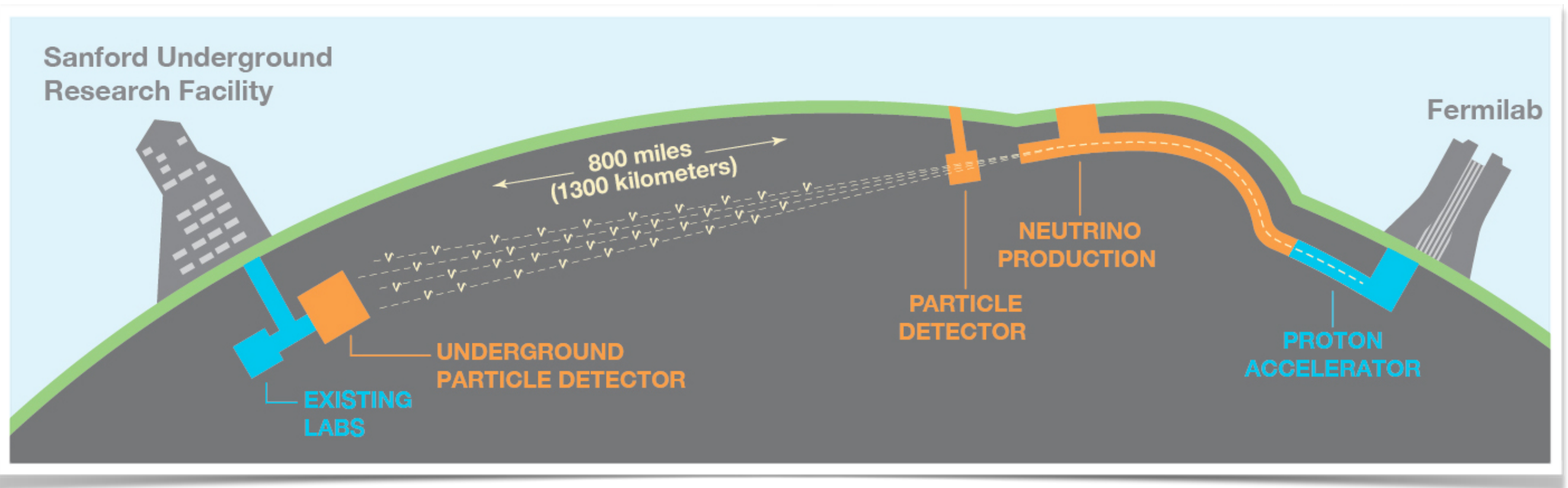


# Technical achievements, challenges of



Kendall Mahn  
(Michigan State  
University)

*Support provided by U.S. DOE  
Award DE-SC0015903*

J-PARC symposium  
Sep 26th 2019



# Disclaimer

- Thank you for the invitation today
- I speak (too) fast in English... sorry...
- Please! raise your hand to remind me to slow down



# Deep Underground Neutrino Experiment



[www.sanfordlab.org](http://www.sanfordlab.org)

*Sanford Underground Research Facility*

*Lead, South Dakota, in the Black Hills*



# Deep Underground Neutrino Experiment



“Quiet” environment, massive detectors will be sensitive to:



# Deep Underground Neutrino Experiment

***Broad physics program***

***~1.5km underground***

*Neutrino astrophysics (supernova neutrinos)*

**Neutrino oscillation**

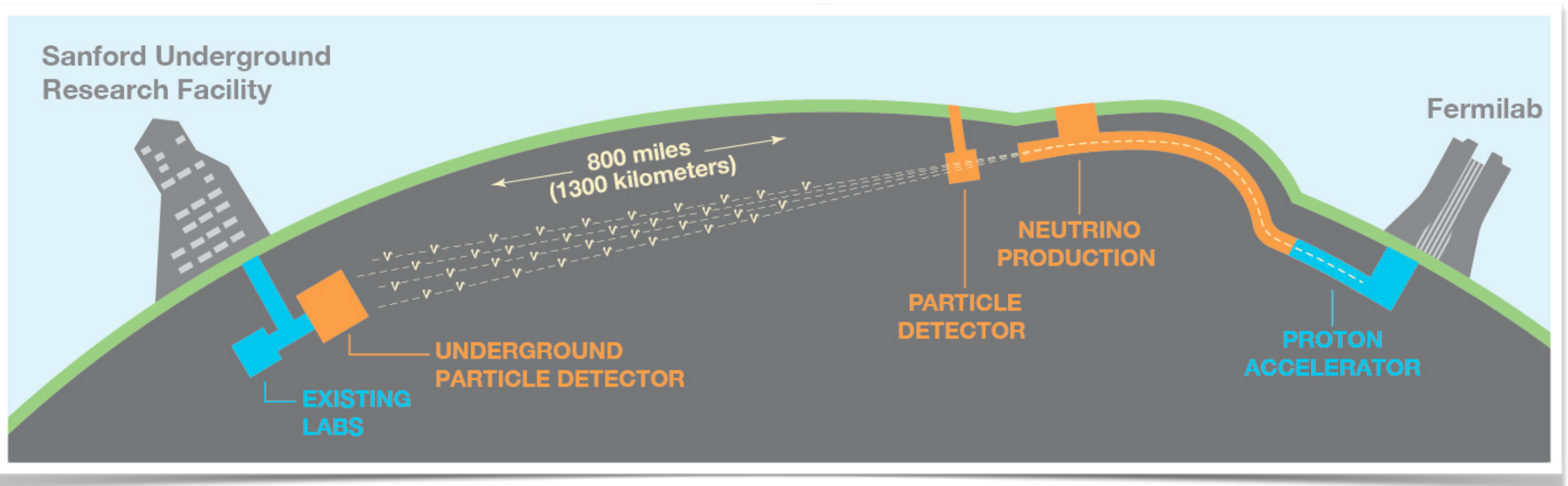
*Grand Unified Theories (nucleon decay)*

*Exotic particle searches*

“Quiet” environment, massive detectors will be sensitive to:

Interim Design Report (IDR) physics: [1807.10334](#)

# Neutrino oscillation program at



Massive “Far detector”

