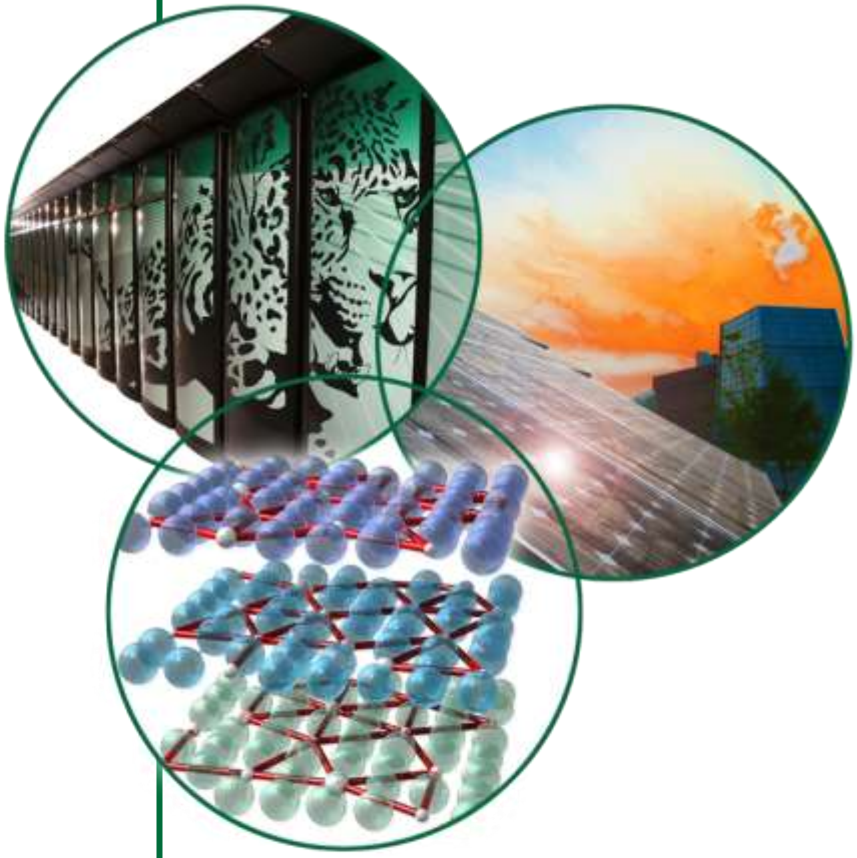
Superconducting Linac Operations and Performance



SNS AAC Review

January 10, 2012

SANG-HO KIM

Superconducting Linac Systems Group

U.S. DEPARTMENT OF ENERGY

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

Outline

- SCL operational status at last review
- Action items
- SCL operational status since last review
- SCL performances & issues
- Plans for 1.4 MW
- Summary

SNS SRF Cavity

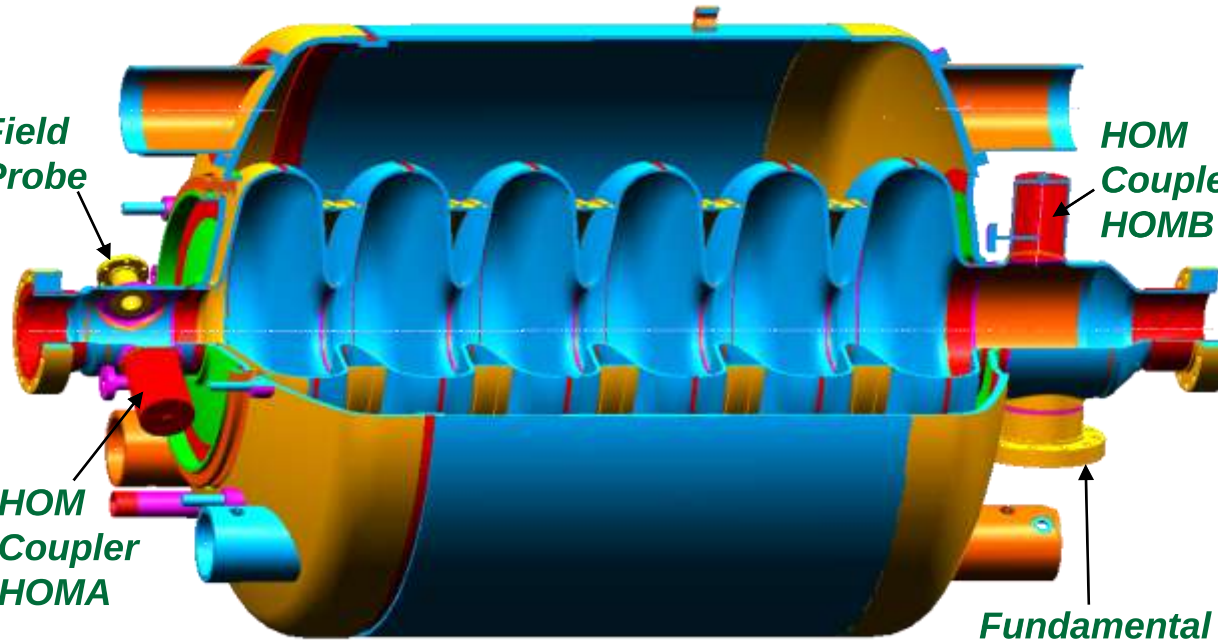
Main Specifications:

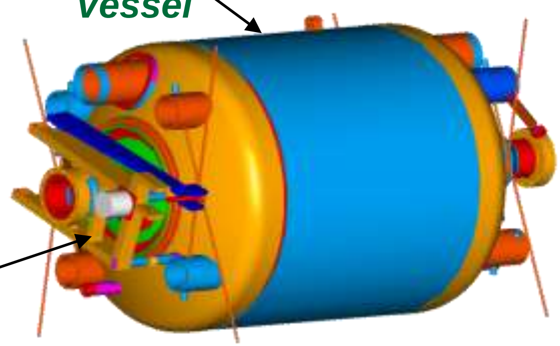
E_a=15.9 MV/m at β=0.81

E_a=10.2 MV/m at β=0.61

&

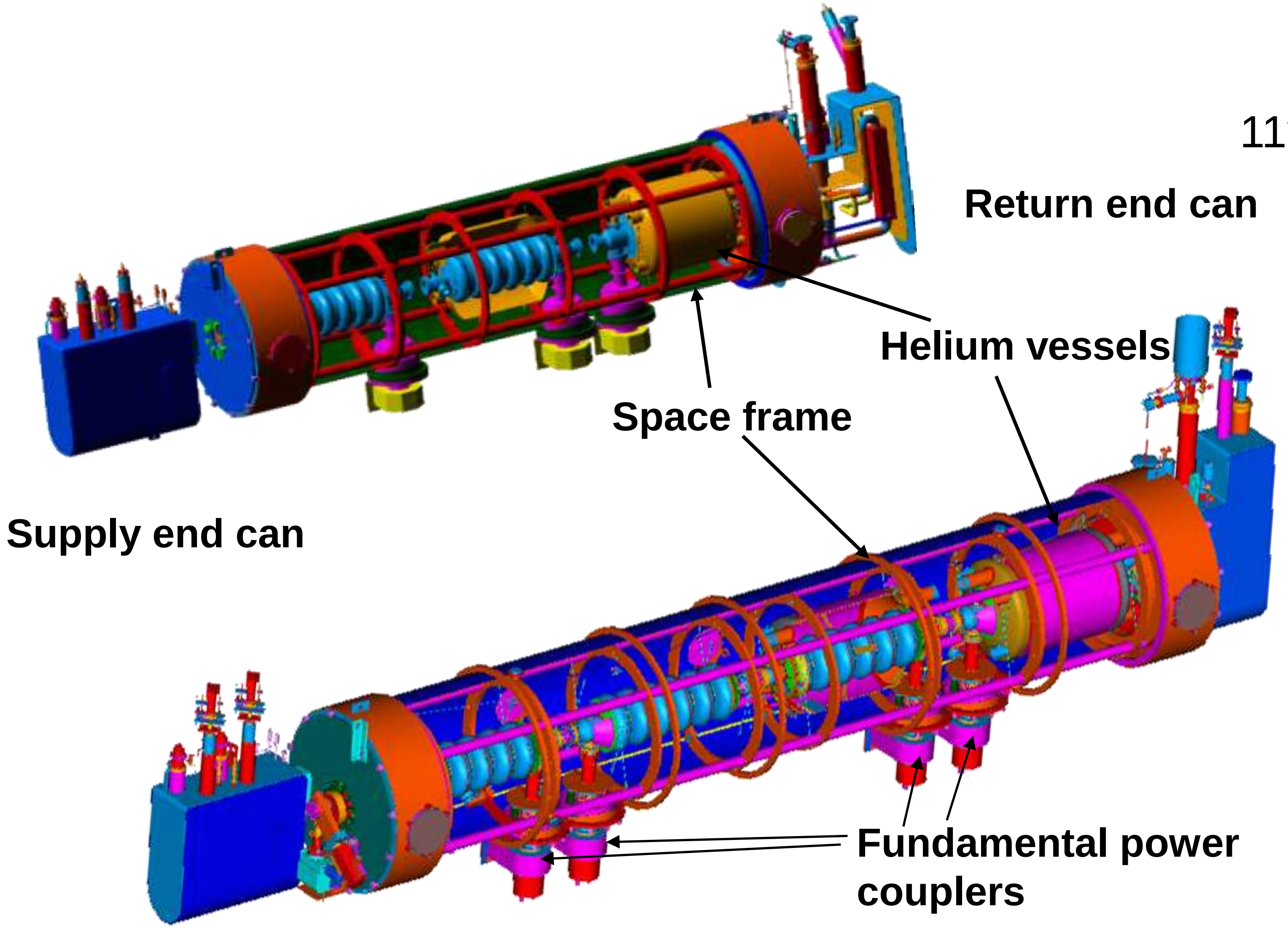
Q_o> 5E9 at 2.1 K





SNS Cryomodule

Designed to operate at 2.1 K (superfluid helium)



11*Medium beta

12*High beta

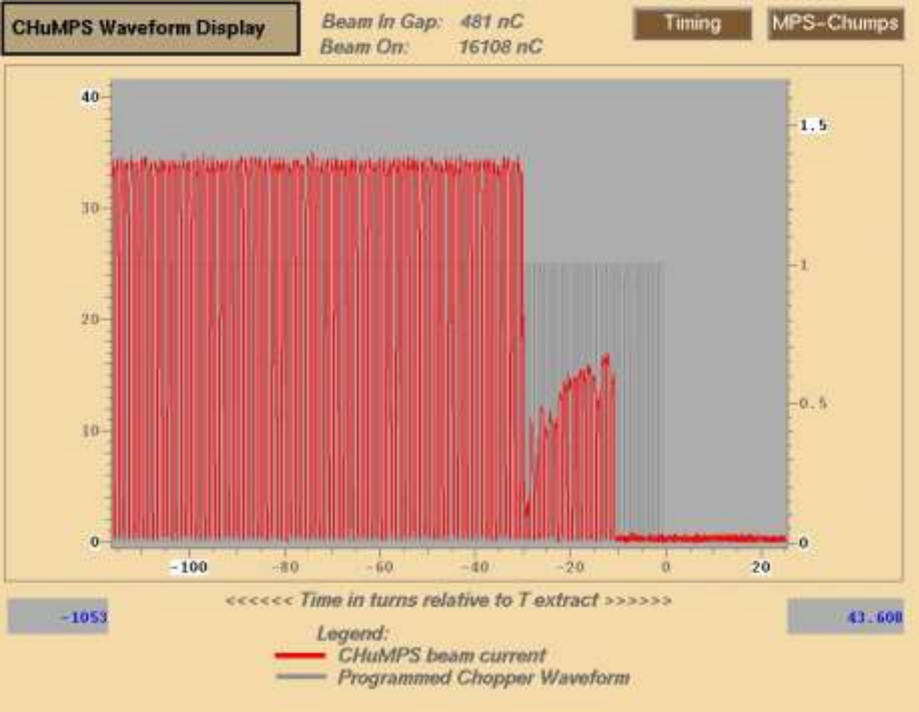
81 cavities

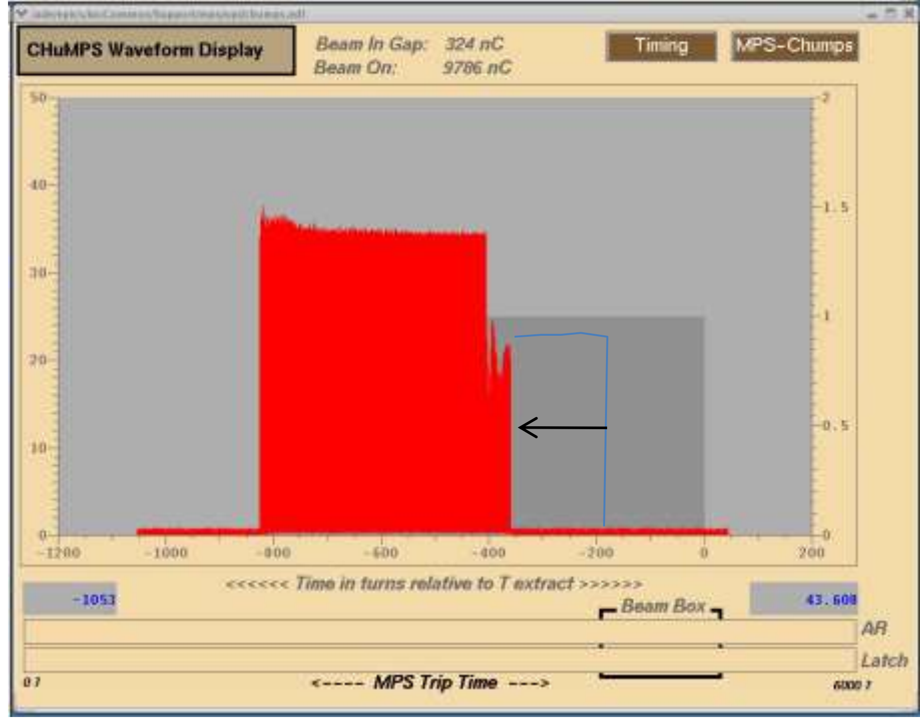
SCL status at last review

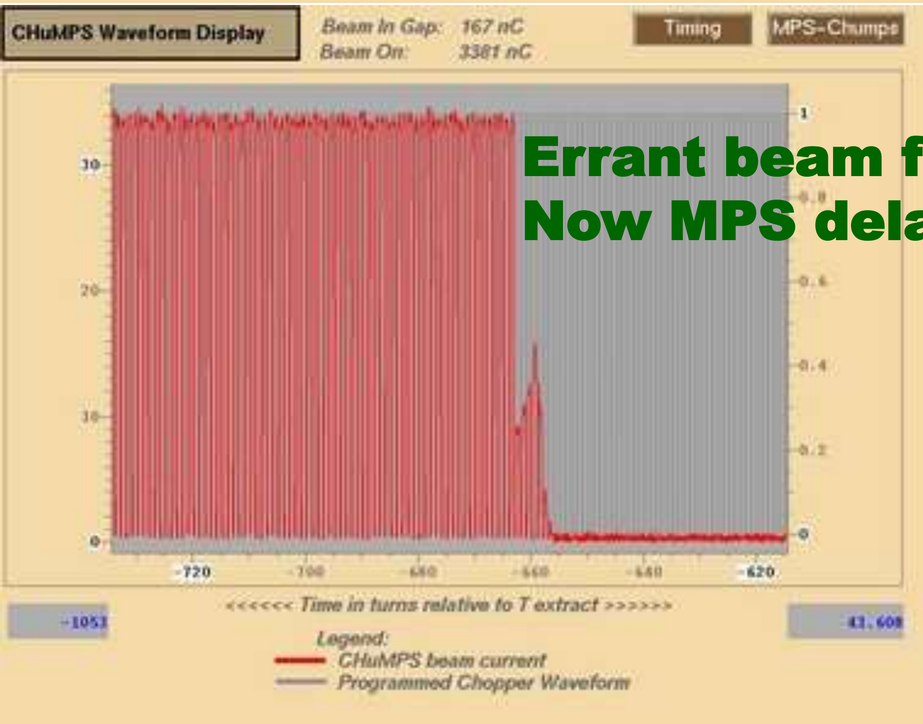
- Supports Neutron production at 928 MeV up to 1 MW with >98 % availability (including SCL related systems)
- Improvements
  - One additional HVCM; Available RF power enough for 26 mA design average beam current
  - 9 Thales klystrons were replaced with CPI klystrons due to output instability
  - DC 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
- Issues
  - 1 incident from water condensation at air side of coupler
  - 2 incidents from errant beam → performance degradation
  - LLRF IOC overloads
- SRF activities (in-situ processing, spares CMs: tomorrow's talk)

