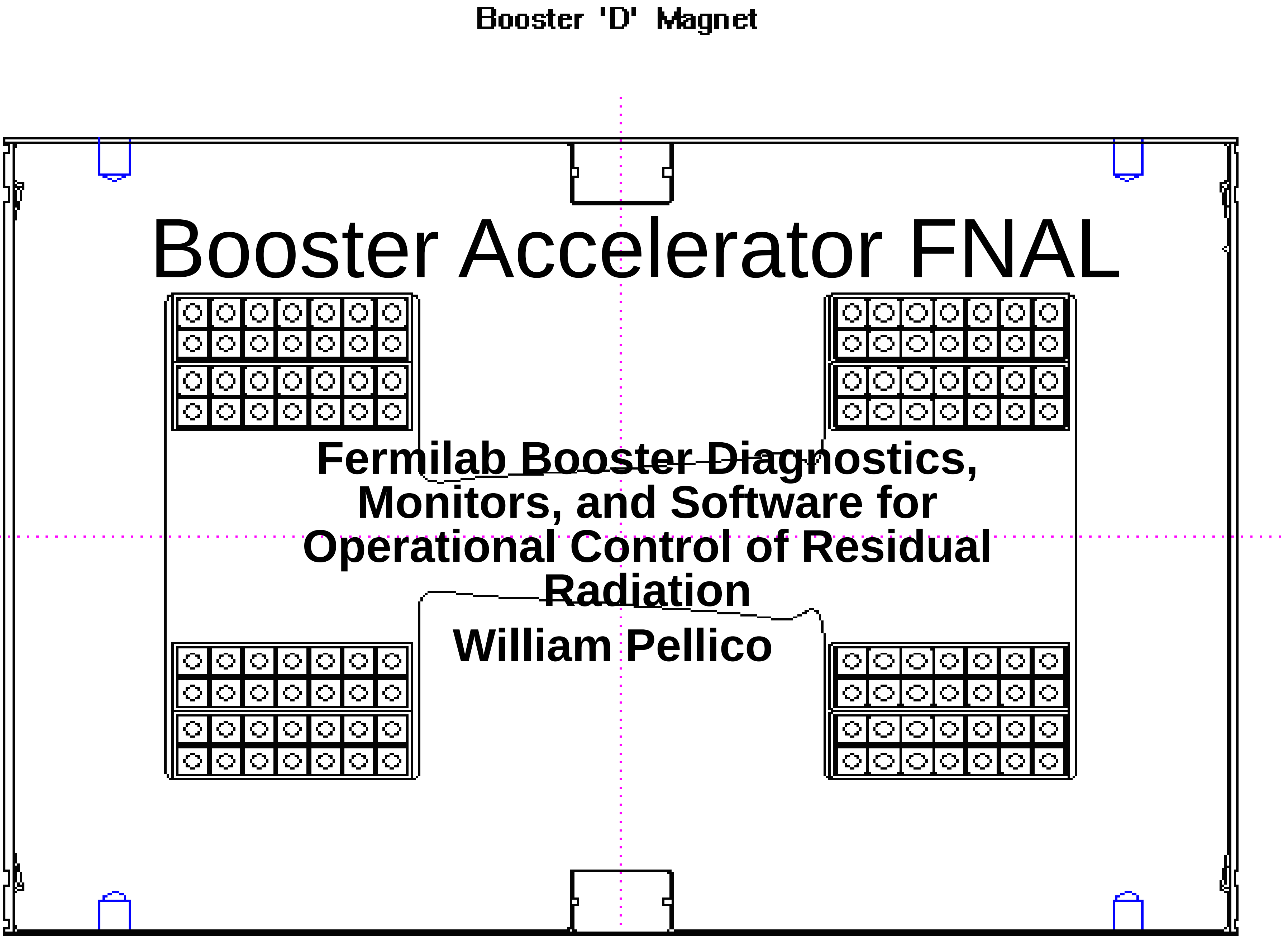


Booster Accelerator FNAL

Fermilab Booster Diagnostics, Monitors, and Software for Operational Control of Residual Radiation

William Pellico

HB2008

Old Man Booster

- Designed in early 60's
  - 15 Hz Resonant Synchrotron
  - 200 MeV - 8 GeV
- First Beam 1970
  - Combined Function
  - Paint Can Loss Monitors
  - Transformer Style BPM
  - Wall Current Monitors
  - Analog Scopes
  - IPM device
  - Multiwire/Single Wire
  - Toroids
- Data Collected by Scopes/Photos
- Digital Scope - 512 points Nicholet (early 80's)
- No Ramped Correction

- During the next 15 years diagnostics improved slowly

  LINAC Upgrade 200 – 400 MeV
  - New BPMs – 80's
  - New BLMs – 80's
    - Based Upon Tev/Pbar
    - Software for new hardware – orbit data!
    - Pingers
  - Ramped Quads - Sextupoles late 80's !!
  - Transverse and Cavity Mode Dampers

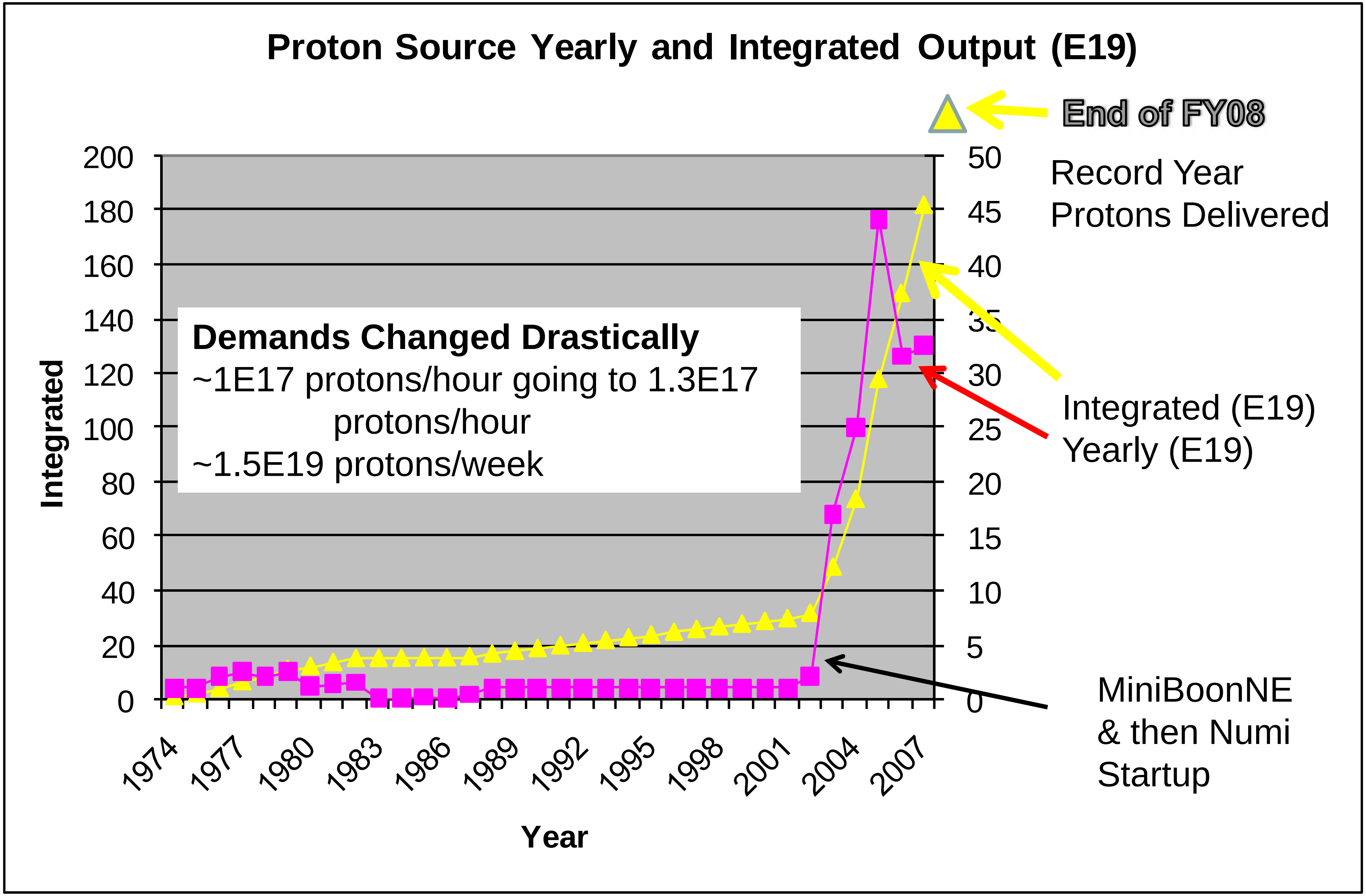
- Beam in Mid 80's

  2E12 – 3E12 Max Pulse

  60 – 68 % efficient

A long ways to go

Why all the changes



Present Operations

- 8 – 11 Turn Beam Operations
  - 10 Turn for Slip Stack Operations : 4.7E12/pulse
    - ~89 efficient (95 % with no notch)
    - Cogged cycle in Booster
  - 8 Turn for Numi slip stack cycles : 4.1E12/pulse
    - ~90 efficient (Cogged Cycle)
  - 10 Turn for MiniBoonNE Operations : 4.7E12/pulse
    - 90 – 91 % efficient
  - 11 Turn for Colliding beam bunches 5.1E12/pulse
    - 95 % efficiency
- Booster uptime over 95%
- Beam Loss Average ~ 450 watts
  - Booster has never lost a magnet but radiation damage is present!
  - Booster needs to run a least another 7 years.
- Presently ~8.5 Hz (Able to run @ 9.5 Hz)

Present Beam Control and Monitoring

- Web Based
  - Mostly Data Logging
    - Losses
      - Long Term Trends
      - Survey data
    - Wire Sigma
    - Beam Current
    - Beam Energy
    - Bunch Length
    - Efficiencies
    - Orbit data

- Console Software
  - New Applications
  - Java apps
- Fast Digital Scopes
- HRM’s (Hot Link Rack Monitor)
- IRM’s (Internet Rack Monitor)
- Front End Software
- Tunnel Hardware
  - Gap Detectors
  - BLMs
  - IRM
  - Striplines
- New Corrector Magnets and PS
- Collimators

Web Based diagnostics

Booster Performance

Each of the ~120 B:BLxxx4 and B:BLxxxD devices are data-logged. This enables us to monitor Booster performance with this system in a manner completely analogous to way it is done with the Chipmunks. For stable running periods, we record the average reading for each BLM and normalize it to the corresponding alarm maximum. The largest value thus obtained, is normalized to the beam delivery rate during that period in order to determine the maximum protons/hour that could have been delivered without tripping one of the BLM's. (A stable running period is a period of at least an hour in which neither the protons delivered per pulse nor the pulse rate varied by more than 5%. Stable periods are defined separately for x1D and x14 event types.

