A FOUNDATION MODEL FOR TPC DATA

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INTERNATIONAL NUCLEAR PHYSICS CONFERENCE
DAEJEON, SOUTH KOREA 대전
MAY 26, 2025

Research Question: Can we build a general deep learning model for time projection chamber data?

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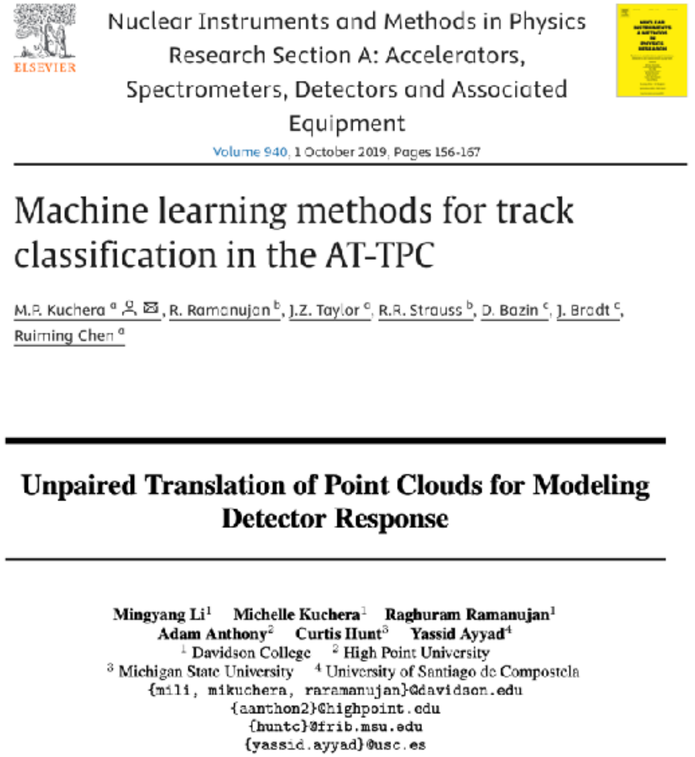
Use case #1: Can a general-purpose model for Active Target Time Projection Chamber data be easily tuned for a variety of experiments?

Already successfully built bespoke models with experimentalists



Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment

Volume 940, 1 October 2019, Pages 156-167

Machine learning methods for track classification in the AT-TPC

M.P. Kuchera [a], R. Ramanujan [b], J.Z. Taylor [c], R.R. Strauss [b], D. Bazin [c], J. Bradt [c], Ruiming Chen [a]

Unpaired Translation of Point Clouds for Modeling Detector Response

Mingyang Li[1] Michelle Kuchera[1] Raghuram Ramanujan[1]
Adam Anthony[2] Curtis Hunt[3] Yassid Ayyad[4]
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Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment

Volume 1072, March 2025, 170002

Full Length Article

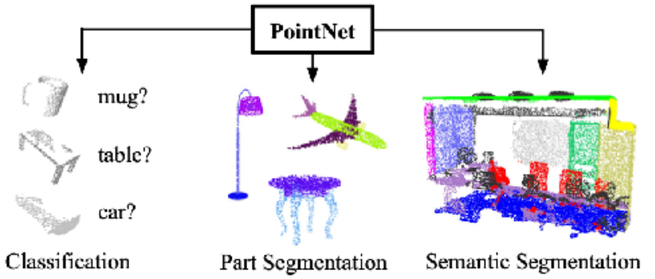
Point-cloud based machine learning for classifying rare events in the Active-Target Time Projection Chamber

Poulomi Dey [a b], Adam K. Anthony [a c d], Curtis Hunt [a], Michelle P. Kuchera [e f], Raghuram Ramanujan [f], William G. Lynch [a c], ManYee Betty Tsang [a c], Joseph M. Wieske [a c], Jessica W. Ajanghah [a b], Saul Beceiro-Novo [a], Kyle W. Brown [a b], Zbigniew Chajecki [b], Kaitlin J. Cook [a h], Skyler Gangestad [d], Tom Ginter [a], Bergen Kendziorski [a], Fanurs Chi Eh Teh [a], HoTing Wong [i a]

Use case #1: Can a general-purpose model for Active Target Time Projection Chamber data be easily tuned for a variety of experiments?

PointNet: Deep Learning on Point Sets for 3D Classification and Segmentation

Charles R. Qi* Hao Su* Kaichun Mo Leonidas J. Guibas
Stanford University



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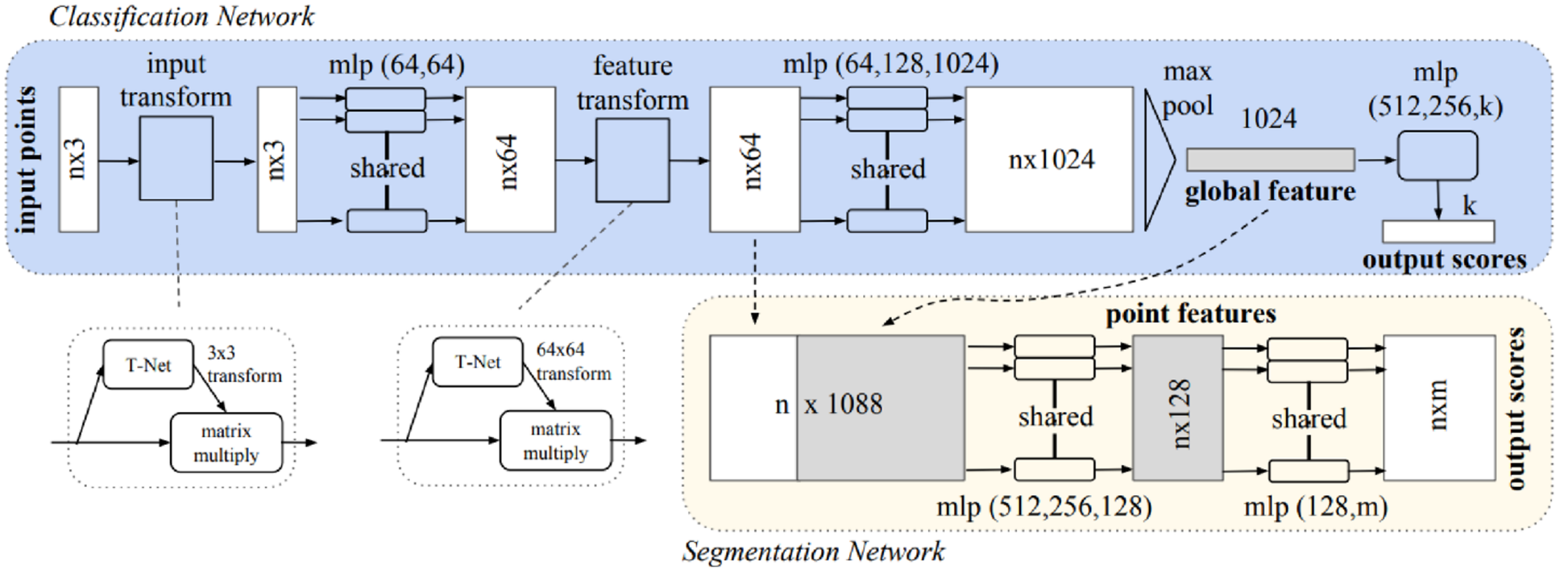

