Science and
Technology
Facilities Council

Neutrinos as Evidence for Dark Matter & Novel Detector Technologies with LiquidO

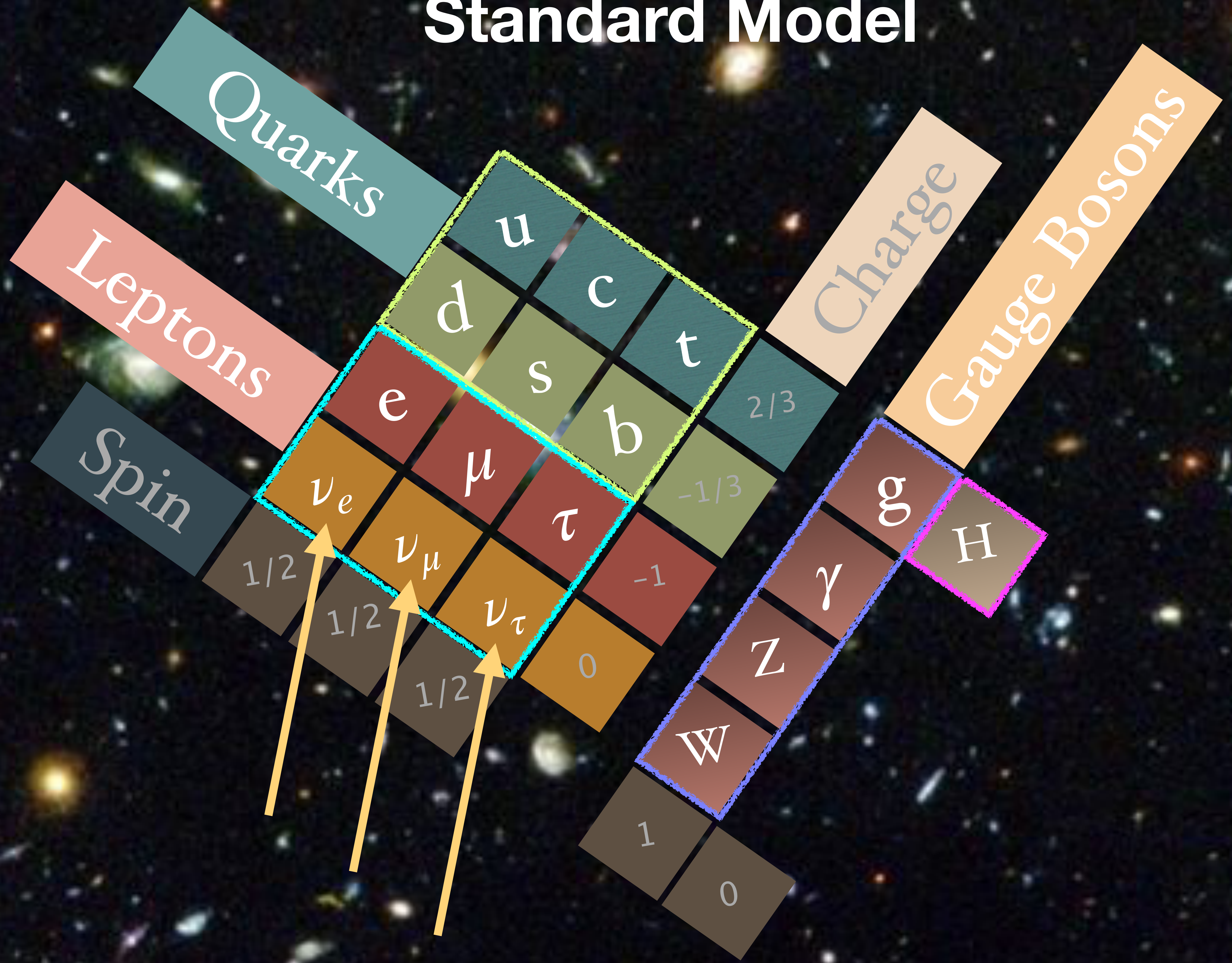
Anna Holin, STFC PPD, 20.02.2024
Jeff Hartnell, Sussex University
Special advisor Claire Shepherd-Themistocleus, PPD

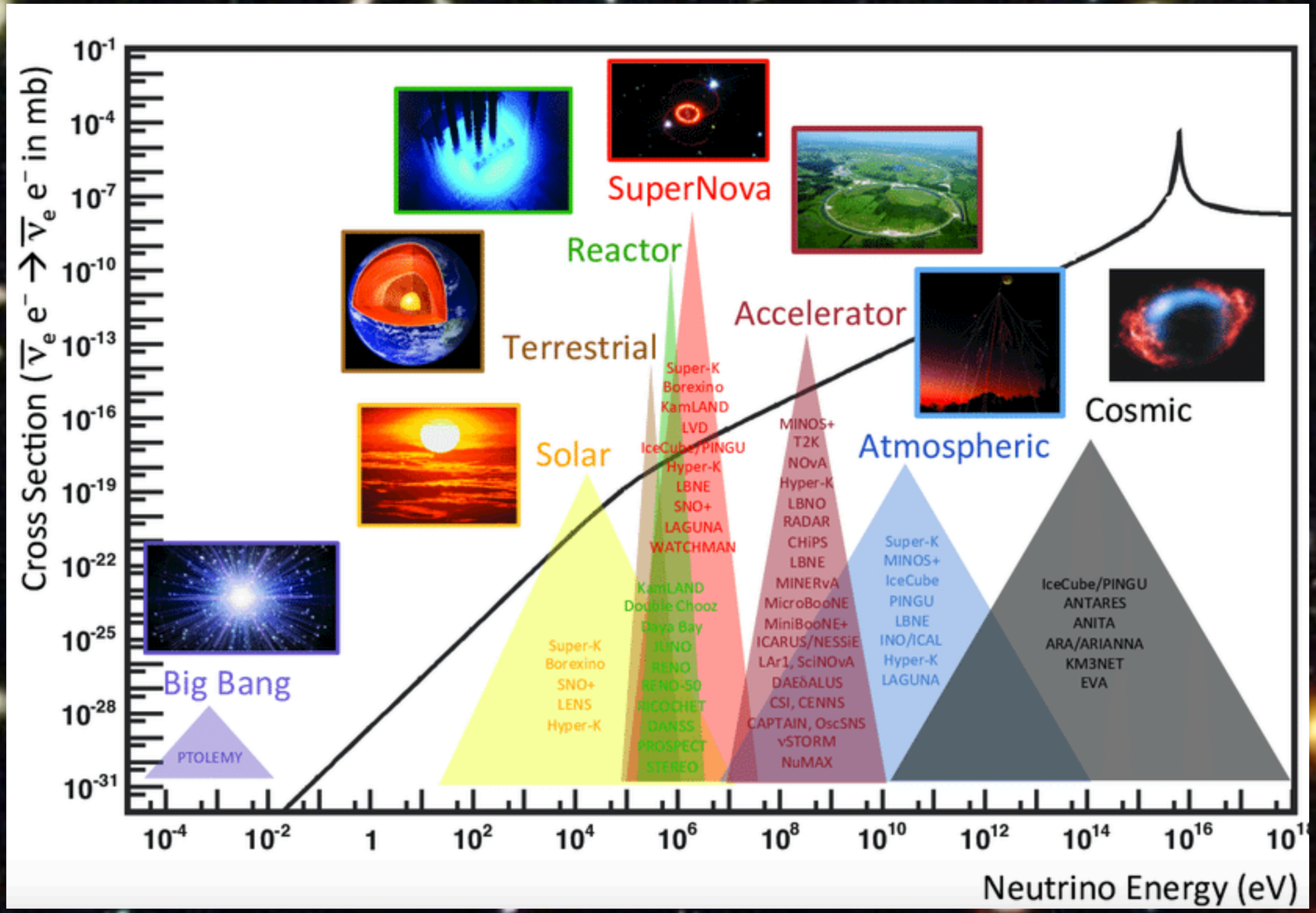
* SuperKamiokande image of the Sun

What are neutrinos?

- Neutrinos are fundamental particles that complete our Standard Model of particle physics
- Neutrino permeate the universe, yet few people realise they even exist as they interact so rarely
- Neutrinos interact via the weak force and gravity, and a neutrino could travel through a wall of lead a light year thick and never interact at all! That's why we also call them ghost particles
- Stars produce neutrinos all the time, in fact we can even image the sun with neutrinos, using our advanced neutrino detectors

