FNAL Linac
Beam Status

Proton Source Workshop

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Proton Source Department
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X 3798

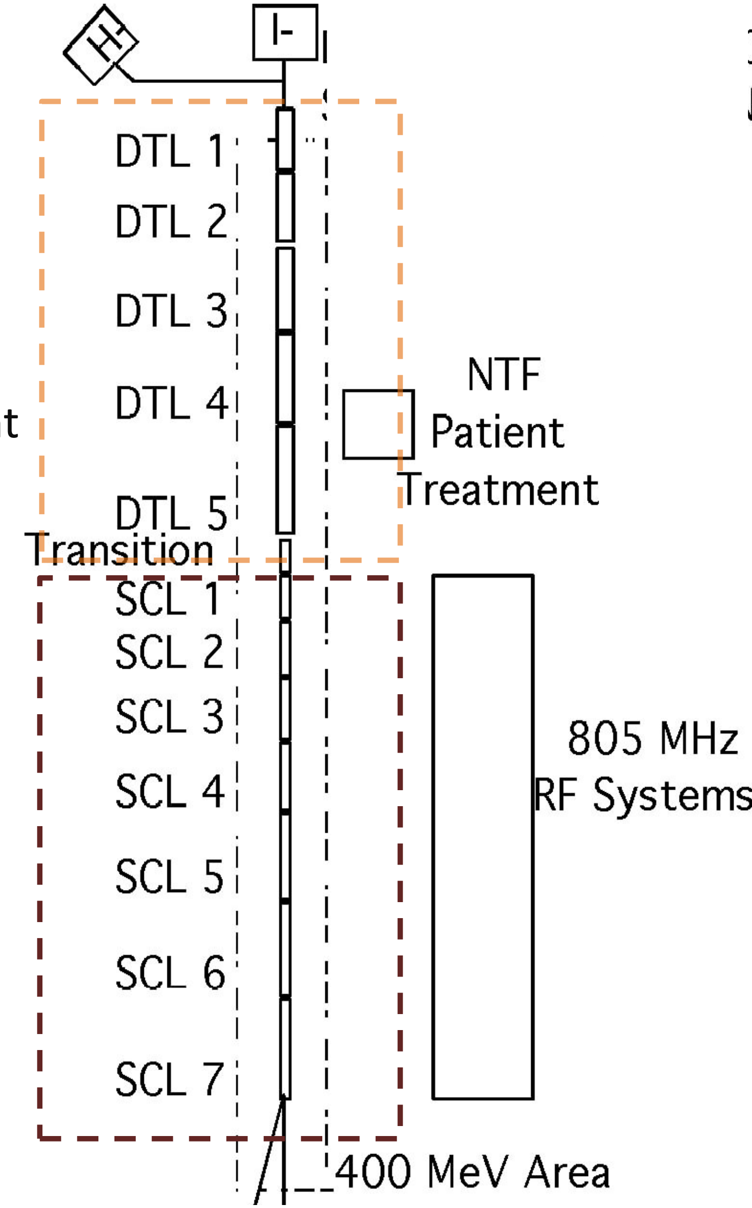
Outline

- Introduction to 400MeV Linac
- Low Energy Linac
- High Energy Linac
- Operations Overview
- Radiation Issues
- Operational Concerns
- Summary

Introduction to Linac

- Linac has been in operation since 1970
  - ~ 90% availability
- Linac operates at 15 Hz
  - NTF takes spare cycles when available
  - Management decision: priority during treatment
- There are two difference sections:
  - 201.25 MHz Low Energy (LE) (β < 0.45)
  - 805 MHz High Energy (HE) (0.45 < β < 0.71)
- There are two 750 keV injectors (I^-/H^-)
  - 80 μsec beam pulse @ ~ 50 mA peak current
- Linac accelerates beam only when requested
  - Normal operation

  34-mA macropulse average current
    - HEP: ~ 7.0 Hz, 22.2 μsec macropulse length
    - NTF: 15 Hz, 64.0 μsec macropulse length
    - Studies: up to 15 Hz, 20 μsec macropulse length
    - MTA: variety of beam demands

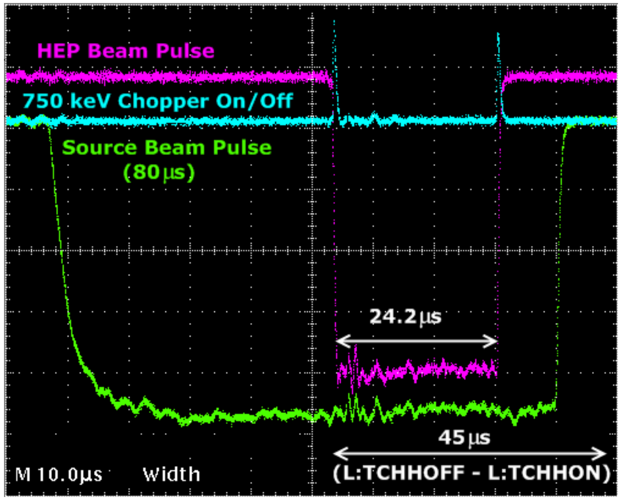


Beam transmitted through Linac

- HEP/Studies/MTA beam pulses are requested by the Beam Switch Sum Box (BSSB) from MCR

- Request is received by the Beam Enable Pulse Shifter Chassis
  - if all the requests/status are in order beam is transmitted to Linac
  - if not source timing is shifted 1msec and beam dies at Tank 1.

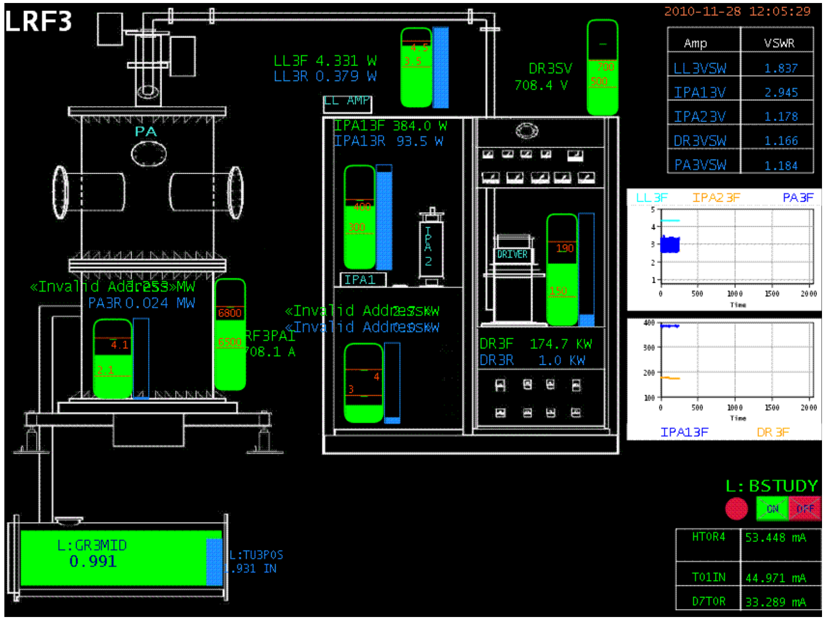
- In the case of HEP, beam is chopped by the low energy (750 keV) and high energy (400 MeV) chopper systems.

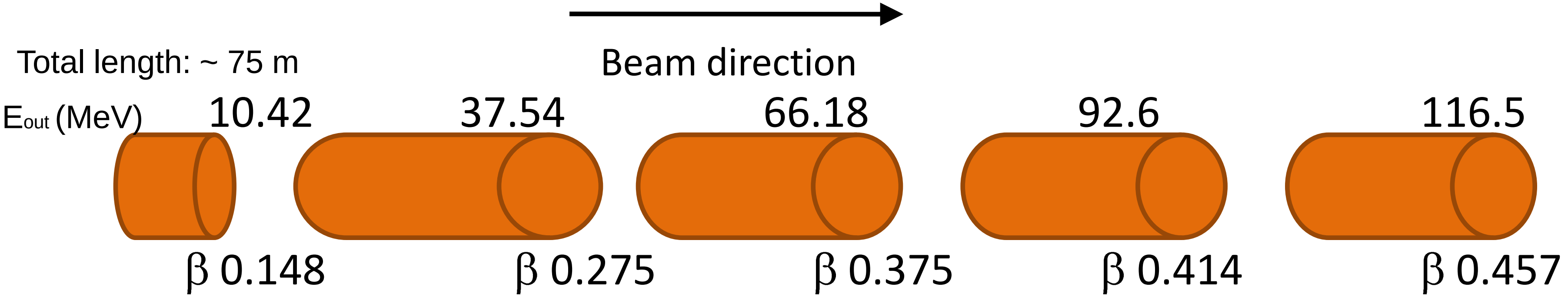


Introduction to Linac - LE Linac (DTL)

- 5 cylindrical, electrical resonant, OFHC cavities,
- ~ two thirds of 200 DTs are located at the low-β region,
- Each cavity is powered by a single 5MW PA @ 201.25 MHz

