Repurposing MINERvA for a DUNE Near Detector Prototype

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On behalf of the DUNE Collaboration

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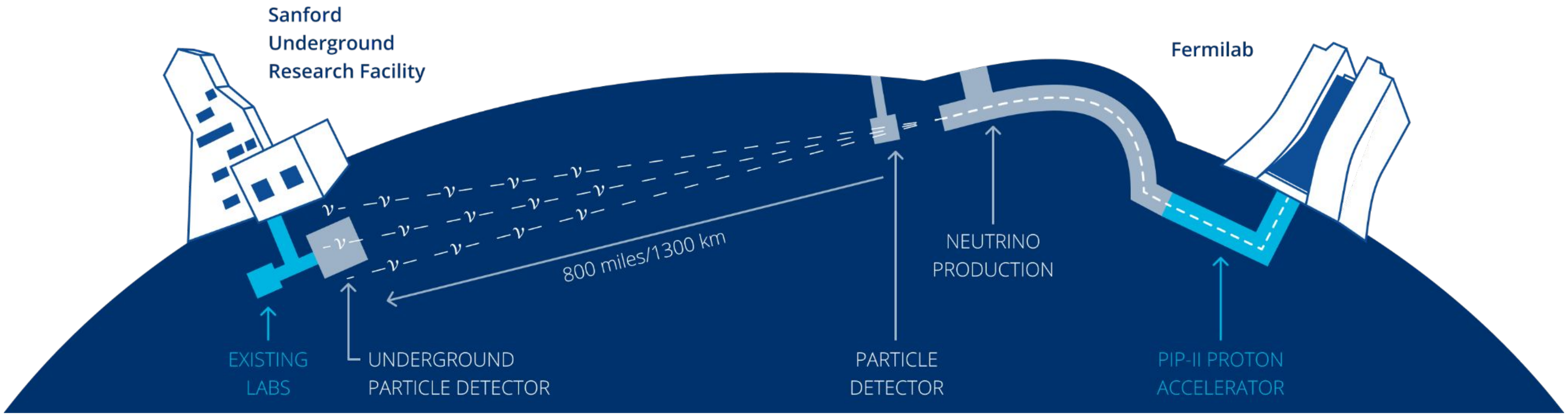
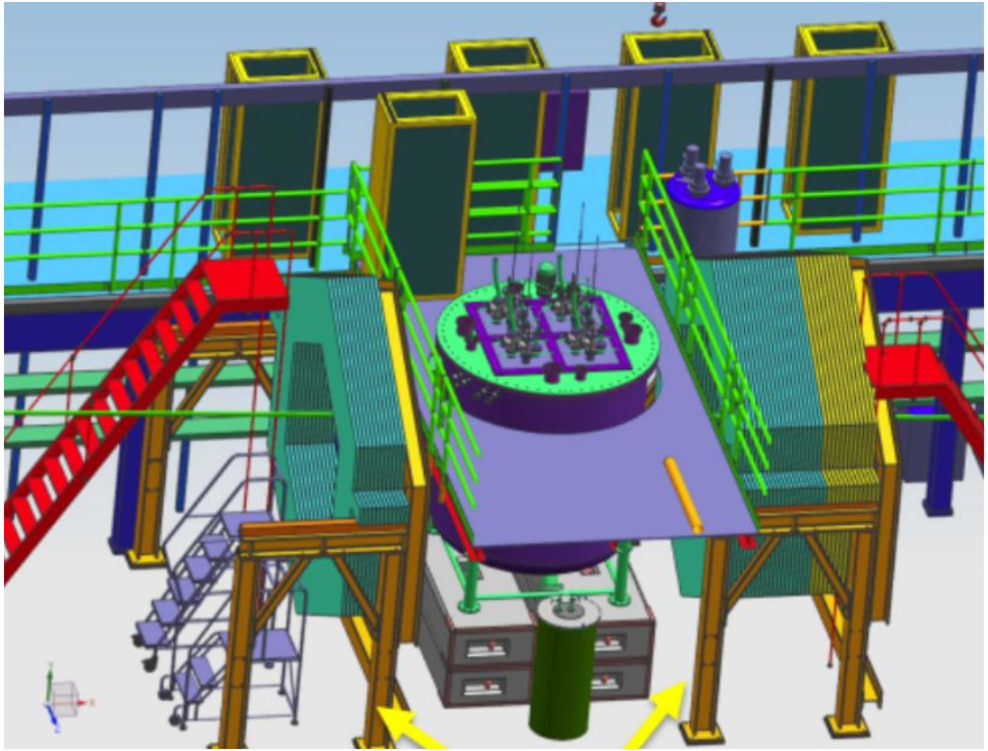
DUNE

