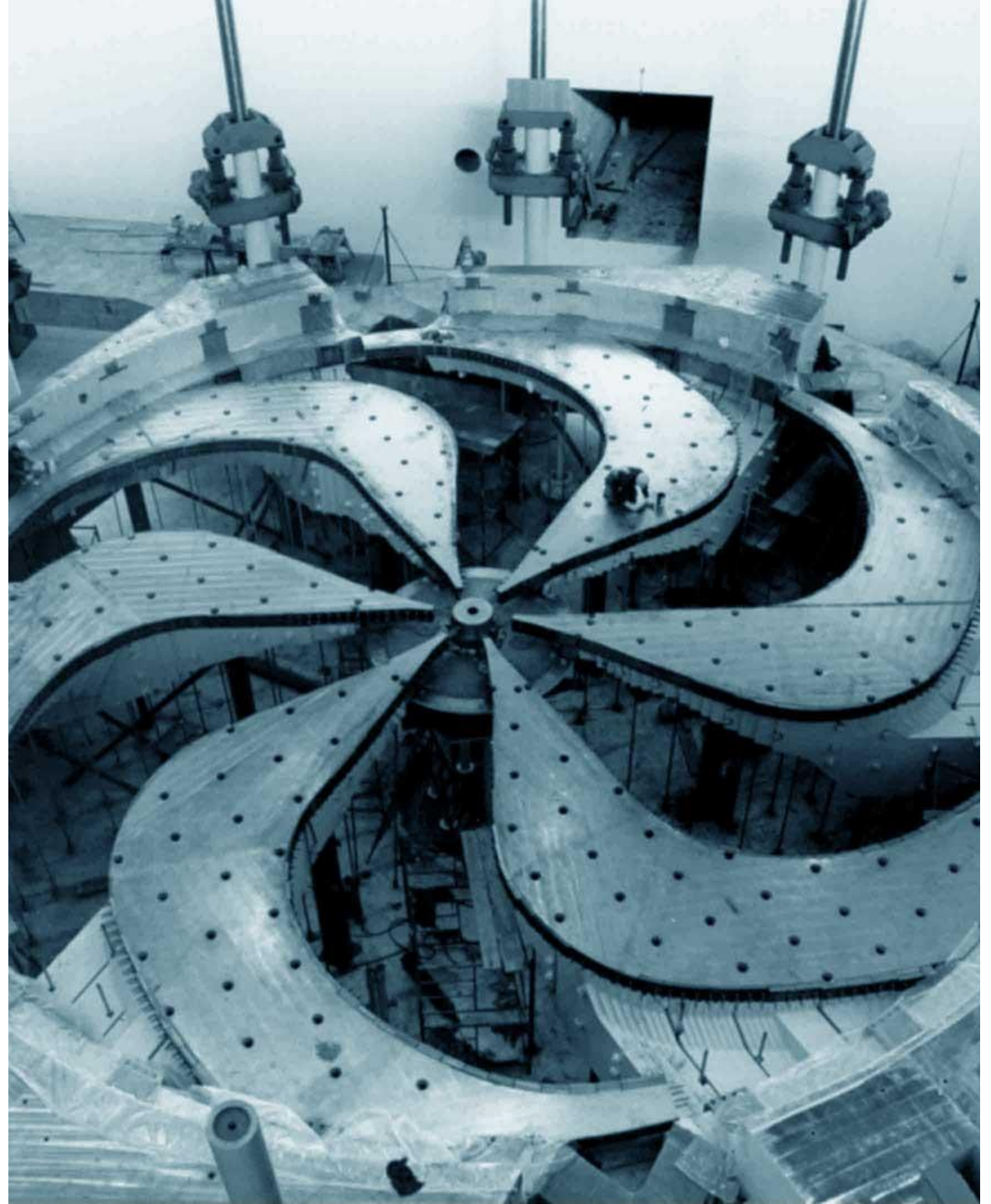


# Beam Tuning Automation Activities at TRIUMF

Spencer Kiy,  
Beam Delivery Group, TRIUMF  
June 28<sup>th</sup>, 2022

2022-07-11



# Summary

2

1. Brief introduction to TRIUMF
2. Define a high-level application
3. Overview of the HLA framework
4. Examples of applications and automated tuning
5. Review

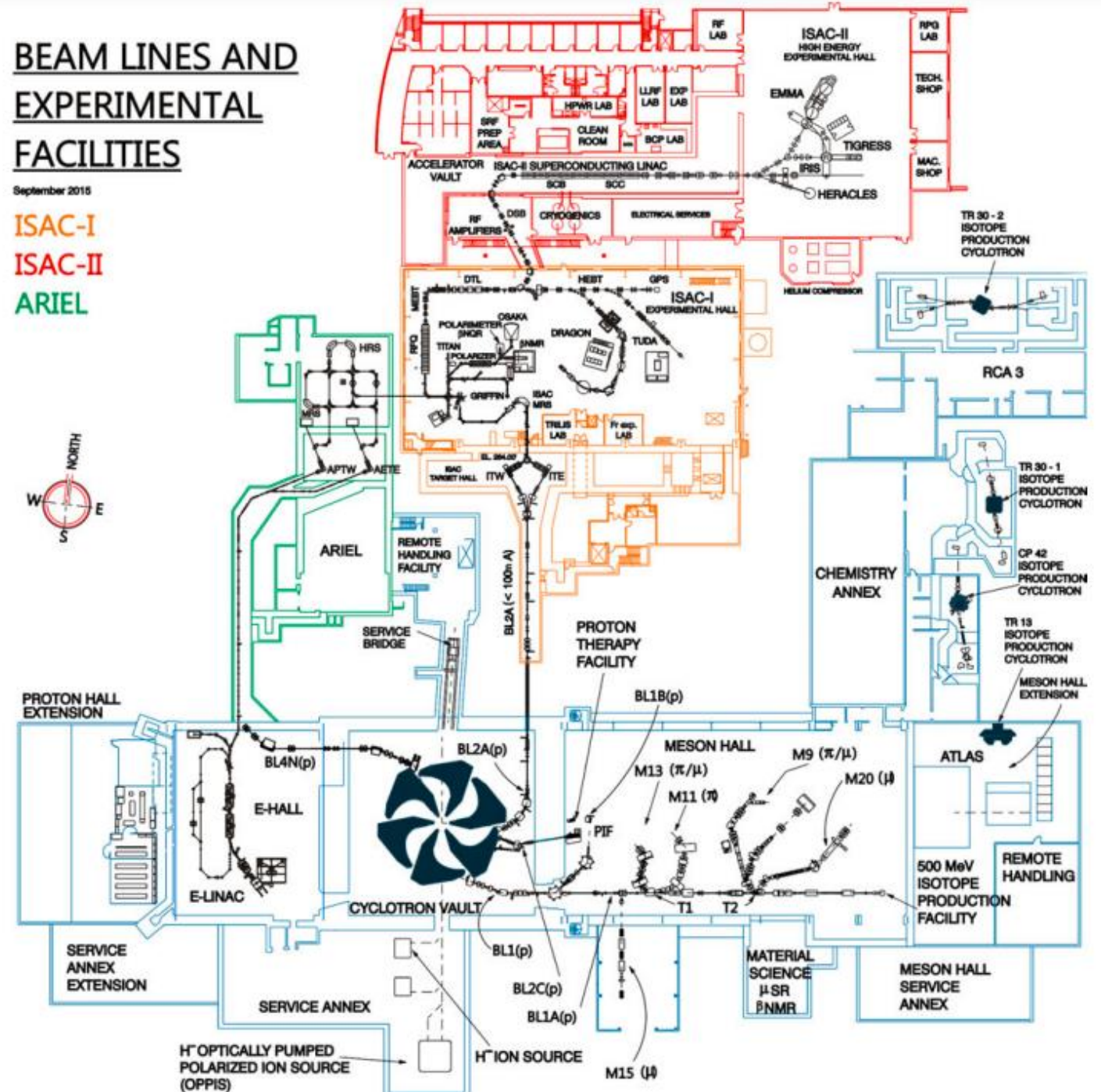
# TRIUMF Overview

- 520 MeV H- cyclotron with 3 secondary beamlines
- 30 MeV e-linac
- Currently 2, on the way to 4 RIB production target stations
- ISAC+ARIEL RIB beamlines to experiment stations
- RIB post accelerators (RFQ, DTL, SC QWR's)

