EIC-BeamAI

Brookhaven National Laboratory

U.S. DEPARTMENT of ENERGY

Injection Optimization & NARAD use case

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4th EIC-BeamAI Collaboration Meeting
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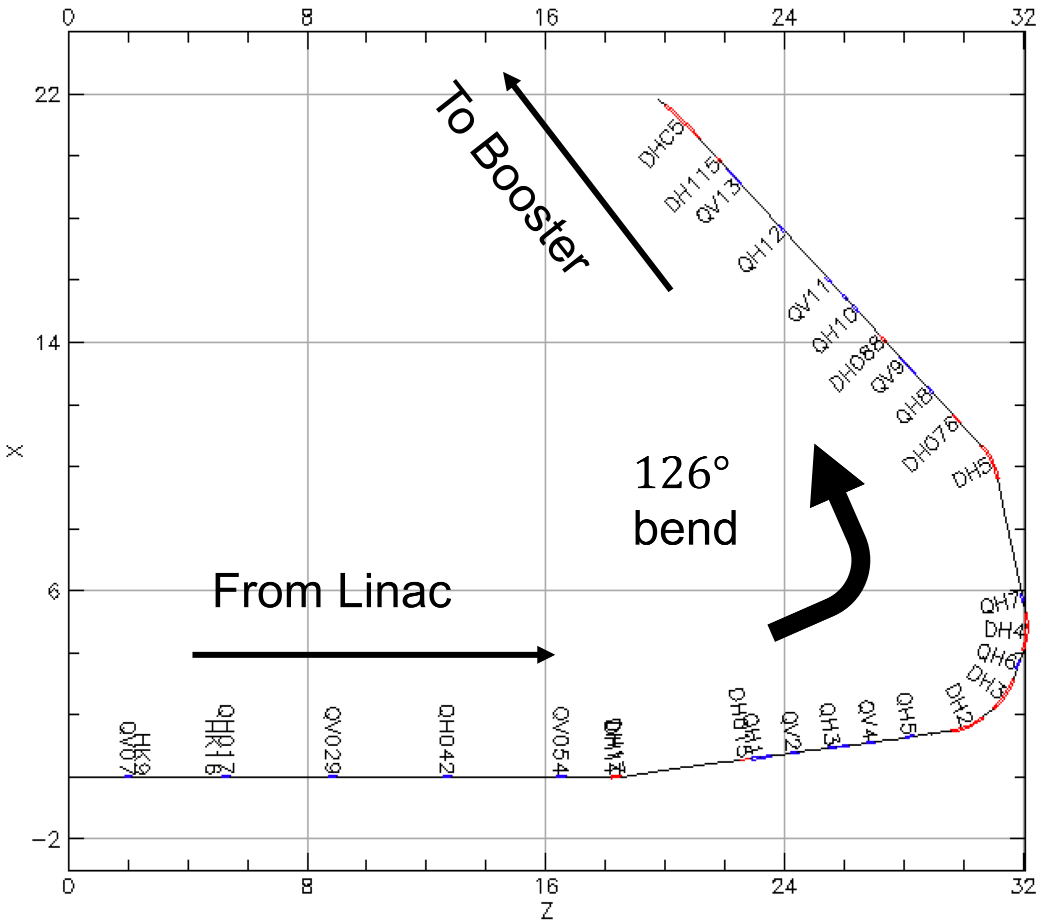
@BrookhavenLab

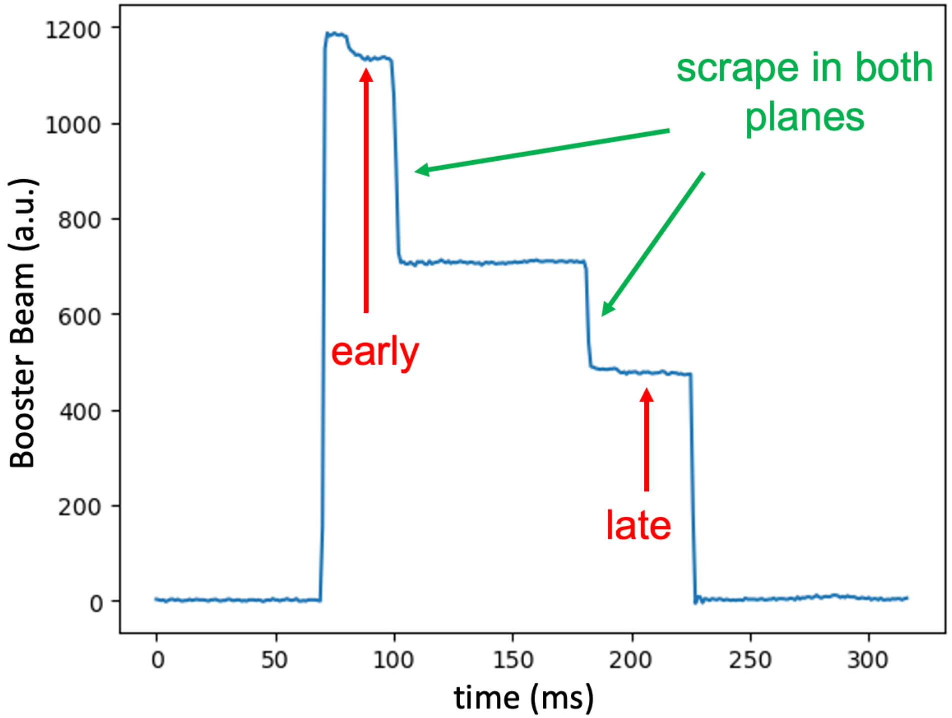
Booter injection

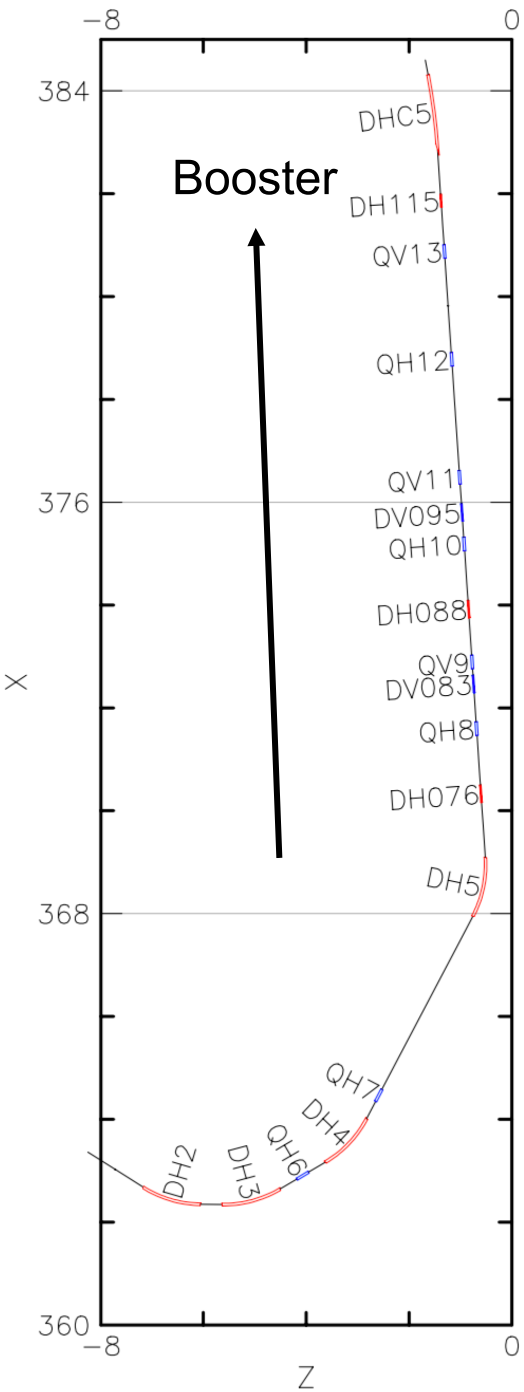
- Booster injection process sets maximum beam brightness for rest of acceleration through RHIC
- Known emittance effect on polarization loss
- Intentional horizontal and vertical scraping reduce emittance to RHIC requirements



