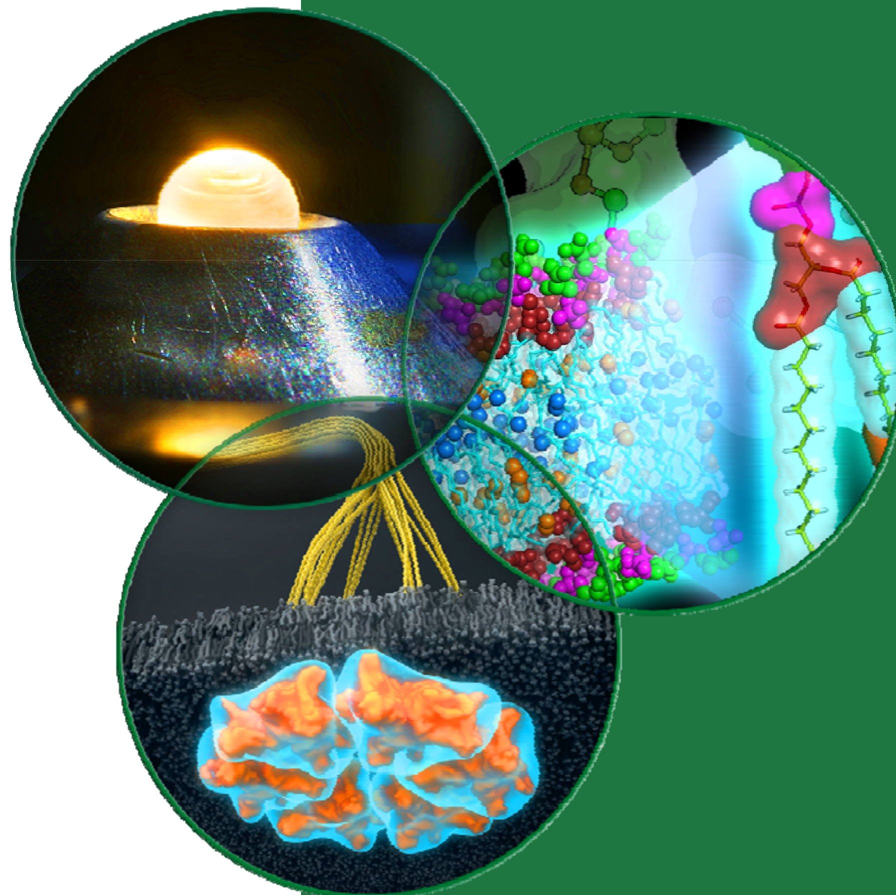
Sustainable, Reliable SNS Operation at 1.4 MW



Presented to
Neutron Advisory Board

Presented by
Kevin Jones
Research Accelerator Division
Director

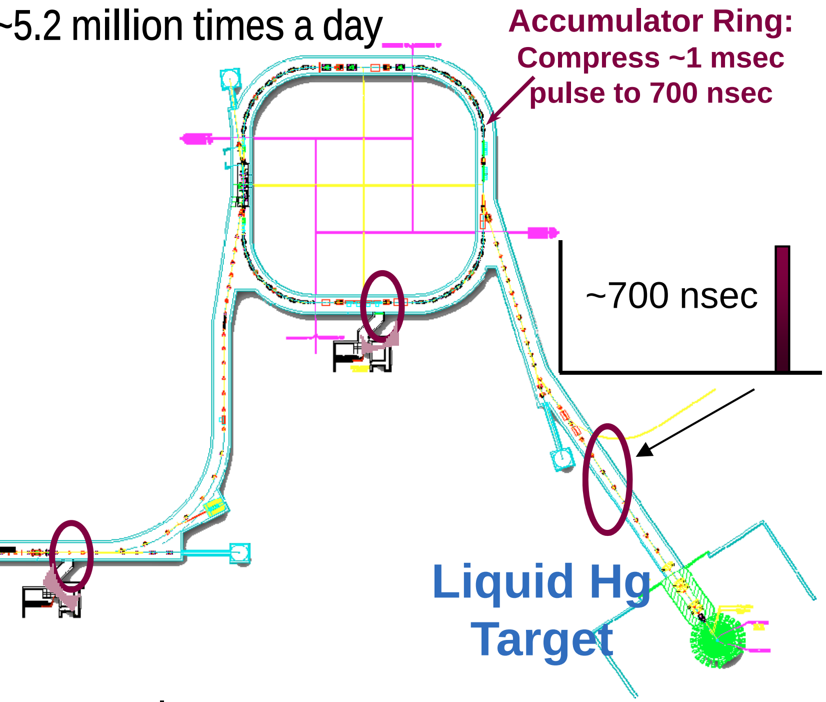
June 30, 2016
Clinch River Cabin
Oak Ridge, Tennessee

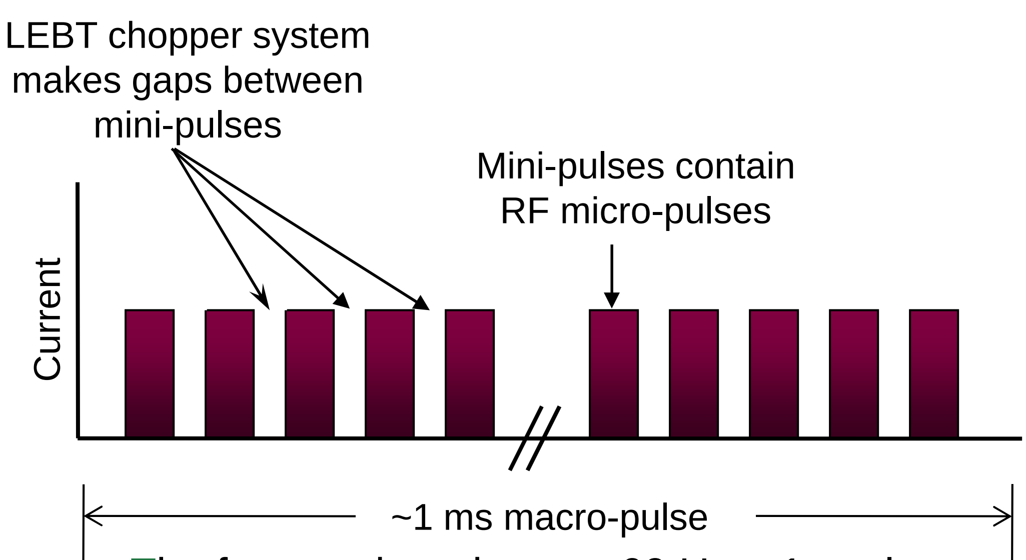
Outline

- Recent SNS operational history
- Core system reliability
- RFQ transmission
- Plasma processing to increase beam energy
- Smart chopping
- Ring injection at high beam power
- Summary

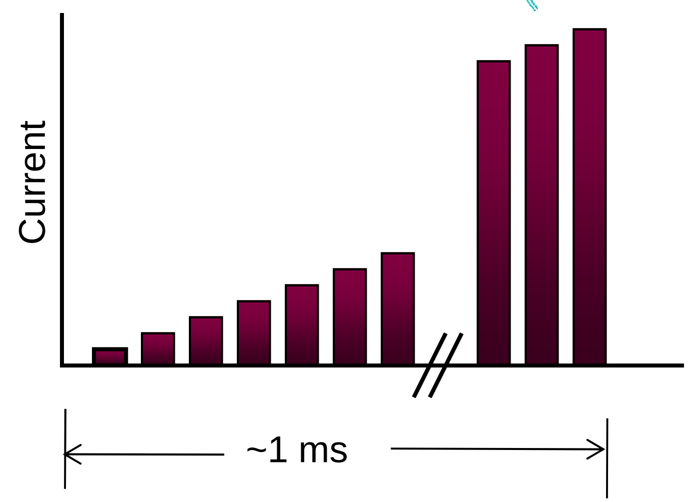
The SNS is a complex machine that performs well – overall system reliabilities (excluding targets) > 90%

