Commissioning Experience of SNS Linac

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CSNS ICFA mini-Workshop on Beam Commissioning for High Intensity Accelerators

June 8-10, 2015

U.S. DEPARTMENT OF ENERGY

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

Outline

- Introduction to SNS
- How we commissioned the SNS linac
- What we should have done differently
- What worked well for us
- Lessons learned
- Present day tuning procedures
- Ramp-up Timeline
- Conclusions

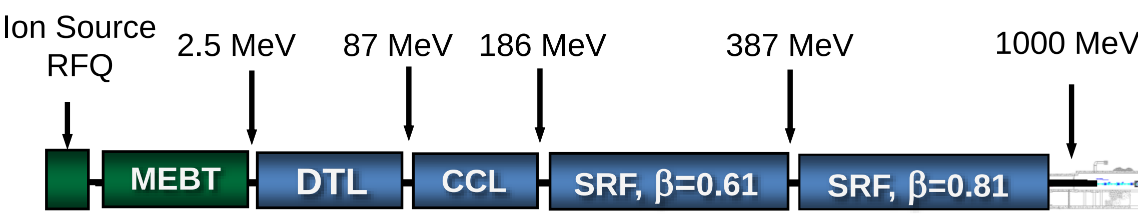
SNS Accelerator Complex

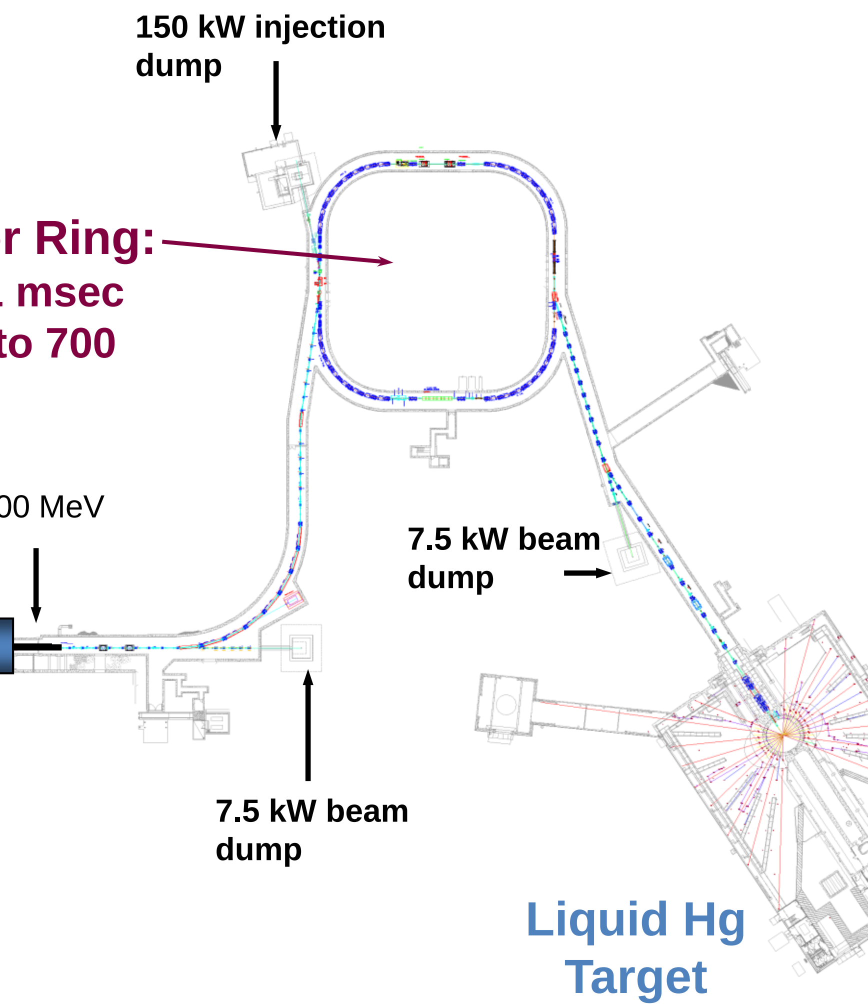
Front-End:

