Superconducting Linac Operations and Performance

SNS AAC Review
February 2, 2010

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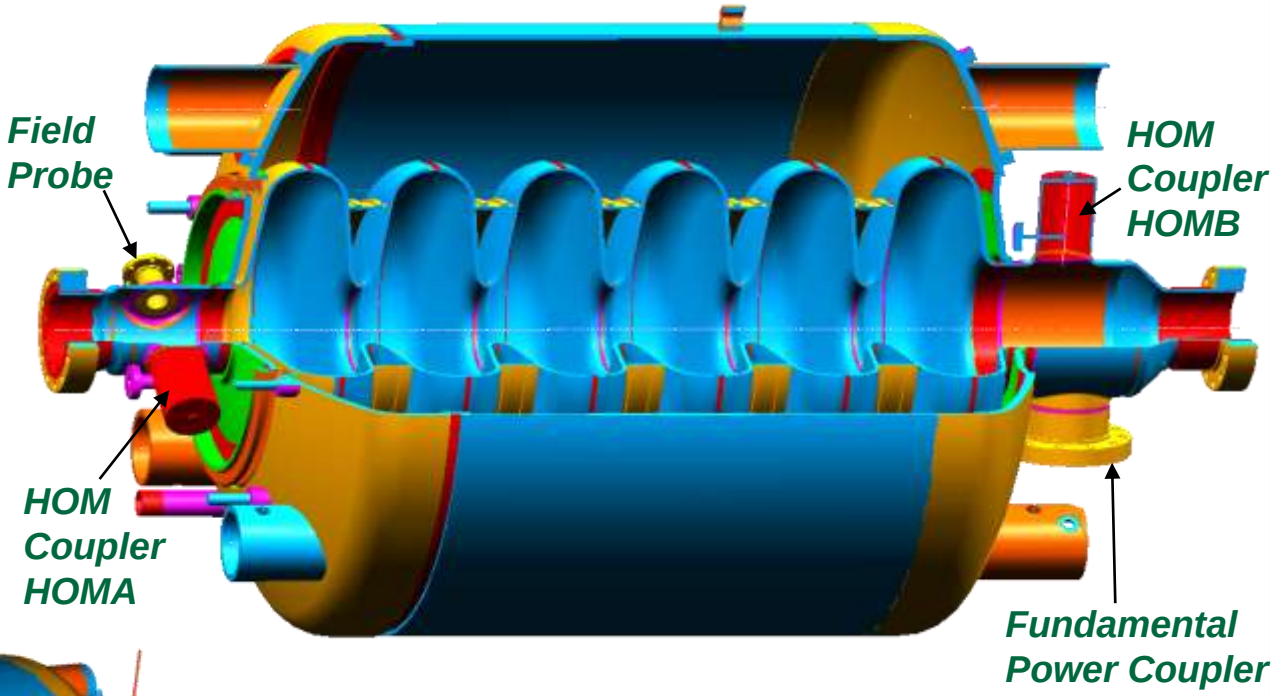
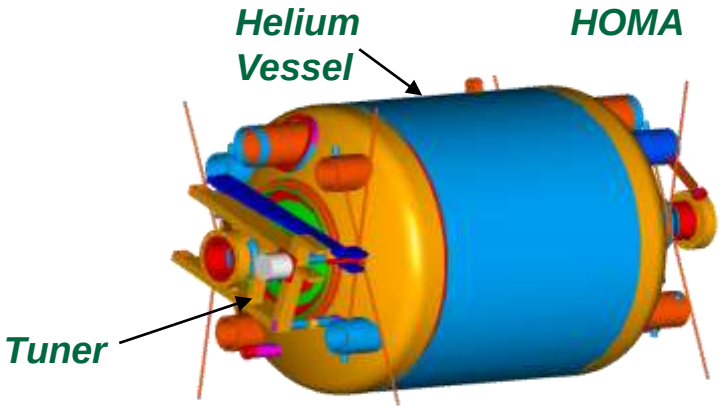
Outline

- SCL operational status
- SCL performances
  - Limits, limiting factors and understandings
- Testing program and R&D
- Summary

SNS SRF cavity

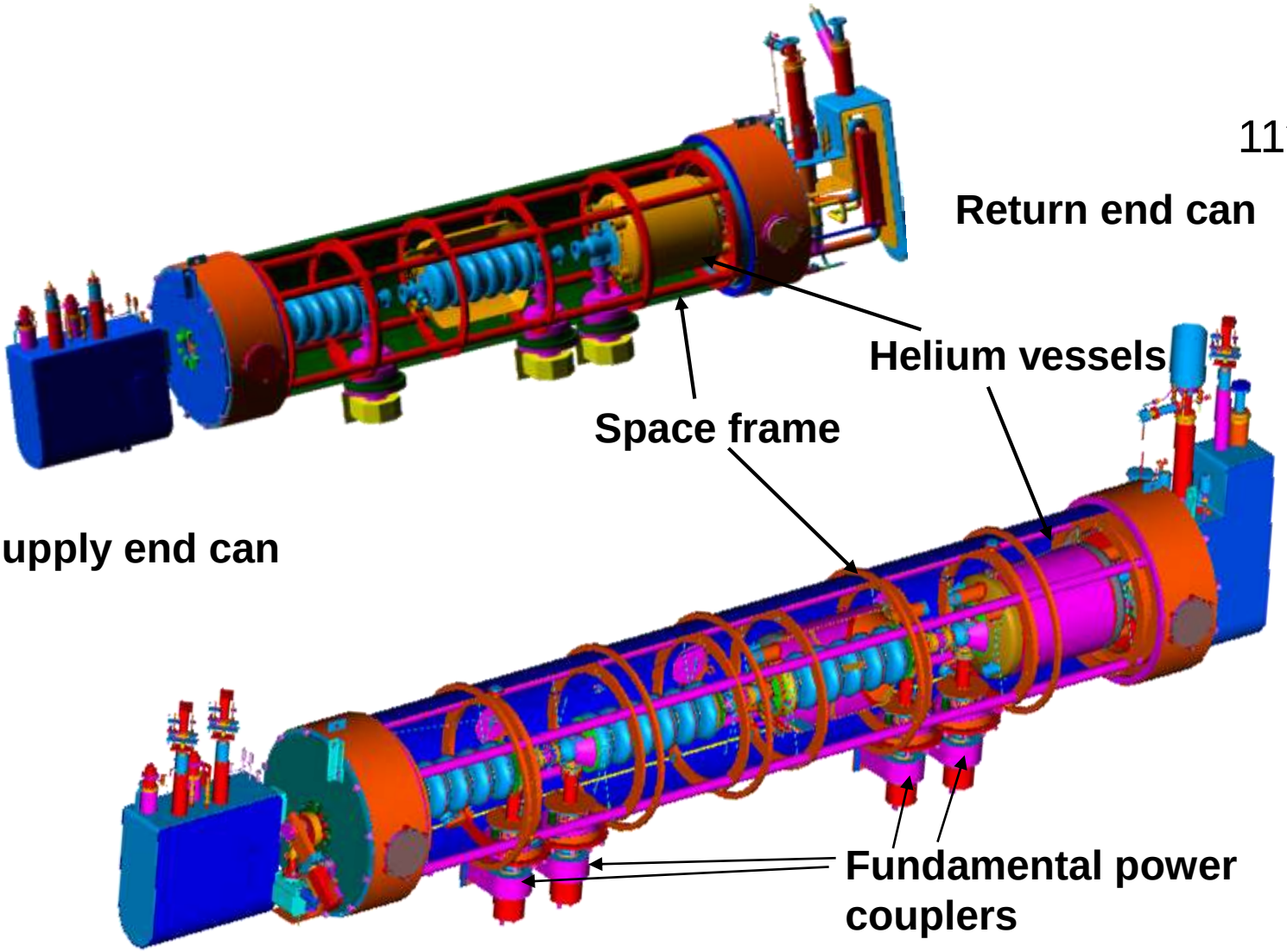
Major Specifications:
E_a=15.9 MV/m at β=0.81
E_a=10.2 MV/m at β=0.61
&
Q_o> 5E9 at 2.1 K





SNS Cryomodule

Designed to operate at 2.1 K (superfluid helium)



11*Medium beta

12*High beta

81 cavities

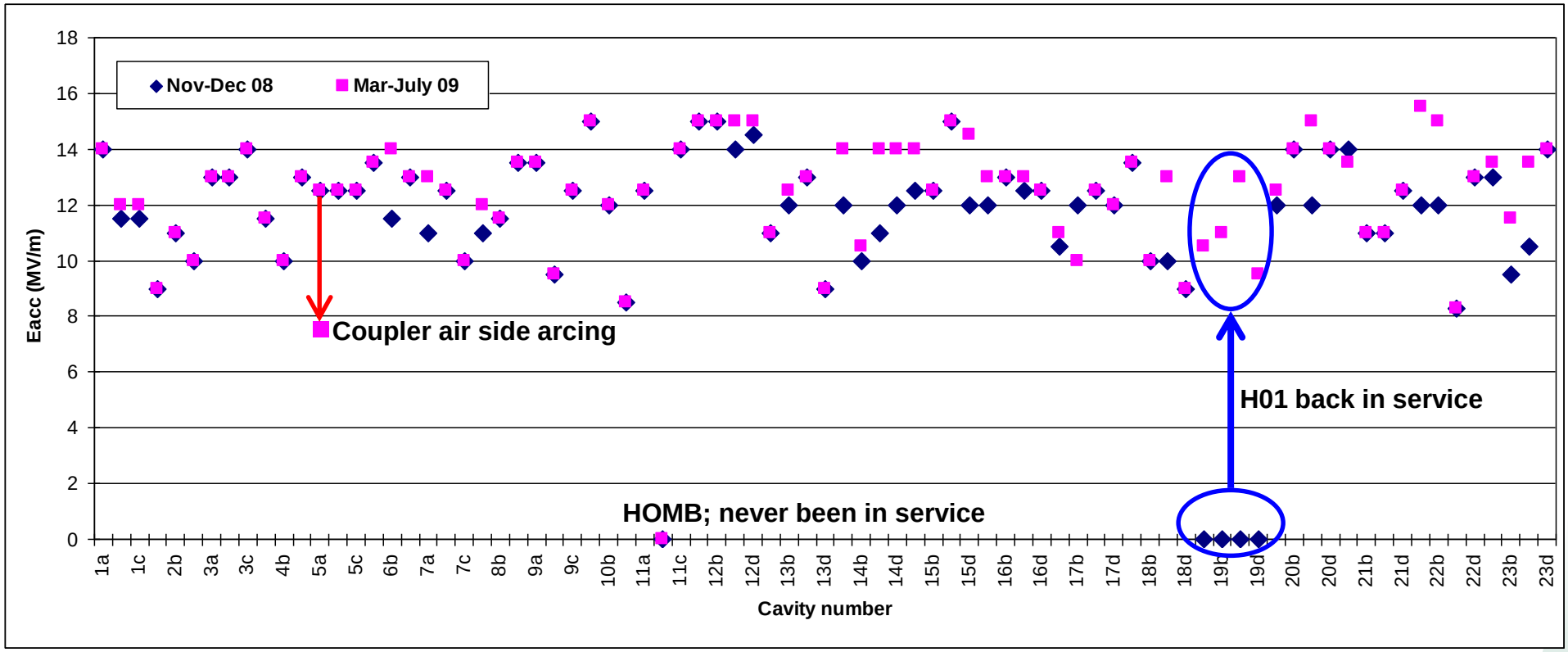
SCL status at around last review

- Operation during Oct. 08-Jan. 09 run; 865 MeV (76 cavities)
  - Out of Service; H01 for repair, 11b
  - Lower gradients to accommodate higher beam loading
  - 23d; in service w/ a few MeV energy reserve
- Upgrade during Jan. & Feb. 09 maintenance period
  - H01 back in service in the slot of CM19
  - One additional HVCM for SCL
    - One 11 pack (71 kV for 1a-4b) + seven 10 pack (75 kV)
      - Enough RF power for design beam current
      - Cavity filling time; 300 us → 250 us
  - DC biasing for selected cavities
    - ~10 cavities enter MP at FPC when >22 mA → coupler heating
  - HPM board upgrade for electron probes
    - Detectable during filling and decay time

SCL operational status since last review (I)

- **March 09 – July 09; 928 MeV + 10 MeV (80 cavities out of 81 cavities)**
  - **New HVCM**
    - **Enough RF for design beam (26 mA)**
  - **DC biasing for selected cavities**
    - **Eliminate coupler heating at 60 Hz**
  - **Several klystrons showed instabilities at operating gradients**
    - **slightly lower gradient for those cavities**
  - **5a air side arcing; water condensation**
    - **12.5 MV/m → 7.5 MV/m**
    - **Inspection during summer maintenance period**

