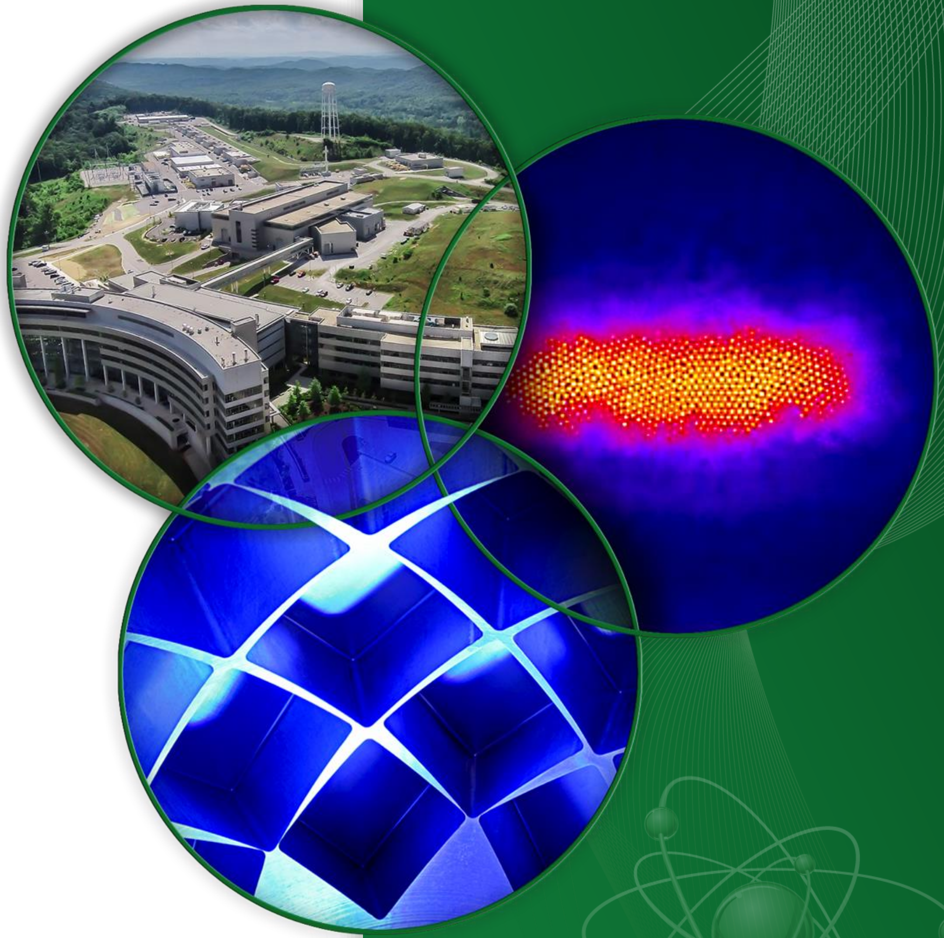
1.4 MW Power Ramp-up and Reliable Operation



J. Galambos

SNS AAC Review

March 24-25, 2015

SNS: Designed for 1.4 MW

The SNS Project Parameter List

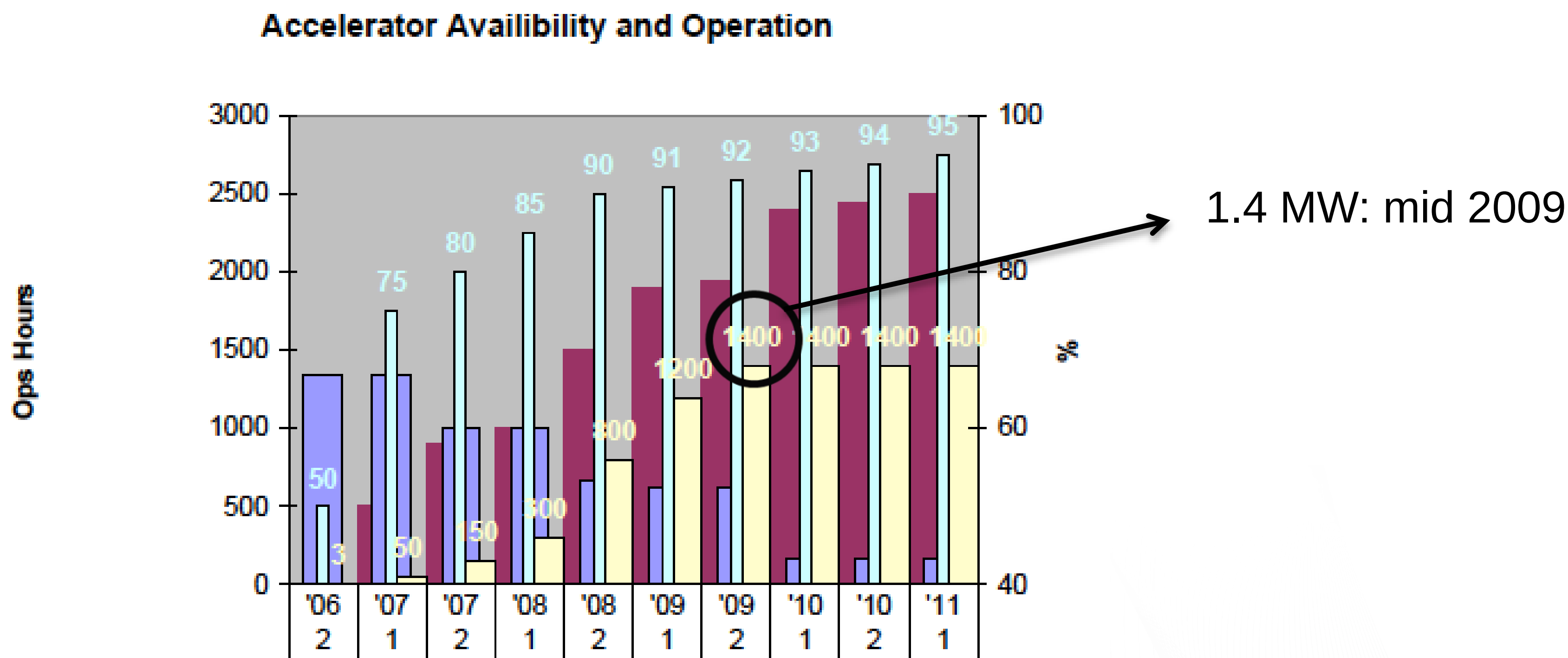
Spallation Neutron Source Primary Parameters

Proton beam power on target	1.4 MW
Average beam current on target	1.4 mA
Pulse repetition rate	60 Hz
Protons per pulse on target	1.5x10^{14} protons
Charge per pulse on target	24 □C
Energy per pulse on target	24 kJ
Proton pulse length on target	695 ns
Ion type (Front end, Linac, HEBT)	H minus
Average linac macropulse H- current	26 mA
Linac beam macropulse duty factor	6 %
Front end length	7.5 m
Linac length	331 m

. . .

