Evolution of Superconducting Linac Output Energy at SNS

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S. Kim, R. Afanador, D. Anderson, D. Barnhart, M. Crofford, B. Degraff, M. Doleans, J. Galambos, S. Gold, M Howell, J. Mammosser, C. McMahan, T. Neustadt, C. Peters, M. Plum, J. Saunders, D.J. Vandygriff, D.M. Vandygriff,
SNS, ORNL

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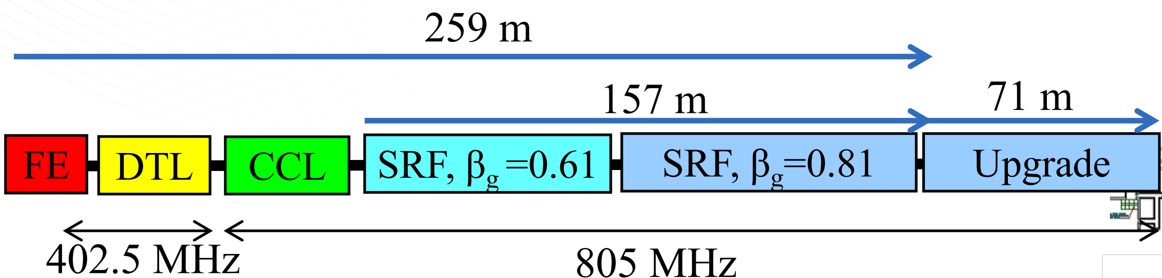
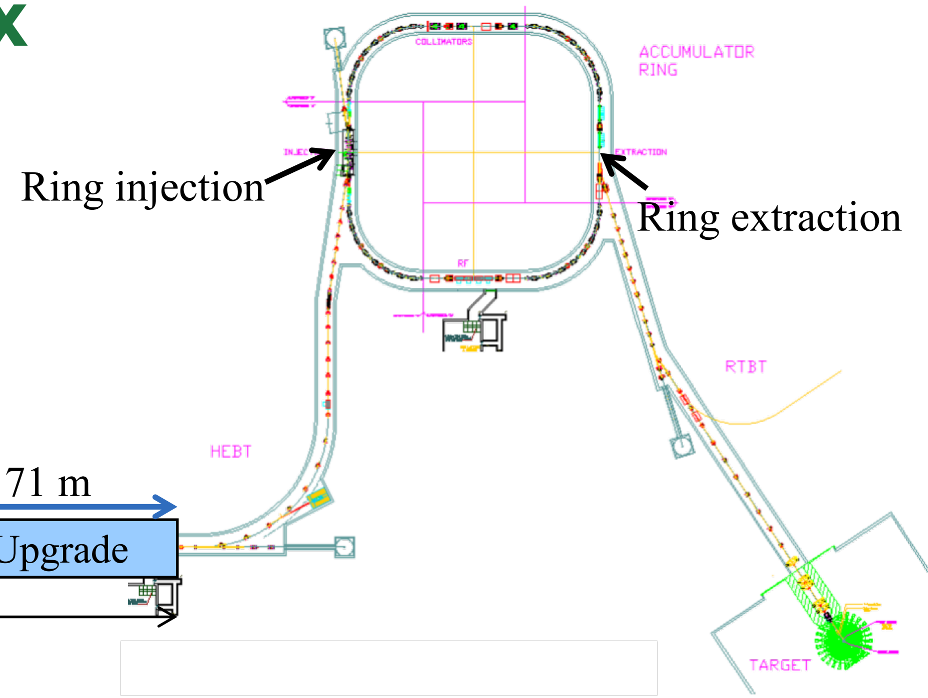
Outline

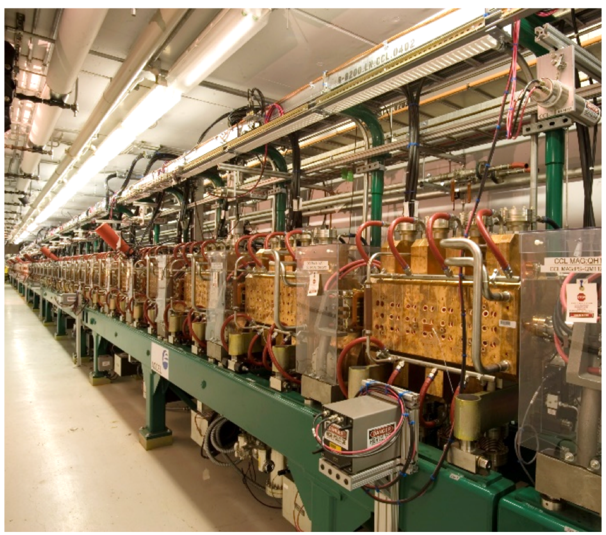
- Overview
- Early state of operation at SNS
- Errant beam
- Spare cryomodule and repairs
- In-situ plasma processing
- SCL strategy for Proton Power Upgrade project (PPU)
- Summary

