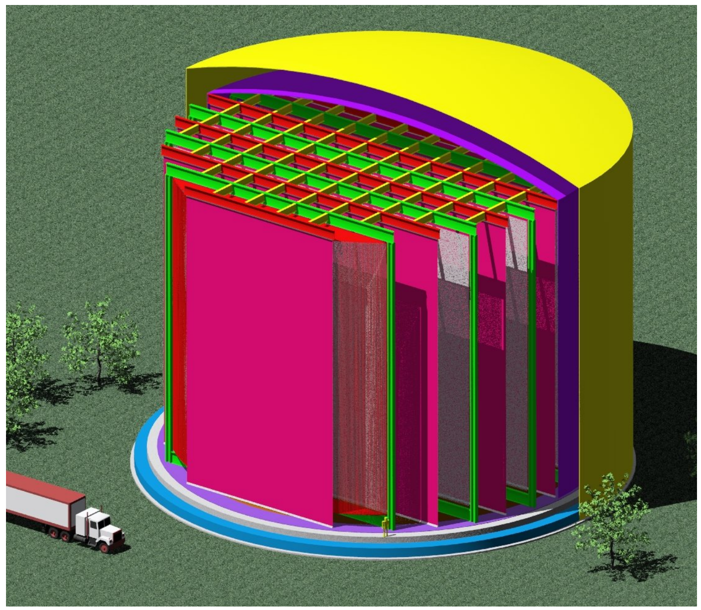
Light Detection in Liquid Argon Time Projection Chambers (LArTPCs)



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arXiv:1101.3013v1 [physics:ins-det]

Outline

LArTPCs

- Motivation
- Goals

MicroBooNE

- A LArTPC to being built at Fermilab
- Detection: Wire chamber + light detection

Light detection

- Creation of light in the detector
- Detection Challenges
- R&D at MIT: Plates and Lightguides

LArTPC – Motivation

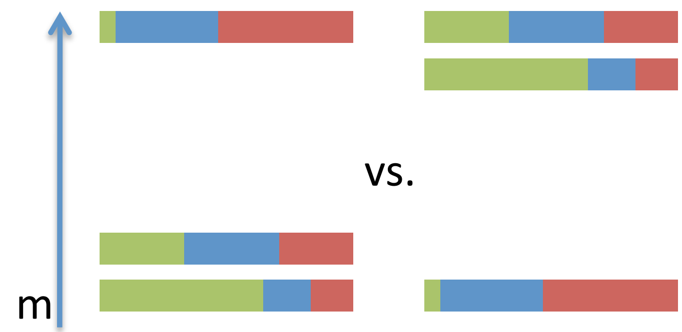
Important measurements to make in neutrino sector

θ_{13}

CP violation

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} c_{13}c_{12} & c_{13}s_{12} & s_{13}e^{-i\delta} \\ -c_{23}s_{12} - s_{13}s_{23}c_{12}e^{i\delta} & c_{23}c_{12} - s_{13}s_{23}s_{12}e^{i\delta} & c_{13}s_{23} \\ s_{23}s_{12} - s_{13}c_{23}c_{12}e^{i\delta} & -s_{23}c_{12} - s_{13}c_{23}s_{12}e^{i\delta} & c_{13}c_{23} \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

Mass hierarchy



To answer these questions, we need *many* fine-grain measurements of neutrino interactions.

LArTPC – Motivation

Liquid Argon (LAr)

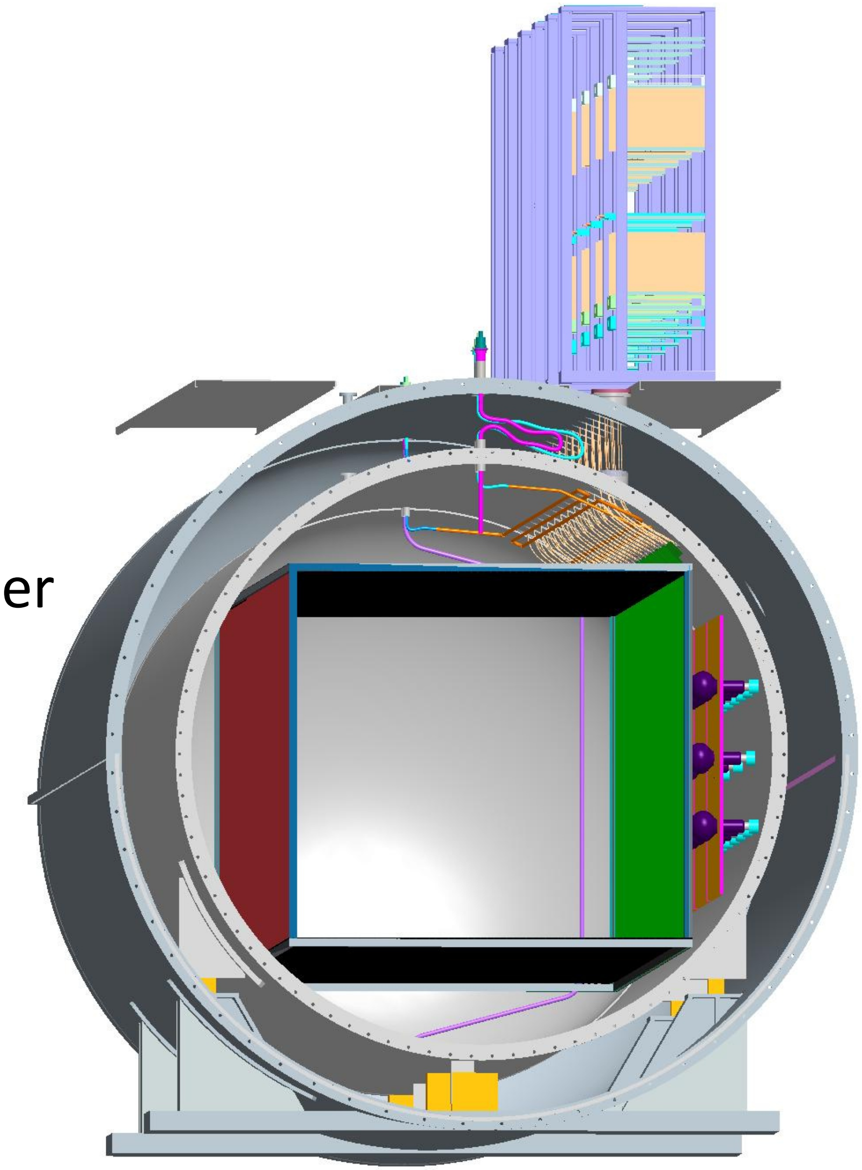
Dense, inert and relatively inexpensive.

Time Projection Chamber (TPC)

Light Detection + Wire Chamber

+ Reconstruct charged particle tracks
+ High resolution

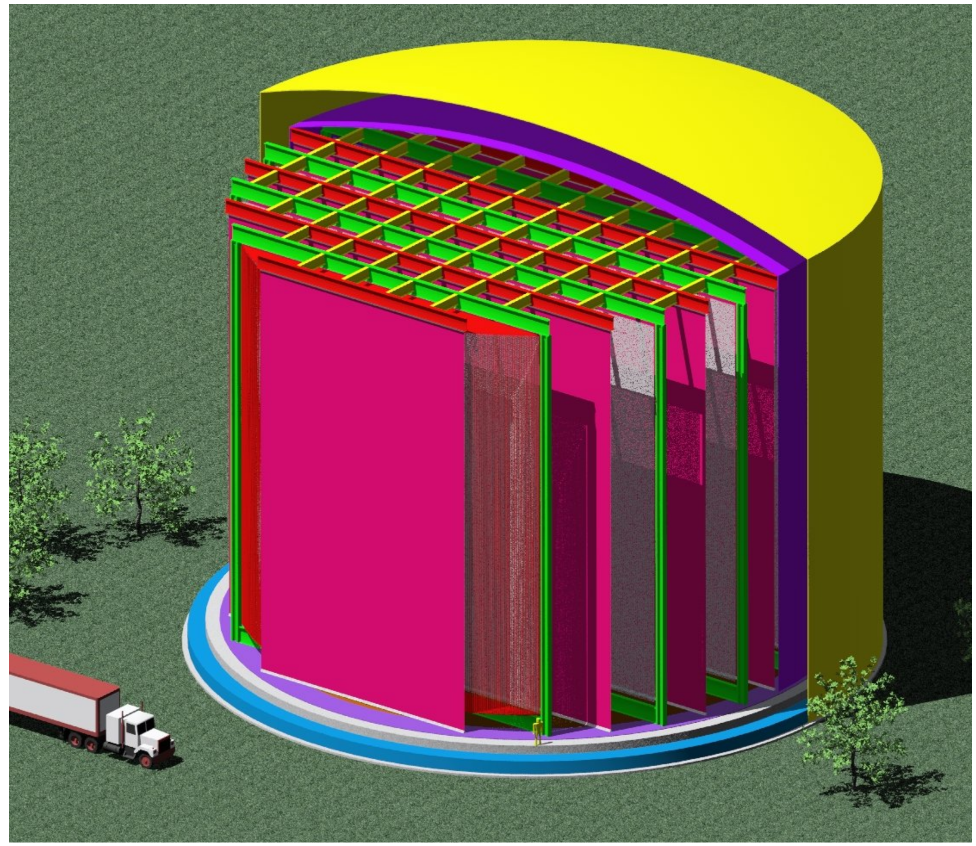
Economically Scalable



LArTPC – Goals

GOAL: 50 kiloton detector

MicroBooNE is part of a research program to achieve this goal.



