SNS SCL Status and Power Upgrade Project (PUP)

TTC Meeting
DESY
January 14, 2008

SANG-HO KIM
For all

SNS Accelerator Complex

Front-End:

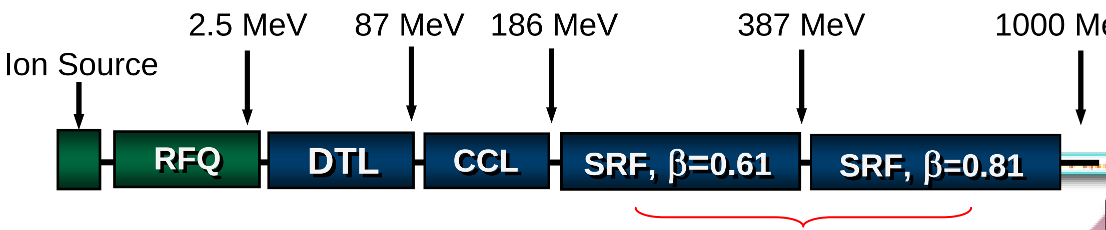
Produce a 1-msec long, chopped, H- beam

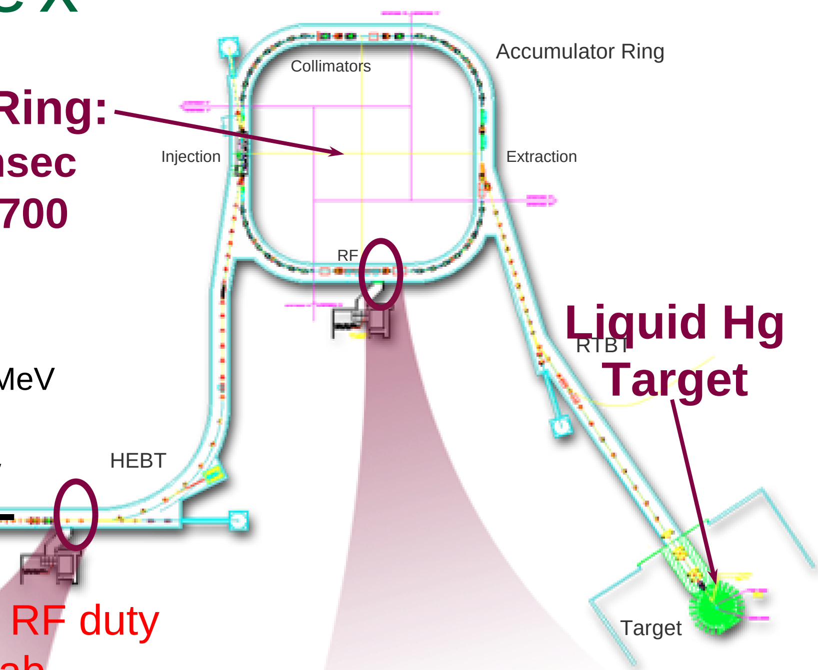
1 GeV LINAC

Accumulator Ring:

Compress 1 msec long pulse to 700 nsec

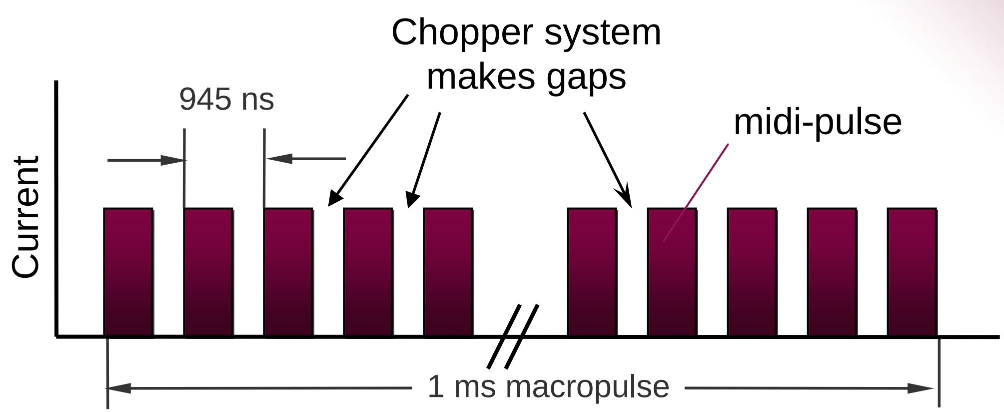
Liquid Hg Target

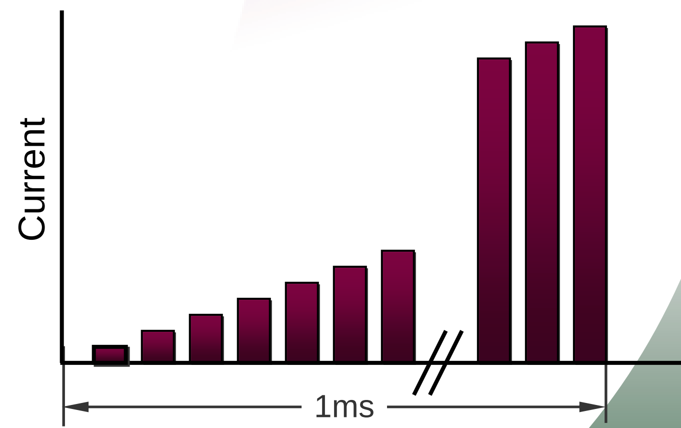




SCL; 805 MHz, 1.3 ms RF, 1.0 ms beam, 60 Hz, 7.8 % RF duty

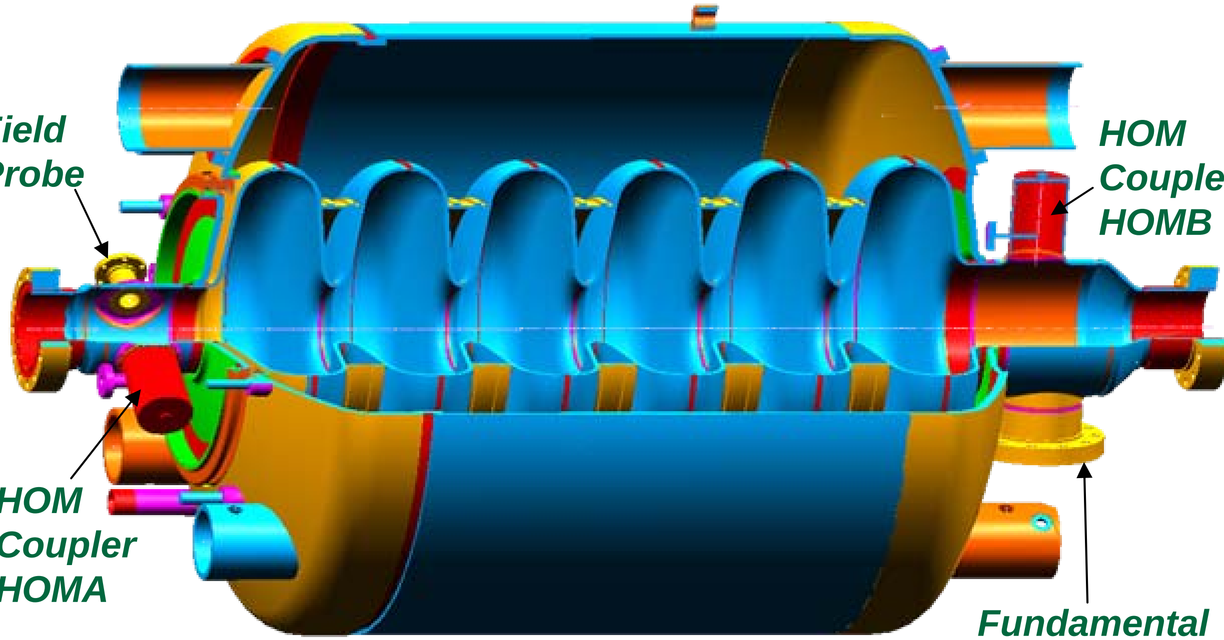
SNS cavities and cryomodules; designed and built at Jlab

