Model Driven Reconfiguration of LANSCE Tuning Methods

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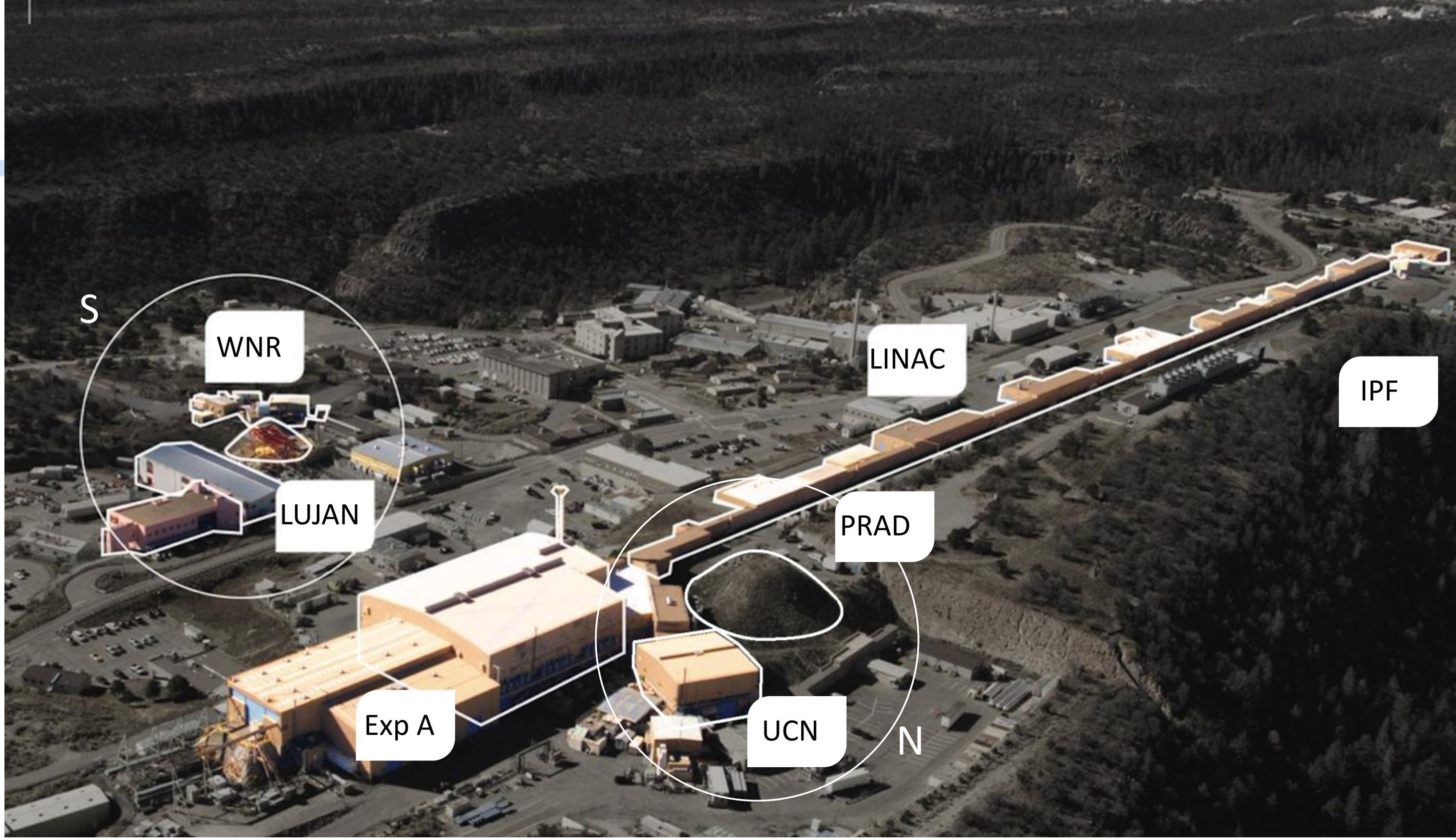
Overview

- The Los Alamos Neutron Science Center (LANSCE) accelerator facility provides many opportunities for U.S. science and technology programs
- Delivers multiple beams to six facilities
- Three major Department of Energy (DOE) Stakeholders:
  - Defense Programs (DP)
  - DOE Office of Science
  - Office of Nuclear Energy, Science and Technology (NE)
- Studies at LANSCE include:
  - Nuclear weapons program
  - National security research
  - Radioisotope production
  - Basic science- (neutrino & dark matter searches)

LANSCE Facilities

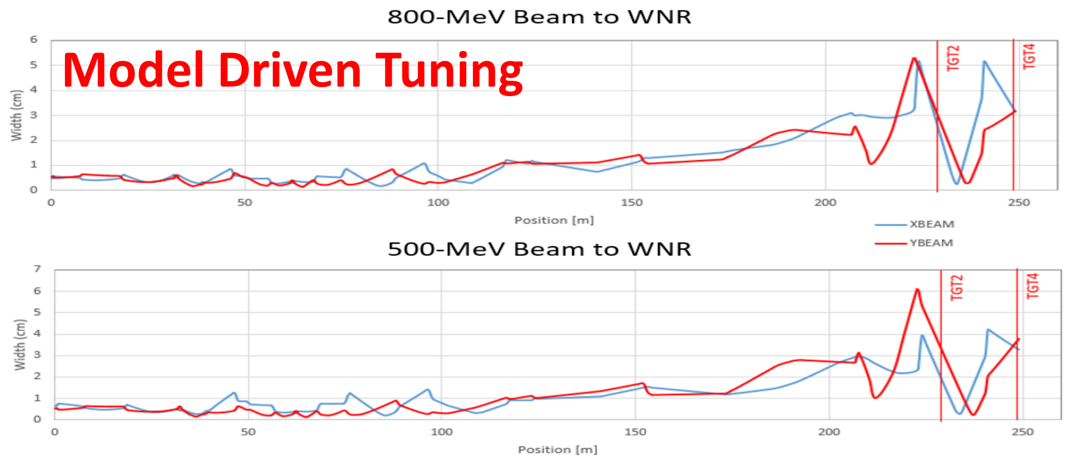
- The LANSCE accelerator complex supports a large set of experiments
- Isotope Production Facility (IPF)
  - Production of medical isotopes
  - Development of short-lived isotopes for defense programs
- Proton Radiography (pRad)
  - Dynamic radiography for defense programs
- Ultra-Cold Neutron (UCN)
  - Nuclear physics and NSF studies
- Lujan Neutron Scattering Center
  - Neutron scattering and imaging for defense programs and nuclear energy
  - Nuclear physics for defense programs
  - Coherent neutrino and dark matter searches
  - Material and electronics testing for industry



