# Pointing to a supernova with the DUNE experiment

Janina Hakenmüller for the DUNE collaboration, Duke University, Durham, NC

## Multimessenger astronomy and DUNE experiment

**Supernova bursts:**

- unique opportunity to derive astrophysical and particle physics insights → detect all available signals
- over 99% of energy released in form of neutrinos
- time frame of burst:
  - neutrinos: ~$10^{-2}$ to ~10s
  - electromagnetic: first signals after a few hours

=> neutrinos as early warning of bursts

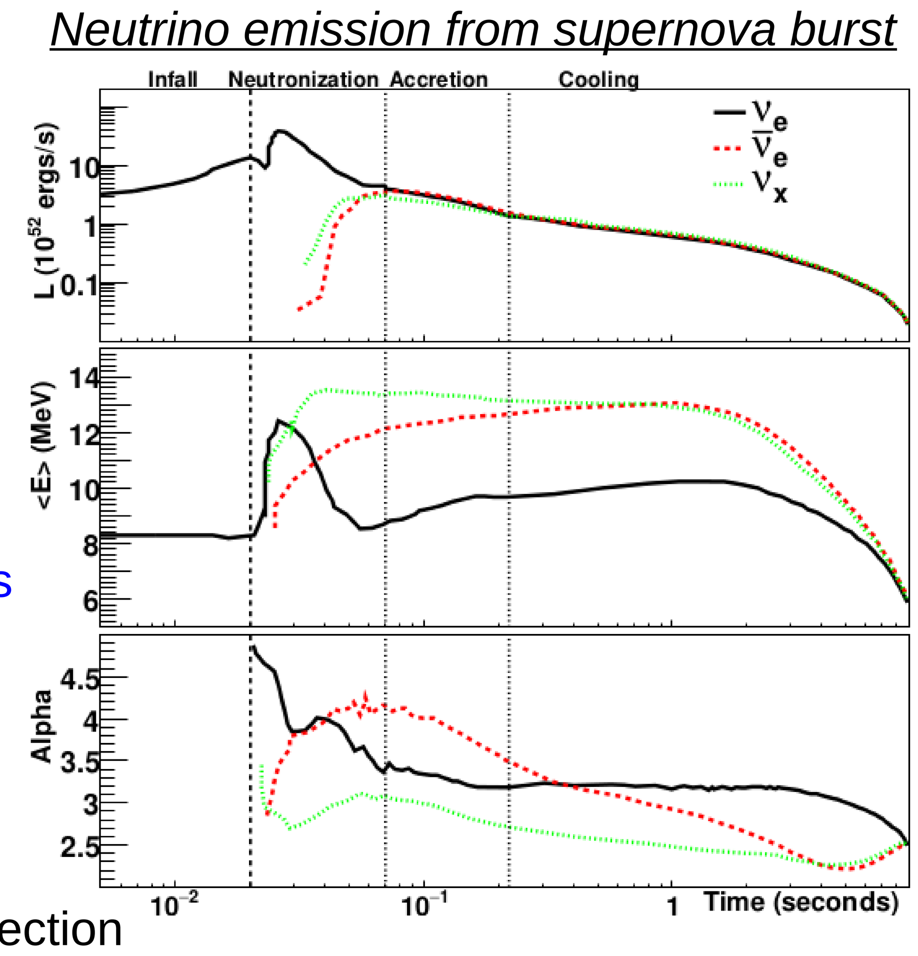
- Neutrinos only interact very weak

=> direct pointing back to source

→ **multimessenger astronomy** (alerts with SNEWS: SuperNova early warning system [2])

Need: fast and directional neutrino detection

*Neutrino emission from supernova burst* [1]




