Accelerator Physics – Progress and Challenges

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SNS AAC Meeting

Jan. 22-24, 2008

On behalf of the AP Team

Accelerator Physics Group Activities

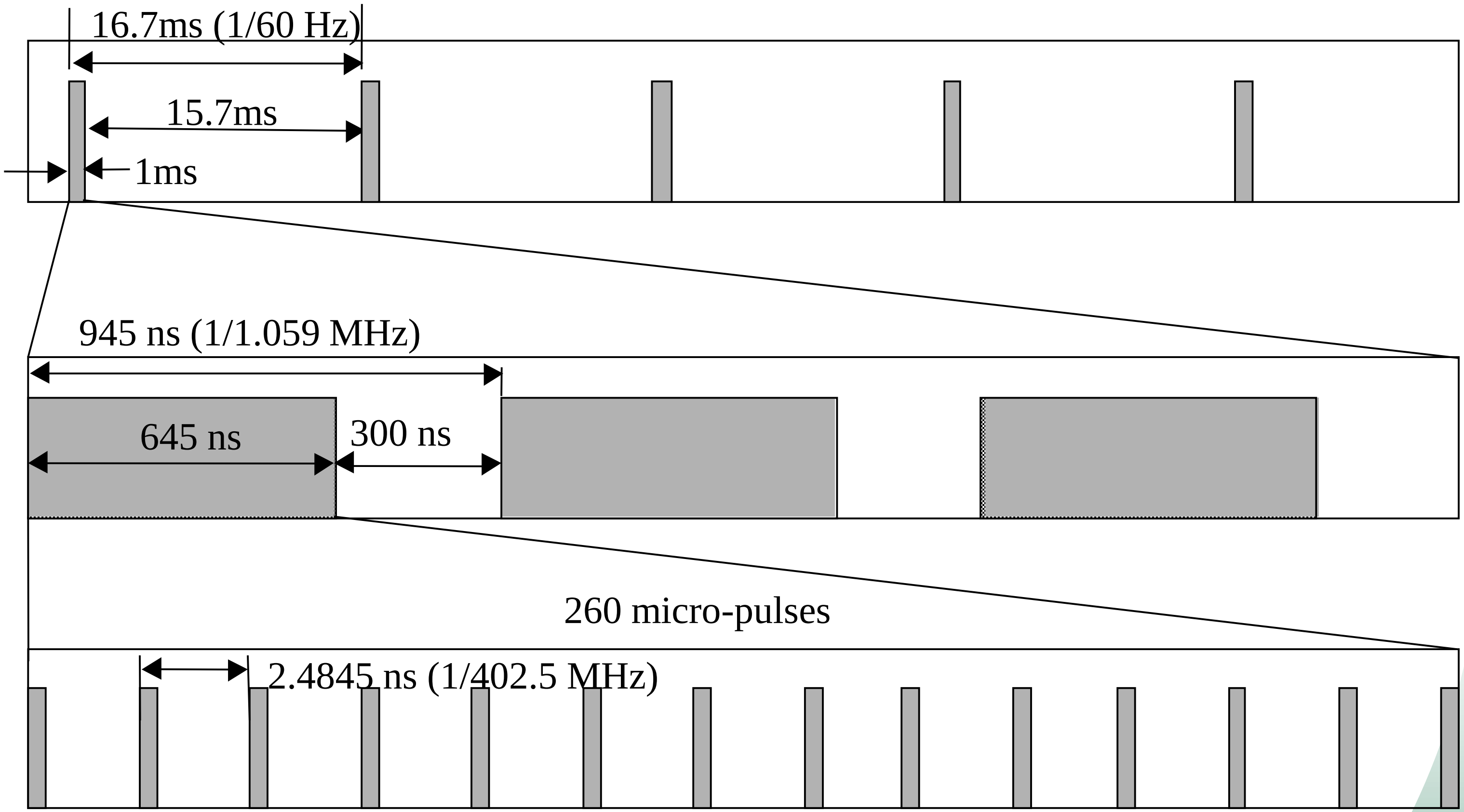
- **Reduce Beam Loss**
- **Perform beam studies**
  - **Same team that commissioned the machine**
  - **Devise measurements to understand and correct causes of beam loss**
- **Request new modified beamline equipment**
- **Develop and maintain the high level software**
- **Perform simulations and beam modeling**
  - **ORBIT code for Ring**
  - **Parmila, IMPACT models for linac**
- **Keep an eye on the future**
  - **high intensity effects**
  - **laser stripping**

SNS Time Structure Nomenclature

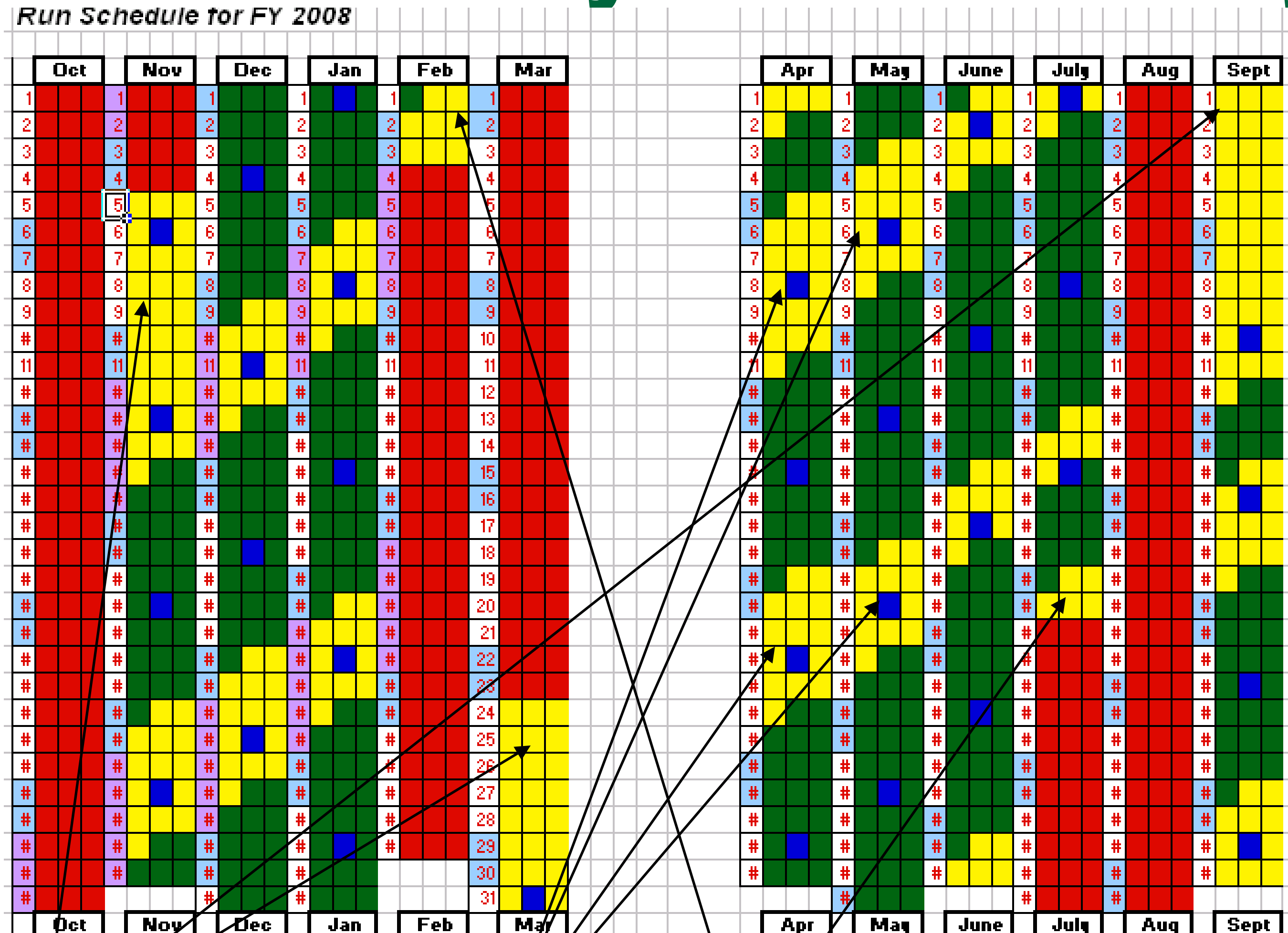
Macro-pulse Structure (made by the High power RF)

Mini-pulse Structure (made by the choppers)

Micro-pulse structure (made by the RFQ)



Accelerator Physics Beam Study Rhythm



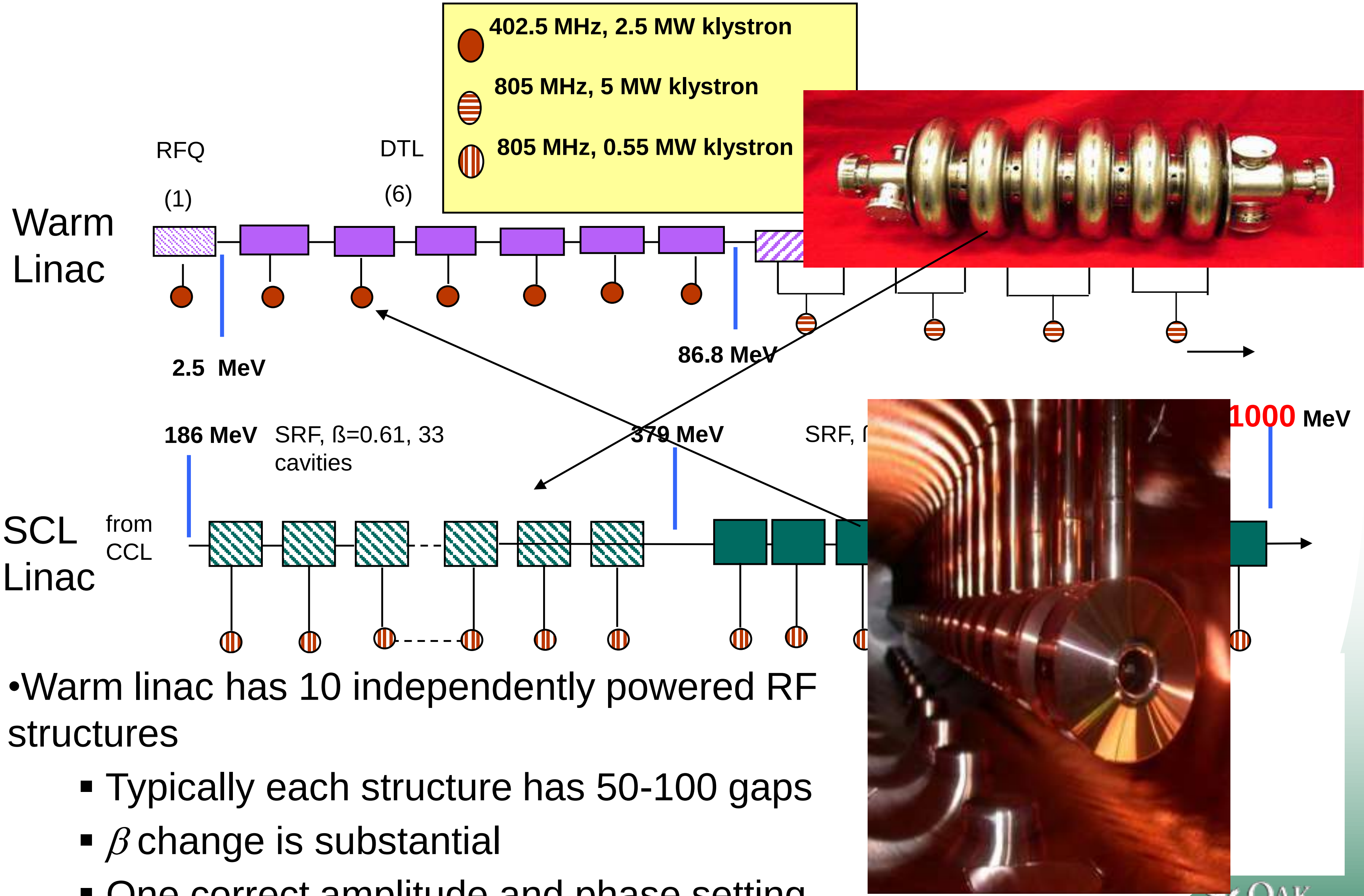
Red – extended outage

Yellow = AP

Green = neutron Production

- **Post extended maintenance: linac setup, beam RF, diagnostic studies, equipment shakedown**
- Inter production periods: incremental power ramp-up, beam studies aimed at loss mitigation, understanding beam behavior
- (*Danilov talk*)

