The SNS Linac and Storage Ring: Challenges and Progress Towards Meeting Them

N. Holtkamp for the SNS Collaboration *
Oak Ridge National Laboratory (ORNL), Oak Ridge, TN 37830, USA

More than 31 SNS Presentations in this conference

- THPLE020 - Algorithms for the SNS MEBT Commissioning*
- WEPRI117 - An Improved Impedance Model of Metallic Coatings
- THPLE013 - Upgrading the SNS Compressor Ring to 3 MW
- THPLE023 - Finite Element Analysis And Frequency Shift Studies for The Bridge Coupler of The Coupled Cavity Linear Accelerator of The Spallation Neutron Source
- THPDO016 - High Power RF Tests on Fundamental Power Couplers for the SNS Project
- TUPLE101 - High Level RF for the SNS Ring
- WEPRI036 - Measurements of the coupling impedance of the SNS extraction kickers
- THPLE016 - Proton Beam Halo Intercept Design in the SNS HEBT Line
- TUPDO037 - A Narrow Quadrupole for the SNS Accumulator Ring
- THPLE017 - SNS Beam in Gap Cleaning and Collimation, S. Cousineau
- THPLE021 - Spallation Neutron Source Application Programming Environment ,
- WEPLE057 - Exploring Transverse Beam Stability in the SNS in the Presence of Space Charge
- TUPLE068 - SNS Extraction Kicker System and First Article BPFN Test
- TUPDO008 - Series Production of Accelerator Cavities for the Spallation Neutron Source
- THPLE011 - Accelerator Physics Model of Expected Beam Loss along the SNS Facility
- WEPLE037 - Coupling Correction for the SNS Accumulator Ring
- THPDO025 - Input Coupling and Higher-Order Mode Analysis of Superconducting Axisymmetric Cavities for the Rare Isotope Accelerator
- TUPDO039 - Elimination of Digitizing Errors in a Rotating Coil Mapper
- TUPDO038 - Characterization of a SNS Transfer Line Dipole
- WEPRI061 - Application of UAL-Based Correction Schemes to the SNS Accumulator Ring
- WEPLE055 - The SNS Ring Dipole Magnetic Field Quality
- THPLE012 - Commissioning of the SNS Front-End Systems at Berkeley Lab
- THPRI079 - Progress in Laser Beam Profile Monitor Development
- TUXGB001 - State of the Art of Multicell SC Cavities and Perspectives
- THPLE019 - Enhancing Surface Ionization and Beam Formation in Volume-type H- Ion Sources
- TUPLE119 - Development of 805-MHz Pulsed Klystrons for SNS
- WEPDO006 - Simulation Results for the Electron Cloud at the PSR and SNS
- THPRI071 - Tune Measurement in the SNS Ring
- MOPLE107 - 1.12 MVA Peak Two Quadrant Pulse Switch Mode Power Supply for SNS Injection Bump Magnet
- THPDO015 - Superconducting Prototype Cavities for the Spallation Neutron Source (SNS) Project
- THPLE024 - Selected Aspects of the SNS-Linac Performance

The Spallation Neutron Source Partnership

Jan 02: Description	EAC		Accelerat.
Project Support	75.3		
Front End Systems	20.6		20.6
Linac Systems	288.4		288.4
Ring & Transfer System	153.1		153.1
Target Systems	98.1		
Instrument Systems	64.1		
Conventional Facilities	308.9		
Integrated Control Syst	59.6		59.6
BAC	1,068.1		
Contingency	124.6	23.9%***	
TEC	1,192.7		
R&D	102.0		81.6
Pre-Operations	117.0		93.6
TPC	1,411.7		696.9

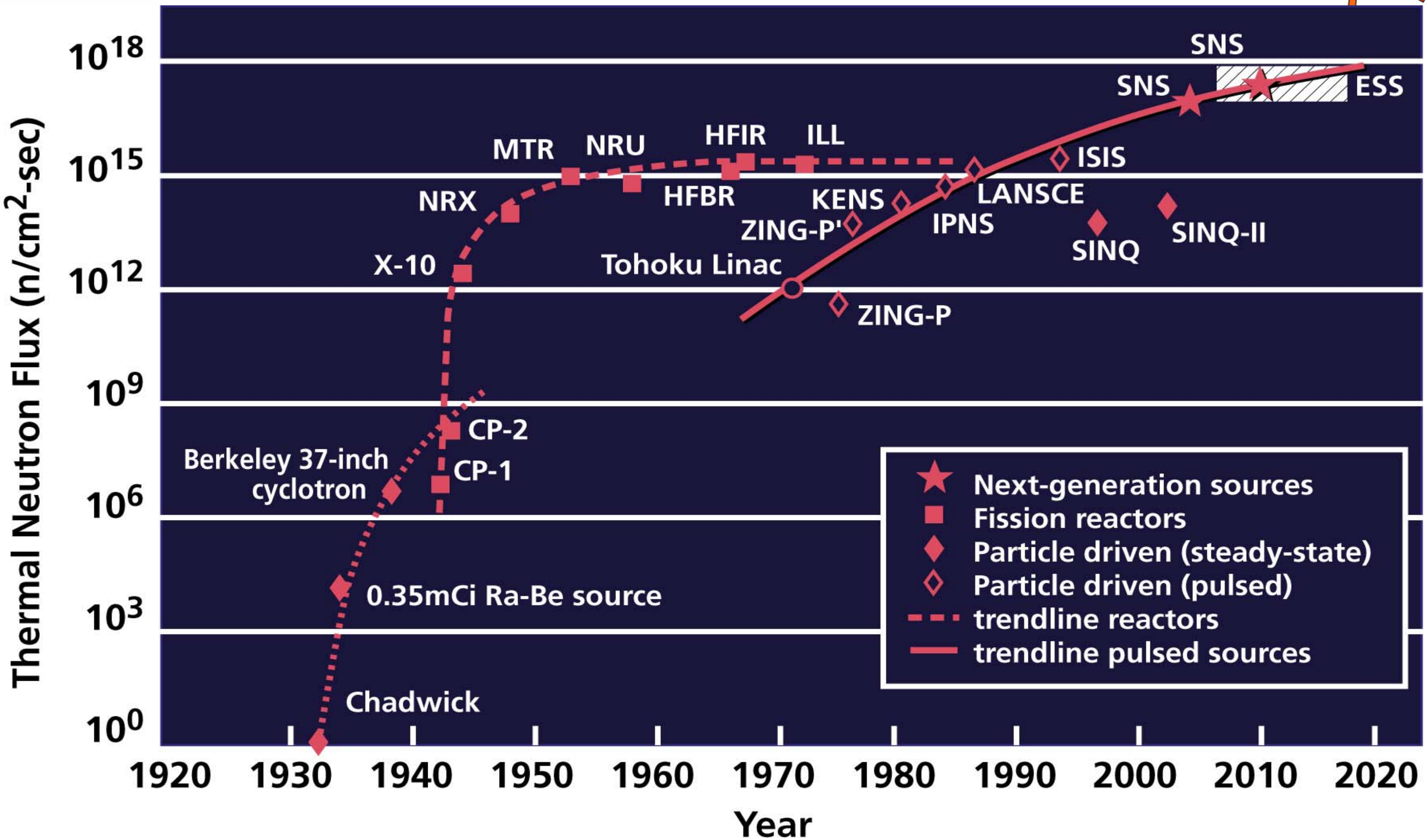
SNS-ORNL Accelerator systems: ~137 M$

~500 People work on the construction of the SNS accelerator

Oak Ridge, TN ????

35° 49' N , 83° 59' W

Development of Neutron Science Facilities



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

97-3924E uc/djr

SNS is the Forefront Facility for Future High Beam Power Accelerators

Highest Beam Power worldwide under construction

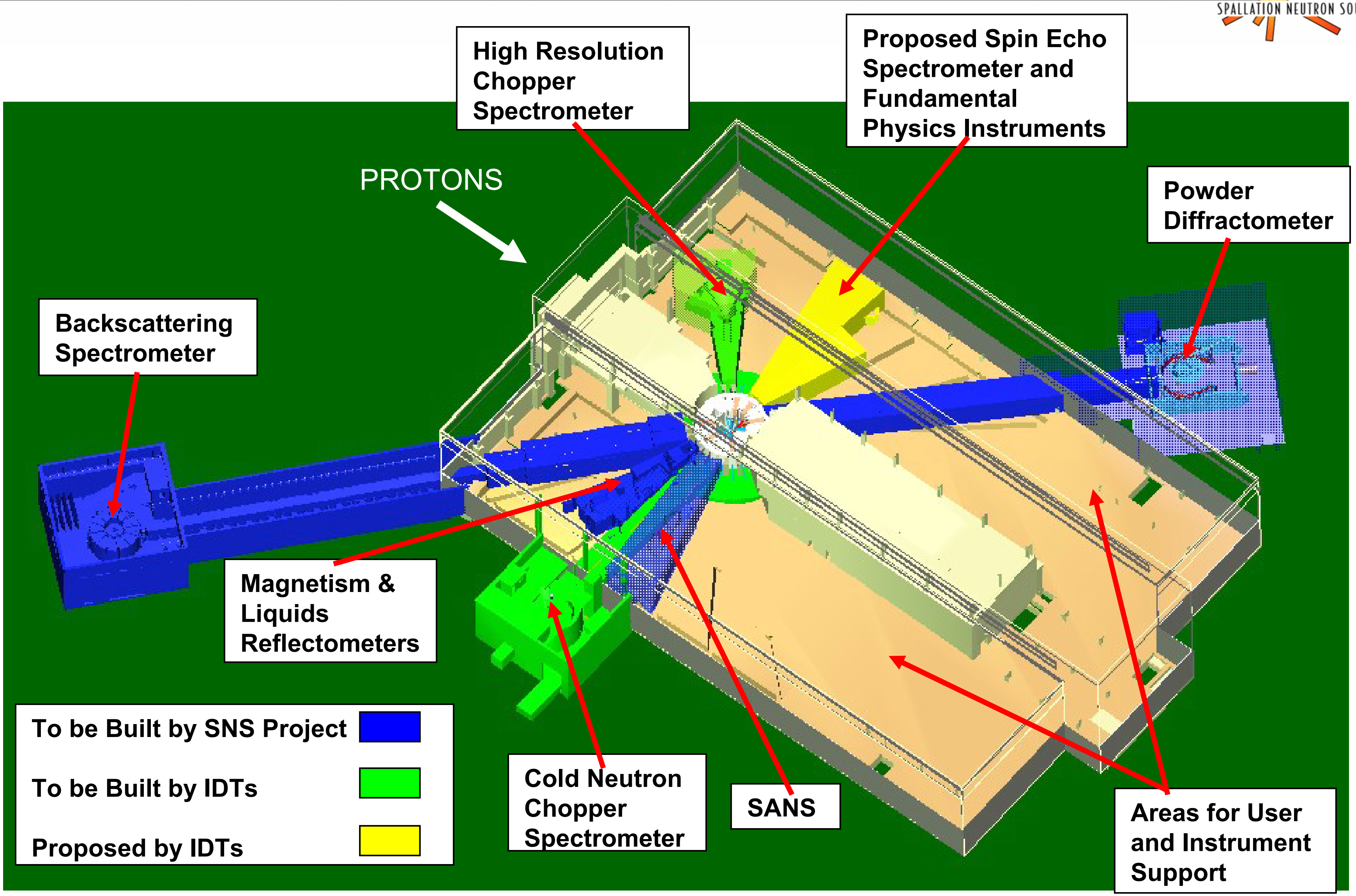
Stepping stone to next generation Spallation Sources

$$\overline{P}_{beam} = E[eV] \cdot I[A] \cdot T_{pulse}[sec] \cdot f_{rep}[Hz]$$

SNS : Goal is to achieve 1.4 -> 2 ++ MW average power

- **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**

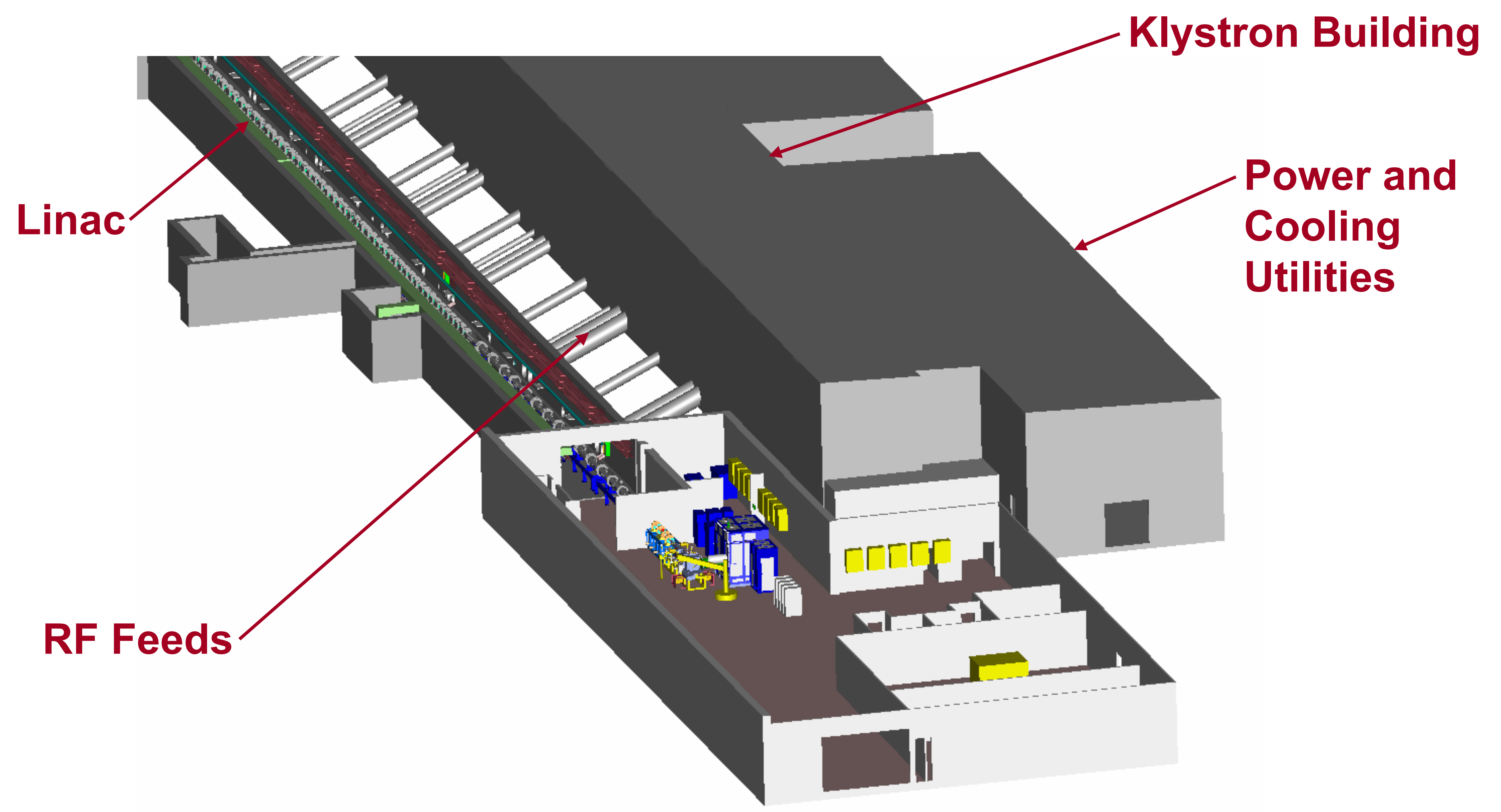
Instrument Layout



The Transformation of Chestnut Ridge into a construction site: More than 600 kH without major Lost workday !!

