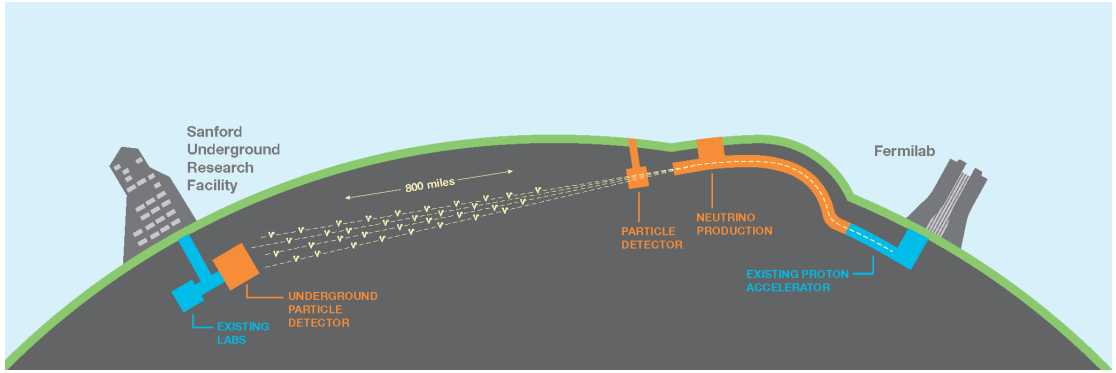
“North American” Accelerator Neutrino Programme

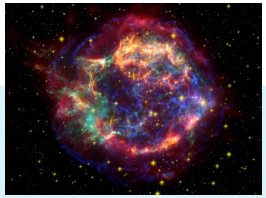
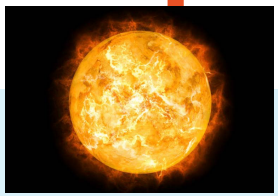
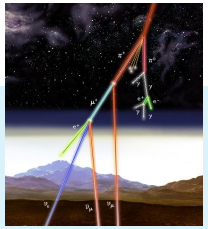
Stefan Söldner-Rembold

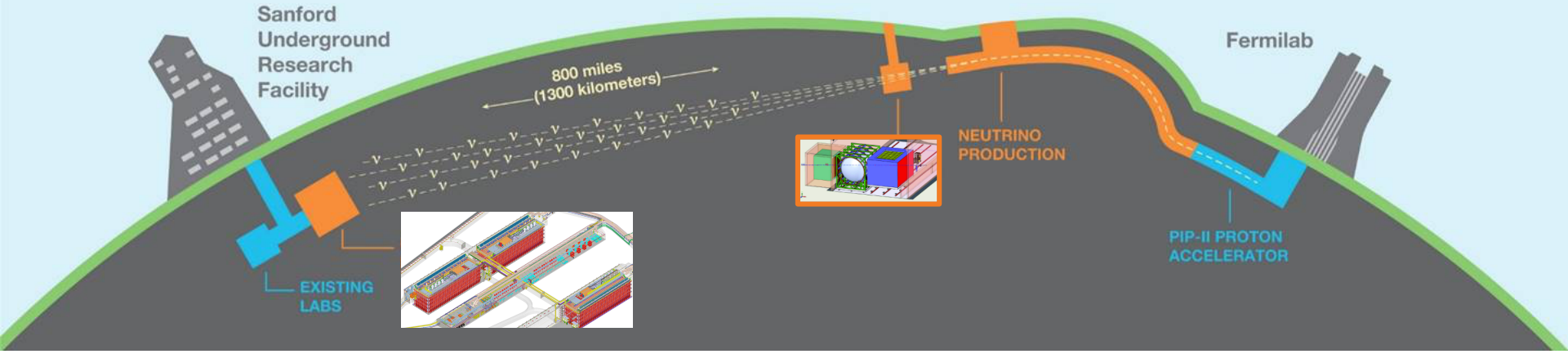
PPAP

19 November 2020



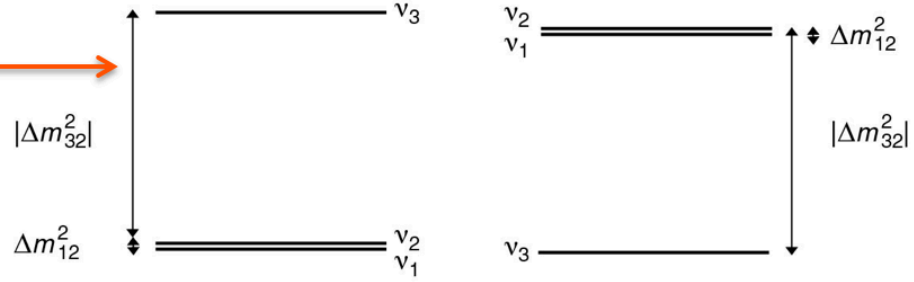
Three pillars of DUNE



1. A high-power (1.2-2.4 MW), wide-band neutrino beam.
2. A ≈ 70 kt liquid-argon underground Far Detector in South Dakota.
3. A capable Near Detector located close to the neutrino source.

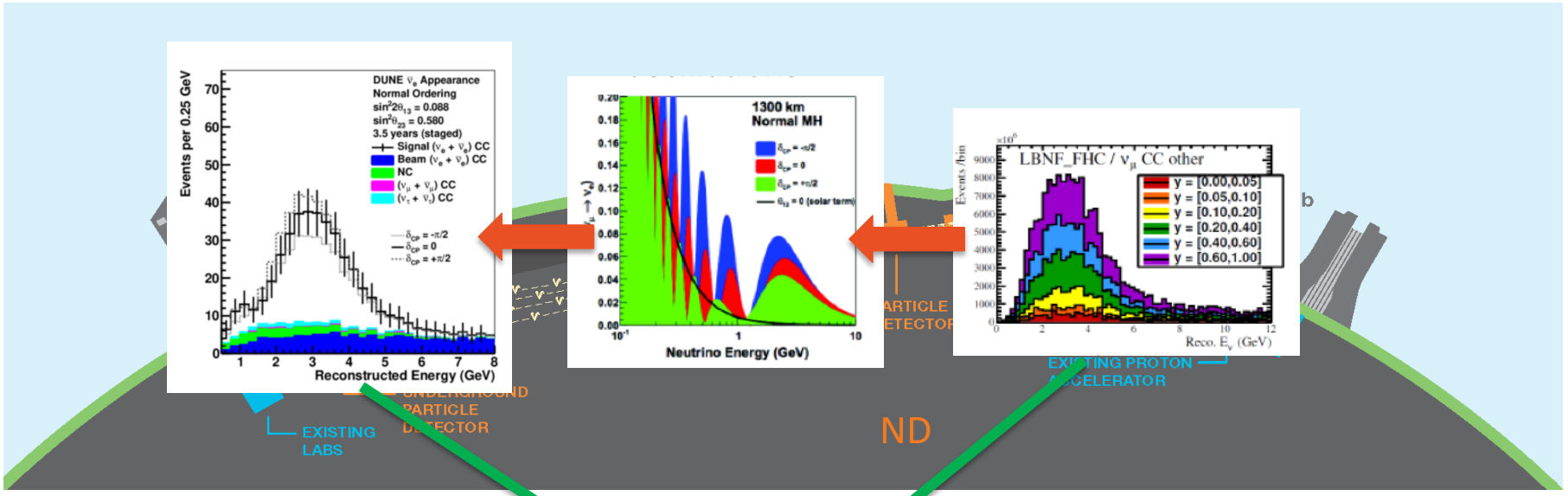
DUNE Science Programme

- Neutrino Oscillation Physics
  - **Search for leptonic (neutrino) CP Violation**
  - Resolve the mass ordering → 

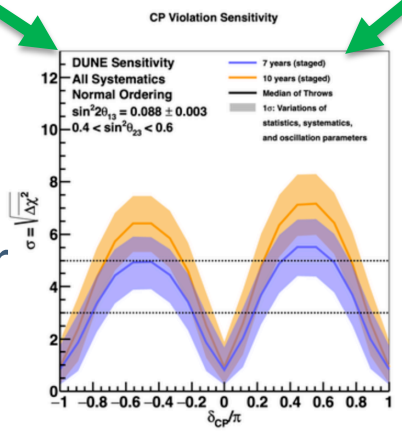
  ($m_3 > m_{1,2}$ or $m_{1,2} > m_3$)
  - Precision oscillation physics
    - Parameter measurements, θ_{23} octant
    - **Testing the current 3-neutrino model, non-standard interactions, …**
- Supernova burst physics and astrophysics
  - 3000 ν_e events in 10 sec from SN at 10 kpc
- Beyond the Standard Model physics, including nucleon decay

+ many other topics (ν interaction physics with near detector, atmospheric neutrinos, sterile neutrinos, WIMP searches, Lorentz invariance tests, solar neutrinos, etc.)

