross-talk among neighboring resonators
  - Sequential procedures developed to deal with the issue
- Ion beam impact although intensity at pA level
  - Block beam by inserting upstream Faraday cup(s)
- Interlock threshold set incorrectly
  - instantaneous forward power trip point was set to the same as the average forward power interlock
- Tuner not reacted (rarely happen)

Stable Operation Issues and Resolutions

- Quick helium bath pressure change induced resonator trip
  - Shared helium transfer line
  - Schedule/coordinate with FRIB tests
- Ambient temperature caused the rf amplifiers instable
  - Amplitude fluctuation of some CM2 resonators could be ~10%
  - Better cooling of the air-cooled amplifiers
- Vibration impact
  - new office building construction (huge impact when digging)
  - Big truck delivery
  - Crane running over
  - Schedule work

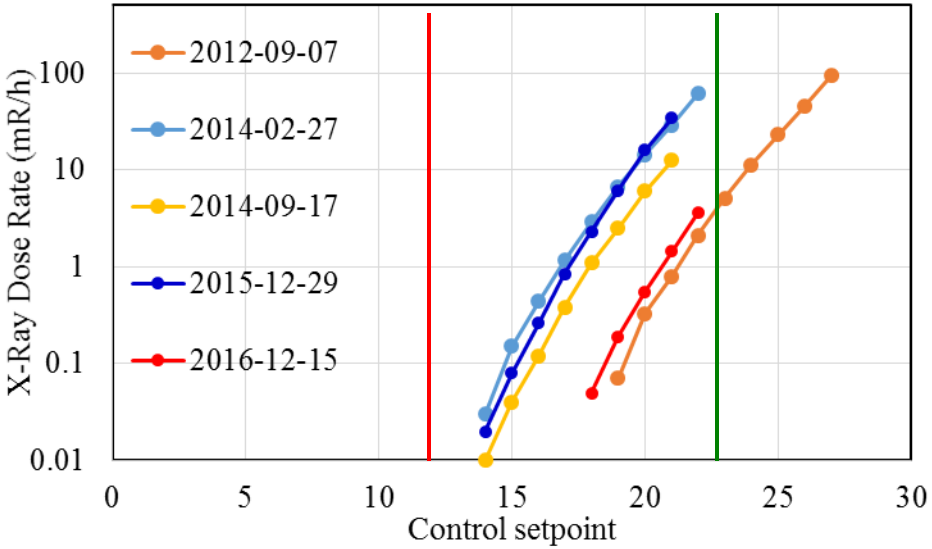
Recent Improvements

- Parameters in the LLRF control adjusted based on experimental tests to increase performance
  - Resonator locked at ~20% field level first and then ramp up
  - “Diagnostics” implemented to record errors that caused trip
  - Speed of stepper motor increased

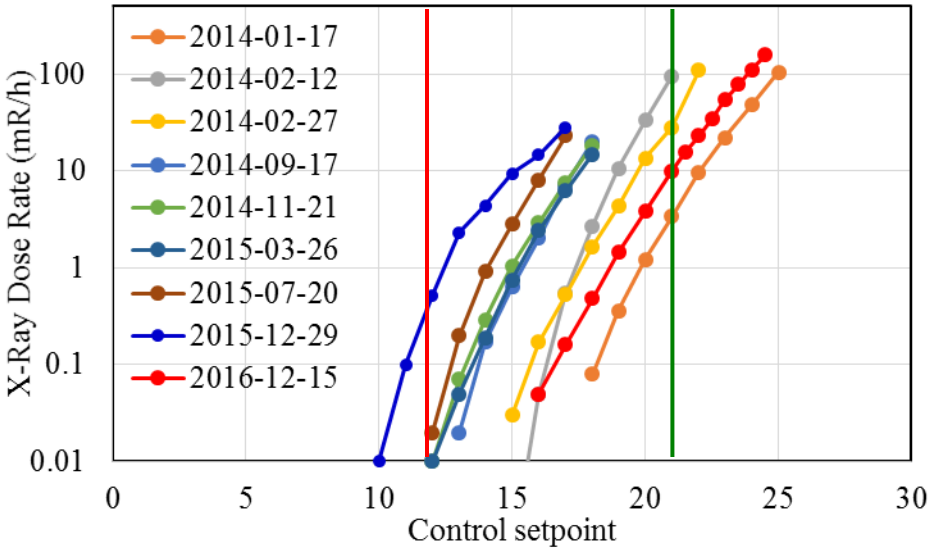
- RF pulse conditioning reduced field emission
  - Two outer resonators in CM2 developed higher field emission that limits their operation gradient
  - High rf power short pulse conditioning was tried and notable recovery was achieved (X-ray reduced)

