The NOνA Neutrino Experiment

Thomas Coan
Southern Methodist University
For the NOνA Collaboration

11th ICATPP
Villa Olmo, Como
2009

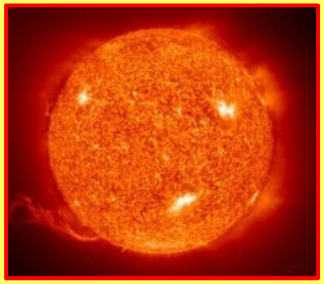
Outline

NuMI **O**ff-Axis ν_e **A**ppearance Experiment

- Neutrino Physics Motivation
- Fermilab Neutrino Beam Upgrade
- NOνA Detector Design and Construction
- NOνA Sensitivities
- Timeline & Summary

Neutrinos Mix

Solar νs



Homestake, Gallex, SAGE, Super-K, SNO, Borexino

Reactor νs

KamLAND, CHOOZ, …

Atmospheric νs

Kamiokande, Super-K

Accelerator νs

K2K, MINOS, MiniBOONE

Neutrinos change flavor

⇒ Neutrinos have mass and mix

flavor eigenstates

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

mass eigenstates

PMNS Leptonic Mixing Matrix

$$|\nu_\alpha\rangle = \sum_i U_{\alpha i}|\nu_i\rangle$$

$U_{\alpha i}$ can be written w/ 3 mixing angles and 1 phase and w/ $c_{ij} \equiv \cos\theta_{ij}$ and $s_{ij} = \sin\theta_{ij}$

