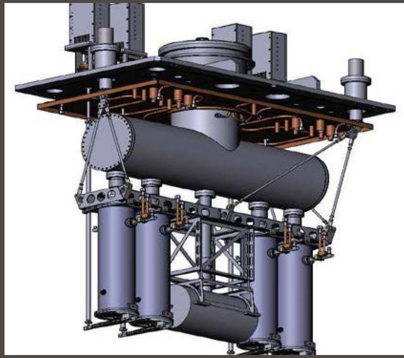
Canada's national laboratory for particle and nuclear physics
Laboratoire national canadien pour la recherche en physique nucléaire
et en physique des particules



Automatic Phasing of SCRF Cavities

Current status and future plans

ARW 2015, April 29, Knoxville, Tennessee

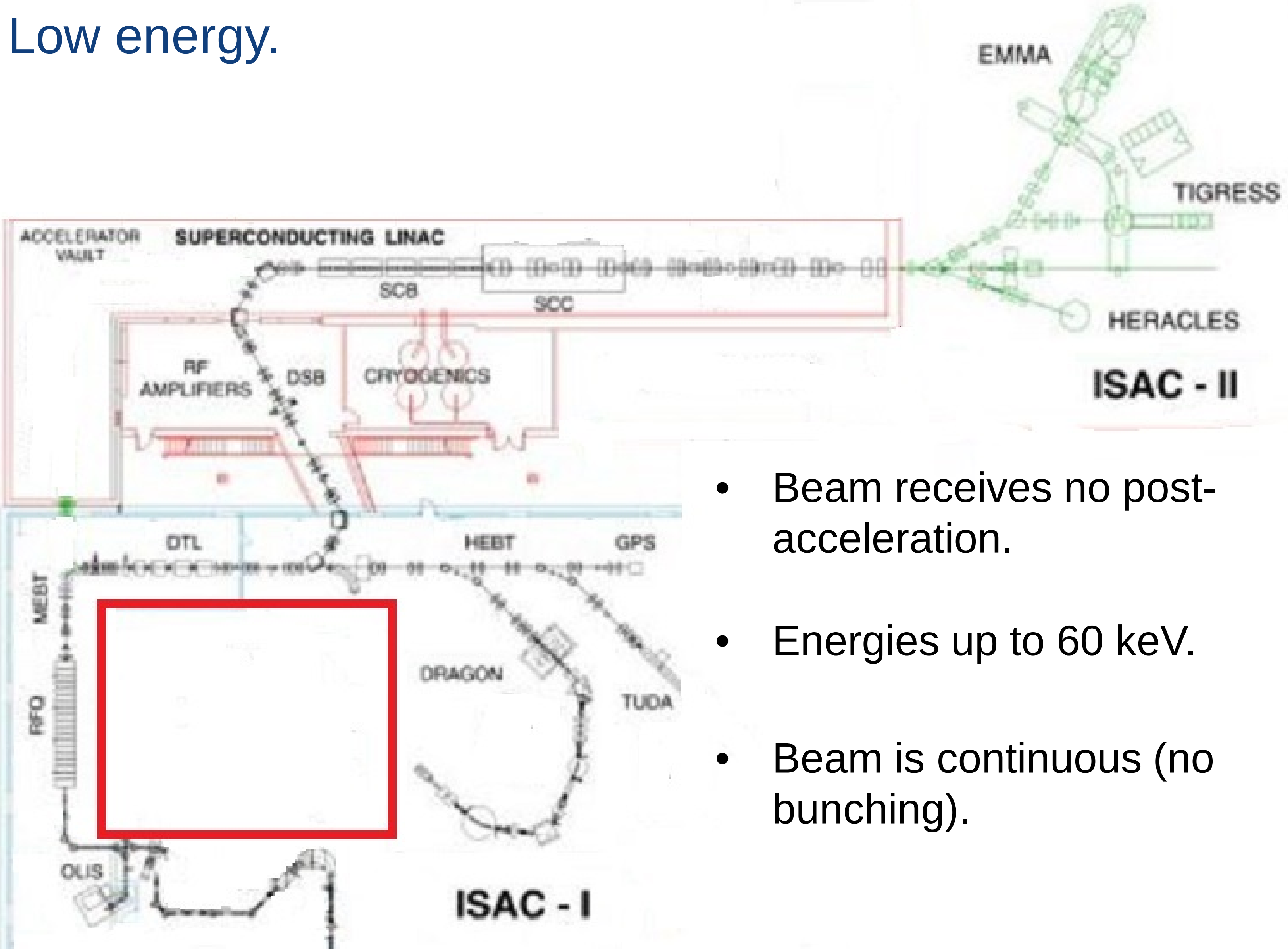
Spencer Kiy | ISAC Accelerator Operator | TRIUMF

Introduction to ISAC

- The Isotope Separator and Accelerator (ISAC) Facility at TRIUMF utilizes the isotope separation on-line (ISOL) method to create and deliver rare radioactive ion beams to various nuclear and particle physics experiments.
  - The driver beam is a 480 MeV proton beam from the TRIUMF cyclotron.
  - ISAC targets accept proton currents of up to 100 μA (dictated by upper limit of license).
  - Radioactive ion beams can be sent to three different experimental areas.

Introduction to ISAC

Low energy.