Early Power Ramp-up Expectations

- *Mason / Holtkamp White Paper, 2002*

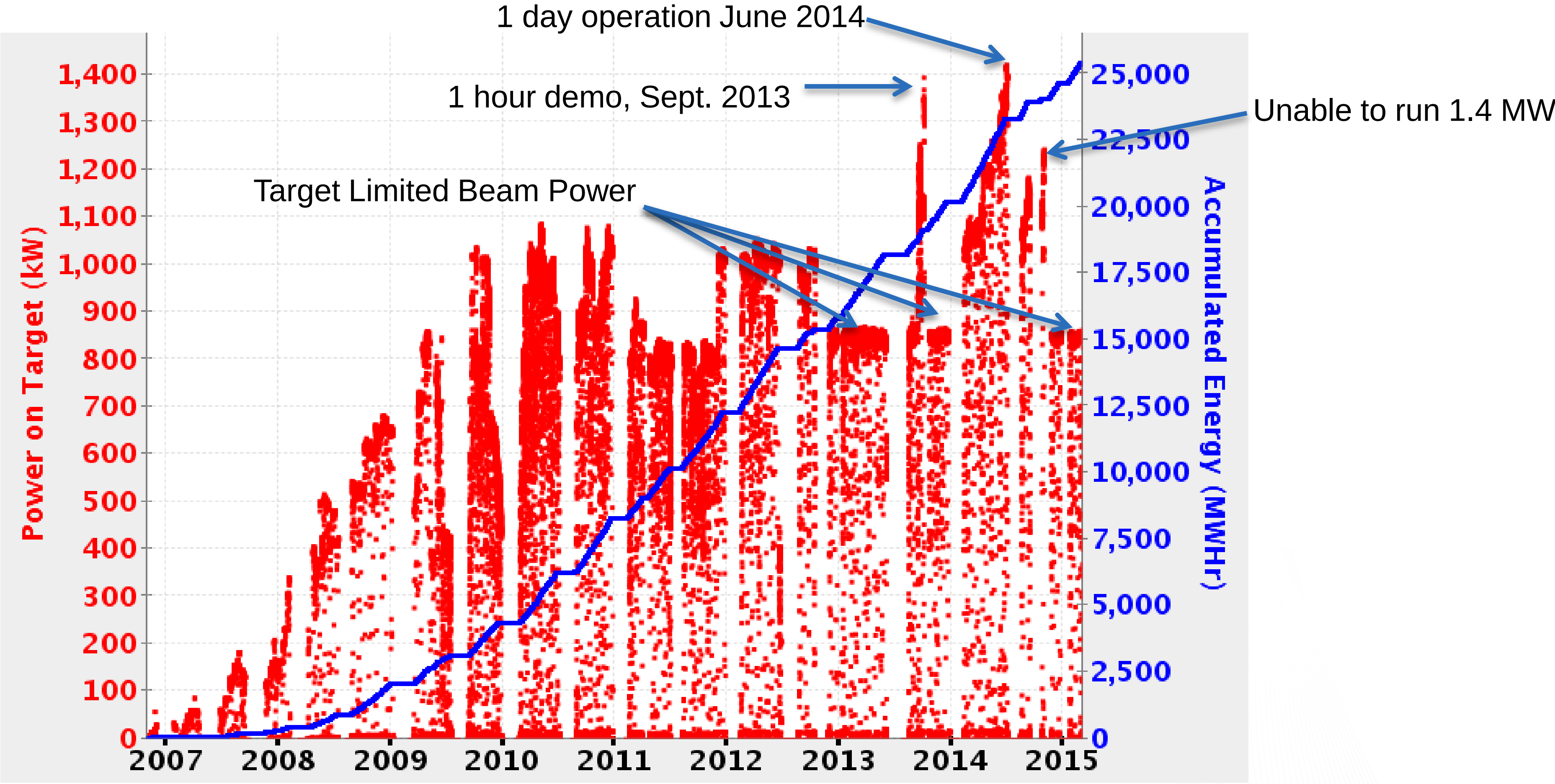


	'06 2	'07 1	'07 2	'08 1	'08 2	'09 1	'09 2	'10 1	'10 2	'11 1
User Ops hours	0	500	900	1000	1500	1900	1950	2400	2450	2500
Accel. Phyics	1344	1344	1008	1008	672	624	624	168	168	168
Beam Power/kW	3	50	150	300	800	1200	1400	1400	1400	1400
Reliability (%)	50	75	80	85	90	91	92	93	94	95

Years

User Ops hours | Accel. Phyics | Beam Power/kW | Reliability (%)

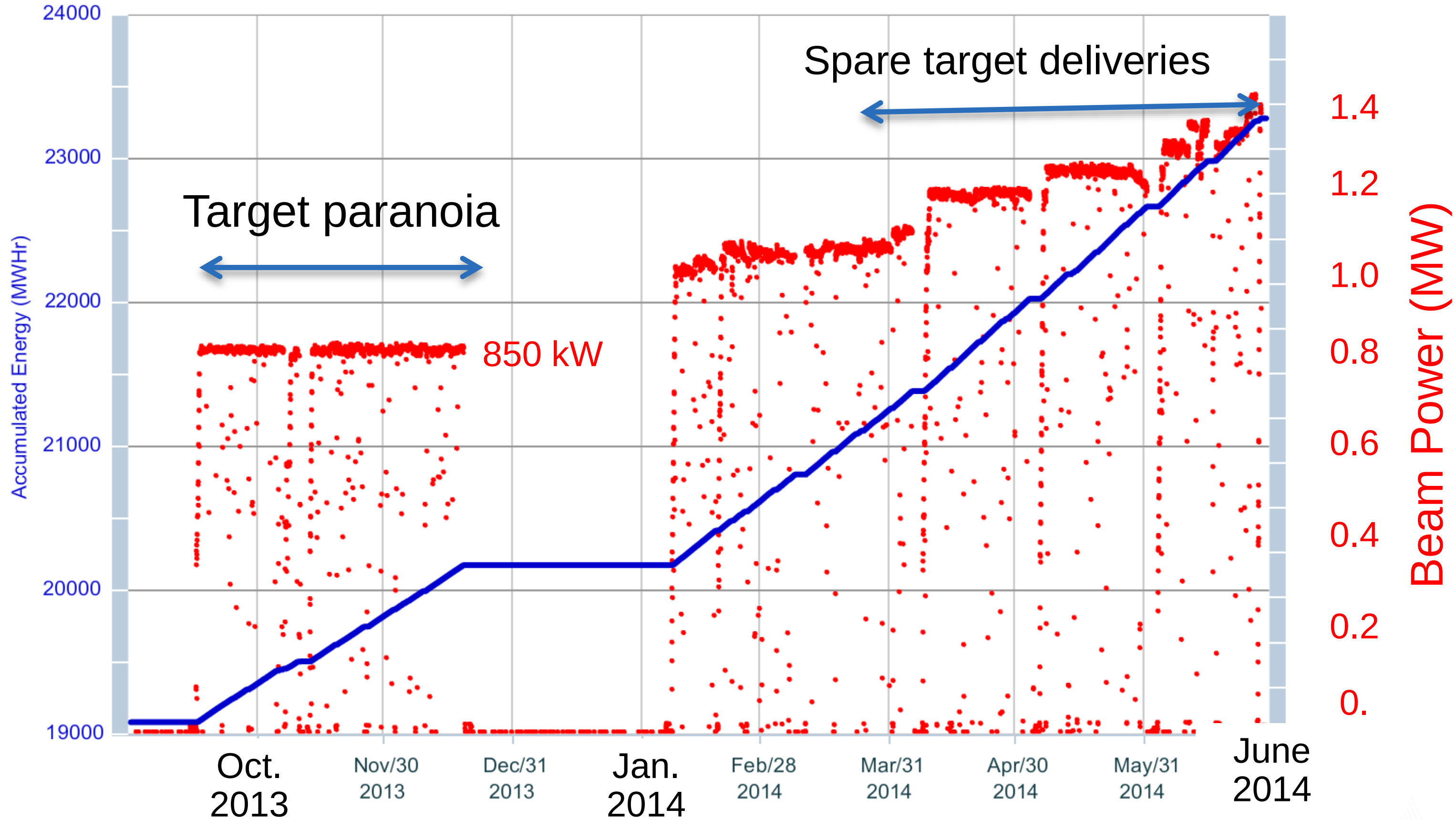
1.4 MW Beam Power at SNS: The Reality



- First neutron production at 1.4 MW: June 27, 2014
  - Sustained power increase during the 2014 run, increasing power from ~ 1. MW to 1.4 MW

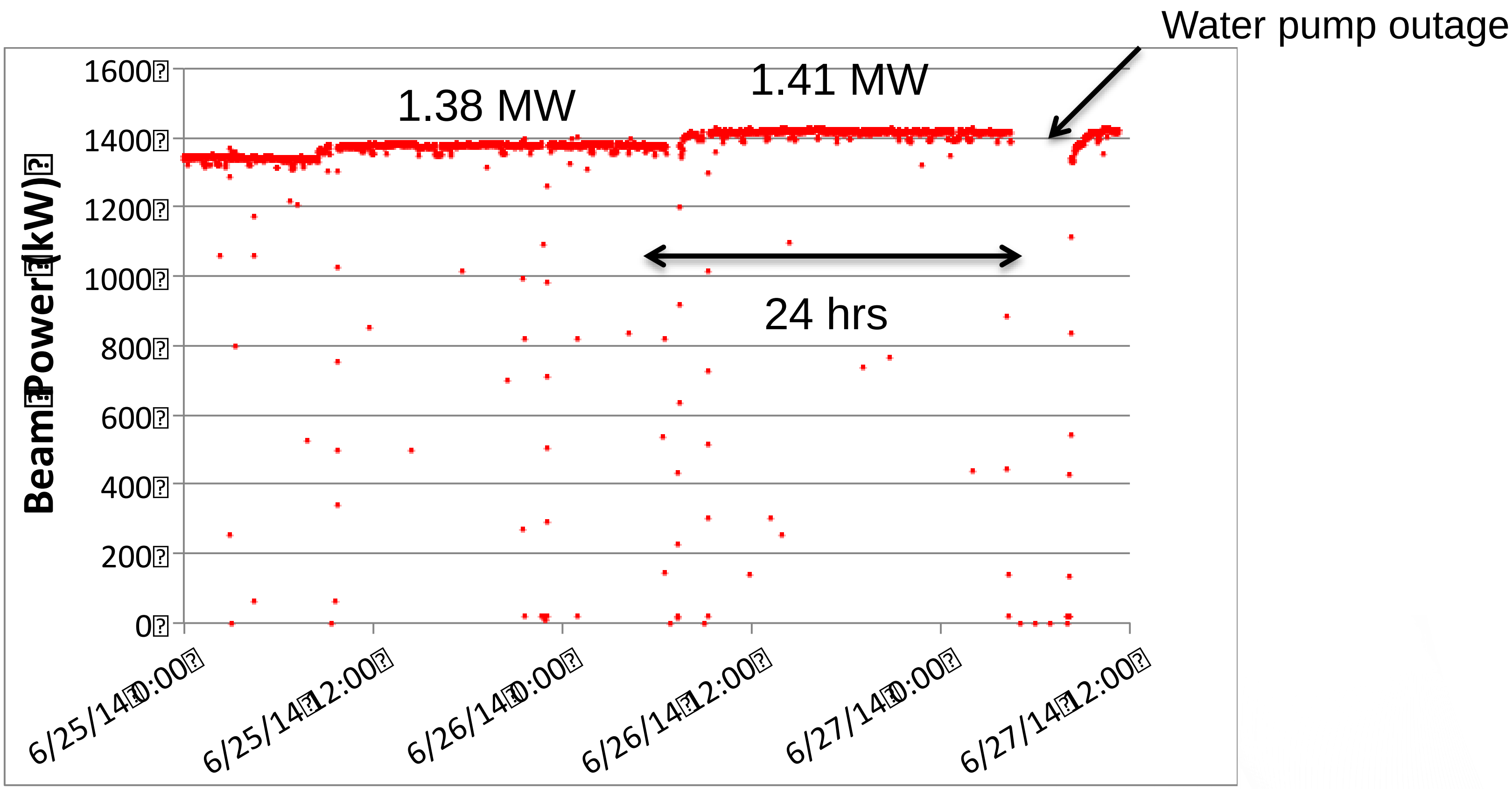
OAK RIDGE National Laboratory | HIGH FLUX ISOTOPE REACTOR | SPALLATION NEUTRON SOURCE

1.4 MW Operation: The Final Assault
FY 14a Run



– Power ramp-up approach:
  - Adiabatic
  - Most effective use of what works
– Plan is to operate at 1.3-1.4 MW from now on