- Long baseline neutrino experiment designed to resolve the mass hierarchy & make measurements of oscillation parameters
- Makes use of liquid argon time projection chambers (LArTPC's) for both the Near & Far detectors



The 2x2 Prototype

- The 2x2 consists of 4 prototype near detector modules, surrounded by reinstalled MINERvA planes.
- Located in MINOS underground hall at FermiLab where it is exposed to the NuMI neutrino beam.
- First demonstration of pixelated LArTPC in a neutrino beam



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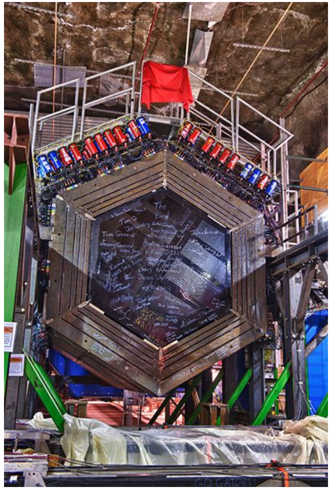
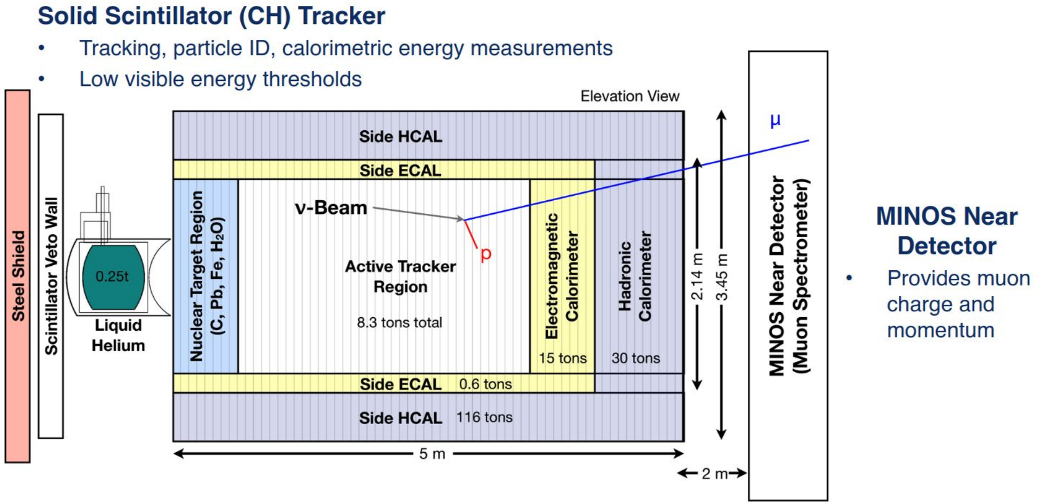
MINERvA

- Fine-grained plastic scintillator detector designed to make precise cross section measurements on various nuclear targets
- Low energy thresholds & relative ease of installation make MINERvA an attractive option for enhancing the 2x2 experiment

