Far Detector Task Force Update

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LBNC Meeting

March 23, 2017

DEEP UNDERGROUND NEUTRINO EXPERIMENT

FD Task Force Charge

The far detector physics task force is charged to:

- Develop a full far detector simulation and reconstruction chain;
- Produce detector optimization studies, for example, 3mm vs 5mm wire pitch, wire angle and the efficiency of the light readout system for different configurations;
- Produce a first update the DUNE long-baseline physics sensitivity studies using full simulation and event reconstruction;
- Develop the simulation and reconstruction for SNB and nucleon decay physics;
- Produce a first report on their findings, which will be presented to the collaboration at the September 2016 collaboration meeting and a final report by March 2017.

It is intended that these studies will, in general, take into account both reference and alternate FD designs.

Today's report

- Since we are nearing the end of the task force, I will go through each item of the charge and remind you what has been accomplished
- I'll provide some highlights on progress since last meeting
- The final report is in preparation and will provide details on every aspect of the charge
  - The draft will be ready in a couple of weeks, and will undergo a collaboration review before being finalized.

FD Task Force Charge

The far detector physics task force is charged to:

- Develop a full far detector simulation and reconstruction chain;

The chain is functional and being continuously improved.

- Develop the simulation and reconstruction for SNB and nucleon decay physics;
- Produce a first report on their findings, which will be presented to the collaboration at the September 2016 collaboration meeting and a final report by March 2017.

It is intended that these studies will, in general, take into account both reference and alternate FD designs.

FD Task Force Charge

The far detector physics task force is charged to:

- Develop a full far detector simulation and reconstruction chain;

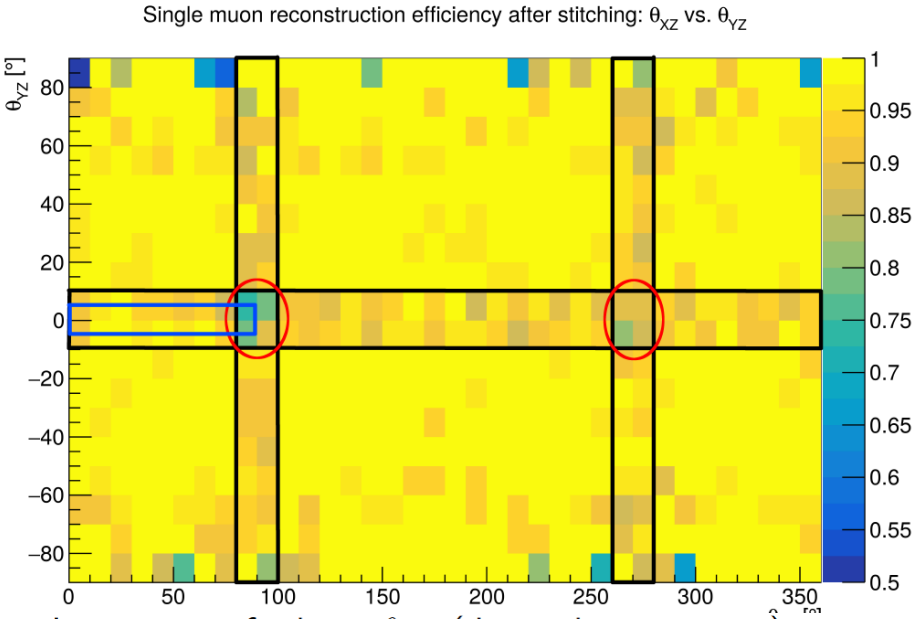
Future studies can take the alternate FD design into account!

- Recall the dual-phase simulation and reconstruction was not implemented in LArSoft when we started
- Geometry and simulation has been developed and dual-phase samples are included in MCCs
- Reconstruction improvements are ongoing

the collaboration at the September 2016 collaboration meeting and a final report by March 2017.

It is intended that these studies will, in general, take into account both reference and alternate FD designs.