Stable 1.4 MW Operation



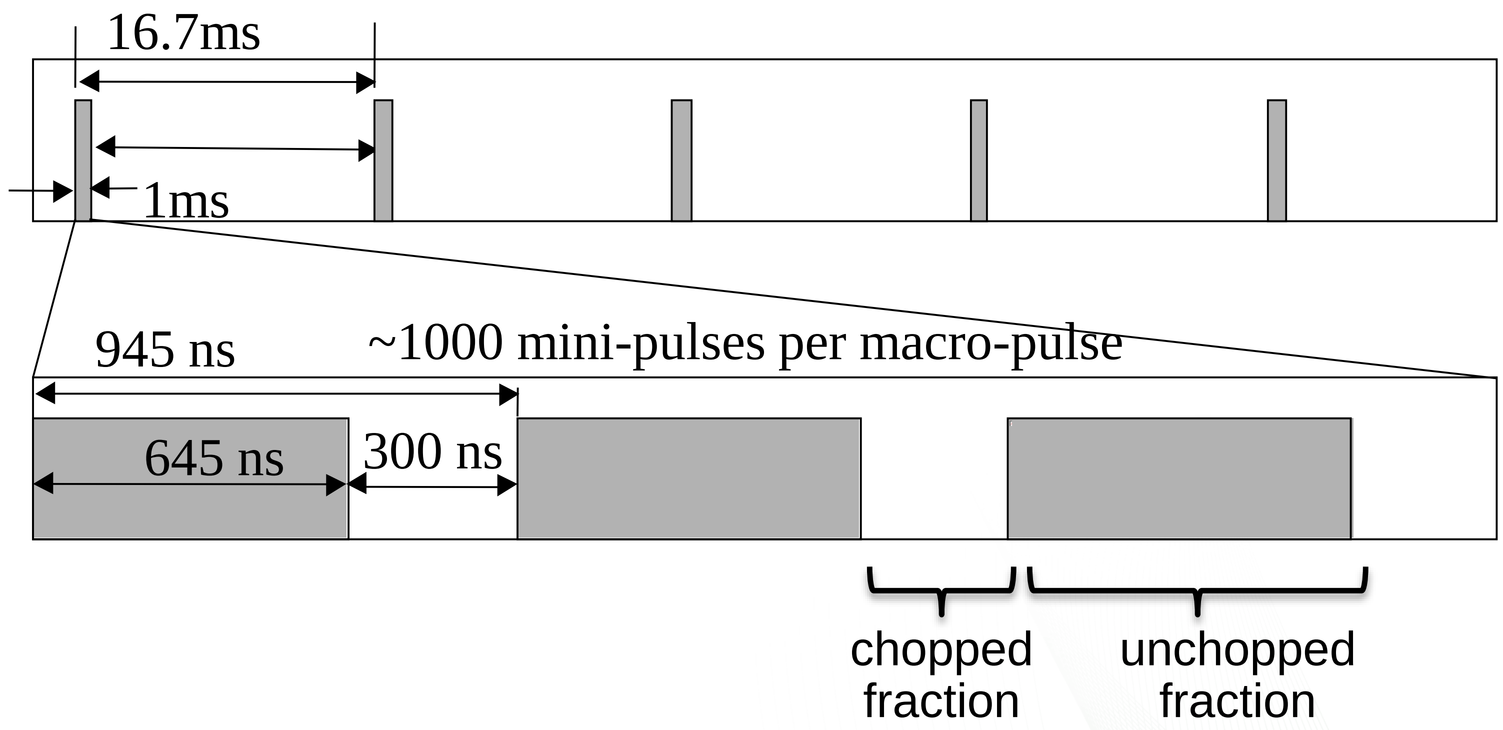
- 1.4 MW operation ~24 hr. scale existence proof
  - Foil works
  - No instability
  - RF supports full beam loading

OAK RIDGE National Laboratory | HIGH FLUX ISOTOPE REACTOR | SPALLATION NEUTRON SOURCE

Some Background: Accelerator Time Structure

Macro-pulse Structure (made by the High power RF – 60 Hz)

Mini-pulse Structure (made by the choppers , 1 MHz)



Chopped gap is to provide an extraction gap in the ring

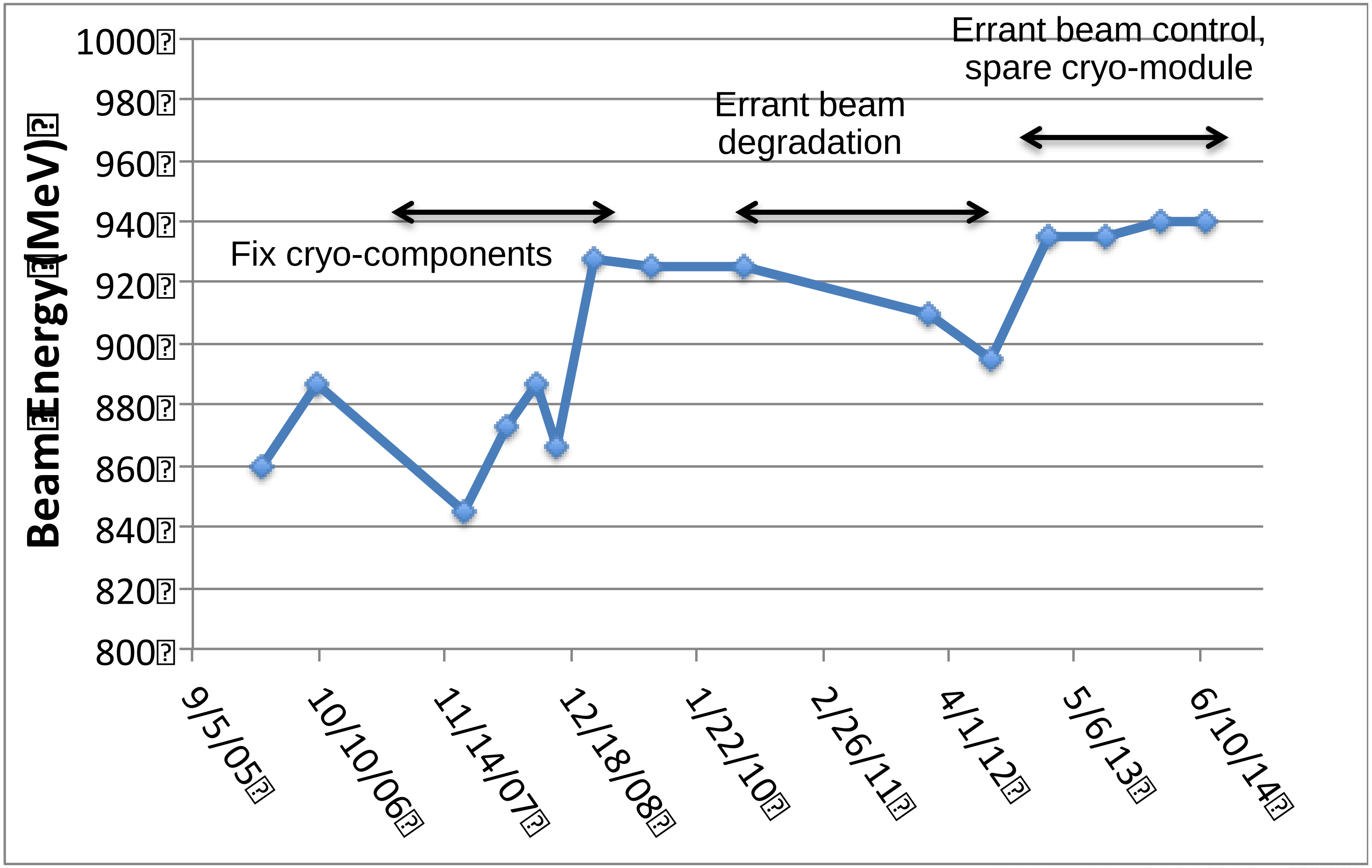
Proton Beam Power

$$P_{beam} = E_{beam} \times Q_{pulse} \times rep\text{-}rate \quad , \textit{where}$$

$$Q_{pulse} = t_{macro\text{-}pulse} \times I_{macro\text{-}pulse} \times f_{un\text{-}chopped}$$