*DUNE experimental setup*

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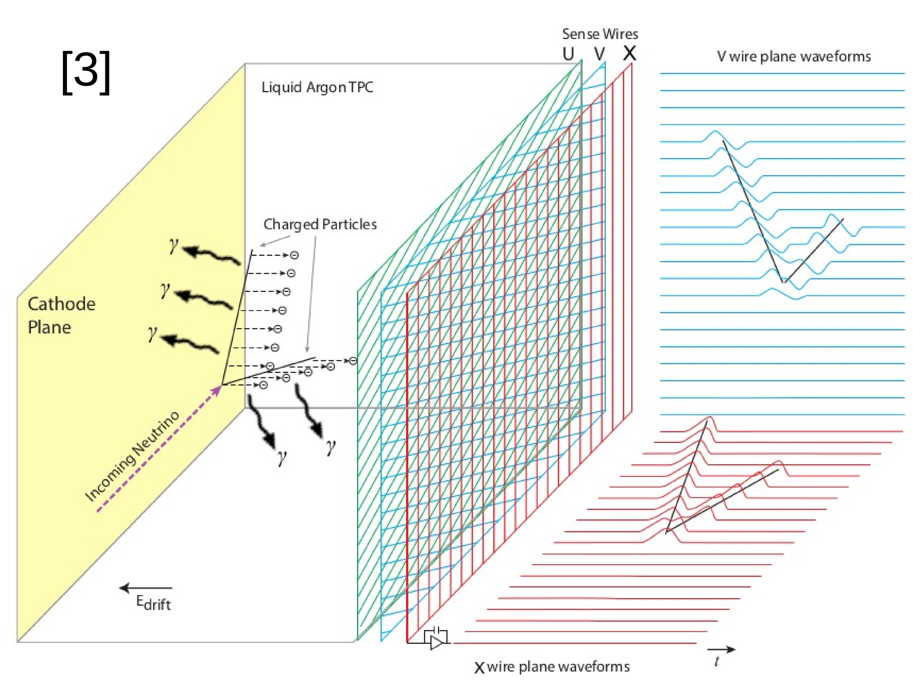
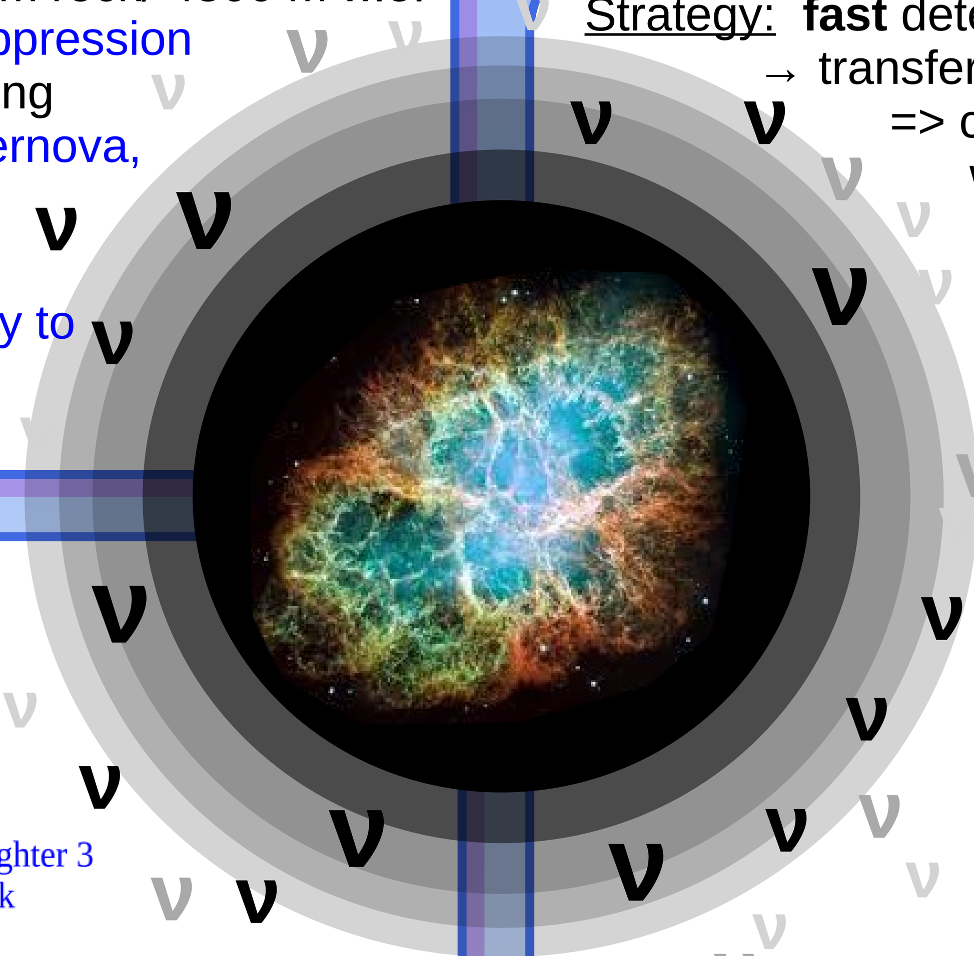