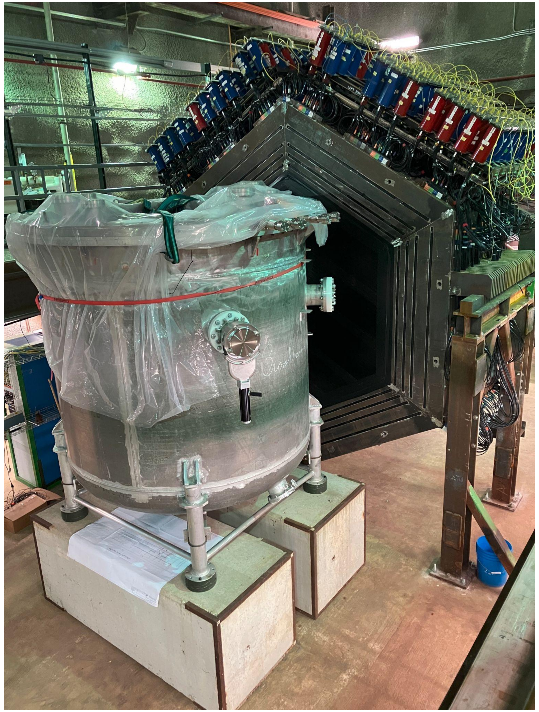


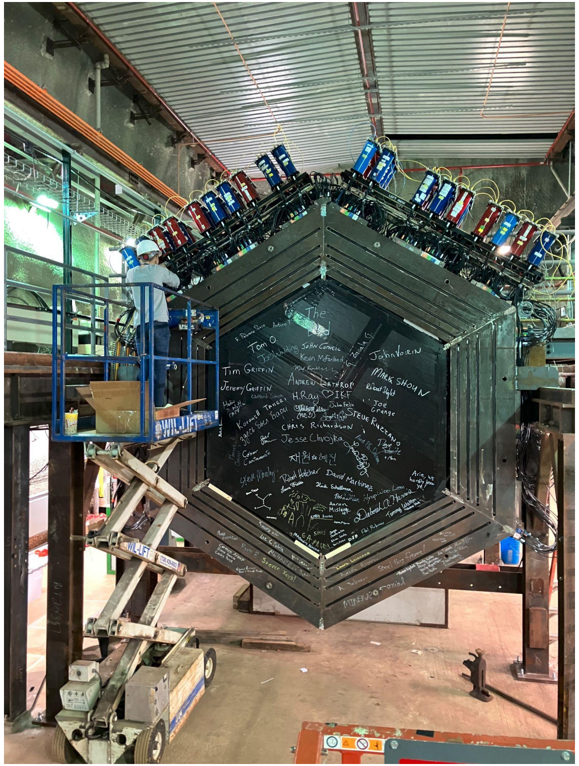


Physics Enhancements

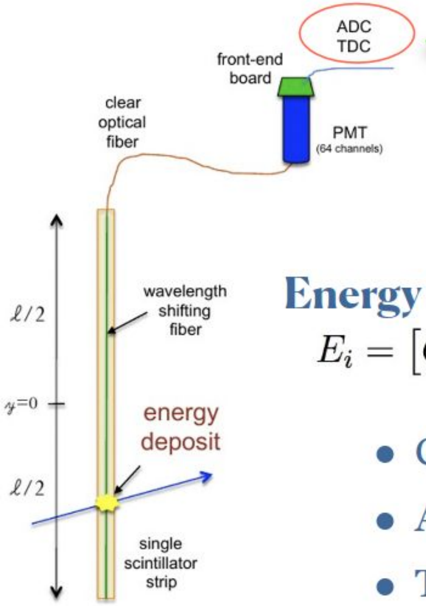
- The 2x2 on its own is not large enough to contain hadrons or easily tag muons
- Particles which punch out the downstream portion of MINERvA are almost guaranteed to be muons
- Veto upstream interactions
- Additional calorimetry for uncontained particles

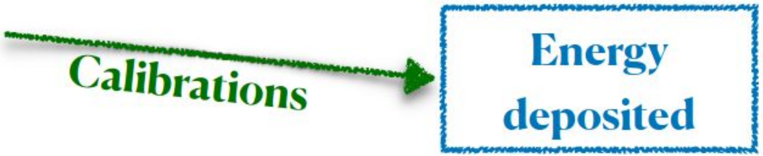
Installation





Calibrations & Software





Energy in strip:

$$E_i = \left[C(t) \cdot S_i(t) \cdot \eta_i^{att} \cdot e^{\ell_i/\lambda_{clear}} \cdot G_i(t) \cdot Q_i(\mathrm{ADC})\right] \times \mathrm{ADC}_i$$

- Calibration applied hit-by-hit, channel-by-channel
- A multi-step process
- Two types of calibration:
  - Ex-situ: constants that we measured once, at the beginning of the experiment
  - In-situ: constants that are kept up-to-date, re-measured frequently

- Currently most of the MINERvA for 2x2 effort is on re-implementing & re-validating the various calibration stages
- Software is often re-usable, but many modifications & updates required

Calibrations cont.

$$E_i = \left[C(t) \cdot S_i(t) \cdot \eta_i^{att} \cdot e^{\frac{l_i}{\lambda_{clear}}} \cdot G_i(t) \cdot Q_i(\mathrm{ADC}) \right] \times \mathrm{ADC}_i$$

