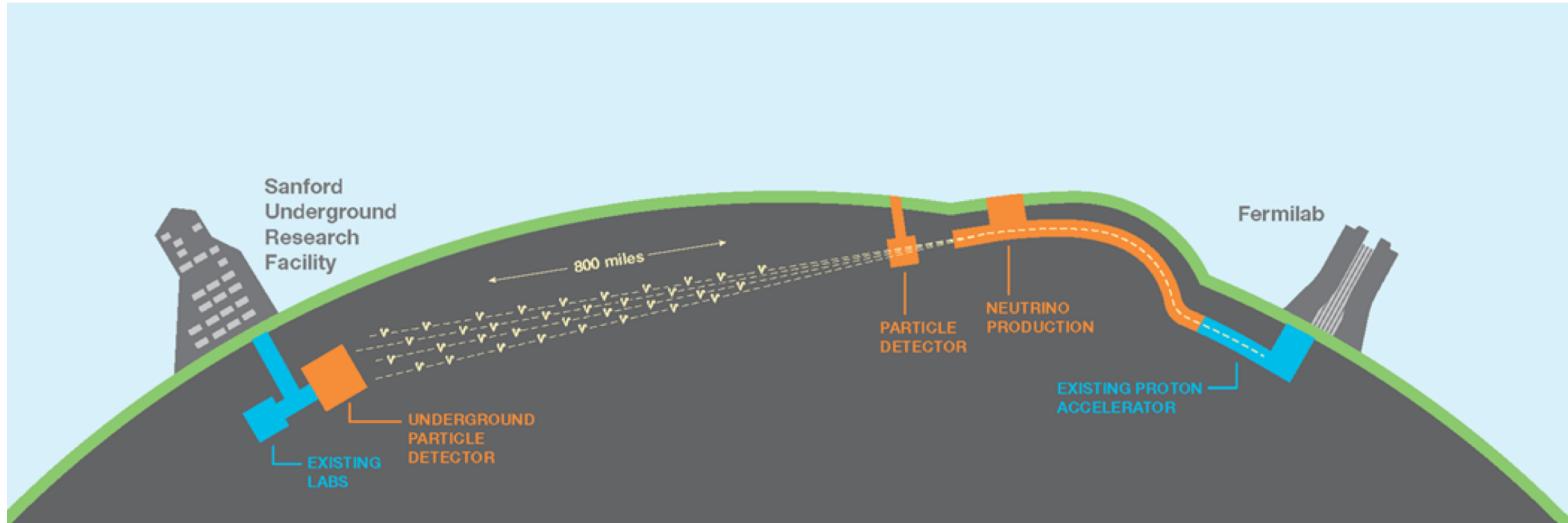


DUNE & FNAL Neutrino Program

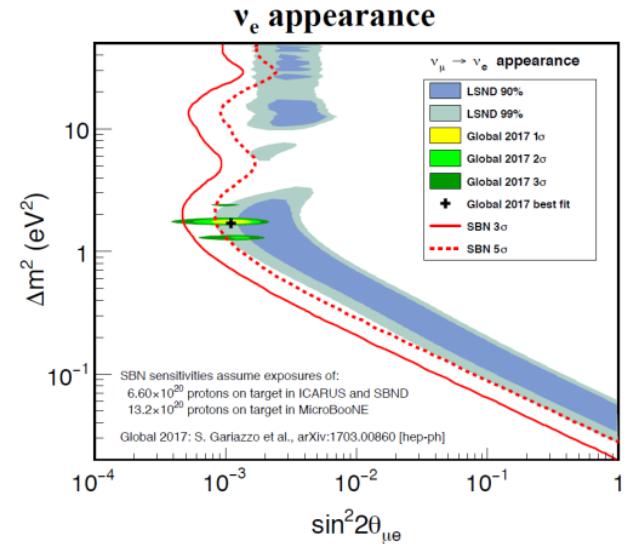
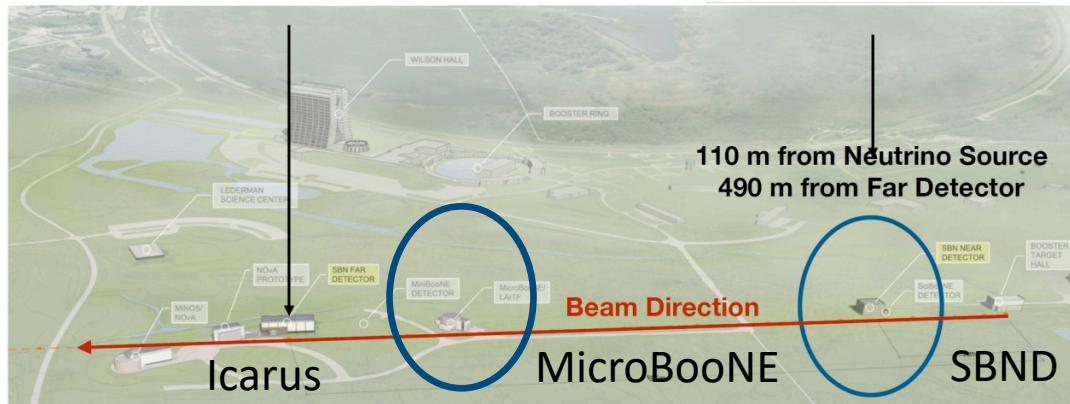
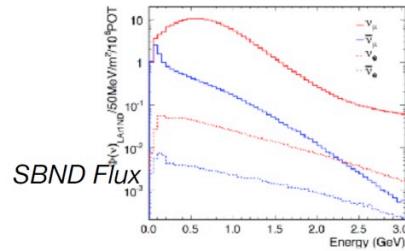
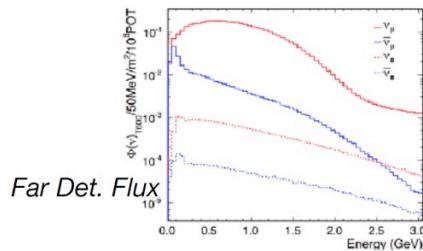


Alfons Weber
RAL, 17-July-2018

Content

- Fermilab Short Baseline Program
 - SBND & MicroBooNE & ~~ICARUS~~
- Fermilab NuMI Program
 - NOvA
- DUNE/LBNF
 - Intro
 - Recent Highlights
 - Plans in the UK
 - Funding Situation
- Strategy

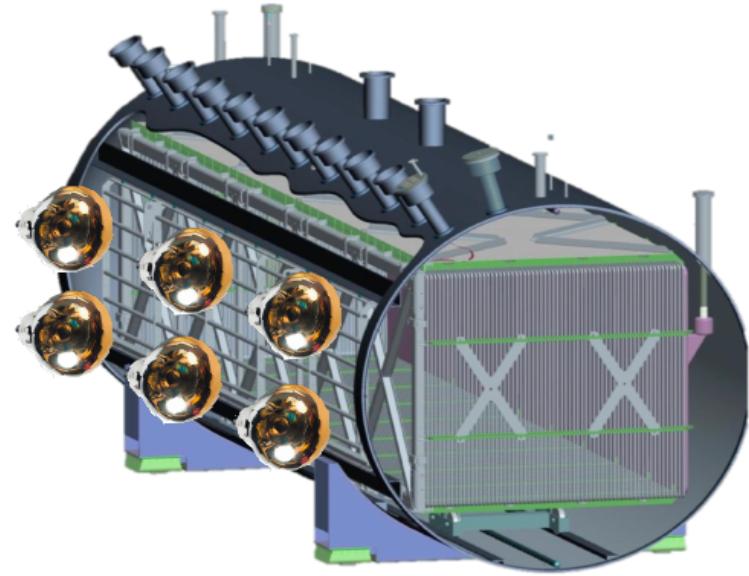
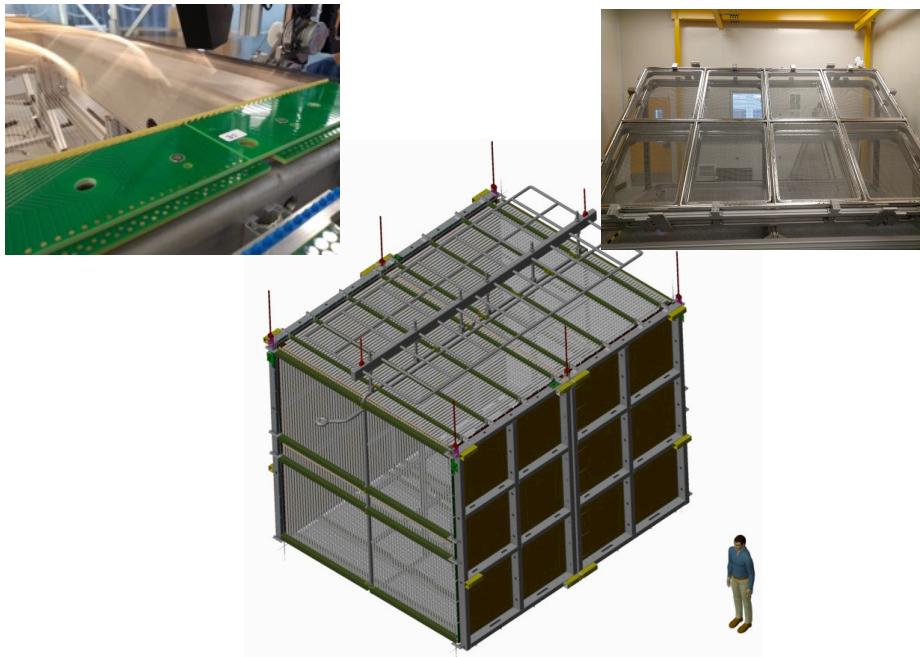
Short Baseline Neutrino Programme