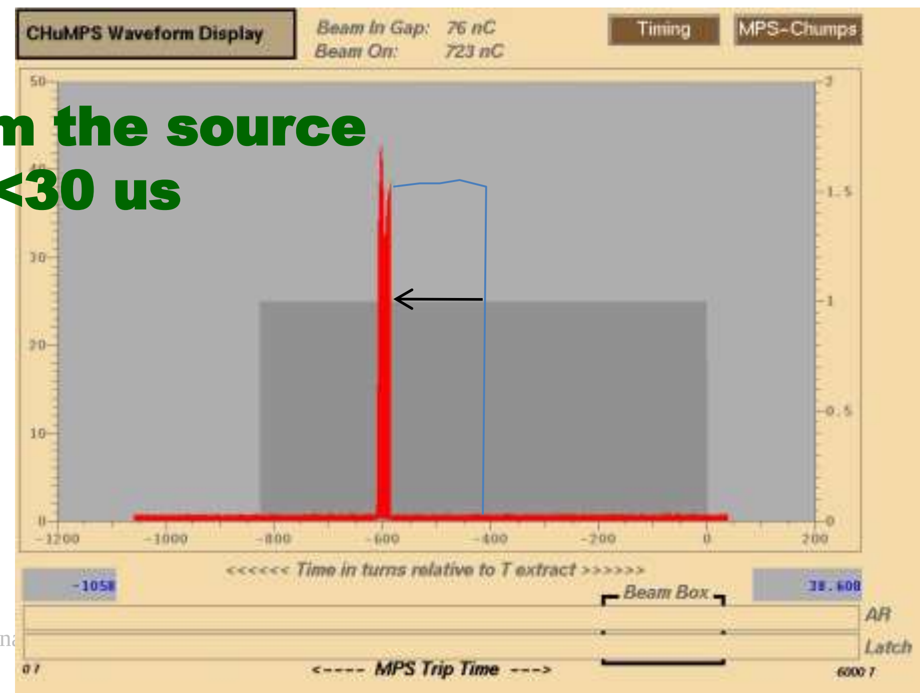
Errant beam in SCL

- MPS
  - When any RF HPM PV counts and/or
  - When BLM signal touches the threshold
  - MPS signal → RFQ/LEBT chopper shut off
  - MPS delay is supposed to be 20-30 us
- Had performance degradations with 2 cavities (5a, 6c)→ claimed that errant beam is too frequent and MPS delay looks long
- Measured all MPS delay in the linac; 50-300 us





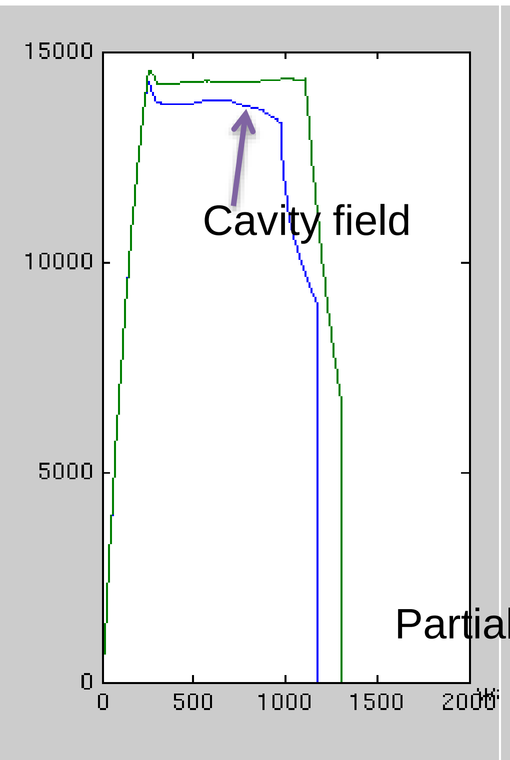


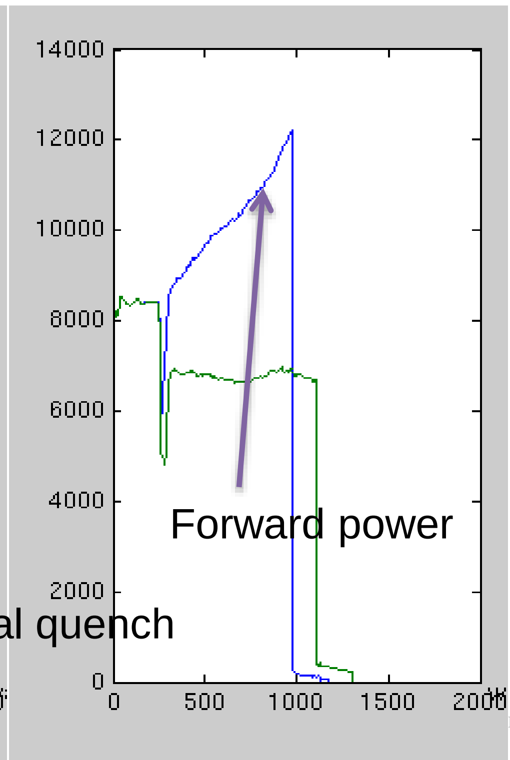


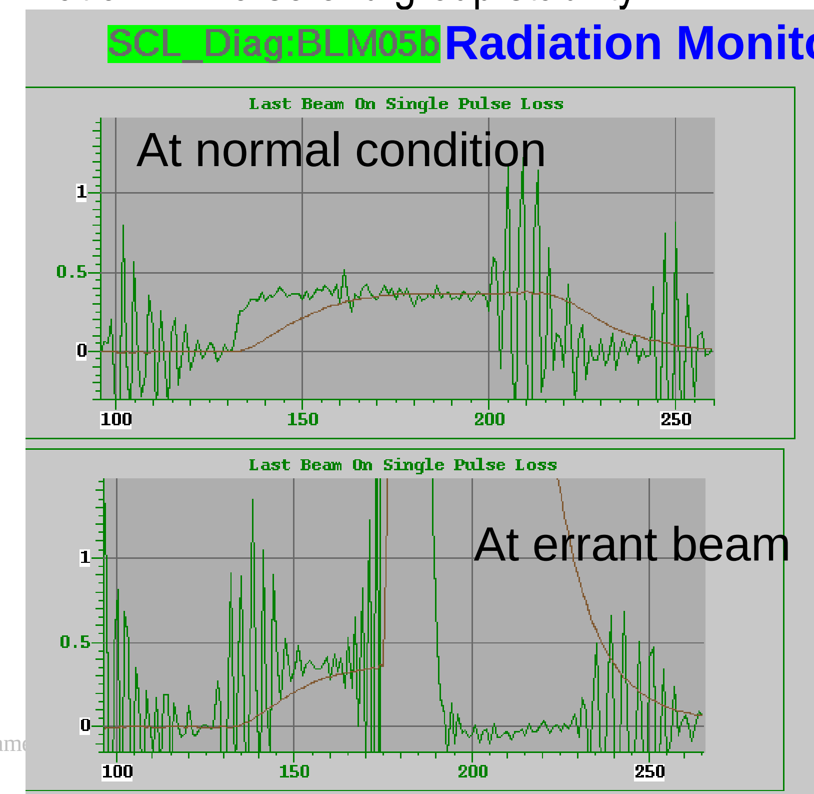
Errant beam from the source
Now MPS delay <30 us

Performance degradation of SRF cavities by errant beam

- First time in 4-years operation + commissioning in Nov. 2009
- Limiting gradient of two cavities (5a, 6c); 14.5 MV/m due to FE → Partial quench at 9 MV/m and became worse → turned off
- Errant beam between MPS trigger and beam truncation → off-energy beam with AFF → much bigger beam loss downstream → gas burst → redistribution of gas/particulate → changes in performance/condition
- Random, statistical events; resulted in surface contamination→ worse end group stability







Action Items (I)

- For the immediate term: Continue RF processing of cavities 5a and 6c to try to recover the original performance. The result will be decisive for further actions. (AAC2010)

→ 5a: conditioned up to 11 MV/m (operation gradient was 10.5 MV/m before errant beam incident)

6c: thermally cycled up to room temperature and conditioned up to 10 MV/m (operation gradient was 13 MV/m before errant beam incident). Not fully recovered. Still see electron activities at the end group.

- It is recommended to carefully examine the hardware and software of the MPS to provide fail safe operation, even under extraordinary operating conditions. (AAC2010)

→ Done by the Controls Systems Group. MPS delay is now about 30 us or less.

Action Items (II)

- Finalize and implement "in situ" plasma cleaning technology (AAC2010)

→ Pending

- For the near term: Assemble and exchange the spare module (after replacing a poor performing cavity so that module meets the PUP spec) (AAC2010)

→ Plan on taking CM20 out from the tunnel in summer down (or next winter down depending on spare cryomodule test results and other operational conditions).