Produce a 1-msec long, chopped, H^- beam

1 GeV LINAC

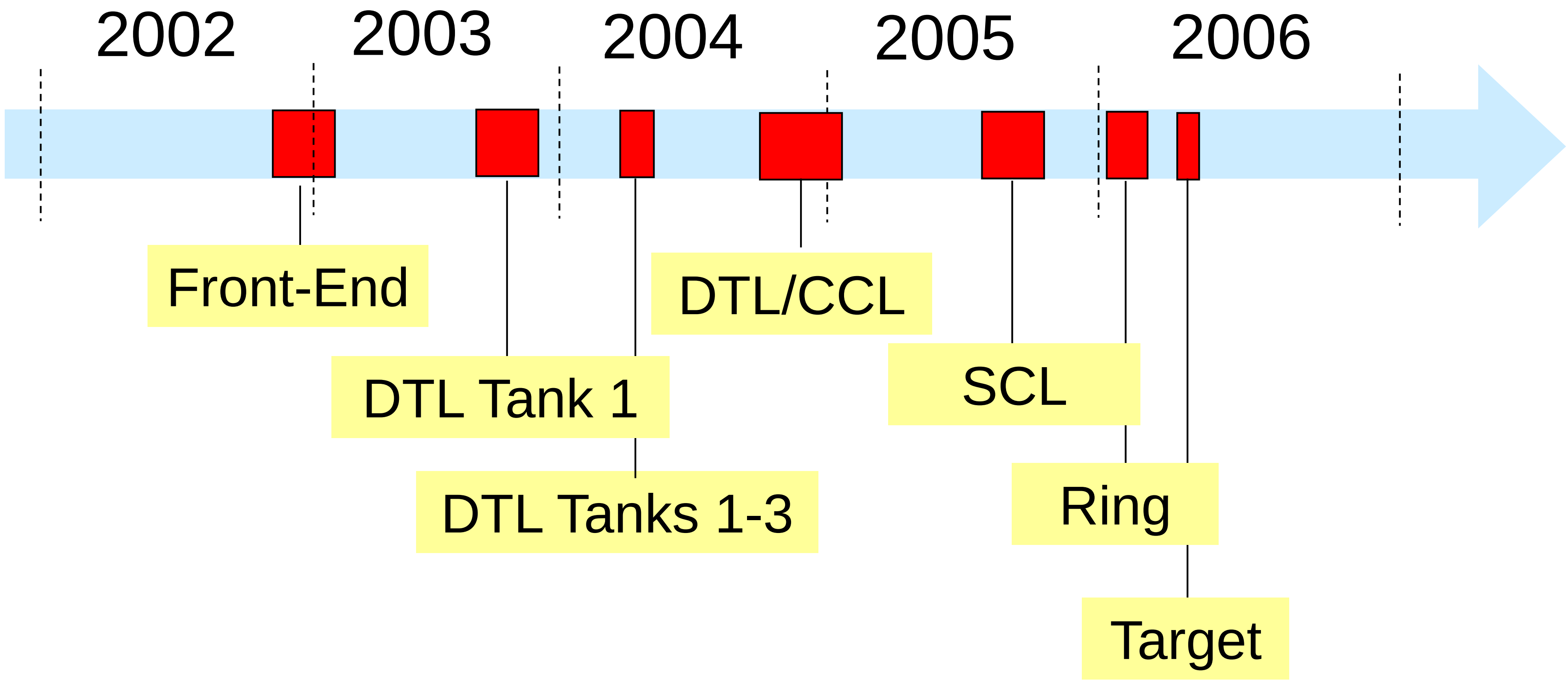
Accumulator Ring: Compress 1 msec long pulse to 700 nsec





Design parameters	
Kinetic Energy [GeV]	1.0
Beam Power [MW]	1.4
Repetition Rate [Hz]	60
Peak Linac Current [mA]	38
Linac pulse length [msec]	1.0
SRF Cavities	81

Commissioning Timeline



5 stages of SNS linac commissioning

2005 Int. Particle Accelerator Conference, Knoxville, Tennessee
LINAC 2006, Knoxville, Tennessee USA

How long did it take (how much time did we spend)?

Section commissioned	days actual*
Front end	33
DTL 1	47
DTL 2-3	12
DTL 4-6 and CCL 1-3	135 (incl. ~40 days of planned shutdown)
CCL 4 thru SCL	63 (incl. ~13 days of planned shutdown)

*Some times could have been shorter. For example we spent a large amount of time studying the beam halo, and some of this work never bore fruit. On the other hand, this could be seen as time well spent gaining experience with the machine.