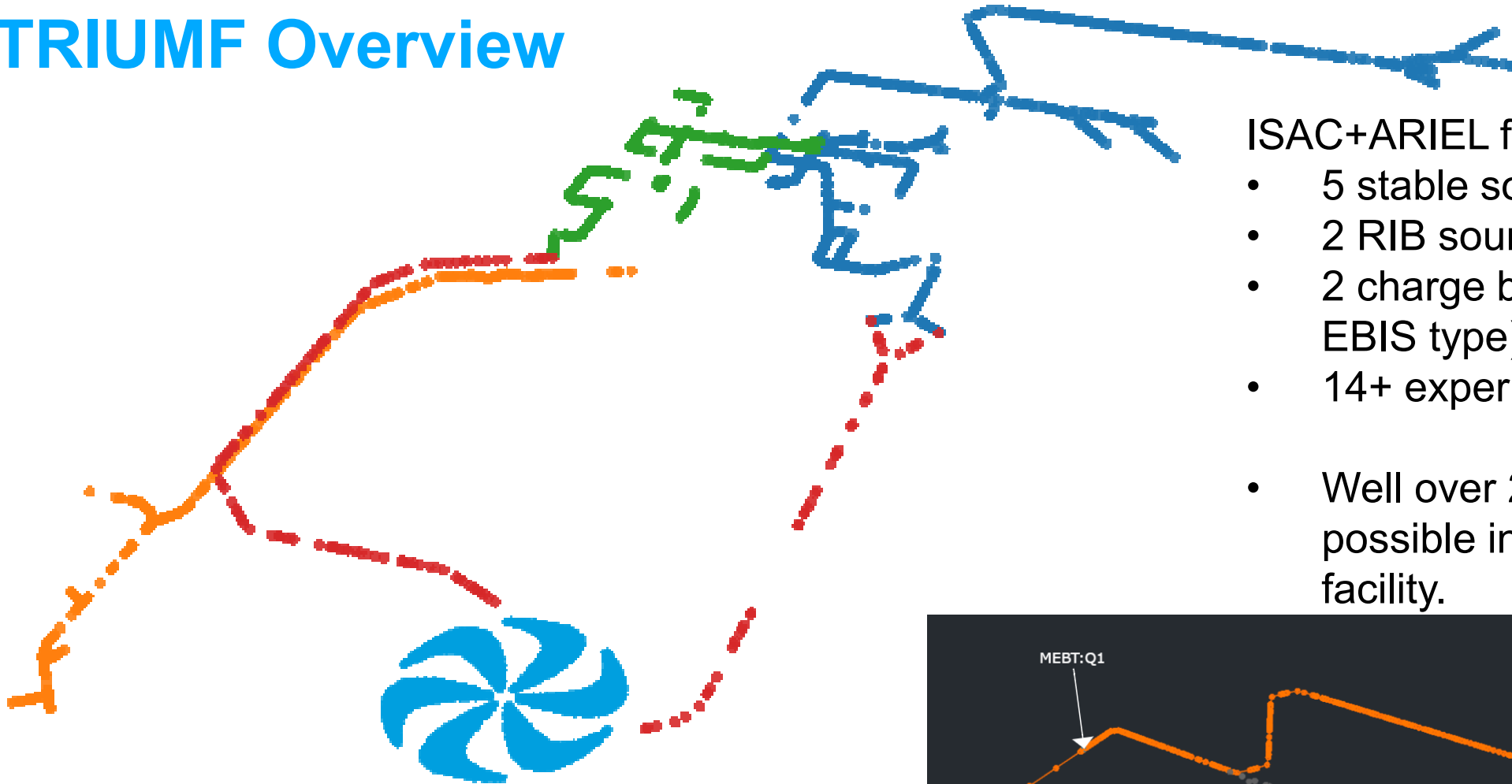
## BEAM LINES AND EXPERIMENTAL FACILITIES

September 2015

ISAC-I  
ISAC-II  
ARIEL



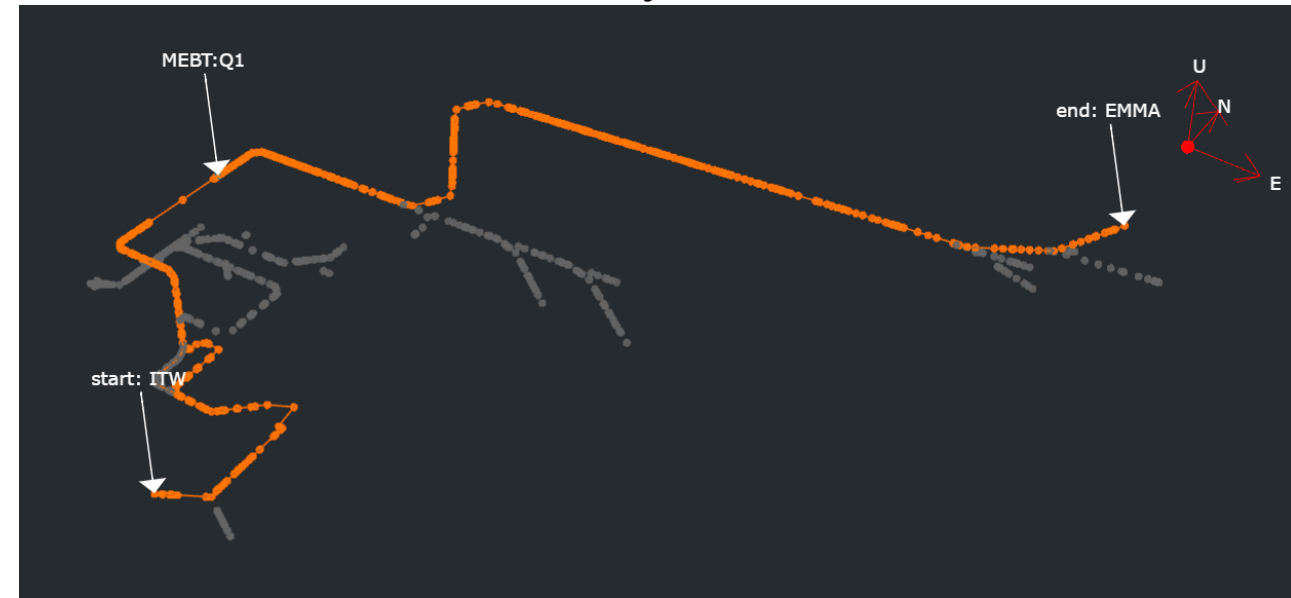
# TRIUMF Overview



ISAC+ARIEL facilities have:

- 5 stable sources
- 2 RIB sources (soon 4)
- 2 charge breeders (ECRIS type, EBIS type)
- 14+ experimental stations
- Well over 200 unique paths possible in the ISAC+ARIEL RIB facility.

4



# Motivation

5

## What is a High Level Application (HLA) and why do we want them?

- The motivation for HLAs at TRIUMF is to reduce overhead and improve quality and reliability of our delivered beams.
- Another primary motivation is that of improving coordination/consistency – make tools that are more generic and are useful for as many facilities at TRIUMF as possible.
- An HLA taskforce was initiated in 2017 with members of operations, beam delivery, beam physics, and controls seconded part time to work on HLAs.
- A true ‘high level’ application would take data from the control system, perform computationally intensive operations like simulations or minimization routines, and result in some sort of feedback into the control system.
- However, there is also lots of low-lying fruit in the realm of automation of routine operator tasks, which we are often also including in the ‘HLA’ definition



# HLA Framework - Overview

There are two primary levels to the HLA framework

- The first is the external tools selected: suite of programming languages, servers, etc.
- The second are the internal tools developed: actual new software, databases, training, etc.

