Status of the SNS Linac: An Overview

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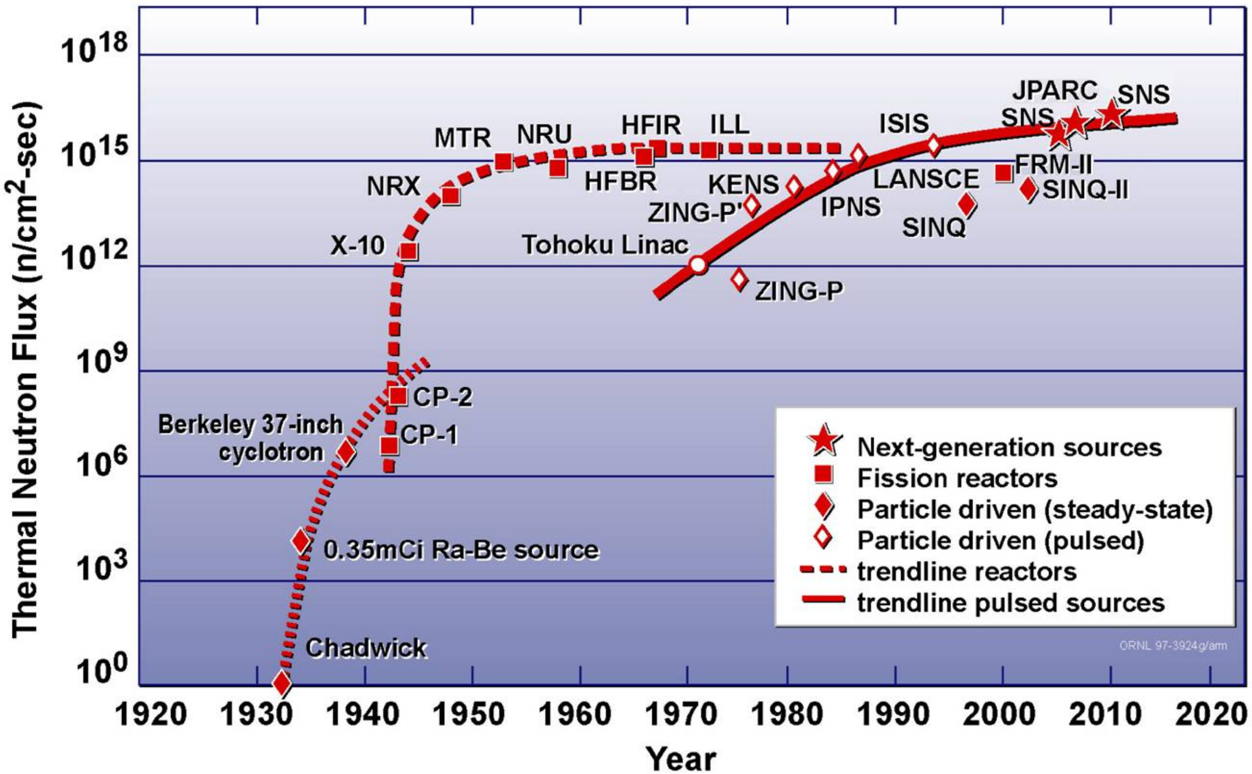
ORNL, Oak Ridge, TN 37830, USA

SNS is the Forefront Facility for Future High Beam Power Accelerators

Highest Beam Power worldwide under construction

Stepping stone to next generation Spallation Sources



(Updated from *Neutron Scattering*, K. Skold and D. L. Price: eds., Academic Press, 1986)

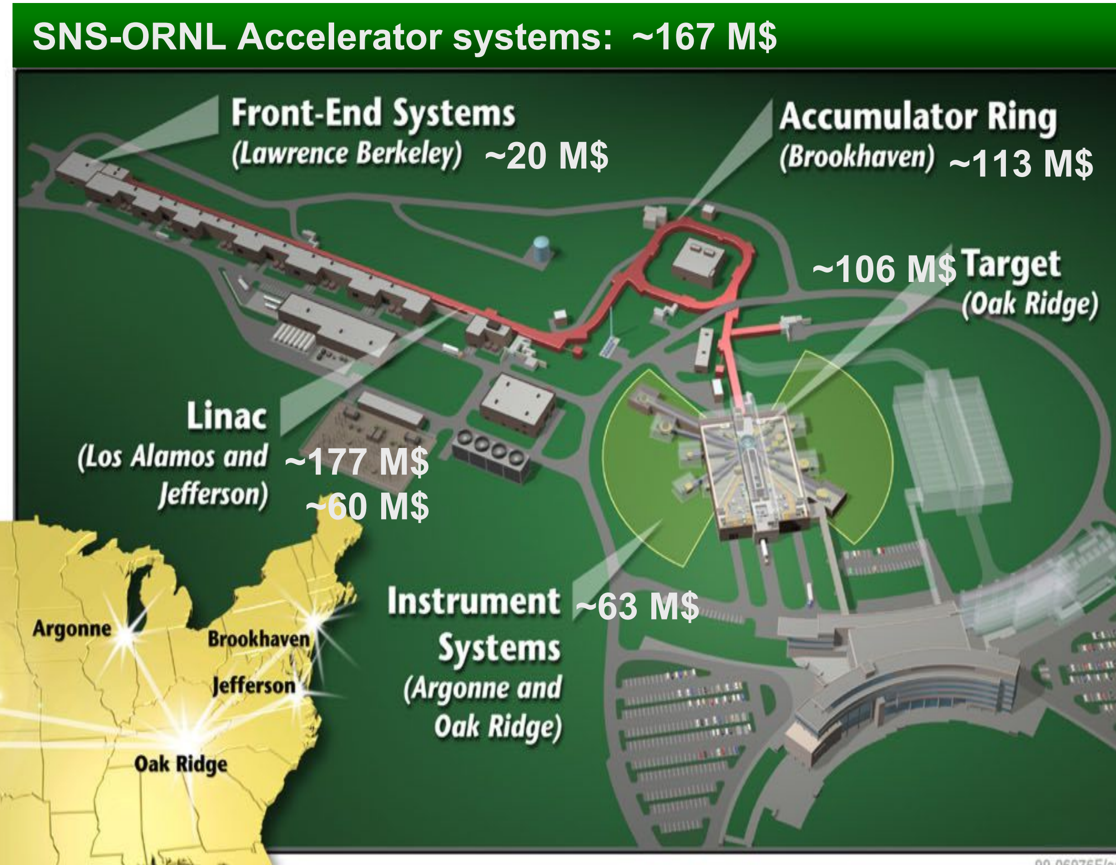
- **The SNS will begin operation in 2006**
- **At 1.4 MW it will be ~8x ISIS, the world's leading pulsed spallation source**
- **The peak thermal neutron flux will be ~50-100x ILL**
- **5000 hours per year at an availability of >90% …… !!!!!!!!!!! (~ in 2009)**

The Spallation Neutron Source Partnership

SNS SPALLATION NEUTRON SOURCE

Description		Accelerator
Project Support	75.6	
Front End Systems	20.8	20.8
Linac Systems	315.9	315.9
Ring & Transfer System	142.0	142.0
Target Systems	108.2	
Instrument Systems	63.3	
Conventional Facilities	378.9	
Integrated Control Syst	59.7	59.7
BAC	1,164.4	
Contingency	28.3	
TEC	1,192.7	
R&D	100.0	80.0
Pre-Operations	119.0	95.2
TPC	1,411.7	713.6

At peak: ~500 People worked on the construction of the SNS accelerator

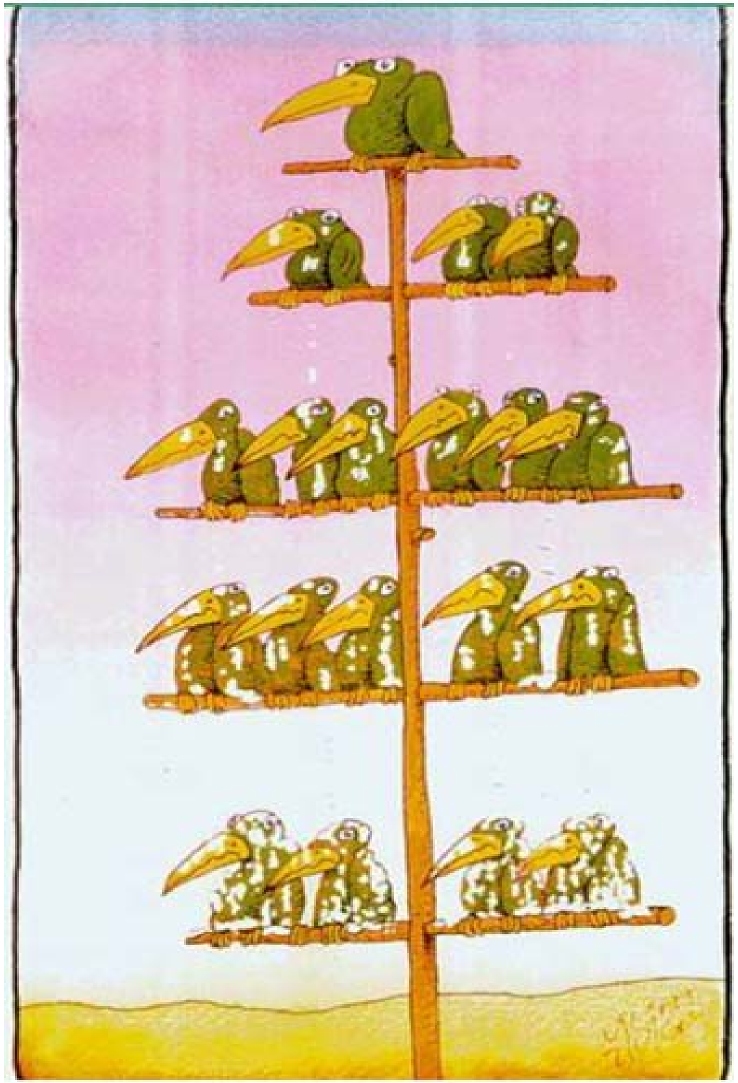


Oak Ridge, TN

35° 49' N , 83° 59' W

SNS Multilab Organizational Chart

- The Multi Lab Organization of SNS has brought an enormous amount of expertise to the table.
- It has made it easier to transition the required workforce in and out of the project.
- SNS is just one of several models that I m sure will be used to built large science projects in the future.
- The Multi Lab Org Chart for SNS is in many ways is not different than a typical one, but it does add a few layers of management.

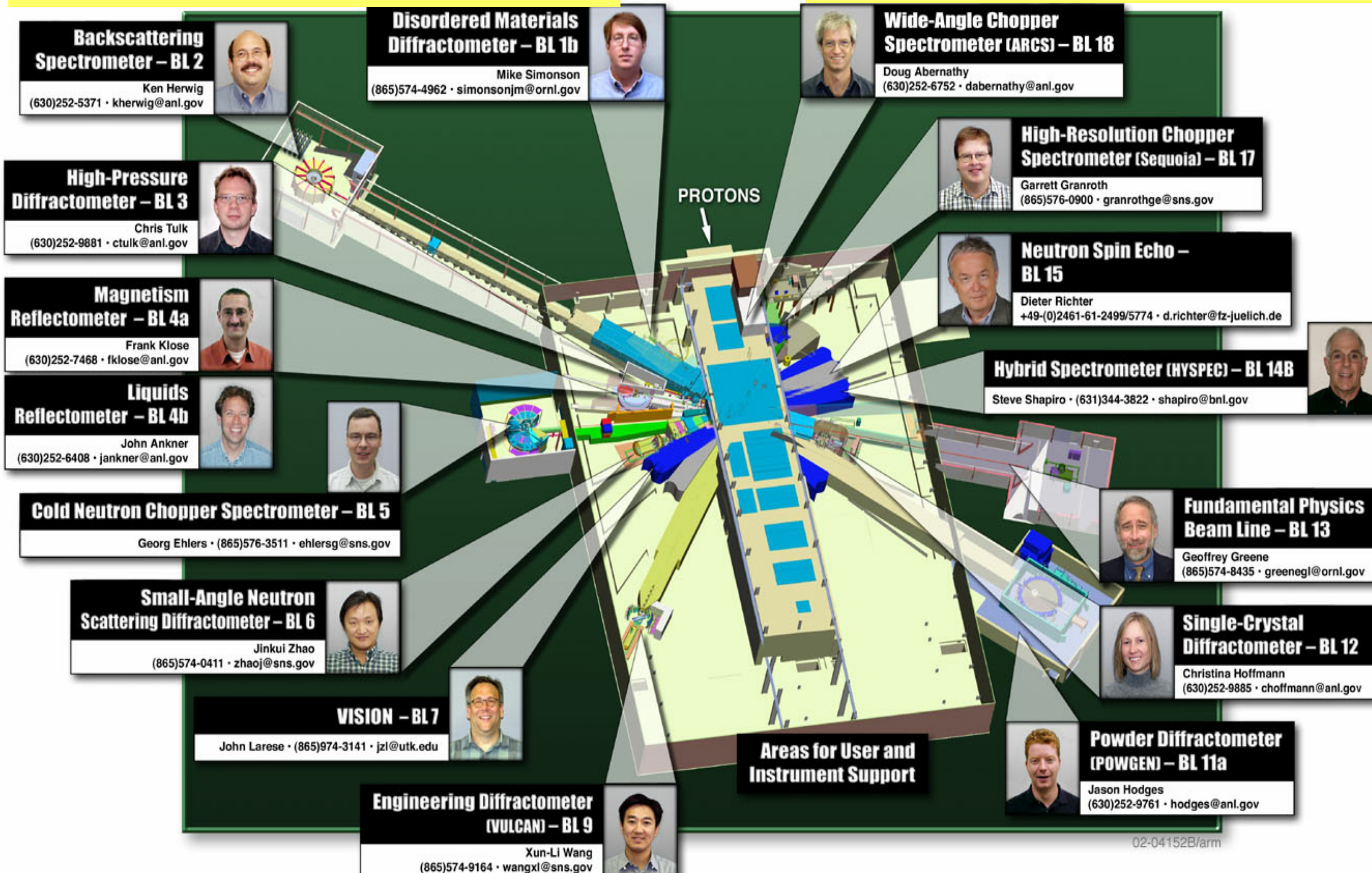


Project Status

- Total cost is $1.4 B (US accounting), peaked in 2002 with $290 M.
- Project has costed or/and awarded almost $1.2B out of $1.4B
  – Overall project design is 94% complete
  – Overall the project is >84% complete (as of July)
  – Within budget and schedule constraints ($1.4B and June 2006 completion)
- ES&H performance outstanding
  – >5 million hours with one lost workday injury (combined hours worked for construction site and SNS/ORNL)

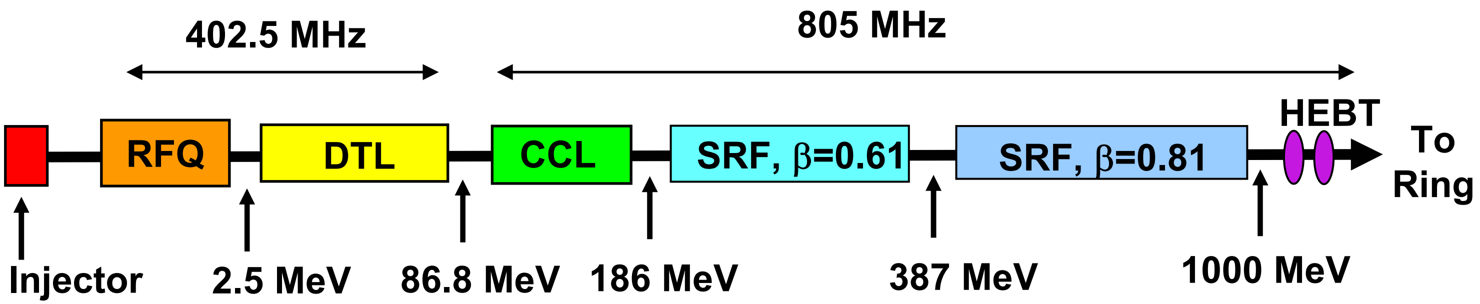
16 Instruments Now Formally Approved

- Fundamental Physics to Engineering
- Chemistry to "Genomes to Life"



