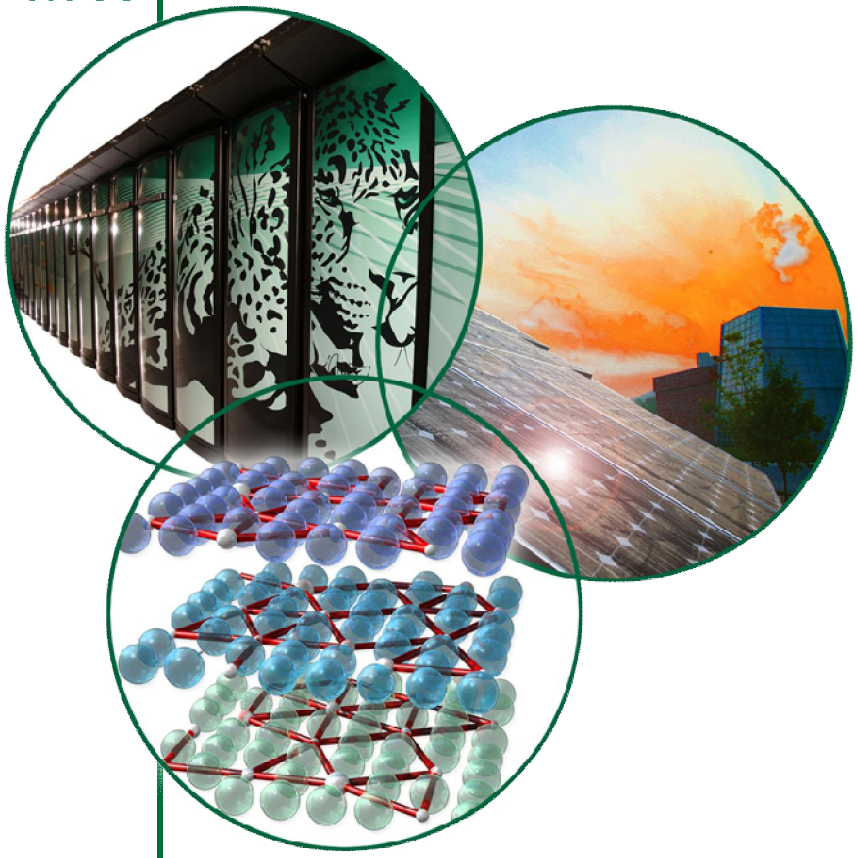
Tuning an Accelerator for 1 MW

C. Peters

WAO 12

August 8th, 2012



U.S. DEPARTMENT OF ENERGY

OAK RIDGE NATIONAL LABORATORY

MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

The Spallation Neutron Source

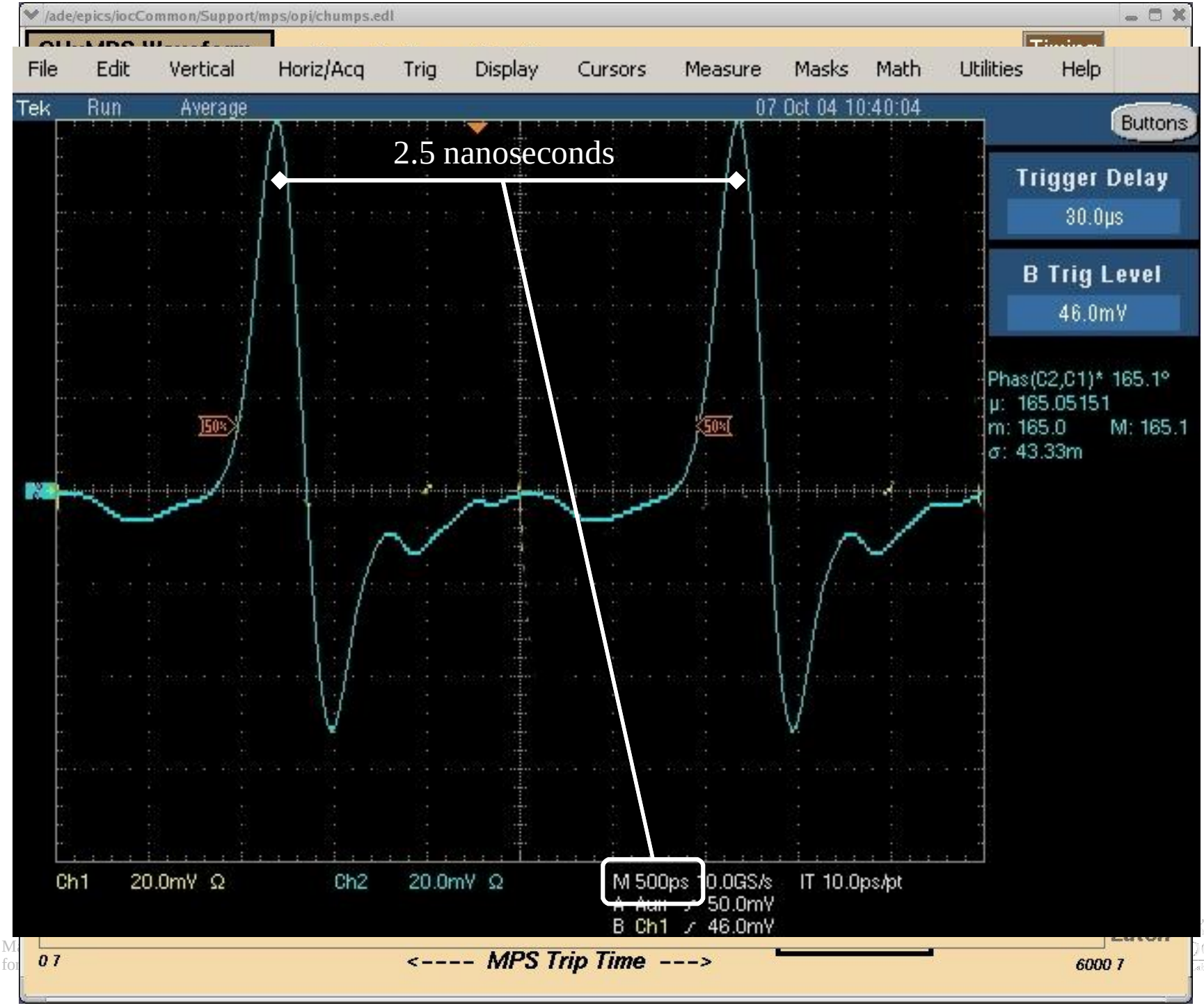
- What
  - A really big microscope (nanoscope?)
    - Produces neutrons by spallation
    - Neutrons are used to study molecular structure and properties of materials
  - Really powerful and power hungry
    - Most intense pulsed neutron source in the world
    - 20 MW in and 1 MW out

