# Towards The Future of Generative Models in Physics Research

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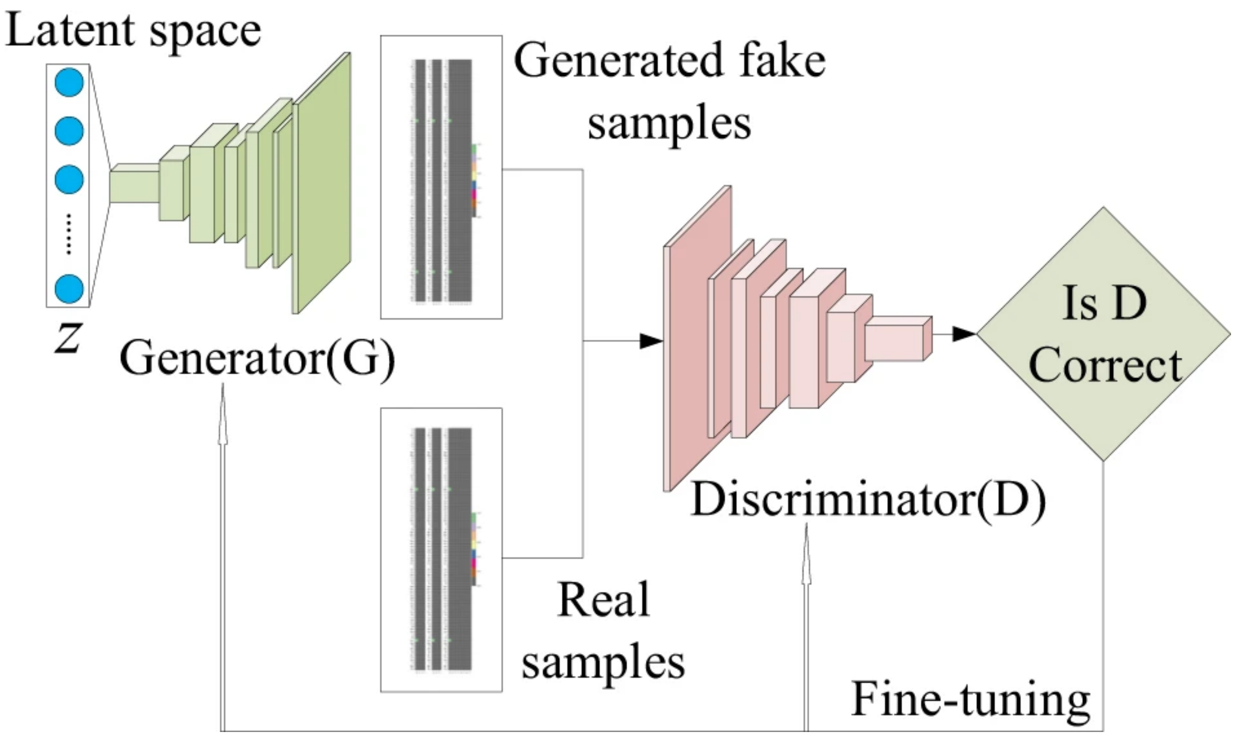
# Introduction & Problem Statement

- Simulation is one of the main components in high-energy physics experiments.
- When making physics study, some simulation, typically Geant-4, would be used to model particle passing through the detector material.
- The most of computing resources in particle physics experiments are spent on precision simulation of stochastic interaction of particles with detectors of the experimental setup.
- There is a new need for faster, stable, and interpretable simulation to maintain the balance between real data and simulated data events.

# Proposed Solution

- The proposed solution would be to utilize ML-Generative models to create events which align to a specific probability distribution.
- Generative Adversarial Networks (GANs), consist of two neural networks (NNs):
  - Generator: generator to create new data samples.
  - Discriminator: evaluates the generator output.



