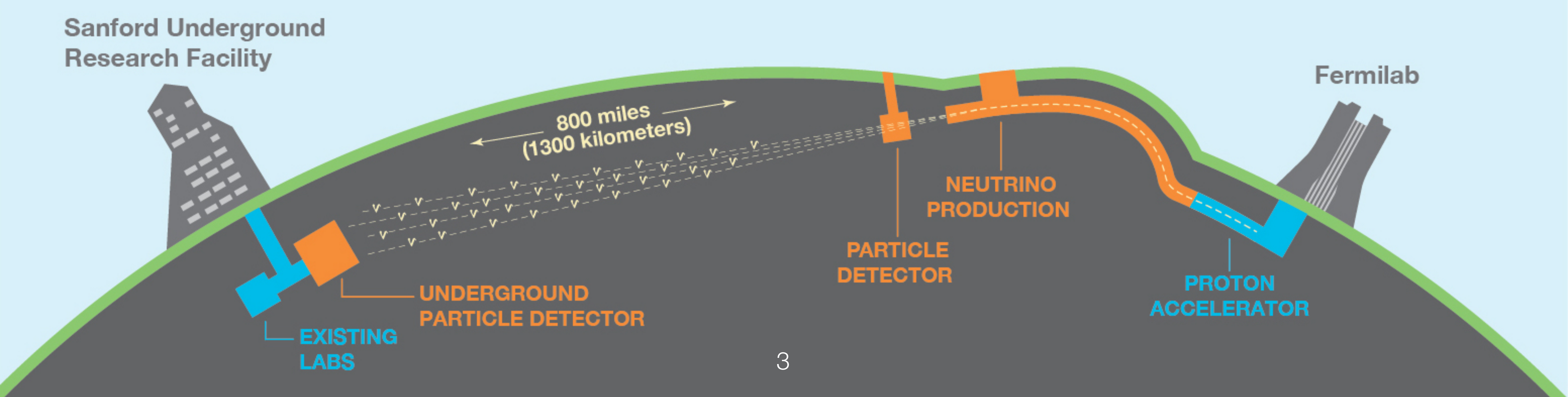
Testing a Swimming Pool for Neutrinos

Milo Vermeulen — 17-12-2018

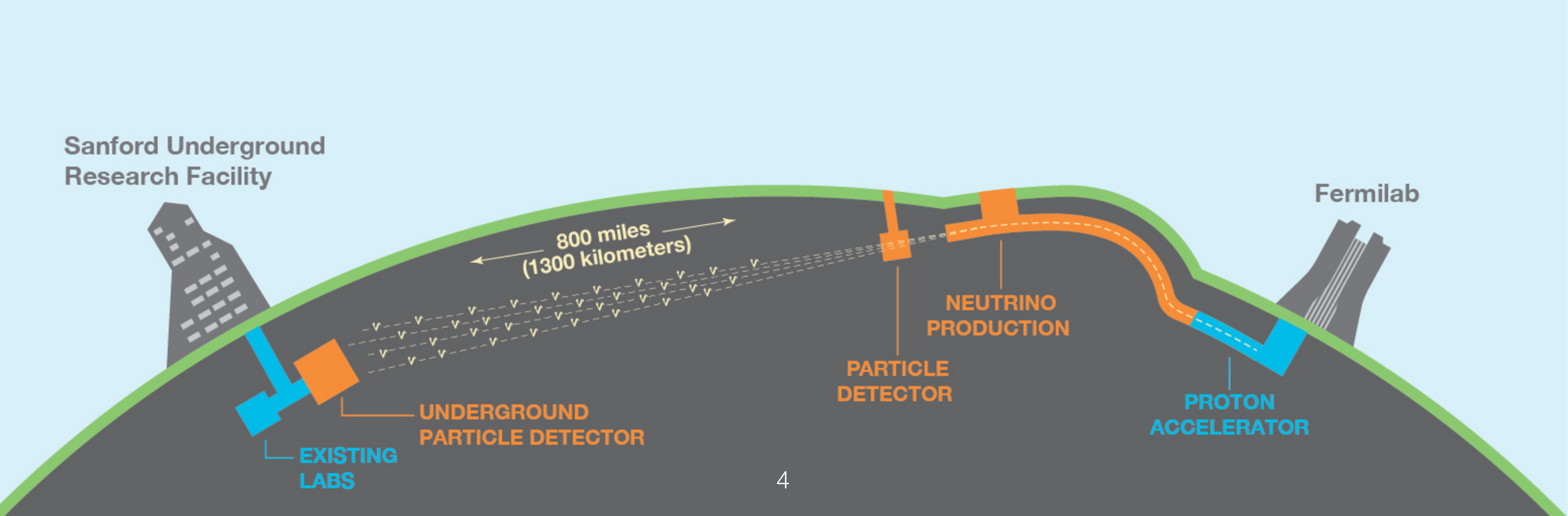
DUNE

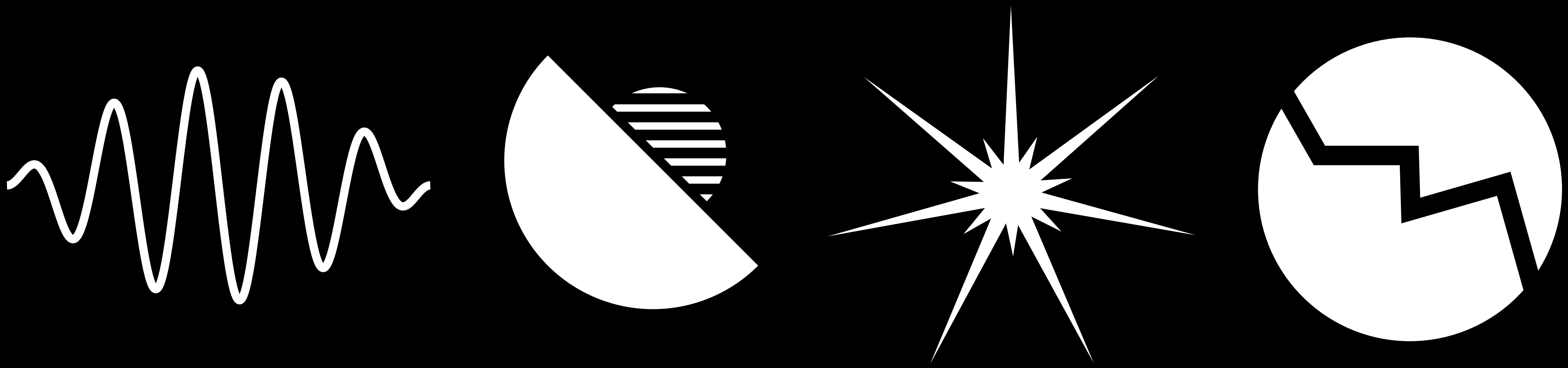
DEEP UNDERGROUND NEUTRINO EXPERIMENT

- Long-baseline neutrino experiment
- From FNAL to SURF
- Most intense neutrino beam in the world
- Biggest liquid argon time projection chamber (LAr TPC) in the world



- 1100+ collaborators
- 170+ institutions
- 32+ countries
- Goal: measure neutrino properties





DUNE Physics

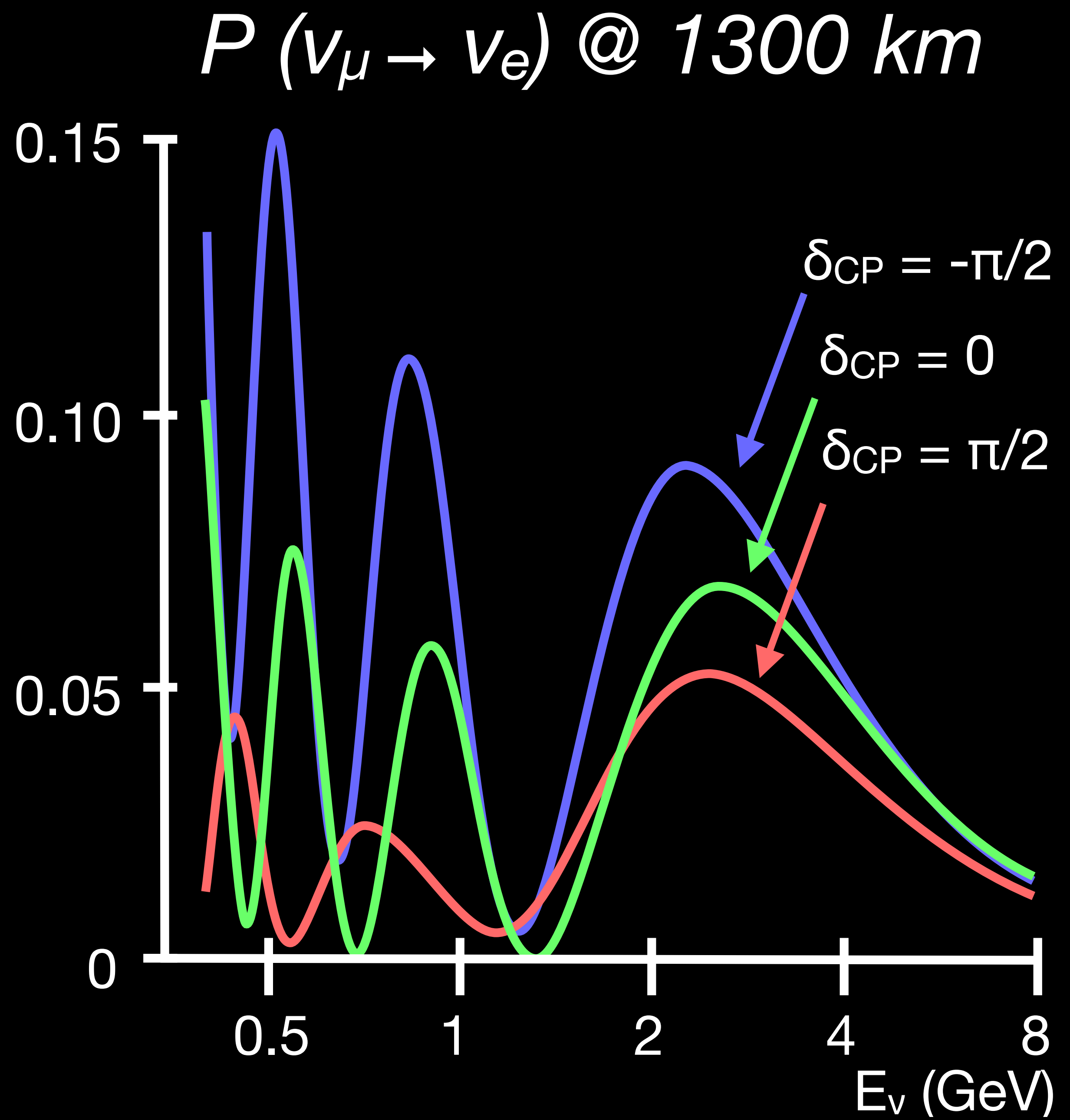
Neutrino Oscillation Parameters

And Other Properties

- Measurement of $P(\nu_\mu \rightarrow \nu_e)$ and $P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e)$ puts limits on:
  - Oscillation parameters
  - CP-violating phase δ_{CP}
  - Mass hierarchy

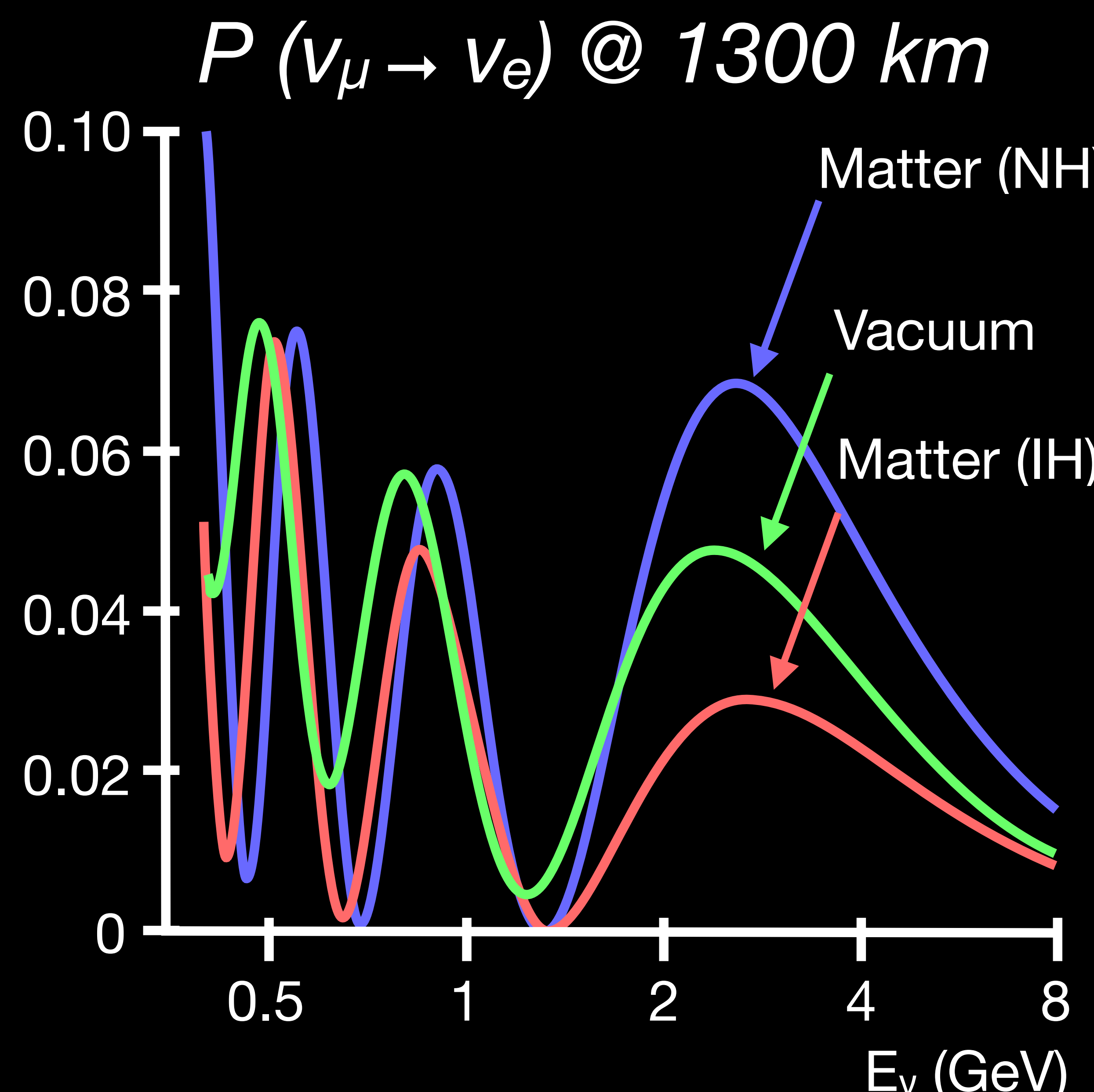
Matter-Antimatter Asymmetry

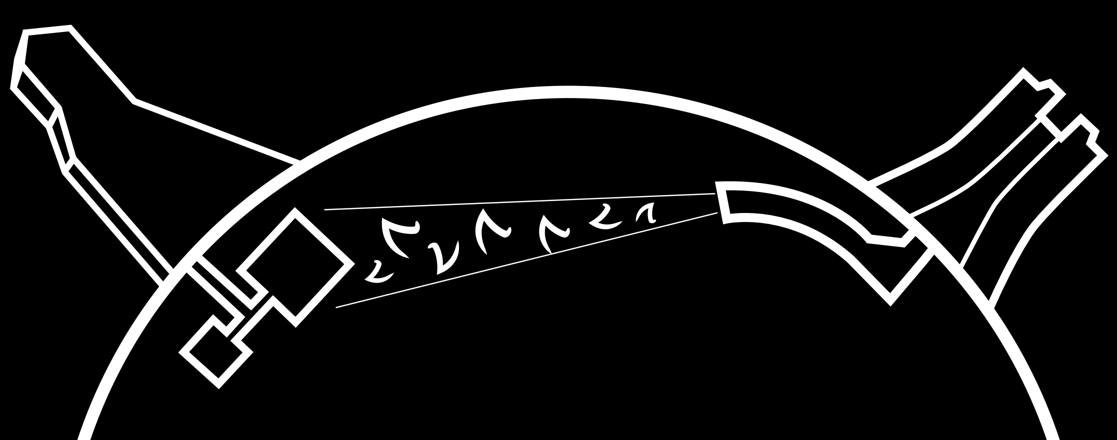
- Measuring energy spectrum of incoming neutrinos determines δ_{CP}
- Important peaks around 3 and 0.7 GeV
- δ_{CP} determined to within 7°—13° in 10 years



