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8th Patras Workshop on Axions, WIMPs and WISPs

for

The NOvA collaboration

PROSPECTIVE EXOTIC SEARCHES WITH THE NOVA DETECTORS

Outline

- Motivation for hidden sector searches with GeV-scale, oscillation-experiment neutrino detectors.
- The NOvA experiment and detectors.
- Short baseline Near detector
- 14 kT Far detector
- Prototype NDOS.
- Detection Methods.
- Potential exotic searches.
- Status and plans.

Motivation for searches with neutrino detectors.

- Depend on the experiment baseline.
  - Provides sensitivities to lifetime dependent measurements
- Oscillation experiments have Far –Near setup.
- Neutrino Far detectors
  - Several kilo-tons.
  - Modern neutrino detectors are optimized for high efficiency detection of low energy particles and showers
  - Can have high speed read-out.
  - Ideal for rare, random, non-oscillation events.
    - Supernova monitoring.
      - E.g. 5,000 neutrinos, ~MeV in 10s from a SN at 10kpc.
    - Passing Monopoles.
      - Presumed very massive, very slow, very ionizing.
      - Flux limits depend on the mass: MACRO: O(10-16) cm^{-2} s^{-1} sr^{-1}
        - Eur.Phys.J. C25, 511-522 (2002)

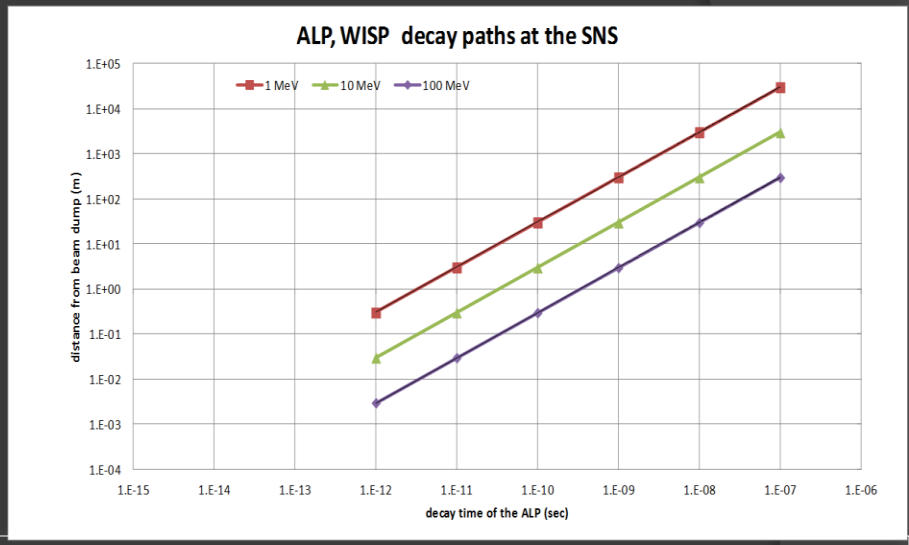
Motivation for using a Near detector

- Near Detectors are optimized for high rates of neutrinos.
- They operate as a “Proton fixed-target experiment”.
  - “Exotic”-beam may be generated within the target.
    - Can be ~10^6 more probable than in a collider (by density alone).
      - Bremsstrahlung, pair-produced, mediated by vector boson.
    - Favors forward production focus
      - $\mathrm{Cos}(\vartheta) > 0.99$ by some models.
- Exotic particles may decay in flight.
  - Detect the product signatures: Di-lepton/di-meson pairs.
- Or can interact in the detector.
  - No-charge interaction: Excess events in the NC channel.
  - Elastic scattering of electrons: Very forward focused product
    - (differentiate from background).

Intensity Frontiers Workshop references: arxiv:1205.2671, 0906.5614, 0711.1363.

Decay path systematized-scan with neutrino Near detectors

- A function of lifetime.
  - Natural parameter of the particle.
    - coupling is associated with models accepted by the various authors.
- The limits of sensitivity are applied on the physical parameters of the experiment.
- Near detectors are stationary.
  - Not all at the same distance.



Limits of sensitivity for elastically generated potential HS particles from the beam-dump of an 1GeV proton accelerator (SNS).

Workshop on Neutrinos at the Spallation Neutron Source
May 3-4, 2012 at Oak Ridge National Laboratory

Proposal at SNS
100-1000m

target

K experiments
KOTO, ORKA
100m

ND280-T2K
280m

MINOS, NOvA
990m

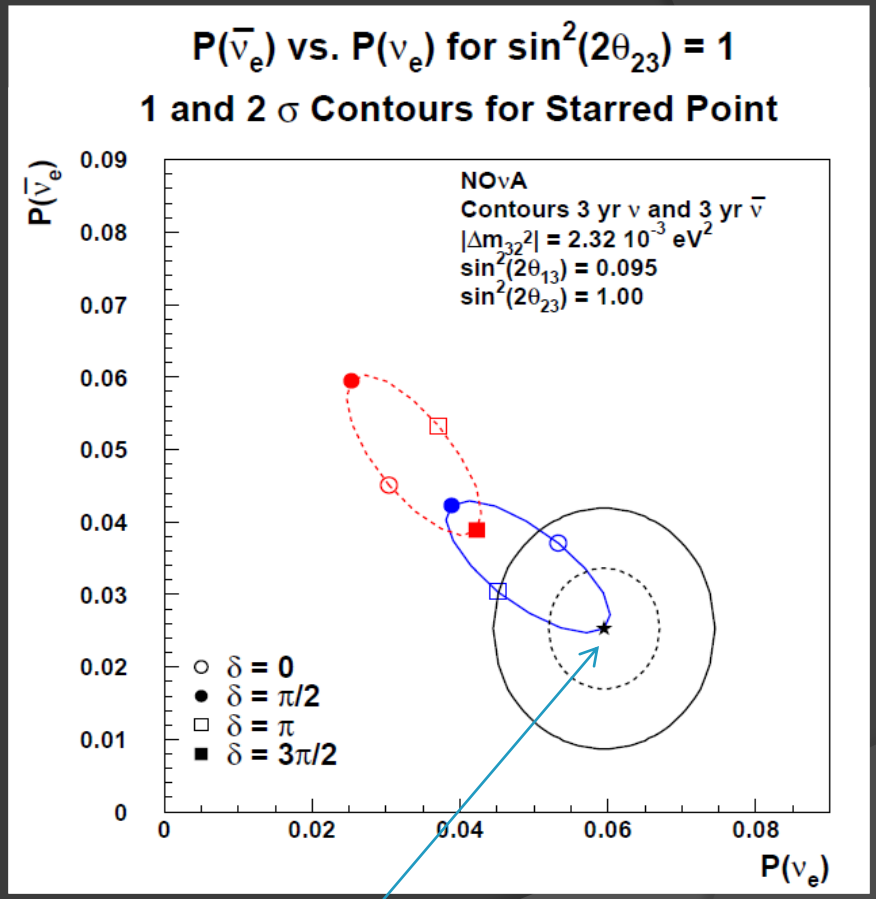
2k LAr
(proposal at T2K)
2km

The NOvA Experiment

- **Long Baseline Neutrino Oscillation Experiment.**
- **Designed to measure:**
  - $\nu_\mu \rightarrow \nu_e$, $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$, $\nu_\mu \rightarrow \nu_\mu$, $\bar{\nu}_\mu \rightarrow \bar{\nu}_\mu$
- **Precision Measurement: of θ_{13} , θ_{23}.**
- **Goals:**
  - **Determination of the mass hierarchy.**
  - **Observation of CP violation in the lepton sector.**
  - **Resolution of θ_{23} octant (θ_{23} < or > 45^o).**
  - **Cross section of ν at 2 GeV.**
- **The Collaboration:**
  - **150+ scientists and engineers from 25 institutions, 5 countries**