# HLA Framework – External tools selected


## Gitlab


- A DevOps platform (Software development and IT operations). This is an approach toward expediting the cycle between developing and deploying new code
- Continuous Integration/Continuous Deployment (CI/CD) feature, which allows custom pipelines of jobs to be executed when new versions of code are committed.
- Applications automatically redeploy when new code is committed to Gitlab
- Serve up repositories of packaged Python code which can easily be installed by users or applications
- Issue tracking feature through which requests, bugs, and improvements are tracked

## Other software used

- |                           |          |                 |
|---------------------------|----------|-----------------|
| • Python+Flask (web apps) | • Celery | • PostgreSQL    |
| • Pyepics                 | • Redis  | • Nginx + uWSGI |

# HLA Framework - Gitlab

 **GitLab** Menu

 **tunex**

Project information

Repository

Issues22

Merge requests0

CI/CD

Security & Compliance



Deployments


Monitor






Infrastructure

Packages & Registries

hla > tunex

 **tunex** 

Project ID: 480 

 **422** Commits  **7** Branches  **35** Tags  **6.3 MB** Files  **16.4 MB** Storage

Application for loading, displaying, and scaling values for different tunes and paths.



Forked from [hla / beam / tuneX](#)






master

tunex /

+

▼

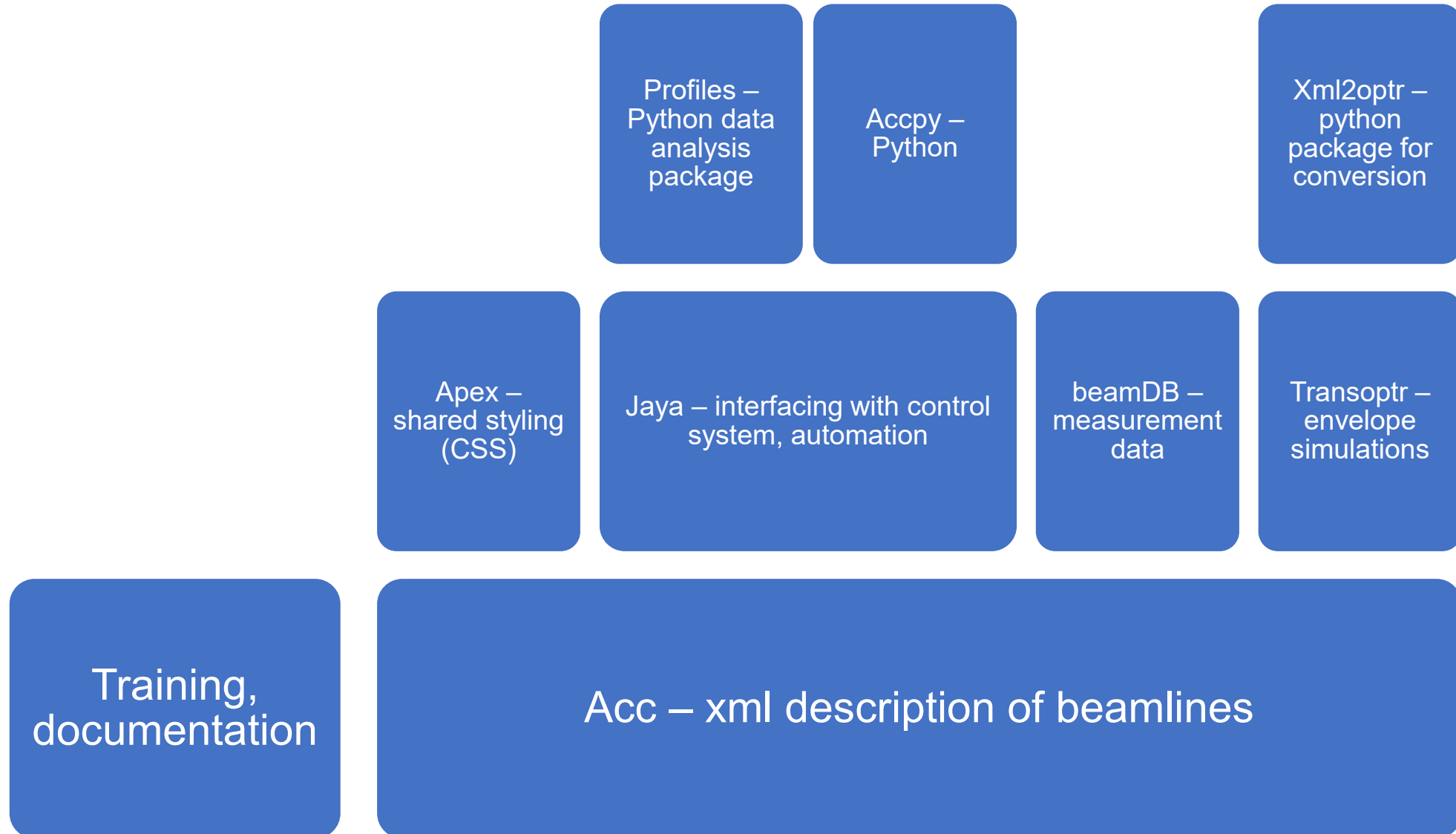
 Merge branch 'diff\_button' into 'master' 

Status	Pipeline	Triggerer	Stages
<div>passed</div> <div>00:00:19</div> <div>1 week ago</div>	Merge branch 'diff_button' into 'master' <a href="#">#97220</a>  v1.0.11  <a href="#">6e43559a</a> latest		<div>✓</div> <div>✓</div>
<div>passed</div> <div>00:03:04</div> <div>1 week ago</div>	Merge branch 'diff_button' into 'master' <a href="#">#97219</a>  master  <a href="#">6e43559a</a> latest		<div>✓</div> <div>✓</div> <div>✓</div>



# HLA Framework - Overview

9



# HLA Framework - Acc

- Collection of xml files describing the TRIUMF beamlines
- Contains all necessary information for envelope modelling, optics settings and scaling, diagnostics.
- Over 20 staff members contributing 1000+ commits (versions)
- A **sequence** is defined as a unique section of beamline before it splits or recombines.
- A **path** is a series of sequences in order from source to destination that defines a unique route the beam can take.
- Automated tests w/ Gitlab check for errors prior to deployment

```
<?xml version='1.0' encoding='UTF-8' ?>
<beampath xmlns:xi='http://www.w3.org/2001/XInclude'>

  <xi:include href='../sequence/ios_mcis.xml' />
  <xi:include href='../sequence/ios_db1.xml' />
  <xi:include href='../sequence/ios_db10.xml' />
  <xi:include href='../sequence/ilt_db33.xml' />
  <xi:include href='../sequence/ilt_db43.xml' />
  <xi:include href='../sequence/ilt_db47.xml' />
  <xi:include href='../sequence/mebt_db0.xml' />
  <xi:include href='../sequence/dtl_db0.xml' />
  <xi:include href='../sequence/hebt_db0.xml' />
  <xi:include href='../sequence/dsb_db0.xml' />
  <xi:include href='../sequence/scb1_db0.xml' />
  <xi:include href='../sequence/sebt_db8.xml' />
  <xi:include href='../sequence/sebt3_db0.xml' />
  <xi:include href='../sequence/sebt3_db4.xml' />


