中央研究院物理研究所
INSTITUTE OF PHYSICS, ACADEMIA SINICA

Framework Review and Outlook

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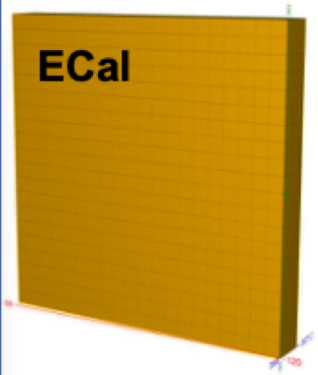
ZDC ML

WAI YUEN CHAN

Part I: ZDC-ML Framework Review

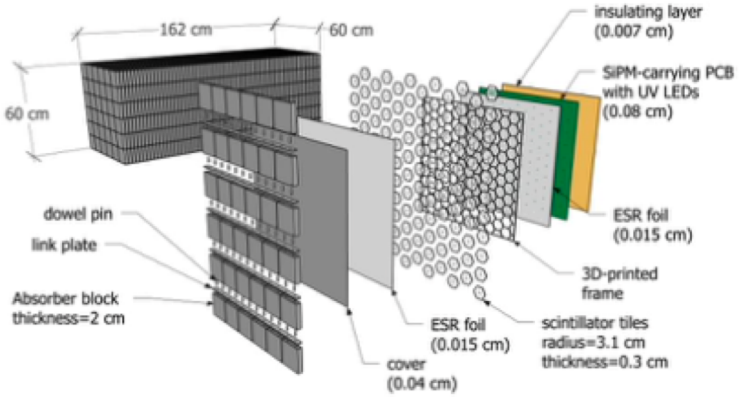
ZDC Data structure

ECal



LYSO Crysal
60cm*60cm
3cm*3cm*7cm / cell
20*20 cells
7cm ~ 6X0 in Z

HCal



65cm in X, 60cm in Y, 163cm in Z
64 layers, 8 slice/layer
1 layer = steel + scintillator tile + SiPM

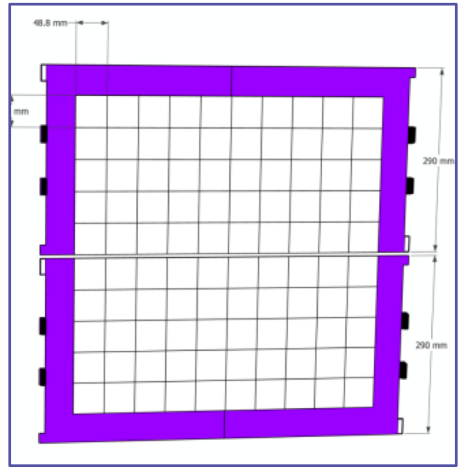
	ECAL	HCAL
Layer in z-direction	1	64
x-y grid	20 x 20	10 x 10 (SiPM prototype)
Total cells	400	6400

MC parameters (per event):

E	p_x	p_y	p_z	θ	ϕ

ECAL Matrix:
[20 x 20]: Contain energy per cell

HCAL Matrix:
[64 x 10 x 10]: Contain energy per cell



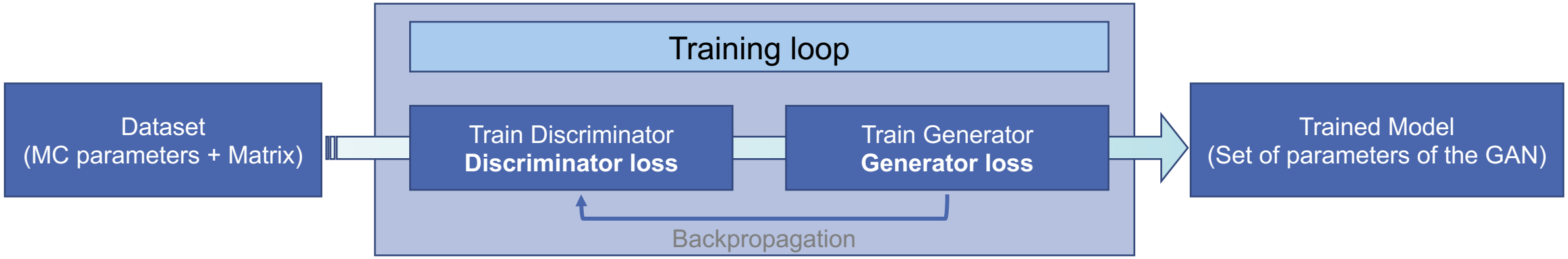
ZDC-ML framework logic

This is a generative adversarial network (GAN), meaning that we have 2 parts in the framework:
Generator and Discriminator.

Generator task:
Based on the MC parameters and ECAL/HCAL matrix, generate an artificial events to fake the Discriminator.