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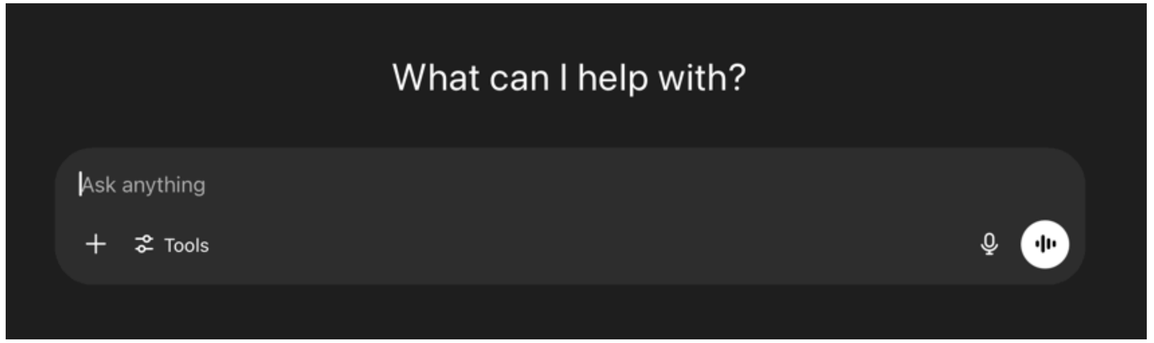
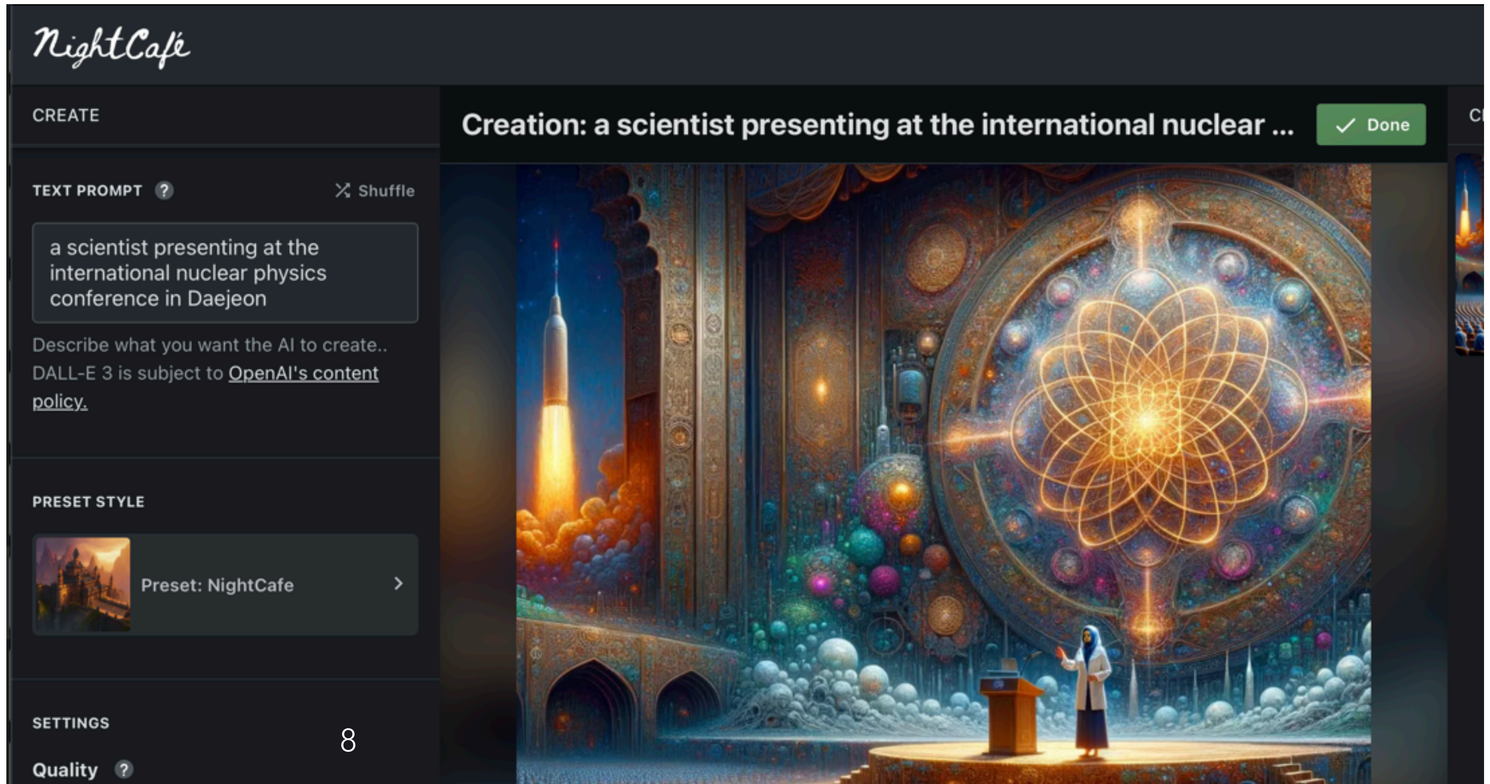
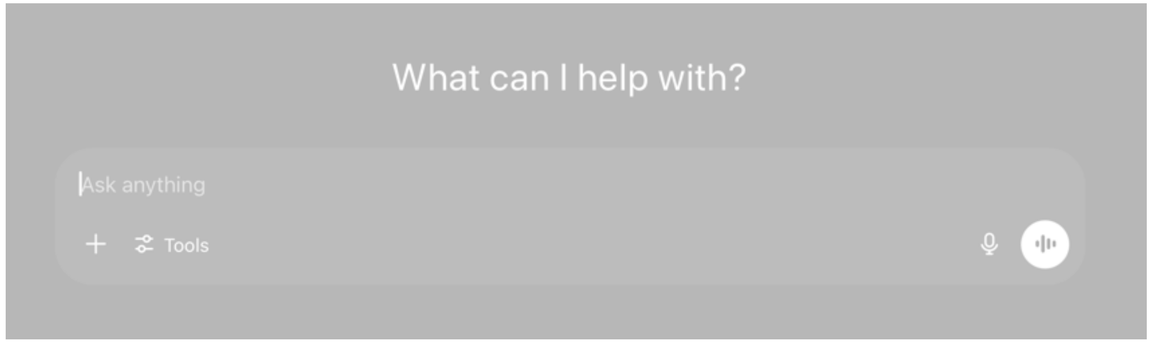
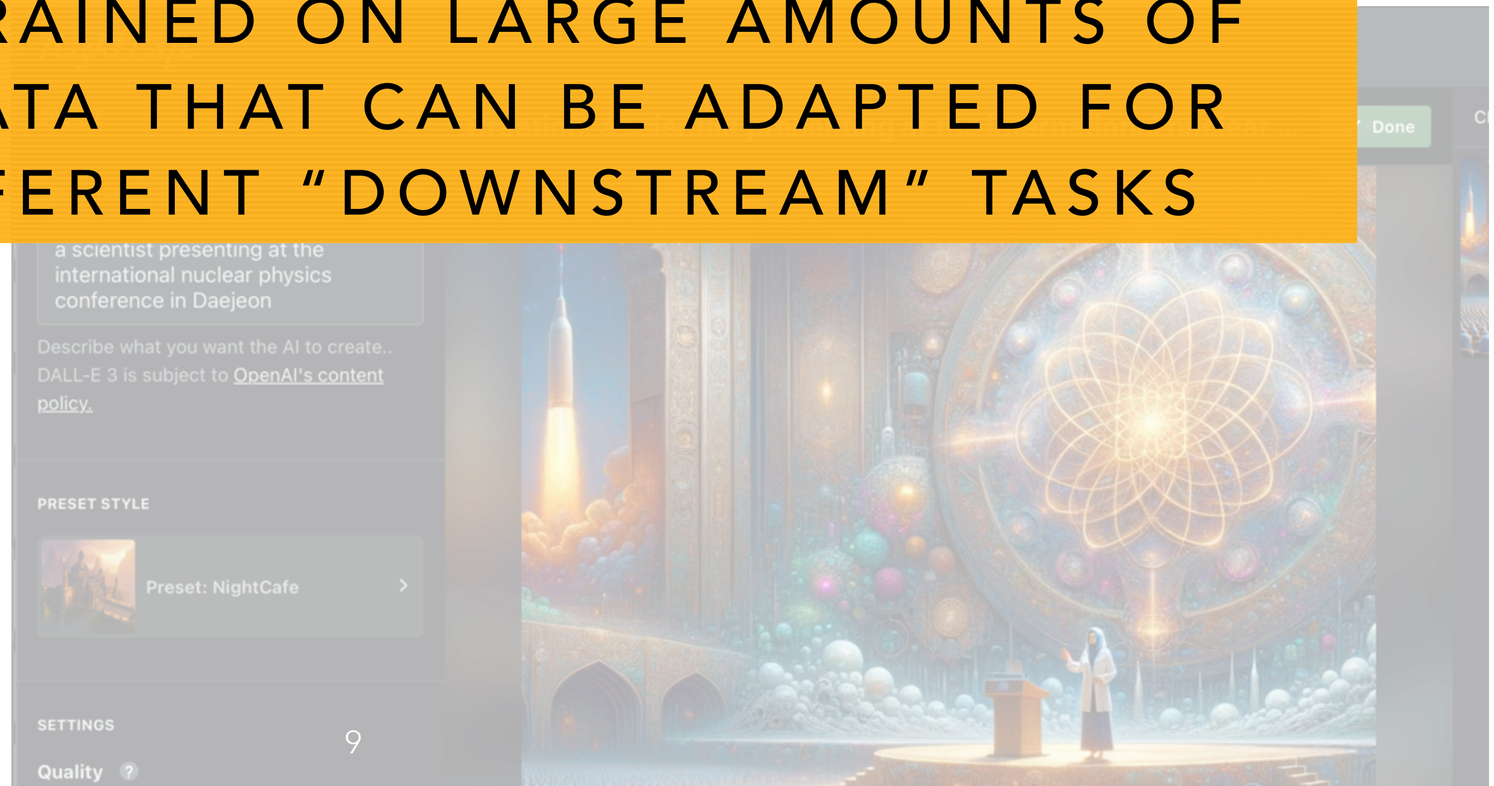