Intense neutrino source

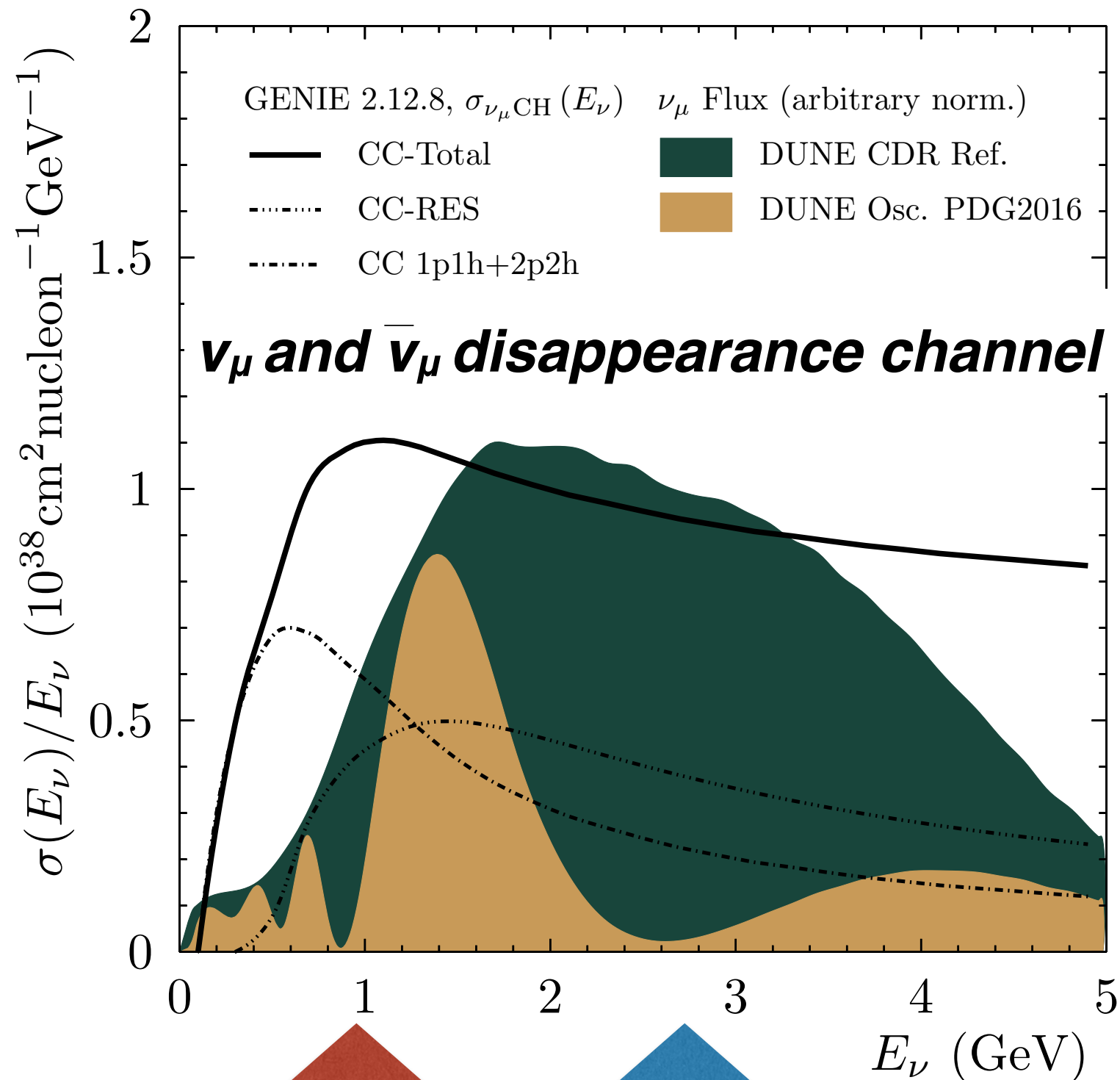


**1300km**

“near” detectors and  
beam monitors



# Neutrino oscillation program at

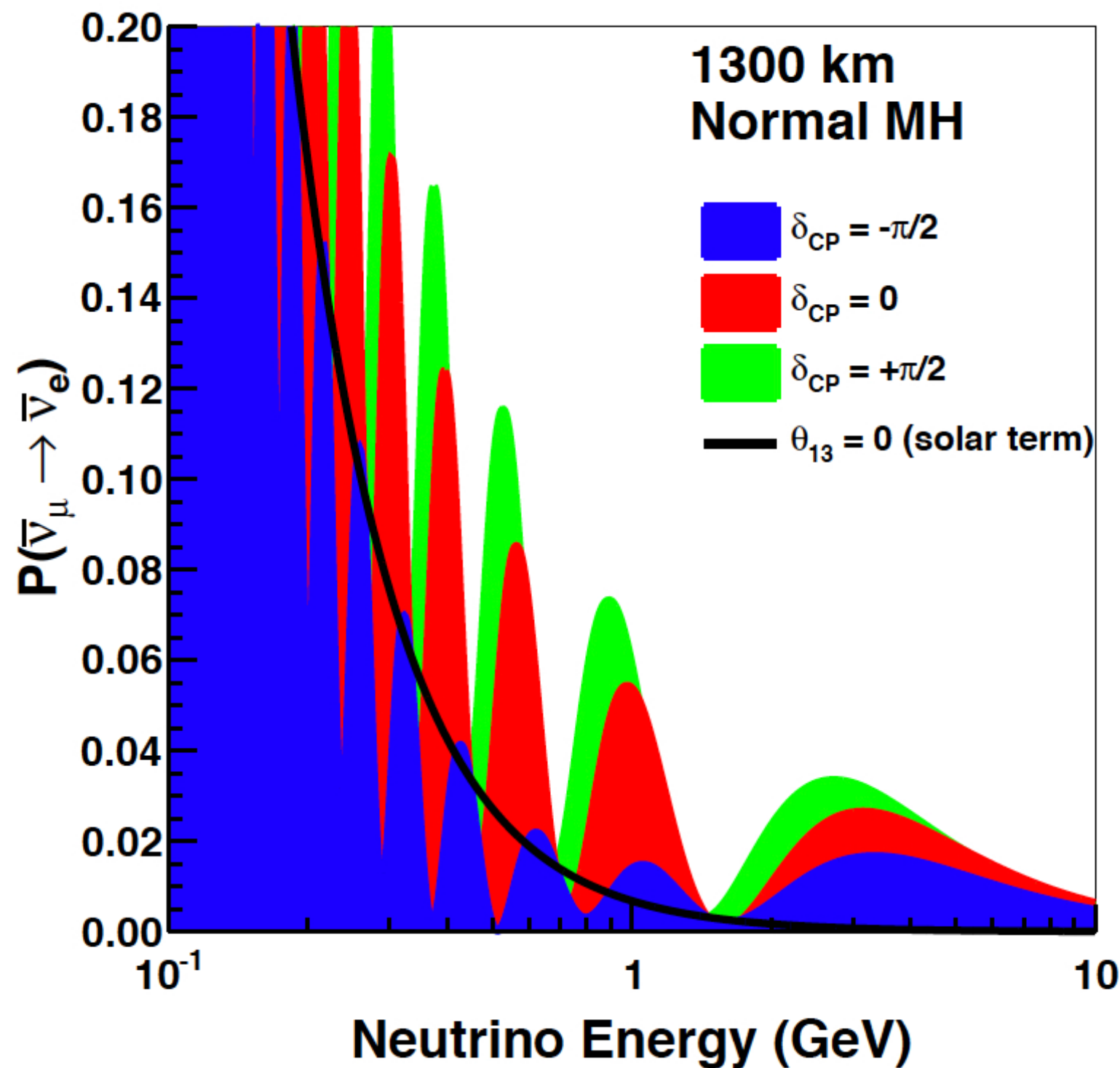


Broad neutrino,  
antineutrino spectrum  
to map out oscillation

*Second osc. max*

*First osc. max @  $L=1300\text{km}$*

# Neutrino oscillation program at



*$\nu_e$  and  $\bar{\nu}_e$  appearance channel*

Appearance, disappearance channels sensitive to open questions:

*Is  $\sin^2(\theta_{23})=0.5$ ? (maximal mixing?)*

*What is the ordering of the neutrino masses (mass hierarchy)*

*Is there CPV in neutrinos?*

*Is this picture complete? Are there non-standard effects or sterile neutrinos?*



# Deep Underground Neutrino Experiment

*Broad physics program*

*~1.5km underground*

*Neutrino astrophysics (supernova neutrinos)*

Neutrino oscillation

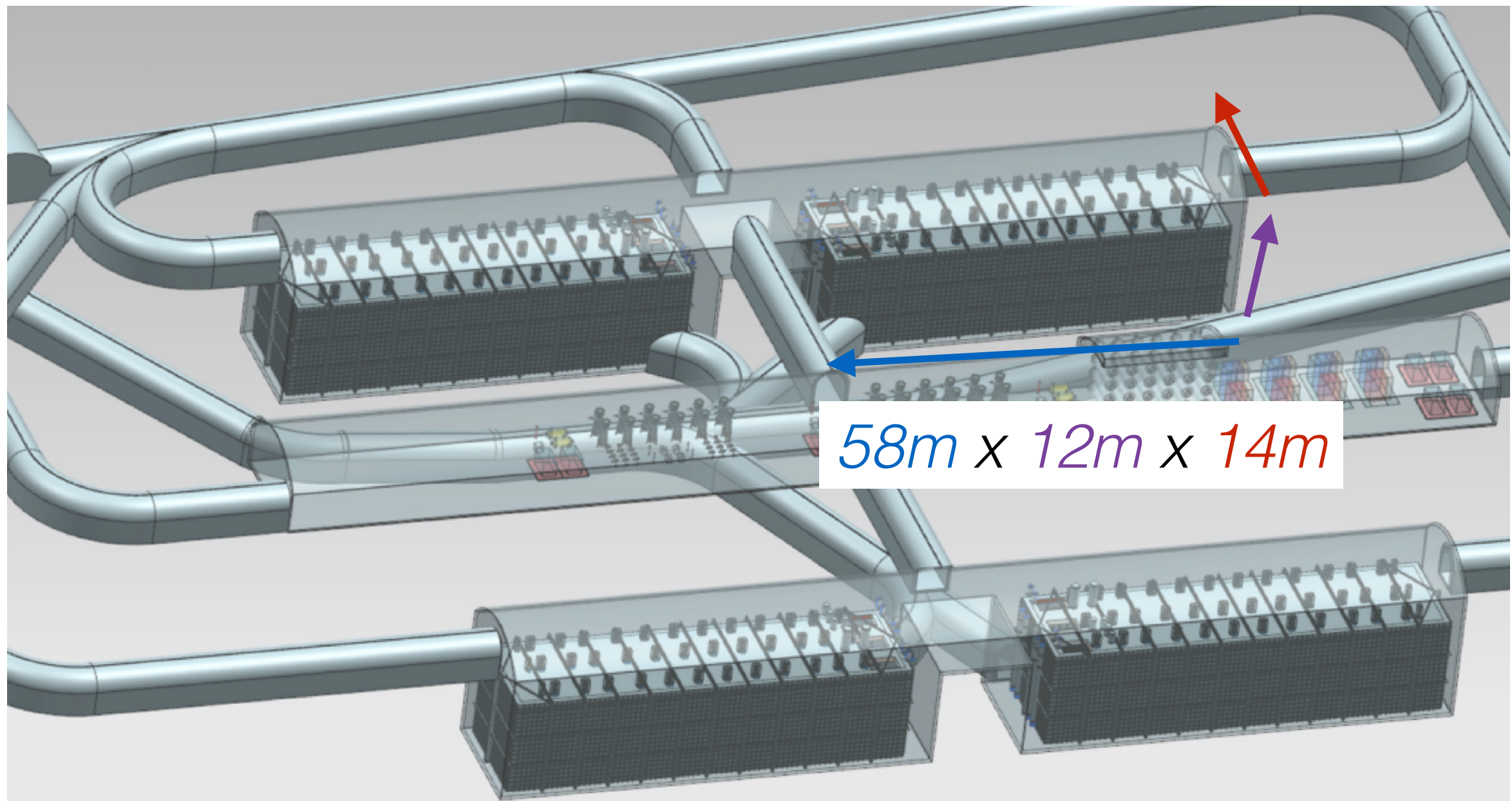
*Grand Unified Theories (nucleon decay)*

*Exotic particle searches*

“Quiet” environment, **massive detectors** will be sensitive to:

Interim Design Report (IDR) physics: [1807.10334](#)

# The detectors

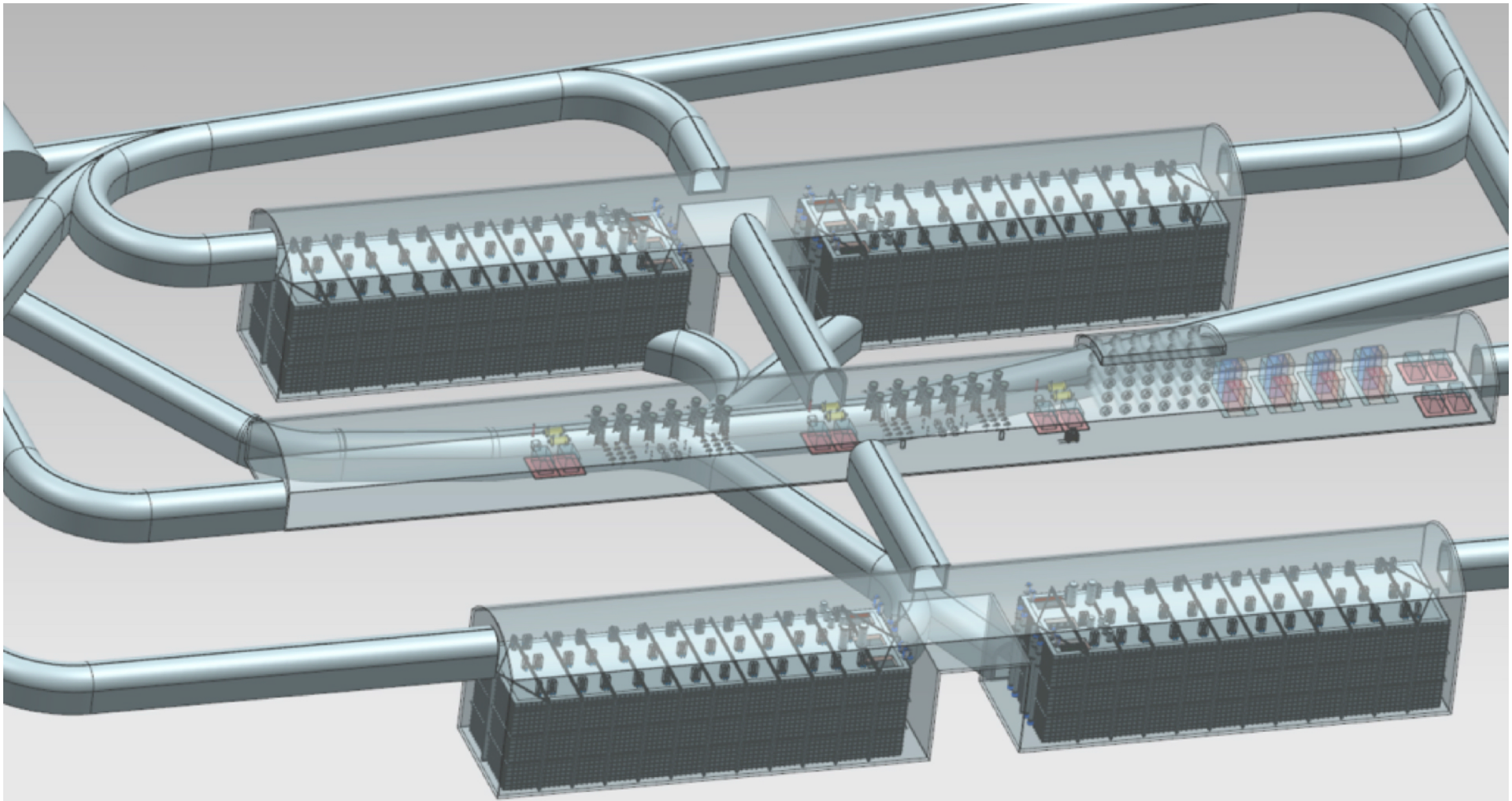


Four halls located underground, each with a massive Liquid Argon Time Projection Chamber (LArTPC)