LtB controls and measurement

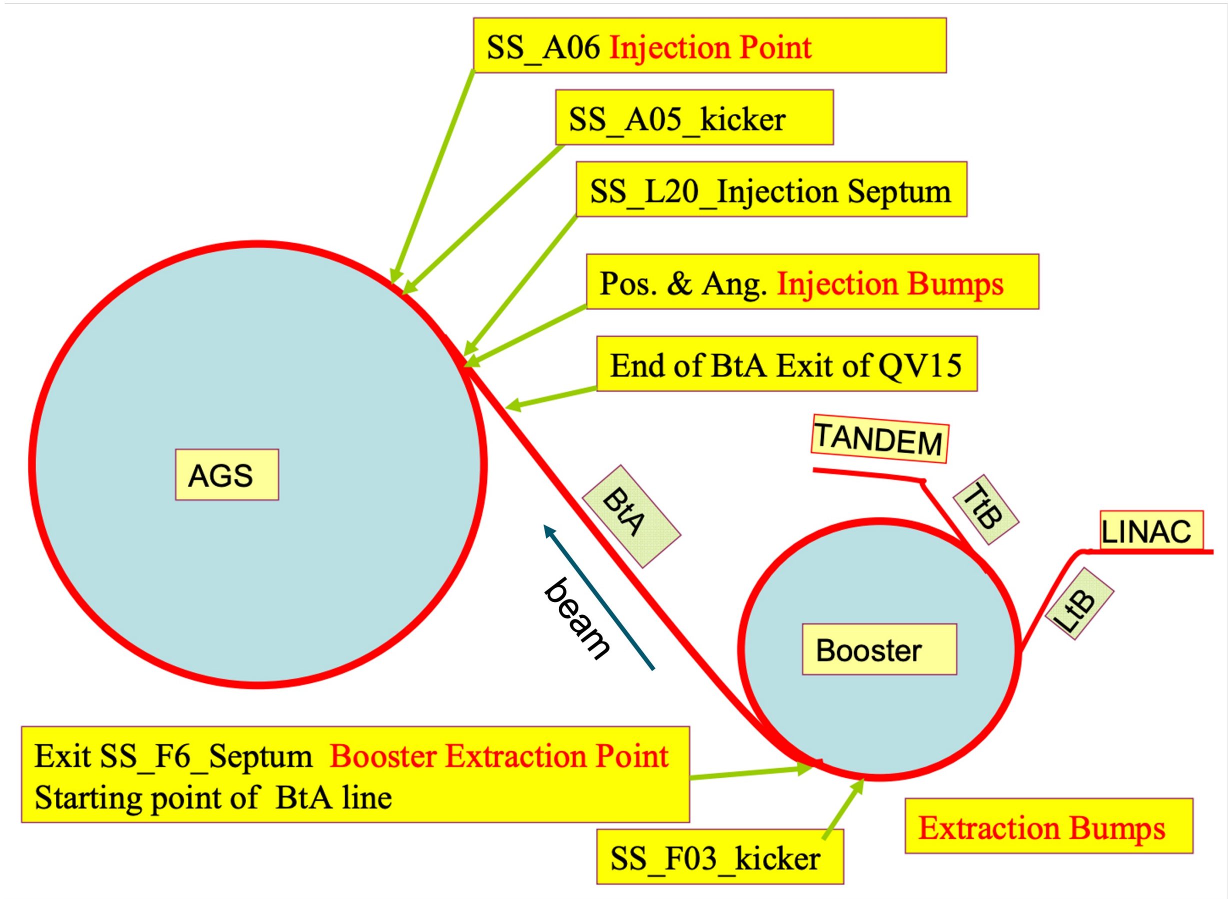
- 13 quadrupoles and 16 correctors between Linac and Booster
- Injection efficiency: Booster input, early, and late intensity
- Beam size measurement at MW006 in BtA
- Polarization measurement at AGS pCNI polarimeter





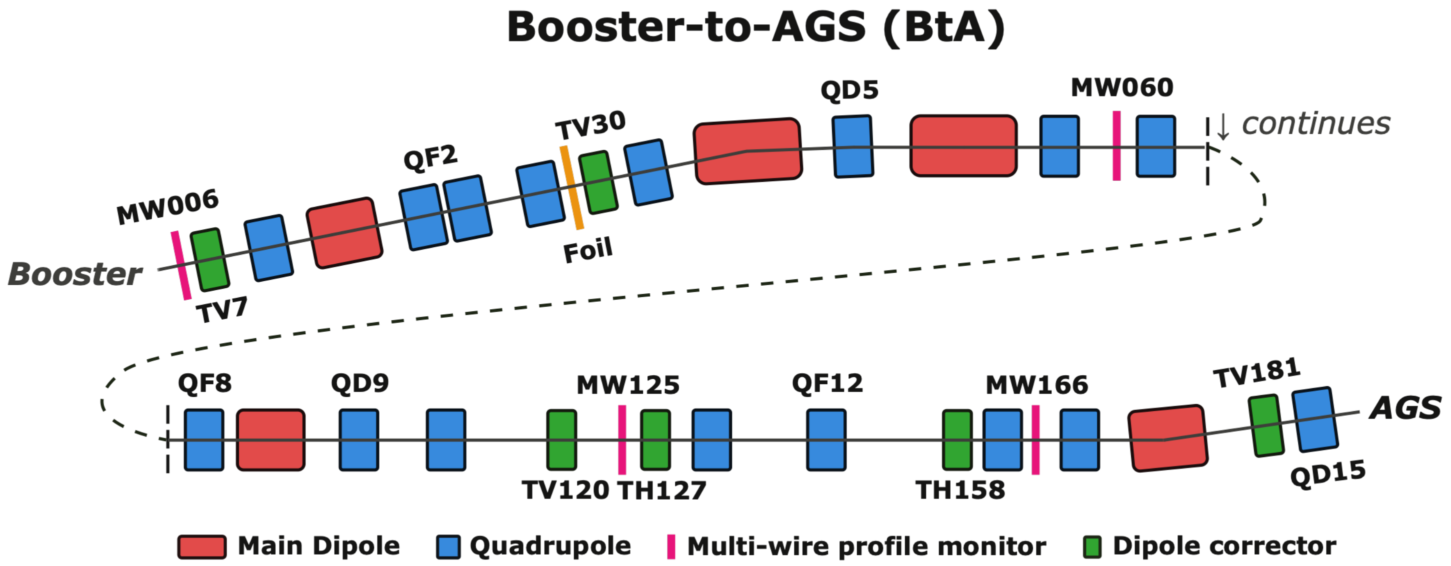
Booster to AGS transfer line

- Extraction septum at F6 in Booster, injection septum at L20 in AGS, no scraping
- 15 quadrupoles, 2 major bends (15° DH2 & 3), 3 small bends (2° DH1, 1° DH4, 8° DH5)
- Multi-wires MW006, MW060, MW125, MW166



BtA controls and measurement

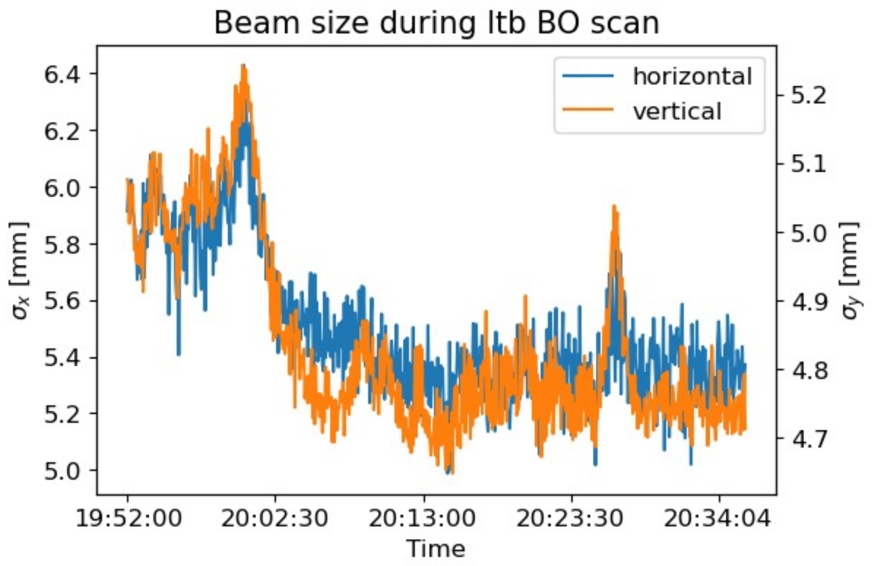
- 5 major bends (4 power supplies)
- 2 horizontal correctors, 4 vertical correctors
- 7 focusing quads, 8 defocusing quads
- Injection efficiency: Booster late, AGS early intensity
- Emittance at AGS IPM
- Polarization at AGS pCNI polarimeter