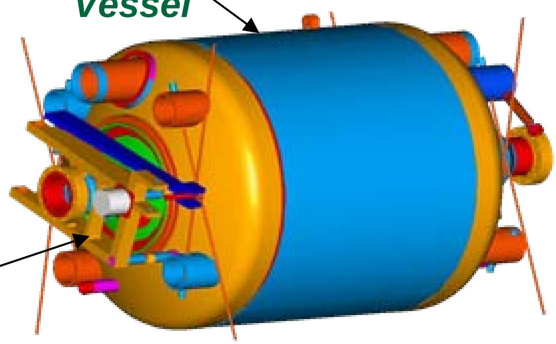




SNS SRF cavity

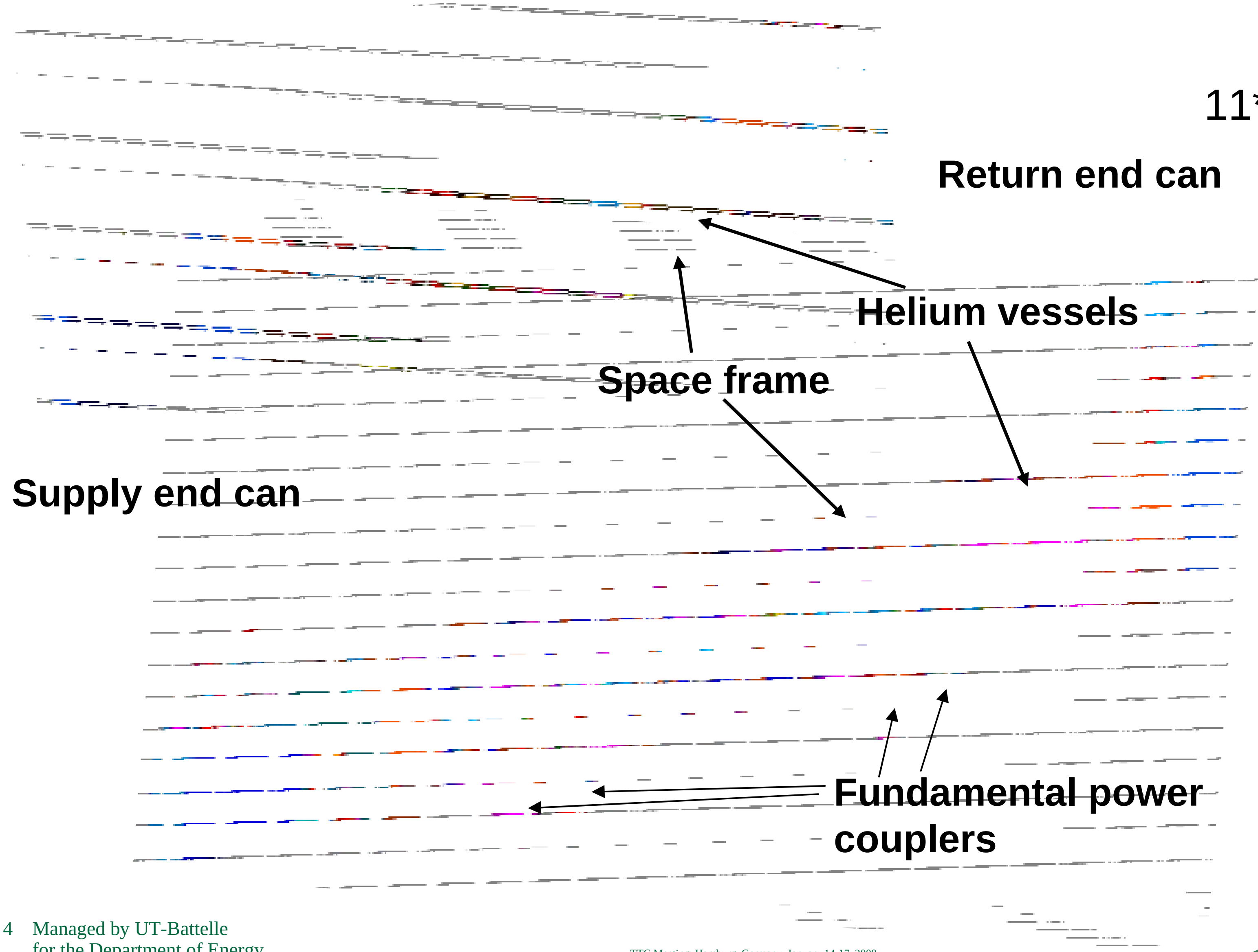
Major Specifications:
Design Op. Gradients
E_a=15.9 MV/m at β=0.81
E_a=10.2 MV/m at β=0.61
&
Q_o> 5E9 at 2.1 K





SNS Cryomodule

Designed to operate at 2.1 K (superfluid helium)