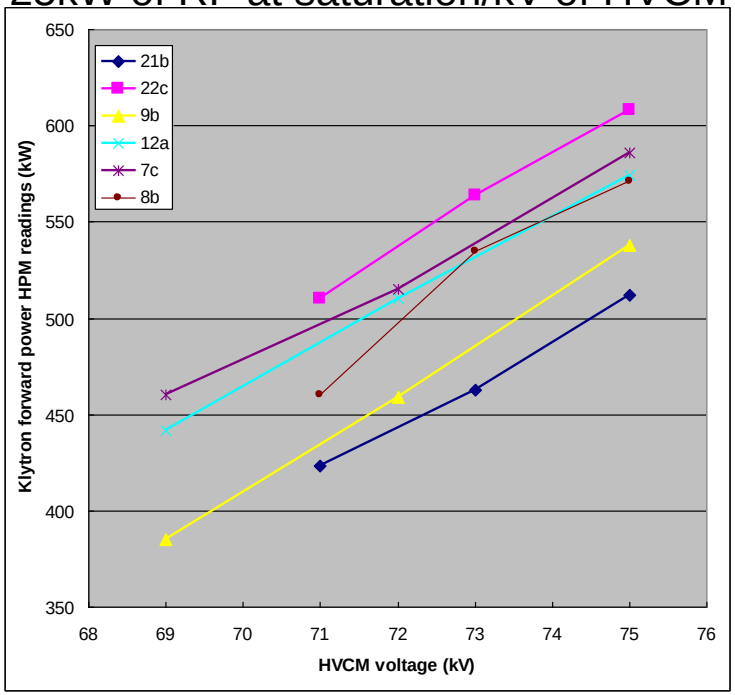
March-July 09 operating gradients

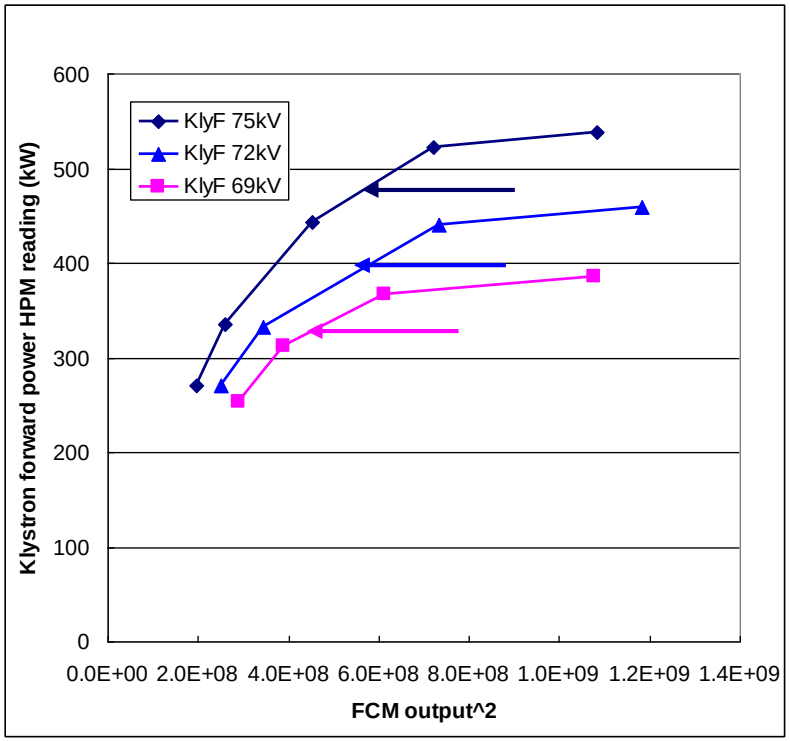


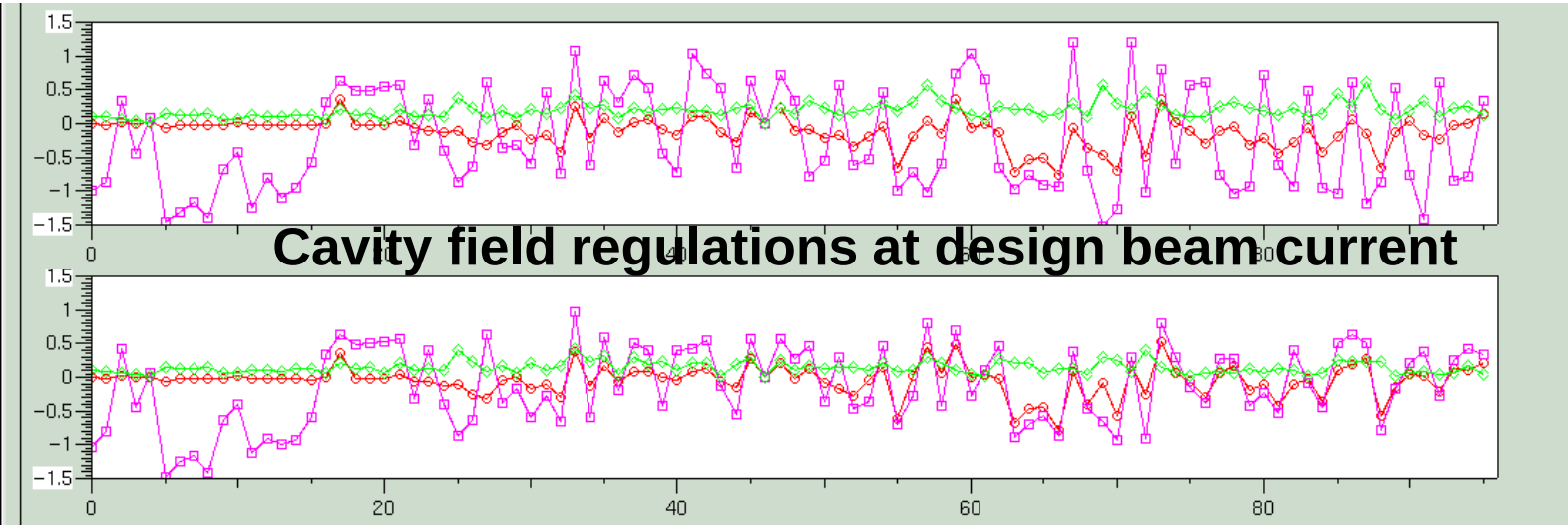
Additional HVCM; enough RF power for design current
DC biasing for selected cavities
H01 repaired and put in the slot of CM19

Linac RF; enough for design current
Tested at design intensity on 7/11/09

~25kW of RF at saturation/kV of HVCM





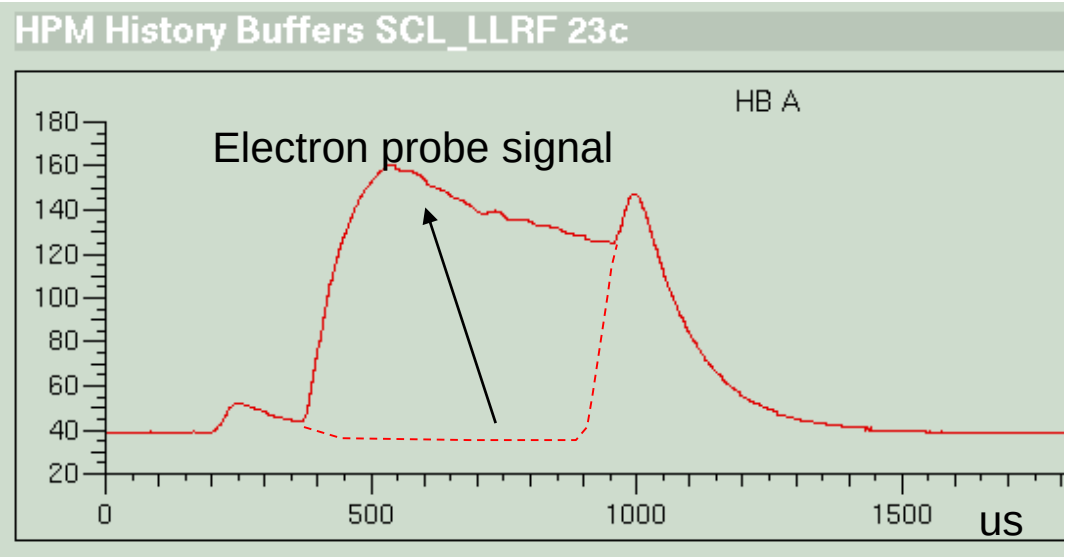


Cavity field regulations at design beam current

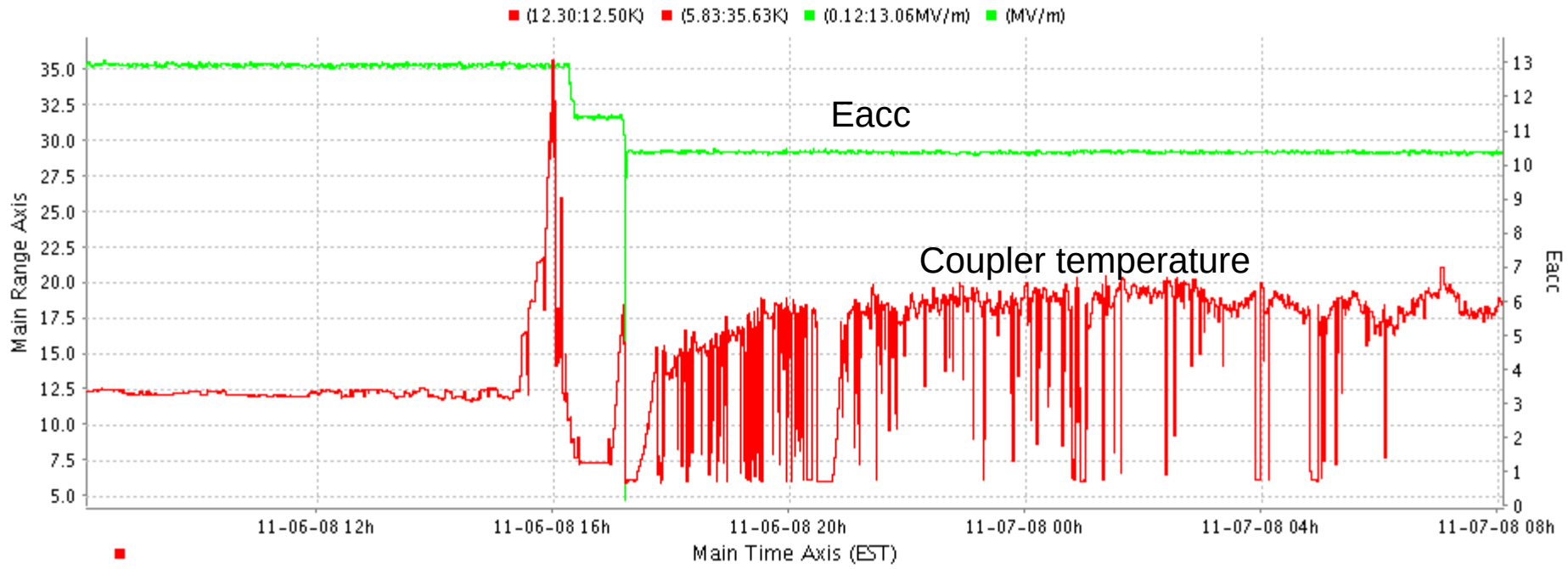
During whole beam pulse

Except first 50us beam

Multipacting at Fundamental power coupler

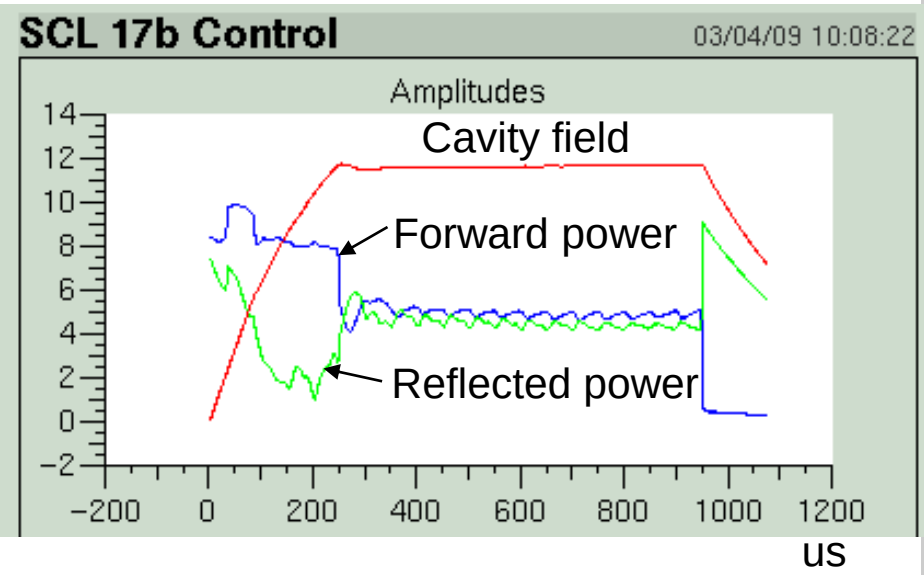


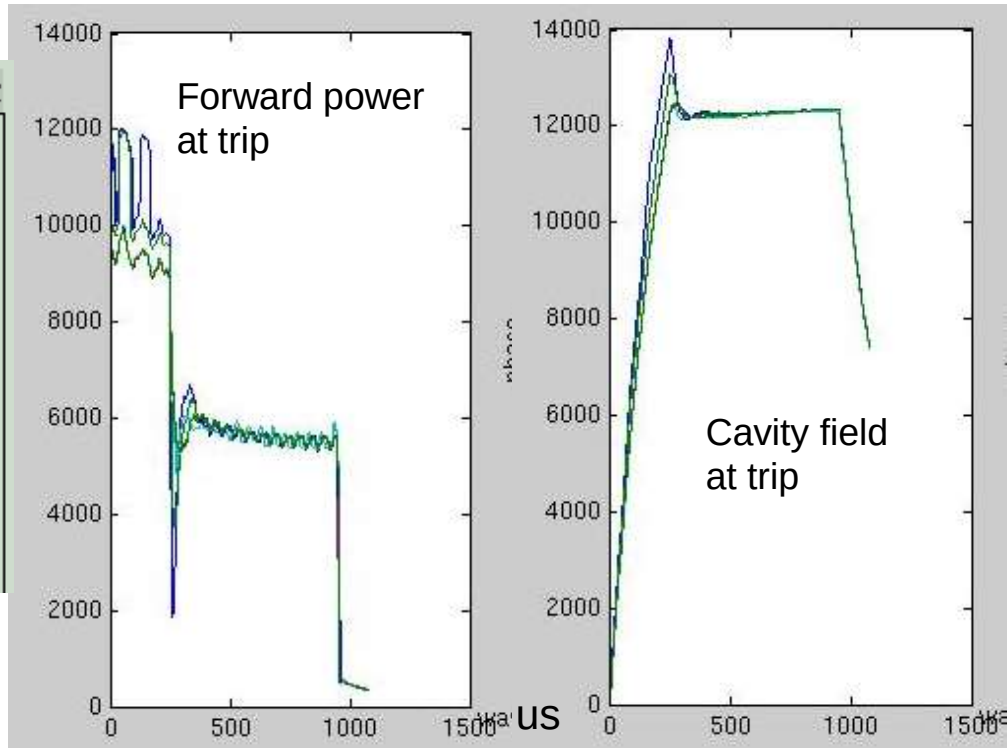
- Reached limits at 21~22mA average current in the previous run
- Lowered gradient for 4 cavities
- Those are MP at FPC only
  - Only depends on Power and SWR
- Prepared DC biasing for higher intensity run
- 15 couplers have DC biasing