- The SNS machine has over 100,000 control points and cycles ~5.2 million times a day
- Power (and base neutron flux) is the product of:
  - Peak Current
  - Chopping Fraction
  - Beam Energy
  - Pulse Length
  - Repetition Rate

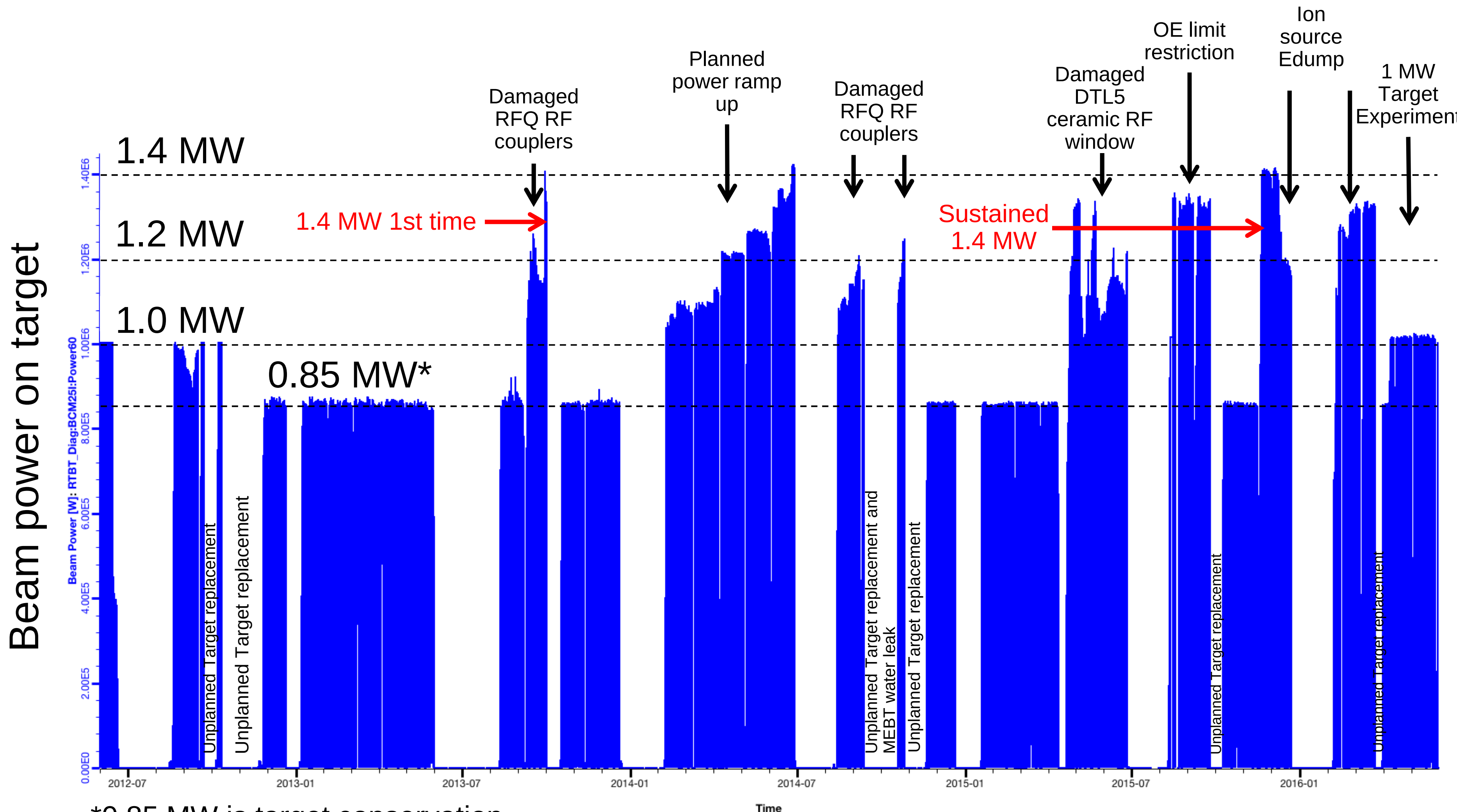




The front end produces a 60 Hz, ~1 ms long chopped H- beam



The SNS four-year beam power history illustrates both successes and challenges



*0.85 MW is target conservation

Jun. 1, 2012 to May 31, 2016

Sustainable and reliable operation at 1.4 MW depends on addressing obsolescence through capital investment

Downtime by System				
System	**Sub-system**	**FY14 [hours]**	**FY15 [hours]**	**FY16 [hours]**
Target	Target Module	89.1	560.2	354.8
Beam Instrumentation	Chopper target	24.3	419.1	1.6
RF	High Power	133.6	152.7	88.8
Electrical	HVCM	70.5	75.6	72.7
Electrical	Power Supplies	25.0	44.8	20.6
Electrical	AC Distribution	25.6	111.6	3.8
Vacuum		21.7	39.5	0.3
Ion Source		25.2	38.4	23.9

