ML tracking

IRIS-HEP fellowship project presentation

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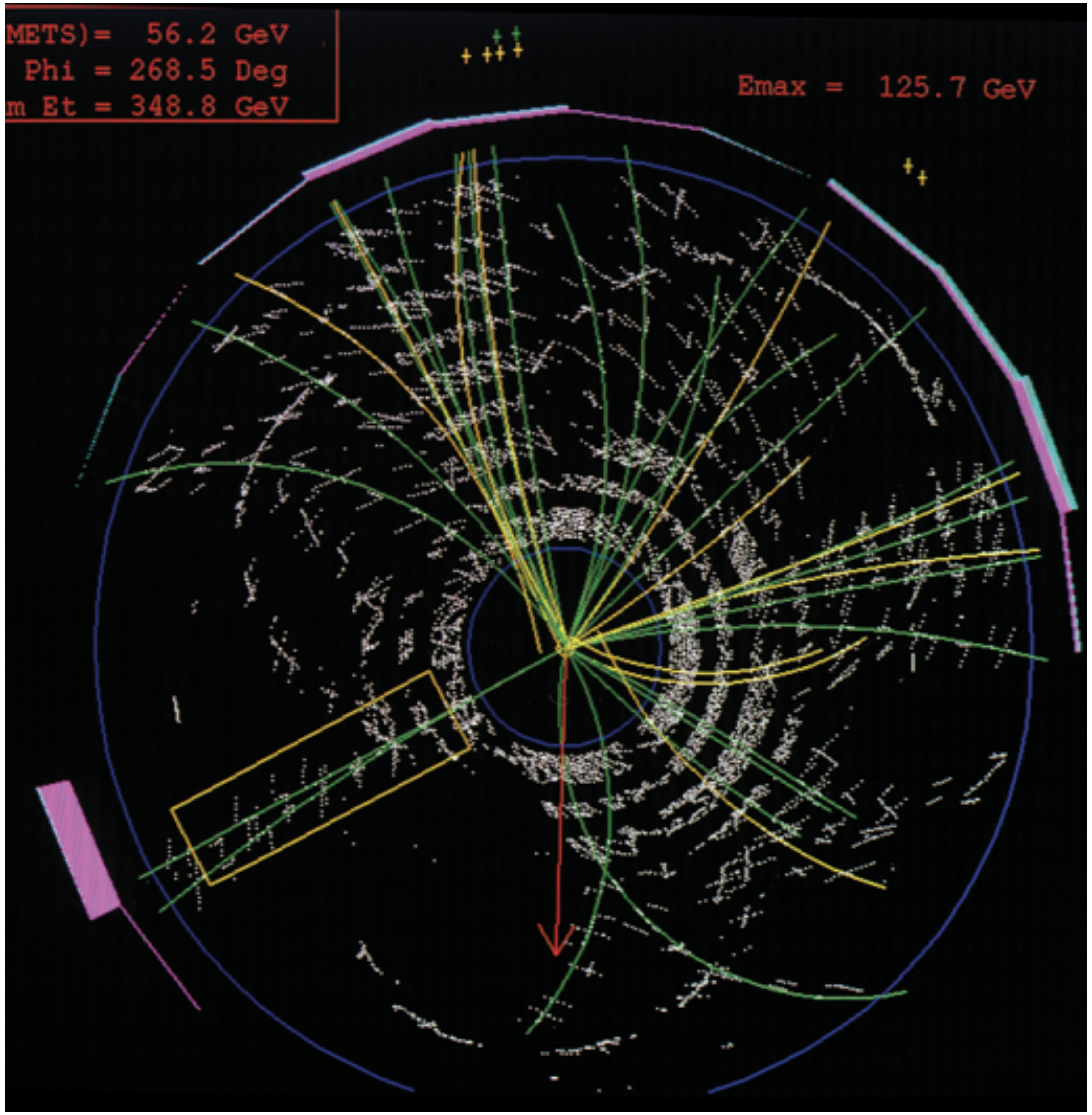
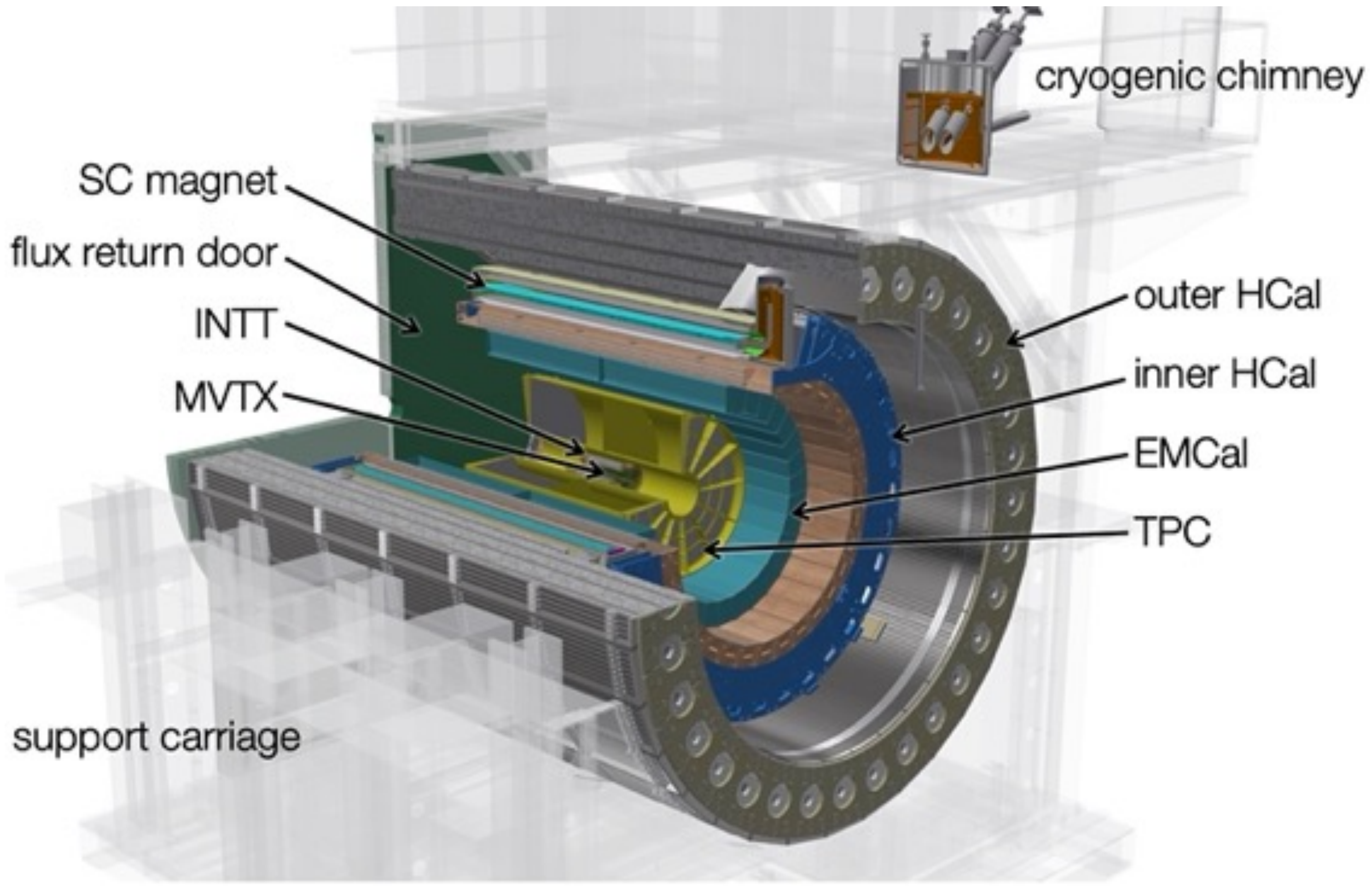


