

# Prospects for solar oscillation measurements at DUNE

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NuFact 2025

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# The deep underground neutrino experiment (DUNE)

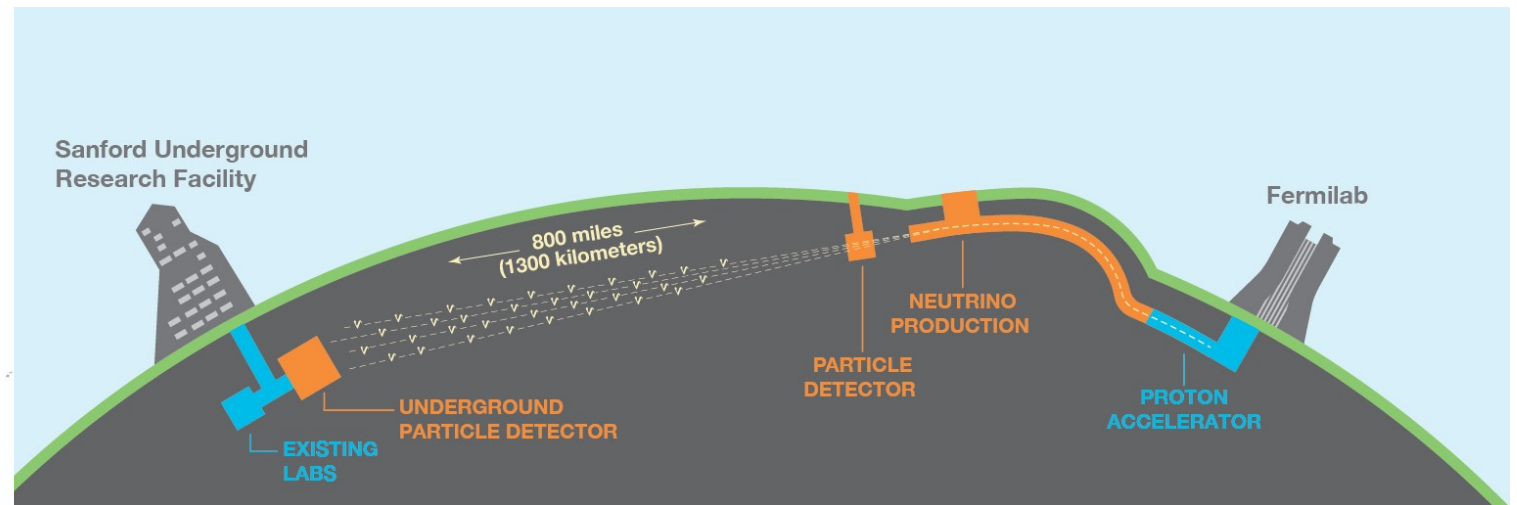
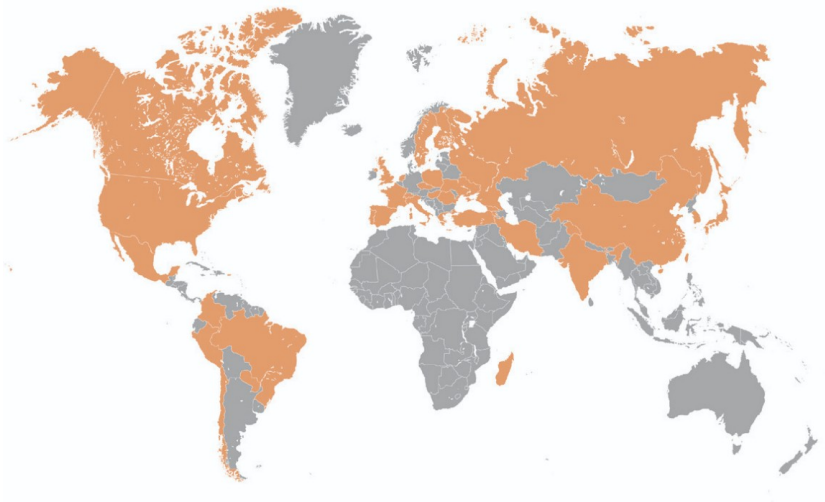
## DUNE science goals:

- A precise measurement of neutrino oscillation parameters ( $\delta_{CP}$ , mass ordering)
- The detection of neutrinos from supernovas and the sun
- Beyond the standard model (BSM) searches

This talk

$\sin^2 \theta_{12}$ ,  $\Delta m^2_{21}$

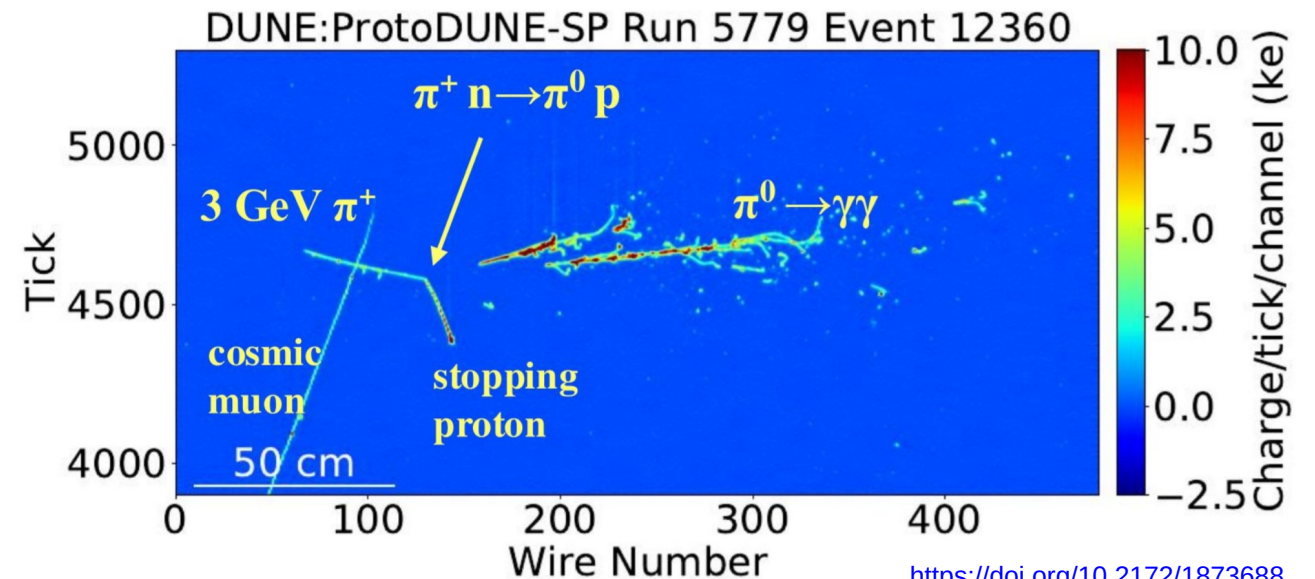
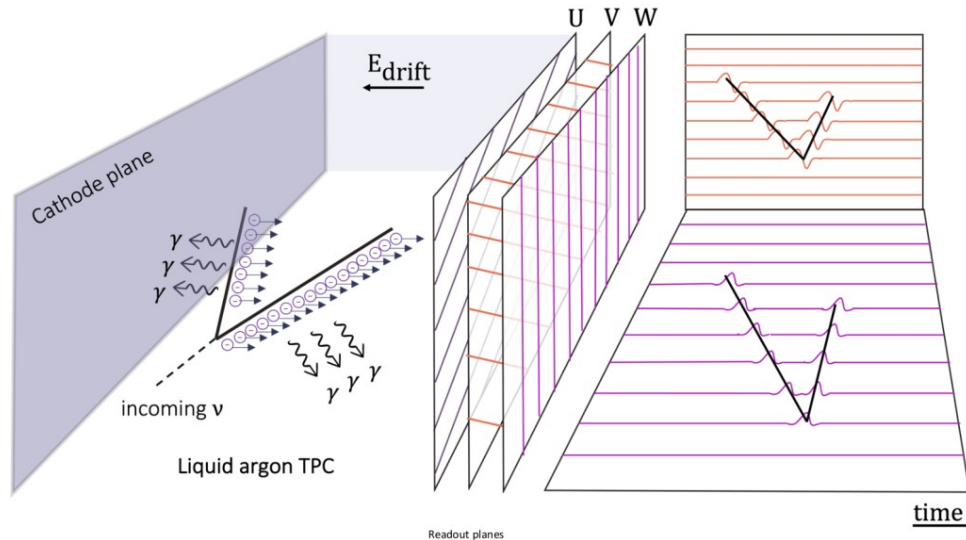
hep flux



# The deep underground neutrino experiment (DUNE)

## The DUNE far detectors:

- Four 17 kton Liquid Argon TPC modules (>40 kton fiducial mass)
- Phase I: FD1 Horizontal Drift (HD) and FD2 Vertical Drift (VD)
- Phase II: Two additional modules with enhanced low-energy capabilities

