

Low-latency pointing to a supernova with neutrinos

for Duke University A3D3 group by Kate Scholberg

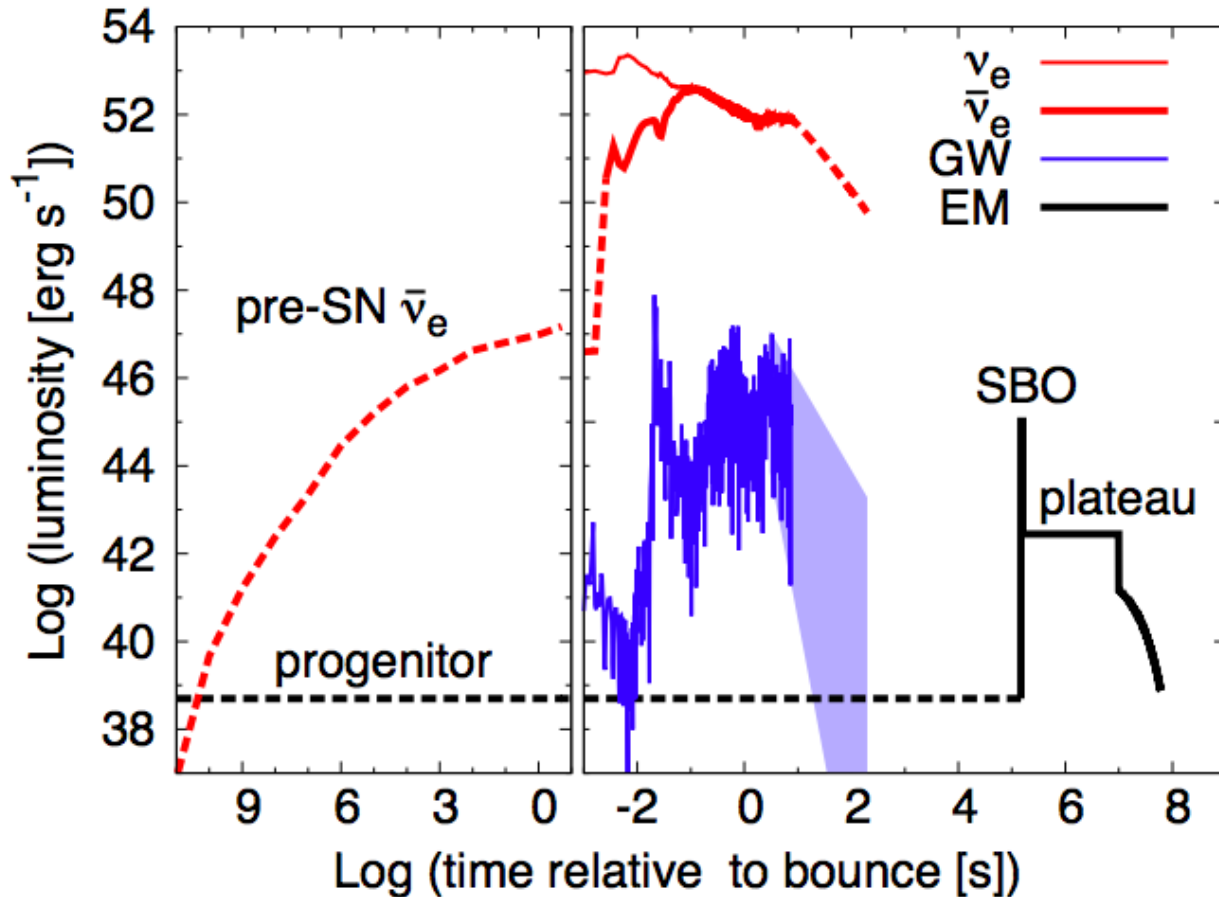
Janina Hakenmüller (postdoc)

Josh Queen (grad)

Van Tha Bik Lian (postbacc) → new postbacc: Lucie Afko

July 10, 2023 - A3D3 High-Throughput AI Methods and Infrastructure Workshop

Multimessenger astronomy



Supernova bursts:

- >99% of energy released in the form of neutrinos
- time scale:
 - neutrinos: 10^{-2} s -10s
 - grav. Waves: 10^{-2} s -10s
 - el.-mag.: $>10^4$ s
- neutrinos interact only weakly with a very small cross section

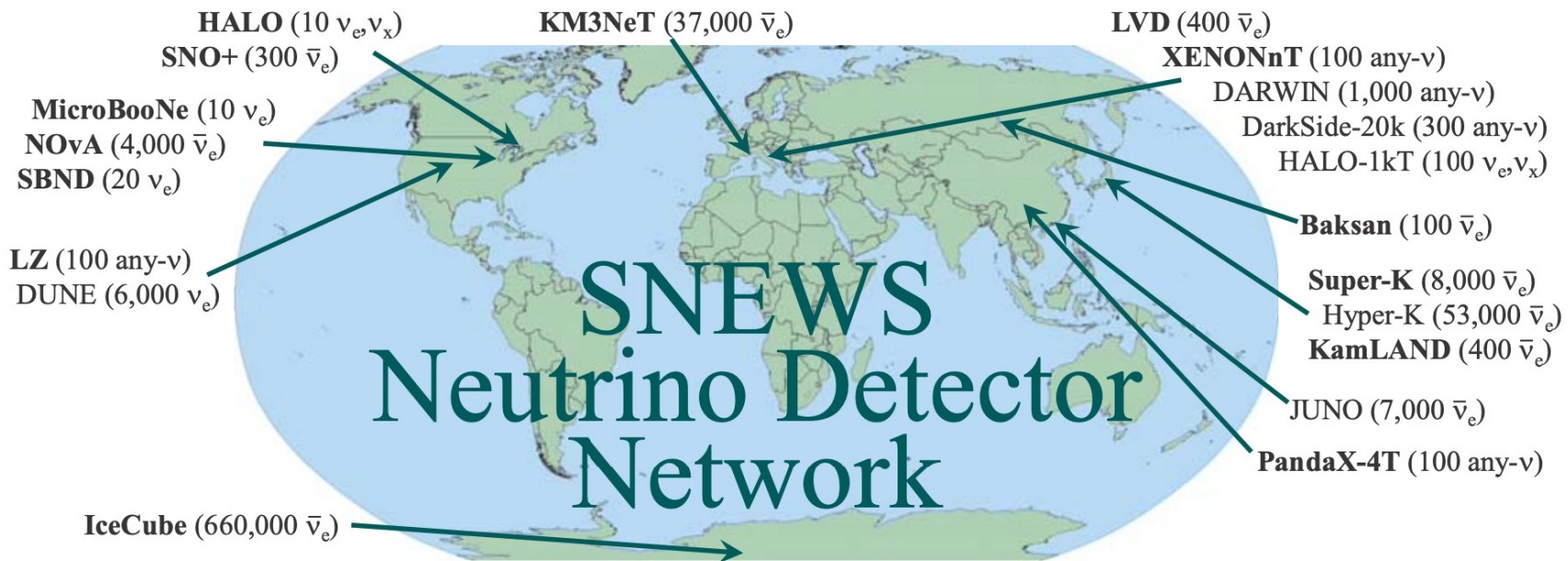
=> neutrino detection for **early warning system of burst**