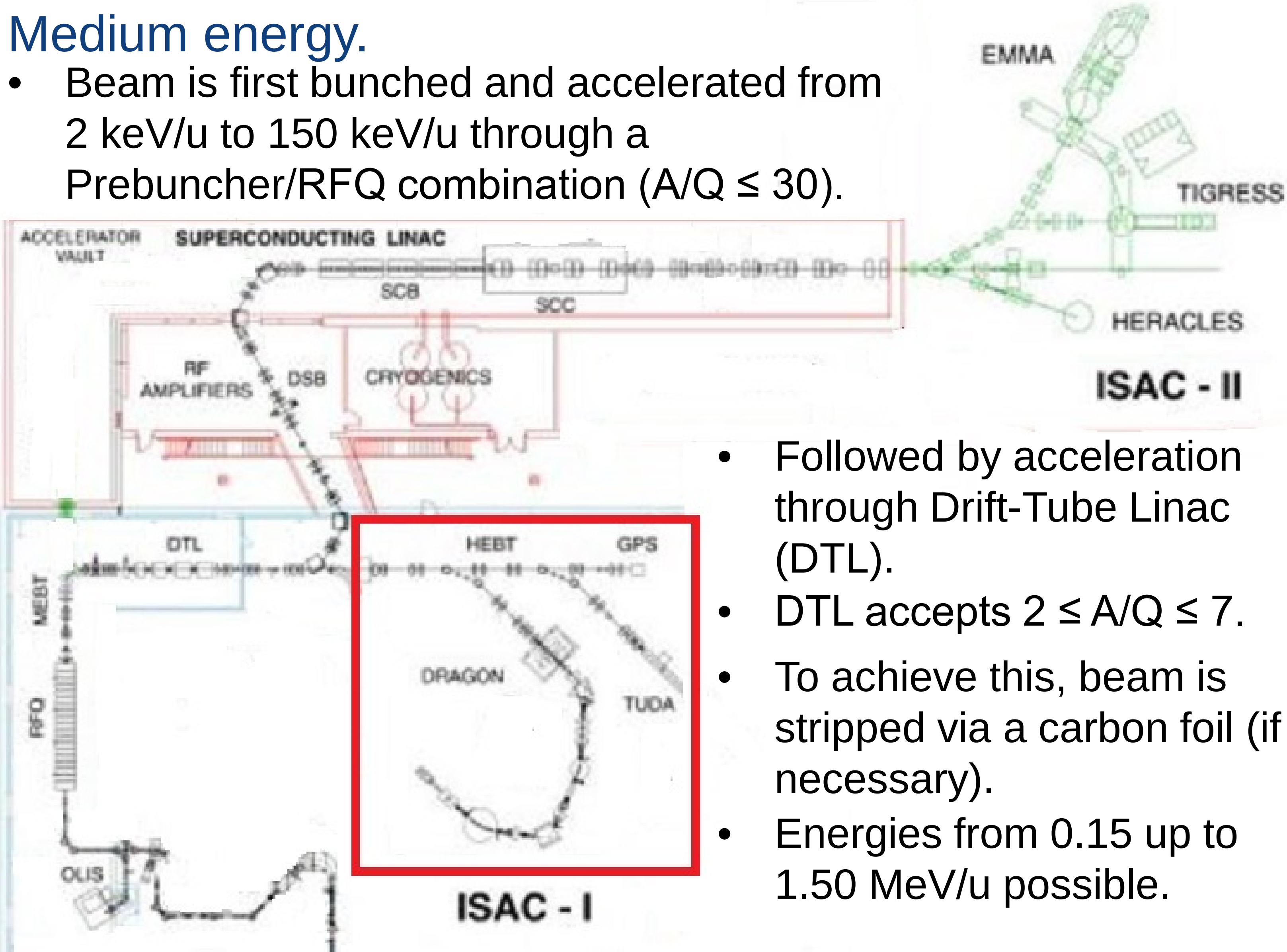


- Beam receives no post-acceleration.
- Energies up to 60 keV.
- Beam is continuous (no bunching).

Introduction to ISAC

Medium energy.

- Beam is first bunched and accelerated from 2 keV/u to 150 keV/u through a Prebuncher/RFQ combination (A/Q ≤ 30).

