

Deep Neural Networks for LArTPC Particle Image Detector *at the HEP Intensity Frontier*

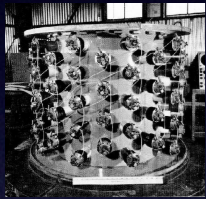
Kazuhiro Terao

SLAC National Accelerator Lab.

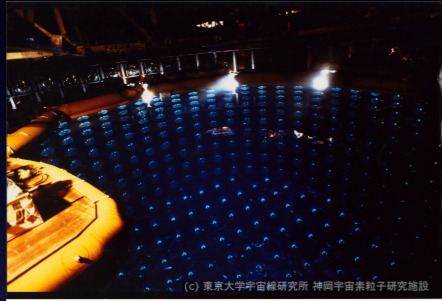
1st ML-at-SLAC Workshop (Feb. 19th 2019)

Physics Interest (sorry): Neutrinos

Small Cross-section (rare interaction)



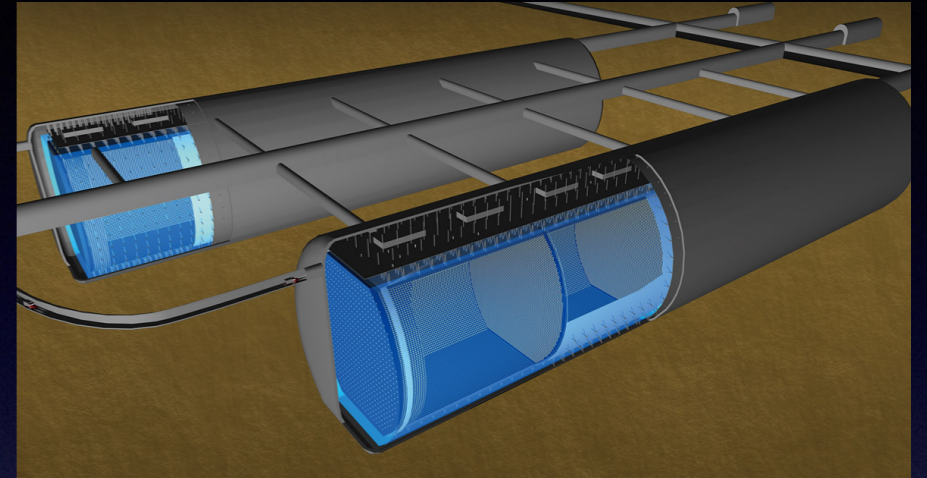
0.4 ton
100 PMTs
(1956)



3000 ton
1000 PMTs
(1956)



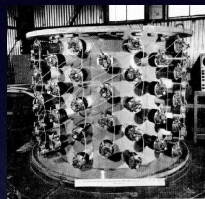
50,000 ton
11,000 PMTs
(1996)



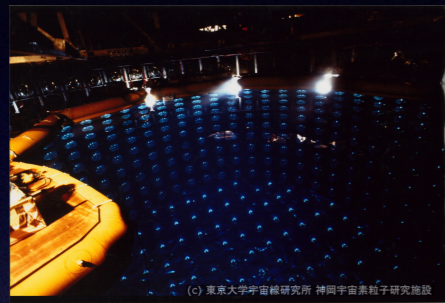
\sim (1M) ton
? PMTs
(202X)

Physics Interest (sorry): Neutrinos

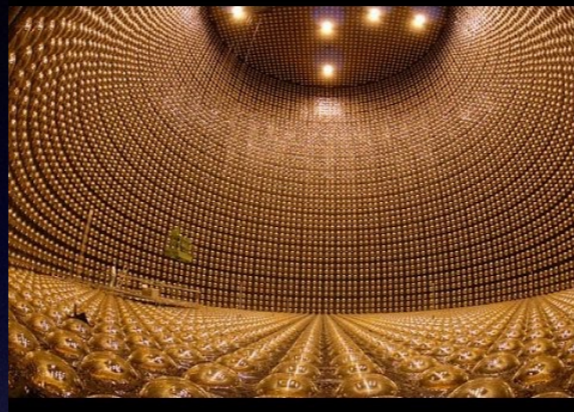
Small Cross-section (rare interaction)



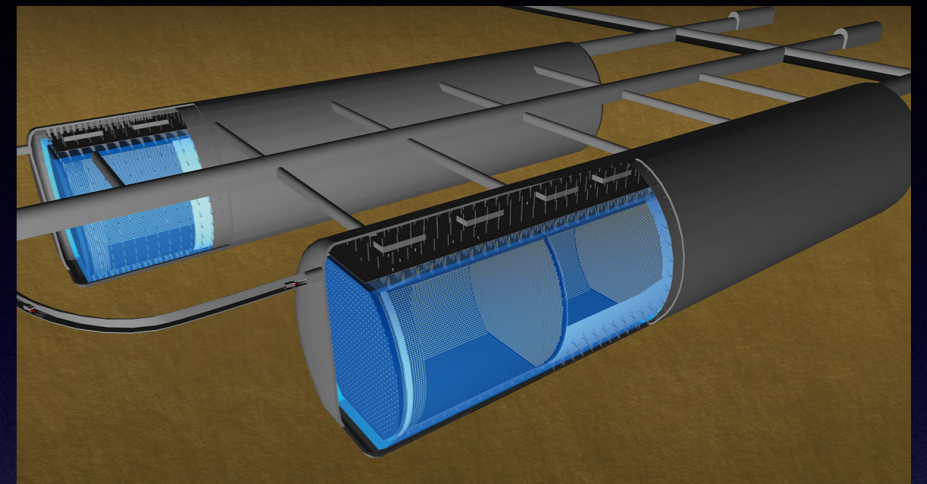
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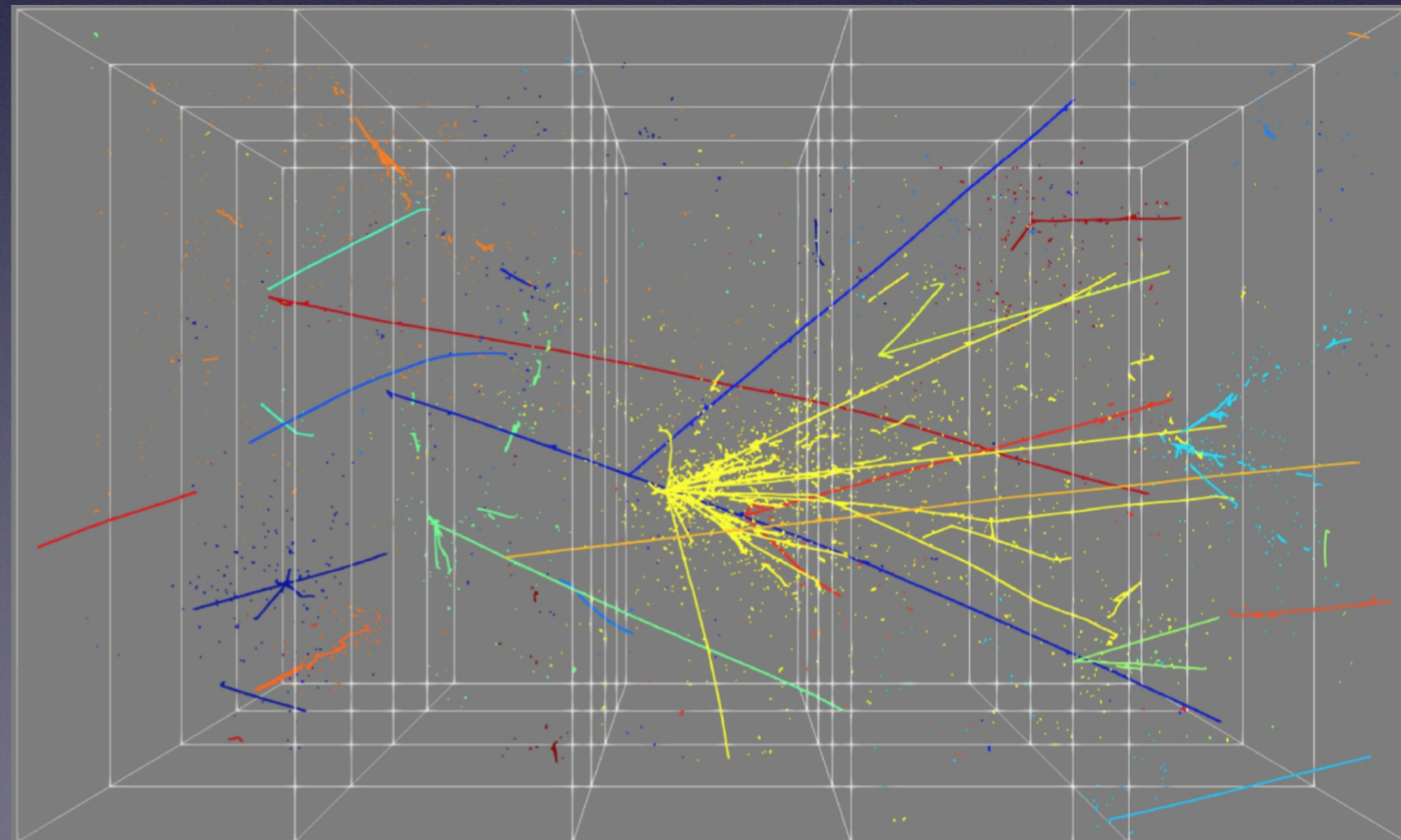
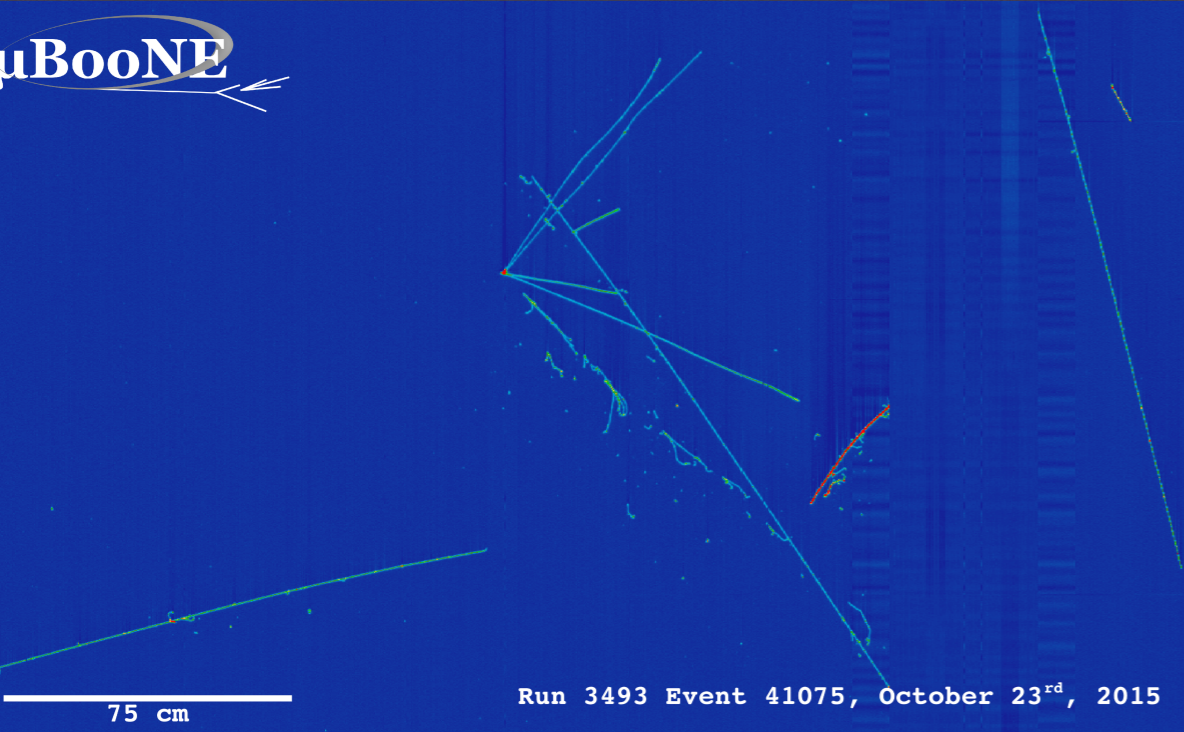
50,000 ton
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(1996)



