



The **SPINE** Reconstruction

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Intensity Frontier AI Jamboree

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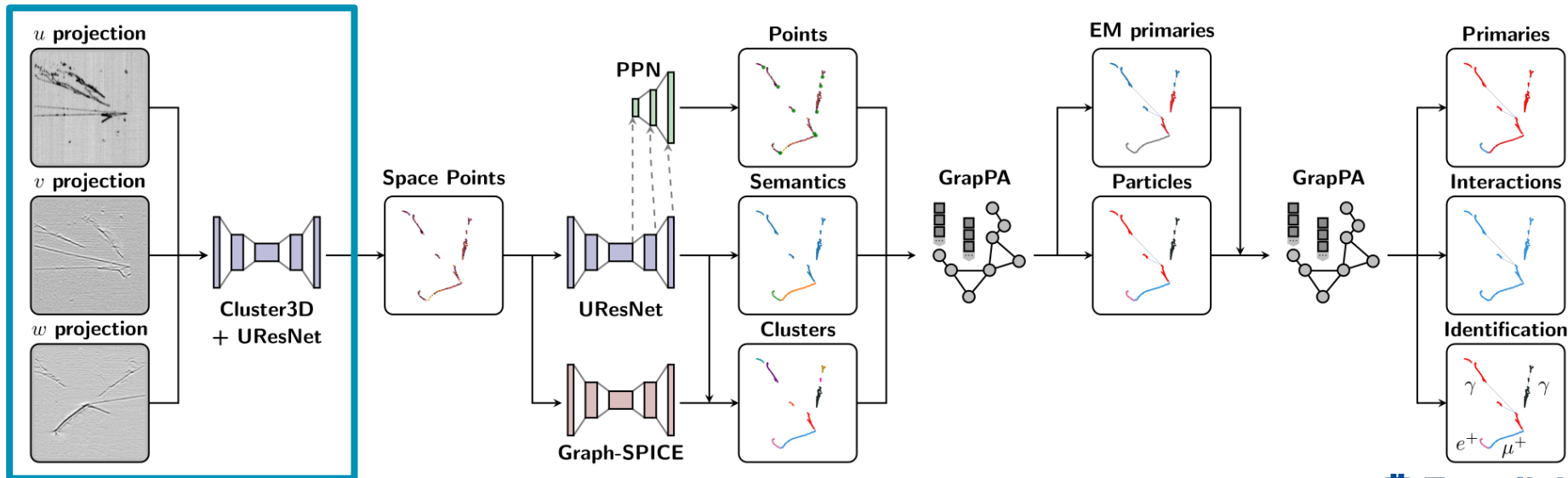
Scalable Particle Imaging with Neural Embeddings

SPINE: End-to-end Machine Learning-based reconstruction chain for ICARUS, SBND, and 2x2

Convolution Neural Net (CNN)

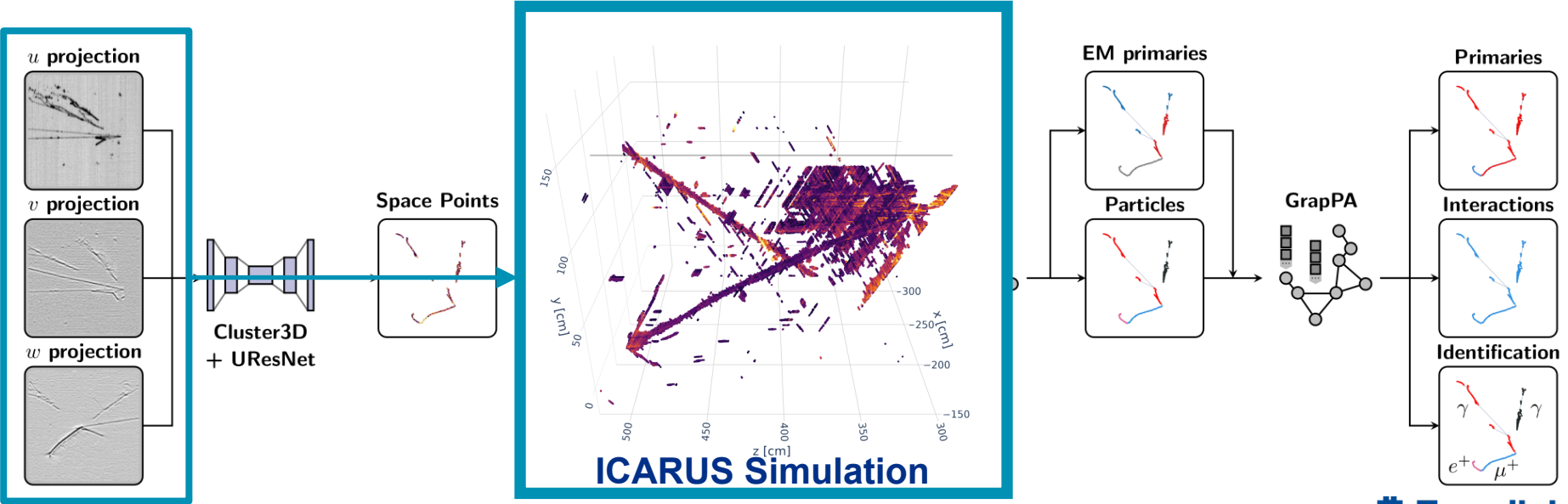
Graph Neural Net (CNN)