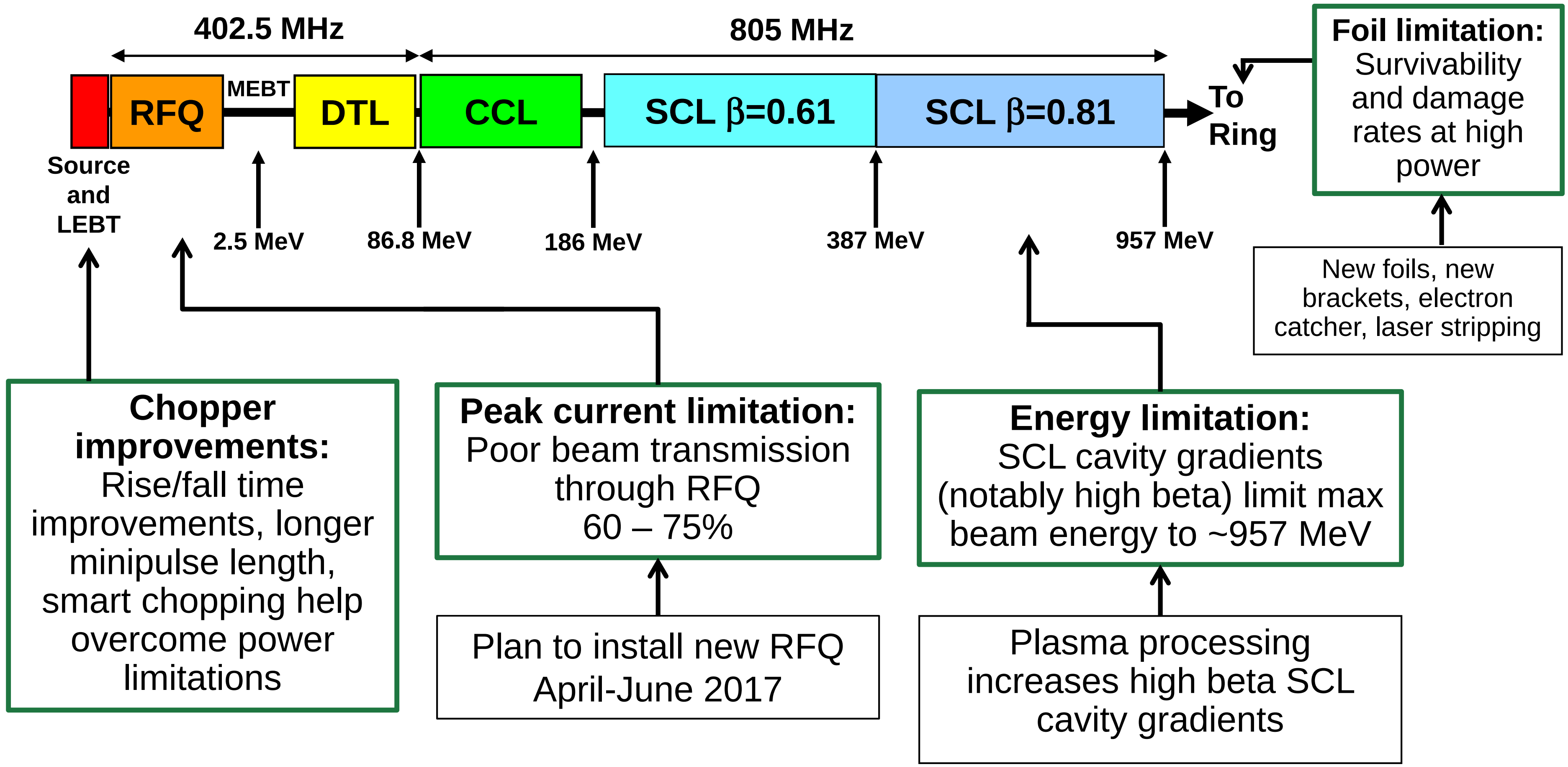
Unique high-consequence event

- Biggest sources of routine availability limitation are linac high power RF and the associated High Voltage Converter Modulators
- No obvious correlation with high beam power
- Developing AIP plan to mitigate obsolescence and maintain performance

*AIP – Accelerator Improvement Project funded by capitalized portion of the accelerator operations field work proposal – currently about $3M annually

OAK RIDGE National Laboratory

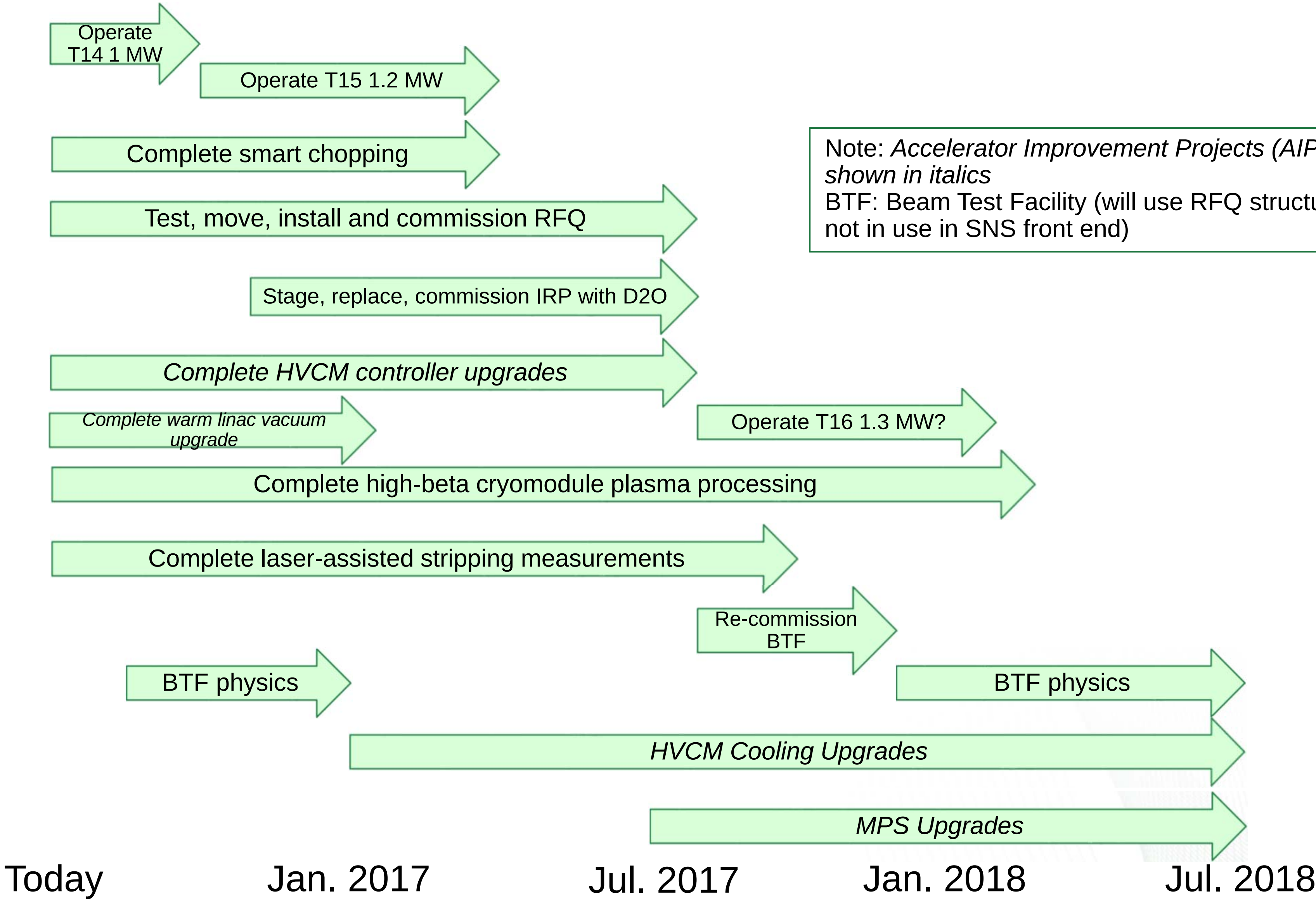
SNS has identified and is addressing barriers to operation at 1.4 MW with margin



Accelerated peak current and beam energy limitations have been offset by LEBT chopper improvements, but we need more margin

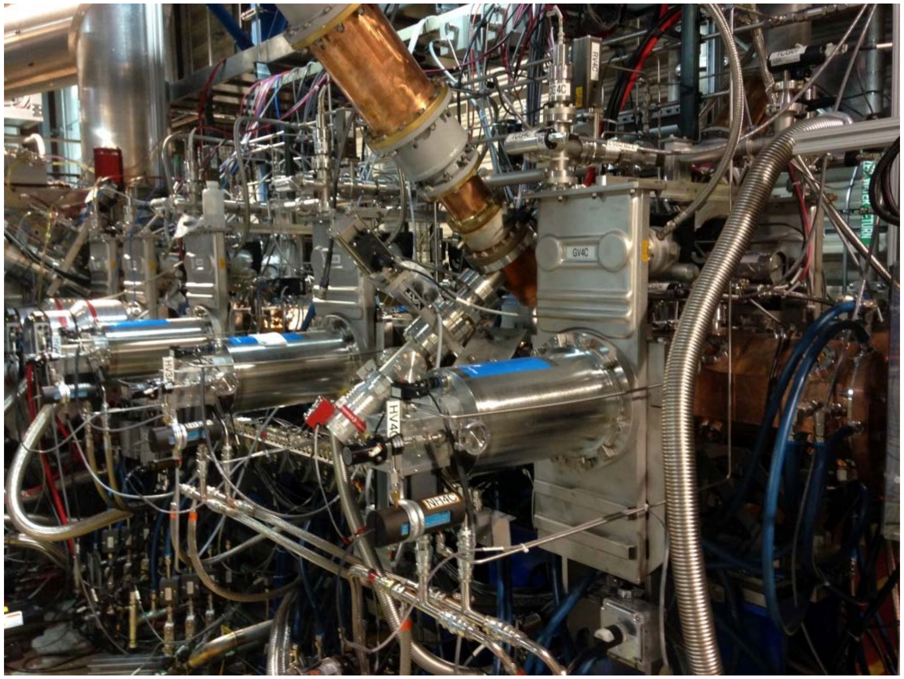
SNS has a comprehensive program underway to address our challenges