FOUNDATION MODELS



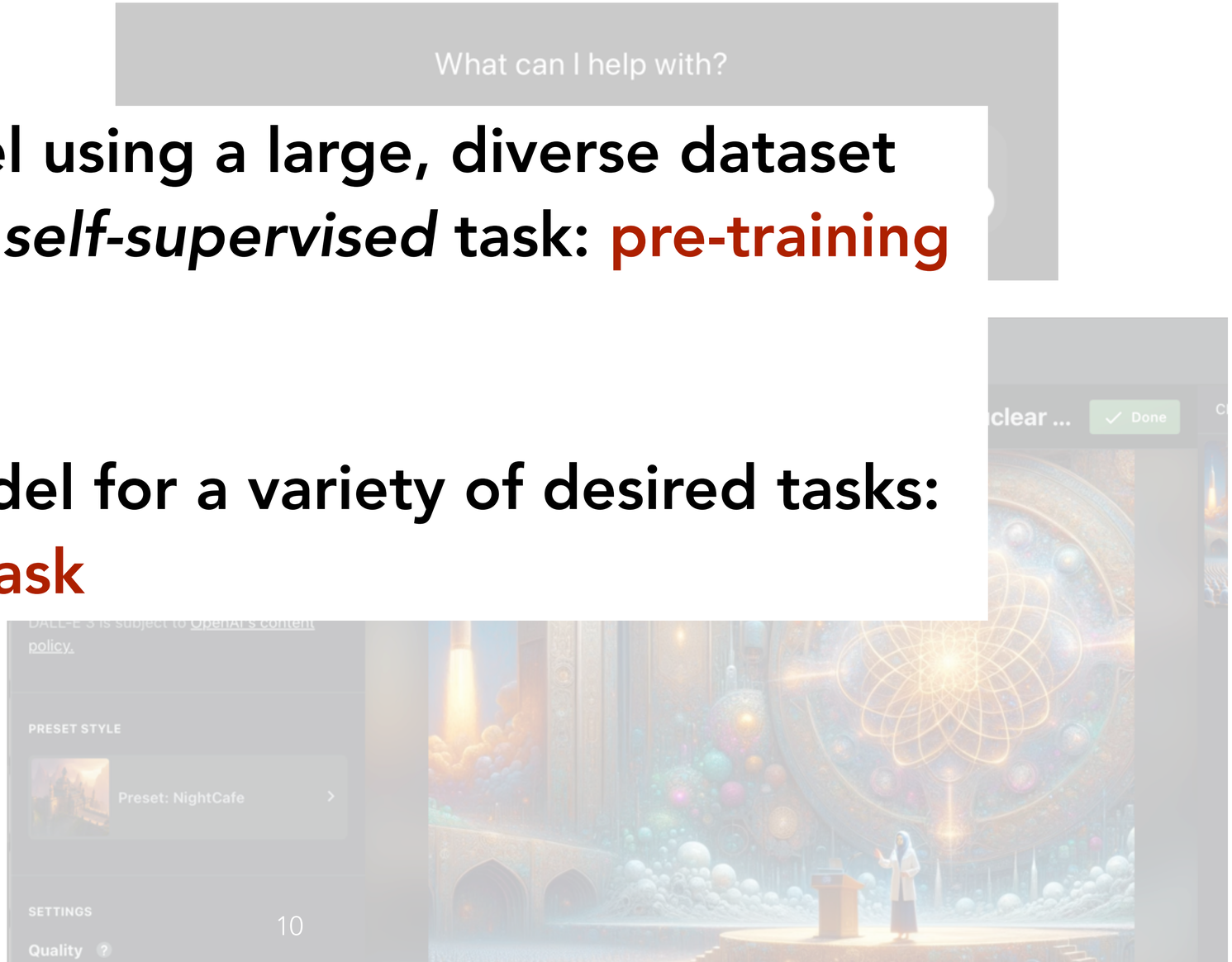
A MODEL TRAINED ON LARGE AMOUNTS OF DIVERSE DATA THAT CAN BE ADAPTED FOR MANY DIFFERENT “DOWNSTREAM” TASKS



FOUNDATION MODELS

1. Build a model using a large, diverse dataset on a (pretext) *self-supervised* task: pre-training task

