MicroBooNE Detector
Beam Requirements & Status

Kazuhiro Terao @ Nevis, Columbia

Neutrino Physics
&
Path Toward MicroBooNE

Outline:

1. Path Toward MicroBooNE

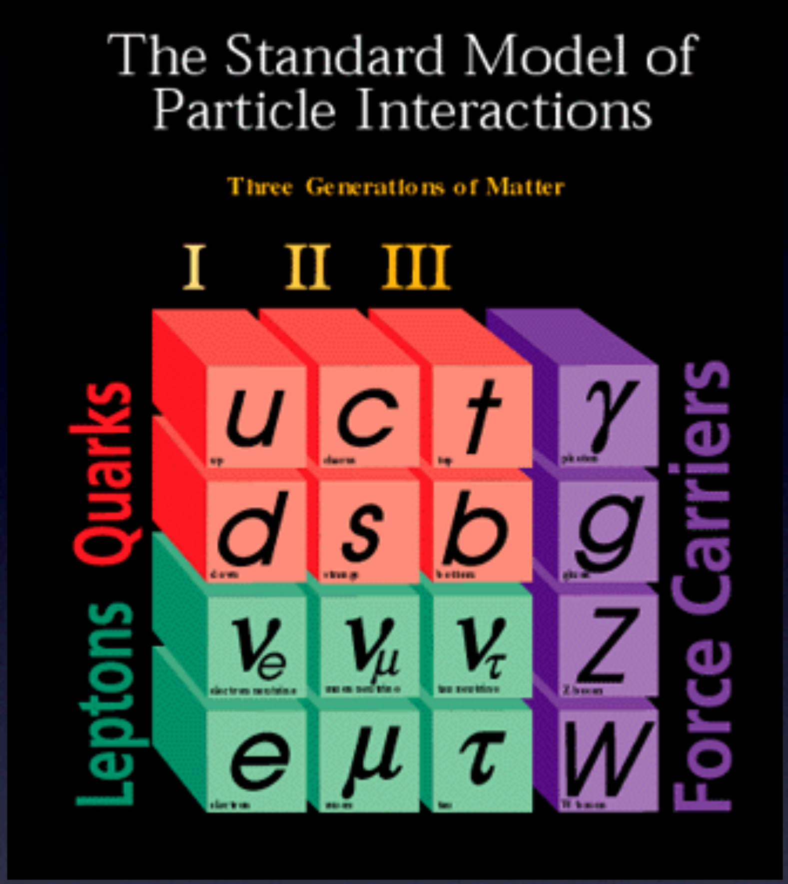
2. MicroBooNE Detector

3. Detector Construction

4. Commissioning Schedule

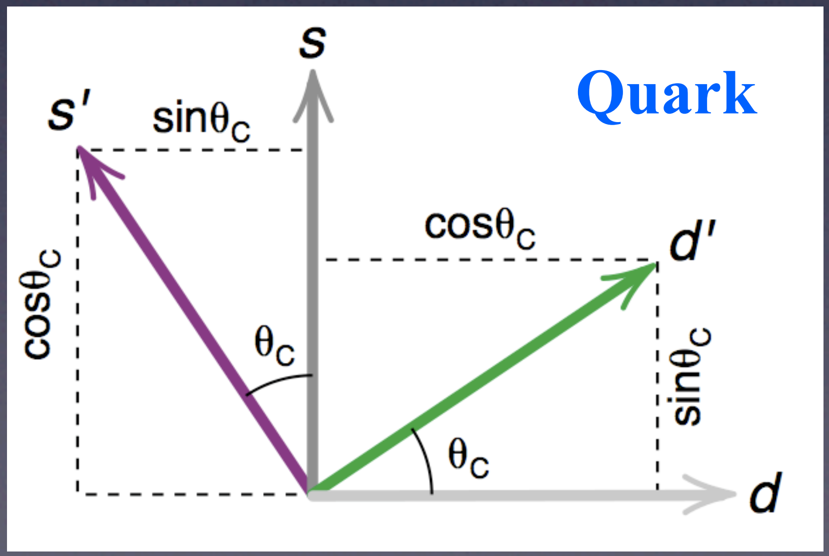
5. Summary

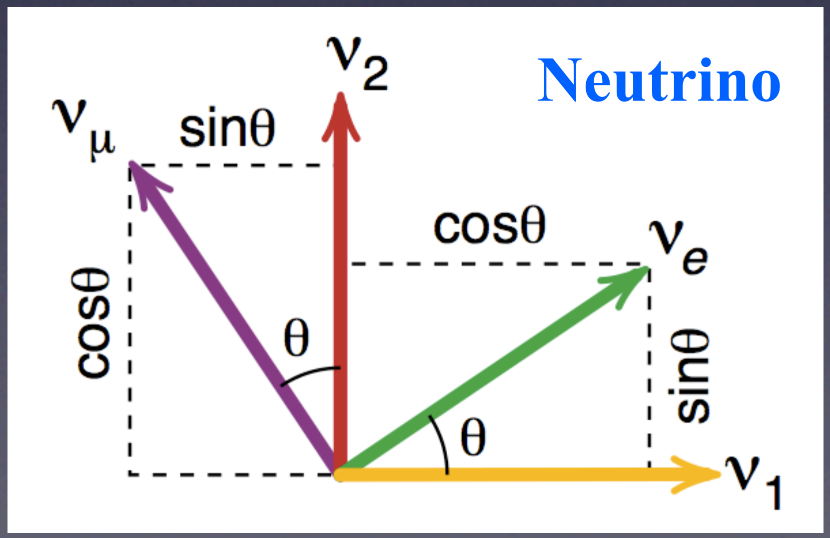
Neutrino Flavor Mixing



What we know about neutrinos

- Neutral, spin 1/2 lepton
- 3 weakly interacting flavors
- At least 3 non-degenerate mass eigenstates
- Very, very tiny mass
- Flavor mixing!





Neutrino Oscillation

$$\begin{pmatrix} \nu_e \\ \nu_\mu \end{pmatrix} = \begin{pmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{pmatrix} \begin{pmatrix} \tilde{\nu}_1 \\ \tilde{\nu}_2 \end{pmatrix}$$

$$U$$

ν_α → $|\nu_\alpha(t)\rangle = \sum_i U_{\alpha i} e^{-iE_i t} |\nu_i\rangle$ → ν_β

Production
(weak interaction)

Propagation

Detection
(weak interaction)

Probability for detecting ν_β

$$P(\nu_\alpha \rightarrow \nu_\beta) = |\langle \nu_\beta | \nu_\alpha(t) \rangle|^2$$
$$= \sum_{i,j} U^*_{\beta i} U_{\alpha i} U_{\beta j} U^*_{\alpha j} e^{-i(E_i - E_j)t}$$

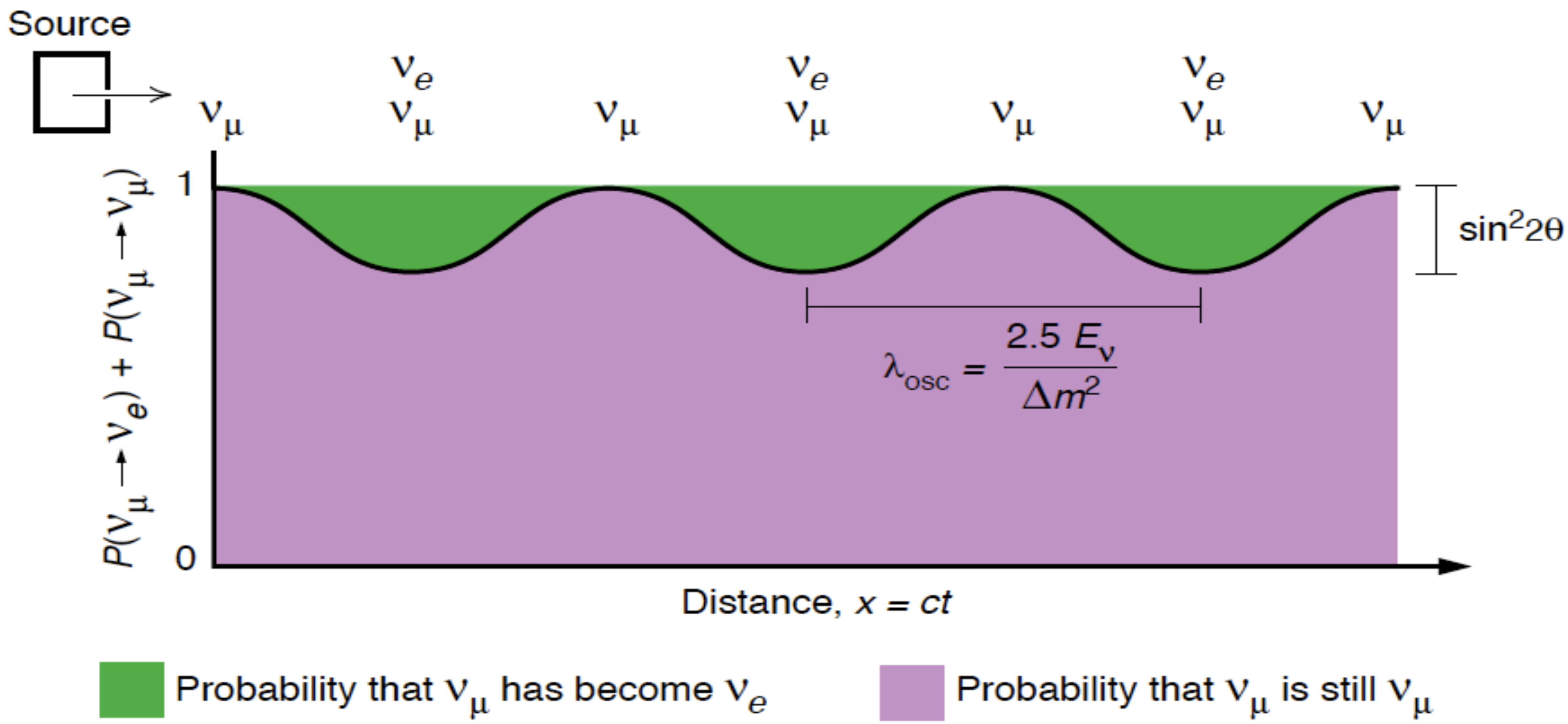
Ultra-relativistic Approx.

$$E_i = \sqrt{\mathbf{p}^2 + m_i^2} \simeq |\mathbf{p}| + \frac{m_i^2}{2|\mathbf{p}|}$$

$$(E_i - E_j) \cdot t = \frac{(m_i^2 - m_j^2)L}{2E} = \frac{\Delta m_{ij}^2 L}{2E}$$

Depends on θ, L, E, and Δm^2

Neutrino Oscillation



Courtesy of "Celebrating Neutrinos" (LANL)

Key points of oscillation experiments

- We produce & detect neutrinos through weak interaction
  - We can see either "disappearance" or "appearance" of specific flavor
- Oscillation effect depends on angle, mass splitting, and L/E

What We Already Know

$$U = \begin{bmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{bmatrix} \begin{bmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta} & 0 & c_{13} \end{bmatrix} \begin{bmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

Accelerator & Atmospheric | **Short Baseline Reactor** | **KamLAND & Solar**

Parameter	best-fit ($\pm 1\sigma$)	3σ
Δm^2_{21} [10^{-5} eV ^{2}]	$7.54^{+0.26}_{-0.22}$	$6.99 - 8.18$
$\|\Delta m^2\|$ [10^{-3} eV ^{2}]	$2.43^{+0.06}_{-0.10}$ $(2.42^{+0.07}_{-0.11})$	$2.19(2.17) - 2.62(2.61)$
$\sin^2\theta_{12}$	$0.307^{+0.018}_{-0.016}$	$0.259 - 0.359$
$\sin^2\theta_{23}$	$0.386^{+0.024}_{-0.021}$ $(0.392^{+0.039}_{-0.022})$	$0.331(0.335) - 0.637(0.663)$
$\sin^2\theta_{13}$ [173]	0.0241 ± 0.0025 $(0.0244^{+0.0023}_{-0.0025})$	$0.0169(0.0171) - 0.0313(0.0315)$

3 neutrino Best Fit quoted from Particle Data Group

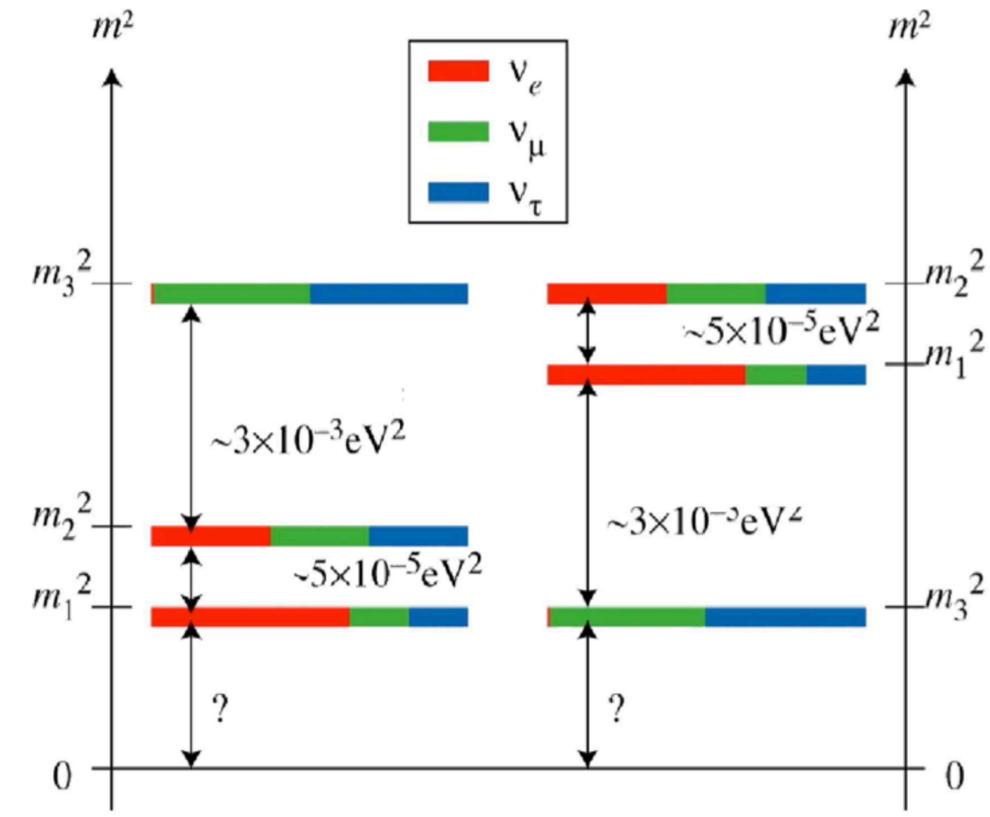
... we are moving toward **precision measurement** era ...

What We Still Need to Learn

$$U = \begin{bmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{bmatrix} \begin{bmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta} & 0 & c_{13} \end{bmatrix} \begin{bmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

Things we still don't know...

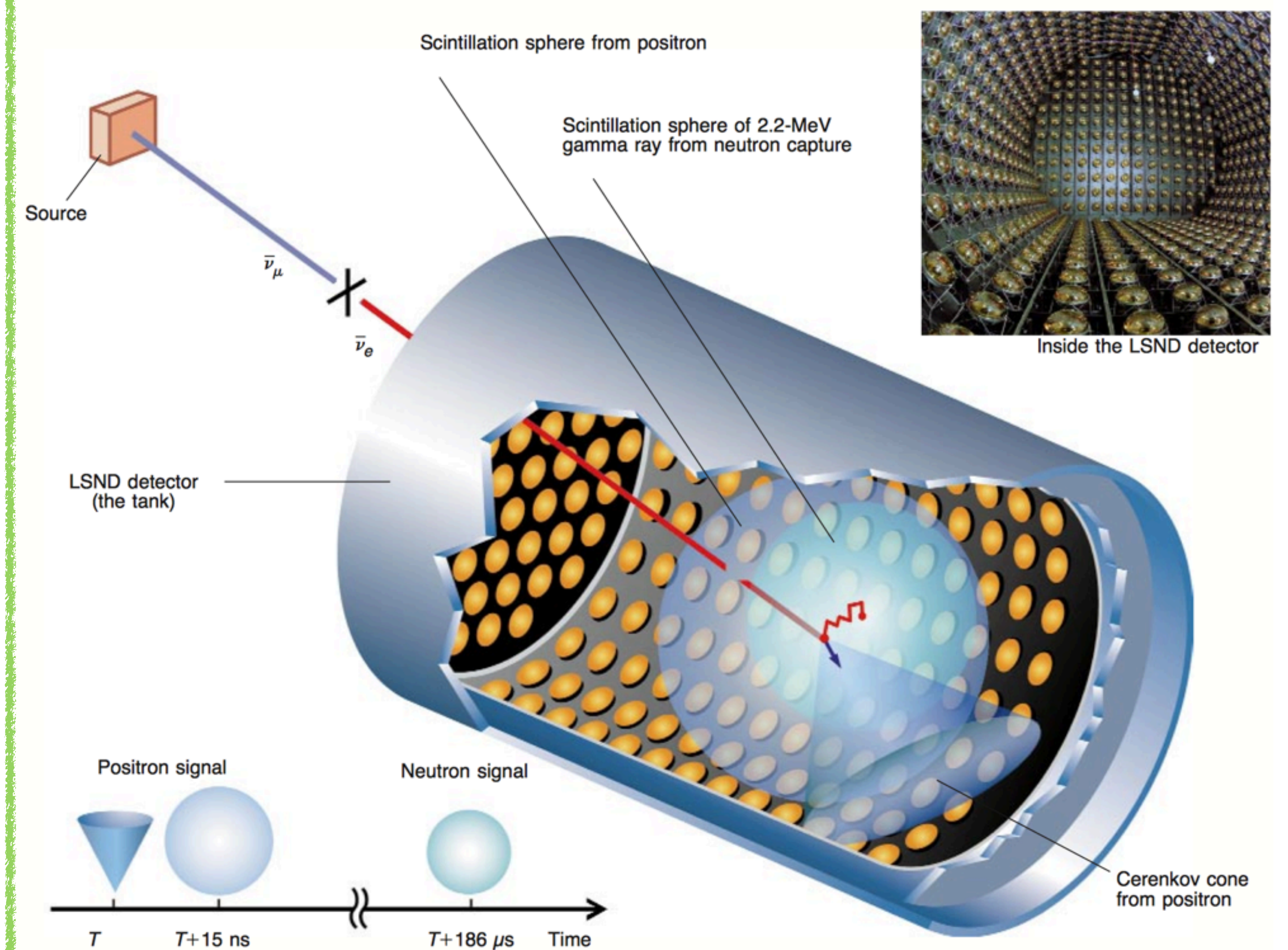
- CP violation
- Mass hierarchy
- Absolute mass
- Dirac vs. Majorana
- **Sterile neutrinos**



LSND Experiment: High Δm^2 Oscillation

- **Liquid Scintillator Neutrino Detector (LSND)**
  - Primary oscillation mode: $\bar{\nu}_\mu \Rightarrow \bar{\nu}_e$ … **L/E ≃ *o* (1 m/MeV)**

LSND Detector



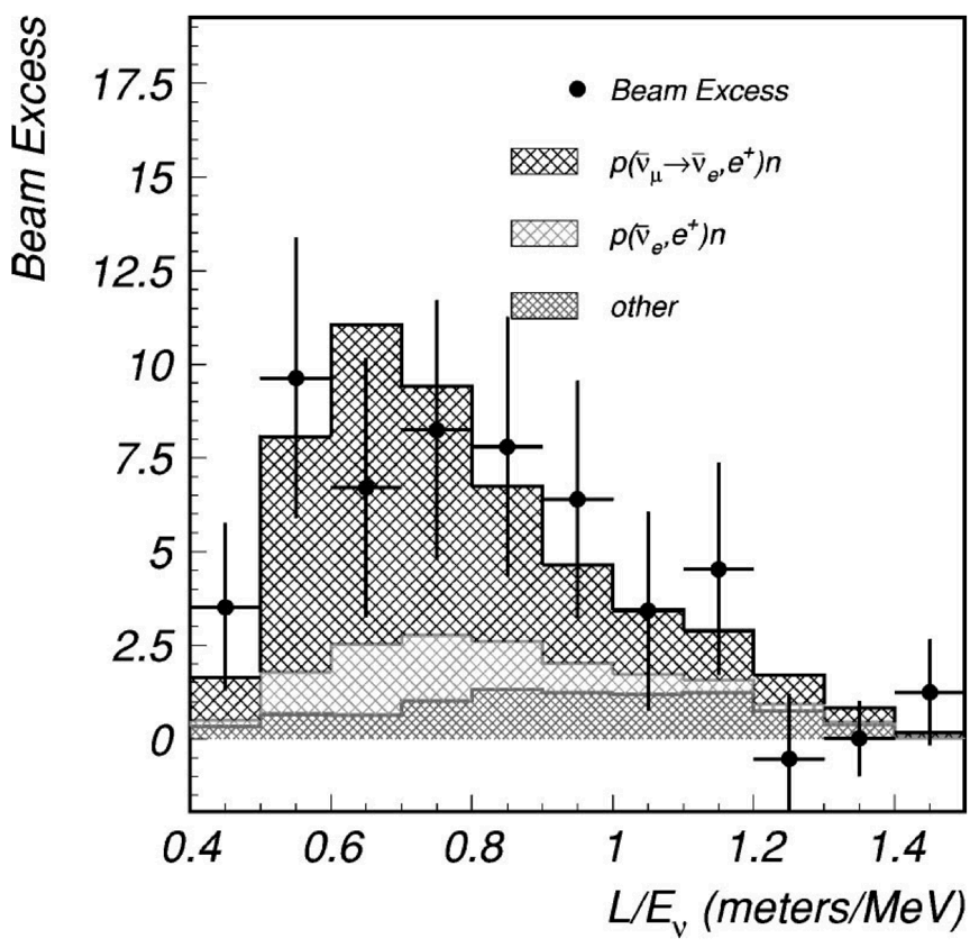
Courtesy of "Celebrating Neutrinos" (LANL)

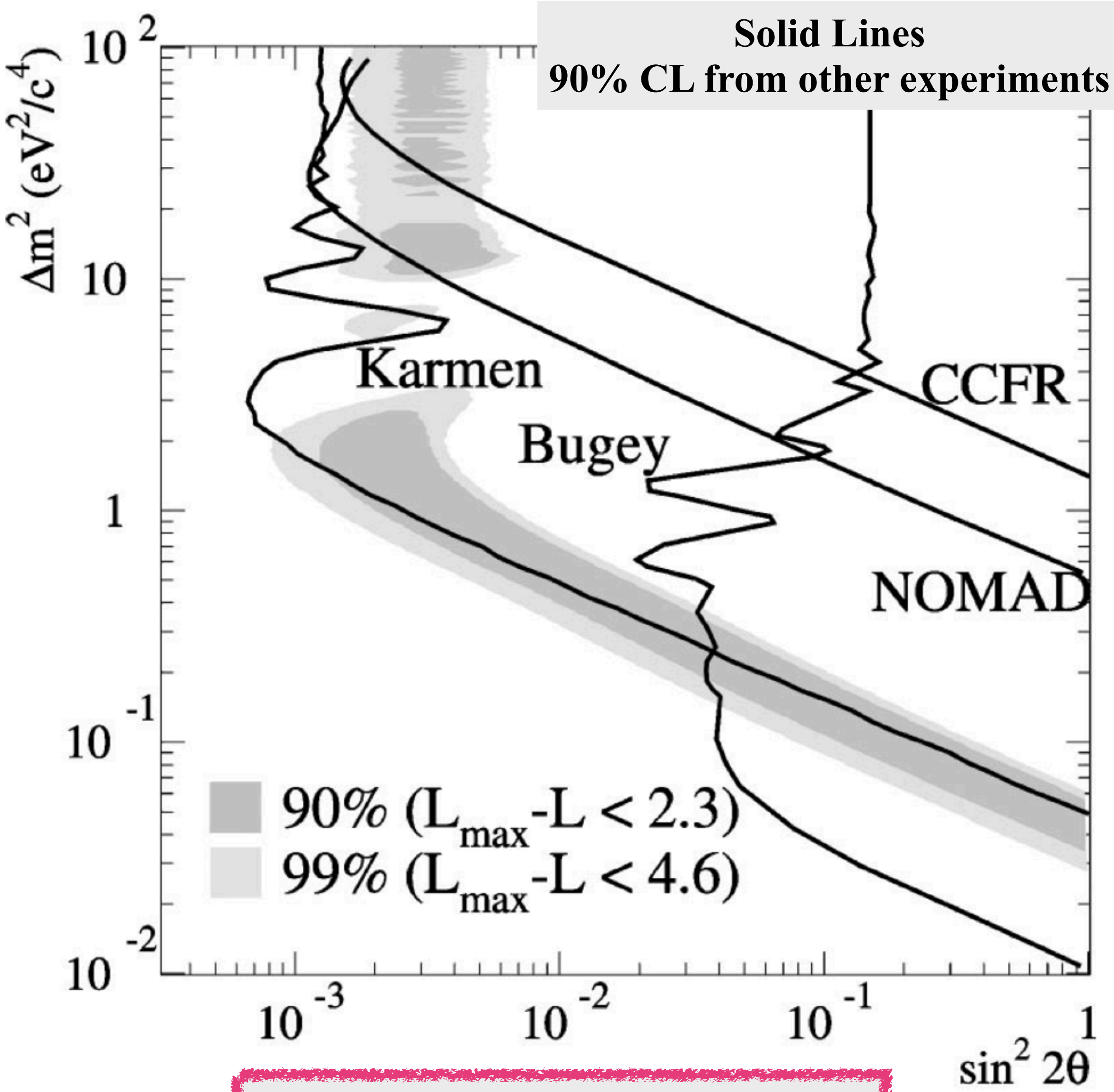
LSND Experiment: High Δm^2 Oscillation

- **Liquid Scintillator Neutrino Detector (LSND)**
  - Primary oscillation mode: $\bar{\nu}_\mu \Rightarrow \bar{\nu}_e$ ... **L/E ≃ *o* (1 m/MeV)**
  - Saw **oscillation signal at high Δm^2**

$$(\sin^2 2\theta, \Delta m^2)_{best\text{-}fit} = (0.003, 1.2\ \ eV^2).$$

- Not seen by others! ... "**sterile neutrino**"



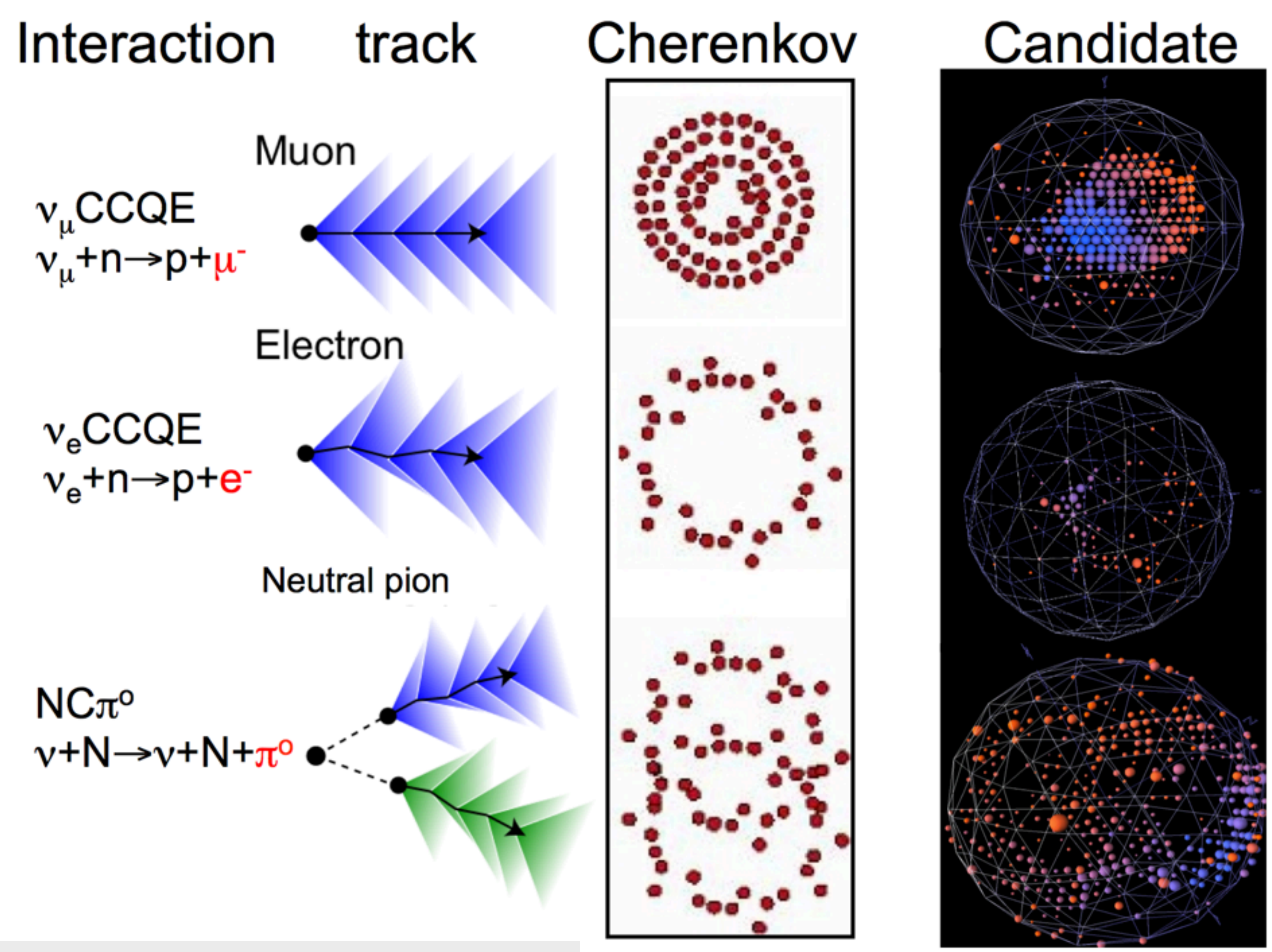


LSND allowed region for Δm^2 vs. $\sin^2 2\theta$
Possible $\Delta m^2 \in [0.2, 2.0]$ eV^2

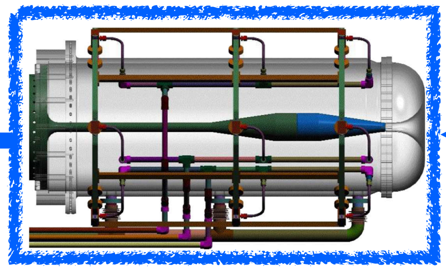
PRD 64, 112007 (2001)

MiniBooNE: Investigating LSND Oscillation

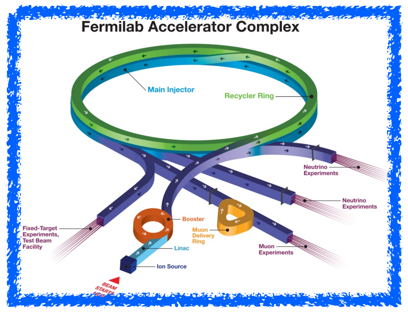
- **MiniBooNE: Booster Neutrino Experiment @ L ≃ 500 m**
  - Oscillation mode: $\boldsymbol{\nu_\mu \Rightarrow \nu_e}$ & $\boldsymbol{\bar{\nu}_\mu \Rightarrow \bar{\nu}_e}$ … **L/E ≃ *o* (1 m/MeV)**
    - **Investigate LSND signal**
  - Cherenkov detector w/ non-scintillating oil
  - Source: Booster Neutrino Beam (BNB)



Mod. Phys. Lett. A27: 1230024 (2012)

