College of Natural Sciences and Mathematics
UNIVERSITY OF HOUSTON

Improving Calibration Methods for NOVA

Dat Tran

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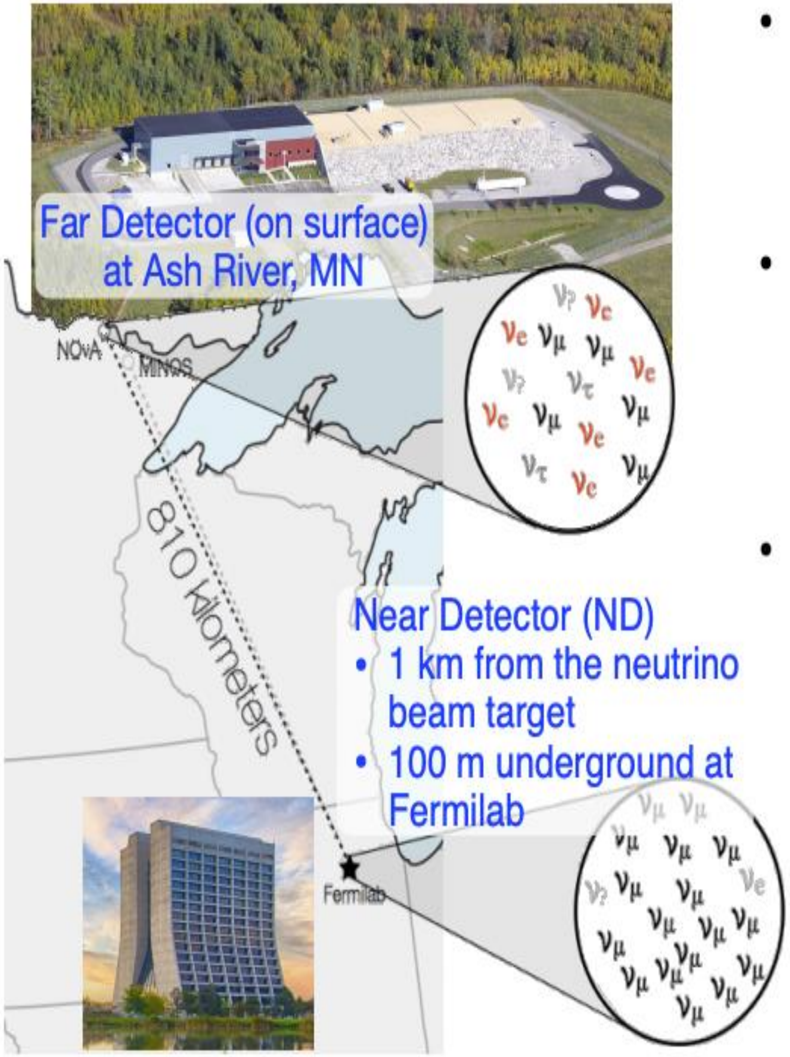
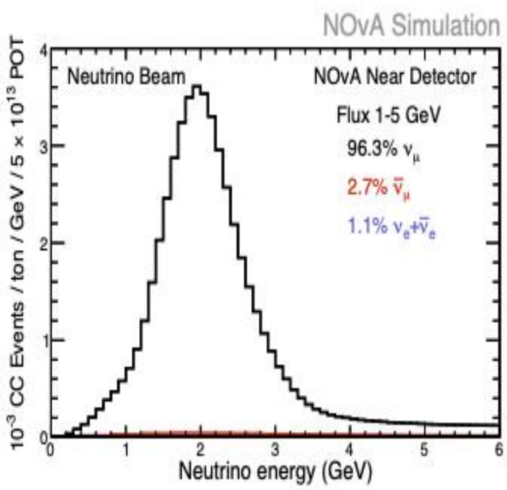
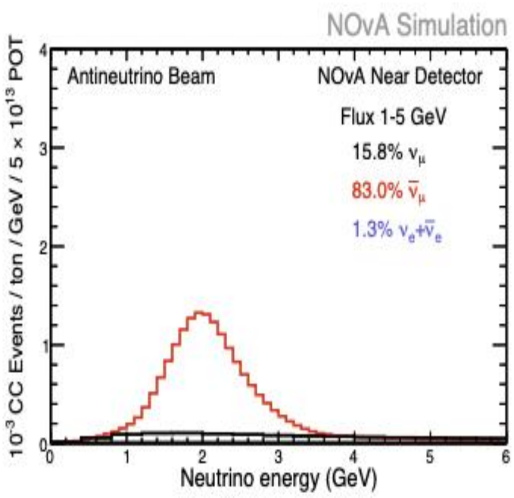
NOvA: NuMI Off-Axis ν_e Appearance Experiment

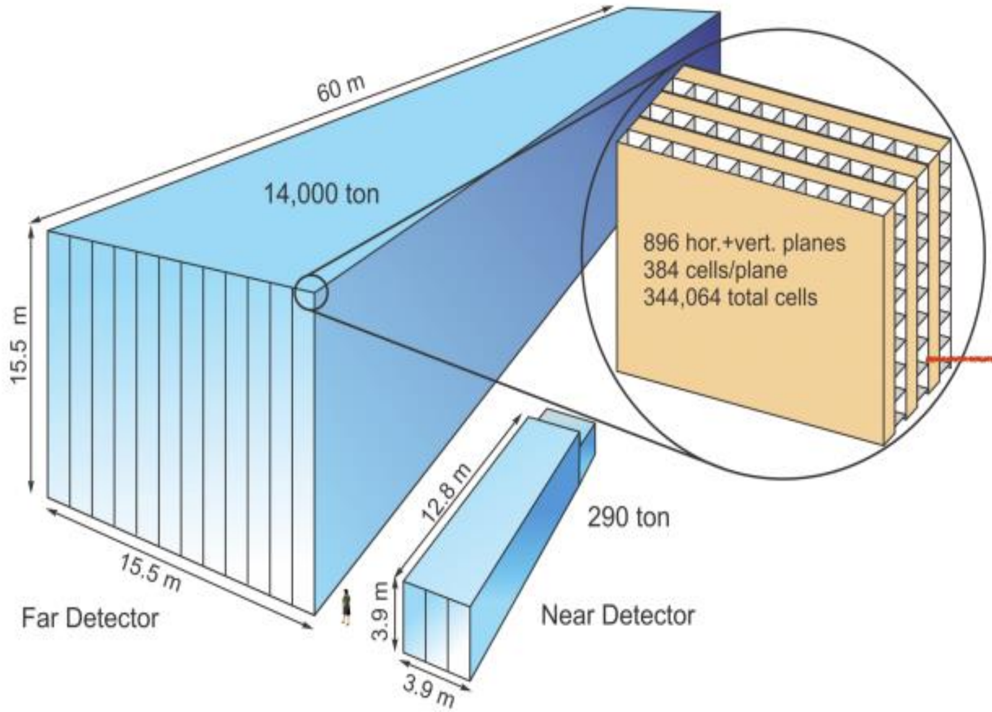


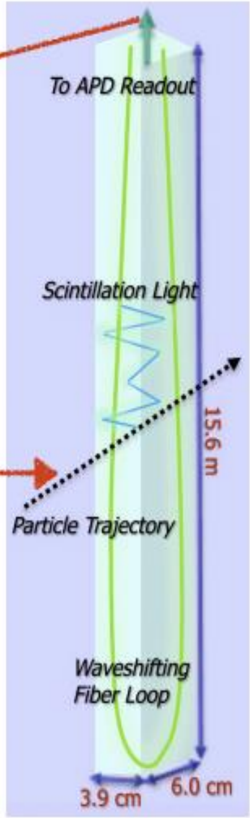
- NOvA is an accelerator-based neutrino experiment
  - Longest baseline in operation (810 km), large matter effect, sensitive to mass ordering
- Muon neutrino beam (NuMI) at Fermilab
  - Two configurations: neutrino mode and antineutrino mode
  - Power record 954 kW in 2023
- ~14 mrad off-axis, narrow-band beam around oscillation max.





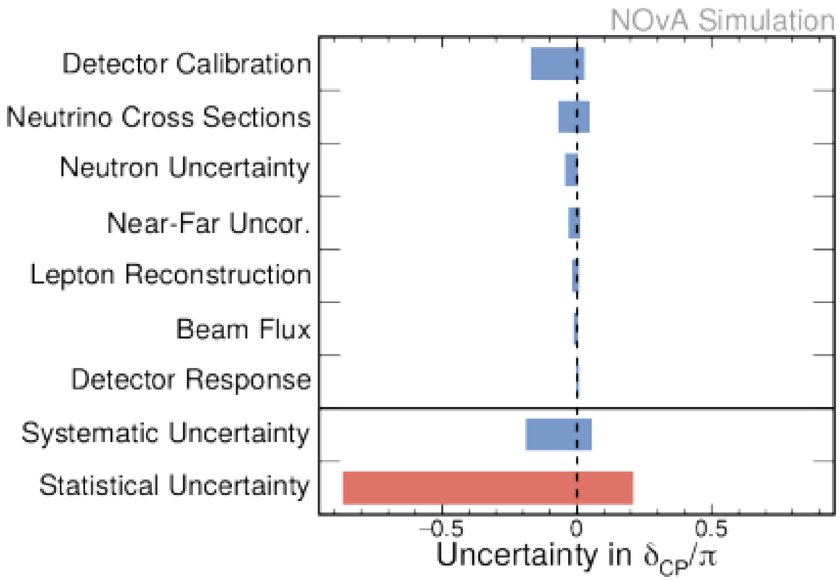
NOvA Detectors

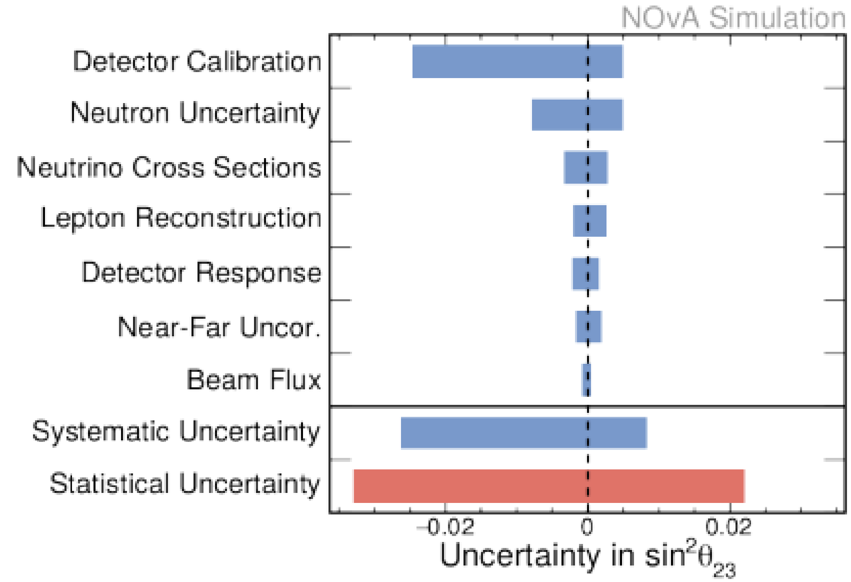


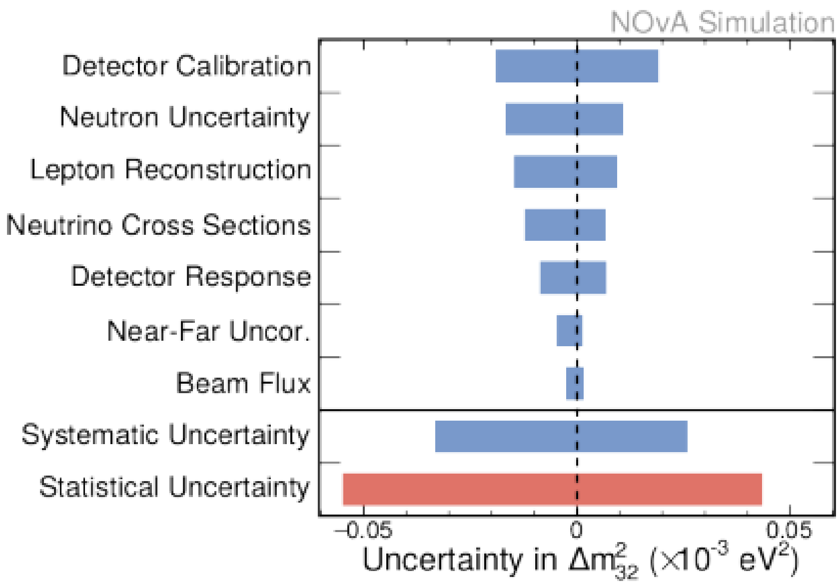


- FD and ND are functionally identical to minimize systematics
- Detectors composed of highly reflective extruded PVC cells filled with liquid scintillator. Alternating horizontal and vertical layers provide 3D views of the events
- Scintillation light captured and routed to APDs via wavelength shifting fibers

Uncertainties on Neutrino Oscillation Parameters







- NOvA is sensitive to several ν oscillation parameters: Δm^2_{32}, $\sin^2\theta_{23}$ and δ_{CP}
- The uncertainties of Δm^2_{32} and $\sin\theta^2_{23}$ are approaching systematic limits
- All three parameters are most influenced by calibration and neutron uncertainties

Energy Calibration

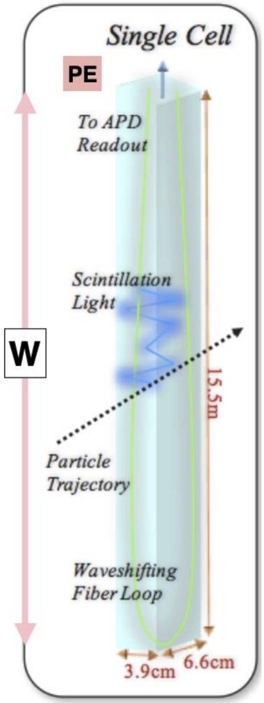
Cosmic Muon Data and MC

PE Photoelectrons → **PECorr** Corrected → **GeV** Energy Deposited

Rescaling of ADC to approximate photoelectrons

Effective PE with all relative effects calibrated out

Energy deposited by each hit, including in dead material



Relative Calibration

- **Attenuation** along length of a given **cell**
- Cosmic Muon Sample

Absolute Calibration

- Energy Scale Factor **(GeV/PECorr)**
- Stopping Cosmic Muon Sample

Relative Calibration

Correct hits to a unit which is **uniformly comparable throughout the detector**, and proportional to energy deposition

- Depends on: **Cell** and longitudinal position in cell, **W**
  - *Fit PE/cm attenuation profiles for each cell*

- Bias in cosmic muon sample must be corrected before attenuation fit — threshold, shielding

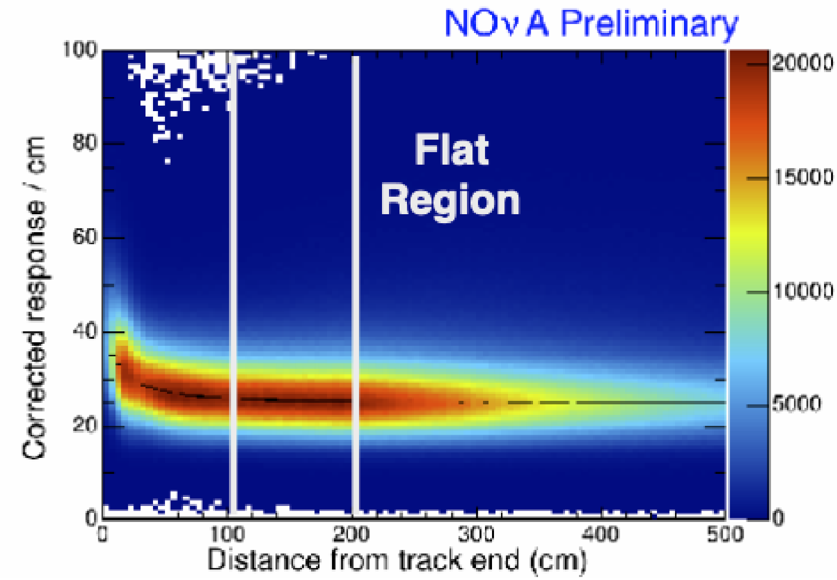
- **Threshold/Shielding Correction** depends on Cell, W (MC)
  - Threshold Effect: Hits < 25 PE not seen by readout
  - Shielding Effect: Energy deposition is not uniform throughout the detector

- **Attenuation Correction:** perform fit on threshold-and-shielding corrected PE/cm vs W plots
  - Data — fit for every cell in every plane
  - MC — fit for each cell in a "representative" plane

Absolute Calibration

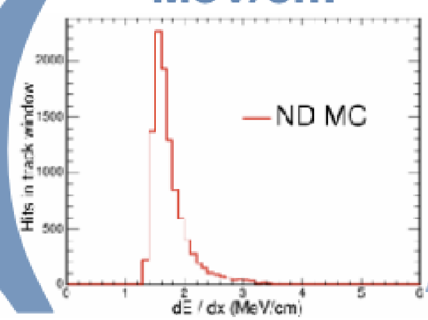
Energy Scale

$$PECorr_{hit} * \left(\frac{MeV}{PECorr}\right) = MeV_{hit}$$

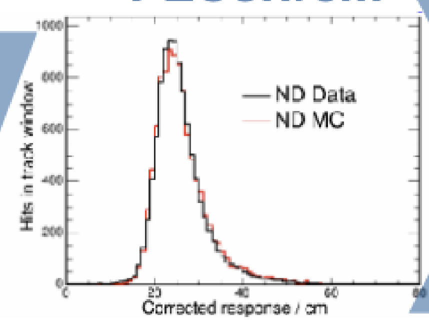


- Select **Stopping Muons**
- Tighten dE/dx peaks by selecting hits in the Bethe-Bloch flat region
- MC: True dE/dx and Response
- Data: Response (PECorr/cm)

(MeV/cm

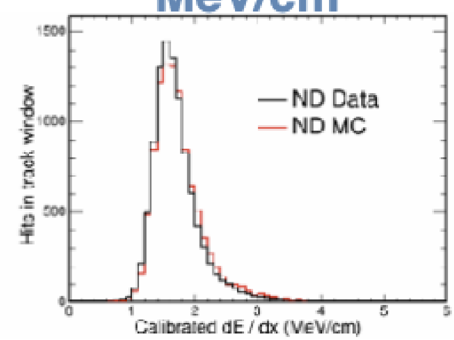


/ PECorr/cm



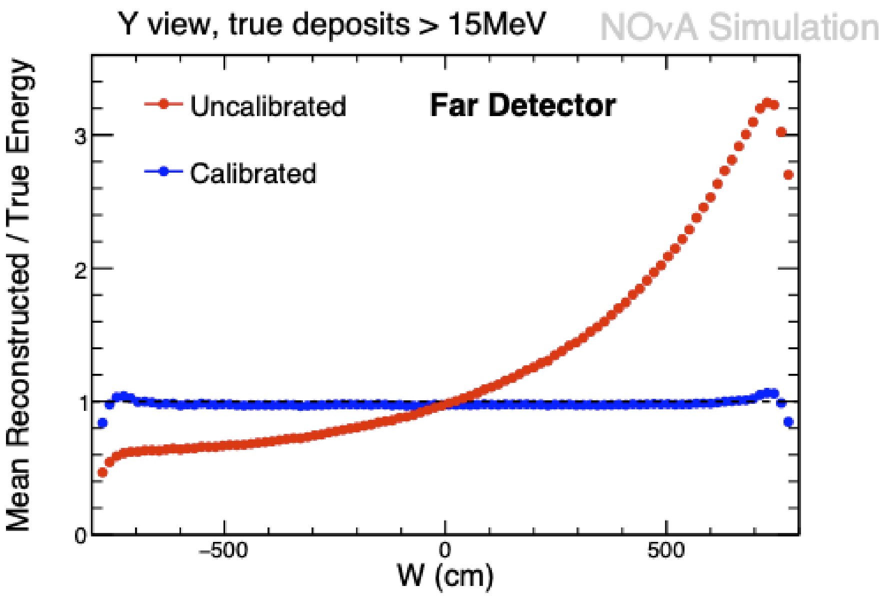
) * PECorr =

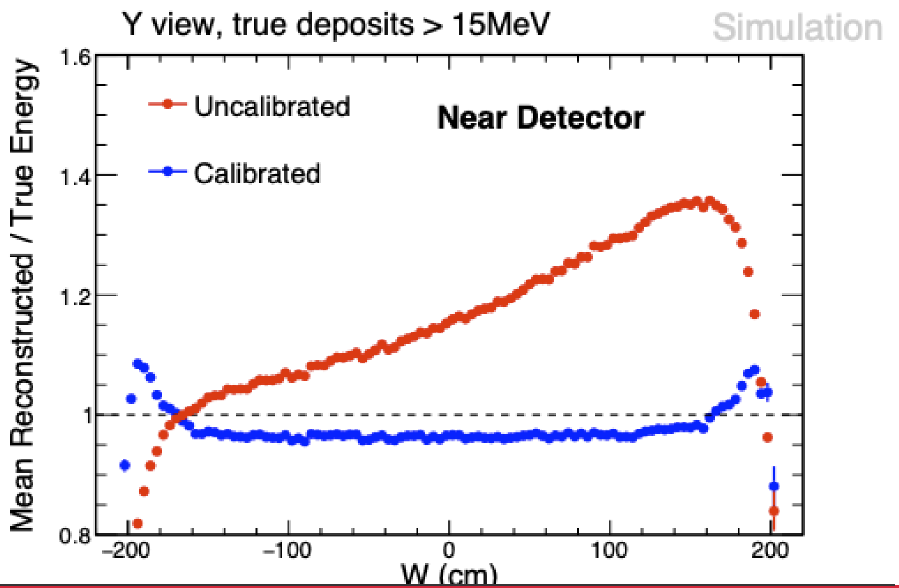
MeV/cm



Verification with MC

- Profile Ratio of Reconstructed over True Energy
  - **Energy Scale**: average vertical deviation from 1
  - **Relative Calibration**: shape along W, cell, plane



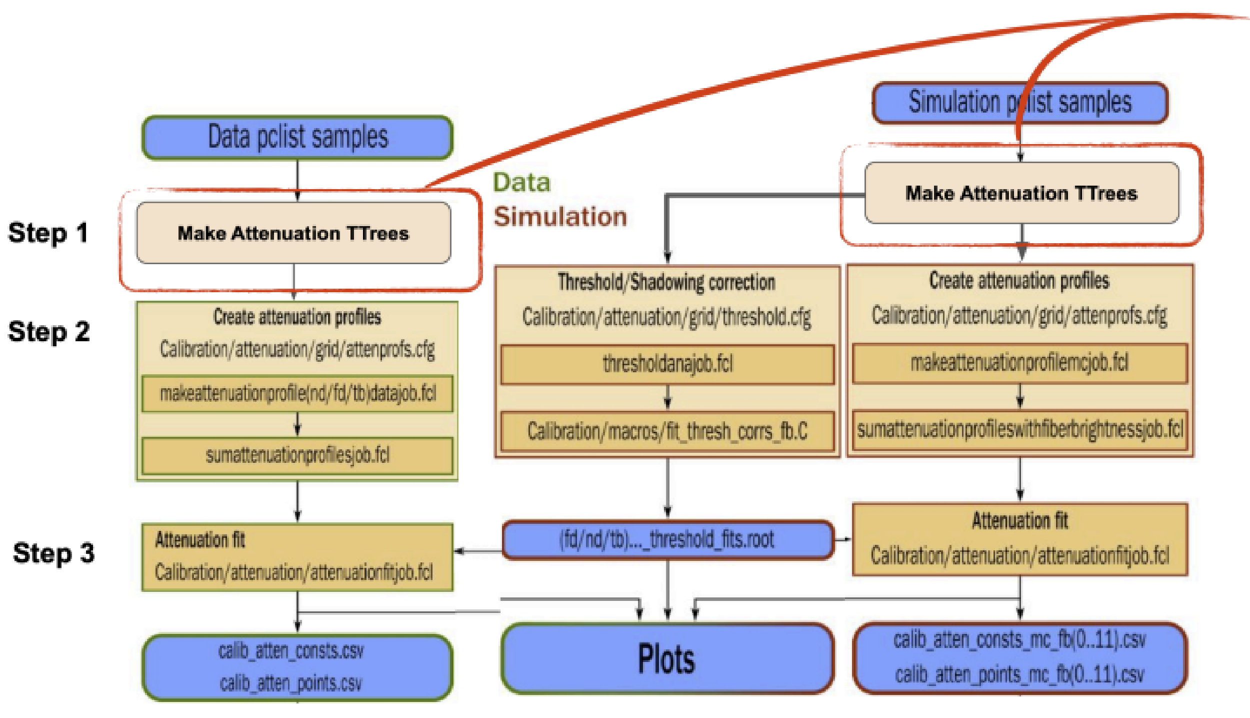


Challenges of calibration

- The calibration code is convoluted, not beginner friendly. It tries to process the samples, calculate constants, make plots, and create a tex file at the same time.
- It is very manual and takes a long time to run, leaving us at risk of running out of memory (and patience) if when processing large samples.
- It’s not easy to redo calibration for a certain sample. One would have to go through the entire workflow again.

- => Goal is to automate the process and make it more approachable for beginners.

Relative Calibration Improvement



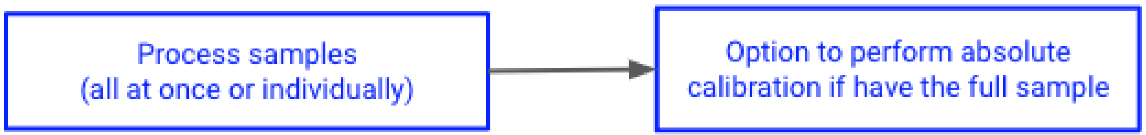
Rather than running over large PCList and PCListStop files **convert to slimmer TTrees** which can be kept around on disk long term.

Want to make sure TTrees **contain all of the correct information** and that that **downstream code can handle them.**

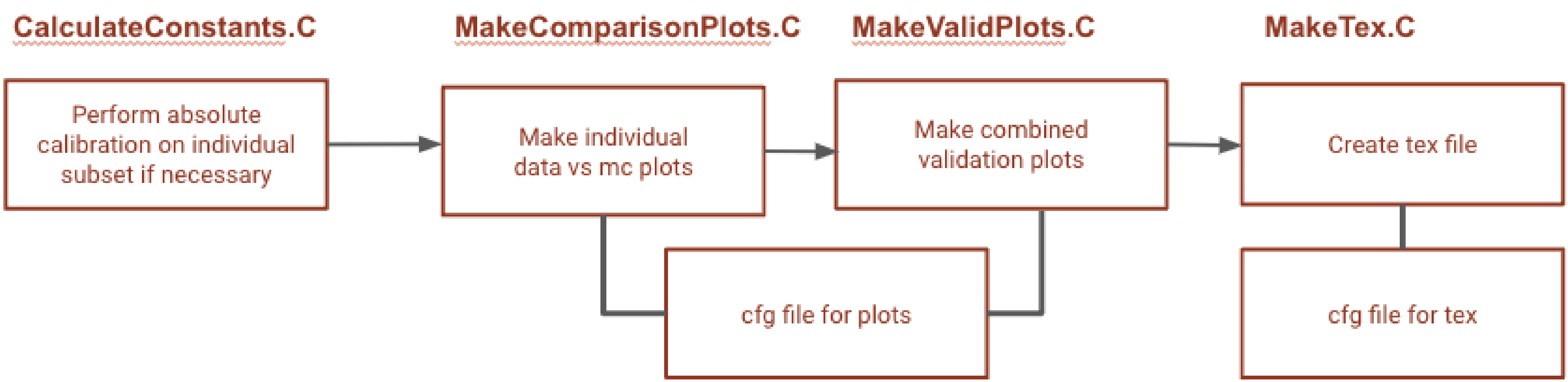
Eventual aim is for full automation, but making life easier for calibrators is a good first step!

Absolute Calibration Improvement

Run on Fermigrid with submit_cafana.py



Run on interactive nodes (gpvms)



Future Goals

- Absolute calibration new software is finished.
- Relative calibration: validation between old and new version at each step of the process.
- Automation (or close to automation) of the entire process.
- Train new people to take charge of calibration for future data.
- Technotes, wiki guides >>> calibration paper.