Nikita Kazeev

Generative Models

What are they and why we need them?

2021

MLHEP 2021

National Research University Higher School of Economics

LAMBDA • HSE

Yandex

School of Data Analysis

EPFL

Schaffhausen Institute of Technology

Generative models

- Regression and classification: $x \to y$
- Generative models
  - Sample $p(x|y)$
  - Approximate density function $p(x|y)$

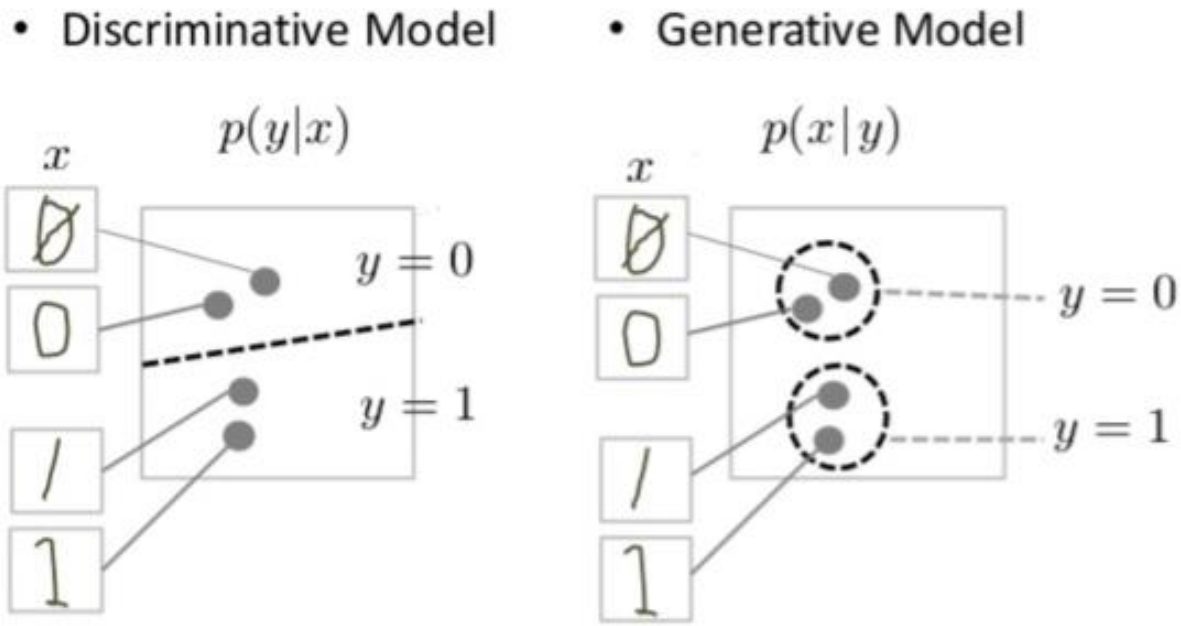


Image: https://developers.google.com/machine-learning/gan/generative

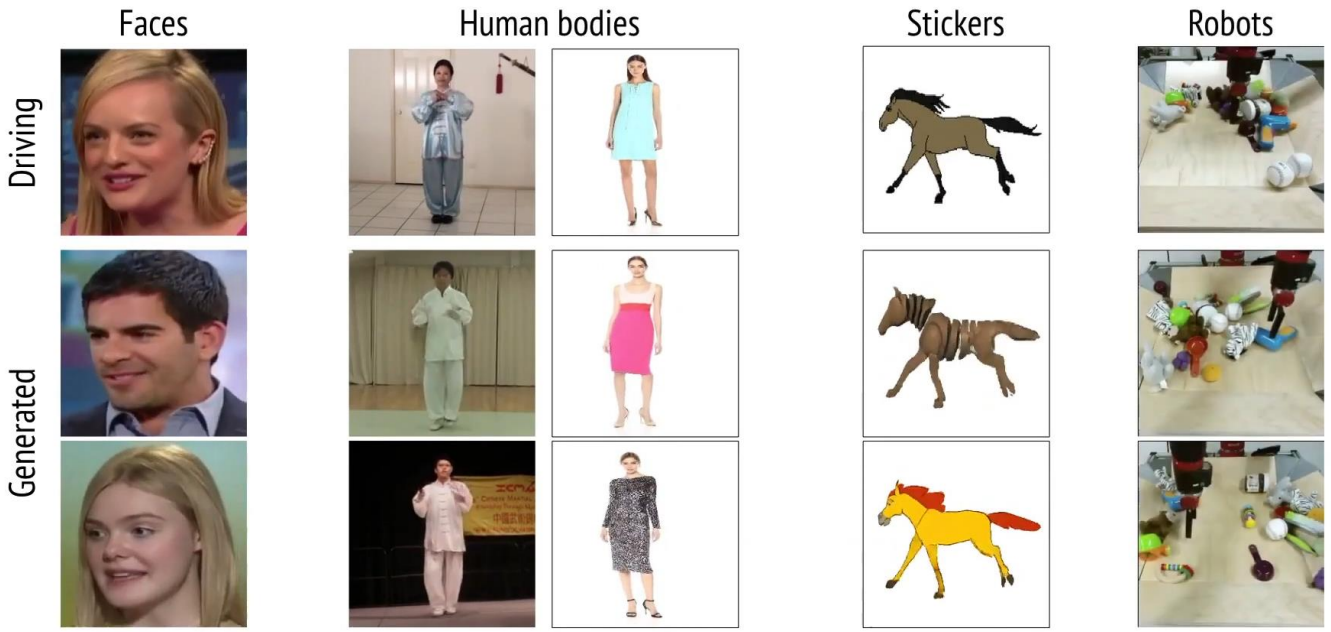
Generative models applications

Image generation for fun & profit: photos