11*Medium beta

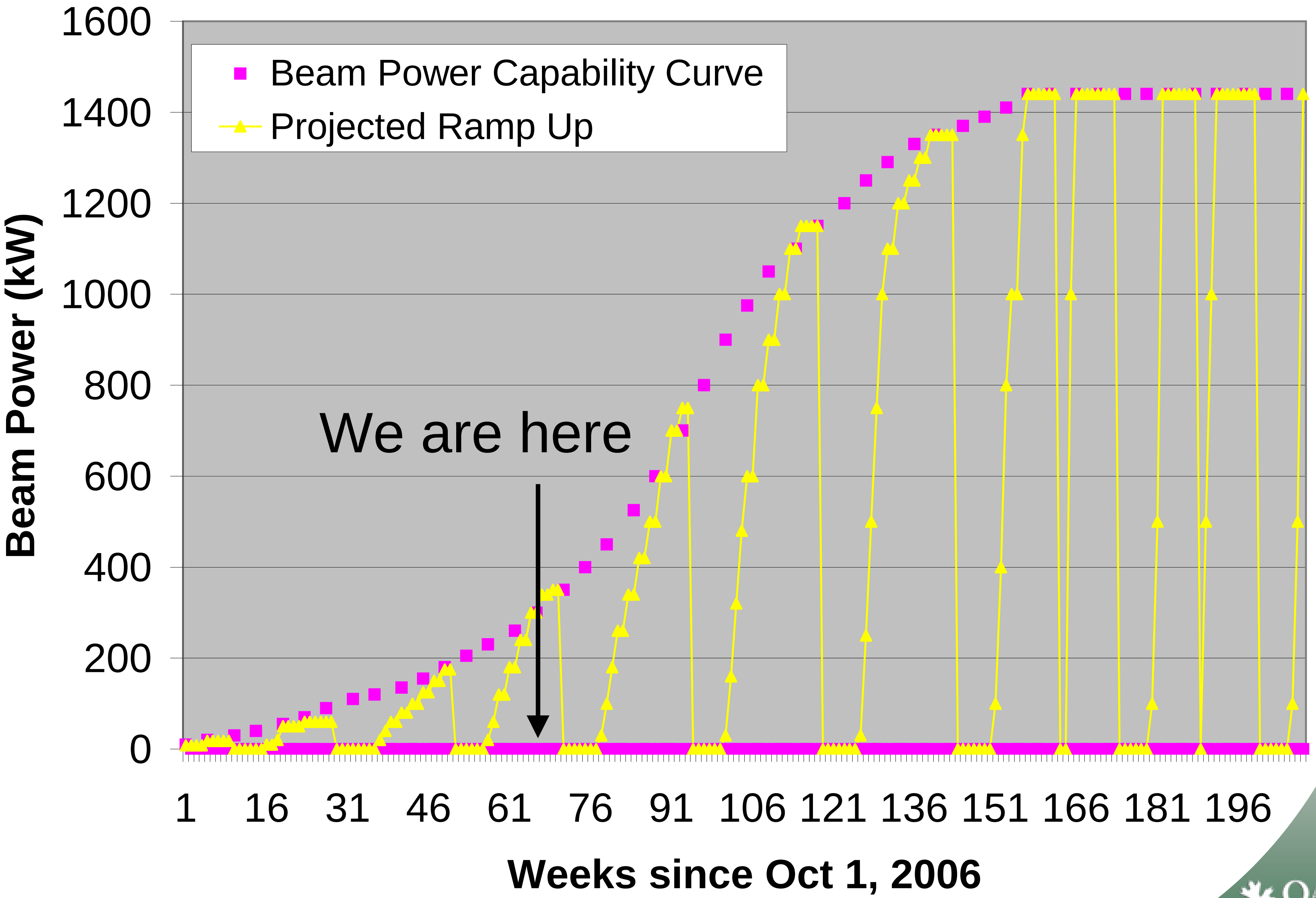
12*High beta

81 cavities

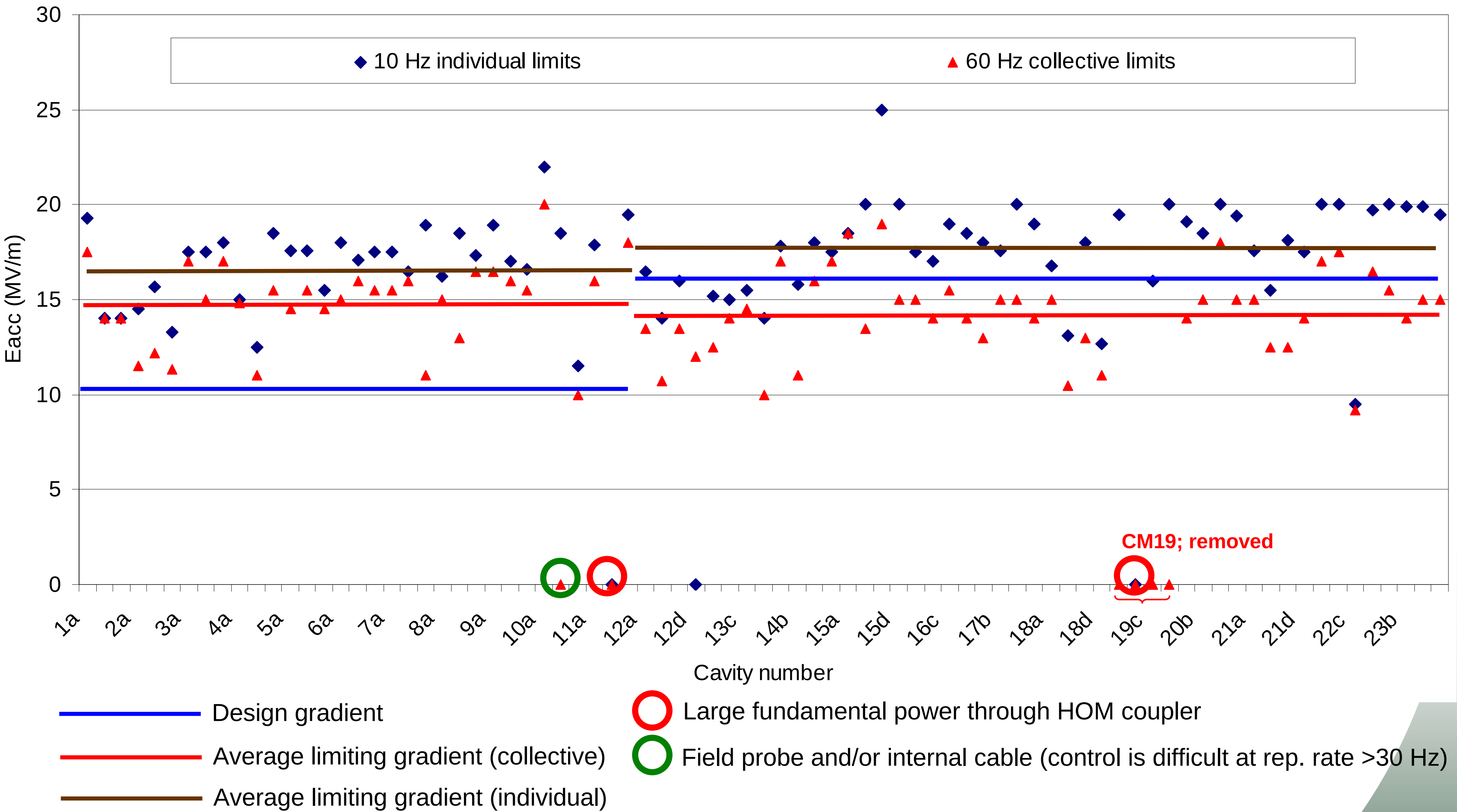
SCL status summary

- **Extensive studies/tests have been successful (since June 06)**
  - Needed more attentions/understandings than expected since it is the first operational pulsed superconducting linac
  - Performed series of (re)evaluations at 10/15/30 Hz and at 60 Hz (First test; powering all cavities in)
  - Had better understandings of cavity physics and limiting conditions of the system in pulsed mode
  - Established balanced operating conditions including all supporting/sub systems as a whole in various operating conditions
- **SCL is now providing a very reliable operation for neutron production following SNS power ramp-up**
  - **Highest priority → reliability**
    - **Gradient setting; based on 60 Hz collective limits**
    - **Continuous efforts to improve/understand the system as a whole including Control/RF/Cryo**
  - **Present setting; 60 Hz, 850 MeV, 2.1 K (75 cavities)**
  - **Trips during the present operation < 0.1 trip/day (all)**
- **SCL is providing high flexibilities for beam study/operation**
- **We are now prepared for high intensity run**

Beam Power Ramp Up Plan



Limiting gradients and statistics

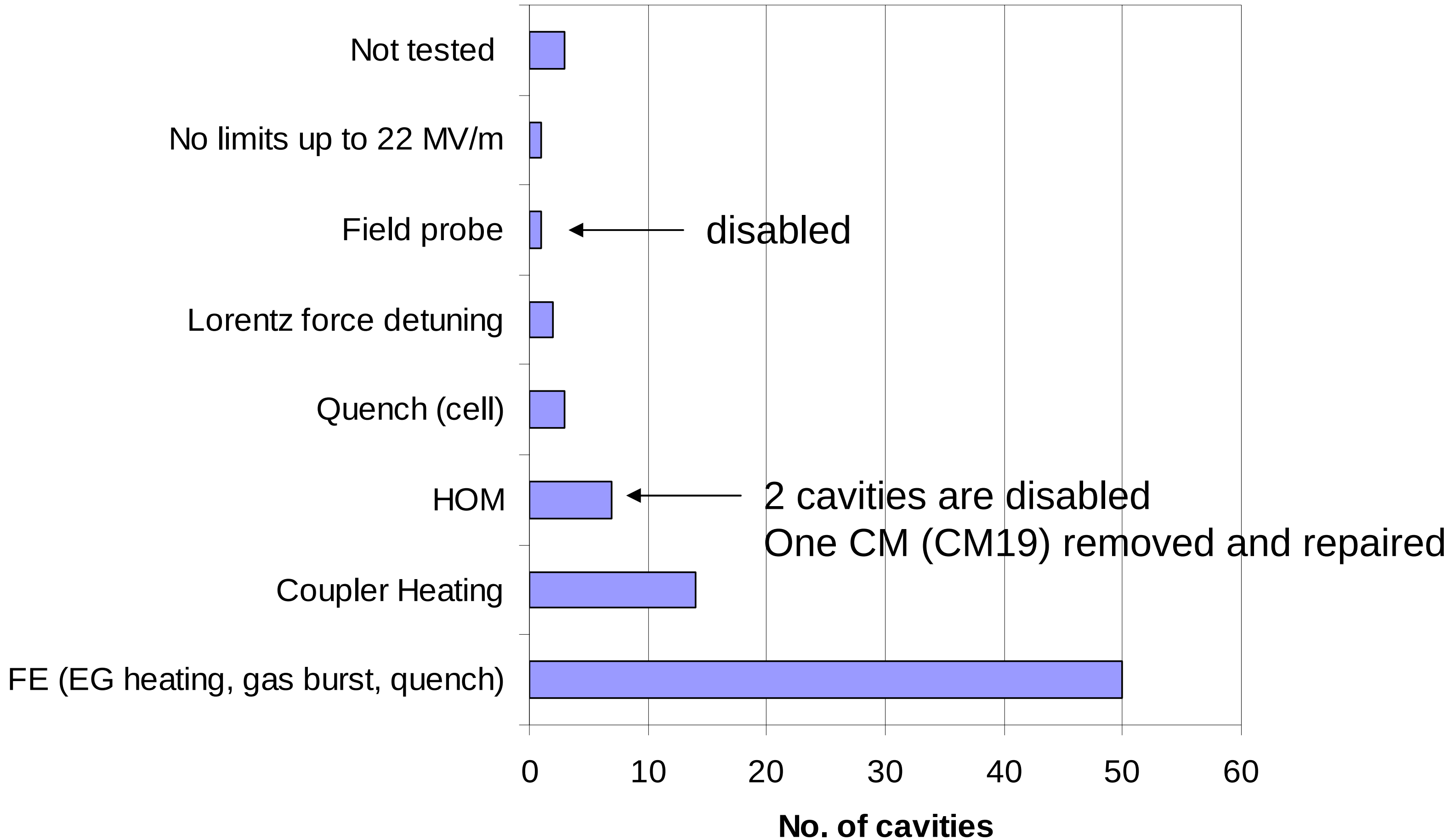


Individual; powering a cavity at a time

Collective; powering all cavities in a CM at the same time

Large performance variations cavity to cavity

Statistics of limiting factors (60 Hz collective)



-Performances of MB cavities are very good.

$E_{lim,avg,MB}$ ~14.9 MV/m, $E_{lim,avg,HB}$ ~14.3 MV/m

-Some cavities have multiple limiting factors.

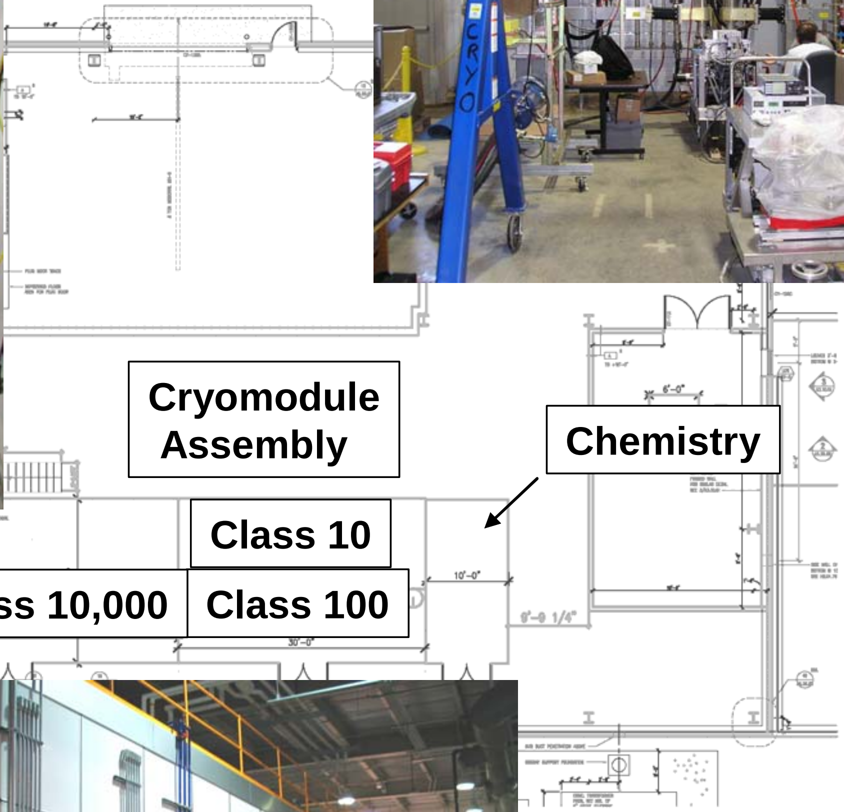
-About 14 HB cavities are limited by coupler heating, but close to the limits by FE.