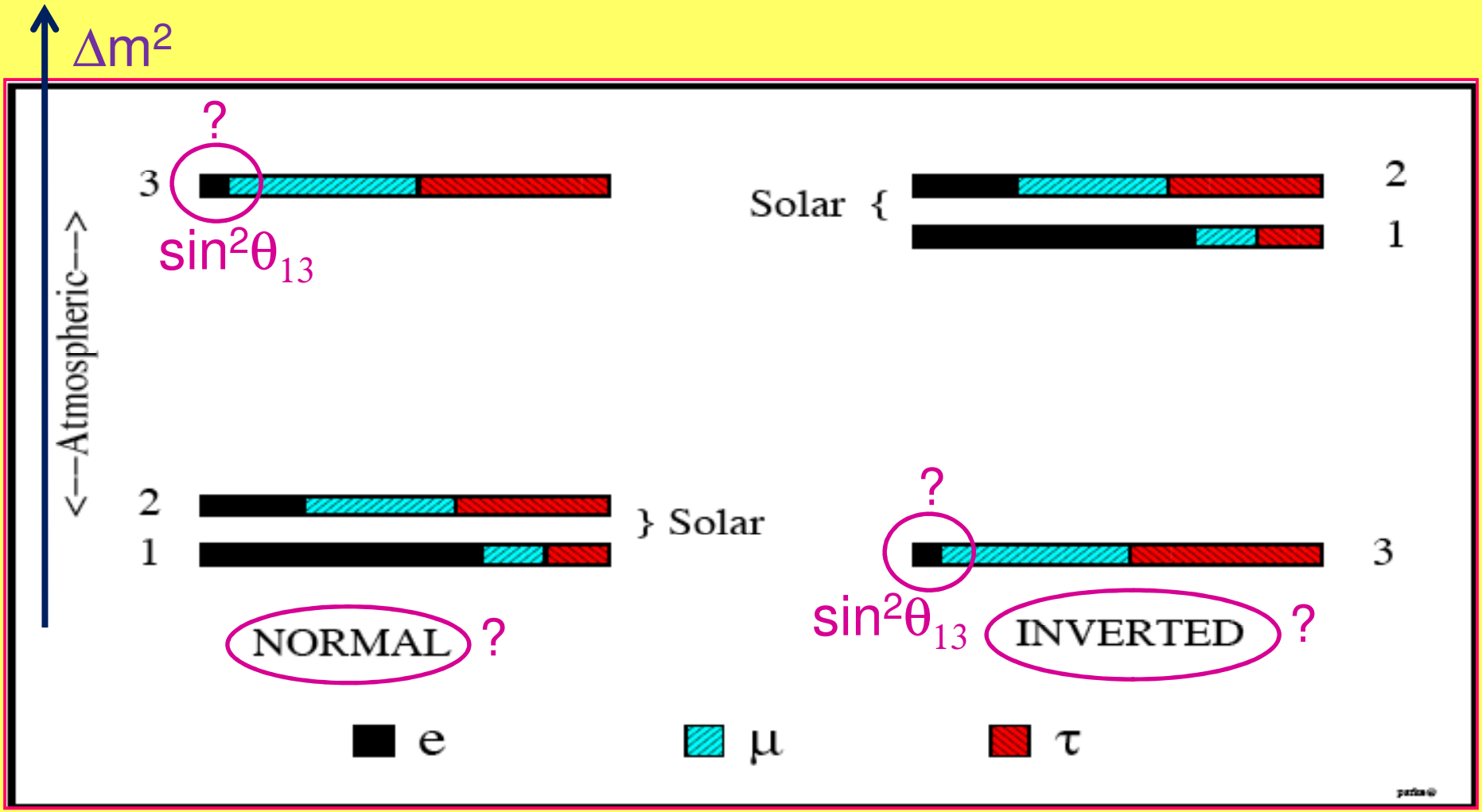
atmospheric cross-mixing solar

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

$$= \begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta} \\ -s_{12}c_{23} - c_{12}s_{23}s_{13}e^{i\delta} & c_{12}c_{23} - s_{12}s_{23}s_{13}e^{i\delta} & s_{23}c_{13} \\ s_{12}s_{23} - c_{12}c_{23}s_{13}e^{i\delta} & -c_{12}s_{23} - s_{12}c_{23}s_{13}e^{i\delta} & c_{23}c_{13} \end{pmatrix}$$

- Mixing angle θ_{13} unknown ($\sin^2 2\theta_{13} < 0.18$).
- CP violating phase δ unknown.

Neutrino Ignorance…



Vacuum Oscillations

Neutrinos propagate as mass eigenstates
Interact as different (i.e., weak) eigenstates

➢ Oscillations result

In absence of matter (key caveat) & to lowest order:

$$P_{vac}(\nu_\mu \to \nu_e) = \sin^2\theta_{23}\sin^2 2\theta_{13}\sin^2\Delta_{atm}$$

$$\Delta_{atm} \simeq 1.27\left(\frac{\Delta m^2_{32}(\mathrm{eV}^2)L(\mathrm{km})}{E(\mathrm{GeV})}\right)$$

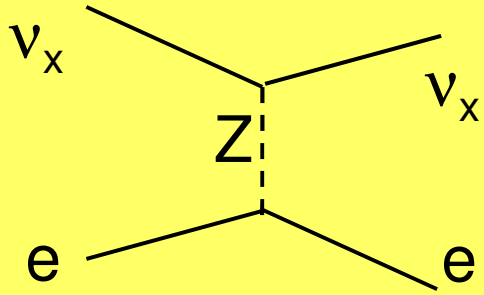
Additional sub-dominant terms, sensitive to CPV phase δ:

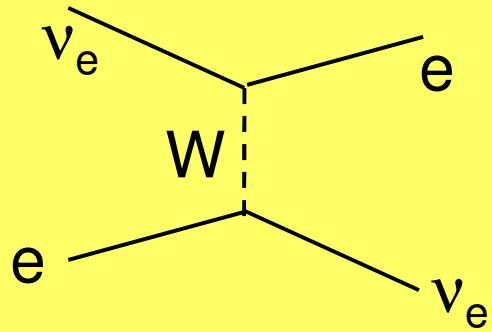
$$\Delta P_\delta(\nu_\mu \to \nu_e) = J\sin\Delta_{sol}\sin\Delta_{atm}(\cos\delta\cos\Delta_{atm} \underset{\nu}{-} \underset{\bar{\nu}}{+} \sin\delta\sin\Delta_{atm})$$

$$J = \sin 2\theta_{12}\sin 2\theta_{23}\sin 2\theta_{13}\cos\theta_{13}$$

… but NOνA's neutrinos travel though Earth ...