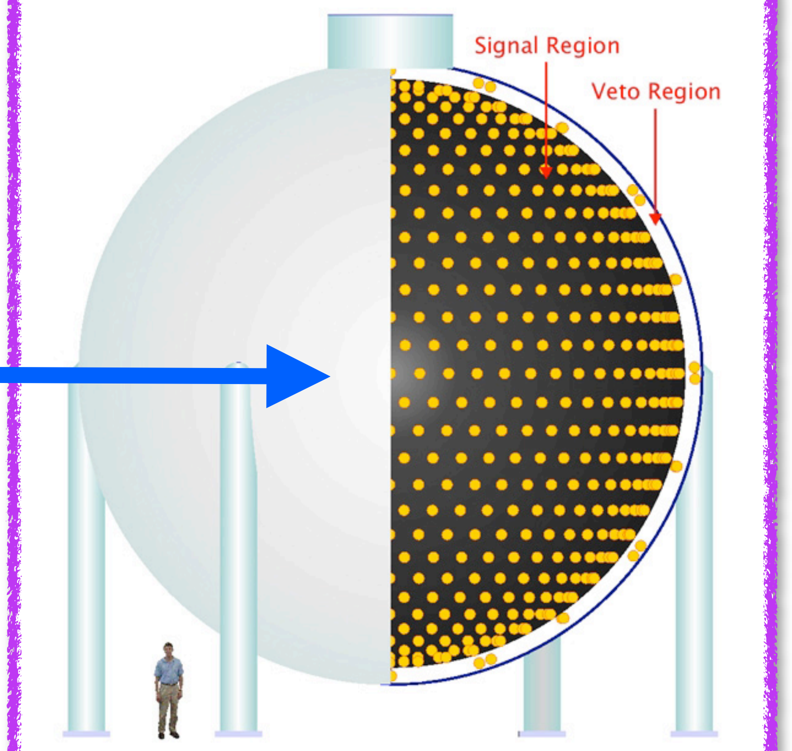


MiniBooNE Horn



BNB

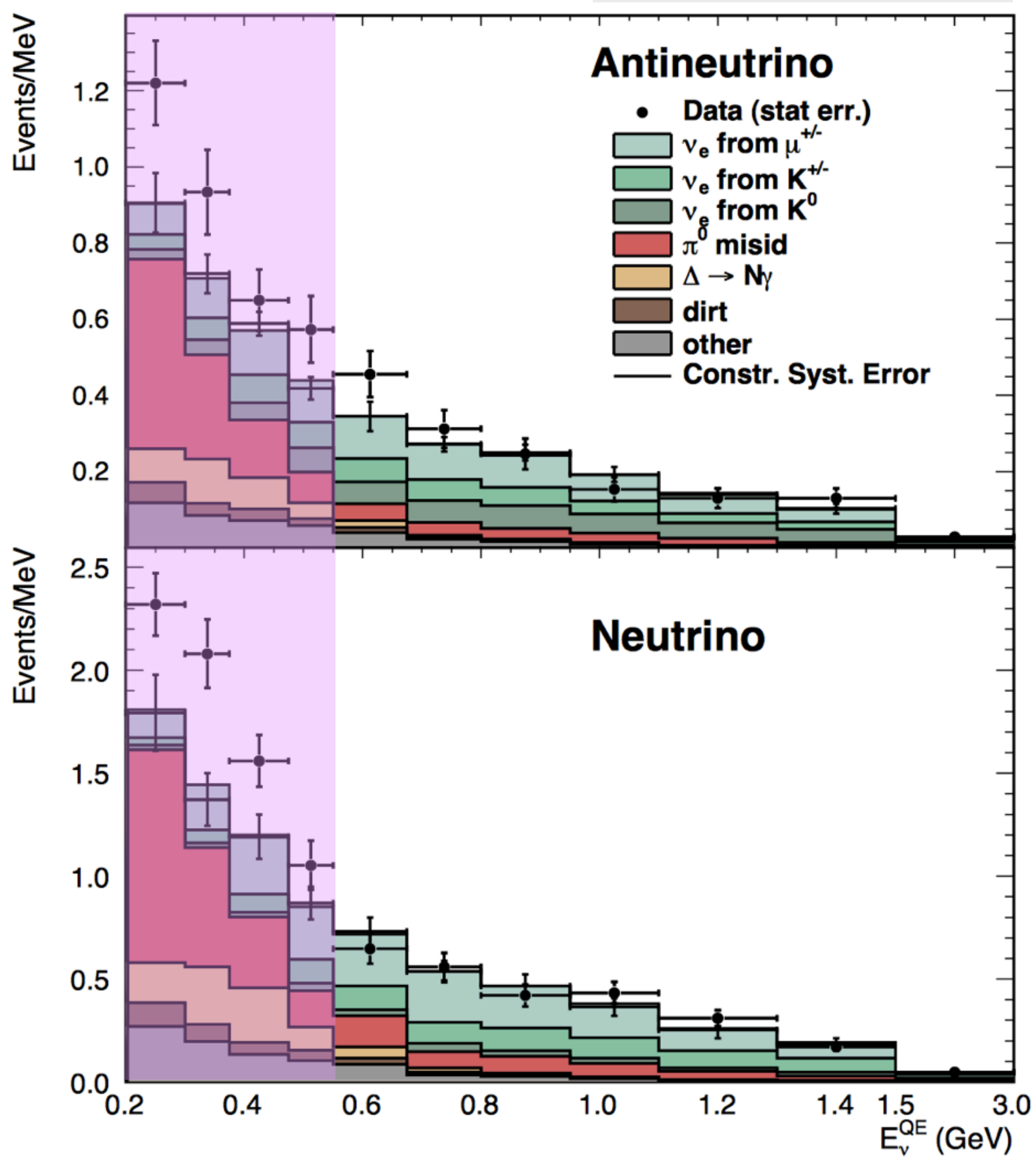
MiniBooNE Detector

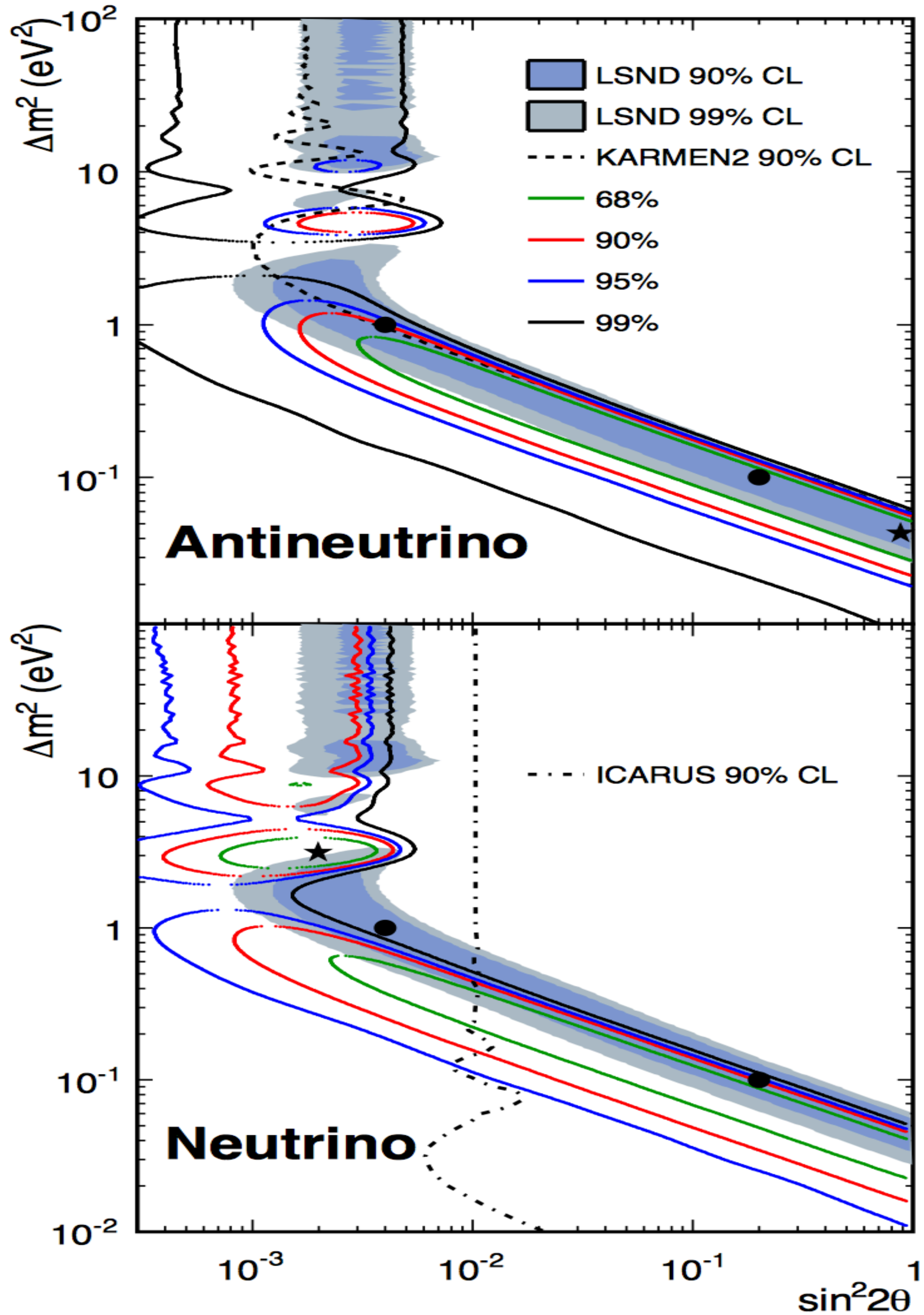


MiniBooNE: Investigating LSND Oscillation

- **MiniBooNE result**
  - *Could be* compatible w/ LSND
  - Saw an excess of (anti) **ν_e in low energy**

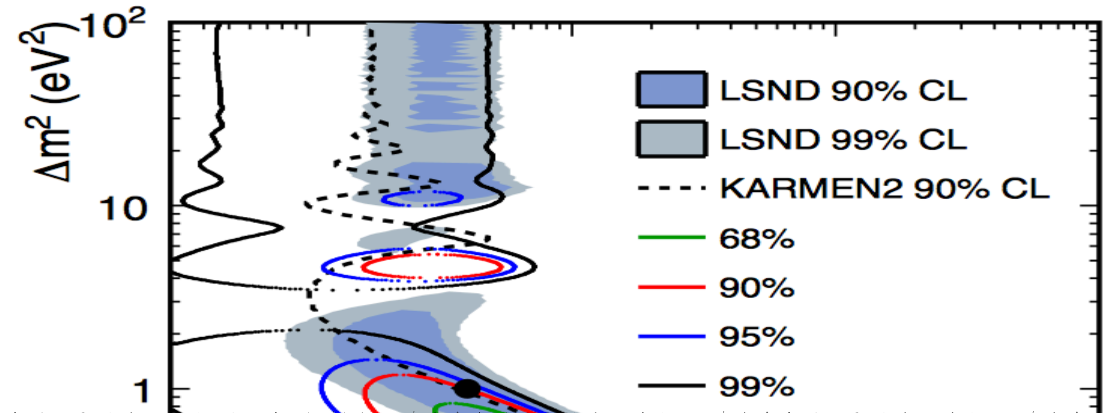
PRL 110, 161801(2013)



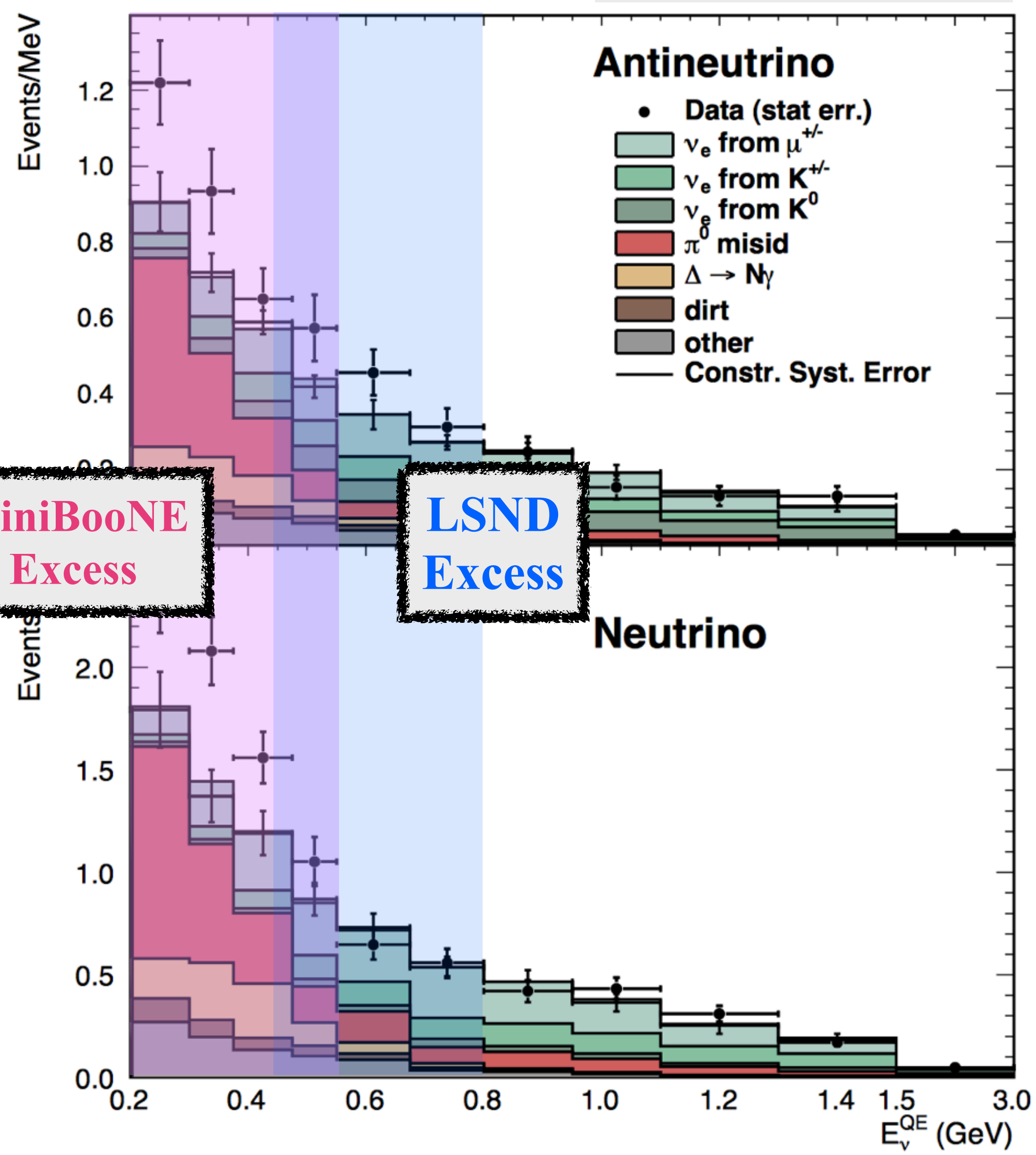


MiniBooNE: Investigating LSND Oscillation

- **MiniBooNE result**
  - *Could be* compatible w/ LSND
  - Saw an excess of (anti) **ν_e in low energy**



PRL 110, 161801(2013)



Event excess are in lower L/E

- Different (?) signature than LSND

Region with large backgrounds

- $\Delta \Rightarrow N\,\gamma$
- $\pi^0 \Rightarrow \gamma + \gamma$

Possible Mis-ID of single e^- vs. γ

(**hard business for Cherenkov Detector**)

Need for definitive measurement!

MicroBooNE Detector
~ High Precision LArTPC ~

Outline:

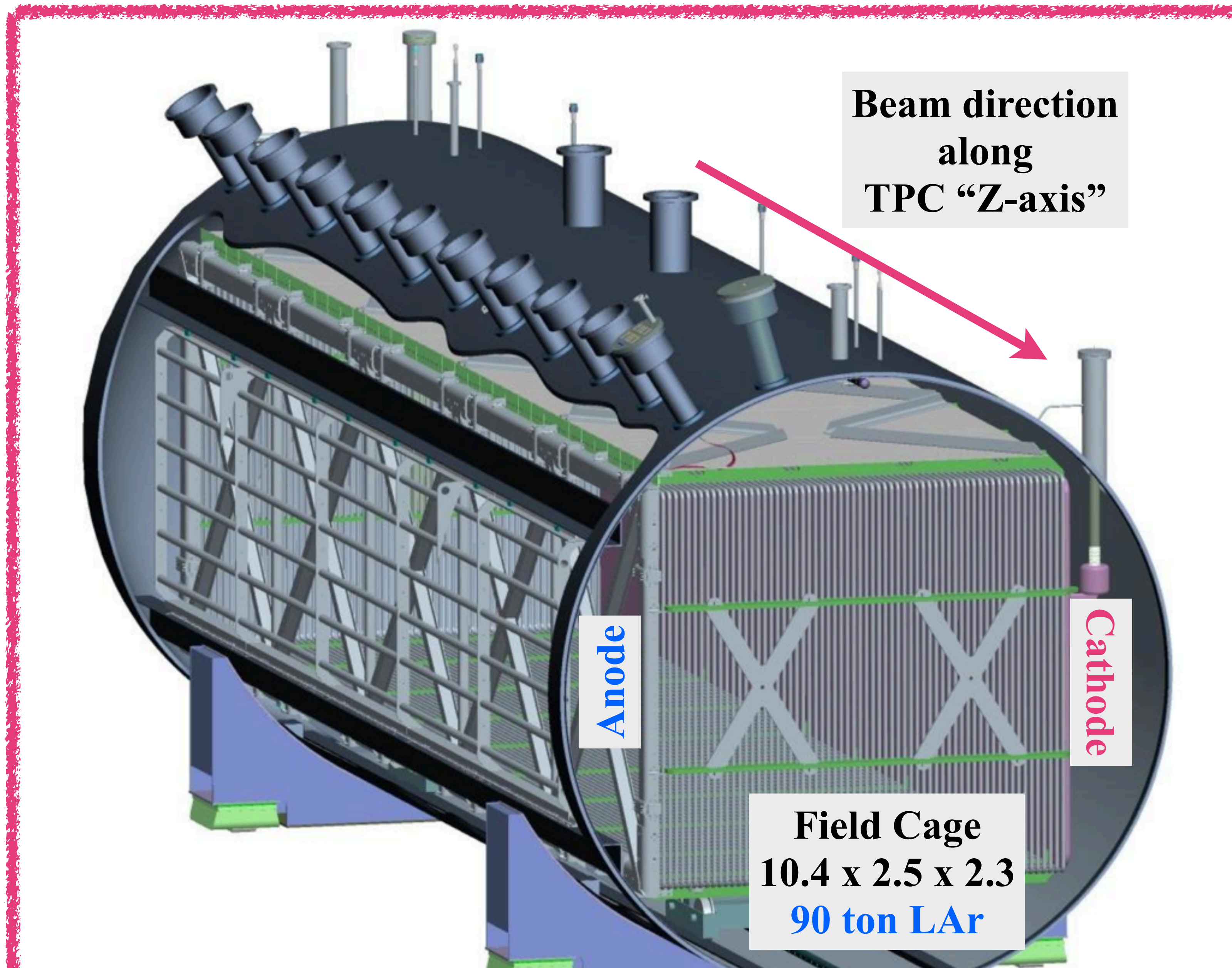
1. Path Toward MicroBooNE
2. MicroBooNE Detector
3. Detector Construction
4. Commissioning Schedule
5. Summary

MicroBooNE Experiment Overview

- **170 ton** Liquid Argon Time Projection Chamber (**LArTPC**)
  - Oscillation mode: $\nu_\mu \Rightarrow \nu_e$ & $\bar{\nu}_\mu \Rightarrow \bar{\nu}_e$ ... **L/E ≃ *o* (1 m/MeV)**
    - **BNB** (on-axis)
    - NuMI (off-axis)
  - Located @ **LArTF**
    - **on surface**
    - in front of MiniBooNE

Three Objectives

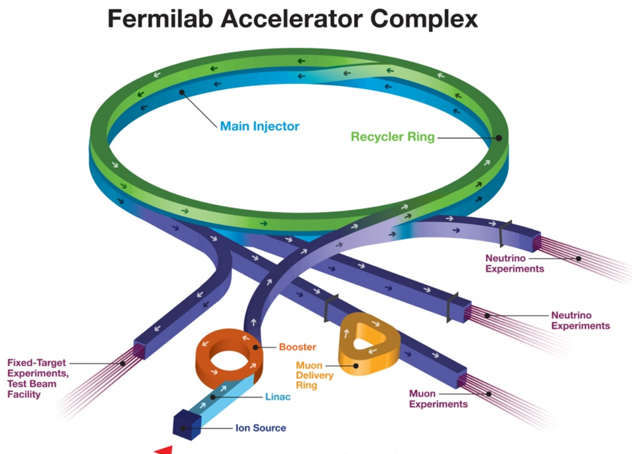
1. **MiniBooNE low E excess**
2. **Low E ν-Ar cross-section**
3. **LArTPC R&D**



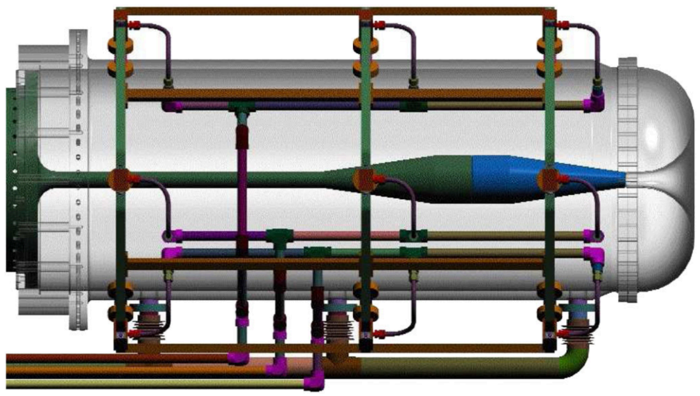
MicroBooNE Cryo-Stat & TPC

BNB: Primary Source of Neutrino

Picture taken from PRD 79, 072002 (2009) and courtesy of FNAL

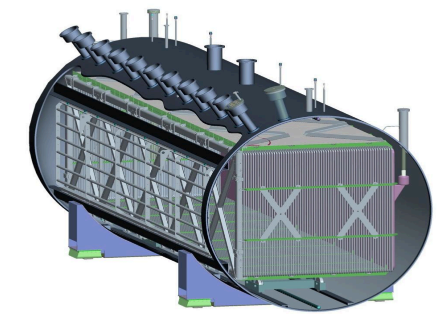


Booster
(8 GeV Protons)



Target + Horn + Decay Tunnel
(Meson Focusing & Decay)

Dirt
(Oscillation)

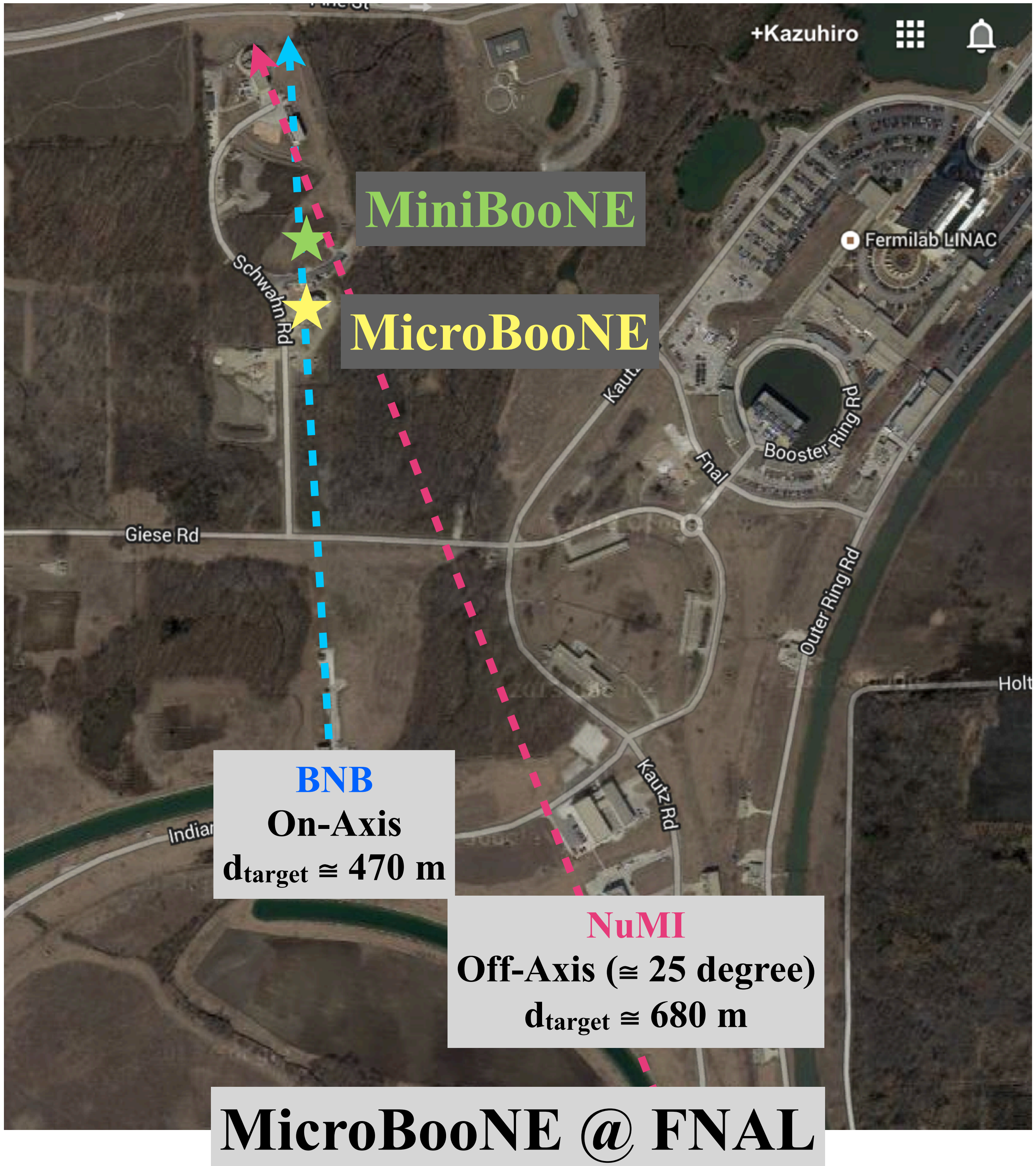


MicroBooNE Detector

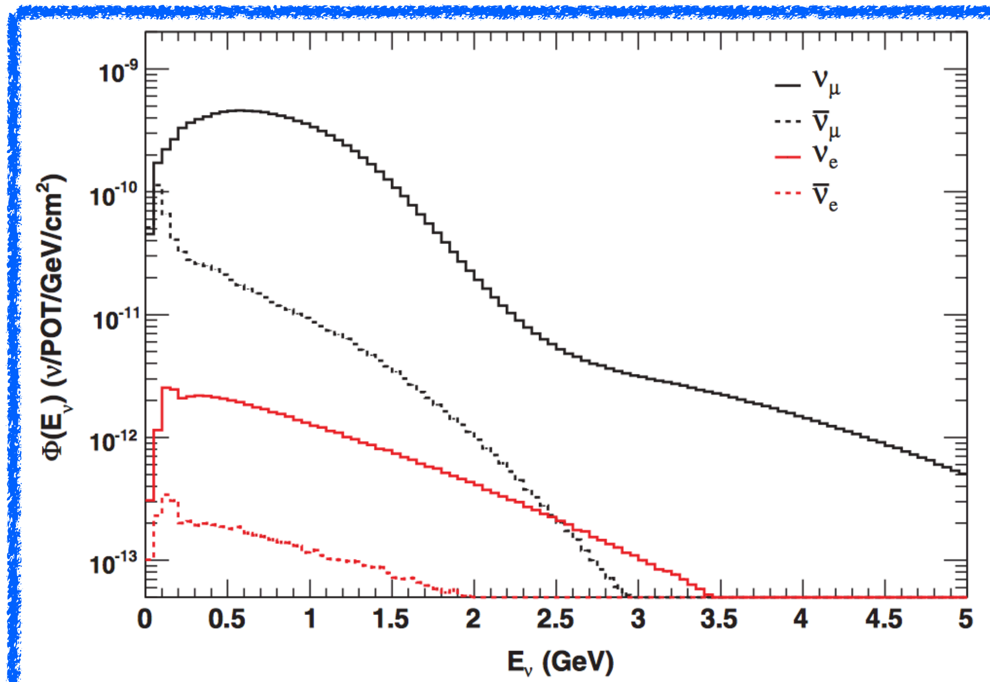
Well... you know this much better than I do ...

- 8 GeV protons from BNB hit Beryllium target @ ≃ 2 Hz
  - Producing mesons, mainly π & K
  - Horn focus mesons of desired polarity
  - Decay produce neutrinos
- Oscillation takes place in dirt (≃ 470 m)
- **Expecting 6.6 E20 POT for 3 years of running**

BNB: Primary Source of Neutrino



PRD 79, 072002 (2009)



Horn: Neutrino Mode

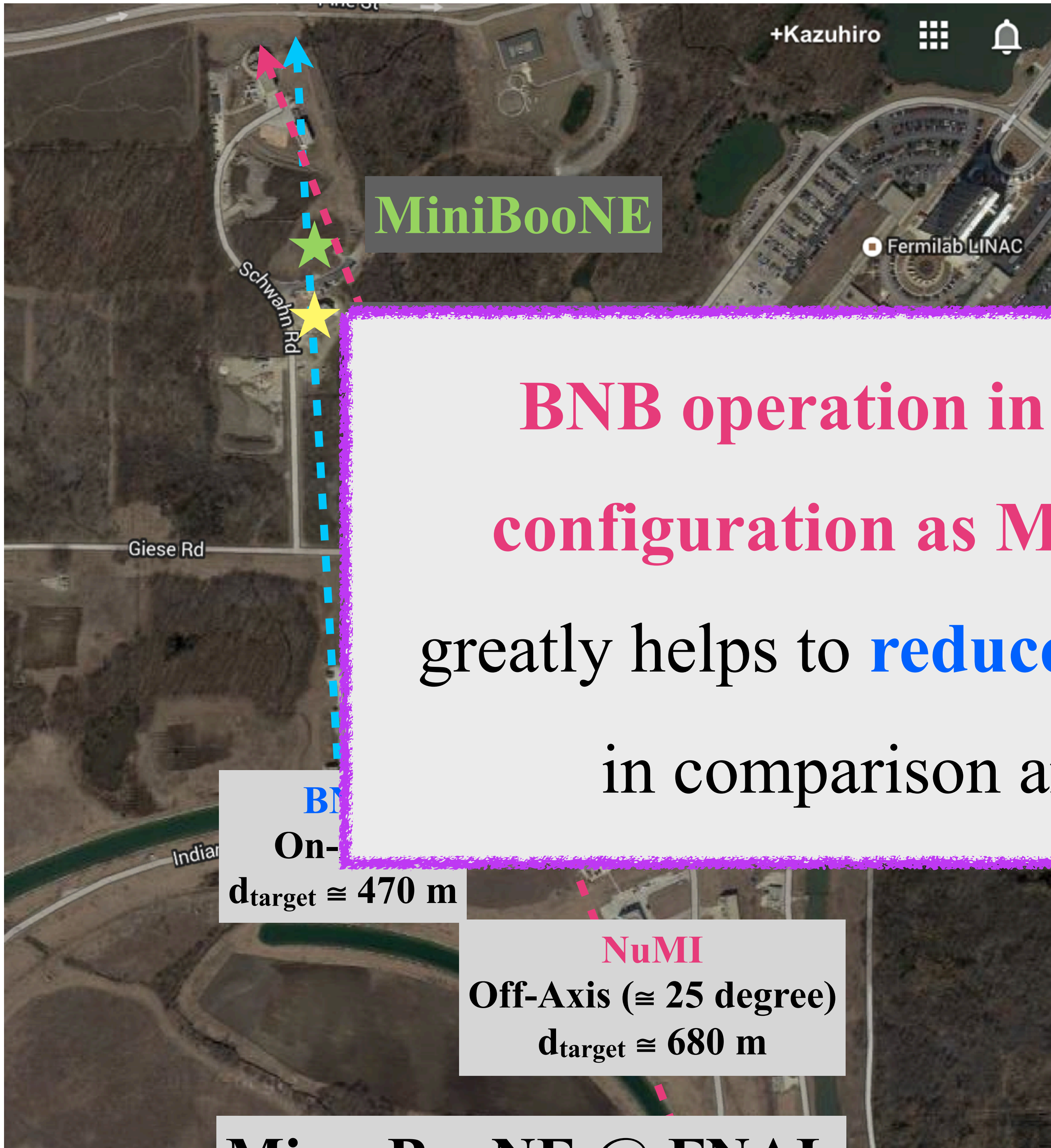
Event Rate Break Down

(flux & xs)

- $\nu_\mu \simeq 98.6\%$
- $\bar{\nu}_\mu \simeq 0.8\ \%$
- $\nu_e \simeq 0.6\ \%$
- $\bar{\nu}_e \simeq 0.02\ \%$

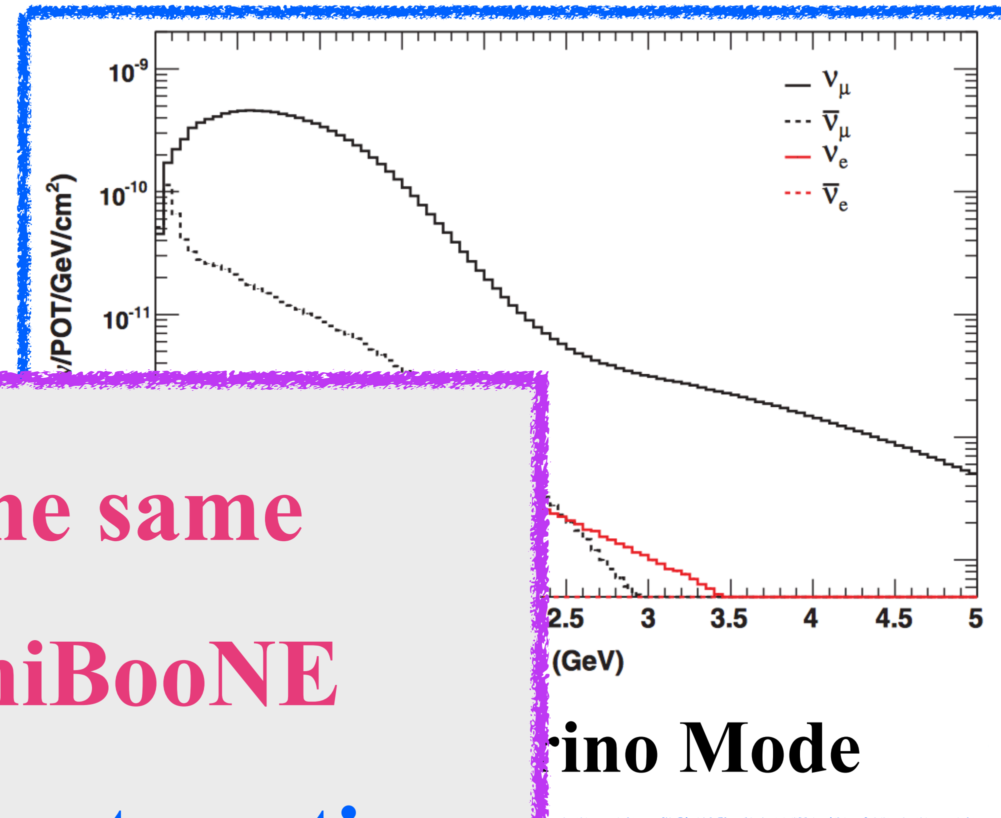
... high purity ν_μ beam ...

