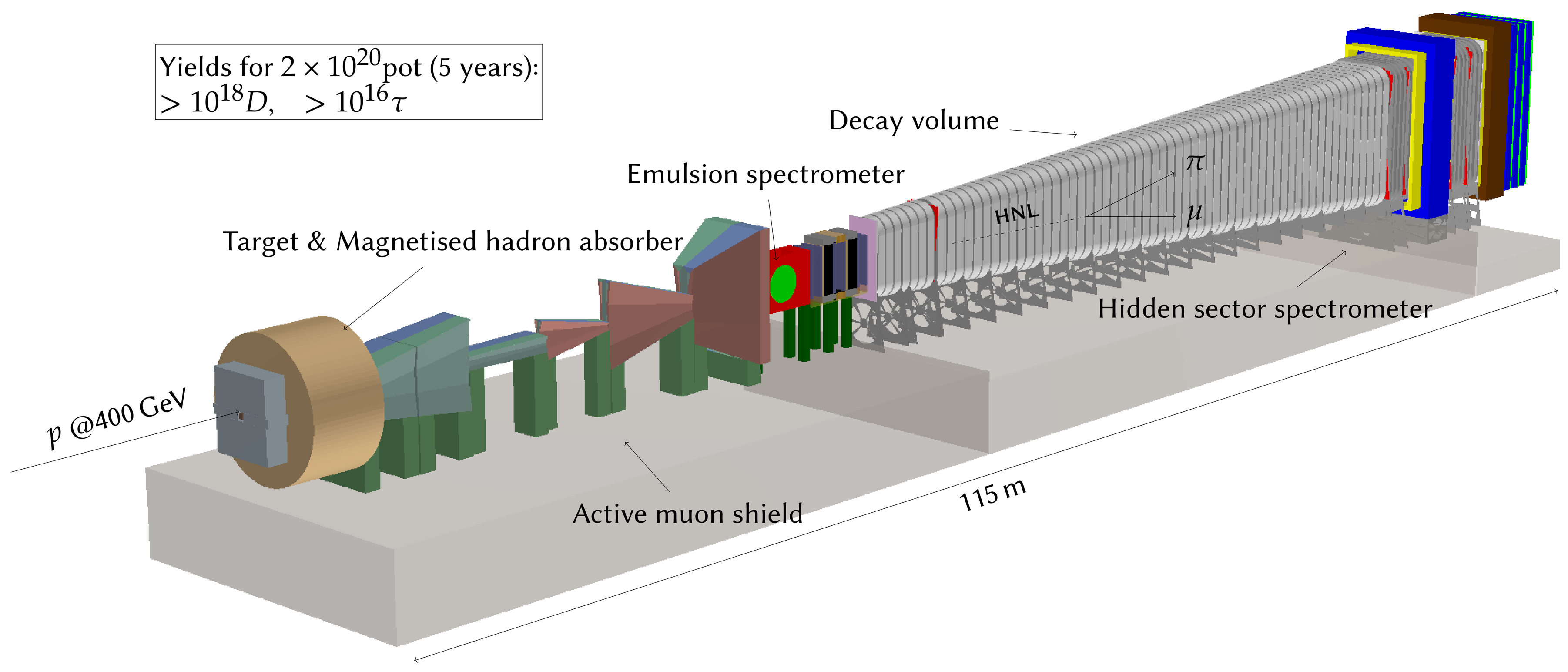
Bayesian optimisation of the SHiP muon shield

Oliver Lantwin
oliver.lantwin@cern.ch

Imperial College London

SHiP
Search for Hidden Particles

Overview of SHiP



Two signatures:

1. Via decay to visible particles in hidden sector spectrometer
2. Via scattering in nuclear emulsion

→ *Generic signatures predicted by many new physics models.*

Crucial to have zero background

Further information

- Technical Proposal: [CERN-SPSC-2015-016]
- Addendum to the Technical Proposal [CERN-SPSC-2015-040]
- Physics Proposal: [CERN-SPSC-2015-017]
- New papers on facility and optimisation this year!

Why optimise the muon shield?