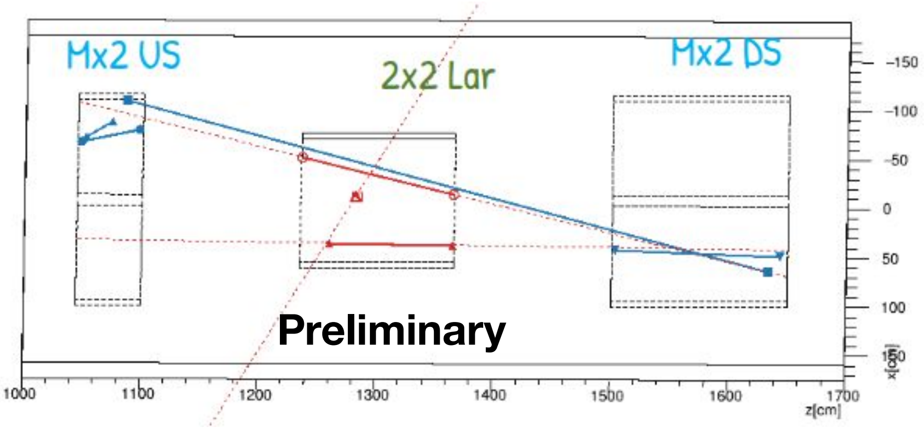
- E_i = Energy in strip i
- ADC_i = ADC count in channel i
- $Q_i(\mathrm{ADC})$ = PMT Gain Q -> PE
- $G_i(t)$ = FEB Calibration ADC -> Q
- l_i, λ_{clear} = Fiber length outside of strip and attenuation
- η_i^{att} = Attenuation correction inside the strip
- $S_i(t)$ = Relative energy correction (strip to strip)
- $C(t)$ = Global energy scale factor PE -> MeV

* *Missing here: Plex, pedestals, alignment, x-talk, timing…*

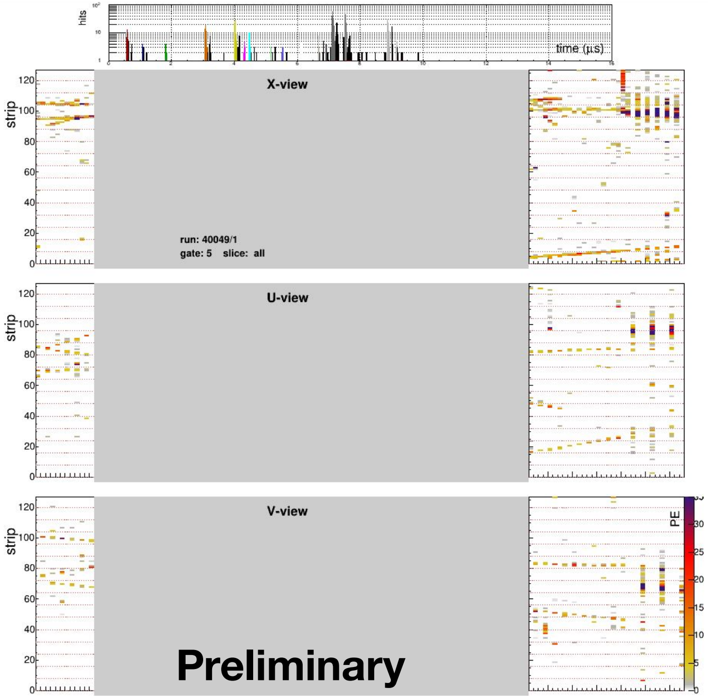
- In some cases calibration constants can be reused
- Most need to be recalculated for the new configuration and aged components

