Universiteit Antwerpen

MYRRHA phase 1 implementation
MINERVA

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Belgian Nuclear Research Centre

Gaussian Process Bayesian Optimization of an Isotope Separator Online system

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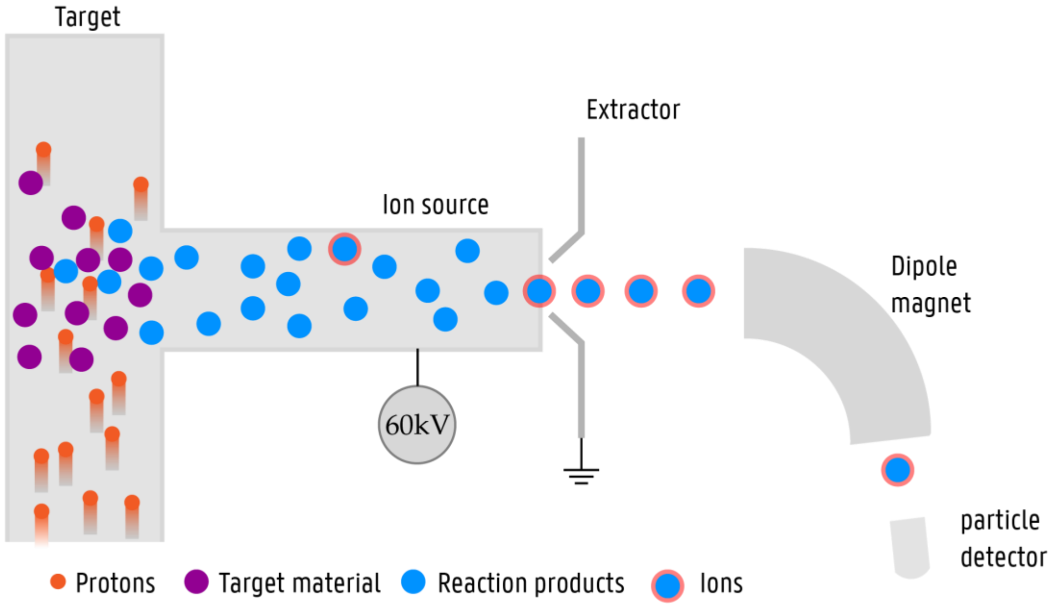
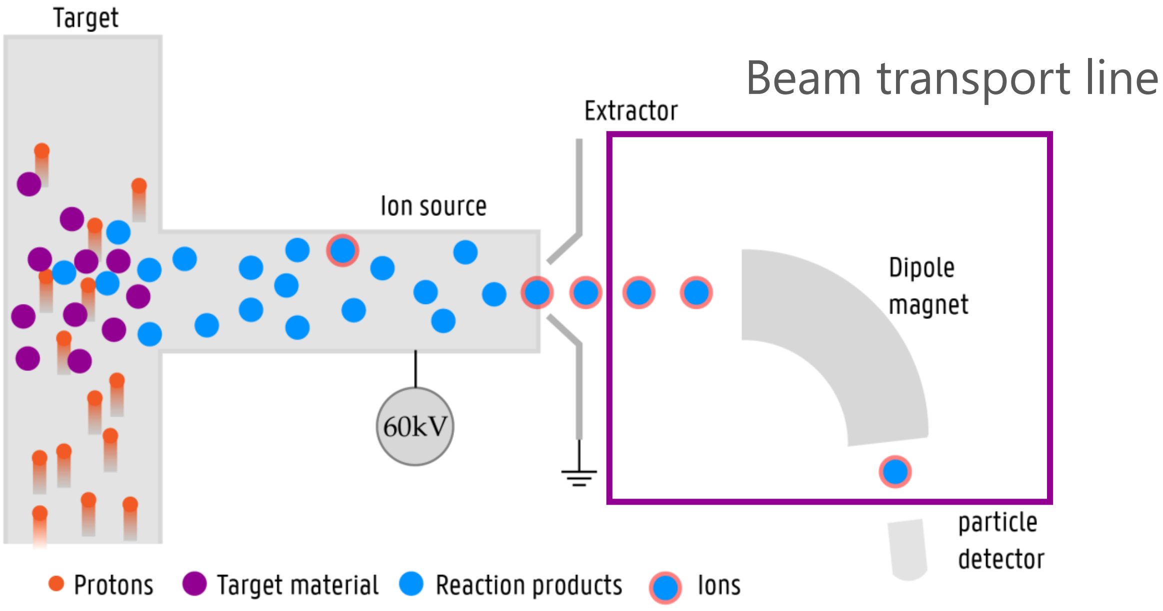
Why is this project relevant?



