Object Condensation Tracking

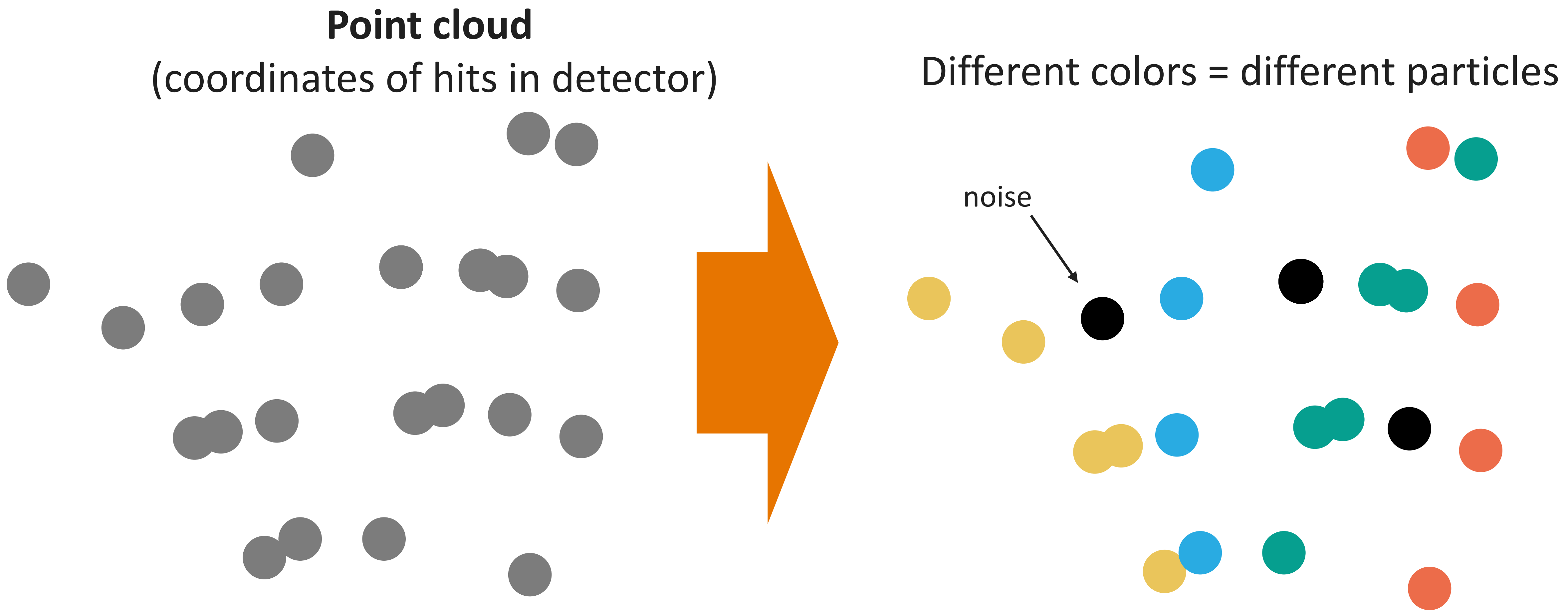

Gage DeZoort[1]
@gageDeZoort

Kilian Lieret[1,2]
@klieret

[1]Princeton University, [2]IRIS-HEP

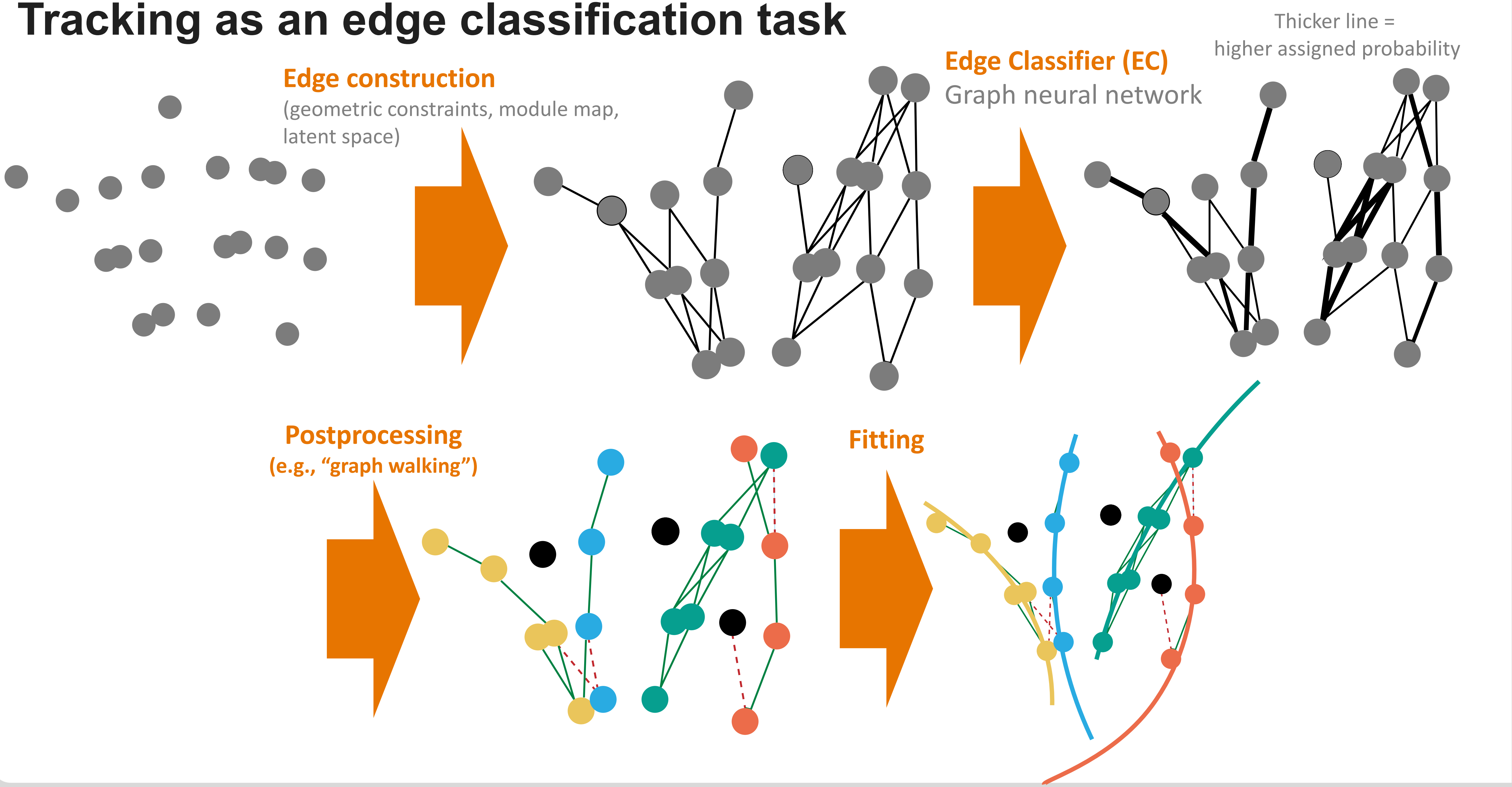
With contributions from
Javier Duarte, Peter Elmer,
Isobel Ojalvo, Savannah Thais

