

High Power Operation of SNS SC Linac

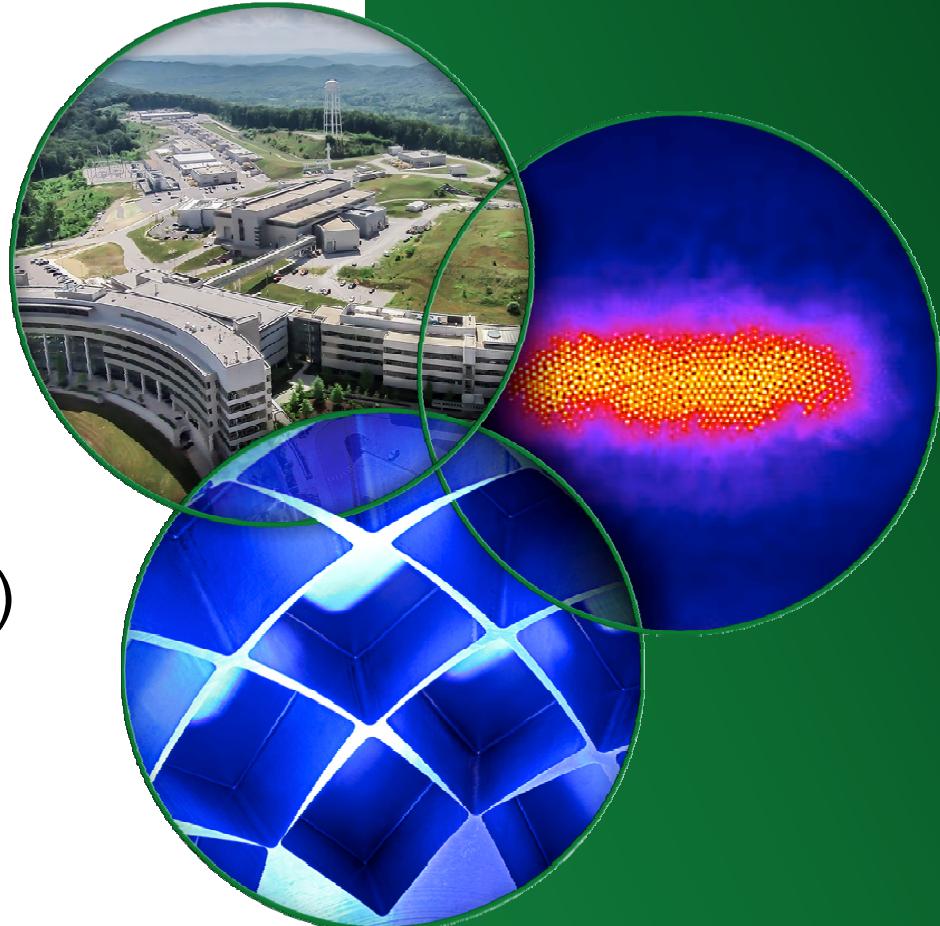
By M. Plum

(on behalf of the SNS project)

Linac16

MSU

Sep. 25-30, 2016



SNS Accelerator Complex

Front-End:
Produce a 1-ms long, chopped, H⁻ beam

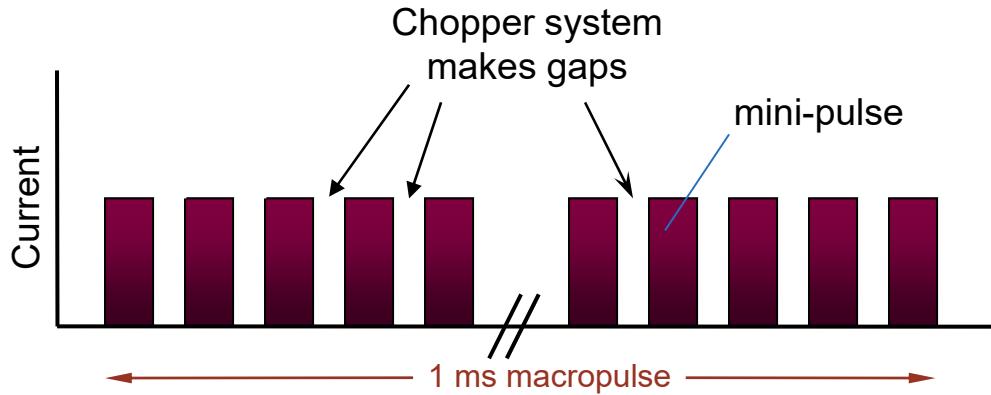
**1 GeV
LINAC**

Accumulator Ring:
Compress 1 ms long pulse to 700 ns

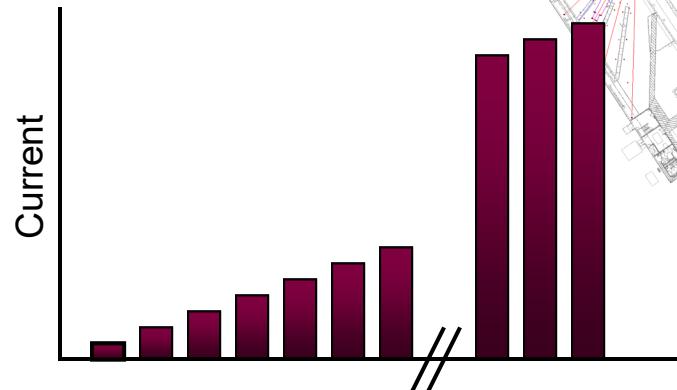
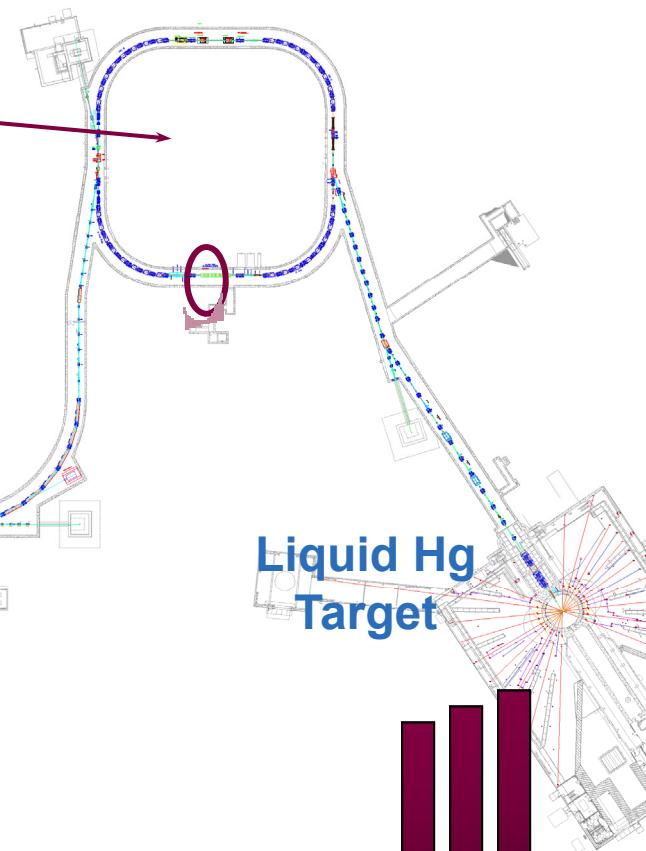
2.5 MeV