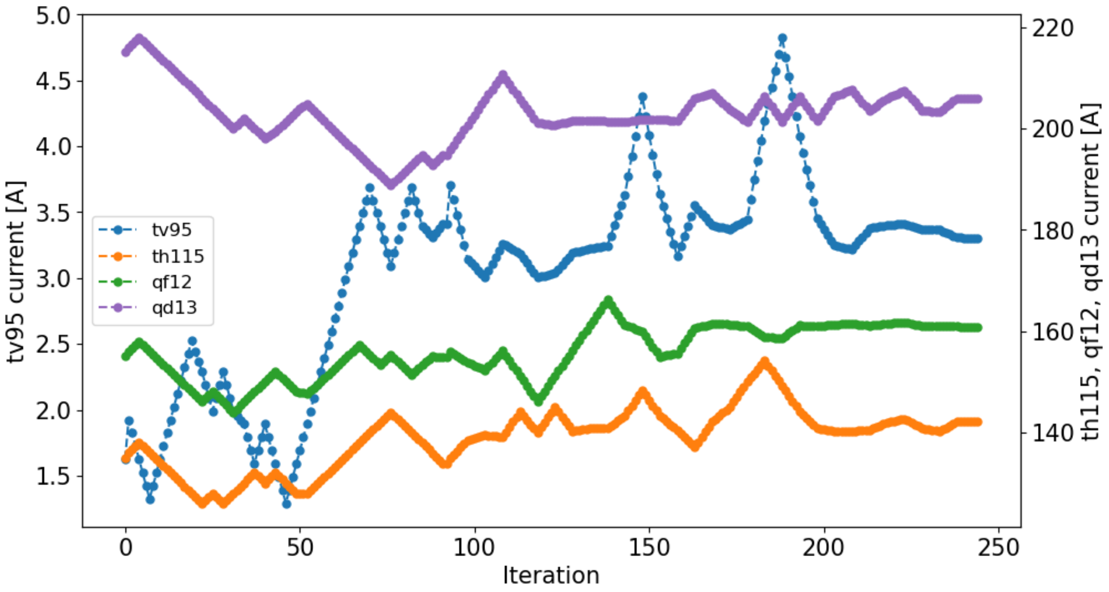


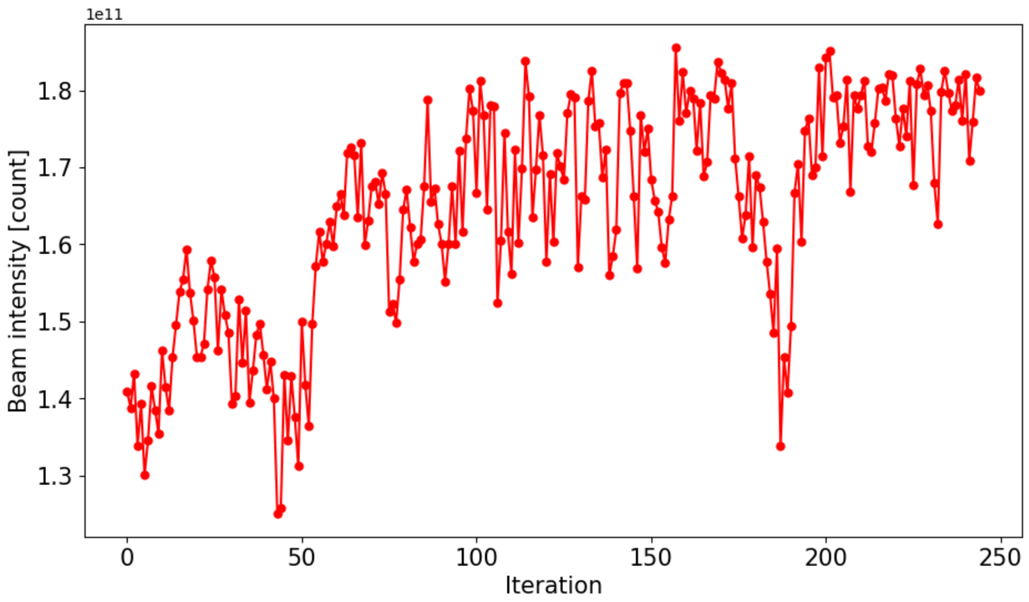
LtB optimization result

- Controls: Power supply currents of two correctors and two quadrupoles at the end of the LtB line
- Beam size decrease in both planes in the BtA line in correspondence with intensity increase

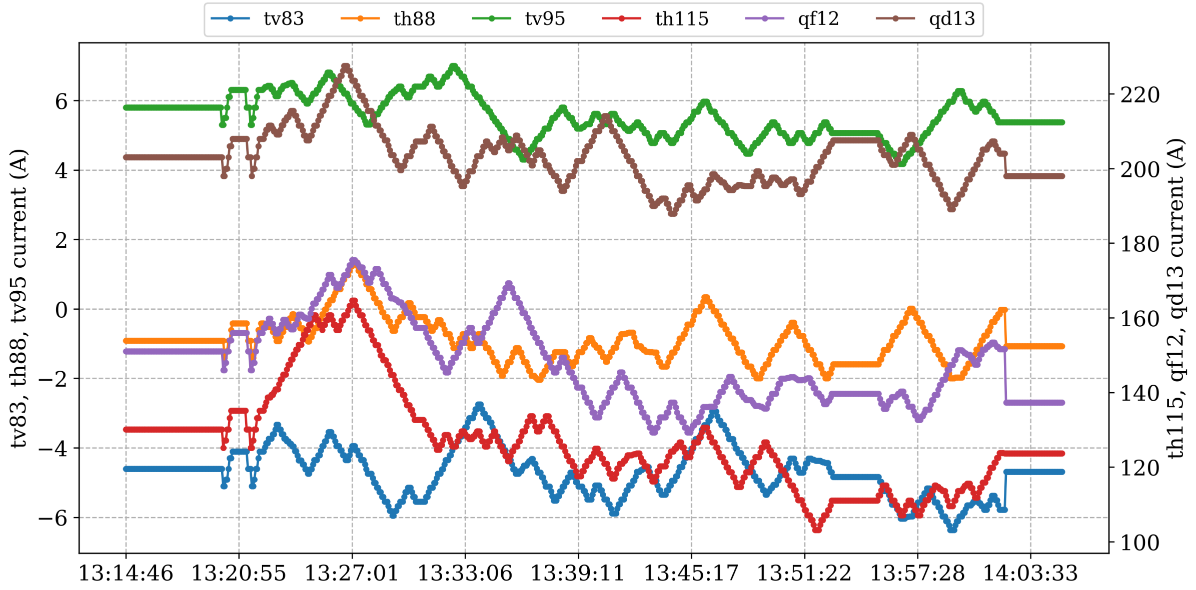
$$\mathcal{L} = \frac{1}{4\pi} \cdot N_b f_{rev} \cdot \frac{N^2}{\beta^* \varepsilon} \sim \frac{N^2}{beam\ size}$$