Standard Model



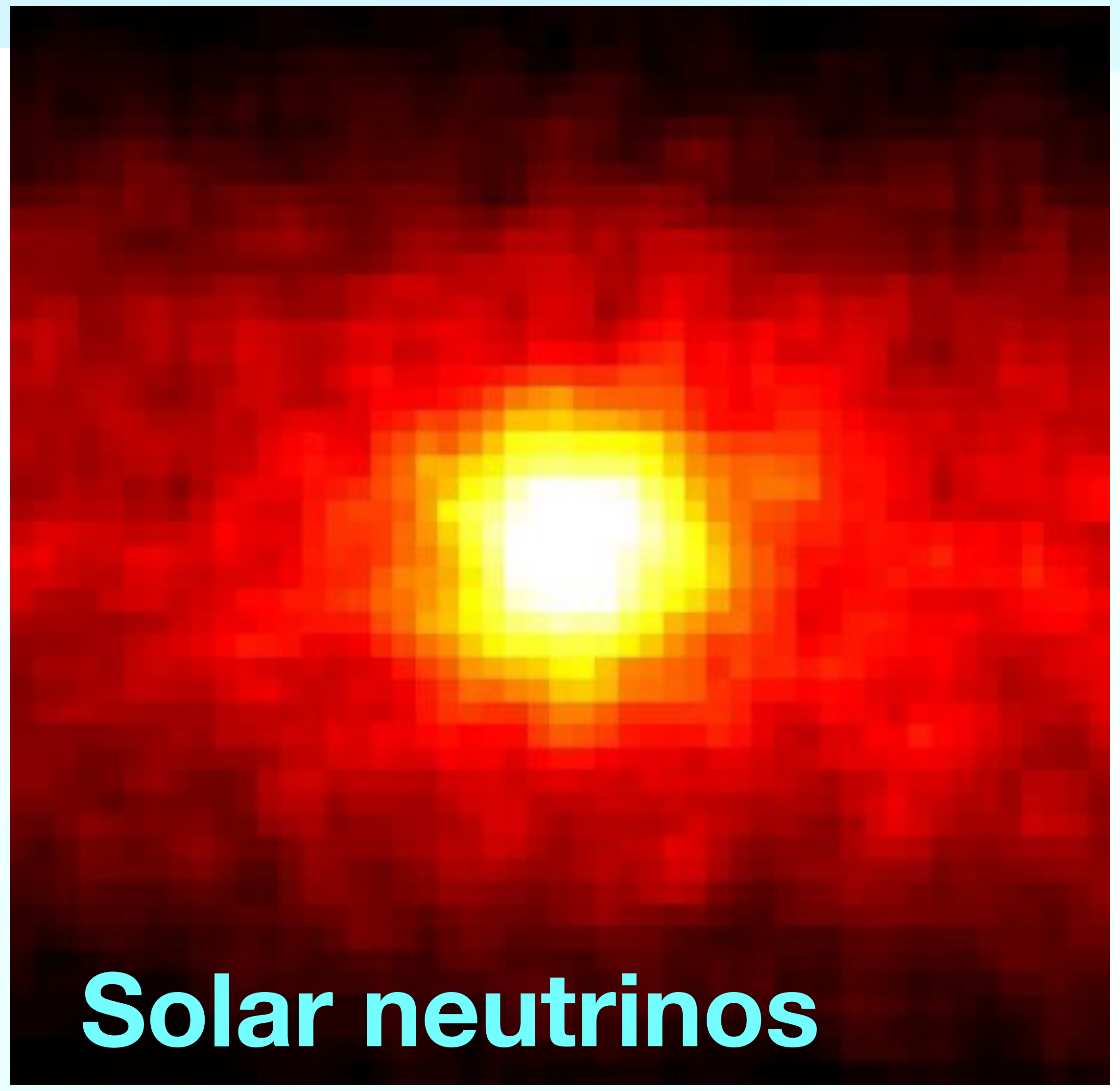


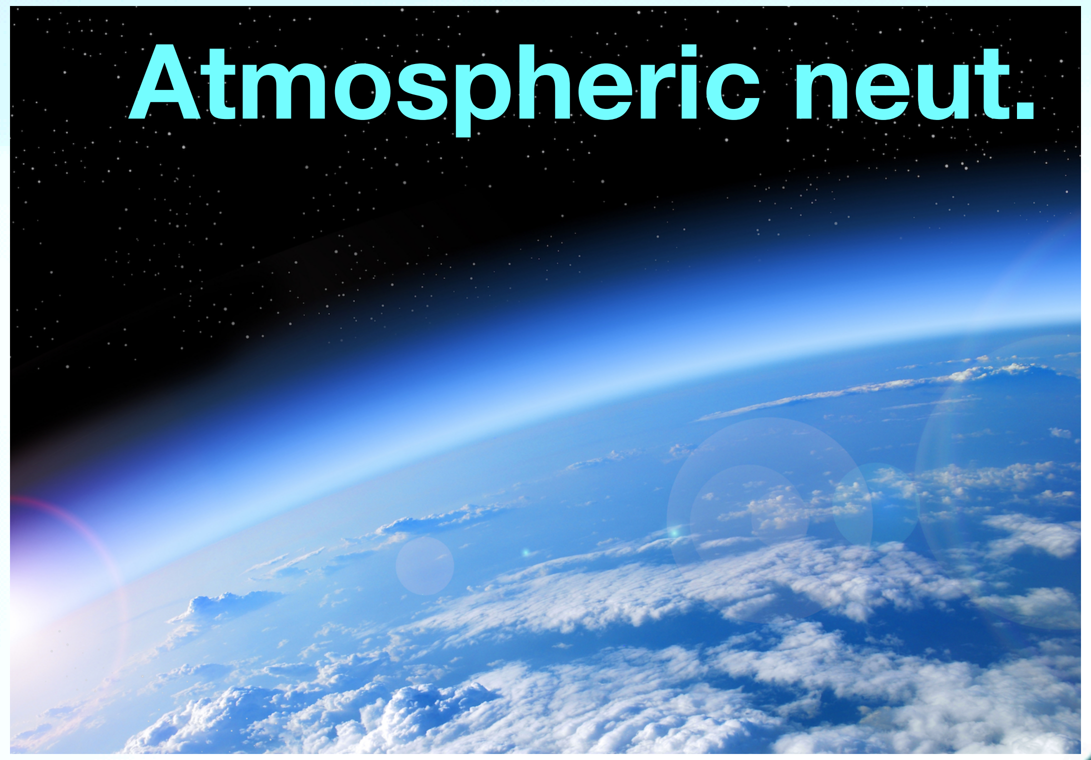
Modern “long-baseline” experiments

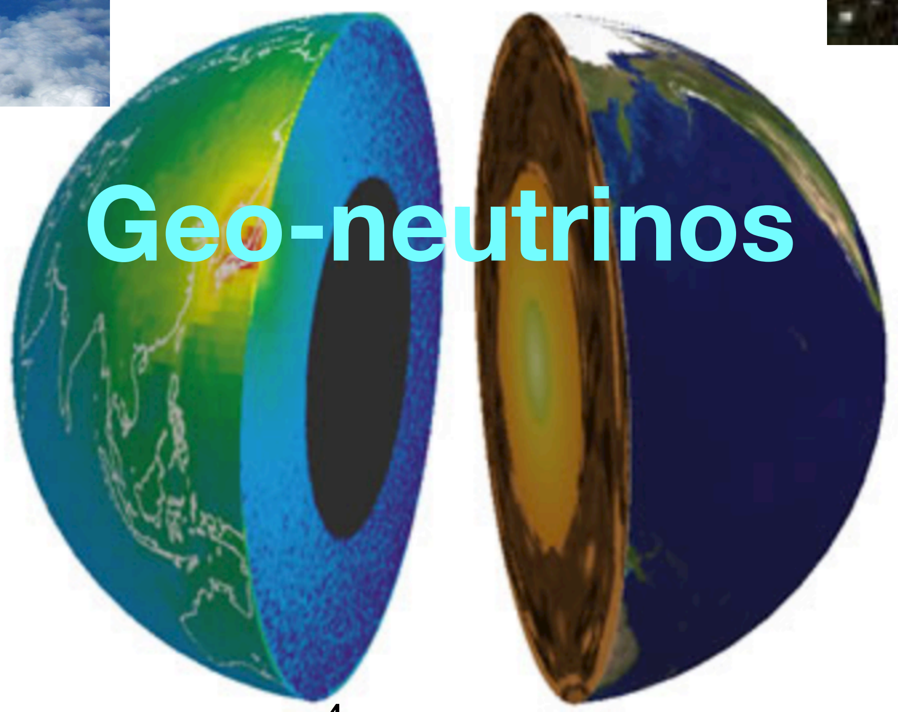
- We now know that neutrinos oscillate, that is change from one neutrino flavour to another as they travel through space and matter
- The gold standard for measuring muon neutrino oscillations is to use “long-baseline” neutrino experiments
- We make a beam of muon neutrinos, measure this beam before oscillations have occurred, and then several hundreds of km away after the neutrinos have oscillated
- This is the main purpose of our modern neutrino experiments such as DUNE and HyperK

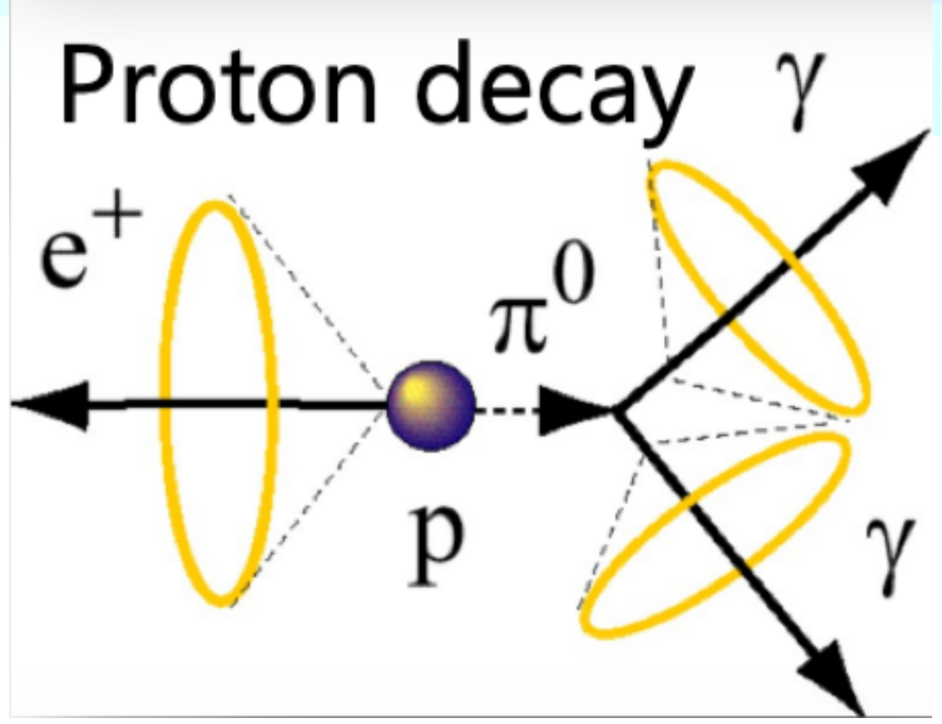
Next generation neutrino experiments DUNE and HyperK

- PPD is involved in the **two biggest next generation neutrino experiments in the world!**
- DUNE and HyperK are both billion dollar (or more!) experiments and will give us answers to the **neutrino oscillations** questions, **but also into so much more!**
- They are both pushing the technological boundaries by their sheer size and precision, being able to see neutrino events even as low as the MeV scale
- They are **modern multi-messenger observatories!**



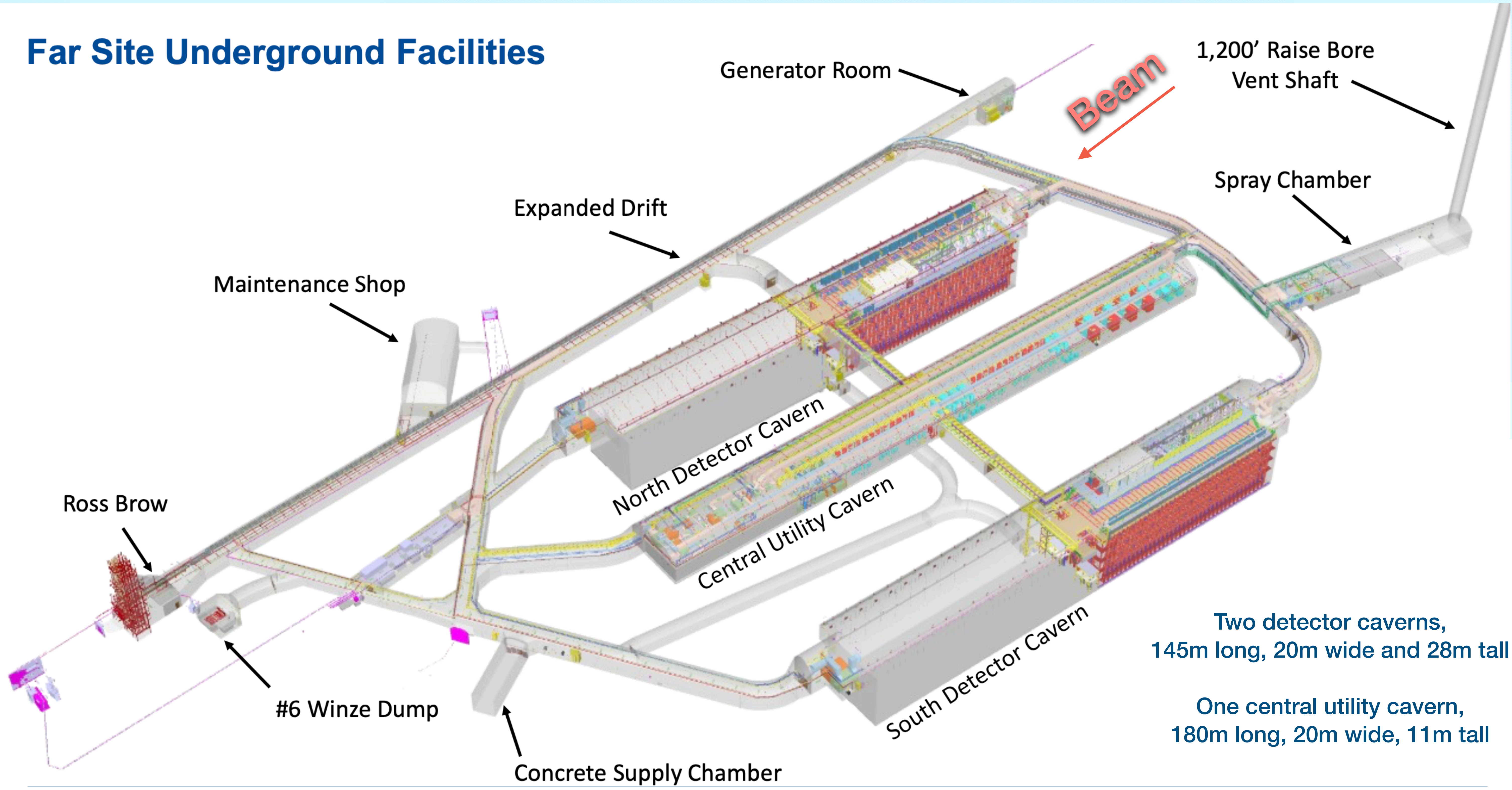






DUNE

- International effort coordinating over a thousand scientists from 35 countries, including a very significant effort from CERN and the UK (DAQ and APA planes)
- Liquid argon temperature is 87K! The prize are exquisite event displays with incredible detail, down to a few mm
- DUNE LAr-TPCs are more than an order of magnitude bigger than any we have built until now
- Two huge 17kton Far detectors, start taking physics data at the end of this decade, with 2 additional detectors in phase 2, plus a complex ND suite to measure neutrino flux at production
- Technology now developed and well tested, ProtoDUNE detectors at CERN, SBN program at Fermilab (MicroBooNE has been running for years)



