Low Energy Physics Program of DUNE

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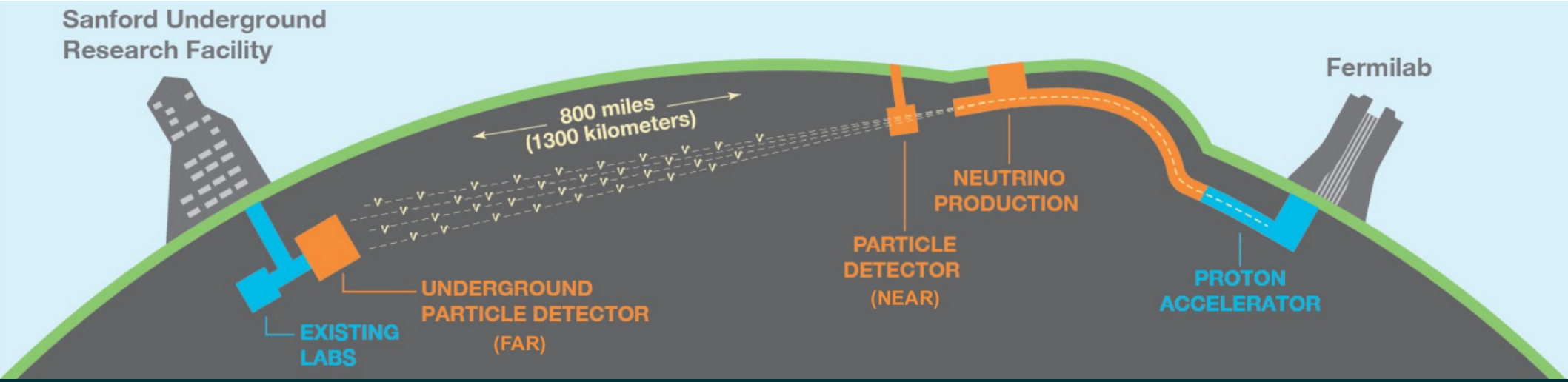
University of Sussex

Seattle Snowmass Summer Meeting 2022
Neutrino Physics Frontier: New Opportunities in Neutrinos

24/JUL/2022

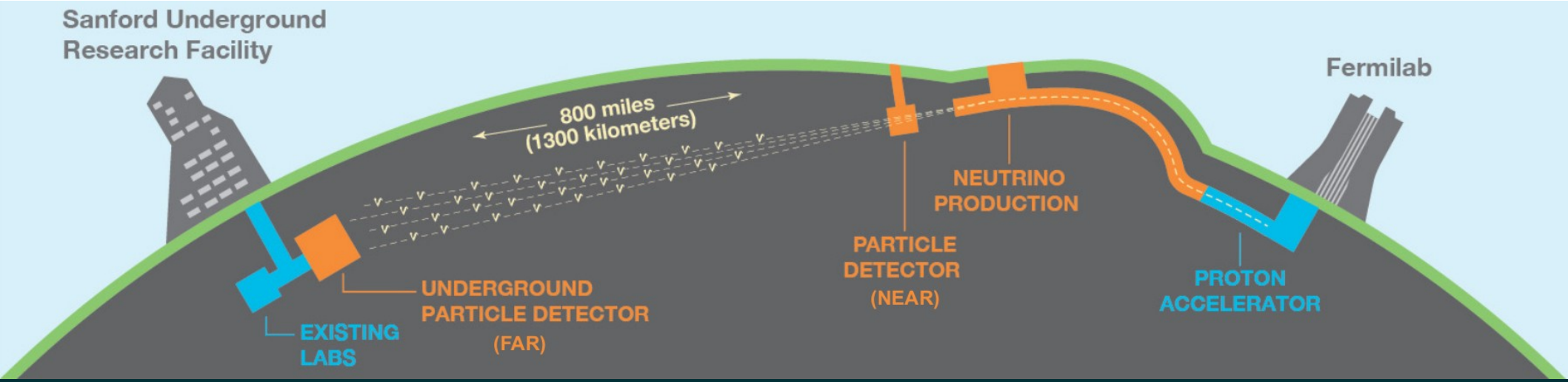
Deep Underground Neutrino Experiment

- Next generation flagship neutrino experiment
  - High intensity neutrino beam
  - Long baseline, with on-axis detector
  - Multiple complementary near detectors

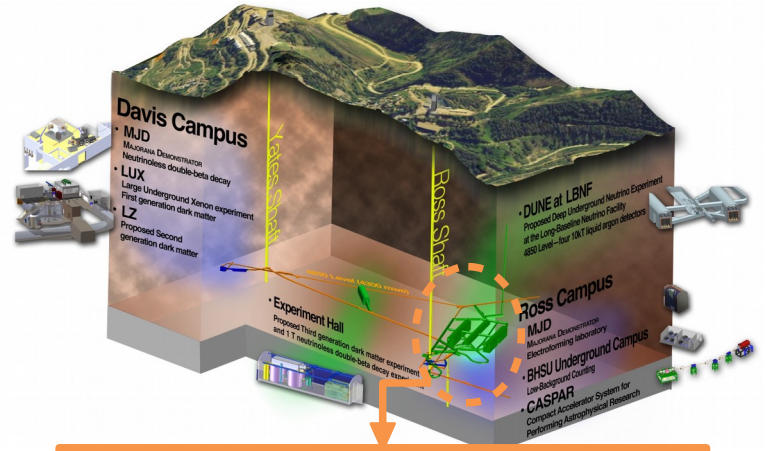


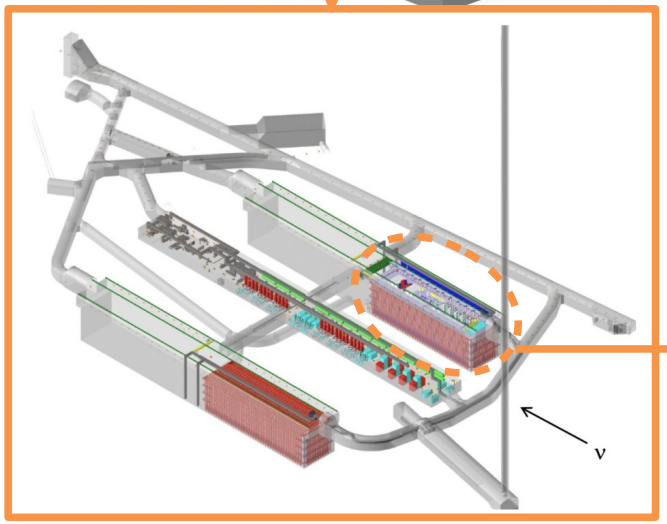
Deep Underground Neutrino Experiment

- Next generation flagship neutrino experiment
  - High intensity neutrino beam
  - Long baseline, with on-axis detector
  - Multiple complementary near detectors
- Aims at fundamental questions:
  - Neutrino oscillations
  - Nucleon decay
  - Core collapse supernova



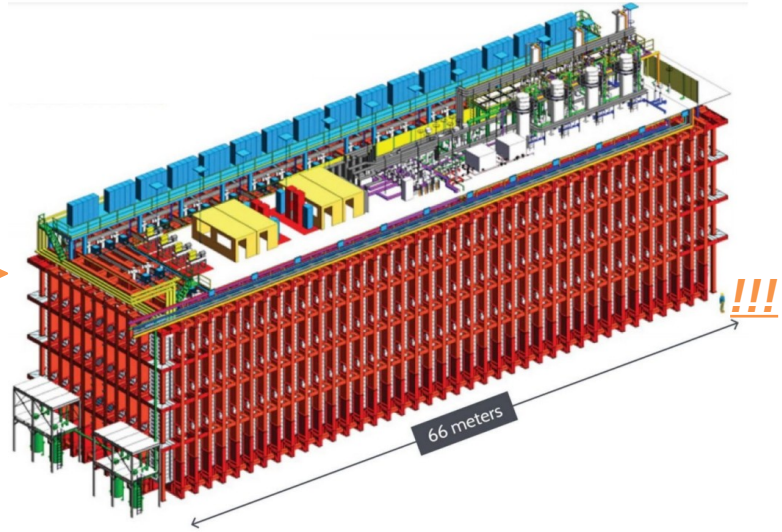
DUNE Far Detectors



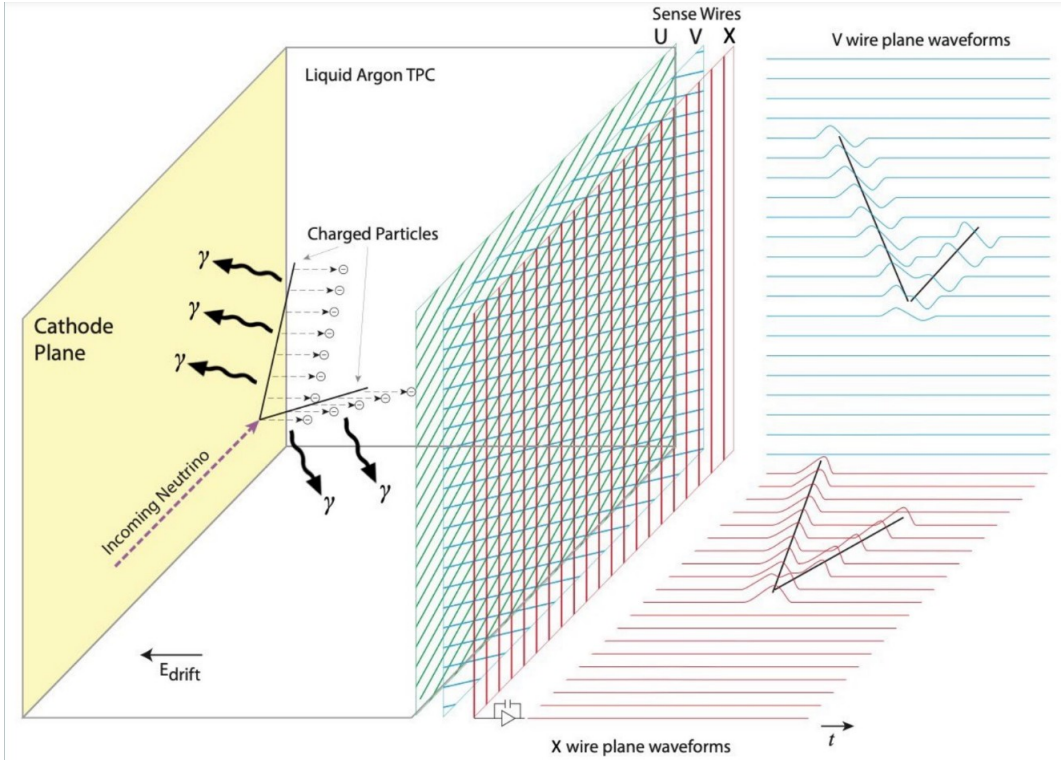


- Four modules (17 kt each)
  - Module 1, 2 & 3: Liquid Argon TPC
  - Module 4: Opportunity Module!