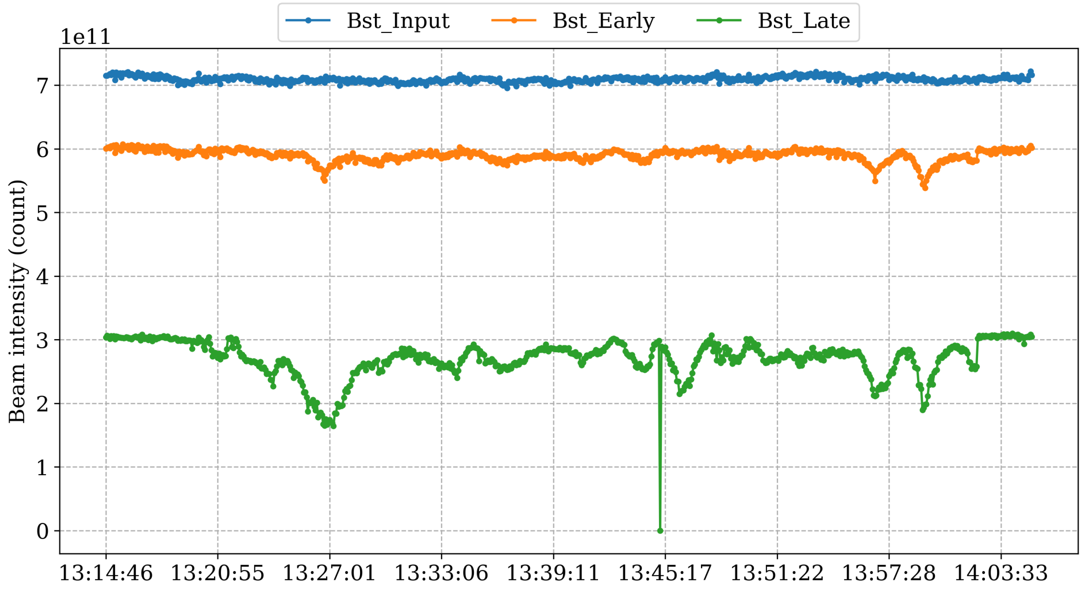


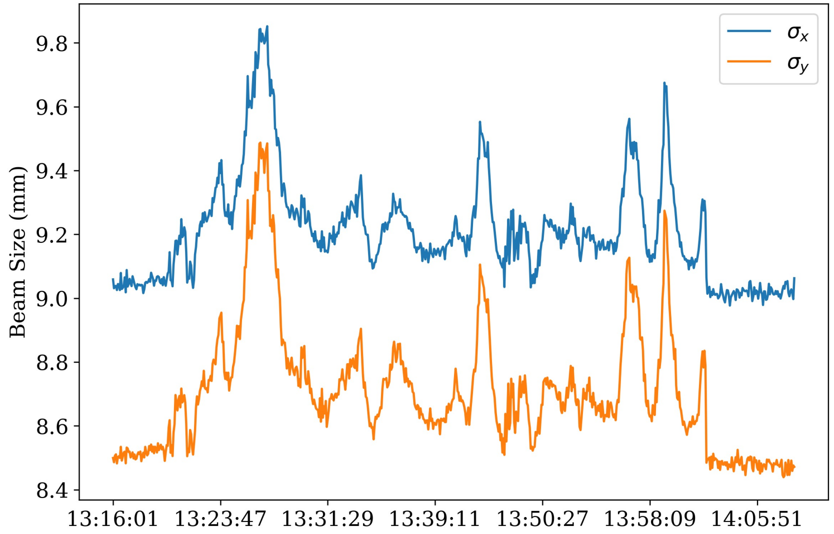


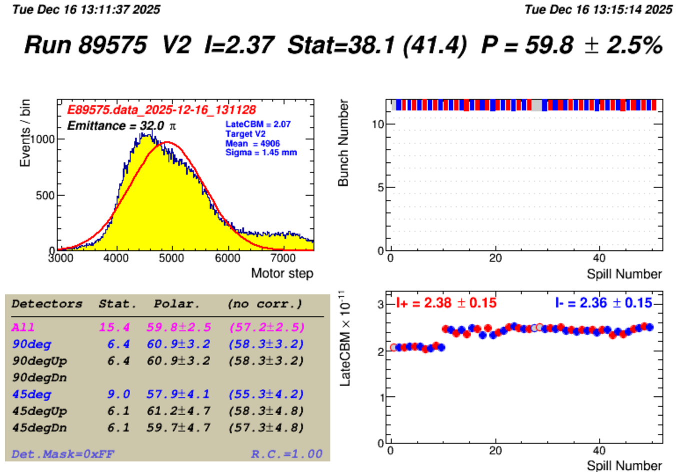


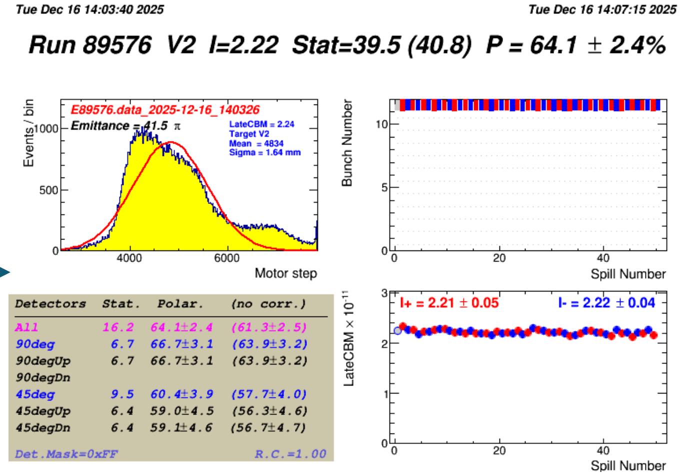
LtB optimization result







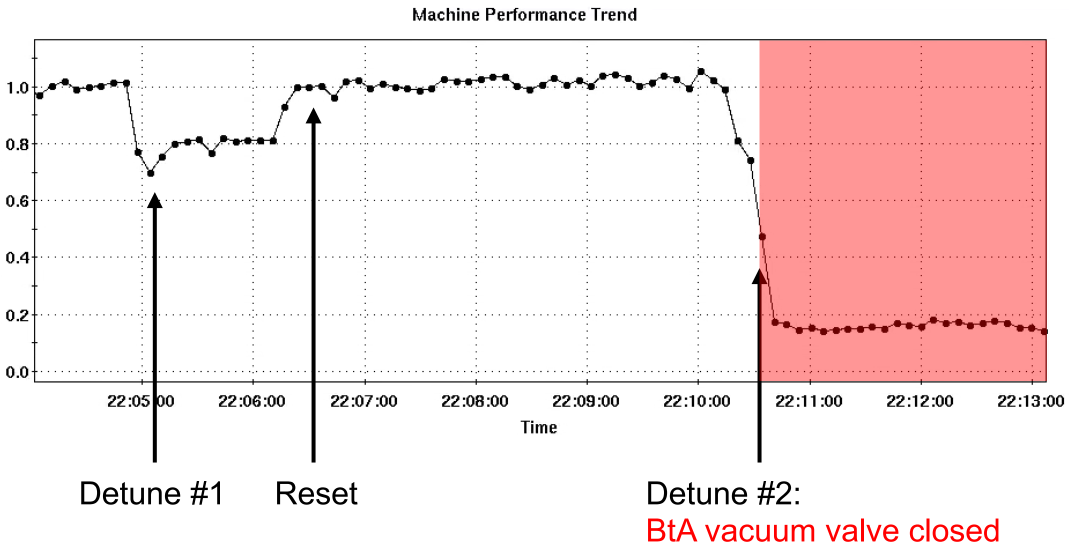


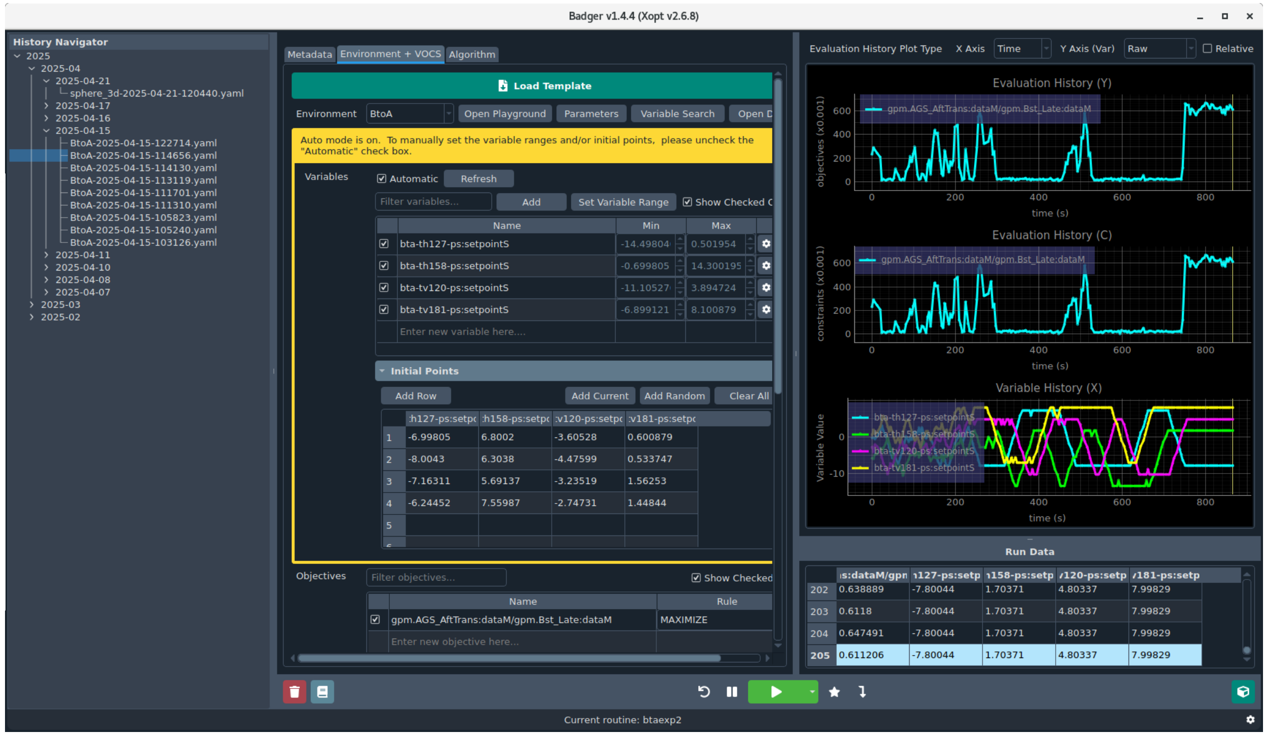


BtA optimization

- BO maximizes beam transmission efficiency using BtA optics.