Goodfellow, Ian, et al. "Generative adversarial nets." *Advances in neural information processing systems*. **2014**.

Karras, Tero, et al. "A style-based generator architecture for generative adversarial networks." *Proceedings of the IEEE conference on computer vision and pattern recognition*. **2019**.

Image generation for fun & profit: videos



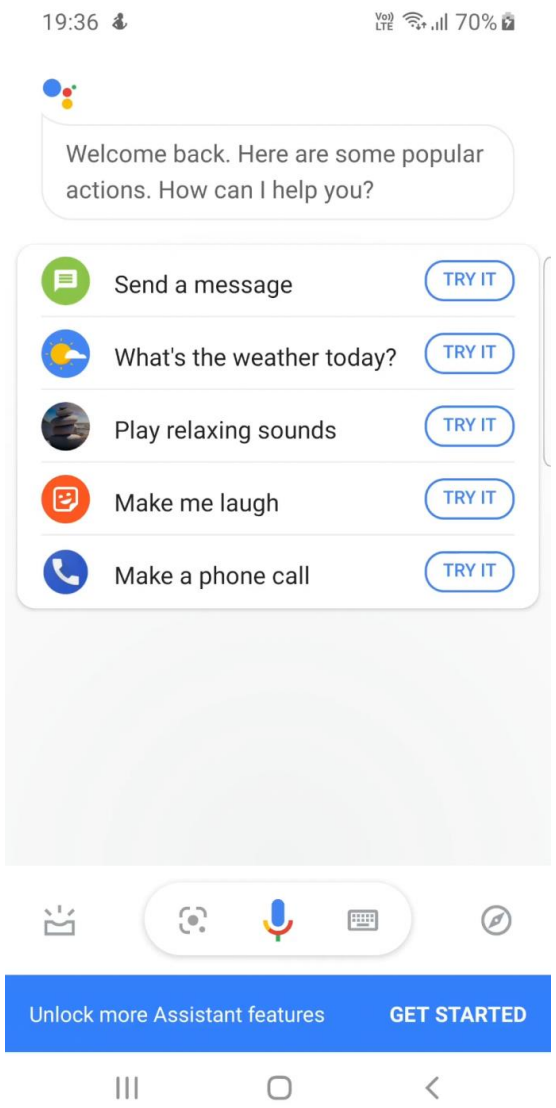
Each video is produced using a single input image

Siarohin, Aliaksandr, et al. "First order motion model for image animation." Advances in Neural Information Processing Systems. 2019.

Text generation

Demo: https://colab.research.google.com/github/graykode/gpt-2-Pytorch/blob/master/GPT2_Pytorch.ipynb