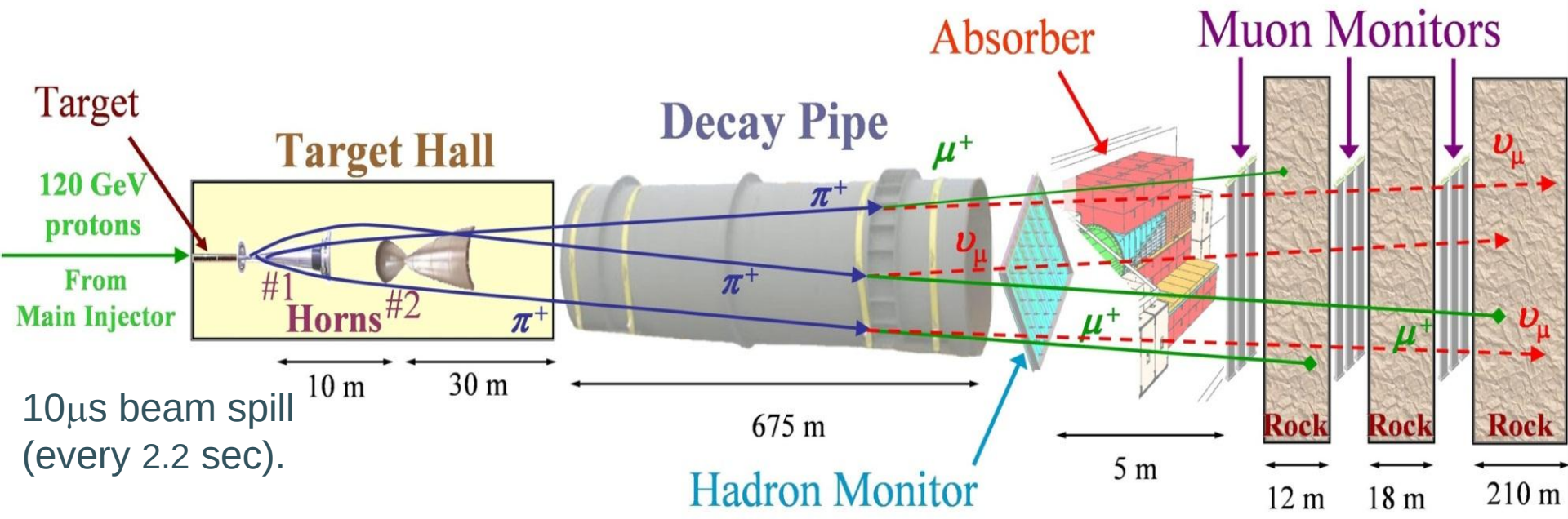
The NOvA measurement

- θ_{13} is well measured.
  - ~9 ^{o} (Fogli et al. '12).
  - NOvA will have large signal rates.
- Independently measured oscillation probabilities.
- Allows for comparison of rates to theory, parameterized in the CP-violation parameter.
- Sensitive to an enhancement/suppression of rates depending on mass ordering
  - ~ 30% effect for NOvA baseline due to matter effects
- NOvA has the potential for 2σ resolution of the mass hierarchy over 38% of the space in δ_{CP}

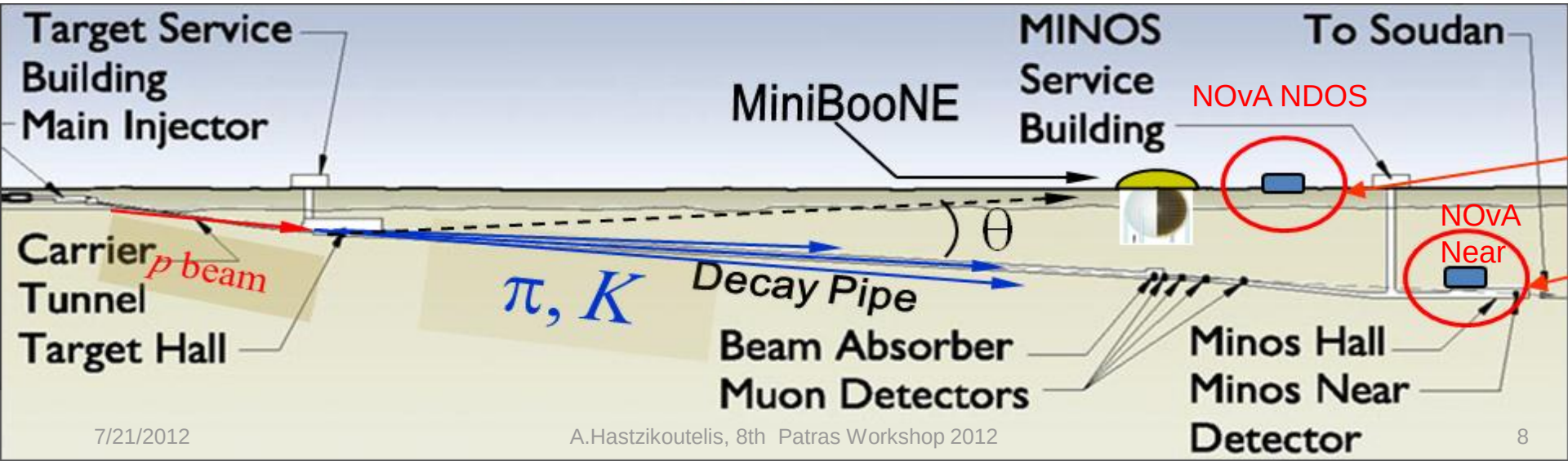


3 year NOvA run on each mode

The NuMI (Neutrinos at the Main Injector) beam.

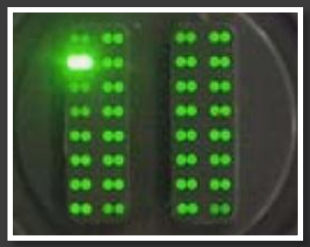


10μs beam spill (every 2.2 sec).

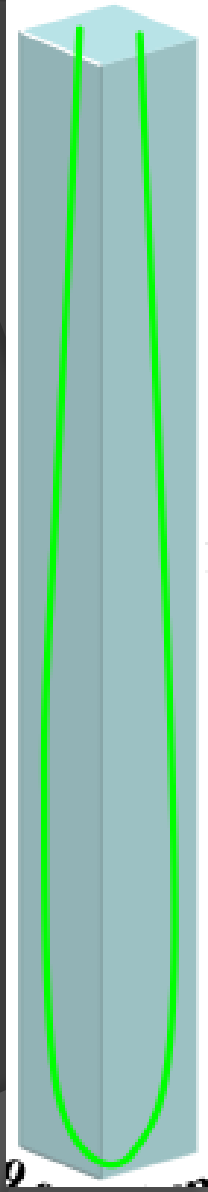


The NOvA detectors design

- **The Detector Cell**
  - **Extruded PVC walls.**
  - **Filled with liquid scintillator**
  - **Instrumented with**
    - **Wavelength-shifting fiber and**
    - **Read out by Avalanche photodiode (APD).**
- **The Readout & Digitization**
  - **32 pixel APD reads out fibers from 32 cells.**
  - **Custom electronics provides amplifier/shaper.**
  - **Each pixel/cell continuously digitized.**
  - **Detection threshold set at ~1/2 MIP**
    - **(6-8 MeV) for muon at far end of cell.**