liquid argon time-projection chambers: **ionization** and scintillation light totally active calorimeter

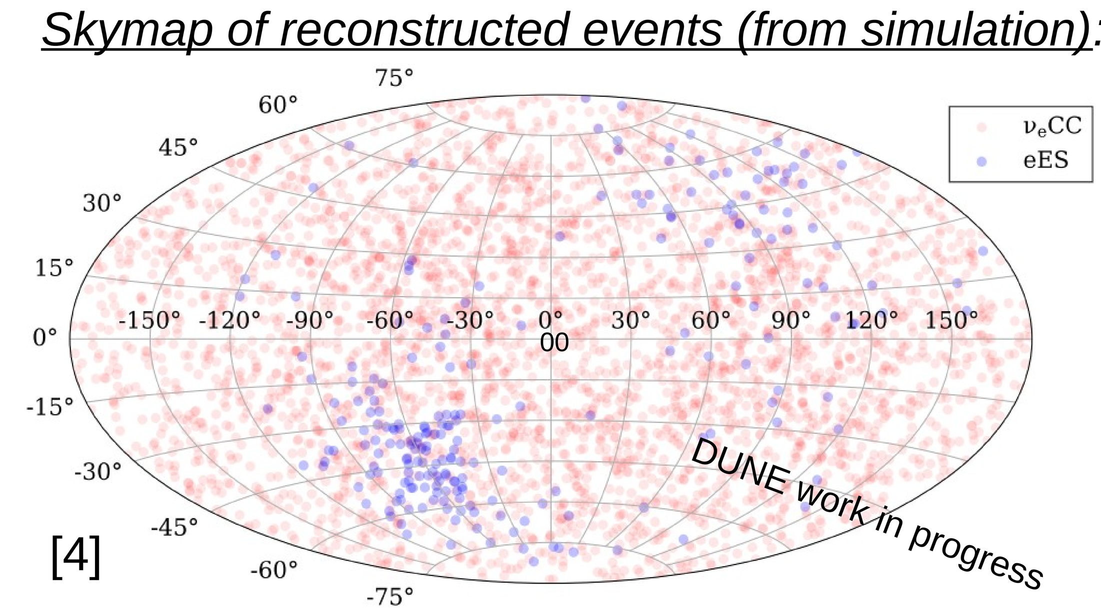
**Highlights:**

- large mass: 4 x 10kt far detector → high statistics
- underground: 1.5km rock/ 4300 m w.e. → background suppression
- excellent 3D imaging → pointing to supernova, multimessenger
- $\nu_e$ detection → complementarity to other experiments



