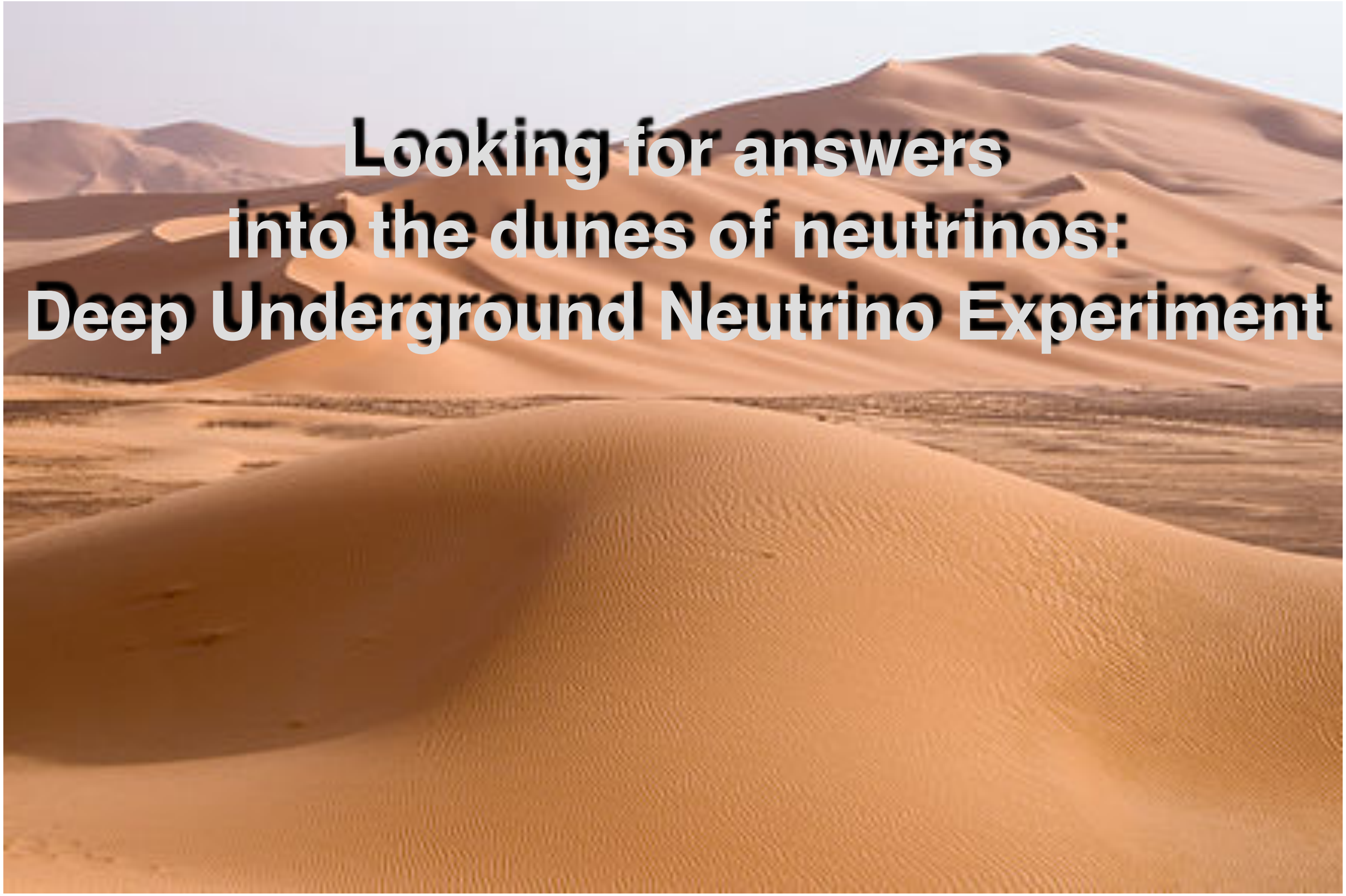
Looking for answers into the dunes of neutrinos: Deep Underground Neutrino Experiment



Miquel Nebot-Guinot

THE UNIVERSITY of EDINBURGH

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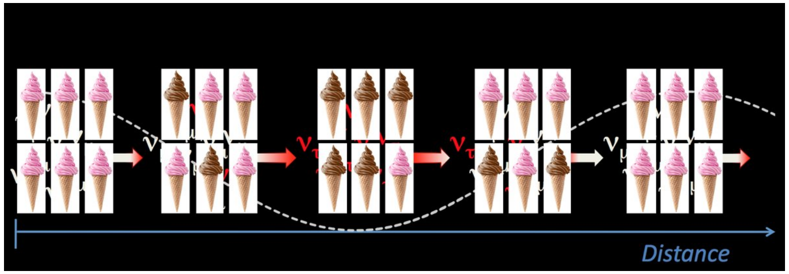
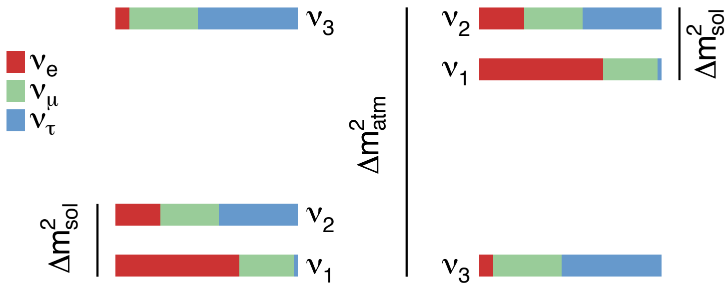
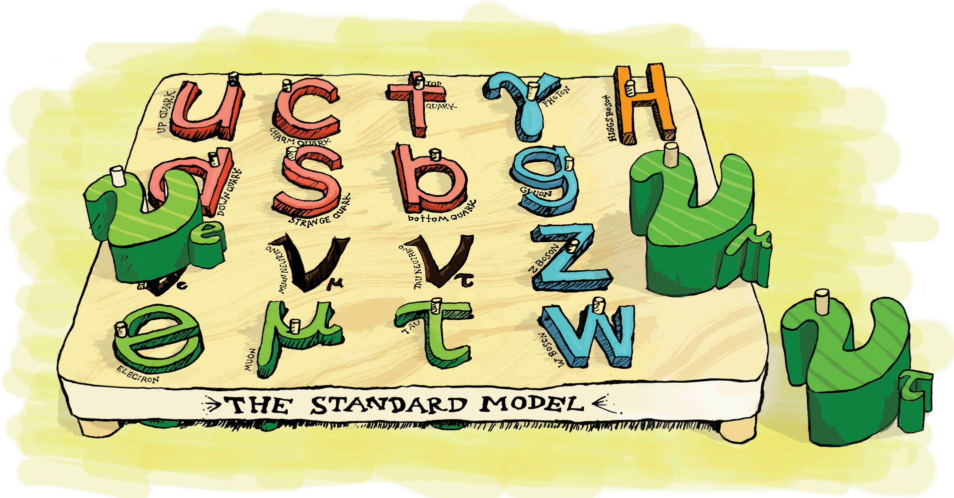
Neutrino scenario - Open questions

- Current knowledge of neutrino ‘misfit’ into the SM indicating physics BSM
  - Neutrino oscillates

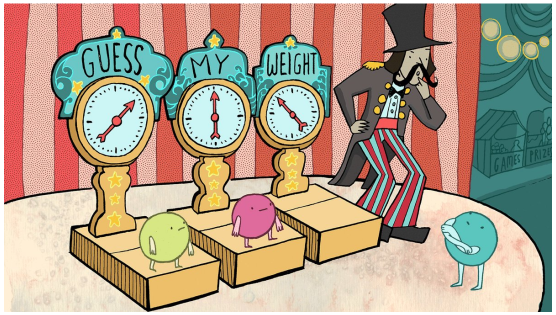


  - Neutrinos have mass and mix





- Measure MH, CPV, and neutrino mixing parameters.
- Neutrino mass, nature and mass origin.



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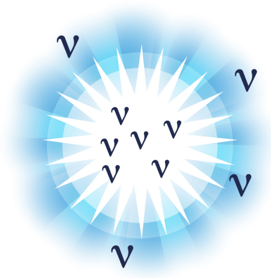
Sources of neutrinos

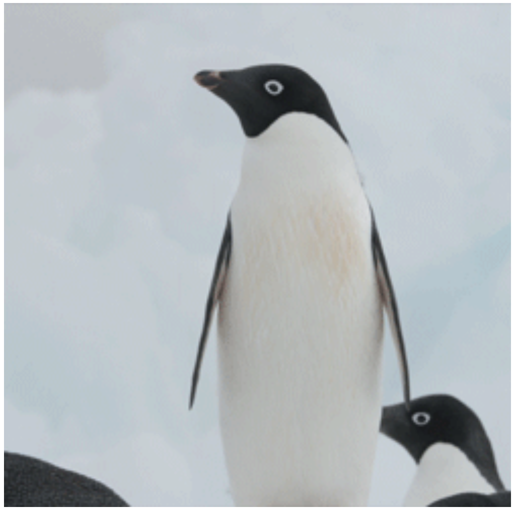
- Radioactive decays
- Nuclear reactions (Solar, Reactors, Supernova…)
- Particle collisions (cosmic rays causing atmospheric neutrinos, neutrino beam produces by particle accelerators..)

DUNE’s scientific goals

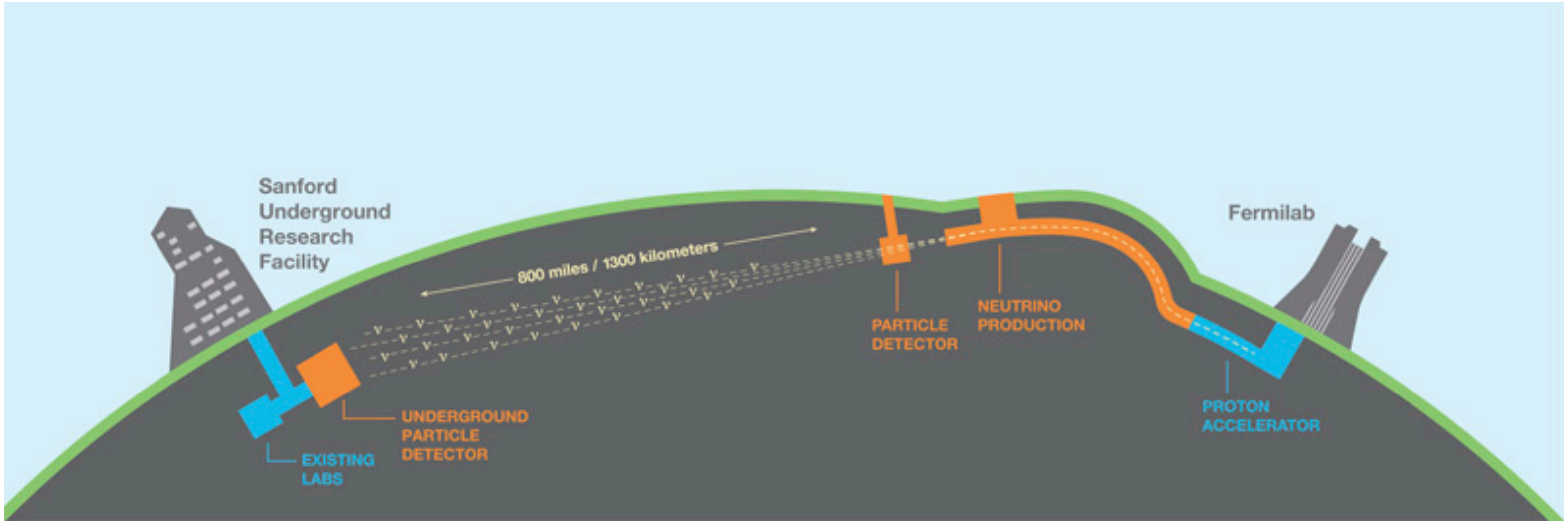
- Origin of matter
  Discover what happened after the big bang: Are neutrinos the reason the universe is made of matter?
- Unification of forces
  Move closer to realizing Einstein’s dream of a unified theory of matter and energy
- Black hole formation
  Use neutrinos to look into the cosmos and watch the formation of neutron stars and black holes in real time

	Primary science goals	Ancillary science program
	**Beam neutrino oscillations** Measure MH, CPV, and neutrino mixing parameters	Other accelerator neutrino physics: BSM, NSI, Lorentz violation, CPT violation, sterile neutrinos, large extra dimensions, heavy neutral leptons, tau appearance Neutrino oscillation using atmospheric and solar neutrinos
	**Search for proton decay**	Neutrino cross sections, nuclear effects
	**Supernova neutrino detection**	Searches for dark matter