Discriminator task:
Identify is the event coming from generator (fake), or from MC (real)

Our goal (or general GAN goal):
Train the Generator to learn about the MC dataset, in order to generate an artificial events which are real enough to confuse the Discriminator.



ZDC-ML framework: Generator workflow

So far, the framework is working with ECAL dataset only, we call this version as ZDC-ML v3.
Here is the workflow of ZDC-ML v3:

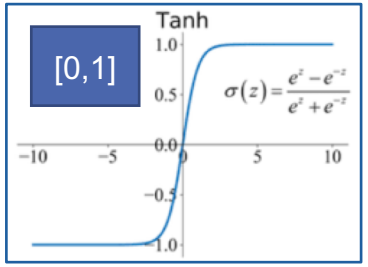
STAGE 1: Data Pre-process

- Input: MC parameters [6]
- Parameter encoder [128]
- Linear Decoder [288]
- Unflatten [b, 3, 3]

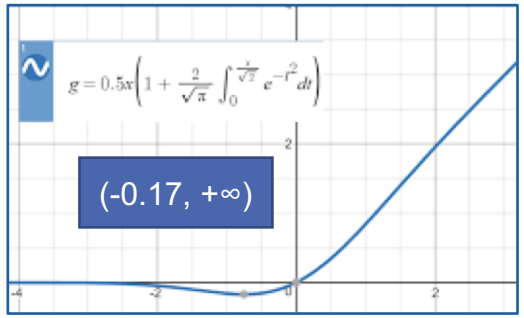
STAGE 2: Convolution Transformation

- ConvTranspose2D [b, 5, 5]
- Conv2DBlocks (+ Pixel Shuffle) [b, 10, 10]
- Conv2DBlocks (+ Pixel Shuffle) [b, 20, 20]
- FiLM (Feature-wise Linear Modulation)

STAGE 3: Activation and loss calculation



- Mask [1, 20, 20] **Position of hits** → Tanh → Mask loss (BCE loss)
- Value [1, 20, 20] **Energy deposited** → GELU → Value loss (MSE loss)