Challenges

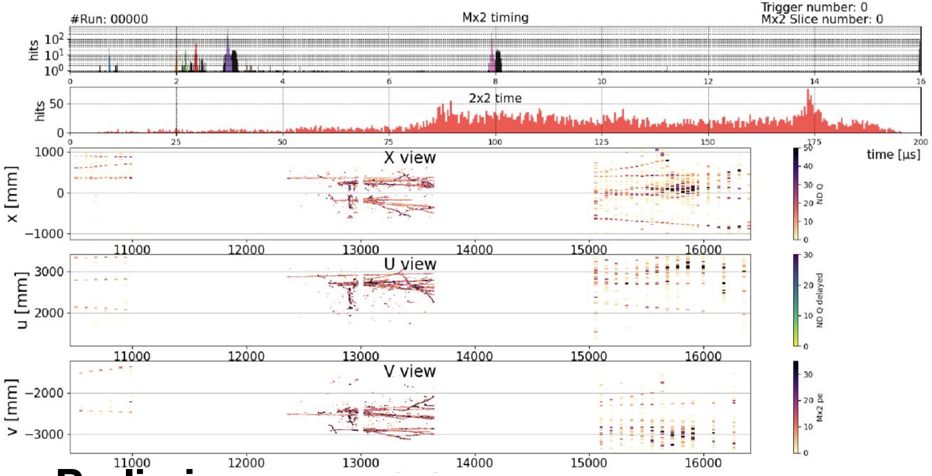
- Track Matching
- Multiple data acquisition systems (DAQs), possibility for asynchronous data taking
- 3 separate data streams being merged into the same analysis files:
  - 2x2 Charge Readout
  - 2x2 Light Readout
  - MINERvA



First 2x2 Neutrino data events



Data event taken July 06, 2023



Preliminary

MC Event with 2x2 LAr spill

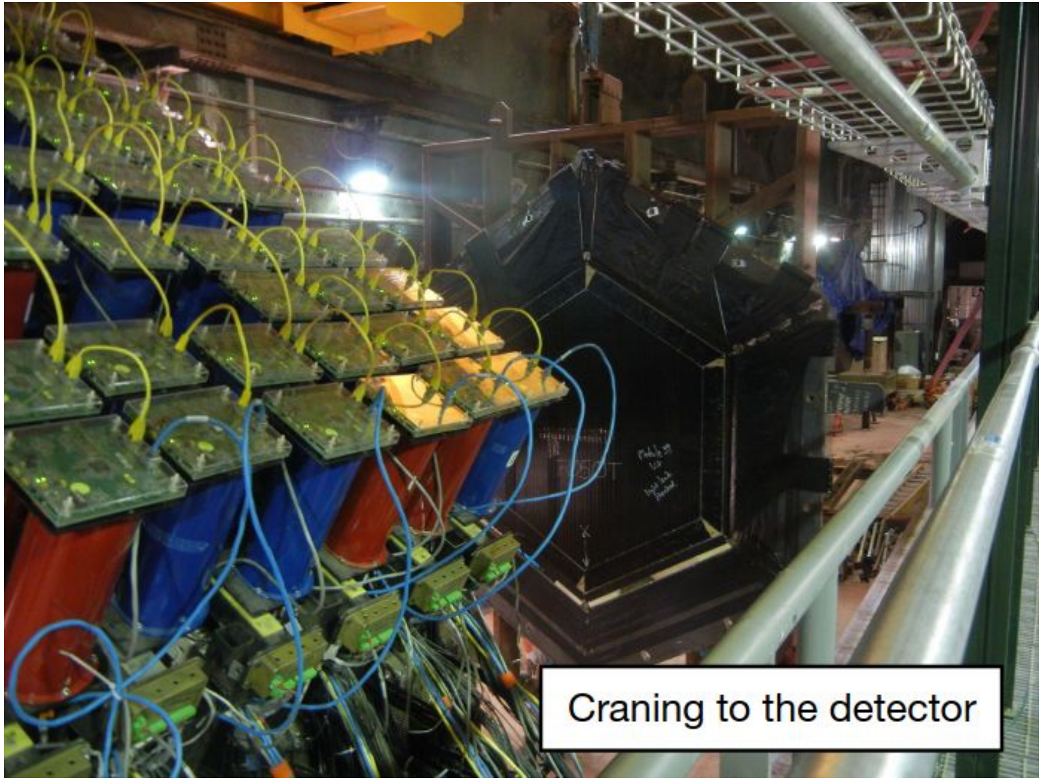
Conclusion

- MINERvA is what takes 2x2 from a demonstrator to an experiment of its own
- Several analogies to later plans of ND-LAr + TMS
- First full 2x2 run expected to begin soon