DUNE experiment



DUNE experiment



Sanford Underground Research Facility,
South Dakota

DUNE

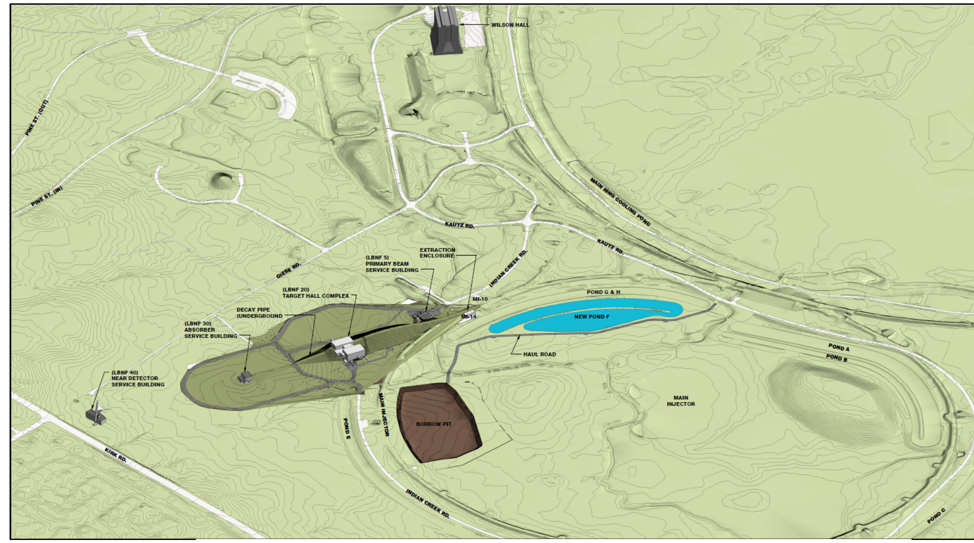
>1000 collaborators & 32 countries

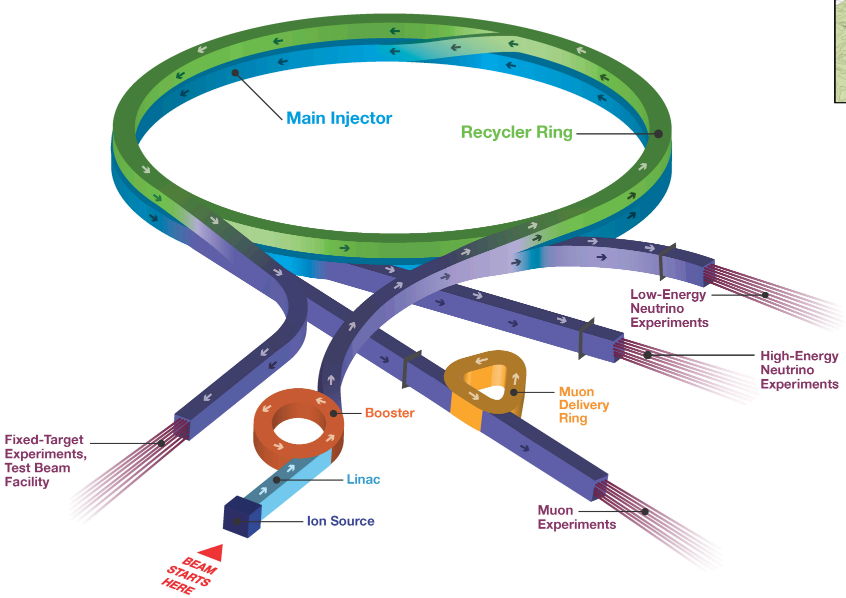
Fermi National Accelerator Laboratory,
Illinois

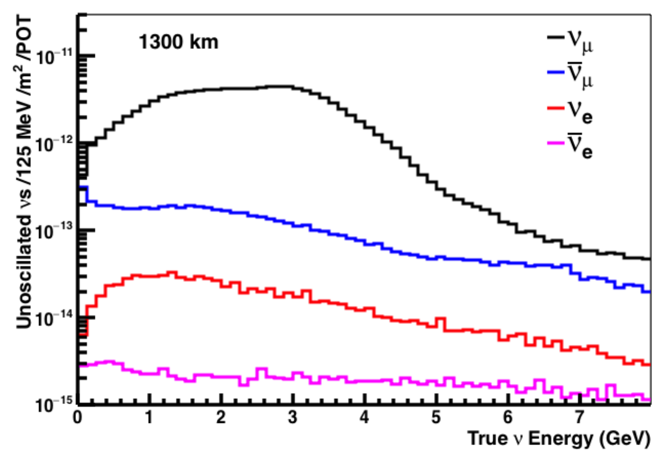
LBNF

LBNF Beam

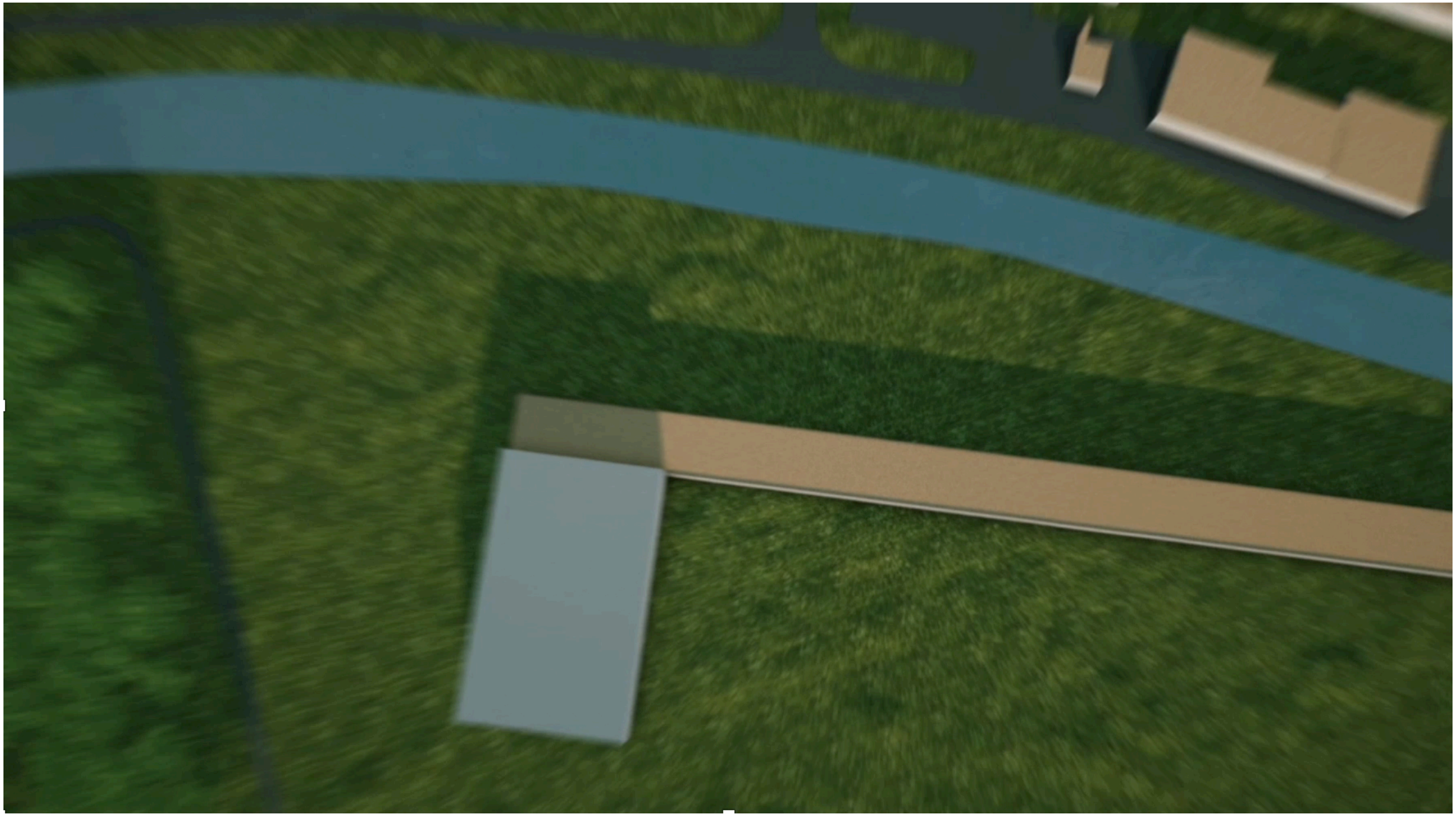
- 60-120 GeV proton beam
- 1.2 MW, upgradeable to 2.4 MW
- Horn-focused neutrino beam line optimized for CP violation sensitivity.
- Neutrino (FHC) and antineutrino (RHC) modes.





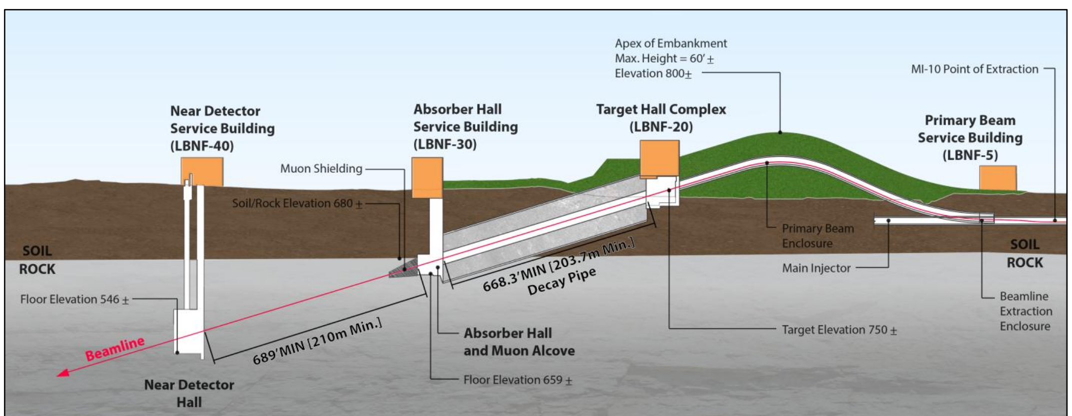


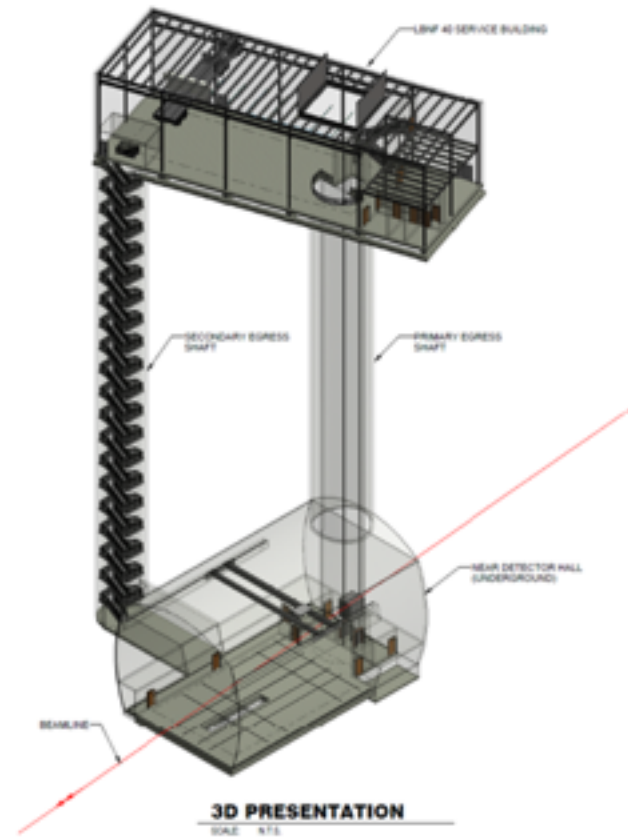
LBNF Beam



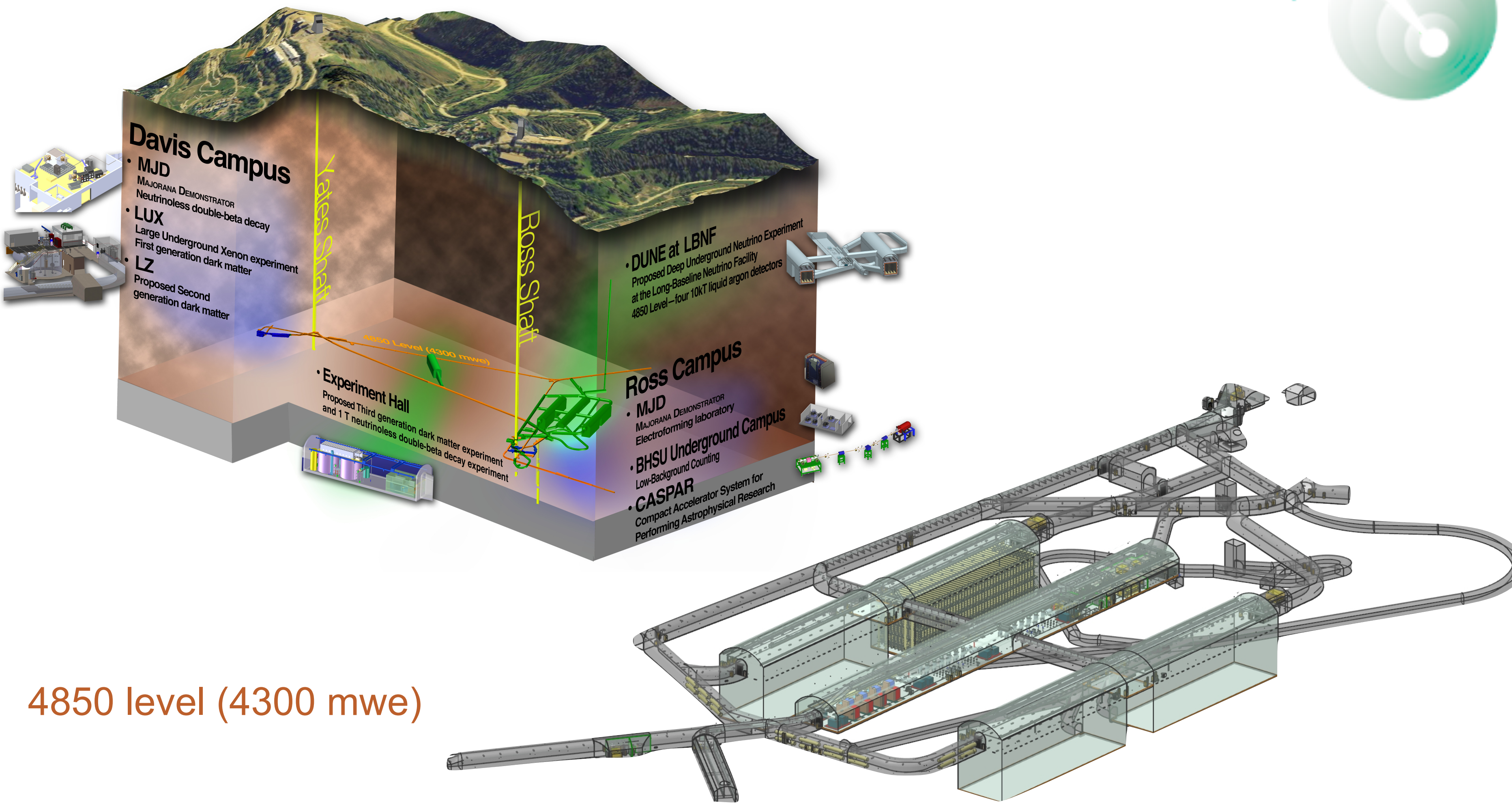
Near detector

- Primary purpose is to constrain systematic uncertainty for long-baseline oscillation analysis as well as flux, cross-section, and detector uncertainties.
- DUNE ND Conceptual Design Report (CDR) planned for 2019
- •DUNE ND design concept is an integrated system composed of multiple detectors:
    - Highly segmented LArTPC
    - Magnetized multi-purpose tracker
    - Electromagnetic calorimeter
    - Muon chambers
    - Conceptual design will preserve option to move ND for off-axis measurements