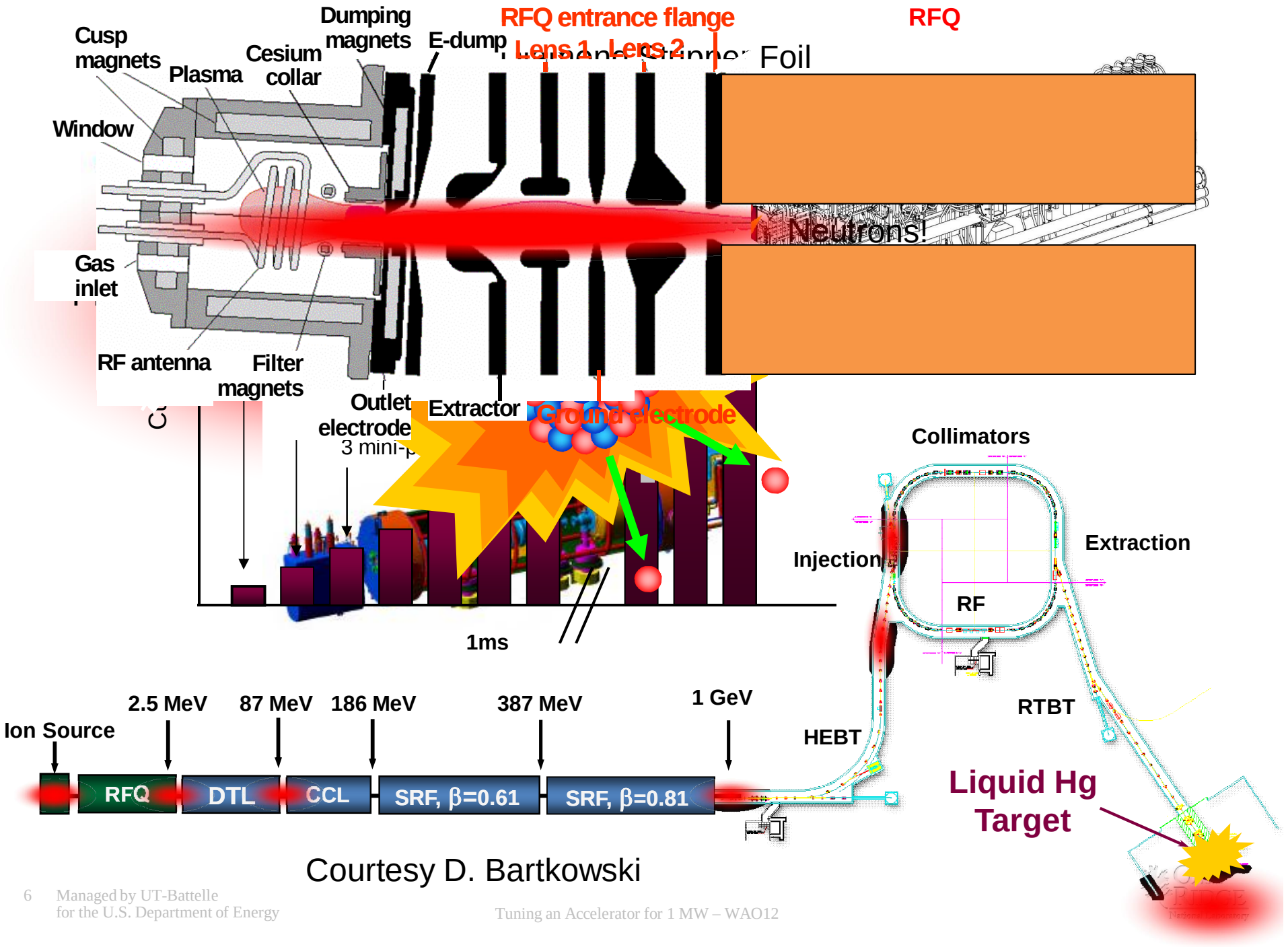
The Spallation Neutron Source

- Where
  - Oak Ridge National Laboratory (ORNL) in Oak Ridge, TN
  - People LOVE their football (not futbol)
  - Oil = Awl
  - It's hot and humid
  - Lots of mountains
  - Lots of really smart people

The Spallation Neutron Source

- How
  - Accelerator
    - H- ion source and Linac (96 accelerating cavities)
      - 1 millisecond long pulse chopped into 700 nanosecond long slices
      - Pulsed at 60 Hz
    - HEBT – High Energy Beam Transport
    - Ring
      - Stacks 700 nanosecond slices into 1 intense pulse
    - RTBT – Ring to Target Beam Transport
  - Target
    - Mercury…….lots of neutrons


/ade/epics/iocCommon/Support/mps/opi/chumps.edl
File
Edit
Vertical
Horiz/Acq
Trig
Display
Cursors
Measure
Masks
Math
Utilities
Help
Tek
Run
Average
07 Oct 04 10:40:04
Buttons
2.5 nanoseconds
Trigger Delay
30.0µs
B Trig Level
46.0mV
Phas(C2,C1)* 165.1°
µ: 165.05151
m: 165.0
M: 165.1
σ: 43.33m
50%
50%
Ch1 20.0mV Ω
Ch2 20.0mV Ω
M 500ps
0.0GS/s
IT 10.0ps/pt
50.0mV
B Ch1 ⁄ 46.0mV
0 7
<---- MPS Trip Time ---->
6000 7