Tracking



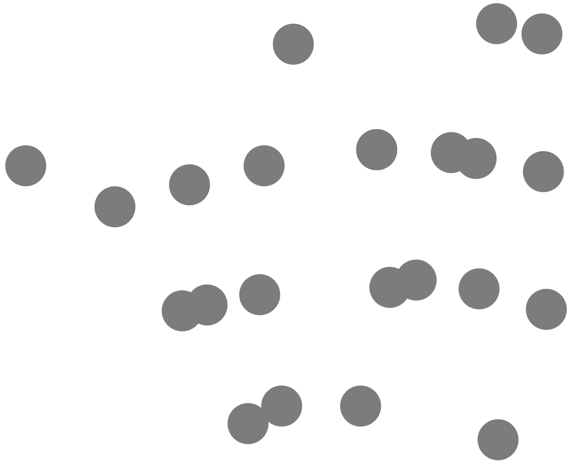
Point cloud
(coordinates of hits in detector)
Different colors = different particles
noise

Tracking as an edge classification task



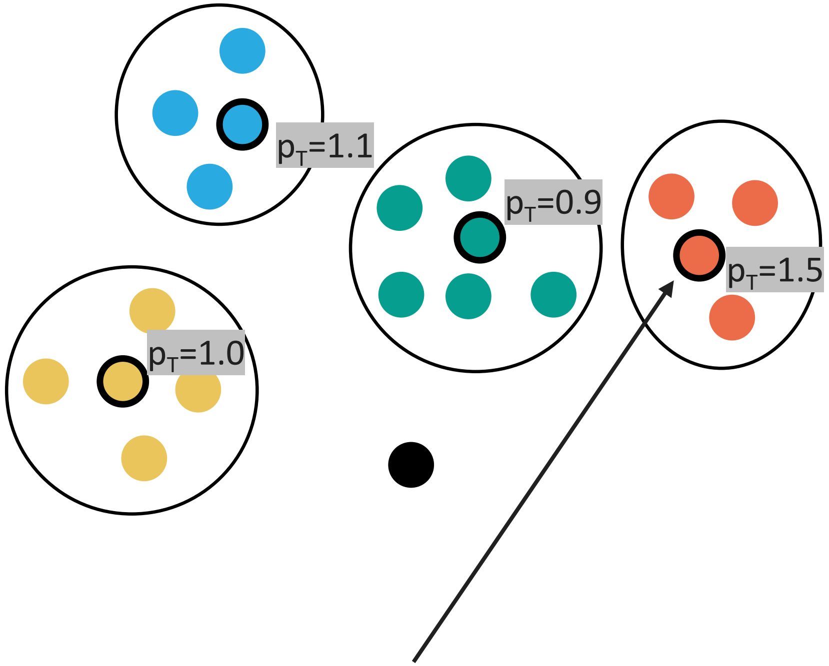
Tracking with Object Condensation: Vision

Point cloud



Repulsion & **attraction**
of points in latent space

Learnt latent space
Hits already clustered by particle;
Clusters can be collected trivially