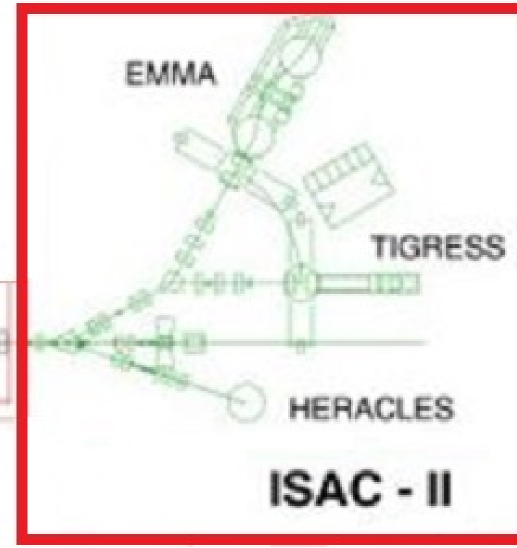


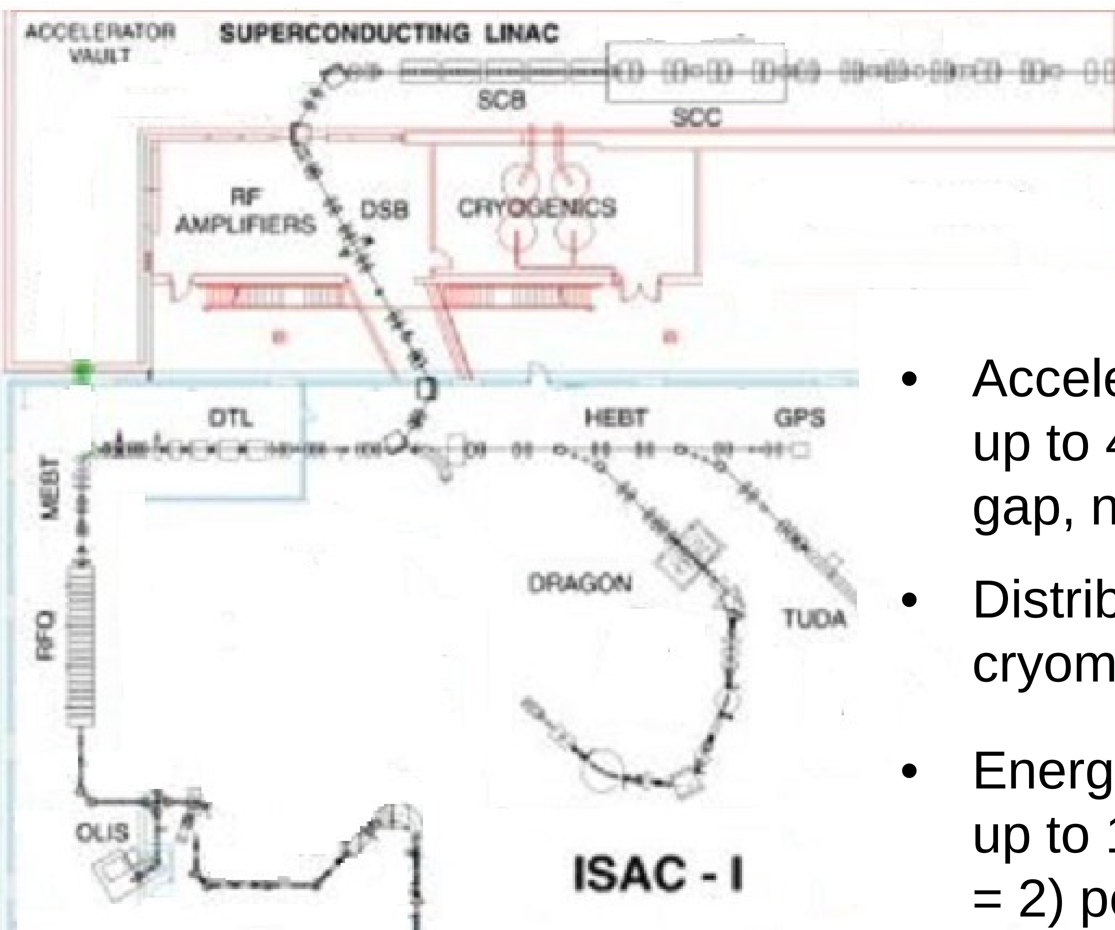
- Followed by acceleration through Drift-Tube Linac (DTL).
- DTL accepts 2 ≤ A/Q ≤ 7.
- To achieve this, beam is stripped via a carbon foil (if necessary).
- Energies from 0.15 up to 1.50 MeV/u possible.

Introduction to ISAC

High energy.

- Beam is injected into the Superconducting Linac at the full DTL energy (1.5 MeV/u).





- Acceleration provided by up to 40 quarter wave, 2-gap, niobium cavities.
- Distributed in 8 cryomodules.
- Energies from 1.50 MeV/u up to 16.5 MeV/u (for A/Q = 2) possible.

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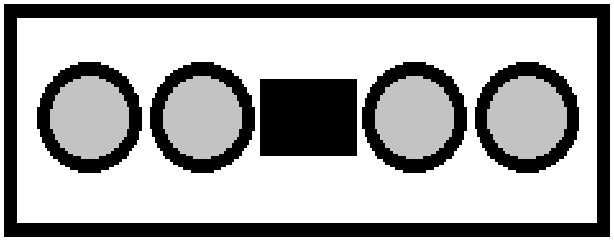
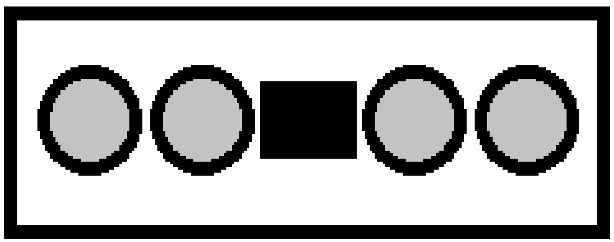
Superconducting Linac

Cryomodules
1 & 2



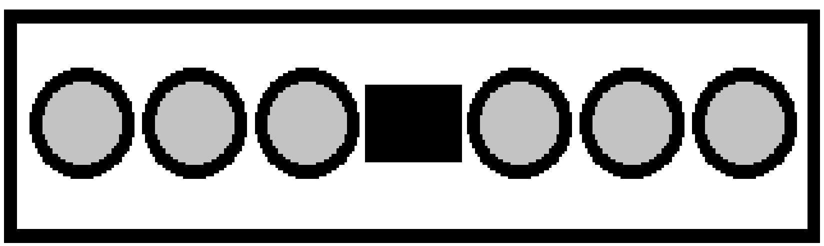
- 4 cavities, 1 solenoid.
- β = 0.057, f = 106.08 MHz

Cryomodules
3, 4, & 5



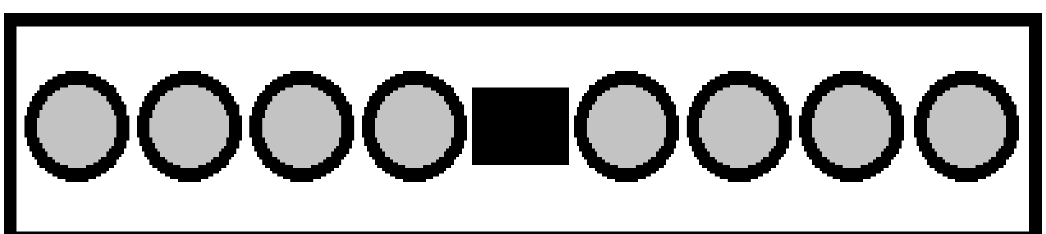
- 4 cavities, 1 solenoid.
- β = 0.071, f = 106.08 MHz

Cryomodules
6 & 7



- 6 cavities, 1 solenoid.
- β = 0.110, f = 141.44 MHz

Cryomodule
8



- 8 cavities.
- 1 solenoid.
- β = 0.110.
- f = 141.44 MHz.