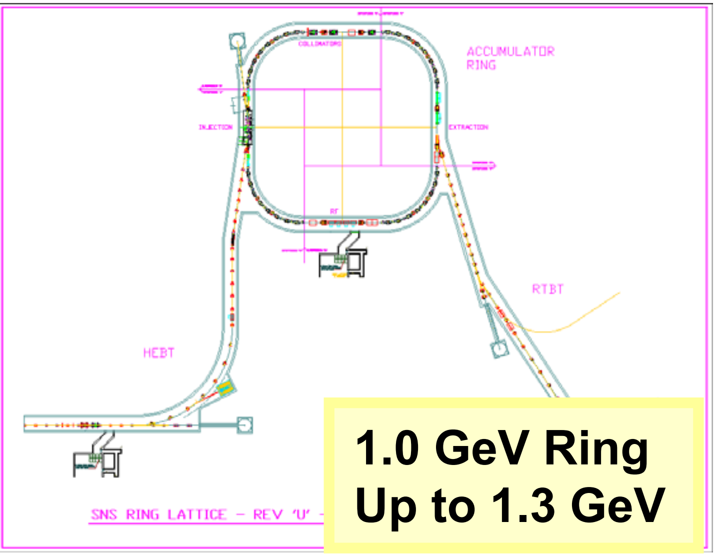
Construction Nearing the End

Major SNS Facility Parameters

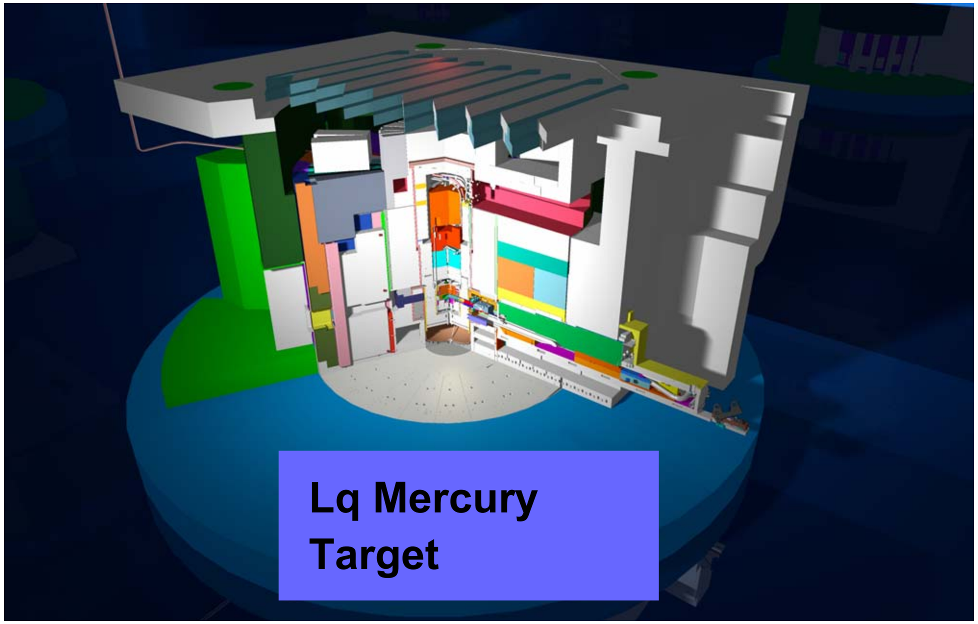


1 RFQ
6 DTL Tanks
4 CCL Modules

11 Medium-β Cryomodules - 3 Nb cavities each
12 High-β Cryomodules - 4 Nb cavities each

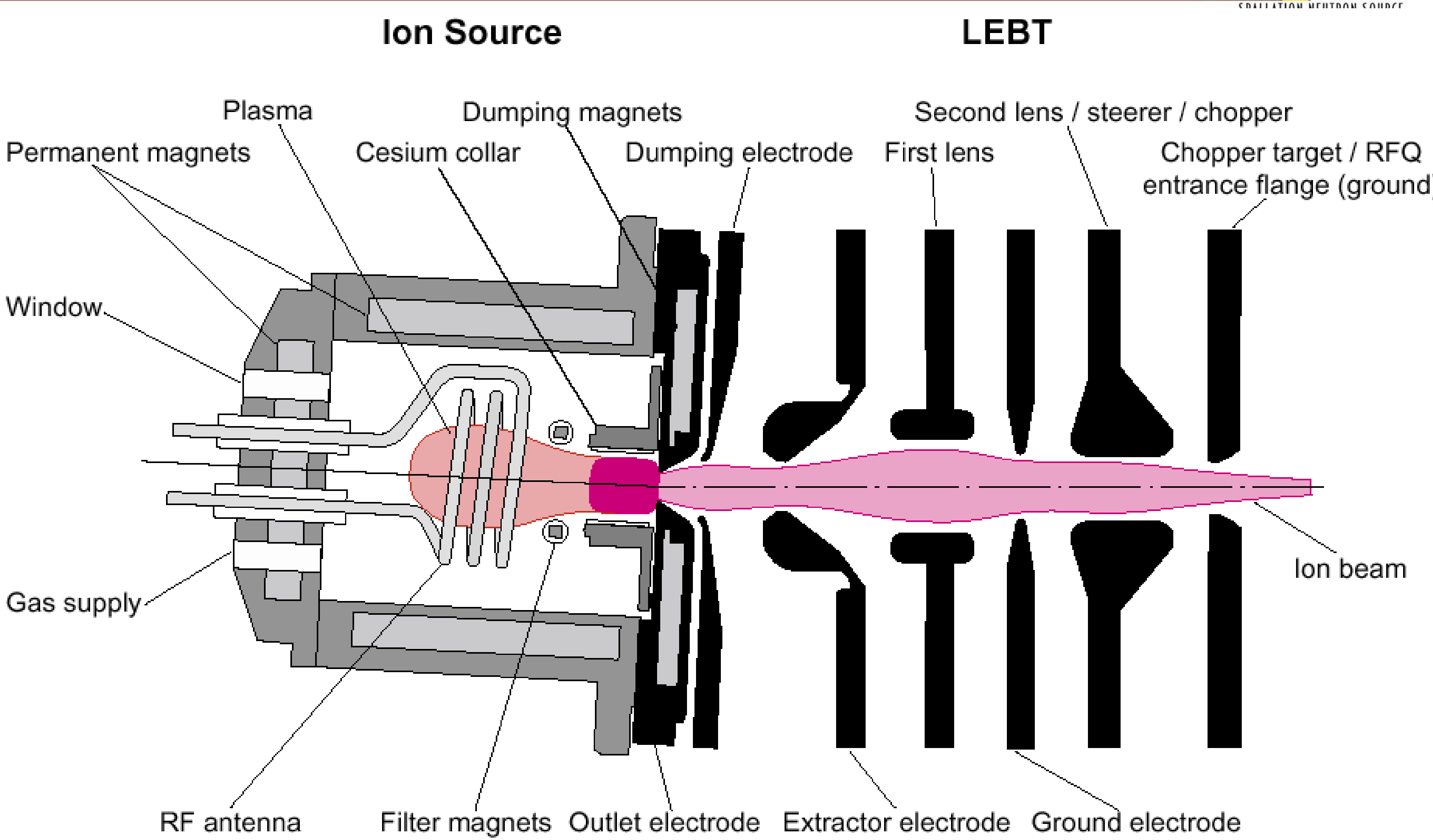


1.0 GeV Ring
Up to 1.3 GeV



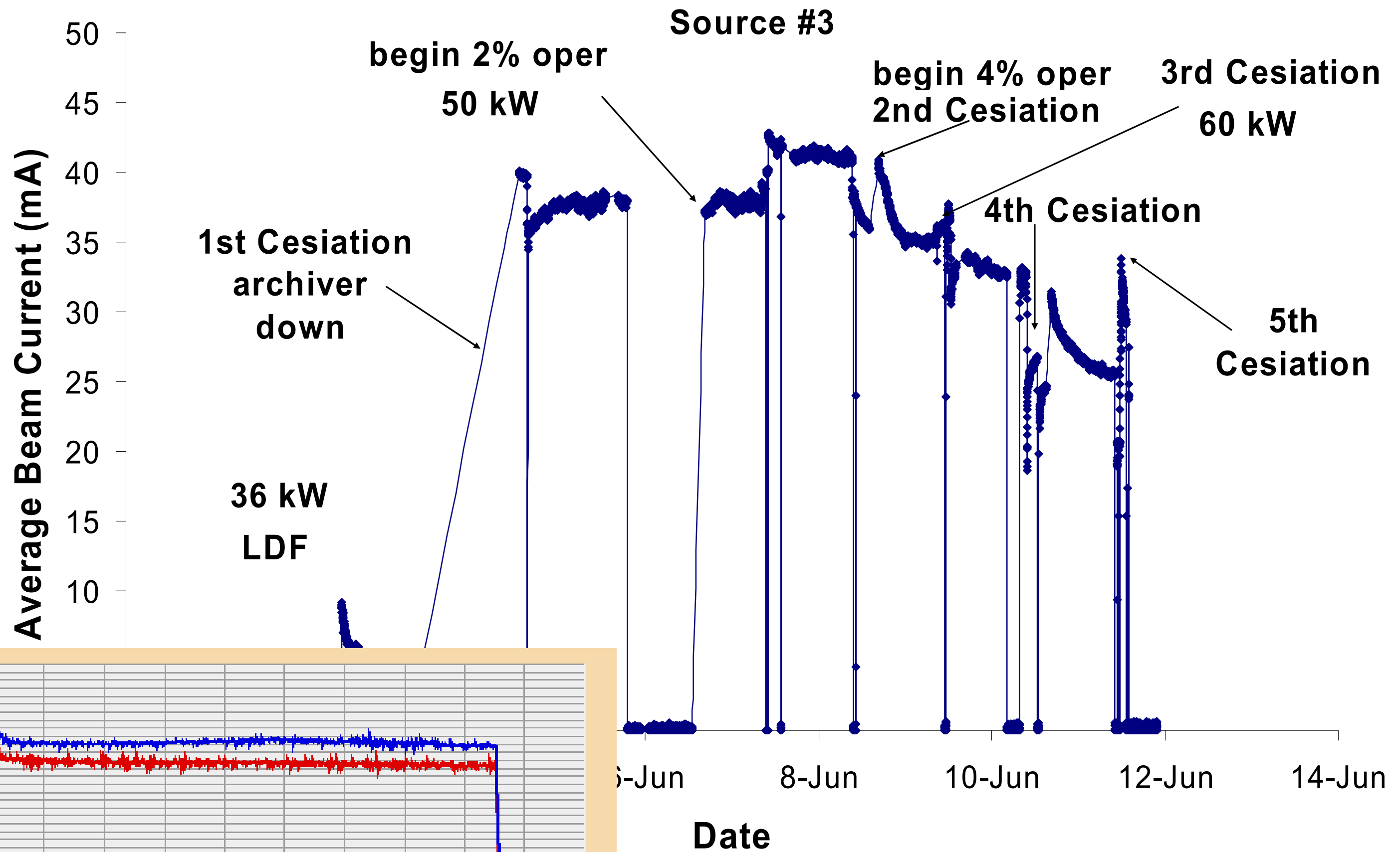
Lq Mercury Target

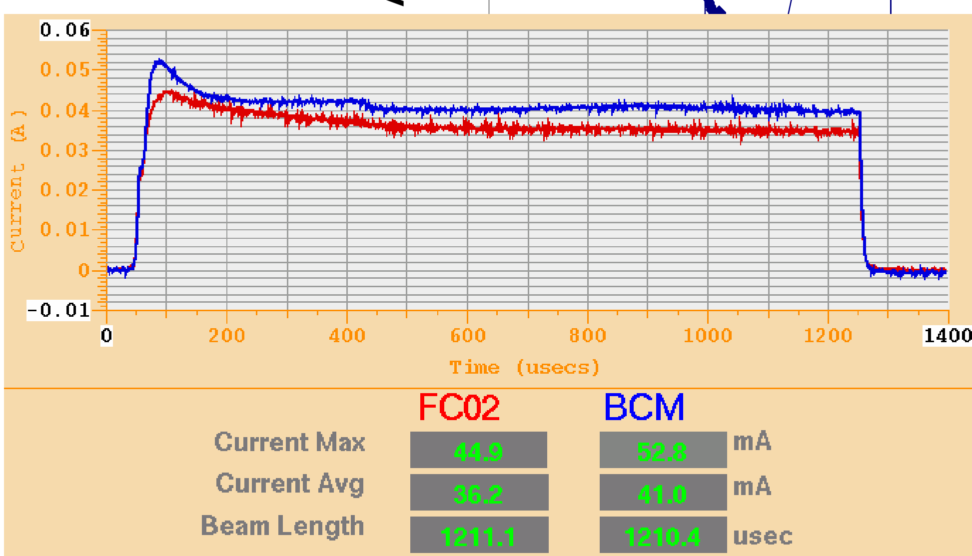
The SNS Ion Source



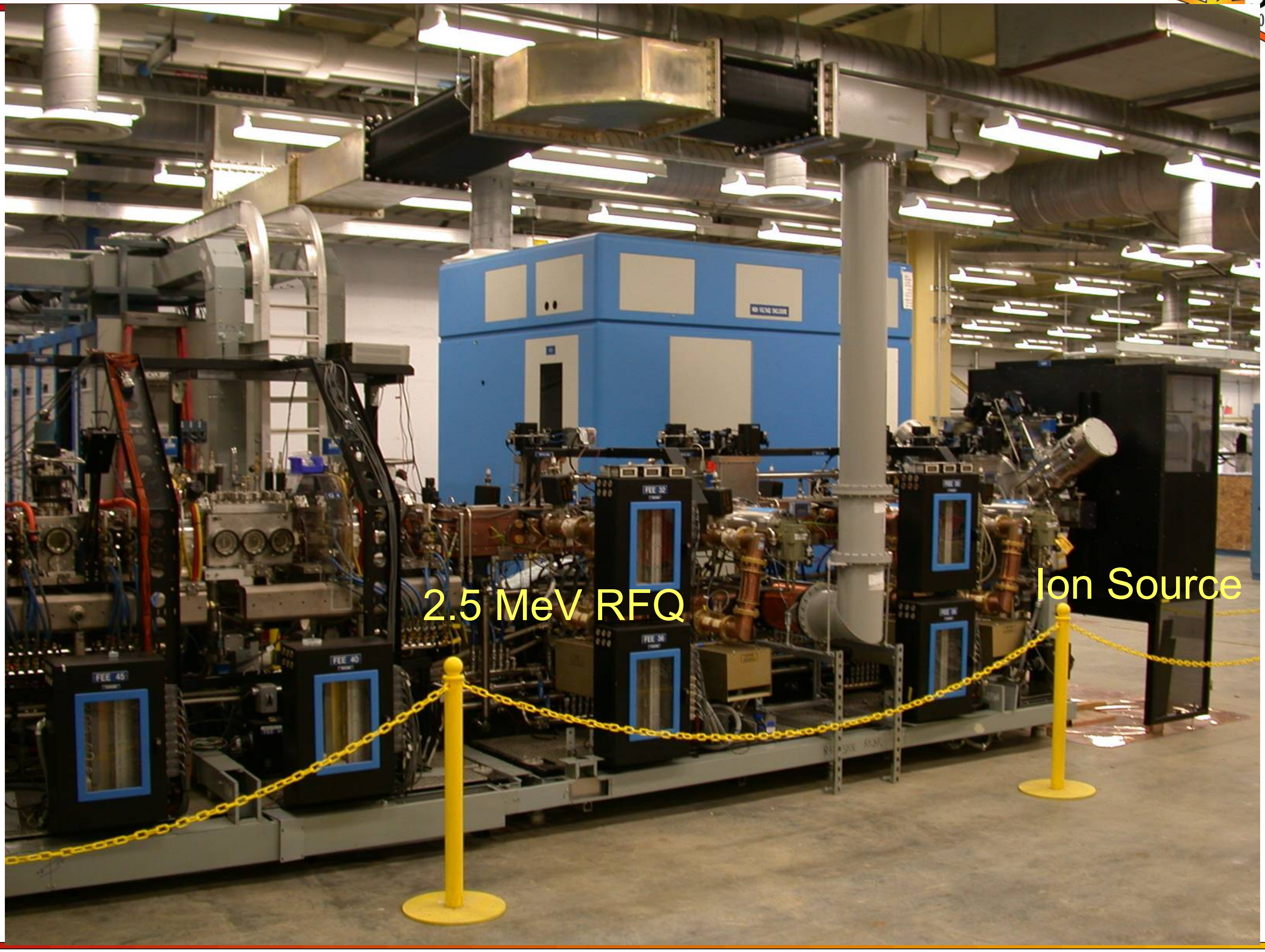
The SNS Ion Source

- *Typically the initial peak current exceeds the average current by ~30%.*





LBNL: Design And Built Front End

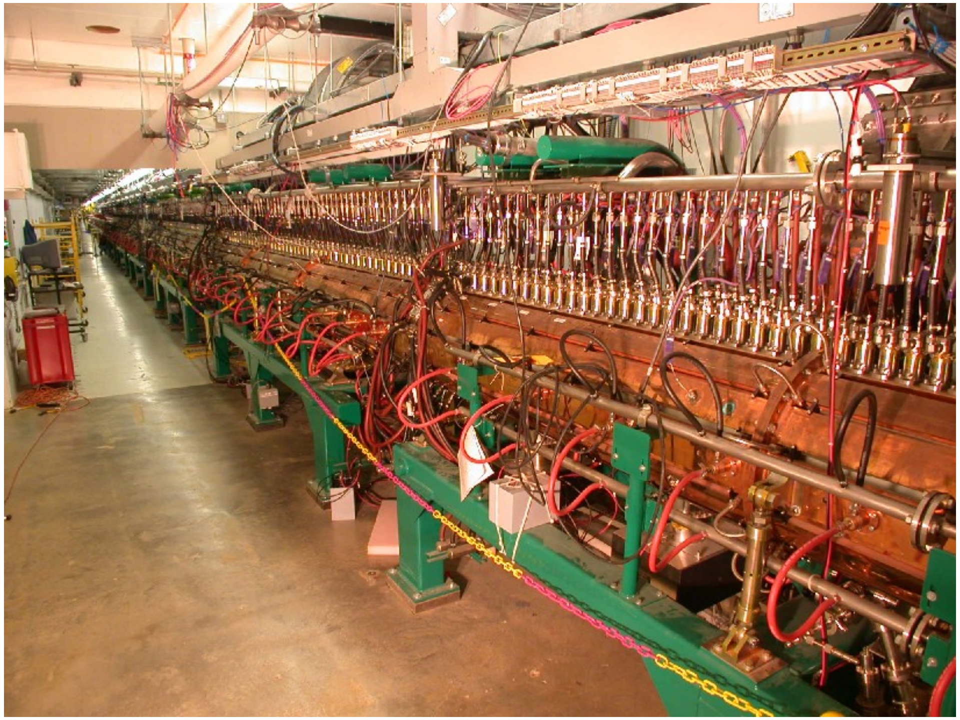


Drift Tube Linac Components

See S. Aleksandrov's
Talk: WE 201

All DTLs

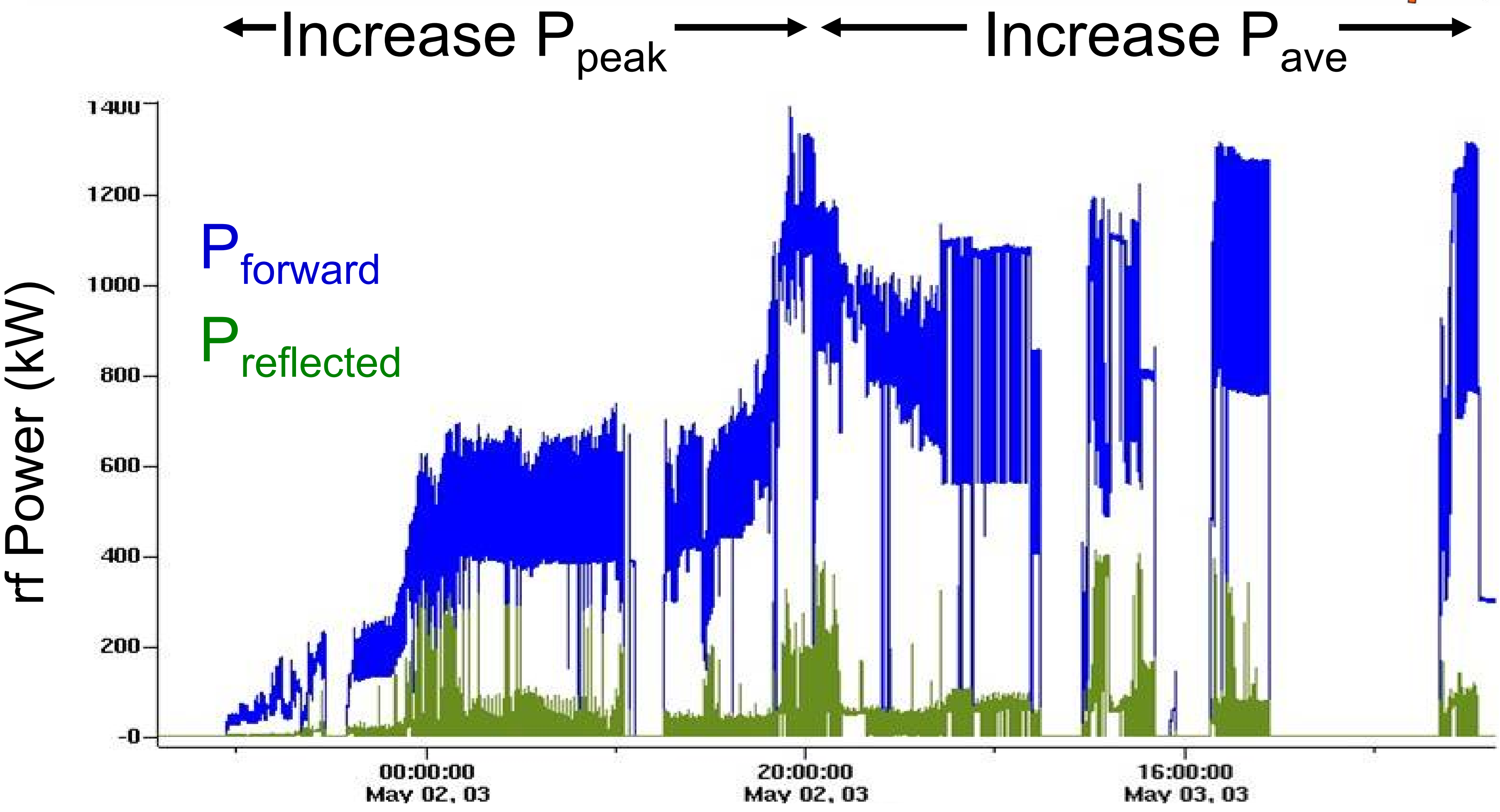
- 402.5 MHz DTL designed at LANL
- Components built to spec in industry (plating at GSI)
- Assembled largely at ORNL