- Setting of multiple parameters
- The quality of the beam must be guaranteed
- Time-varying system
- Monitoring of multiple variables
- Multiple stages

- Online optimization of ISOL@MYRRHA performance through an automated control system

Application into the ISOL system



- There is a beam available from the extraction electrode
- The beam is aligned along the transport line
- Idealized quadrupole

- Transport the beam from the extraction electrode to the focal point of the pre-separator, and separate masses with a specific resolution

Gaussian Process Bayesian Optimization

Why this technique?

- Systems with multiple parameters

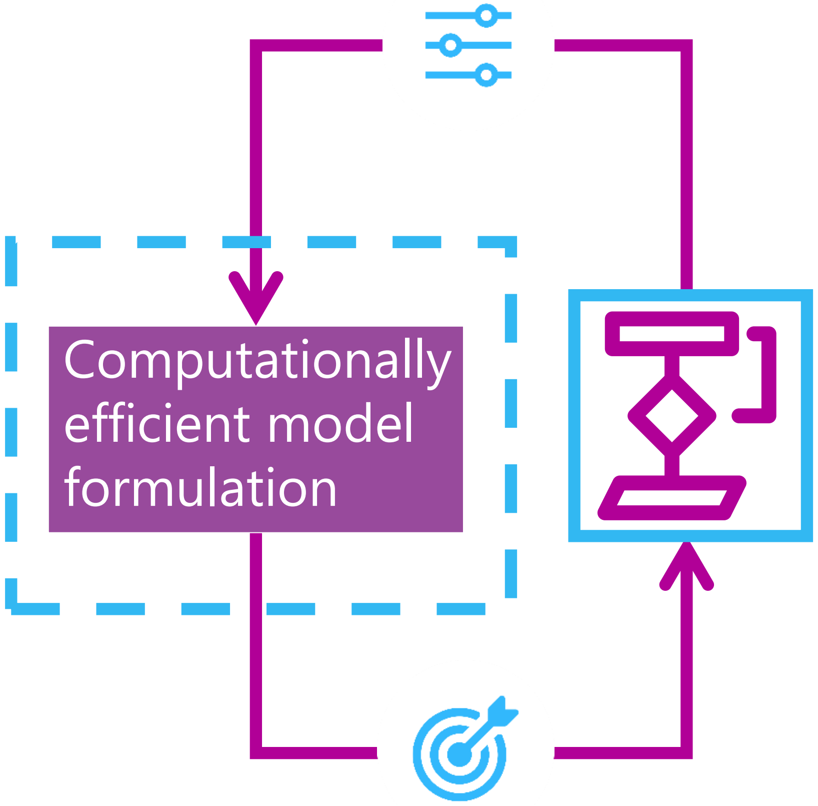
- Suitable for expensive-to-evaluate objective functions

- Suitable for noise-corrupted data

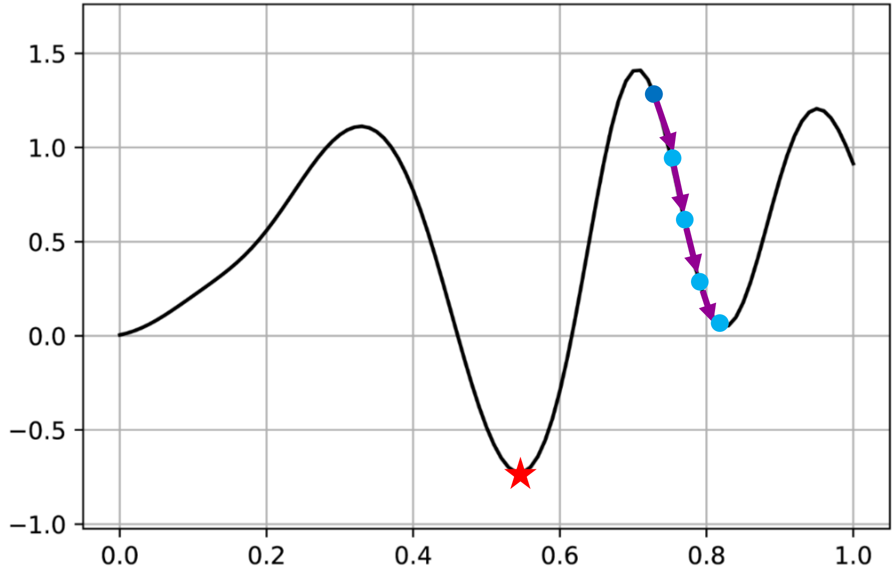
- There is no available dataset to train models