Progress on the Construction Site

Accelerator Infrastructure



Linac Tunnel

<u>March 13, ‘02</u>
Light at the end of the tunnel and through the side penetrations

<u>March 13, ’02</u>
First inserts in installation before the Klystron Building is finished

High Level Baseline Parameters for the SNS

Proton beam energy on target	**1.0**	**GeV**
Proton beam current on target	**1.4**	**mA**
Power on target	**1.4**	**MW**
Pulse repetition rate	60	Hz
Beam macropulse duty factor	6.0	%
Ave. current in macro-pulse	26	mA
H^- peak current front end	38	mA
Chopper beam-on duty factor	68	%
RFQ output energy	2.5	MeV
FE + Linac length	335	m
DTL output energy	87	MeV
CCL output energy	185	MeV

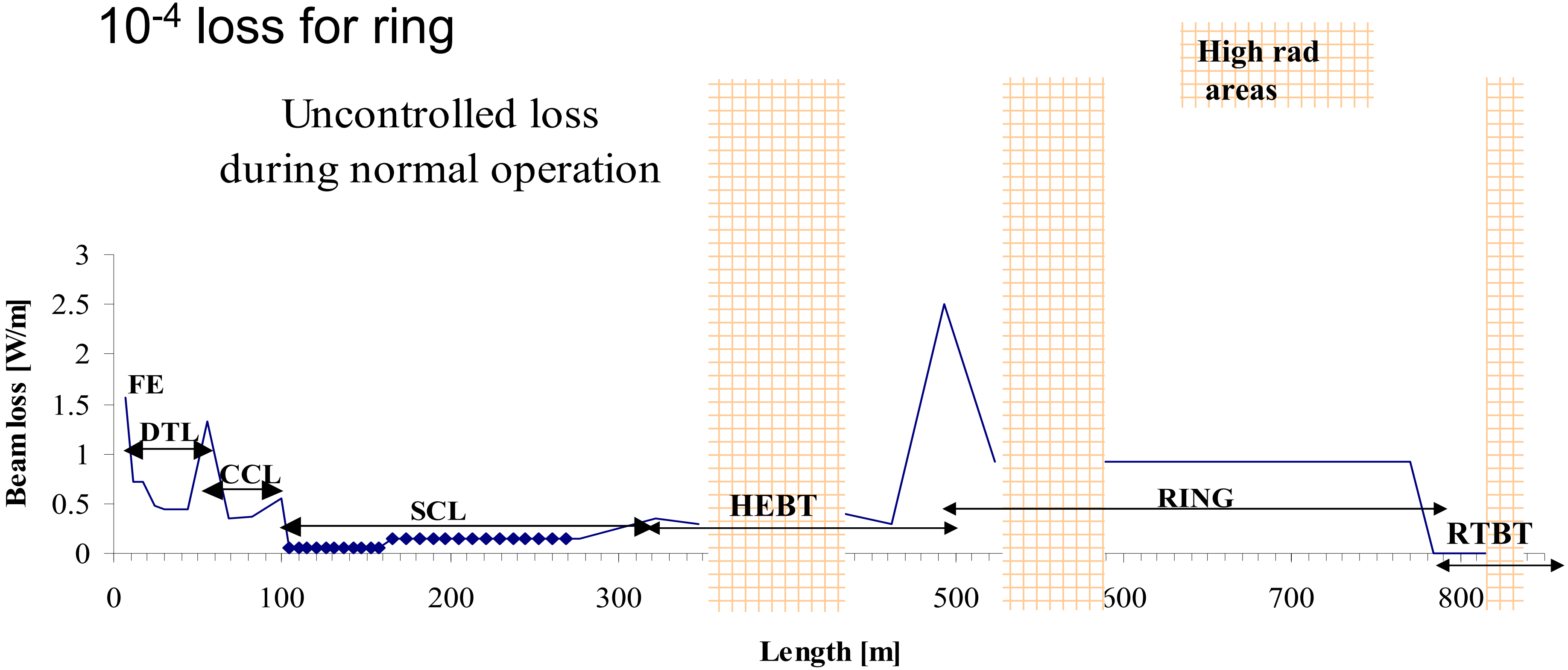
SC linac output energy	1.0	GeV
HEBT length	170	m
Accumulator ring circ.	248	m
Ring fill time	1.0	ms
Ring beam extraction gap	250	ns
RF systems	h=1 +h=2	
RTBT length	150	m
Protons per pulse on target	$1.5x10^{14}$	
Proton pulse width on target	695	ns
Target material	Hg	

AP Issue: Minimize losses along the accelerator chain !!!!

→1 Watt per meter (or 1 nA) apart from collimators

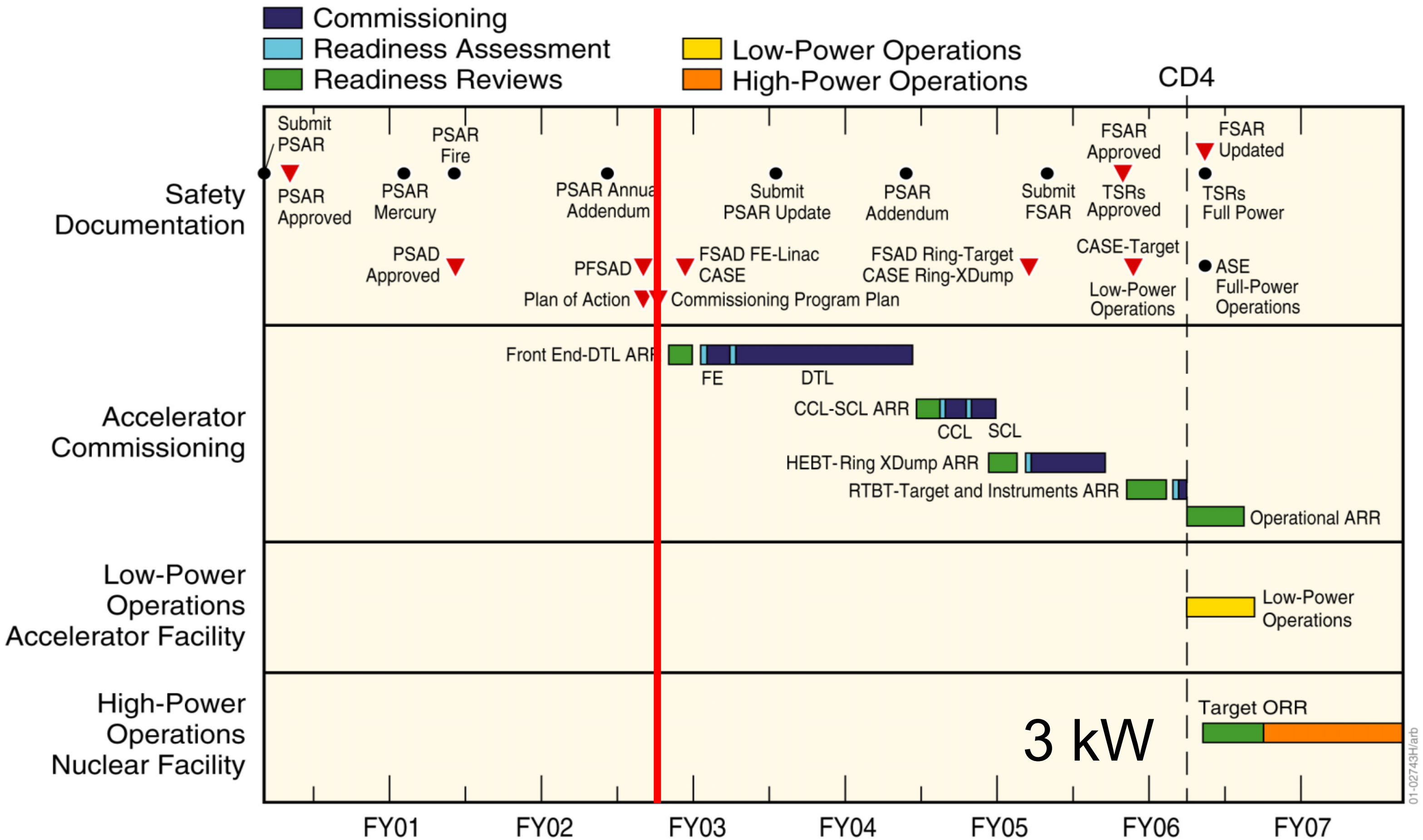
Primary Concern: *Uncontrolled Beam Loss*

- 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



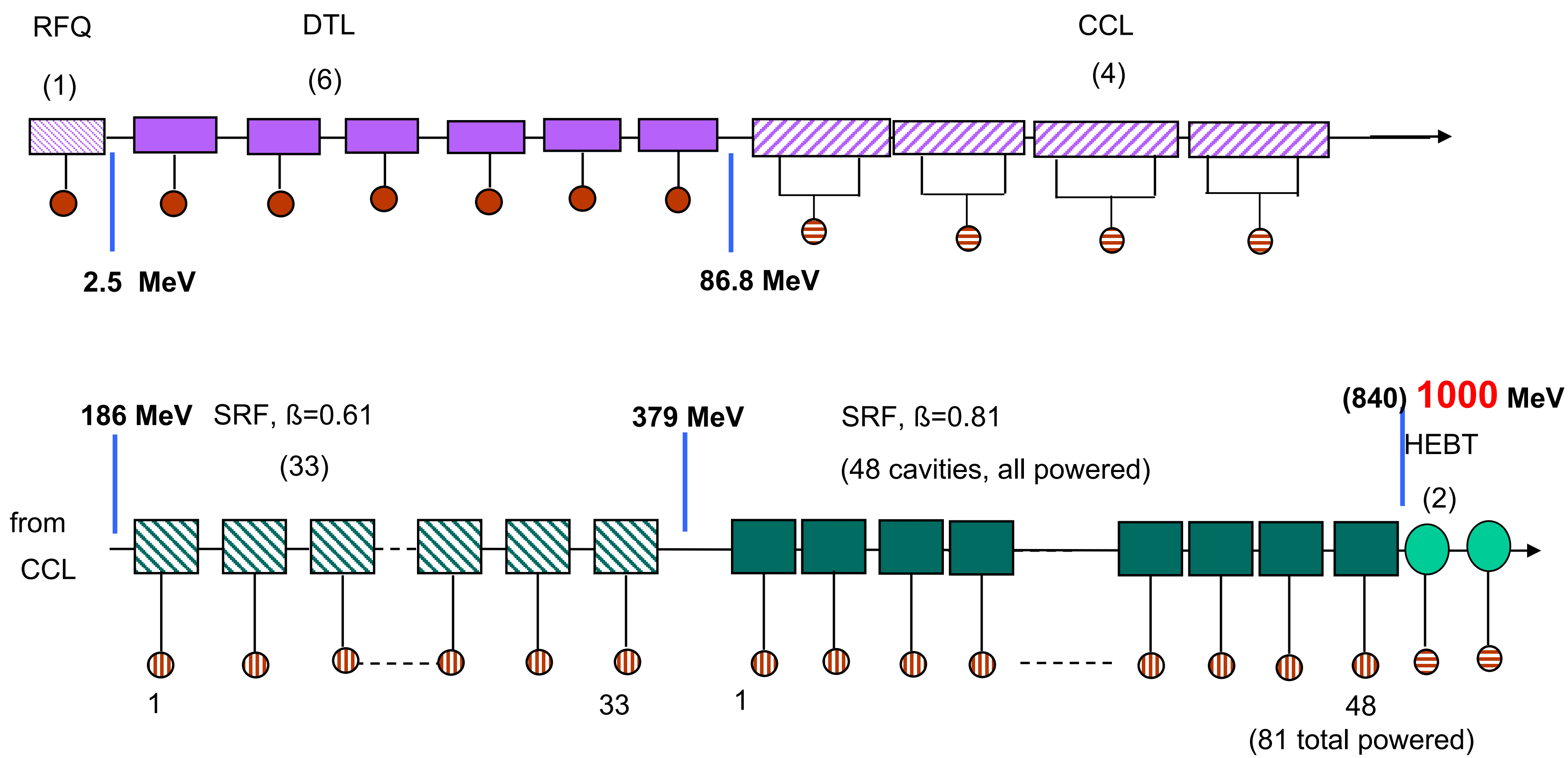
SNS Project Commissioning Schedule

- Installation, Testing and Commissioning will happen at the same time



Layout of Linac RF with NC and SRF Modules

402.5 MHz, 2.5 MW klystron	3 Transmitter	3 Modulators
805 MHz, 5 MW klystron	4 Transmitter	4 Modulators
805 MHz, 0.55 MW klystron	16 Transmitter	8 Modulators

