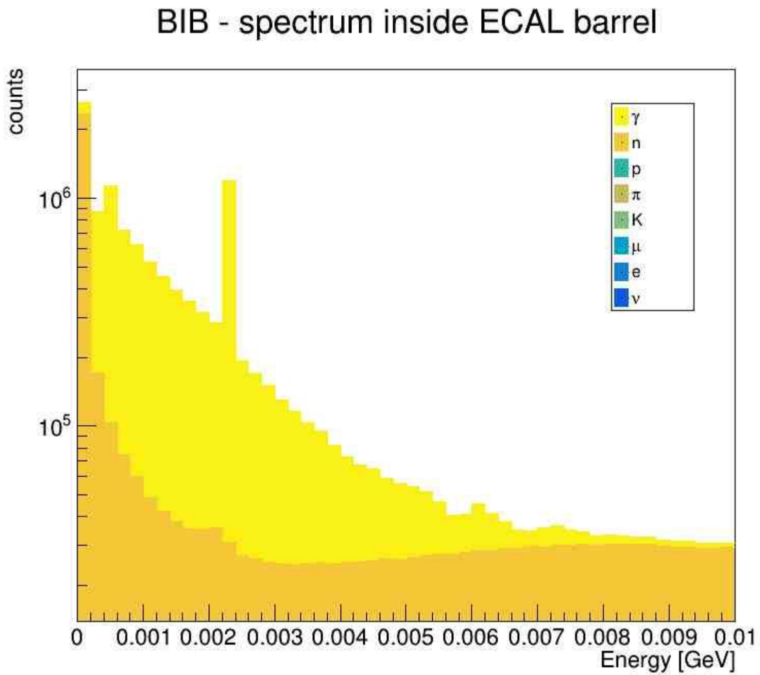
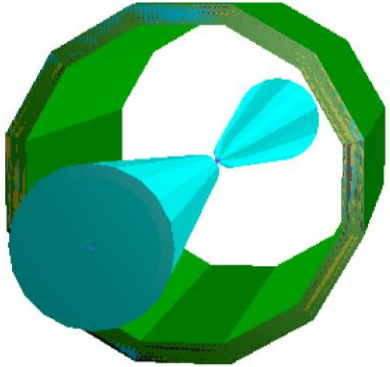
Towards design studies of a Muon Collider ECal

Federico Nardi, Tommaso Dorigo, Julien Donini

BIB - photons

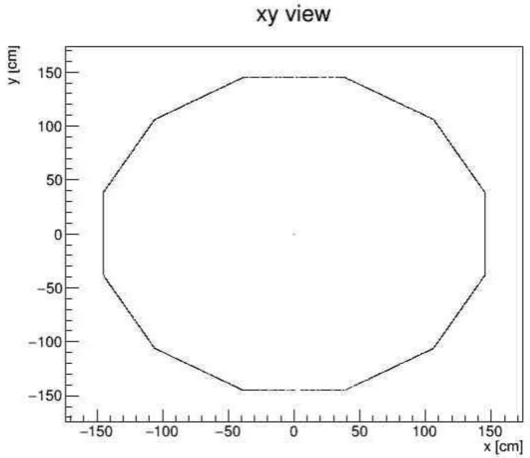
- Data from MARS15 simulation: interactions with nozzle
- Focus on photons component
- Using Crilin design (v1)
    - 1x1x4 granular cells (neglect electronics)