- Applicable for online optimization

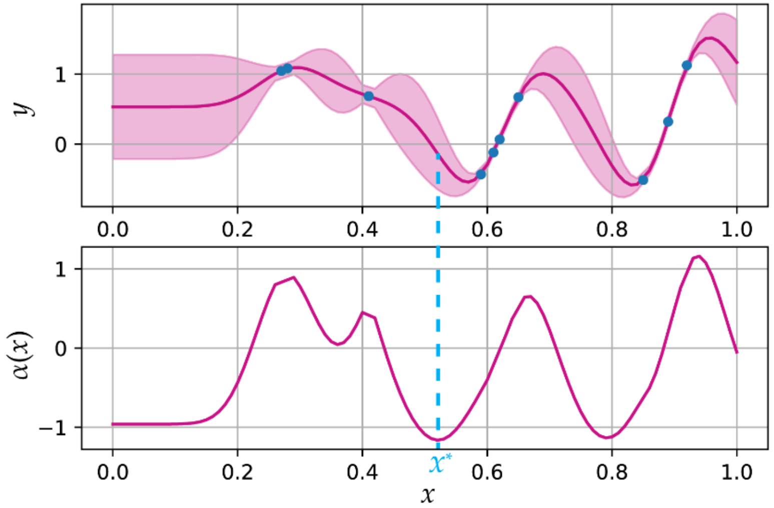
Gaussian Process Bayesian Optimization



Gradient methods



Bayesian optimization



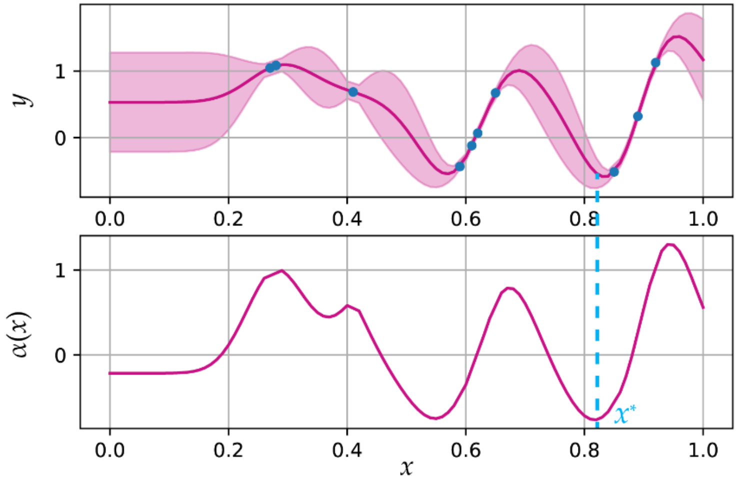
Gaussian Process Bayesian Optimization working principle

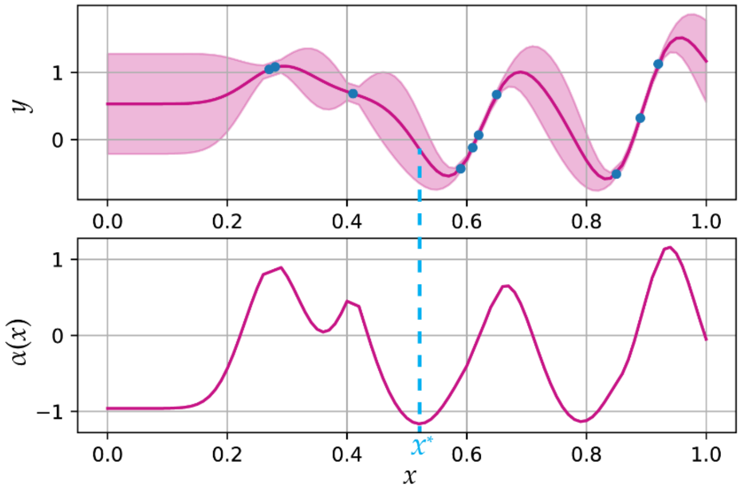
$$x^* = \underset{x}{\operatorname{argmin}}\, \boldsymbol{\alpha}(\boldsymbol{x}) = \boldsymbol{\mu}(\boldsymbol{x}) - \beta\boldsymbol{\sigma}(\boldsymbol{x})$$