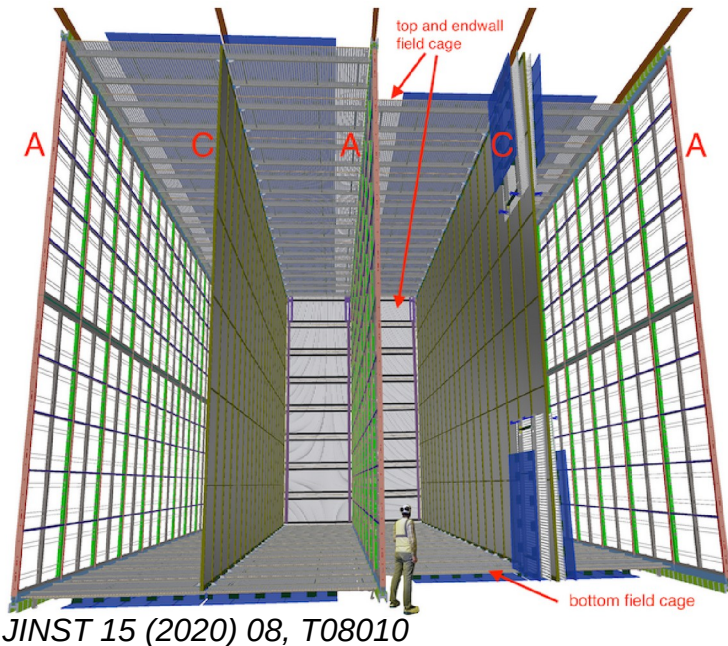


<https://doi.org/10.2172/1873688>

# The deep underground neutrino experiment (DUNE)

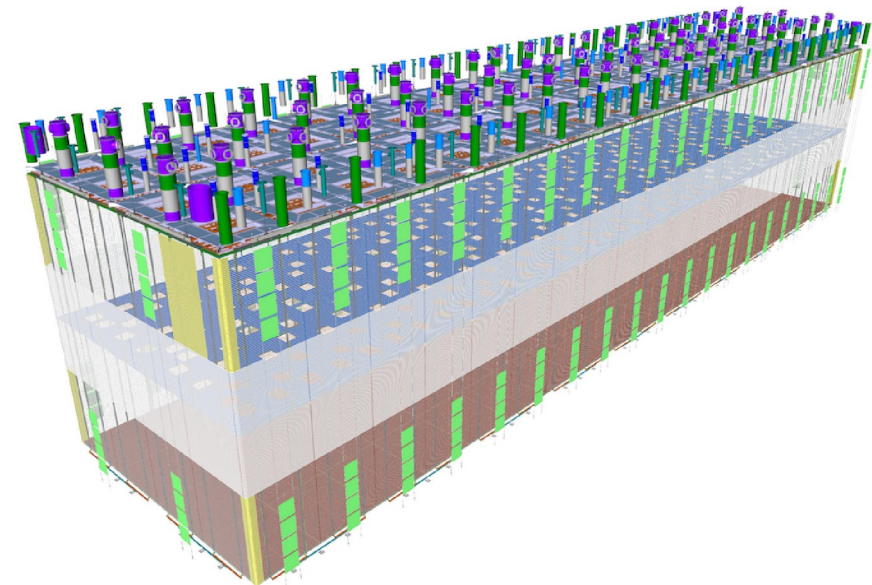
## The DUNE Horizontal Drift module:

- Four drift regions of 3.6 m each
- Wire readout plane (APA) technology
- X-ARAPUCA photon detectors integrated in anode planes



## The DUNE Vertical Drift module:

- Two drift regions of 6.25 m each
- Charge readout plane (CRP) technology
- X-ARAPUCA photon detectors integrated in cathode plane and membrane walls

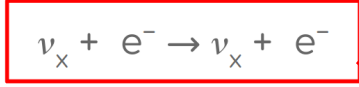


# Low energy interactions at DUNE

• **CC channel**

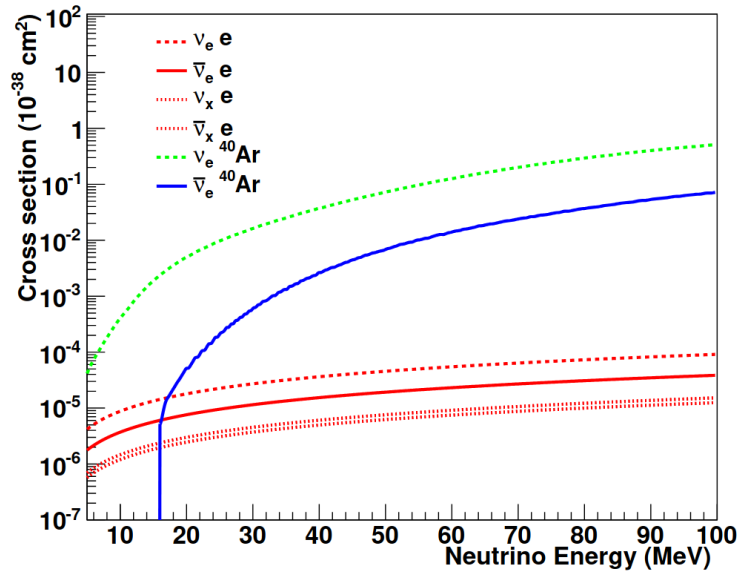


• **ES channel**

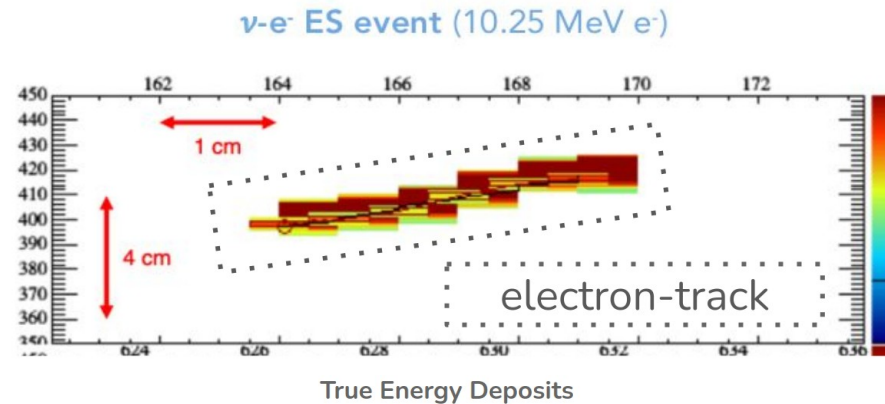
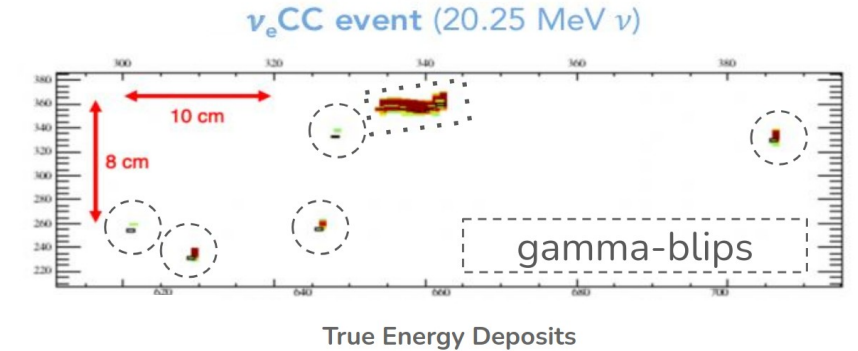


- Short electron track, accompanied by gammas
- High statistics
- Higher energy threshold
- Coincidental gammas harm energy reconstruction

- Clean track-like signal
- Offers some directionality
- Lower energy threshold
- Lower statistics



[PRD 107 \(2023\) 112012](#)



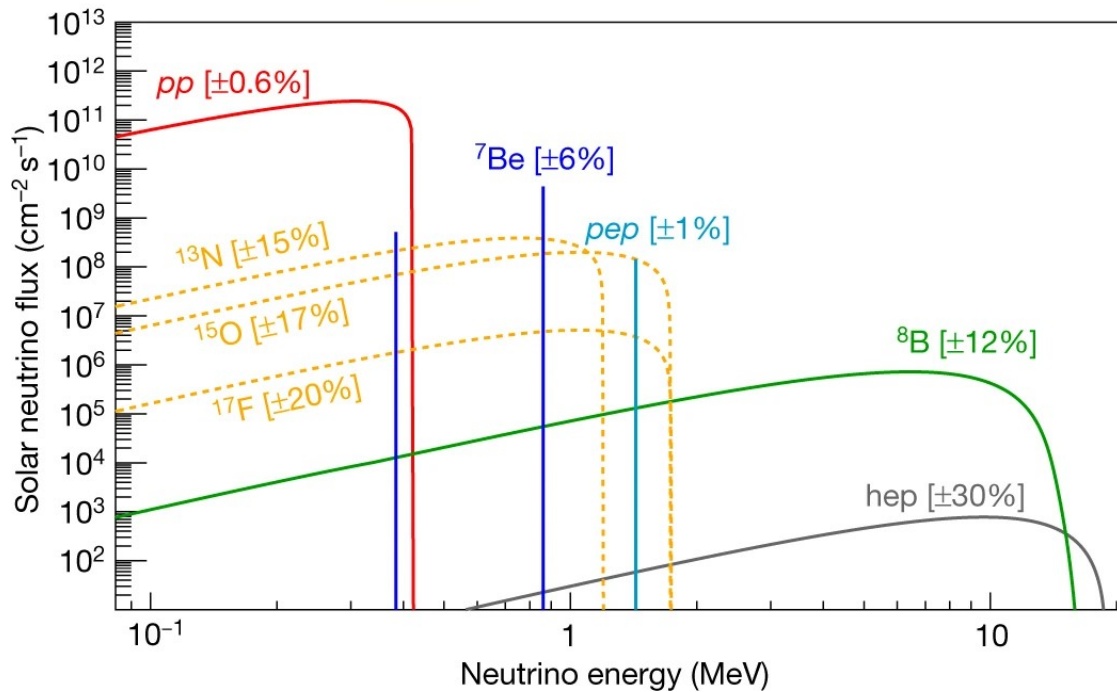
[EPJC 81 \(2021\) 423](#)

# Solar neutrinos at DUNE

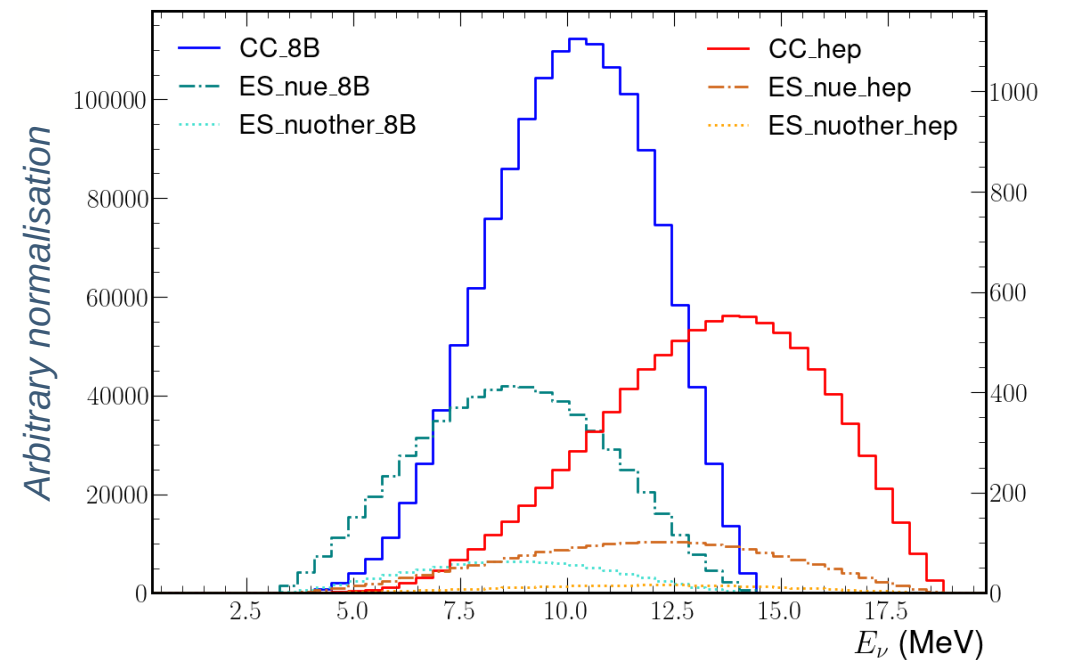
- Use the large  $^8\text{B}$  flux to measure the **oscillation parameters**
- Attempt to measure (discover!) the **hep flux** using the CC interaction