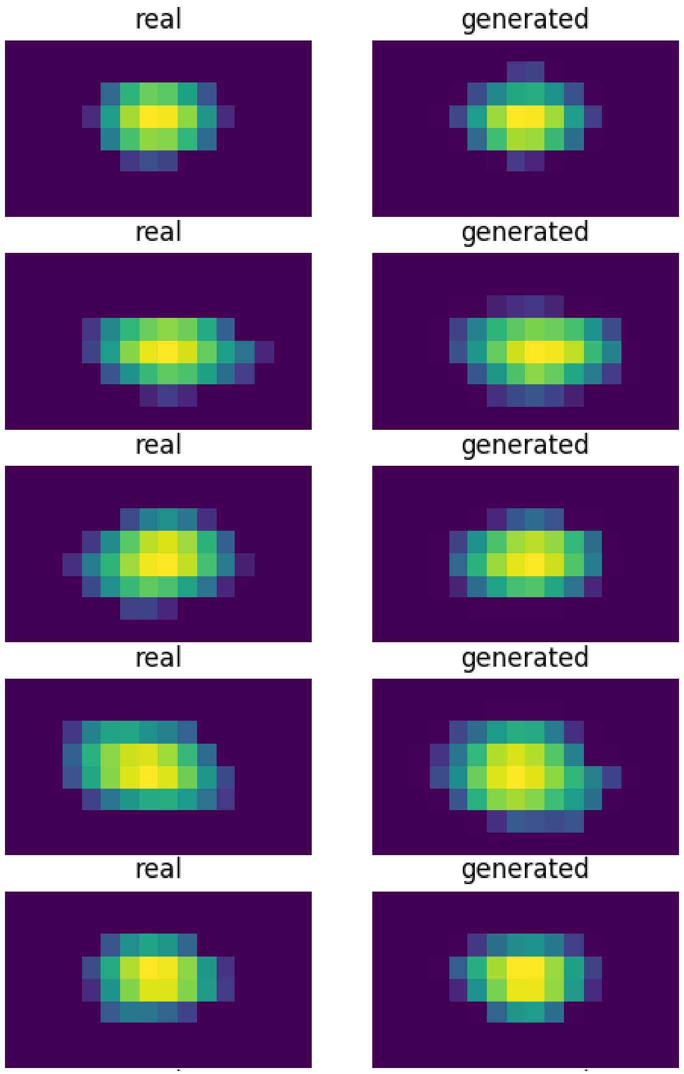
# GANs Pros and Cons

- Advantages:

Sampling is Fast. Flexibility. Smooth distributions.

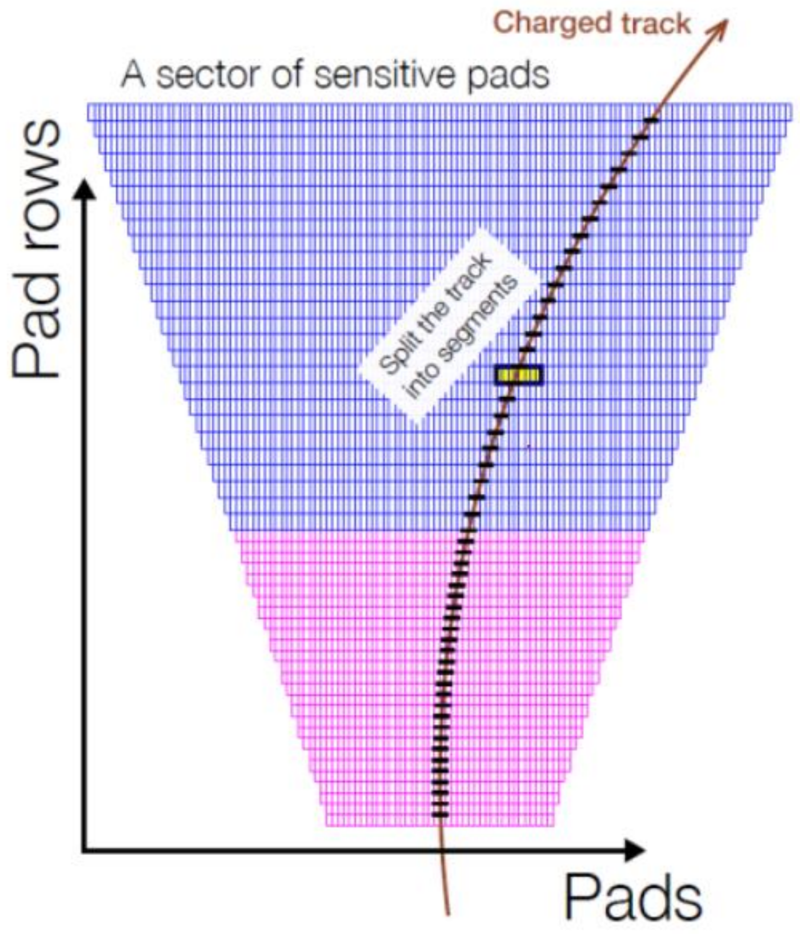
- Disadvantage:

Training requires control to ensure precision. The need for dimensionality reduction when simulating detectors.



