The Astrophysics Program of the NOvA Neutrino Experiment

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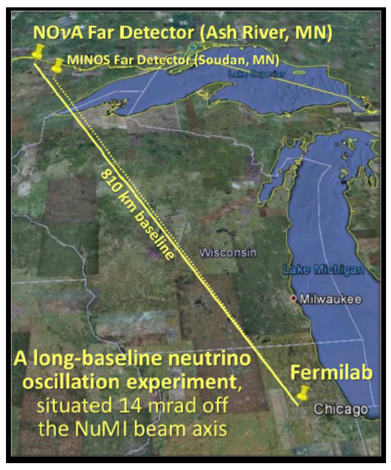
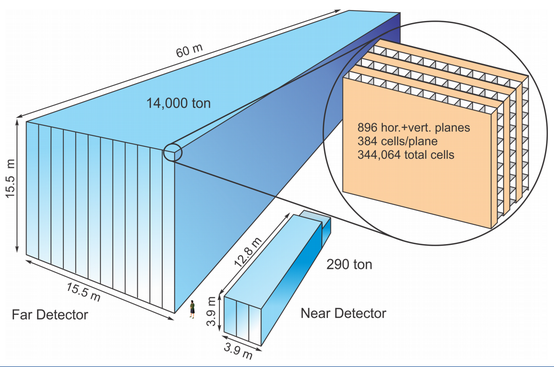
The NOvA detectors, designed primarily to discover and measure electron neutrino appearance in a muon neutrino beam, are versatile instruments being used for a variety of astrophysical analyses.

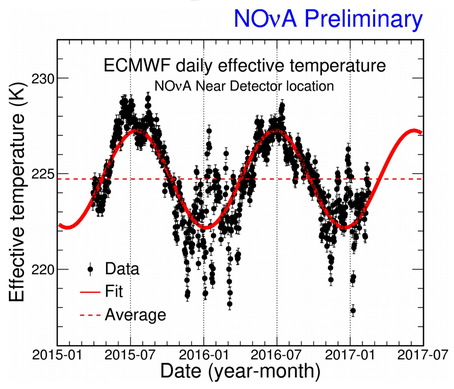
The NOvA Detectors

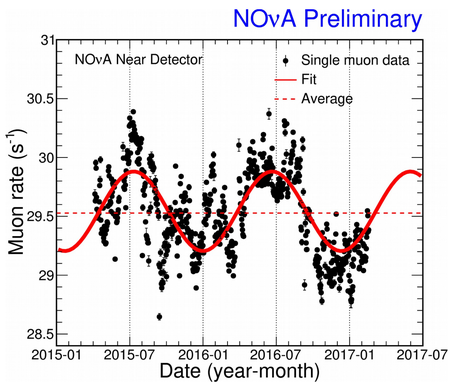


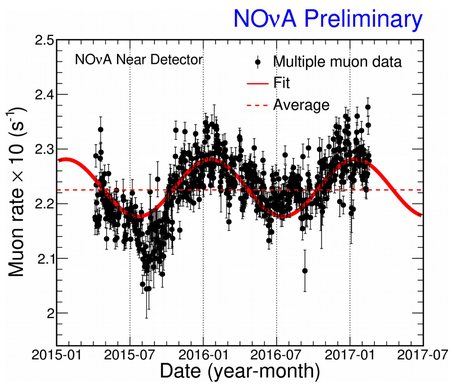


- Segmented liquid scintillator detectors
- Far detector on the surface
- Near detector underground, 300 meters water equivalent
- All data continuously digitized
- Buffered for ~20 minutes while trigger decisions are made
- Triggers can request a data time window of 50μs to 45 seconds
- Enables rich non-oscillation physics program