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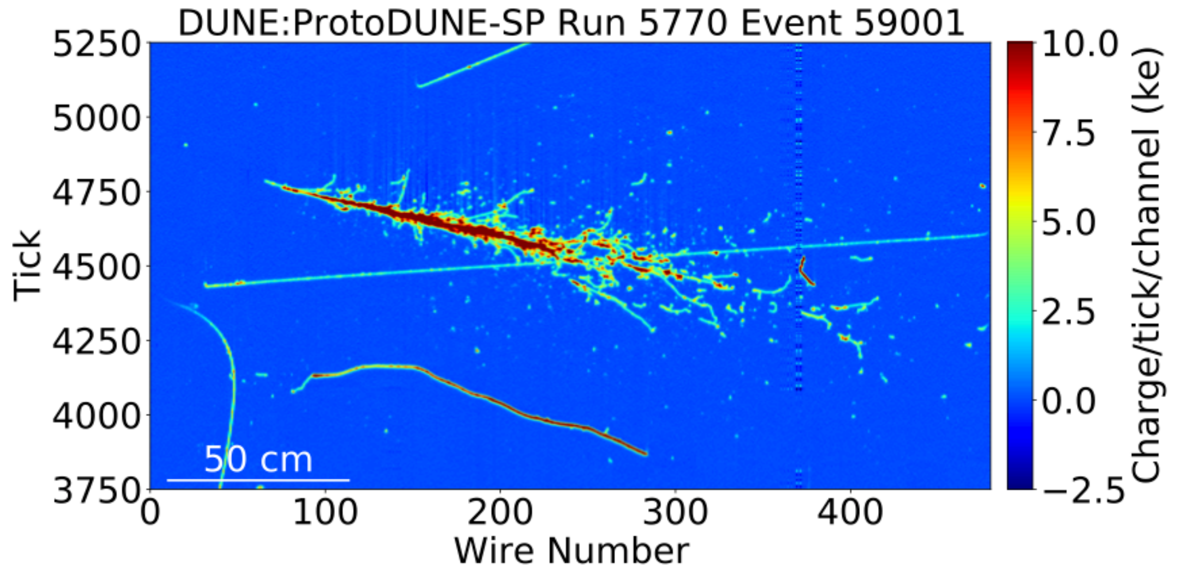
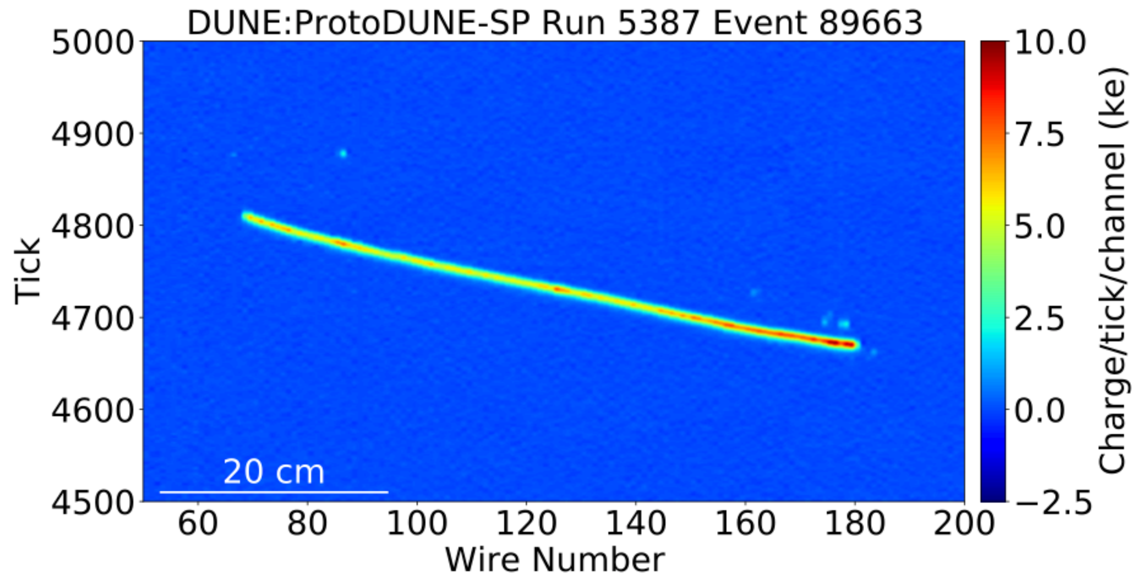


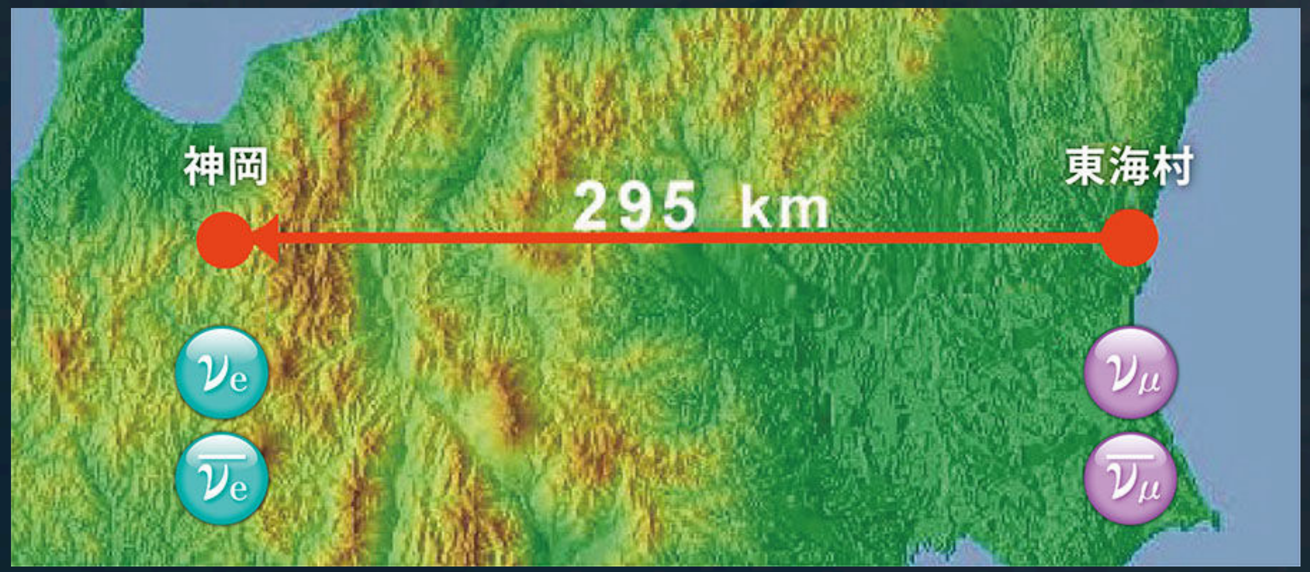
(b) A 6 GeV/c electron candidate.

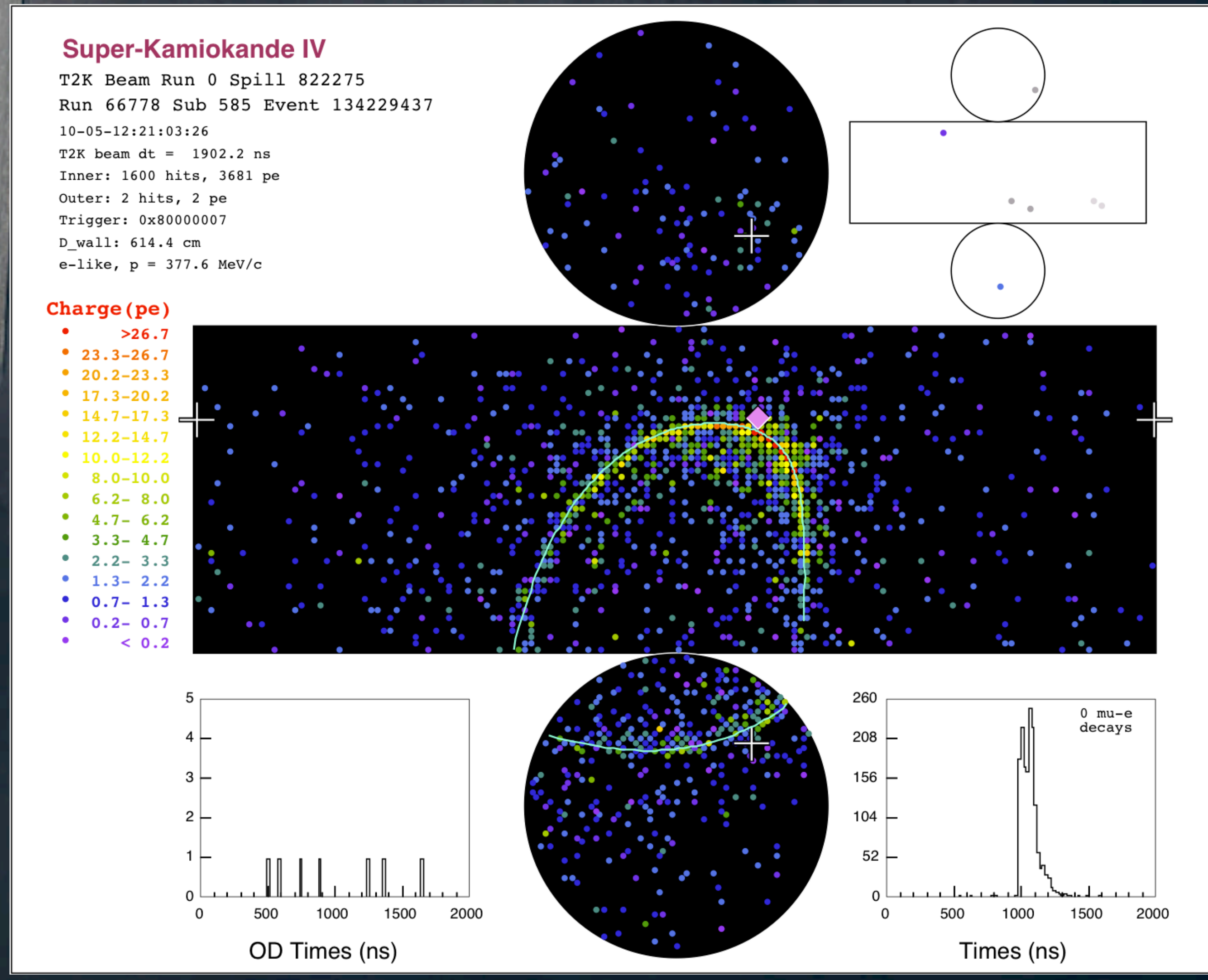


(e) A 1 GeV/c stopping proton candidate.