Mass Hierarchy

- Neutrinos in beam encounter electrons in the earth
- Causes asymmetry between neutrino and antineutrino oscillations





Mass Hierarchy

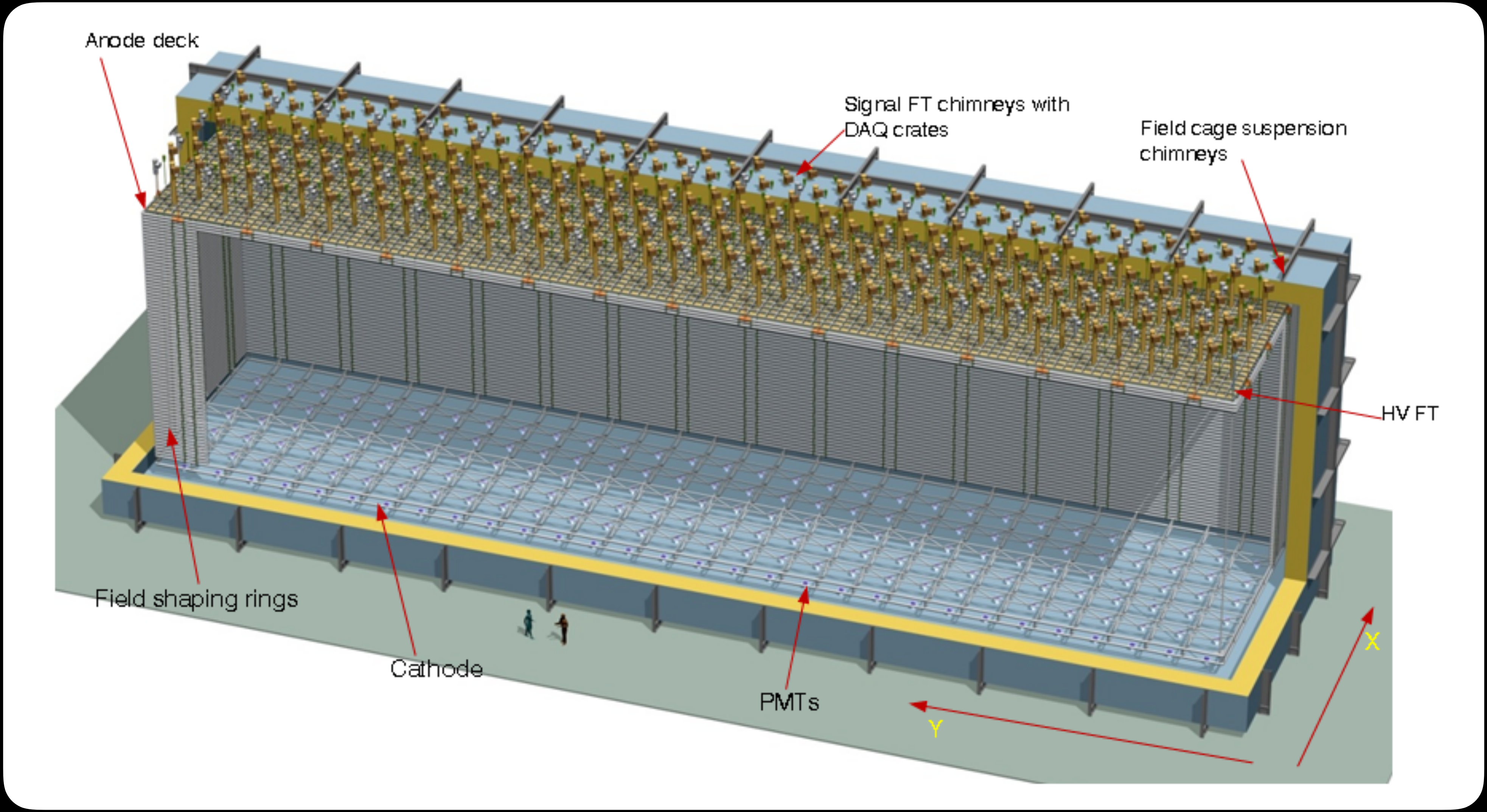
- Sign of asymmetry depends on sign of Δm^2_{31}
- Mass hierarchy determined (or confirmed) at 5σ in 2—5 years

$$\mathscr{A} = \frac{P(\nu_\mu \to \nu_e) - P(\bar{\nu}_\mu \to \bar{\nu}_e)}{P(\nu_\mu \to \nu_e) + P(\bar{\nu}_\mu \to \bar{\nu}_e)}$$

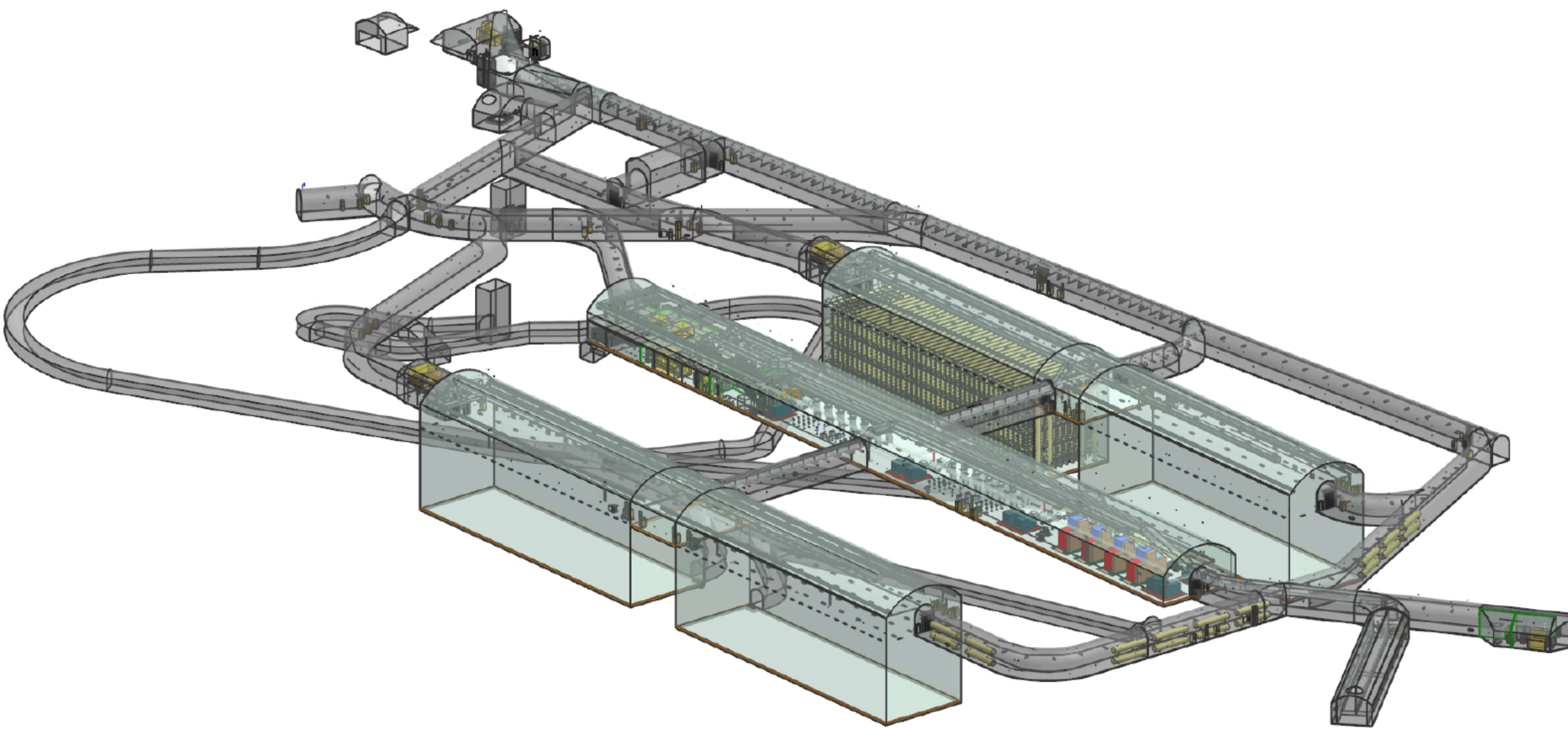
Supernova Neutrinos
Nucleon Decay

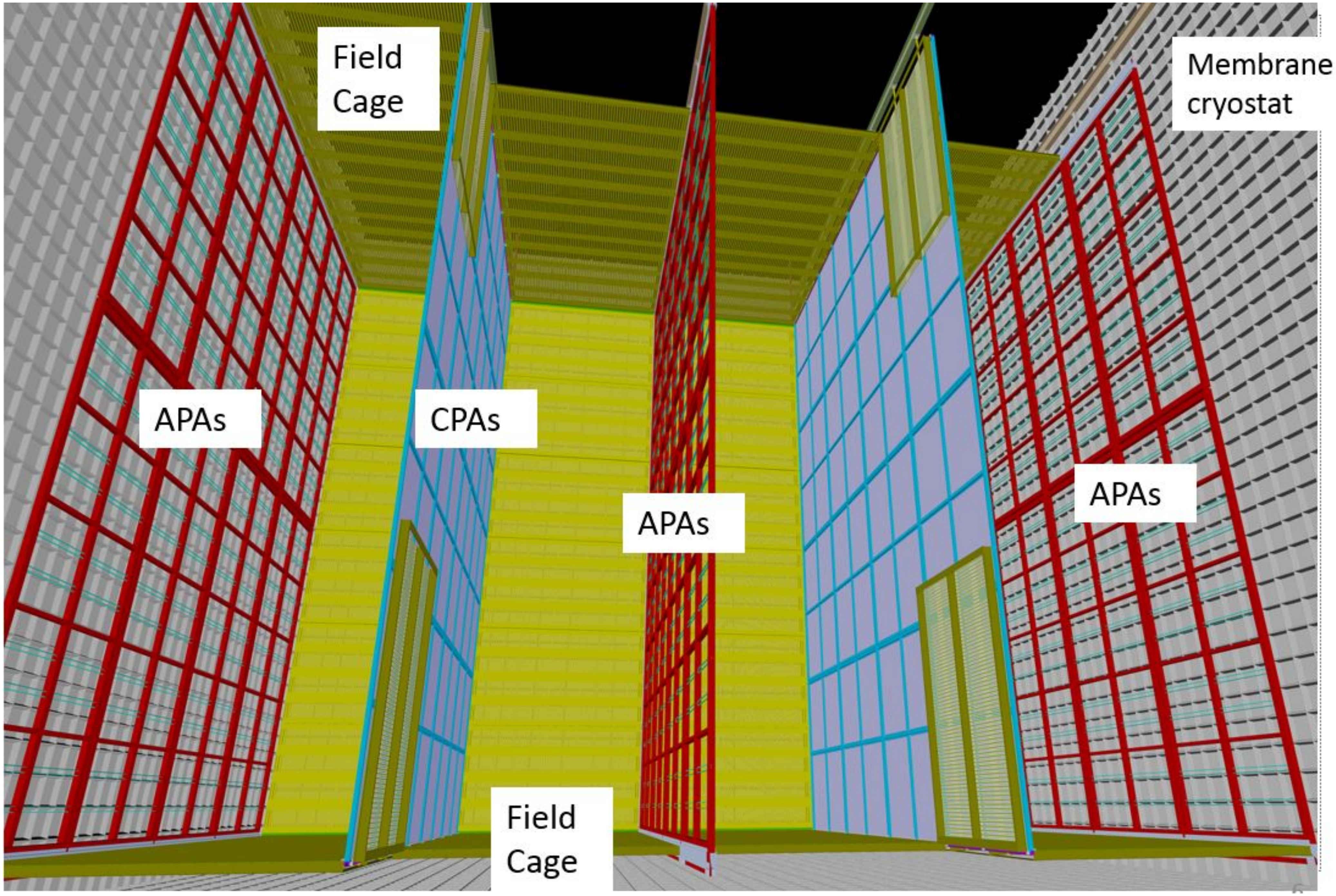
- DUNE is sensitive to ν_e coming from supernovae
  - Relatively low-energy neutrinos of O(10 MeV)
- DUNE's low background environment and high mass makes it suitable for nucleon decay studies
  - Put limits on proton decay ($\tau > 10^{33}$ years)

- 10 kt fiducial liquid argon per module (~17 kt total)
- Neutrino counter (both CC and NC)



DUNE




Field
Cage
Membrane
cryostat
APAs
CPAs
APAs
APAs
Field
Cage

- Previous largest LAr TPC was ICARUS at 600 tonnes
- Going from ICARUS' 0.6 kt to DUNE's 4x17 kt is a big leap