Voice generation



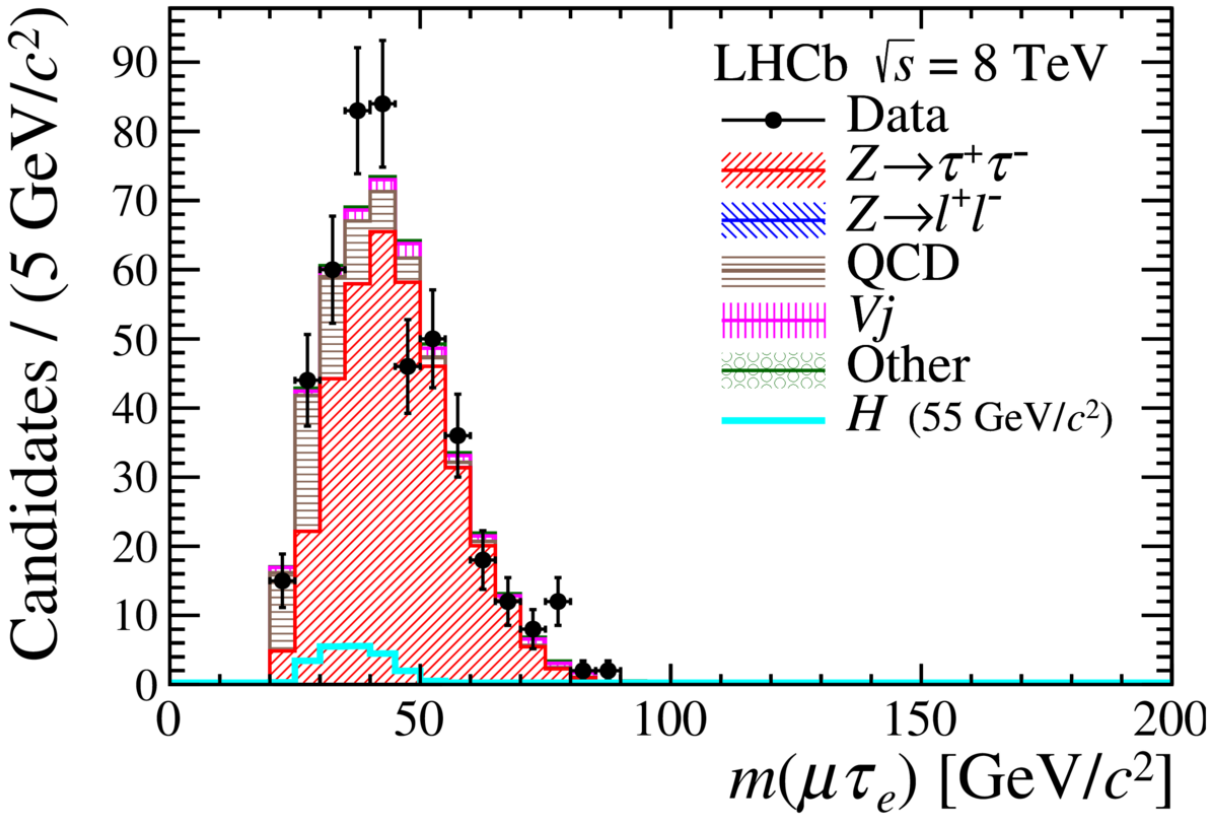
Quick conclusion

Why do we have all those nice things now?

- Large amount of similar data available
- Powerful hardware
- Commercial interest in consumer applications
- Loosely defined objectives

Generative models: physics

Histogram, the simplest generative model



Kernel density estimation

Aka slightly improved histograms

- Used for estimating probability density in for low-dimensional case
- Usually better accuracy than histogram
- Harder to analyse than histogram
- See the next lecture for details