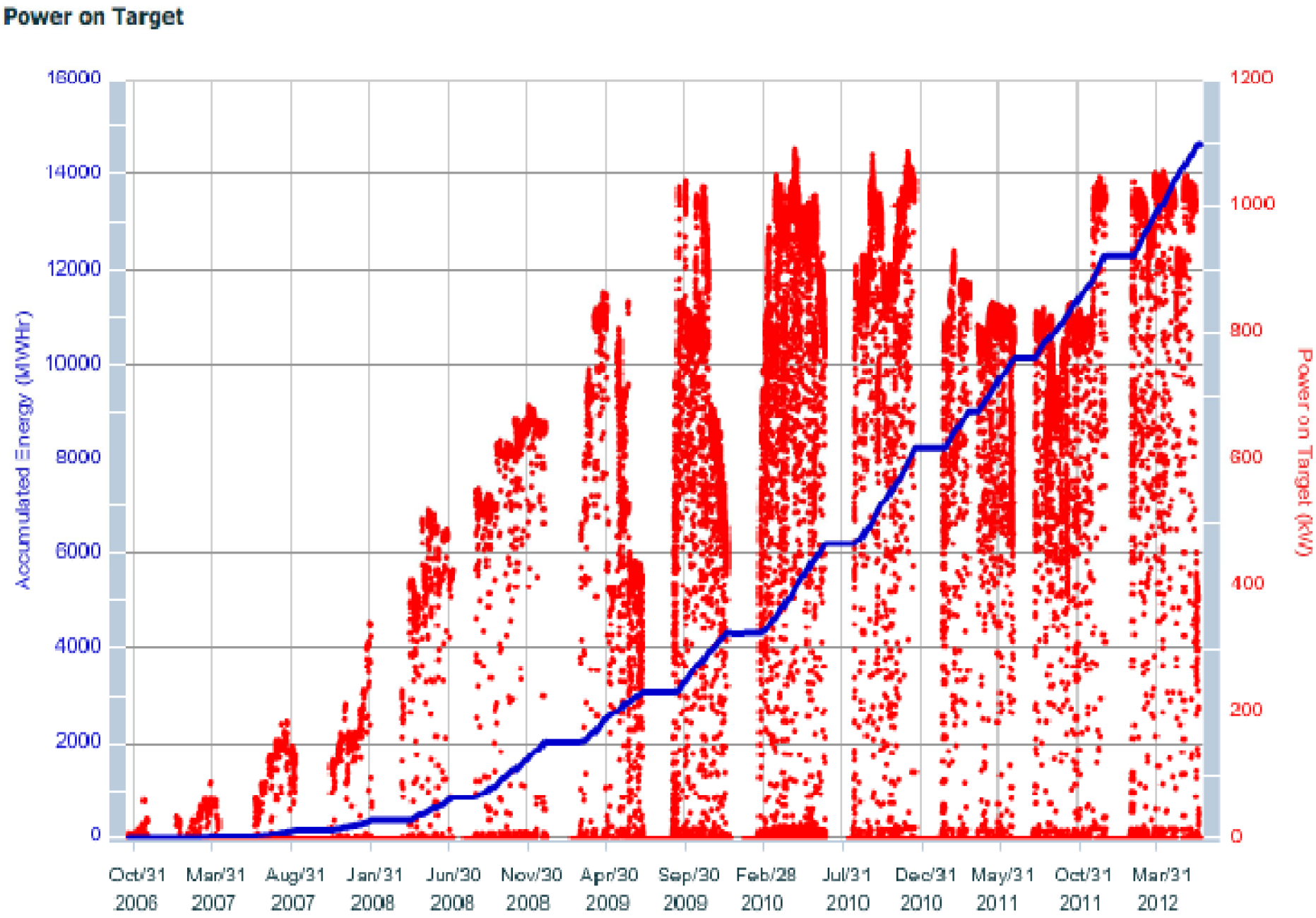


Courtesy D. Bartkowski

The Spallation Neutron Source

- Typical numbers lately
  - Ion source pulse is about 36 to 38 mA for about 850 microseconds
    - 1e14 ppp or about 17 kW per pulse
  - About 4500 hours of neutron production
  - About 630 hours of accelerator physics
  - Machine availability > 92%
  - Average about 15 short trips per day
- How did we get there?

