High-level Physics Controls Applications Development for FRIB

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MICHIGAN STATE UNIVERSITY

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Outline

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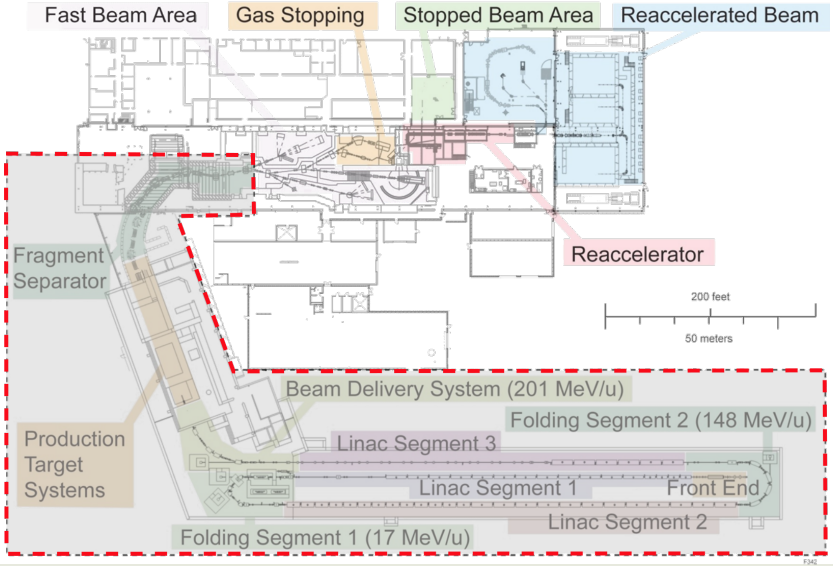

Fast Beam Area
Gas Stopping
Stopped Beam Area
Reaccelerated Beam
Fragment Separator
Reaccelerator
200 feet
50 meters
Beam Delivery System (201 MeV/u)
Folding Segment 2 (148 MeV/u)
Production Target Systems
Linac Segment 3
Linac Segment 1
Front End
Linac Segment 2
Folding Segment 1 (17 MeV/u)

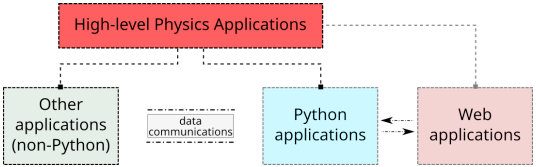
Accelerator System

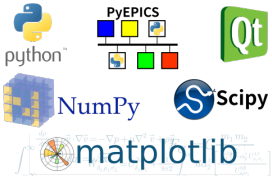
- particle source, beam transport, experimental end stations, ...
- devices: optics, diagnostics, ...
- distributed controls units (Channel Access): EPICS input & output controllers (IOCs)

High-level Physics Applications

- Final goal: operating accelerator facility
- Purpose: have robust and functional beam tuning algorithms
- Solution: software environment for high-level physics controls

High-level Physics Applications = Physics Algorithms + Controls Software





Fundamental Requirements

- Quick prototyping: dynamic programming language, powerful&friendly development environment
- Features: plenty of third-party packages
- End-users: good UI/UX with proven physics algorithms
- Agile development: develop → build → test → deploy