How is the science done?



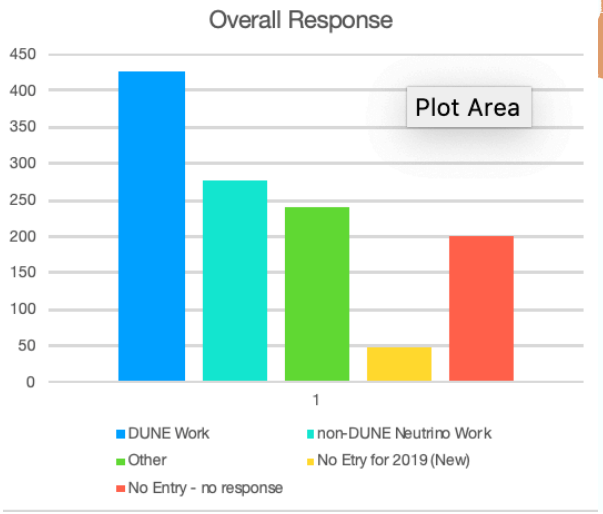
The measurement is performed by comparing the measured energy spectra in the Near and Far Detectors (χ^2 test).



- The Far Detector is dominated by statistics – need large volume and intense beam.
- The Near Detector controls systematics – this drives ND requirements.

DUNE – a global Collaboration

1214 collaborators from
202 institutions in 32 countries (incl. CERN)



- Daresbury, Durham, Imperial College, Lancaster, QMUL, RHUL, RAL, UCL, Birmingham, Bristol, Cambridge, Edinburgh, Liverpool, Manchester, Oxford, Sheffield, Sussex, Warwick
- 18 institutions
- 169 UK collaborators

- About 420 FTEs on DUNE reported in database for 2019
- 50:50 US – non-US

European Strategy Update

2020 Strategy Statements

1. Major developments from the 2013 Strategy

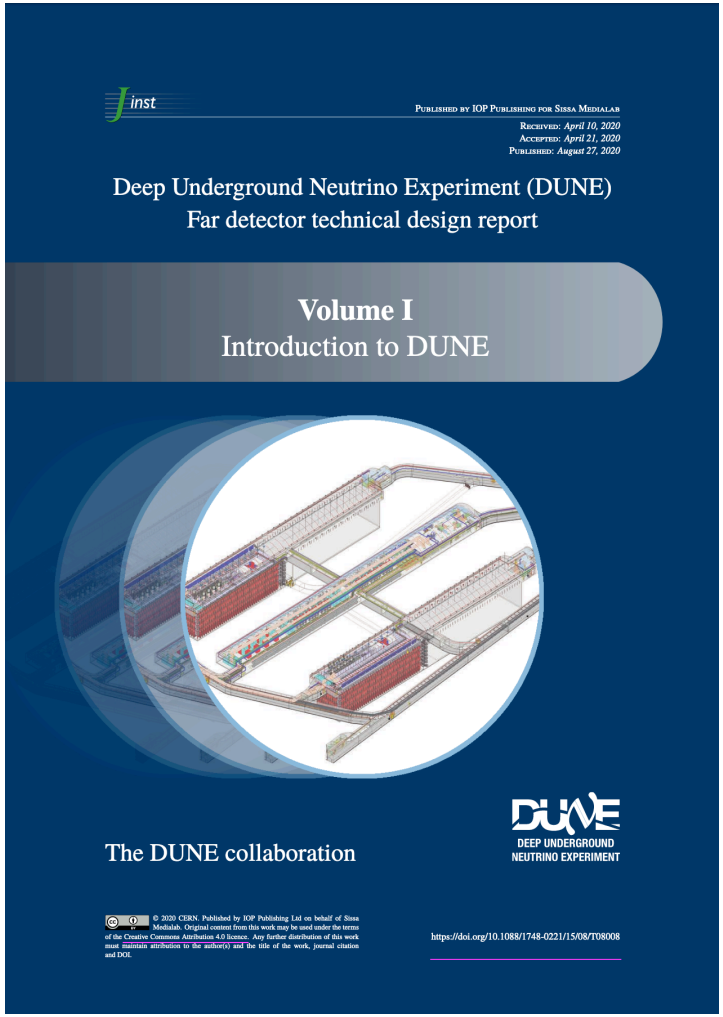
Neutrino oscillations are a compelling sign of new physics, making neutrinos massive particles

- They are much lighter than charged leptons
- Not all oscillation parameters are yet fully known (observed very different mixing patter from quarks)
- Essential to pursue the exploration of the neutrino sector with accelerator, reactor, solar, atmospheric and cosmic neutrino experiments
- Two complementary approved programmes are in preparation with the DUNE (US) and Hyper-Kamiokande (Japan) experiments - strong participation of European physicists with CERN support through notably the Neutrino Platform
- The community is very keen for the Neutrino Platform to continue operation at CERN
- Balanced European support for this worldwide effort important to secure the determination of neutrino properties

b) The existence of non-zero neutrino masses is a compelling sign of new physics. The **worldwide neutrino physics programme** explores the full scope of the rich neutrino sector and commands strong support in Europe. Within that programme, the Neutrino Platform was established by CERN in response to the recommendation in the 2013 Strategy and has successfully acted as a hub for European neutrino research at accelerator-based projects outside Europe. *Europe, and CERN through the Neutrino Platform, should continue to support long baseline experiments in Japan and the United States. In particular, they should continue to collaborate with the United States and other international partners towards the successful implementation of the Long-Baseline Neutrino Facility (LBNF) and the Deep Underground Neutrino Experiment (DUNE).*

Strong support for DUNE!

FD Technical Design Report



TDR volumes I, III, and IV now published in JINST

Vol I:
https://iopscience.iop.org/article/10.1088/1748-0221/15/08/T08008

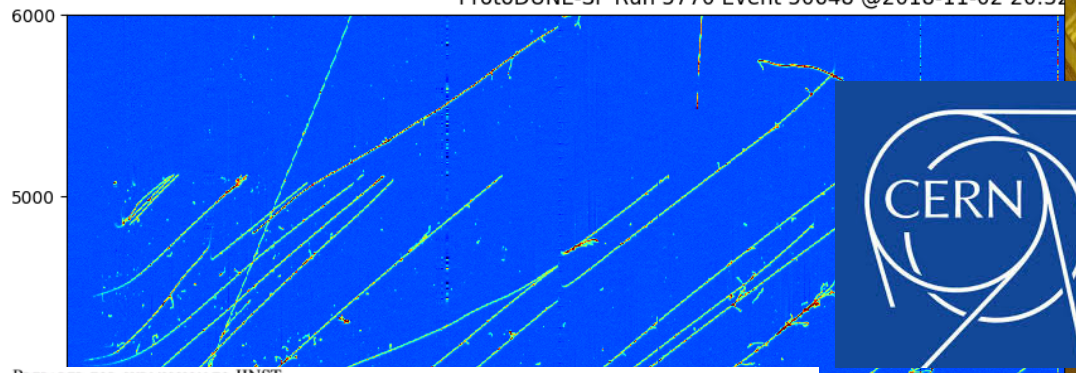
Vol III:
https://iopscience.iop.org/article/10.1088/1748-0221/15/08/T08009

Vol IV:
https://iopscience.iop.org/article/10.1088/1748-0221/15/08/T08010

Physics volume published as three separate papers in EPJC, plus PRD on CVN reconstruction

ProtoDUNE-SP provided crucial design validation.

