LHC studies:
simulations and data

L. Coyle[□], T. Pieloni[□], B. Salvachua*, M. Schenk[□], J. Wenninger*

*CERN & [□]EPFL, Switzerland

Overview

- **Introduction:** brief summary of Loïc's work
  - Project overview
  - Main results and outlook

- **Loïc's upcoming PhD project**

- **LHC surrogate model from simulations**
  - Idea
  - Discussed topics

- **Other LHC machine learning use-cases**

Introduction: brief summary of Loïc's work
Project overview

Title: LHC beam intensity lifetime optimization

Objective: first time use of machine learning techniques to
- characterise unexplained beam losses along LHC cycle
- determine which parameters have strongest impact on losses
- help optimise and suggest operational configurations
  - **maximise integrated luminosity reach**

Strategy: create model of LHC beam lifetime
- Online optimisation not feasible in LHC at this stage
- Simulations are compute-intensive
- Missing simulation code that combines incoherent and coherent effects
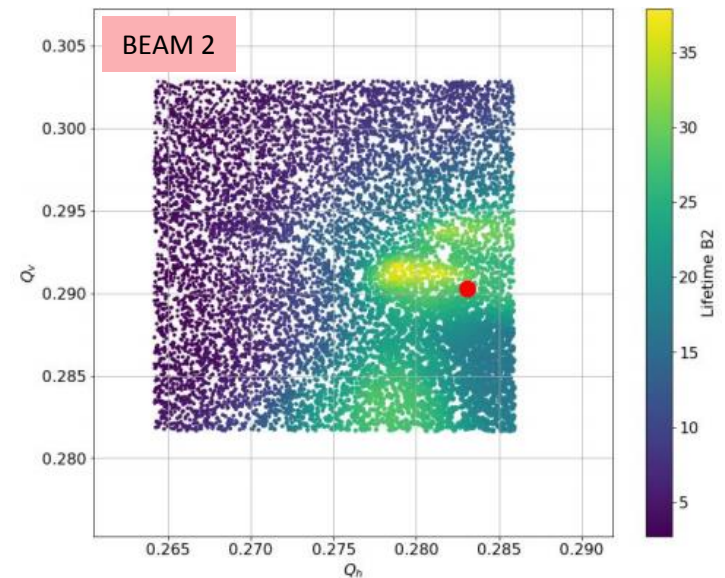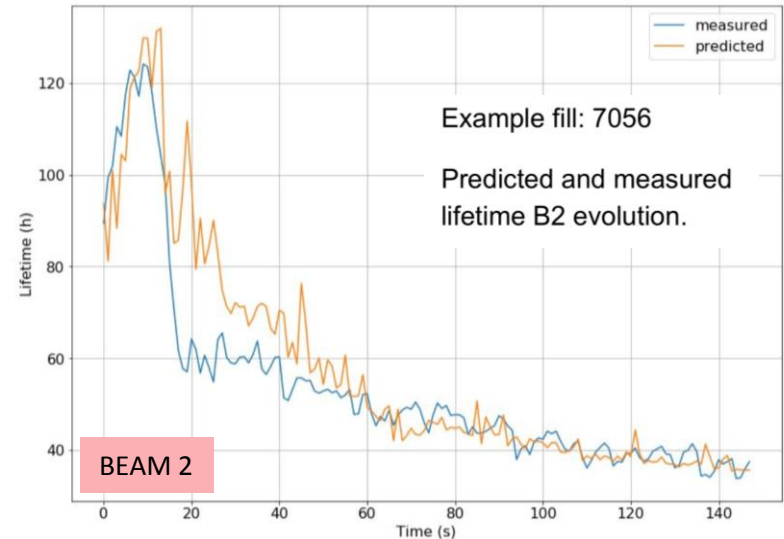 - **develop data-driven supervised learning model**

Some challenges
- Setting up infrastructure
- Beam lifetime depends on many parameters
- Large amounts of *uncleaned* data

Introduction: brief summary of Loïc's work
Main results and outlook

Preliminary results

- **Evaluated various machine learning models** best performance with Gradient Boosted Decision Trees

- **Promising study**
  - Model predicts optimum working point *(red)* in agreement with MD data
  - Trends in beam lifetime vs. time predicted correctly

Example fill: 7056

Predicted and measured lifetime B2 evolution.