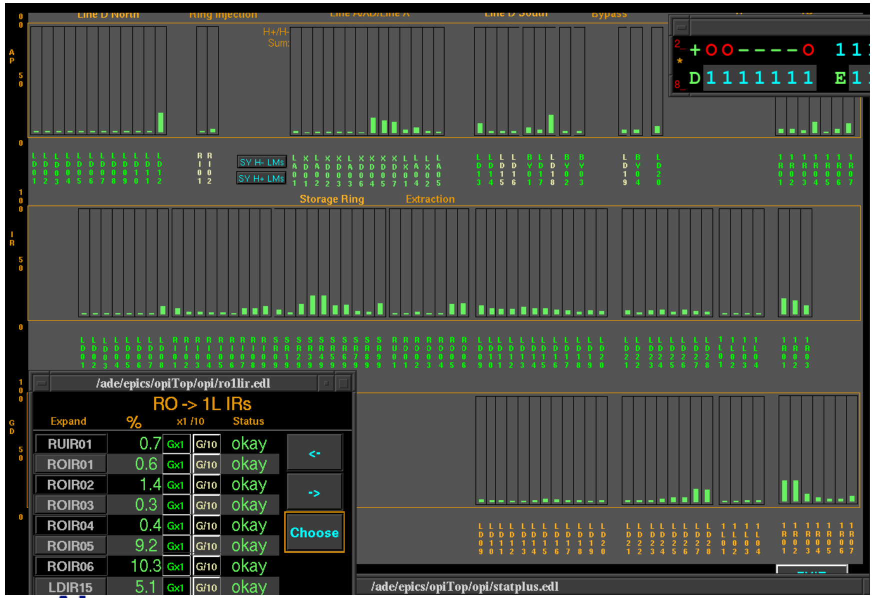
- Weapons Neutron Research (WNR)
  - Nuclear physics for defense programs and criticality safety
  - Electronics testing for industrial and global security
- Experimental Area A
  - Originally the primary facility for muon production and study
  - The LSND experiment was the key to the discovery of sterile neutrinos
  - Several concepts are under review for new high-profile experiments

Tuning Methods

Model Driven Tuning



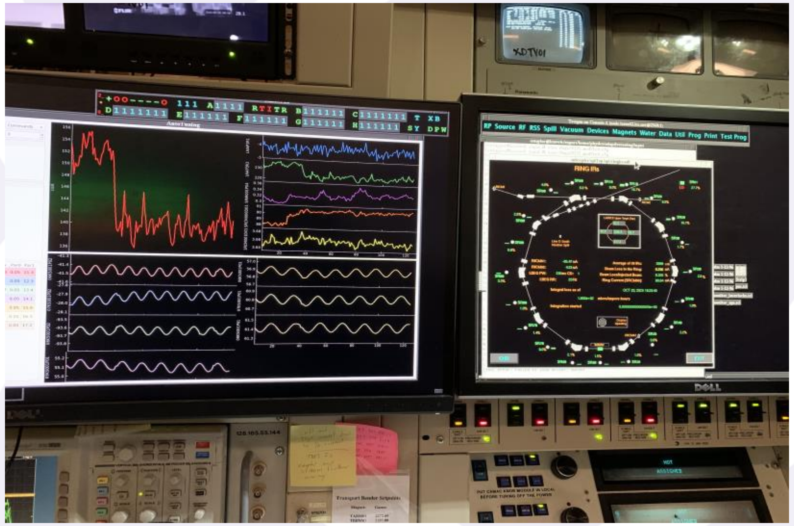
Model Independent Tuning



- There are two primary categories for beam tuning
  - *Model driven*
  - *Model independent*
- **Model driven** methods are used for the initial tune of an accelerator, such as;
  - Initial optical transport tune of the low-energy beam transports (LEBT)
  - Beam capture and acceleration of the radio-frequency modules
  - Energy matching and bunching within the accumulation/acceleration rings
- **Model independent** methods dominate the optimization of an accelerator tune, like;
  - Optical element corrections to reduce beam loss in the accelerator
  - The steering of beam in the transport lines to reduce beam loss
  - Optimization of all component parameters to improve average beam current delivered to the target facilities
- Both categories of tuning could be automated

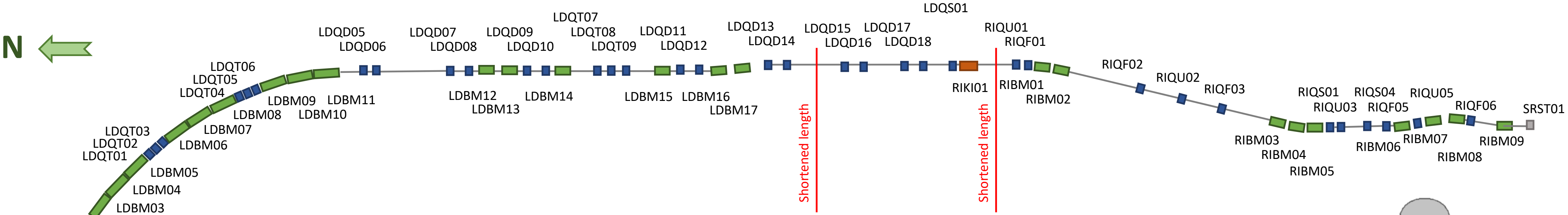
Tuning Strategies

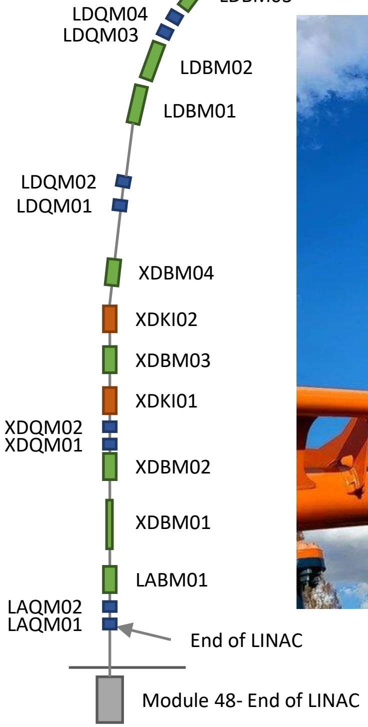
- There are two primary strategies for both model driven and independent methods:
  - Beam **Acceptance Tuning**
  - **Adaptive Tuning** for desired performance
- Most of LANSCE's recent *automation* efforts are centered around the automation of the model independent methods
  - Adaptive tuning for reduction of loss and increased current
  - Machine Learning for system responses
  - Accelerator alarm system based on analysis with neural network applications
- Preliminary results have already shown promising results
- We are now building new models and applications for assisted and/or automation of model centric tuning