# TPC FastSim (Fast4)

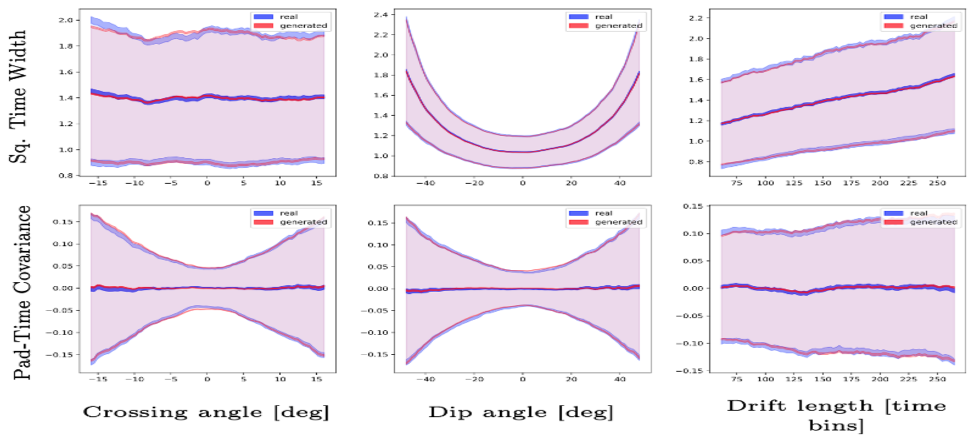
- TPC is the main tracking detector of the central barrel of the MPD experiment.
- TPC has 95232 pads, responses from which are collected in 310 time bucket.
- To reduce the dimensionality: the track is divided into segments contributing to a pad row.
- Fast4 model was introduced: a GAN model which is trained on 4 input features (dip angle, crossing angle, drift length, and pad coordinate).



# Low and High-level validation (Fast4)

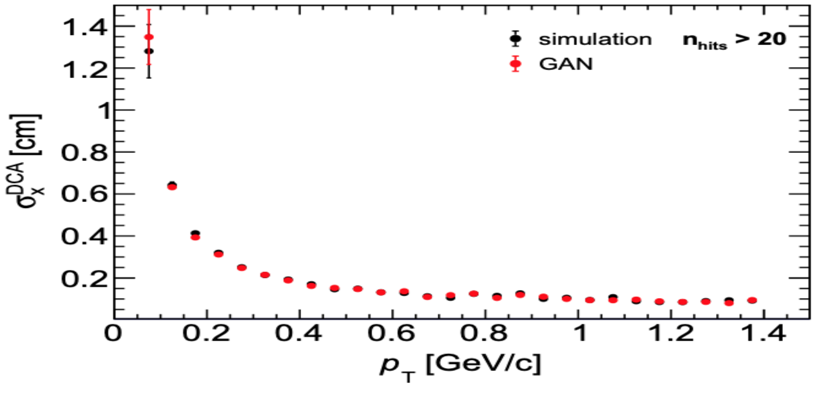
- Low level:

For each pad response image, 1st , 2nd order moment and integrated amplitude are calculated for generated and original pad response images.




- High level:

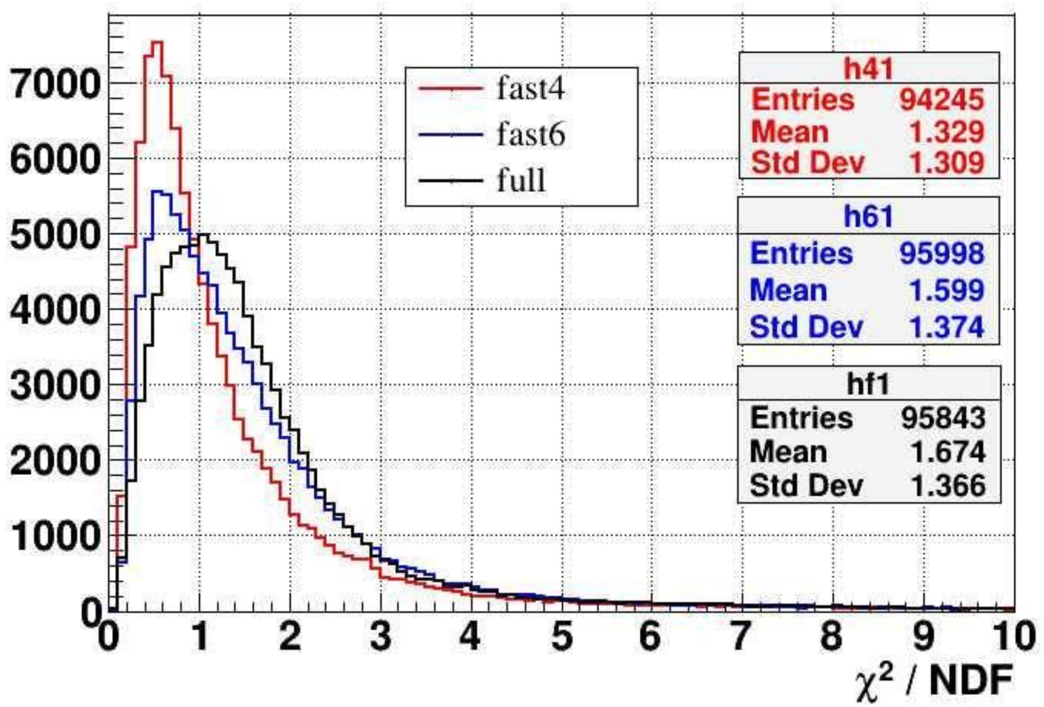
Integrate the model into the software stack of the detector simulation, and compare the reconstruction qualities.




Distance of closest approach resolution along $x$

# TPC fast-sim (Fast6)

- Fast6 is an upgrade for Fast4, which utilizes transverse momentum and pad row as additional input features during training.
- A plot for the statistical distribution of chi2/NDF for multiple reconstructed tracks for 3 different approaches has been made.
- Results shows that utilizing transverse momentum and pad row enhances the results but still does not fit the reference Geant simulation.