Klystron output instability

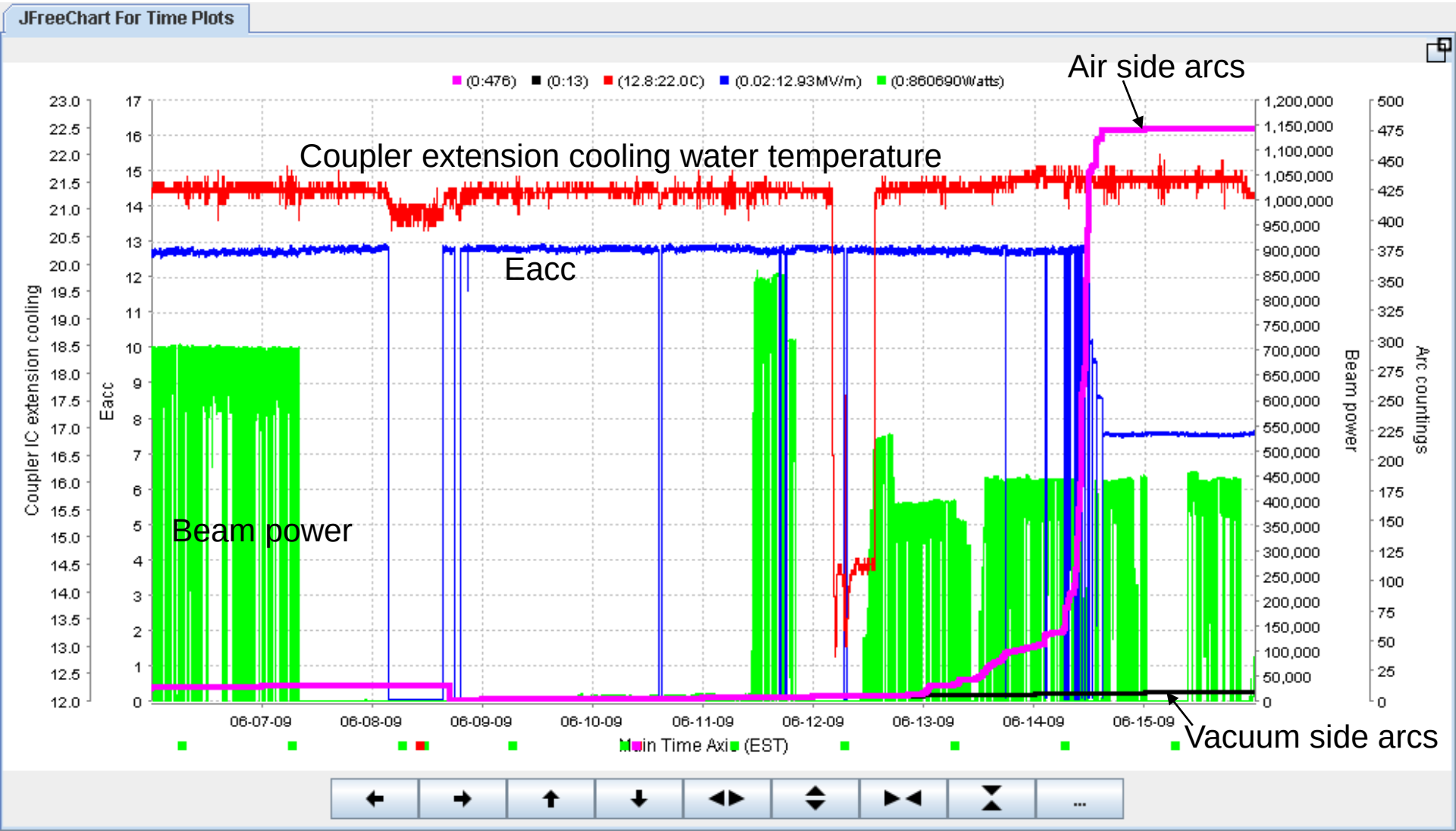
- Thales Klystrons have shown unstable output at a constant drive
- This instability sit in the operating conditions of several cavities
- Run at slightly lower gradients
- Request Klystron changes (Hardek's talk)





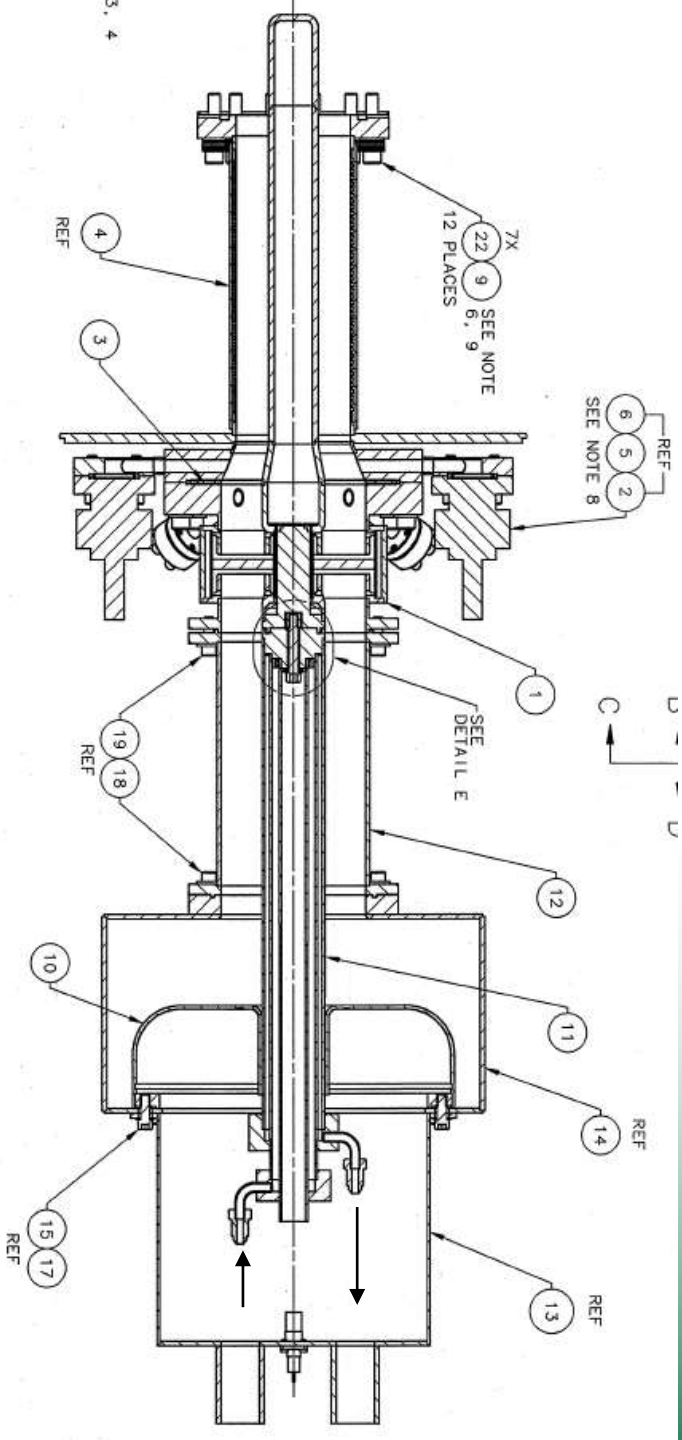
5a air side arcing after QMCS water in manual mode

- Eacc; 12.5 → 7.5 MV/m and Rescaled SCL



5a air side arcing

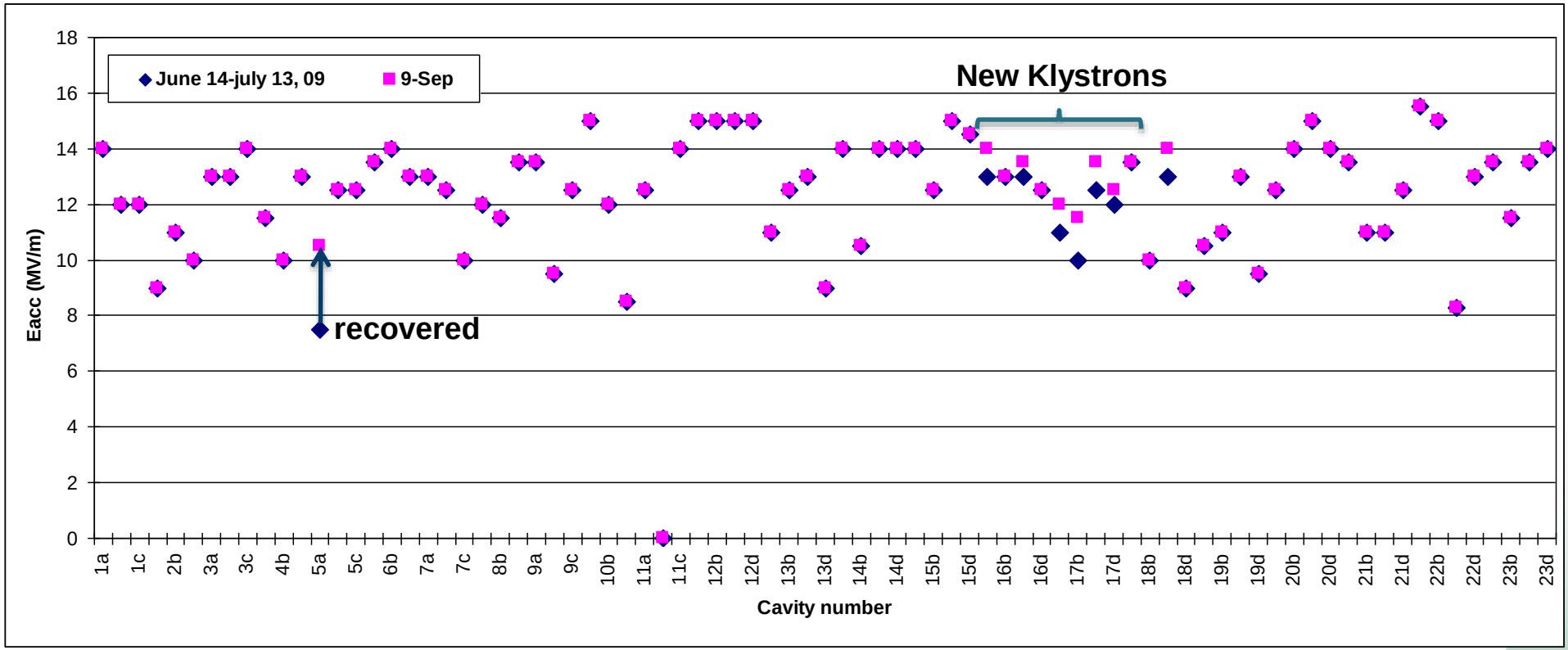
- **Inspection during the summer maintenance**
  - **Dried out**
  - **Window looks fine**
  - **Some arcing spots on inner and outer conductor extensions**
- **Conditioning before September run**
  - **Conditioned up to 12 MV/m**
  - **Set at 10.5 MV/m for next run**
- **Preparation of dry gas purging system (cryo group)**



SCL operational status since last review (II)

- Sep. 09 – Dec. 09; starting 928 MeV + 12 MeV (80 out of 81 cavities)
  - Replacement of Thales klystrons (15d-17d; 9 klystrons)
  - Beam ramp up scheme for high intensity beam
  - IOC overload issue at 825 us AFF
  - Cavity performance degradations possibly by errant beam
    - Cavity performance degradations; First time at SNS
    - Nov. 15 ; 5a turned off, re-phasing SCL, use 23d energy reserve
    - Dec. 16; 6c turned off, turn on 5a at 7 MV/m, re-phasing SCL, use 23d & set phase at ~0 for last 5 cavities
    - Errant beam duration could be longer than expected
      - Questions on MPS delay/speed (White's Talk)

