Generative Adversarial Networks for the fast simulation of the Time Projection Chamber responses at the MPD detector

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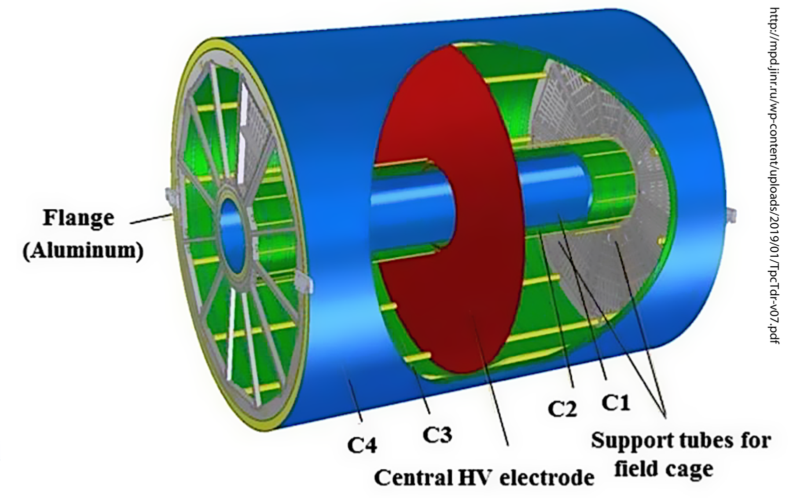
TPC tracker of the MPD experiment

- Main tracker of the central barrel
- Provides PID through dE/dx
- Fast simulation model is very much wanted
  - Computational bottleneck in the electron drift simulation
- **Our goal: accelerate TPC response simulation with a high-fidelity and physically acceptable generative surrogate**