"Matter Effects"





ν_e – e scattering Hamiltonian modified

Effective mass eigenstates & mixing angles altered

$$P_{mat}(\nu_\mu \to \nu_e) \simeq (1 \pm 2\frac{E}{E_R}) P_{vac}(\nu_\mu \to \nu_e)$$

$E_R \cong 12$ GeV (earth's mantle)

$E(\nu) \cong 2$ GeV $\Rightarrow$ 30% enhancement/suppression

NOνA's long baseline key

NOνA Goals at a Glance

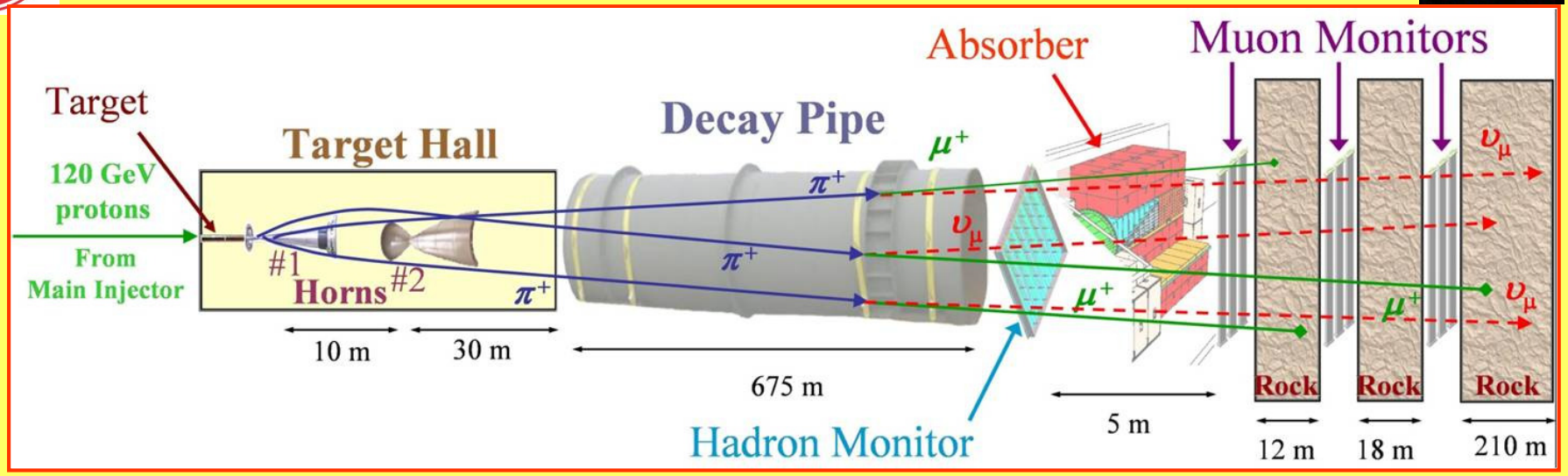
- Observe $\nu_\mu \rightarrow \nu_e$ transition
- Measure θ_{13}
- Determine mass hierarchy (sign of Δm^2_{23})
- Measure $\sin^2(2\theta_{23})$ w/ high precision
- Constrain δ_{CP}