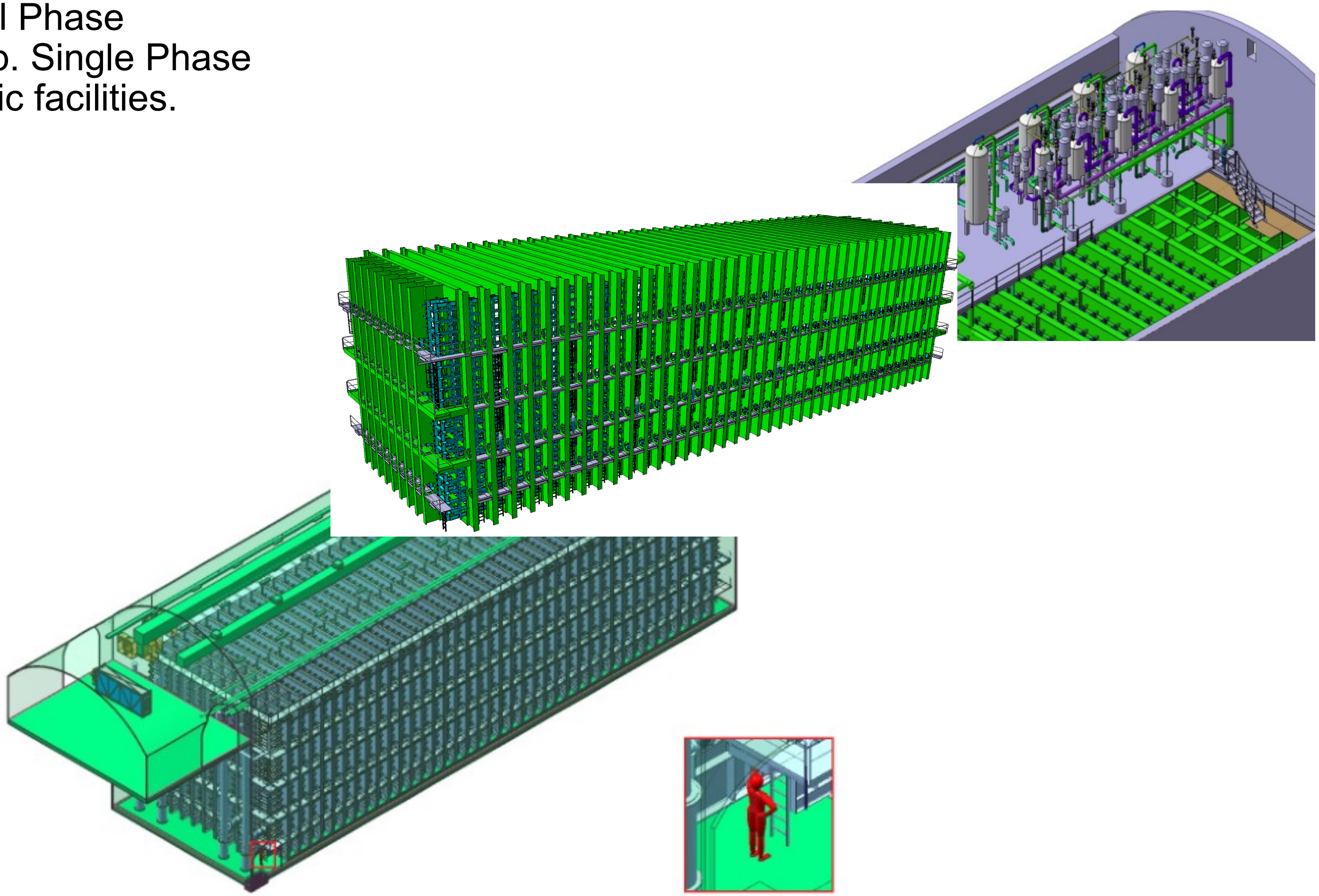
Far detector (facilities)



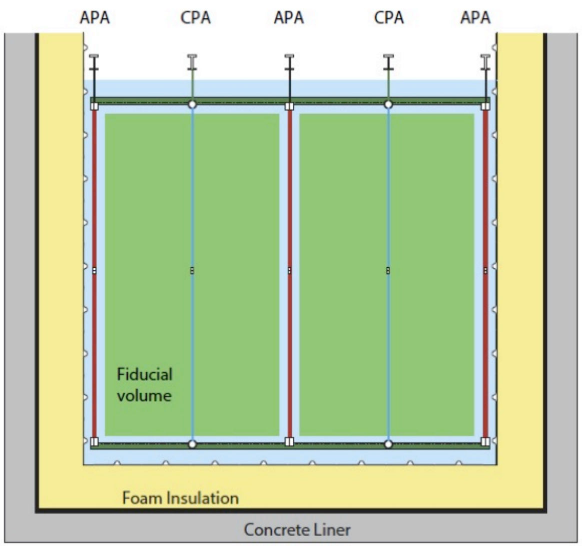
4850 level (4300 mwe)

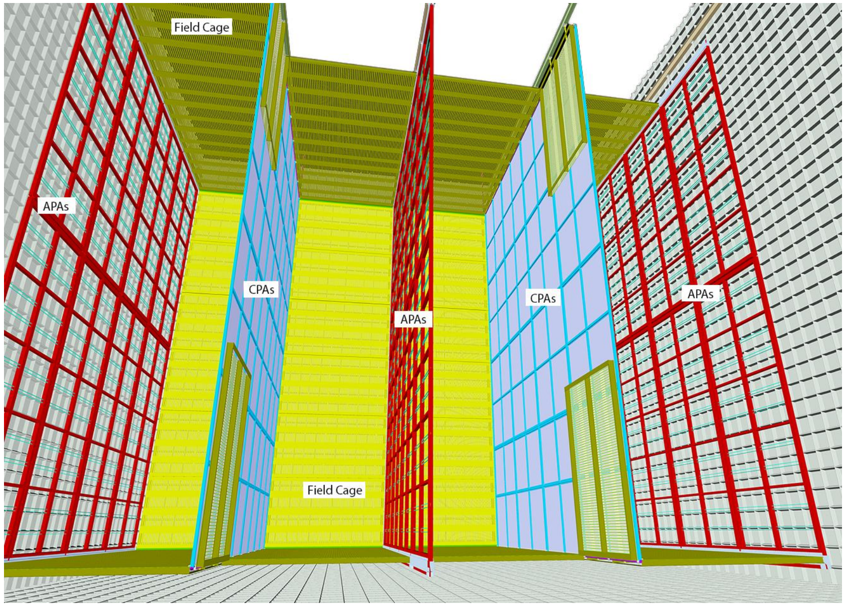
Far detector (facilities)

- 4x10-kt (fiducial) liquid argon TPC modules:
    - Single Phase
    - Dual Phase
    - Prob. Single Phase
- Cryogenic facilities.

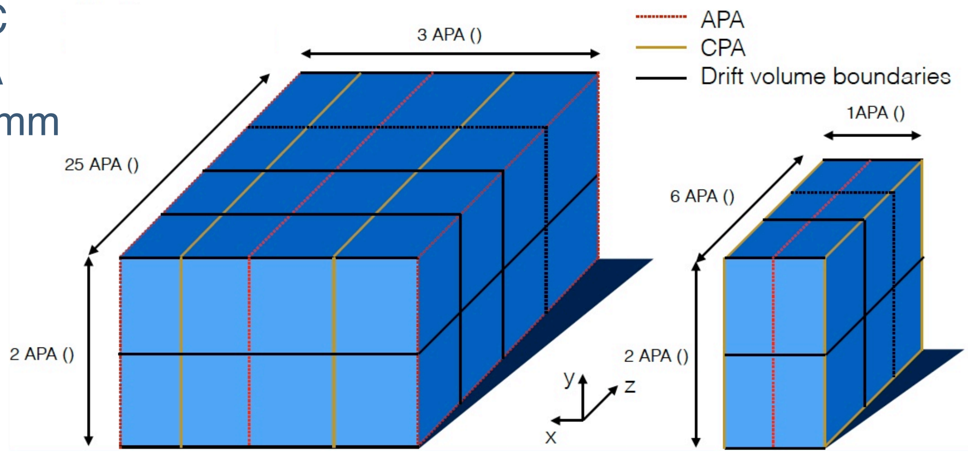


Far detector (Single Phase)





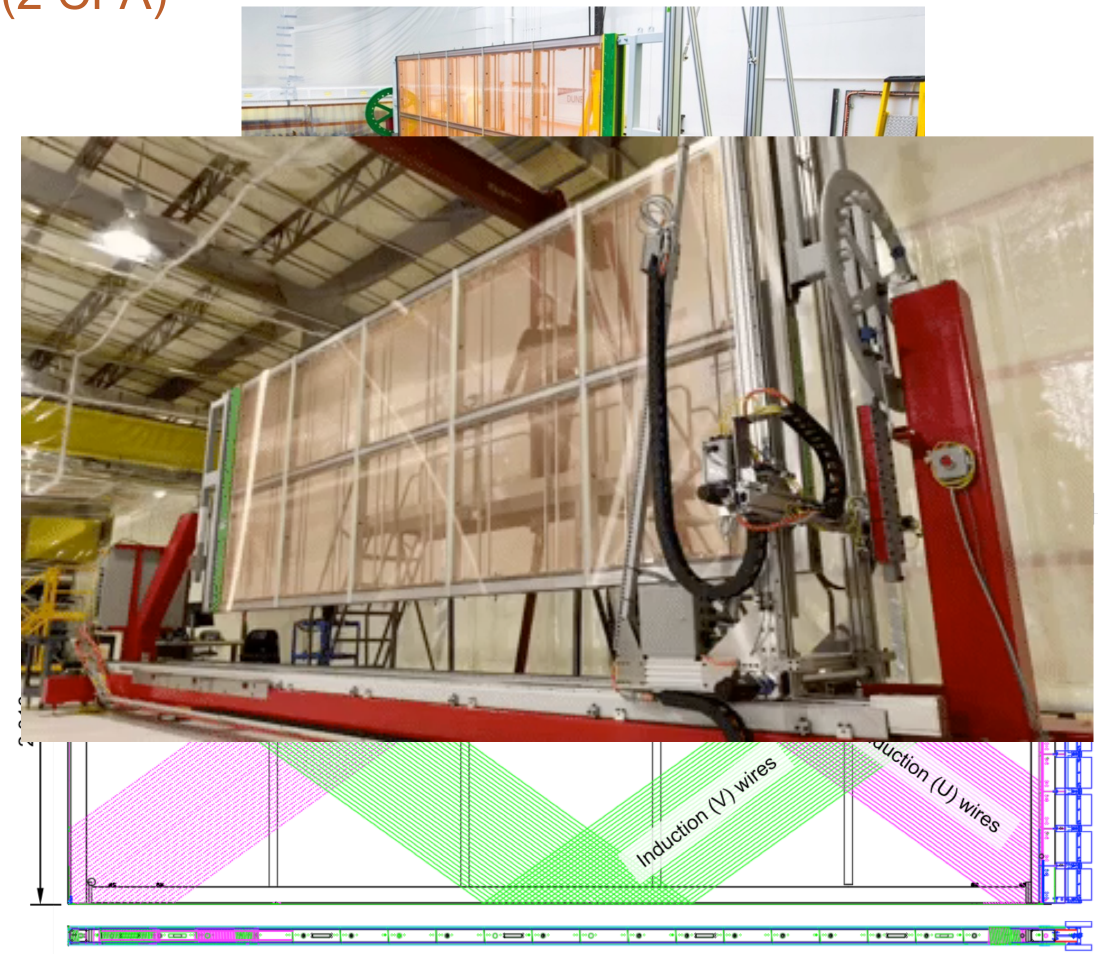
- Per 10kt 200 TPC
- Per 10kt 150 APA
  - Wire pitch 4.7mm
  - PDS 12 scintillator bars/APA



Far detector (Single Phase)

12m Cathode Plane Assembly (2 CPA)