Action Items (III)

- The committee acknowledges the professional and successful activity of the SRF group at SNS. In order to assure a long lasting implementation of this effort, the committee recommends the re-examination of the presently highly matrixed organization, and consideration of the formation of a specific group within RAD. (AAC2009)

→SRF group was formed within RAD in Nov. 2010

- 4 members + 1.5 matrixed + 3 FTE supported from RF, Control, Mechanical

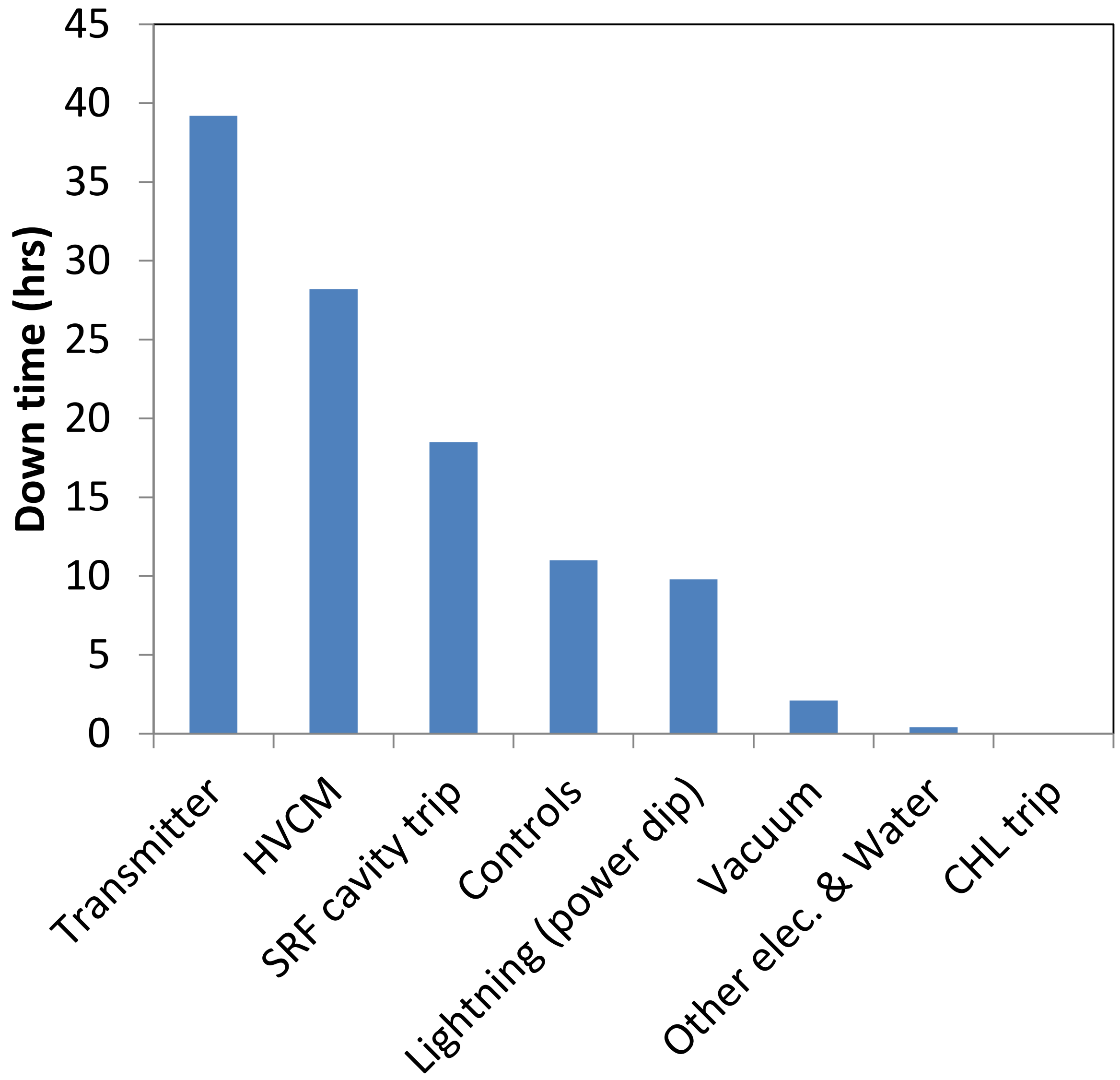
→SCL systems group in Nov. 2011

- Cryogenic systems group and SRF group combined
- 12.5 members + 4 FTE supported from RF, Control, Mechanical
- SCL, CHL, SRF/Cryo Facilities, R&Ds, support for other groups/organizations

SCL operational status since last review (I)

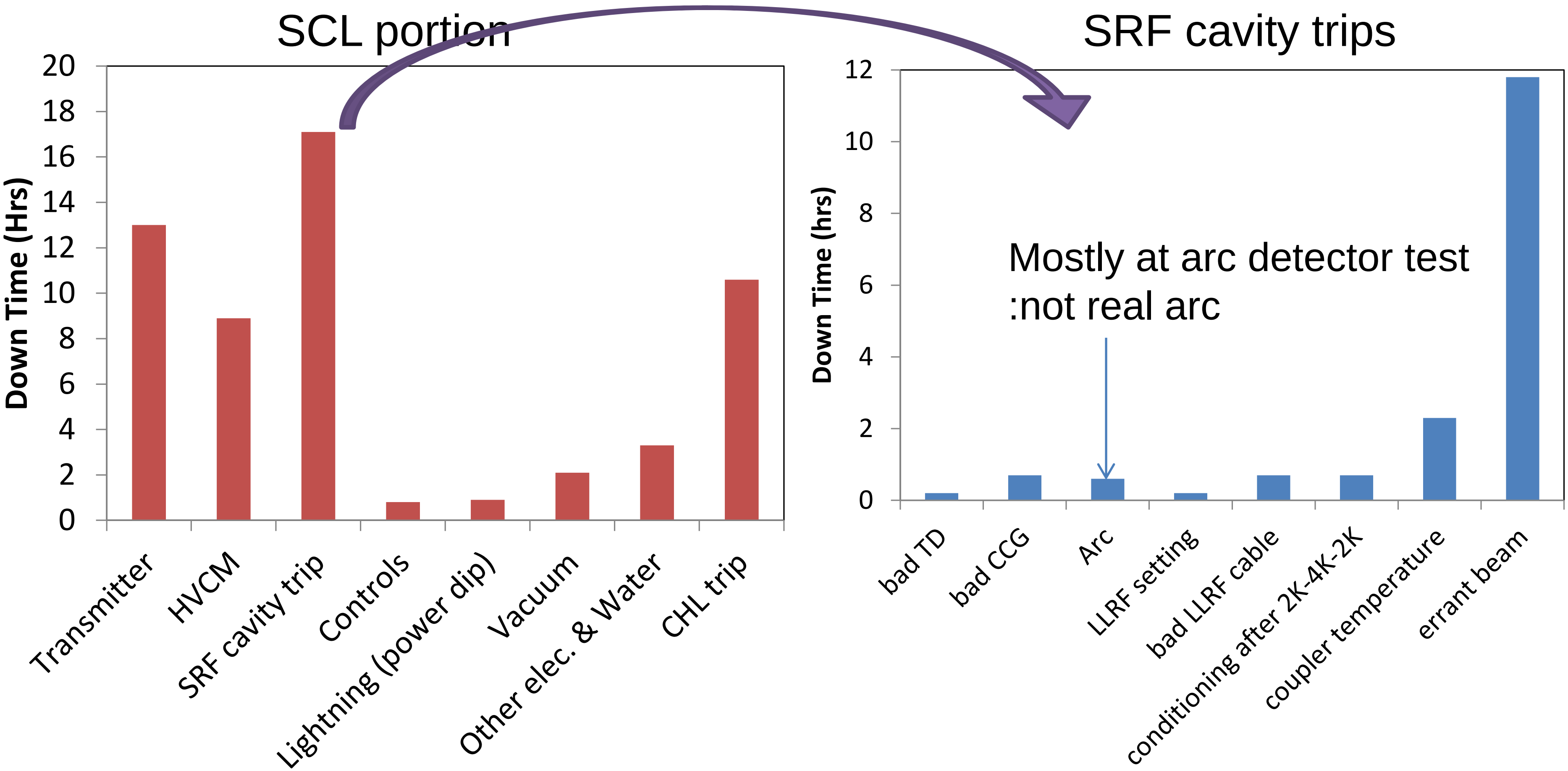
- 925 MeV + (0-12 MeV energy reserve) with high availability

- Down time statistics of SCL and related systems in FY11
- Total down time: 90.7 hours (98.2 %)
- 70 % of cavity trips by errant beam



Down time statistics of SCL and related systems in last run (Aug.-Dec.11)

