Machine Learning for Monte Carlo Event Generator

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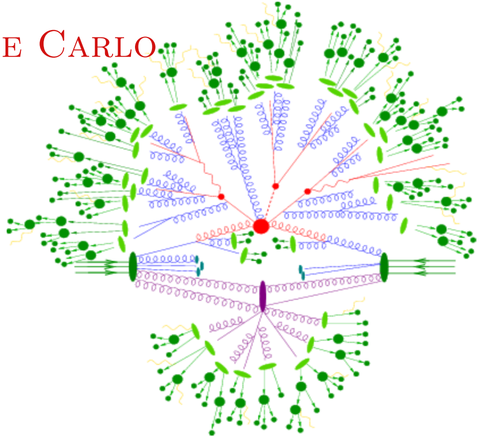

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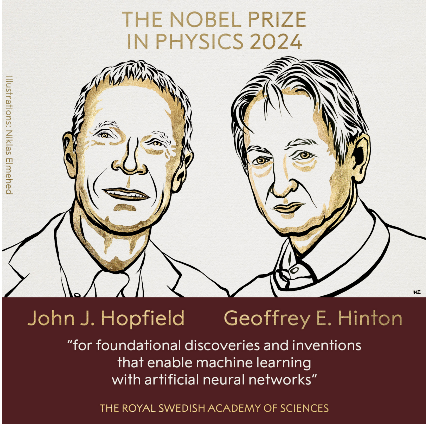
Machine Learning (or AI) has become a hot topic in the world. The Nobel Prize in Physics 2024 was awarded to the inventors of neural networks. Modern machine learning techniques, including deep learning, have been applied, adapted, and developed for high energy physics.

Learn more:

- HEP ML Living Review
- T. Tilman *et al.*, arXiv:2211.01421
- A. Butter *et al.*, arXiv:2203.07460



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NNPDF [R. Ball *et al.*, 2021]

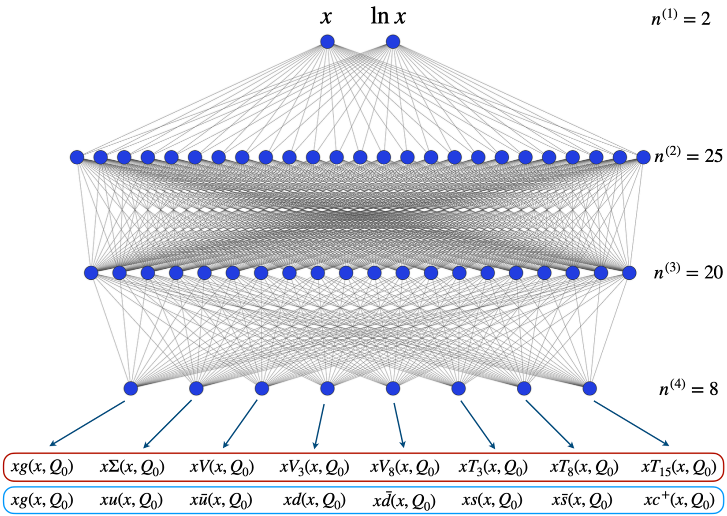
Neural Network Parton Distribution Function (NNPDF) is the first PDF set to be based on a methodology fully selected through a machine learning algorithm.
The parameterization of PDFs are:

$$xf_k(x, Q_0; \theta) = A_k x^{1-\alpha_k}(1-x)^{\beta_k}\mathrm{NN}_k(x;\theta),\ k = 1, 2, ..., 8,$$

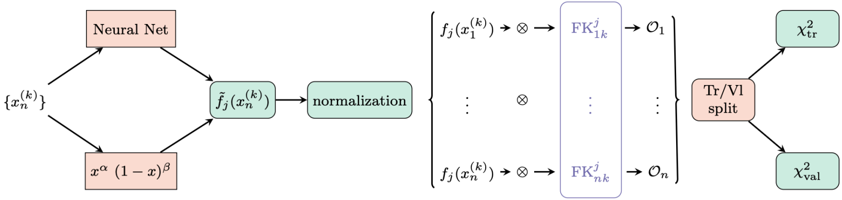
where k runs over the elements of the PDF basis, $\mathrm{NN}_k(x;\theta)$ is the k-th output of a neural network, and θ collectively indicates the full set of NN parameters.