Anode Plane Assembly



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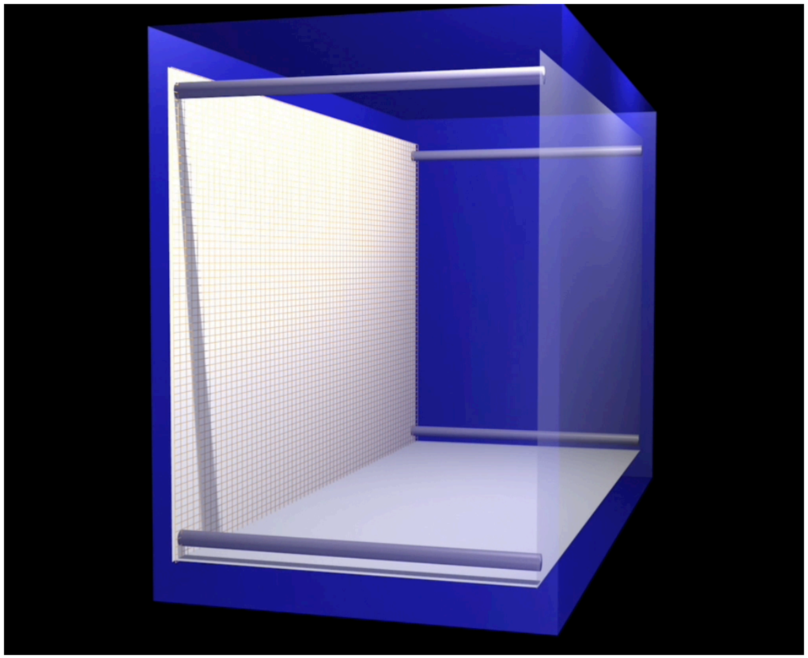
DUNE FD SP: Detection concept

TPC-wires



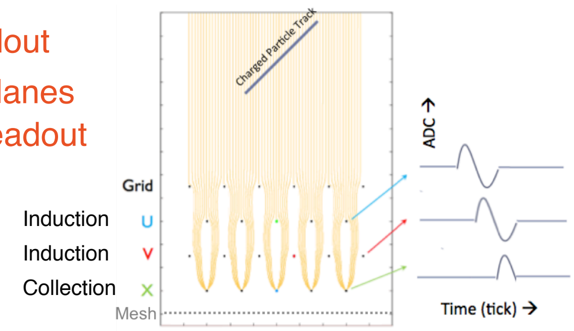
TPC

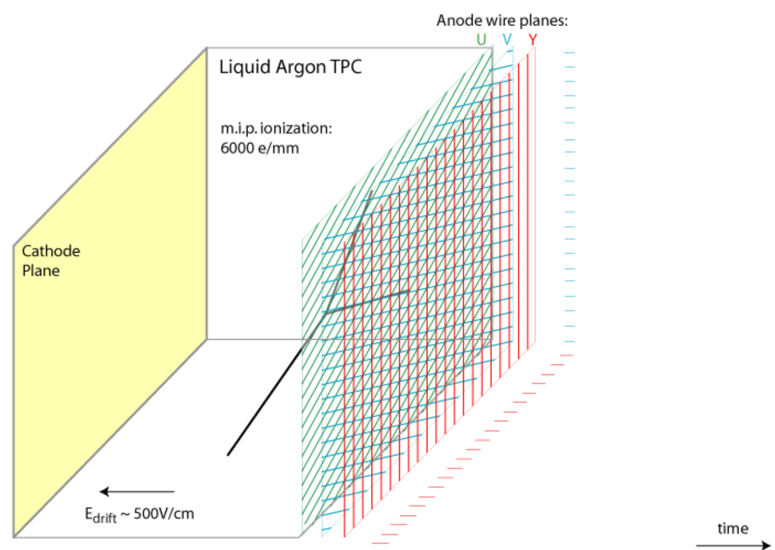
Particles interact in the LAr

Ionised electrons drifted towards the APA

Readout

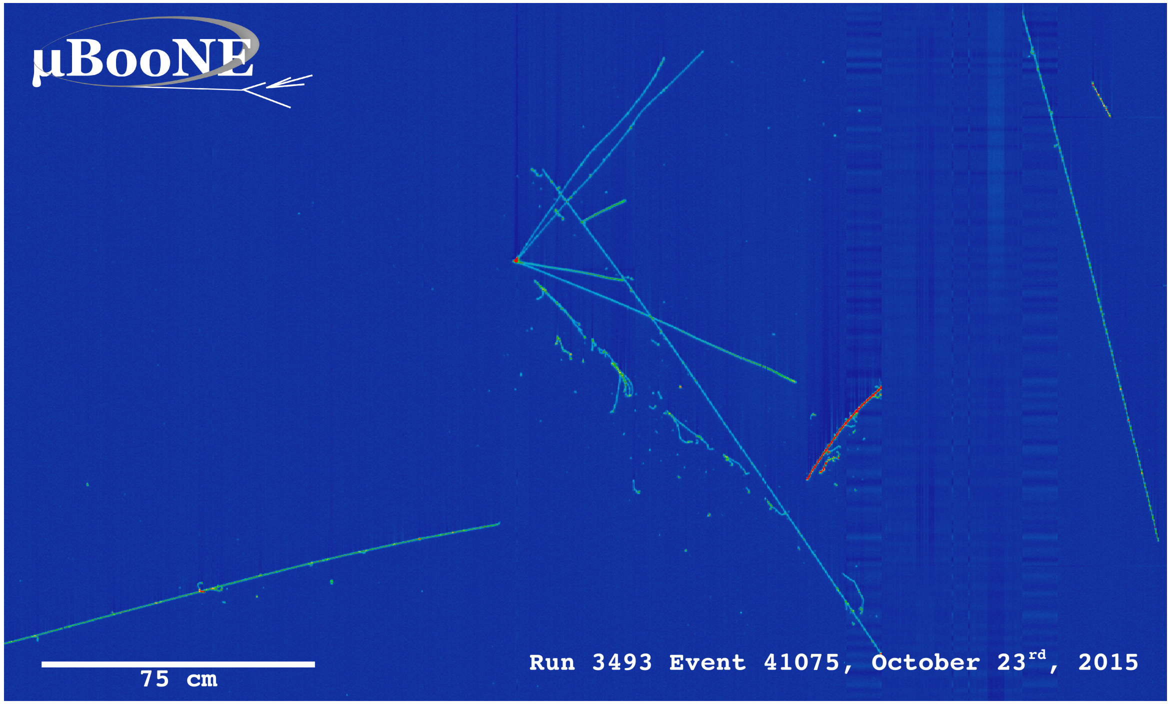
3 wire planes (APA) readout





DUNE FD SP: Detection concept

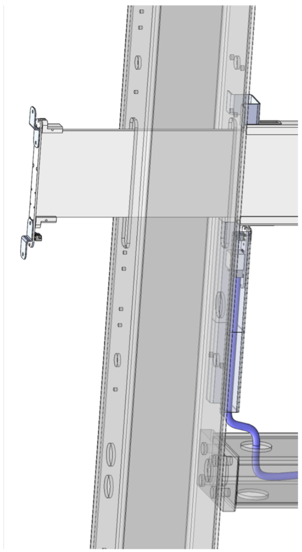
TPC-wires

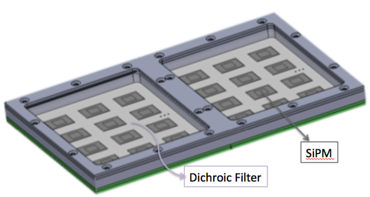


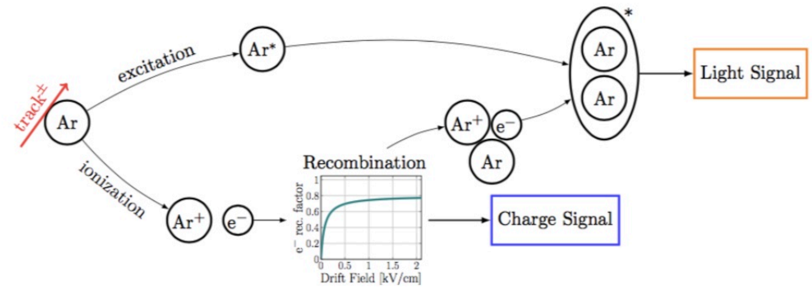
With the waveforms from the wire planes
precise 2D images can be reconstructed