After 100 Kton years:  
 $O(2 \times 10^5)$  CC events from  $^8\text{B}$   
 $O(3 \times 10^2)$  CC events from hep

Solar flux prediction from the SSM

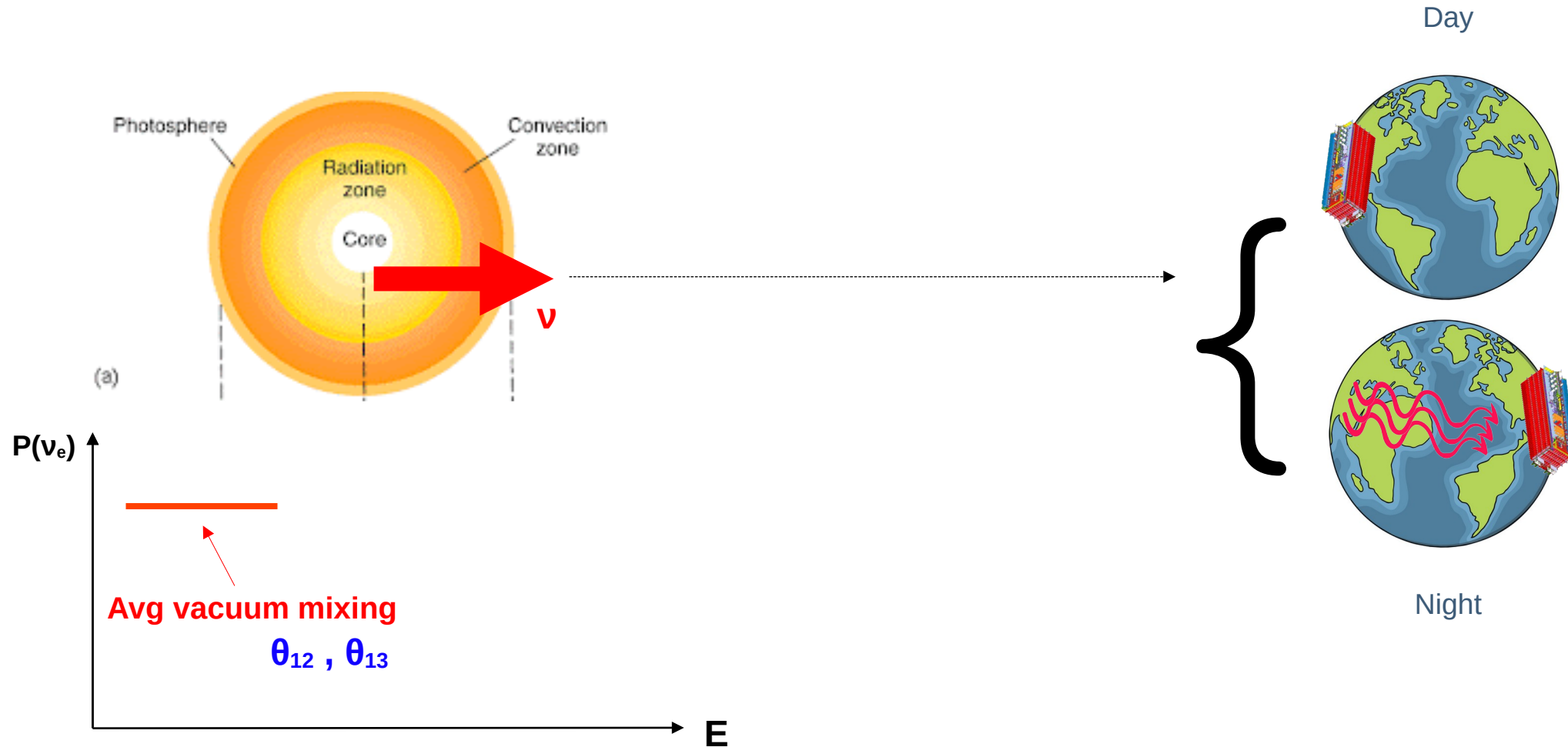


Unoscillated event rates at earth