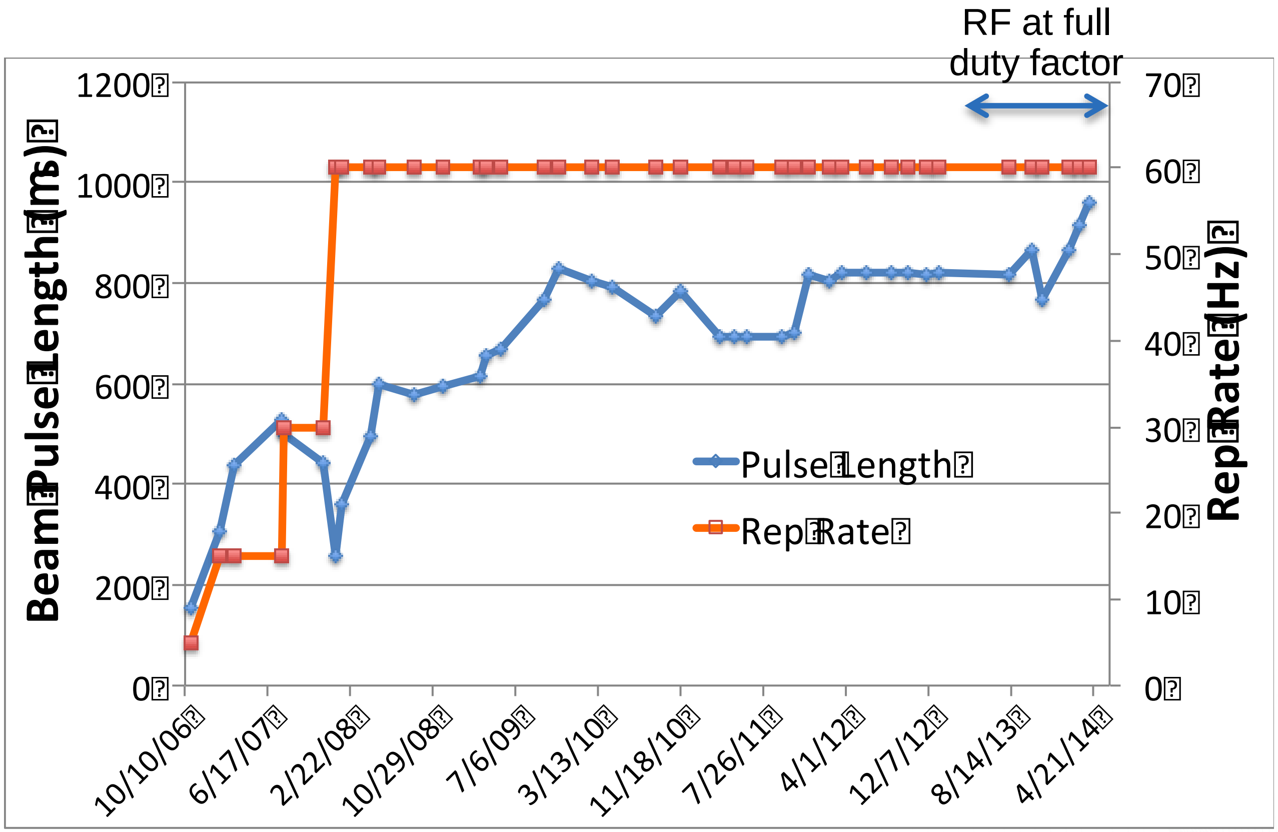
- Not many knobs:
  - Beam energy (E_{beam})
  - Rep-rate
  - Beam current ($I_{macro\text{-}pulse}$)
  - Macro-pulse length ($\tau_{macro\text{-}pulse}$)
  - Chopping fraction ($f_{un\text{-}chopped}$)

Beam Energy History



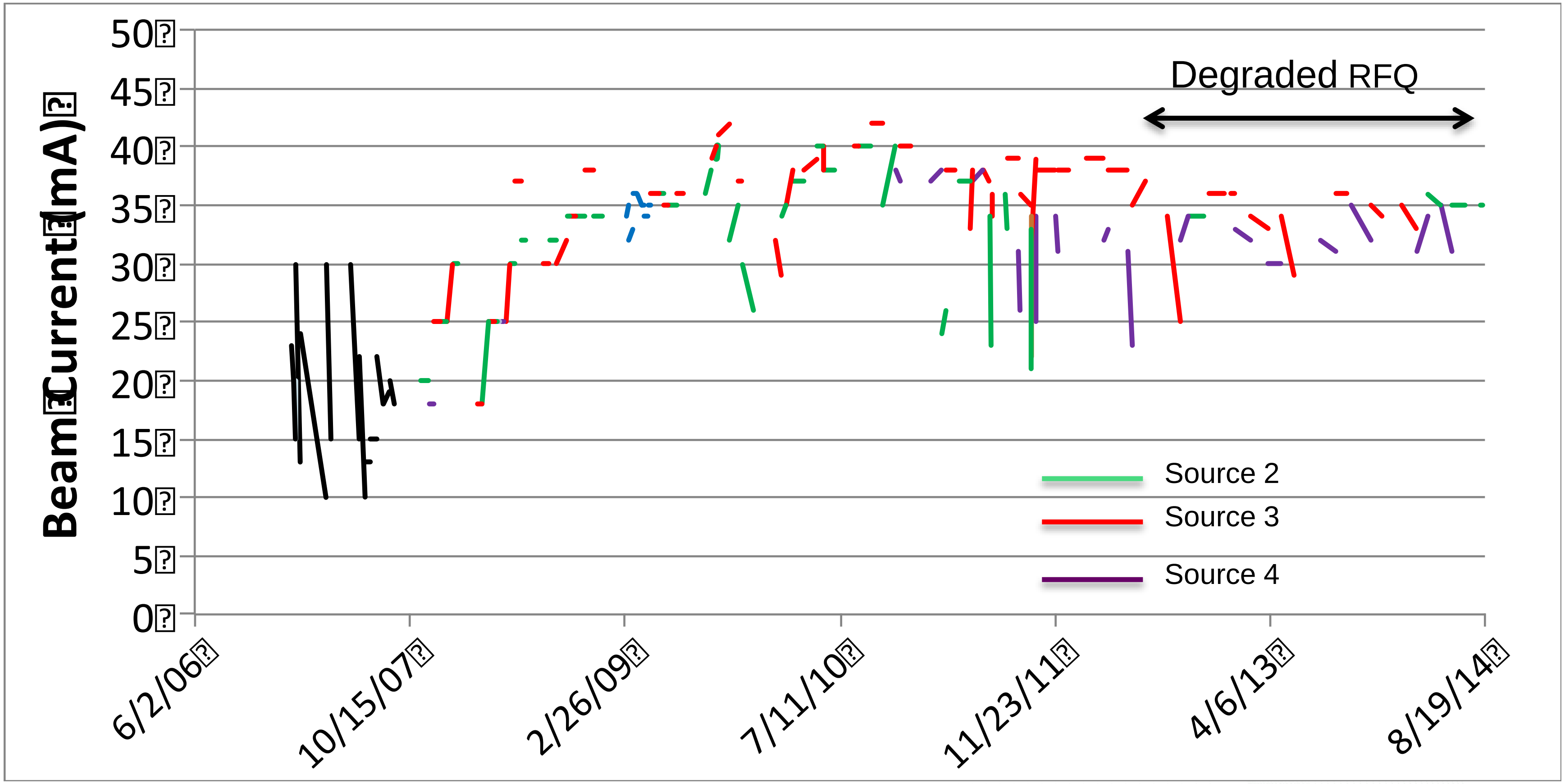
- Never run 1 GeV production
- Beam energy constant for last 1.5 years
- Plan to increase to 1 GeV in 1-2 years: plasma processing

Duty Factor History



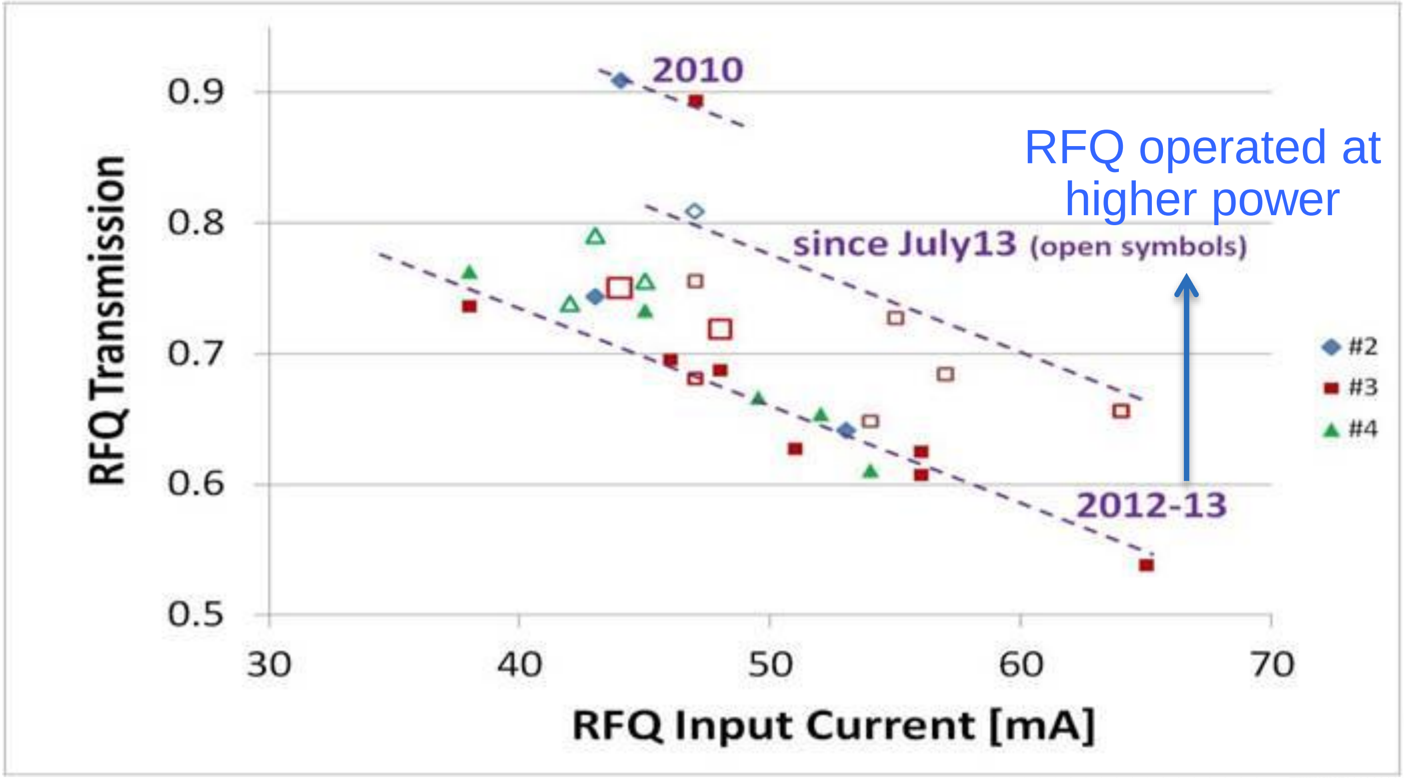
- Duty factor (=rep-rate x pulse length) is a driver on equipment stress
  - Slow increase in pulse length since initial operations
  - Final push in 2014

Ion Source History: RFQ Output
(Courtesy M. Stockli)