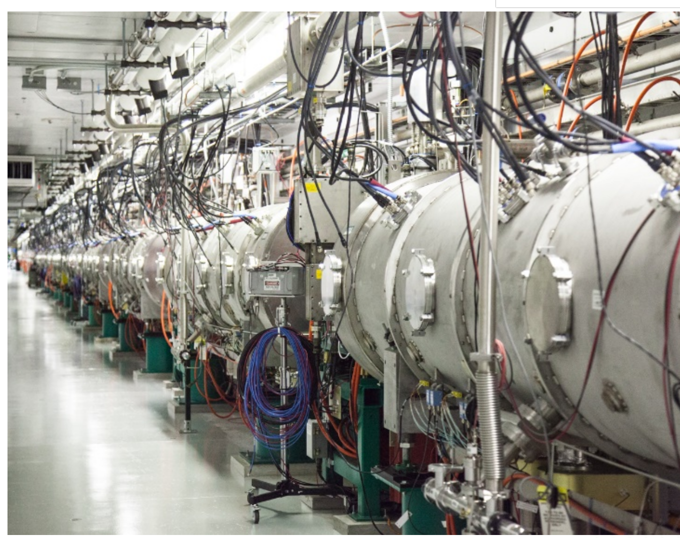
SNS accelerator complex

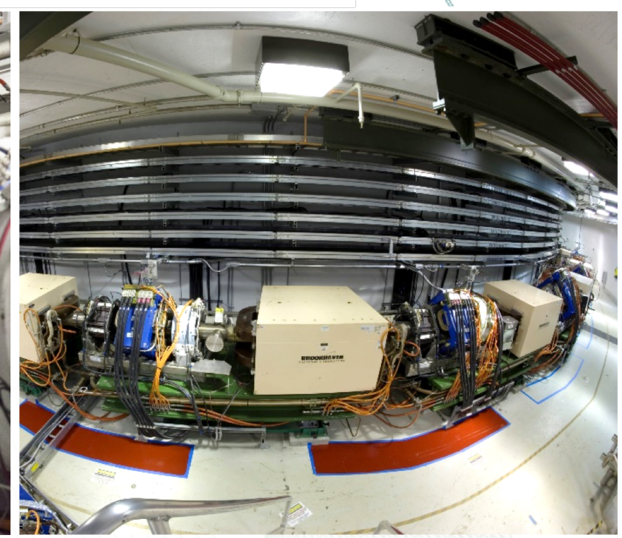
- Superconducting Linac: Two types of cavities (β_g=0.61 medium beta and β_g =0.81 high beta) covers acceleration from 186 MeV to 1000 MeV (or beyond for upgrade)











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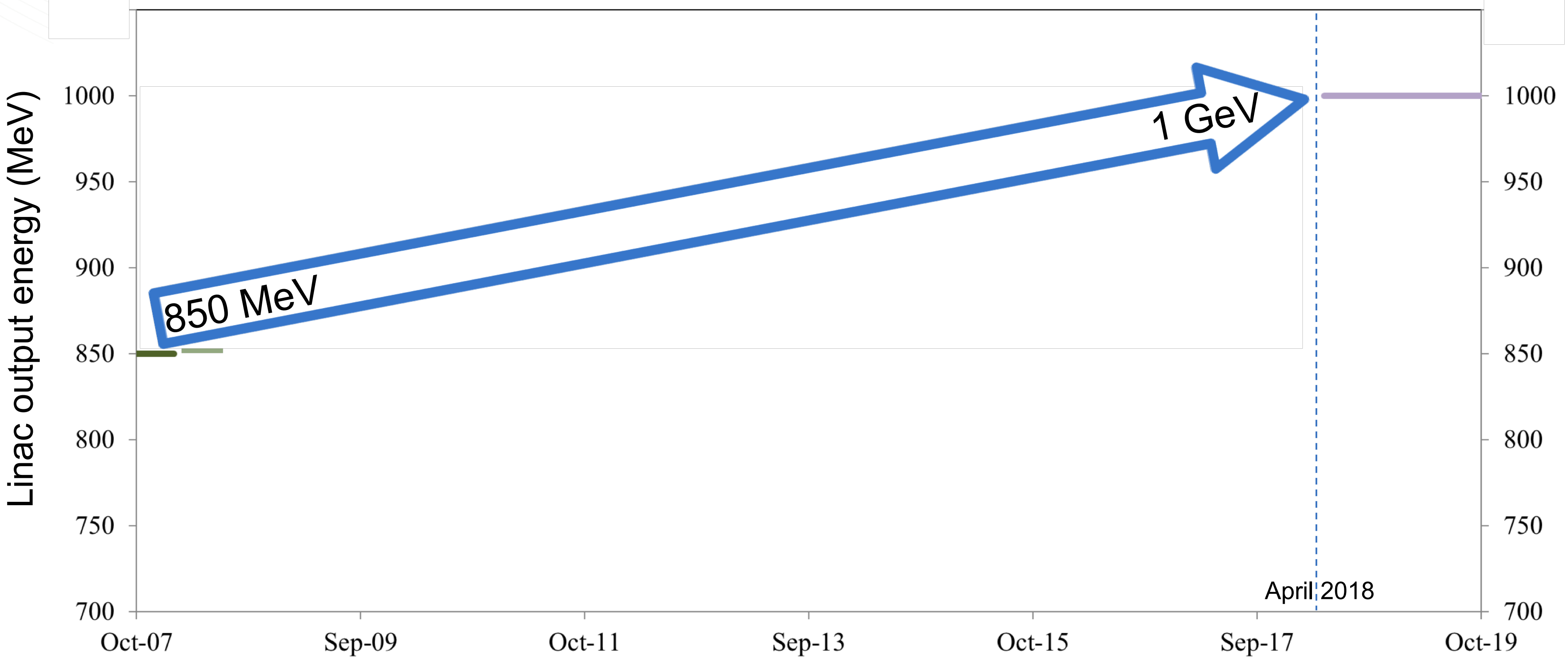
SNS SCL output energy at 60-pps operation evolved from 850 MeV to ~1 GeV

- 60-pps operation started in FY08
- SCL output energy during last run was 990 MeV
- 1 GeV+ is expected for the next run (starting in May 2018)