Project description

Particles collision data

Simulated by sPHENIX project

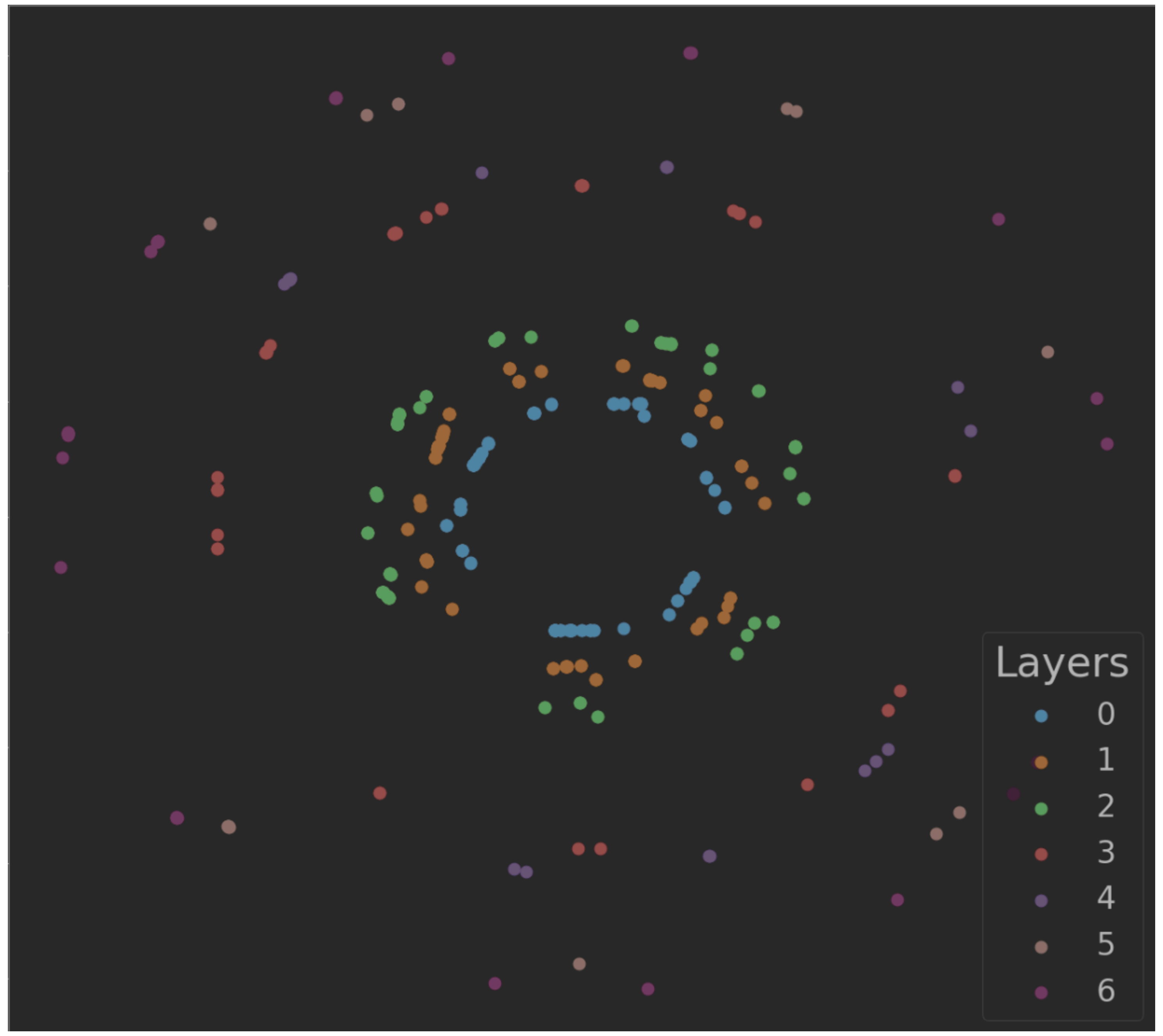
- After beams' collision
- Detection
- Analysis

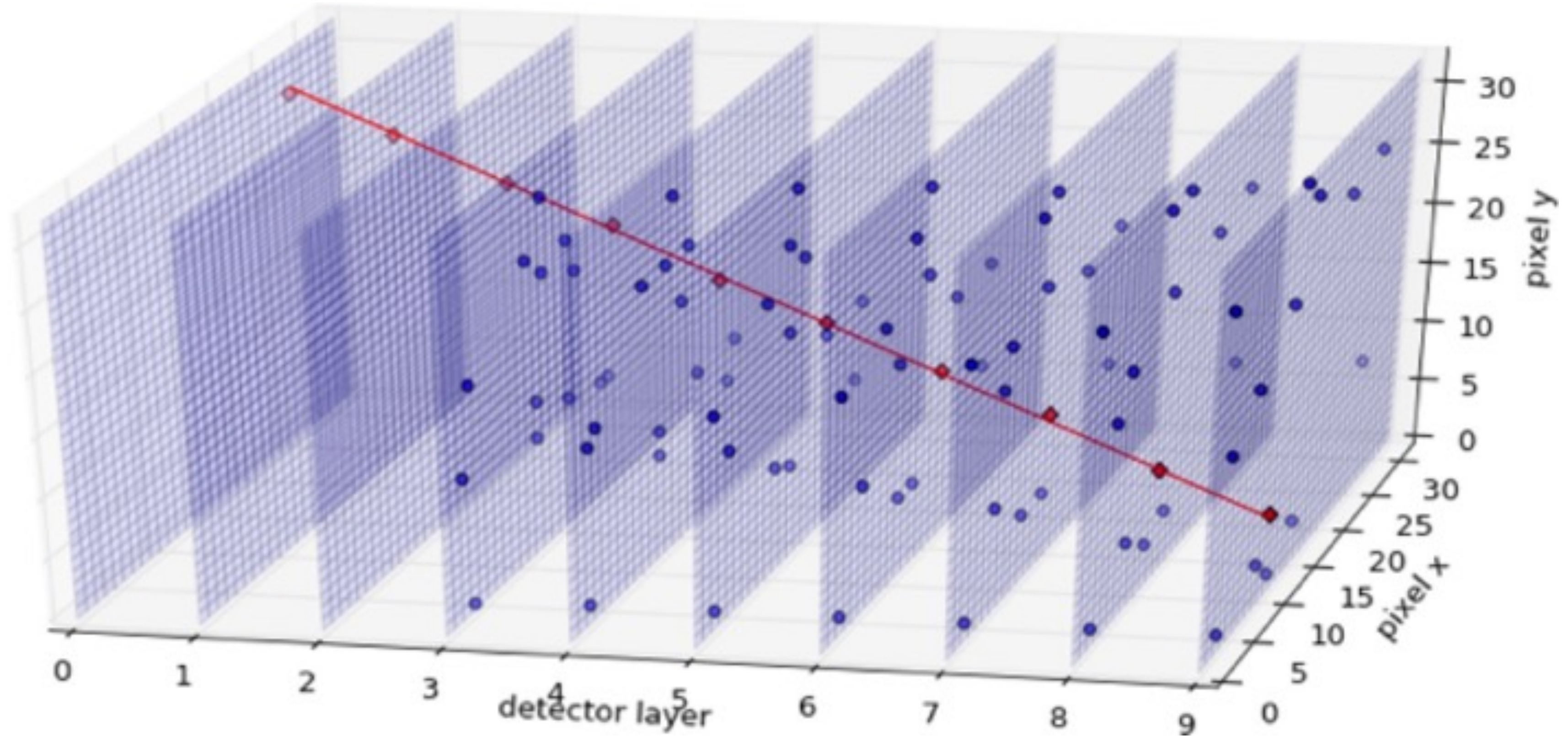


Detection

MVTX & INTT detectors

- Complex detector geometry
- High dimensionality (9k x 9k x 3)
- Variational input data
- Solutions: models with flexible data dimensionality + reduction of the useless data