Long Term BLM monitoring ..

Performance versus Time: Here we plot, as a function of time, the maximum protons per hour that could have been delivered without tripping. The points are colored coded according to the average protons per pulse.

Performance versus Intensity: Here we plot the maximum p/hr versus the average protons/pulse. The points are colored coded according to the time the period occured.

Best Performance Period: This plot shows the loss distribution for the best running period with an intensity greater than 4E12 protons/pulse. It shows the trip fraction for each BLM normalized to 1e17 p/hr. The horizontal axis is the location of each BLM in "Booster sector units".

Limiting Location versus Time: Shows the location of the BLM with the highest normalized reading. The points are colored coded according to the maximum protons/hour that was possible during the period.

Limiting Location versus Performance: Shows the correlation between performance and the location of the limiting BLM. The points are colored coded according to the time the period occured.

Trip Fractions versus Time: This plot shows how close we were to tripping **assuming the current trip points**. Note that trip fractions greater than one indicate that we would not have been able to run with the current trip settings. The points are colored coded according to the protons/hour being delivered at the time.

Plot Selector: Here you can generate plots of various types including time lines for indivdual BLM's.

Plotting Options

http://www-bd.fnal.gov/proton/booster/blms/

Web Based diagnostics

Booster BLM Data

Create color-coded scatter plot

Horizontal axis: Time

Vertical axis: Maximum protons/hour

Color scale: Protons/pulse

☐ Normalize trip fractions to 1e17 p/hr.

PLOT

Create multi-variable scatter plot

Select six BLM trip fractions starting at Long 15

Horizontal axis: Time

Vertical variable 1: L08 trip fraction

☐ (skip) **Vertical variable 2**: S08 trip fraction

☐ (skip) **Vertical variable 3**: L09 trip fraction

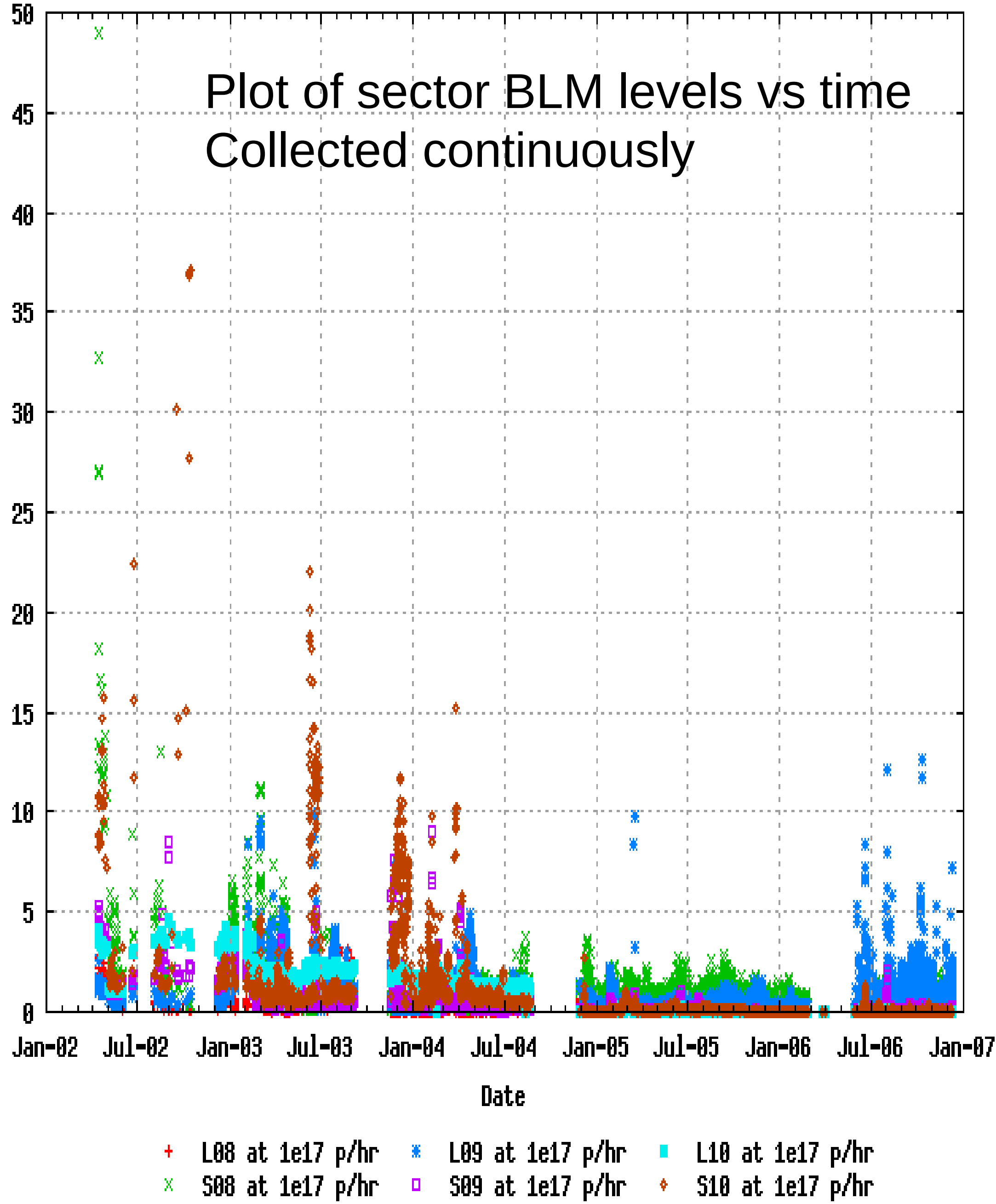
☐ (skip) **Vertical variable 4**: S09 trip fraction

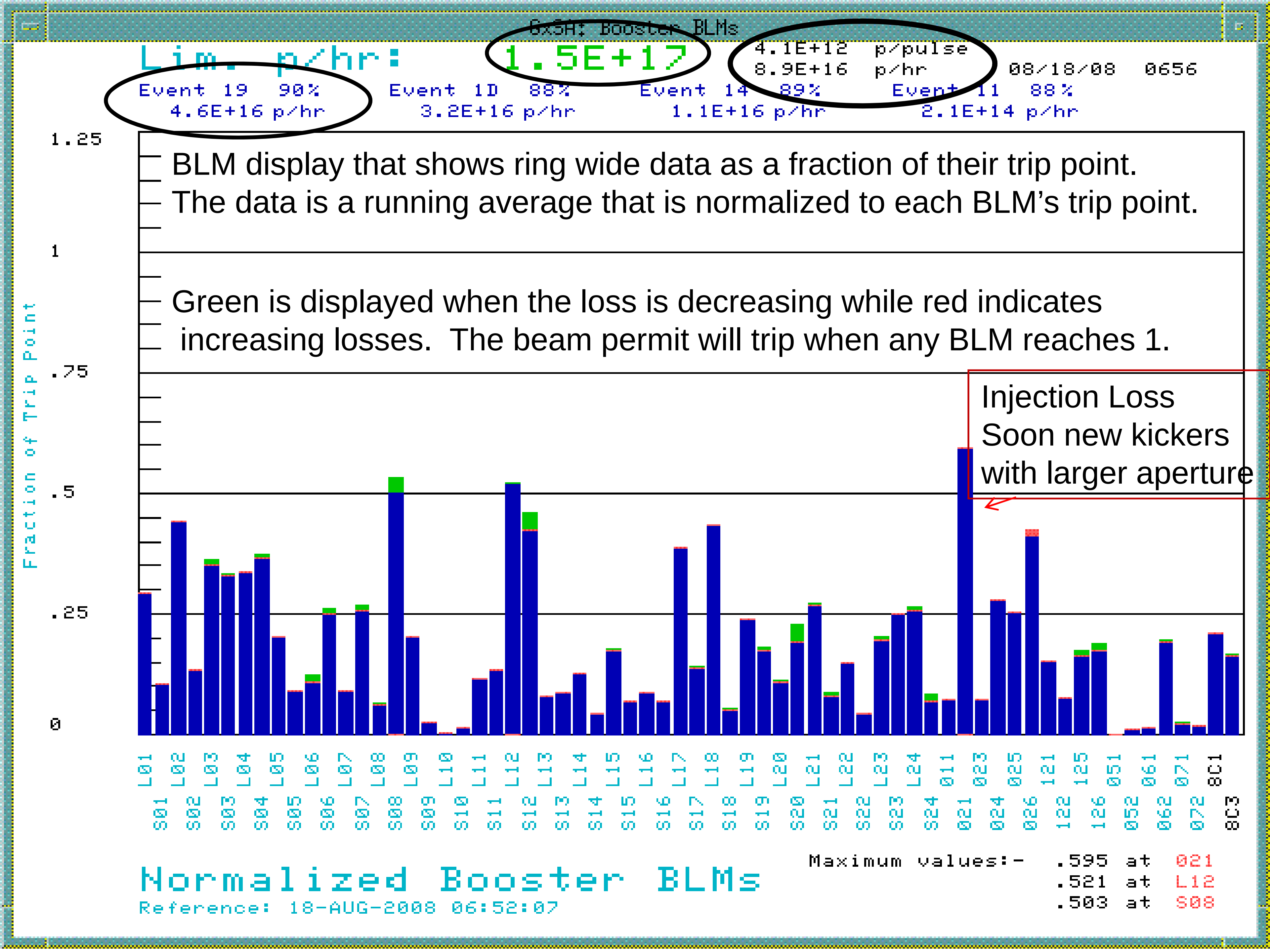
☐ (skip) **Vertical variable 5**: L10 trip fraction

☐ (skip) **Vertical variable 6**: S10 trip fraction

☑ Normalize trip fractions to 1e17 p/hr.