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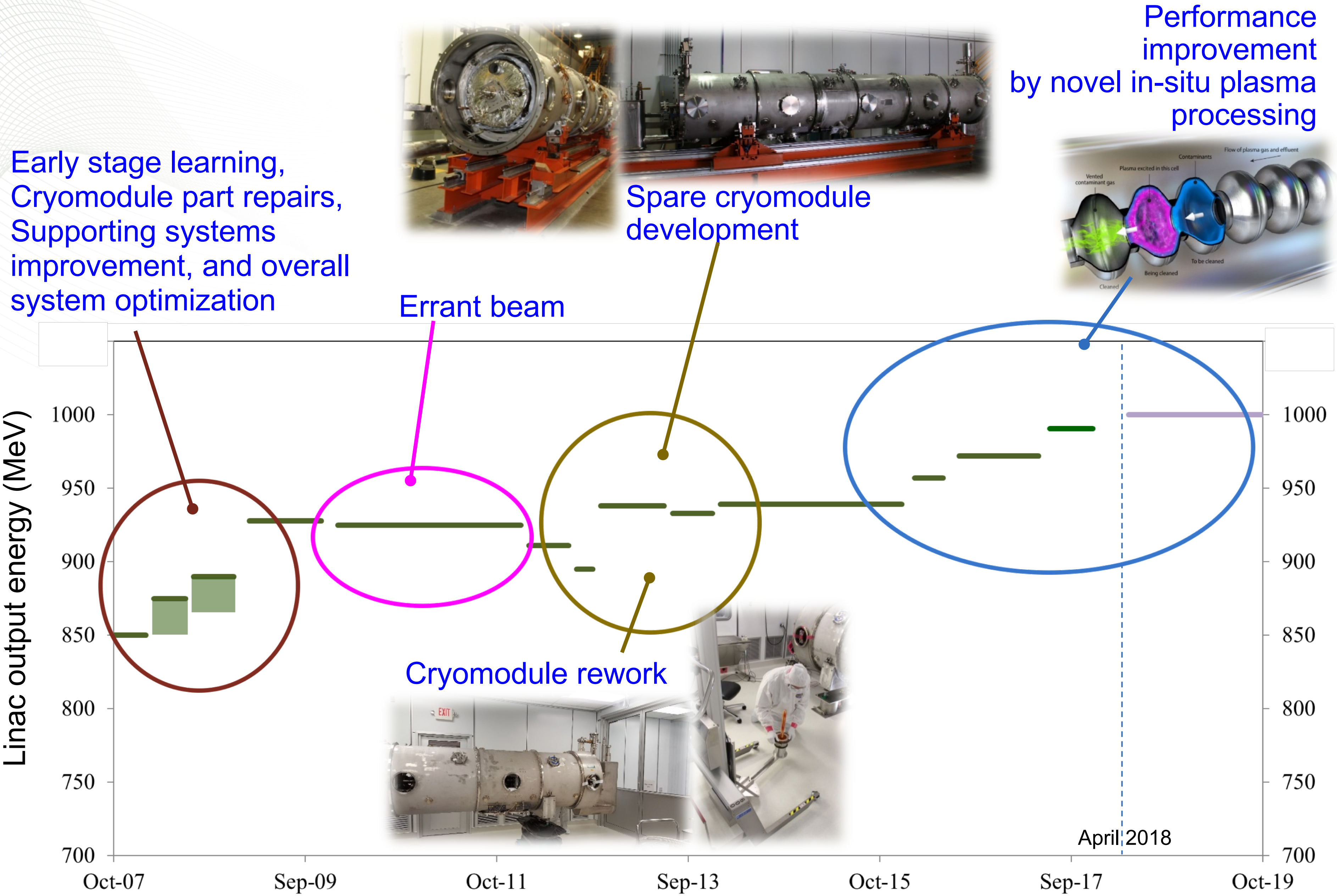
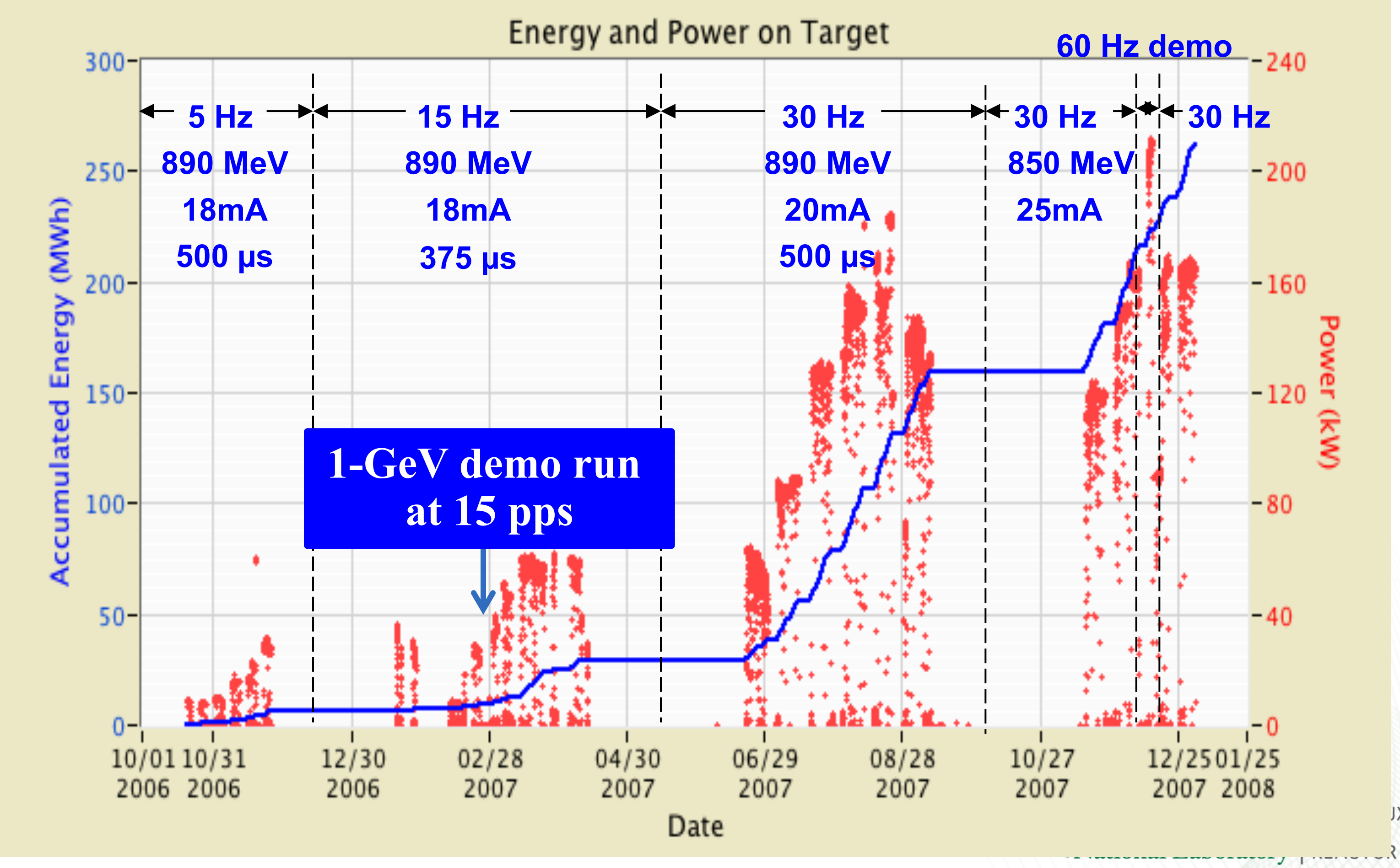