HyperKamiokande

- HyperK is the next evolution of the existing SuperKamiokande and T2K experiments in Japan
- Expect to start taking data towards the second half of 2027
- Far detector is cylindrical water Cherenkov detector, inner detector volume 60m tall and 60m diameter
- It will be huge! ~260ktons, with fiducial volume about 8 times bigger than existing SuperK detector
- Uses the JPARC muon neutrino beam
    - complex Near detector suite at JPARC
    - IWCD 1km from the beam source for precision beam/cross-section measurements





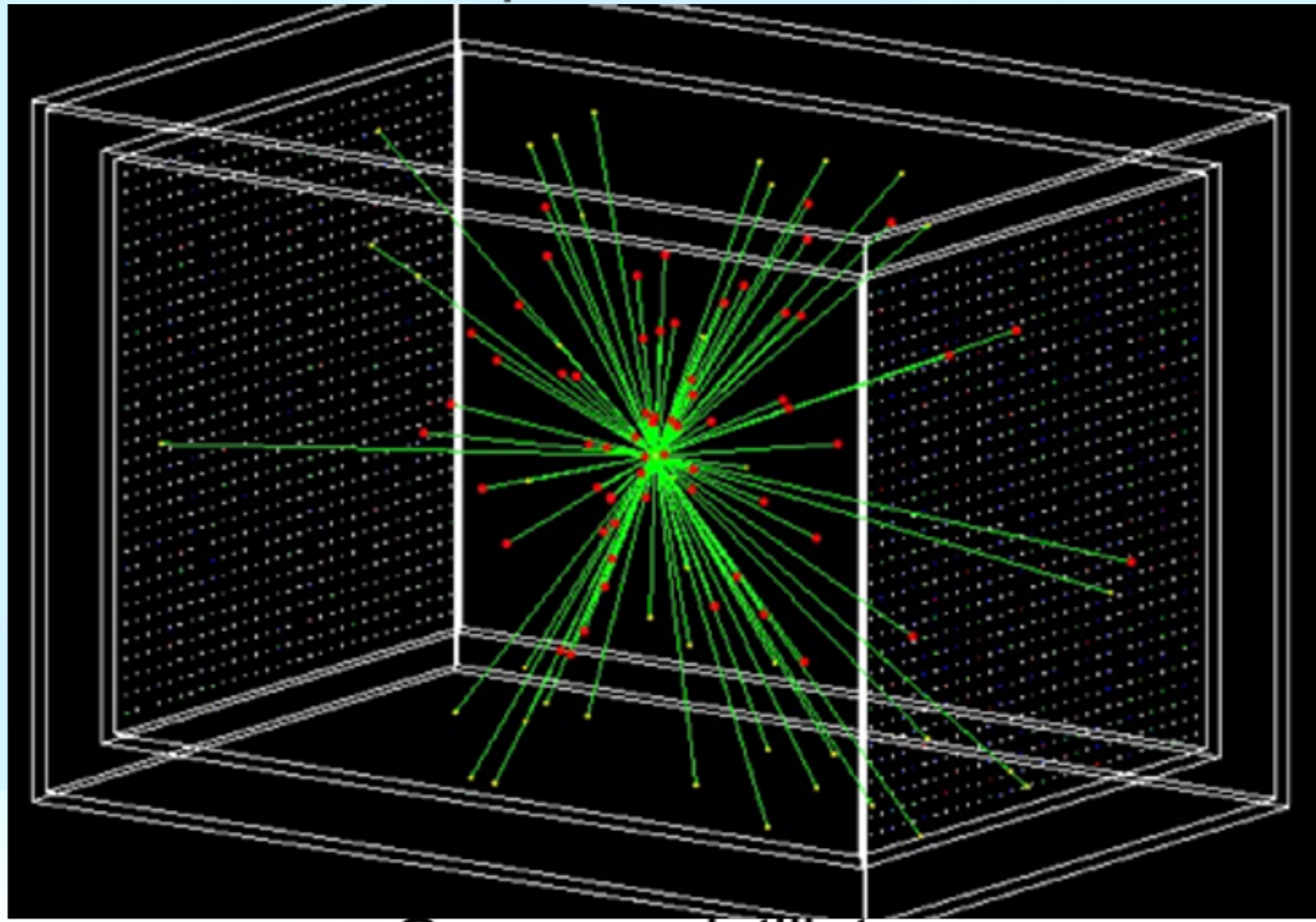
Dark Matter with neutrinos

- HyperK and DUNE should be able to detect neutrinos from Dark Matter!
- WIMPs, a strong candidate for DM, can decay/annihilate and produce SM particles and therefore neutrinos! Depending on the model, it could happen in stars (e.g. the sun), and in the Galactic centre
- Two possible areas of investigation for this PhD
    - 1. We will explore the potential of HK and DUNE to be used as neutrino telescopes to carry out indirect DM searches coming from the galactic centre - can search for an excess of neutrinos coming from the direction of the Galactic centre
    - 2. We can also search for monoenergetic neutrinos coming from the sun; pion decay at rest and kaon decay at rest coming from DM capture and annihilation in the sun will produce monoenergetic muon neutrinos with energies 29.8MeV and 235.6MeV respectively - the muon neutrinos will oscillate on their way to the earth

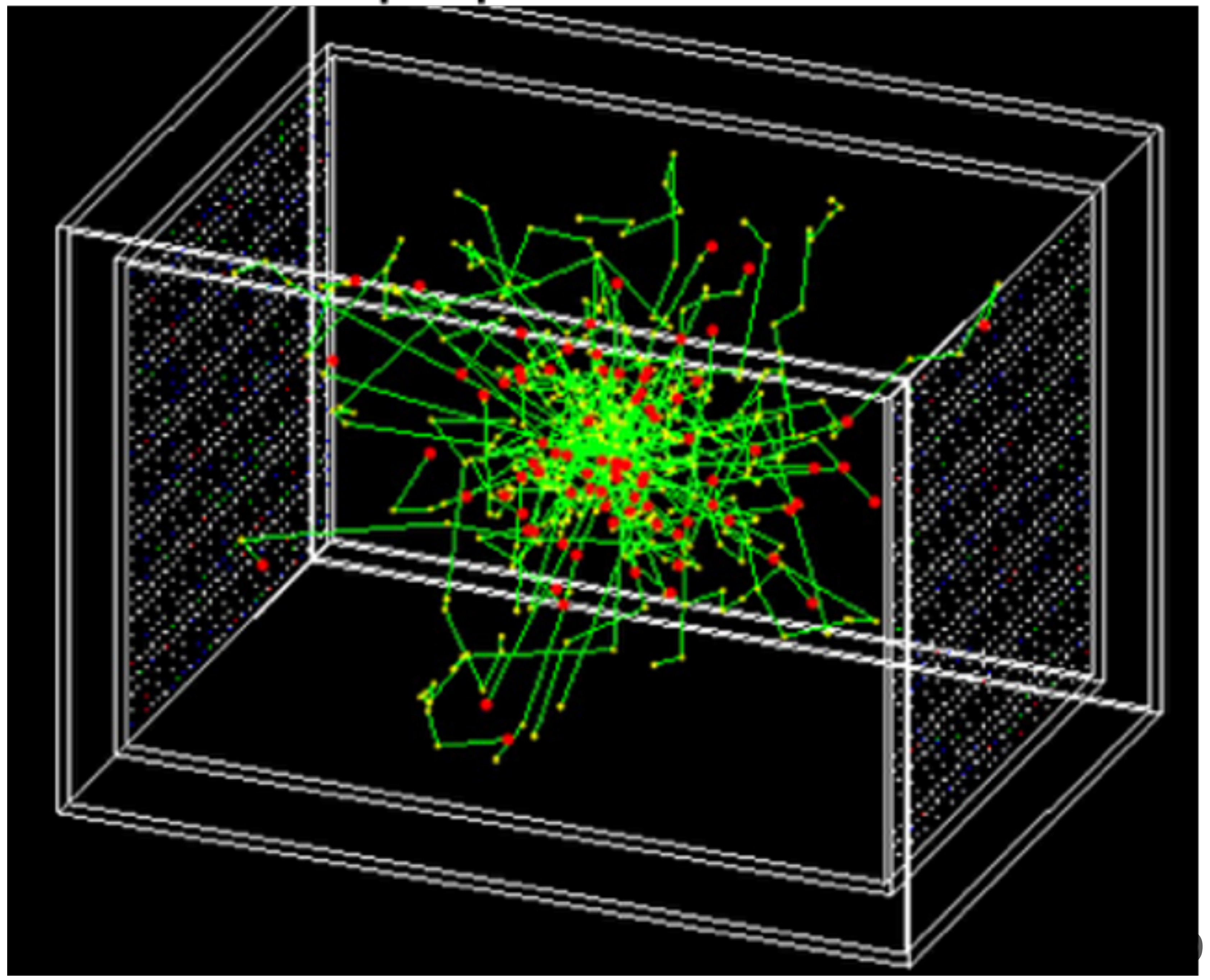
LiquidO

- The second part of the project focuses on future detector technology with incredible potential!
- It turns the paradigm of having transparent detectors completely on its head, using opaque detectors instead!
- Opaque scintillator + lattice of WLS fibres to read out the light
- Would be easy to build, safe, and scalable to big sizes, while providing incredible, liquid argon like, event detail
- Photons are confined tot he point of production via scattering, which makes dense “light balls” around energy deposits

Transparent scintillator

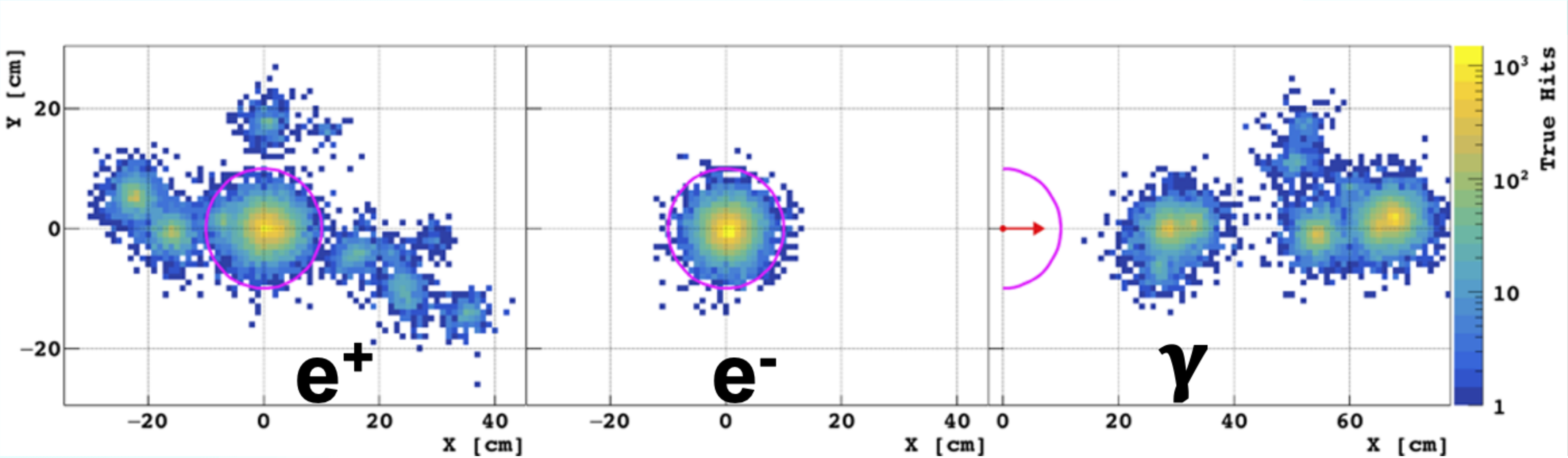


Opaque scintillator



LiquidO

- High resolution imaging for particle identification
- Distinguish 2MeV positrons from point-like energy depositions (e.g. electrons, protons, alphas)