PHANTASY

Physics High-level Applications aNd Toolkit for Accelerator SYstem

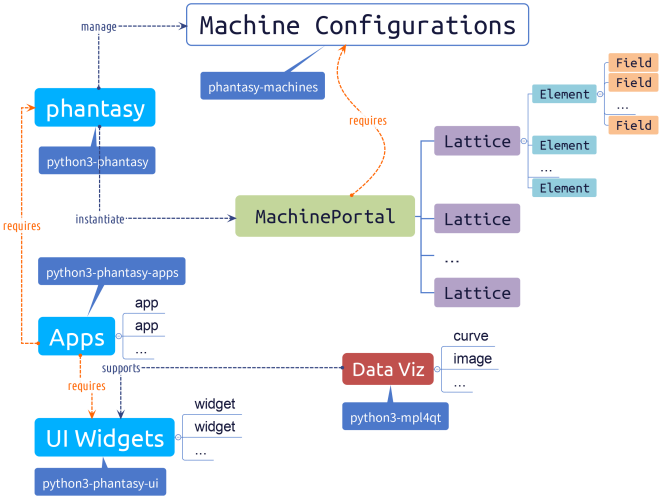
Features Highlight

- Device configuration management: maintainability, portability
- Device abstraction: object-oriented
- Online modeling: physics model-depends machine representation
- Python interactive scripting environment for high-level controls: development and control
- Virtual accelerator based on EPICS and physics model: test physics algorithms
- Web service integration (channelfinder, scanserver, UNICORN ...): extendability

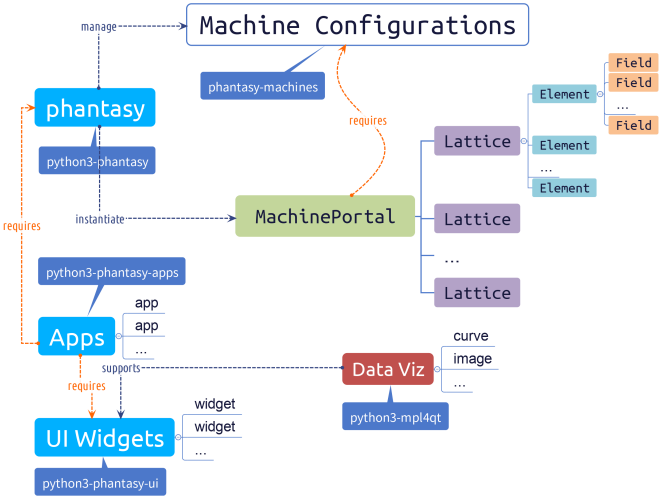
Deployment

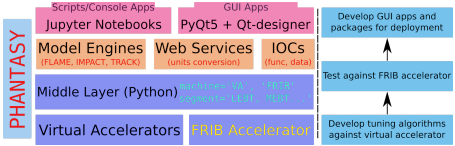
- Target OS: Debian 8, 9, 10
- Meta package: phantasy (~20 packages)
- Physics model engines: FLAME, IMPACT, TRACK

Architecture of PHANTASY Project



Architecture of PHANTASY Project





Code Facts

- Python 2 and 3, Debian OS
- phantasy (core) ~19k LOC
- UI widgets: ~11k LOC (incl. dataviz, excl. ui)
- Apps: ~26k LOC (excl. ui)

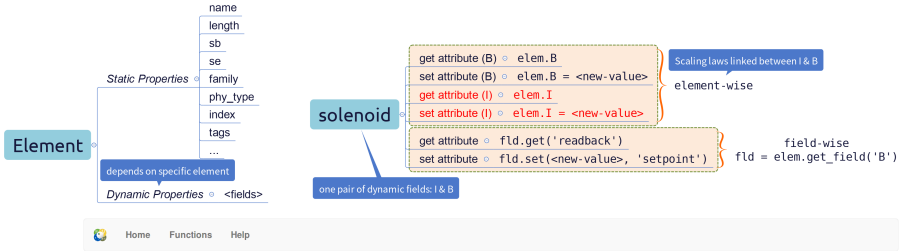
Dev Guideline

- Device ⟶ Python object
- List of devices ⟶ Lattice
- Lattice manipulation
- Scripting/GUI apps (facility-agnostic)
- Package ⟶ deployment

Device Abstraction

- Standardize device description data file
- Handle EPICS Channel Access (CA) in OO level
- Benefits: WORA, facility-agnostic script/apps

- Manage physics and engineering units by dedicated web app
- REST APIs for units interpretation
- Benefits: availability and extendability



Read/write policy from/to device could be defined with REST APIs.