Challenges:

+ Purity of Argon
+ Cold electronics (80 K)
+ Scalability

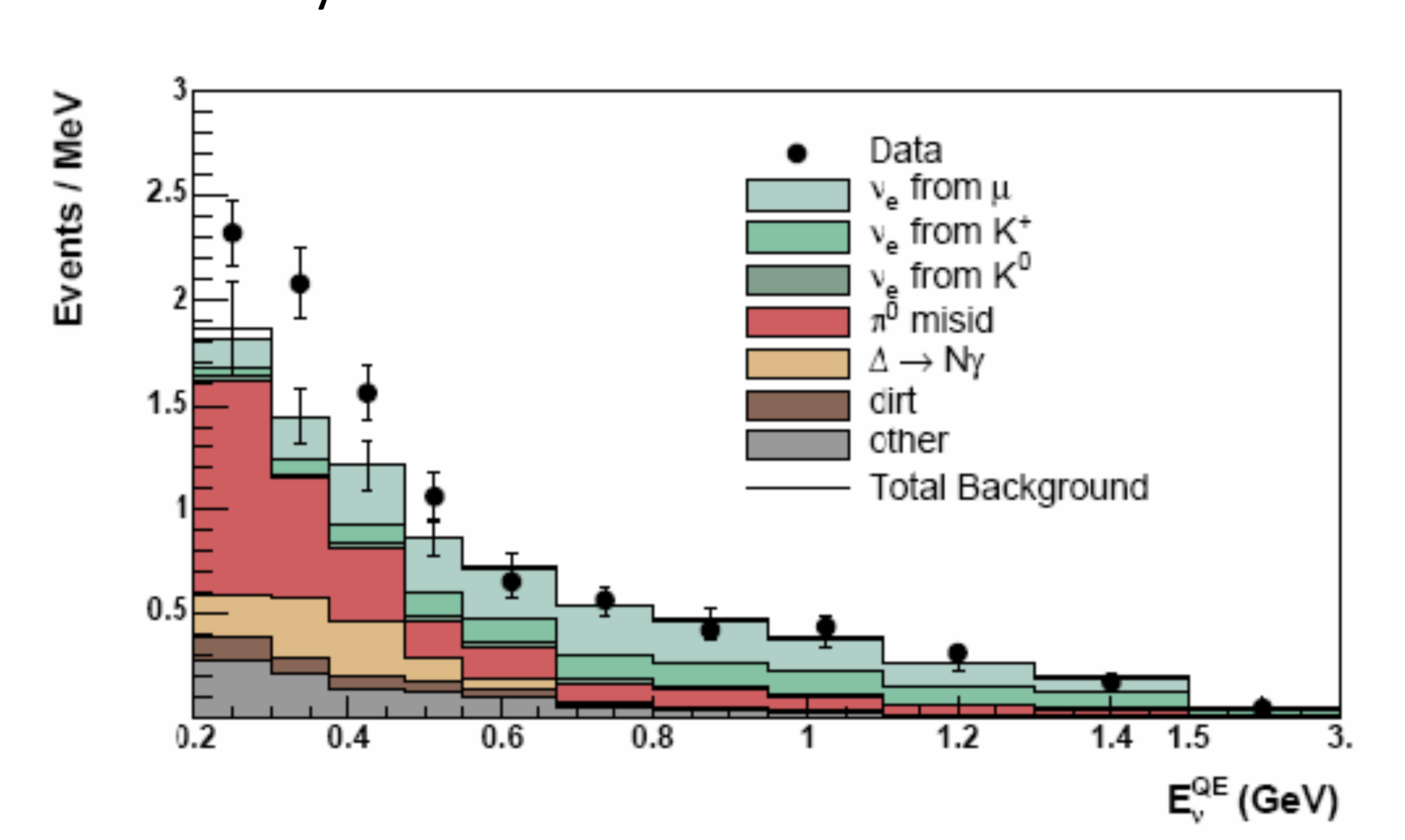
MicroBooNE

Measure neutrino cross-sections in liquid argon

Investigate low-energy excess measured by MiniBooNE

MicroBooNE can differentiate between low energy e and $\gamma \to e^+e^-$ events.

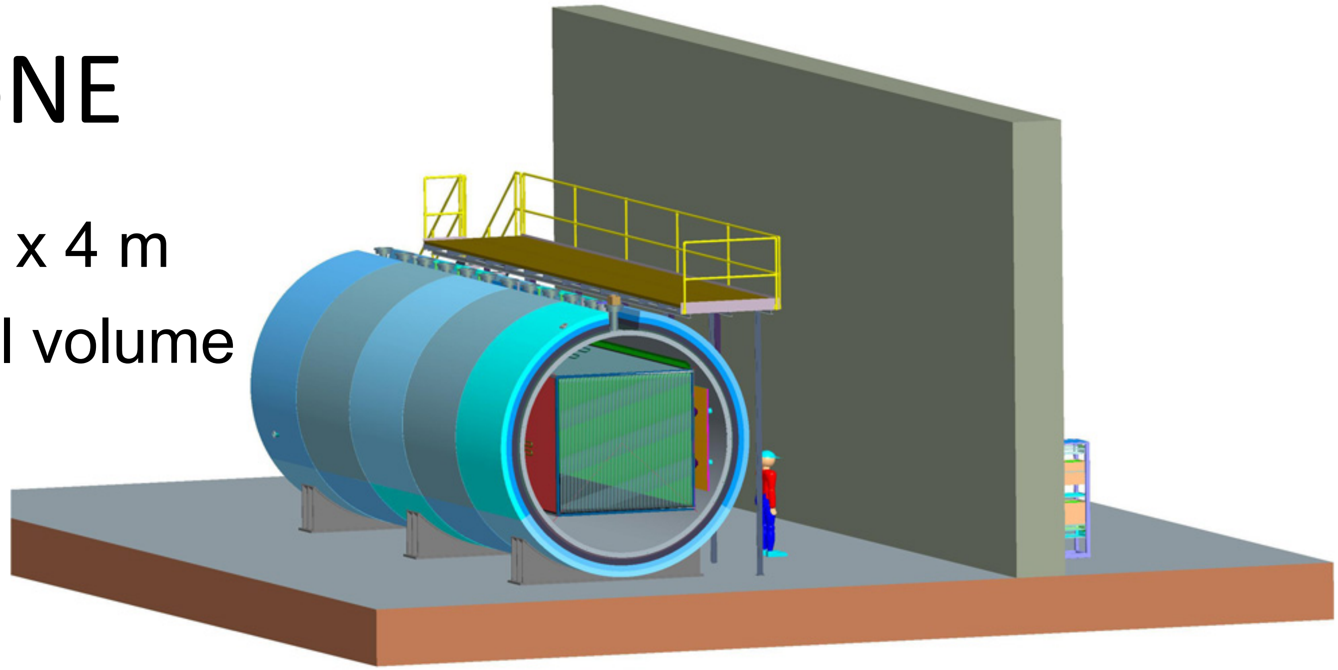
MiniBooNE cannot.