BNB: Primary Source of Neutrino



MicroBooNE @ FNAL

PRD 79, 072002 (2009)



BNB operation in the same configuration as MiniBooNE

greatly helps to **reduce systematics**

in comparison analysis

reak Down

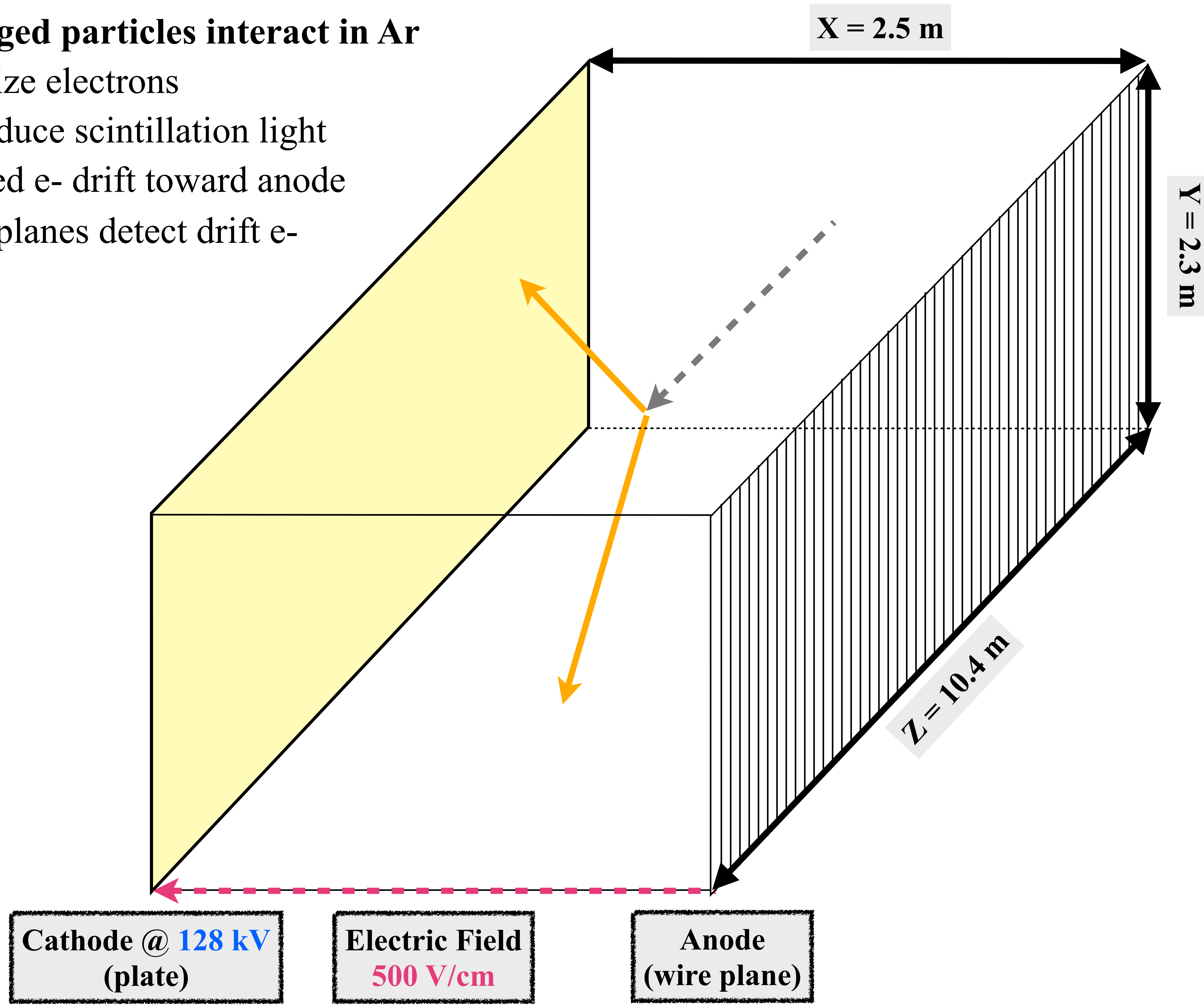
& xs)

- $\nu_\mu \simeq 0.8$ %
- $\nu_e \simeq 0.6$ %
- $\nu_e \simeq 0.02$ %

... **high purity ν_μ beam** ...

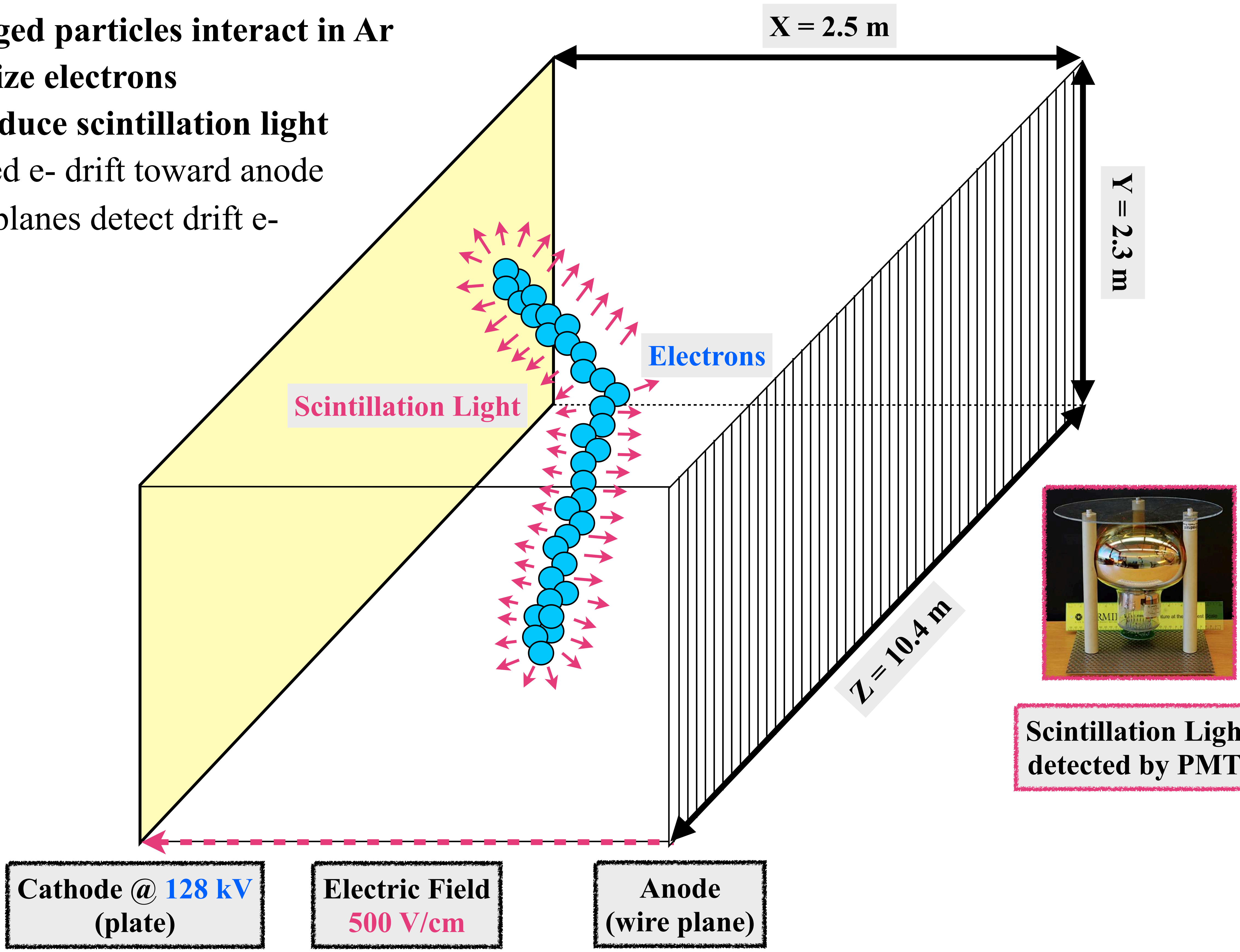
TPC Working Principle

1. **Charged particles interact in Ar**
    - Ionize electrons
    - Produce scintillation light
2. Ionized e- drift toward anode
3. Wire planes detect drift e-



TPC Working Principle

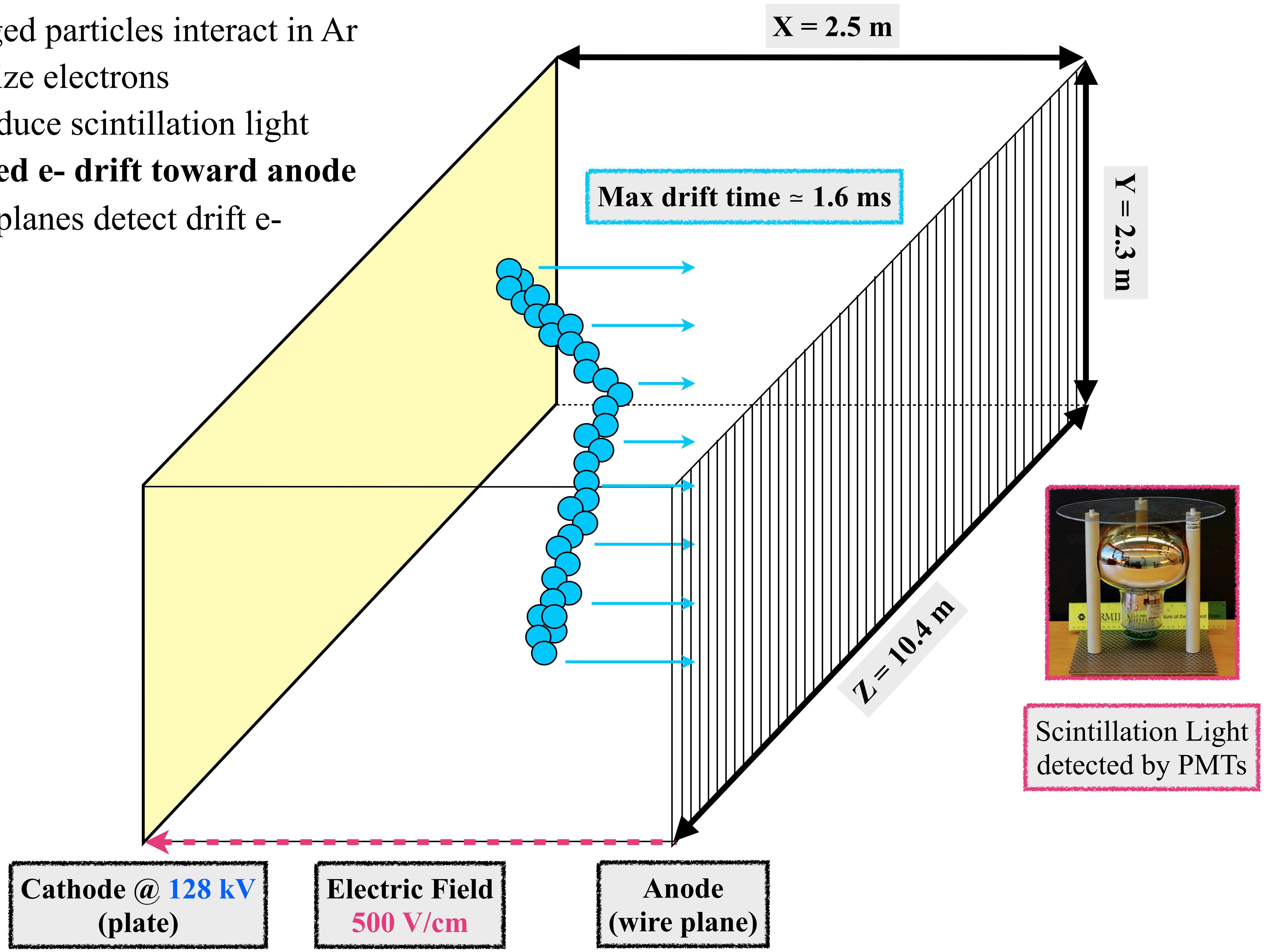
1. **Charged particles interact in Ar**
   - **Ionize electrons**
   - **Produce scintillation light**
2. Ionized e- drift toward anode
3. Wire planes detect drift e-



Scintillation Light detected by PMTs

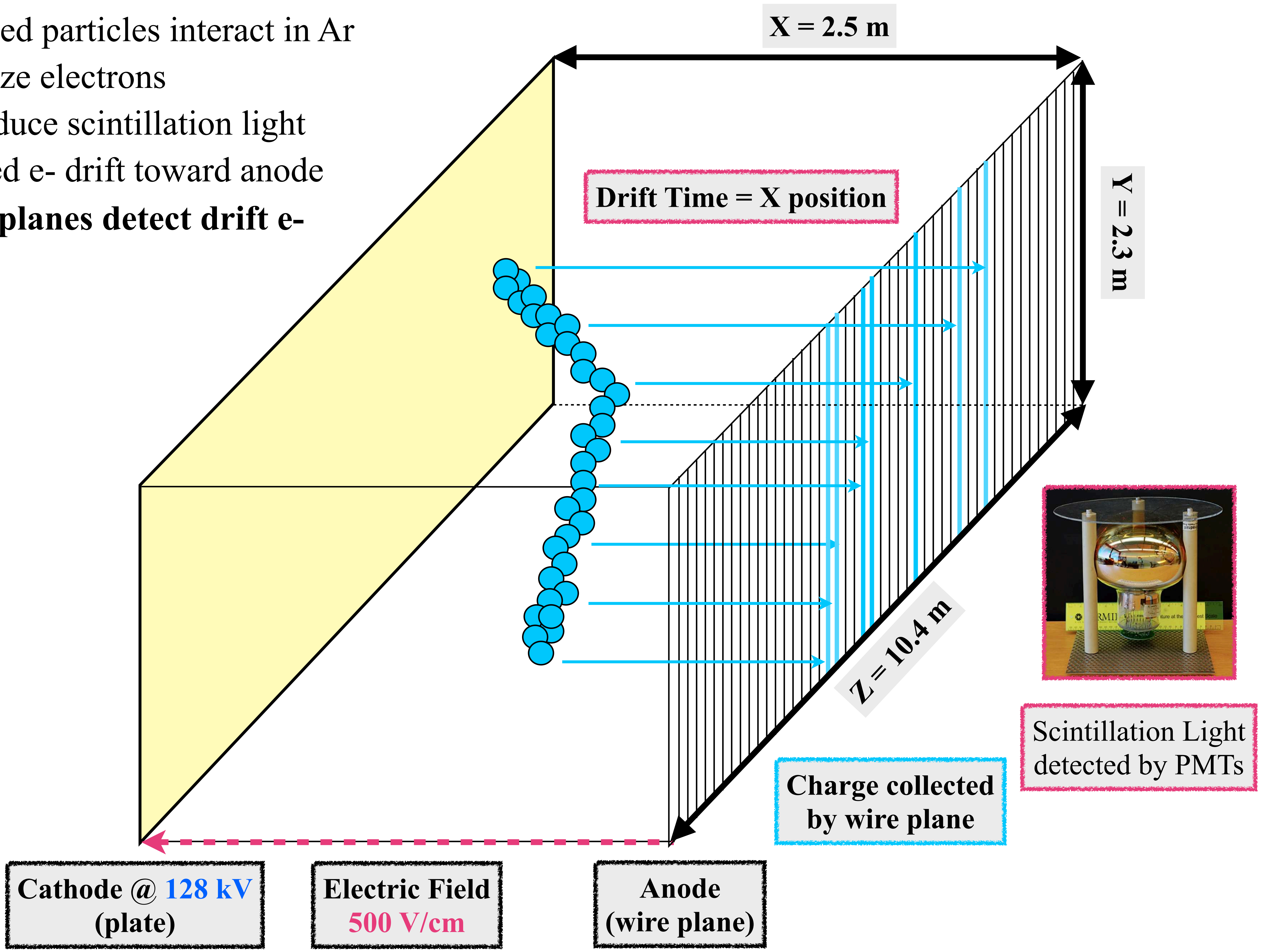
TPC Working Principle

1. Charged particles interact in Ar
   - Ionize electrons
   - Produce scintillation light
2. **Ionized e- drift toward anode**
3. Wire planes detect drift e-

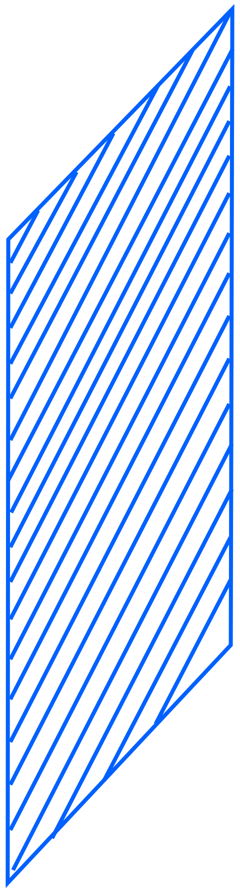


TPC Working Principle

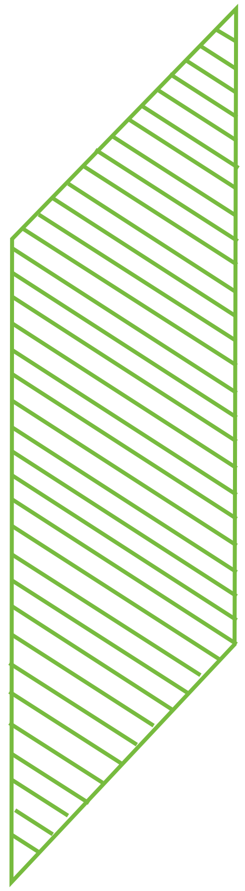
1. Charged particles interact in Ar
   - Ionize electrons
   - Produce scintillation light
2. Ionized e- drift toward anode
3. **Wire planes detect drift e-**



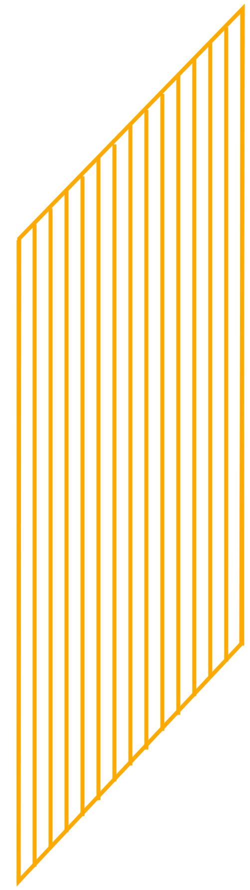
Three Wire Planes



U plane
(induction)

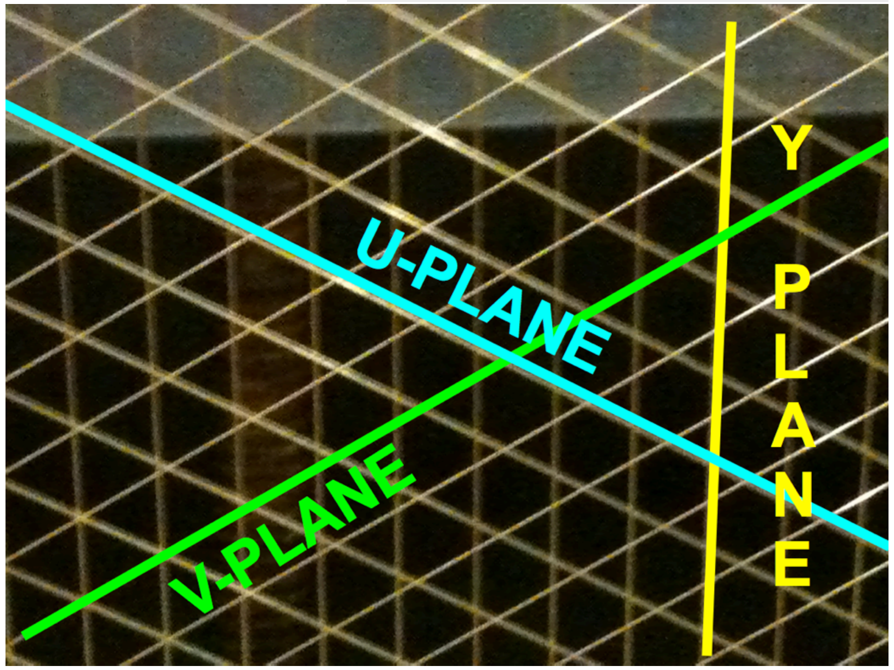


V plane
(induction)



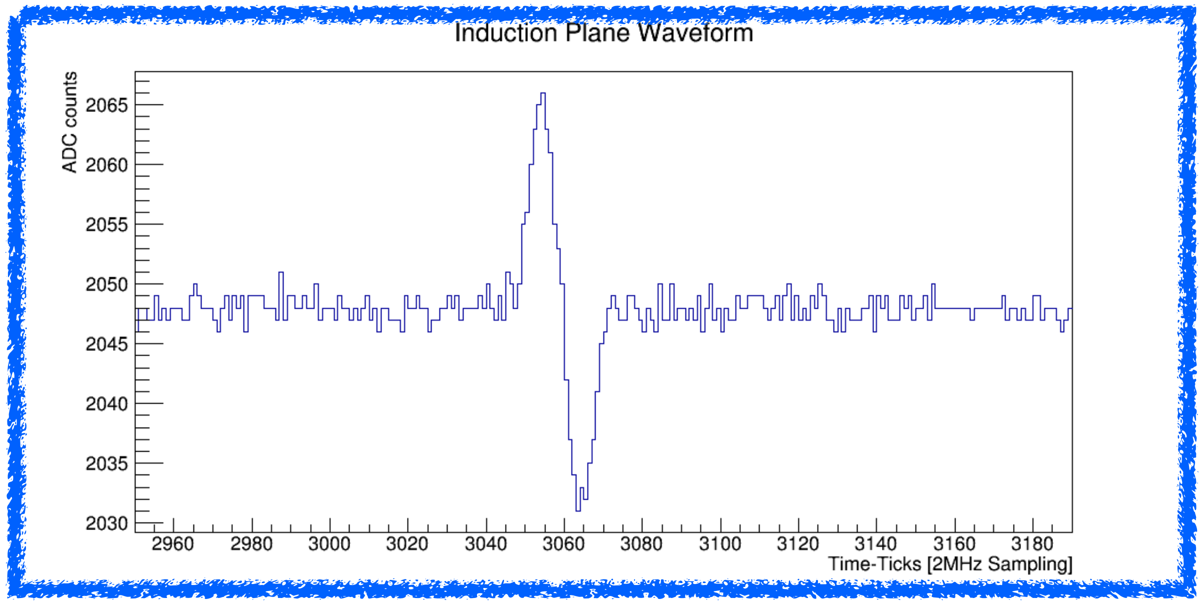
Y plane
(collection)

Picture courtesy of J. Assadi

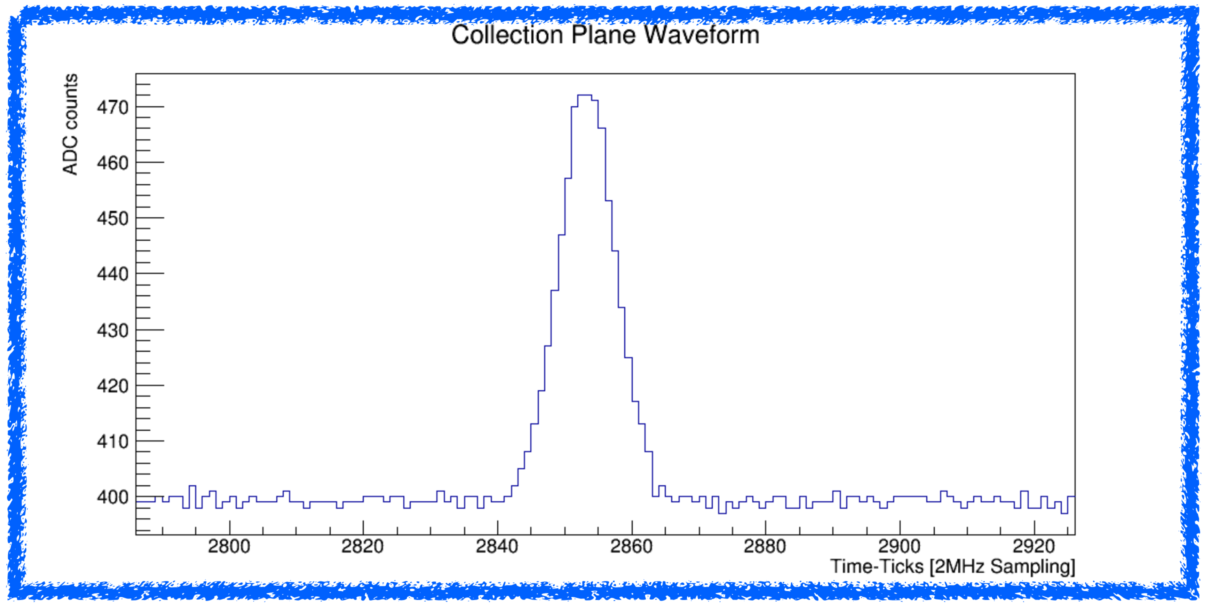


8256 wires w/ **pitch = 3mm**

(Y, Z) = coincidence on wire



Induction Plane MC Waveform
(Bi-polar pulse as e⁻ pass through)

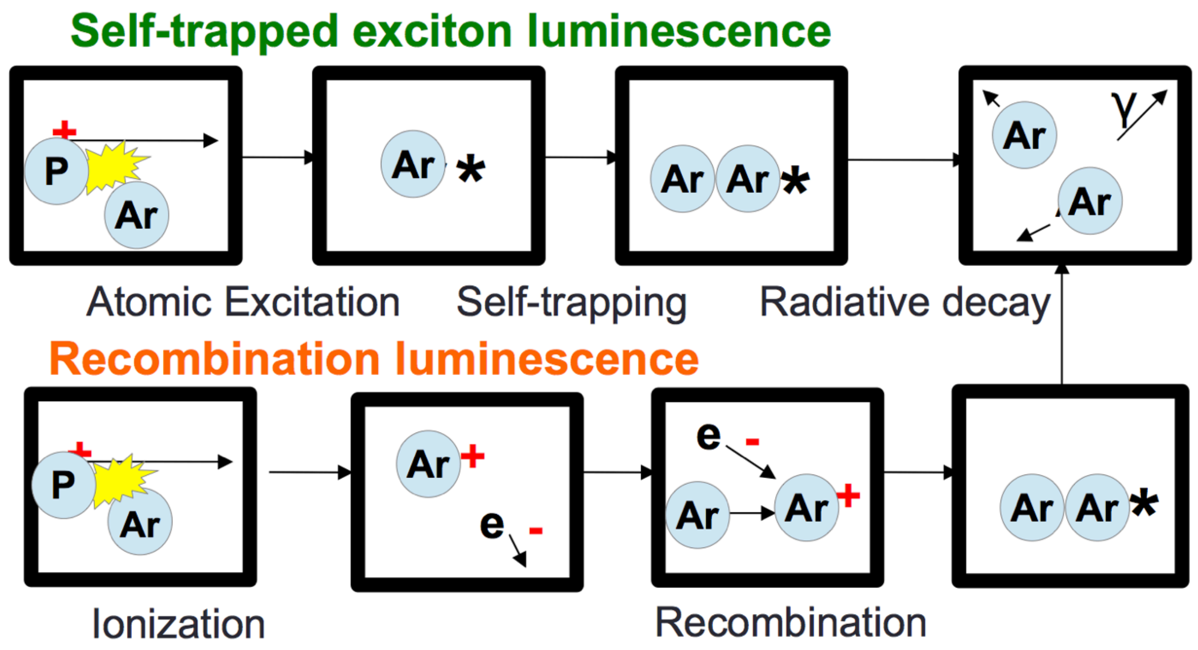


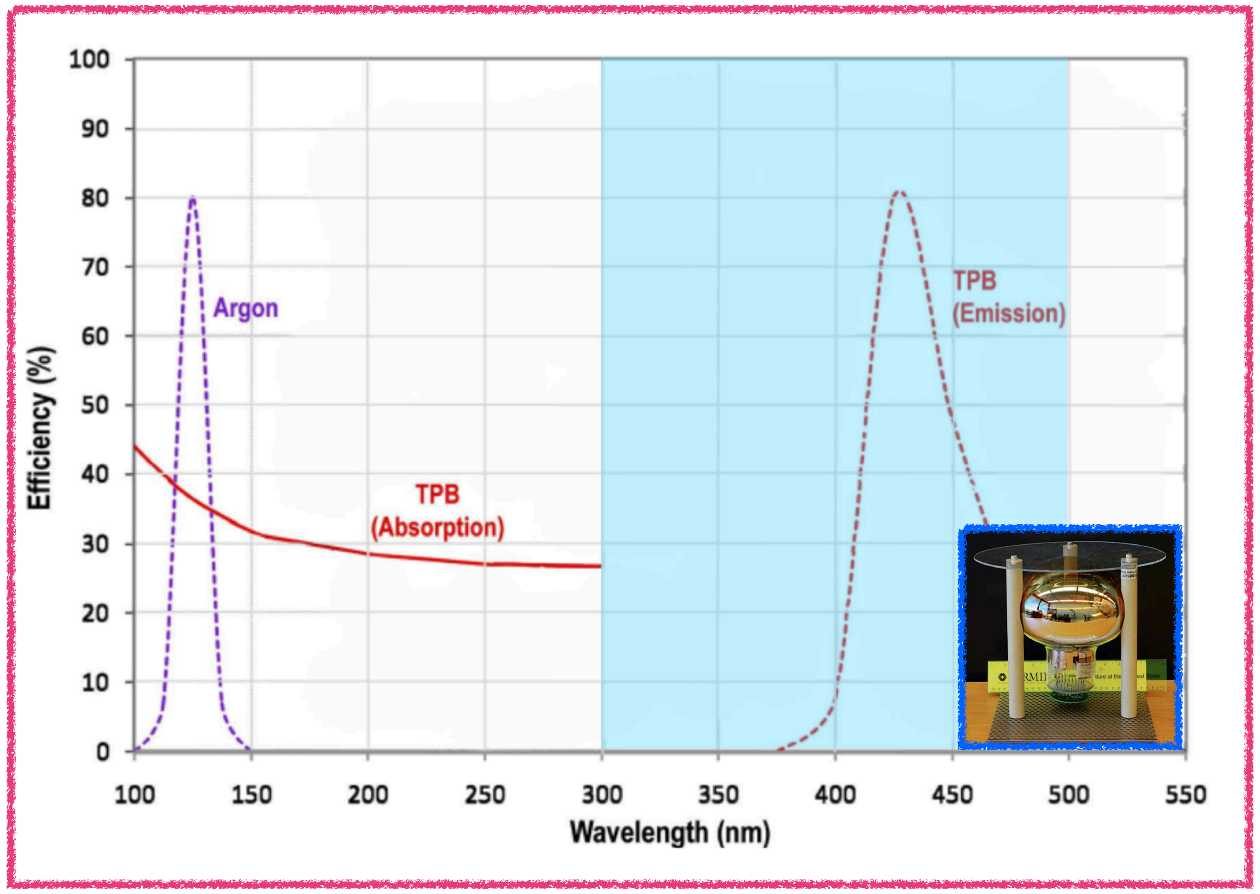
Collection Plane MC Waveform
(Uni-polar pulse as e⁻ pass through)

Optical Detector

- **LAr optical properties**
  - Two paths for light production
  - Two scintillation time constants
    - **singlet & triplet** ($\tau \simeq$ 6 ns & 1.6 μs)
  - **"Transparent" to its own light**
    - Wavelength shift by TPB
  - High light yield ≃ 4e4 / MeV

Image Credit: B. Jones

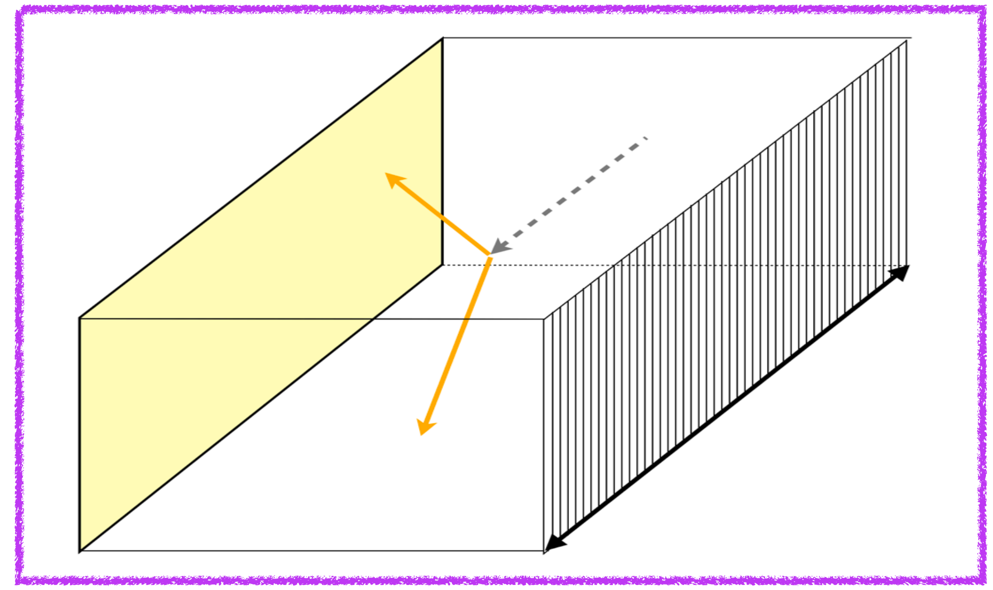




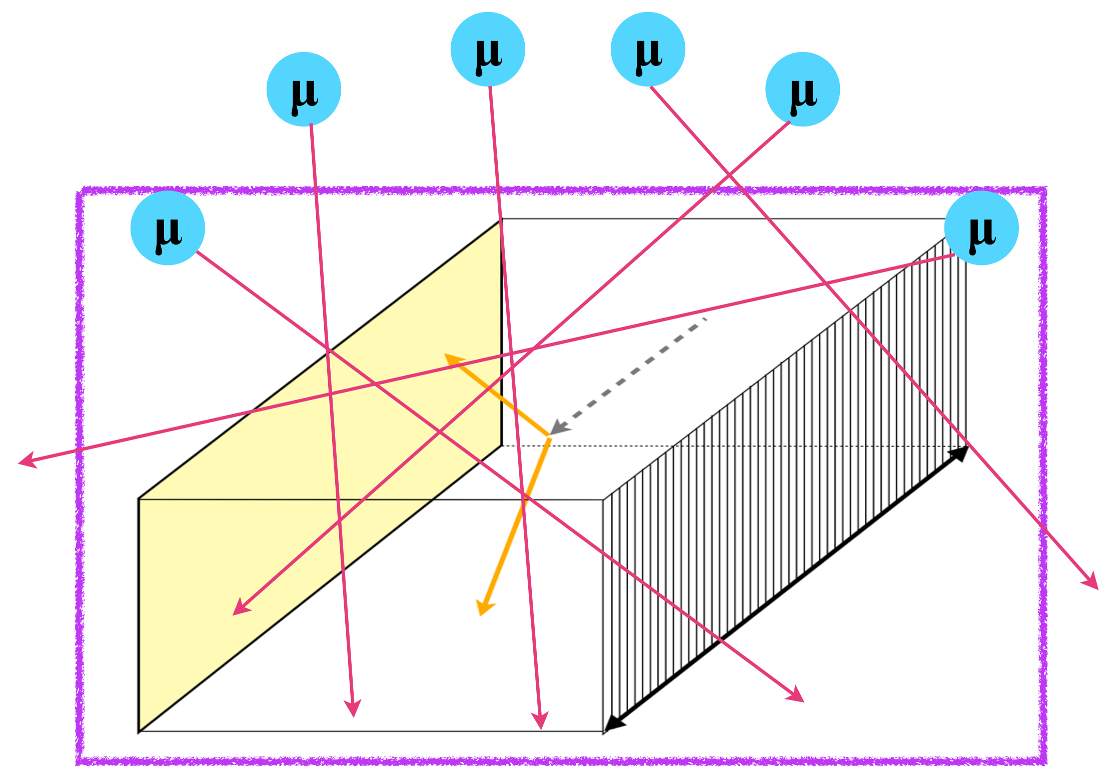
Optical Detector

- **LAr optical properties**
  - Two paths for light production
  - Two scintillation time constants
    - **singlet & triplet** (τ ≃ 6 ns & 1.6 μs)
  - **“Transparent” to its own light**
    - Wavelength shift by TPB
  - High light yield ≃ 4e4 / MeV
- **Optical Detector**
  - 32 of 8” PMTs
  - 3 important motivations
    - **Getting T0**
    - **Reconstructing YZ**
    - **Cosmic background rejection**

Crucial for MicroBooNE
because of
high cosmic ray rate (~5kHz) @ surface!