2. Tune the model for a variety of desired tasks: downstream task



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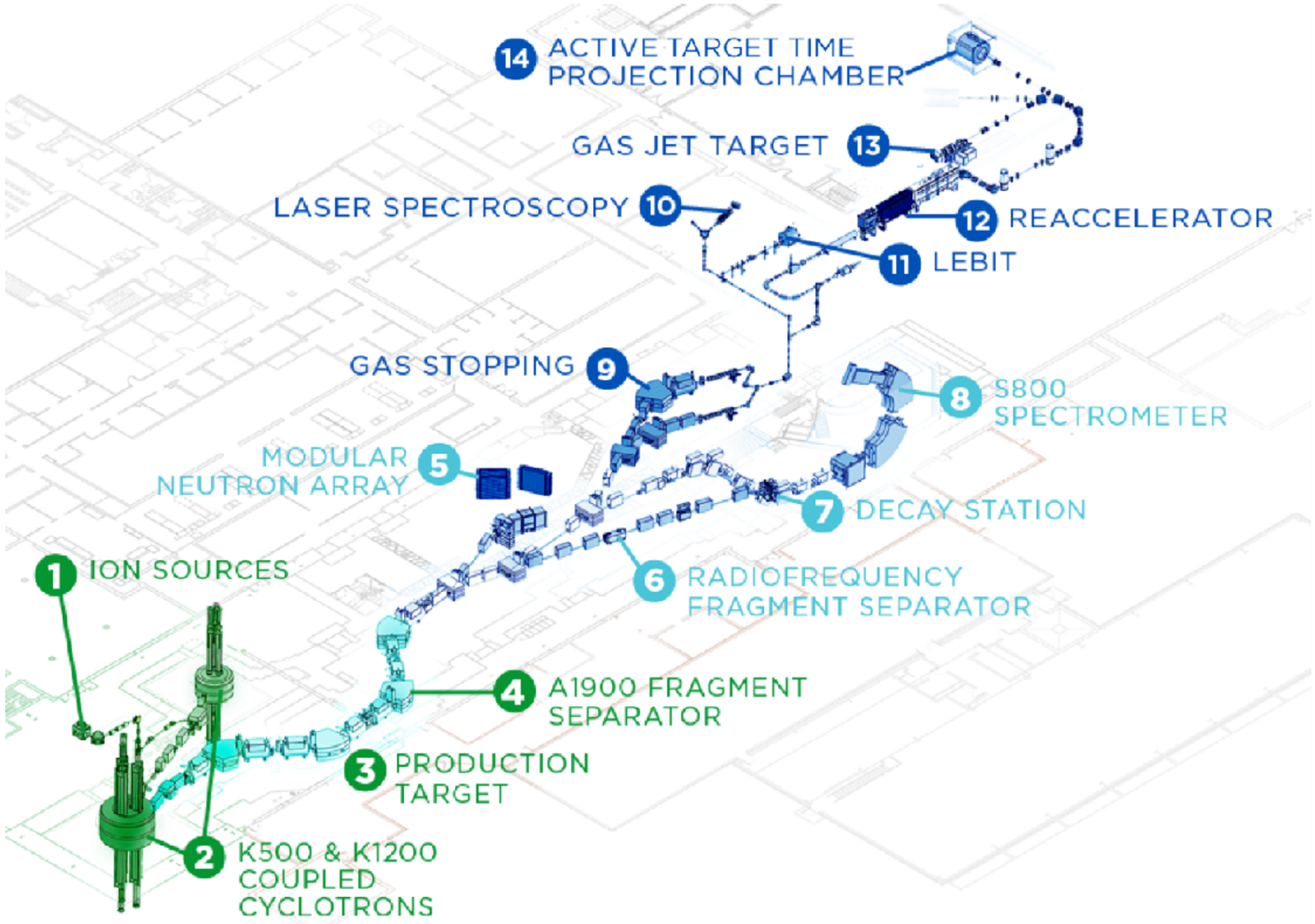
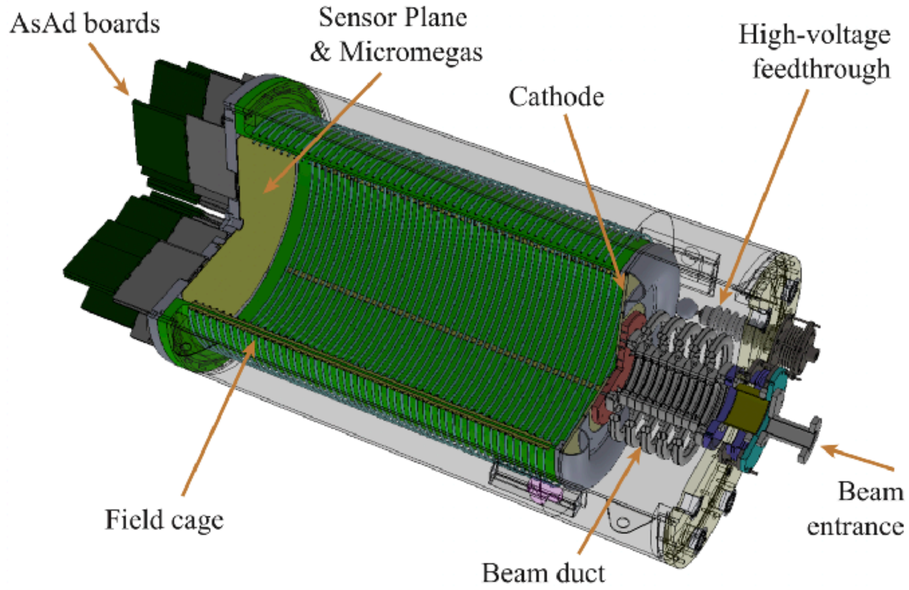
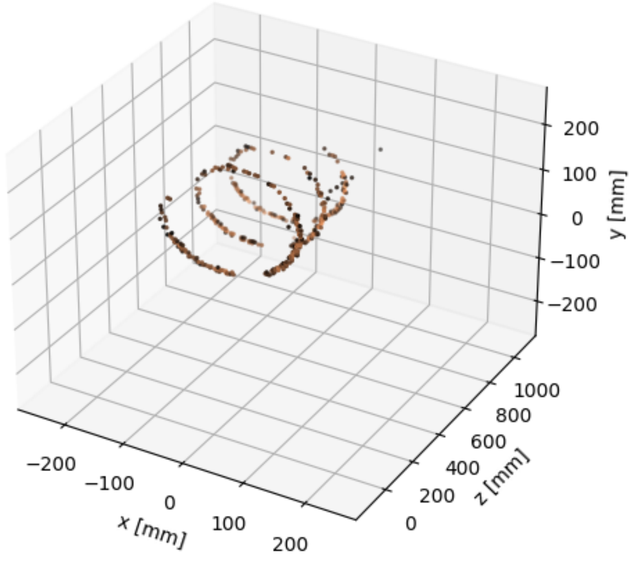
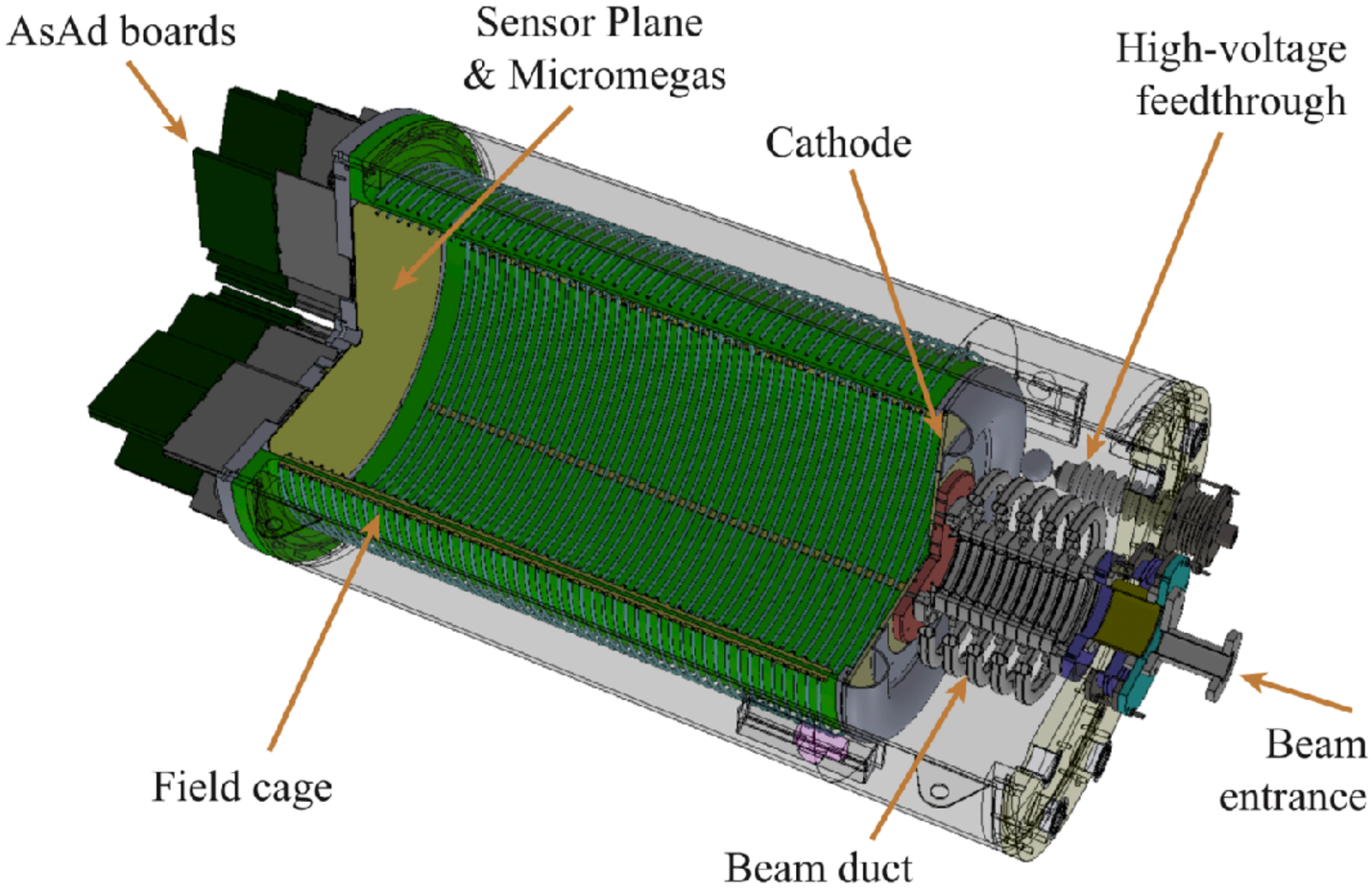