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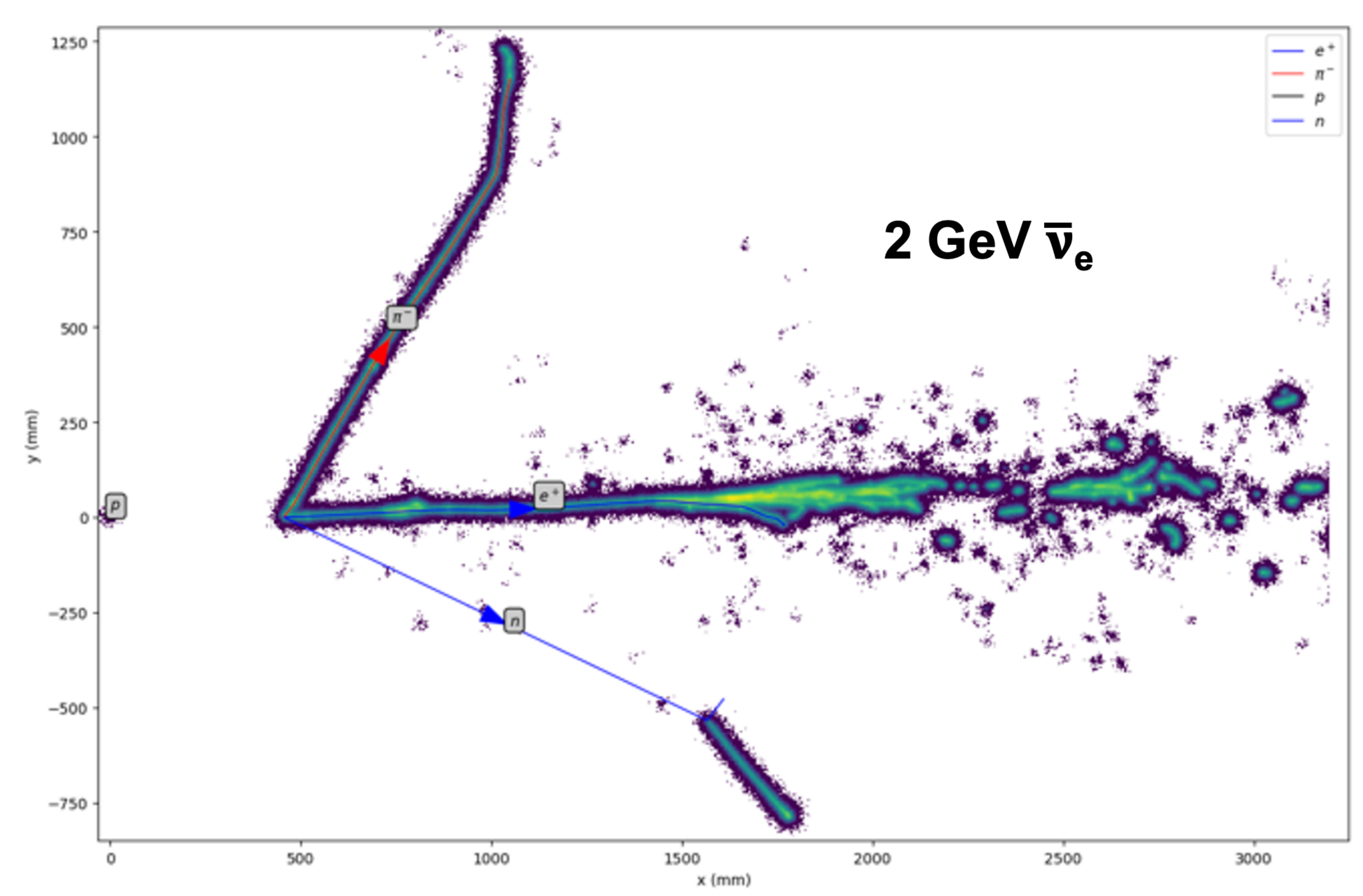
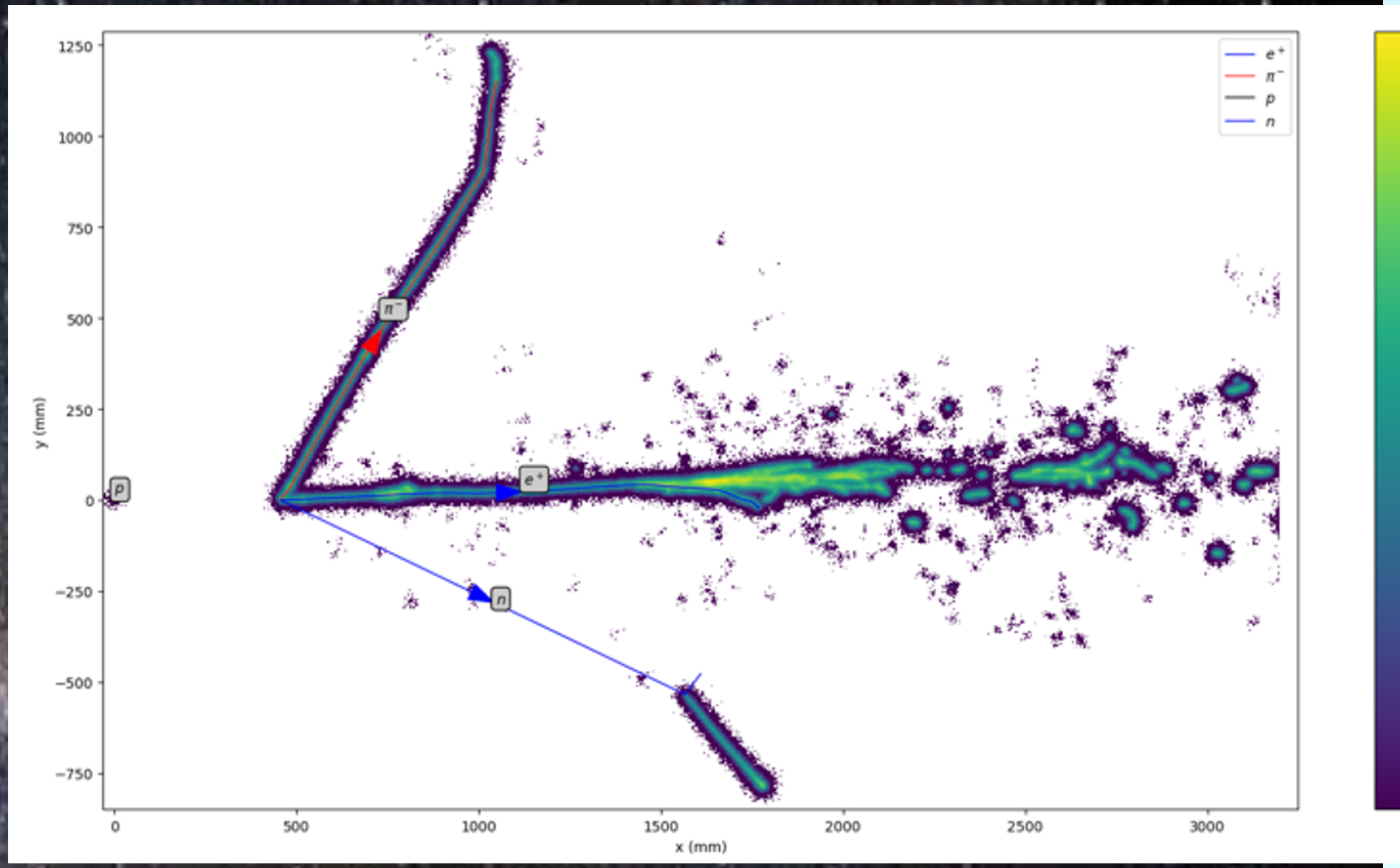
LiquidO

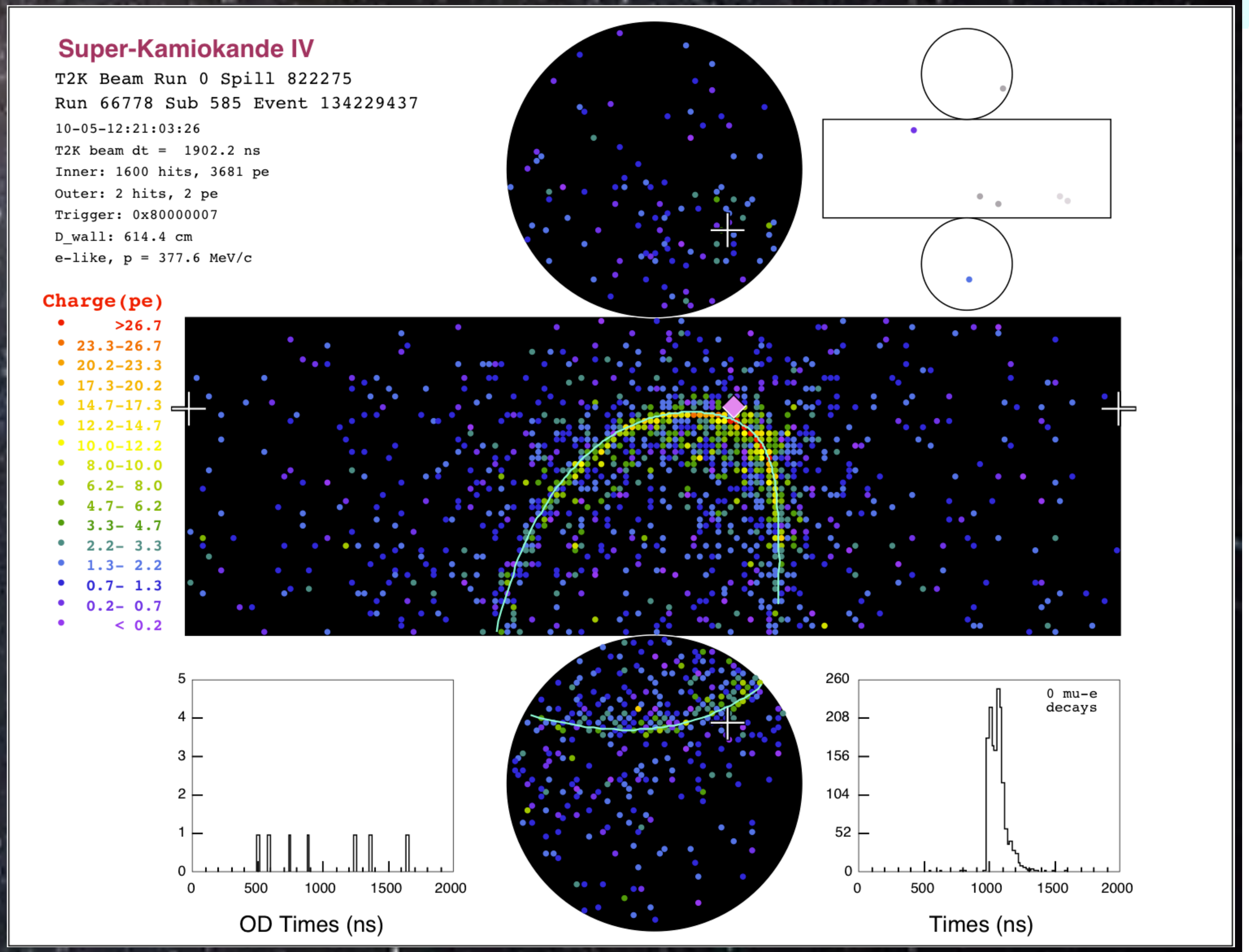
- RAL have joined the LiquidO collaboration in the summer of last year, and Jeff Hartnell has spearheaded the LiquidO concept work at Sussex since its very beginning
- Plan to build a prototype at RAL for R&D development work starting asap
- Also possibility of getting involved in CLOUD, a LiquidO type detector being built at the Chooz reactor site
- Look at the design of future detector upgrades, for example for the HK near detector suite
- Very exciting possibilities!