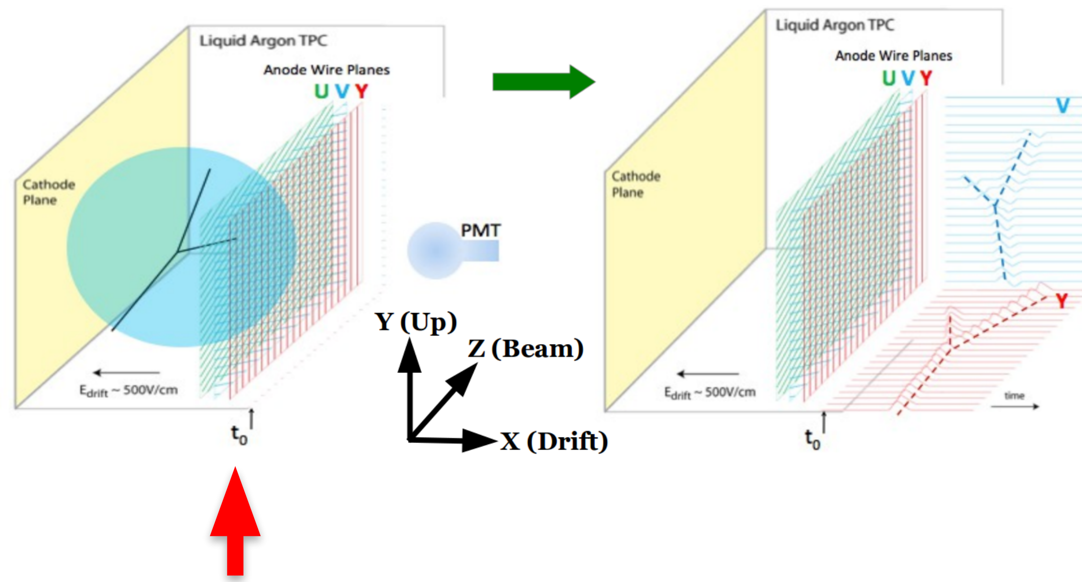
DUNE FD SP: Detection concept

PDS





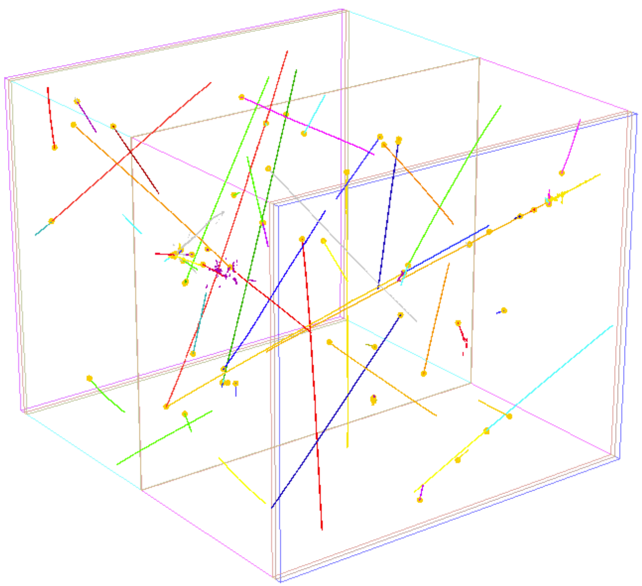




PD bars inserted in the APA
Arapucas

DUNE FD SP: Detection concept

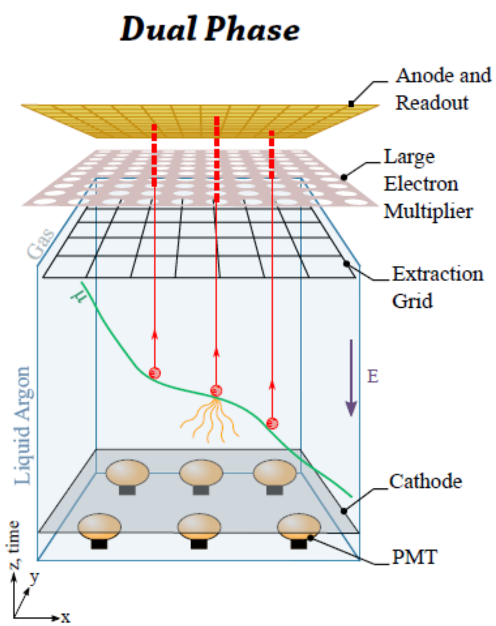
PDS

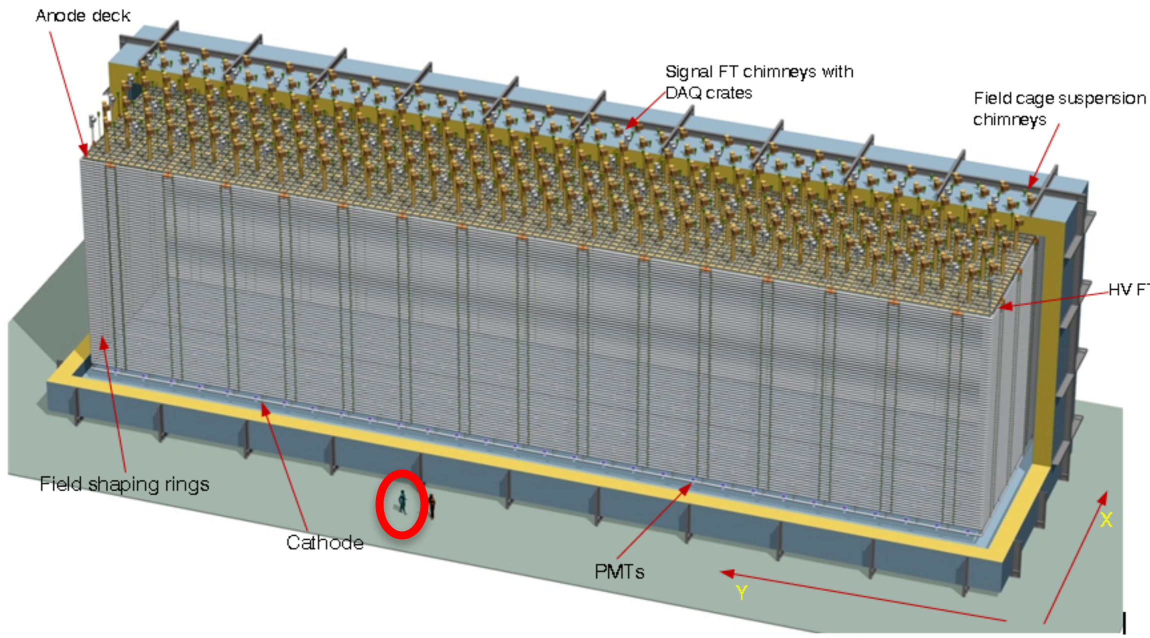


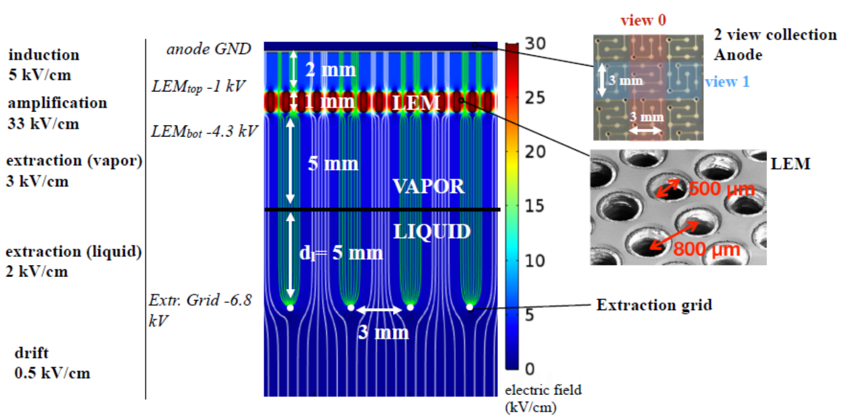
3D reconstructed tracks

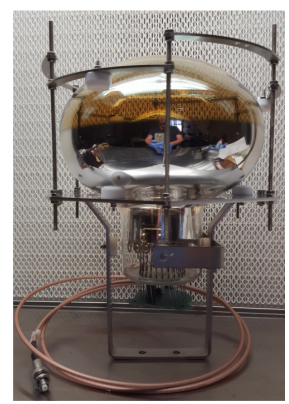
		Supernova Bursts	Nucleon Decays	Atm. Neutrinos	Beam Neutrinos
	fiducial volume		X	X	
T0 for	TPC drift correction	X	X	X	
	sub-ms timing	X			
	Triggering	X	X	X	
	Direct calorimetry	X	X		X
	Position Reconstruction	X	X	X	
	Michel *e* Detection		X	X	X

Far detector (Dual Phase)









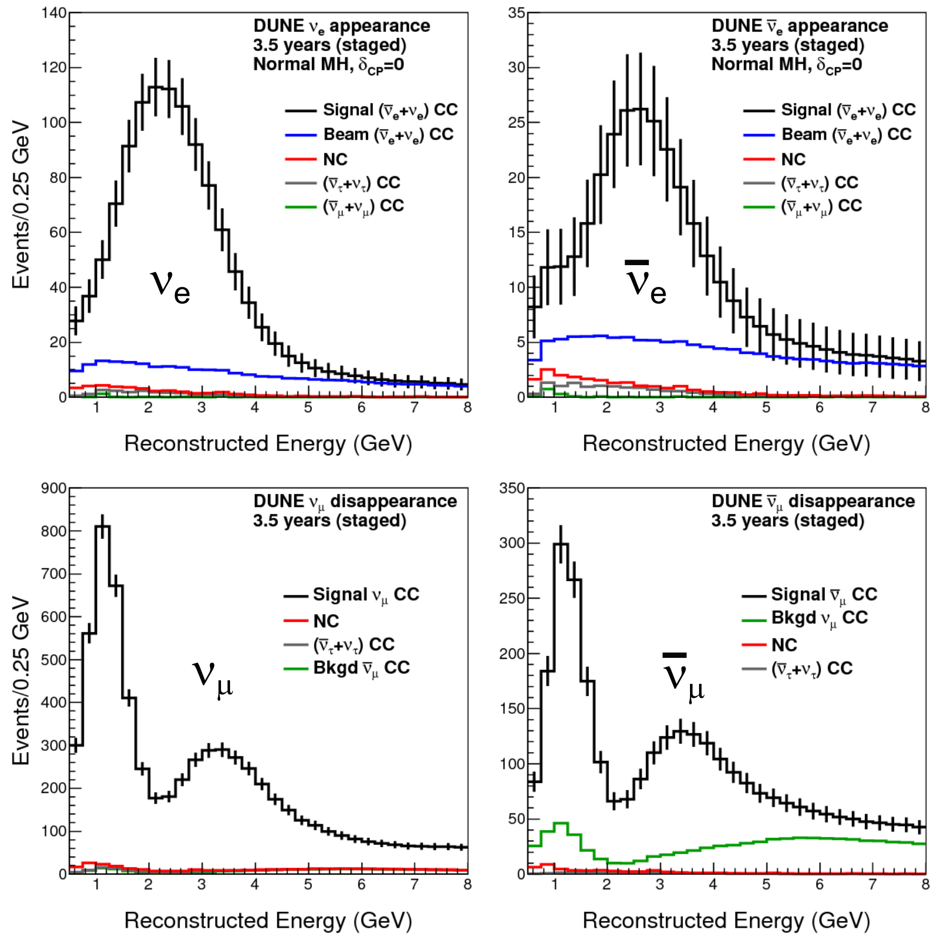
Physics sensitivity

Oscillation

Supernova

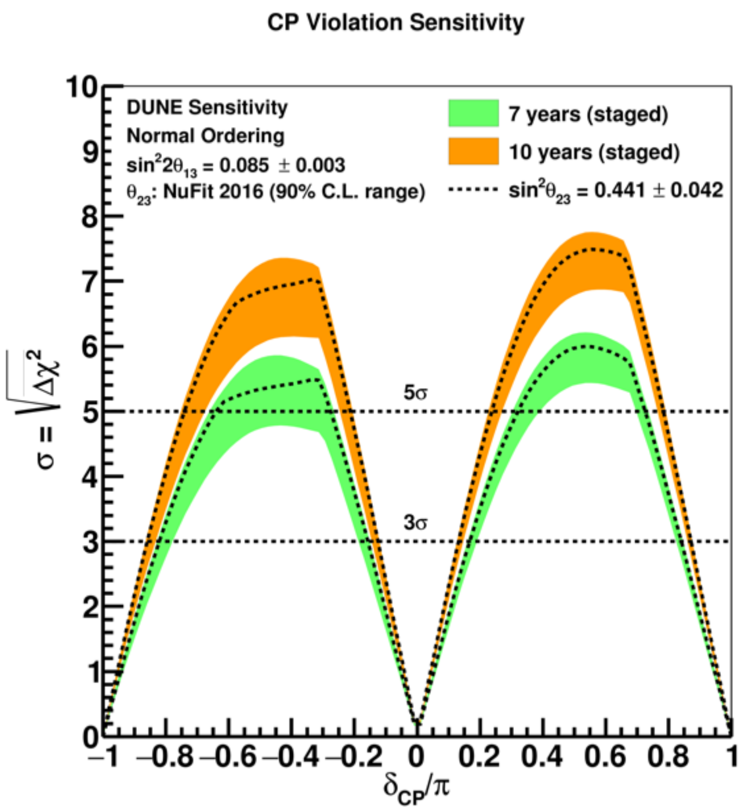
Oscillation Sensitivity

- Reconstructed spectra based on GEANT4 beam simulation, GENIE event generator, and Fast MC using detector response parameterized at the single particle level
- Efficiency tuned using hand scan results
- Order 1000 ν_e appearance events in ~7 years of equal running in neutrino and antineutrino mode
- Simultaneous fit to four spectra to extract oscillation parameters
- Systematics approximated using normalization uncertainties
- GLoBES configurations arXiv: 1606.09550
-

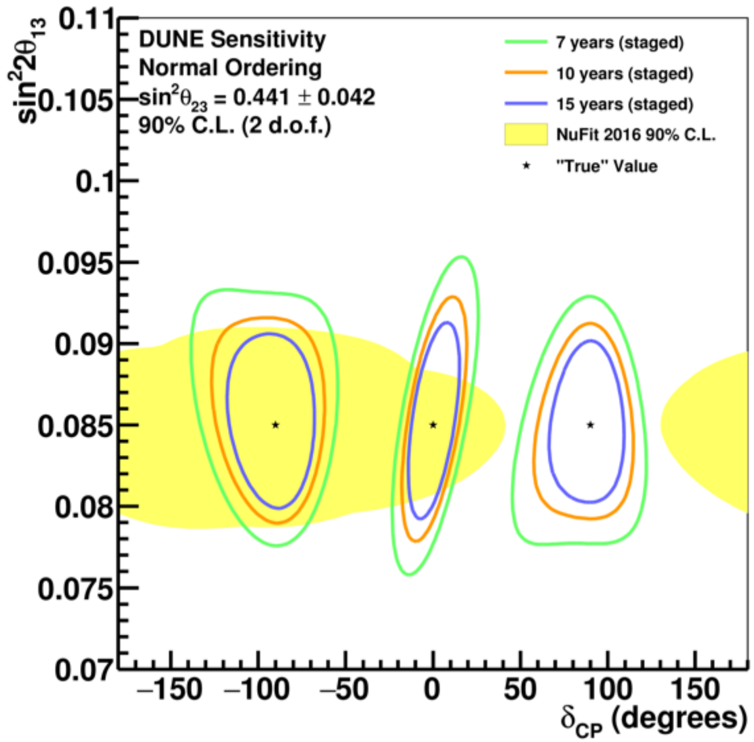


DUNE Conceptual Design Report (CDR) arXiv:1512.06148

Oscillation: CP Violation Sensitivity



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



Simultaneous measurement of neutrino mixing angles and δ_{CP}

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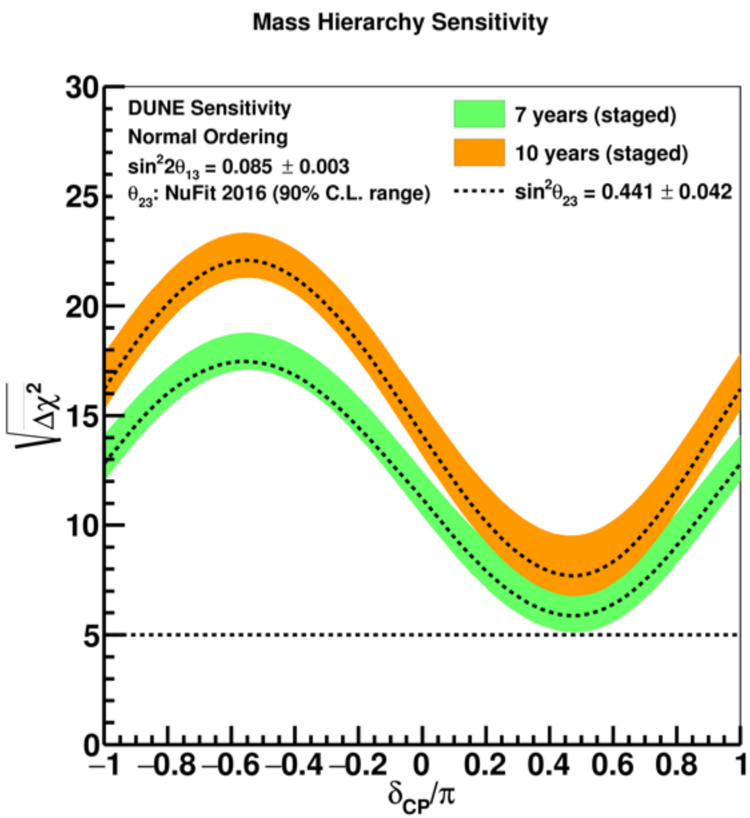
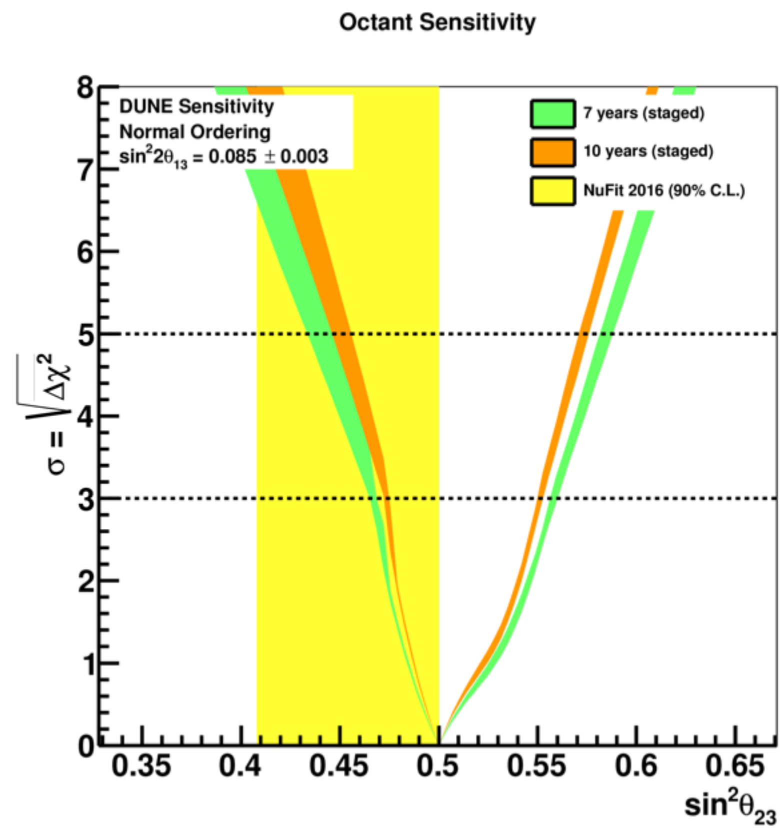
Oscillation: MH and octant sensitivity

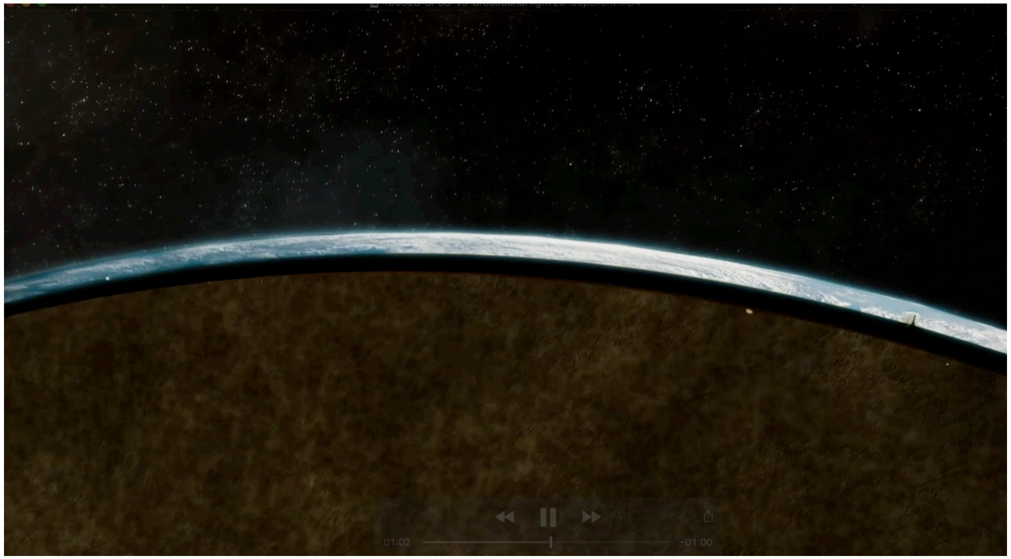




Width of band indicates variation in possible central values of θ_{23}

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

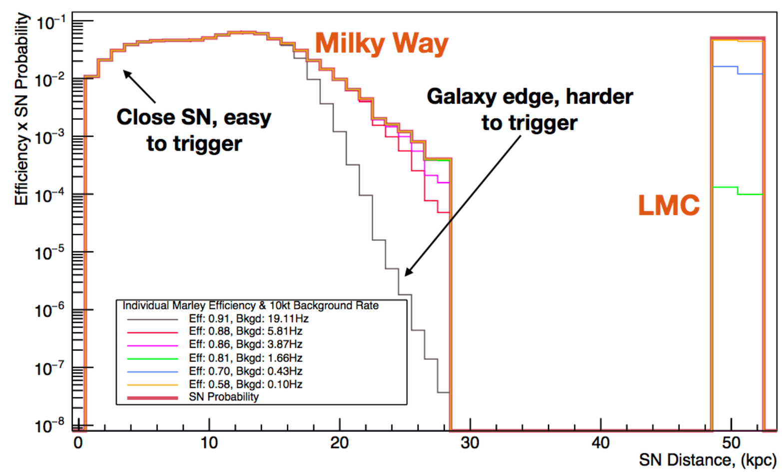
Supernova sensitivity



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

- Early alert

- Supernova physics:
  core collapse mechanism, time evolution, cooling of supernova protostar, nucleosynthesis of heavy nuclei, black hole formation



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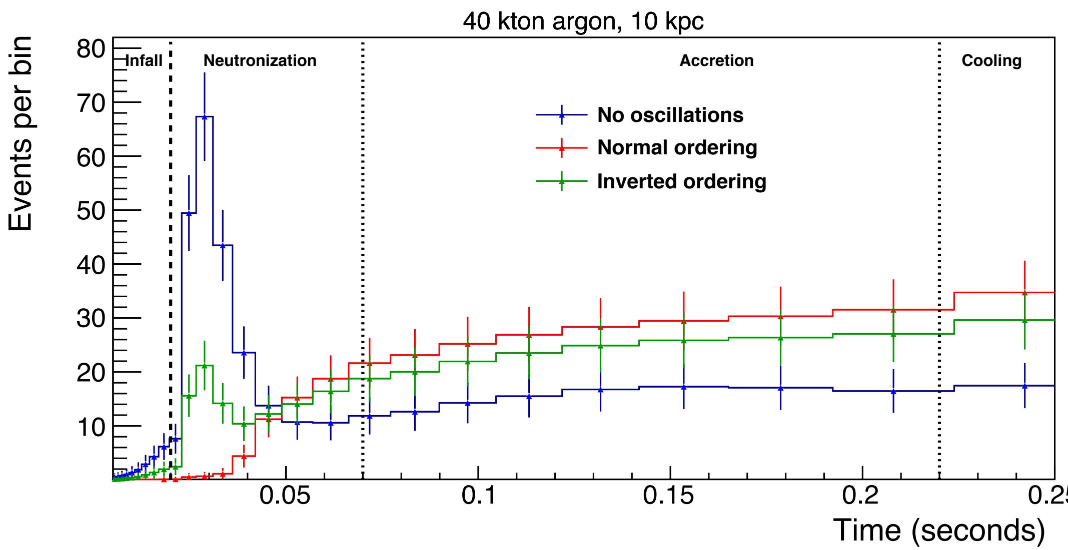
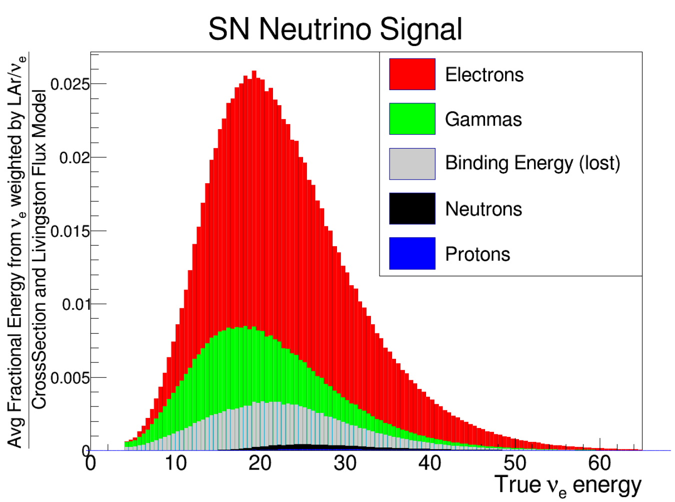
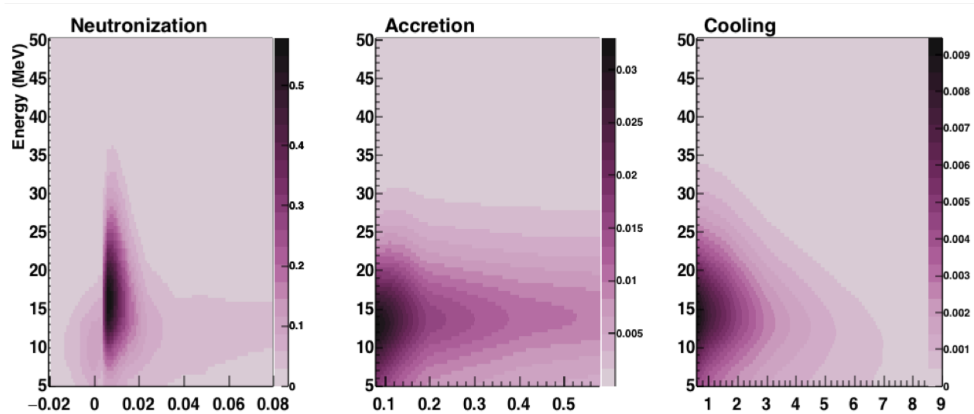
Supernova sensitivity

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

- Neutrino physics: flavour transformation in SN core/Earth, absolute mass, sterile, magnetic moment, axions, extra dimensions



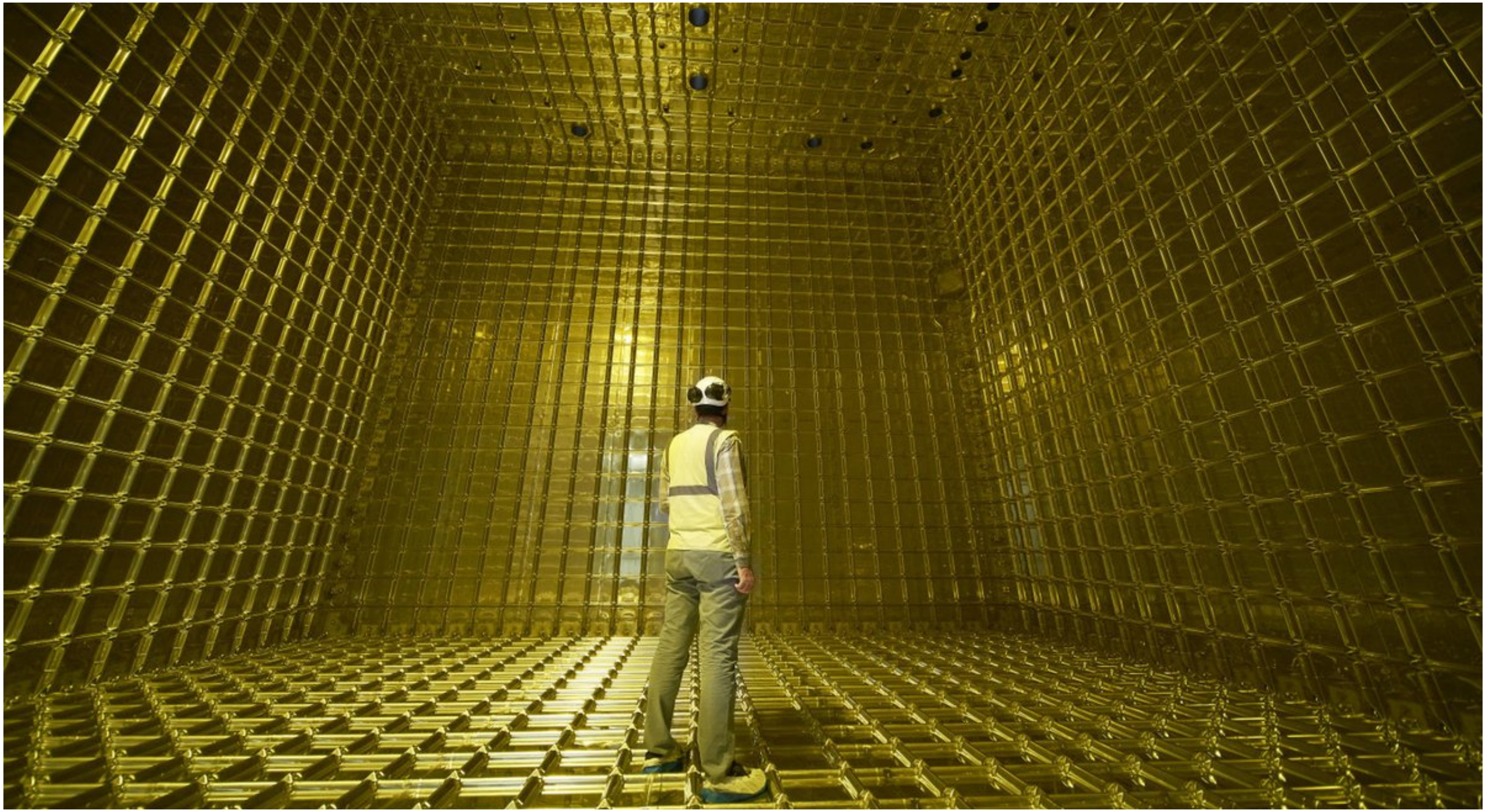




protoDUNE

Benchmark the design

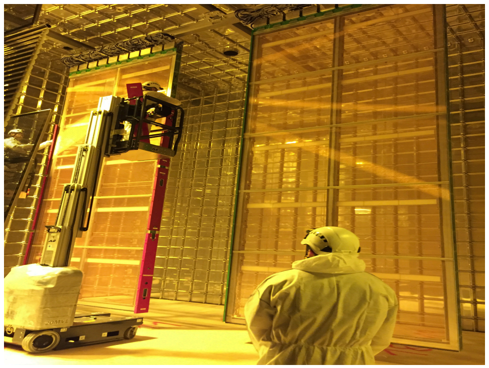
protoDUNE

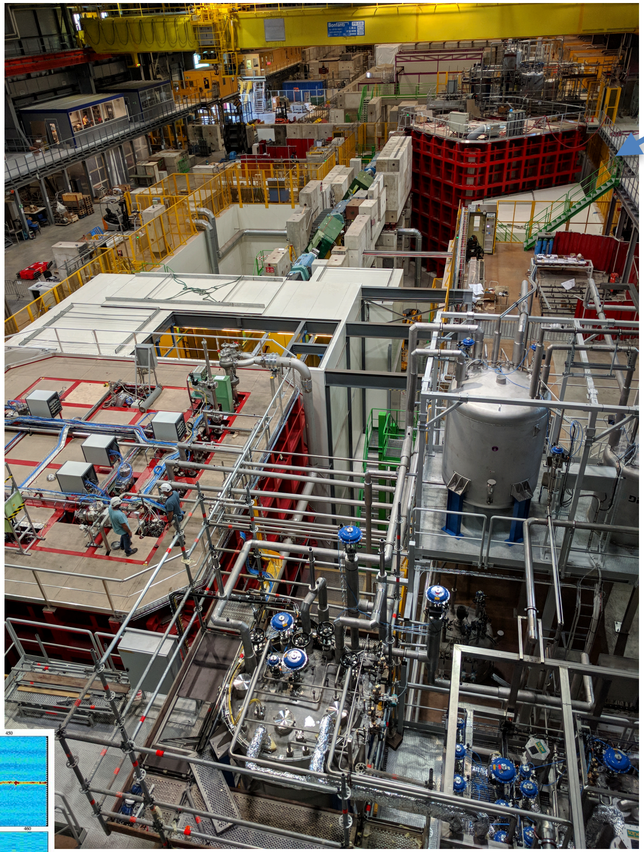


The most complicated unboxing ever filmed! HUGE delivery at CERN!
https://www.youtube.com/watch?v=zDA0cc6W2yQ&feature=youtu.be