How we did it

- Staffed 24/7
- Commissioned with beam in 7 stages (5 for linac, 2 for Ring and target) over 3.5 years
- Front End through CCL-3 “control room” was a few computer stations in the Front End building, hard hats and safety shoes were required
- Commissioned DTL-1 (7.5 MeV output energy) with a special diagnostics beam line (D-plate) that had a high-power beam stop. We used it to demonstrate 1.0 MW equivalent power (26 mA pk, 650 us, 60 Hz) in 2003. After that did not return to 1 MW beam parameters until 2009.

How we did it (cont.)

- Most of used software was developed before particular stage of commissioning
- Today we're still improving our linac tuning algorithms
  – Utilize beam phase measurements inside the same warm linac cavity whose set points are being determined
  – New algorithms (DeltaT, PASTA, One BPM algorithm)
  – Tuning automation (Warm Linac 6-8 hours -> 50 min , SCL 8 h -> 32 min)

Beam Diagnostics for Commissioning

- BPM – Beam Position Monitors. They measure transverse coordinates of the center of the beam, the arrival time (as a phase), and a Fourier harmonic amplitude of the longitudinal density distribution.
- Wire Scanners – transverse profiles
- Slit-Harp Emittance Devices – transverse emittance
- Faraday Cup with an energy degrader
- BCM - Beam Current Monitors – beam peak current
- BLM – beam loss monitors (Ionization chambers + neutron detectors)
- Sets of insertable apertures in MEBT to reduce peak current