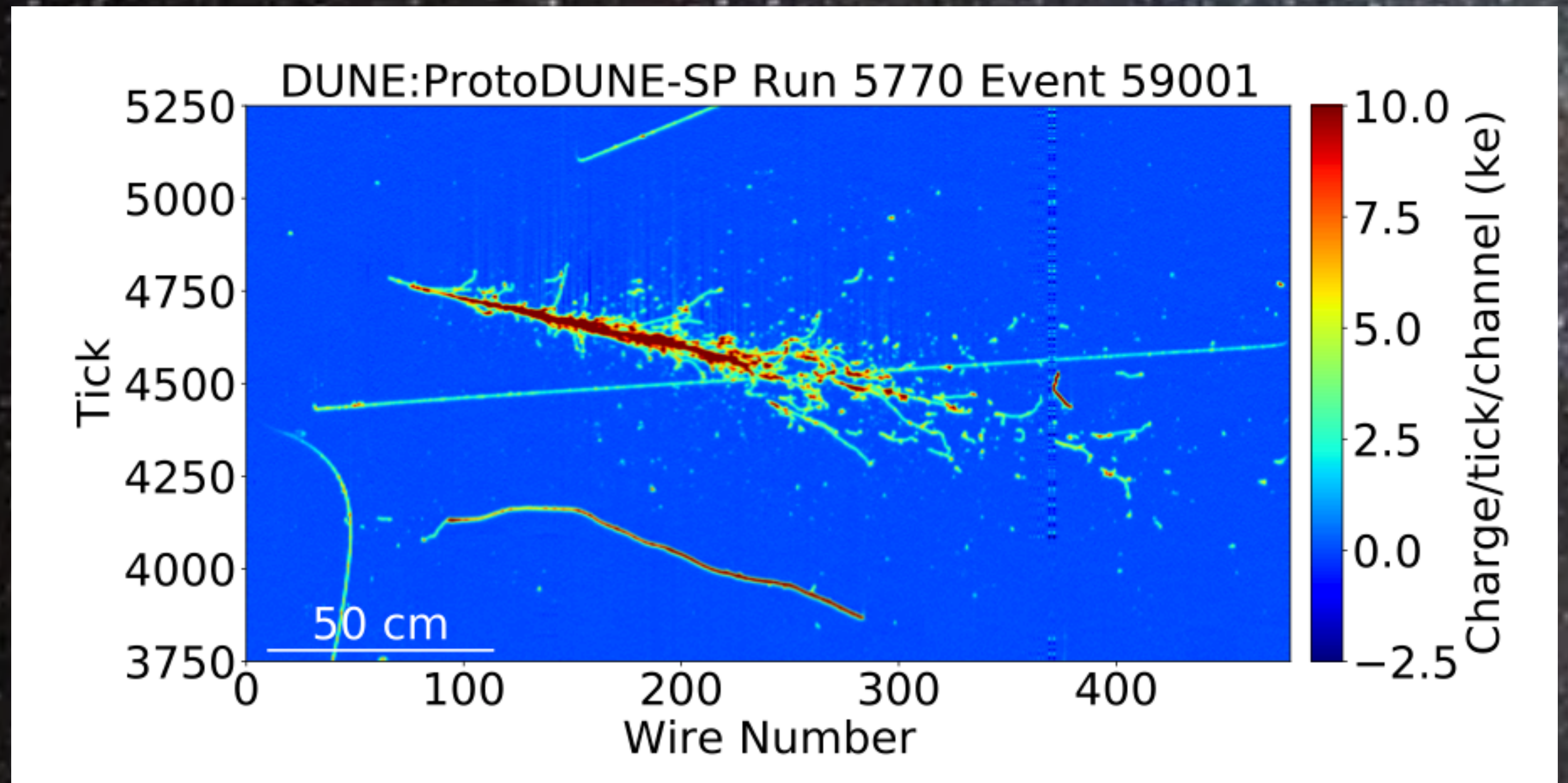


Summary

- We are looking for a motivated PhD student for this very exciting project, looking to the future of particle physics!



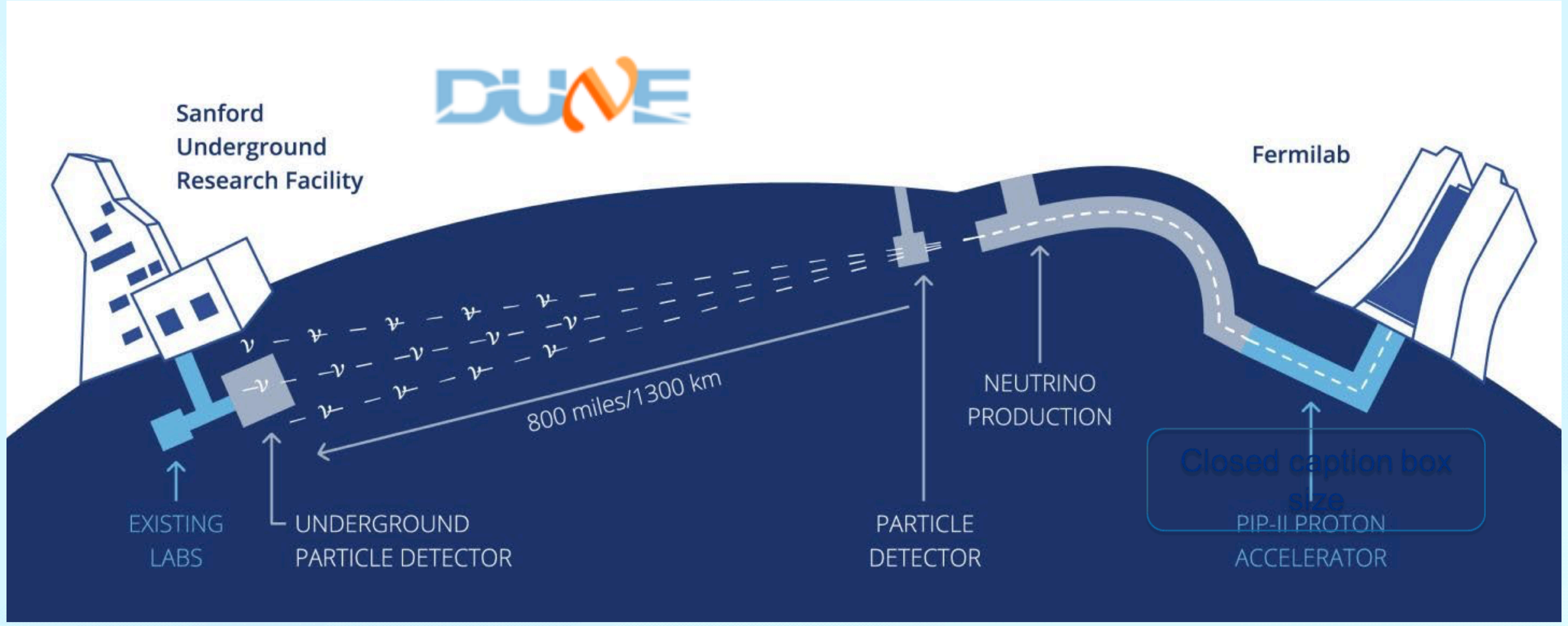




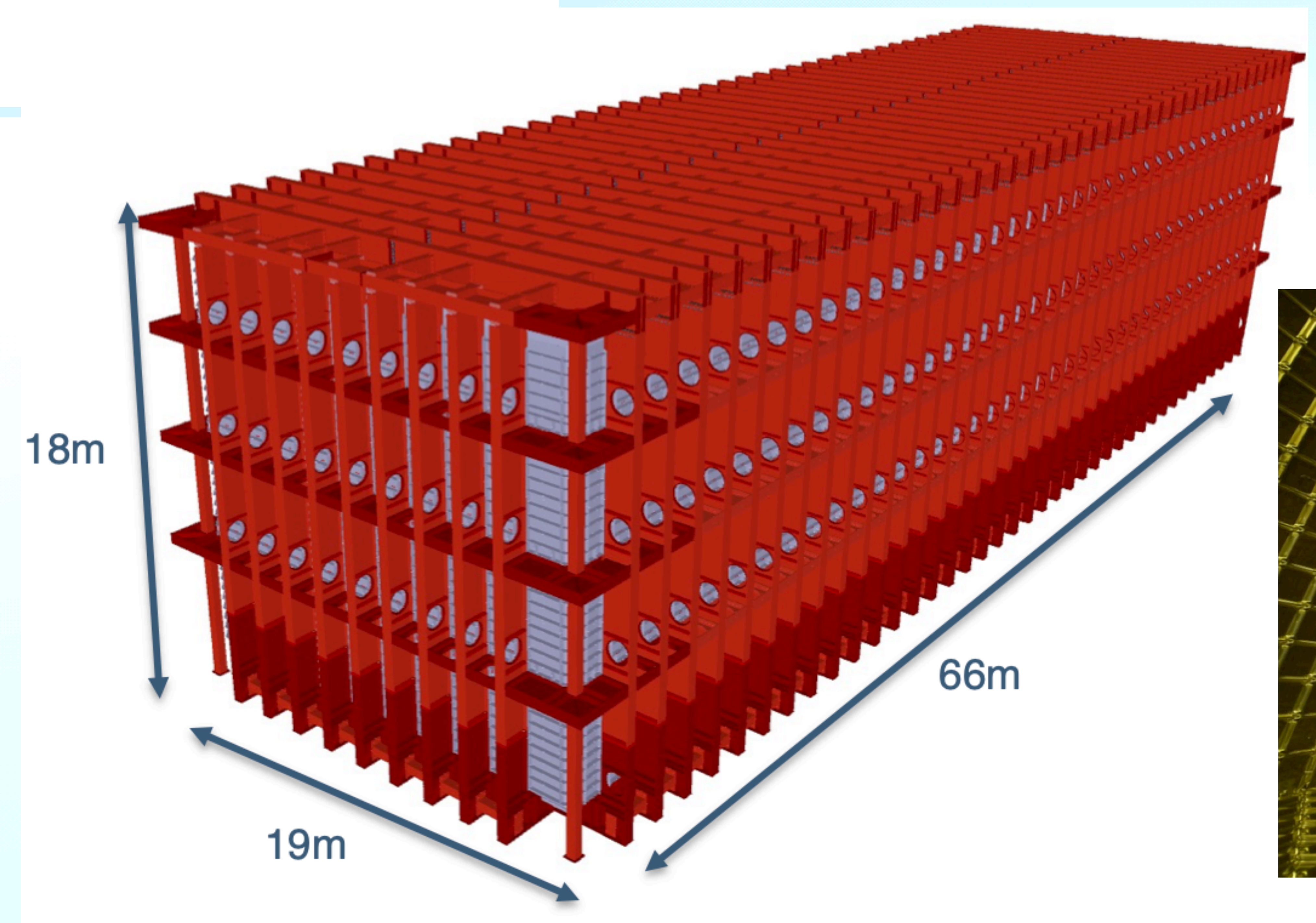
(b) A 6 GeV/c electron candidate.