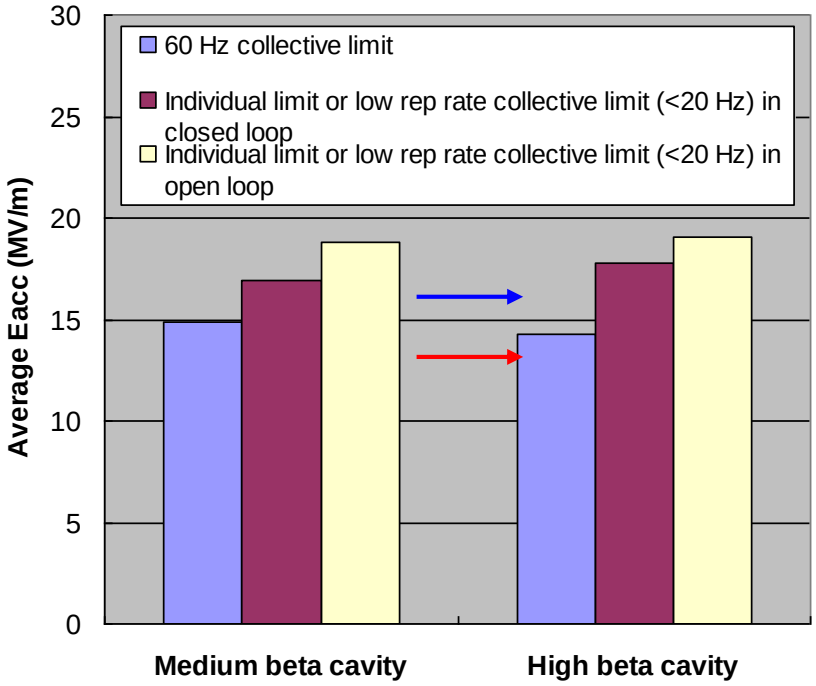
Sept. 09 Operating gradients

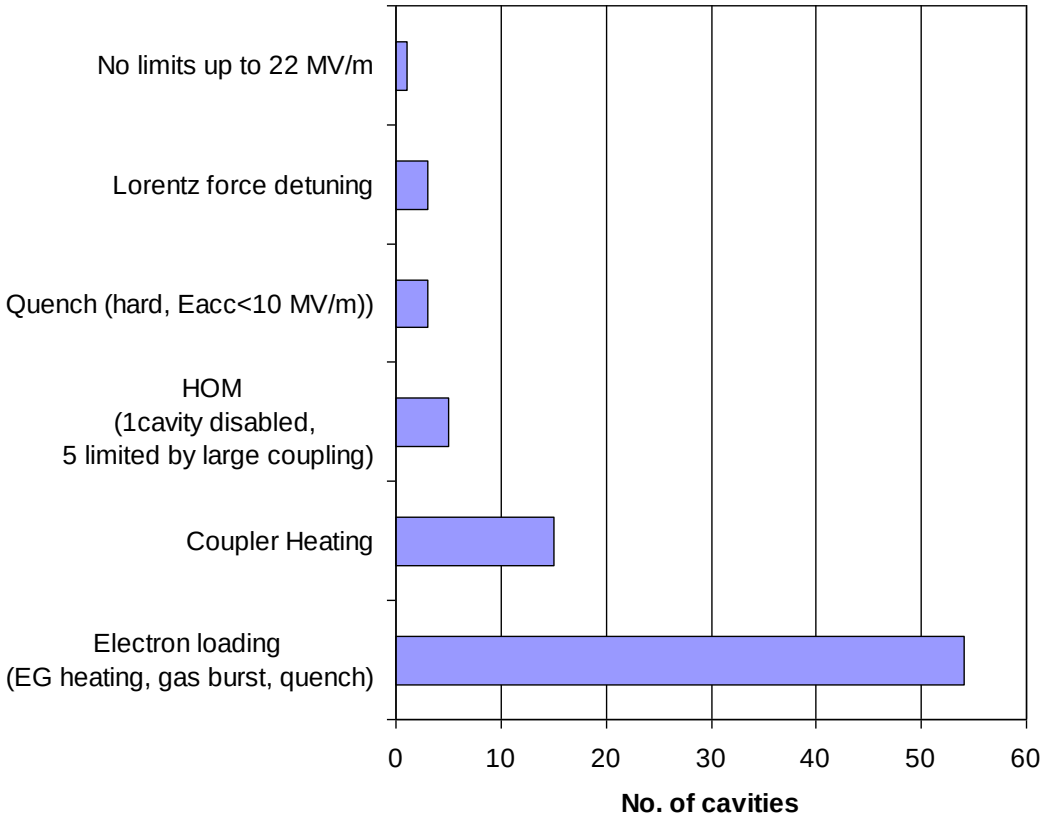


Operating gradients are mostly limited by cavity performances (mainly field emission, multipacting…)

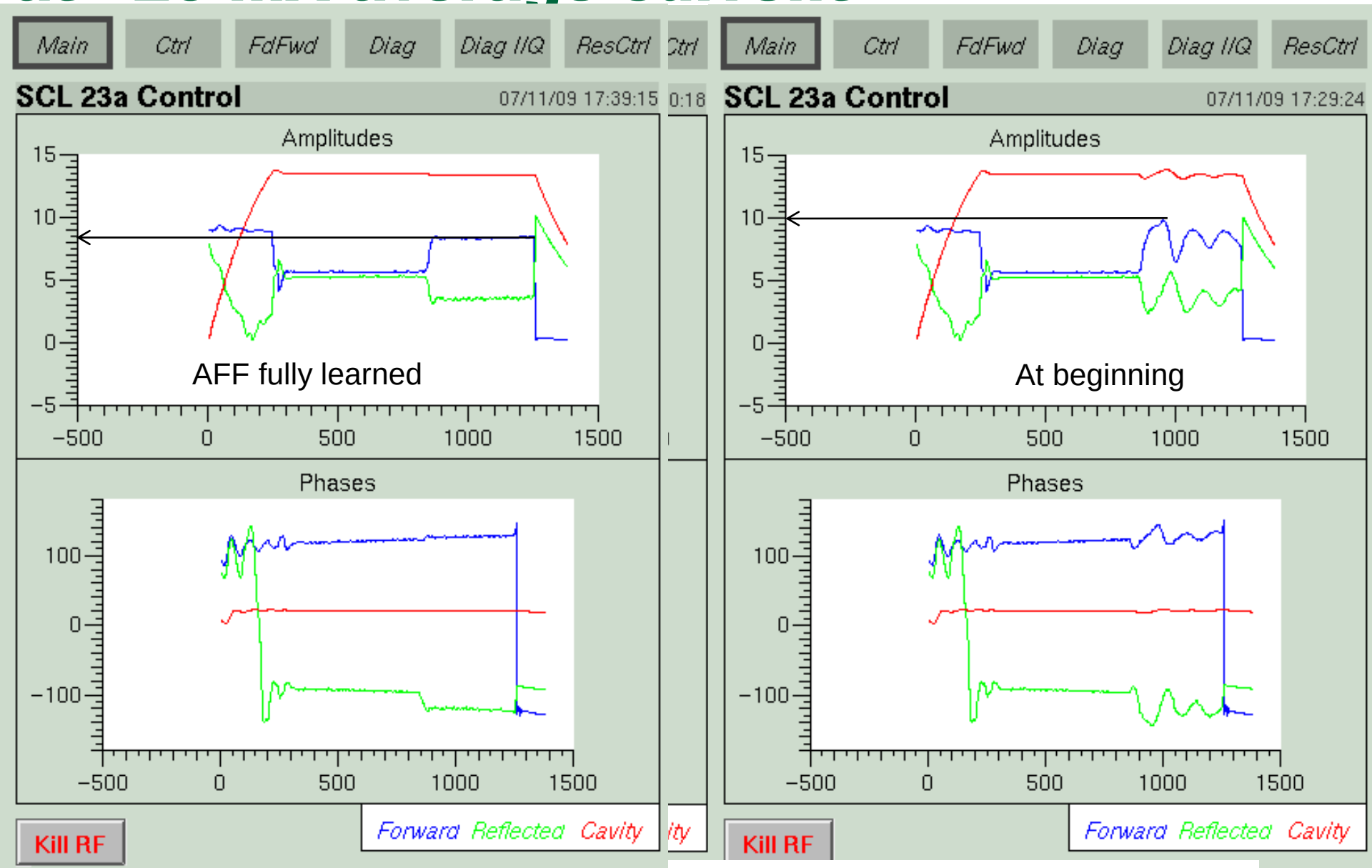
Cavity performance limitations

- Field emission (major limiting factor)
- Coupler heating
- Others





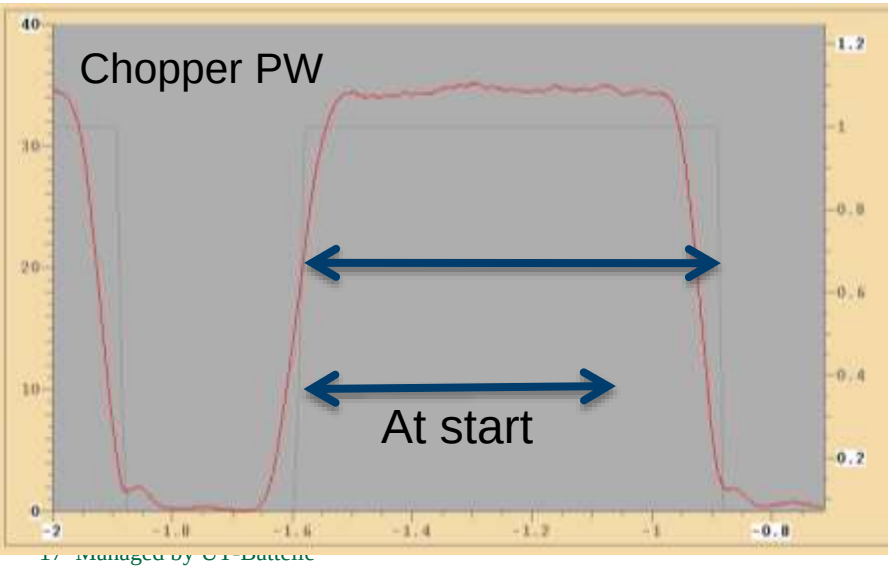
Adaptive Feed Forward (AFF) learning at ~20 mA average current