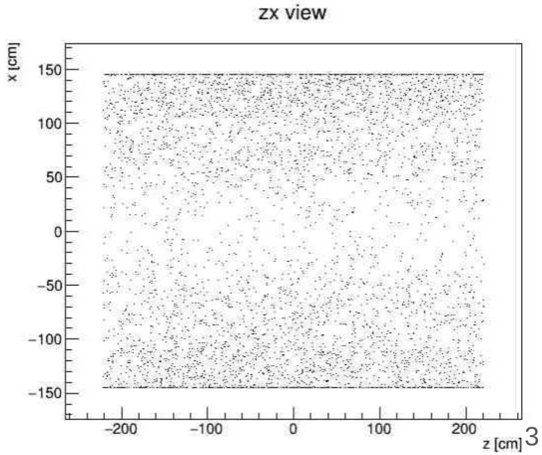


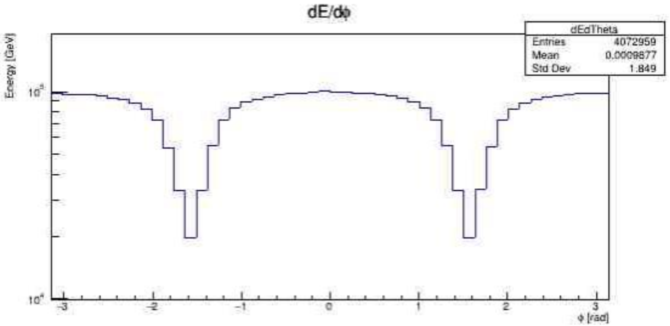


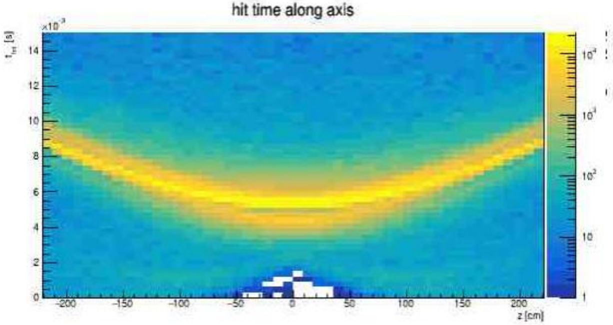
Photons II

- Hit distribution, propagated to **barrel** surface
- Symmetry in ϕ=0 plane, less hits on top and bottom edges
  - (Explanation still unsure)
  - Non-homogeneous -> optimization might give interesting results
- Well defined hit time distribution -> interesting for later studies (i.e. optimal placement of timing layers)