- All DTLs installed with 210 drift tubes in place.
- Operates at 1.3 x Kilpatrick max.
- Drift tubes have integrated permanent magnet quads
- 24 steering dipoles

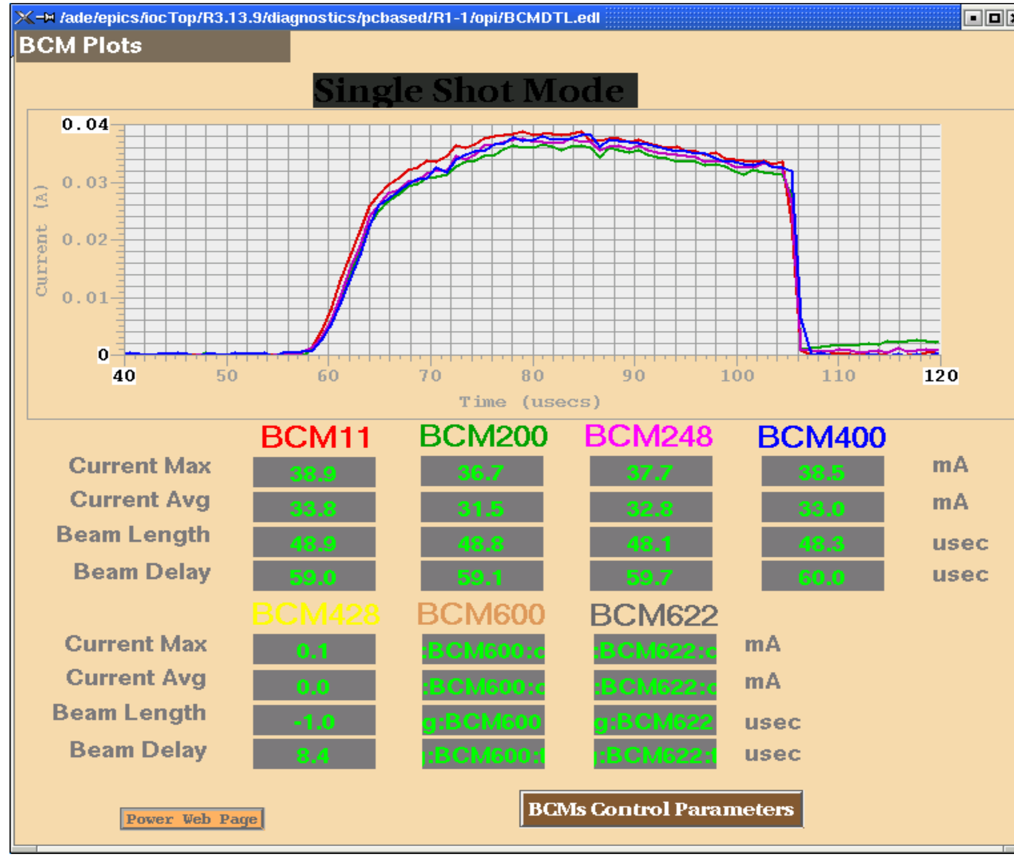
- 10 beam position +phase
- monitors
- 12 beam loss monitors
- 6 beam current monitors 6
- 5 wire scanners
- 5 Faraday cups
- 12 neutron detectors

Tank 3 Conditioned to Full Field and 40% Duty Factor in 30 hr !



DTL 1-3 Commissioning: 40 MeV

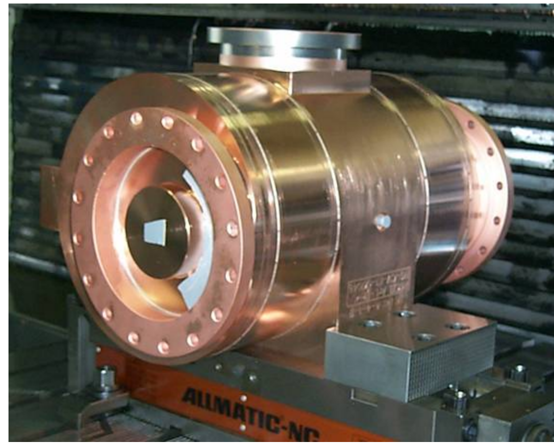
- Can only run very short pulse and little beam power from now on.
- Beam Commissioned DTL1-3 in April 2004:
- Had beam through DTL3 36 hours after approval for operation:
  - Achieved design 38 mA peak current
  - 100% transmission



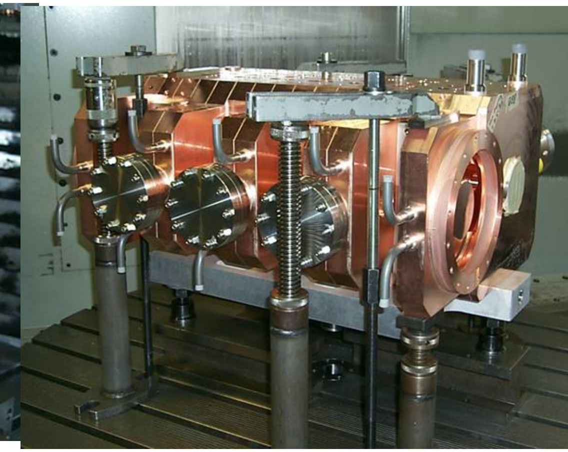
Coupled-Cavity Linac (CCL) Construction by LANL done in Industry

SNS
SPALLATION NEUTRON SOURCE

- **Contract awarded to Industry**
- **Hot model operated at 130% of peak field and 190% average power**



Bridge Coupler 44 final machining



Segment 1-6 fiducial machining

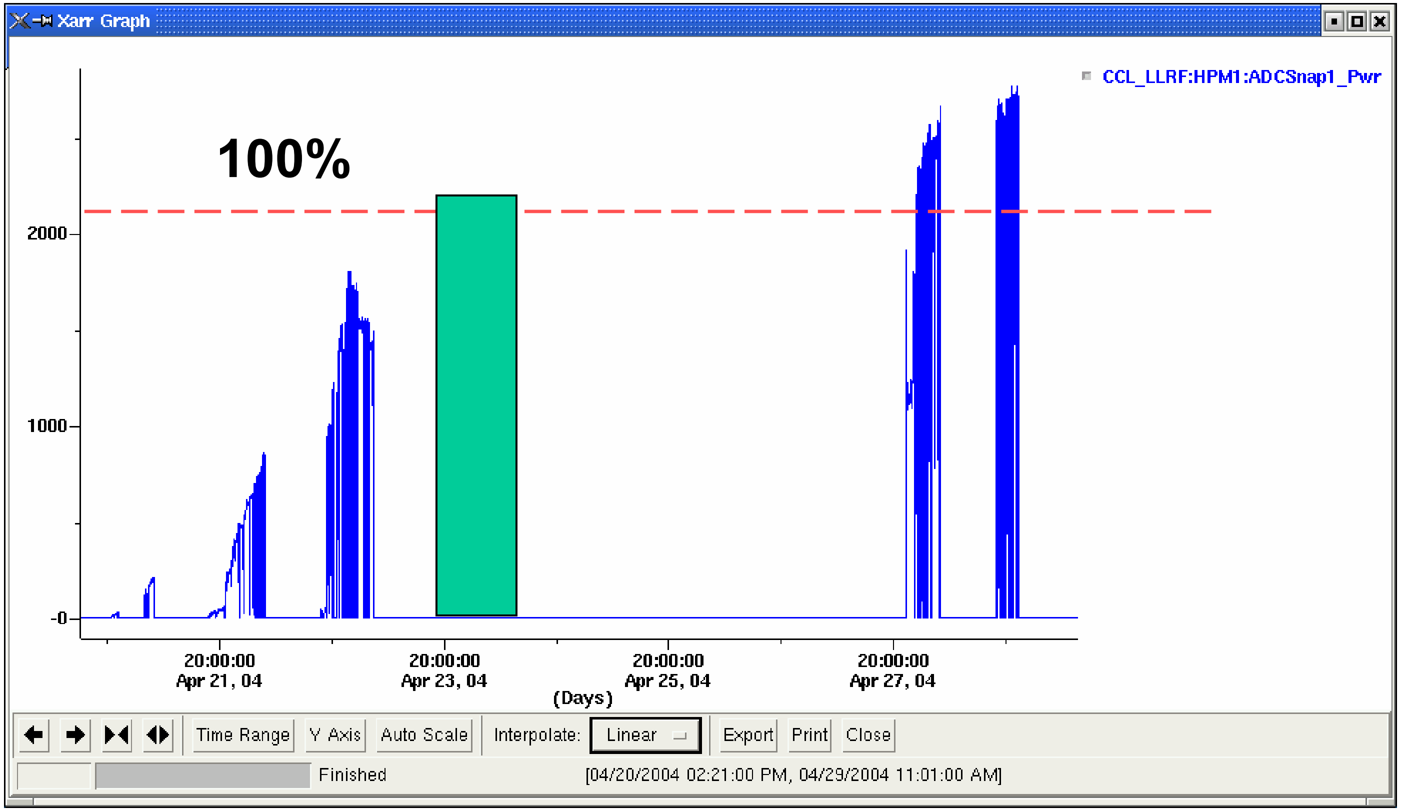
Production Segments

Coupled-Cavity Linac Deliveries Support September 2004 Commissioning Start

- 55 m long linac divided into 4 modules
- Designed at LANL, build and tuned in industry.
- Operates at 1.3 x Kilpatrick max.
- 48 quadrupoles and 32 steering magnets between segments.

- 10 beam position and phase
- monitors
- 28 beam loss monitors 1 current monitors
- 7 wire scanners
- 1 Faraday cups
- 3 bunch shape monitors
- 8 neutron detectors

CCL1 Module 1 Successfully RF Conditioned



Achieved: 2.5 MW (~120% of nominal power) @

20Hz, 1ms after 5 x 12 hour shifts

HVCM Simplified Block Diagram

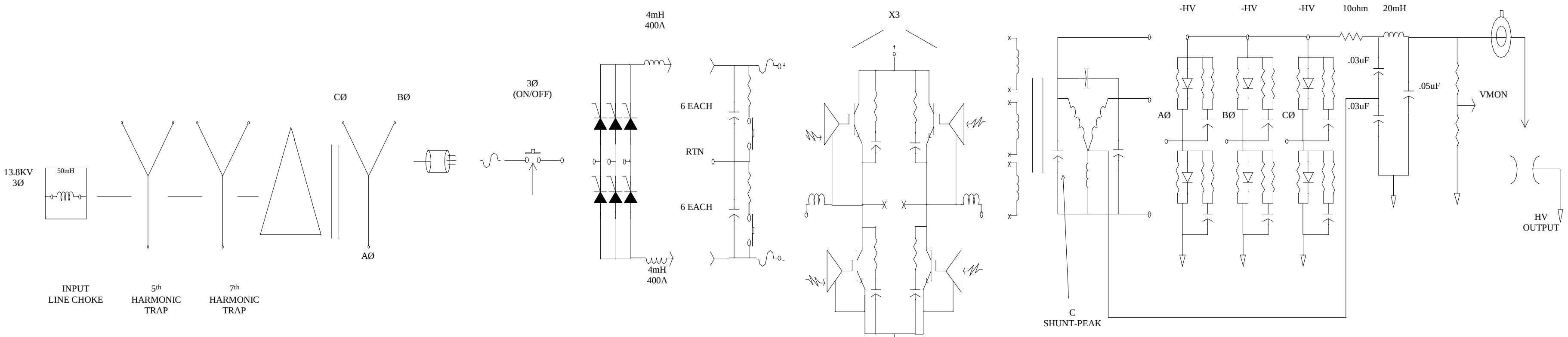
RECTIFIER TRANSFORMER AND FILTERS

SCR REGULATOR

ENERGY STORAGE/SWITCHING

BOOST TRANSFORMER

HV RECTIFIER AND FILTER NETWORK



RECTIFIER TRANSFORMER AND FILTERS

SCR REGULATOR

HIGH VOLTAGE CONVERTER/MODULATOR

EQUIPMENT CONTROL RACK

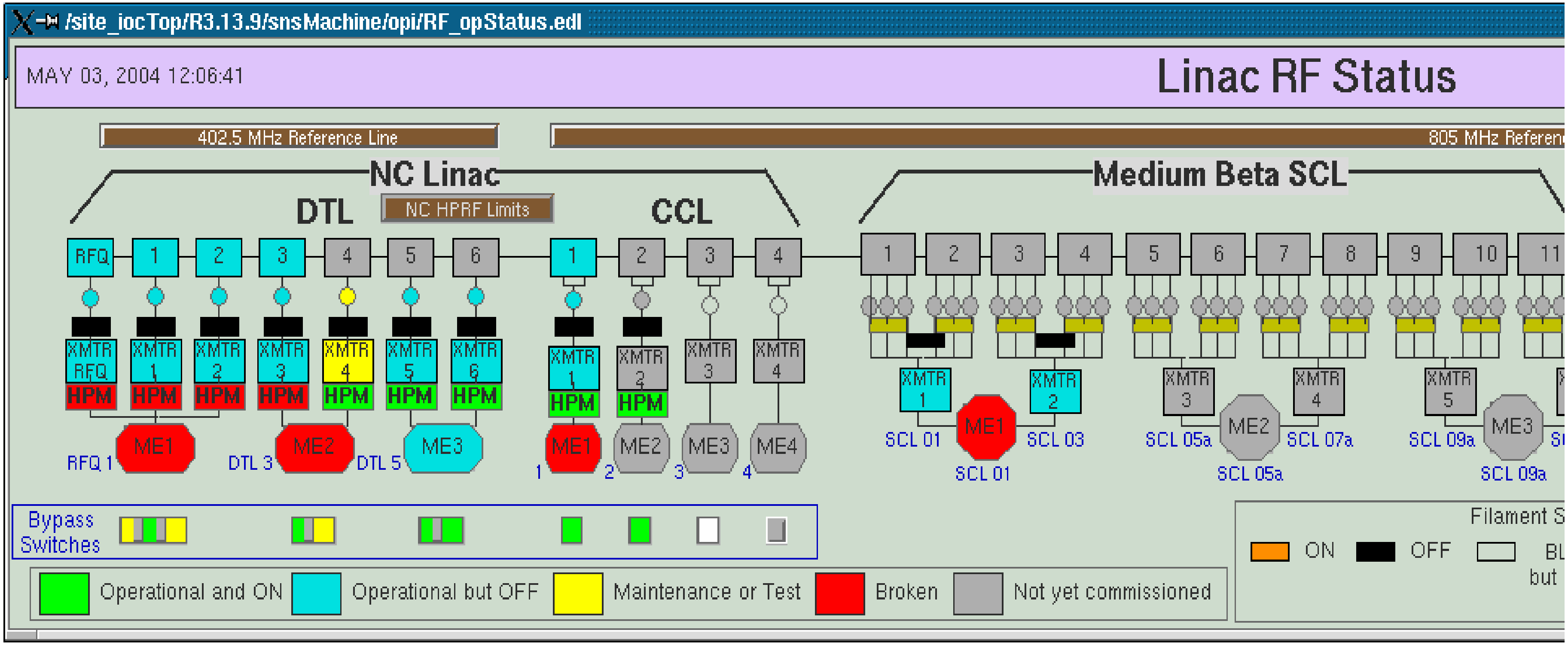
HVCM Descritpion

- 11 HVCM out of 14 for the linac are installed.
- All 11 have been operated/tested.
- Combination of built to spec/built to print contract in industry.
- They have operated a total of ~8000 h at a variety of η with approximately 1500 at full load (η=7.5%).
- Depending on the klystron the operate between 75 and 115kV driving up to 12 klystrons in parallel.
- Have a very compact IGBT driven high Frequency (20kHz) converter with a compact polyphase transformer.
- The power density in the modulator compared to ~20 y ago went up by ~ x50. …. Which has its challenges!

High-Power RF Installation Progress

- All RFQ / DTL HPRF Systems complete and operational. 2.5 MW - 402.5MHz klystron with 2-3 per HVCM
- All four CCL systems are complete. 5 MW – 805MHZ klystron with 1 per HVCM.
- 60 of 81 SCL klystrons installed. 550kW- 805MHz klystrons with typically 12 per HVCM.
  - 2 SCL modulators tested
- All klystrons are made in industry in Europe and the US.