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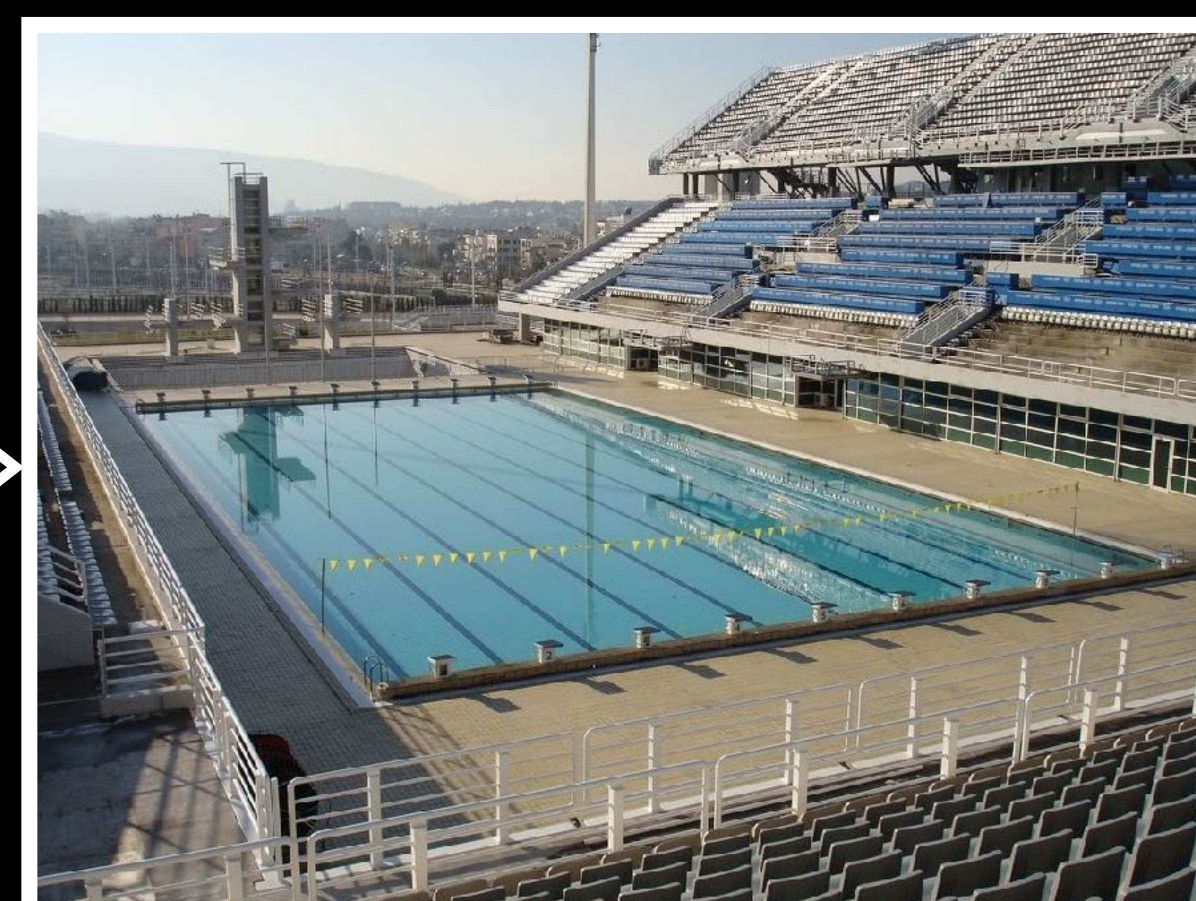
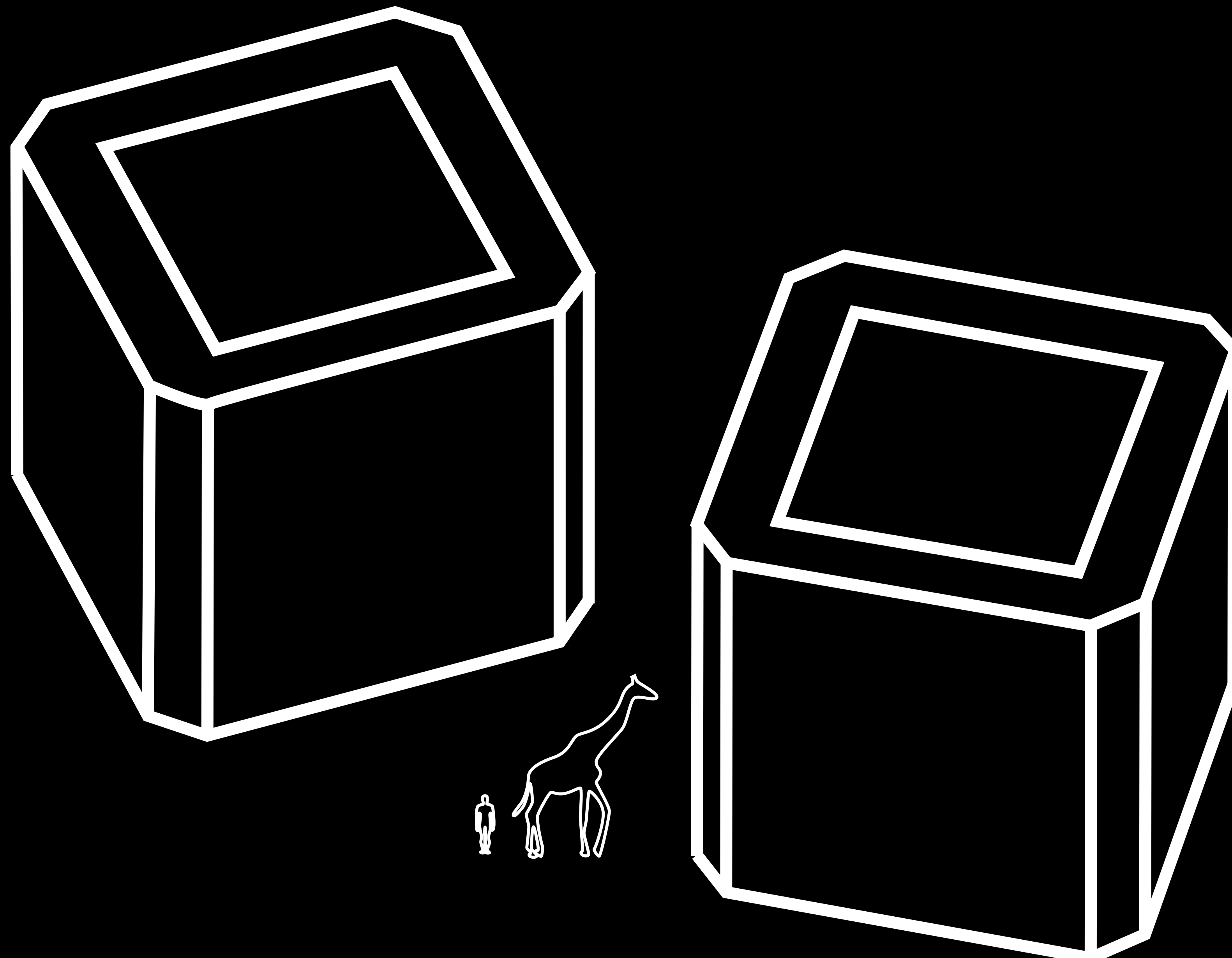


- Prototyping is needed!
  - Validation of technology at full scale
  - Test detector response of various beam particles
    - 0.5 — 7 GeV protons, pions, electrons and some kaons
  - Develop reconstruction algorithms

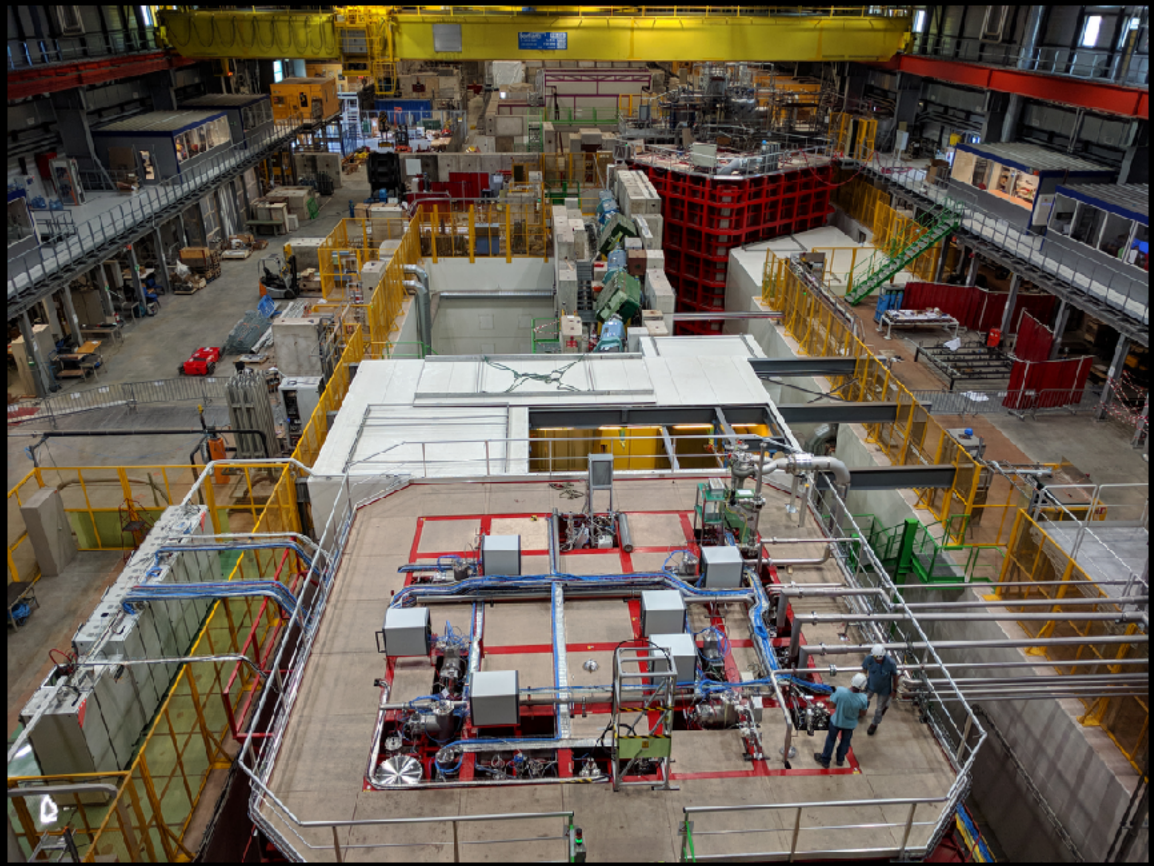


ProtoDUNE SP

ProtoDUNE SP

- Prototype for DUNE
- 1% of final detector size
- Built in two years
- Uses same components