What we want

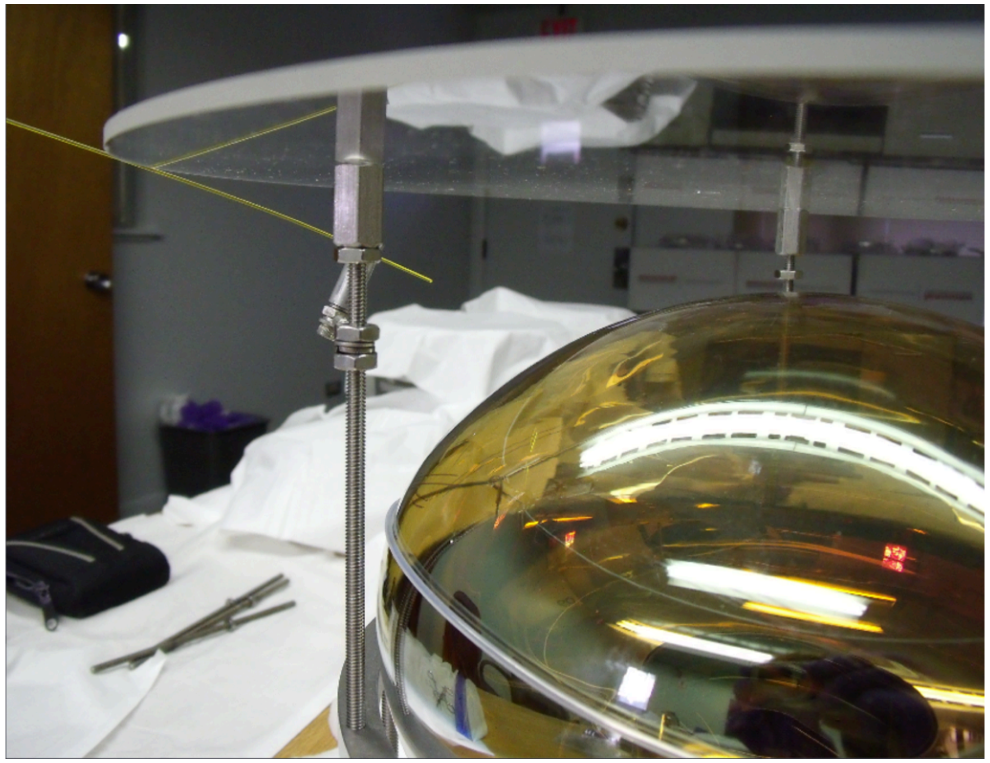


What we will have
several cosmics within
the **same drift time period (1.6 ms)**

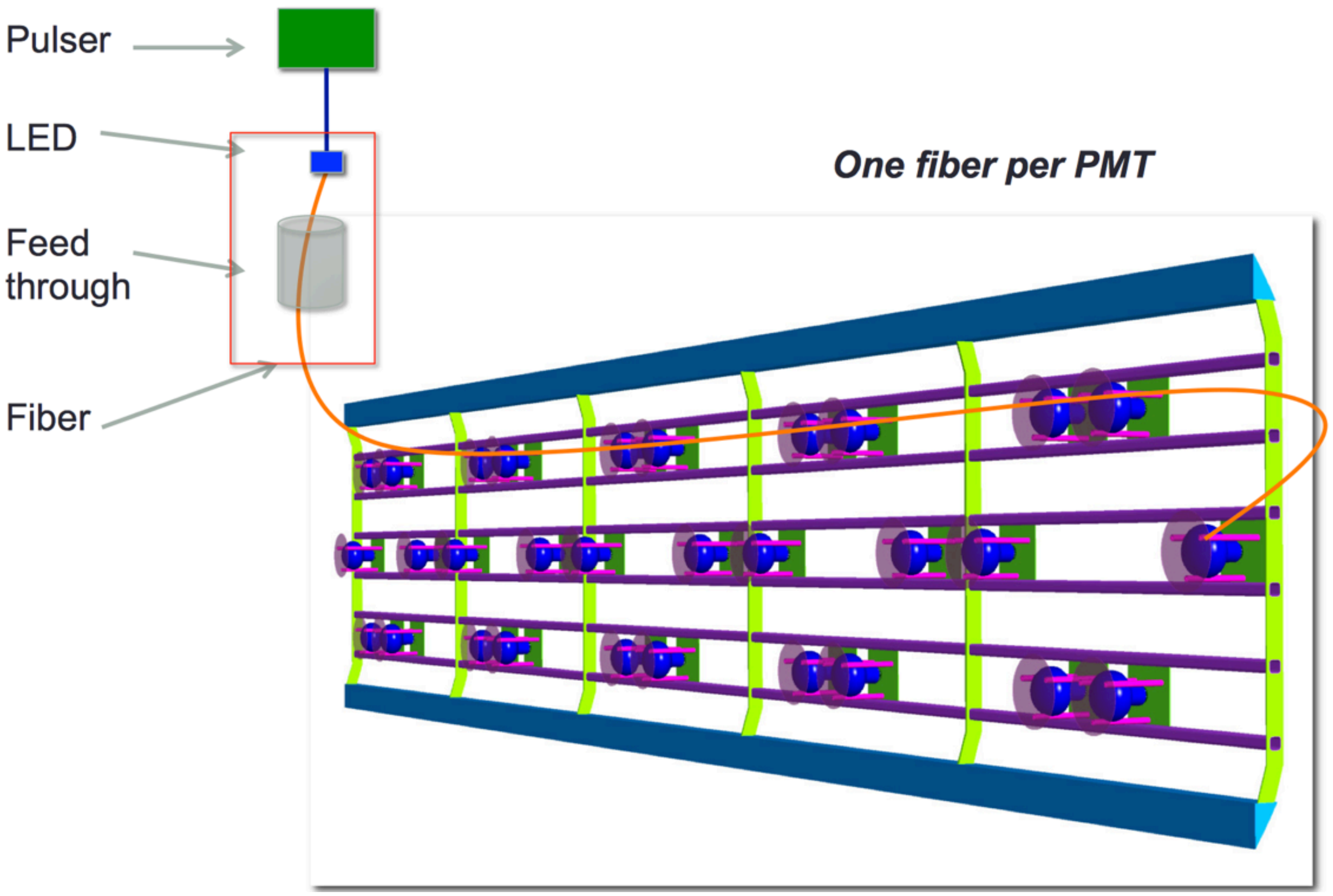
Optical Detector

Picture & drawings courtesy of B. Jones

- **LAr optical properties**
  - Two paths for light production
  - Two scintillation time constants
    - **singlet & triplet** ($\tau \simeq$ 6 ns & 1.6 μs)
  - **"Transparent" to its own light**
    - Wavelength shift by TPB
  - High light yield ≃ 4e4 / MeV



- **Optical Detector**
  - 32 of 8" PMTs
  - 3 important motivations
    - **Getting T0**
    - **Reconstructing YZ**
    - **Cosmic background rejection**



- **PMT Calibration**
  - LED flasher system
    - Gain & T0 calibration

Why LAr?

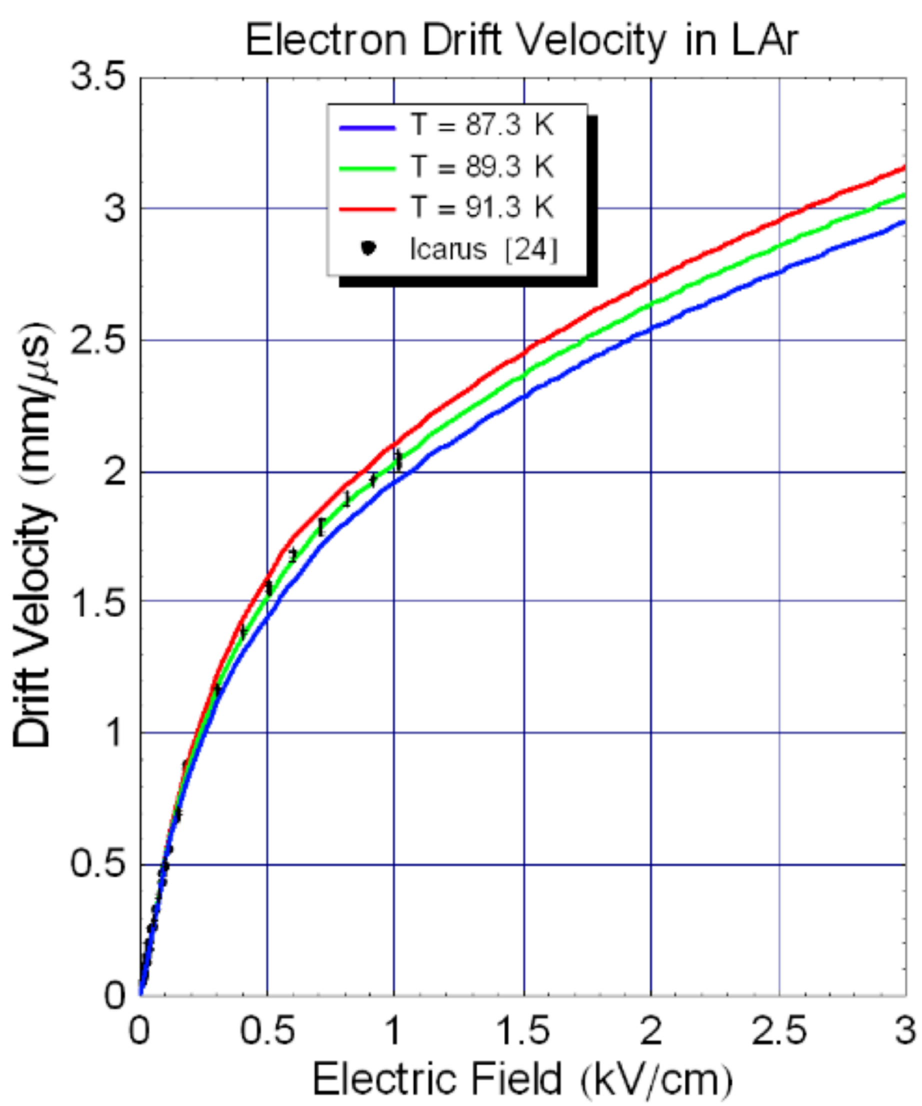
	He	Ne	Ar	Kr	Xe	Water
Boiling Point [K] @ 1atm	4.2	27.1	87.3	120.0	165.0	373
Density [g/cm^3]	0.125	1.2	1.4	2.4	3.0	1
Radiation Length [cm]	755.2	24.0	14.0	4.9	2.8	36.1
dE/dx [MeV/cm]	0.24	1.4	2.1	3.0	3.8	1.9
Scintillation [γ /MeV]	19,000	30,000	40,000	25,000	42,000	
Scintillation λ [nm]	80	78	128	150	175	
Price	$\simeq$ \$10/L	$\simeq$ \$500/L	$\simeq$ \$2/L	$\simeq$ \$700/L	$\simeq$ \$3000/L	

Table ... Courtesy of M. Soderberg
Price Range ... Courtesy of J. Asaadi

It's **dense, easily ionizable, has high light yield, and cheap!**

LArTPC: Temperature & HV

- **Stability** ... key for stable operation & detector systematics
  - Argon **temperature** and **HV**
  - LAr purity (later slide)



Temperature & Electric field affect **drift velocity**!

Drift velocity depends on **T** & |***E***|

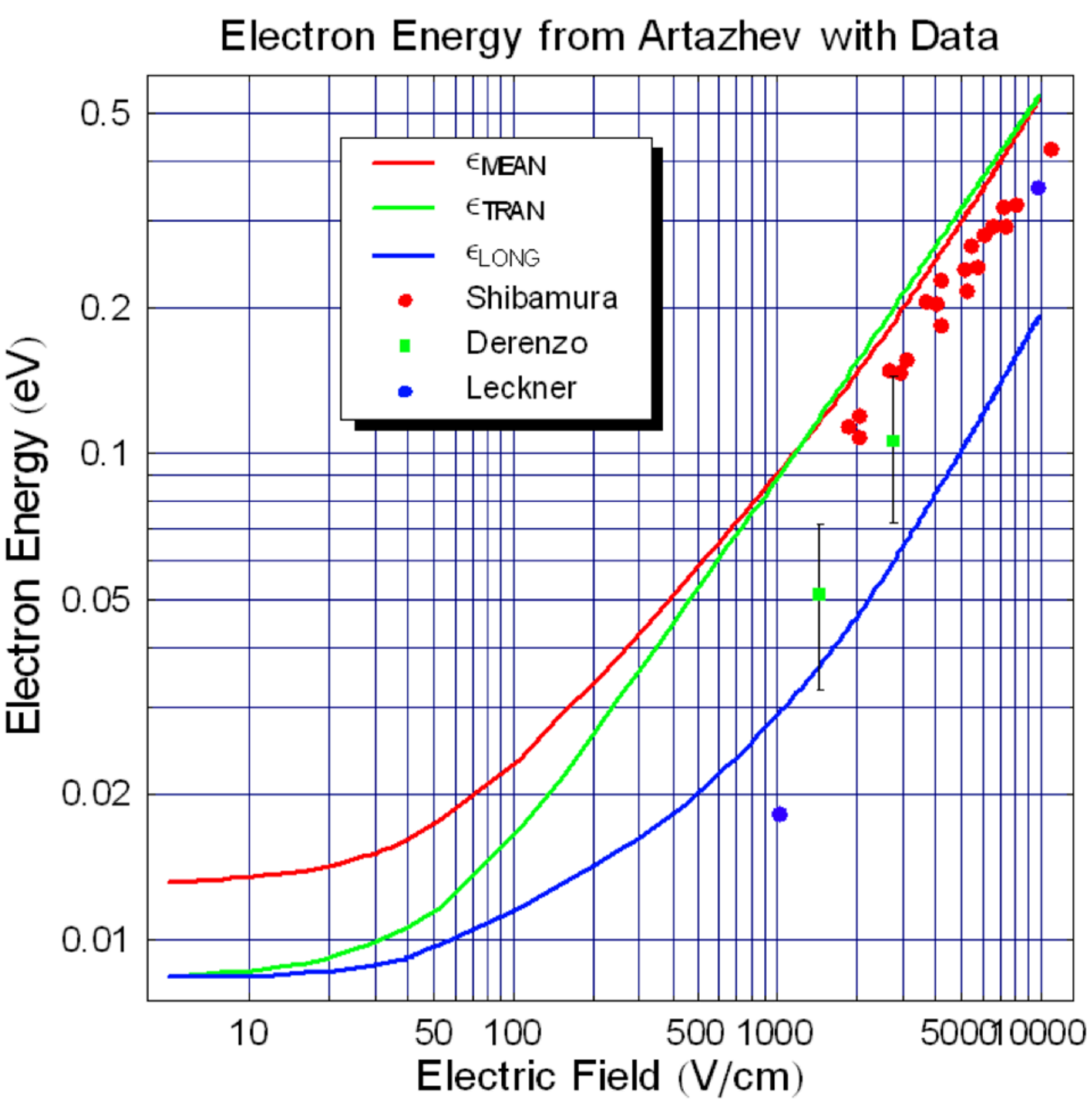
$$v_d(T,|\boldsymbol{E}|) = (P_1(T-T_0)+1)\left(P_3|\boldsymbol{E}|\ln\left(1+\frac{P_4}{|\boldsymbol{E}|}\right)+P_5|\boldsymbol{E}|^{P_6}\right)+P_2(T-T_0).$$

W. Walkowiak NIM A449 p.288 (2000)

which **affects measurement of X position**

LArTPC: Temperature & HV

- **Stability** ... key for stable operation & detector systematics
  - Argon **temperature** and **HV**
  - LAr purity (later slide)



Electric Field
affects **Electron Energy**

Drift velocity depends on **T** & $|E|$

$$v_d(T,|E|) = (P_1(T-T_0)+1)\left(P_3|E|\ln\left(1+\frac{P_4}{|E|}\right)+P_5|E|^{P_6}\right)+P_2(T-T_0).$$

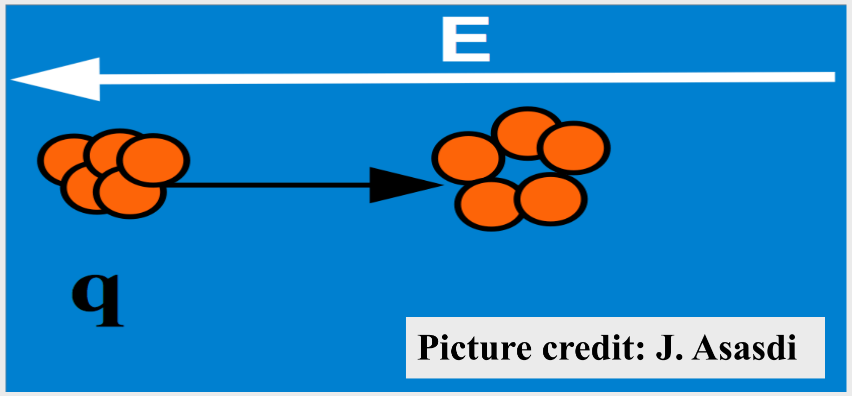
W. Walkowiak NIM A449 p.288 (2000)

which **affects measurement of X position**

Diffusion (σ) depends on **drift distance** & $|E|$

$$\sigma = \sqrt{\frac{2\varepsilon z}{E}}$$

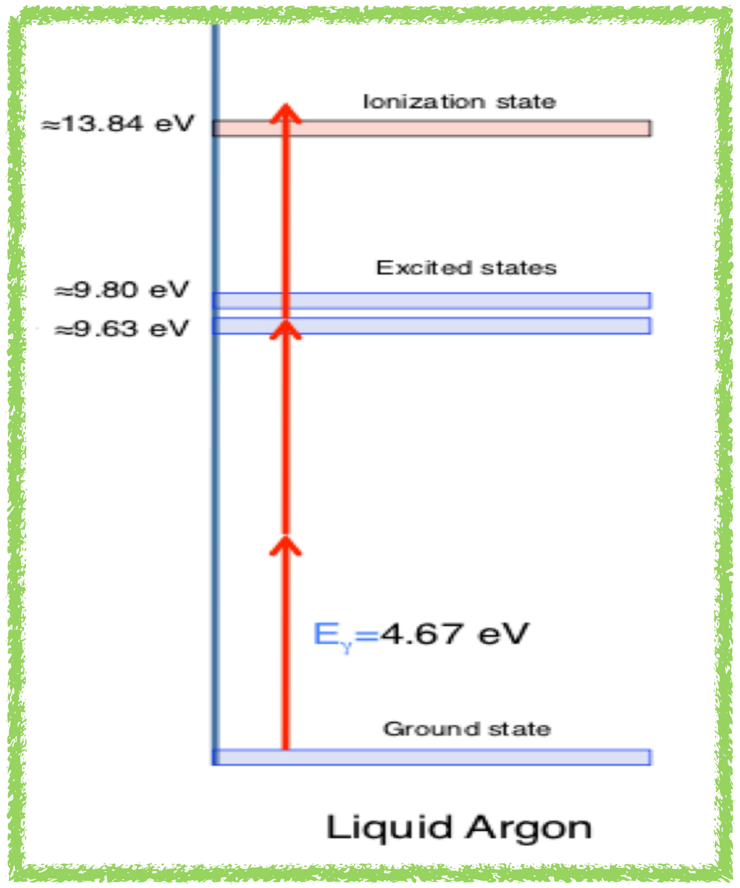
ε : electron energy
z : drift distance
E: field strength



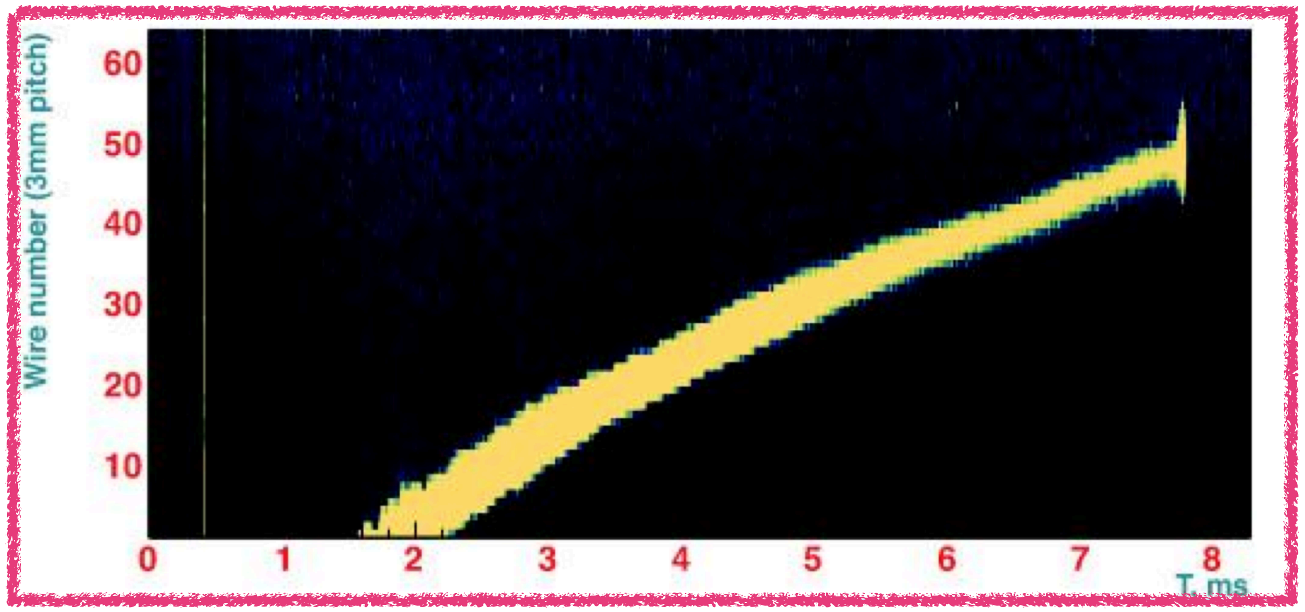
Temperature & HV are keys to understand detector response

Electric Field Uniformity

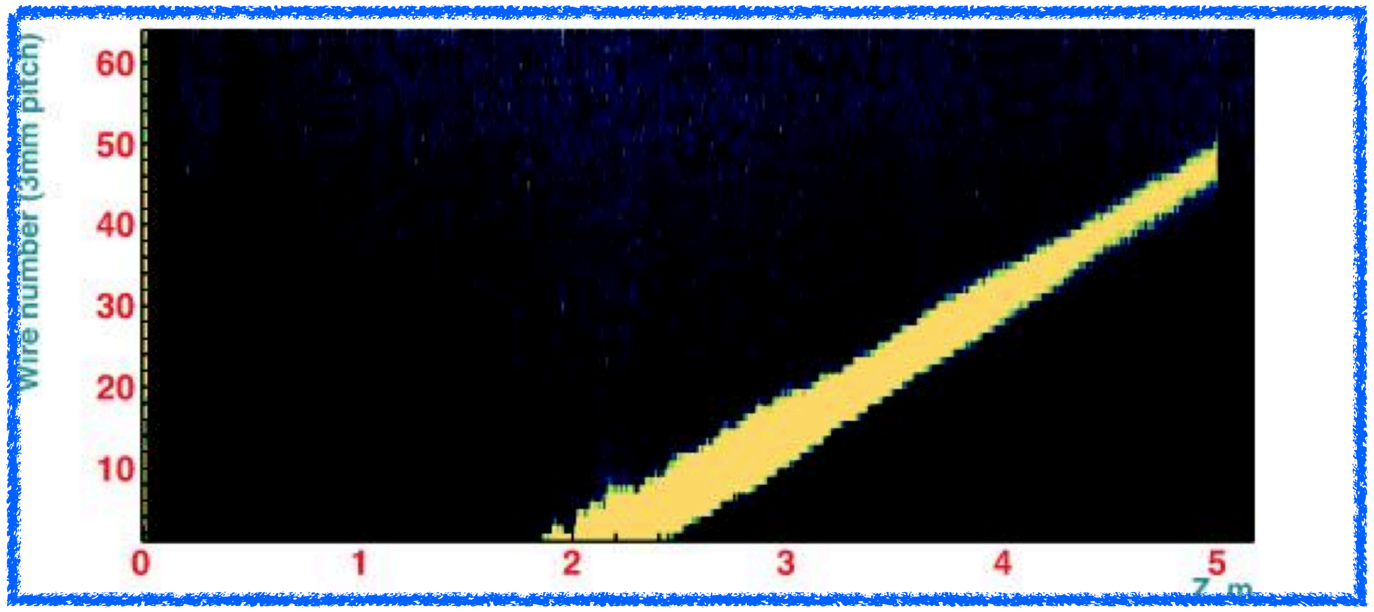
- Field non-uniformity arise
  - Distortion expected by Ar^+ accumulation @ cathode
  - Needs to be calibrated out
- Laser Calibration System (LCS)
- LCS inject laser to ionize Ar along the path
  - λ ≅ 266 nm, need high intensity to ionize
  - Distortion shows up in the reconstructed signal path



Plot & Diagram ... courtesy of C. Rudolf



Laser path @ ArgonTube
(**Uncalibrated**)

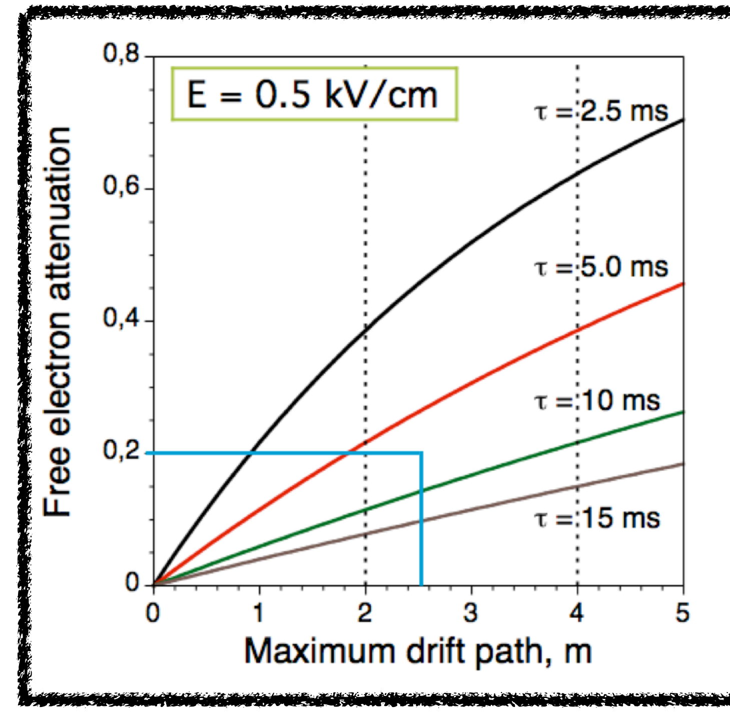


Laser path @ ArgonTube
(**Calibrated**)

LAr Purity

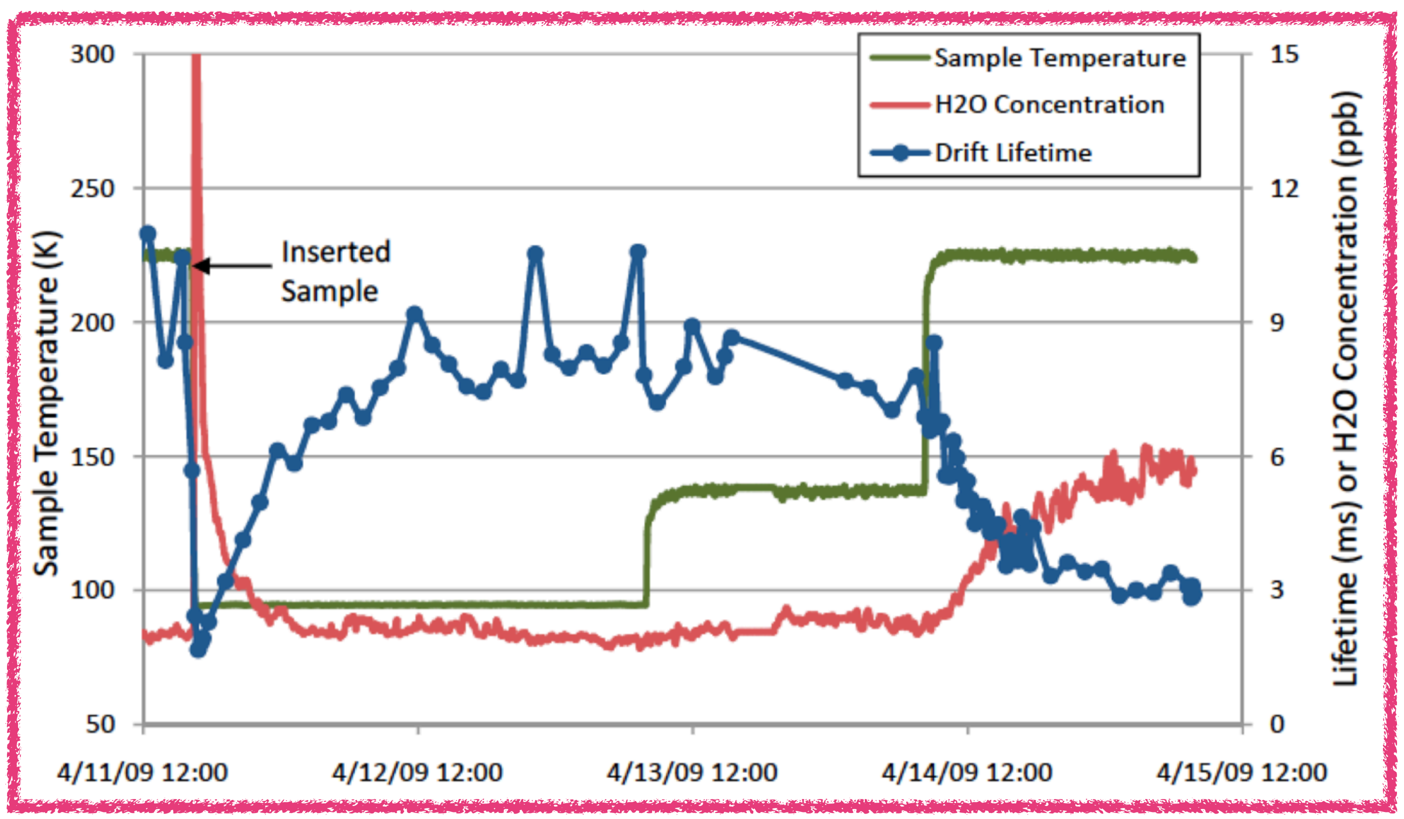
- High purity LAr necessary for 2.5 m drift!
  - Water & Oxygen affect **electron lifetime**
    - shorter lifetime = larger attenuation
  - Nitrogen causes **scintillation light quenching**
  - Goal: O_2 < 100 ppt & N_2 < 1 ppm