BEAM 2

BEAM 2

L. Coyle et al.

21.06.2019

Introduction: brief summary of Loïc's work
Main results and outlook

Preliminary results

- **Evaluated various machine learning models** best performance with Gradient Boosted Decision Trees

- **Promising study**
  - Model predicts optimum working point *(red)* in agreement with MD data
  - Trends in beam lifetime vs. time predicted correctly

- **Beams 1 and 2 behave differently**

- **Clean, high-quality data is important**
  - Fake correlations between the two beams
  - Differences between available measurement devices
  - Acquired clean data set during dedicated MD

- **Collective effects can be relevant:** impedance, electron-cloud, etc.

L. Coyle et al.
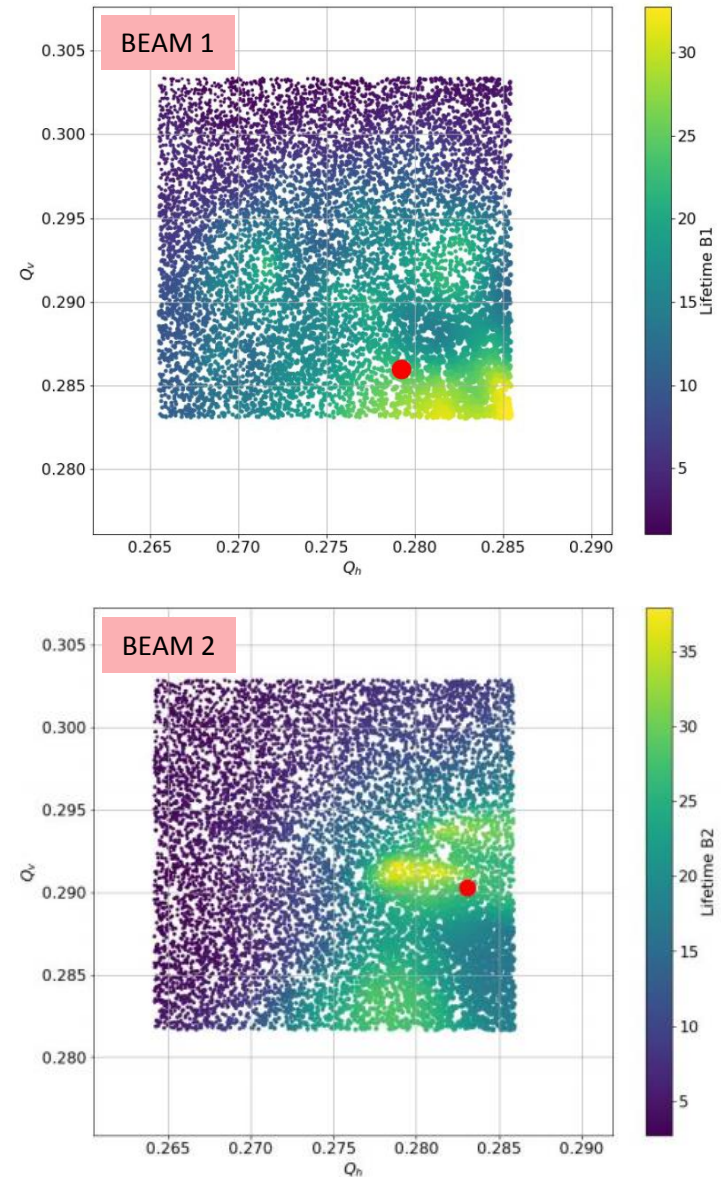
# Introduction: brief summary of Loïc's work
Main results and outlook

Outlook

- **Multi-objective optimisation:** beam lifetime *and* emittance for example
- **Improve diagnostics and preprocessing of data** *(e.g. tune, chromaticity readings)*
- **Extract more information at bunch-level** rather than at beam-level
- **Define an online use** to support operators with operational choices
- **Back up with numerical simulations:**

    => potentially need to combine single-particle tracking with collective effects
       codes: recent proof-of-principle *PySixtrackLib + PyHEADTAIL*

Loïc's upcoming PhD project
With F. Blanc (EPFL), J. Wenninger (CERN)

- **LHC loss maps (LM) are measured continuously during operation** (1 Hz)

- **They provide information on**
  - Quality of beam cleaning by collimators
  - Plane of the losses
  - Population of abort gap
  - Luminosity at Interaction Points (IPs)