Front-End **LINAC**

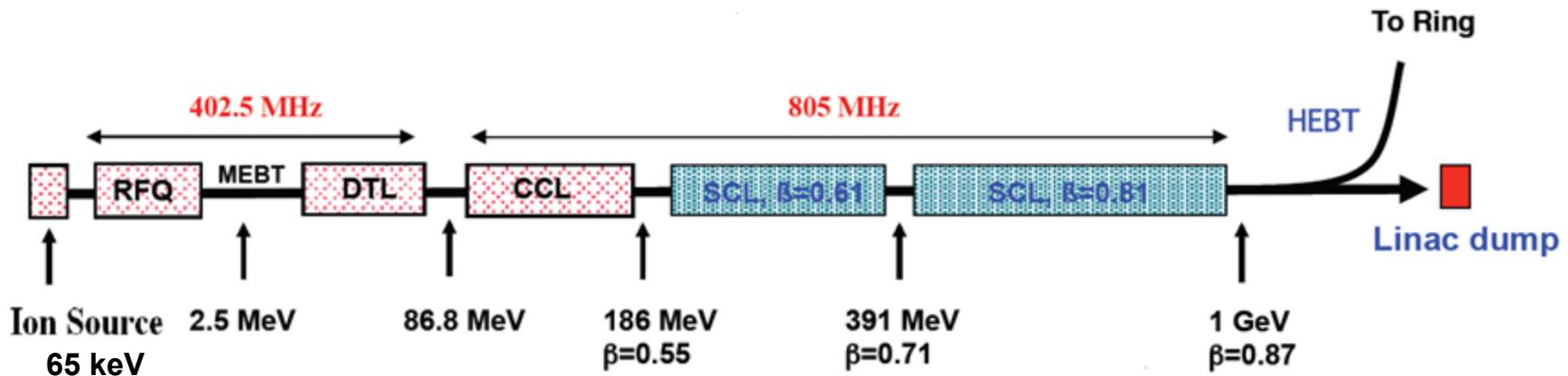
1000 MeV



Design parameters: 60 Hz, 1.4 MW



SNS Linac Structure



Length: 330 m (Superconducting part 230 m)

Production parameters:

Peak current: 38 mA

Repetition rate: 60 Hz

Macro-pulse length: 1 ms

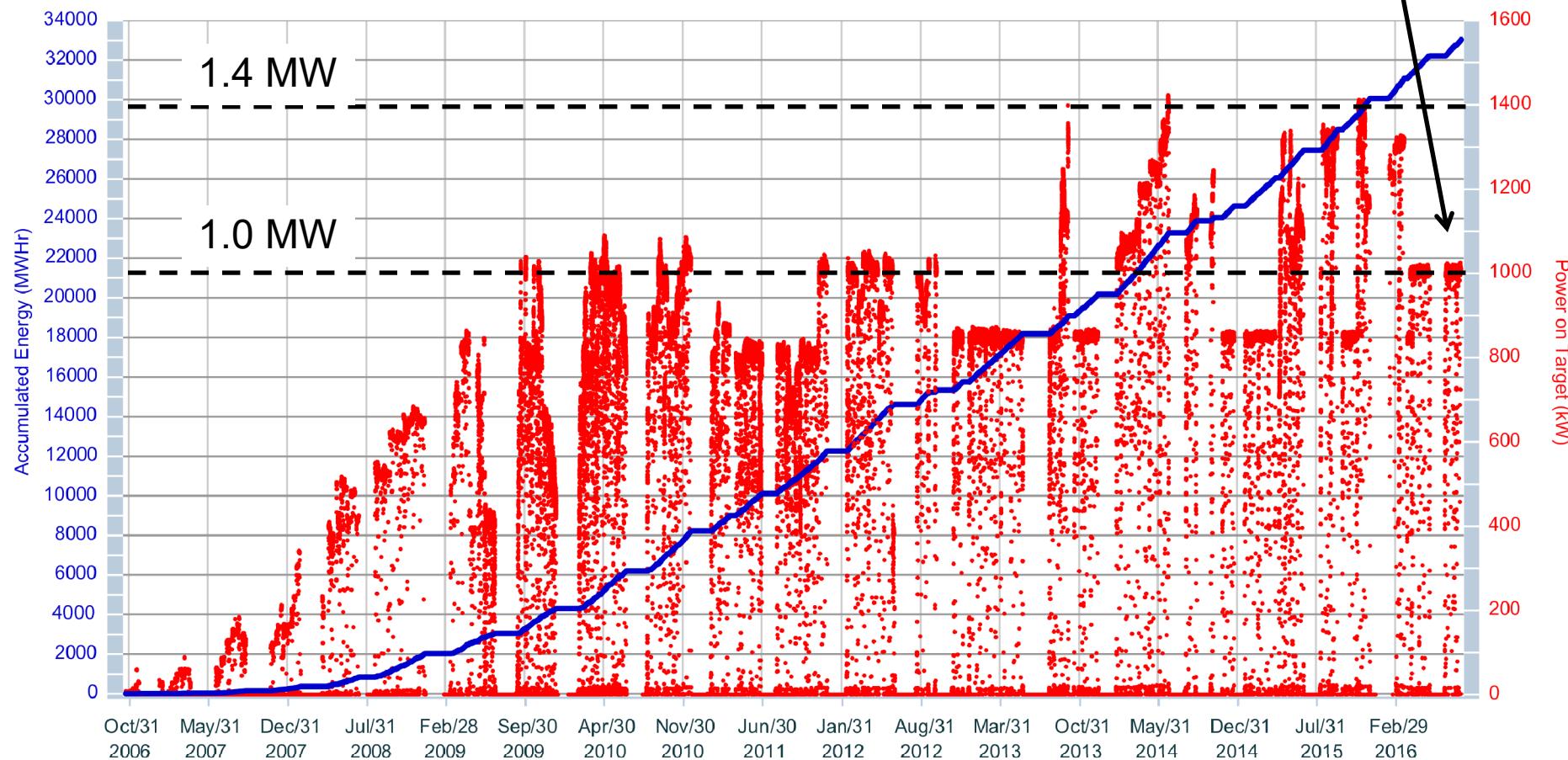
Final Energy: 972 MeV (1000 MeV design)