*17kton (10kt fiducial volume)*



# The detectors

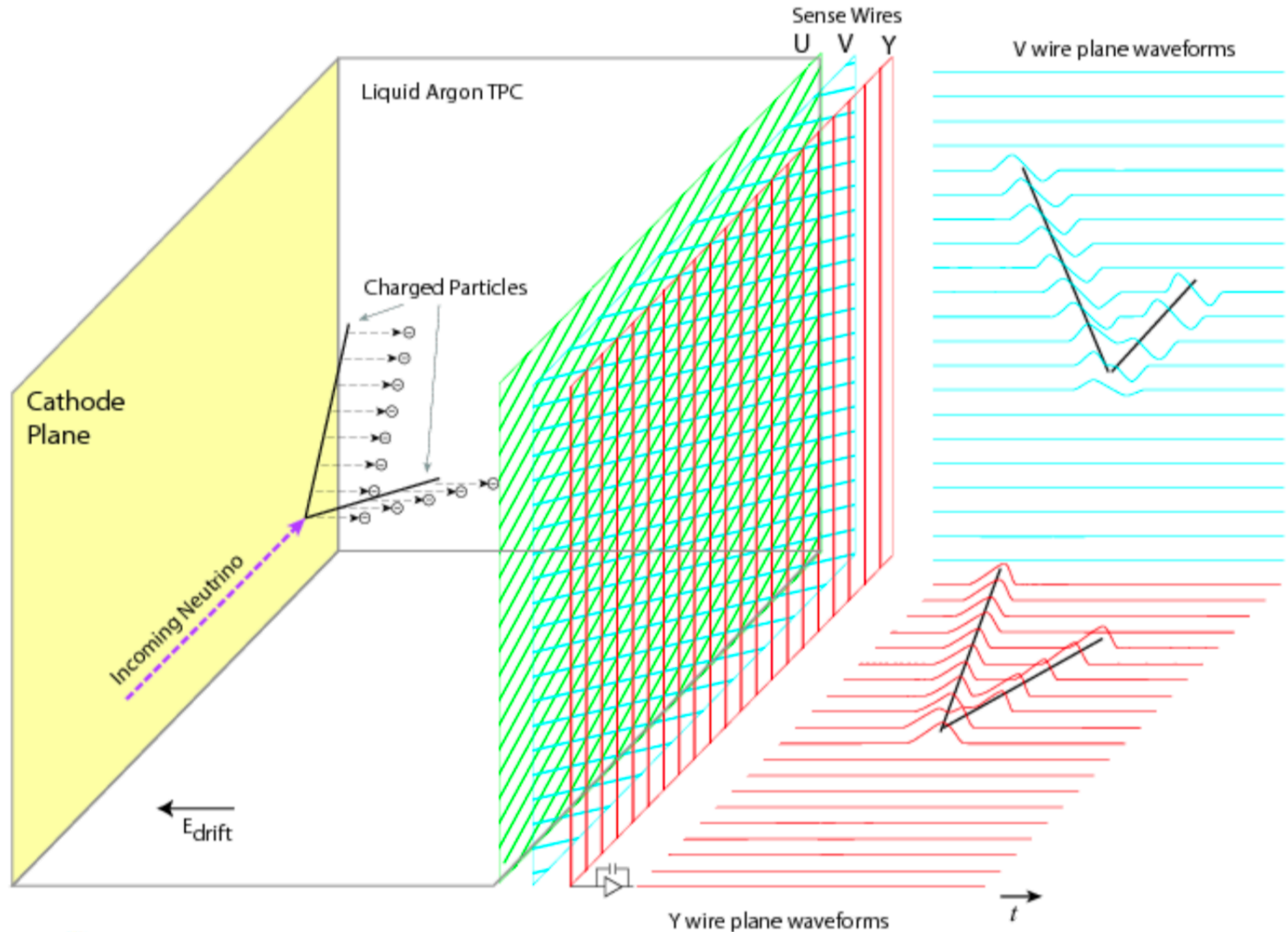


Four halls located underground, each with a massive Liquid Argon **Time Projection Chamber** (LArTPC)

Two kinds:  
“Single  
Phase” (SP)

“Dual  
Phase” (DP)