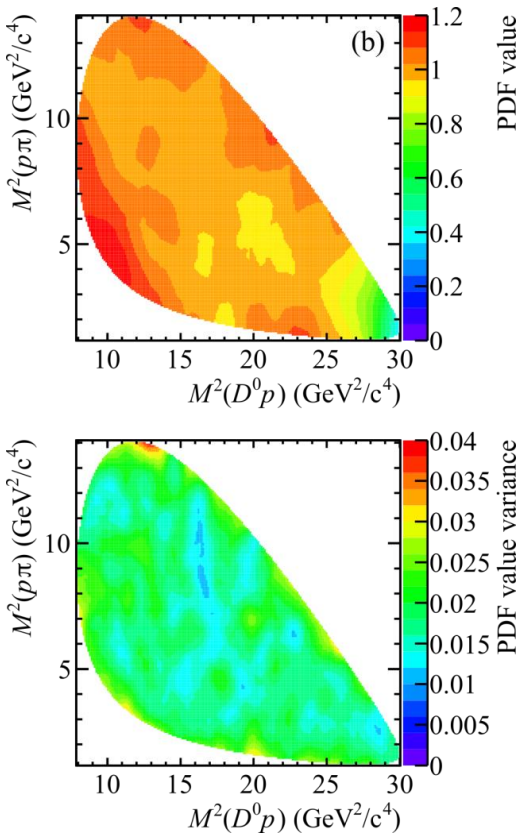
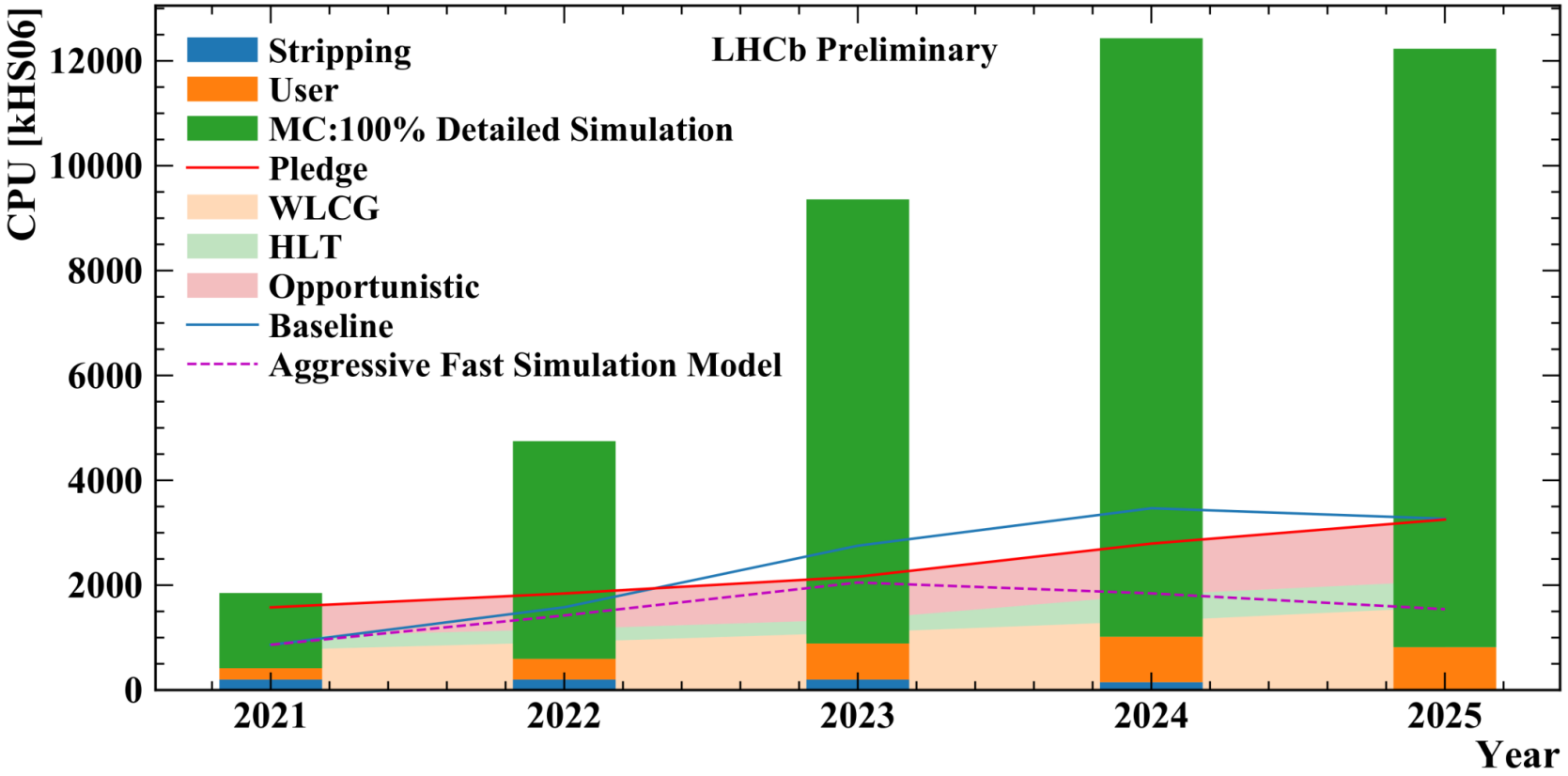


Image: Poluektov, Anton. "Kernel density estimation of a multidimensional efficiency profile." *Journal of Instrumentation* 10.02 (2015): P02011.