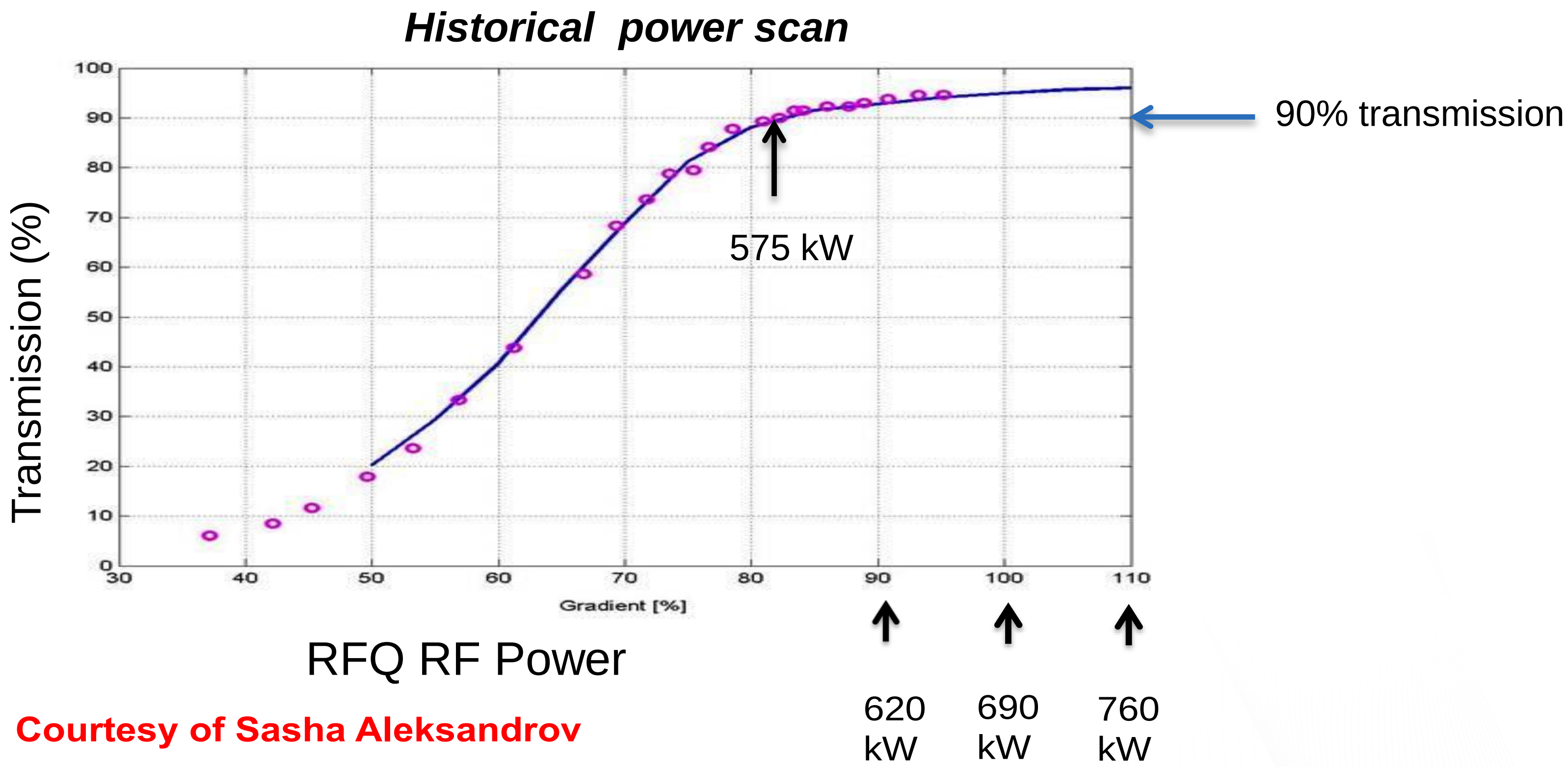
- RFQ output current fairly constant last 2 years

RFQ Transmission is Low (Courtesy M. Stockli)



- Reduced RFQ transmission 2012-present
  - 60-75%
- Input current 45-55 mA

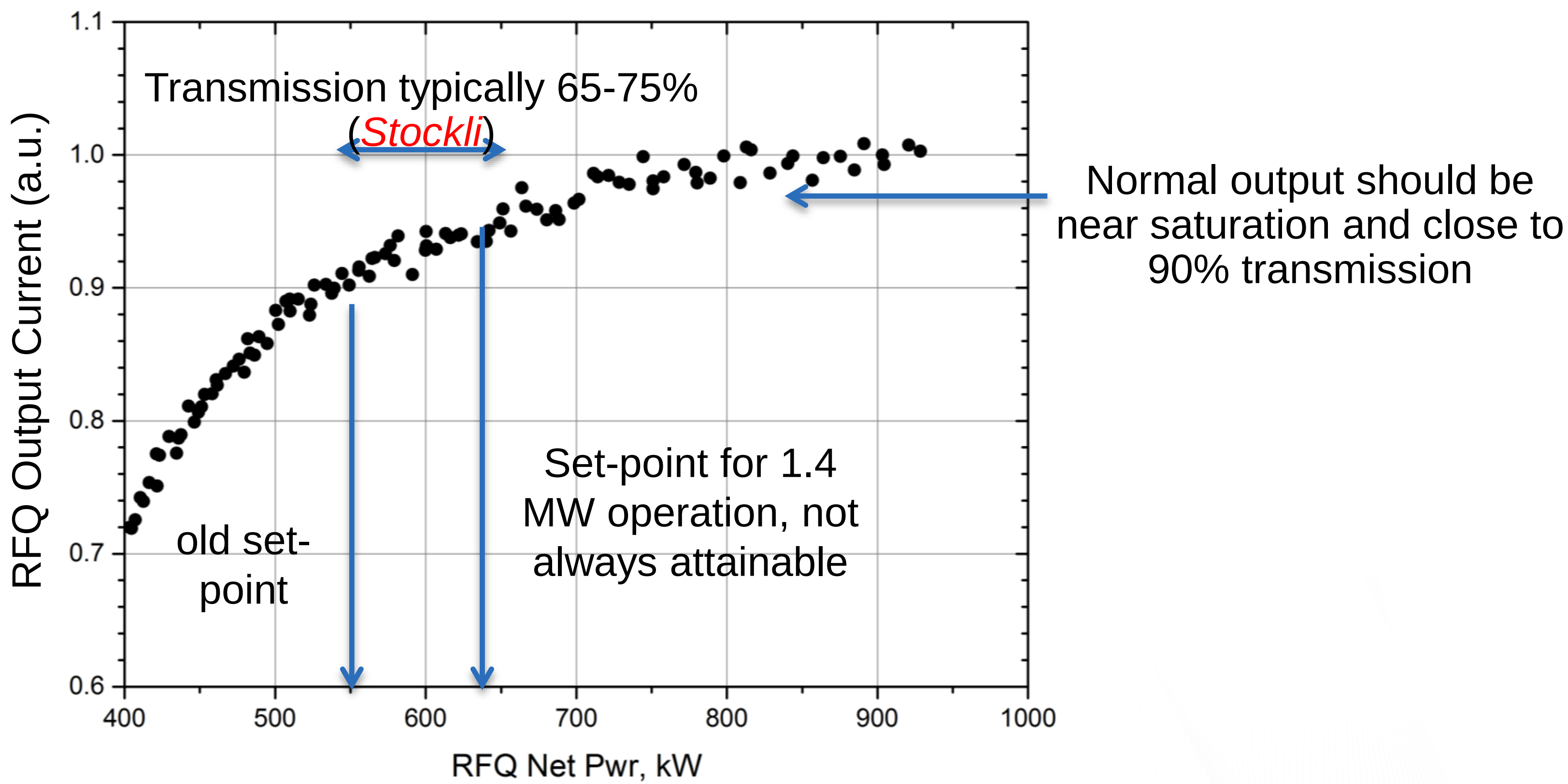
Historical RFQ Performance



Courtesy of Sasha Aleksandrov

- Nominal: operate with ~ 600 kW, 90% transmission

Getting the most out of a wounded RFQ
(Courtesy A. Shishlo)

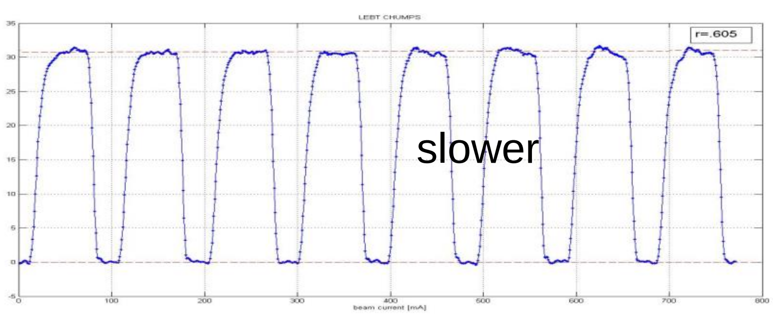


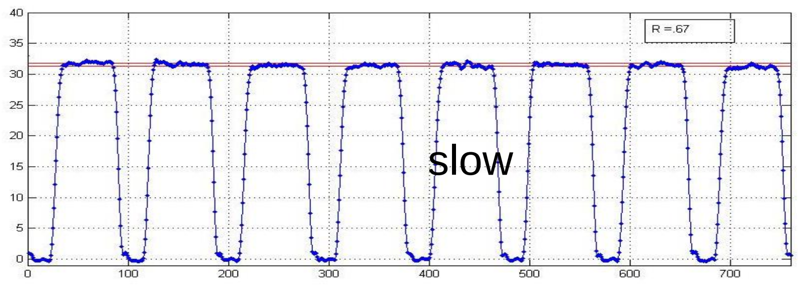
- Running at higher RFQ power gives more current…
  - But we are significantly below the expected transmission
  - Running at 600+ kW is not always possible (*Champion*)
  - New RFQ is a key step in path to reliable 1.4 MW operation