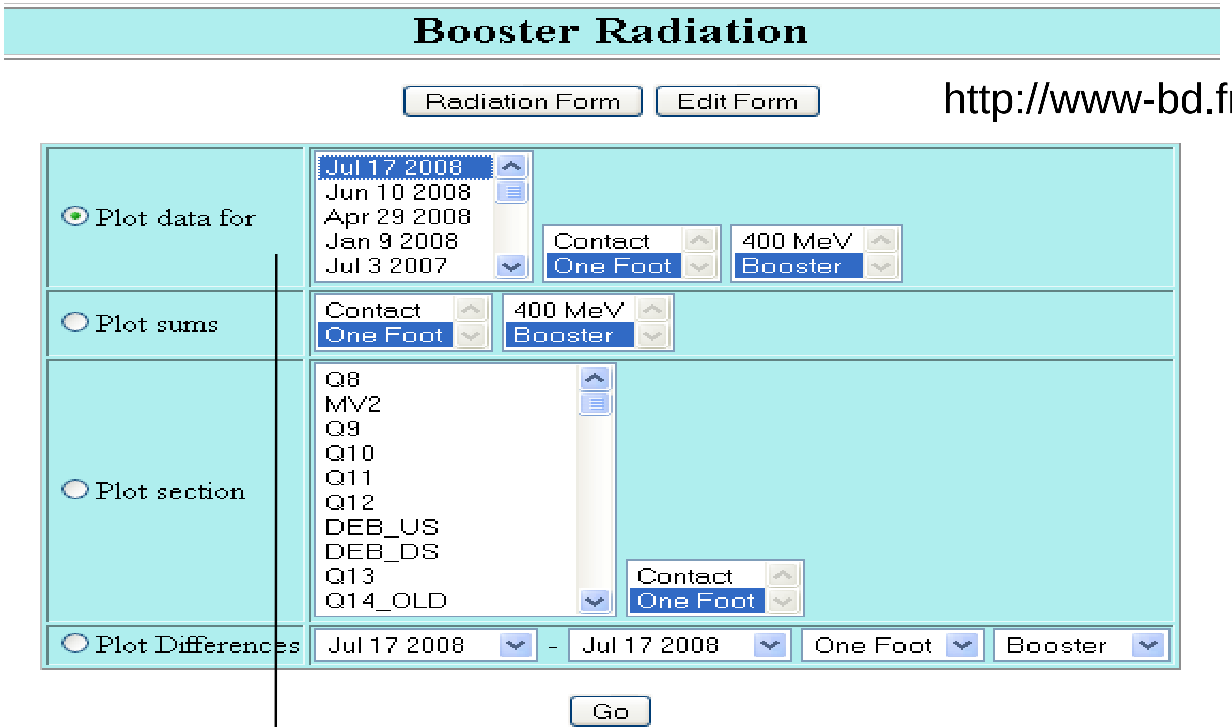
PLOT



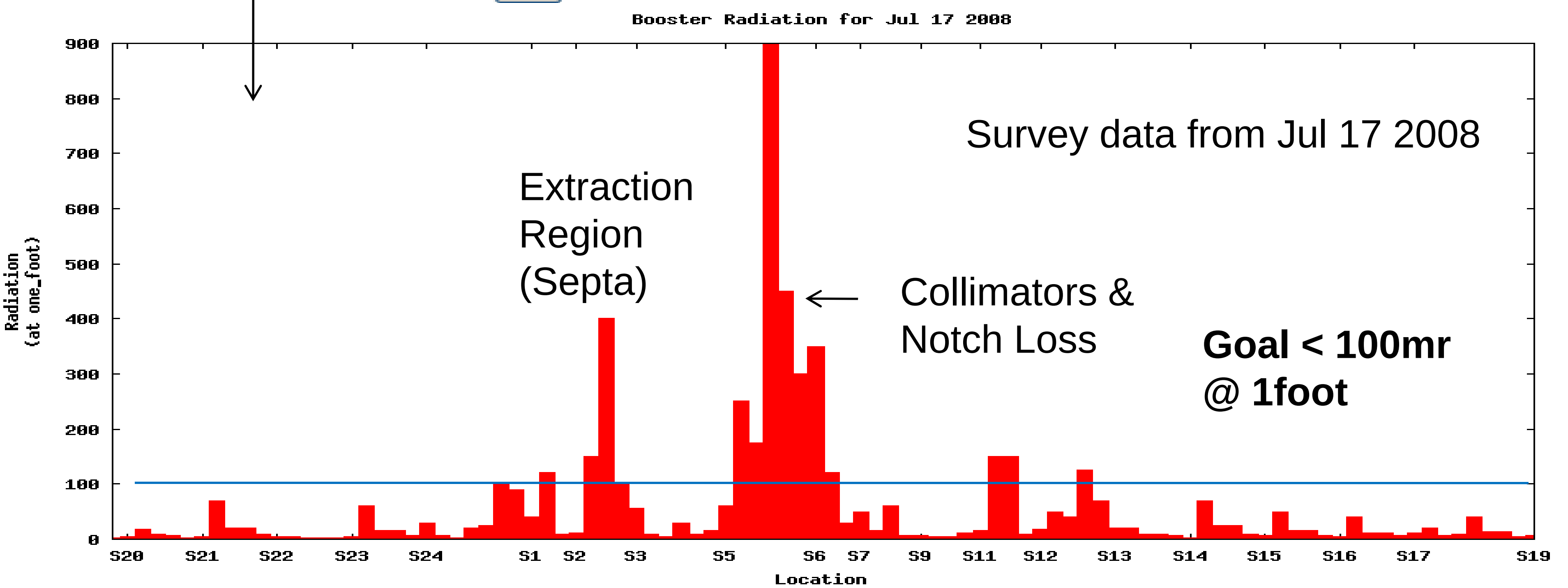

Lim. p/hr: 1.5E+17
4.1E+12 p/pulse
8.9E+16 p/hr
08/18/08 0656
Event 19 90%
4.6E+16 p/hr
Event 1D 88%
3.2E+16 p/hr
Event 14 89%
1.1E+16 p/hr
Event 11 88%
2.1E+14 p/hr
BLM display that shows ring wide data as a fraction of their trip point.
The data is a running average that is normalized to each BLM's trip point.
Green is displayed when the loss is decreasing while red indicates increasing losses. The beam permit will trip when any BLM reaches 1.
Injection Loss
Soon new kickers
with larger aperture
Fraction of Trip Point
1.25
1
.75
.5
.25
0
Normalized Booster BLMs
Reference: 18-AUG-2008 06:52:07
Maximum values:-
.595 at Q21
.521 at L12
.503 at S08

Web Based diagnostics

http://www-bd.fnal.gov/cgi-booster/rad_survey.pl



Radiation survey data is stored in a database that can be accessed from the Booster web homepage. The data can be displayed several ways – including difference (Date 1 – Date 2) or individual BLM history.



Andrew Feld
Todd Sullivan
July 17, 2008

Start: 0707
End: 0740
Beam Off: 0538

	Q8	MV2	Q9	Q10	Q11	Q12	DEB_US	DEB_DS	Q13	MH2	Q15	Q16_US	Q16_DS	INJ
CONTACT	-	-	-	-	-	-	-	-	-	-	-	-	-	-
FOOT	0	0	4	3	3	5	3	3	0	3	4	6	3	3

Survey Data Form

Running stacking and BNB at 10T. Numi off, permit trip on RAW expansion tank level low.

NAME	CONTACT	1 FOOT
L20	-	2
S20	-	5
L21_RF9_US	-	17
L21_RF9_DS	-	8
L21_RF10_US	-	7
L21_RF10_DS	-	3
S21	-	5
L22_RF11_US	-	70
L22_RF11_DS	-	20
L22_RF12_US	-	20
L22_RF12_DS	-	10
S22	-	4
L23_RF13_US	-	5
L23_RF13_DS	-	3
L23_RF14_US	-	3
L23_RF14_DS	-	2
S23	-	4
L24_RF15_US	-	60
L24_RF15_DS	-	15

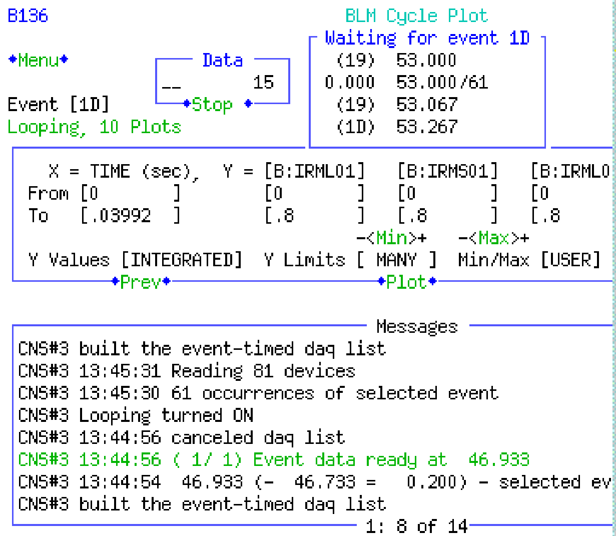
NAME	CONTACT	1 FOOT
L24_RF16_US	-	15
L24_RF16_DS	-	7
S24	-	28
L1_US	-	7
VCA	-	3
LVT	-	20
L1_DS	-	25
L1_2(1)	-	100
L1_2(2)	-	90
S1	-	40
L2_US	-	120
L2_DS	-	10
S2	-	12
L3	-	150
MPO2	-	400
BEX2	-	100
S3	-	55
L4	-	9
S4	-	5

NAME	CONTACT	1 FOOT
L5	-	30
HORZ.PR.IN	-	10
HORZ.PROUT	-	15
S5	-	60
VER.PR IN	-	250
VER.PR OUT	-	175
L6	-	900
SEC. COL 6A	-	450
SEC. COL 6B	-	300
S6	-	350
L7	-	120
L7 DS	-	30
S7	-	50
L8	-	15
S8	-	60
L9	-	7
S9	-	6
L10	-	4
S10	-	5

