DEEP UNDERGROUND NEUTRINO EXPERIMENT

STATUS OF PHYSICS WORKING GROUPS

Elizabeth Worcester (BNL), Ryan Patterson (Caltech)

LBNC Meeting

March 23, 2017

Overview

- Physics coordination
  - Charge
  - Major milestones
  - Organizational update
  - Collaborative tools
- Physics working groups
  - Working group highlights
  - Assessment exercise
- Response to LBNC recommendations

Lots of progress: will be the bulk of the talk – still not enough time to discuss everything!

Charge

- Extend our understanding of scientific capabilities of DUNE with the detector and beam line configurations being developed
  - Updated sensitivity calculations
  - Studies of impact of beam and detector design choices
  - Development of (ever more realistic) MC-based analyses
- Further develop the scope and strength of the physics program for DUNE through exploration of new ideas, with inputs from the experimental and theoretical communities at large
  - Collaborating with and providing experimental configurations to phenomenology community
  - BSM physics working group
  - Interest in solar neutrino/earth science (Low-E/SNν working group)

Major Milestones

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- Q1 2017: Update long-baseline sensitivity calculations
- Q1 2017: Complete assessment exercise
- Q1 2017: Input to final task force reports
- Q1-Q2 2017: Launch and populate approved plots page
- Q2 2017: Incorporate tools developed for task forces into physics working groups
- Q4 2017: Determine physics analysis results needed for detector TDR
- Q1 2018: Determine methods to be used for primary results in physics TDR
- Q3 2018: Finalize physics results for detector and physics TDRs
- Q1 2019: Physics TDR draft

Organization

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High-level coordination

Ryan Patterson
Deputy: Elizabeth Worcester

Theory conveners

New conveners as of last briefing have taken full responsibility for their groups.

New conveners since last briefing have been added for coordination of specific tasks:
Alex Himmel: PDS sim/reco
Dan Cherdack: LBL fitting

Physics Working Groups

Far Detector Sim/Reco
Alex Himmel, Xin Qian, Tingjun Yang

Long-Baseline
Matt Bass, Dan Cherdack, Mayly Sanchez, Silvia Pascoli

Near Detector
Mike Kordosky, Steve Manly

BSM/Exotic
Alex Sousa, Jae Yu

Nucleon Decay
Jen Raaf, Michel Sorel

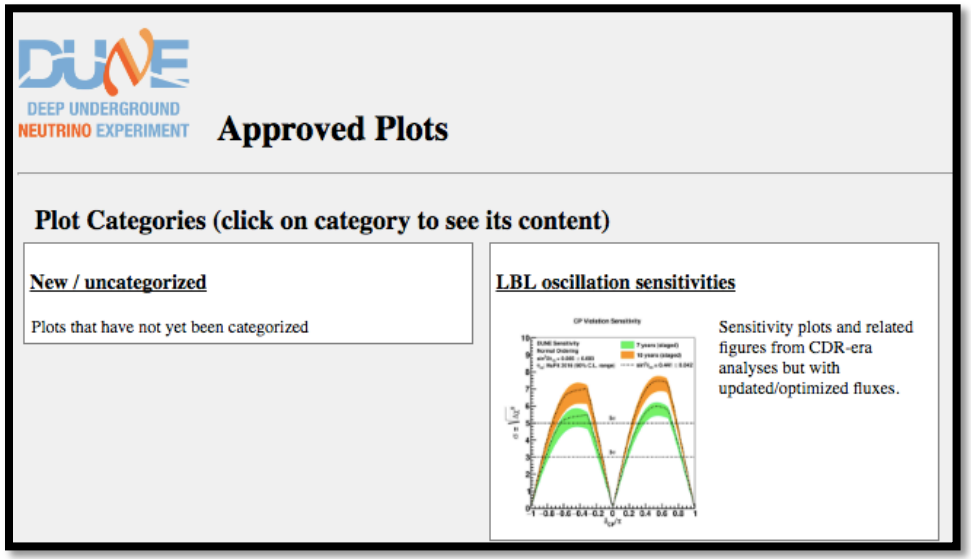
Atmospherics
Hugh Gallagher, Alessandra Tonazzo