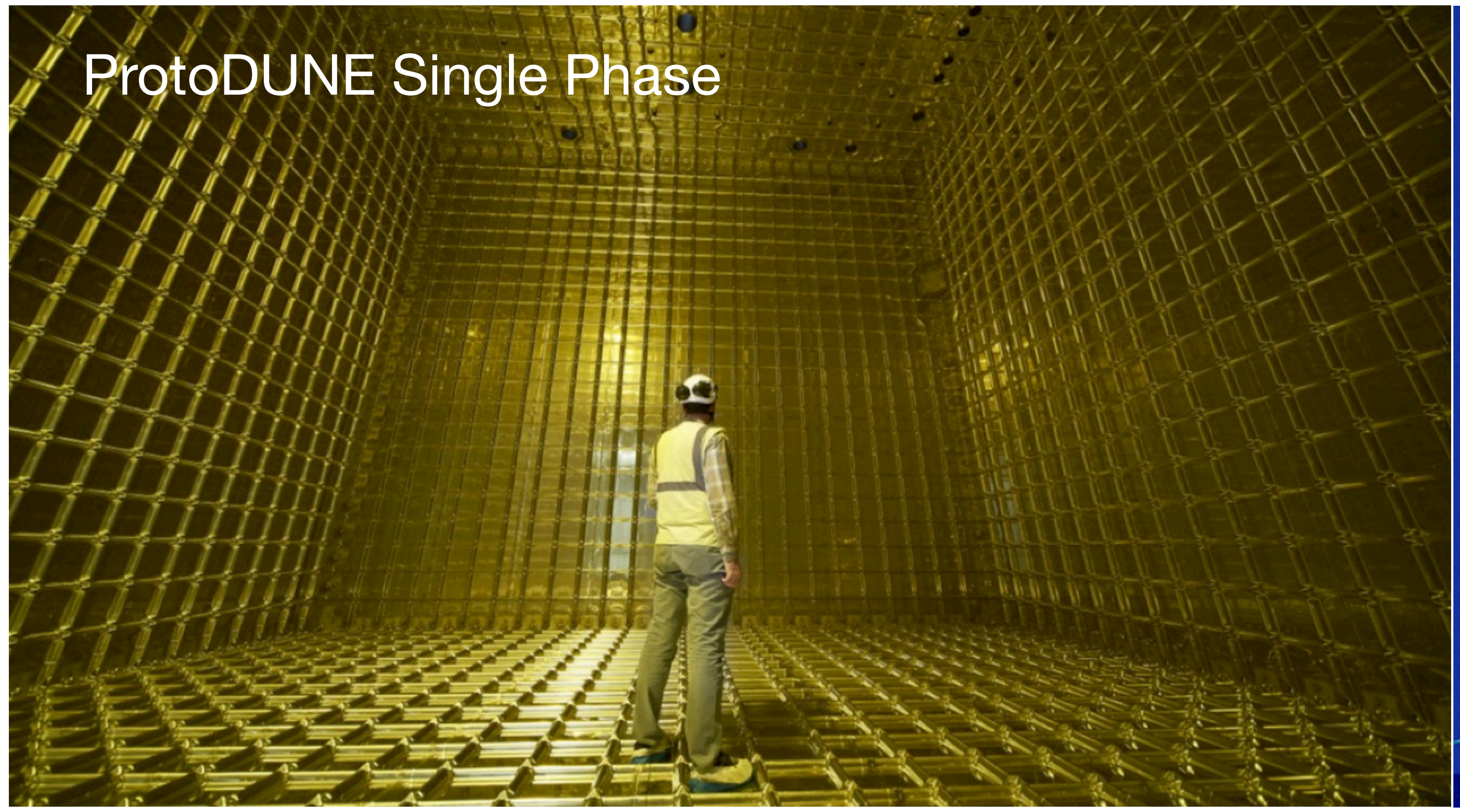
Back Up

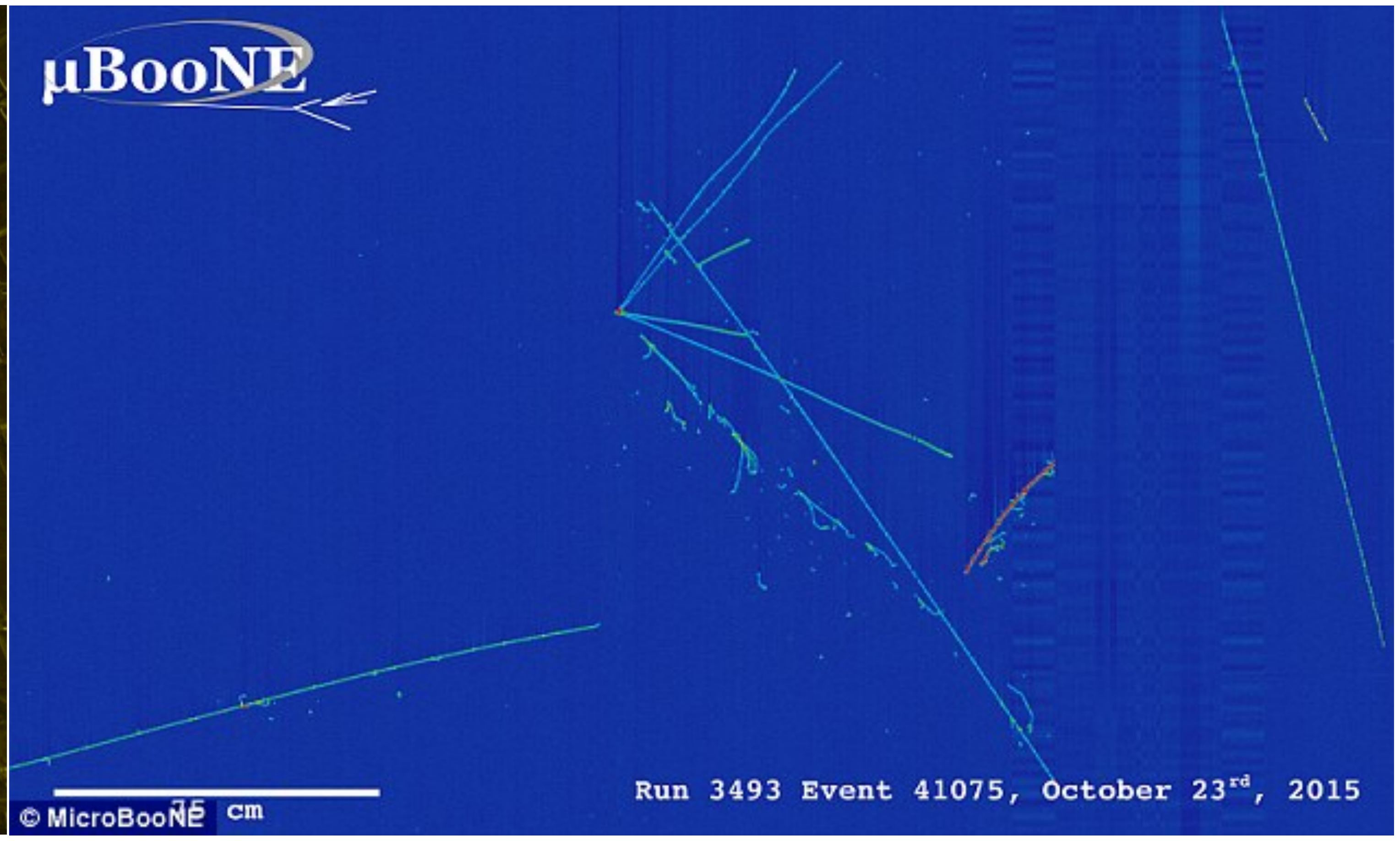
DUNE



- State-of-the-art liquid argon TPC detector technology, giving exquisite event displays allowing us to see real time events with mm precision!
- Near site 550m from beam source, Far site 1300km away
- Most powerful neutrino beam ever, 1.2MW power during phase 1 (starting 2031), upgradable to 2.4MW in phase 2 - RAL building the targe for the beam!
- Wide band beam (several GeV) - being able to see a range of neutrino interactions, from QE to DIS
- Two huge 17kton Far detectors, start taking physics data in 2029, with 2 additional detectors in phase 2
- Extensive Near detector suite, including movable liquid argon detector, for precision beam flux and cross-section measurements



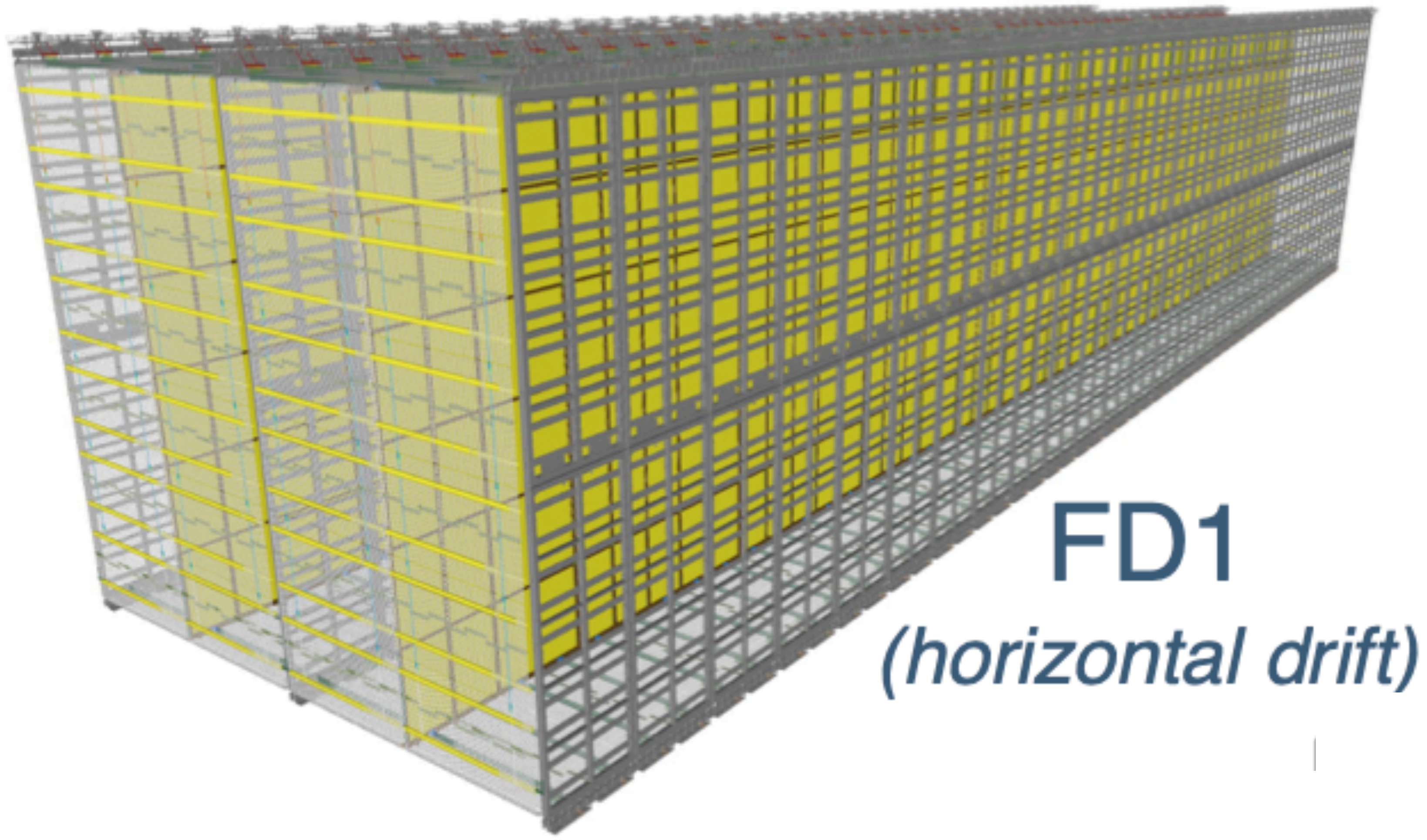




An incredibly complex endeavour

DUNE APA plane tested at Daresbury Lab

- Getting to this point has taken many years in incremental effort, both R&D and building on previous world-leading neutrino experiments
- The liquid argon has to be very pure/clean to drift electrons
- The scintillation light produced in LAr is in the far UV, 127nm, needs to be wavelength-shifted to be read out by our light detectors, which need to be able to function at 87K (-186C)!
- The engineering effort to build the huge cryostats 1000m underground at SURF is incredible, building huge chambers that will house the neutrino detectors
- All the readout electronics need to be able to function at low temperatures, read out thousands of wires for each APA plane
- Environmental and safety concerns, both at the Near and Far sites