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Superconducting Linac

Tuning the Linac

- The Linac is very flexible in accelerating a variety of heavy ion beams to a wide range of energies, as each 2-gap cavity can accept over a wide range of β.

  - This flexibility of the Linac however does have the drawback that each of the 40 cavities are phased individually.
  - This can lead to lengthy setup times, ranging from 8 to 16 hours.

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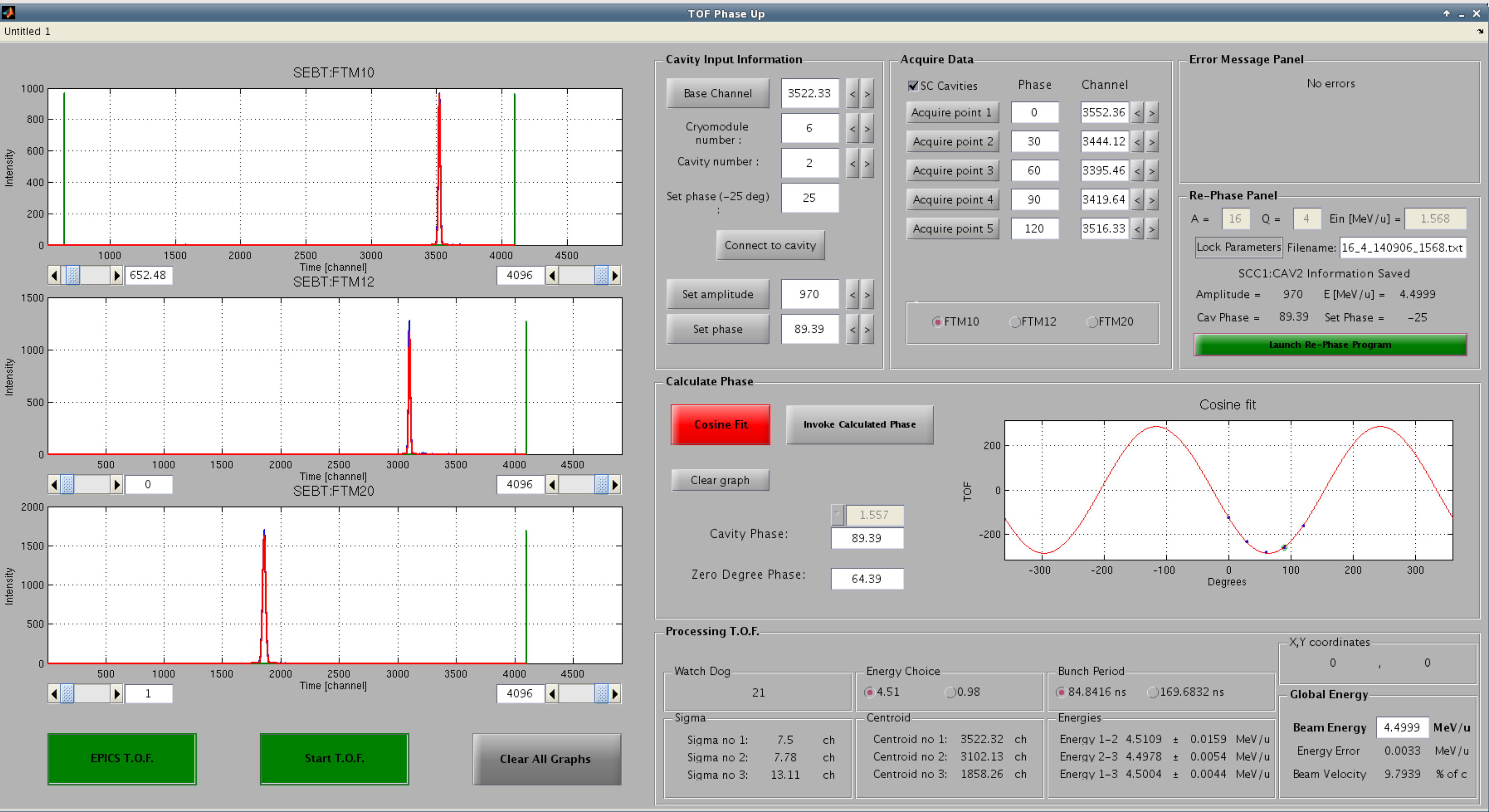
Linac Phasing Program

- Phasing program is written in MATLAB, uses a MATLAB Channel Access (MCA) toolbox to read and write to EPICS variables



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SCRF Cavity Trip Response

- Further to long setup times, significant downtime can be incurred if a single SCRF cavity fails.

- The current response by operators when a cavity trips while delivering to an experiment is:

    - Attempt to restore the cavity. Downtime ≤ 0.5 hours.

    - Contact an SCRF Expert. If outside of regular business hours, call an expert in. Downtime = 1 – 4 hours.

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Response to Cavity Failure

- Occasionally the SCRF expert will determine that something has changed in the cavity performance, and that the cavity can no longer operate reliably at the same gradient.

  - Option 1: Reduce the cavity amplitude to 90.6% its initial value, and adjust the cavity phase from -25˚ to 0˚. Downtime = 0.5 hours.

  - Option 2: Re-tune the Linac from the failed cavity on. Downtime = 4 – 24(+) hours.