Seasonal Multiple-muon Effect

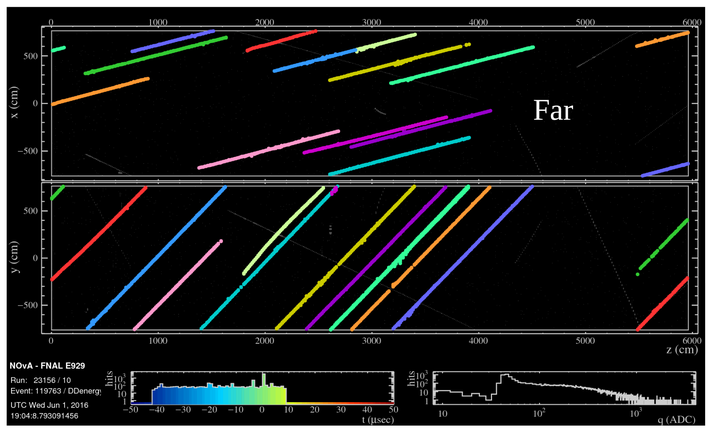


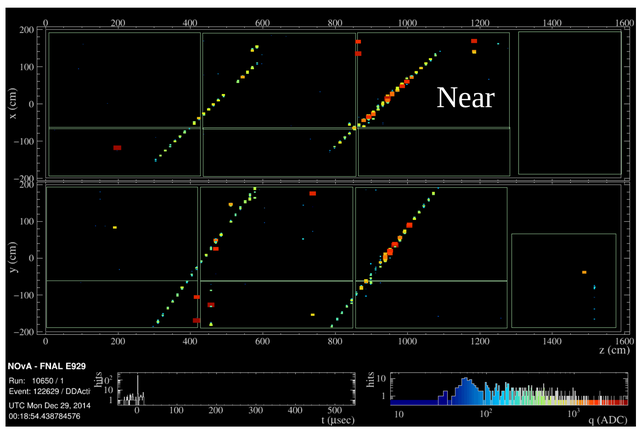




- Total muon rate underground is well-known to be higher in the summer
- MINOS observed winter maximum for multiple muons
- NOvA now confirms this using our Near Detector
- Far Detector analysis underway

- Origin of effect is unknown, but thought to be caused by secondary interactions of pions in the denser winter atmosphere

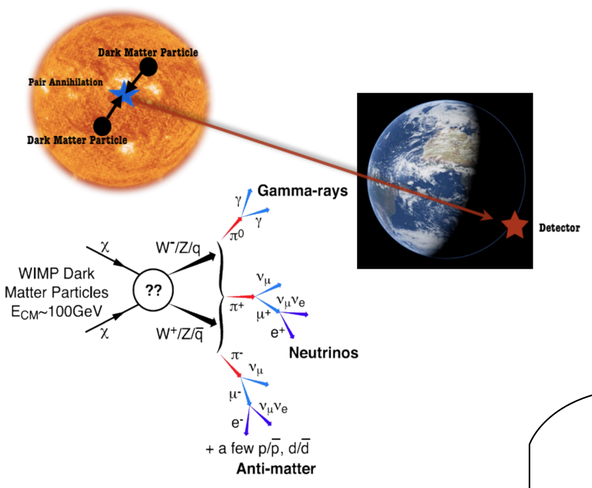




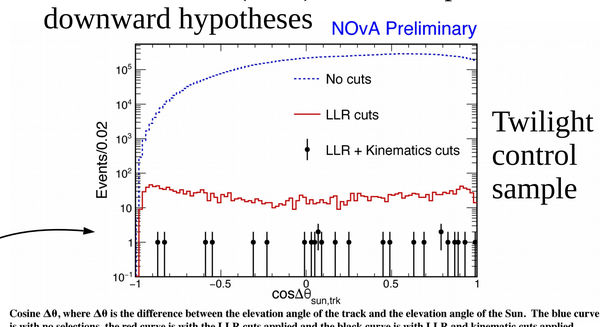
Supernova Neutrinos

See poster #13 in this session.

Dark Matter



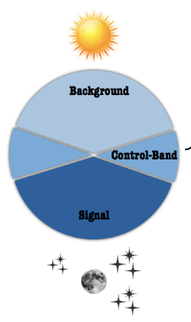
- Search for dark matter annihilation in the Sun
- ν_μ interact under and inside Far Detector
- Trigger on upwards-going muons at night
- Distinguished from downward-going cosmic muons primarily by timing: using log-likelihood ratio (LLR) between upward and downward hypotheses

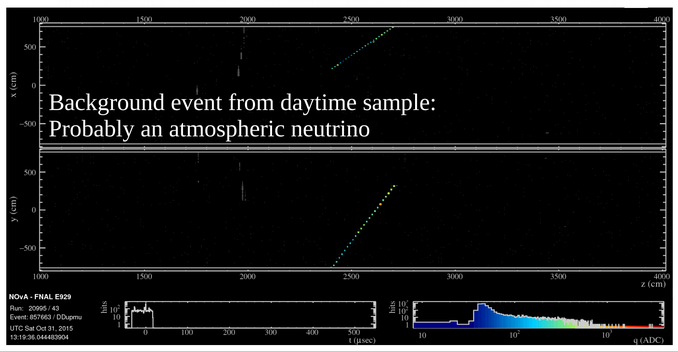


Twilight control sample

Cosine Δθ, where Δθ is the difference between the elevation angle of the track and the elevation angle of the Sun. The blue curve is with no selections, the red curve is with the LLR cuts applied and the black curve is with LLR and kinematic cuts applied.