Wire TPCs only



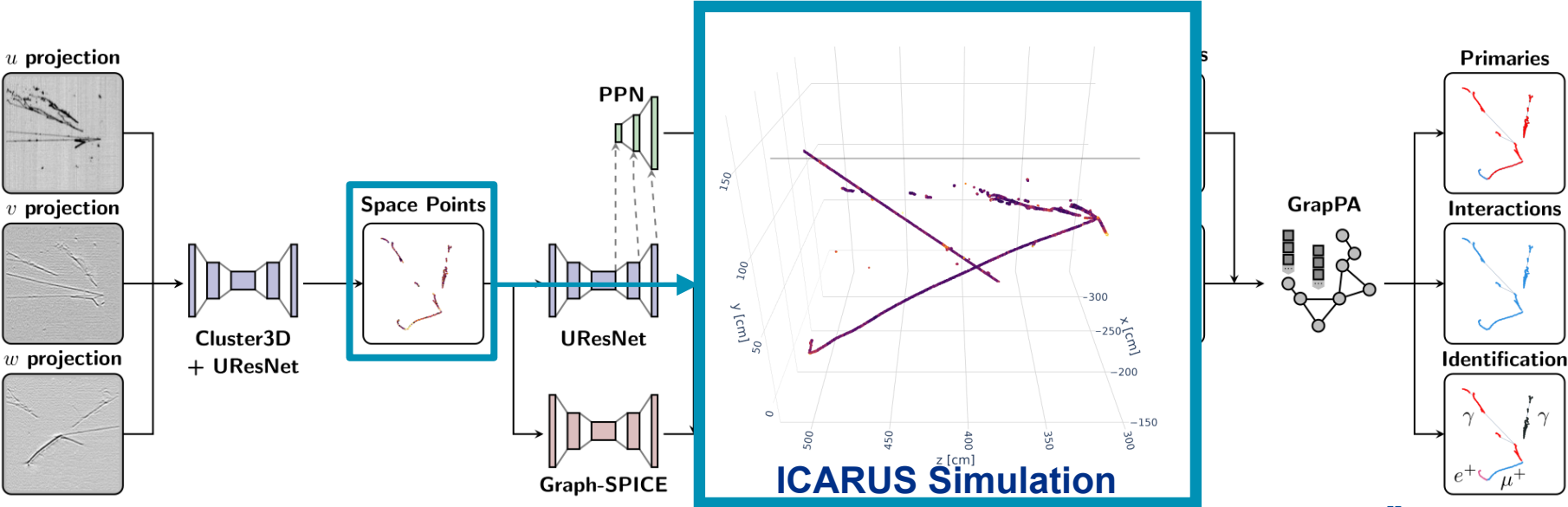
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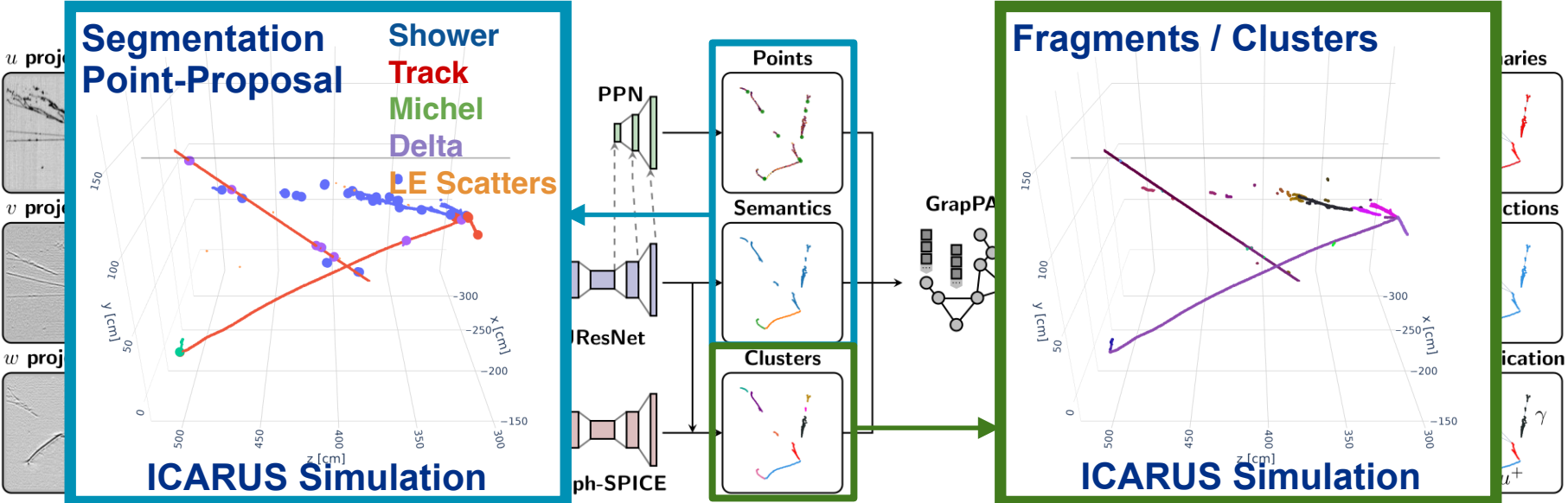