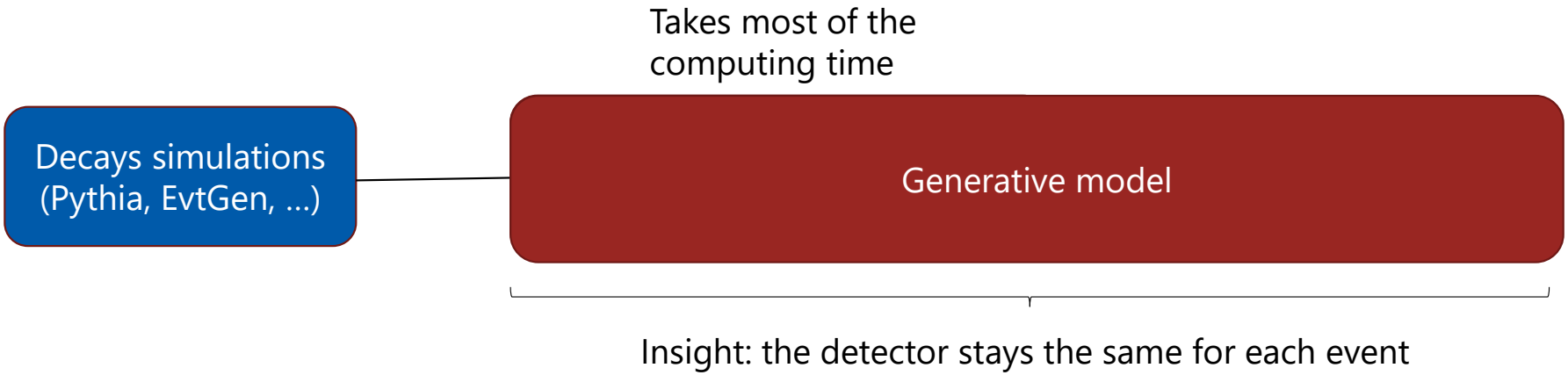
LHC upgrade needs faster simulation



Projected LHCb computing needs breakdown by category

https://indico.cern.ch/event/773049/contributions/3474742/

Simulation in HEP



Simulation in HEP: particle identification

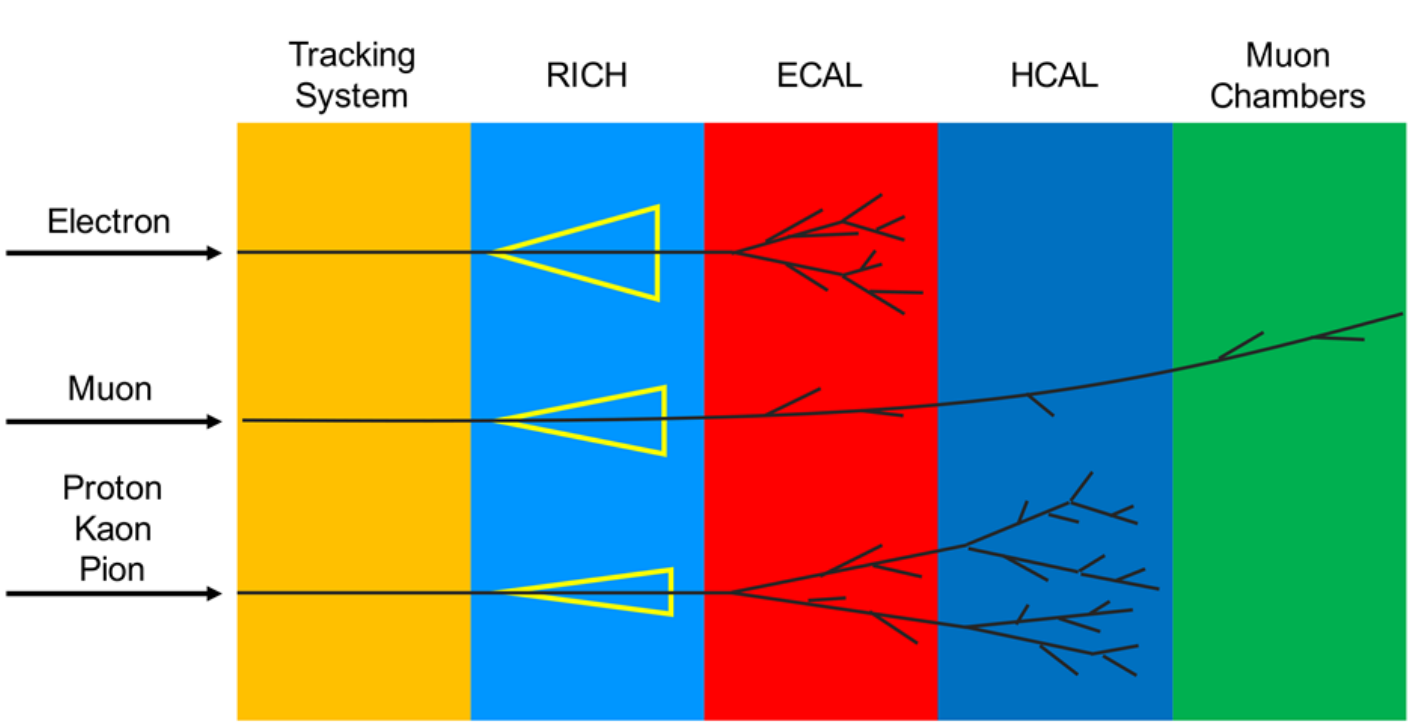
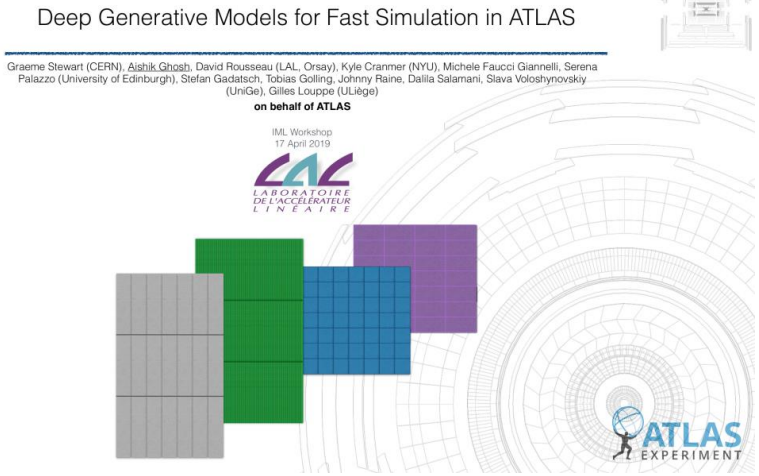
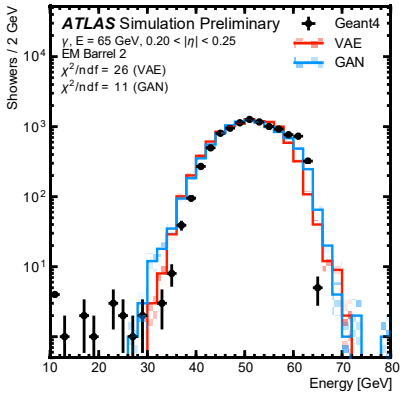
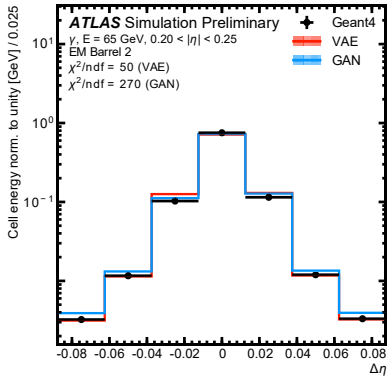