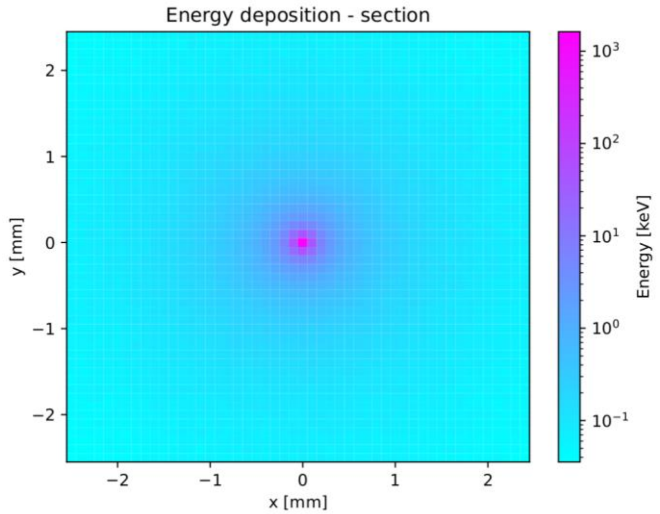


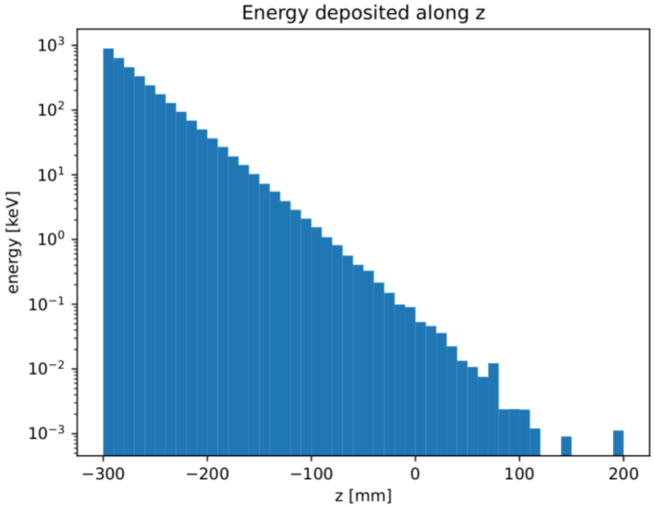




Energy deposition in PbF2

- Geant4 simulation of photons through a PbF2 block
- Particle energies selected using BIB spectrum
  - Successively scaled depending on position inside the detector
  - Can do it if flux is high enough
- Radial symmetry with respect to beam axis
  - Can obtain a model of energy deposition f(r|z) dependent only on z-coordinate and distance from z-axis



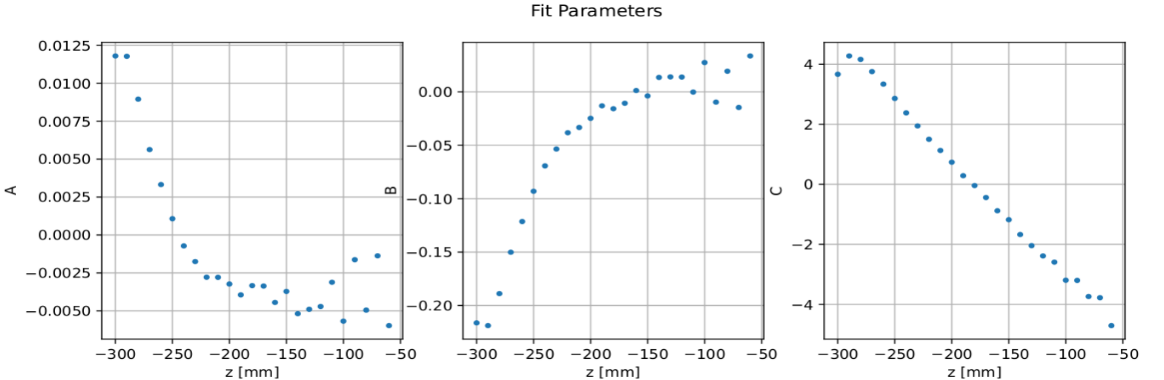


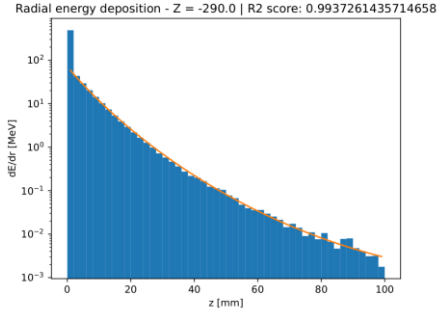
Parametrization of energy deposition

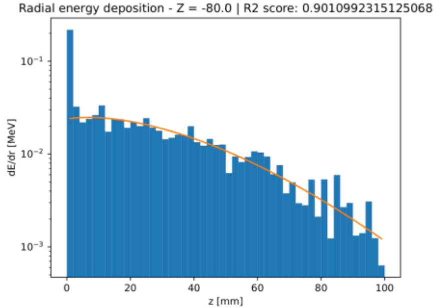
- 25 bins with z-values
- Radial distribution obtained by fitting on each bin

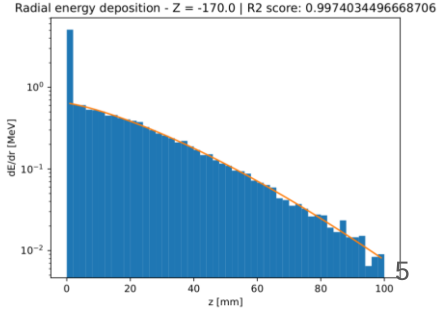
$$f(r) = A \times \mathcal{N}(b, c)$$

- Z-dependence of fit parameters allows to define a continuous and differentiable parametrization to run optimization cycles