=> detection has enormous **physics potential for astronomy and particles physics**

SNEWS

(SuperNova Early Warning System)

- SNEWS1.0: simple 10s coincidence, running in automatic mode since 2005
- Upgrade to SNEWS2.0: improved latency, **neutrino based pointing, including triangulation**



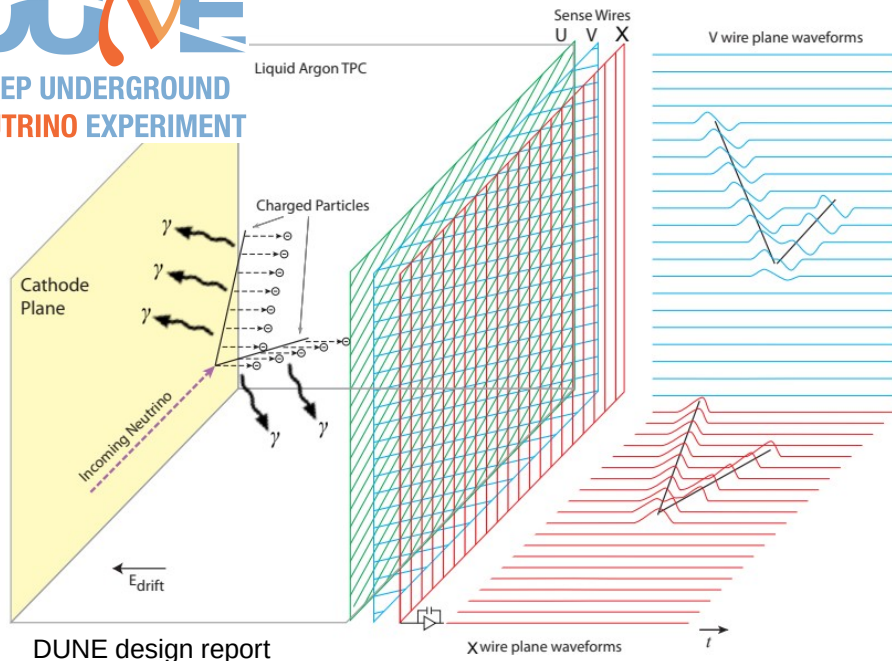
<https://snews2.org/>

Detection materials: water-based, **argon**, scintillator, lead, noble liquid dark (dark matter exp.)



DUNE

(Deep Underground Neutrino Experiment)



- **liquid argon time-projection chambers:** **ionization** and scintillation light totally active calorimeter
- far detector in South Dakota: LAr mass 4 x 10kt
- underground: 1.5km rock/4300 m w.e.
- **GeV scale:** Neutrino oscillations in long baseline beam, study of atmospheric neutrinos, BSM physics, baryon number violation
- **low energies:** supernova neutrinos, solar neutrinos, diffuse supernova background

large mass



high statistics

underground



background suppression

excellent 3D imaging



pointing to supernova, multi messenger

ν_e detection



complementarity to other experiments
(JUNO, Hyper-Kamiokande)

Supernova neutrino detection with DUNE

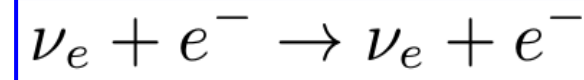
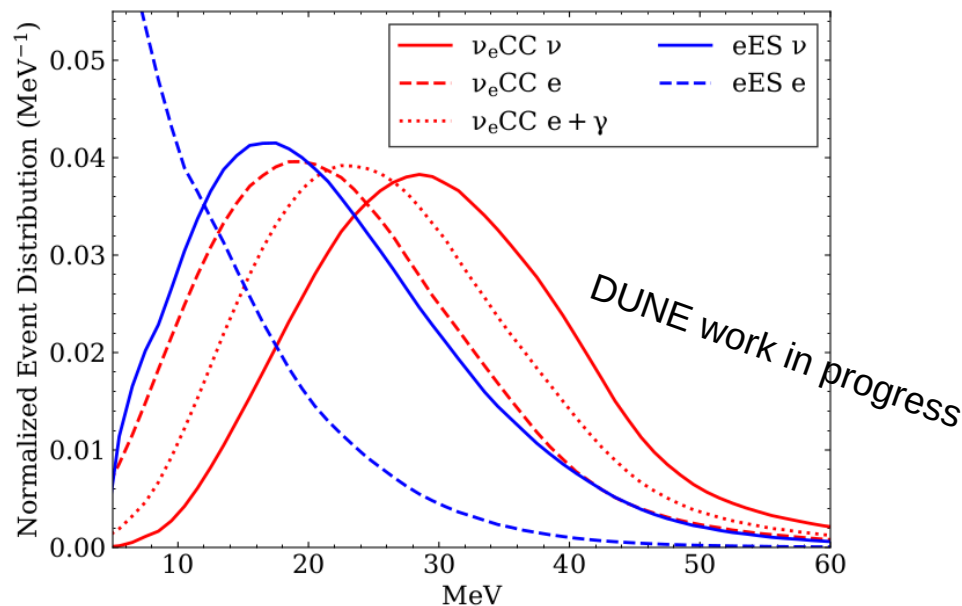
Dominant channels: charge-current interaction (ν_e CC) and elastic electron scattering (eES)

Additional channels: ES of other flavors, NC scattering on Ar, ...