Energy and power on target from October 2006

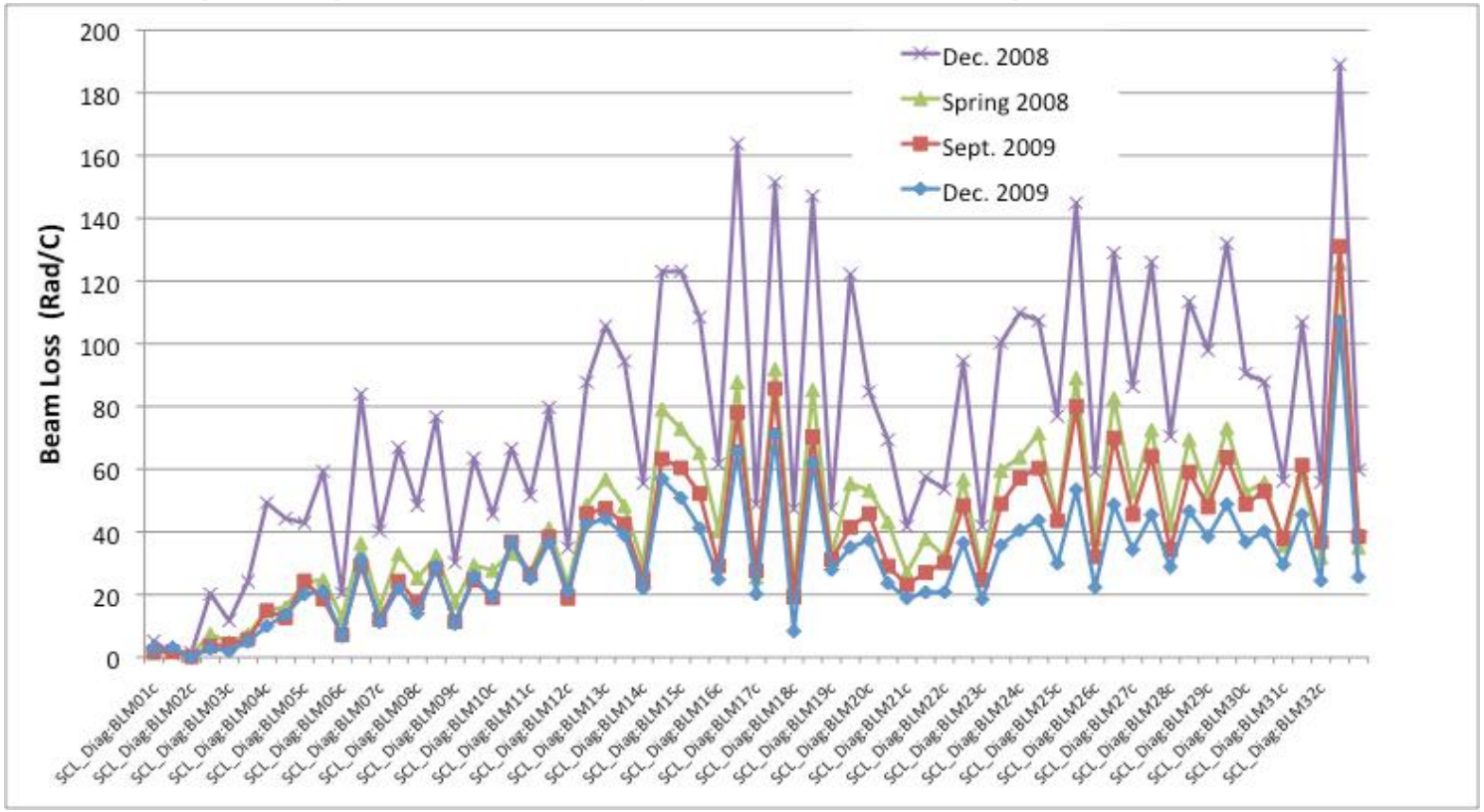


AP development then

- Early on (2006 – 2007)
  - Low power production beam (< 200 kW)
  - Accelerator physicists did it all
    - Timed in linac RF cavities
    - Ring set up
    - Corrected orbits
    - Set beam parameters on target at the beginning of each run and at each ion source change
  - Accelerator physicists tuned the beam in an emergency
  - Operators in general did not tune……don't touch!
- Slowly operators began helping with AP studies
  - Short pulse, low rep rate, beam orbit tuning
- AP studies time decreased as neutron production time increased so operators started tuning more

AP development to operations

- As power has increased
  - Neutron production time dominates
    - Operators find trends (got to do something for 12 hours)
    - RF and quadrupole fine tuning at 60 Hz beam rep rate – BE CAREFUL



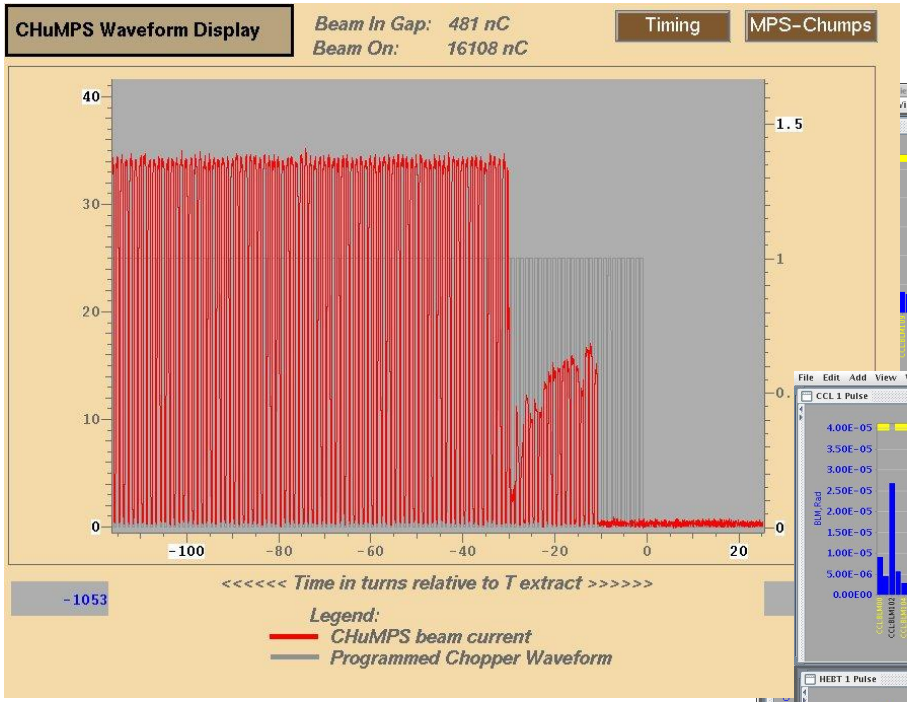
How to make sure operators can't break it