Average power: 1.4 MW

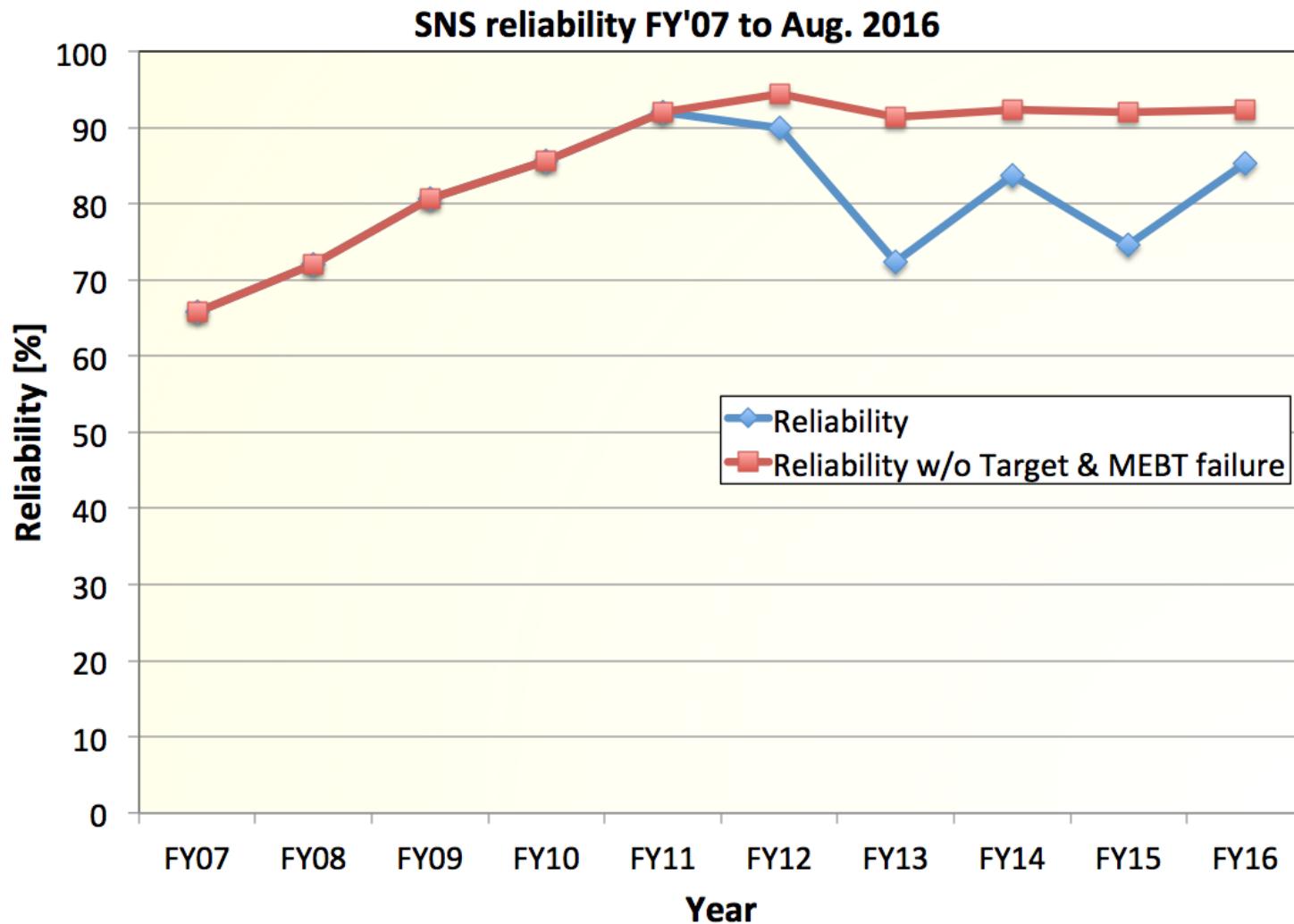
Beam power history

Now running at 1 MW until target change in Oct. 2016, then will run at 1.2 MW until April 2017, for target experiment

Power on Target



Accelerator reliability



Accelerator reliability >90% except for MEBT water leak in 2014

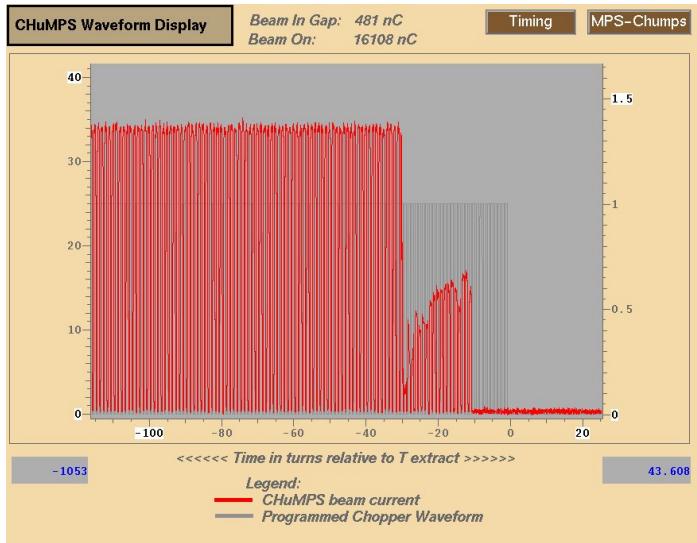
Challenges facing the SCL

- Reliability and availability is excellent, but...
- Gradients must sometimes be (temporarily) reduced
 - Errant beam
 - Contaminant gases from ion pumps
 - Particulates from vacuum valves
- Beam energy is limited
 - Now 972 MeV, compared to design value 1000 MeV
 - Mainly due to as-installed gradients in the high-beta section that are lower than design
- Beam loss is acceptable, but we always want it to be lower

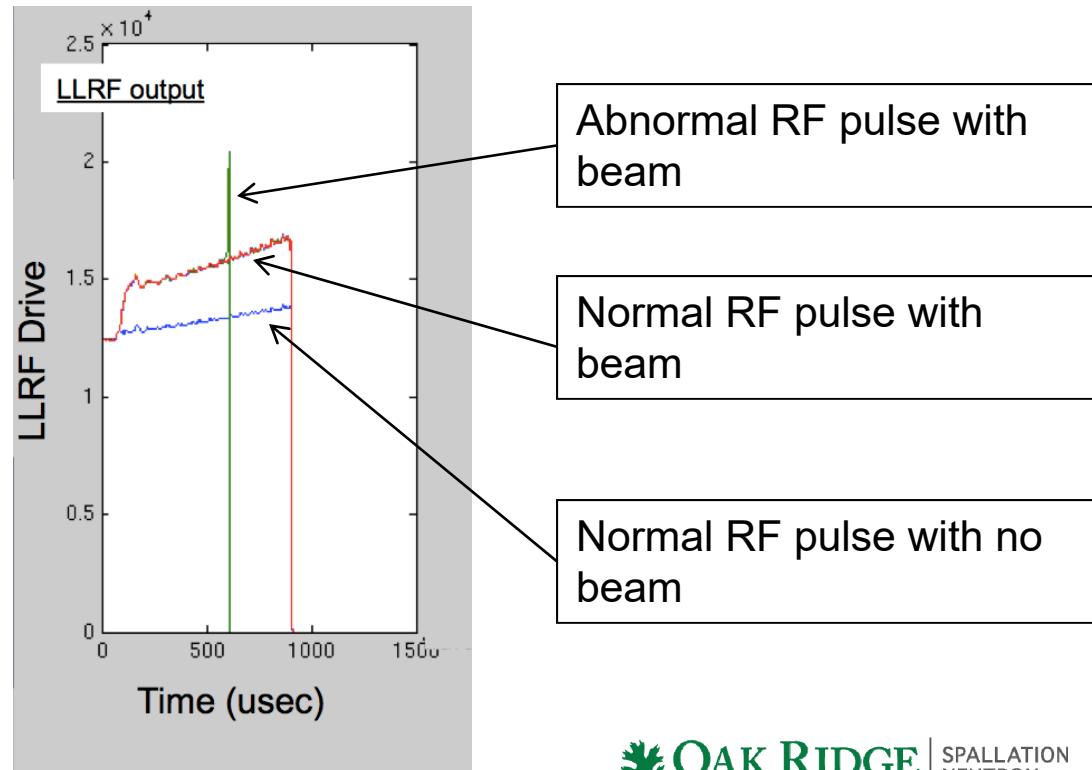
Errant beams

- Definition: sudden beam loss caused by off-normal beam pulse or pulses
- Beam loss region typically spans several to ten cryomodules