14 ACTIVE TARGET TIME PROJECTION CHAMBER
GAS JET TARGET 13
LASER SPECTROSCOPY 10
12 REACCELERATOR
11 LEBIT
GAS STOPPING 9
8 S800 SPECTROMETER
MODULAR NEUTRON ARRAY 5
7 DECAY STATION
1 ION SOURCES
6 RADIOFREQUENCY FRAGMENT SEPARATOR
4 A1900 FRAGMENT SEPARATOR
3 PRODUCTION TARGET
2 K500 & K1200 COUPLED CYCLOTRONS


AsAd boards
Sensor Plane & Micromegas
Cathode
High-voltage feedthrough
Field cage
Beam duct
Beam entrance

ACTIVE TARGET TIME PROJECTION CHAMBER

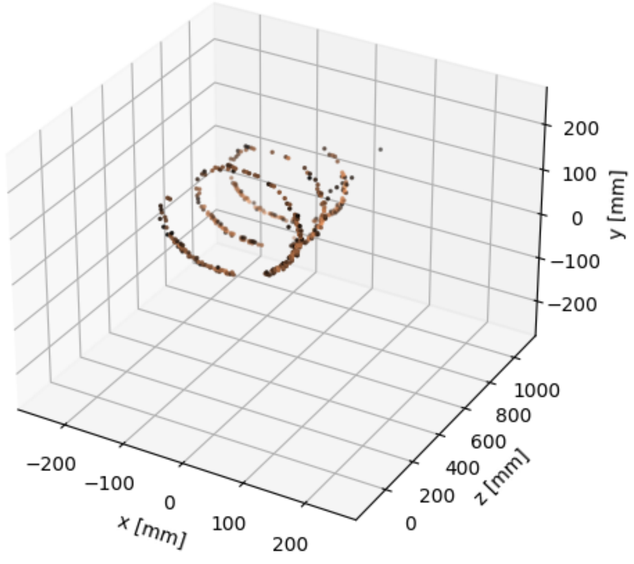


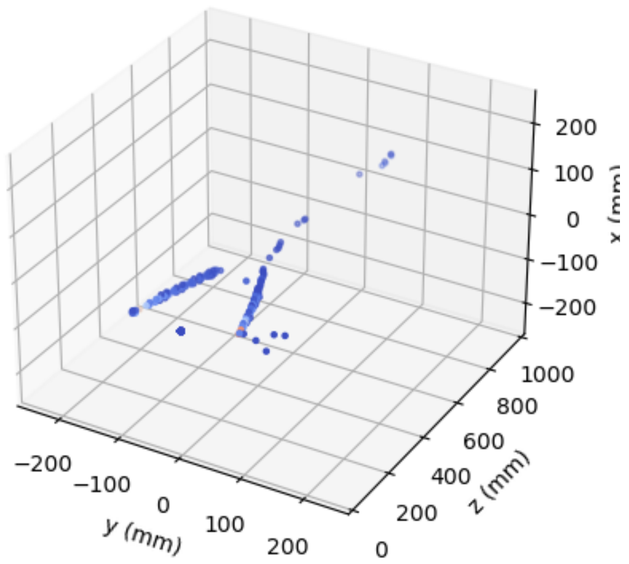


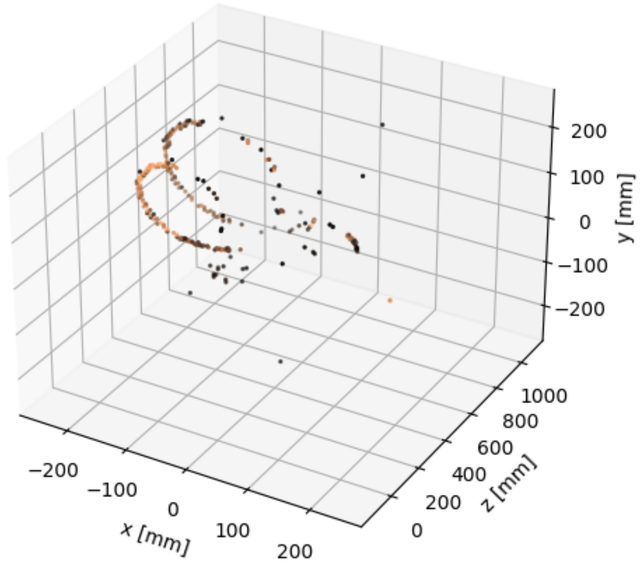
FRIB

J. BRADT ET. AL., *NUCLEAR INSTRUMENTS AND METHODS*, 2017.

ACTIVE TARGET TIME PROJECTION CHAMBER



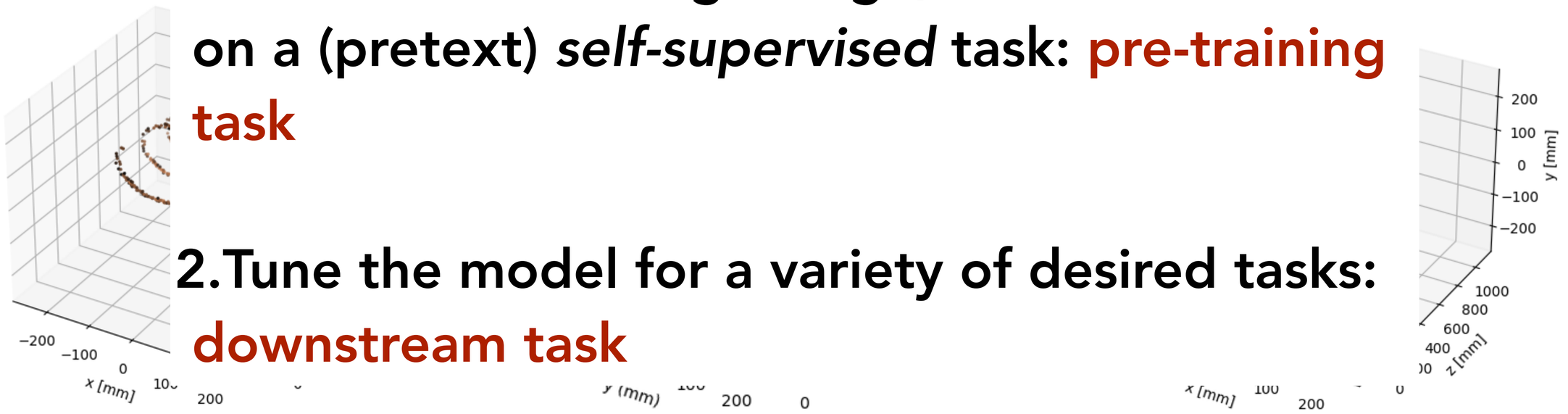




ACTIVE TARGET TIME PROJECTION CHAMBER

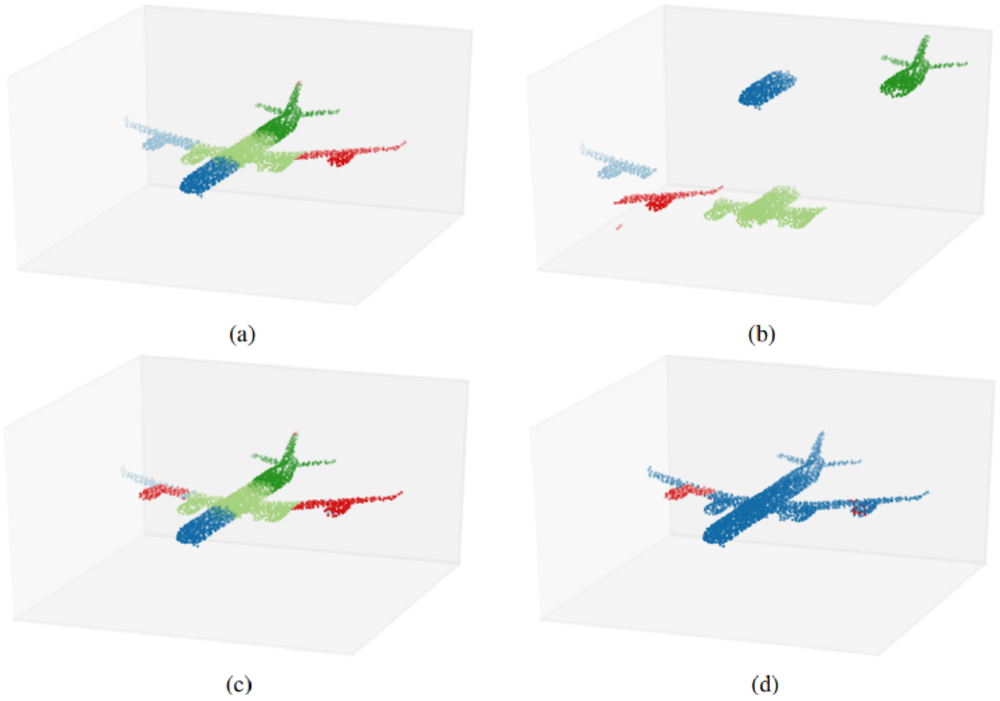
1. **Build a model using a large, diverse dataset on a (pretext) *self-supervised* task: pre-training task**

2. **Tune the model for a variety of desired tasks: downstream task**



J. BRADT ET. AL., *NUCLEAR INSTRUMENTS AND METHODS*, 2017.

SELF-SUPERVISED PRE-TRAINING TASK



Shuffling task

Self-Supervised Deep Learning on Point Clouds by Reconstructing Space

Jonathan Sauder
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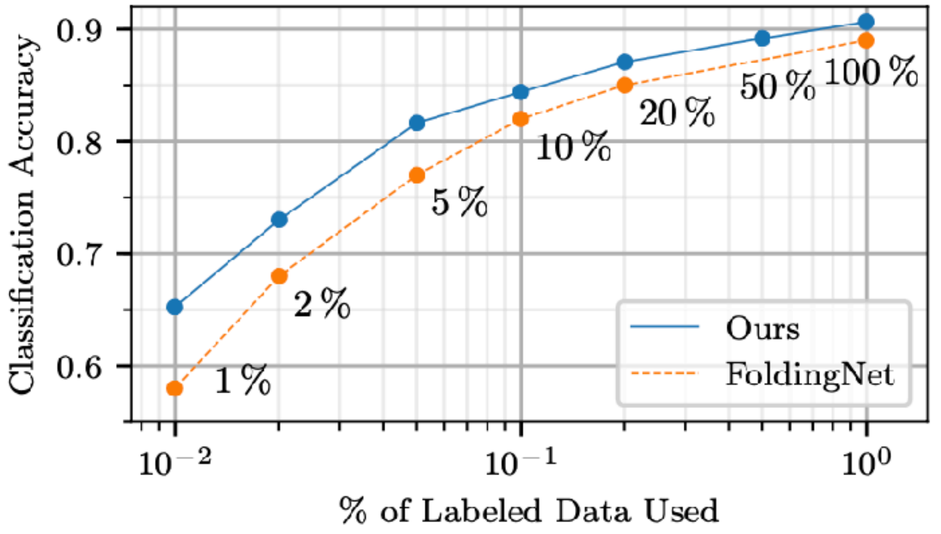
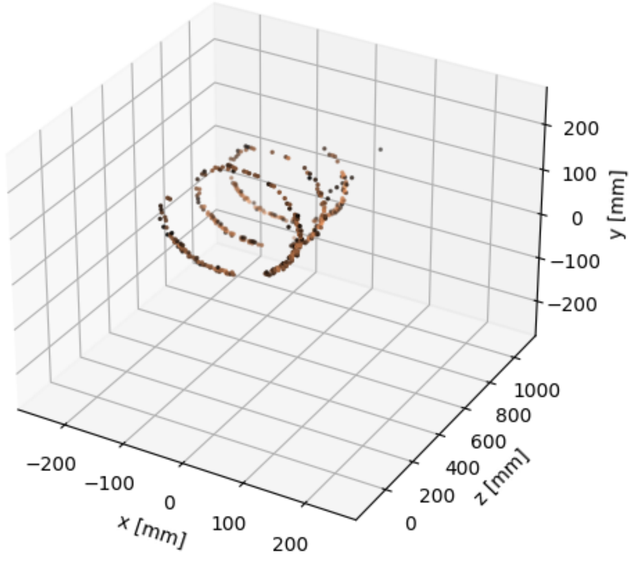
jonathan.sauder@student.hpi.de

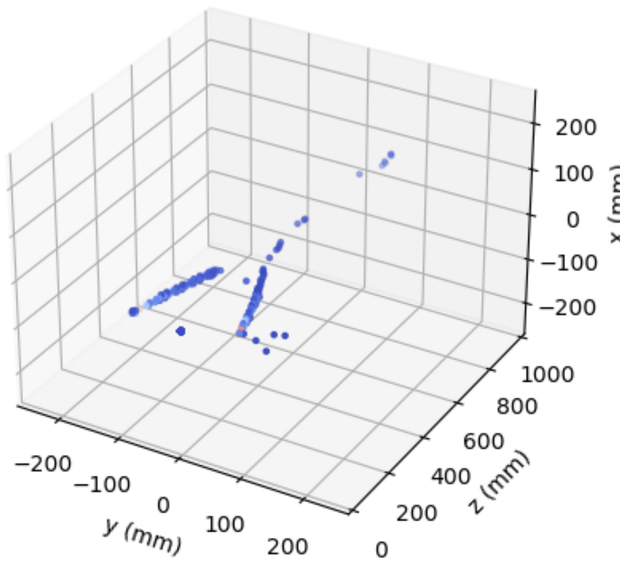
Bjarne Sievers
Hasso Plattner Institute
Potsdam, Germany
bjarne.sievers@student.hpi.de