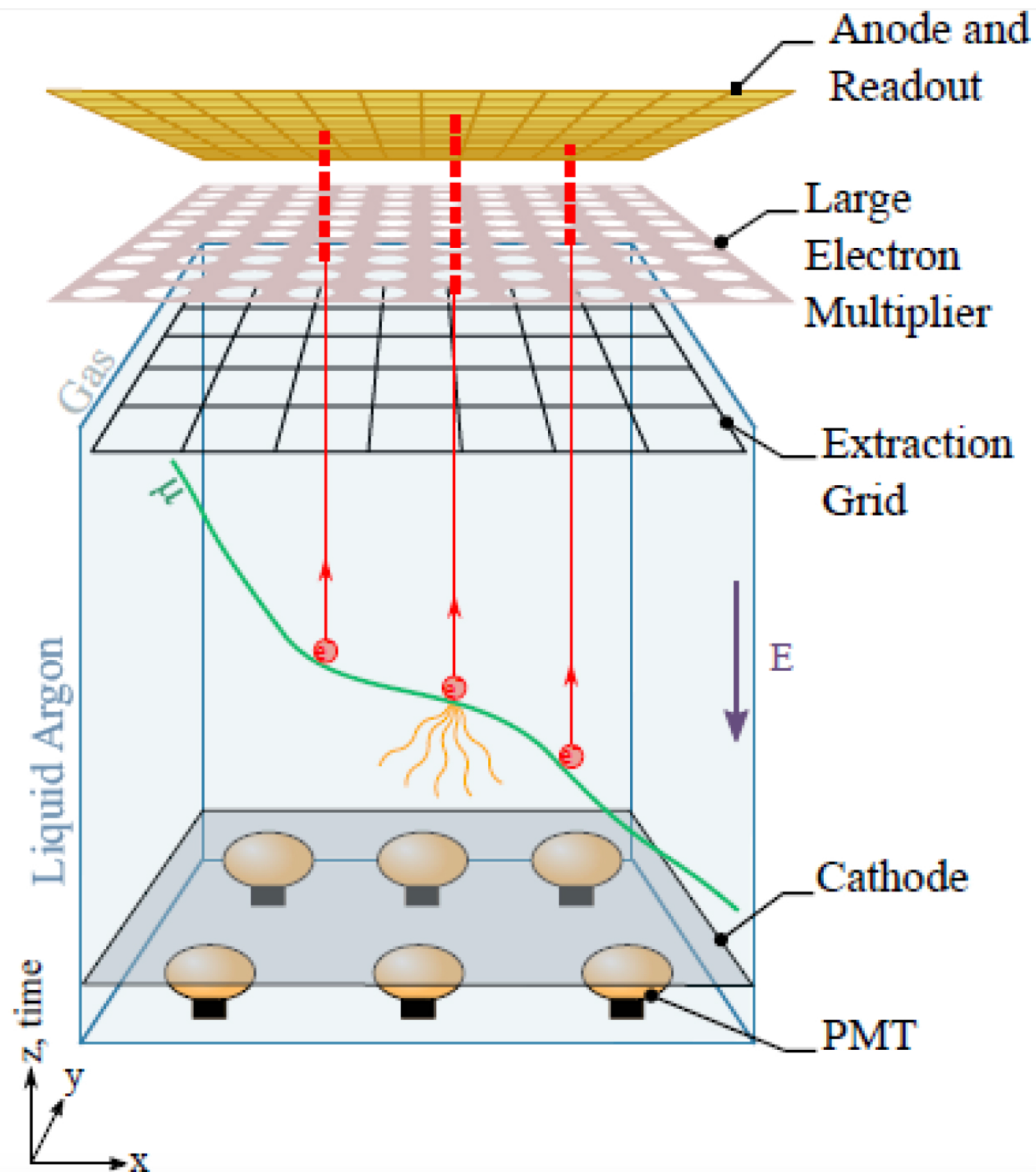
# The DUNE detectors: single phase



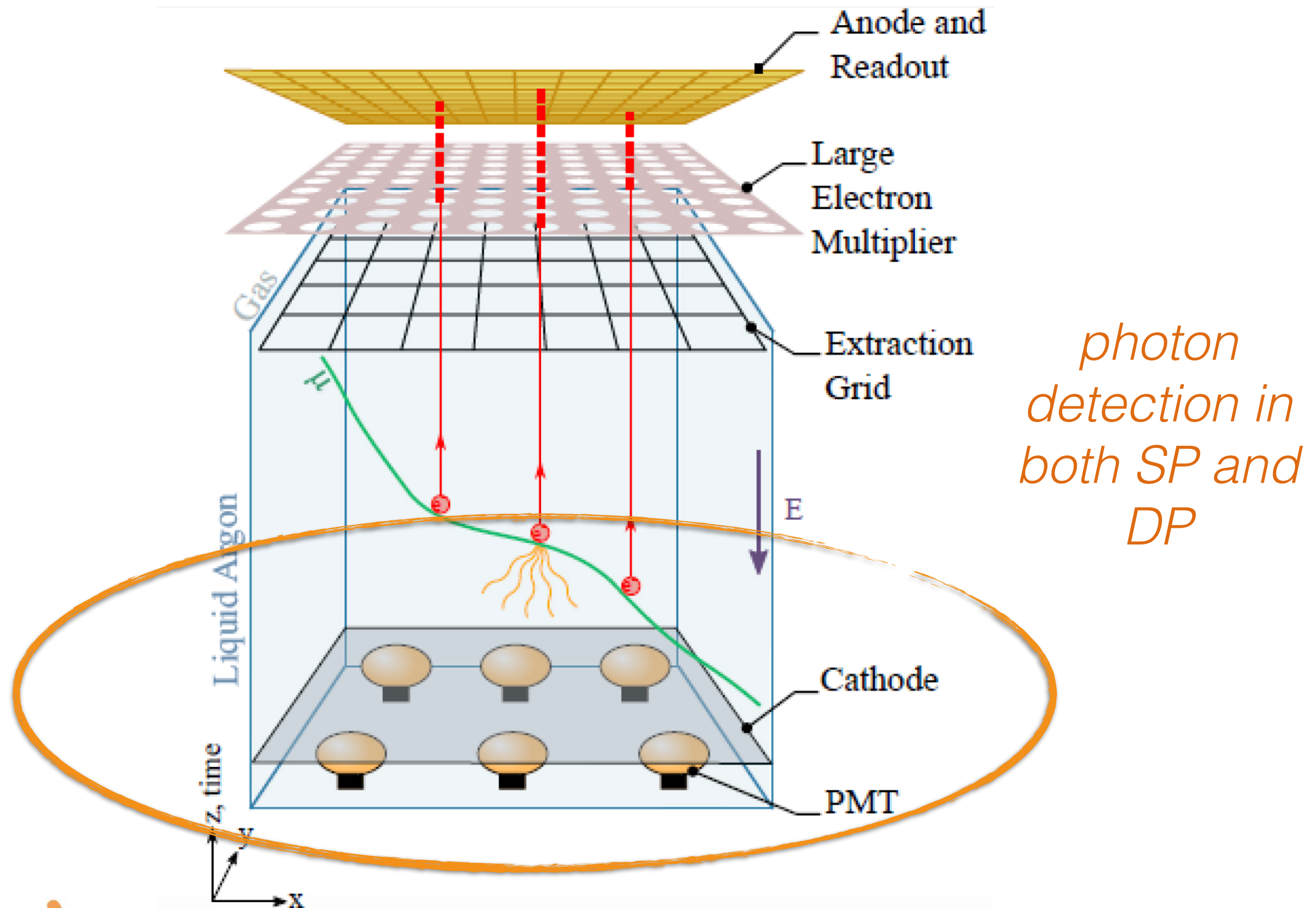
credit: B. Yu, y2u.be/IH88L5nVvmY



# The DUNE detectors: dual phase



# The DUNE detectors: **scintillation light**, too



# Challenges of

*Massive detectors!*

*New capabilities (e.g. photon detection)*

*Intense neutrino beam*

*Control of systematics uncertainties*



# Challenges of

*Massive detectors!*

*New capabilities (e.g. photon detection)*

**US-Japan R&D**

*Intense neutrino beam*

*Control of systematics uncertainties*