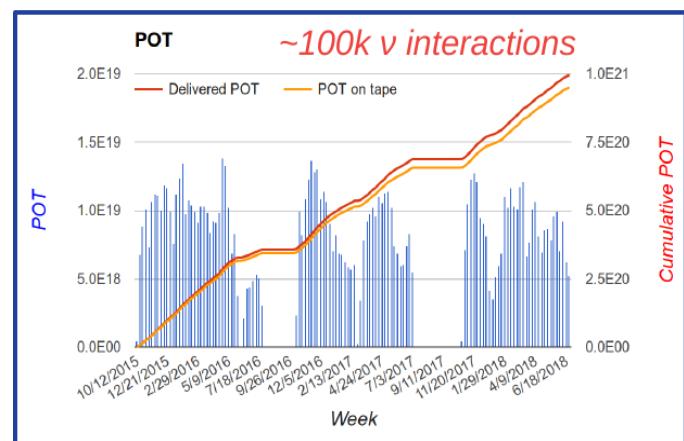
5 sigma test of allowed oscillation parameter regions

- Part of the LArTPC R&D for DUNE
 - Readout Planes
 - LAr reconstruction software
- Physics programme
 - Search for Sterile Neutrinos
 - Neutrino interactions cross sections (7M CC events)

SBND & MicroBooNE

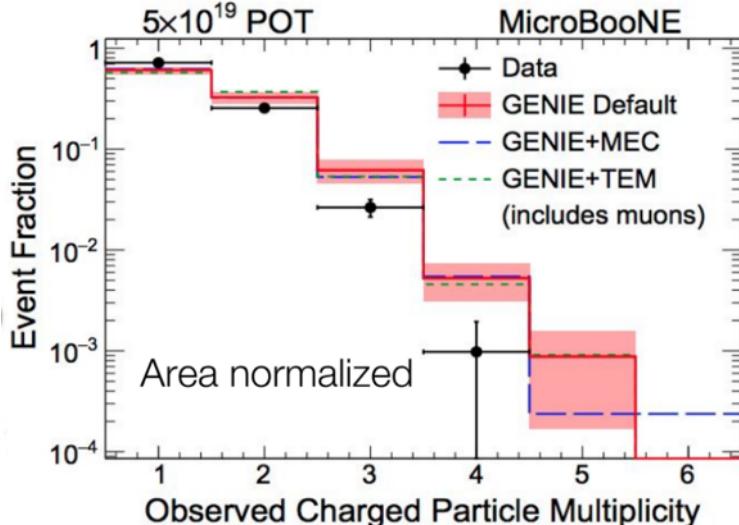


- Two 4m x 2.5m Anode Plane Assemblies (APAs) per side (drift region)
- Central cathode

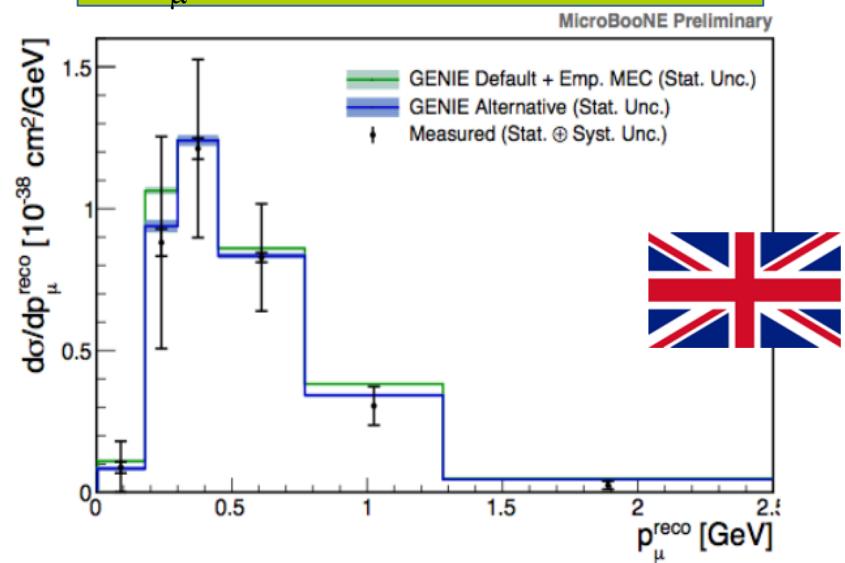


MicroBooNE First Results

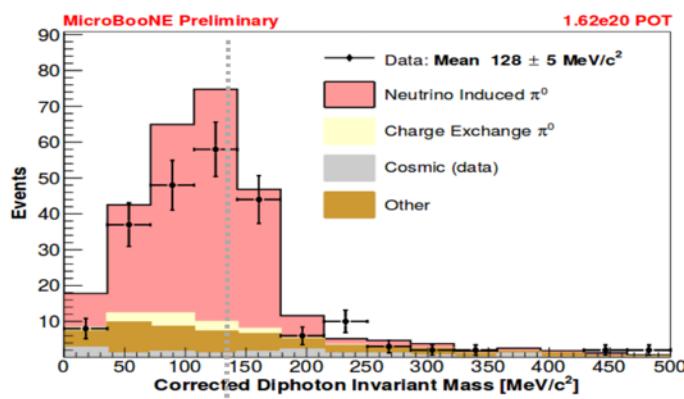
Charged Particle Multiplicity



ν_μ -inclusive cross-section



CC- π^0 cross-section



MicroBooNE physics analyses use the PANDORA reconstruction suite (developed in the UK)
Eur.Phys.J. C78 (2018) no.1, 82