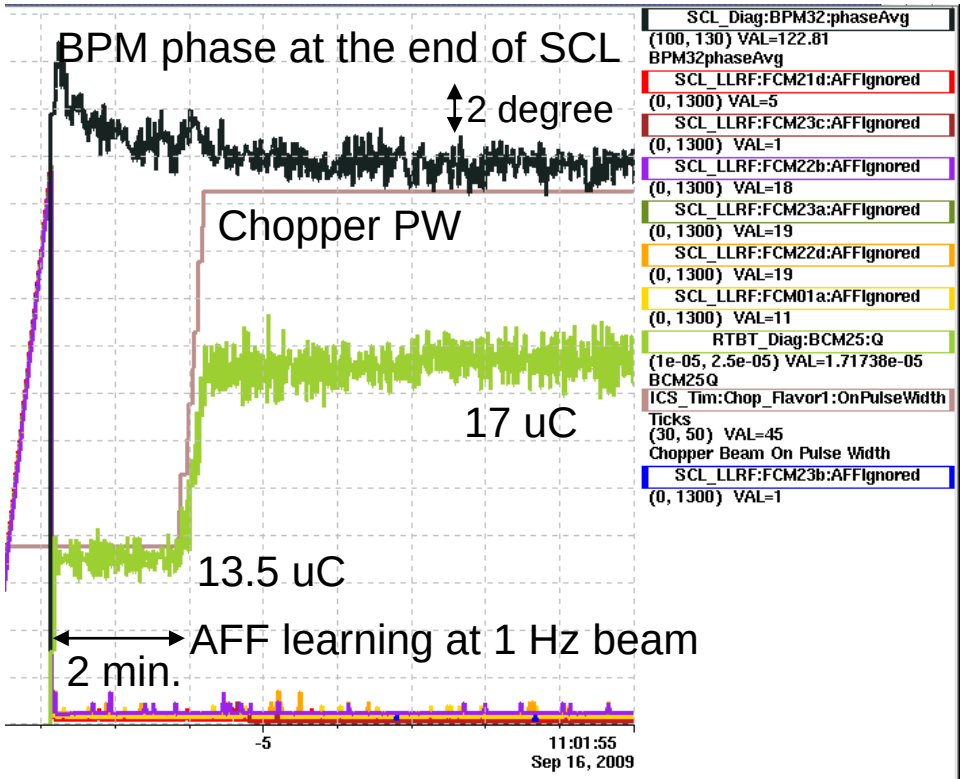


Some cavities need ~>25 % more RF at the beginning of AFF

AFF & Beam ramp-up

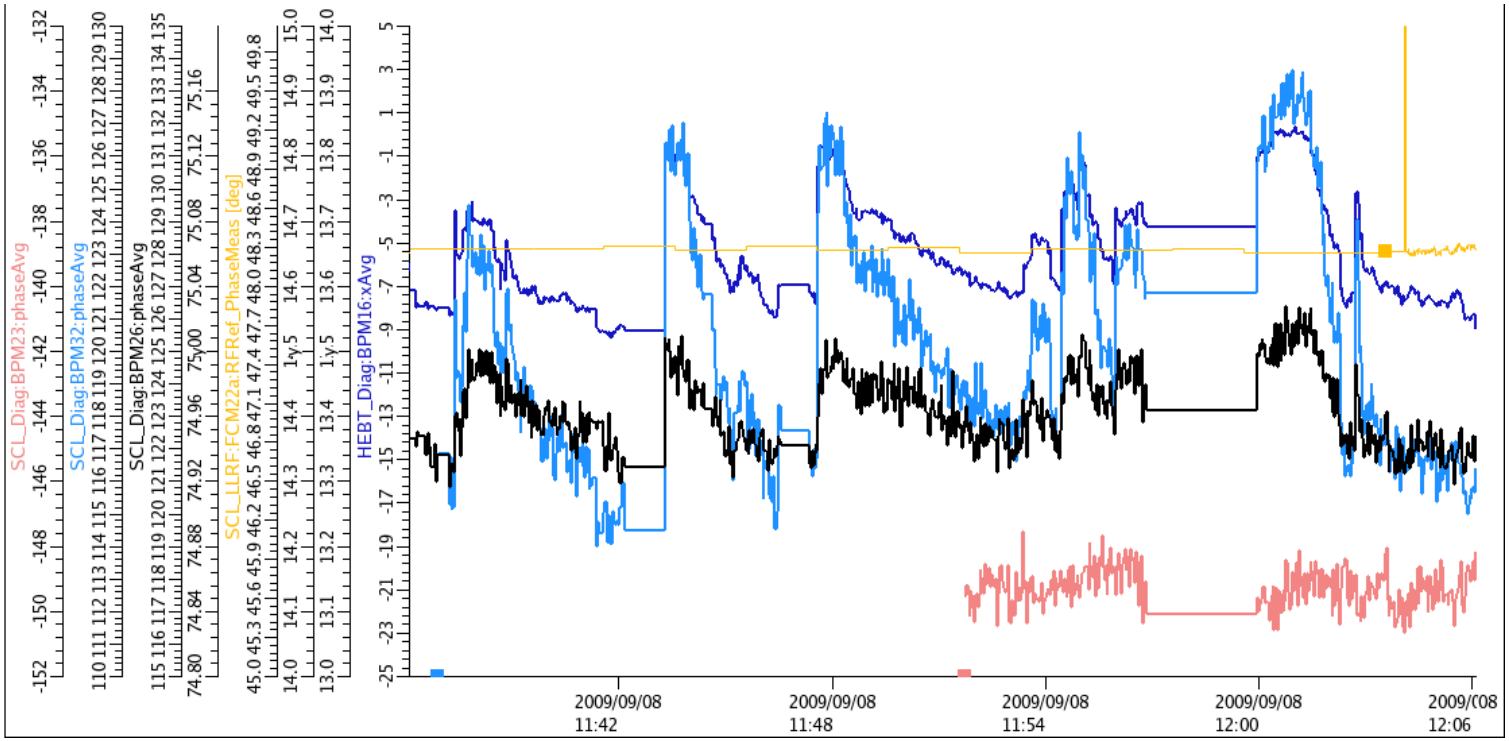
- When beam current is bigger than ~18 mA average
  - field regulations go beyond the threshold → RF truncation → AFF can not learn
  - BLM trips → AFF can not learn
- Klystron power is usually those at saturation
  - Non-linear
- We use PW (chopping pattern; ratio between mini-pulse and gap)
  - Starting around <18 mA $I_{b,avg}$ → after AFF learned → increase $I_{b,avg}$





LLRF control IOC overload

- At 825 beam pulse (AFF); observed fluctuations of linac output energy



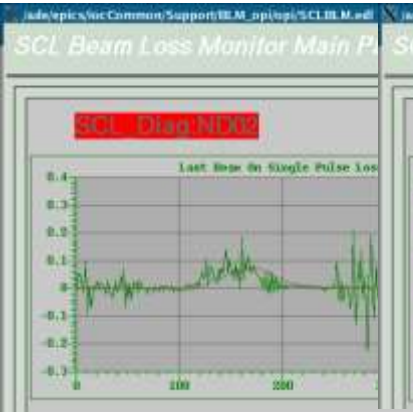
- Before finishing calculations, next pulse comes in → ignore pulse with beam on condition → random combinations along the SCL
- In SCL, one IOC handles two LLRF systems
- IOC loads exceed 85 % (sometimes 95 %)

Temporary fix (K. Kasemir, M. Crofford)

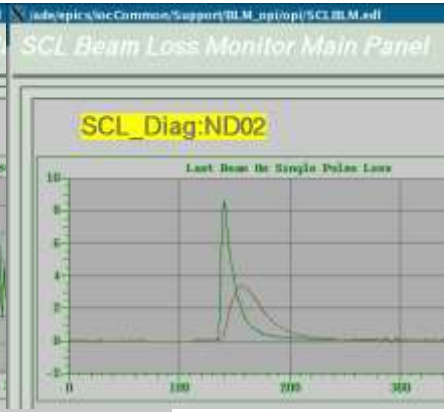
- Force algorithm to finish processing even though the next pulse comes in
- Increase the history buffer sampling period by 1.25 (2.4 us → 3 us)
- Other minor software changes
- Working fine up to 825 us beam
  - Processing ratio; > 90 % (enough)
- Could be an issue at a longer pulse
  - New IOC preparation (White's talk)

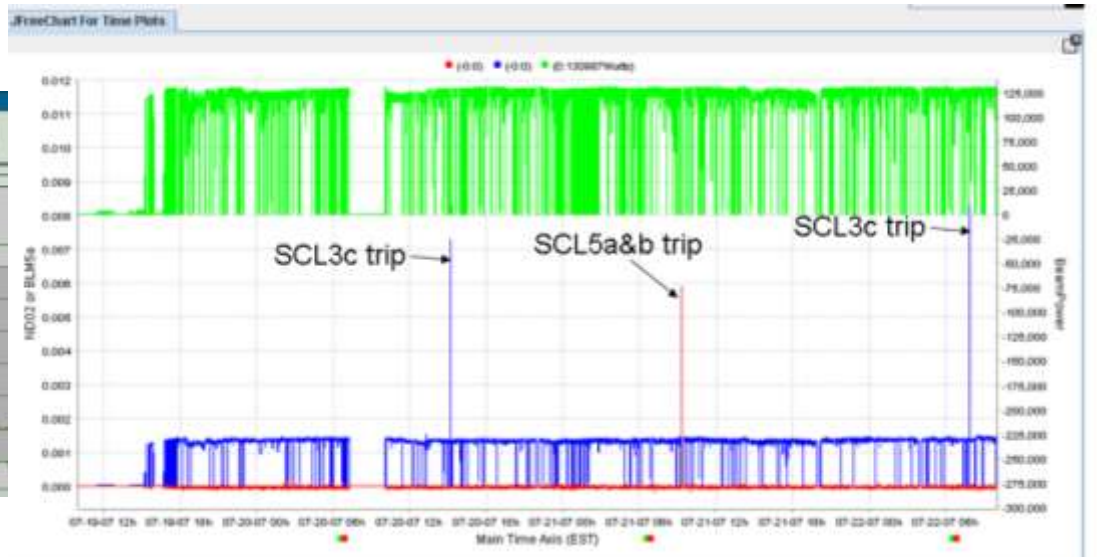
Cavity trips by errant beams (I)

At normal beam

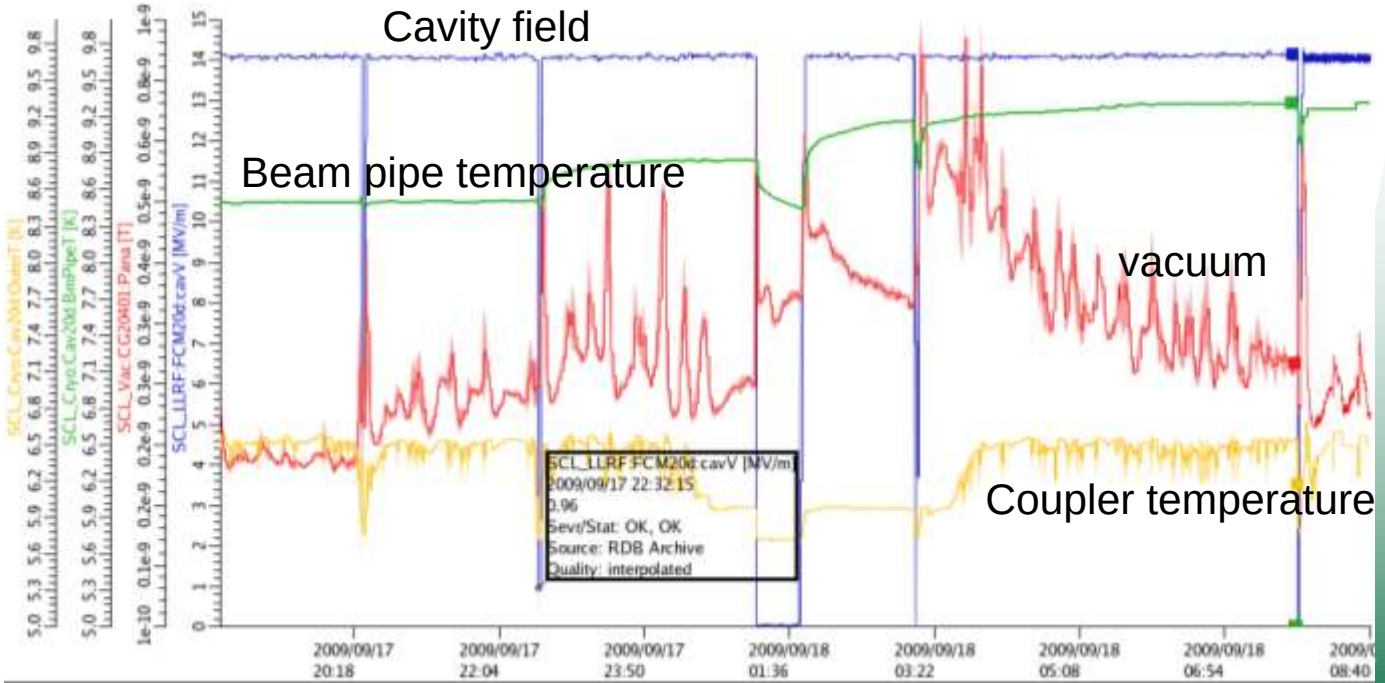


At errant beam



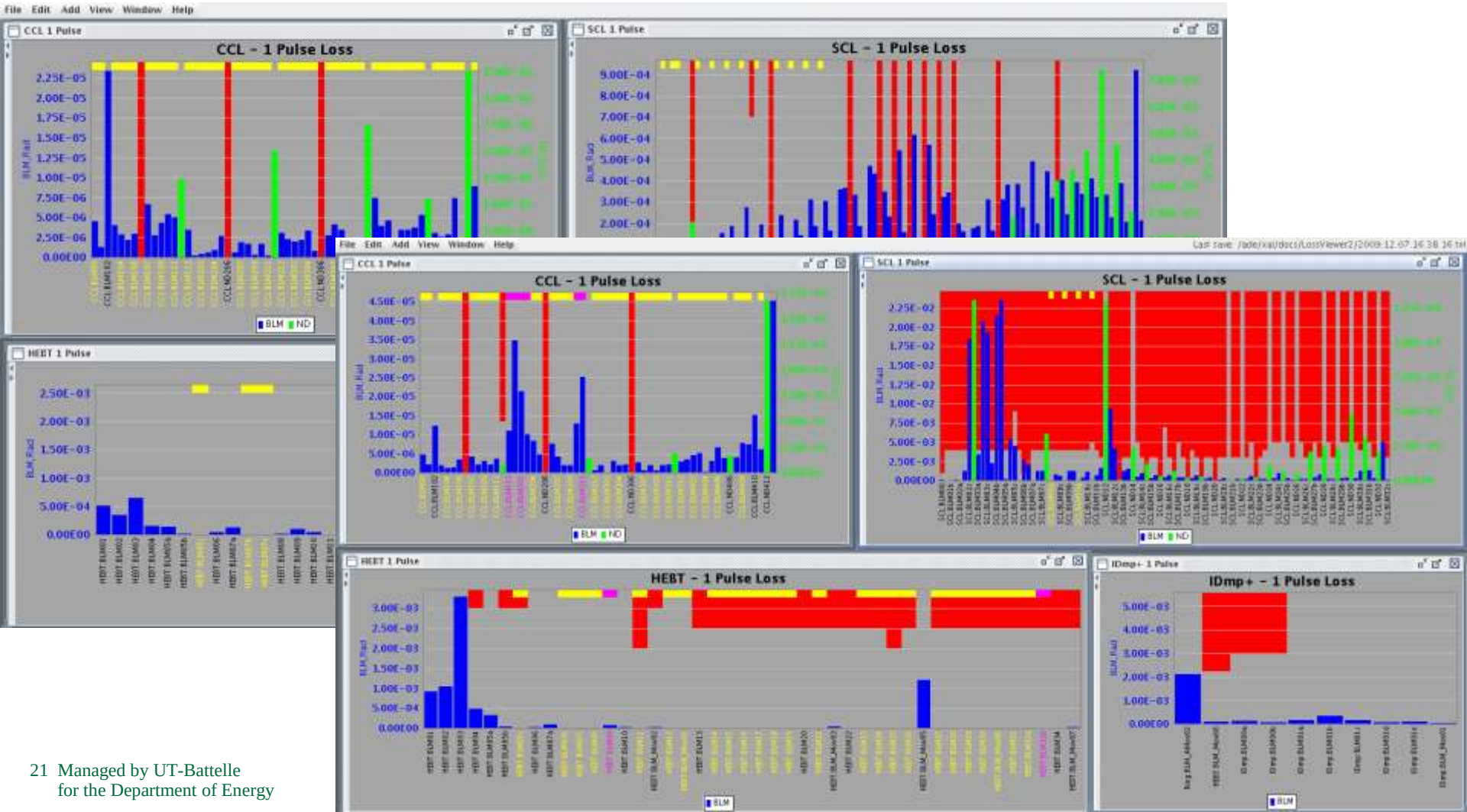


Errant beam hits→
Sometimes trip with vacuum burst
→ Valve closed (IP trip)
→ change surface conditions → recover