- DUNE Phase I:
  - Module 1: 3.6 m horizontal drift (wires anode) + light detectors
  - Module 2: 6.5 m vertical drift (PCB anode) + light detectors



Liquid Argon TPCs



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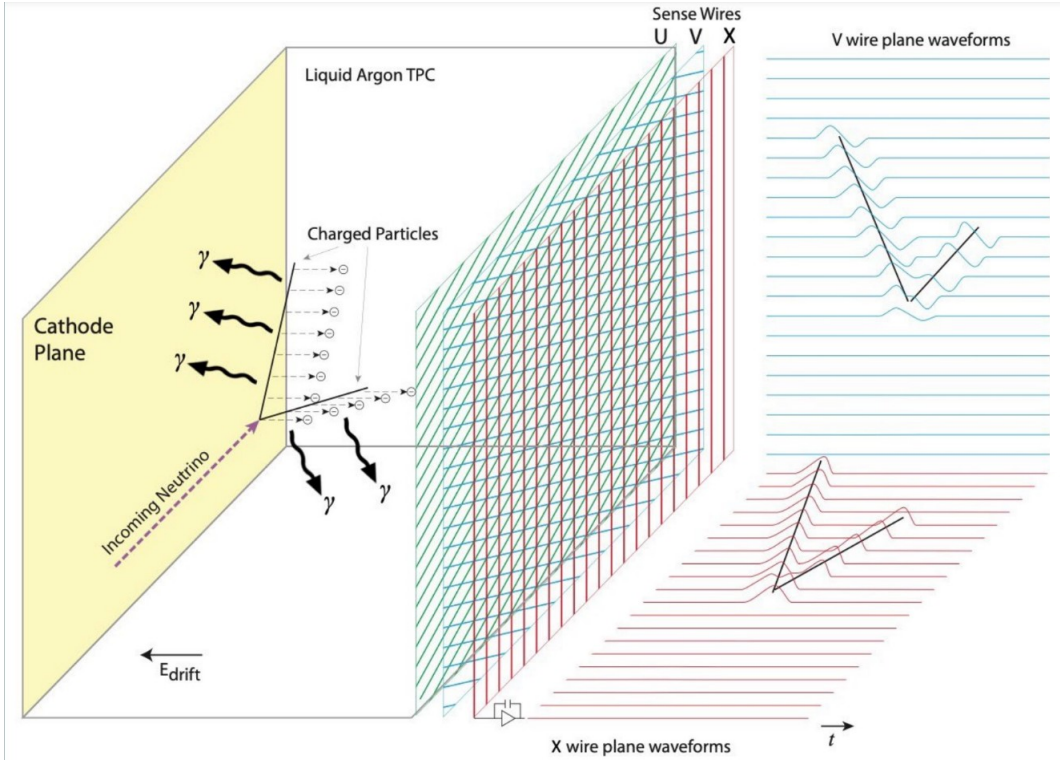
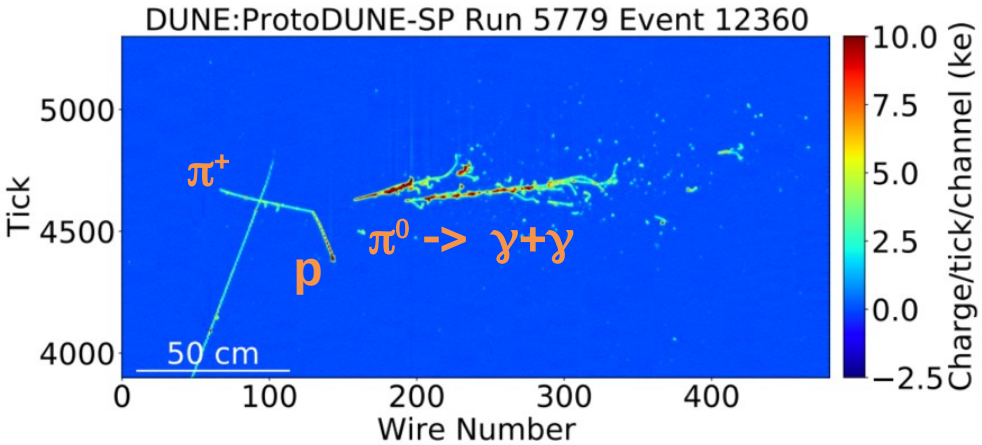
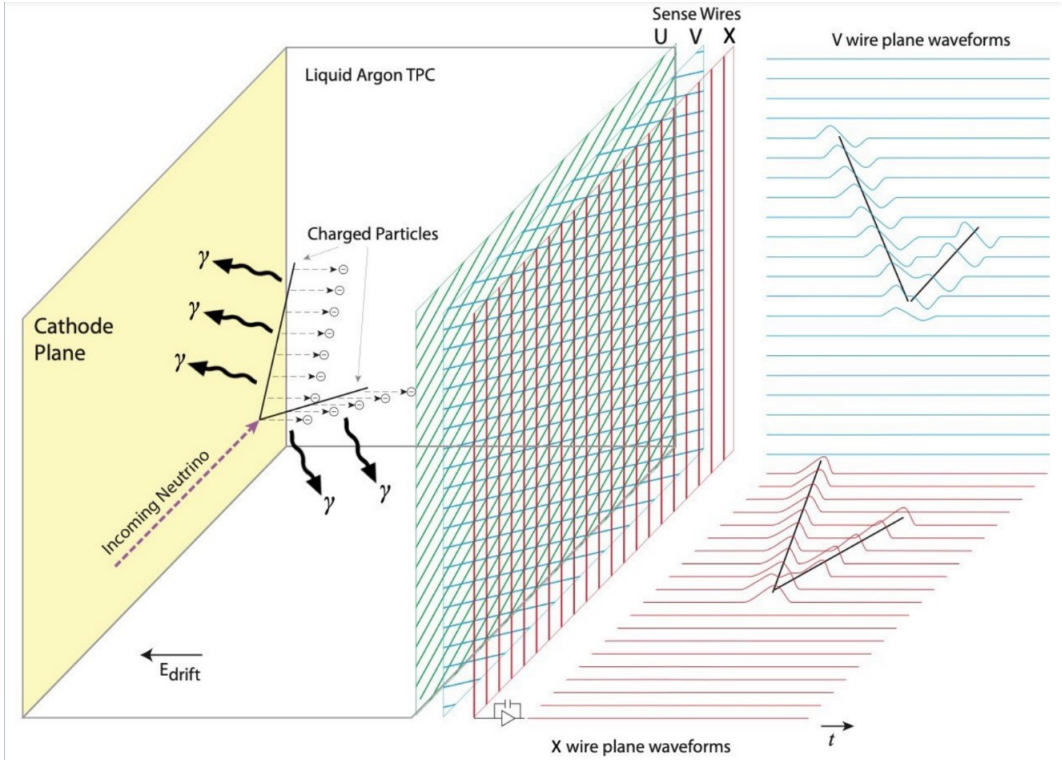
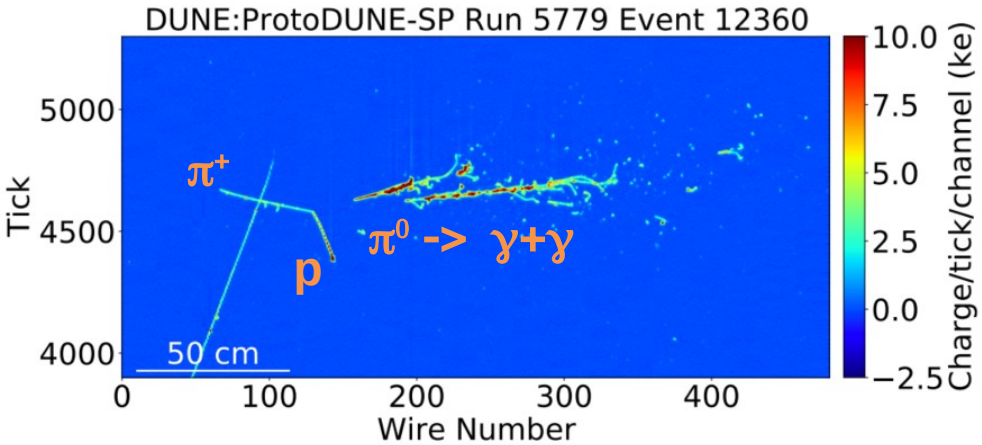




- Excellent 3D imaging
  - few mm scale over large volume detector

Liquid Argon TPCs





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- Excellent energy measurement capability
  - totally active calorimeter

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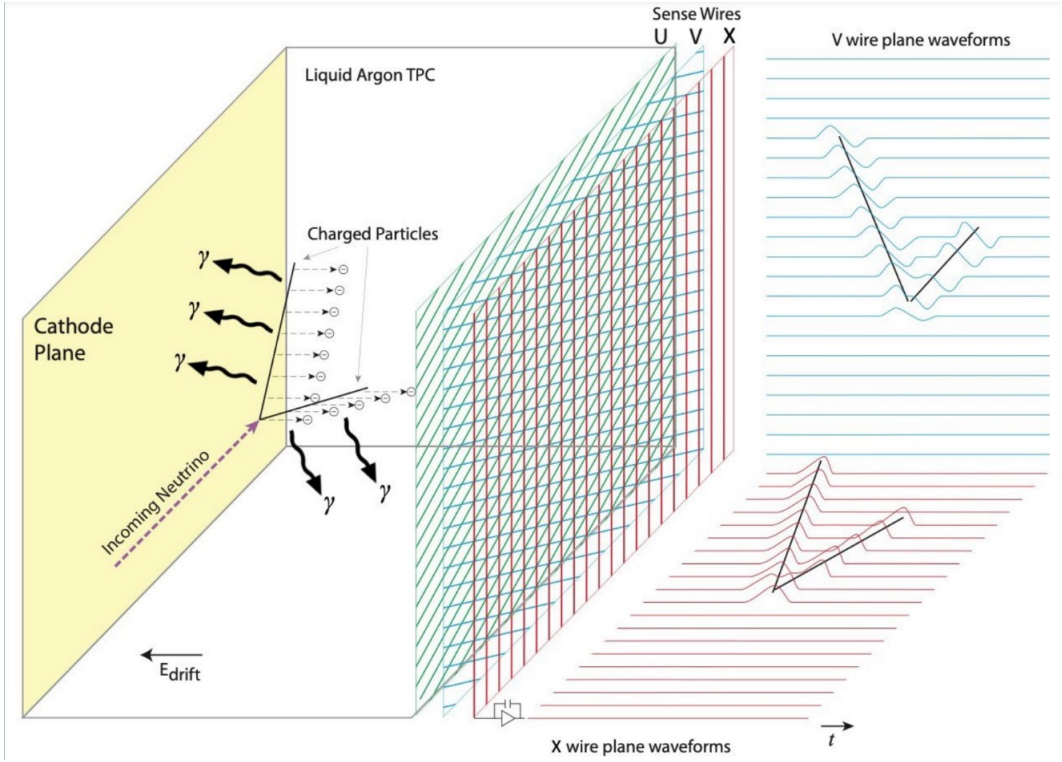
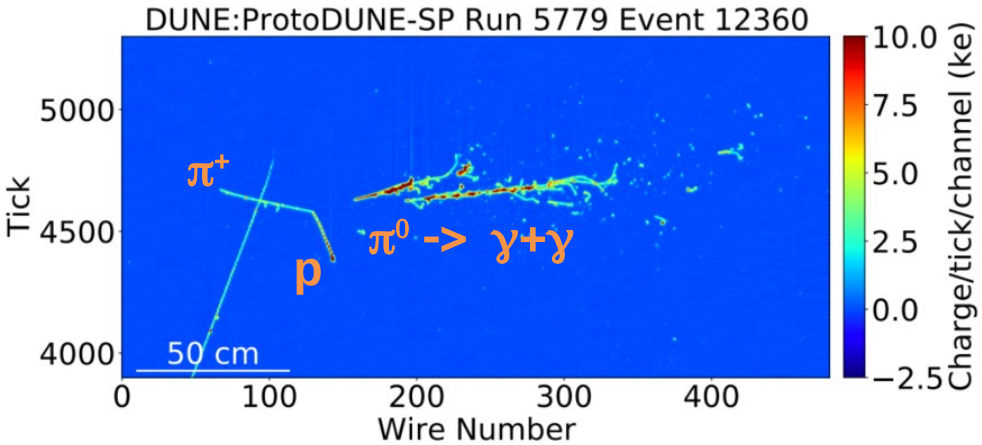
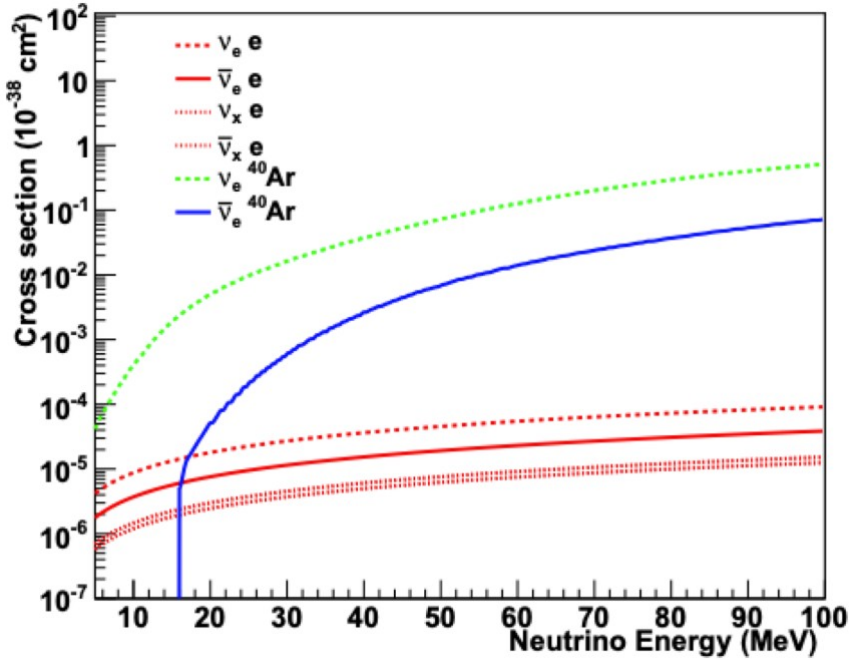




- Excellent 3D imaging
  - few mm scale over large volume detector
- Excellent energy measurement capability
  - totally active calorimeter
- Powerful particle ID
  - dE/dx, range, event topology

Low Energy interactions in LAr

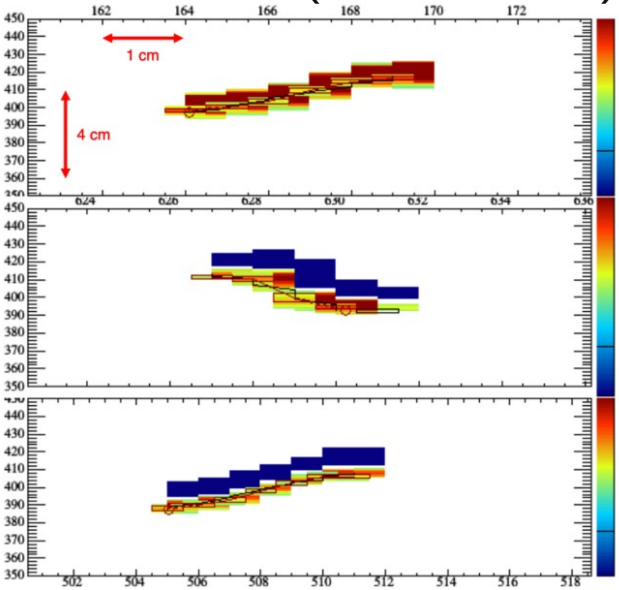
- DUNE FDs are sensitive to Solar and core-collapse supernovae (5 < E < 50 MeV)
- Charged-current (CC) interactions on Ar
  - $\nu_e + {}^{40}Ar \rightarrow {}^{40}K^* + e^-$ (dominant)
  - $\bar{\nu}_e + {}^{40}Ar \rightarrow {}^{40}Cl^* + e^+$
- Elastic scattering on electron
  - $\nu_x + e^- \rightarrow \nu_x + e^-$
- Neutral current (NC) interactions on Ar
  - $\nu_x + {}^{40}Ar \rightarrow \nu_x + {}^{40}Ar^*$



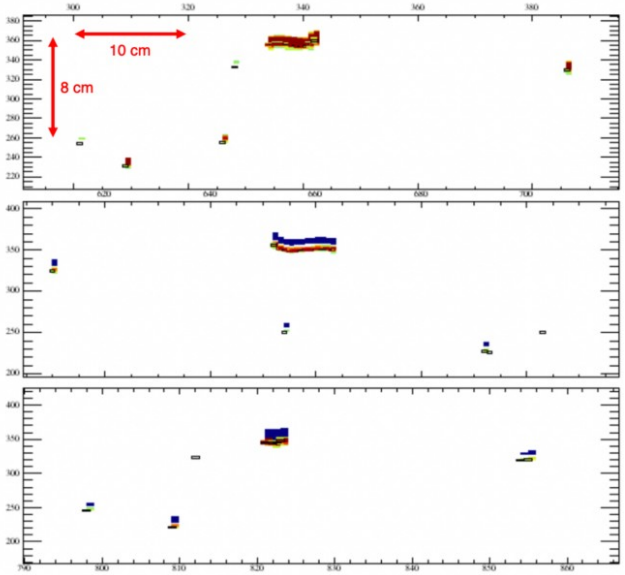
- Possible to discriminate interaction by classification of photons from K, Cl or Ar deexcitation (CC and NC) or by the absence of photons (ES)

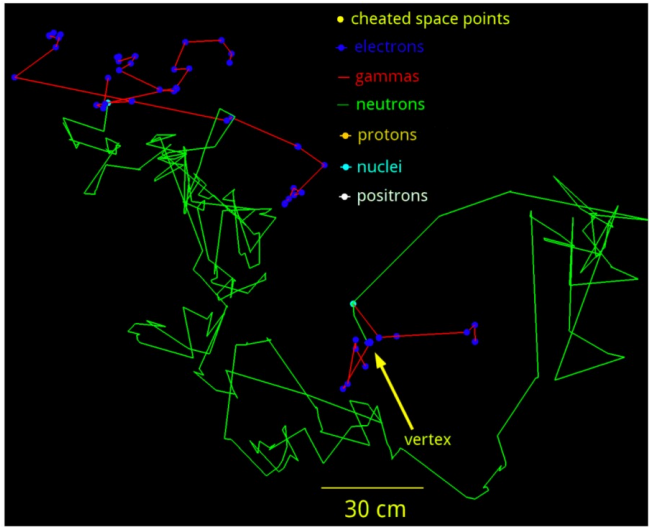
Low Energy Reconstruction

ν-e⁻ ES event (10.25 MeV e⁻)



ν_e CC event (20.25 MeV ν_e)





Core-Collapse Supernova

Fermilab animation

- Huge source of neutrinos of all flavours
  - ~ 10 sec burst
  - 1~3 per century in our galaxy

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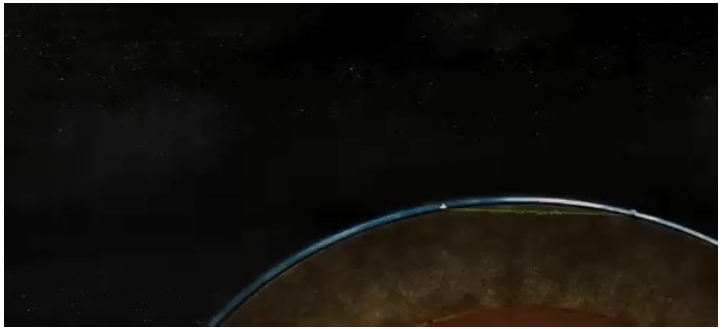

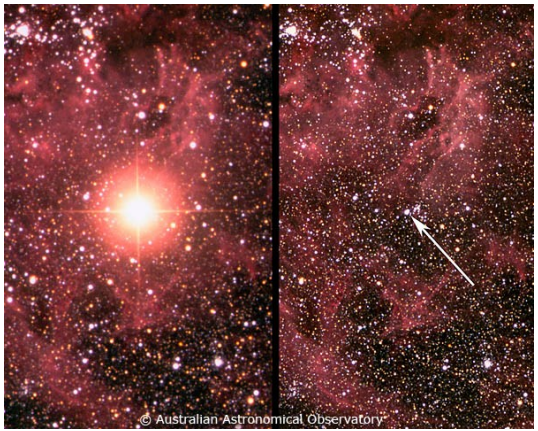

- SN1987A
  - Kamiokande
  - IMB
  - Baksan

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    - Collapse mechanism
    - Time evolution
    - Black hole formation

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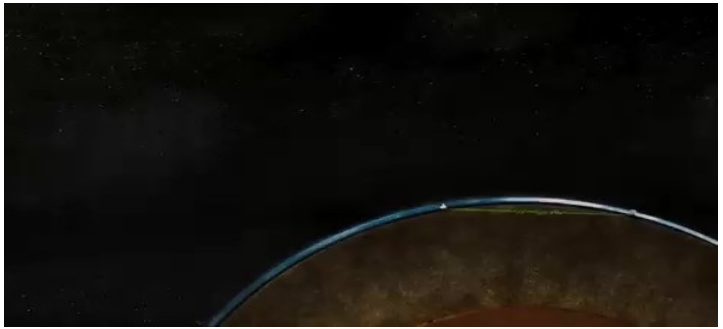

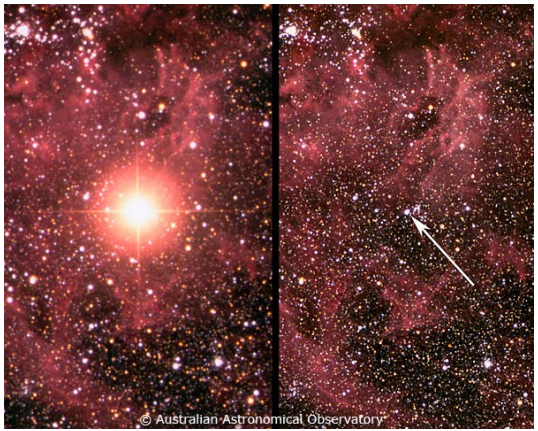

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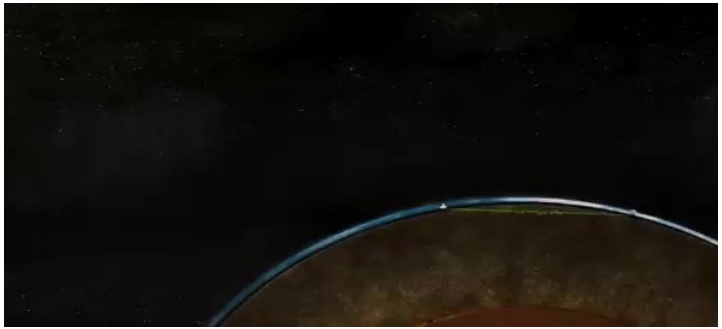
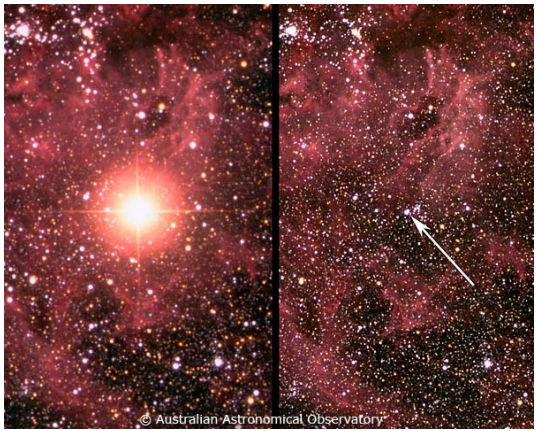
  - Neutrino physics
    - Oscillation
    - Absolute mass

Fermilab animation





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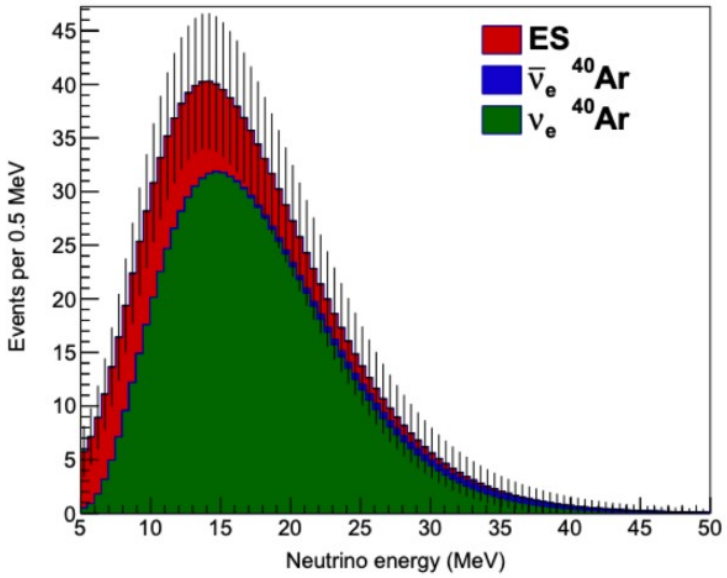
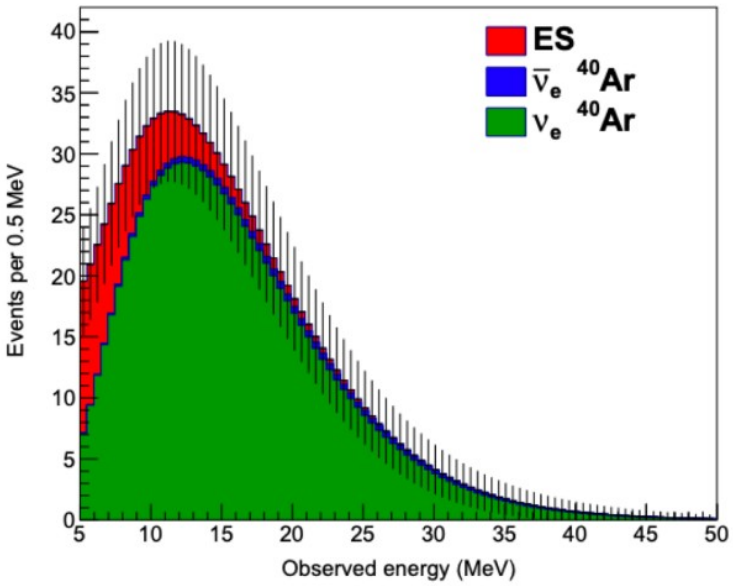
Expected signal in DUNE





Channel	Garching
$\nu_e + ^{40}\text{Ar} \rightarrow e^- + ^{40}\text{K}^*$	882
$\bar{\nu}_e + ^{40}\text{Ar} \rightarrow e^+ + ^{40}\text{Cl}^*$	23
$\nu_X + e^- \rightarrow \nu_X + e^-$	142
Total	1047

- 40 kt LAr
- 10 kpc SN

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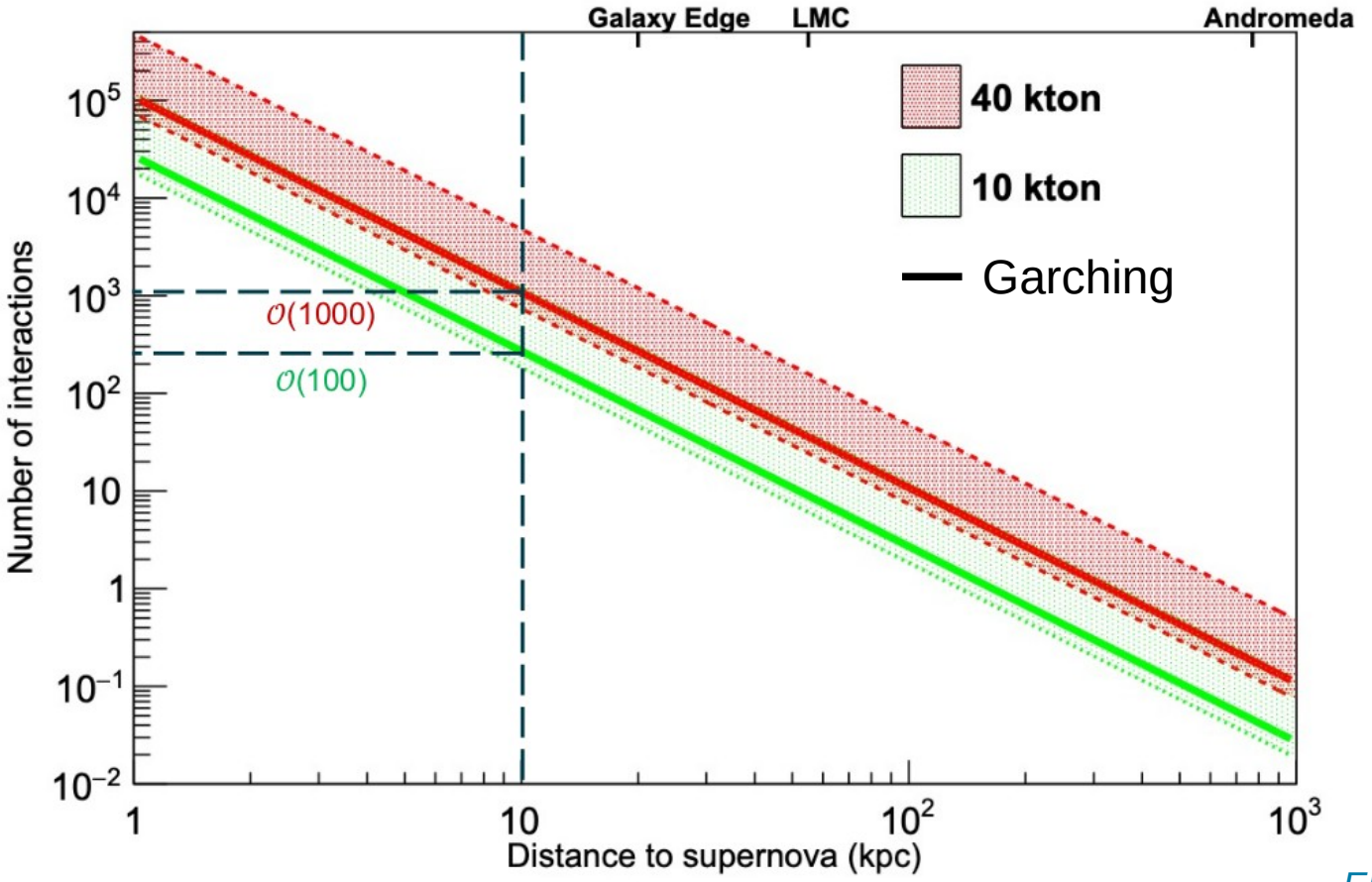

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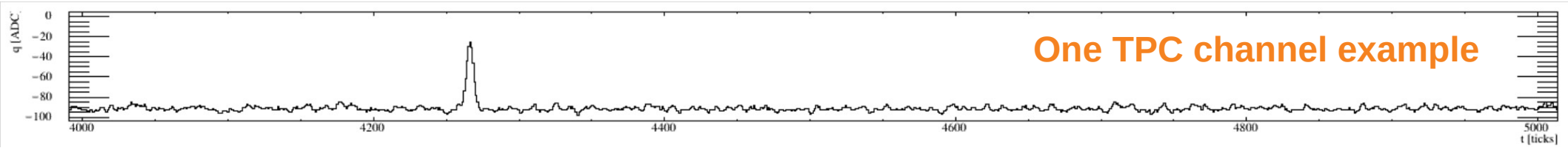
Supernova ν Burst Triggering

- Online monitoring of raw waveforms



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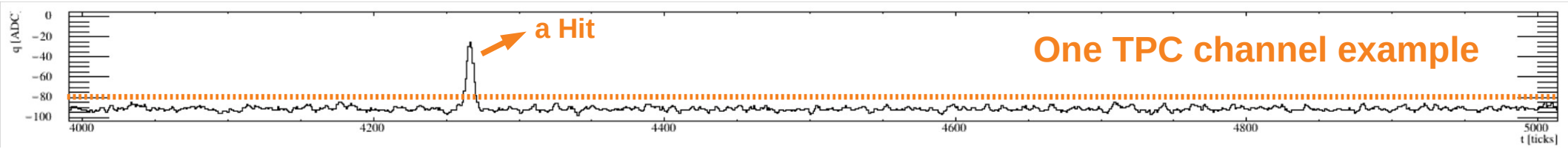

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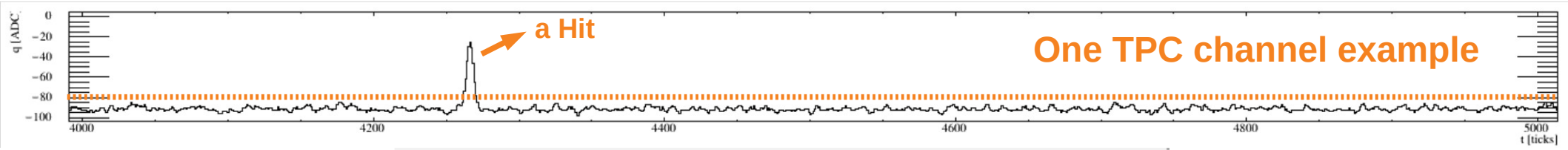
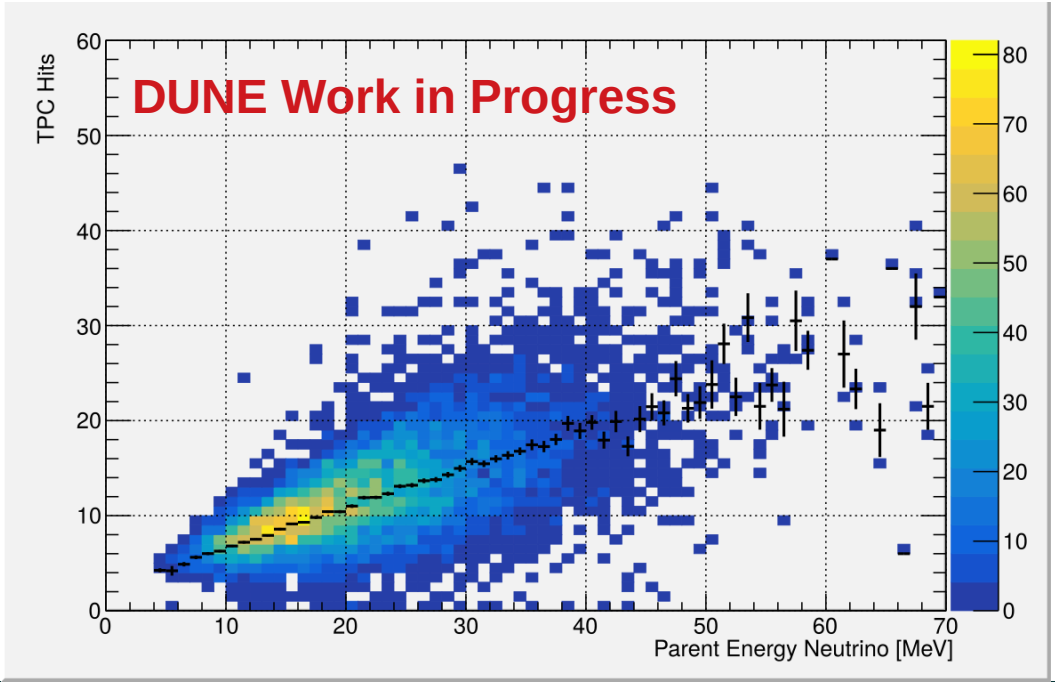
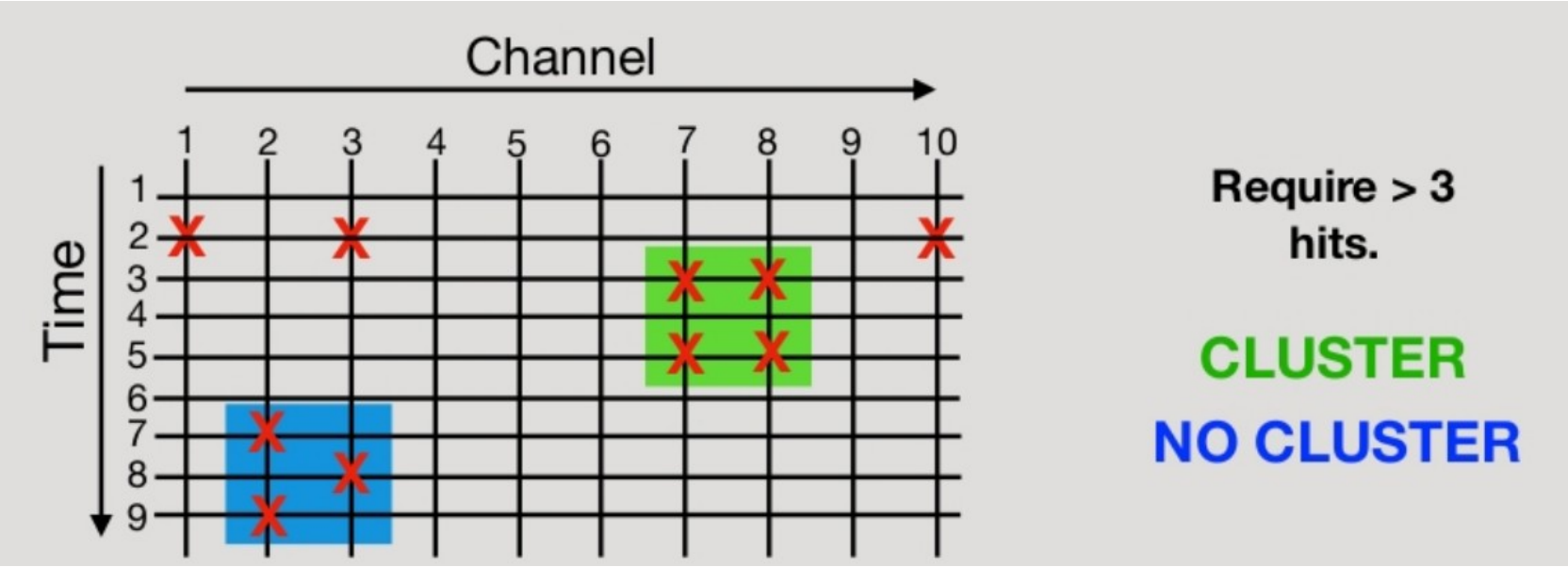




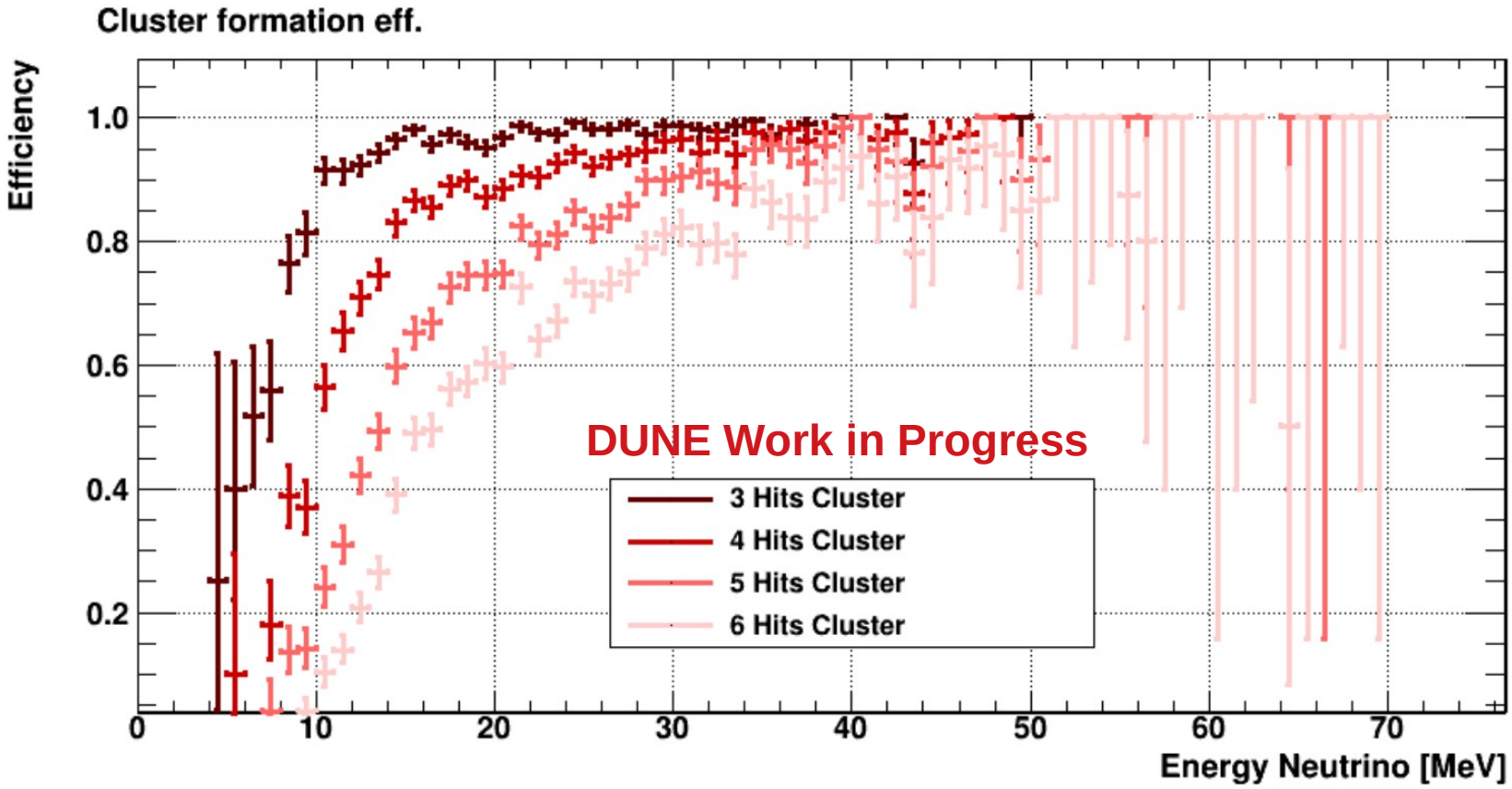
Supernova ν Burst Triggering

- Hits clustering



Supernova ν Burst Triggering

- Hits clustering → Selection efficiency



Radiologicals

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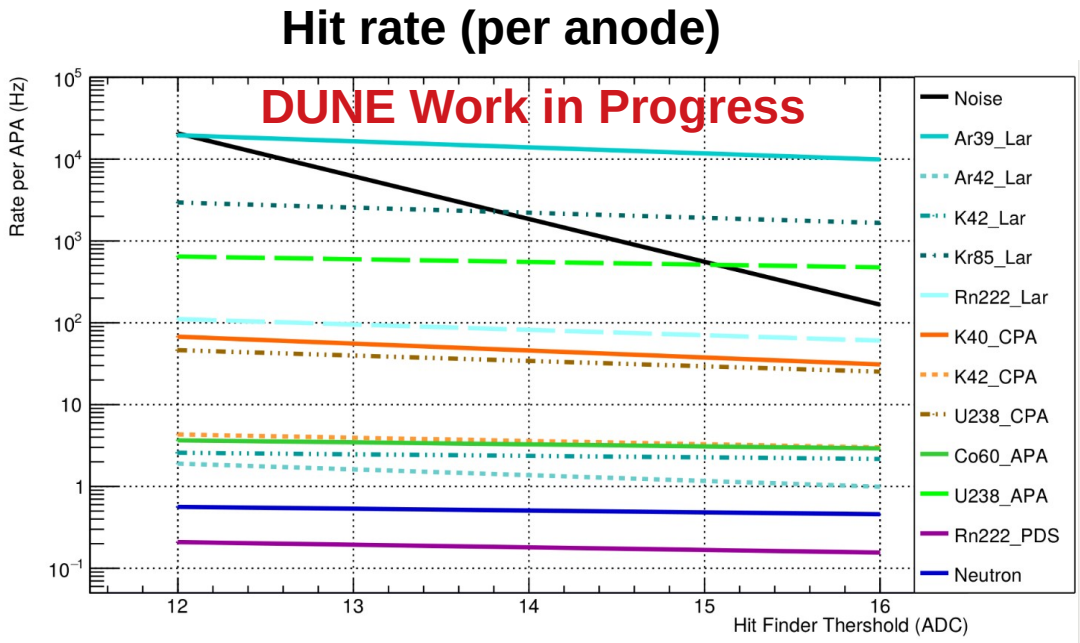

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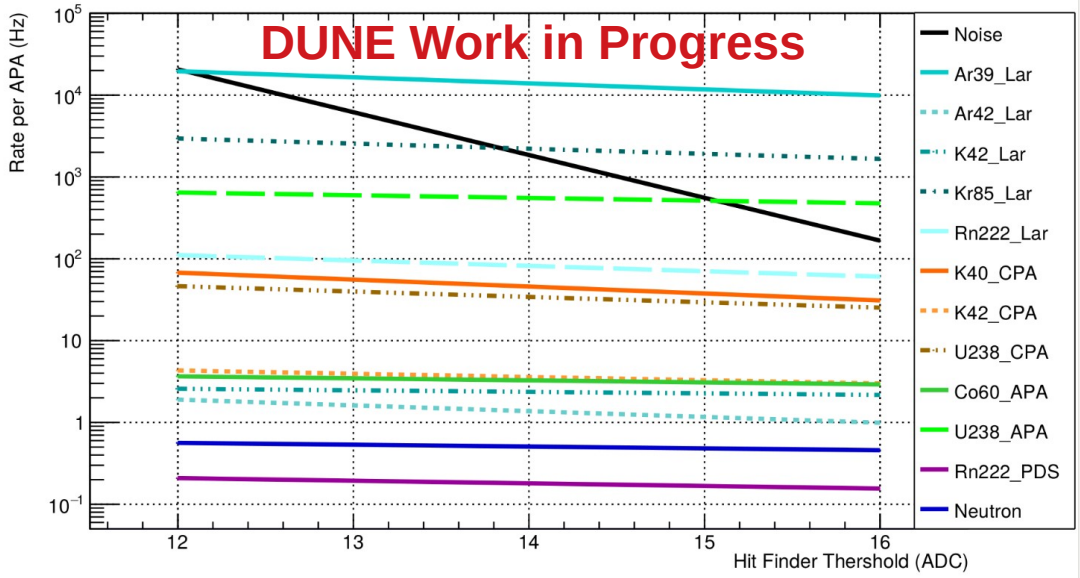
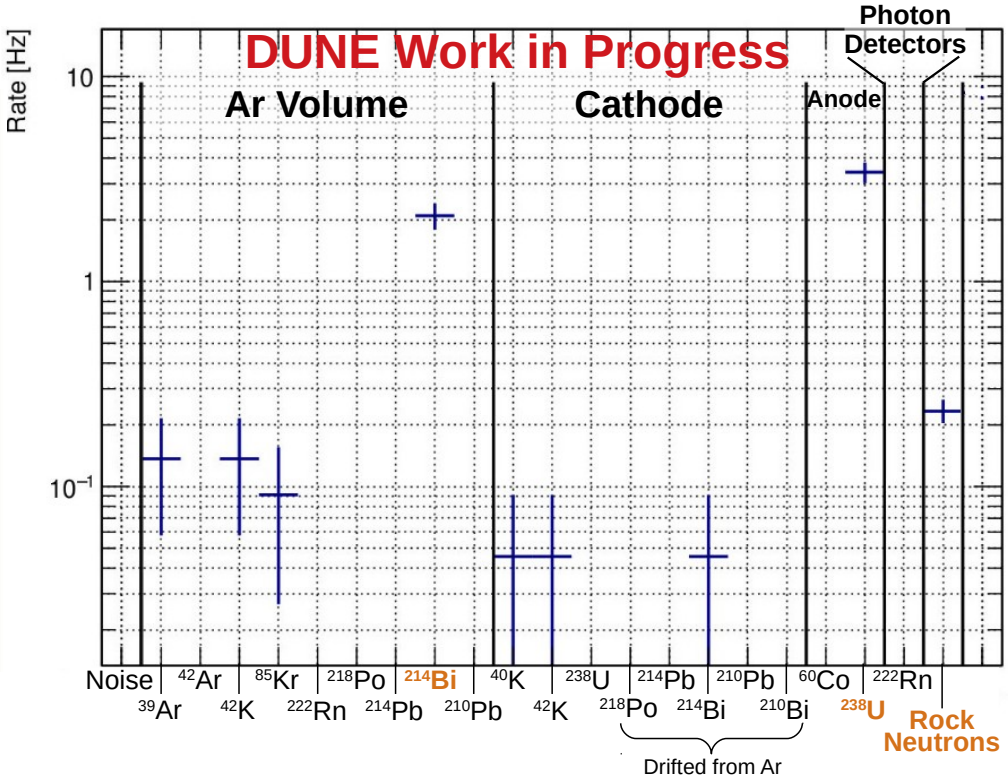
Hit rate (per anode)

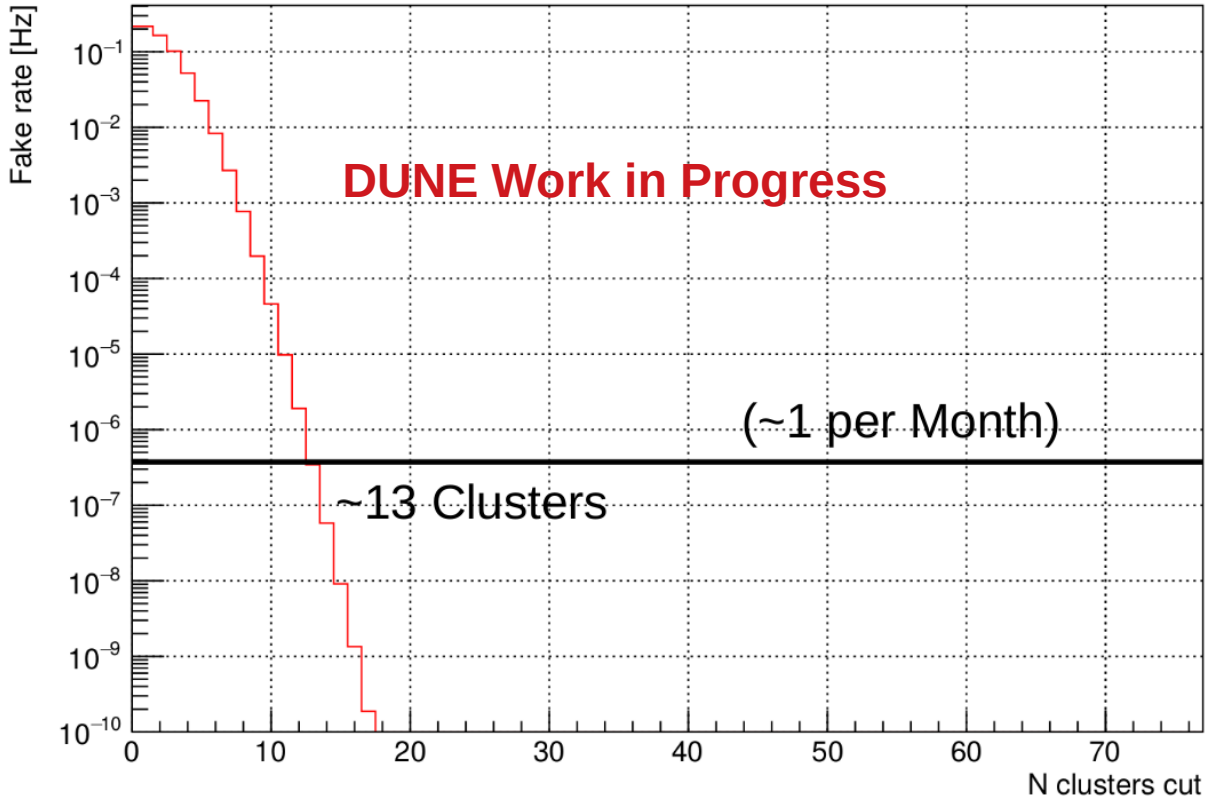


4 hits-cluster rate (per 10 kt)



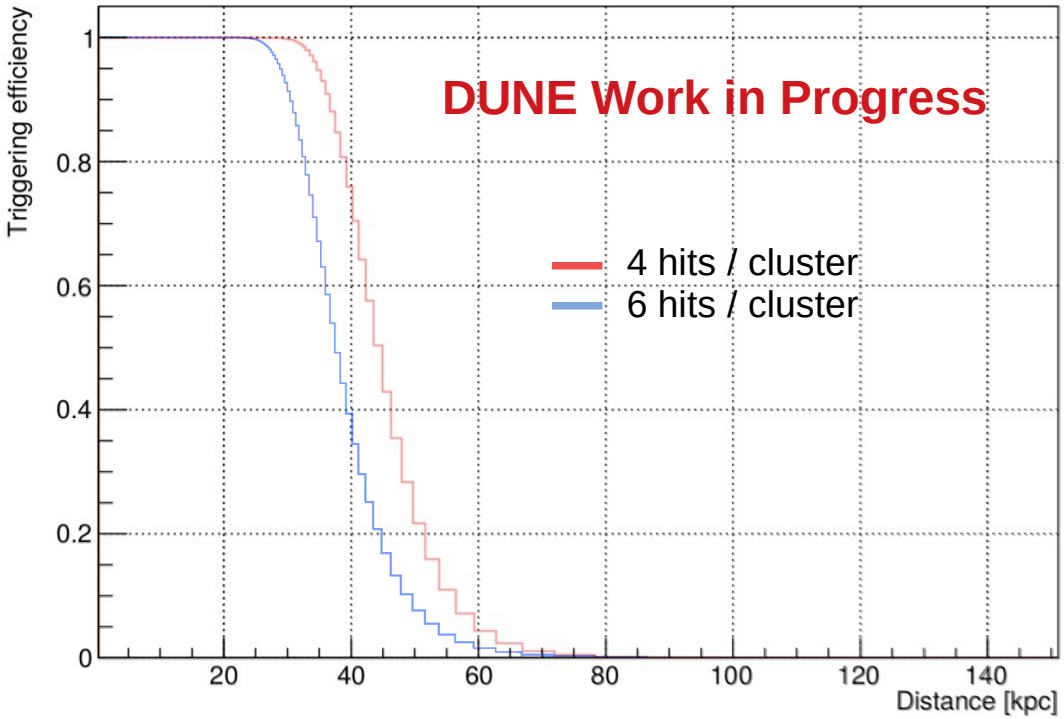
Radiologicals

- Radiologicals determine the ***fake trigger*** rate
  - Clusters in a 10 seconds window:



Triggering Efficiency

- SNB triggering efficiency (for 11.2 $M_{\odot}$ with Hudepohl model and 10 kt)



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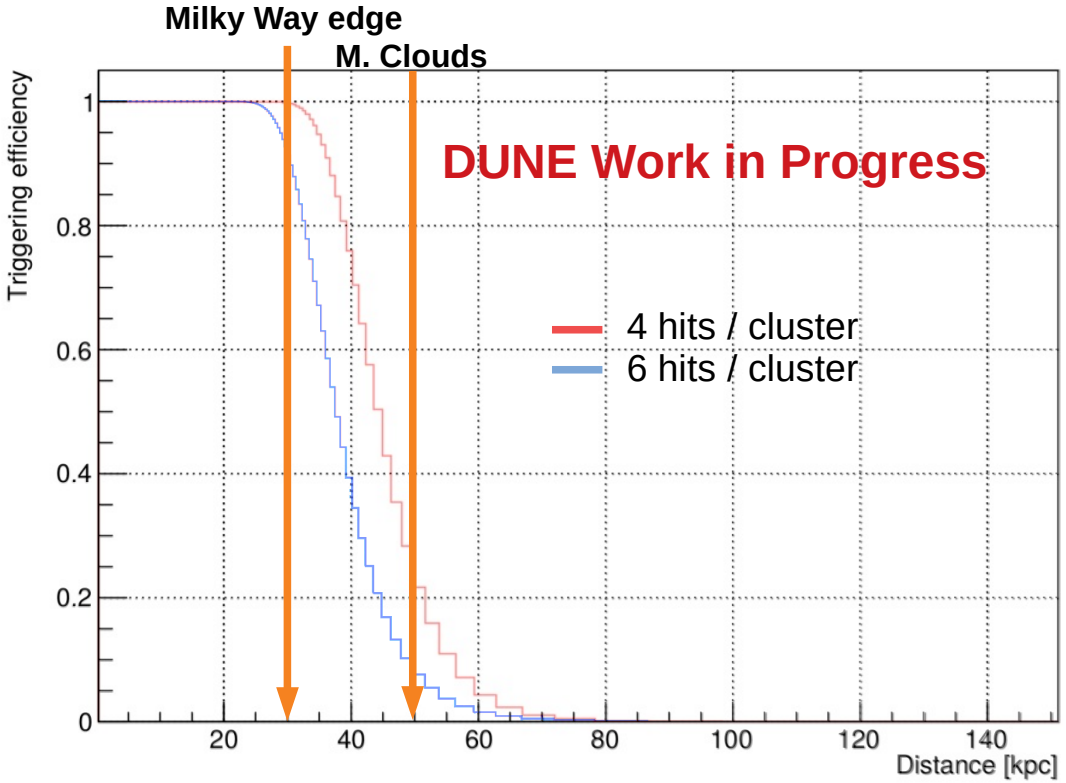
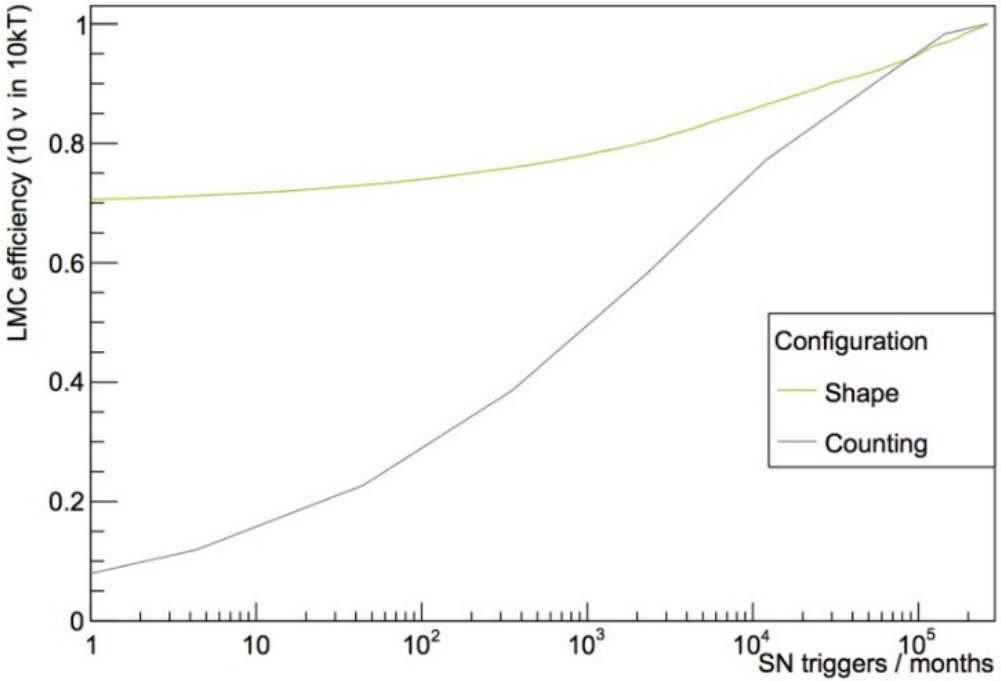


Triggering Improvements I

- Triggering improvement with shape info
  - Shape -> charge of clusters



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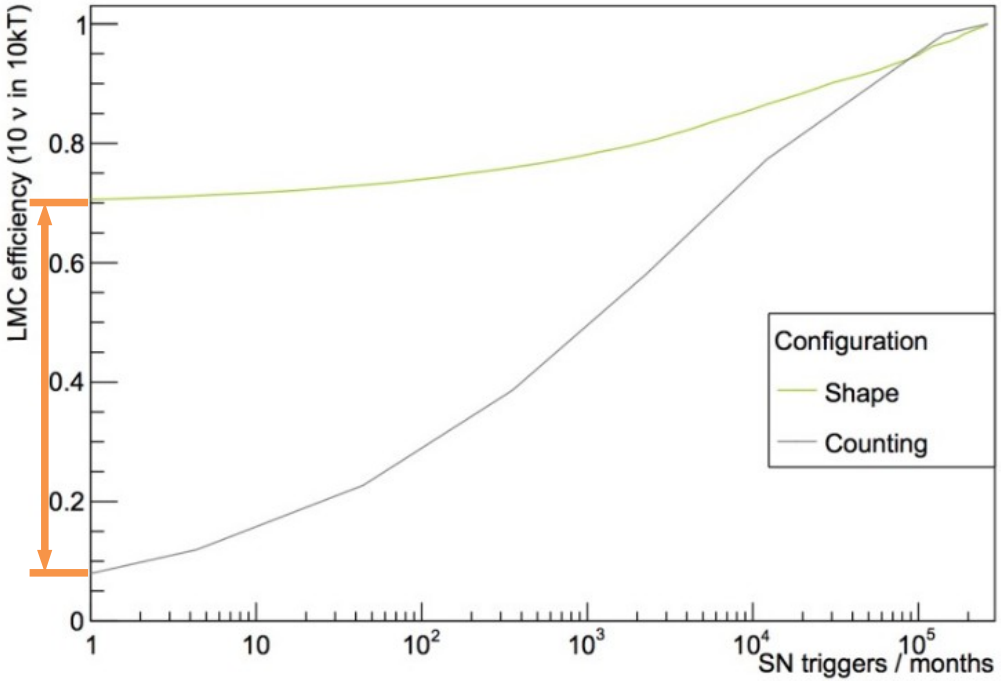

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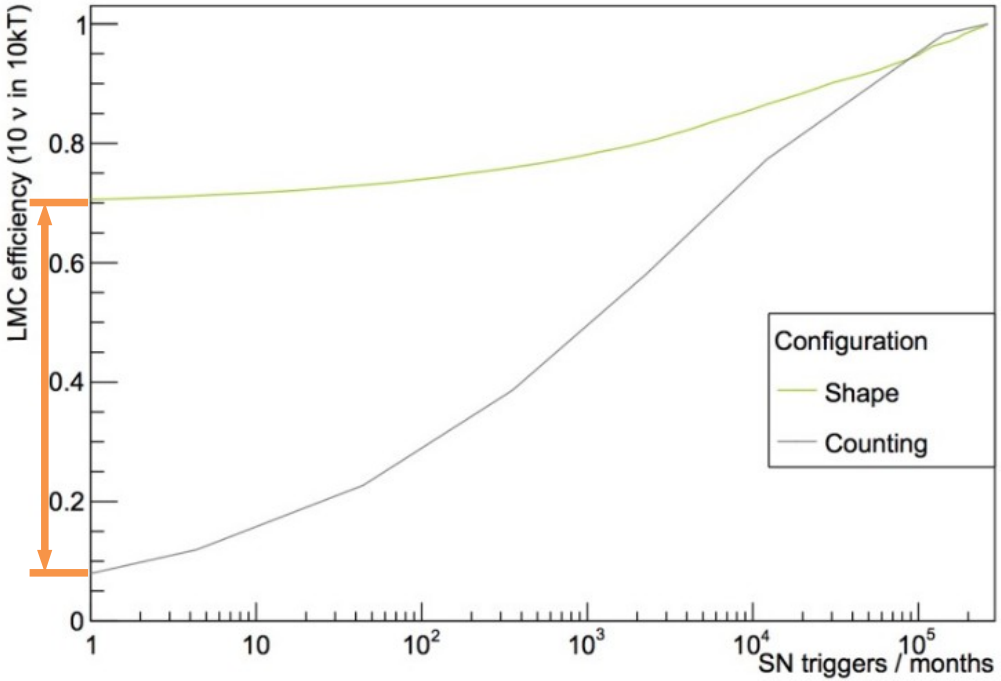
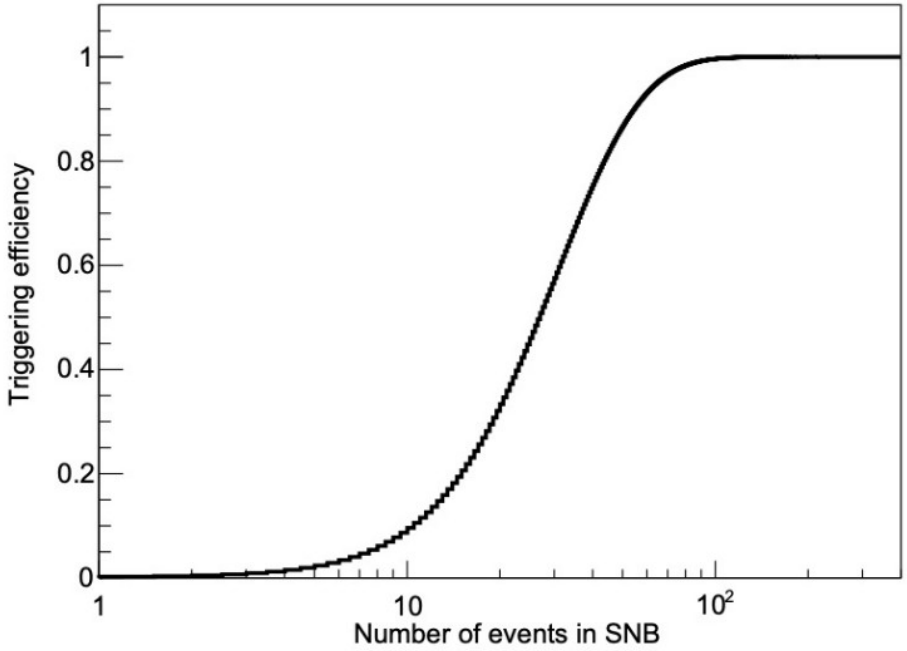


- Triggering with ***photon detectors*** also feasible
  - Gives T_0 of trigger (~ns)



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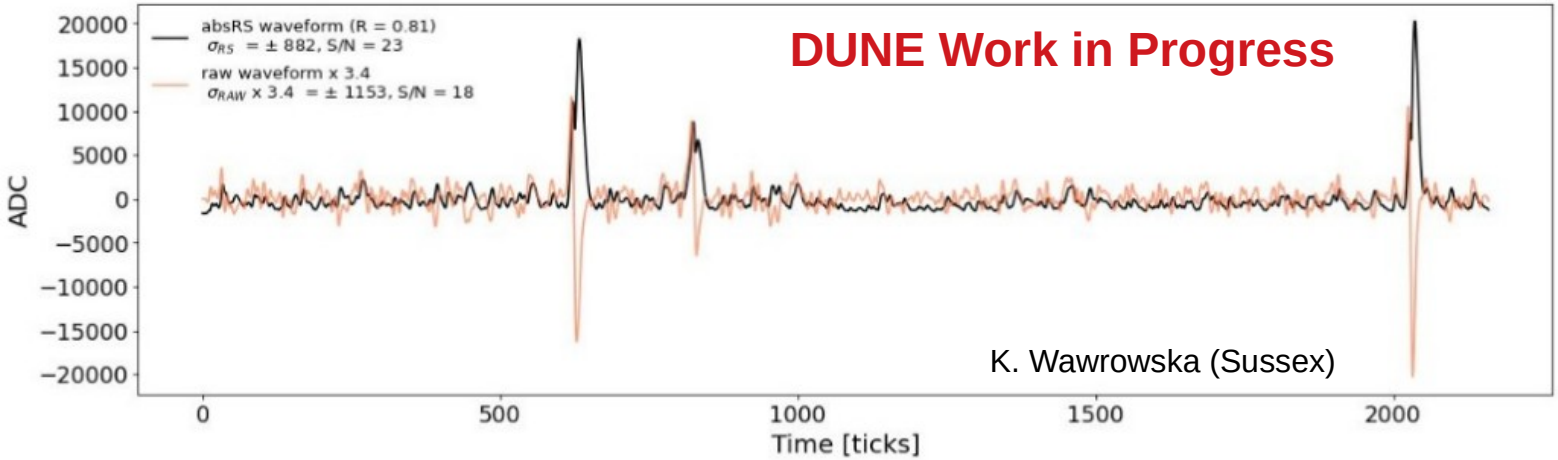
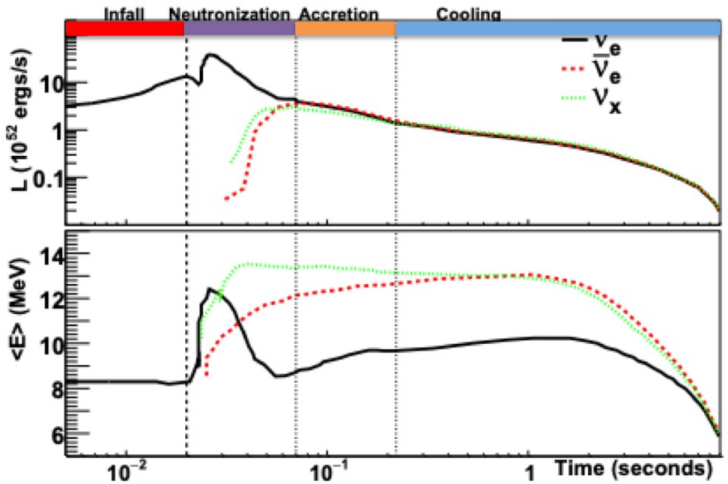
Triggering Improvements II

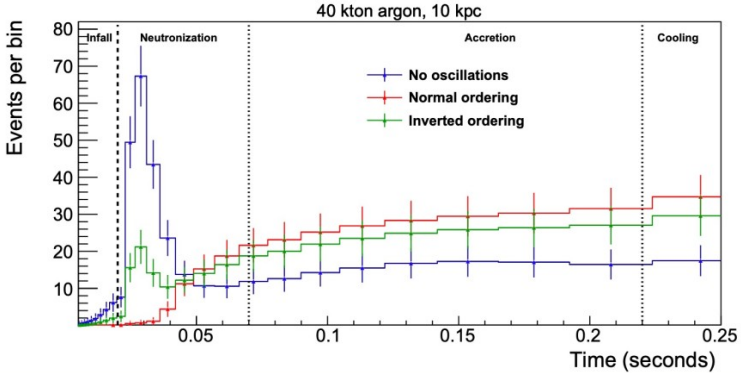
- Induction wires
  - For **R**egion **o**f **I**nterest triggering
    - Reduced data-rates
  - More TPC hits available → better efficiencies
- Online conversion to unipolar pulse:



Supernova ν Burst Physics

- Sensitivity to neutronization phase
- Possibility to determine the mass ordering
- Neutrino mixing from detected spectrum
- Also sterile-ν; self-interactions, absolute ν mass, etc.
- Stellar evolution
- Explosion mechanisms
- Black hole formation





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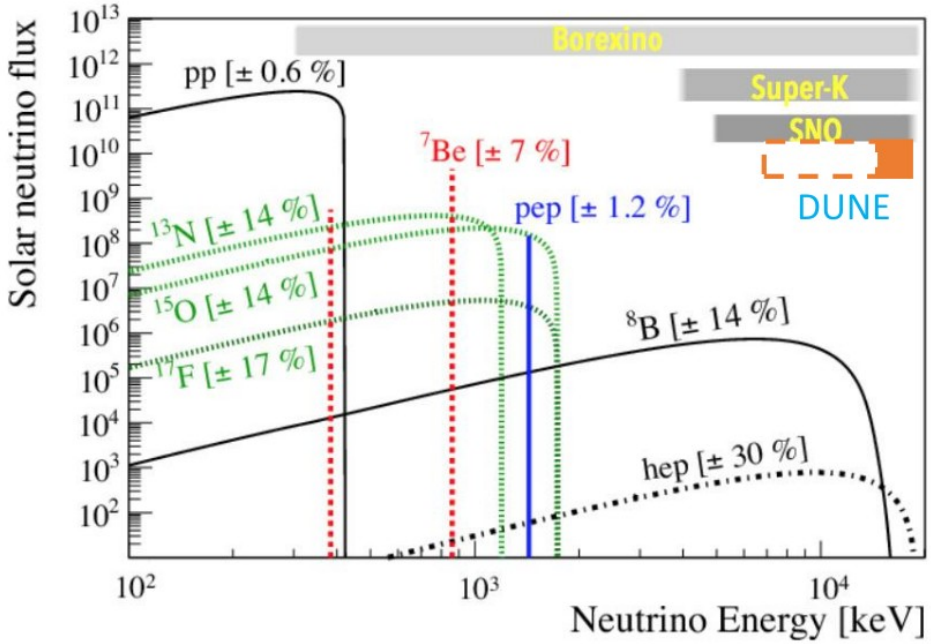
Solar-ν

- DUNE sensitive to **^{8}B** and **hep** fluxes
  - ^{8}B to measure oscillation parameters
  - hep flux has not been observed yet



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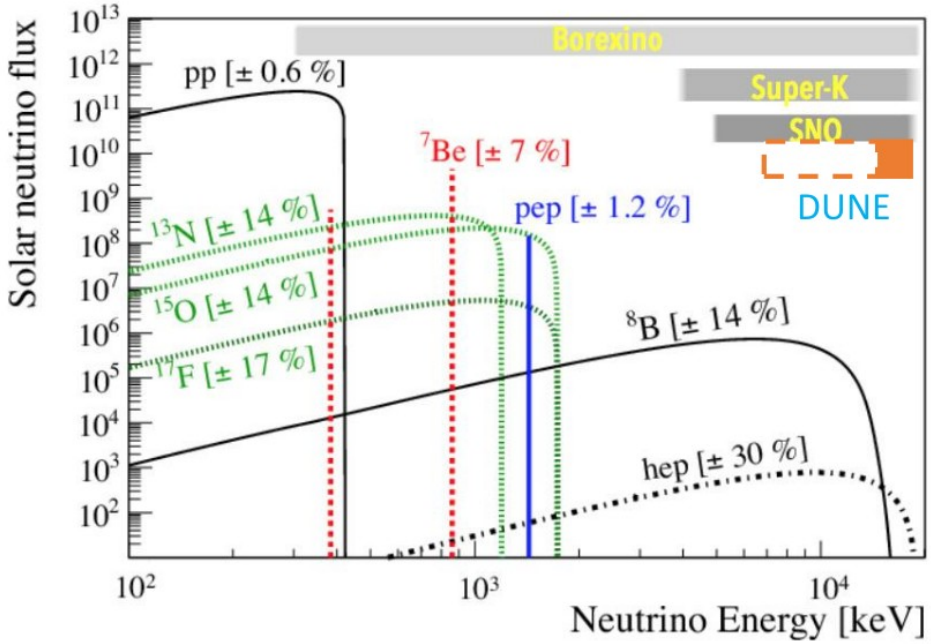

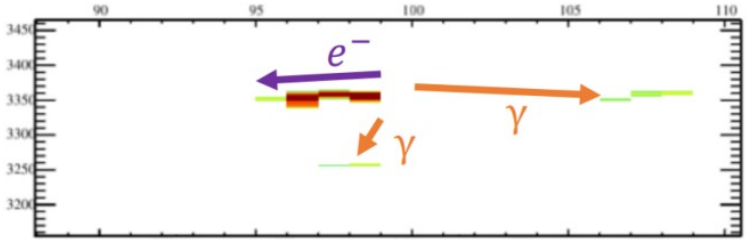

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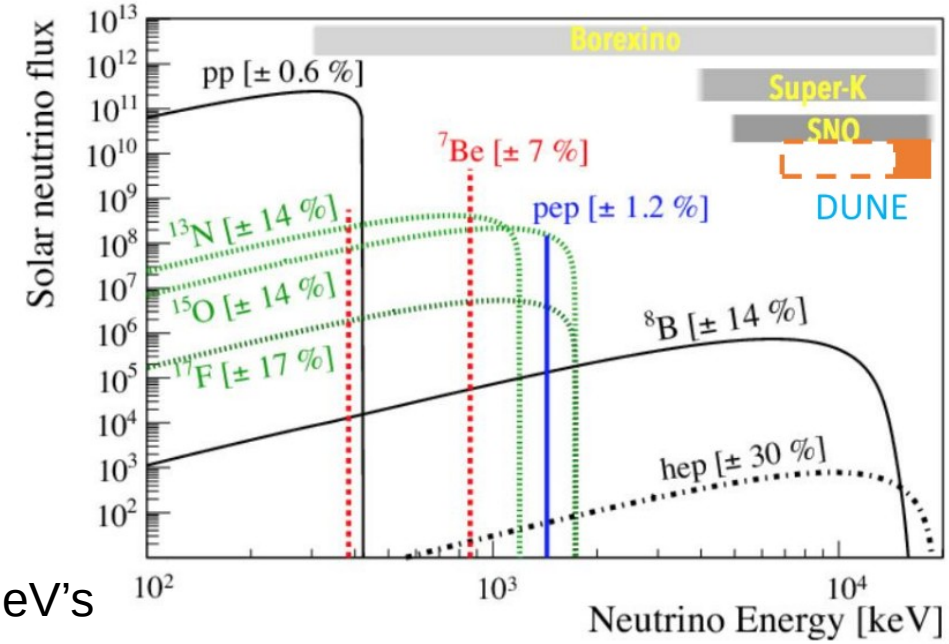
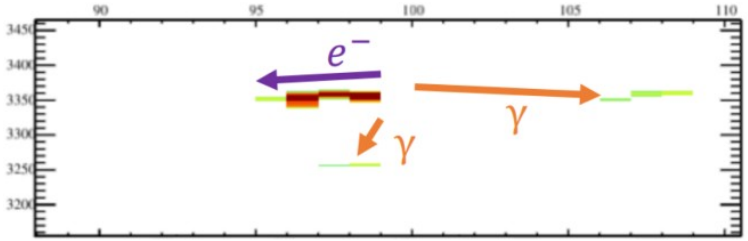
- CC as dominant channel
- Tracks and gamma cascade (TPC) + light
- Triggering threshold → large bkg rate at several MeV's

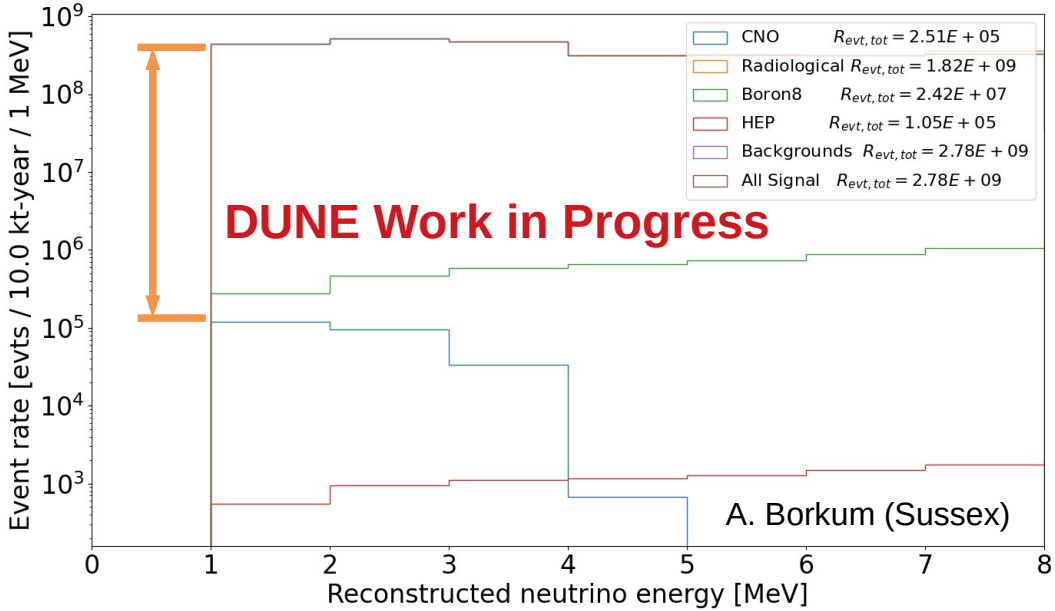




$$\nu_e + {}^{40}Ar \rightarrow e^- + {}^{40}K^*$$

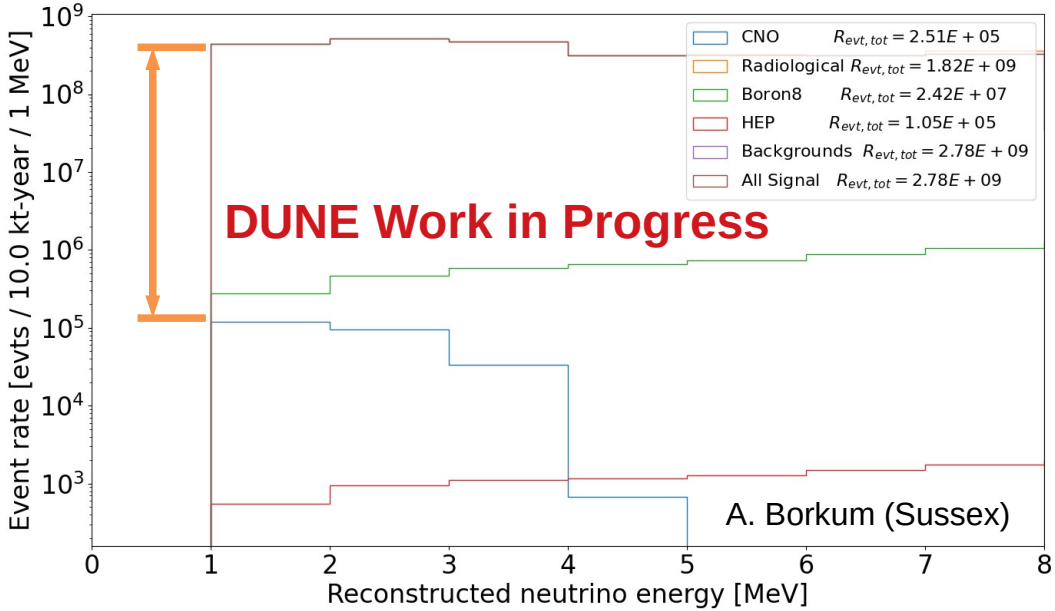
How large backgrounds?

- CNO flux “buried” by ~1000 factor

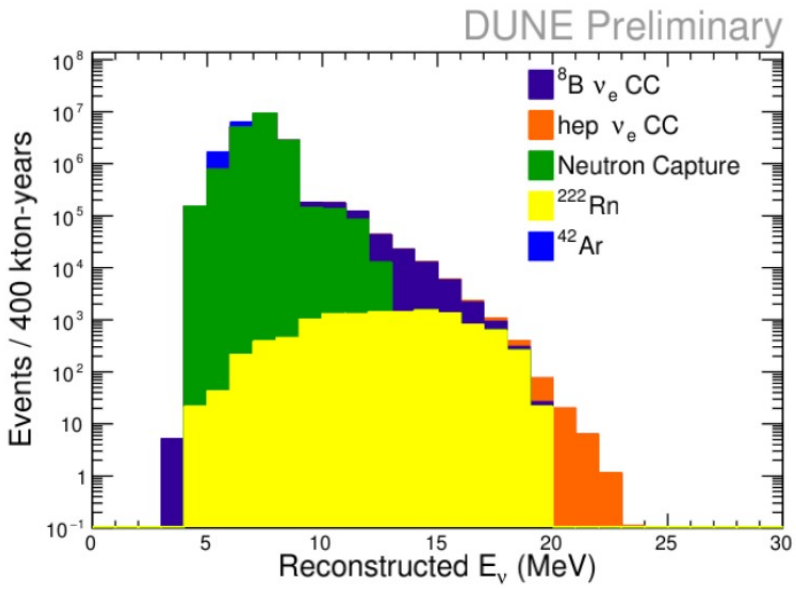


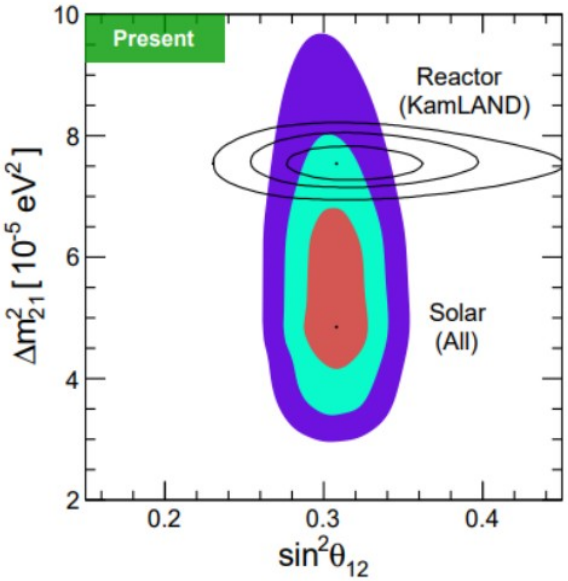
How large backgrounds?

- CNO flux “buried” by ~1000 factor
  - Possible ideas to overcame this challenge exists (4th module?)
    - *A. Avasthi et al., arXiv:2203.08821*

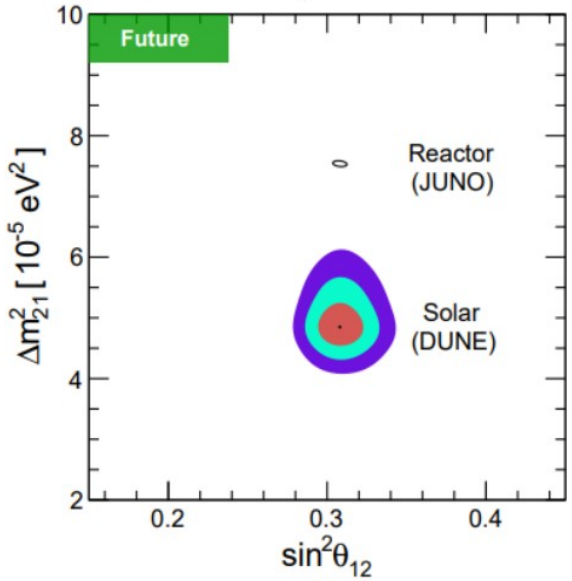


Sensitivity to solar oscillations





Capozzi et al., PRL **123** 131803

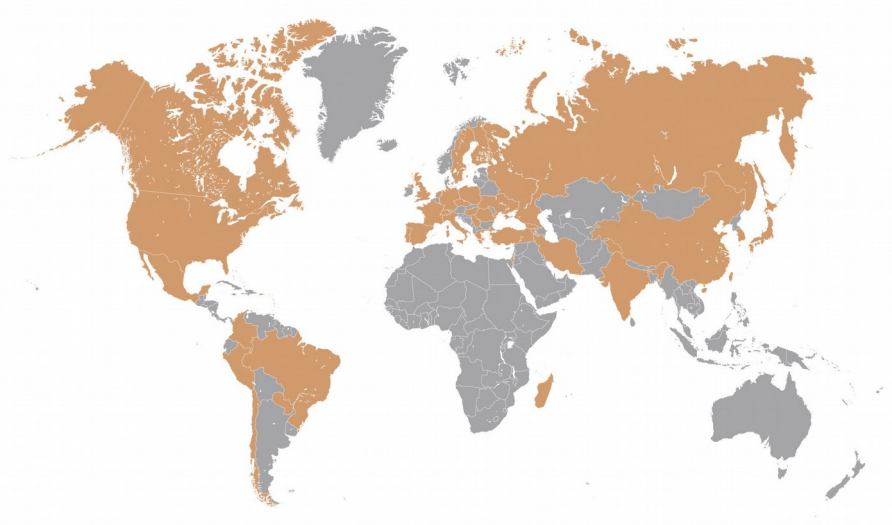


- Favourable sensitivity for measuring Δm^2_{21} from day/night effect
- May push current tension between SK/SNO and KamLAND to 5σ

Summary

- Beyond precision measurement of neutrino oscillation, DUNE will provide large datasets of **astrophysical** neutrinos
- Argon detectors uniquely sensitive to **ν_e flux**
- **Large** mass and **excellent** tracking
- Huge physics potential in the early running: discovering of **hep** solar neutrino flux and **100-1000's events** from any galactic supernova with just **one** FD module (before arrival of the first beam pulse!)

The DUNE Collaboration



Thank you
for listening!