Many of these algorithms adopted in protoDUNE

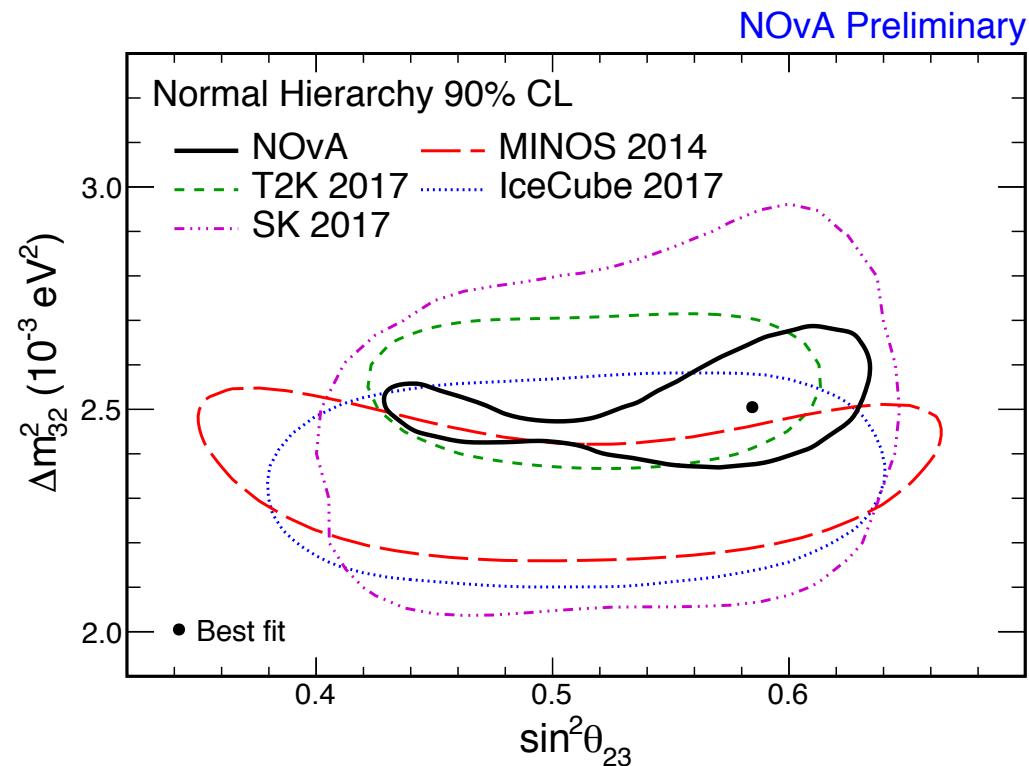
MicroBooNE Involvement

- Cambridge, Lancaster, Manchester, Oxford (2 more joining)
 - 13 UK PhD students
- **Leadership positions**
 - Cross-section physics convener: A. Furmanski
 - Data Quality Convener: P. Guzowski
 - Run Coordinator, Autumn 2018: P. Guzowski
 - Technical Board: A. Szelc
 - Speakers Board: S. Soldner-Rembold, J. Evans
- **CG Request**
 - 1.57 FTE PDRA for 3 yrs
 - 0.35 core post

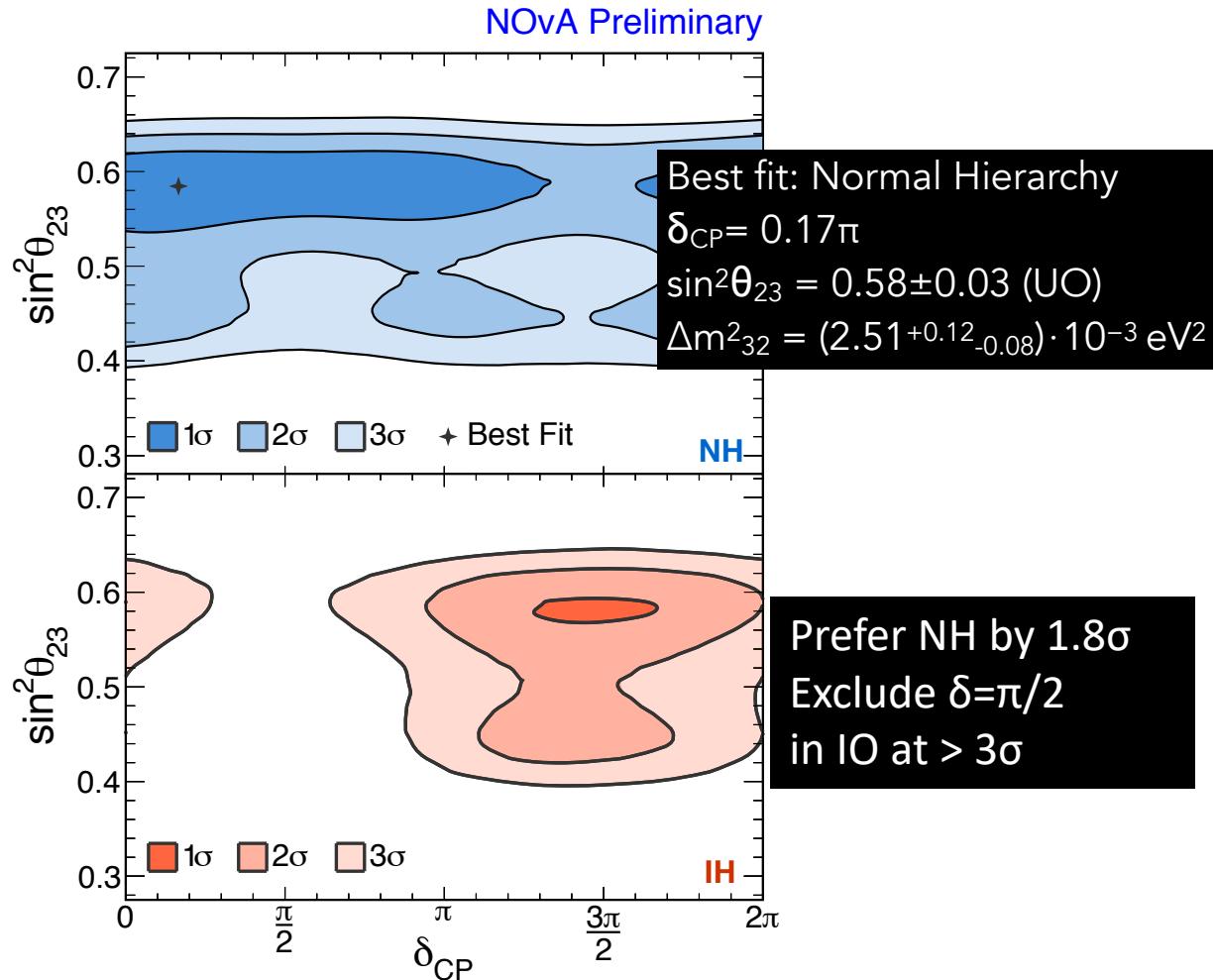
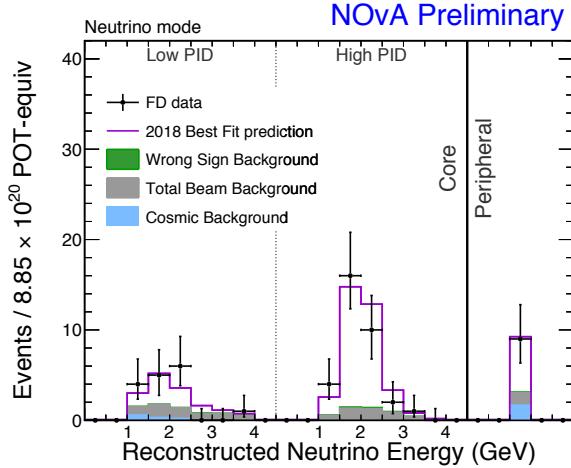
SBND Involvement

- Manchester, Liverpool, Sheffield, Lancaster
 - Active graduate student & RA involvement
- **UK Leadership**
 - 2 physics analysis convenors from UK: C. Andreopoulos & A. Szelc
 - Development & Monte Carlo production: D. Brailsford
 - Pandora reconstruction package: A. Blake
 - Pile-up study, CRT, optical library, shower reco, event selection, ...
- **CG Requests**
 - 2.43 FTE PDRAs for 3 years
 - 0.7 FTE core support for 3 years

- 750 kW beam from FNAL to northern MN
- Physics
 - Precision mixing angle
 - Mass ordering
 - CP constraints