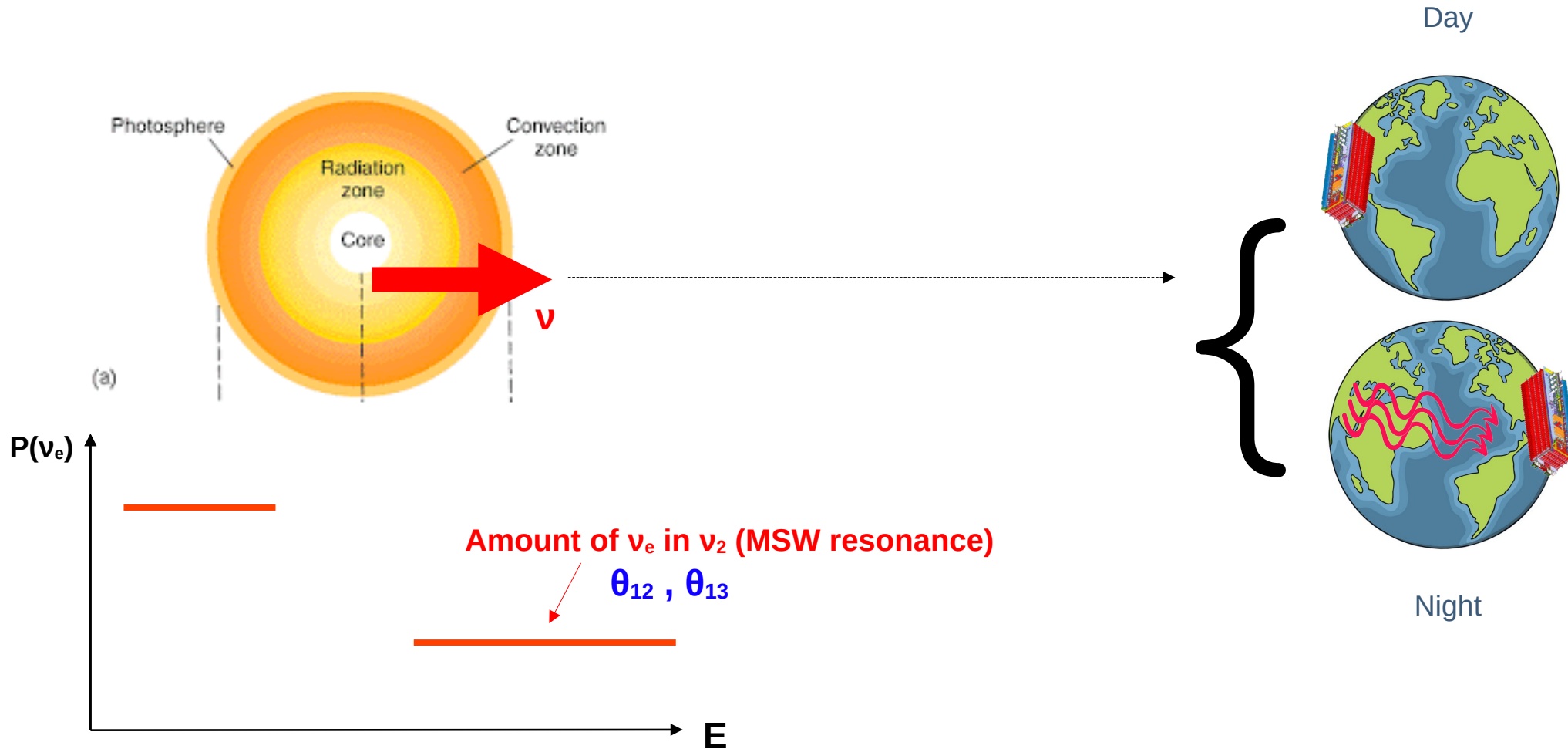


<https://doi.org/10.1038/s41586-018-0624-y>

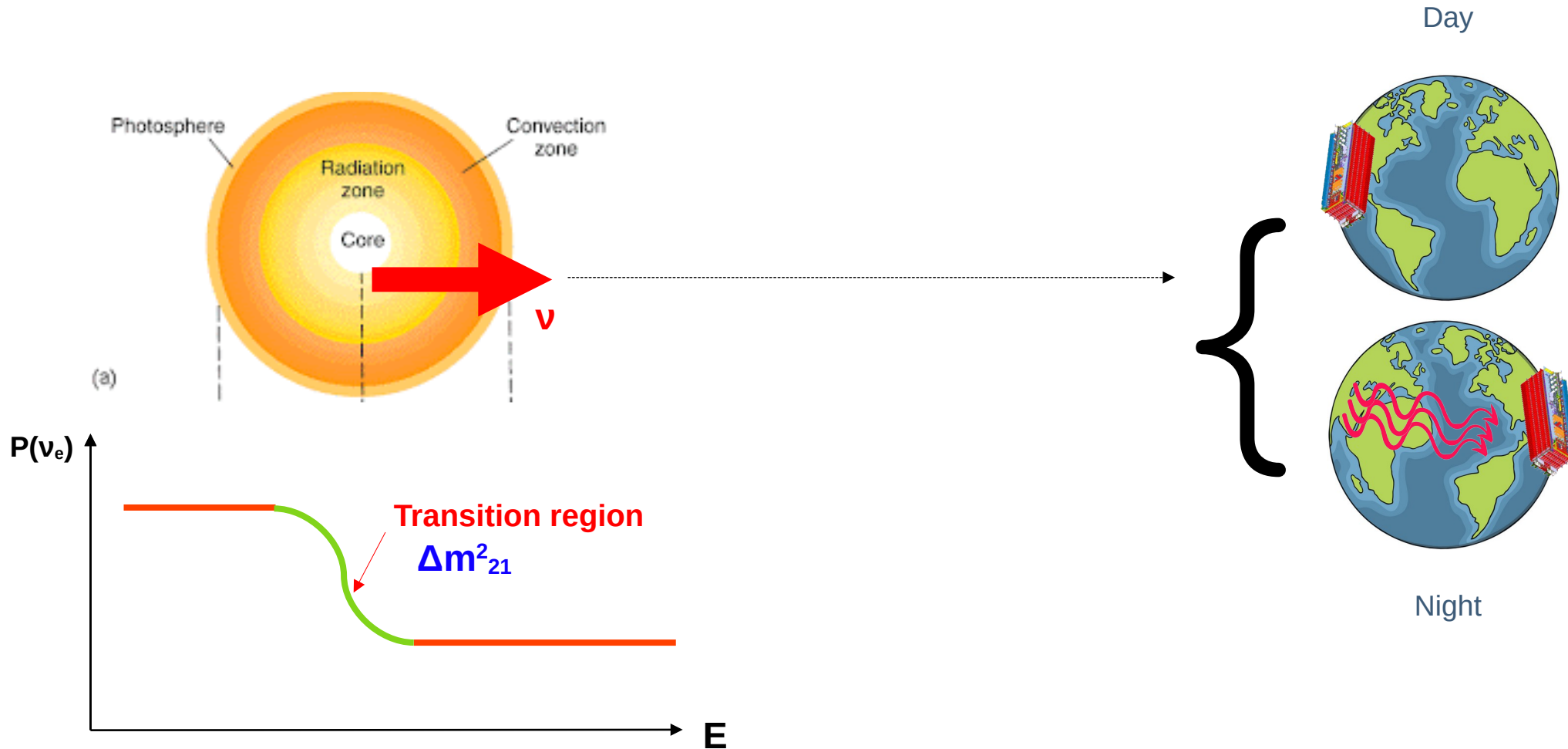
# Solar neutrinos at DUNE



# Solar neutrinos at DUNE

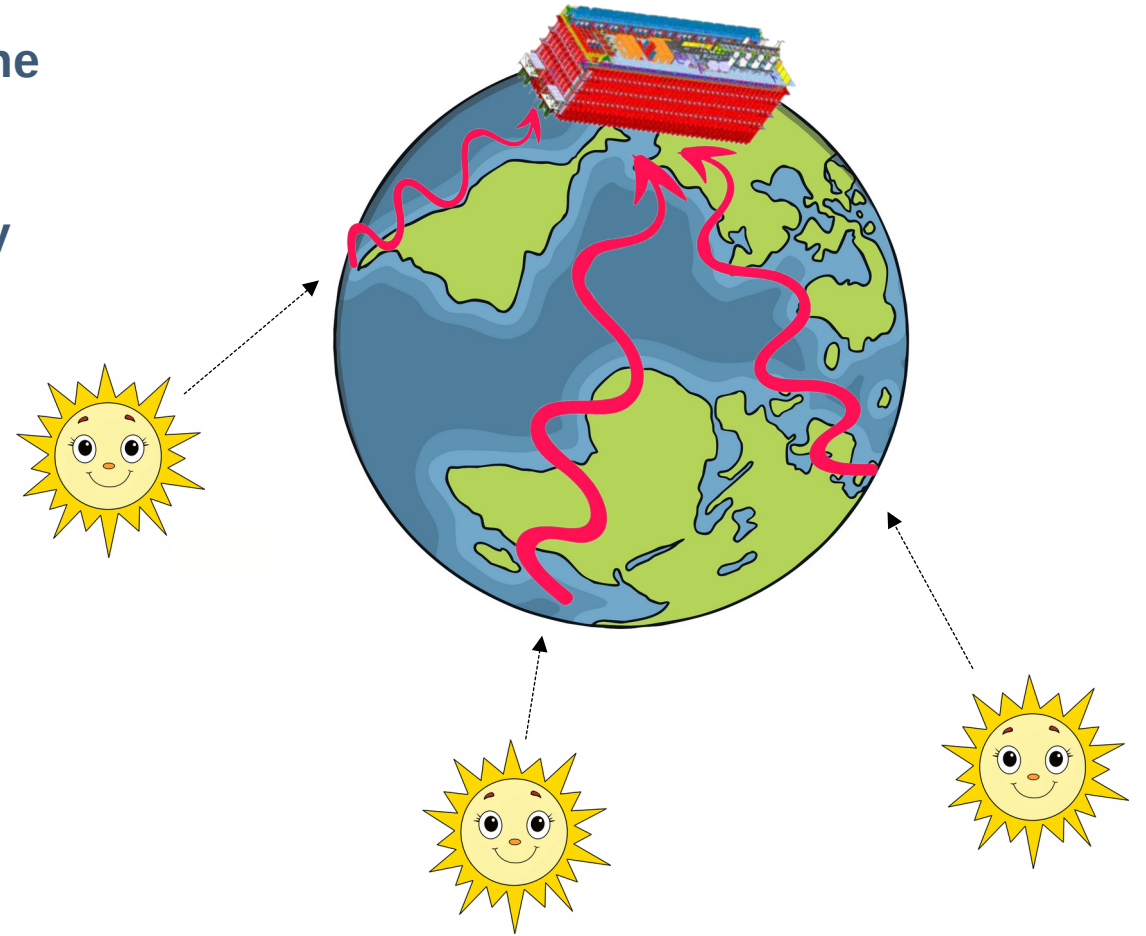
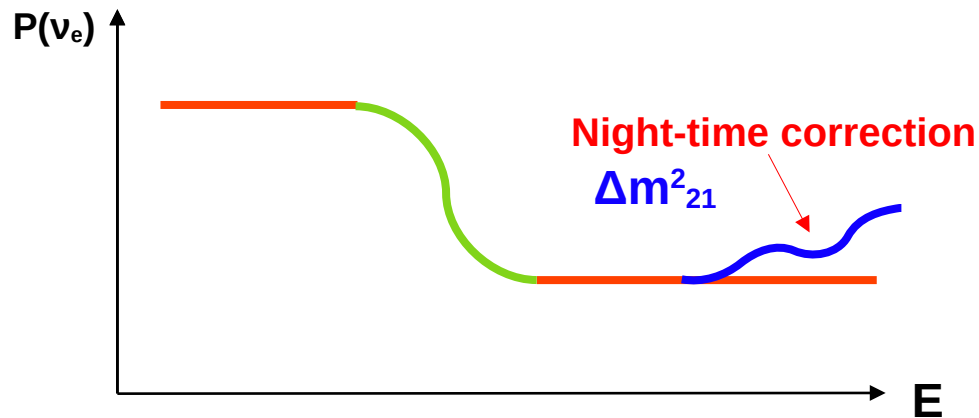