```

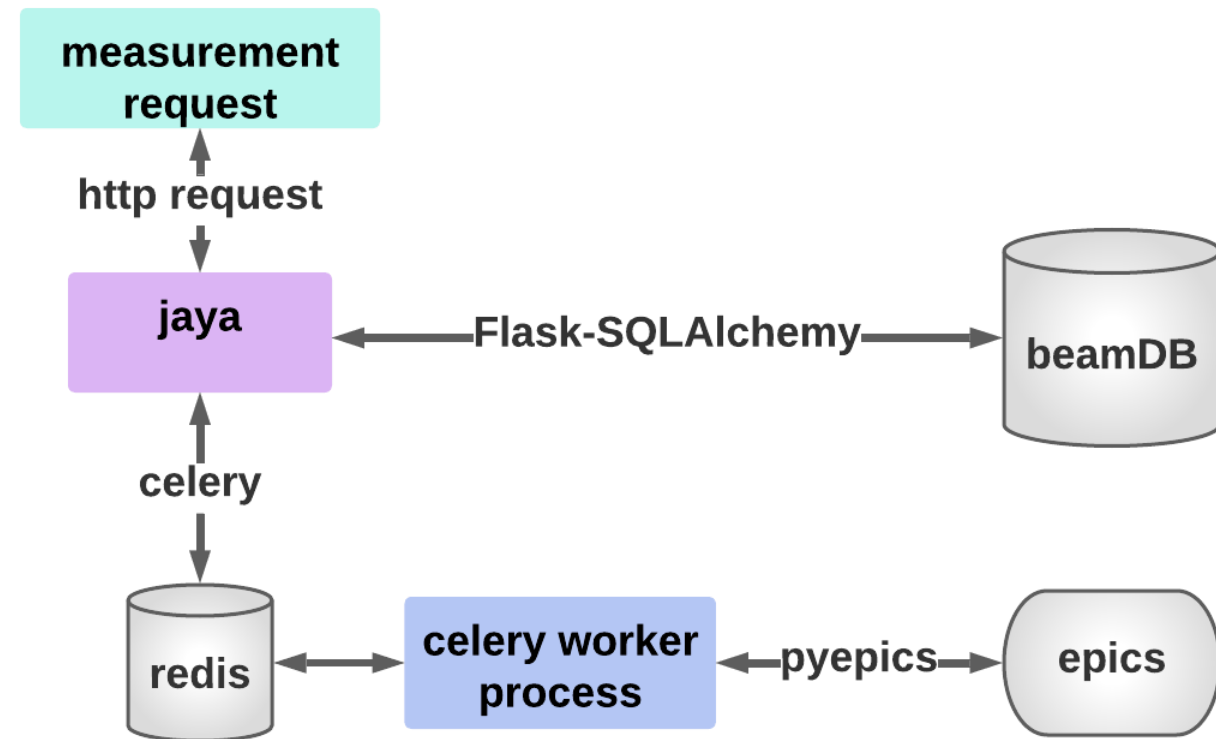
```
<notes> Danfysik 1987 L2 - #87141 </notes>
<element id="SEBT:Q9" type="mq" s="930.7086*mm" l="331.7*mm">
  <layout x="32878.88*mm" y="106740.83*mm" z="7873.7717*mm"/>
  <epics>
    <setpoint pv="SEBT:Q9:CUR" unit="A" min="0.0" max="85.0" type="current"/>
  </epics>
  <optr Btip="- (9177*G*(SEBT:Q9:CUR/(100*A)) + 82*G*(SEBT:Q9:CUR/(100*A))^3 -
    1174*G*(SEBT:Q9:CUR/(100*A))^5 )" aperR="2.6*cm"/>
</element>

<notes> Danfysik 1987 L2 - #87142 </notes>
<element id="SEBT:Q10" type="mq" s="1525.7086*mm" l="331.7*mm">
  <layout x="33473.877*mm" y="106740.81*mm" z="7873.8036*mm"/>
  <epics>
    <setpoint pv="SEBT:Q10:CUR" unit="A" min="0.0" max="85.0" type="current"/>
  </epics>
  <optr Btip="+ (9177*G*(SEBT:Q10:CUR/(100*A)) + 82*G*(SEBT:Q10:CUR/(100*A))^3 -
    1174*G*(SEBT:Q10:CUR/(100*A))^5 )" aperR="2.6*cm"/>
</element>
```

# HLA Framework - Jaya

11

- Middle layer that allows communication with the underlying control system.
- Maintains channel access (CA) monitors on over 5000 process variables (PVs)
- PV values are stored in an in-memory database (Redis).
- Backend processes that allow for long running measurement (Celery).
- Interfaces with beamDB to save measurement data.



# HLA Framework - Transoptr

- TRANSOPTR is a first-order beam envelope code written in FORTRAN, in use at TRIUMF since 1984.
- Calculates the beam's sigma matrix, representing the beam envelope in 6-dimensional phase space  $(x, Px, y, Py, z, Pz)$ .
- Notable benefits include the available expertise at TRIUMF, fast execution times, and the ability to integrate through on-axis field maps of accelerating cavities.
- Has simulated annealing or downhill simplex methods available for internal optimization
- Uses Runge-Kutte integration with an adaptive step size to solve the envelope equations.
- Python package 'xml2optr' converts xml files from Acc into transoptr input files.

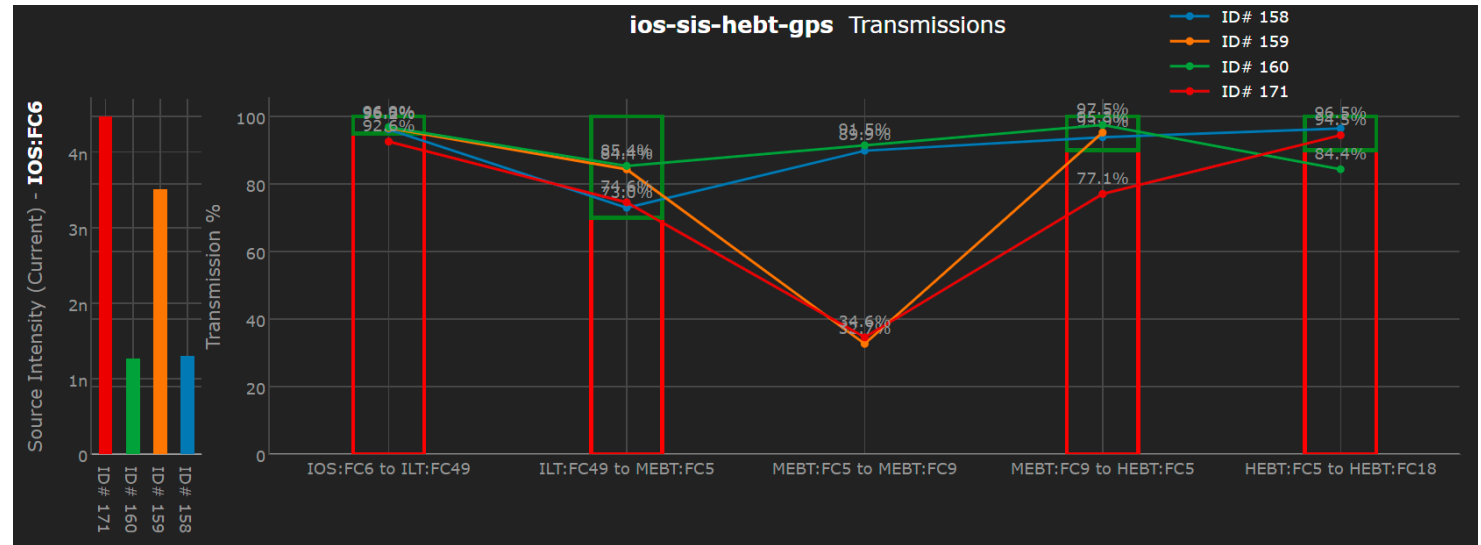
# Apps - Overview

13

- Snapshot (data collection)
- ISAC-II autophasing
- Machine learning based beam steering

# Apps - Snapshot

- Automated data collection from Faraday cups and wire scanners.
- Primarily developed by an operator
- A way of regular storing data to beamDB for future ML applications



From

- Up to 15 separate windows
- 50+ button clicks
- Repeated every shift
- 5-10 minutes of operator's attention each measurement



To

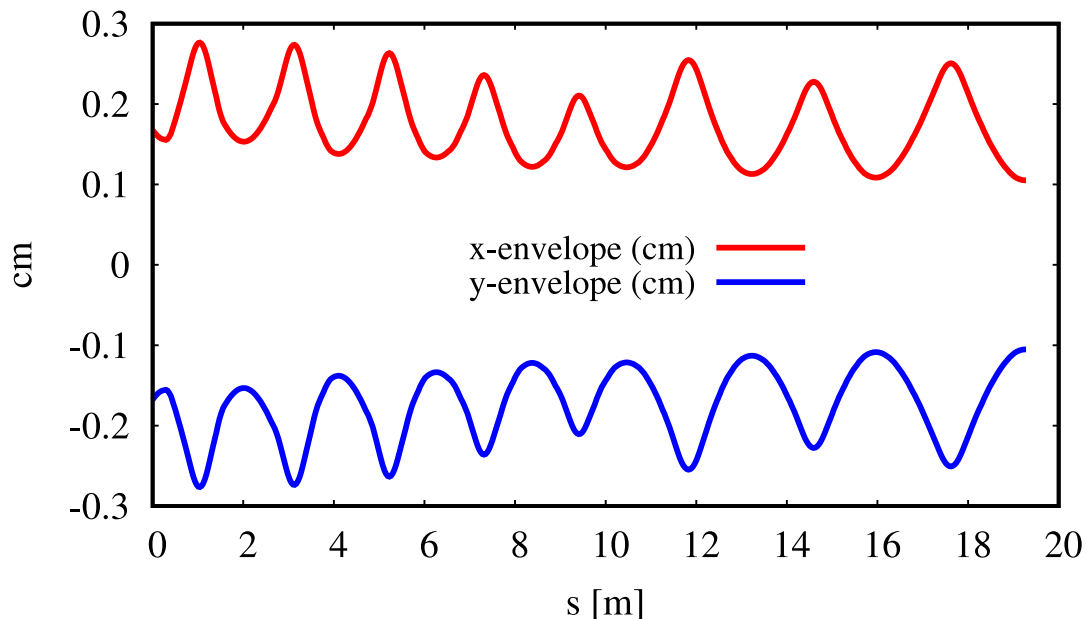
- One window
- 5 button clicks
- <1 minute of operator's attention