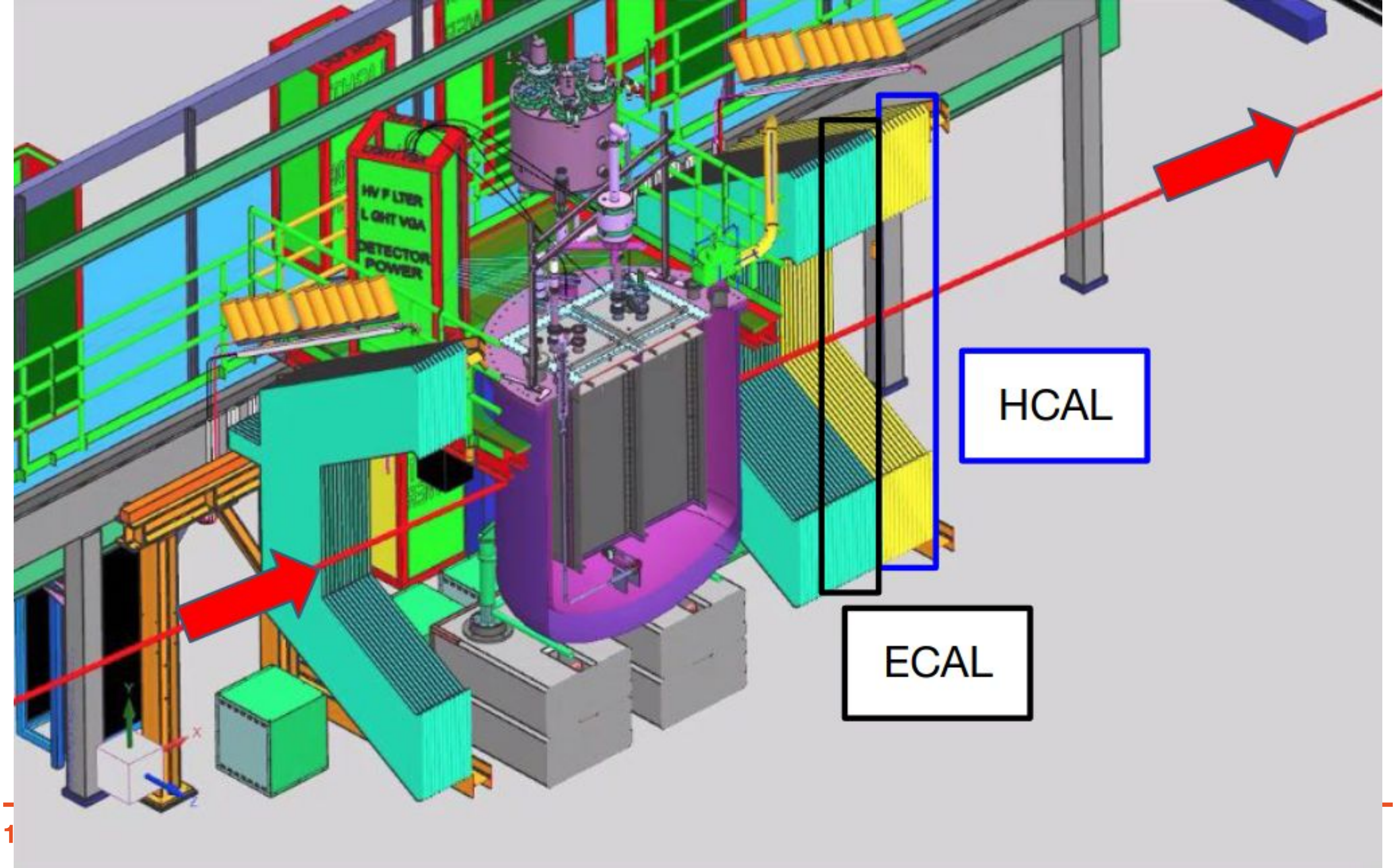
Backup

Installation

Mounting on the strongback



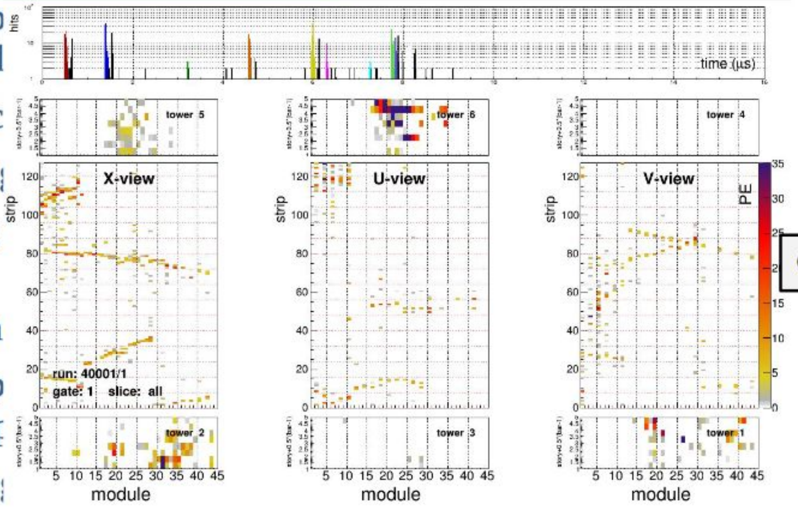
Craning to the detector


HCAL
ECAL
DETECTOR
POWER

MINERvA Collaboration

- What sort of work is required
  - Plex (matching old files to new geometry)
  - Pedestals (rewriting p
    code, uploading regul
  - FEB correction (matc
  - Attenuation (matchin
  - Alignment (rewriting
    calibration code)
  - Strip to strip (implem
  - Absolute energy (imp
    something simpler, u
  - Timing (implementin
  - Cross talk (matching old files to new geometry)