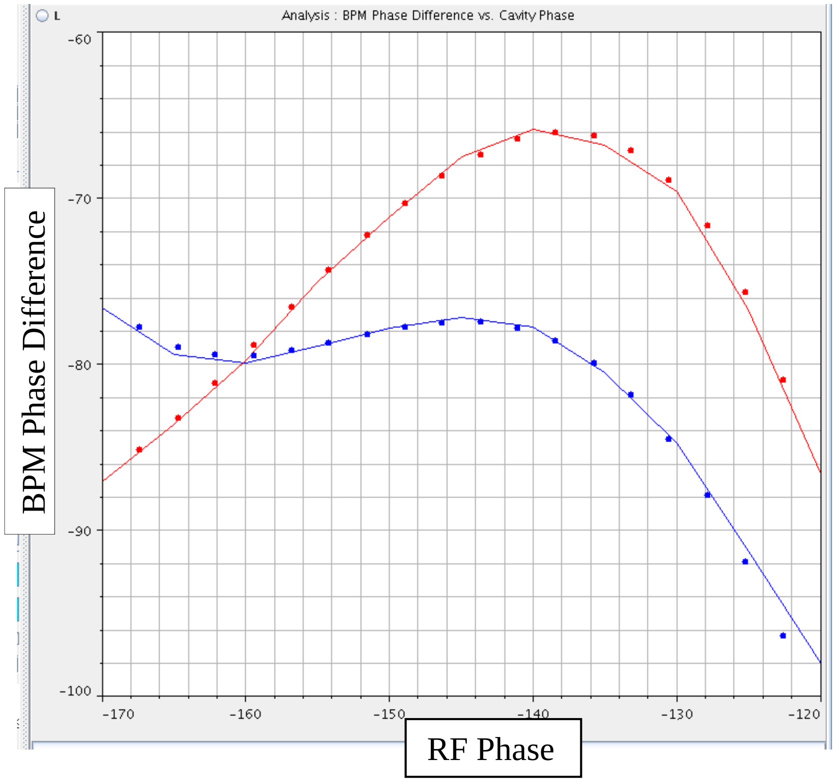
Layout of Linac RF with Warm and SCL Modules



•Warm linac has 10 independently powered RF structures

- Typically each structure has 50-100 gaps
- β change is substantial
- One correct amplitude and phase setting

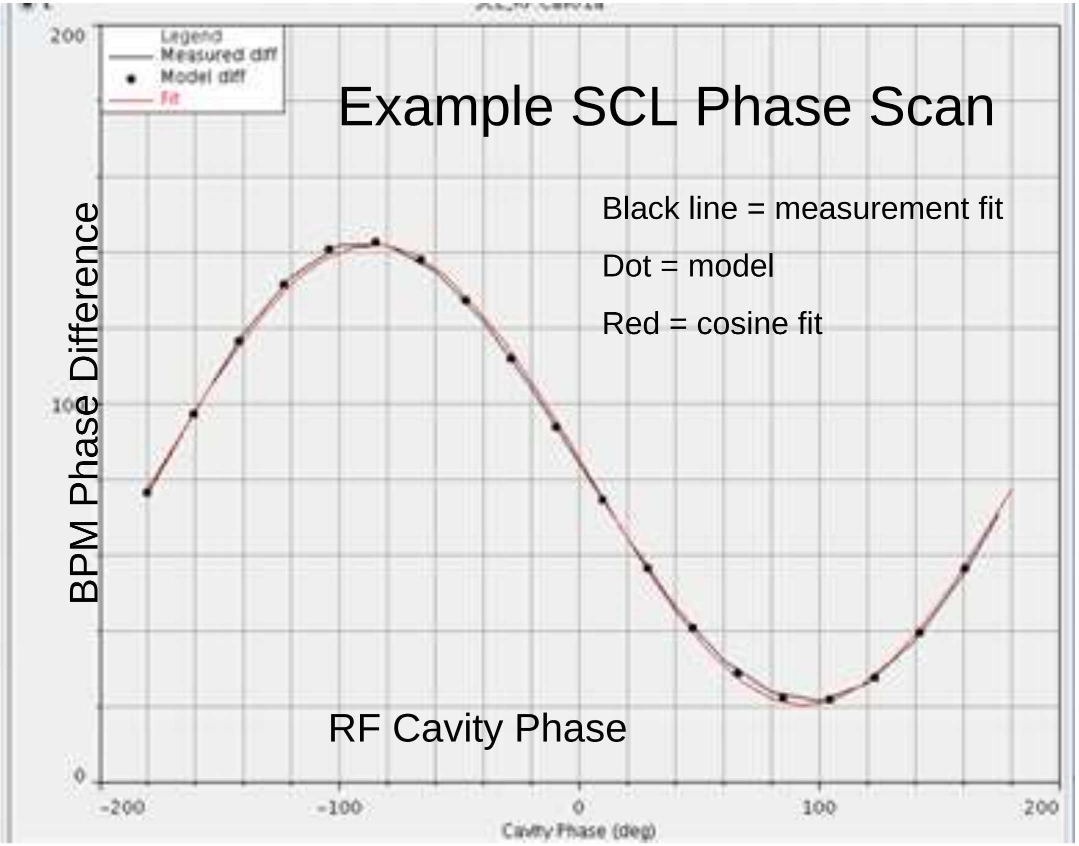
Normal Conducting LINAC Tuneup Procedures



- Scan RF phase for multiple amplitude settings
- Solve for input beam energy, RF amplitude calibration, RF phase offset

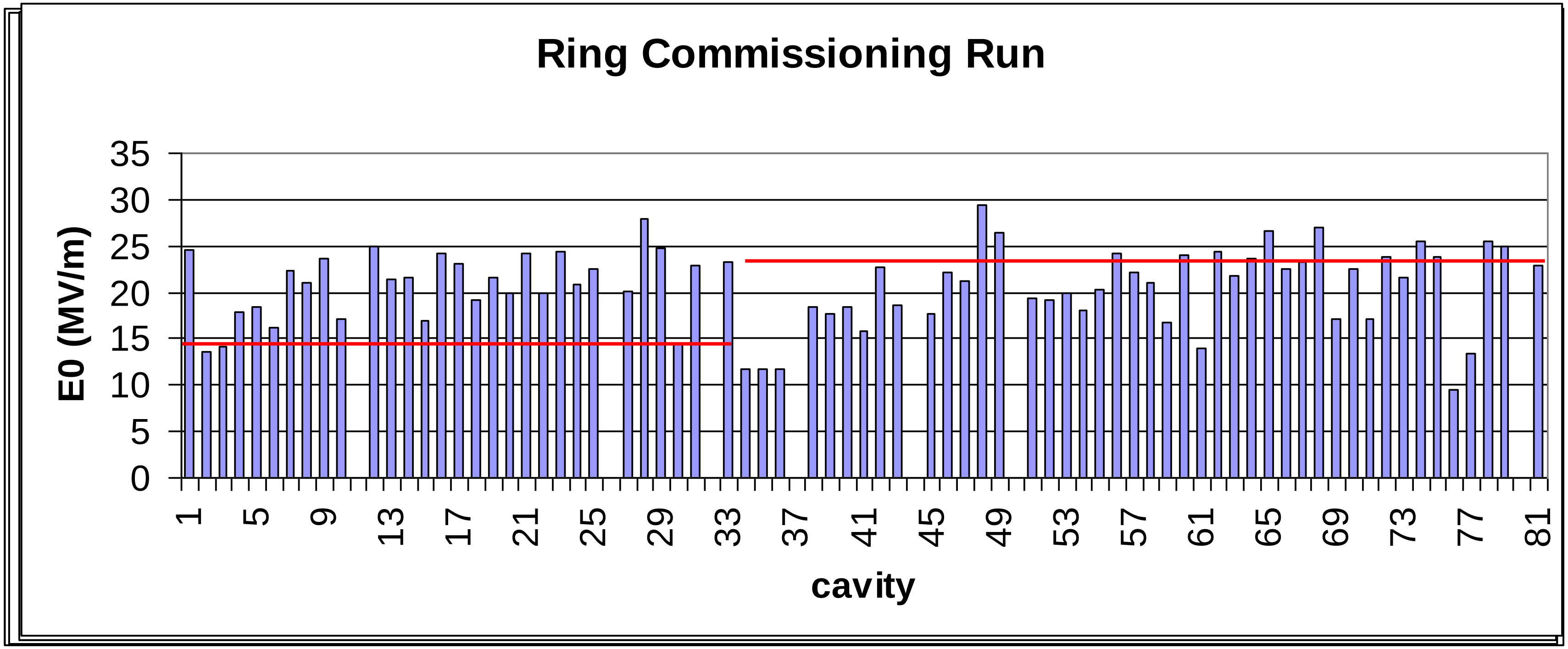
- **Warm Linac RF Amplitude and phase setpoints determined with a phase scan method**
  - **Accurate to ~ 1%, 2 degrees**
- **Use design quadrupole strengths and RF settings**
- **First machine to routinely use this method**

SCL Cavity Tuneup



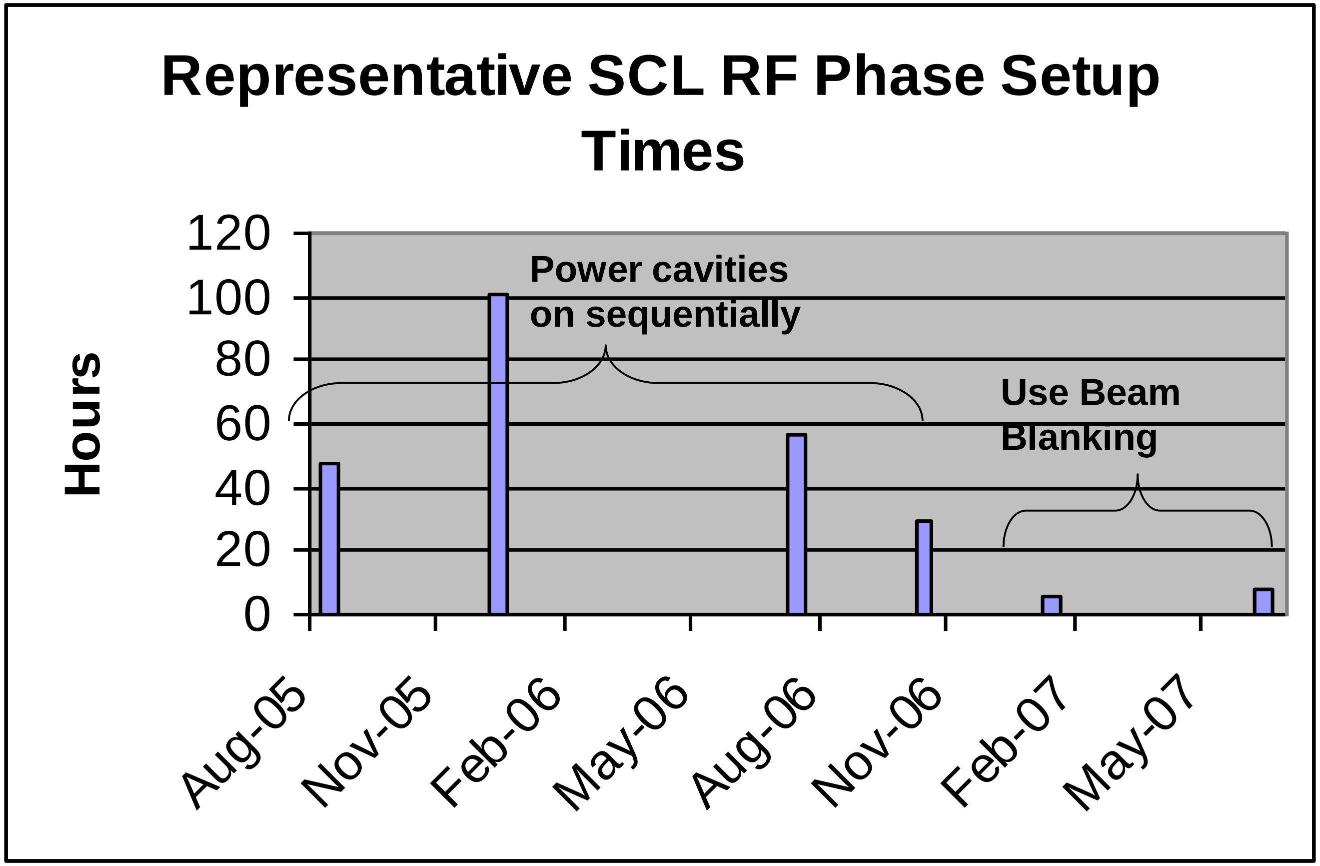
- **Use highest available SCL gradients – far from design**
- **Set the SCL cavity phases using phase scan technique**
- **Scale design quadrupoles with beam energy**