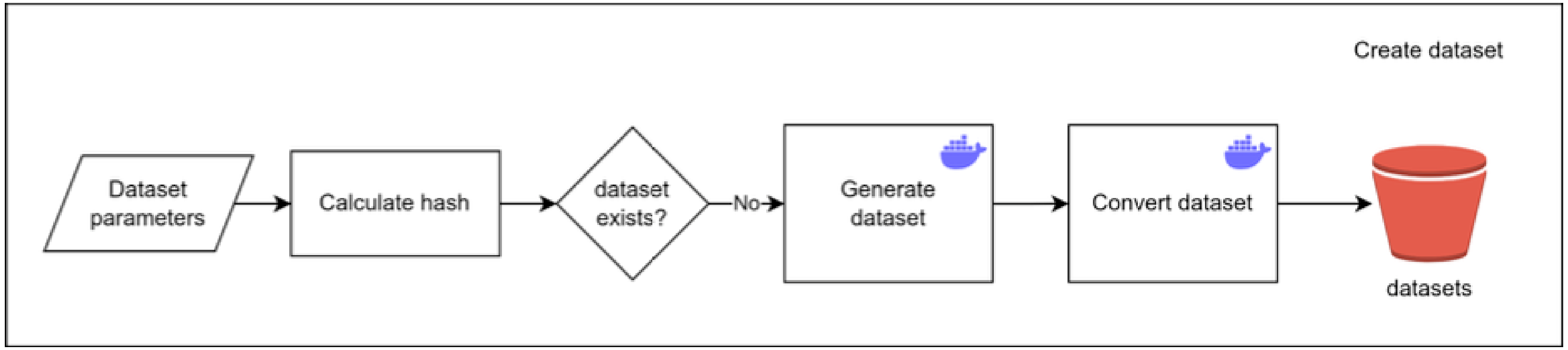


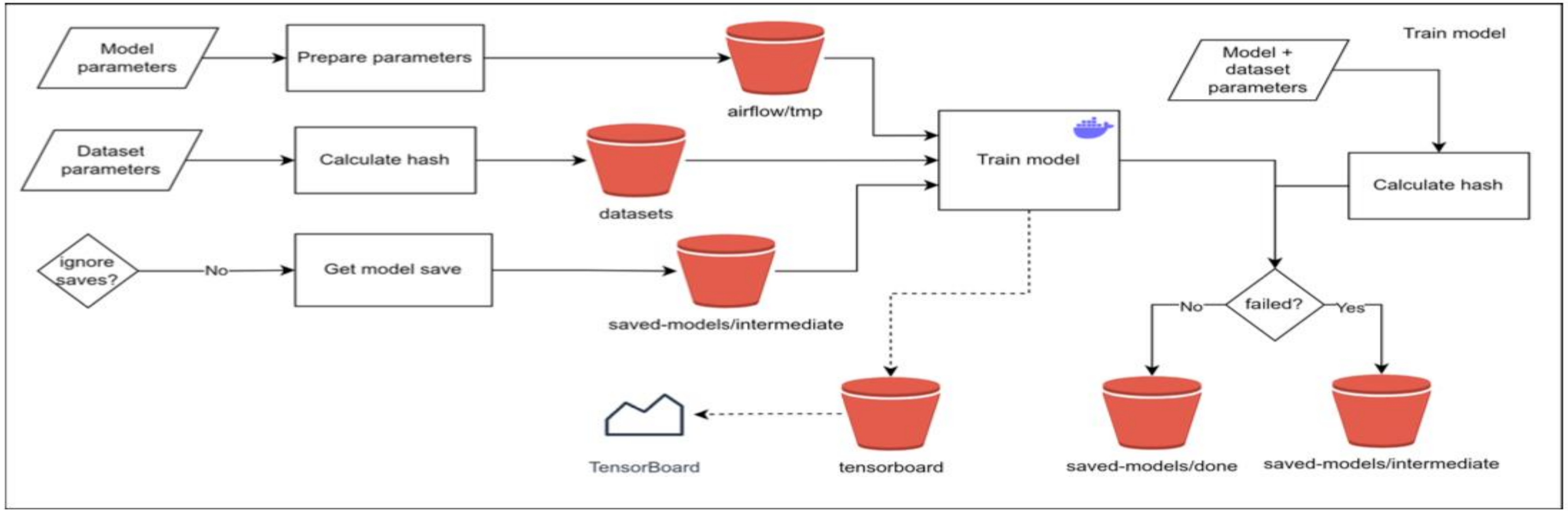
# Software Integration (The Digital Twin).

- Machine learning models are widely used in various stages of the data processing pipelines.
- Machine learning models are powerful, however directly depend on the data they are trained on.
- For model integration into an already existing software stack, various steps needs to be taking under consideration:

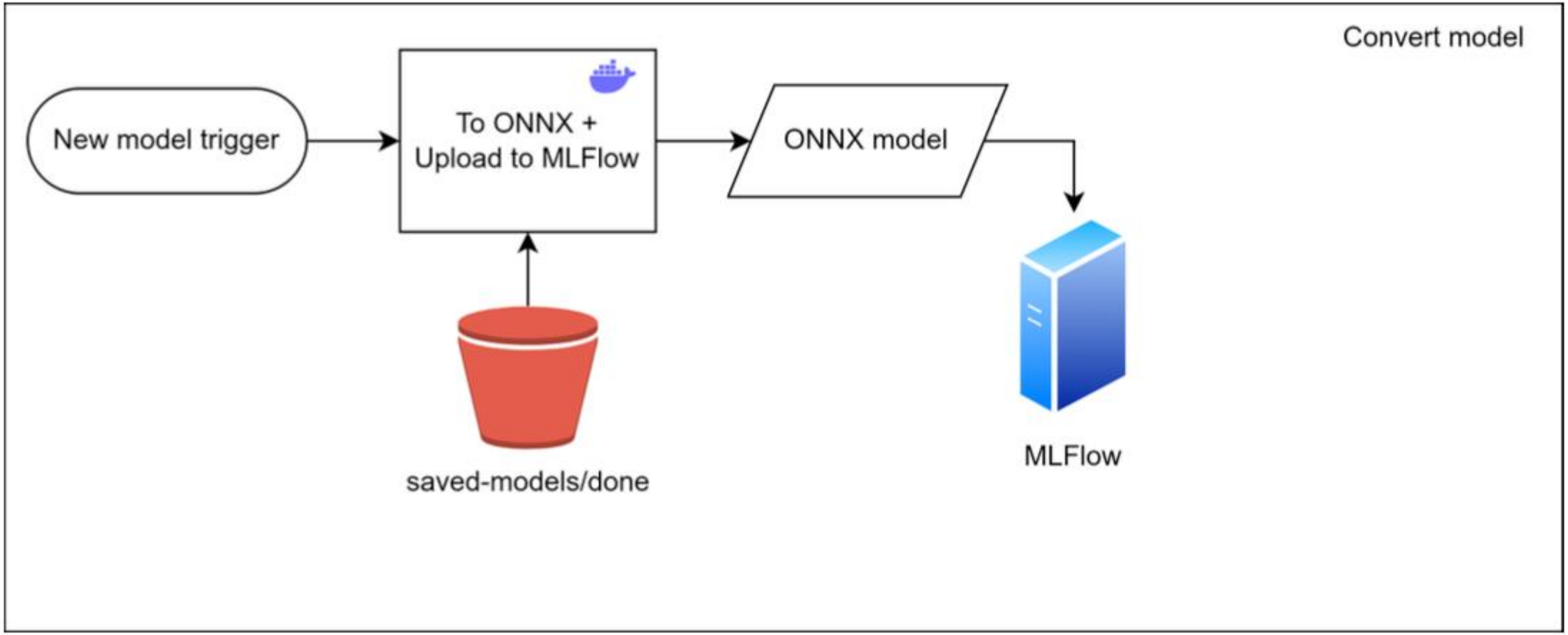
1. Model training.
2. Model storage and cataloging.
3. Model validation.