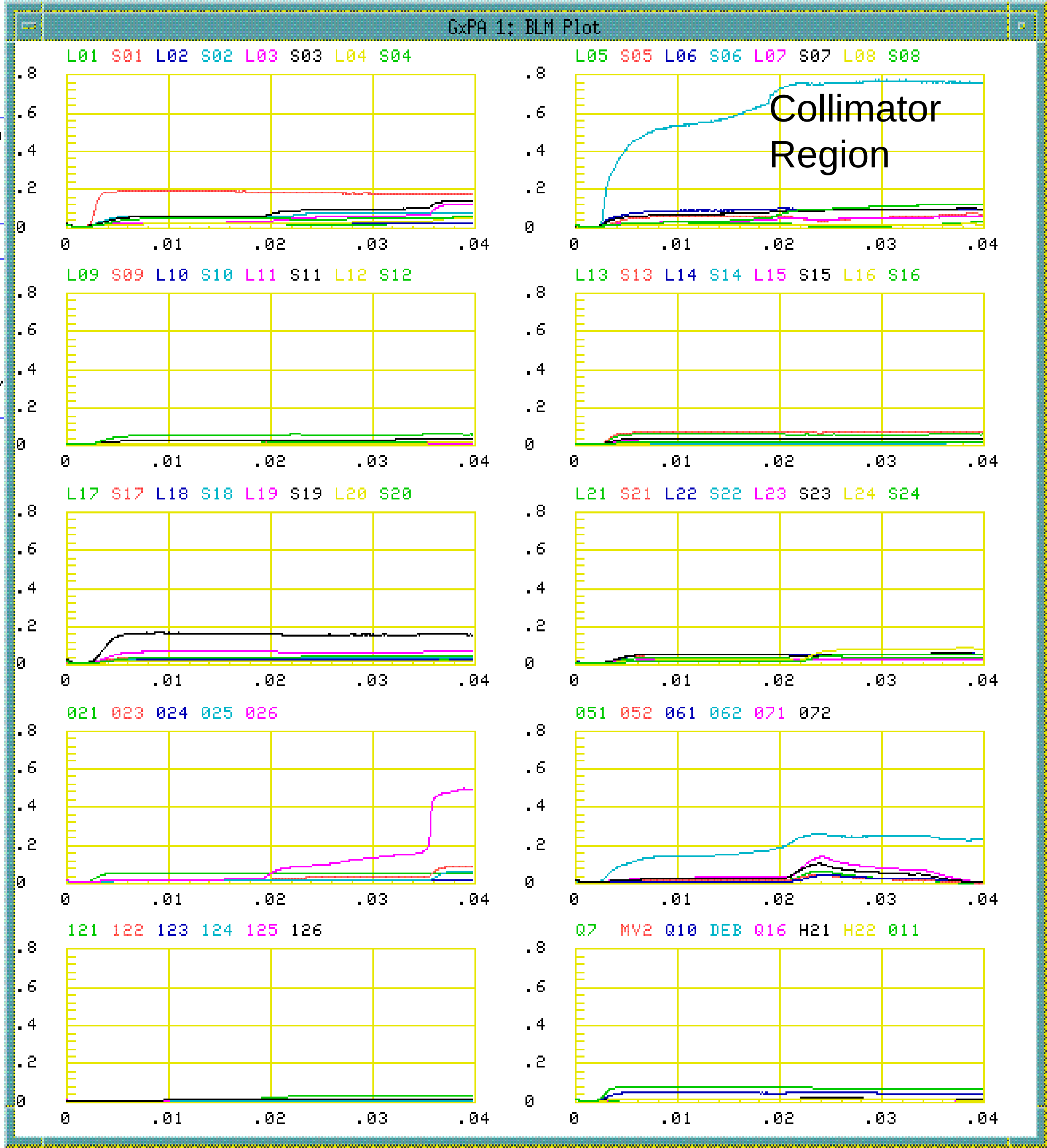
NAME	CONTACT	1 FOOT
L11	-	12
S11	-	15
L12_OUT_US	-	150
L12_IN_US	-	150
L12_DS	-	10
S12	-	17
MAGNET 12_3	-	50
MAGNET 12_4	-	40
L13_US	-	125
L13_DS	-	70
S13	-	20
L14_RF1_US	-	20
L14_RF1_DS	-	8
L14_RF2_US	-	8
L14_RF2_DS	-	6
S14	-	3
L15_RF3_US	-	70
L15_RF3_DS	-	25
L15_RF4_US	-	25

NAME	CONTACT	1 FOOT
L15_RF4_DS	-	10
S15	-	7
L16_RF5_US	-	50
L16_RF5_DS	-	15
L16_RF6_US	-	15
L16_RF6_DS	-	7
S16	-	5
L17_RF7_US	-	40
L17_RF7_DS	-	12
L17_RF8_US	-	12
L17_RF8_DS	-	6
S17	-	12
L18_RF19_US	-	20
L18_RF19_DS	-	6
S18	-	8
L19_RF17_US	-	40
L19_RF17_DS	-	13
L19_RF18_US	-	13
L19_RF18_DS	-	5
S19	-	7

Collimator Secondary Set #1



Console application that plots any/all BLMs on selected event. The data is collected and displayed every 2 sec.

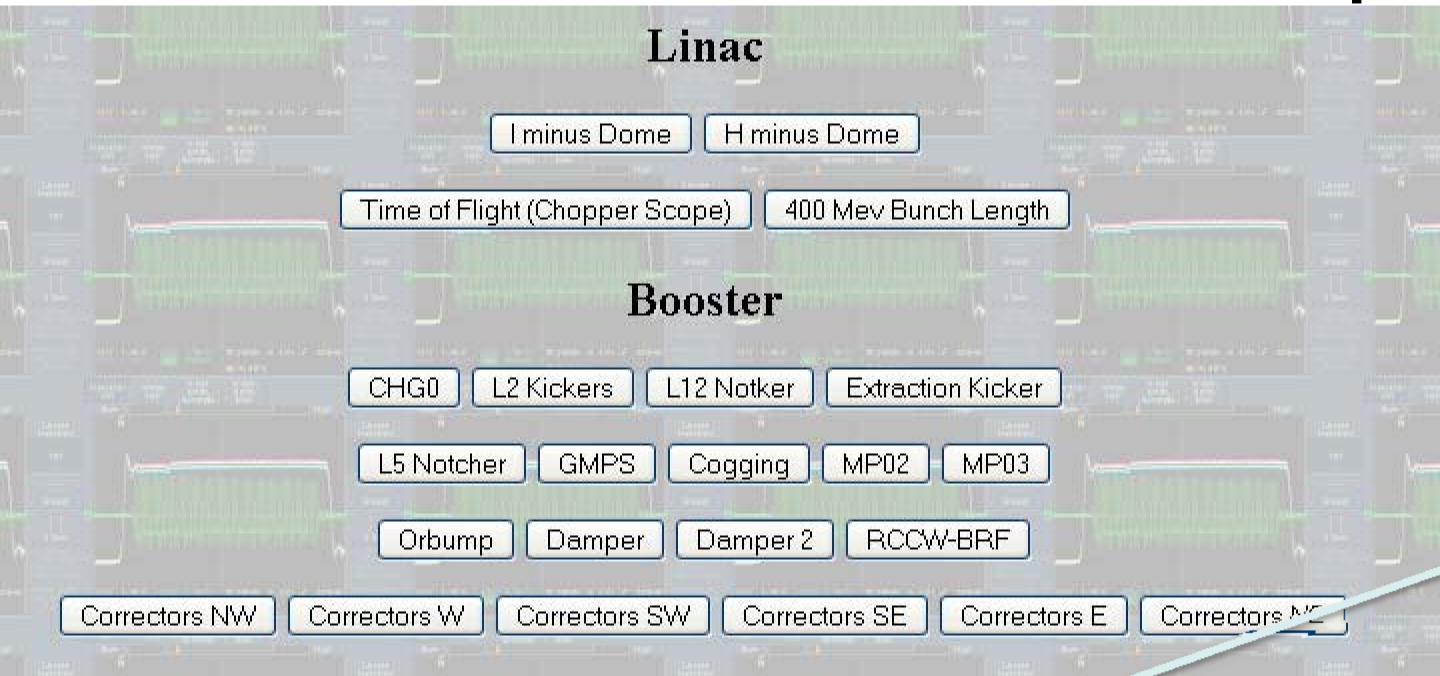


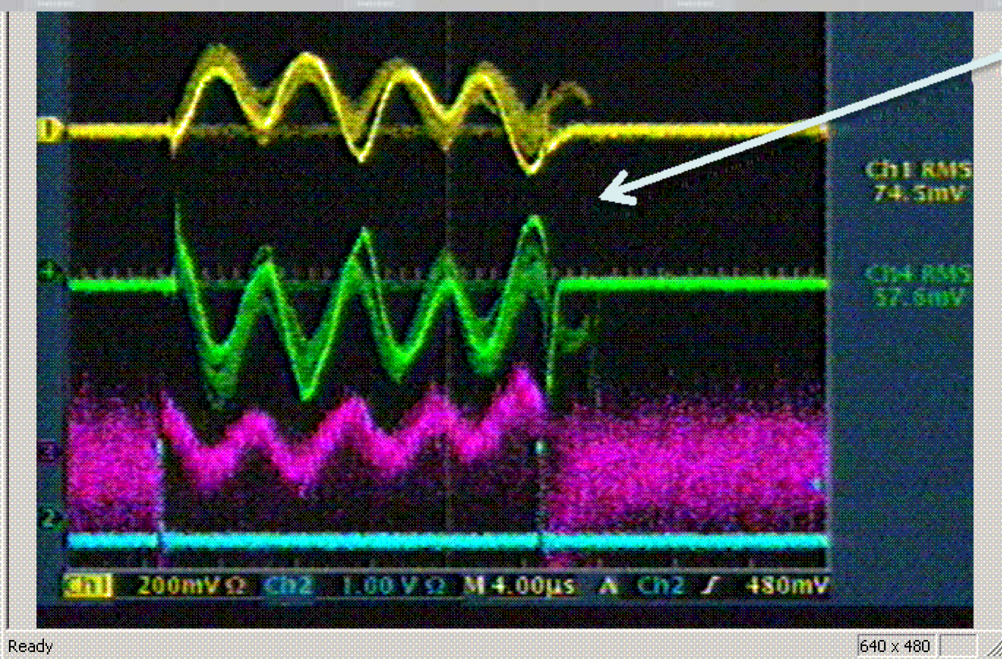
New Diagnostics – Beam Control

- Injection Monitoring
  - Energy
  - Bunch Length
  - Transverse Beam Parameters
    - Multi Wires
    - Crawling Wires
    - BPM upgrade
- Acceleration Monitoring
  - Longitudinal
    - Couple Bunch
    - Transverse Modes (Including Head-Tail)
  - Transverse
    - Instabilities
    - Orbits
    - Higher Order Harmonics
- Extraction Monitoring
  - Energy
  - Transverse Parameters
  - Phase Errors


Gnuplot
Linac Output Current
Efficiency
4.7E12/pulse
Extracted Beam
transverse sigma
$14 cycle
Web Based diagnostics
http://www-ad.fnal.gov/proton/booster/booster.html
Injected Beam
Bunch Length
Loss/Watts
A VXI based software provides
a running average of beam loss.