o(1M) ton
? PMTs
(202X)

Study Secondaries

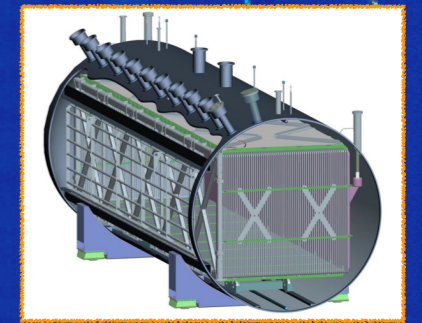
μBooNE



Particle Imaging @ HEP-IF

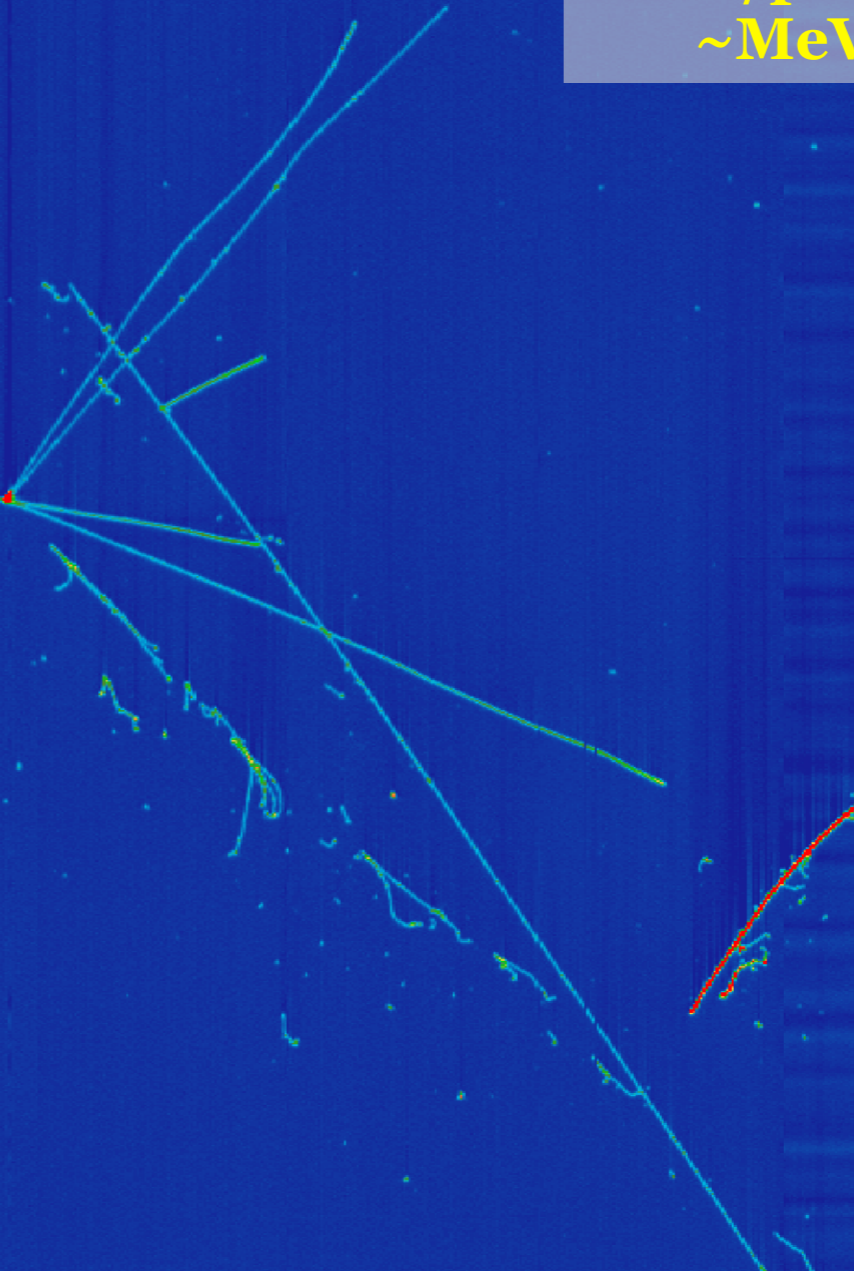
μ BooNE

~mm/pixel spatial resolution
~MeV level sensitivity



MicroBooNE
~87 ton (school bus size)

ν_μ



Bubble Chamber

Liquid Argon Time Projection Chamber

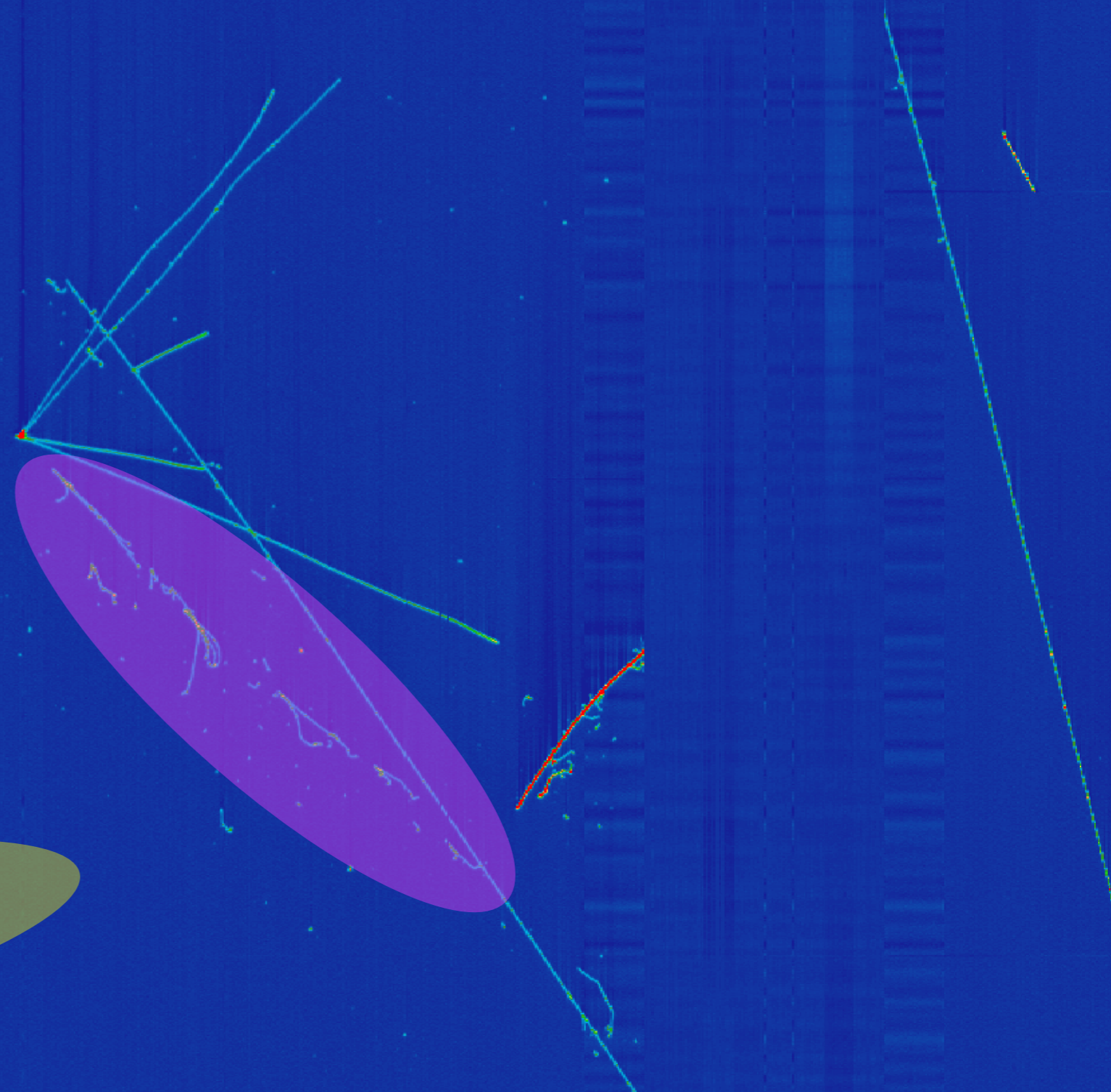
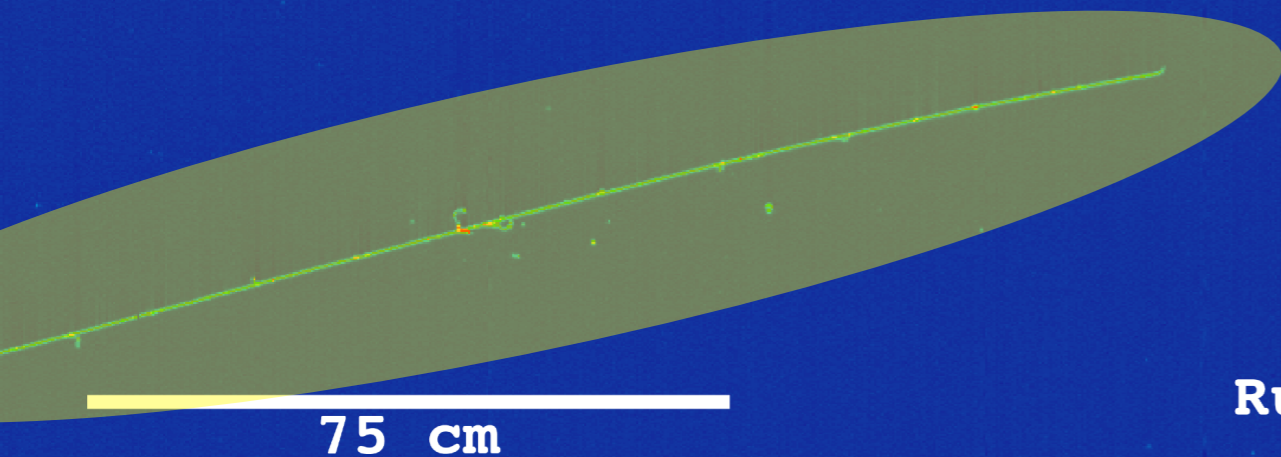
- Chamber-like images: digitized electronics readout
- Calorimetric measurement + scalability to a large mass

2015

Particle Imaging @ HEP-IF

μ BooNE

Topological shape
difference is a major
distinction for
“shower” particles

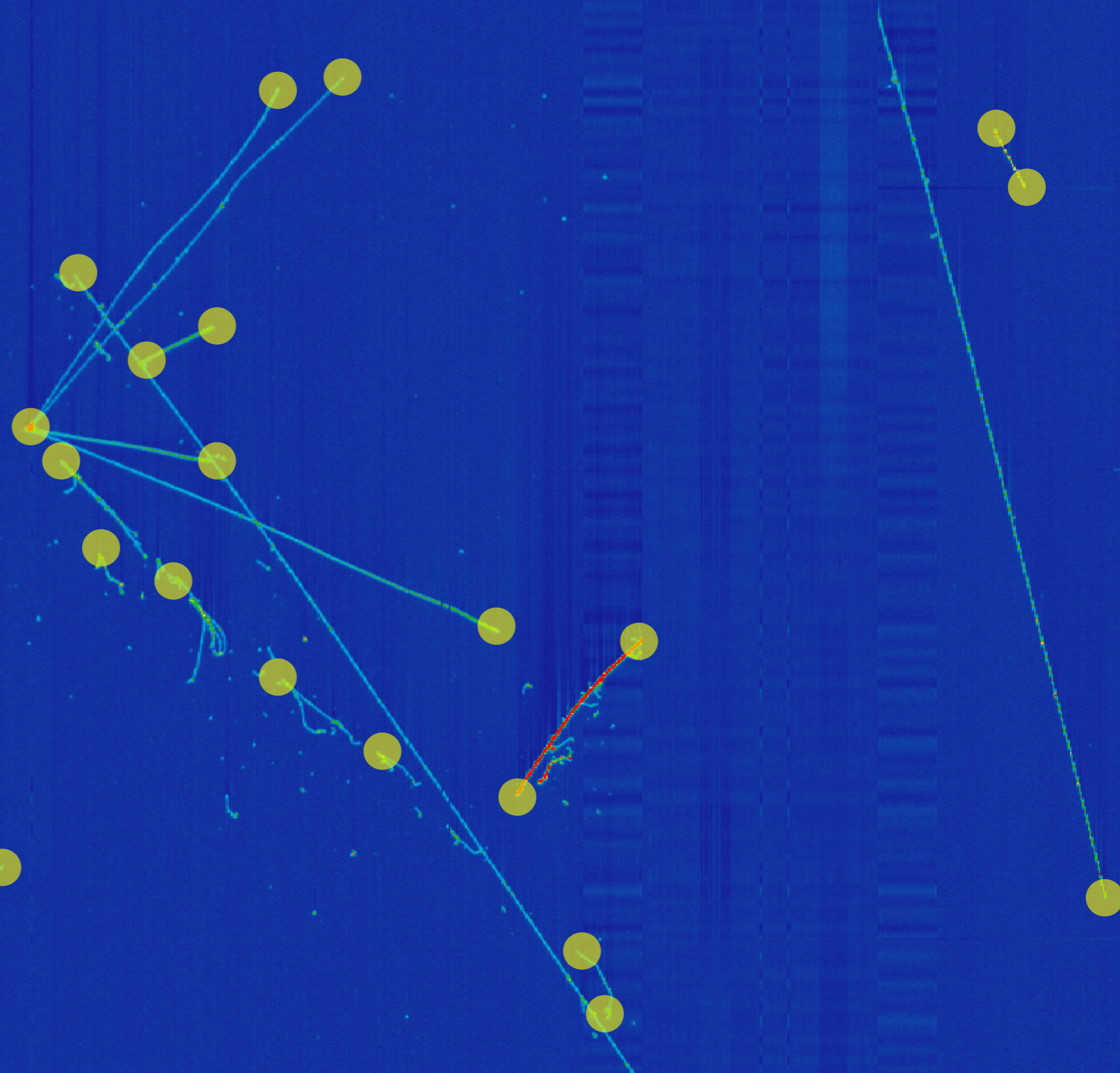


Run 3493 Event 41075, October 23rd, 2015

Particle Imaging @ HEP-IF

μ BooNE

Trajectory ends
are distinct, and
useful for seeding
particle clustering
and trajectory fitting



75 cm

Run 3493 Event 41075, October 23rd, 2015

Particle Imaging @ HEP-IF

μ BooNE

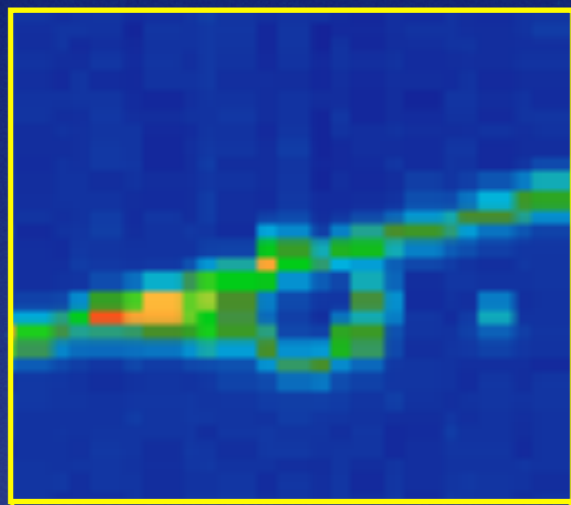
Many, local kinks
caused by Multiple
Coulomb Scattering
process can be used for
momentum estimation

75 cm

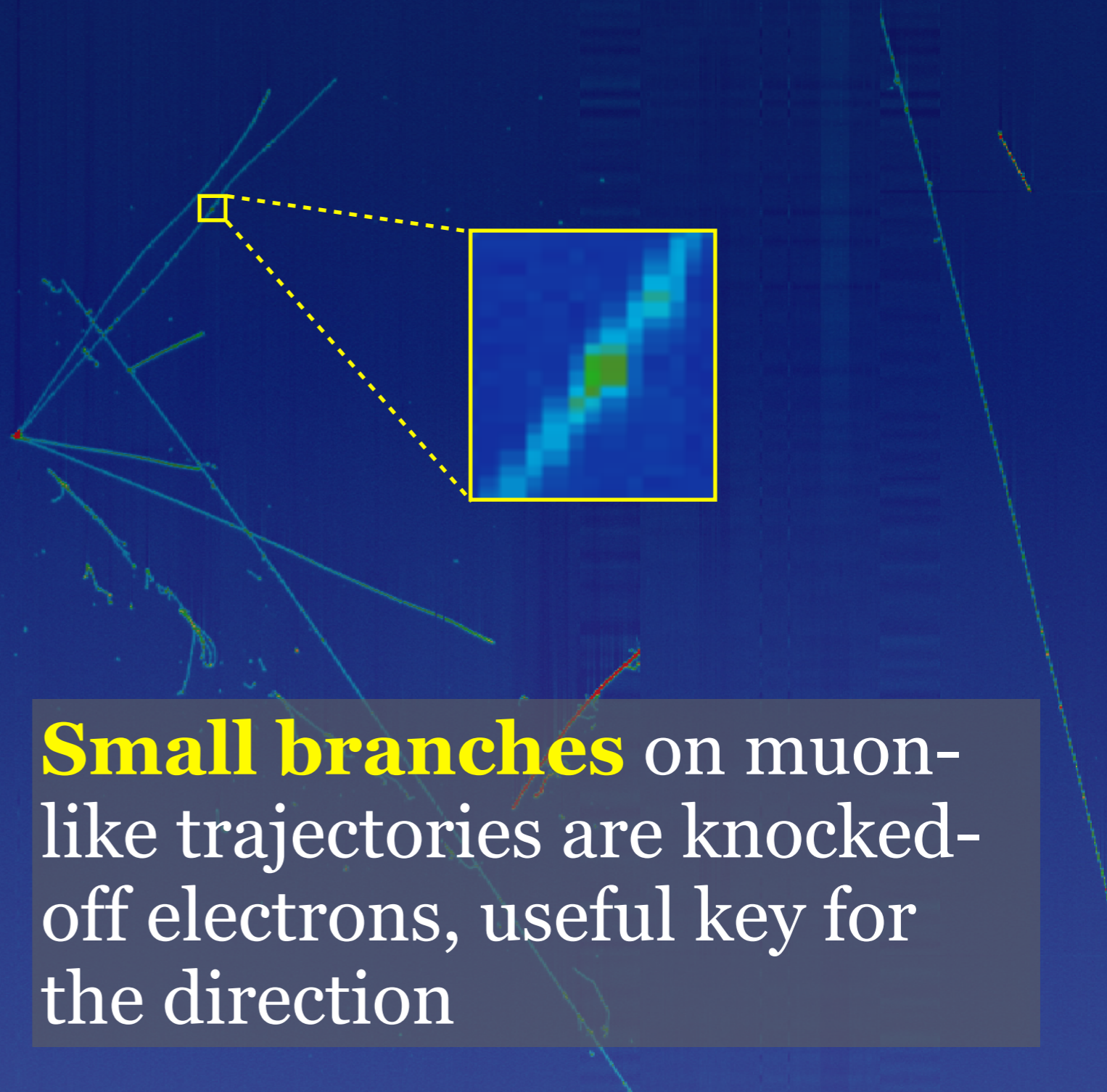
Run 3493 Event 41075, October 23rd, 2015

Particle Imaging @ HEP-IF

μ BooNE



75 cm



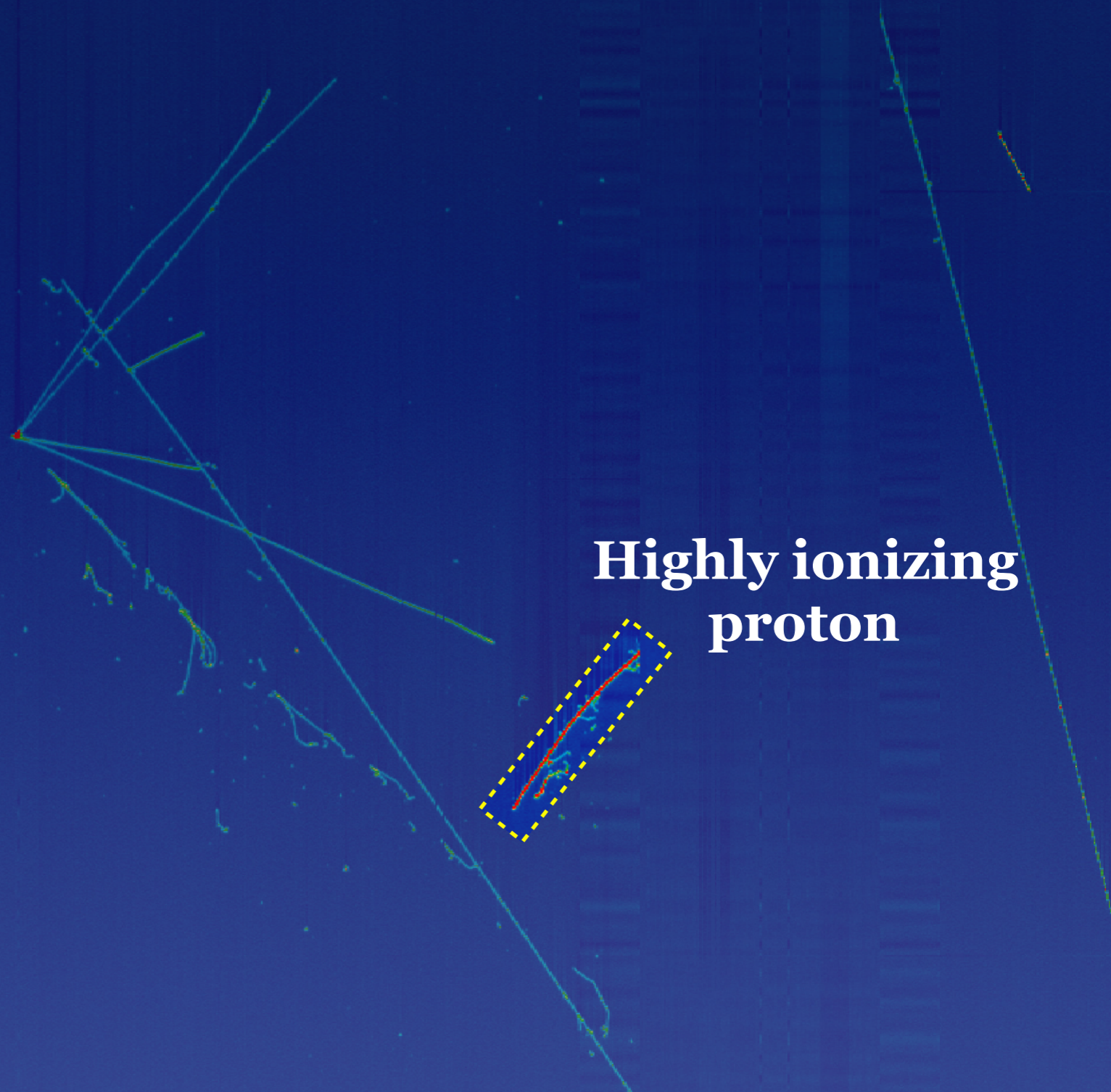
Small branches on muon-like trajectories are knocked-off electrons, useful key for the direction

Run 3493 Event 41075, October 23rd, 2015

Particle Imaging @ HEP-IF

μ BooNE

Energy deposition patterns (dE/dX) vary with particle mass & momentum, useful for analysis



Highly ionizing proton

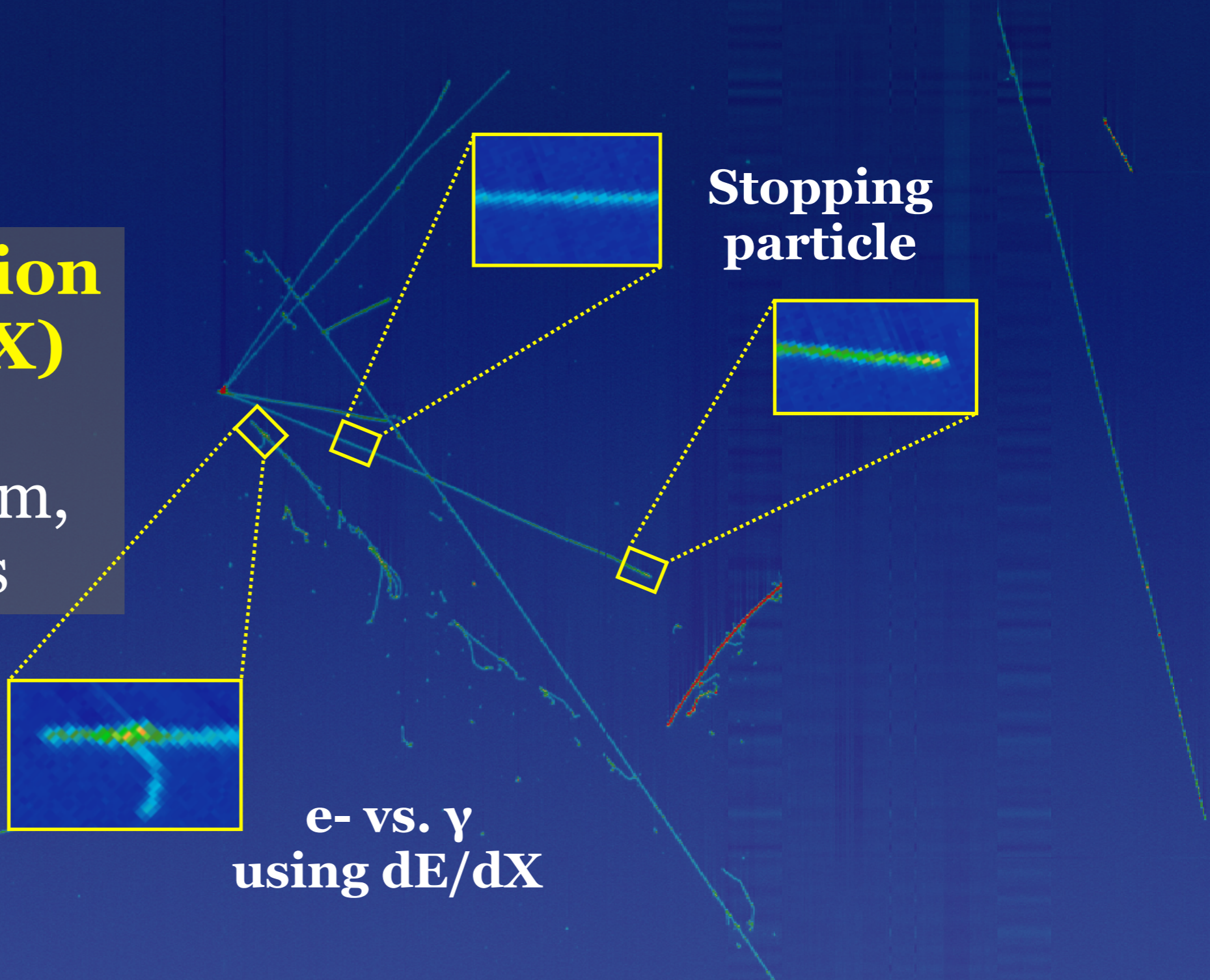
75 cm

Run 3493 Event 41075, October 23rd, 2015

Particle Imaging @ HEP-IF

μ BooNE

Energy deposition patterns (dE/dX) vary with particle mass & momentum, useful for analysis