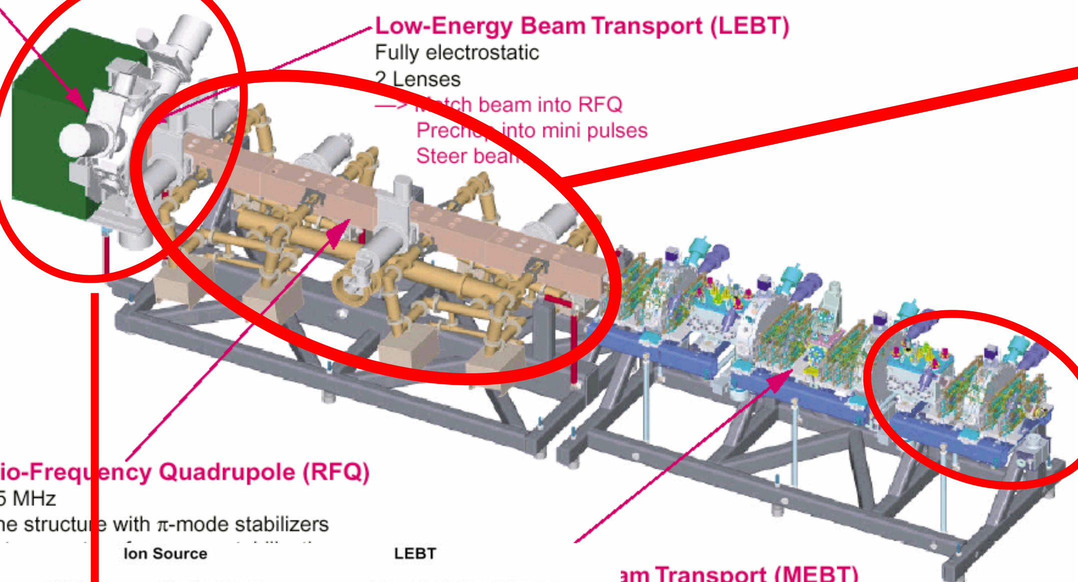


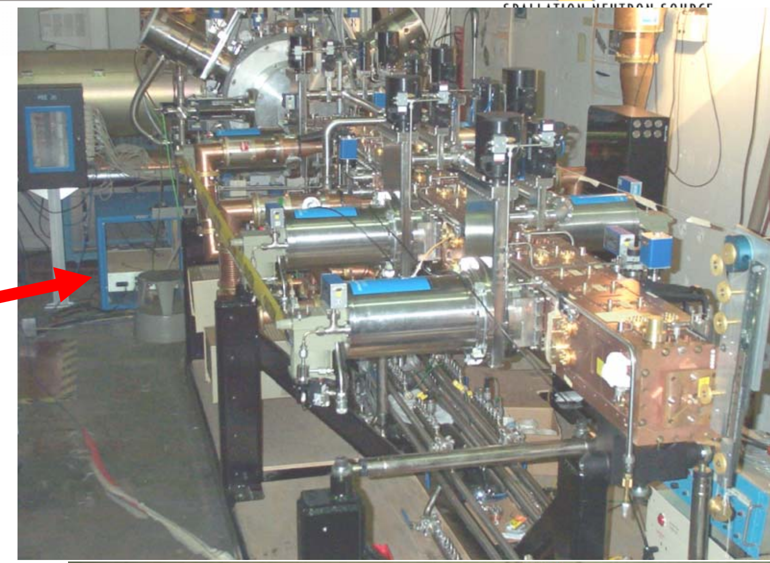
LBNL: The SNS Front End Systems

Ion Source
Multicusp, rf driven, cesium-enhanced
—> Create beam of about 50 mA, 65 keV
Dump extracted electrons at 5 keV

SNS Front End (Linac Injector)
Built and commissioned at LBNL Berkeley

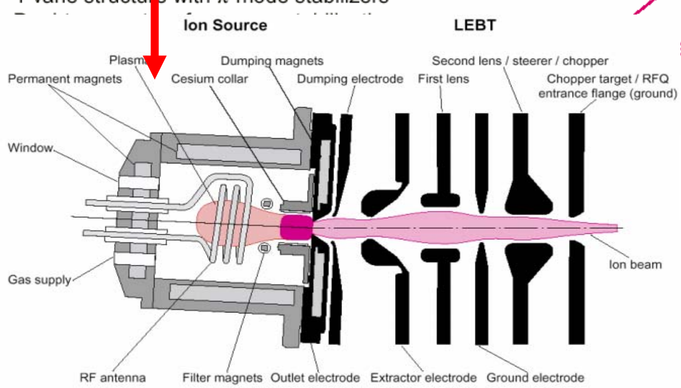
Low-Energy Beam Transport (LEBT)
Fully electrostatic
2 Lenses
—> Match beam into RFQ
Prechop into mini pulses
Steer beam

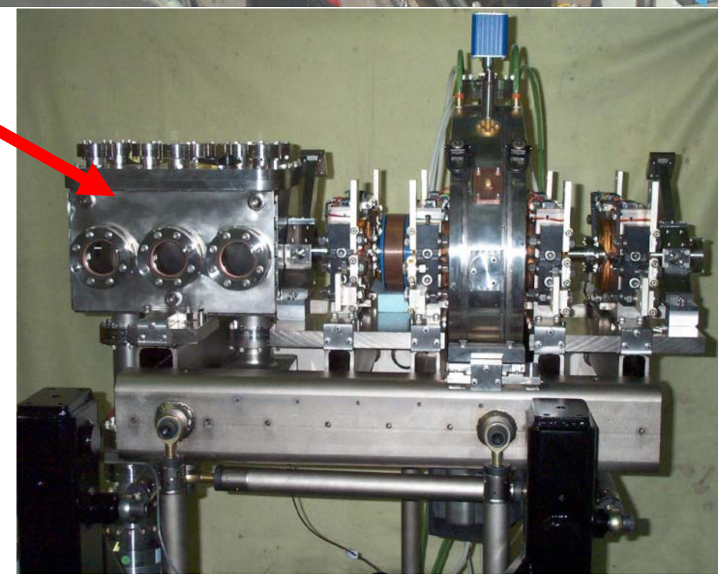




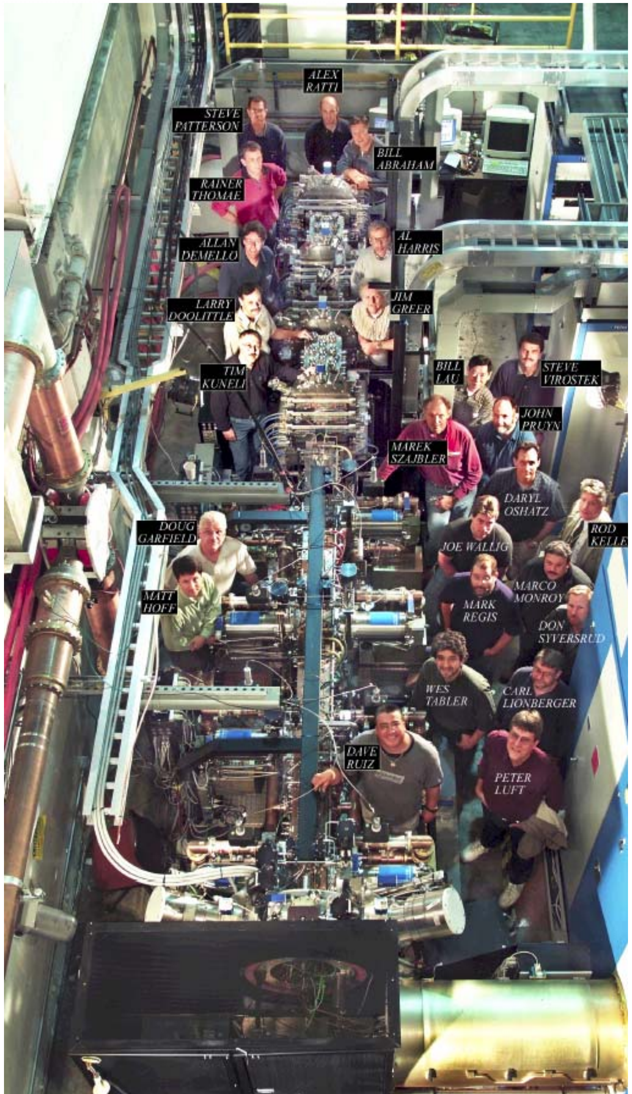
Radio-Frequency Quadrupole (RFQ)
402.5 MHz
4-vane structure with π-mode stabilizers

am Transport (MEBT)





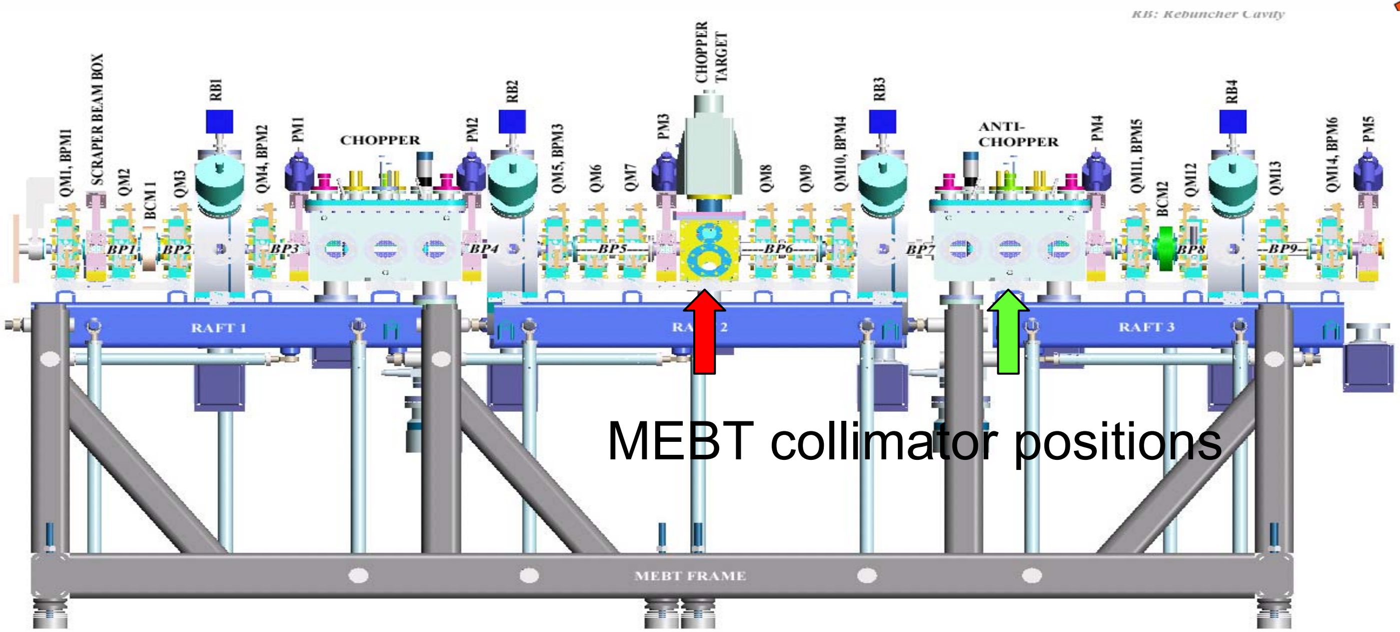
Front-End Systems Commissioned @ LBNL



- Ion source performance adequate for SNS early operations
  - 50 mA average pulse current achieved
  - Established lifetime exceeds 100 hrs
  - Expected to be much longer with latest antenna design: thicker coated antenna
- Feasibility of fully electrostatic LEBT proven
  - Good match of 40-mA beam into RFQ
- RFQ performs better than planned
  - More than 90% transmission at 40-mA current
- MEBT commissioning started on 4/4/2002
  - A maximum of 36 mA was achieved :

$$\varepsilon_{x,y} \approx 0.3\ \pi \text{ mm mrad}$$

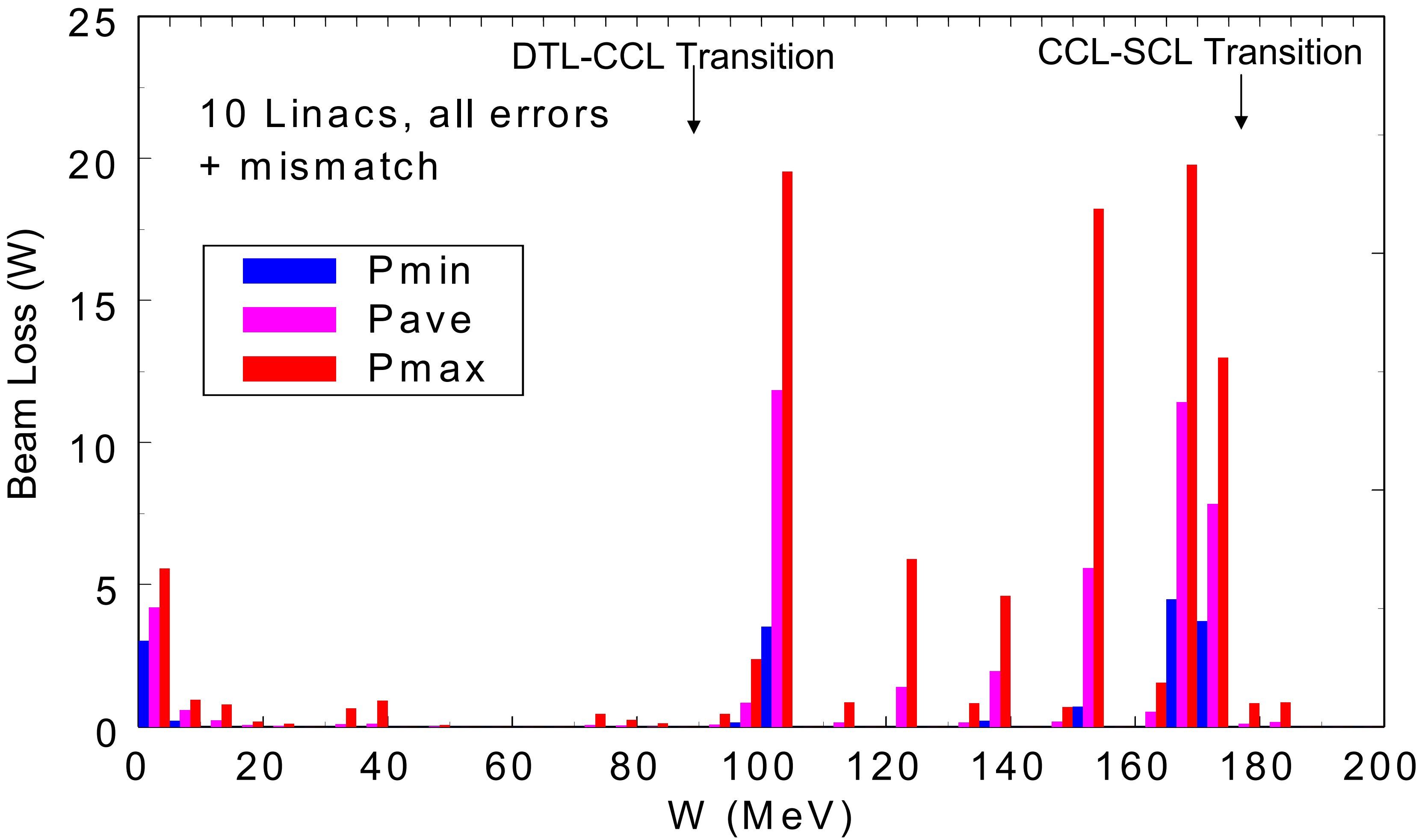
MEBT Collimation: Mitigate Halo when it develops!