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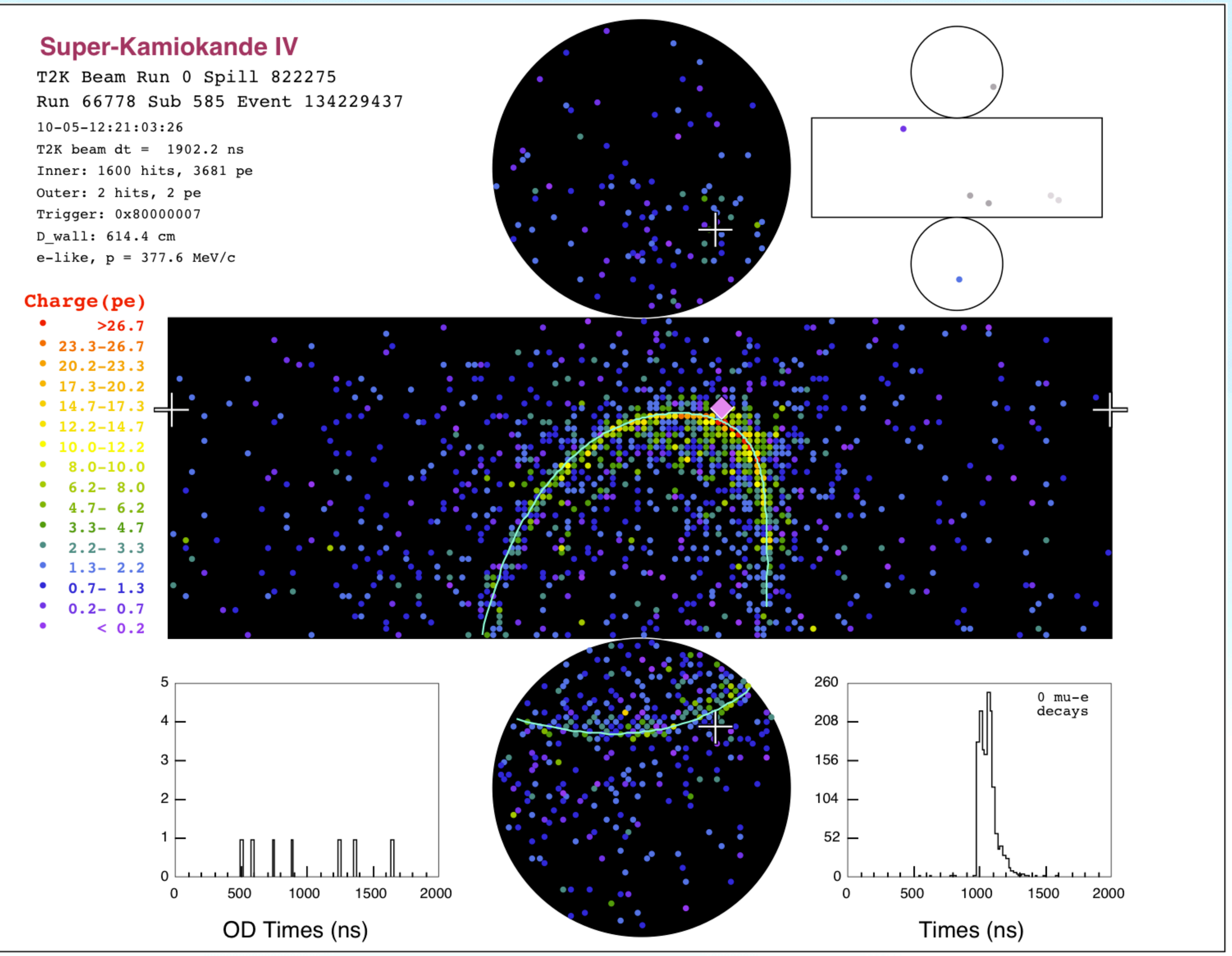
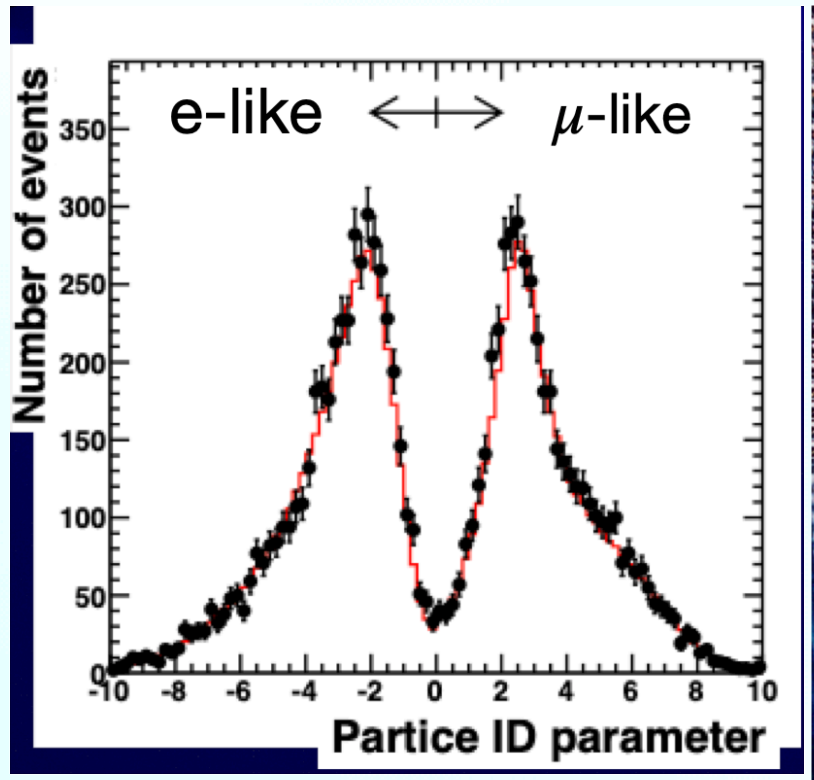
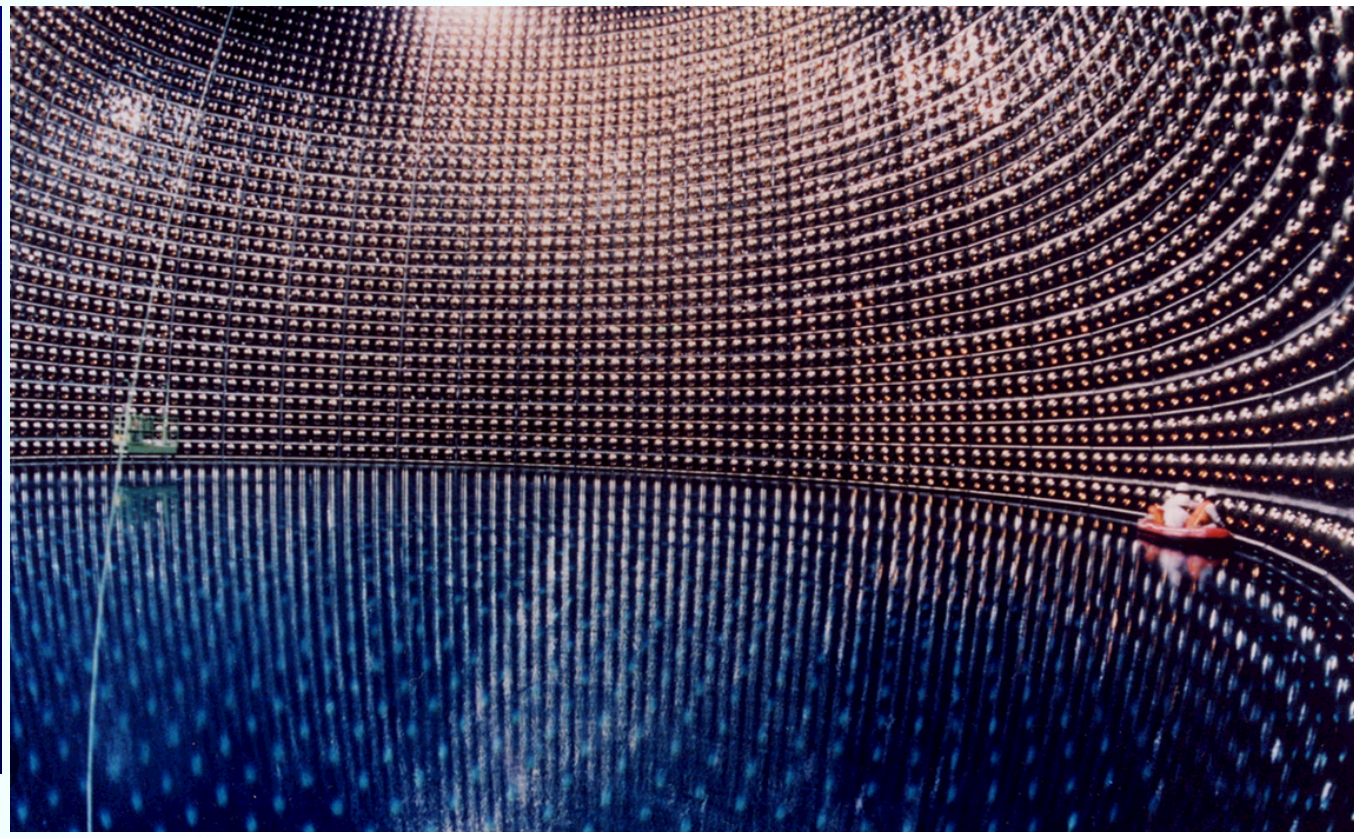
A well understood technology







- Neutrinos are detected by the observation of Cherenkov radiation produced in ultra pure water - can reliably identify muon and electron neutrinos for the oscillation analysis
- 20,000 High-QE 50cm PMTs (plus mPMTs) reaching low MeV energy events for a huge array of physics potential
- Incredible detector size: volume is 260kton, with FV of 188kton (SuperK is 50kton, with FV 22.5kton)
- Complex suite of Near detectors, including a movable IWCD, for precision beam flux/cross-section measurements - the ND280 and Ingrid detectors already exist, and have been used for a long time now by the T2K experiment (ND280 just upgraded with a new SuperFGD scintillator detector)
- Narrow band (off-axis) beam peaked at the oscillation maximum
- UK plays leading role - DAQ, beam target, detector electronics, calibration, Outer Detector (cosmic ray veto)