Stopping particle

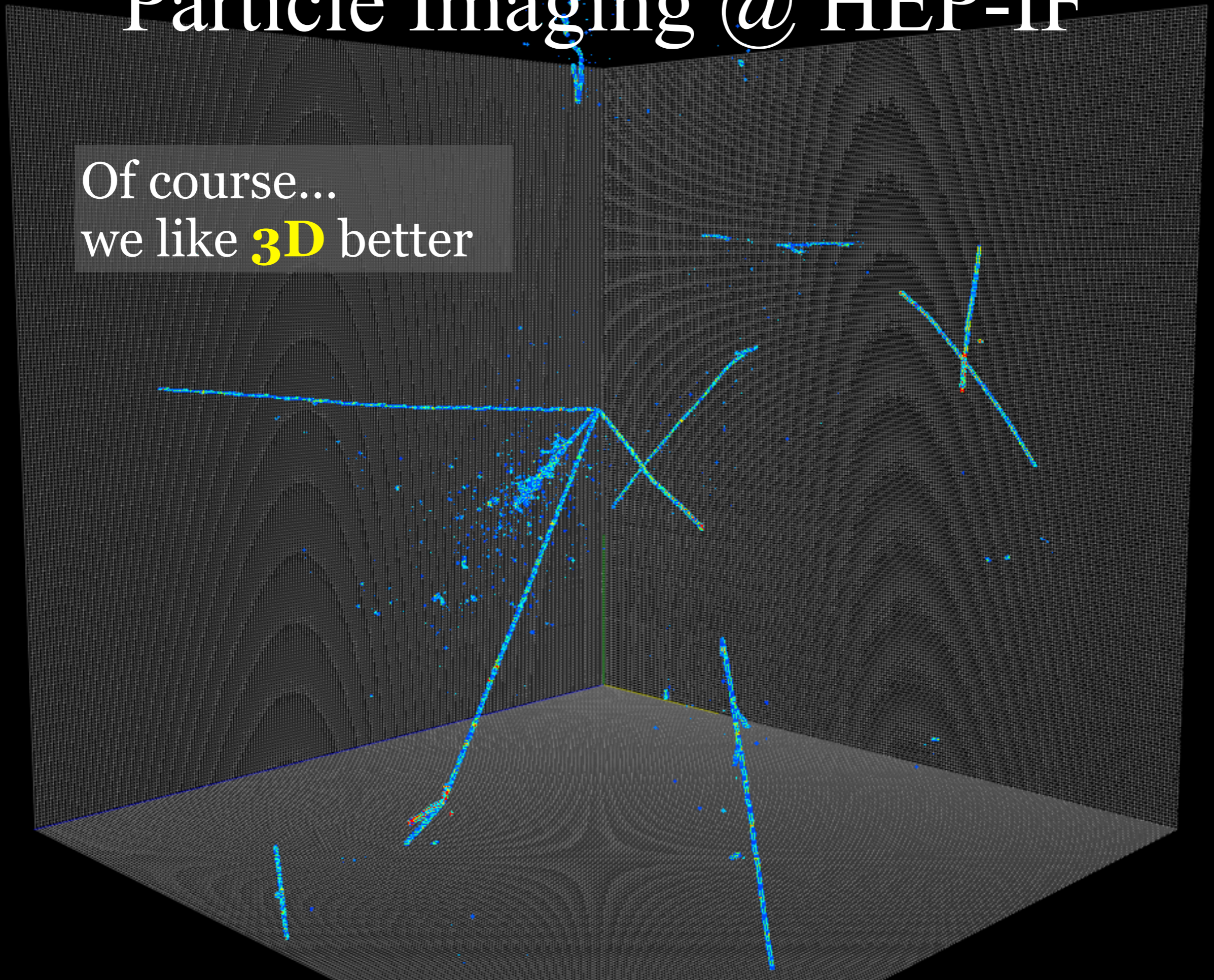
**e- vs. γ
using dE/dX**

75 cm

Run 3493 Event 41075, October 23rd, 2015

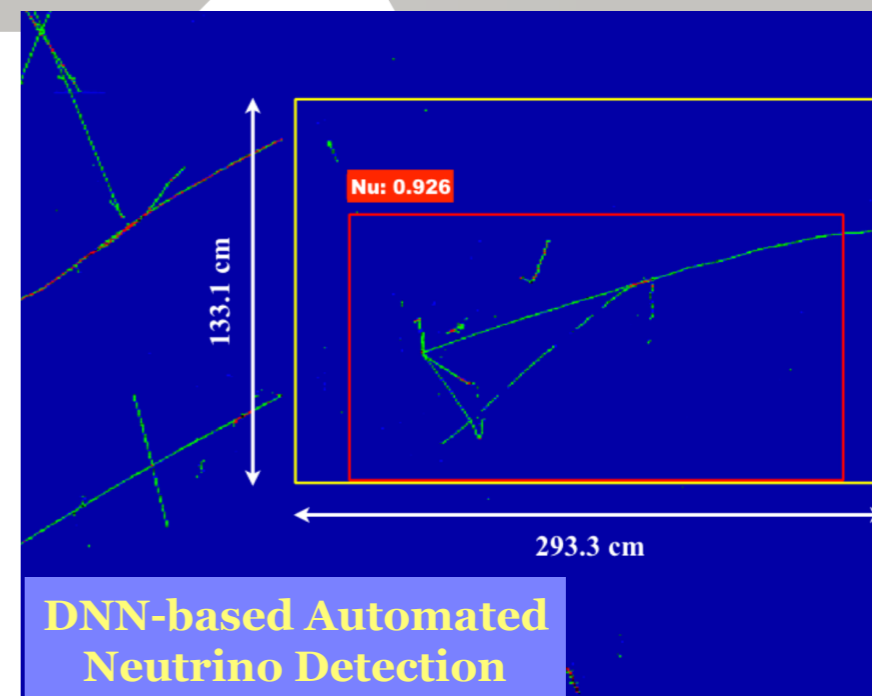
Particle Imaging @ HEP-IF

Of course...
we like **3D** better

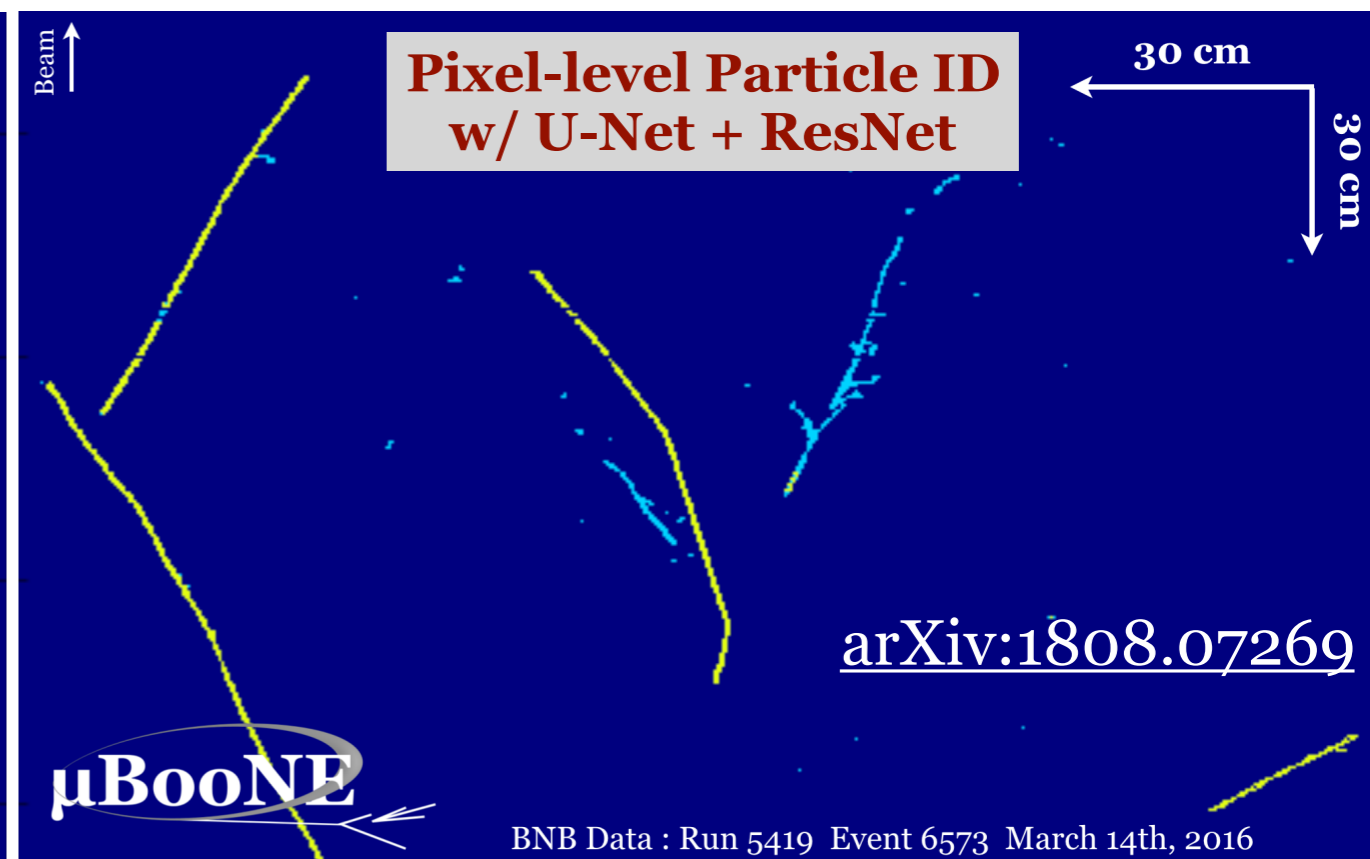
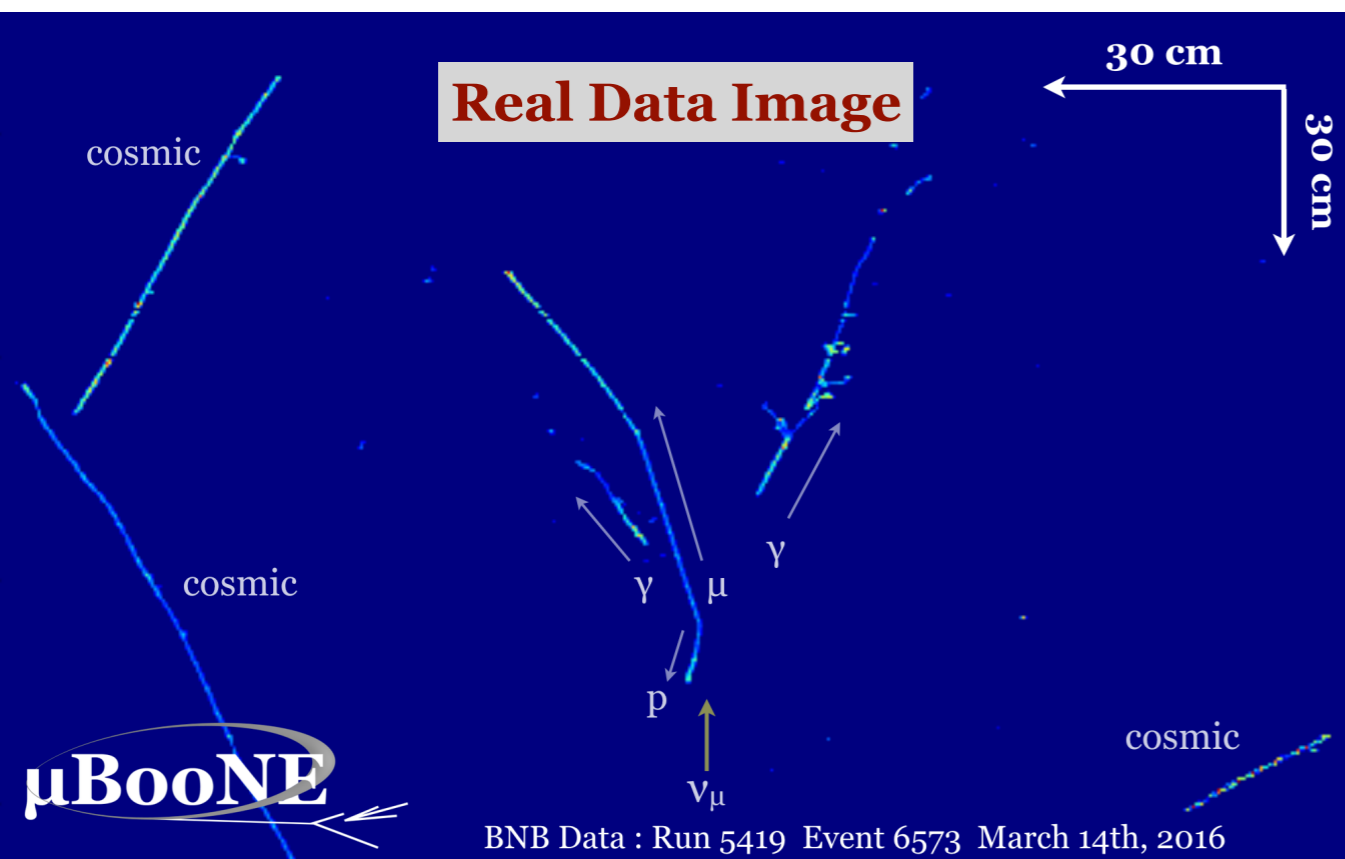


- **DNN for image data analysis**

- Computer Vision: use DNNs to extract interesting features for physics from image data ([JINST 12, P03011](#)) down to pixel-level ([arXiv:1808.07269](#))
- **Crucial**: avoid & study discrepancies in simulation (train) and data (test) domains