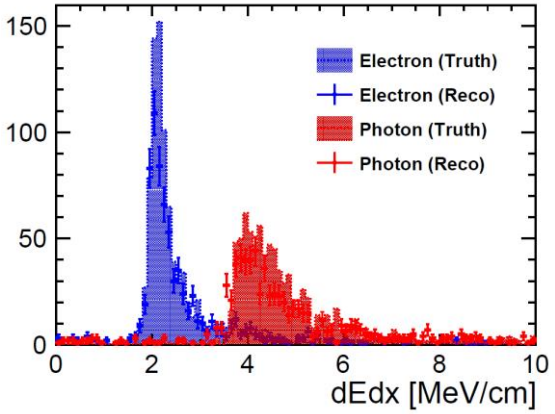
Dual-phase Reco Highlights

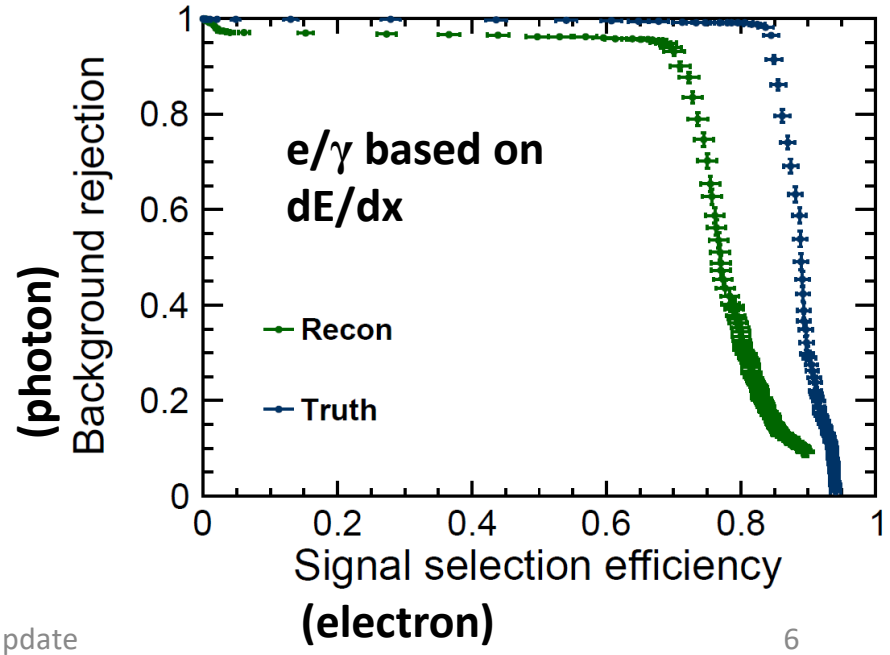


- Large errors for large θ_{YZ} (due to low statistics)
- black boxes: muon is seen only a few wires in one view
- red circles: muon along drift direction

Validation of tracking algorithms, checking the efficiency for muon reconstruction (>93% for sample of muons with isotropic angular distribution).

dE/dx studies





FD Task Force Charge

NDK: sim/reco chain is in place! Reconstruction will continue to be optimized, but sensitivity for p->νK channel based on full sim/reco, including backgrounds, is in progress.

- Produce a first update the DUNE long-baseline physics sensitivity studies using full simulation and event reconstruction;
- Develop the simulation and reconstruction for SNB and nucleon decay physics;
- Produce a first report on their findings, which will be presented the collaboration at the September 2016 collaboration meeting and a final report by March 2017.

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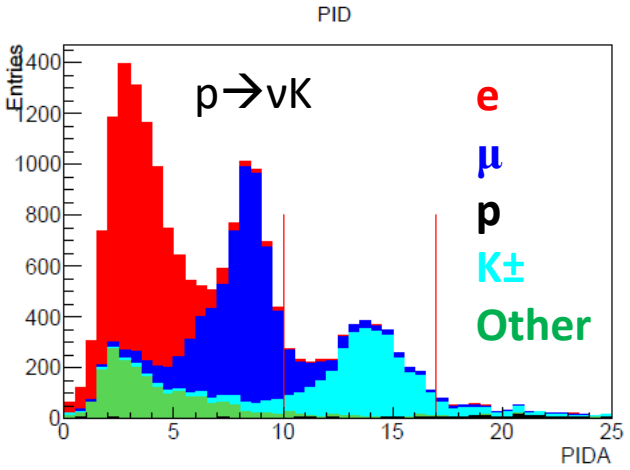
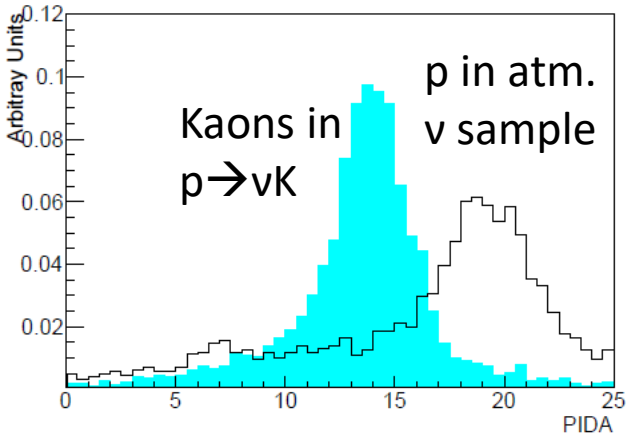
NDK Highlights

- Validation of NDK modes in GENIE 2.12 (which also now includes n-n̄ oscillation)
- Reconstruction and analysis of p $\longrightarrow \nu$ K decay mode
  - Kaon FSI is now properly included in GENIE; modifies kaon momentum distribution.
  - Event selection and reconstruction are improving
- Assessment of backgrounds from atmospheric neutrinos and cosmogenics
- Feasibility studies for other baryon number violating modes (e.g., n-n̄ oscillation)