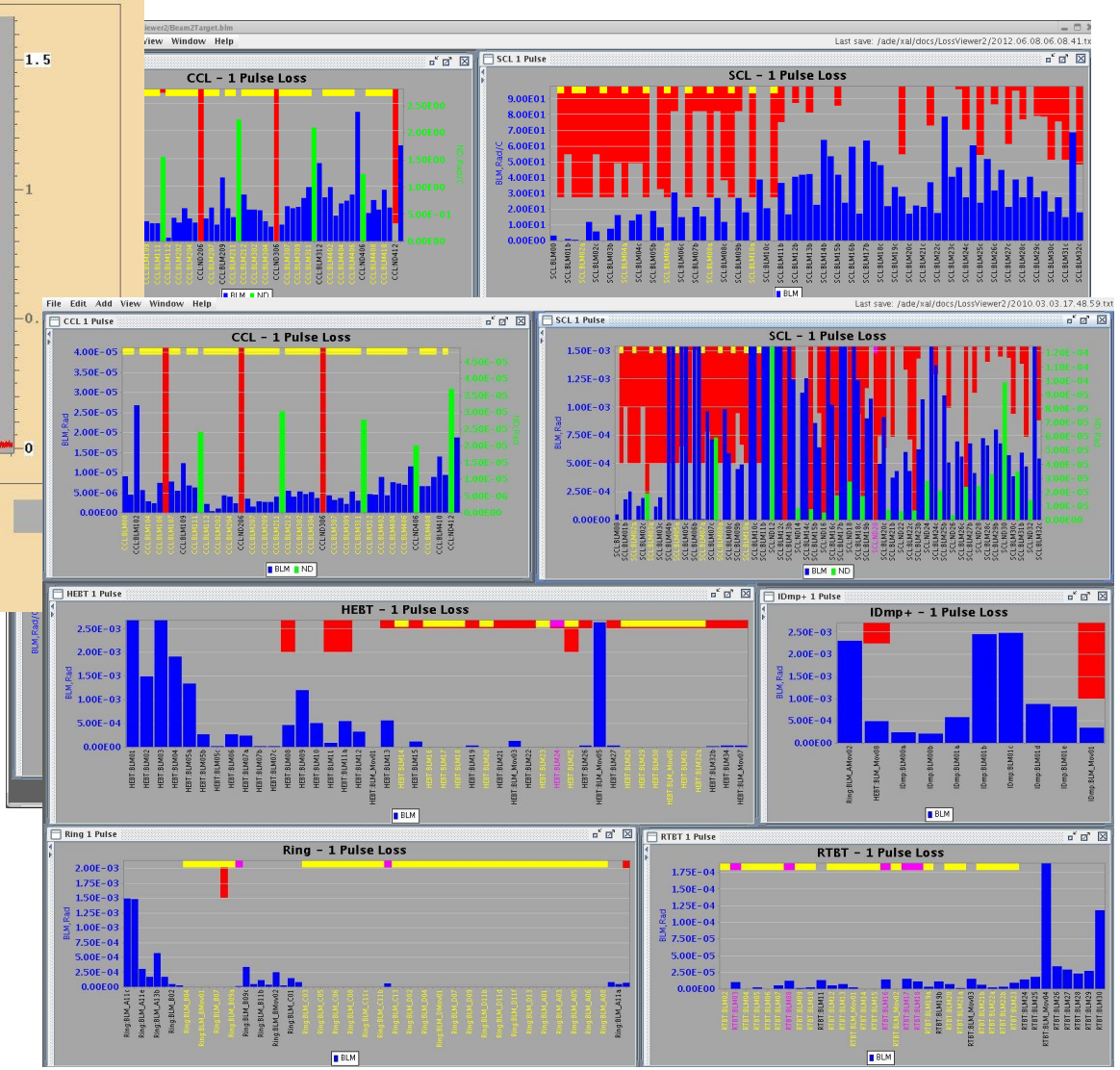
- Machine Protection System (MPS)
- Errant beam controls
- Operation Shift Checklist
- Errant beam alarms & production documentation

Machine Protection System

- MPS does exactly what it states
  - Turns off the beam really fast (fault to beam off in ~ 20 microseconds)
  - Turn off RFQ and ion source pulses, and tell chopper to chop away all of the beam
  - FPAR (Fast Protect Auto Reset)
    - Turns off beam, miss the next pulse, allows beam
    - Holds beam off until operator reset if a fault happens too many times (chatter fault limit)
  - FPL (Fast Protect Latch)
    - Turns off beam
- Operators need to know the MPS will turn off the beam
  - Make a mistake tuning and the MPS turns off the beam fast
- Gotcha
  - MPS signals can be bypassed
  - Rules in place
    - Control Room Shift Supervisor needs expert and manager approval in order to bypass almost all MPS signals in almost all cases
    - Control Room Shift Supervisor can bypass BLMs at 1 Hz beam repetition rate

Machine Protection System





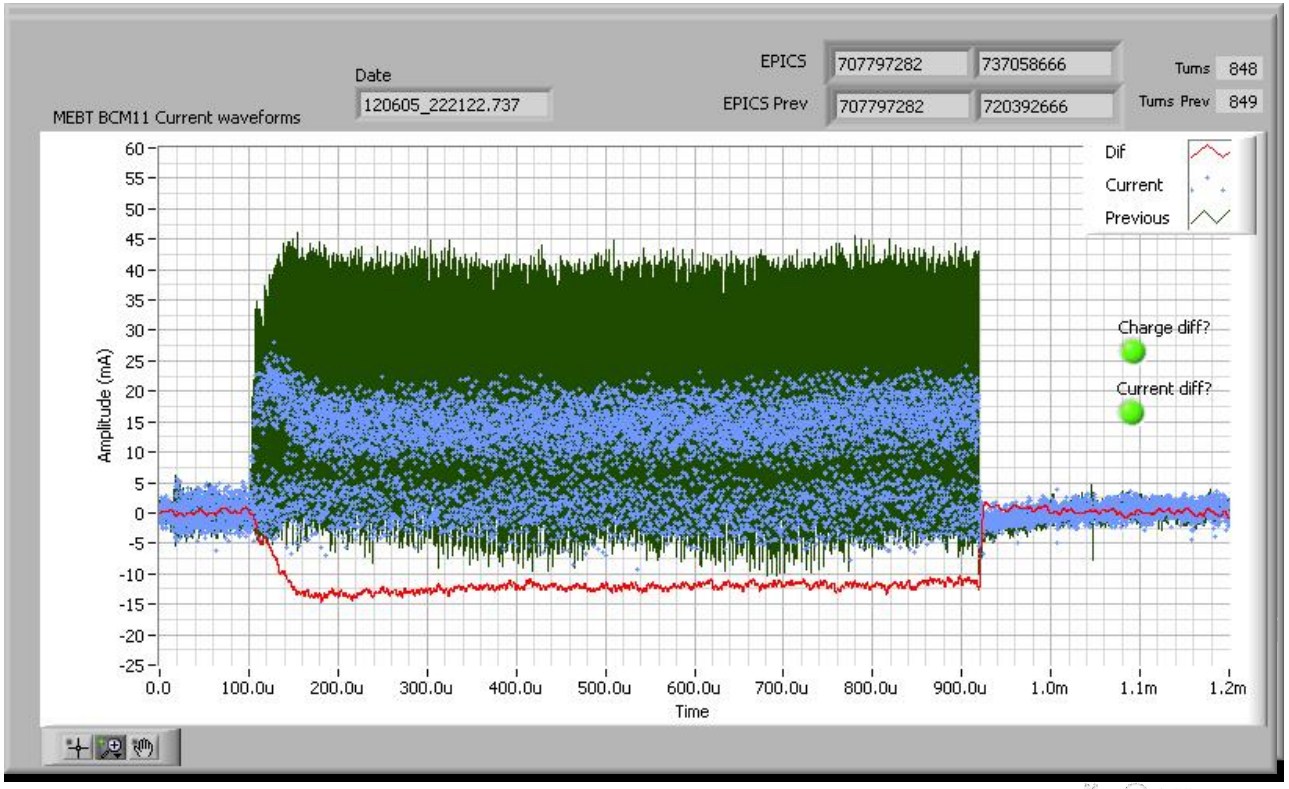
- Ion source or RF faults may not be detected by internal protection hardware
  - Ion source power supply malfunction not detected until BLMs in the SCL