Image: Hushchyn, M, CERN-Poster-2018-647

EM calorimeter shower fast simulation in ATLAS





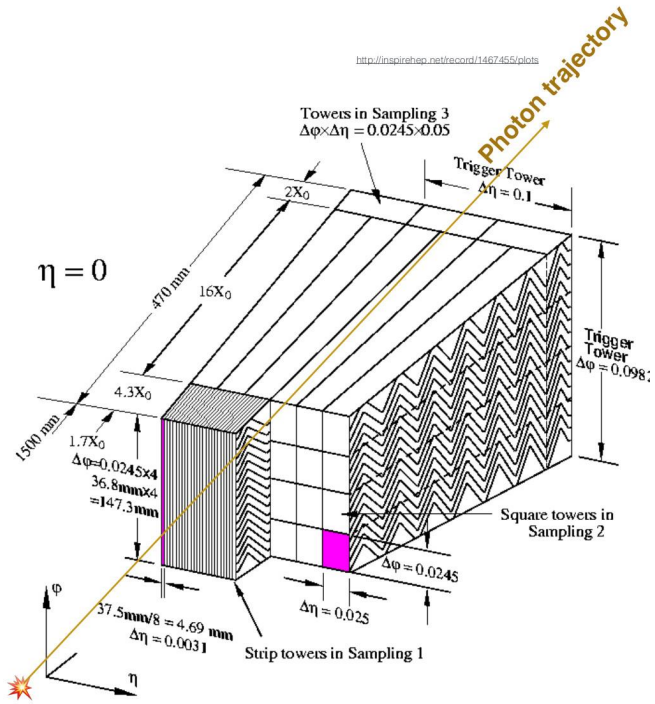


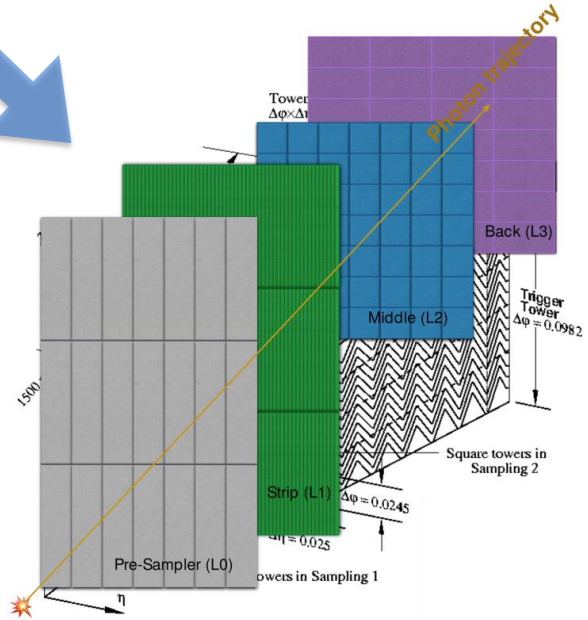
Decent reproduction of physics observables ($\Delta\eta$, $\Delta\varphi$, $E_{\text{sim}}/E_{\text{truth}}$, etc.)

https://indico.cern.ch/event/766872/contributions/3357991/

EM calorimeter shower fast simulation in ATLAS

Generating output for 3D calorimeter structure (4 calorimeter layers, 266 output channels)



