Machine Learning applications in particle physics

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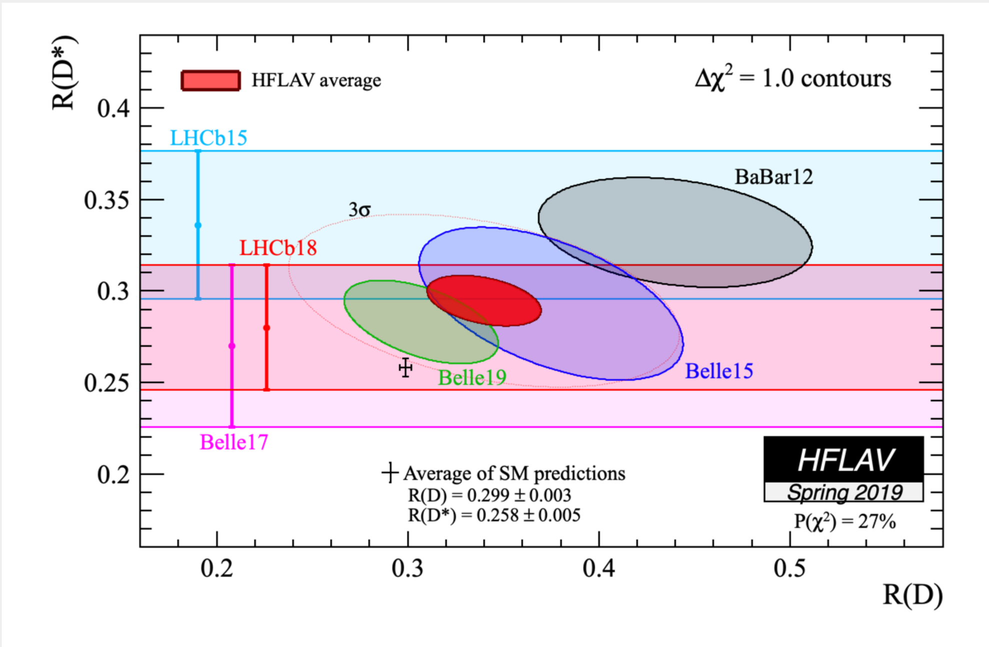
Flavour anomalies in semileptonic B-decays

Recent results from experiment show coherent, albeit inconclusive if taken singularly, hints of lepton flavour universality violation (LFUV) in semi-leptonic B decays [1]

$$R(D^{(*)}) = \frac{\mathrm{B} \to \mathrm{D}^{(*)}\tau\nu}{\mathrm{B} \to \mathrm{D}^{(*)}\mu\nu}$$

The $R(D^{(*)})$ observable is theoretically clean, but experimentally difficult in a hadronic environment due to the missing neutrino(s) in the final state.

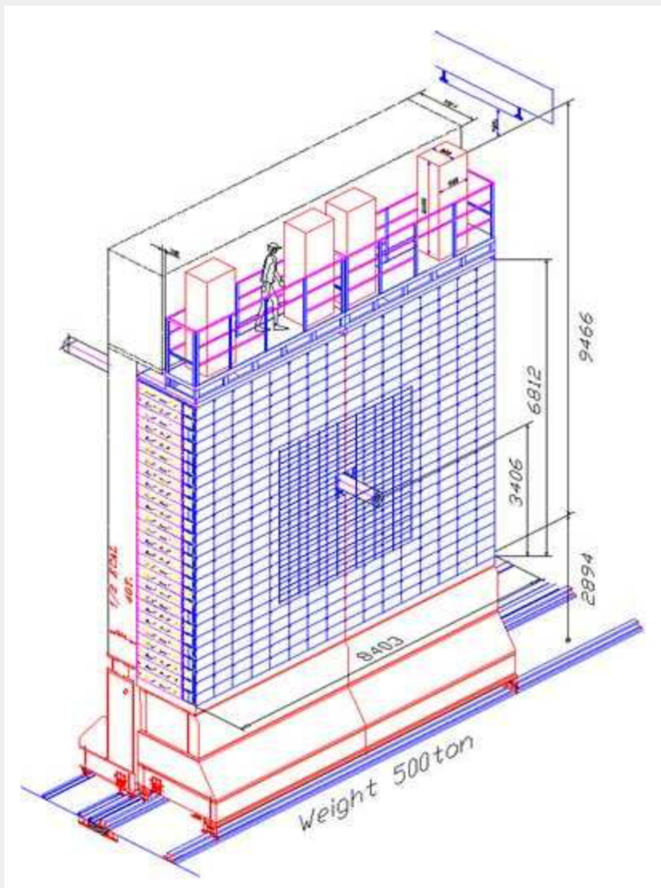


A large sample of Monte Carlo data is needed in order to perform the $R(D)$ analysis at LHCb.