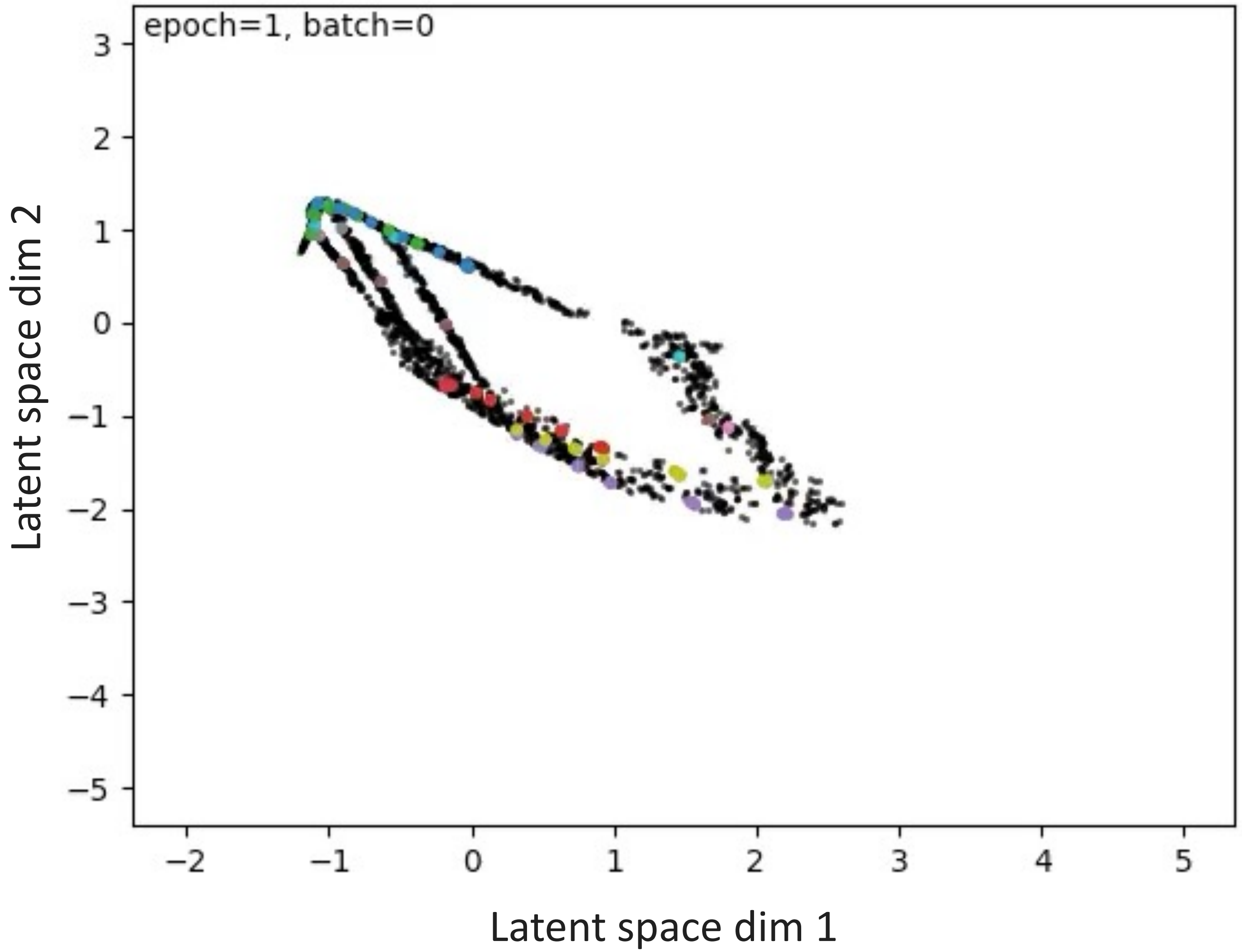
Condensation point
Represents the track, can learn
track parameters like pT (WIP)

Object condensation in action

2D latent space; random selection of particles colored

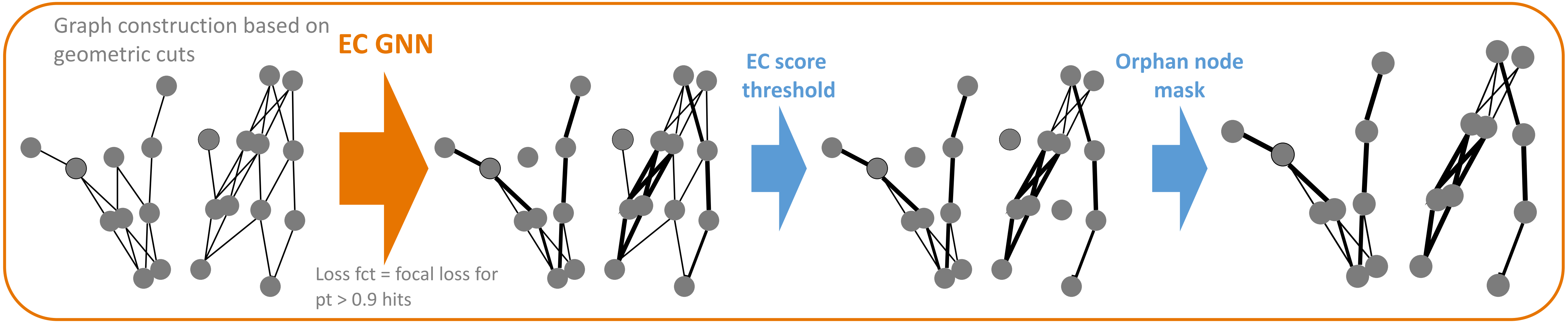
Early simplified study (much fewer hits than in real life)

[Click here if video doesn't play]