SCL Cavity Amplitudes



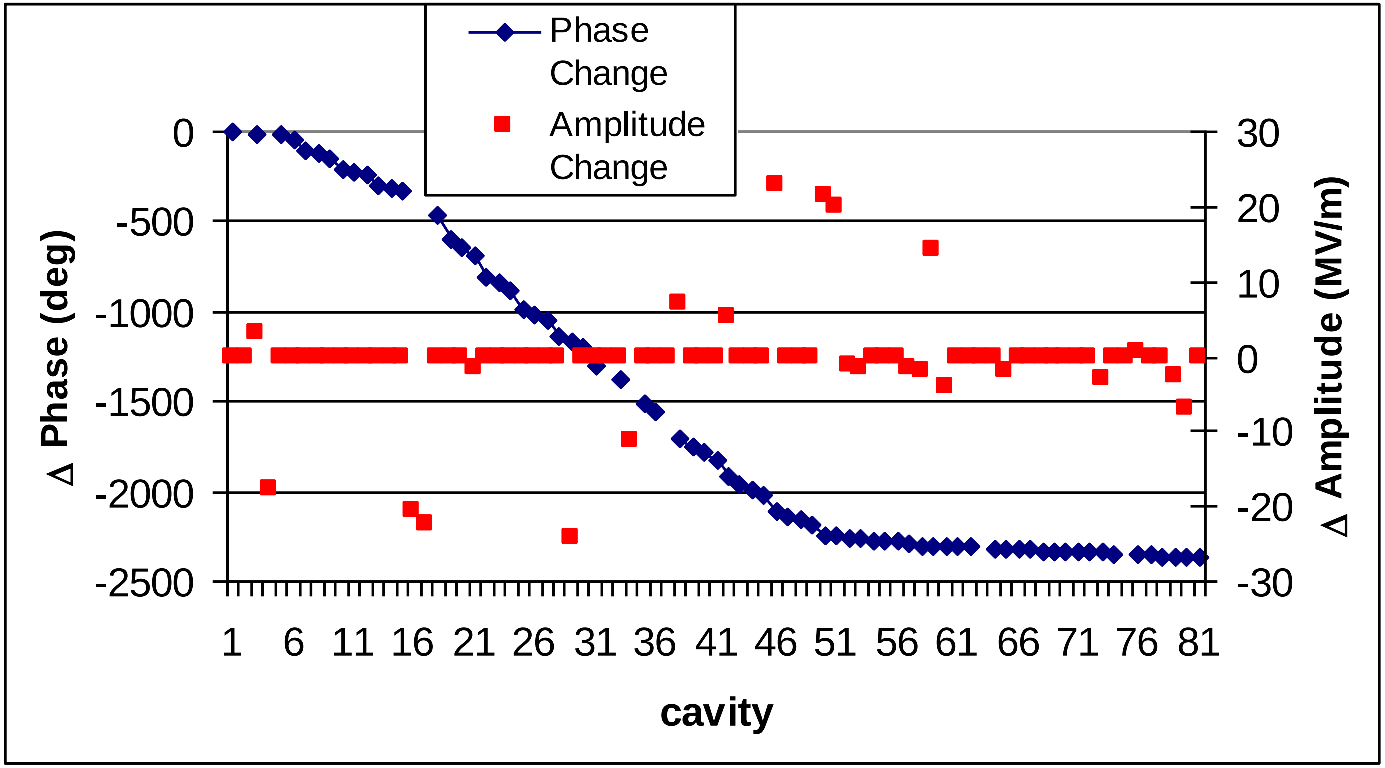
- **Strategy is to run cavities at their maximum safe amplitude limit (*S. Kim's talk*)**
- **Need to be *flexible* – SRF capabilities change, not near the design**
- **Linac output energy is a moving target**

SCL Setup Times are Decreasing



- ***The procedures used to setup the superconducting linac have matured, and the setup time is now minimal***
- ***Still exists a need for fast recovery from changes in the SCL setup***

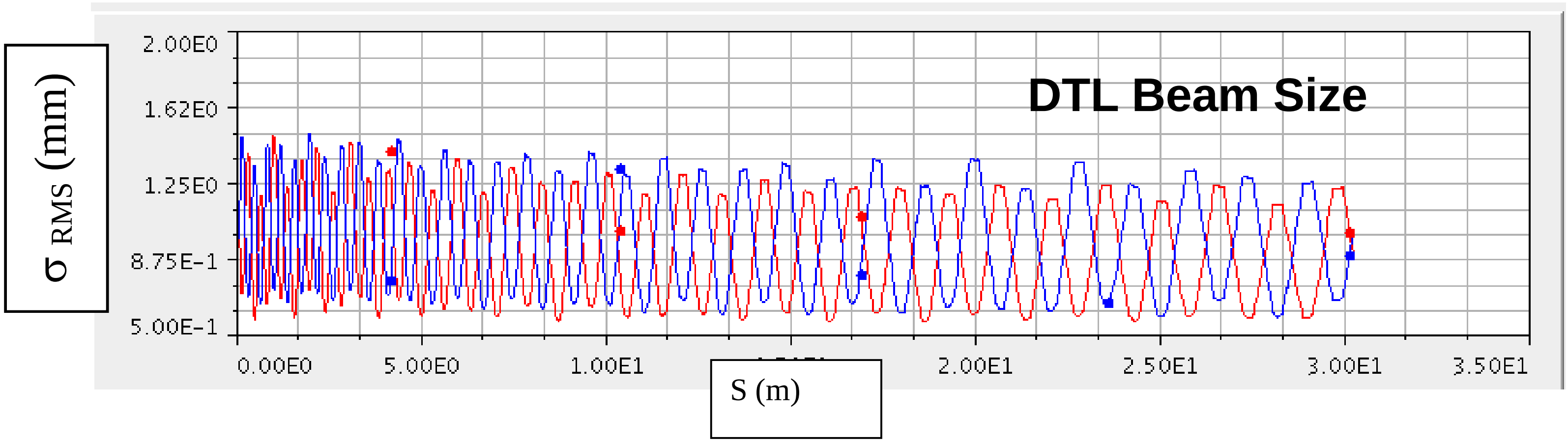
SCL Cavity Fault Recovery Scheme

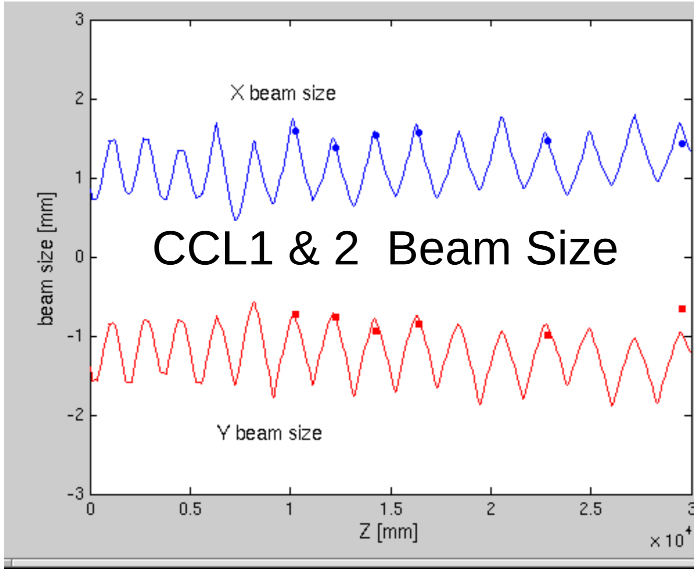


- **1 GeV is not ultra-relativistic – change in upstream cavity has a large imapct on downstream cavity phase settings**
- **Use a model to predict change in measured downstream arrival times from a change in an upstream cavity**
- **In April 2007 the SCL was lowered from 4.2K to 2 K to facilitate 30 Hz operation, 20 cavity amplitudes changed**
- **The fault recovery scheme restored beam to the previous loss state**

Linac RMS Beam Size *(Nov. 2007)*

Lines are model predictions with design Twiss parameters, and dots are wire profile measurements

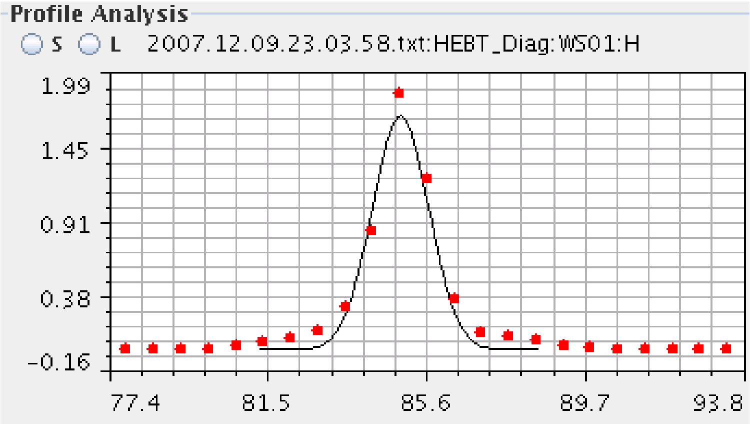


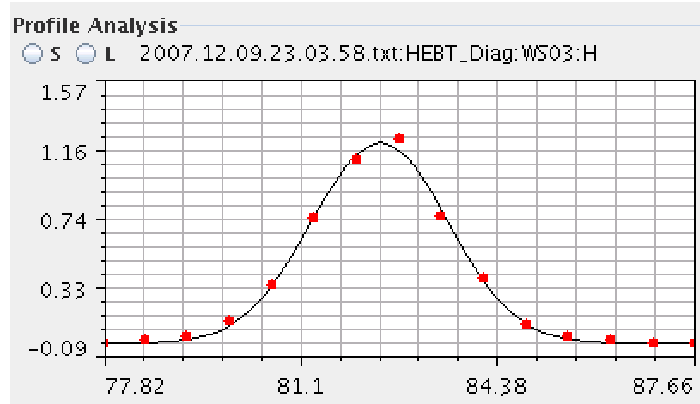


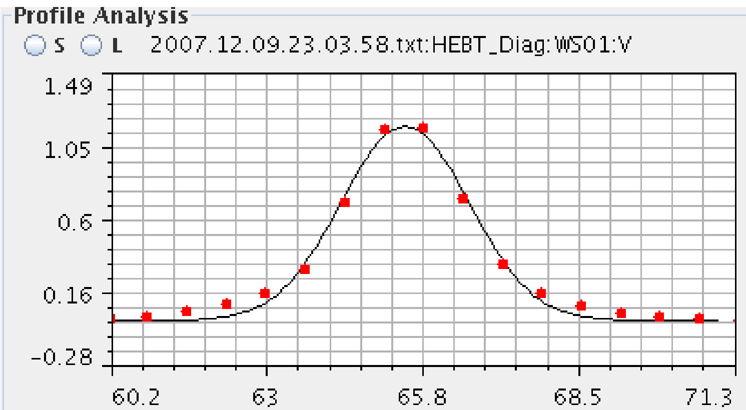
- **Warm linac beam size is in good agreement with design values**