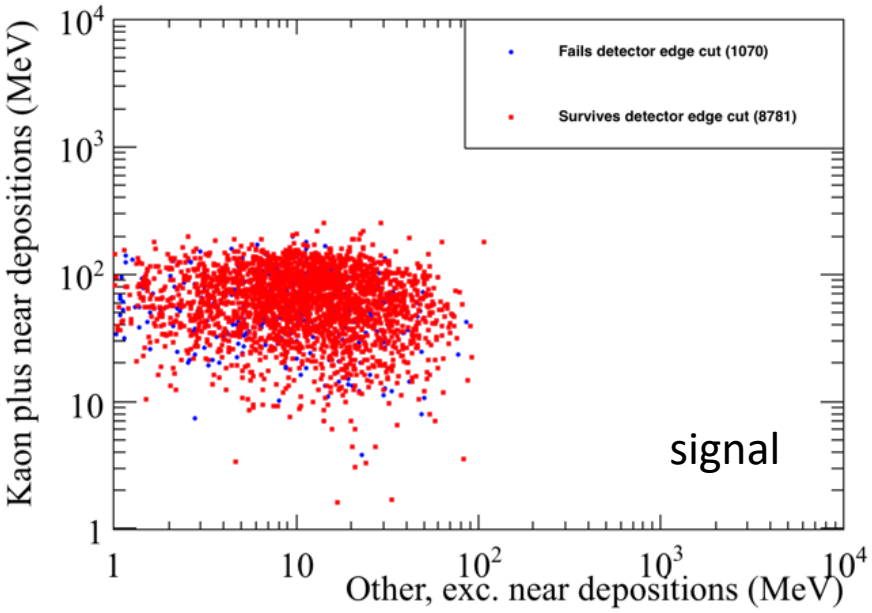
p→νK analysis and atmospheric neutrino backgrounds

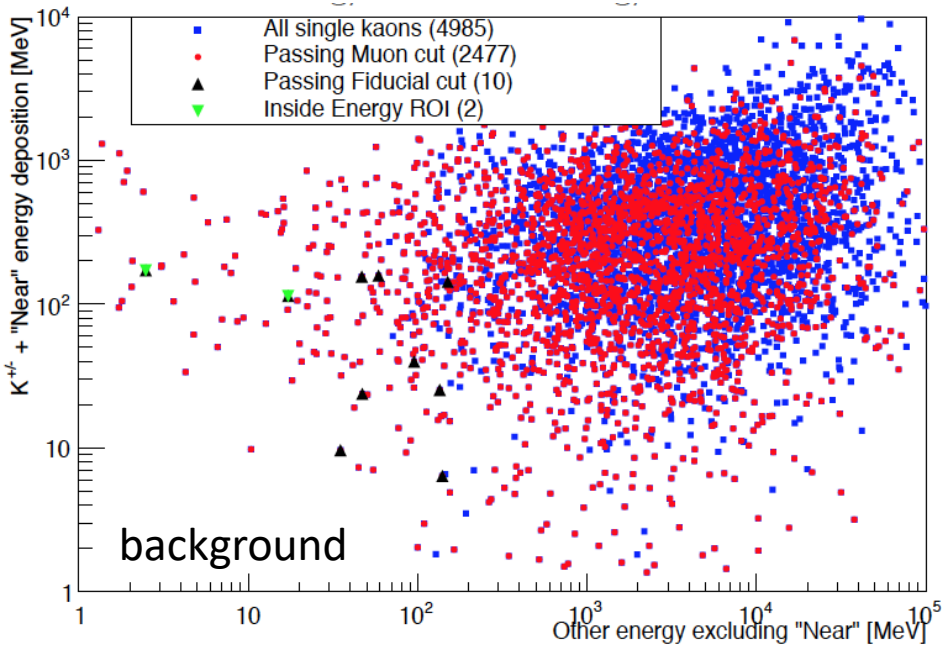




Requirement	$p \to \bar{\nu} K^+_{\mu 2}$ signal efficiency (%)	Atmospheric ν background rate ($\mathrm{Mton}^{-1} \cdot \mathrm{year}^{-1}$)
None	100.0	2.9×10^5
Kaon tracking efficiency	61.8	N/A
Kaon and muon ID	38.0	9.2×10^3
Not shower-like	30.7	1.0×10^3
Vertex-muon separation	23.2	1.2×10^2

p→νK cosmogenic background





2×10^9 muons were generated, 401.4 years of live time for a 10 kt detector. **Only MC truth**.

Cuts:

- No primary muon track longer than 20 cm.
- Single kaon.
- No hits within 2 cm from the walls.
- Kaon energy deposition <300 MeV (includes intra-nuclear interactions).
- Other energy depositions (excluding tracks from the kaon vertex) <30 MeV.

Kaon energy depositions versus other energy deposition (except tracks from the kaon vertex).

FD Task Force Charge

SNB: sim/reco chain is in place!