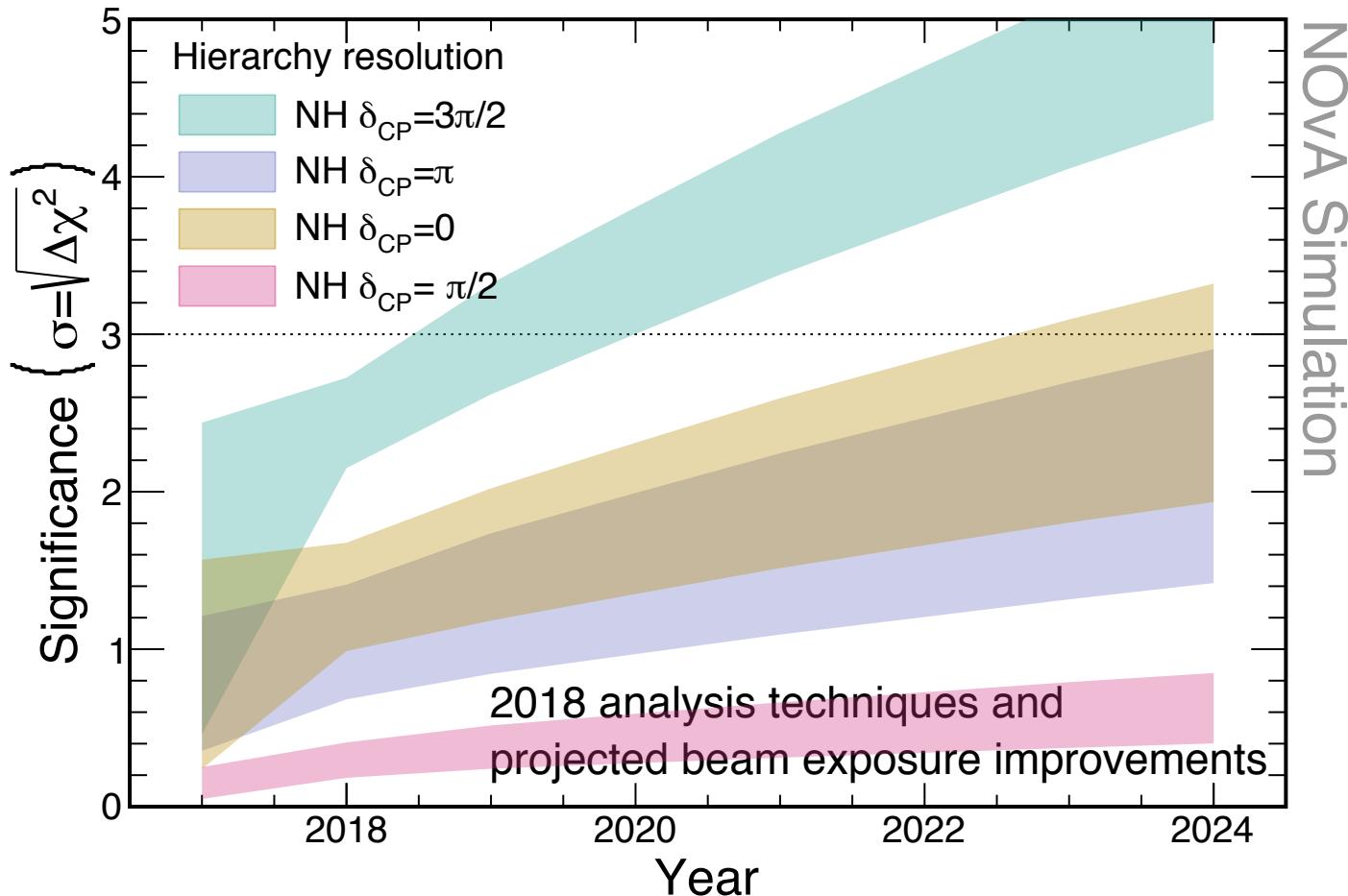


Electron (Anti-)Neutrino Appearance



Future Sensitivity

$$\sin^2\theta_{23}=0.4-0.6, |\Delta m_{32}^2|=2.5\times 10^{-3}\text{eV}^2, \sin^2 2\theta_{13}=0.082$$



NOvA Involvement

- UCL and Sussex
- **Leadership**
 - CG Chair of the IB and EC member: J. Hartnell
 - Co-convenors of the two primary analyses
 - Nue Appearance: C. Backhouse
 - NuMu Disappearance: J. Hartnell
 - Calibration and beam co-convenors: R. Nichol, L. Cremonesi
- **CG Request**
 - 1.5 PDRA for 3 years

Strategy

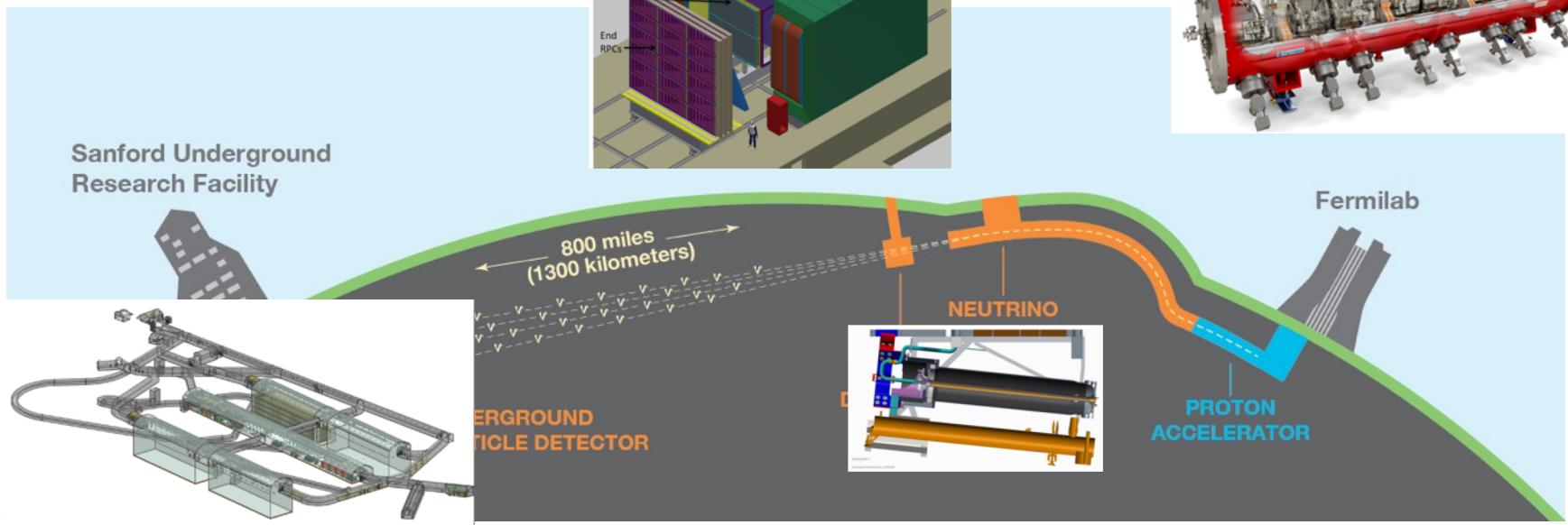
- **NOvA**
 - Discovery potential for the mass hierarchy
 - Combination with complementary T2K experiment in 2021
- **SBND**
 - Complete detector construction & commissioning
 - Physics exploitation
 - High statistics cross section and flux measurements
- **MicroBooNE**
 - Continue high statistics physics exploitation
 - Not only learning for DUNE