From C. Montanari, June 2007



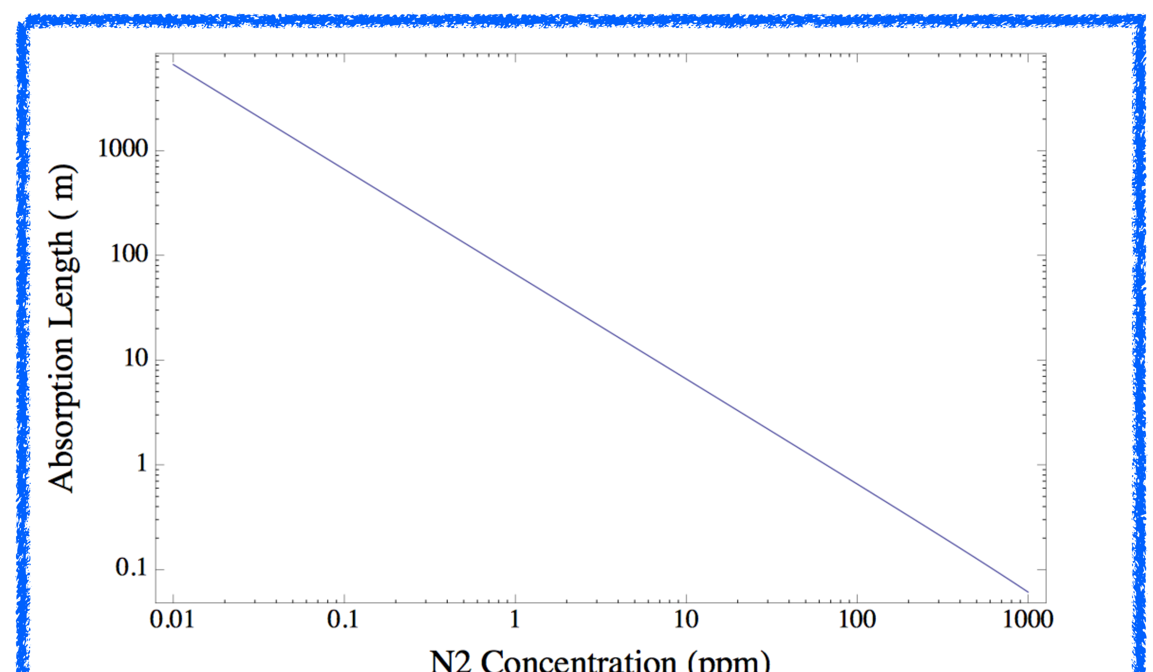
τ_e & e^- attenuation

Example
H_2O Conc. vs. Lifetime



NIM A605, 306 (2009)

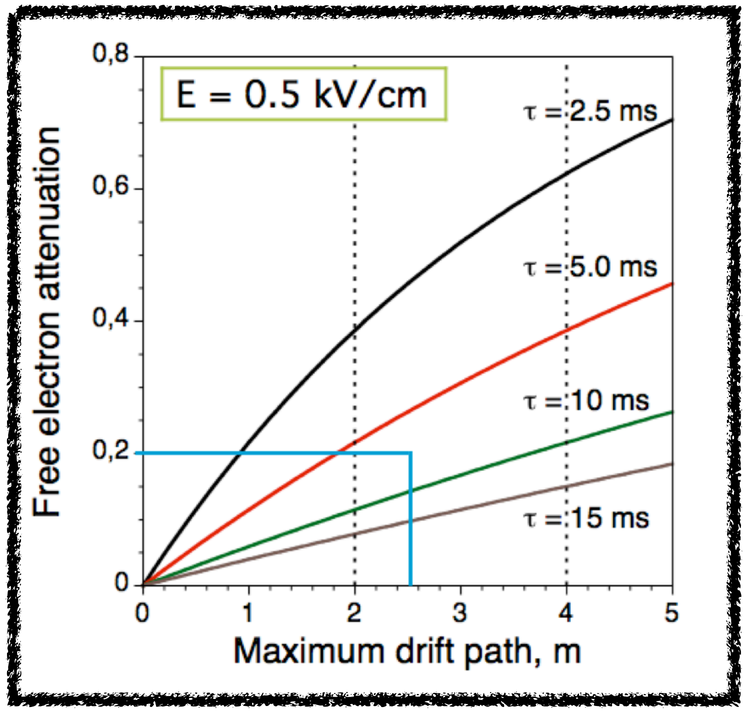
arxiv 1306.4605



Example
N_2 Conc. vs. Light Attenuation

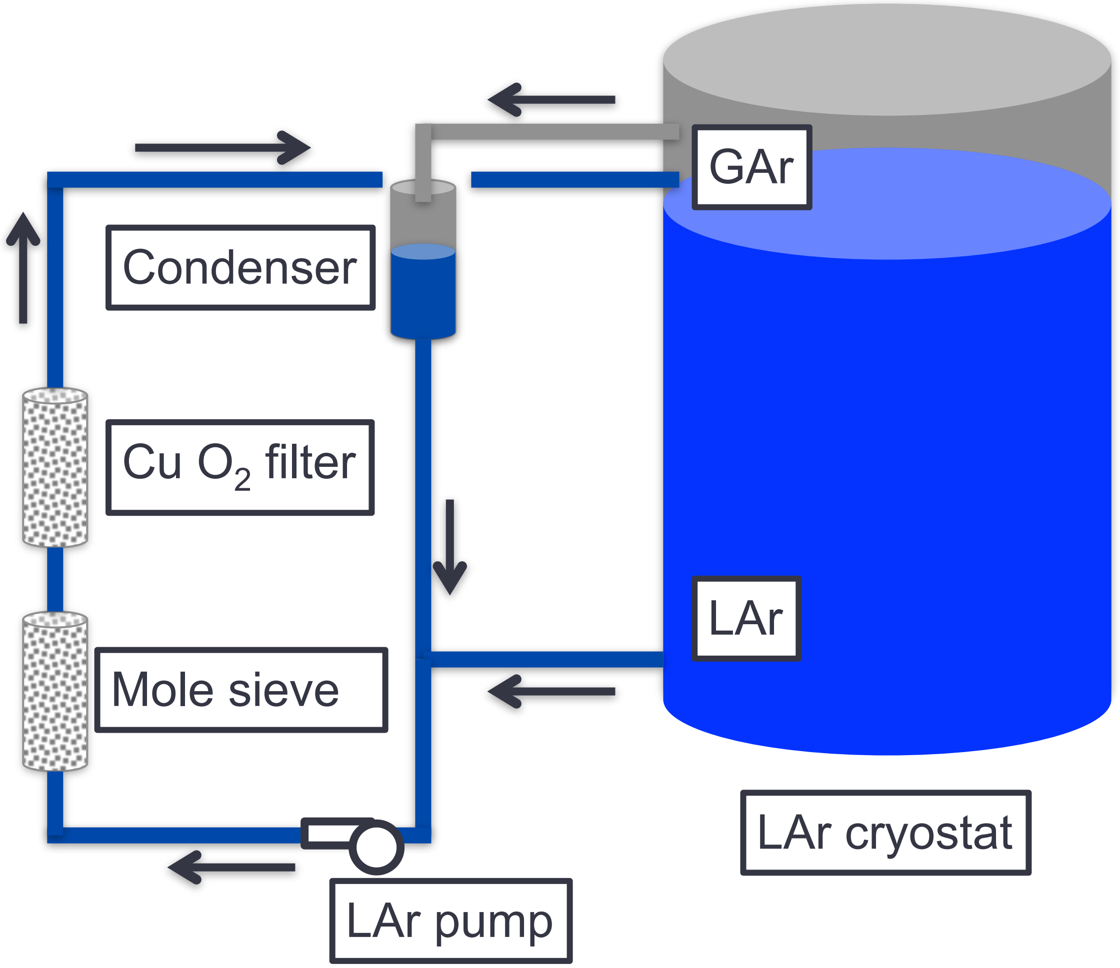
LAr Purity

From C. Montanari, June 2007



τ_e & e^- attenuation

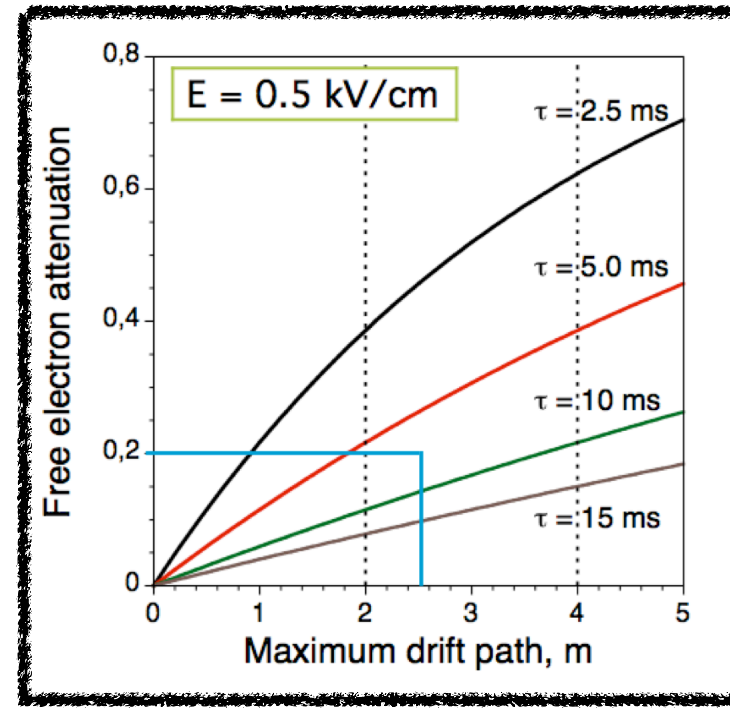
- High purity LAr necessary for 2.5 m drift!
  - Water & Oxygen affect **electron lifetime**
    - shorter lifetime = larger attenuation
  - Nitrogen causes **scintillation light quenching**
  - Goal: O_2 < 100 ppt & N_2 < 1 ppm
- Filling & Purification System ... LAPD
  - **Purge the detector with GAr first**
    - Evacuating a large TPC volume is not very practical



LAr Purity

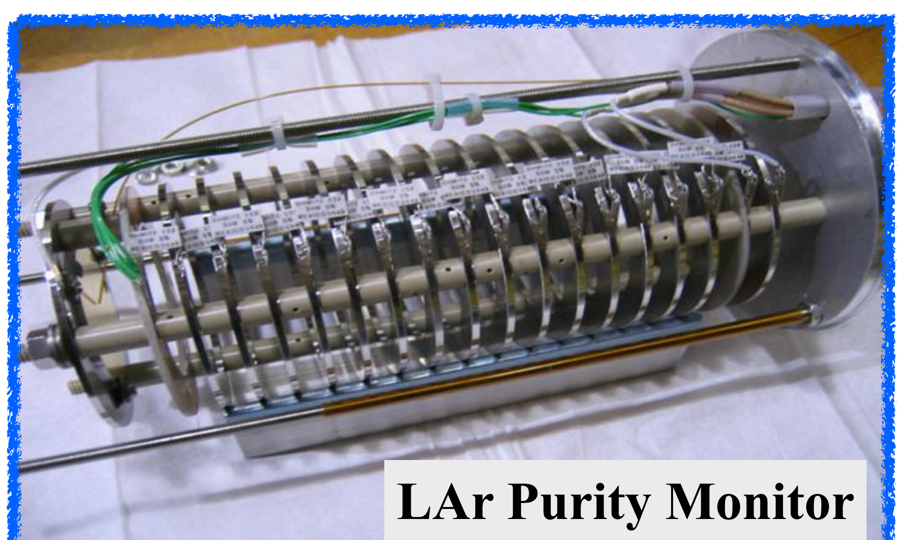
From C. Montanari, June 2007

- High purity LAr necessary for 2.5 m drift!
  - Water & Oxygen affect **electron lifetime**
    - shorter lifetime = larger attenuation
  - Nitrogen causes **scintillation light quenching**
  - Goal: O_2 < 100 ppt & N_2 < 1 ppm



τ_e & e^- attenuation

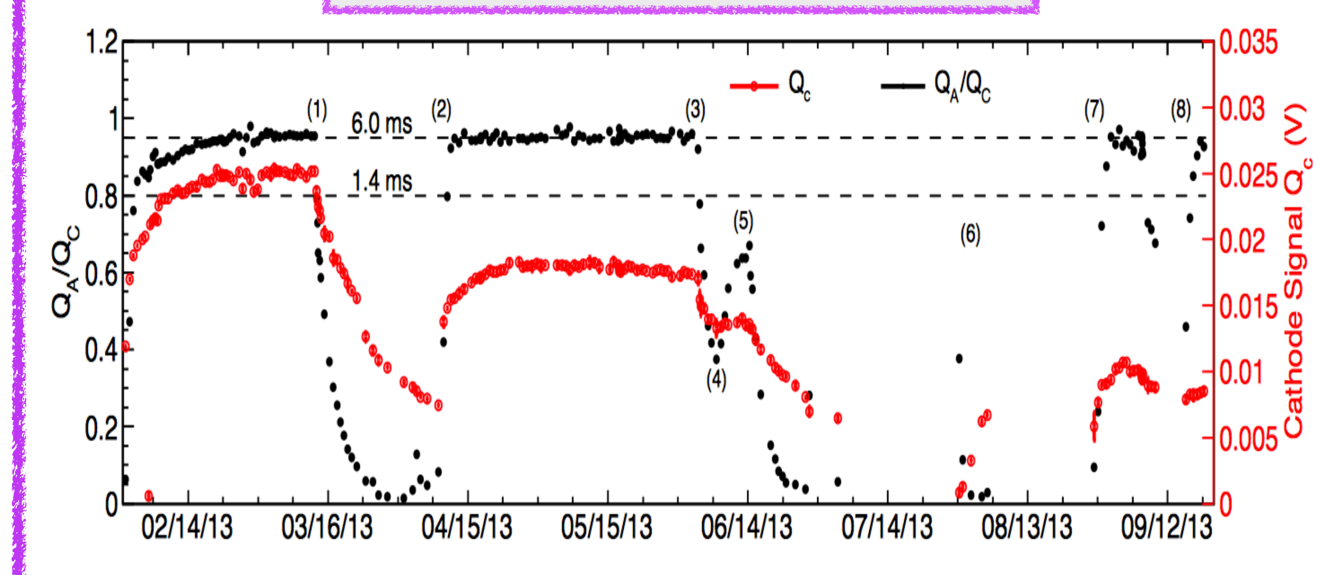
- Filling & Purification System ... LAPD
  - **Purge the detector with GAr first**
    - Evacuating a large TPC volume is not very practical
- LAr Purity Monitor ... field cage w/ cathode & anode (design from ICARUS)
  - Xe flash lamp to liberate electrons
    - $Q_{anode}/Q_{cathode}$ tells us τ_e



LAr Purity Monitor

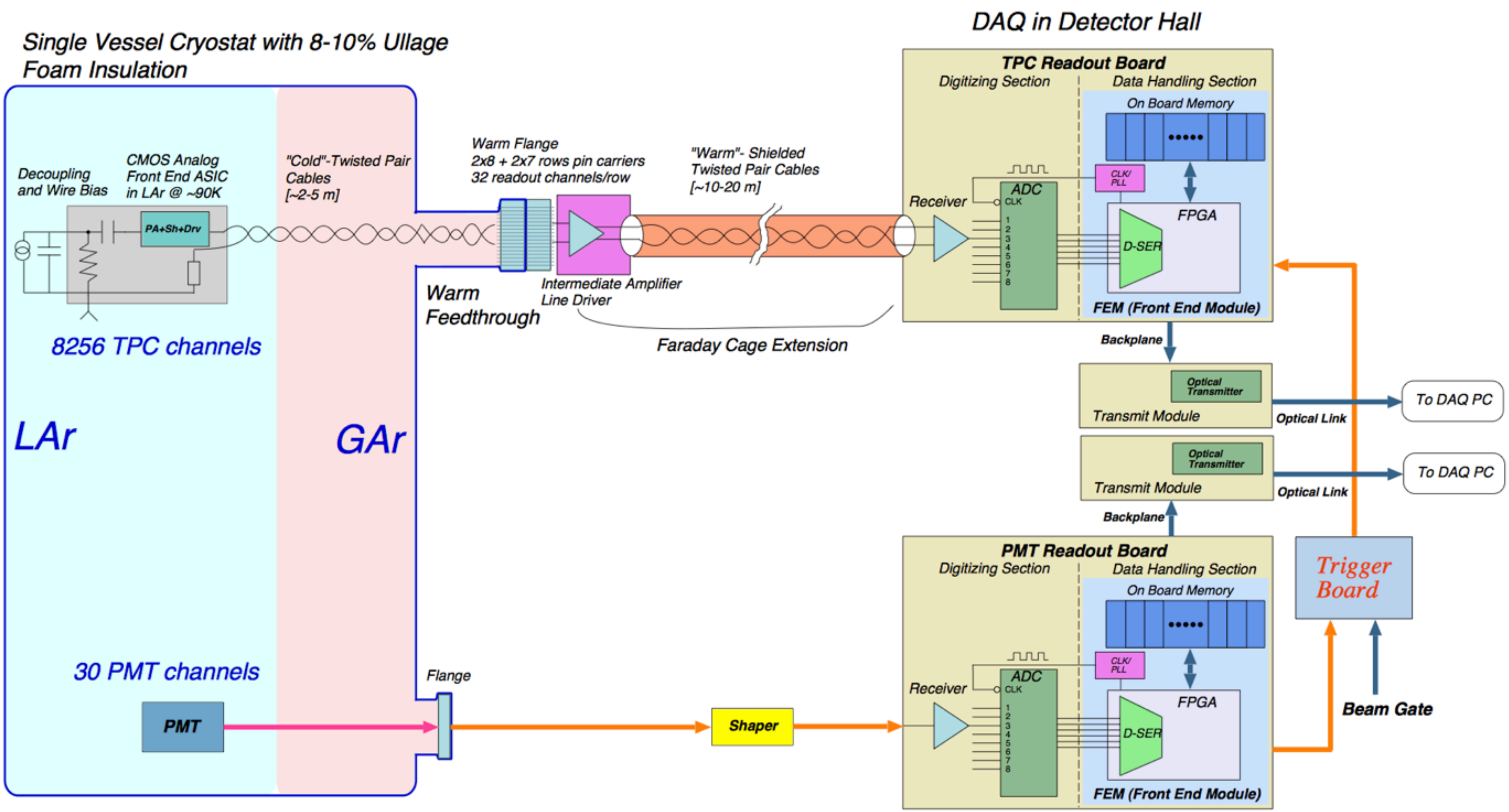
Demonstrated & Works

$\tau_e \simeq$ **6ms** for many weeks!



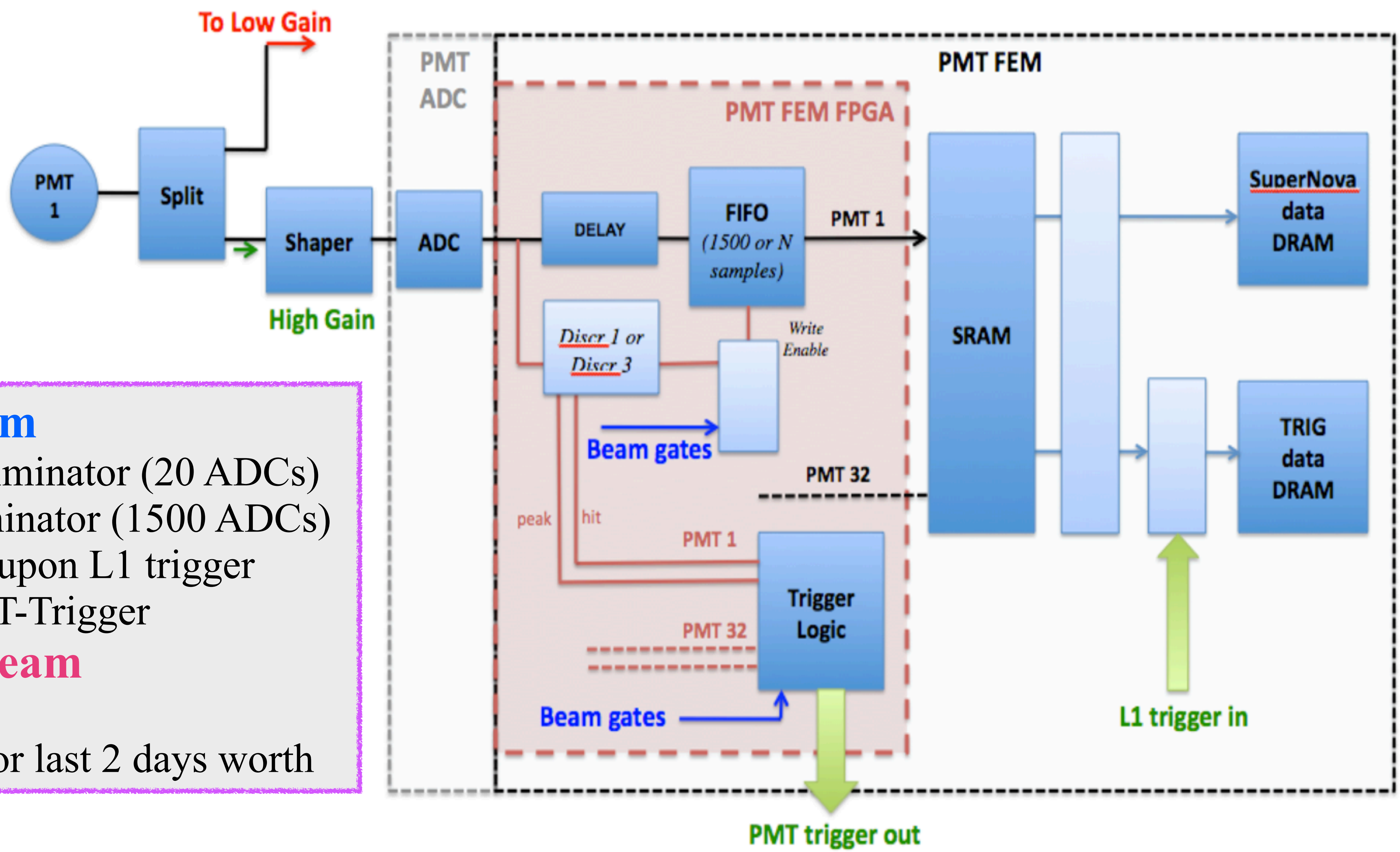
Cold Readout

- **Reading signal from LAr**
  - "**Cold electronics**" (by BNL) resides in LAr (reduced noise)
    - first stage amplification & shaping of signal
  - "**Warm electronics**" (by Nevis) resides in DAQ racks
    - Trigger & signal readout



Warm Readout

- **Optical detector readout**
  - "High" & "Low" gain ... 32 x 2 channels digitized @ 64 MHz
  - Two readout stream to store waveform using discriminator logic
    - **Neutrino** (triggered readout)
    - **SuperNova** (continuous)



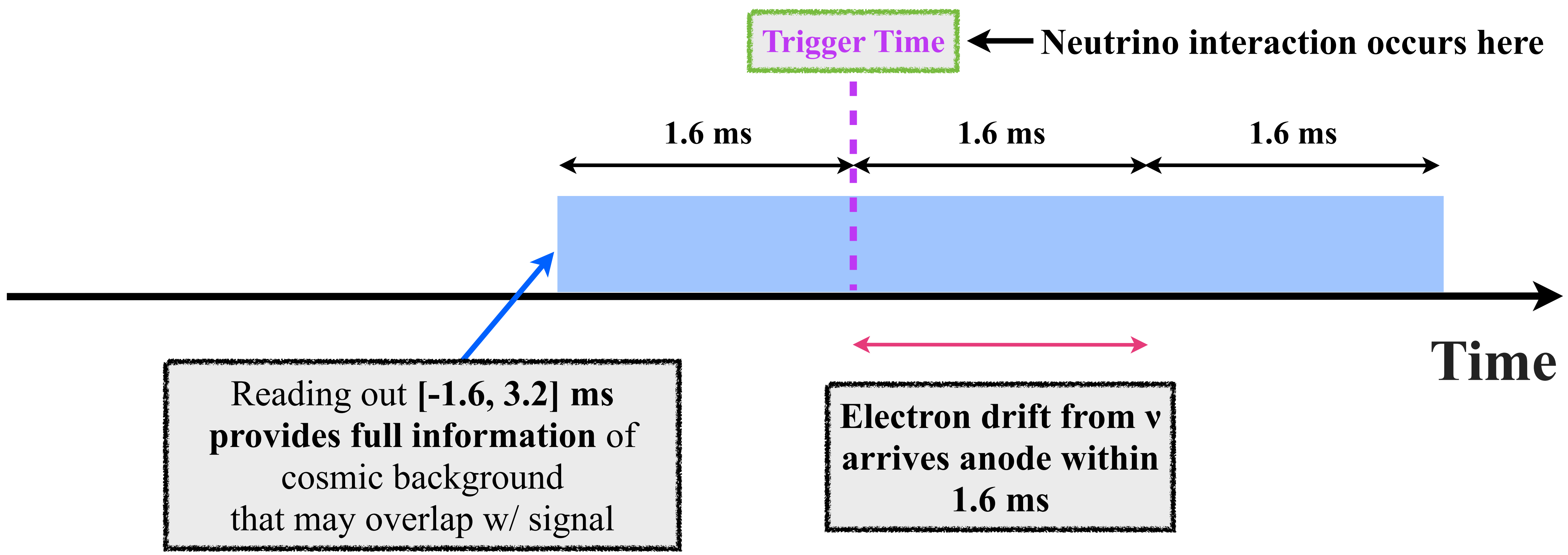
Neutrino stream
- Cosmic discriminator (20 ADCs)
- Beam discriminator (1500 ADCs)
- Stored based upon L1 trigger
- Generate PMT-Trigger

SuperNova stream
- Continuous
- Stored only for last 2 days worth

Warm Readout

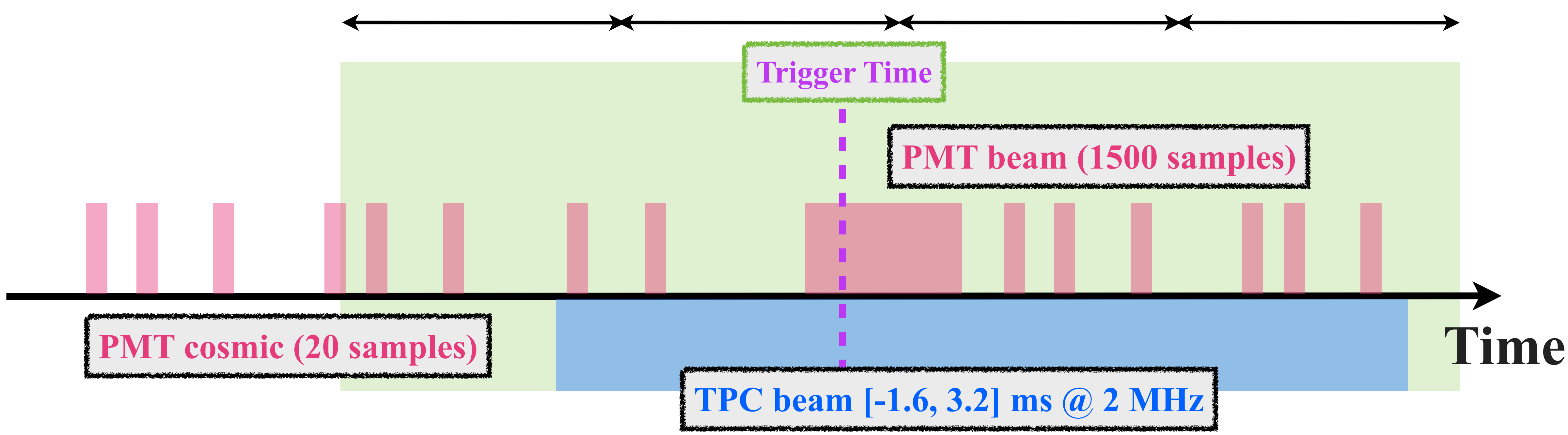
- Optical detector readout
  - "High" & "Low" gain ... 32 x 2 channels digitized @ 64 MHz
  - Two readout stream to store waveform using discriminator logic
    - **Neutrino** (triggered readout)
    - **SuperNova** (continuous)

- **TPC readout**
  - 8256 channels digitized @ 2 MHz ... **Neutrino** & **SuperNova** readout stream
    - **Neutrino** records [-1.6, 3.2] ms upon trigger
    - **SuperNova** records every 1.6 ms

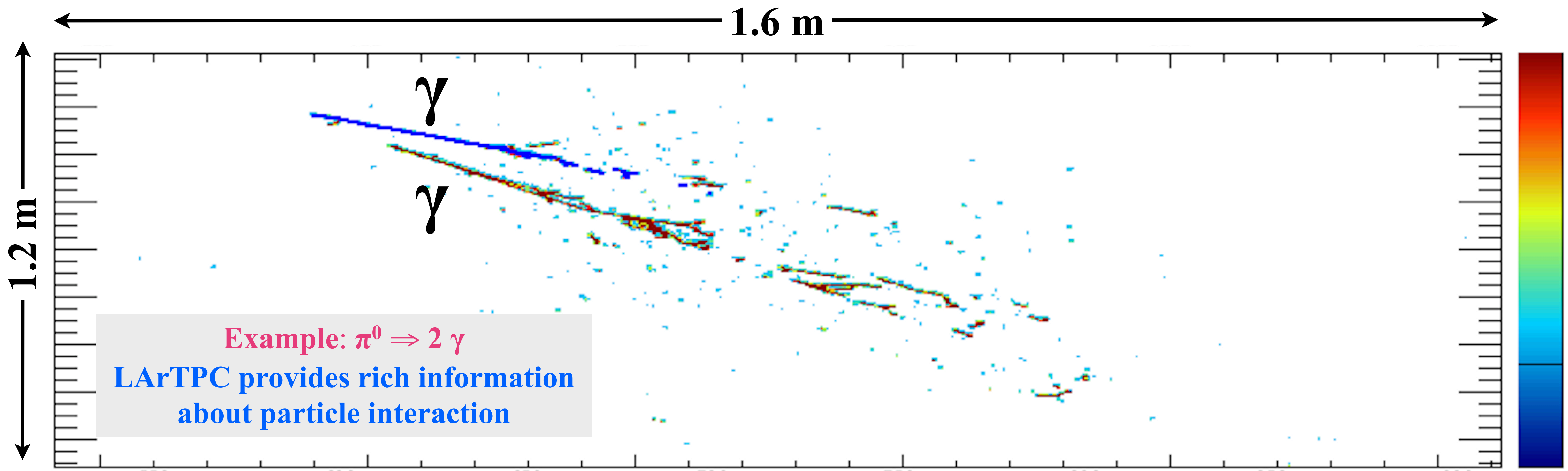


Warm Readout

- Optical detector readout
  - "High" & "Low" gain ... 32 x 2 channels digitized @ 64 MHz
  - Two readout stream to store waveform using discriminator logic
    - **Neutrino** (triggered readout)
    - **SuperNova** (continuous)
- TPC readout
  - 8256 channels digitized @ 2 MHz ... **Neutrino** & **SuperNova** readout stream
    - **Neutrino** records [-1.6, 3.2] ms upon trigger
    - **SuperNova** records every 1.6 ms
- **Trigger**
  - Readout **4 x 1.6 ms frames @ coincidence of beam pulse & PMT-Trigger**



... When All Work Out Well ....



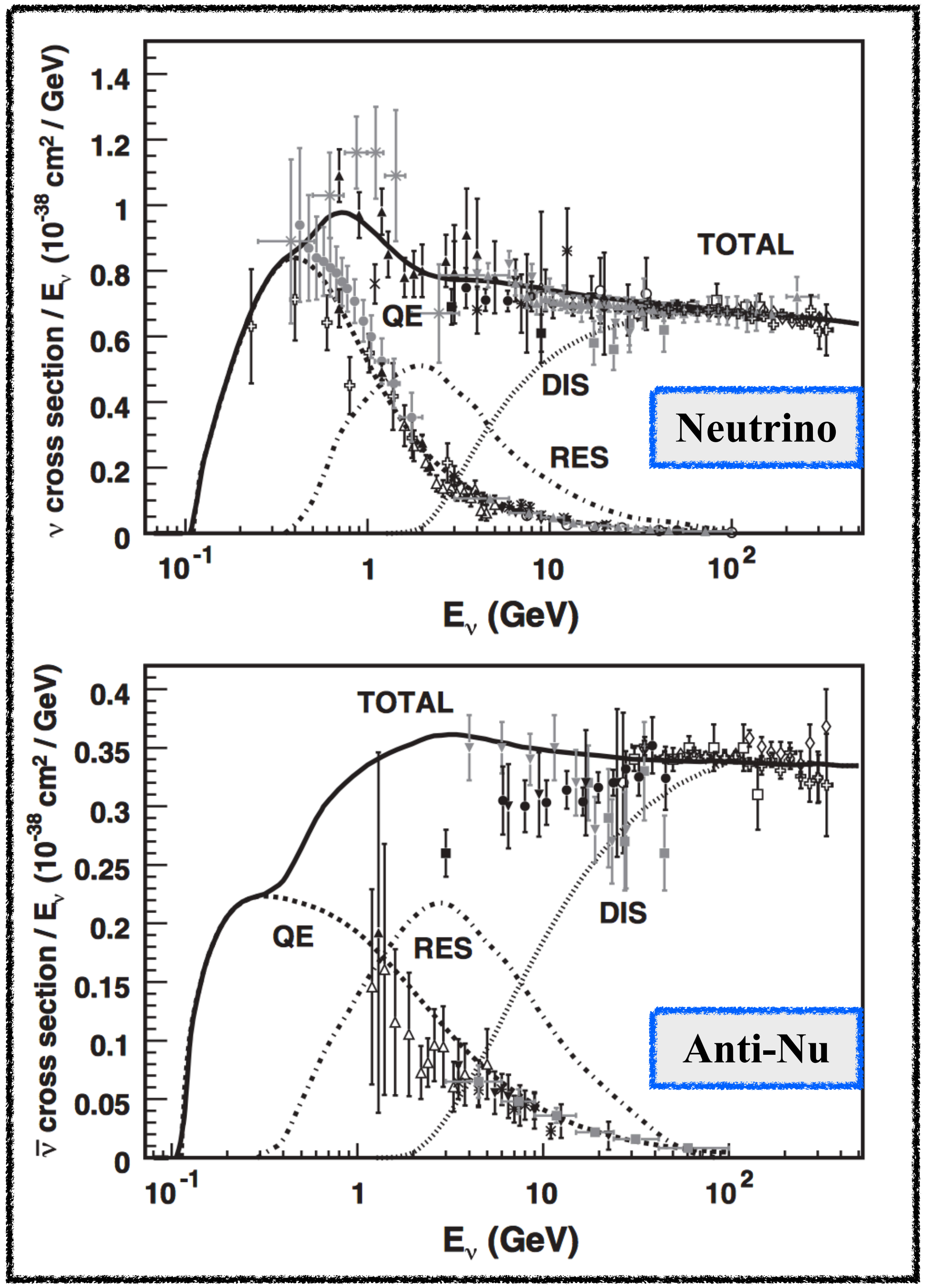
Reconstructed "Hit" on the **collection plane**
Color = deposited charge

- **We get**:
  - **Great detail of particle tracks**
  - **Calorimetry information from 3 planes**
- **Huge effort on automated reconstruction**
  - **Very active & exciting development frontier**
  - Unfortunately I have to skip this time (a whole another talk!)