Large neutrino luminosity & detector mass req'd

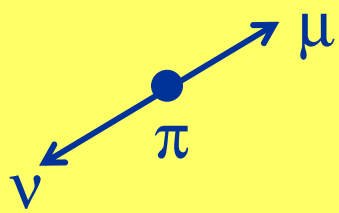
NOνA Collaboration

- 180+ scientists/engineers
- 27 institutions
- 4 countries

Off-Axis Beam Technique



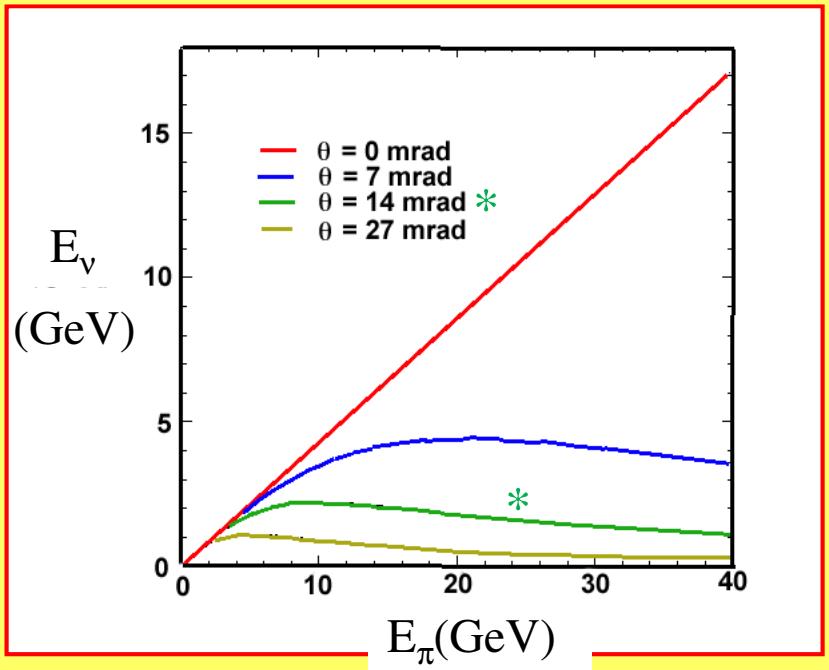
CoM:



Lab Frame:

$$E_\nu \propto \frac{E_\pi}{1 + (E_\pi/m_\pi)^2\theta^2}$$

∴E(ν) ~independent of parent hadron E



Accelerator Upgrade

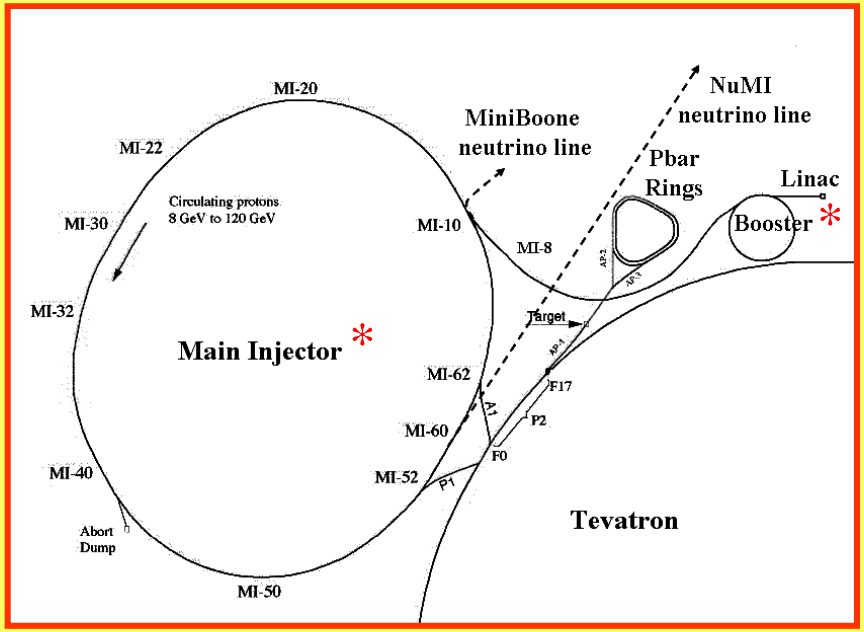
⇒ post-Tevatron era ⇐

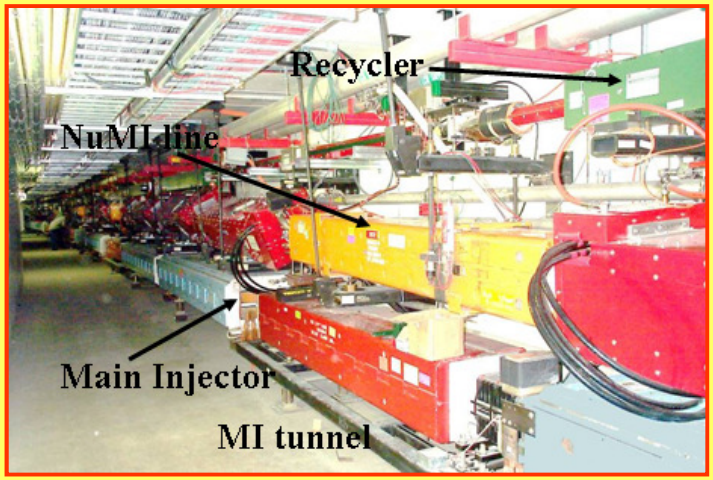
Booster → Recycler → MI → target

p: 8 GeV → 120 GeV

- Recycler: $\overline{p}$ → p storage ring
  - slip-stack batches in Recycler
  - single turn extraction into MI
  - 53 MHz RF added

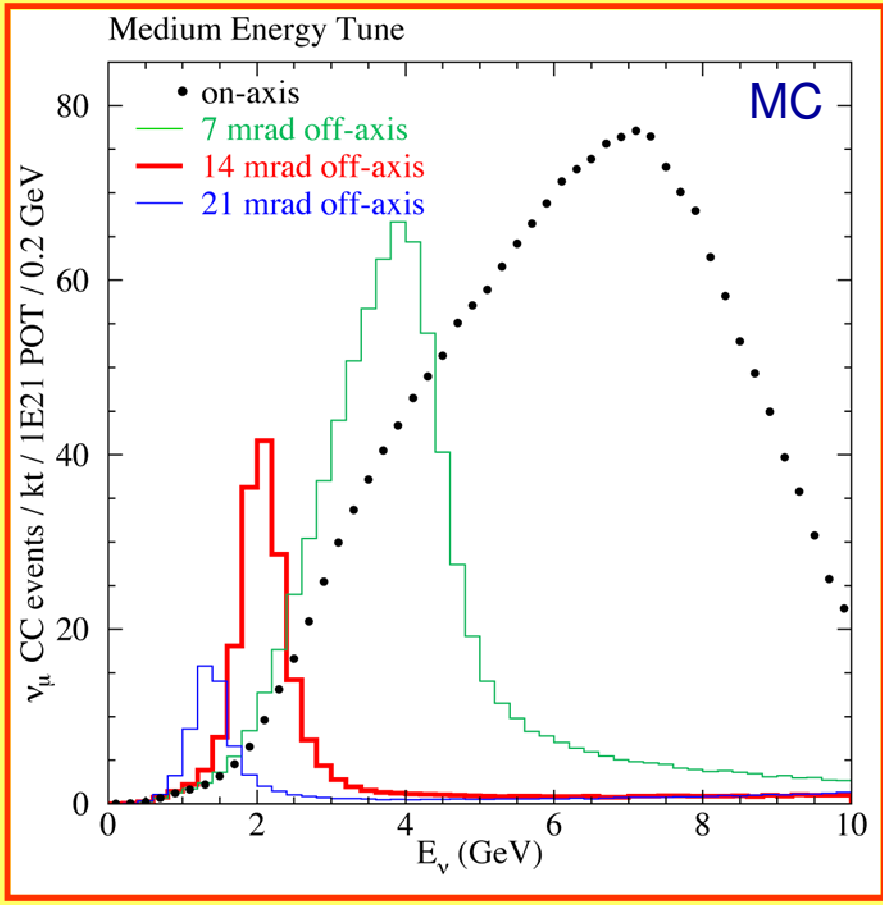
- MI cycle time: 2.2 s → 1.33 s
  - more 53 MHz RF