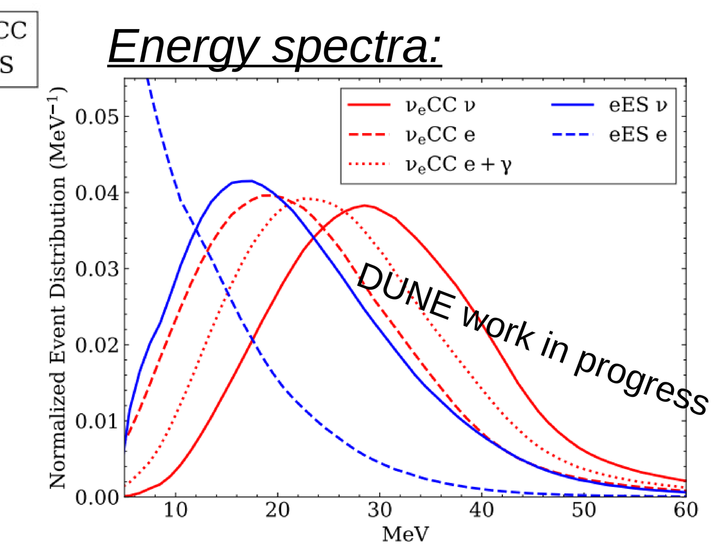
## Supernova neutrino detection with DUNE

*Skymap of reconstructed events (from simulation):*




[4]

*Energy spectra:*




**Dominant detection channels in liquid argon:**

Charge current interaction **$\nu_e$CC**: $\nu_e + {}^{40}\mathrm{Ar} \rightarrow e^- + {}^{40}\mathrm{K}^*$

~3000* events for supernova burst at @10kPc

→ overall flat angular distribution

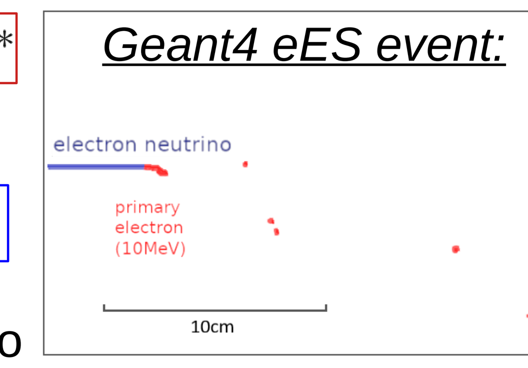
Elastic electron scattering **eES**: $\nu_e + e^- \rightarrow \nu_e + e^-$

~300* events for supernova burst at @10kPc

→ direction scattered eletron related to incoming neutrino

(*event numbers determined with GKVM model in SNOwGLoBES)

*Geant4 eES event:*




→ **Challenges:** directional disambiguation
differentiation of event types (channel tagging)

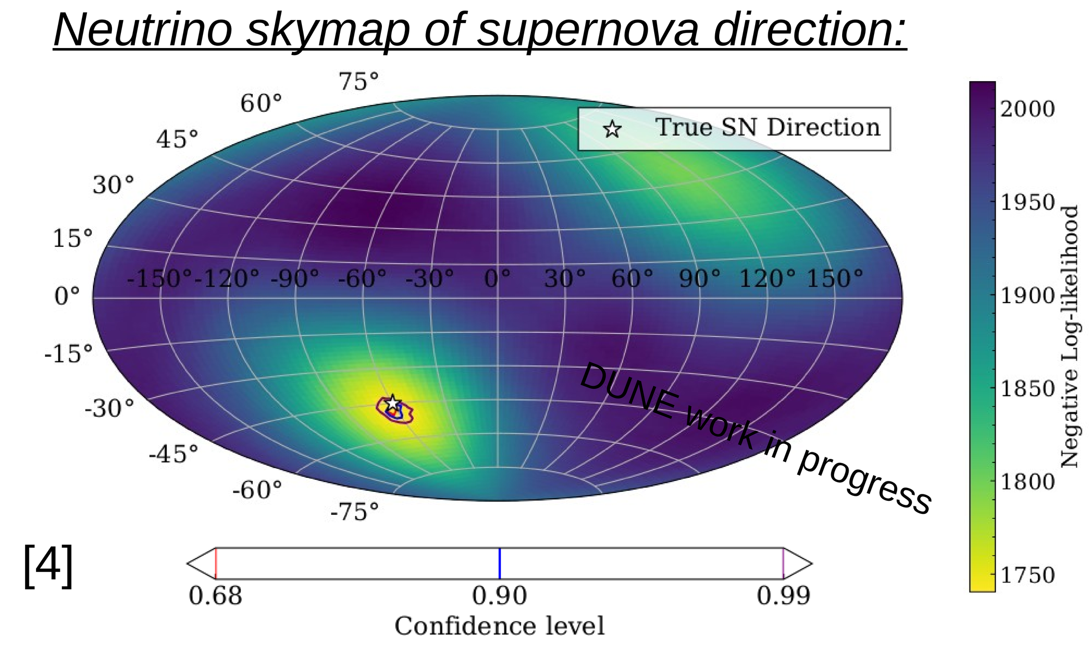
## Machine learning and online pointing code