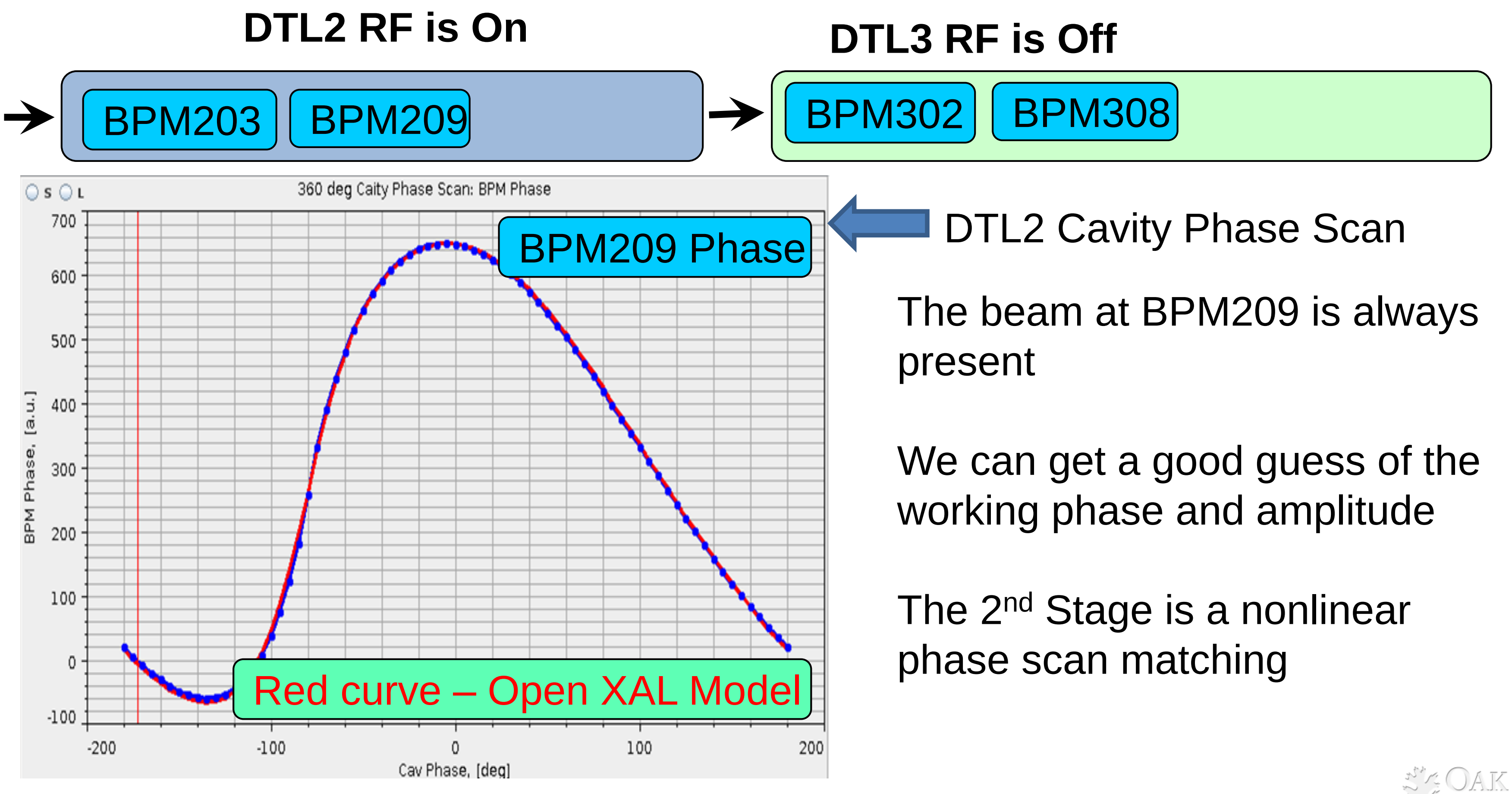
High Level Physics Applications

- **In the beginning**: Combination of Matlab and XAL (Java) scripts
- **Later**: XAL only
- SCORE – save/restore all parameters relevant for tuning
- 1D and 2D Scan Application (many purposes including MEBT bunchers setup, DTL acceptance scan, and Detla-T)
- Orbit Correction Application
- PASTA – (Phase and Amplitude Scan and Tuning Application) phase signature matching replacement of Delta-T
- Orbit Difference Application – for optics control including cavities setup
- SLACS – SCL cavities tuning application
- Loss Viewer – beam loss viewer along the whole accelerator

Present Day Warm Linac Tuning

- Warm Linac Wizard – OpenXAL app for MEBT-DTL-CCL tuning
- It is automated tuning – Operators are just watching the process (< 1h)
- It uses generalized phase signature matching (sometimes even only one BPM is needed) and the BPMs inside the same cavity