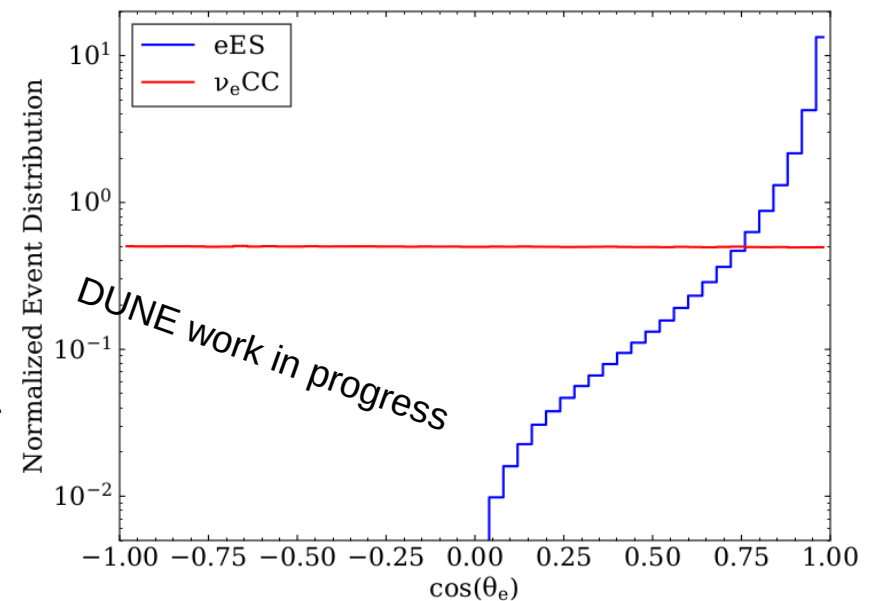
~**3000** events @10kpc (GKVM model)
flat angular distribution

Energy spectra:



~**300** events @10kpc (GKVM model)
primary e^- direction ~ ν_e direction

Overall angular distributions:



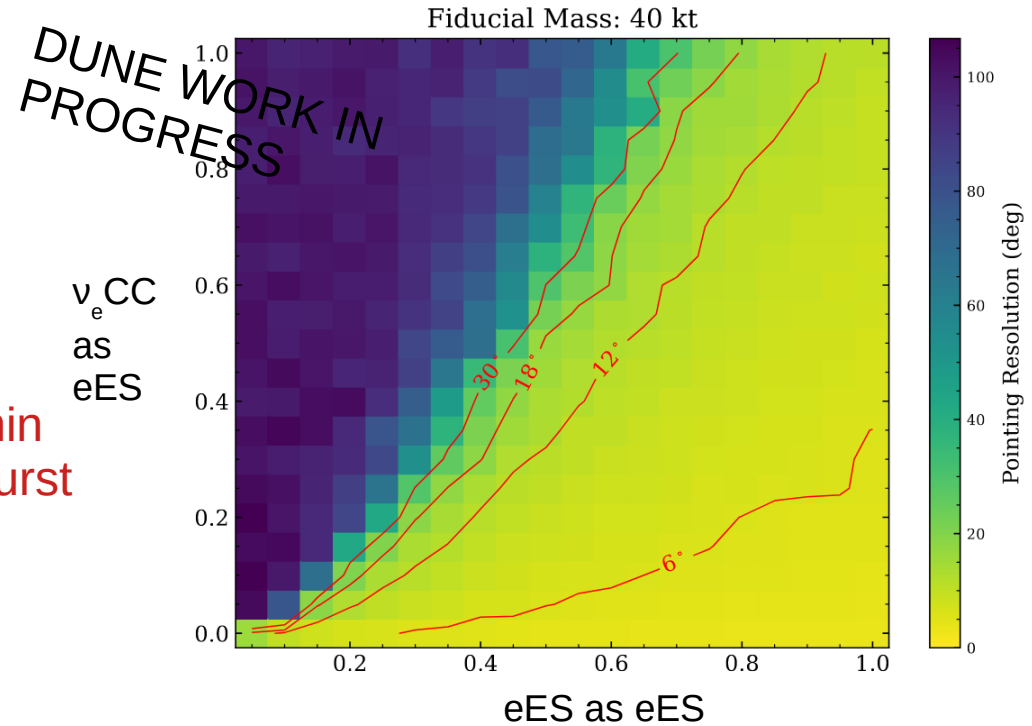
→ channel tagging: distinguish ν_e CC and eES

DUNE supernova pointing results

Procedure:

- simulation of supernova events, noise and background
 - **reconstruction of single events:**
 - Identification of supernova events
 - energy
 - direction, daughter flipping for head-tail disambiguation
 - **combination of events to burst:**
 - minimum energy: 10MeV
 - maximum log likelihood
 - assumptions on channel tagging
- publication in preparation

>>1min per burst



LAr volume	40kt	10kt (one module)
Perfect disambiguation	3.7 deg	7.4 deg
4% ν_e CC as eES	5.0 deg	10.6 deg

(68% confidence level)