**Calibration**

**Near detector**

# Challenges of

*Massive detectors!*

*New capabilities (e.g. photon detection)*

## **Prototype detectors**

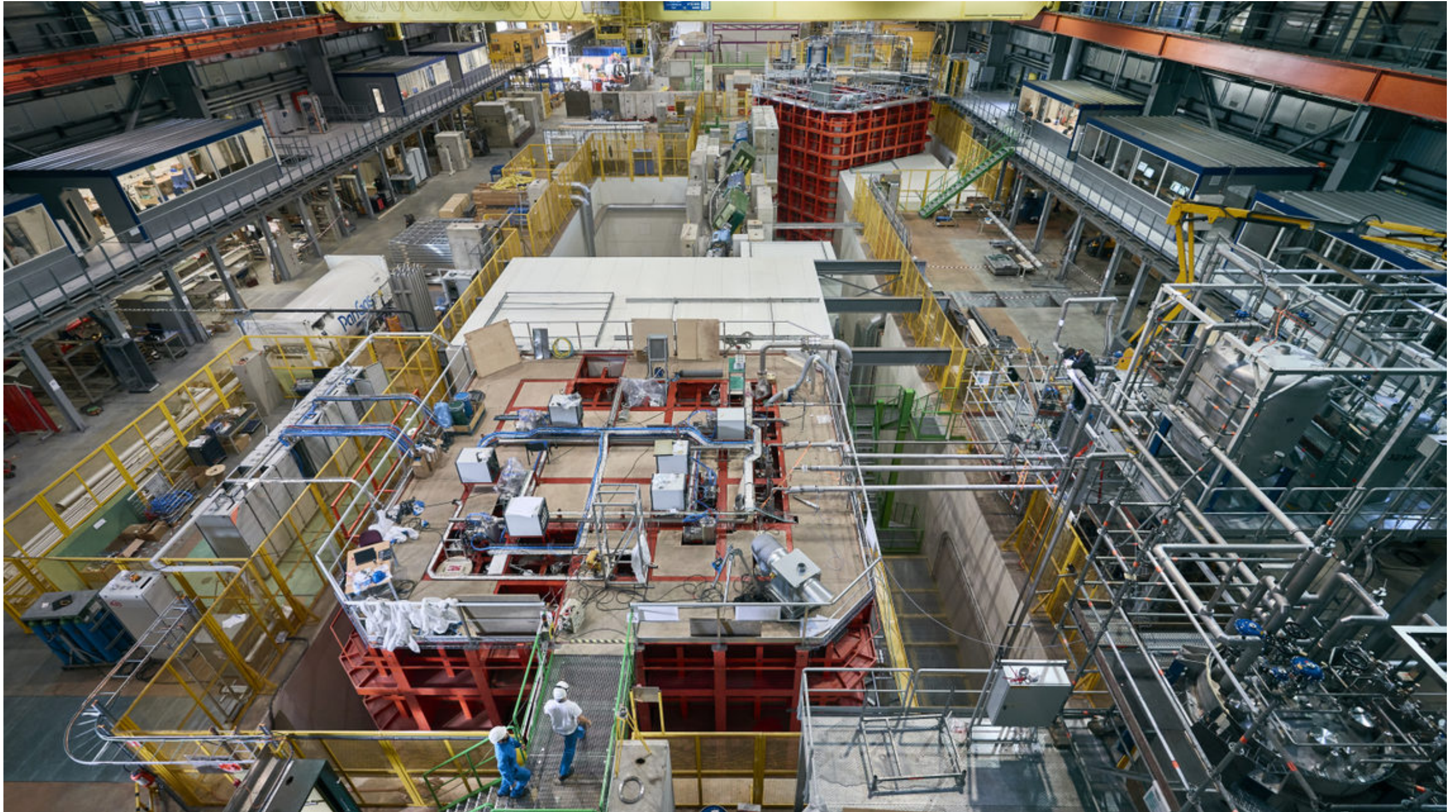
*Intense neutrino beam*

*Control of systematics uncertainties*



# Particles in (Proto)DUNE

Prototype detectors sit in a charged particle beam at CERN

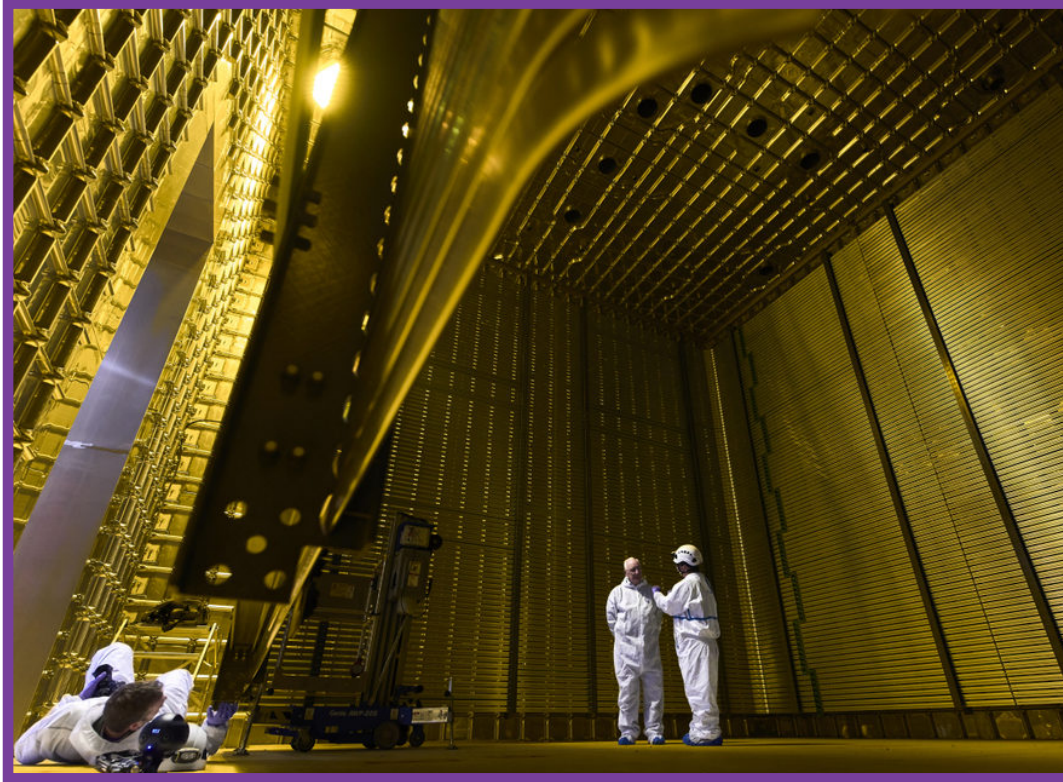


credit: CERN



# Particles in (Proto)DUNE

*Dual Phase*



credit: CERN



credit: CERN

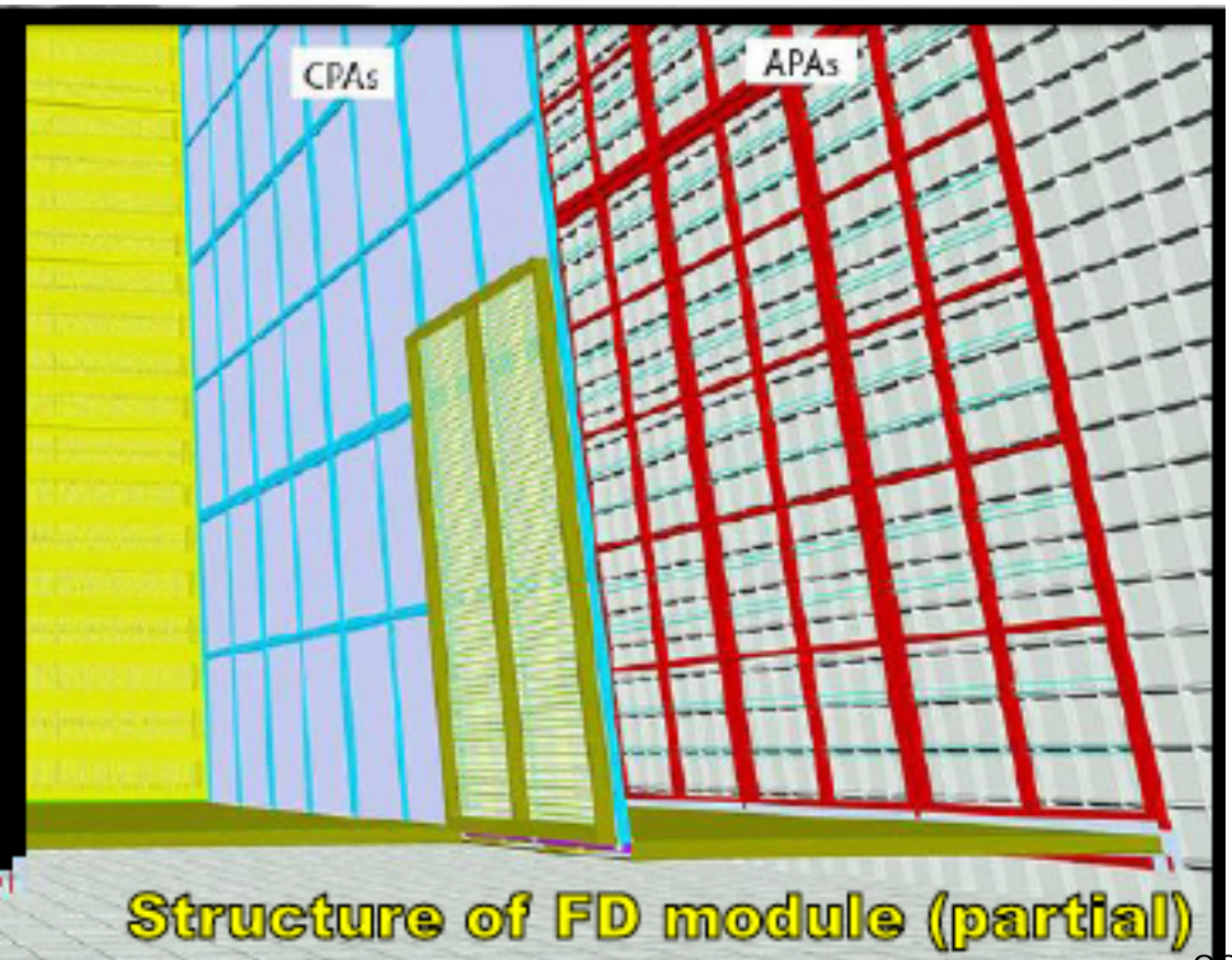
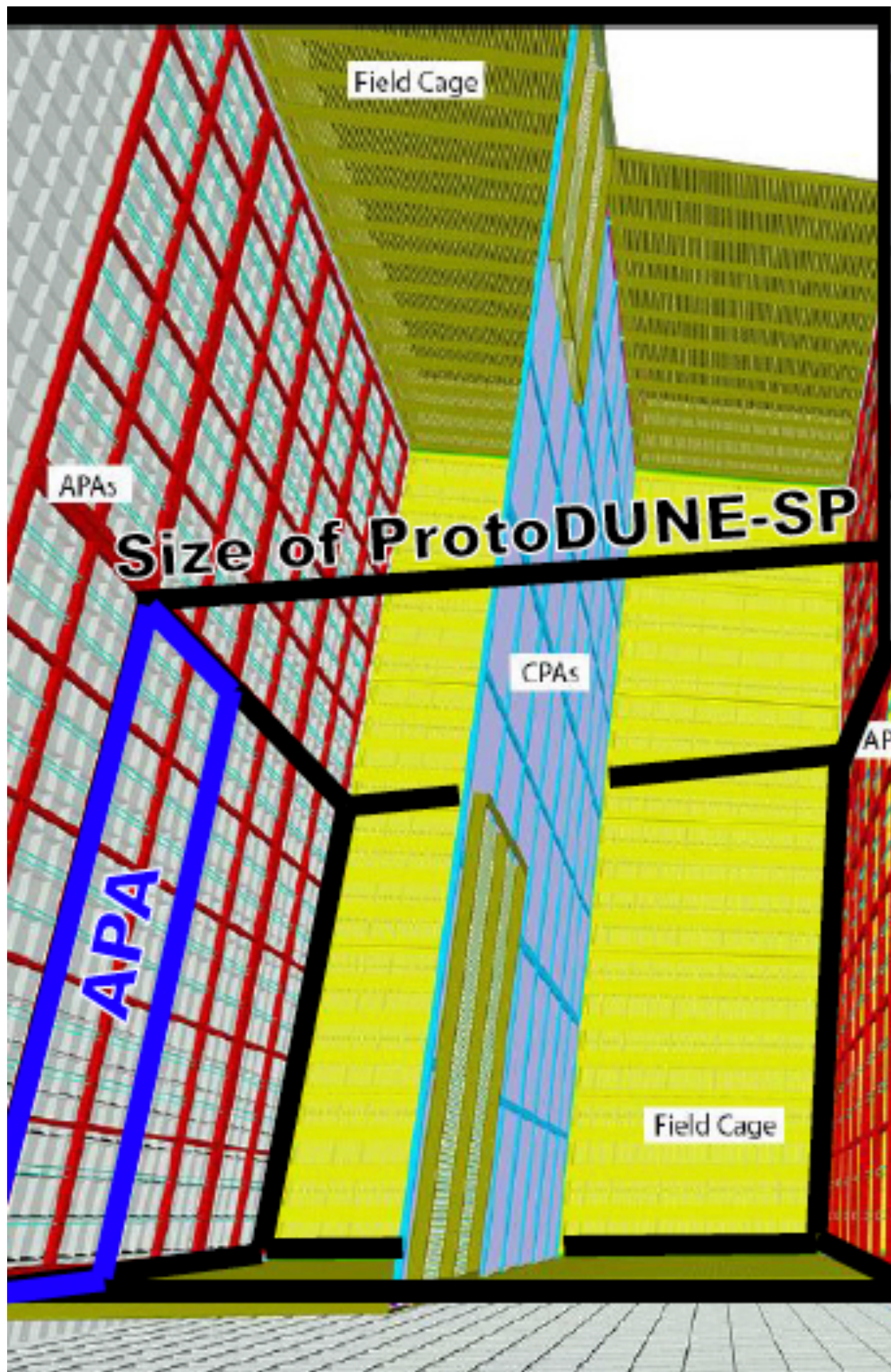