- **About 98.4 % availability**
- **70 % of cavity trips from errant beam**



High availability

- Operational flexibility of SCL: energy reserve is essential
- Proactive maintenance
- Down times till full recovery, if
  - Cryomodule warm-up is needed: 8-10 days
  - 2K Cold box trips: 10 hours
  - More coupler flow is needed: 5 hours
  - Small part/board changes in the klystron gallery: 3 hours
  - SCL is retuned: 3 hours (using energy reserve)
    - To circumvent problems that can't be addressed during operation or to minimize a down time
    - Every run (~5 month) needed 2-3 times retuning

SCL operational status since last review (II)

- Tuner repairs
  - 5c (Feb. 2010): tuner malfunction found at machine start-up
    - Since then, implement tuner test procedure at every shut-down and start-up
  - 17b, 23b: showed irregular vibration (Jul. 2010): motor and/or HD
  - 9b: has shown irregular vibration and is not functioning after 4 K transition on 12/23/2011→ repair is ongoing
- Coupler air side water condensation:
  - Low temperature alarm has been implemented
  - All have dry air purging system
- New LLRF IOC: resolved IOC overload problem

SCL operational status since last review (III)

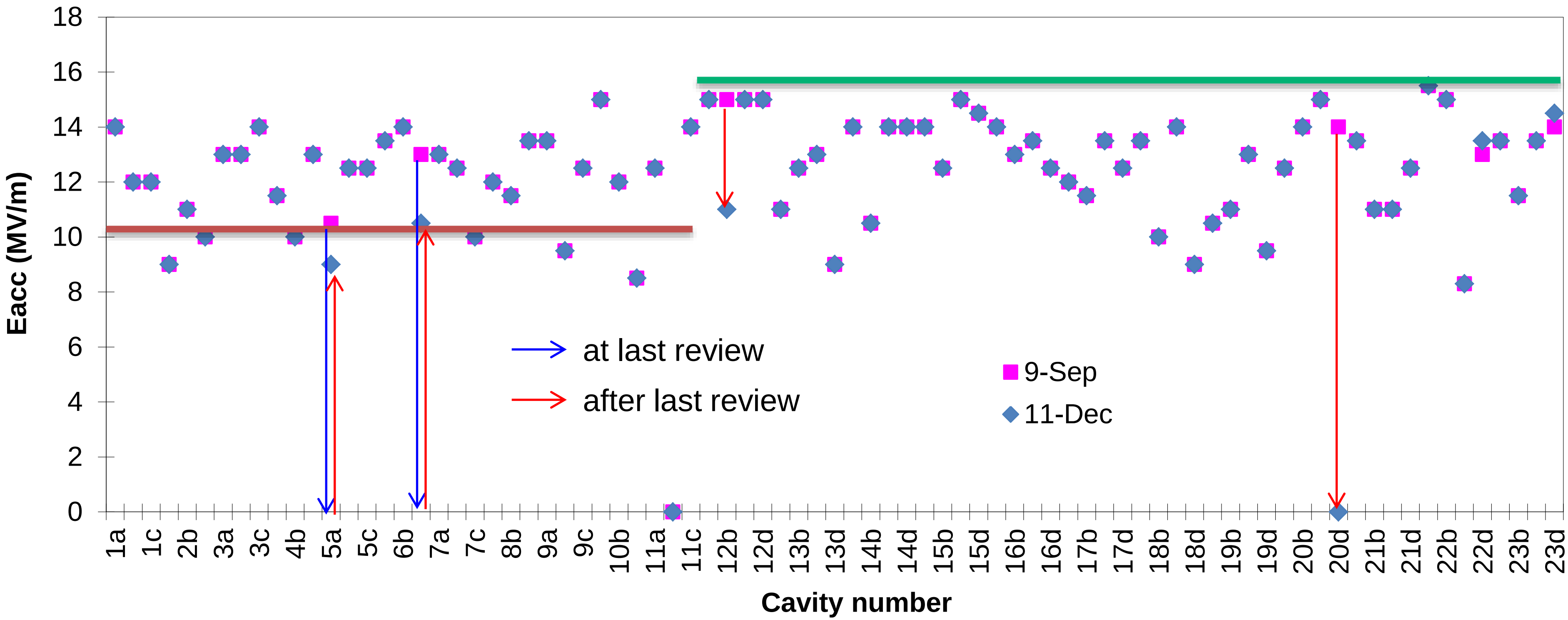
- CHL trips (5 times since last review)
  - CC2 speed sensor, CC3 displacement sensor: inspection on going
  - Heater PS failure: Safeguard to PLC logic during this down time
  - Ground fault, Power distribution switchgear loose wiring
- CHL turbine 1 (T1) failure in Dec. 2010: replaced in Jan. 2011
  - Inspected T2 & T4 last week
  - Found possible explanation for T1 failure. Further monitoring is ongoing

SCL operational status since last review (IV)

- 5a, 6c conditioning: partial recovery
  - RF conditioning:
    - 5a conditioned up to 11 MV/m (10.5 MV/m before errant beam hits)
    - 6c conditioned up to <10 MV/m (13 MV/m before errant beam hits)
  - CM6 warm-up
    - 6c conditioned up to 12 MV/m (still see instability at the end group)
- 20d: higher beam line vacuum ~1.5e-8 torr (possible air leak caused by errant beam events)
  - No degradation of cavity gradient observed
  - Turned off in Oct. 11 as a precautionary measure
- 12b: end group partial quench at lower gradient after recovery from 2KCB trip in Nov. 11
- 19b: dynamic cryo-load has increased by factor of 8 during last run
- Ion pump failure: Warm section between CM18 & 19 (Oct. 11)
  - No vacuum reading when IP fails (vulnerability: need spare vacuum reading)

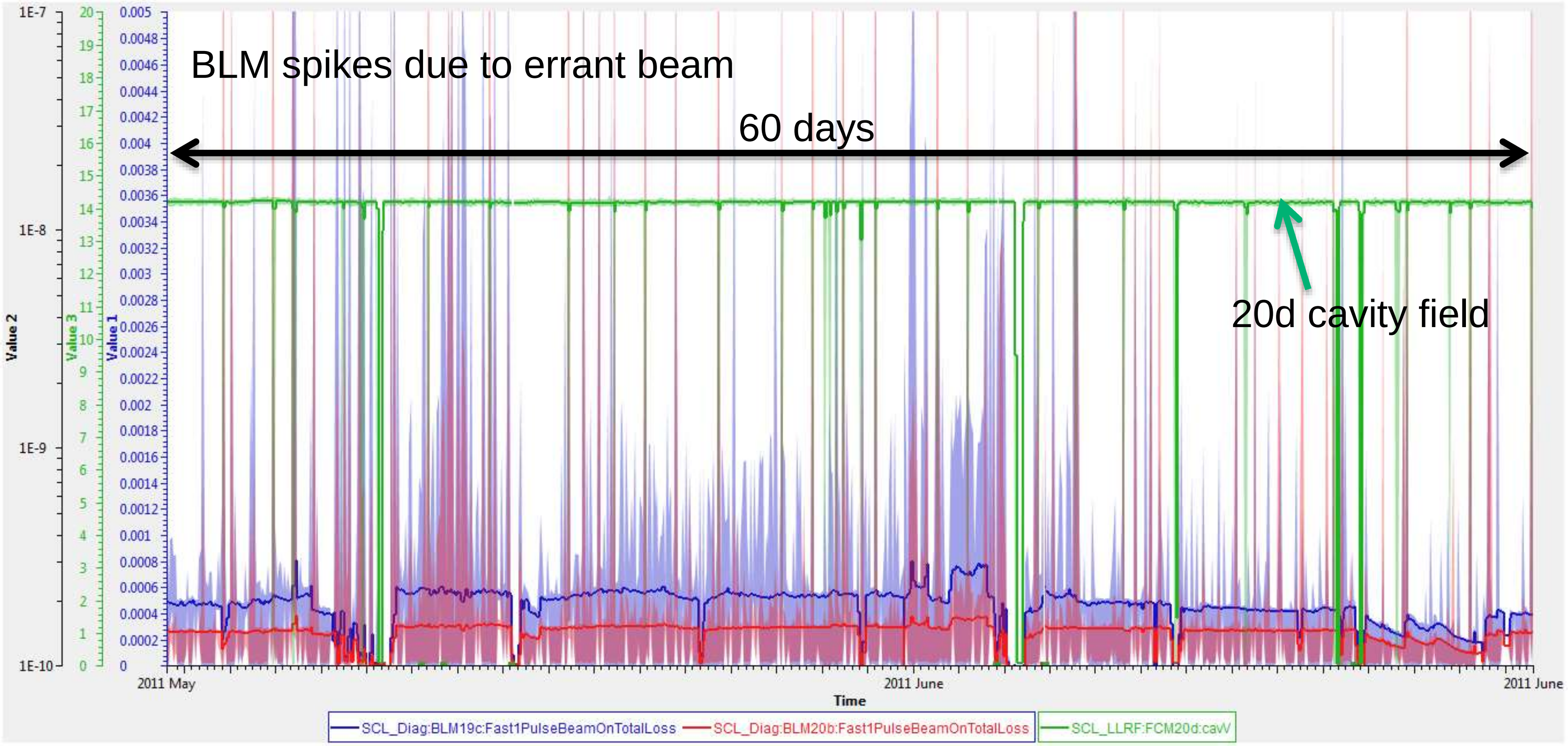
Operating gradients

- **5a, 6c: partially recovered**
- **12b: end group partial quench at lower gradient after recovery from 2KCB trip in Nov. 11**
- **20d: higher beam line vacuum ~1.5e-8 torr (possible air leak caused by errant beam events)**