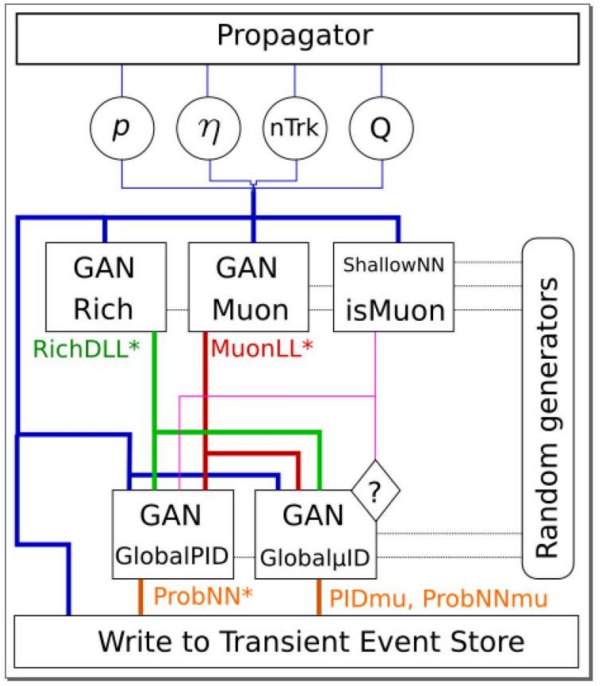


https://indico.cern.ch/event/766872/contributions/3357991/

Reconstructed data simulation

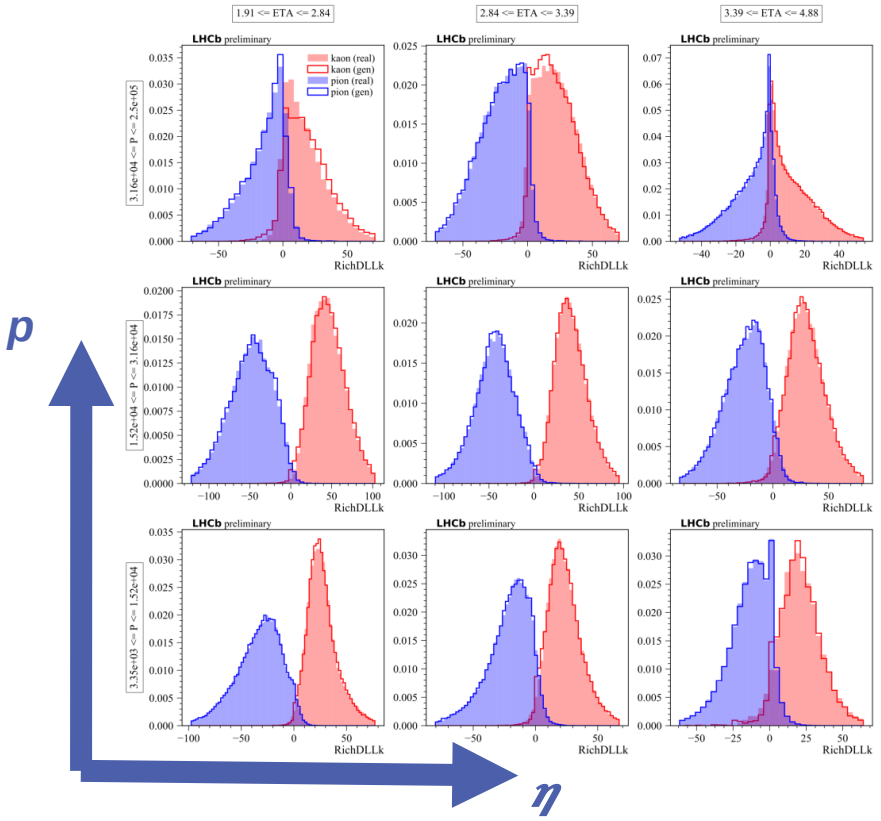
Aka fully parametric simulation

- Previously: generate detector response then reconstruct it
- Idea: generate the reconstructed events directly