1st Stage of Automated Tuning



DTL2 Cavity Phase Scan

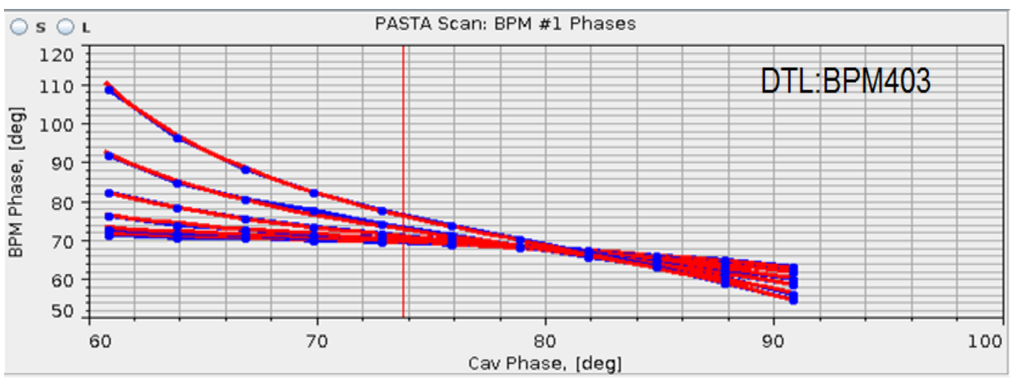
The beam at BPM209 is always present

We can get a good guess of the working phase and amplitude

The 2nd Stage is a nonlinear phase scan matching

Delta-T, PASTA, and General Phase Matching Comparison

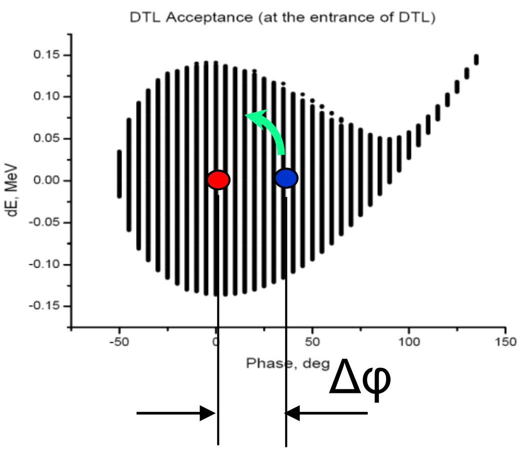
Algorithm	Descriptions
Delta-T	• Developed at Los Alamos Lab • Uses 2 BPMs • Uses BPMs signals for RF On/Off • Linearized response from the model
PASTA (name inside XAL)	• Method itself was developed at FNAL • Implemented in XAL by John Galambos (SNS) • Uses 2 BPMs • Can use BPMs signals for RF On with or w/o Off • Nonlinear phase matching
General Phase Scan Matching	• Implemented in OpenXAL application • Can be used with one BPM only

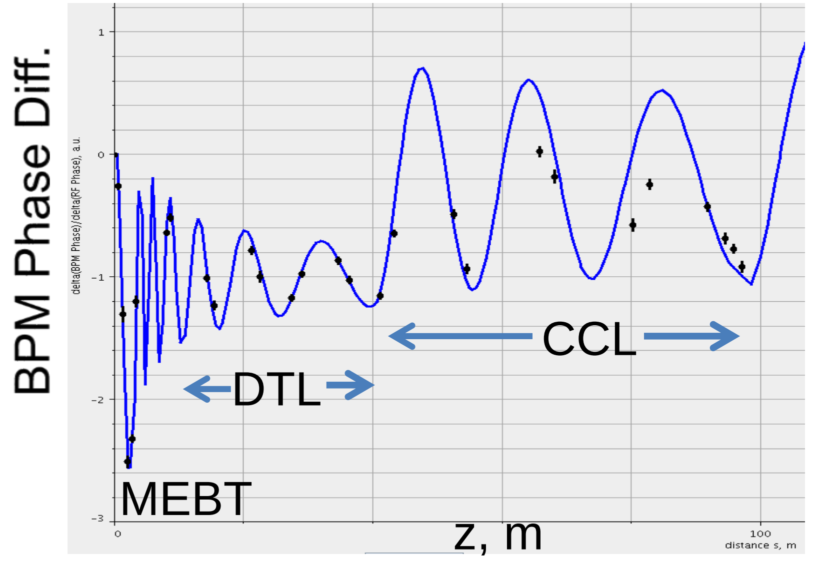


Example:
DTL3 Amp. and Phase tuning using only one BPM outside the cavity

Global RF Tune Control: RF Shaker

OpenXAL RF Phase Shaker





Idea from Sasha Aleksandrov

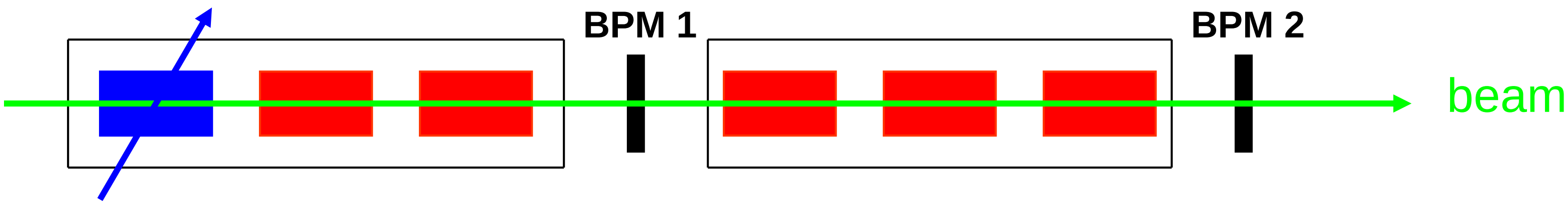
● BPMs Phases Diff — OpenXAL

- OpenXAL Phase Shaker allows to test the RF phase set up for several cavities or even the whole SNS linac
- If we see increase in beam loss we can check if the cause is a bad longitudinal tuning

SCL commissioning

- Initially commissioned at 4.2 and 2.1 deg. K, but cryo-plant at 2.1 K was not stable at the time
- Cavity amplitudes set to maximum stable gradients – much different than design gradients
- Determining cavity phase set points was a lot easier than expected, partly due to the large acceptance of the SCL
  - Had two methods prepared: Beam Induced Signal (Drifting Beam method) and Phase Scan. Phase Scan method in combination with RF blanking and MEBT beam attenuation worked great, no need to further develop Drifting Beam method.
- Operated at 4.2 K from 2005 to 2007 to give time for cryoplant adjustments needed for stable 2.1 K operation, and also because 4.2 K met operations needs during that time