X-ray Measurements

- Two outer resonators in CM2
- X-ray less than 10 mRem/hour for operation



First resonator in CM2



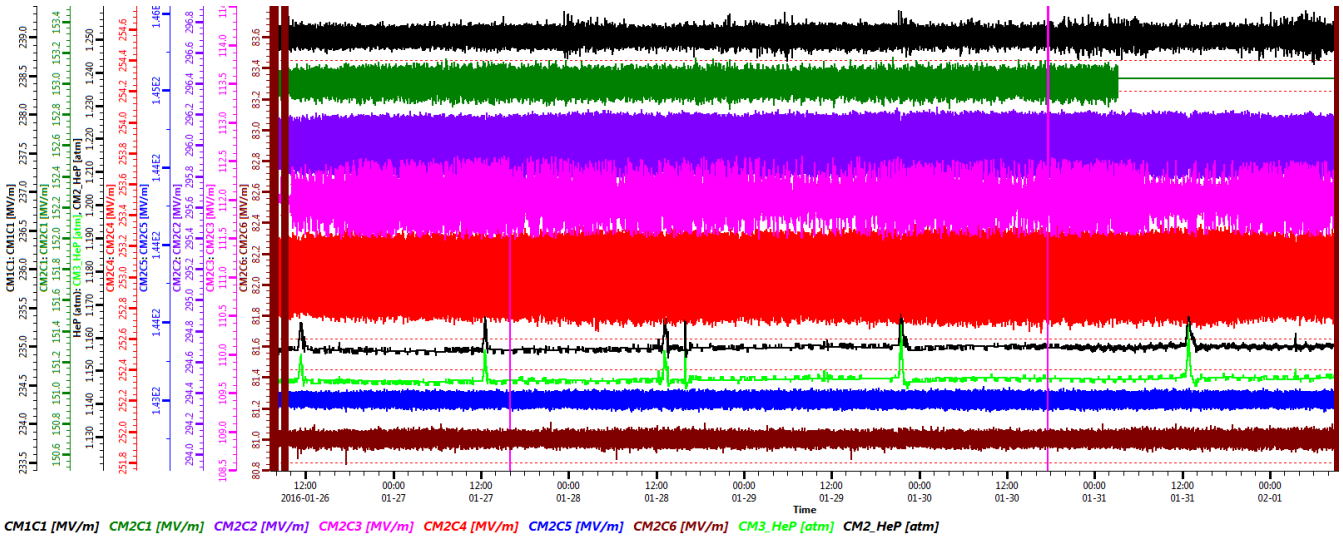
Last resonator in CM2

Other Experiences

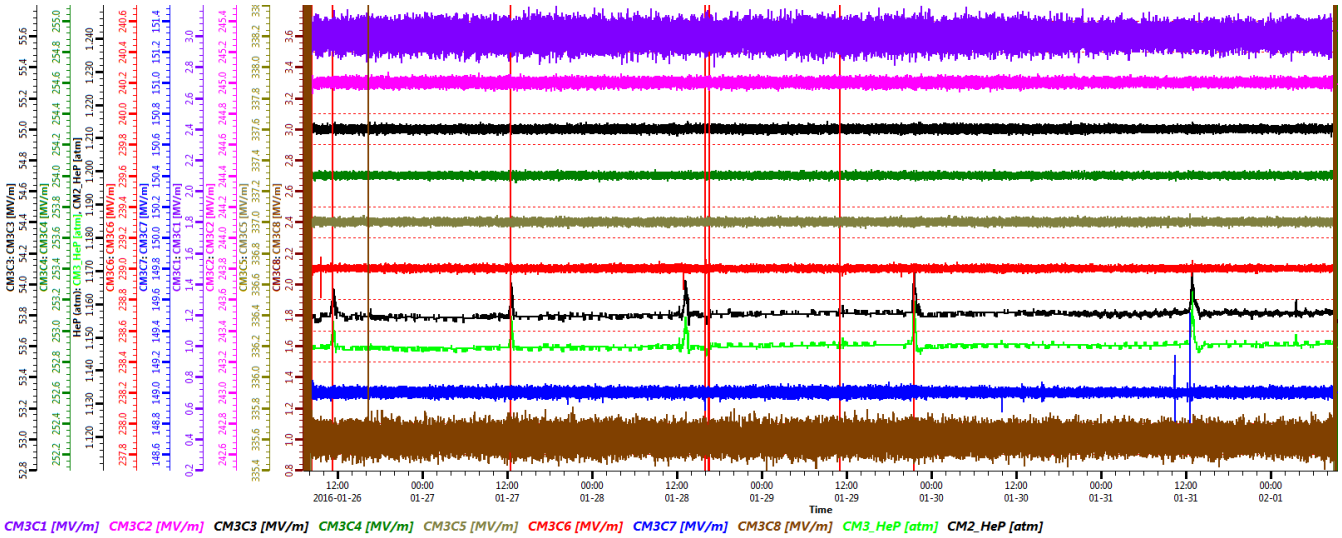
- Long-term resonator operation stability well within specifications
- Operation of resonators is very reproducible
- Cryogenic heat load seems to match predicted values
- Alignment of cold mass seems repeatable after several thermal cycles
- Lots of gas released during warmup cryomodles
  - Leaks in insulating vacuum as well as in beam line vacuum of CM2
  - Vacuum could reach mTorr level
  - Mainly H, He, C, N, O, H_2O, CO_2 analyzed by RGA

Stable Operation in a 6-day Experiment

Phase jitter within ±0.3° (peak to peak) for all 7 β=0.041 resonators with maximum amplitudes



Phase jitter within ±0.2° (peak to peak) for all 8 β=0.085 resonators with maximum amplitudes



Summary

- ReA has been successfully serving users for two years
  - ReA3 performance was improved
  - Upgrade to Re6-12 being pursued
- Most resonators have been operating stably and reliably