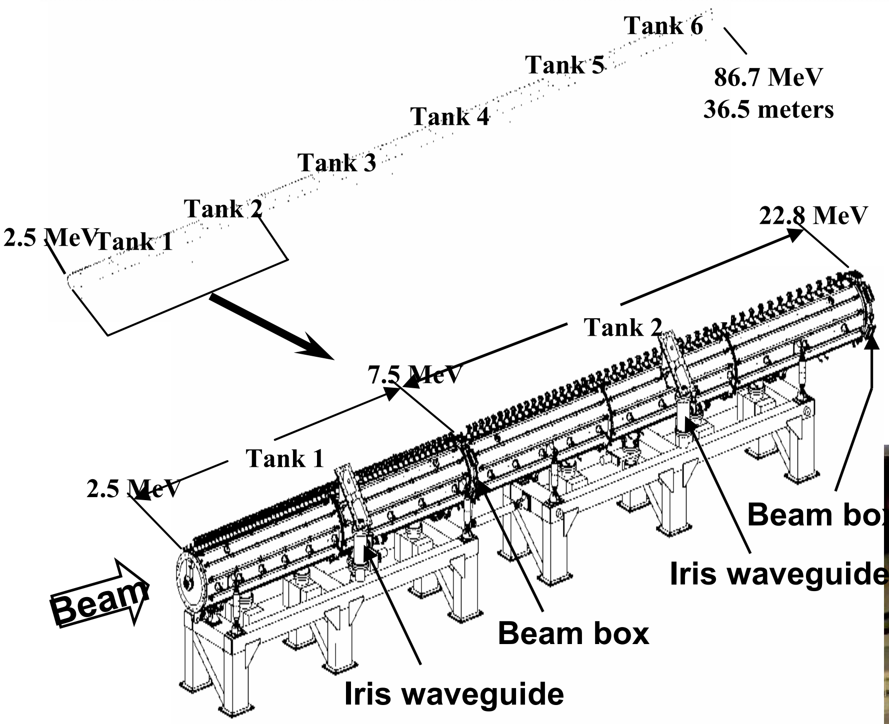
- MEBT is the biggest contributor to halo formation$\Rightarrow$ Collimate there!
  - Nonlinear space charge force due to large beam eccentricity (chopper box to anti-chopper box) is responsible for halo formation in MEBT
- Alternative MEBT optics and collimation at the chopper target box preempt halo formation, removing 97% of halo at CCL
- Beam loss potentially jeopardizes quadrupole performance if collimated in the DTL

Beam Loss Occurs Primarily at Structure Interfaces for Mismatched Beams

Does not yet include MEBT scraping!



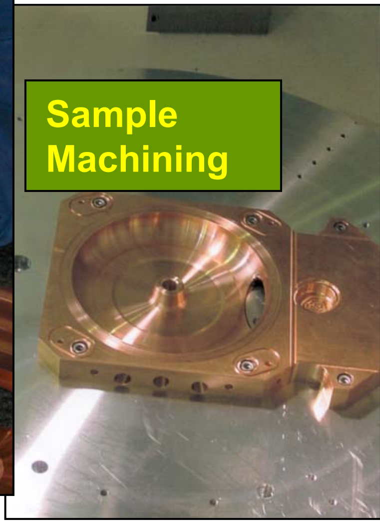
LANL: Design, Accelerator Physics and Linac Components

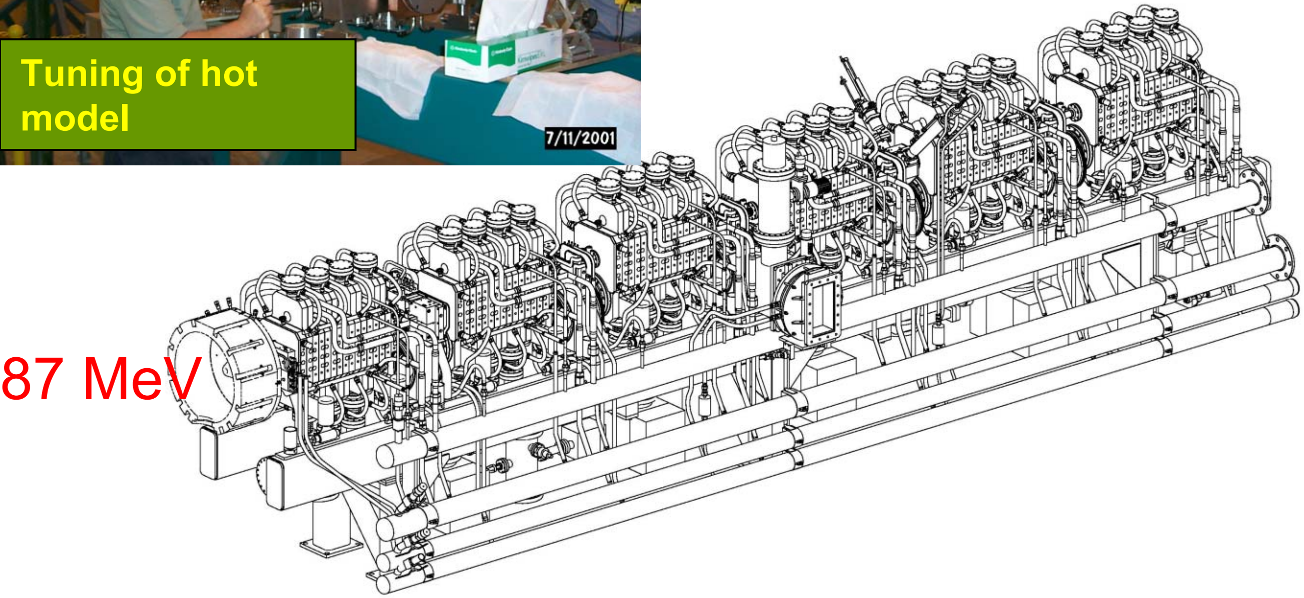


- DTL is in full production
- First operation this summer

CCL Construction is Underway

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



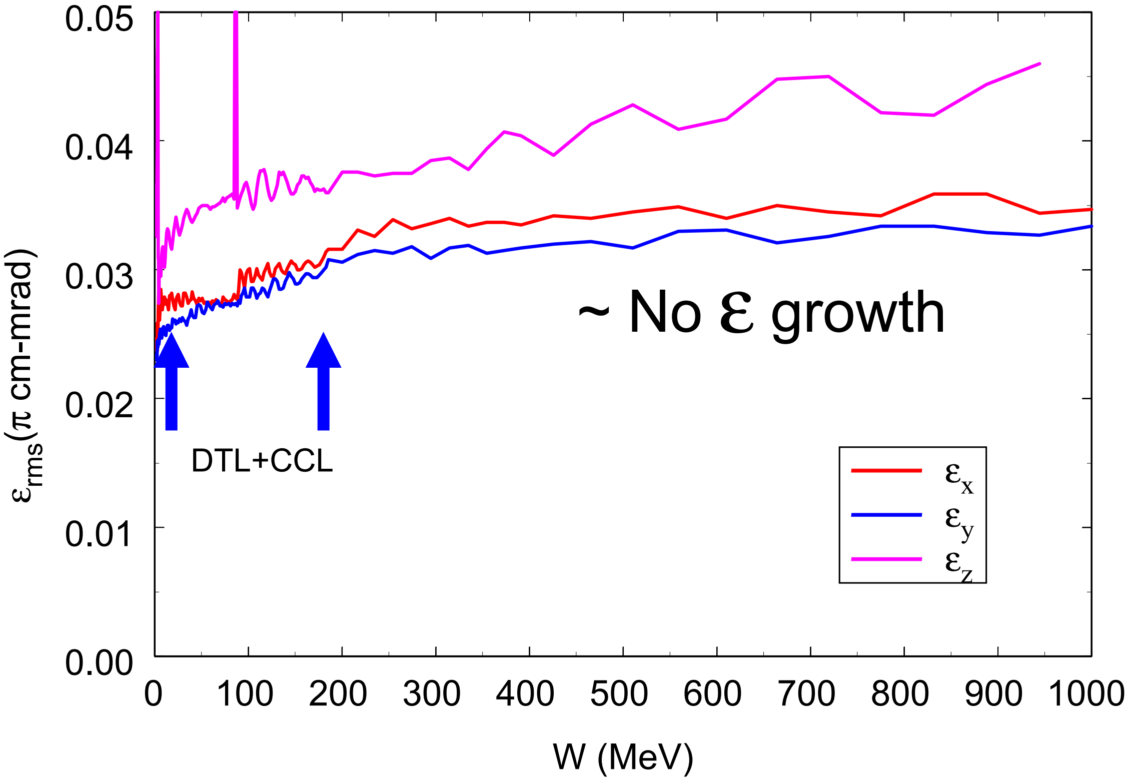


LANL:The RF Systems

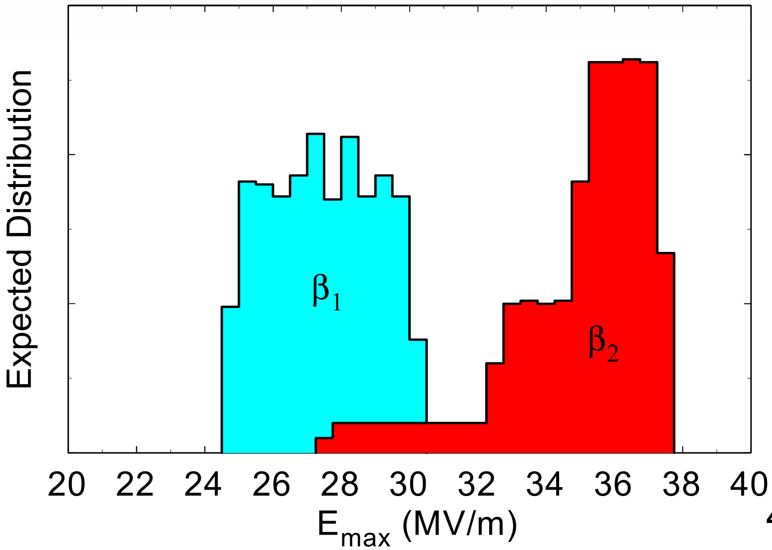
~ 100 Klystron stations @ SNS

JLab: The Superconducting Linac

- Emittance Growth and Halo Scraping
- SC cavities have large apertures and high field
  - Saves real estate, operational money, reduces beam loss (since most of it comes from gas stripping or aperture restrictions)

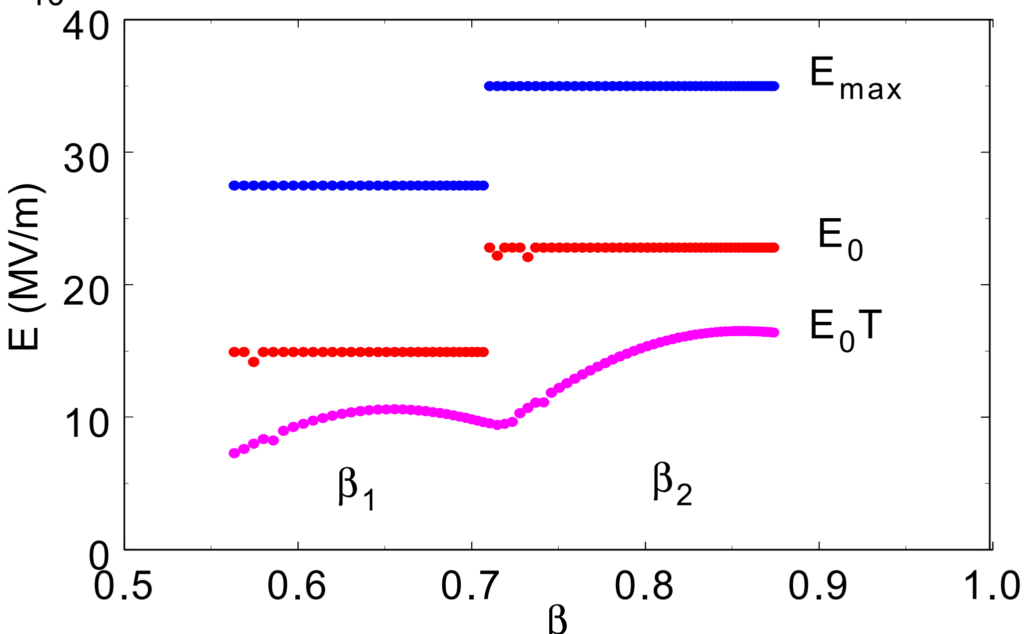


Varying β In Cavity Fixed Geometry



- Distribution assumed as a result of cavity production for β=0.61 and β=0.81cavities
- High β cavities will be electropolished