▹ WORA: Write Once, Run Anywhere.

Interactive Python Scripting Environment

```
In [1]: from phantasy import MachinePortal
        from phantasy import disable_warnings
        disable_warnings()

In [2]: mp = MachinePortal("FRIB", "LEBT")

In [3]: mp
Out[3]: [FRIB] MachinePortal | Valid segment: *LEBT, MEBT, LEBT2FS1A, LEBT2FS1B, MEBT2FS1A, MEBT2FS1B, LINAC

In [4]: lat = mp.work_lattice_conf

In [5]: layout = lat.layout

In [6]: fig1, ax1 = layout.draw(span=(1.05, 1.1), fig_opt={'figsize': (20, 8), 'dpi': 120}, ax_opt={'aspect': 6})
```


```
In [7]: lat
```

Out[7]:

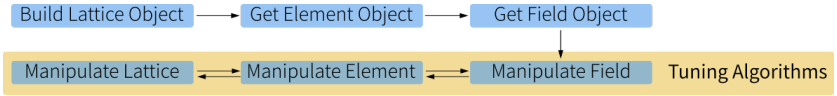
	Name	Family	Position	Length
0	FE_SCS1:SOLR_D0704	SOL	70.2069949964	0.3998
1	FE_SCS1:DCV_D0709	VCOR	70.9469949964	0.0
2	FE_SCS1:DCH_D0709	HCOR	70.9469949964	0.0
3	FE_SCS1:DH_D0717	BEND	71.1819949964	1.0
4	FE_SCS1:DCV_D0723	VCOR	72.3441949964	0.0
5	FE_SCS1:DCH_D0723	HCOR	72.3441949964	0.0
6	FE_SCS1:QHE_D0726	EQUAD	72.5292949964	0.2052
7	FE_SCS1:QVE_D0730	EQUAD	72.864294996039999	0.2052
8	FE_SCS1:QHE_D0733	EQUAD	73.1992949964	0.2052
9	FE_SCS1:FC_D0739	FC	73.7692949964	0.0

```
In [8]: sol = mp.get_elements(type='SOL')[0]

In [9]: sol
Out[9]: FE_SCS1:SOLR_D0704 [SOL] @ sb=70.206995
```

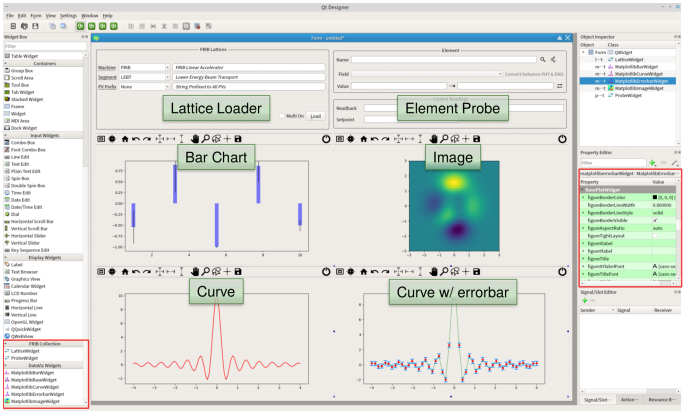
70	FE_LEBT:FC_D0977	FC	97.66932979	0.0
71	FE_LEBT:DCV_D0979	VCOR	97.68935	0.0
72	FE_LEBT:DCH_D0979	HCOR	97.68935	0.0
73	FE_LEBT:SOLR_D0982	SOL	98.0101	0.3998
74	FE_LEBT:PM_D0986	PM	98.629999	0.0
75	FE_LEBT:CAV_D0987	CAV	98.735	0.0
76	FE_LEBT:BCM_D0989	BCM	98.881492	0.0
77	FE_LEBT:DCV_D0992	VCOR	99.19935	0.0
78	FE_LEBT:DCH_D0992	HCOR	99.19935	0.0
79	FE_LEBT:SOLR_D0995	SOL	99.3201	0.3998
80	FE_LEBT:FC_D0998	FC	99.7955237	0.0
81	FE_LEBT:PM_D0998	PM	99.8138409	0.0

```
In [8]: sol = mp.get_elements(type='SOL')[0]

In [9]: sol
Out[9]: FE_SCS1:SOLR_D0704 [SOL] @ sb=70.206995

In [10]: sol.I
Out[10]: 0.1

In [11]: sol.B
Out[11]: -0.0002898000000000083

In [12]: sol.I / sol.B
Out[12]: -346.02076124567475

In [17]: sol.B = -0.5

In [18]: sol.I
Out[18]: 173.01038862283735

In [ ]:
```