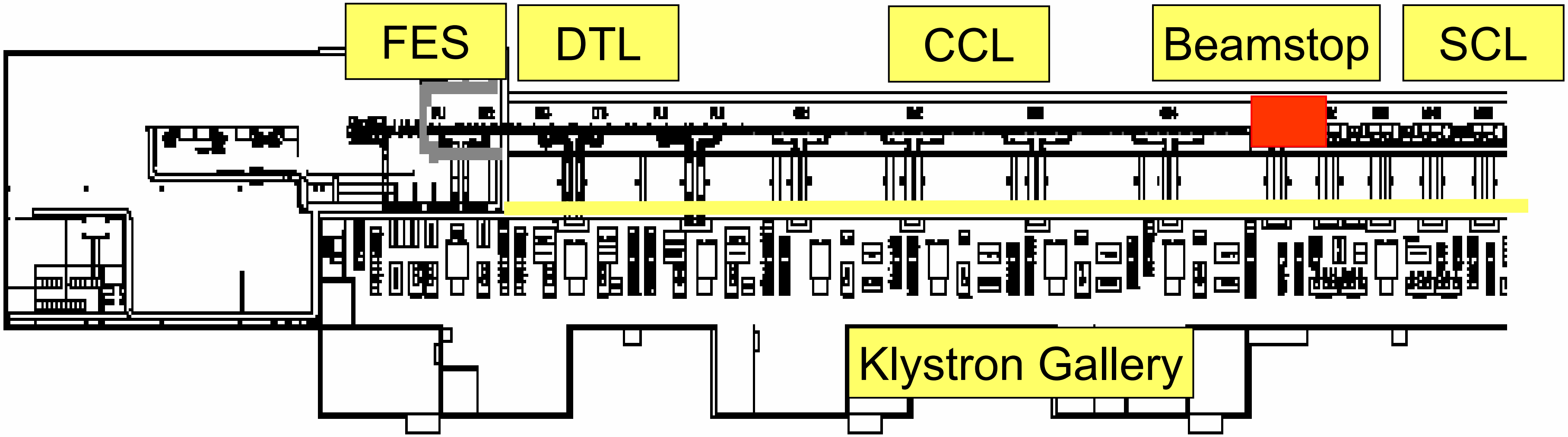
RF System / Modulator Configuration Screen



- Status of each Klystron, HVCM and transmitters displayed along with a description of its readiness.

DTL-CCL Commissioning And Cryomodule Testing In The Tunnel Sept. 04

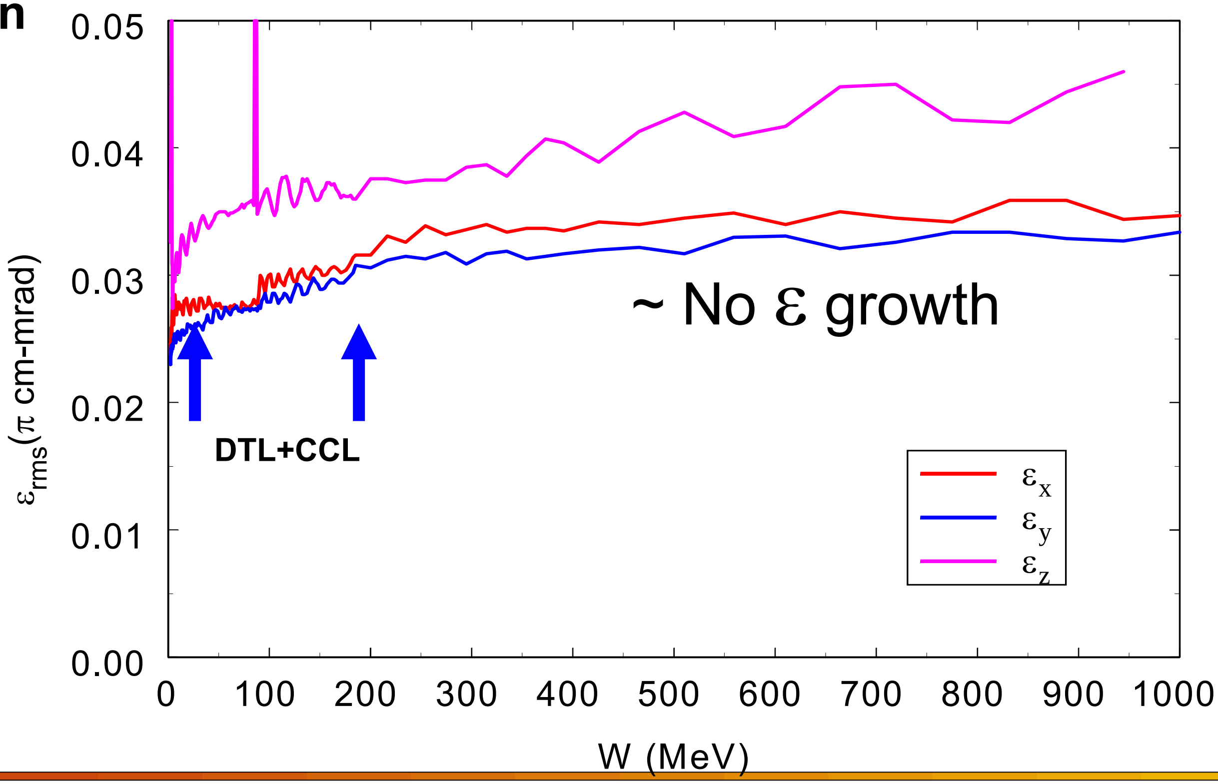
- The DTL – CCL enclosure will include the whole linac as one PPS area Decided to install shielding wall between CCL and SCL to minimize interference with conditioning, commissioning and SCL installation and testing.
- SCL cryomodule testing in the tunnel will begin mid-August.



JLAB: The Superconducting Linac

Superconducting RF Advantages:

1. Flexibility ➔ gradient and energy are not fixed
2. More power efficient ➔ lower operational cost
3. High cavity fields ➔ less real estate
4. Better vacuum ➔less gas stripping
5. Large aperture ➔ less aperture restrictions ➔ reduced beam loss ➔reduced activation



The Superconducting Linac

- All 81 + 25 cavities are built, chemically pre treated and initially tuned in industry
- Linac has a total of 23 CM's; 11 medium β (MB) and 12 high β (HB). 9 more slots available.
- Cavities over-perform by ~25 % compared to spec for MB and HB. So far tested at JLab only.
- Linac is 157 m long and has 32 warm sections between CM's and 67 quadrupoles with h+v steerer windings and a special laser diagnostics for emittance measurements

Medium Beta

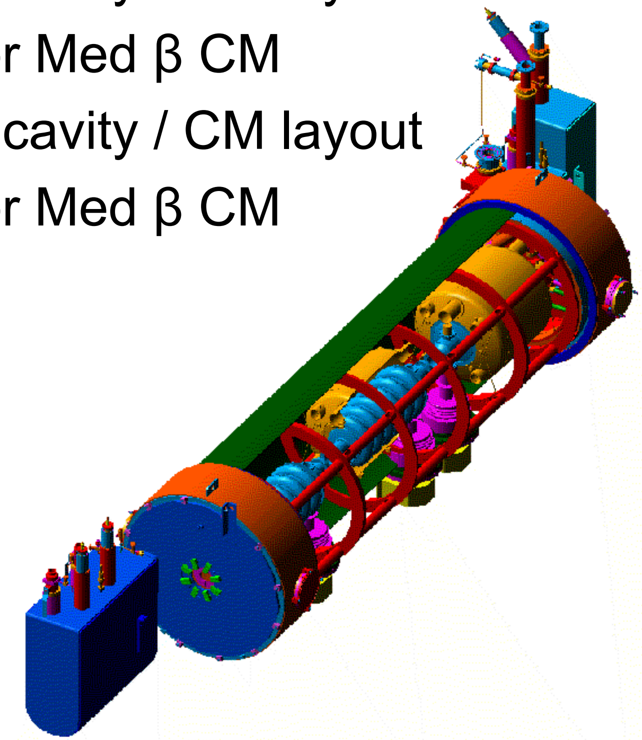
7	**CM – in tunnel tested**
3	**CM – in tunnel untested**
1	**CM – complete at JLab**

High Beta

0	**CM – in tunnel tested**
1	**CM – in tunnel untested**
3	**CM – complete at JLab**
5	**CM – in progress**
2	**Cavities delivered**

SNS Medium Beta Cryomodule

3 cavity / CM layout
for Med β CM
4 cavity / CM layout
for Med β CM

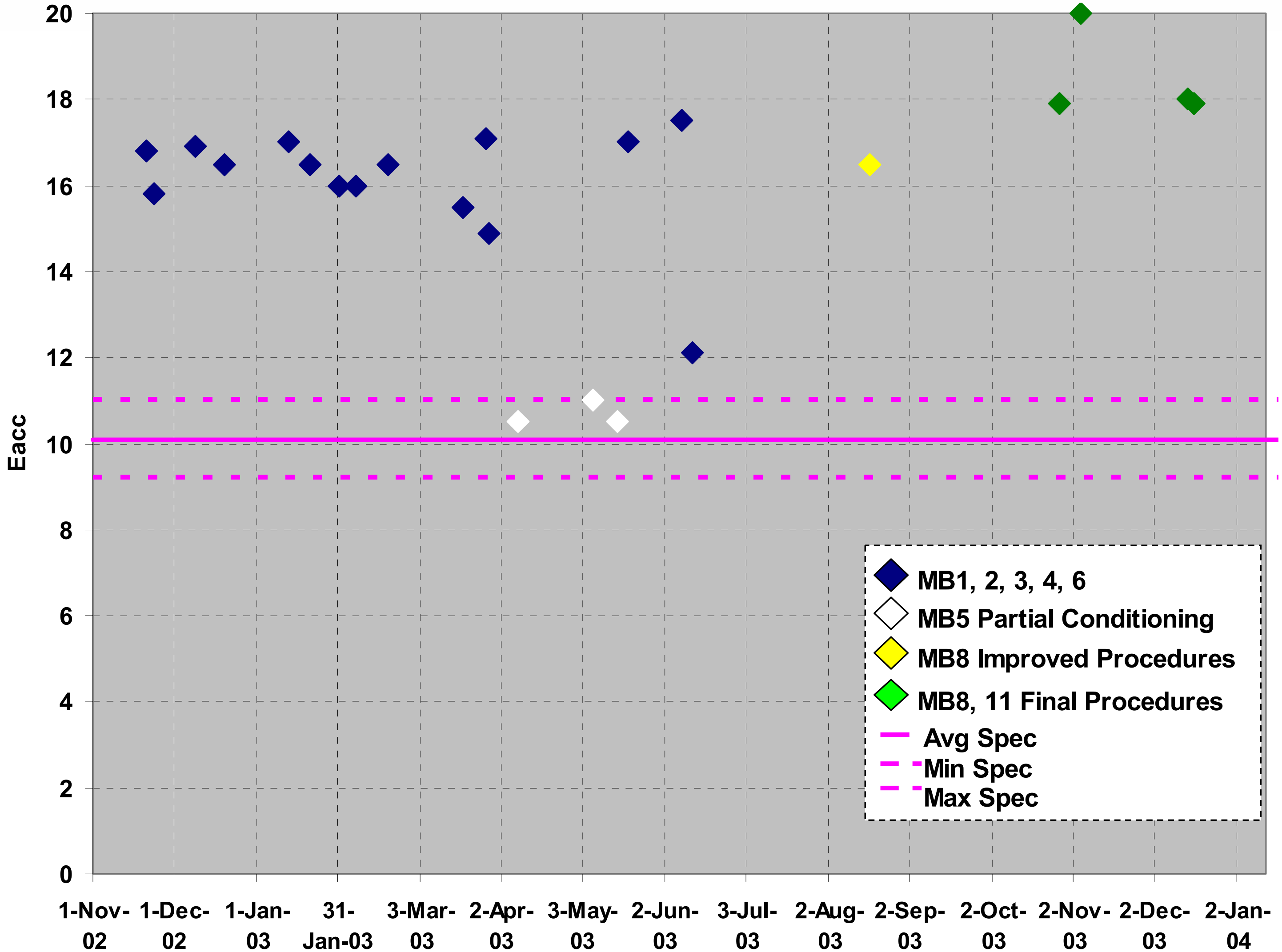


11 CM's in the SNS Tunnel

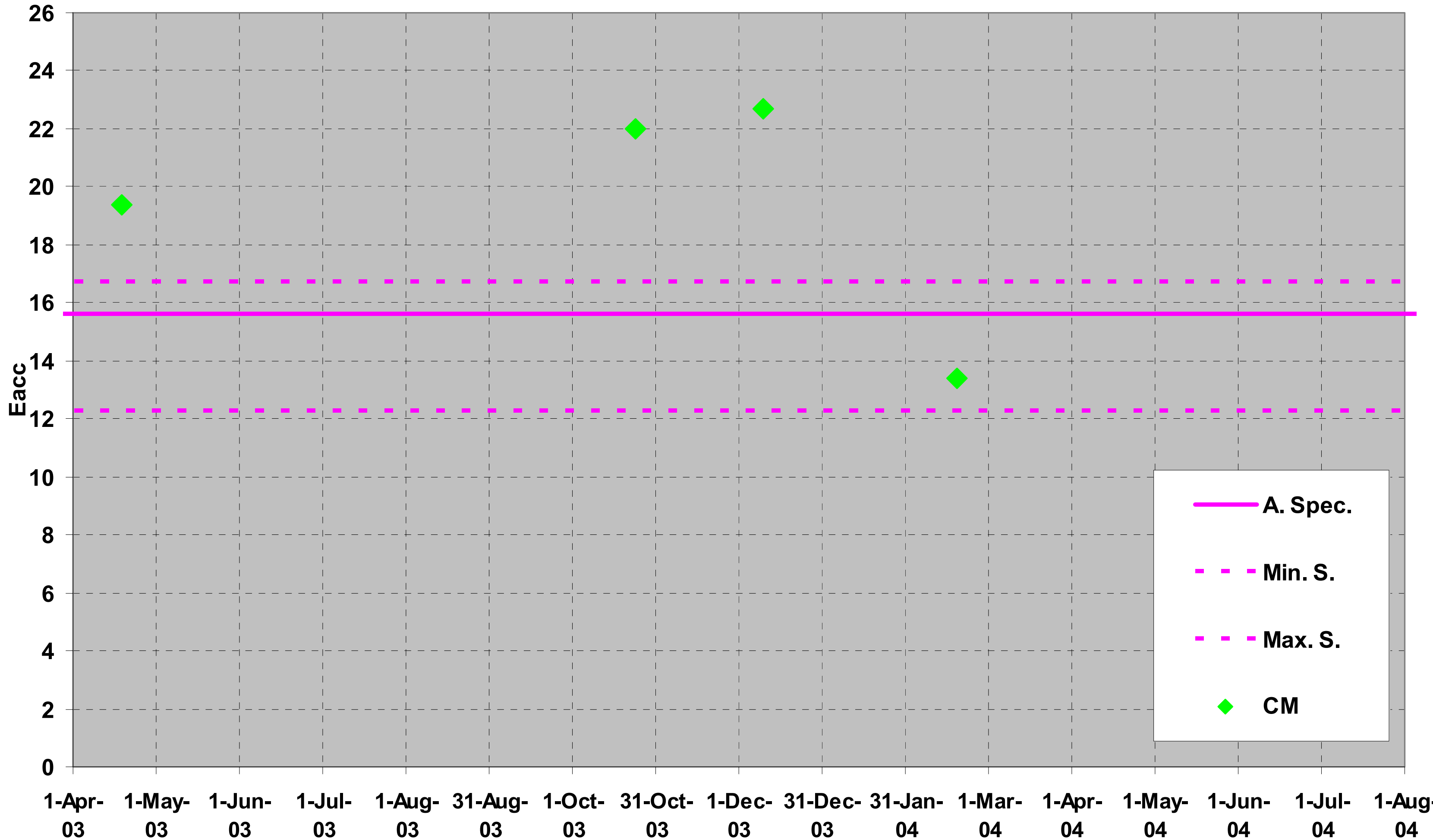
High β Cryomodule 5 + 6 at JLab

- Test of first 2 CM in the tunnel has started as of last week.
- Testing of crymodules at JLab includes the first 12. All results shown are from there.
- Test of the remaining eleven is done at SNS in the tunnel