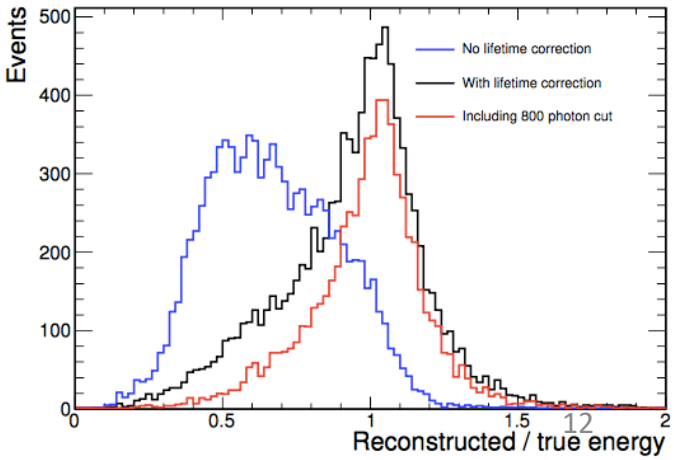
- Generators have been incorporated into LArSoft and reconstruction tools now work for < 20-MeV events.
- Improvements are underway
- More work is required for analysis based on full simulation and reconstruction

- Develop the simulation and reconstruction for SNB and nucleon decay physics;
- Produce a first report on their findings, which will be presented to the collaboration at the September 2016 collaboration meeting and a final report by March 2017.

It is intended that these studies will, in general, take into account both reference and alternate FD designs.

SNB/LE Highlights

- **2nd Supernova Hack Days** in January 2017
- Realistic **SN neutrino event generation**:
  - deexcitation γ and nucleons (**MARLEY**) **now integrated into LArSoft**
  - samples generated for multiple studies
  - time profile simulation work underway
- **Tagging** algorithms: work underway on NC-induced γ's, brems/deex for ν_e CC event tagging
- **Radiological backgrounds**:
  - Studies of the ^{39}Ar background in the low energy reconstruction
  - **Full radiological sim now available** (radiopurity group)
- **Photon detector** contributions: attenuation correction, reconstruction contribution studies underway
  - **photon backtracker** in use for studies



FD Task Force Charge

The far detector physics task force is charged to:

- Develop a full far detector simulation and reconstruction chain;
- Produce detector optimization studies, for example, 3mm vs 5mm wire pitch, wire angle and the efficiency of the light readout system for different configurations;
- Produce a first update the DUNE long-baseline physics sensitivity studies using full simulation and event reconstruction;

The capability to produce the sensitivities has been developed.
Reconstruction and event selection will continue to improve.

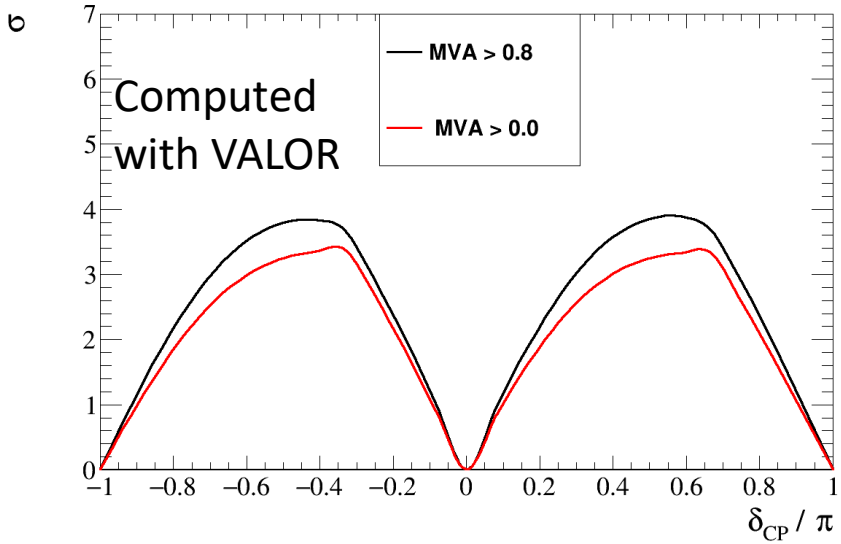
  the collaboration at the September 2016 collaboration meeting and a final report by March 2017.

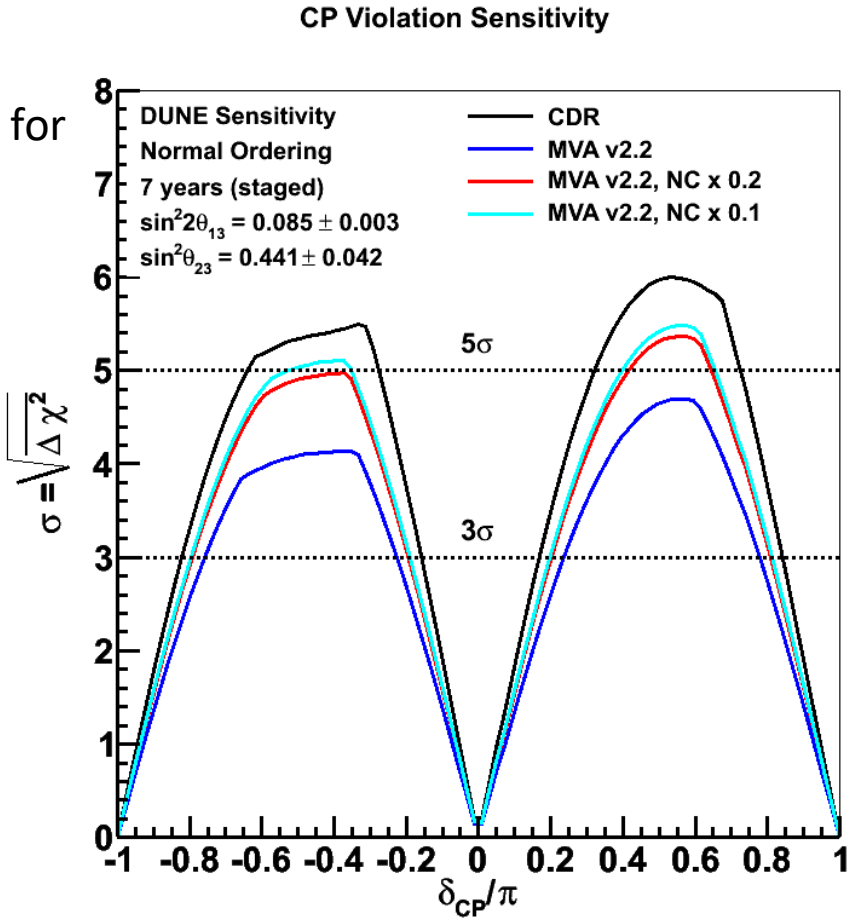
It is intended that these studies will, in general, take into account both reference and alternate FD designs.