Simulating LHCb Calorimeter response with GANs

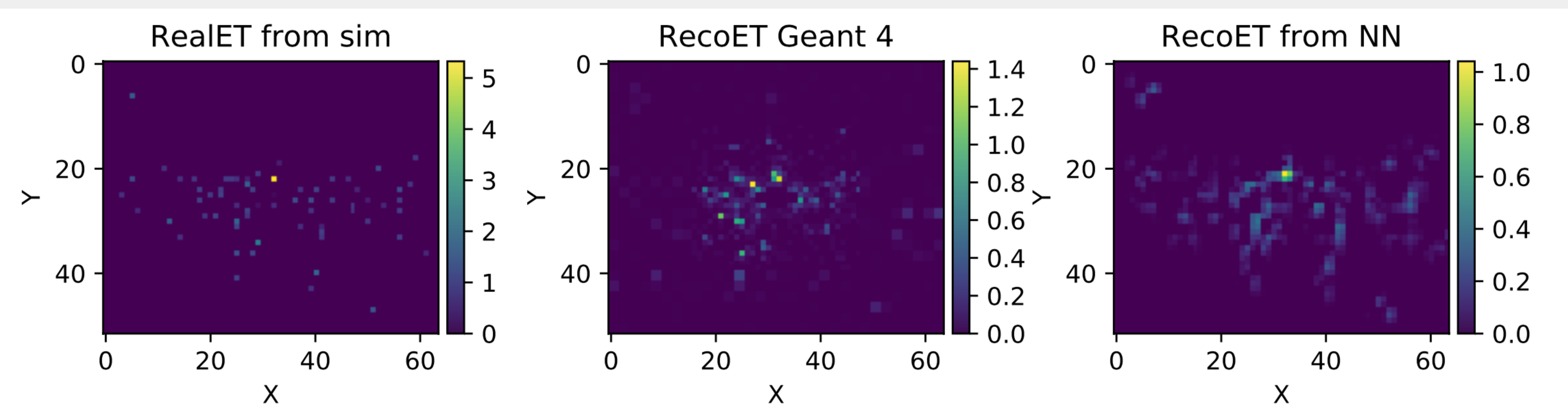
A large amount of computing resources are dedicated to the simulation of the LHCb Hadron Calorimeter (HCAL) response, it implements 70 **%** of Level 0 trigger [2].

- HCAL is triggered in presence of high p_t hadrons and its response can be thought as an image: each pixel corresponds to a cell and it's value to the transverse energy recorded
- Generative Adversarial Networks (DCGAN) are ML architectures that can be trained to reproduce distributions of multidimensional datasets



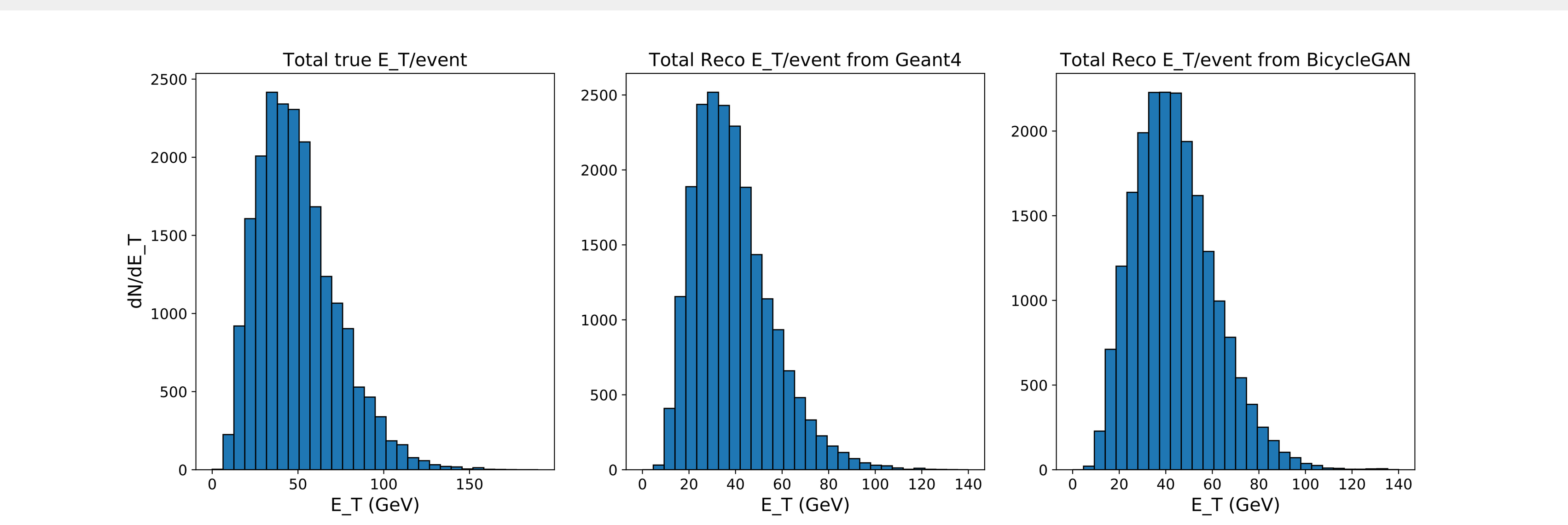
Bicycle GANs as a tool for fast simulation

BicycleGANs [3] are used to map onto each other different distributions of images. They are trained to connect sets of images containing the Monte Carlo truth with the corresponding images of the HCAL response.



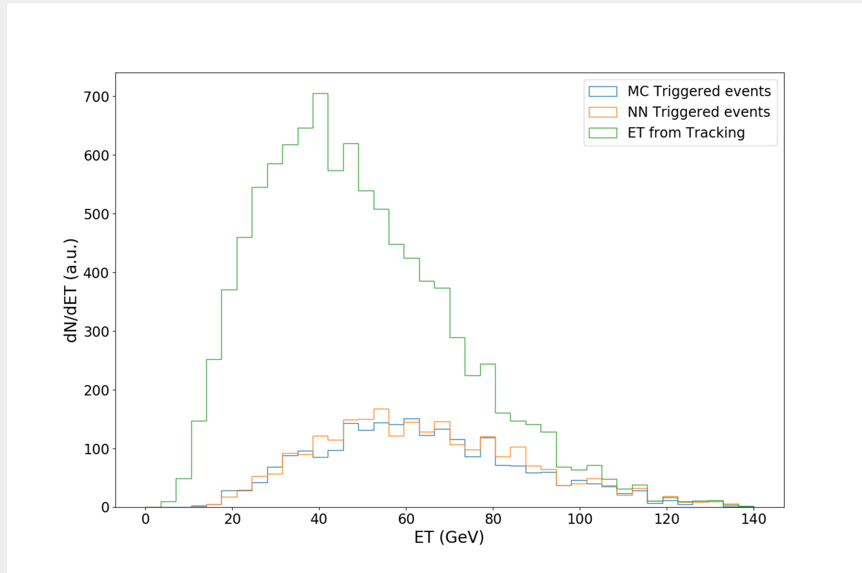
Precisely reproducing data distributions with GANs

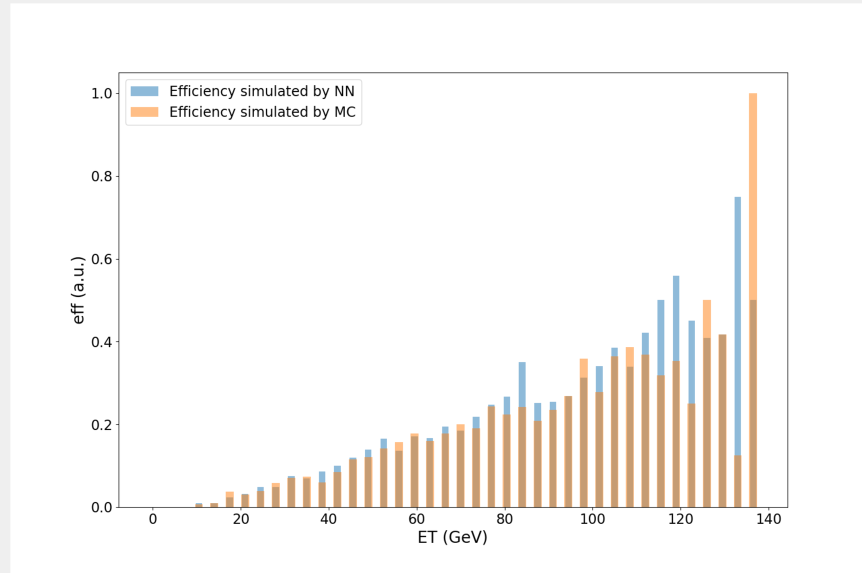
- Training on the full event simulation from GEANT4, and summing over the energy recorded by each cell we obtain:



Trigger efficiency estimation

- Our main aim is to simulate L0 Hadron trigger efficiency. By comparing GEANT4 and our work results we obtain:

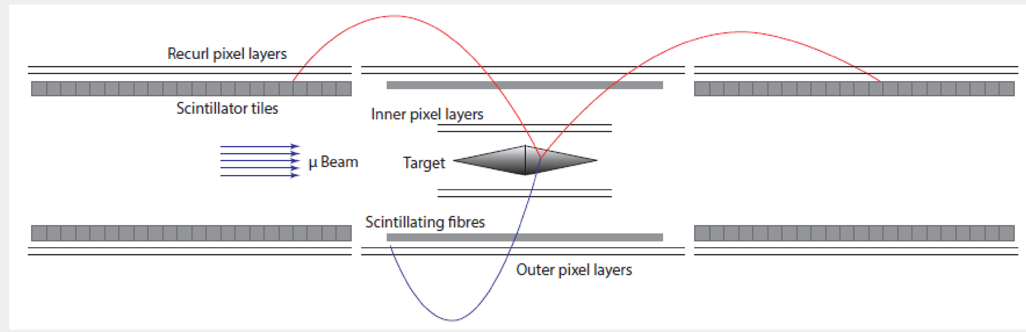




An example of master thesis project: search for charged LFV at Mu3e

The Mu3e experiment [5] searches for charged lepton flavor violation (cLFV) such as:

$$\mu^- \to e^- e^+ e^-$$

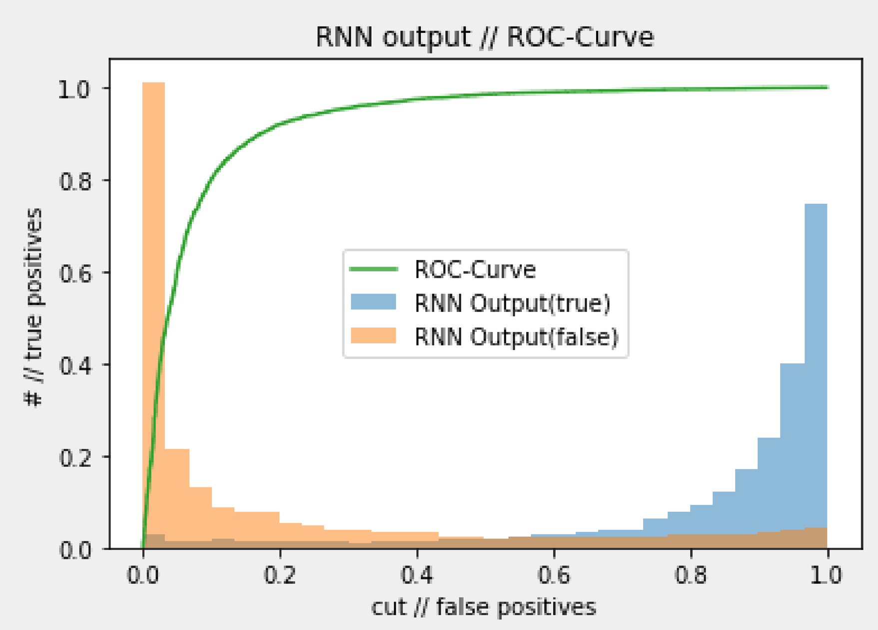


Once produced, charged particles are deflected back into the detector. If they have a low transverse momentum, they get deflected back into the central station, creating additional unwanted hits. As a result, the χ^2 method reconstructs the right path only in around **52%** of the cases.

Results with ML approach

Model	Accuracy (cut at **0.5**)	ROC-AUC
Best χ^2	**52.01%**	/
RNN	**87.63%**	**0.93**

Using this system of RNNs proves to be a viable solution to this problem and brings gain in accuracy, while also outperforming other machine learning solutions.



Future Prospects

GANs for calorimetry

- Integrate in LHCb simulation software and extend to future analyses in order to cope with the increased luminosity in Upgrade I
- Use the gained expertise to extend the use of generative models to different datasets

RNN for tracking

- Allow an arbitrary track length using a dynamic RNN.
- Replace the tracking completely through RNNs. Besides the improvement in accuracy, this also brings a gain in speed over the χ^2 method.

References

[1] Heavy Flavour Averaging Group, http://www.slac.stanford.edu/xorg/hfag/

[2] LHCb Collaboration, LHCb Calorimeters: Technical Design Report CERN-LHCC-2000-036

[3] J. Zhu et al. Towards multimodal Image-to-Image translation, arXiv:1711.11586

[4] D. Lancierini, P. Owen, N. Serra, 10.1393/ncc/i2019-19197-3

[5] A. Perrevoort (Mu3e Collaboration) arXiv:1812.00741v1

[6] Barak A., https://doi.org/10.1162/neco.1989.1.2.263