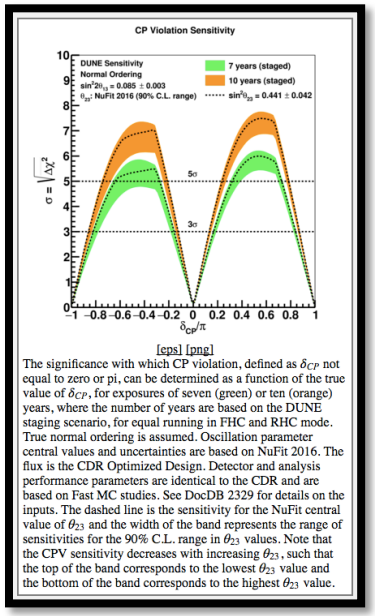
Cosmogenics
Dan Dwyer, Vitaly Kudryavstev

Low-E/SNν
Ines Gil Botella, Kate Scholberg, Alex Friedland

Approved Plots Page

- Single “go-to” location for material approved for public talks
- Powered by DocDB, using same machinery as NOvA
- Password protected: collaboration only
- Plots, graphics, and photos approved by working groups for public presentation are posted, with explanatory captions
- Physics coordinator serves as curator of page
- http://internal.dunescience.org/plots/





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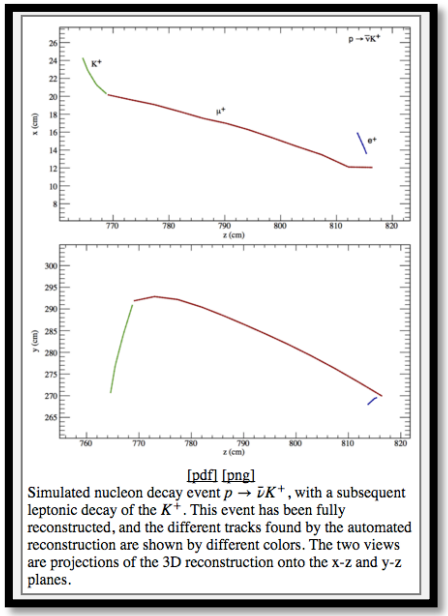
The significance with which CP violation, defined as δ_{CP} not equal to zero or pi, can be determined as a function of the true value of δ_{CP}, for exposures of seven (green) or ten (orange) years, where the number of years are based on the DUNE staging scenario, for equal running in FHC and RHC mode. True normal ordering is assumed. Oscillation parameter central values and uncertainties are based on NuFit 2016. The flux is the CDR Optimized Design. Detector and analysis performance parameters are identical to the CDR and are based on Fast MC studies. See DocDB 2329 for details on the inputs. The dashed line is the sensitivity for the NuFit central value of θ_{23} and the width of the band represents the range of sensitivities for the 90% C.L. range in θ_{23} values. Note that the CPV sensitivity decreases with increasing θ_{23}, such that the top of the band corresponds to the lowest θ_{23} value and the bottom of the band corresponds to the highest θ_{23} value.