Note: *Accelerator Improvement Projects (AIP) shown in italics*
BTF: Beam Test Facility (will use RFQ structure not in use in SNS front end)



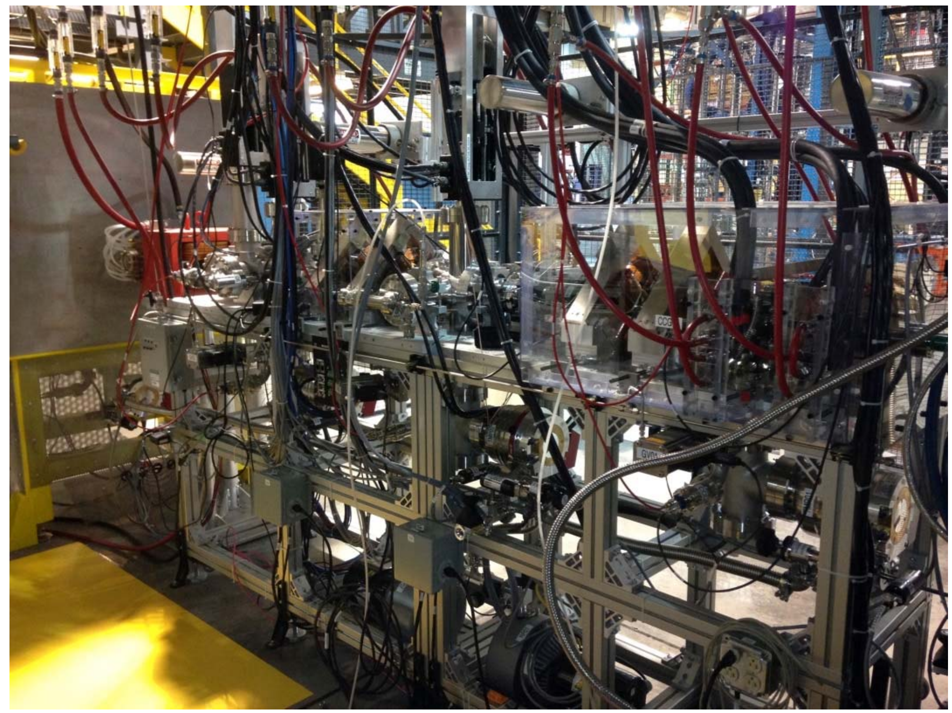
OAK RIDGE National Laboratory

The new Beam Test Facility is awaiting DOE authorization to demonstrate that the spare RFQ functions as designed



View from RFQ high energy end toward ion source showing vacuum and RF services

Medium Energy Beam Transport toward 7.5 kW Beam Stop



OAK RIDGE National Laboratory

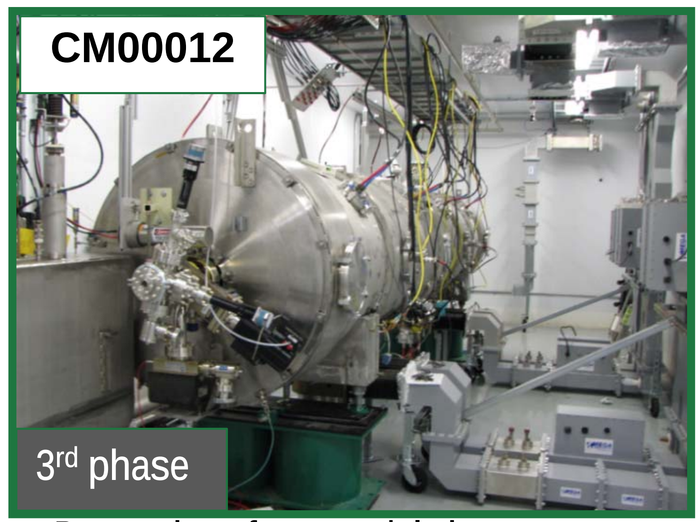
Successful in-situ plasma processing of high-beta cavities is being used to increase the beam energy

R&D with Nb samples and offline cavities

Processing of 6-cell cavity in HTA*

In-situ processing in linac tunnel

On-going
FY16
FY17

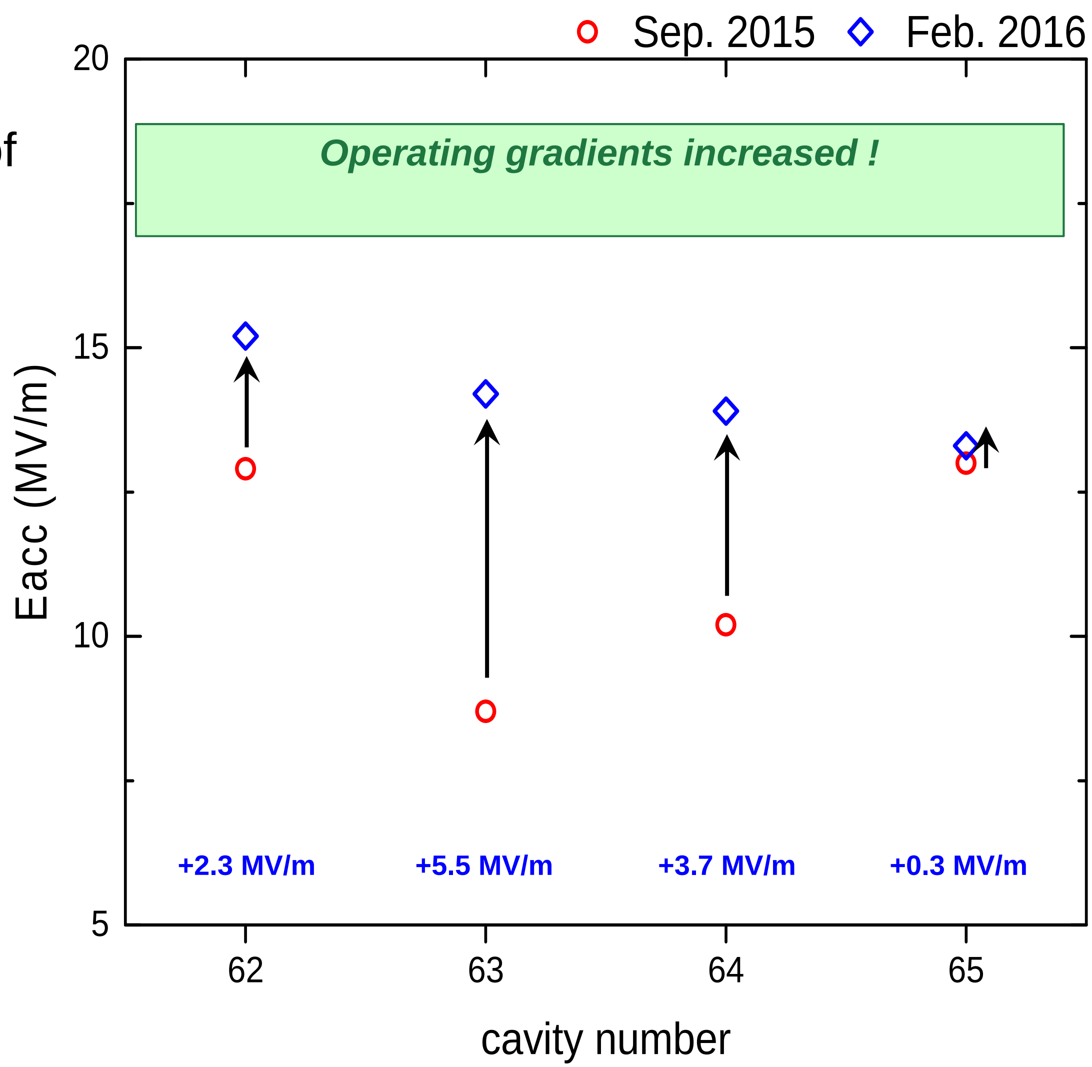


Processing of cryomodule in test cave

*HTA: Horizontal Test Apparatus

In-situ plasma processing raises the linac energy by reducing field emission to increase accelerating gradients