Machine Protection System

- Problems in 2009
  - SCL cavity damage possibly due to linac errant beam
    - Ion source HV, DTL, CCL RF malfunctions
  - MPS delay measurements performed
    - When a fault occurred in some instances 300 microseconds or more of beam was accelerated before MPS turned beam off
    - Long delays found throughout MPS
- A few more things
    - BLMs had chatter fault setting for 2 bad pulses in 60 cycles
    - BLM trip limits were set too high above operating levels
- All fixed and looking good!
  - But linac errant beam continues……..

Linac errant beam is going to happen

- Differential BCM diagnostic
  - BCMs in CCL and HEBT showed beam is lost in the SCL (15 to 30 turns)
  - Most instances caused by DTL and CCL RF
    - Undetected by RF protection module
- Plan for future
  - Differential BCM system connected to MPS for faster turn off to protect SCL
    - Beam turn off time of 5 microseconds
  - Ion source beam pulse history
    - Turn off beam if source pulse differs from previous



How to make sure operators can't break it

- Machine Protection System (MPS)
- RTBT errant beam controls
- Operation Shift Checklist
- RTBT errant beam alarms & production documentation

RTBT errant beam controls

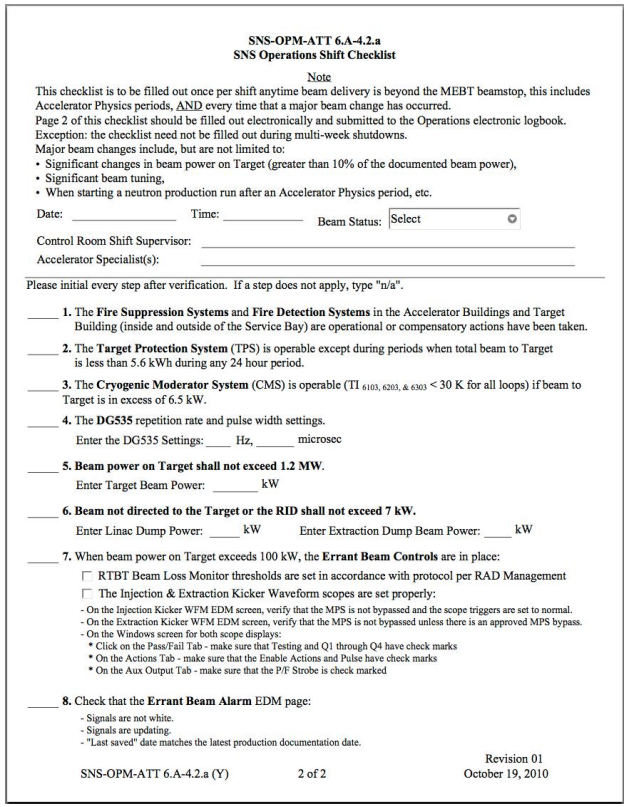
- Protect the target
  - RTBT BLM limits set tighter in case of kicker misfire
  - Ring and RTBT magnets have current windows
    - If a power supply readback goes outside of a set window then the MPS turns off the beam
      - All RTBT power supplies (quads, correctors, extraction septum, DH13)
        - » Power supply windows set based on Operations Envelope
      - Injection kicker power supplies waveform and extraction kicker power supplies waveform mask monitoring
        - » Scopes running Windows XP operating system
  - All set prior to beam power on target exceeds 100 kW

How to make sure operators can't break it

- Machine Protection System (MPS)
- RTBT errant beam controls
- Operation Shift Checklist
- RTBT errant beam alarms & production documentation

Operations Shift Checklist

- Once per shift check operating parameters
  - Verify important systems are working
  - Verify errant beam controls are engaged and working properly
  - If something is not correct then fix it
  - Elog completed checklist
- Operators have created an OS checklist script
  - Verify parameters are within spec, run script, and the script elogs the checklist



SNS-OPM-ATT 6.A-4.2.a
SNS Operations Shift Checklist

Note

This checklist is to be filled out once per shift anytime beam delivery is beyond the MEBT beamstop, this includes Accelerator Physics periods, AND every time that a major beam change has occurred.
Page 2 of this checklist should be filled out electronically and submitted to the Operations electronic logbook.
Exception: the checklist need not be filled out during multi-week shutdowns.
Major beam changes include, but are not limited to:
- Significant changes in beam power on Target (greater than 10% of the documented beam power),
- Significant beam tuning,
- When starting a neutron production run after an Accelerator Physics period, etc.

Date: _____ Time: _____ Beam Status: Select

Control Room Shift Supervisor: _____

Accelerator Specialist(s): _____

Please initial every step after verification. If a step does not apply, type "n/a".

____ **1.** The **Fire Suppression Systems** and **Fire Detection Systems** in the Accelerator Buildings and Target Building (inside and outside of the Service Bay) are operational or compensatory actions have been taken.

____ **2.** The **Target Protection System** (TPS) is operable except during periods when total beam to Target is less than 5.6 kWh during any 24 hour period.

____ **3.** The **Cryogenic Moderator System** (CMS) is operable (TI $_{6103, 6203, \& 6303}$ < 30 K for all loops) if beam to Target is in excess of 6.5 kW.