See C. Marshall's talk from the January Workshop



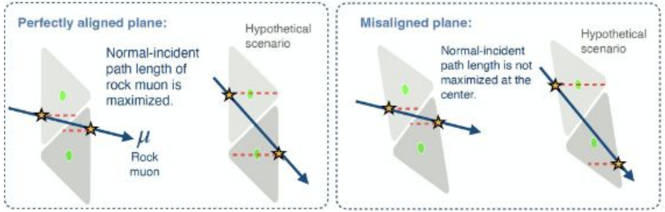
C. Pernas

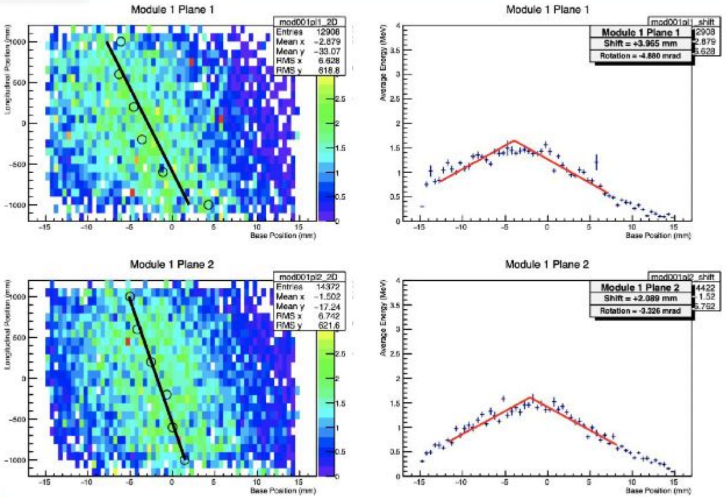
MINERvA calibrations for 2x2

Scintillator Plane Alignment Calibration

R. Vizarreta

- Work by Renzo Vizarreta
- Uses rock muons to measure O(mm) and O(mrad) misalignments in the scintillator
- Leverages the triangular shape of the strips





Jack Smedley

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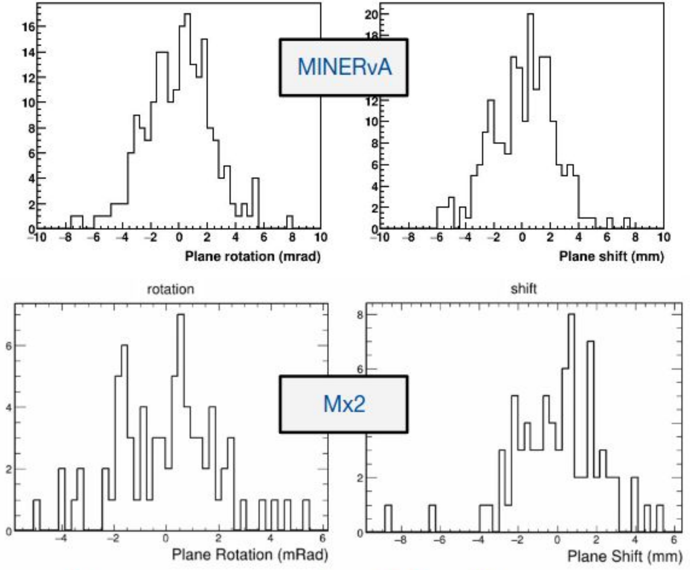
Scintillator Plane Alignment Calibration