- Badger successfully deployed in the control room after customization for the BNL control system.

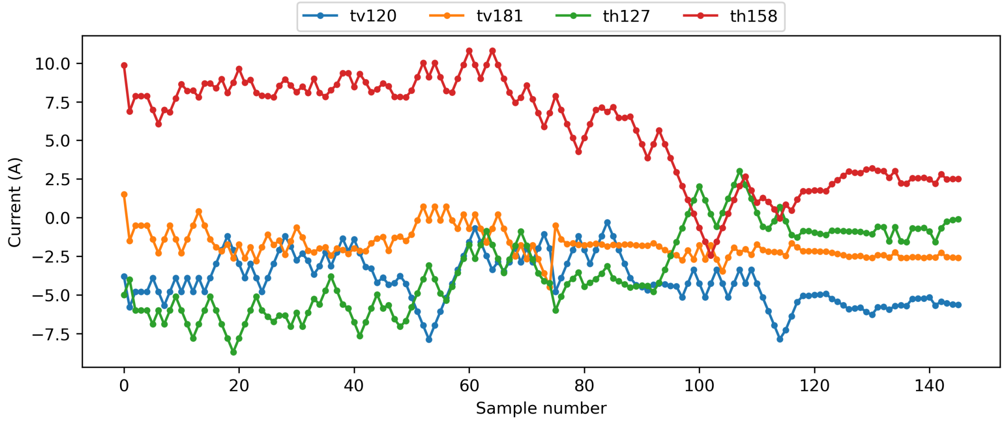
SCoR 2024/07/08 ;)

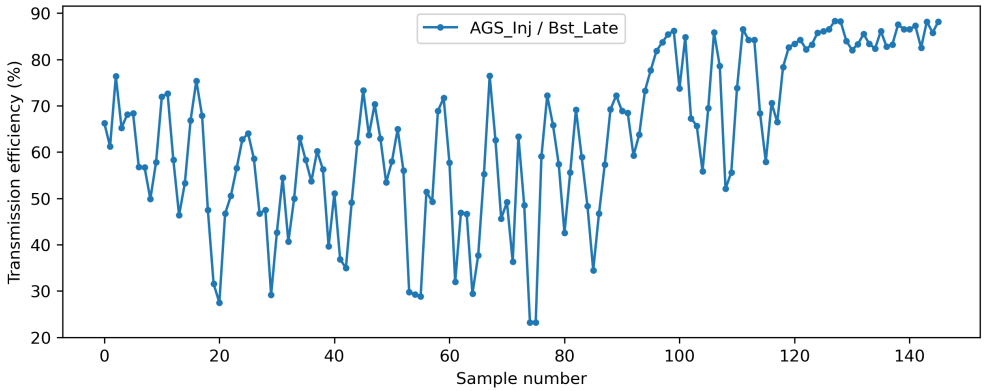


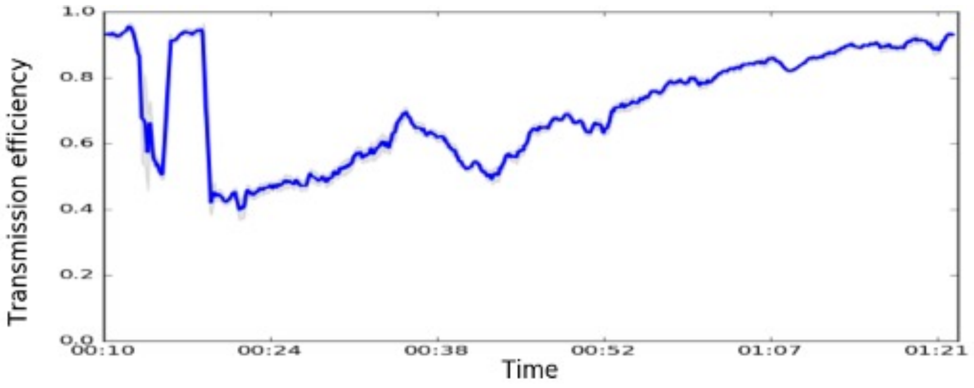


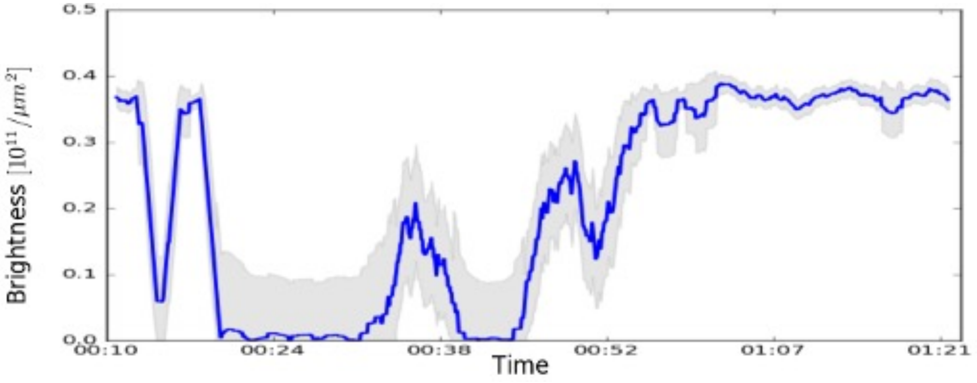
BtA optimization results

- 20% improvement from operational settings during latest test.
- Emittance measurement from IPM is very unreliable, no working BPM in BtA line.