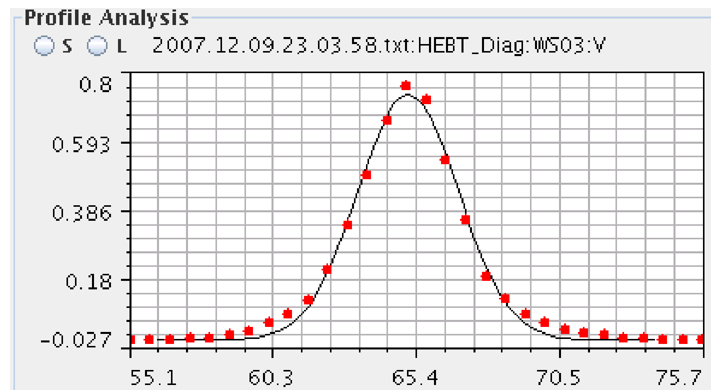
Oak Ridge National Laboratory

Linac Beam Profiles





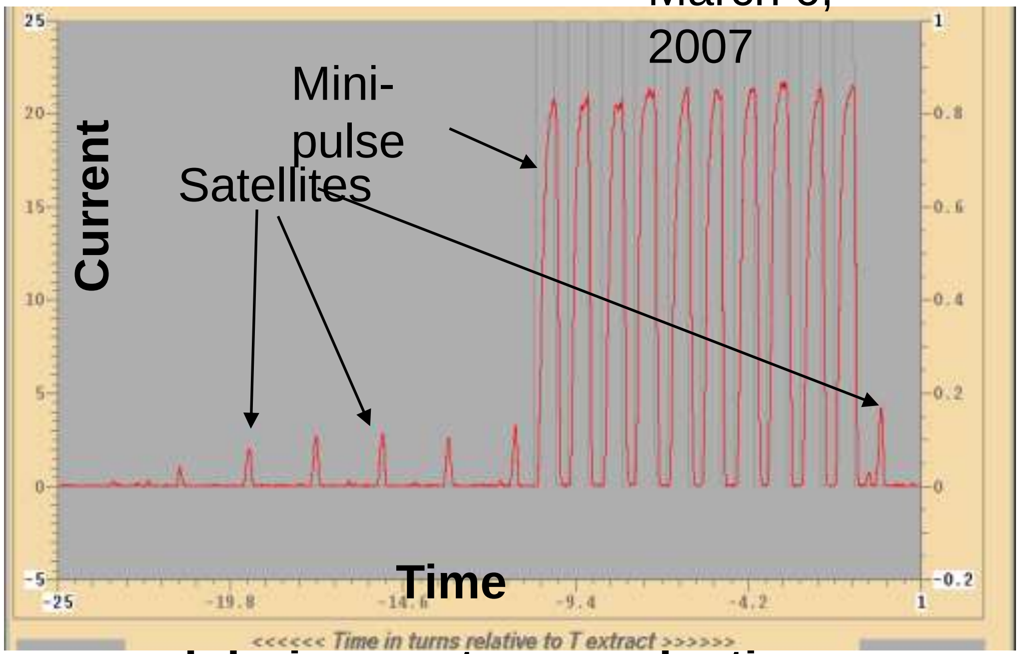




- **Profiles at the start of the HEBT 12/10/2007**
- **Beam profiles are close to Gaussian at the end of the linac than previously observed**
  - **Ignore startup portion of the beam**
  - **Quadrupole settings are closer to design values**
  - **Source dependent**

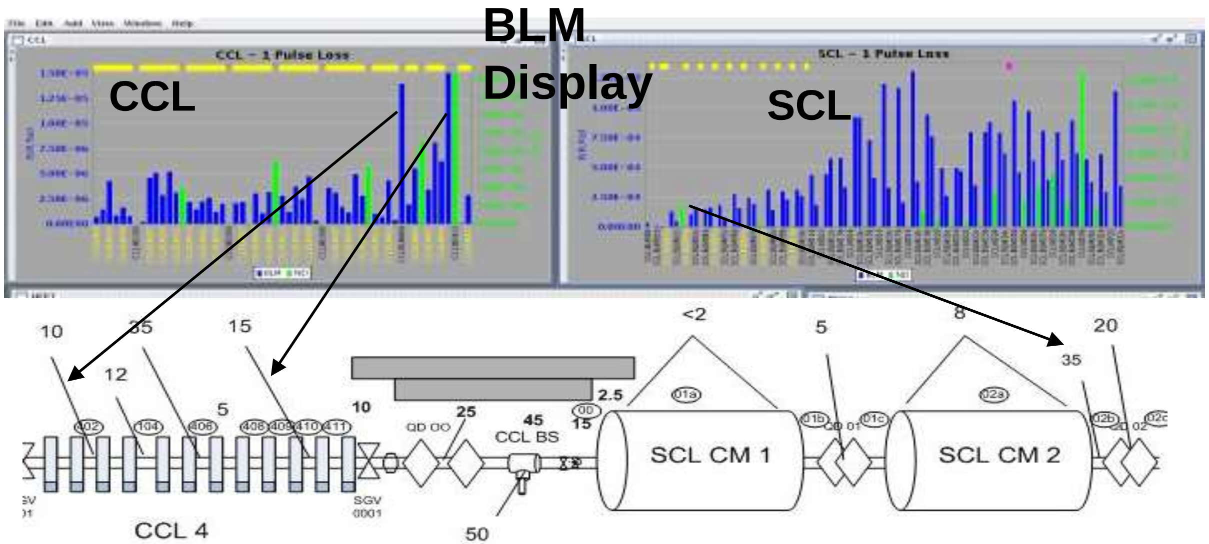
Linac concern: Chopper Quality (*S. Aleksandrov's Talk*)

- **The chopper system provides clean gaps between mini-pulses to provide a gap to fire the extraction kicker in the Ring**
- **It is a 2 stage system designed to clear the gap to 1 part in 10^4**
  - **LEBT chopper at 65 keV**
  - **MEBT chopper at 2.5 MeV**



- **The MEBT chopper has never been used during neutron production**
- **Sometimes have leading/trailing satellites**
- **Protection measures introduced in the LEBT system have slowed the rise / fall times**
- **Improperly centered beam through the LEBT can cause mini-pulse to mini-pulse position jitter - effectively increasing the beam size.**

Beam Loss / Residual Activation

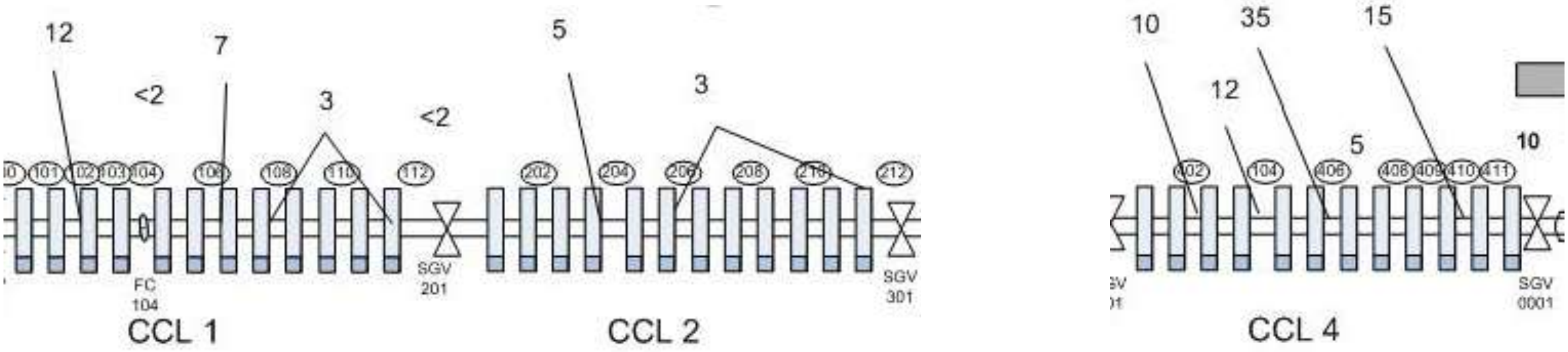


Radiation survey (mRem/hr at 30 cm after ~ 24 hrs)

- **SNS is designed to be a hand's on maintainable accelerator**
- **100 mRem/hr at 1 foot is considered the limit for relatively easy hands on maintenance**
  - **Corresponds to ~ 1 W/m beam loss**
- **BLMs give a measure of beam loss**
  - **(~ 400 BLMs throughout the machine)**
- **Residual activation measured after every production run**
- **Use the relationship between BLM readings/ measured activation to predict activation during production setups and prioritize areas for beam study**

CCL Residual Activation

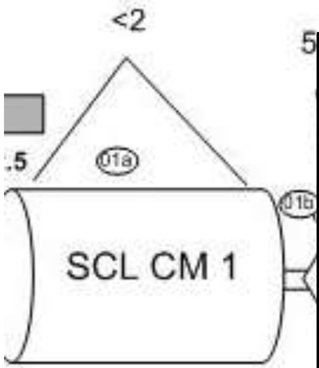
1/7/2008 Measurements

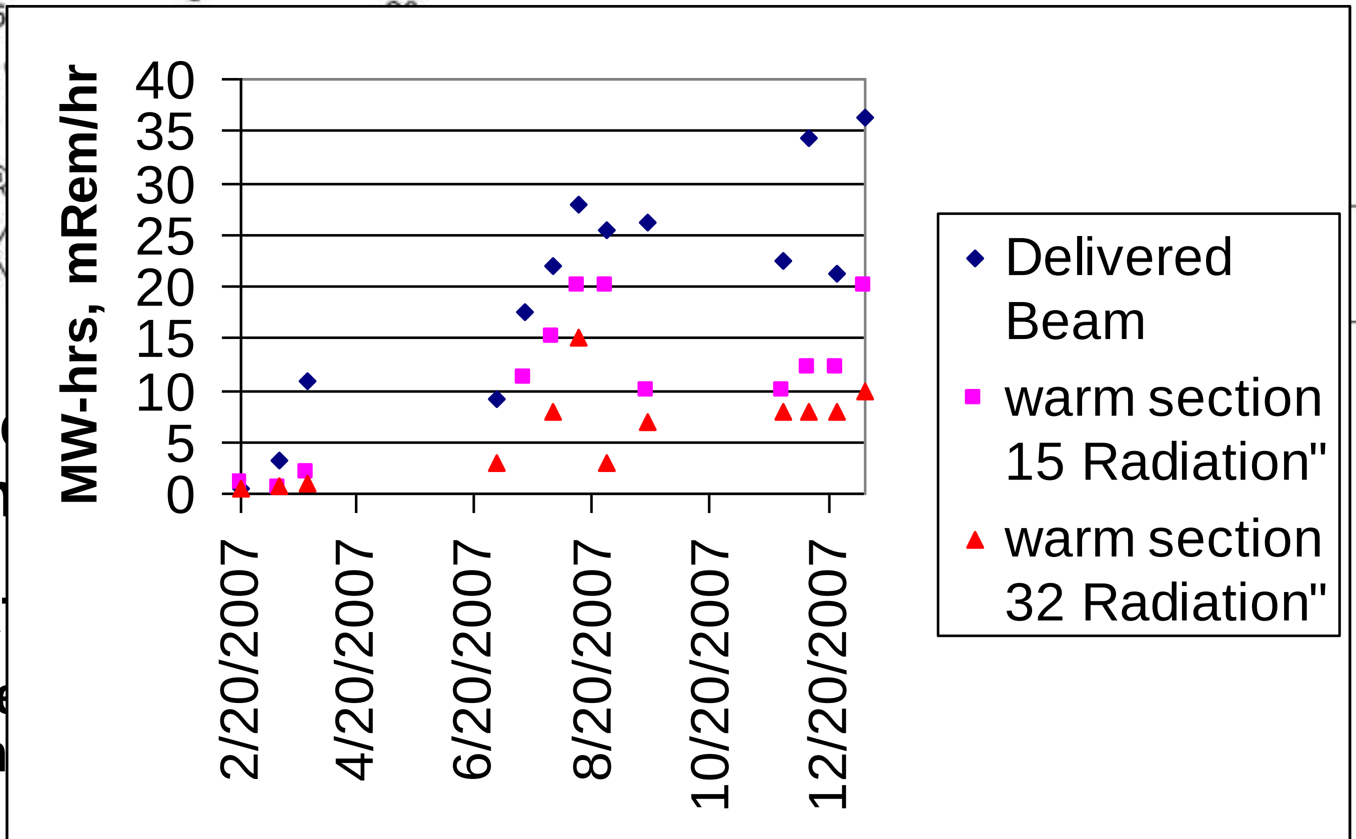


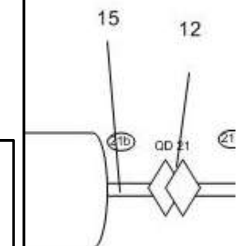
- **Hot spots:10-30 mRem/hr**
- **Scaled to 1.4MW: 90-250 mRem/hr**
- **Context: similar residual activation as Dec. 2006 at ~ 30 kW**
  - **Better trajectory control (*S. Aleksandrov's talk*)**
  - **Additional BLMs**
- **Keys to further improvement:**
  - **Longitudinal RF setup refinement**
  - **Transverse matching**
  - **MEBT chopping**