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Main Problems

1. Long setup times for each different experiment.
    - Want a way to utilize the flexibility of the Linac, rather than allow it to hinder the setup of tunes.
2. Downtime incurred by failed SCRF cavities can accumulate quickly.
    - Want to minimize downtime.
3. Keeping 10 operators trained on the Linac uses a lot of beam time.
    - Want to minimize training time.

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Potential Solution

- Since the cavity parameters are known, the arrival time of the beam at each cavity can be calculated.

  - Use this to calculate the change in arrival time at each cavity when a cavity fails. This makes an automatic re-phasing of the Linac possible.

  - This can also be used to avoid phasing of the Linac altogether. The known cavity parameters can be used to automatically set the cavity phases for future tunes.

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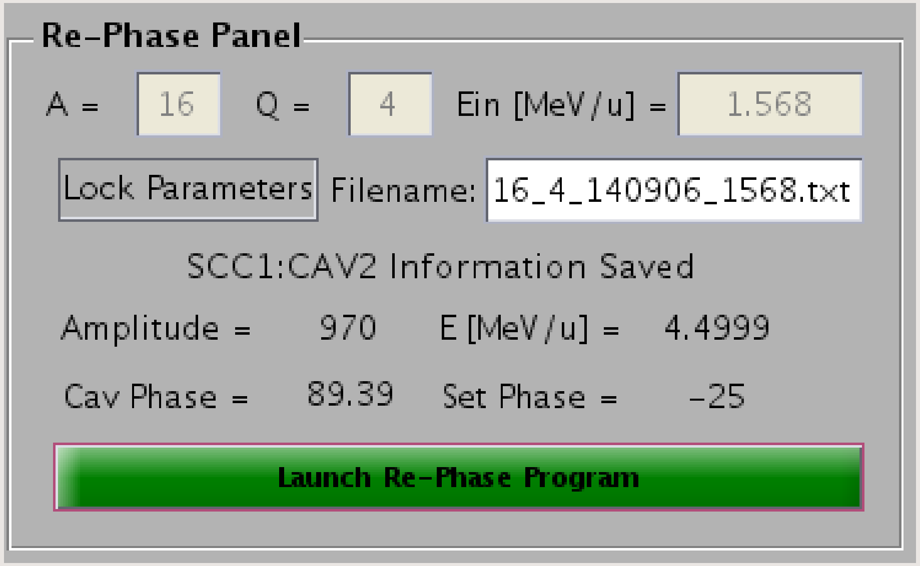
Implementation

Update the current Linac phasing program to automatically log cavity phases, amplitudes, and energies as the Linac is phased.

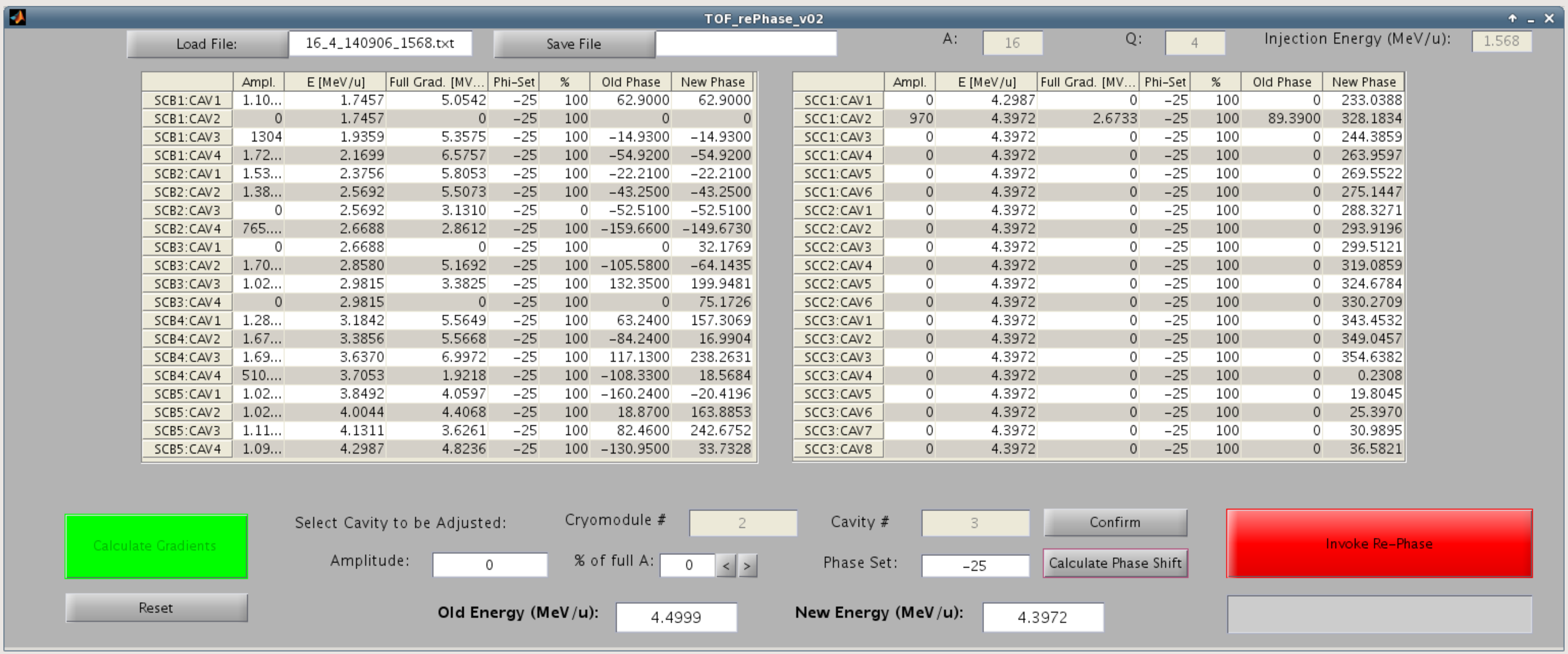
- This has been tested and shown to work. Logged information is saved in a text file with a time stamp and beam parameters.