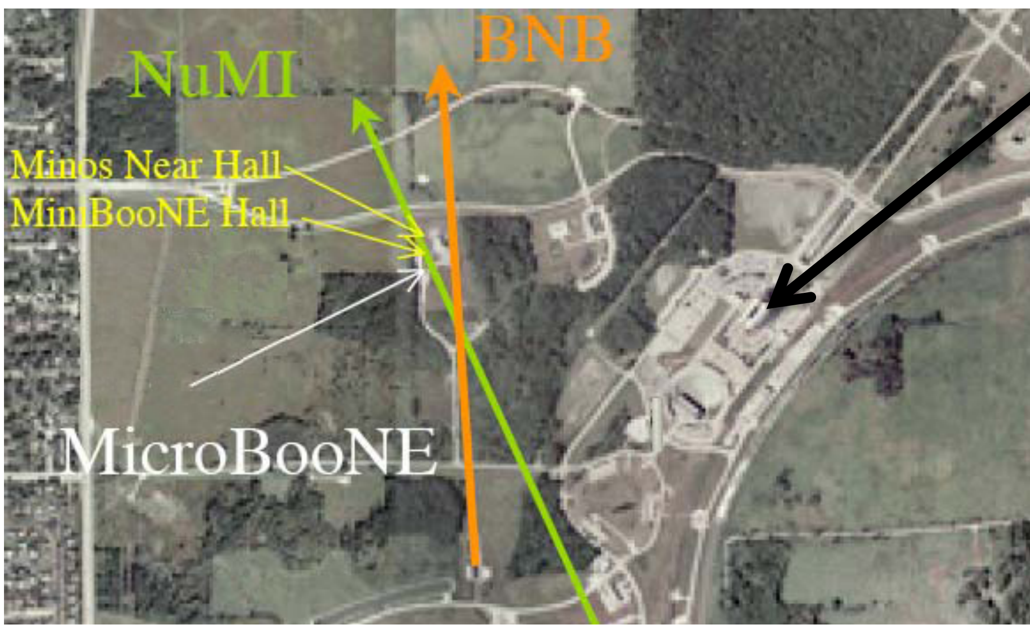


MicroBooNE

Cryostat: 12 m x 4 m

~70 ton fiducial volume

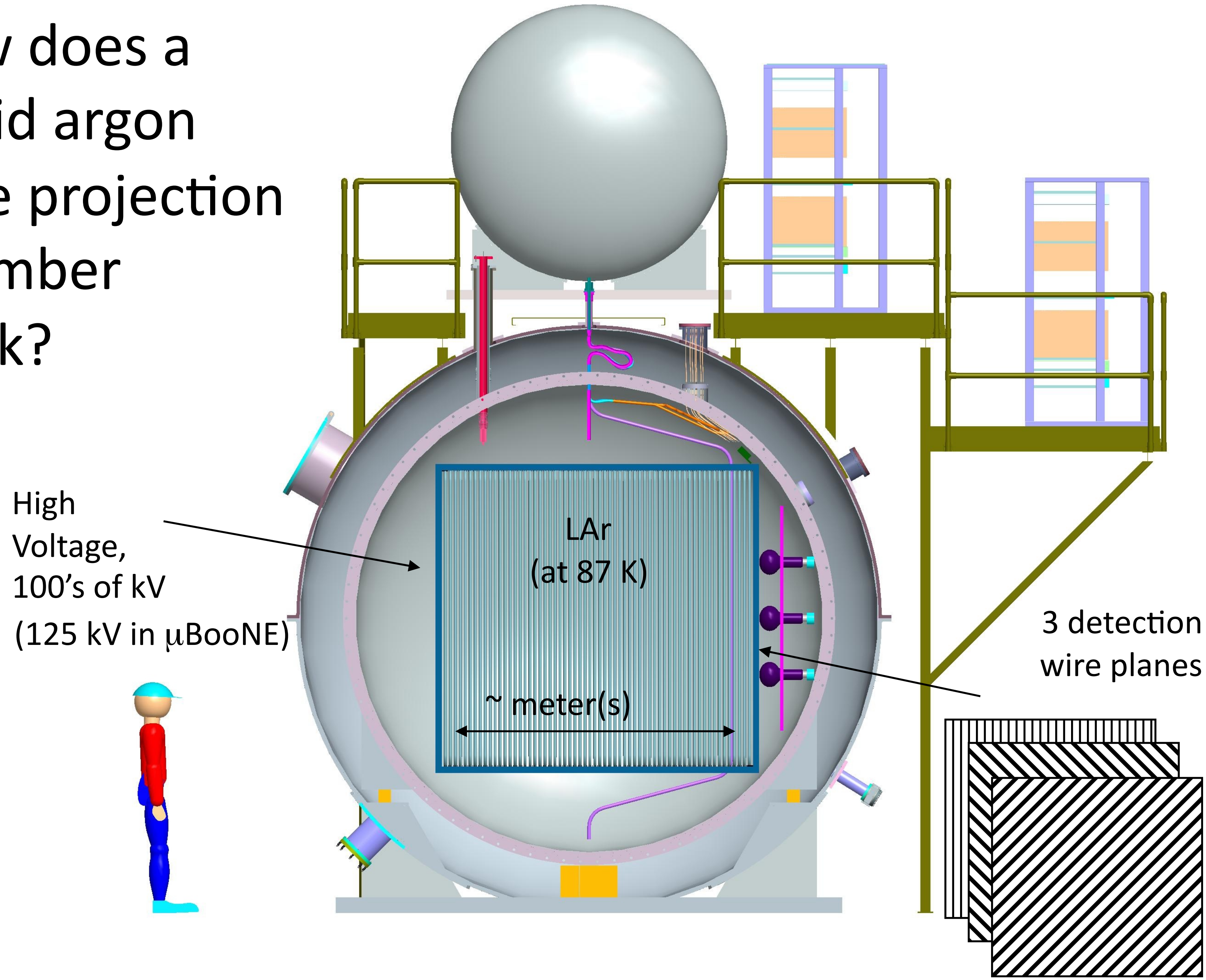


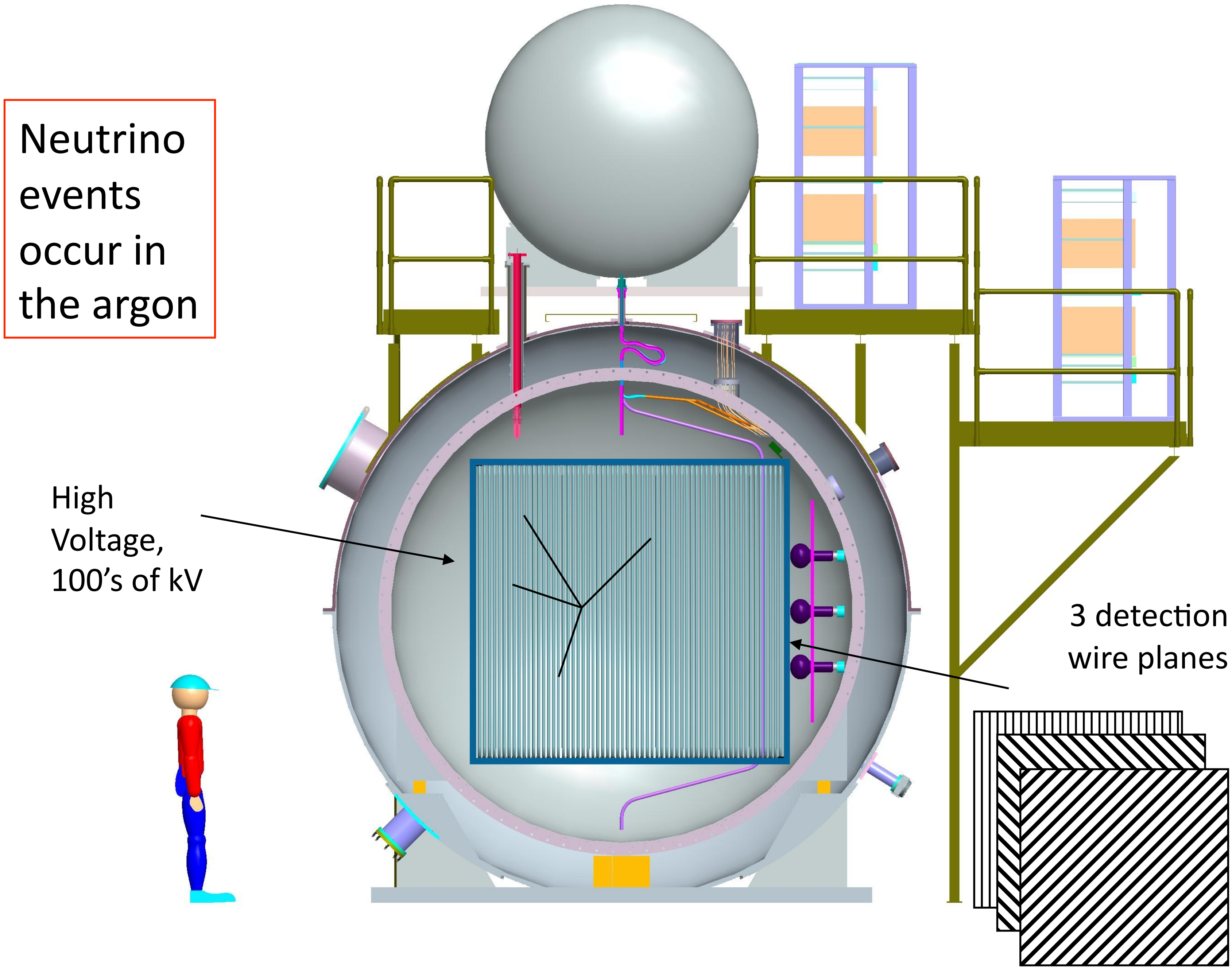


You are here.

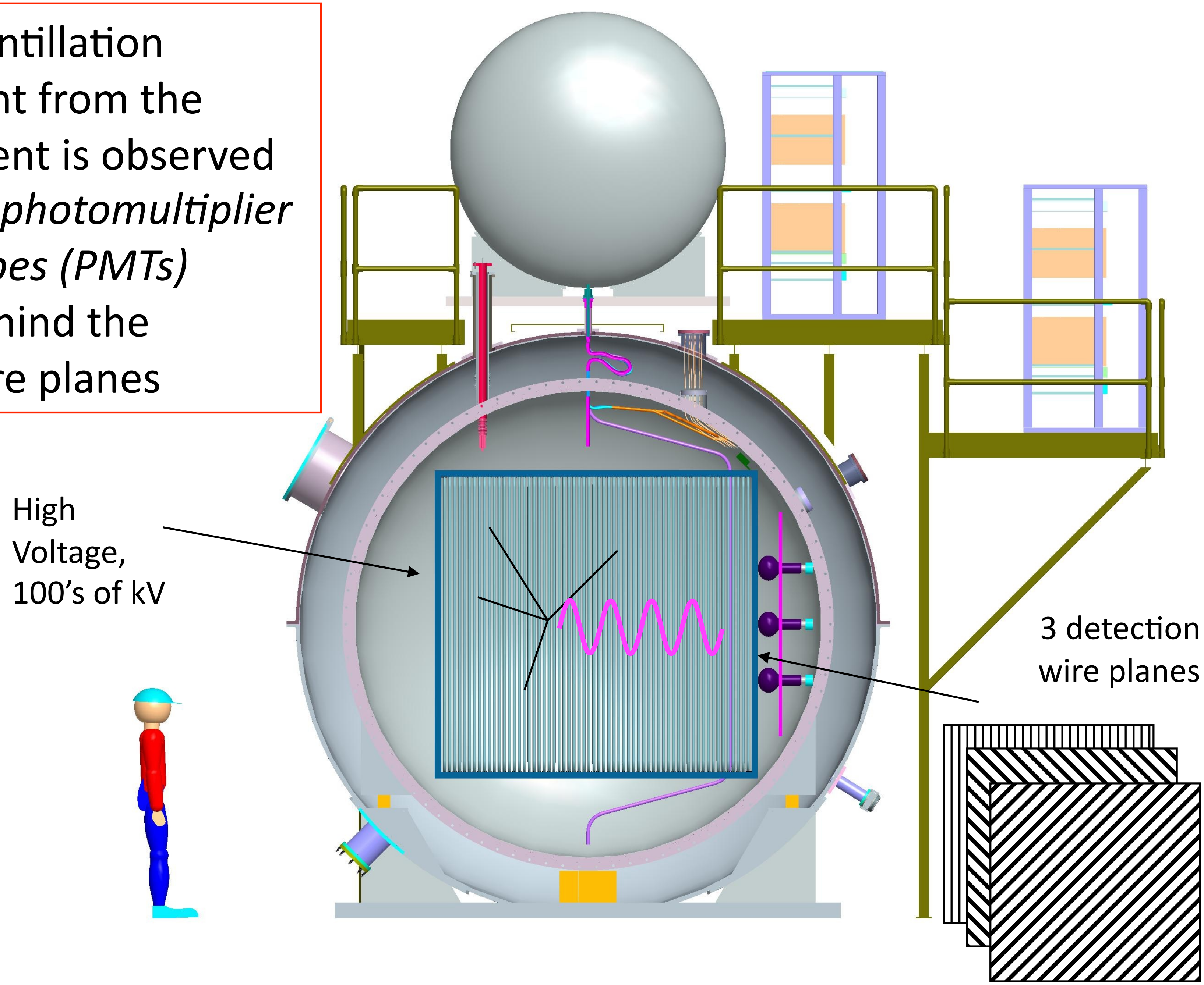
Measure events from Booster and NuMI beams