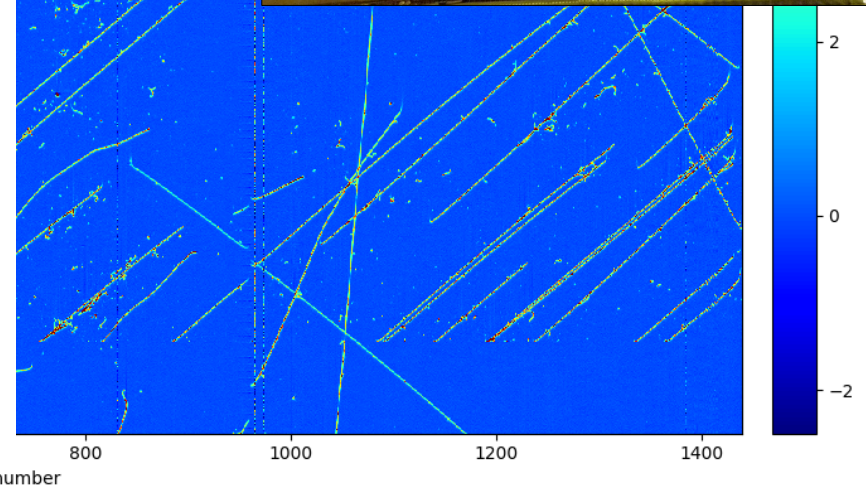
Published in JINST



Prepared for submission to JINST

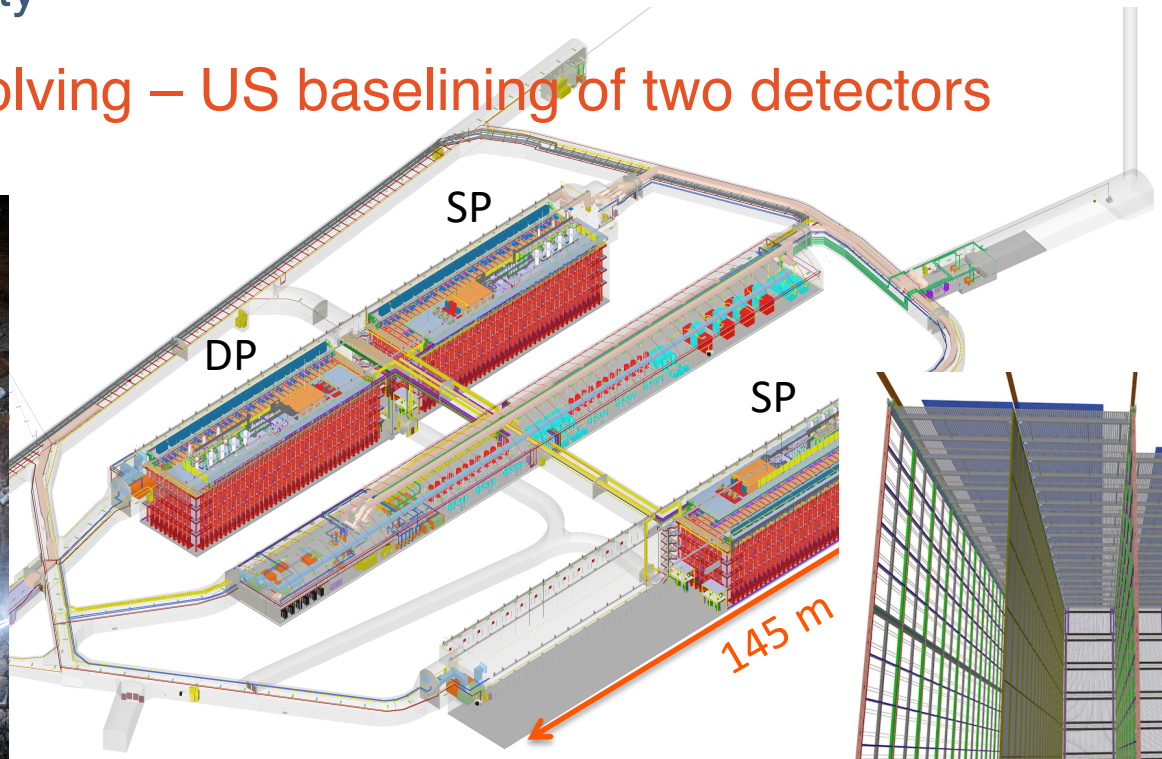
First results on ProtoDUNE-SP LArTPC performance from a test beam run at the CERN Neutrino Platform

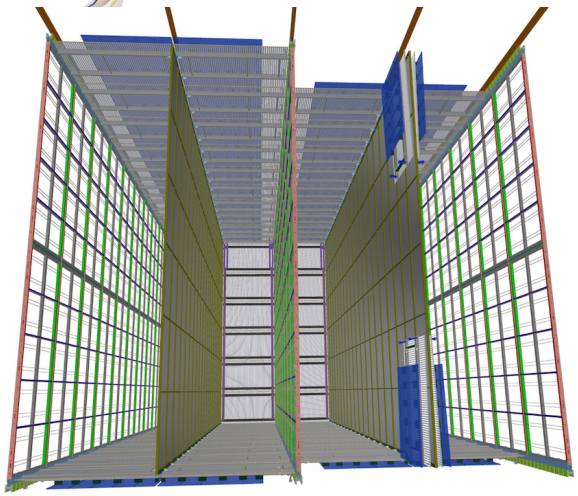
Abstract: The ProtoDUNE-SP detector is a single-phase liquid argon time projection chamber (TPC) with an active volume of $7.0 \times 6.0 \times 3.6$ m^3. It is installed in a specially-constructed calibration beam that provides samples of incident particles with well-measured momenta and high-purity particle identification. The ProtoDUNE-SP detector is a prototype for the first far detector module of the Deep Underground Neutrino Experiment, and it incorporates full-size components as designed for that module. ProtoDUNE-SP's successful operation during 2018 and 2019 and its production of large samples of high-quality data demonstrate the effectiveness of the single-phase far detector design. This paper describes the beam line, the TPC, the photon detectors, the signal processing and particle reconstruction. It presents the first results on ProtoDUNE-SP's performance. These results include TPC noise and gain measurements, dE/dx calibration for muons, protons, pions and electrons, drift electron lifetime measurements, and photon detector noise, signal sensitivity and time resolution measurements.



DUNE Far Detector in TDR

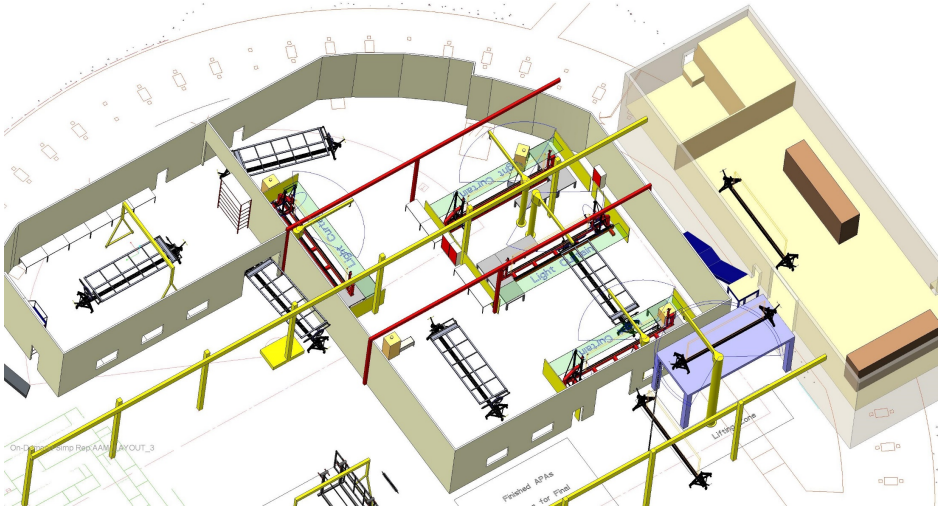
- Four separate 17 kt (about 10 kt fiducial) LAr TPCs
- 4 identically sized cryostats: 2 single phase (SP) + 1 dual phase (DP) +1 “opportunity”
- Strategy evolving – US baselining of two detectors