Implementation

Create a Re-Phase program that takes the data logged during the initial tuning and calculates new phase setpoints in the event of a cavity failure.

- Program has been written and some preliminary tests have been done.



	Ampl.	E [MeV/u]	Full Grad. [MV...	Phi-Set	%	Old Phase	New Phase
SCB1:CAV1	1.10...	1.7457	5.0542	-25	100	62.9000	62.9000
SCB1:CAV2	0	1.7457	0	-25	100	0	0
SCB1:CAV3	1304	1.9359	5.3575	-25	100	-14.9300	-14.9300
SCB1:CAV4	1.72...	2.1699	6.5757	-25	100	-54.9200	-54.9200
SCB2:CAV1	1.53...	2.3756	5.8053	-25	100	-22.2100	-22.2100
SCB2:CAV2	1.38...	2.5692	5.5073	-25	100	-43.2500	-43.2500
SCB2:CAV3	0	2.5692	3.1310	-25	0	-52.5100	-52.5100
SCB2:CAV4	765....	2.6688	2.8612	-25	100	-159.6600	-149.6730
SCB3:CAV1	0	2.6688	0	-25	100	0	32.1769
SCB3:CAV2	1.70...	2.8580	5.1692	-25	100	-105.5800	-64.1435
SCB3:CAV3	1.02...	2.9815	3.3825	-25	100	132.3500	199.9481
SCB3:CAV4	0	2.9815	0	-25	100	0	75.1726
SCB4:CAV1	1.28...	3.1842	5.5649	-25	100	63.2400	157.3069
SCB4:CAV2	1.67...	3.3856	5.5668	-25	100	-84.2400	16.9904
SCB4:CAV3	1.69...	3.6370	6.9972	-25	100	117.1300	238.2631
SCB4:CAV4	510....	3.7053	1.9218	-25	100	-108.3300	18.5684
SCB5:CAV1	1.02...	3.8492	4.0597	-25	100	-160.2400	-20.4196
SCB5:CAV2	1.02...	4.0044	4.4068	-25	100	18.8700	163.8853
SCB5:CAV3	1.11...	4.1311	3.6261	-25	100	82.4600	242.6752
SCB5:CAV4	1.09...	4.2987	4.8236	-25	100	-130.9500	33.7328

	Ampl.	E [MeV/u]	Full Grad. [MV...	Phi-Set	%	Old Phase	New Phase
SCC1:CAV1	0	4.2987	0	-25	100	0	233.0388
SCC1:CAV2	970	4.3972	2.6733	-25	100	89.3900	328.1834
SCC1:CAV3	0	4.3972	0	-25	100	0	244.3859
SCC1:CAV4	0	4.3972	0	-25	100	0	263.9597
SCC1:CAV5	0	4.3972	0	-25	100	0	269.5522
SCC1:CAV6	0	4.3972	0	-25	100	0	275.1447
SCC2:CAV1	0	4.3972	0	-25	100	0	288.3271
SCC2:CAV2	0	4.3972	0	-25	100	0	293.9196
SCC2:CAV3	0	4.3972	0	-25	100	0	299.5121
SCC2:CAV4	0	4.3972	0	-25	100	0	319.0859
SCC2:CAV5	0	4.3972	0	-25	100	0	324.6784
SCC2:CAV6	0	4.3972	0	-25	100	0	330.2709
SCC3:CAV1	0	4.3972	0	-25	100	0	343.4532
SCC3:CAV2	0	4.3972	0	-25	100	0	349.0457
SCC3:CAV3	0	4.3972	0	-25	100	0	354.6382
SCC3:CAV4	0	4.3972	0	-25	100	0	0.2308
SCC3:CAV5	0	4.3972	0	-25	100	0	19.8045
SCC3:CAV6	0	4.3972	0	-25	100	0	25.3970
SCC3:CAV7	0	4.3972	0	-25	100	0	30.9895
SCC3:CAV8	0	4.3972	0	-25	100	0	36.5821