Improvements to phase scan method



- When we first commissioned the SCL we turned off the RF to the cavities downstream of the cavity whose phase was being scanned. It took about 15 minutes to turn on the next cavity and move on.
- Now we just blank the RF at 1 Hz (59 RF pulses on, 1 pulse off) and that can be turned on or off in about 1 second
- We use low peak currents (~5 mA) and short pulses (~3 us) to minimize the cavity excitations and beam loading
- In the first years of routine operations the SCL phase scans took about 12 hours. Today they are automated and take about 40 minutes.

What we should have done differently

- During commissioning many system adjustments and modifications were needed to get everything working together. The rapid pace did not accommodate careful reviews of the modifications.
  – Modifications to the Machine Protection System should have been more carefully reviewed. Low pass filters were added to some MPS inputs to help with false trips due to noise. This ended up slowing down the response time of the MPS.
- MEBT Chopper was burned and replaced with more robust one later. Now we do not have it at all.

What worked well for us

- Thorough magnet measurement program allowed “dialing-in” magnet currents and immediately transporting beam.
- Physics apps were integrated with the on-line model and the control system, and well developed before start of commissioning (by using Virtual Accelerators)
- Physics apps written by commissioning team members
- Commissioning the machine in stages
- Good set of beam instrumentation (lots of beam position/phase monitors, beam profile devices, and beam loss monitors)

Some lessons learned

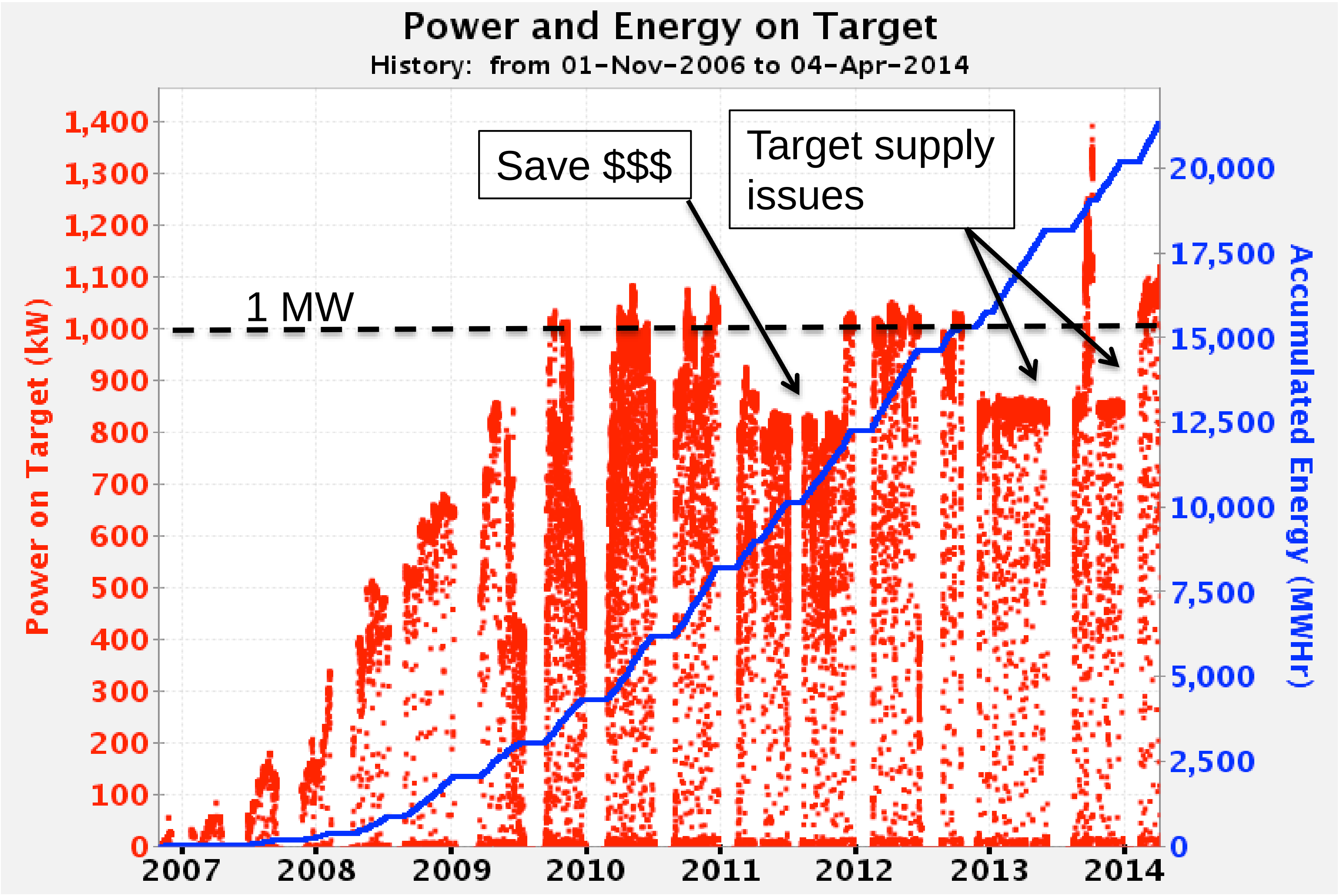
- Equipment checkout with beam takes a large fraction of the time
  - Beam instrumentation
  - RF & LLRF
  - Control system
  - Machine Protection System
- Initial commissioning at low beam power was easy once the equipment was running properly
- Be careful with modifications to critical systems (e.g. MPS system)
- There could be surprises – SCL beam loss
- Automated applications for long tasks are working better than human
- The high power ramp up was and still is our biggest challenge