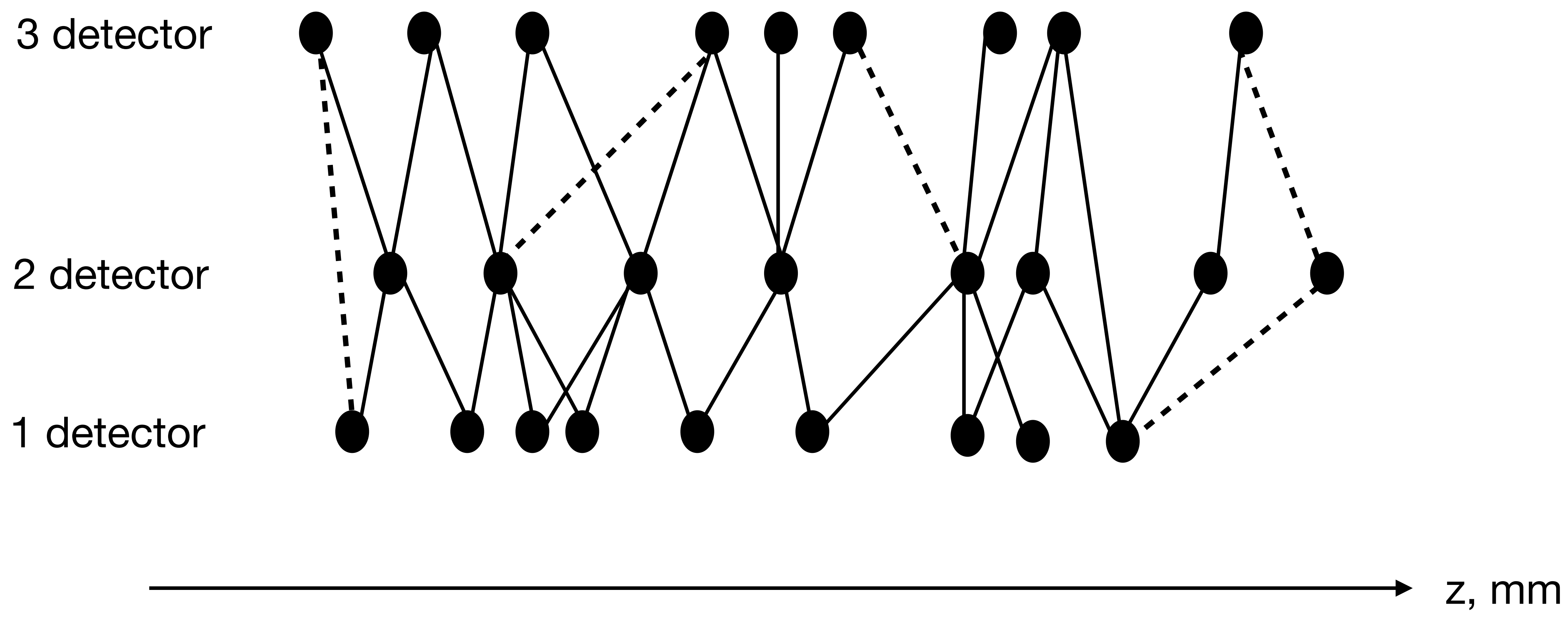




0	1	0	0	0	0	0	0	0	0	0
1	1	1	1	0	0	0	0	0	0	0
0	1	1	0	0	0	0	0	2	0	0
0	0	0	0	0	0	0	2	2	0	0
0	0	0	0	0	0	0	2	2	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	3	3	0	0	0	0	0
0	0	0	3	3	3	3	0	0	0	0

Tracks

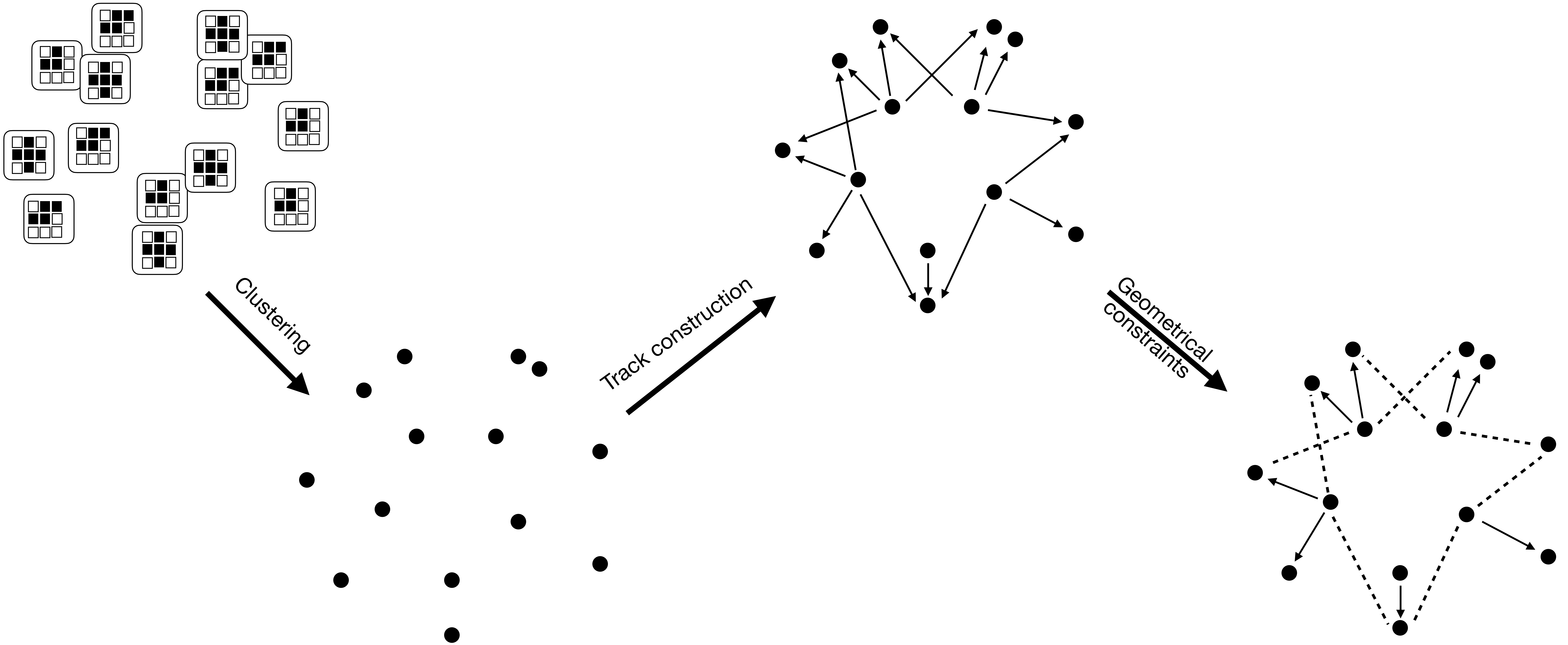
& their representations



- Tracks ~ graphs
- Geometrical constraints: $\delta(\phi) \leq \frac{\pi}{4}, \quad \delta(z) \leq 300$ mm
- With each iteration we find more relevant tracks and automise the process of matching the hits into graphs