Web accessible scopes



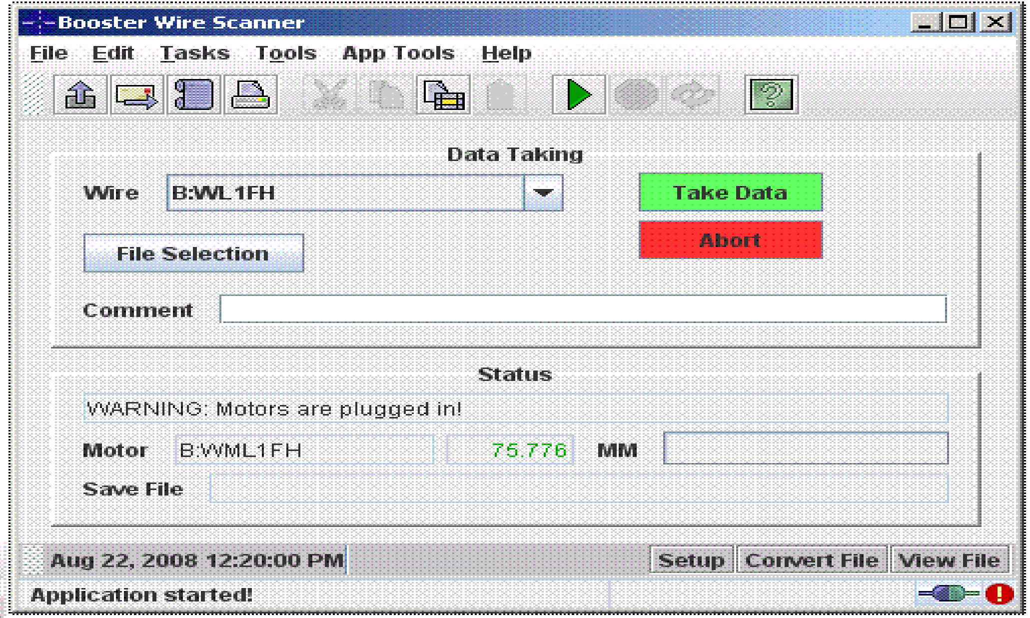


Energy Error
Input to a energy correction feedback loop - Klystrons

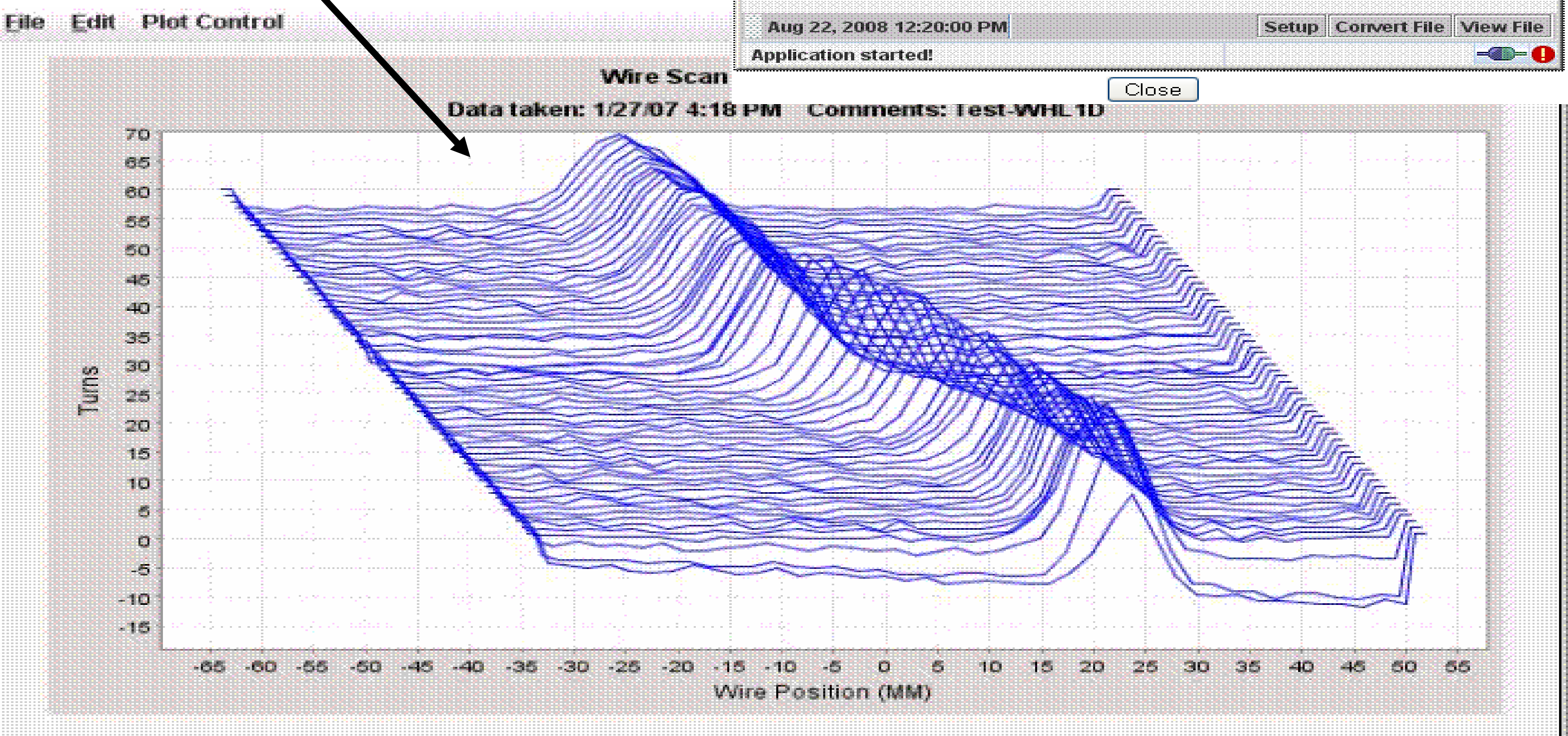
Fast digital scopes with web software are being used extensively. They are also connected to CATV system which allows quick – real time viewing.

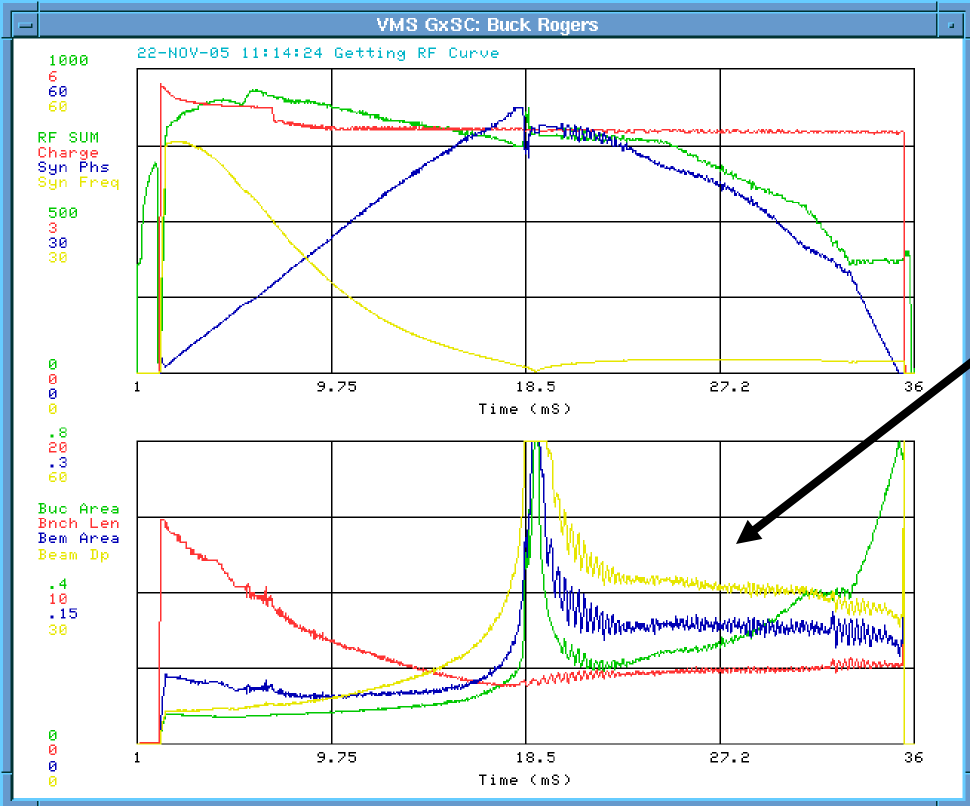
The LINAC energy is monitored by mixing two strip line detectors 50 m apart. A energy error results is a phase shift – shown as a voltage offset on the scope.

Wire scanner program that collects data from a fast scope. The software uses wavelets to reduce background noise. The software also has some basic fitting and analysis capabilities.