Power ramp up (the commissioning after the initial commissioning)

- Two schools of thought here:
  1) Keep the beam power low, get all the bugs worked out, don't endanger beam availability, don't activate beam line components until everything is working well
  2) Aggressively push beam power to identify weak components and to solve high-power problems before the users expect/demand high availability
- At SNS we choose the latter, and we are glad we did
- At 1 MW we paused to focus on beam availability. Budget and then target problems caused us to stay at 1 MW for longer than we had hoped.
- We are now back on the trajectory to further increase the beam power

Beam power vs time

- Typical beam power today is 1.1 MW



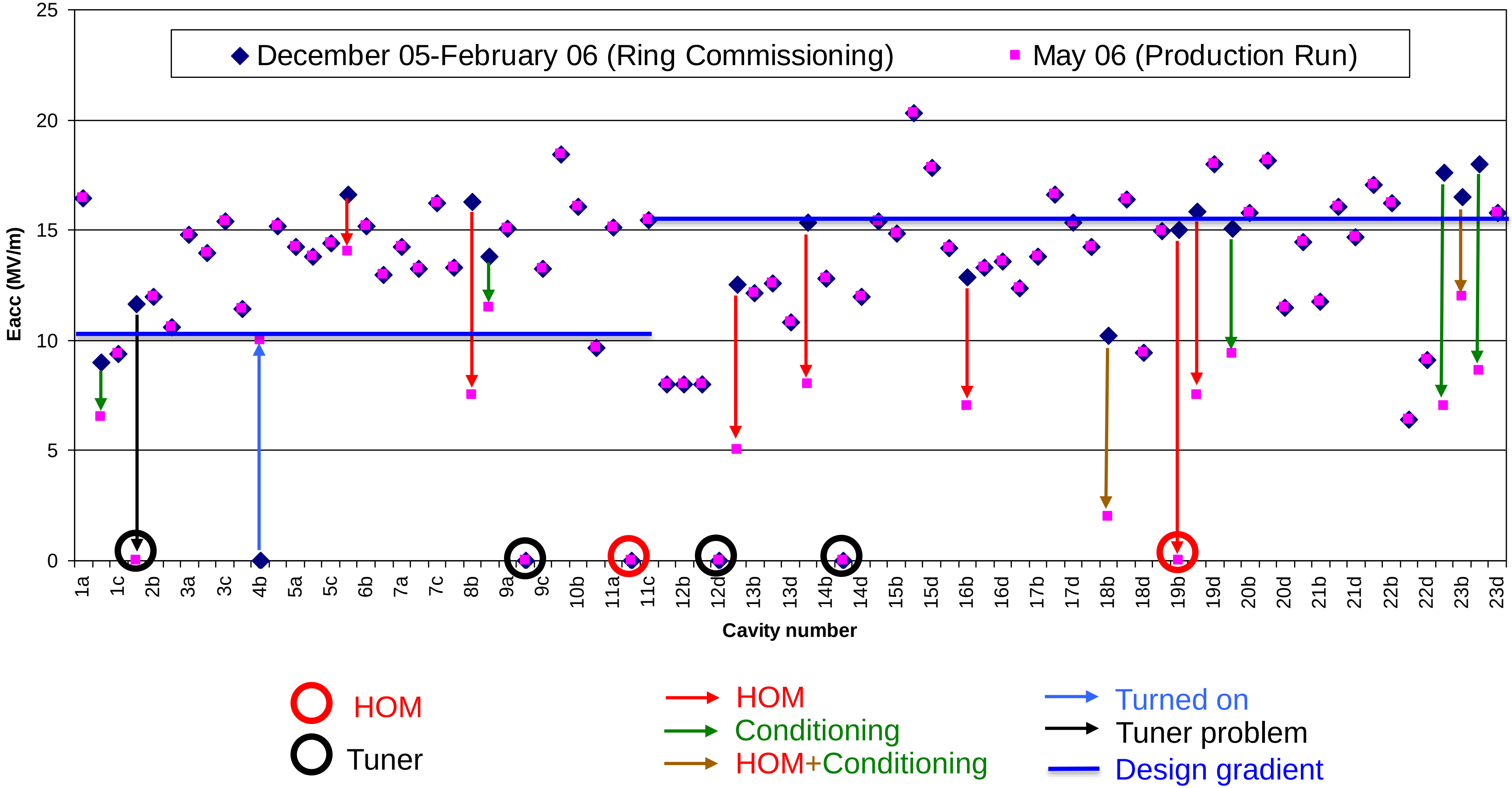
Conclusions