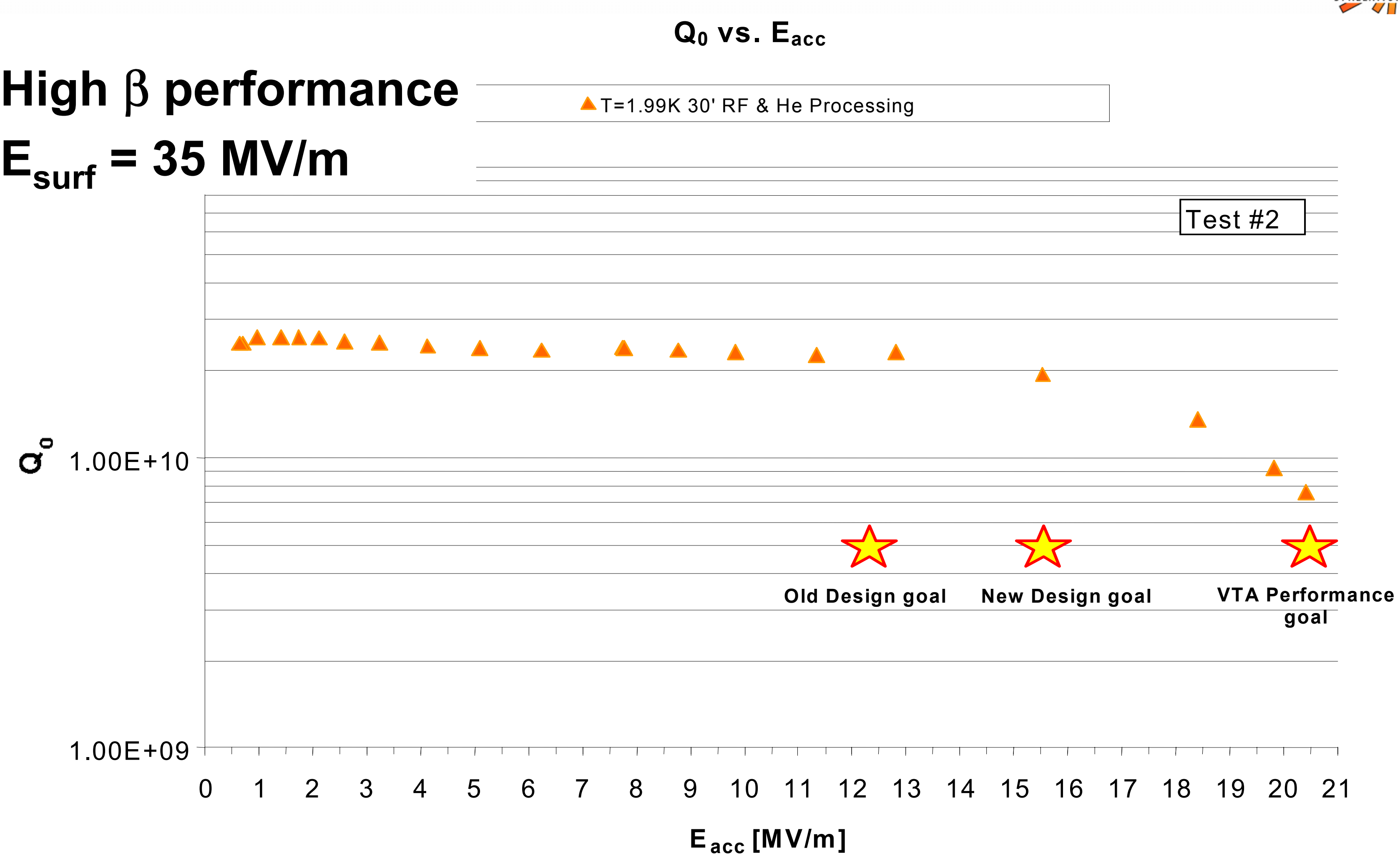
- Surface Field: E_{max}
- On axis field: E_0
- Accelerating field: E_0T
  - Variation of E_0T because of varying β of particles



Prototype Cavity Performance

High β performance

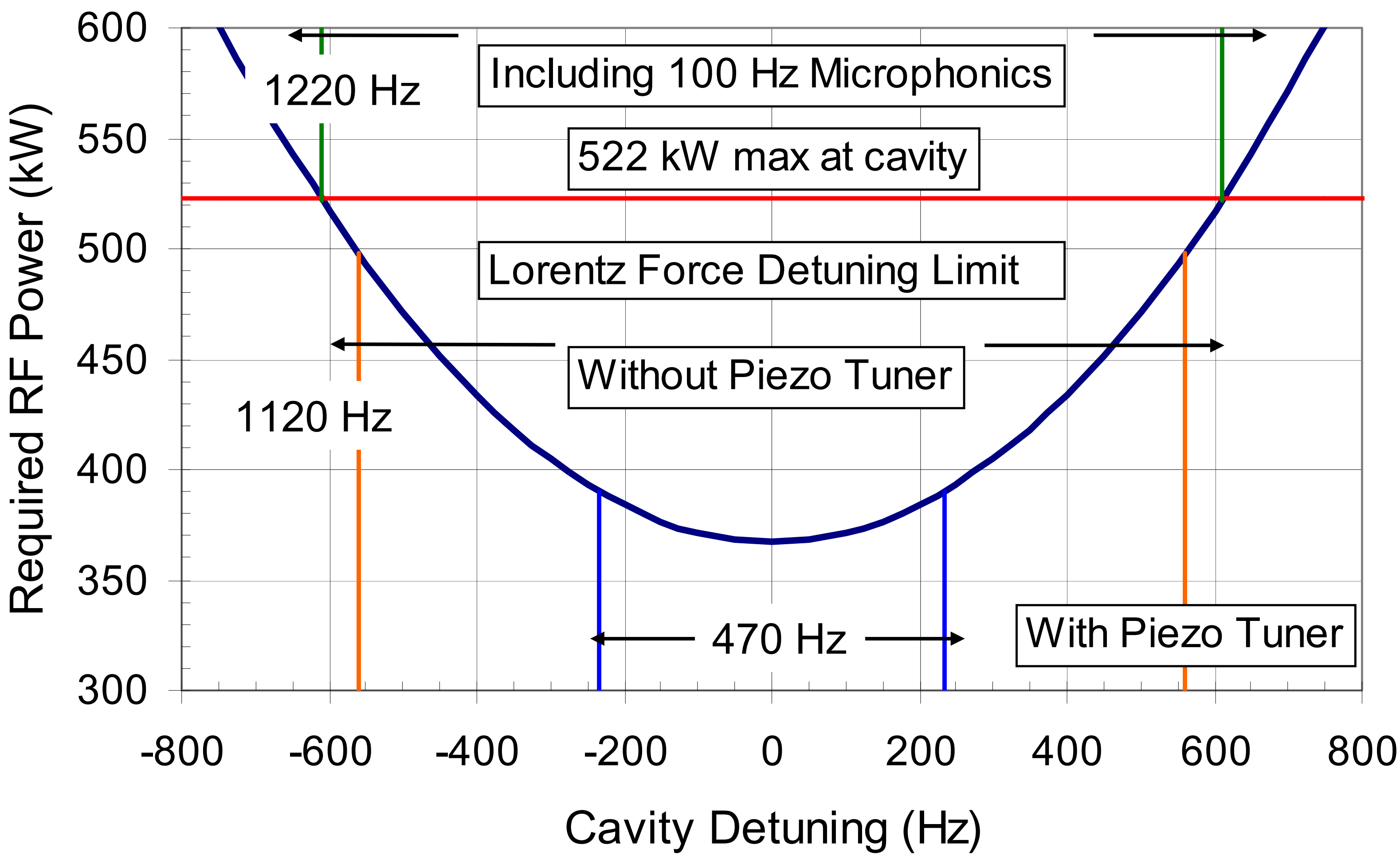
E_{surf} = 35 MV/m



Performance of 6-cell, β=0.81 cavity, stiffening ring at 80 mm.

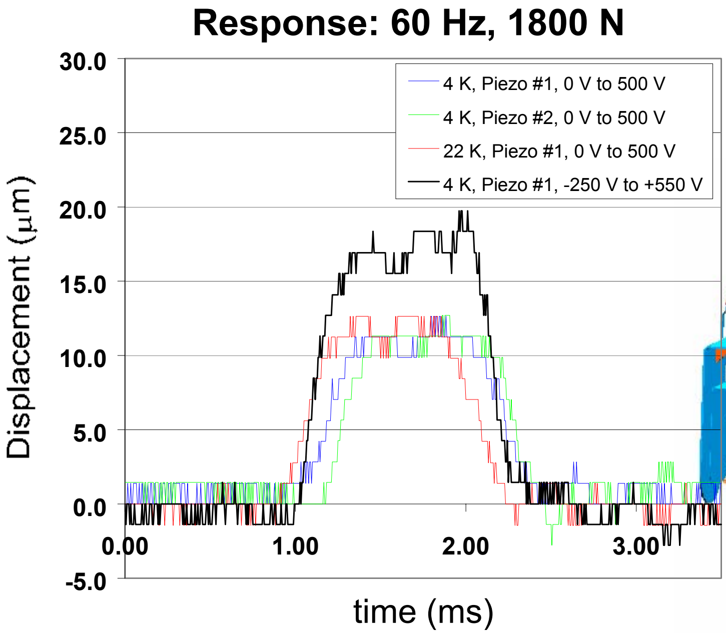
High Power Requirements:
25%-50% Power Reserve in high and medium β

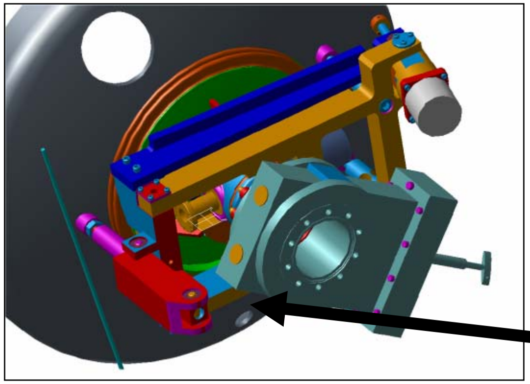
Example: High β cavities

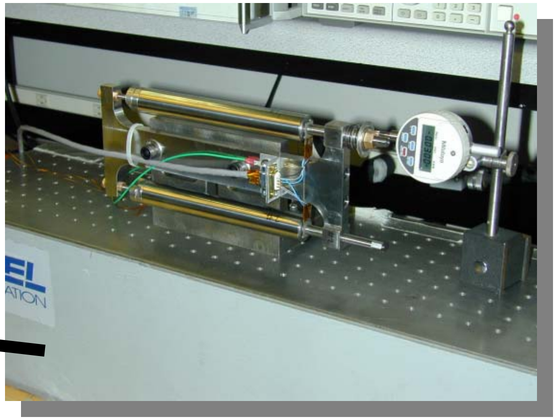


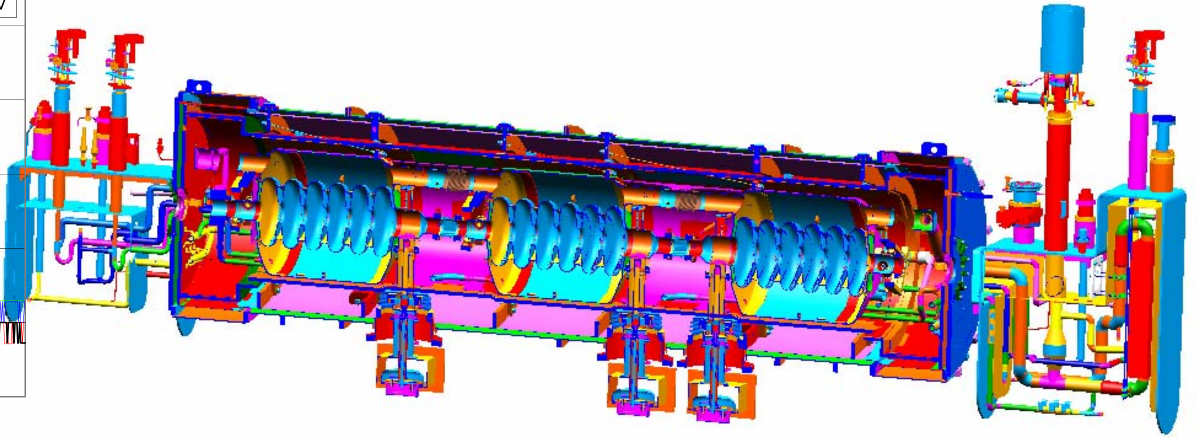
Development of the SC RF Cryomodules

- Prototype cryomodule (3 x β=0.61) in test cave
- Piezo tuners: Development underway and in the baseline
- Tuner test ongoing
- Response @ 4 K
- Need 15 μm





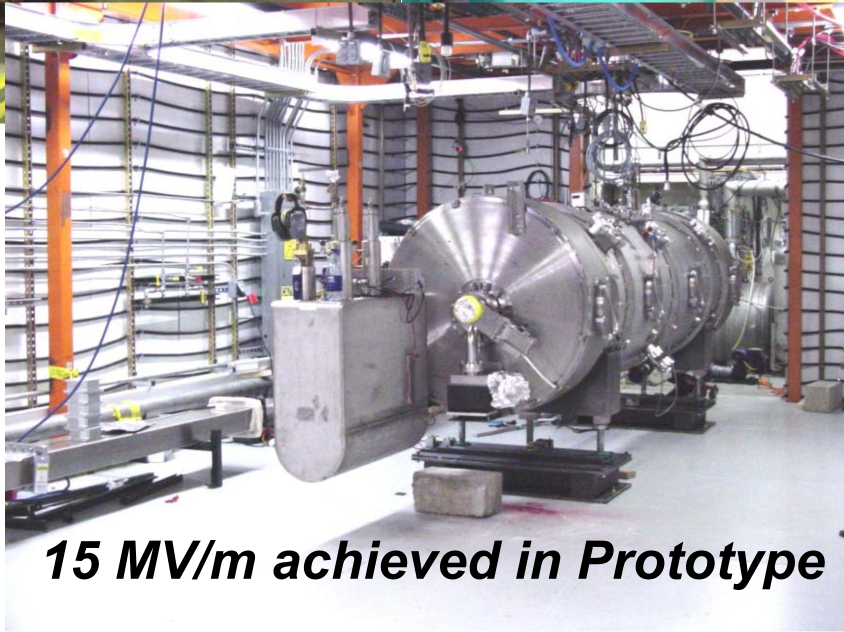




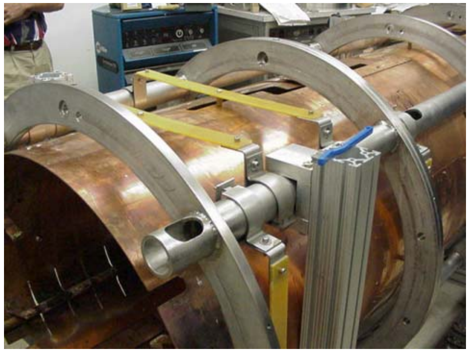
Production Cryomodule subassemblies

- Complete refrigeration system components and start refrigeration installation (ORNL)
- Complete prototype cyromodule testing
- Cryomodule production
  - Full cavity production
  - Start production cryomodule assembly
- Install electropolish cabinet

Schedule is tight!