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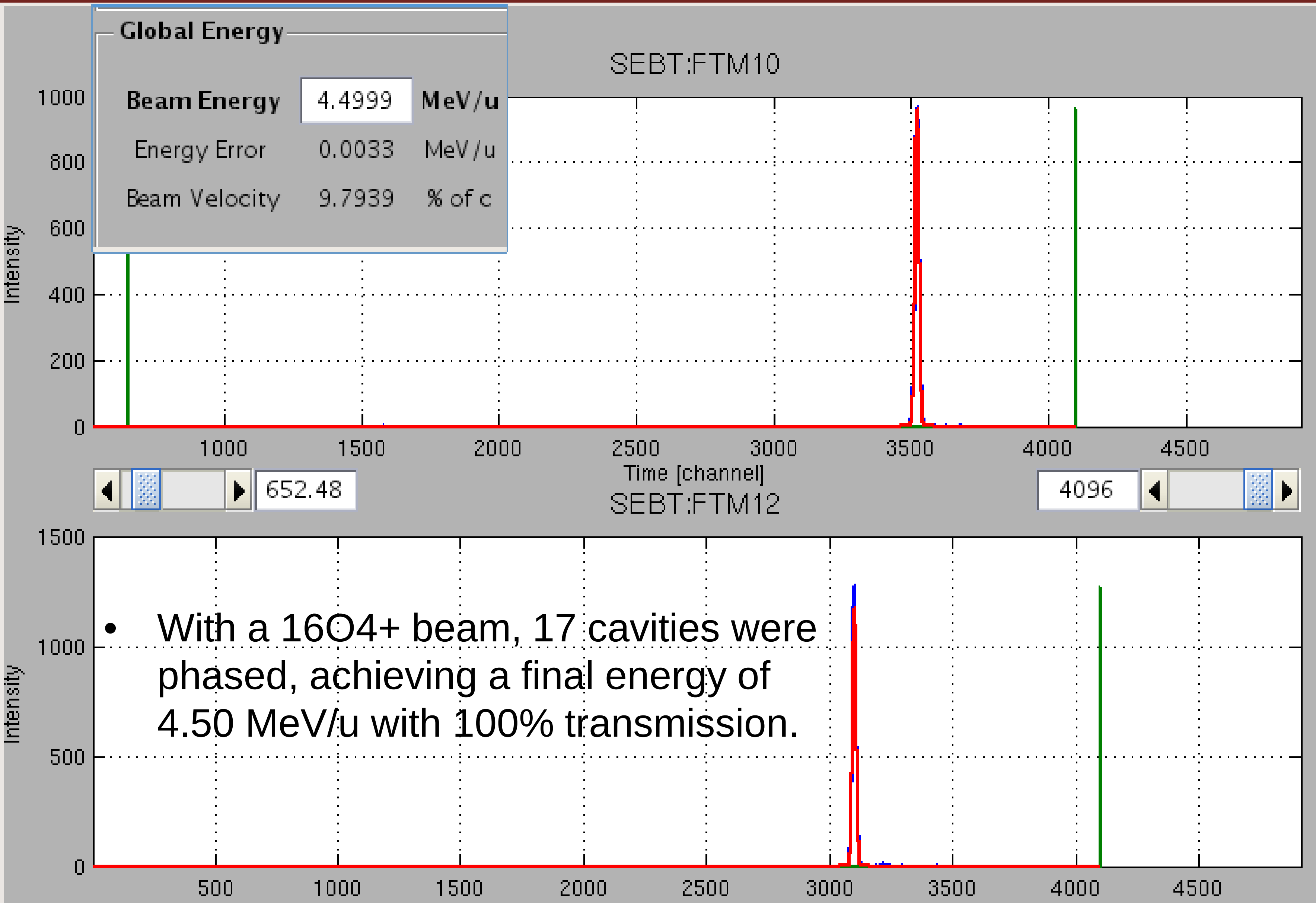
Re-Phase Test Result



- With a 16O4+ beam, 17 cavities were phased, achieving a final energy of 4.50 MeV/u with 100% transmission.

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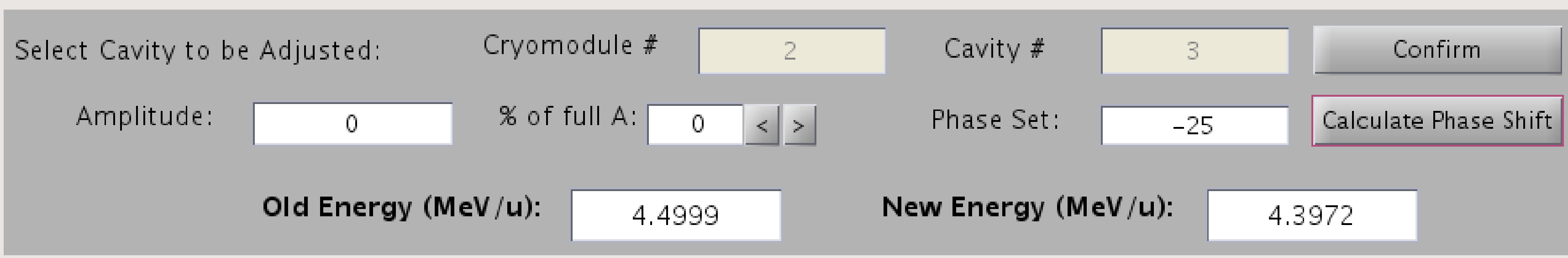
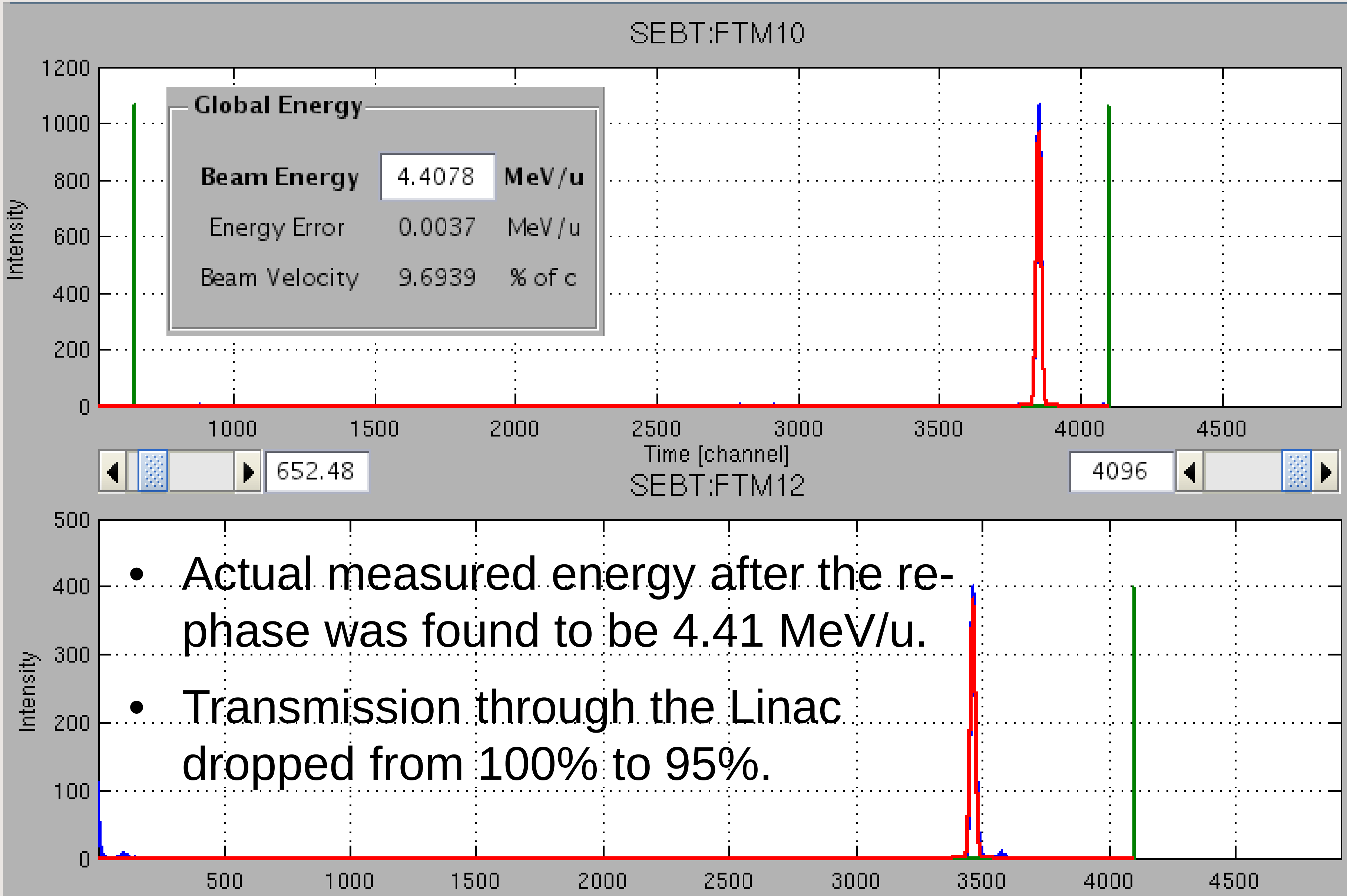
Re-Phase Test Result