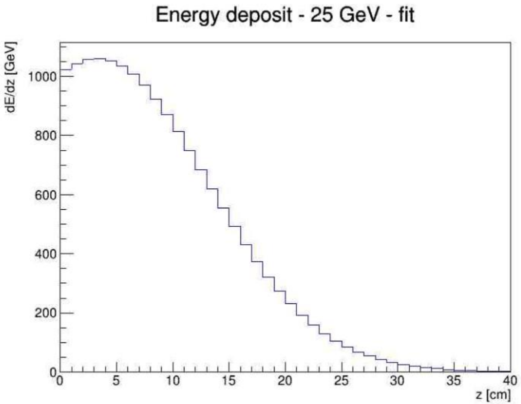


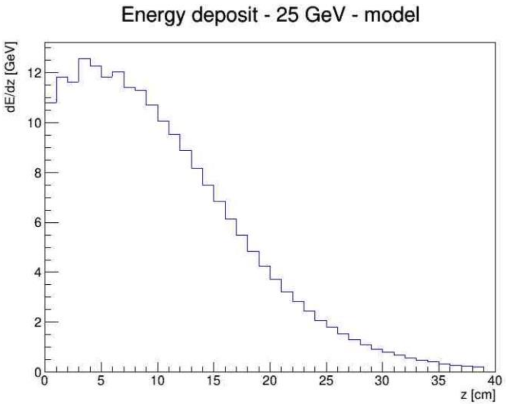




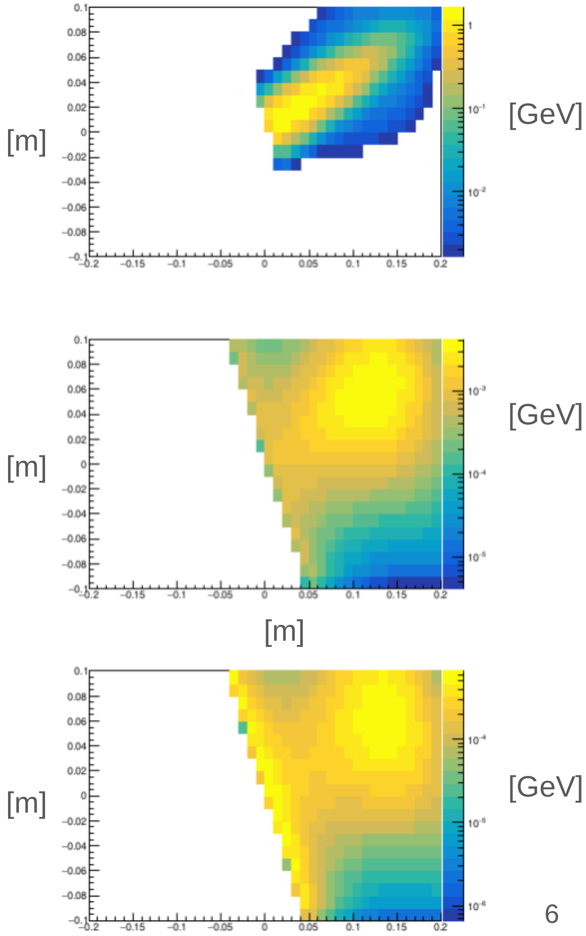
Simulation of detector layers

- Parametrization for both BIB and signal
  - Monochromatic photons with random angle from IP
- Normalization enforced to match Geant4 deposition



