MTE Splitting Automated Parameter Drift Correction

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Introduction *(Multi-Turn Extraction)*

- How to do **Multi-Turn Extraction** (MTE) at **PS**
  - Create **four stable islands** in horizontal phase space using sextupolar and octupolar magnetic fields
  - The **horizontal tune** is brought close to the **fourth-order resonance**
  - This **splits the beam** into **five beamlets** in **horizontal phase space**
  - Beamlets are **extracted** over **five** consecutive **turns**
- They are **sent** to **SPS** to provide **continuous spills** for the **North Area** experiments
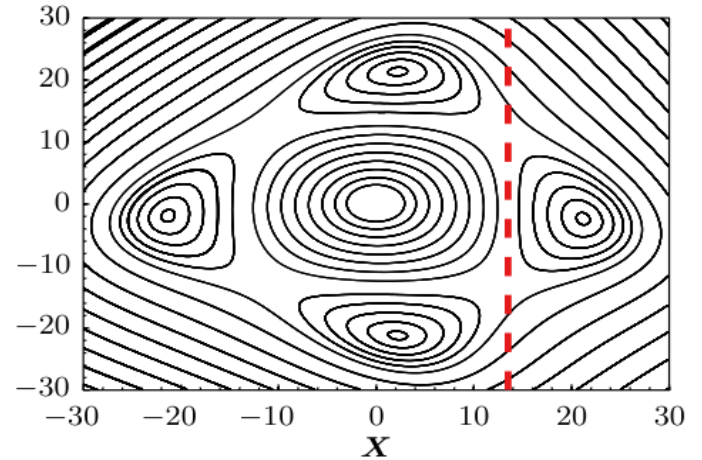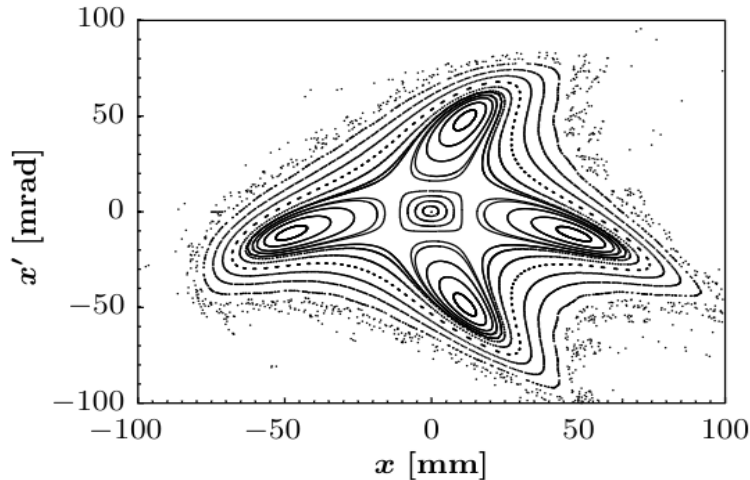
Problem Statement

$$\eta_{MTE} = \frac{\langle I_{Island} \rangle}{I_{Total}}, \qquad (1)$$

where $\langle I_{Island} \rangle$ and I_{Total} stand for the average intensity in each island and the total beam intensity, respectively.

- Splitting quality (*Splitting efficiency η_{MTE}*) is **measured** by the **uniformity of intensities** across the beamlets
- Machine parameters involved to adjust splitting:
  - *Horizontal tune*
  - *Transverse feedback gain*
  - *Transverse feedback excitation frequency*