____ **4.** The **DG535** repetition rate and pulse width settings.
Enter the DG535 Settings: ____ Hz, _____ microsec

____ **5. Beam power on Target shall not exceed 1.2 MW.**
Enter Target Beam Power: _____ kW

____ **6. Beam not directed to the Target or the RID shall not exceed 7 kW.**
Enter Linac Dump Power: ____ kW Enter Extraction Dump Beam Power: ____ kW

____ **7.** When beam power on Target exceeds 100 kW, the **Errant Beam Controls** are in place:
☐ RTBT Beam Loss Monitor thresholds are set in accordance with protocol per RAD Management
☐ The Injection & Extraction Kicker Waveform scopes are set properly:
- On the Injection Kicker WFM EDM screen, verify that the MPS is not bypassed and the scope triggers are set to normal.
- On the Extraction Kicker WFM EDM screen, verify that the MPS is not bypassed unless there is an approved MPS bypass.
- On the Windows screen for both scope displays:
  * Click on the Pass/Fail Tab - make sure that Testing and Q1 through Q4 have check marks
  * On the Actions Tab - make sure that the Enable Actions and Pulse have check marks
  * On the Aux Output Tab - make sure that the P/F Strobe is check marked

____ **8.** Check that the **Errant Beam Alarm** EDM page:
- Signals are not white.
- Signals are updating.
- "Last saved" date matches the latest production documentation date.

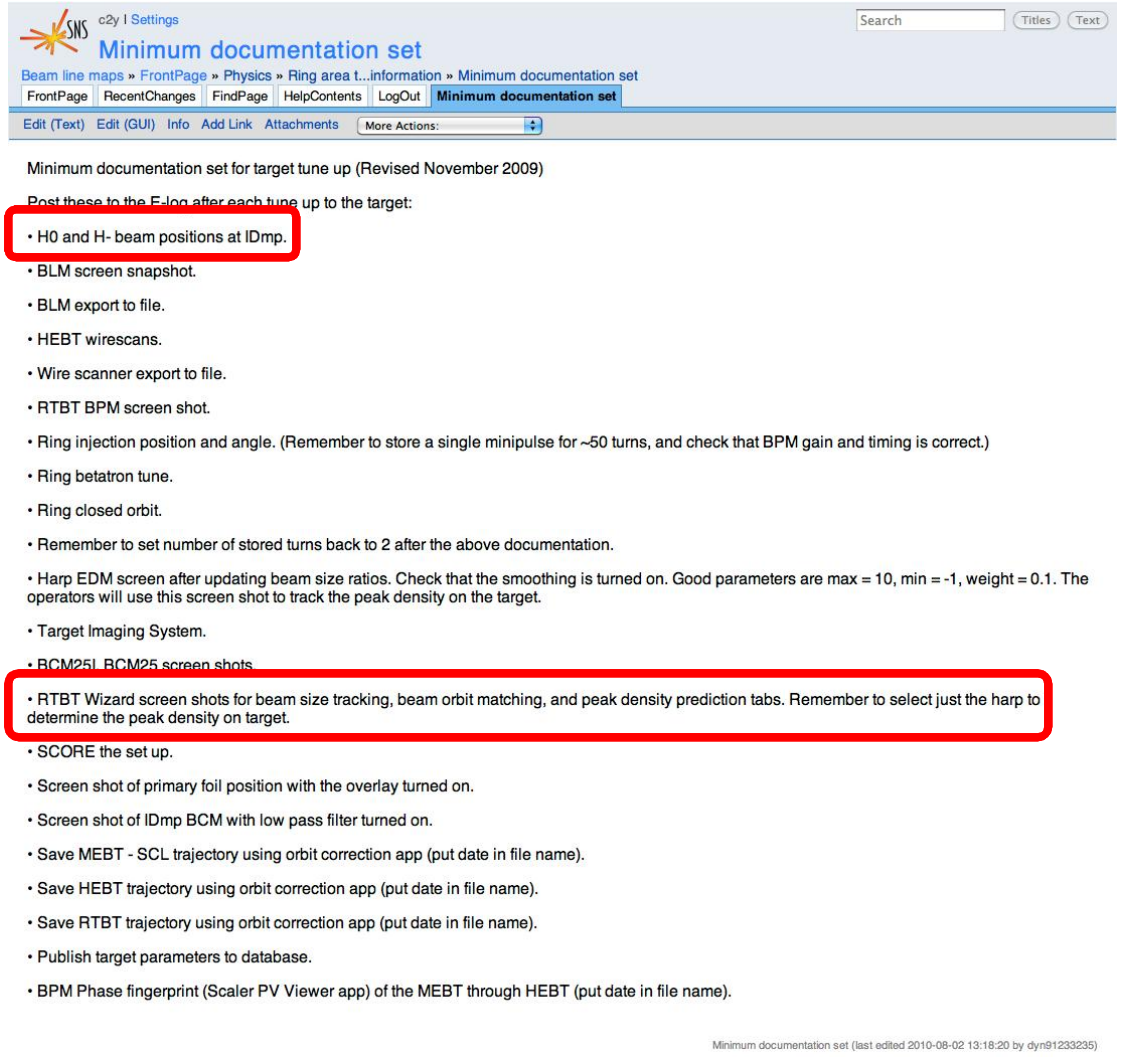
SNS-OPM-ATT 6.A-4.2.a (Y) 2 of 2 Revision 01 October 19, 2010

How to make sure operators can't break it

- Machine Protection System (MPS)
- RTBT errant beam controls
- Operation Shift Checklist
- RTBT errant beam alarms & production documentation

Production documentation

- At beginning of run and at each ion source change
  - Document beam parameters
    - Beam positions in the injection dump
    - Beam size on target
    - Beam peak density on target
    - Beam position on target
  - Wiki-ized list of parameters to save



c2y | Settings

Search Titles Text

Minimum documentation set

Beam line maps » FrontPage » Physics » Ring area t...information » Minimum documentation set

FrontPage | RecentChanges | FindPage | HelpContents | LogOut | **Minimum documentation set**