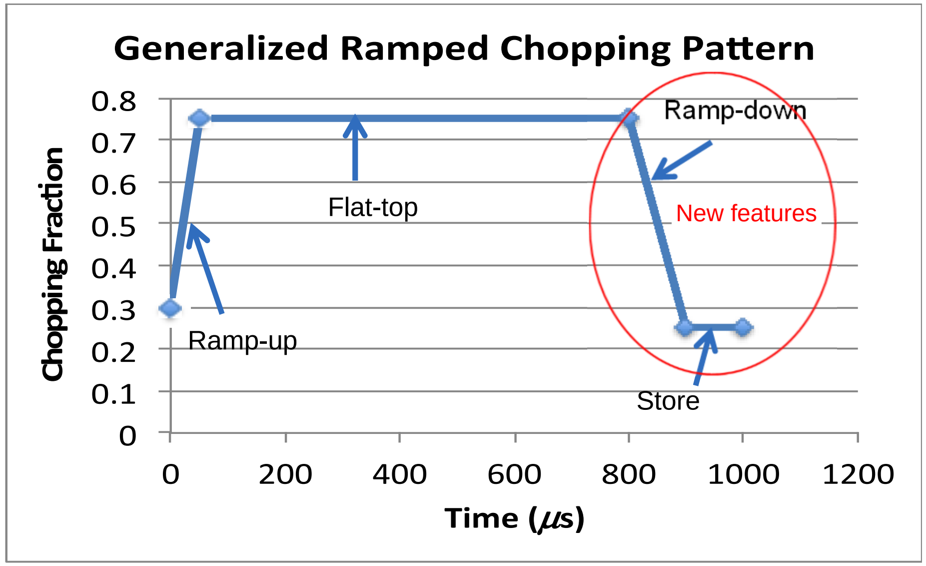
- Maximum accelerating gradients in many high-beta cavities significantly below design value of 15 MV/m
- Hydrocarbon contamination is a key contributor to increased field emission
- During last winter outage, processed cryomodule in slot 19
- Average accelerating gradient
  - 11.2 MV/m before plasma processing
  - 14.2 MV/m after plasma processing
- Beam energy increase from plasma processing of slot 19
  - ~11 MeV

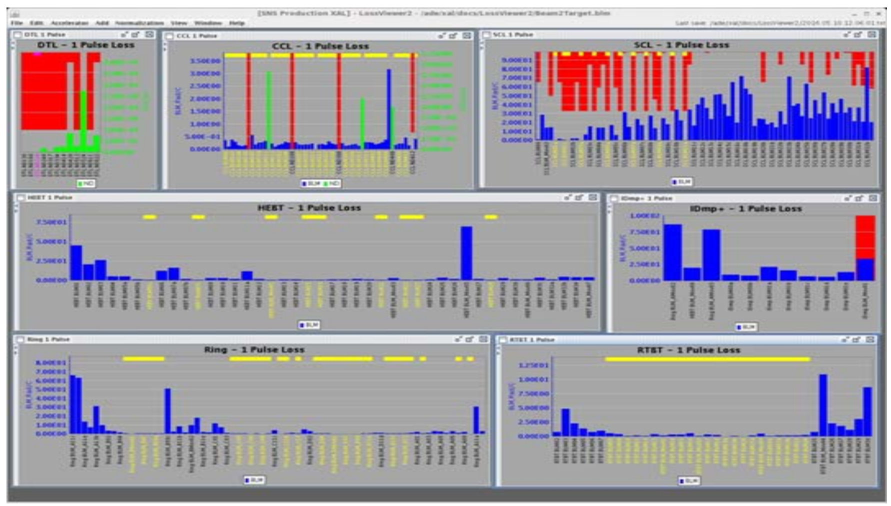


OAK RIDGE National Laboratory

"Smart chopping" offers the possibility of further increasing accumulated beam charge in the ring

- Status:
  - Basic capability established
  - Initial experiment suite complete
- Identified need for additional ramp-down/store software options
- New tools under development



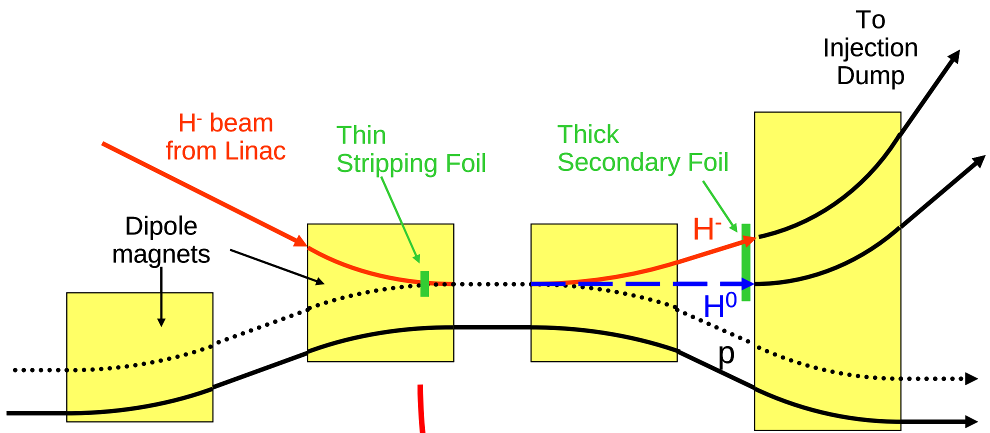


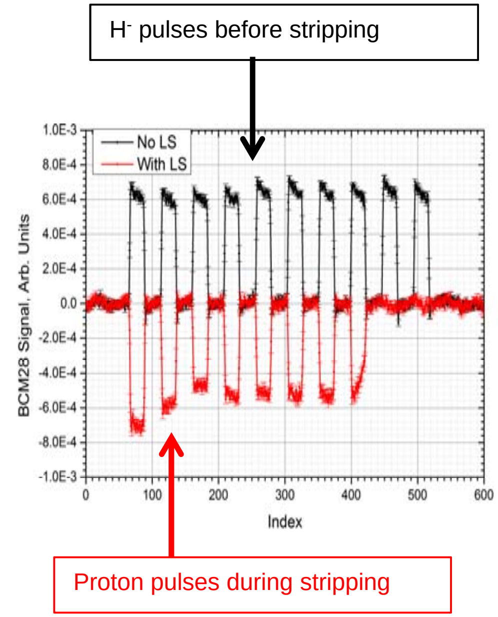
Demonstrated near-nominal extraction losses with PW of 54 and 200 turns of storage

Up to ~7% increase in "average un-chopped" fraction may be possible

OAK RIDGE National Laboratory

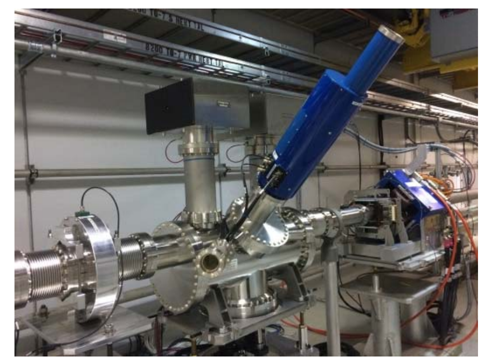
SNS beam injection presents foil survivability challenges at high beam power