-Operating gradients are around 85~95% of E_{lim}

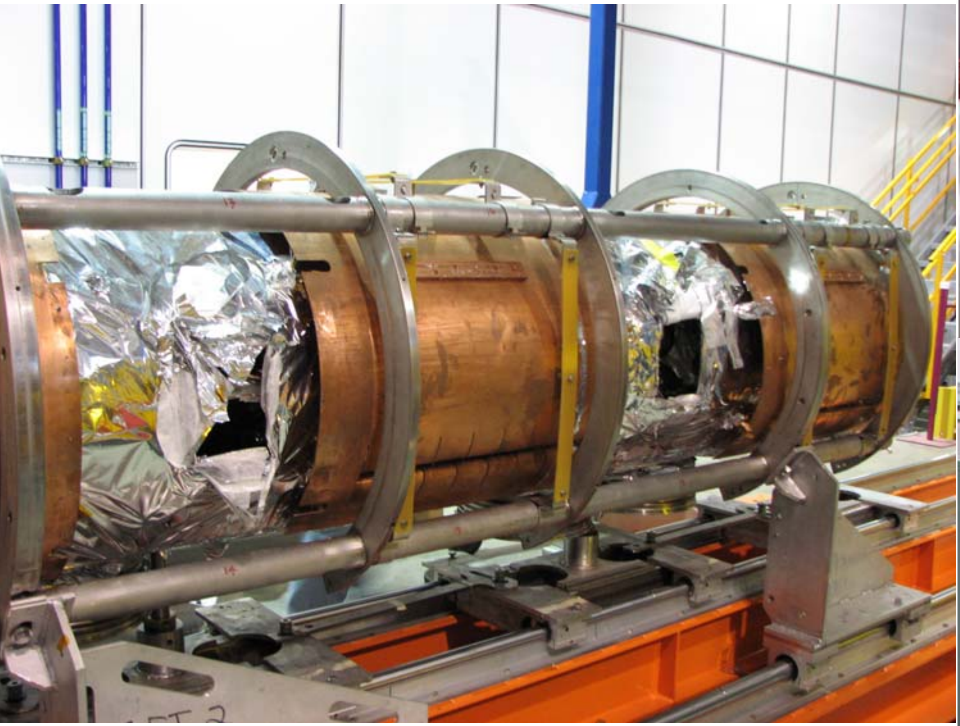
Concerns and Components that need attentions/improvements

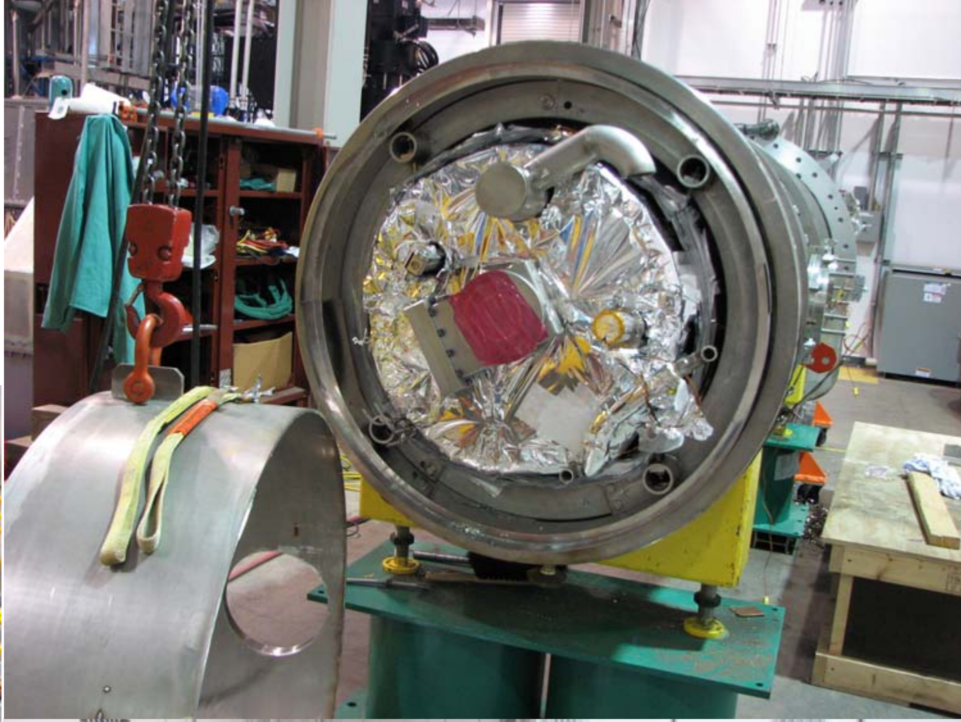
- **Cavity cell**
  - **Field emission;**
    - **Collective behavior**
    - **End group heating (gas burst, quench)**
- **Sub-components**
  - **Initial (the first) powering-up, pushing limits, increasing rep. rate (extreme care, close attention)**
    - **Aggressive MP, burst of FE → possibly damage weak components**
      - **Abnormal behaviors of HOM couplers and FP**
    - **Similar situation after thermal cycle (and after long shut down too)**
  - **FPC**
    - **Cooling**
    - **Interlock (CCG)**
  - **Tuner**
    - **Motor, harmonic driver, piezo**
- **Efforts for SRFTF works are in progress at SNS**
  - **CM Repair (CM19 is done, next one will be CM12 for more works)**
  - **Spare CMs (1 MB + 2 HB)**
  - **Facilities**

SRF Test Facility



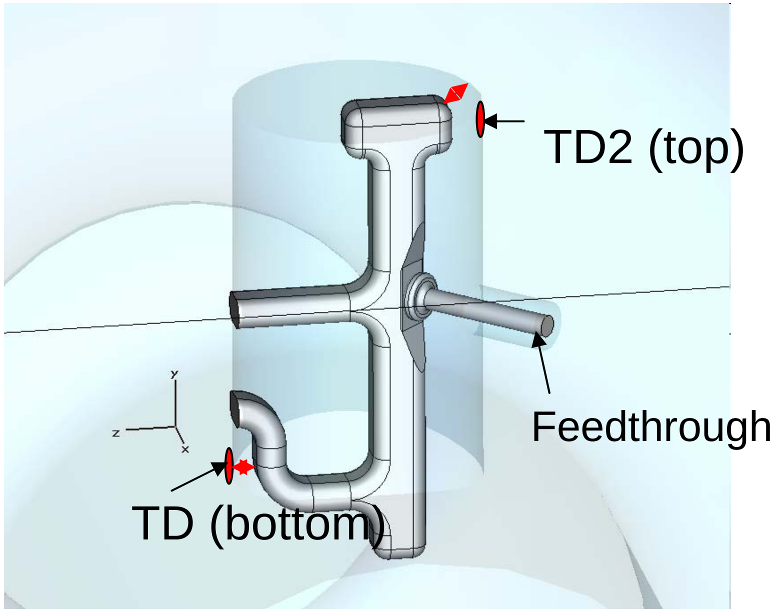
MB Prototype disassemble





CM19 repair & in test cave

CM19 test in test cave after repair



Both feedthroughs of 19b HOMA and B ; removed (details in John's talk)
Add thermal diode (TD)
at around multipacting regions

All individually tested up to 16 MV/m at 4 K, 30 Hz, 1ms, in open loop, (about the same gradient we got in the linac tunnel at 30 Hz, collectively)

-**No degradations** in cavity performances were observed after repair.
-The repair procedure was **confirmed**.
-We **gain 19b** (processing was possible by removing feedthroughs)
-Electron activities in the HOM coupler seem to cause many electron activities, thermal loads and vacuum.
-Large heat loads were observed while processing.
-Final check will be 60 Hz collective limit test in the tunnel.