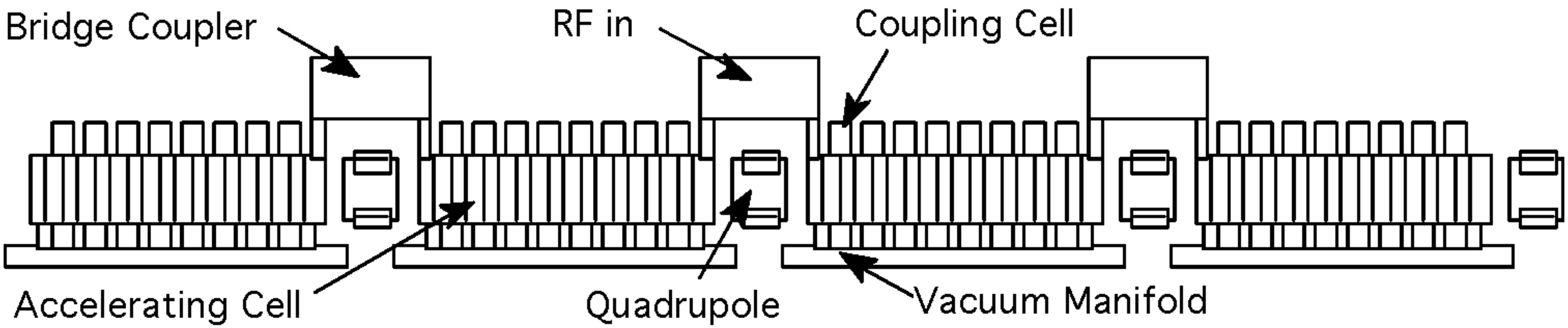
  ~ 1.5 MV/m with an Average Power 20 KW
- Space between tanks are occupied either by beam valves, dipole trim packages or beam position monitors.





Introduction to Linac - HE Linac (SCL)

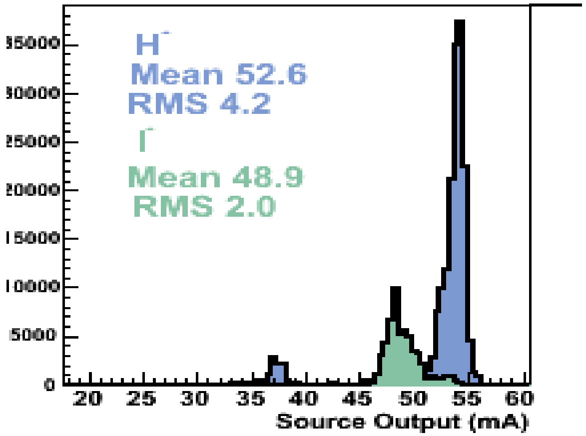
7 805 MHz SCL modules, 4 sections with 16 accelerating cells, independent 12 MW Klystrons @ ~7.0 MV/m

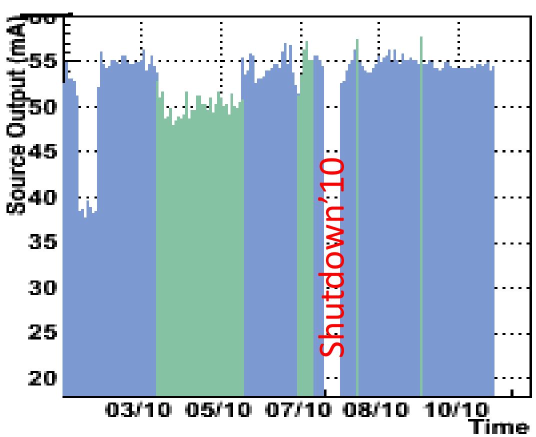


Beam Operations

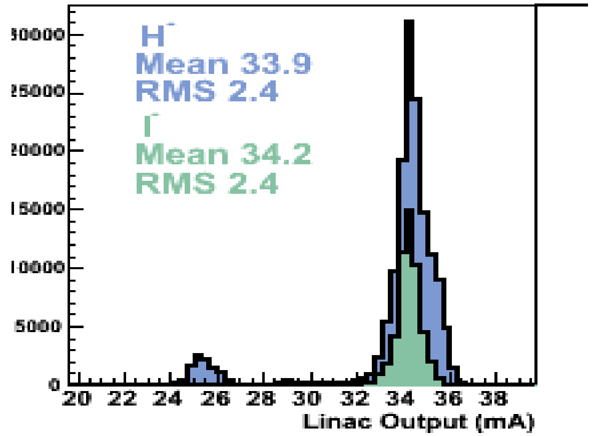
Operational Beam Parameters (2010)