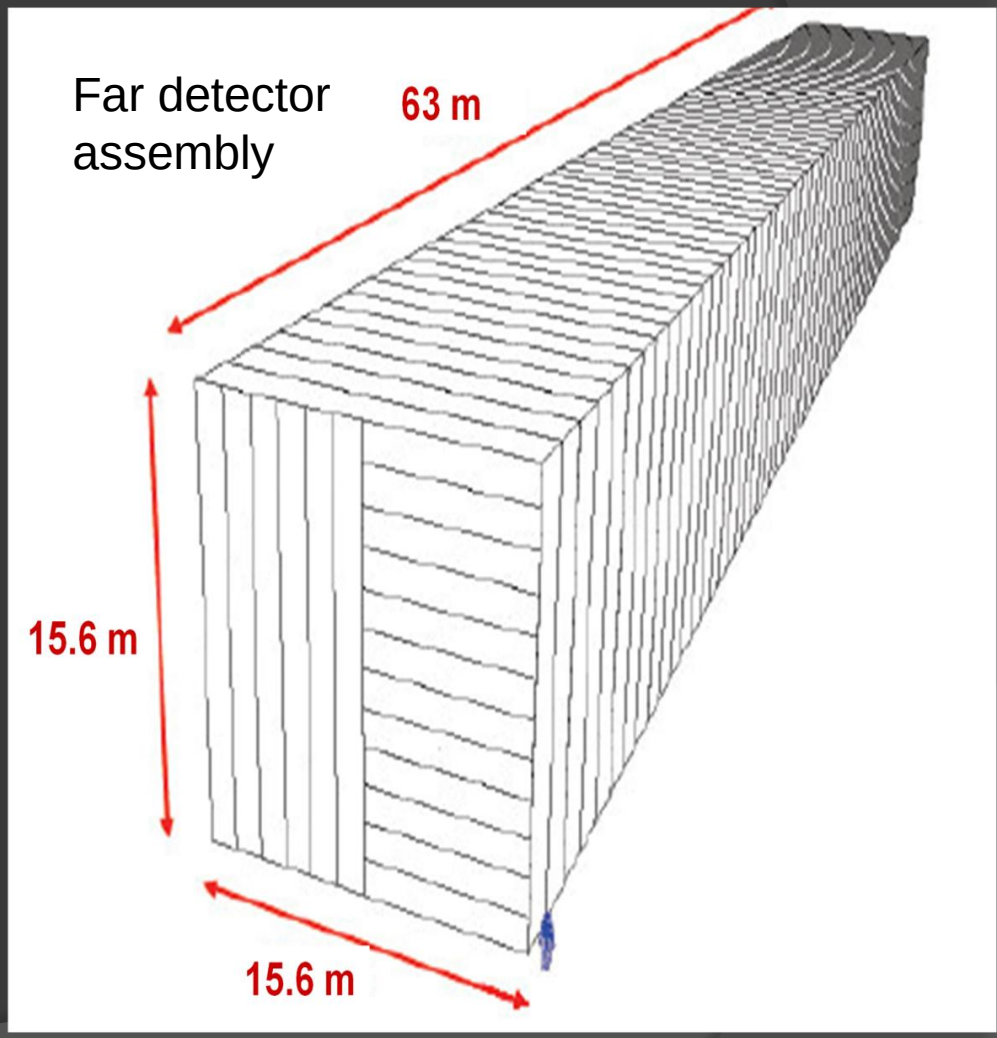
32 pixel APD



4cm*6cm*15m

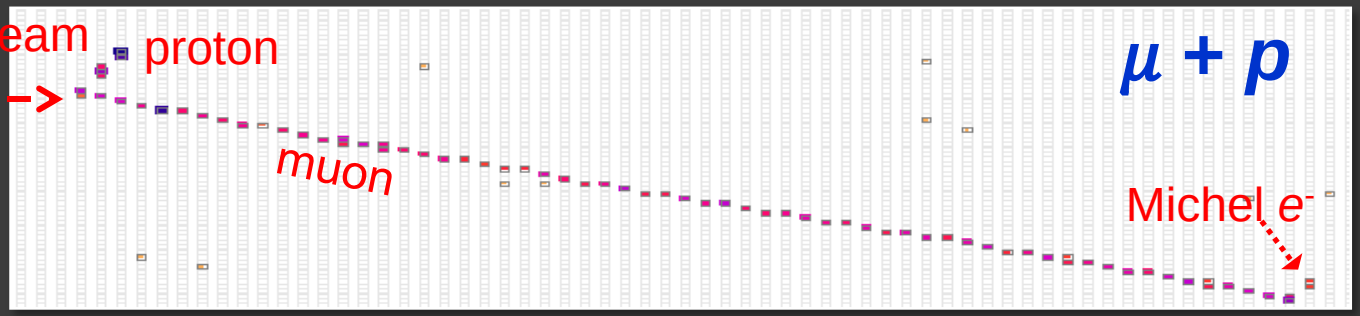
The NOvA detectors

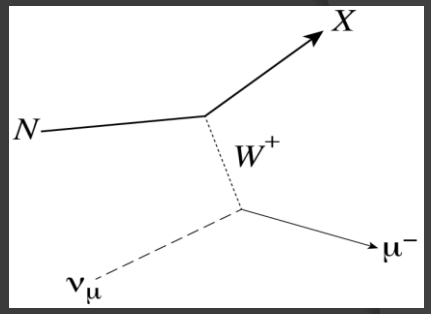
- Far detector:
  - ~14-kton,
  - ~14,700 m^2 sr acceptance.
  - low-Z, highly-active.
  - tracking calorimeter.
  - High segmentation.
    - 960 planes x384 cells.
    - 360,000 total channels.
    - 64% active by mass.
    - X_0=38cm (~6cells)
- Near detector:
  - 0.3-kton
    - Functionally identical as Far.
  - 18,000 channels.
- High speed, dead-timeless, continuous readout.