- **Objective:** Due to **frequent shifts** in PS conditions (mainly **supercycle changes**):
  - Need frequent parameter readjustments
 - Manual optimization can be challenging and time-consuming ⟹ **Automated continuous control**
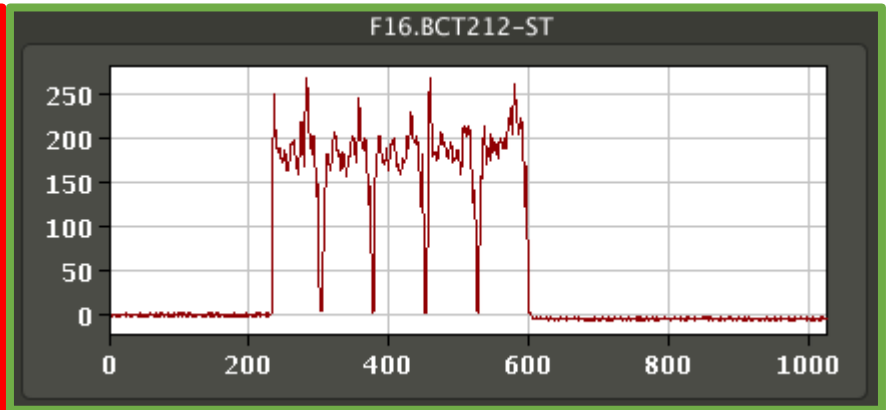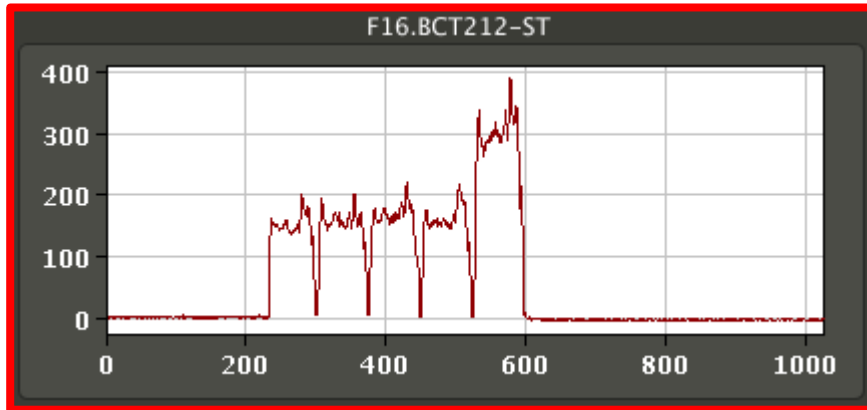
Analysis

- Motivation:
    - **Sample efficiency**
    - Understanding the **dynamics** of the **problem** → potentially **reduce dimensionality**
- Extensive analysis of the **parameter dependencies**
    - **Gaussian Process** model was used to visualize the **response** (*Splitting efficiency*)
    - For fixed *Transverse feedback gain* level, we plot the interaction of the **other two parameters**
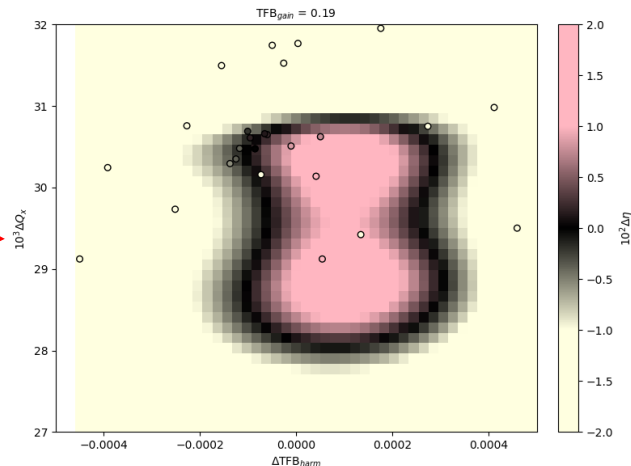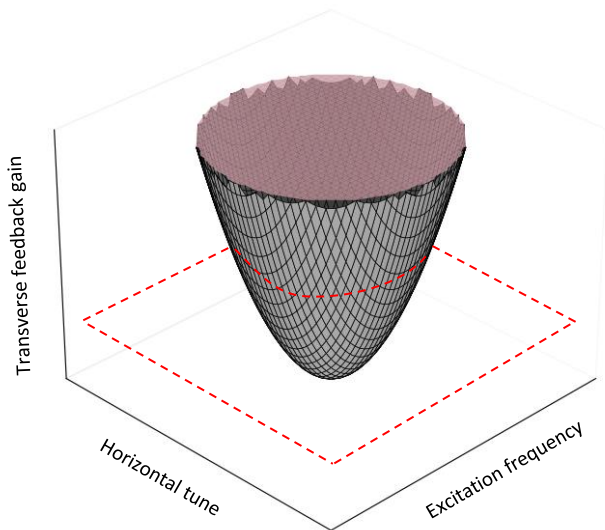
Analysis

- Motivation:
  - **Sample efficiency**
  - Understanding the **dynamics** of the **problem** → potentially **reduce dimensionality**

- **Simulation** was conducted as well to **confirm the results qualitatively** (by BE-ABP)