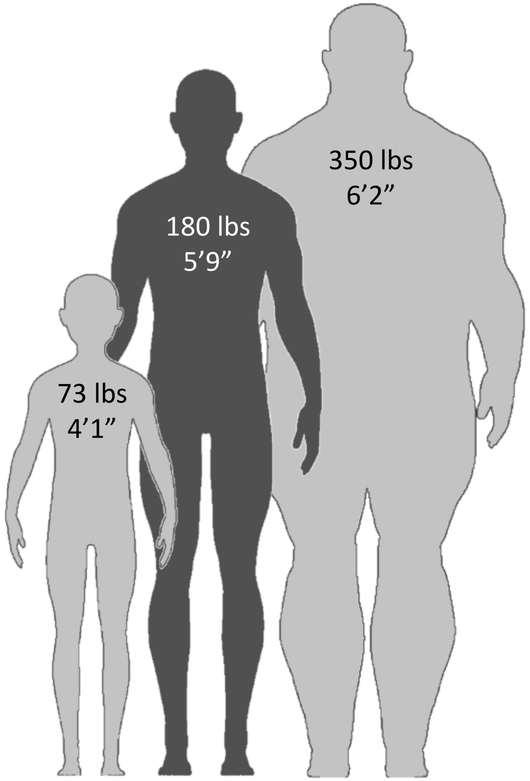
A. Scheinker, EC Huang, and C. Taylor. "Extremum Seeking-Based Control System for Particle Accelerator Beam Loss Minimization." *IEEE Transactions on Control Systems Technology* 30.5 (2021): 2261-2268.

Tuning of the Transport Lines: Acceptance Tuning

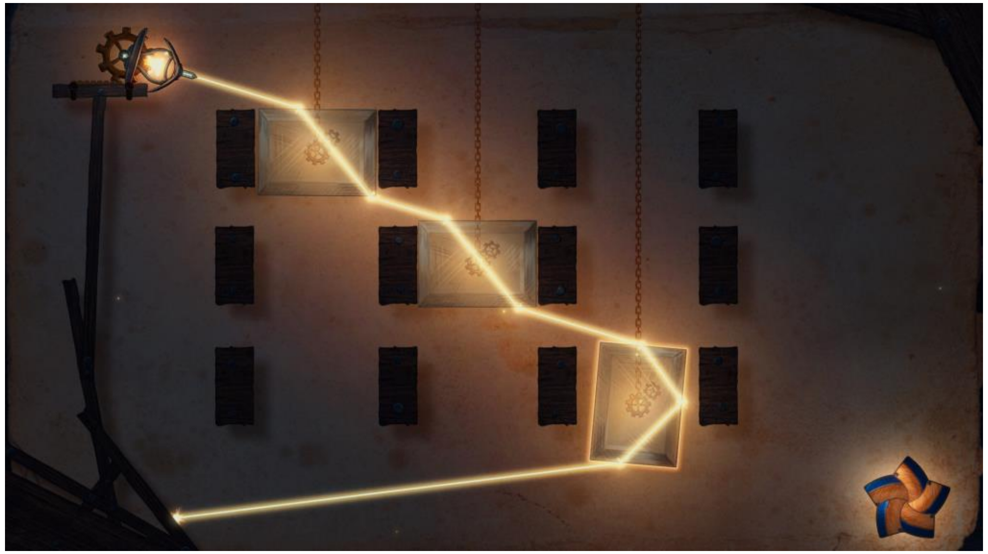




- Think of the HEBT as a roller coaster with people,
  - designed for individuals greater than 100 lbs, but less than 250 lbs
  - People at 180 lbs are ideally accepted
- Any other weight and the people will fly off the rollercoaster
- An adjustable system would be needed to allow for lighter and heavier people



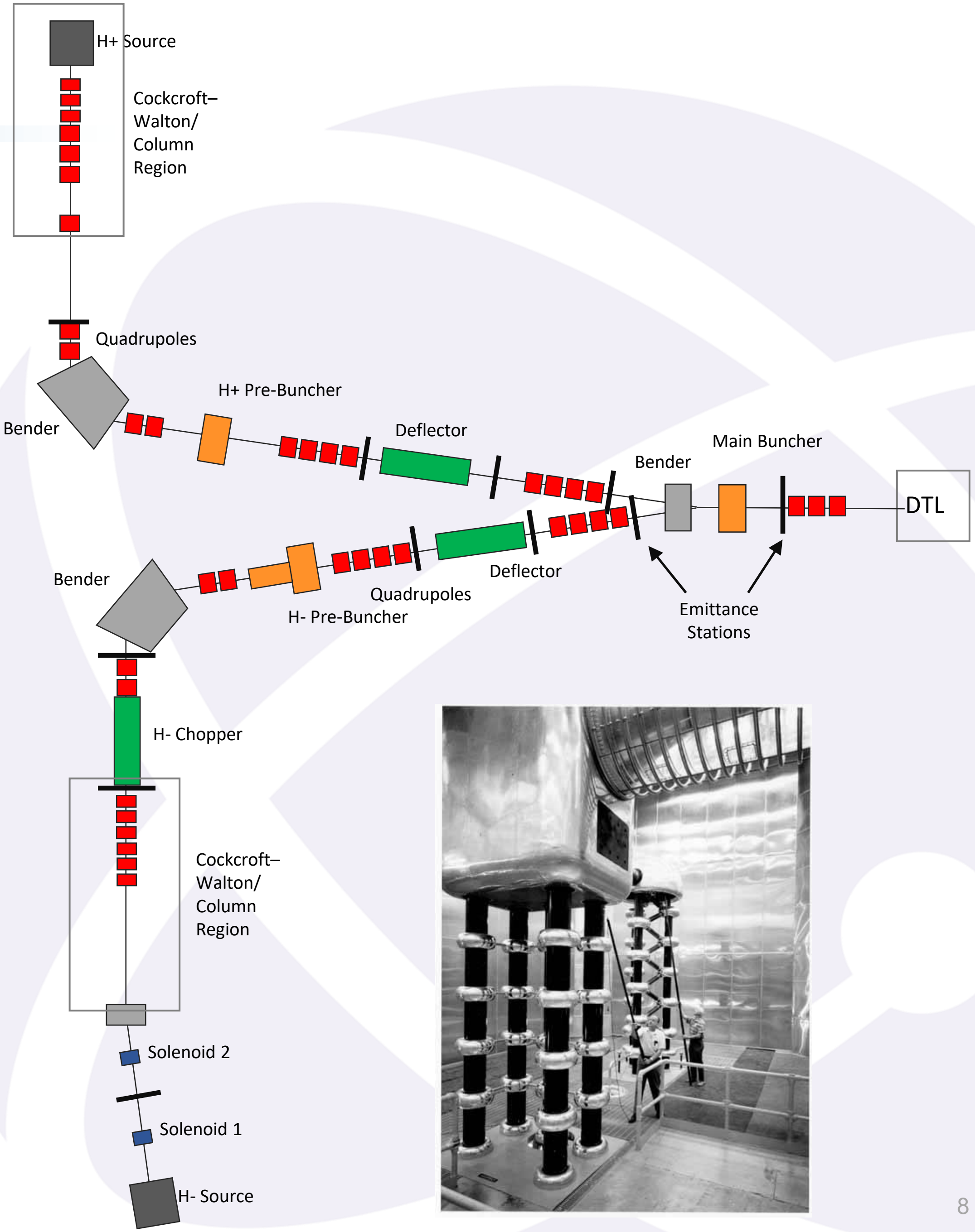
Tuning of the Transport Lines: Adaptive Tuning