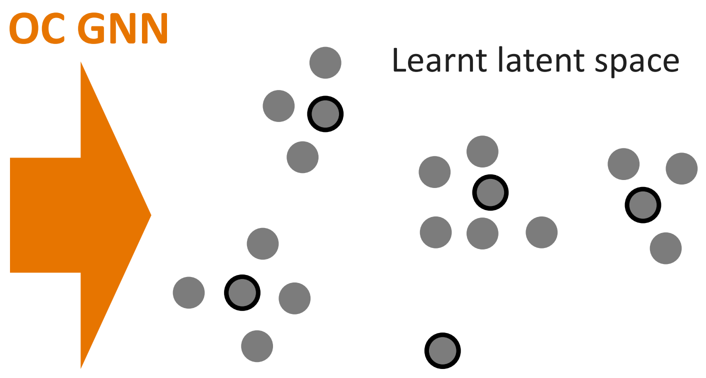


Object condensation: Our current pipeline

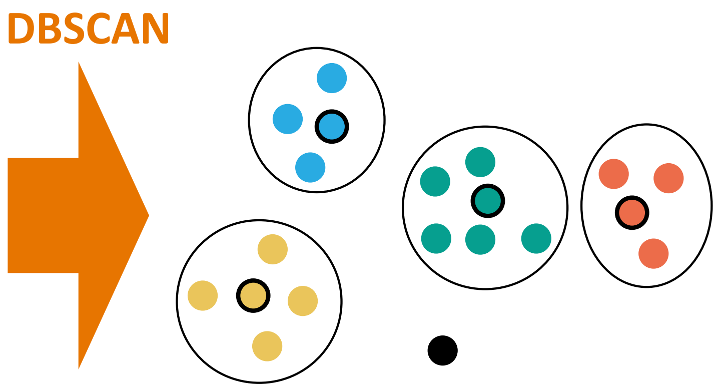
STAGE 1: EC → Working on replacing this with dynamic edge creation "Point cloud network"



STAGE 2: OC



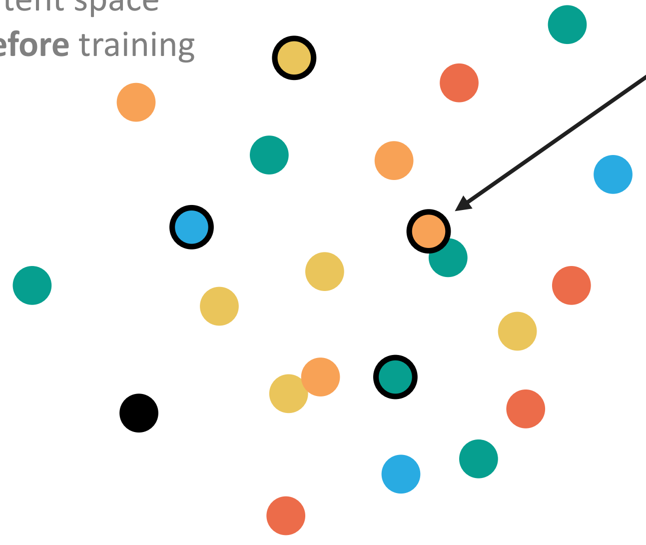
STAGE 3: Collect clusters



- All three stages have their own hyperparameters
- Can be trained/optimized separately (fixing the previous stage)

Object condensation: Training losses

Latent space
before training



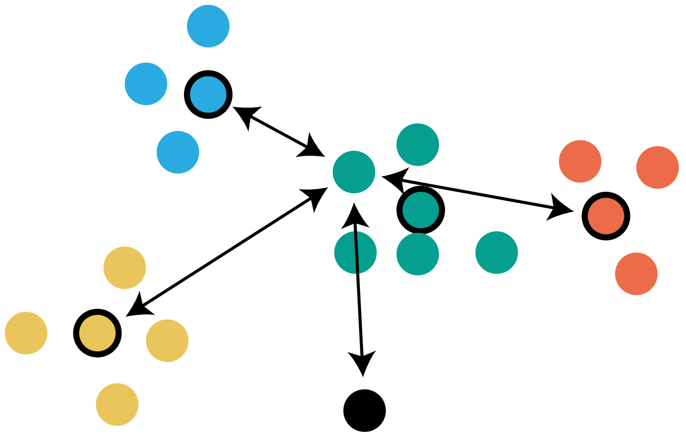
GNN predicts **condensation likelihoods (CL)** for every hit.
Hit with max CL for particle* is **condensation point (CP)**

*during inference: for cluster

Repulsive loss function

penalizes hits close to <u>other</u> CP

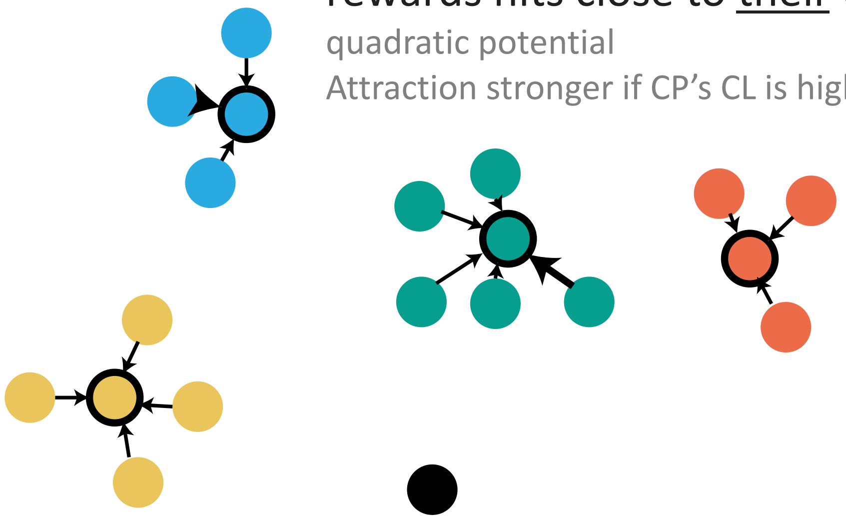
hinge loss: no more repulsion after certain distance
repulsion stronger for strong CP CLs