... So ...
what physics can we do?

MicroBooNE Physics: XS Measurement

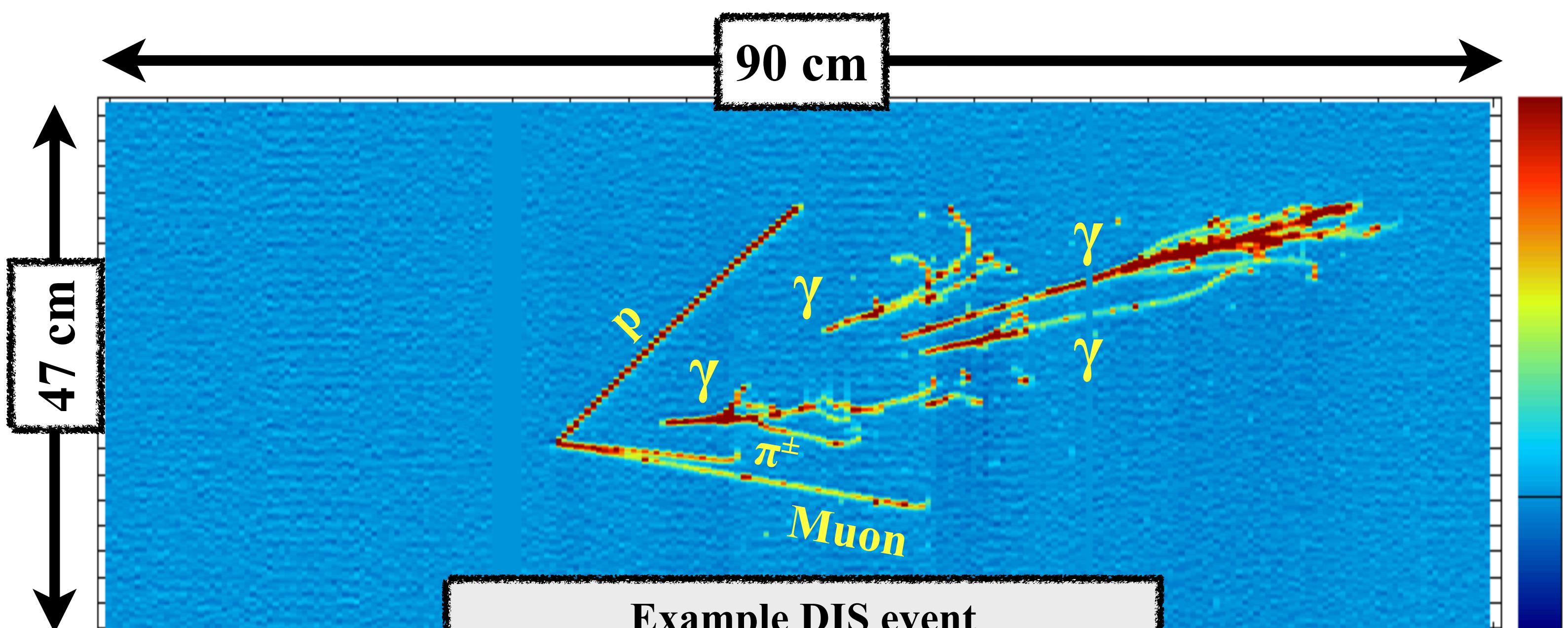
- MicroBooNE adds **data points < 1 GeV**
  - The region that is not well explored
  - Crucial for future LAr experiments



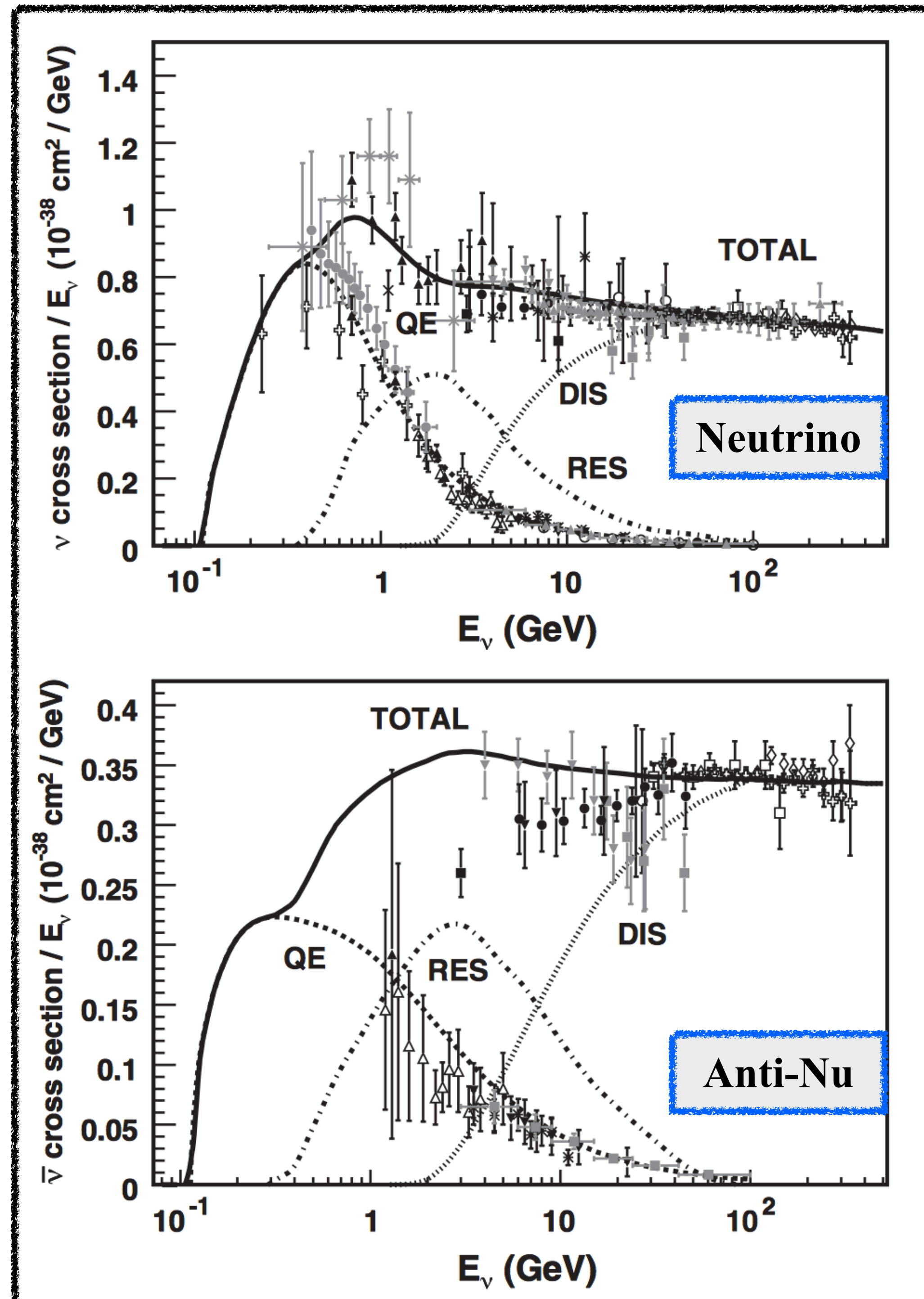
Neutrino per Nucleon XS
Rev. Mod. Phys. 84, 1307 (2012)

MicroBooNE Physics: XS Measurement

- MicroBooNE adds **data points < 1 GeV**
  - The region that is not well explored
  - Crucial for future LAr experiments
- **Probe various nuclear final state**
  - Huge effort on nuclear model on-going
  - Probe in this energy range is crucial



Example DIS event
(courtesy of ArgoNeuT collaboration)

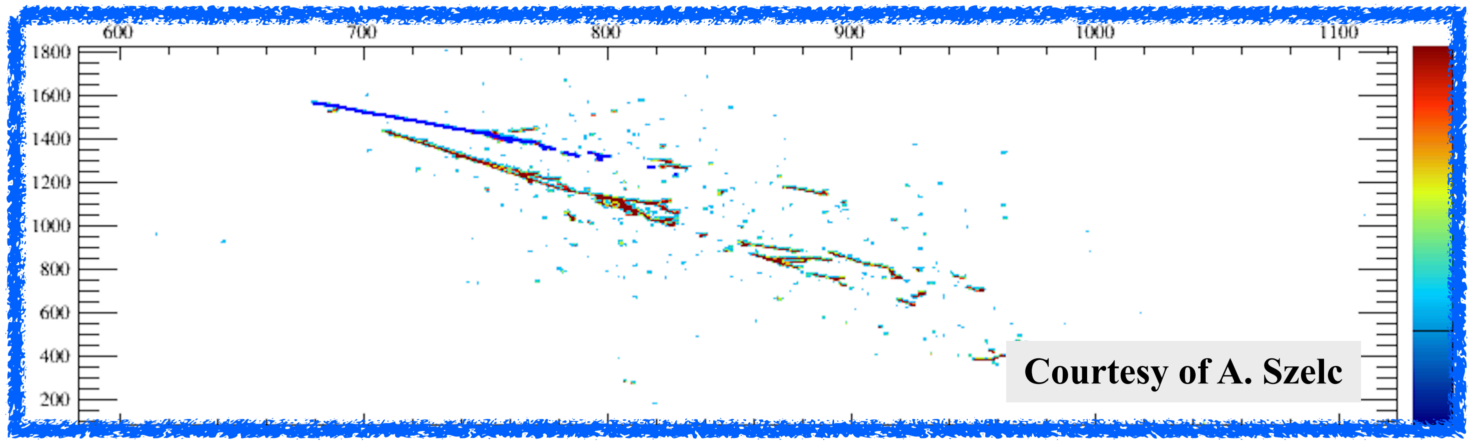


Neutrino per Nucleon XS
Rev. Mod. Phys. 84, 1307 (2012)

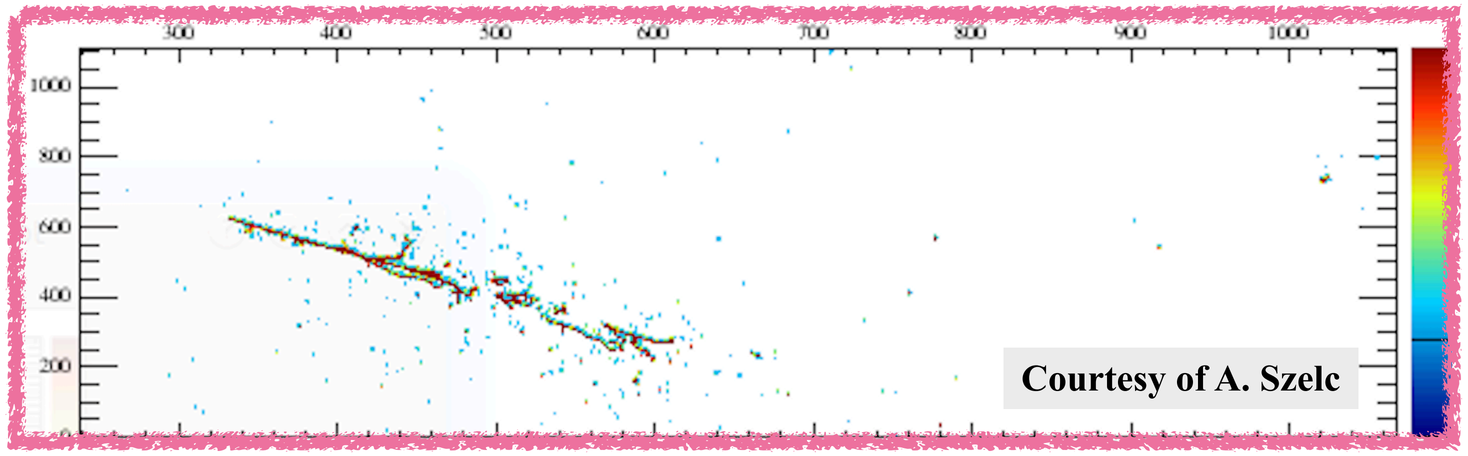
MicroBooNE provides crucial knowledge about **ν-Ar cross-section** for future LArTPC

MicroBooNE Physics: Low E Excess

- Excellent PID = better BG rejection
  - Clear signature for π^0 decay



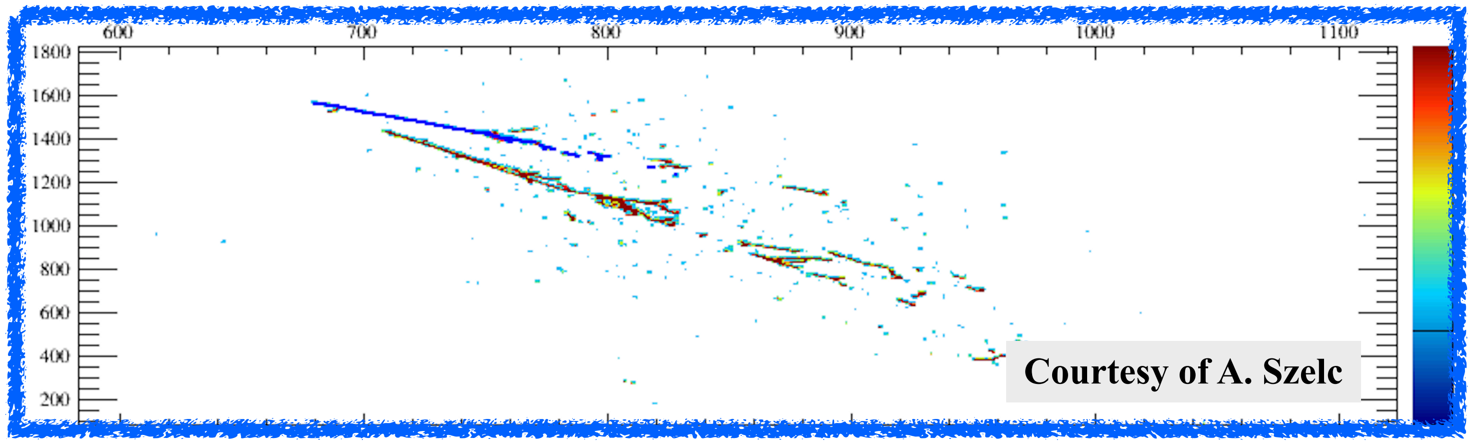
π^0 decay MC
(shown: reconstructed **hits on the collection plane**)



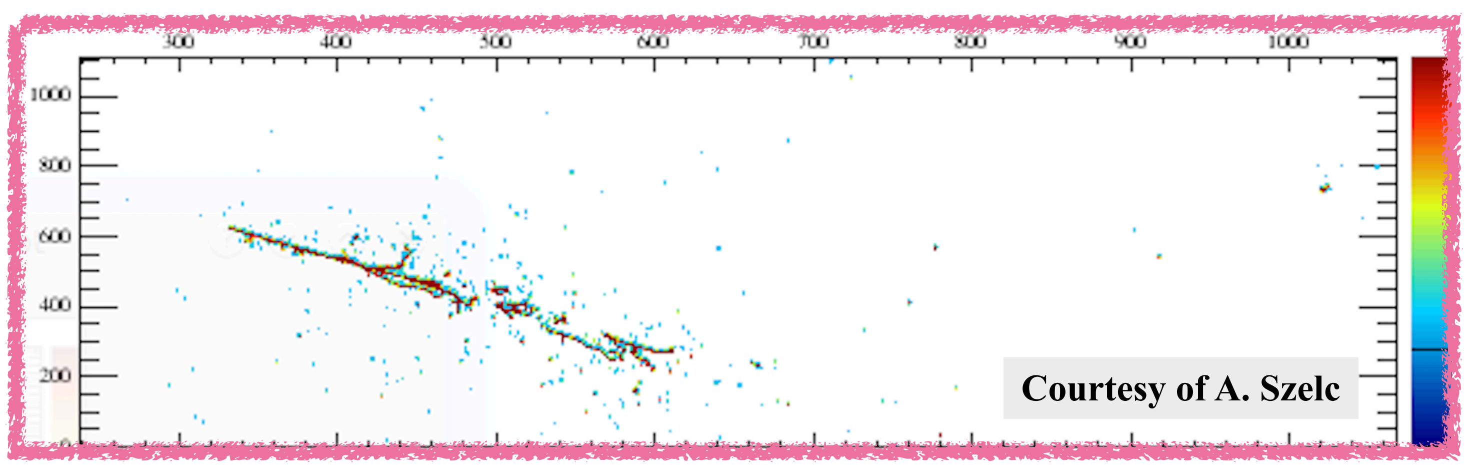
Single e^- MC
(shown: reconstructed **hits on the collection plane**)

MicroBooNE Physics: Low E Excess

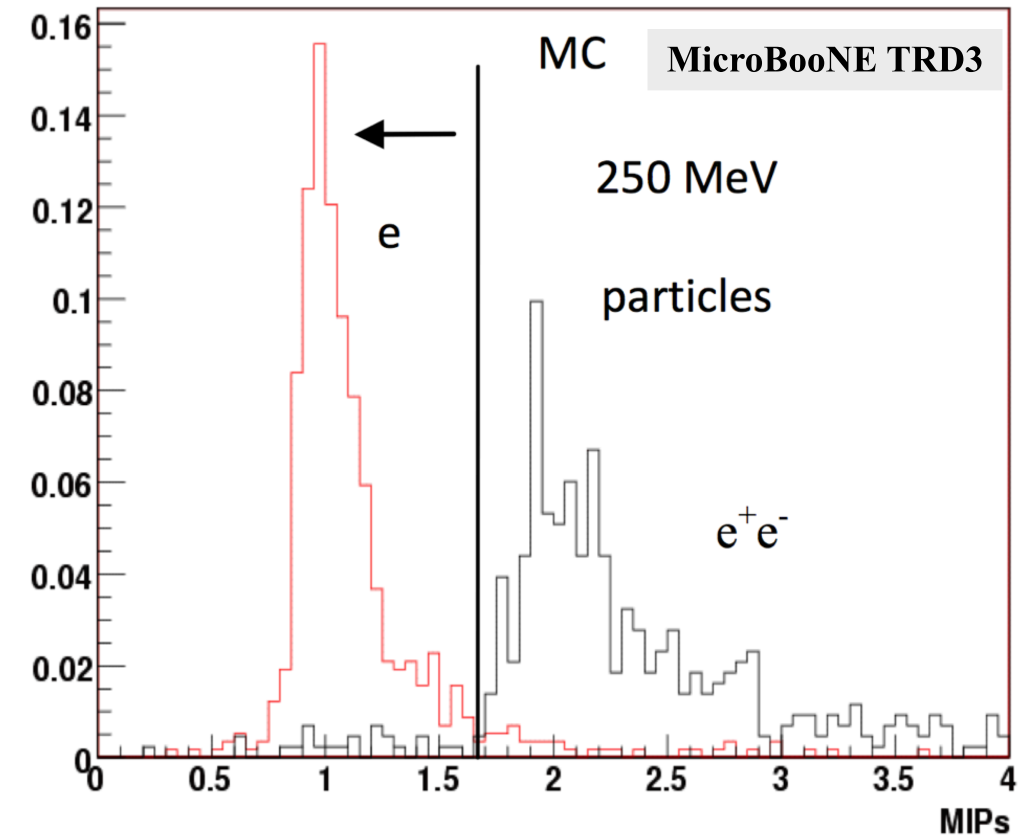
- Excellent PID = better BG rejection
  - Clear signature for π^0 decay
  - dE/dX distinguish single e^- from γ



π^0 decay MC
(shown: reconstructed **hits on the collection plane**)



Single e^- MC
(shown: reconstructed **hits on the collection plane**)



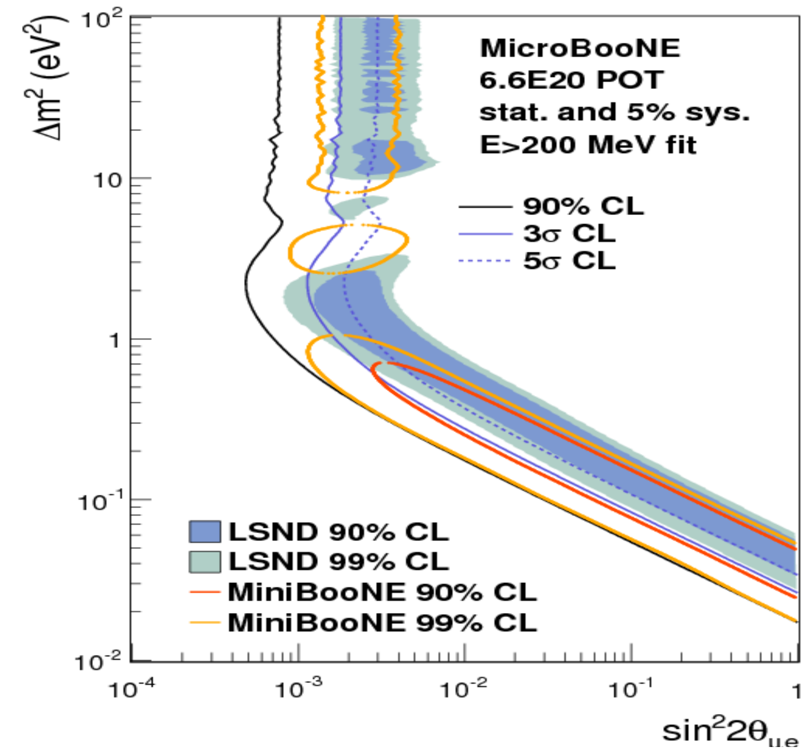
First 2.4 cm of shower gives:

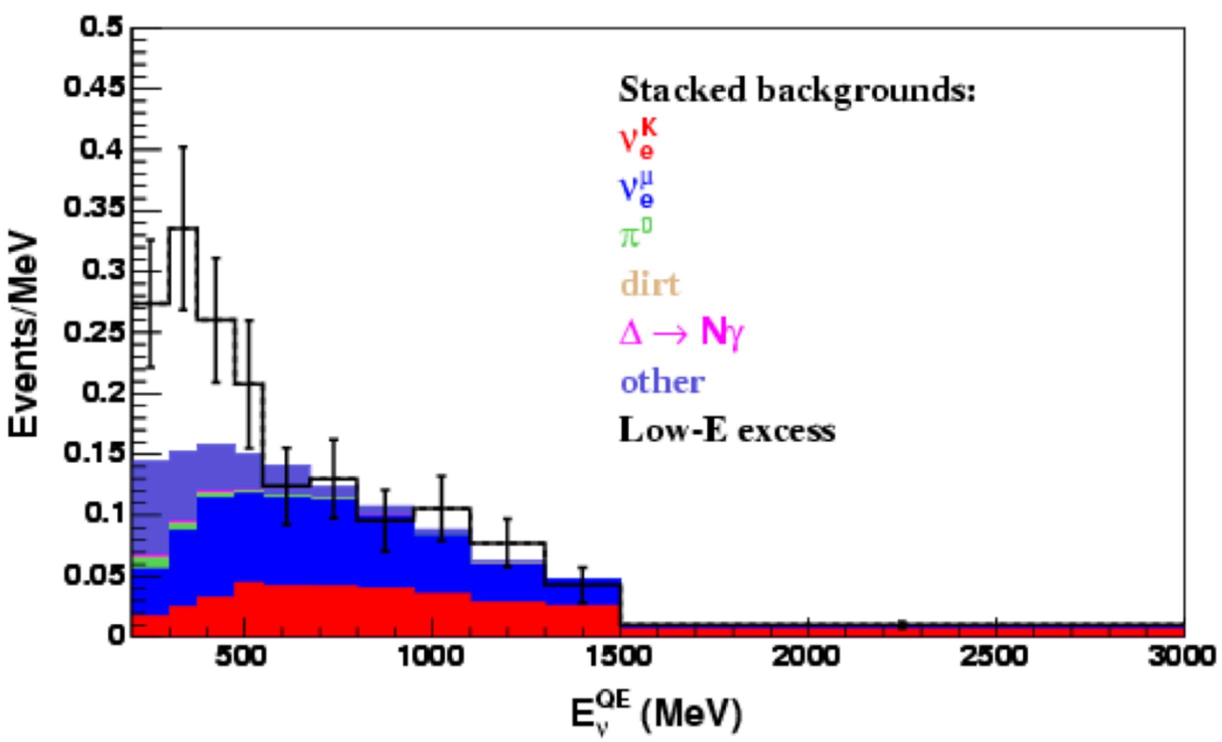
- **1 MIP for single e^-**
- **2 MIPs for single γ**

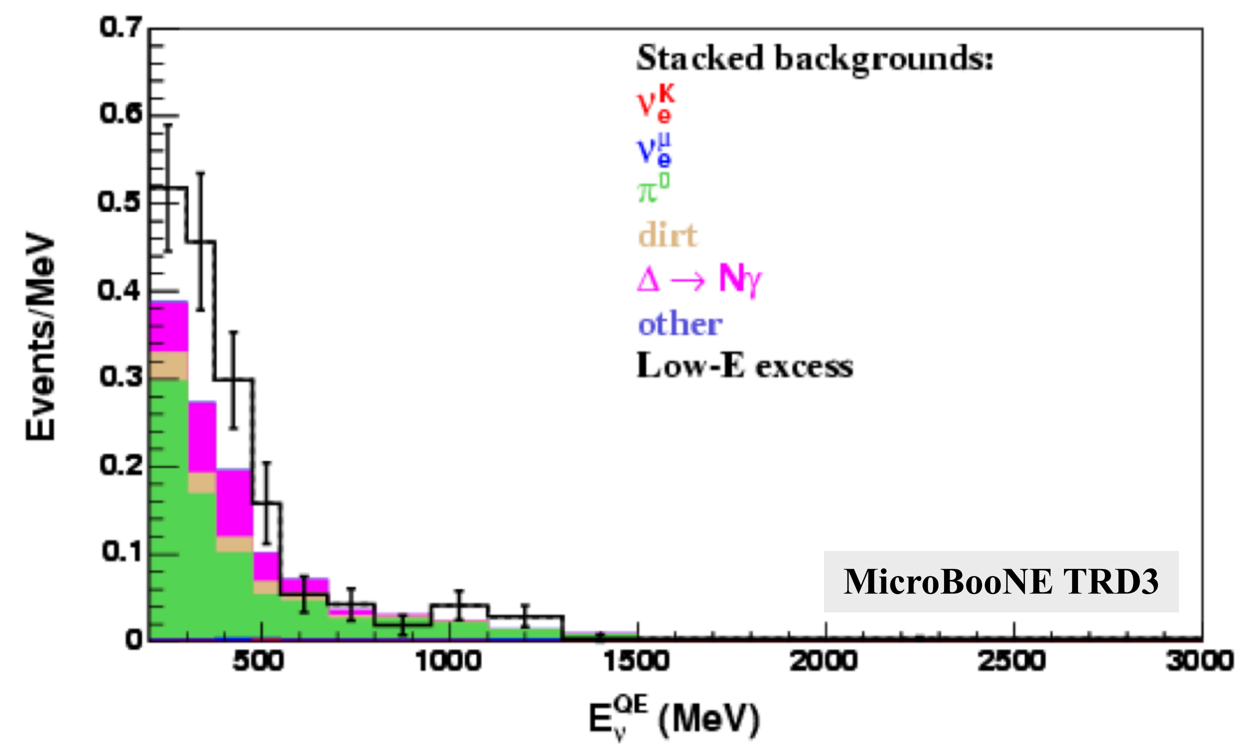
Above plot shows a separation @ E=250 MeV

MicroBooNE Physics: Low E Excess

- Excellent PID = better BG rejection
  - Clear signature for π^0 decay
  - dE/dX distinguish single e^- from γ
- MicroBooNE can prove low E excess!
  - Smaller volume but improved BG rejection
    - Can be competitive w/ MiniBooNE
  - and important XS measurement







Scenario A: e^- signal selection
5σ signal sensitivity

Scenario B: γ signal selection
4σ signal sensitivity

MicroBooNE

~ Year 2013 ~

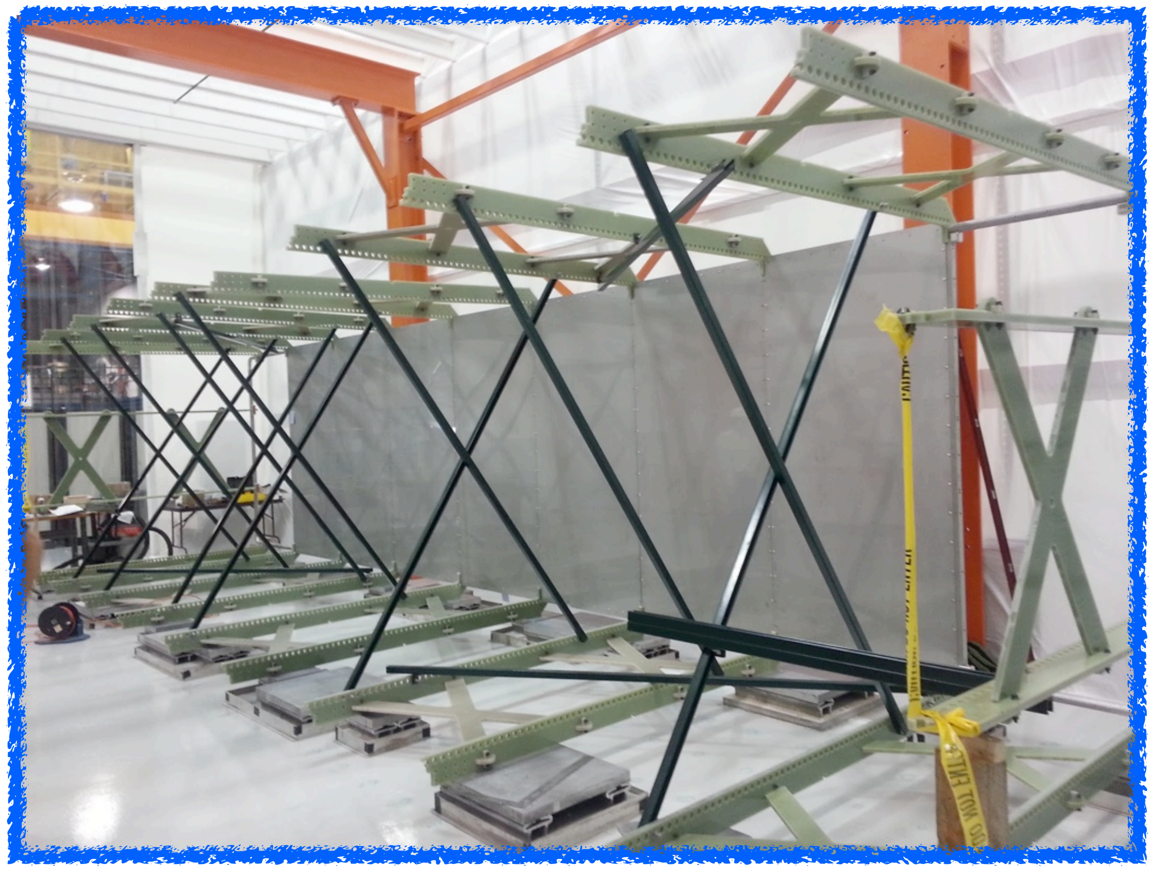
Detector Construction

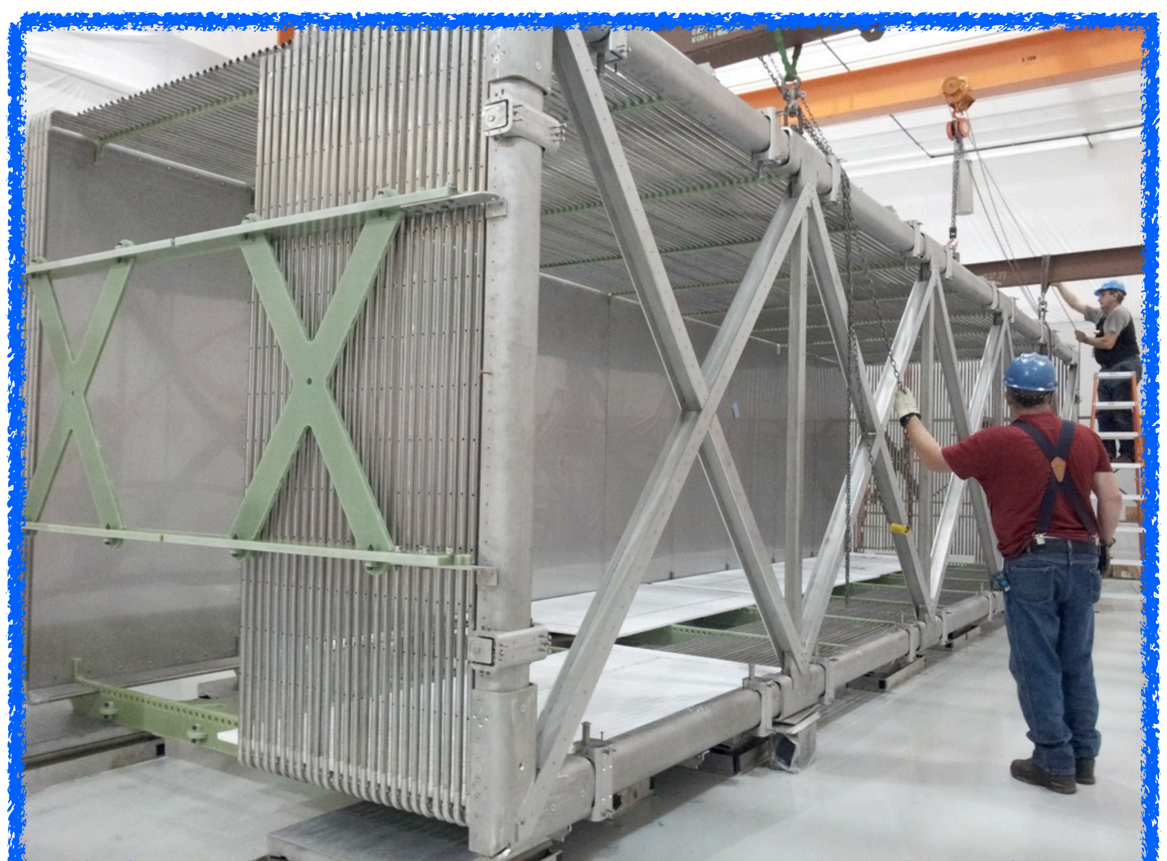
Outline:

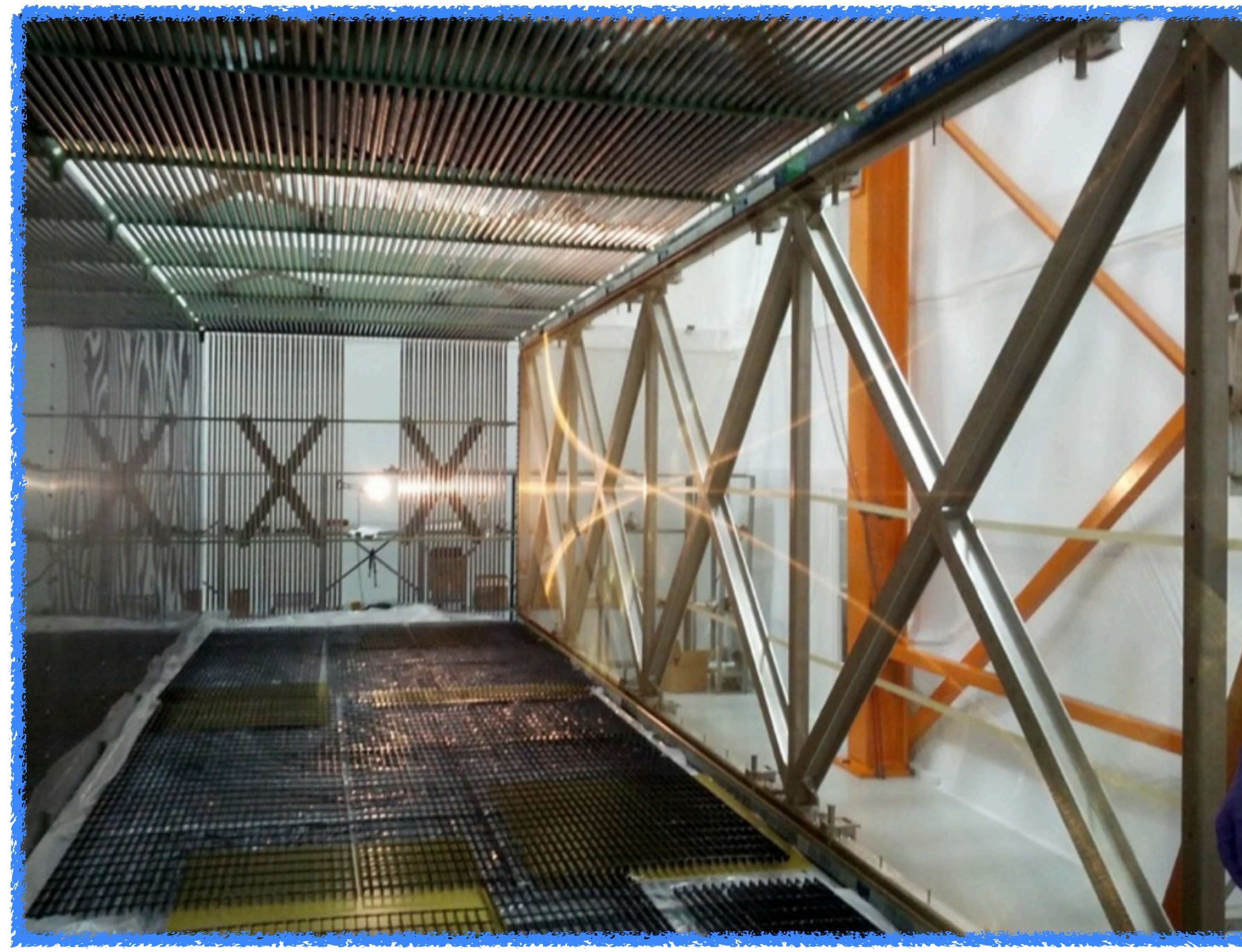
1. Path Toward MicroBooNE
2. MicroBooNE Detector
3. Detector Construction
4. Commissioning Schedule
5. Summary

TPC/PMT/Cryostat Preparation @ DAB

TPC/PMT/Cryostat Preparation @ DAB

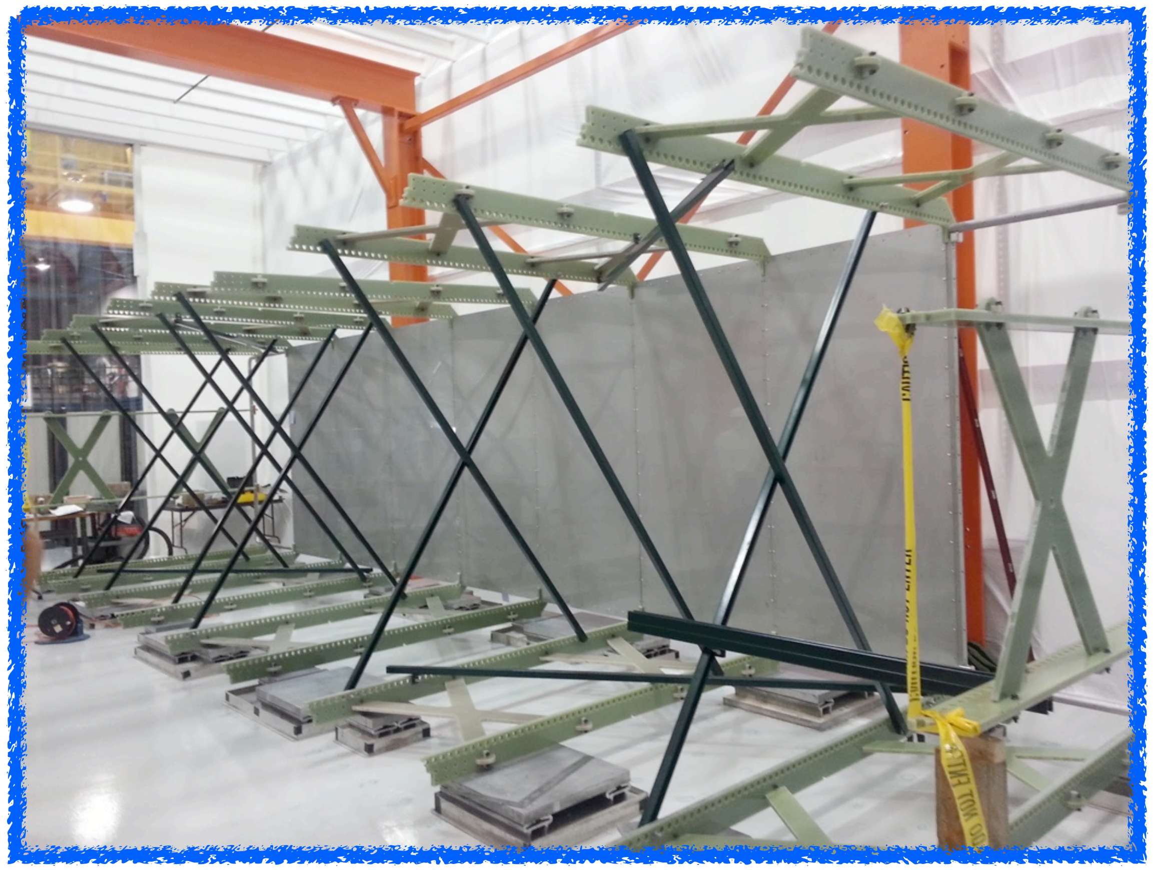




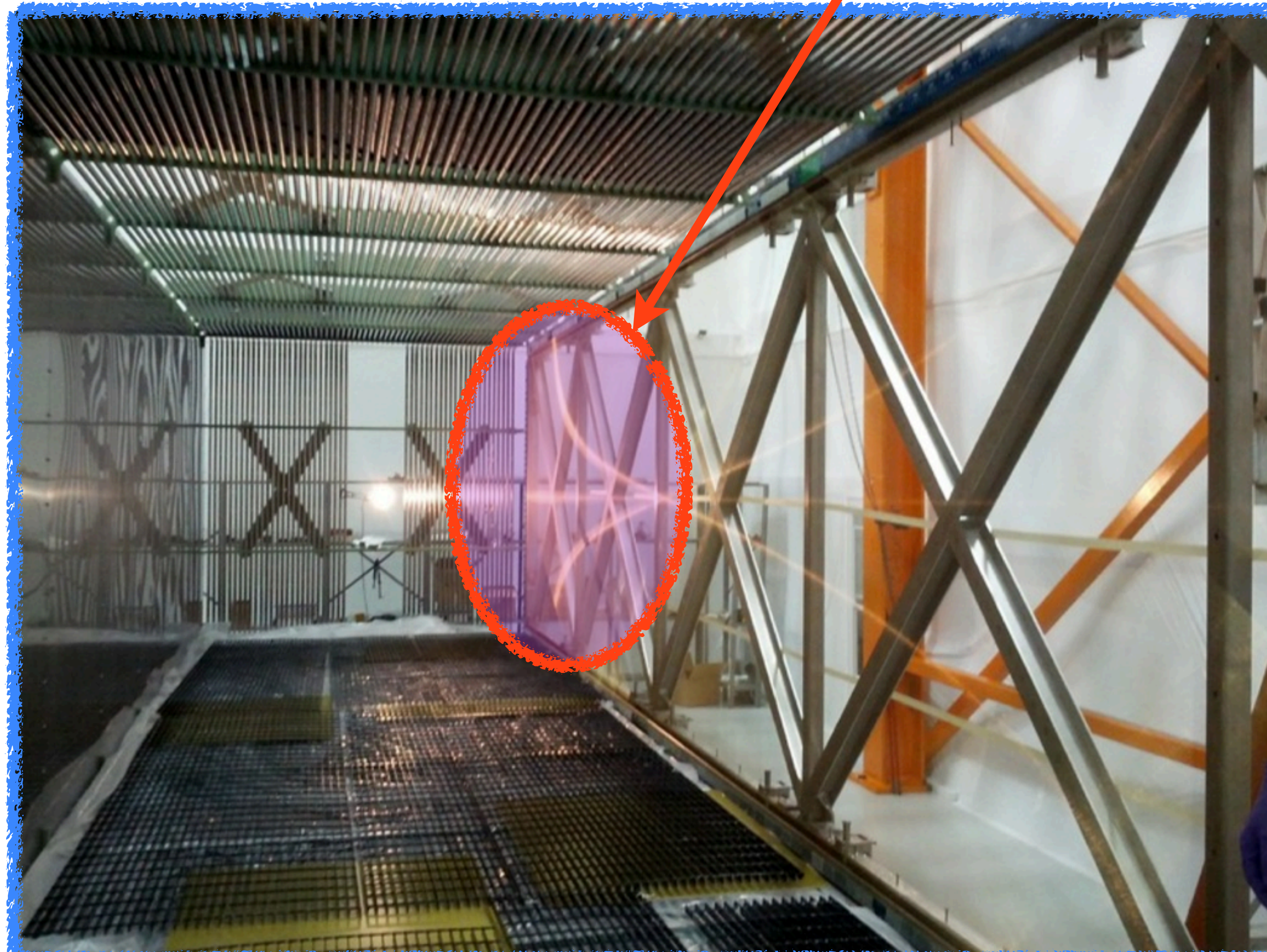


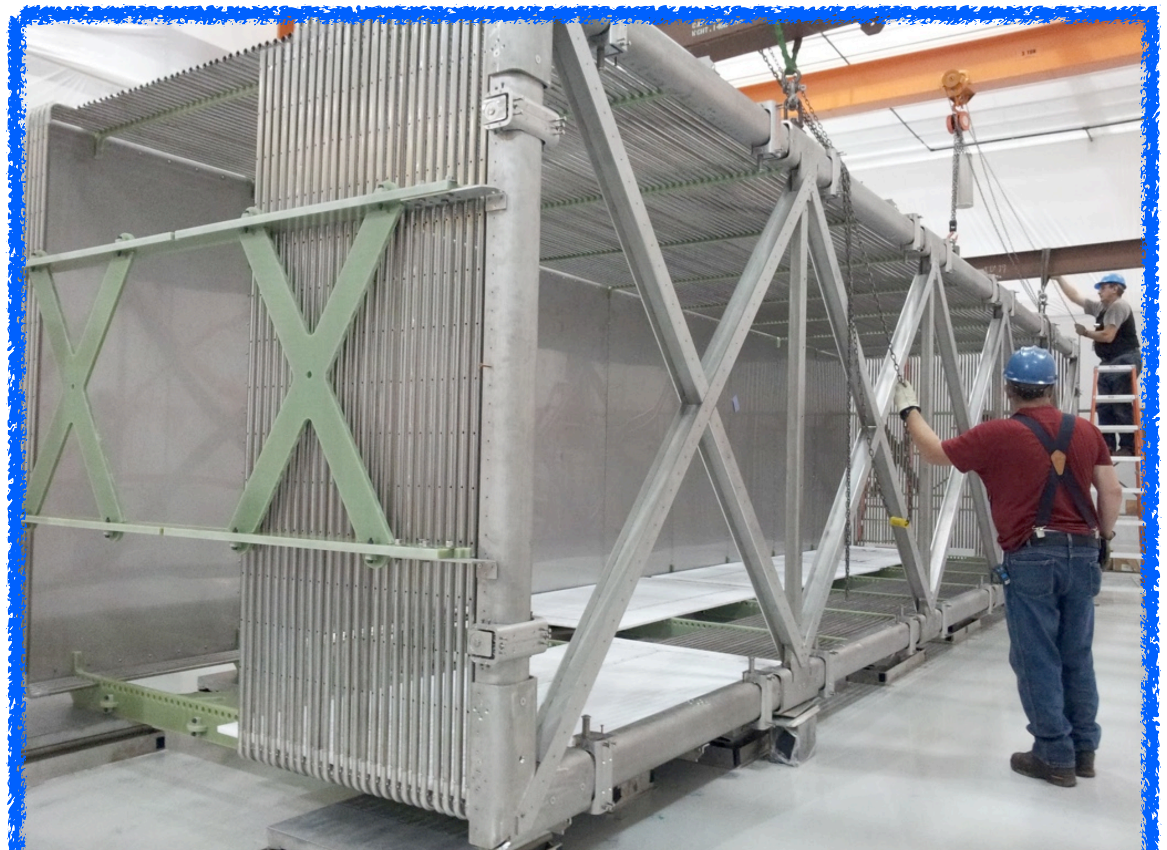
TPC built w/ 8256 wires!
w/ big effort on tension measurement!

TPC/PMT/Cryostat Preparation @ DAB



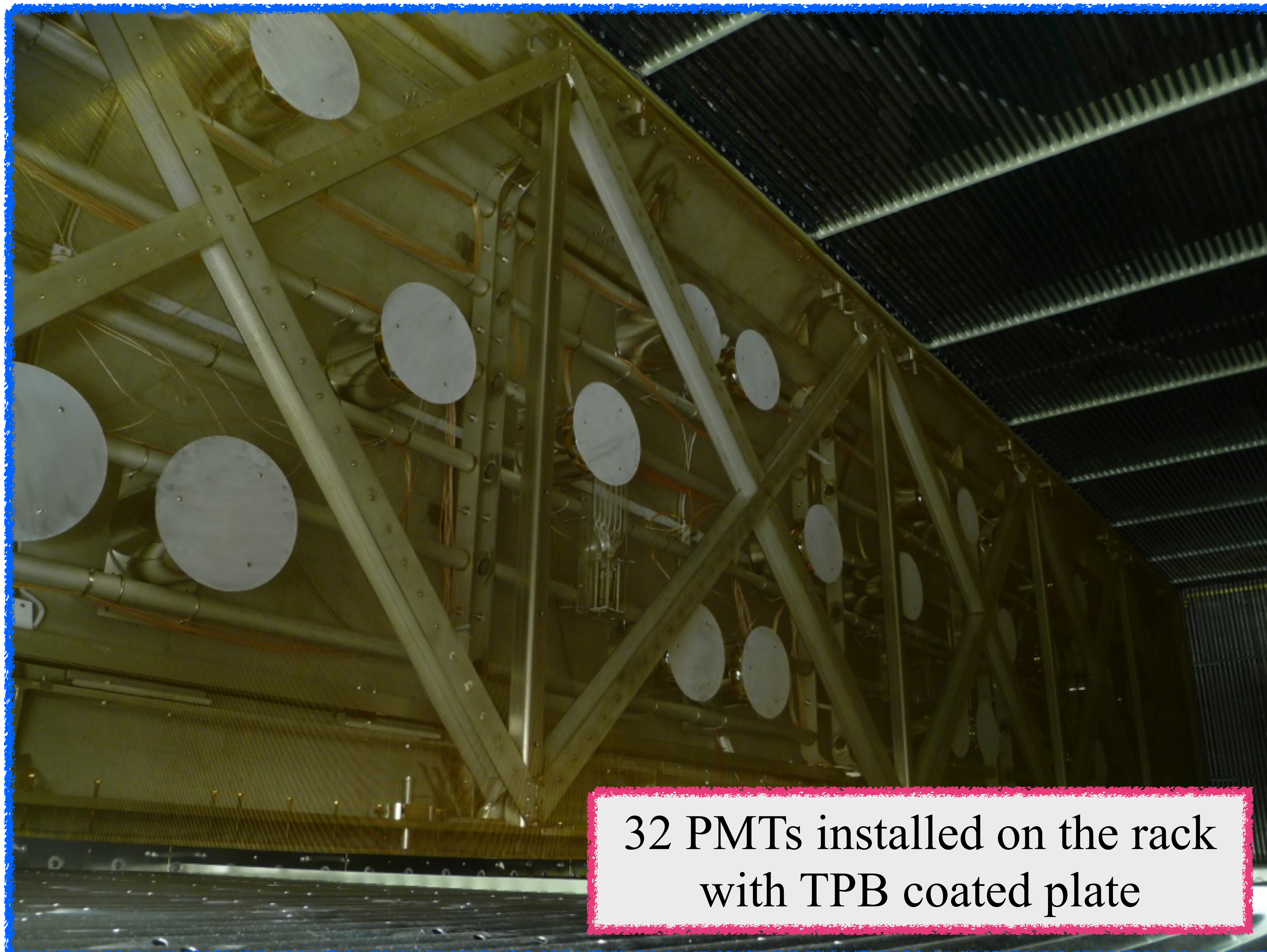
Light reflection shows three wire planes!





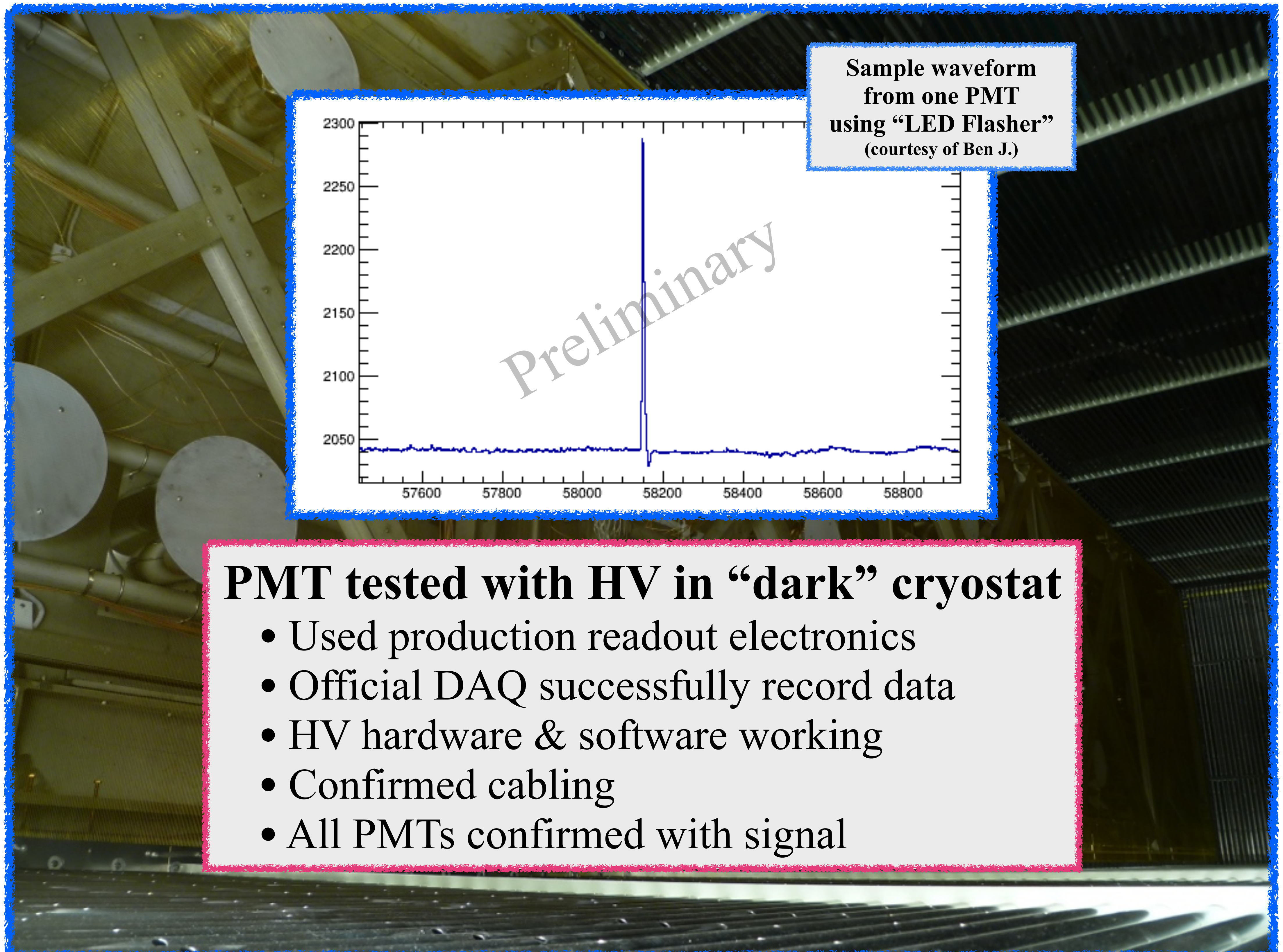
TPC built w/ 8256 wires!
w/ big effort on tension measurement!

TPC/PMT/Cryostat Preparation @ DAB



This picture is taken with 60 [s] exposure time in covered (dark) cryostat
Courtesy of Christoph Rudolf von Rohr

TPC/PMT/Cryostat Preparation @ DAB



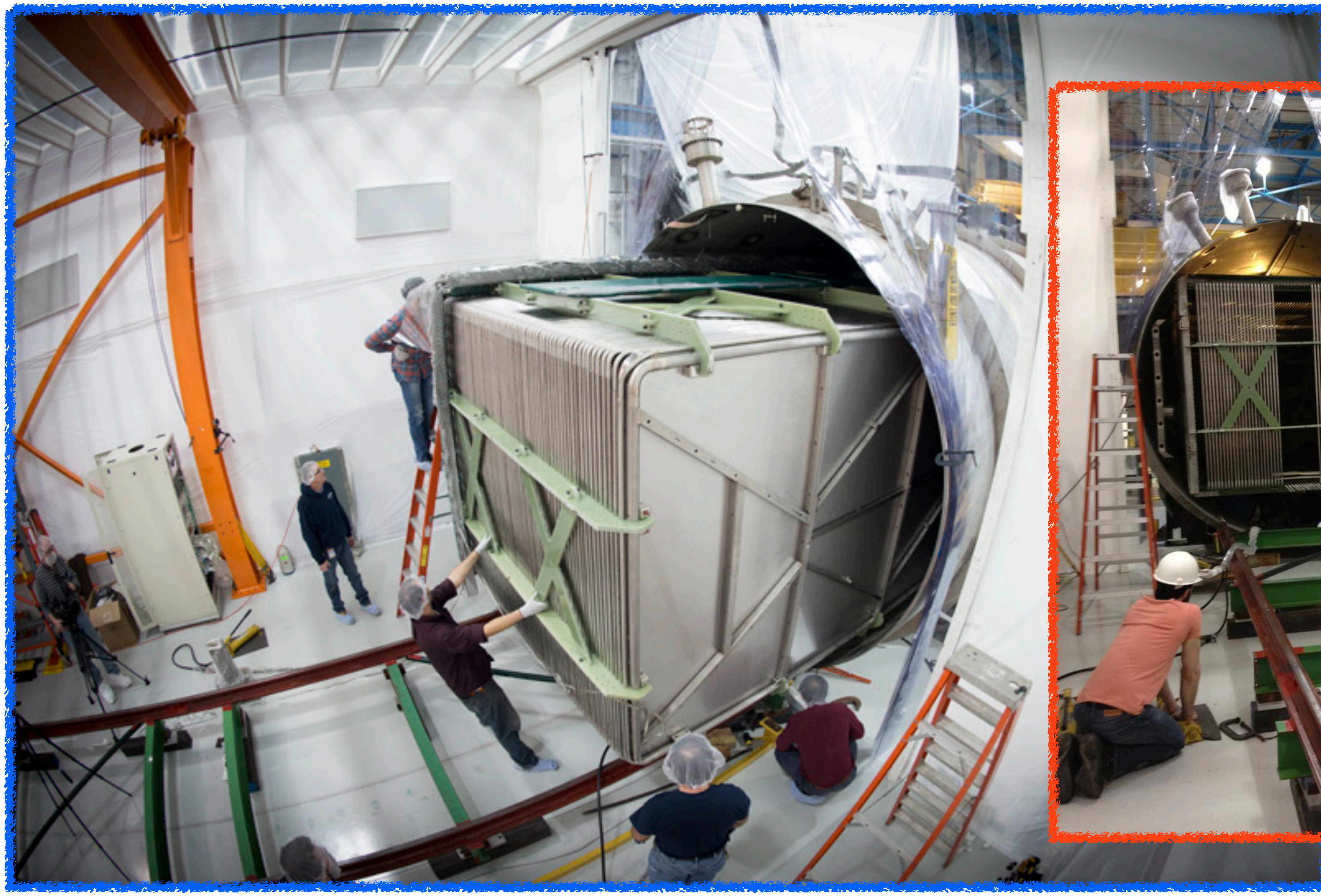
Sample waveform from one PMT using "LED Flasher"
(courtesy of Ben J.)

PMT tested with HV in "dark" cryostat

- Used production readout electronics
- Official DAQ successfully record data
- HV hardware & software working
- Confirmed cabling
- All PMTs confirmed with signal

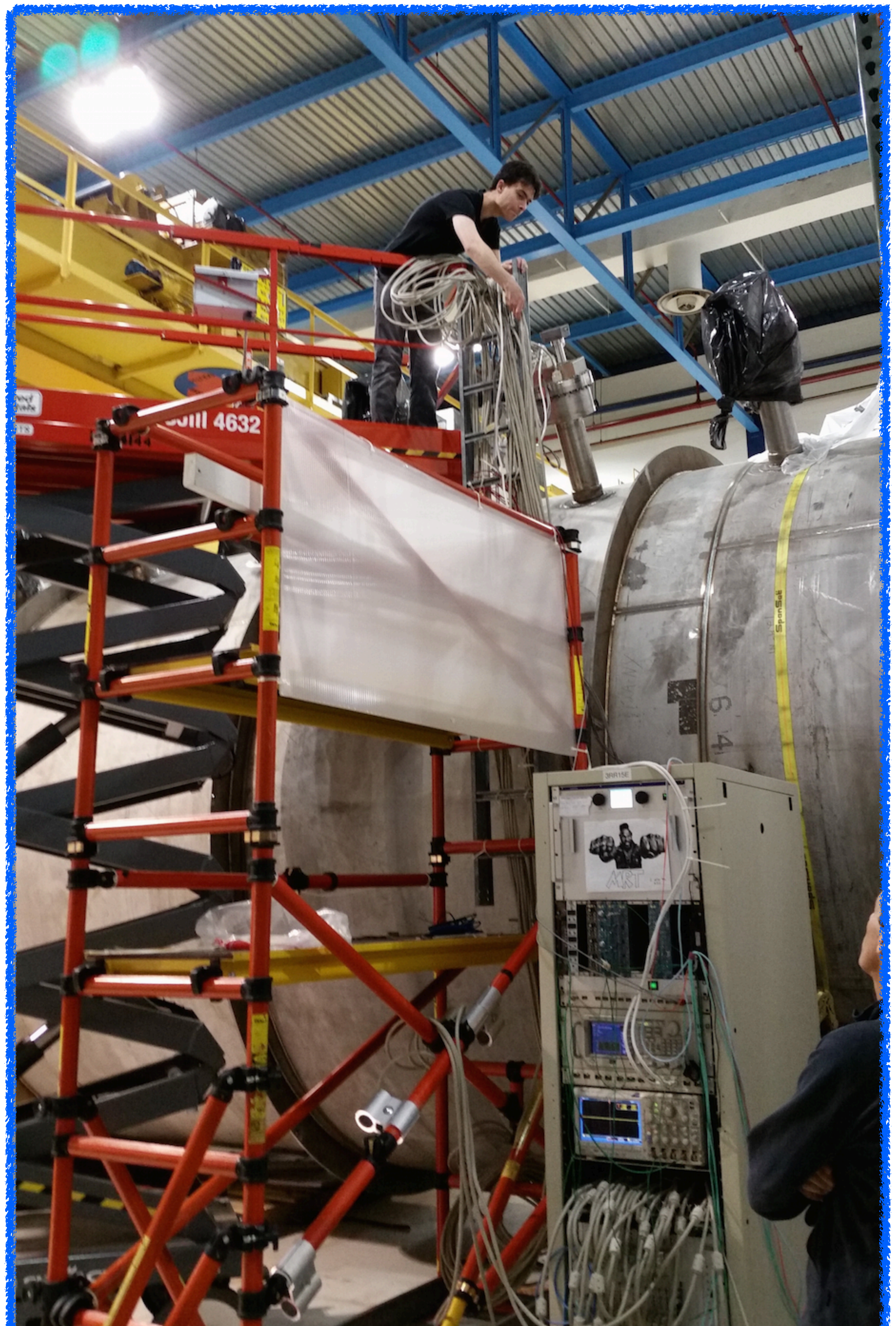
This picture is taken with 60 [s] exposure time in covered (dark) cryostat
Courtesy of Christoph Rudolf von Rohr

TPC/PMT/Cryostat Preparation @ DAB



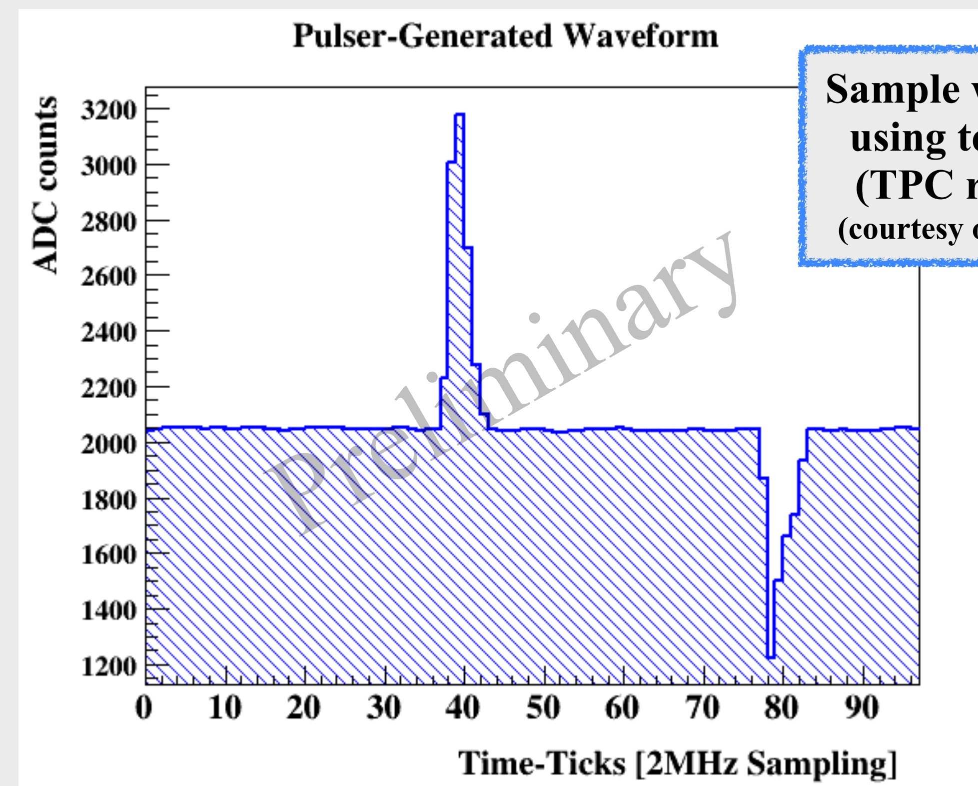
... testing to see if all fits ...

TPC/PMT/Cryostat Preparation @ DAB



After insertion... TPC tested

- Inject test pulse & readout
- DAQ successfully readout data



Sample waveform using test pulse (TPC readout)
(courtesy of David C.)