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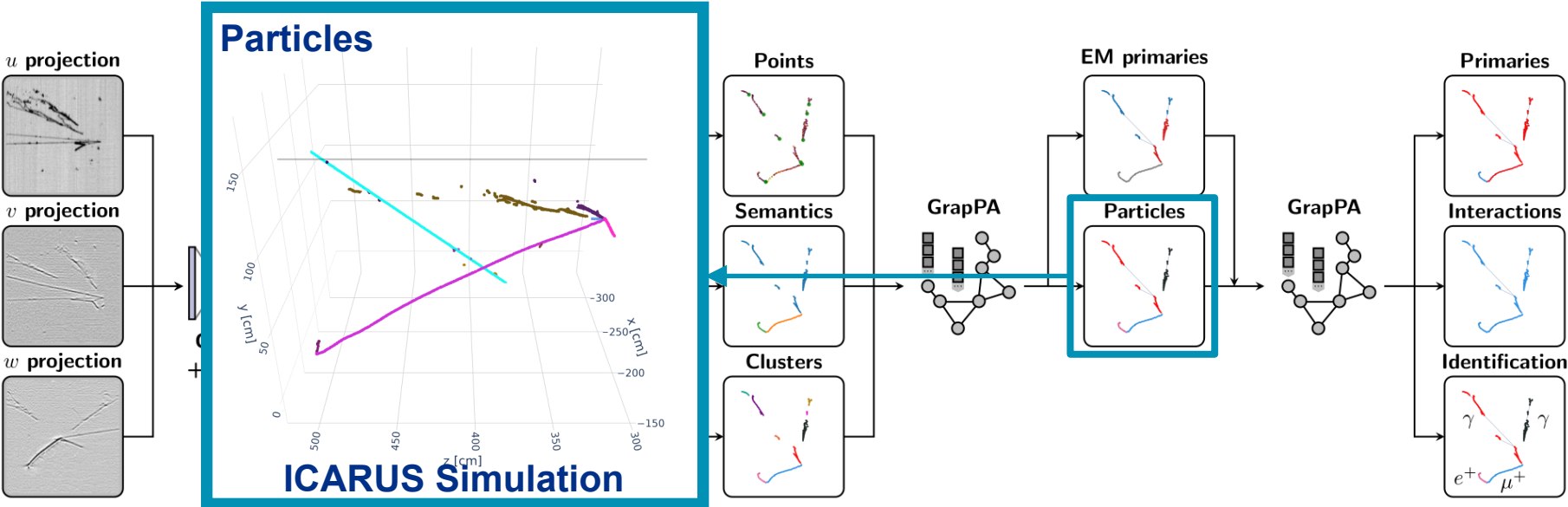
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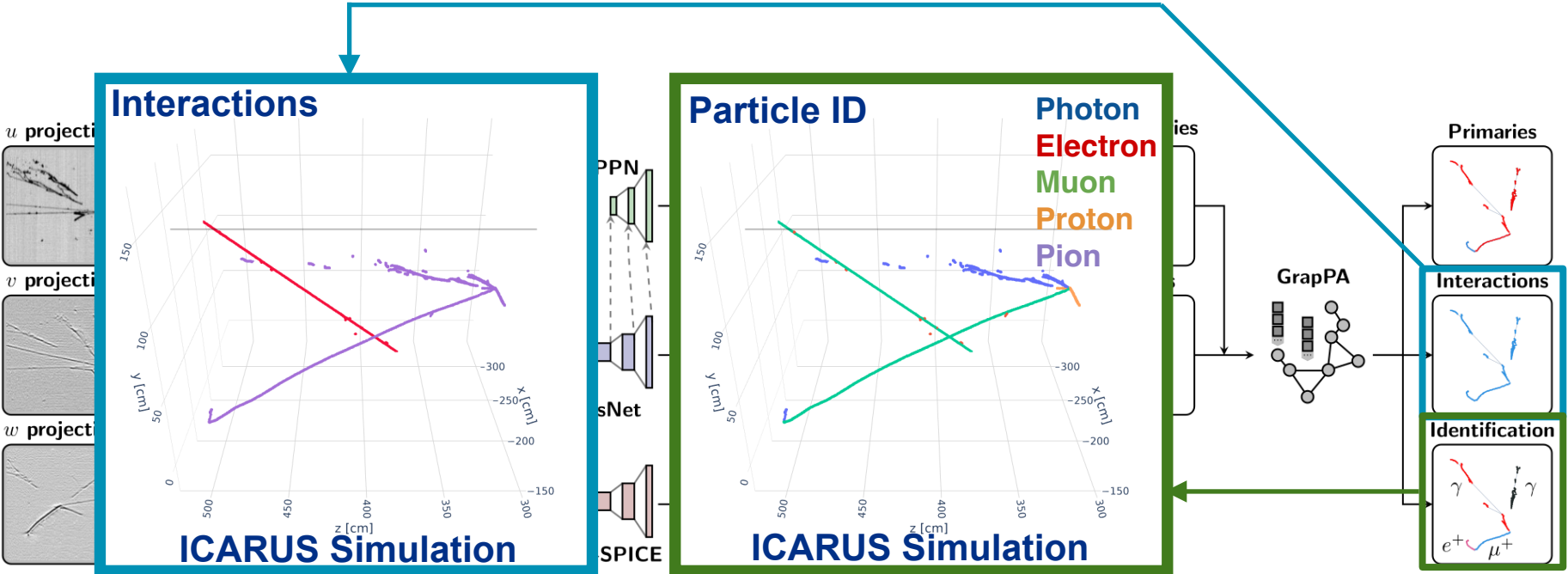
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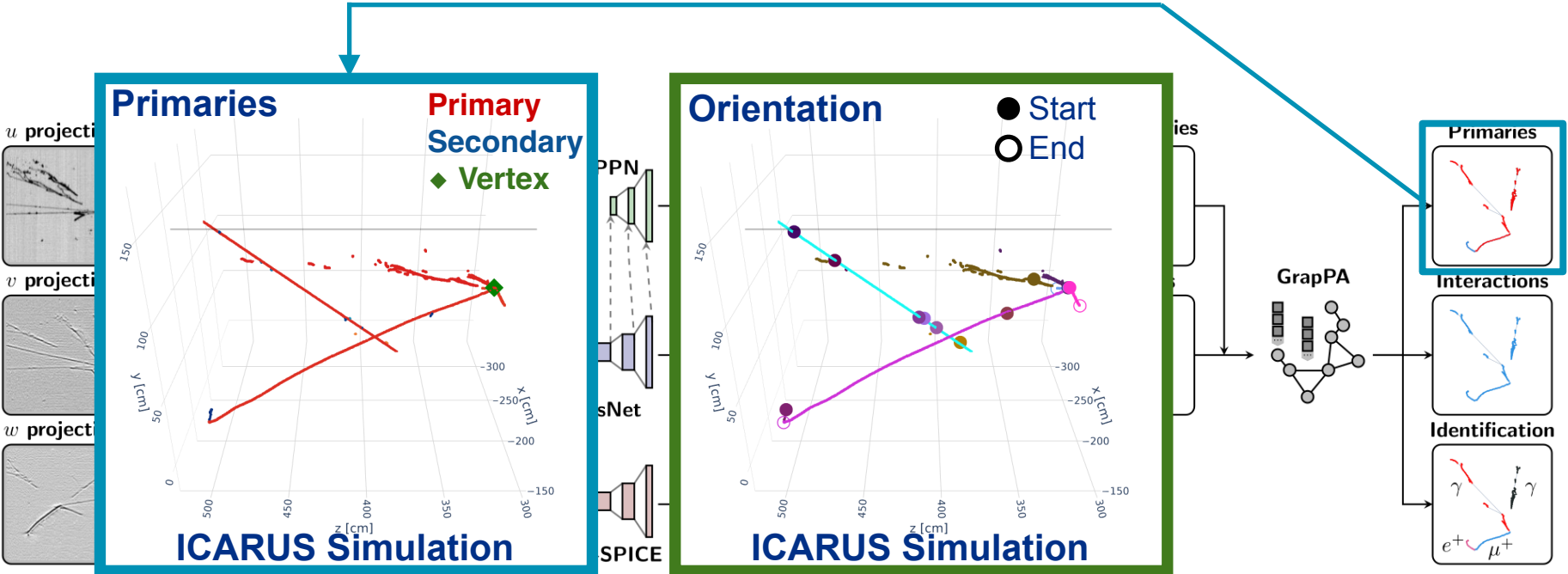
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