Attractive loss function

rewards hits close to <u>their</u> CP

quadratic potential
Attraction stronger if CP's CL is high



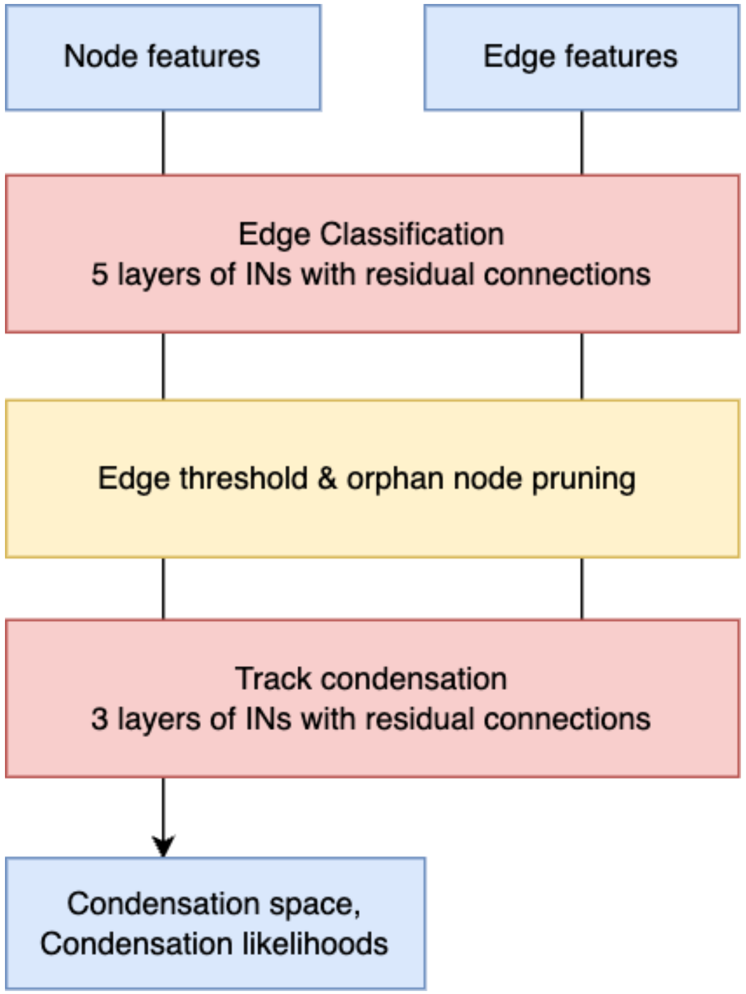
Background loss function

noise hits should have low CL

Loss functions implemented from Kieseler 2020 ([2002.03605](2002.03605))

Some details

Detailed sketch in backup



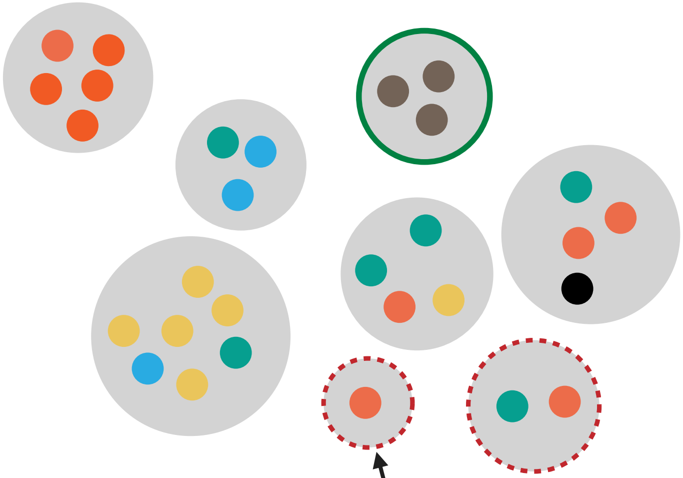
IN: Interaction Network

- Full event is sectorized in 32 sectors (see 2103.16701); 5 random sectors per batch
- **Graph construction**
  - Currently: **Geometric cuts** only (see 2103.16701)
  - Soon: Comparison to module map
  - Mid term: transitioning to a point cloud network
- Main building block: **Interaction Networks** (1612.00222)
- **Edge classification** (EC) performance is vital:
  - Using FocalLoss (https://arxiv.org/abs/1708.02002) for class imbalance
  - Ignoring false negatives for edges connecting $p_T < 0.9$ GeV hits
  - EC threshold is around maximum attainable MCC (and this is used to rank different ECs)
- Track condensation network starts from edge classification latent space
- **Condensation space** dimension is ~10