- Active muon shield that has to reduce muon flux by at least 6 orders of magnitude
- kinematic range of muons up to $p \sim 350\,\text{GeV}$
- kinematic range of muons up to $p_T \sim 8\,\text{GeV}$

The muon shield is the critical component to optimise to maximise the experimental acceptance

Challenges of the optimisation

- ~50 free parameters (lengths), each varying from cm to m
- Doubly statistically limited
  - Not enough simulation
  - Not enough computing power to use entire simulation for optimisation
- Underlying physics inherently stochastic
  - Nearly identical configurations may have very different performance
  - With a different random seed entirely different muons pass the shield

⟶ *Evaluation of points very expensive, gradient information not available and can not be approximated*

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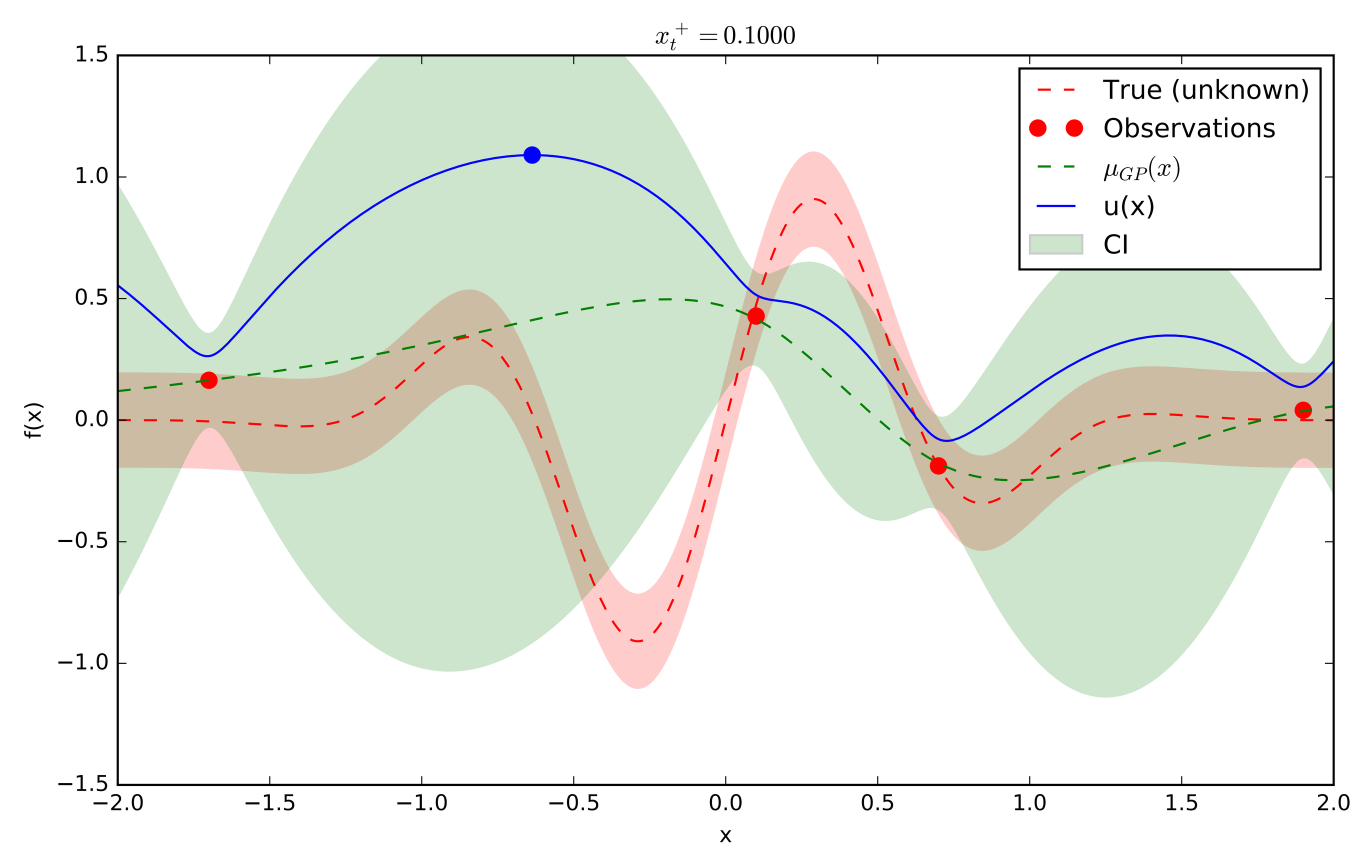
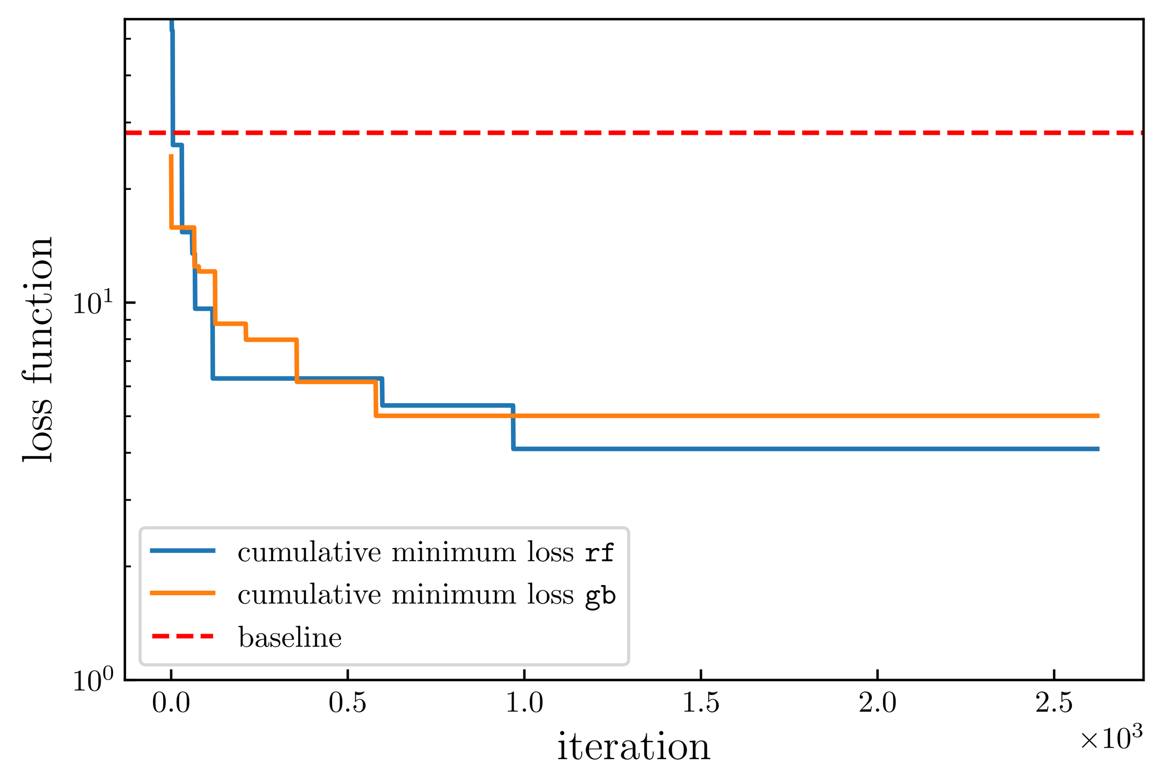