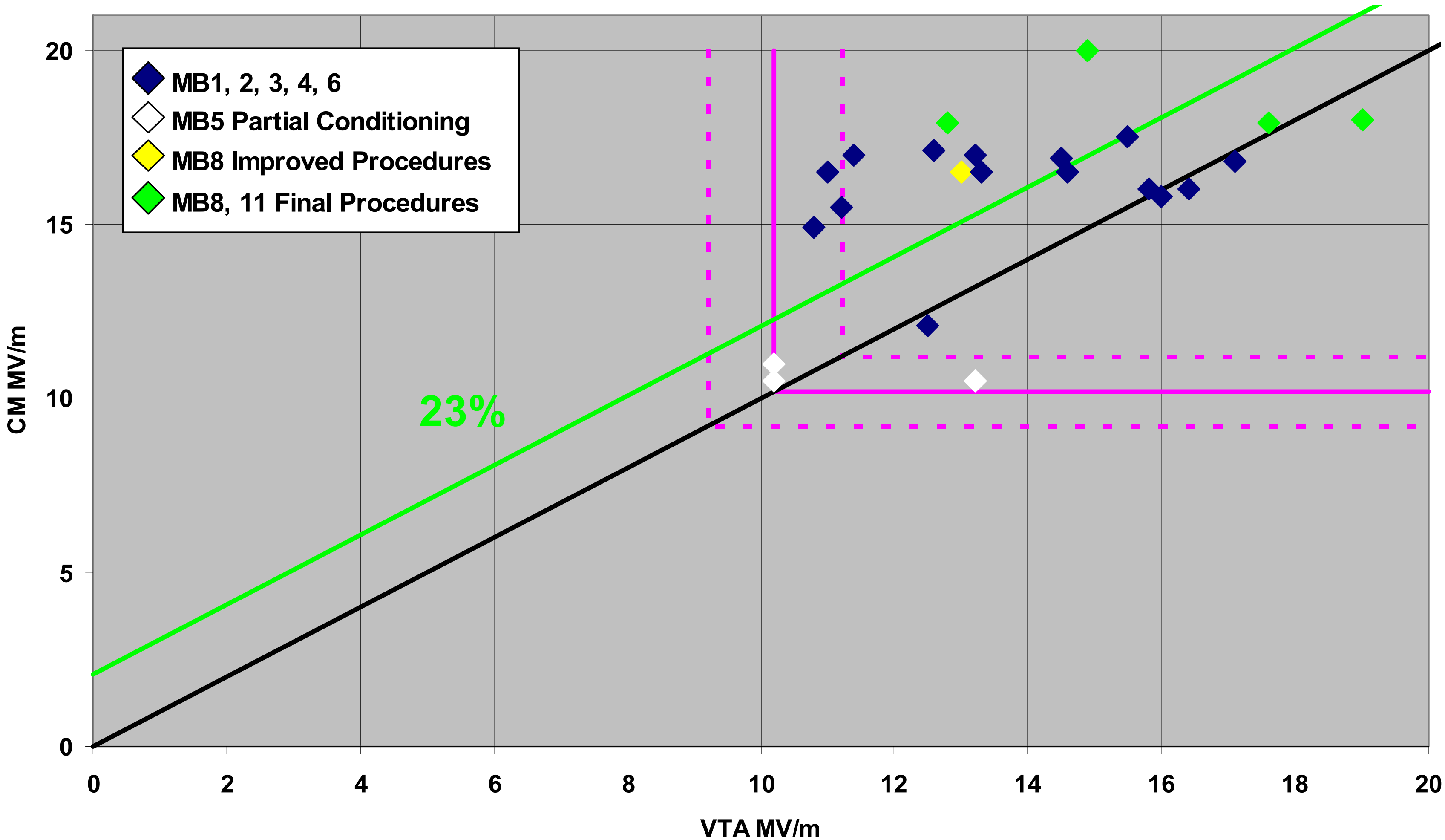
Med. β CM Performance E_{acc} @ $Q_o = 5*10^9$



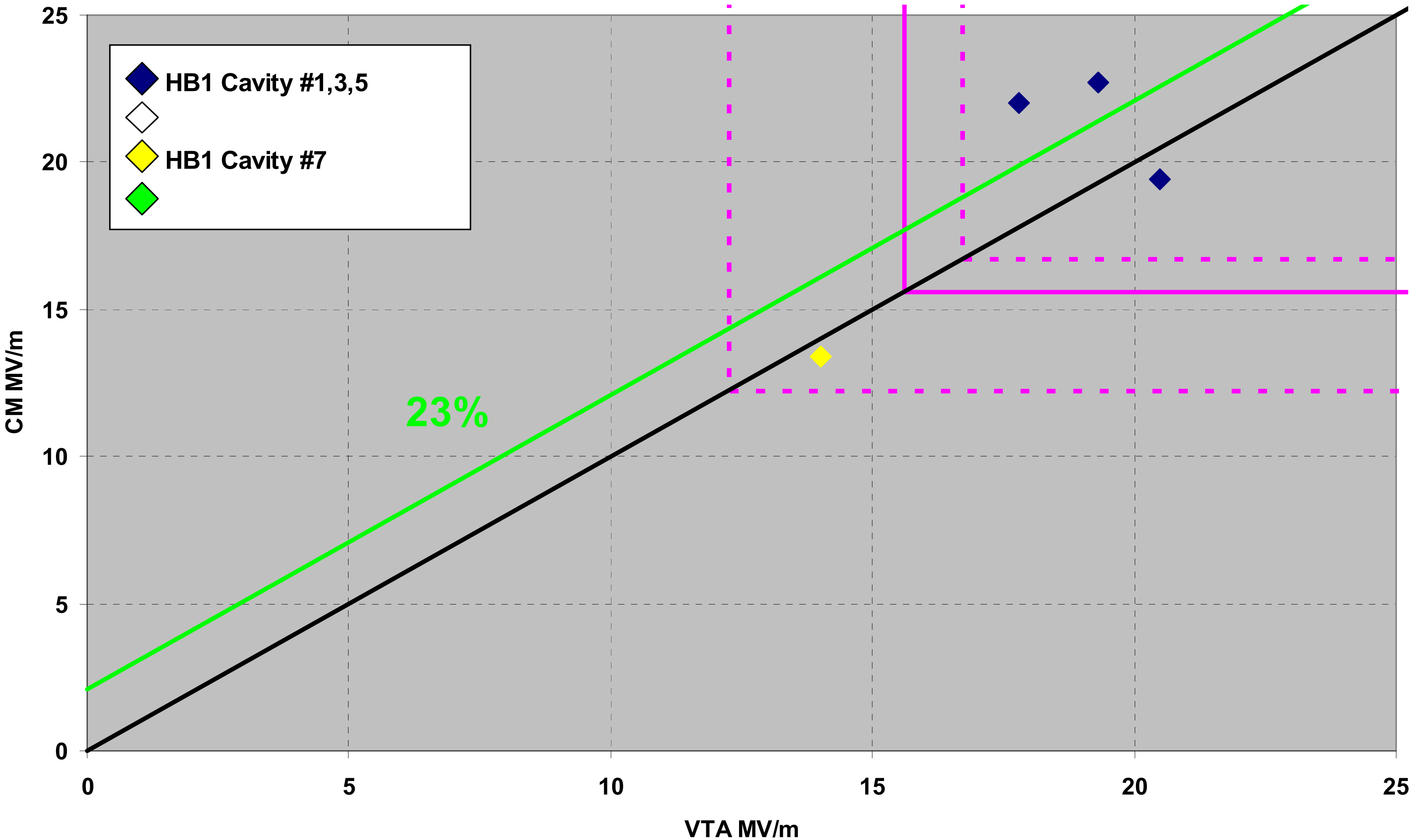
High β CM Performance E_{acc} @ Q_0=5*10^9



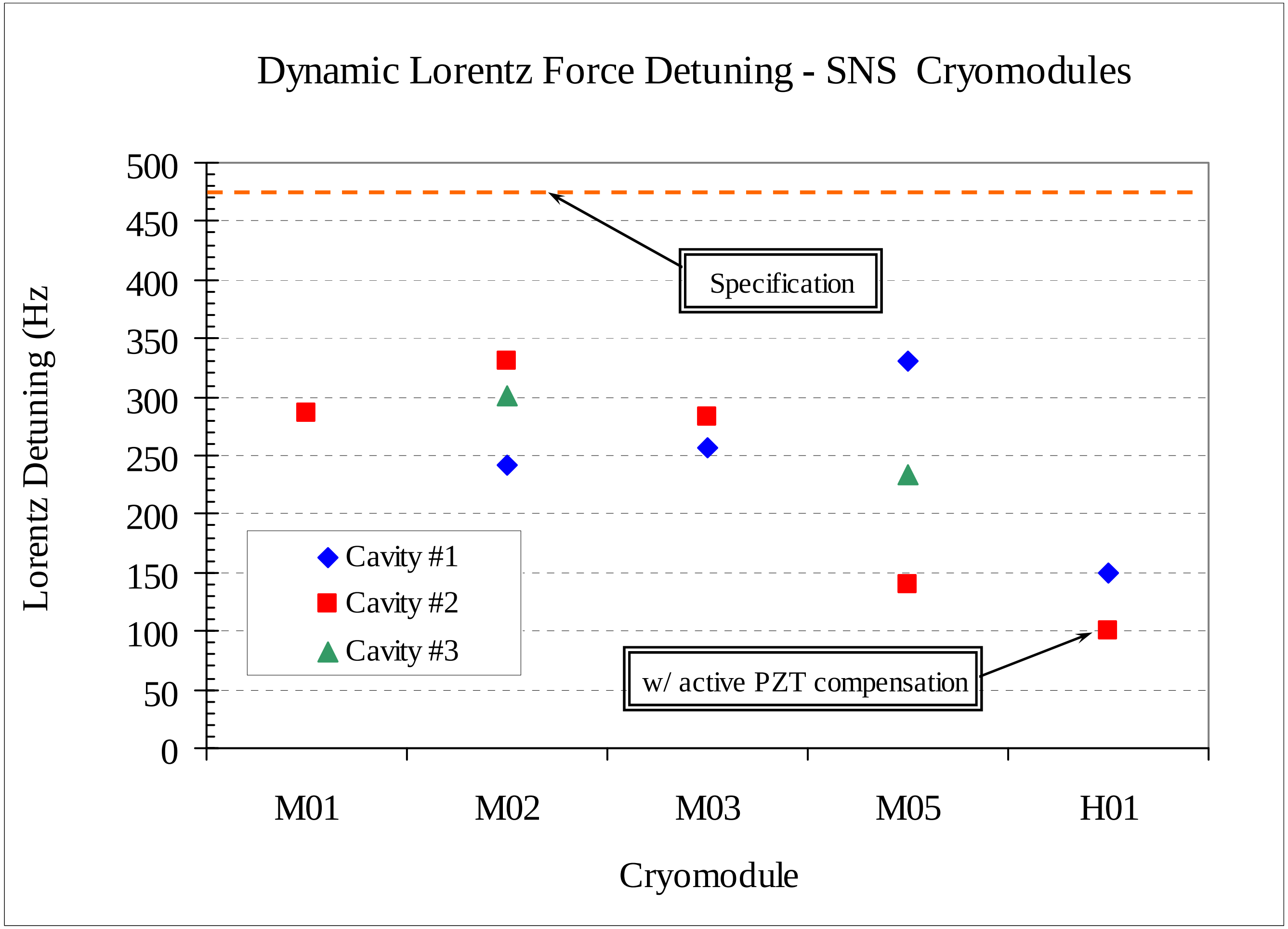
Medium β CM Versus Vertical Test



High β CM Versus Vertical Test



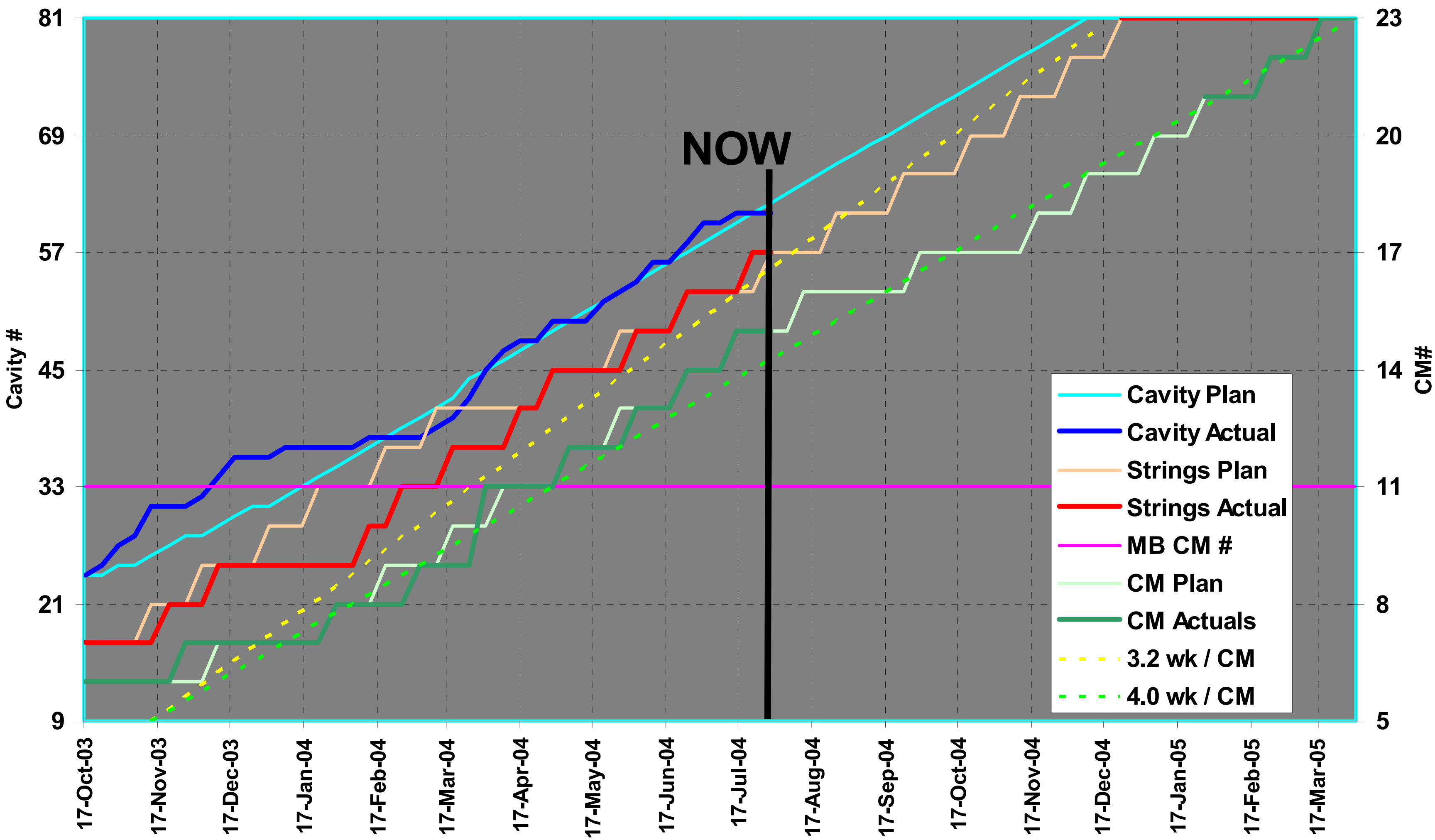
Lorentz Force Detuning



- If we could keep all cavities @ 100Hz, the presently installed rf system can support ~ twice the beam power.

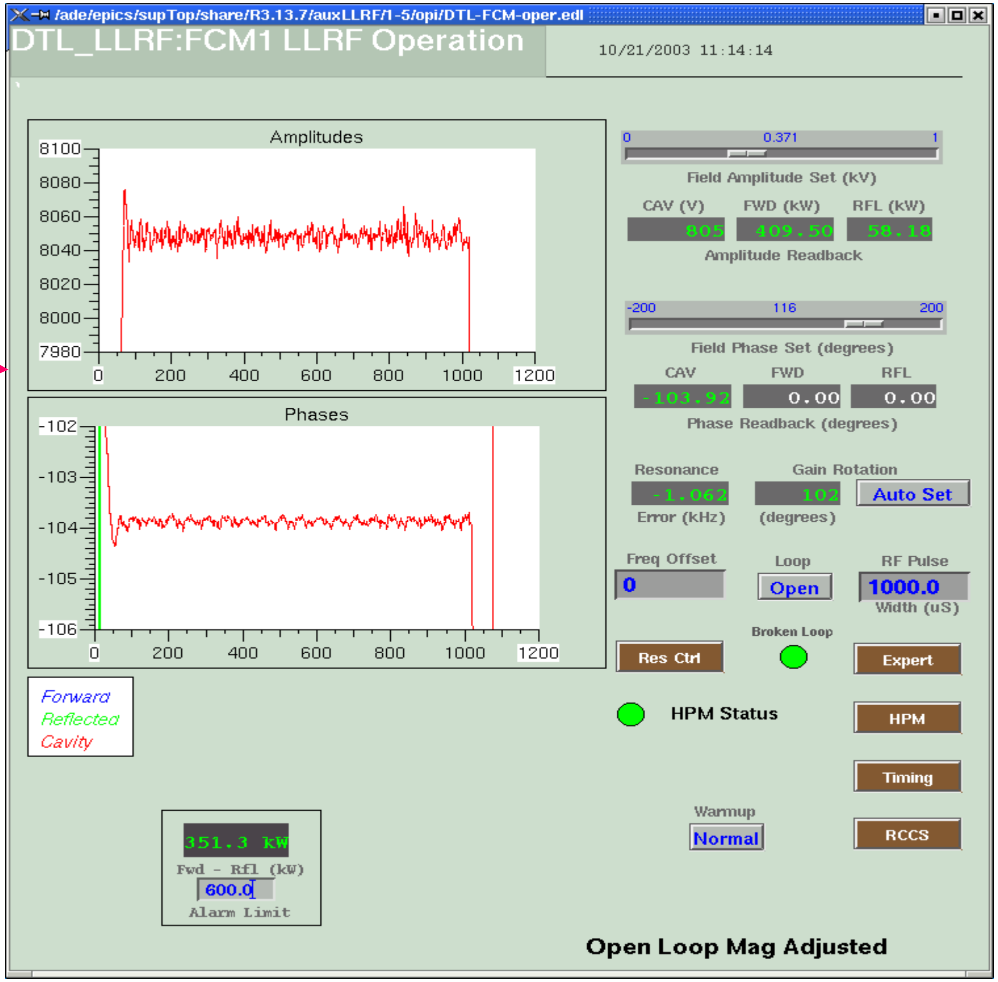
- 1 HB had a resonance and was x4 out of spec. Not clear why yet.