Saving 100+ hours of operator hours per year  
Adding consistency, searchability to data  
No 'oops' errors – force safe conditions before moving cups



# Apps - ISAC-II Autophase

- Linac contains 40 superconducting quarter wave cavities.
- Each cavity has an independent phase shifter.
- RF engineer determine max. amplitudes, experiment specifies isotope, energy
- Linac has been modelled with transoptr and calibrated with beam.



1. Enter beam properties

Isotope	C-12
Charge	2.0
Relative phase	-25.0
DTL energy/nucleon	1.50
Requested energy/nucleon	5.1

☒ Initial Linac Tune    ☐ Energy Change    ☐ Re-phase after Cav Failure

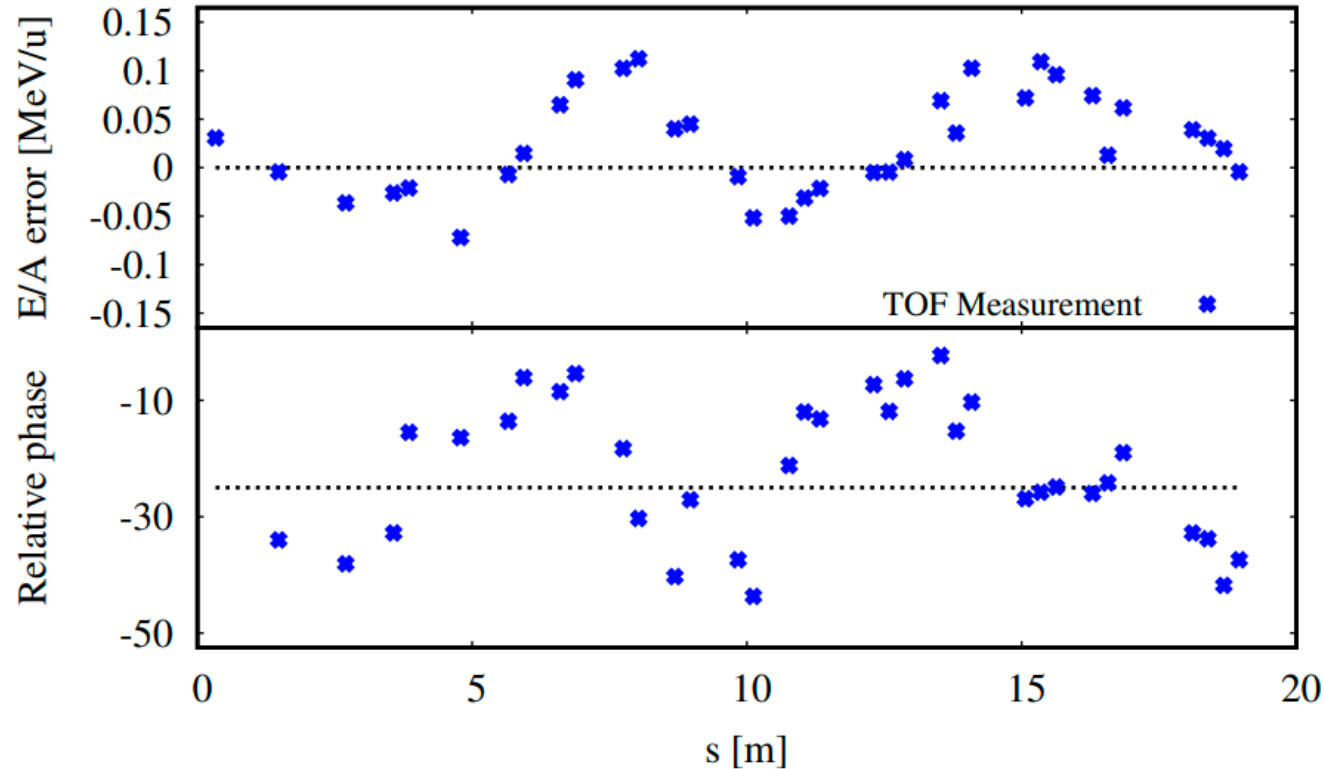
**Submit**

SCB5:CAV3 optimized to -25.0 degrees in transoptr.

15

1. Operator inputs requested properties
2. Model optimizes cavity by cavity, reading in amplitude from control system and finding correct phase.
3. Model fine-tunes amplitude of last cavity to meet request
4. Model optimize solenoids to provide transverse focus between each cryomodule
5. Operator can then review envelope and load to the control system.

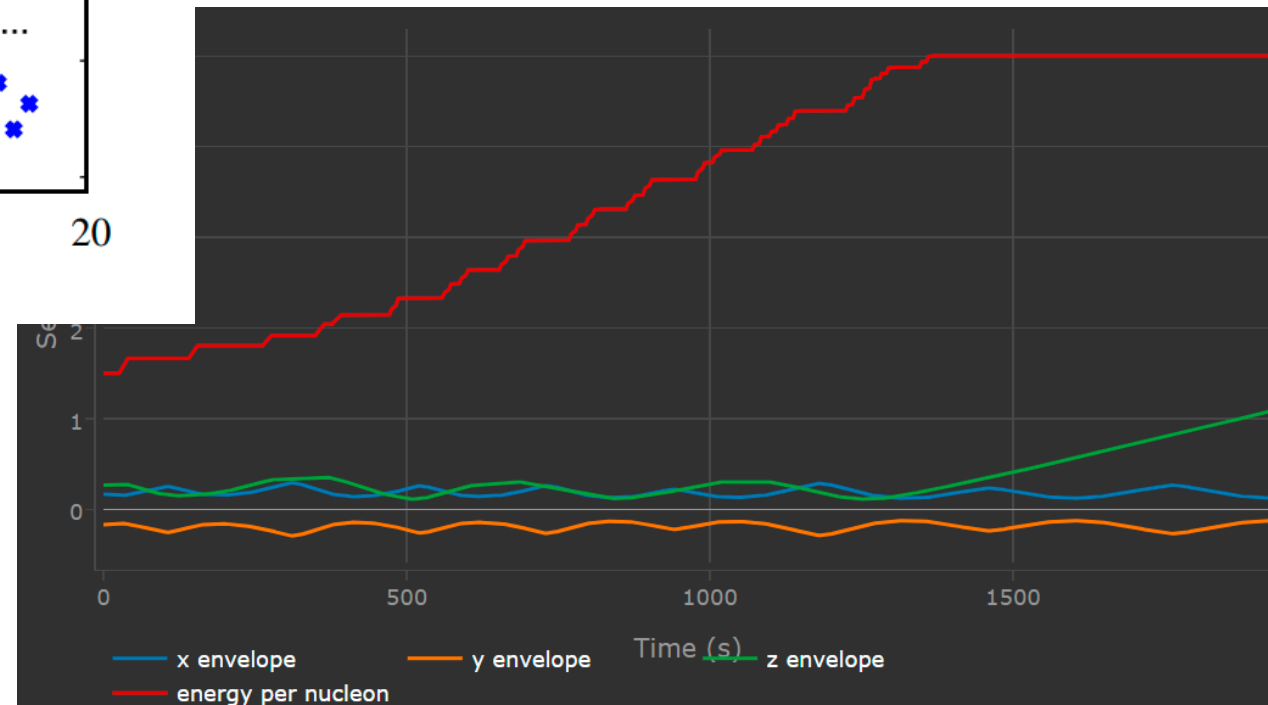
# Apps - ISAC-II Autophase



- Two tests were successfully completed.
- Energy per nucleon error was less than 0.15 MeV/u
- Cavity phase error was less than 20 degrees
- Linac transmission averaged over 90%
- Both established tunes were successfully used for delivery to an experiment.
- **Now capable to setup the linac for a new experiment in under an hour where it historically has required over 1 shift (8 hours).**