- The 6th cavity was then turned off and the Re-Phase program was used to calculate and set the new phases of the 11 down stream cavities.

  - Estimated new energy calculated by the program was 4.40 MeV/u



Re-Phase Test Result



- Actual measured energy after the re-phase was found to be 4.41 MeV/u.
- Transmission through the Linac dropped from 100% to 95%.

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Re-Phase Test Result

- A second test was done, pushing all cavities from -25˚ to -10˚, while keeping all cavities on, to attempt to achieve a higher energy.
    - The original 16O4+ tune at 4.50 MeV/u energy was reloaded and confirmed, 100% transmission.
    - The Re-Phase program was set to shift all cavities to -10˚. Estimated new energy calculated by the program was 4.74 MeV/u.
    - New energy was measured to be 4.68 MeV/u. Transmission fell from 100% to 77%, however no optics were adjusted to account for the energy change.

Development Plans

- 1 week of beamtime has been allotted in August 2015 for development relating to delivery through the SC Linac.
    - Phase convention will be checked for all 40 cavities.
    - Global phase, that is intended to move all cavities together, will be checked to confirm that it does just that.
    - Intercavity distances will be measured with beam, to eliminate potential sources of error (currently the design distances are used).

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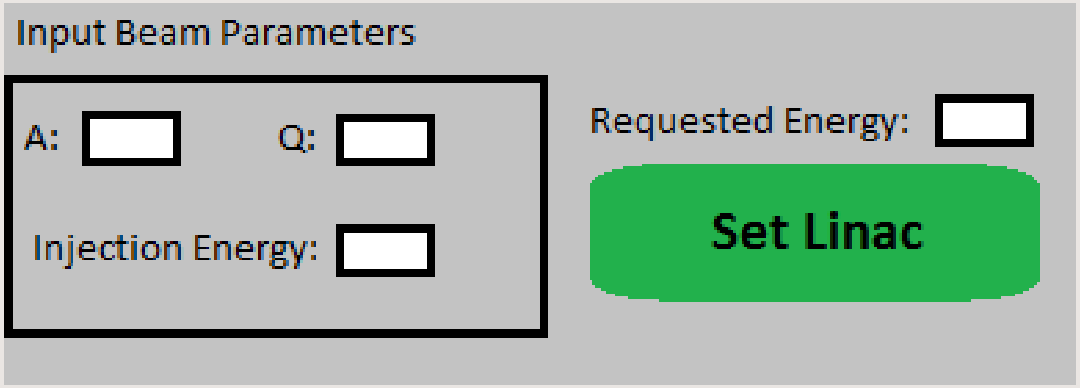
Planned Upgrades

- Include optics setpoints in the programs.
  - Phasing program should also log the solenoid and steerer settings in the linac, as well as quadrupole settings downstream of the linac
  - Re-Phasing program should scale optics when the cavity phases are adjusted for a new energy.
- Update intercavity distances using values to be measured during upcoming development time in August.

Planned Upgrades

- Simplify user interface to allow an operator to setup the Linac without having to phase a single cavity.

- Increase functionality of the program to allow for automatic phasing of the entire Linac.



End Goal

- Reduce amount of stable beamtime required for refresher training of operators.

  (8 Operators)*(4 Setups/Operator)*(12 hours/setup)
  = 384 hours = 16 days.

- Reduce amount of stable or radioactive beamtime required for setup of tunes to experiments.

  (10 Setups/Year)*(12 hours/setup)
  = 120 hours = 5 days.

- Minimize downtime due to SCRF cavity issues/instabilities.
  - Can potentially use re-phasing as a first response by operators before an SCRF expert is called in.
- Minimize downtime due to SCRF cavity failures.

Thank you!

Merci

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