

SPATIAL RECONSTRUCTION

OF EXO-200 EVENTS USING

**DEEP NEURAL
NETWORK**

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OUTLINE



RADIOACTIVE DECAY

- ❖ Double beta decay
- ❖ Neutrinoless double beta decay

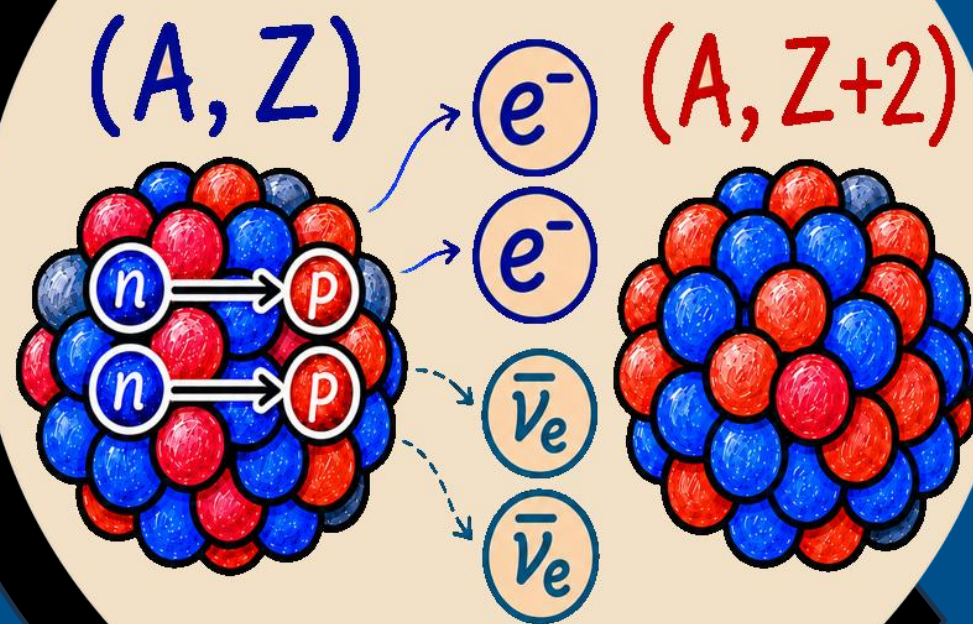
EXO-200

- ❖ EXO-200 detector
- ❖ Event Detection and Topology

DEEP NEURAL NETWORK

- ❖ Training, results and future work

DOUBLE BETA DECAY






□ Occurs in nuclei where single β decay is energetically forbidden — second order weak interaction

□ Half-life of order $10^{18} - 10^{21}$ years, exceeding the age of the universe

□ Observed experimentally in isotopes including ^{136}Xe and ^{76}Ge

LAWS CONSERVED

-  Charge conservation
-  Lepton number conservation
-  Baryon number conservation

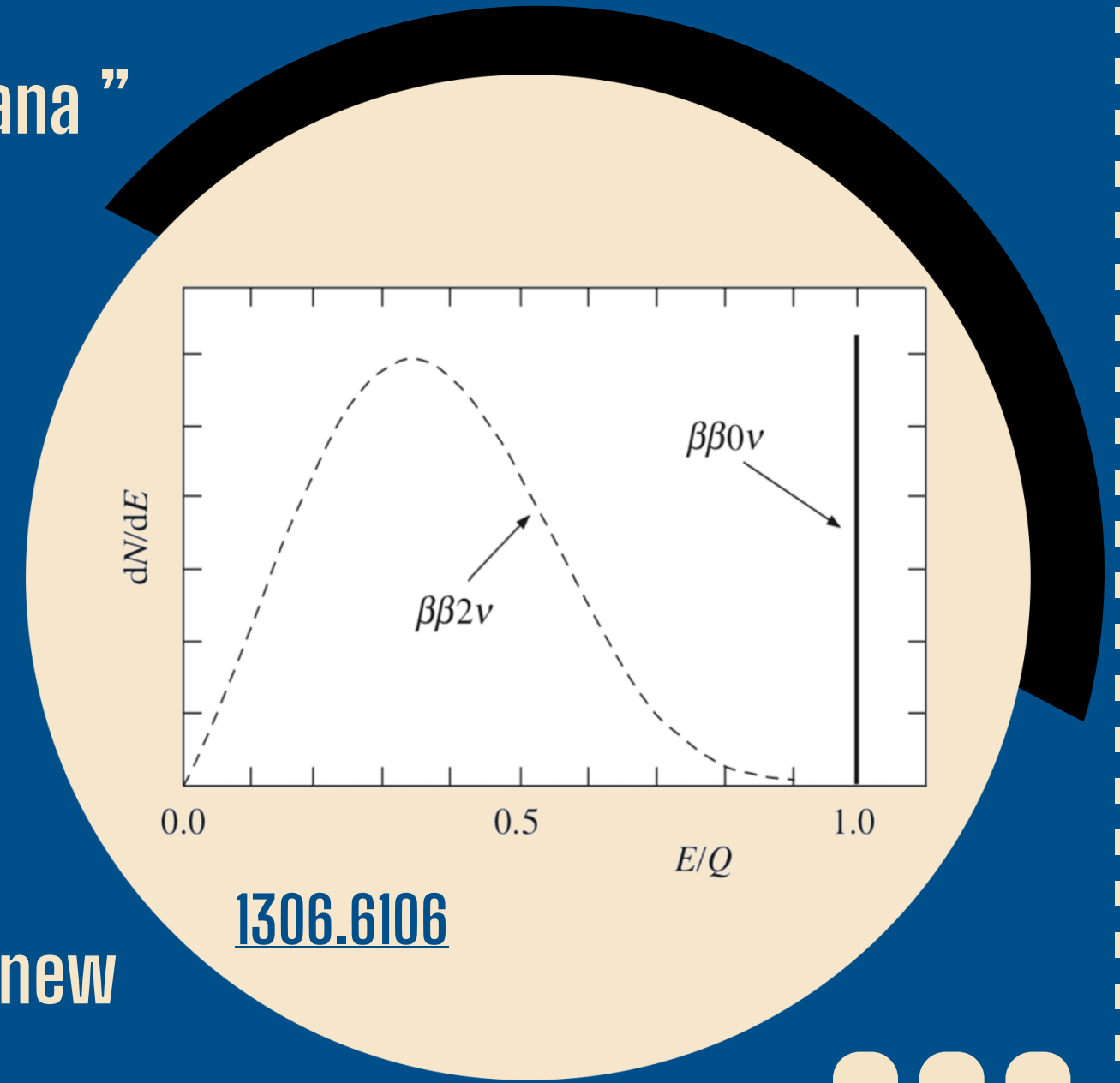
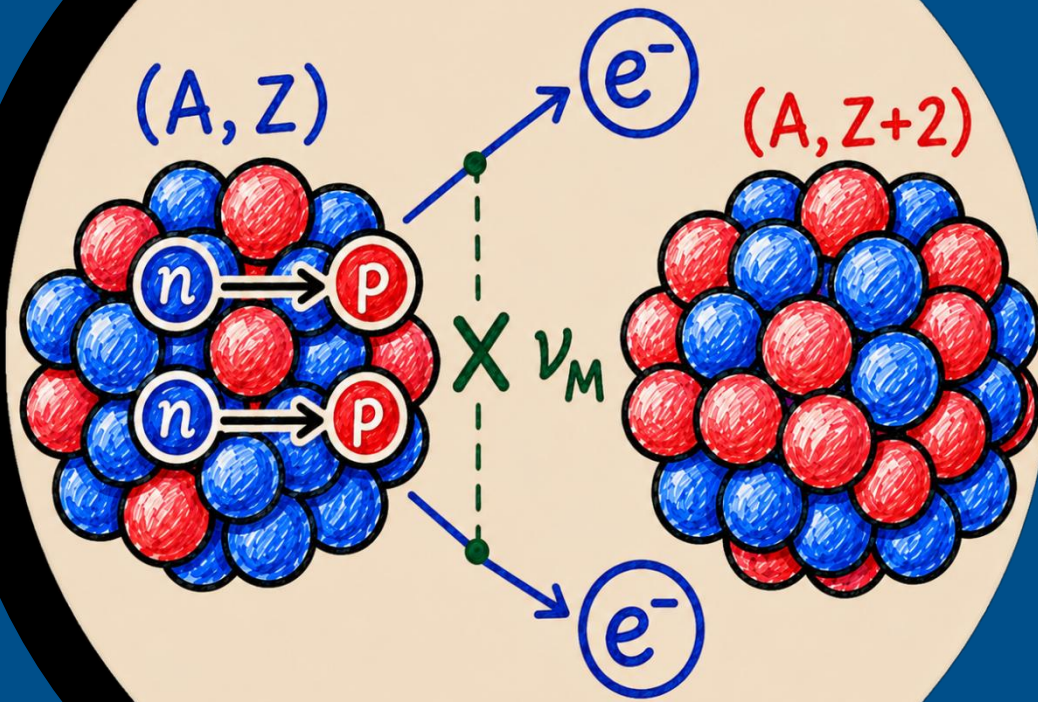
NEUTRINOLESS DOUBLE BETA DECAY