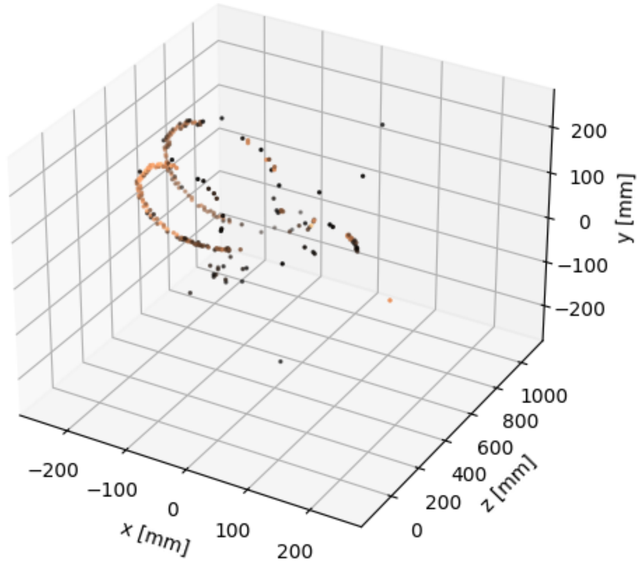


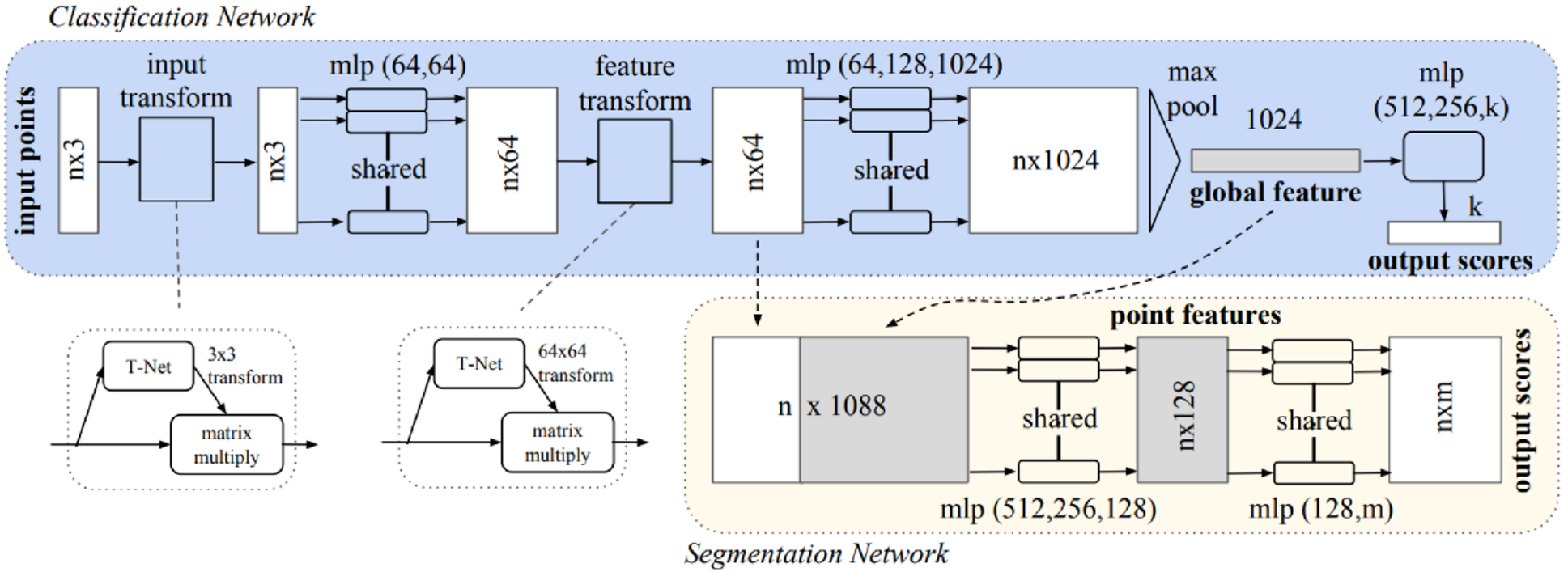
~12k examples

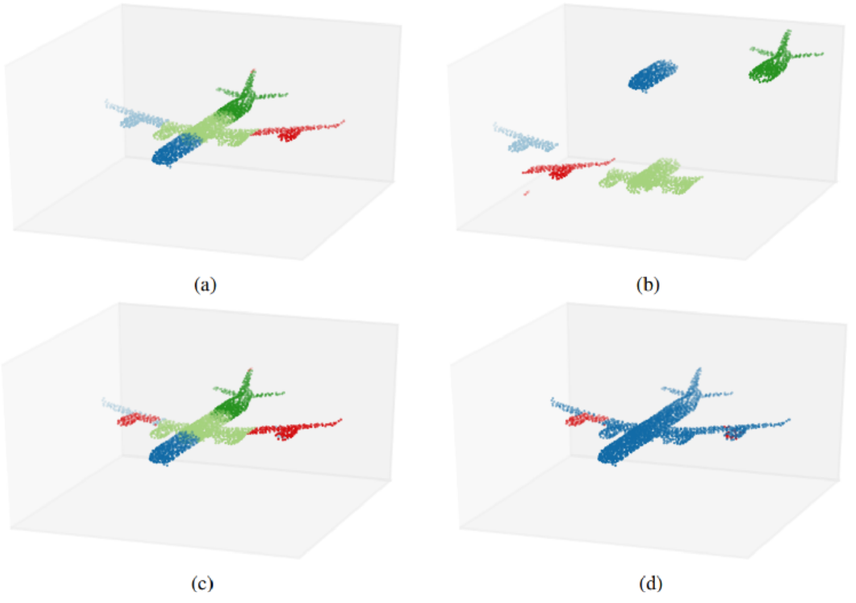
ACTIVE TARGET TIME PROJECTION CHAMBER

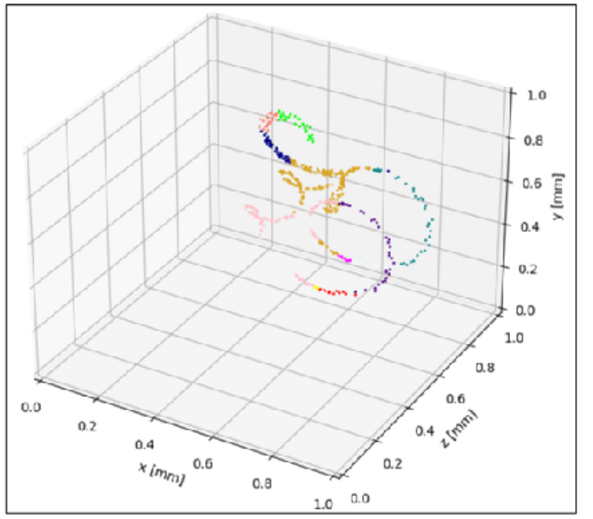


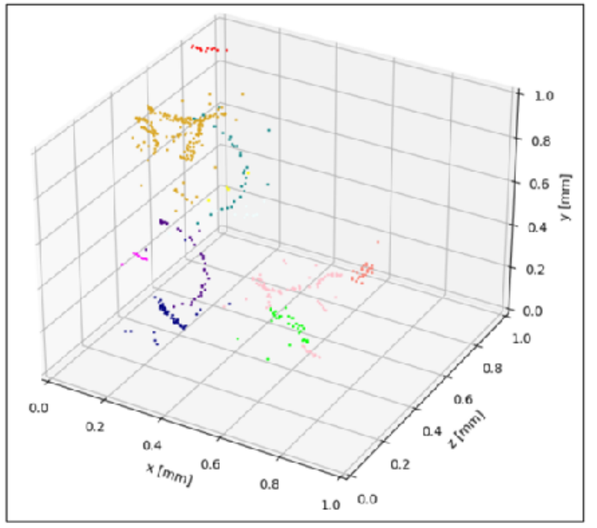


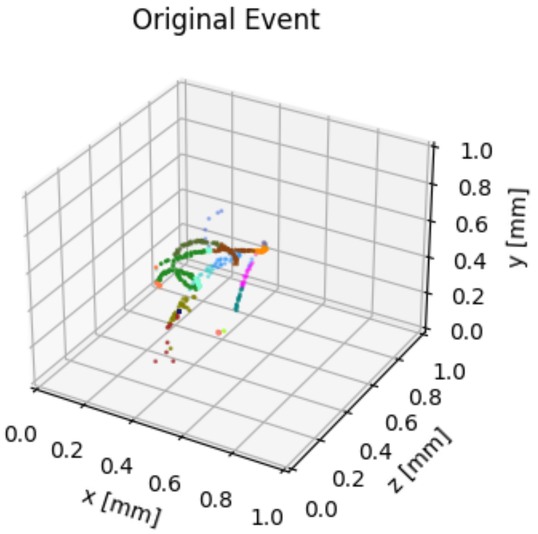


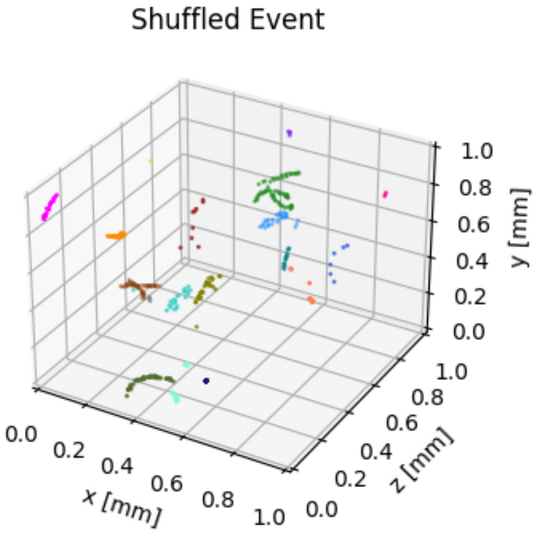

Classification Network
input points
nx3
input transform
nx3
mlp (64,64)
shared
nx64
feature transform
nx64
mlp (64,128,1024)
shared
nx1024
max pool
1024
global feature
mlp (512,256,k)
k
output scores
T-Net
3x3 transform
matrix multiply
T-Net
64x64 transform
matrix multiply
point features
n x 1088
shared
nx128
shared
nxm
output scores
mlp (512,256,128)
mlp (128,m)
Segmentation Network