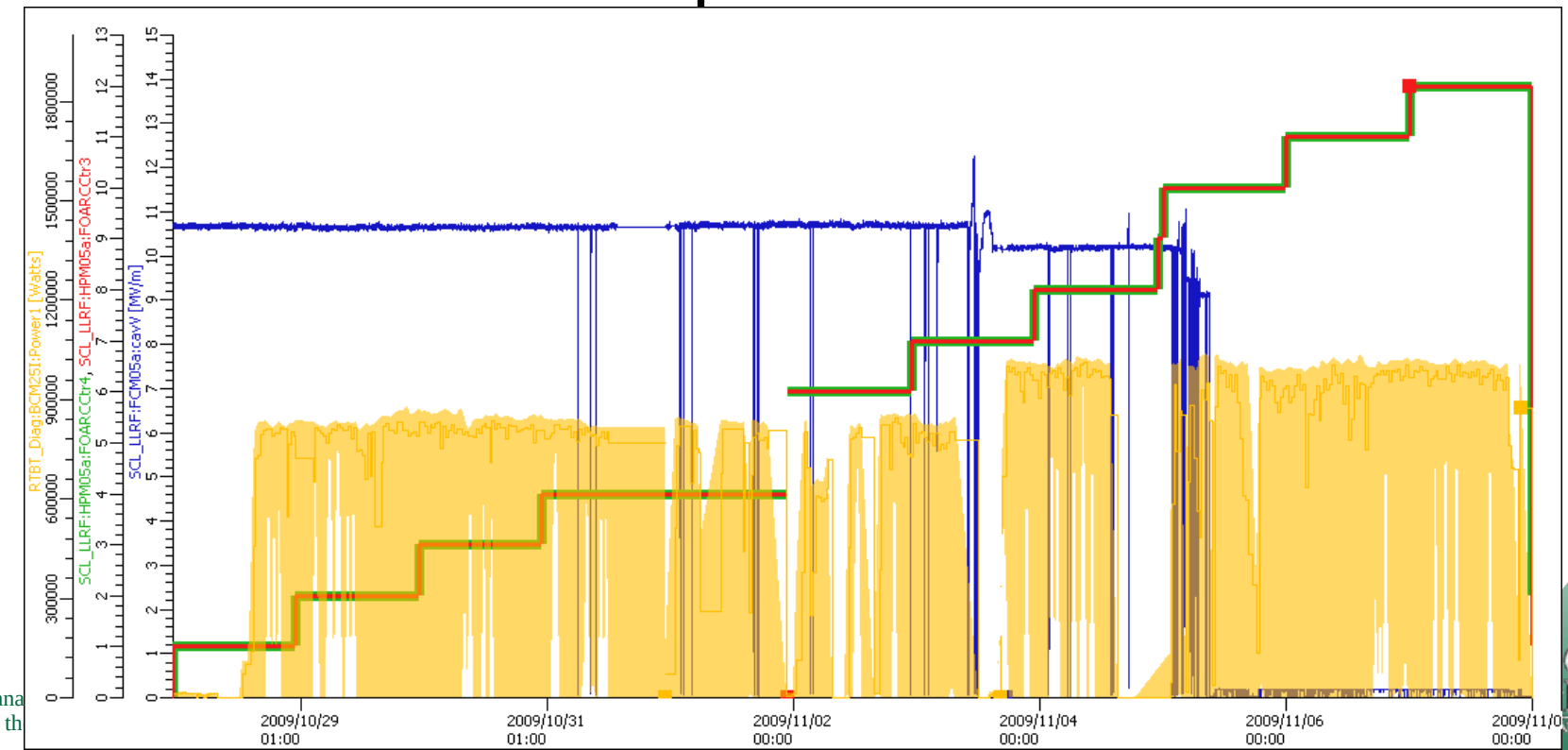
Cavity trips by errant beams (II)

- All along the linac; random
- (Another example) At cavity 3b, 3c trips← from CCL RF truncation; vacuum burst, valve closed, different loss pattern



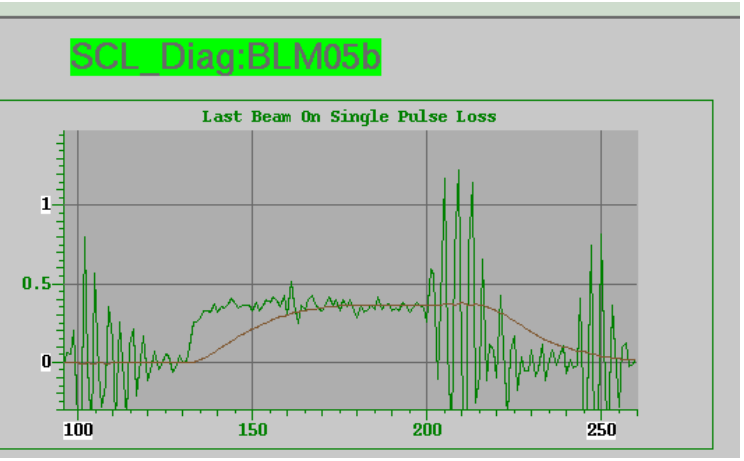
5a incident

- After several trips by errant beam, showed performance degradation
- No correlations with upstream RF truncations
- Cavity quenched even at 8 MV/m with HOMB spikes with RF only
  - No arcing at both air and vacuum sides
- Turned off on 11/5/09, re-phased SCL
- Plans were made for MPS speed measurements