□ If neutrino is its own antiparticle \rightarrow “Majorana”

□ Only two electrons come out carrying all the energy

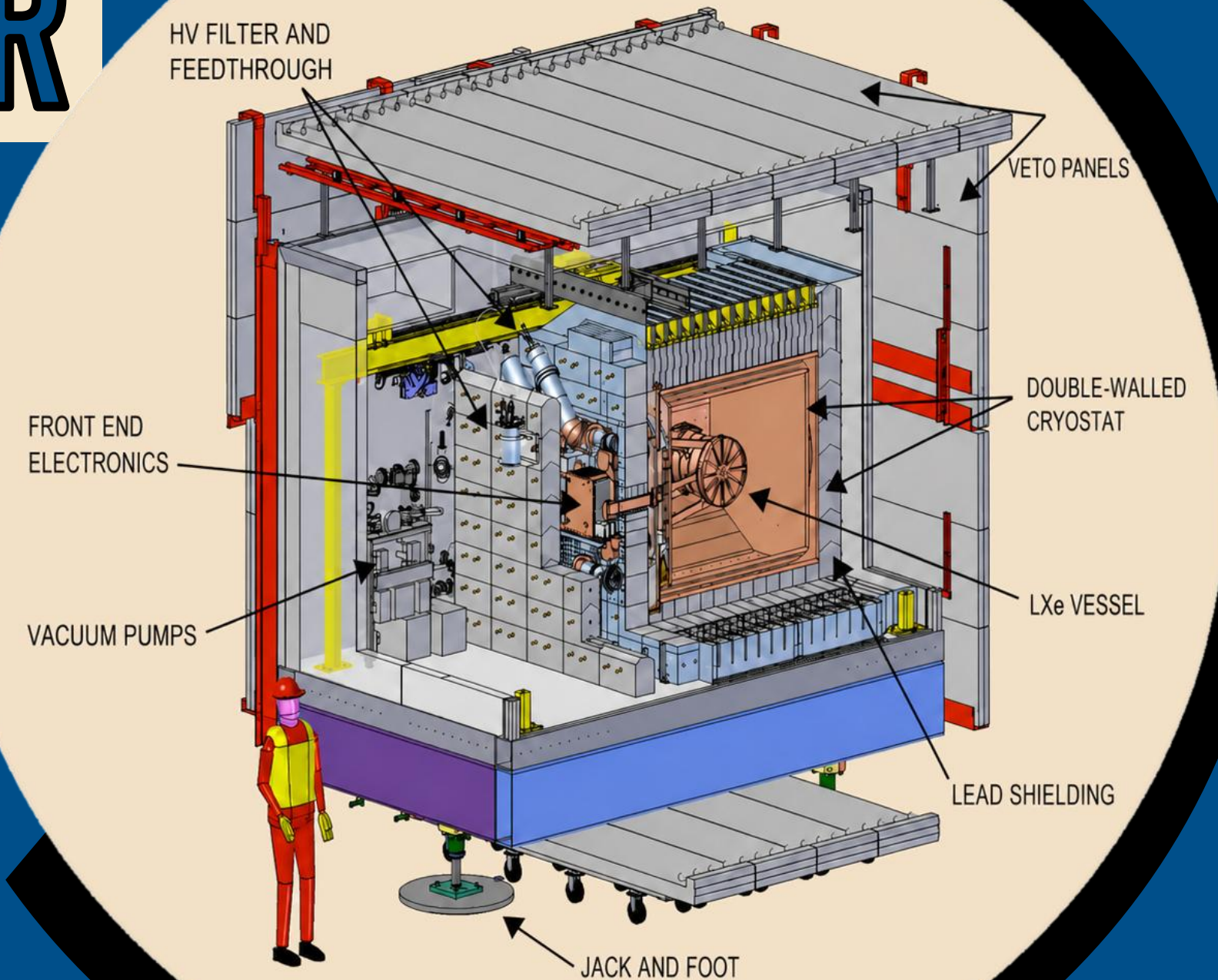
□ Lepton number violated — goes from 0 to +2

□ Potential explanation of matter anti-matter asymmetry \rightarrow path to new physics



EXO -200 DETECTOR

- ❑ Searching for neutrinoless double beta decay in ^{136}Xe
- ❑ Location 655 m underground at WIPP, New Mexico
- ❑ 200 kg liquid xenon (LXe) inventory with 110 kg in active detector volume
- ❑ Detector → HFE 7000 coolant → insulated cryostat → lead shielding → veto panel