Cryomodule Assembly

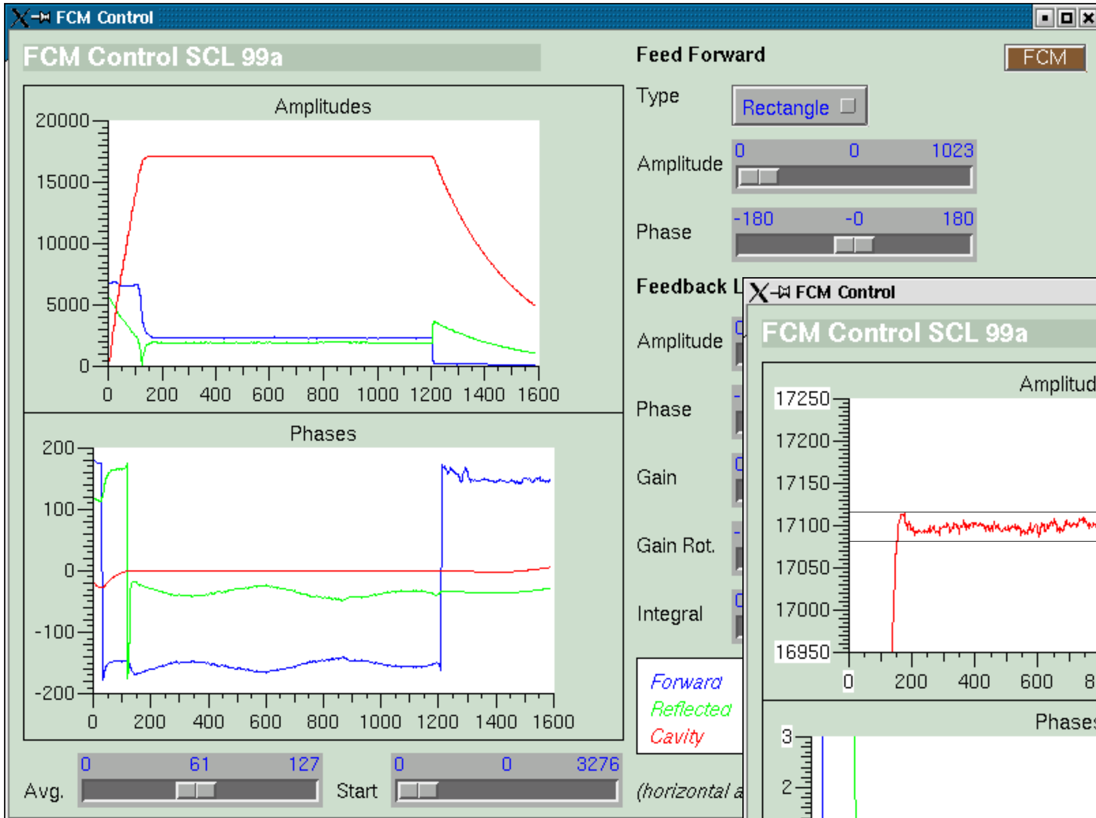


The Low-level RF Control System

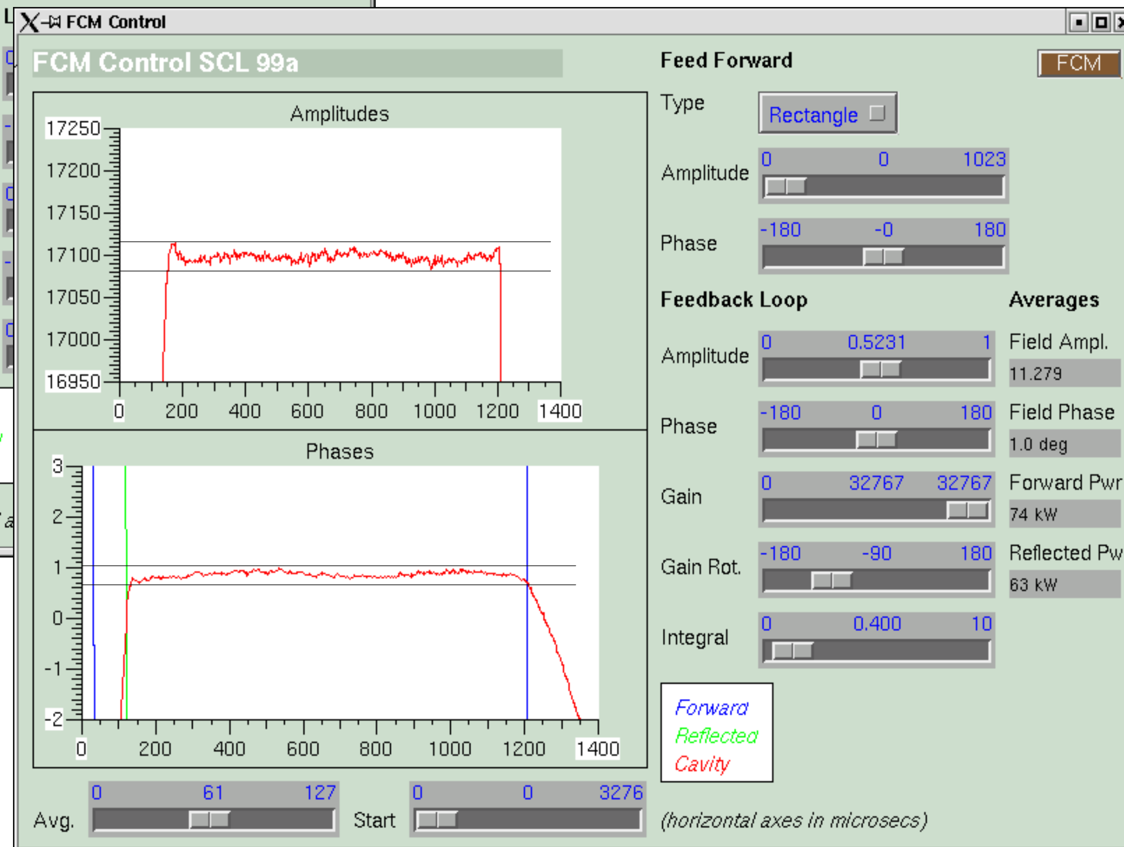
- **Production systems 97% complete.**
  - **Collaboration between LBNL, LANL and ORNL.**
  - **Production is under way with 20 units delivered.**
  - **LANL supporting ORNL with ECAD, EPICS vendor QA, acceptance testing, installation (consulting & change-of-station assignments)**
  - **LBNL continues to do FPGA code development.**
- **Installation and Integration in the Tunnel is underway.**



FCM Test On A Cryomodule



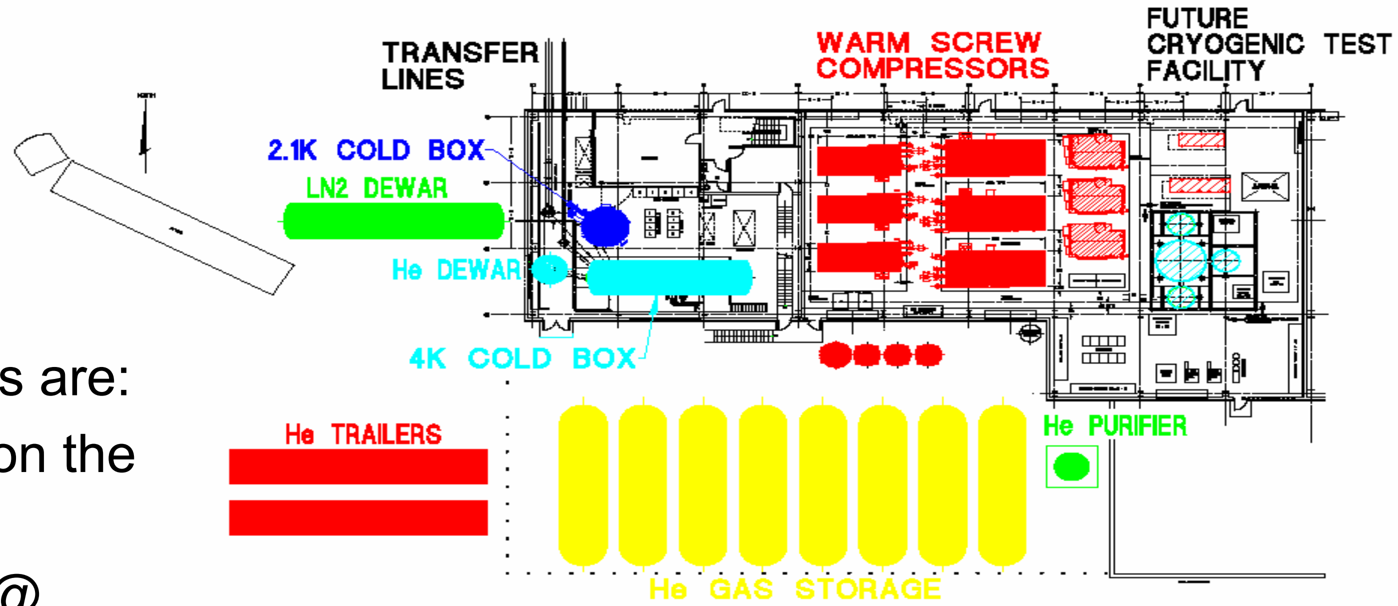
11.3 MV/m, 30 Hz, 1.2 ms, 2.1 K



- **specification of ±1%, ±1deg**
- **±0.1%, ±0.2deg achieved**

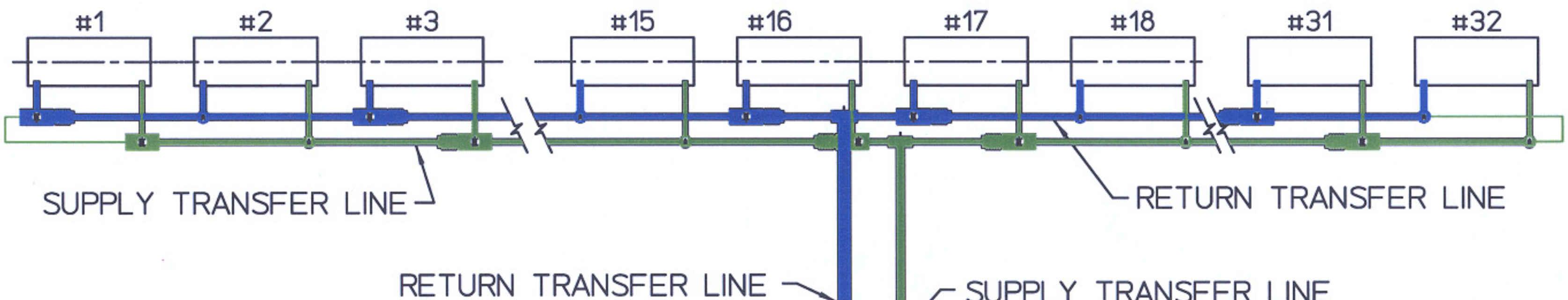
SNS CHL Facility

- Cold box specifications are:
- 8300 Watts on the shield
- 2400 Watts @ 2.1Kelvin
- 15g/s Liquefaction



SNS HELIUM REFRIGERATION SYSTEM EQUIPMENT ARRANGMENT

SNS/SRF Cryogenic Distribution System



- Transfer line is installed for 9 additional cryomodules to be ready for the linac energy upgrade

- Transfer line; tested and leak checked. Same for expansion cans and piping.
- Built in house at OR

SNS Warm Compressor

- Procured by JLab in industry
- Warm compressors are operating after initial issue with heat exchangers.
- Three streets with one being redundant.

SNS 4.5 K Cold Box

- Procured by JLab in industry
- 4K Coldbox has operated in 3 different runs and is considered commissioned.
- July: Reached 100% of spec with lowered interstage pressure and somewhat lower efficiency.
- Presently transferline and 2 CM are at 4.5 K for test.

The 2.1K Cold Box

- Procured by JLab in industry.
- Had several issue due to shipment damage of turbines.
- Have still an issue with electrical feedthroughs that drive the turbines.
- Run foreseen in October after 4.5 K cooldown of transferline and cavities for first systems check

SNS Diagnostics Deployment

Operational

FY04

New to 2004

New to FY04

½ Laser in 04

FY2004/5

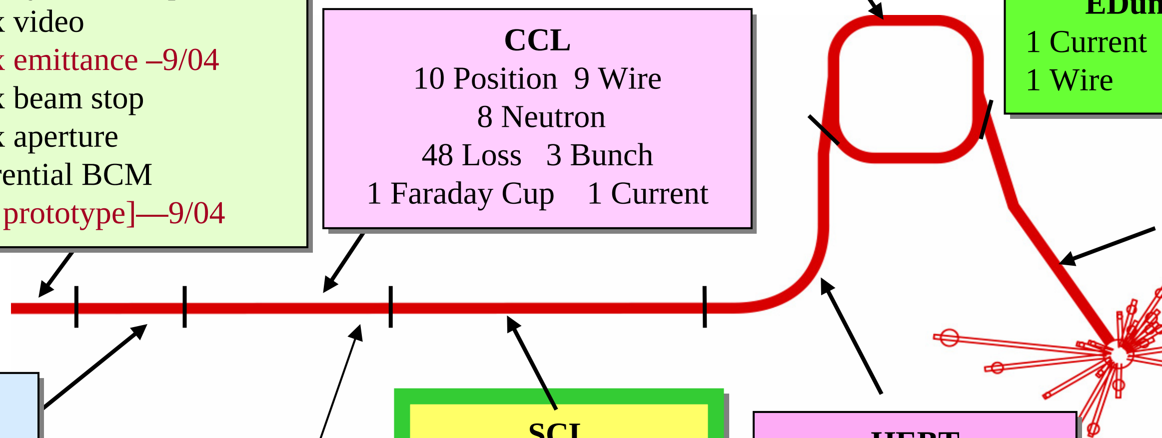
MEBT
6 Position
2 Current
5 Wires
[2 Thermal Neutron]—9/04
[3 PMT Neutron] —9/04
1 Emittance
[1 fast faraday cup]—9/04
1 faraday/beam stop
D-box video
D-box emittance –9/04
D-box beam stop
D-box aperture
Differential BCM
[laser prototype]—9/04

IDump
1 Position
1 Wire
1 Current
6 BLM

RING
44 Position 2 Ionization Profile
70 Loss 1 Current
5 Electron Det. 12 FBLM
2 Wire 1 Beam in Gap
2 Video 1 Tune

CCL
10 Position 9 Wire
8 Neutron
48 Loss 3 Bunch
1 Faraday Cup 1 Current

EDump
1 Current 4 Loss
1 Wire



RTBT
17 Position
36 Loss
4 Current
5 Wire
1 Harp
3 FBLM

DTL
10 Position 5 Wire 12 Loss
5 Faraday Cup 6 Current
6 Thermal and 12 PMT Neutron

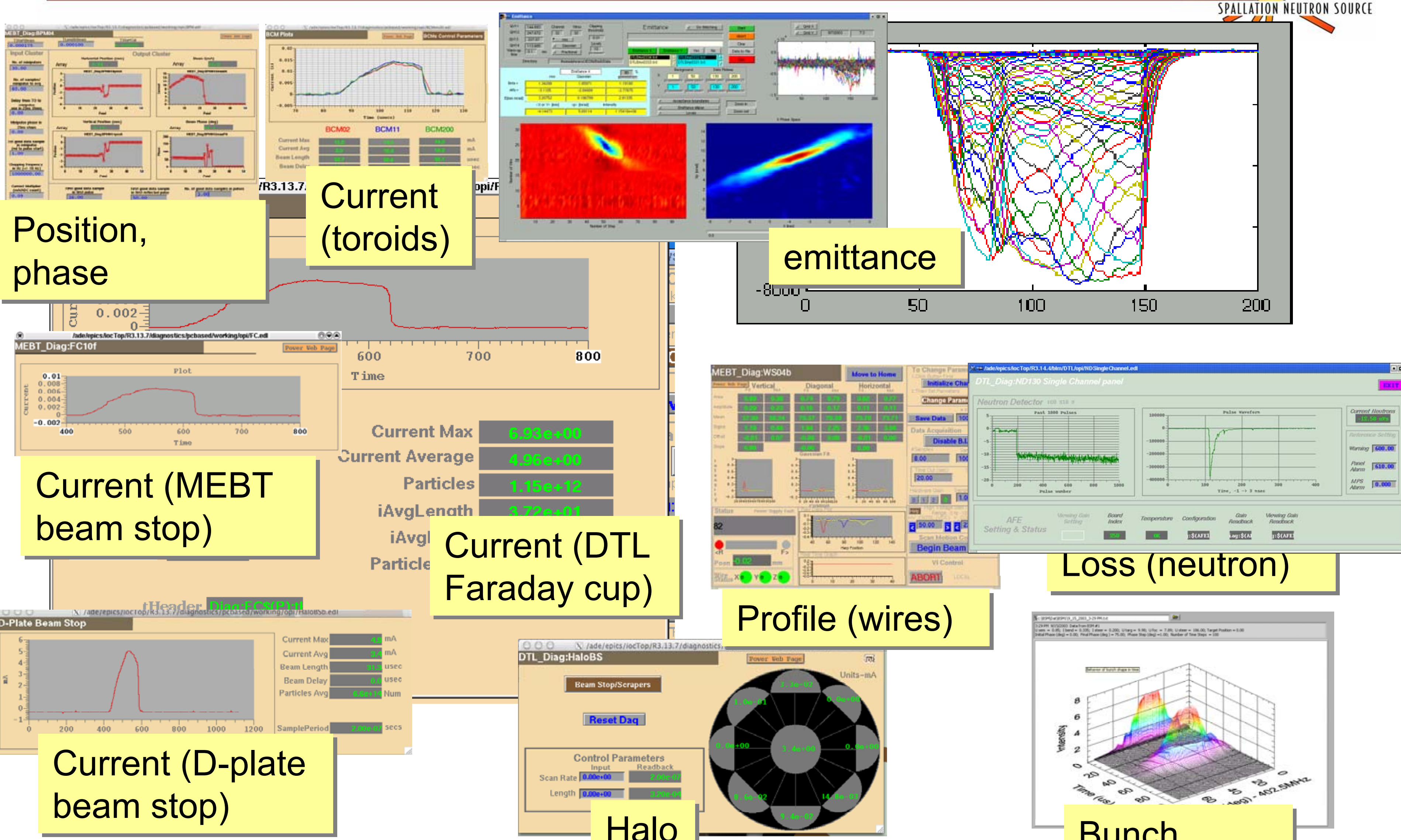
SCL
32 Position 86 Loss
8 Laser Wire
7 PMT Neutron

HEBT
29 Position 11 Wire
46 BLM, 3 FBLM
4 Current

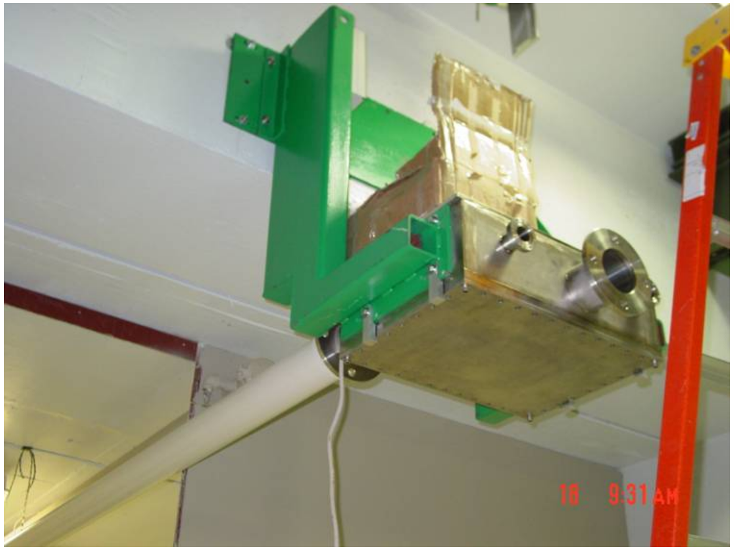
CCL/SCL Transition
2 Position 1 Wire
1 Loss 1 Current