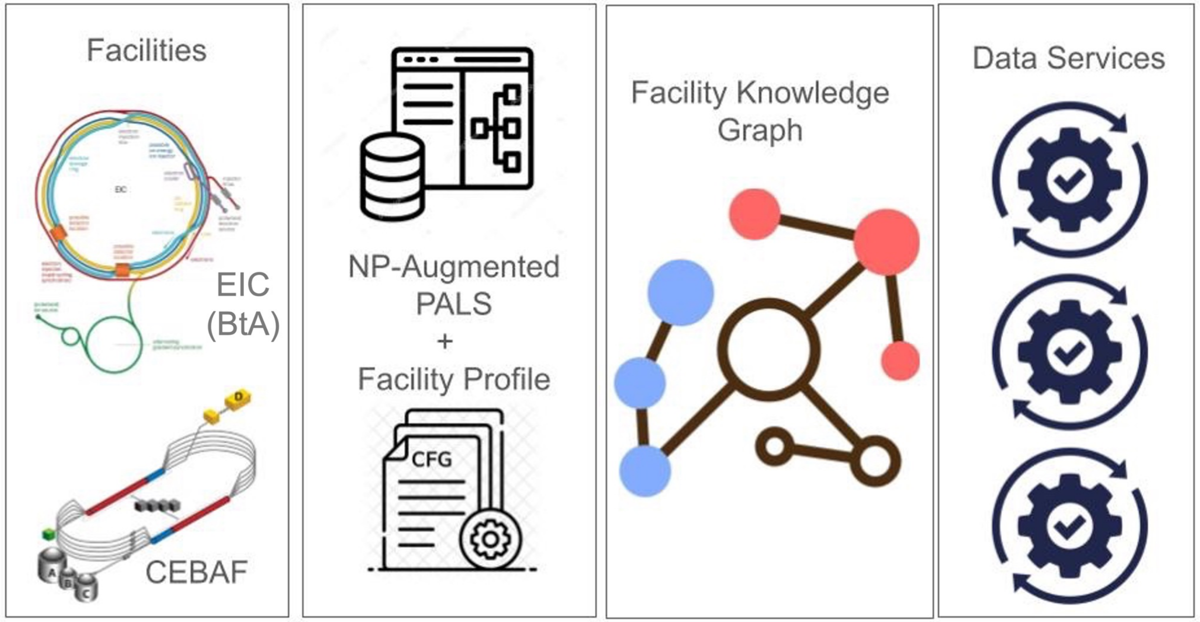


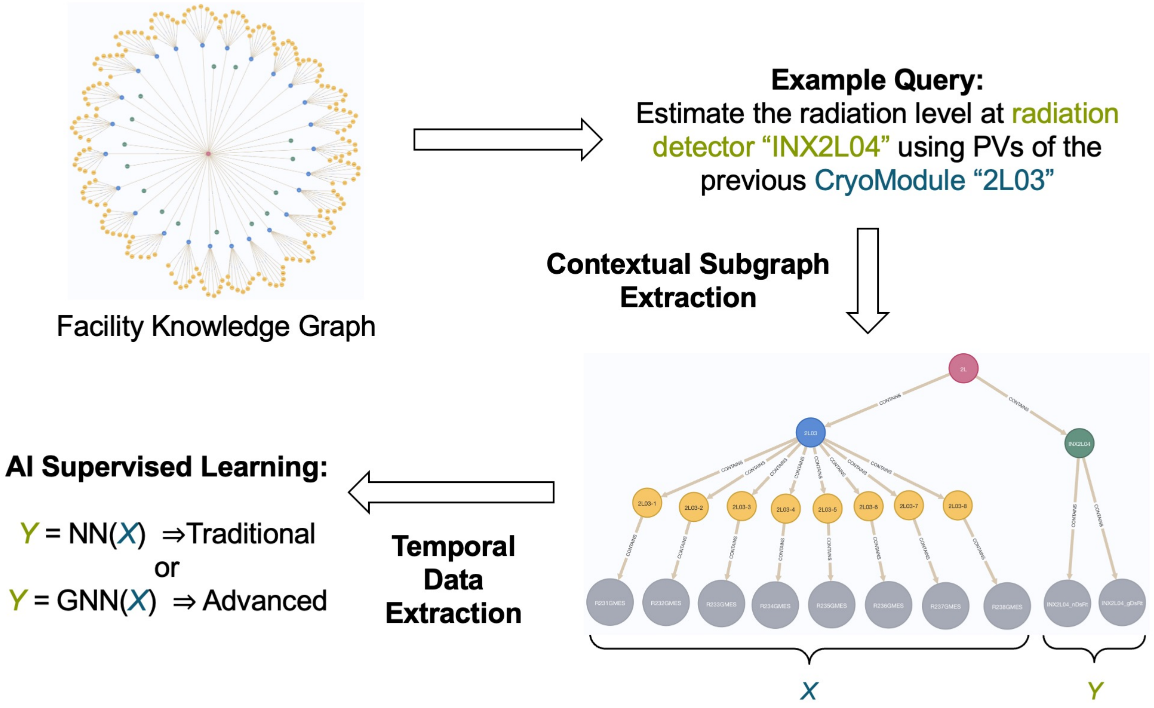


NP AI-Ready Accelerator Data (NARAD)

Goal: Develop FAIR, context-rich, AI-ready accelerator data and common ontology for cross-facility AI applications (BNL, JLab, LBNL, PNNL).

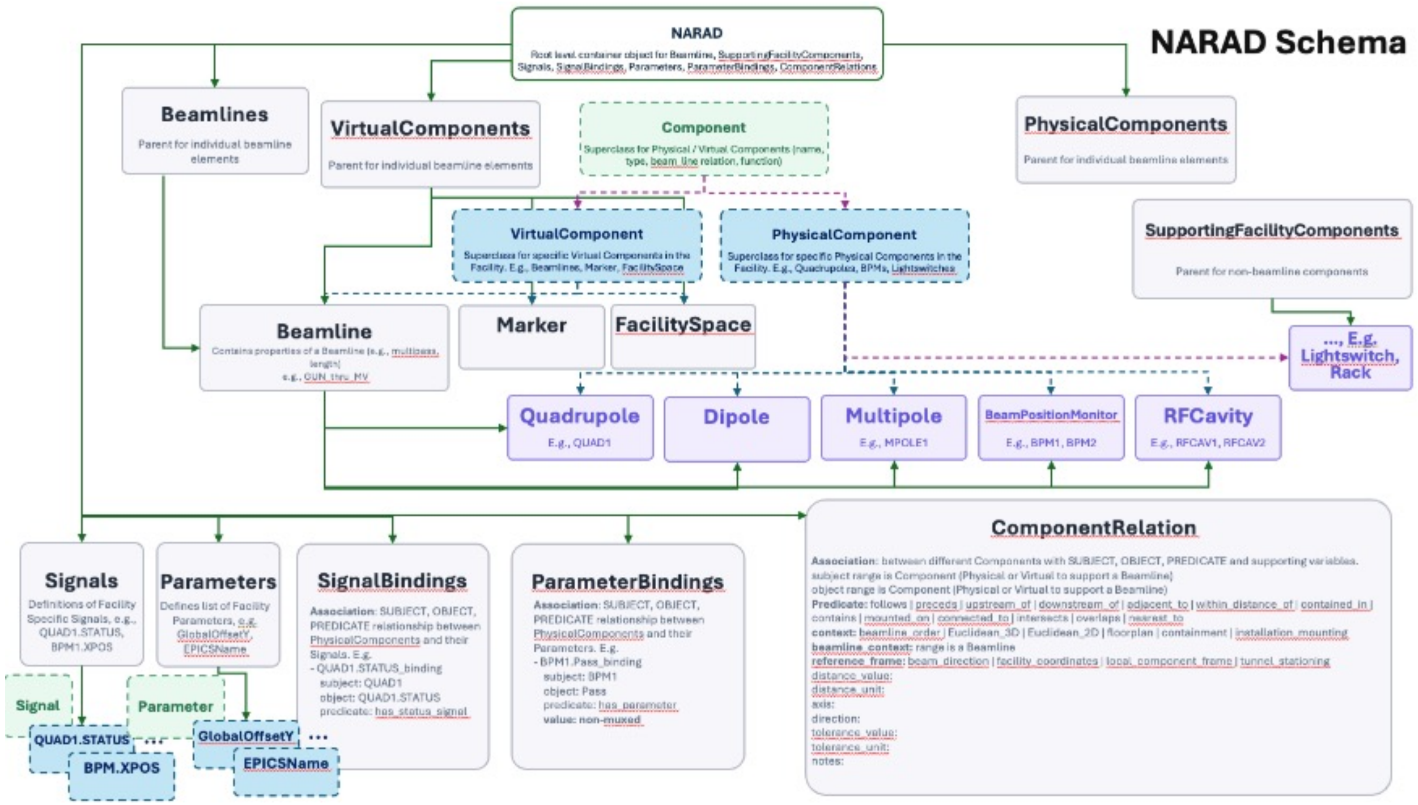
BNL use case: BtA transfer line





NARAD LinkML schema

- LinkML is a flexible modeling language that allows user to create **schemas** ("models") in YAML that describe the structure of their data.
- A human-readable YAML accelerator schema defines:
  - Components and beamlines
  - Physics parameter groups
  - Signals and relationships
  - Required fields, types, and controlled vocabularies
- LinkML validation catches structural and semantic errors early.