How does a liquid argon time projection chamber work?

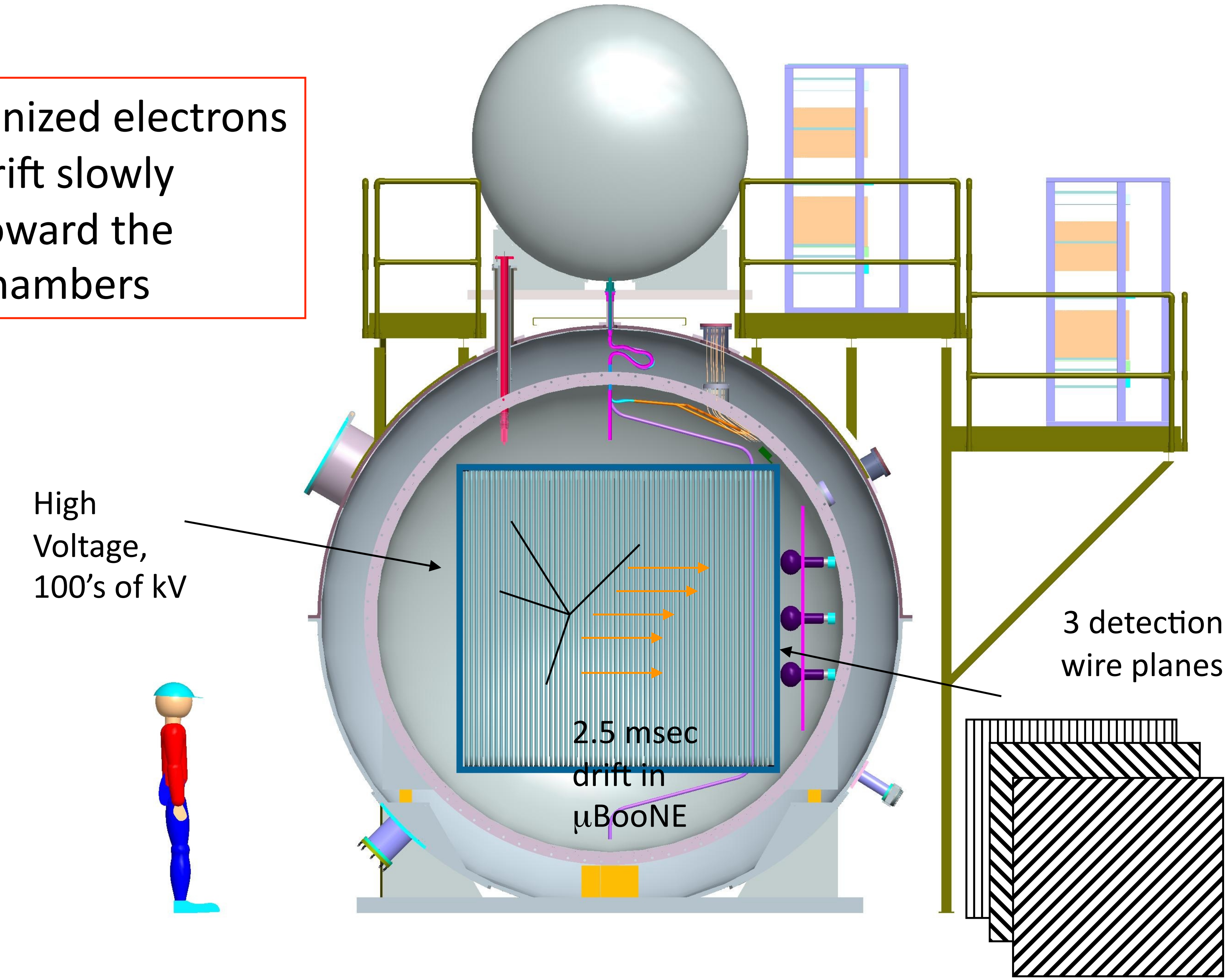



Neutrino events occur in the argon
High Voltage, 100's of kV
3 detection wire planes

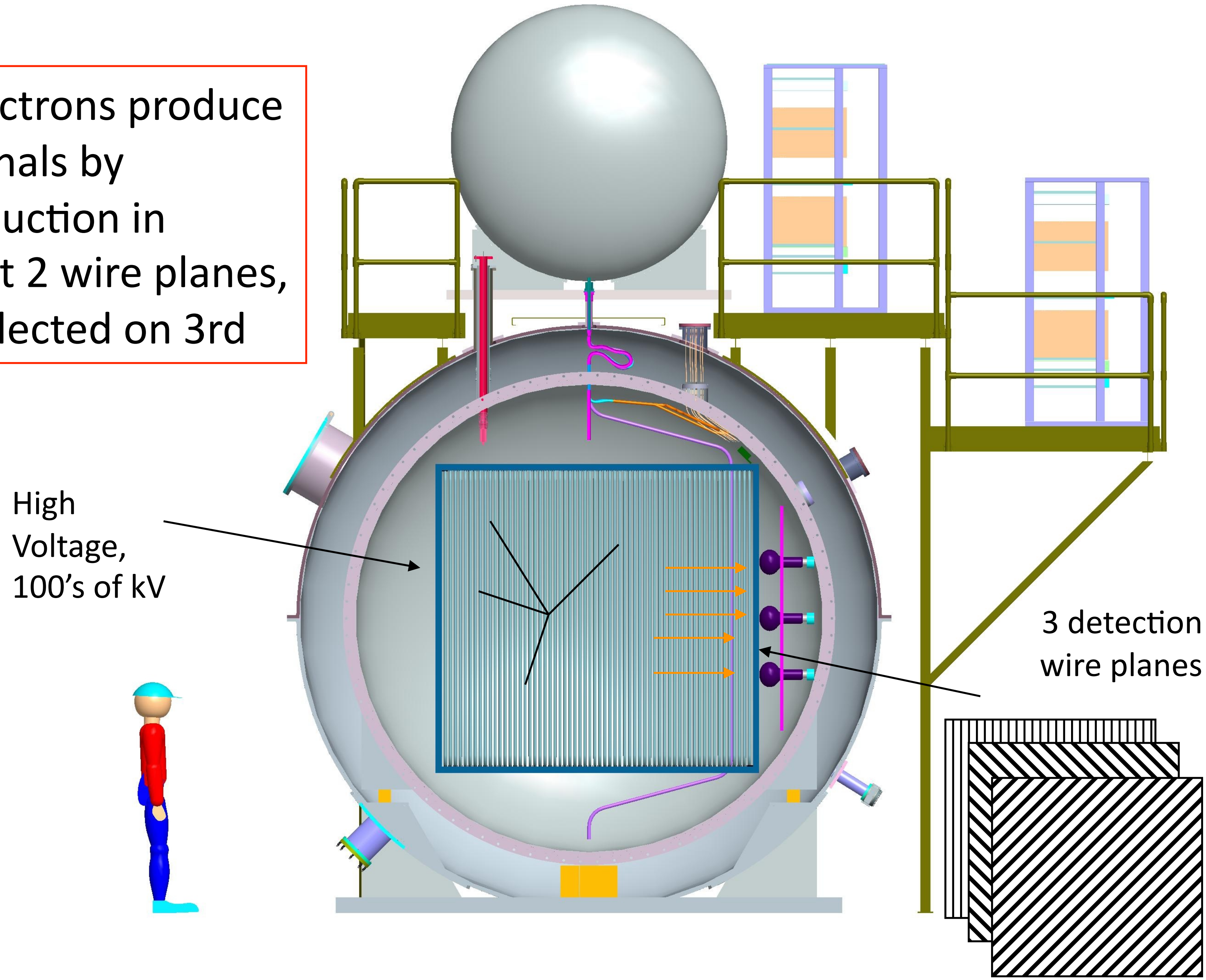
Scintillation light from the event is observed by *photomultiplier tubes (PMTs)* behind the wire planes