Errant beam events around CM20

- **BLM trips: Several times/day**
- **Cavity 20d: ~0.4 cavity trips/day**
- **20d RF recovery was OK but trips were getting more frequent and vacuum has been staying at 1.5e-8 torr (same reading for both CCGs)**



FMEA for CHL (M. Howell et. al.)

- Failure Modes and Effects Analysis
  - Break the work down to task level for analysis
  - This process delivers
    - Weaknesses in our process
    - Ranked items in need of focus
    - An opportunity for a group to focus on a process
- Process Failure Modes and Effects Analysis (PFMEA) for CHL process
  - Evaluates process functions
  - Identifies failure modes and their effect
  - Lists potential causes
  - Specifies process variables for process control
  - Enables a prioritization system (RPN)
  - Documents corrective action activities
- Started in FY09: ~ 300 items are identified. Proactive maintenances are go going. Lots of improvements since then.

FMEA example

- What happens if a JT actuator fails?
  - Loss of control of liquid level in cryomodule
  - Requires depressurization of supply transfer line to replace
    - Shut down neutron production and 2KCB
    - Regularly occurring problem with high severity
- Developed tooling and procedure to allow for an actuator change without depressurizing
  - Practiced change on Dummy Cryomodule at pressure
  - Lowers severity from 7 to 4
  - Lowers RPN from 196 to 112
- Working on detection method to lower it to 64

For Design Beam Power 1.44 MW

- **Present gradient settings are based on collective limits at 60 Hz**
  - Main limiting factor is field emission
  - Thermal instability at the end group
  - Presently beam energy (925 MeV) is lower than design (1000 MeV)
  - There are large scattering in cavity performances
- **Strategy for long term sustainability and for reaching 1 GeV+25 MeV energy reserve**
  - **SRF facility:** For offline rework capability, cryomodule development and R&D
  - **Spare cryomodule:** To replace low performing/damaged cryomodule
  - **Plasma processing:** To recover from cavity gradient degradation and to Increase High beta cavity gradients by 15%

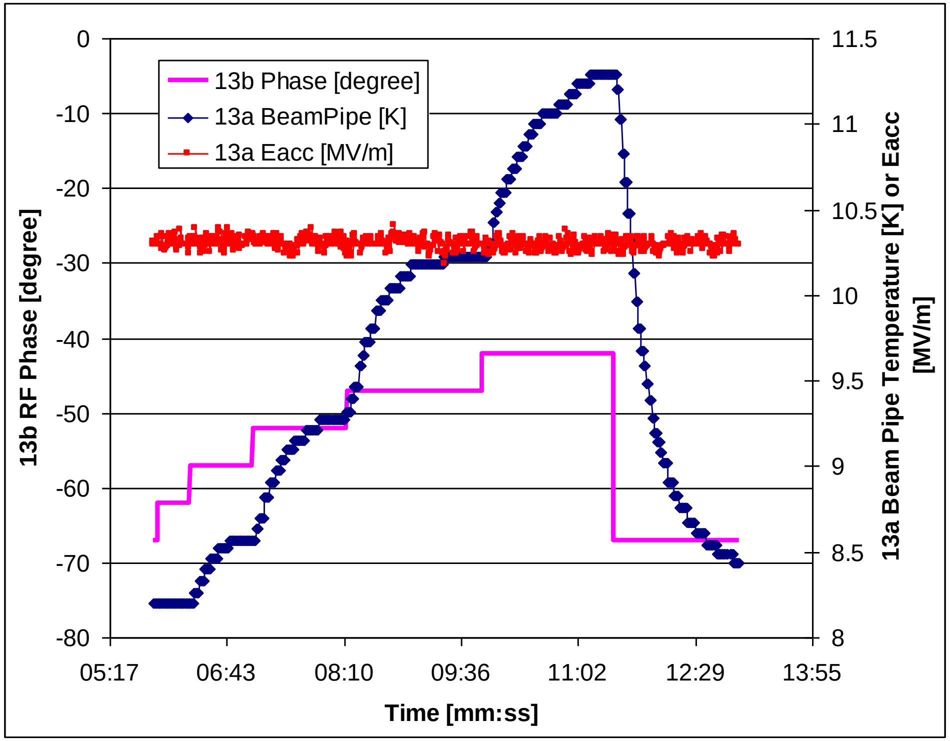
Collective behaviors

individual limits; 19.5, 15, 17, 14.5 MV/m

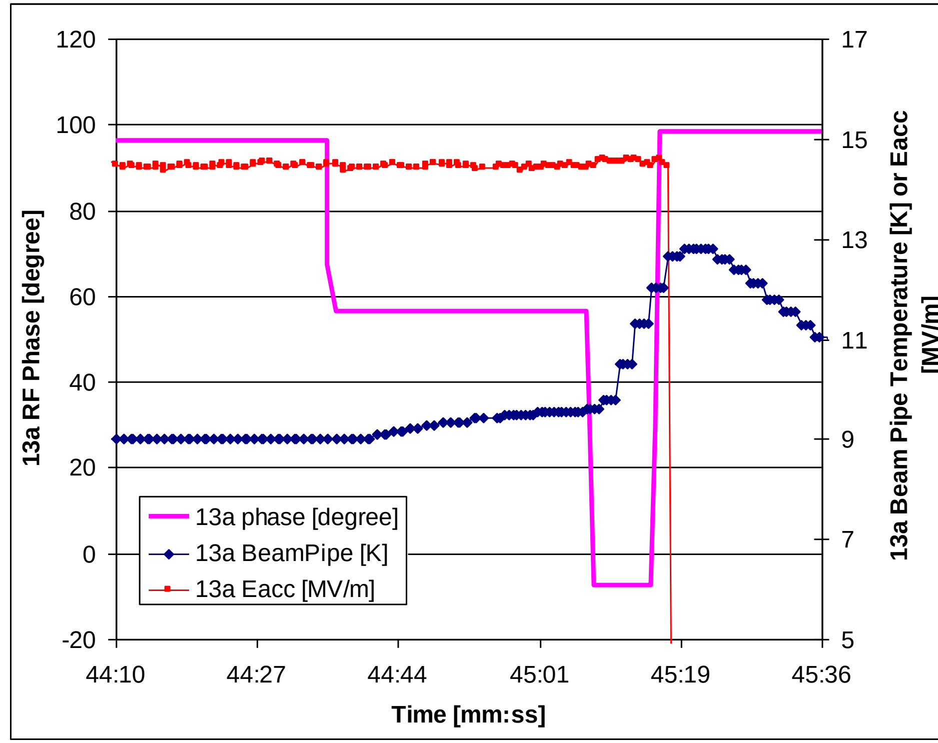
collective limits; 14.5, 15, 15, 10.5 MV/m