The DUNE Collaboration



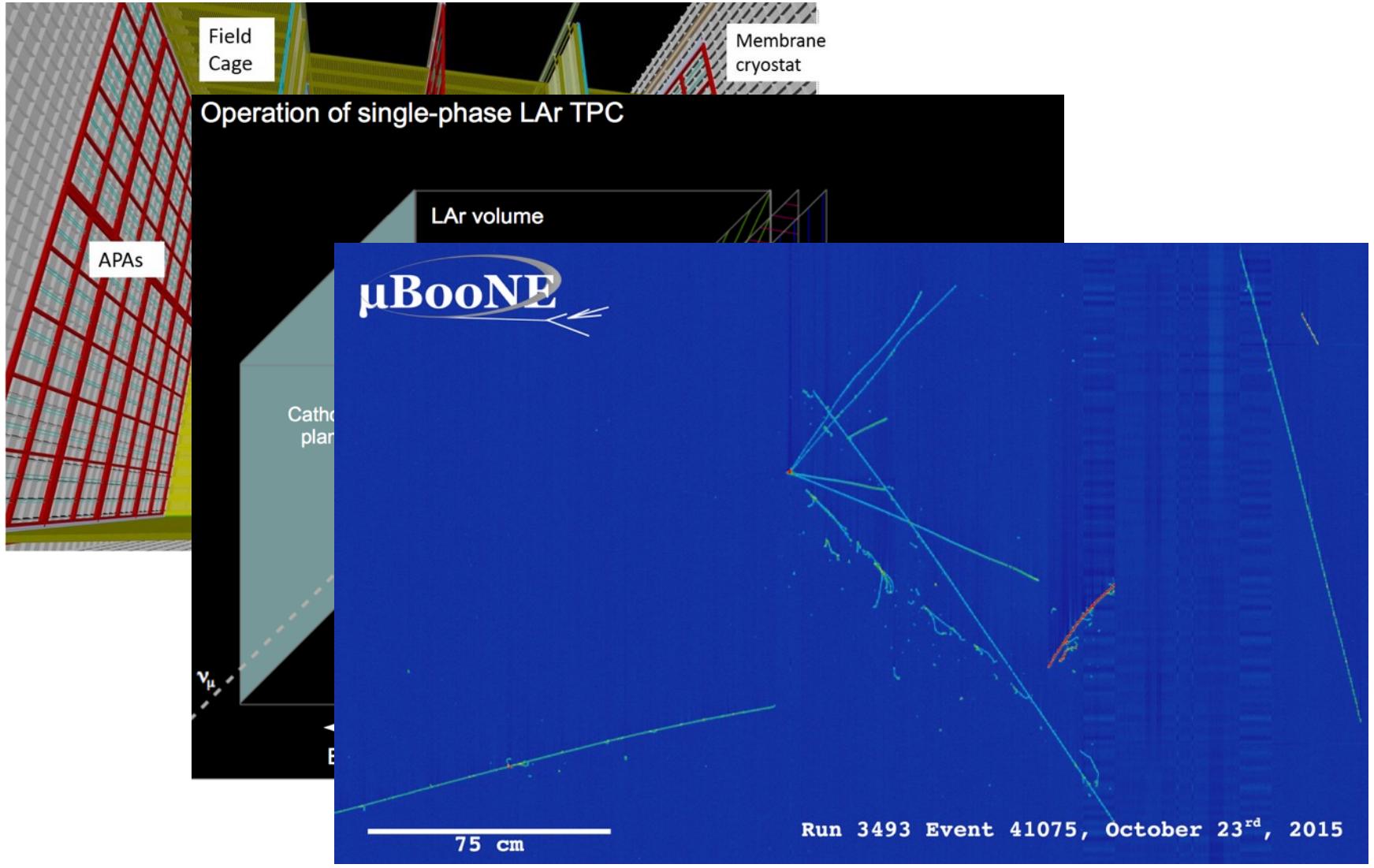
- 255 registered participants at main meeting

Layout

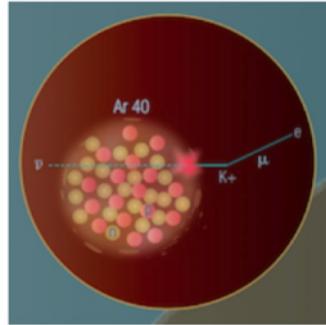
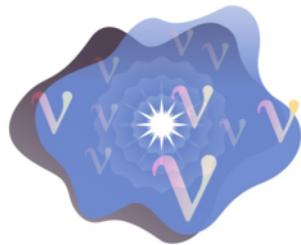
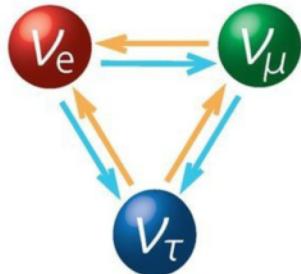


- LBNF/DUNE is Long Baseline Neutrino Facility of the future
 - 40 kt FM Liquid Argon TPC from 2024
 - 1-2 MW neutrino beam from 2026
 - Baseline 1300 km

LAr TPC



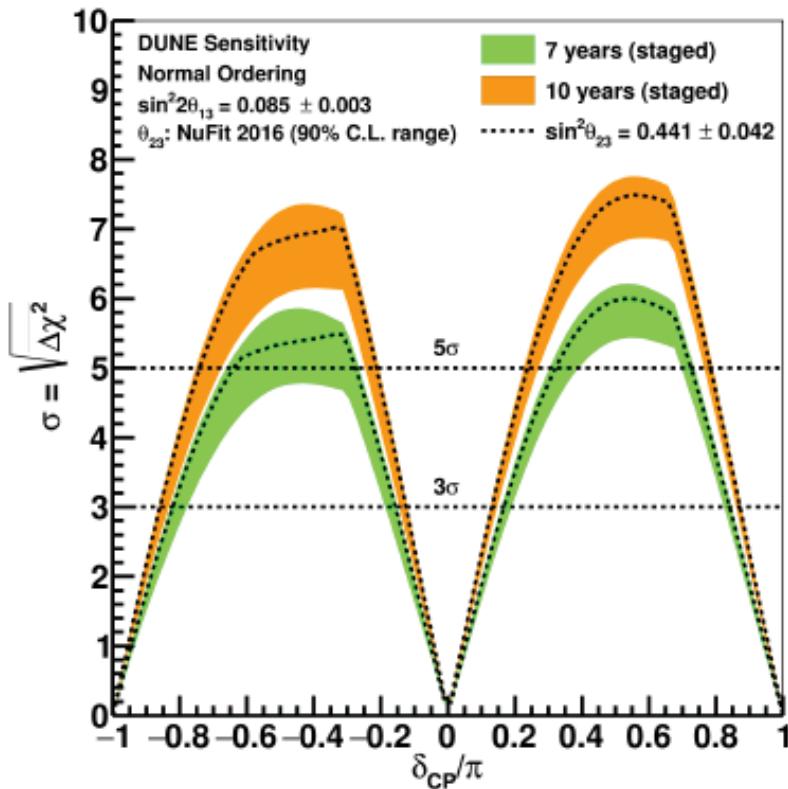
Physics Program



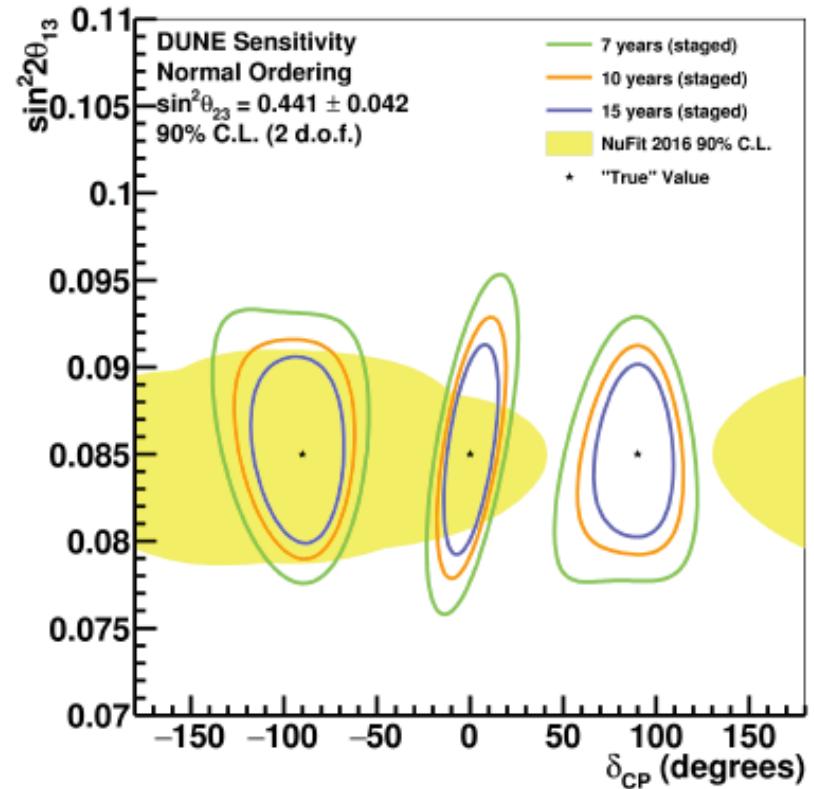
- **Neutrino Oscillations**
 - Search for leptonic CP violation
 - Determine neutrino mass ordering
 - Precision PMNS measurements
- **Supernova Physics**
 - Observation of time and flavour profile provides insight into collapse and evolution of supernova
 - Unique sensitivity to electron neutrinos
- **Baryon number violation**
 - Predicted by many BSM theories
 - LAr TPC technology well-suited to certain proton decay channels (e.g., $p \rightarrow K^+ + \bar{\nu}$)
 - $\Delta(B-L) \neq 0$ channels accessible (e.g., $n \rightarrow \bar{n}$)