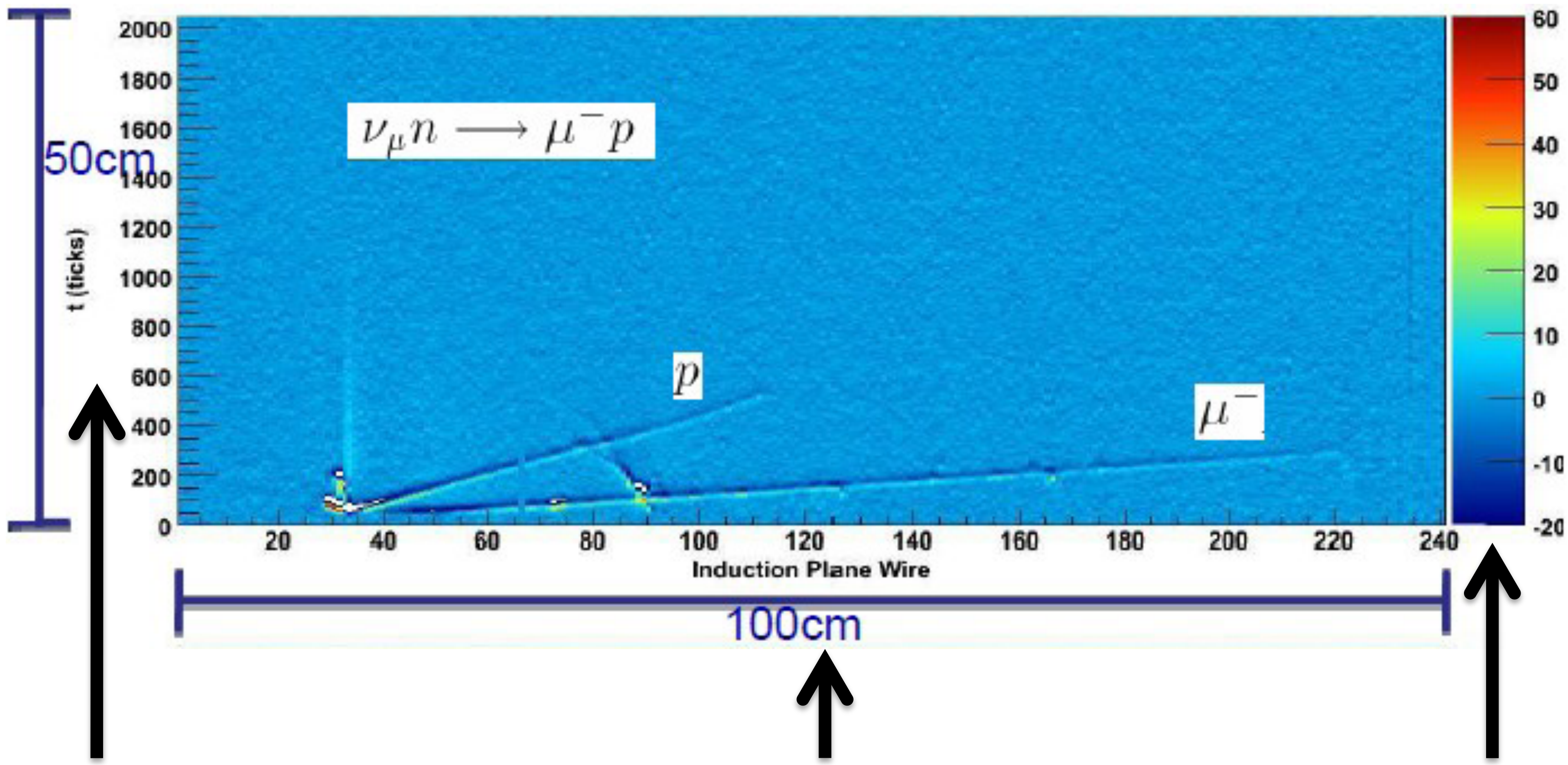
Ionized electrons drift slowly toward the chambers



Electrons produce signals by induction in first 2 wire planes, collected on 3rd



Example: Event in ArgoNeut

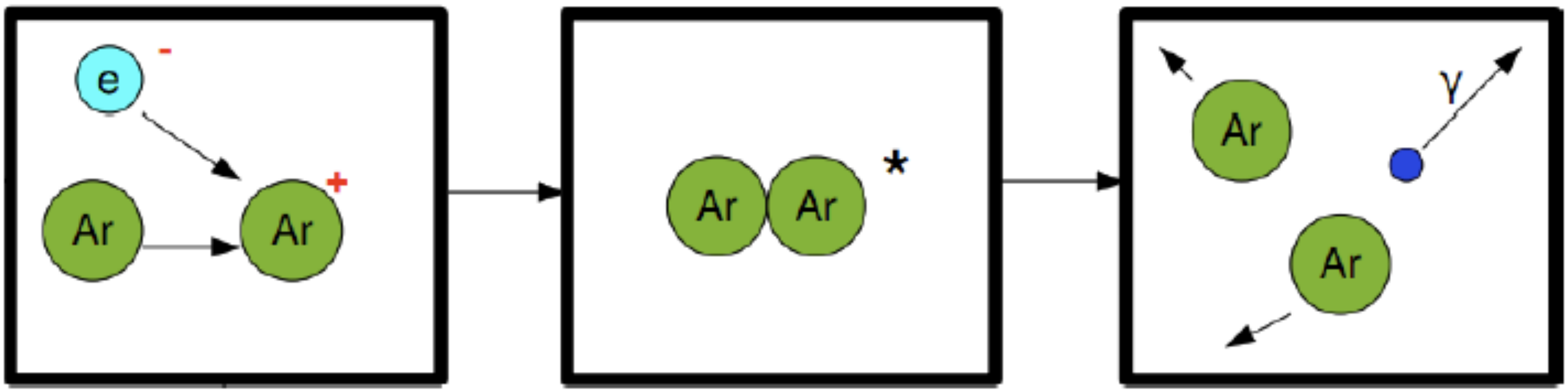


Time
Distance from detection wires

Wire
z coordinate in chamber

# of Drift electrons
Energy deposited in chamber

Light Detection Challenges



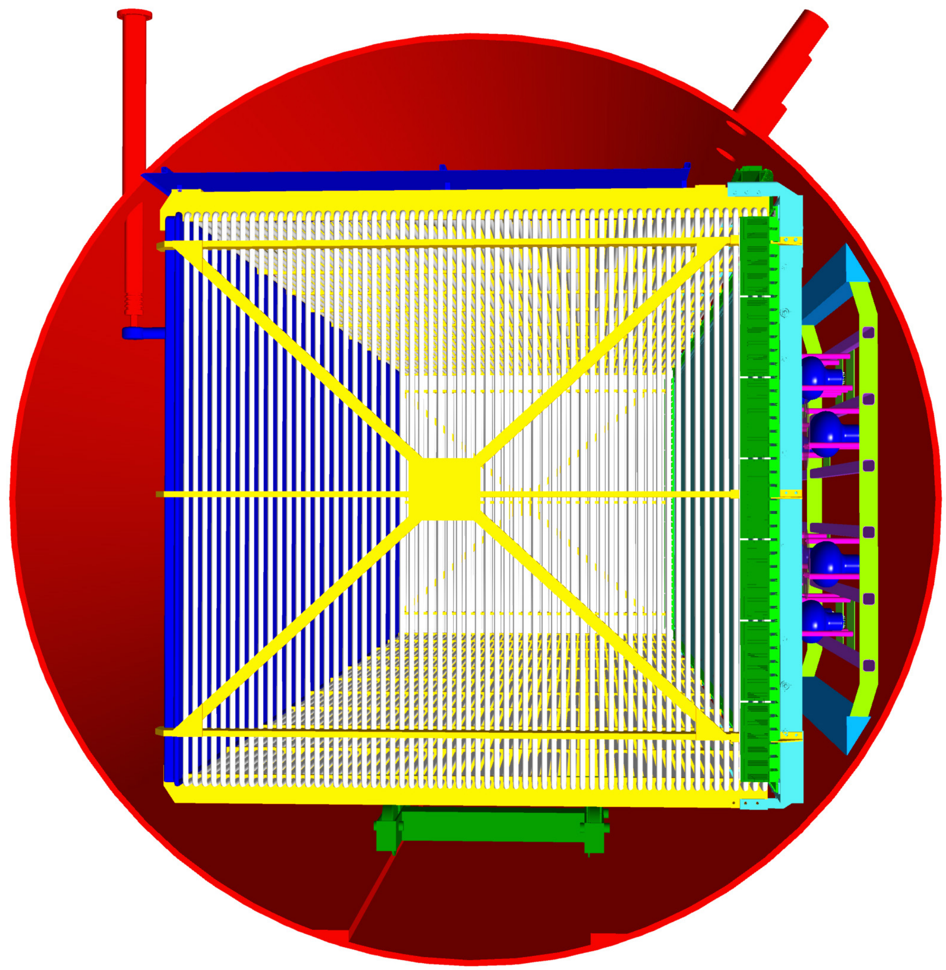
+ Light is created through bonding and separation of argon dimers.
+ Light created at 128 nm (UV)
+ Glass of **PMTs** is **opaque to UV**.