Continue with more complex work...



Outline




```
tong@zhangt-mint ~$ makeBasePyQtApp
usage: makeBasePyQtApp [-h] [--app APP] [--template TEMPLATE]
                       [-l [LIST_TEMPLATES]]

Initialize PyQt5 app project based on app template (--template), pass --app
with the name of application to generate files in the current working
directory, or with the full path to generate to any other directory.

optional arguments:
  -h, --help            show this help message and exit
  --app APP             path of app to create
  --template TEMPLATE   name of app template
  -l [LIST_TEMPLATES]   list all available app templates
```

- Standardized UI style (package: phantasy-ui)
- Standradized app development workflow
- Publish-ready quality figure
- High productivity
- Facility-agnostic apps
- Streamline deployment (package: phantasy-apps)

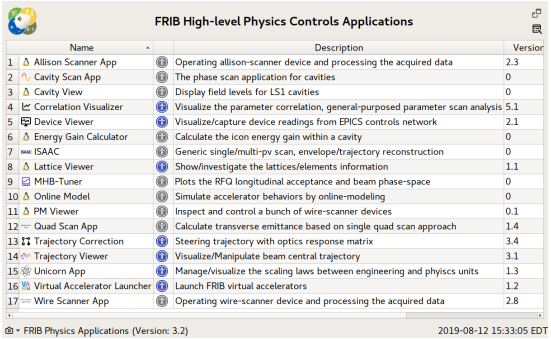
- FRIB Collection: lattice, element, etc.
- DataViz Widgets: curve, curve w/ errorbar, image, etc.
- Commands: run_designer, frib_designer, makeBasePyQtApp

Package: mpl4qt

- ✓ Toolbar system
- ✓ Configuration system
- ✓ Qt-designer widgets

▷ mpl4qt: Data visualization widgets implmeneted with matplotlib for Qt5.

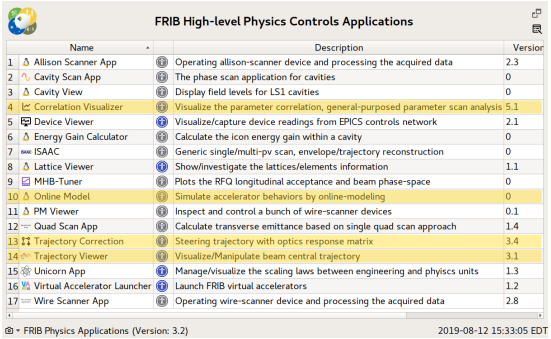
App Launcher: Manage All Apps in One Place



Features

- Global entrypoint: right-clicking context menu → ‘Phyapps Apps’
- Configuration file (.ini) controlled for easy maintaining
- Run app by double-clicking, w/ or w/o console, keep logs or not

App Launcher: Manage All Apps in One Place



Features

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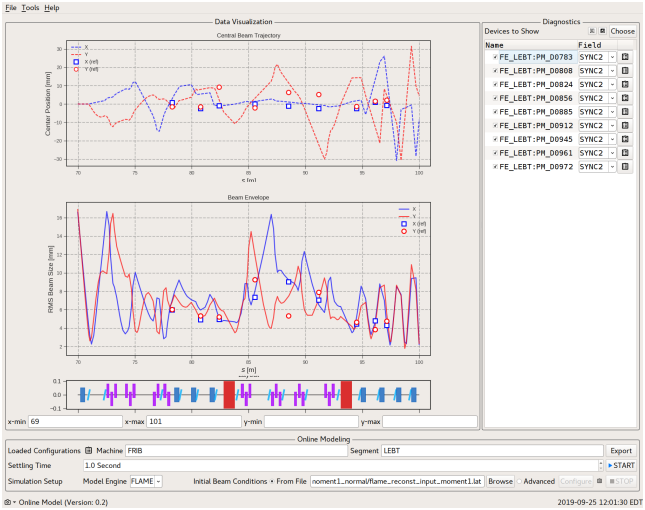
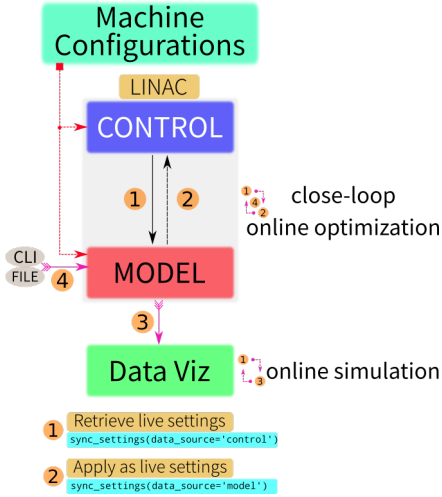
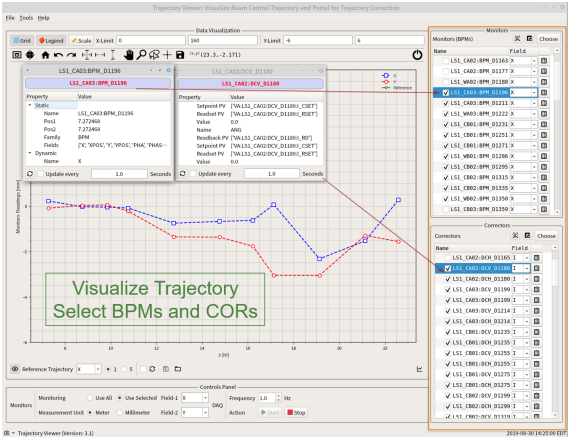
Accelerator Online Simulation: Predict Live Physics Performance





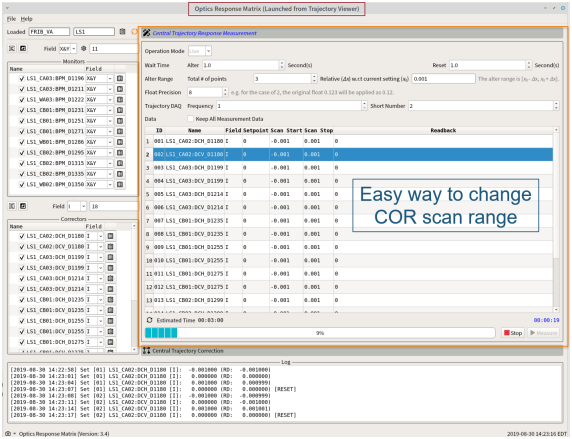
▷ FLAME: Fast Linear Accelerator Model Engine, envelope simulation code (C++/Python) developed at FRIB.

Online Central Trajectory Correction: Based on response matrix



Trajectory Viewer App

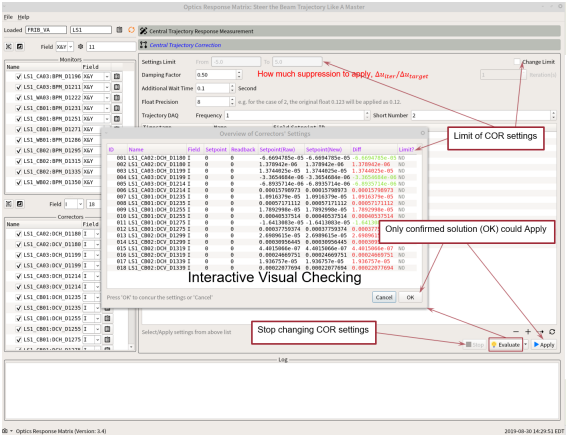
- Load lattice, Tools → Load Lattice
- Select BPMs and Correctors
- Visualize trajectory

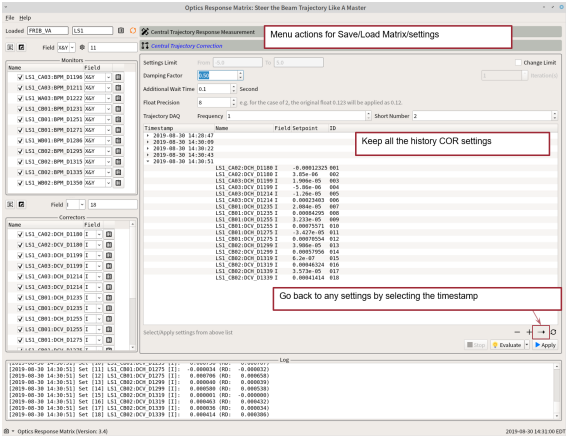


Optics Response Matrix App

- Set up correctors alter ranges
- Measure optics response matrix, save/load
- Correct trajectory with optics response matrix

Online Central Trajectory Correction: Based on response matrix

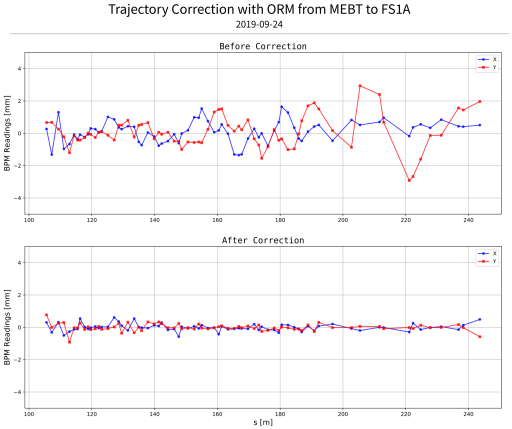


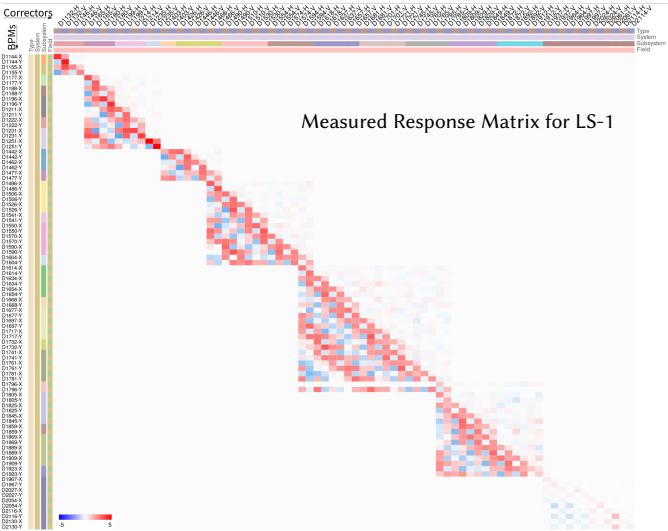


- Gradually suppress trajectory
- Secure tuning range of correctors
- Visual confirmation for each solution
- Stop button

- Keep all the history settings of correctors
- Go back and forth at any history settings
- Save/load settings, matrix