15 MV/m achieved in Prototype

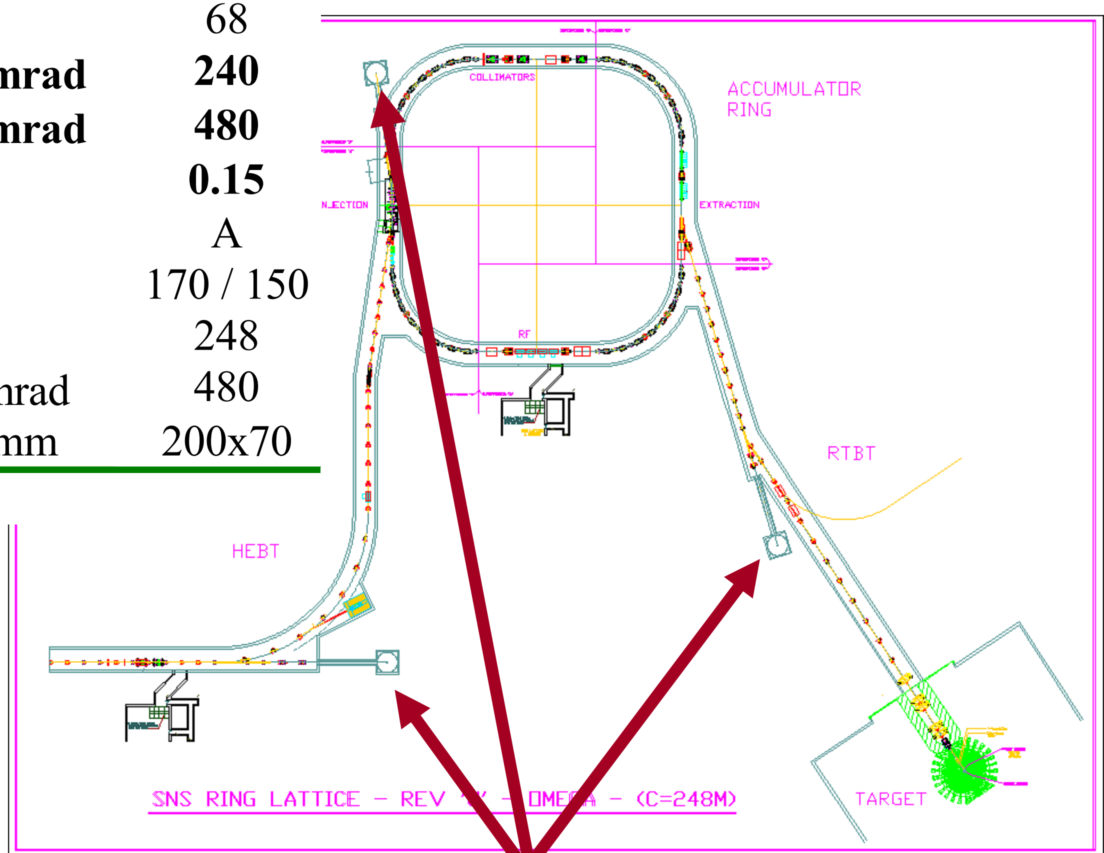


BNL: Accumulator Ring and Transfer Lines

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

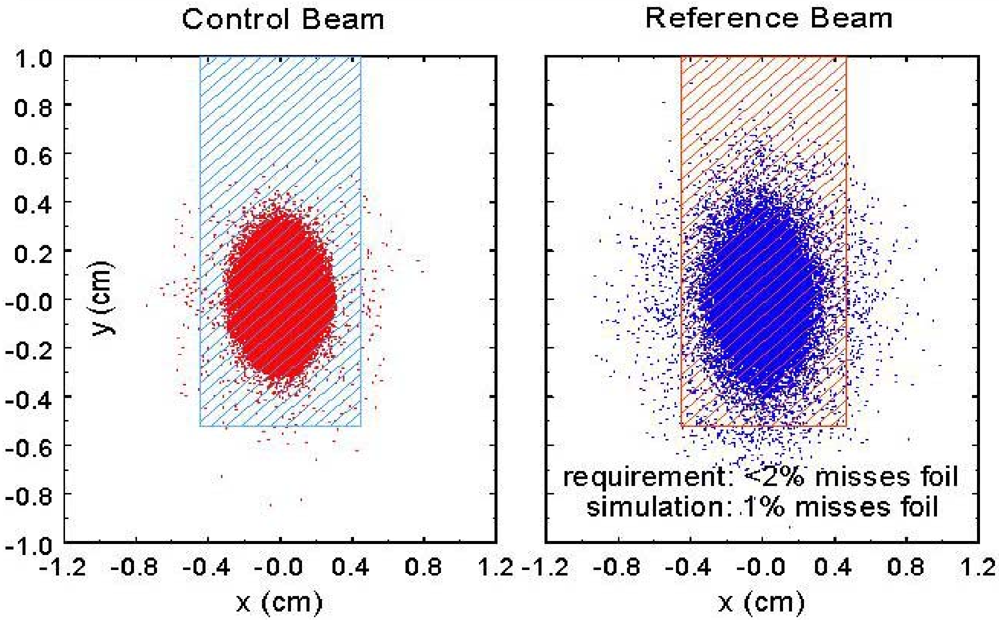
Totals:

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



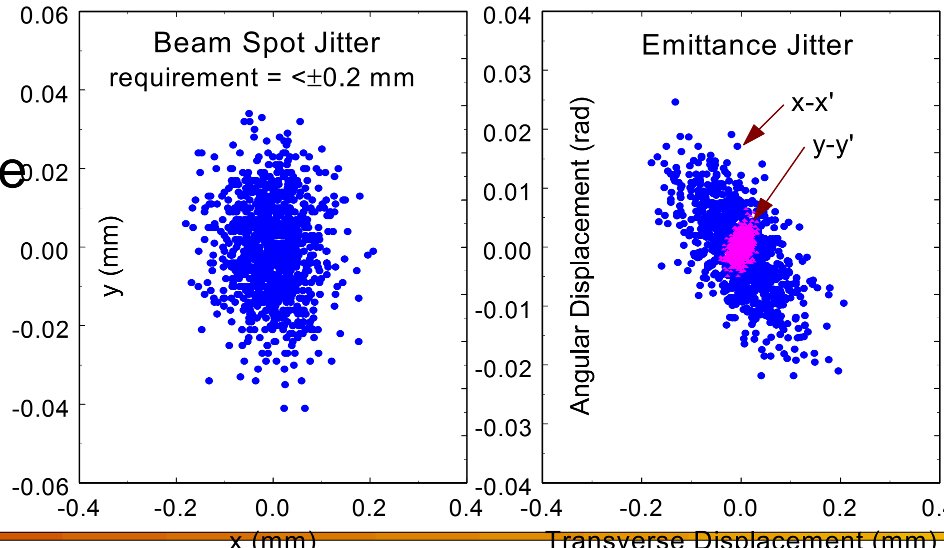
Several commissioning beam dumps

1% of the Reference Beam Misses the Injection Foil



- Some fraction of uncollimated beam will miss the foil
- <u>200 kW</u> "injection beam dump" (H^0,H^+)

- Transverse Jitter at the Foil is a Function of Quad Vibrations & Increases the Effective Emittance
- This drives tolerance for mechanical design



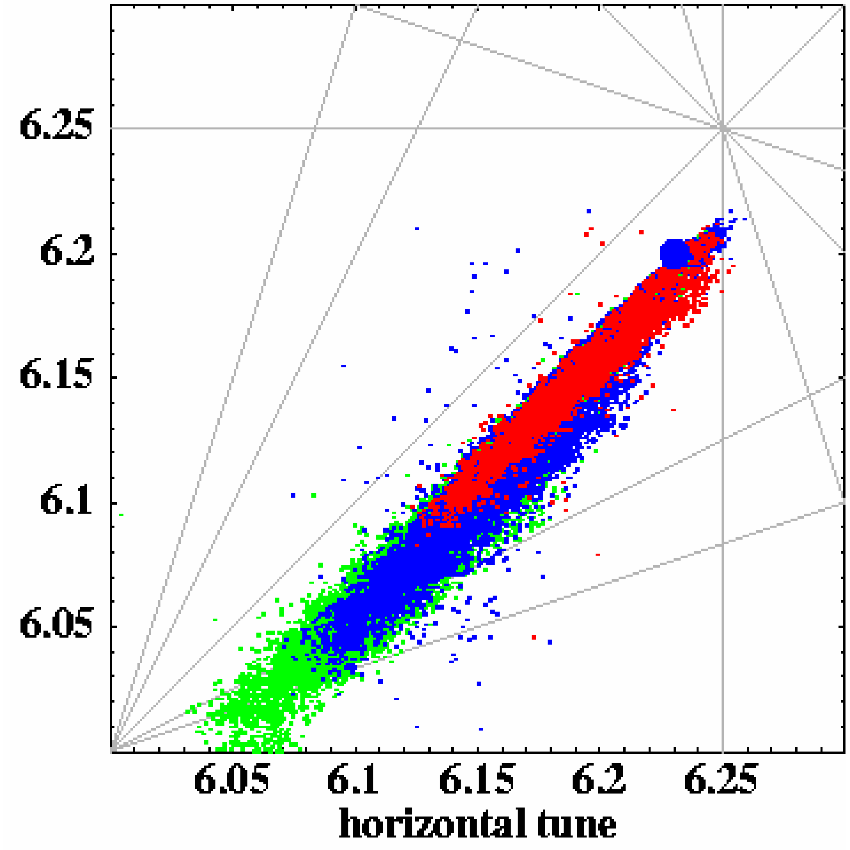
Combined tune spread: various intensities

Tune Diagram during Accumulation

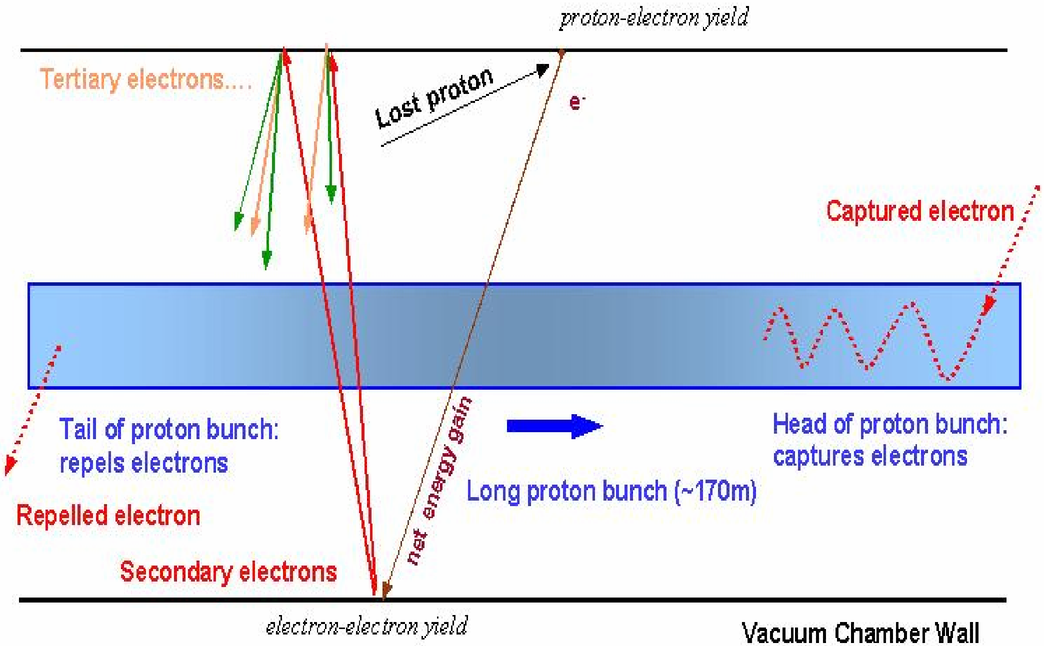
N=0.5*10^{14} – 263 turns

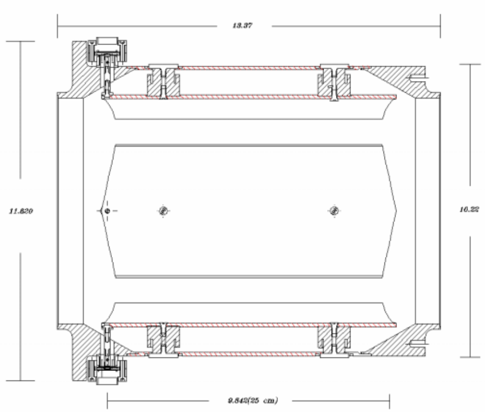
N=1.0*10^{14} – 526 turns

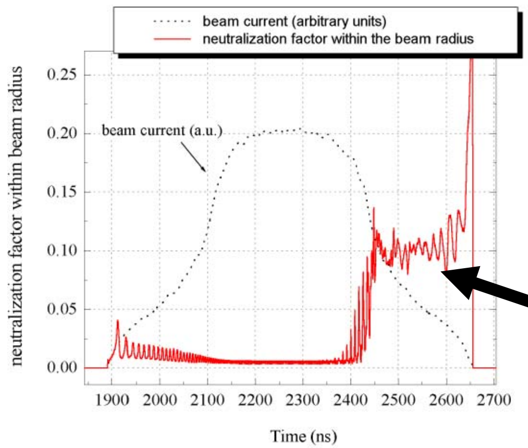
N=2.0*10^{14} – 1052 turns



Electron Cloud
Coating, Clearing Electrodes, Studies







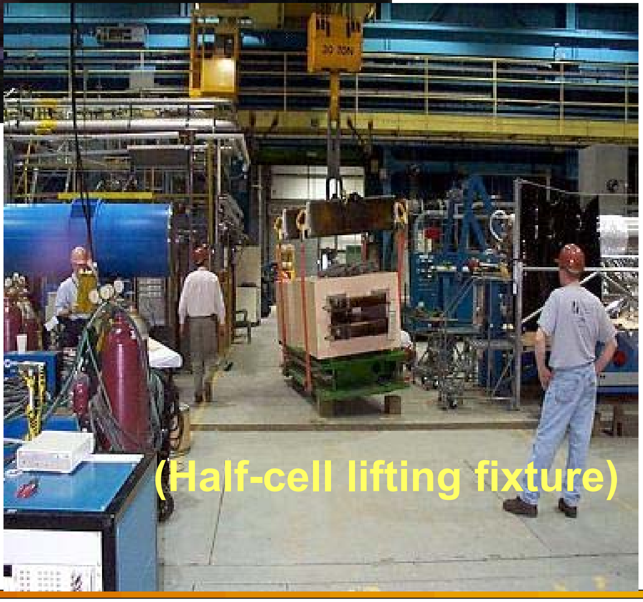
- Electron-cloud: a potential threat to full-intensity performance
- Floating-ground BPMs serve dual purpose as clearing electrodes
  - 42 BPM, each holding ~ +/- 1 kV
  - No change of design
- Clearing electrodes near injection foil assembly
- TiN coating fully in progress