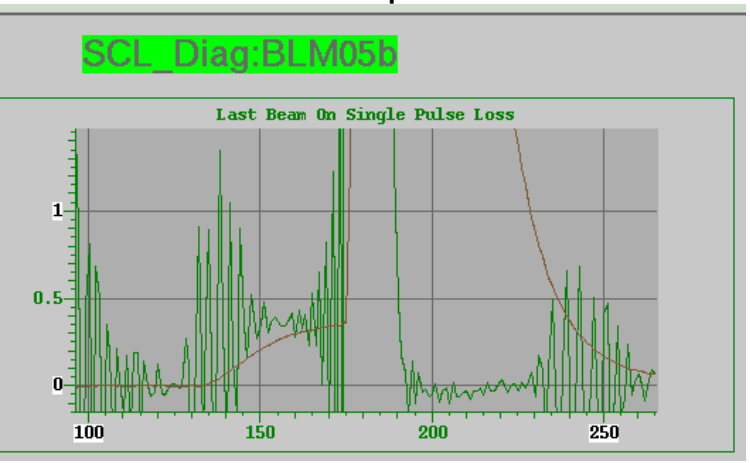


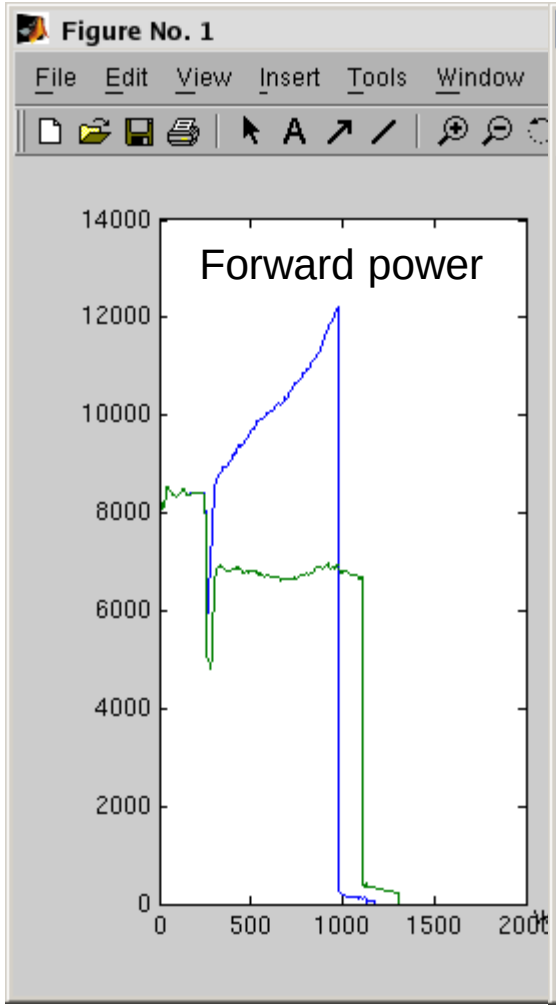
BLM at trips & Partial quench 5a

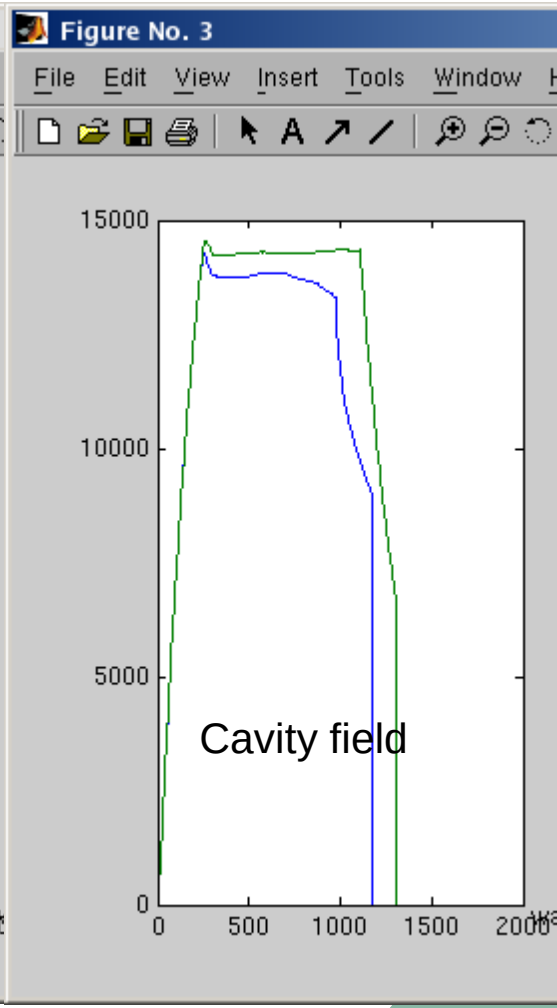
At normal operation



At trip

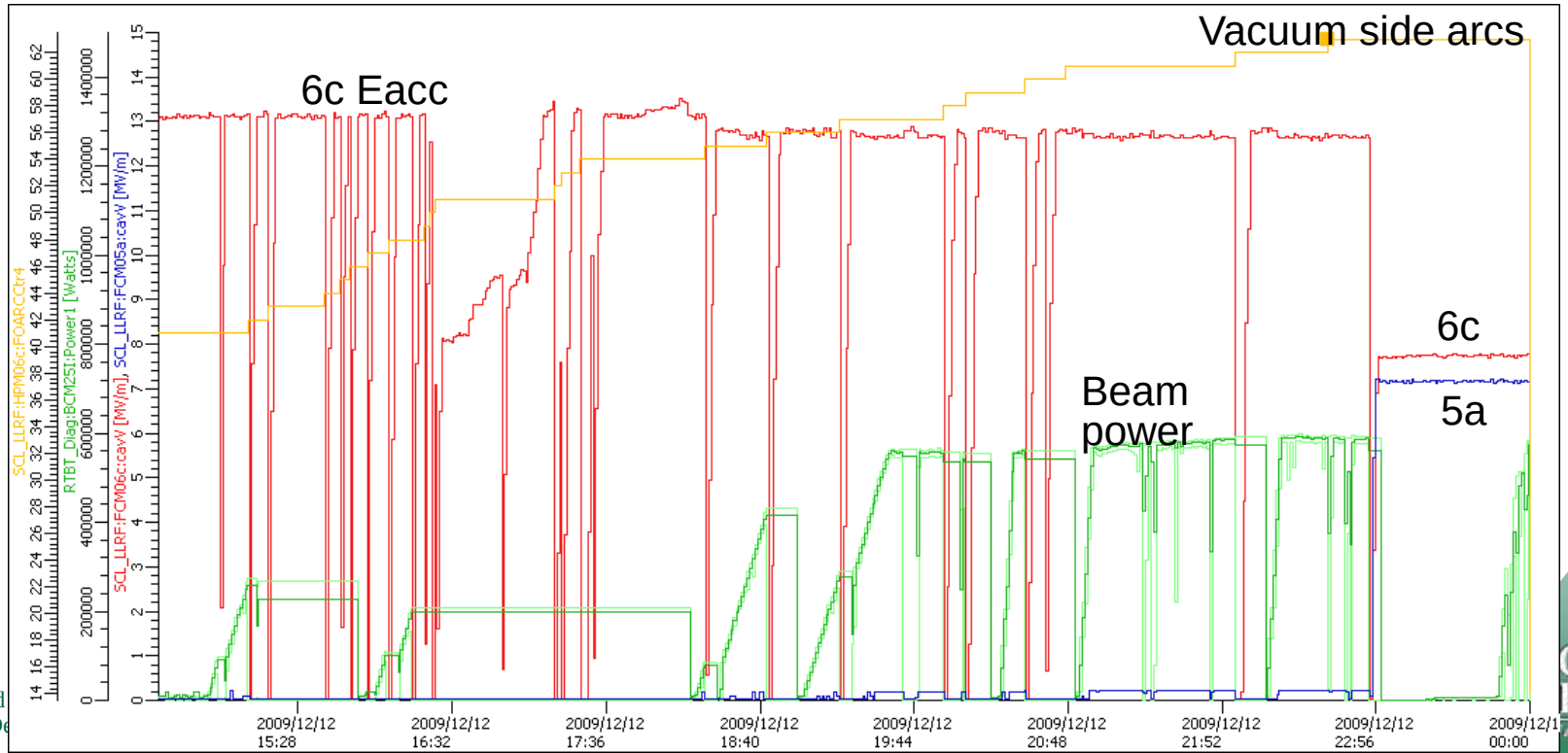






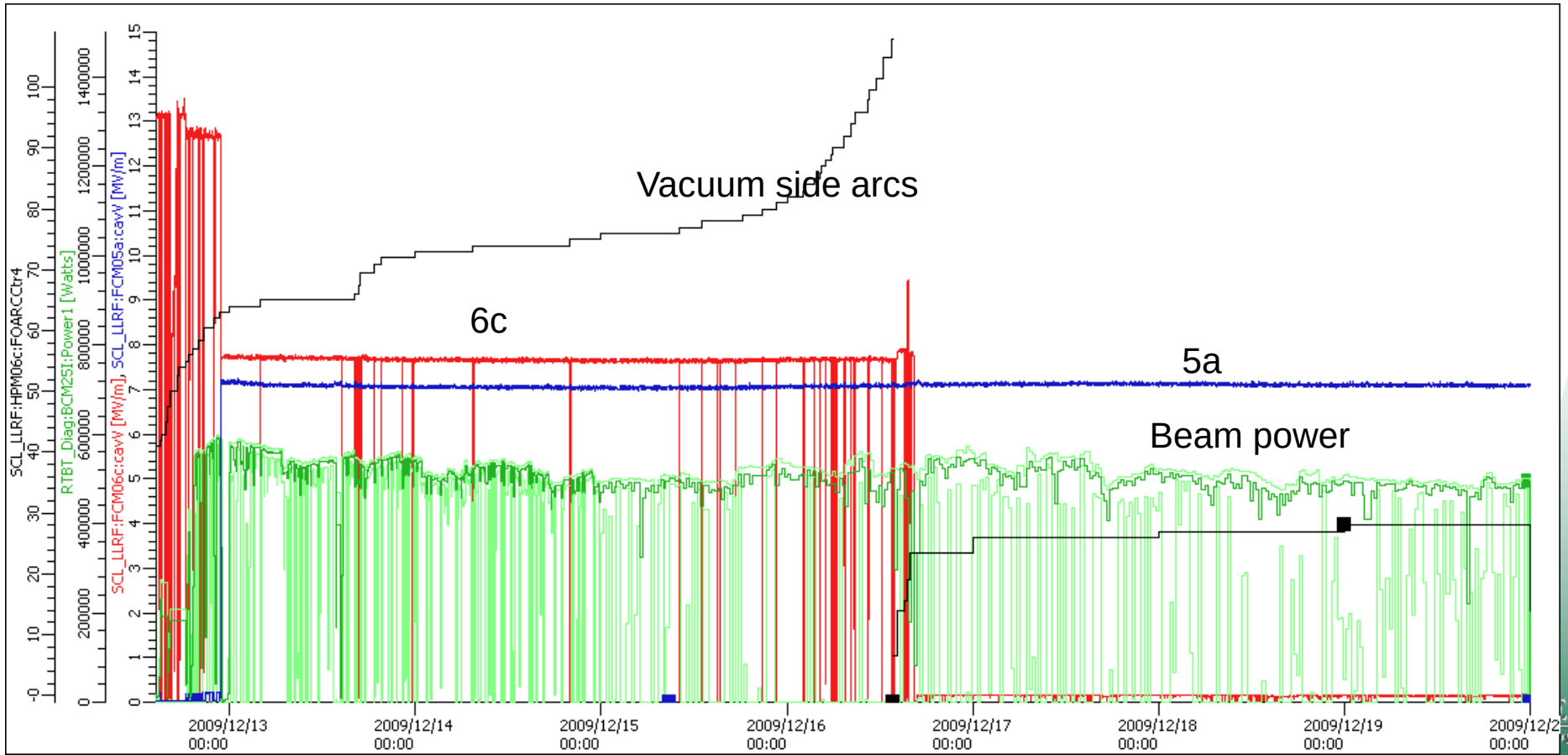
6c incident

- After 5a turned off, 6c tripped by errant beam hit (1~2/day)
  - Checked performance during maintenance days
  - No degradations were found until 12/12/09
- Since 12/12/09, it started quenching with arcing at vacuum side and noisy HOMB signals
  - Followed same path as 5a
  - Lowered gradient down to 8 (from 13) on 12/12/09

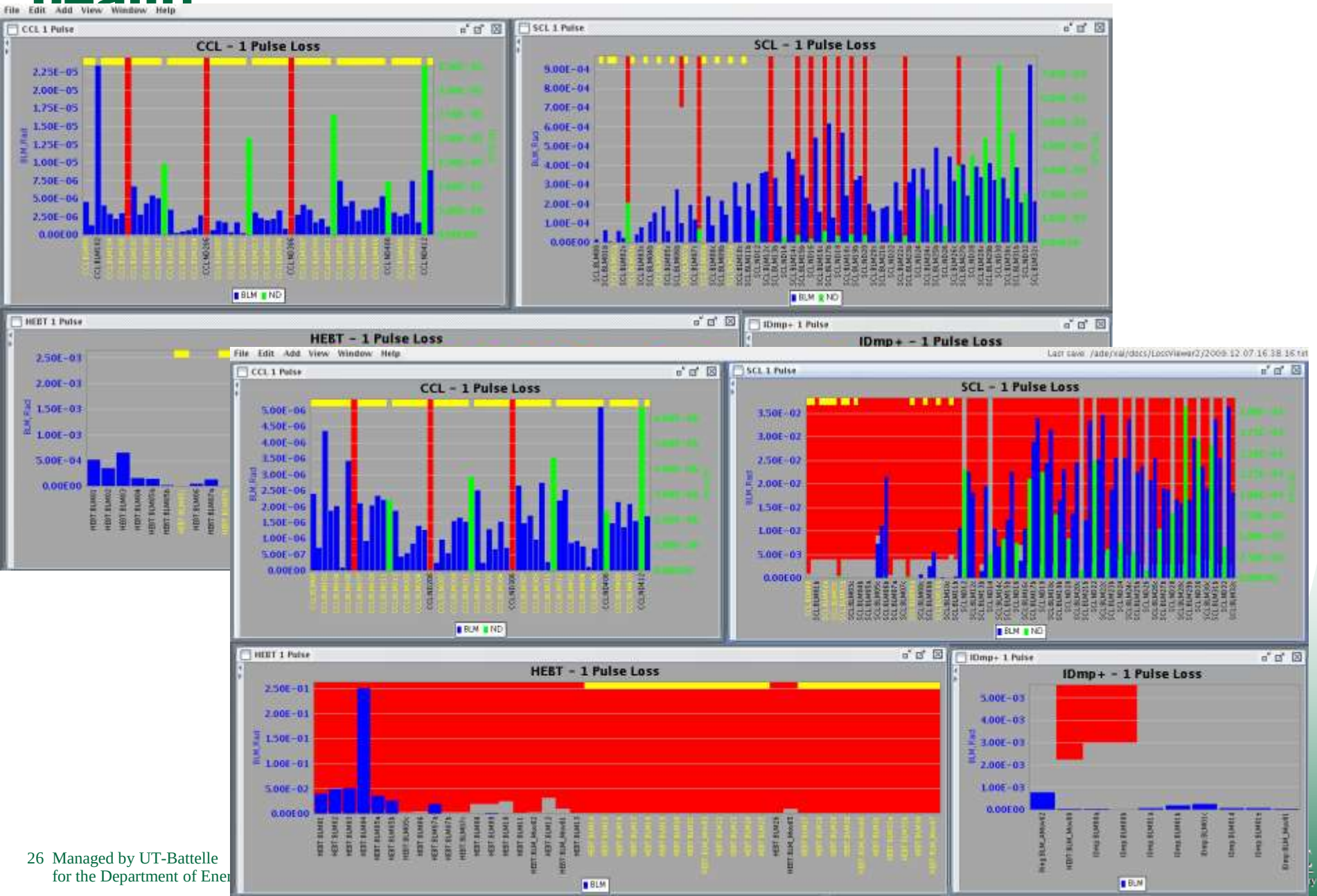


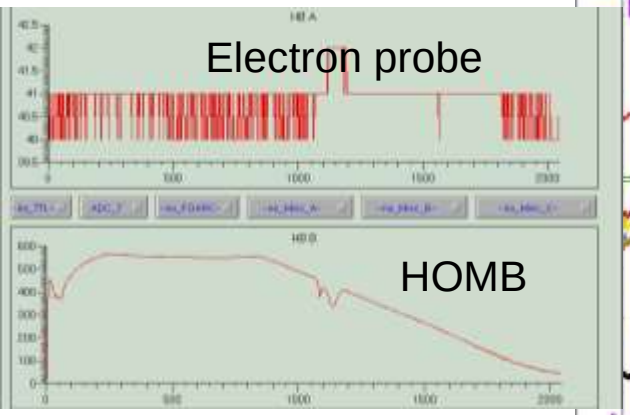
6c incident (II)

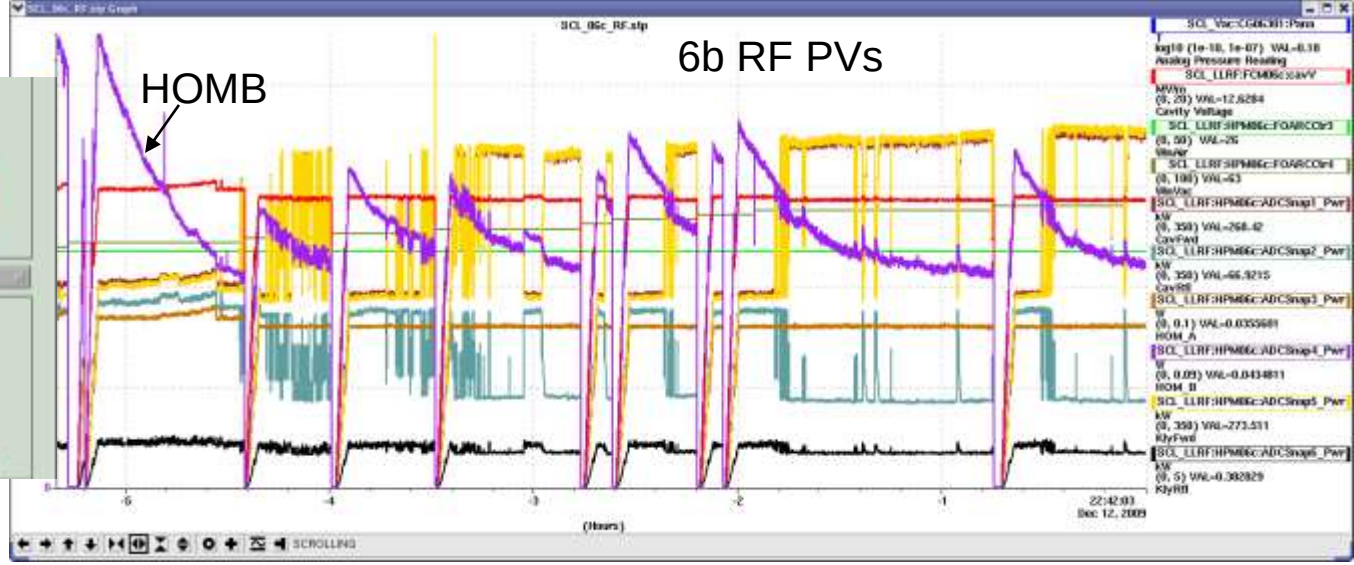
- **On 12/16/09, trips by itself at 7 MV/m without beam**
  - **Turned off, re-phase SCL**