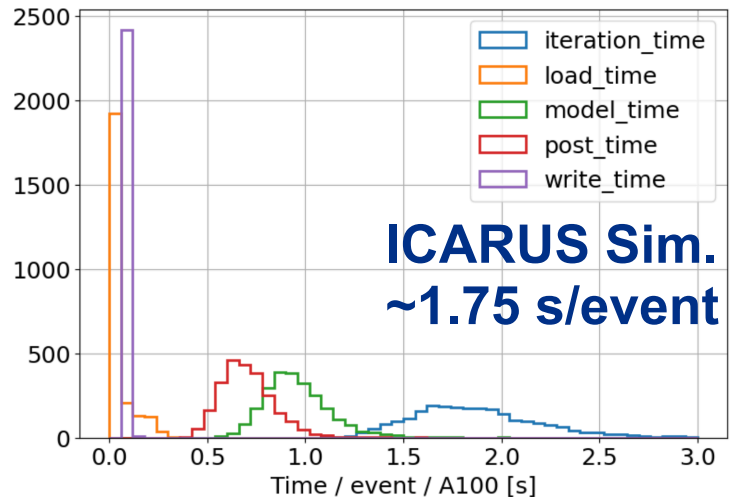
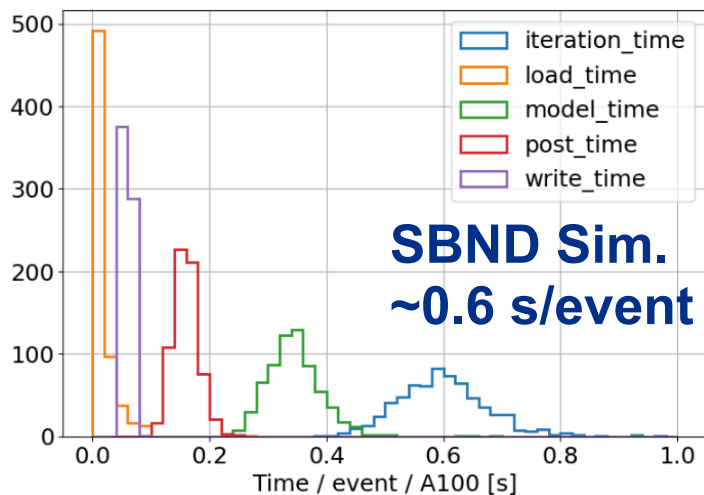
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Scalability