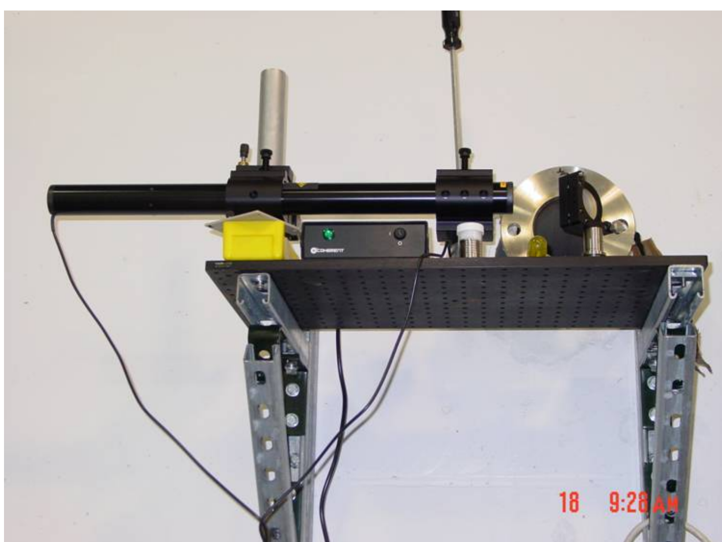
LDump
6 Loss
6 Position
1 Wire

Diagnostics Is Online During Commissioning



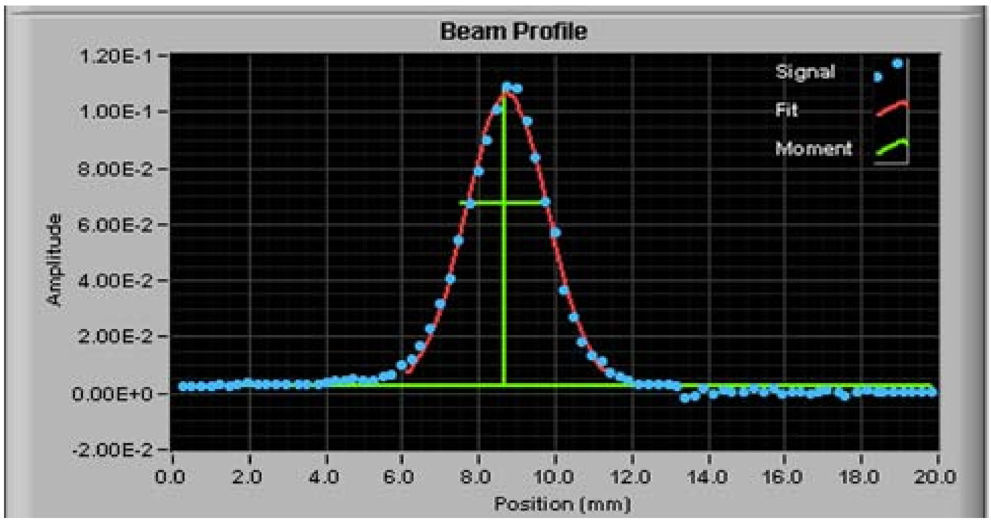
SCL Laser Transport-line Installation:





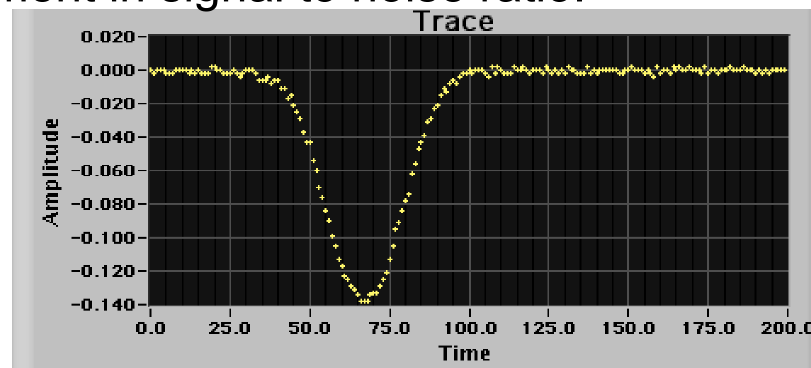
Laser Profile Monitor Progress

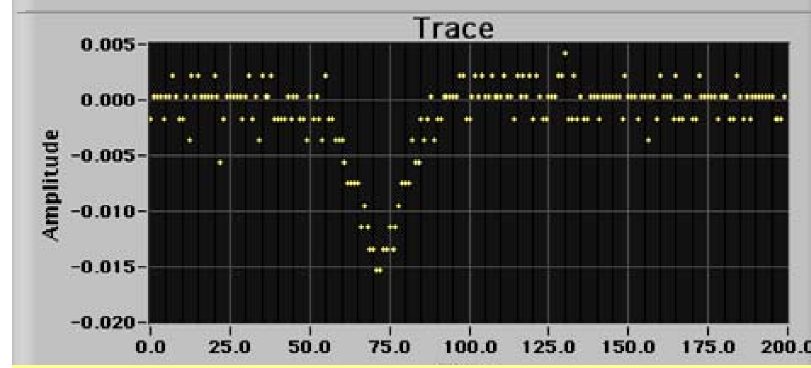
- Verification of electron collector for SCL laser profile monitor
- Reliable measurements to about **3 sigma**
- Anti-reflection coating has been applied to the final windows.
- We expect an order of magnitude improvement in signal to noise ratio.



Horizontal Profile

Gaussian fit plotted out to 2.5x Sigma
Sigma = 1.07 mm

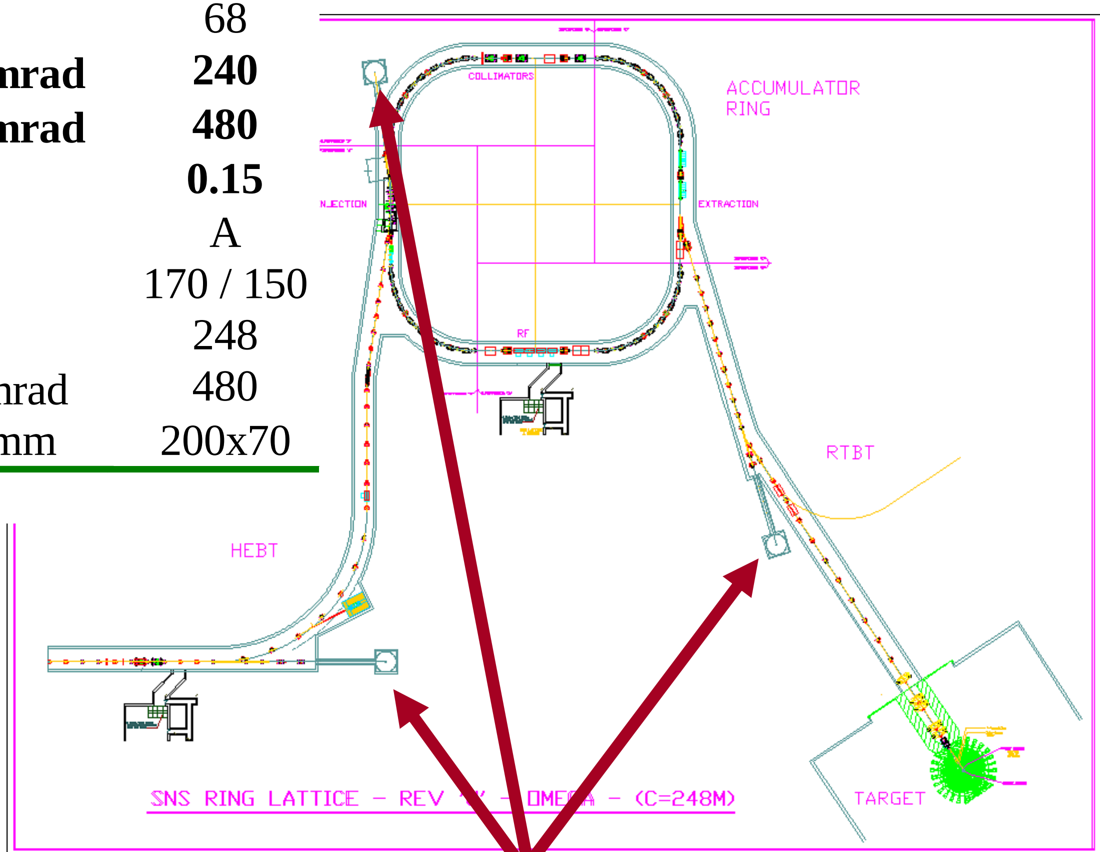




Signal from electron collector
Top: laser intercepting beam core
Bottom: laser intercepting beam tail

BNL: The Accumulator Ring and Transfer Lines

Nr of injected turns		1060
Ring revolution frequency	MHz	1.058
Ring filling fraction	%	68
Ring transverse emittance 99%	**πmm mrad**	**240**
Ring transverse acceptance	**πmm mrad**	**480**
Space charge Tune shift	**$\Delta Q_{x,y}$**	**0.15**
Peak Current	52	A
HEBT / RTBT Length	m	170 / 150
Ring Circumference	m	248
RTBT transverse acceptance	πmm mrad	480
Beam size on target (HxV)	mm x mm	200x70



Several commissioning beam dumps

Totals:

235 Low Power Bipolar Supplies (< 5 kW)
24 Medium Power Bipolar Supplies (5-50 kW)
101 Medium Power Supplies (5-50 kW)
42 High Power Supplies (>50 kW)
22 Kicker Power Supplies

Baseline: 1.0 GeV, 2 MW

Designed and built for 1.3 GeV

BNL: Ring/HEBT Installation Progress

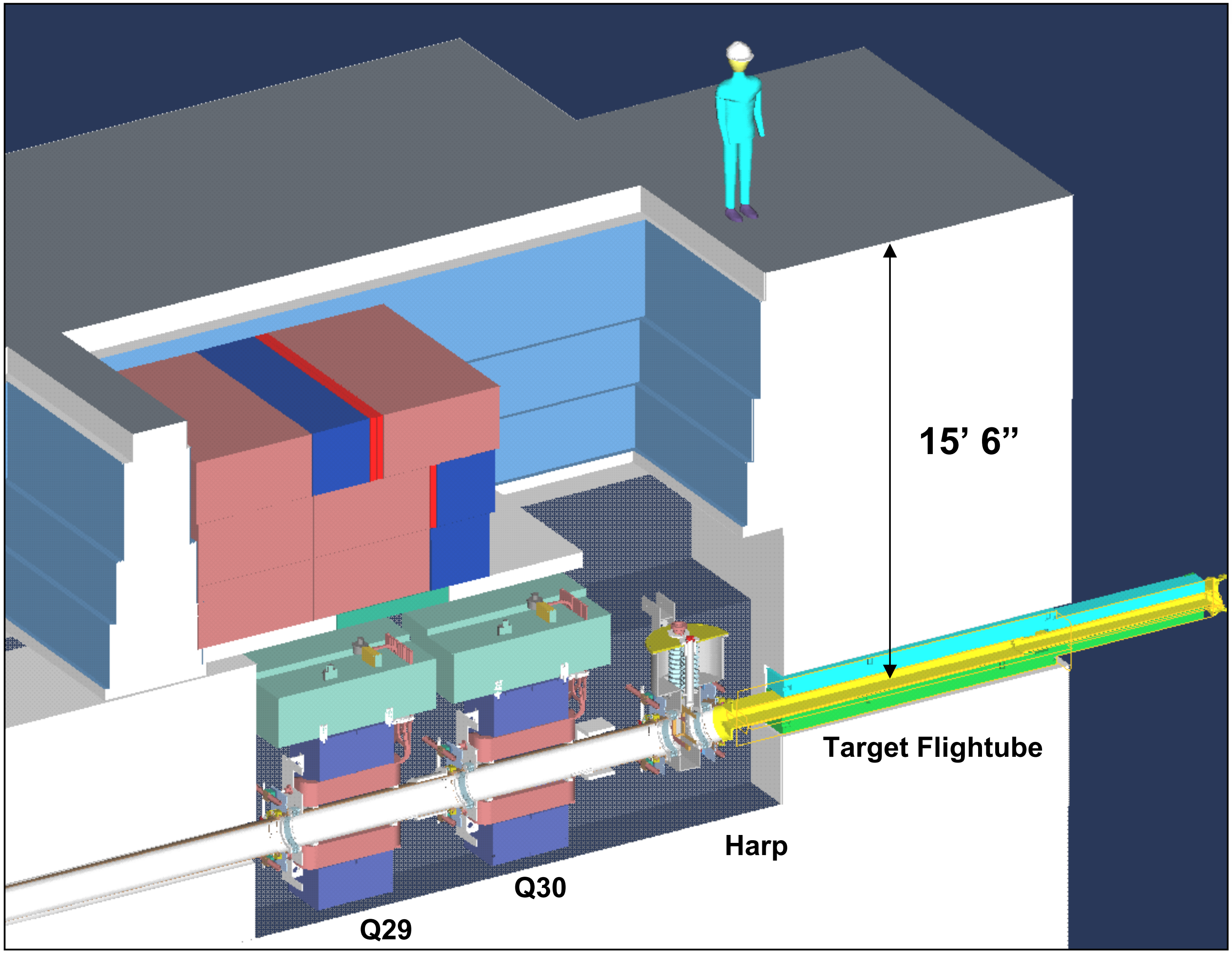
SNS
SPALLATION NEUTRON SOURCE

- Beam line installation “Linac to Ring” complete.
- Ring installation ~ 80% complete.
- Beam line installation “Ring to Target” has not started.

- The ring has an aperture of 460 π*mm*mrad (~ 15 cm diameter) to allow a 25 A average circulating current.

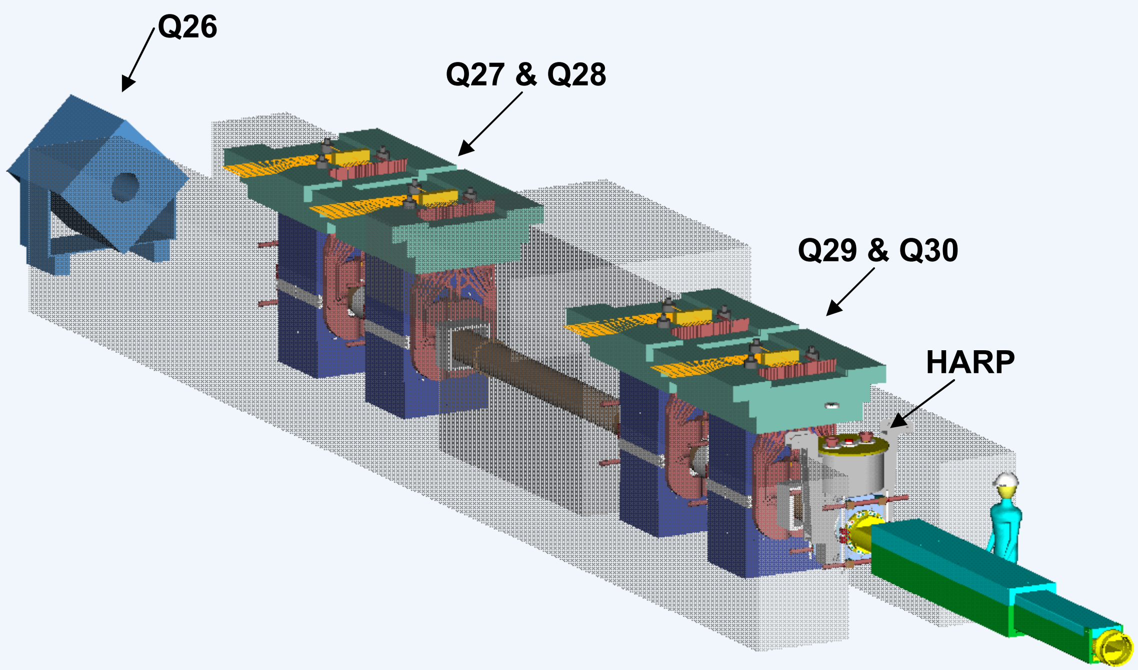
- Energy per pulse is ~ 25 kJ.