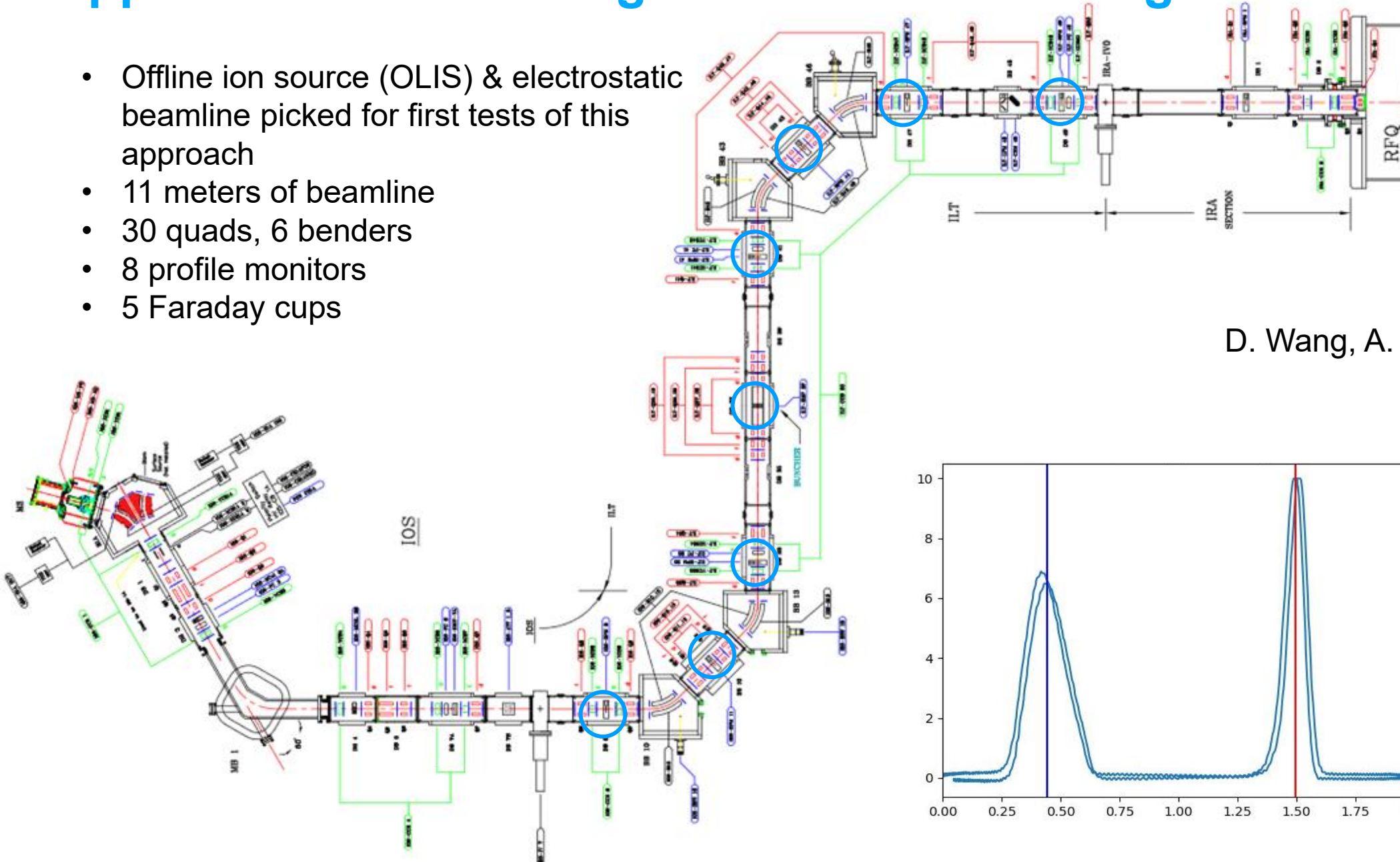
16

\*\*See poster TUP19

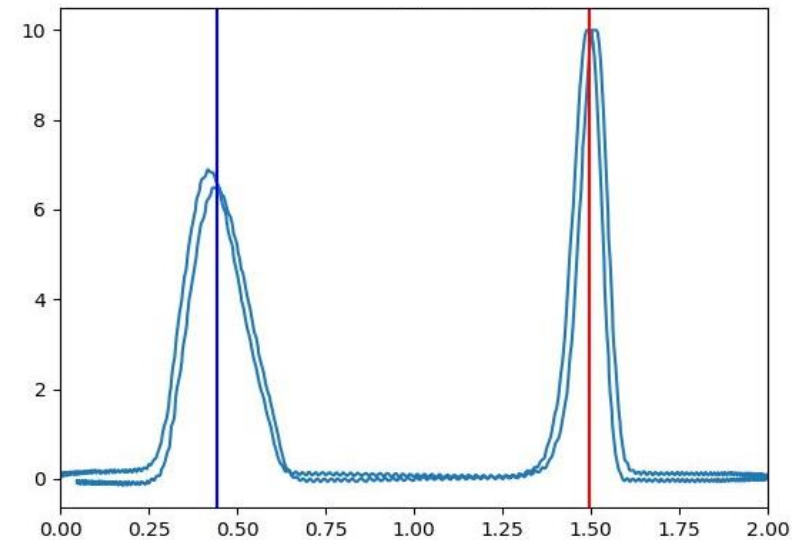


# Apps - Machine learning based beam steering

- Offline ion source (OLIS) & electrostatic beamline picked for first tests of this approach
- 11 meters of beamline
- 30 quads, 6 benders
- 8 profile monitors
- 5 Faraday cups



D. Wang, A. Andres, W. Fedorko

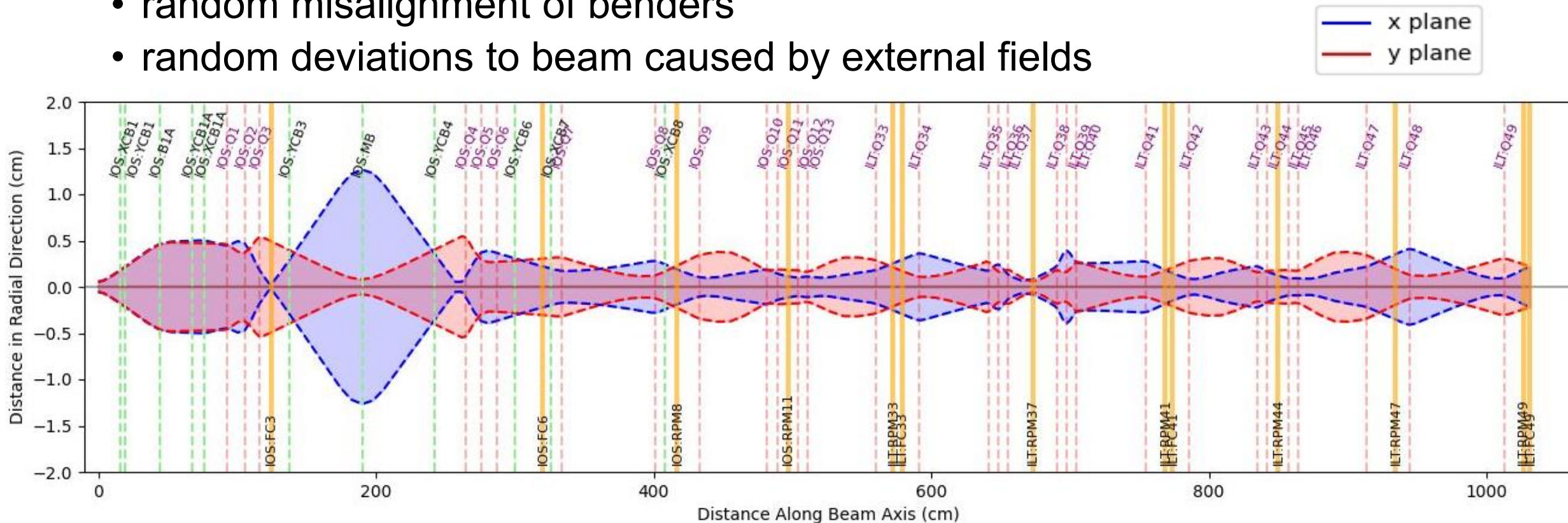


# Apps - Machine learning based beam steering

- Training environment for agent
  - TRANSOPTR – beam envelope code widely used at TRIUMF
- Simulate:
  - random misalignment of quadrupoles
  - random misalignment of benders
  - random deviations to beam caused by external fields