# Digital Twin: Model Training

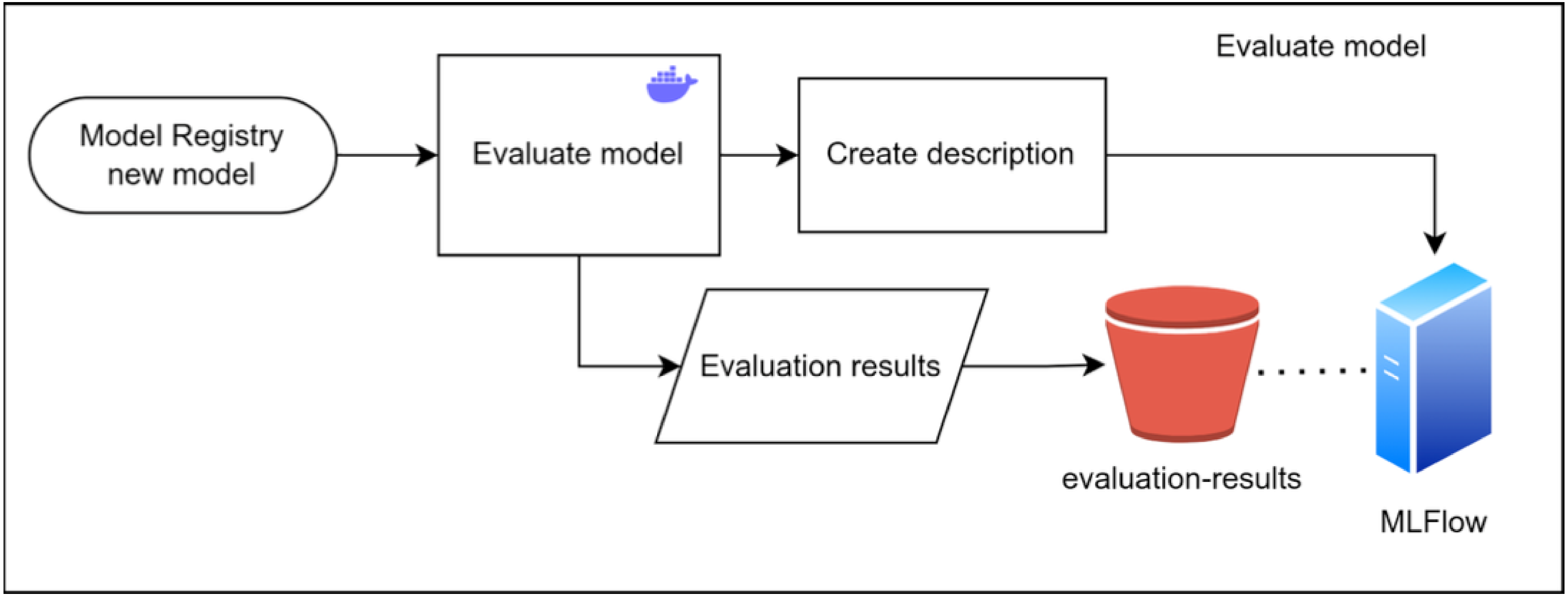


# Digital Twin: Model Storage



# Digital Twin: Model validation



# Conclusion

- Fast simulation approach of TPC detector can be achieved by utilizing generative ML approach (GANs).
- More complex Fast6 model outperform Fast4 model, but there is still a window for improvements to fit the reference solution (Geant).
- Future work include:
  - figure out specific requirements and/or extension to the training procedure for the model to fit our physics driven requirements by using in-depth analysis.
  - implement the (semi) automatic system for training, bookkeeping and encapsulation FastSim models.

# Thank you for listening

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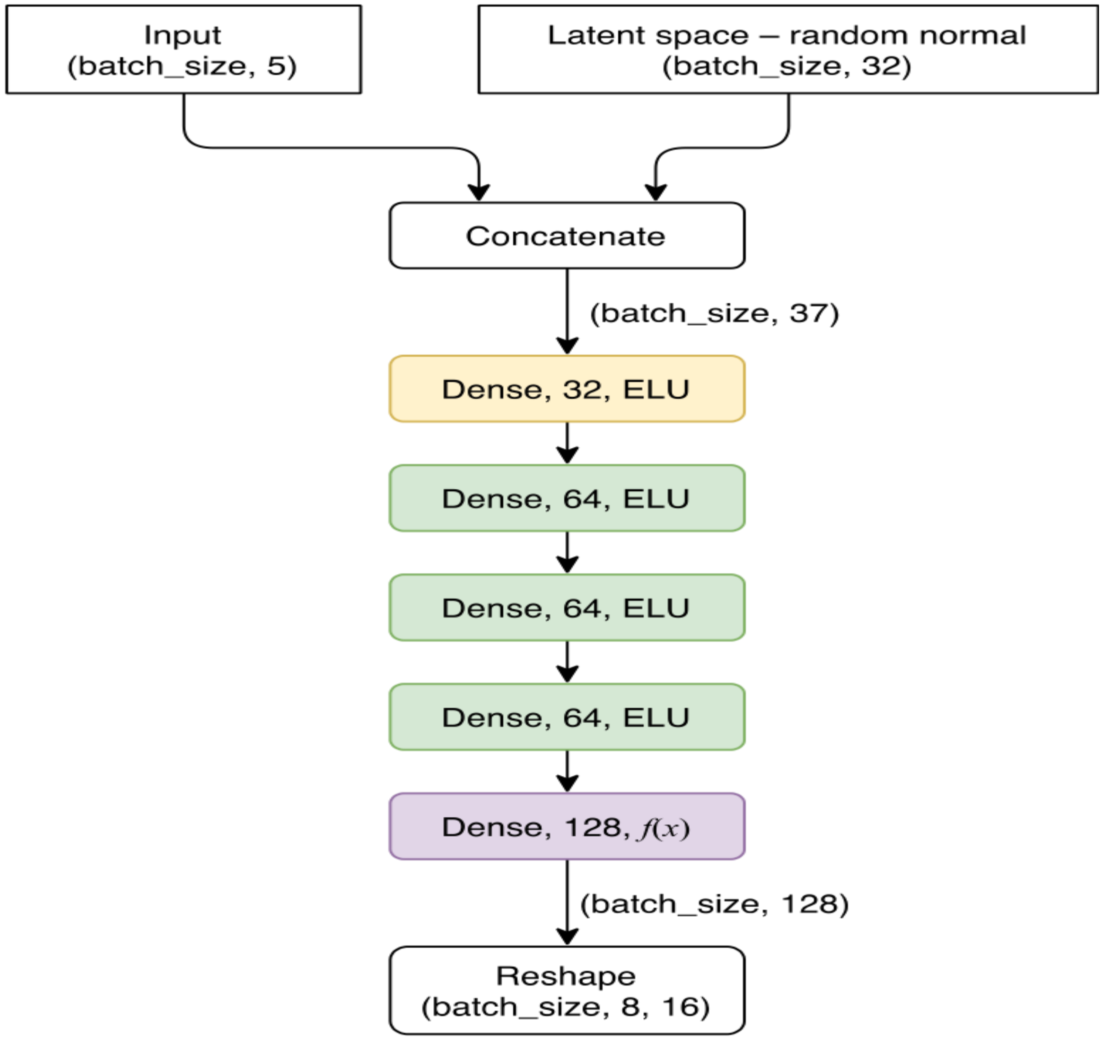
# Backup