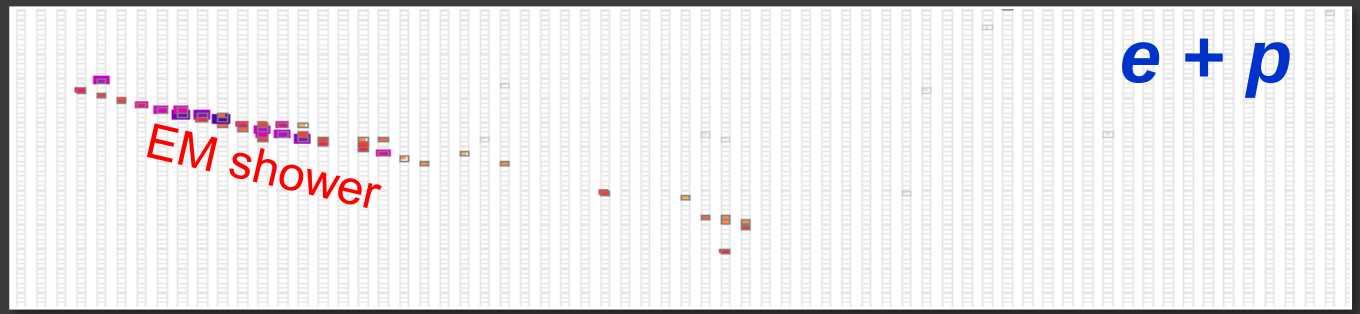


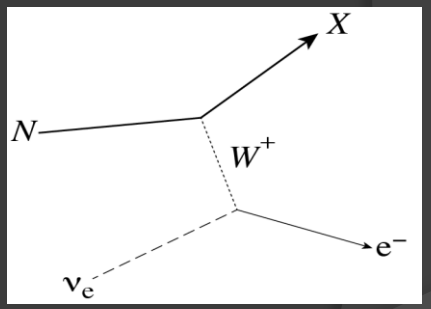
Event topologies

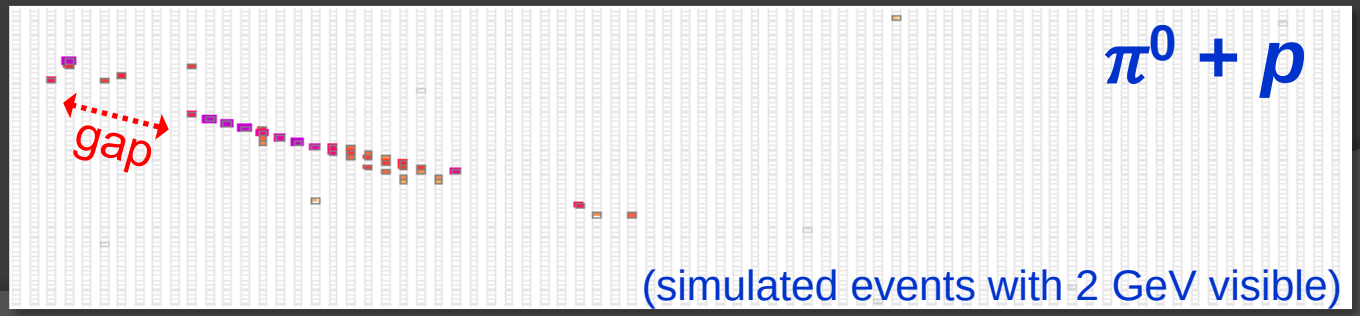
Efficiency 48% identifying ν_e CCQE and 0.1% fake NC rate
Proton recoil ~ few MeV.

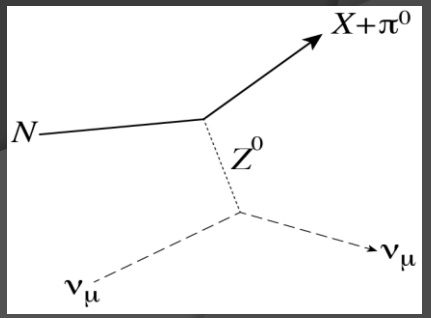






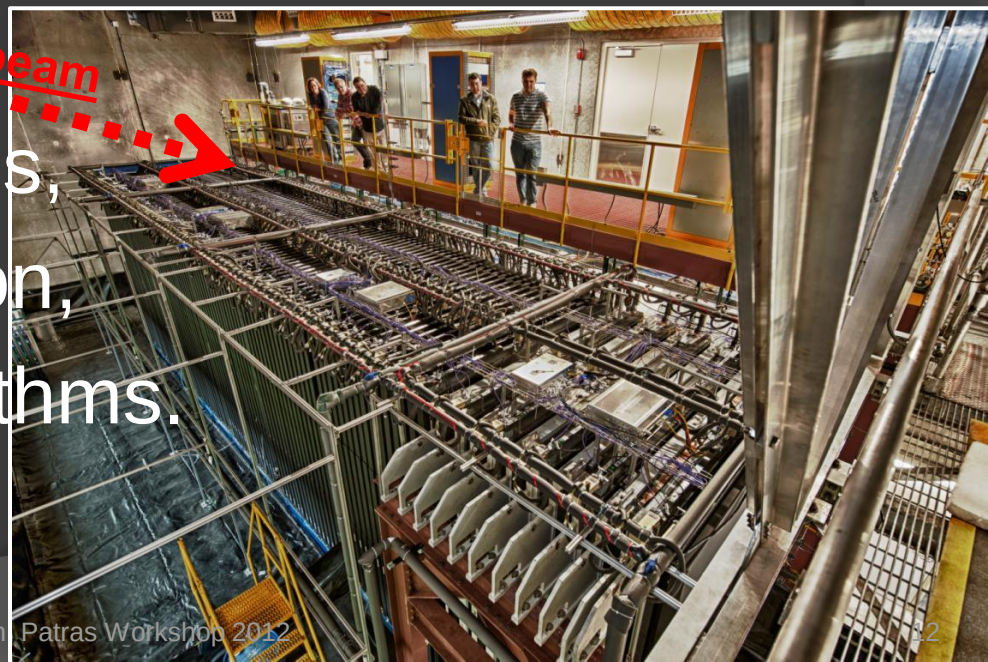






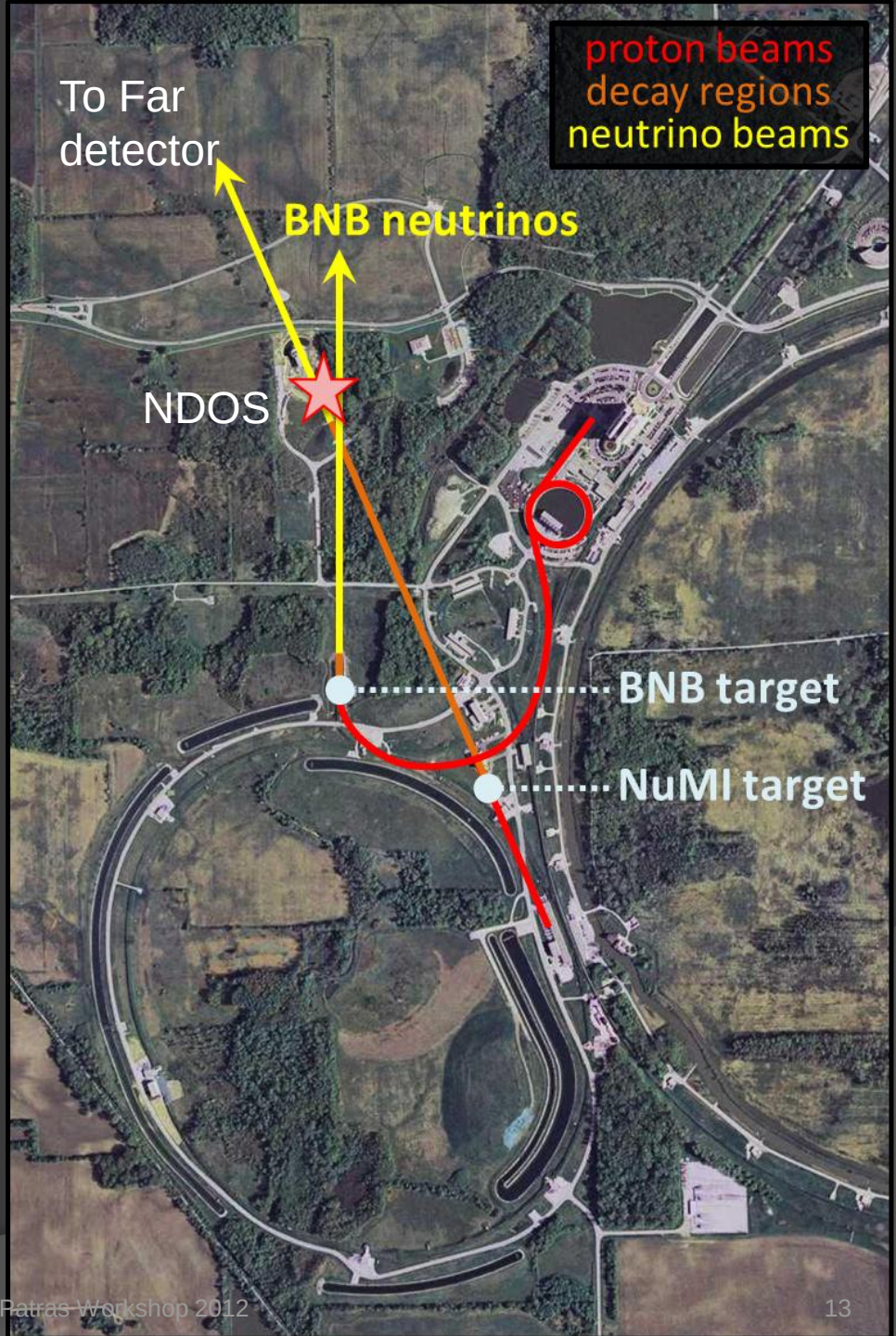
NOvA prototype Near detector

- Near Detector On the Surface (NDOS).
- Used for component production, installation, integration.
- Used for development of:
  - DAQ and Controls
  - Calibration procedures,
  - Validation of simulation,
  - Reconstruction algorithms.