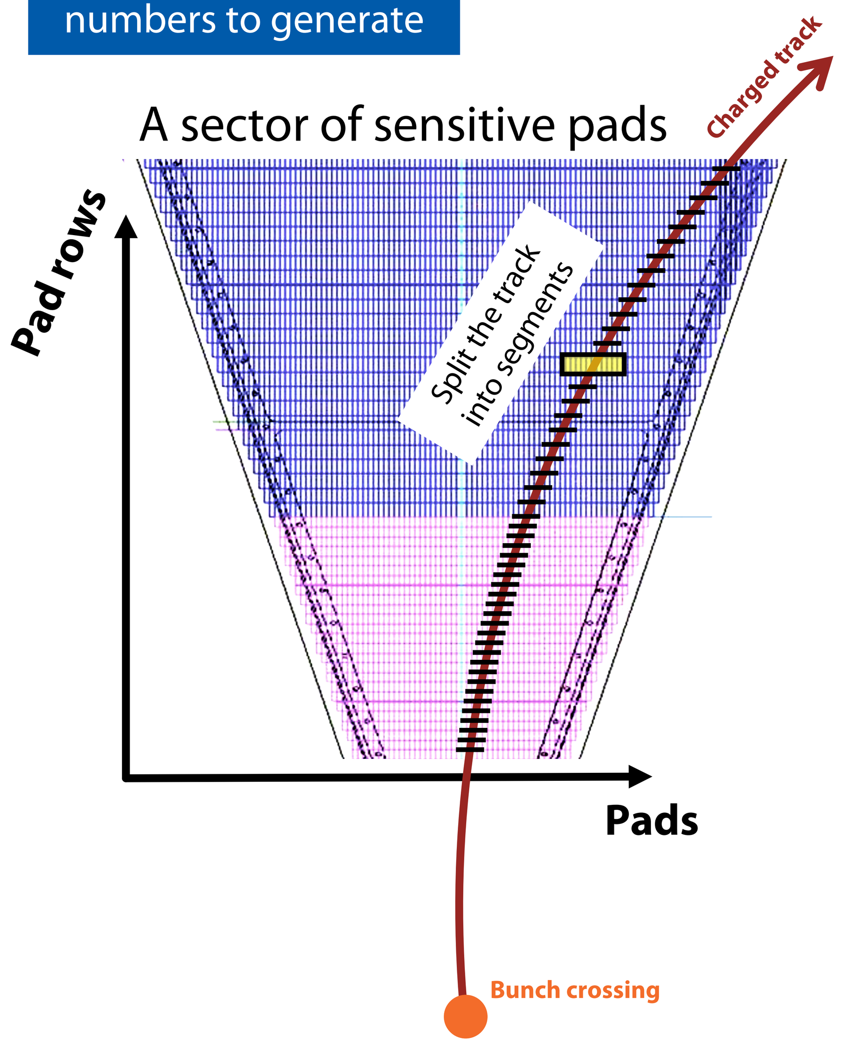


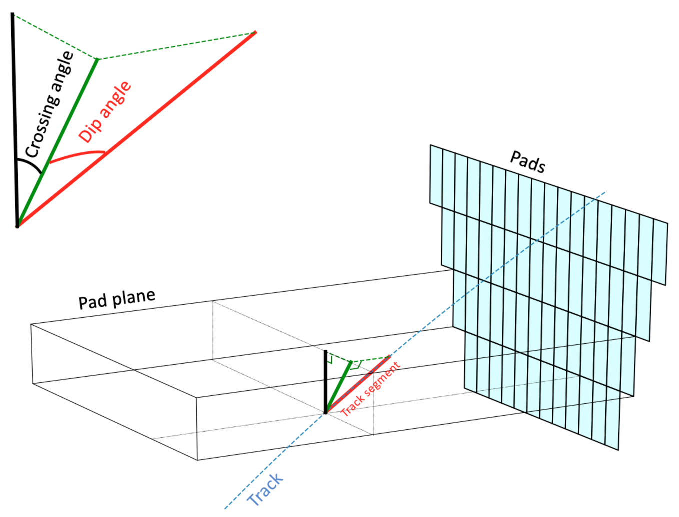
Fast simulation approach

- How can we use a GAN to produce raw pad responses?
- Output space too large:

95 232 sensitive pads × 310 time buckets per bunch crossing = almost 30M numbers to generate

- Factorize the problem: split the track into segments that contribute to a single row of pads each
  - Ignore inter-row correlations
- Utilize the spatial and temporal localization of the signal from a single segment
  - Only small fraction of pads from a row is hit, in a small fraction of time intervals
- Output size reduced:
  - from 30M to 128 = 8 pads × 16 time bins
- Input parameterized by the segment's location and direction



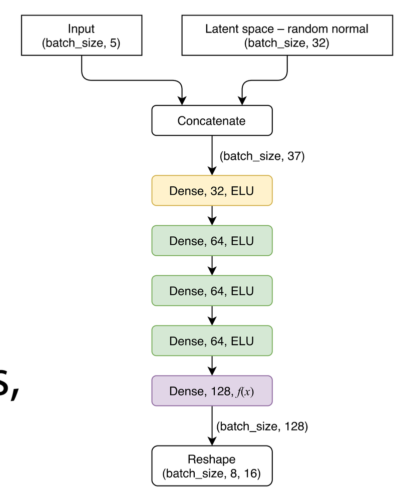


- Training data from detailed simulation
- Pion tracks flat in angles and coordinates, constant p_T

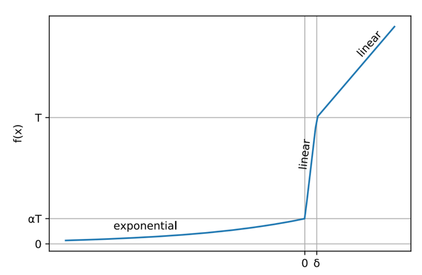
Architecture – key features:

- Custom generator activation at output to simulate the noise threshold in a differentiable manner
- Convolutional discriminator, but fully-connected generator (faster at inference time, without loss in quality)

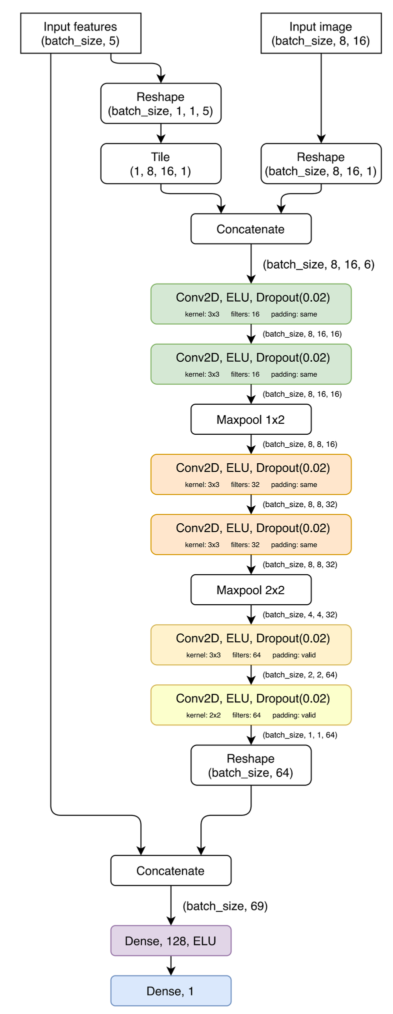
Generator



Custom activation



Discriminator



Model validation

- Two levels of quality assessment:
  - At raw signal level, for prompt checks and model selection
  - At reconstruction level, after having implemented our best model into the MPD simulation pipeline