$\Rightarrow$ *Need to **shift UV light** to visible light to detect with PMTs*

Light Detection Challenges

+ PMTs are sensitive to electric fields used by wire chamber
+ PMTs can only be in zero field region of detector
+ Reduces available light coverage

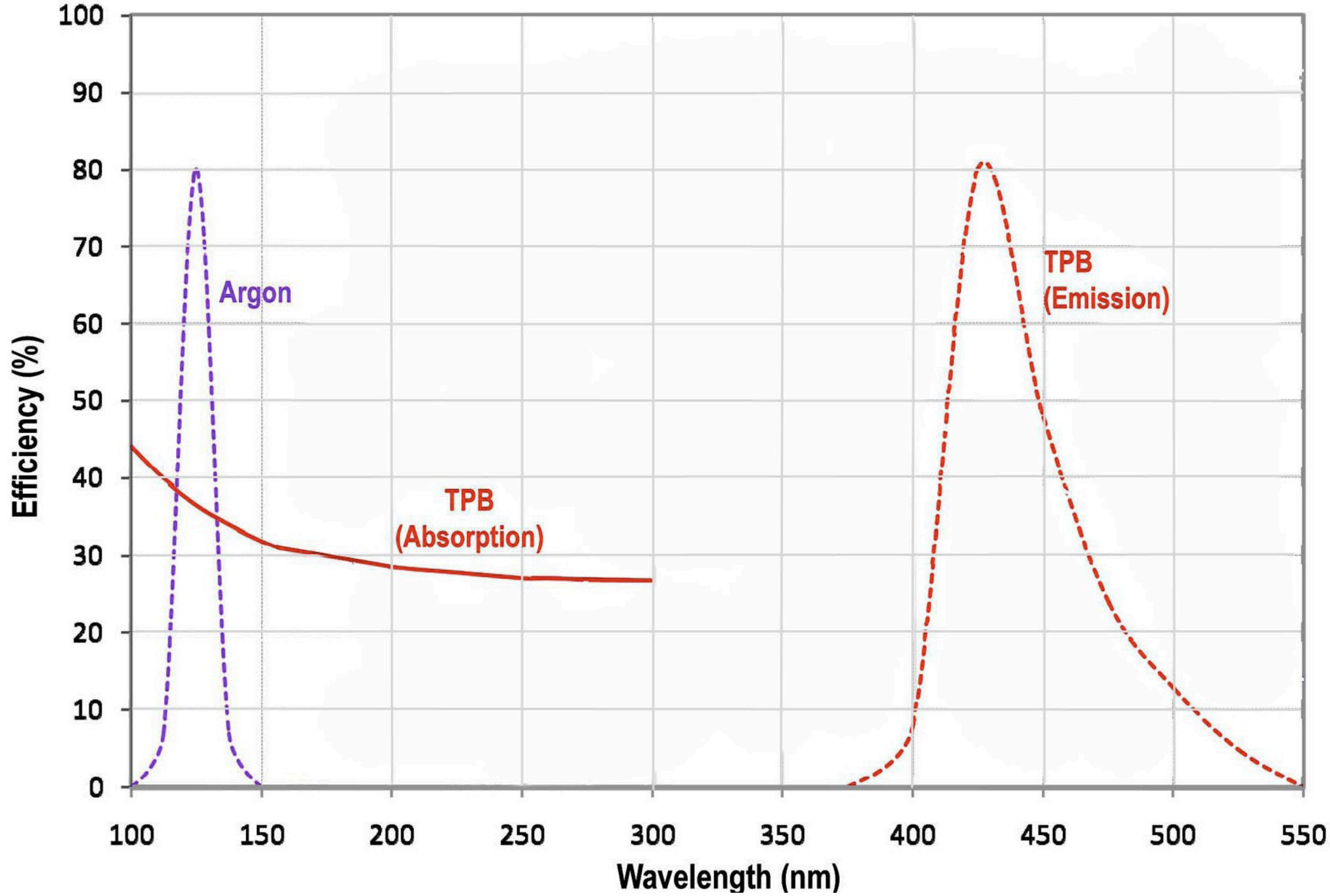
⟹ *Need to* ***increase coverage*** *for larger detectors.*



Shifting Light

TPB (Tetraphenyl butadiene) – wavelength shifter

Absorbs UV light and emits blue light

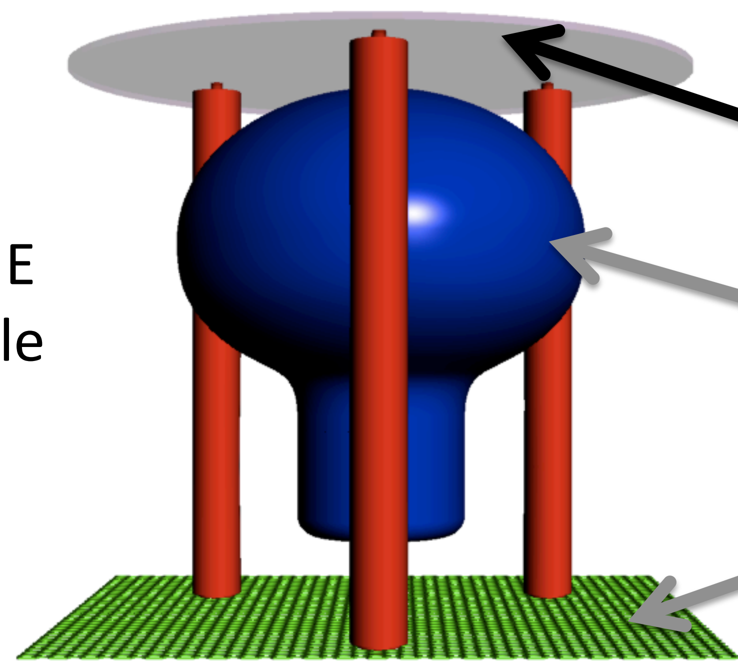


Light Detection – Plates (MicroBooNE)

+ Acrylic plates coated with TPB and polystyrene
+ Incident UV light is remitted as blue light.
+ Plates coated with 50% TPB and 50% polystyrene.

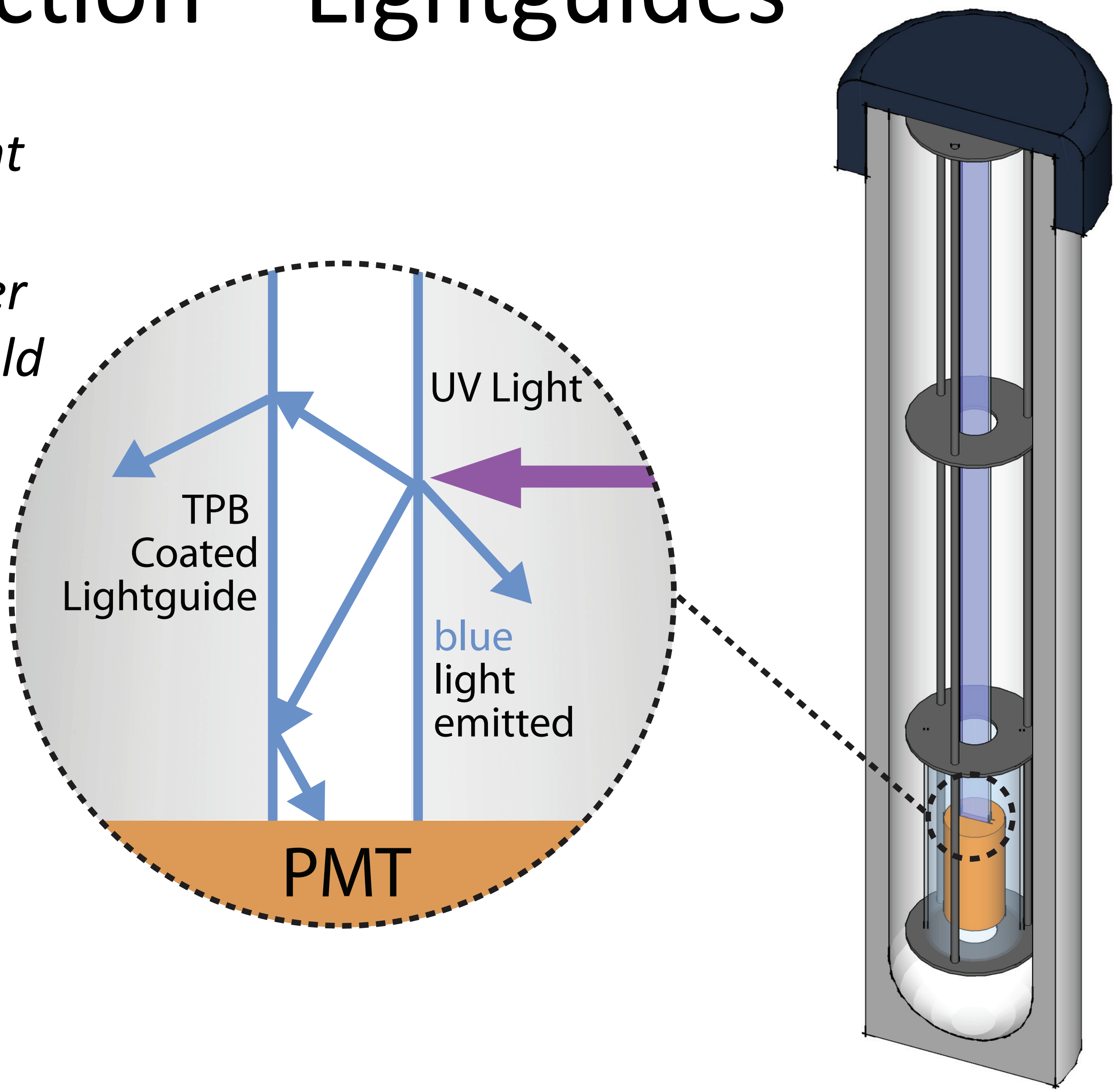
Sample Plate

MicroBooNE PMT Module



Light Detection – Lightguides

Lightguides relay light from field intense regions of chamber to PMTs in zero field region.