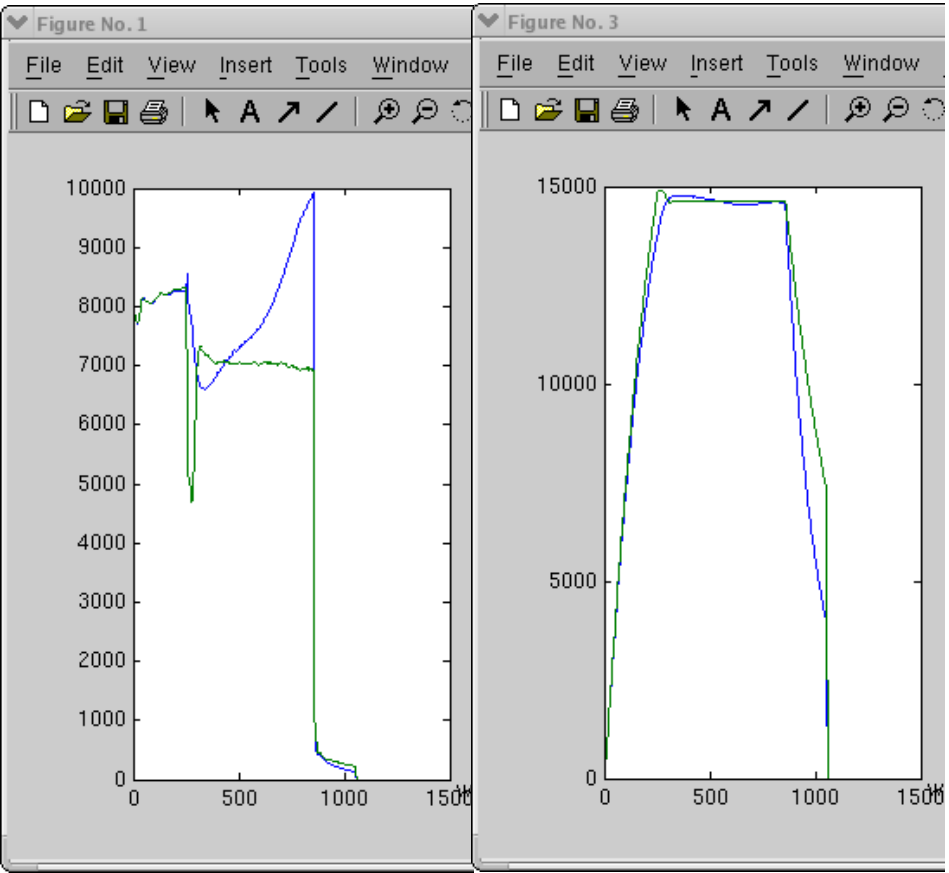
Loss pattern comparisons (6c trip by errant beam)

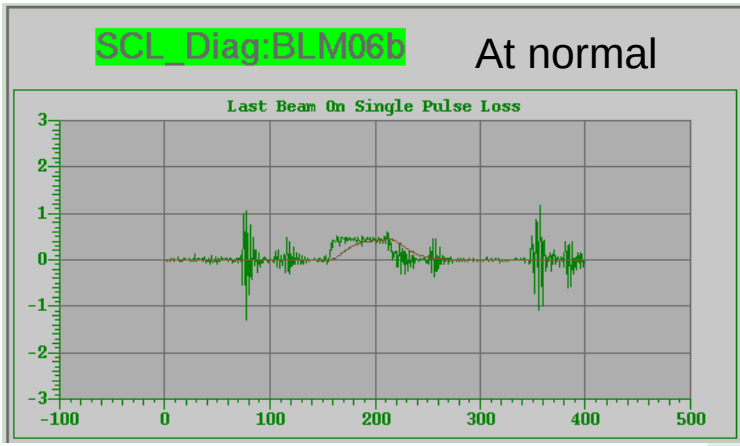


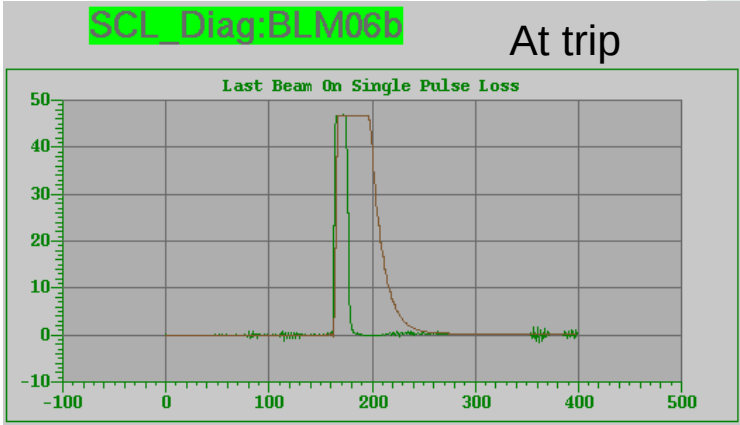




Partial Quench







SCL availability

-Gradient settings;

based on **60Hz collective limits**

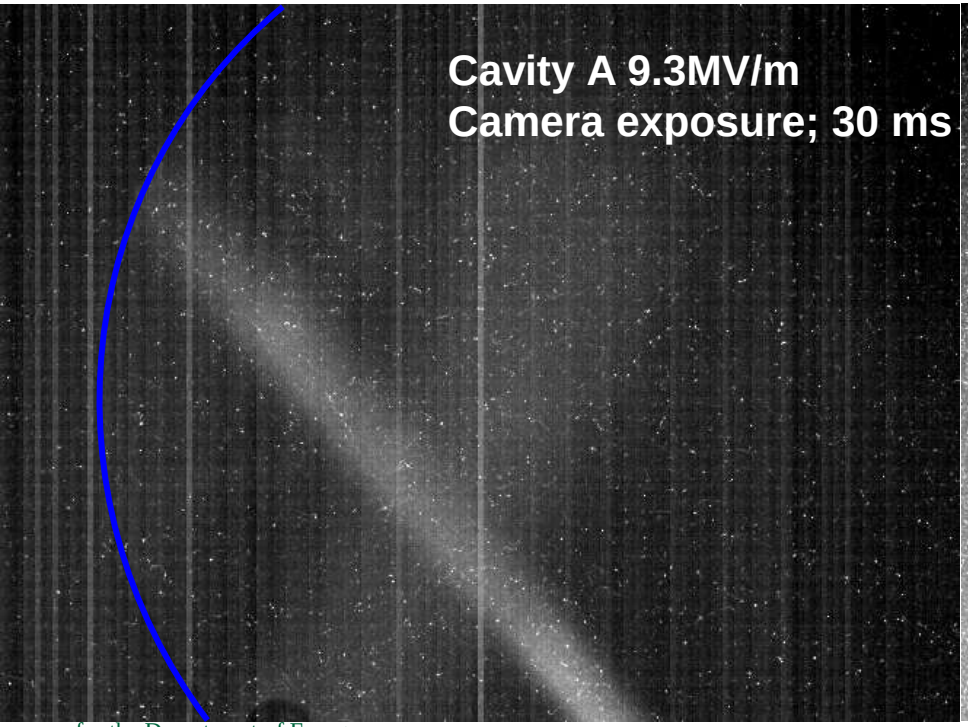
-Downtimes;

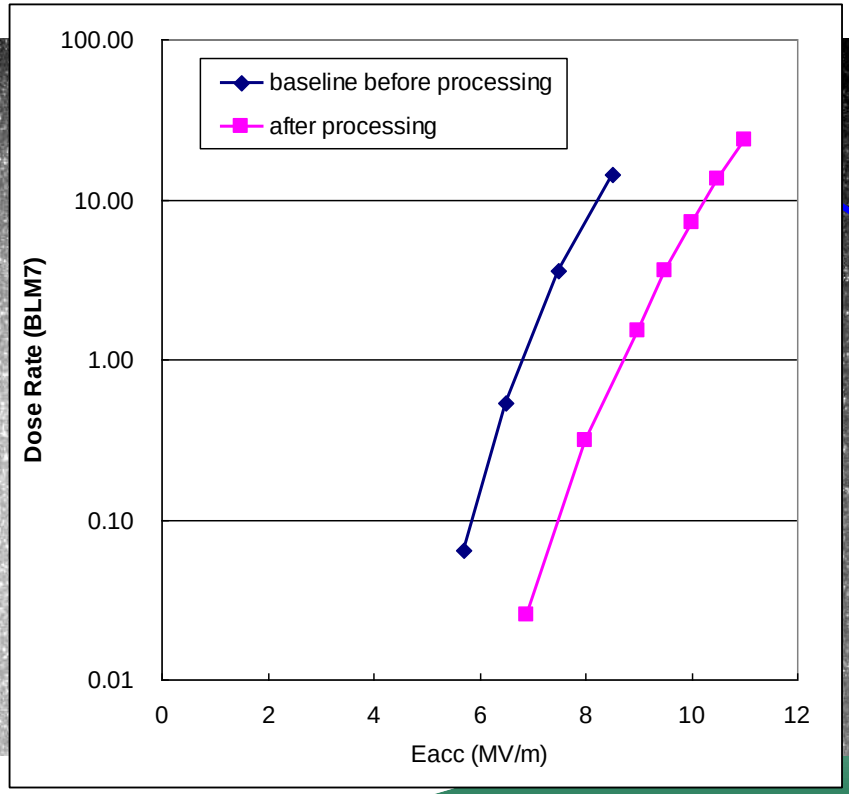
Experienced cavity performance degradations;
~20 hours of downtime from the 3 events

Most of operation except those 3 events;
While conditioning (after maintenances) a few trips a day
During production run < 0.1 hr/day

R&D program

- Linac output energy; mainly limited by cavity performance now
- In-situ plasma processing; First attempt with H01 showed very promising results
- Set a systematic R&D program to find optimum processing conditions
- Hardware preparations are in progress (Mammosser's talk)



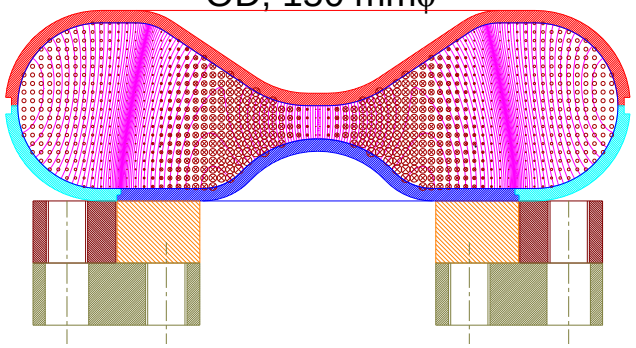


R&D tools

TM020 Test cavity

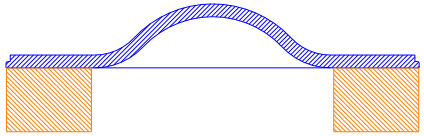
3.4 GHz, TM020 mode
Ep/Bp=1.12 (MV/m)/mT
Ex. Ep=50 MV/m, Bp=56 mT
P_{diss}=36 W at 4.2 K

OD; 150 mmϕ

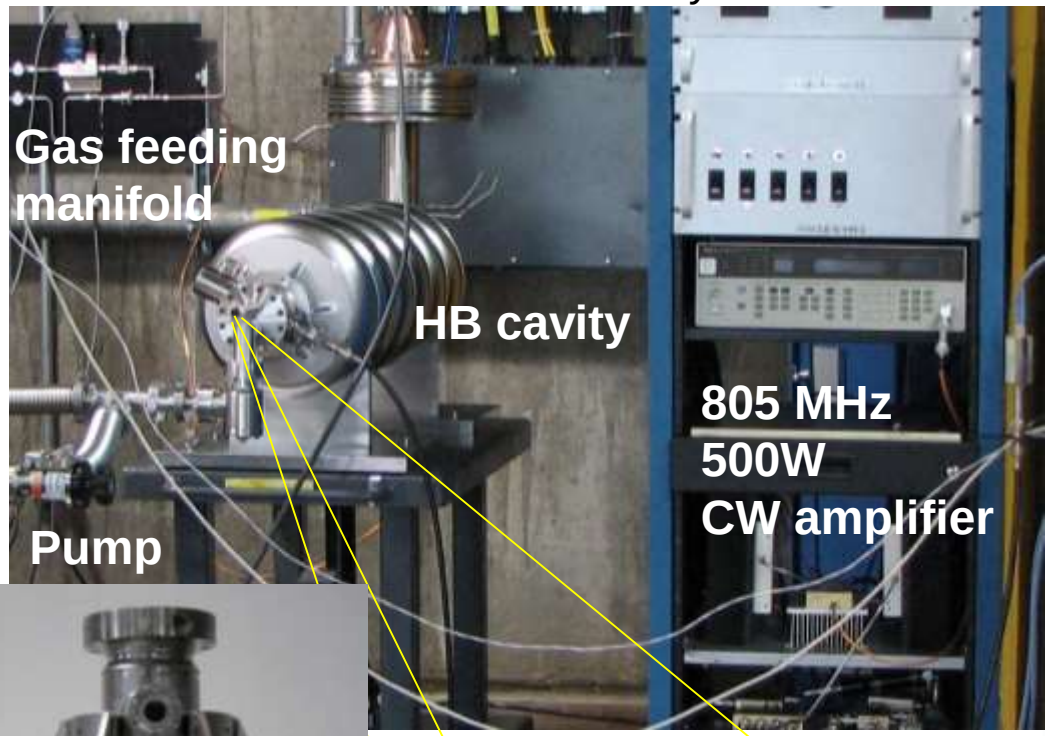


-Cold test
w/ dual mode (CW or pulse)
-Plasma processing

Demountable
witness plate



6-cell cavity



3-cell cavity

Summary

- Support Neutron production at 928 MeV up to 1 MW
  - 1 incident from water condensation at air side of coupler
  - 2 incidents from errant beam → performance degradation
- Improvements
  - One additional HVCM; Available RF power
  - 9 New klystrons; Output instability
  - DC biasing for selected cavities; MP induced coupler heating
  - Coupler water temperature alarm; water condensation
  - Temporary fix for LLRF IOC; AFF learning issue, IOC overloading issue
- Next run preparation
  - First, conservative RF conditioning will be on 5a, 6c in a week
  - Output energy goal; about same energy (928 MeV + some reserve)
- Further improvements
  - MPS delay issue for errant beam; some are very slow → improvements are in progress
  - LLRF IOC
  - Coupler air side water condensation
    - 4CMs has dry air purging system for the next run
      - If successful, all during the next maintenance in summer
- R&D program for in-situ plasma processing