# Solar neutrinos at DUNE

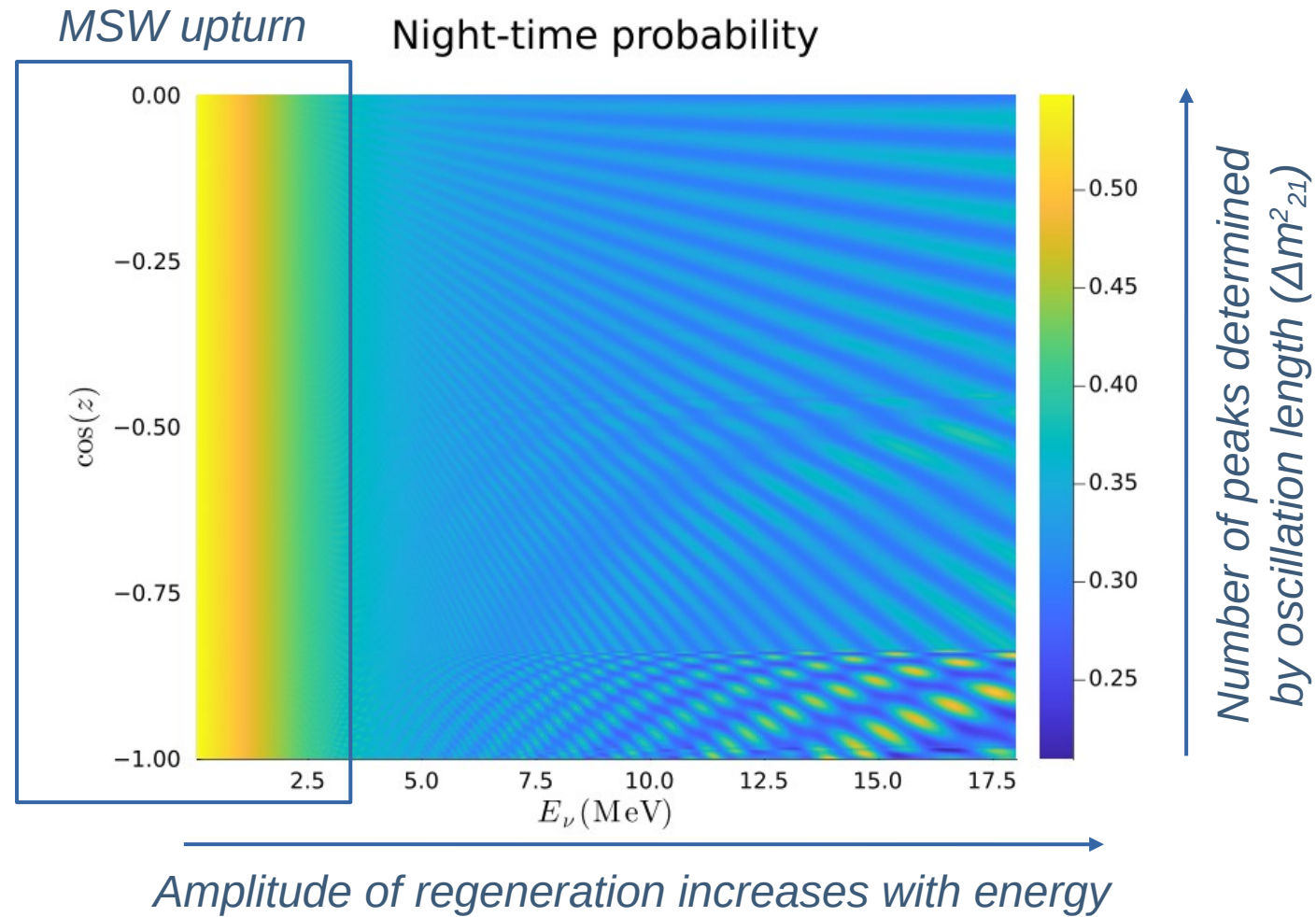


# Solar neutrinos at DUNE

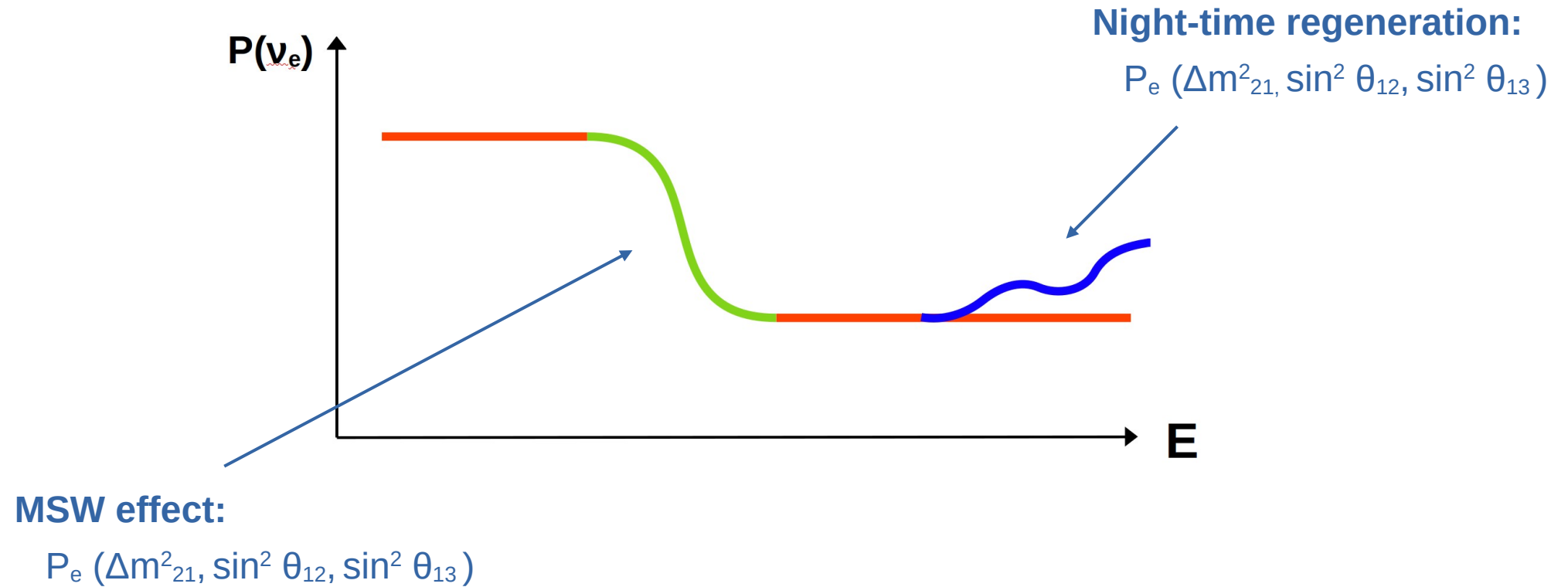
- At **night**, the survival probability depends on the **angle** between the detector and the sun
- The night-time correction **increases with energy**



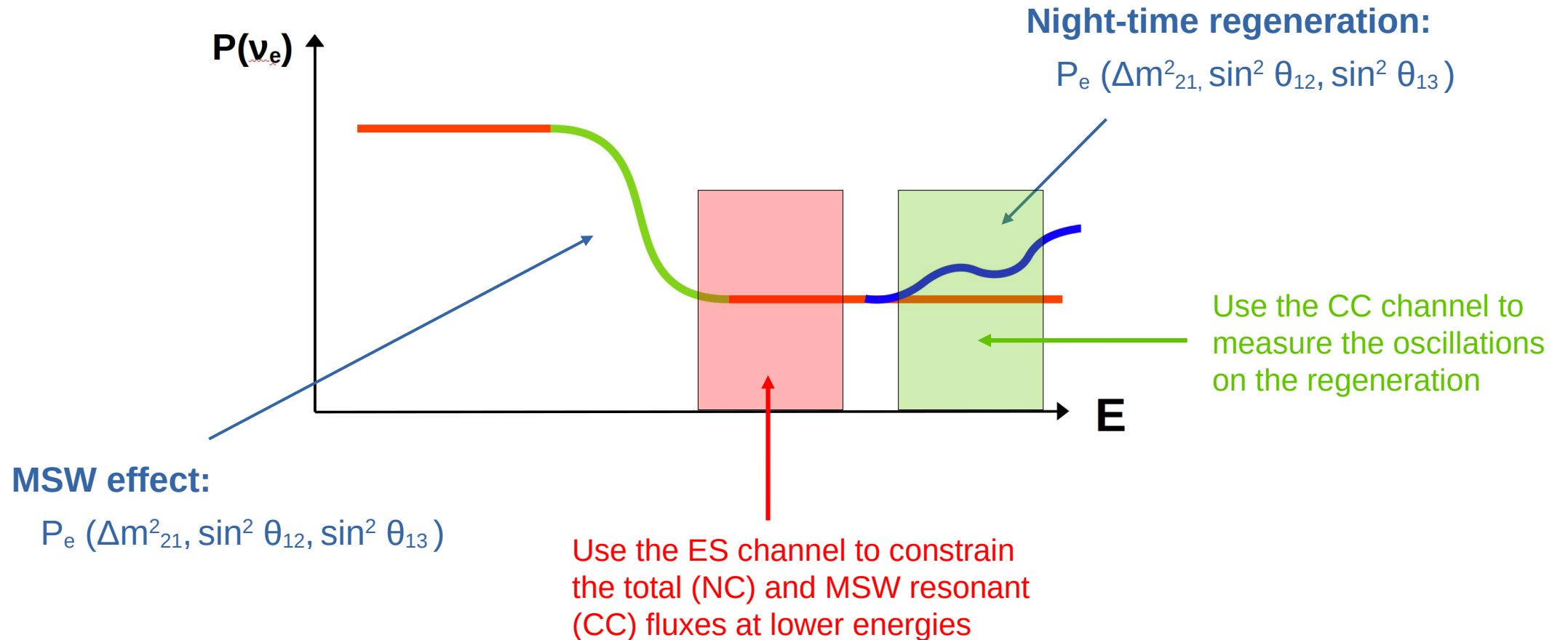
# Solar neutrinos at DUNE



# The measurement strategy



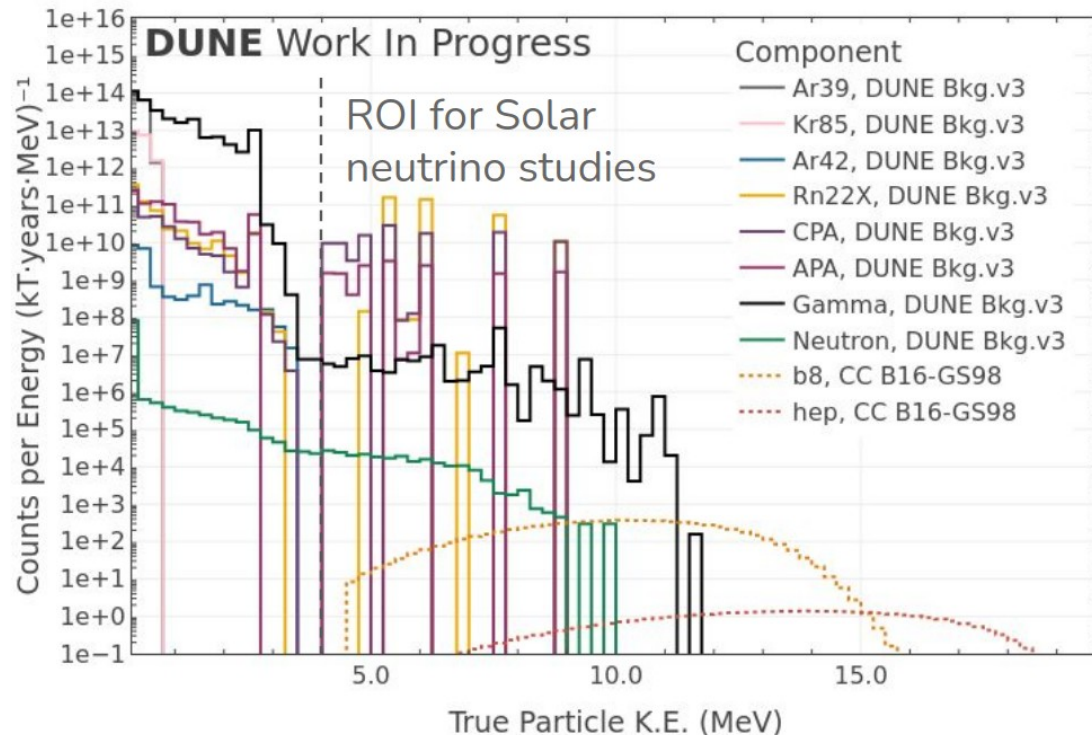
# The measurement strategy



# Things are never that easy

Radiological backgrounds dominate the low-energy regime. The main culprit: **fast neutrons**:

- Cannot be fiducialised
- Coincidental gammas prevent us from accurately reconstructing the CC interaction



LAr:

- Bulk contributions: **Ar39**, **Kr85**, **Ar42**
- Isotopes with ion drifting towards cathode: 42K, **Rn222** chain, **Rn220** chain (212Pb)

HD internal contributions (inside cryostat):

- **CPA**: 42K (ion drifting from LAr), 40K, 238U chain, 232Th chain
- **APA** board: 40K, 238U chain, 232Th chain
- **APA**: 60Co, 238U chain, 232Th chain
- **PDS**: 222Rn daughter plate-out (210Pb chain)