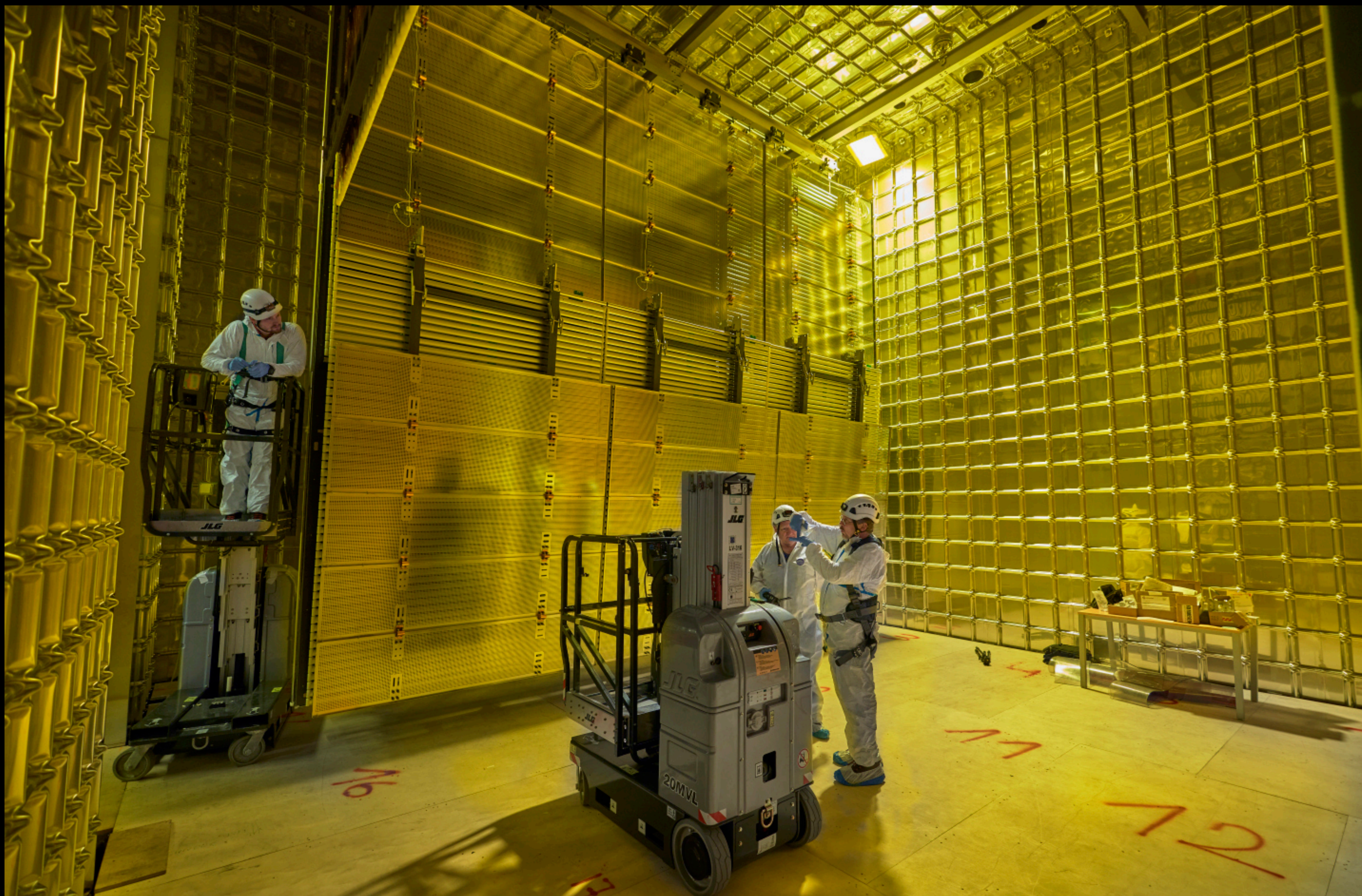
18th of October 2016



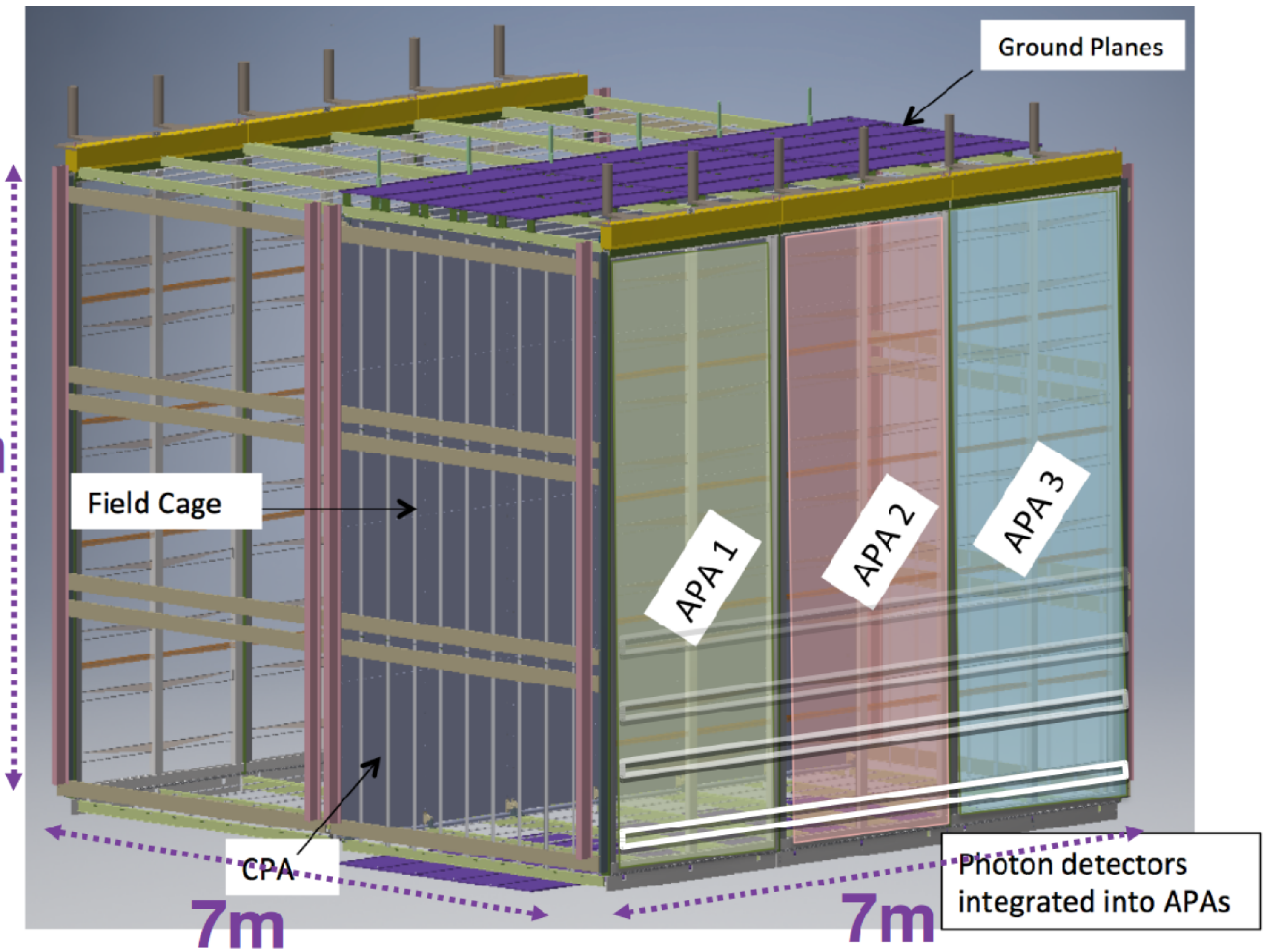
2nd of October 2018

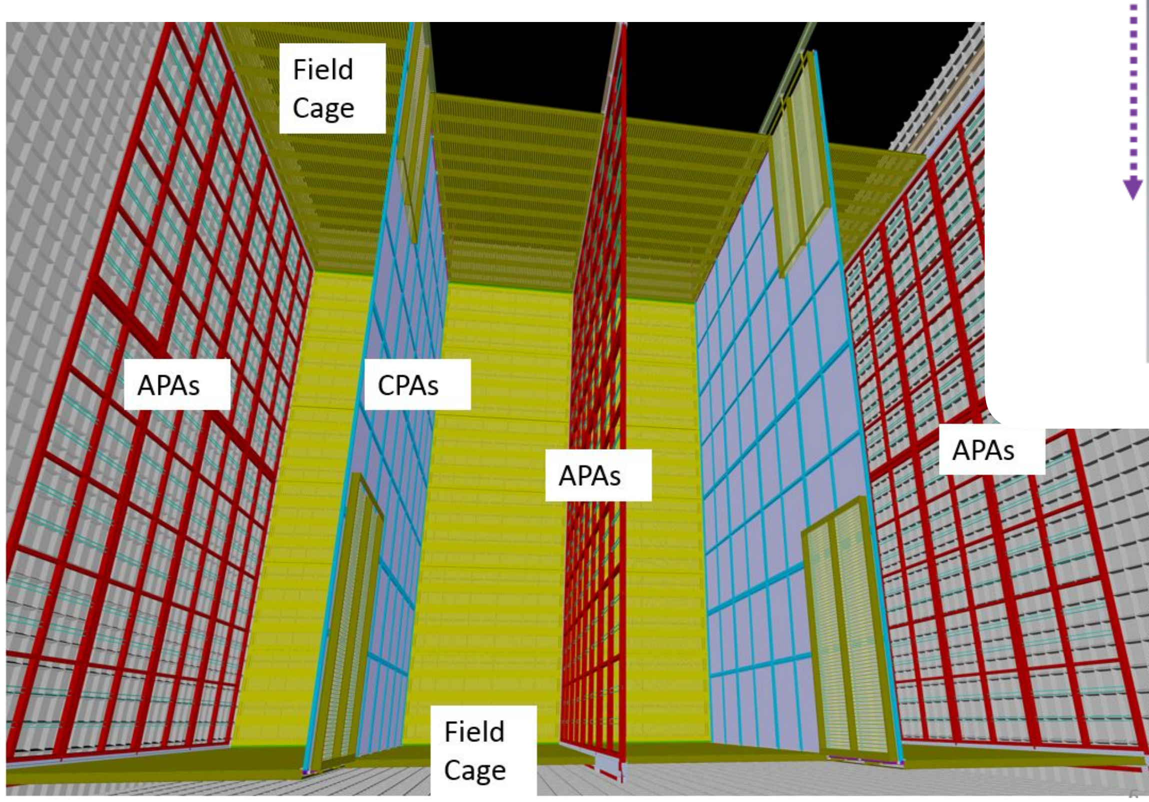
Images from R. Acciarri, NuInt18

ProtoDUNE SP



ProtoDUNE SP





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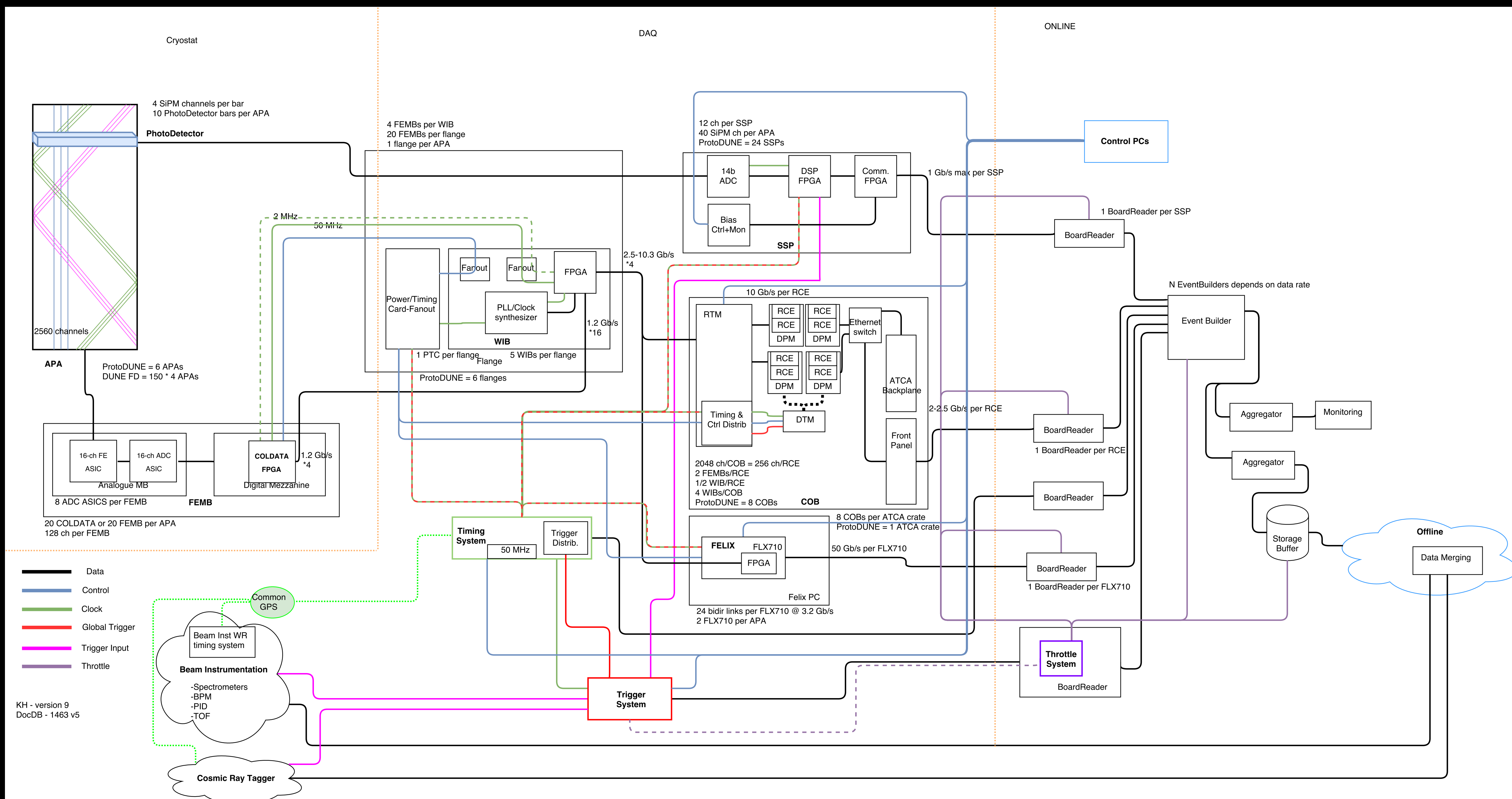
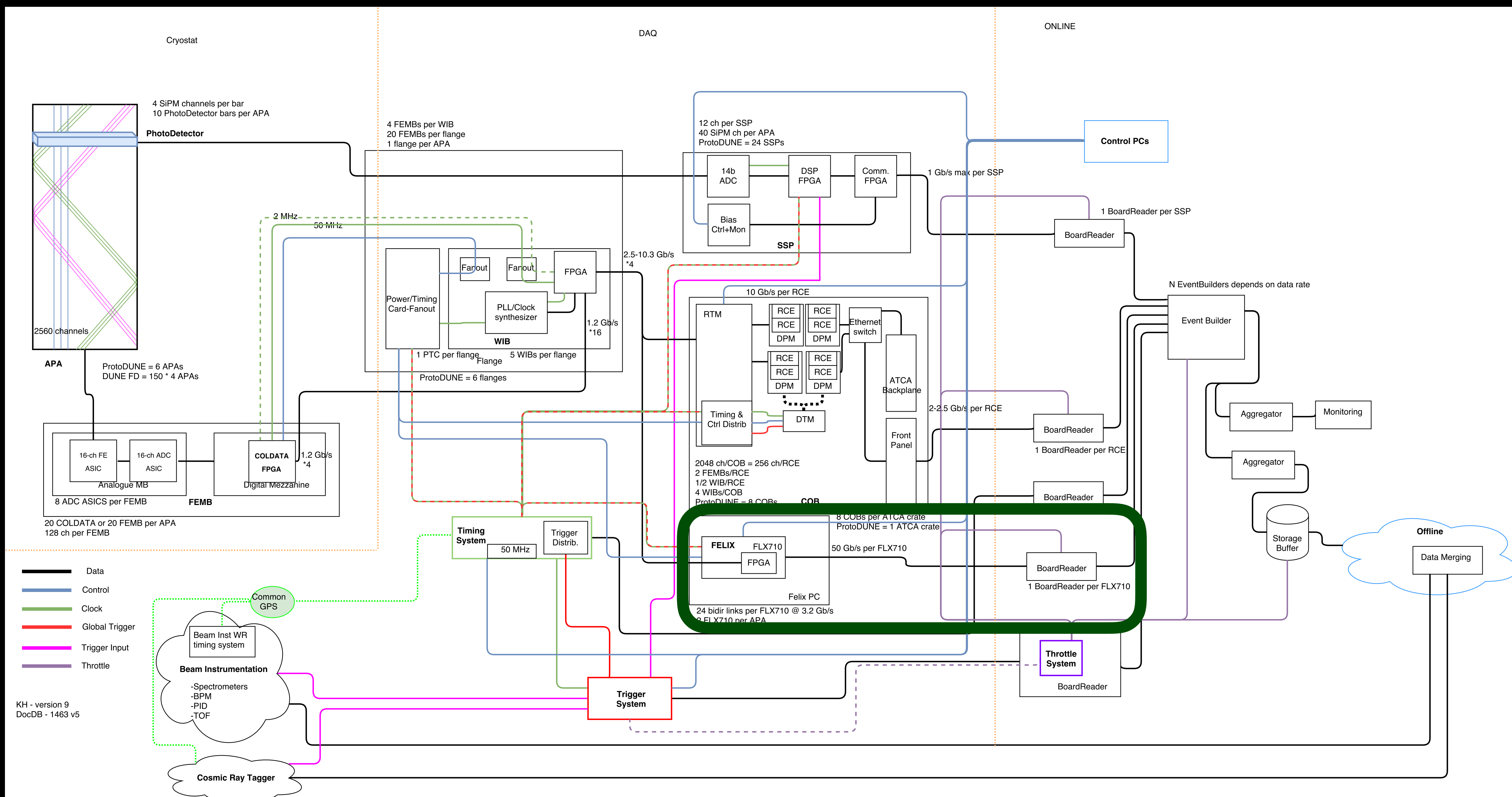
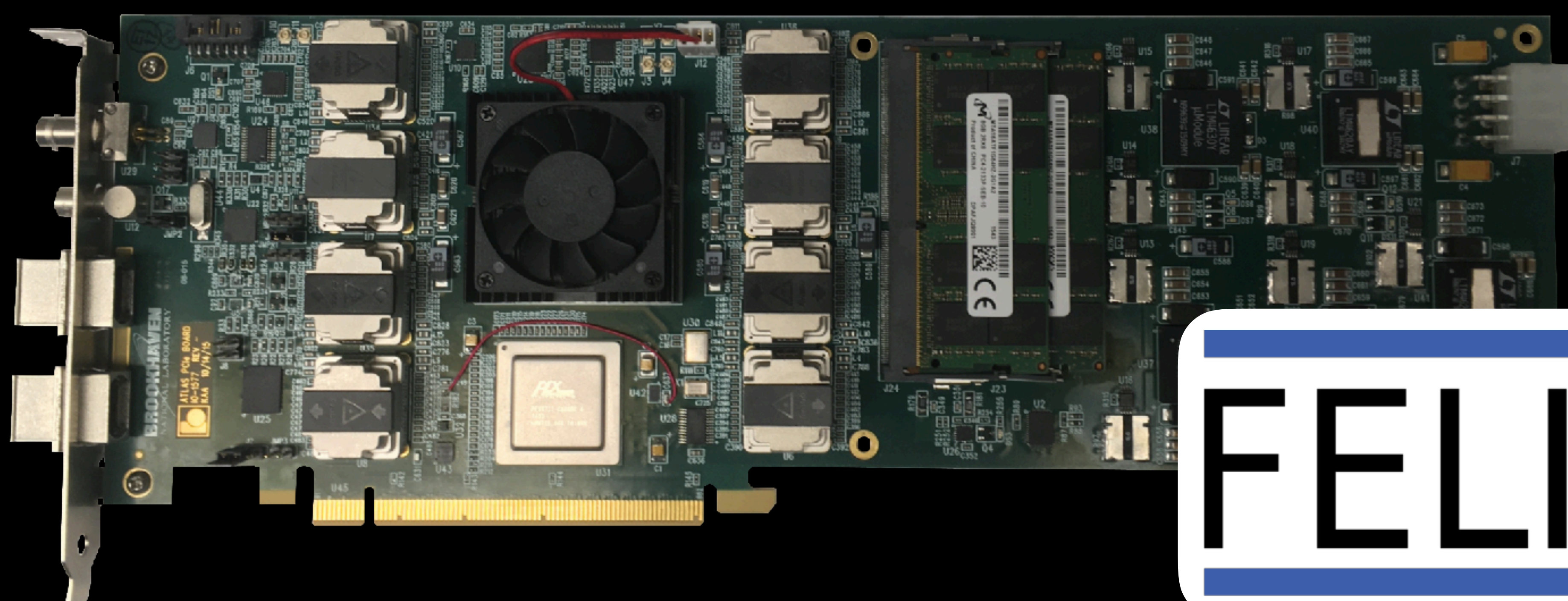


ProtoDUNE SP



ProtoDUNE SP

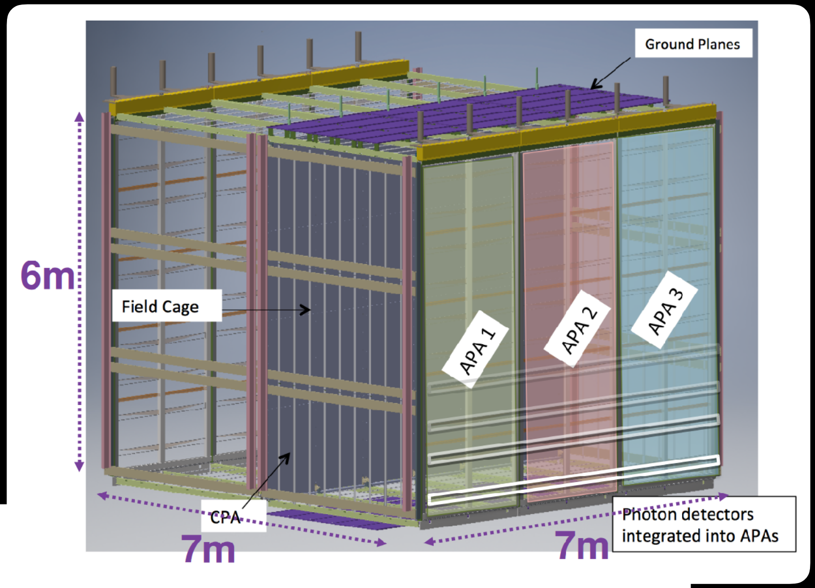
- FELIX is an ATLAS DAQ system
- Front-End LInk eXchange
- ProtoDUNE-SP: 96 Gb/s of data from one entire APA
  - 2560 wires x 12 bits x 2 MHz + overhead

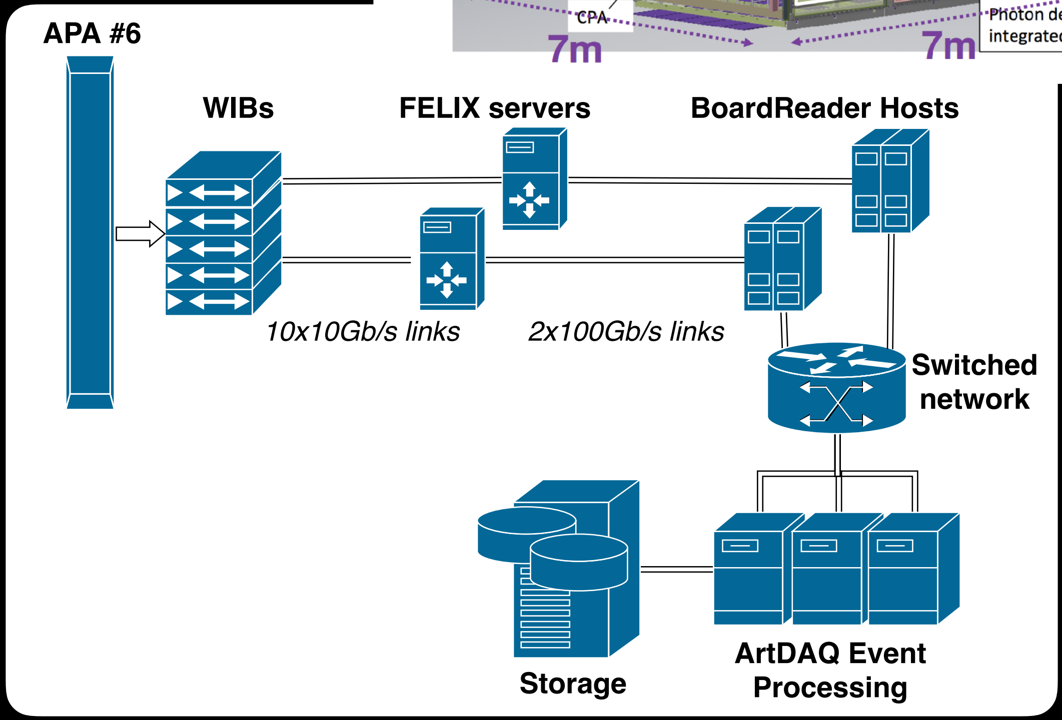


FELIX

ProtoDUNE SP

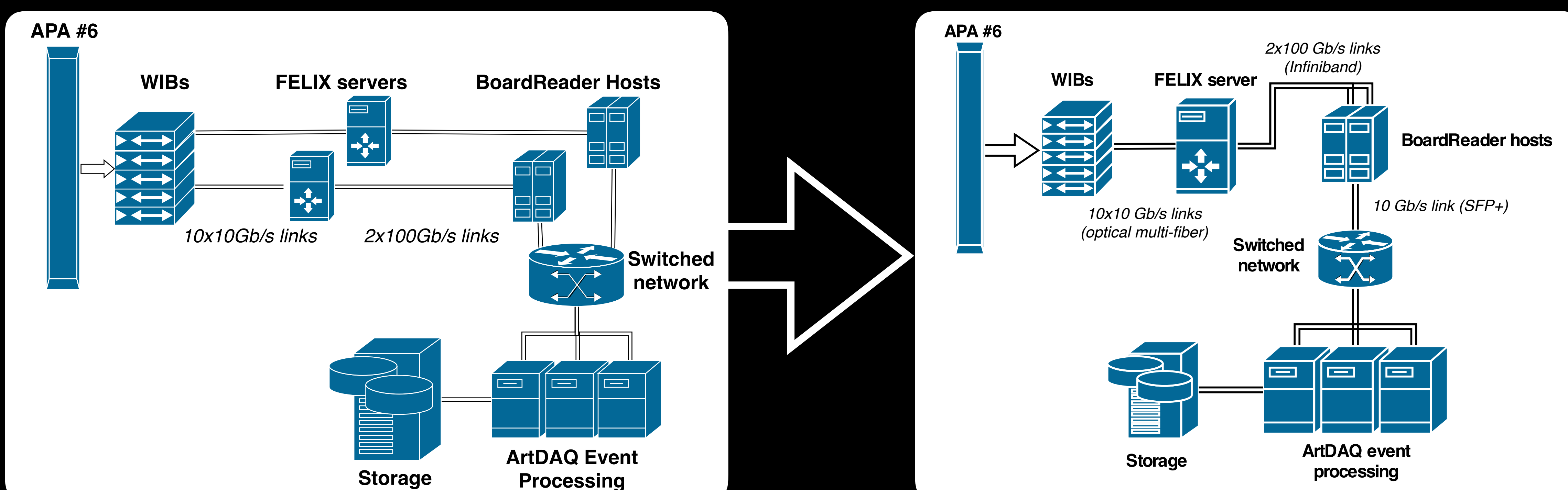
- Principle: use commodity hardware as much as possible
  - Make use of industry advances
- Two cards in use in ProtoDUNE-SP
- Nikhef contributes soft-, firm- and hardware

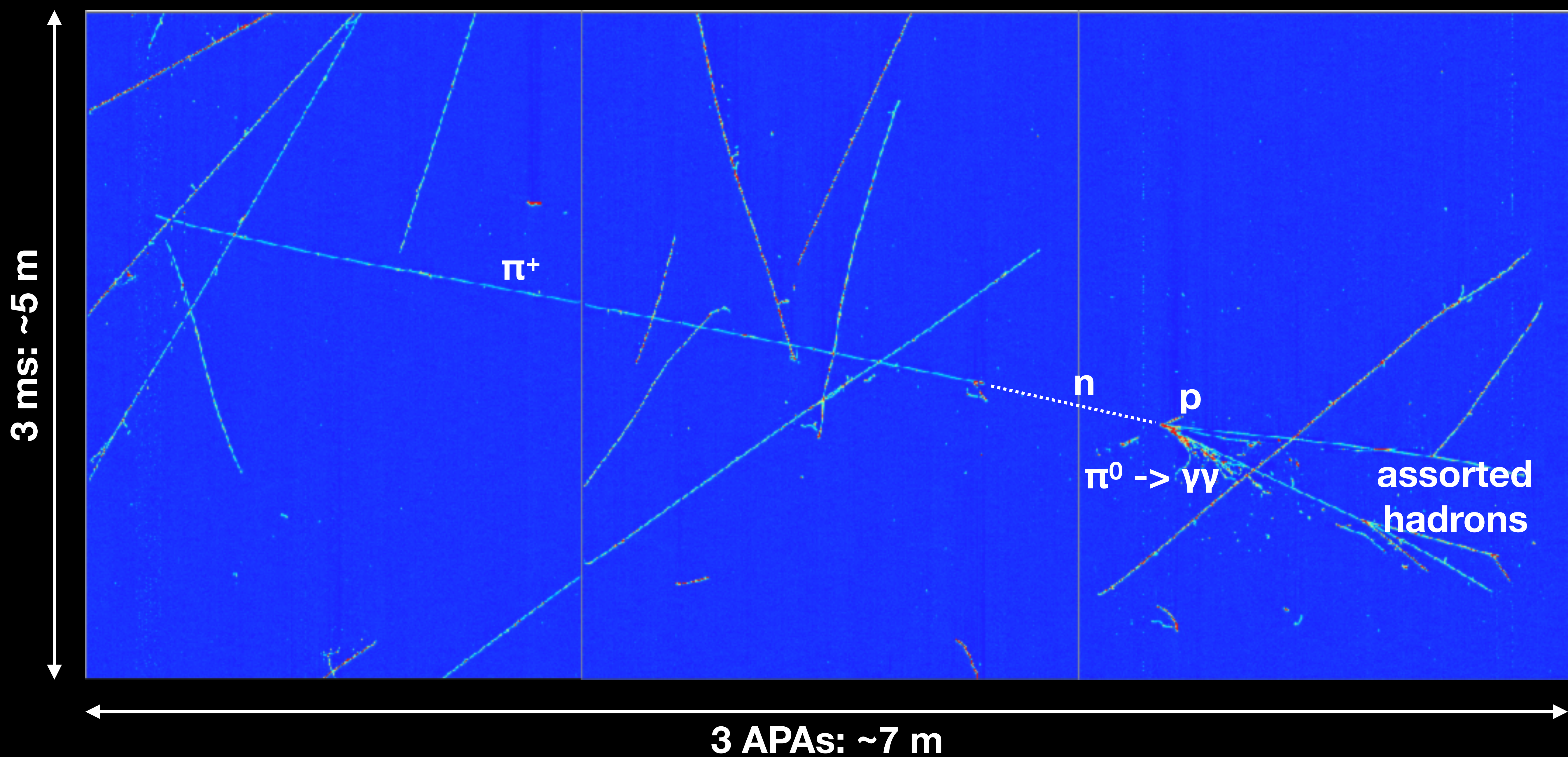


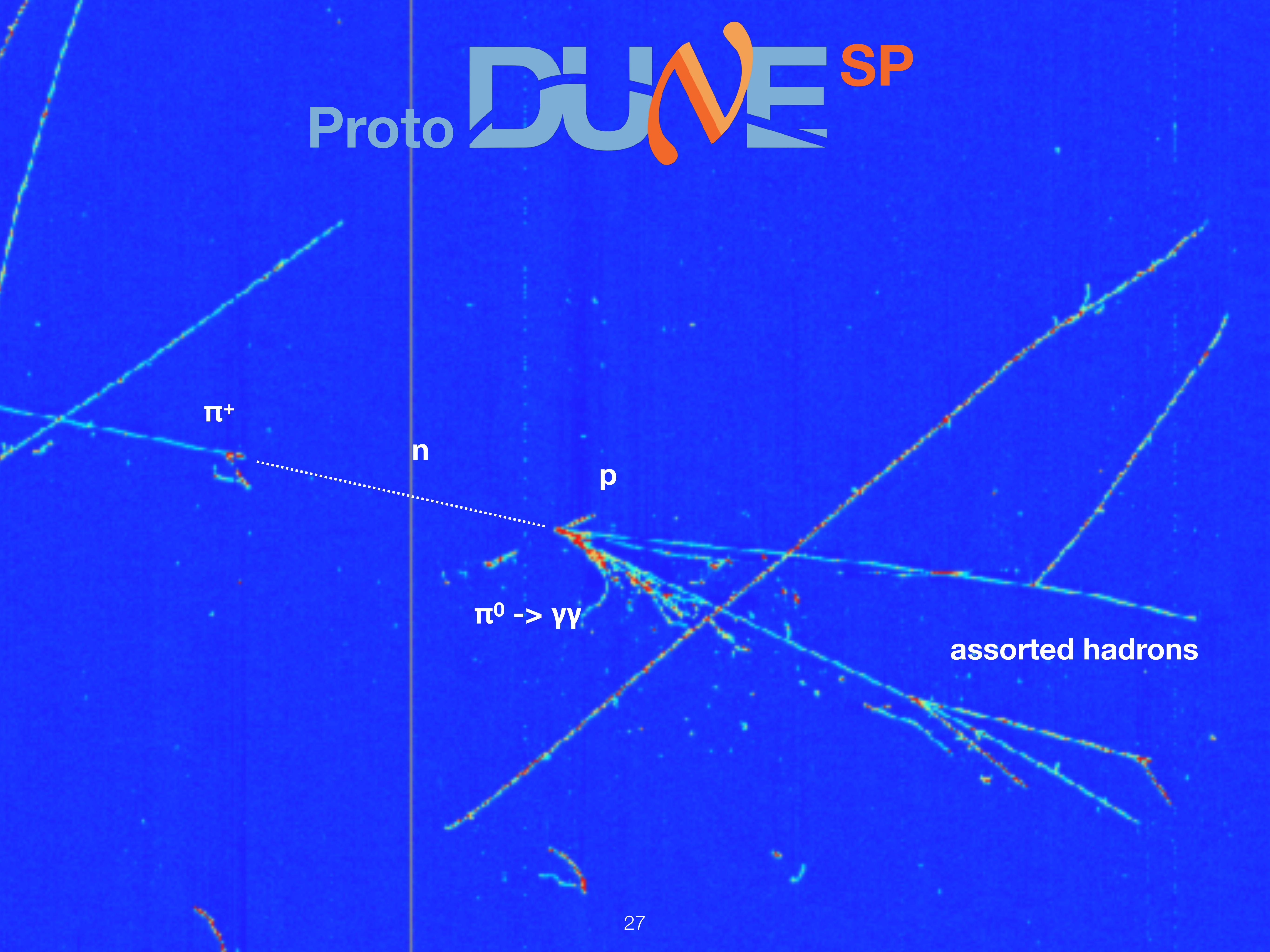


ProtoDUNE SP

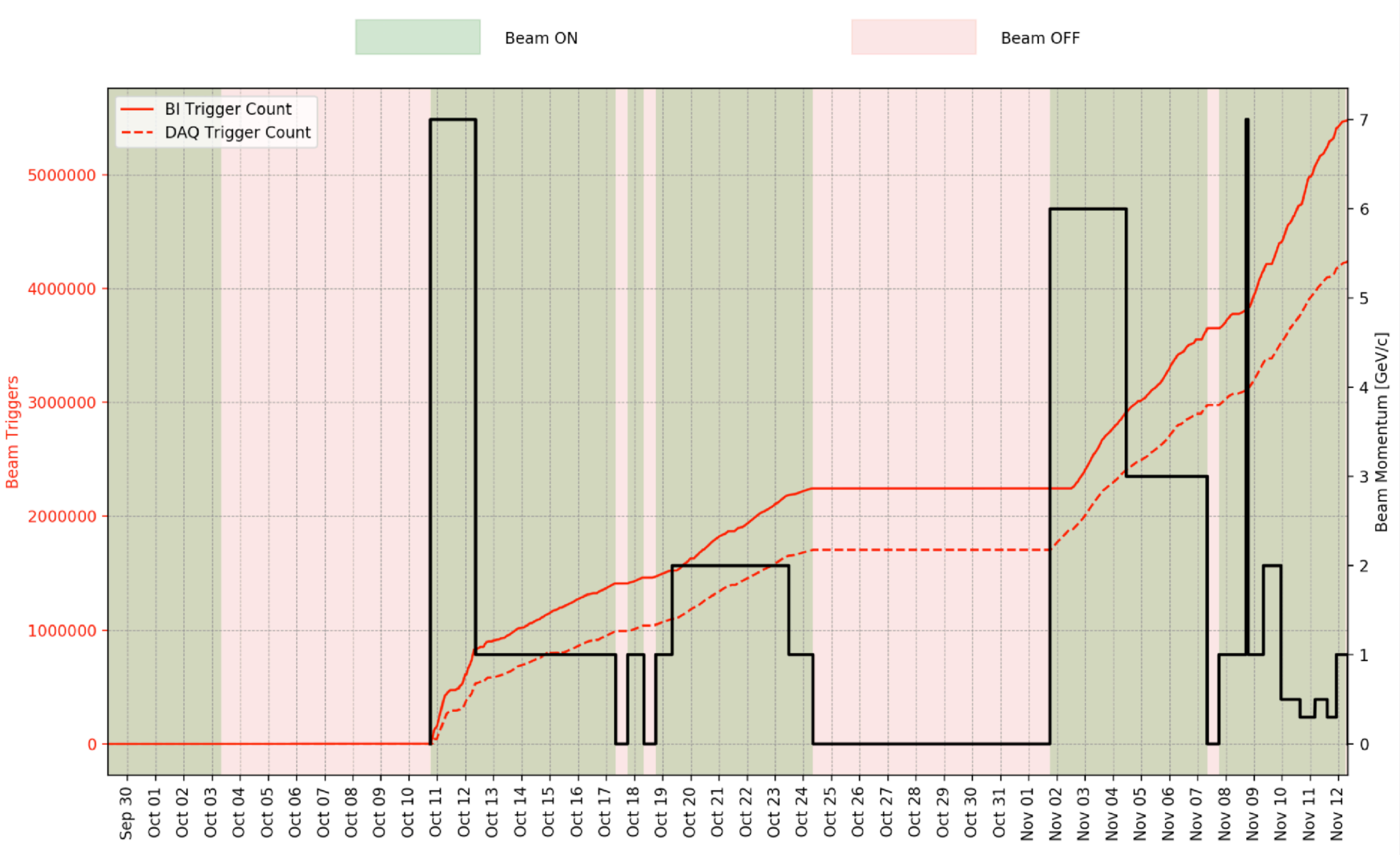
- Recently: single FELIX server to read out an entire APA
- FELIX was chosen over the baseline RCE DAQ system for DUNE




3 ms: ~5 m
π+
n
p
π0 -> γγ
assorted
hadrons
3 APAs: ~7 m


ProtoDUNE SP
π+
n
p
π0 -> γγ
assorted hadrons

ProtoDUNE SP



Plot by Kevin Wood

ProtoDUNE SP

- Goal: 300k pions and 100k electrons at 1, 2, 3, 6, 7 GeV

Momentum	Total Triggers	Expected Pi trig.	Expected Proton trig.	Expected Electr. trig.	Expected Kaon trig.
0.3 GeV/c	269K	0	0	242K	0
0.5 GeV/c	340K	1.5K	1.5K	296K	0
1 GeV/c	1089K	382K	420K	262K	0
2 GeV/c	728K	333K	128K	173K	5K
3 GeV/c	568K	284K	107K	113K	15K
6 GeV/c	702K	394K	70K	197K	28K
7 GeV/c	477K	299K	51K	98K	24K
All momenta	**4175K**	**1694K**	**779K**	**1384K**	**73K**

Data by Roberto Acciarri

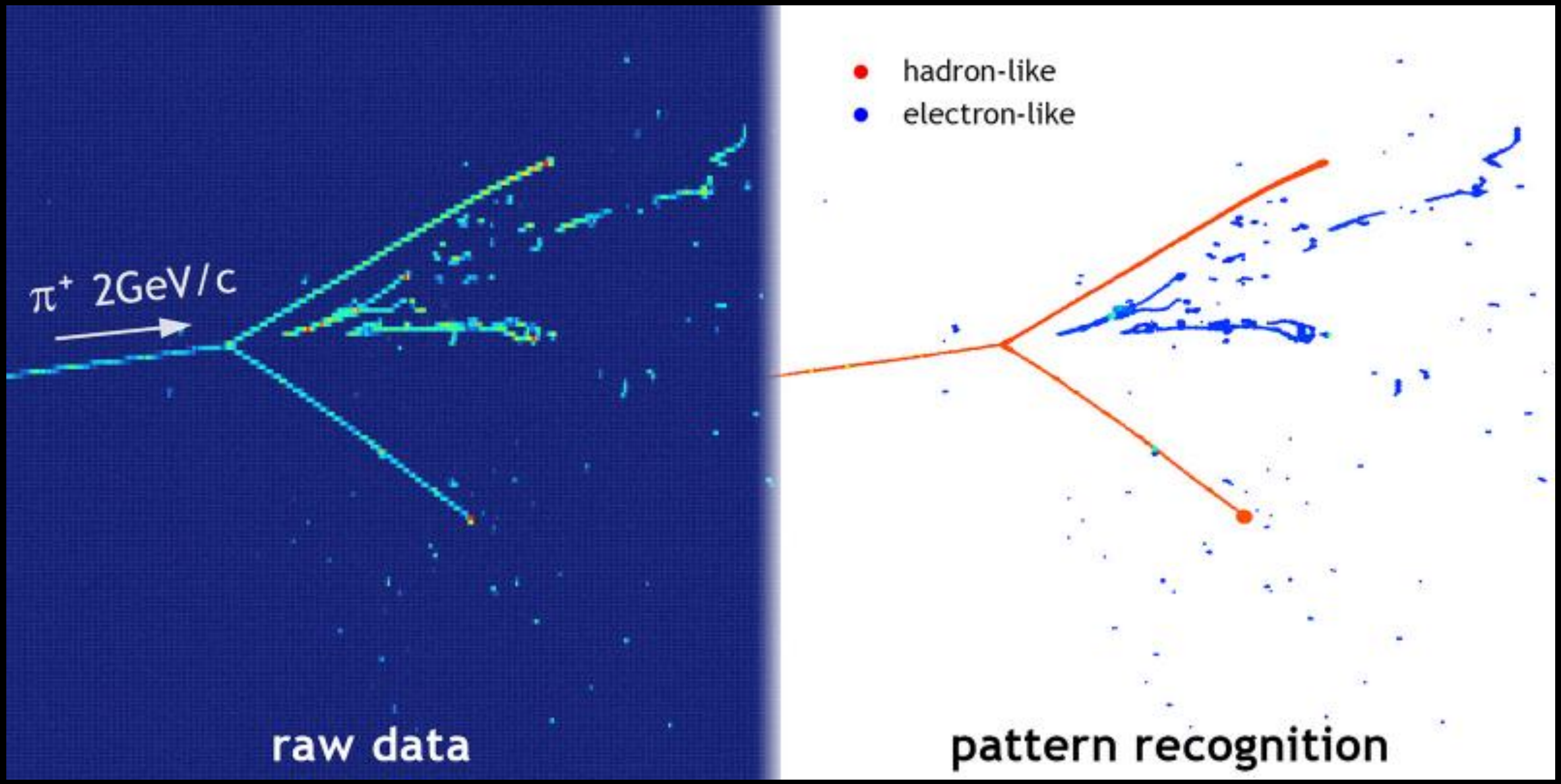
ProtoDUNE SP

Lessons learned

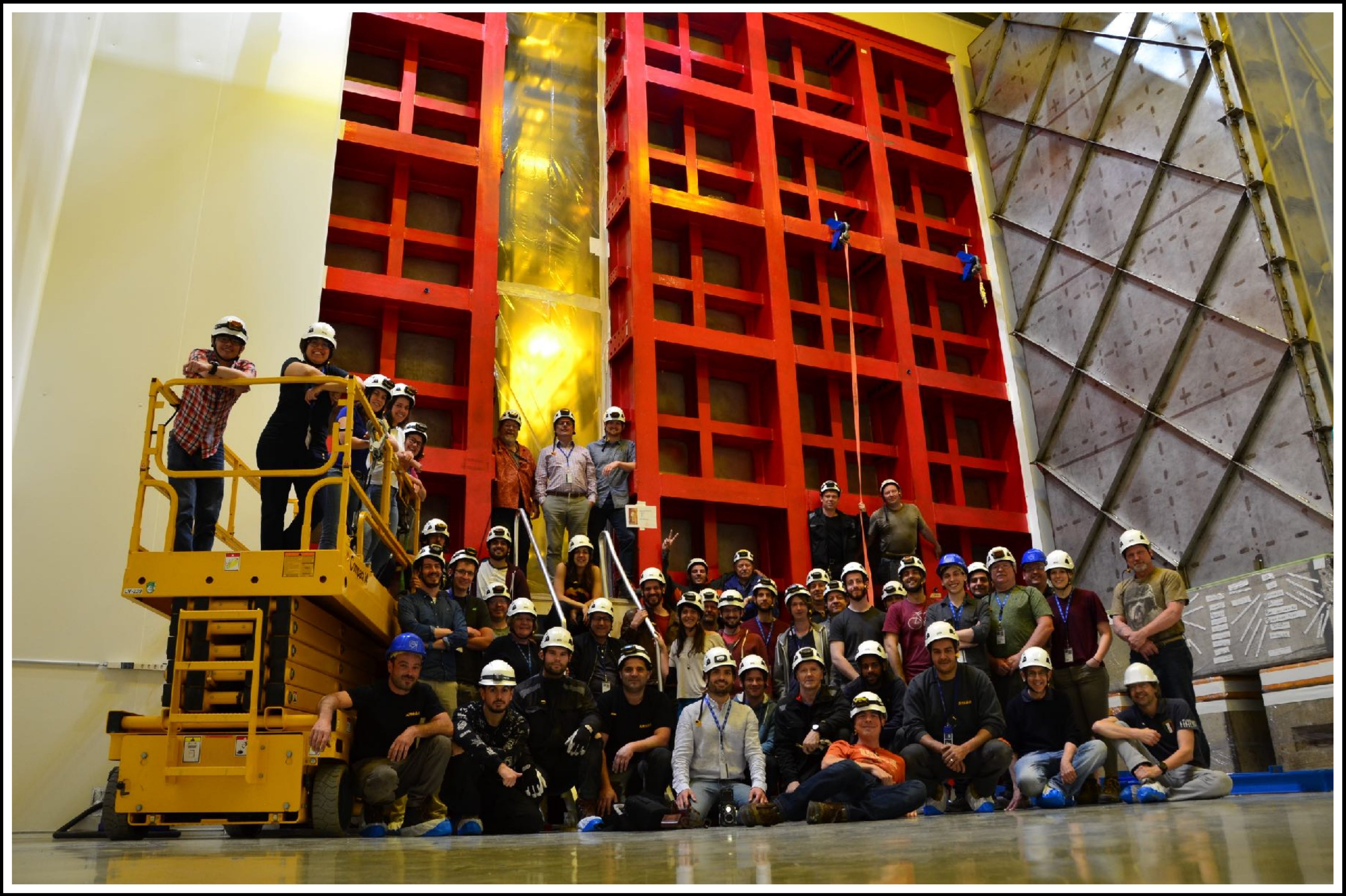
- Cryostat remained intact
- HV glitches still under investigation
- High DAQ uptime (but upscaling to DUNE nontrivial)
- Preliminary noise level 500-750 ENC (comparable to previous experiments)
- Good resolution (wire pitch ~5 mm)

ProtoDUNE SP

- Reconstruction efforts well under way
- Understand data quality well by now (and it looks promising)
- Current projects: dE/dx calibration, space charge effects investigations



ProtoDUNE SP



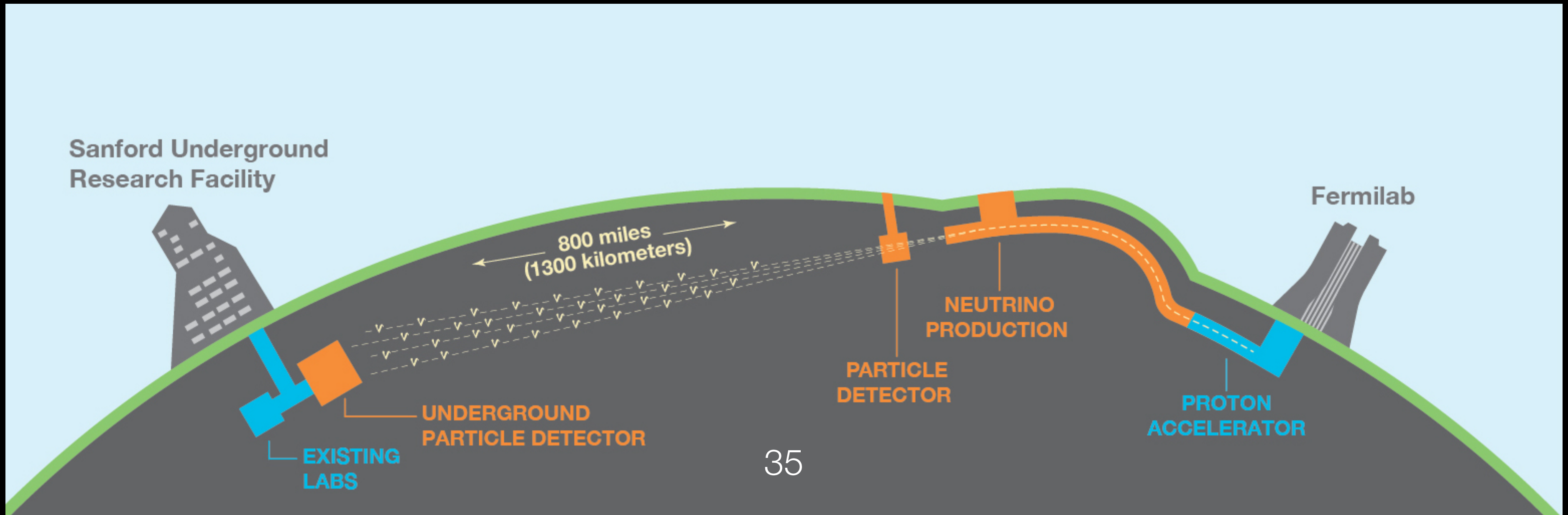
- DUNE: 70 kt LAr TPC neutrino detector
    - To resolve multiple outstanding questions in neutrino physics
- ProtoDUNE: 800 t “small” prototype for DUNE
    - Great success with recent beam run
    - Looking forward to understanding the detector and reconstruction performance

ProtoDUNE SP

Backup

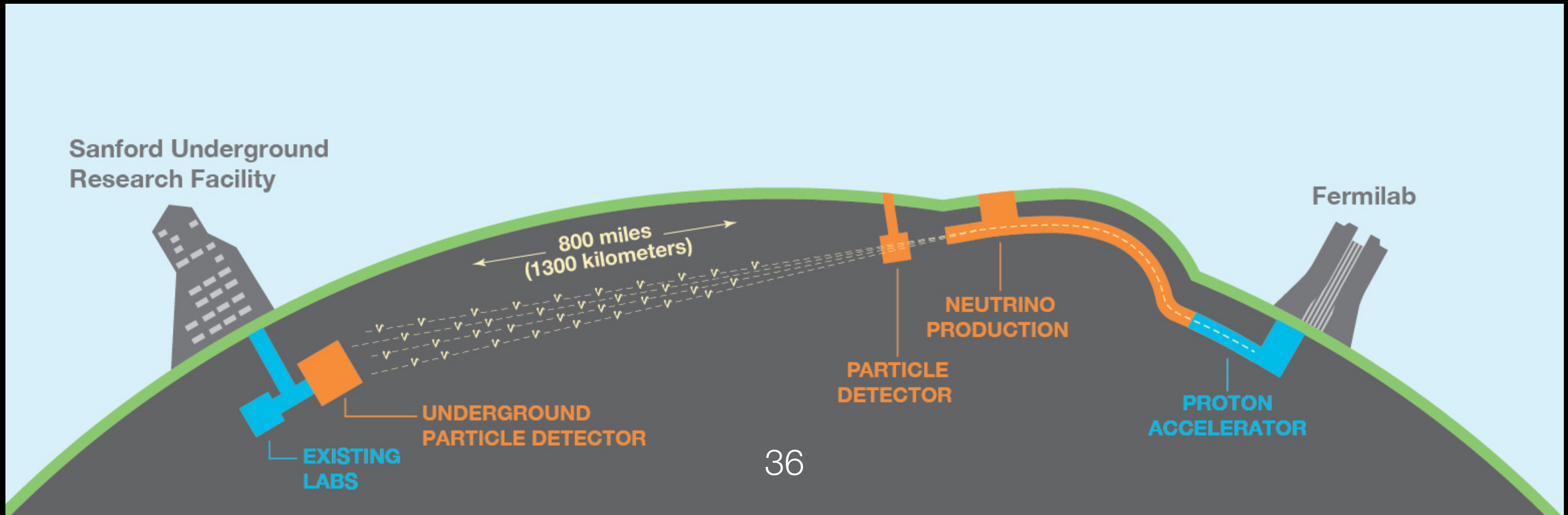
DUNE Timeline

- 2017: Far detector construction begins
- 2018: ProtoDUNEs at CERN
- 2021: Far detector installation begins
- 2024: First physics data
- 2026: Neutrino beam available