- If we instead regulate the transport system instead of the input source, we can perform *adaptive tuning* to reduce beam loss
- Now imagine the transport as a laser transport through a pinball machine
  - Angle varies mirrors are tilted (top)
  - Wavelengths shift, refactors are shifted (bottom)
- The rollercoster-like *acceptance tuning* methods are ideal during reproducible run cycles
- However, with *low-energy* runs, *adaptive tuning* is essential to improve beam quality achieved with scaled *acceptance tuning*
- During our studies, we applied both methods together and successfully transported the beam

H^- and H^+ Beam Injection

- The LANSCE front-end section includes two independent injectors for H^+ and H^- beams
- The low-energy transport (LEBT) for each beam species include a pre-buncher for modulation of the DC beam
- There are 10 emittance stations, 7 harps, 11 current monitors, and 6 beam apertures with readouts
- The H^- beam includes a low-frequency buncher for compression of multiple pulses into the RF structure of the accelerator
- Currently only the H^- beamline has a chopper for multiple user facilities, a key beam control component
- The lines are merged just before entrance to the 205.25 MHz drift tube linac (DTL) where they are first conditioned by the main buncher



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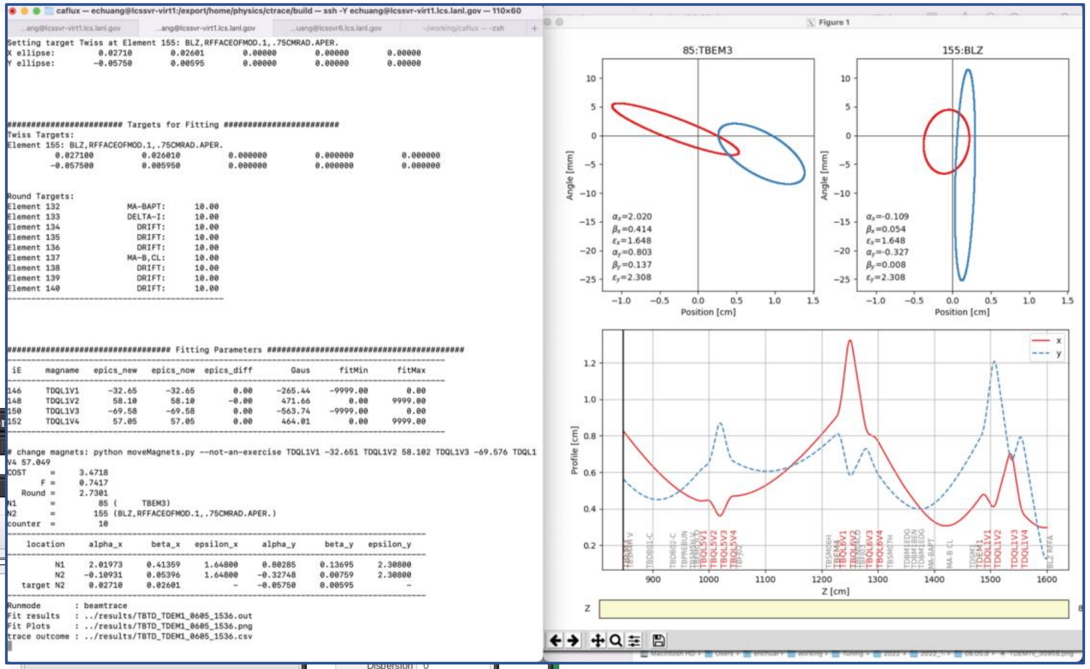
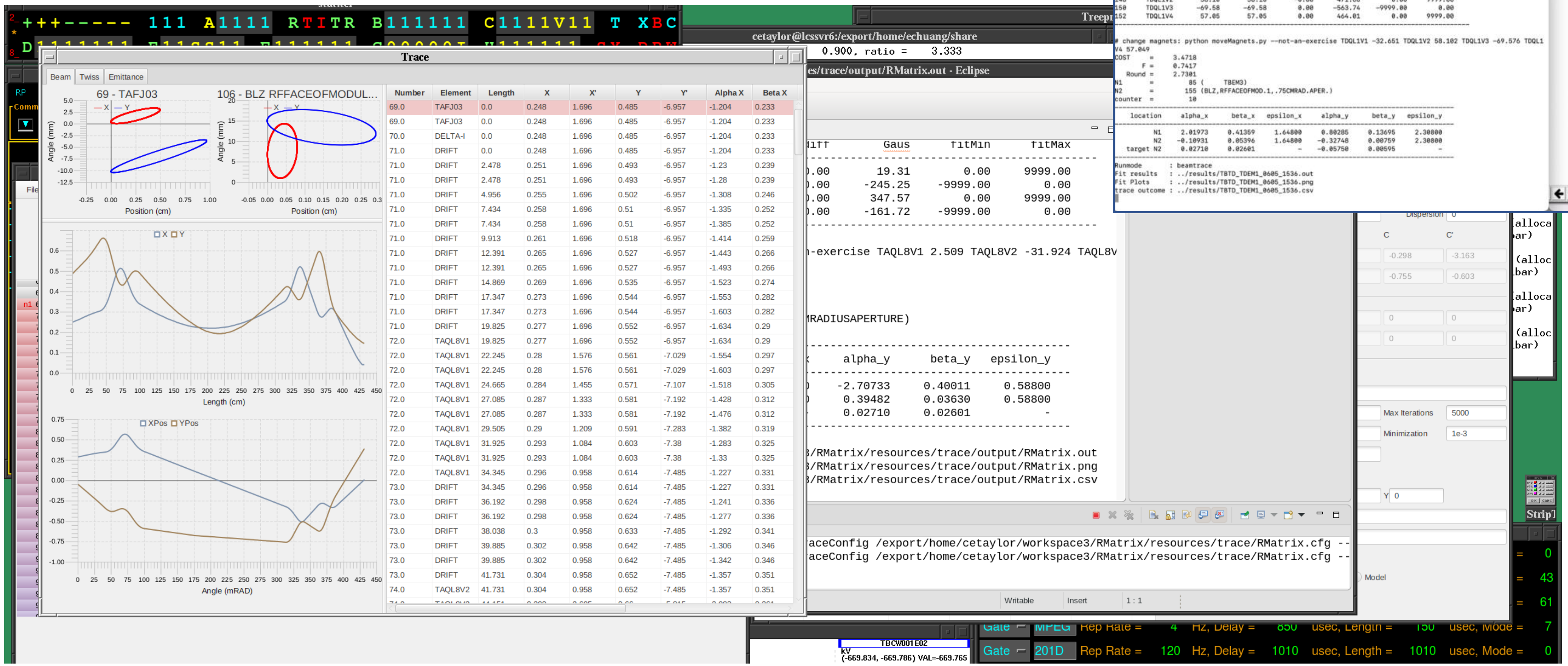
Tuning Methods for the Low-Energy Beam Transport