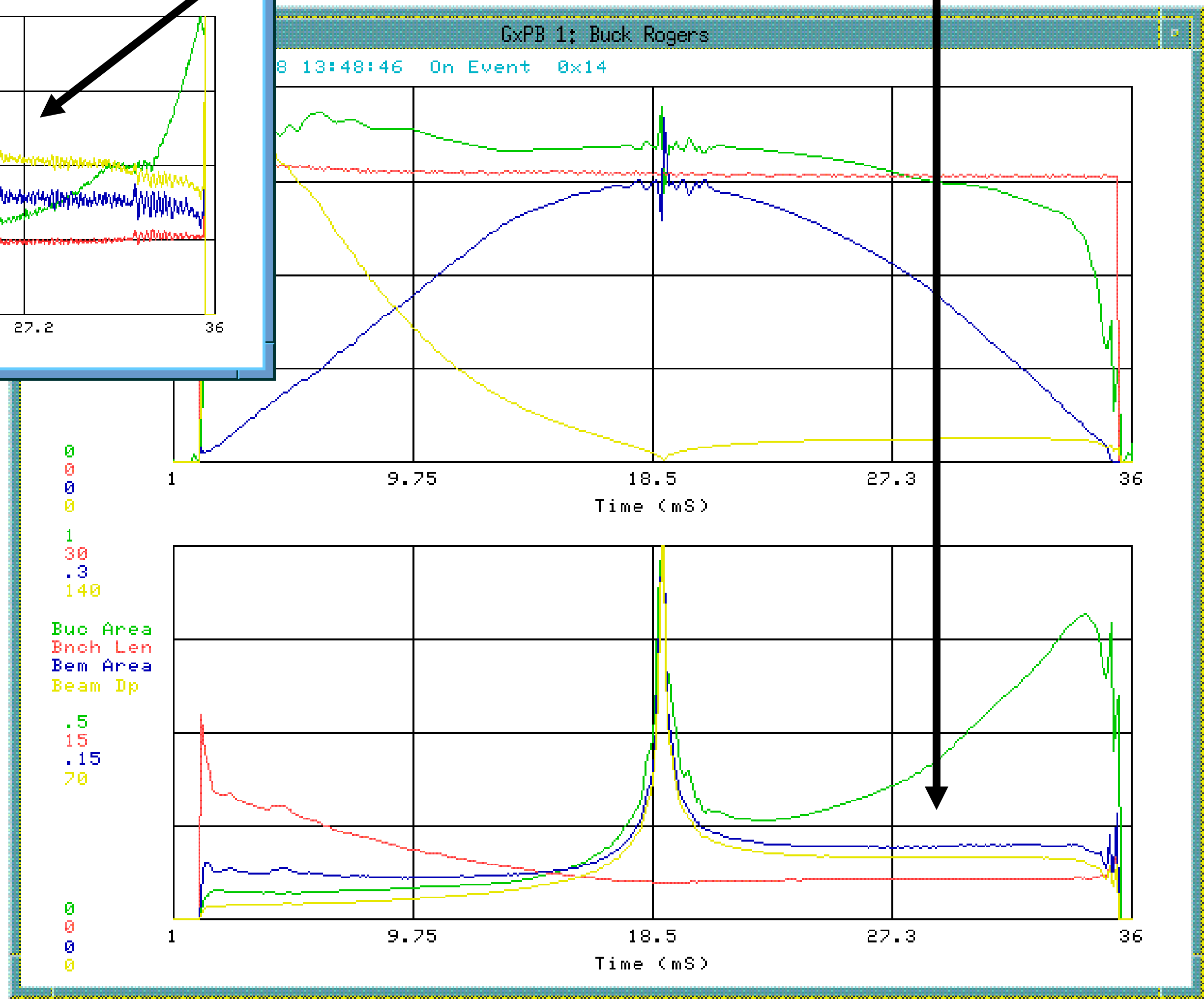
Injected beam moving from injected orbit to closed orbit



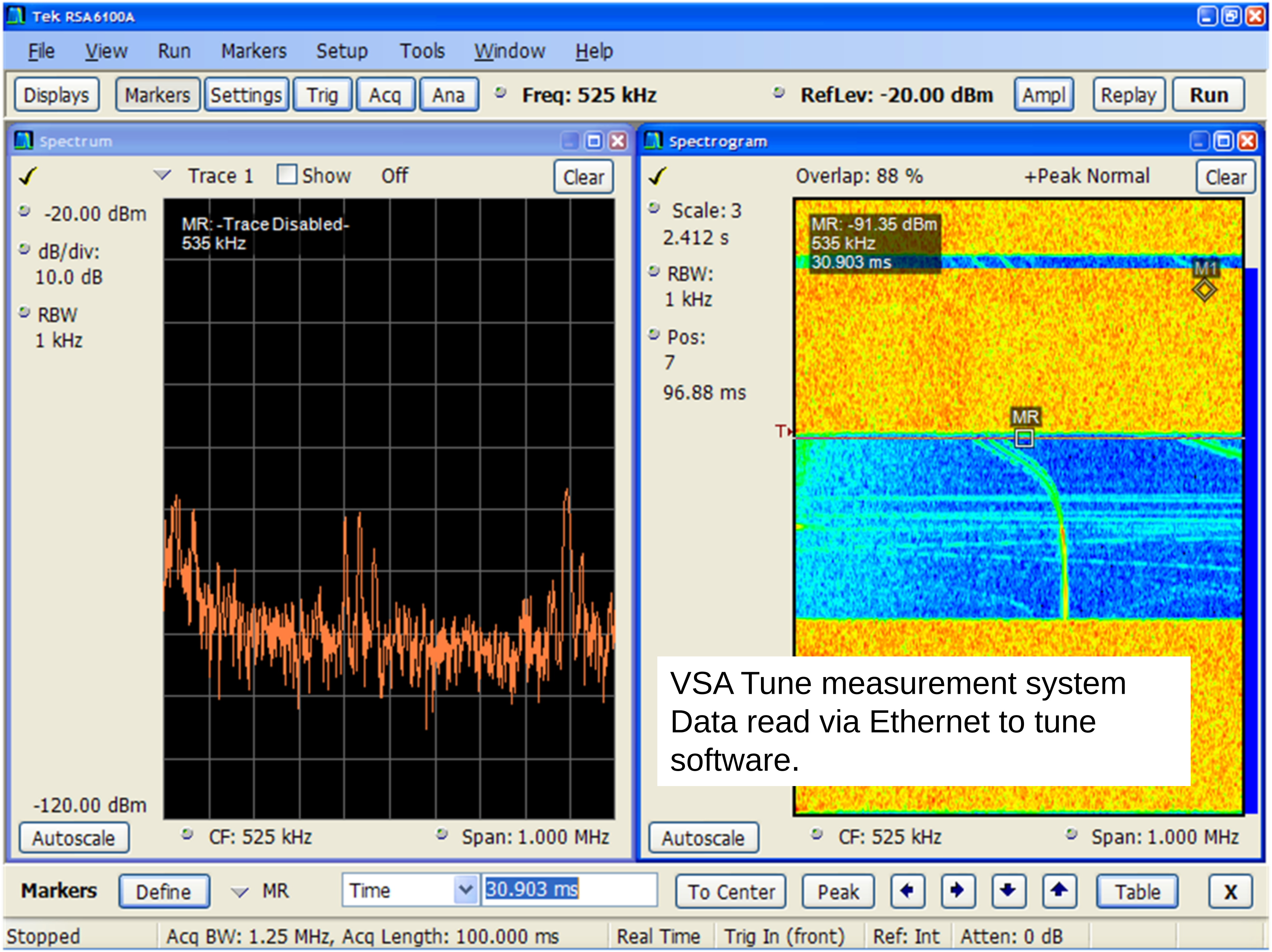


Longitudinal fuzz is due to mistuned transition and dampers.