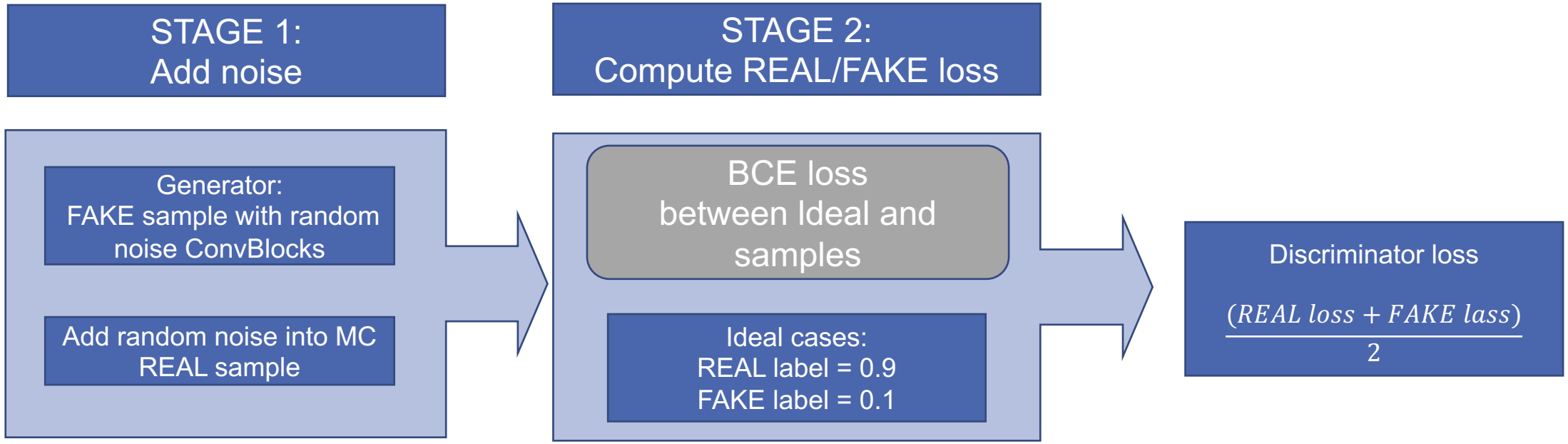


Generator loss

Mask loss + Value loss

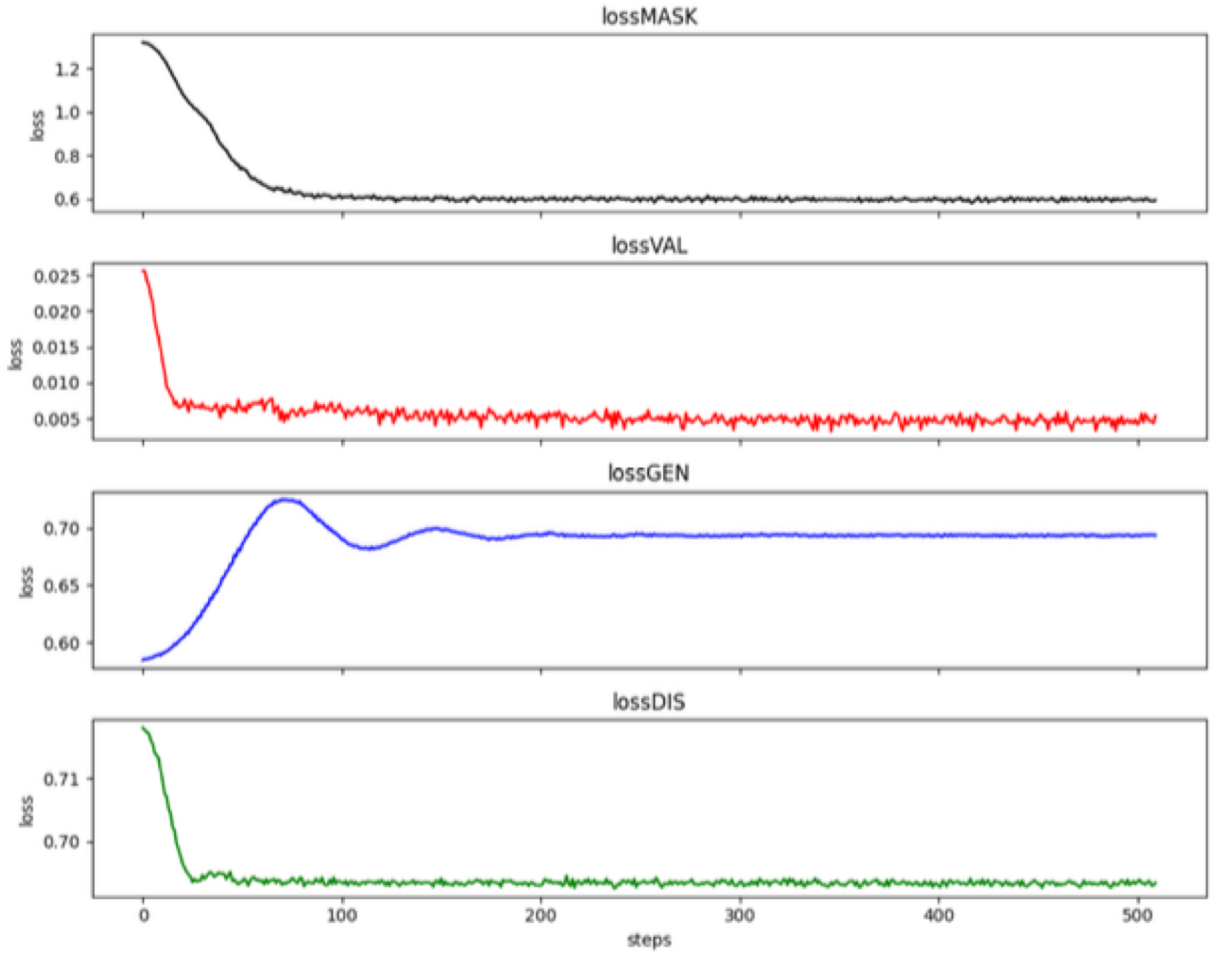
ZDC-ML framework: Discriminator workflow

In discriminator, samples are generated by generator (Noise path) as well, then being compare with MC sample.



ZDC-ML framework: What should we expect?

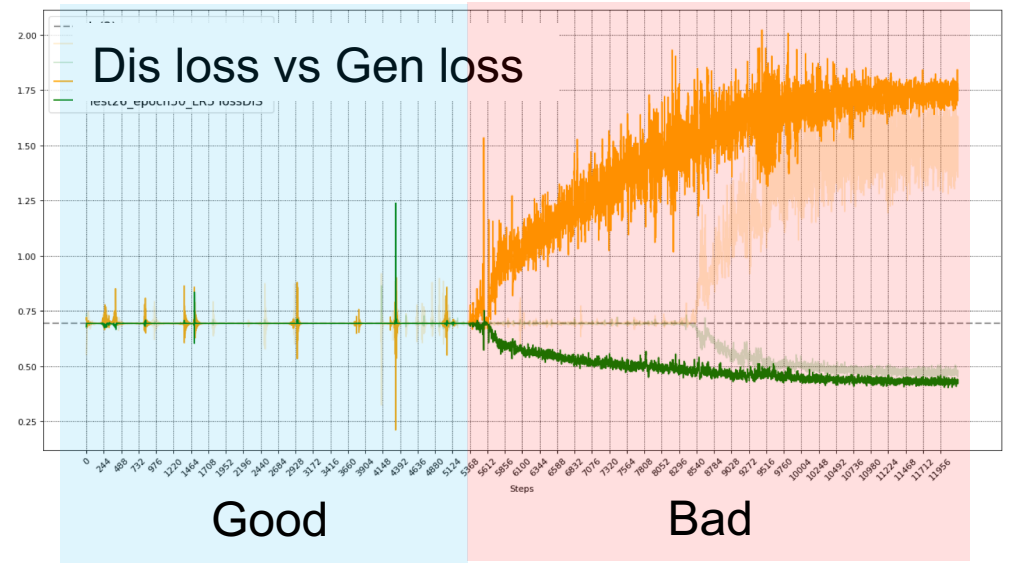
We judge the training performance by looking at the loss curve.