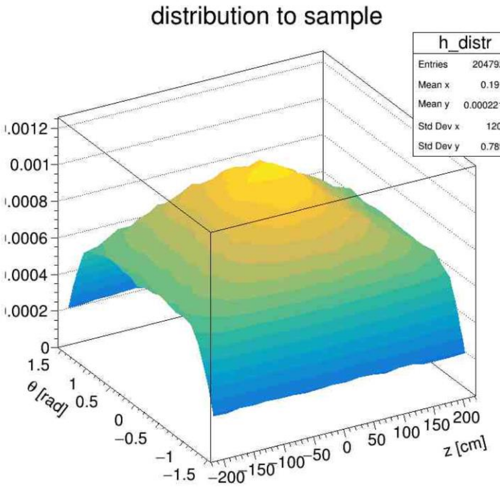


75 GeV photon

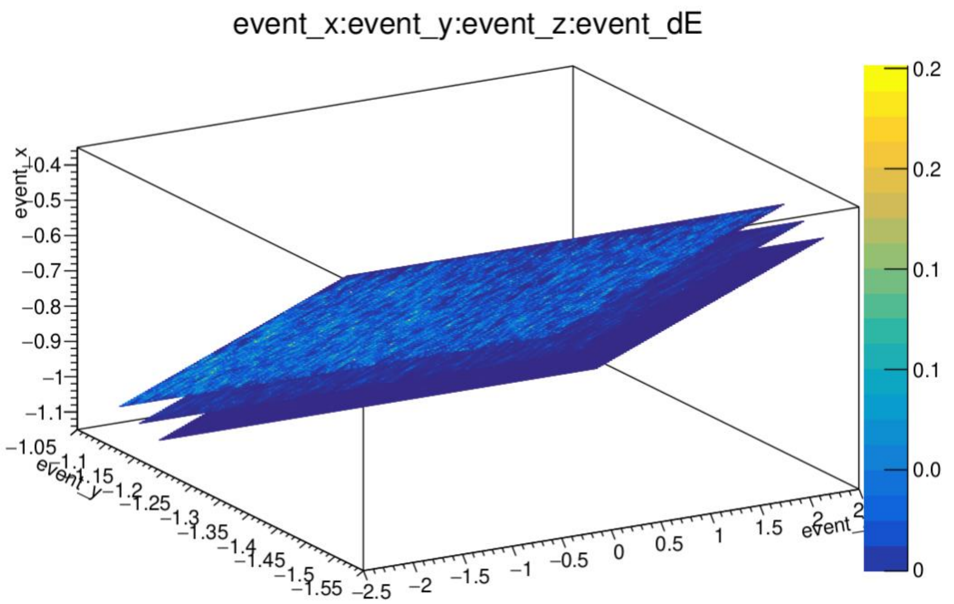


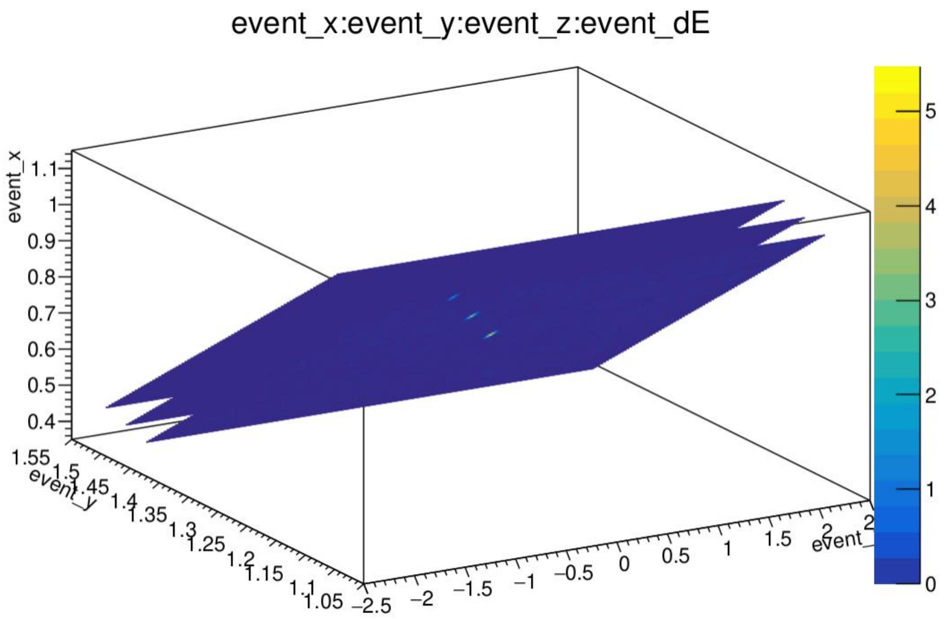
Full detector simulation

- Basic MC sampling of hit position on surface
- 4e5 photons generated (correct by a factor 10x)
- Signal area stored on root ntuple