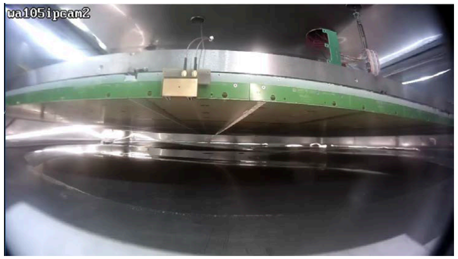
protoDUNE

In the EHN1 at CERN



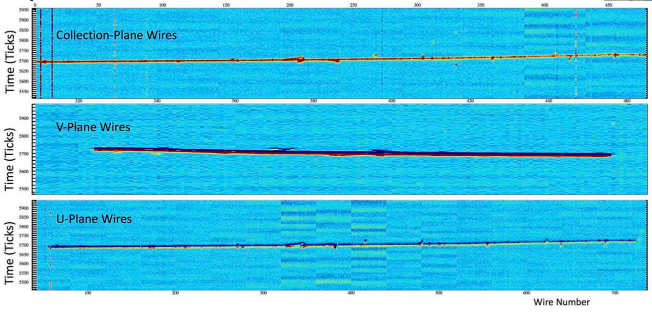


protoDUNE DualPhase

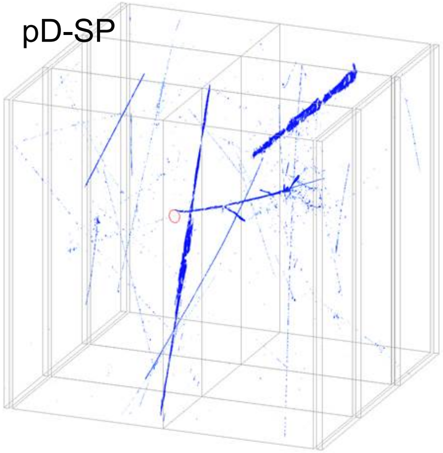


protoDUNE SinglePhase

pD-SP



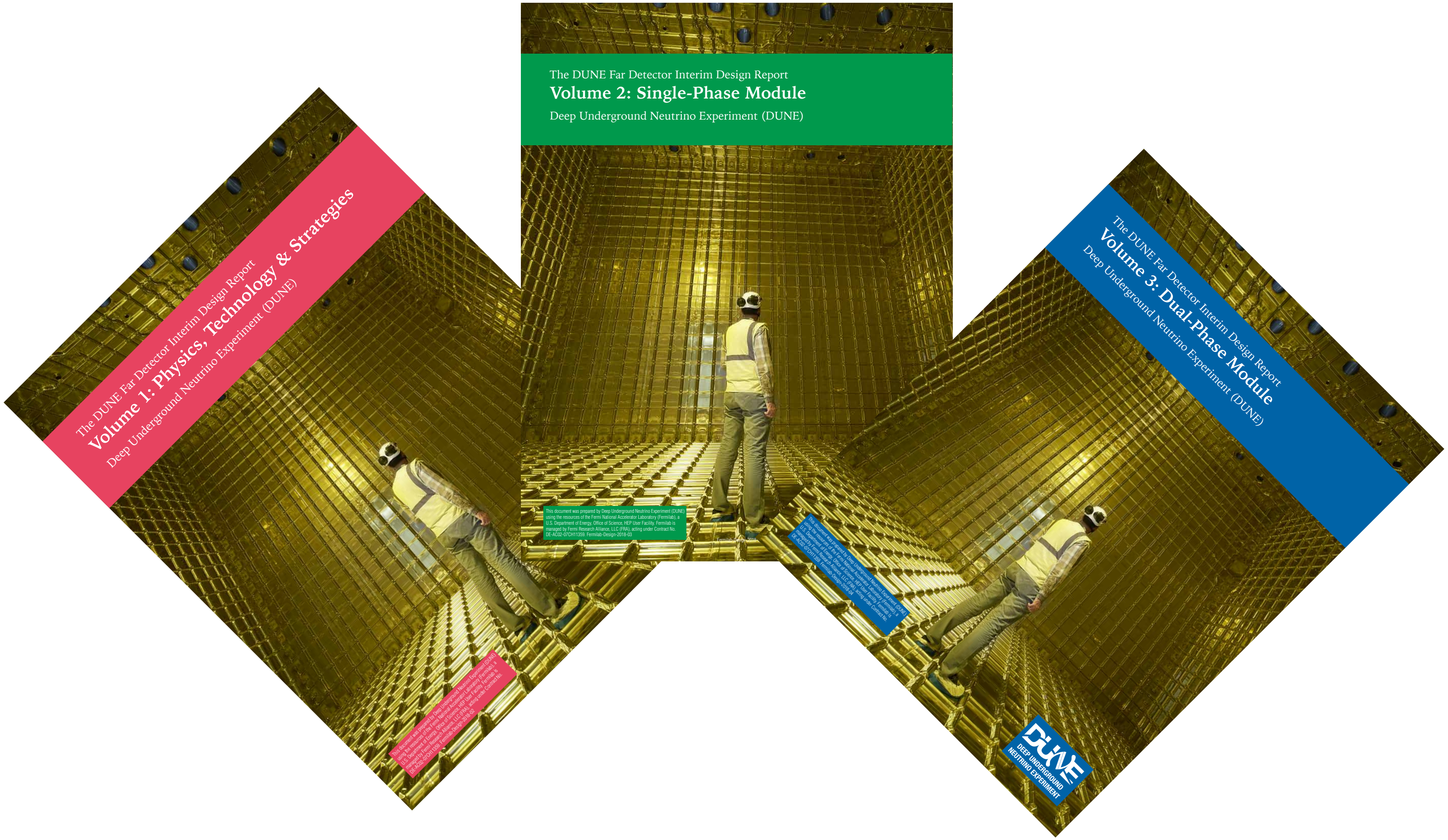
pD-SP



Thank you!

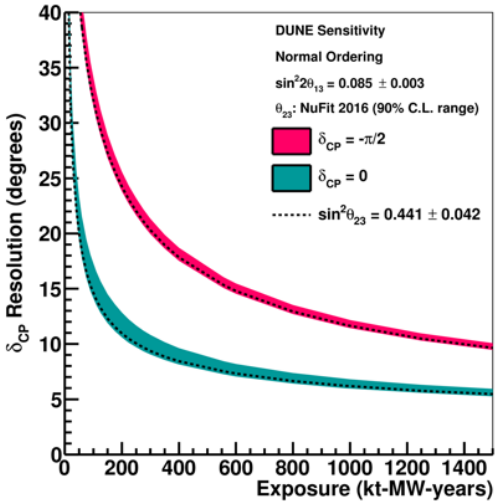
Merry Christmas

Backup

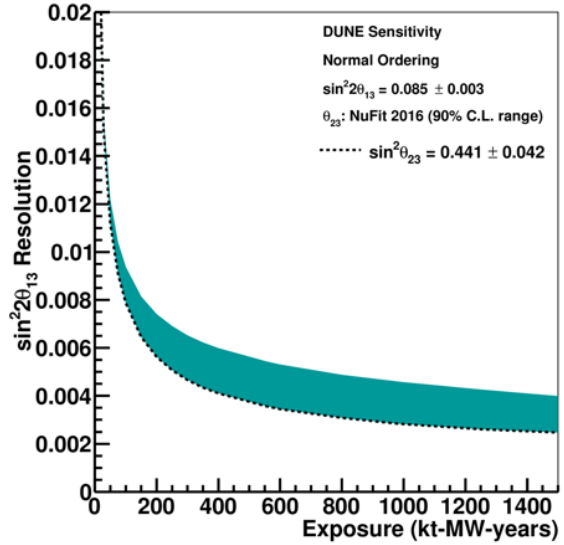


https://arxiv.org/abs/1807.10334
https://arxiv.org/abs/1807.10327
https://arxiv.org/abs/1807.10340