- The commissioning and an initial power ramp-up of SNS was performed according to the planed schedule (even slightly ahead)
- Now our goal is 1.4 MW power at availability more than 90%
- We still improving our knowledge of the machine
- There still have puzzles that we are working on

Thank you for your attention!

Backup Slides

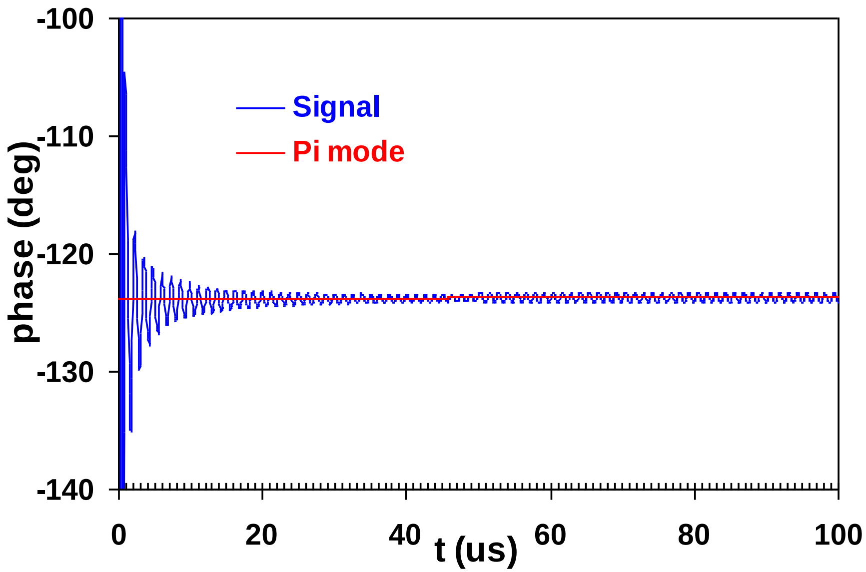
Design vs operation SCL gradients



(from R. Campisi, June 2006)

Drifting beam method

- This is the alternative method we developed to determine the SCL set points
- Not used since the phase scan method worked well
- Requires longer beam pulses (~30 us) which can create much more beam loss (compared to ~3 us for phase scan method) in downstream portion of SCL



Simulation for 466 MeV,
38 mA, 50 μs, rms size 3 deg

(Courtesy Y. Zhang)

Evolution of PPS Enclosures with Commissioning