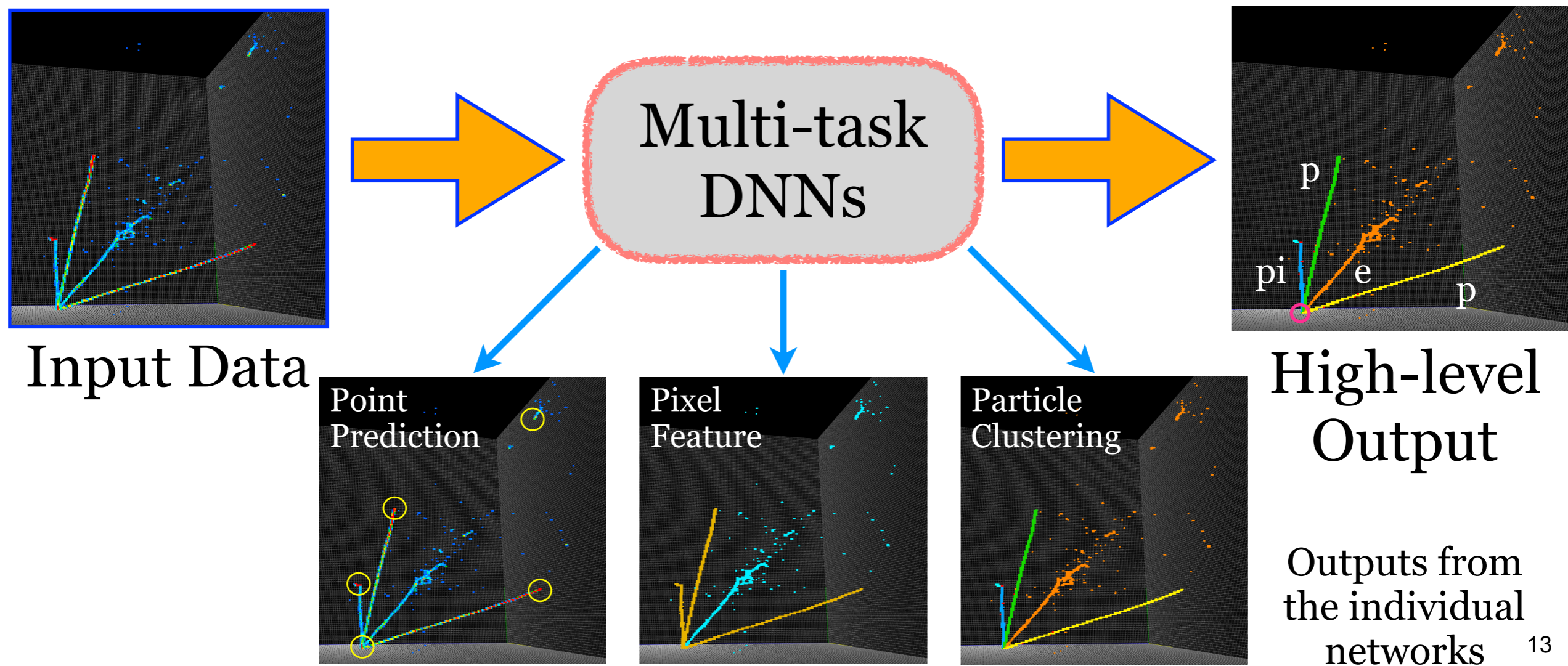


Detection Network



Multi-task DNN for Physics Reconstruction

Introduce physical feature extraction tasks (auxiliary targets) to bias the data transformation path to support producing a logical conclusion. Optimize the whole reconstruction chain.



Outputs from the individual networks

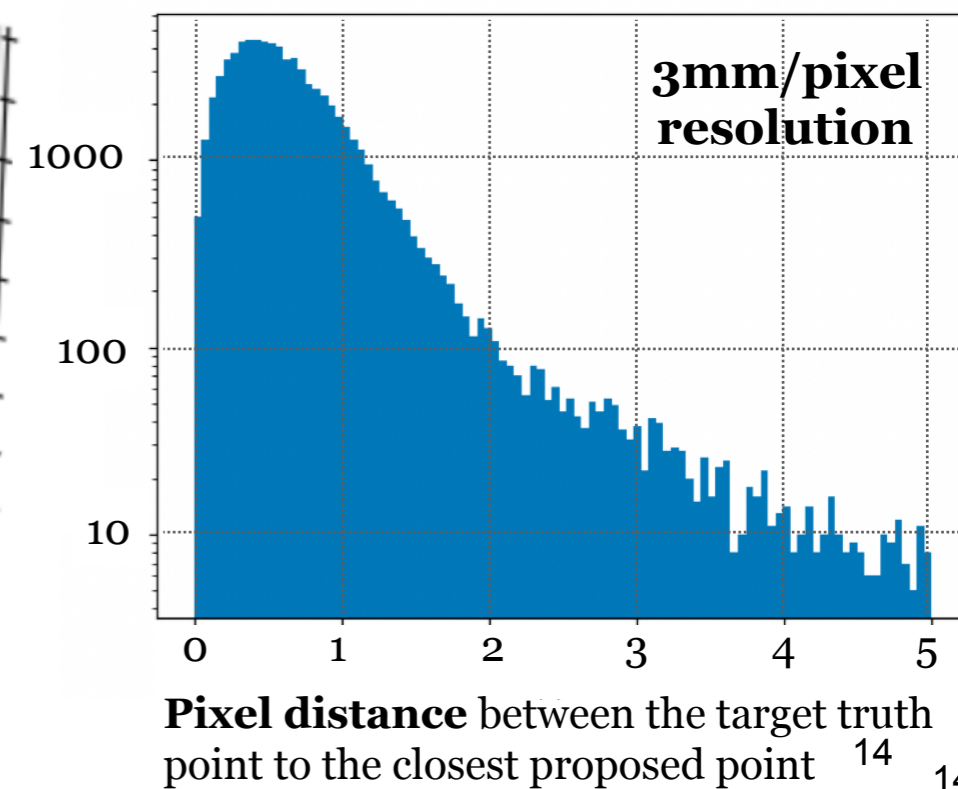
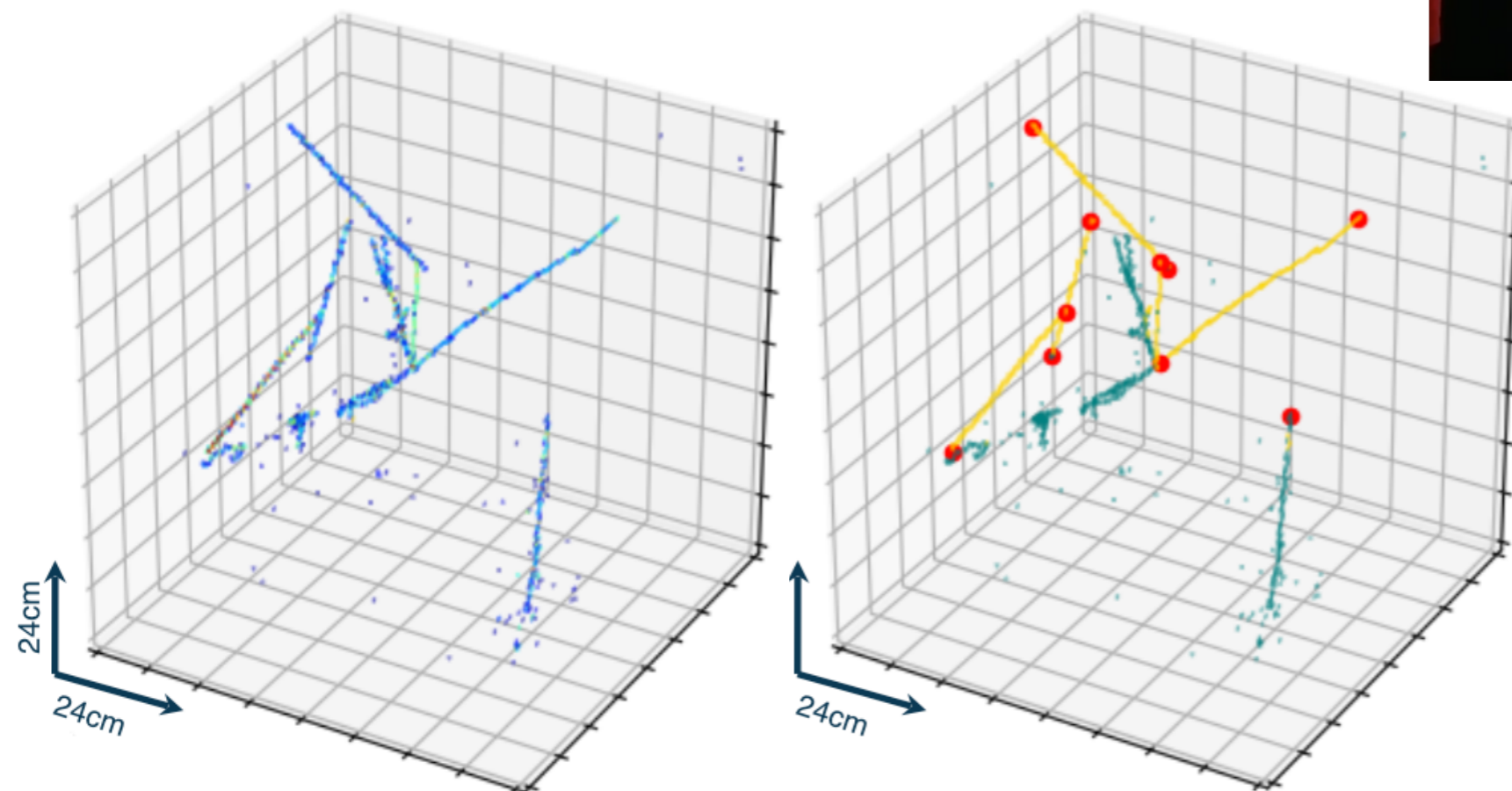
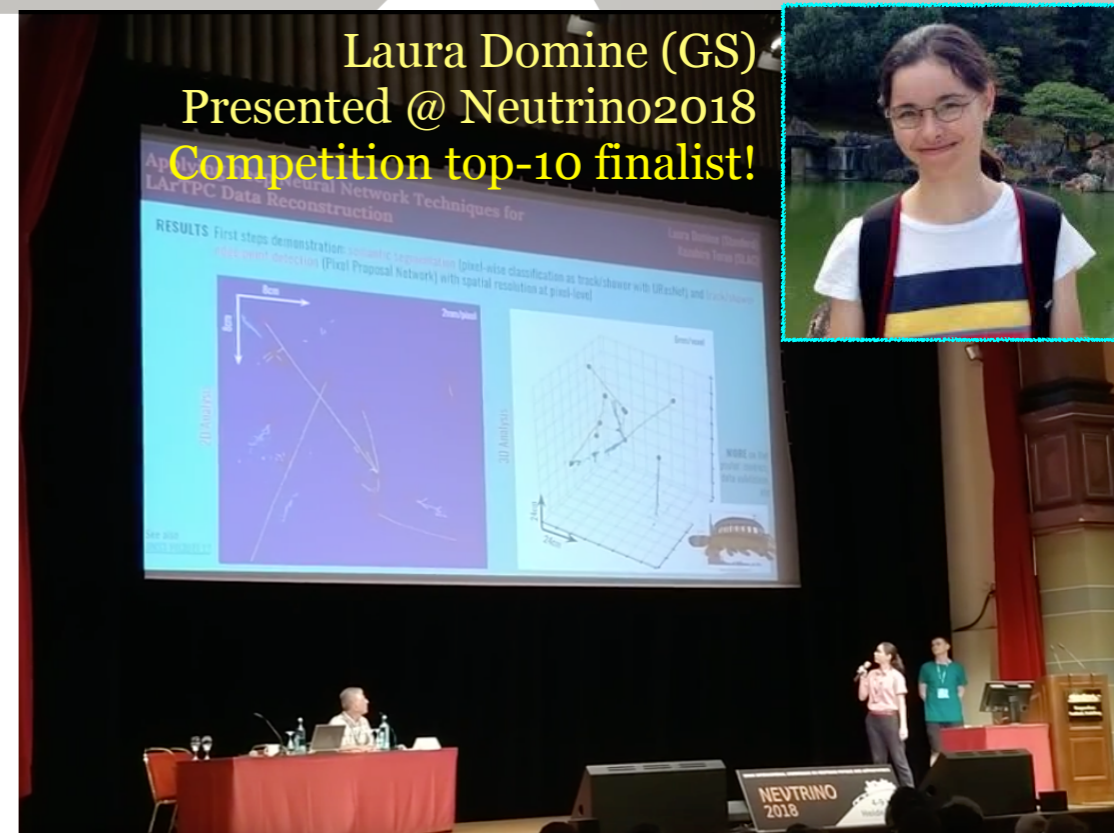
ML @ HEP-Intensity Frontier