RTBT/Target Interface



Section through RTBT/Target Flight-tube Interface

Expected Dose Rates

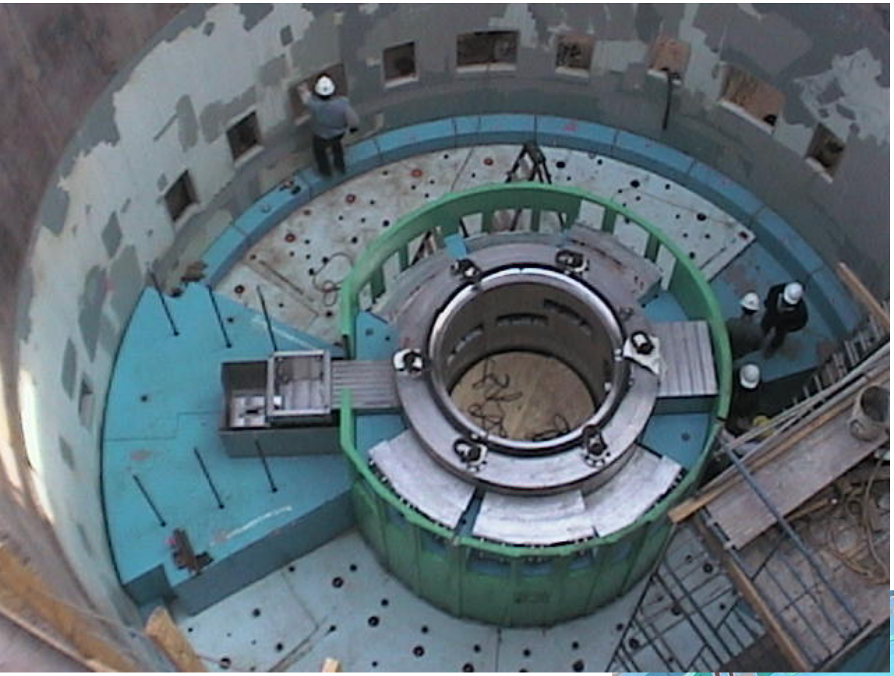


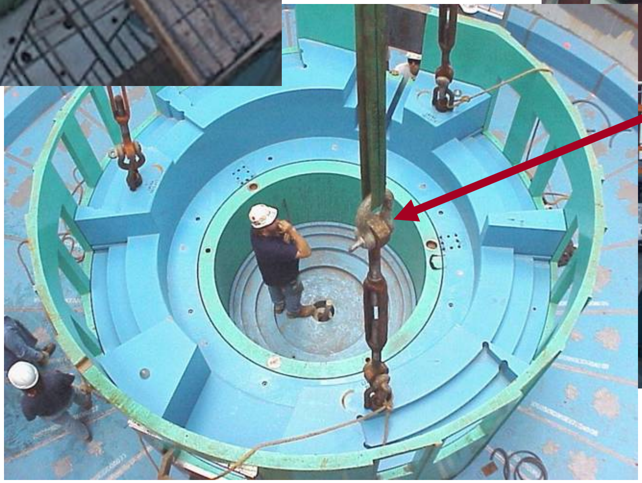
Potential Active Maintenance Work Areas

- Prompt dose levels during operation (2 MW) – 1500 rem/hr@ working area (Franz Gallmeier)
- Residual levels 2 hours – 1 week after shutdown, factor of ~1000 less – 1.5 rem/hr
- Updated dose rate calculations underway with existing design (Irina Popova)
- Recent calculated dose rates for dumps & back streaming from target (DH13) are very high

Status as of July 2004 with construction activity limited to Target &
Central Laboratory building and Nano Science Center

Target Monolith Region

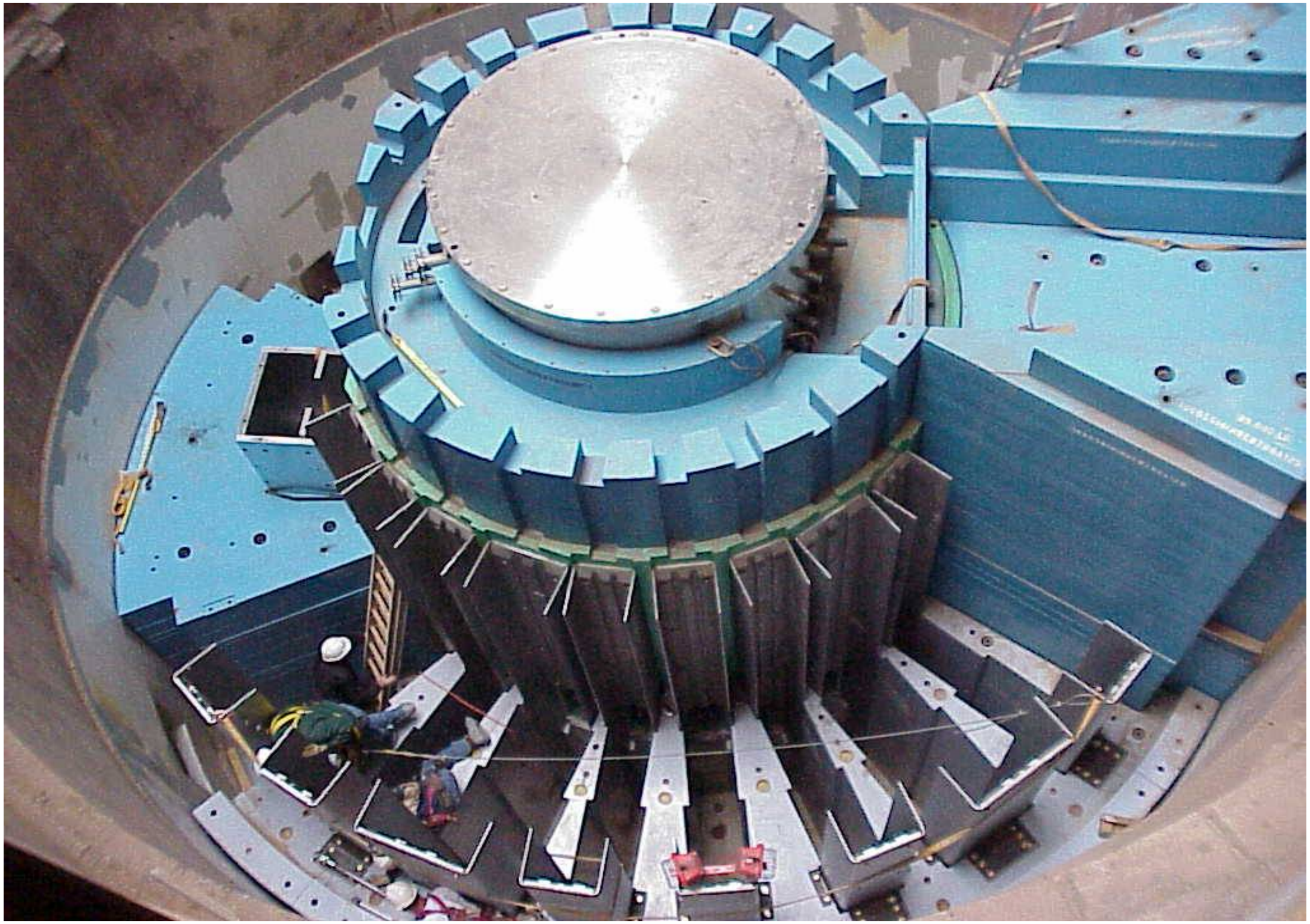




Monolith Installation - Sept 2003

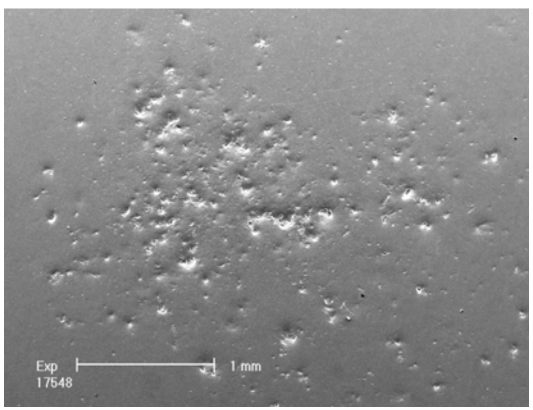
Core Vessel and Shielding

Target Installation

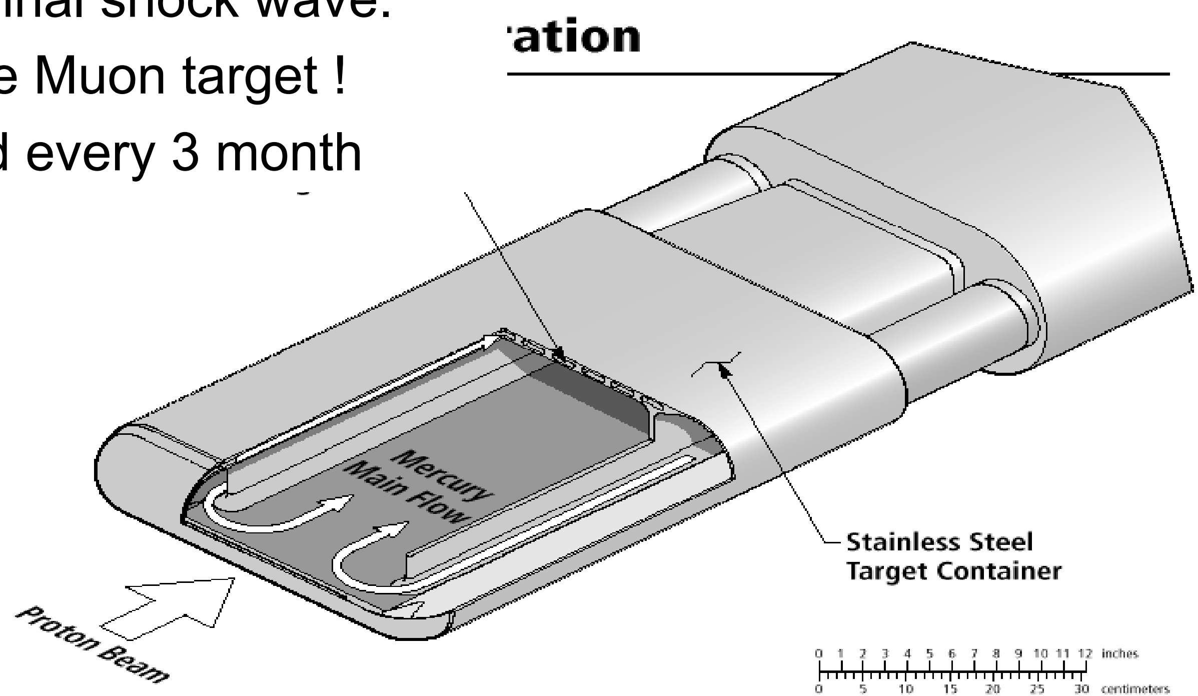


The SNS Target: 2-MW Design

- **Cavitation-induced pitting is an issue.**
- **Options for mitigation:**
    - ***Materials, Geometry → Mitigation***
- 25 kJ/pulse at 7x15cm beam size sets of transverse and longitudinal shock wave.
- “Peanuts” compared the Muon target !
- Needs to be exchanged every 3 month

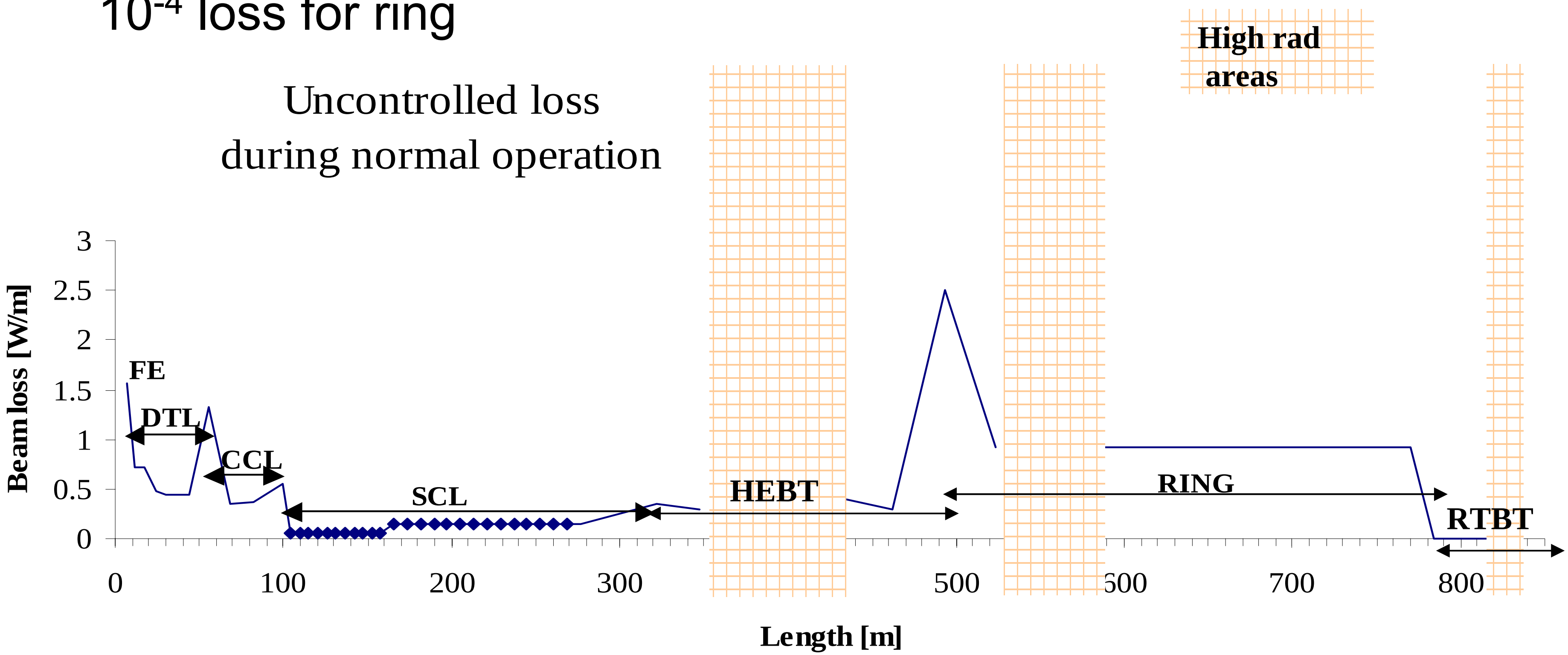


Pits on inner surface in this geometry



Primary Concern: *Uncontrolled Beam Loss*

- Hands-on maintenance: no more than 100 mrem/hour residual activation (4 h cool down, 30 cm from surface)
- 1 Watt/m uncontrolled beam loss for linac & ring
- Less than 10^{-6} fractional beam loss per tunnel meter at 1 GeV; 10^{-4} loss for ring



A 20-Year Plan- The Long Term Future for SNS

	Baseline	Upgrade	Ultimate
Kinetic energy, E_k [MeV]	**1000**	**1300**	**1400**
Beam power on target, P_{max} [MW]	**1.4**	**3.0**	**5.0**
Chopper beam-on duty factor [%]	**68**	**70**	**70**
Linac beam macro pulse duty factor [%]	**6.0**	**6.0**	**6.0**
Average macropulse H- current [mA]	**26**	**42**	**65**
Peak Current from front end system	**38**	**59**	**92**
Linac average beam current [mA]	**1.6**	**2.5**	**3.9**
SRF cryo-module number (med-beta)	**11**	**11**	**11**
SRF cryo-module number (high-beta)	**12**	**12 + 8 (+1 reserve)**	**12 + 8 (+1 reserve)**
Number of SRF cavities	**33+48**	**33+80 (+4 reserve)**	**33+80 (+4 reserve)**
Peak gradient, E_p (β=0.61 cavity) [MV/m]	**27.5 (+/- 2.5)**	**27.5 (+/- 2.5)**	**27.5 (+/- 2.5)**
Peak gradient, E_p (β=0.81 cavity) [MV/m]	**35 (+2.5/-7.5)**	**31**	**34**
Ring injection time [ms] / turns	**1.0 / 1060**	**1.0 / 1100**	**1.0 / 1110**
Ring rf frequency [MHz]	**1.058**	**1.098**	**1.107**
Ring bunch intensity [10^{14}]	**1.6**	**2.5**	**3.8**
Ring space-charge tune spread, ΔQ_{sc}	**0.15**	**0.15**	**0.2**
Pulse length on target [ns]	**695**	**691**	**683**

P. Lapostolle, †

Summary

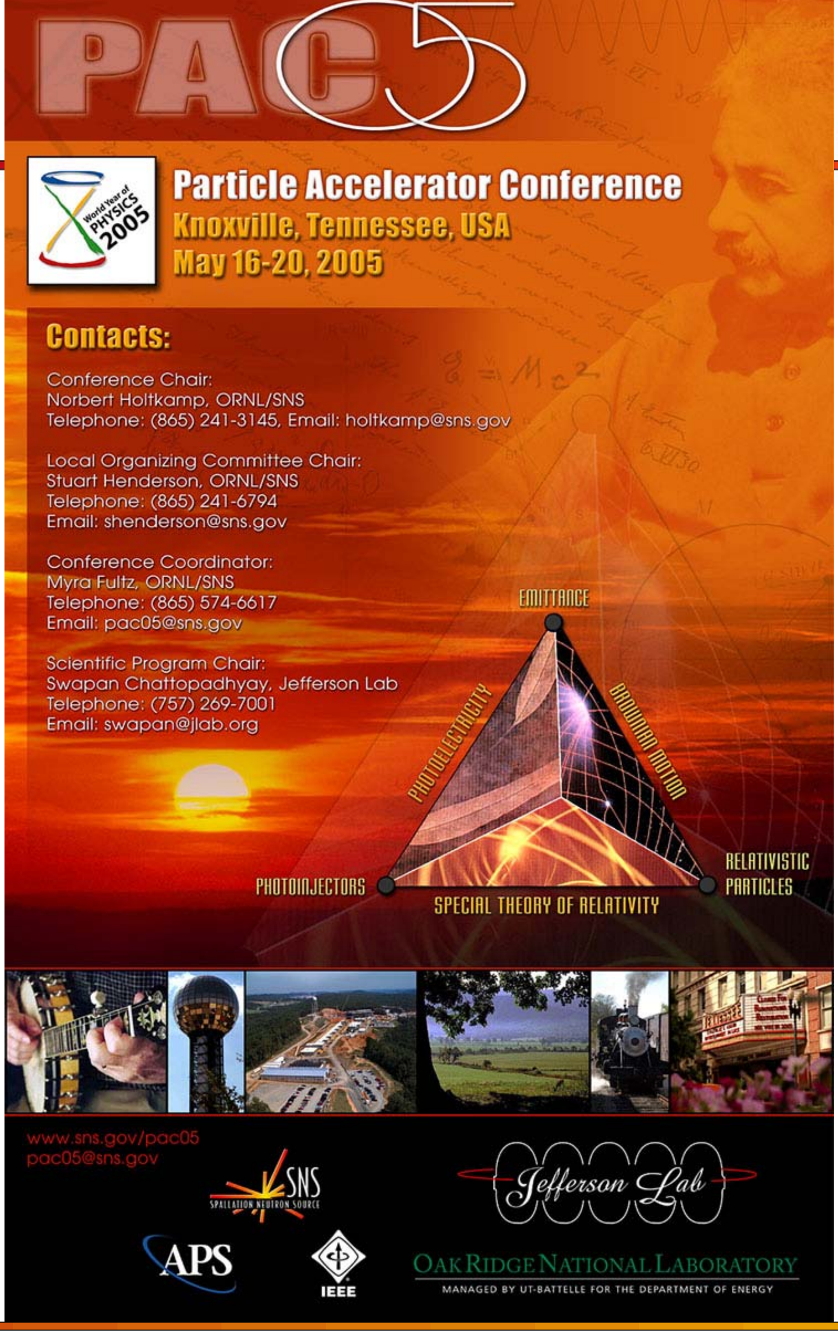
- The SNS project is still on track for achieving a June 06 finish date within the appropriated 1.4 Billion $. The construction is more than 85% complete.
- The program has benefited from enormous support in Washington with funding appropriated every year as planned.
- Commissioning has progressed as installation continues with 40MeV achieved at full spec.
- The next major step is the commissioning of complete warm linac (DTL + CCL).
- The full linac should be in commissioning next spring during PAC 05.

- It has been and still is a very successful collaboration between six partnering DOE laboratories.
- Please come visit us next year during PAC or whenever you get a chance.

PAC05

- PAC 05 will be in Knoxville, TN, 25 miles from the site.
- There will be a site tour on Saturday

- Please come to visit us…..



SNS SPALLATION NEUTRON SOURCE