APA factories

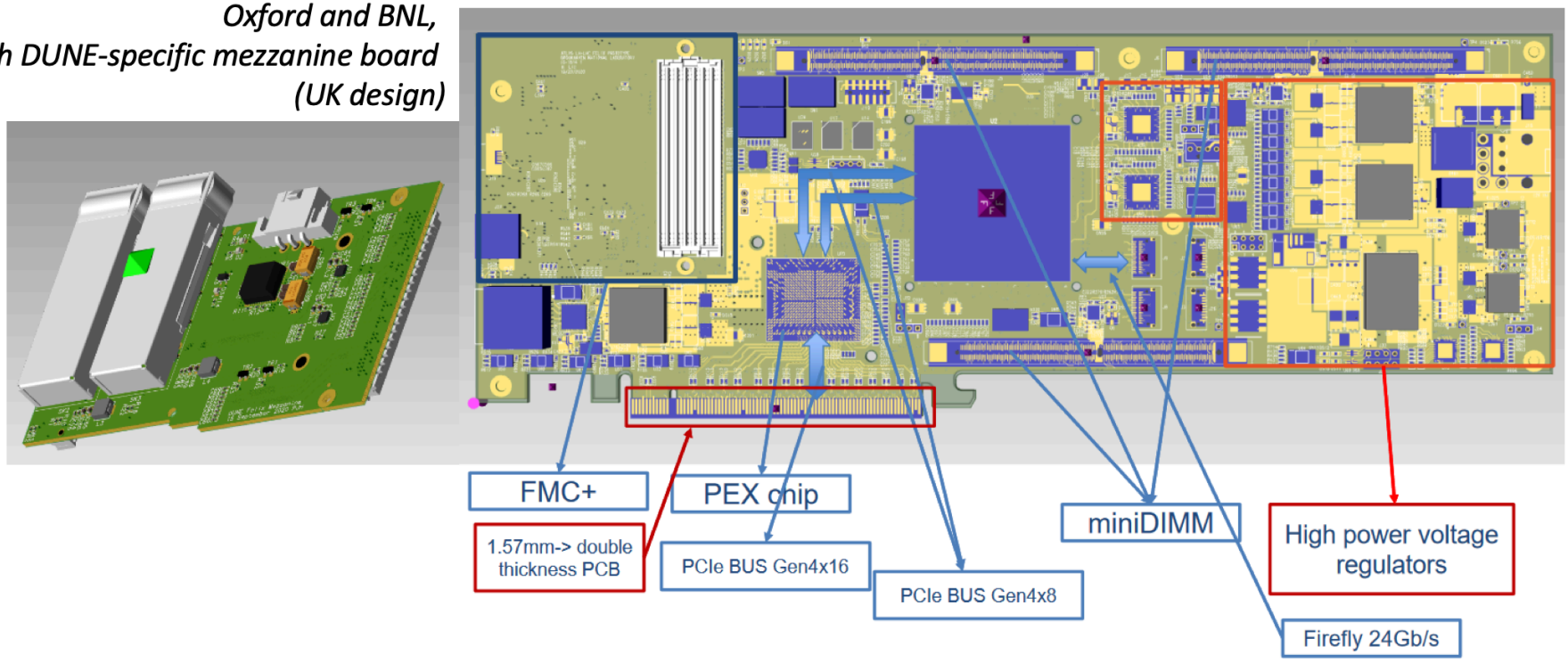
- Daresbury (UK): purpose built factory inside repurposed accelerator hall
- 4 winding machines, 10 process carts; 5 new dedicated swing arm pillar cranes
- 1,085 m^2 including pre- and post- processing areas, safety systems
- UK factory ready to go – starting to build APAs for ProtoDUNE-II



Simon Peeters, Giles Barr

UK leading in Far Detector UK

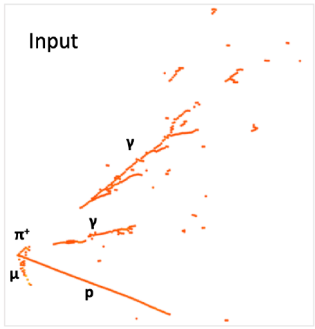
New FELIX board design by Oxford and BNL, with DUNE-specific mezzanine board (UK design)



John Marshall, A. Blake

Pandora Pattern Recognition

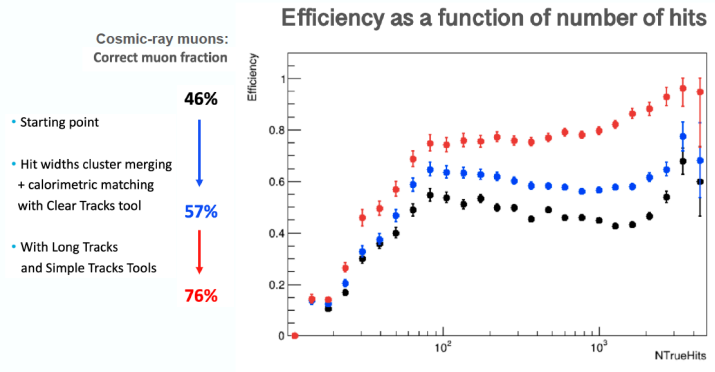
Progress on multiple fronts. Some recent highlights:



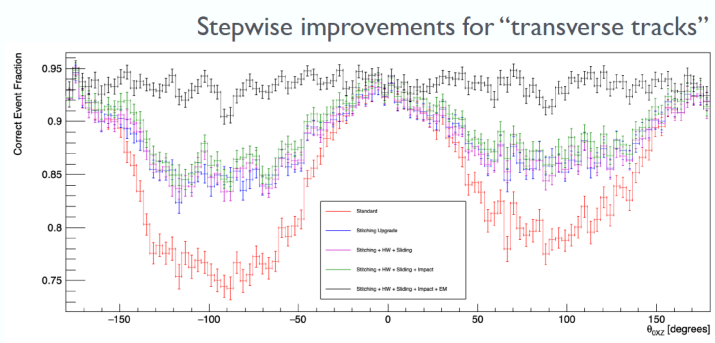
True\Net	Track	Shower
Track	92.1%	18.4%
Shower	7.9%	81.6%
Σ	100%	100%

Tab: Confusion matrix for hit classification

Pandora: A marriage of deep-learning and multi-algorithm approaches.