1. Model to predict the objective function
2. Acquisition function that suggests the new observation to incorporate into the model

μ

σ



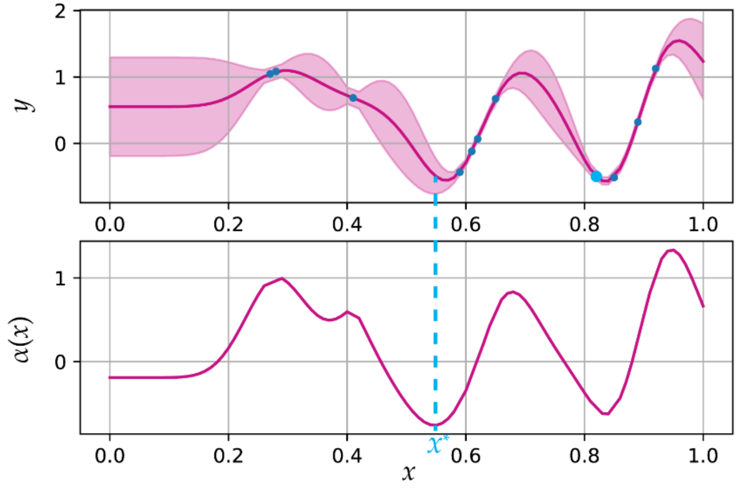


$\beta \ll 1$

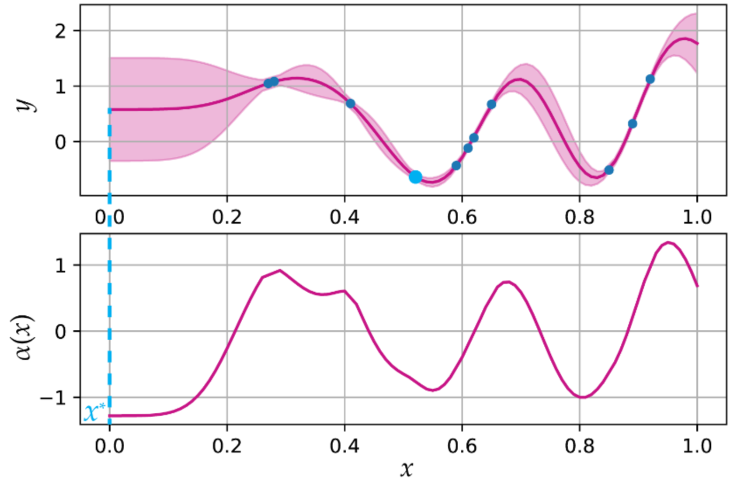
Exploitation

$\beta \gg 1$

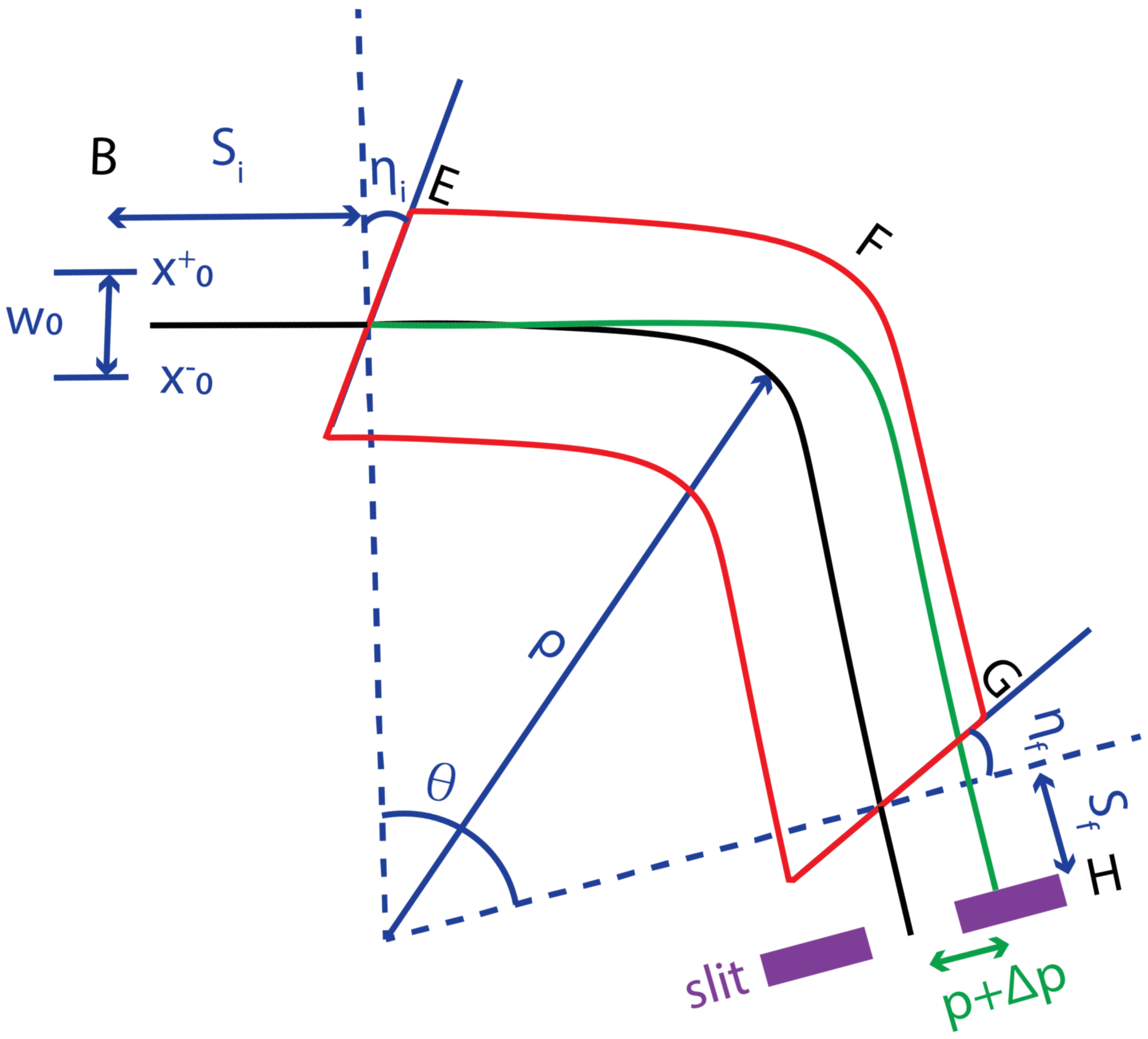
Exploration



- Predictions are not expensive to evaluate
- The model contains insights into the uncertainty



Bending magnet [1]



$$S_i = S_f = S \qquad \eta_i = \eta_f = \eta$$

$$D = \rho(1 - \cos\theta) + S[\tan\eta\,(1 - \cos\theta) + \sin\theta]$$

$$S = \rho \frac{\cos\theta + \sin\theta\tan\eta}{\sin\theta\,(1 - (\tan\eta)^2) - 2\tan\eta\cos\theta}$$

Relativistic approach ⟶ $2\frac{\Delta p}{p} = \frac{\Delta m}{m}$

$\frac{m}{\Delta m}$ = Mass Resolving Power (MRP)

$$\boxed{\frac{m}{\Delta m} = \frac{D}{w_0}}$$

D ≈const, $w_0 \downarrow \Rightarrow MRP \uparrow$

[1] Nature.Livingood, J. J. (1969). OPTICS OF DIPOLE MAGNETS.