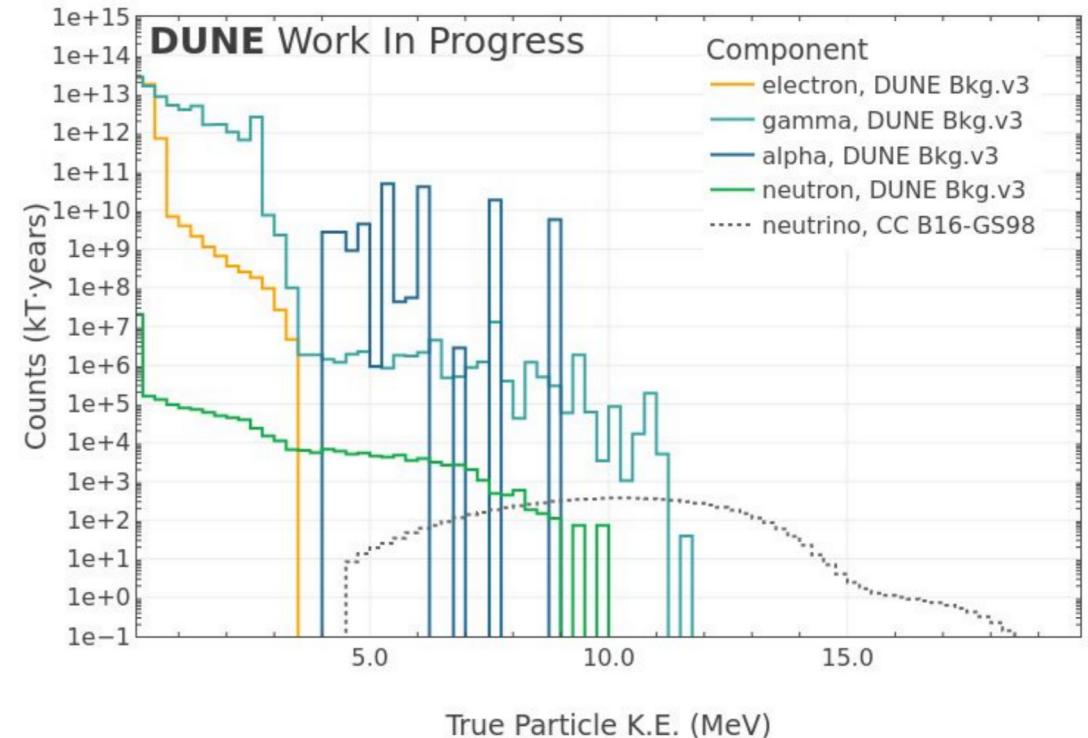
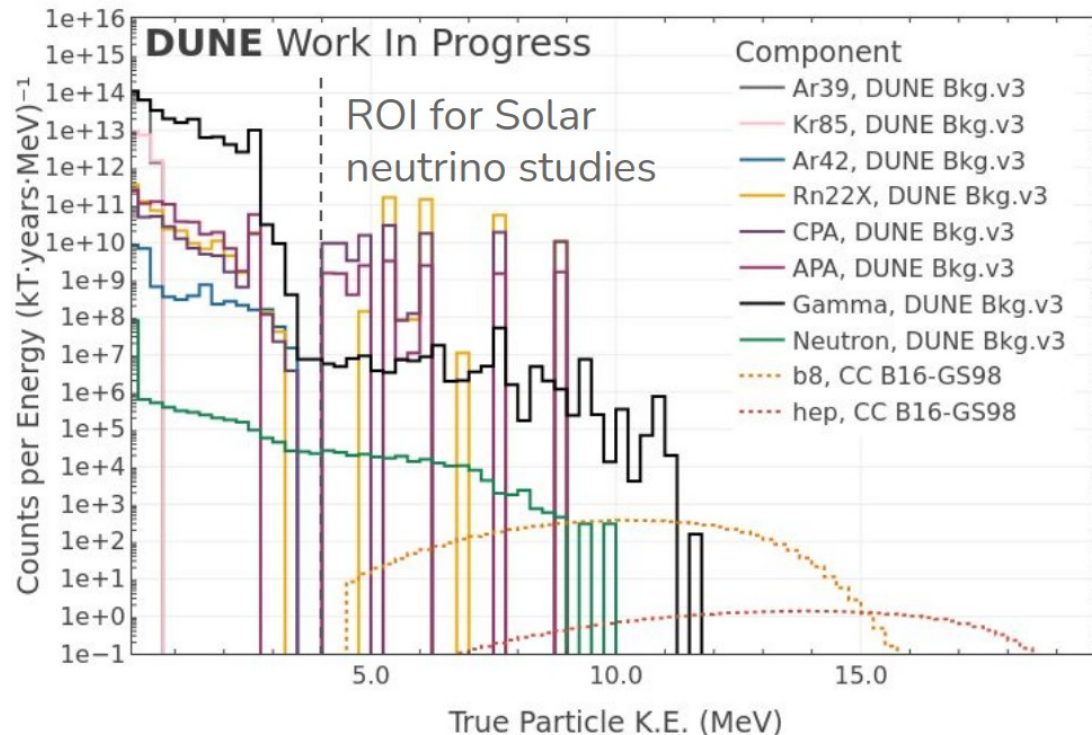
External contributions:

- Cavern: **neutrons**, **gammas** (238U and 232Th chains, 40K), **gammas** from neutron capture in the cavern, and **gammas** from neutron capture in the cryostat
- Cryostat foam: **gammas** (238U and 232Th chains, 40K).

# Things are never that easy

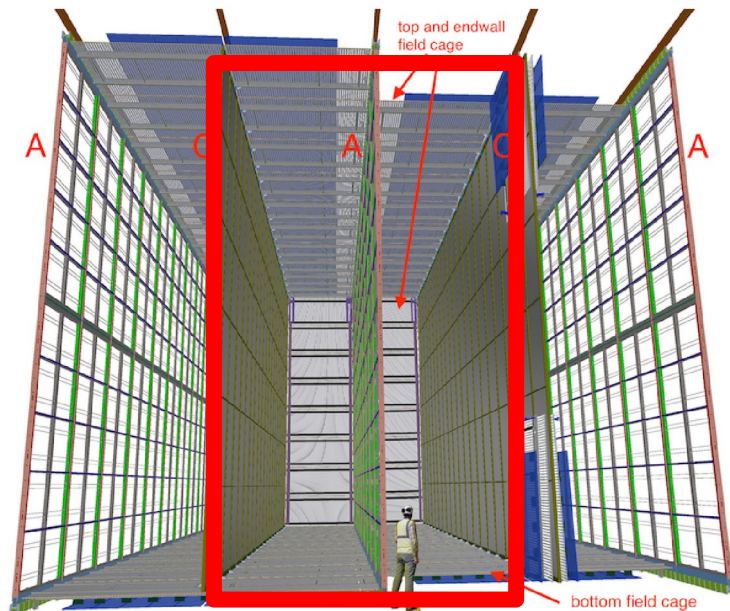
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# Things are never that easy – The good news

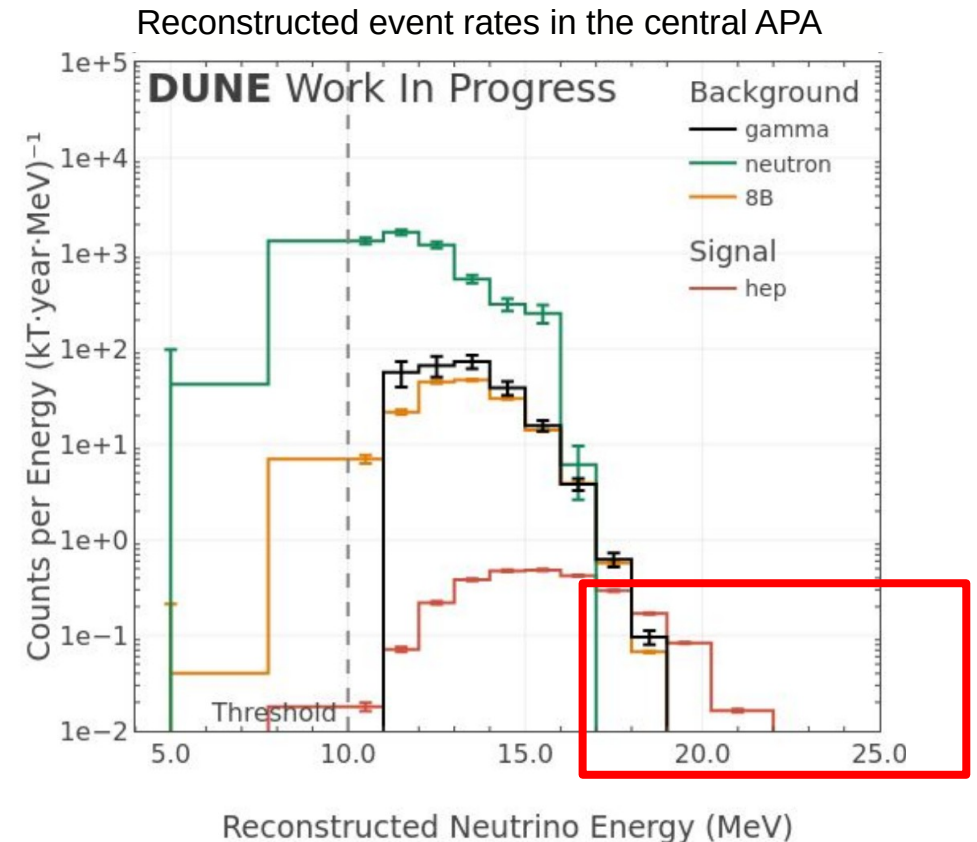
- After a large reconstruction and selection effort, we expect the hep flux to extend past the radiological backgrounds of the HD module