Keys for Reduced Chopping Fraction *(courtesy R. Saethre)*

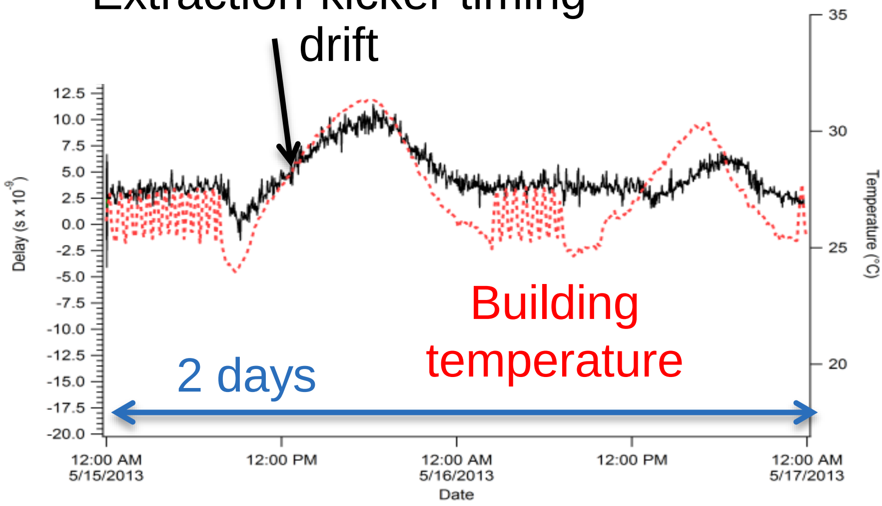
- Fast, reliable clean single stage chopping (LEBT)
- Clean up Ring extraction kicker jitter

Beam chopping circa 2009

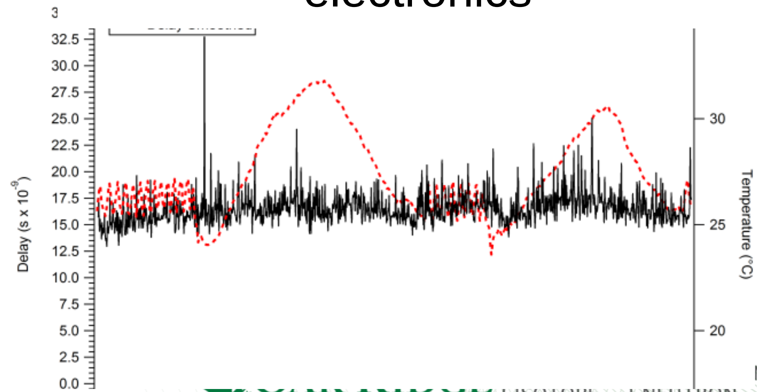




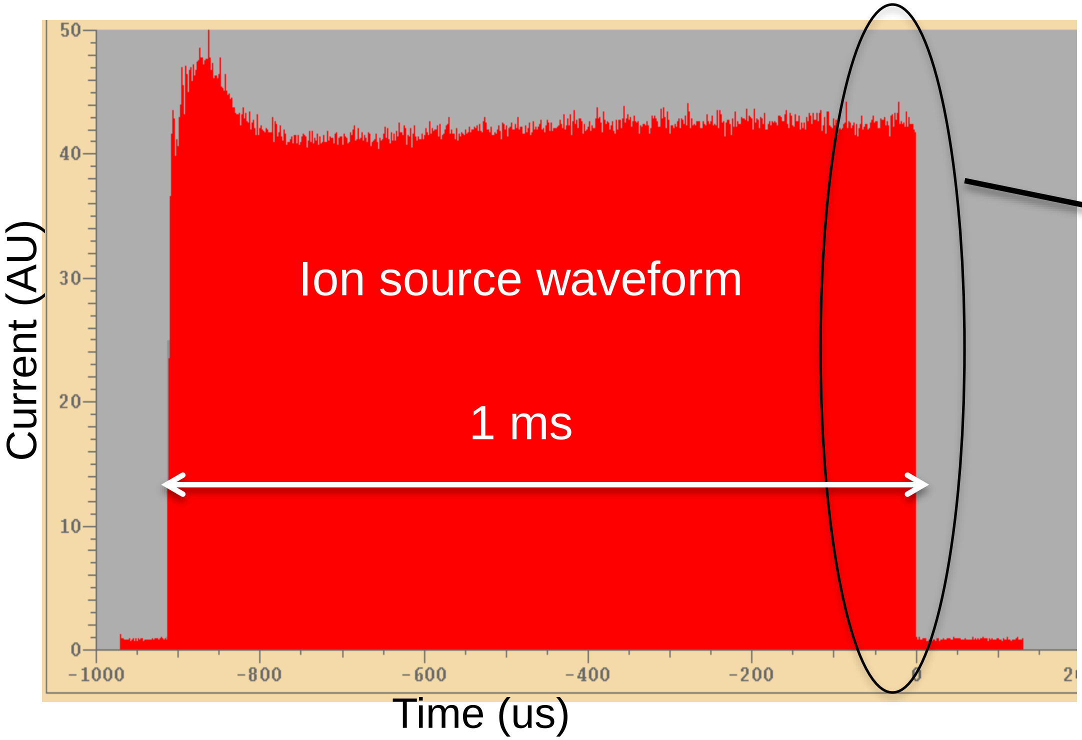
Extraction-kicker timing drift

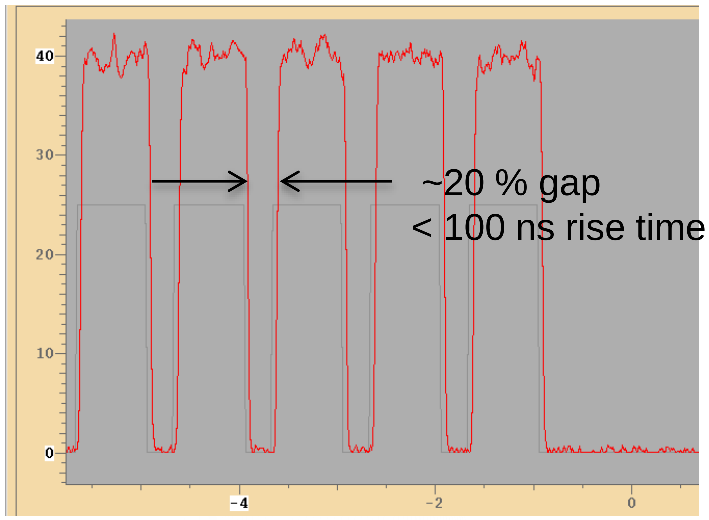


After thermal isolation of trigger electronics



Beam Current: Better Chopping





- Chopping quality for 1.4 MW operation
  - Smaller gaps than previously used
  - High quality LEBT chopping

1.4 MW: The Final Assault

	1.4 MW Design	1.08 MW Operation (March 2014)	1.4 MW Operation (June 2014)
Energy (GeV)	1.0	0.94	0.94
Rep rate (Hz)	60	60	60
Macro-pulse length (ms)	1.0	0.87	0.97
RFQ output beam current (mA)	38	32	35
"un-chopped" fraction	0.68	0.72	0.78

- Improved chopping covered up other deficiencies
- We need to provide margin in beam energy, current and pulse length to permit reliable, steady 1.4 MW operation