*Single Phase*



## Validation of “full scale” modules

- Demonstrate stability, detector component R&D
- Measurements of charged particle response (0.5-7 GeV  $e, p, \pi, \mu$ )





# ProtoDUNE status

## Single Phase

Assembly

Filling, Purifying

Cosmic data

Beam data (Aug - Nov  
2018)

## Dual Phase

Assembly

Filling, Purifying

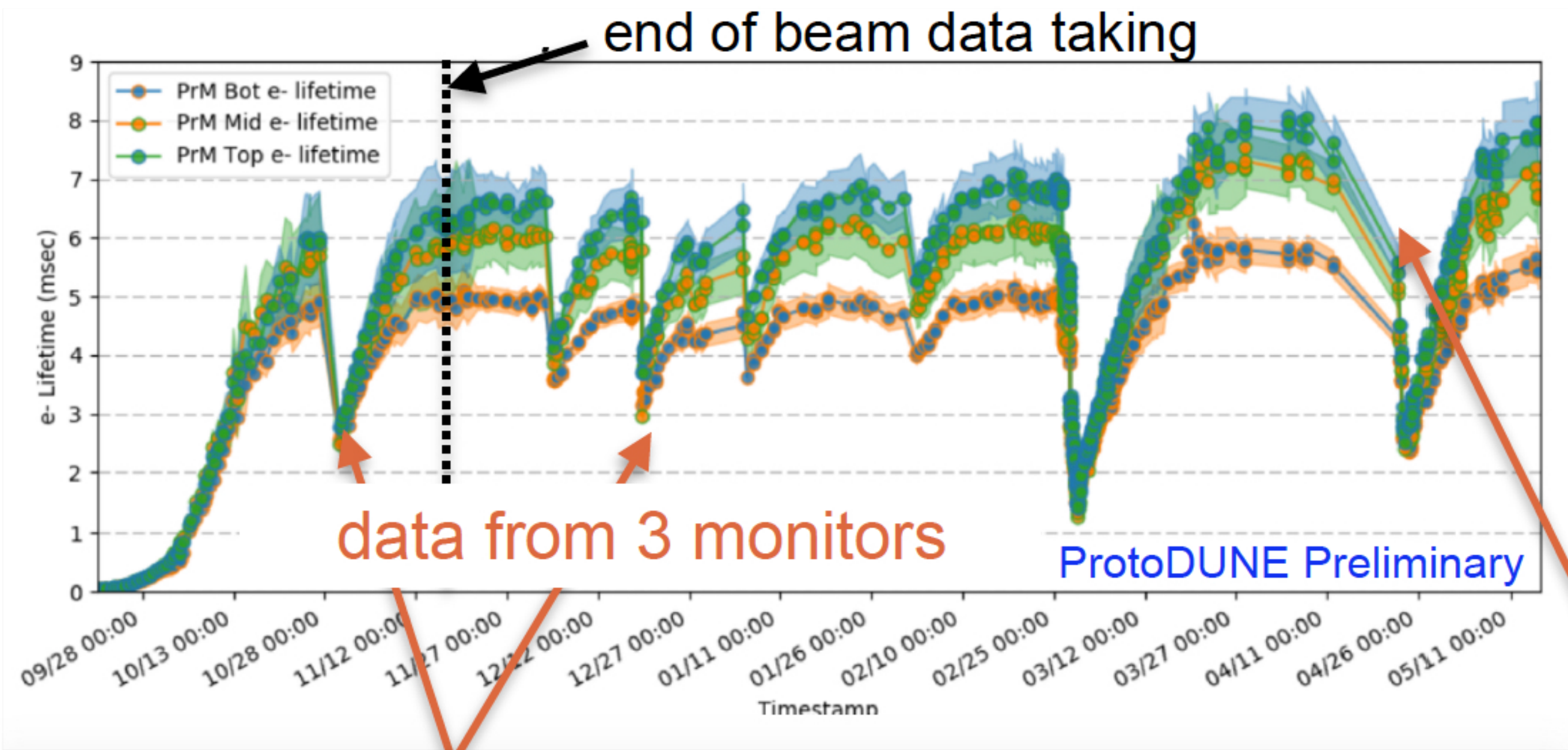
*Testing individual subsystems*

*Technical paper on DP demonstrator:*

B. Aimard et al, JINST13 P11003 (2018),

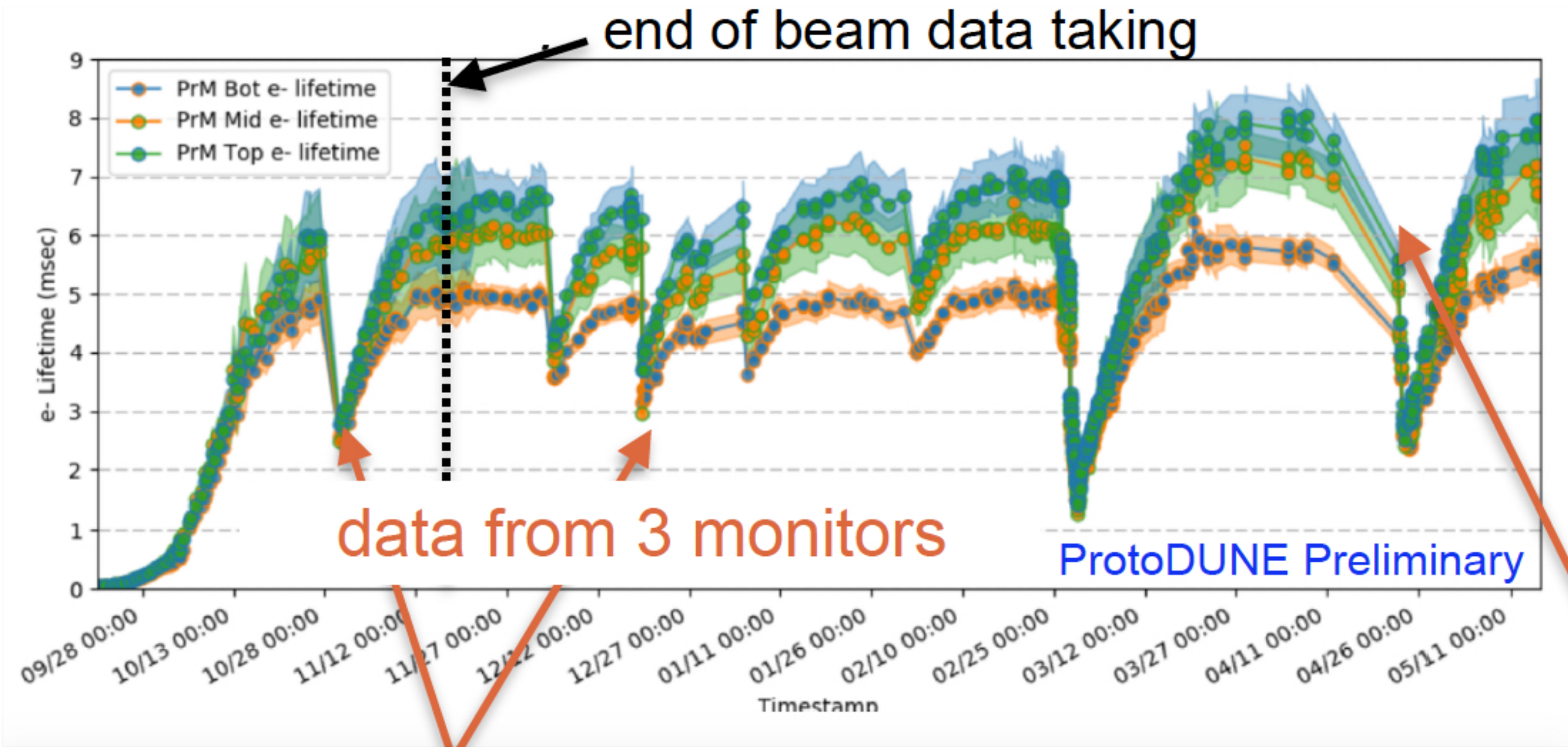


# ProtoDUNE-SP: LAr purity



**Demonstrated:**  $< \text{ppb}$  purity for necessary drift time

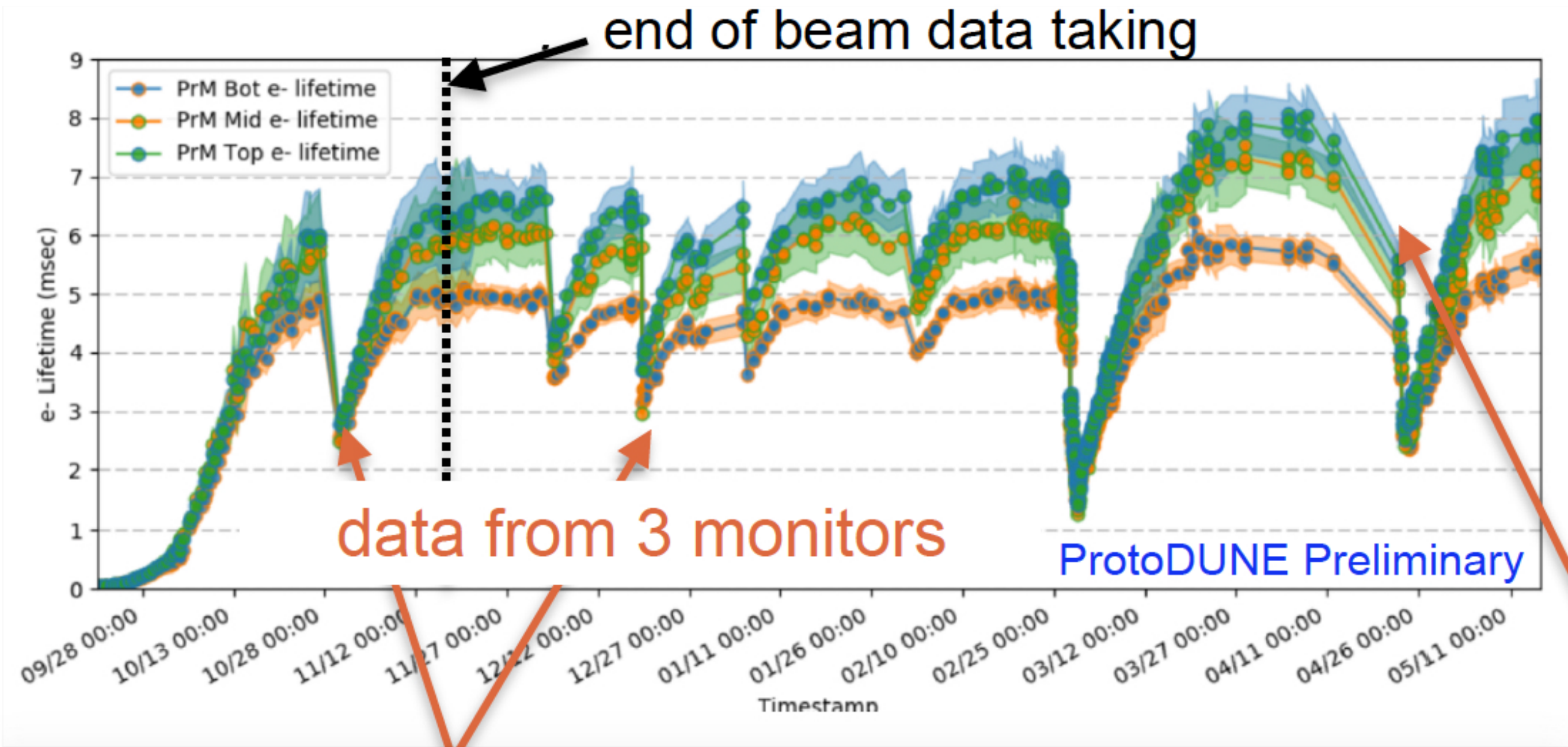
# ProtoDUNE-SP: LAr purity



**Early feedback:** saturation of  
O2 filter during filling, pump  
stoppages



# ProtoDUNE-SP: LAr purity



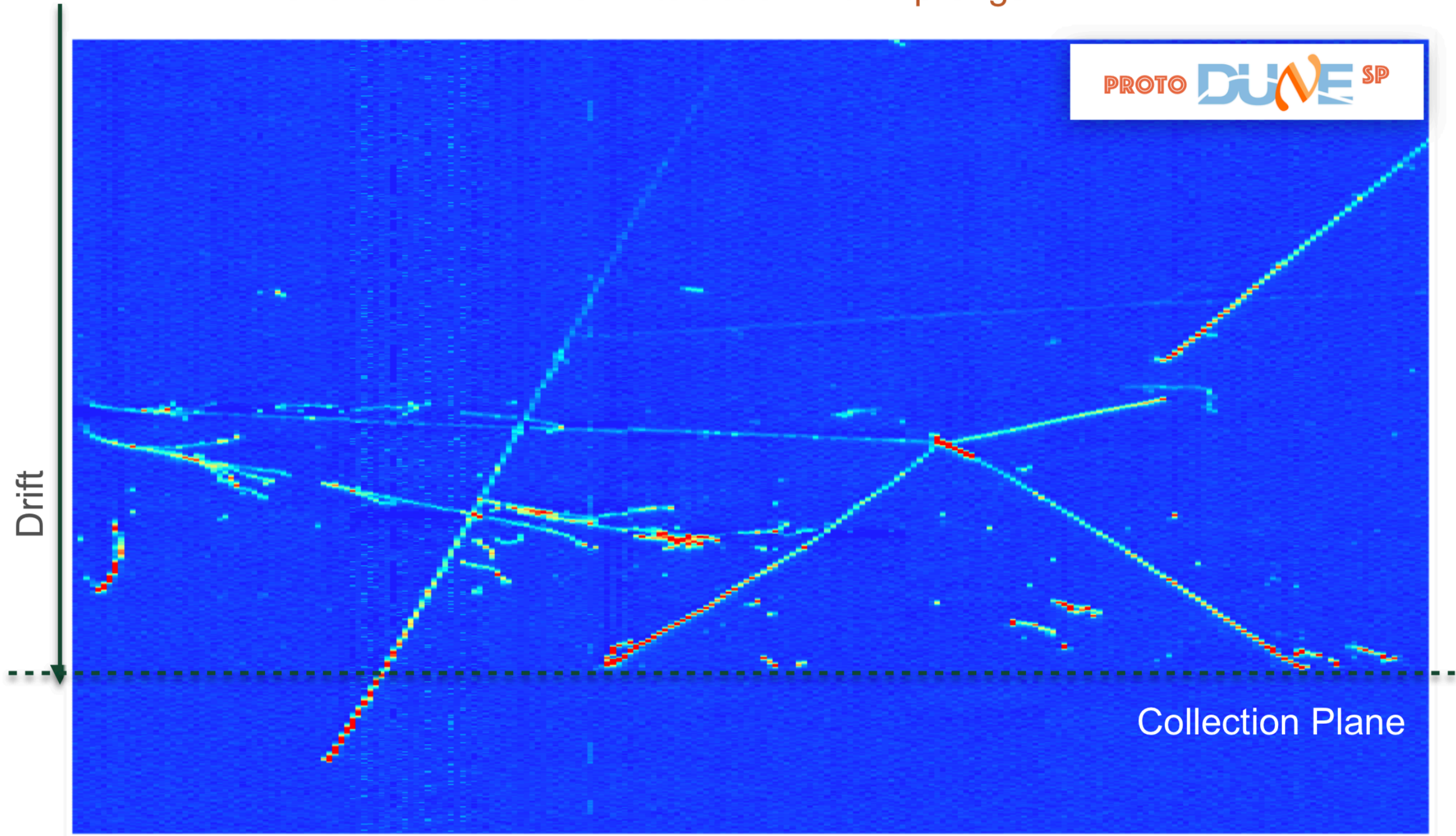
**Early feedback:** saturation of O2 filter during filling, pump stoppages

**saturation effects of monitor during stable running**

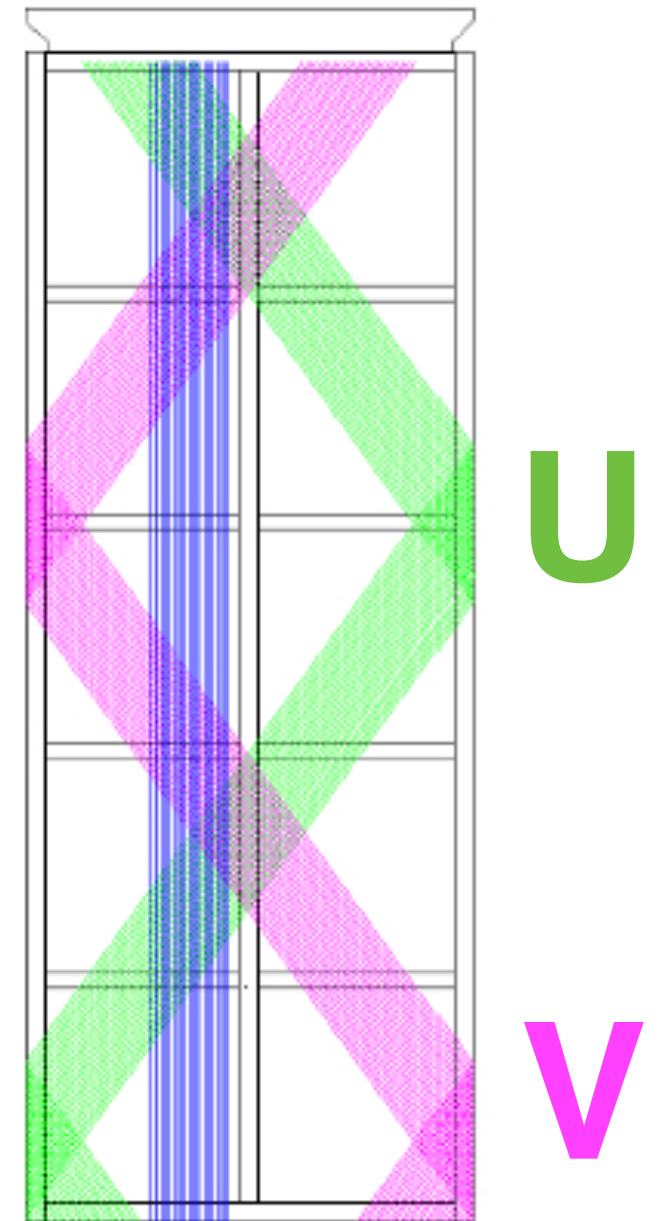
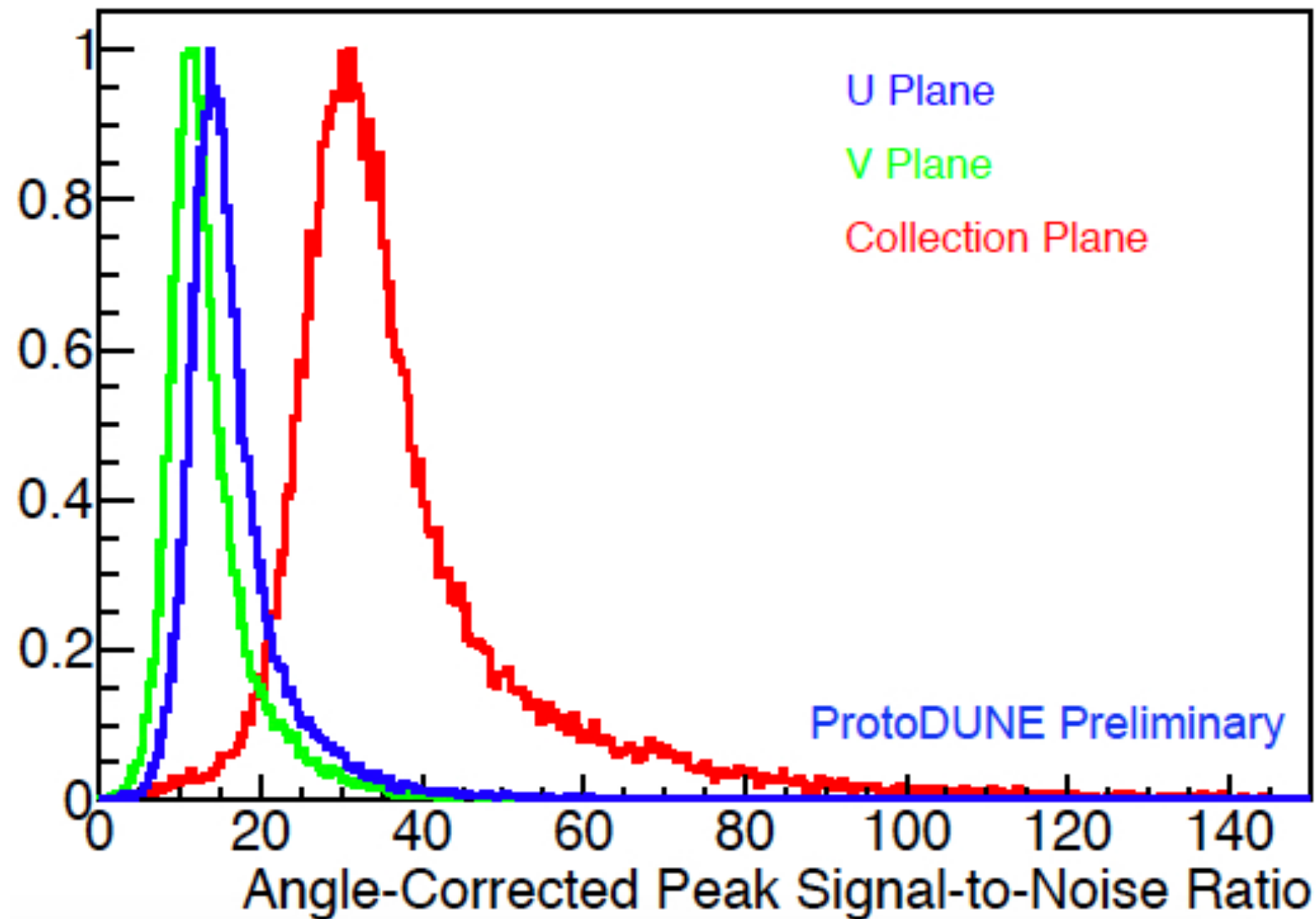