18

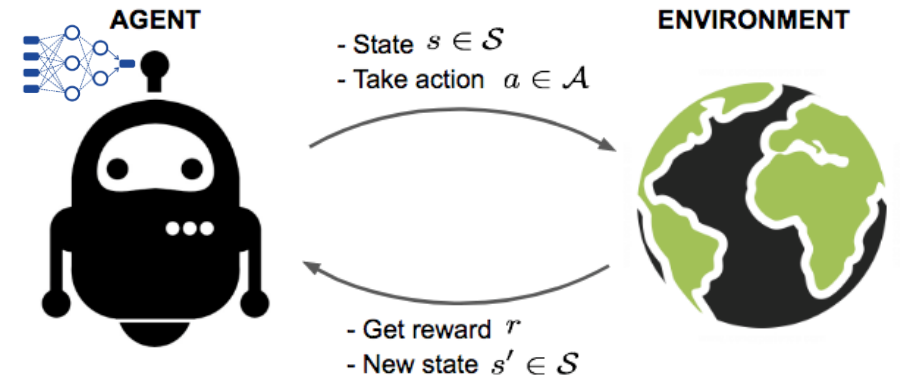
D. Wang, A. Andres, W. Fedorko



# Apps - Machine learning based beam steering

19

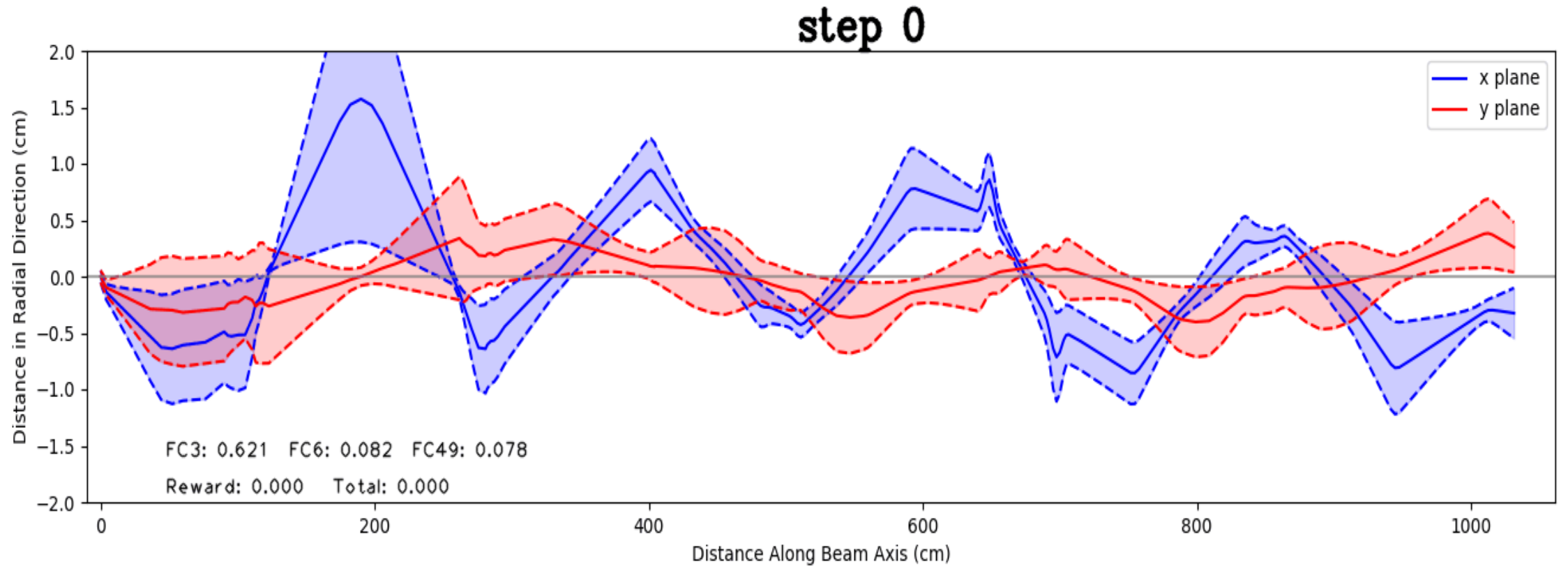
- Partially observed **state**:
  - Measurement of FC and RPM at only a few locations
  - Last actions of the agent
- High dimensional and continuous **actions**:
  - Voltage values to set for each steerer/bender
- Designed **reward**:
  - High reward if a lot of beam reaches the FCs
  - High reward if the beam is centered at the RPMs





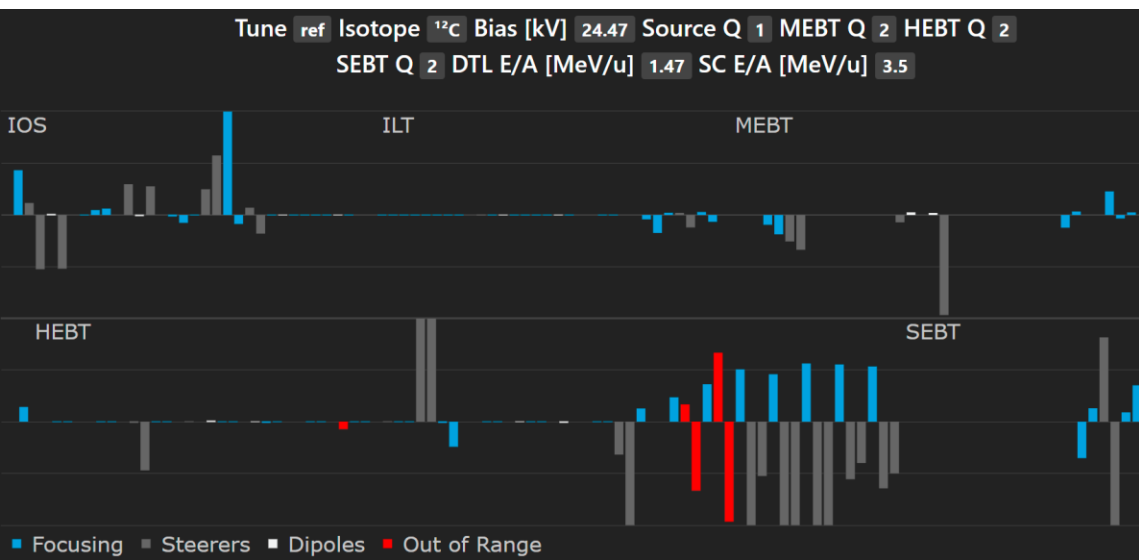
# Apps - Machine learning based beam steering