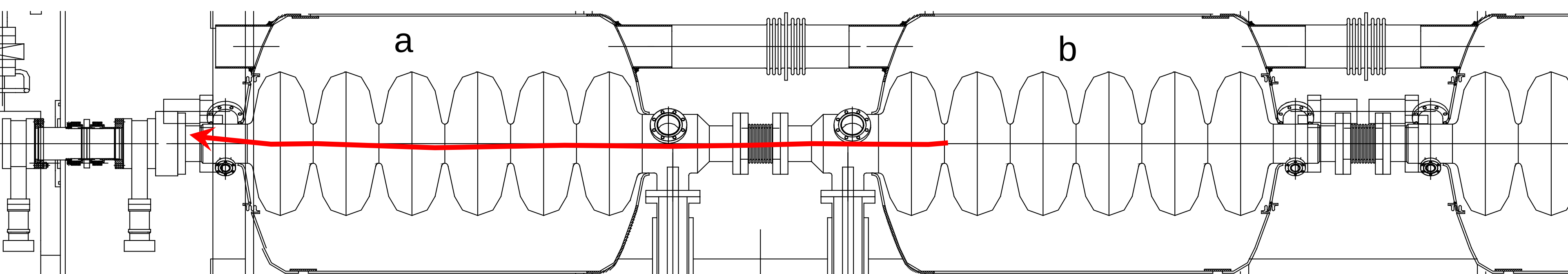
Example: CM13

b cavity phase → a cavity beam pipe



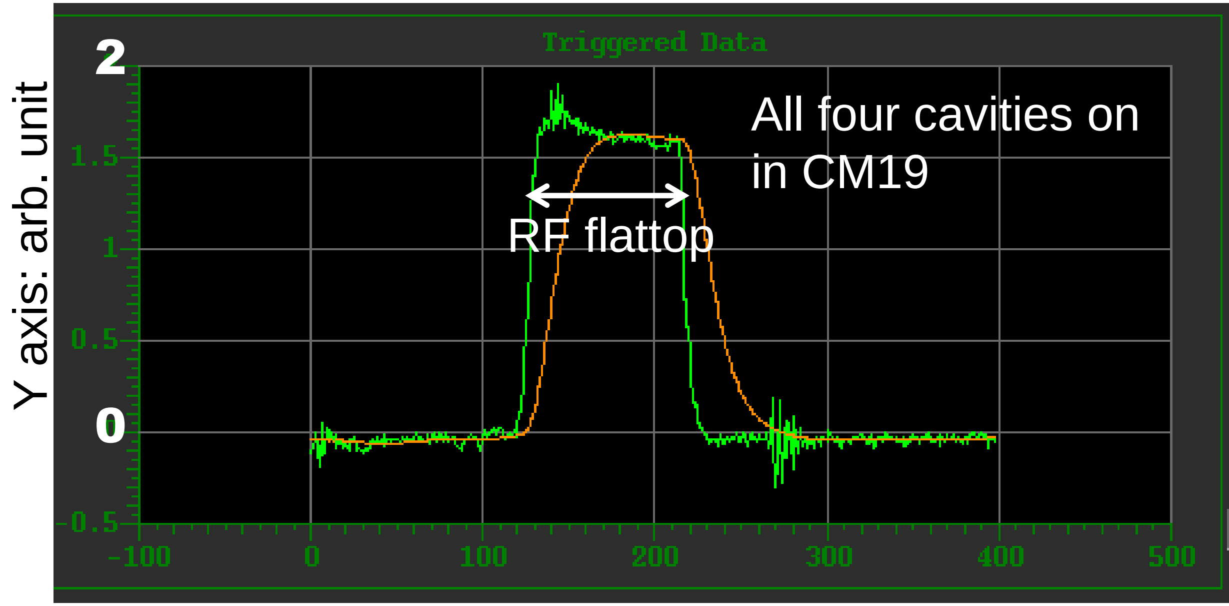
a cavity phase → a cavity beam pipe

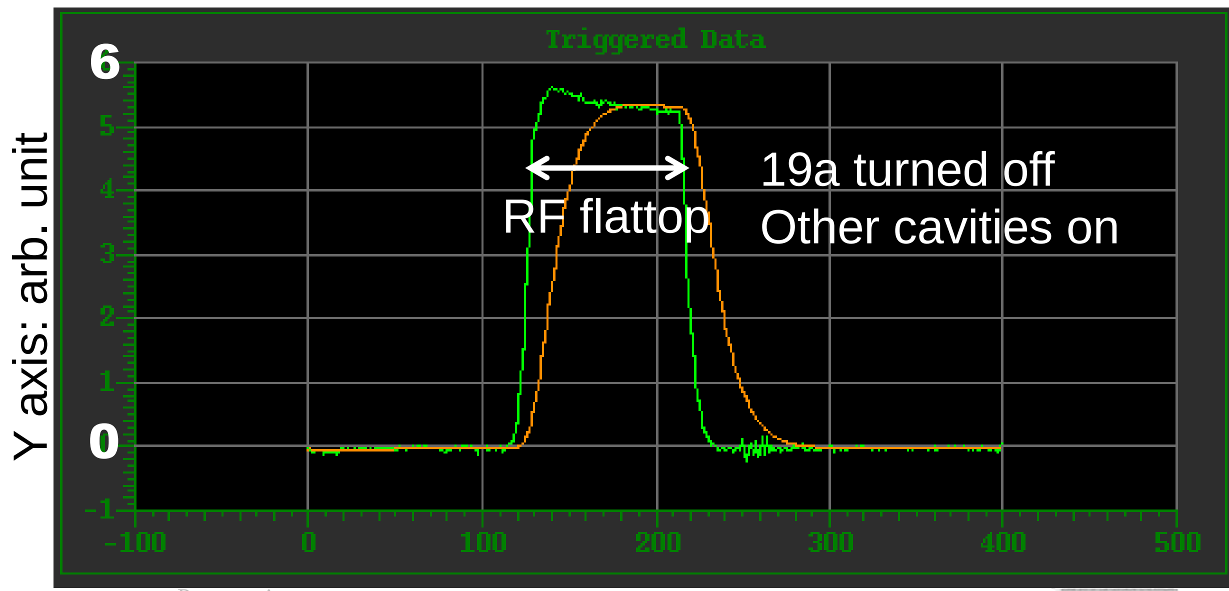




Collective behaviors

- **Example: CM19**
- **Radiation signal at the upstream of CM19**





Motivation for in-situ processing in the tunnel

- Medium term
  - Recover from cavity performance degradations
  - Reach 1GeV + energy reserve (Increase high beta cavity gradients by about 2 MV/m on average)
- Long term
  - 42-mA beam loading with 2nd target station: Need narrower performance scattering → Efficient utilization of RF power (ideally constant RF power/cavity is preferred)
- Develop a cost effective processing method with minimal impact on machine operation

Cryomodule Rework

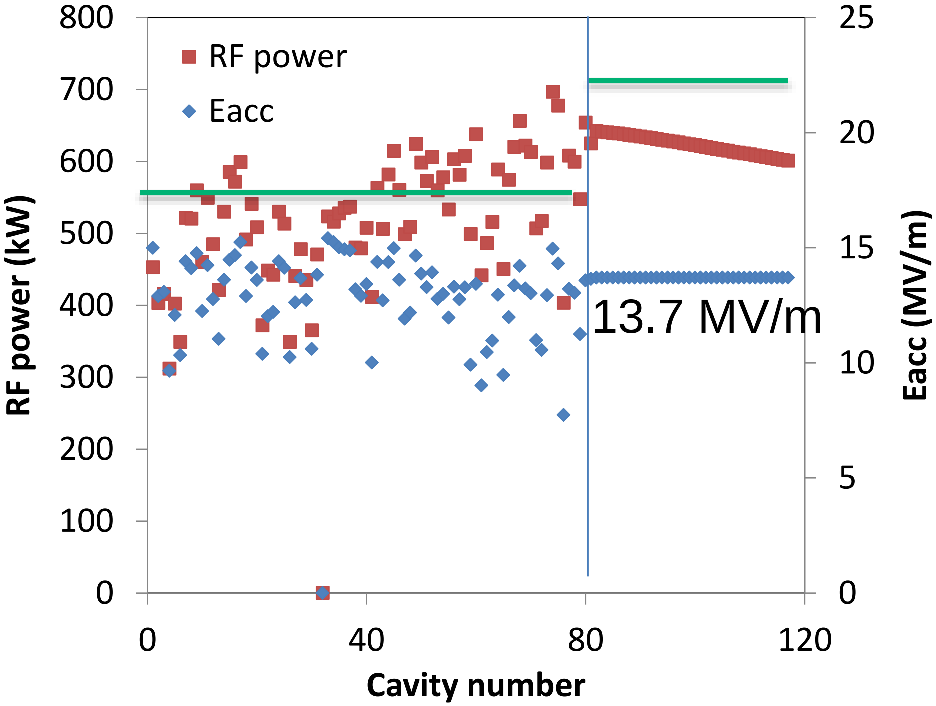
- **Only option for unrecoverable damages**
- **High beta spare is about complete**
  - Rework cryomodule 20
    - Possible air leak across RF window on cavity 20d
    - Cavity 20d currently turned off
  - Rework cryomodule 13
    - Superfluid leak, possible HOM feedthrough leak
    - Large variation between individual and collective limits
- **Medium beta spare is in planning**
  - Rework cryomodule 9
    - Large air leak to insulating vacuum: has separate pumping cart in the tunnel
  - Rework cryomodule 11
    - Cavity 11b has never worked, HOM problem
    - May require full disassembly
- **Performance degradations have been observed in some cavities. Need proactive preparation for spares cryomodule and plans for rework.**

