Towards ECAL optimisation

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On behalf of HSE/Yandex team

Upgrade Ib/II calorimeter meeting
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Outline

- Team
- Problem Statement
- Current Status
- Open Questions

Current Team

HSE: Denis Derkach, Alexey Boldyrev.
YSDA: Andrey Ustyuzhanin, Fedor Ratnikov, Andrey Shevelev, Leonid Matyushin.

Problem Statement and Method Choice

Problem: Find optimal configuration of the new calorimeter given physics and resources goal using a dataset obtained from DELPHES and confirmed by GEANT.

Comments from Computer Science side:
- The simulation of calorimeter is CPU intensive task, which gives constraints on the choice of methods.
- What's more, we do not expect to have an analytic form of the function that connects input observables to the output ones.

This all looks like a typical black-box optimisation problem.
It can be solved by the Bayesian optimisation with Gaussian processes.

Black-box optimisation

Goal: keep the number of calls of functions to be optimised as low as possible.

Two main ingredients

Surrogate model:

- approximates the true function;
- cheap to evaluate;
- in general, any regression can be chosen, with preference to that returning variance of prediction.

Acquisition function:

- estimates profit for optimisation;
- uses surrogate model.

Surrogate modelling with Gaussian process

Gaussian process regression is commonly used approach to the surrogate modeling.

The main idea: each point in the fitted space is sourced from Gaussian distribution. We thus are able to produce prediction for the next point.

Pros:

- predictions include variance.

Cons:

- computationally expensive ($O(n^3)$).

Let look how Gaussian Process approximates $f(x) = x \sin x$ with only 14 observations sampled randomly.

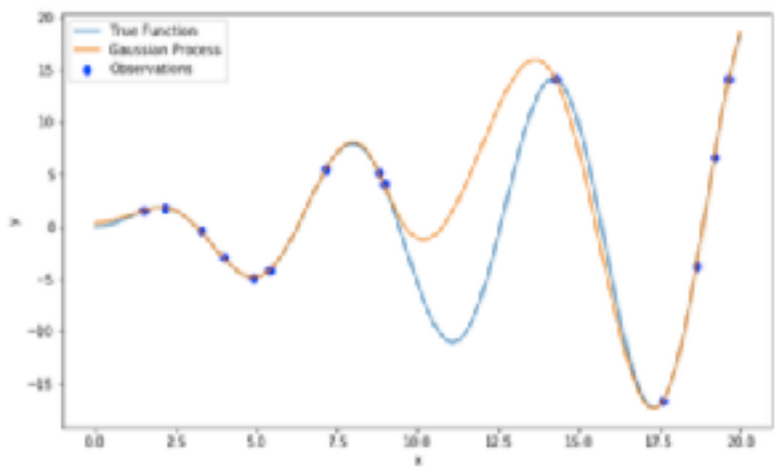
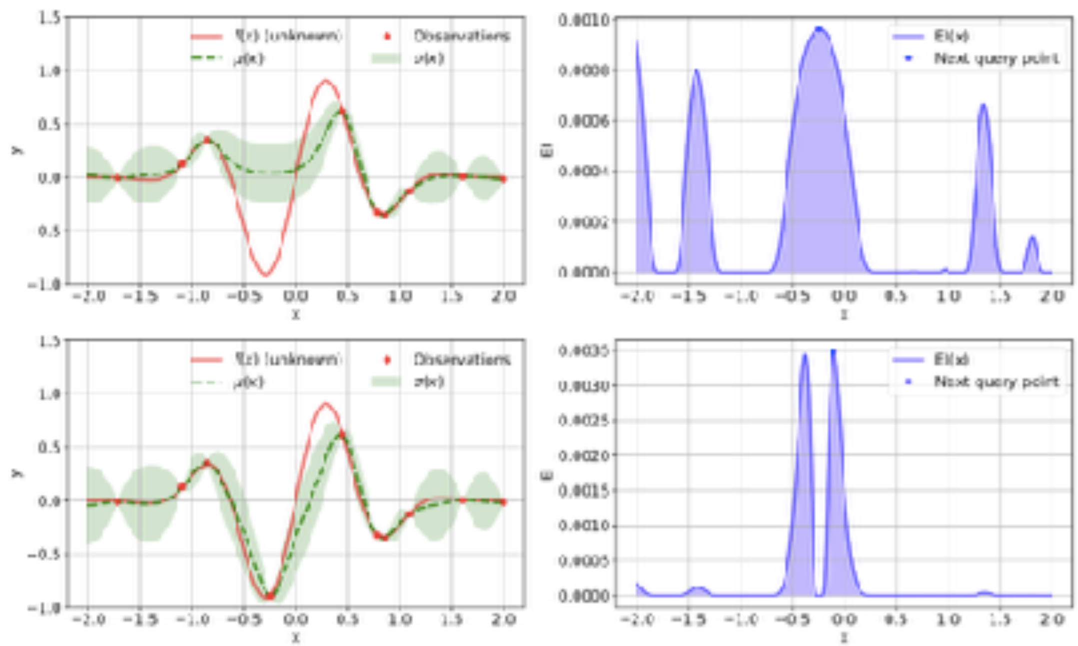