Example: ion source current drop



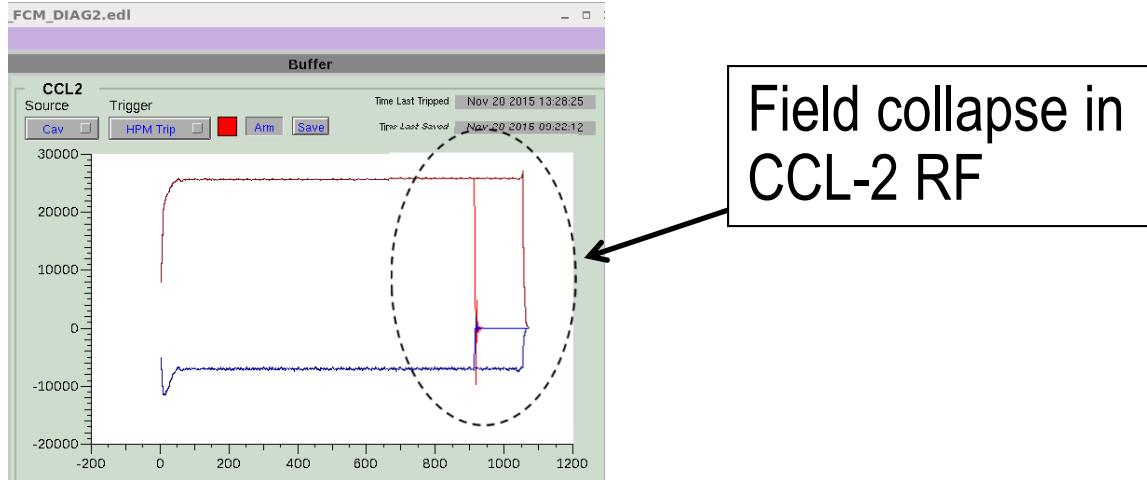
Example: warm linac RF trip



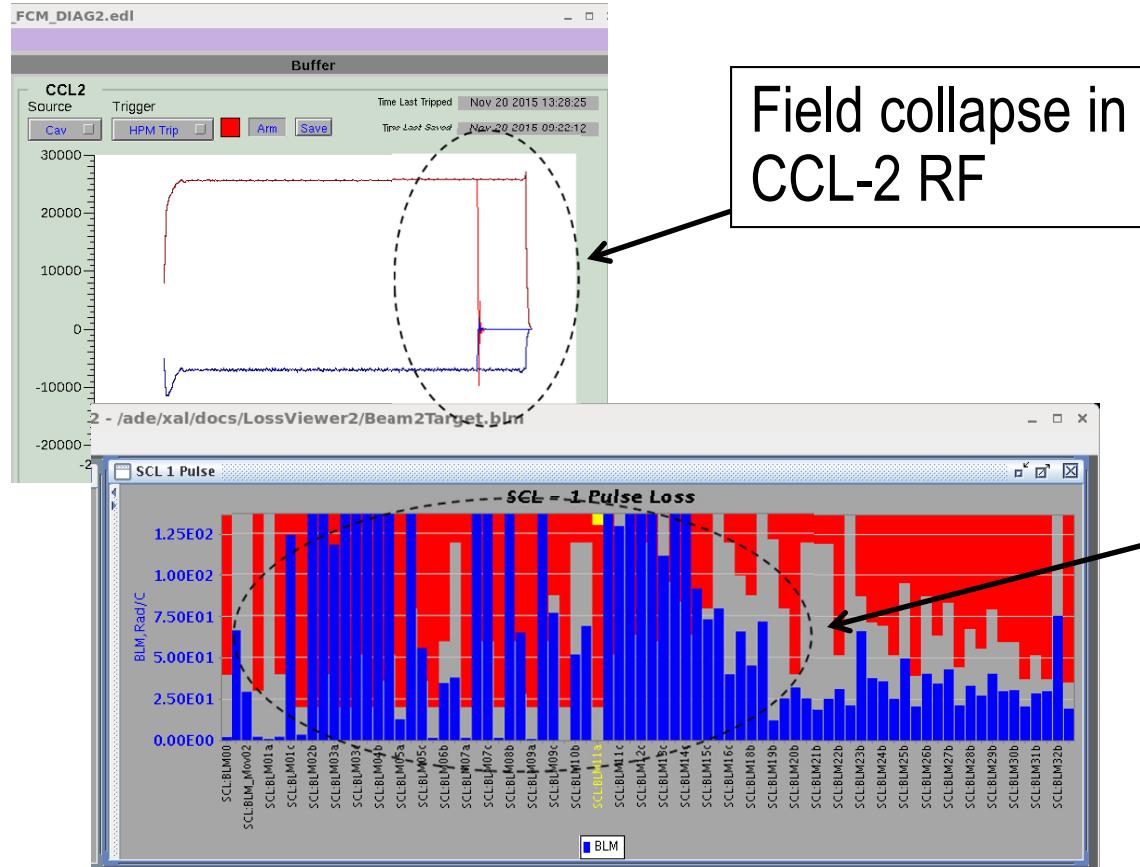
Why errant beam is important

- Errant beams damage the SCL cavities
 - Before installing DBCM system we would typically lose 10 – 20 μ s of beam during errant beam event
 - Equivalent up to 467 Joules of energy, depending on beam energy and amount of lost beam charge
 - Beam hitting rf cavity surface desorbs gas and creates an environment for arcing / discharge
- Super Conducting Linac (SCL) cavity performance degrades over time
 - SCL cavities do not trip with every errant beam pulse, but the probability for a trip increases with time
 - SCL cavity fields must sometimes be lowered, or even turned off
- SCL cavity performance degradation from errant beam can usually be restored (except for cavity 06c)
 - Requires cavity warm up during a long shutdown and then RF conditioning before beginning beam operation