PUP-SCL portion for STS

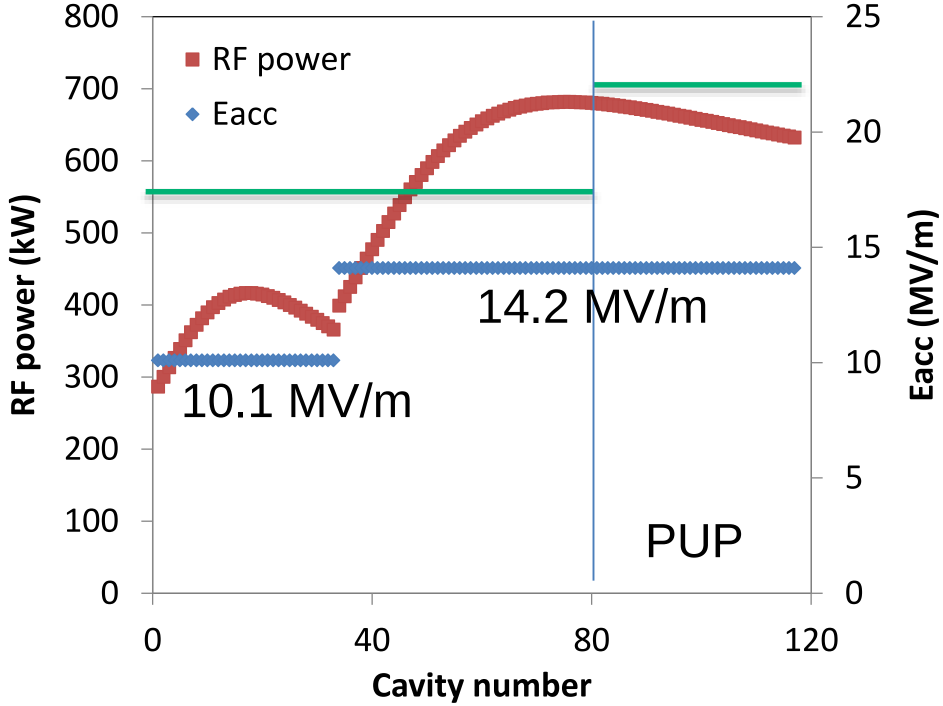
- **8+1 cryomodules for 42 mA, 1.3 GeV + energy margin**
- **Strategy for RF power, Coupler average power, Eacc**

*** RF power, 15 % RF control margin included in plots**

Present Eacc+13.7 MV/m for PUP cavity
Eacc and *RF power required at klystrons



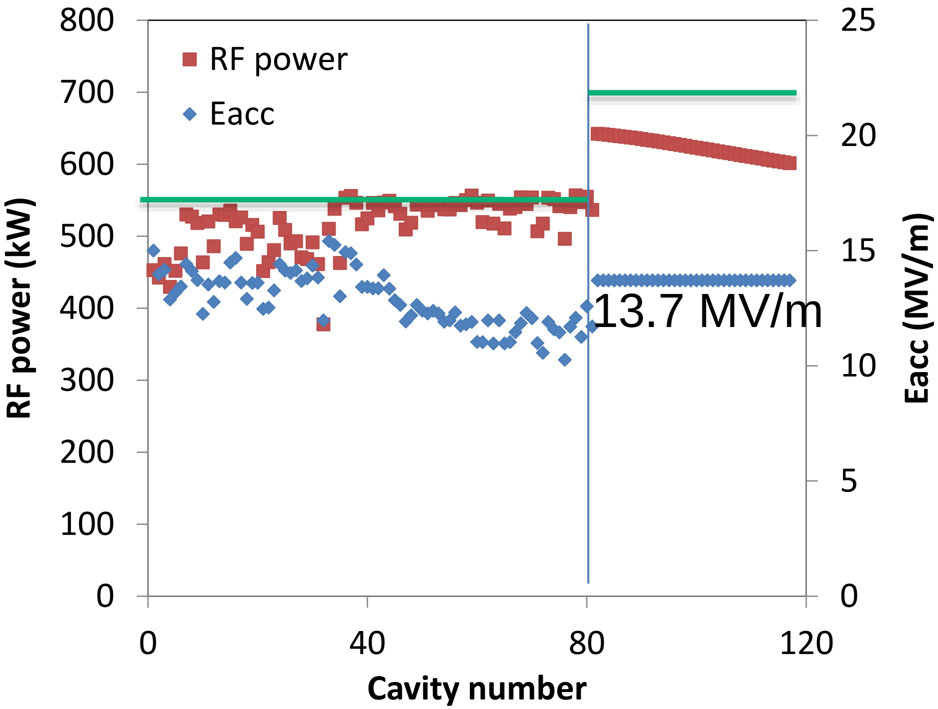
PUP design parameters in 2006
Eacc and *RF power required at klystrons



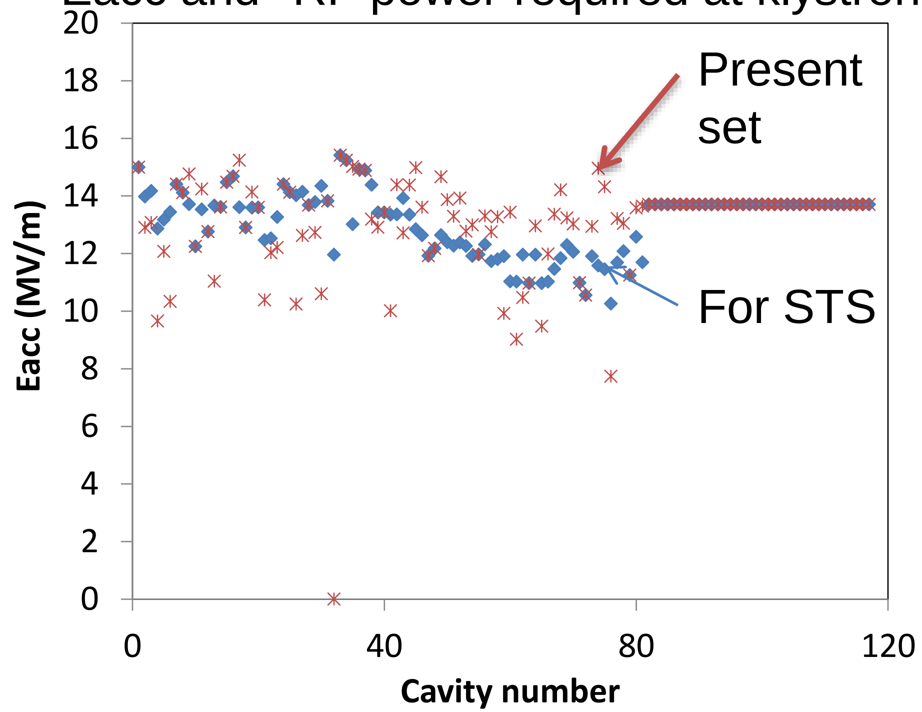
PUP-SCL portion for STS

- 8+1 cryomodules for 42 mA, 1.3 GeV + energy margin
- Strategy for RF power, Coupler average power, Eacc
- About constant power/cavity is preferable for existing ones
- Need processing or rework for lower performers

Eacc for STS
Eacc and *RF power required at klystrons



Eacc comparisons
Eacc and *RF power required at klystrons



PUP SCL Portion: Basis of Design

- **Cavity performance requirements**
  - Stable operating gradient: 13.7 MV/m average
  - Field emission onset: >12 MV/m
- **Pressure boundary is compliant with 10 CFR 851**
  - Conducted internal and external reviews
  - Vacuum vessel built to ASME BPVC Section VIII
  - Helium piping built to ASME B31.3
  - All welding conducted in accordance with ASME code
- **Interface points are the same as previous design**
  - U-tube connections held constant
  - Waveguide connections held constant
  - Instrumentation connections are very similar with the exception of the Joule-Thomson valves
- **SCL Design Criteria Document complete (PUP0-302-DC0001)**

Summary

- Support Neutron Production at 925 MeV up to 1 MW
  - High reliability: operational flexibility and proactive maintenance
  - Energy margin: essential
  - RF capability/Eacc settings: enough for design beam current 26 mA
- Next run preparation
  - Will try to recover cavity performances: may have to run at lower beam energy to maintain some energy reserve
  - Equipment/part maintenances
- Plans for long term sustainability and reaching design beam power 1.44 MW
  - SRF facilities
  - Spare cryomodules for rework
  - In-situ plasma processing