Simulation

Experiment
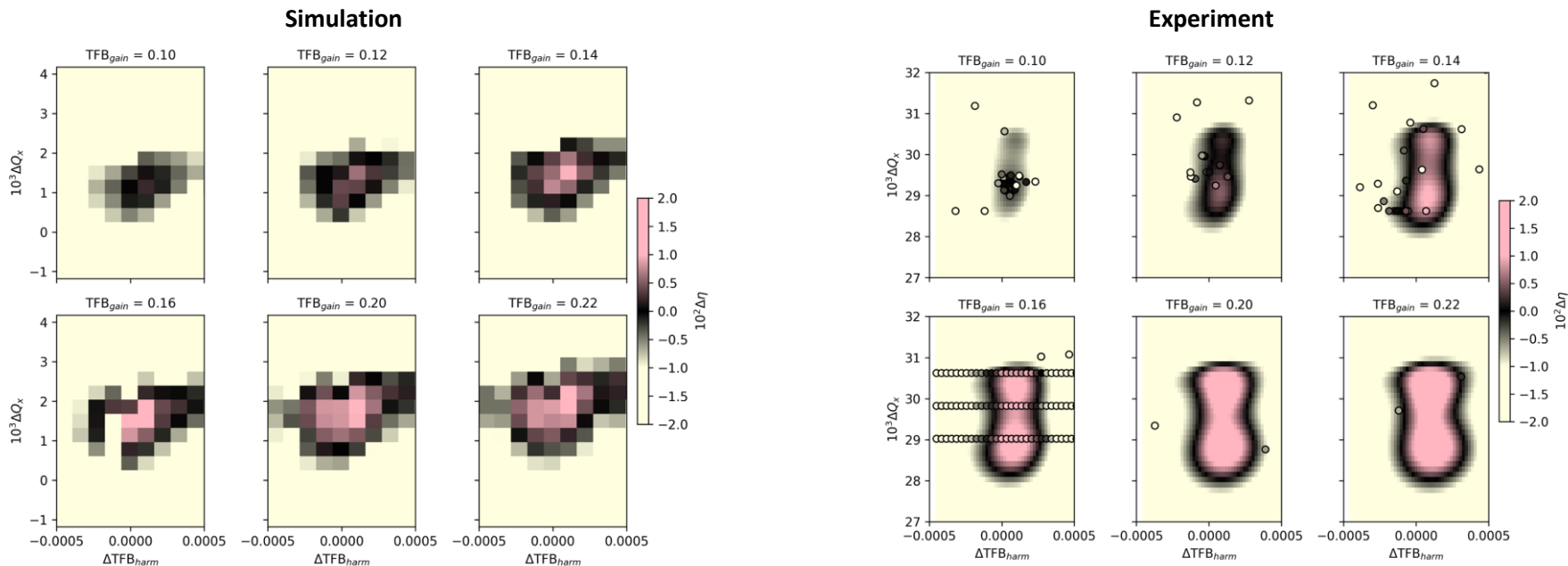
Approach

- Tried in the past: **Hybrid controller**
  - Continuous extremum seeking (ES) interleaved with numerical optimizer (BOBYQA) when far off target