Machine Learning for Particle Image Analysis

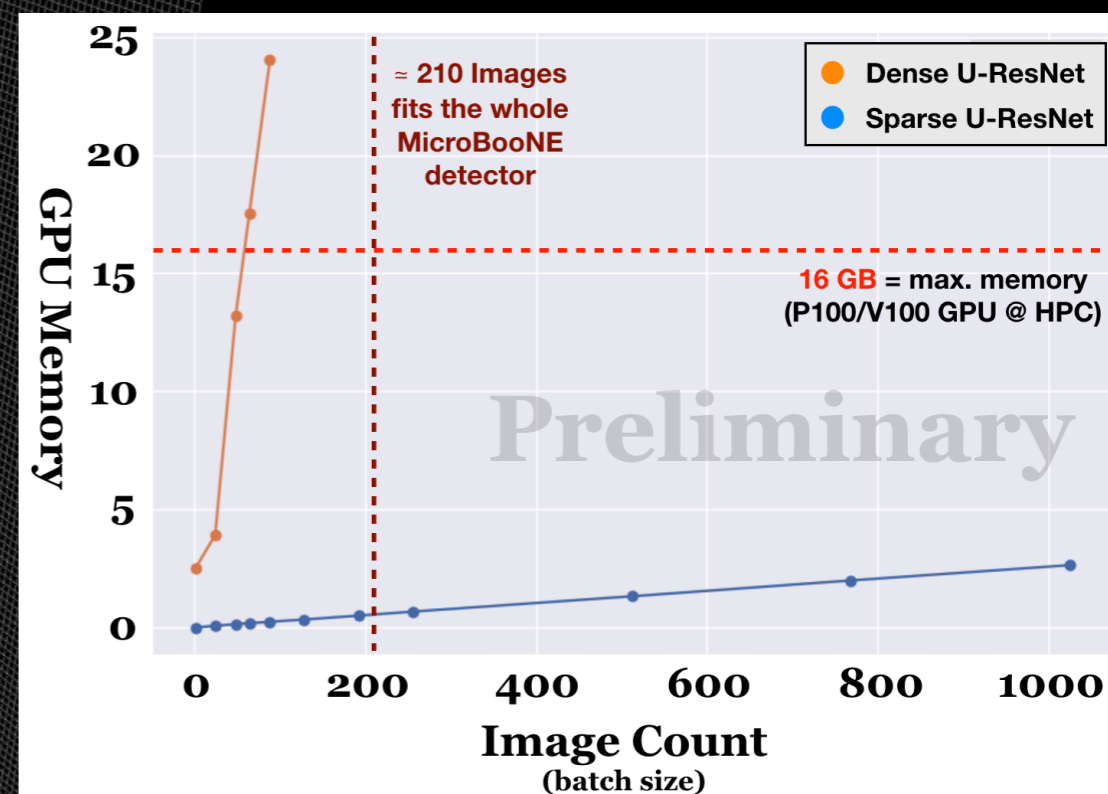
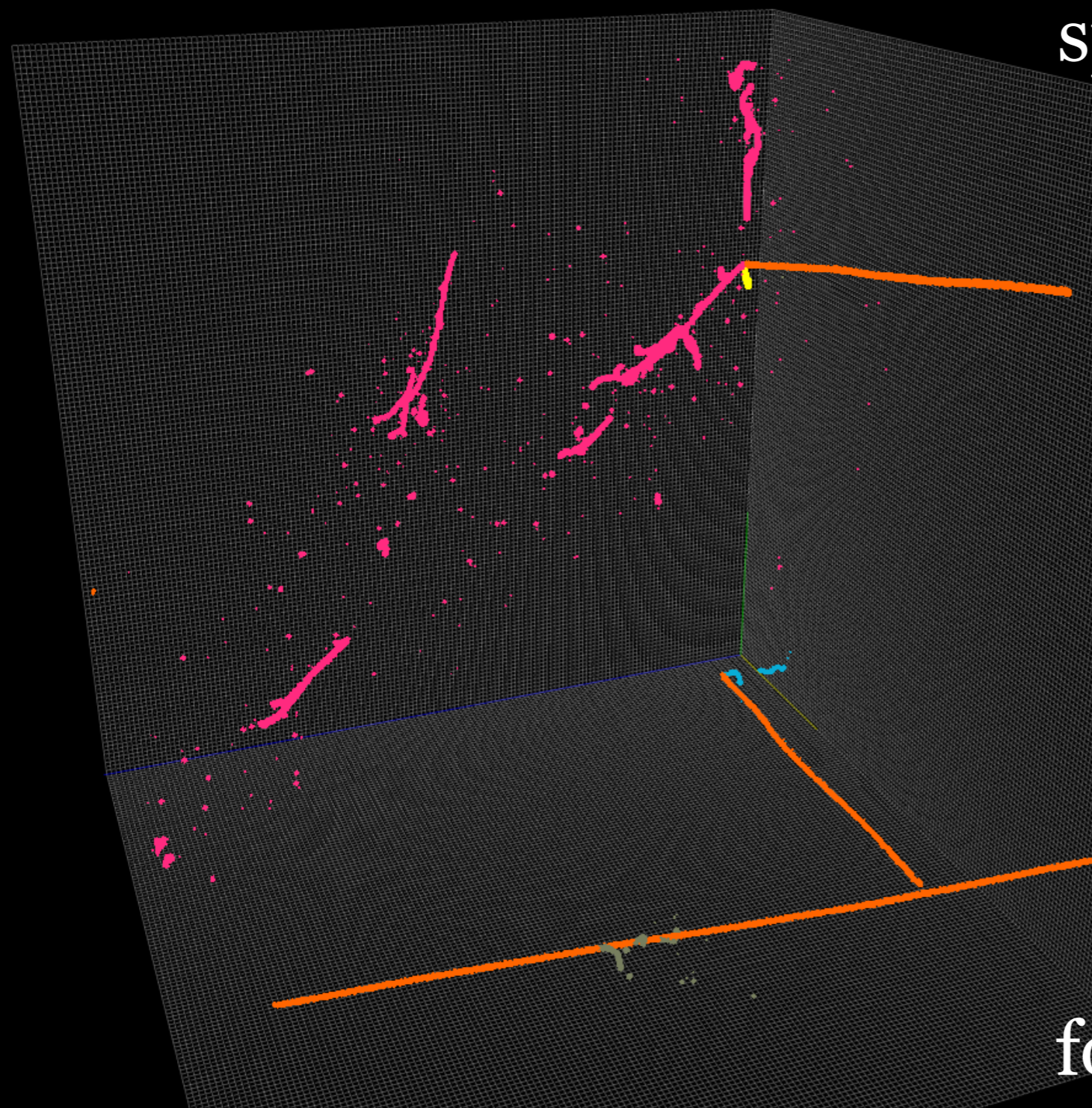


Multi-Task Network Cascade

- **Chain of Segmentation + Detection**
 - Feature points: “shower start” and “track edges”
 - Classify each pixel into “shower” vs. “track”
- **Extension to 3D data**
 - Change in tensor dimensions, identical algorithms



Data feature: generally sparse, locally dense image, and very large volume (1e10 to 1e12 pixels)



Dedicated DNN libraries for sparse data are essential

ML connects research frontiers!

- **HEP-ML cross-frontier** with **Michael K. & Phil M.**
- Computer Vision DNN for Cryo-EM with **Yee T. & Wah C.**
- ... and other misc. consultations with random visitors to my office
- Workshop/Tutorials (e.g. ML-for-HyperK @ TRIUMF in April)
- **DeepLearnPhysics**: cross-experimental organization for R&D

Sharing of R&D data & software

- [Open data sample](#)
- Software distribution w/ containers ([docker](#), [singularity](#))
- ... some R&D papers using those soon hopefully :)

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... and I won't have a summary ...

Please find me with questions during breaks!