PALS lattice to skeleton NARAD schema

Input information:

- PALS component definitions
- Element types and lengths
- Bend and multipole parameters
- Nested beamlines
- Inheritance
- Repetition and reversed lines

Generated NARAD information:

- facility.components
- facility.beamlines
- facility.component_relations
- Empty signals
- Empty signal_bindings


```yaml
description: Control-system-neutral NARAD skeleton generated from bta.pals.yaml.
kind: PALSAccelerator
version: 0.1.0
notes:
- 'Translated from Bmad lattice file: bta.run_oct30.bmad'
- Generated from PALS source data without control-system enrichment.
facility:
  components:
  - id: inst:BEGINNING_B1
    kind: BeginningEle
    native_types:
    - BeginningEle
    - Beginning_Ele
    functions:
    - Mark
    beamline_relation: Inline
    ReferenceP:
      pc_ref: 2160058016.715229
      species_ref: proton
      id: inst:BEGINNING_B1/ReferenceP
    TwissP:
      beta_a: 12.5509384
      beta_b: 4.072941886974975
      alpha_a: 1.8249910306663342
      alpha_b: -0.6499756770851368
      eta_x: 2.7207960780961375
      etap_x: -0.4222600658627664
      id: inst:BEGINNING_B1/TwissP
```

```yaml
- id: inst:BTA_LINE_DR001_PRECEDES_MW006
  subject: inst:DR001
  predicate: pals:precedes
  object: inst:MW006
  context: beamline_order
  beamline_context: inst:BTA_LINE
```

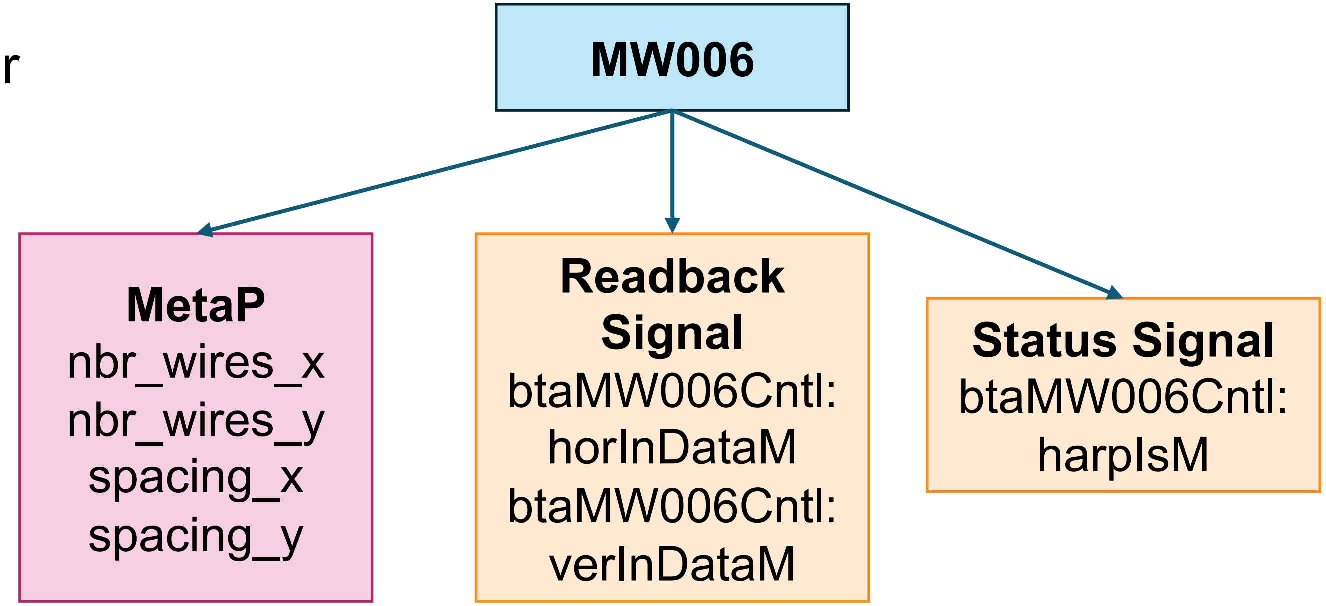
BtA NARAD instance with Control information

Device information

- Identifies BtA-specific device types
- Classifies MW006 as a BeamProfileMonitor
- Adds wire count and spacing metadata
- Classifies PUE devices as BeamPositionMonitor

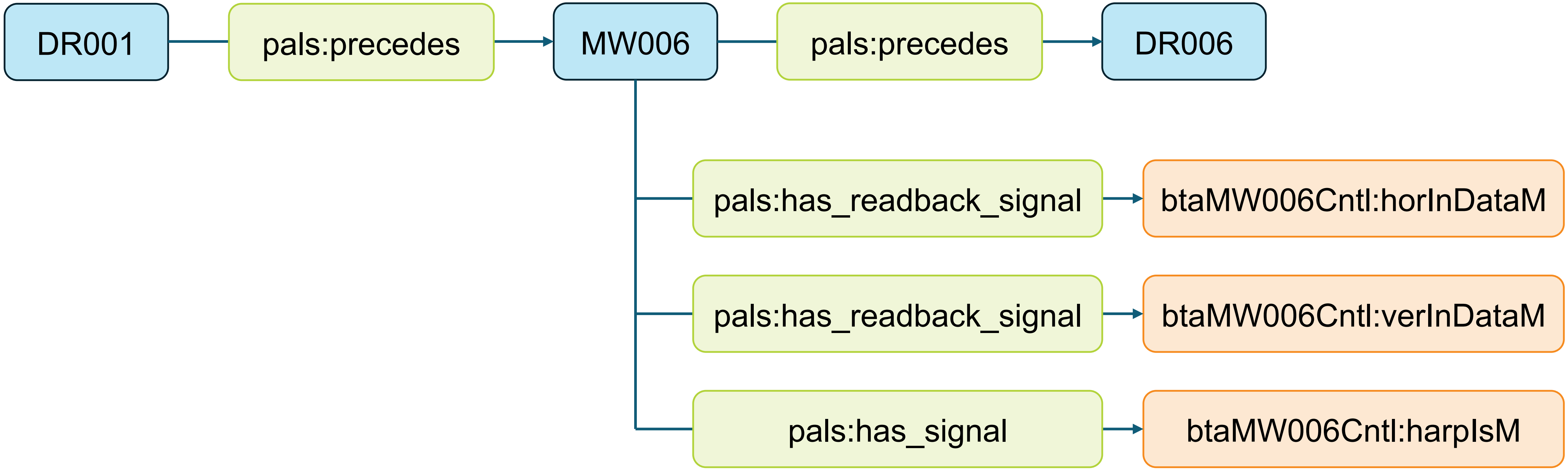
ADO information

- Uses regex naming rules for quadrupoles, kickers, and multiwires
- Creates one Signal for each native ADO endpoint
- Creates SignalBinding edges between components and signals