Electrons behind bunch

Ring Progress – Vacuum, Coating, Handling

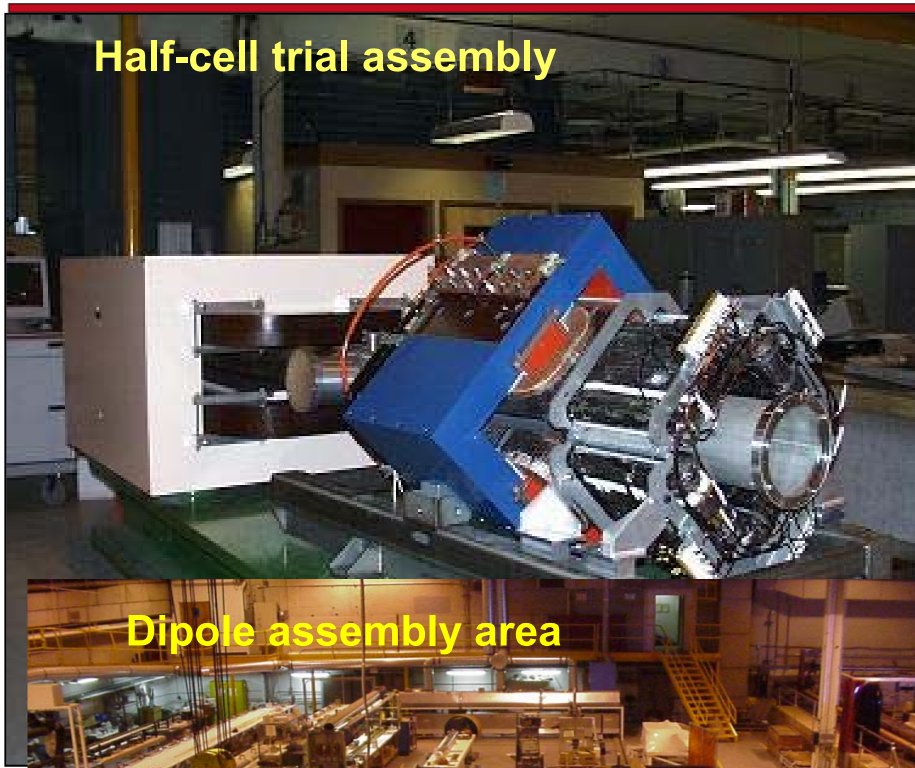
(Half-cell chamber welding)

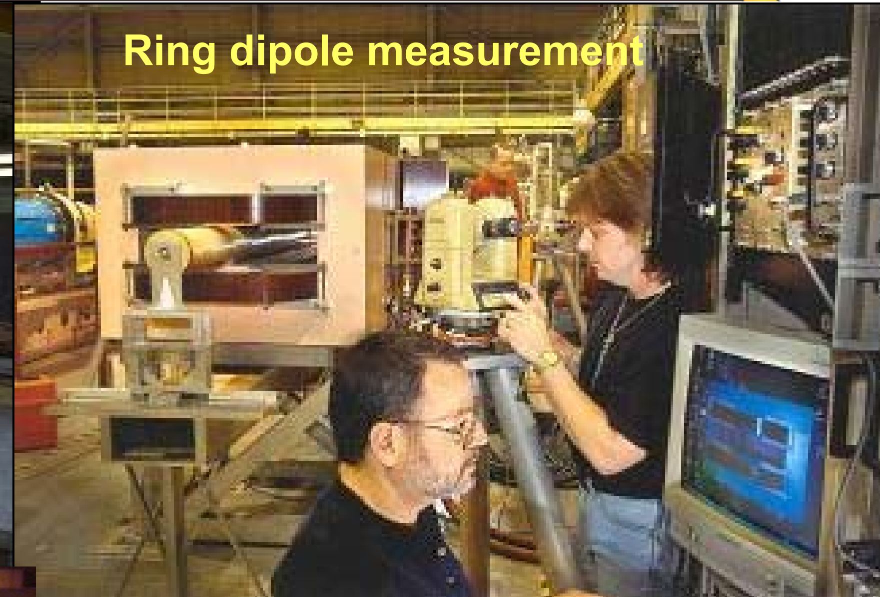
(Titanium Nitride Coating)

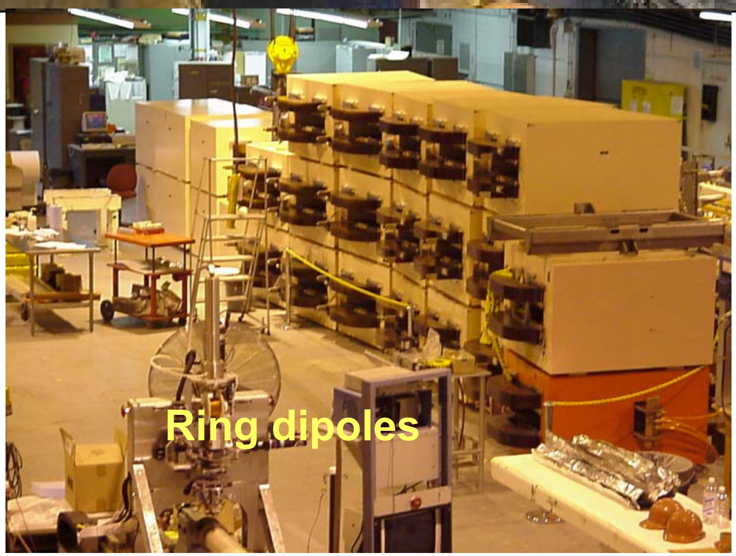


(Half-cell lifting fixture)

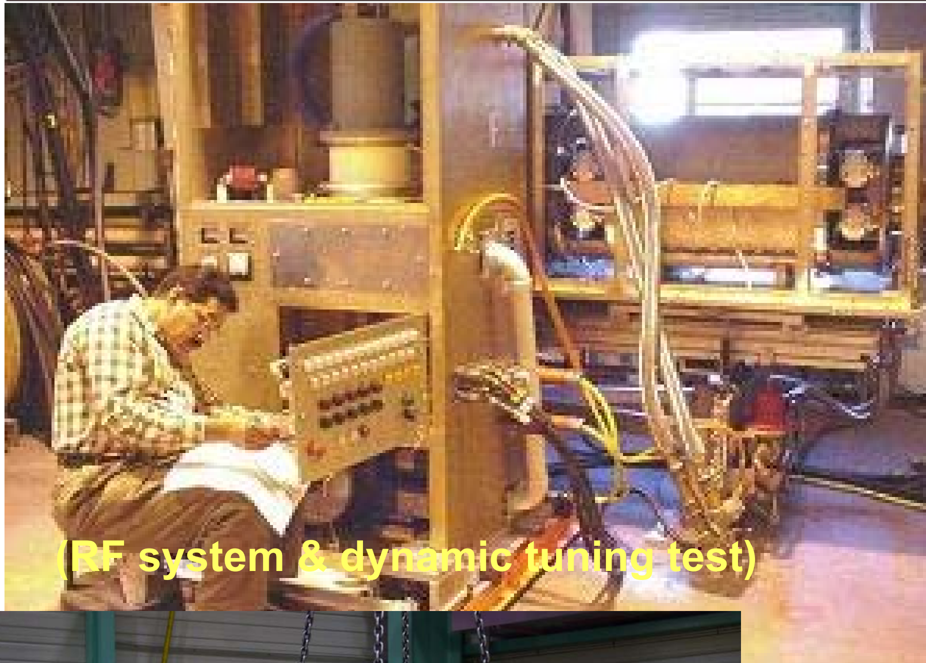
Ring Progress –Magnet, Assembly, Measurements







Ring Progress –
RF, Injection, Extraction, Collimation

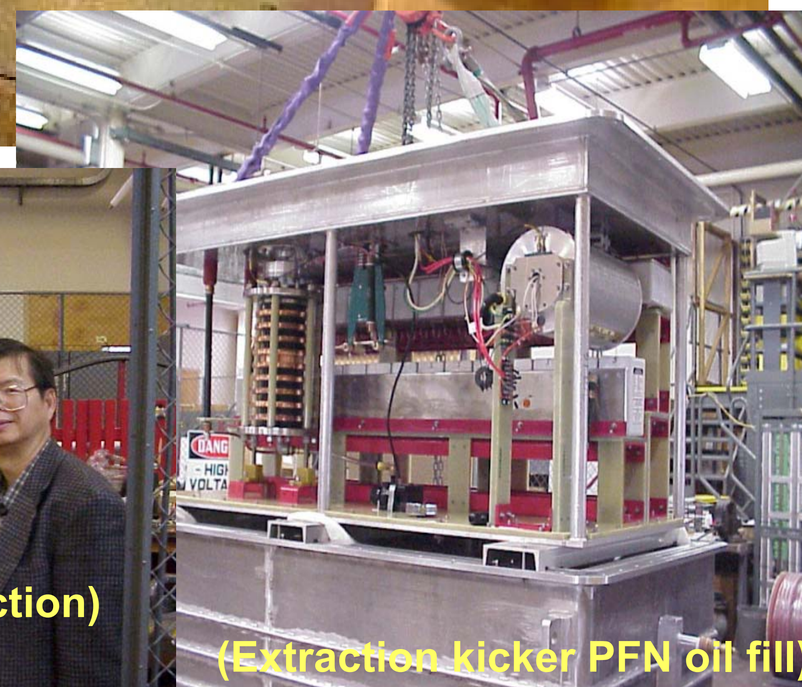


(RF system & dynamic tuning test)

(Injection foil changer)

(RTBT collimator)

(Extraction kicker section)

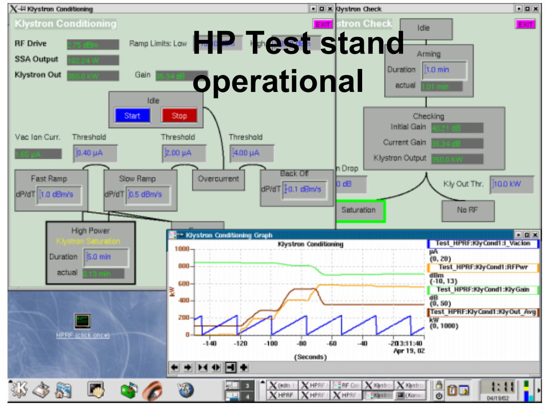


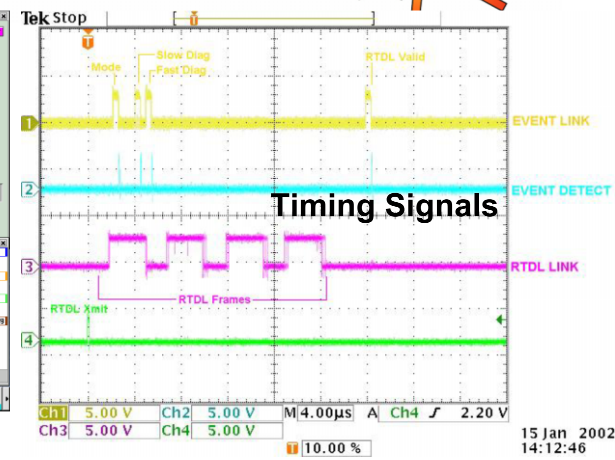
(Extraction kicker PFN oil fill)

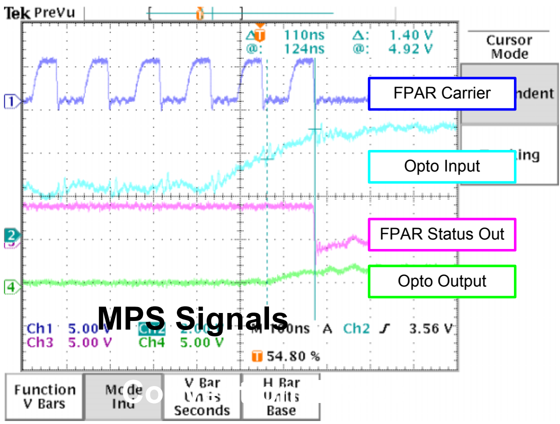
Controls Team: Scattered Effort over 5 Labs

SNS SPALLATION NEUTRON SOURCE

- MPS, PPS, Timing…
  Everything under EPICS
- Support has been provided for Front End runs at Berkeley
- Global components are arriving. Timing and MPS components distributed among partner labs for testing and integration
- Linac Controls ready for DTL Installation
- Have been operating FES @ Berkeley from ORNL +data analysis→GAN







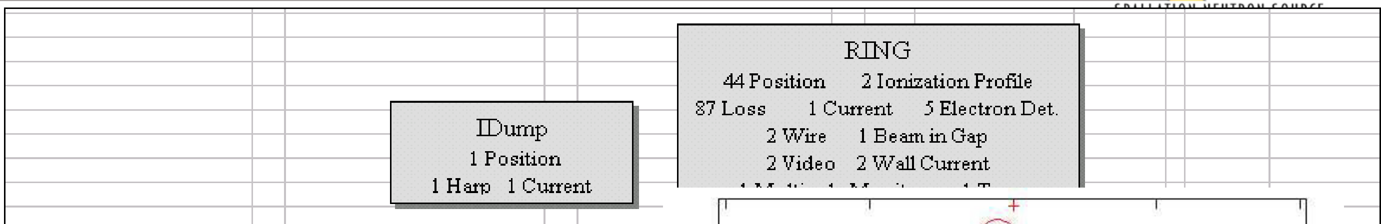
The Installation and Production of Components

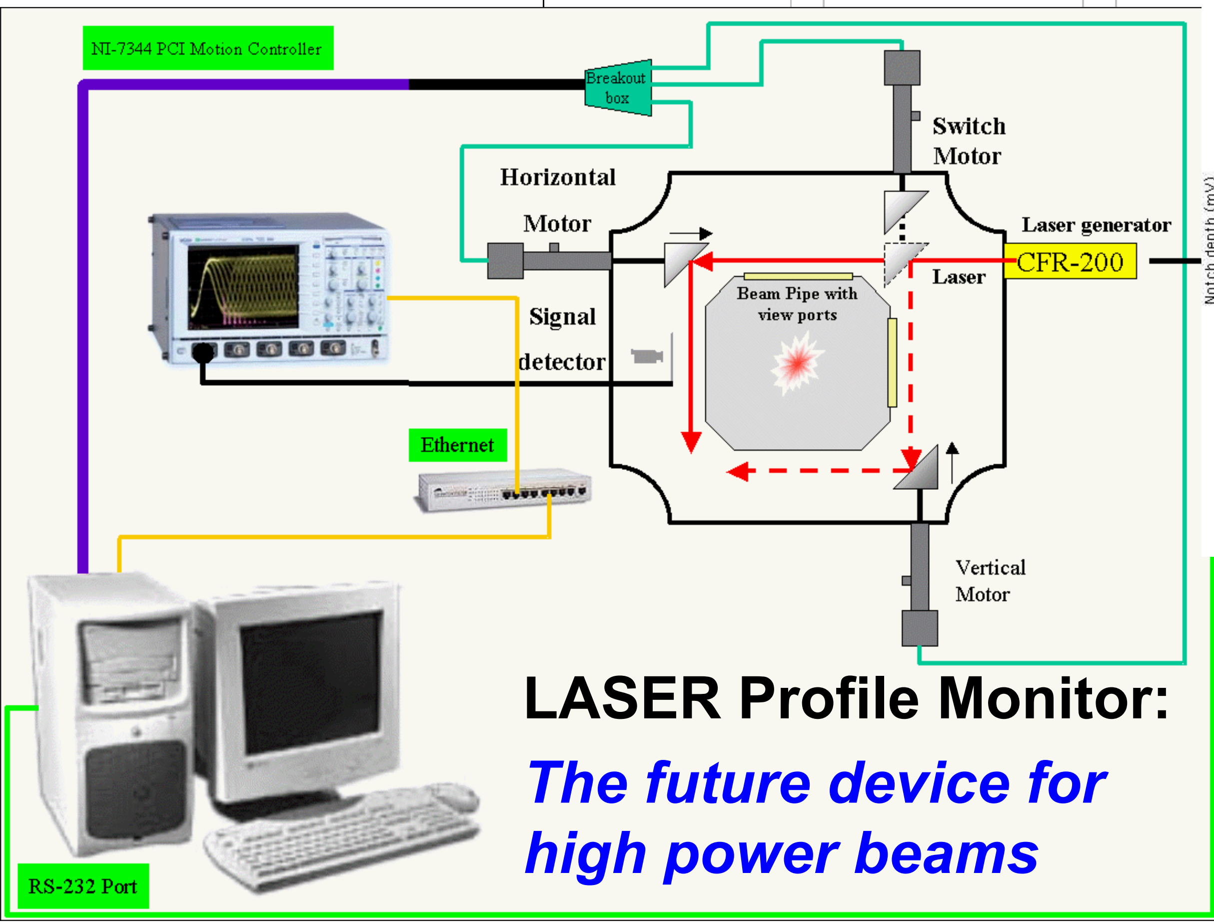
- Design, construction, transport and installation
  - Transfer line installation
  - Chase insert installation on site
  - Buss bar production

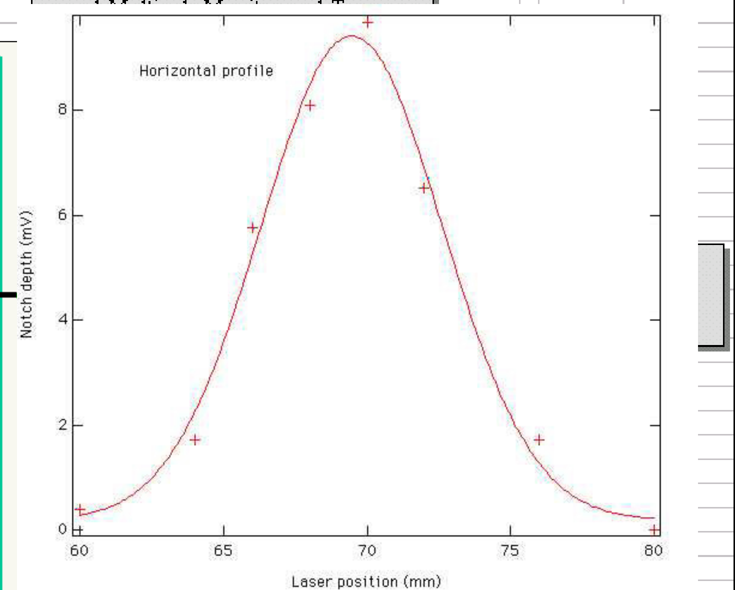
ASD

ORNL

Diagnostics: Scattered Effort over 5 Labs





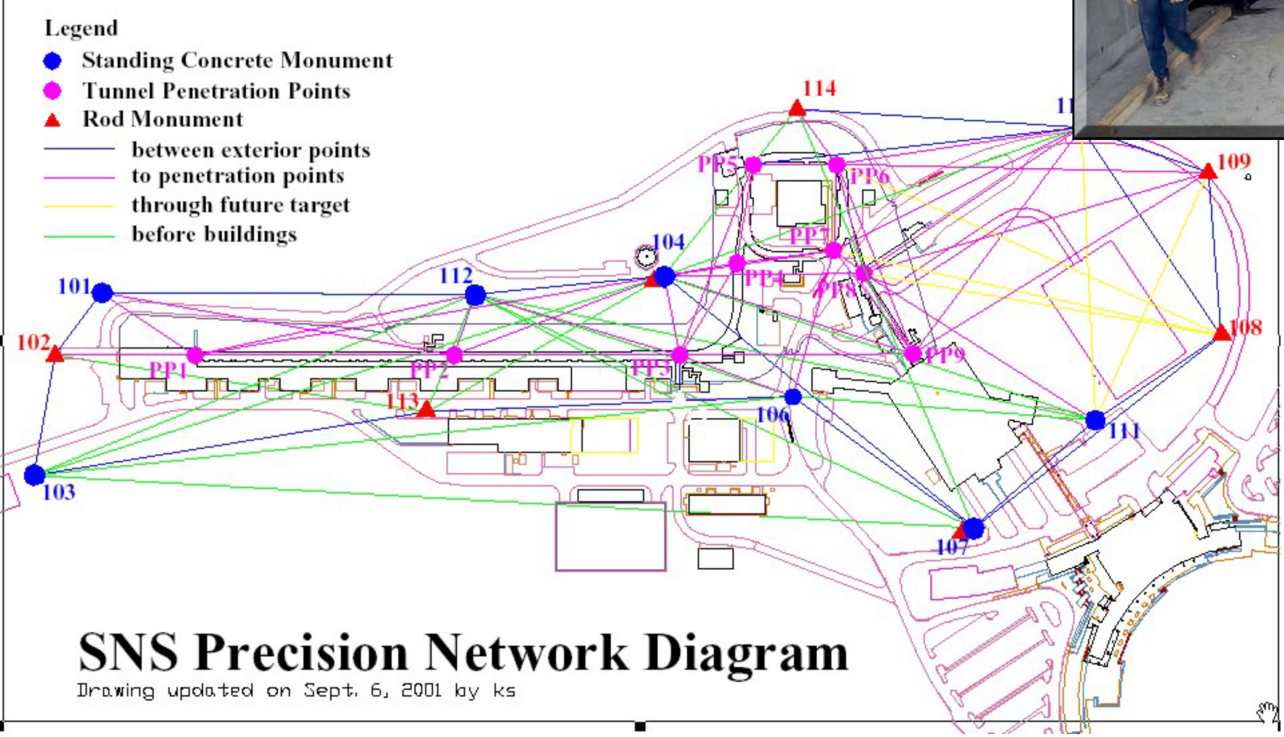


LASER Profile Monitor:

The future device for high power beams

Survey and Alignment Group (6/7)

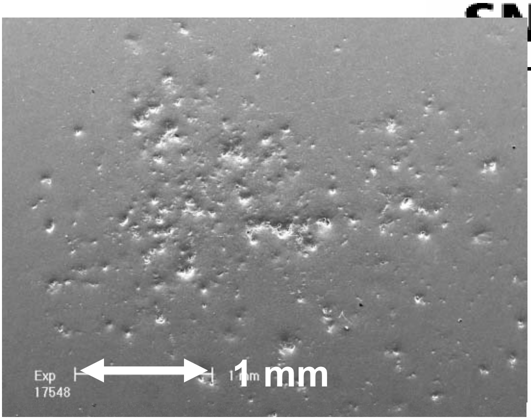
- Establish independent network on the site
- Verification of construction
- Establish Laser Tracker as prime tool to speed up installation and alignment
- Enable long-term survey



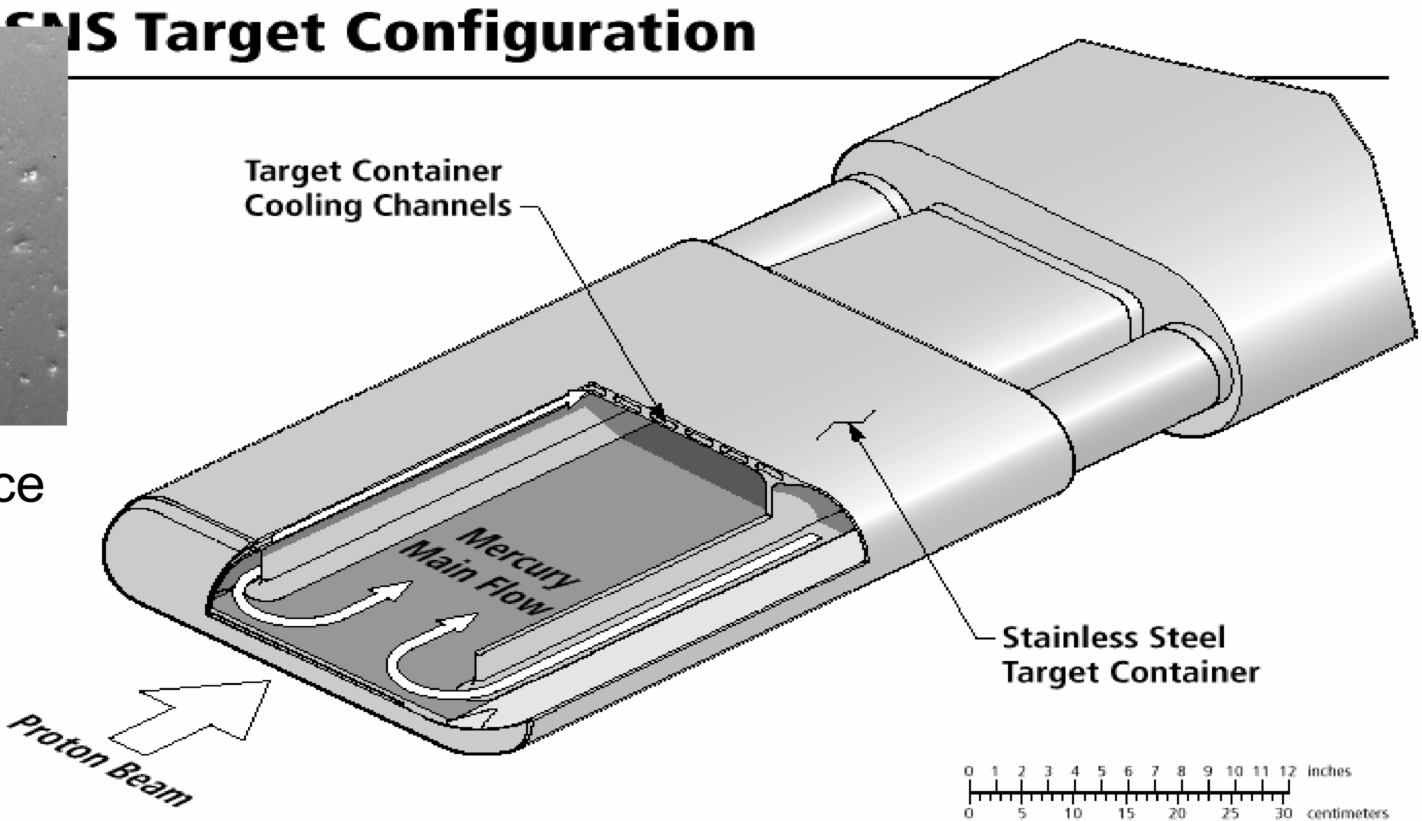
The SNS target: A 2 MW design

Cavitation is most recent issue !

Several routes out …: Materials, Geometry, Mitigation



Pits on inner surface using cylindrical geometry



Summary

- With delivery of the Front End Systems to ORNL installation on the site has begun.
- The first of the 5 partnerlabs is transitioning out of the collaboration after delivery (LBNL).
- The Project is on track for commissioning of the target in December ’05.
- Major issues (at least the ones we know about) are addressed and solutions are identified

- My Assessment:

It is a very fruitful, intellectually and technically challenging and certainly very productive collaboration. Thanks to the contributors !!!!