The TRIUMF Optimization Platform and Application to the E-linac Injector

Chris Gong, Yu-Chiu Chao

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TRIUMF

Outline

- Genetic optimization
- Genetic optimization for accelerators
- TRIUMF optimization software
  - Requirements
  - Design
- Apply to TRIUMF e-linac

TRIUMF

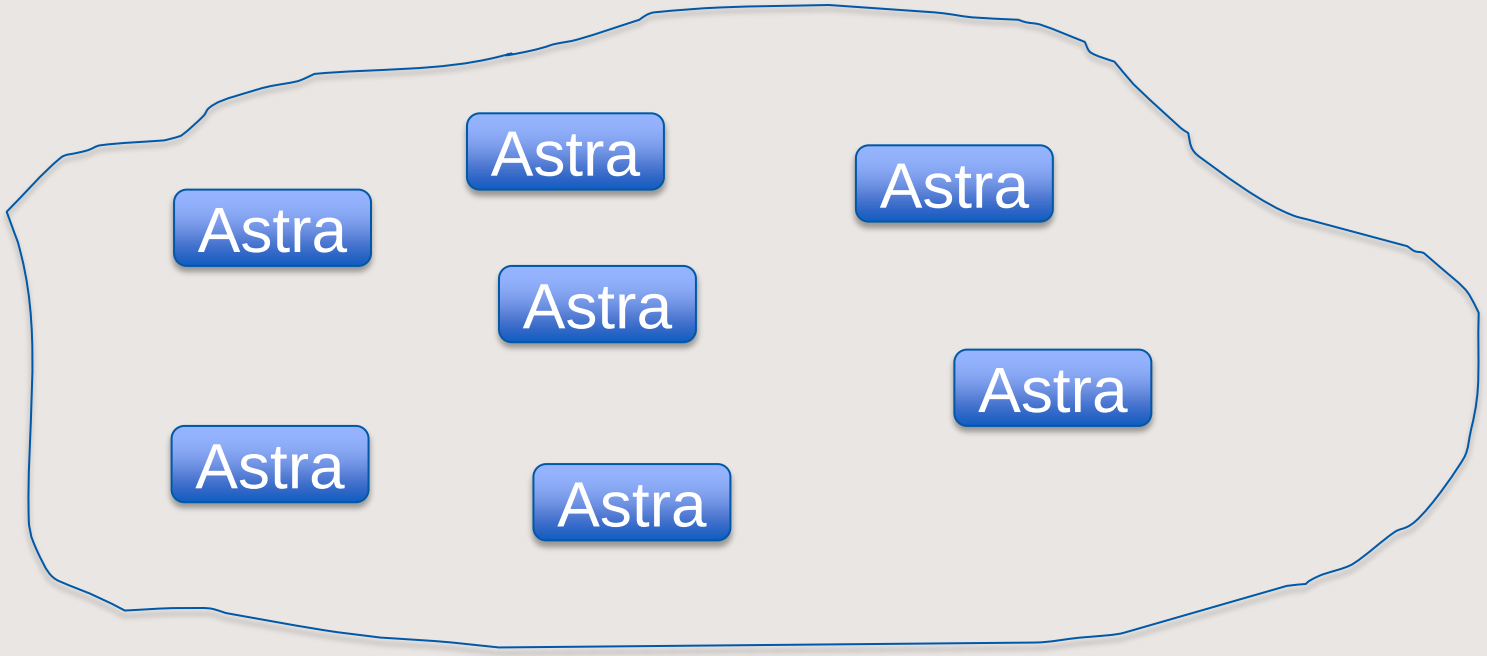
Multi-Objective Global Optimization

- Multi-Objective Genetic Algorithms (MOGA)
  - Define *variables*, *constraints*, *objectives*
  - Initial population
  - Iterate:
    - Select parent individuals
    - Create child individuals (mutation, crossing)
  - Pareto dominance

- Benefits:
  - True global optimization (with caveates)

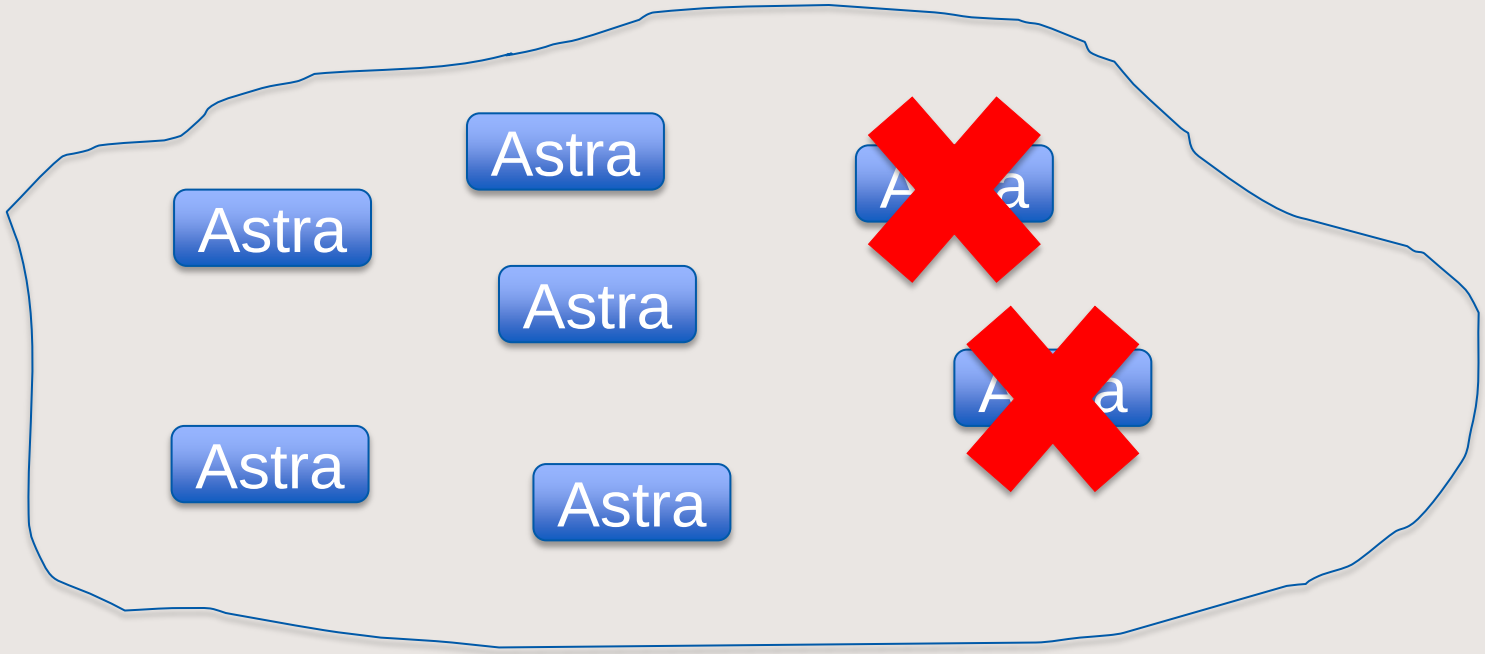
MOGA for Accelerator Design

- Wrapper (Astra, ELEGANT, etc)
- Run Astra many times
  - Different input parameters
  - Covers all search space



MOGA for Accelerator Design

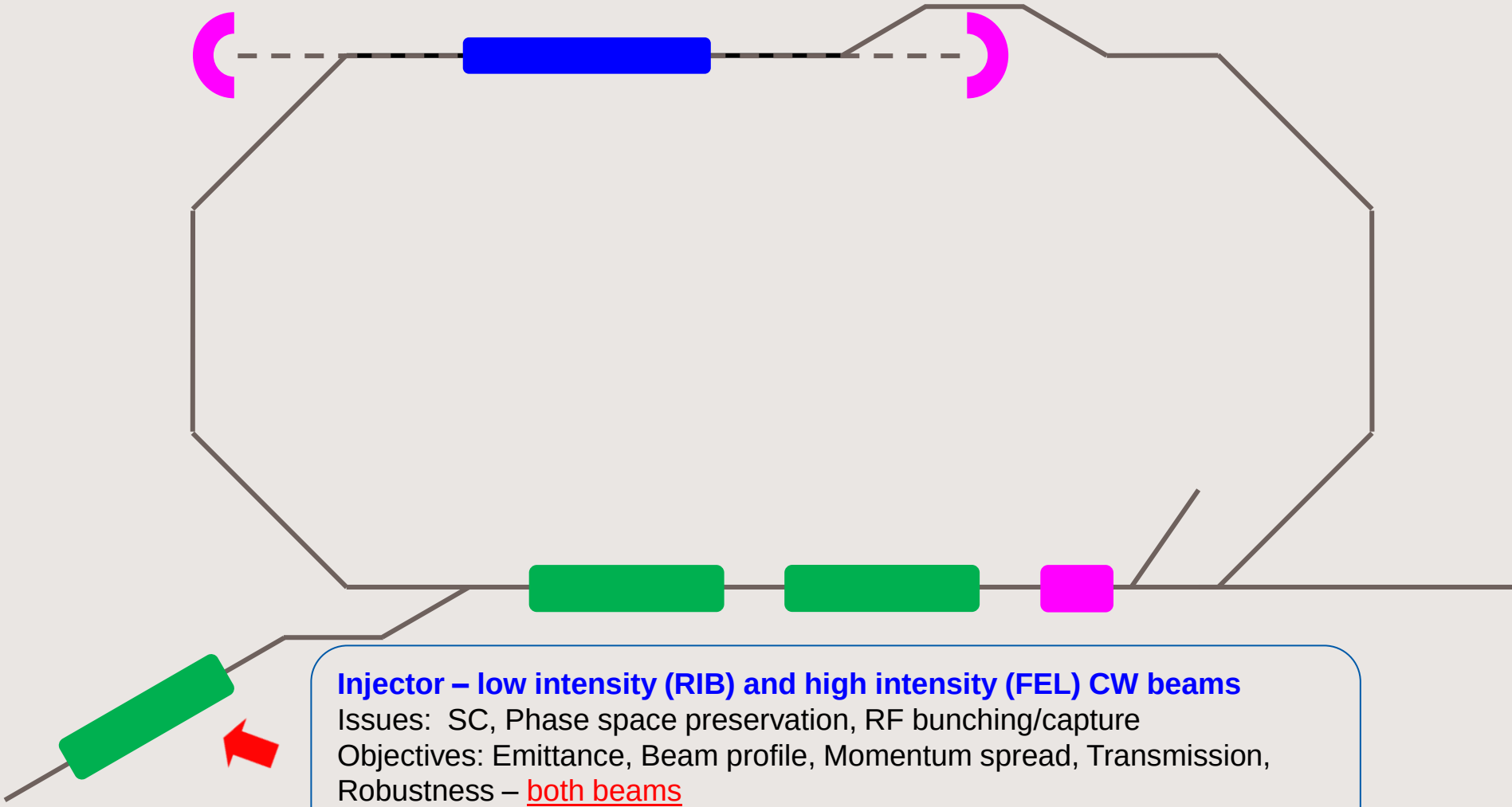
- Extract constraints/objectives
  - Emittance, bunch length, etc.
- Discriminate toward solutions



Motivation

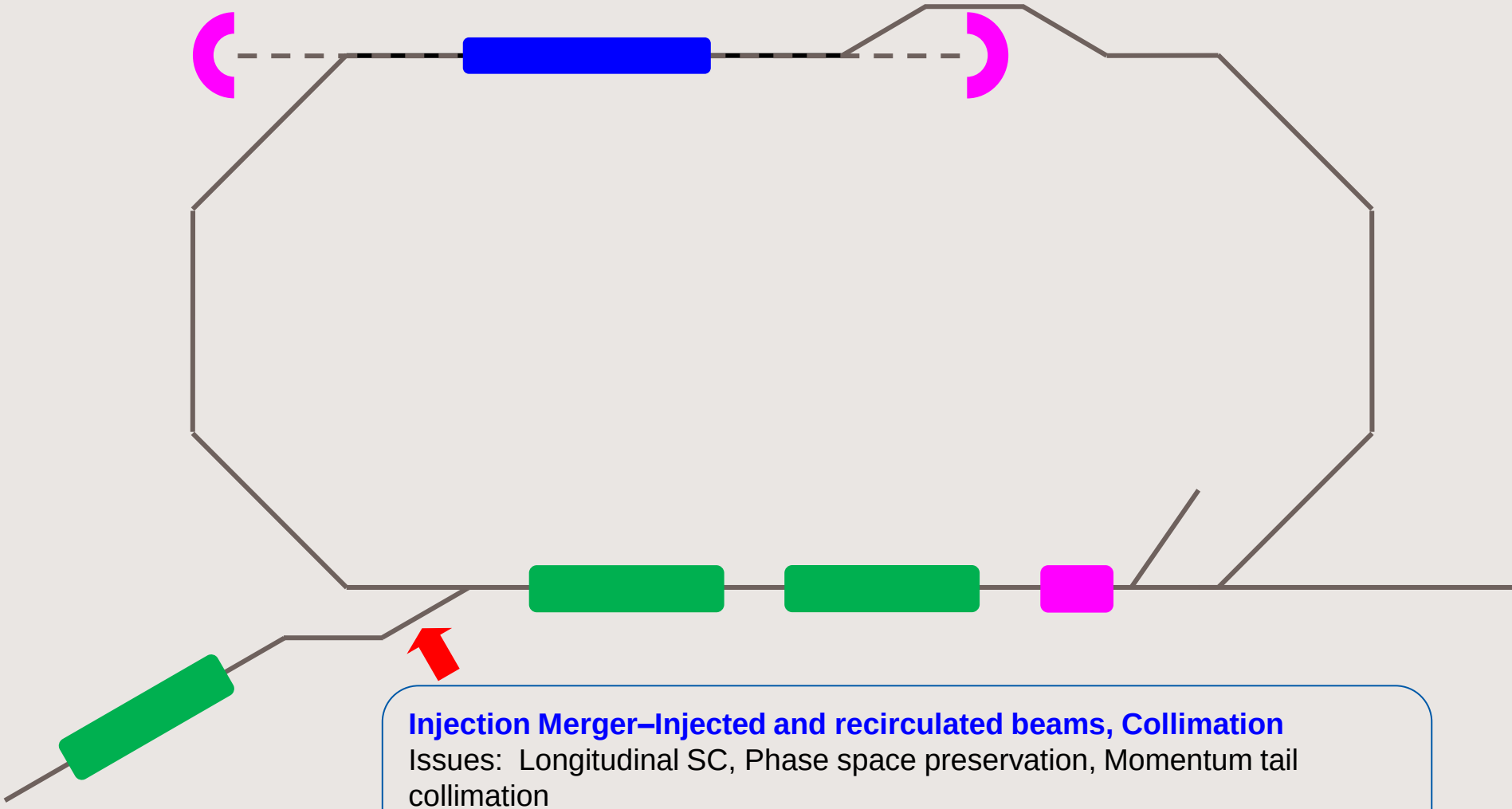
- Multi-engine simulations
  - Single beam in multiple distinct sections
  - Multiple beams through same section, different time-dependent effects
  - E-linac for FRIB/FEL
  - Expertise
- Single-engine MOGA is limited

FRIB/FEL



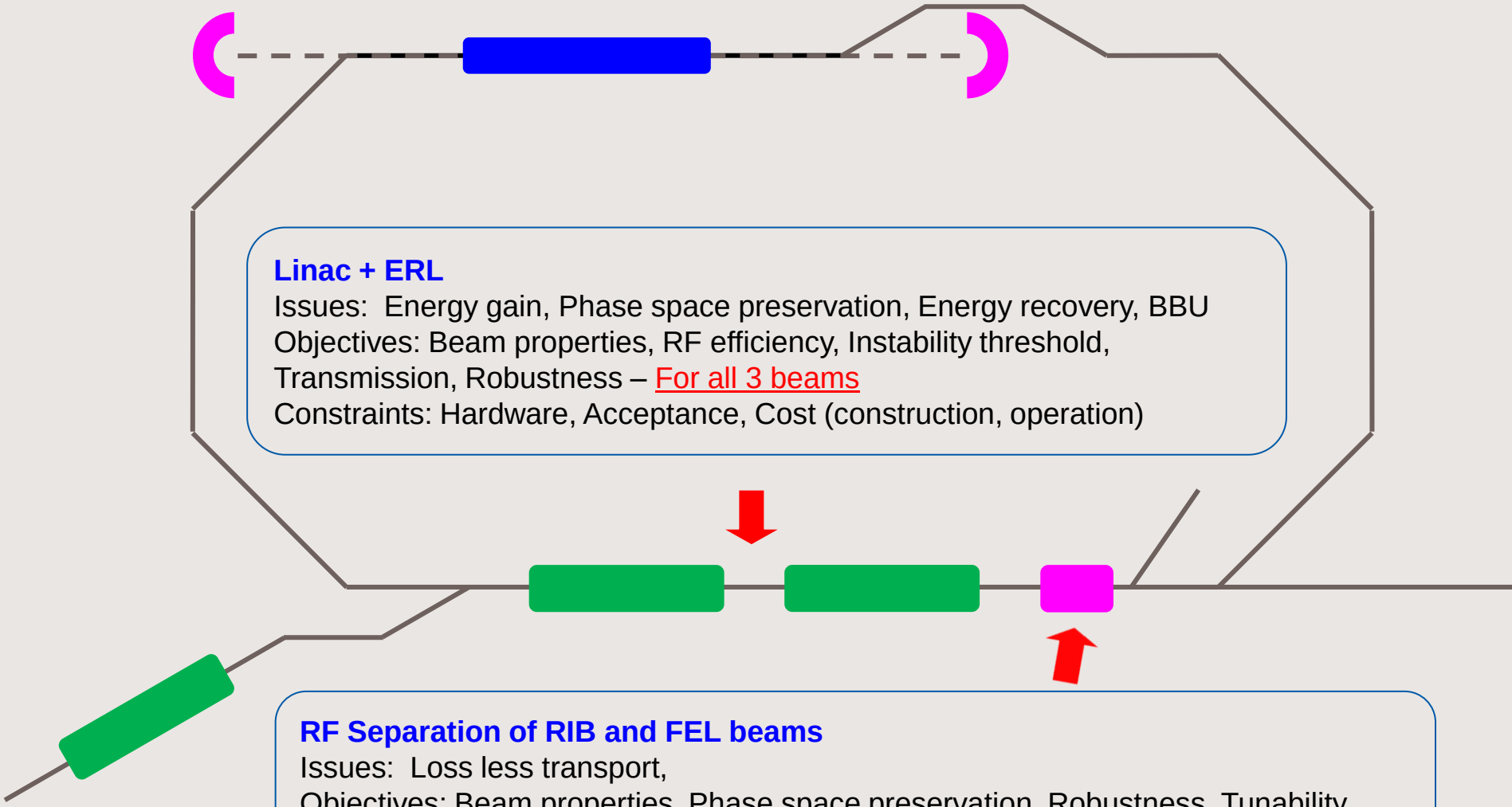
Injector – low intensity (RIB) and high intensity (FEL) CW beams
Issues: SC, Phase space preservation, RF bunching/capture
Objectives: Emittance, Beam profile, Momentum spread, Transmission,
Robustness – both beams
Constraints: Hardware, Acceptance, Cost

FRIB/FEL Issues



Injection Merger–Injected and recirculated beams, Collimation
Issues: Longitudinal SC, Phase space preservation, Momentum tail collimation
Objectives: Emittance, Transmission, Tunability
Constraints: Hardware, Acceptance

FRIB/FEL Issues

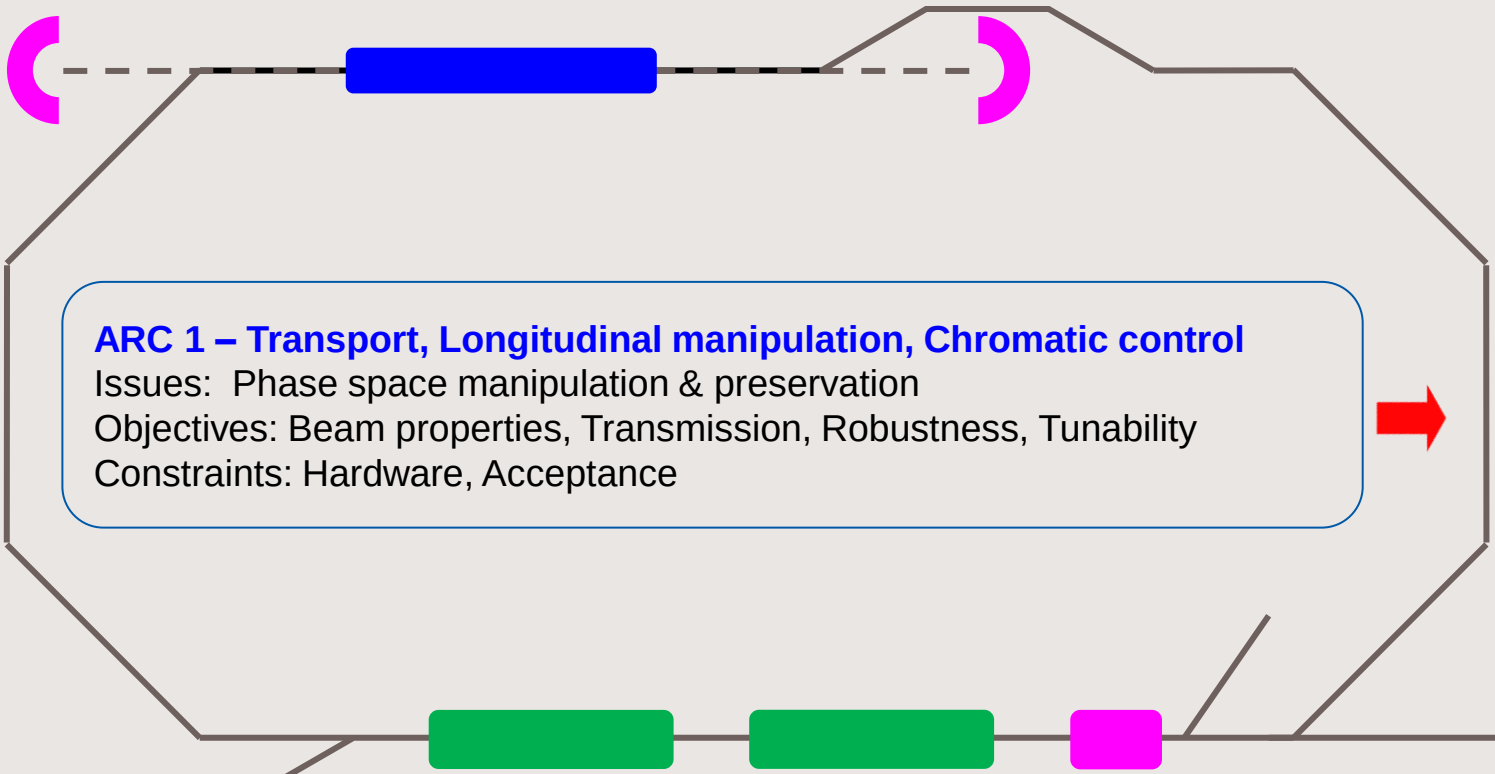


Linac + ERL
Issues: Energy gain, Phase space preservation, Energy recovery, BBU
Objectives: Beam properties, RF efficiency, Instability threshold,
Transmission, Robustness – For all 3 beams
Constraints: Hardware, Acceptance, Cost (construction, operation)

RF Separation of RIB and FEL beams
Issues: Loss less transport,
Objectives: Beam properties, Phase space preservation, Robustness, Tunability
Constraints: Hardware, Acceptance

FRIB/FEL Issues

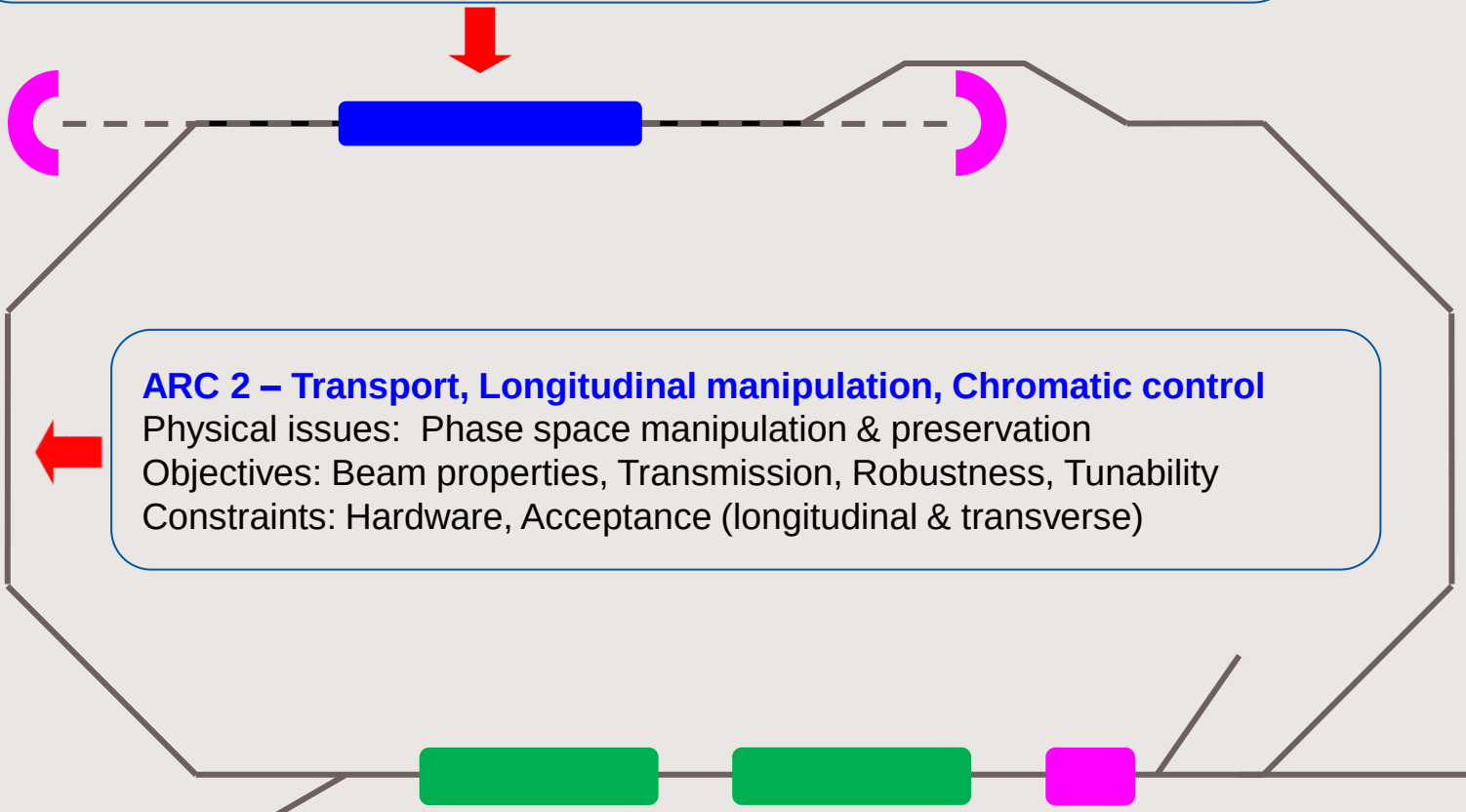
Compression Chicane
Physical issues: Phase space manipulation
Objectives: Beam properties, CSR, Tunability
Constraints: Hardware, Acceptance



ARC 1 – Transport, Longitudinal manipulation, Chromatic control
Issues: Phase space manipulation & preservation
Objectives: Beam properties, Transmission, Robustness, Tunability
Constraints: Hardware, Acceptance

FRIB/FEL Issues

Wiggler
Physical issues: FEL- Beam interaction
Objectives: Beam properties, FEL efficiency and performance parameters, Tunability
Constraints: Hardware, Acceptance (longitudinal & transverse)



ARC 2 – Transport, Longitudinal manipulation, Chromatic control
Physical issues: Phase space manipulation & preservation
Objectives: Beam properties, Transmission, Robustness, Tunability
Constraints: Hardware, Acceptance (longitudinal & transverse)

Motivation

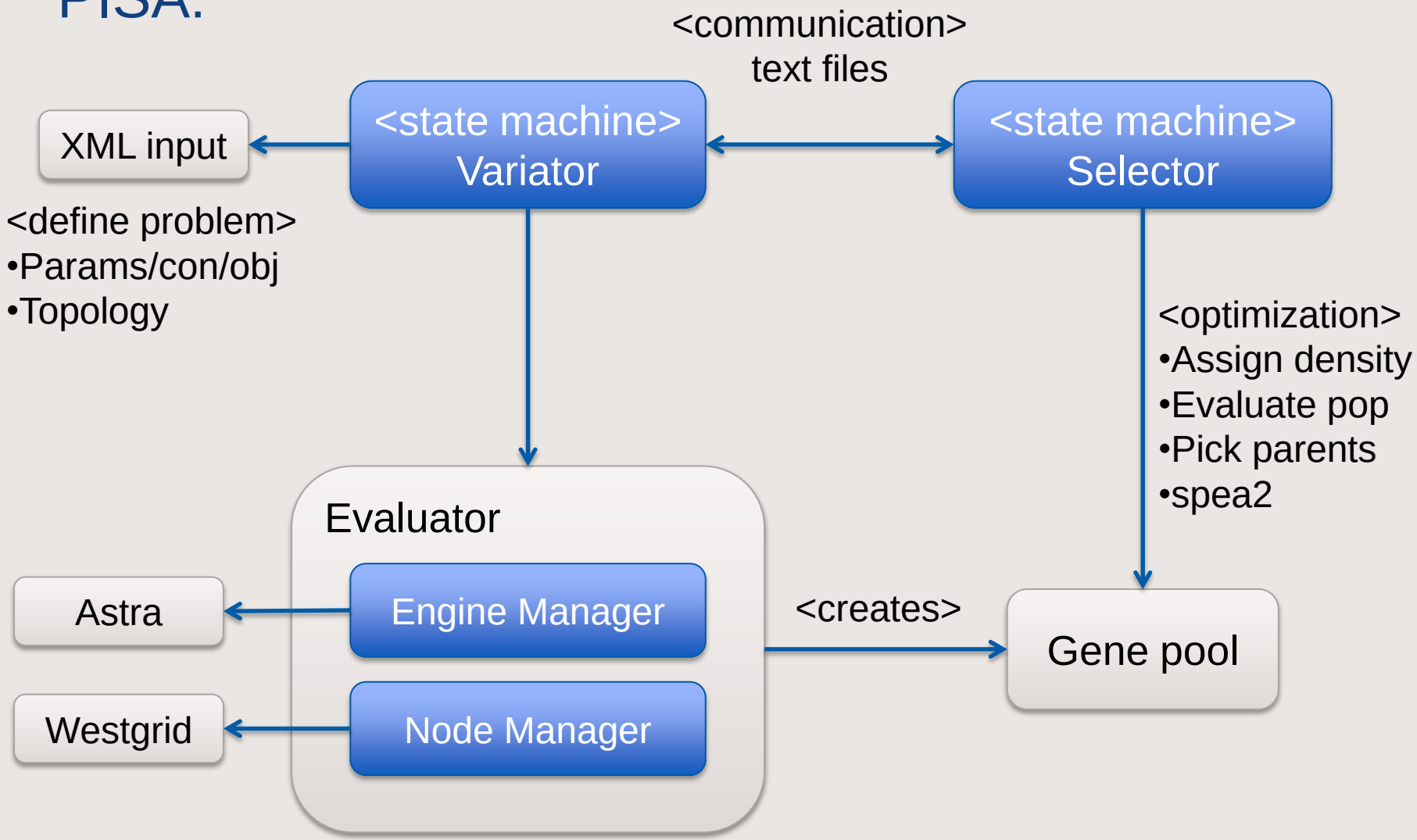
	Field map required	Space charge	Radiation field interaction	3D	Matrix/ tracking
Astra	1D	Yes		limited	
GPT	1D-3D	Yes		Yes	
MADX	No	Yes			Both
Elegant		No			Both
CSRTrack	Multipole	Yes	Yes		Tracking
Genesis			Yes		Tracking

Design

- Software platform:
  - **Multi-engine**
  - **Arbitrary problem topology**
    - Engines can run sequential or parallel
  - Parallel-capable (qsub, qstat)
  - Flexible XML input format
  - Good error handling
  - C++/Linux, dash of python

Design

PISA:


<communication>
text files
<state machine>
Variator
<state machine>
Selector
XML input
<define problem>
•Params/con/obj
•Topology
<optimization>
•Assign density
•Evaluate pop
•Pick parents
•spea2
Evaluator
Astra
Engine Manager
<creates>
Gene pool
Westgrid
Node Manager

Design

- Input XML:
  - Generic, suitable for all engines
  - Optimization parameters
    - Decision variables
    - Constraints
    - Objectives
    - Connecting variables
  - Topology (graph)
    - Engines execute in serial
    - Engines execute in parallel
  - Units
  - Designed to be intuitive, flexible

TRIUMF

Format of Input Files

```
<ParamList>
        <Param name="B_S4"      min="0"       max="0.10"      unit="T" />
        <Param name="s_S4"      min="4.2"     max="5.0"       unit="m" />
        <Param name="K1_Q1"     min="0"       max="150"       unit="dimensionless"
        <Param name="K1_Q2"     min="-150"    max="0"         unit="dimensionless"
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</ParamList>

<ConstraintList>
        <Constraint param="sigmax_2" direction="GT" bound="0.007" unit="m" />
        <Constraint param="sigmax_2" direction="LT" bound="0.015" unit="m" />
        <Constraint param="sigmay_2" direction="GT" bound="0.007" unit="m" />
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</ConstraintList>

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        <Objective direction="minimize" param="K1_Q1" />
        <Objective direction="maximize" param="K1_Q2" comment="defocusing, so 0 is ma
</ObjectiveList>

<Topology>
        <Vertex name="a1" type="ASTRA" inputdir="2069X" prereqs="" timeout="600" />
        <Vertex name="mad" type="MADX" inputdir="mad" prereqs="a1" timeout="60" />
</Topology>
```

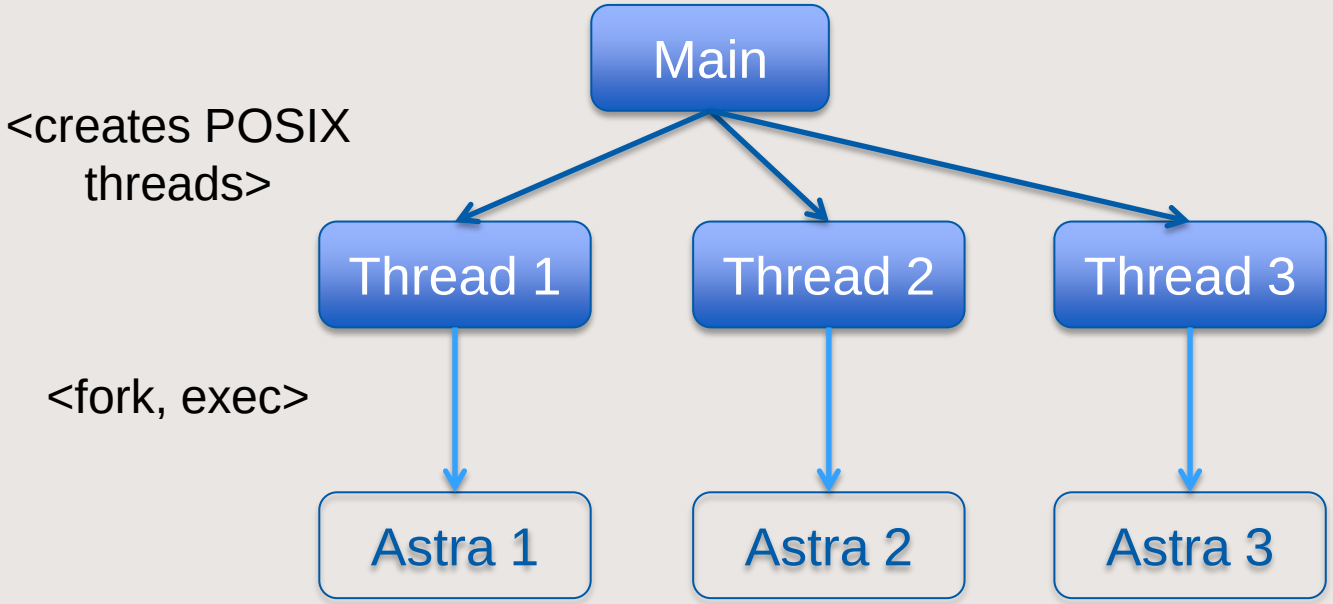
Design

- Parameters/Constraints/Objectives:
  - Beam parameters at arbitrary locations
  - Derived parameters
  - Massage parameters between engines
  - Need algebraic manipulation
- Custom python code:

```
# neck, also transition between astra and mad
file1 = "%s/input.0559.001" % sys.path[0]
if os.path.isfile(file1):
        d1  = astra.ReadAstraFile(file1)
        common.SetValue("betx_n", astra.GetBetax(d1))
        common.SetValue("bety_n", astra.GetBetay(d1))
        common.SetValue("alfx_n", astra.GetAlphax(d1))
        common.SetValue("alfy_n", astra.GetAlphay(d1))
        common.SetValue("E_n", astra.GetE(d1))
        common.SetValue("emitx_n", astra.GetXemitrms(d1))
        common.SetValue("emity_n", astra.GetYemitrms(d1))
        common.SetValue("sigmax_n", astra.GetSigmaxrms(d1))
        common.SetValue("sigmay_n", astra.GetSigmayrms(d1))
```

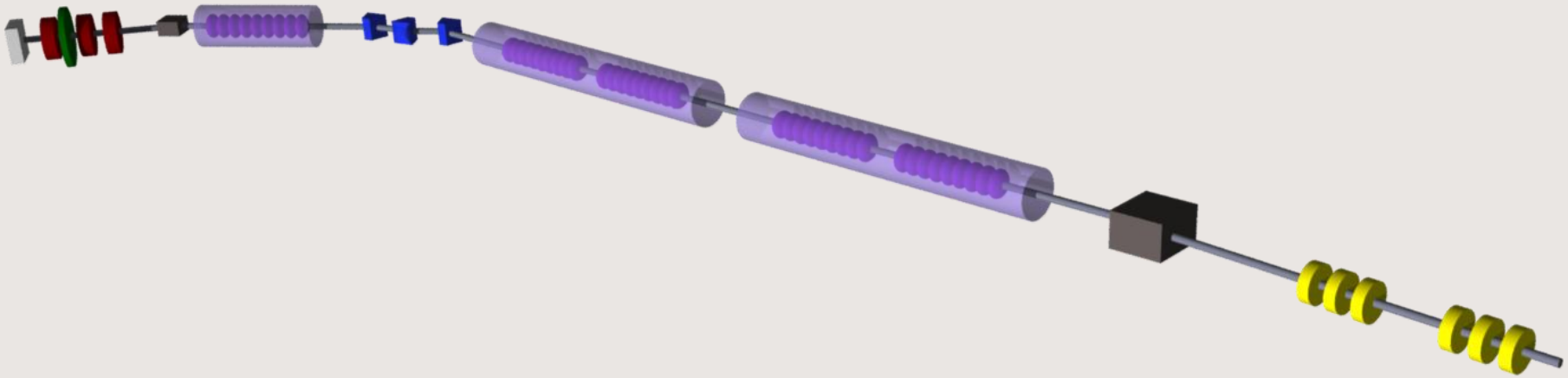
Design

- Exception handling:
  - Not all engines behave well
  - Kill if necessary (ssh does not work)
  - Thread problems, network problems: need to monitor



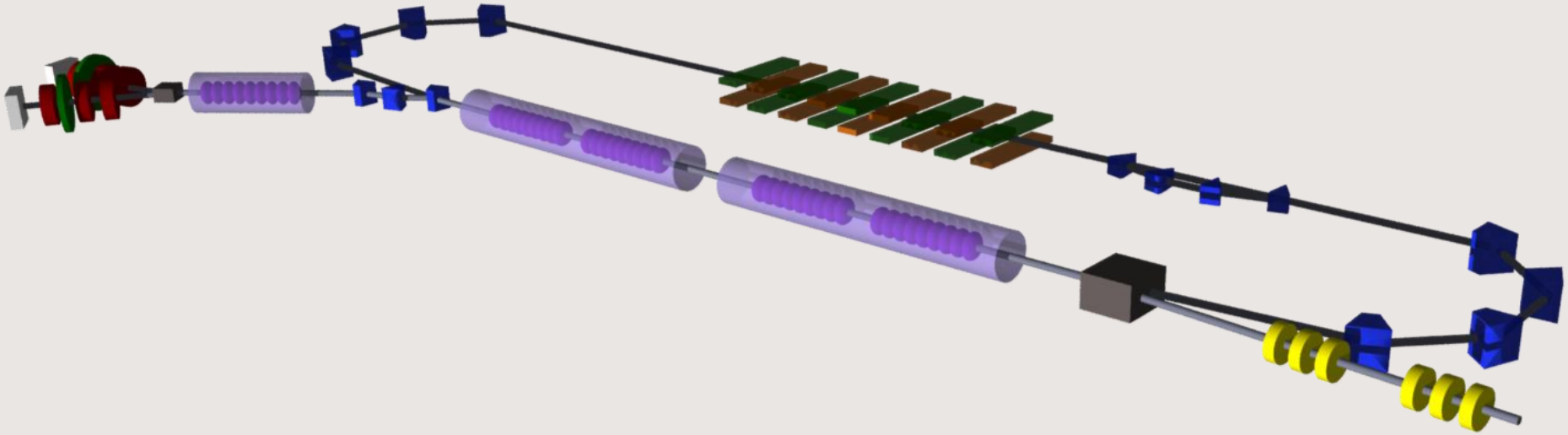
TRIUMF Ariel Overview

- 50 MeV, 0.5 MW, CW
- 5 SCRF cavities



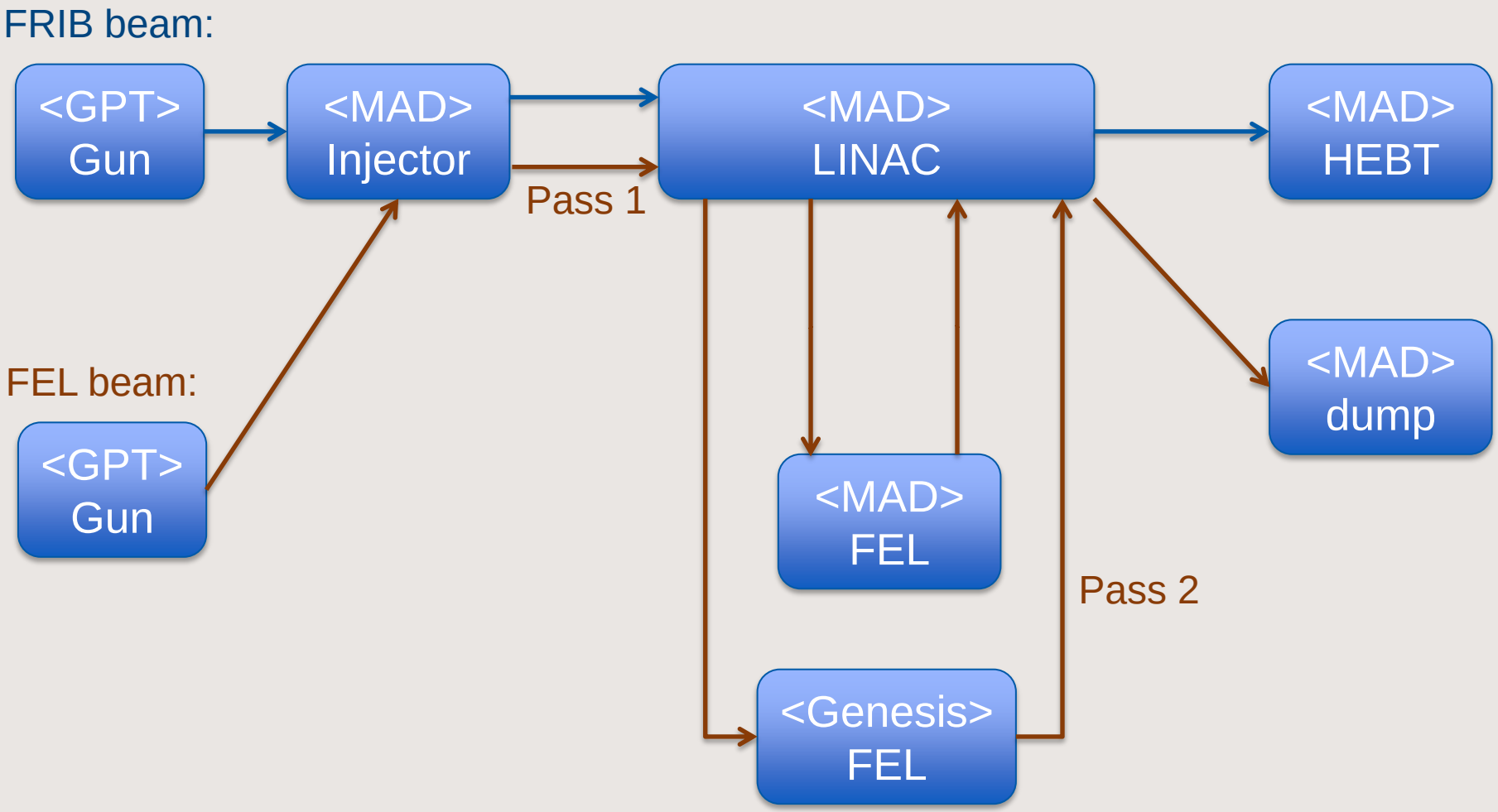
TRIUMF Ariel Overview

- Upgradeable to ERL
- Simultaneous photo-fission / light source

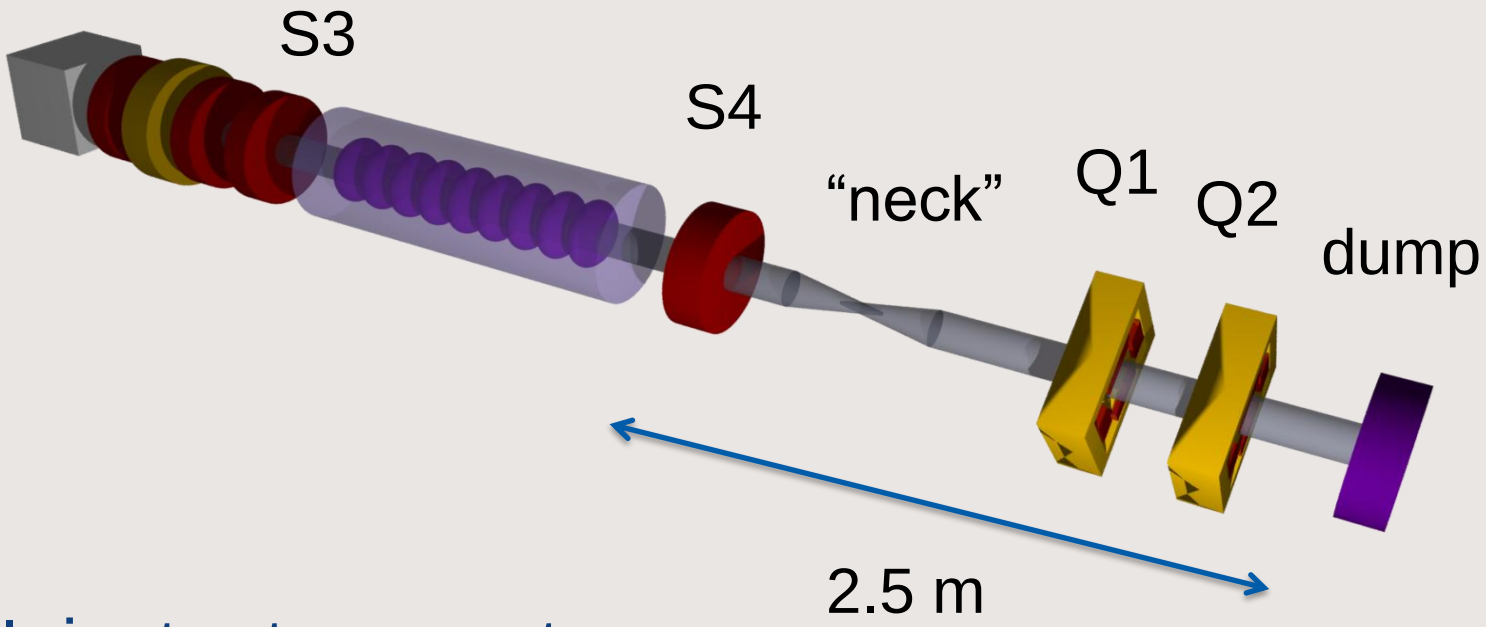


Goal: Start-to-End Optimization

In the future:

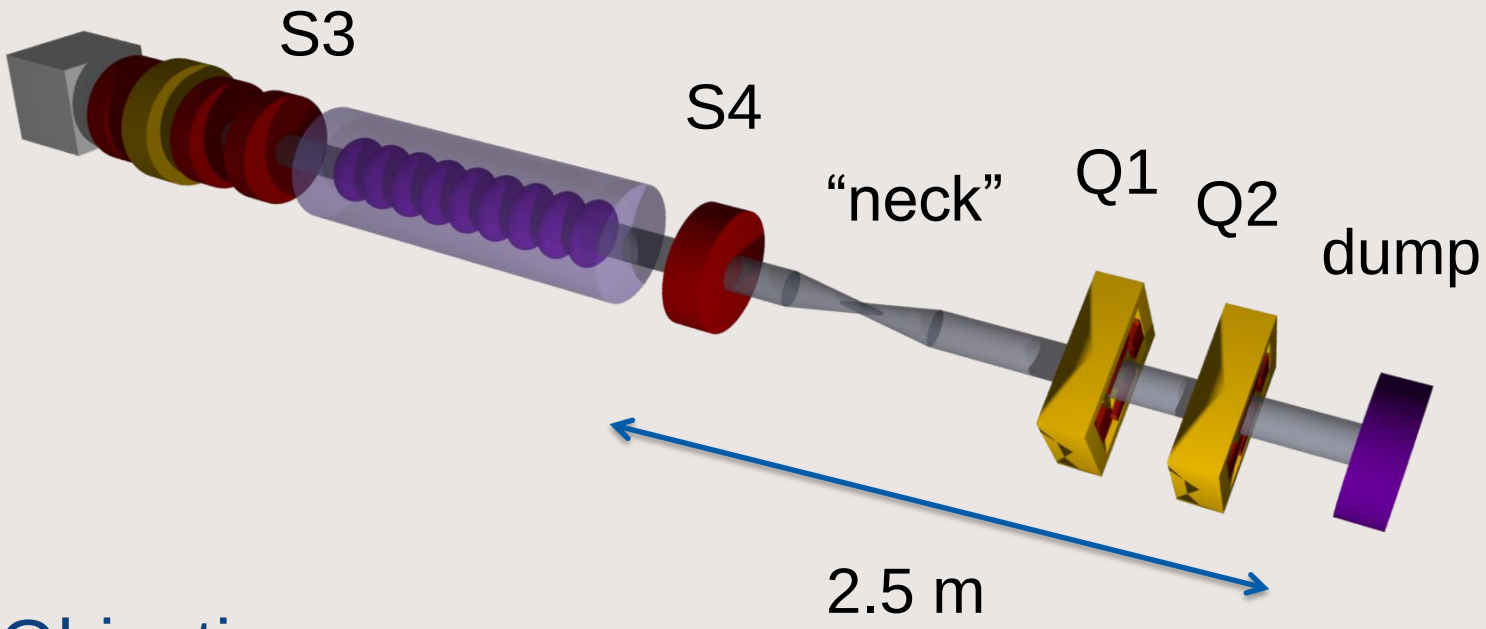


Injector Cryomodule to Dump



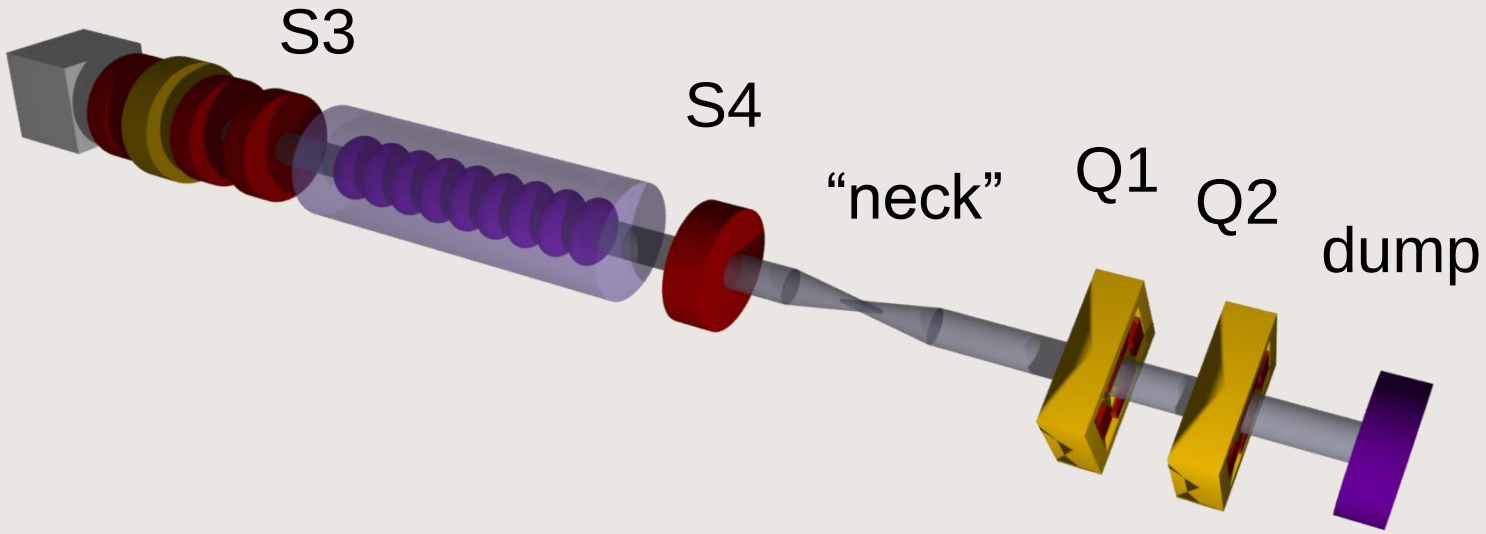
- Injector transport:
  - Scheduled for end of 2012
  - 300 keV beam from gun
  - Cryomodule -> 10 MeV
  - Terminate on dump

Injector Cryomodule to Dump



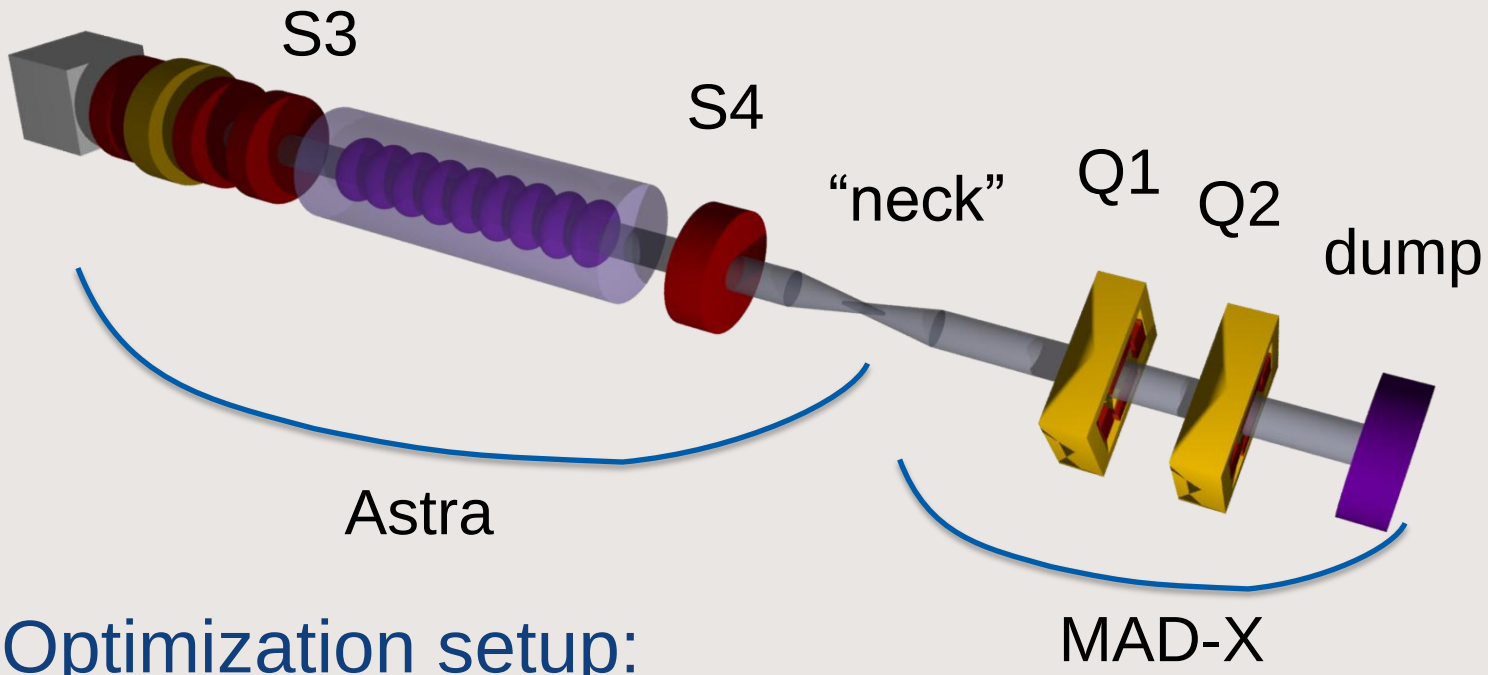
- Objectives:
  - Neck: squeeze beam
  - Dump: blow up beam (~1 cm)
  - Undemanding magnet settings
  - Length feasible?

Injector Cryomodule to Dump



- Parameters:
  - Solenoid 3 field
  - Solenoid 4 field, position
  - Quadrupole 1 field, position
  - Quadrupole 2 field, position

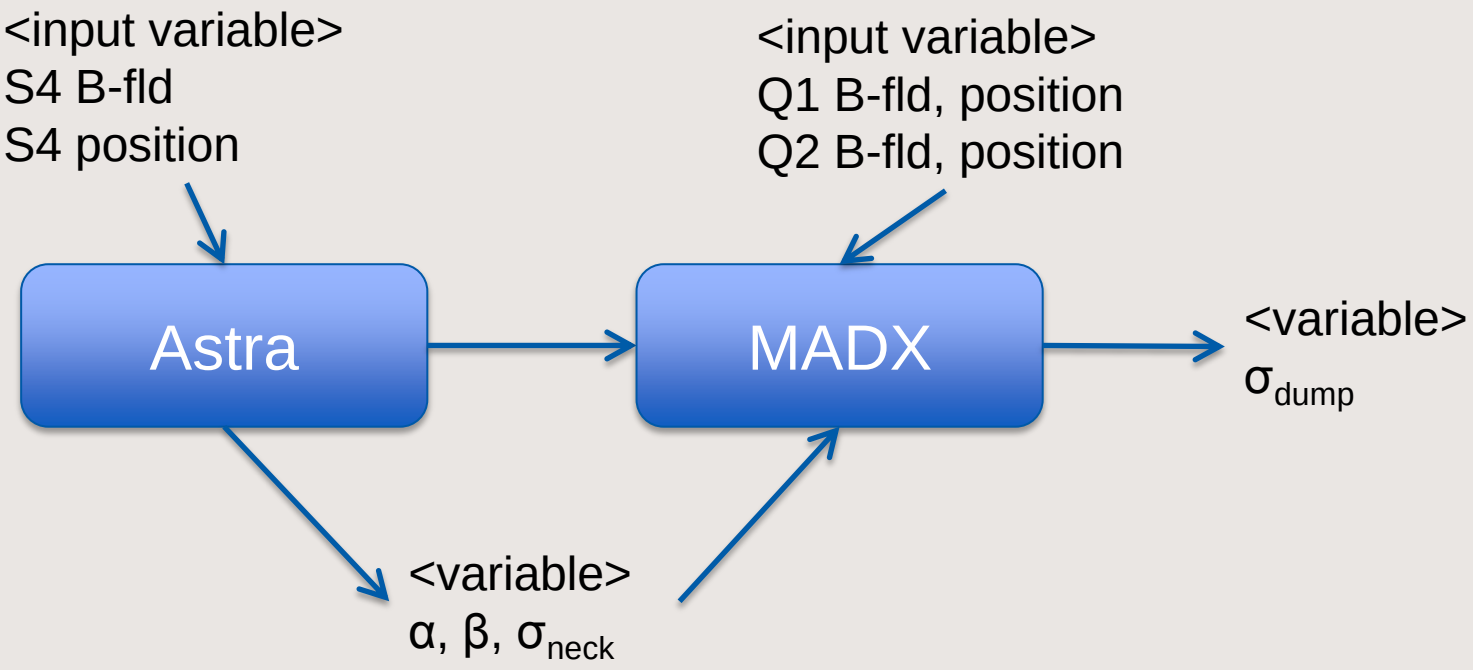
Injector Cryomodule to Dump



- Optimization setup:
  - Astra: gun-to-neck
  - MADX: neck-to-dump
  - Unit conversion, parameter passing taken care of

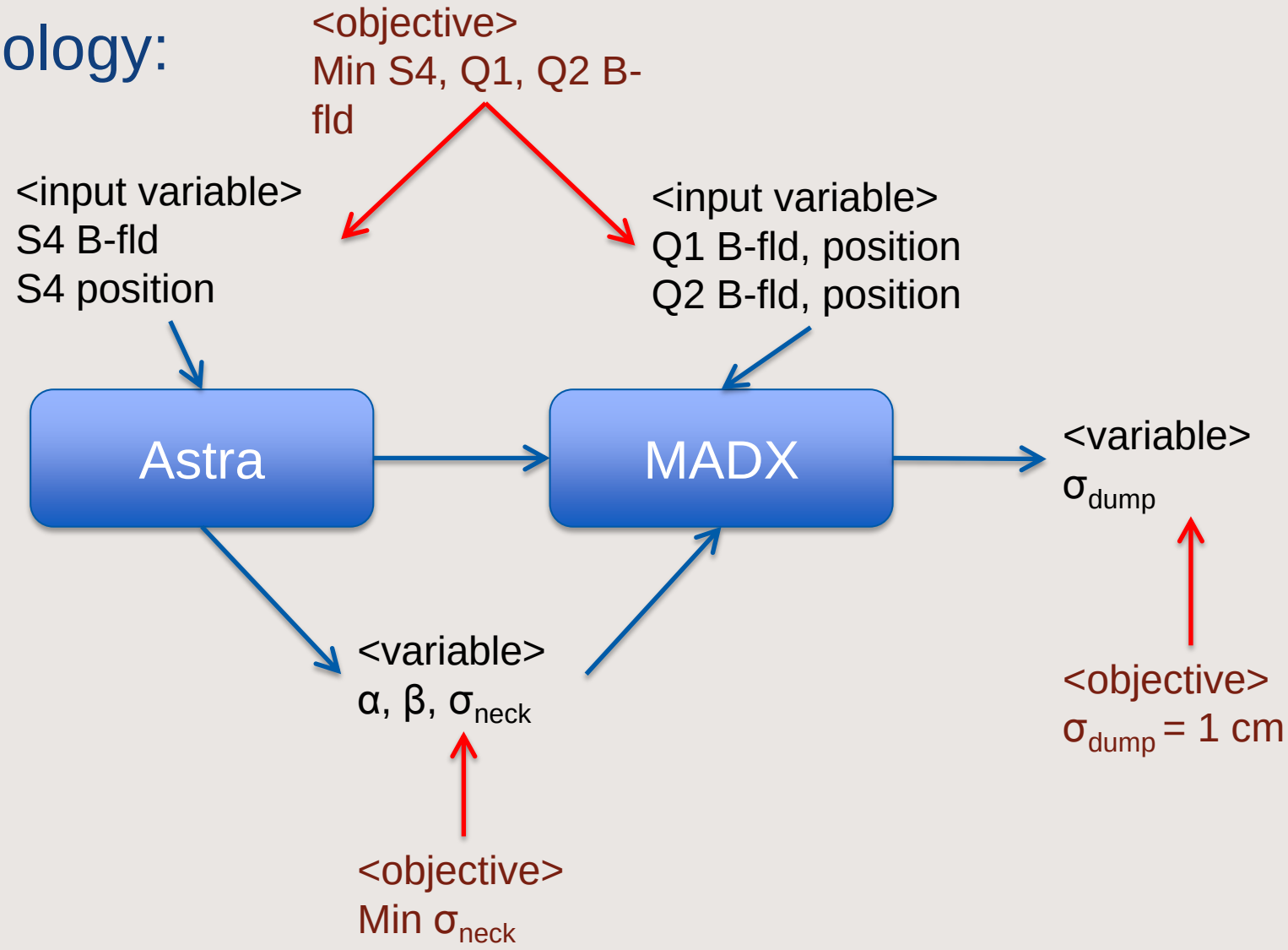
Injector Cryomodule to Dump

Topology:

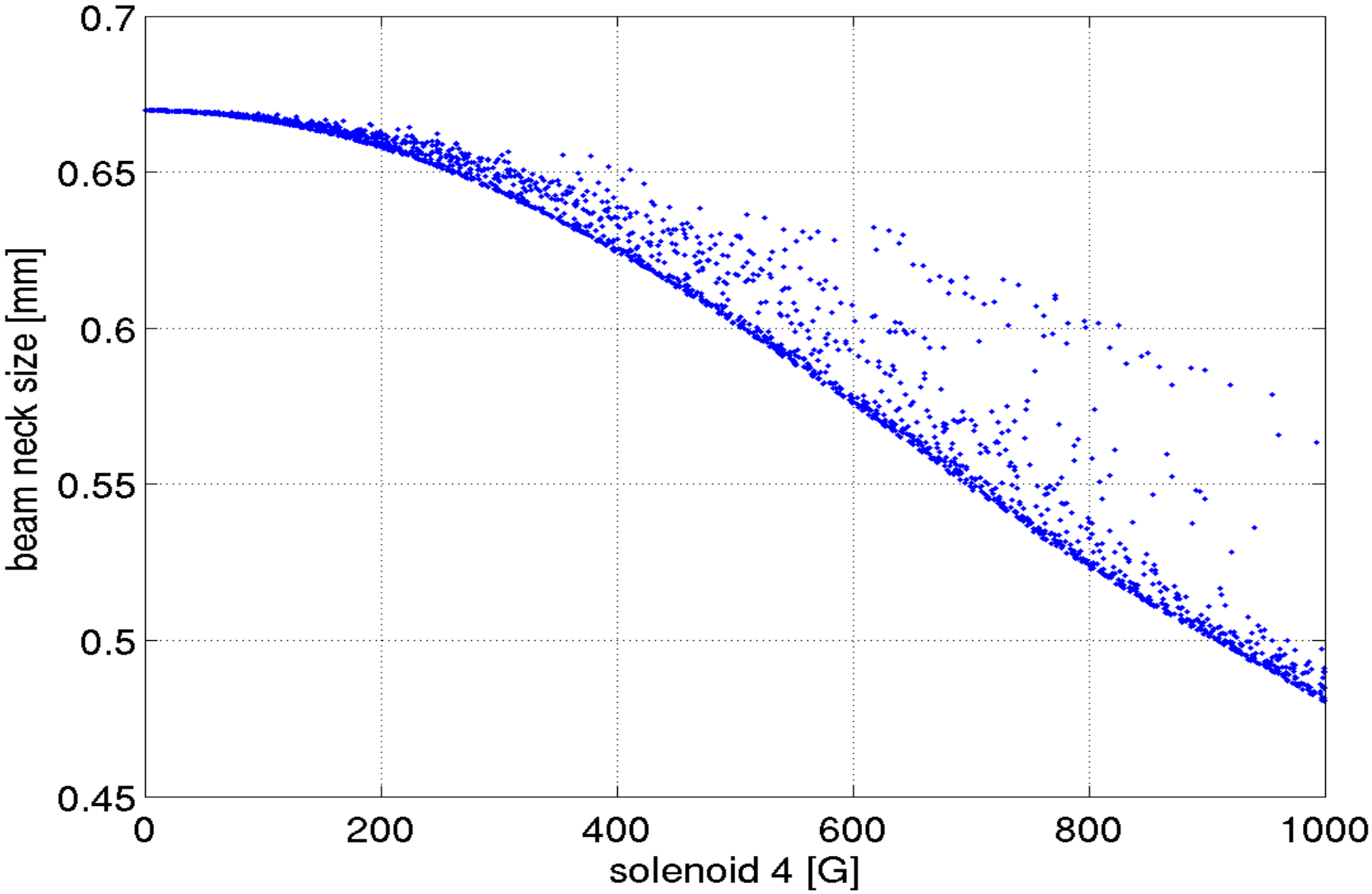


Injector Cryomodule to Dump

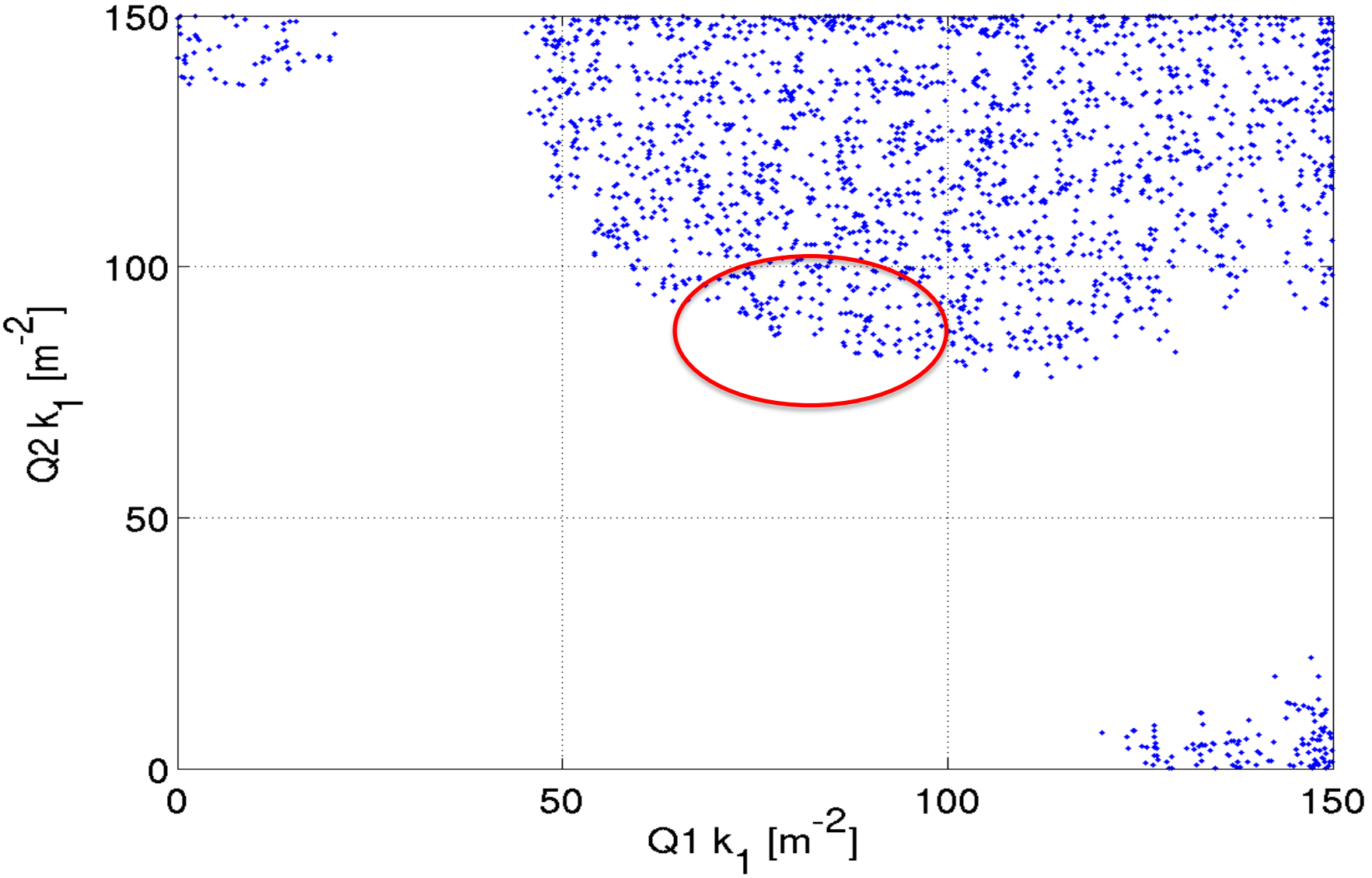
Topology:



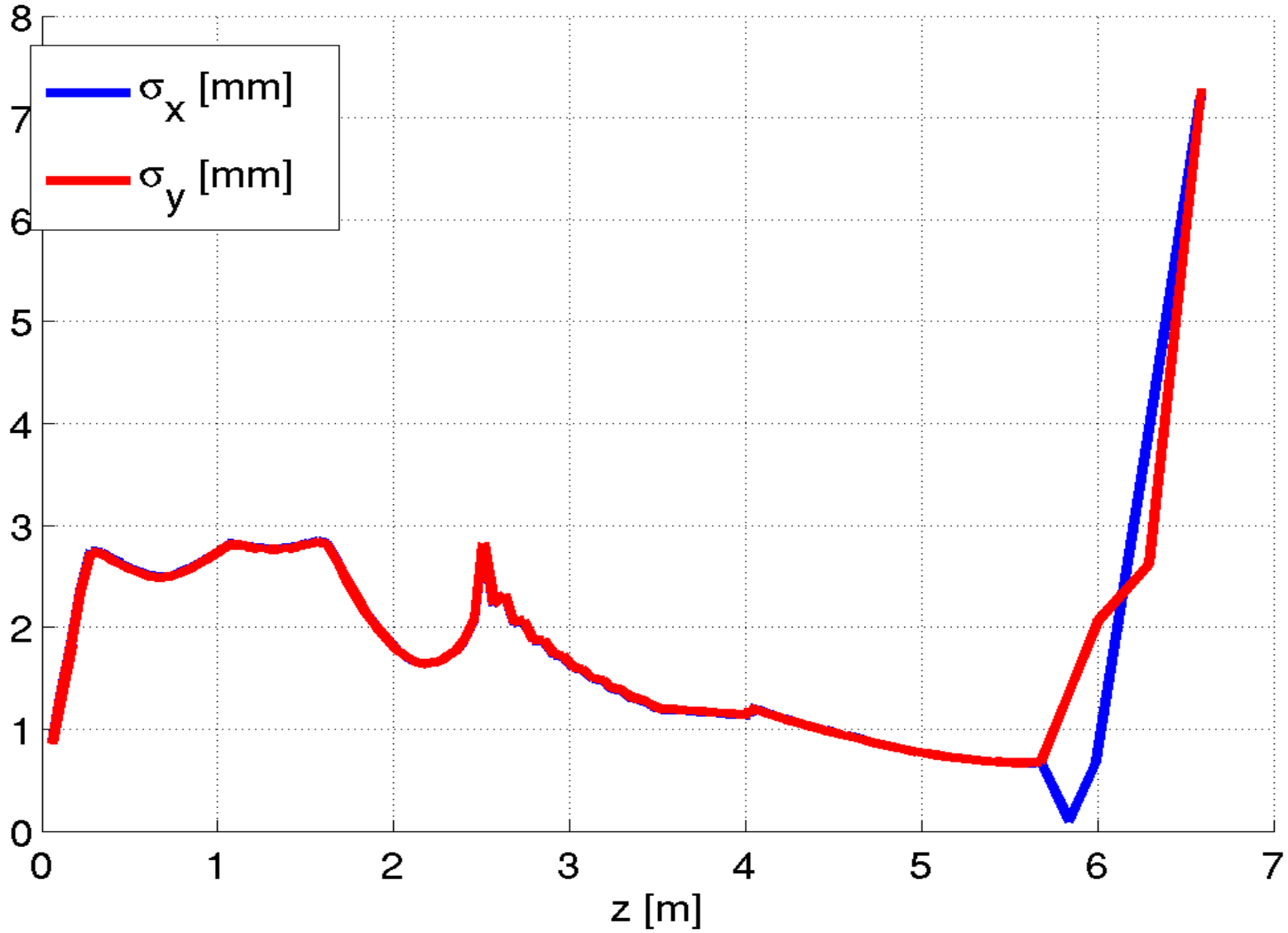
Results


0.7
0.65
0.6
0.55
0.5
0.45
beam neck size [mm]
0
200
400
600
800
1000
solenoid 4 [G]

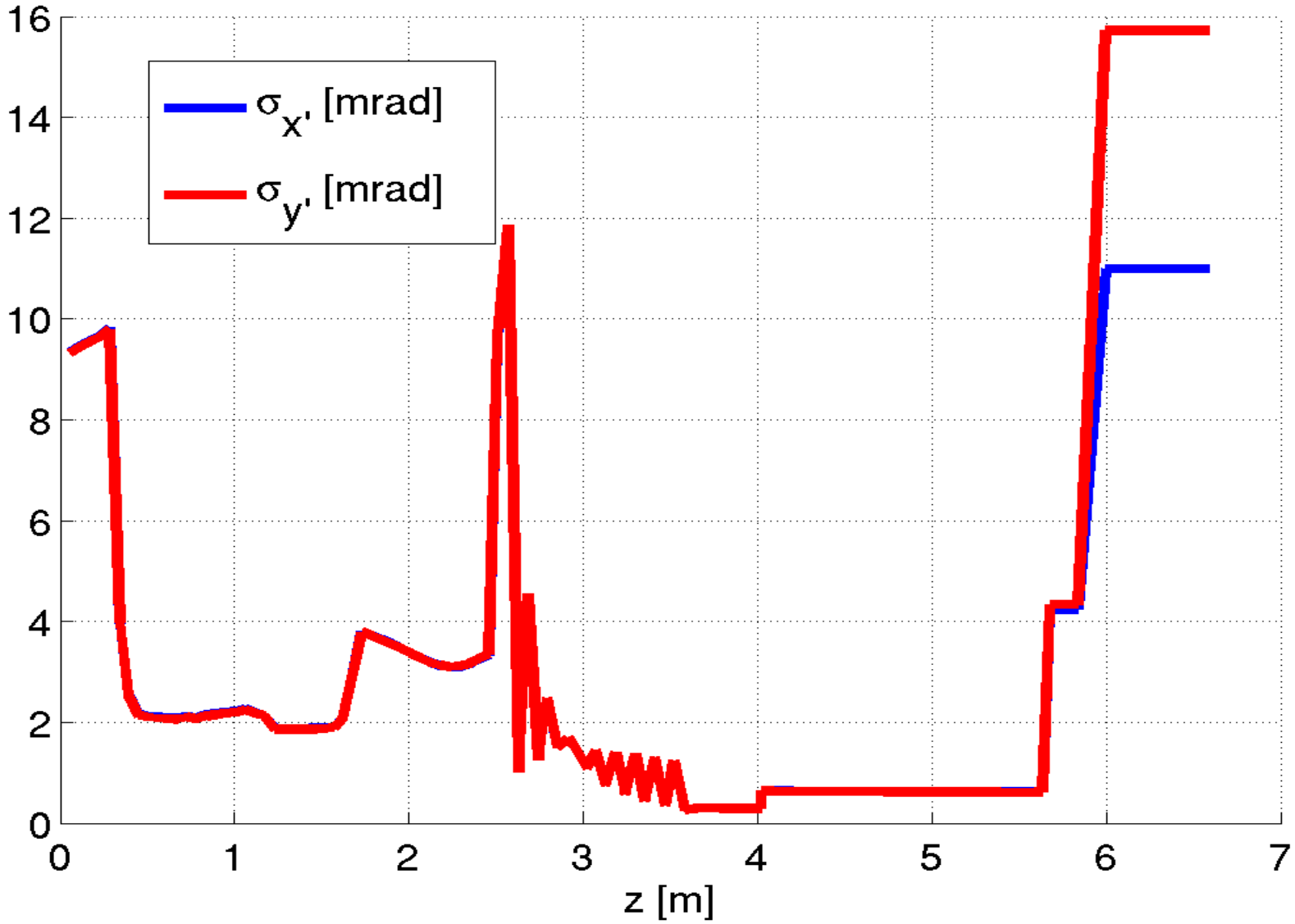
Results



Results



Results



Current Status

- Optimization platform tested, in-use
- Working on optimizing CSR in chicane
- Looking for more problems
- Improving features

References

- [1] PISA - *www.tik.ee.ethz.ch/pisa/*
- [2] I. Bazarov, APISA - *http://www.lepp.cornell.edu/~ib38/apisa/*
- [3] G. Goh, YAPISA, TRIUMF
- [4] M. Borland, Elegant MOGA - *http://www.aps.anl.gov/Accelerator_Systems_Division/Accelerator_Operations_Physics/software.shtml*
- [5] E-linac - *http://www.triumf.ca/ariel*