Pipeline overview

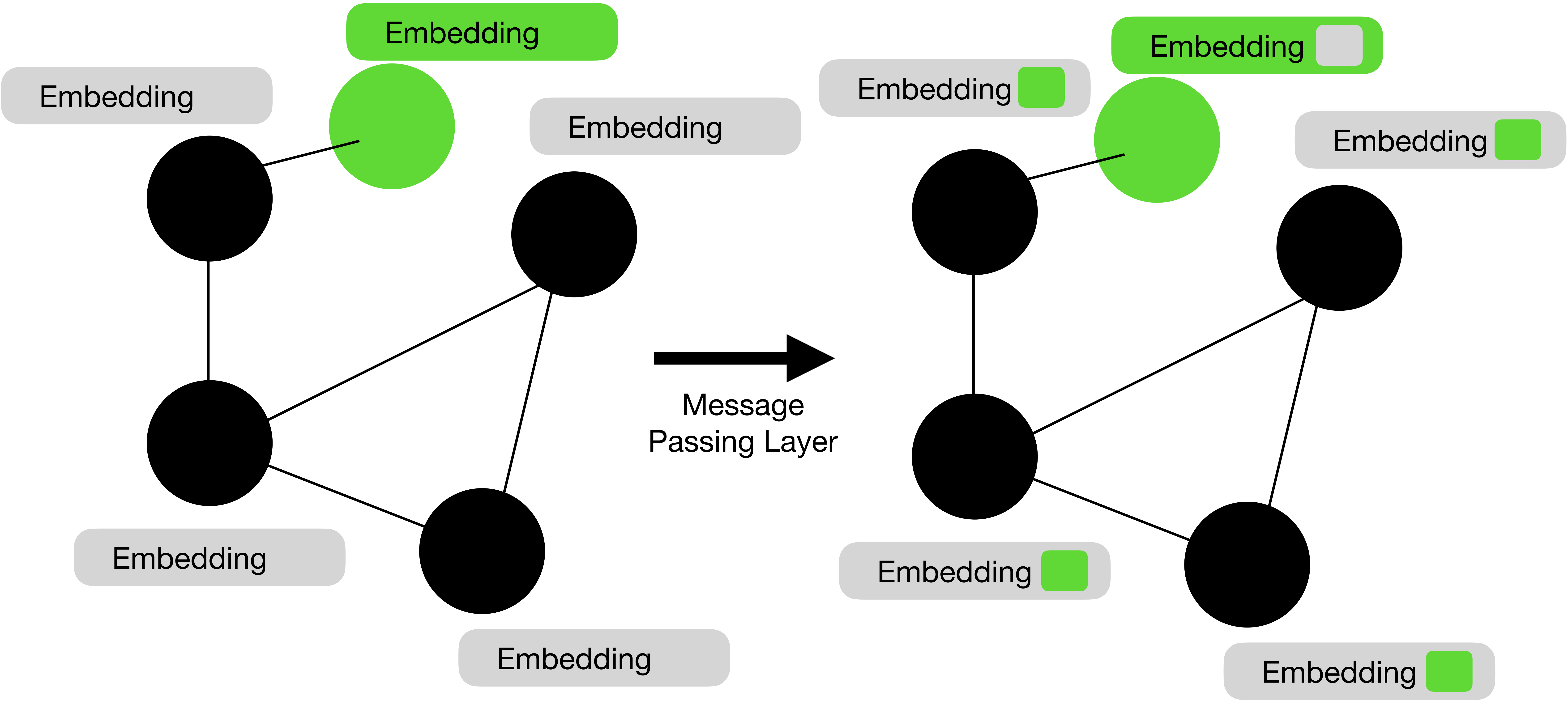
Track reconstruction



Graph Neural Networks

GNN idea

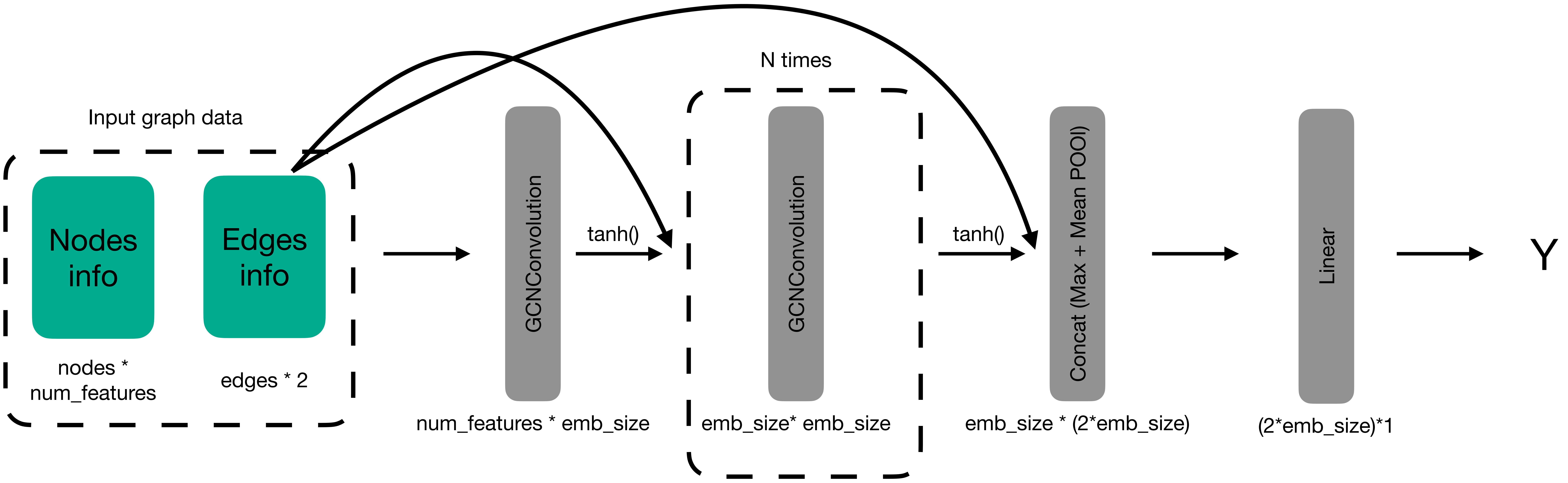
G = F(N, E)



- Predictions: node level, edge level, graph-level
- Hyper parameters: Embedding size, MPL amount.
- Python lib for working with GNN - PyG (PyTorch geometrical)