Looks good :)

- Standardized as a test procedure

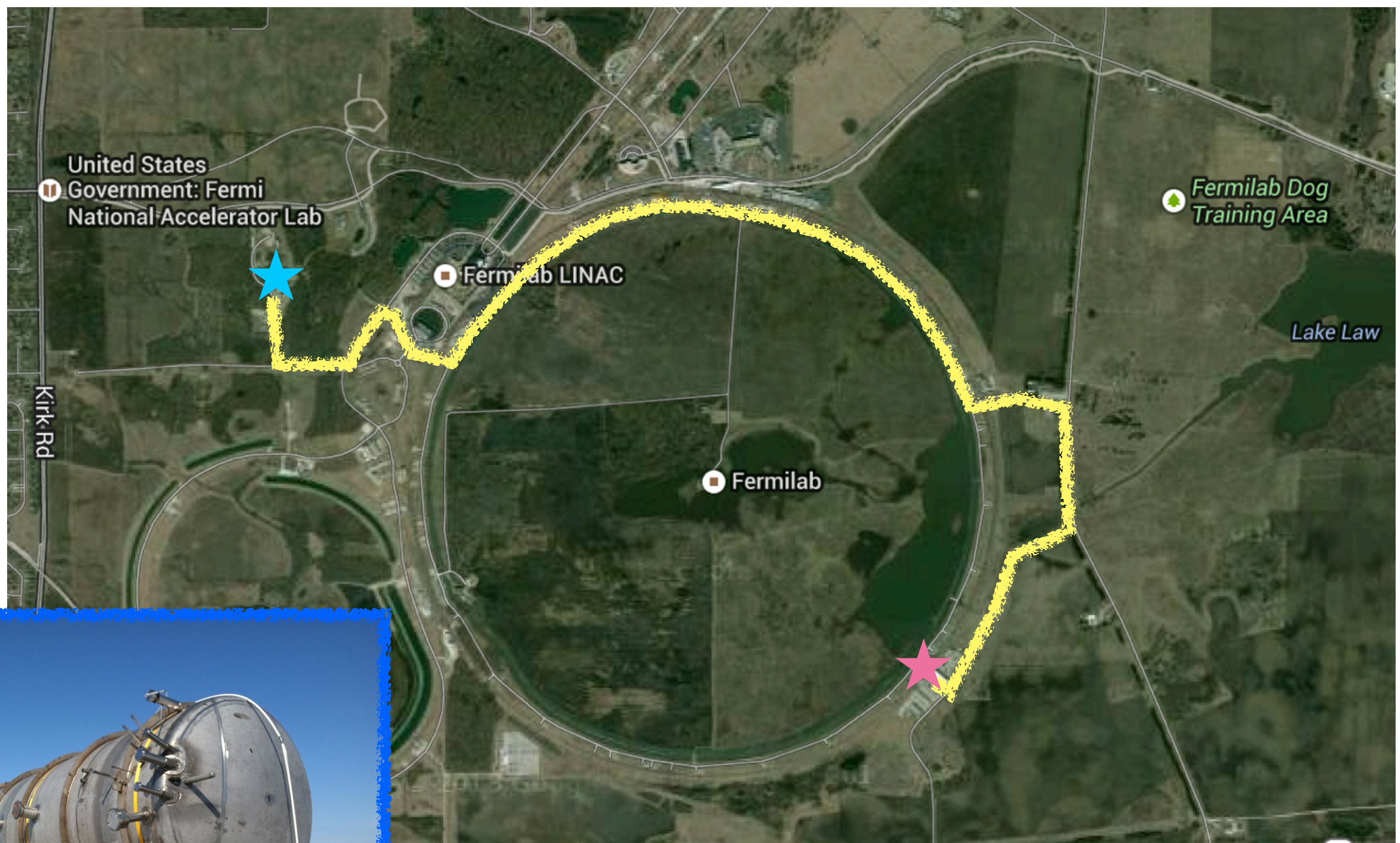
MicroBooNE
Commissioning Schedule

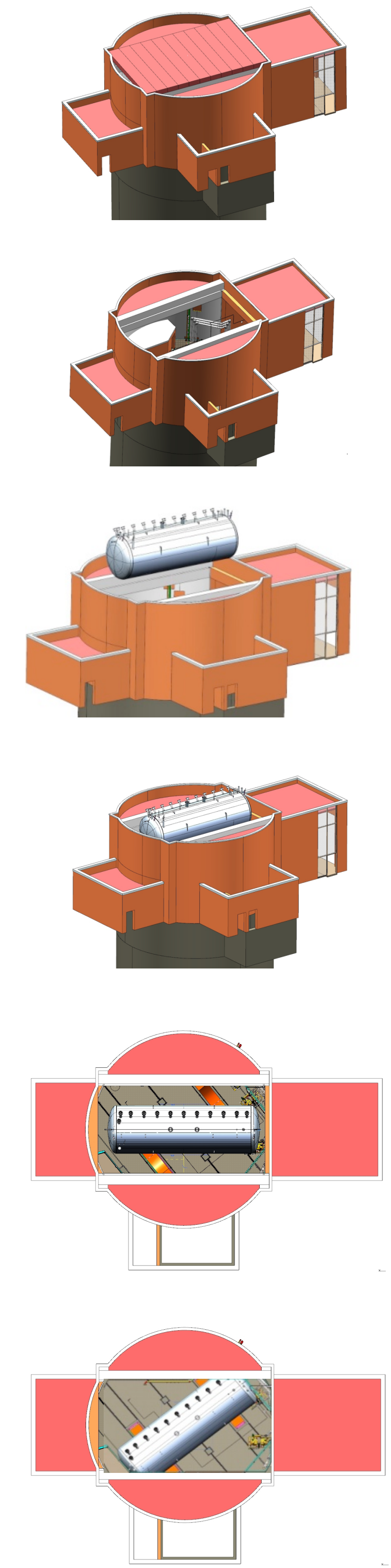
Outline:

1. Path Toward MicroBooNE
2. MicroBooNE Detector
3. Detector Construction
4. Commissioning Schedule
5. Summary

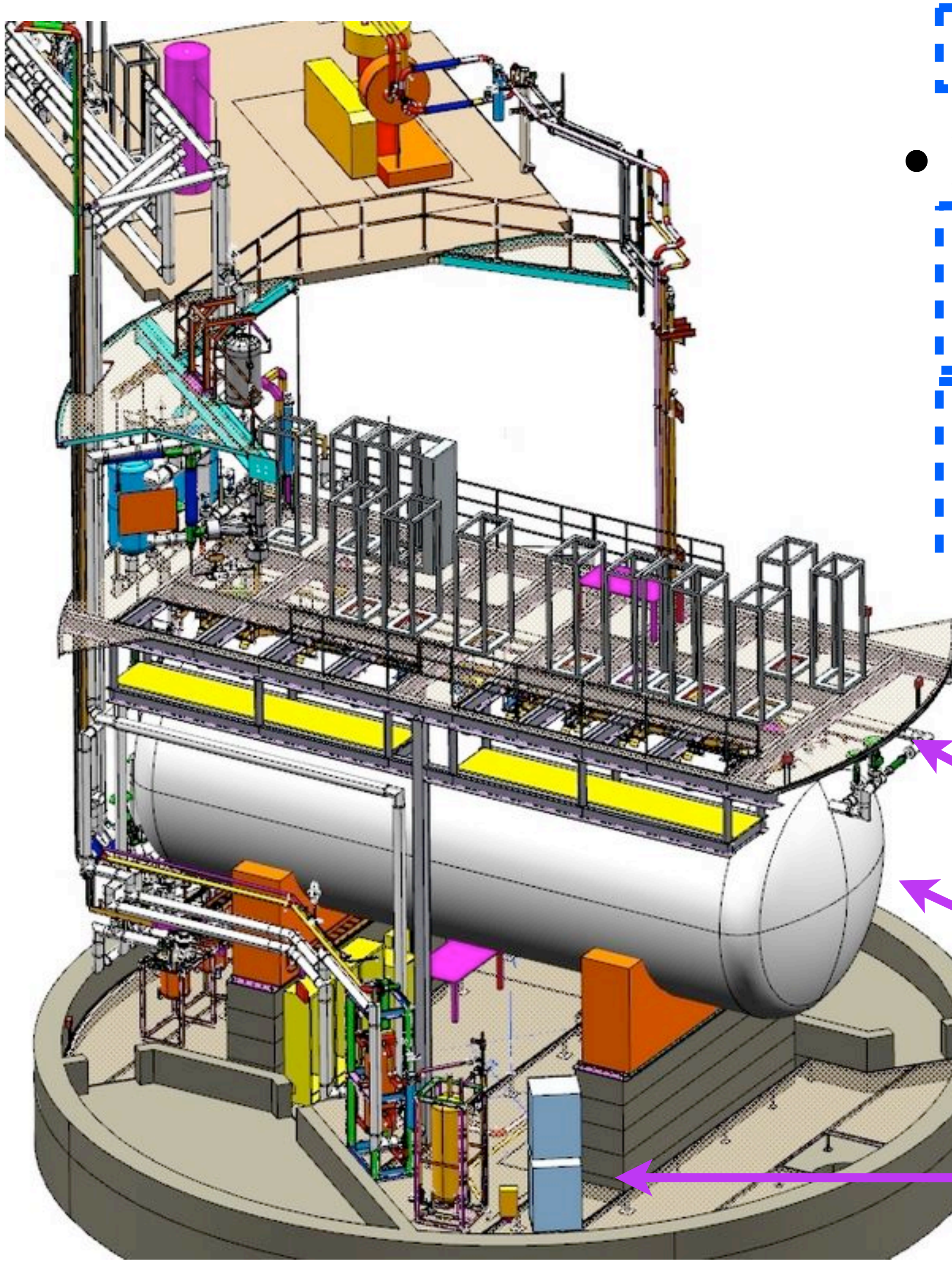
Moving to LArTF

- The detector end cap welded on ... **in 2 weeks!**
- Move the cryostat from DAB to LArTF





Post-Moving / Installation Tasks @ LArTF



- Task followed by moving
  - TPC & PMT testing
- Installation tasks
  - Preparation of platform
  - Cryostat insulation
  - Complete cryogenic piping
  - Readout racks & cables

≃4 months for installation

Platform w/ readout racks

Cryostat

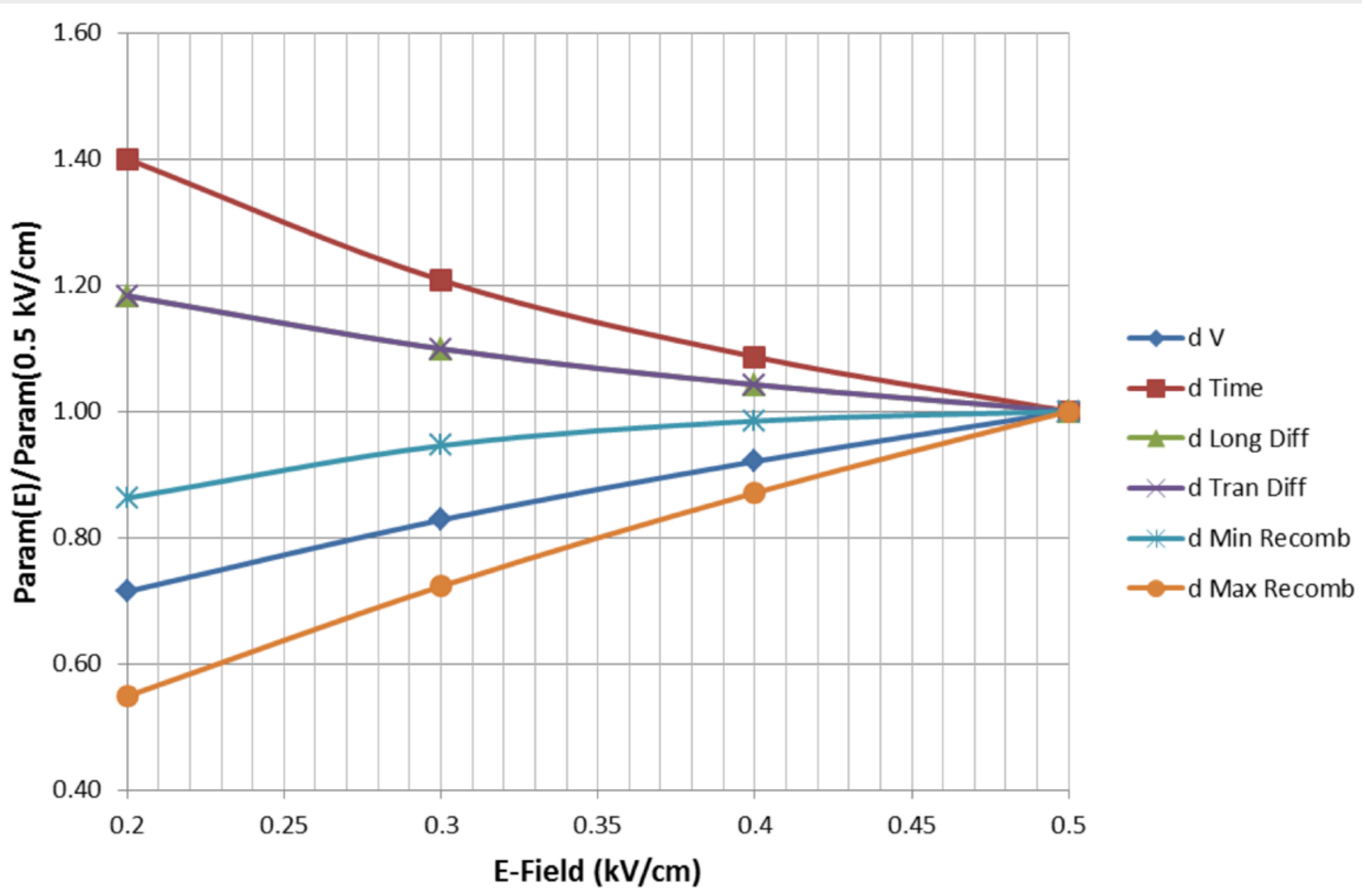
Cryogenic pumps, filters, etc

Detector Commissioning

- Cryogenics ... ≃ **2 months**
  - GAr purging, recirculation w/ purification
  - Cool down of cryostat
  - LAr filling followed by purification
- Detector ... ≃ **2 months**
  - **Test run @ TPC HV 64 kV** ... we request low intensity BNB
    - 1 week to ramp up

Detector Commissioning

- Cryogenics ... ≃ **2 months**
  - GAr purging, recirculation w/ purification
  - Cool down of cryostat
  - LAr filling followed by purification
- Detector ... ≃ **2 months**
  - **Test run @ TPC HV 64 kV** ... we request low intensity BNB
    - 1 week to ramp up



What Do We Expect @ 64 kV?

- **40% longer drift time**
  - increase in cosmic background
- **20% increase in diffusion broadening**
- **15 to 45 % reduction in collected Q**
  - Variation from MIP to stopping protons

Study & Plot courtesy of B. Baller

Detector Commissioning

- Cryogenics ... ≃ **2 months**
  - GAr purging, recirculation w/ purification
  - Cool down of cryostat
  - LAr filling followed by purification

- Detector ... ≃ **2 months**
  - **Test run @ TPC HV 64 kV** ... we request low intensity BNB
    - 1 week to ramp up
    - 1 week for stable run ... **low intensity BNB**, cosmic ray, laser calibration
  - Review before ramping the HV to 100+ kV
  - **Test run @ TPC HV 128 kV** ... we request high intensity BNB
    - 5 weeks to ramp up + short runs, followed by review for stable run
    - 4 weeks for stable run ... **high intensity BNB** desired for neutrino data!

Summary

Outline:

1. Path Toward MicroBooNE
2. MicroBooNE Detector
3. Detector Construction
4. Commissioning Schedule
5. Summary

Summary

- **MicroBooNE** is 170 ton LArTPC experiment
  - **Definitive measurement on the low energy event excess** from MiniBooNE
  - Perform **crucial ν-N cross-section measurement** at BNB energy range
  - **Important R&D** for future LArTPC experiments
- **MicroBooNE Status**
  - TPC/PMT/Cryostat built & tested @ DAB
  - **Ready to move into LArTF after lid closure**
- **Plan for Commissioning**
  - 4 months to complete installation work @ LArTF
  - 2 months to complete LAr filling
  - 2 months for commissioning data taking
    - Need **low intensity BNB for 64 kV running**
    - Need **high intensity BNB for 128 kV running**
    - Schedules are preliminary but we are looking forward to achieving it!

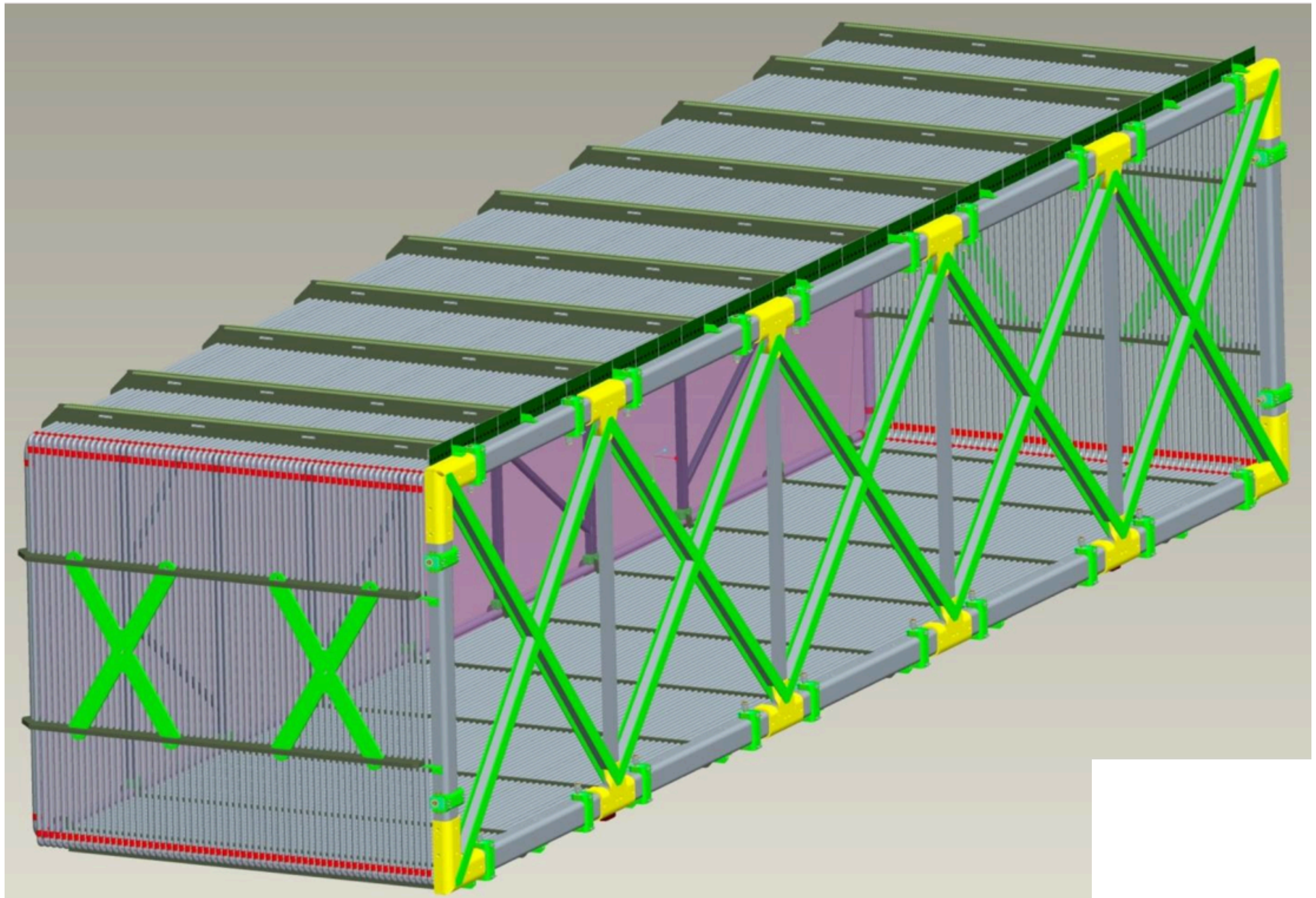
Back Up Slides

MicroBooNE Physics: More

- **SuperNova**
  - **Can** detect ν_e capture on Ar ... **dominant xs**
  - **Cannot** trigger on its own ... **small volume & too much cosmics!**
  - **Can** analyze SuperNova data stream upon ***SNEWS***
    - **That's why we have it!**
- **Proton Decay**
  - **Cannot** study proton decay: $p \Rightarrow K^+ \nu$ ... **too small :(**
  - **Can** study cosmic induced background rate: $K^0 p \Rightarrow K^+ n$
    - **Important measurement for future LArTPC**
    - High cosmic rate can be helpful sometimes :)

Active work on-going on these fronts!

MicroBooNE Detector: Numbers

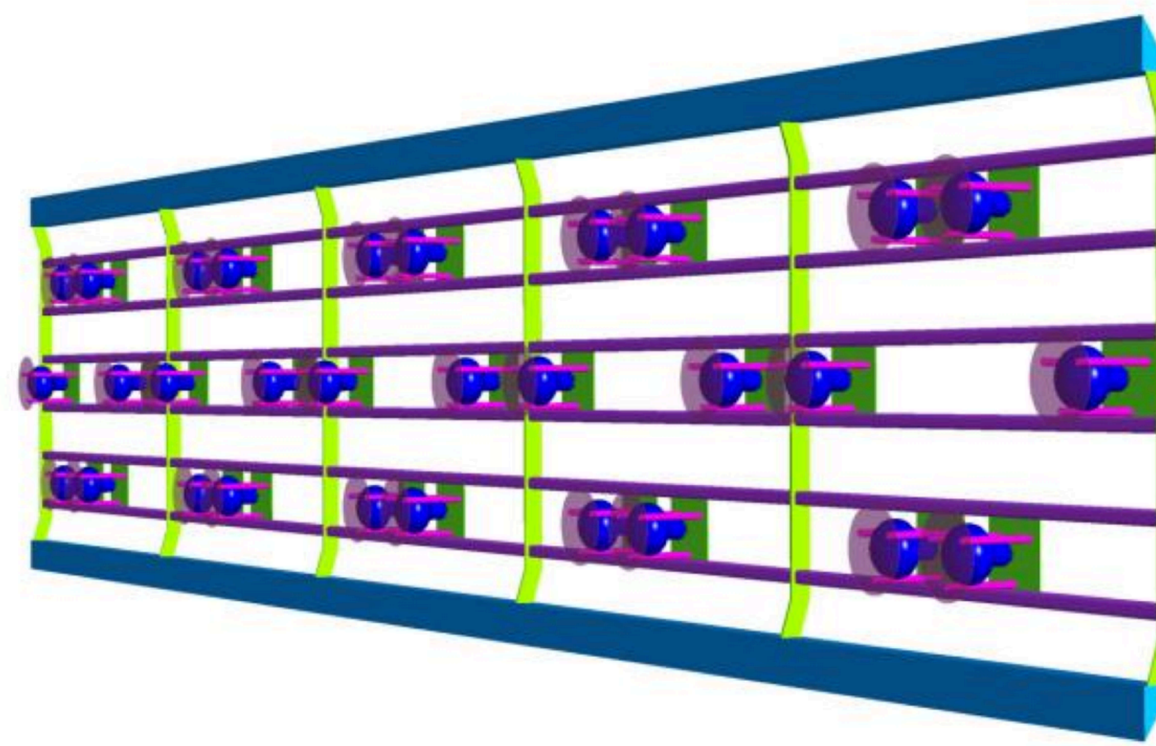


TPC

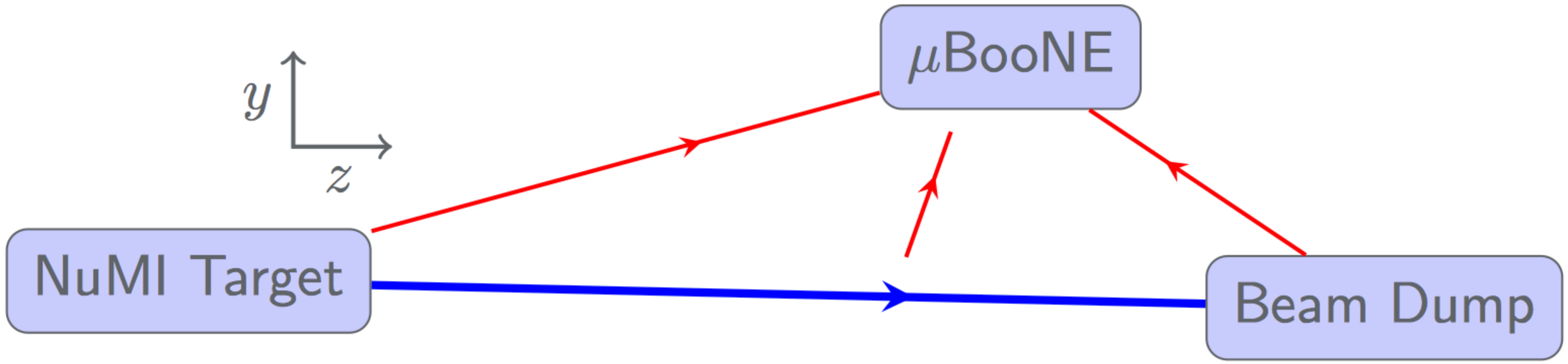
TPC Volume [ton]	90
Dimension [m]	10.4 x 2.5 x 2.3
# Channels	8256
Wire Diameter [mm]	0.15
Wire Pitch [mm]	3
Operating Temp. [K]	87
Max Drift Length [m]	2.53
Electric Field	500 V / cm

Light Collection System

PMT Type	Hamamatsu R5912-02
PMT Size	8”
# Channels	32
Wavelength Shifter	TPB coated acrylic plate



NuMI @ MicroBooNE

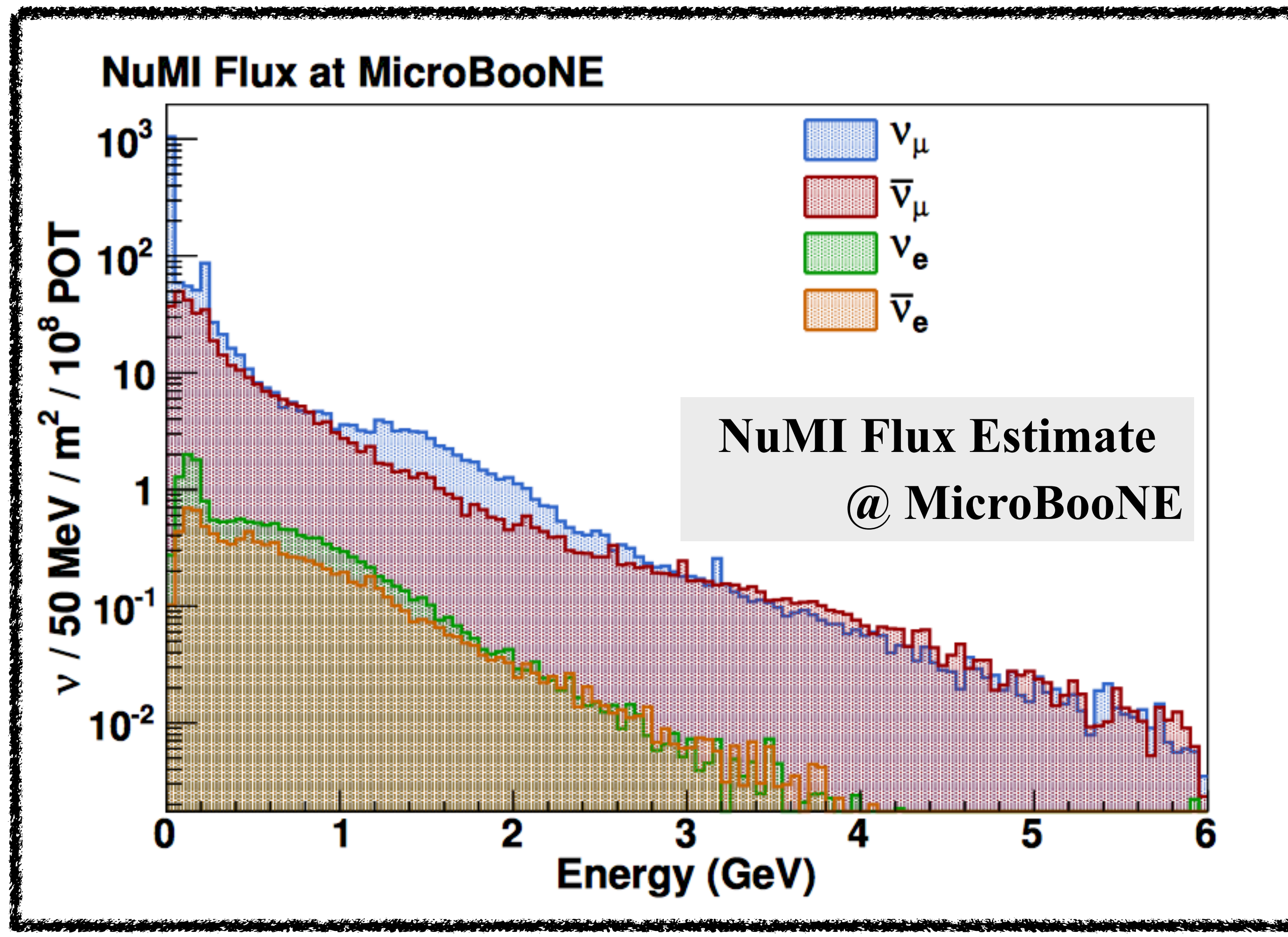


- We can trigger on NuMI beam
  - "Off-Axis" ≃ 25°
  - Target-Detector ≃ 690 m
  - Absorber-Detector ≃ 100 m

Events	BNB	NuMI
Total	145k	60k
ν_μ CCQE	68k	25k
NC π^0	8k	3k
ν_e CCQE	0.4k	1.2k
POT	6×10^{20}	8×20^{20}

Expected Event Rate
(2~3 years running)

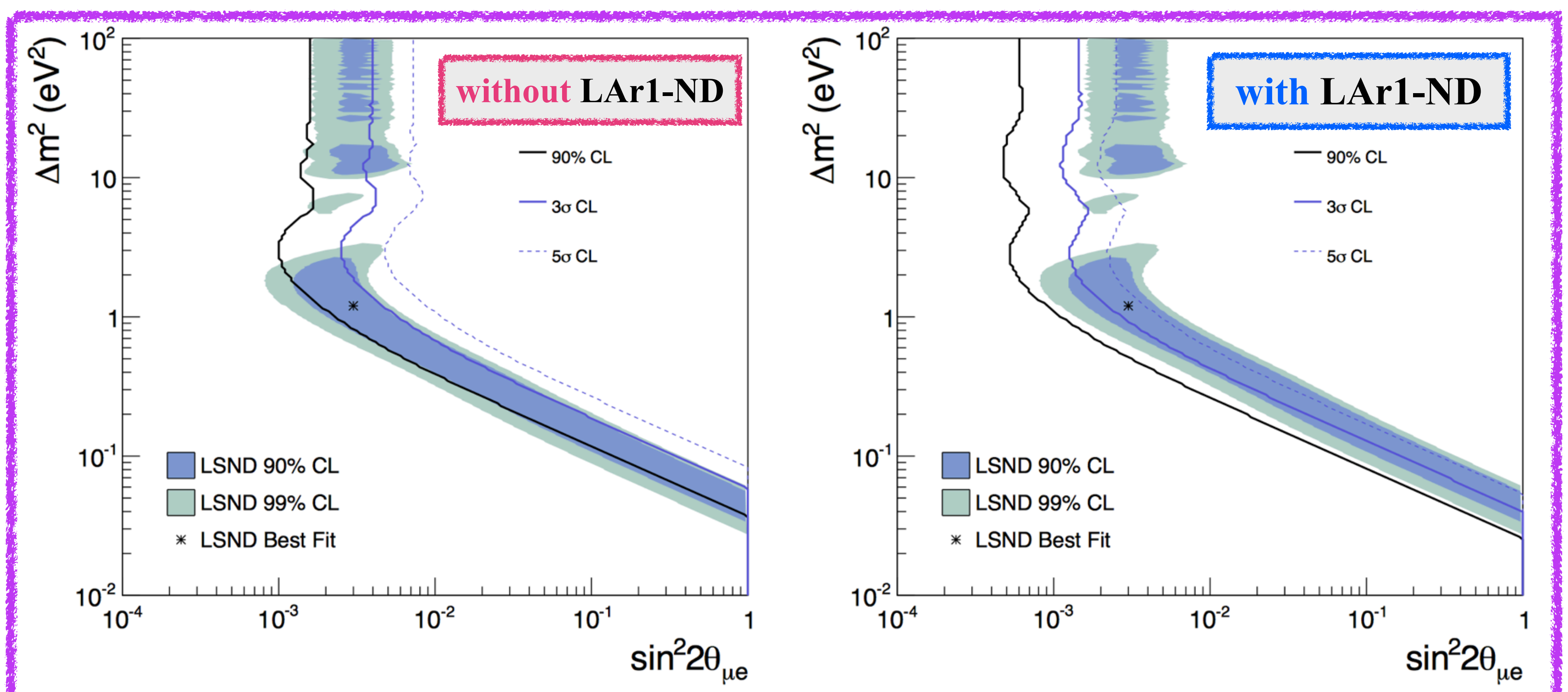
Plots/Numbers/Diagram
Courtesy of D. Davis



MicroBooNE Physics: More++

- **Near Detector for MicroBooNE ?**
  - **Is anomaly due to oscillation or beam (intrinsic)?**
    - definitive answer from having a near detector (ND)
  - **LAr1-ND**
    - Proposed 40 ton LArTPC ND for LAr1 program
    - BNB on-axis @ 100 m from target
    - **Can be MicroBooNE ND!**
  - **Greatly improve MicroBooNE sensitivity**

arxiv 1309.7987



- **Left ... without LAr1-ND**
  - Assume 20% ν_e syst.
- **Right ... with LAr1-ND**
  - Same syst. error
  - Almost 2σ improvement!

LAr1-ND greatly help MicroBooNE