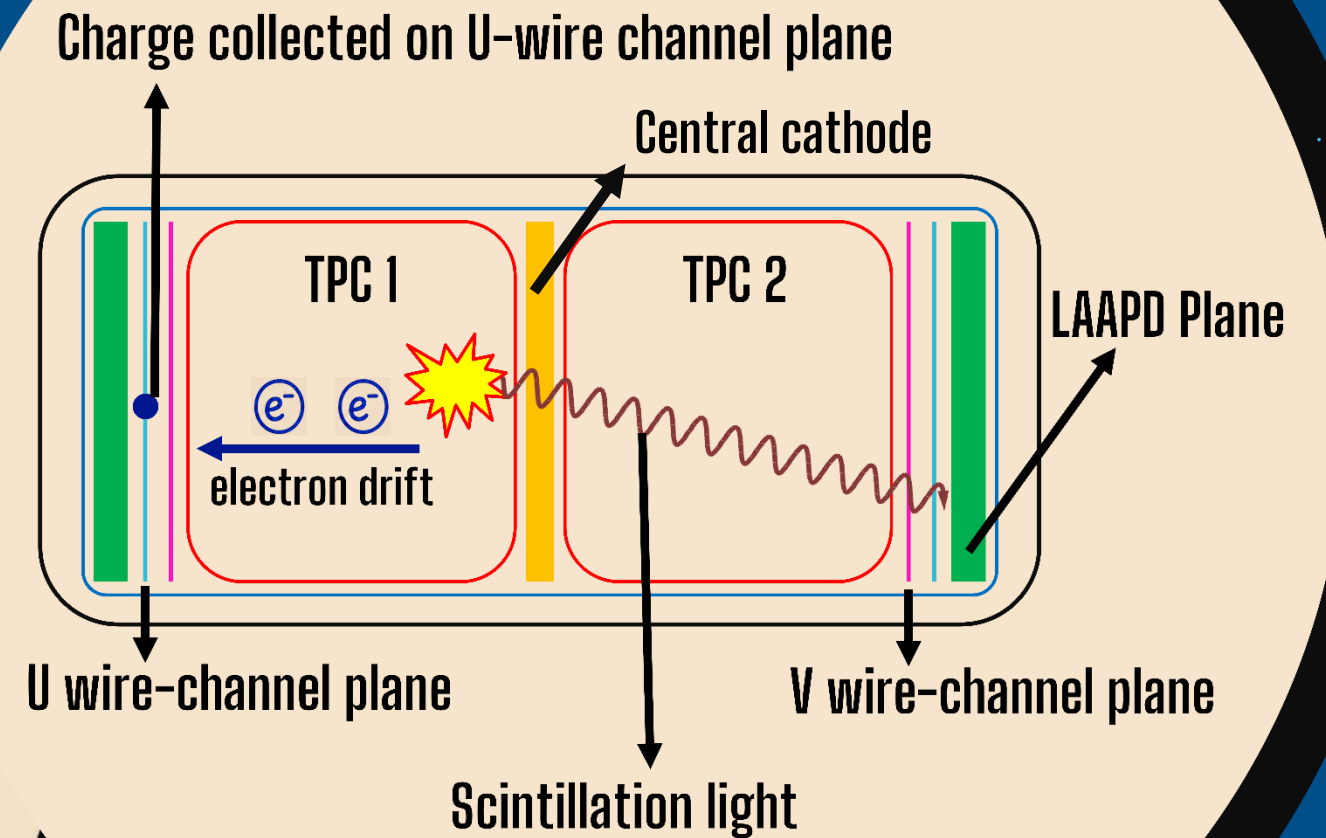
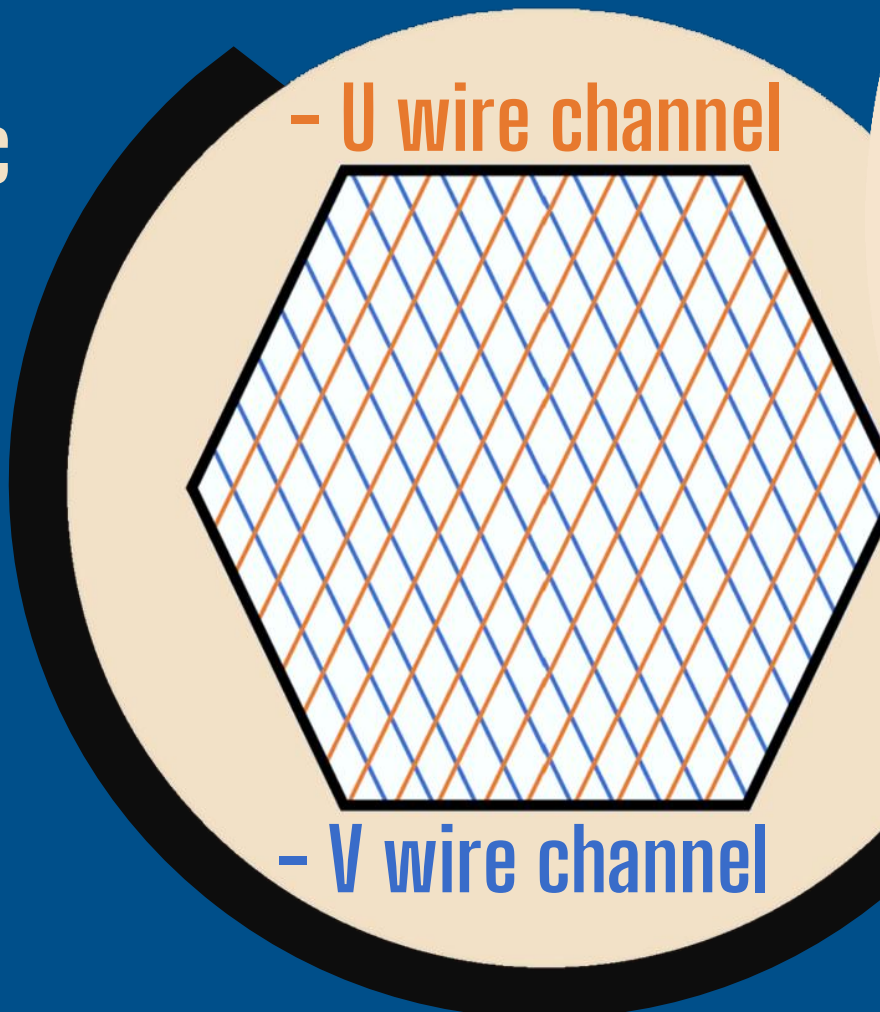


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EVENT DETECTION

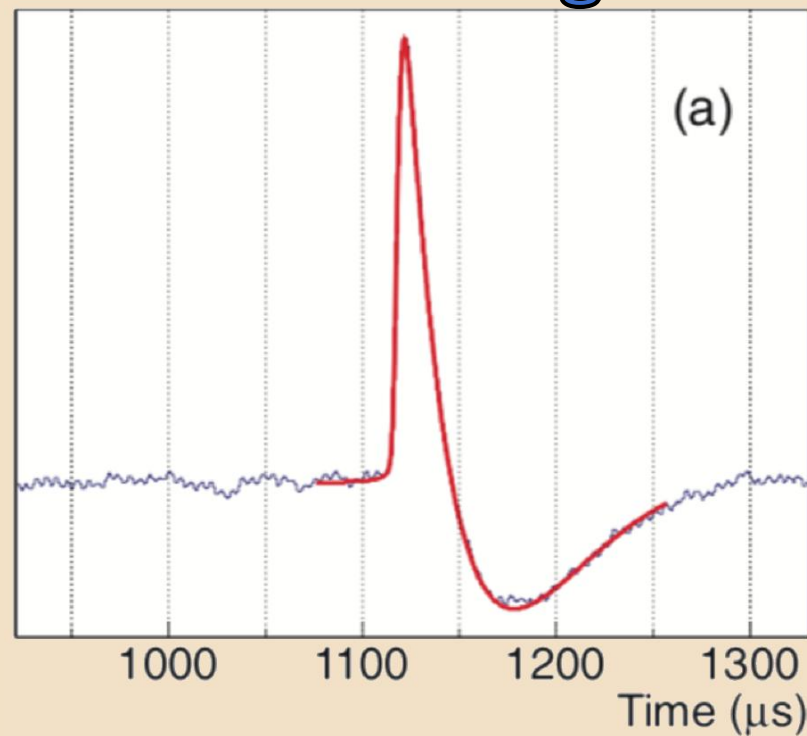
- Energy deposition in LXe \rightarrow ionization charge and scintillation light
- Ionized electrons drift under electric field \rightarrow pass through V-wire and U-wire channel plane
- Scintillation light detected by LAAPD on both sides
- U and V Wire plane \rightarrow 38 readout channel each, inclined at 60 degrees

- $Z = v_{\text{drift}} (t_{\text{charge}} - t_{\text{scintillation}})$, $v_{\text{drift}} = 1.71 \text{ mm}/\mu\text{s}$



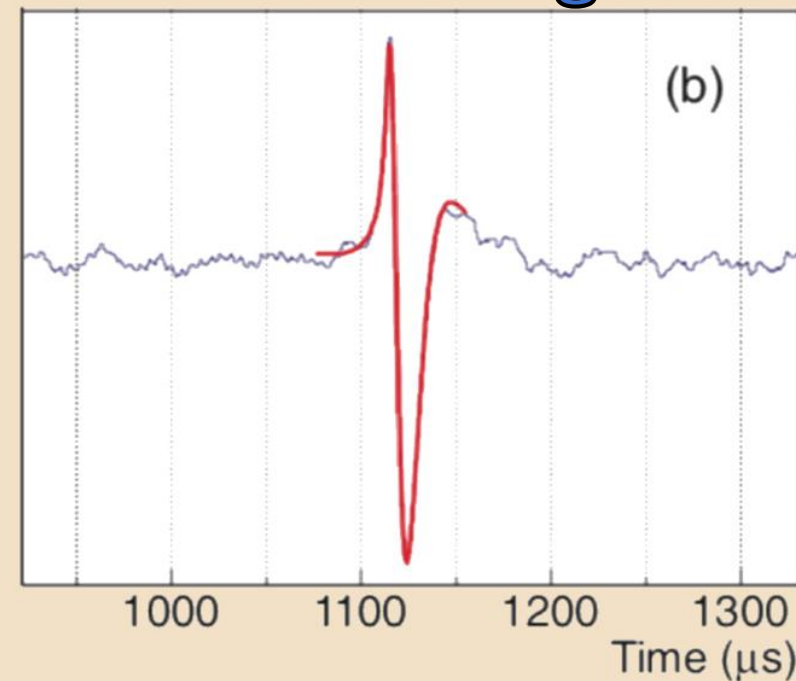
EVENT DETECTION

Collection signal



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Induction signal



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□ Charge interaction → collection and induction signal on U-wire channel, induced signal on V-wire channel

□ In both planes, each readout channel = 3 wire triplets, 9 mm effective readout pitch

□ **Single-Site (SS) event** →

Nu = 1 : single-channel deposit

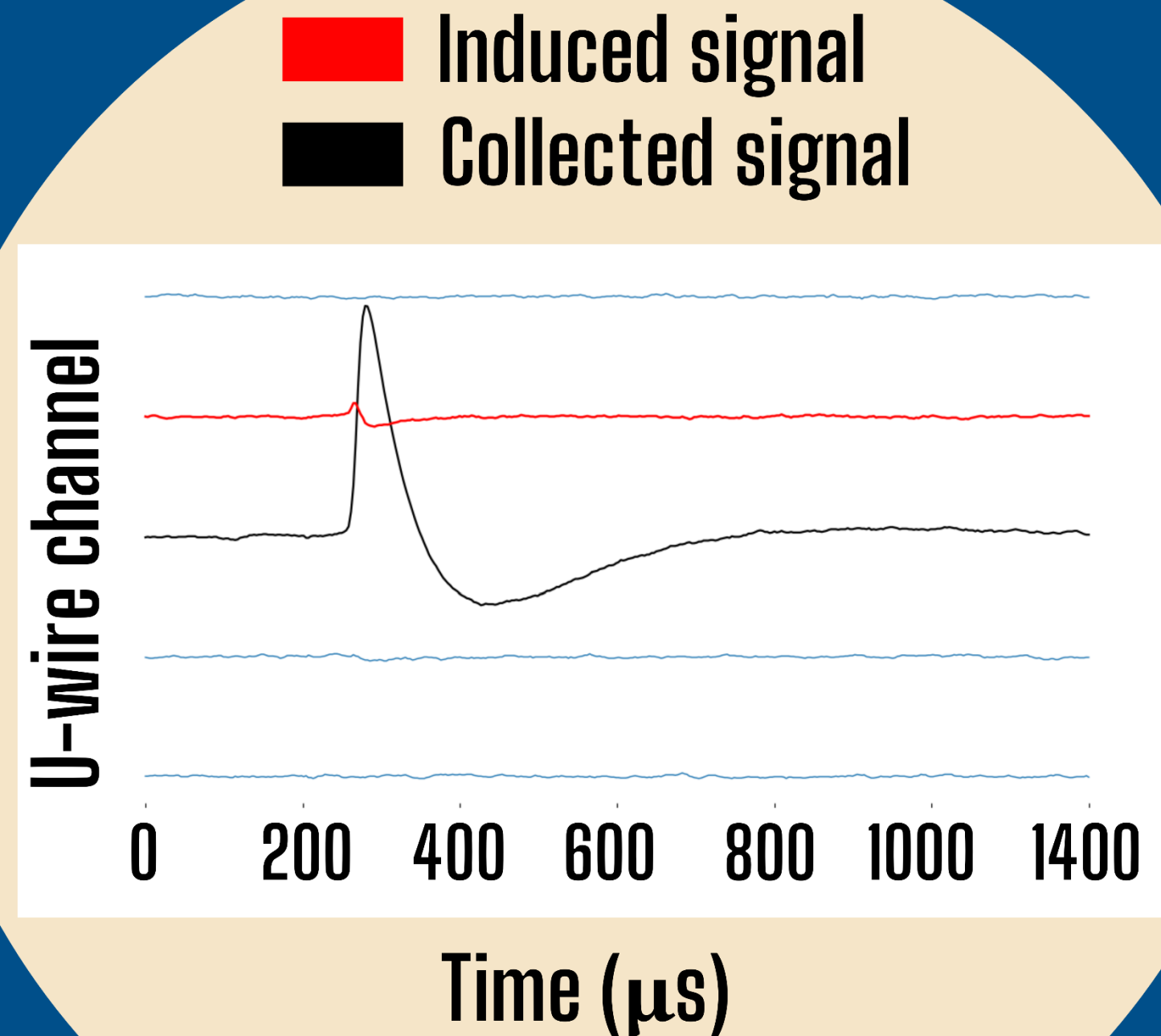
Nu = 2 : dual-channel deposit

□ **Multi Site (MS) event** →

Multiple channel deposit

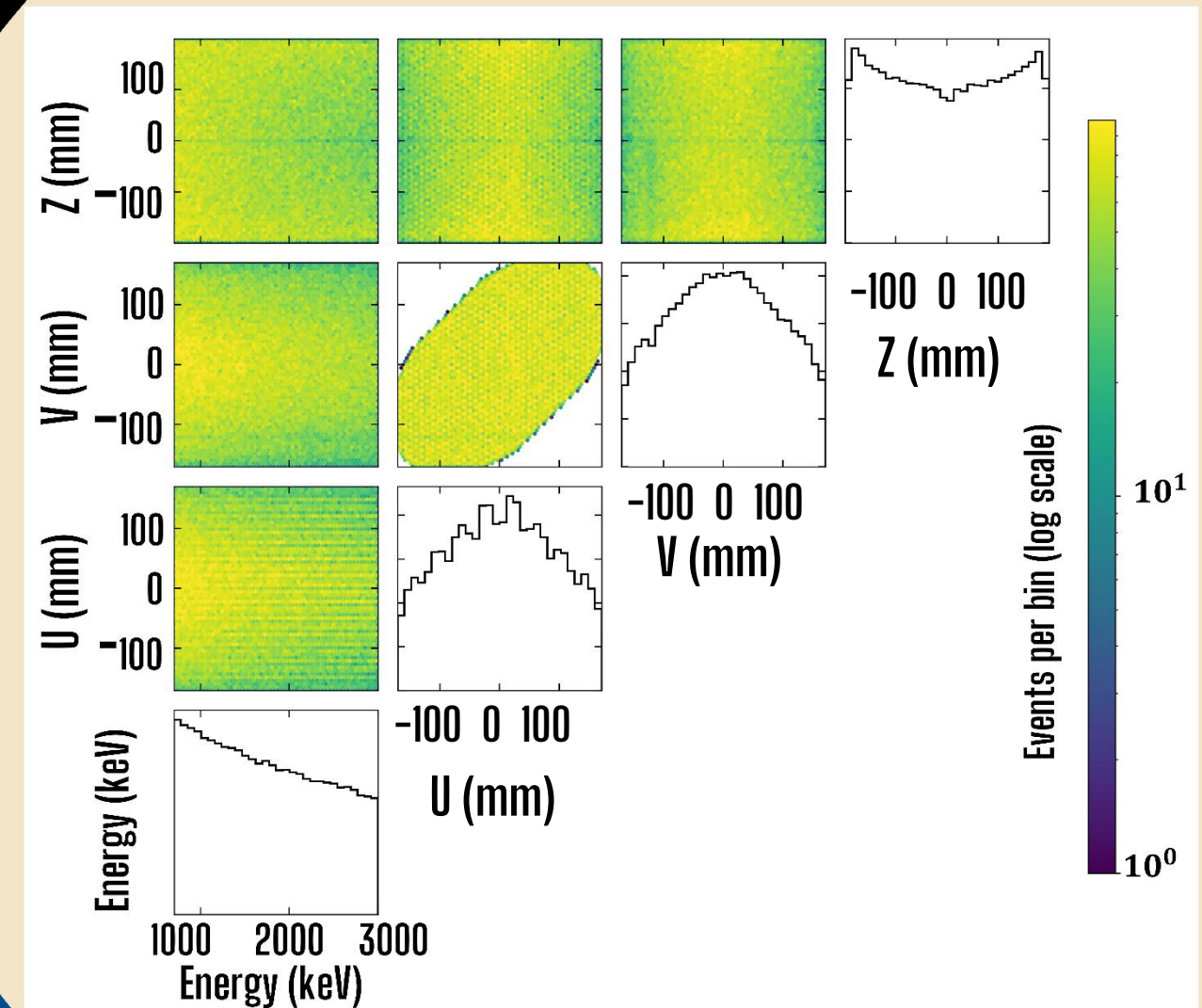
OBJECTIVES

- ❑ Further DNN development → to use simulated electrons for spatial reconstruction of EXO-200 events
- ❑ Existing DNN from previous work uses CNN with ~ 15 million parameters, improvement from 1.7mm → 0.5 mm
- ❑ To establish spatial relationship between events and energy



EVENT TOPOLOGY

- Monte Carlo simulation of SS electron events to train DNN
- Diagonal panels → 1D distributions of Energy, U, V, Z → covers broad range of energy and active volume detector
- Off diagonal → hexagonal boundary in U-V : physical geometry of the wire grid
- Broad spatial coverage → DNN learns reconstruction and no bias

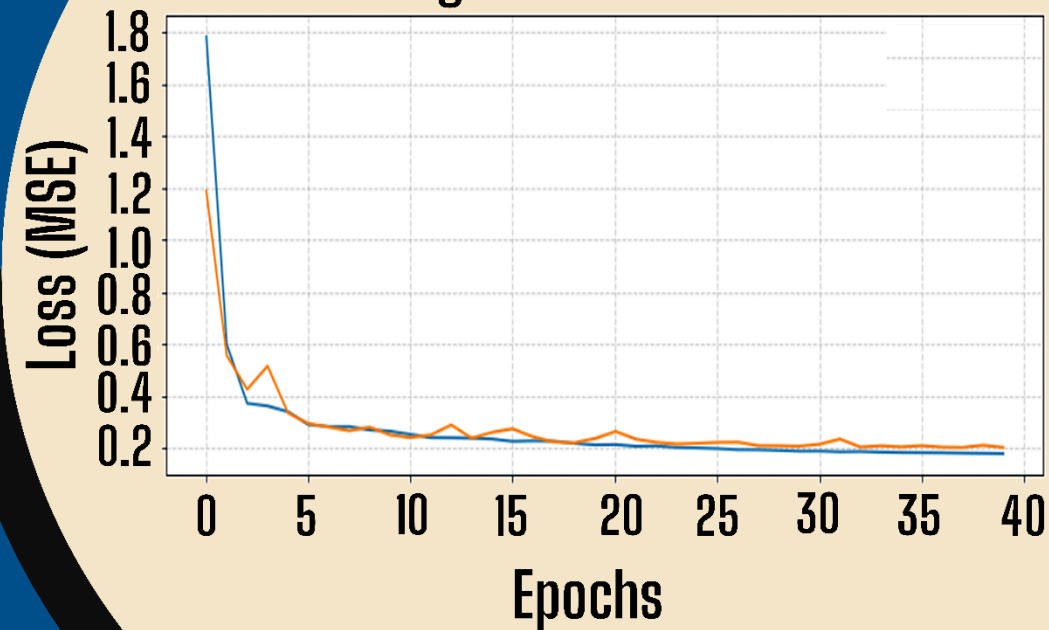


NEW DNN TRAINED

- ❑ Model A (classifier) : predicts charge-collecting U-wire channel with ~95% accuracy
- ❑ Model B (regression) : spatial refinement using identified wire channel+ 2 neighbouring U-wire channel each side
- ❑ Training set : 90%, validation set 10% events
- ❑ Training done in two steps

MODEL B

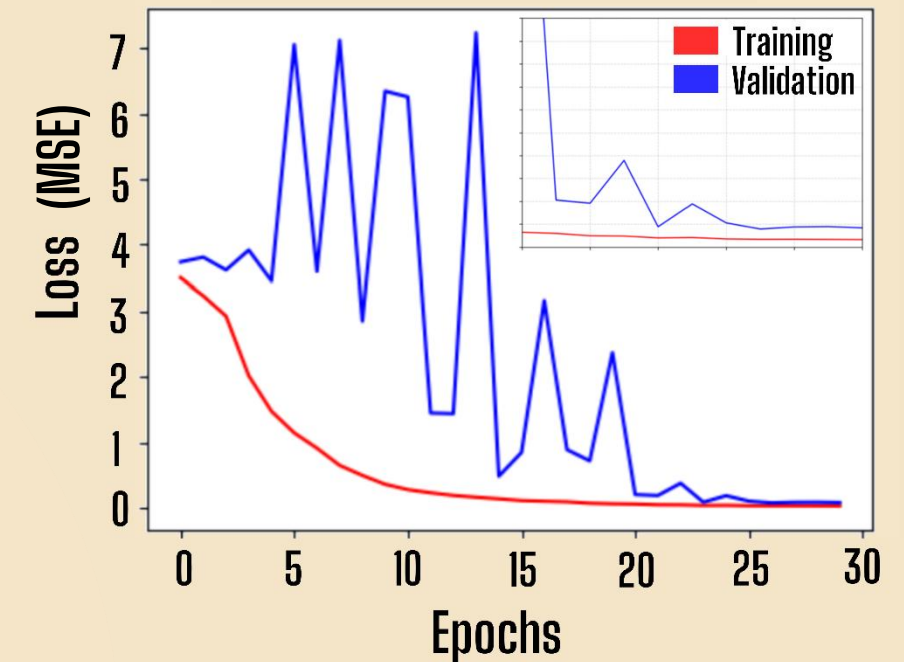
Training and validation loss



49,783 parameters

MODEL A

Training and validation loss



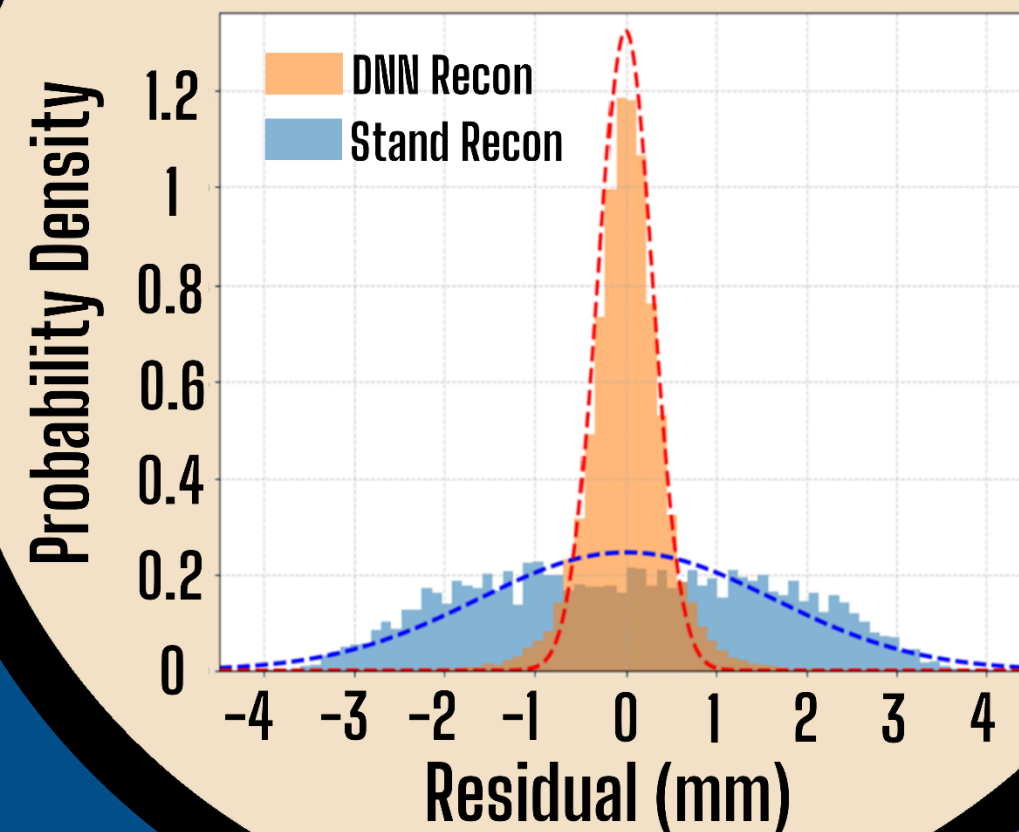
555,974 parameters

- ❑ Combined: 605,757 fitting parameters

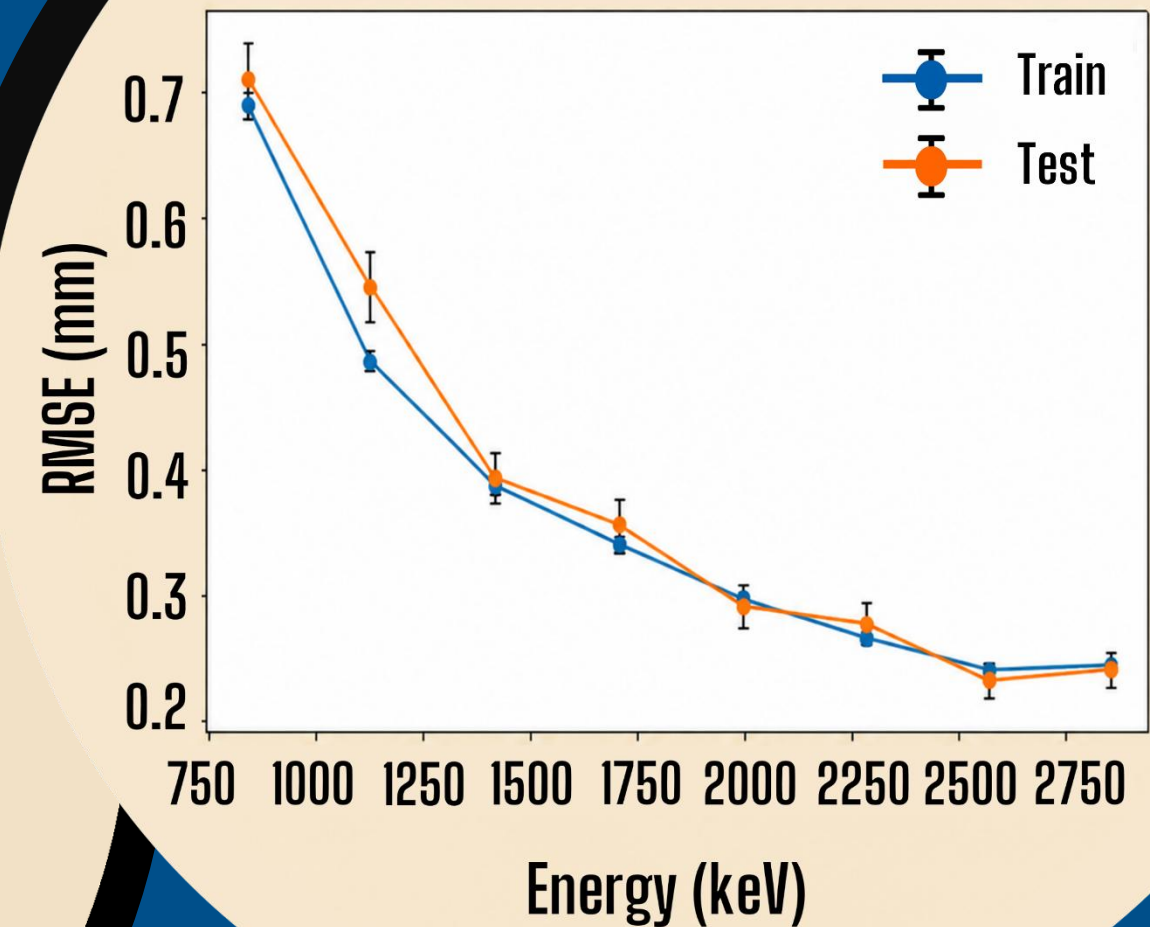
RESULTS

- Residual (Δu)
 $= u_{\text{predicted}} - u_{\text{true}}$
- Improved DNN achieves
 $\sigma = 0.31 \text{ mm}$
- Spatial resolution
increases with energy
- DNN generalizes well,
Consistent performance
across all SS events

$\mu = 0.01 \text{ mm}, \sigma = 0.30 \pm 0.01 \text{ mm}$
 $\mu = 0.01 \text{ mm}, \sigma = 1.62 \pm 0.01 \text{ mm}$
Training result

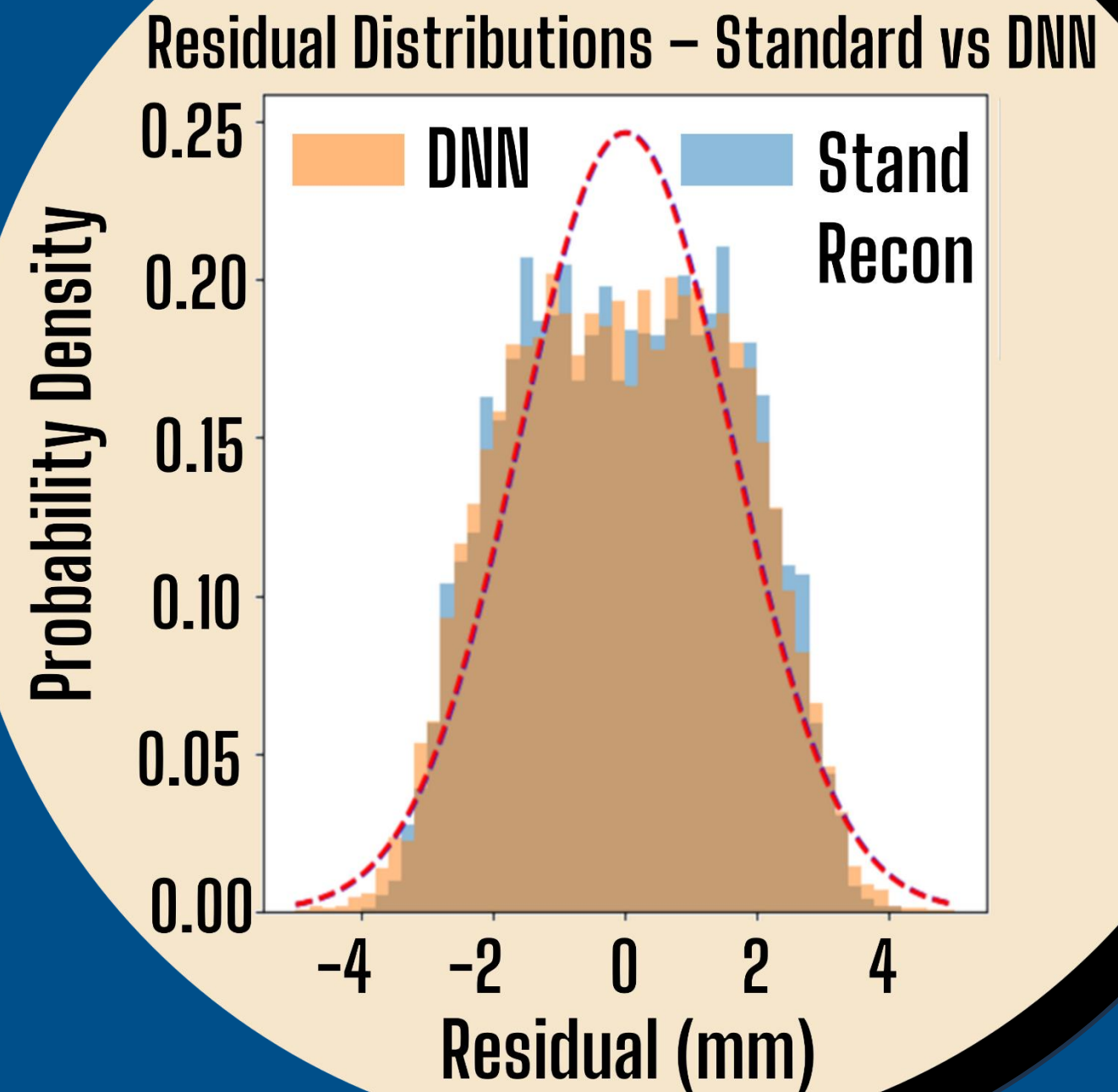


RMSE vs Energy (Train vs Test)



DNN'S EDGE

- ❑ Standard reconstruction uses only charge-collecting wire
- ❑ DNN exploits induced charge on neighboring U-wires
- ❑ Sub-wire spatial resolution → by induction signals
- ❑ Without neighboring wire input DNN yields $\sigma = 1.67$ mm

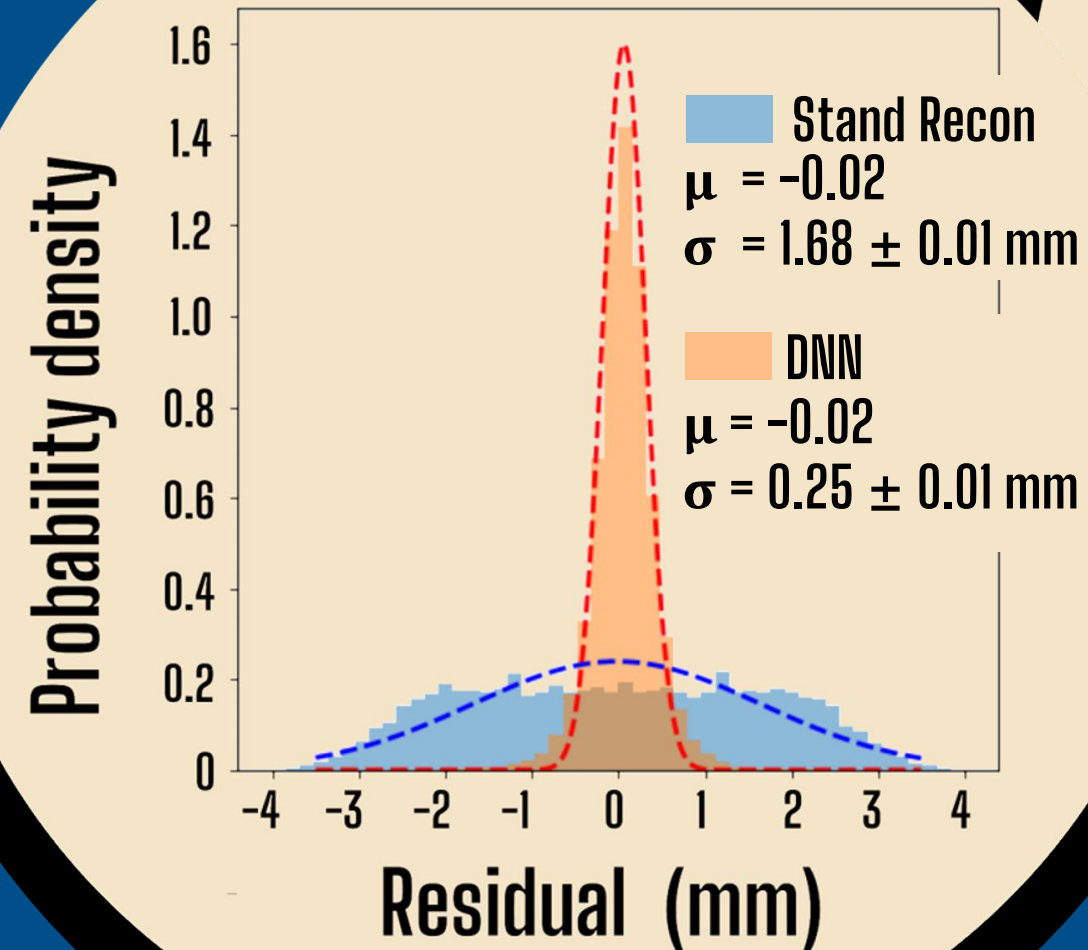


BENCHMARK

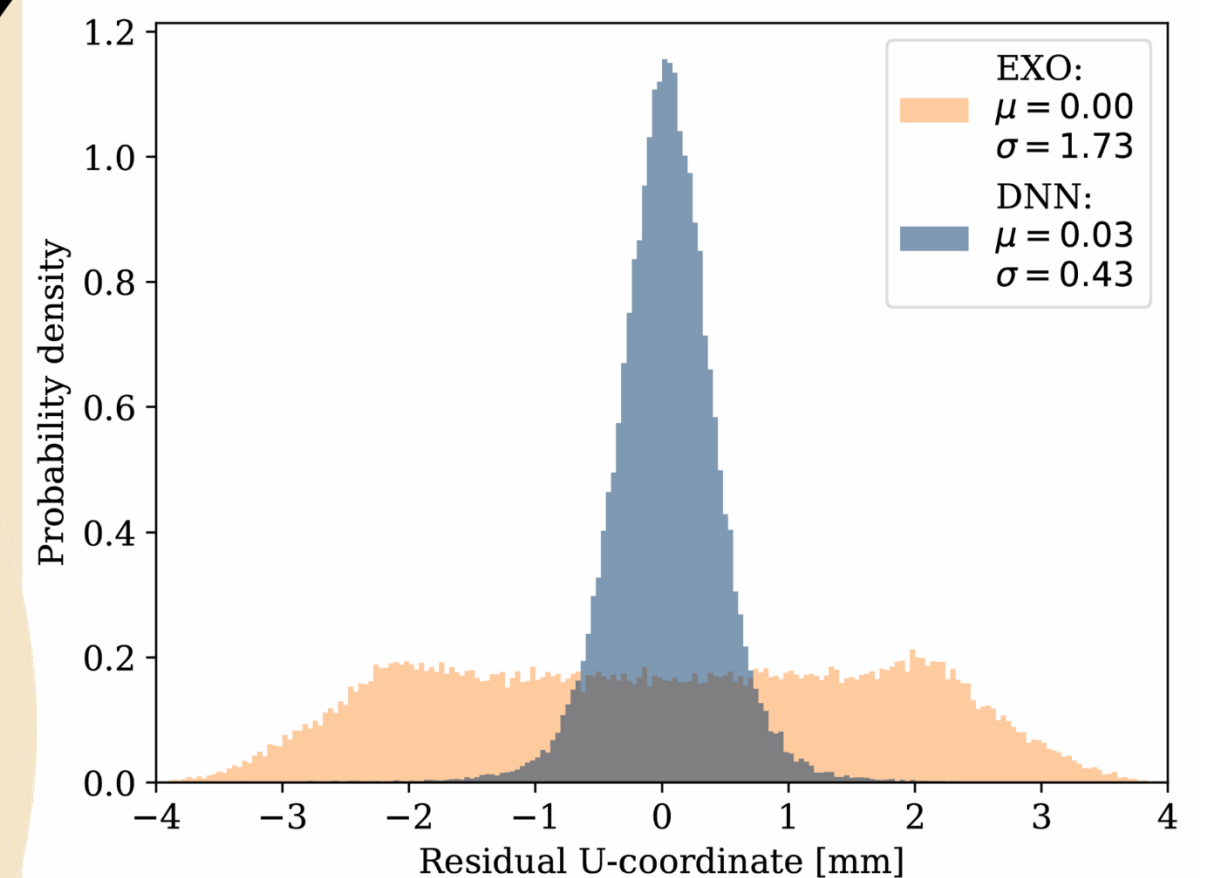
Previous result (Johannes Links) for U coordinate : obtained using high energy gamma

Independent Test : average resolution across 750 – 3000 keV

Independent Test



Johannes' result



Master thesis

CONCLUSION

- ❑ DNN (new)-based reconstruction **improves** the U-coordinate compared to standard reconstruction **more than 5 times**
- ❑ Number of fitting parameters for new DNN reduced by **25 times**
- ❑ Reduced computational costs (new DNN)
- ❑ **Electron as the primary event** for spatial reconstruction

❑ **3D SPATIAL RECONSTRUCTION**

❑ **COMPLEX TOPOLOGY (MS event)**

❑ **REAL DATA INVESTIGATION**

FUTURE WORK



THANK YOU