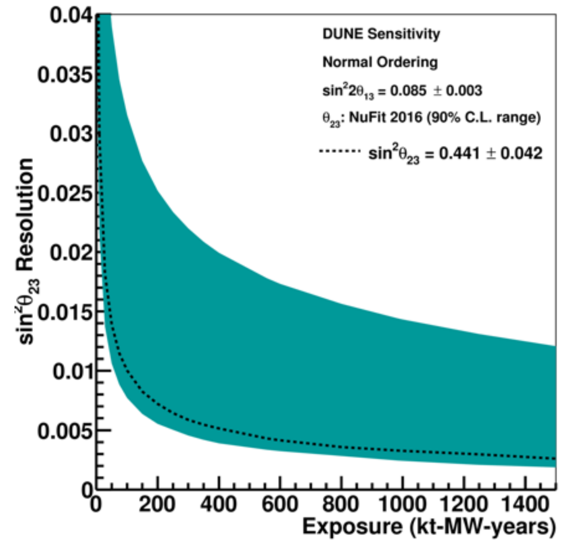
δ_{CP} Resolution



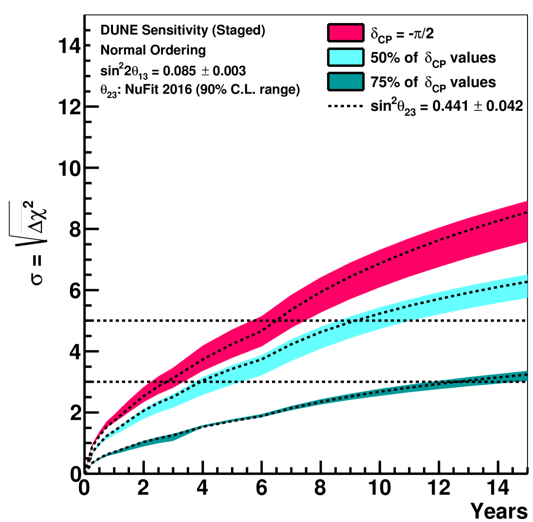
$\sin^2 2\theta_{13}$ Resolution



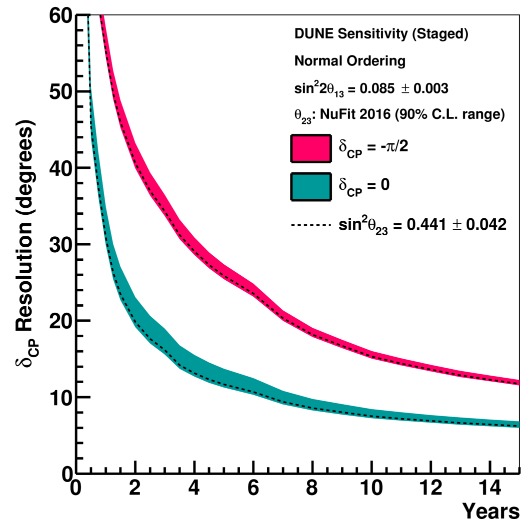
$\sin^2\theta_{23}$ Resolution



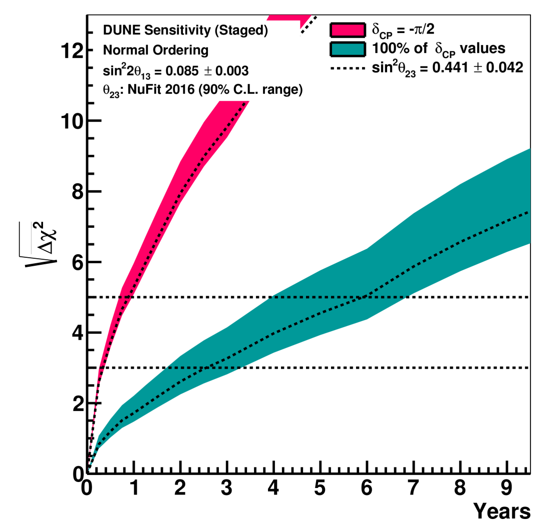
CP Violation Sensitivity



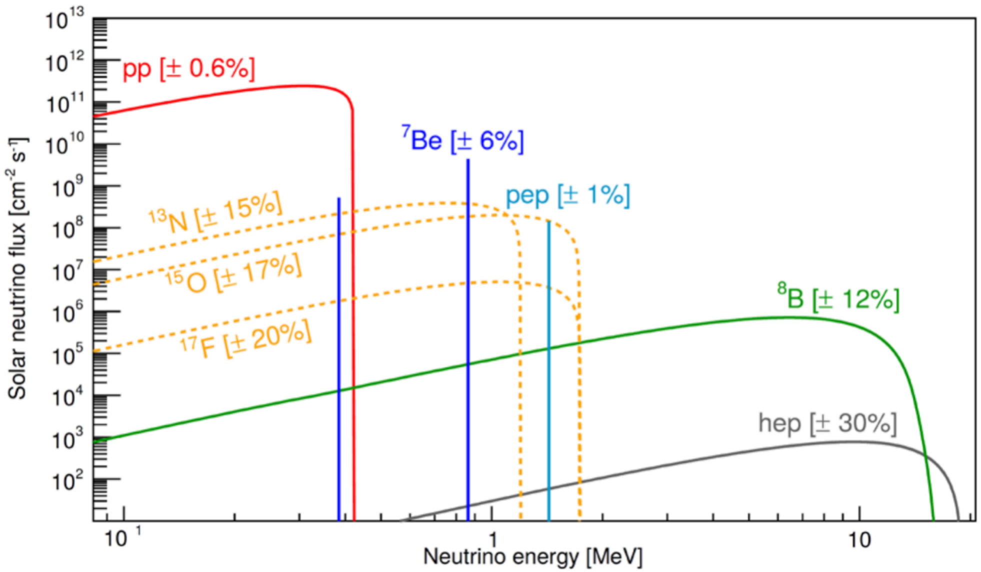
δ_{CP} Resolution



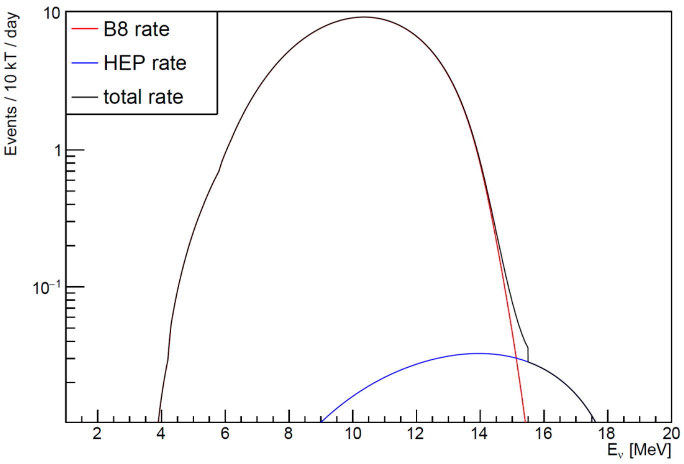
MH Sensitivity



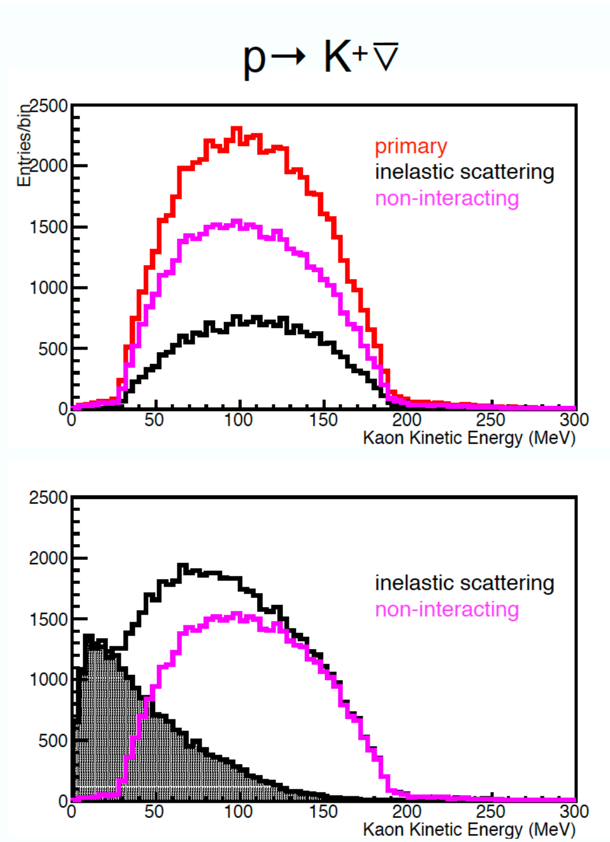
Solar neutrinos in DUNE



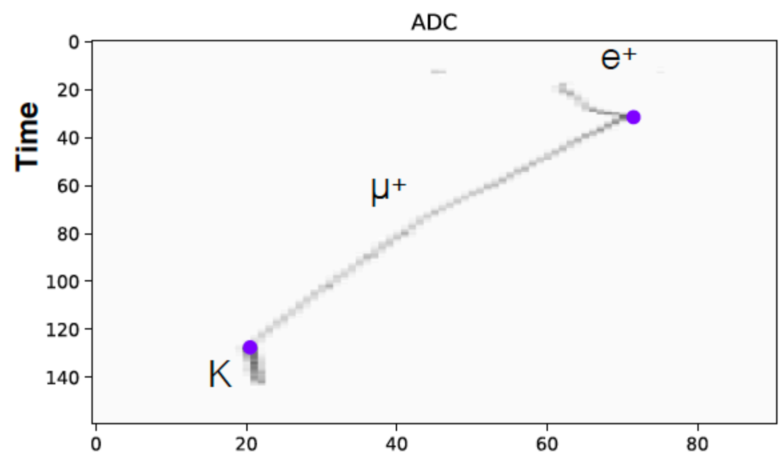
ARXIV:1812.02326



NDK

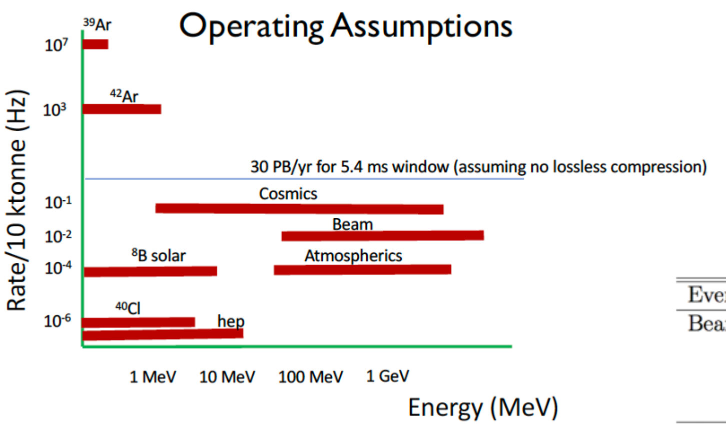


p→ K+ν̄
Entries/bin
2500
2000
1500
1000
500
0
50
100
150
200
250
300
Kaon Kinetic Energy (MeV)
primary
inelastic scattering
non-interacting
inelastic scattering
non-interacting



ADC
Time
e+
μ+
K

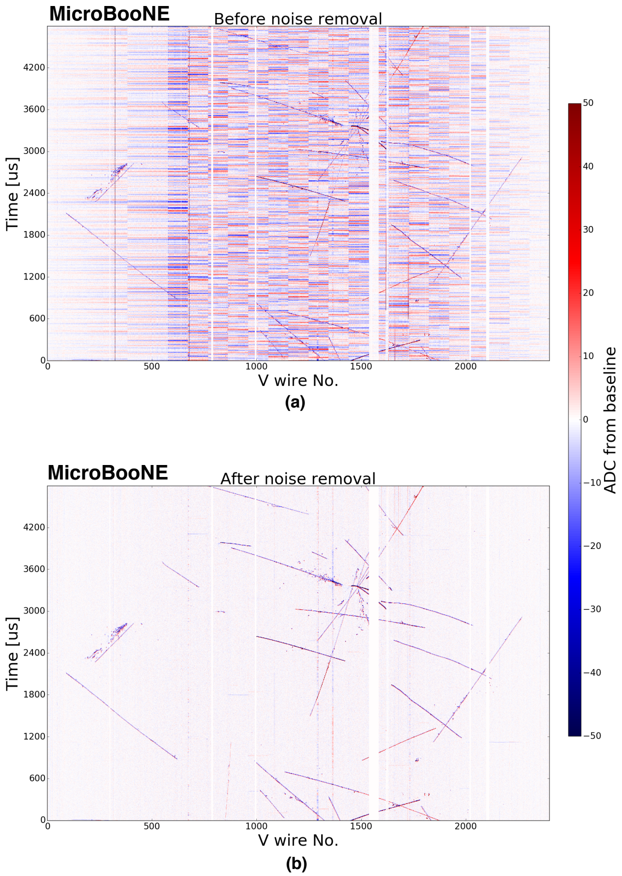
Data rates

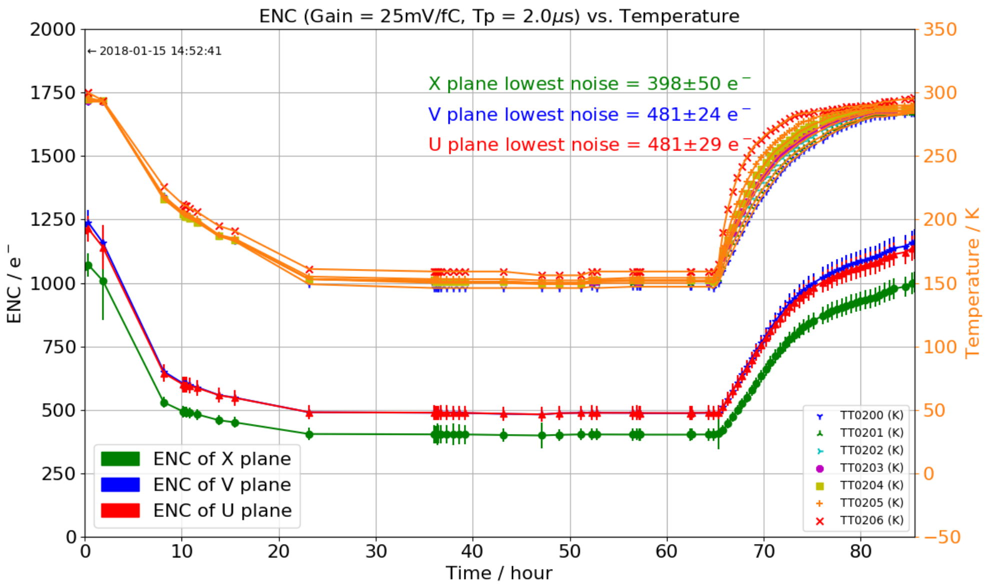


Summary Table

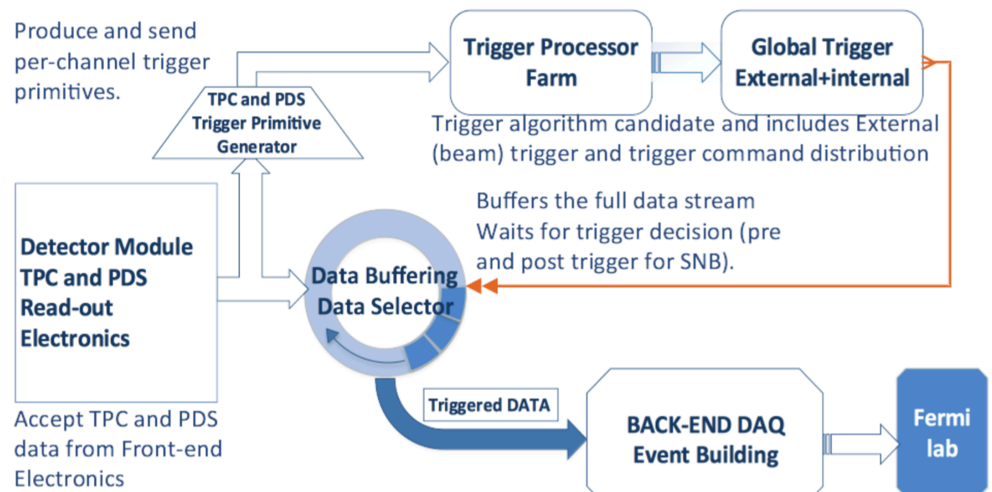
Event Type	Data Volume PB/year	Assumptions
Beam-related Events	0.04	926 beam and 2000 dirt muons; 10 MeV threshold in coincidence with beam time; include 2800 accidental cosmics
Cosmics	10	10MeV threshold, anti-coincident with beam time
Front-end calibration	0.004	Existing test-stand scheme
Atmospheric *nus*	0.007	CDR interaction rates
Solar νs	0.07	*Upper limit* assuming rate above 4.5 MeV ν energy
Radioactive source calibration	0.2	Source rate $\leq$10Hz; single fragment readout; lossless readout, 4 times/year
Laser calibration	0.184	800,000 total laser pulses, lossy readout
Supernova candidates	1.4	100 seconds full readout, average once per month
Random triggers	0.1	45 per day
Trigger primitives	8	All three wire planes; 12 bits per primitive word; 4 primitive quantities; ^{39}Ar-dominated

Noise


MicroBooNE
Before noise removal
Time [us]
V wire No.
(a)
MicroBooNE
After noise removal
Time [us]
V wire No.
(b)
ADC from baseline


ENC (Gain = 25mV/fC, Tp = 2.0μs) vs. Temperature
← 2018-01-15 14:52:41
X plane lowest noise = 398±50 e⁻
V plane lowest noise = 481±24 e⁻
U plane lowest noise = 481±29 e⁻
ENC of X plane
ENC of V plane
ENC of U plane
TT0200 (K)
TT0201 (K)
TT0202 (K)
TT0203 (K)
TT0204 (K)
TT0205 (K)
TT0206 (K)
ENC / e⁻
Temperature / K
Time / hour

DAQ



Abi, NNN18