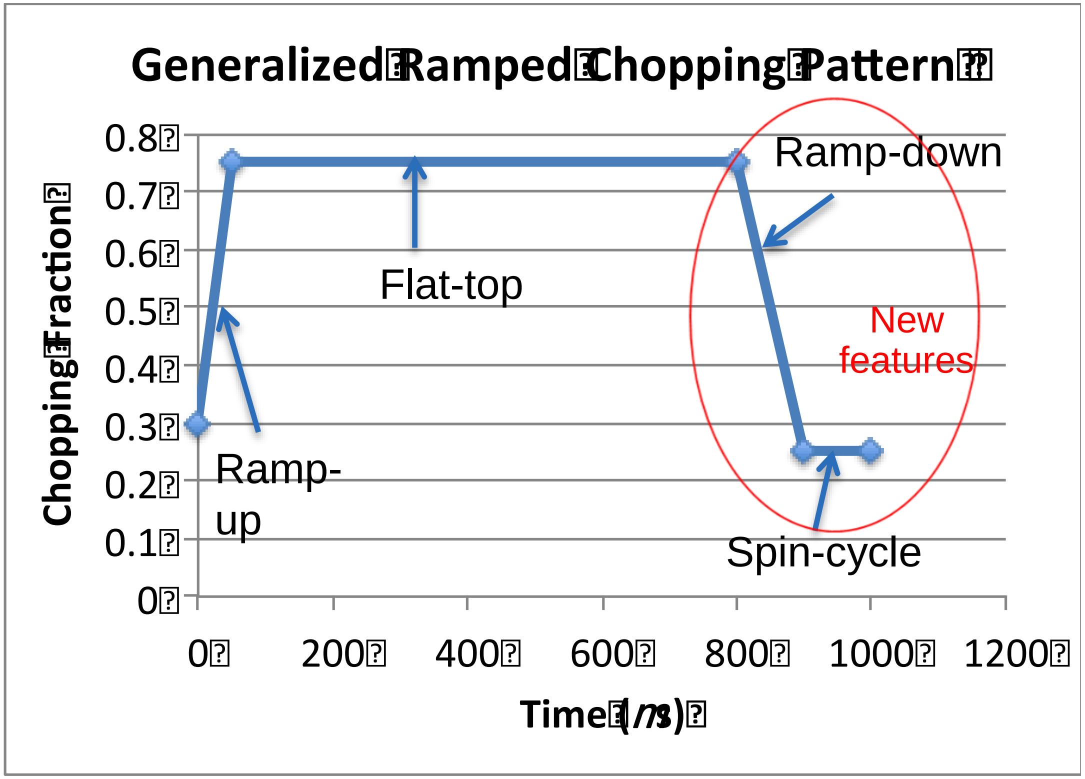
2013 AAC Recommendations

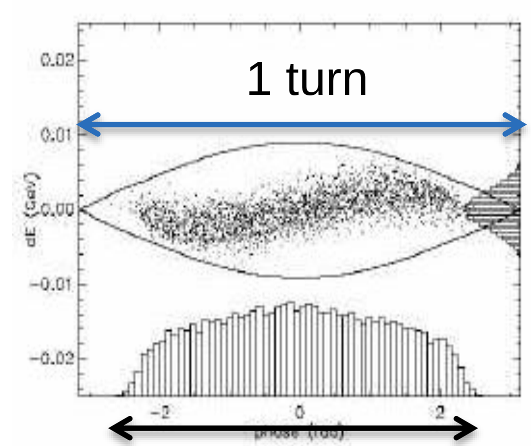
- *30. Establish an accelerator operations and development strategy based on beam tests that can be safely performed during the restrictions on operational power, followed by exploration of high power limits as soon as a sufficient spares queue is established.*
- *31. Retain flexibility to respond to development outcomes by adjusting to new points in (E, I, L) space if the primary plan does not pan out.*
- *32. Socialize the above strategy with the neutron user community.*
  - Have explored 1.4 MW operation space
  - Power increases / decreases were communicated to users

We Need Margin for Reliable 1.4 MW Operation

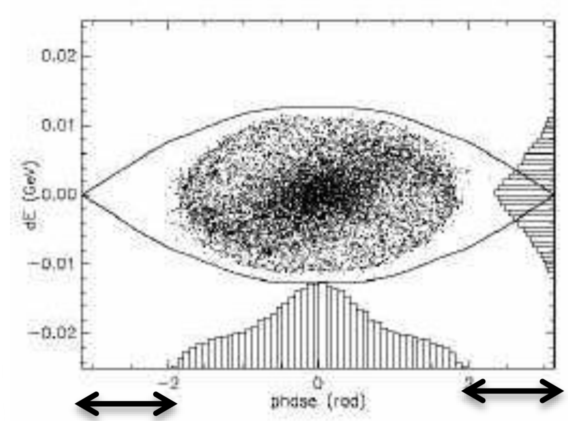
- We can run 1.4 MW "when the stars are aligned"
- Areas that will provide "power margin"
  - Spare RFQ needs testing with beam: 15-20% increase in transmission (*Champion, Aleksandrov*)
  - Smart Chopping: 5-10% (*Plum*)
  - Beam energy: plasma processing: 7% increase in beam energy (*Kim/Doleans*)
  - HVCM (modulator) development: ~5% from pulse flattening (*Anderson*)
- Some additional areas for attention
  - Injection area: Foil changer, foil holders, electron catcher (*Plum*)
  - Targets (*Abercrombie, Galambos*)

Smart Chopping





Relatively large un-chopped flattop most of injection



Longitudinal “tricks” to recover big gap at extraction time

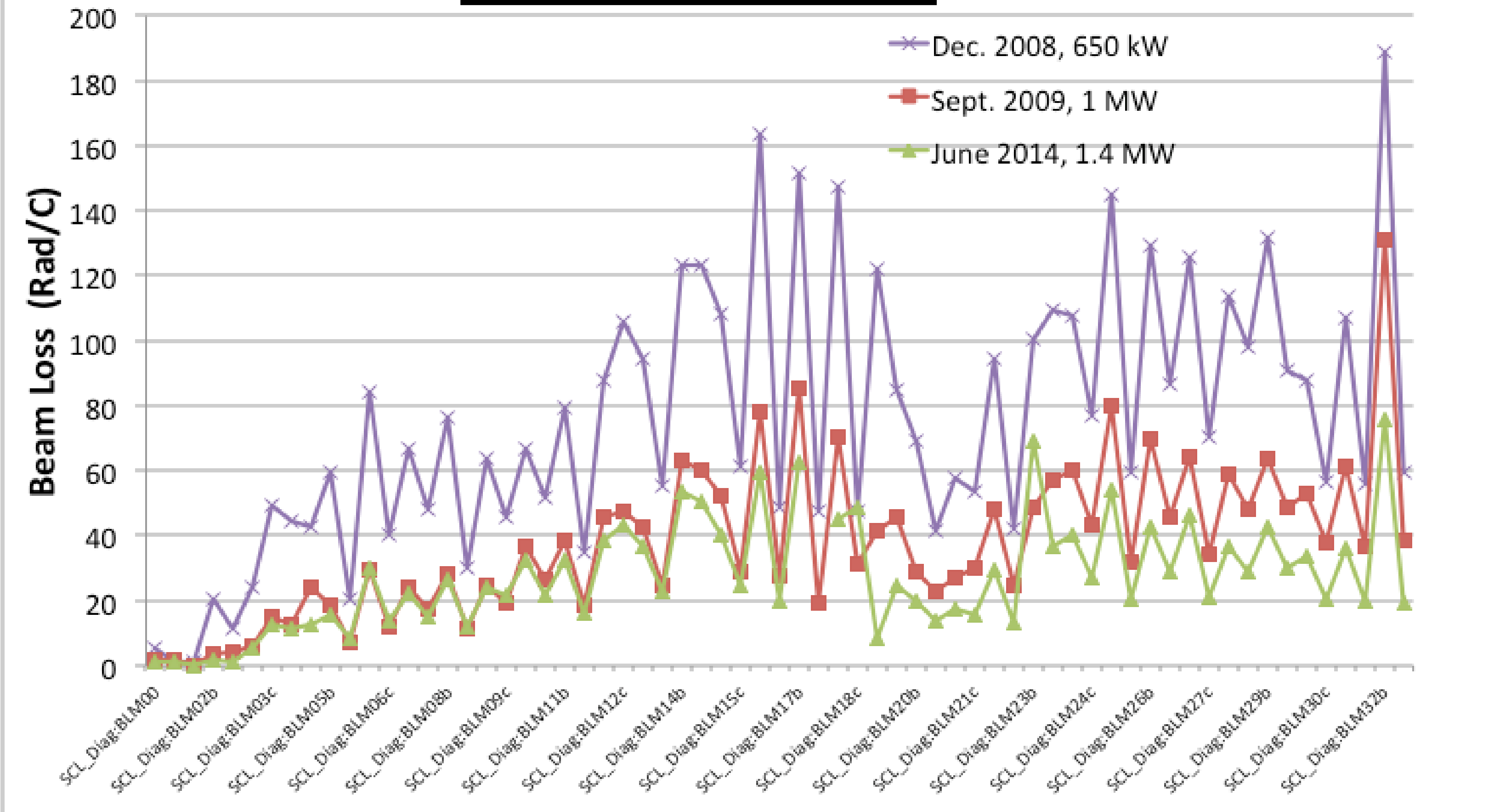
- Implementing chopper controller changes this summer
  - 10% increase in “average un-chopped” fraction may be possible

Beam Loss / Machine Activation at ~1.4 MW

- Linac beam loss
  - Compare beam loss along the SCL for different powers
  - Track historical activation trend
    - Average residual activation along the SCL at 30 cm
- Ring beam loss
  - Compare beam loss at injection (dominate loss) for different powers
  - Track historical activation of injection region
    - Hottest spot down-stream of foil, at 30cm