Strategy: **fast** determination of direction O(1min), **increased precision** over time

→ transfer code to standalone code outside of DUNE LArSoft framework

=> complete workflow to test machine learning upgrades within this insitu computing setup

*Neutrino skymap of supernova direction:*

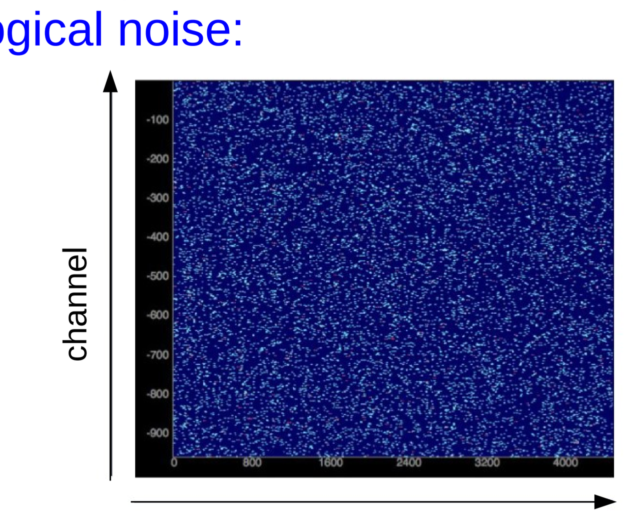



[4]

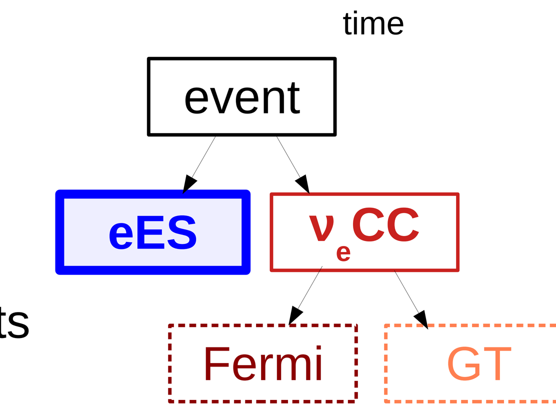
→ desired output for **multimessenger astronomy**

### Machine Learning approaches

- hit finding in noise (charges on wires)
  →e.g. 1D-CNN to extract low energetic signals from raw waveforms
  see M. H.L.S. Wang et al., NIM A 1028 /20022) 166371, poster by Van Tha Bik Lian on auto encoder
- combination of hits to tracks:
  3D pattern reconstruction, track reconstruction at low energies
  head tail disambiguity → studies with ICEBERG, poster by Joshua Queen
- real time event selection above background/radiological noise:
  start at raw image input 480 x 64 (wire x time)
  → first ever exploration of employing 2D-CNNs on FPGAs for DUNE:
  Jwa, Yeon-jae, Giuseppe Di Guglielmo, Lukas Arnold, Luca Carloni, and Georgia Karagiorgi. "Real-time Inference with 2D Convolutional Neural Networks on Field Programmable Gate Arrays for High-rate Particle Imaging Detectors." Frontiers in AI 5 (2022): 855184.