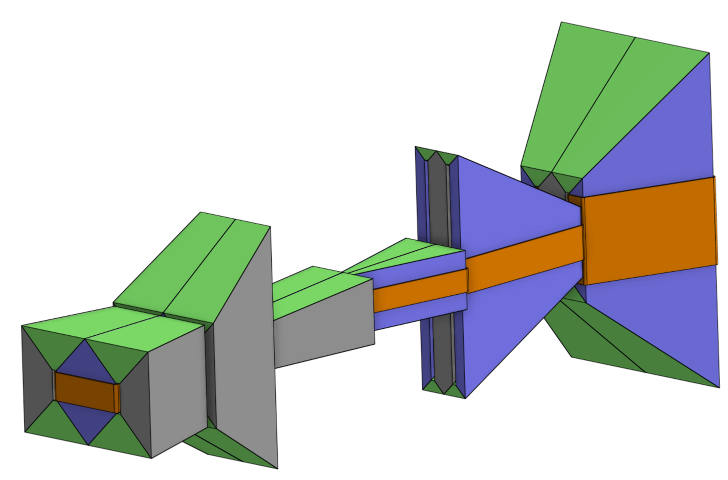
- Bayesian optimisation does not scale well to so many dimensions
- Computing model imposes additional constraints.
- 1600 cores available at Yandex ⟶ Make up to 100 guesses at once (with 16 nodes parallelising every function evaluation)
- Use `scikit-optimize` implementation of Bayesian optimisation
- Use Gaussian processes and random forests as surrogate models
- Reduce muon sample by factor ~40 to speed up evaluation and even out coverage of phase space:
  - Currently manual data-driven method
  - Evaluating importance sampling and other options

Convergence



- Two optimisers shown here: still evaluating different regression algorithms to determine which performs best
- Performance here is on the reduced muon sample: perform follow-up studies on the full dataset to confirm performance

Results



- Significant reduction in weight (⟶cost)
- Same performance with significantly reduced magnetic field

Configuration	length/m	weight/kt	reduced sample	full sample
baseline @1.8 T	34.60	1.72	27±5	70±15
new optimum @1.7 T	34.82	1.28	22±3	42±6

Future work

- Close collaboration with engineers at misis to progress to a detailed engineering design using grain-oriented steel
- Fully automate process, add additional constraints to loss function and improve the shield further!

Prototyping

Construct five different prototypes to test technologies in test beams at cern:

- Different joints for grain oriented steel
- Assembly of magnet elements

LaTeX TikZposter