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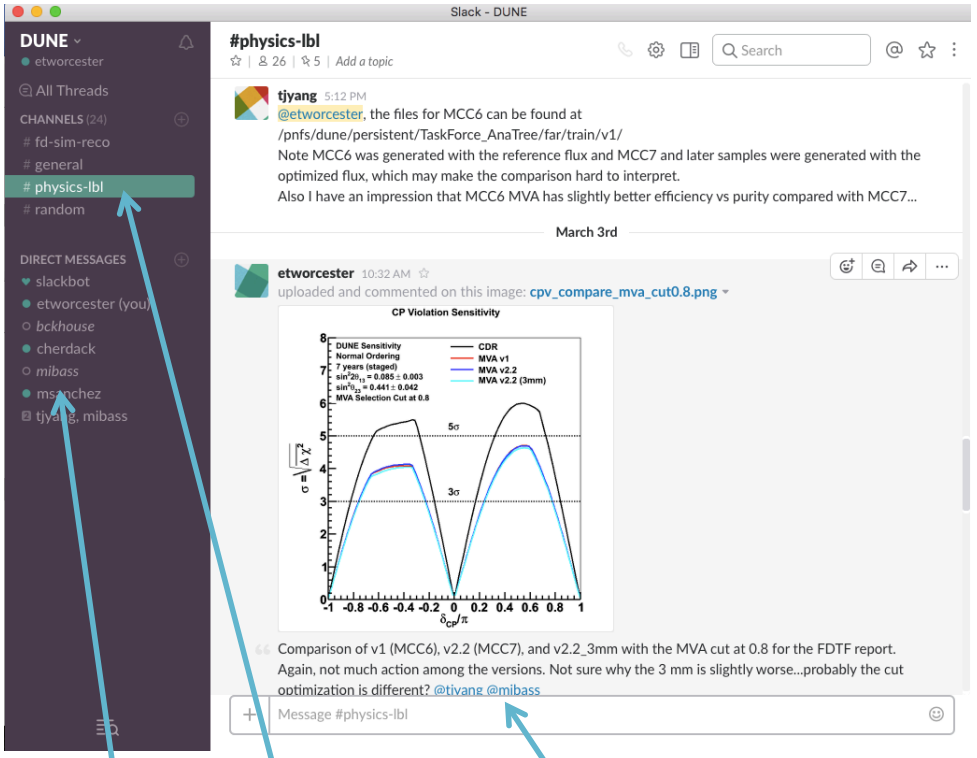
Simulated nucleon decay event $p \to \bar{\nu}K^+$, with a subsequent leptonic decay of the K^+. This event has been fully reconstructed, and the different tracks found by the automated reconstruction are shown by different colors. The two views are projections of the 3D reconstruction onto the x-z and y-z planes.

Slack Channels

- Slack: modern platform for collaborative work (group and private messaging, file sharing, etc) with desktop and mobile apps – very useful!
- DUNE slack: dunescience.slack.com
  - 24 “channels” so far
  - In use for some time by SNν group…many photon detection and SN-related channels
  - Newly active long-baseline channel

Screenshot of my desktop app:



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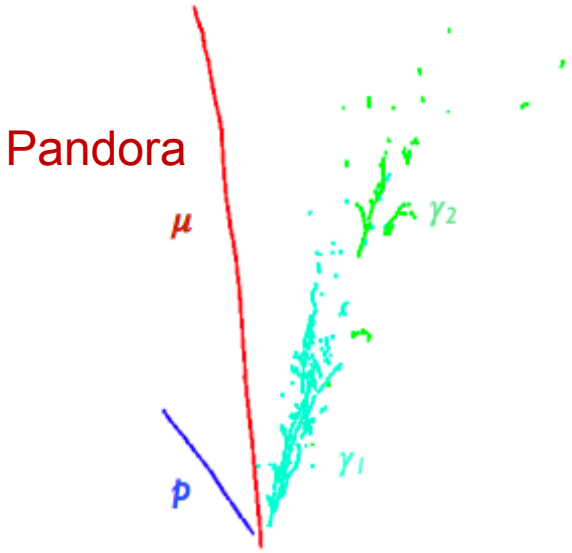
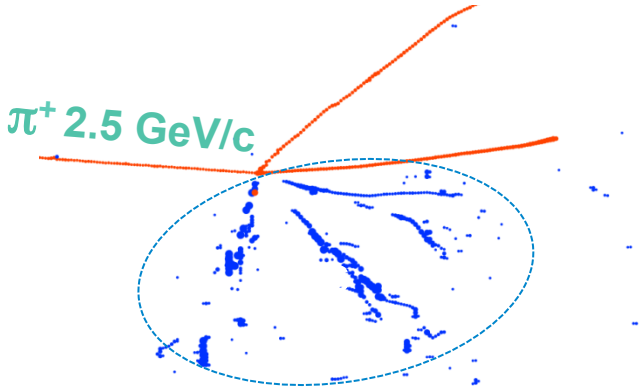
PHYSICS WORKING GROUP HIGHLIGHTS