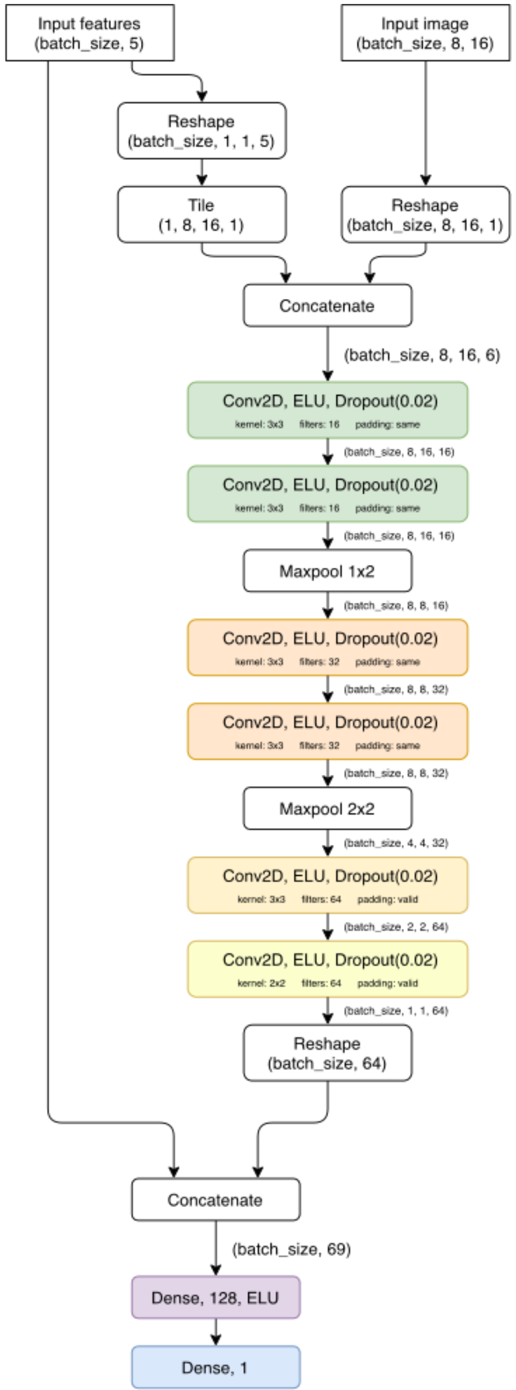
# TPC fast-sim: Features description

- Fast 4 utilizes 4 input features which are:
  - crossing angle — the angle between the transverse projection of the particle momentum and the normal to the pad plane;
  - dip angle — the angle between the full momentum and its transverse projection;
  - drift length — distance from the center of the segment to the triggered pad row, measured in the number of time buckets from the bunch crossing to the pad response generation;
  - pad coordinate — coordinate along the pad row direction of the projection of the track segment center onto the triggered pad row, measured in pad widths.
- Fast 6 utilizes 2 additional input features which are:
  - Transverse momentum: the component of momentum perpendicular to the beam line.
  - Pad row number.

# TPC fast-sim: Model architecture (Generator).



# TPC fast-sim: Model architecture (Discriminator).



# Digital Twin: General Structure and Workflow.