This is just an example to show that what we should expect:

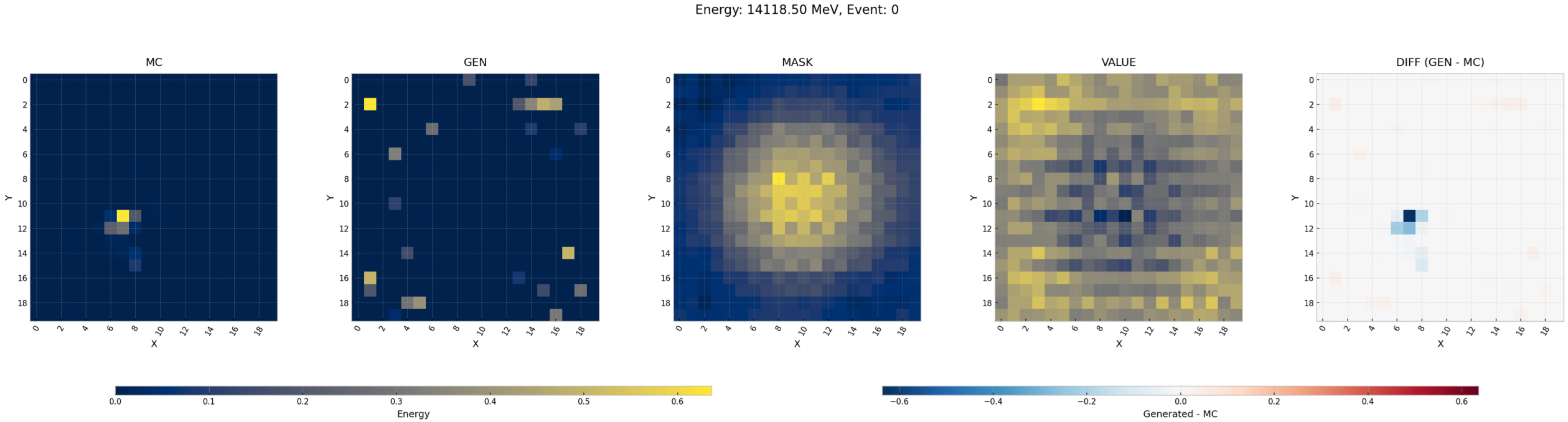
Mask loss and Value loss:
Reduce along the iteration, then become stable.

Generator and Discriminator loss:
Becoming stable around 0.69 ($log2$), and the trend should against each other.



ZDC-ML framework: Test and visualization

Besides the loss curves, we will use another dataset to test how well the model is.
After the test, one can check the energy distribution to justify the model.



Here we would like to compare the MC and Model generated distribution to judge the performance.
One can also check the global performance by calculate the MSE loss between MC and Model generated events across the input energy spectrum, but we would show it here.