Metrics

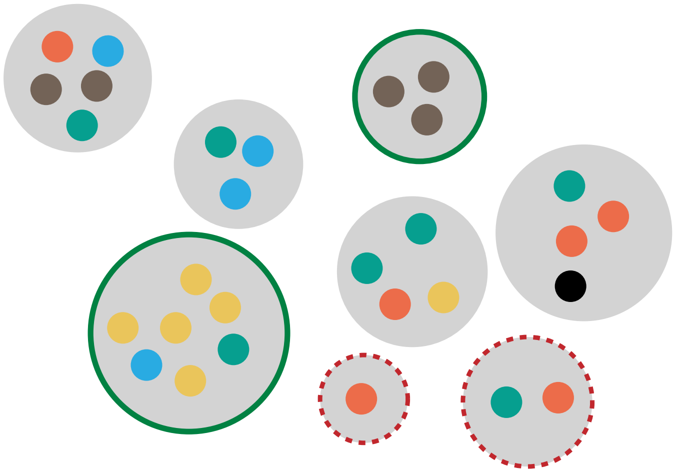
Perfect

Cluster contains only hits from one particle
and
no hits outside of cluster



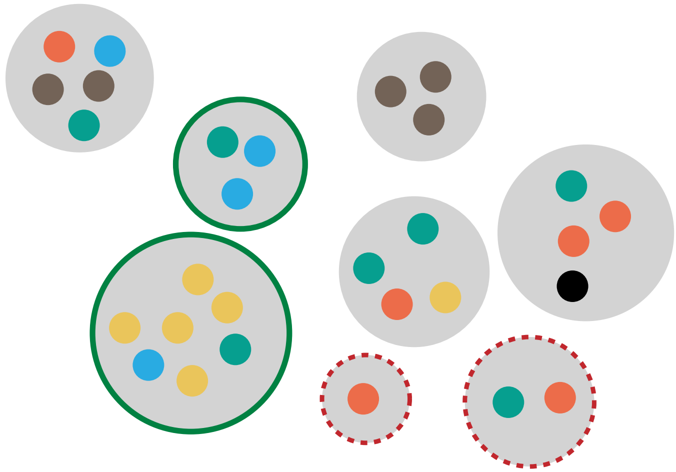
LHC

Cluster contains >= 75% hits from one particle



Double Majority

Cluster contains >= 50% hits from one particle
and
This particle has < 50% of its hits outside



Clusters with < 3 hits or non-reconstructable majority particle are discarded

#reconstructable particles

Perfect efficiency = **1/5**
Perfect fakes = **5/5**

#clusters with >= 3 hits & majority particle reconstructable

LHC efficiency = **2/5**
LHC fakes = **4/6**

#reconstructable particles

DM efficiency = **2/5**
DM fakes = **4/5**

We also evaluate these **metrics at pT thresholds**: pT cut is applied to majority particle of cluster or particle (this is <u>not</u> a truth cut on the data, but simply a efficiency vs pT study)

Reconstructable: >= 3 hits

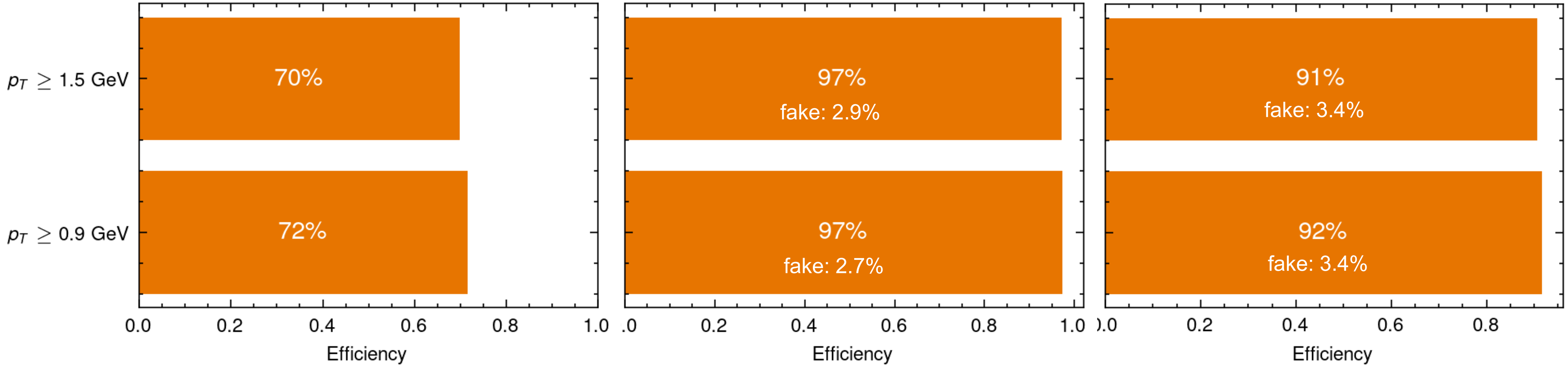
Most recent result

Regarding 🍏 to 🍎 comparisons for HL-LHC benchmarking:

- Evaluated on trackML 2.0 dataset (generated with the ACTS geometry)
- **Pixel layers only: This might be a harder problem than using the full detector** (very dense regions)!
- Full trackML detector results very soon

No truth cut on pT or other simplification

Perfect ("cluster = particle") | **LHC** ("homogeneous clusters") | **Double Majority** ("1:1 match cluster <> particle")