# ProtoDUNE-SP event display

2 EM showers and a Pion Interaction with 4 prongs



# ProtoDUNE-SP basic performance



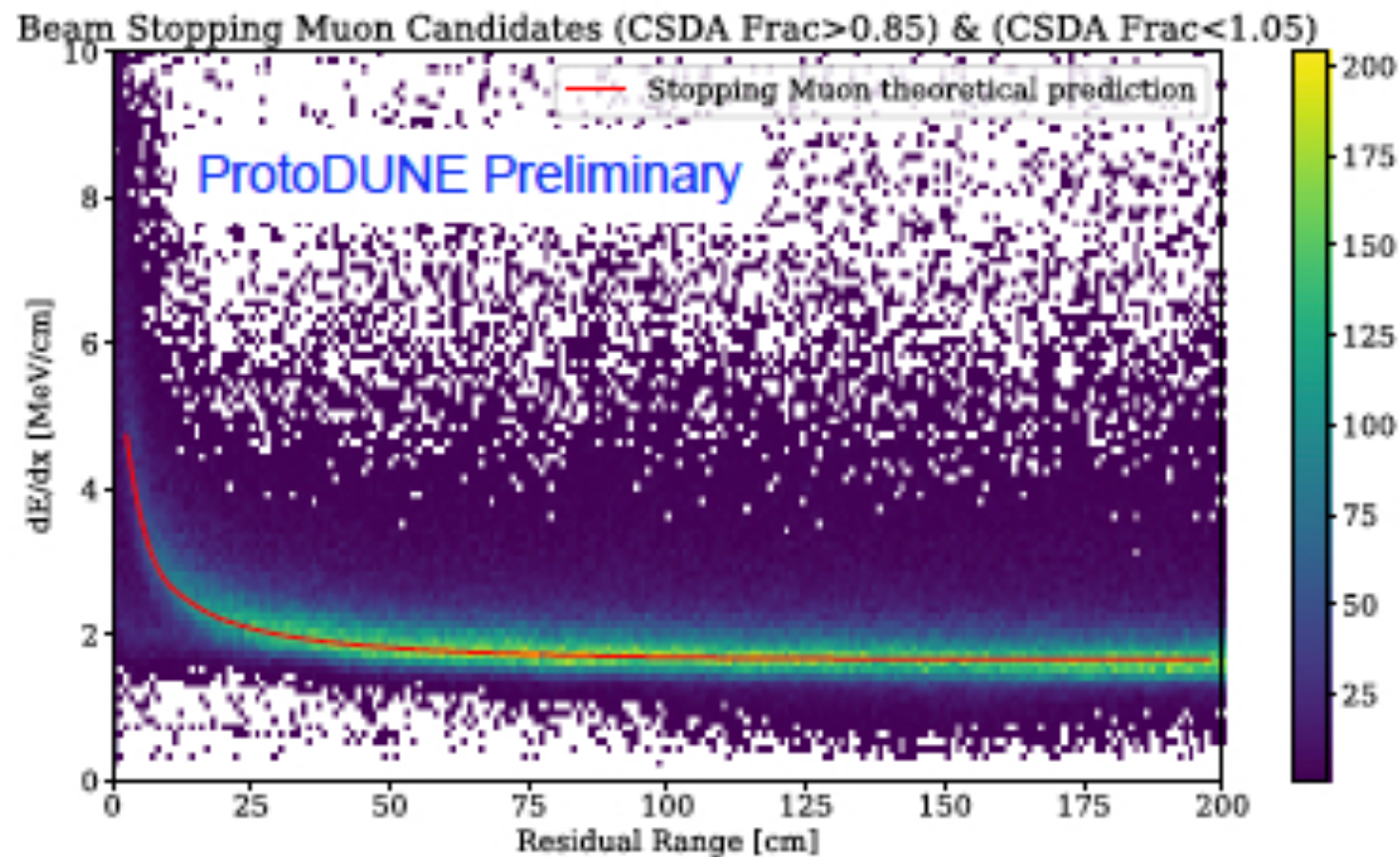
**Demonstrated:** excellent  
signal/noise ratio from cosmics