OAK RIDGE
National Laboratory

SNS Power Upgrade Project

SNS Power Upgrade Primary Parameters

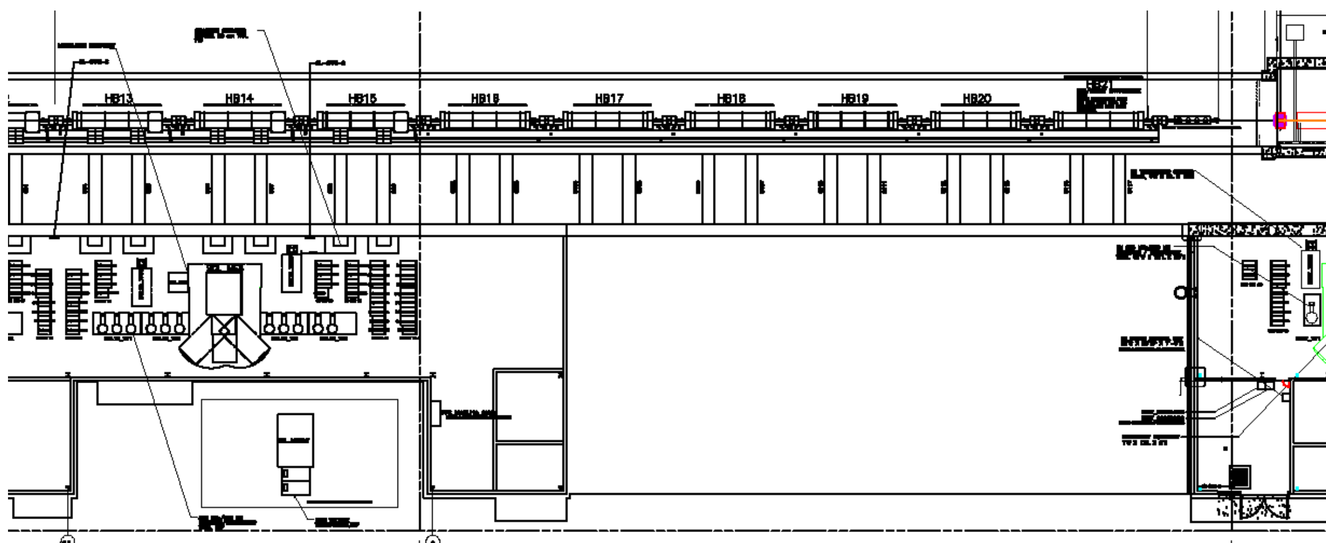
Parameter	Initial SNS Baseline	Power Upgrade
Kinetic energy [MeV]	1000	1300
Beam power [MW]	1.4	3.0
Chopper beam-on duty factor [%]	68	70
Linac beam macropulse duty factor [%]	6.0	6.0
Average macropulse H- current, [mA]	26	42
Peak macropulse H- current, [mA]	38	59
Linac average beam current [mA]	1.6	2.5
SRF cryo-module number (medium-beta)	11	11
SRF cryo-module number (high-beta)	12	12+8 (+1 reserve)
SRF cavity number	33+48	33+80 (+4 reserve)
Peak surface gradient (b=0.61 cavity) [MV/m]	27.5 (+/- 2.5)	27.5 (+/- 2.5)
Peak surface gradient (b=0.81 cavity) [MV/m]	35 (+2.5/-7.5)	31
Ring injection time [ms] / turns	1.0 / 1060	1.0 / 1100
Ring rf frequency [MHz]	1.058	1.098
Ring bunch intensity [10^{14}]	1.6	2.5
Ring space-charge tune spread, DQ_{sc}	0.15	0.15
Pulse length on target [ns]	695	691

SCL Scope and Improvement for PUP

- **<u>Scope</u>**
- Beam energy; 1 GeV → 1.3 GeV (1st stage)
- Beam current; 26 mA → 42 mA (2nd stage)
- 9 additional high beta cryomodules (36 high beta cavities)
  - With all supporting systems (RF; 750kW klystrons, HVCM, Cryogenics)

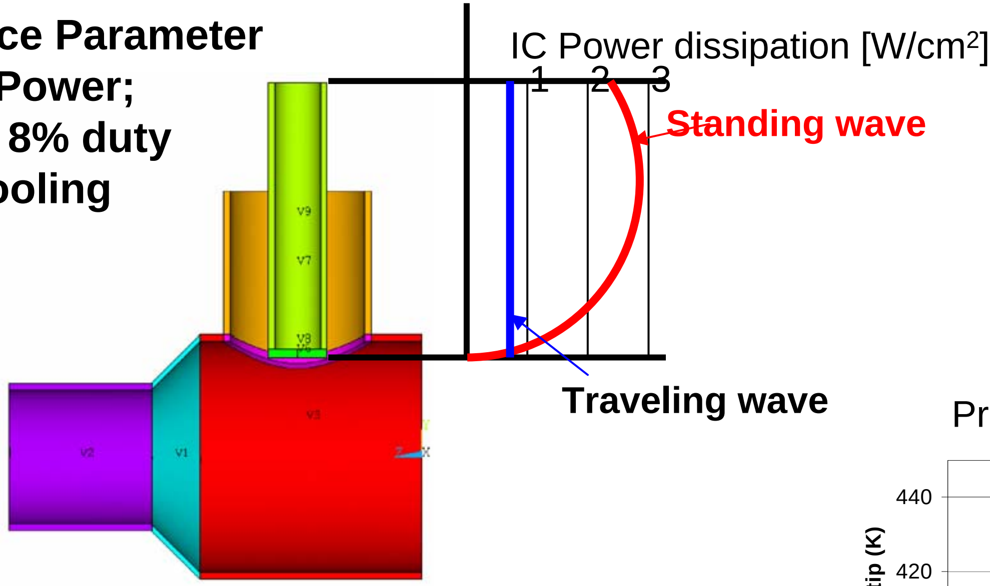
- **<u>Outline</u>**
- Fundamental power coupler
- Cavity performance (Field emission free cavities up to 16 MV/m)
- End group improvement
- HOM coupler
- Tuner & valve

9 additional cryomodules to fill the empty spaces at the end of the linac tunnel



FPC

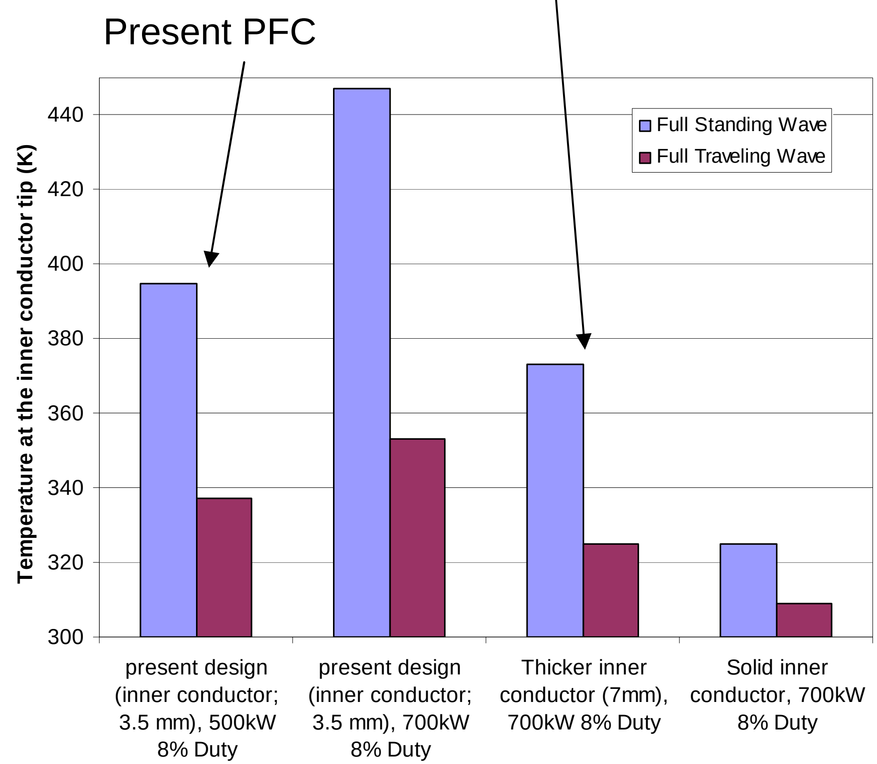
Reference Parameter
Source Power;
500 kW, 8% duty
No IC cooling

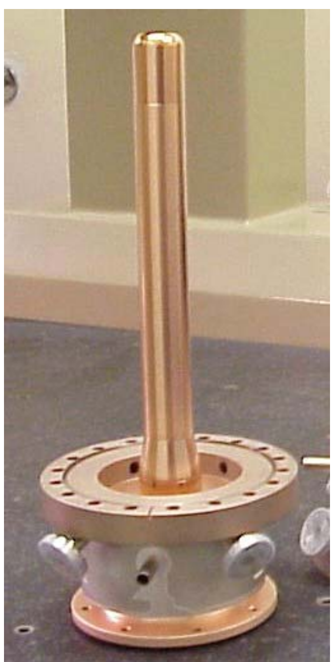


Inner conductor heating
→thermal radiation on end group

PUP; 50 % more RF power capable

7 mm thick inner conductor can handle
Additional thermal load
Mechanical stability need to be checked





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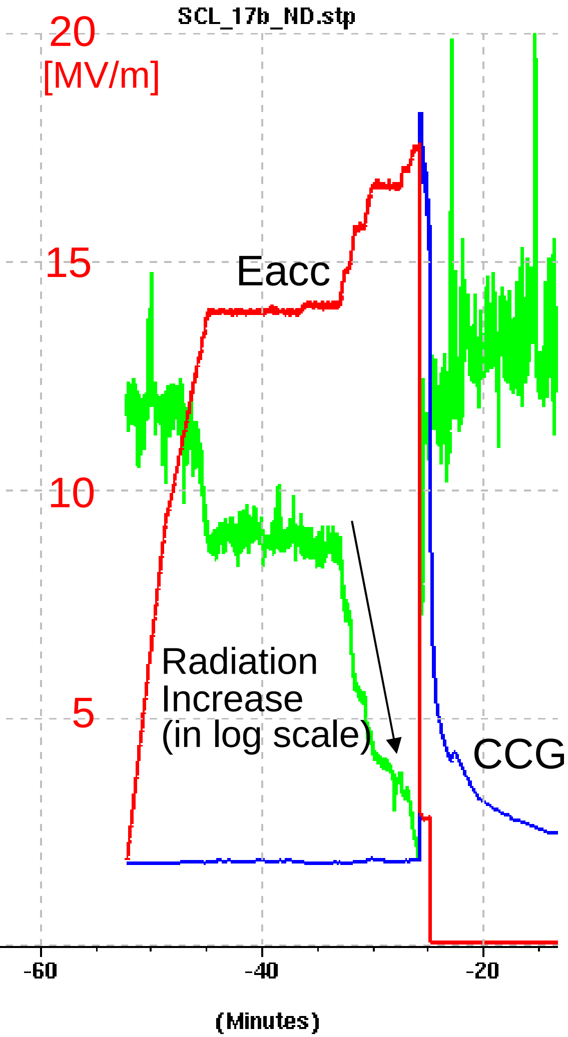
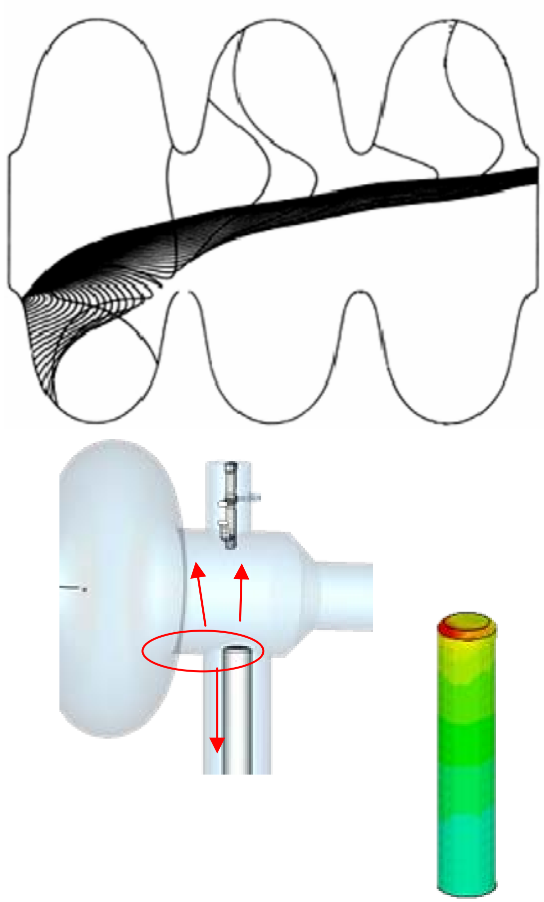
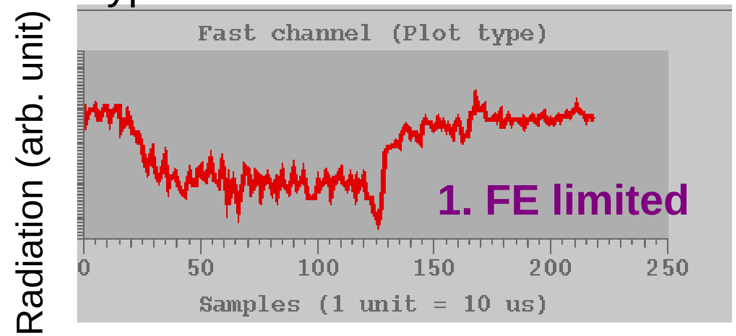
Radiation

Ex. 17b individual

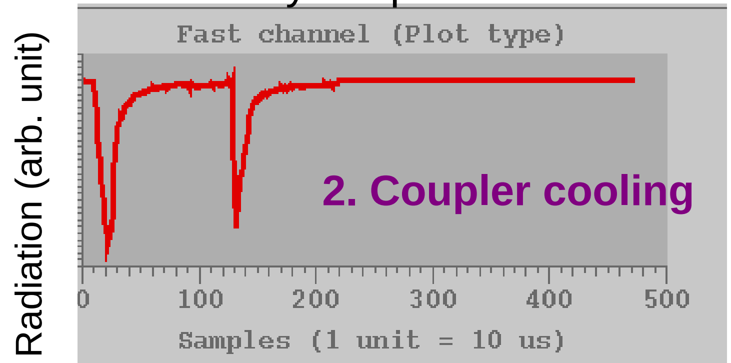




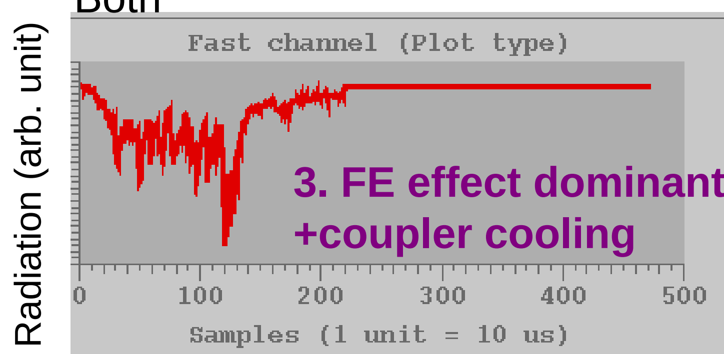
Typical field emission



From Cavity-coupler interaction



Both

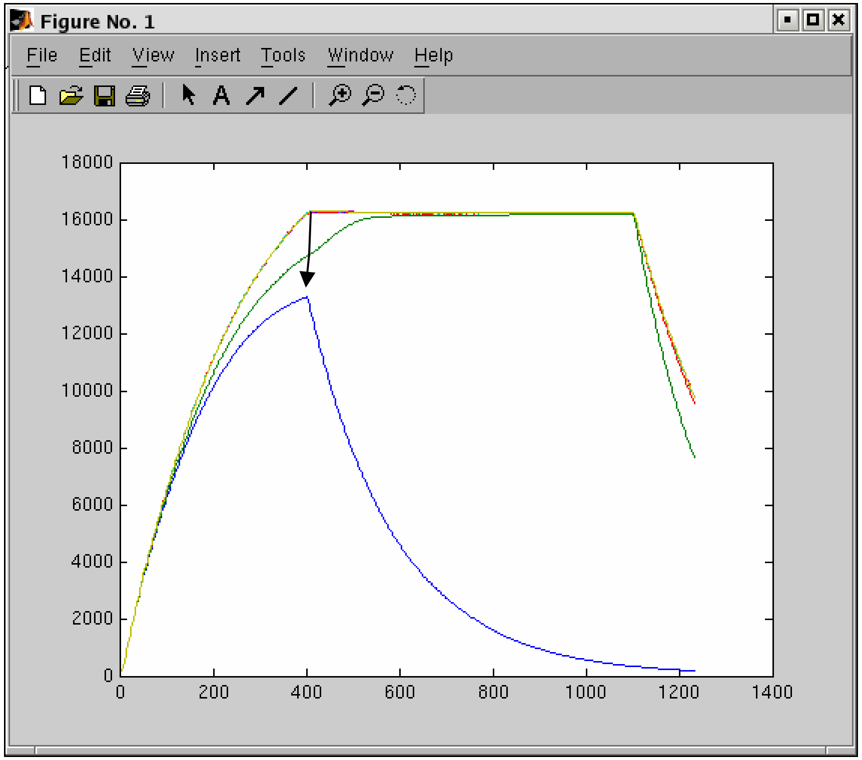


Most of cryomodules are limited by 1. and 3.

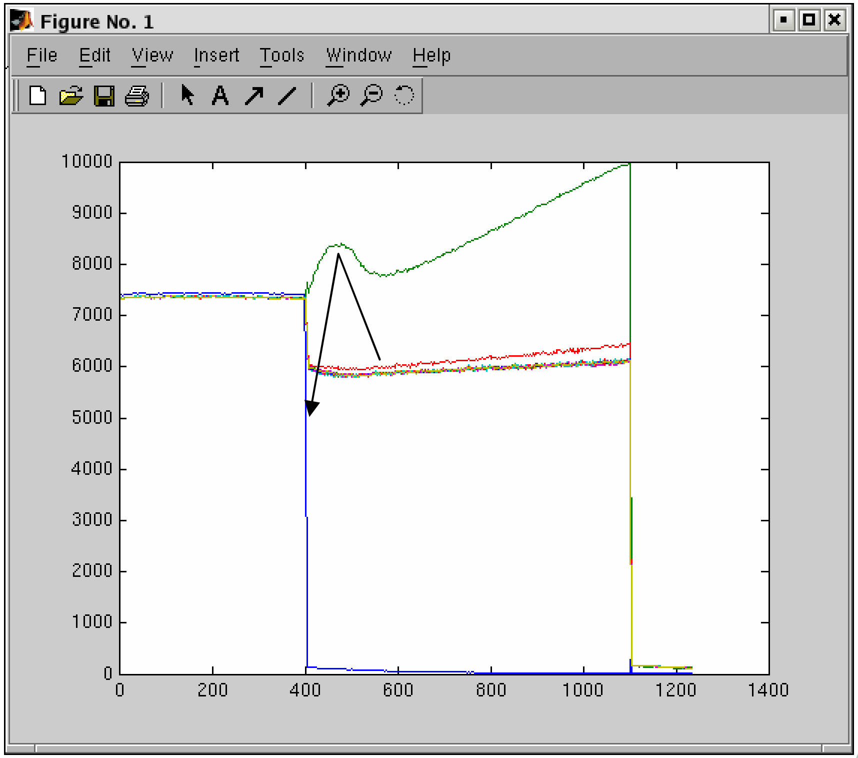
FE → End group heating → Partial quench

Usually with beam pipe heating + gas burst

Ex. 12c in closed loop (CM12 shows highest FE)