NNPDF [R. Ball *et al.*, 2021]

2 Applications



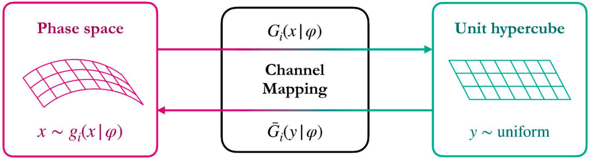
NNPDF [R. Ball *et al.*, 2021]

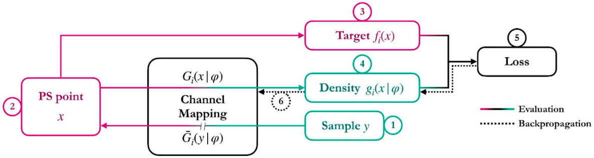


- α_k and β_k are varied in a range that is determined iteratively in a self-consistent manner.
- The normalization constants A_k are constrained by the valence and momentum sum rules.
- FK indicates the tabulated kinematic data, and it connect the PDF and observables.
- These observables allow us to calculate the loss functions for backpropagation.

MadNIS [T. Heimel *et al.*, 2023]

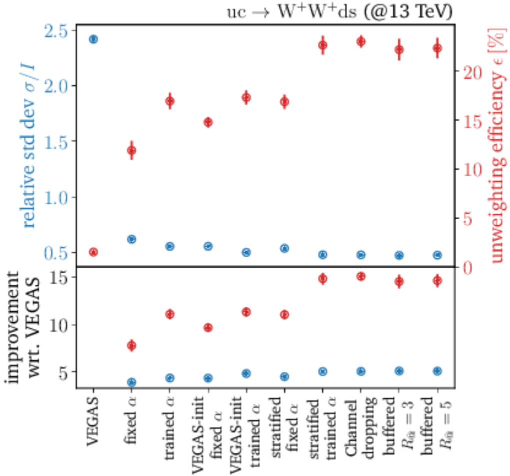
- A fast VEGAS to initialize α_i and g_i.
- α_i is determined by a feed-forward neural network and g_i is given by a normalizing flow.
- Combine online training and buffered training to ensure speed and precision.





MadNIS [T. Heimel *et al.*, 2023]

2 Applications



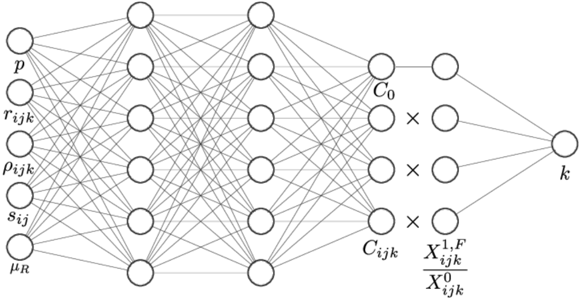
- The goal is to reduce the variance of the integral estimation.

One-Loop ME emulation [D. Maître *et al.*, 2023]

Assuming a $2 \to n$ process, the k-factor can be parameterized to:

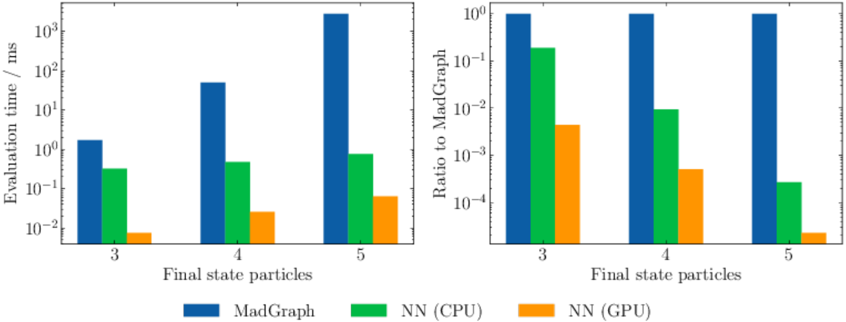
$$k_{n+1} = C_0 + \sum_{ijk} C_{ijk} \frac{X^{1,F}_{ijk}}{X^0_{ijk}},$$

where i, k are the hard partons, j is the unresolvable parton. X are the finite-substracted antenna functions.



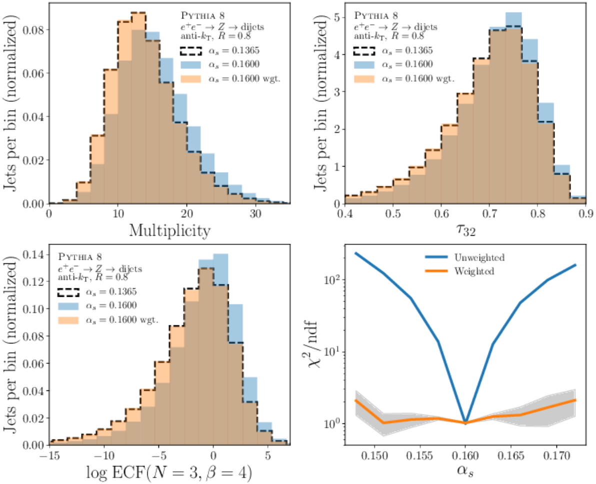
One-Loop ME emulation [D. Maître *et al.*, 2023]

Speed up by ONNX runtime.



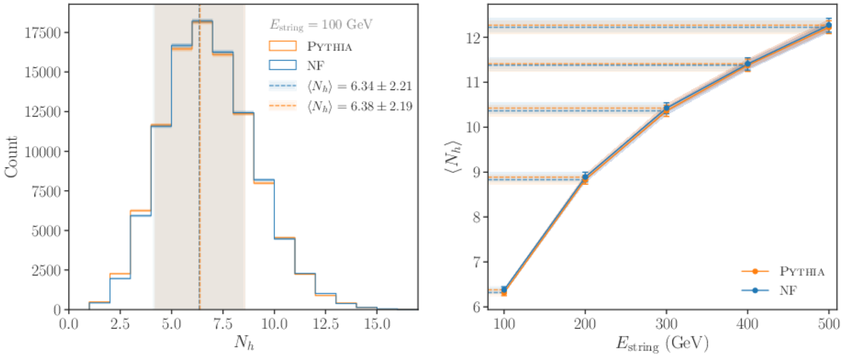
DCTR [A. Andreassen and B. Nachman, 2019]

Two simulations with a same phase space have two probability densities $p_0(x)$ and $p_1(x)$. The function $w(x) = p_0(x)/p_1(x)$ is the ideal per-event weight. A NN is used to learn this weight.

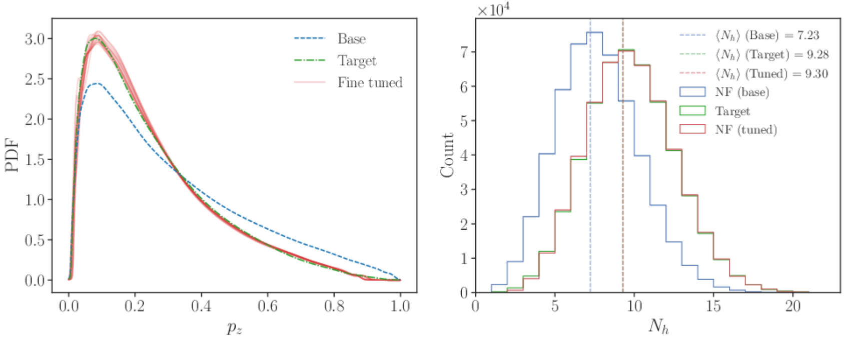


MLHAD [C. Bierlich *et al.*, 2023]

- A Normalizing Flow model is trained to obtain a fragmentation function.
- Model is fine tuned to predict kinematic observables.
- Uncertainies are estimated by training a Bayes Normalizing Flow model.

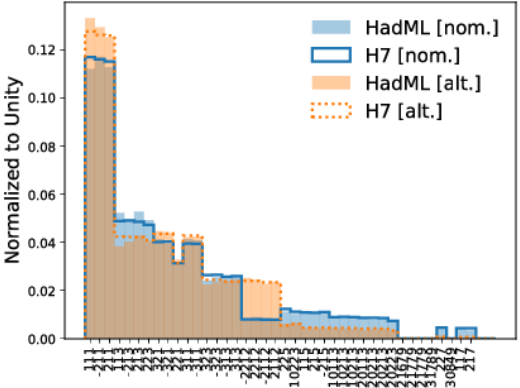


MLHAD [C. Bierlich *et al.*, 2023]



HADML [J. Chan *et al.*, 2023]

- A Generative Adversarial Network (GAN) is trained to generate the kinematics and flavour of hadrons.
- Dataset is generated by Herwig 7 with LEP setup. A alternative input for Herwig 7 is considered for comparison.



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Summary

- ML techniques have been widely applied in the MC event generation.
- ML is powerful but has some limitations.
- Many challenges remain.

Q&A

Thank you for listening!
Your feedback will be highly appreciated!