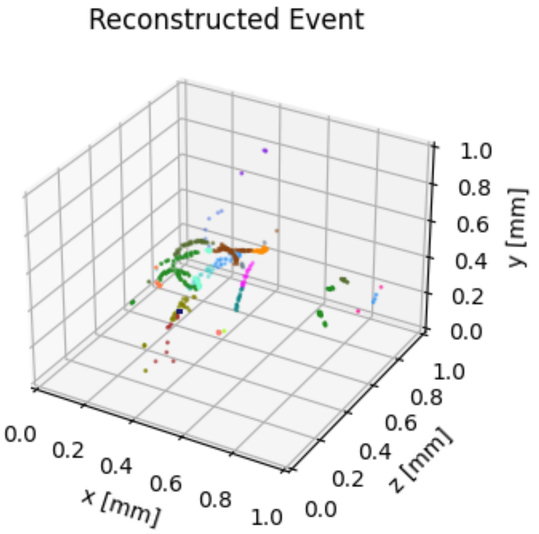

(a)
(b)
(c)
(d)

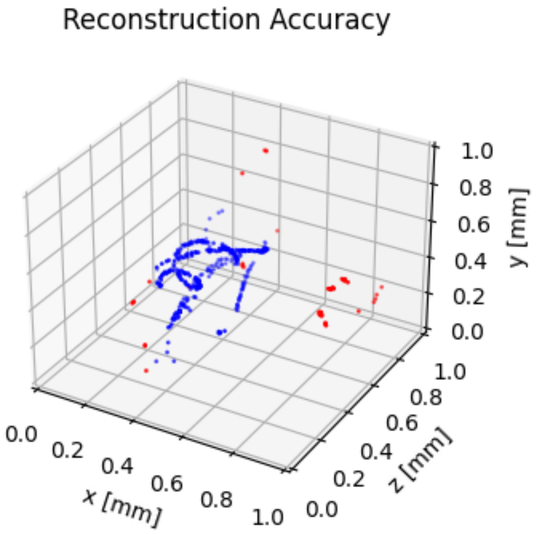

x [mm]
z [mm]
y [mm]

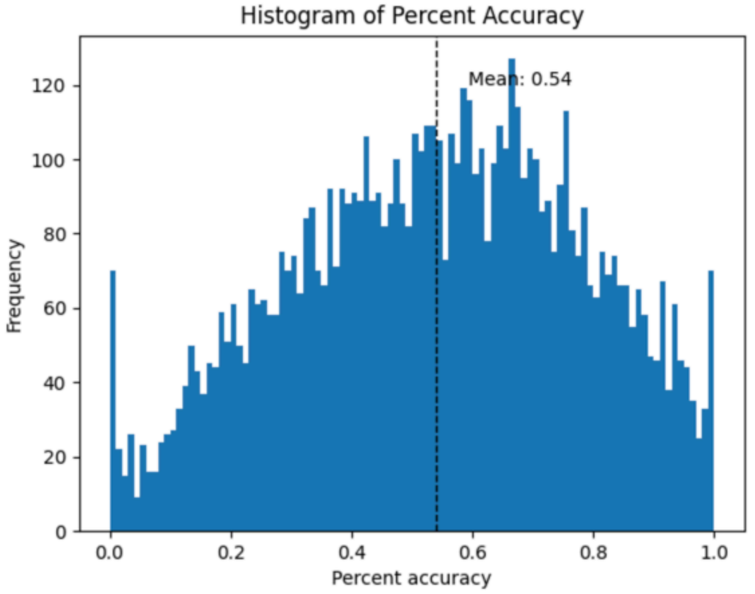

x [mm]
z [mm]
y [mm]

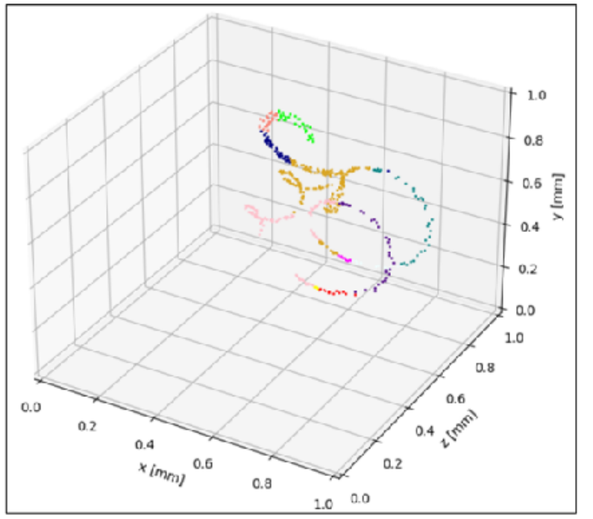

Original Event
x [mm]
z [mm]
y [mm]

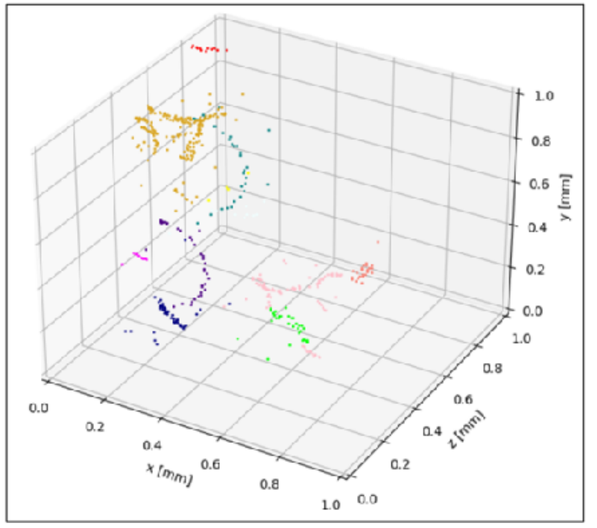

Shuffled Event
x [mm]
z [mm]
y [mm]


Reconstructed Event
x [mm]
z [mm]
y [mm]


Reconstruction Accuracy
x [mm]
z [mm]
y [mm]


Histogram of Percent Accuracy
Mean: 0.54
Frequency
Percent accuracy





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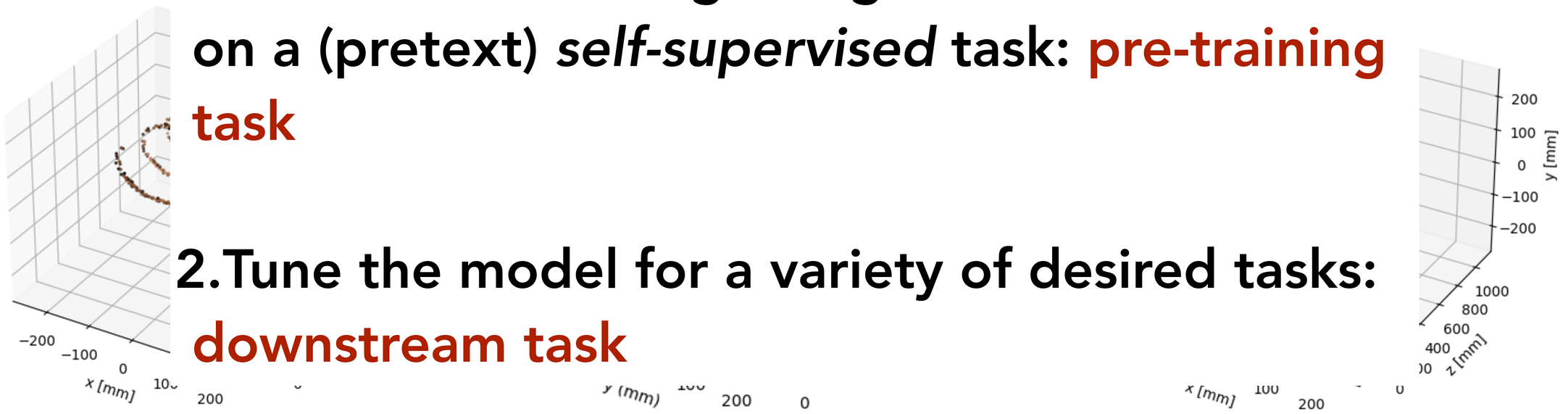