Figure: Gaussian Process example

More information in A. Filatov's talk at [StatWG meeting](#)

Acquisition function

In order to predict the next point, we define expected improvement acquisition function that depends on the position of the previous best value and the quality of our predictions of the next points



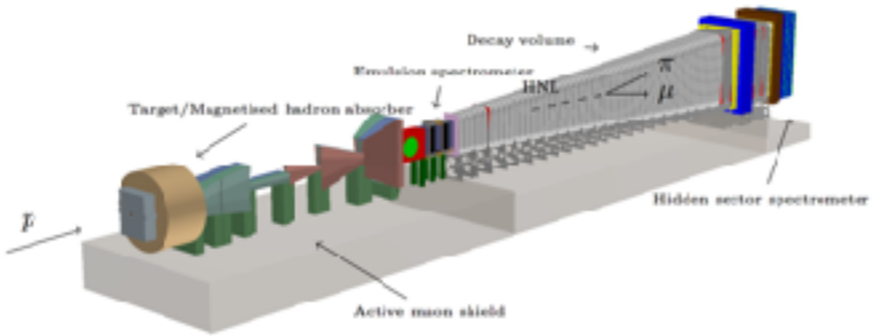
More information in A. Filatov's talk at [StatWG meeting]

Full optimisation cycle

1. Construct surrogate model over known history.
2. Find the maxima of EI.
3. Evaluate suggested point using DELPHES.
4. Add point to history.
5. Repeat.
6. Look at the best results, evaluate with GEANT.

The approach was already used in scientific applications SHiP muon shield optimisation, SHiP tracker optimisation; and in industry: A350XW wing shape optimisation.

SHiP muon shield



The shield consists of 8 magnets with each magnet parametrized by 7 values. It cost about 4000 $ per ton.
We need to find a cheap and efficient solution which minimize backgrounds.

We constructed a function which accounts for:

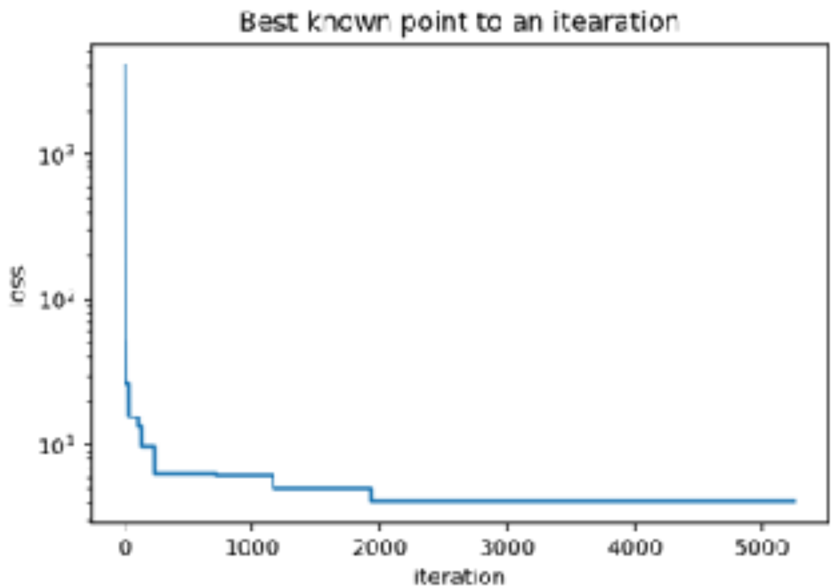
- shield physics performance Σ (closely related to the amount of background still passing through
- total shield mass W for the solution (W_{bl} is the mass of starting solution)

$$\mathbf{L(\Sigma, W) = (1 + \Sigma)(1 + \exp(10(W - W_{bl})/W_{bl}))}$$

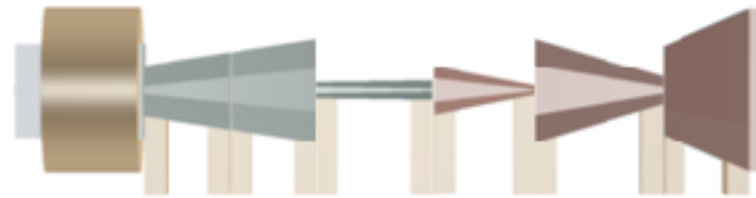
The aim was to find configuration that minimises **L**

Optimisation process

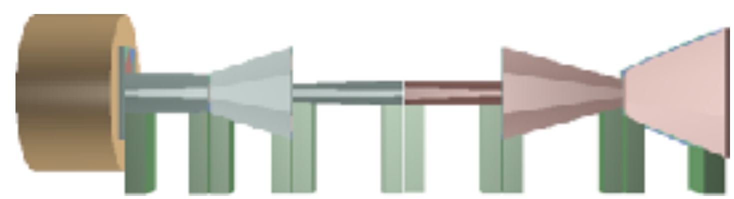
The optimisation started from the simple rectangular configuration, but quite fast we were able to propose a configuration that was 25% lighter than the baseline (with the same amount of background).