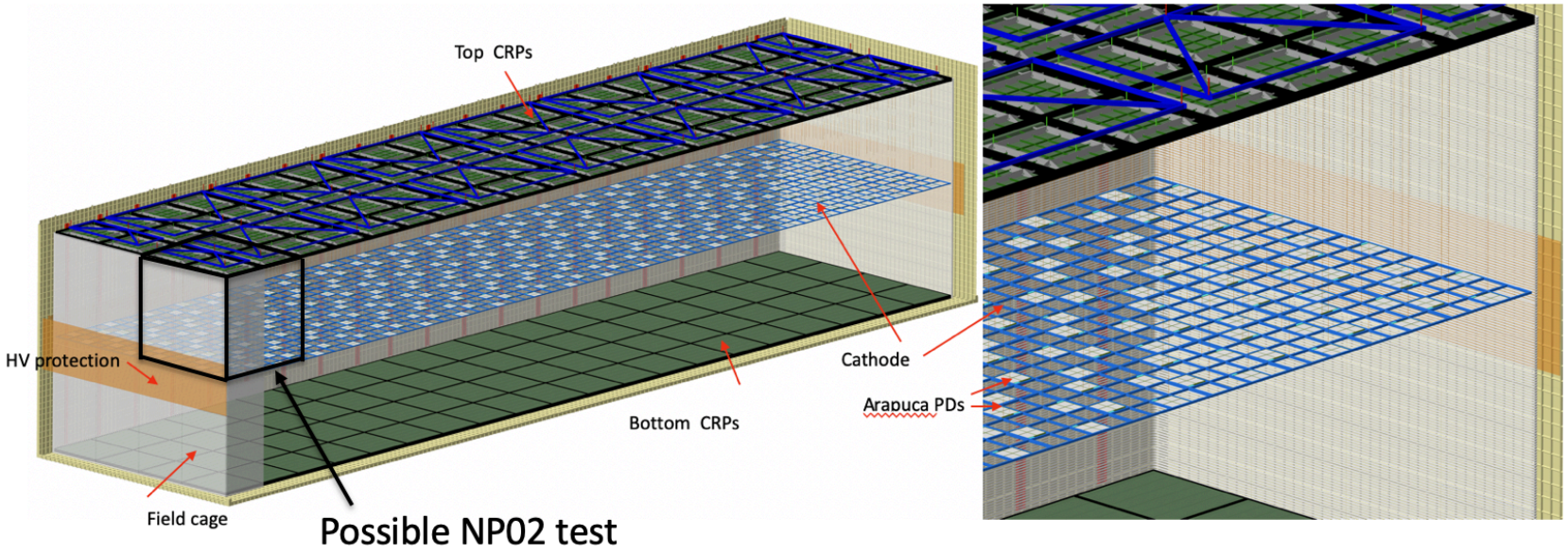


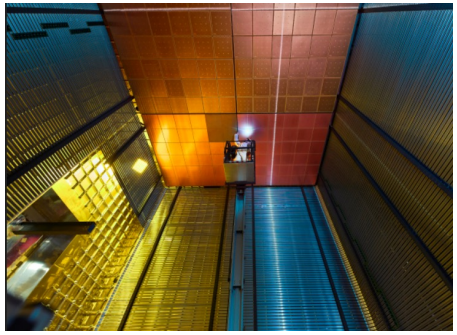
New algorithms and tools that begin targeting two-view patrec at e.g. ProtoDUNE-DP



New algorithms and tools to finesse the cosmic-ray muon reconstruction at DUNE FD

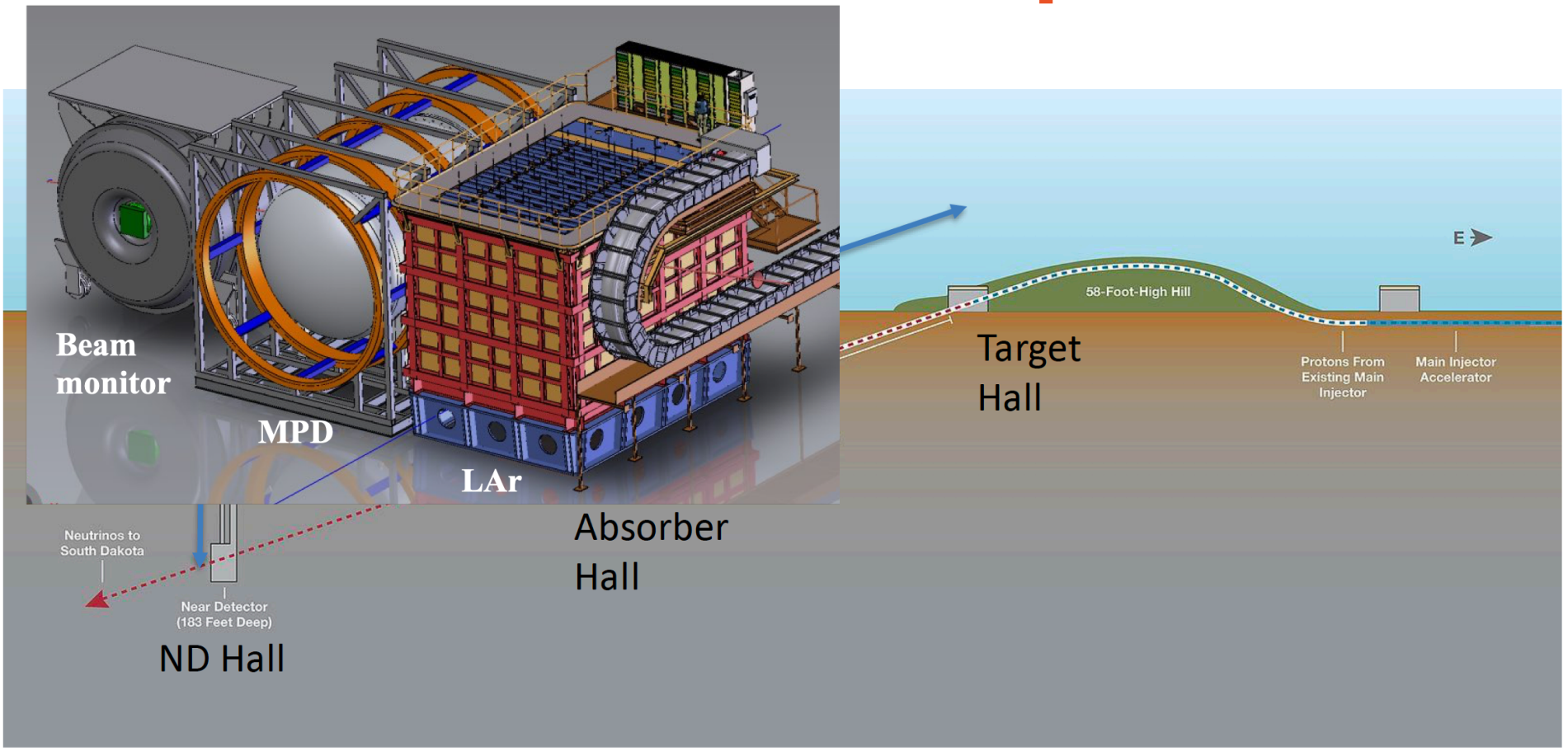
Possible Vertical Drift Module





- Development based on DP with potential advantages, but also challenges
- Full prototype on time scale 2023/24.

Near Detector Concept



UK leads Task Force on ND-DAQ (A. Kaboth) and Design Group (A. Weber)

DUNE moves to the next stage with a blast

06/24/20 | By Lauren Biron and Leah Hesla

Construction workers have carried out the first underground blasting for the Long-Baseline Neutrino Facility, which will provide the space, infrastructure and particle beam for the international Deep Underground Neutrino Experiment.

Contract awarded for the excavation of gigantic caverns for the Deep Underground Neutrino Experiment

November 18, 2020 | Kurt Riesselmann

Construction of the enormous underground facility for the largest international physics experiment in the United States took a major step forward as project managers at the Department of Energy's Fermi National Accelerator Laboratory are preparing for the project's next phase.

MicroBooNE at FNAL

THE UNIVERSITY of EDINBURGH

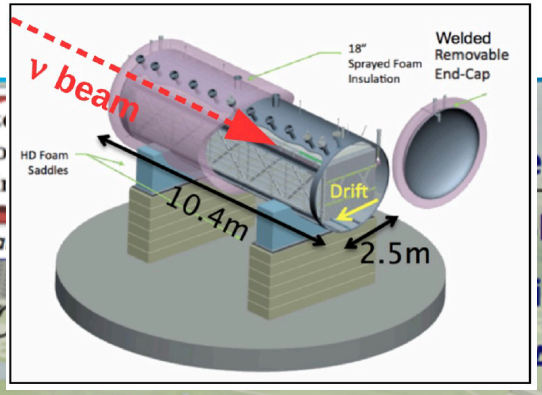
THE UNIVERSITY OF WARWICK

Lancaster University

UNIVERSITY OF CAMBRIDGE

MANCHESTER 1824
The University of Manchester

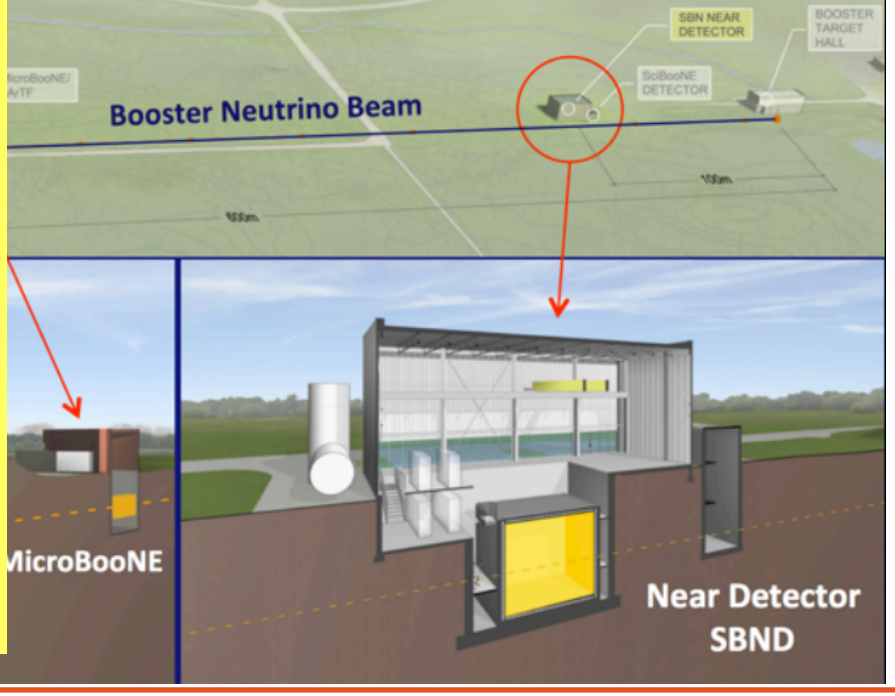
MicroBooNE: first SBN detector



A Proposal for a Three Det
Short-Baseline Neutrino Oscillatio
in the Fermilab Booster Neutri
Submitted FNAL PAC January 2015