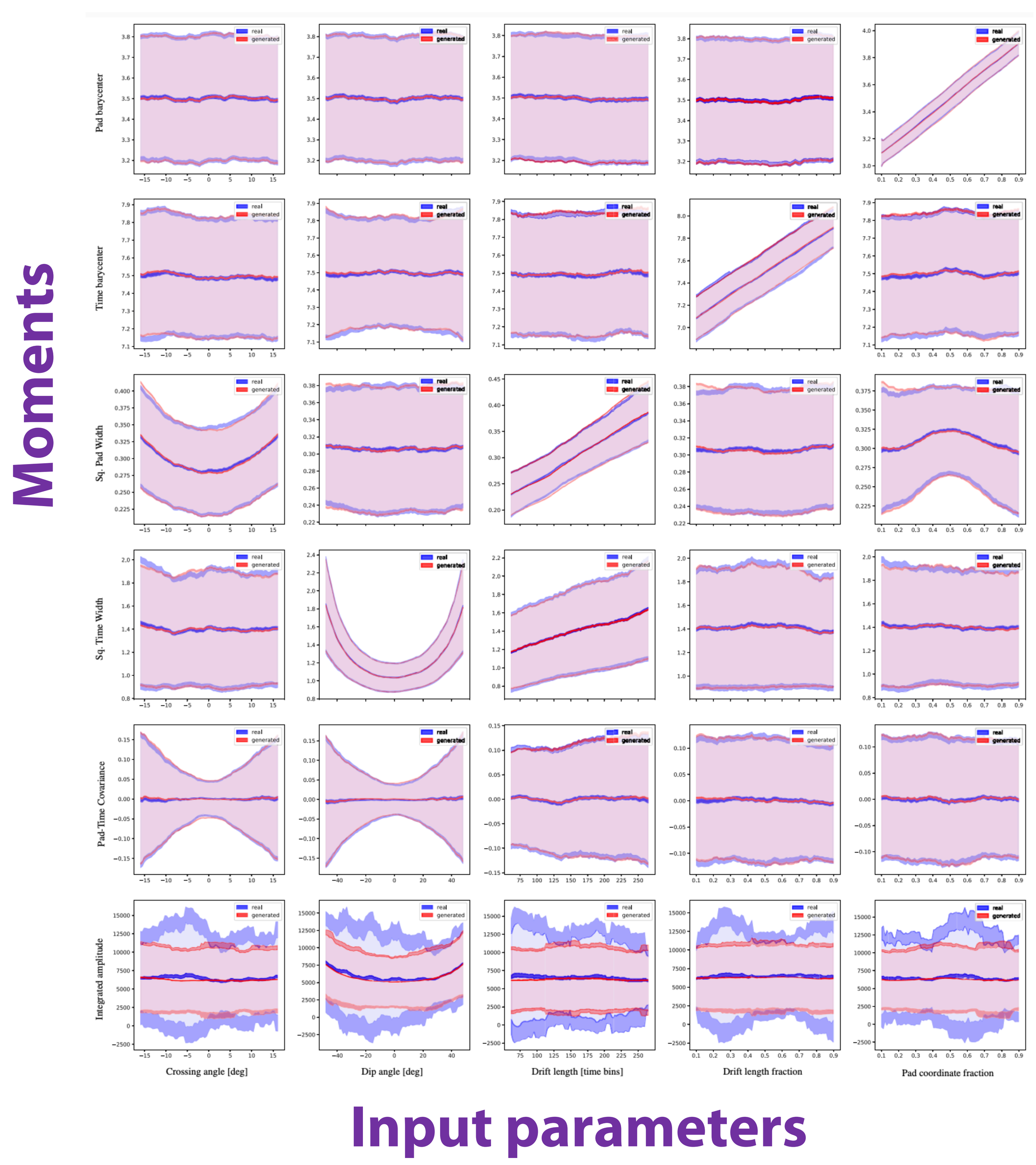
Raw signal level validation

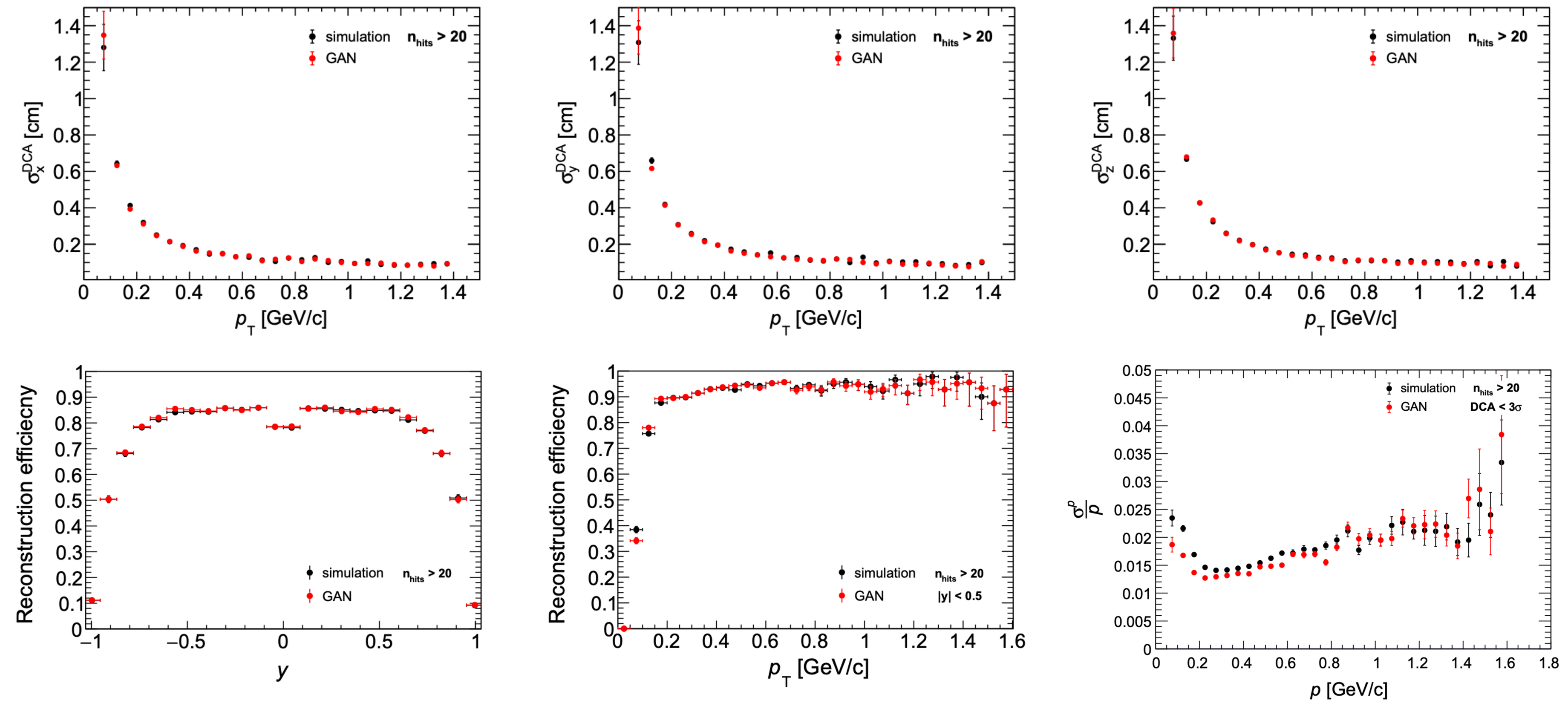
- Describe individual signals (2D images in pad-time plane) using their integral amplitude along with 1st and 2nd order moments:
  - Barycenter (center of mass) location, widths & covariance
  - Total: 6 numbers per image
- Compare distributions of these moments between GAN and the detailed sim
  - As the function of track segment parameters (each moment vs each parameter)