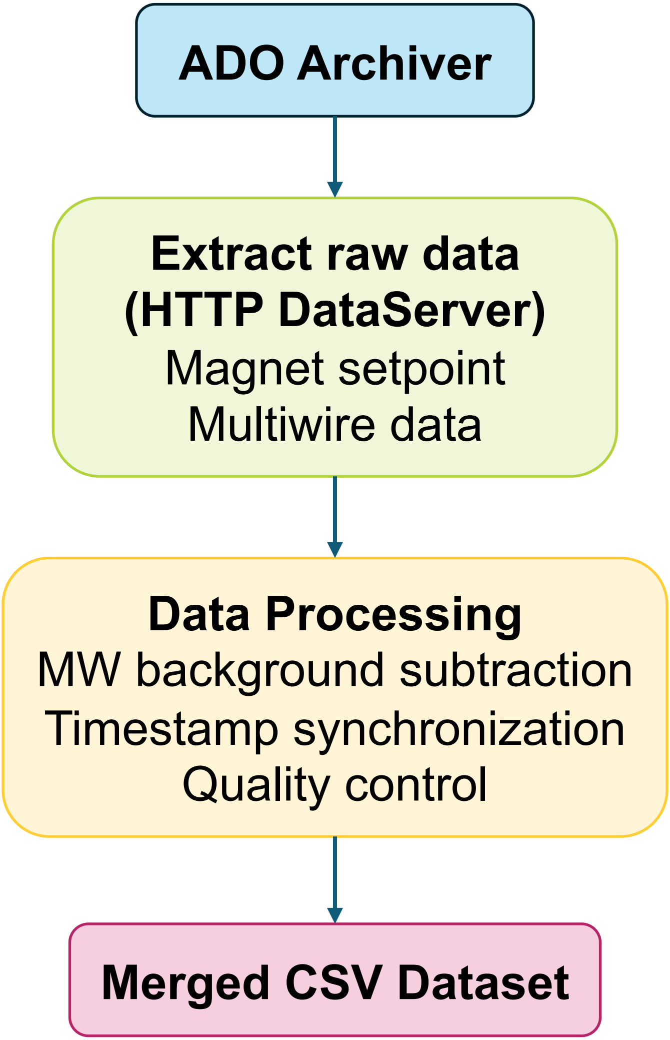


BtA RDF/OWL graph

- Resource Description Framework (RDF) graph: makes BtA model queryable as a graph
- Web Ontology Language (OWL) graph: include formal meaning and hierarchy of NARAD classes and predicates



Archive to AI-ready dataset

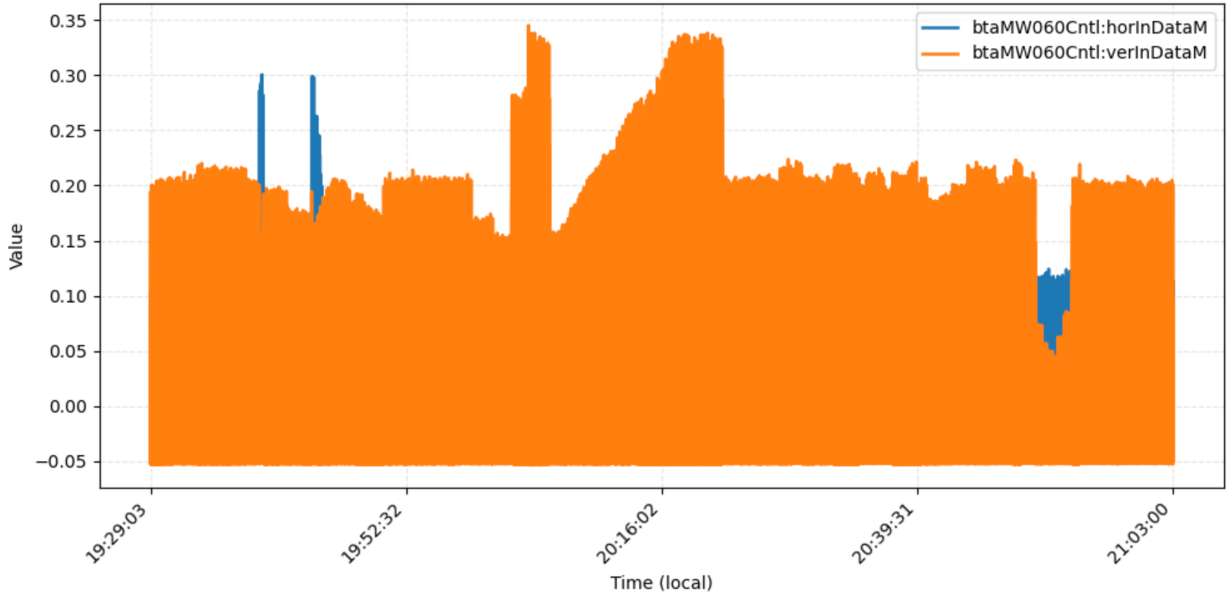


- Python workflow to grab and process archived ADO data
- BtA beam study example: corrector and quad scans by Eiad on Feb 04, 2026

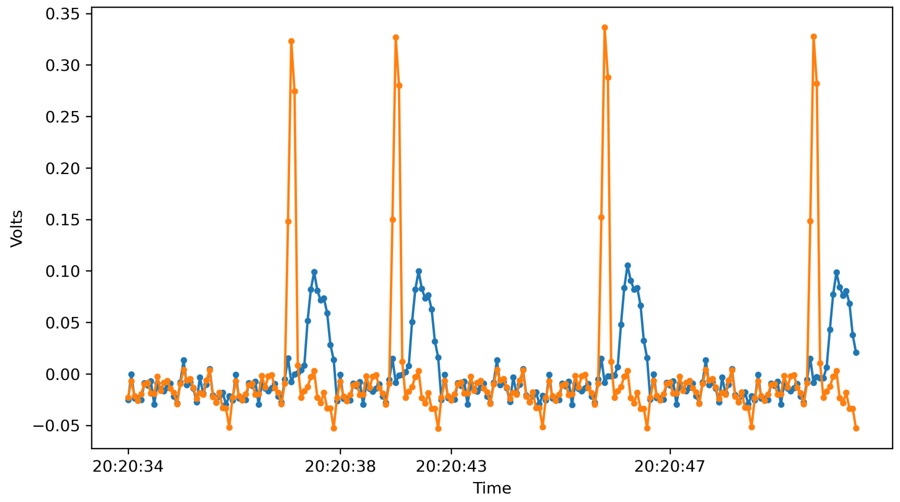
```
params_mw = ['btaMW060Cntl:horInDataM' ,'btaMW060Cntl:verInDataM']
file_mw = '/operations/app_store/Gpm/Booster/Instrumentation/Multiwires/btaMWprofile_U4.logreq'

result_mw = parse_data(filepath=file_mw, params=params_mw, count=5000000, start=start, end=end, debug=False)

fig, ax = plot_multi_series_simple_linspace(
    result_mw,
    params_mw,
    time_label_format="%H:%M:%S",
    max_xticks=5
)
```



FAIR documentation



Quality Control

- Background subtraction
- Timestamp correlation
- Bad wire in MW
- Missing hysteresis data
- Unstable acquisition (simultaneous magnet changes)

Genesis Data Card

- Dataset description
- Variable definitions
- Processing history
- Quality information
- Instrument metadata
- AI usability

Datacard for BtA MW060 Quadrupole and Corrector Scan Dataset

Last Updated: 2026-07-13

Machine Usability Snapshot

Intended Capability	DataCard Support
Discoverability	Yes
Accessibility	Yes
Interoperability	Yes
Reusability	Yes
Governed Use	Yes
AI Usability	Yes
License Clarity	Yes
Checksum / Fixity	No
Semantic Context	No

---- Discoverable ----

Description

Dataset Description

This dataset contains synchronized magnet control settings and processed beam profiles collected during a Booster-to-AGS (BtA) beam study performed at Brookhaven National Laboratory on **2026-02-04**. The study consisted of quadrupole and corrector scans while observing the beam at the MW060 multi-wire profile monitor. Each row corresponds to one processed MW060 acquisition.