- The LEBT tuning depends on a source with limited reproducibility
- The use of *adaptive tuning* is necessary
- The *model driven* software we developed here could be expanded to the HEBT



cTrace: conversion of Scilab code to C++



RMatrix: user interface for cTrace tuning

Drift-Tube Linac (DTL)

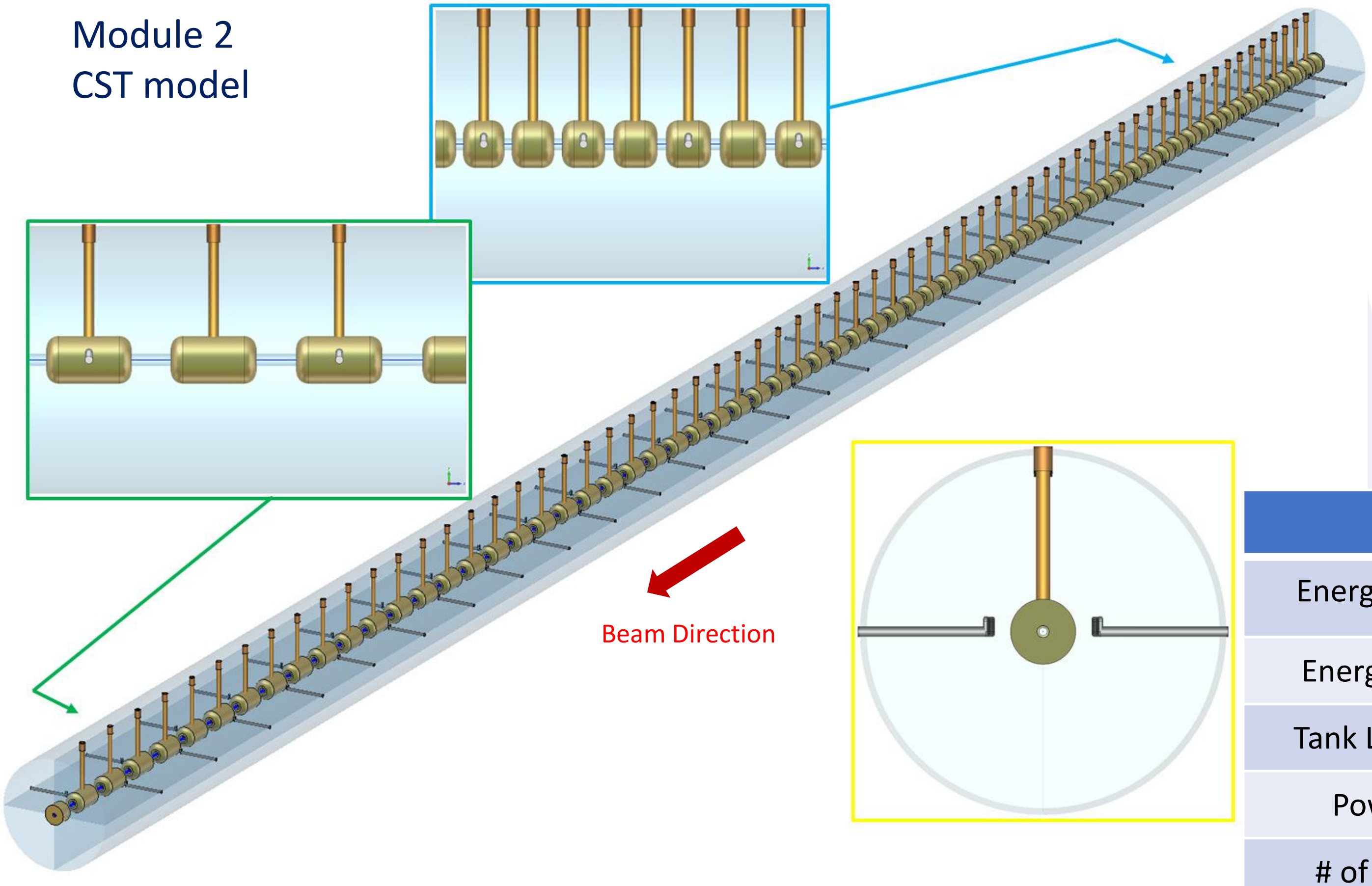


Image from Sergey Kurennoy

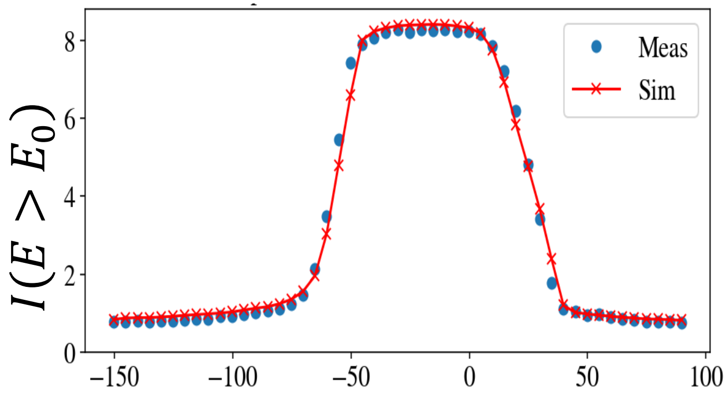
- The H^- and H^+ beams are matched from the LEBT into the DTL accelerator
- The DTL accelerates the 750 keV beams up to 100 MeV
- There are 4 DTL modules with differing lengths and cell dimension

	Tank 1	Tank 2	Tank 3	Tank 4
Energy gain	4.64 MeV	35.9 MeV	31.4 MeV	27.7 MeV
Energy out	5.39 MeV	41.3 MeV	72.3 MeV	100 MeV
Tank Length	326 cm	1969 cm	1875 cm	1792 cm
Power	0.305 MW	2.697 MW	2.74 MW	2.67 MW
# of cells	31	66	38	30
Bore Radius	0.75 cm	1 - 1.5 cm	1.5 cm	1.5 cm