Oscillation Highlights (I)

CP Violation



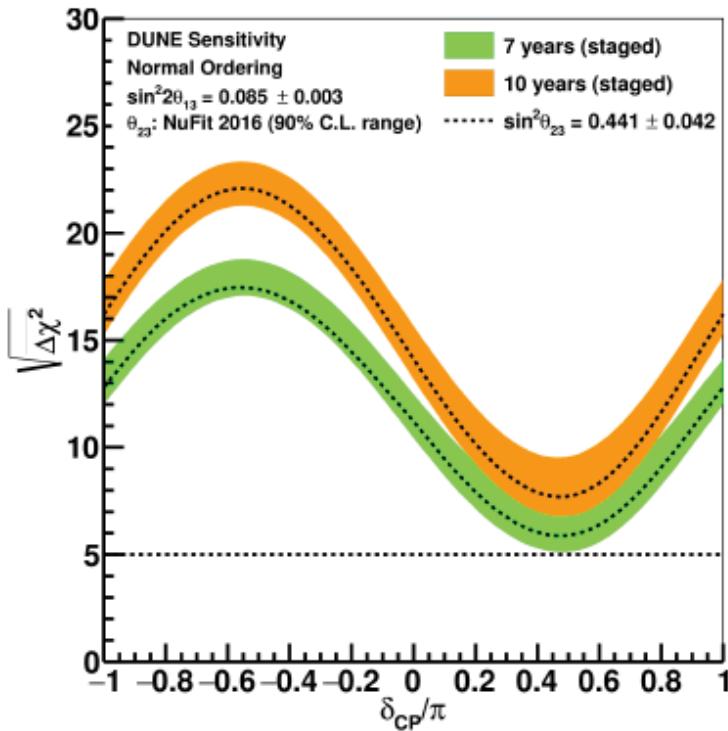
Width of band indicates variation in possible central values of θ_{23}



Simultaneous measurement of neutrino mixing angles and δ_{CP}

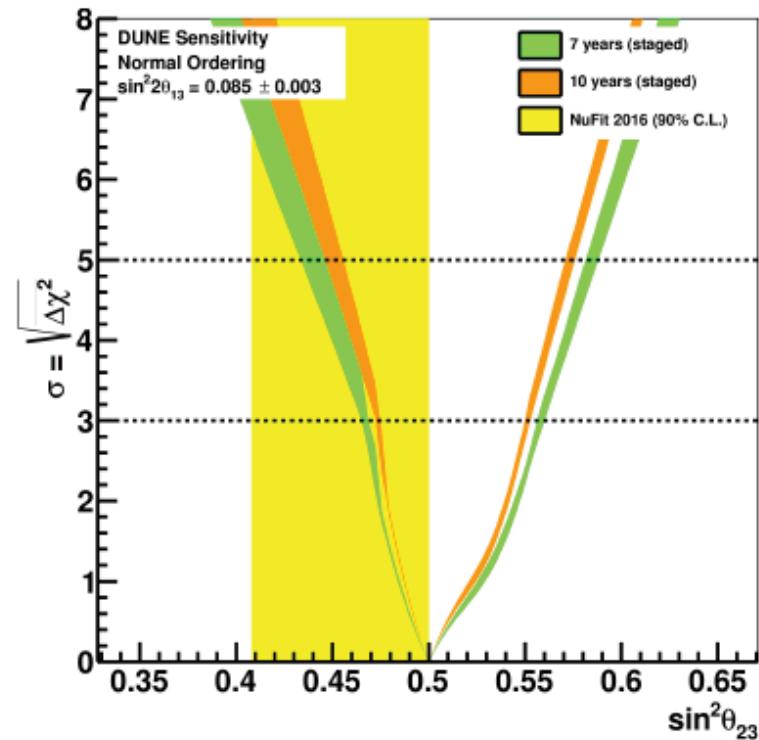
Oscillation Highlights (II)

Mass Ordering



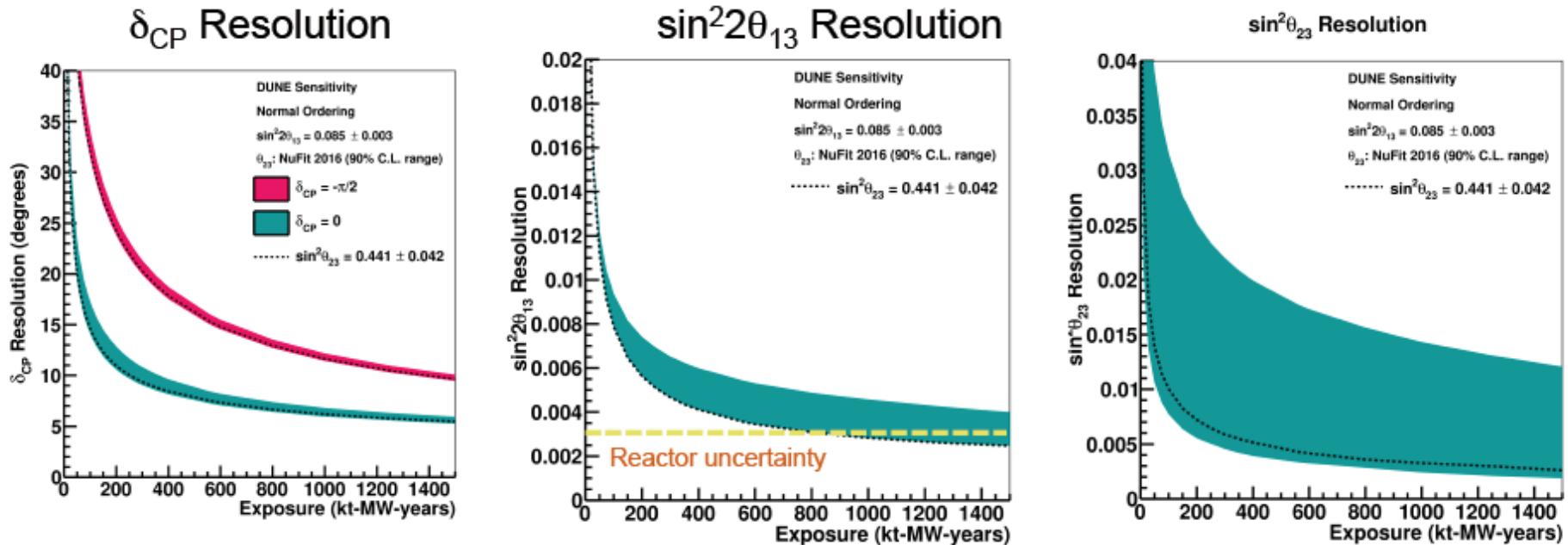
Width of band indicates variation in possible central values of θ_{23}

Octant



Width of band indicates variation in possible true value of δ_{CP}

Oscillation Highlights (III)