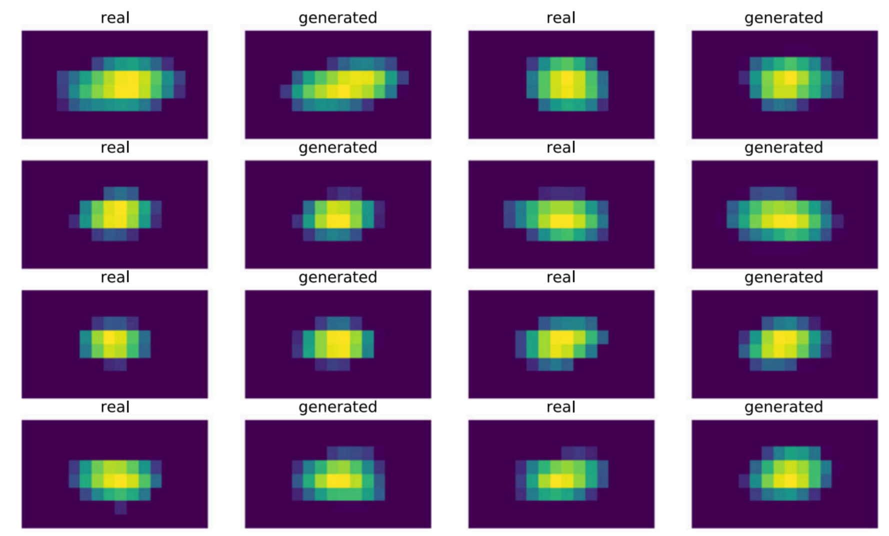
Reconstruction level validation

- Comparing coordinate resolution, reconstruction efficiencies and more (see the paper)
- Most characteristics are spot on! (srsly, see the paper!)
- Inconsistencies are well-understood and will be fixed at the next iteration (haven't you seen the paper yet?)

RAW SIGNAL LEVEL VALIDATION



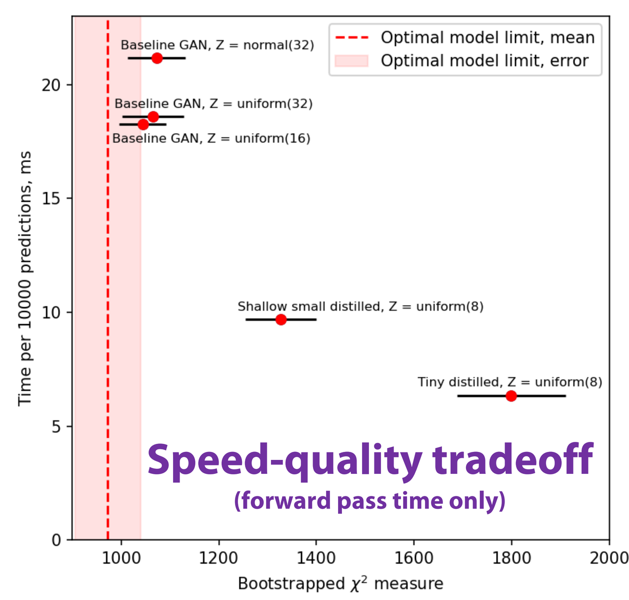




Example signals

Model speed

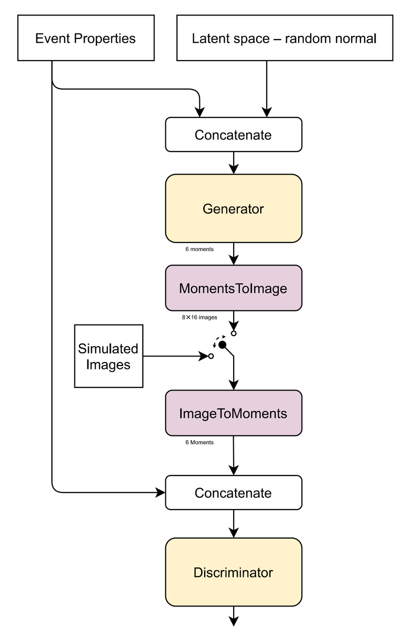
- TPC digitization sped-up by a factor of 12 for the expected-occupancy events (running on CPU)



KEY RESULT

12x acceleration achieved for TPC with physically acceptable quality

Alternative approach [WIP]: generating moments



- Optimize the raw metrics directly
- Convert the metrics (5 moments + amplitude) into raw signal image
  - Not a trivial operation: getting biased image by evaluating 2D-Gaussian at discrete grid nodes
  - Learning to account for these biases by generating adjusted moments in the first place
- Training not stable, looking for improvements

For more details, see our EPJC paper

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