R. Vizarreta



- Machinery is ready to go
- Preliminary results show misalignments on par with original MINERvA
- Will be rerun and alignment constants will be exported once higher rock muon stats and other calibrations are available

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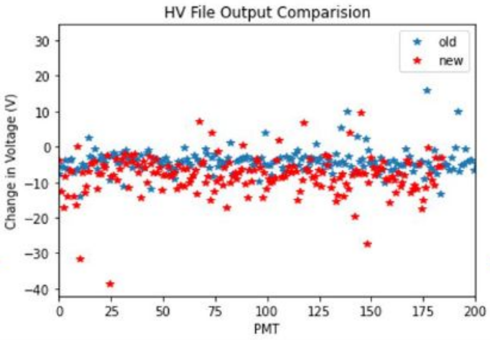
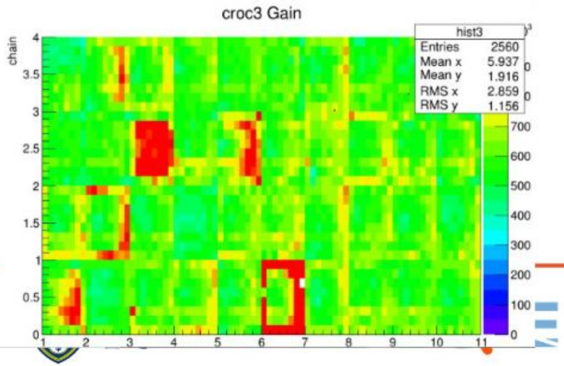
PMT Gain Calibration

B. Schuld

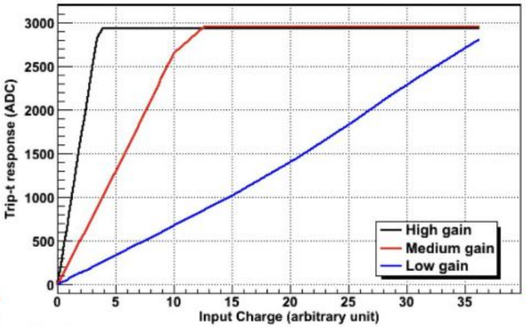
- Work by Brooke Schuld
- Uses light injection data to calculates gain of each PMT
- Returns optimal voltage configuration for each PMT to normalize detector response
- Allows for conversion from ADCs to PEs, an input for many higher level calibrations
- Should be performed regularly during operation





FEB calibration: Qi(ADC)

- Convert ADC to charge equivalence for the Front End Boards' low, medium, and high ADC channels.
- Constants were measured in 2009 using a tri-linear fit for high, med, and low gains.
- There are 18 parameters: slopes and starting point of the three linear segments
- A table with all the constants exists for each FEB in the MINERvA DB (text files).
- Not time-dependent, need to update the DB only when there is a FEB swap



Timing Calibrations

- Corrects for timing offsets on each FEB, and average PE-dependent "slewing" effect due to scintillator and fiber decay times
- Calibration is determined using through-going rock muons
- Calibration is measured in an iterative procedure using hit time and PE (done 8 iterations)
- The slewing effect is measured once; board offsets change any time the FEBs are power cycled, so calibration has to be repeated when there are hardware swaps
- This calibration is critical for 2x2 in order to do timing-based track matching between MINERvA and LAr

Basic procedure for timing

- Select through-going rock muons
- Iteratively:
    - Measure the track time by averaging over hundreds of hits
    - Apply board offset corrections from the previous iteration, and determine peak slewing effect vs. PE
    - Apply peak slewing effect vs. PE from the previous iteration, and determine board offsets
- Do this 8 times so that it converges

Muon Energy Unit (MEU) Calibration

- MEU calibration calibrates the overall energy shift as a function of time.
- The number of PE the detector measures for a given deposited energy changes over time due to the ageing of the scintillator.
- The peak location of energy per unit distance of each rock muon track is compared between data and simulation.
- MINERvA used MINOS for muon curvature.
- Mx2 uses only the range method
- Using an old MINERvA file to make MC files.

Physics Enhancements

- The 2x2 on its own is not large enough to contain hadrons or easily tag muons.
- Particles which punch out the downstream portion of MINERvA are almost guaranteed to be muons
- Veto upstream interactions
- Electromagnetic & hadronic calorimetry for uncontained particles