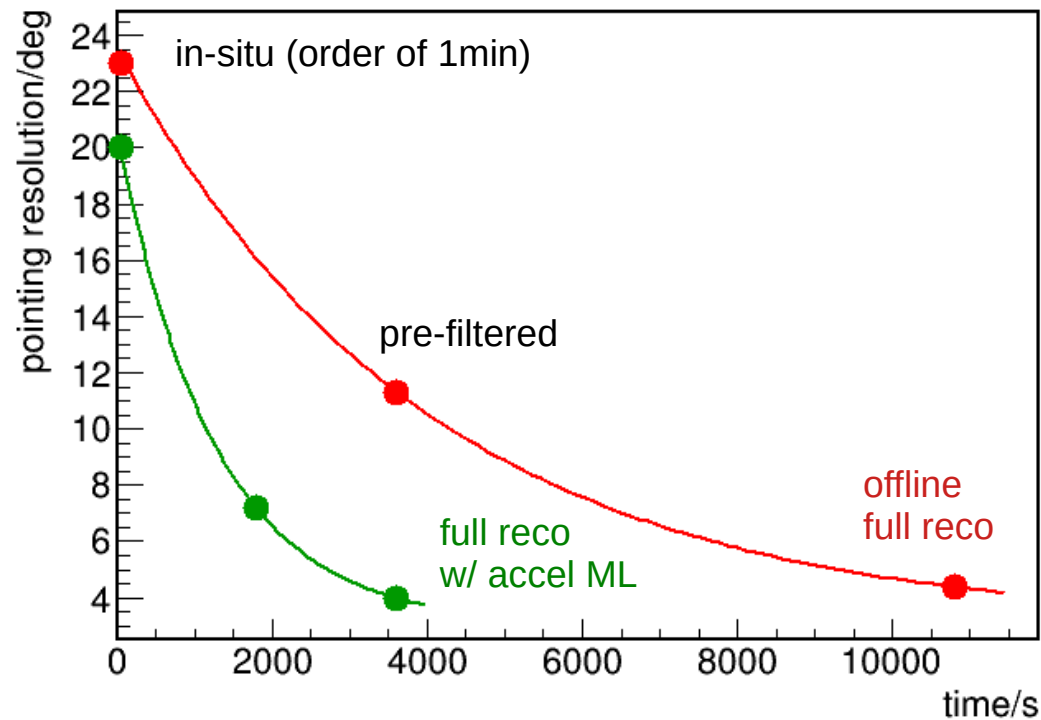
GKVM model,
10kpc distance

Online Pointing and machine learning

Strategy: prompt, low-resolution followed by successive improvements
(“kaizen” approach, coined for this by K. Scholberg at Accelerating physics with ML in Boston)

- convert offline code to complete standalone pipeline, upgrade with ML
- also test upgrades of offline code with ML

Illustration:



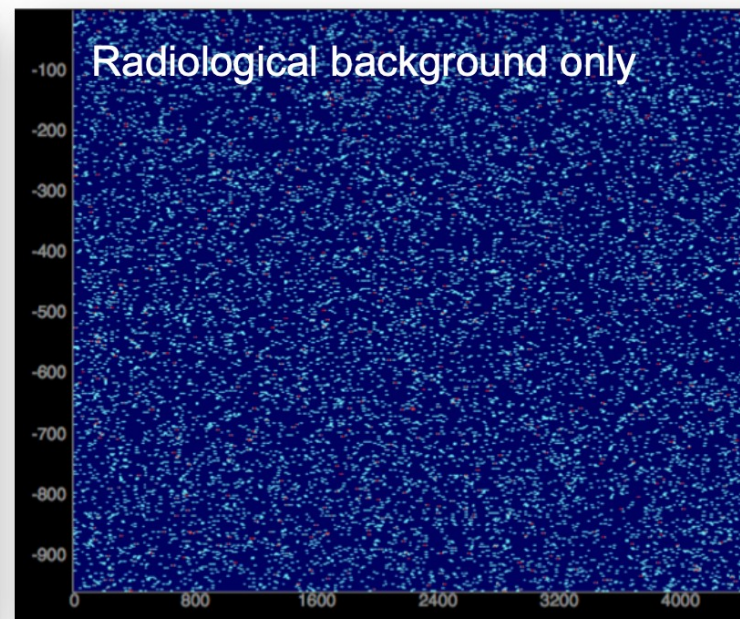
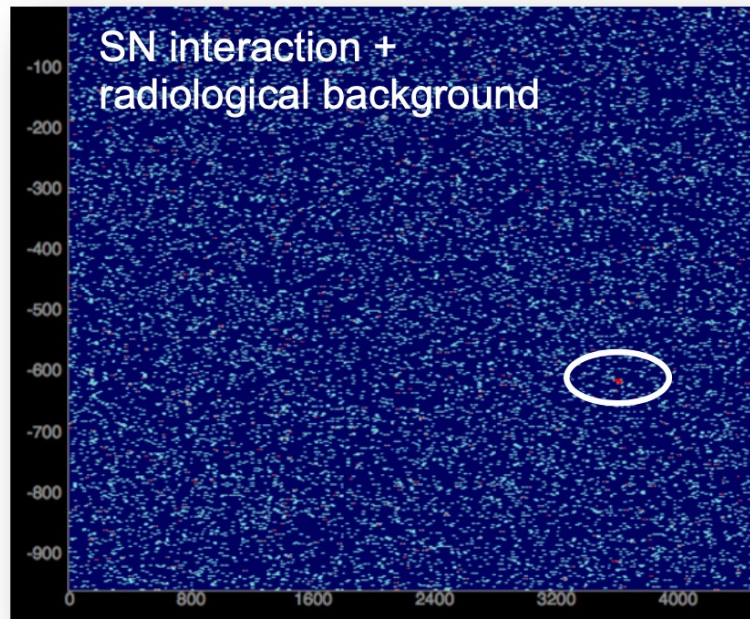
poster by JH

Identifying supernova events

High resolution “video stream”: 11.5 Mega Pixel frames per 2.25ms, 12 bits resolution

Special challenge: **neutrinos from supernova core collapse**

Very low energy and small (in extent) topology, similar to radiological background activity in the detector



Need $O(10^4)$ overall background suppression, while maintaining high efficiency to a frame containing a supernova neutrino interaction

[simulation]

Real-Time Inference With 2D Convolutional Neural Networks on Field Programmable Gate Arrays for High-Rate Particle Imaging Detectors

