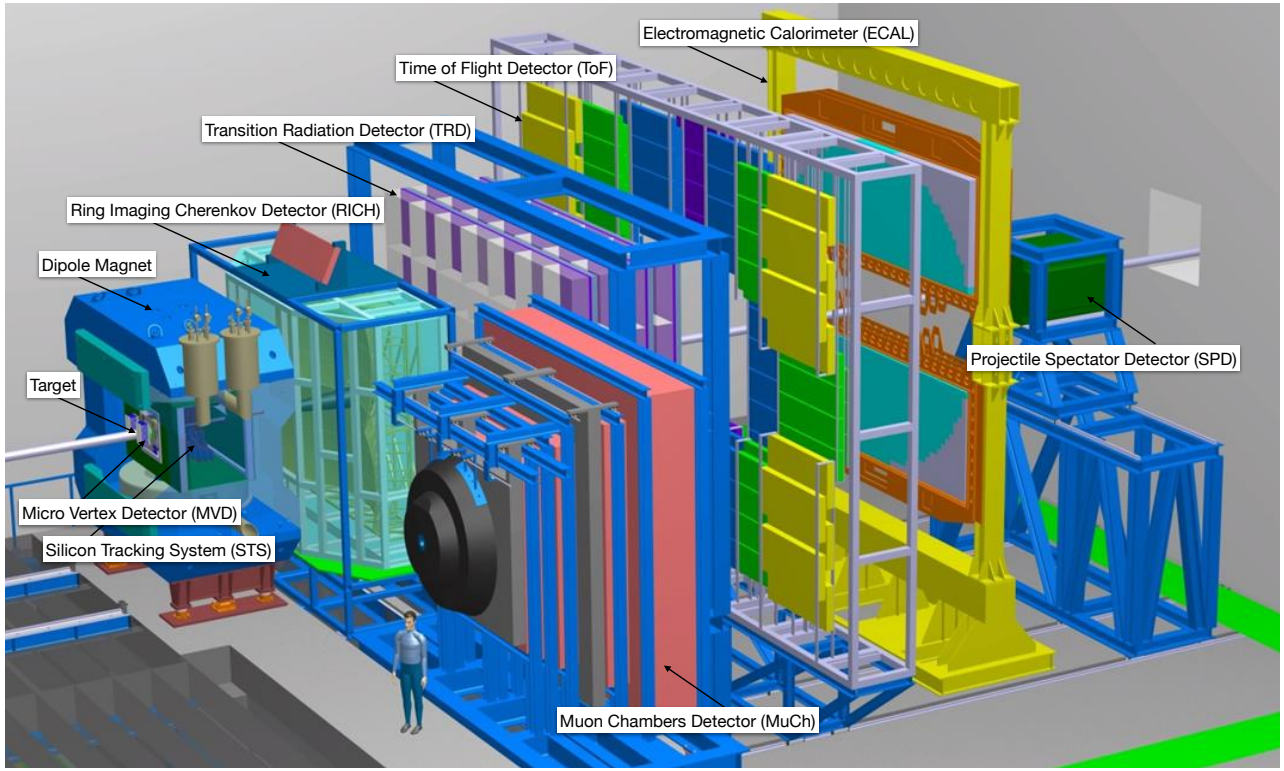
Enhancing Electron Identification Using RCNet: A Deep CNN Approach for RICH Ring Reconstruction

I. Kisel[1,2,3,4], A. Mithran[1,2]

[1]Goethe-University Frankfurt, Frankfurt am Main, Germany
[2]Frankfurt Institute for Advanced Studies, Frankfurt am Main, Germany
[3]Helmholtz Research Academy Hesse, Frankfurt am Main, Germany
[4]Helmholtz Center for Heavy Ion Research, Darmstadt, Germany

CBM Experiment

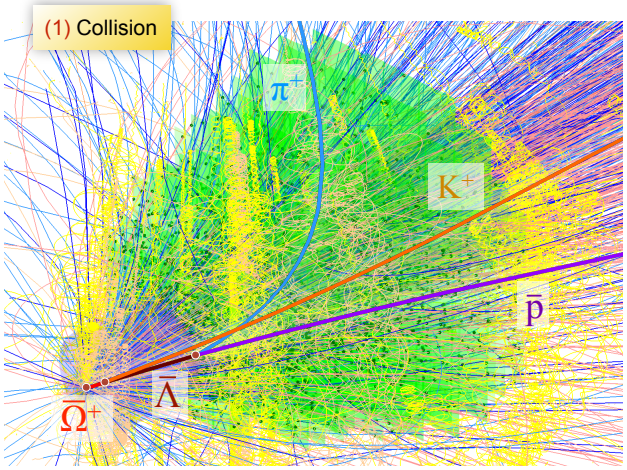
- Compressed Baryonic Matter (CBM) is currently being constructed at FAIR accelerator facility in Darmstadt.
- Highest baryon densities will be created and the properties of super-dense nuclear matter will be explored.
- The experimental program of CBM is to measure a large number of observables at various beam energies and different collision systems. Many of them are extremely rare, like multi-strange anti-hyperons, open and hidden charm.

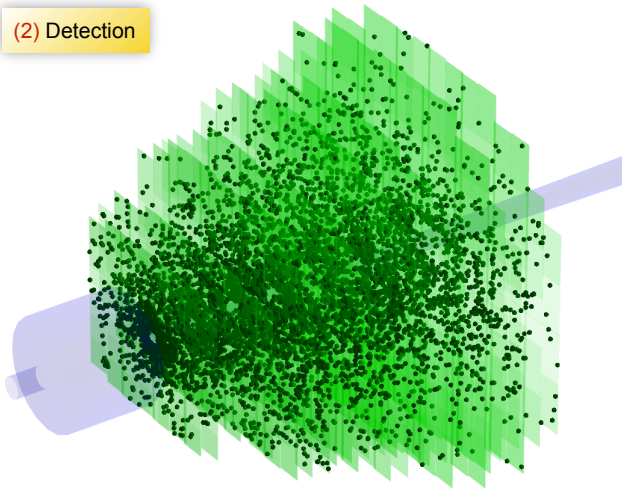


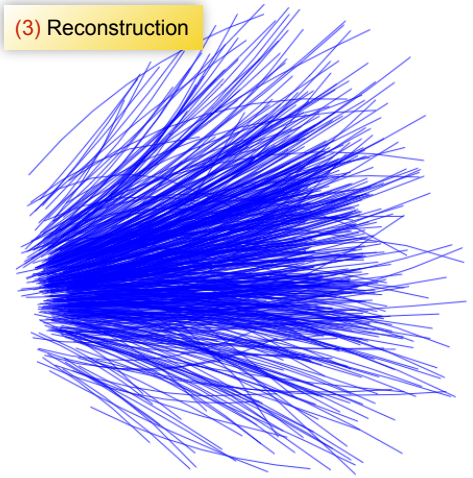
The CBM setup: target, dipole magnet, Micro Vertex Detector (MVD), Silicon Tracking System (STS), Ring Imaging Cherenkov (RICH), Muon Chambers (MuCh), Transition Radiation Detector (TRD), Time-Of-Flight (TOF), Electromagnetic Calorimeter (ECAL), Projectile Spectator Detector (PSD)

Such a multifunctional and versatile structure of the detector setup will make it possible to study the most complex processes in the collision of heavy ions

Reconstruction Challenge in CBM





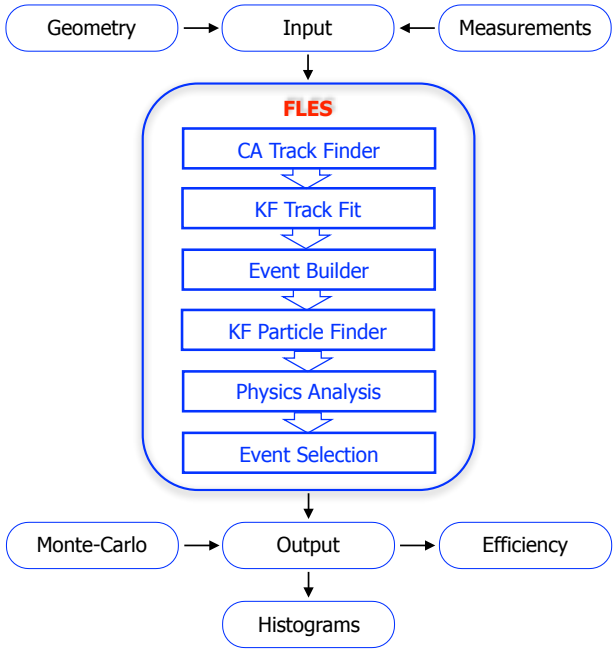


- Future fixed-target heavy-ion experiment at FAIR
- Explore the phase diagram at high net-baryon densities
- 10^7 Au+Au collisions/sec
- ~ 1000 charged particles/collision
- Non-homogeneous magnetic field
- Double-sided strip detectors
- 4D reconstruction of time slices.

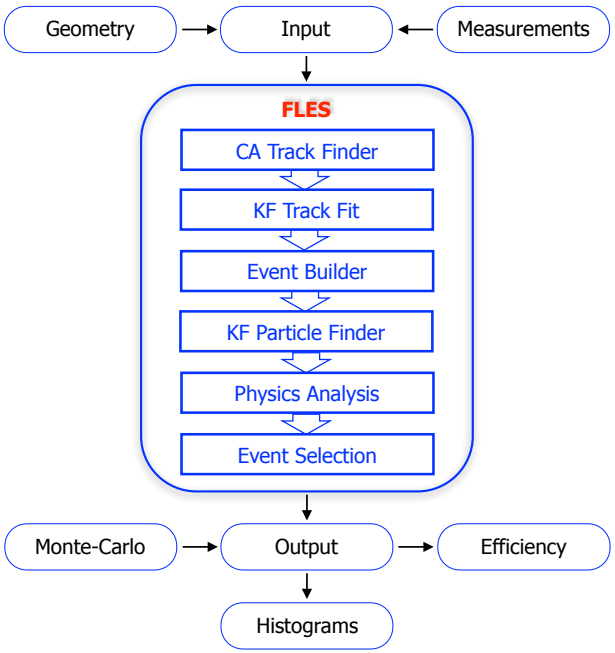
The full event reconstruction will be done on-line at the First-Level Event Selection (FLES) and off-line using the same FLES reconstruction package.

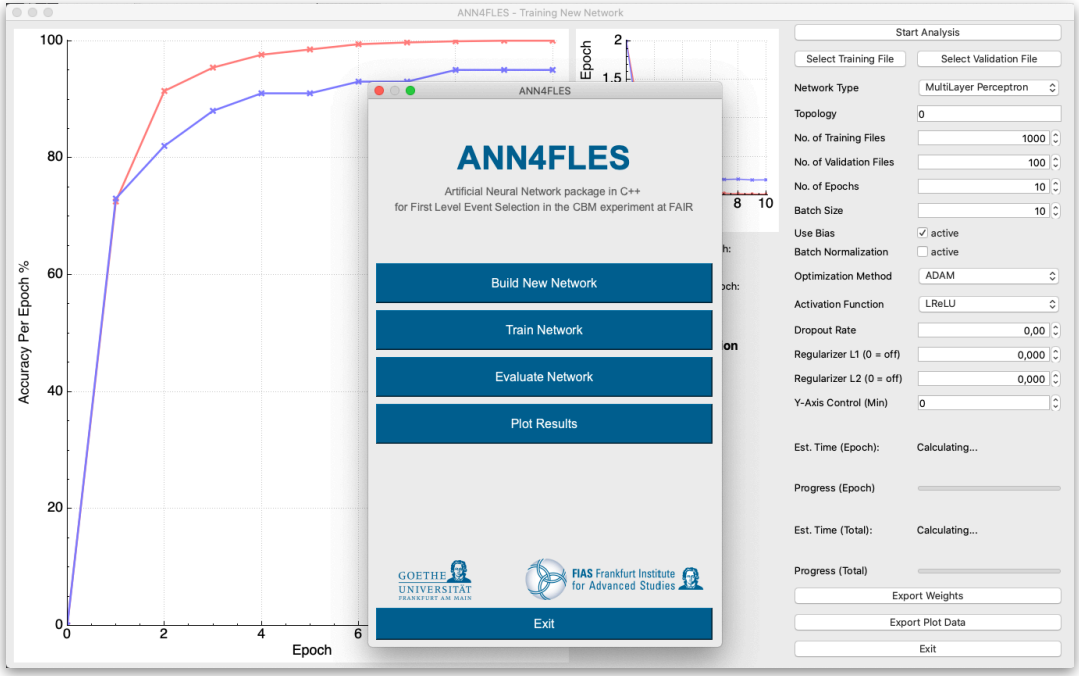
- Cellular Automaton (CA) Track Finder
- Kalman Filter (KF) Track Fitter
- KF short-lived Particle Finder

All reconstruction algorithms are vectorized and parallelized.



ANN4FLES: ANNs for First Level Event Selection



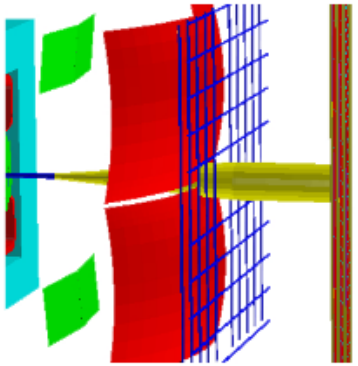


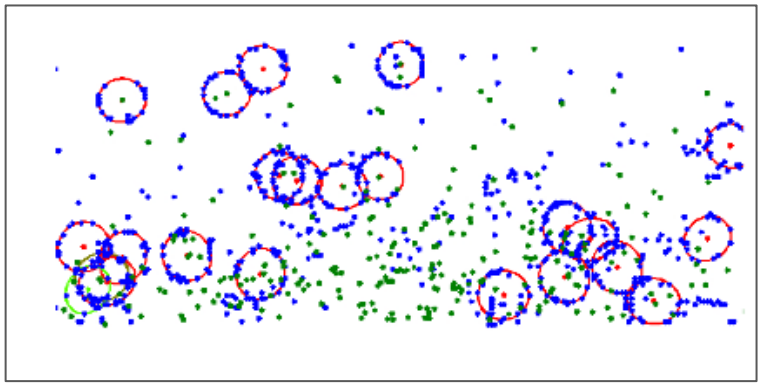
- ANN4FLES is a fast **C++ package** designed for use of Artificial Neural Networks (ANN) in the CBM experiment.
- It provides a variety of network architectures with **minimal additional programming** required.
- The package includes a Graphical User Interface (GUI) for **network selection** and **hyperparameter** adjustment.
- **Implemented networks** in **ANN4FLES** include:
  - Multilayer Perceptron (MLP),
  - Convolutional Neural Network (CNN),
  - Recurrent Neural Networks (RNN),
  - Graph Neural Networks (GNN), and
  - Bayesian Neural Network (BNN).
- Extensive **testing** on datasets like **MNIST**, **CIFAR**, **Cora**, etc., has been **performed** and **compared** with PyTorch.

Cherenkov Radiation

- Cherenkov Effect :- Radiation emitted by a particle moving in a medium with a speed greater than the speed of light in that medium.
- The photons are radiated at a fixed angle, determined by the properties of the medium and the speed of the particle.
- These photons form a cone, which gives a ring on the photodetector plane (see figure below).

Sketch of the RICH setup as used in simulations (outer gas box omitted)



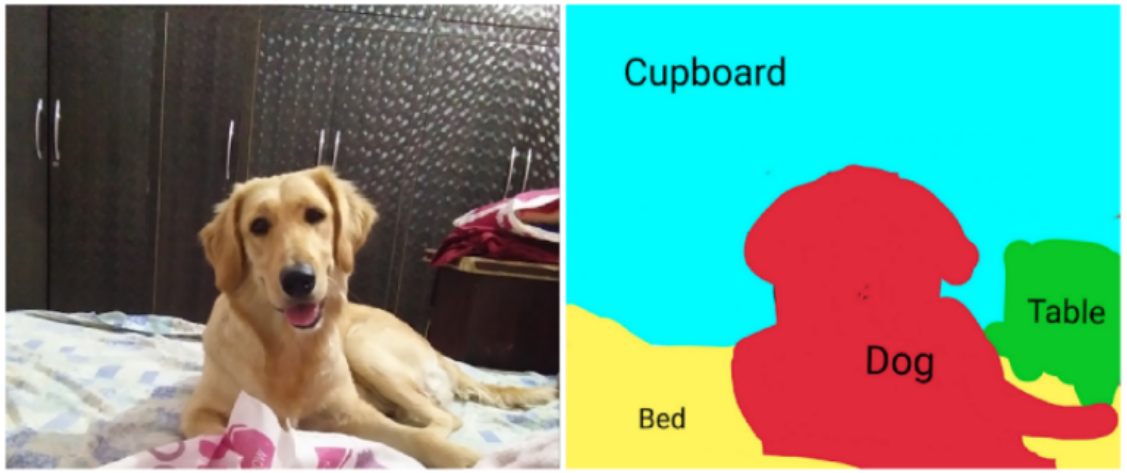


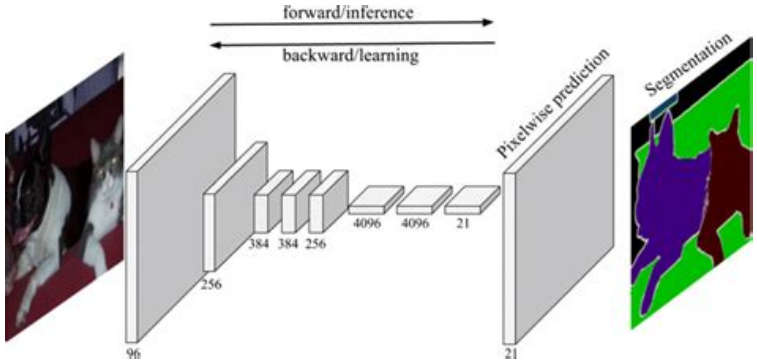
Part of one typical event in the smaller CO2-RICH: RICH hits (blue), found RICH rings (red), track projections form the STS (green).

- The emission angle of the cone is determined by the speed of a particle. Thus, having the same momentum particles with different masses forms ring with different radius.

Segmentation Models

- Unlike image classification task, assign a class to each pixel of the image.
- A segmentation model returns much more detailed information about the image.

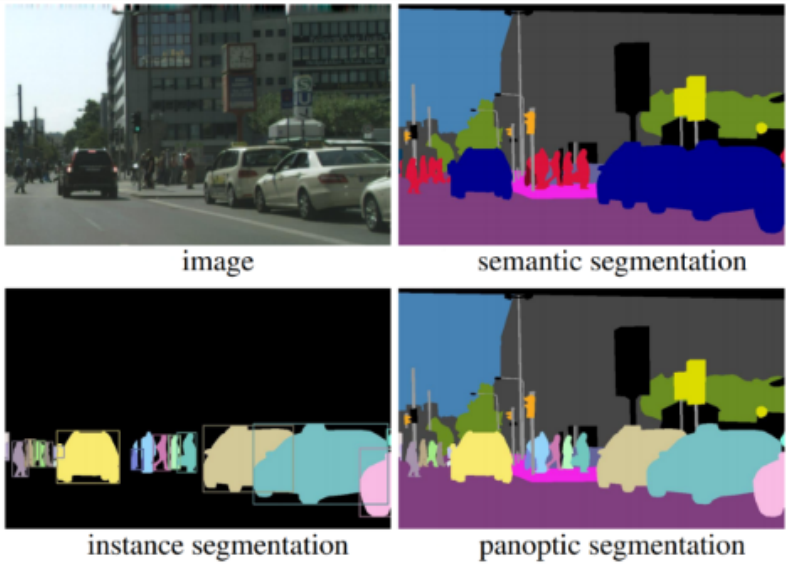




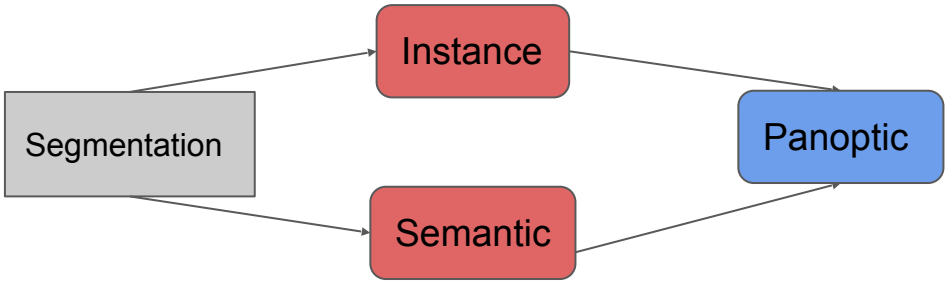
Fully Convolutional Network (FCN) architecture
(https://arxiv.org/pdf/1411.4038.pdf)

- Image segmentation has many applications in medical imaging, self-driving cars and satellite imaging, just to name a few.

Segmentation Types



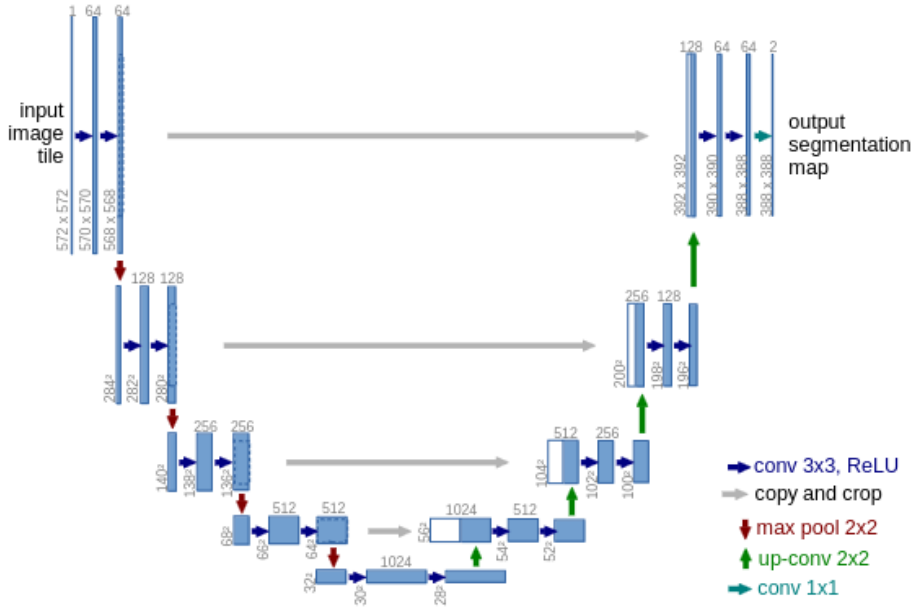
Types of segmentations
(https://arxiv.org/pdf/2001.04074v1.pdf)



- **Semantic**: Involves finding objects inside an image and categorising them according to predetermined categories.
- **Instance**: Detect each object or instance of a class present in an image and assigns it a different mask or bounding box with a unique identifier.
- **Panoptic**: Unified image segmentation approach. Each pixel in a scene is assigned a semantic label (due to semantic segmentation) and a unique instance identifier (due to instance segmentation).

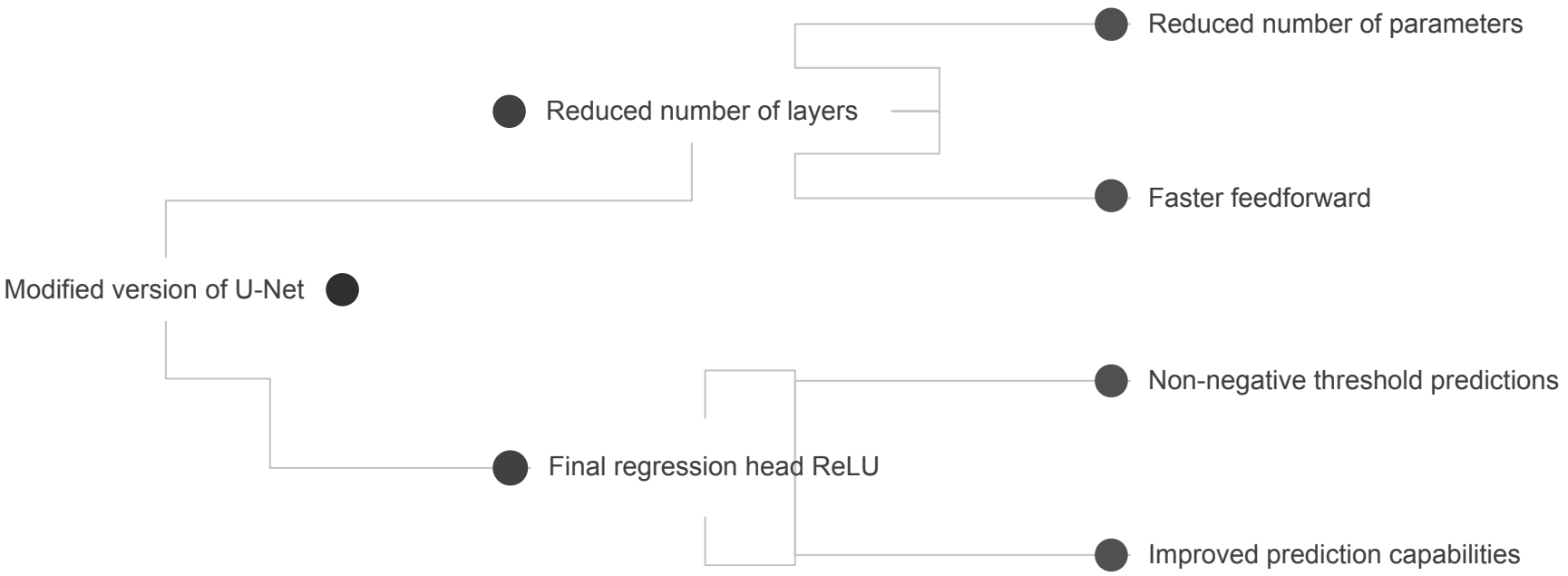
U-Net Model

- U-shaped semantic segmentation which has a contracting path and an expansive path.
- During the contraction, the feature information is increased while spatial information is decreased.
- On the other hand, every step of expansive path feature map size by a factor of 2.
- Then the reduced feature map is concatenated with the corresponding cropped feature map from the contracting path.

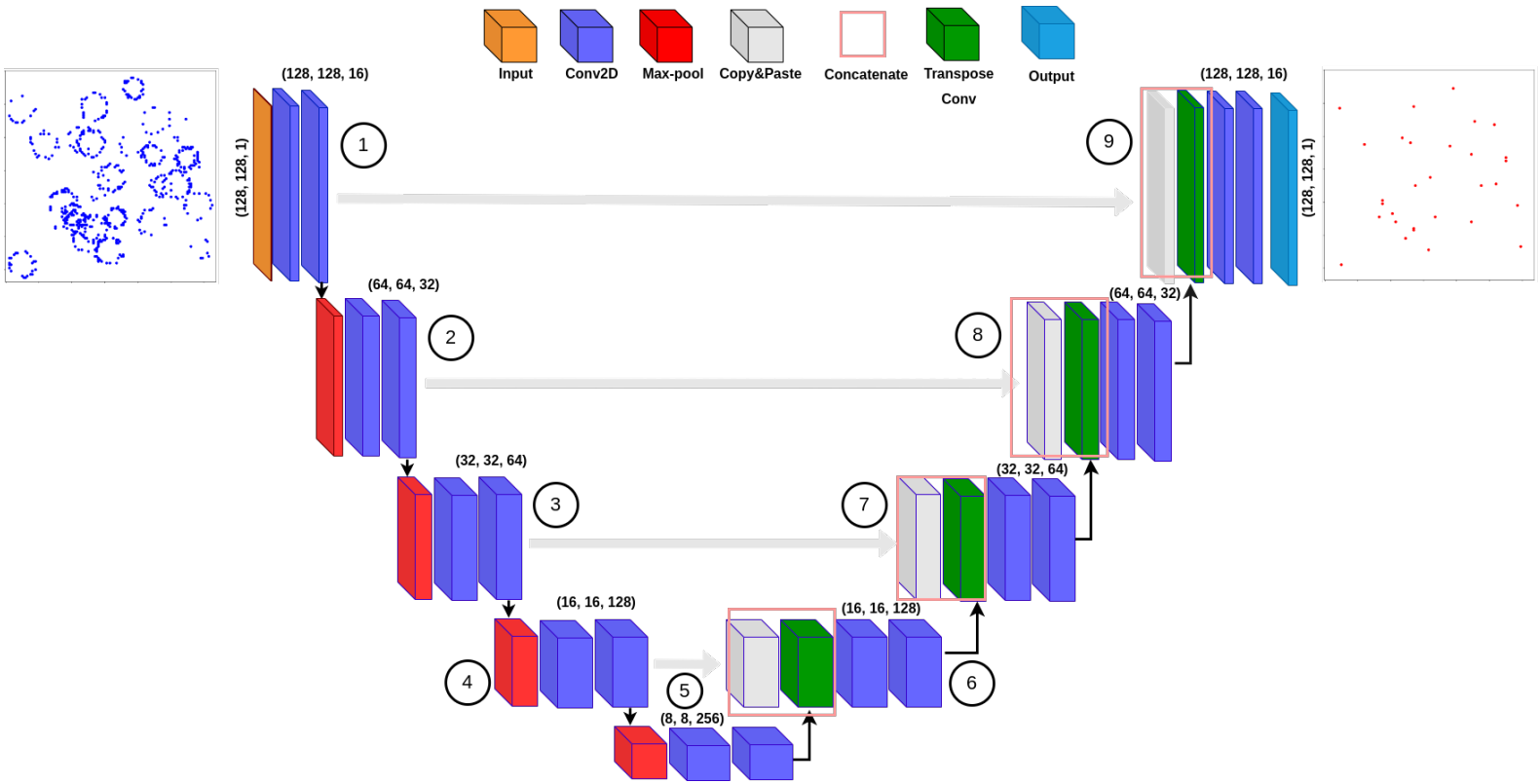


U-Net architecture (https://arxiv.org/pdf/1505.04597.pdf)

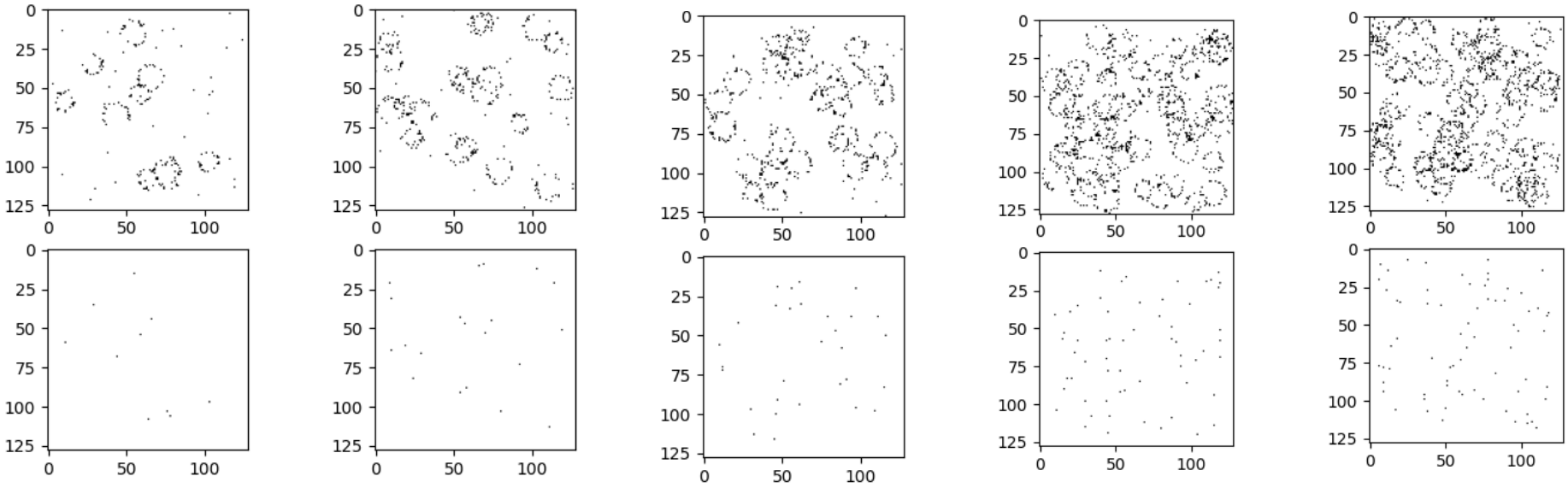
RCNet (RingCenter-Net)



RCNet (RingCenter-Net)

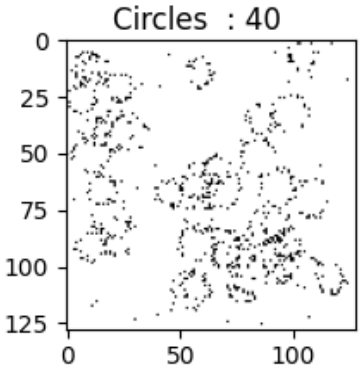


Simulation for Training

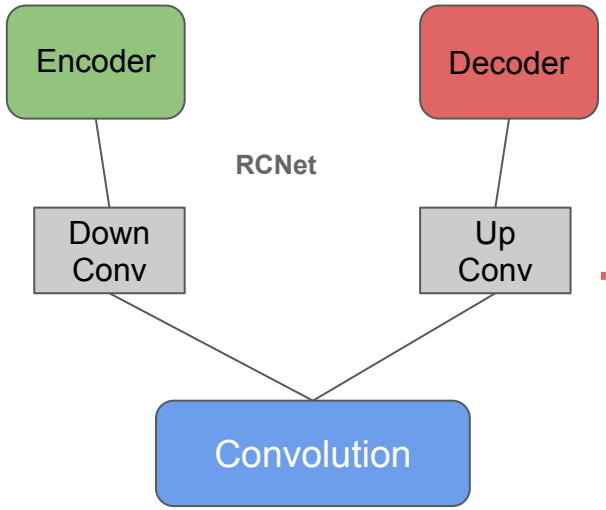


Simulation of rings for various numbers.
Examples (top) and labels (bottom)

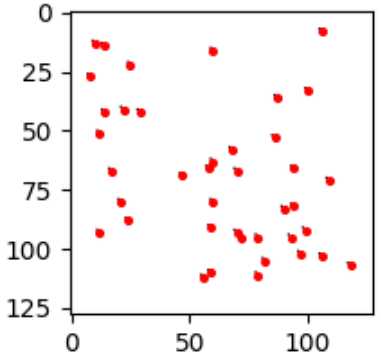
RCNet Pipeline



Input



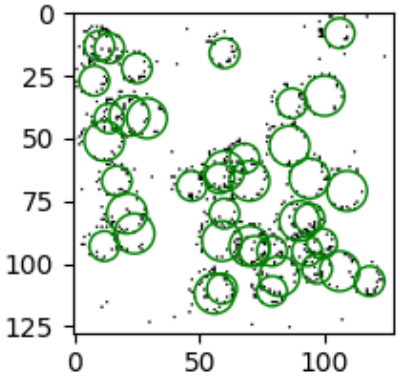
Predicted Centers



Final Parameters Estimation

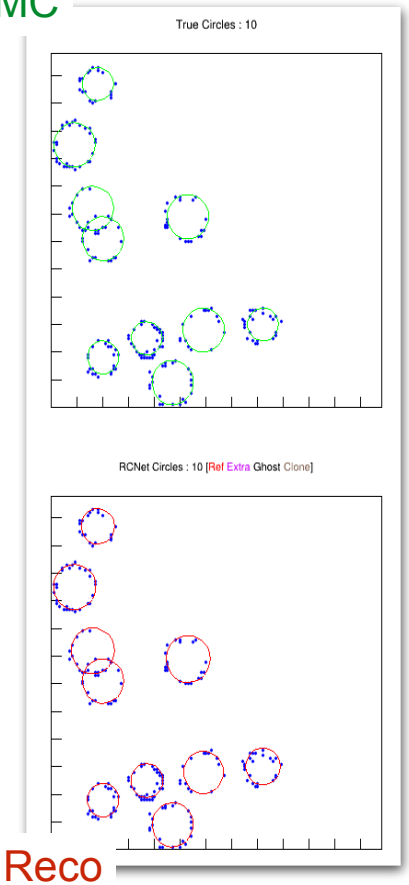
Parameter Fitting

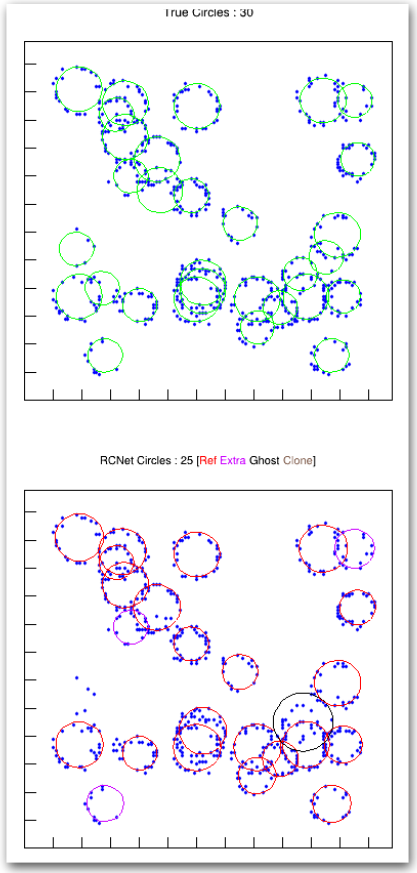
Final Predictions

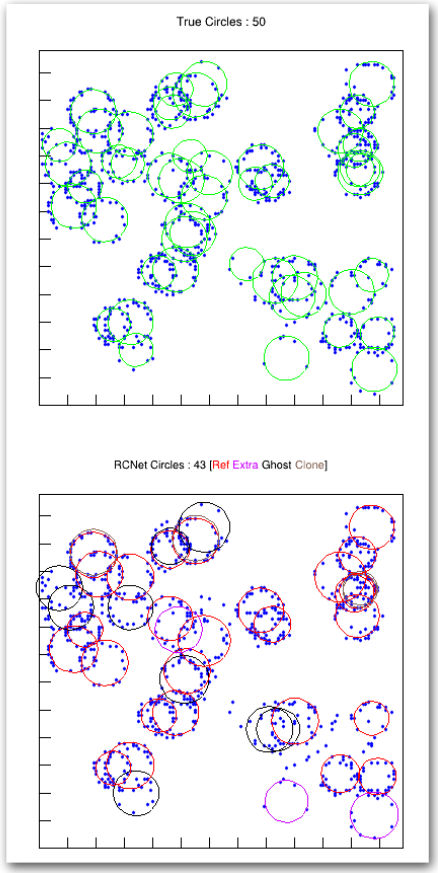


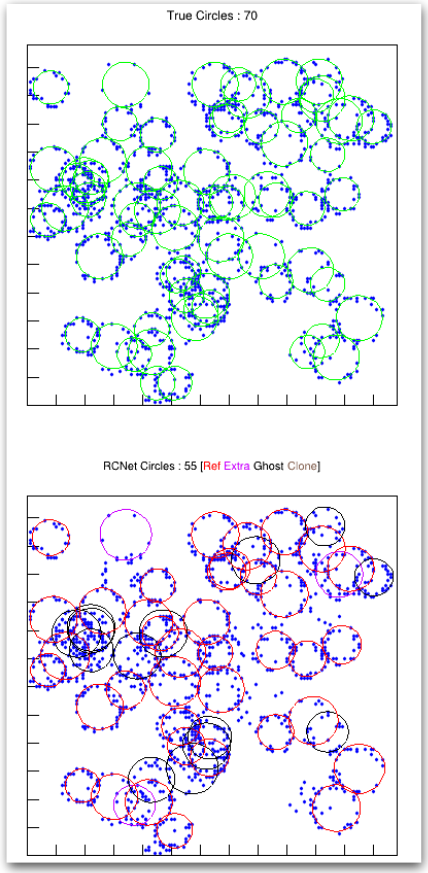
RCNet for Ring Finding in RICH High Density Regions

MC









Reco

10 Rings *30 Rings* *50 Rings* *70 Rings*

RCNet is capable to find rings in high density regions

Summary

- A C++ package of Artificial Neural Networks for the First Level Event Selection (ANN4FLES) was created for the CBM experiment.
- All networks implemented in the package have been successfully tested on a number of standard datasets and show comparable results to the PyTorch library.
- The ANN4FLES package is now being investigated for various reconstruction and analysis tasks in the CBM FLES package.
- The implementation of RCNet (RingCenter-Net) shows reliable performance even in higher density regions of RICH.