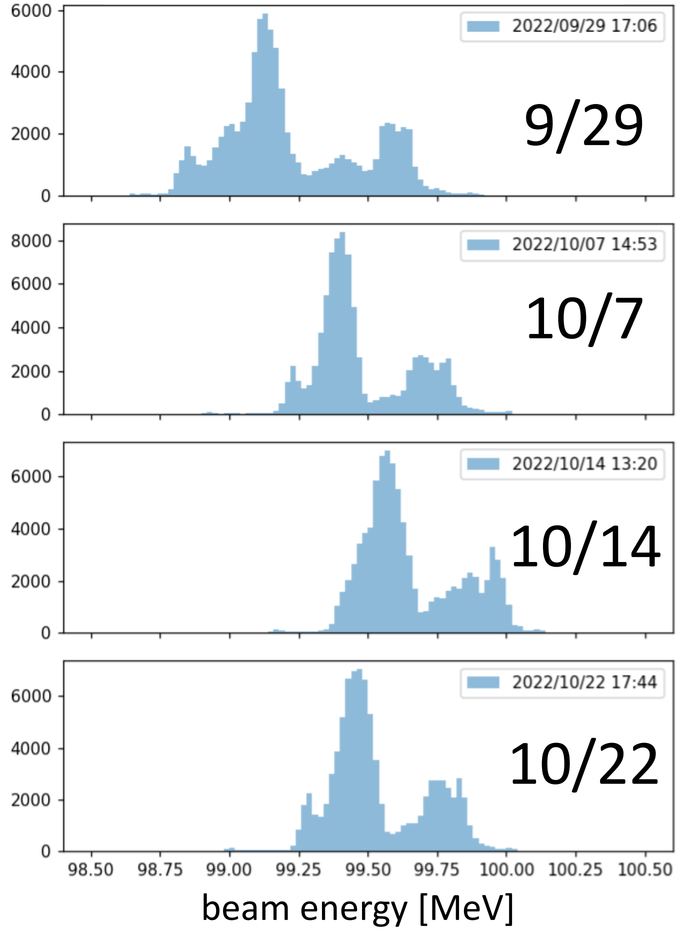
HPSim model for the 100 MeV H+ for IPF

- A model driven system is being developed for H+ beamline in LEBT and IPF
- Phase scan data for H+/H- were taken in 2022 run cycle
  - Fitted with HPSim for 6 RF cavities (pre buncher, main buncher, Module 1-4 in the DTL)
- Simulated with HPSim for 23 days with 1-min interval prior to the phase scan
  - Mean energy drifting consistent with observed beam phase changes
- Online model was created and communicated with operation team to allow real-time prediction or with archive data, waiting for H+ beam for 2023
- The HPSim tool has also been developed, but not fully tested for the side-coupled cavity linac
- Development of the high-energy beam transport is currently being coded into the HPSim applications

Module 1 Phase Scan



Beam Energy Distribution



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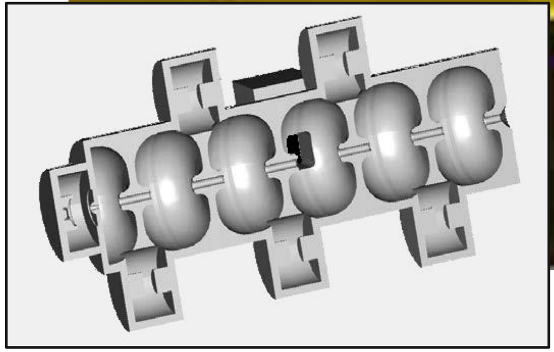
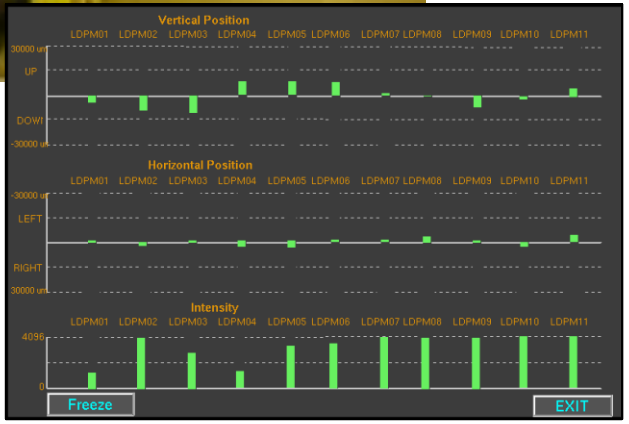
Side Coupled-Cavity Linac (CCL)

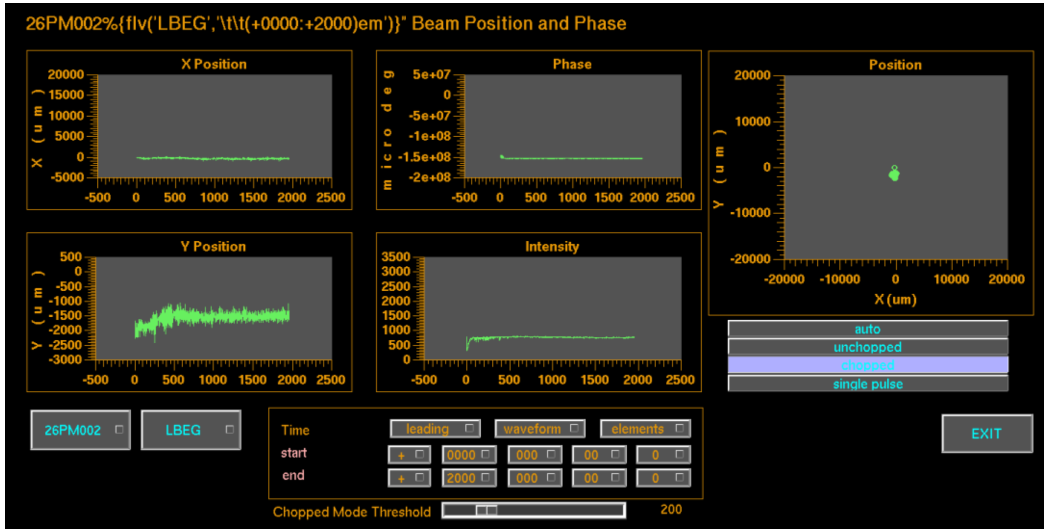
- After the Drift Tube Linac (DTL) accelerates proton beam to 100 MeV it is transported to the 805-MHz CCL
- Beam Position & Phase Monitors (BPPM) are used to measure the beams acceleration for each module
- The BPPM also are the primary method used for steering
- Wire scanners are used to document the beam profile