**Collection**

*Design: cold electronics*

*Construction: avoid ground loops*

# ProtoDUNE-SP basic performance



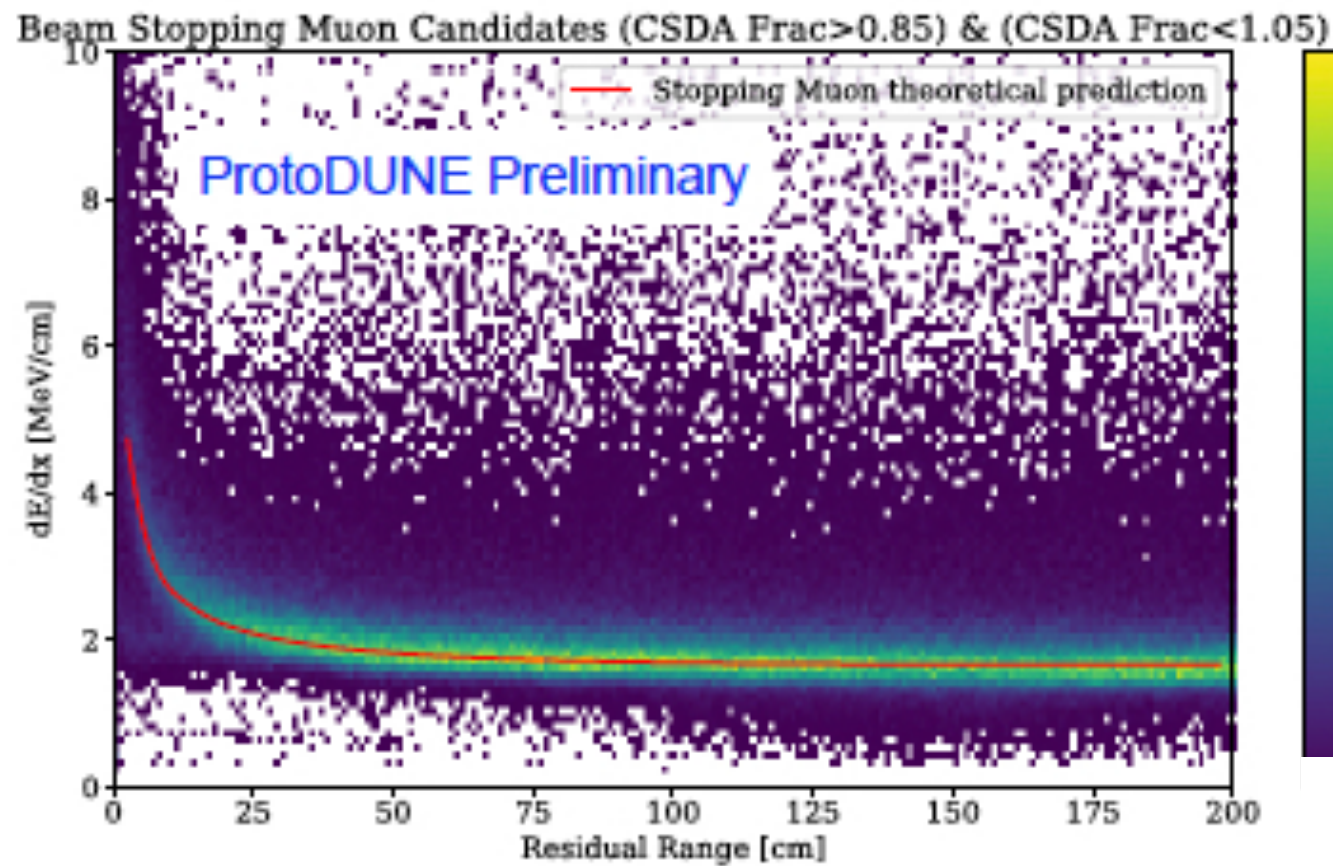
Bethe-Bloch prediction

beam  $\mu$

**Demonstrated:** Energy  
loss response for muons  
(and beam protons)



# ProtoDUNE-SP basic performance

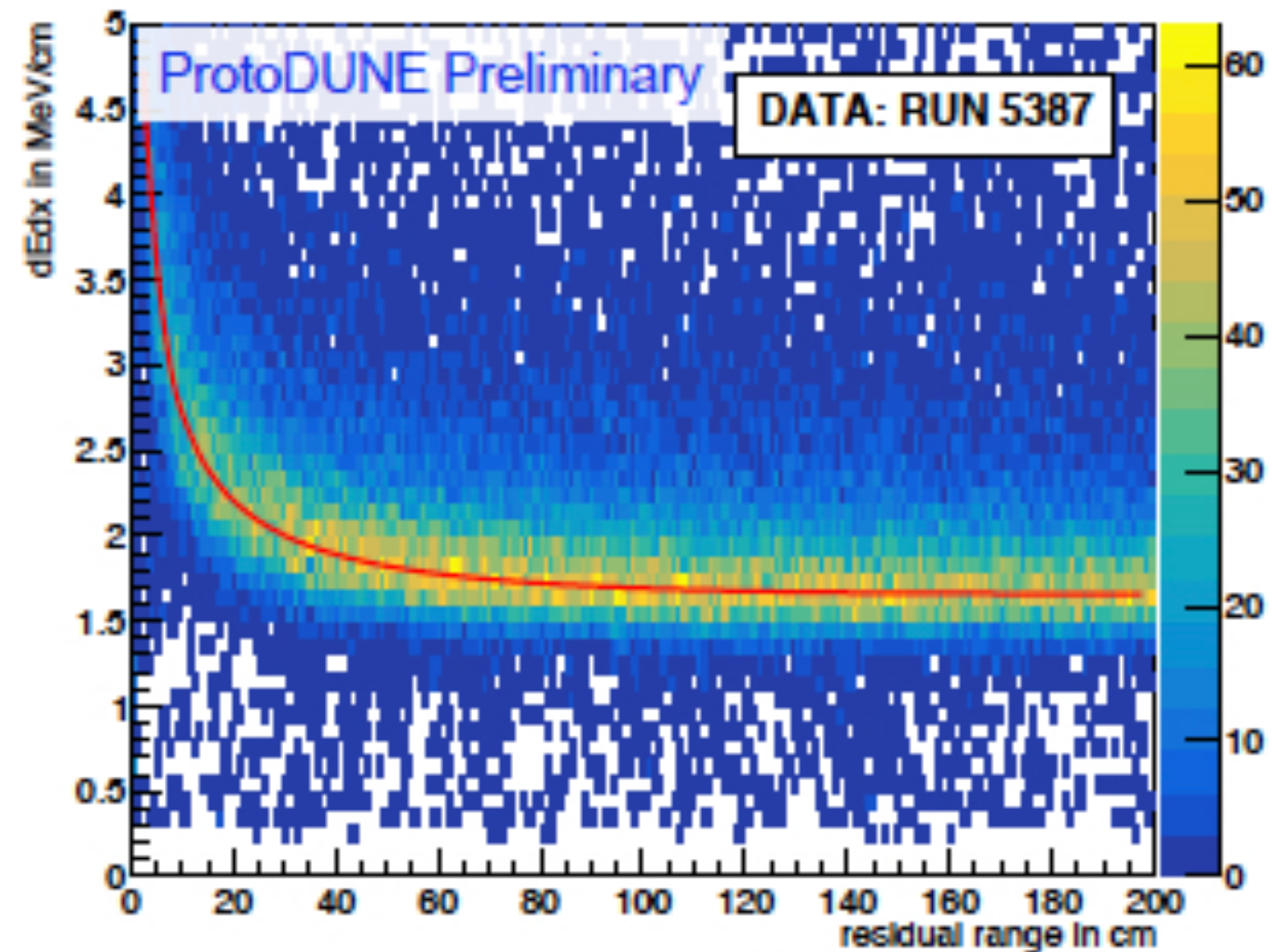


Bethe-Bloch prediction

cosmic  $\mu$

beam  $\mu$

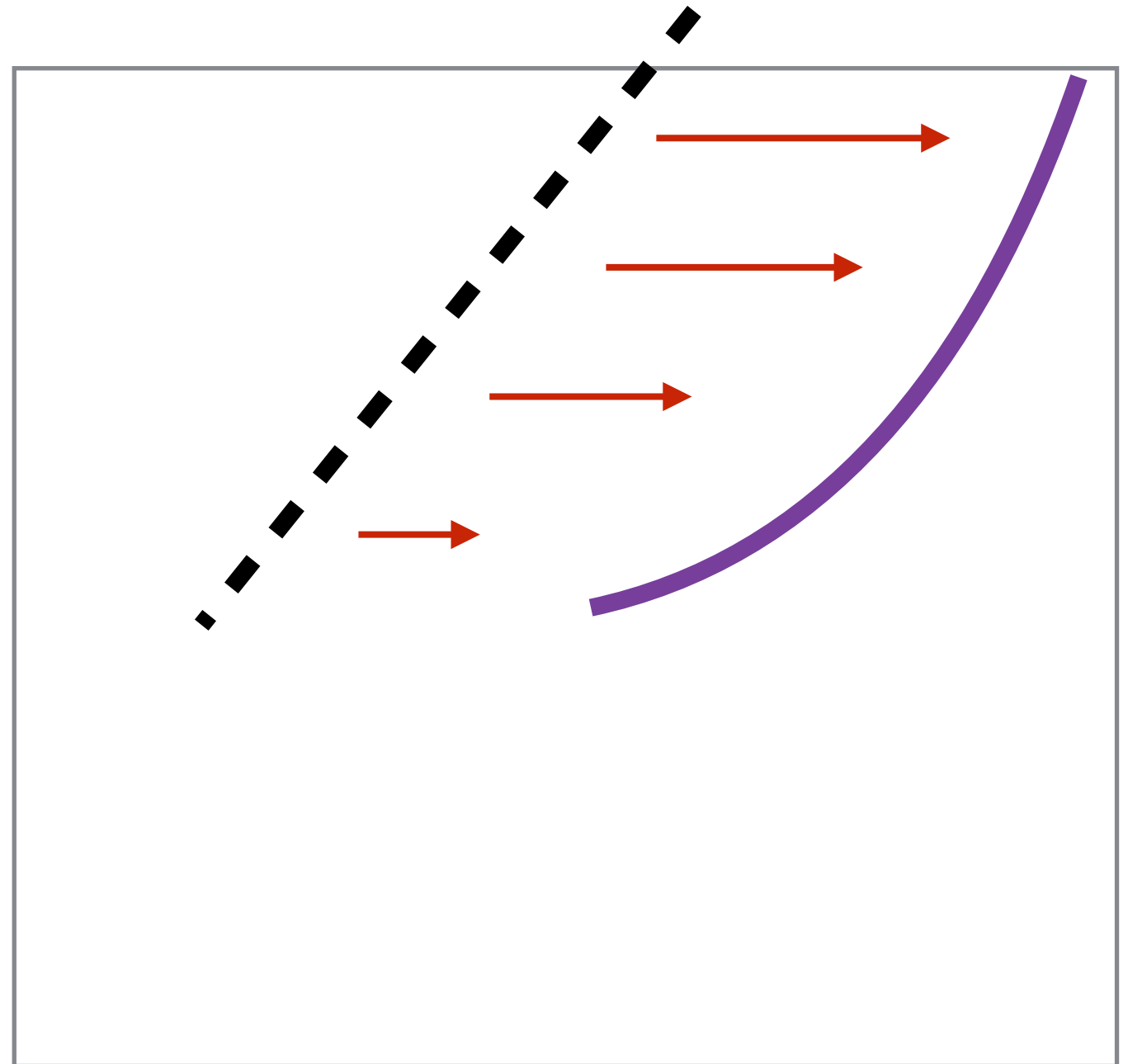
**Demonstrated:** Energy loss response for muons (and beam protons)



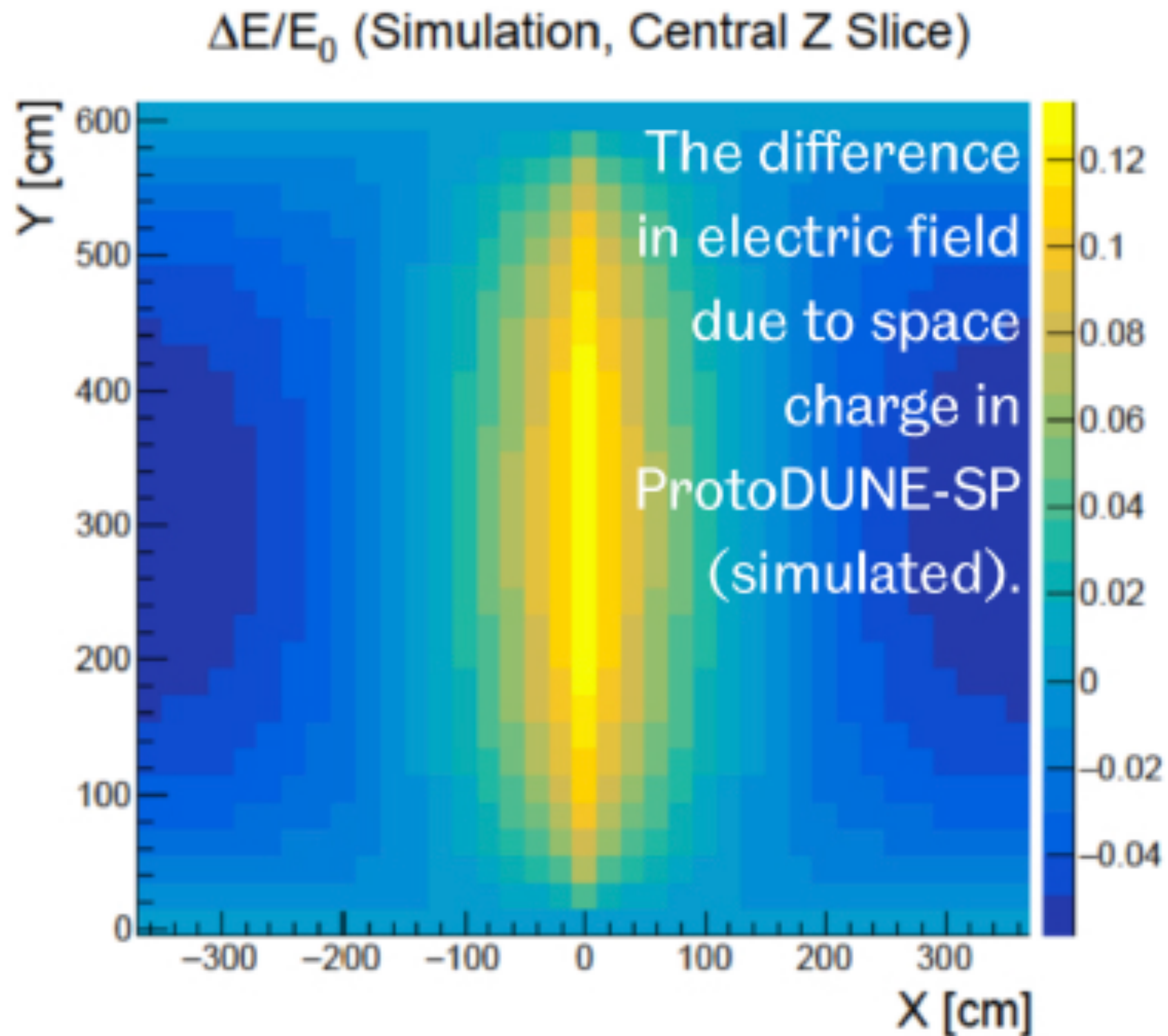
# Interlude: space charge

Accumulation of ions results in  
a **local E field** and **distorted**  
**tracks**

Produced in surface detectors



# ProtoDUNE-SP basic performance



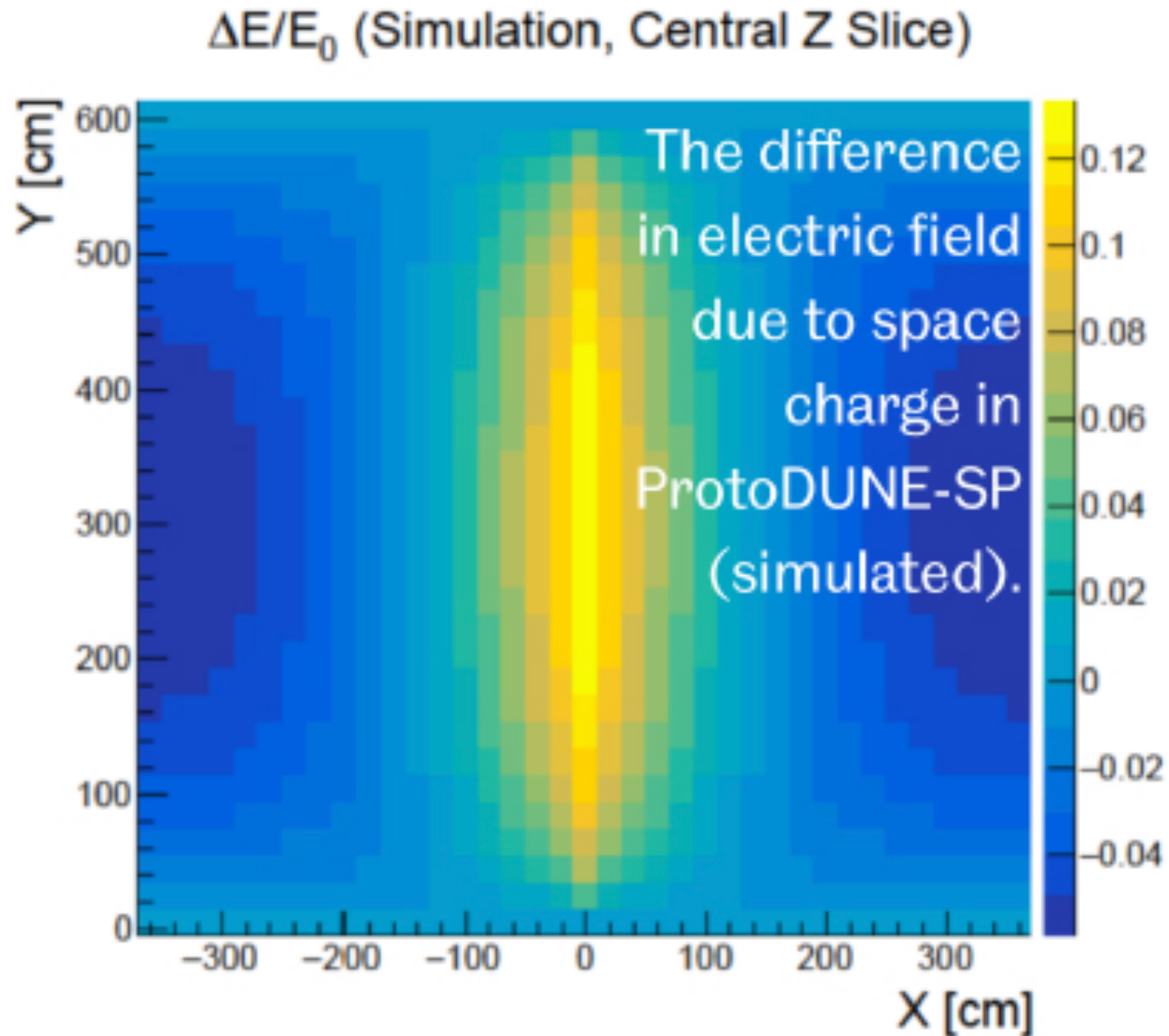
Electric field distortions due to ion flow ('space charge')



# ProtoDUNE-SP basic performance

## Opportunity in prototype:

Develop methodology to detect and mitigate detector effects



Electric field distortions due to ion flow ('space charge')

# DUNE future

ProtoDUNE-II (SP/DP) after CERN Long Shutdown (2021)

- Upgrade detector elements, additional beam data, test calibration systems



# DUNE future

ProtoDUNE-II (SP/DP) after CERN Long Shutdown (2021)

- Upgrade detector elements, additional beam data, test calibration systems

~2026 timeline to start operation

- far site pre-excavation underway
- Timeline will be finalized when international project is baselined





# DUNE future

ProtoDUNE-II (SP/DP) after CERN Long Shutdown (2021)

- Upgrade detector elements, additional beam data, test calibration systems

~2026 timeline to start operation

- far site pre-excavation underway
- Timeline will be finalized when international project is baselined

Technical Design Report submitted to two independent, international oversight committees





**1106 collaborators from 184 institutions in 31 countries**



# Backup