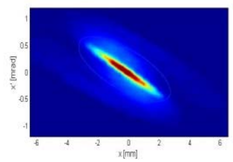
- Evaluating new TZM brackets - almost zero damage at full 1.4 MW beam power

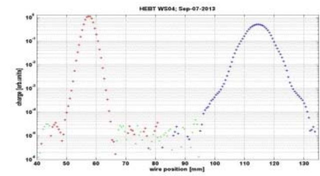
- We are developing laser-assisted stripping (HEP grant through UTK) – recently demonstrated ~10μs stripping at >90% efficiency



OAK RIDGE National Laboratory

Integration of beam measurements and simulations is leading to improved beam loss management





6D phase space measurement on Integrated Test Stand

Add linac simulation capability to PyORBIT

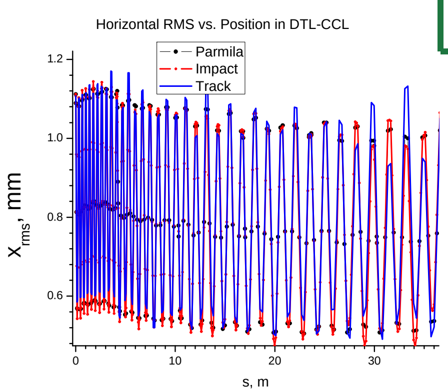
Benchmark simulations with measurements

Beam-based measurement of lattice parameters

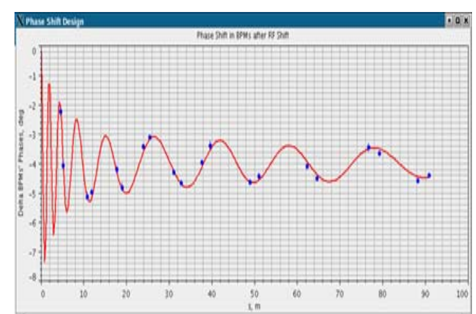
Need accurate input distribution for simulation codes