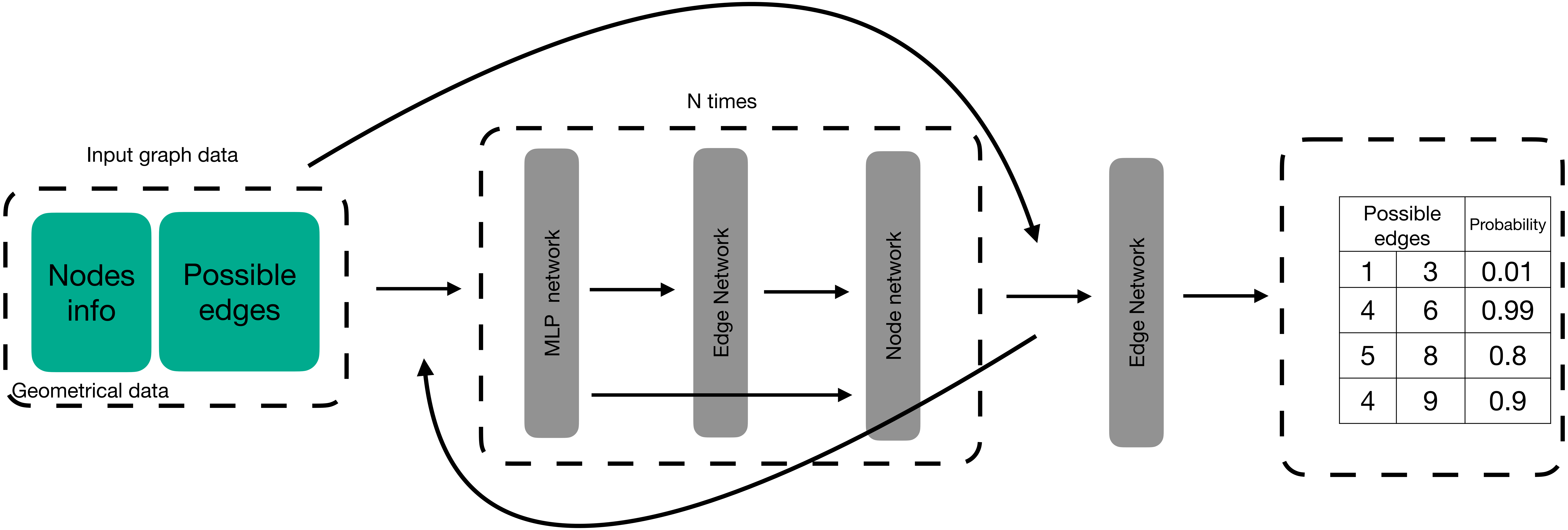
Graph Convolutional Network

graph level prediction



Graph Convolutional Network

node-level prediction - project task



Data analysis + preprocessing

Raw data

Simulated by sPHENIX project

- Generated json samples containing events
- Each event consist of: metadata, detectors data/positions/ids, points ids/pixel data/position/chip info, particles energy/momentum info, ground truth about vectors (containing particle ids etc.)


```
{
"Events" : [
{
    "MetaData": {
        "Description": "These are meta data for this event. Not intended to use in ML algorithm",
        "EventID": 0,
        "Unit": "cm",
        "CollisionVertex": [
            0.0026662557331342347,
            0.0025958270878951186,
            -10.565255027683989
        ],
        "Layer_Count": 3,
        "PixelHalfLayerIndex_Count": 6,
        "Layer0": {
            "PixelPhiIndexInLayer_Count": 6144,
            "PixelPhiIndexInHalfLayer_Count": 3072,
            "PixelZIndex_Count": 9216,
            "HalfLayer_Count": 2,
            "Stave_Count": 12,
            "Chip_Count": 9,
            "Pixel_Count": 524288
        },
        "Layer1": {
            "PixelPhiIndexInLayer_Count": 8192,
            "PixelPhiIndexInHalfLayer_Count": 4096,
            "PixelZIndex_Count": 9216,
            "HalfLayer_Count": 2,
            "Stave_Count": 16,
            "Chip_Count": 9,
            "Pixel_Count": 524288
        },
        "Layer2": {
            "PixelPhiIndexInLayer_Count": 10240,
            "PixelPhiIndexInHalfLayer_Count": 5120,
            "PixelZIndex_Count": 9216,
            "HalfLayer_Count": 2,
            "Stave_Count": 20,
```

Preprocessing part

Goals and steps

Main steps should be:

1) unpack json raw data2

2) read carefully points data by ids

3)concatenate points from INTT and MVTX

4) reconstruct tracks from ground truth

5) cluster points on 1 detector

6)calculate cylindrical coordinates

7)segment possible edges by geometrical constraints

8) scale features

9) save in appropriate format.

Clustering

Collect all nearby points -> calculate mean euclidian (center) -> save center coordinates and number of pixels

0	1	0	0	0
1	1	1	1	0
0	1	1	0	0
0	0	0	0	0
0	0	1	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

Preprocessed data

Before training

Preprocessed data (per event), which can be considered to serve as input for the model, consist of next characteristics:

1) Scaled geometrical data: r vector value, phi angle value, z coordinate across cylindrical axe, amount of pixels on chip used in clustering

2) Possible edge combinations between point ids

3) Ground truth - each track consist of some points

Train process overview

Technology stack for training

Tools and technologies

- Remote developing, ssh, linux, conda3
- Python software engineering (OOP) for constructing training class, data loaders and models
- Torch, PyTorch geometrical, numpy, distributed programming
- Utils: wandb - for experiment tracking.