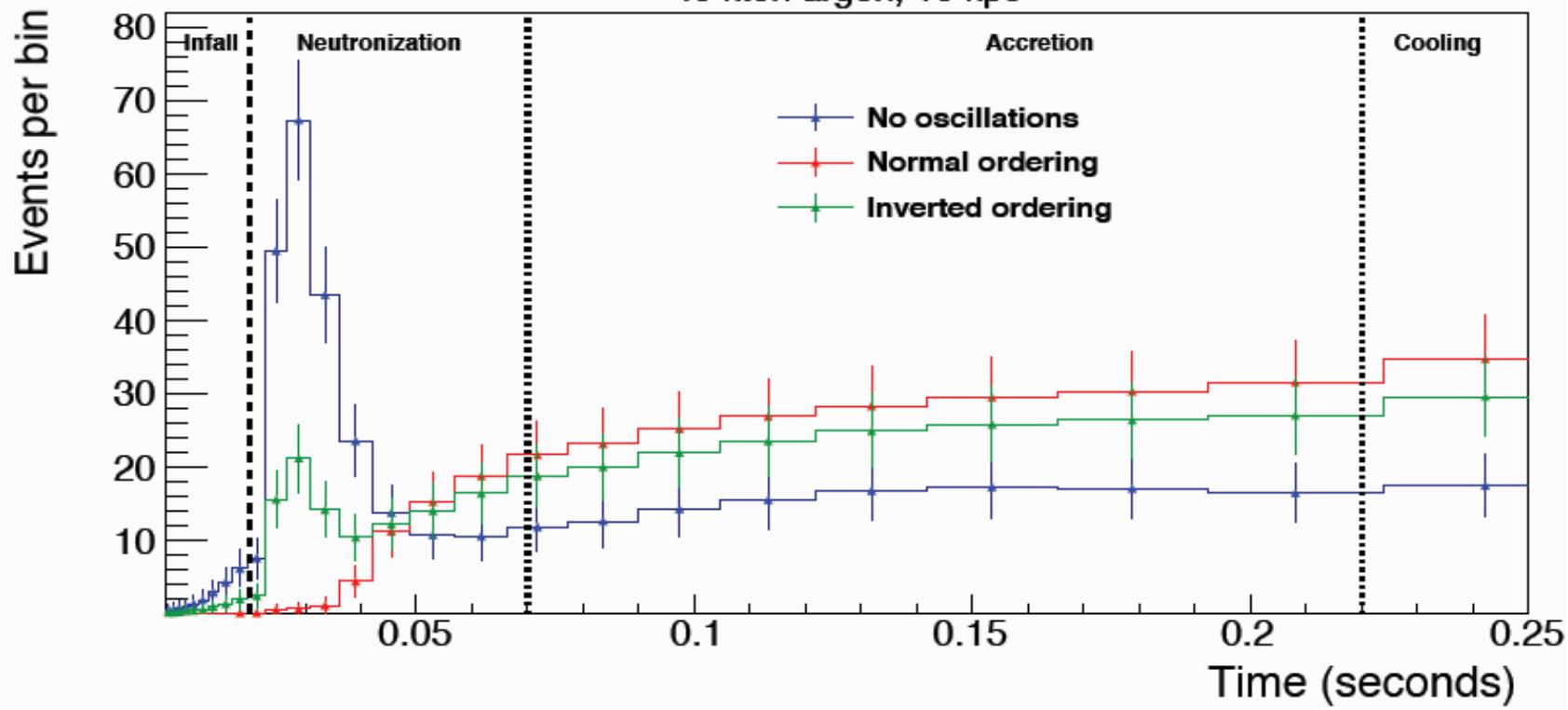
Other Highlights

In LArTPC, SNB signal

dominated by electron neutrinos:



40 kton argon, 10 kpc



Observation of early time development yields sensitivity to neutrino mass ordering and details of SNB model.

The DUNE Collaboration

May 2018:

1095 collaborators from 175 institutions in 31 nations

Armenia, Brazil, Bulgaria, Canada,
CERN, Chile, China, Colombia,
Czech Republic, Spain, Finland,
France, Greece, India, Iran, Italy,
Japan, Madagascar, Mexico,
Netherlands, Paraguay, Peru,
Poland, Romania, Russia, South
Korea, Sweden, Switzerland,
Turkey, UK, Ukraine, USA



DUNE is still growing: $dN/dt > 100$ collaborators/year!

Ultimate size: 1500?

International Context

★ The US is committed

- LBNF/DUNE is the future flagship of Fermilab & the US domestic particle physics programme
- LBNF/DUNE is now an approved project:
 - CD-3A approval in September gives US DOE legal authority to commit ~\$300M for the far site construction/excavation
 - US total project cost of ~\$1.5B
- Strong cross-party political support & at highest levels of US DOE
 - Both houses of congress included “start of construction” language in FY17 president’s budget request

★ Strong Support from CERN

- Follows European strategy for particle physics
- Major investment in CERN Neutrino platform
 - 75 MCHF up to end of current 5-year MTP – mostly for DUNE
- CERN commitment to construct the first FD cryostat at SURF
 - The first investment in an experiment outside of CERN !

International Context

★ Strong international support, e.g.

- **Brazil:** R&D funding from FAPESP
- **China:** in-kind contribution LBNF beam line
- **France:** funding for dual phase and protoDUNE
- **Germany:** Near Detector included in strategy
- **India:** >\$100M in-kind contribution to PIP-II + Annex II
- **Italy:** agreed contribution to PIP-II, discussing DUNE
- **Spain:** R&D funding for protoDUNE
- **Switzerland:** large investment in protoDUNE, discussing DUNE
- **UK:** £2.1M preparatory grant + £0.9M capital for protoDUNE
+ £65M from BEIS for capital for DUNE and LBNF/PIP-II
+ STFC program contributions

★ Prospects

- DUNE is going ahead
- Funding matrix is being lined up

Schedule/Timeline

★ Costs and technical schedule are understood

- Multiple independent reviews
- FD excavation started

★ Schedule based on a realistic funding profile

- DOE planning line (including large contingency)
- Planned CERN contributions
- Anticipated international contributions

★ International Key Milestones:

- **2017:** start of construction at SURF
- **2018:** operation of two large-scale prototypes at CERN
- **2019:** International approval of DUNE funding matrix
- **2021:** start of installation of first 17-kt far detector module
- **2024:** start of operation of 17-kt far detector module
- **2026:** start of beam operation (1.2 MW) with two 17-kt FD modules

DUNE/LBNF-UK



UNIVERSITY OF
BIRMINGHAM



UNIVERSITY OF
CAMBRIDGE



The
University
Of
Sheffield.



FACULTY OF MATHEMATICAL AND PHYSICAL SCIENCES



MANCHESTER
1824

The University of Manchester



Science & Technology
Facilities Council

Imperial College
London



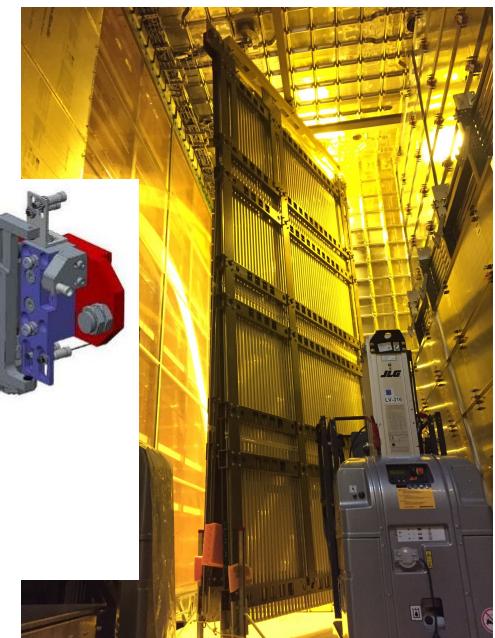
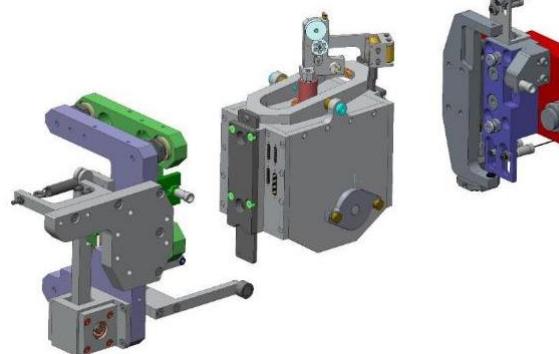
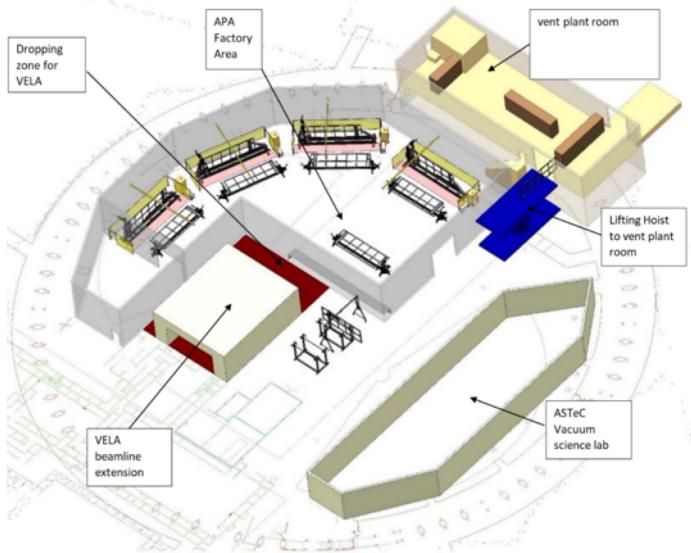
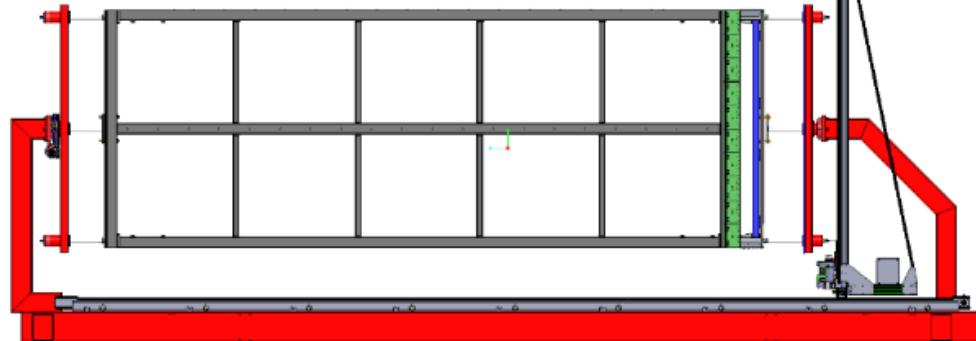
UK Leadership