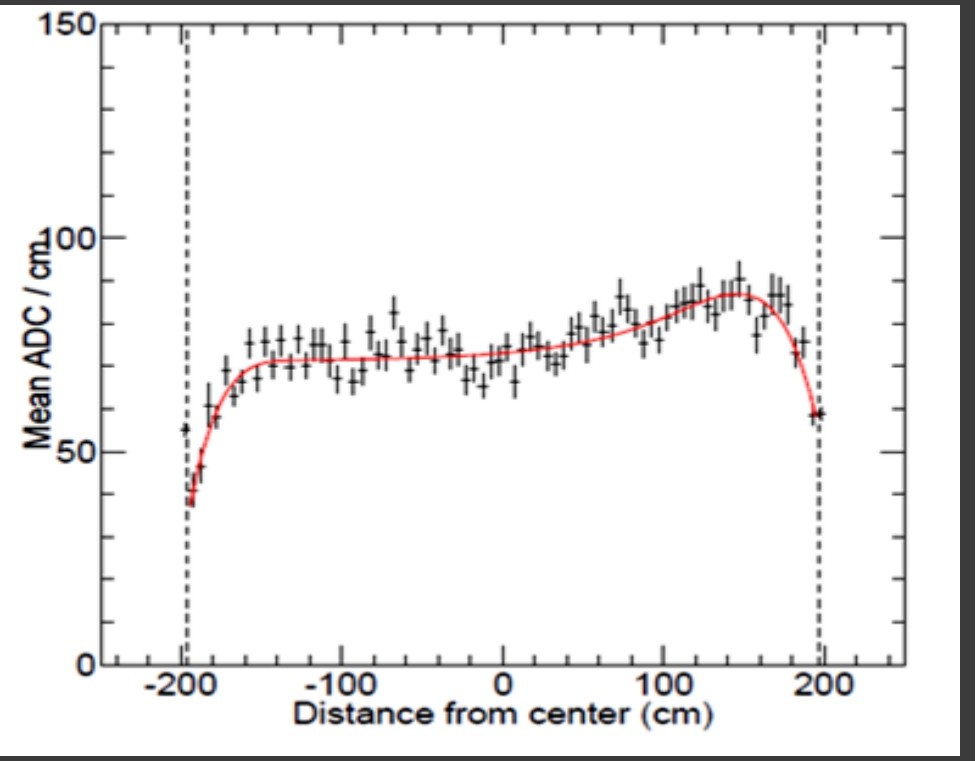


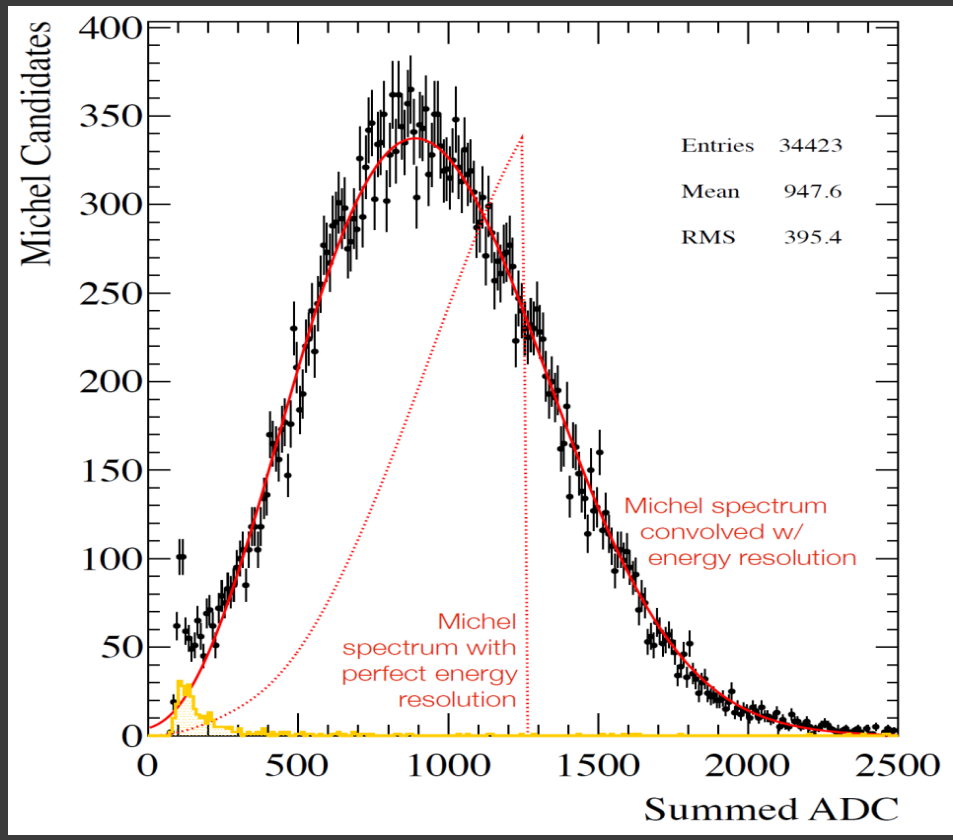
NDOS runs

- Installation completed in May 2011.
- Positioned
  - 900 m from the NuMI target.
  - Between 2 beams
    - NuMI: Parallel and 110mrad off center.
    - Booster: 23 deg rotated and inline.
  - 100m above the beams.
- Physics runs until May 2012.
- Continuing engineering runs.