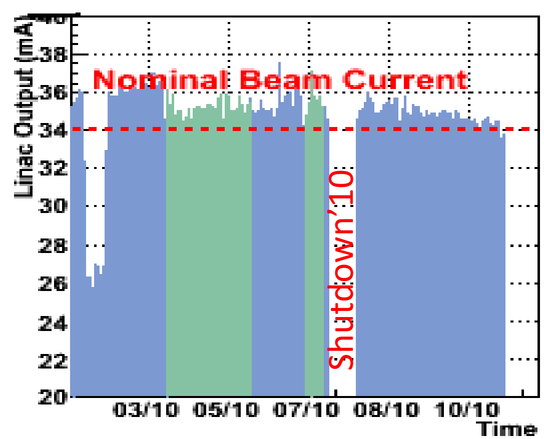
Source Output



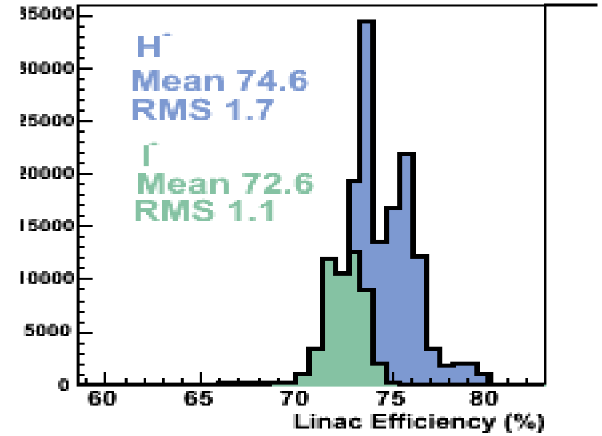


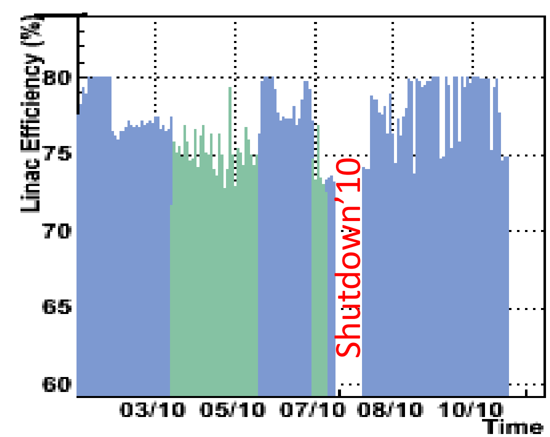
Linac Output



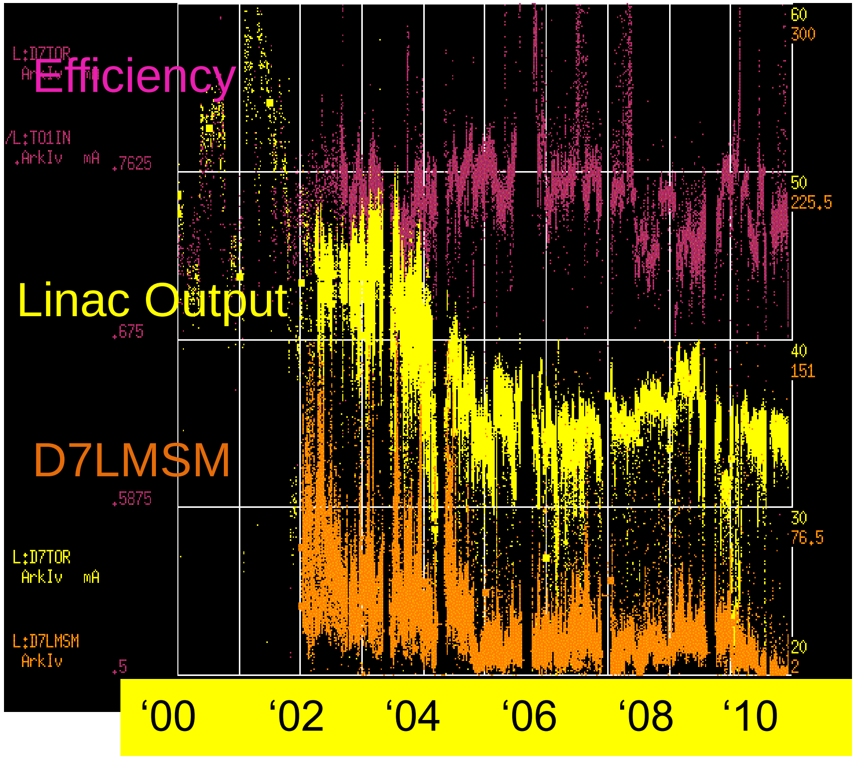


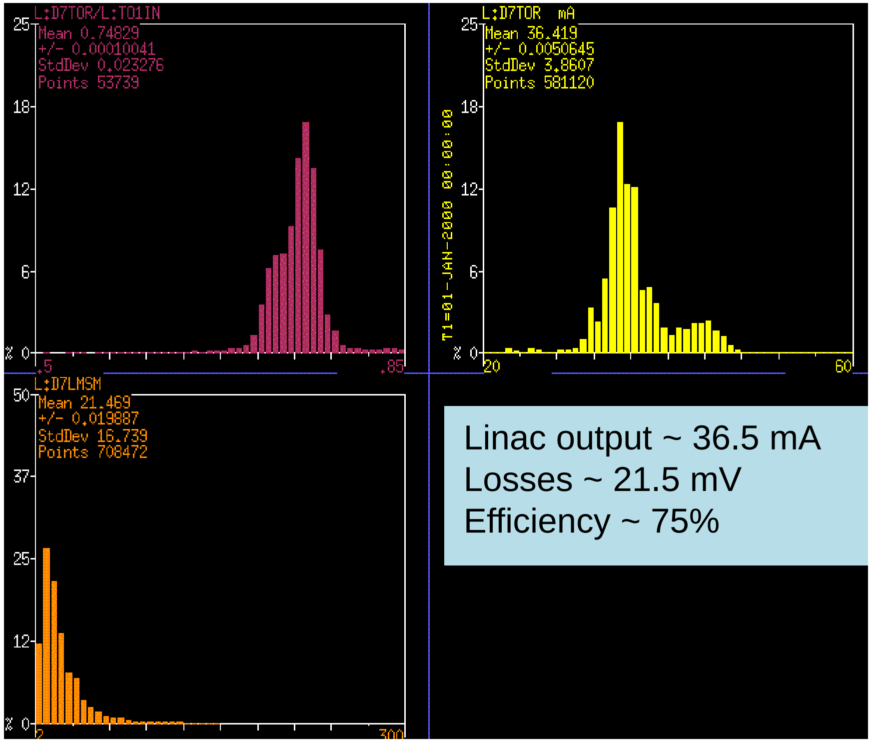
Linac Efficiency





Operational Beam Parameters (2000-2010)

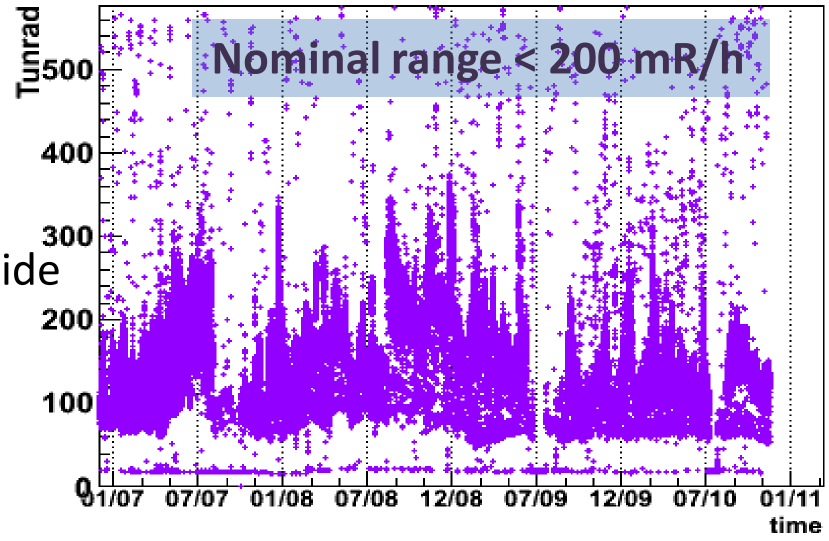


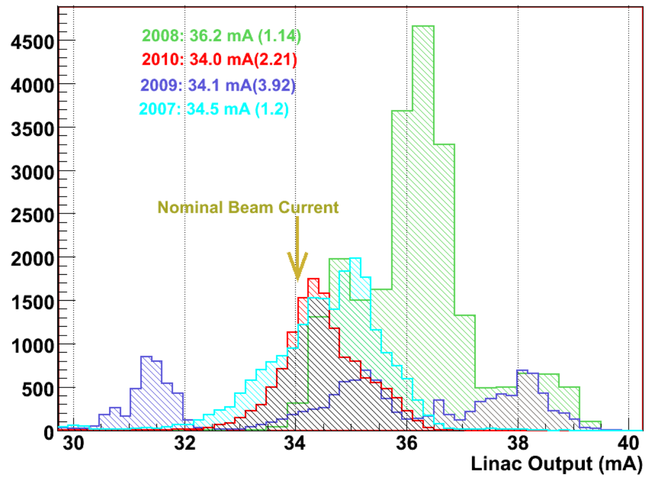


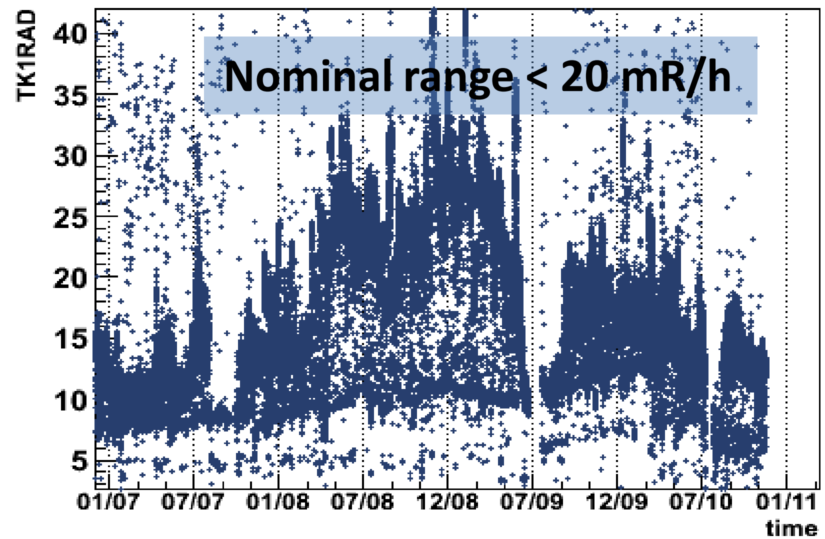
Linac output ~ 36.5 mA
Losses ~ 21.5 mV
Efficiency ~ 75%

LE Beam losses

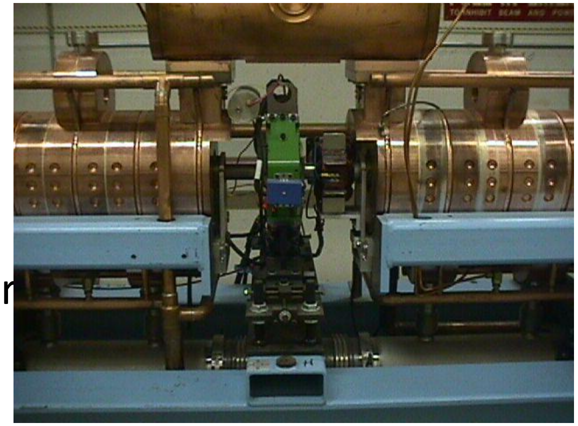
- Remnant radiation at energies < 10 MeV is negligible.
- **TK1RAD** and **TUNRAD** are chipmunks located inside the Linac tunnel by TK1 and TK4-5 respectively.
  - Daily tuning to minimize these devices while maintaining the required Linac output.
  - There is other instrumentation (chipmunks) in Linac. Minimizing these at the front end produce positive results through out the low energy region.



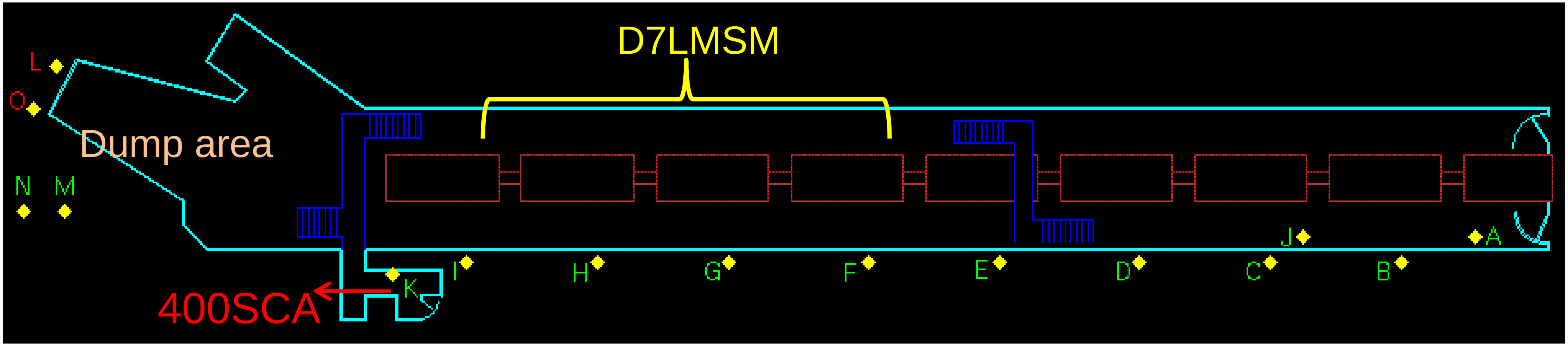




HE Beam Loss Monitoring



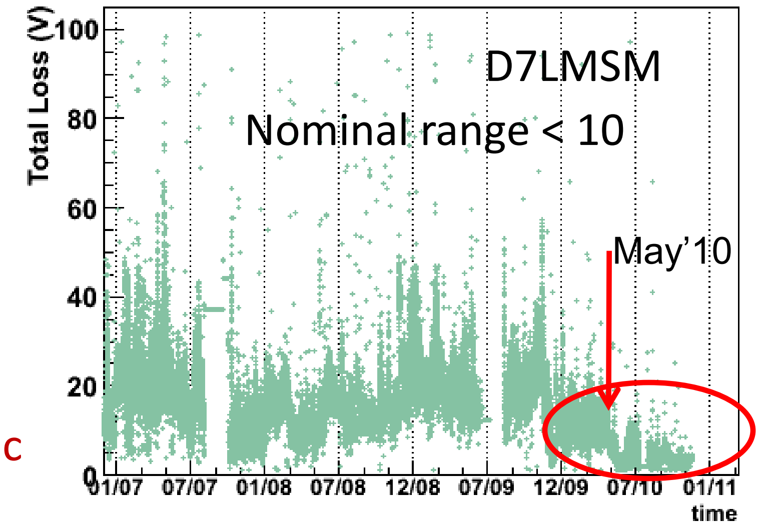
- SCL cavities
  - Loss monitors are located between each module section
  - **D7LMSM** is a sum of the readings of 36 loss of the monitor
- 400 MeV Area
  - **400SCA** is a chipmunk located at the entrance of the 400MeV area (labyrinth)
  - There are also loss monitors located in the dump line area

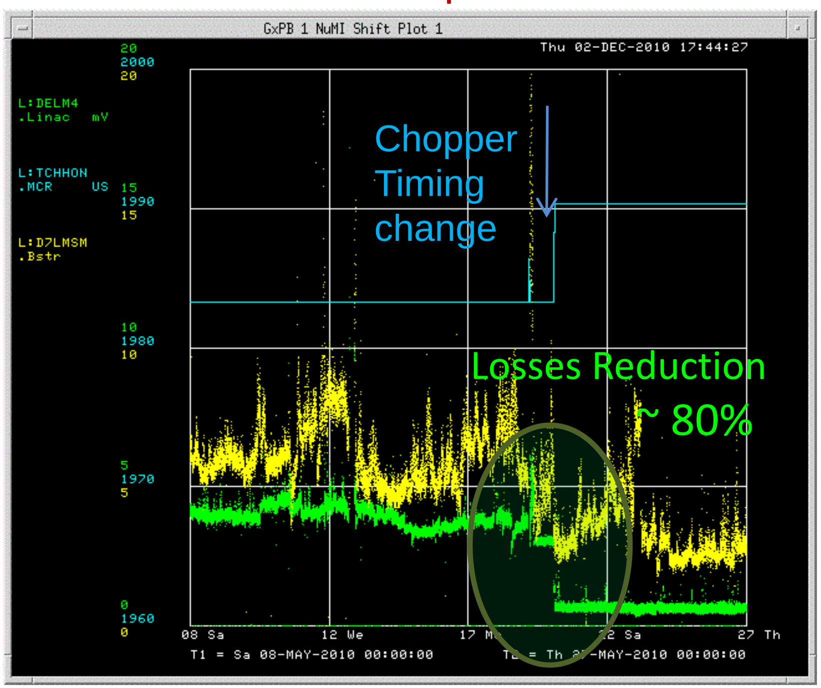


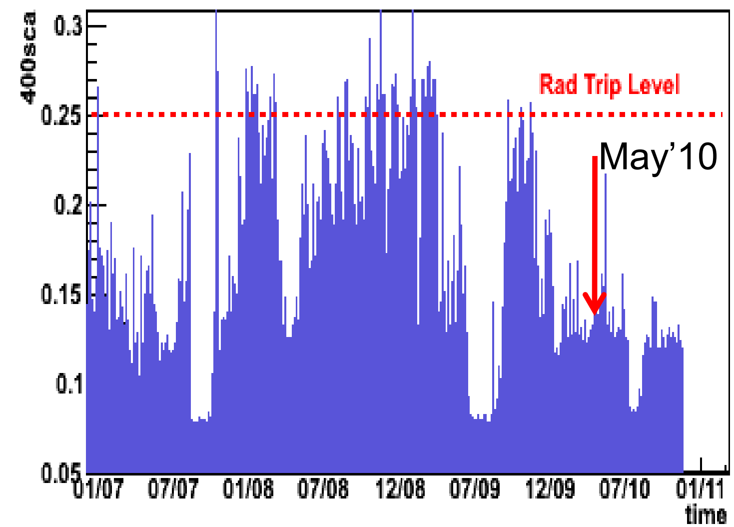
HE Beam losses

- Proton Plan funded an important project for Linac, the LE LLRF Upgrade
  - Improve amplitude regulation
  - Provide phase stability and
  - Reduce beam losses

Beam sent to dump was reduced from 10 to 2 μsec

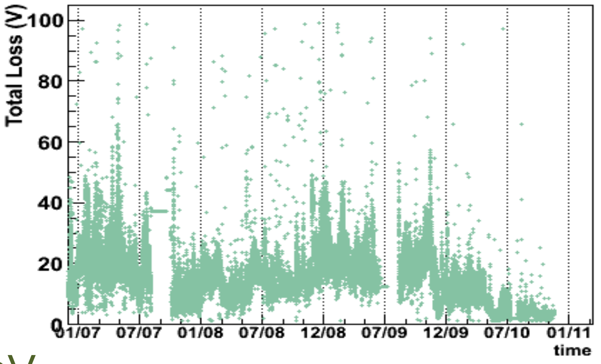






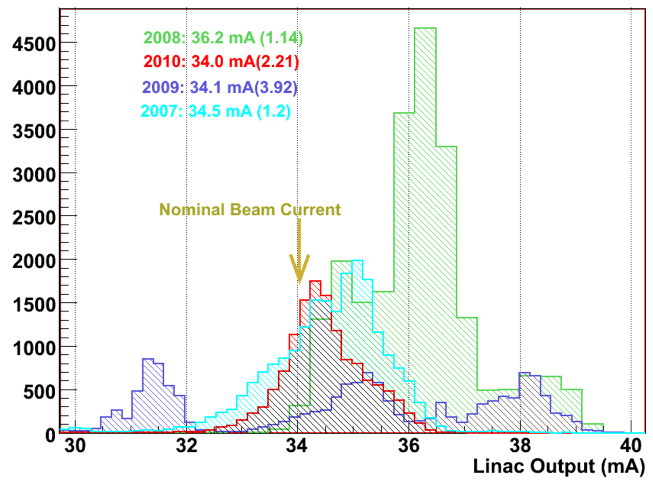
HE Radiation issues

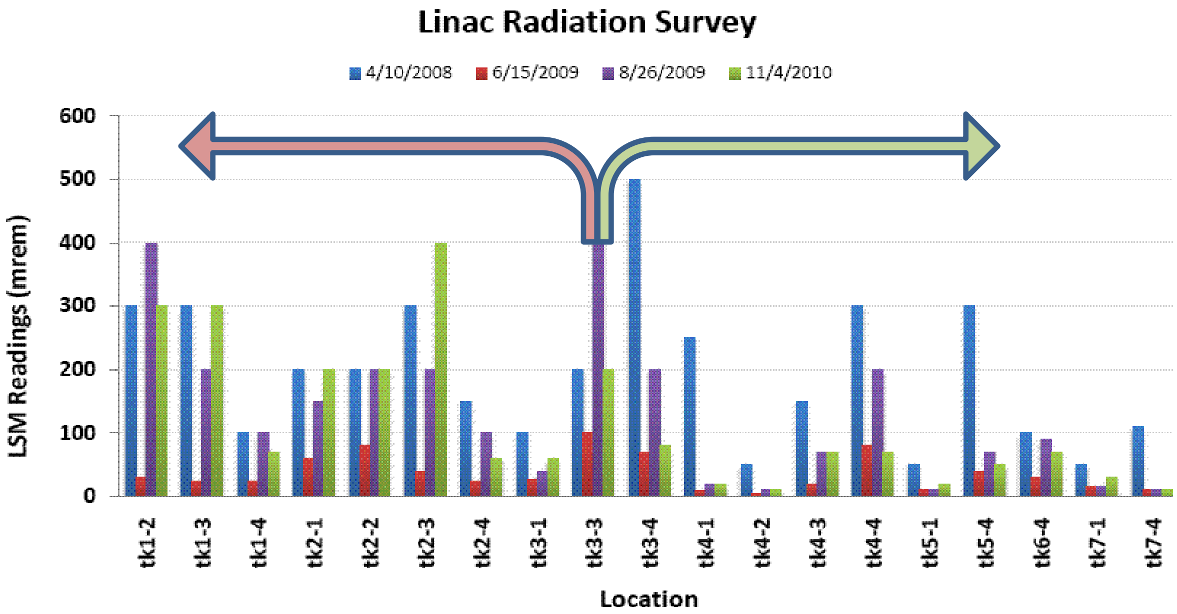
During the rare occasion of access in Linac, a radiation survey has regularly been performed since 2008.



SCL front end remains unchanged

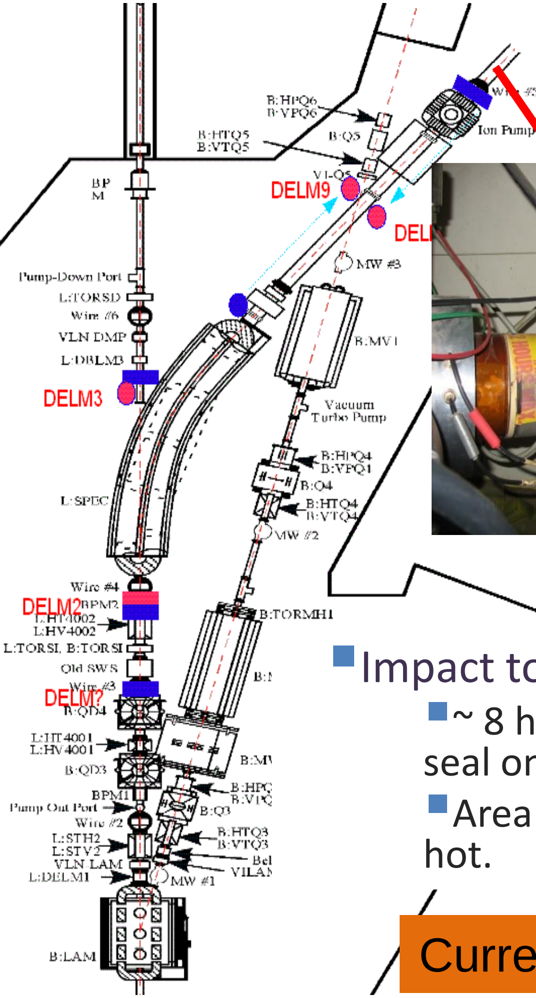
Improvement in equipment activation at region > 230 MeV

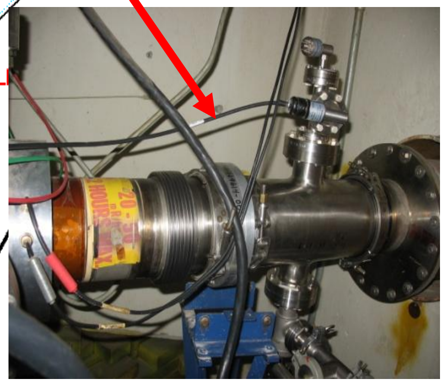




Operation Concerns I

Momentum Dump Vacuum





Quick background

A leak developed in the Linac Momentum dump in Dec'07. A Ti window was installed to isolate the rough vacuum at the dump from the beamline vacuum.

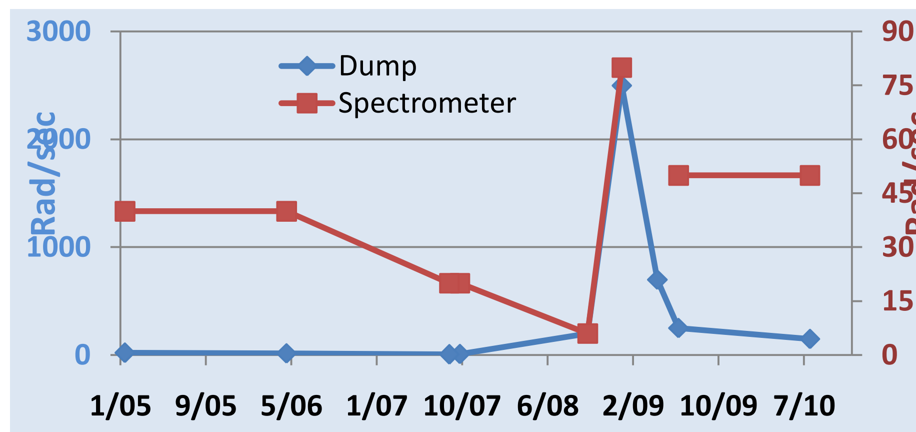
Vacuum at the momentum dump area started degrading on January 7th, 2009. Suspect the original leak got worse.

A Working Group was initiated in Feb'09 to formulate a long term solution for the Linac dump#2 area.

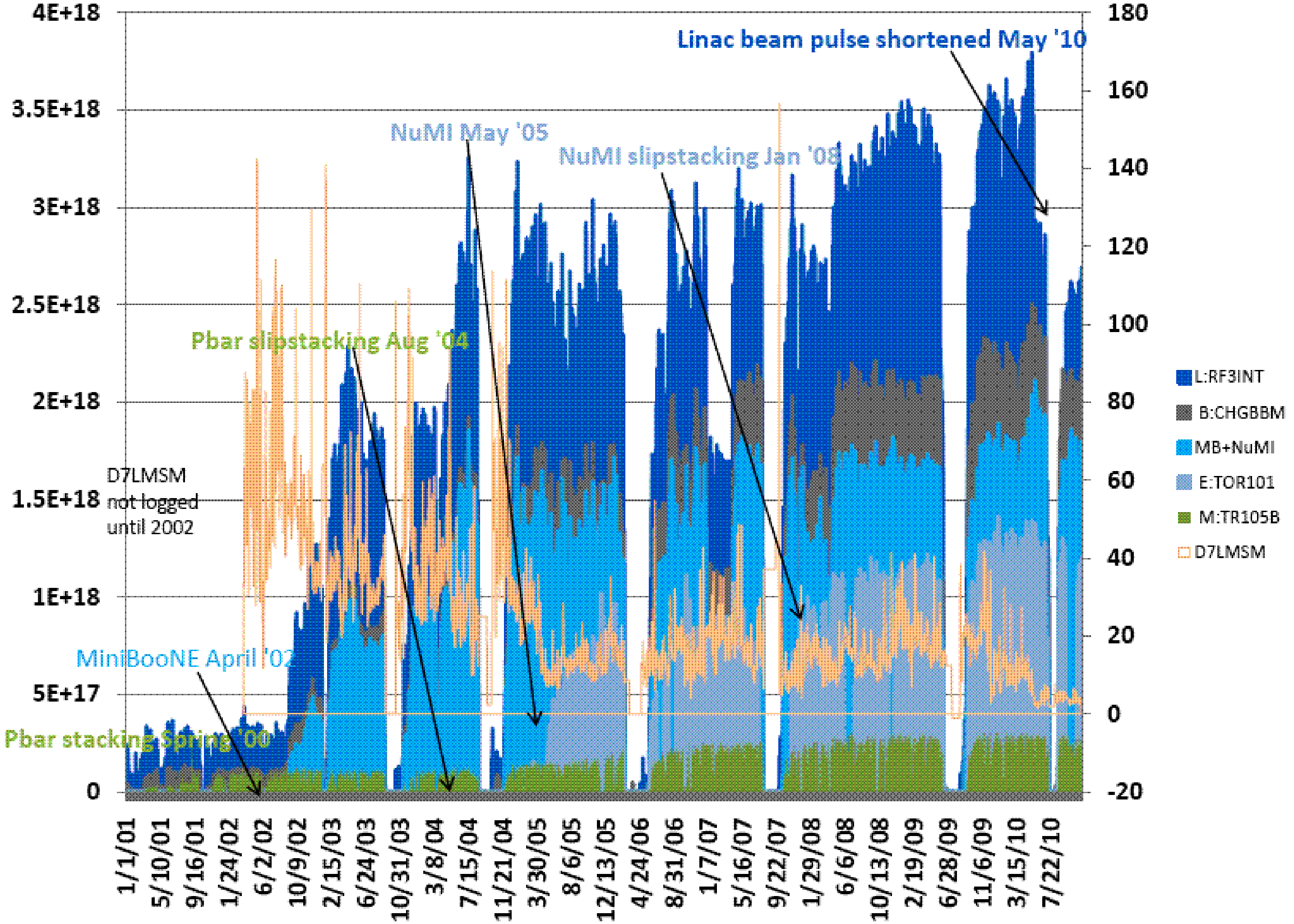
See R. Reilly's talk at this WS.

- Impact to Operations:
  - ~ 8 hrs downtime when the seal on the window failed
  - Area became radiological hot.

Current Eff: > 90%



Beam throughput over the past decade



Final Remarks

- All protons for the laboratory program until Project X comes online depend on this machine
- 200 MHz Linac and some power systems are 40 years old
- Linac runs at 15Hz regardless of beam demand or not
  - Current HEP rate is ~ 7.0 Hz
- Present RF power availability is not a limitation for 15 Hz operations
  - @ 15 Hz Average RF Power is ~ 20 KW
    - 7835 max plate dissipation : average=150KW
- Concerns going to 15 Hz
  - Activation levels
  - 201 MHz system reliability?
    - How much will the modulator failure/downtime increase?

BACKUP SLIDES

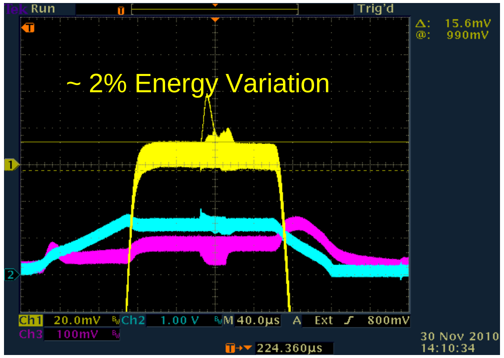
Operation Concerns

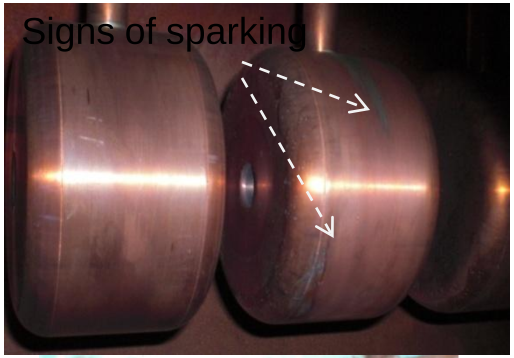
Operation Concerns I

Oscillations in Tank 1

- Tuning Slug possibly contributing to oscillations. Why?
  - Years ago the finger stock/spring ring was removed due to concerns that is was causing sparking in the cavity and causing the tuning slug to bind and wearing out the drive screw.
  - Absence of finger stock/spring ring may allow slug to vibrate

- Shutdown 2010: Re-Install contact finger stock/spring ring
  - Plan was developed using existing drawings of the tuner slug and port.
  - Installed system has different port as stated on the drawings.
  - Work was not complete. Back to white board...

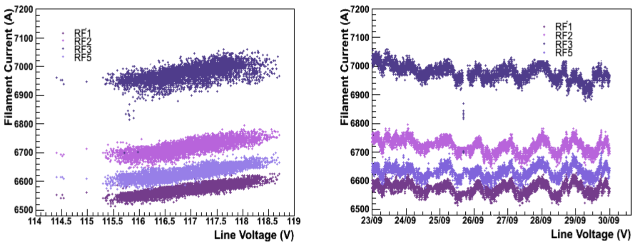


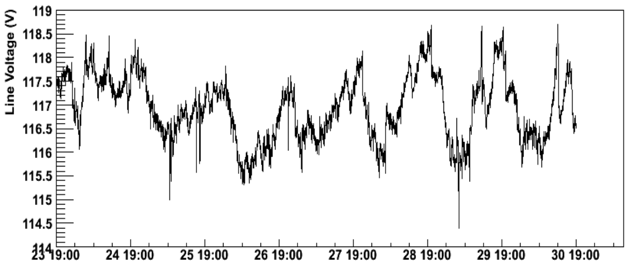


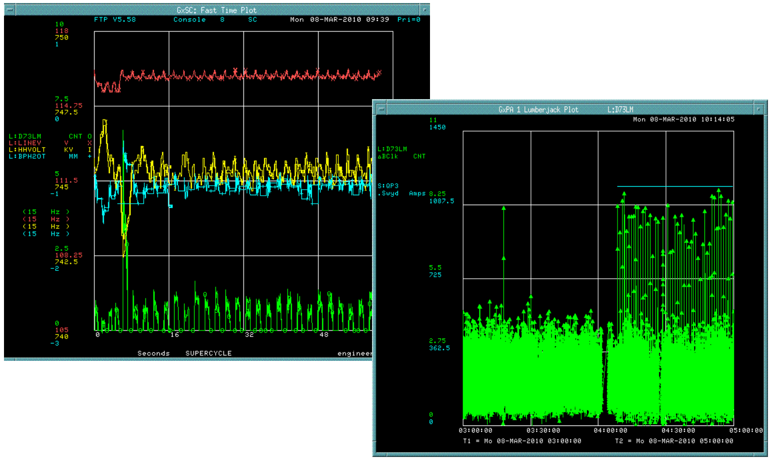
July 17, 2010

Operation Concerns II

Line Voltage Sensitivity







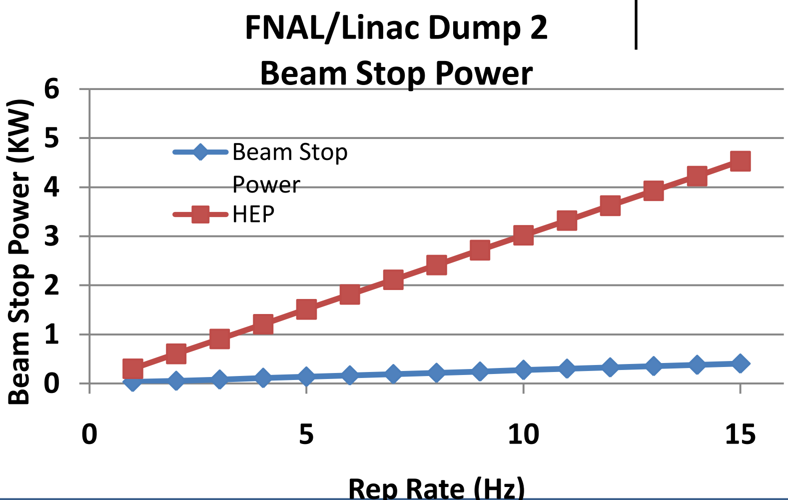
- Direct effects on Linac equipment from line voltage variation are observed in low energy PA filament currents
  - Results in operating the filaments at a higher current than necessary and reducing tube lifetime.
  - Possible mitigation: New regulation system
    - See T. Butler’s talk

- Large variations effect Haefley High Voltage changing the source output energy
  - Triggered by SWYD ramp event
  - Linac beam loss increase

+/- 1% day/night variation

Linac Running at 15 Hz

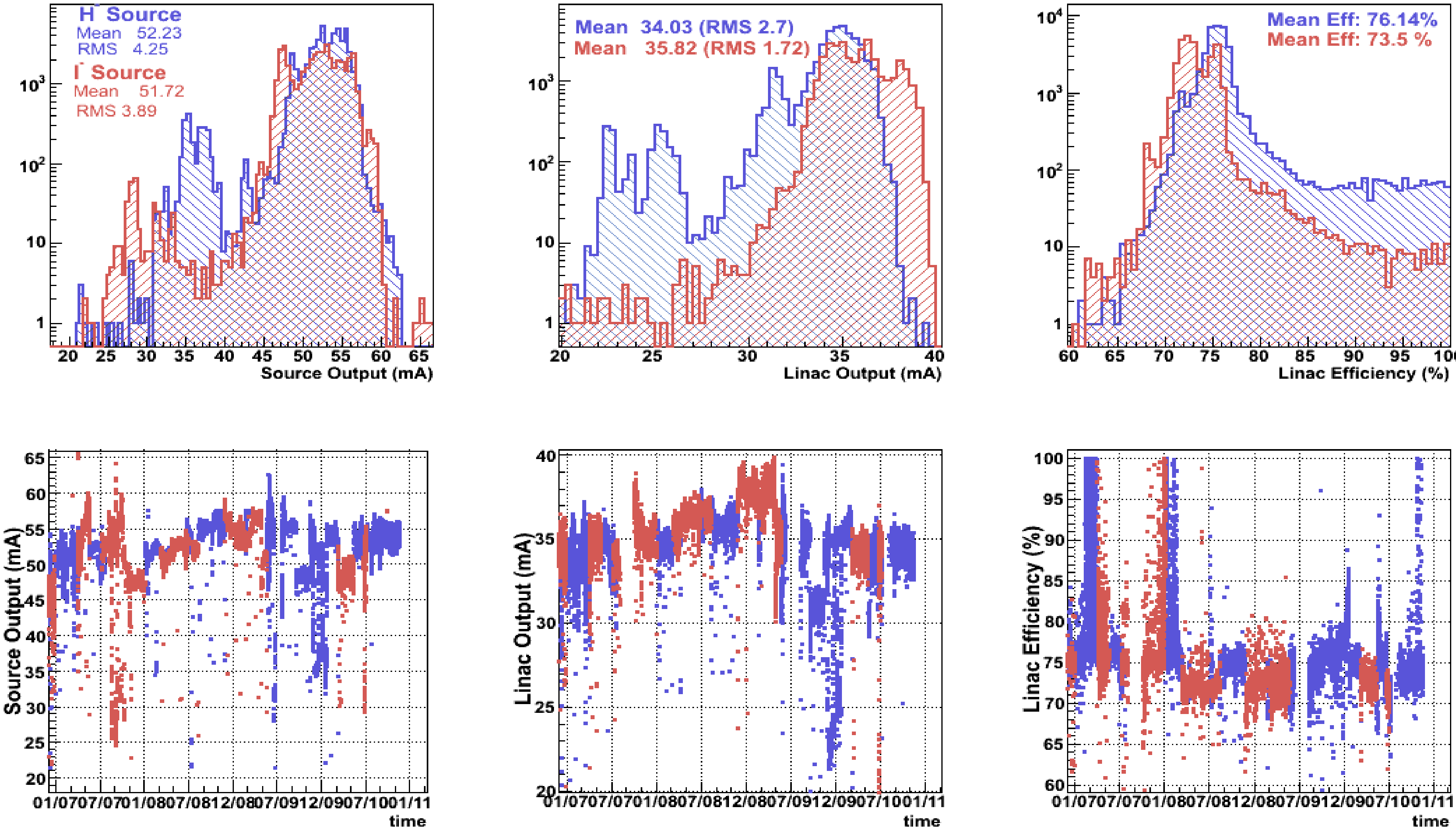
LINAC PARAMETERS	Beam to HEP		Beam to Dump	
Linac Peak Current	34	ma	34	mA
Linac HEP Pulse Repetition Rate	15	Hz	15	Hz
Linac HEP Beam Width	24	usec	2	usec
Linac HEP Particles per pulse	5.1E+12	ppp	4.25E+11	ppp
Linac HEP Particles per second	7.65E+13	pps	6.375E+12	pps
Linac HEP Particles per hour	2.754E+17	pph	2.295E+16	pph
Linac HEP Peak Beam Power	4.896	kW	0.408	kW
Linac HEP Peak Beam Power	0.3264	kJ	0.0272	kJ



Cavity number	**Units**	**1**	**2**	**3**	**4**	**5**
Proton Energy In	MeV	0.75	10.42	37.54	66.2	92.6
Proton Energy Out	MeV	10.42	37.54	66.18	92.6	116.5
β Proton velocityOUT of Tank	0.04 into Tk1	0.148	0.275	0.375	0.414	0.457
Cavity Length	m	7.44	19.02	16.53	16.68	15.58
Cavity Diameter	cm	94	90	88	88	84
Drift-Tube Diameter	cm	18	16	16	16	16
Bore-Hole Diameter	cm	2.0 - 2.5*	3	3	3	4
Cell Length (L) (First cell)	cm	6.04	12.2	41.1	53.3	61.8
Cell Length (L) (Last cell)	cm	21.8	40.8	53	61.5	67.9
Gap Length (G) (First cell)	cm	1.3	4.4	12.2	19.5	22.6
Gap Length (G) (Last cell)	cm	6.7	12.7	19.3	25.1	26.9
G/L (First cell)		0.21	0.2	0.3	0.37	0.37
G/L (Last cell)		0.31	0.31	0.36	0.41	0.4
Axial transit-time factor (First Cell)		0.64	0.86	0.82	0.75	0.73
Effective Shunt Impedance (First cell)	Mohm/m	27	53.5	44.6	35	29.6
Effective Shunt Impedance (Last cell)	Mohm/m	47.97	44.8	35.2	28.5	25
Drift Space Following Cavity	m	0.22	0.6	0.75	1.175	0.825
Number of Full Drift Tubes		55	59	34	28	23
Average Axial Field	MV/m	1.60-2.31	2	2.6	2.6	2.56
Average Gap Field (First cell)	MV/m	7.62	10	8.7	7.03	6.9
Average Gap Field (Last cell)	MV/m	7.45	6.45	7.2	6.3	6.4
Peak Surface Field (First cell)	MV/m	8.9	12.6	13.1	12.9	14
Peak Surface Field (Last cell)	MV/m	10.2	9.7	12.9	13.2	14.1

LINAC PARAMETERS	Capable of	TYPICAL
Linac Peak Current	52ma	34mA
Linac HEP Pulse Repetition Rate	15Hz	7.5Hz
Linac HEP Beam Width	10usec	24.2usec
Linac HEP Particles per pulse	3.25E+12ppp	5.14E+12ppp
Linac HEP Particles per second	4.88E+13pps	3.86E+13pps
Linac HEP Particles per hour	1.76E+17pph	1.39E+17pph
Linac HEP Beam Power	3.12kW	2.47kW
Linac Study Pulse Repetition Rate	15Hz	3Hz
Linac Study Beam Width	20usec	20usec
Linac Study Particles per pulse	6.50E+12ppp	4.25E+12ppp
Linac Study Particles per second	9.75E+13pps	1.28E+13pps
Linac Study Particles per hour	3.51E+17pph	4.59E+16pph
Linac Study Beam Power	6.24kW	0.82kW

Beam Parameters (Dec'06-Dec'10)



All Experimenters Meeting
April 20th 2009

Linac Low-Level RF Upgrade

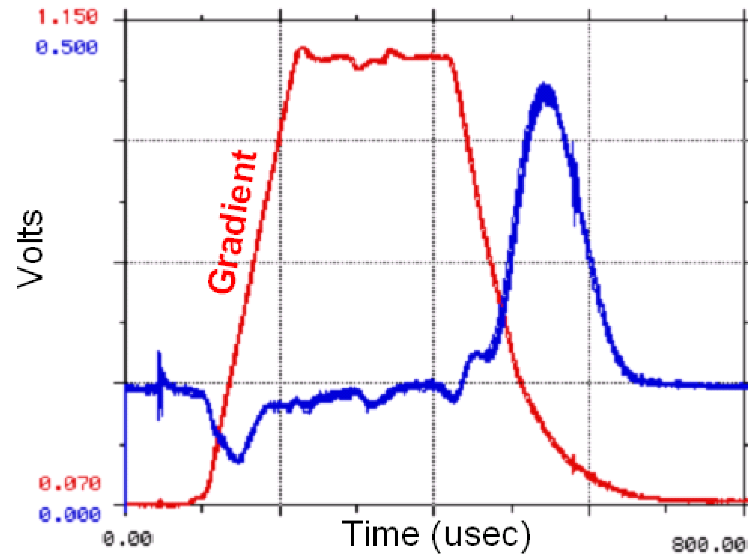
Presenters: Ed Cullerton (AD/RF Dept)
& Trevor Butler (AD/Proton Source Dept)

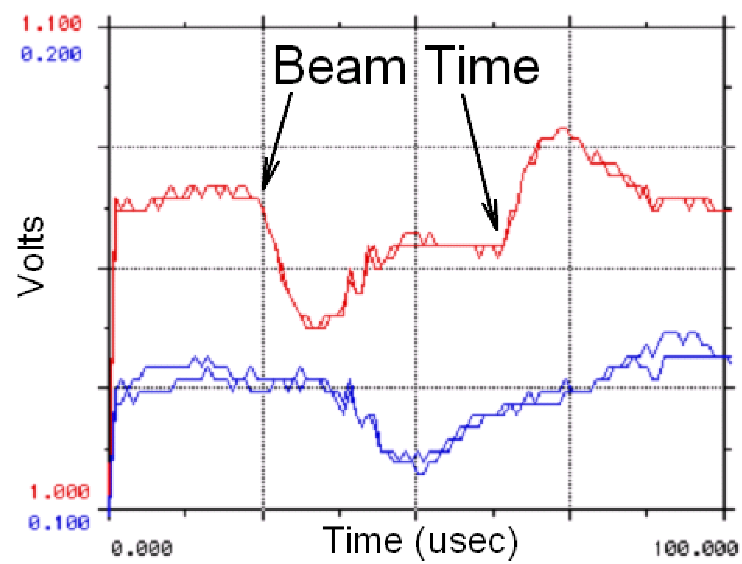
Contributors: Larry Allen, Fernanda Garcia (AD/PS),
Brian Chase, Paul Joireman,
Vitali Tupikov, Philip Varghese (AD/RF),
Michael Kucera (AD/Controls)

Linac LLRF Design Goals

- Generate 201.25 MHz RF from 805 MHz reference line to provide a phase reference for each station.
- Improve RF Amplitude and Phase regulation during the beam pulse.
- Improve beam injection into the Booster.
- Expand working knowledge of the low energy Linac RF system.

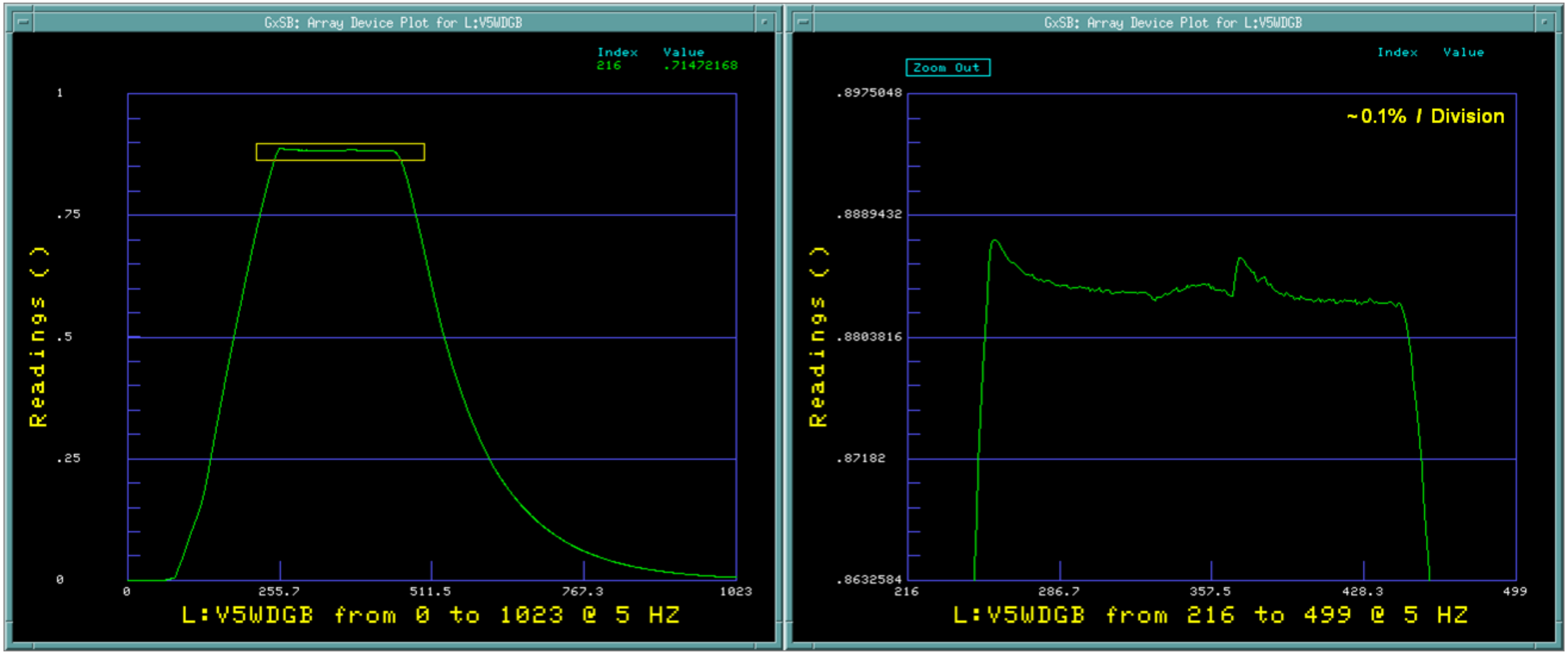
Design Specification	Previous LLRF System	New LLRF System Goals
Cavity Gradient Beam Loading	~1%	< ±0.2%
Cavity RF Phase Stability	~2°	< ±0.5°
Beam Settling Time	10 µs	< 2 µs





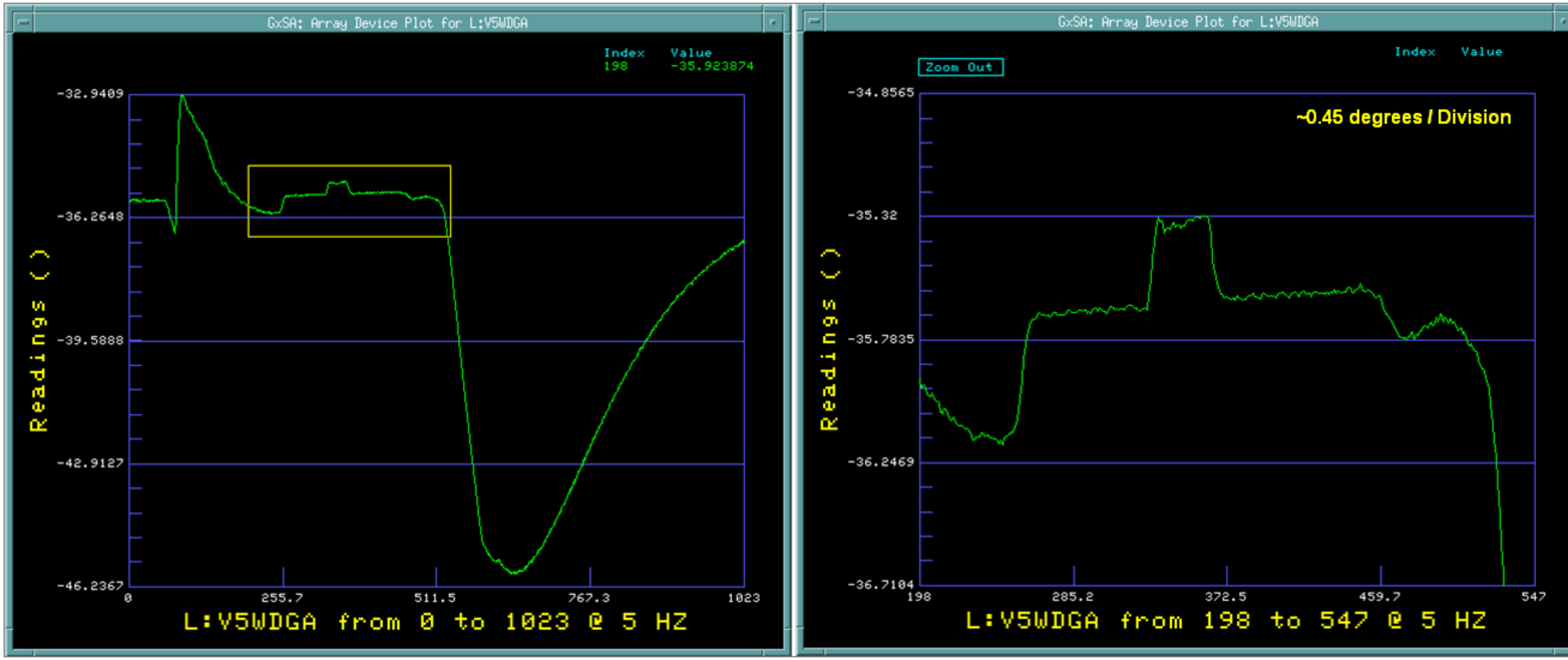
Operational Effects on RF Gradient

0.034% Gradient Flatness on Station 5 LLRF (Goal < ±0.2%)



The LLRF amplitude feed-forward loop is able to achieve design specifications for HEP gradient flatness.

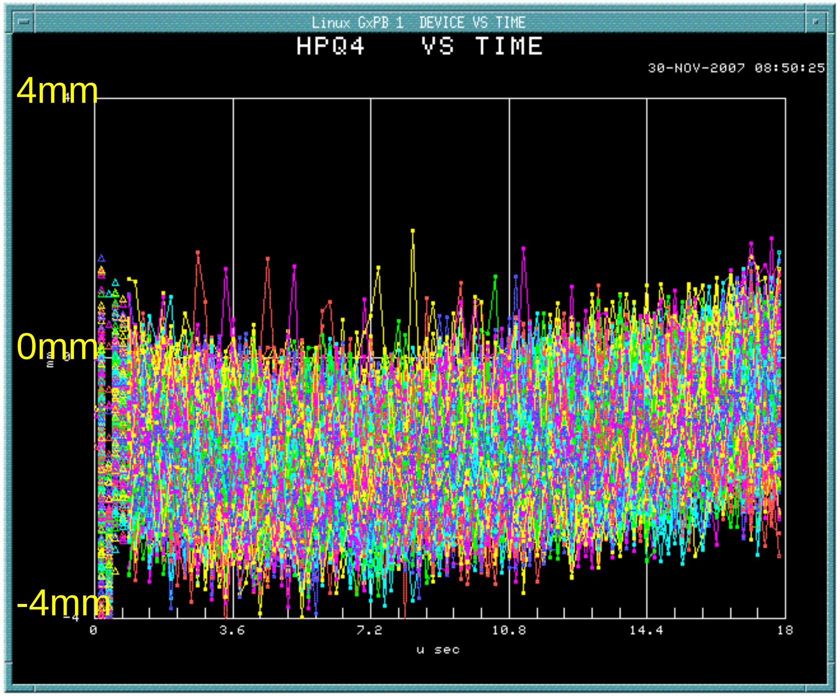
Operational Effects on RF Phase



Operational Effects on Beam Stability

A BPM, located in a high dispersion region of the 400 MeV beam line, shows the beam position variation. This variation is partially due to momentum shifts caused by instabilities of the Linac RF phase and gradient. After a combination of High Energy and Low Energy Linac LLRF work, a reduction of beam position fluctuation from 4mm to 2mm is seen in the BPM monitor plots below.

Previous LLRF (11/30/07)
~4 mm variation



New LLRF (04/13/09)
~2 mm variation