LBL Sensitivity Highlights

Plans for improvement:

- Reconstruction:
  - Optimization of the Pandora framework for DUNE
  - Improvements to the shower reconstruction
- Improvements to the MVA selection
- Convolutional neural network based particle identification





Computed with GLoBES

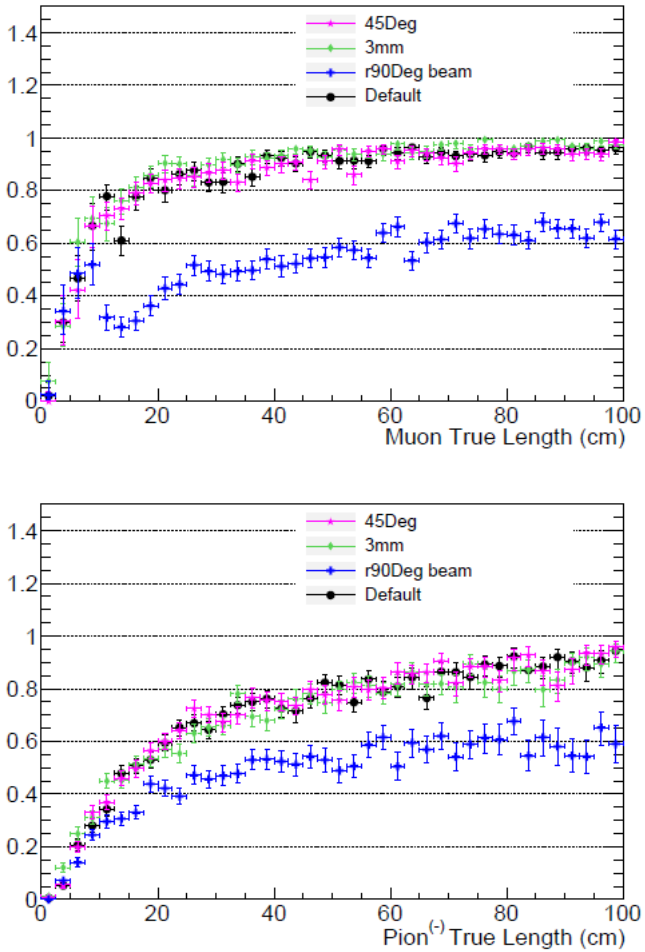
FD Task Force Charge

The far detector physics task force is charged to:

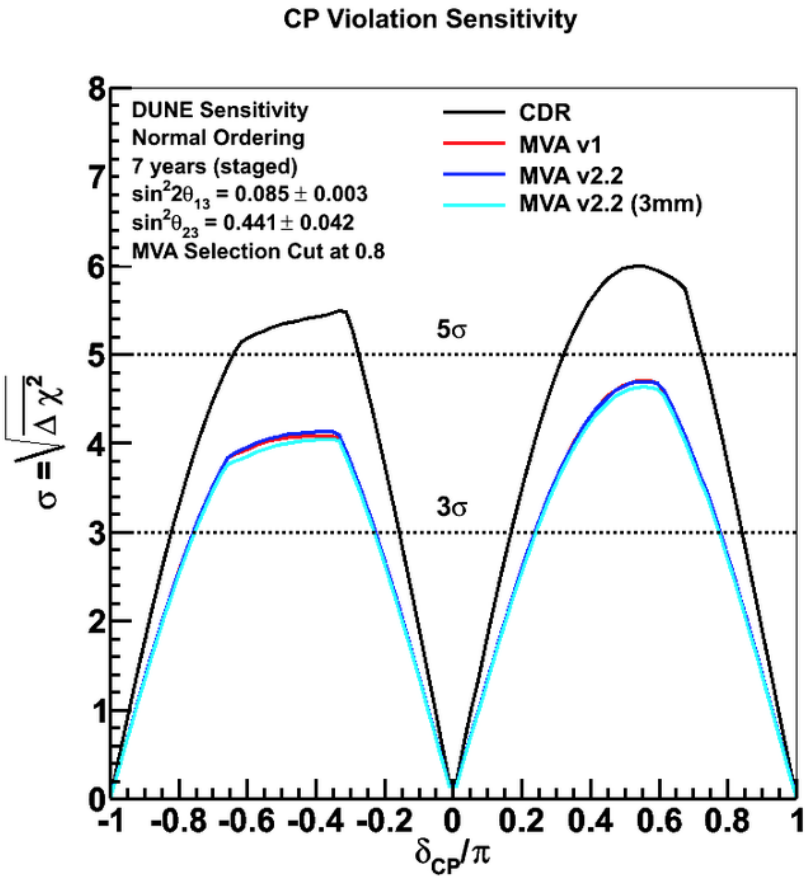
- Develop a full far detector simulation and reconstruction chain;
- Produce detector optimization studies, for example, 3mm vs 5mm wire pitch, wire angle and the efficiency of the light readout system for different configurations;
- Have studies of tracking efficiency, e/γ separation, event selection for different geometries;
- Other detector optimization (like para. vs perp. APA, no. of wire planes, electronics requirements) have been studied
- Photon detector task force is addressing light yield question