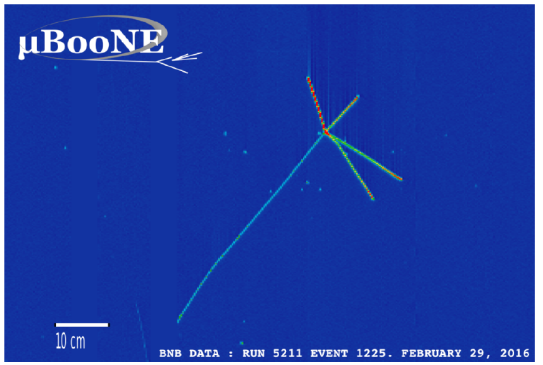
$$\frac{\langle L_\nu \rangle}{\langle E_\nu \rangle} \sim \frac{600\ \text{m}}{700\ \text{MeV}} \sim C$$

tector	Distance from BNB Target	Active LAr Mass
ND	110 m	112 ton
icroBooNE	470 m	87 ton
ARUS	600 m	476 ton

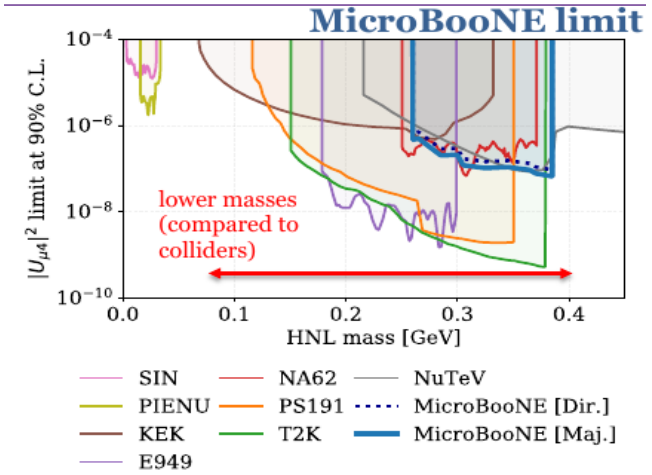


- Longest running LArTPC in a neutrino beam
- Crucial demonstration of long-term operation of LAr technology for DUNE.
- Strong UK involvement, already at construction stage: more than 30 PG students (10 graduated)

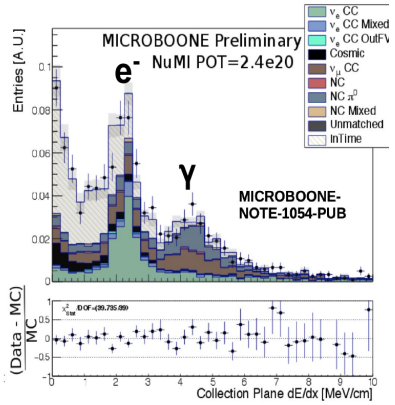
MicroBooNE Physics



- Selected UK-led results:
  - ν_μ CC Inclusive
    Phys.Rev.Lett. 123 (2019) 13, 131801
  - ν_μ CC N-protons/0 pions
    ArXiV:2010.02390 [hep-ex]
  - Search for Heavy Neutral Leptons
    Phys.Rev.D 101 (2020) 5, 052001

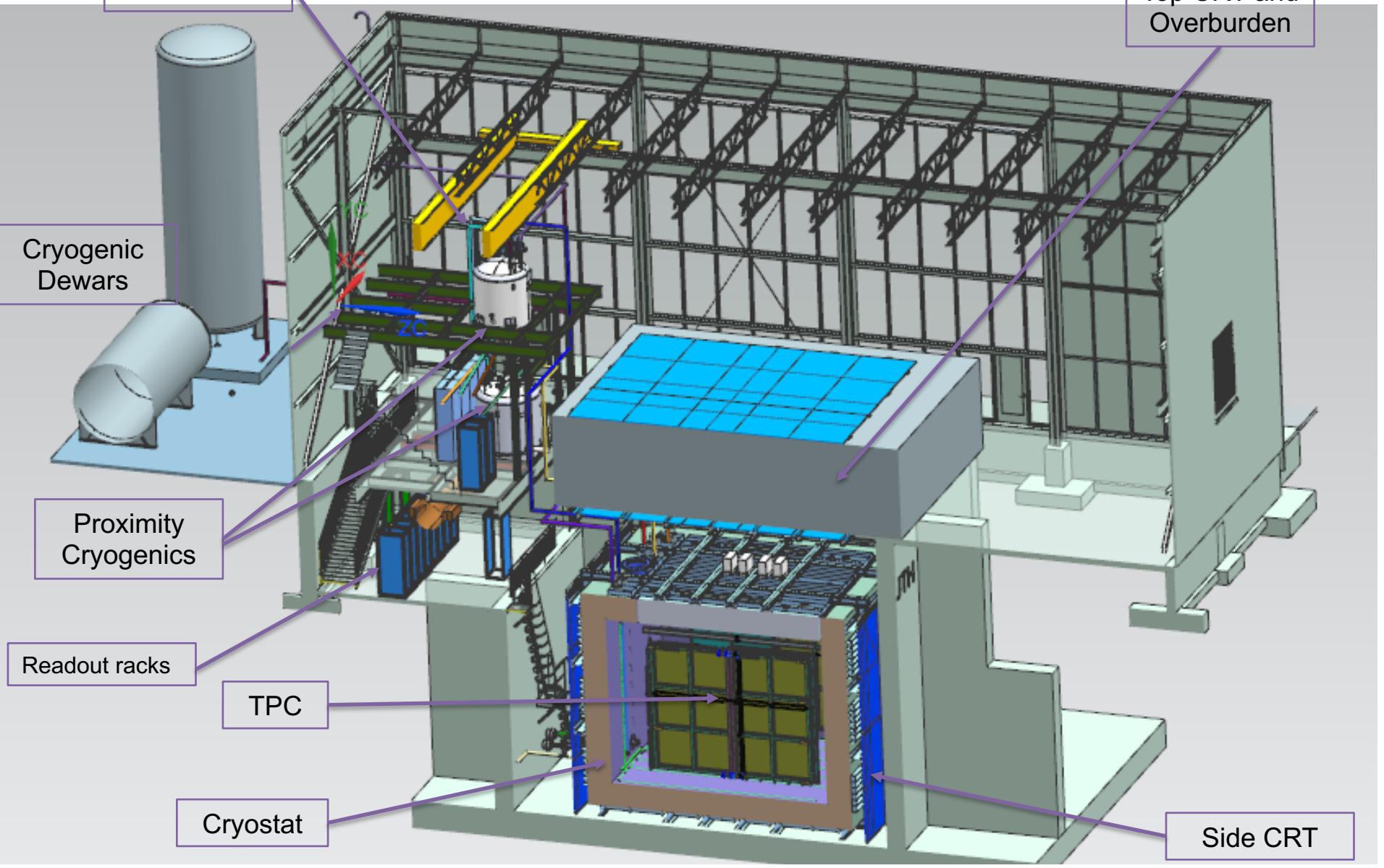


- Coming Soon:
  - CC ν_e from NUMI beam
  - Search for Higgs-portal scalars.
  - Search for MiniBooNE LEE.