- Event classification (channel tagging):
  e.g. application of YOLO (you-only-look-once) by Georgia Karagiorgi and Judicael S.E. Clair for DUNE
- combination of events to bursts:
  find minimal required amount of information for an acceptable precision
  → focus on fast extraction of these information
  use classifiers from supervised learning for hints




➡ implementation of final code in FPGA to be deployed underground, hls4ml tools („high level synthesis for machine learning“)

## Evaluation of pointing resolution

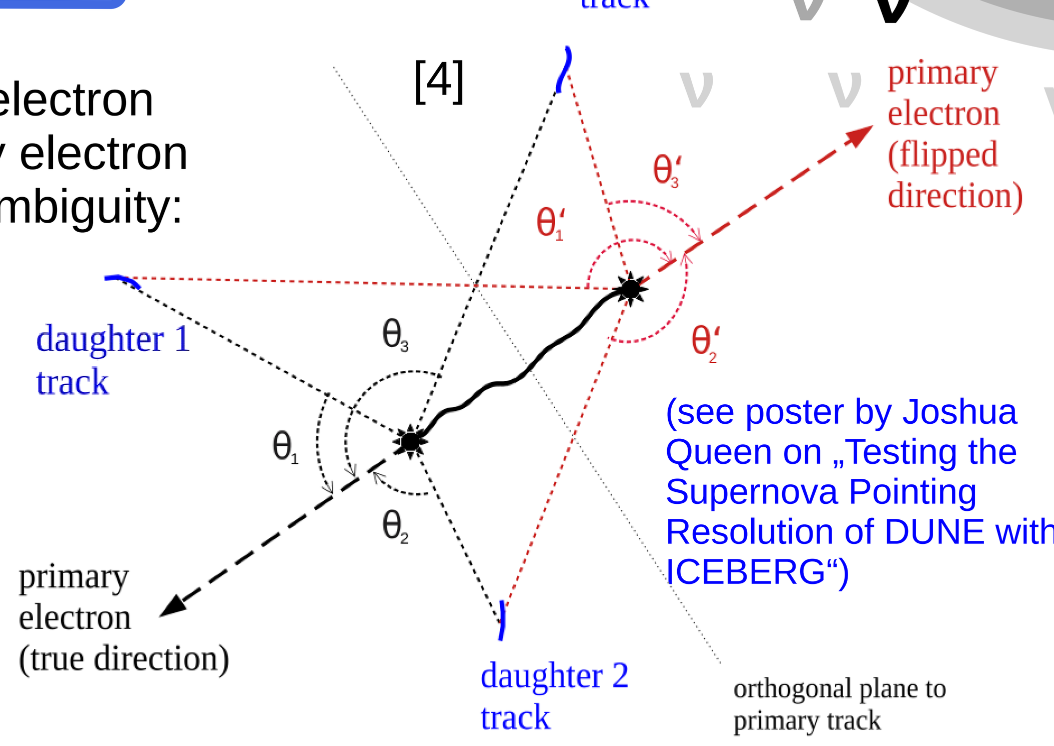
### simulation

of neutrino-induced events, background and noise with Geant4 and Marley wtihin DUNE LArSoft framework

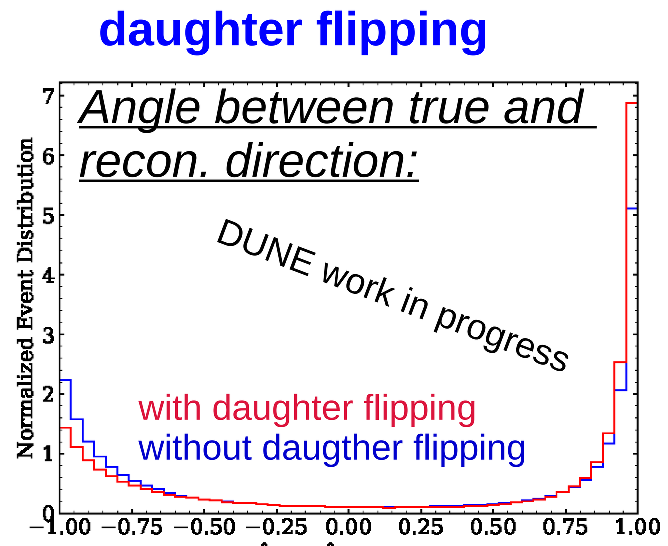
### reconstruction

- identify supernova events
- determine energy of primary electron
- determine direction of primary electron
  → resolution of head-tail disambiguity: **daughter flipping**