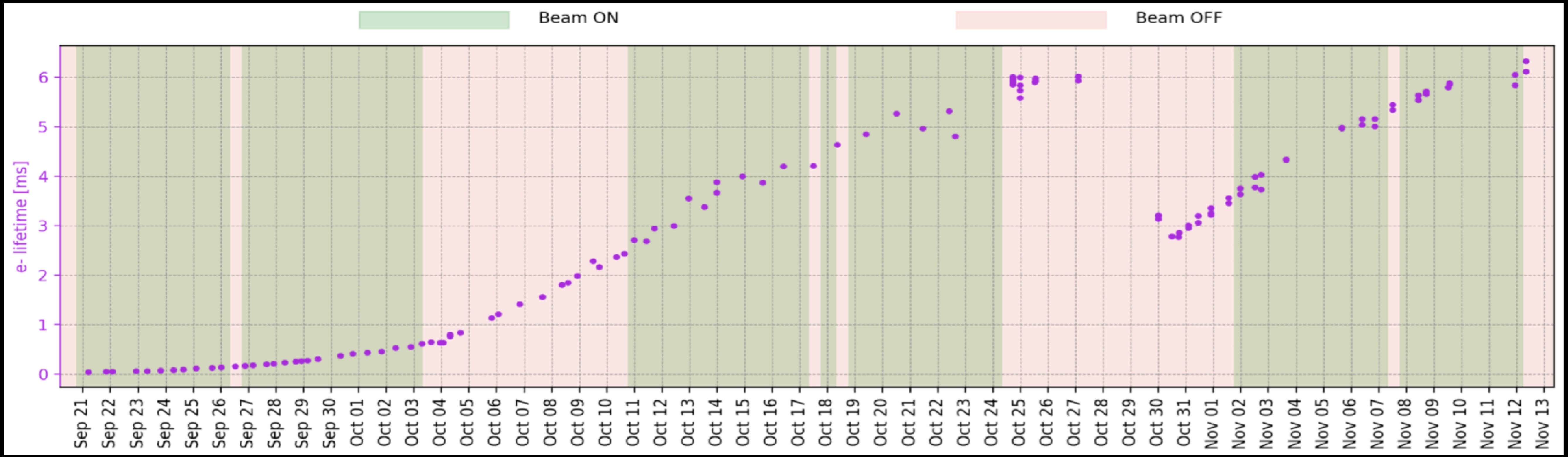


DUNE Cost

- Total: ~ $2 billion
- DUNE far detector: ~ $480 million
- US DoE: ~ $1.5 billion envisioned
- UK: ~ $88 million pledged



- Purity measured by seeing how far electrons can travel
- Electron drift velocity in this case ~1.6 m/ms
    - 6 ms -> 9.6 m!

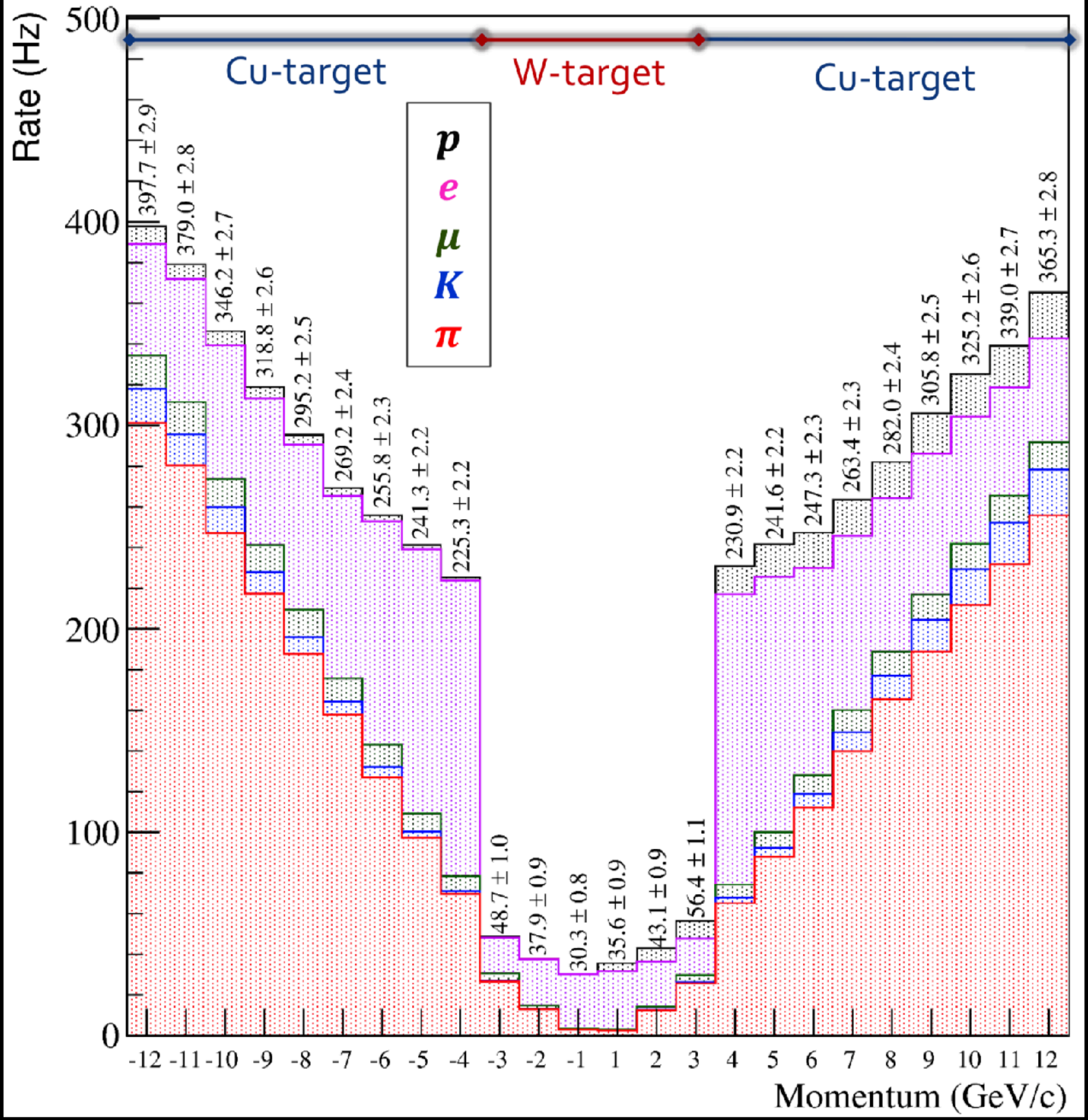


Plot by Kevin Wood

High Voltage Glitches

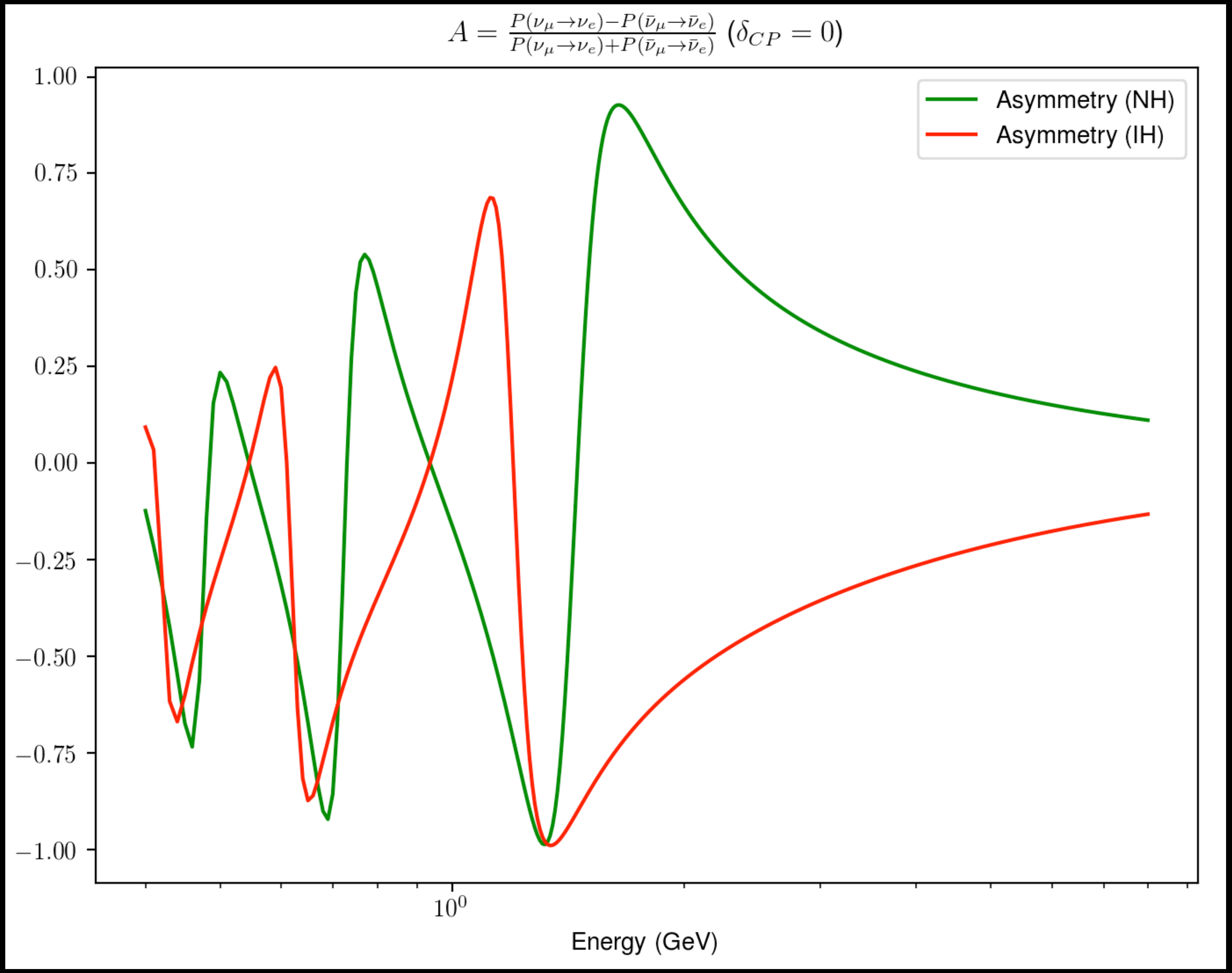
Plot by Kevin Wood

Beam Composition



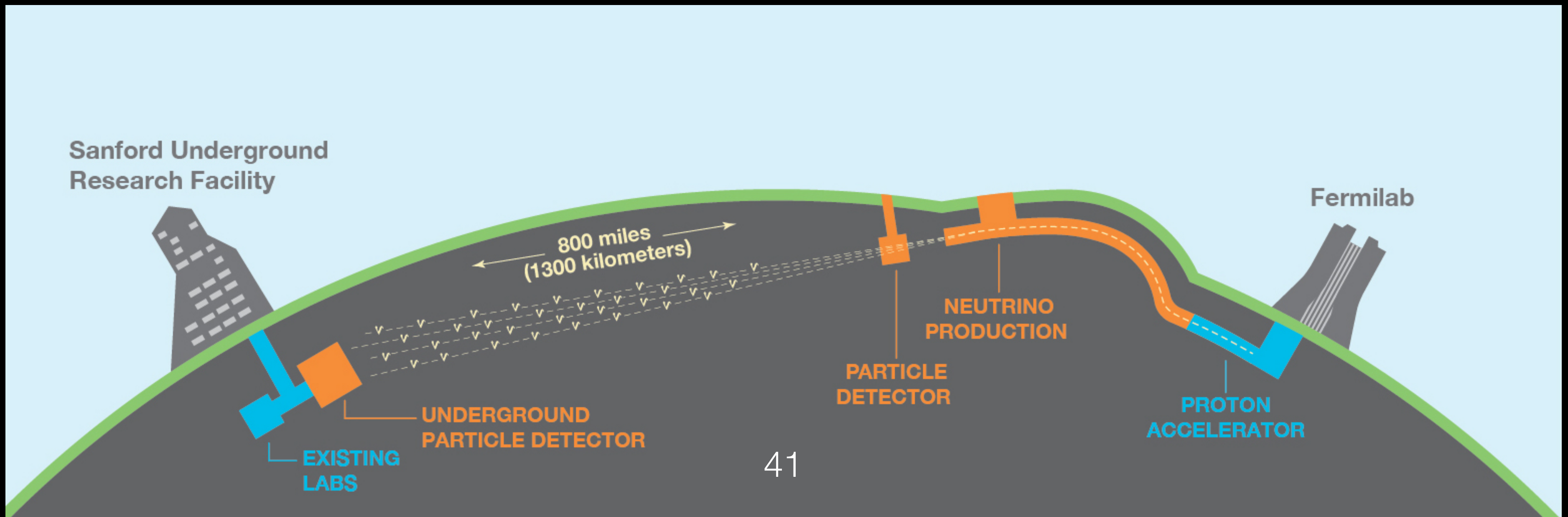
Graph by Marcel Rosenthal

Neutrino Asymmetry



DUNE Measurement Projections

- Mass hierarchy determined at 5σ in 2—5 years
- δ_{CP} determined to within 7°—13° in 10 years
- Could catch Milky Way supernova neutrinos: 10,000 events over 10 seconds
- Put limits on proton decay ($\tau > 10^{33}$ years)