It is intended that these studies will, in general, take into account both reference and alternate FD designs.

Detector Optimization Studies



Tracking efficiency for different geometries



CP sensitivity with different wire spacing

Electronics Requirements

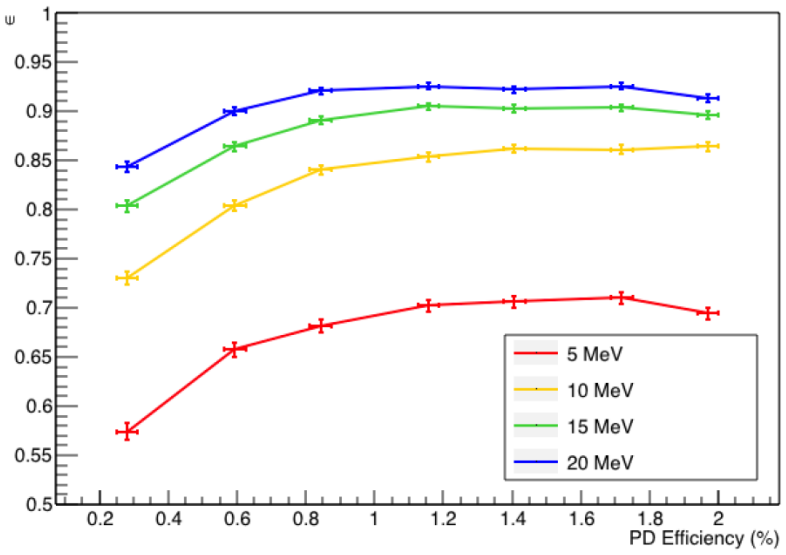
To ensure good signal to noise ratio for induction wire plane for as many as event topologies as possible, it is crucial to minimize electronics noise

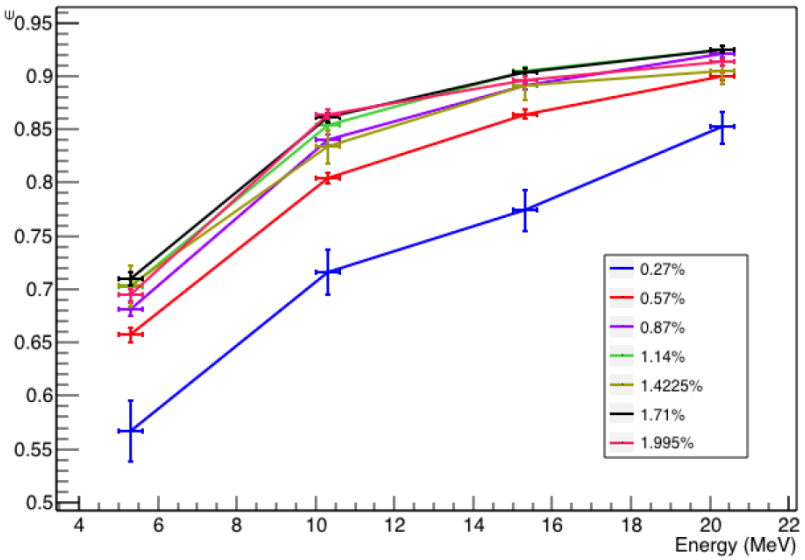
- Given the expected inherent electronics noise associated with the cold electronics **(~600 equivalent noise electrons)**, **an ideal 10-bit ADC** can satisfy the physics requirement of **"Digitization Noise" << "Electronics Noise associated with the first transistor"** with a reasonable coverage of dynamic range
  - Optimization of gain/shaping time settings and the digitization frequency needs to balance the Nyquist' theorem, charge resolution, and the dynamic range

Photon Detector Highlights

- Improvements in sim/reco tools
- Reference design performance
- Physics studies (example below)
- Exploring new ideas

SN signal efficiency study





FD Task Force Charge

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- Produce a first update the DUNE long-baseline physics sensitivity studies using full simulation and event reconstruction;

Preliminary: Done; Final: In progress!