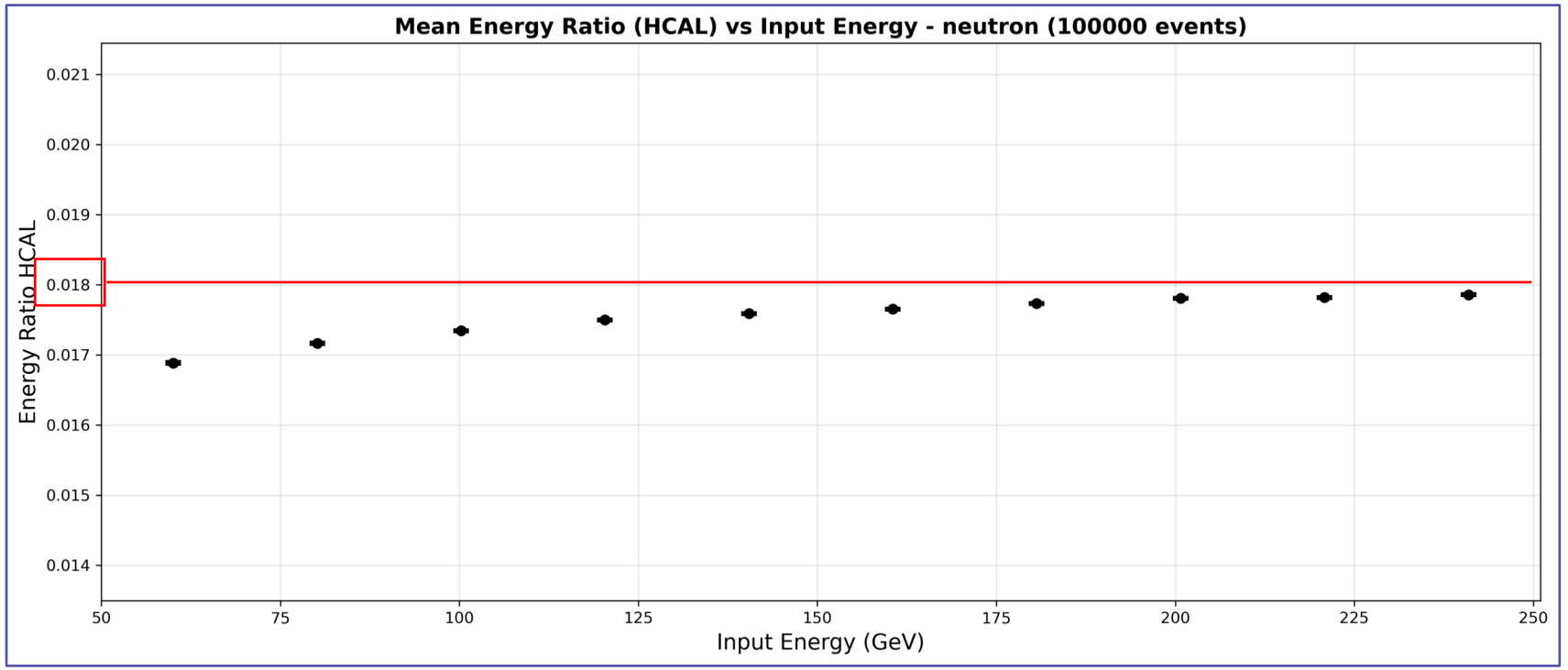
Part II: From ECAL only to ECAL+HCAL

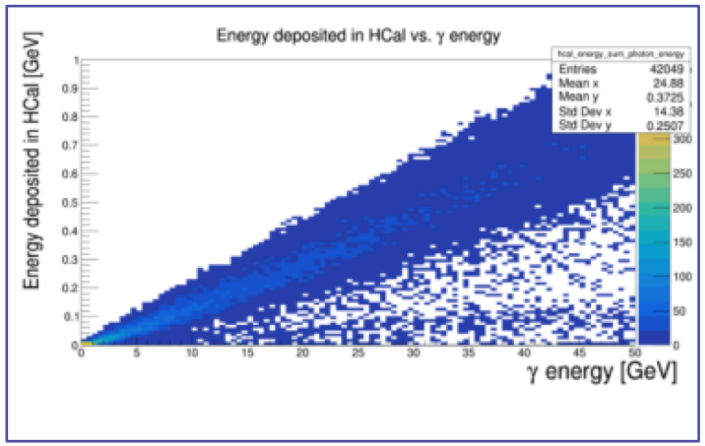
ZDC HCAL: Energy fraction

We have some e-mail exchange with Alessio I. from University of Connecticut, who works in ZDC reconstruction
His study confirmed that our observation about most of the energy are missing in the HCAL is **CORRECT.**

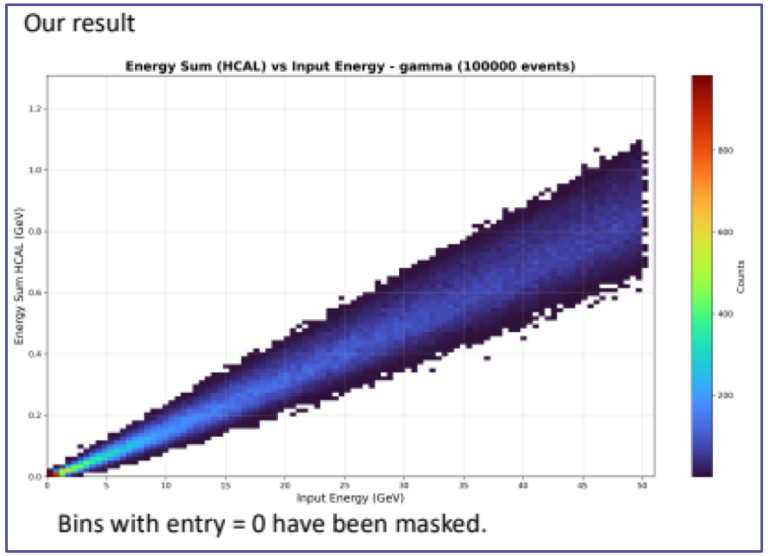
In his understanding, the G4 simulation only consider hits which is recorded on the scintillator tile.
Therefore only fraction of the beam energy is being capture.