Example of errant beam



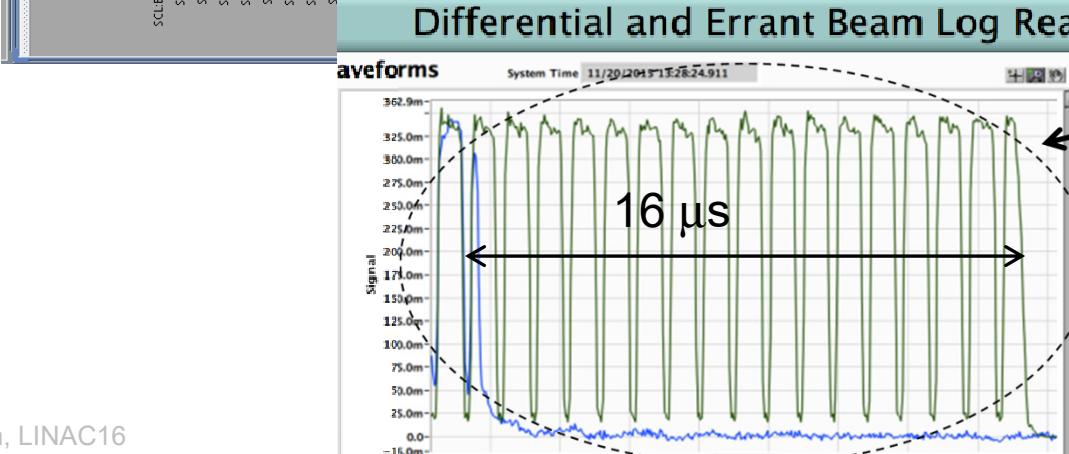
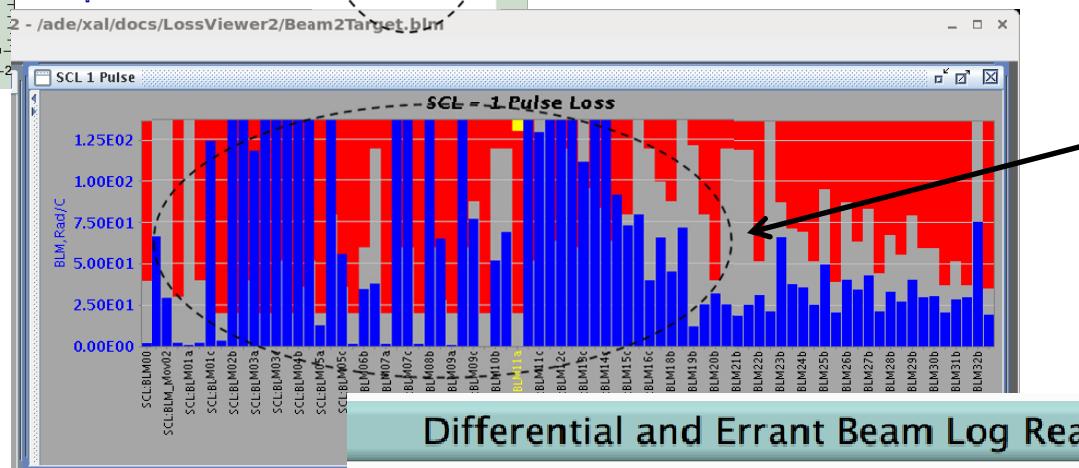
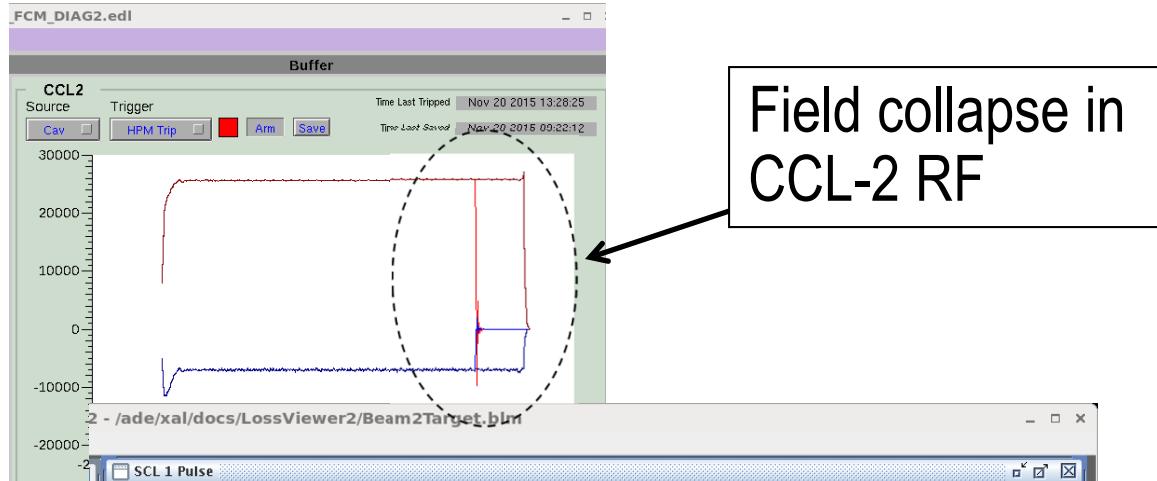
Example of errant beam



Field collapse in
CCL-2 RF

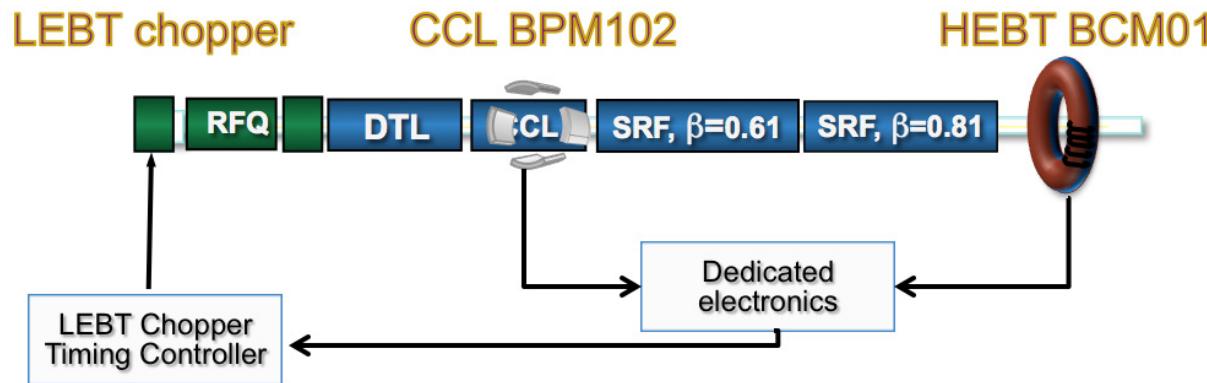
Many beam loss
monitors trip in SCL

Example of errant beam



Errant beam mitigation – turn off time

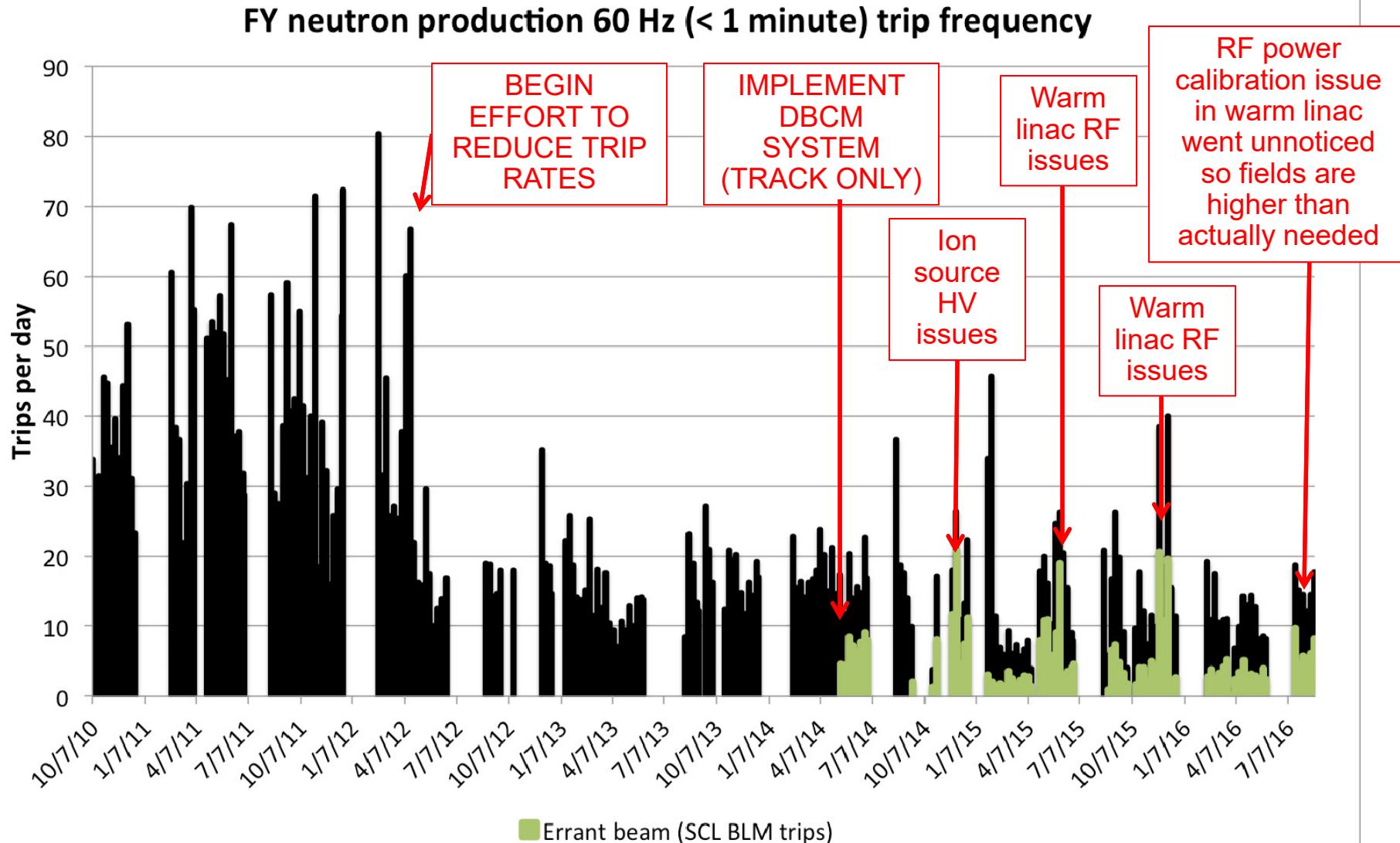
- Goal: Reduce energy deposited in cavities by reducing time to shut off beam
- Solution: Installed fast differential beam current monitor system
 - Based on BPM in CCL and BCM in HEBT
 - Dedicated electronics connected directly to LEBT chopper system to bypass the machine protection system
- Commissioned in first half of 2016
- Beam shut off time reduced from 10 – 20 μs down to 7 – 8 μs



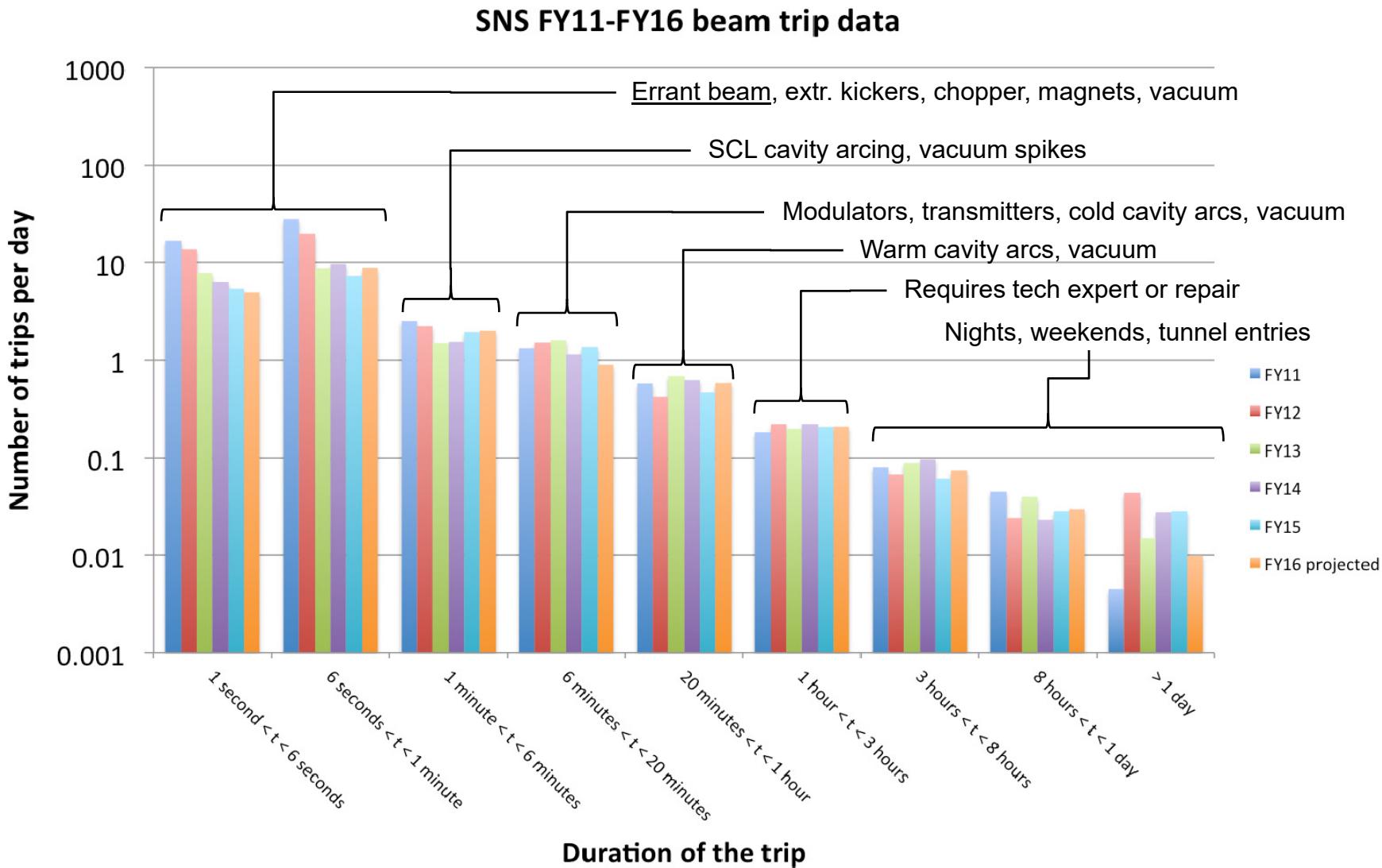
Errant beam mitigation – reduce trip frequency