Upgraded NuMI Beam

- 14.6 mrad off-axis ν beam
- 10 μsec spill every 1.3 sec
- Horns @ "medium energy tune"
- 4.9×10^{13} p/pulse @120 GeV/p
- 700 kW beam power
- 6×10^{20} POT/yr
- Plan 3 yr ν_μ & 3 yr $\overline{\nu}_\mu$ running

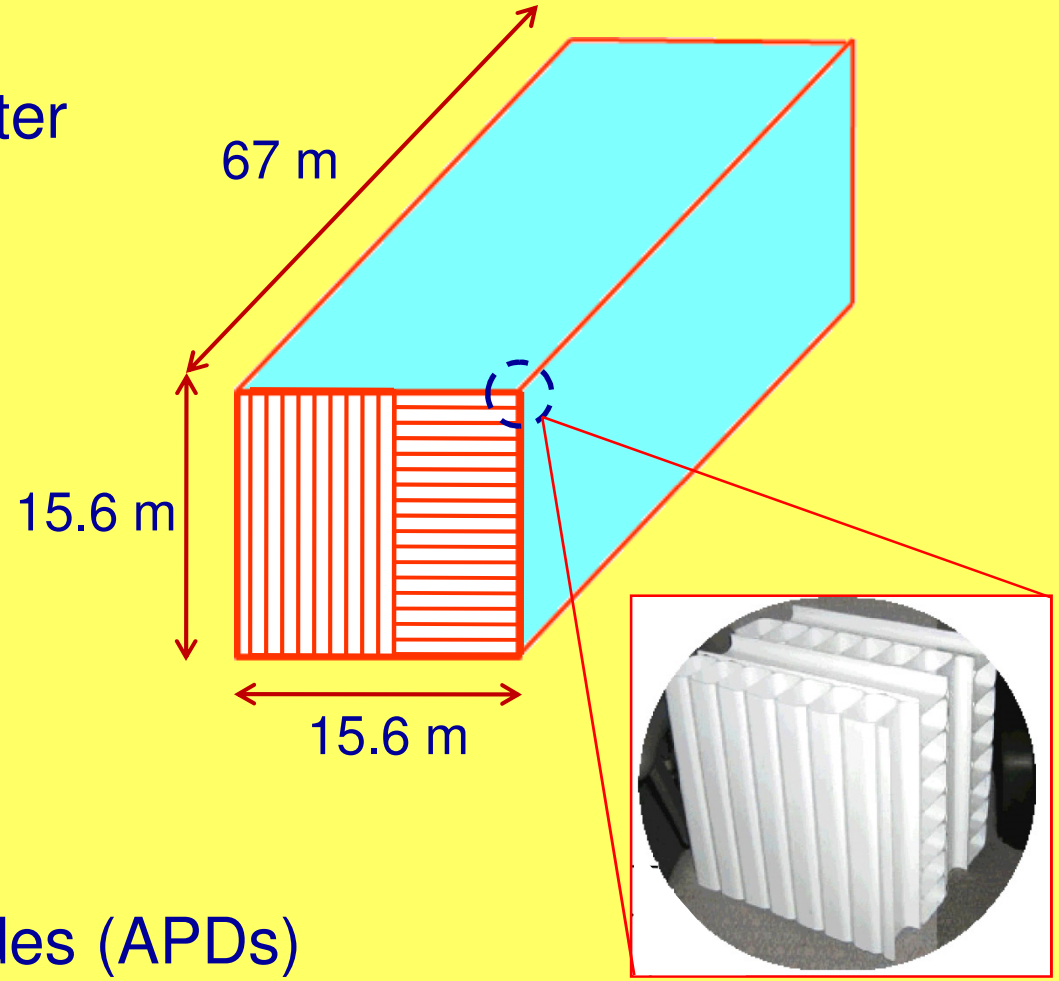


2-Detector Configuration

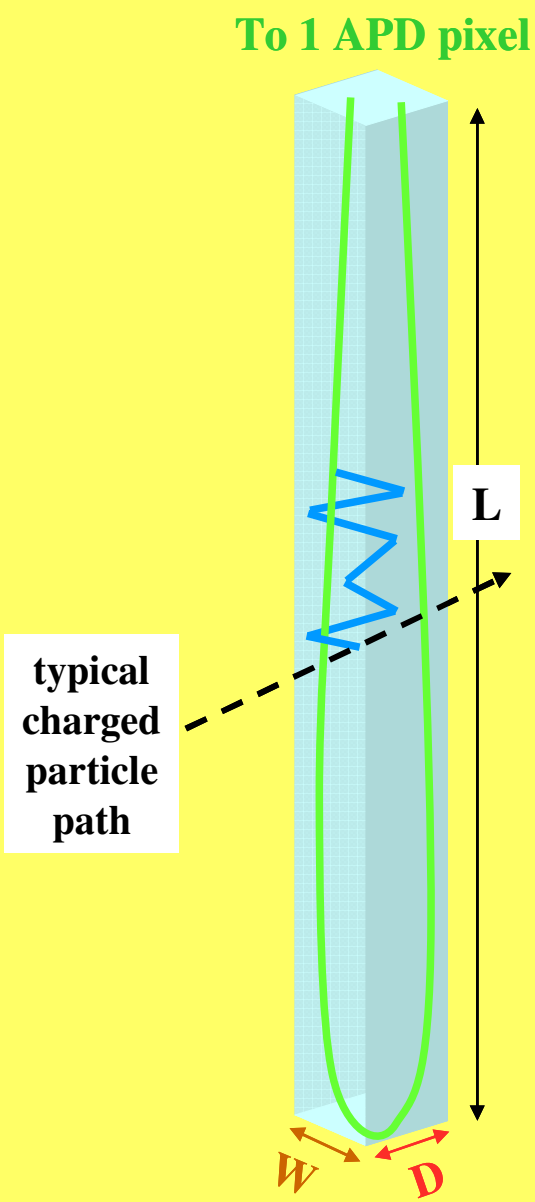
- Near detector measures ν flux, measures background rates
- Far detector measures osc ν flux

NOνA Far Detector Overview

- Low-Z tracking calorimeter
- Surface location
- 14 kT total mass
- 930 Detector planes
  - Alternate x-y layers
  - 73% active
- Liquid scintillator cells
  - 4 cm x 6 cm x 1540 cm
- 1-sided readout/plane via avalanche photodiodes (APDs)



NOνA Detector "Atom"



Liquid Scintillator

- Mineral oil solvent
- Primary scintillator: 4.1% (BW) pseudocumene
- Waveshifters: PPO + bis-MSB

Hollow PVC cells provide granularity

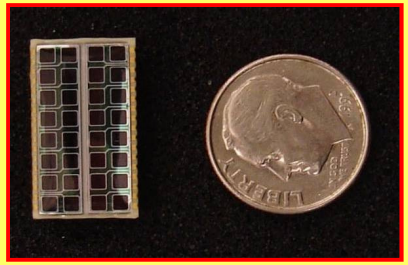
- 15% (BW) TiO_2: high reflectivity walls
- Horizontal cell: 3.87 cm x 6.0 cm x 15.4 m long
- Vertical cell: 3.76 cm x 5.7 cm x 15.4 m long