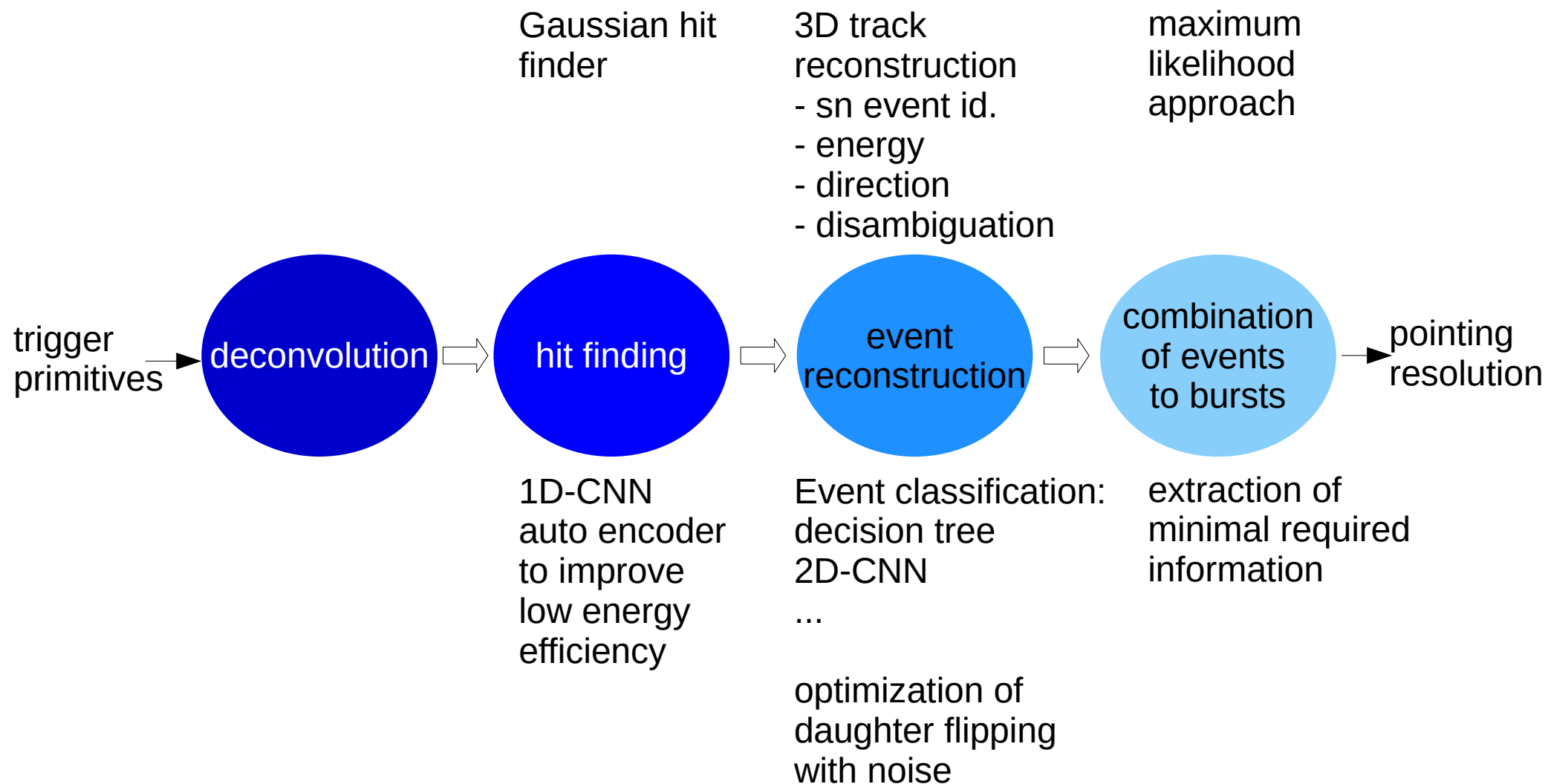
Yeon-jae Jwa (Columbia U.), Giuseppe Di Guglielmo (Columbia U.), Lukas Arnold (Columbia U.), Luca Carloni (Columbia U.), Georgia Karagiorgi (Columbia U.) (Jan 14, 2022)

Published in: *Front.Artif.Intell.* 5 (2022) 855184 • e-Print: [2201.05638](https://arxiv.org/abs/2201.05638) [physics.ins-det]

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Georgia Karagiorgi, Columbia @ Fast Machine Learning - 2019

by G. Karagiorgi group, Columbia

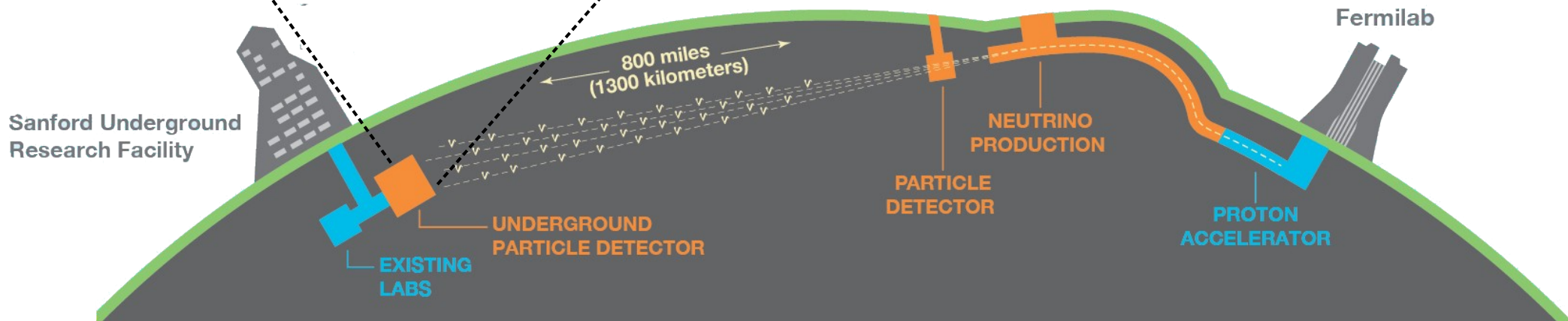
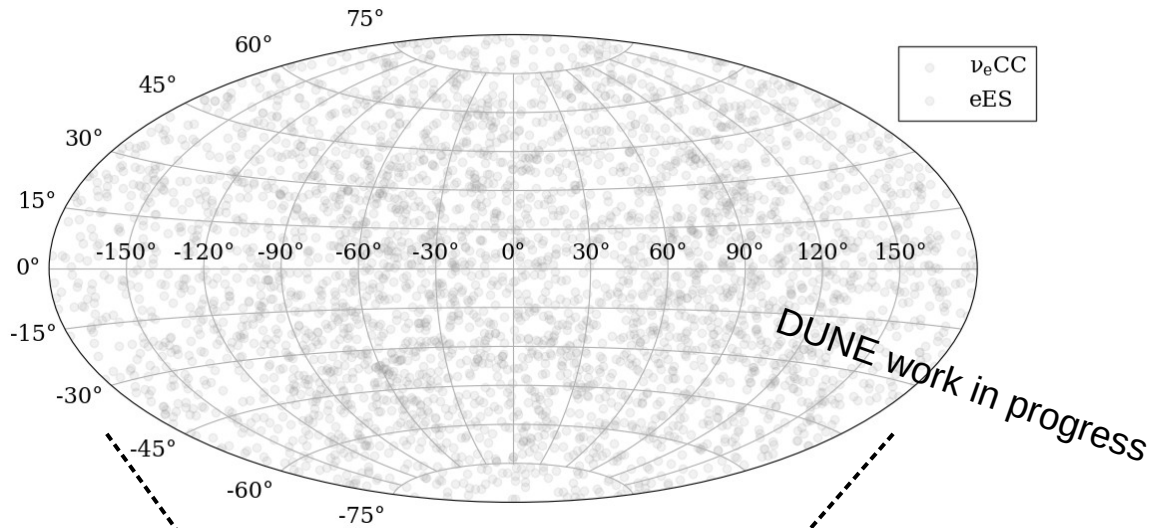
Standalone pointing code for DUNE