- Produce a first report on their findings, which will be presented to the collaboration at the September 2016 collaboration meeting and a final report by March 2017.

It is intended that these studies will, in general, take into account both reference and alternate FD designs.

Preliminary Report: DocDB-1752

Major Milestones

Milestone	Status	Planned Completion Date	Actual Completion Date
Beam event selection	Completed	01/2016	01/2016
Sim/reco chain (non-beam)	Completed	04/2016	09/2016
Dual-phase sim/reco chain	Completed	06/2016	09/2016
CP sensitivity	Completed	09/2016	09/2016
CP sensitivity (dual-phase)	Ongoing	12/2016	
Sensitivities for non-beam physics	Completed	03/2017	03/2017
CP sensitivity Improvement	Completed	03/2017	03/2017
Wire pitch and angle studies	Completed	03/2017	03/2017
Other optimization studies	Completed	03/2017	03/2017
Study of PDS requirements	Ongoing	03/2017	
Dual-phase optimization	Ongoing	03/2017	

More reconstruction optimization is needed for dual-phase before the CP sensitivity study or any optimization studies can be completed.

The PDS Task Force has made good progress, but their work will continue.

Response to LBNC Recommendations

Recommendation	Review	Review Da	Owner	Responsible	Item Description	Due Da	Close Da	Statu	Actions
2016-06	LBNC	10-Jan-16	Whitehead	FD Task Force	DUNE Collaboration management should take all necessary steps to increase engagement for all gaps in effort.	30-Jun-17	15-Feb-17	closed	We are continually working towards this goal, increase collaboration engagement and attracting new collaborators.
2016-36	LBNC	12-Jun-16	Whitehead	FD Task Force	Define a plan to address reconstruction below 50 MeV	30-Jun-17	15-Feb-17	closed	The plan was developed and executed through a series of SuperNova WG hackathons. Dedicated reconstruction now exists.
2016-37	LBNC	12-Jun-16	Whitehead	FD Task Force	Review whether there is sufficient manpower to conduct the full range of physics studies laid out in the TF charge	30-Jun-17	15-Feb-17	closed	TF will complete its report as planned and all areas have been addressed at some level. Work we continue toward as the collaboration progresses towards the TDRs.
2016-38	LBNC	12-Jun-16	Whitehead	FD Task Force	Review whether feedback from physics studies to reconstruction algorithm development is working effectively	30-Jun-17	15-Feb-17	closed	Reconstruction activities moved into relevant physics WGs. This tighter coupling of the reconstruction development and the physics goals has been effective.
2016-39	LBNC	12-Jun-16	Whitehead	FD Task Force	Update the LBNC with the status of actual versus planned manpower across the TF at the fall meeting	30-Jun-17	15-Feb	closed	Some level reporting at Fall meeting.
2016-107	LBNC	23-Oct-16	Whitehead	FD Task Force	Complete the DP implementation in LArSoft	31-Mar-17		in process	A useable DP simulation is now available. PMT simulation needs to be added.
2016-108	LBNC	23-Oct-16	Whitehead	FD Task Force	Lack of manpower in various analysis efforts needs to be addressed	23-Mar-17	15-Mar-17	closed	Closed. The Task Force is finalizing its final report.

Summary

- The FD Task Force has met the goals laid out in the charge
  - The tools and infrastructure are now in place to do FD optimization studies
- Physics working groups are now working closely with the FD sim/reco group, and detector optimization studies will continue
  - The task force will end, but working groups will focus their efforts on FD studies needed for TDR – final report will address this briefly
- The final report is in preparation now

Backup

Preliminary Report

Report: DocDB-1752
Summary given in Oct 21 weekly phone meeting: Slides

DUNE Far Detector Task Force Preliminary Report

October 31, 2016

Contents

1 Introduction

The DUNE Far Detector Task Force was formed in September 2015 and charged to:

- develop a full far detector (FD) simulation and reconstruction chain (Section 2);
- produce detector optimization studies, for example, 3 mm vs 5 mm wire pitch, wire angle and the efficiency of the light readout system for different configurations (Section 6);
- produce a first update the DUNE long-baseline physics sensitivity studies using full simulation and event reconstruction (Section 5);
- develop the simulation and reconstruction for SNB and nucleon decay physics (Section 4);
- take into account both reference (single-phase TPC) and alternate (dual-phase TPC) FD designs in the studies (Section 3).

These goals were motivated by the status of DUNE's simulation and reconstruction tools and physics sensitivity studies at the time the task force was formed. The long-baseline oscillation sensitivity studies up until that time had been performed with GLoBES [1, 2]. GLoBES

From September 2015 FD Task Force plenary talk

Back to the Charge

Sounds like a lot to do in 18 months! Let's manage our expectations:

- Full simulation and reconstruction chain
  - We don't have to develop the "final" version of all our reconstruction tools. We can have the chain without every step being perfect.
- FD Optimization
  - We can't study every single possible detector design choice and determine the effect on every single possible physics result. But we can focus on some major questions.
- Long-baseline sensitivities based on full simulation and reconstruction
  - We are developing the *capability* to produce sensitivities with a full FD MC sample. Sensitivities produced this way might not be very good at first (or match our GLoBES estimates). It will take some more time and work to get there.
- Simulation and reconstruction for SNB and nucleon decay physics
  - The goal is simply to bring all the physics studies under the umbrella of the same simulation and reconstruction.

