# RICH software

46nd CBM Collaboration Meeting

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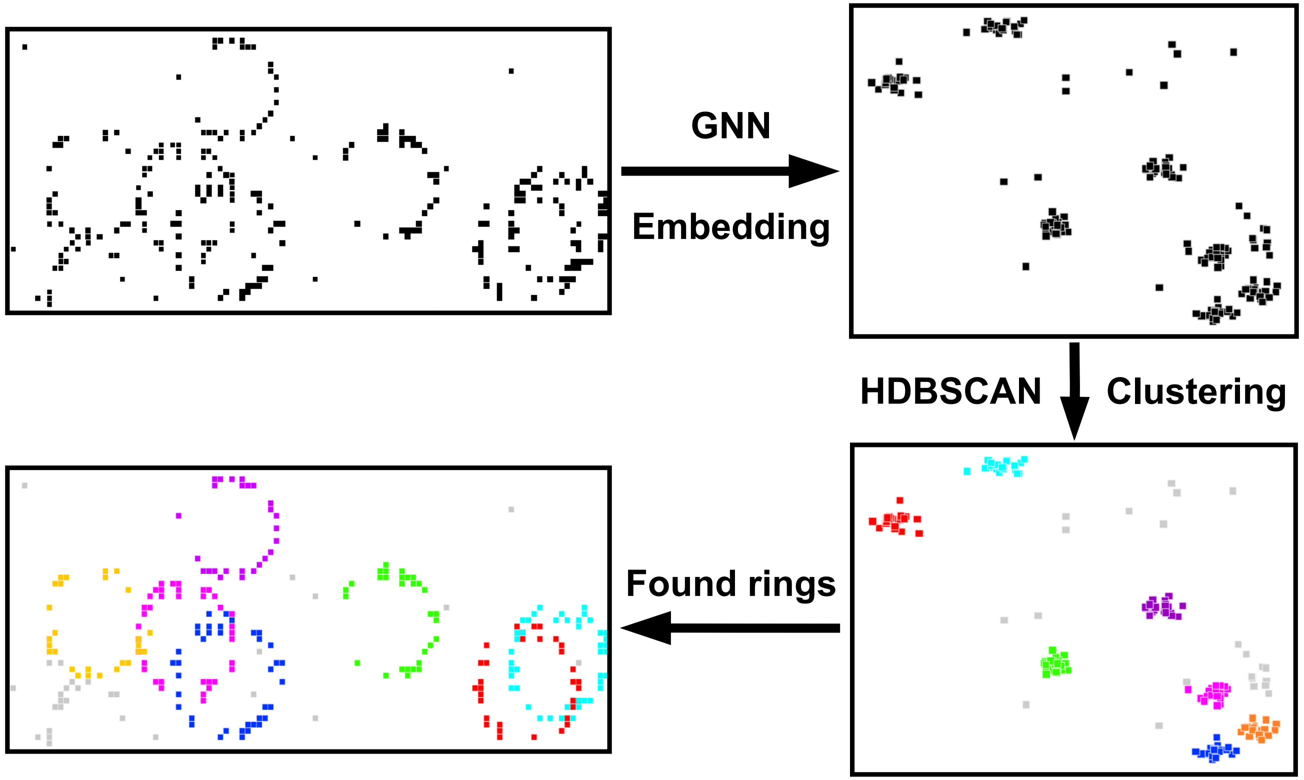
# 1. First look: GNN + HDBSCAN based ringfinder

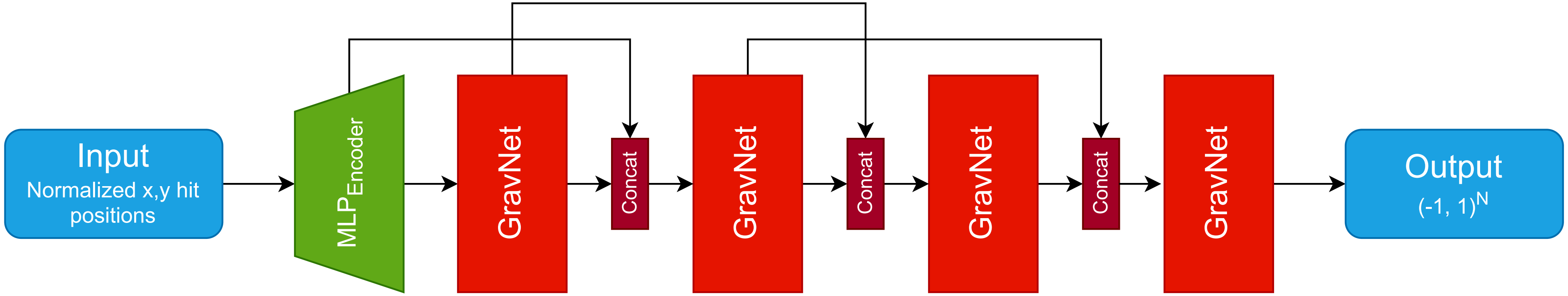
# GNN + HDBSCAN reconstruction chain

1. Point cloud of Hits
   → Embedding space via GNN
2. Clustering via HDBSCAN
   → Reconstructed rings
3. Ellipse fitting in input space
   (not included in this work)

GNN: graph neural network



# GNN with dynamic graph contruction using k-NN




- **Input:** Normalized Hit positions (x, y) → encoder multilayer perceptron
- GravNet GNN layers (uses k-nearest neighbors) with dynamic edge construction
- Concatenate previous layer outputs via skip connections
- **Output:** N dimensional embedding space coordinates via $\tanh$ activation

# GNN training for object seperation

## Contrastive loss

[Attraction] Pull together Hits from the same object.
[Repulsion] Push apart Hits from different objects.
→ Object separation in the embedding space

$$\mathrm{Loss}_{\mathrm{Total}} = \mathrm{Loss}_{\mathrm{Attraction}} + \mathrm{Loss}_{\mathrm{Repulsion}}$$

$$\mathrm{Loss}_{\mathrm{Att.}} = \frac{1}{N_{objects}} \sum_{k \in objects} \frac{1}{N^{(k)}_{hit\ pairs}} \sum_{i>j} {d_{ij}^2}^{(k)} e_{ij}$$

$$\mathrm{Loss}_{\mathrm{Rep.}} = \frac{1}{N_{\substack{non\ zero\\ entries}}} \sum_{i,j \notin noise\ hit} max(-\log(d_{ij}), 0)^2 \, (1 - e_{ij})$$

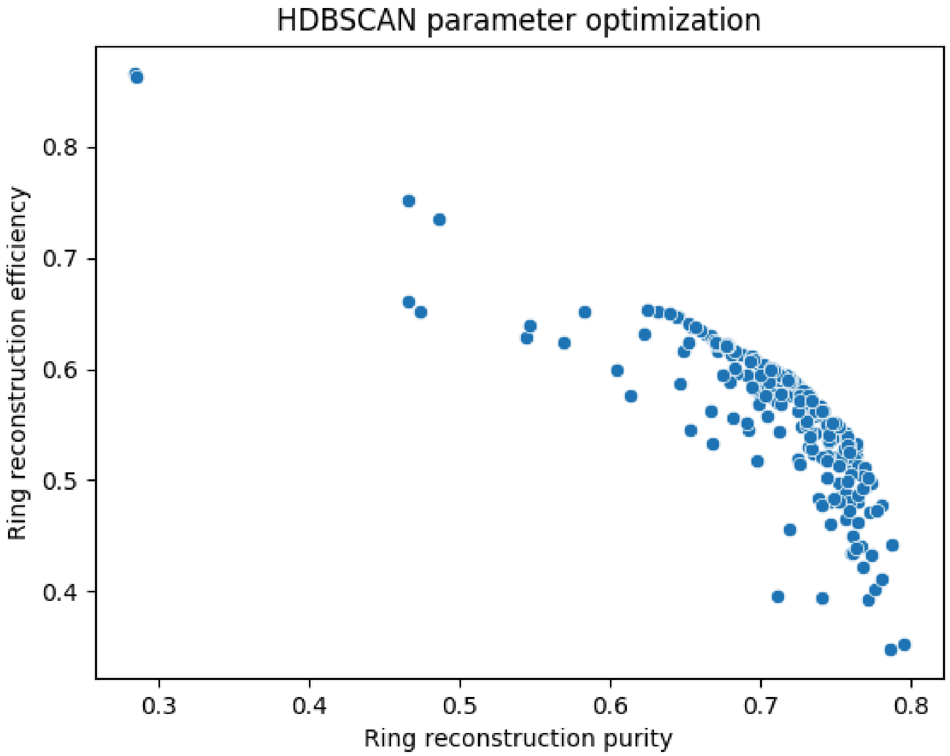
$$e_{ij} = \begin{cases} 1 & \text{, hit i and j from the same object} \\ 0 & \text{, otherwise} \end{cases}$$

## Training data

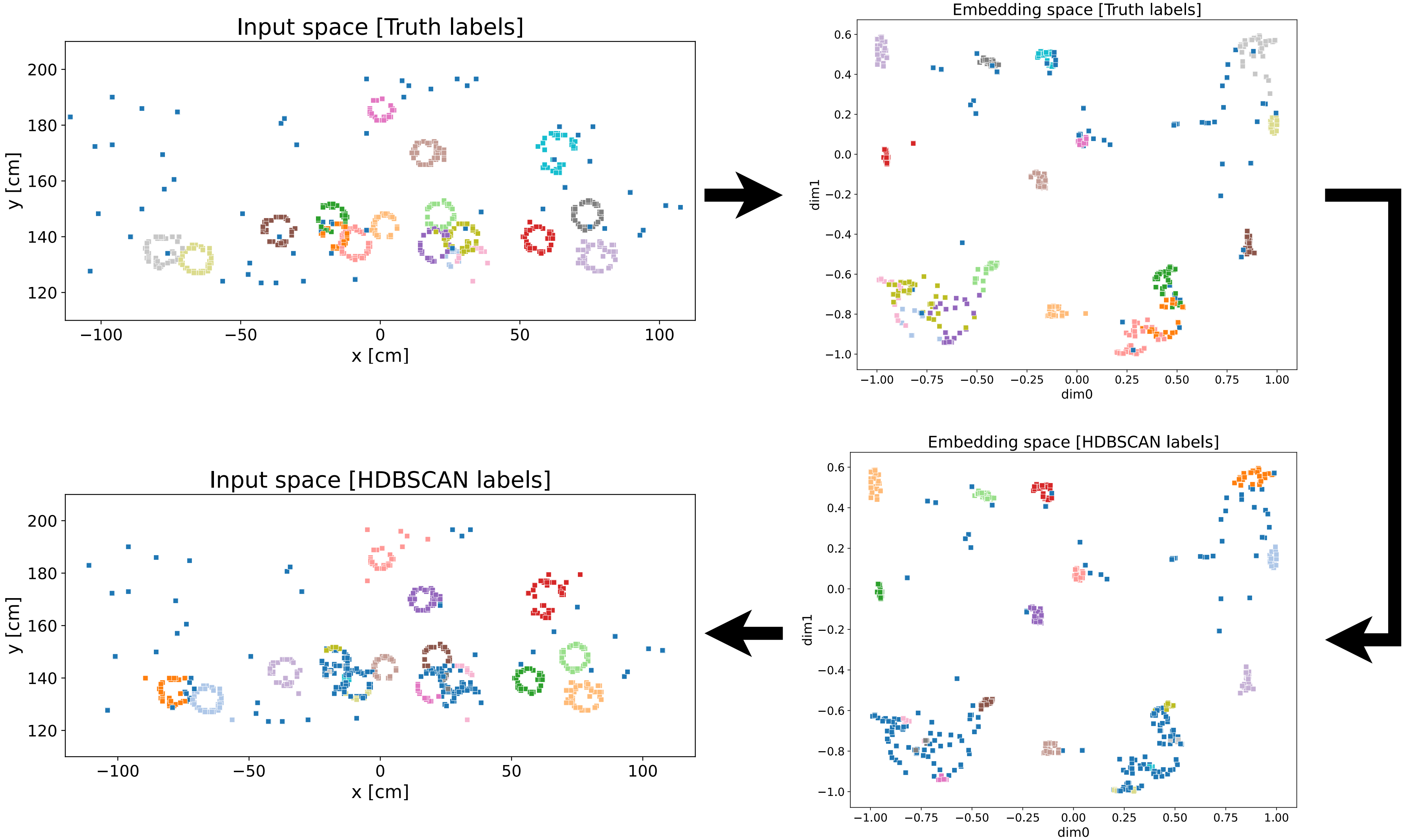
- GNN trained supervised on 50,000 11AGeV Au+Au central events
- 1 PLUTO $\rho^0$ signal embedding in each event

# HDBSCAN parameter optimization (embedding dim. 10)

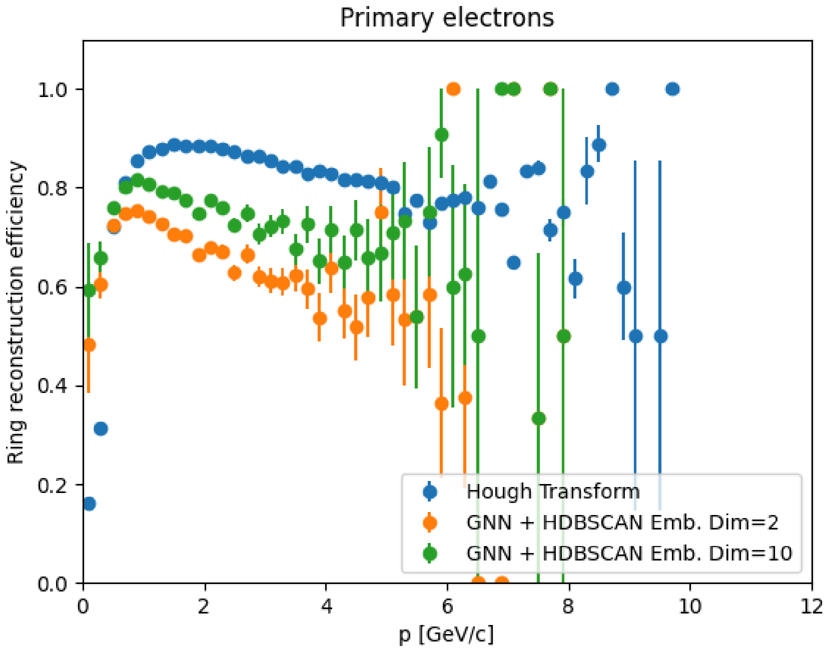
- Crucial step to maximize ring reconstruction efficiency and purity
- Use of Bayesian optimization, minimizing
  Loss = - (log(Efficiency) + log(Purity))

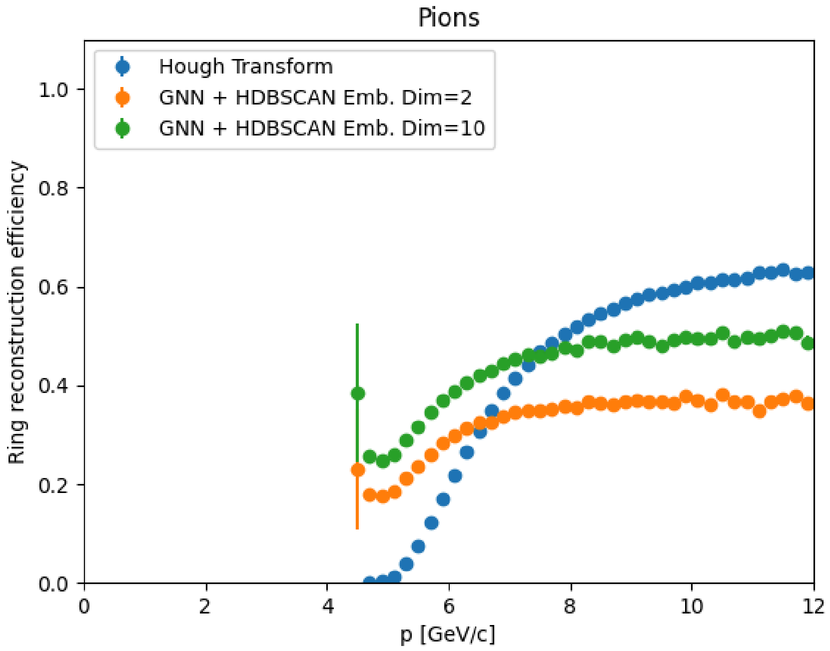


# CBM 11AGeV Au+Au central event (test data), embedding dim. 2



# Ring reconstruction efficiency vs momentum




- Overall, not competitive yet compared with the Hough ringfinder
- Already looking promising for low-momenta rings, i.e. smeared rings and rings with fewer Hits

(GNN + HDBSCAN only evaluated on 100k events due to performace bottleneck, Hough Transform on 600k events)

## Overall performace summary

| Setting | Primary electron efficiency | Primary electron efficiency < 0.5GeV/c | Primary electron efficiency < 1GeV/c | Pion efficiency | Purity | Latency (CPU ST) / event |
|---|---|---|---|---|---|---|
| HT baseline param. + ANN [default] | 0.8565 | 0.2867 | 0.8058 | 0.2524 | **0.8570** | 650ms |
| HT optimiz. param. + BDT (afterburner) | 0.8258 | 0.3931 | 0.7978 | 0.3582 | **0.8562** | 11ms |
| GNN + HDBSCAN (embedding dim. 2) | 0.7196 | 0.5929 | 0.7433 | 0.2884 | 0.7290 | 15ms + 20ms |
| GNN + HDBSCAN (embedding dim. 10) | 0.7864 | 0.6522 | 0.7966 | 0.3837 | 0.7288 | 15ms + 20ms |

HT: Hough transform ringfinder
ST: CPU single thread

# GNN ringfinder summary

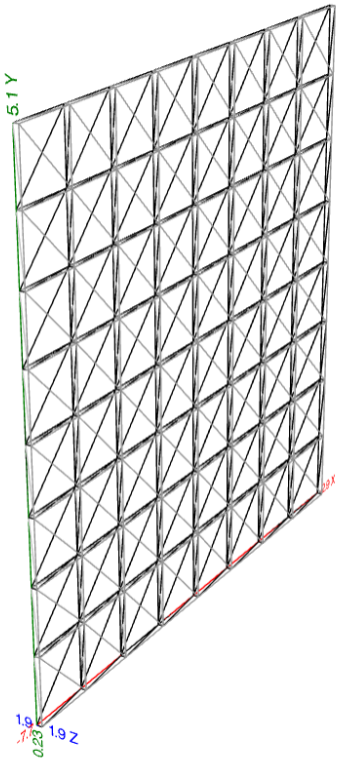
- First GNN reconstuction chain running, including efficiency calculation (in python)
- Current results show little ring structure awareness (i.e. overlapping ring reconstruction), but already looking promising for (isolated) smeared & low Hit count structures
- Overall, not competitive yet compared with the Hough ringfinder

# Outlook

- Hit timestamps to be included
- Add auxiliary noise classification downsteam task
- Overall reconstuction chain improvements, i.e. GNN model, loss function, clustering …
  Preliminary reconstuction chain → replacements and changes are very likely
- More QA, e.g. ring reconstruction efficiency vs. ring distance (overlapping rings)

## 2. RICH detector response for Cherenkov photons in simulation

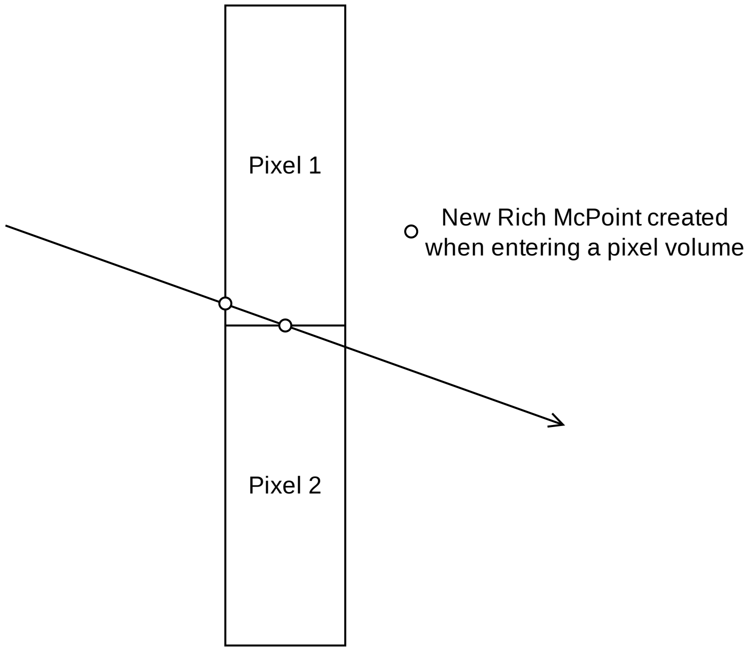
Hamamatsu MAPMT H12700



MAPMT geometry description
via pixel volumes

# Current response to Cherenkov photons in simulations

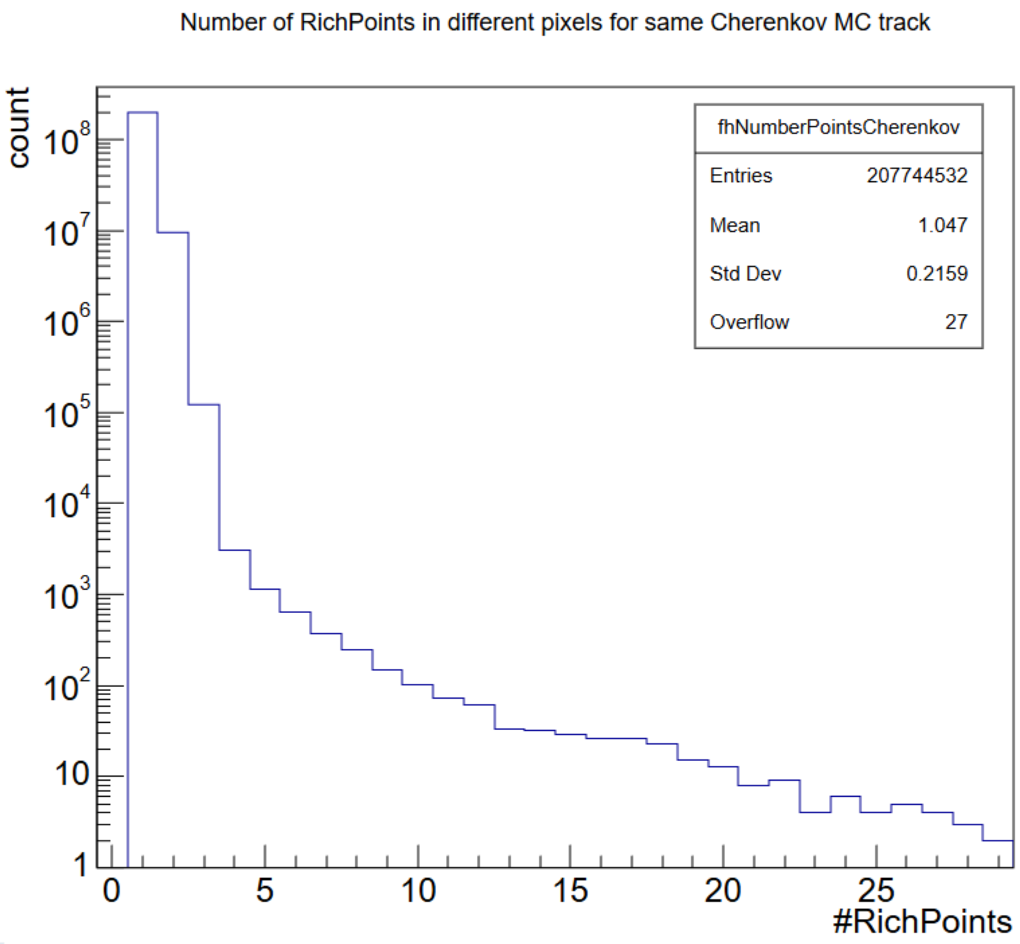
- RichPoints stored when Cherenkov photon **entering** MAPMT pixel volume
- Cherenkov photons are **not** stopped when entering MAPMT pixel volume
- One Cherenkov McTrack may cross and leave Rich McPoint's in multiple pixels!
- Response expected/we want:
  - Cherenkov photon always absorbed entering a volume
  - Rich McPoints only stored from the MAPMT front



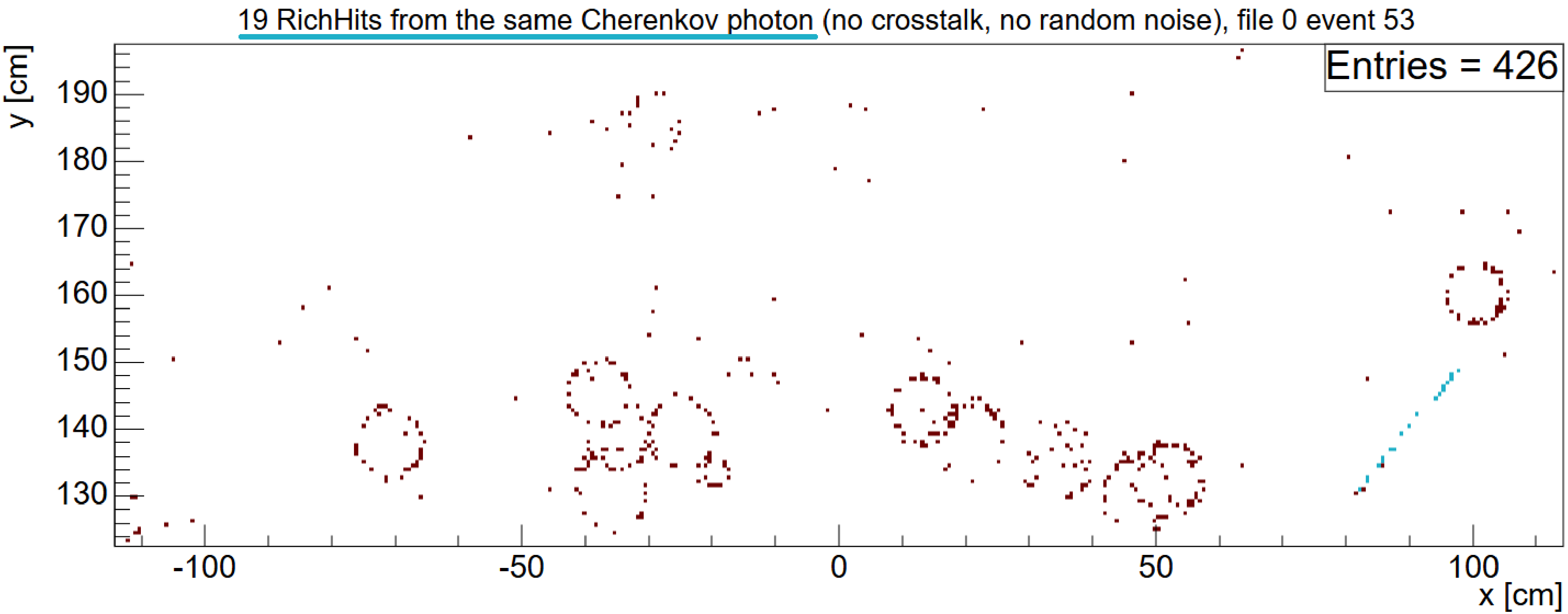

MAPMT: Multi-anode photomultiplier tube

# Multiple RichPoints for same Cherenkov photon

- 4,62% of Cherenkov photon McTracks leave multiple RichPoint's
- Some rare artefacts can also be seen, e.g. multiple Hits per photon & unusual Hit times (see backup)

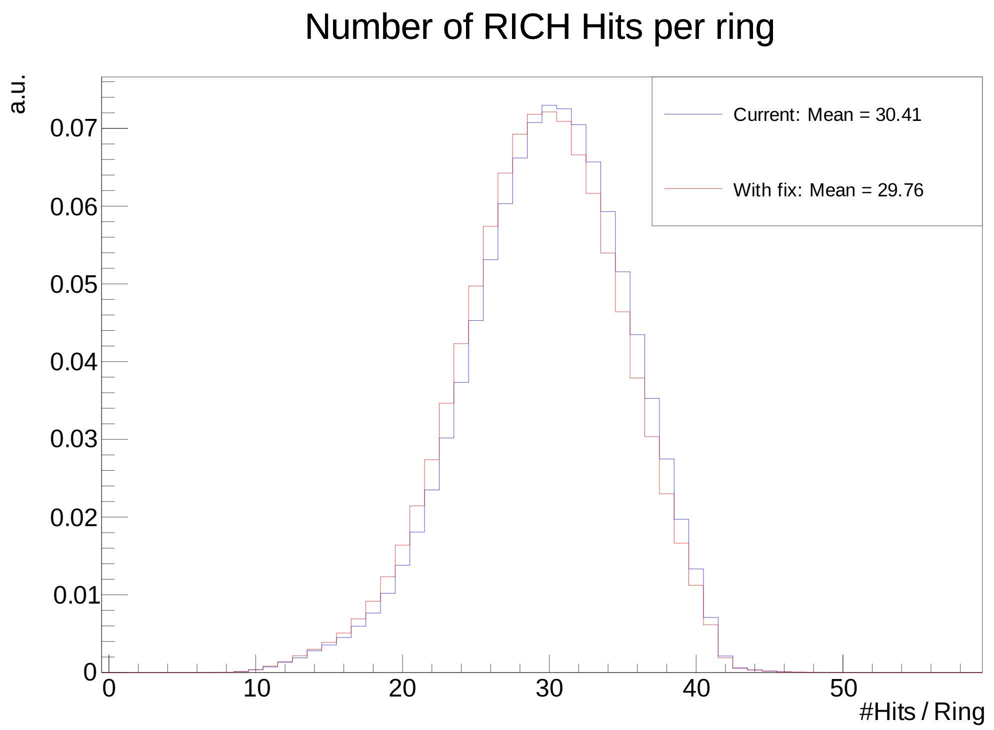


# Rare artefact



# Change to number of Hits per ring (with fix)

- Working fix in transport step:
  - Always stop Cherenkov photons entering a MAPMT pixel volume
  - Only store Rich McPoints from the front side of the MAPMT
    (by checking normal of pixel surface)
- Reduction of mean Hits/ring by 0.65 (~2%) for primary electrons
- Removes artefacts
- Still under discussion how to solve it the best way, i.e. in geometry/materials definitions and/or transport/digitization




100,000 BoxGenerator events of 5e+ 5e- each with 0GeV/c < $p_T$ < 3GeV/c 2.5° < $\theta$ < 25.0°

# RICH software summary & overview

- GNN based ringfinder [early stage, long term project]
- RICH Cherenkov photon response in simulation [finalizing]

- RICH offline QA (triggered by geant3→4) [in progress]
- RICH reconstruction port to cbm::algo [starting soon]
- Improving ring-track matching [in progress]

# References / inspiration taken from:

- EggNet: An Evolving Graph-based Graph Attention Network for Particle Track Reconstruction
- Object condensation: one-stage grid-free multi-object reconstruction in physics detectors, graph and image data
- End-to-End Multi-Track Reconstruction using Graph Neural Networks at Belle II

# Backup

# Datafiles used for GNN training/testing

UrQMD: "/lustre/cbm/prod/gen/urqmd/auau/12gev/centr/urqmd.auau.12gev.centr.*.root"

PLUTO: "/lustre/cbm/users/galatyuk/pluto/epem/12gev/*/*.root"

# Efficiency calculation

Efficiency = #True reconstructed rings / #Accepted rings

Purity = #True reconstructed rings / #Reconstructed rings

Accepted ring: 7 hits from the same MC particle [same camera]

True reco. ring: 70% of matched hits are from the same MC particle

# More artefacts: RichHits times in event