[4]




(see poster by Joshua Queen on „Testing the Supernova Pointing Resolution of DUNE with ICEBERG“)



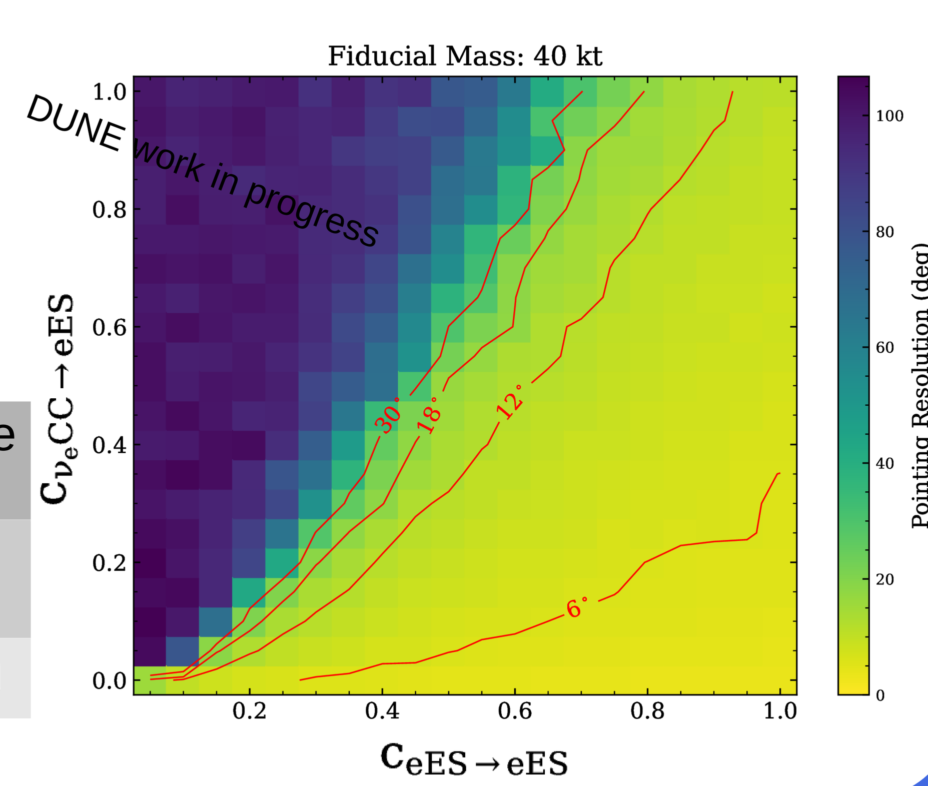

### combination of events to burst

maximum likelihood estimation of burst direction

→ make assumption on ratio of missreconstructed events

| LAr volume | 40kt | 10kt (one module) |
|---|---|---|
| perfect disambiguation | 3.7 deg | 7.4 deg |
| 4% $\nu_e$CC as eES | 5.0 deg | 10.6 deg |

→ publication in preparation [4]




**Literature:**
Figure Crab Nebula: NASA, STScI
Figure DUNE facitlities: https://www.dunescience.org/
[1] DUNE collaboration, Eur. Phys. J. C (2021) 81: 423
[2] Al Kharusi, S., et al., New J Phys 23.3 (2021): 031201.
[3] DUNE collaboration TDR, Journal of instrumentation 15.08 (2020): T08008
[4] DUNE internal document docdb #27538 (publication in preparation)

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