Remark: This list of ML efforts is for sure not complete.

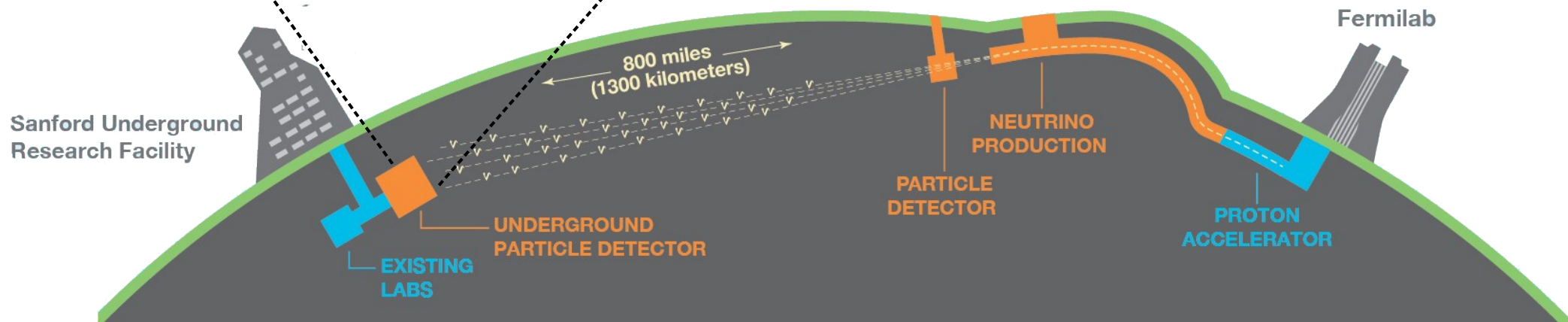
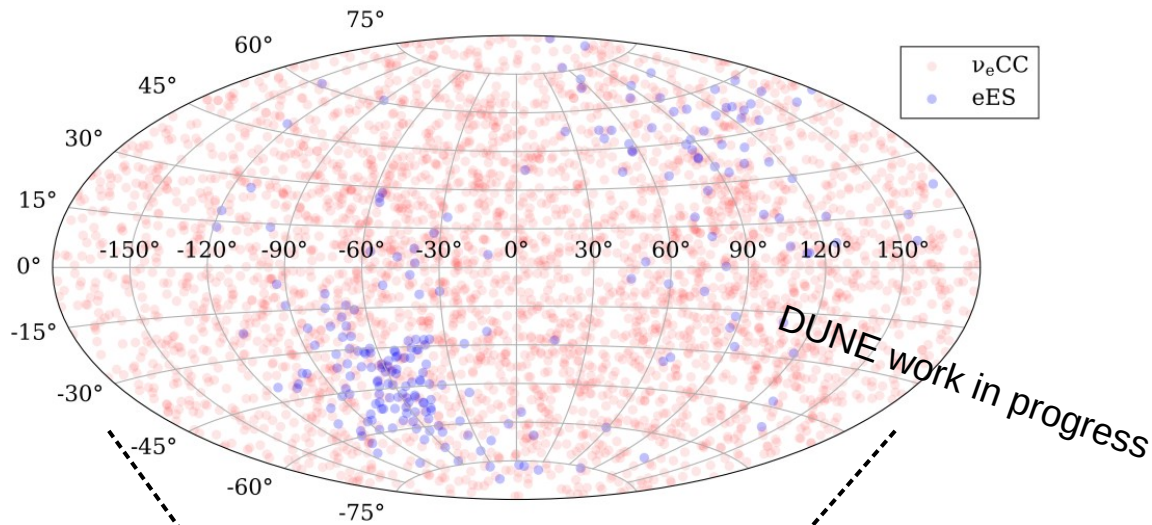
Supernova detection with DUNE