Calibration (NDOS)



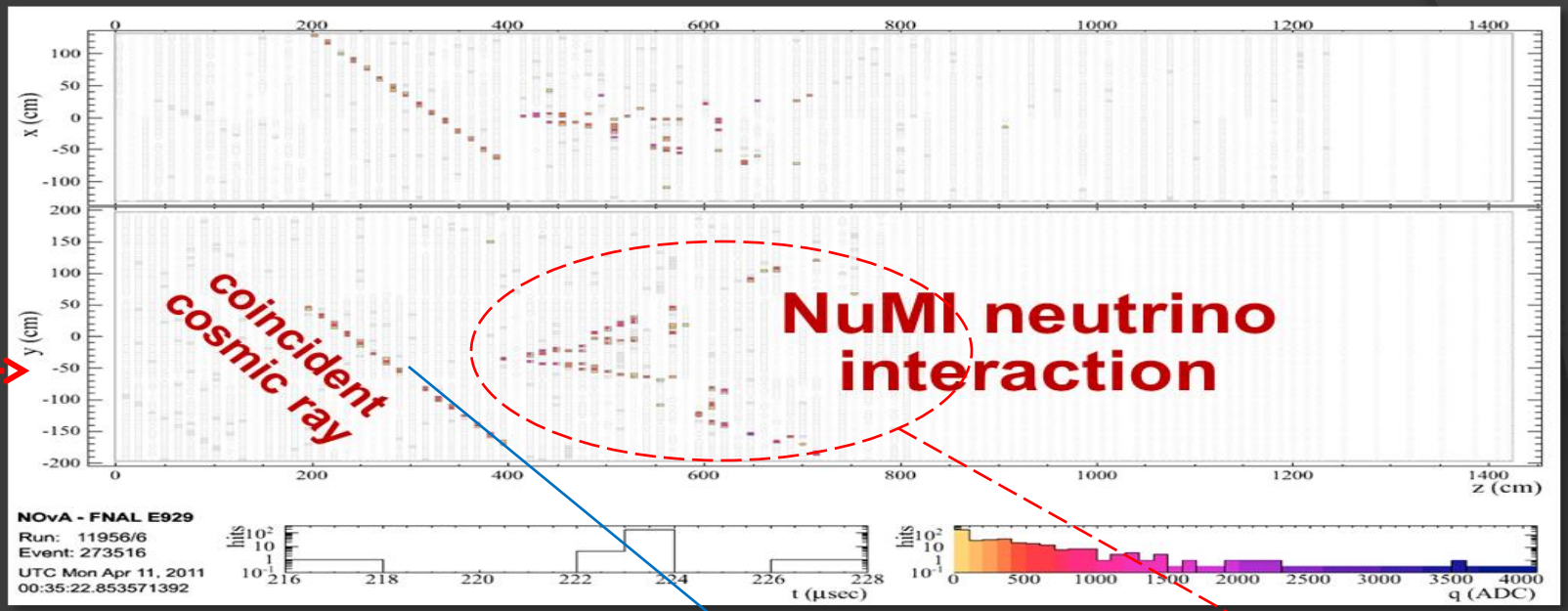


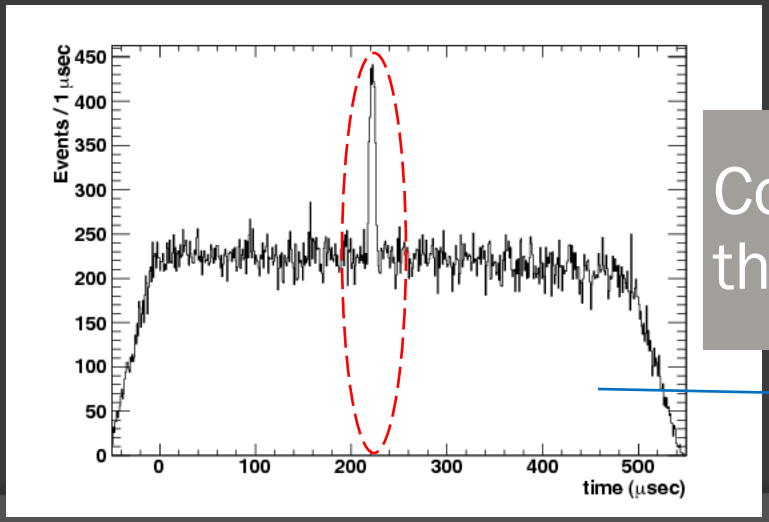
Position dependence of cell response (light attenuation)