Side-Coupled Cavity



Beam Position Bar



BPPM Program

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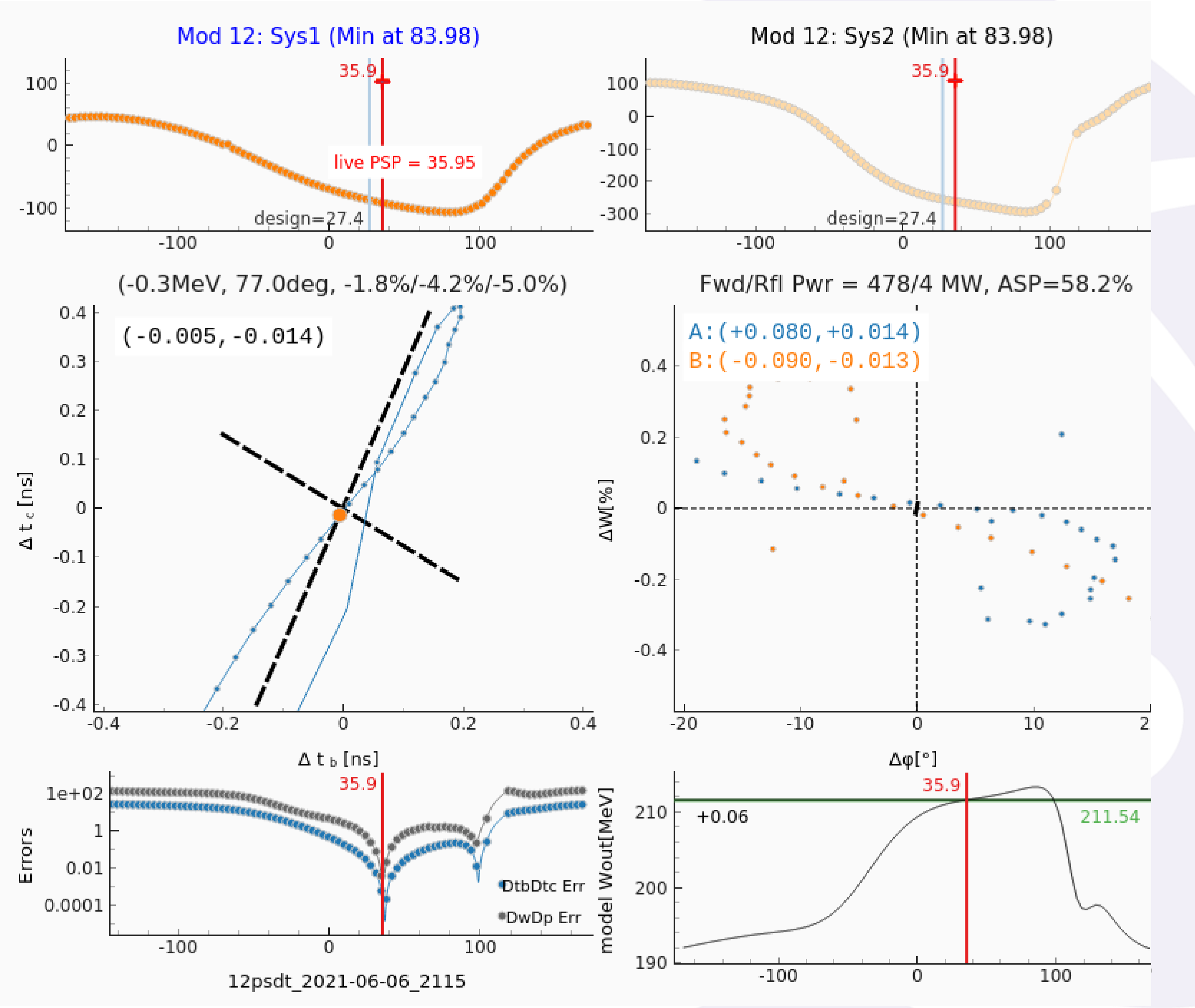
Side Coupled-Cavity Linac (CCL)

- A model driven phase shape method is used for the ΔT of the CCL
- Digital RF system upgrades from old analogue systems
- More accurate beam energy measurements
- Modernized method for tuning the CCL modules
- Working on refinements of the data acquisition system
- Develop adaptive tuning methods for improved tuning and operation



HEBT Simulation: Acceptance Tuning

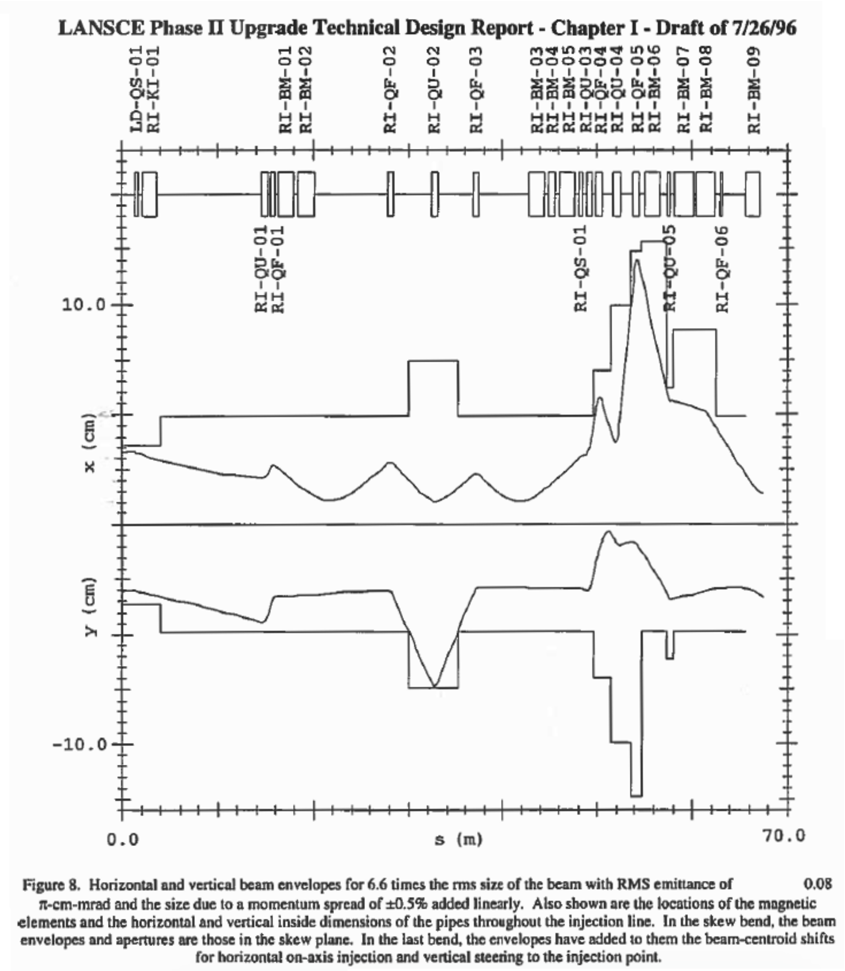
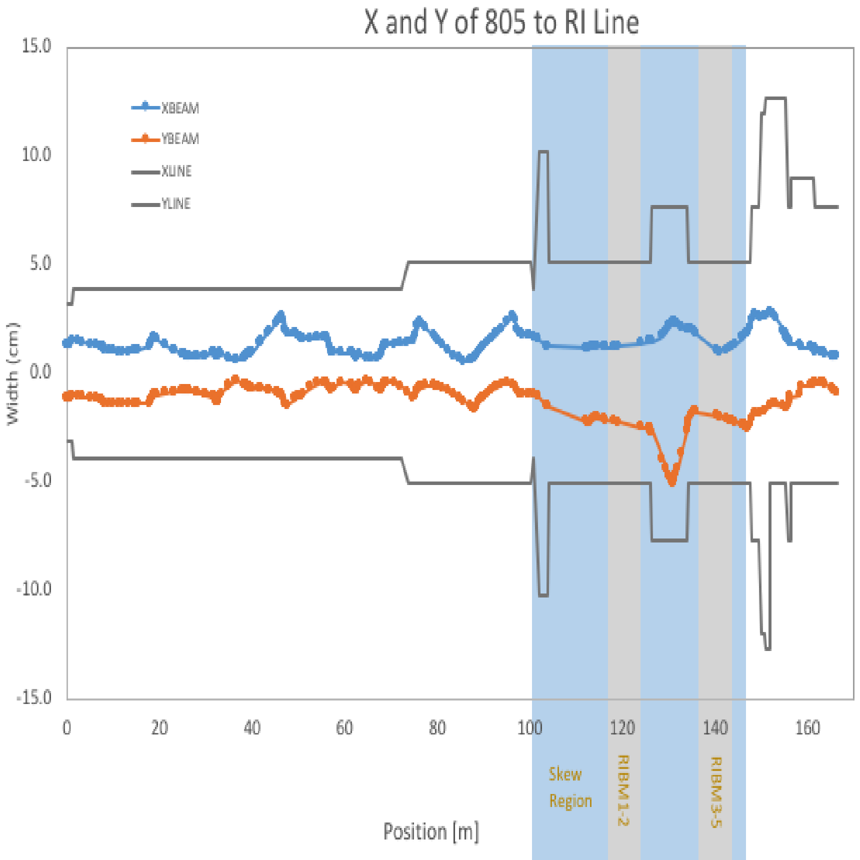