Need good linac simulation code

Need accurate SNS linac lattice

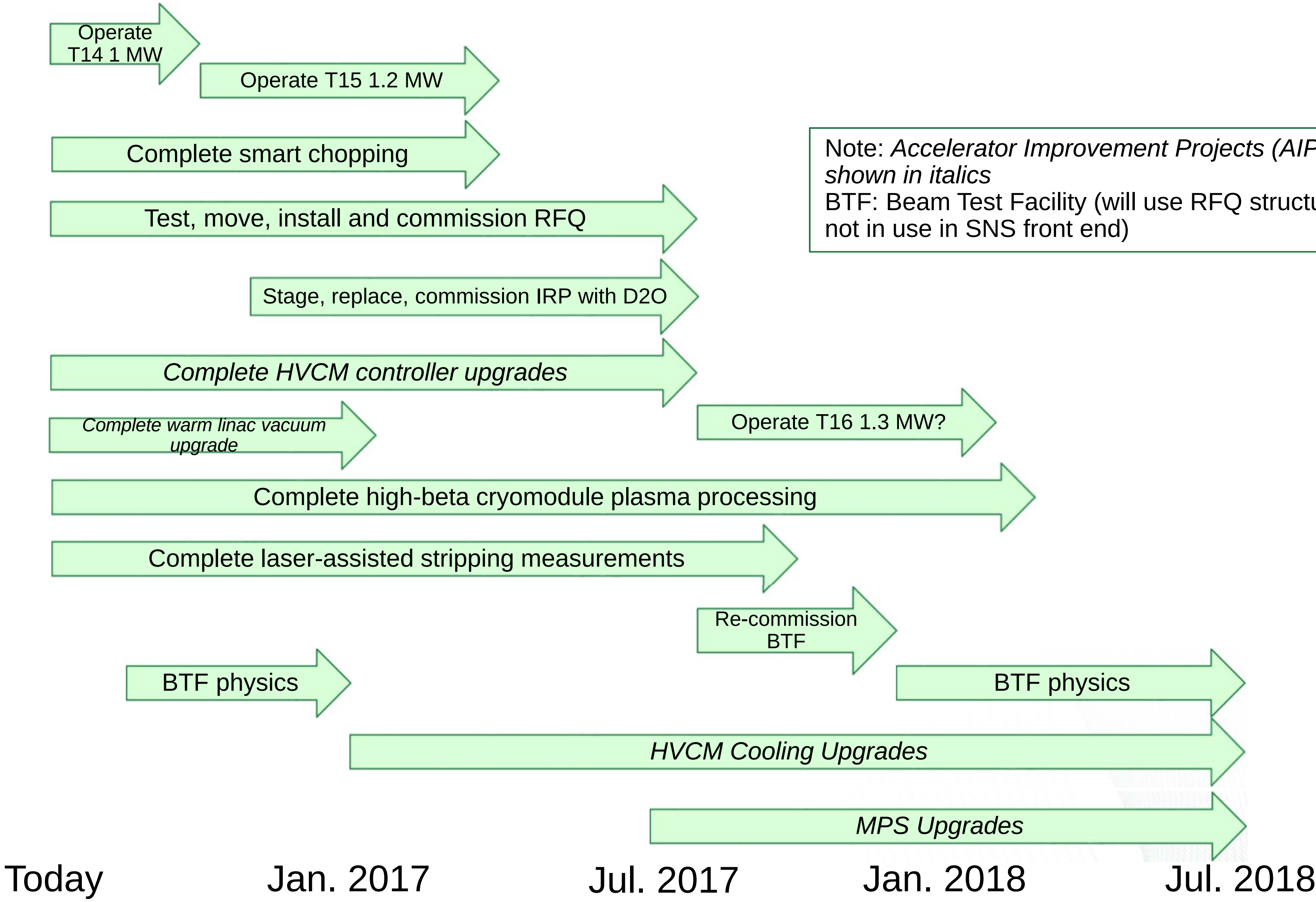


Simulation determines parameters for minimum beam loss



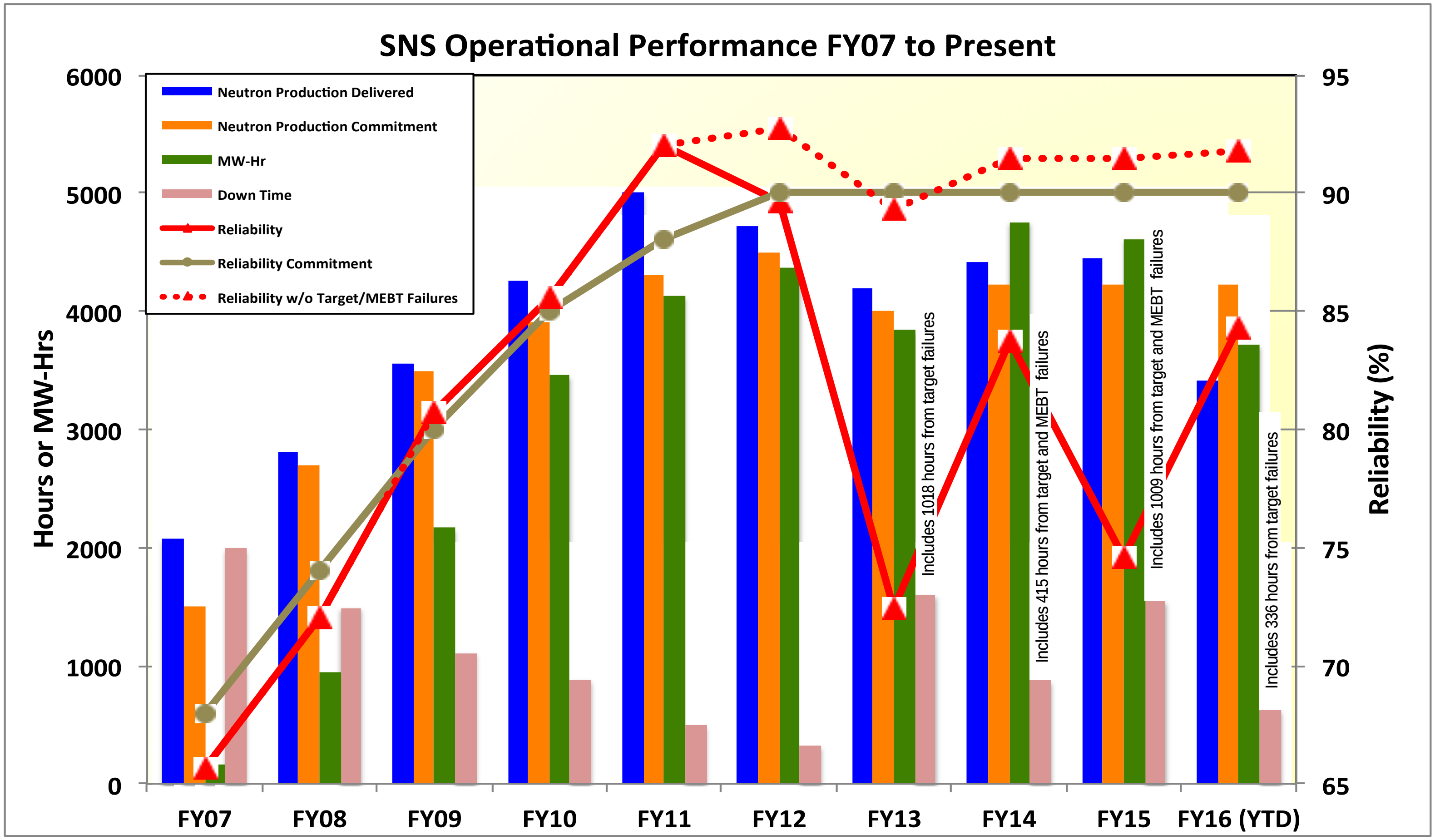
Summary: SNS has a comprehensive program underway to address our challenges

Note: *Accelerator Improvement Projects (AIP) shown in italics*
BTF: Beam Test Facility (will use RFQ structure not in use in SNS front end)



Additional information

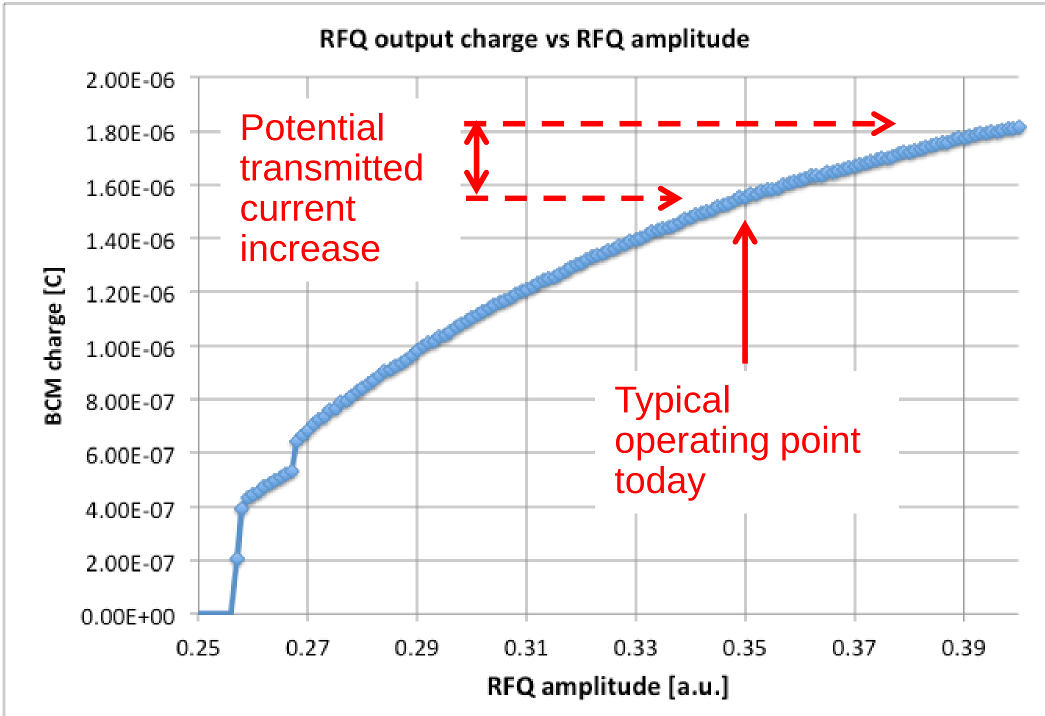
Since FY13 both predictability and reliability have been significantly affected by target end-of-life conditions and one other unique event



Sponsor has expressed a strong preference for predictability and reliability over peak power – recent overall availability was a cause for sponsor concern in the outcome of the Triennial Review held in August 2015

Beam transmission through the RFQ is the primary limitation on beam power

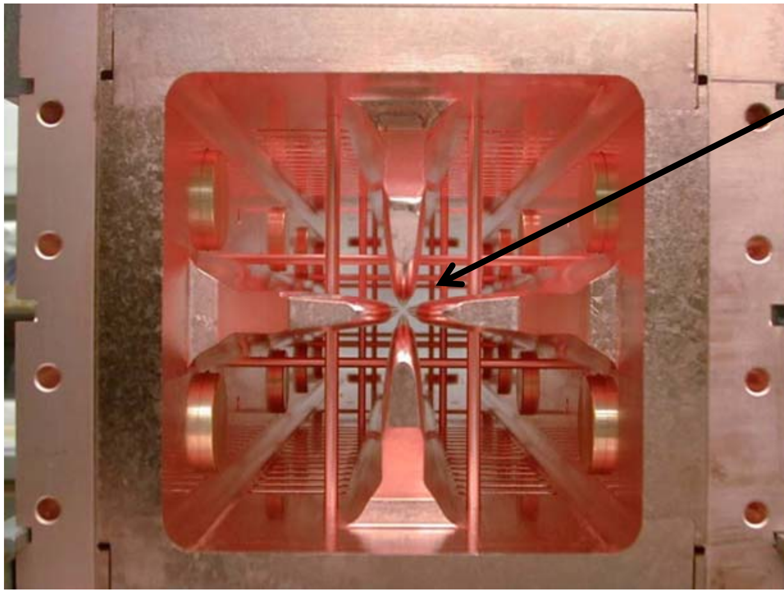
- Structure has experienced three detuning events
- Due to thermal (resonance) instability we cannot operate the RFQ at the design field
- Measured transmission is 12 – 30% less than design
- This is the primary limitation in 1.4 MW margin
- Absolute RF field measurements are difficult, and there is uncertainty in the actual fields



Courtesy A. Shishlo
Oct. 27, 2015

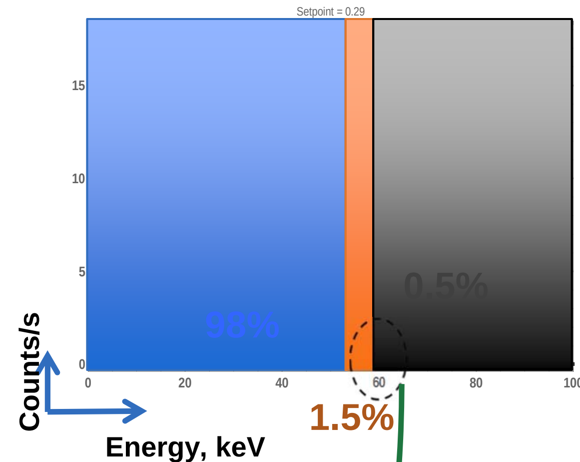
A team of experts has been established to evaluate all aspects of RFQ and front-end performance to assure management that the problem does indeed reside in the RFQ structure – report due by November 2016