Michel electrons

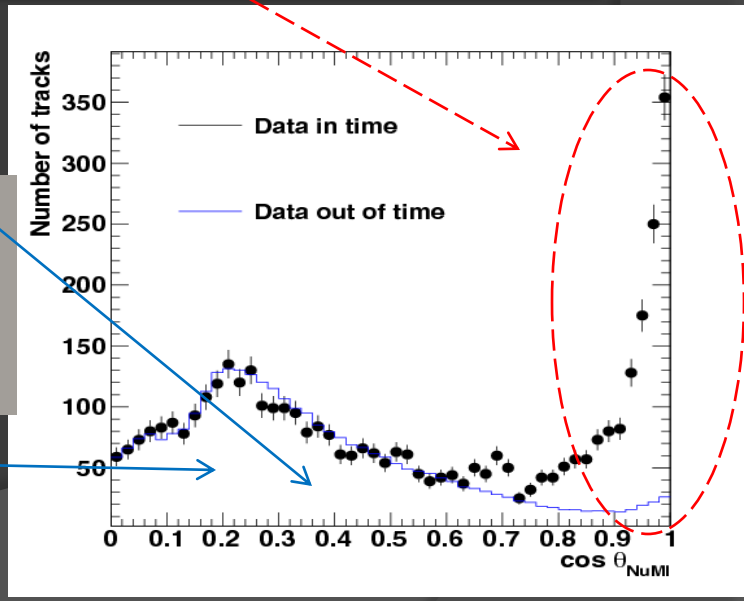
Neutrino events from the NuMI beam

beam



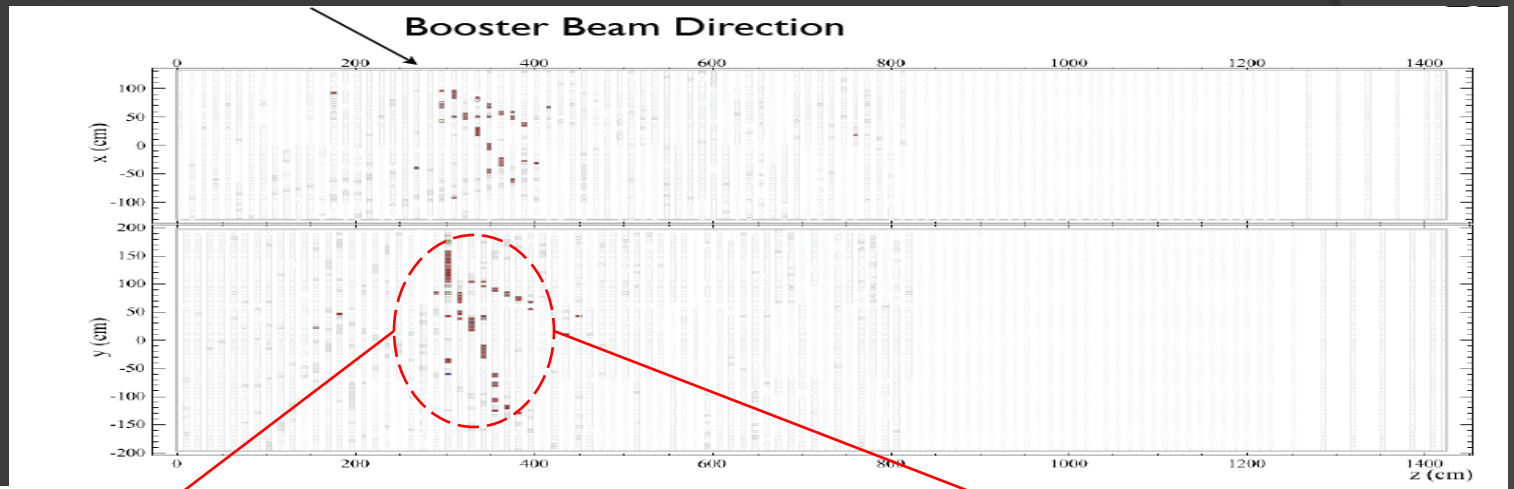


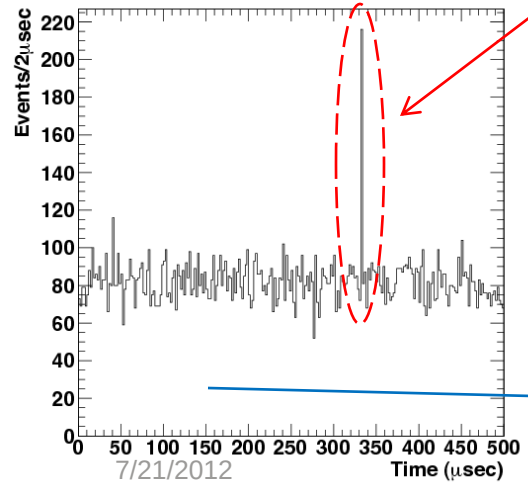
Cosmics within the trigger

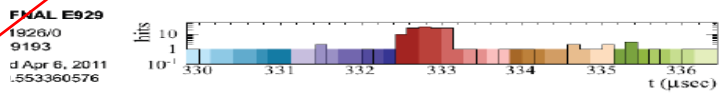


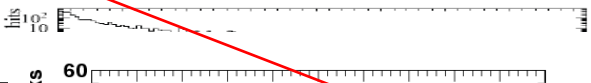
Neutrino events from the BNB beam

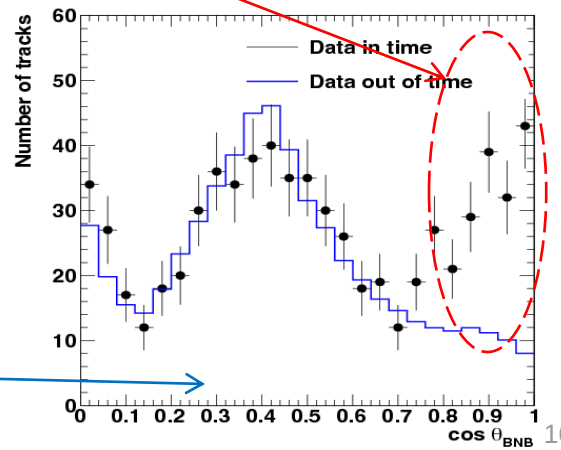
The reconstruction analysis can find the Booster neutrino directions at 23 deg from the axis of the detector setup.











Far detector Status

Beneficial occupancy of the building since April 2011.
Construction started Summer 2012.

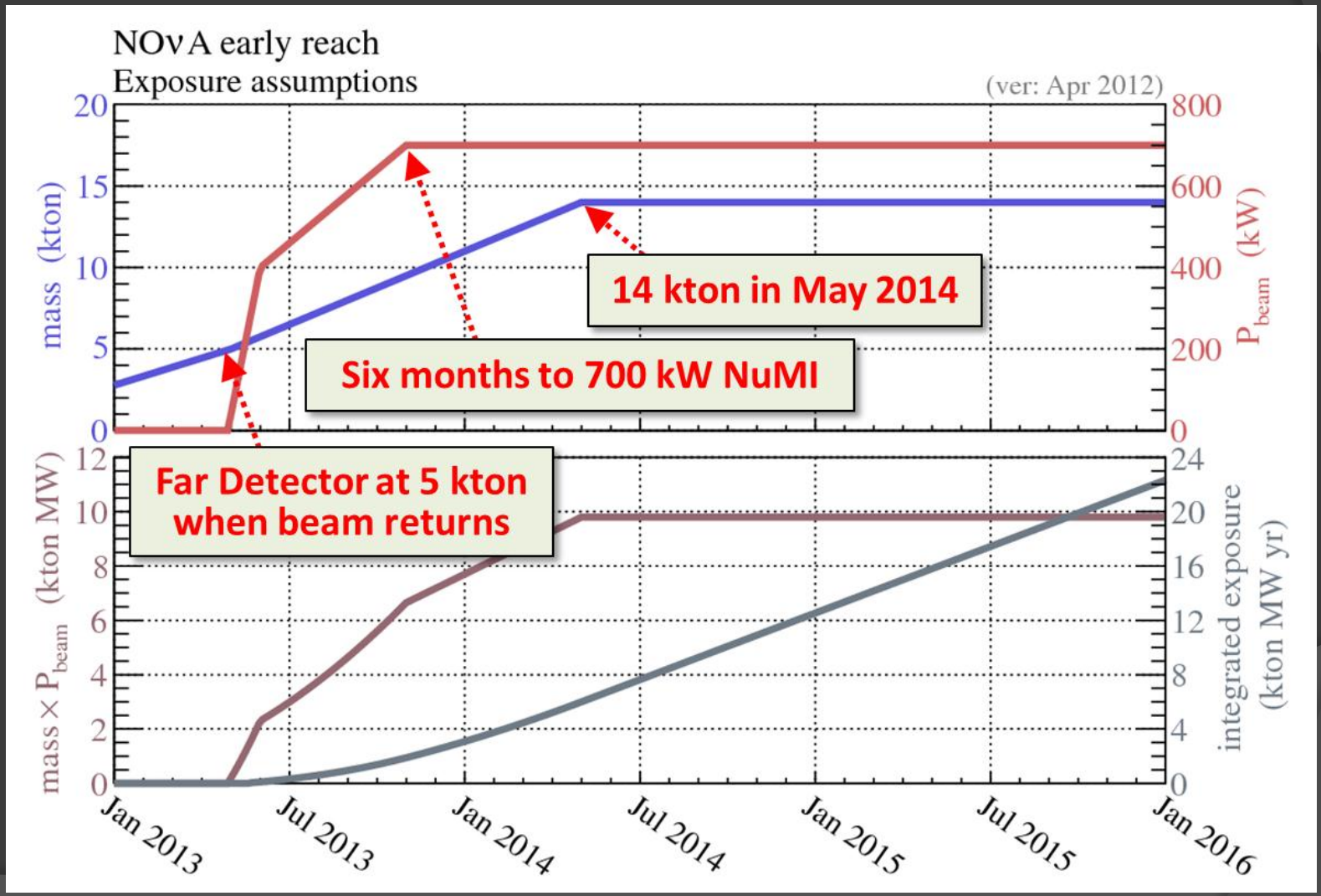
NOvA construction plans

Supernova and Monopoles at NOvA Far detector

- Monopole Signatures :
  - Very Slow.
  - Highly ionizing.
  - Penetrating tracks.
- Triggering methods
  - Data driven.
  - Time over threshold.

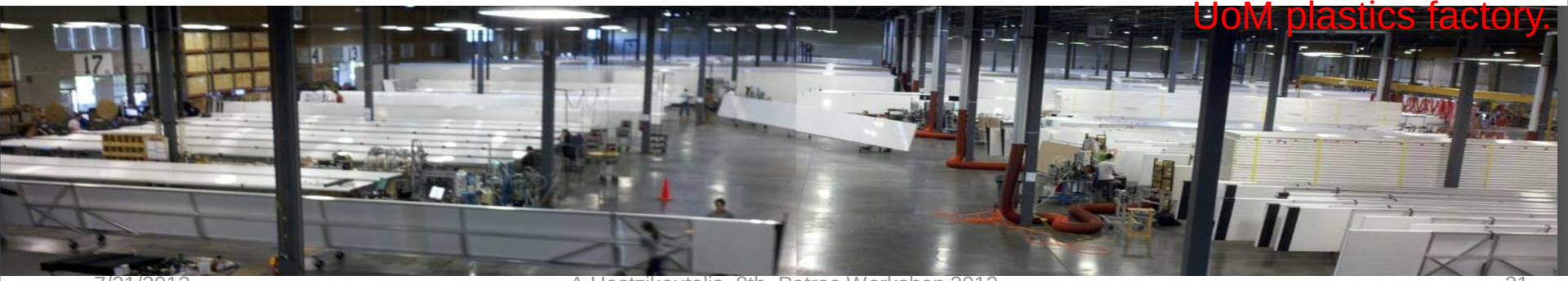
- Supernova signature:
  - Multi-neutrino events.
  - Low energy interactions.
  - Random arrival.
- Triggering in real time.
  - Data driven triggers
  - Long event buffering (>20s)

Detector mass vs. beam power



Conclusions

- The NOvA detectors are capable of more than the primary goals of the neutrino experiment.
  - Supernova, monopole and WIMP, at the Far detector,
  - Hidden Sector and Axion-like particles in the Near.
- The prototype NDOS has been valuable in understanding the deployment and the detection capabilities of these type of detector.
- The NOvA Far detector is starting assembly now.
- The Near is planned for 2014.
- The 700kW beam will provide a total 10^{21}POT for what is to be a very exiting experiment in the early days of the Intensity Frontier of physics research.