Performance improvement by novel in-situ plasma processing
Early stage learning, Cryomodule part repairs, Supporting systems improvement, and overall system optimization
Errant beam
Spare cryomodule development
Cryomodule rework
Linac output energy (MeV)
1000
950
900
850
800
750
700
Oct-07
Sep-09
Oct-11
Sep-13
Oct-15
Sep-17
Oct-19
April 2018
EXIT

The first 1.5 years operation

- Most sub-systems were not commissioned for operation at full duty factor
  - System learning at low repetition rate, short beam pulse and low beam current



Early stage of operation

- Performance of SRF cavities at 15-pps was above design:
  - 75 cavities out of 81 was used for the 1-GeV demo at 15 pps.
- Some subsystems at the SNS were designed to be substantial improvements compared to existing accelerators while other subsystems were first of a kind.
  - Some performance and reliability aspects required a learning curve, and it took time to understand the systems as a whole and to determine the need for additional performance improvements.
- Superconducting linac output energy was 850 MeV for 60-pps operation
  - Reduced operating E_{acc} due to thermal instability at 60-pps by electron activities
  - E_{acc} of a dozen of cavities was limited by available RF power due to lower operating voltage of high voltage converter modulator (HVCM)
    - In 2009 one additional HVCM was installed to relieve loads on HVCMs and increase the HVCM voltages
  - One or two cryomodules were out of service for repair
  - Addressed issues with sub-components and control/LLRF systems

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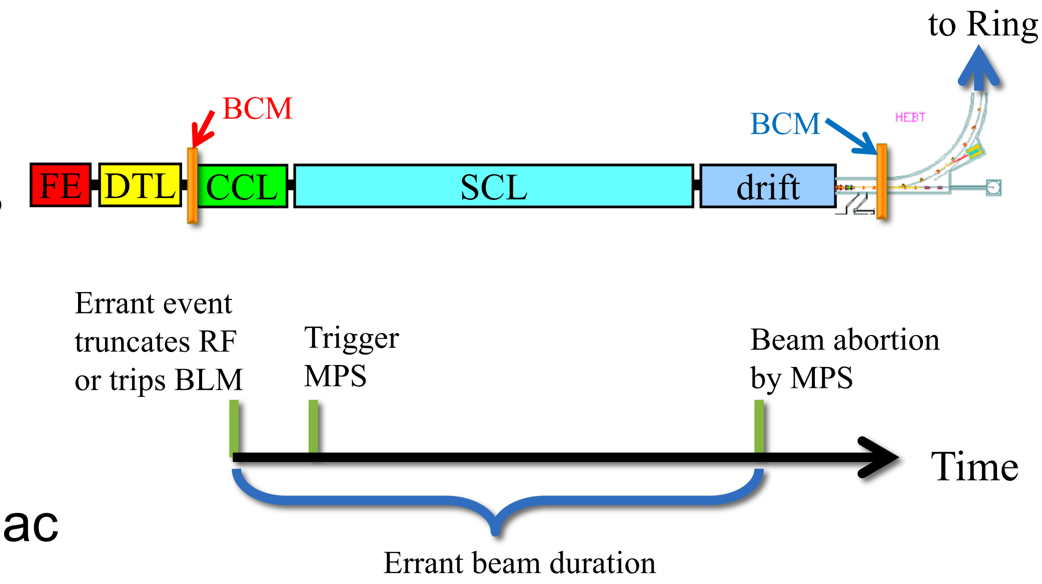
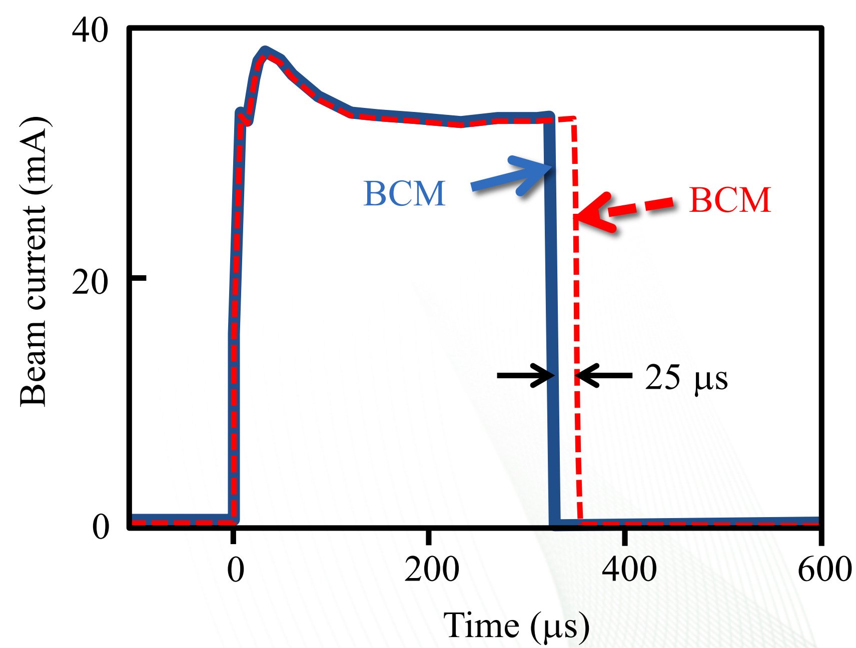
Errant beam