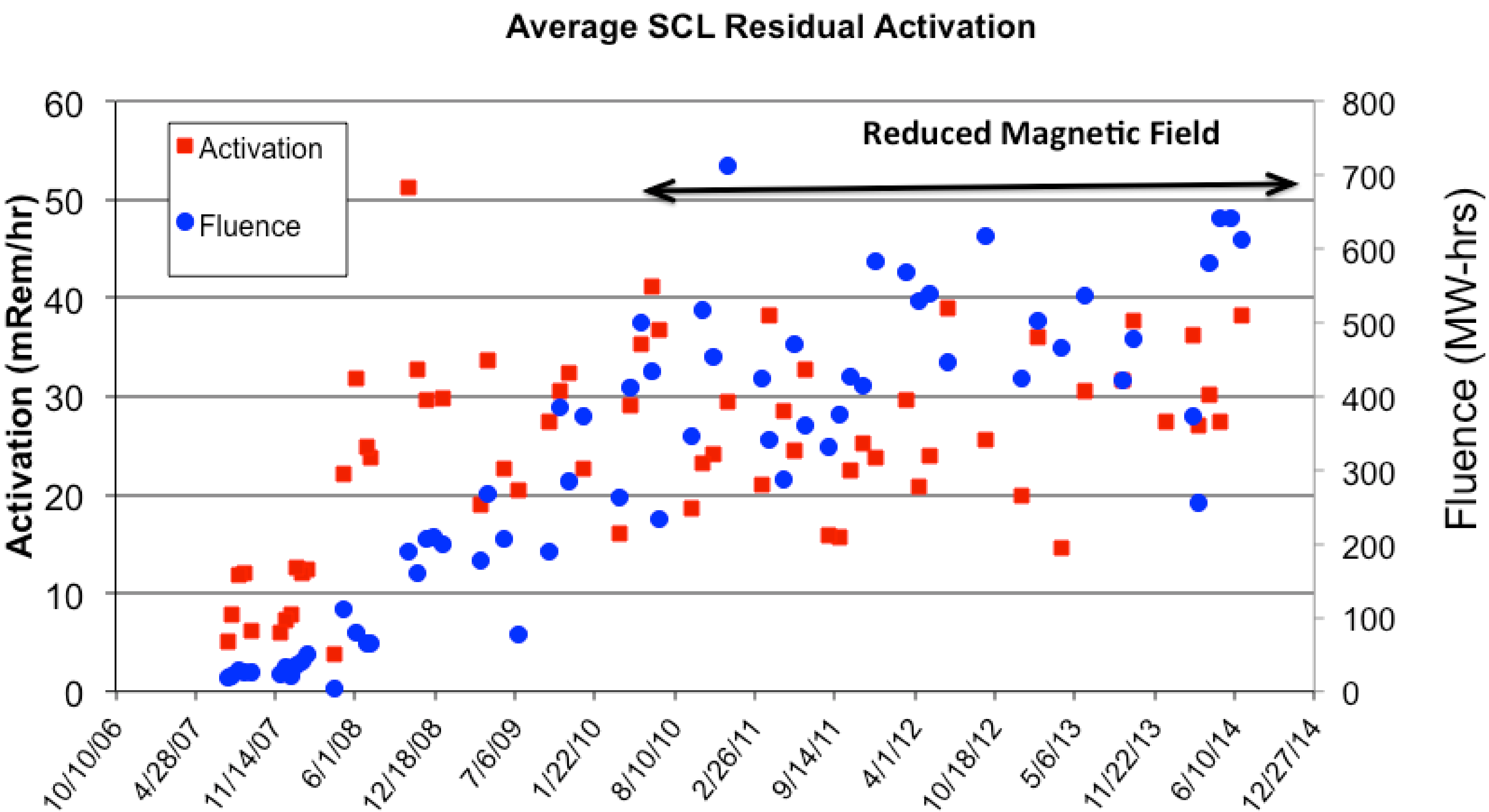
Superconducting Linac Beam Loss History

BLMs along the SCL



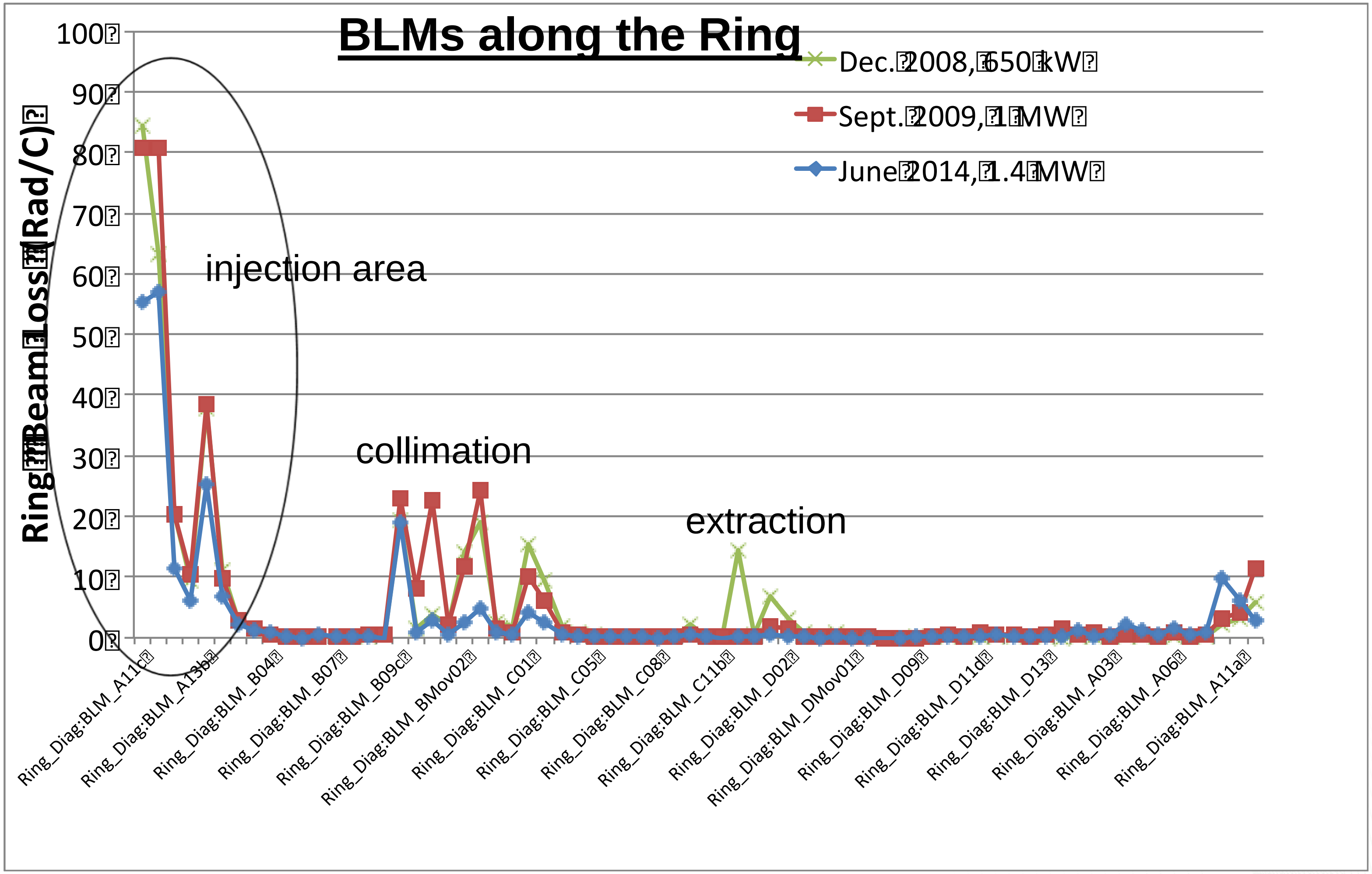
- Big drop in losses with focusing strength reduction in early 2009
- Modest benefit since

SC Linac Activation: Not Horrible
(Courtesy C. Peters)



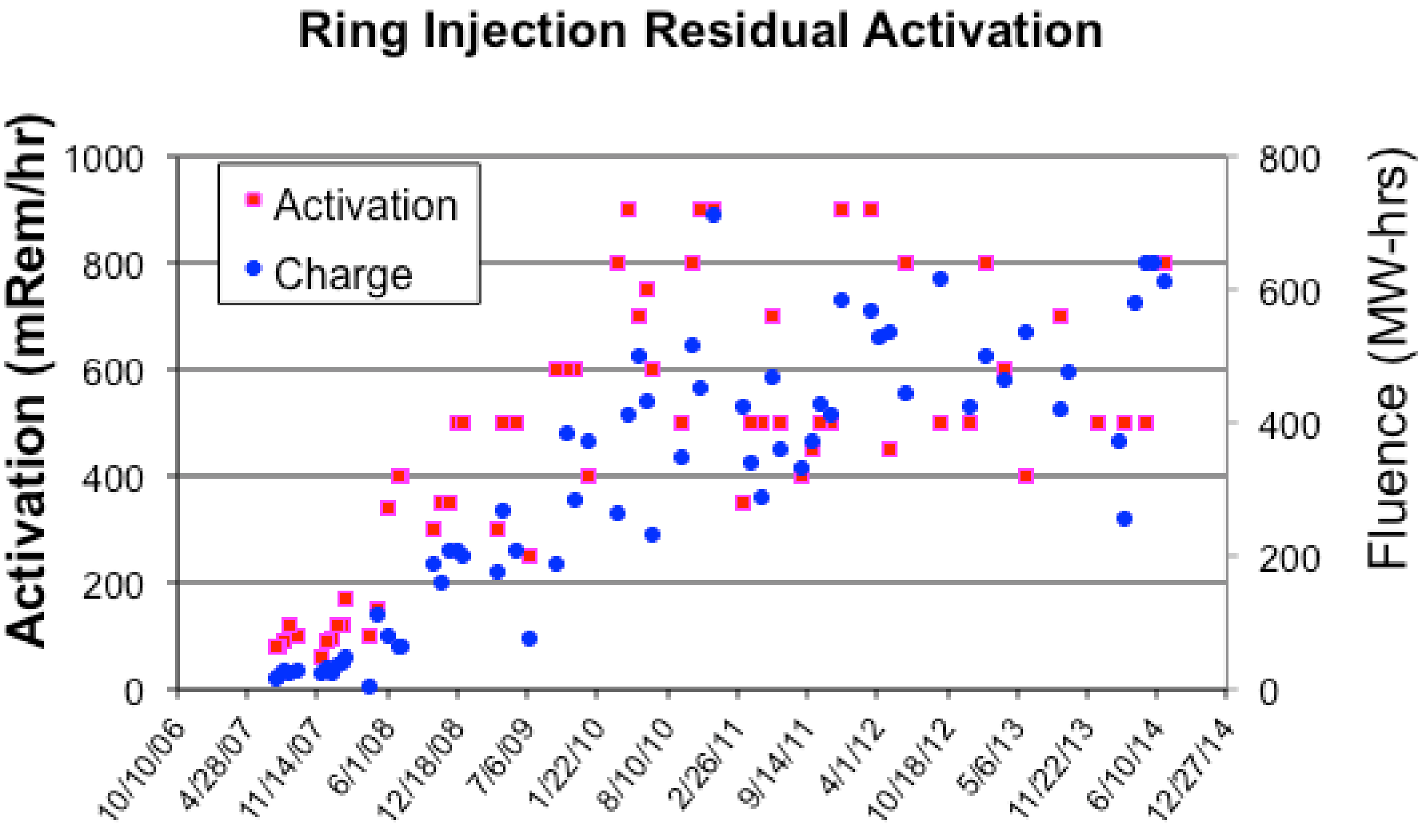
- Fairly steady activation level since 2010

Ring Beam Loss History



- Ring loss not getting worse – a bit of improvement

Ring Injection Activation (Peak)
(Courtesy C. Peters)



- No obvious jump in activation downstream from the foil

Summary

- SNS was designed to operate at 1.4 MW
  - 1.4 MW was achieved, albeit not as designed
  - Minimal operational margin though
- Margin is possible with
  - Proper RFQ behavior (new RFQ)
  - Smart chopping
  - Plasma processing
  - Modulator flattop