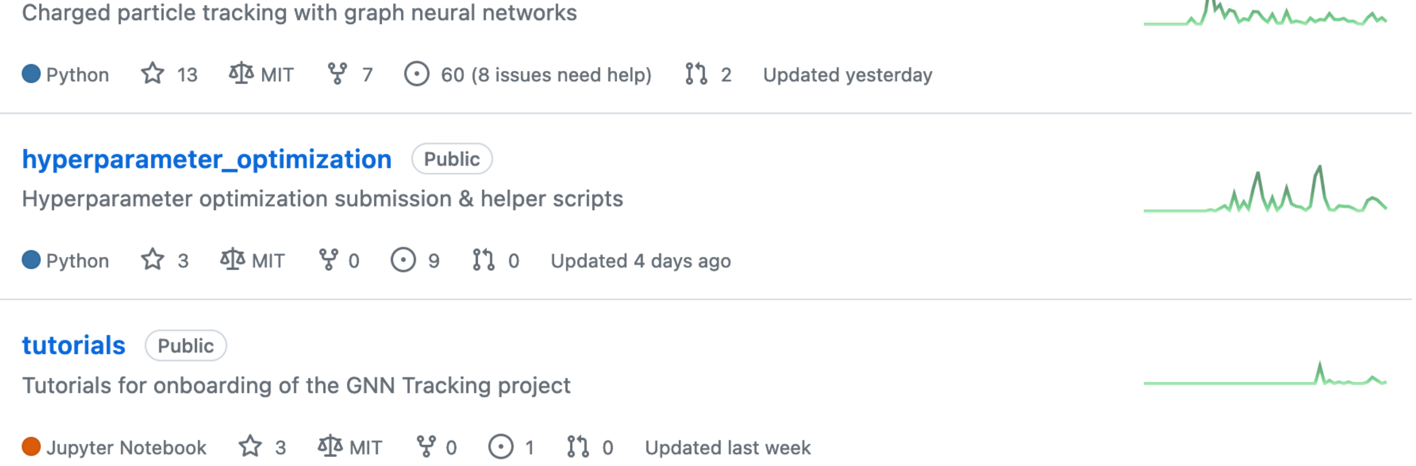


EC FocalLoss currently set to ignore low p_T false negatives → lower performance for low p_T

Summary

- Proof of concept for object condensation applied to the HL-LHC tracking challenge without truth cuts
- **Promising performance on trackML pixel layer: > 90% of particles with pT > 0.9 GeV are uniquely (double majority) matched to a cluster**
- Currently working on on applying to full detector geometry
- Much to be explored: Point cloud networks and more
- **Fully open-source framework**: Let's make prototyping new architectures for tracking accessible to everyone