“**SPINE** would be ‘PINE’ without scalability...” — Francois Drielsma

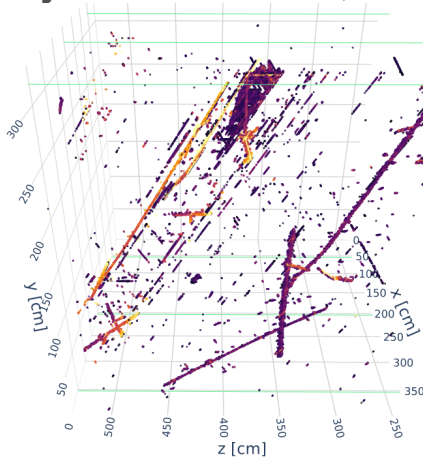
- **SPINE** leverages **GPU acceleration** extensively
- **Scales with activity**, i.e. number of active voxels (DUNE-FD \ll SBND)
- Reco time: **1 day of SBND in-time data \sim 3 hours with 1 GPU** (ANL/NERSC have 1000s)



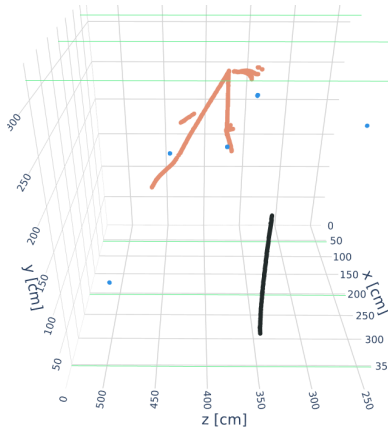
Reconstruction Outputs

SPINE is built upon **3D images** of interactions in LArTPCs and extracts high-level information

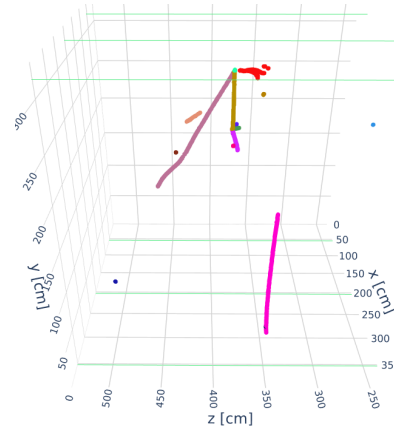
- List of **interactions**: collection of particles belonging to a single parent neutrino / cosmogenic interaction
 - For each interaction: a **vertex**, a list of all **particles** from the parent activity.
 - For each particle: the **charge depositions** comprising the particle, **particle identification**, **primary identification**, **kinetic energy**, **orientation**, etc.