Edit (Text) Edit (GUI) Info Add Link Attachments More Actions:

Minimum documentation set for target tune up (Revised November 2009)

Post these to the E-log after each tune up to the target:

- H0 and H- beam positions at IDmp.
- BLM screen snapshot.
- BLM export to file.
- HEBT wirescans.
- Wire scanner export to file.
- RTBT BPM screen shot.
- Ring injection position and angle. (Remember to store a single minipulse for ~50 turns, and check that BPM gain and timing is correct.)
- Ring betatron tune.
- Ring closed orbit.
- Remember to set number of stored turns back to 2 after the above documentation.
- Harp EDM screen after updating beam size ratios. Check that the smoothing is turned on. Good parameters are max = 10, min = -1, weight = 0.1. The operators will use this screen shot to track the peak density on the target.
- Target Imaging System.
- BCM25L BCM25 screen shots
- RTBT Wizard screen shots for beam size tracking, beam orbit matching, and peak density prediction tabs. Remember to select just the harp to determine the peak density on target.
- SCORE the set up.
- Screen shot of primary foil position with the overlay turned on.
- Screen shot of IDmp BCM with low pass filter turned on.
- Save MEBT - SCL trajectory using orbit correction app (put date in file name).
- Save HEBT trajectory using orbit correction app (put date in file name).
- Save RTBT trajectory using orbit correction app (put date in file name).
- Publish target parameters to database.
- BPM Phase fingerprint (Scaler PV Viewer app) of the MEBT through HEBT (put date in file name).

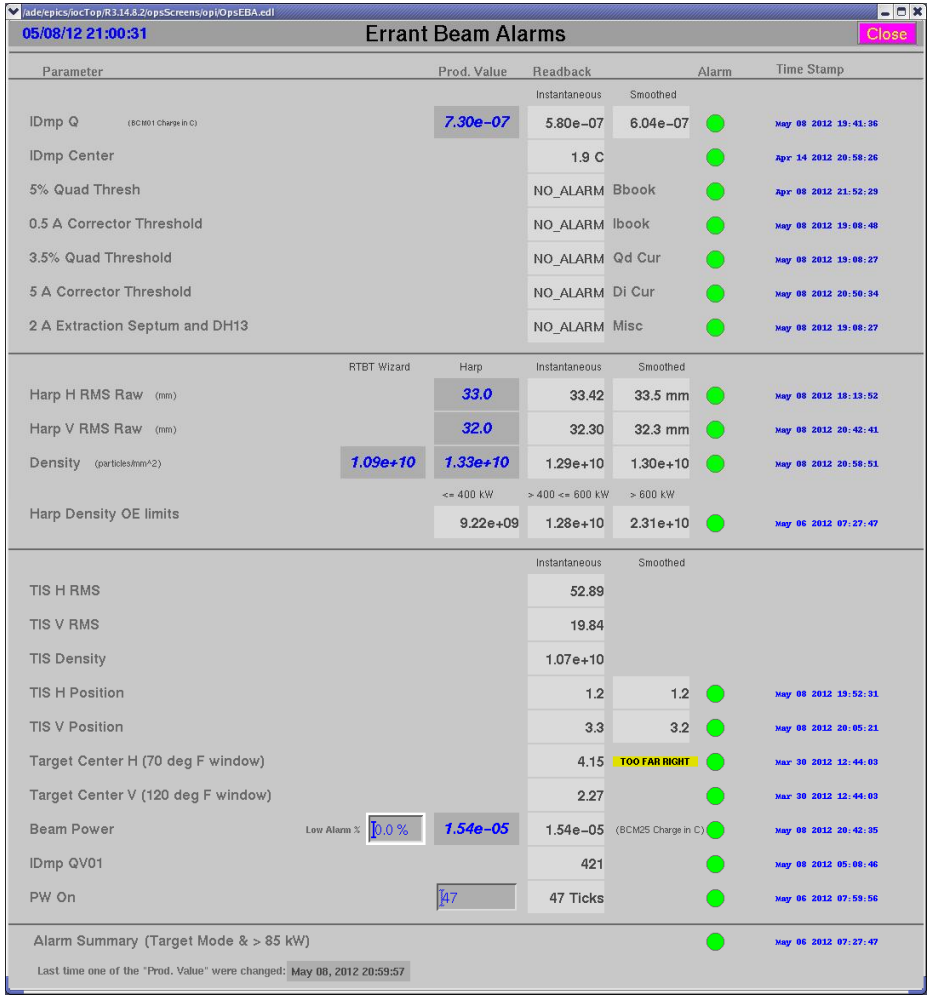
Minimum documentation set (last edited 2010-08-02 13:18:20 by dyn91233235)

Errant beam alarms

- Alarms set based on the production documentation and errant beam controls
  - Monitoring errant beam controls always
  - Monitoring beam parameters always
    - +/- 10% in harp beam size
    - +/- 6 mm by +/- 4 mm target position
    - +/- 10% in beam peak density on target (measured at the harp)
    - +5% in beam power on target
    - +20% in beam power on injection dump
  - Values are set using Control System Studio (CSS)
    - CSS records information in the elog

Errant beam alarms

- Alarms are very important for tuning
  - Systems are tied together
    - Change position at the foil to reduce beam loss and beam size on target changes
  - EDM page displays documented parameters from tune up
    - Don't have to search through elog or notebook to find what the parameters should be



AP development to operations now

- How things have run recently
  - Accelerator physicists and operators together set up Linac RF and Ring for 5 month run
    - Time in linac RF cavities (1-2 shifts)
    - Ring set up (1-2 shifts)
    - AP studies begin (the interesting stuff)
  - When physicists are done playing
    - Machine specialist and operators
      - Correct orbits
      - Set beam parameters on target
      - Production documentation at the beginning of the run and at each ion source change for the remaining run
  - Operators own production

AP development and operations future

- Eliminate time consuming tasks
  - Target Imaging System
    - Use this system to dete
      based on RTBT beam s
  - RID Imaging System
    - Add imaging system to
- Move machine setup
  steel)
  - Automate and speed
    - Now have an automate
      a different story)
    - Production documenta
  - Create thorough bear
- Creates more time fo