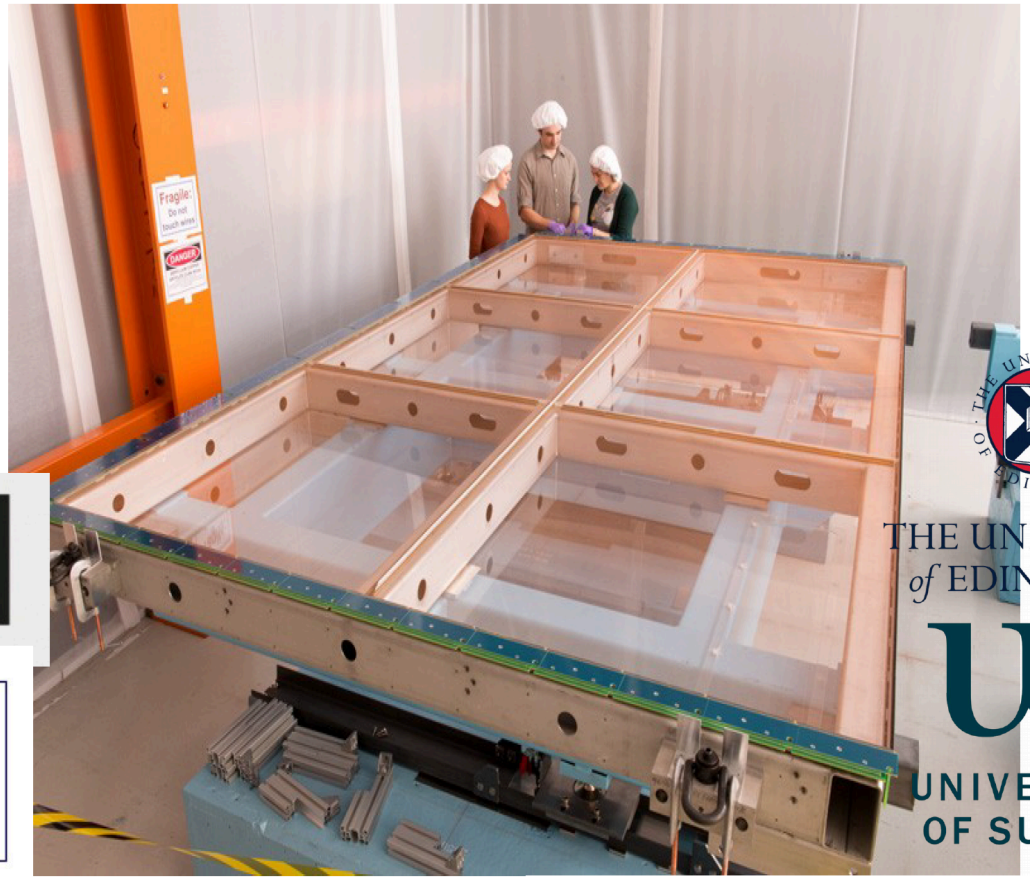


Crucial cross section measurements and development of BSM analyses for DUNE

SBND at FNAL


20 ton crane
Top CRT and Overburden
Cryogenic Dewars
Proximity Cryogenics
Readout racks
TPC
Cryostat
Side CRT

UK on SBND



Particle Physics
STFC Rutherford Appleton Laboratory

UCL

The University Of Sheffield.

Lancaster University

MANCHESTER 1824
The University of Manchester

UNIVERSITY OF LIVERPOOL

THE UNIVERSITY of EDINBURGH

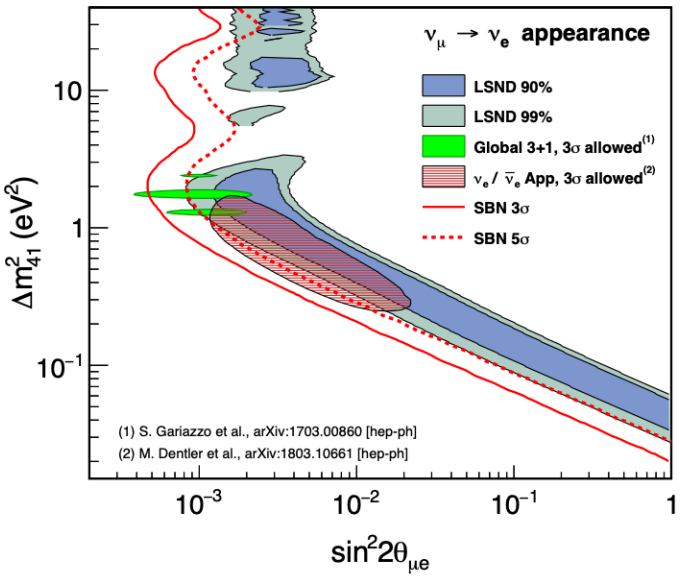
UNIVERSITY OF SUSSEX

Jarek Nowak

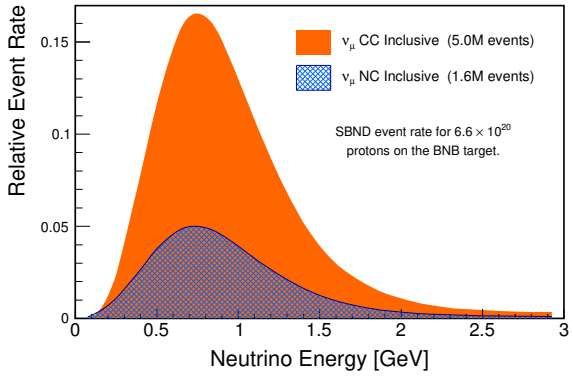
Strong UK physics leadership

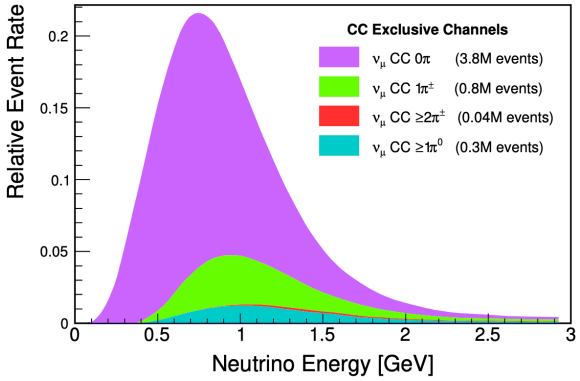
SBND: 7 million ν_μ interactions (0.2-3 GeV) and 50,000 νe interactions in 3 years

$\nu_\mu \rightarrow \nu_e$ Appearance sensitivity



SBN can cover the parameters allowed by past anomalies at ≥ 5σ significance





The broad program of neutrino-argon interaction measurements in SBND will have direct application for controlling systematic uncertainties in the future long-baseline program at DUNE.

SBND Key Milestones

Milestone	Description	Milestone Date	Forecast
S-1	SBND is ready for transport from Dzero Assembly Building to the SBN ND hall	Feb 2021	Aug 2021
S-2	SBND detector is ready to fill with liquid argon	Nov 2021	Apr 2022
S-3	SBND detector is filled with liquid argon and ready for detector commissioning (LAr purity adequate for physics has been achieved)	June 2022	Nov 2022
S-4a	SBND detectors are ready for physics data - *CRT is operational*	Aug 2022	Jan 2023
S-4b	SBND detectors are ready for physics data - *Shielding in place*	Sept 2022	Feb 2023

Baseline dates for were originally set in 2018. They were revised in April 2020 schedule re-planning

Forecast dates show significant delay primarily from COVID-19 and are subject to additional delays – working to minimize and accelerate final steps

Fermilab

23 11/17/20 Peter Wilson I Short Baseline Neutrino Program

MANCHESTER 1824 DUNE

Best Fit

Normal hierarchy

$\Delta m^2_{32} = (2.41 \pm 0.07) \times 10^{-3}$ eV^2

$\sin^2\theta_{23} = 0.57^{+0.04}_{-0.03}$

$\delta = 0.82\pi$

See no strong asymmetry in the rates of appearance of ν_e and $\bar{\nu}_e$

Consistent with hierarchy-octant-δ combinations which include some "cancellation" of matter effect and CPv.