github.com/gnn-tracking

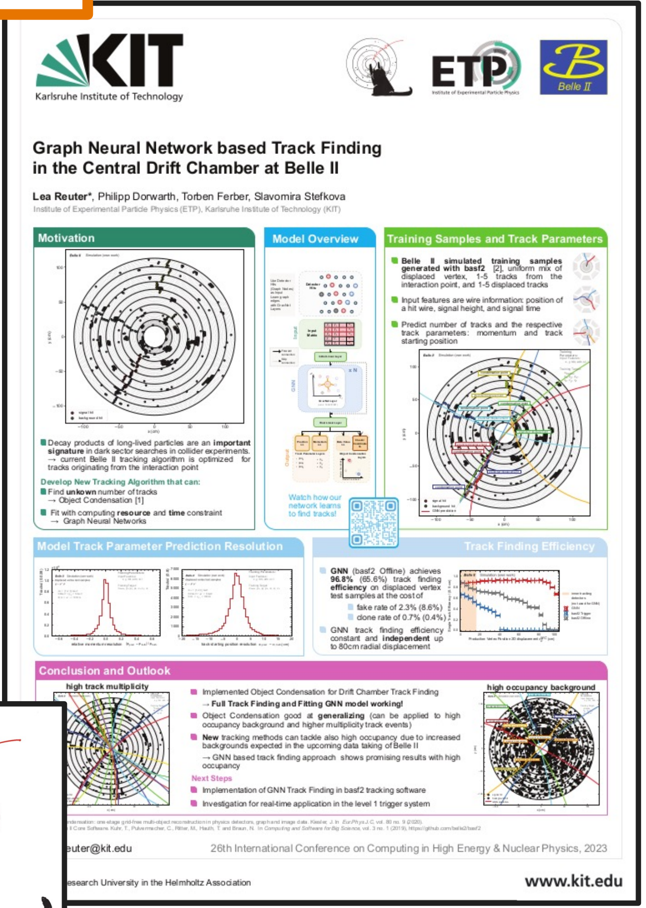


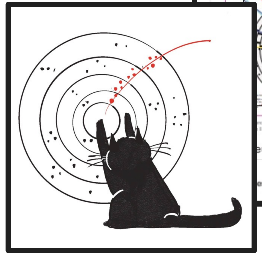
PyTorch PyG RAY tune Weights & Biases

Shoutouts: More object condensation

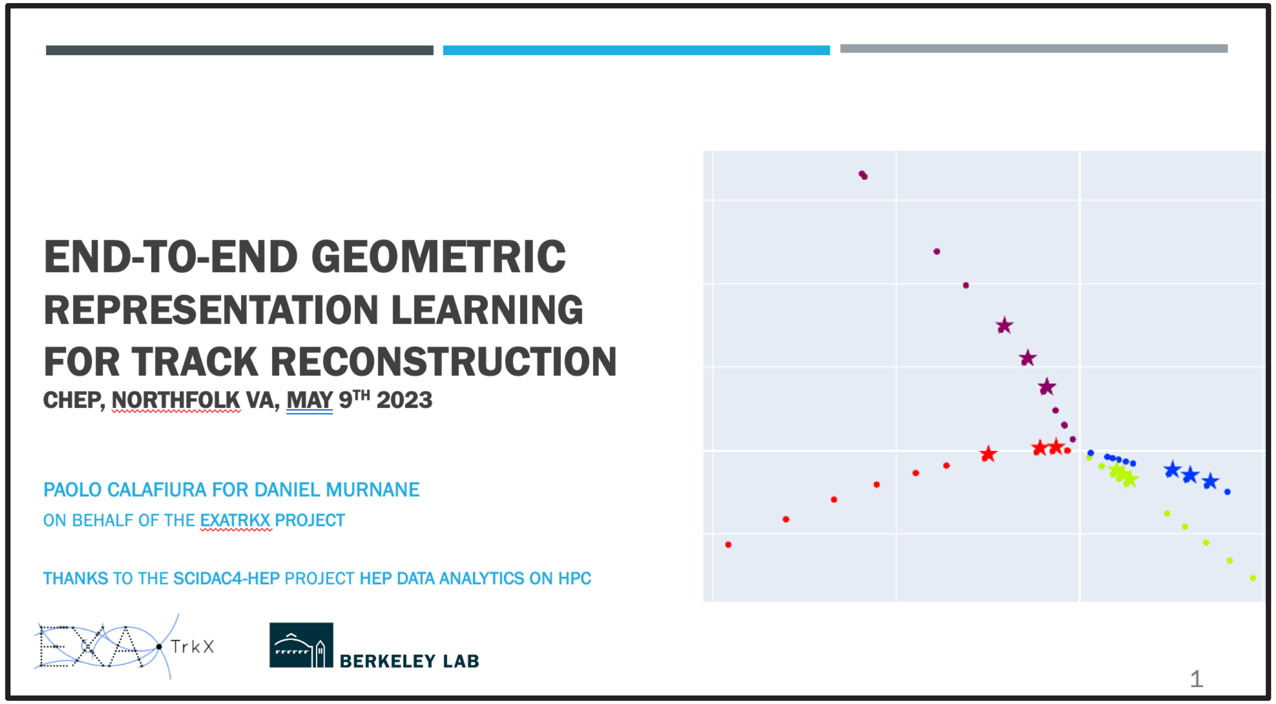
Poster #10

Lea Reuter
Object condensation tracking at Belle II



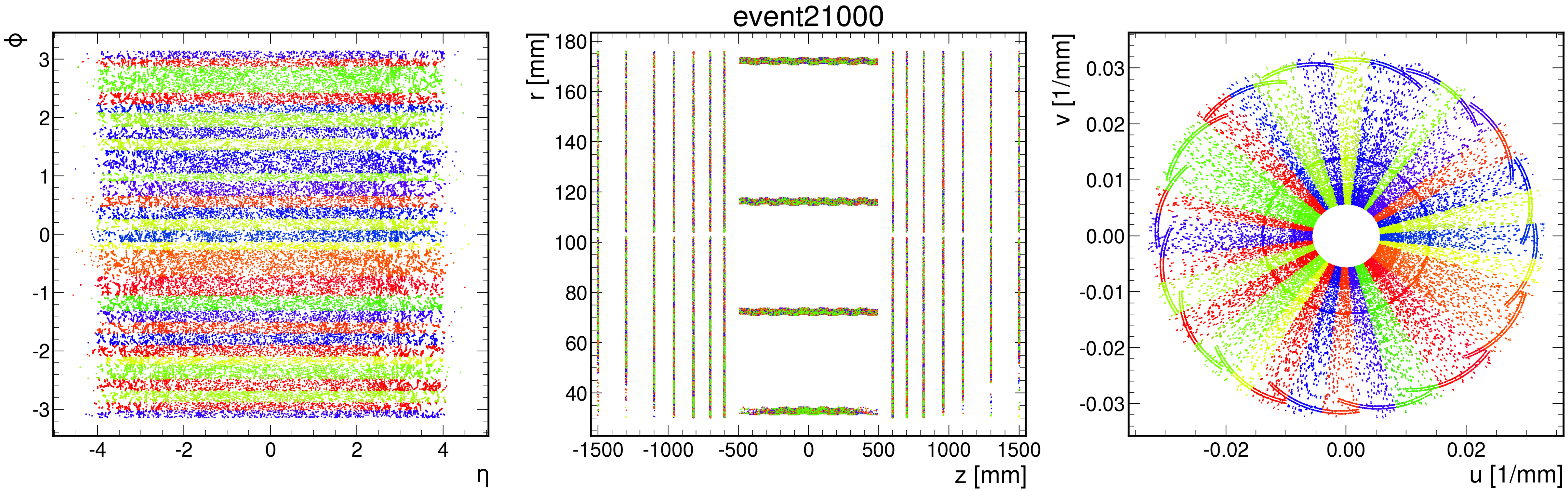


Daniel Murnane/Paolo Calafiura
Object Condensation with "Influencer" approach



Backup

Point cloud sectorization



Architecture