Less than 1.8% of the energy is being deposited.





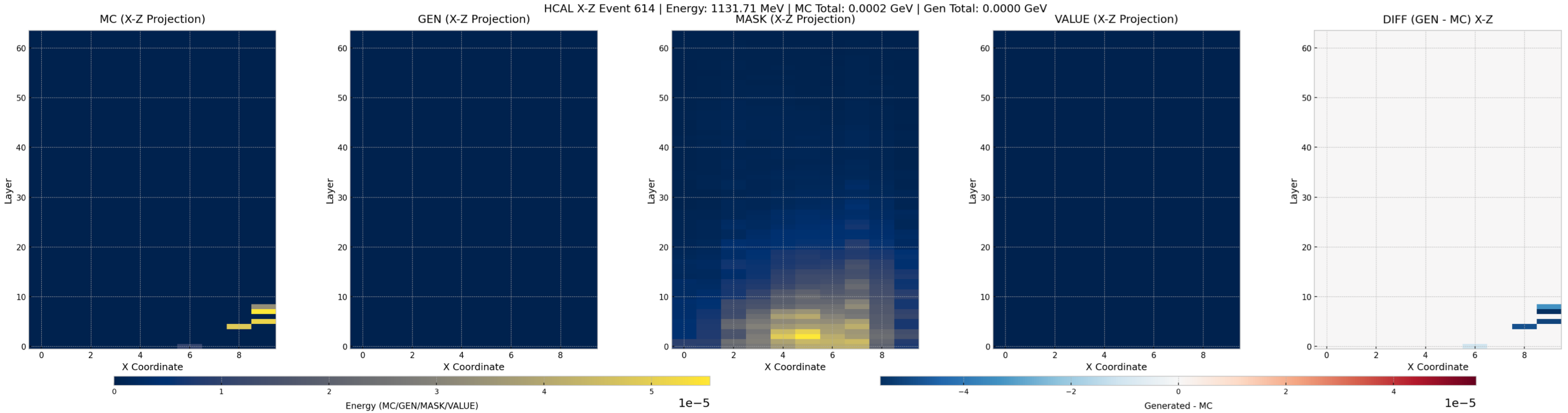
Our result



ZDC-ML Framework: HCAL implementation

We have 64 layers of SiPM in the HCAL and therefore the our dataset is a 3D matrix: [64 x 10 x 10]
The easiest way to implement HCAL dataset is just following ECAL approach with 3D Convolution Blocks.

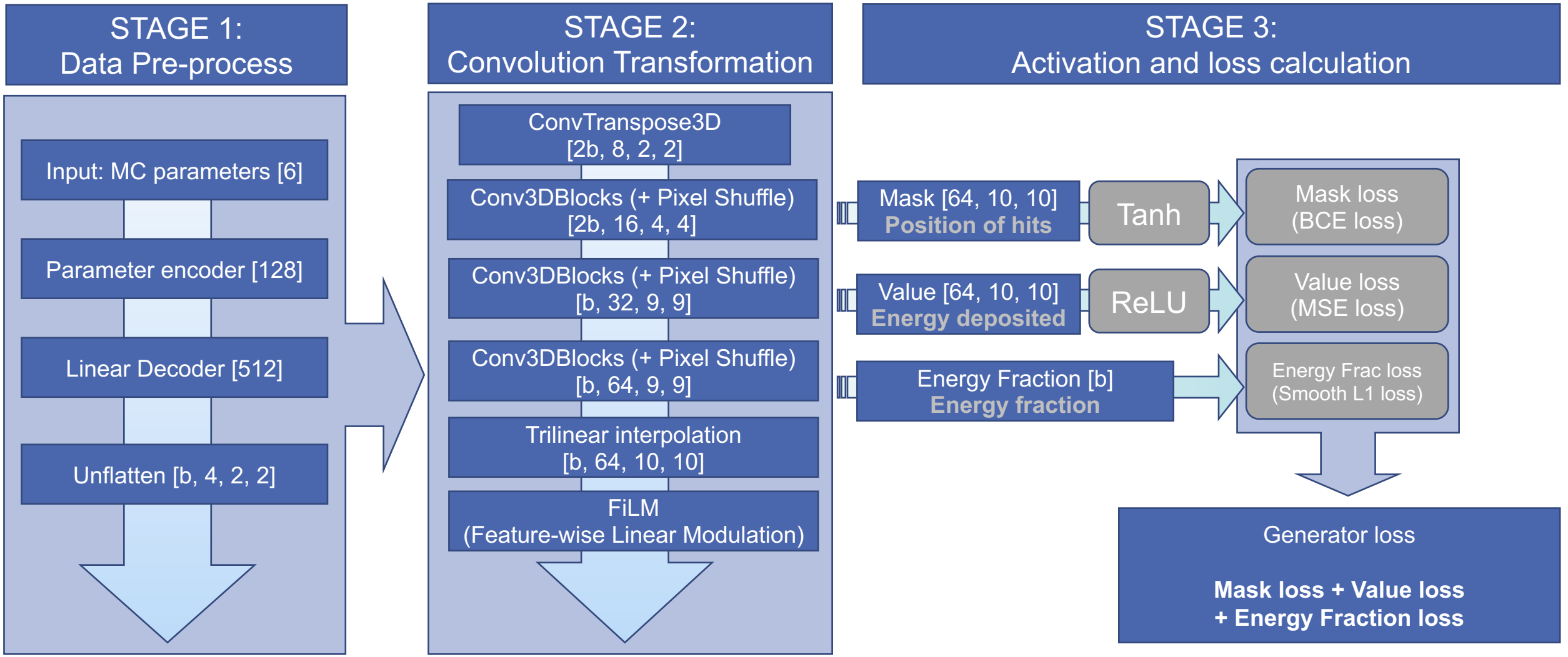
Here we train a model with HCAL then visualise in the **X-Z plane** to justify the performance.