20

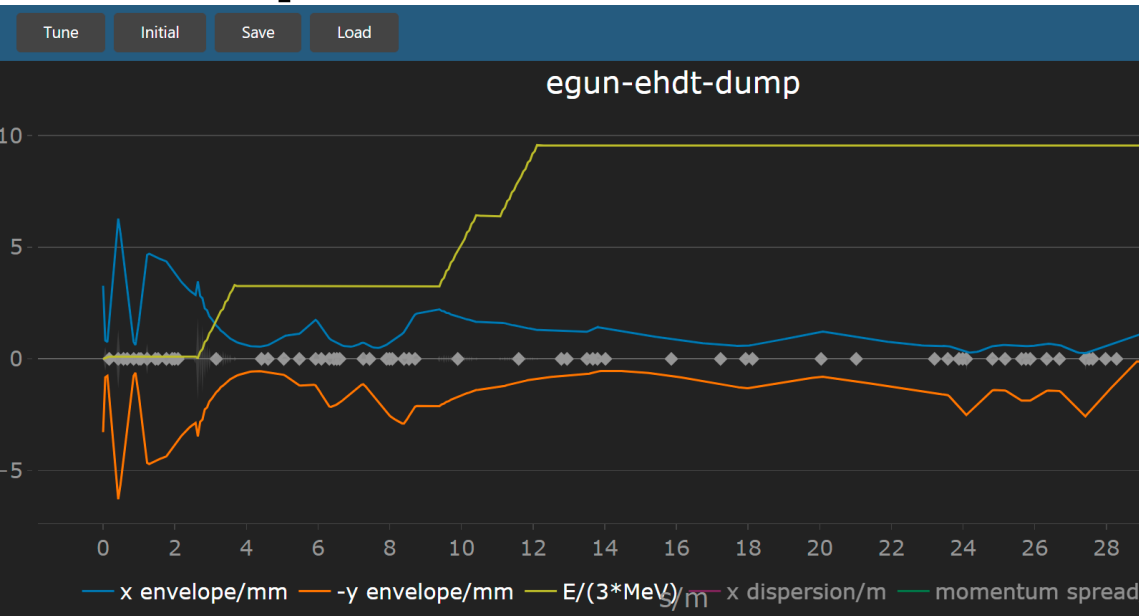




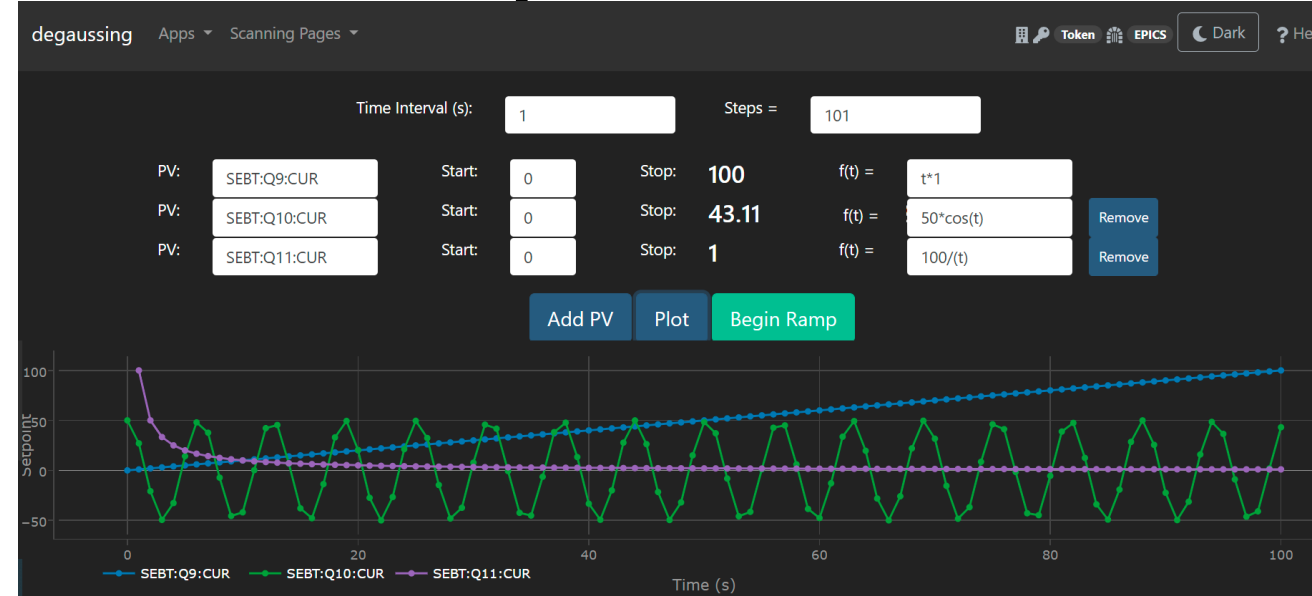
# tuneX



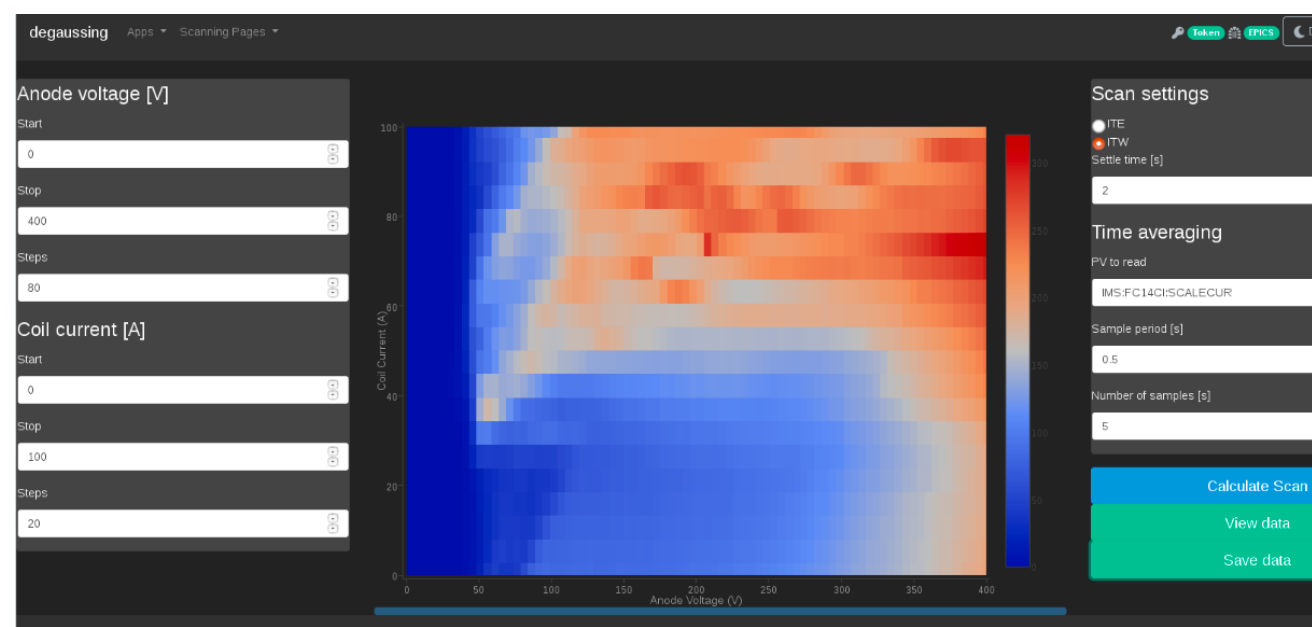
# envelope



# Generic ramp



# scan



# Review

- An HLA framework has been established at TRIUMF to reduce overhead and improve beam quality
- Various different applications have been developed, more exciting developments to come!

## What has worked well

- Open source code that anyone can see/run, contribute to, give feedback on.
- Letting developers explore ideas and start creating an app without rigid requirements.
- Letting developers explore areas of interest to them
- Using more modern tools: python, gitlab, etc.

## Contributors

P.M. Jung, K. Lucow, T. Planche, S. Radel, O. Shelbaya,<sup>22</sup>  
B. Stringer, B. Schultz, D. Thomson, K. Ezawa, C.  
Barquest, K. LeBlanc, J. Pon, K. Raywood, E.  
Tikhomolov, D. Prevost, E. Chapman, T. Angus, W.  
Fedorko, J. Adegun, S. Kiy, F. Maldonado.

## Co-op Students

J. Nasser, D. Wang, H. Bagri, K. Wu, O. Lailey J.  
Lawrence, C. Macdonald, M. Stewart, J. de Luna, M.  
Bleszynski, D. Sehayek, V. Mazumdar, M. Corwin, D.  
Tattan, D. Sehayek, S. Marcano

Very special thanks to **Carla Barquest**

<https://hla.triumf.ca/>

Thank you  
Merci

[www.triumf.ca](http://www.triumf.ca)

Follow us @TRIUMFLab