  - β=0.041 resonators over 5 years, β=0.085 ones for 2 years
- Field emission increased in some β=0.041 resonators
  - Especially the first and the last in the second cryomodule
  - RF condition is quite effective to recover the degradation
- Severe multipacting appeared in a few resonators
  - Recovered after warm-up

Acknowledgements

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  - ReA: D. Crisp, A. Lapierre, S. Nash, R. Rencsok, T. Summers, A. Villari, …
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  - Cryogenics: F. Casagrande, A. Ganshyn, M. Thrush, …
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  - …
- Valuable advice and guidance from many external colleagues

Main Design Parameters of ReA Resonators

Location	ReA3		ReA6-12
Type	$\lambda/4$	$\lambda/4$	$\lambda/4$
Optimum β	0.041	0.085	0.085
Frequency	80.5 MHz	80.5 MHz	80.5 MHz
Ep	16.5 MV/m	21.1 MV/m	32.8 MV/m
Va	0.45 MV	1.08 MV	1.78 MV
Eacc	2.8 MV/m	3.4 MV/m	5.6 MV/m
Bp	29 mT	47.4 mT	54.6 mT
Temperature	4.5 K	4.5 K	4.5 K
Active Length	0.157 m	0.317 m	0.317 m
Aperture Diameter	30 mm	30 mm	36 mm
Number of Resonators	7	8	24