Objective function formulation

$$\gamma u^2 + 2\alpha u u' + \beta u'^2 = \varepsilon$$

Uprigth beam $\Rightarrow \alpha_{xB} = 0°$

$\phi_{xB} = 90°$

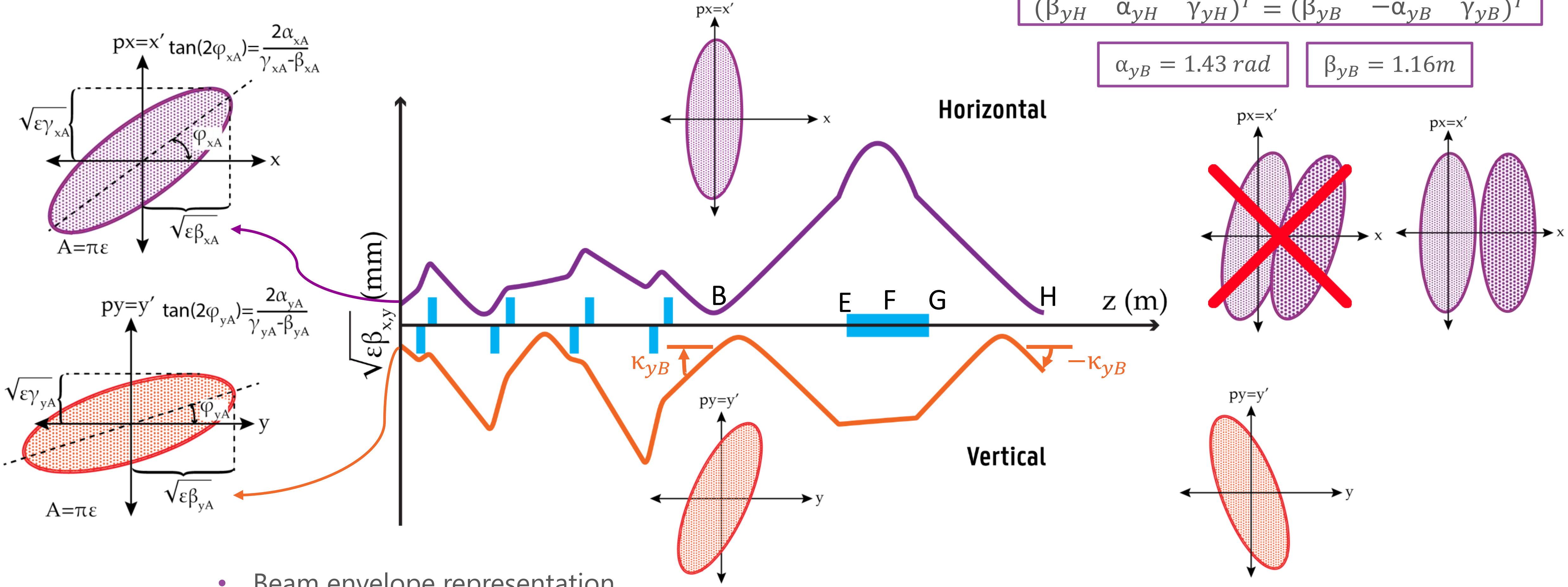
MRP= $\frac{D}{w_0}$

$\beta_{xB} \leq 0{,}196\ m$

$(\beta_{yH} \quad \alpha_{yH} \quad \gamma_{yH})^T = (\beta_{yB} \quad -\alpha_{yB} \quad \gamma_{yB})^T$