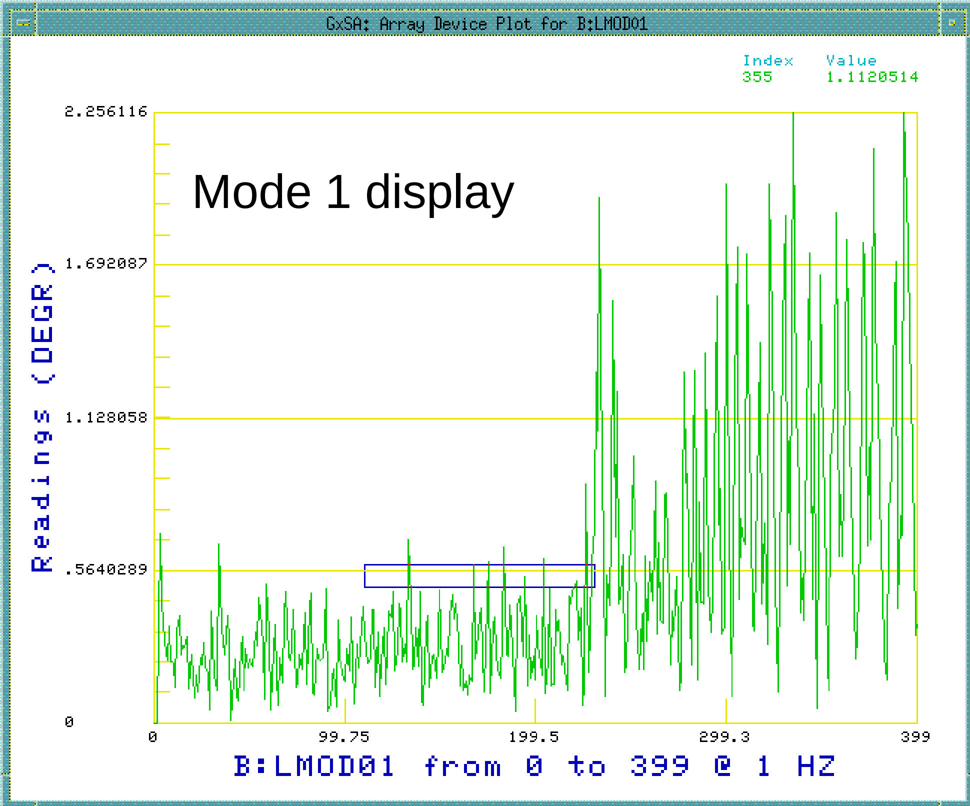
Reduced Bunch Length

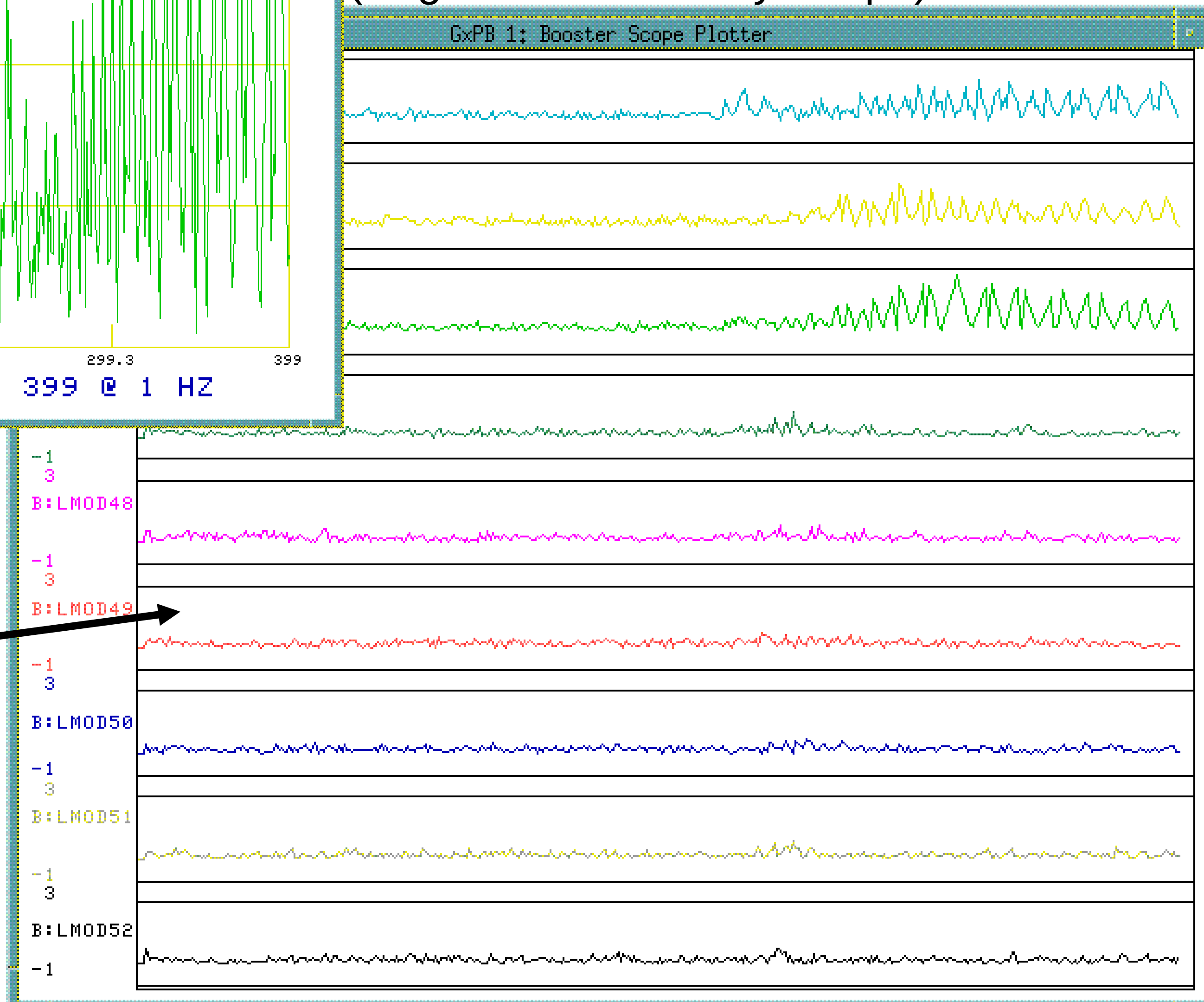


A diode detected signal and RF sum collected by an IRM displays calculated longitudinal parameters. Used to monitor quad and Longitudinal dampers performance.

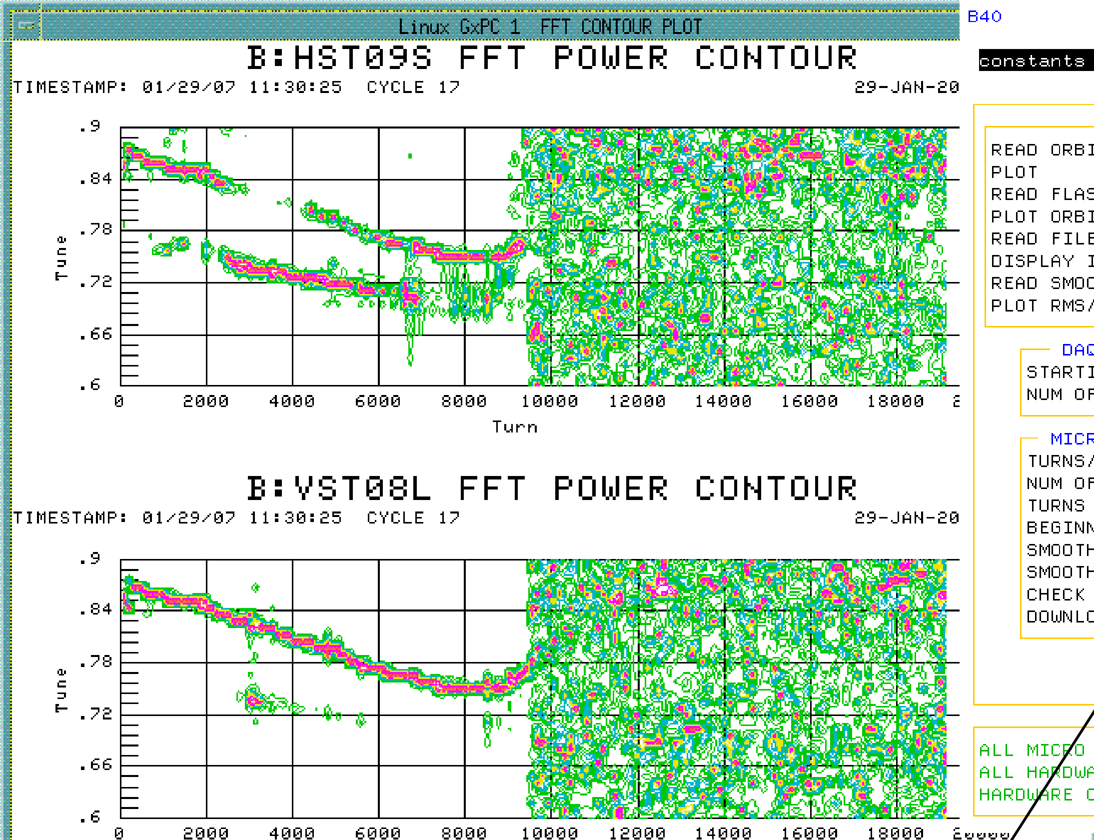

Tek RSA6100A
File View Run Markers Setup Tools Window Help
Displays Markers Settings Trig Acq Ana
Freq: 525 kHz
RefLev: -20.00 dBm
Ampl Replay Run
Spectrum
Trace 1
Show
Off
Clear
-20.00 dBm
dB/div:
10.0 dB
RBW
1 kHz
MR: -Trace Disabled-
535 kHz
-120.00 dBm
Autoscale
CF: 525 kHz
Span: 1.000 MHz
Spectrogram
Overlap: 88 %
+Peak Normal
Clear
Scale: 3
2.412 s
RBW:
1 kHz
Pos:
7
96.88 ms
MR: -91.35 dBm
535 kHz
30.903 ms
M1
MR
T
VSA Tune measurement system
Data read via Ethernet to tune
software.
Autoscale
CF: 525 kHz
Span: 1.000 MHz
Markers
Define
MR
Time
30.903 ms
To Center
Peak
Table
X
Stopped
Acq BW: 1.25 MHz, Acq Length: 100.000 ms
Real Time
Trig In (front)
Ref: Int
Atten: 0 dB

A fast digital scope running Labview collects data from a gap detector, RF sum and triggers from a mountain range trigger box. Longitudinal modes and bunch lengths are calculated and displayed. (Segmented Memory Scope)