SCL Residual Activation Status

1/7/2008 Measurements







- **Averag**
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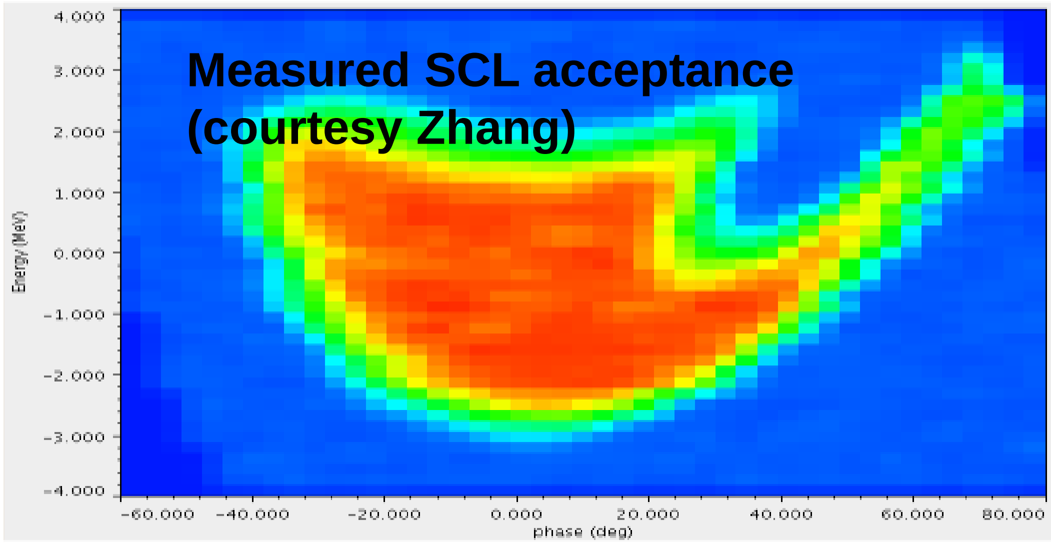
  - **These**
    beam
- **Scaled to 1.4 MW: 90-250 mRem/hr**

SCL Beam Loss / Mitigation Efforts



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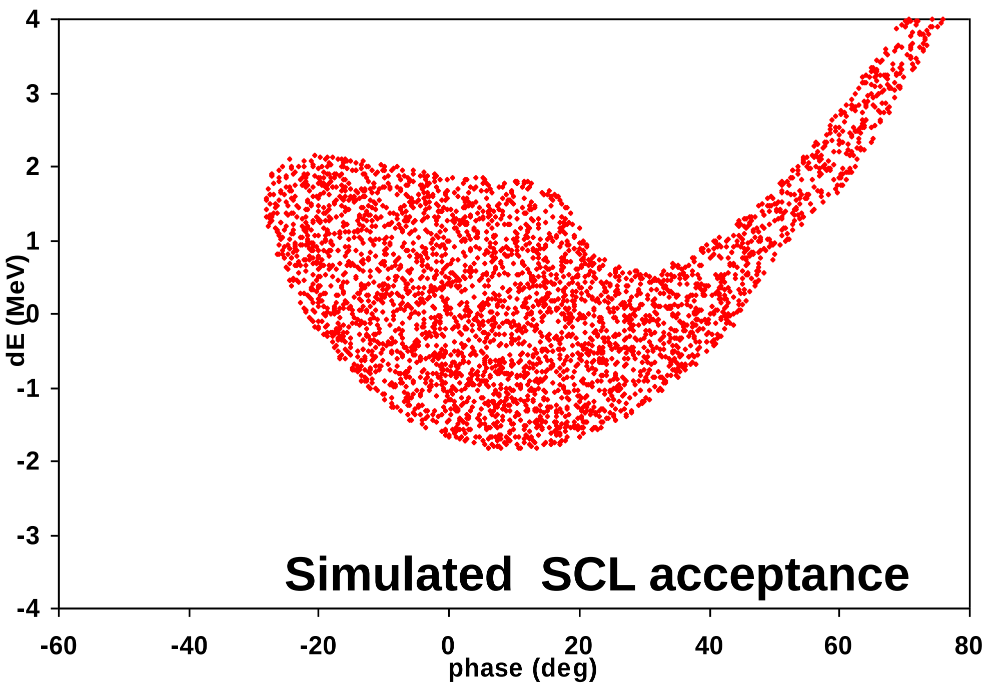
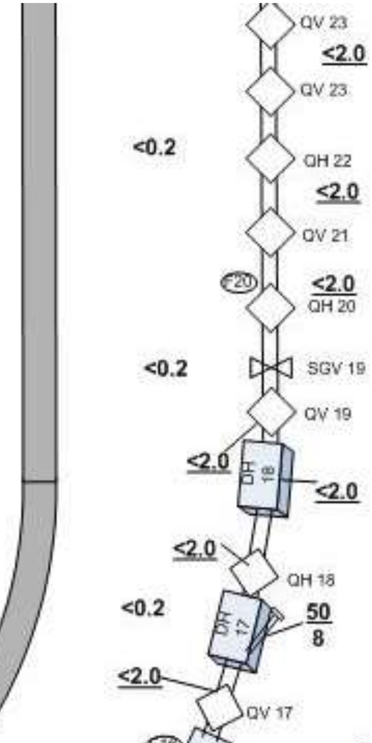
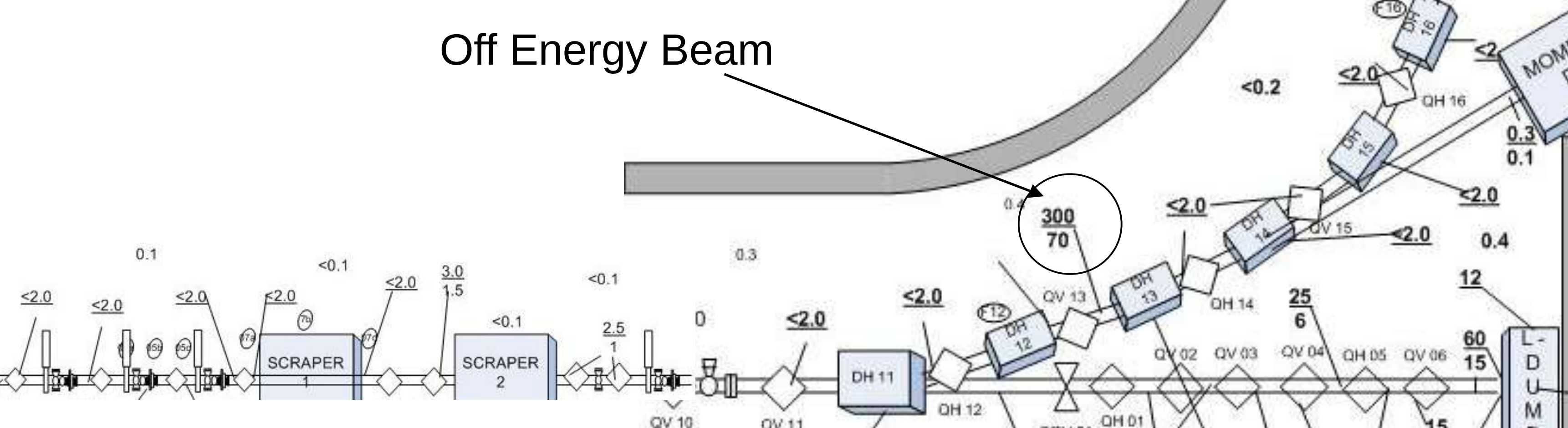


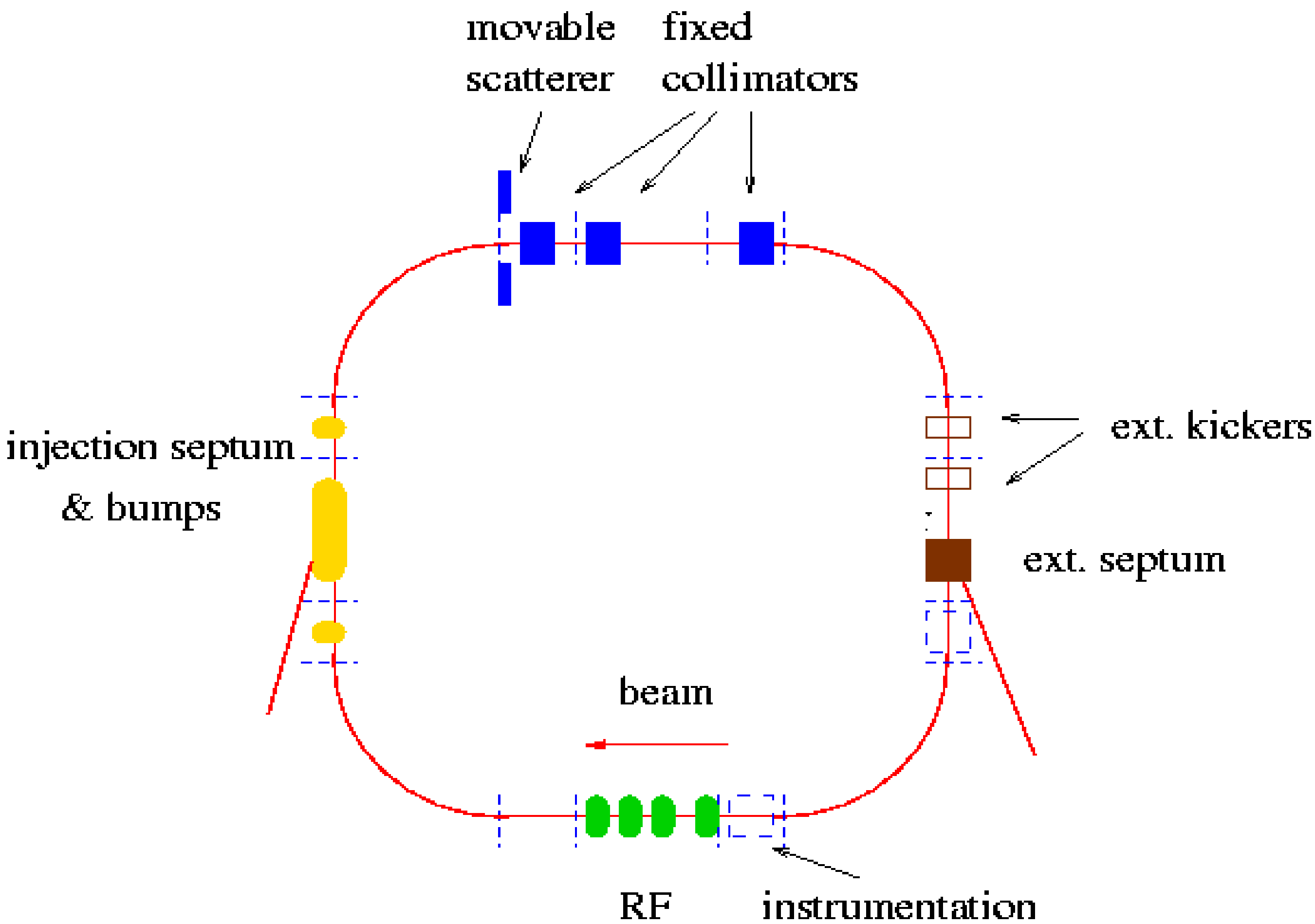
HEBT Transport Line

- **Not much beam loss / activation**
- **Upstream transverse + momentum collimation has been tested but is not used**
  - **Causes more beam loss in the arc than halo reduction benefit**



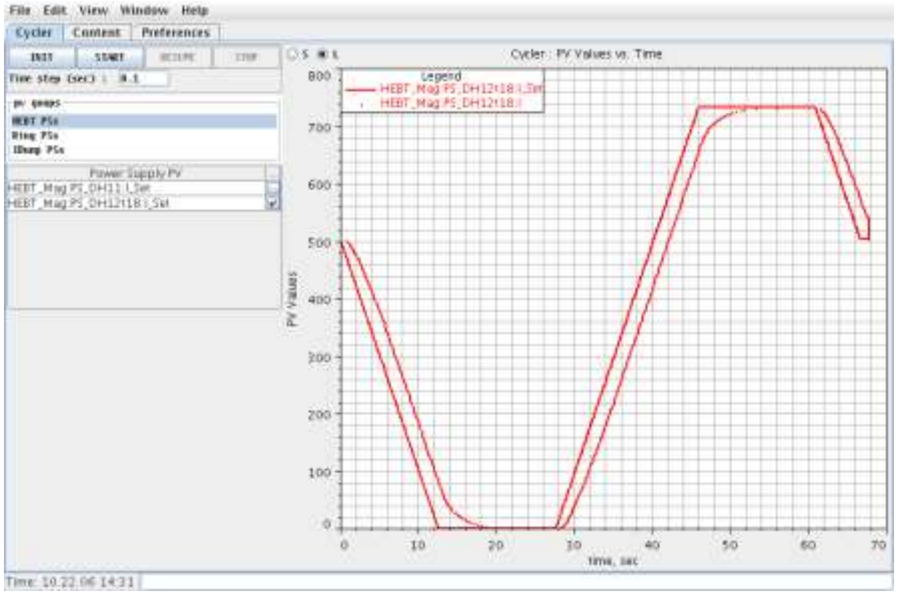


Ring

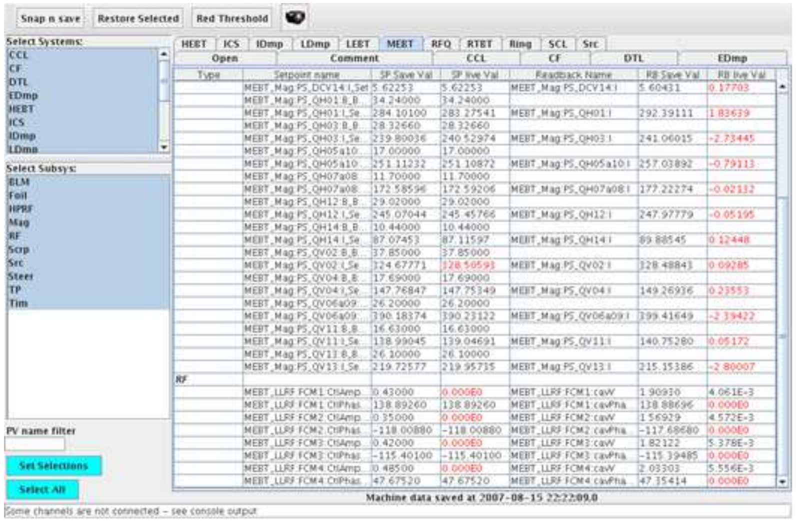


- **Primary functions:**
  - **Injection**
  - **Fast Extraction**
  - **Collimation**
  - **RF**

Ring Setup Recovery / Repeatability is Good



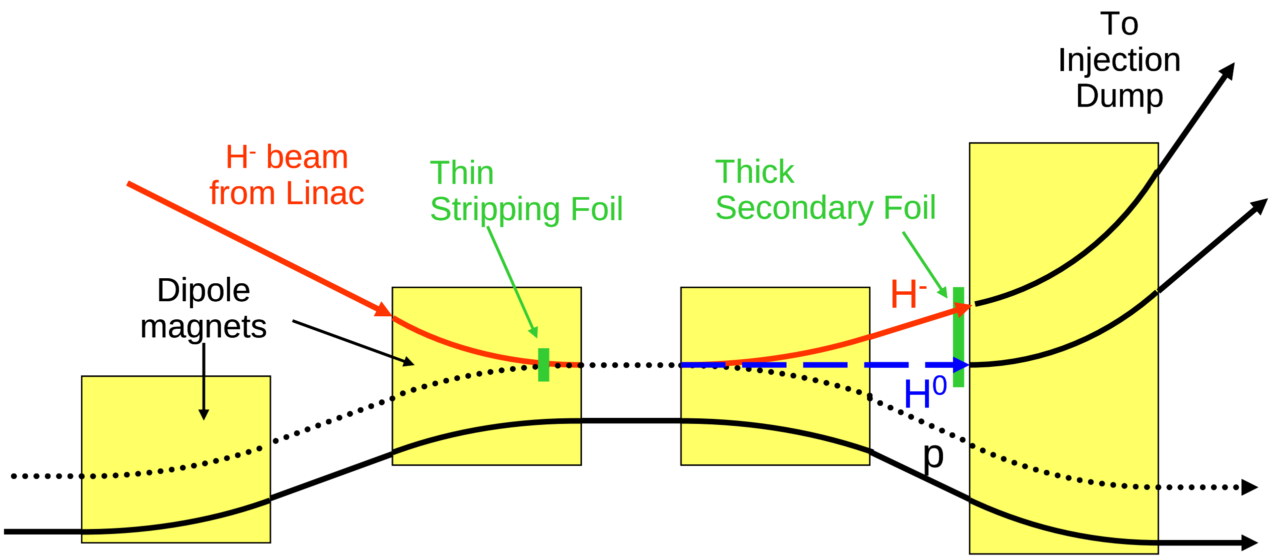
Magnet cycling



Save / Compare / Restore

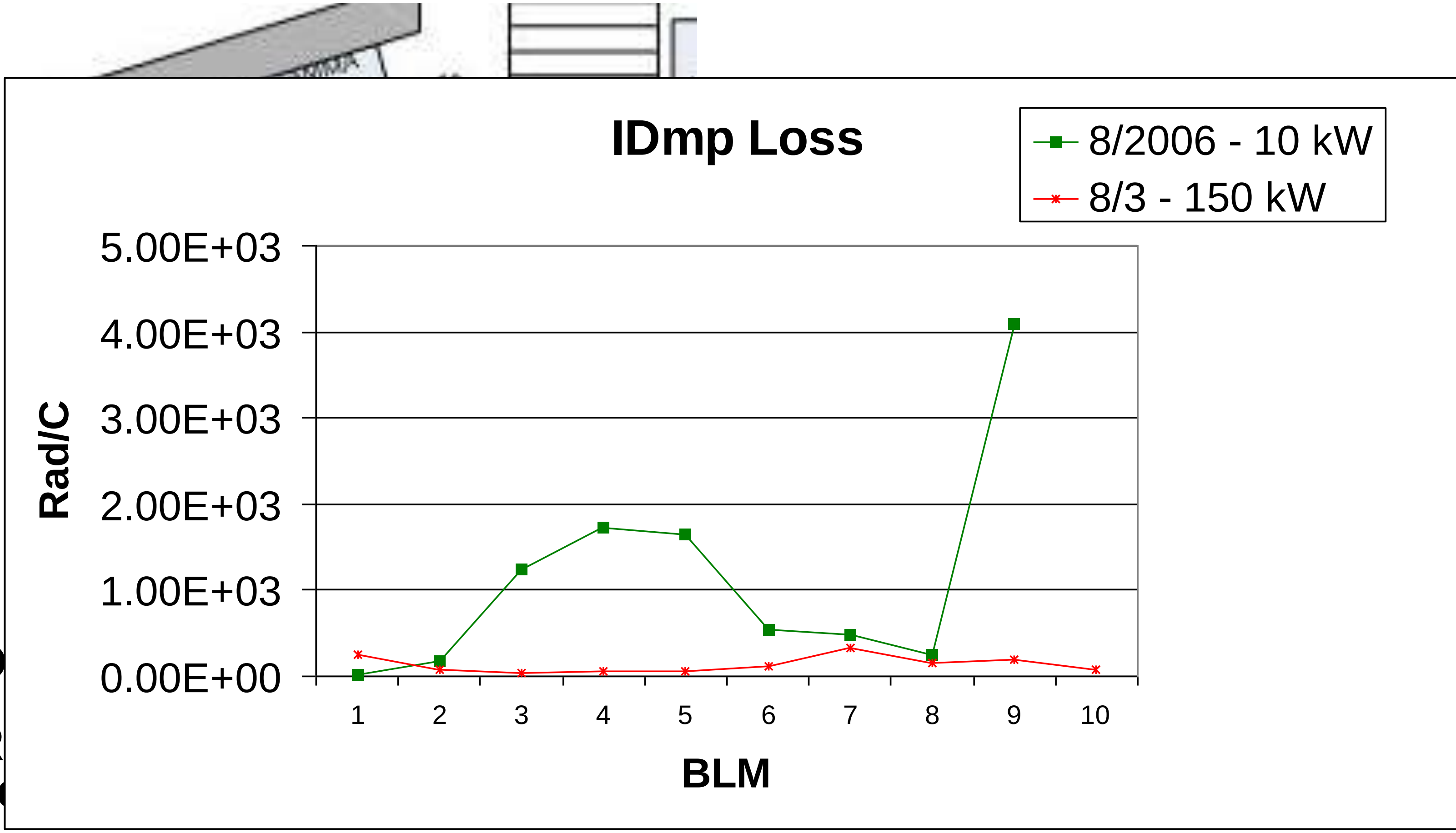
- **~ 1 shift to recover a Ring / Transport line setup after an extended maintenance period**
- **Magnet cycling application for hysterisis effects**
  - **Determine which magnets require cycling and the minimal cycling periods**
- **Sophisticated save/compare/restore application**

Ring Injection Area (*M. Plum's talk*)



- **"As delivered" Ring could not transport beam to the injection dump and circulate beam in the Ring (*M. Plum's talk*)**
  - **Inconsistency in chicane values for Ring and dumpline designs**
  - **Did not fully appreciate the influence of 3-D magnetic effects**
- **Remedial actions**
  - **Moved chicane**
  - **Use oversize injection foil (reduce fractional beam to the Injection dump)**
  - **Added additional diagnostics and magnet to the dumpline to understand waste beam transport**
  - **Further upgrades are planned**

Injection Dump-line Beam Loss



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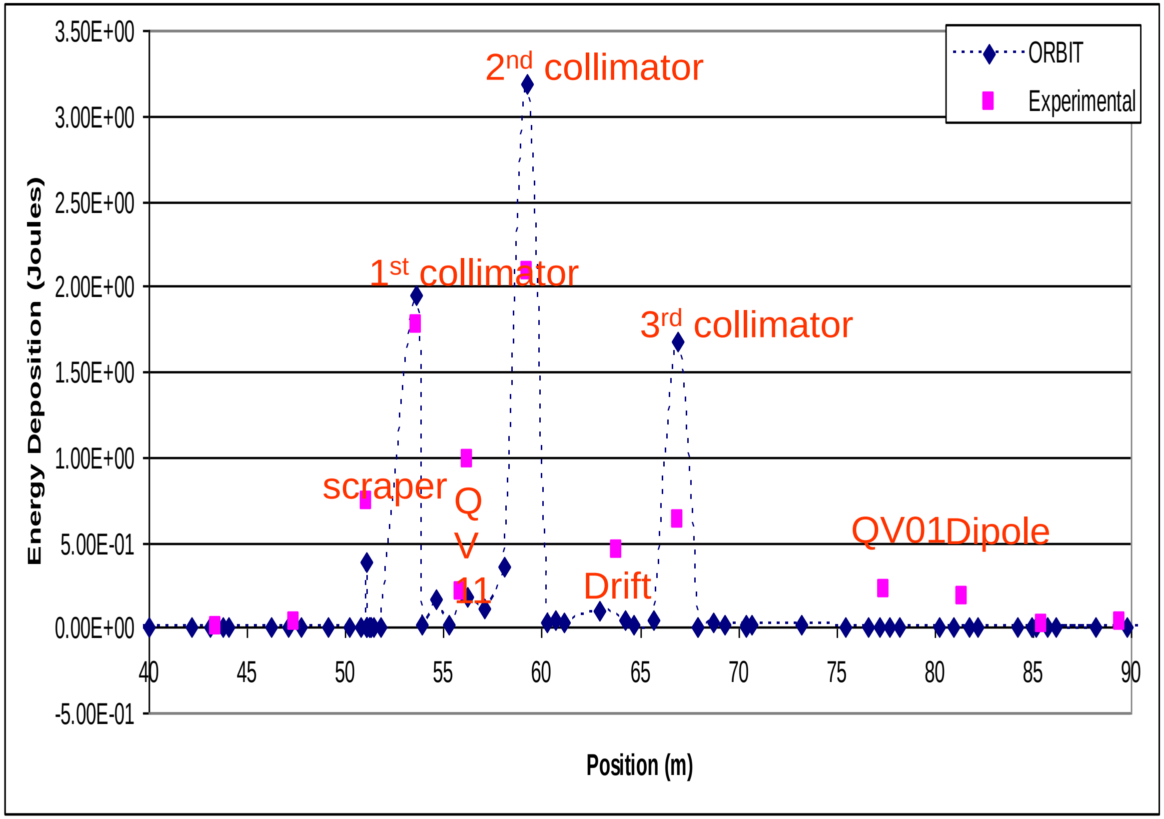
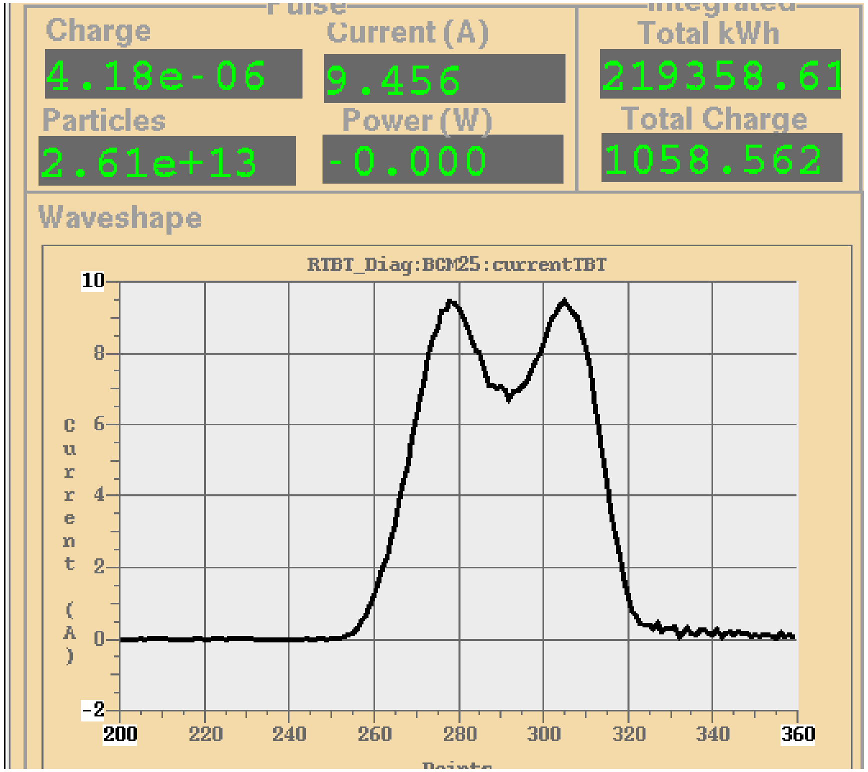
- **Future upgrades:**
  - **New, larger aperture septum to be installed in Feb. 08 outage**
  - **Additional quadrupole in the injection line**

Ring Extraction / Collimation beam loss

- **Extraction area is sensitive to beam in gap**
- **Collimation works close to expectations (*J. Holmes talk*)**
  - **Presently we are using short pulse beams (small beam size) and to not employ collimation**



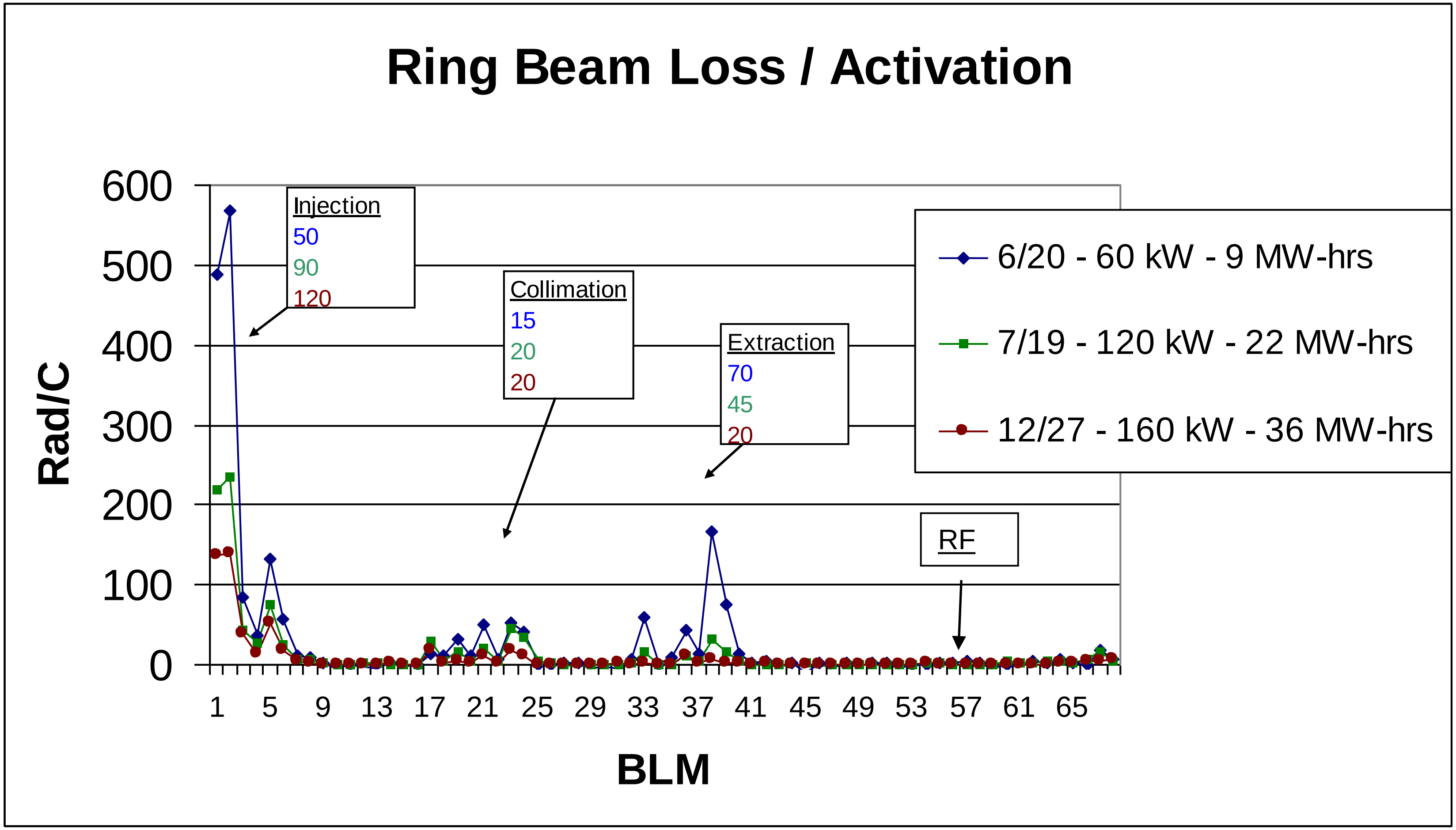
Ring RF



Bunch Shape at Extraction

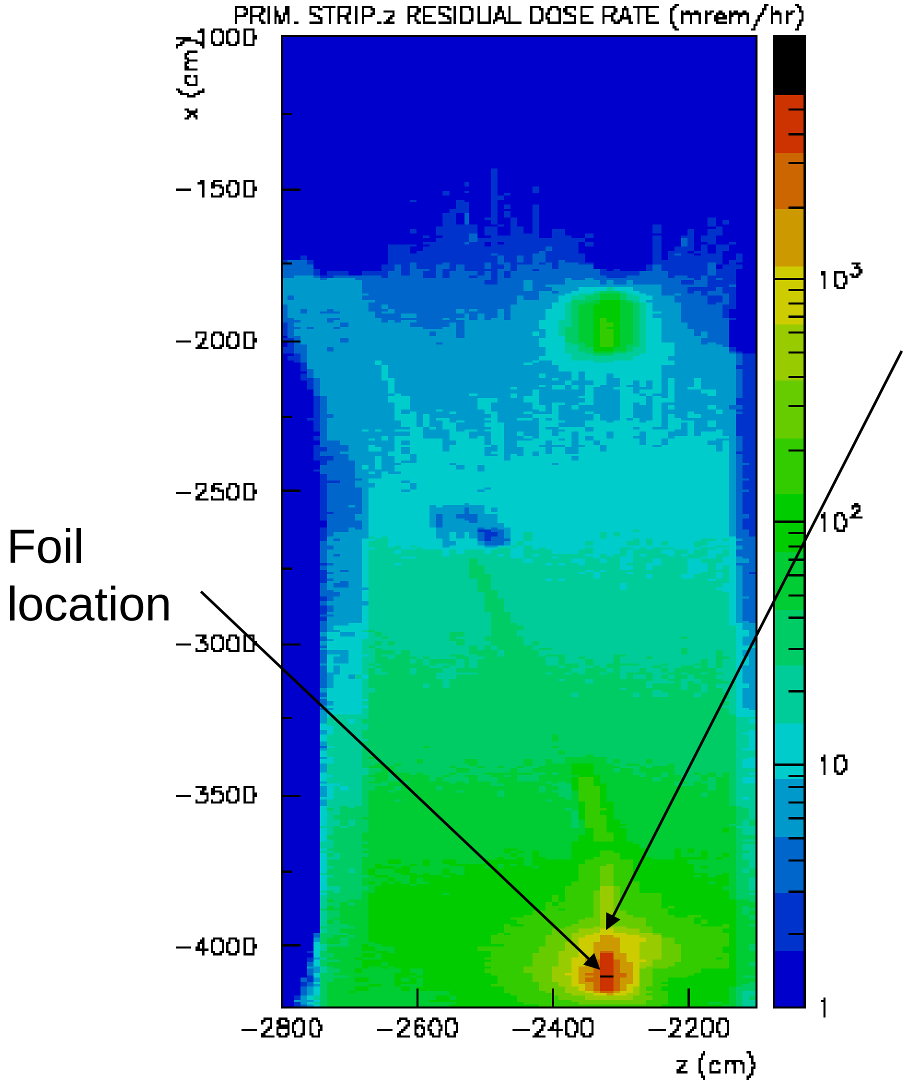
- Use 2 fundamental cavities, 1 2^{nd} harmonic cavity
  - Purpose of the dual harmonic is to reduce the bunch factor to minimize space charge
  - 2^{nd} harmonic useful for gap cleaning
  - Can further clean the gap with RF manipulations, but time scale is long (100's of turns) – injection losses increase.

Ring Beam Loss Progress



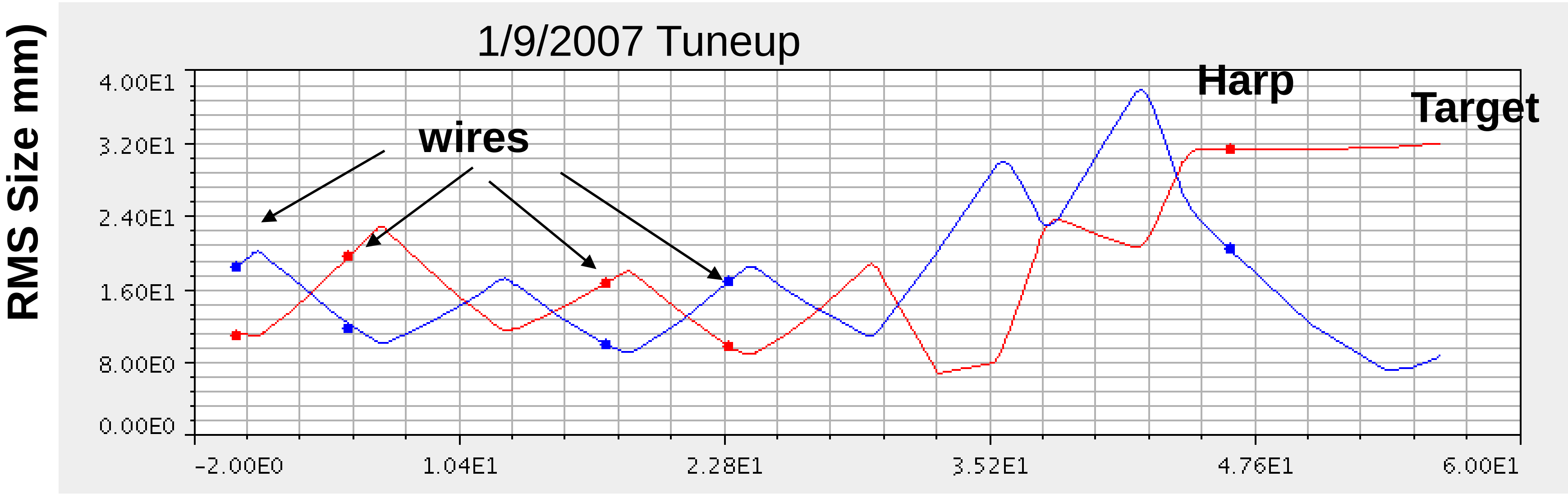
- In general we are making progress
- Ring injection is the toughest area in the accelerator
- Most of the Ring is loss free

Ring Injection Straight Prediction –
Residual activation from foil scattering



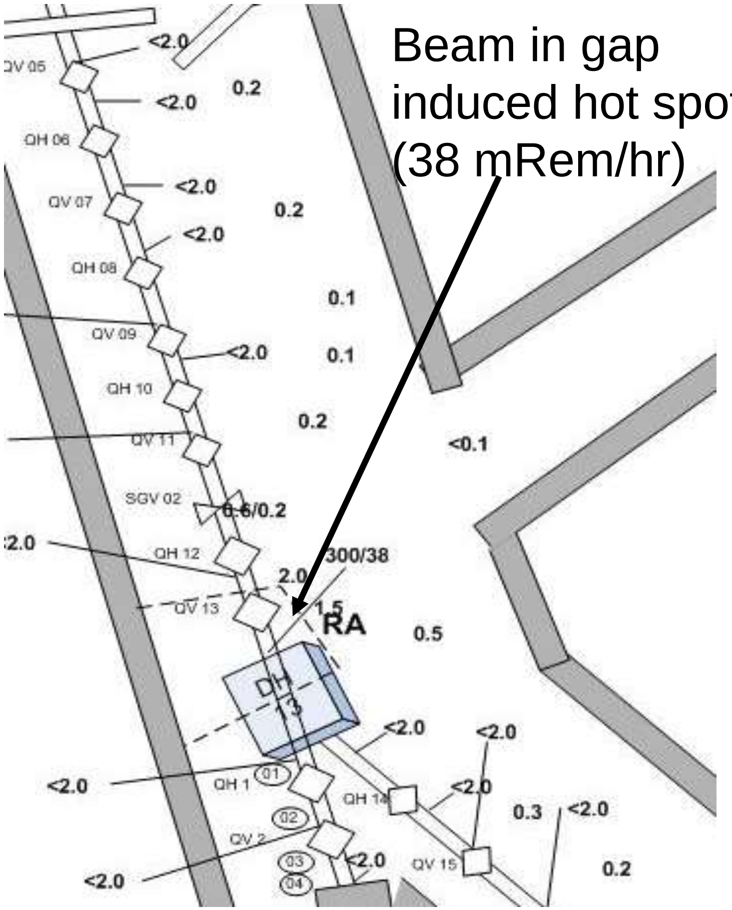
- **5000 hrs operation @ 1.4 MW, 3 hrs after shutdown**
- **> 1000 mRem/hr downstream from the foil – we are on track**
- **Keys to improvement is reducing foil traversals with:**
  - **better injection painting**
  - **Reduced linac beam tails**
  - **Smaller / thinner foil**

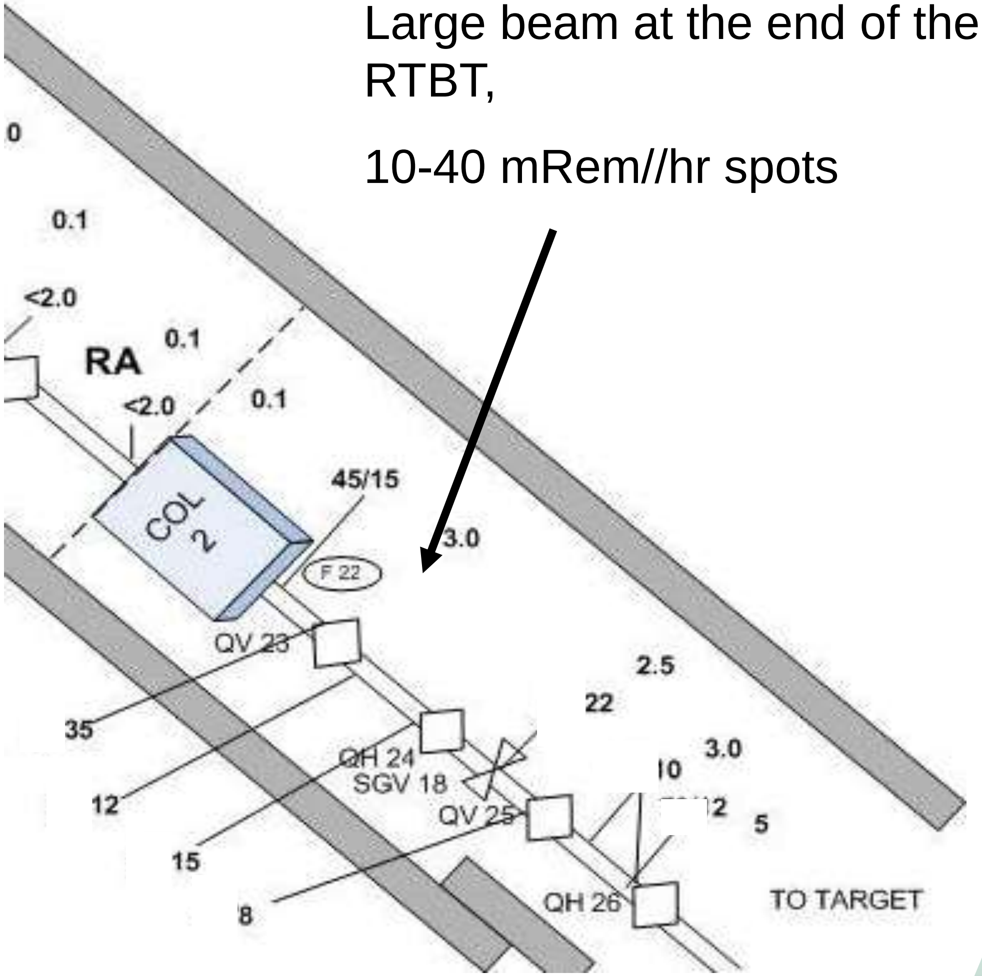
Beam Size Control On Target



- **Use wire profiles and harp to predict the beam size and beam density on the Target (*T. McManamy's talk*)**
- **Difficulties understanding transport in the RTBT *(M. Plum's talk*)**
  - **Swapped plane in harp, coupled H/V beam in the RTBT**
- **Reluctance to vary RTBT quads from values used with view-screen during commissioning**
- **With the power density on Target at the upper limit**
  - **Painting a larger beam in the Ring is the only option, but this causes excessive beam loss at the end of the RTBT**

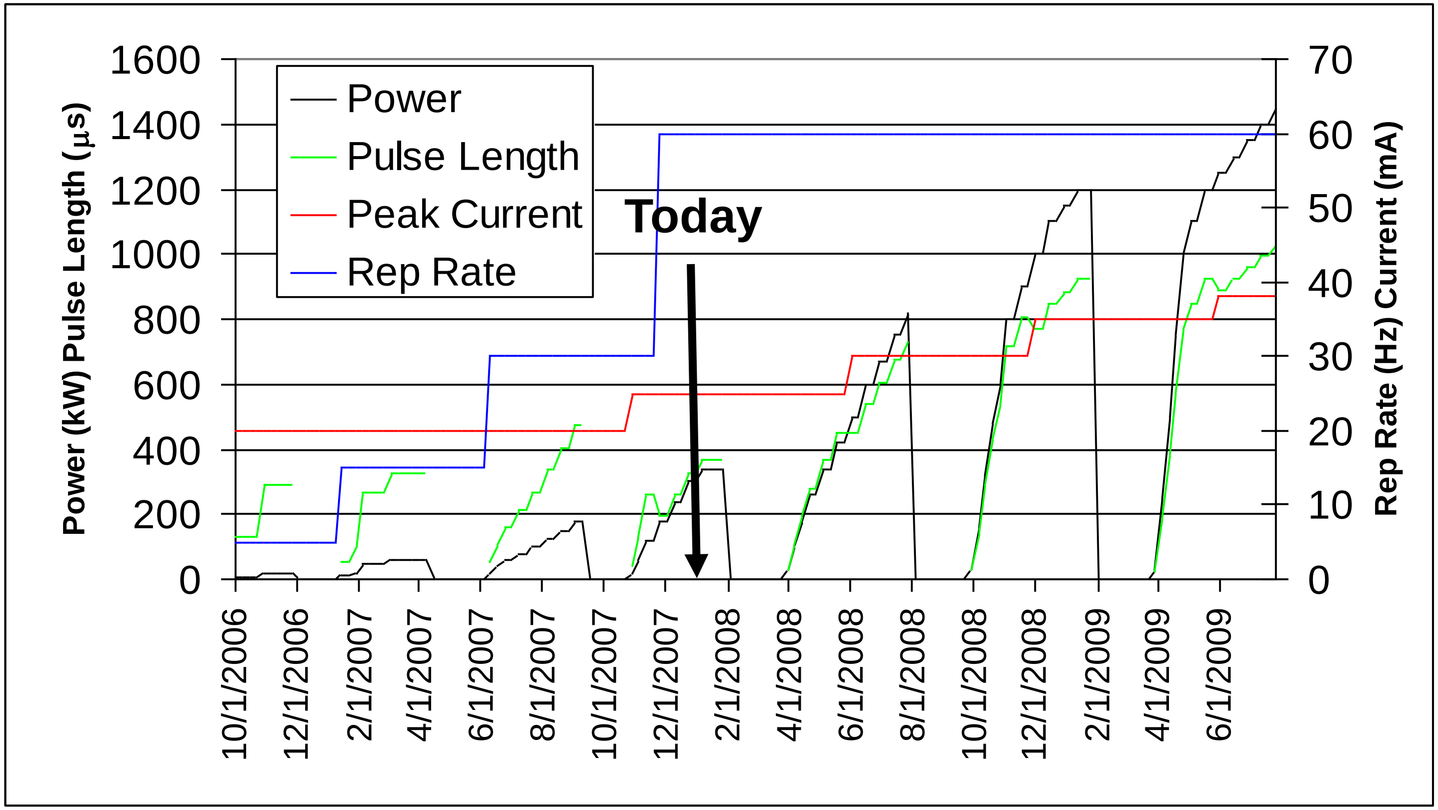
RTBT Radiation





- **Hot spot from extraction loss – reduced with improved chopping**
- **End of RTBT losses reduced with updated lattice to keep the beam small there.**

Equipment Requirements for 1.4 MW Capability



- **Ion source current, pulse length and repetition rate requirements to meet the power ramp-up**
  - **These requirements assume a 1 GeV beam**
- **Presently at 60 Hz we are limited to:**
  - **~ 850 MeV beam energy**
  - **~ 880 μs flattop pulse length**
  - **~ 30 mA current at ~700 μs**

Equipment Concerns for Power Ramp Up

- **Ion source needs to provide 38mA at 1 mS/60 Hz.**
  - *M Stockli's talk*
- **SCL needs to provide ~20% more accelerating gradient with an additional installed cryomodule + enhanced high beta cavity gradients through cavity reworking and surface processing.**
  - *S. Kim's + J. Mammosser's talks*
- **Starting the SCL RF fill during the HVCM ramp-up will provide ~ 70 μS longer flattop .**
  - *S. Kim's talk*
- **Increase the (medium β / high β) HVCM operating voltages from the present (69/71) kV settings to 73/75 kV to provide an additional 50 μs flattop capability, support the increased cavity gradients, and support beam loading associated with 38 mA.**
  - *D. Anderson's and T. Hardek's talks*

AP Concerns

- **Linac**
  - **Quality of beam chopping (*A. Aleksandrov's talk*)**
  - **Understanding and controlling the source of beam loss in the SCL (*A. Aleksandrov's talk*)**
  - **Controlling the transverse beam size and halo delivered to the foil**
- **Ring**
  - **Injection area**
  - **Clean transport of waste beams to the Injection Dump (*M. Plum's talk*)**
  - **Good understanding and control of the beam distribution delivered to the Target (*M. Plum's talk*)**
  - **Foil scattering losses**
  - **Foil survivability (*M. Plum's talk*)**
  - **High intensity effects (*V. Danilov's talk*)**

Summary

- We have increased beam powers from a few kW to > 200 kW.
  - Large reductions in normalized beam loss through the ramp-up
- Have been equipment issues, but none are show-stoppers.
- Now we are dealing with low loss fractions, and are continuing to develop strategies to understand them and further reduce them.