- Current approach: **Bayesian optimisation**
  - **Target** variable: _Splitting efficiency_
  - **Feature** variables: _Horizontal tune_, _Excitation frequency_
  - _Transverse feedback gain_ is fixed (currently **intensity** dependent)
  - **Preceding 2 played cycles** taken into account
  - **Continuous monitoring** of splitting efficiency, **only optimising** if **needed**
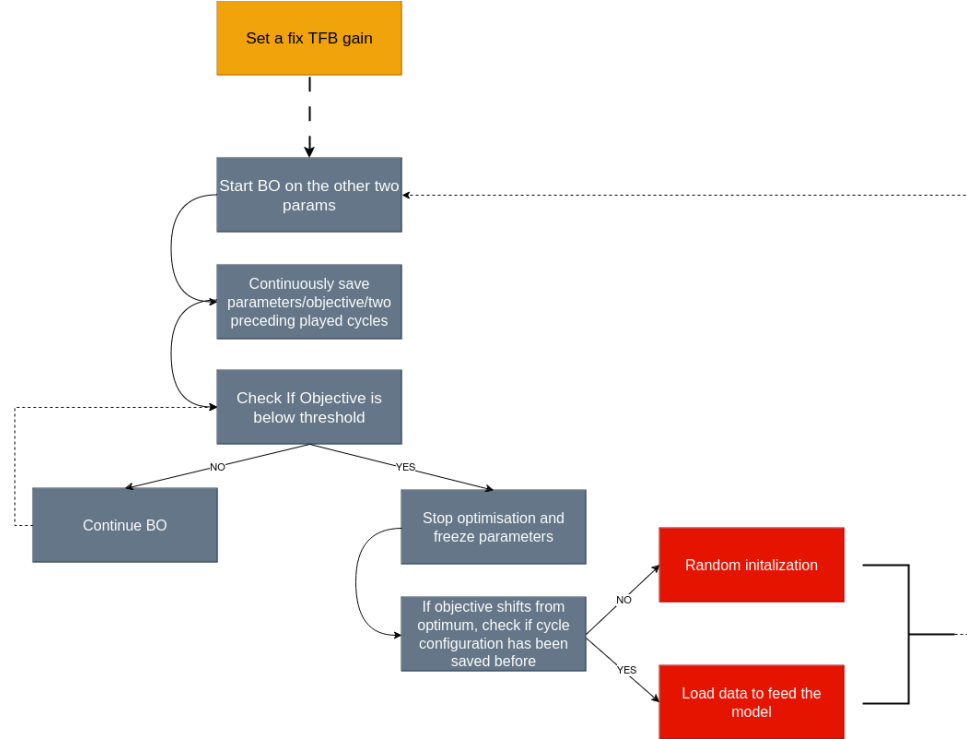
Results
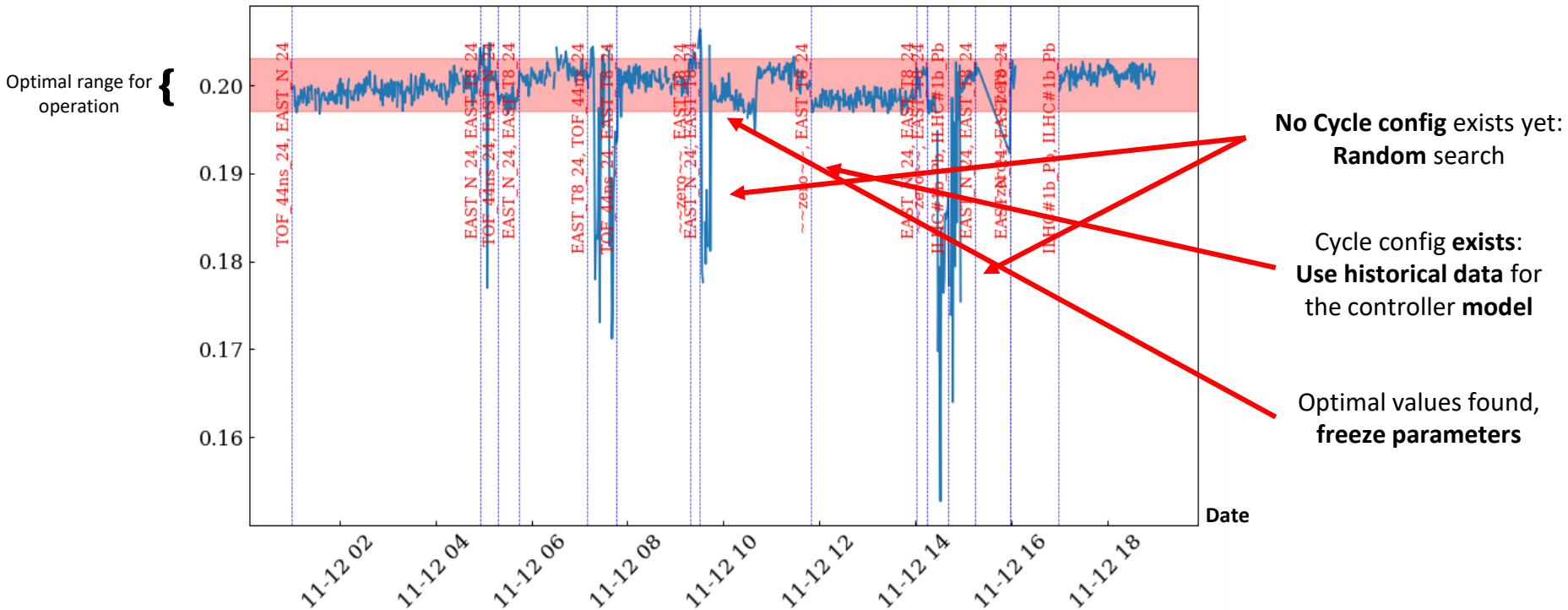
Plans for the year

- **Fix & Improve**:
  - Measure _Transverse feedback gain_ **dependence** on **intensity** (_potentially other parameters as well_)
  - **Preceding** Antiproton decelerator (**AD**) cycle is currently **ignored**
  - **Cycle instances** at different BP index would require **different optima/trims** (potential options under discussion)
  - Verify that **exploration** during random phase is **not problematic**
  - **Documentation**

- Continue testing from March (~week 12) with short-parallel MDs
- Aim for full-feature prototype by end of July '25

- More **multi-day parallel testing:**
  - Different **conditions** such as **low/high intensity** and **rare supercycles**
  - **Quantitative comparison** to current "**state-of-art**"