Fiducialisation

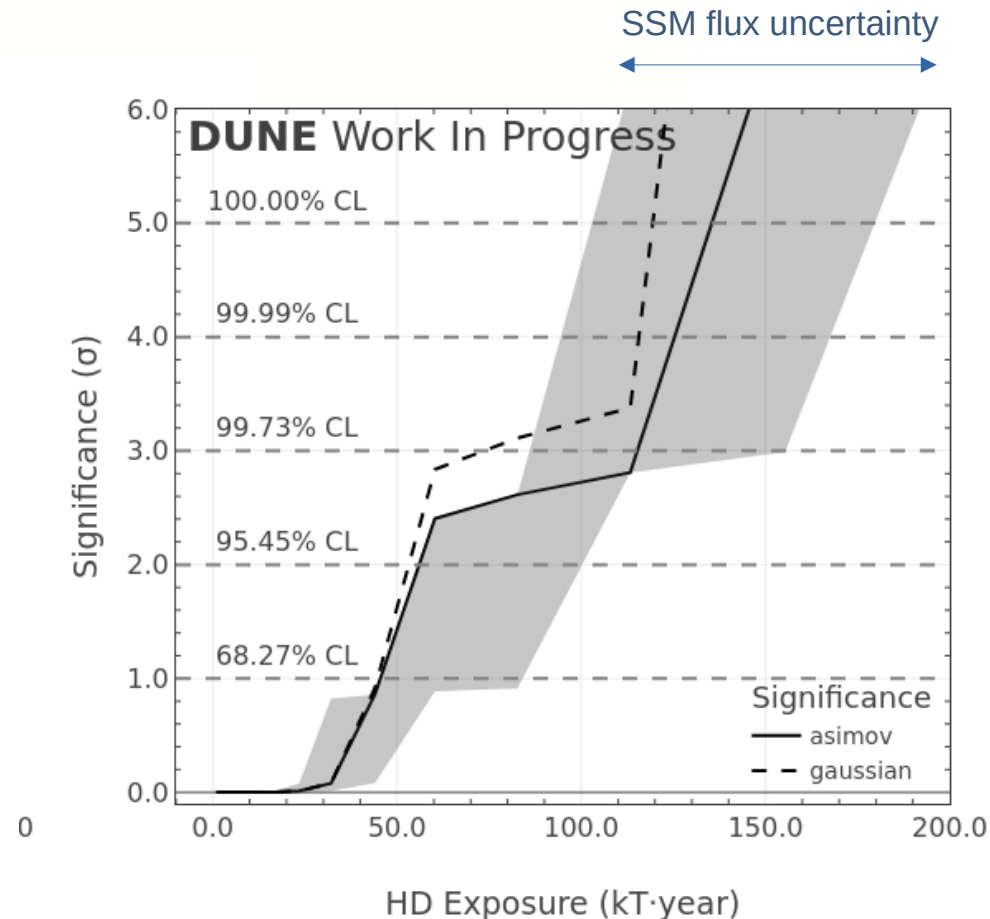
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Selection cuts targeting the highest energies



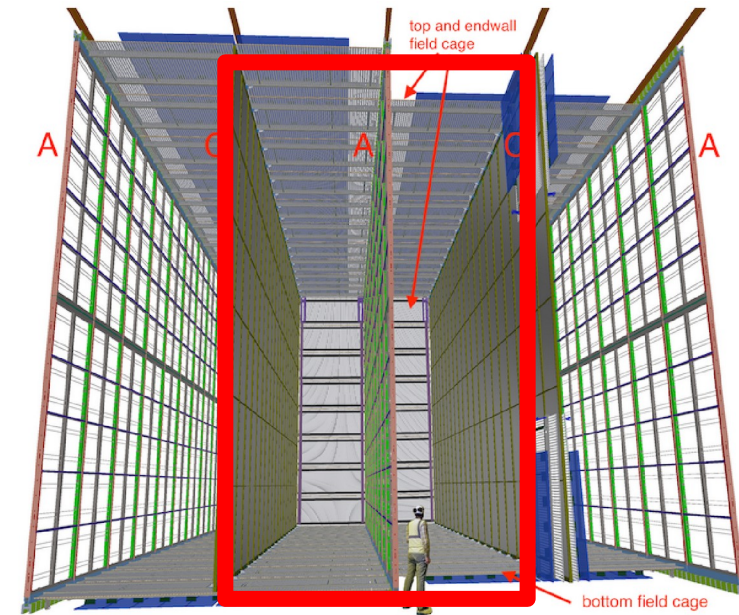
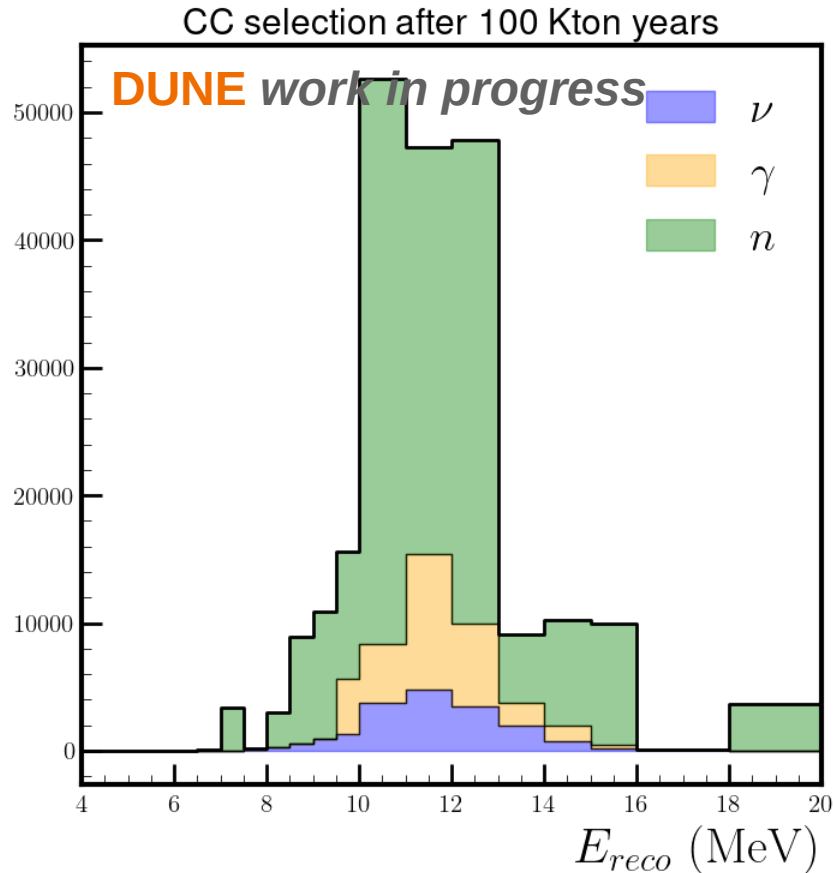
# Things are never that easy – The good news

Hep discovery should be possible even just with the HD!



# Things are never that easy – The bad news

- The background rates on the HD are extremely large, even after the selection cuts



Fiducialisation

+

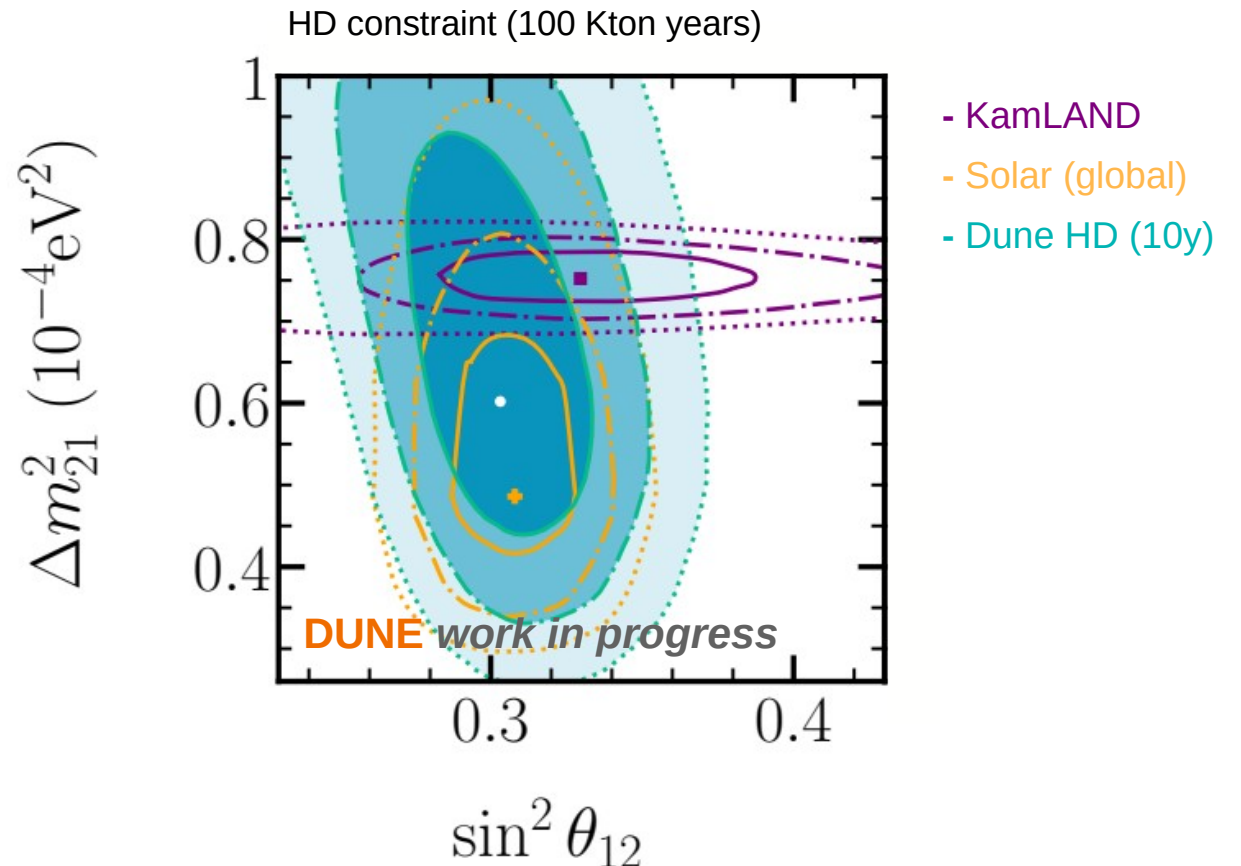
More aggressive cuts targeting the  ${}^8\text{B}$  ROI

# Things are never that easy – The bad news

- The background rates on the CC channel limit our constraining power on the solar oscillation parameters

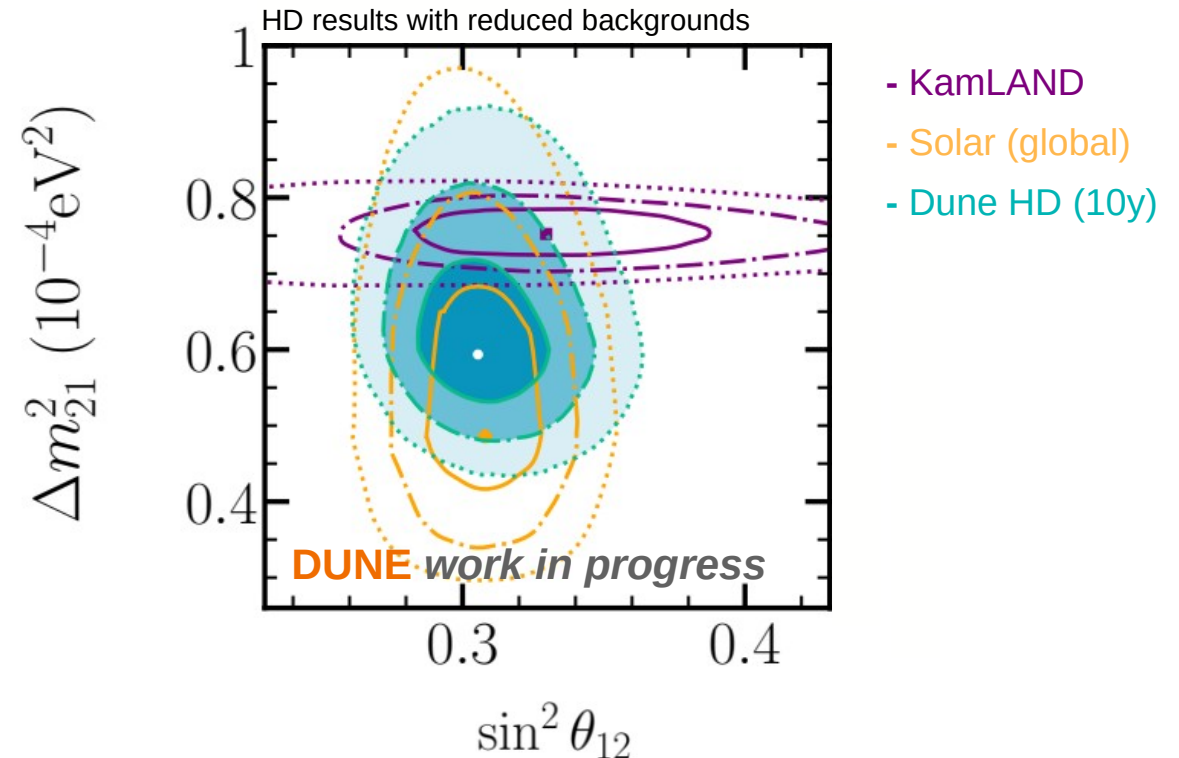
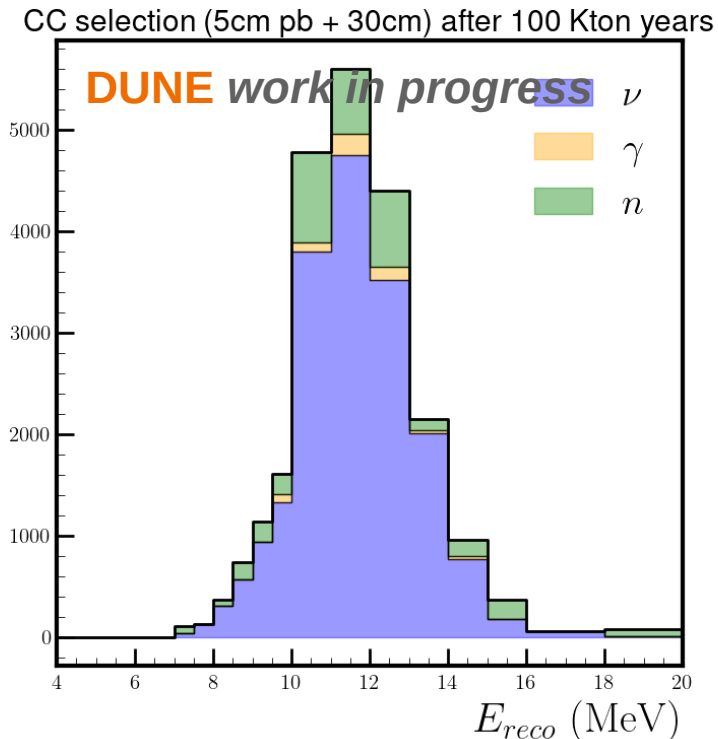
Preliminary study:

- **CC channel only**
- Prior on  $\theta_{13}$  from reactor experiments
- Prior on  $\phi_{8B}$  with 4% uncertainty (Imitating ES channel constraint)
- **HD module geometry**



# Things are never that easy – Reducing the backgrounds

- Even with moderate amounts of passive shielding, the same analysis yields large improvements on sensitivity
- A proposal to shield the VD module is under consideration. Extrapolating from this analysis we can expect a similar boost in sensitivity



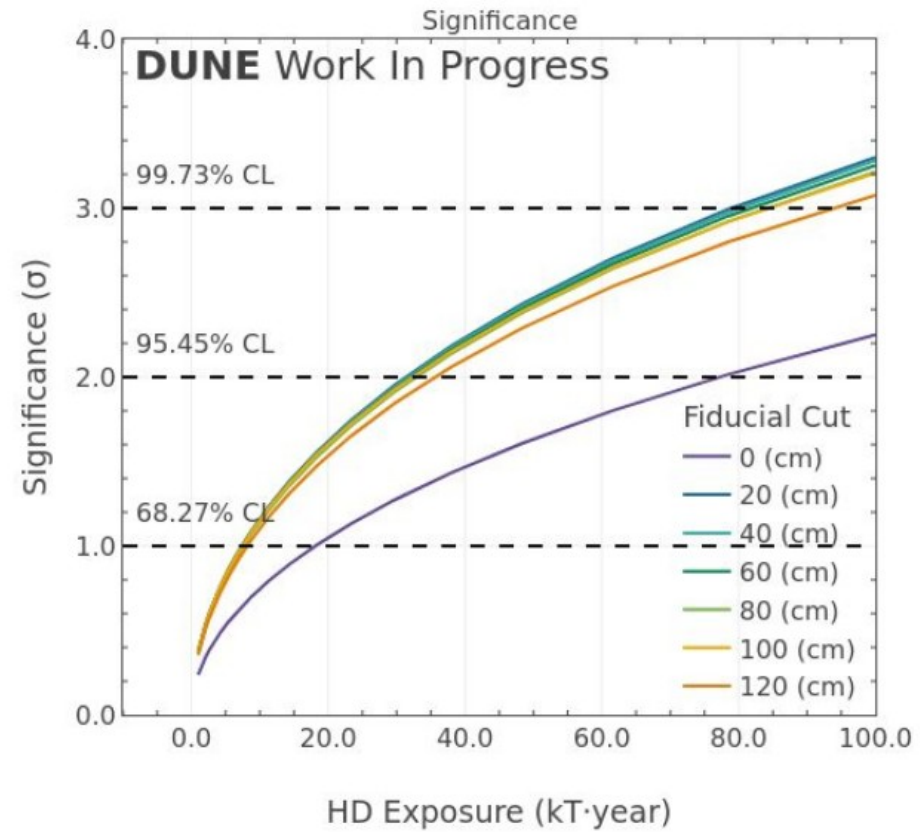
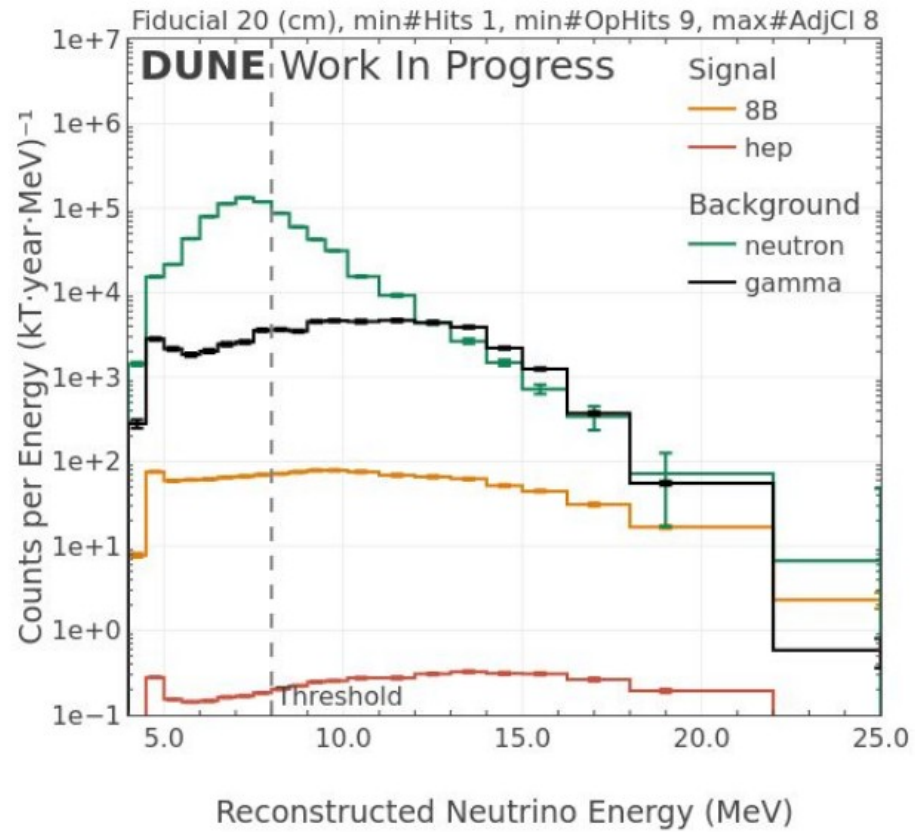
# Conclusions

- DUNE will exploit its high-statistics CC channel to attempt to **measure the solar hep flux**.
- Solar **oscillation measurements are particularly challenging** and plagued with large backgrounds.
- A push to **shield the VD module** would enable competitive measurements of the solar parameters even in phase I
- **Passive shielding in phase II will be crucial** for maximising DUNE's solar oscillation measurement capabilities

# Thanks

# Backups

HD sensitivity to day-night asymmetry (assuming global best-fit point)



# Backups

## Significance for hep discovery

### Asimov approximation for median significance

To get median discovery significance, replace  $n$ ,  $m$  by their expectation values assuming background-plus-signal model:

$$n \rightarrow s + b$$

$$m \rightarrow \tau b$$

$$Z_A = \left[ -2 \left( (s + b) \ln \left[ \frac{s + (1 + \tau)b}{(1 + \tau)(s + b)} \right] + \tau b \ln \left[ 1 + \frac{s}{(1 + \tau)b} \right] \right) \right]^{1/2}$$

Or use the variance of  $\hat{b} = m/\tau$ ,  $V[\hat{b}] \equiv \sigma_b^2 = \frac{b}{\tau}$ , to eliminate  $\tau$ :

$$Z_A = \left[ 2 \left( (s + b) \ln \left[ \frac{(s + b)(b + \sigma_b^2)}{b^2 + (s + b)\sigma_b^2} \right] - \frac{b^2}{\sigma_b^2} \ln \left[ 1 + \frac{\sigma_b^2 s}{b(b + \sigma_b^2)} \right] \right) \right]^{1/2}$$

# Backups

## Solar neutrino signal at DUNE