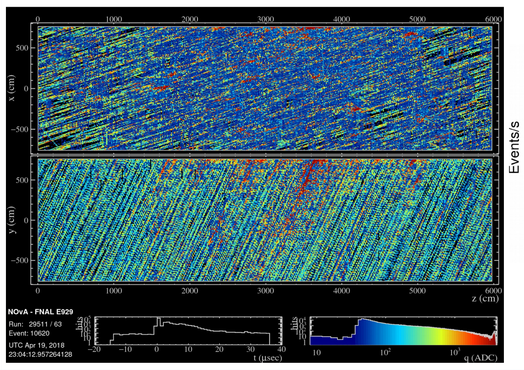
- Major background: **atmospheric neutrinos**
- Data-driven background estimate: day sample
- Analysis validation: twilight sample

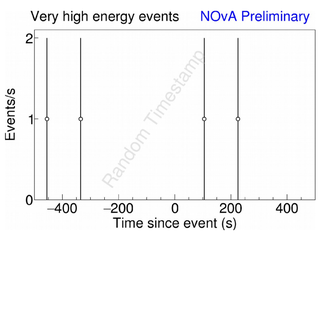


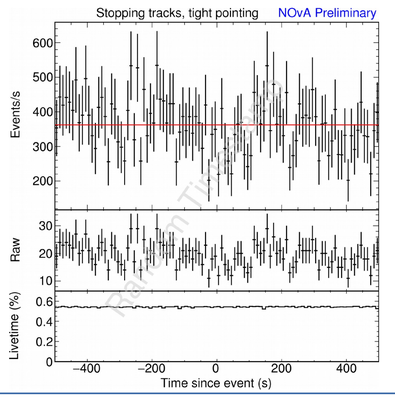


Gravitational Wave Coincidence

- Near and Far detectors up for all six LIGO/Virgo events
- Sensitive to MeV-PeV signals
- At GeV and above, tracks point to source
- ND 100% live for ~100MeV and up
- FD 100% live for certain event topologies ≳1GeV, otherwise 1.4%
- Analysis of existing events underway
- For LIGO/Virgo's O3 run, we plan to receive triggers and read out a 45s window as we do for supernovae







Neutron/Anti-neutron Oscillations

- Search for n → $\bar{n}$ conversion in ^{12}C
- Conversion suppressed in nuclei, but less in carbon than oxygen: advantage over water detectors
- Typical signature is several annihilation pions in a momentum-symmetric star
- Despite being on the surface, expect to be limited by the **atmospheric neutrino** background with ~10kt fiducial mass
- Will begin triggering on n → $\bar{n}$-like events summer 2018

$\bar{n}+p$		$\bar{n}+n$	
$\pi^+\pi^0$	1%	$\pi^+\pi^-$	2%
$\pi^+2\pi^0$	8%	$2\pi^0$	1.5%
$\pi^+3\pi^0$	10%	$\pi^+\pi^-\pi^0$	6.5%
$2\pi^+\pi^-\pi^0$	22%	$\pi^+\pi^-2\pi^0$	11%
$2\pi^+\pi^-2\pi^0$	36%	$\pi^+\pi^-3\pi^0$	28%
$2\pi^+\pi^-2\omega$	16%	$2\pi^+2\pi^-$	7%
$3\pi^+2\pi^-\pi^0$	7%	$2\pi^+2\pi^-\pi^0$	24%
		$\pi^+\pi^-\omega$	10%
		$2\pi^+2\pi^-2\pi^0$	10%

arXiv:1109.4227

Magnetic Monopoles

- Magnetic monopoles predicted by various grand unified theories
- Not much theoretical guidance on the mass
- $10^5 - 10^{18}$ GeV
- NOvA Far Detector is unique in being a large tracking detector on the surface
- Sensitive to low mass monopoles that would range out before reaching underground detectors
- Slow monopoles, β < 0.01 are detected via unmistakable slow track
- Fast monpoles, β > 0.01 are detected by consistent highly ionizing straight track
- 1000 live-days of monopole-triggered data on tape as of May 2018

$$\nabla \cdot E = 4\pi\rho_e$$

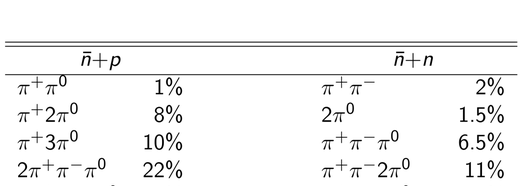
$$\nabla \cdot B = 4\pi\rho_m$$

$$\nabla \times E = \frac{1}{c}\left(4\pi J_m + \frac{\partial B}{\partial t}\right)$$

$$\nabla \times B = \frac{1}{c}\left(4\pi J_e + \frac{\partial E}{\partial t}\right)$$

East/West Effect

- Measurement of the east/west asymmetry of the low energy cosmic ray muon flux
- Caused by Earth's magnetic field: some trajectories of low energy primaries are forbidden
- Measurement of the field and its impact on cosmics is an input for low-energy atmospheric neutrino simulations
- Must be disentangled from detector overburden asymmetries



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