- Goal: Reduce number of errant beam trips
- Solution: Most errant beam events are due to warm linac RF trips
 - Probably due to an arc in the cavity or near the vacuum window
- Reduce trip frequency by
 - Slight changes in cavity resonant frequency. This improves multipacting near the RF window.
 - Slight changes in the RF fill ramp
 - Frequent NEG pump regens
- Trip frequency in warm linac reduced from 20 – 30 trips per day down to ~5 trips per day

Trip rates since 2010



Trip rate trends and durations

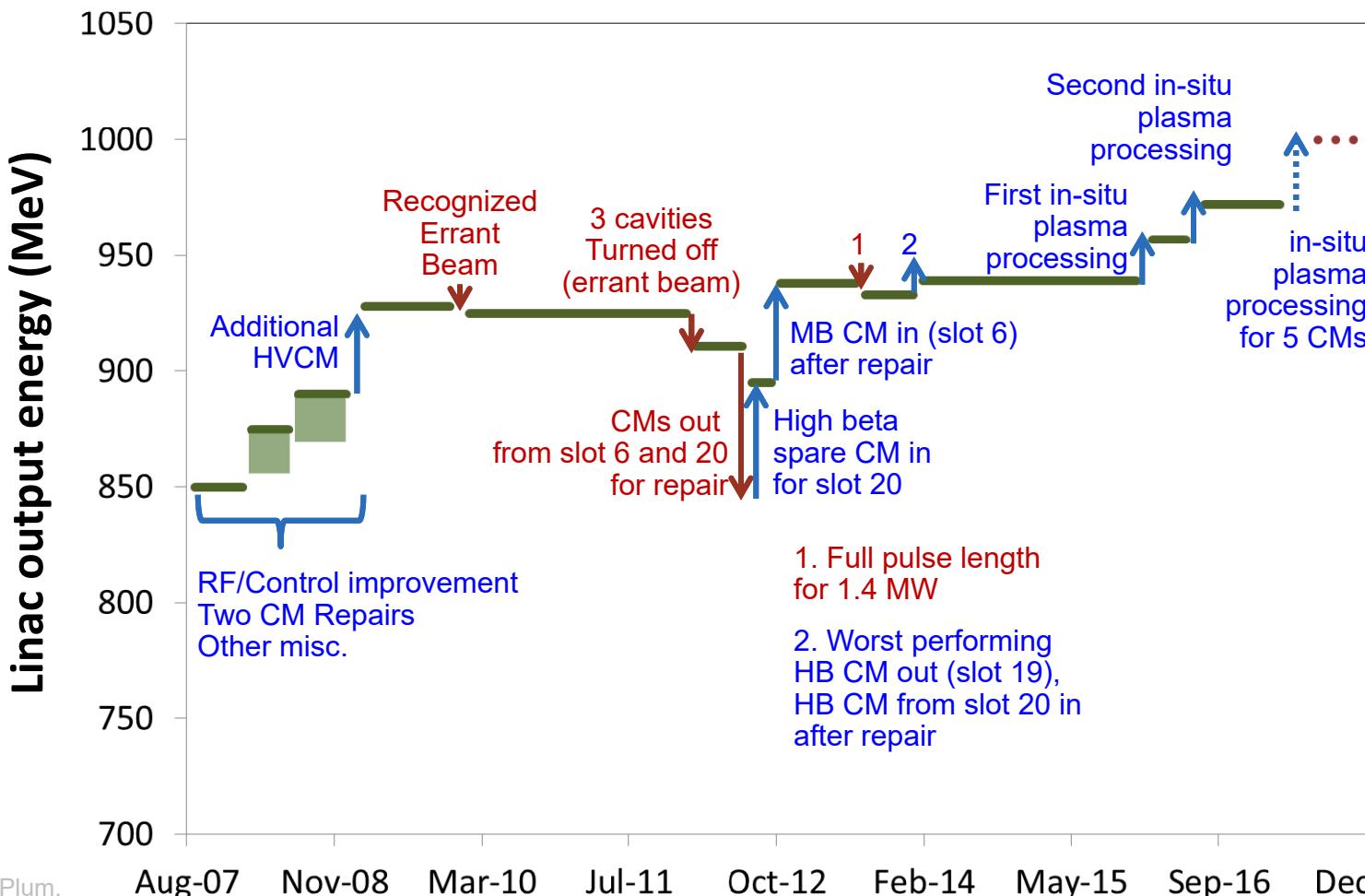


Linac output energy

- Beam energy today limited to 972 MeV with last cavity in reserve (comp. to 1000 MeV design).
 - Two cavities today are off line. One since day 1; one since April 2015, probably due to errant beam
- Cavity improvement program, including plasma processing (see talk by Marc Doleans), has led to a steady increase in beam energy
- We can still reach our design beam power of 1.4 MW on target by reducing the chopping fraction below the design value
 - Faster rise/fall time in chopper
 - Smaller gap in ring

Linac output energy history and projection

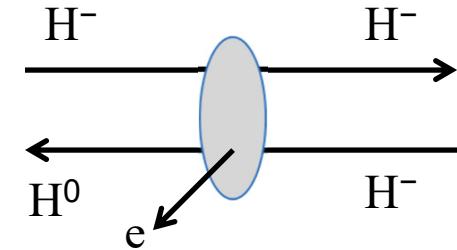
- Changes of output energies are the results from specific activities and events
- Overall, output energy is increasing (no systematic performance degradation of SRF cavities).
 - Current output energy is 972 MeV. Before deploying in-situ plasma processing output energy was limited at 939 MeV.



(Courtesy Sang-ho Kim)

SCL beam loss

- Beam loss today is tolerable
 - Activation levels are 0.05 to 0.45 mSv/h after 3 – 5 hours cool down after operating at 1.3 MW
- Beam loss in SCL is dominated by intra-beam stripping
 - Proportional to (beam density)²
- We plan to reduce loss by increasing the beam size, both longitudinally and transversely, to make maximum use of available aperture
 - But first we need an accurate model of our linac



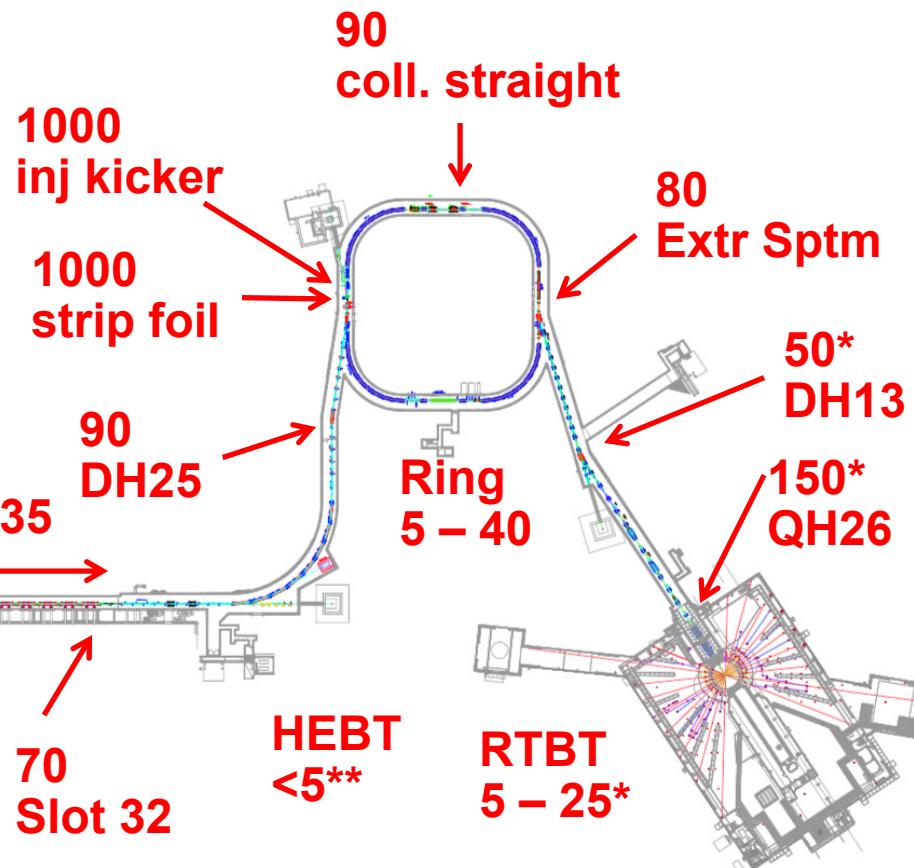
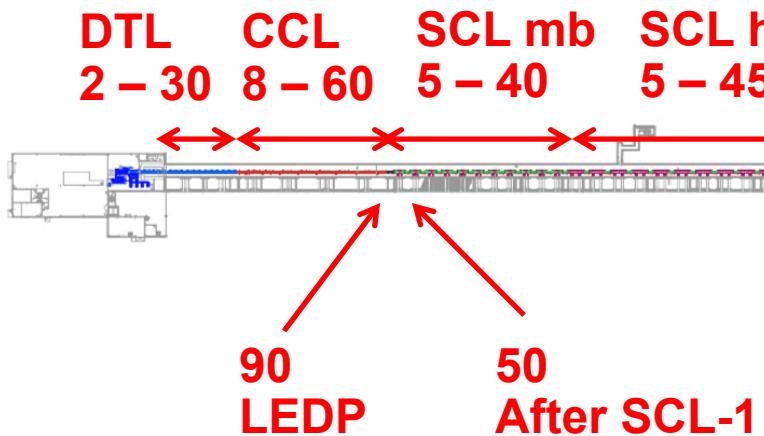
Activation levels

1.3 MW until 3 to 5 hours before survey

Sept. 22, 2015

All numbers are mrem/h at 30 cm

100 mrem/h = 1 mSv/h



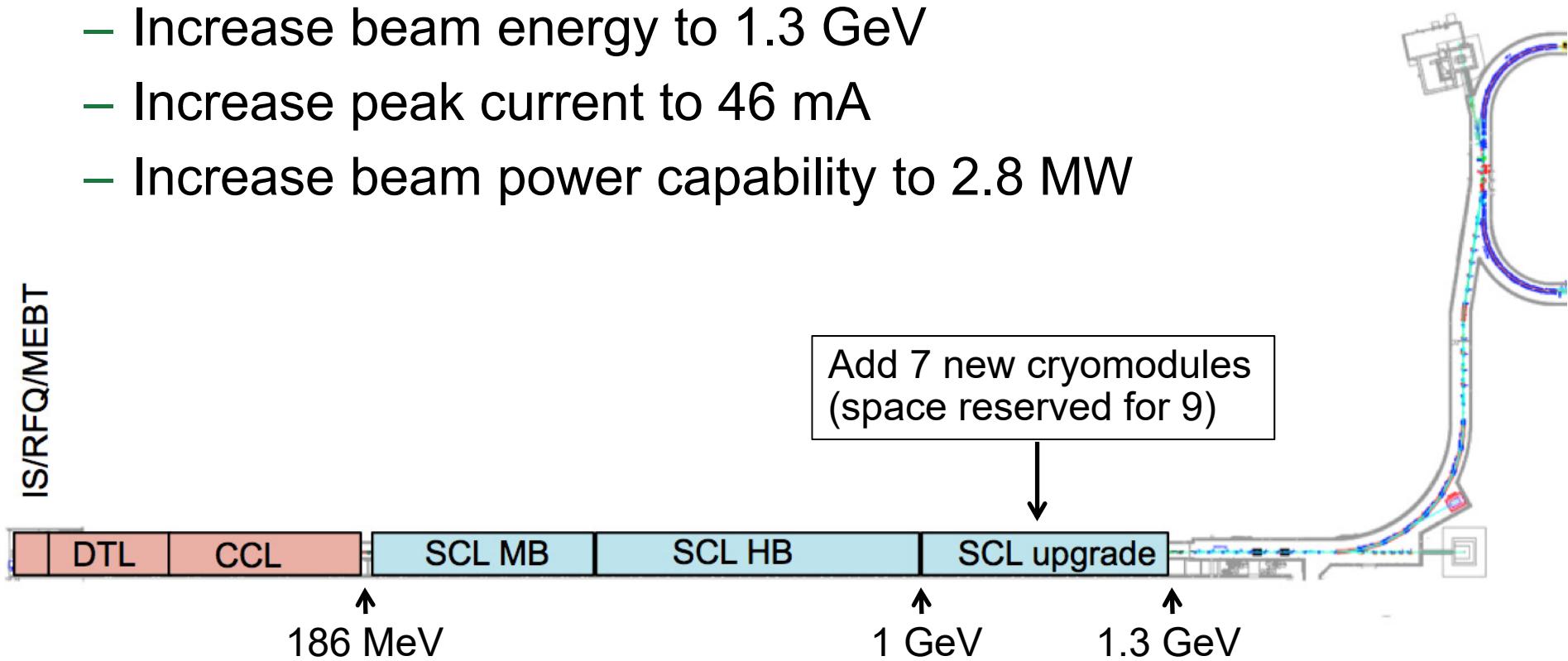
Except for a few hot spots, the dose rates are relatively low

* 3 days after 1.3 MW

** No survey near this time, indicated dose rates are typical

SCL future

- Proton Power Upgrade project:
 - Add seven new cryomodules
 - Increase beam energy to 1.3 GeV
 - Increase peak current to 46 mA
 - Increase beam power capability to 2.8 MW



Summary

- The SNS SCL has performed very well over the last 11 years
- Some of the biggest challenges have been errant beams, trip rates, beam energy, and beam loss
- Damage due to errant beams has been mitigated by DBCM system and trip rate reduction
- Beam energy is steadily increasing – 28 MeV to go
- The Proton Power Upgrade project will double the SCL beam power to 2.8 MW

Thank you for your attention!