Clear UK leadership, providing

→ Physics analysis coordinator

→ 3-Flavour oscillation convenor

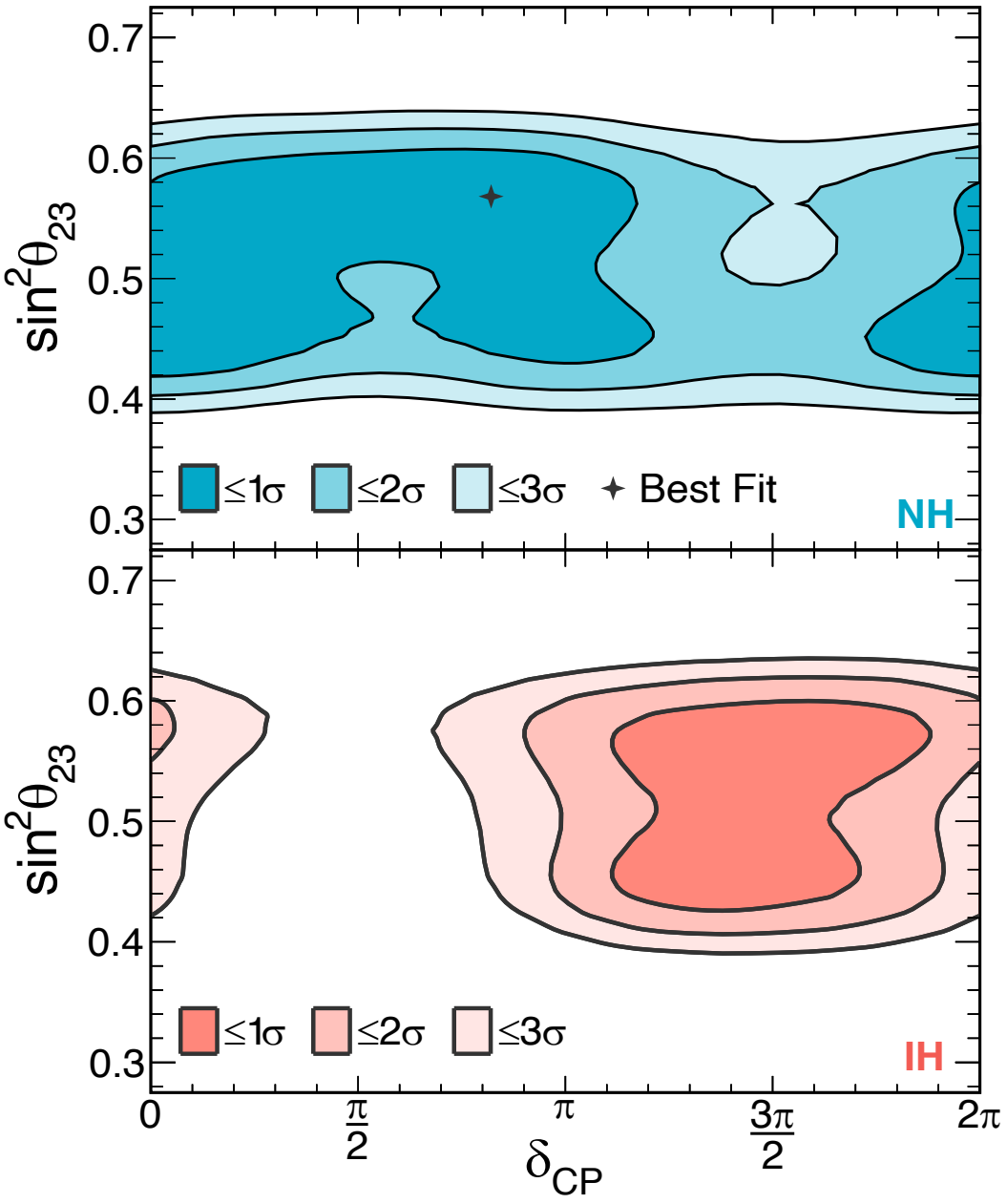
→ Institutional Board Chair

New UK group: **QMUL**, joins Sussex and UCL

STFC provided vital postdoc support in 2019 consolidated grant

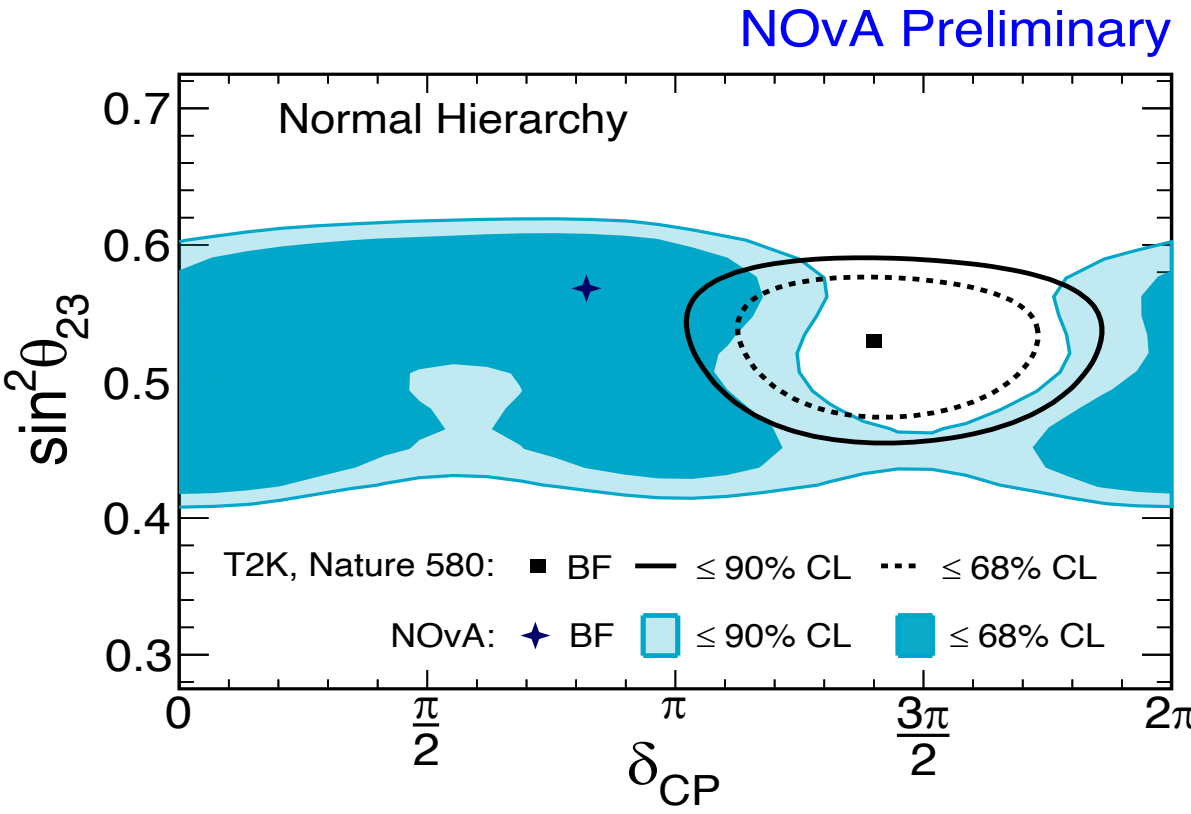
Jeff Hartnell

NOvA Preliminary



Comparison with T2K

- Tension with T2K's preferred region
- Quantifying consistency requires a joint fit of the data from the two experiments, which is already in the works
  - UK NOvA and T2K groups heavily involved
  - Provide a member of cross-experiment senior leadership team (from NOvA)



NOvA will run to 2025 or beyond
(>2.5x more data to come)

Summary

- Vibrant and exciting accelerator-based neutrino physics programme located in North America with strong UK leadership.
- UK groups participate in DUNE, MicroBooNE, SBND, and NOvA.
- UK groups contribute to all stages of experiments – planning, design, R&D, construction, operation, data analysis.
- Primary physics drivers are search for CP violation in lepton sector, astrophysical neutrinos (supernovae), sterile neutrino searches, BSM physics.