However, given that the energy dump in HCAL is extremely small compare the beam energy. The model struggle to learn about the energy scale (As we can see nothing showing in **Value**).
In order to constraint the phase space, we should add the energy fraction into the framework as well.

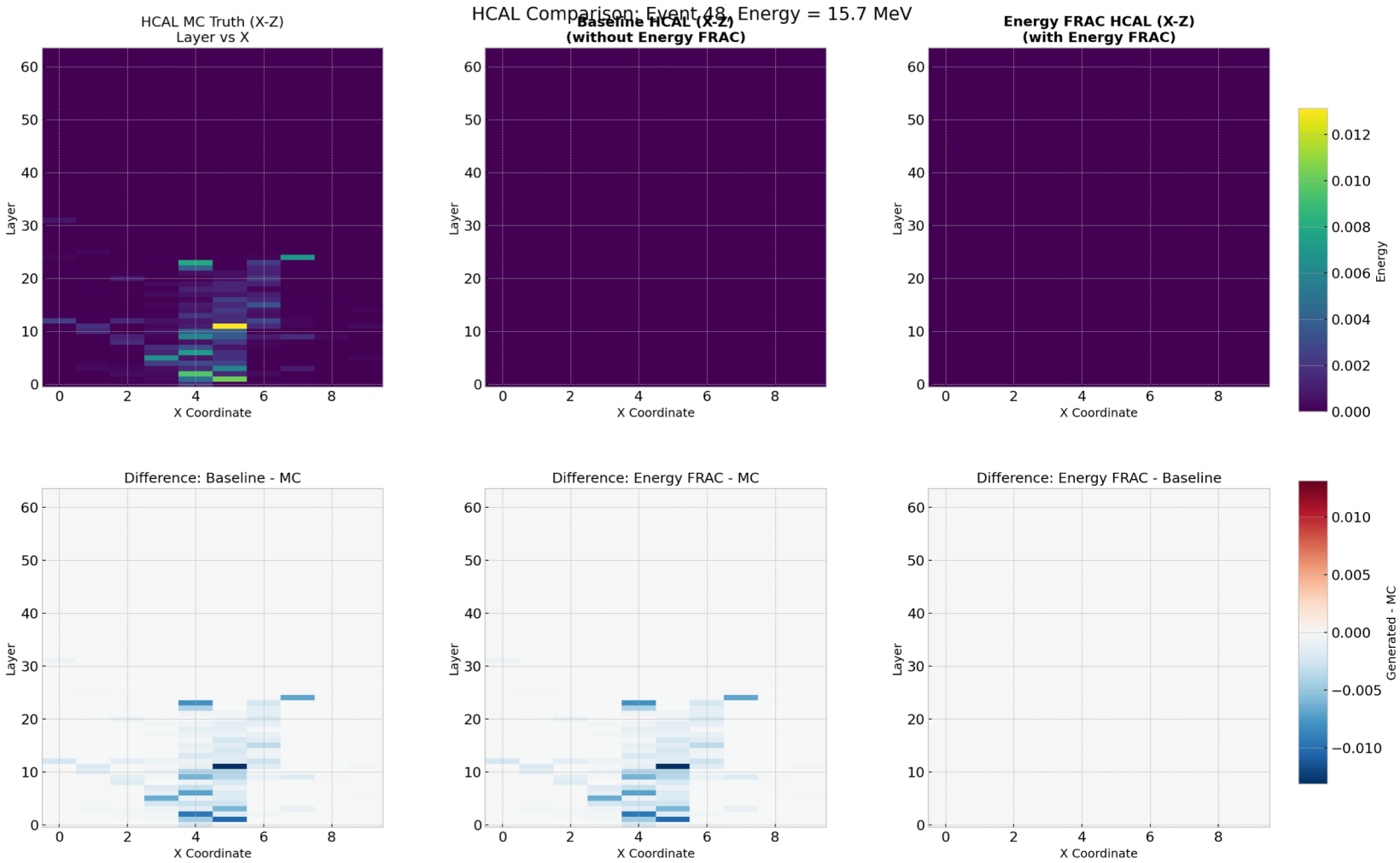
ZDC-ML framework: HCAL Generator workflow

In ZDC-ML v5, we have added HCAL generator with energy fraction as a loss.



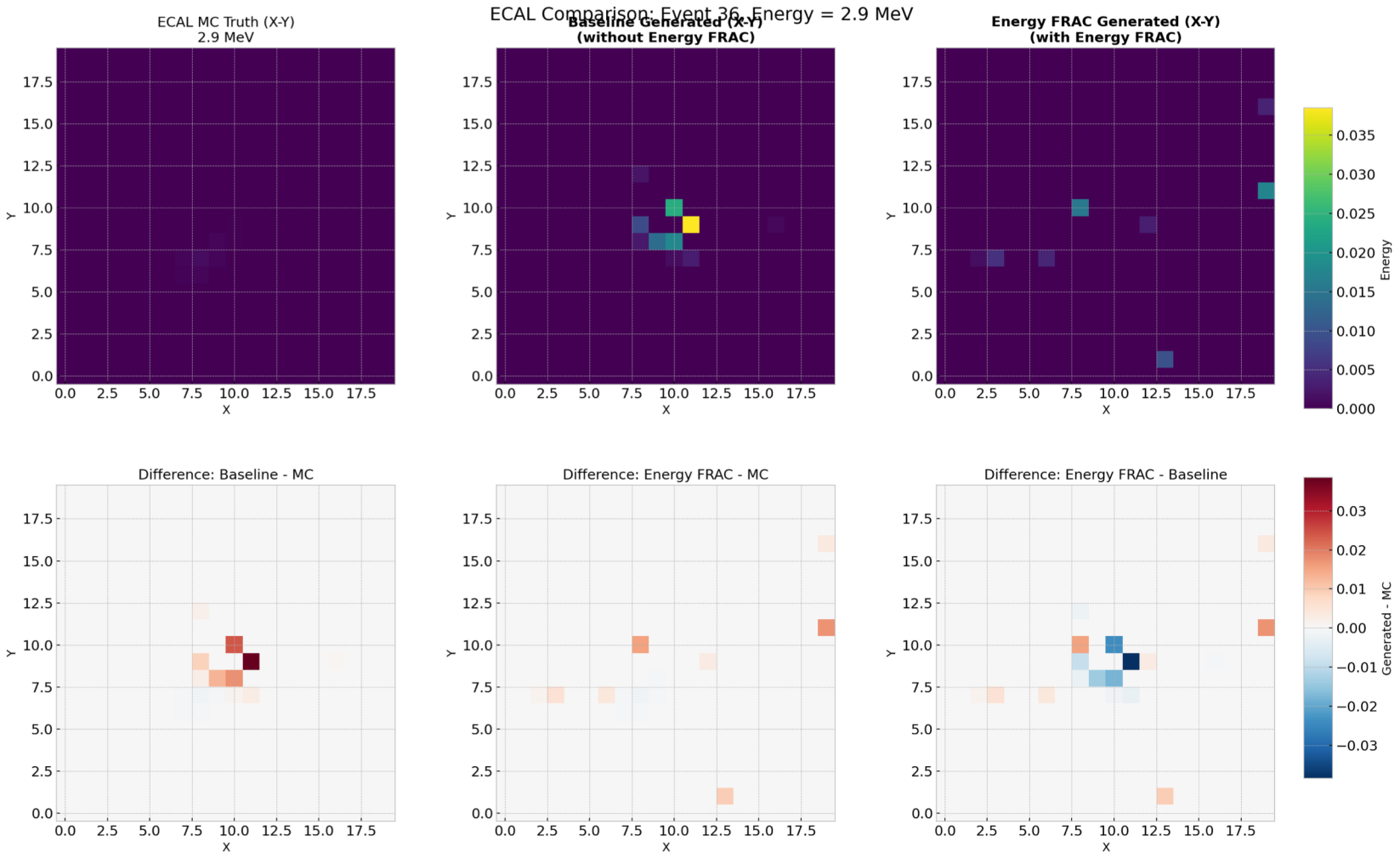
ZDC-ML Framework: HCAL implementation

Here we compare the X-Z plane with and without Energy frac loss. We can't see the impact in HCAL.



ZDC-ML Framework: HCAL implementation

We have add the energy frac loss into ECAL as well and here we can see some impact.



ZDC-ML framework: What next?

Besides the energy fraction in HCAL (and ECAL) and fine-tuning the weighting, we should also consider:

1. Relation between layers (also ECAL <-> HCAL)
2. Global showering pattern
3. Better connection between Mask and Value for each cell