Cavity field



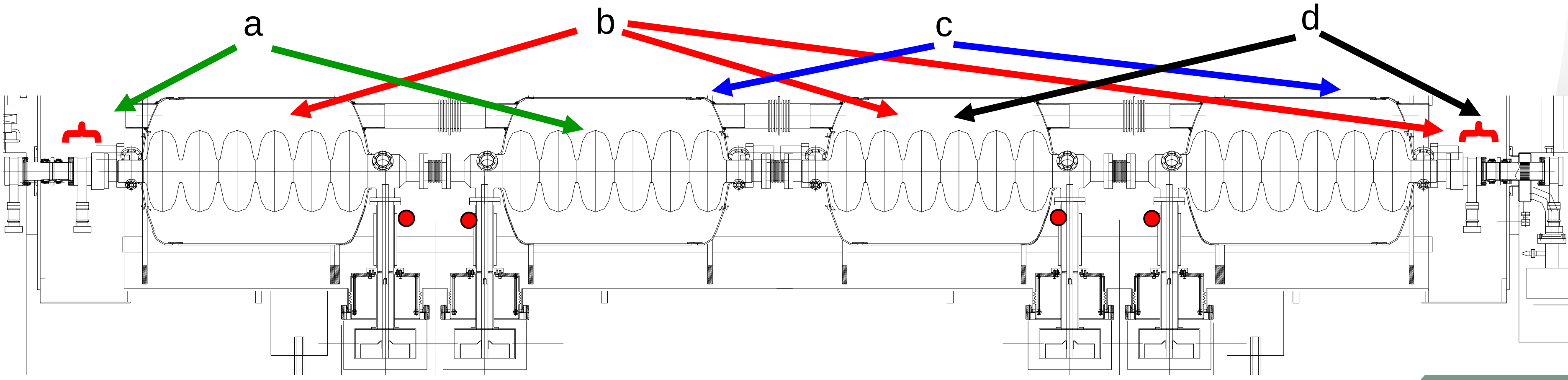
Forward power

Collective limits
(clear indication at higher rep. rate)

- **Field Emission;**

  steady state electron activity + sudden burst
  affects other cavities
  electron landing place (relative phase, amplitude)
  leads continuous gas activity, even though all signals look quiet
  hits intermediate temperature region (5-20K); H_2 evaporation (burst of gas)
  redistribution of gas→ changes cavity/coupler conditions

CM13 individual limits; 19.5, 15, 17, 14.5
CM13 collective limits; 14.5, 15, 15, 10.5



PUP cavities need close control of FE

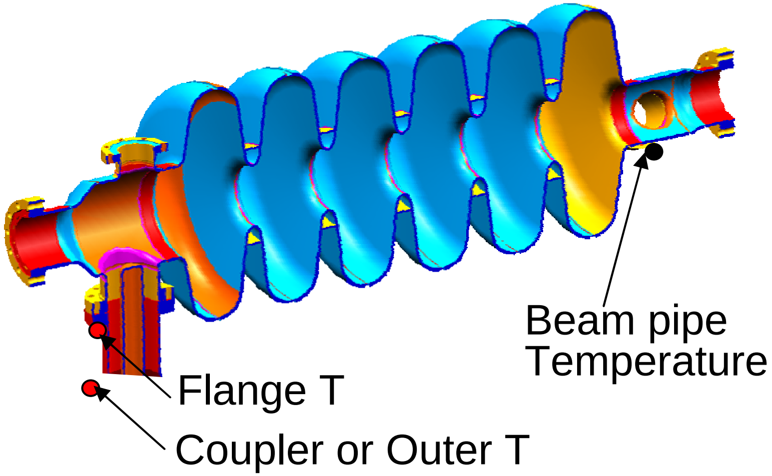
End-group heating

- Active control
  - Field emission (cell surface control)
  - Power coupler thermal radiation (Inner conductor cooling)

- Passive control
  - higher thermal conductivity niobium (higher RRR)
  - Add cooling

    Passive cooling with copper straps

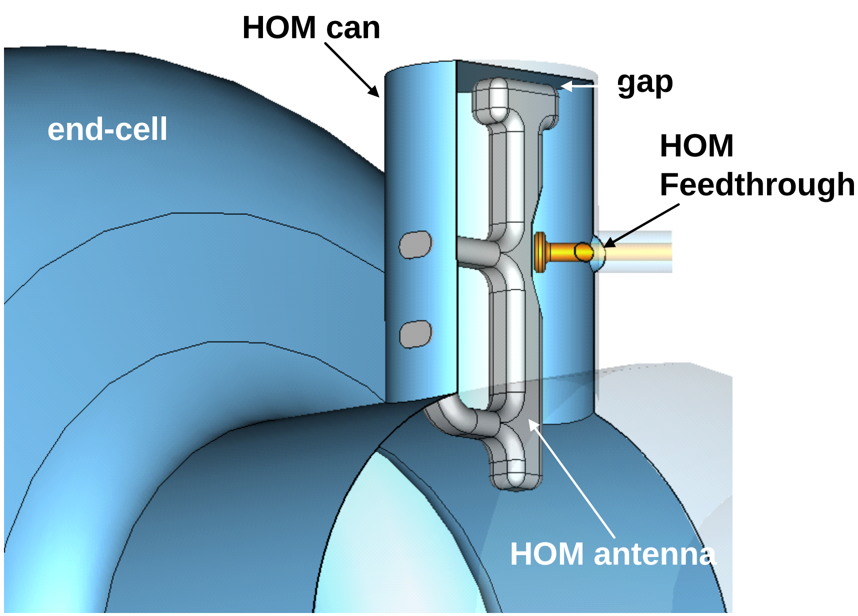
    Active cooling with coupler cooling He circuit



HOM coupler

- When Q_{hom}>10^5, there's a concern of HOM power (TM monopoles)
  - but the probability is very low
  - One (or two), if any, could have large HOM induced power
  - So far no observation
- Extra insurance
- Coaxial type notch filter scaled from TTF was chosen and installed.
- Low power tests confirmed its functionality
  - Damping; dangerous modes to have Q_{hom} ○ 10^4

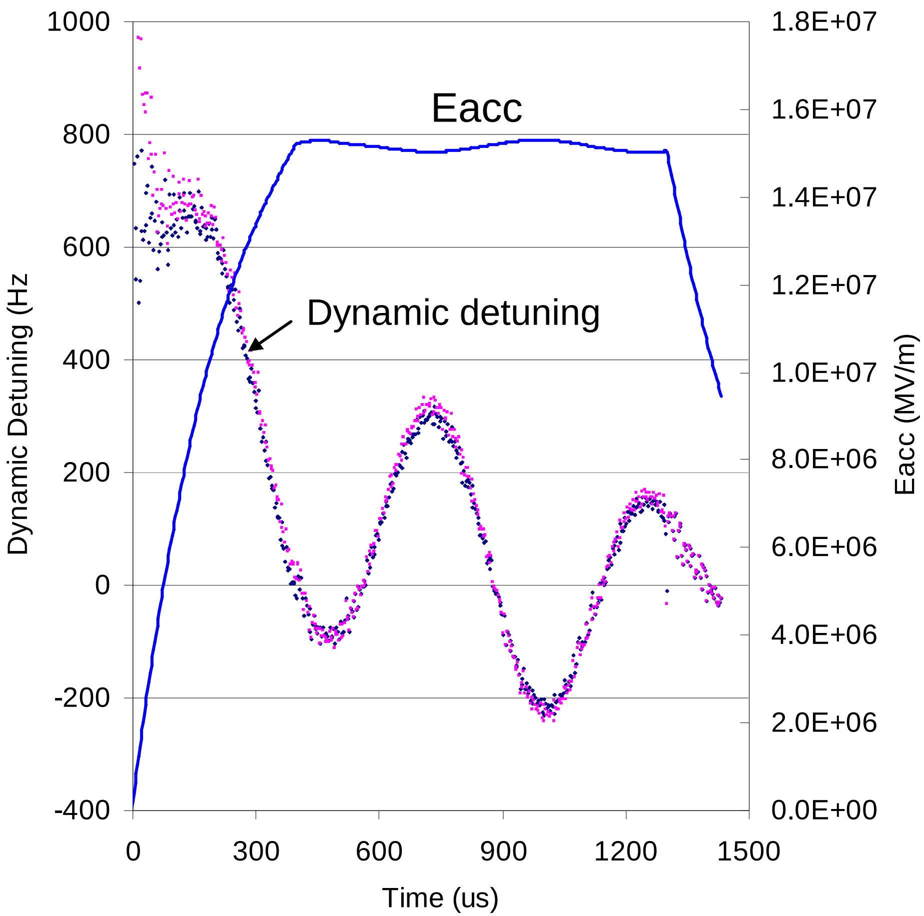
Any electron activity
→Destroy standing wave pattern
(or notching characteristics)
→Large fundamental power coupling
→Feedthrough/transmission line damage
→Irreversible