J. BRADT ET. AL., *NUCLEAR INSTRUMENTS AND METHODS*, 2017.

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USE DATA FROM AN EXPERIMENT NOT SEEN IN PRE-TRAINING TASK

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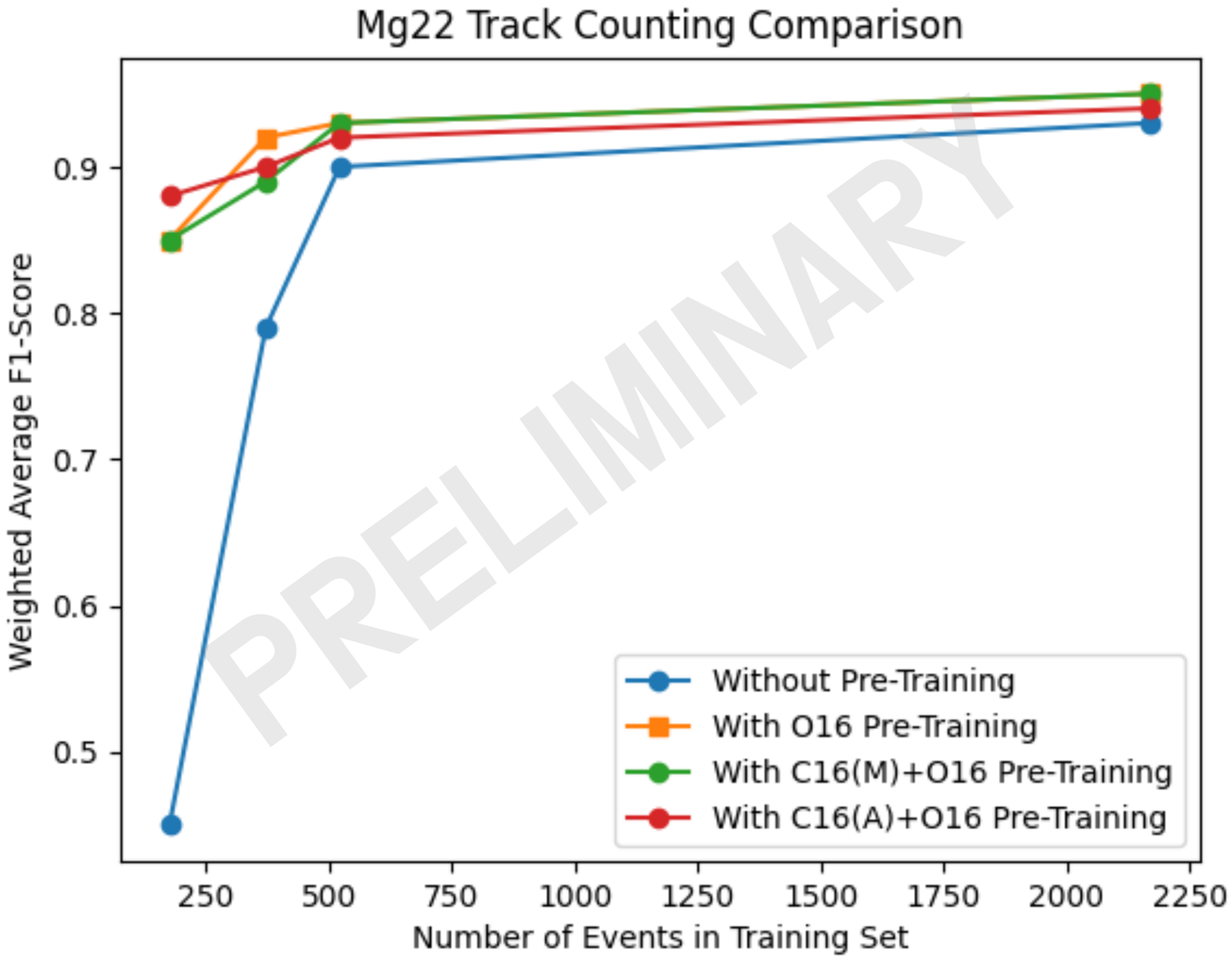
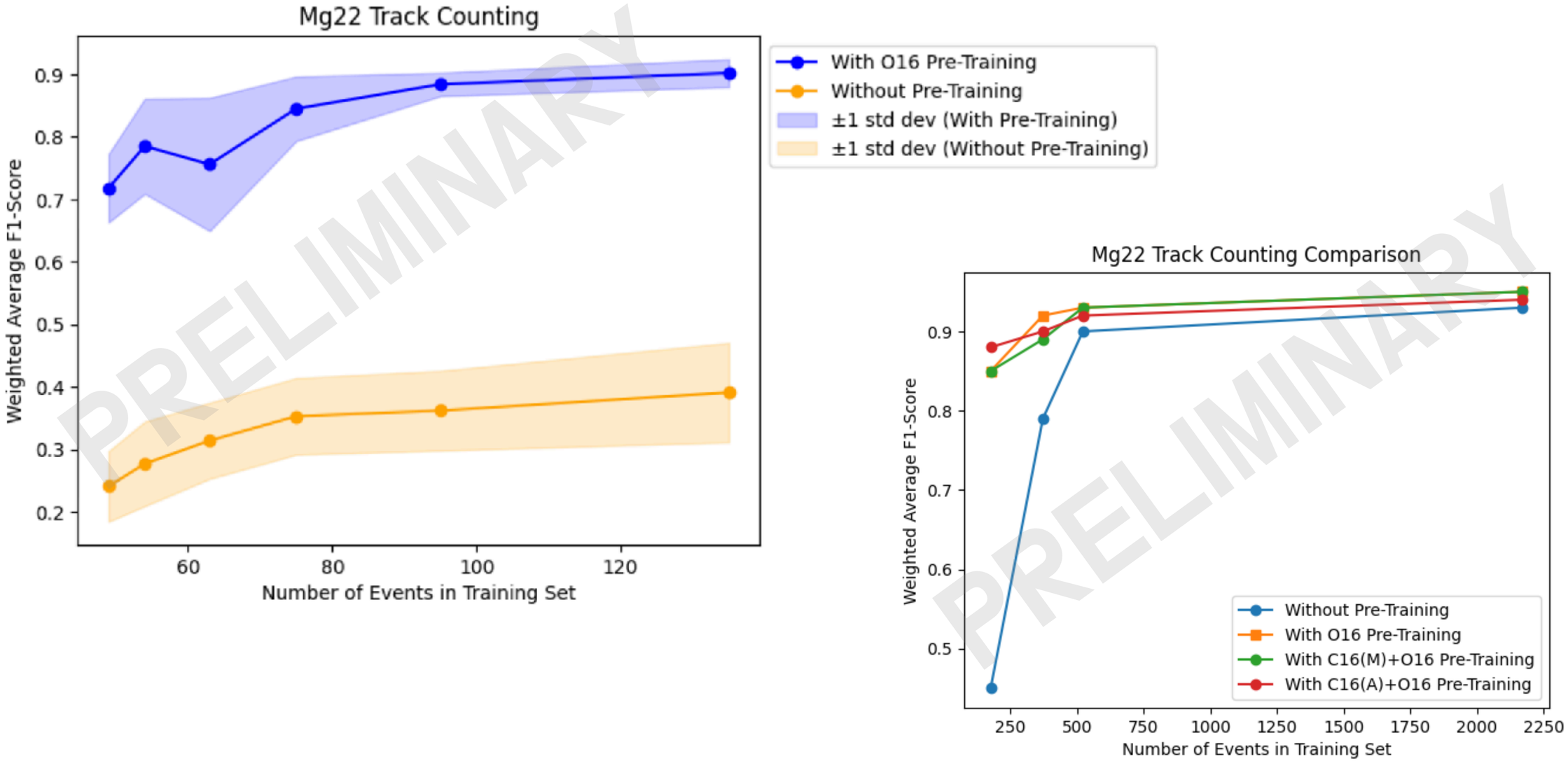
TEST HOW LITTLE DATA IS NEEDED VS TRAINING FROM SCRATCH

Use case #1: Can a general-purpose model for Active Target [illegible] a variety of experiments?

USE DATA FROM AN EXPERIMENT NOT SEEN IN PRE-TRAINING TASK


Mg22 Track Counting Comparison
Weighted Average F1-Score
0.5
0.6
0.7
0.8
0.9
250
500
750
1000
1250
1500
1750
2000
2250
Number of Events in Training Set
Without Pre-Training
With O16 Pre-Training
With C16(M)+O16 Pre-Training
With C16(A)+O16 Pre-Training
PRELIMINARY

RESULTS


Mg22 Track Counting
Weighted Average F1-Score
Number of Events in Training Set
With O16 Pre-Training
Without Pre-Training
±1 std dev (With Pre-Training)
±1 std dev (Without Pre-Training)
Mg22 Track Counting Comparison
Weighted Average F1-Score
Number of Events in Training Set
Without Pre-Training
With O16 Pre-Training
With C16(M)+O16 Pre-Training
With C16(A)+O16 Pre-Training
PRELIMINARY
PRELIMINARY

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CHALLENGE

1. Sourcing data from a wide variety of data is both easy (lots of data) and hard (different people/groups maintain data)

    - Technical: Different processing
    - Cultural: Different outlooks on data use
    - Is broad access to such a model realistic?

CURRENT WORK

1. More thorough testing: datasets, tasks

2. Implementing in sparse tensor networks

3. Testing many other pretraining tasks

4. Working with data from another TPC, GADGET

THANK YOU!

- Raghu Ramanujan and the Davidson ALPhA crew
- The AT-TPC Group
- Broader FRIB Collaborators

ALPhA
DAVIDSON COLLEGE

FRIB

DAVIDSON

NSCL