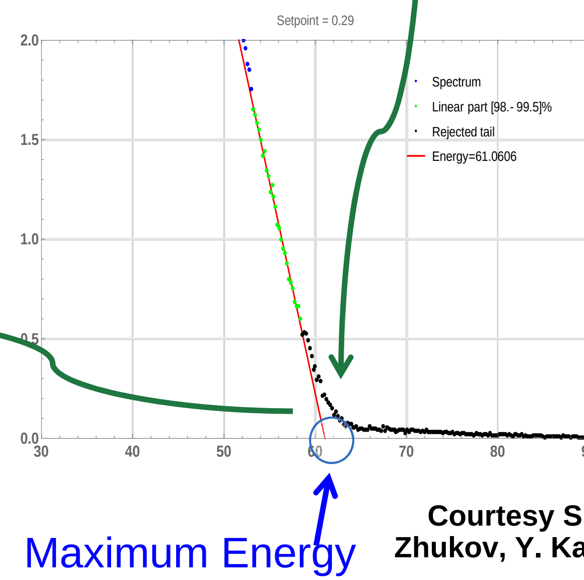
One technique to understand performance is to measure the operating vane voltage using emission x-rays



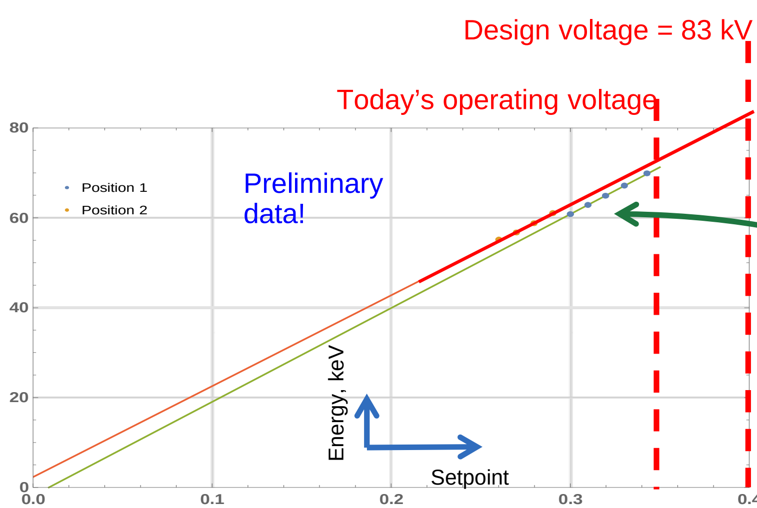
Measure x-ray spectrum emanating from center of RFQ

Gives absolute measurement of maximum voltage between vane tips, and thus absolute measurement of RFQ field amplitude





Absolute field measurements suggest the voltage is low by about 15%

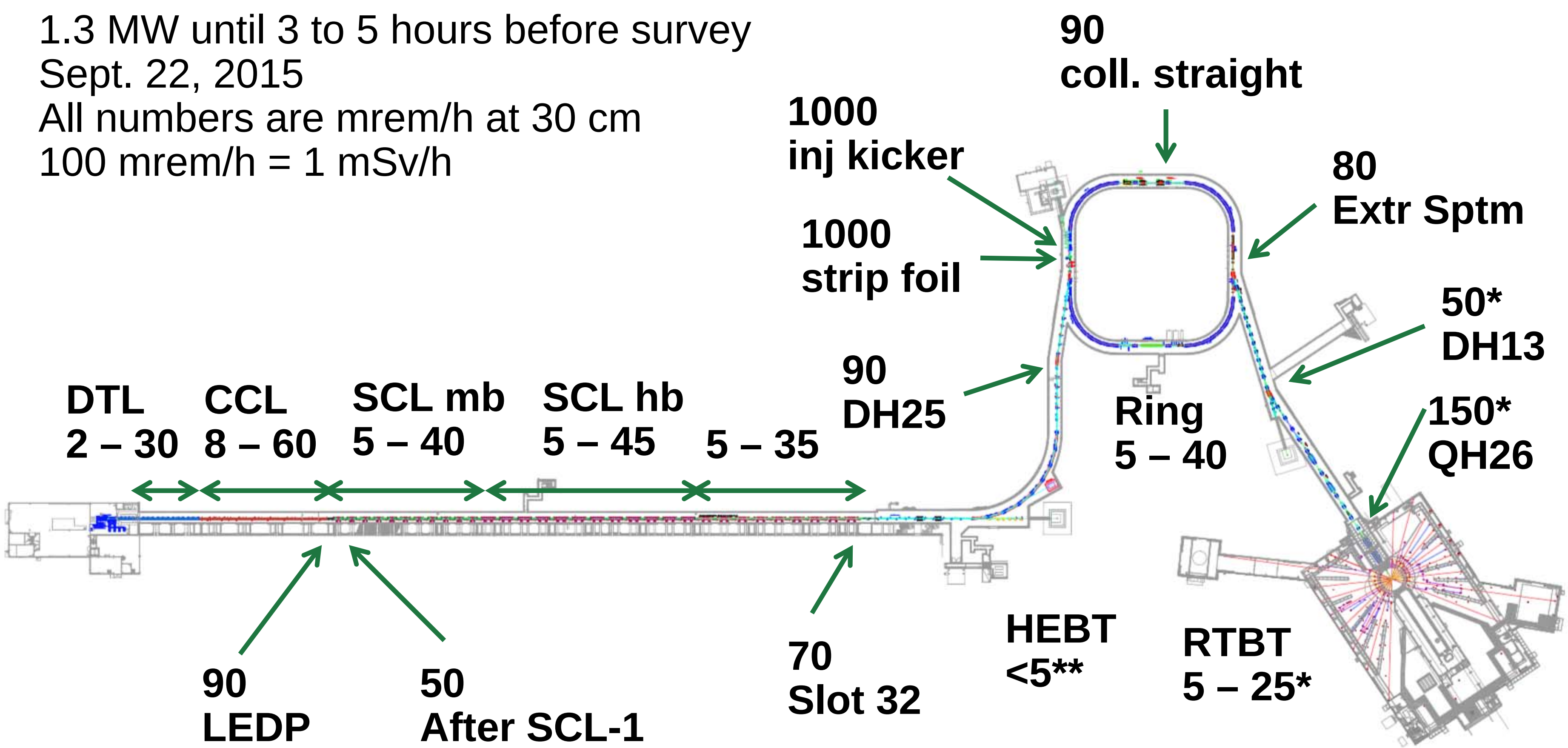


Courtesy S. Zhukov, Y. Kang

OAK RIDGE National Laboratory

Residual activation levels in the machine must be managed for sustainable high-power operation

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 but improvements are needed

* 3 days after 1.3 MW
** No survey near this time, indicated does rates are typical

Summary: SNS has a well-defined path to high power, high availability operation

- Replace RFQ
  - Plan to install April 2017, assuming RI RFQ commissioning successful
- Increase high-beta SCL cavity gradients
  - Started Jan. 2016, ongoing
- Develop gradient improvement for medium-beta SCL
- Smart chopping
  - Started Fall 2015, ongoing
- Addressing foil support and convoy electron issues
- Implementing analytical tools with fundamental R&D to address halo formation and beam loss control
- AIP program to address reliability issues
  - In progress