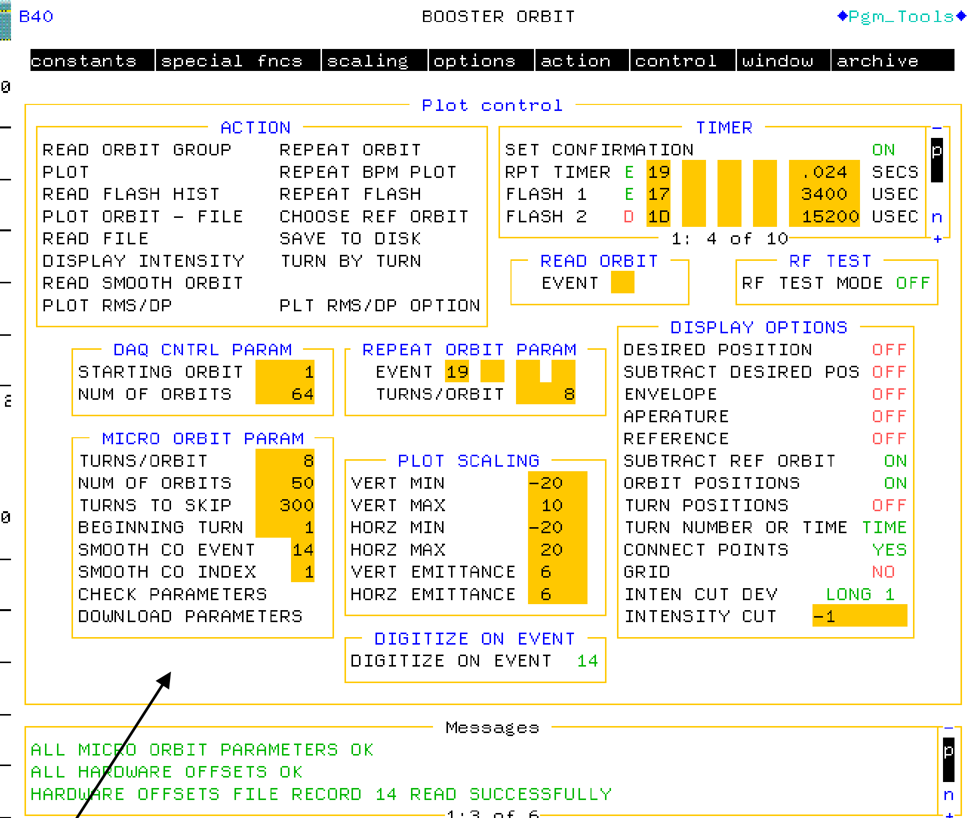


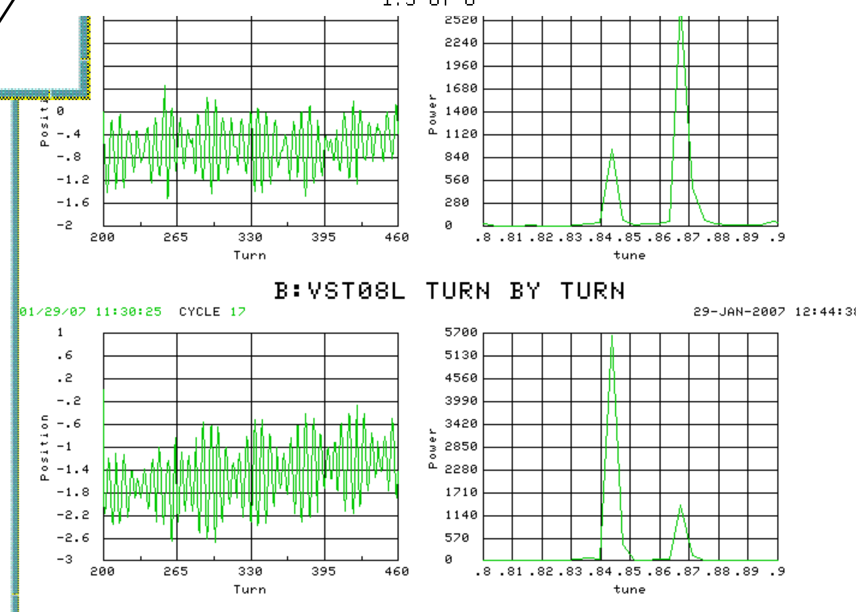


The software allows 9 mode plots or single mode display.



Pinged beam to transition



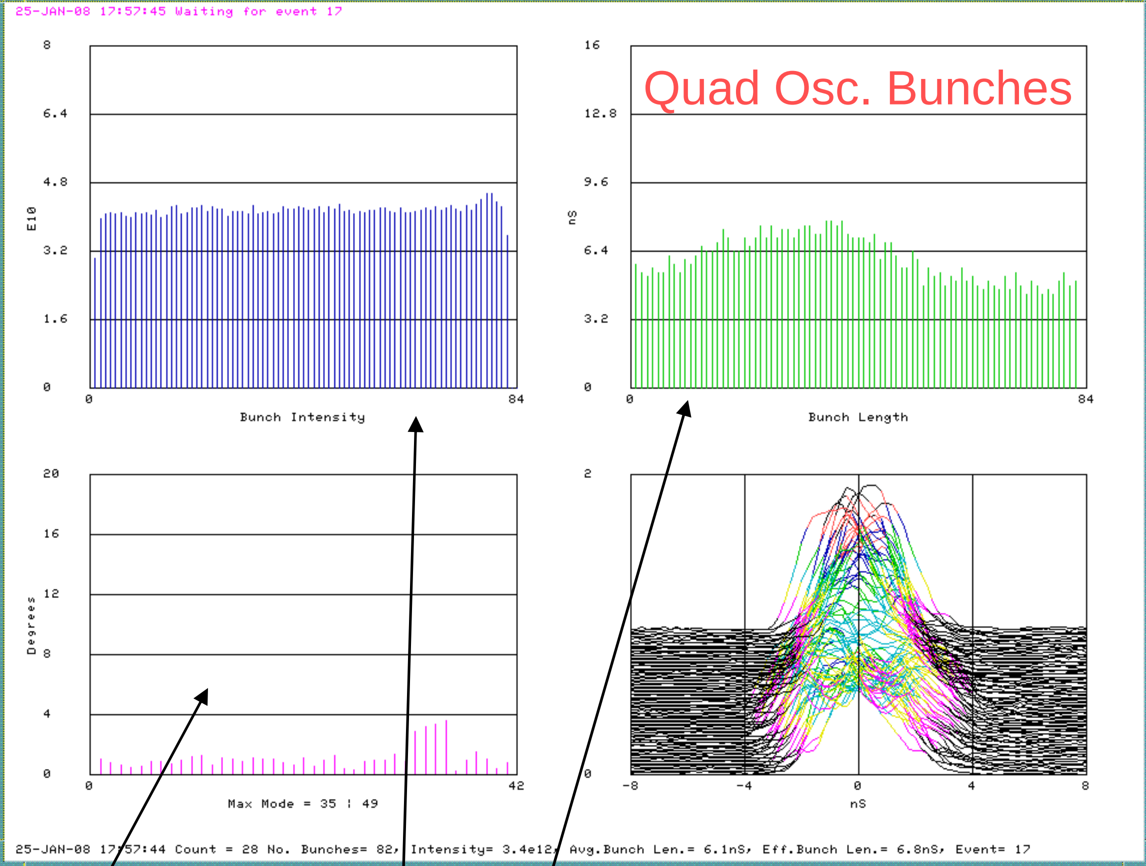


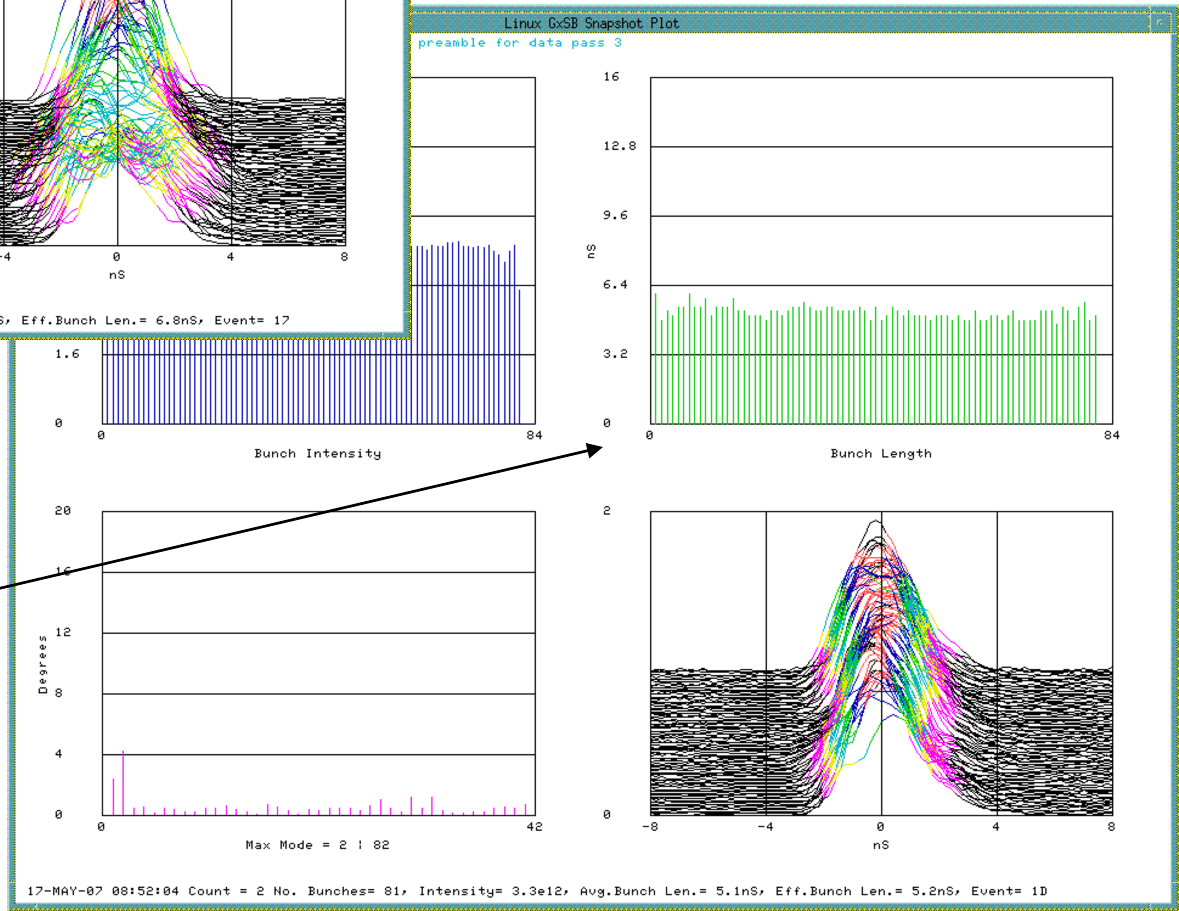
Every turn is saved and written to file on any Booster beam cycle.

Booster BPM software is used to measure orbits, tunes and coupling.

Automated data collecting every night on all cycles. Used for orbit smoothing with monitoring/alarm capabilities.

Application that collects data from a fast scope that digitizes a gap detector in the MI-8 line.
The software analyzes the bunches and calculates longitudinal modes, bunch – intensity, length and phase
The software can display the data In several forms (Mtn. Range, Contour…)





Mode Line

Bunch Intensity

Bunch Length

New software/hardware < 2yrs

- Fast digitizing cards
  - BLM card
    - 15 Hz capabilities
  - Pulse stretcher
    - All pulsed devices – bdot probes with circular buffers
    - Snapshot plots
- Very fast digitizers with large FPGA
  - Damper systems
    - Transverse just tested
    - Longitudinal next step
- New Correctors/BPM
- HRM's being installed
  - All BPM's can be read turn by turn
  - At present only BPM's in the extraction region are read and data logged at a turn by turn rate.
- Booster LL system VXI based system is being designed using DSP designs embedded in FPGAs

Contributions

- Bill Ashmanskas FNAL
- Craig Drennan FNAL Proton Source
- Jim Lackey FNAL Proton Source
- Peter Kasper FNAL
- Bill Marsh FNAL Controls
- Dave McGinnis FNAL
- Brian Schuphach FNAL Operations
- Alex Waller FNAL Proton Source
- Bob Webber FNAL
- Bob Goodwin FNAL Controls