Event visualizations





Still some issues

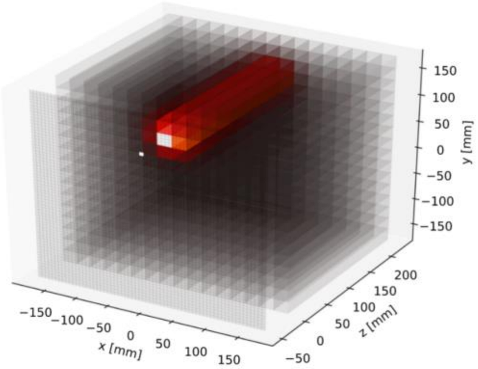
- Strong dependence of deposition on incidence angle
  - Improves with denser voxels
- BIB generation slow -> O(hours) per single signal event
  - Keep stochastic nature of BIB
  - Switch to a energy flux modelling instead of event hits

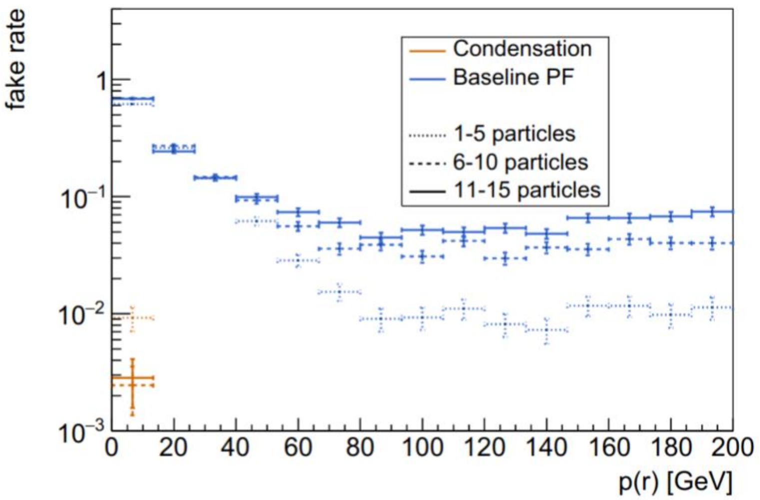
Object Condensation for reconstruction

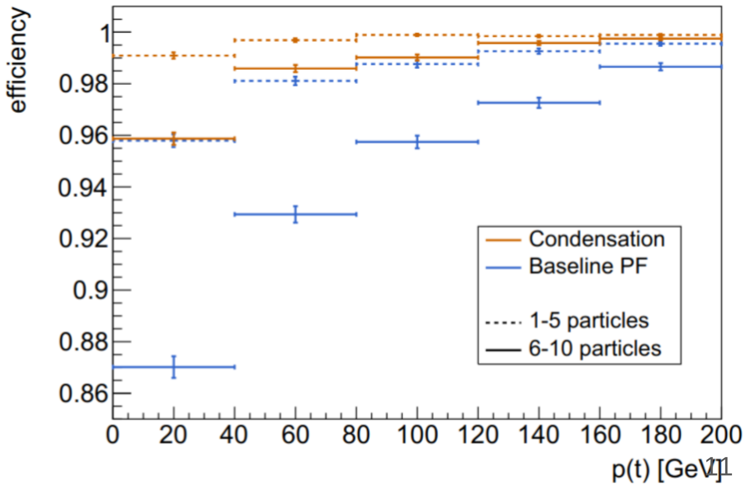
- Need a differentiable reconstruction engine
- Keep (or improve) original efficiencies
- Use Deep Learning techniques, analogous to image recognition methods
- DeepJetCore -> Library developed for jets at CMS HGCal
    - J. Kieseler, *Object condensation: one-stage grid-free multi-object reconstruction in physics detectors, graph, and image data,* EPJC **80** 866 (2020)