- In 2009, ‘Errant beam’ was first recognized.
- ‘Errant beam’ is an off-energy beam created
  - Mostly by upstream warm linac RF cavity faults or oddly shaped beam pulse from ion source
  - Beam lost in SCL till beam abortion by MPS system
- Errant beam hitting SRF cavity surface desorbs gas: Can create discharge condition and lead to performance degradation





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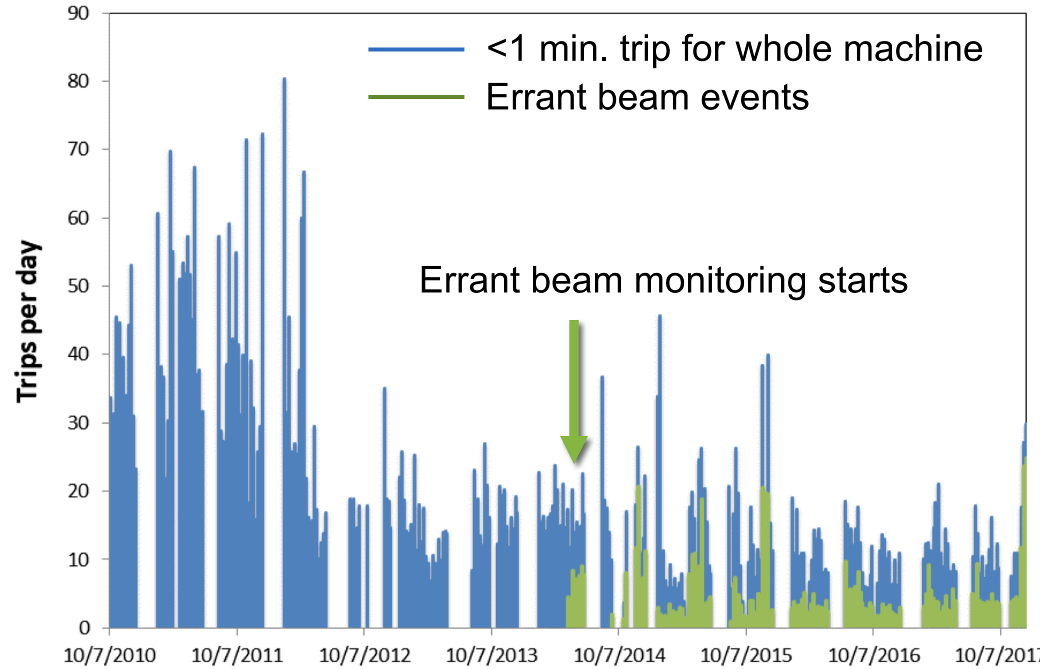
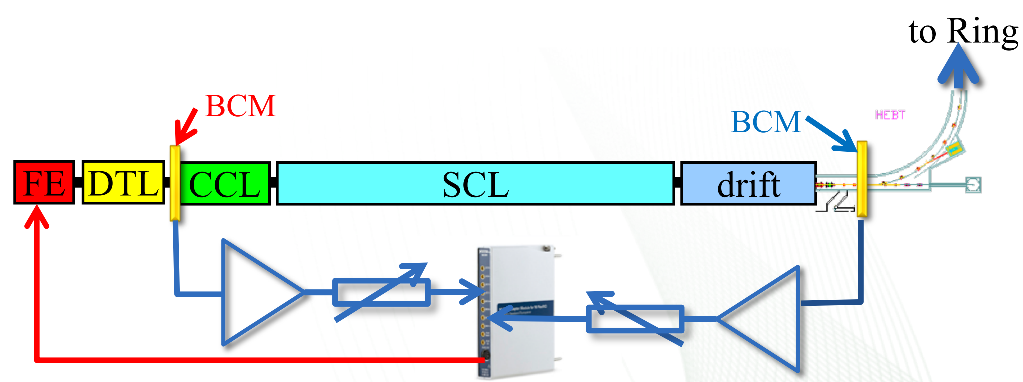
Reduction of errant beam events

- Severity depends on location where the beam is lost, on frequency of events and on duration of errant beam
  - Frequency of events is associated with warm linac and ion source conditions. More careful conditioning and vacuum system improvement helped.
  - Duration of errant beam
    - New dedicated MPS monitors the loss of beam current
    - MPS response time shortened to 7~8 μs