DUNE Measurement Projections

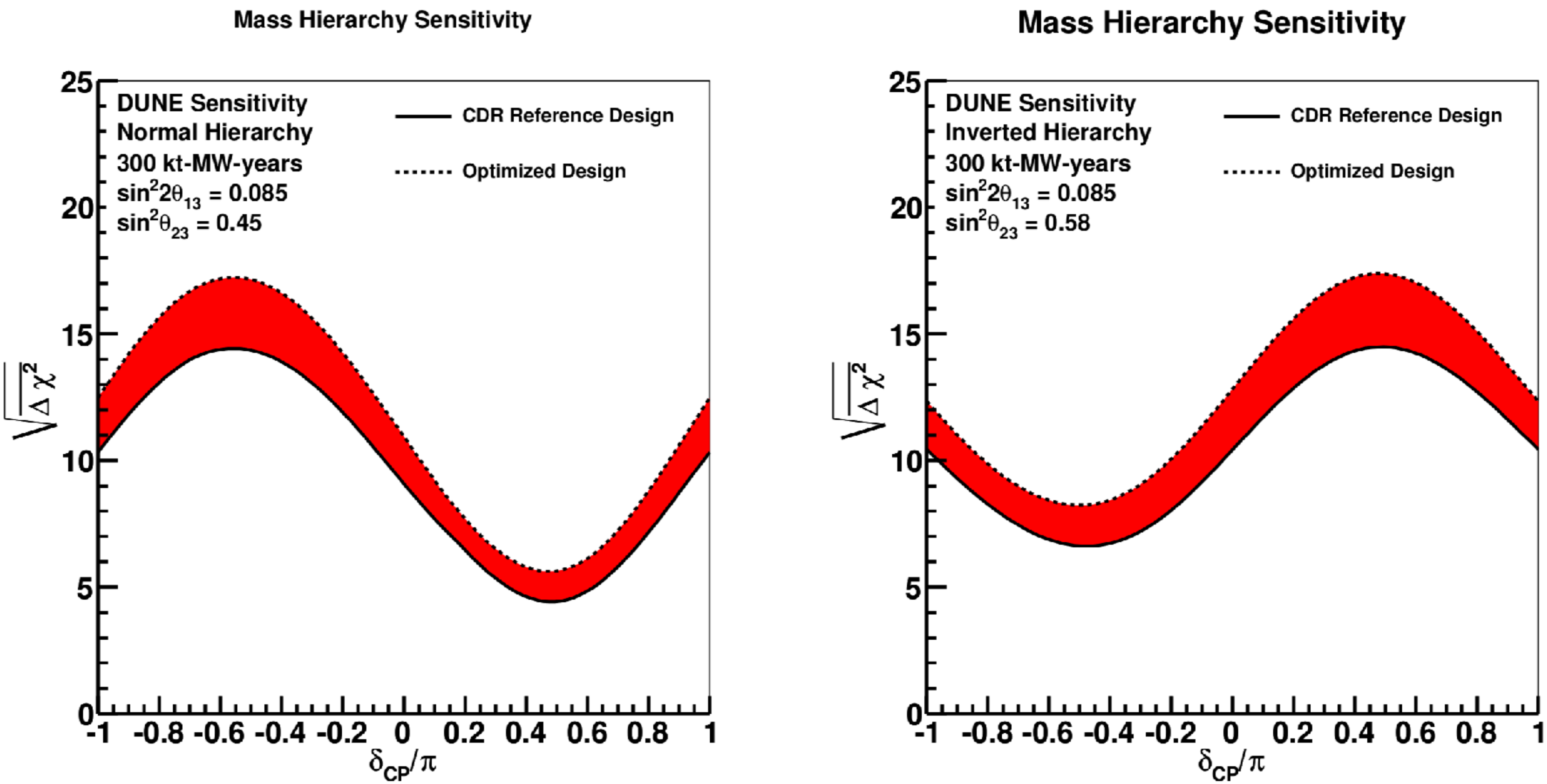


Figure 3.7: The significance with which the mass hierarchy can be determined as a function of the value of δ_{CP} for an exposure of 300 kt · MW · year assuming normal MH (left) or inverted MH (right). The shaded region represents the range in sensitivity due to potential variations in the beam design.

Plots from LBNF/DUNE CDR Vol. 2

DUNE Measurement Projections

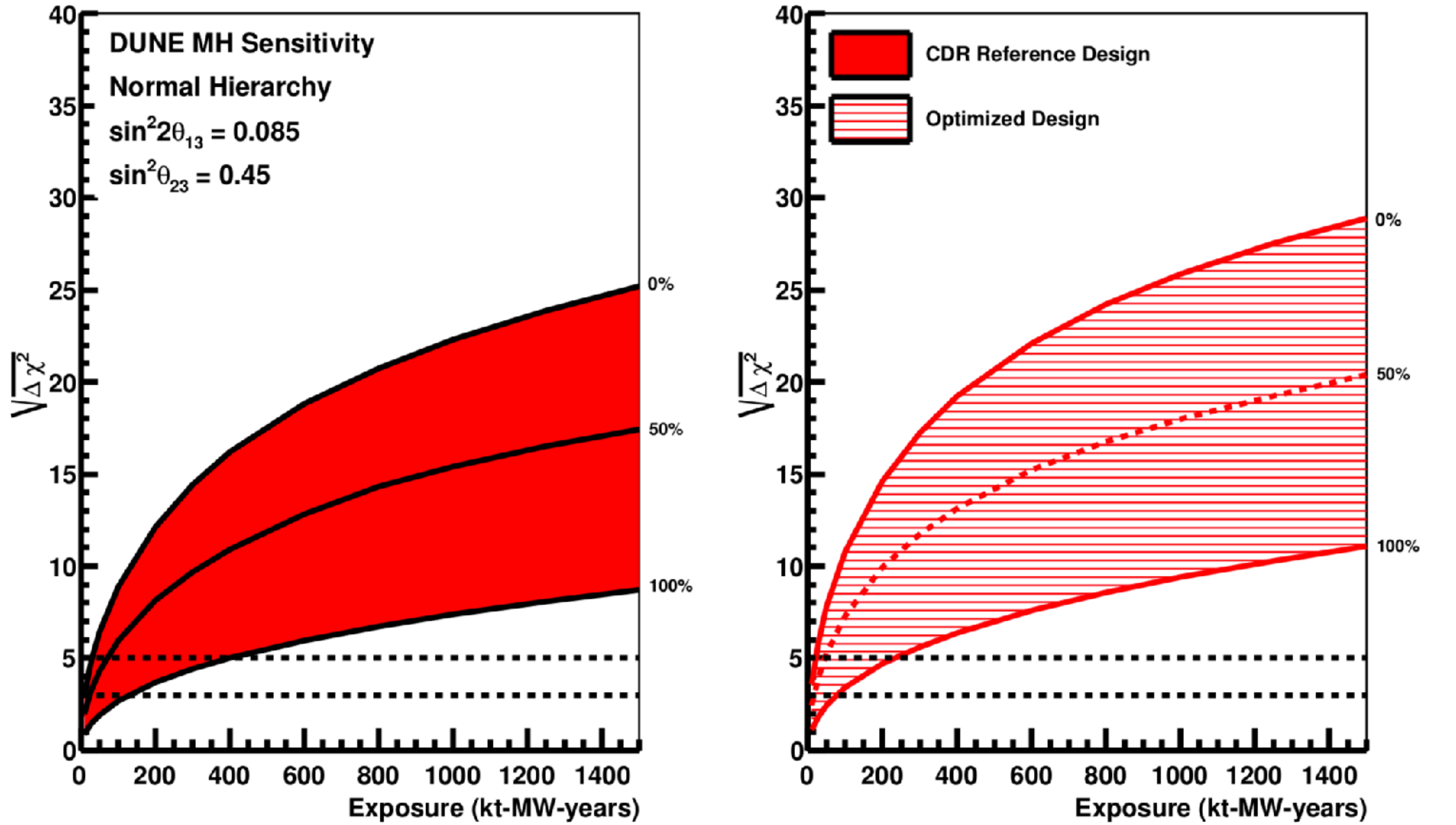


Figure 3.8: The minimum significance with which the mass hierarchy can be determined for all values of $\delta_{\rm CP}$ (100%), 50% and in the most optimistic scenario (0%) as a function of exposure. The two different shaded bands represent the different sensitivities due to variations in the beam design. This plot assumes normal mass hierarchy. (The inverted hierarchy case is very similar.)

Plots from LBNF/DUNE CDR Vol. 2

DUNE Measurement Projections

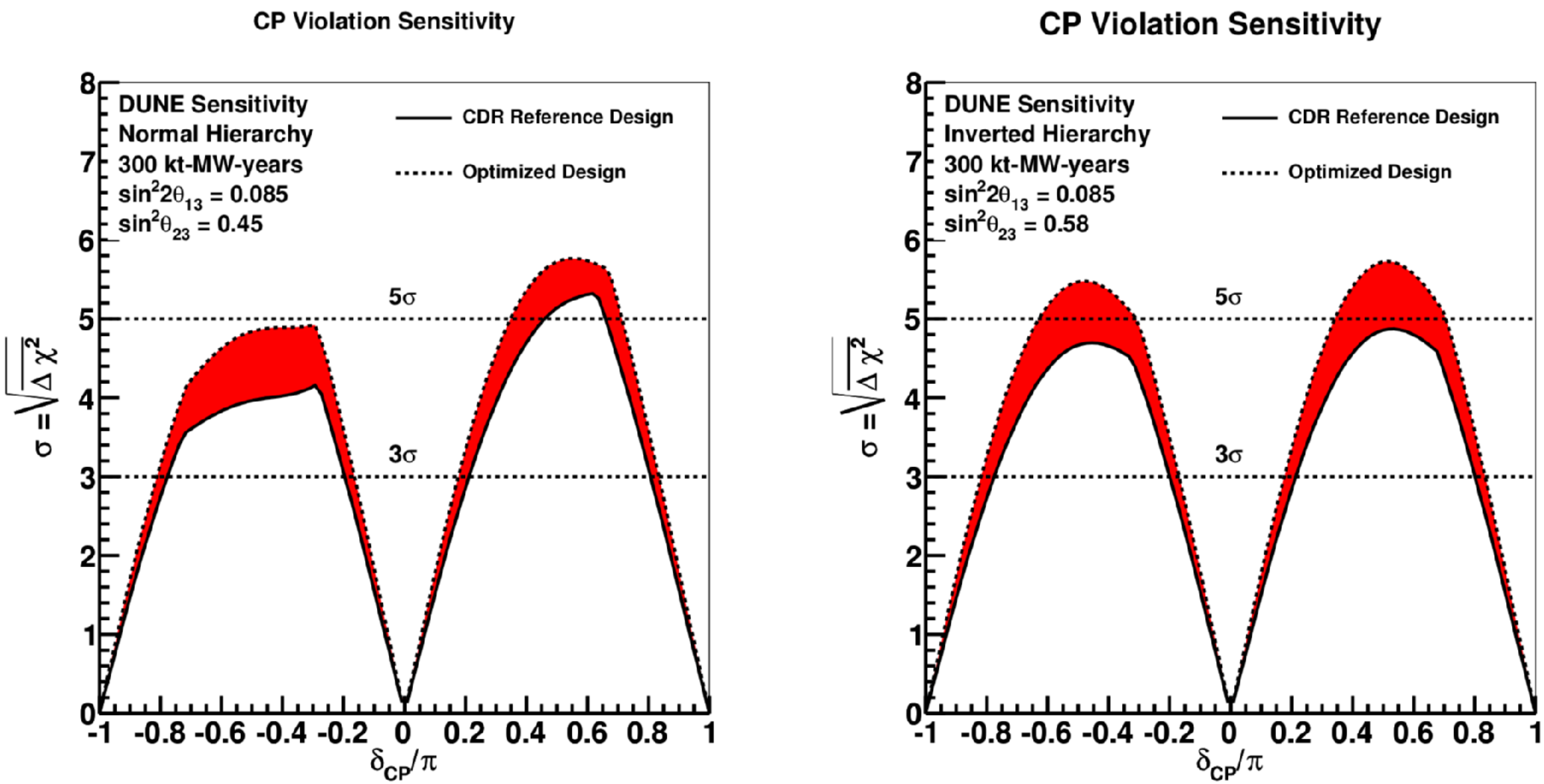


Figure 3.13: The significance with which the CP violation can be determined as a function of the value of δ_{CP} for an exposure of 300 kt · MW · year assuming normal MH (left) or inverted MH (right). The shaded region represents the range in sensitivity due to potential variations in the beam design.

Plots from LBNF/DUNE CDR Vol. 2

DUNE Measurement Projections

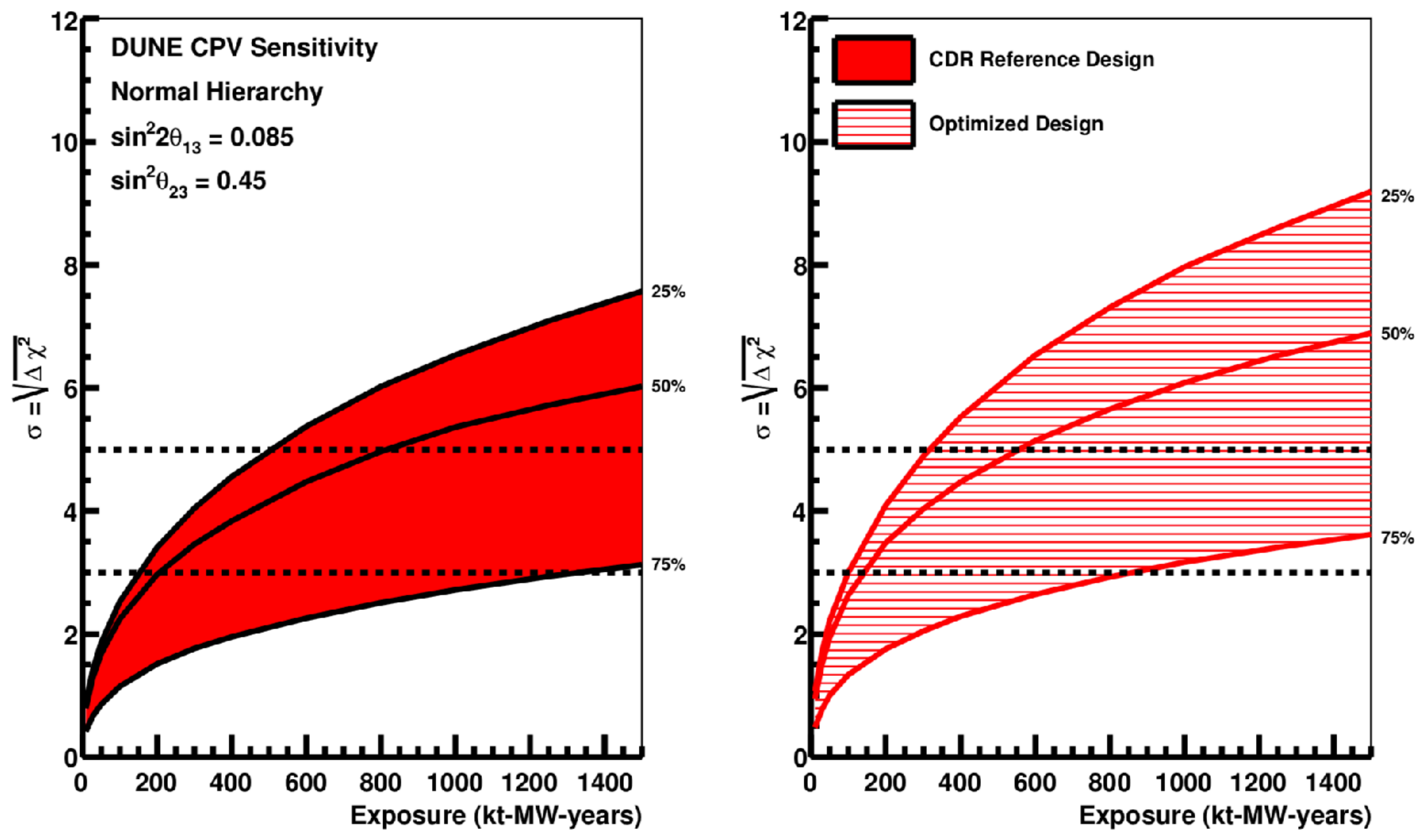


Figure 3.14: The minimum significance with which CP violation can be determined for 25%, 50% and 75% of $\delta_{\rm CP}$ values as a function of exposure. The two different shaded bands represents the different sensitivities due to potential variations in the beam design. This plot assumes normal mass hierarchy.

Plots from LBNF/DUNE CDR Vol. 2