Training overview

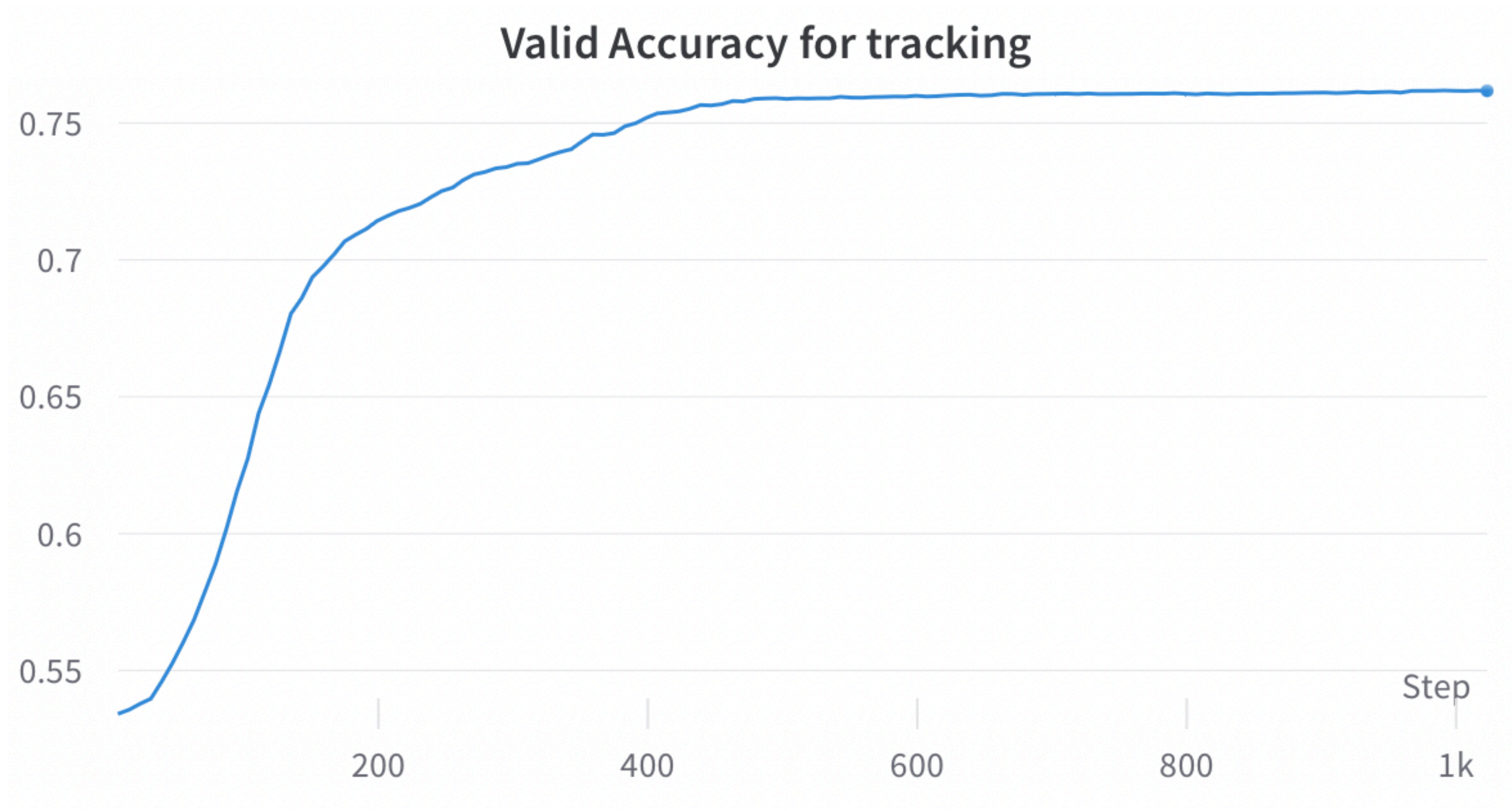
Optimizer and model

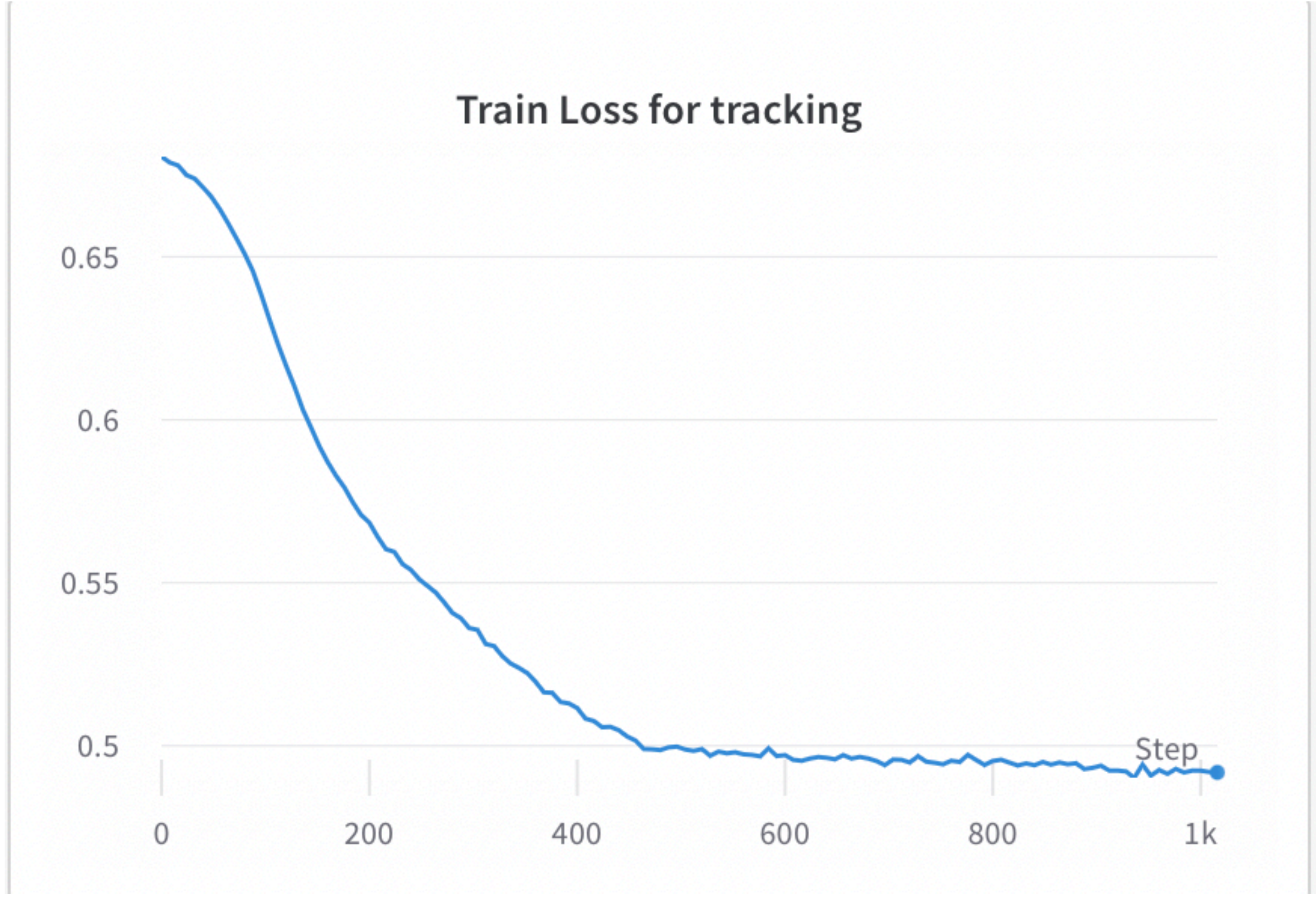
- Optimizer - Adam, with 1e-4 learning rate, weight_decay 1e-4, and lr decay schedule, starting from 60th epoch with 0.1 factor + l1+l2 regularisation
- Model: Graph Neural Network, consisting of MLP + Edge + Node networks (num of parameters = 753 and 2,5k)
- Loss: Binary cross-entropy
- Accuracy: precision (correctly predicted edges/all edges)
- Data: 800 training events + 200 validation (2000, 400)