- Co-Spokesperson Stefan Söldner-Rembold
 - Consortium Leaders
 - APA Christos Touramanis
 - DAQ Dave Newbold
 - Near Detector Design Study AW
 - Executive Board (all the above)
 - Speakers Board Jarek Nowak
 - And many other ...

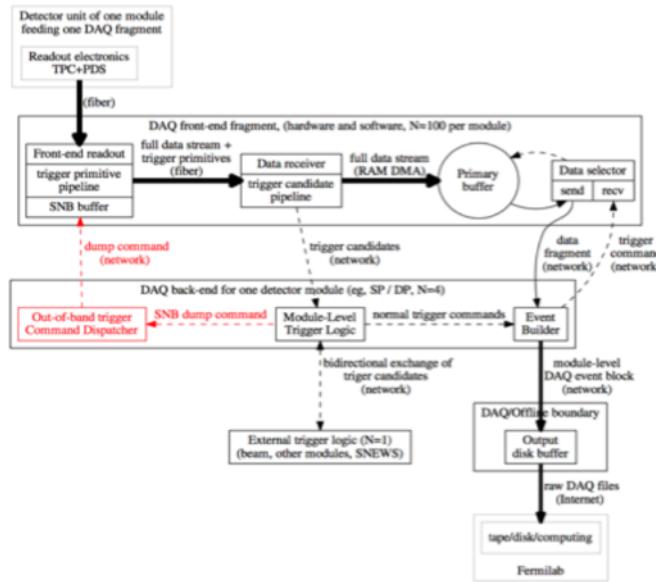
LBNF/DUNE Plans

- Ambitious program with the help of BEIS capital
 - From 2019 to 2026
 - Currently/soon under PPRP review
- DUNE
 - Physics (Oscillations, reconstruction software, GRID)
 - DAQ (Reading out the 2 first detectors)
 - LAr TPC (Building 150 APAs, half of 2 SP modules)
- LBNF
 - Use UK expertise in high power targets (NuMI, T2K)
- Accelerator upgrade
 - Use UK expertise from ESS to build 3 SRF cryo-modules for PIP-II

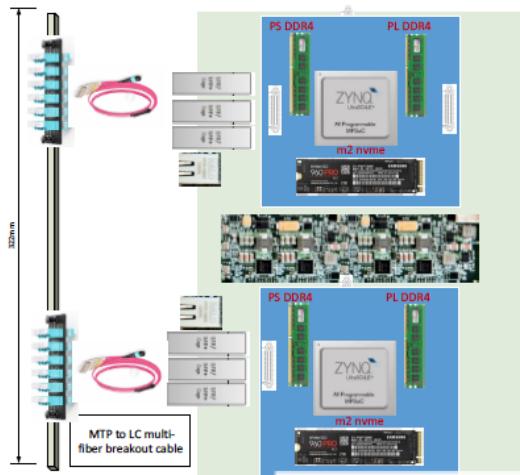
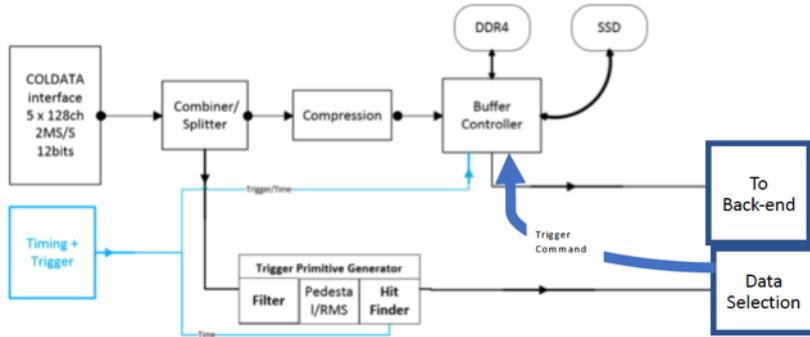
APA Production



DAQ



Overall Conceptual Design

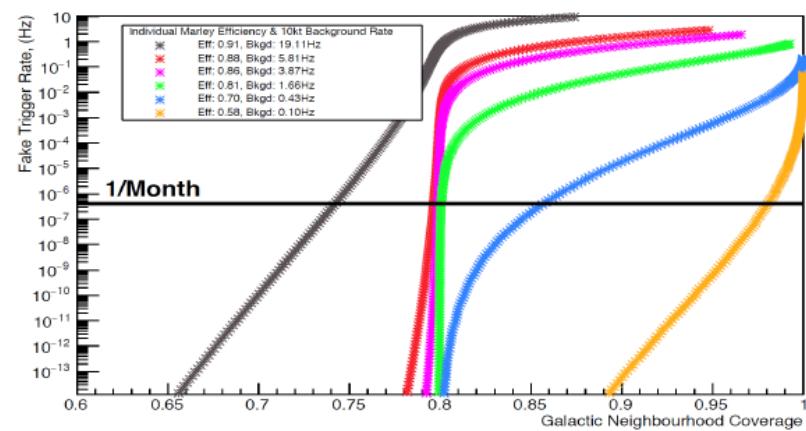


HW/FW/SW
development

protoDUNE



SN Triggering



Funding Planning

- DUNE (profile to be revised)

FY year	19/20	20/21	21/22	22/23	23/24	24/25	25/26	26/27	Total £k
CG	375	750	750	750	750	500	500	250	4,875
Capital	1,000	2,000	4,000	5,000	6,000	6,000	5,000	1,000	30,000
Resource	1,000	2,200	2,200	2,200	2,100	2,000	2,000	1,000	14,700

- LBNF
 - Target and target hall facilities
 - 6 M£ capital & some resource over 6-8 years
- PIP-II
 - Superconducting RF
 - 24 M£ capital & some resources over 6 years

European Strategy

- Last European Strategy
 - Call for Europeans to join international programs
- Has happened massively!
 - LBNE & Laguna/LBNO → DUNE
- Now
 - Ground work has been laid and is uncontroversial
 - Have to build and fund full program
 - 2 MW beam
 - 40 kton fiducial mass
 - THE facility for neutrino oscillations
 - Needs additional partners and funding

Summary & Conclusion

- Vibrant UK program
 - Running (NOvA, MicroBooNE)
 - Soon commissioning (SBND)
 - Construction (DUNE)
- Major UK contribution to next big facility in PP
 - DUNE/ LBNF
- Essential program for the future of neutrino physics