PDS Task Force Charge

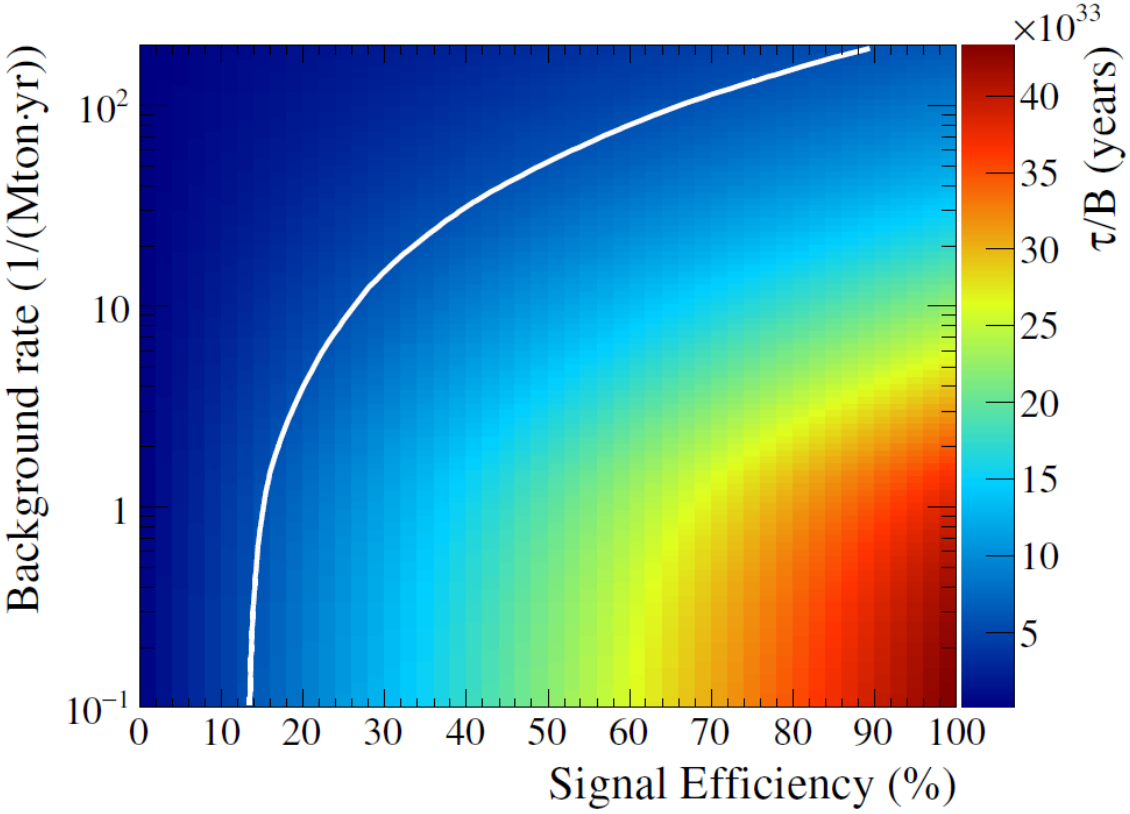
The PDS Task Force is charged to determine if

1. The existing PDS and TPC requirements are sufficient define a detector capable of performing scientifically relevant measurements that support the DUNE physics program, which for this charge shall be defined as both the beam physics program and non-beam physics associated with proton decay, atmospheric neutrinos, and SNB events.
2. The existing light detection response parameter of 0.1 photoelectron-per-MeV of energy deposition is sufficient to support the DUNE physics program, and how rapidly scientific benefits would increase as this light yield is increased.
3. Addition of specific mean detection efficiency requirements for various minimum visible energy depositions would significantly enhance the DUNE physics program.
4. Addition of specific uniformity of detection efficiency requirements for various minimum visible energy depositions would significantly enhance the DUNE physics program.

Examples of future studies (towards the TDR)

- Detector Performance:
  - Energy Scale uncertainty vs neutrino energy and type
  - Energy Resolution vs neutrino energy and type
  - Particle Purities and Contaminations depending on PID cuts for e, Y, π, k, and Protons
  - Detection efficiencies for e,Y,π, k, P depending on momentum
  - Photon detection efficiencies depending on distance from the sensors.
- Detector Design Validation:
  - Detector Calibration/Cosmic Ray Analysis/LAr impurities
  - Impact of Dead Channels on detector performance
  - Impact of different levels of detector noise on performance
  - Impact of Showers overlapping APA and CPA on detector performance
  - Supernova trigger and data buffering.

NDK (p→νK)



DUNE's expected sensitivity as a function of signal efficiency and background rate for a 400 kton-year exposure at 90% CL