Training results

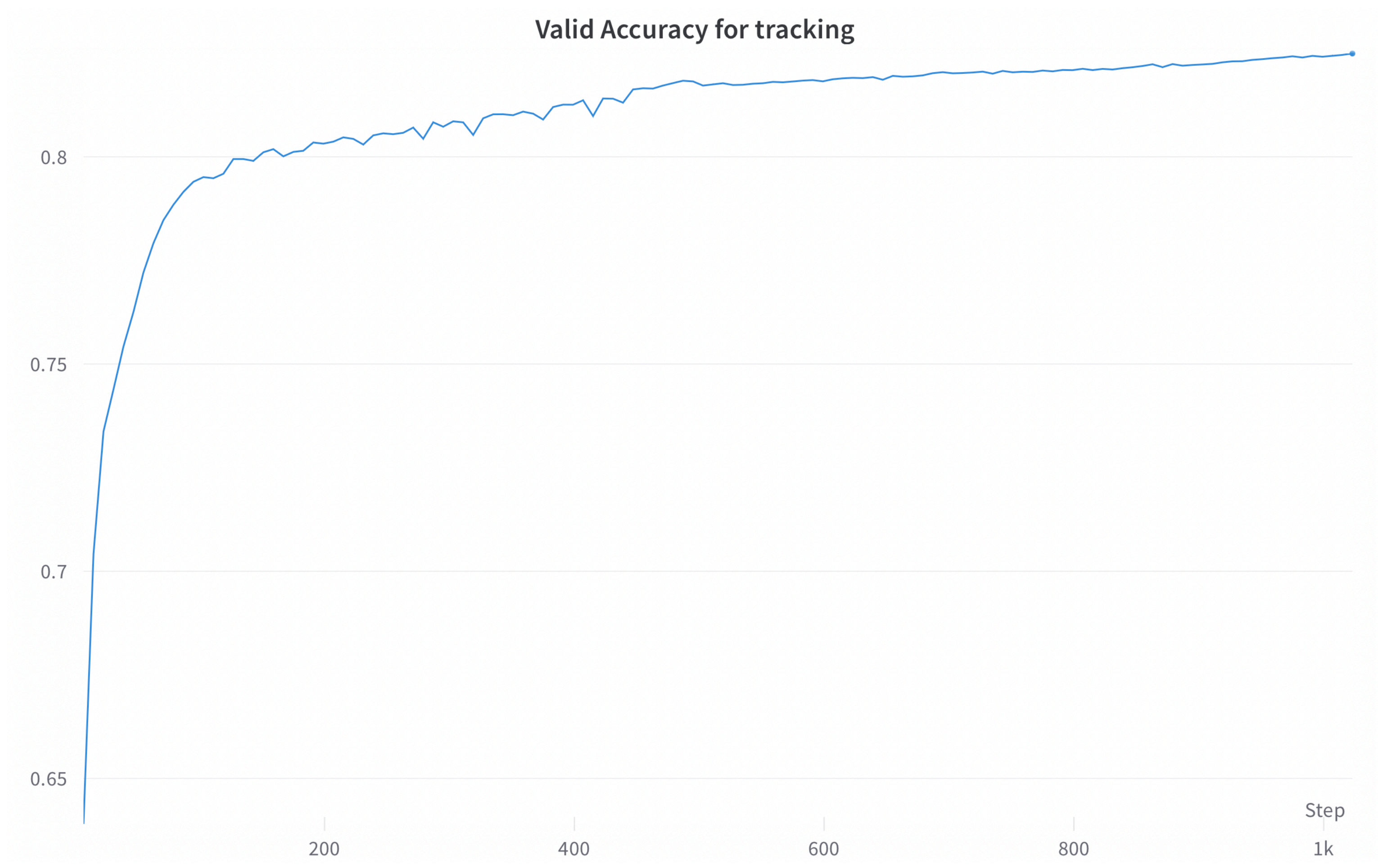
Process and performance

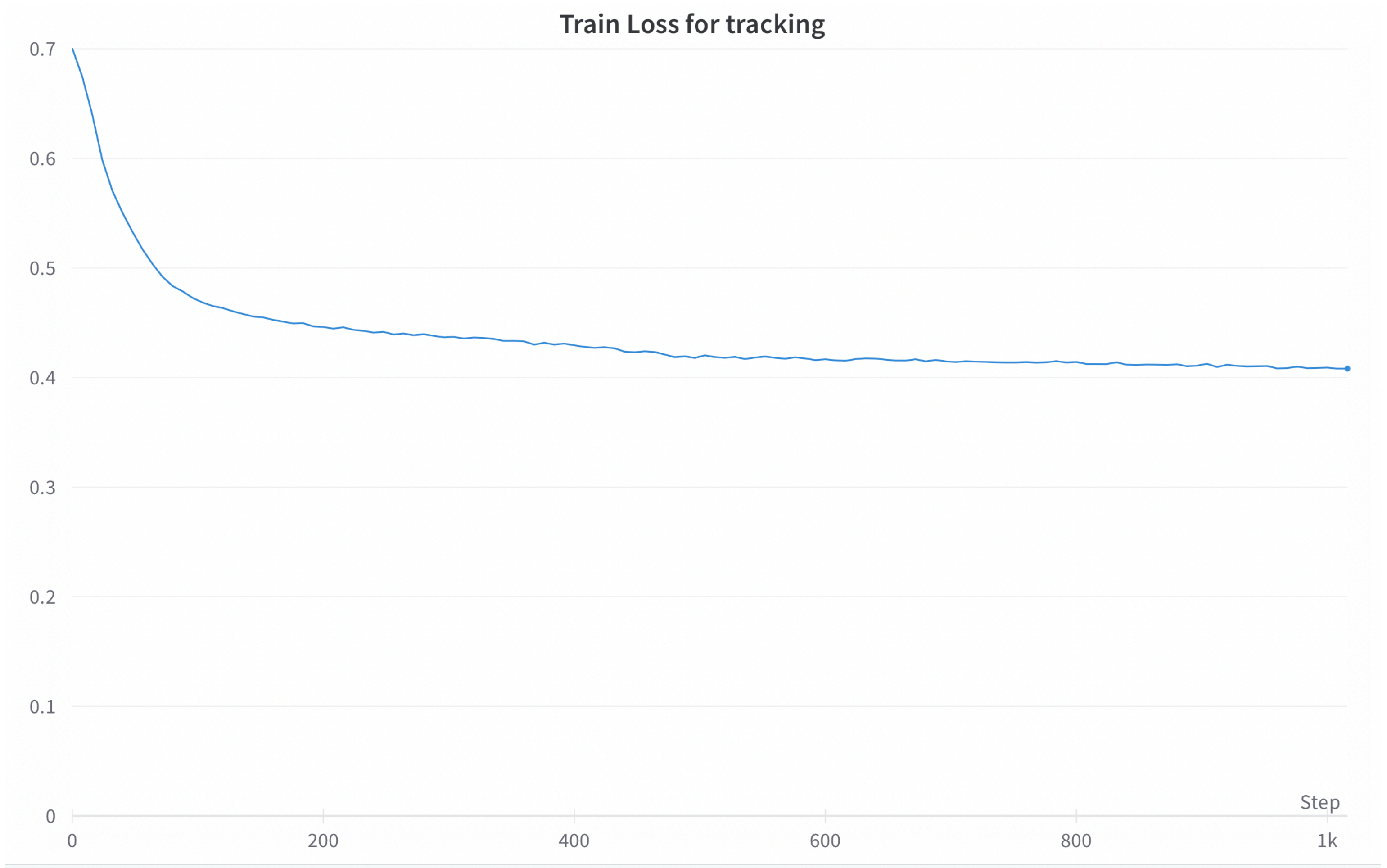
- 700 parameters, 800 training events ->