DeepJetCore performance

- Electrons and photons from 1 to 200 GeV
- Granular bulk of PbWO4 cells, with tracker in the front
- Compared with PF algorithm







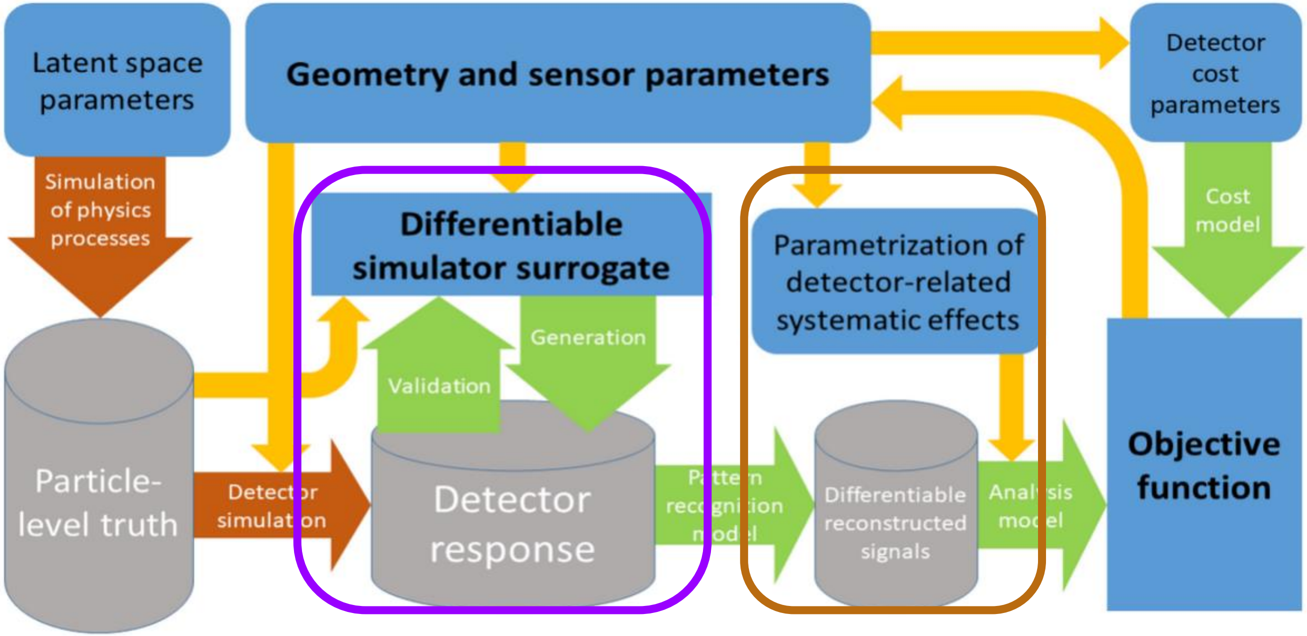
Status

- Training ongoing for monochromatic photons in Crilin ECal
  - With and without BIB (3TeV)
- Aim: present first results in the next weekly meetings

Towards optimization of ECAL design

- MODE Collaboration: Machine-Learning-Optimized Design of Experiments
  - https://mode-collaboration.github.io
- Idea: Use automatic tools to come up with better solutions in experimental setups
  - Heuristics and intuition work great, but what if we can approach it in a more systematic way?
- 4 elements needed:
  - Event generator
  - Simulator of detector response
  - Object Reconstruction algorithm
  - Loss function
- Note: Every part needs to be differentiable, we need automatic differentiation to minimize the loss function!

Design optimization: how?



Backup

TOMOPT - muon tomography framework

WORK IN PROGRESS!

From G.Strong's presentation at ICHEP2022

- Task is to infer presence of uranium block in container filled with scrap metal
  - Inference uses a dedicated summary statistic
  - The U block can be anywhere in the volume, so intuitively expect the detectors should be placed centrally in XY over the volume
- Detectors start in corner of volume and optimisation does indeed move them to cover the volume

- Optimised detector provides large improvement to ROC AUC