Figure 8. Horizontal and vertical beam envelopes for 6.6 times the rms size of the beam with RMS emittance of 0.08 π-cm-mrad and the size due to a momentum spread of ±0.5% added linearly. Also shown are the locations of the magnetic elements and the horizontal and vertical inside dimensions of the pipes throughout the injection line. In the skew bend, the beam envelopes and apertures are those in the skew plane. In the last bend, the envelopes have added to them the beam-centroid shifts for horizontal on-axis injection and vertical steering to the injection point.

Original Design RI Line model

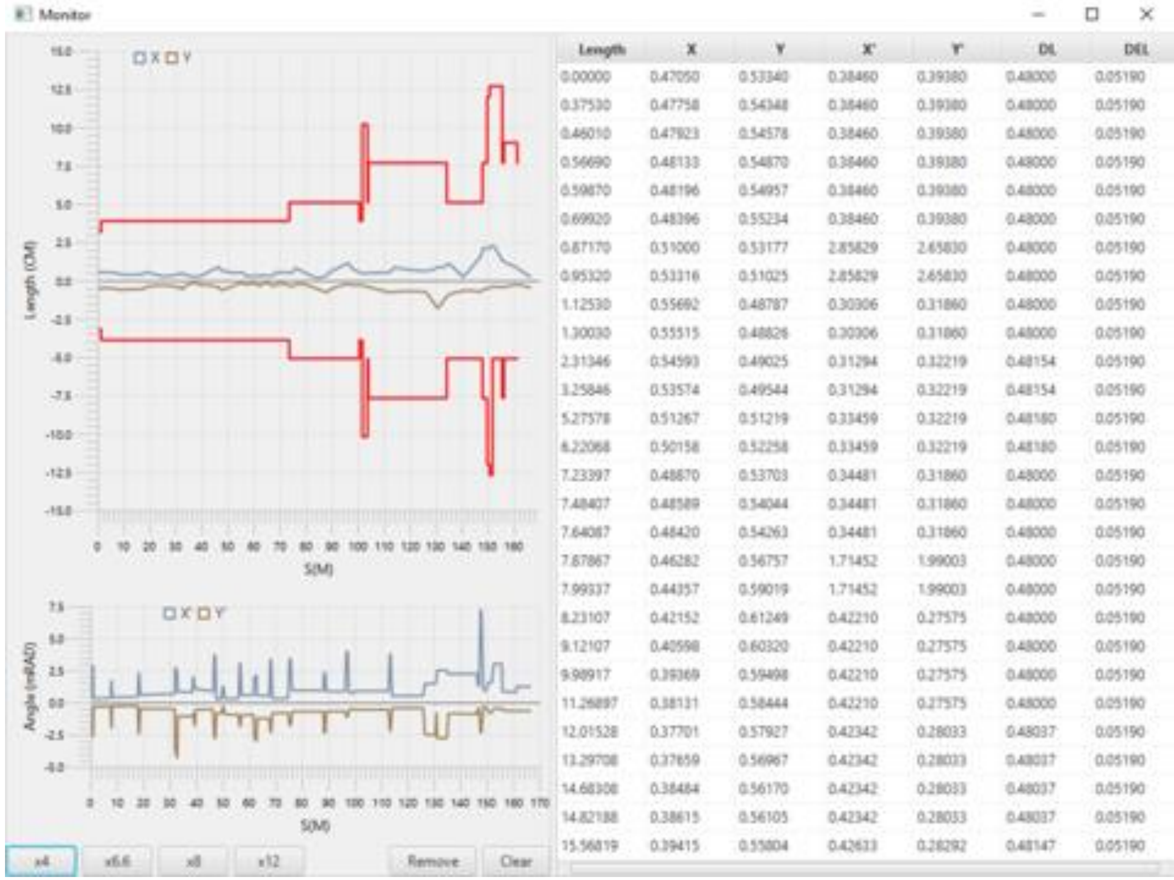
- We start with scaled *Acceptance tuning*
- The beam acceptance can be calculated by finding the point at which the emittance increase causes the beam to touch the side of the beam line
- In 2021 (right), the beam RMS does a much better job of staying within the confines of the beam pipe dimensions when compared with the initial design parameters (left)

2021 Horizontal and vertical beam envelopes for 6.6 times the RMS size, from the end of the LINAC to the point of ring injection.



Current RI Line model

HEBT Simulation: Adaptive tuning and Optimization Visualization



- RMatrix has been developed to use the TRANSPORT optics code to transform our HEBT tuning into a model driven process
- This mode includes two modes of operation:
  - Tuning match for beam parameters
  - Optimization Visualization
- The visualization reads the magnets real-time and allow the operator see the changes in the beam envelope
- The Rmatrix is ready to be used for the LEBT startup this year
- The HEBT method will need more time in testing to validate results

Summary

- The LANSCE accelerator is tuned by both model driven and independent methods
- The front-end of the accelerator is tuned with **adaptive tuning** and the rest is predominately optimized through beam **acceptance tuning**
- Over the past several years we have been developing automation routines for model independent tuning
- In the last two years, have introduced new automated **model driven** methods
- Initial results have shown good prediction of beam behavior

Questions?