Manufacturing Concerns

+ **Attenuation**
  - Light signal degrades in acrylic
  - Attenuation depends on acrylic quality
+ **Coating Quality and Smoothness**
  - Bumps in coating result in light exiting the rod, never reaching PMT.
  - Coating efficiency increases with TPB but more TPB reduced optical clarity.

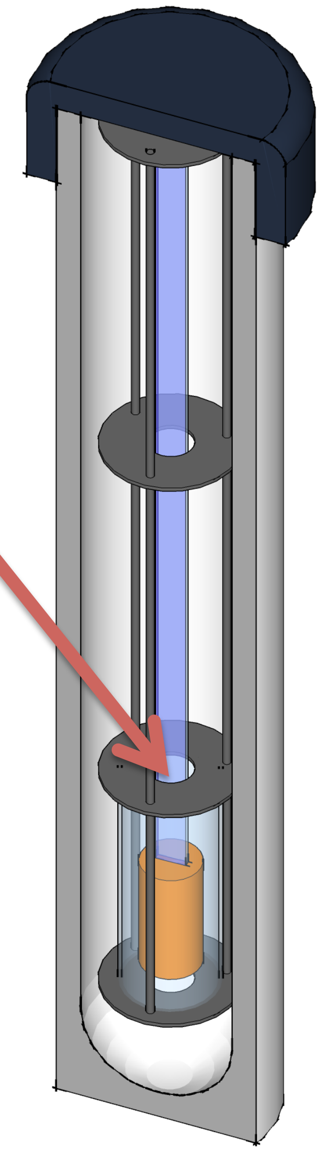
Three lightguides with 3, 2, and 1 coat(s) of 1:3 TPB to polystyrene coating.

Testing Lightguides

+ Coating - 1:3, TPB to Polystyrene
+ Measured light detected from
  5.3 MeV alpha in argon
+ Lightguide dimensions:
  1” x 3/16” x 21.5”

Incident UV Photons:	1000 Photons
Ideal Response:	10 +/- 3 PE
Measured Response:	7.5 +/- 2.5 PE
Efficiency:	0.1%

Test Dewar



Alpha source (Polonium 210) attached to lightguide 10 cm from PMT

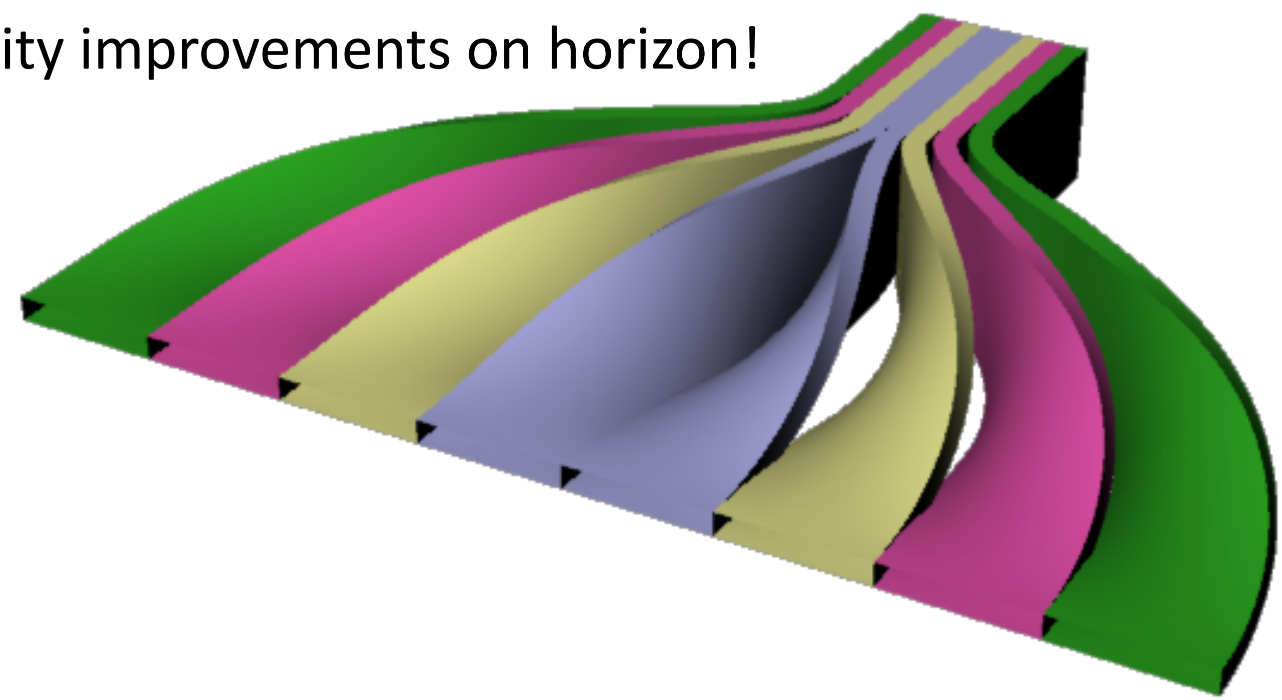
Lightguides in Large-Scale Detectors

Our prototype lightguides are sufficiently efficient to register events in large-scale detector!

Need 30 paddles to trigger on 5 PE created by 40 MeV protons in MicroBooNE.

Lightguide quality improvements on horizon!

8 lightguides bend to connect to 2” PMT face.



Conclusion

MicroBooNE will investigate important physics and will be an important step toward creating larger LArTPCs.

At MIT we are investigating cost effective light detection possibilities for use in large-scale detectors.

arXiv:1101.3013v1
[physics:ins-det]

Conclusion

MicroBooNE will investigate important physics and will be an important step toward creating larger LArTPCs.

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Thank you!

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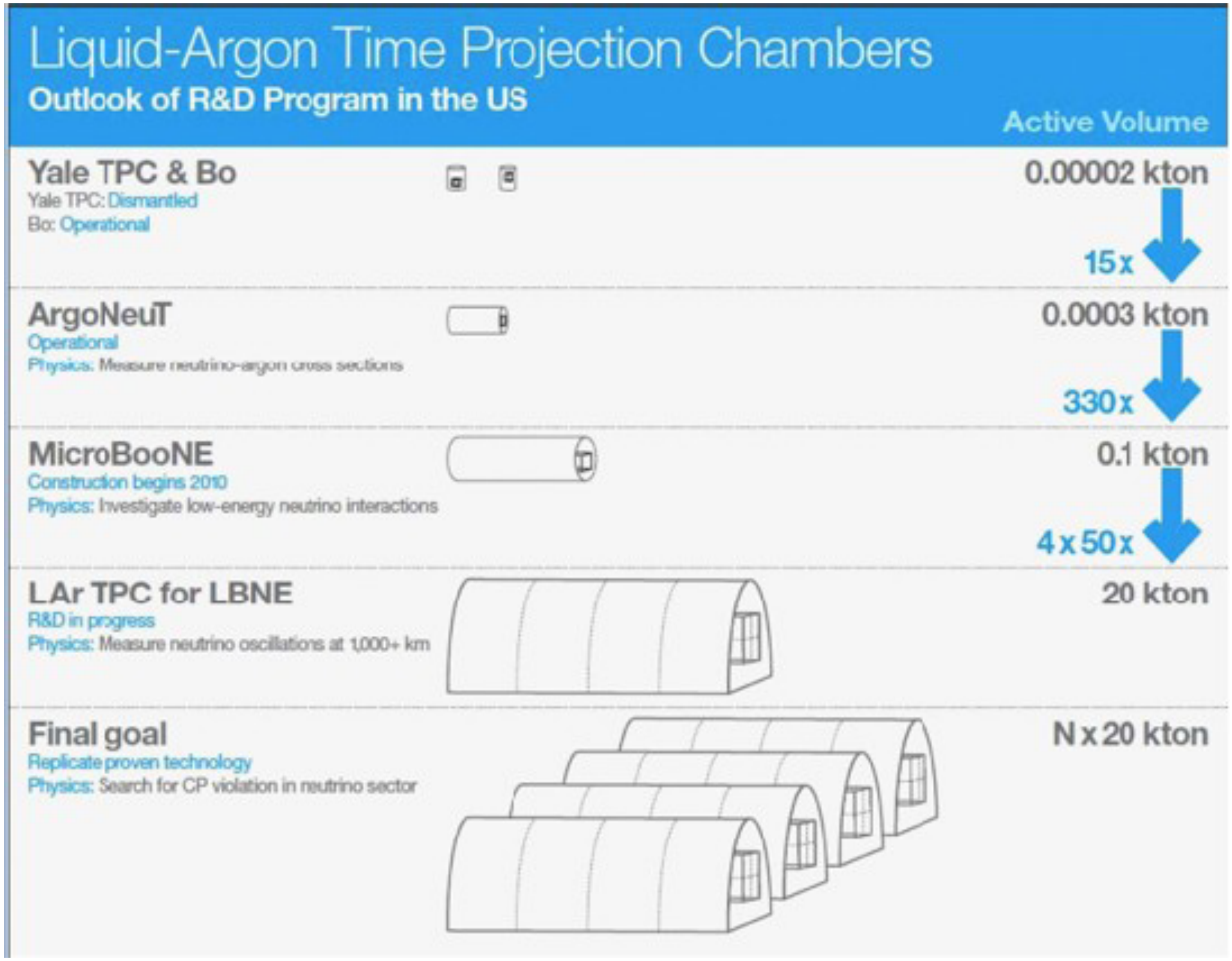
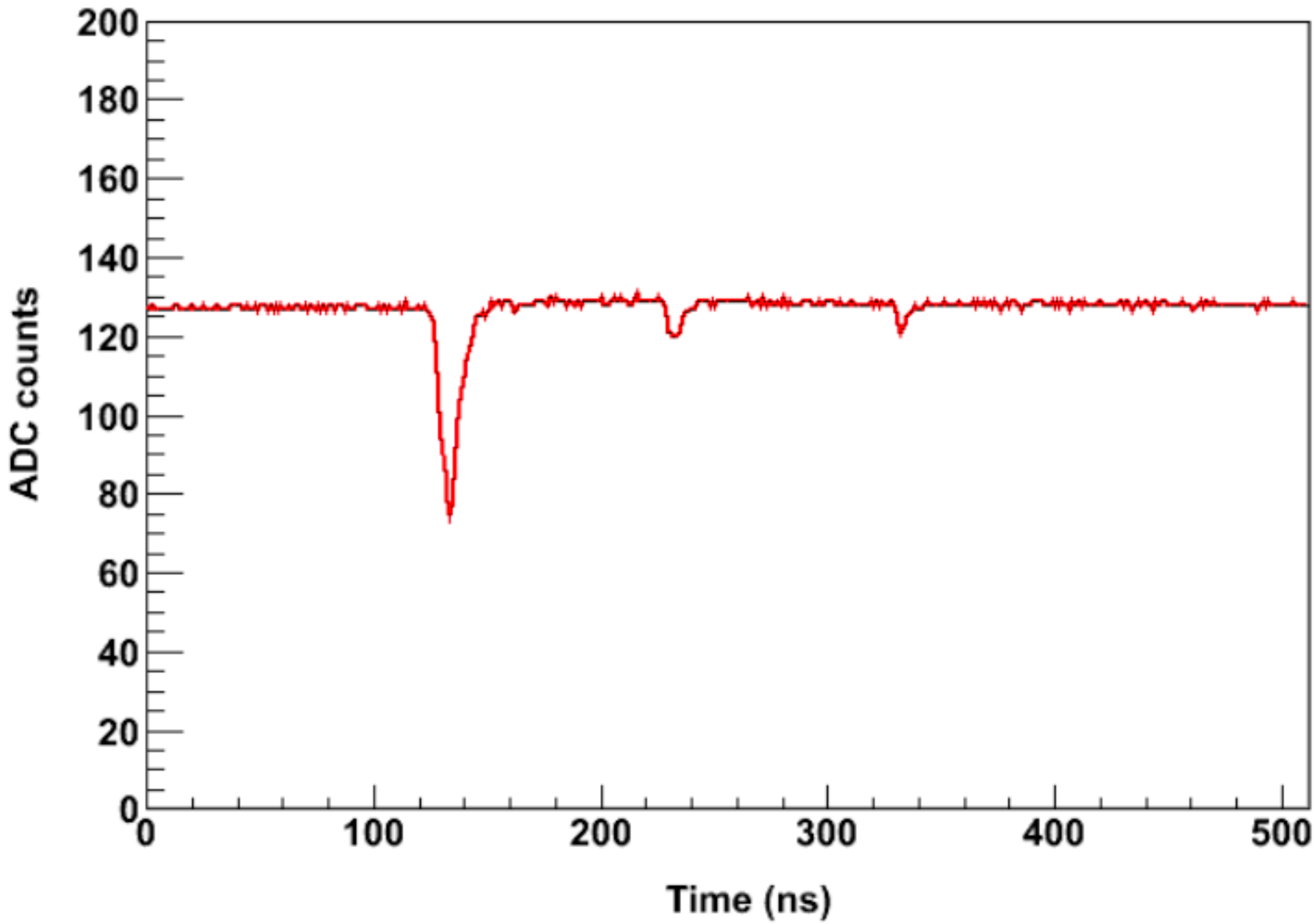