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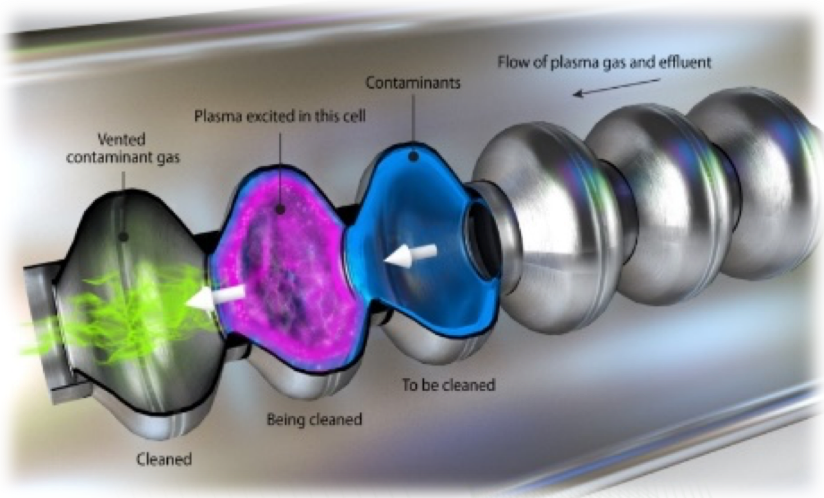
Cavity performance recovery, cryomodule repair and spare cryomodule

- Recovery of cavity performance to previously attained operating gradients
  - RF conditioning and/or thermal cycling: successful so far
- Cryomodule repair activities critical to sustain cryomodule performance and reliability
  - Rework (in-situ or off-line) is necessary for unrecoverable damage
  - Six cryomodules have been removed from the tunnel for repairs since FY07
- One additional high beta cryomodule was developed in-house and installed in the tunnel in 2012
  - Highest performing cryomodule in the tunnel to date
  - Allows offline repair of high beta cryomodules
  - Prototype for PPU cryomodule
- Development of a spare medium beta cryomodule is in progress

Performance improvement

- From 2009 to 2015, maximum linac output energy for the stable neutron production was 930-940 MeV
  - E_{acc} of each cavity was set based on collective limits at 60 pps.
- SNS looked for cost effective method to decrease electron activities and to increase E_{acc}
  - In-situ plasma processing was identified as an important area of R&D
- R&D started in 2012 to develop a reliable technique for in-situ plasma processing for high beta cavities
  - Focused on removal of residual contamination using low density reactive oxygen plasma to decrease electron activities (field emission and multipacting)



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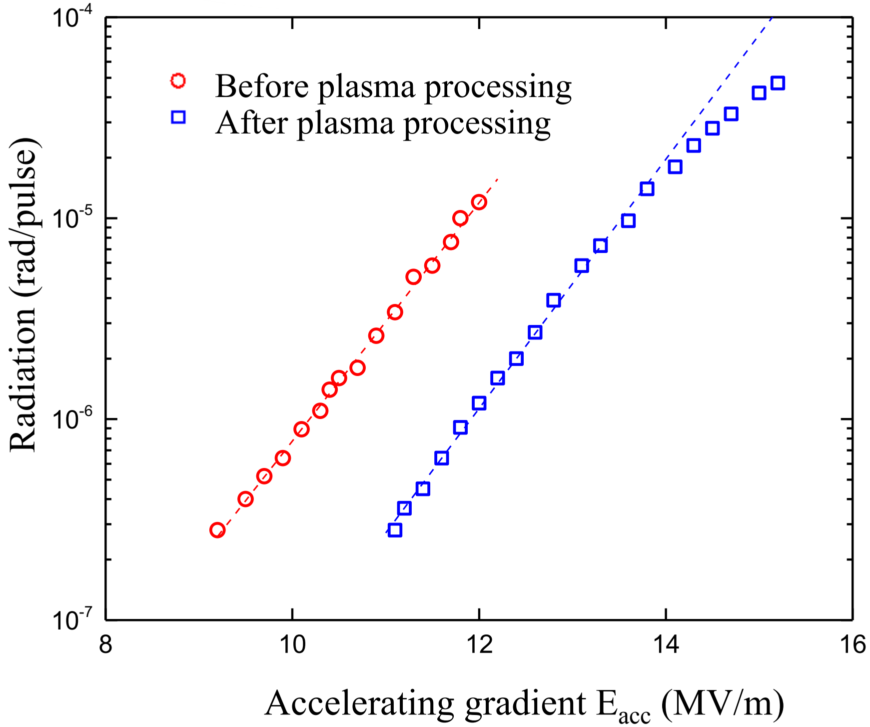
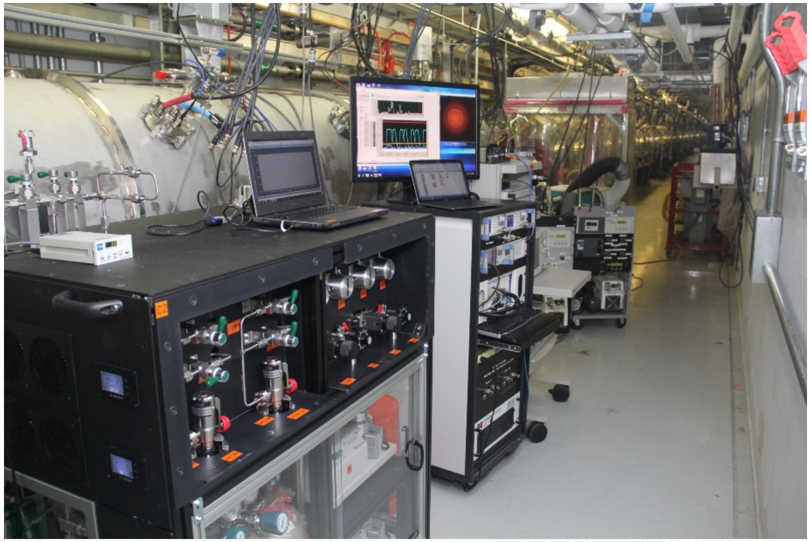
Deployment of in-situ plasma processing

- SRF cavities in 8 high beta cryomodules have been plasma processed (7 cryomodules in the tunnel and 1 offline)
  - Accelerating gradients increased by 25% on average
  - No performance degradation observed so far
  - Qualification of the 3 most recently processed cryomodules is in progress





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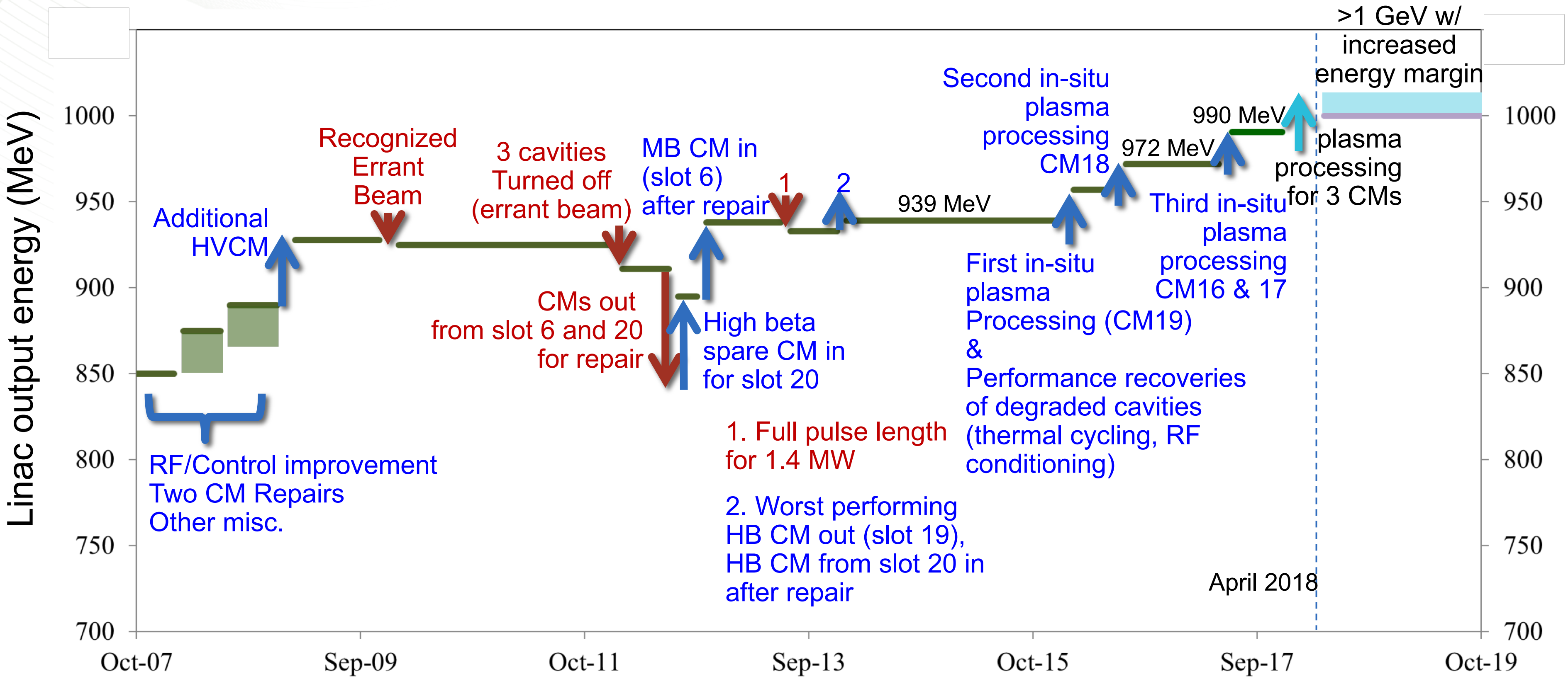
Linac output energy history



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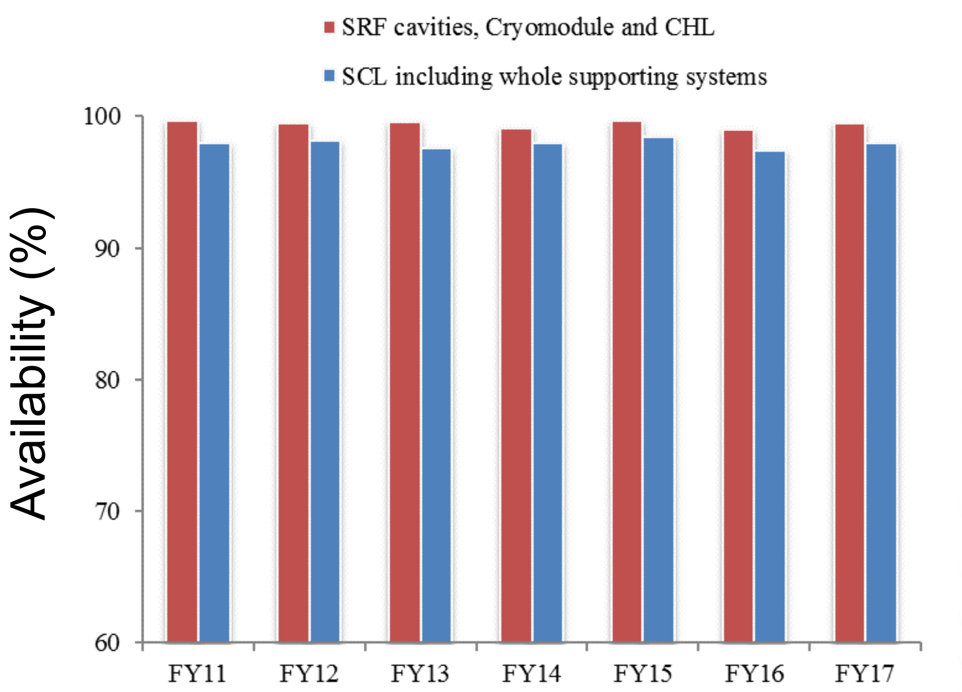
Numerous lessons have been learned to achieve stable and reliable operation of the SCL

- Availability last 7 years:
  - Whole SCL including RF, HVCM, Control, Vacuum, etc.: ~98 %
  - SRF cavities, cryomodules, and CHL: >99 %
    - Average trip or downtime: <1 trip/day corresponding to <5 min./day



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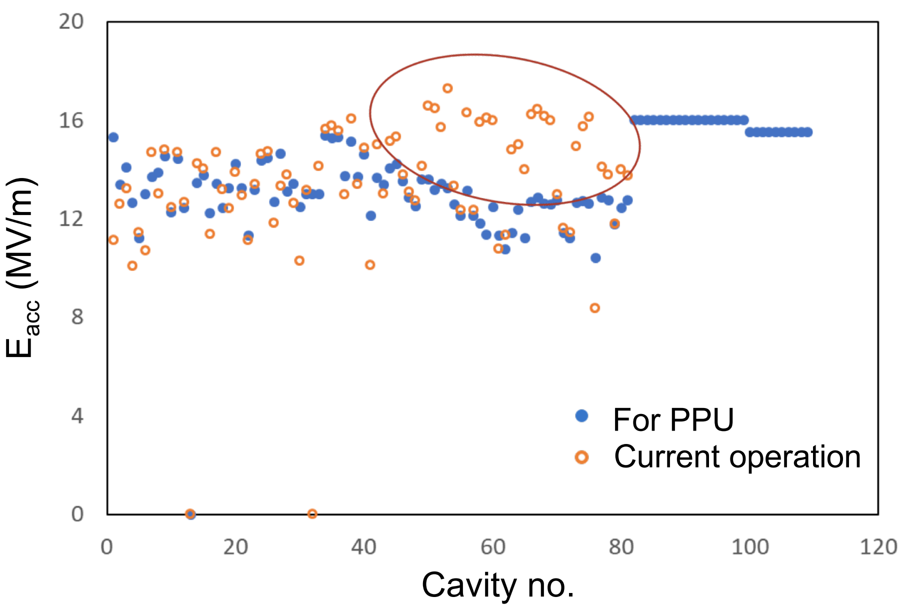
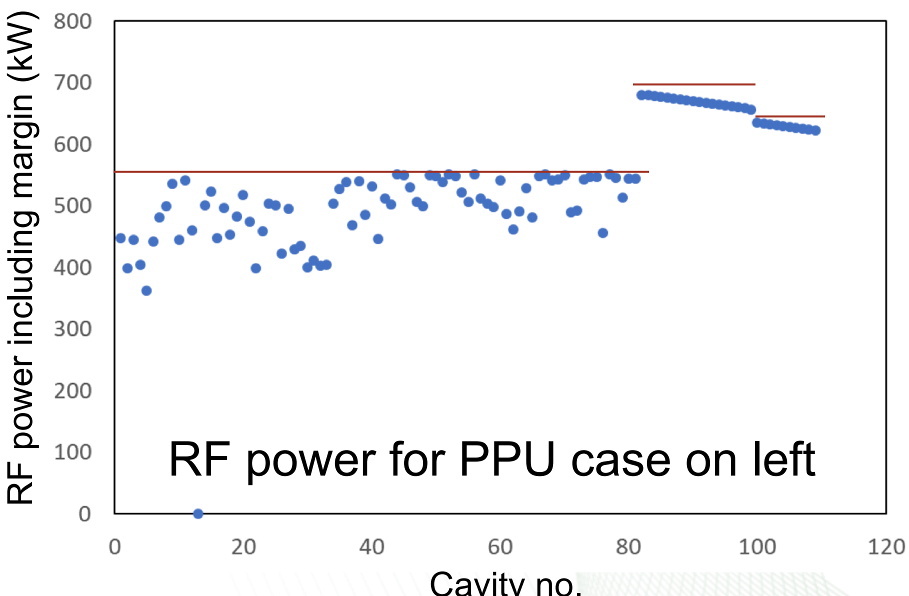
SCL for Proton Power Upgrade (PPU) project

- After PPU, SNS accelerators will be capable to deliver 2.8 MW beam at 1.3 GeV and 38 mA
  - 7 additional high beta cryomodules will be installed
    - E_{acc} of the new PPU SRF cavities will be 16 MV/m using 700 kW klystrons
  - Existing SRF cavities will use the existing 550-kW klystrons
    - E_{acc} of some high beta cavities will need to be reduced due to limited available RF power
    - Some medium beta cavities will be plasma processed to better utilize the available RF power





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Summary

- SNS has conducted a multi-faceted approach to increase linac output energy while keeping the machine highly reliable
  - Through various efforts, the linac output energy has been progressively increased toward 1 GeV
  - The availability of cryomodules, SRF cavities and Cryogenic plant has been > 99%