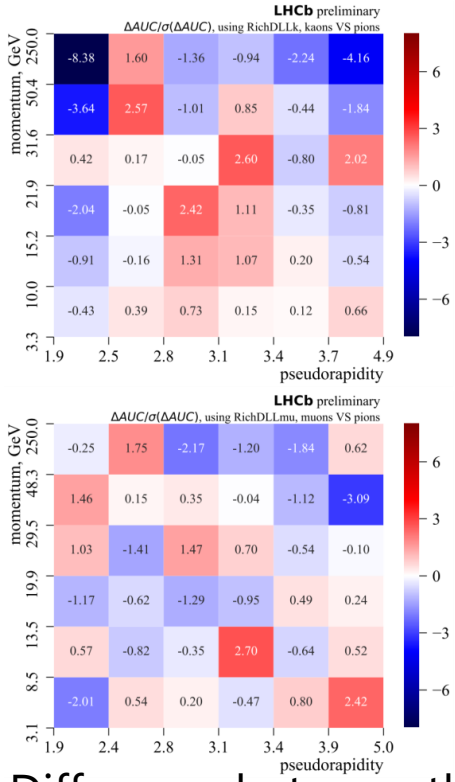


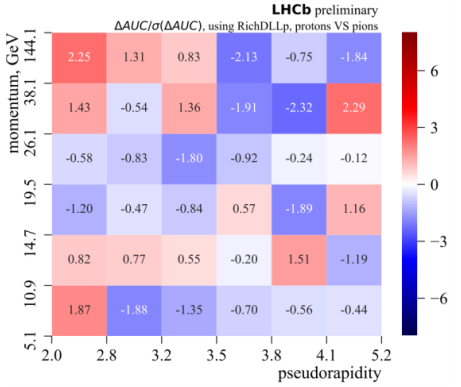
https://indico.cern.ch/event/850731/contributions/3584359/

Fast simulation of Cherenkov detectors at LHCb



Detector response to kaons and pions (real data vs generated with GAN)





Difference between the real and generated ROC AUCs in units of statistical uncertainty.

https://arxiv.org/abs/1905.11825

Fast simulation with ML: pros and cons

Pros

- Fast, orders of magnitude speed-up compared to Geant4
- Can be trained on data, not MC
- Can be easily retrained in case of a detector update

Cons

- Requires training data
- Another source of systematic uncertainty to account for

Conclusion

- Generative models are a hot subject in the current ML research
  - Many *fun* ML applications are based on them
- There are promising HEP applications
- Stay tuned for the next lectures in this section!

Thank you!

Credits

Deep fake model:
Siarohin, Aliaksandr, et al. "First order motion model for image animation." *Advances in Neural Information Processing Systems*. 2019.
Lecture, voice acting: Nikita Kazeev
Deep fake creation, voice acting: Tatiana Gaintseva
Generative models in LHCb and ATLAS slides: Artem Maevskiy
Video editing: Elizaveta Kondakova
Albert Einstein photo: Johan Hagemeyer
Colorization: alexlimcolorization
Fabiola Gianotti photo: AGF s.r.l./REX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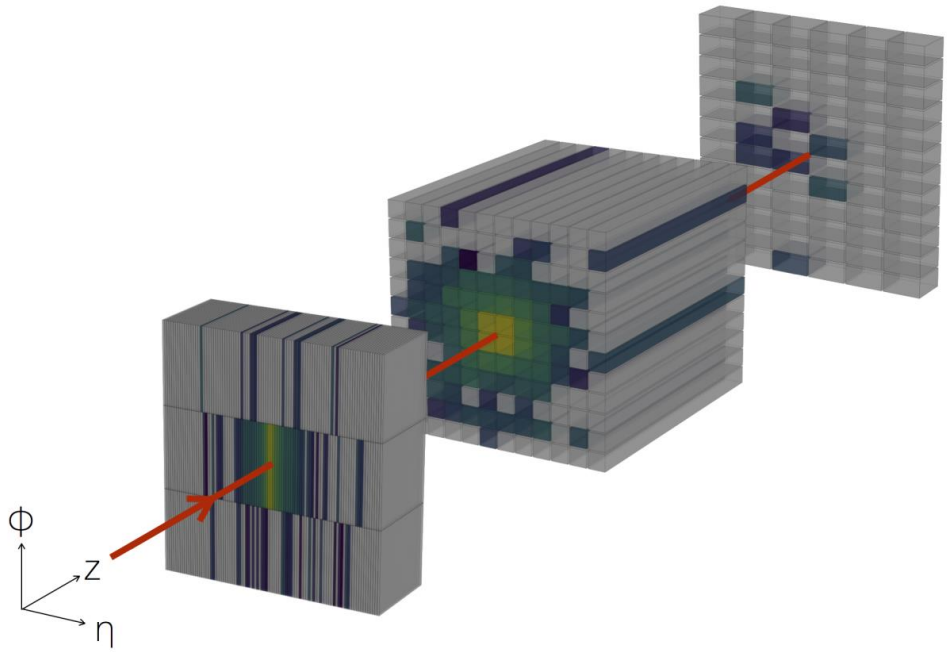
Backup

Calorimeter simulation



Paganini, M. et al. "CaloGAN: Simulating 3D high energy particle showers in multilayer electromagnetic calorimeters with generative adversarial networks." *Physical Review D* 97.1 (2018): 014021.

More examples

- https://arxiv.org/abs/2001.05486
- https://arxiv.org/abs/2003.06413
- https://journals.aps.org/prd/abstract/10.1103/PhysRevD.101.076002
- https://hal.archives-ouvertes.fr/hal-02276243/document