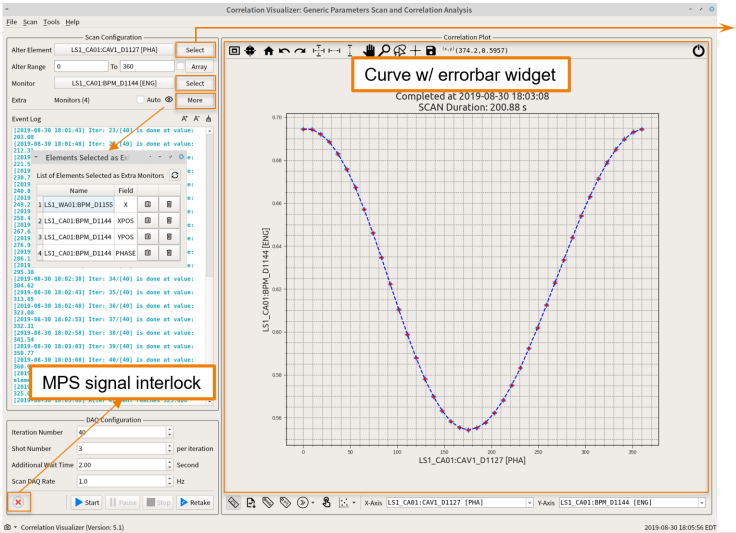
Online Central Trajectory Correction: Based on response matrix



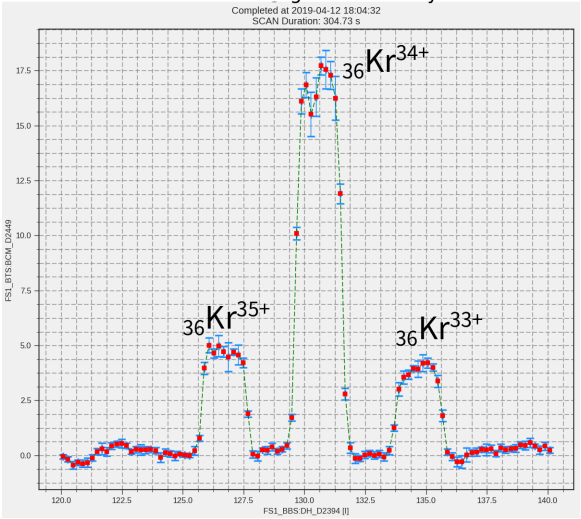


General Parameter Correlation Analysis and Visualization

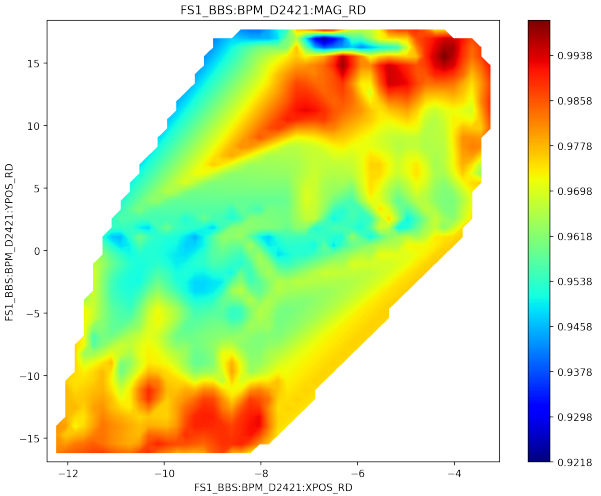
Scan parameters by mouse clicking



Multi-charge states study



Extend to Higher Dimensions



Outline

- Developed Python-based software framework (PHANTASY) for high-level physics controls at FRIB
- PyQt5 based modularized generic GUI apps are developed for FRIB
- Efficient machine tuning is achieved with the developed apps for FRIB LINAC commmissioning
- Apps based on PHANTASY also work with other EPICS-based facilities, no phyiscs model dependency
- Development of physics model progresses as the commissioning advances

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Future Development Plan

DATA	Unify and standardize data interface of all physics apps, streamline the data post-processing
GUI	Develop GUI toolkit for high-level physics apps development by any developer
MODEL	Based on the data flow from PHANTASY framework, refine physics model by machine-learning
COLLABORATION	https://github.com/phantasy-project/

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Thank you for your attention!