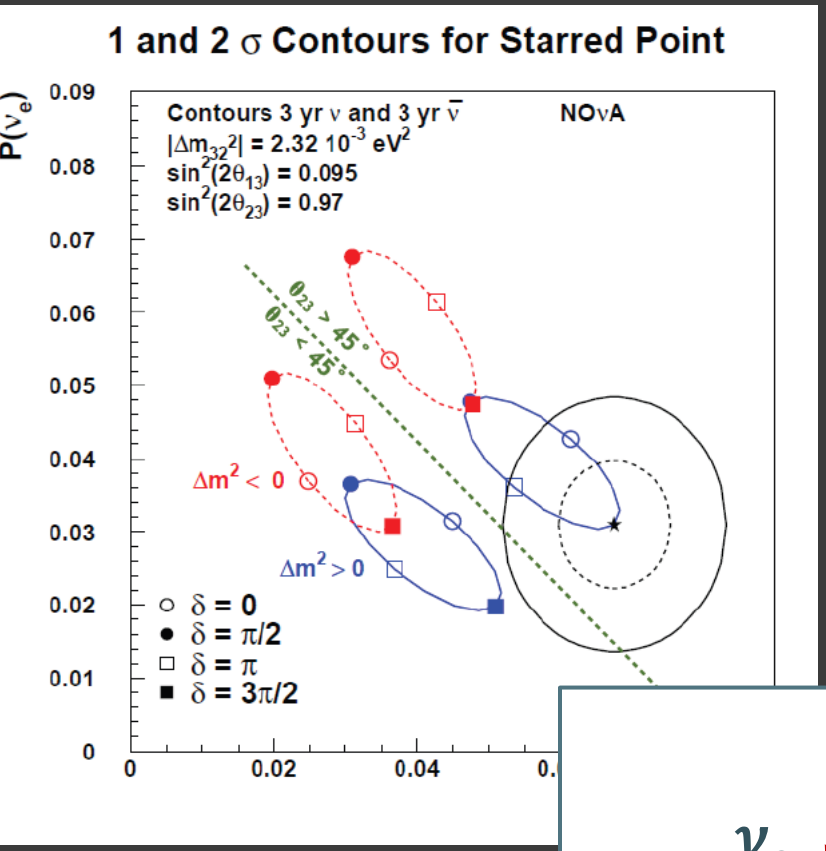
NOvA Collaboration

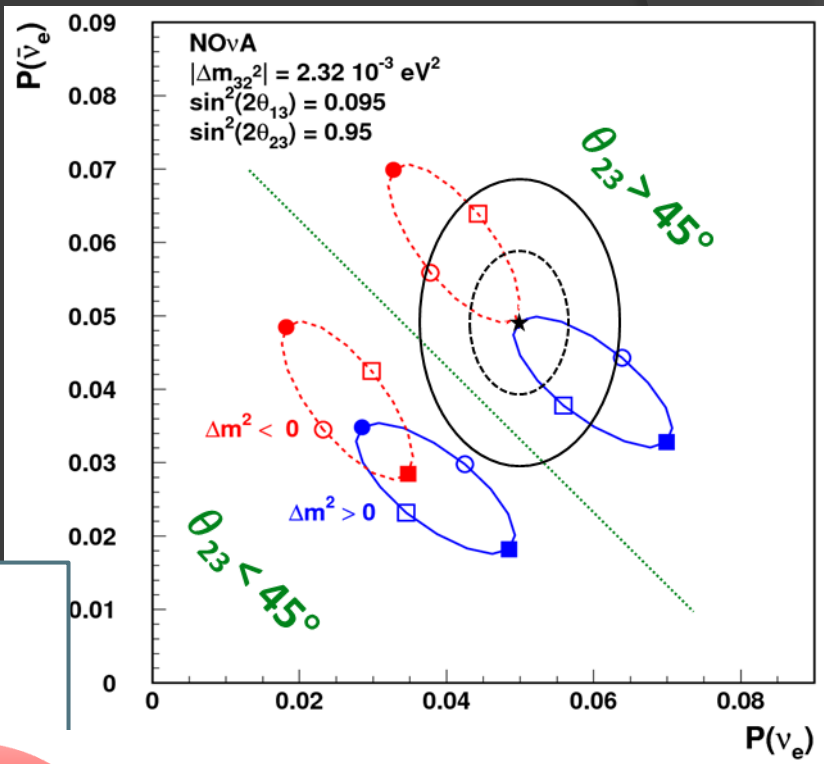
ANL / Athens / Caltech / Institute of Physics ASCR / Charles University / FNAL / Harvard/ India Universities Consortium / Indiana / Iowa State / Lebedev / Michigan State Minnesota, Crookston / Minnesota, Duluth / Minnesota, Twin Cities / INR Moscow / South Carolina /SMU / Stanford / Tennessee / Texas, Austin / Tufts / Virginia / WSU / William & Mary

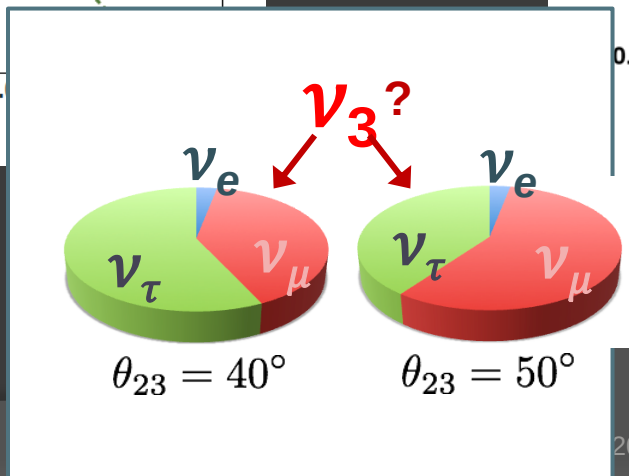
Extra slides

NOvA measurement example

Expected NOνA contours for one example scenario at 3 yr + 3 yr







Simultaneous hierarchy, CP phase, and θ octant information from NOνA

In "degenerate" cases, hierarchy and δ information is coupled. θ_{23} octant information is not.

Intensity Frontier: Accelerator and NuMI upgrades

- Shutdown May 2012 – April 2013.
  - Increase beam power to 700 kW.
  - The Recycler will be converted to an accumulator.
  - Cycle time of the Main Injector reduced to 1.33 s.
    - double the beam intensity for NOvA
- NuMI will be outfitted
  - New target and horns.
  - Shielding pile will be un-stacked
  - Move horn 2 to its location for NOvA .
    - 10m downstream of its current location.