Skymap



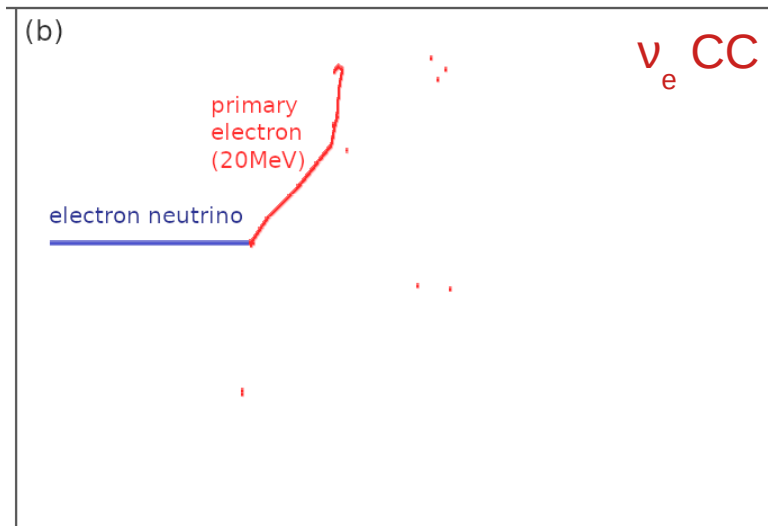
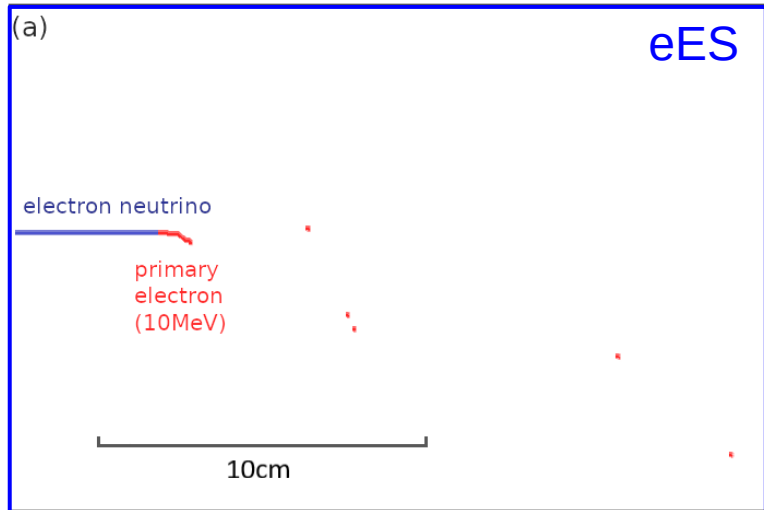
Supernova detection with DUNE

Skymap



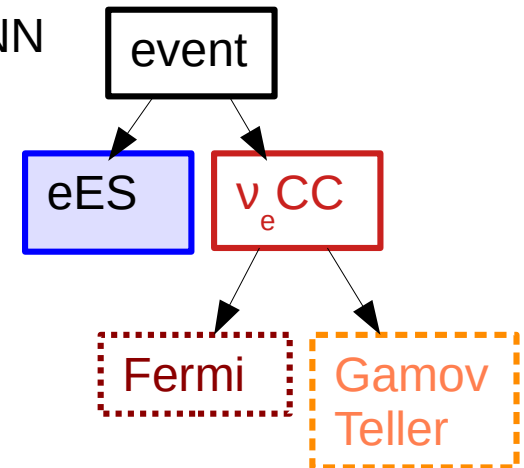
Event classification

Geant4 event displays:



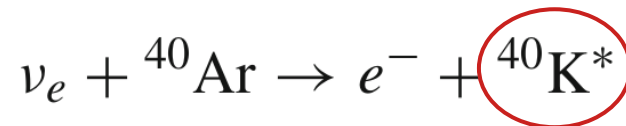
ML approaches ongoing:

- E. Conley (Duke) <https://zenodo.org/record/4122909#.Y9pfpY-B3pA>
 → boosted decision tree (ave. track length, charge,...)
 → ~5% missidentification seems feasible
- G. Karagiorgi's group: YOLO (CNN for object detection)
- M. H.L.S. Wang et al.: 2D CNN
- ...



Possible to derive information for pointing?
 overall flat angular distribution,
 BUT:

the two types of deexcitation of $^{40}\text{K}^*$ carry directional information

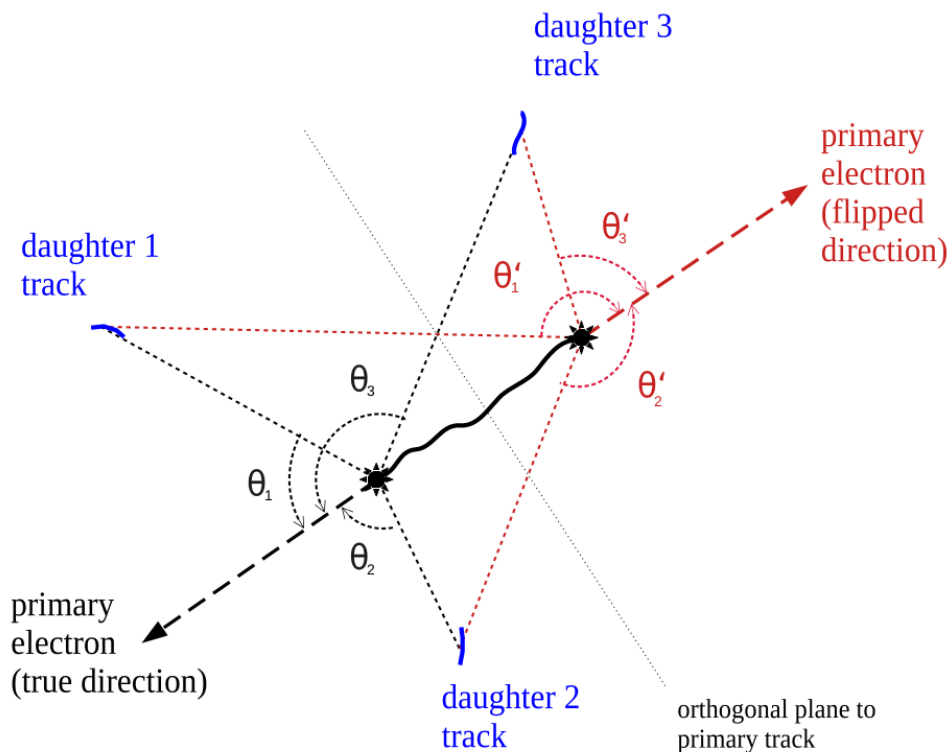


Directional head-tail disambiguation

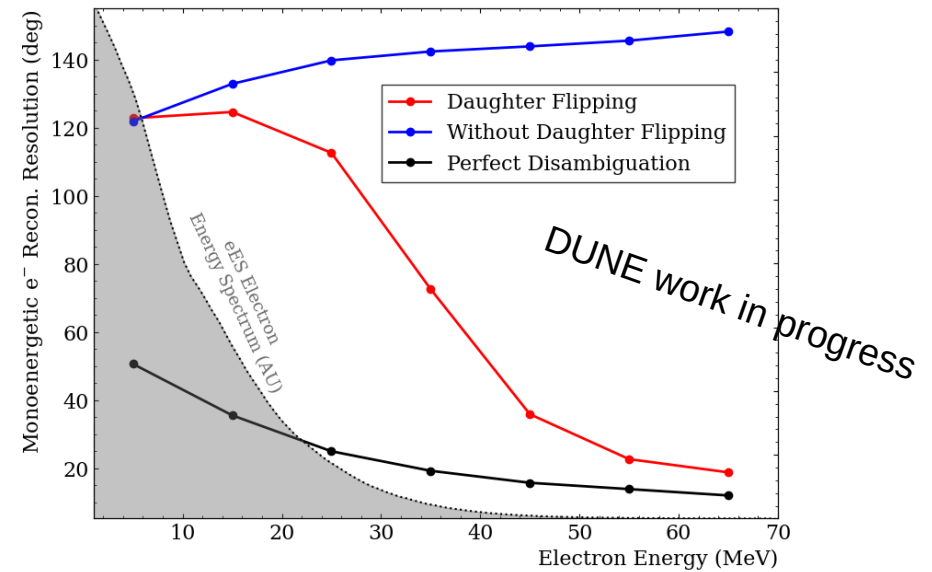
Daughter flipping:

mean $\cos(\theta_i) > \text{mean } \cos(\theta'_i)$

→ resolving head-tail direction disambiguities



Performance (from simulations):



test daughter flipping performance with Michel electrons (from cosmic muons) in **ICEBERG** (~1t LArTPC with Dune electronics)

→ study daughter flipping

with data in presence of noise

→ acquire test data set for ML applications

→ examine performance improvements with ML

poster by Joshua Queen

Low energy events

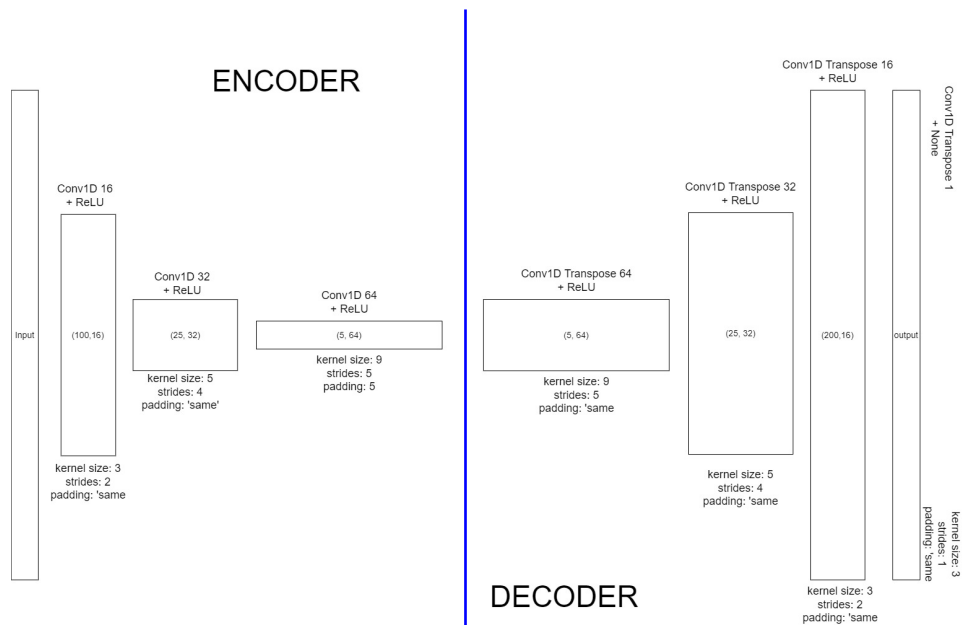
In cooperation with Michael H.L.S. Wang (Fermilab):

Extracting low energy signals from raw LArTPC waveforms using deep learning techniques — A proof of concept

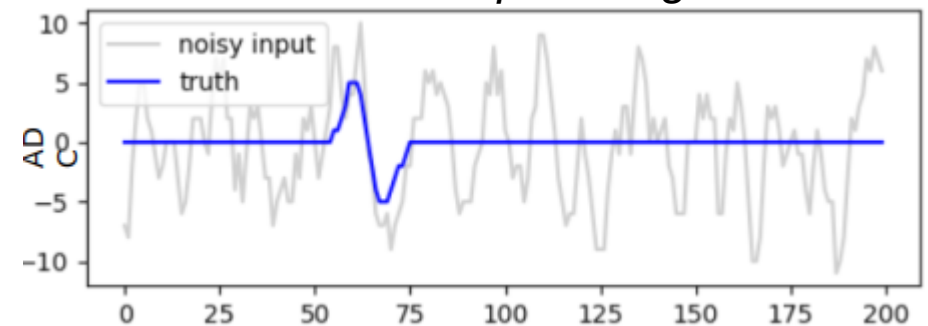
Lorenzo Uboldi (CERN), David Ruth (Unlisted, US, IL), Michael Andrews (Carnegie Mellon U.), Michael H.L.S. Wang (Fermilab), Hans Joachim Wenzel (Fermilab) et al. (2021)

Published in: *Nucl.Instrum.Meth.A* 1028 (2022) 166371 • e-Print: [2106.09911](https://arxiv.org/abs/2106.09911) [physics.ins-det]

→ 1D-CNN => next step auto encoder



induction plane signal



- improve LAr TPC detection efficiency at low energies (<1 MeV energy deposition)
- method to denoise input waveforms

poster by Van Tha Bik Lian

Summary and outlook

Multimessenger astronomy for supernova burst detection:

- Neutrino emission: high luminosity, fast, direct pointing back to source
→ detect all the neutrinos to provide direction for el-mag. detection systems
- SNEWS early warning system

DUNE: 4 x 10kt LArTPC

- detection of electron neutrinos
- 3D imaging reconstruction
- Offline pointing resolution without ML:
3.7 deg in 40kt (perfect channel tagging)
5.0 deg in 40kt (4% ν_e CC as eES)

→ online pointing code and ML

- “kaizen”: provide first result ~ 1 min, improve precision over time
- set up complete pipeline, upgrade with ML: channel tagging, directional reconstruction and daughter flipping, low energy events, combination to burst,...