Looped Wavelength Shifting Fiber

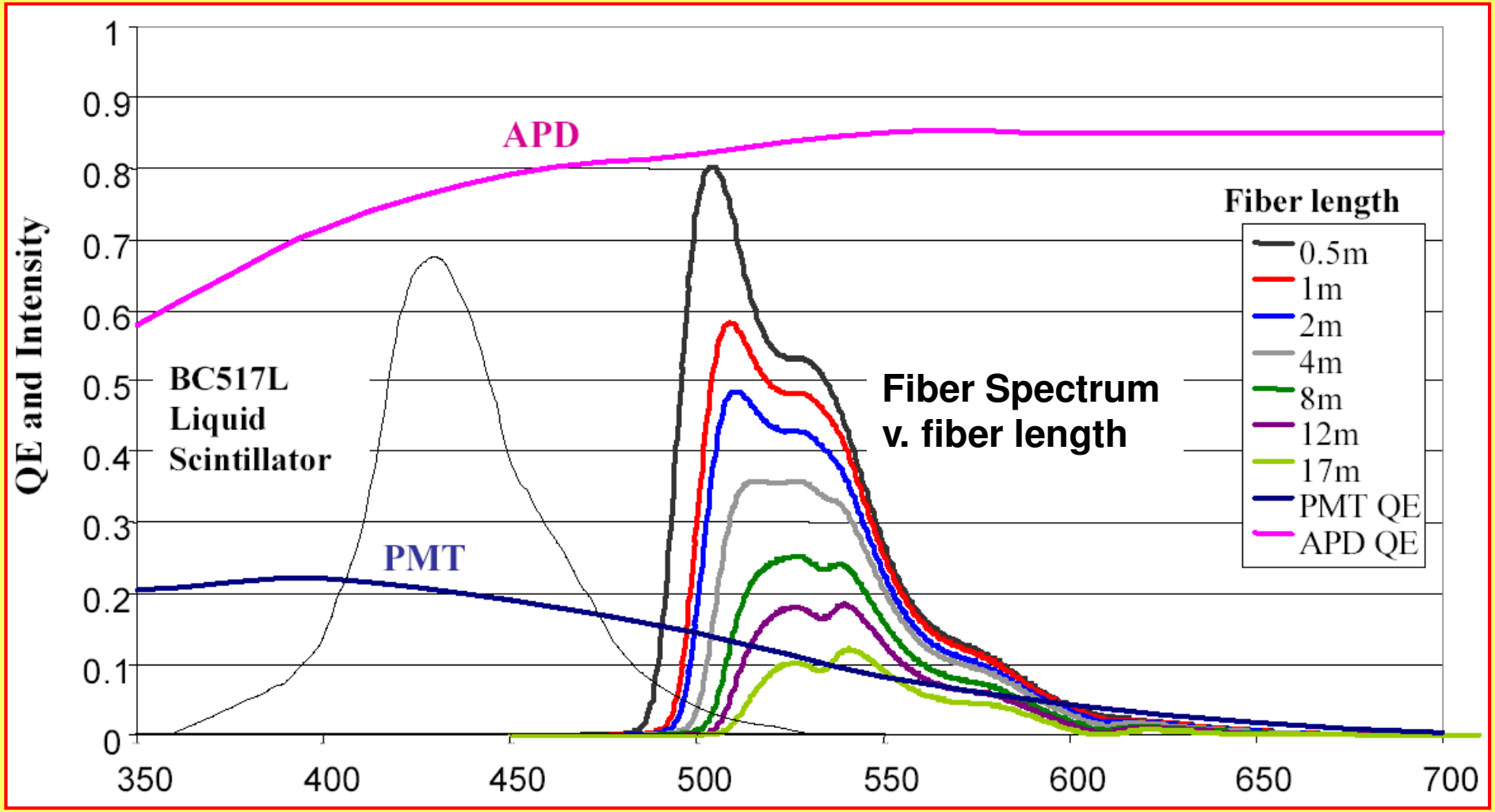
- Maximizes light collection: no mirrors
- Diameter = 0.7mm, K-27 dye @ 300ppm

Avalanche Photodiode

- QE = 85%
- Gain = 100
- T_run = -15 C



Why APDs


QE and Intensity
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
350
400
450
500
550
600
650
700
APD
PMT
BC517L
Liquid
Scintillator
Fiber Spectrum
v. fiber length
Fiber length
0.5m
1m
2m
4m
8m
12m
17m
PMT QE
APD QE

λ (nm)

Far Detector Module Construction

ERROR: stackunderflow
OFFENDING COMMAND: ~

STACK: