Overview and Immediate plans for Calibration Task Force

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DUNE Calibration Task Force meeting
September 7, 2017

DUNE Physics requirements

- Unprecedented physics requirements
  - A 2% uncertainty on energy scale is already a big deal.
  - A 1% lepton bias uncertainty is a big deal
  - Other uncertainties can only amplify the impact of this
- No detailed ties (yet) exist between high-level requirements and knowledge of calibration parameters
  - Fiducial volume better than 1%=1% knowledge of v_d everywhere. What does that mean for field map?
  - what does better than 1% energy bias mean for lifetime, recombination and electronics calibration?
- DUNE is unique in many ways
  - Huge size, biggest LArTPC ever to be built
  - Cosmic ray rates are low; ND different from FD...

Task Force Goals

Main Charge:

- What are our calibration-driven physics requirements? Associated impact on oscillation physics (and others)
- A Calibration strategy for the TDR timeline
  - Clarify assumptions about each source of uncertainty and how it is measured
  - Demonstrate reasonable arguments to achieve necessary precision

Sub Charge (near term):

- Recommendation on Calibration hardware

(Unfortunately, timeline is awfully close to finalize Cryostat interfaces for calibration – We need to start thinking about it seriously starting NOW. Anything we say NO needs to be proved otherwise.)

The Calibration Challenge

TPC response model

Argon ionization energy
Electron drift velocity
t_0 offsets
Electron lifetime
Recombination parameters
Electric field
Longitudinal and transverse electron diffusion
Wire positions/geometry
Wire field response
Channel gain
Overall electronics analog transfer function
Electronic crosstalk
Electronics noise, including correlated noise
ADC linearity (differential and integral).

Photon detector response model:

<similar list here>

(See Backup for more)

High level quantities

Position reconstruction biases
Direction reconstruction biases
Energy scale
Energy resolution
Particle ID efficiencies
Noise removal efficiencies
…
…

Particle response

Charged hadron propagation
Neutron response
…

- Is this list complete?
- Position/time dependance?
- Needed precision?
- How to constrain? How much can you relay on external measurements?

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Worry about Correlations?
And
Whether all of this can converge
from Cosmics alone?

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- Position/time dependance?
- Needed precision?
- How to constrain? How much can you relay on external measurements?

TF Initial Strategy

- Develop a refined list of things that need calibration and available sources
  - Get a number next to each quantity based on literature survey, prior measurements, best estimates etc. – We need a starting point.
- From this list, identify
  1. What are the lowest hanging fruits?
     - Universal constants (Ionization energy?), ex-situ measurements, past experiments (recombination?), Calculable (diffusion, drift velocity?)
  2. Propagate them to physics, confirm and push them out the door
     - Need tools that can propagate calibration uncertainties to physics and make our suite of plots
  3. What are those final set of measurements that require in-situ measurements
     - Never measured before; <u>requires a specific calibration source</u>; biggest impact on physics;...

Immediate focus

- We need to finalize Cryostat Penetrations (first week of October)
  - Can we do calibration without a laser system? Do we need Radio active source calibration? What else are we missing?
  - Don't be too optimistic: Can't relay too much on the models, data always has surprises.
  - Think Redundancy; we need as many test samples and measurements as possible.
  - Also think outside the box: There is a lot we can learn from non-LArTPC experiments that can possibly mitigate challenges seen by designs traditionally used for LArTPC experiments
    - E.g. T2K TPC laser system
- **Your input/feedback/thought/concerns will be very valuable!**

Meeting Focus:
Cryostat Instrumentation Feed Throughs

Defining Cryostat Penetrations

- Defining cryostat penetrations ties to a bigger problem since one needs to understand the needed calibration systems for DUNE and to some level the instrumentation of devices so accommodations can be made in terms of
  - Numbers of feedthroughs (Spares?)
  - Location/Distribution of feedthroughs
  - Width of each feedthrough
- Note that at this point we are only defining interfaces not the designs of the actual systems

TF recent activities

- Calibration Task Force is working closely with the Cryogenics Instrumentation and Slow Controls Consortium and also started working closely with the APA consortium where a big chunk of calibration sits
  - Both of these consortia are places where these issues will be discussed more actively, so subscribe to their general lists and look out for their agenda in the coming days
    - DUNE-FD-APA-CNSRT
    - DUNE-FD-CRYO-SC-CNSRT
- Kendall and I have been taking input from key stakeholders and holding focused meetings to develop specific questions/studies/charge we would need answered to address this problem
- If you have input, we are here, please contact us!

Challenge: Timeline

- Ultimate deadline: First week of November
- But, need to converge by first week of October
  - Two Technical Board meetings in September to discuss any new additions or modifying existing design
- We have **3 to 4 weeks to converge** on this
  - Time is very short
  - Need Collaboration input and help to meet the deadlines

Possible systems to consider

- Calibration and cryostat instrumentation systems need to be considered to make accommodations with the cryostat penetration design:
  - Thermometry
  - Purity monitors
  - Radioactive source calibration
  - Photon gain monitoring
  - Cameras (Cold vs Inspection)
  - Laser system
- Keep the no. of penetrations as minimal as possible, but at the same time we want to make sure we can calibrate our detector!
  - Possible scenario: one feedthrough shared b/n multiple systems (e.g. radioactive source & thermometers, or thermometers & PMs)

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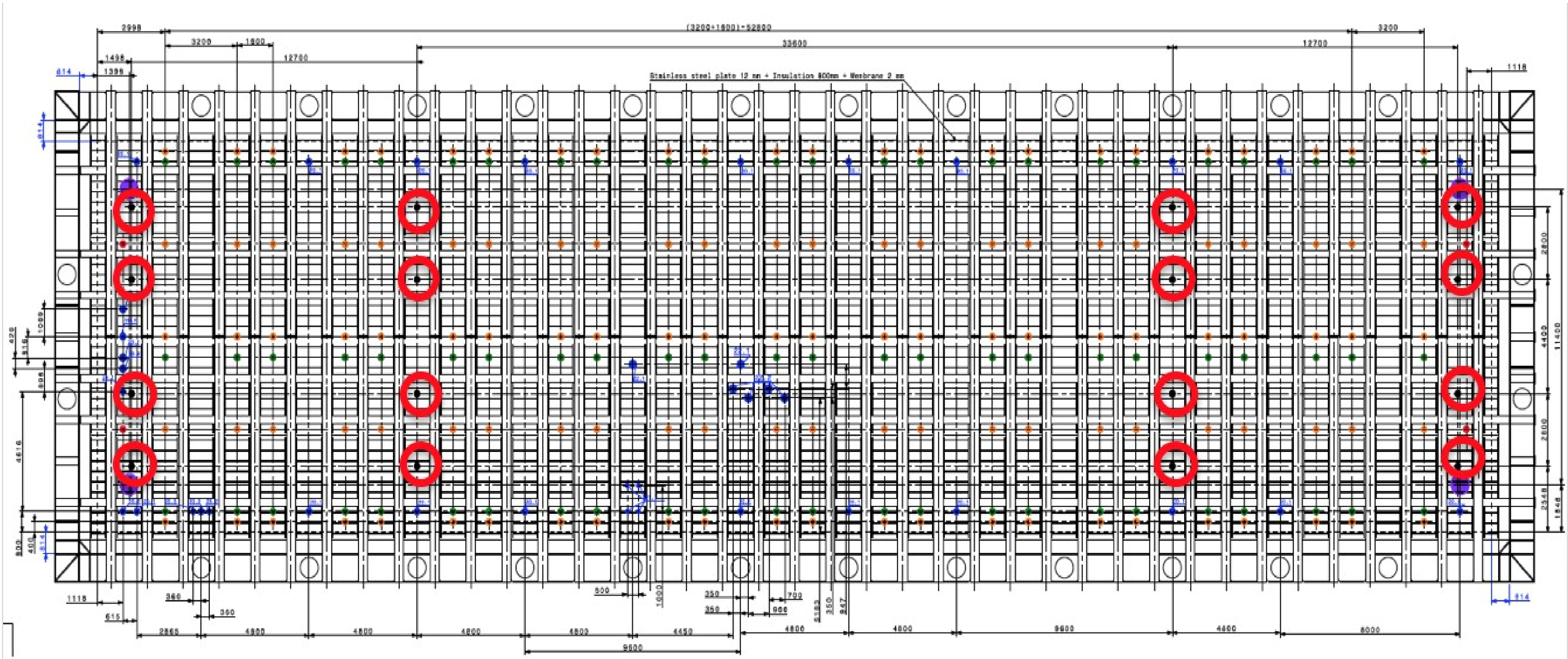
Do we need all these systems?

From the physics point of view, these systems are well motivated. (unprecedented physics requirements, so think redundant)

Each system comes with its own challenges and risks, which need to be addressed and mitigated through valid arguments/studies. That is the goal.

Current design for cryostat penetrations
(only showing the instrumentation ports)



Pos.	Diameter [mm]	Quantity	Description
1	Ø250	120	Support
2	Ø250	72	Cable
3	Ø250	4	High voltage
4	Ø250	16	Instrumentation
5	Ø800	4	Manholes

- 16 instrumentation ports
- 250 mm diameter (current design)

- About 0.5 m clearance on the sides
- About 0.7 m clearance on top from the surface of liquid argon

Current status of Cryostat Penetrations

- Baseline design is being updated Friday/Monday, but those adjustments do not change the current instrumentation
  - Exploring feasibility of port size increase for a few ports (300 mm)
  - Investigating a couple small penetrations closer to the wall. This could be useful if a scheme can be found to do a field response calibration.
  - Plan to add a few spare penetrations at the ends of the detector
- Laser photon system is NOT included (discussed later) which would require additional ports
  - Leadership is aware we may be making a request for additional or modified calibration and instrumentation.

Current systems and requirements

- **Thermometers:** Monitor the detector during cool down; provide information on fluid and gas flow
  - Fixed thermometers vs Dynamic-vertical T-Gradient thermometers for cross calibration. Latter (favored) puts requirements on penetration width
  - How many thermometers? – not clear. Need to estimate from fluid flow simulations
- **Cameras (Fixed vs steerable?):**
  - Consider this as one system that can be deployed using an instrumentation port. Purpose/requirements need to be defined.
  - Cold Cameras: Arcs, sparks etc.
  - Inspection Cameras: ability to shine light and look inside the detector
- **Purity Monitors**: during commissioning, initial data runs and low purity times
  - No. of purity monitors, requirements on FT width – not studied
  - Can ProtoDUNE design be extrapolated to DUNE? Not clear.

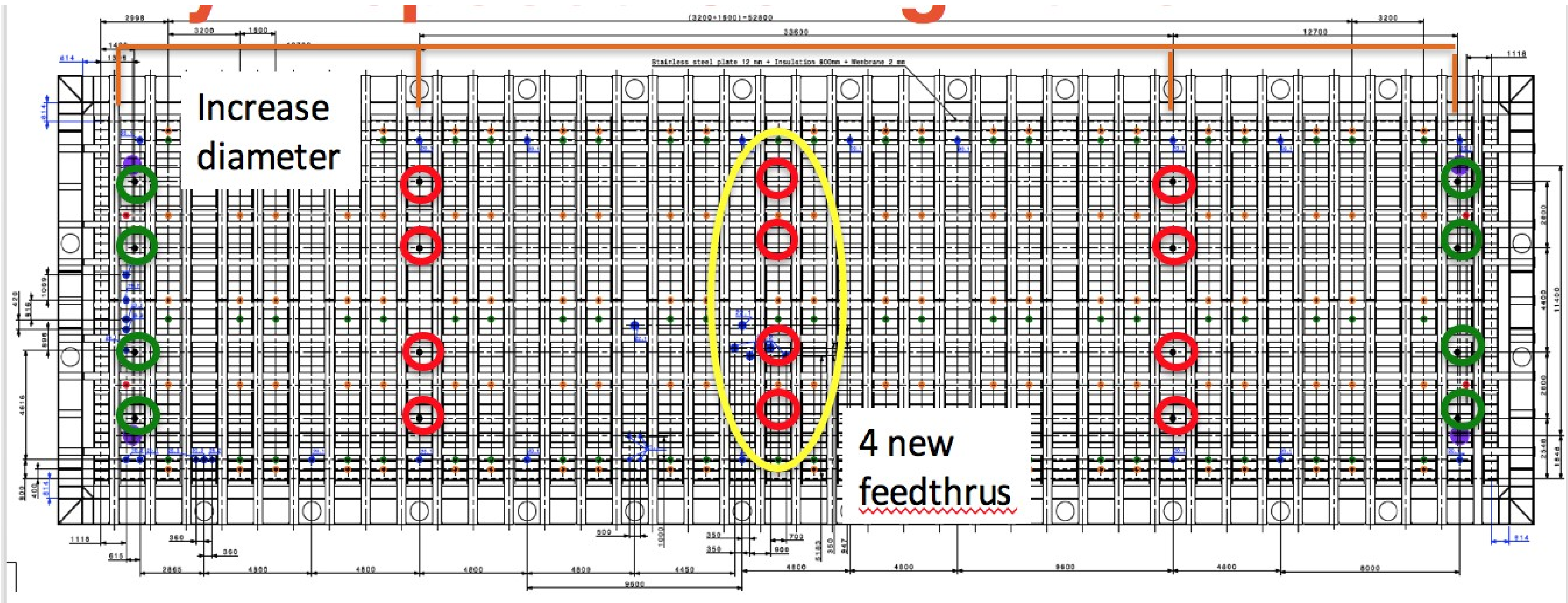
Current systems and requirements

- **Radioactive sources:** Low energy calibration; strong physics motivation
  - Requirement on position resolution and how the current design impacts physics – not clear.
- **Photon gain monitoring:** Light flashing system for commissioning the photon detector and monitoring its relative gain
  - Needs optical feedthroughs for fiber optics. The fibers are fragile and a significant number needed along the plane.
- **Laser system**
  - If we want to do this, will need 16 (?) additional penetrations
  - DUNE has unique challenges, so need well founded arguments that line up with physics requirements

What is clear though: Making instrumentation ports accommodate multiple systems is a good strategy. Needs calculations on the penetration width taking into account various systems.

One proposed design for penetrations – Jim Stewart

(only showing the instrumentation ports)



- **Increase the size of penetrations to accommodate multiple systems:**
  - Change 250 mm → >275 mm (maximum allowed); 300 mm is risky
  - It is not clear what is actually needed based on width requirements from Multiple systems?

- **Adding additional 4 feedthroughs**
  - motivated for Radioactive source calibration to get better position resolution
  - The argument for adding 4 new ports Vs spreading the existing (red) 8 ports need to compared/studied (8 vs 12)

Addressing the FT width question?

- What are the FT width requirements for various systems? (take into account multiple systems will share a single FT)
- **Strategy:** Get the requirements from users from each port and draft a plan.

Charge to various people:

- Radioactive source (Jonathan, Juergen): A table listing the most desirable radioactive sources for DUNE and for each choice what is the required FT size?
- Thermometers (Jelena, Anselmo, Ines): Assuming protoDUNE design can be extrapolated, what is the FT requirement? (take into account fixed vs dynamic vertical T-gradient). Need Fluid flow simulations required to understand no. of thermometers (pursue Eric Voirin, Stephen Pordes)
- Purity Monitors (Andrew, Jianming, Mario): Can protoDUNE model be extrapolated? How many PMs? FT width requirement?
- Need to have discussion on Cameras and Photon gain monitoring

Do we need additional 4 FTs?

(charge to Jonathan, Juergen, Kate, Bob)

- What are the energy and position resolution requirements for DUNE for low energy calibration?
- Position resolution studies comparing 8 vs 12 scenario Vs spreading the 8 over the cryostat center (symmetry important). Strong arguments or studies showing either change is needed?
- Other considerations:
  - How close can one take the source to the field cage? (Jonathan, Bo)
  - Risk factors: Radioactive source can get stuck (well founded concern), what can be done to assess the risk, mock-up tests and considerations in mechanical design? (Juergen)
  - How does this impact other systems? E.g. What accommodations does DAQ have to make in their design? Pre-scale triggers, hardware triggers, special run control etc. (Juergen)
  - Other factors that can impact the design or physics and limit the performance? e.g, field variations, flow patterns etc.

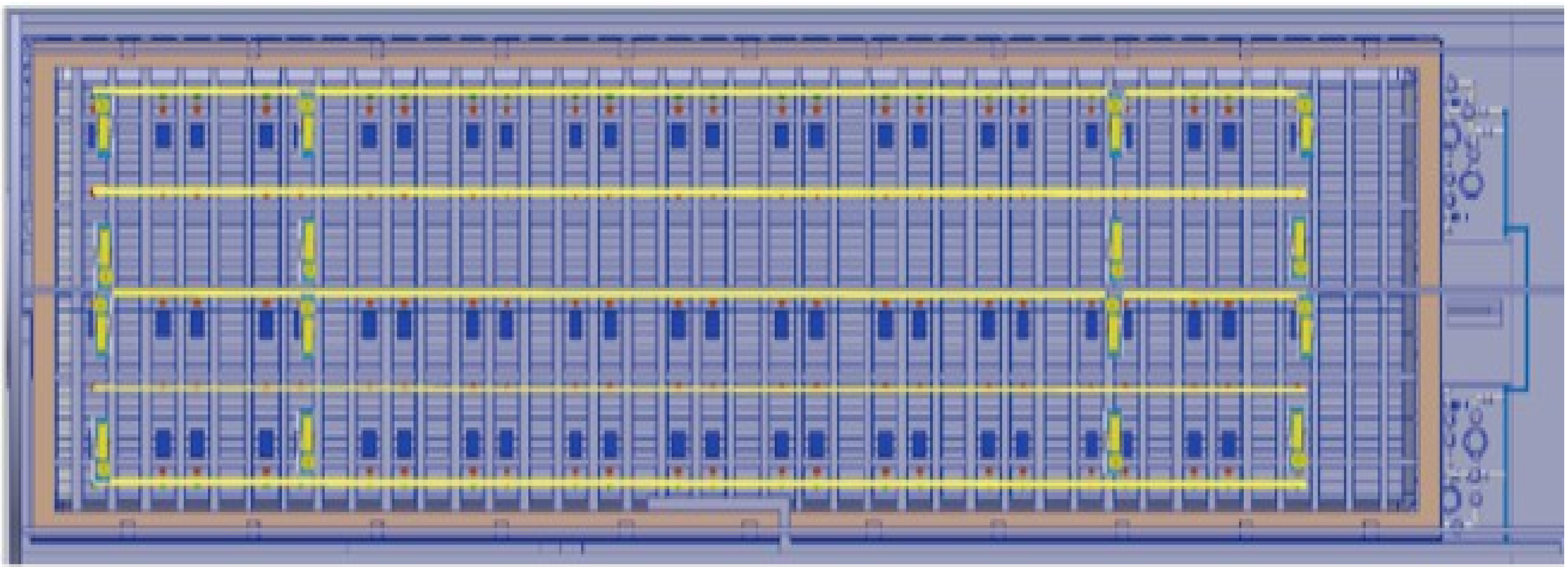
Laser System

(Francesco, Michele, Igor, Vitaly & ICARUS experts)

- Currently case studies:
  - ICARUS, MicroBooNE, CAPTAIN, T2K, Reactor (?)
- Multiple scenarios:
  - 1 penetration, 100% coverage: Keep it close to APA and the laser can sweep from APA to CPA
  - Partial coverage, localized and then extrapolate
  - Ionization vs Photo-calibration system
- Advantages: Redundancy, superiority to cosmic rays
- Disadvantages: ionization along the track, high energy, range
- Calibration with cosmics vs Laser – studies needed; need to tie to high level physics requirements
- Will need additional penetrations. Risk/Cost assessment: penetrations now vs later

Laser System: Proposed 16 Fts

(https://docs.dunescience.org/cgi-bin/private/ShowDocument?docid=4769)



Discussion for next week, Tuesday!

Moving forward

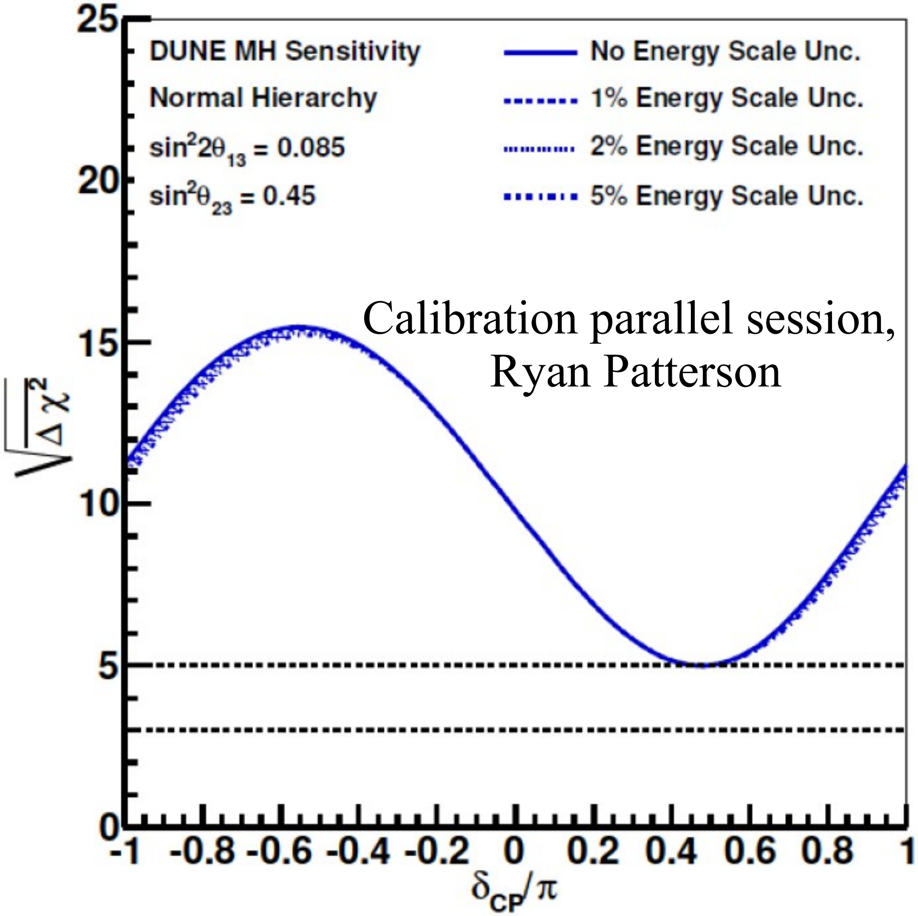
- Experts and key stake holders for each system being identified.
  - Focused meetings with experts followed by specific questions and request for additional studies/arguments
- Better understanding of physics-driven calibration requirements will be the focus.
  - Understanding calibration reach with cosmics needs quantified
  - Short term focus: defining cryostat penetrations
- For the cryostat design timescale, detailed studies not possible. But, will pursue experts to provide their best arguments and preliminary studies.
- Let's hope that this converges in the next 4 weeks!

Backup

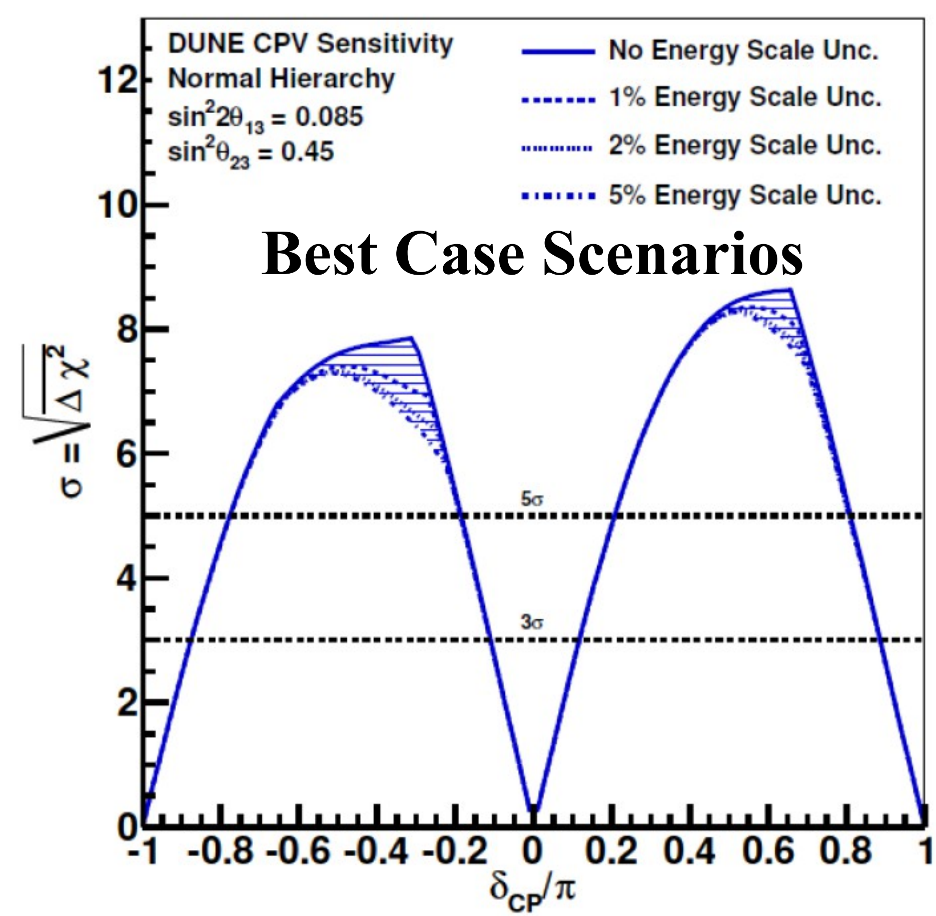
Issue: Unprecedented Physics Requirements
Brave new world

CDR

Mass Hierarchy Sensitivity



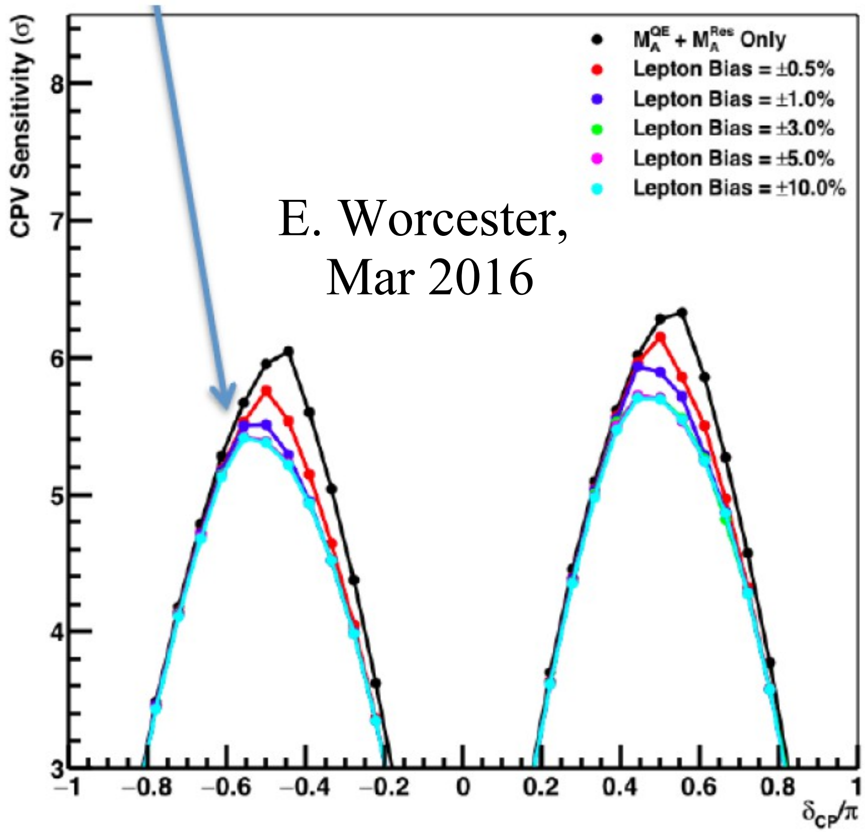
CP Violation Sensitivity



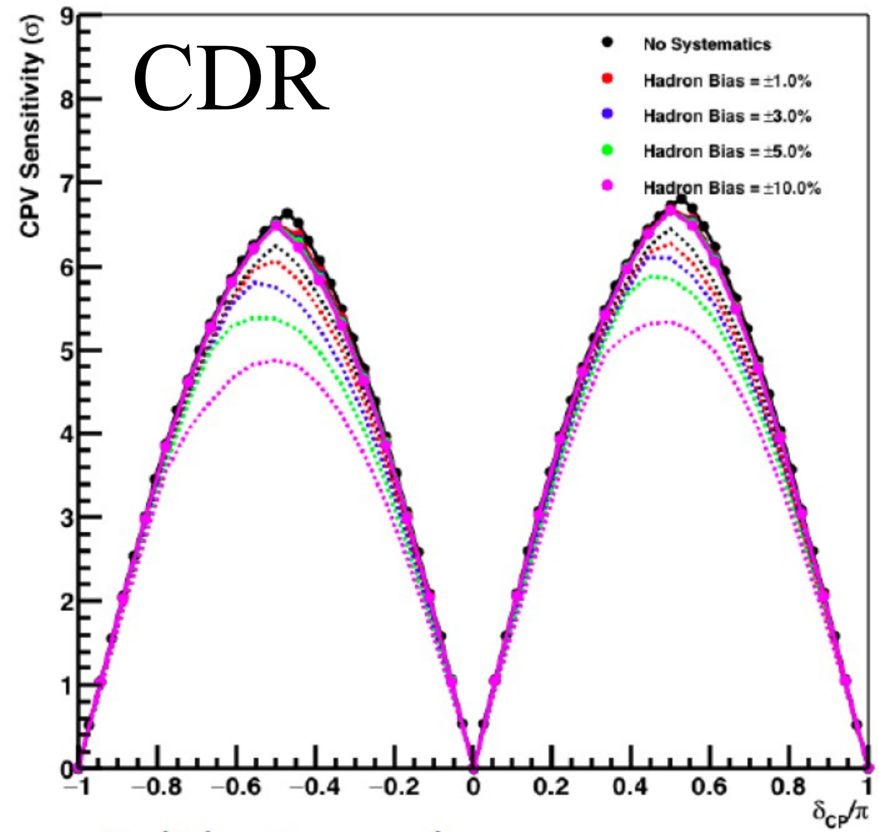
A 2% uncertainty on energy scale is already a big deal!
Other uncertainties can only amplify the impact of this.

Issue: Unprecedented Physics Requirements
Brave new world

https://indico.fnal.gov/contributionDisplay.py?contribId=4&confId=11718



Calibration parallel session,
Ryan Patterson



Solid = 4 sample
Dashed = ν_e only

Lepton E bias: even 1% is a big deal!
Other uncertainties can only amplify the impact of this.

What are our Calibration source options?

- Purity Monitors
- Temperature monitors
- Survey
- Current monitors
- υ_μ CC events
- Michel electrons
- Stopping muons
- Stopping protons
- Muon Crossers, APA/CPA piercers
- Ar^{39}
- Laser system
- CRT tagger
- Other radioactivity

- Michel electrons
- υ_μ CC events
- π^0 mass peak
- Other decays (K^0s…)
- Tagged events

What else??

- Keep in mind each source comes with its own challenges
- Best Strategy: Option of multiple ways to calibrate