- **Large number** of monitors (~3500), **high data rates**, and **complex loss patterns**
  ⇨ analysis so far with 'classical' techniques, requires sub-selection of monitors …

- **PhD objective:** use machine learning techniques for on- and offline diagnostics of the LHC beams and collimation system
  - Online diagnostics of injection losses, stability of injection configuration, uncaptured beam losses during energy ramp, LM 'sanity checks' along entire LHC cycle
  - Surrogate models of the LMs and beam lifetimes to predict LMs and detect anomalies
  - Develop online, 'first line' collimation LM validation
  - Surrogate model of the LHC losses based on particle simulations
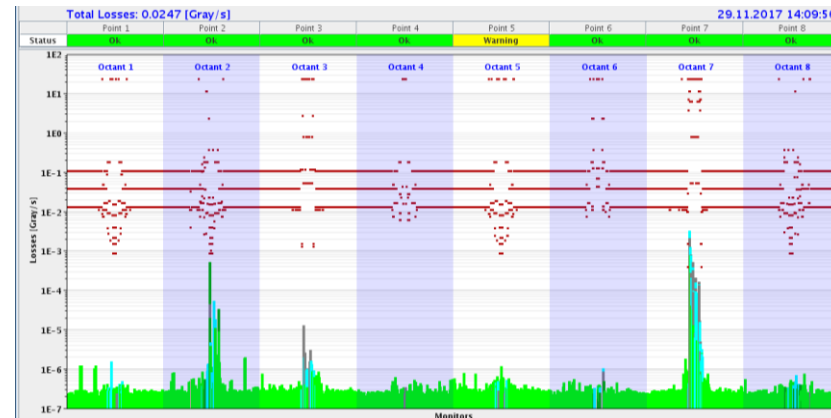
LHC surrogate model
Overview

Objectives

- Build online surrogate model for LHC machine configurations based on Sixtrack[*] simulations
- Include dependencies on main machine and beam parameters
- Model that grows in complexity over time *(more parameters, larger range)*

Motivation

- Working point optimisation in terms of beam lifetime / losses
- Loss map model for prediction / validation
- Simulation data for comparison with machine observables (= Loïc's work)
- Preparation in view of LHC Run 3

Strategy

1. **Produce high-fidelity dataset:** continuously and automatically submit and manage Sixtrack parameter scans on BOINC[⬚] if capacity available
2. **Supervised machine learning:** train surrogate model on that data

[*] *Sixtrack is a single particle 6D symplectic tracking code optimised for long term tracking*
[⬚] *BOINC is an open-source software platform for computing using volunteered resources*

LHC surrogate model
Discussed questions

What should model be able to predict: LHC observables

- **Beam lifetime:** translated from dynamic aperture studies using scaling laws
  Ongoing work by M. Giovannozzi, M. Titze, F. Van der Veken
- **Loss distribution** (= maps) around machine
  - Use existing mechanical aperture model
  - Potentially: *FLUKA* simulations to compare to LHC beam loss monitors
- **Other**

Job and study management mechanisms?

- **Results stored in one database:** keeps track of studied configurations
  Ongoing work by A. Mereghetti, X. Lu
- **Duplicate studies not launched**, instead results returned directly from DB
- From existing results decide next parameter scan to **improve surrogate model efficiently**

Timeline / actions

- BOINC machinery should be **ready by ~August 2019**
- **Use existing Sixtrack studies to gain experience in modeling requirements,** e.g. parameter resolution, what parameters are relevant, etc., starting with beam lifetime first
  - *=> Involvement of SDSC:*
    We will provide scripts and full data set (details will follow next week)

Other LHC machine learning use-cases

CERN Beams department held [Machine Learning and Data Analytics Forum](#) to collect potential use-cases, share knowledge, establish collaborations, etc.

Selection: beam instrumentation and diagnostics

- Collective instabilities: "ObsBox" data (= head-tail monitor)
  - Instrument produces huge amounts of data
  - Trigger based on machine learning to reduce false positives
  - Analyse and classify instabilities automatically rather than manually
  - First preliminary study done by Loïc shows promising results
- Identify tunes in noisy spectra
- Detect outliers for various instruments: beam loss monitors, beam position monitors (*see work done by E. Fol*), wire-scanners, …

> **Some of these applications will go hand in hand with, or even be required for the beam lifetime optimisation project**