Liquid-Argon Time Projection Chambers
Outlook of R&D Program in the US
Active Volume
Yale TPC & Bo
Yale TPC: Dismantled
Bo: Operational
0.00002 kton
15x
ArgoNeuT
Operational
Physics: Measure neutrino-argon cross sections
0.0003 kton
330x
MicroBooNE
Construction begins 2010
Physics: Investigate low-energy neutrino interactions
0.1 kton
4 x 50x
LAr TPC for LBNE
R&D in progress
Physics: Measure neutrino oscillations at 1,000+ km
20 kton
Final goal
Replicate proven technology
Physics: Search for CP violation in neutrino sector
N x 20 kton

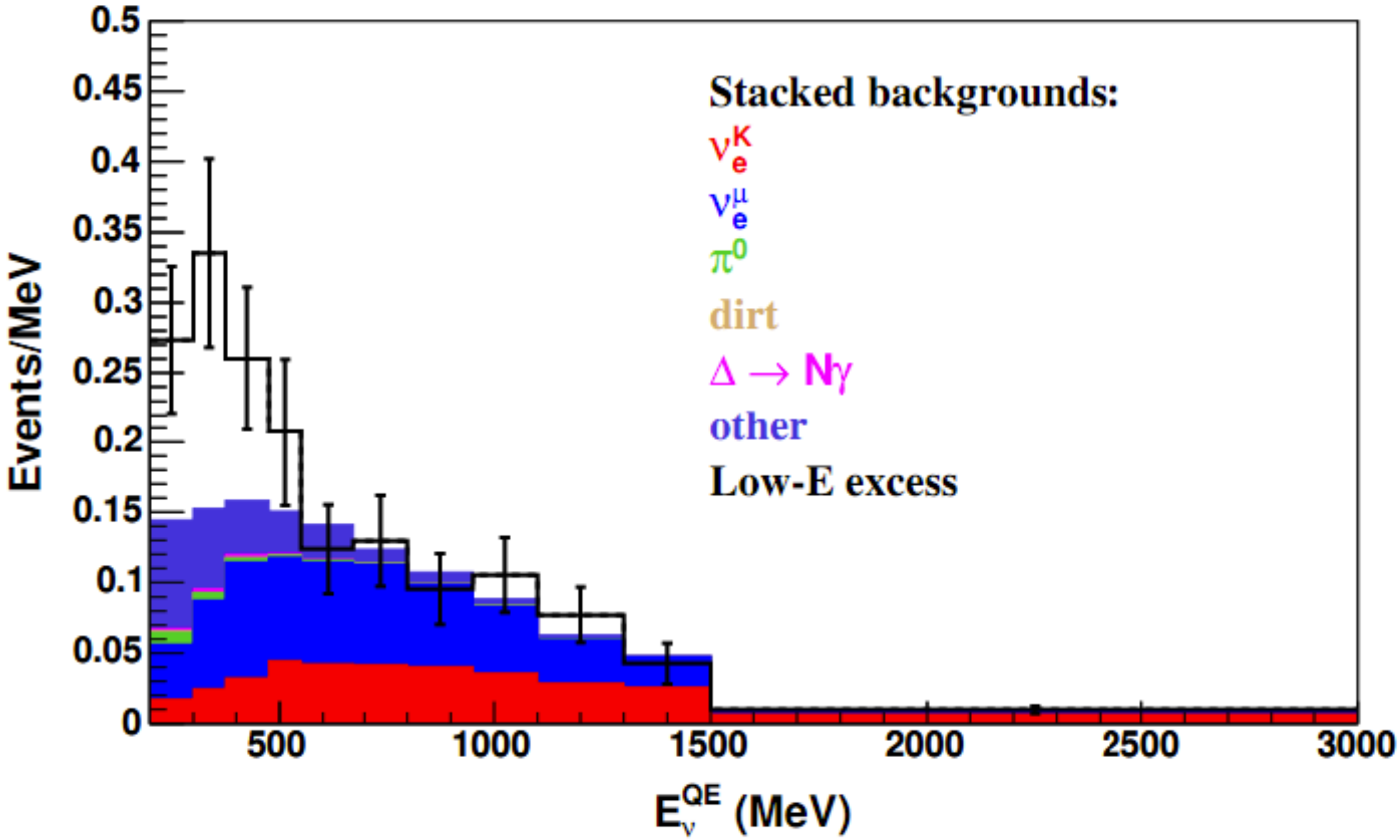
Parameters Used in Ideal Calculations				
#	Parameter	Value in Calc.	Source	See Sec(s)
Related to UV light production				
1	Early (< 10 ns) UV γ/MeV (MIP)	7600	Ref. [14]	4 & 6
2	Light reduction factor for α	0.72	Ref. [14]	4
3	Light reduction factor for p	0.81	Ref. [15]	6
Related to Geometry of Teststand				
4	Acceptance of UV light	0.33	calculated	4
Conversion and Capture in the Bars				
5	UV/visible γs, evaporative coat	1.0	Ref. [16]	4 & 6
6	Response, bar coating to evap.	0.1	measured	4 & 6
7	Capture fraction	0.05	calculated	4 & 6
PMT response				
8	QE of 7725 PMT	0.25	Ref. [9]	4 & 6
9	Cryogenic modification factor	0.8	Ref. [10]	4 & 6
Combining Parameters to Calculate Efficiencies				
	Efficiency	Value	Combined Params.	See Sec(s)
10	Efficiency to convert and capture	0.005	$5 \times 6 \times 7$	4 & 6
	Total Ideal Efficiency	0.001	$8 \times 9 \times 10$	4 & 6

Table 1: Parameters used in ideal calculations presented in Secs. 4 and 6 for light production and bar acceptance. # is the parameter number appearing in the text and in the last two rows of this table, under "Combined Params." "MIP" means minimum ionizing particle. "QE" is quantum efficiency. "Measured" ("calculated") indicates that this is a measurement (calculation) by the authors described in the text.

Raw Data from Testing Lightguides



MiniBooNE: Electron-like events



MiniBooNE: Photon-like events