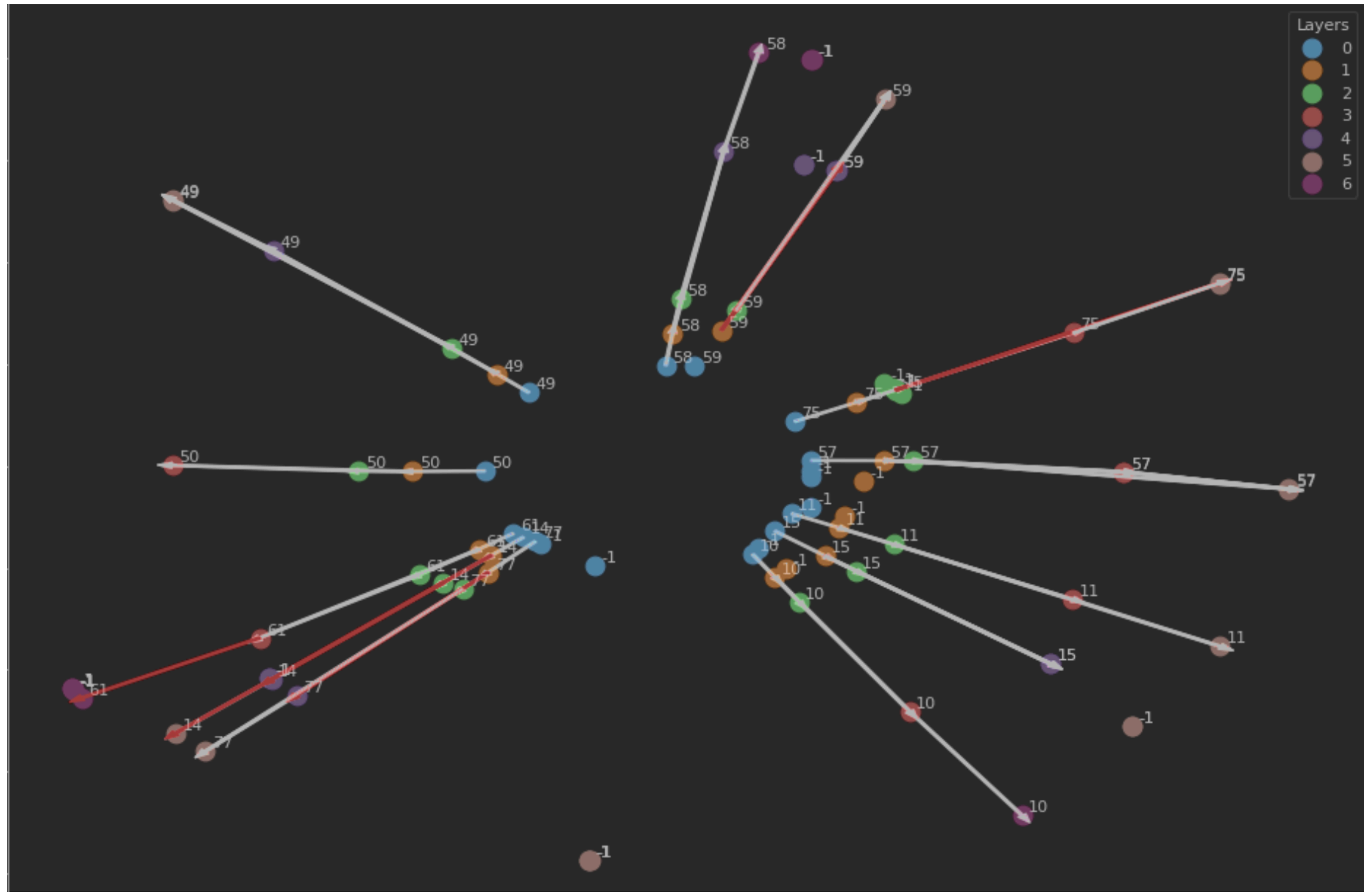
- 2,5k parameters, 2000 events ->

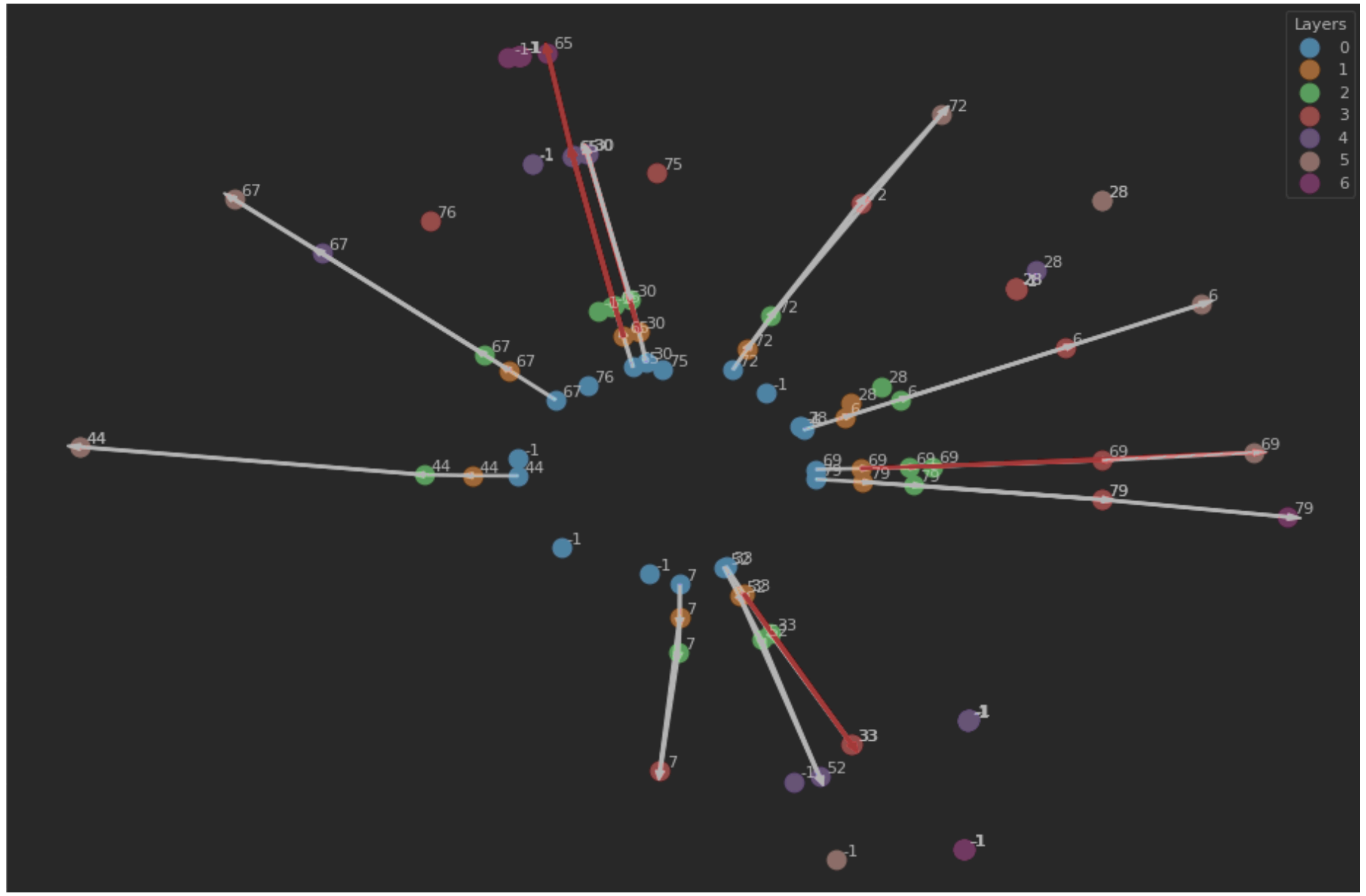




Example picture

Inference track reconstruction





Ideas for improving

Training and data preprocessing

- Any scaling of the raw parameters should be applied in the initial layers of the network, since scaling parameters can harm feature importance and should be fine-tuned by the model to maximise the performance

- Energy and momentum are not counted right now in the pipeline, which can be a significant improve in results, because of extra input information.

- Hyperparameters tuning

- Models increasing + dataset expanding

Conclusion

Conclusion

- I learned Graph Neural Networks models from zero and implemented some of their variations in the new library PyTorch geometrical
- I met new people, who taught me a lot on coding, data analysis, physics context overview and nuclear physics itself.
- I expanded my thoughts about international scientific cooperation, by directly participating in it.
- It is an honour to be a part of such interesting and cutting-edge project, which combines classical scientific subjects, such as physics, together with machine learning engineering.

Acknowledgment

- I would like to acknowledge help of Dantong Yu in providing working resources and inviting me for his project.
- Also I would like thanks Tingting Xuan for helping with pipeline and sharing ideas of the implementation.

Thanks for attention