ICARUS Run 7924,
Event 4966



Reconstructed
interactions

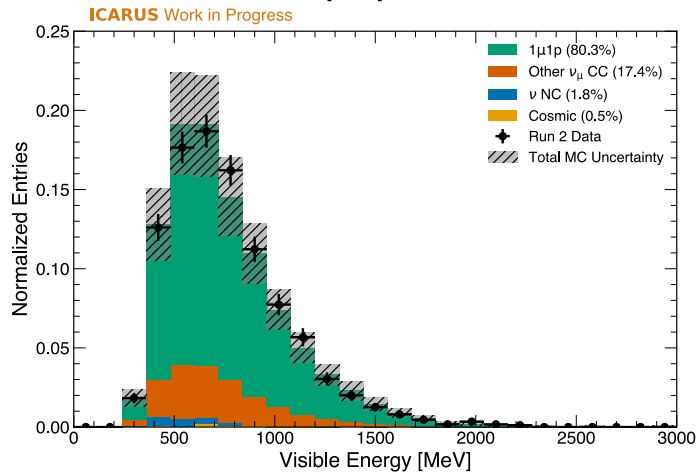


Reconstructed
particles

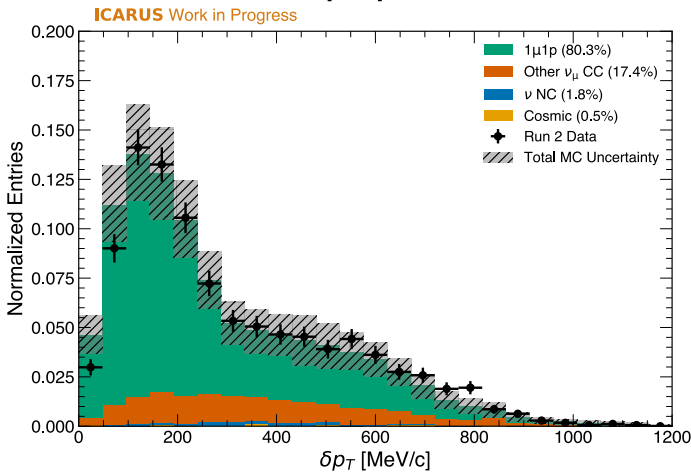
Performance @ ICARUS

Selection Cut	$1\mu 1p$ Purity [%]	$1\mu 1p$ Efficiency [%]	$1\mu Np$ Purity [%]	$1\mu Np$ Efficiency [%]	ν_μ CC Purity [%]	ν_μ CC Efficiency [%]
No Cut	0.0	99.9	0.1	100.0	0.1	100.0
Fiducial Volume	0.1	98.8	0.1	98.8	0.3	98.2
Containment	1.1	94.9	1.5	95.0	3.5	94.1
Final State	66.2	73.9	71.2	77.9	9.5	86.3
Flash Time	80.1	72.4	83.0	76.4	87.8	84.5
CRT Veto	80.3	71.3	83.3	75.4	90.4	83.3

Selected $1\mu 1p$ Candidates



Selected $1\mu 1p$ Candidates

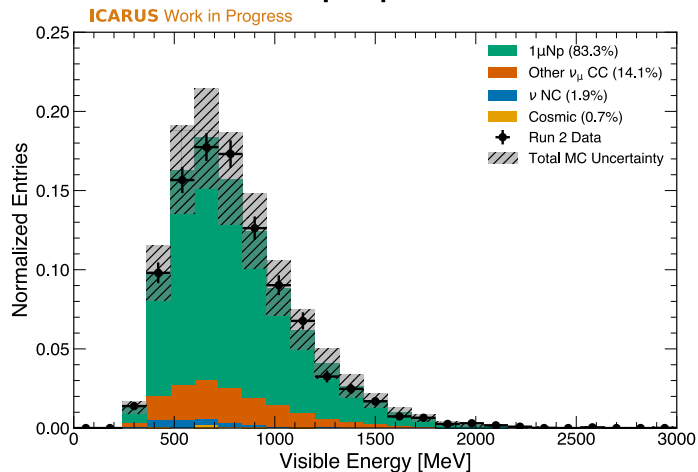


Distributions are normalized to 10% of ICARUS Run 2 data!

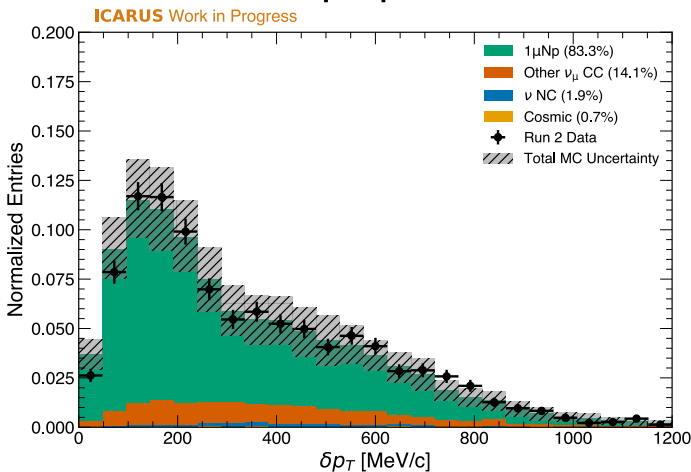
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Selected $1\mu Np$ Candidates



Selected $1\mu Np$ Candidates

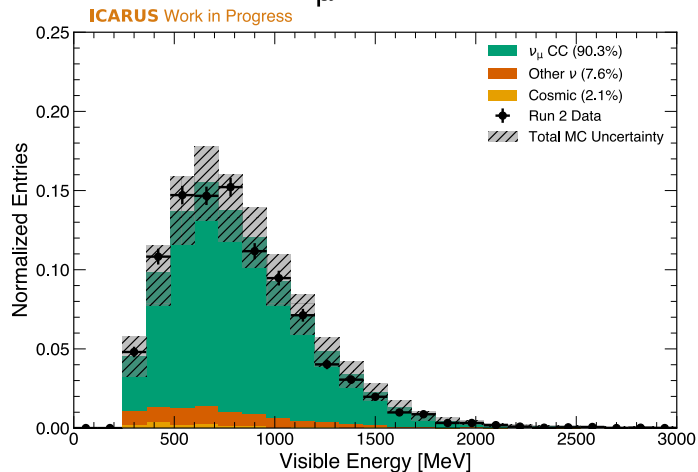


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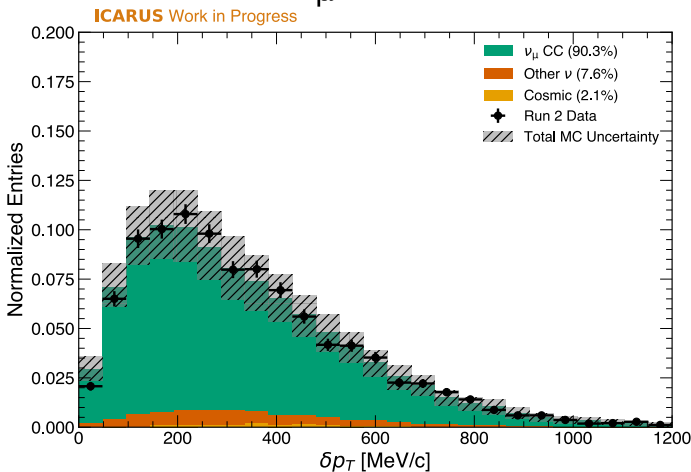
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Selected ν_μ CC Candidates



Selected ν_μ CC Candidates



This **exceeds** one of the performance benchmarks outlined in the SBN proposal!

Distributions area normalized to 10% of ICARUS Run 2 data!

Summary

- **SPiNE** is an end-to-end **Machine Learning**-based reconstruction chain for **ICARUS**, **SBND**, and **2x2**
- Performance on **ICARUS** simulation and **data** with benchmark selections is excellent, performance on **SBND** simulation (not shown here) is consistent with **ICARUS** out-of-the-box (no fine-tuning)
 - **Actively** being used for ongoing **ICARUS** analyses
 - Deployment into SBN-wide analyses is **rapidly** progressing

Much more to come, stay tuned!

Backup

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Stage	Type	Description
UResNet Deghost	CNN	Classification of space points as reconstruction artifacts or real charge depositions
UResNet	CNN	Semantic segmentation (voxel-level classification of activity)
PPN	CNN	Prediction of start/end points of showers/tracks
Graph-SPICE	CNN	Coarse clustering of space points into particle fragments
GrapPA-Shower	GNN	Clustering of shower fragments into complete showers
GrapPA-Track	GNN	Clustering of track fragments into complete tracks
GrapPA-Interaction	GNN	Clustering of particles into complete interactions with PID and primary designation