$\alpha_{yB} = 1.43\ rad$

$\beta_{yB} = 1.16 m$

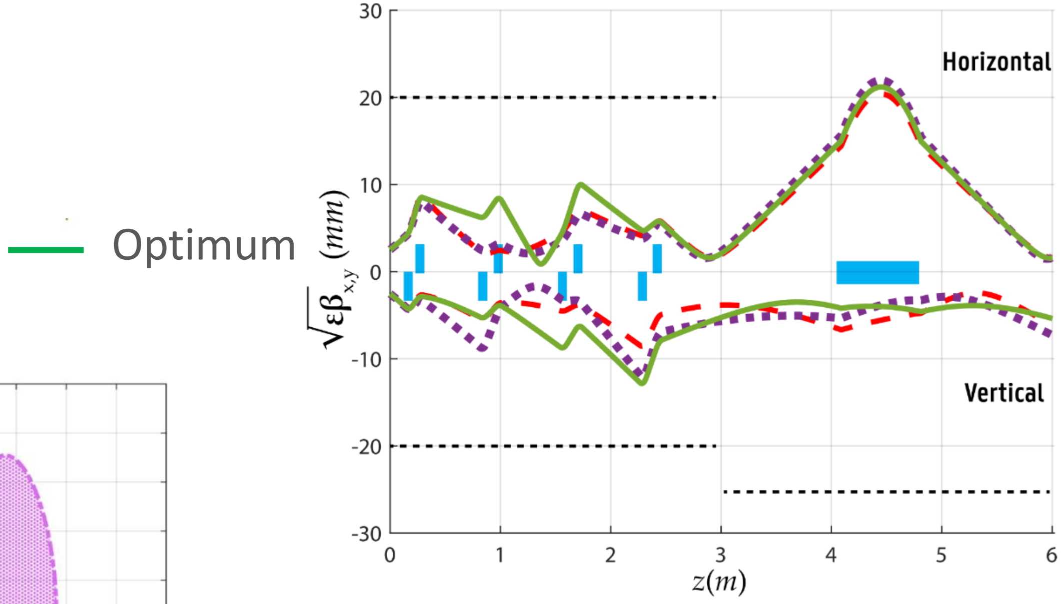


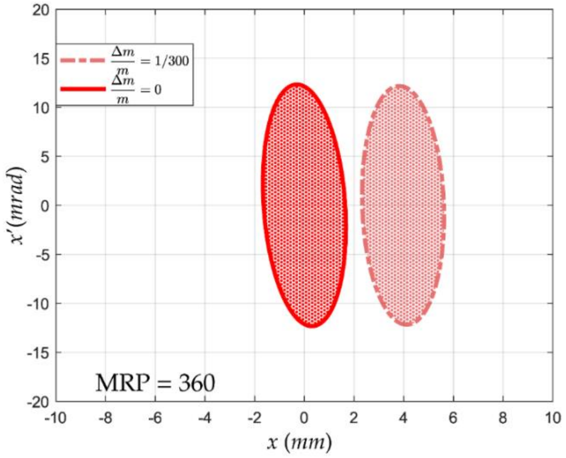
- Beam envelope representation

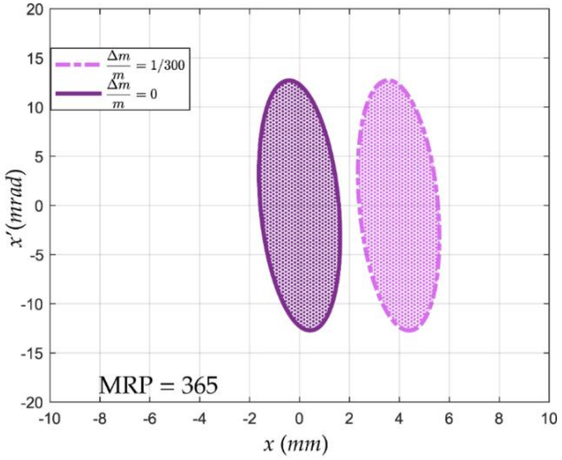
$$f(V_1, V_2, \cdots, V_8) = \omega_1(\alpha_{xB})^2 + \omega_2(0.15 - \beta_{xB})^2 + \omega_3\left(1.43 - \alpha_{yB}\right)^2 + \omega_4\left(1.16 - \beta_{yB}\right)^2$$

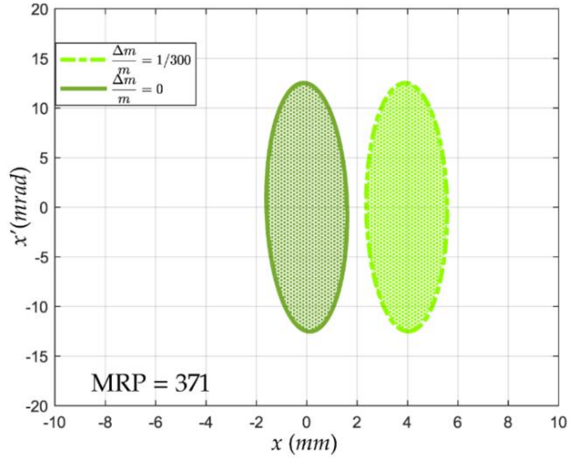
Results

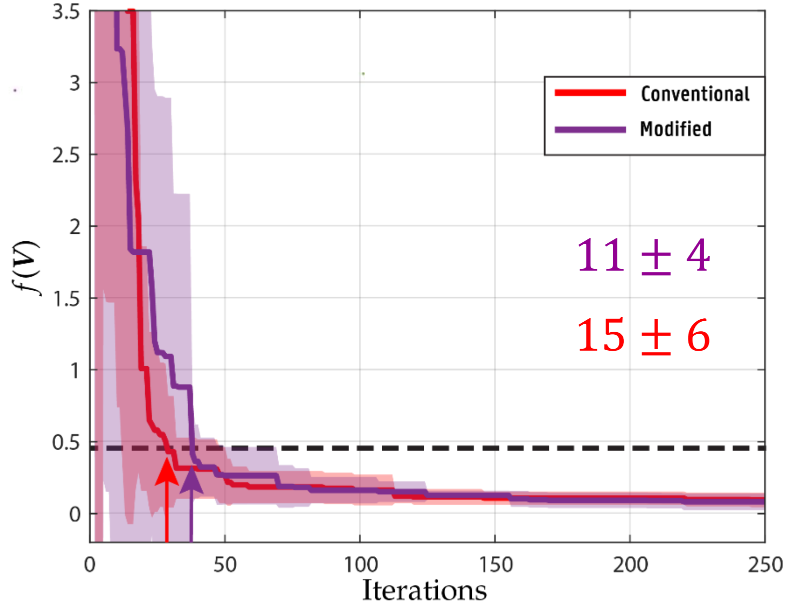
- 5 Gaussian Process for modelling f, g_1, g_2, g_3, g_4
- Initial samples consist of 10 random voltage combinations



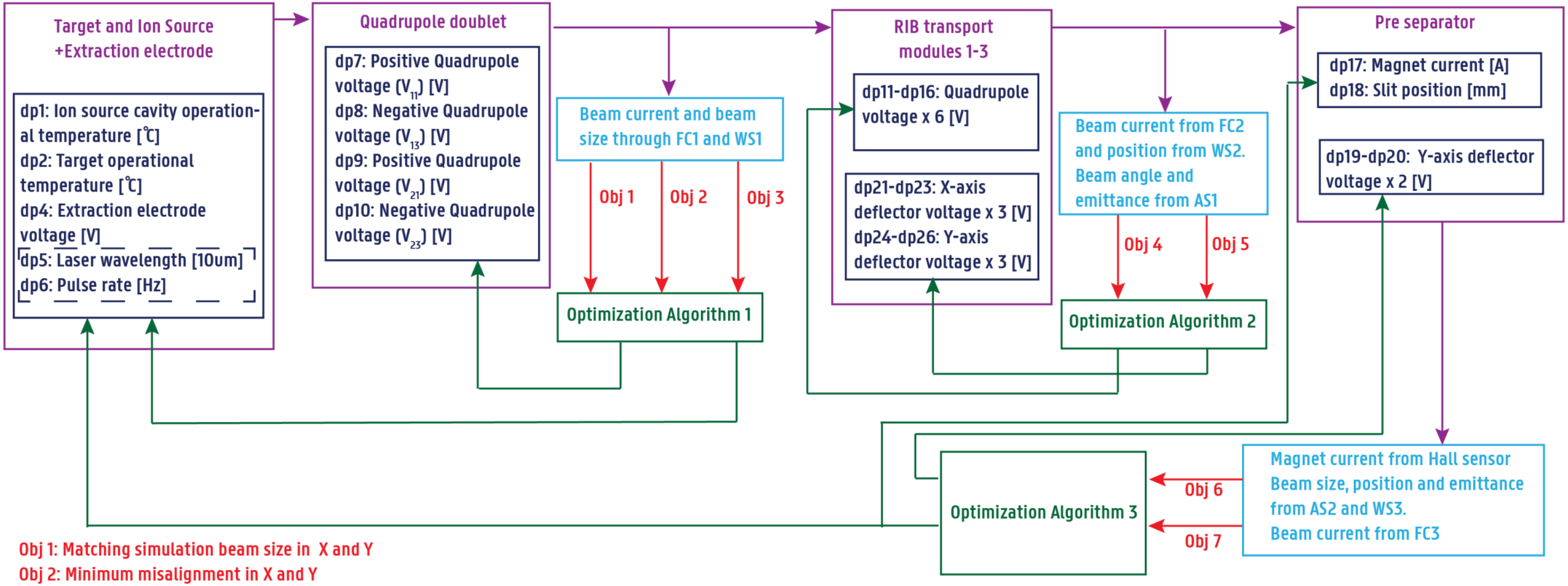








Future work



Obj 1: Matching simulation beam size in X and Y

Obj 2: Minimum misalignment in X and Y

Obj 3: Beam quality maximization (emittance minimization)

Obj 4: Matching pre separator acceptance $\alpha_{xB}=0$, $\beta_{xB}=\beta_{des}$, $\alpha_{yH}=-\alpha_{yB}$, $\beta_{yH}=\beta_{yB}$

Obj 5: Minimum misalignment in X and Y

Obj 6: Minimum misalignment in Y

Obj 7: Weighting of maximum isotope yield and beam purity

FC: Farady Cup
WS: Wire Scanner
AS: Allison Scanner

Design parameters
Objective functions
ISOL subsystems
Beam diagnostic elements
Extra parameters for laser ionization
Transport beam line system

- What parameters often change during the operation of an ISOL system?
- What are those parameters that require constant retuning during operation?

Thank you for your attention

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