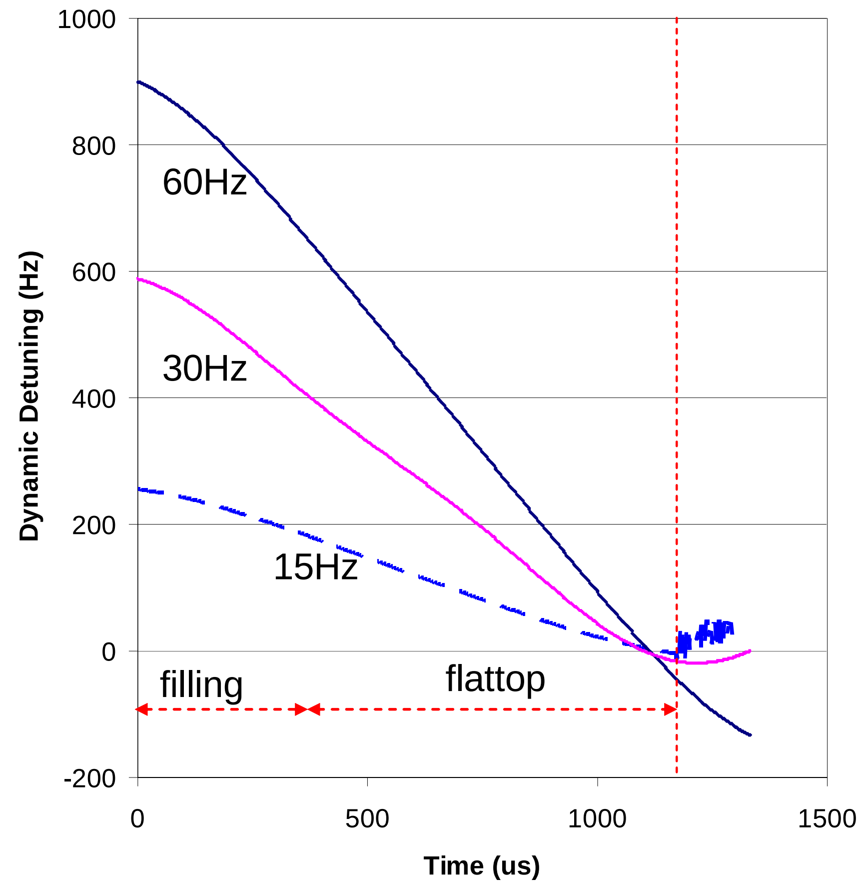


PUP cavity will not have HOM couplers

Lorentz force detuning

Most cavities show dynamic detuning as expected
($K_{LFD} \rightarrow$ 3-4;medium, 1-2;high)
But, a few cavities show bigger resonance phenomena as higher repetition rate



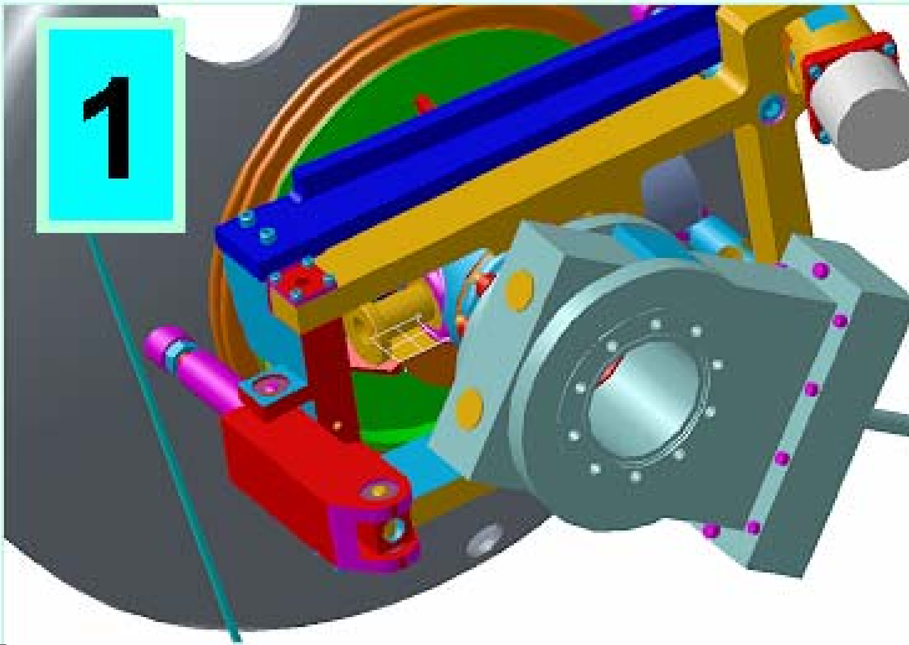


The 2 kHz components shows resonances
at higher repetition rate
in one medium beta cavities.

In this example the accelerating gradient is 12.7 MV/m.
High beta cavity

Others

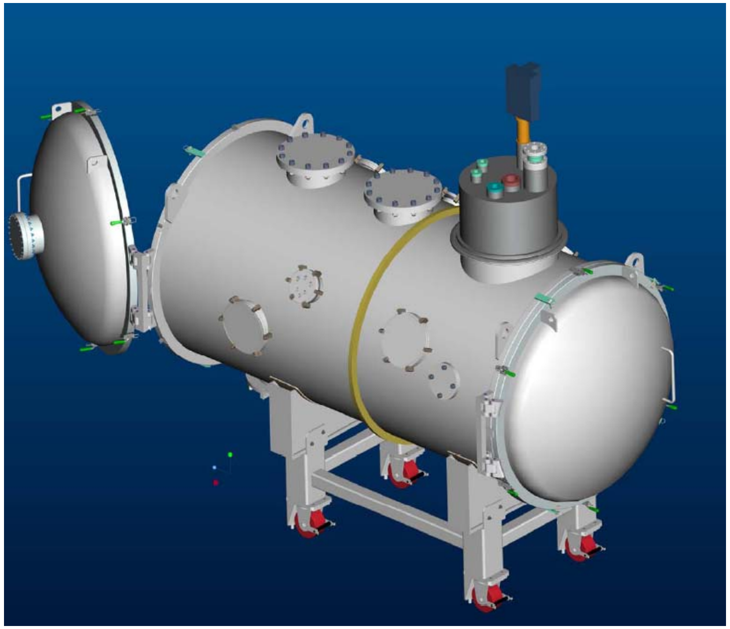
- **Piezo Tuner**
  - **In series stack**
  - **Fail→ availability of cavity**
  - **Never used in SNS**

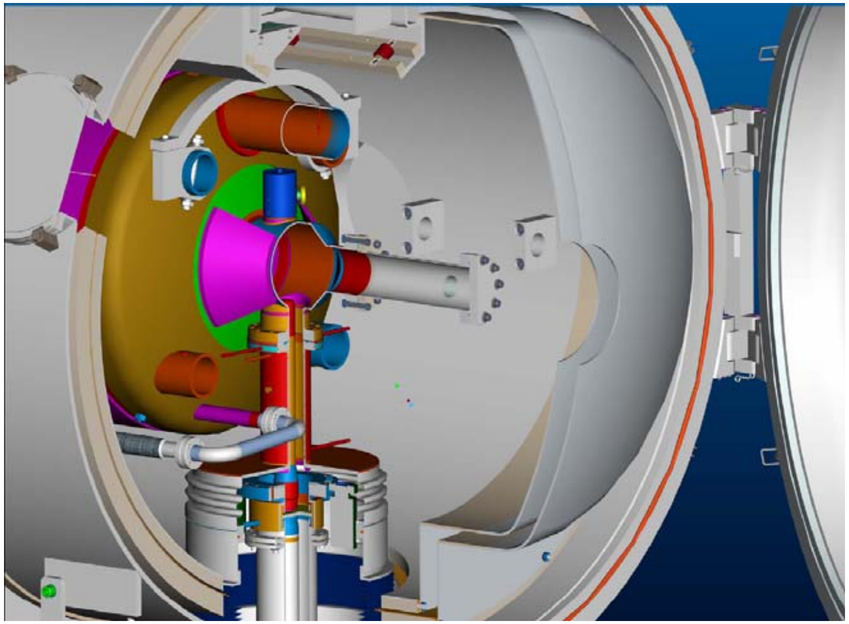


- **Cryogenics process lines**
  - **Thermocouple feedthroughs**
- **Cryomodule Gate valves**
  - **Elastomer seals**

PUP CMs and SRF Facility

- **All PUP R&D activity**
- **PUP Cavity/CM assembling & Critical processing**
- **PUP cavity qualification/CM tests**
- **Experience with spare CM acquisition→ PUP CMs procurement**





Horizontal Test Apparatus for cavity assembly test

Milestones of PUP SCL

Milestones	Early dates
Begin Design activities	Oct. 08
Start Cryomodule production	Sep.10
Start Cryomodule deliveries	May 11
Start Cryomodule testing	Jun. 11
Start Cryomodule installation	Jan. 12
Complete Cryomodule deliveries	Apr. 12
Complete Cryomodule installation	Jan. 13
ARR	Feb. 13
Commissioning	Mar. 13