Baseline

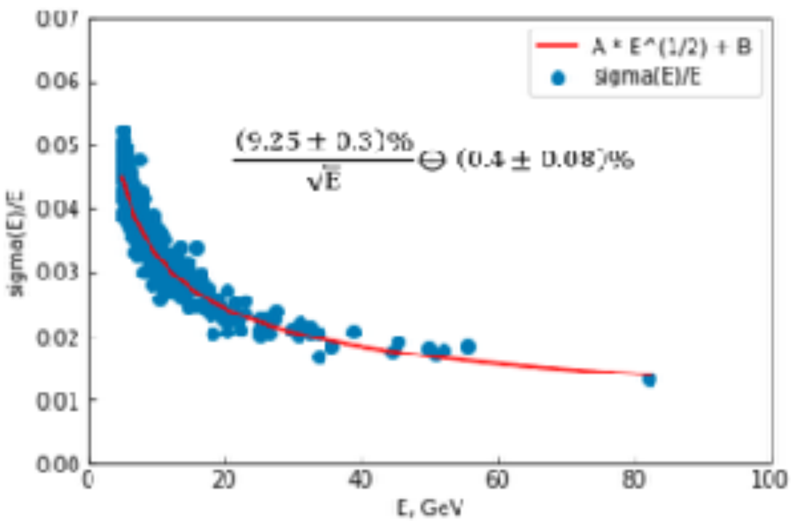


Our solution



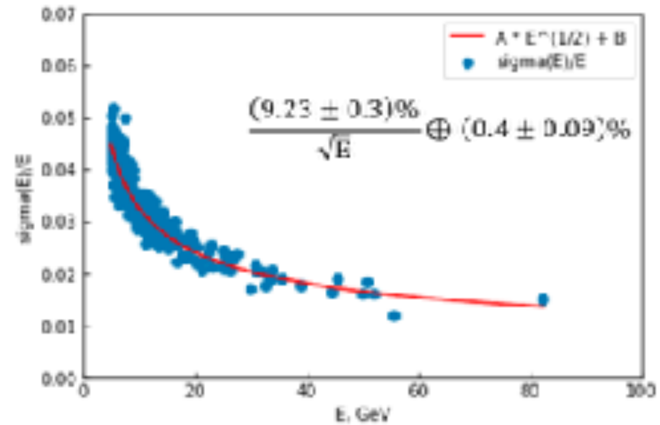
Current Status

With help from Adam, Benedetto and Markus we are able to produce the DELPHES simulation and varied the cell sizes for current ECAL configuration (2 August version of code).

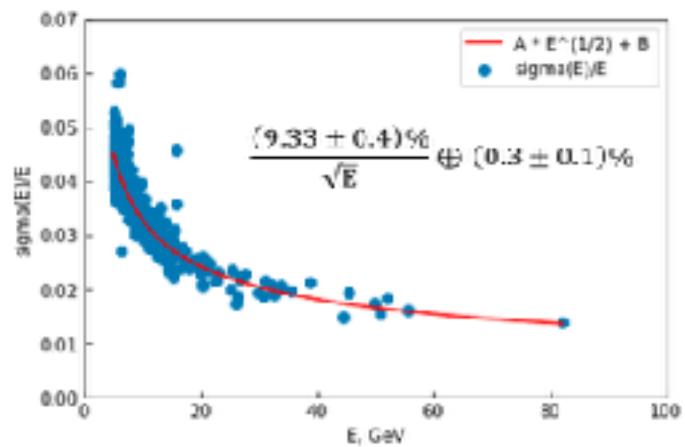


size 4x4, 6x6, 12x12 cm^2

Smaller cell size: 2.7x2.7, 4x4, 8x8 cm^2



Larger cell size: 8x8, 12x12, 24x24 cm^2



Open questions

- Which parameters we can vary?
  - Cell size?
  - Inner/outer region size?
  - Position?
- What target characteristics we should measure?
  - Resolution curve?
  - Amount of reconstructed photons/pions?
  - Control channels efficiencies?
- Do we have any additional constraints?
  - Material limitations?
  - Physics boundaries?

The more rules we define now, the better solution we obtain.