Far Detector Sim/Reco: Progress

- Completed full simulation and reconstruction chain
  - DocDB 1689
  - Used by all physics working groups
- Initial ν_μ and ν_e event selections (MVA)
- Neutrino energy reconstruction
- 2D deconvolution improves raw signal processing
- Pandora pattern recognition improved
- Optimization of reconstruction for proton decay
- Event feature labeling with convolutional neural network (CNN)
  - Electromagnetic activity selection
  - Vertex classification
- Implemented photon backtracker to aid photon detector reconstruction.





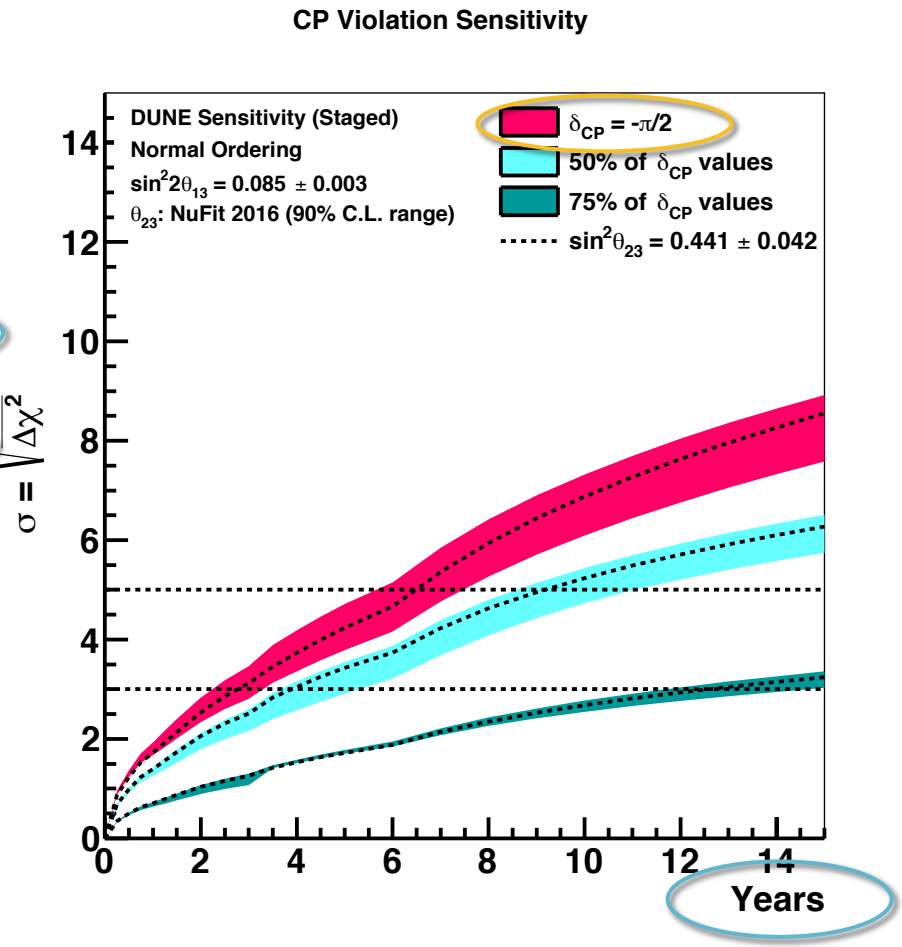
EM activity selected by CNN

Far Detector Sim/Reco: Organization

- See T. Yang's talk this afternoon for more highlights and full status report
- Integration of Sim/Reco into the physics working groups has been very successful
  - Frequent joint meetings between Sim/Reco group and Long-Baseline group
  - Long-Baseline group making good progress on "high-level" reconstruction tasks (energy reconstruction, event selection)
  - Nucleon decay group validating/improving relevant simulations
  - LowE/SNν group improving simulation of supernova neutrinos and radiological background

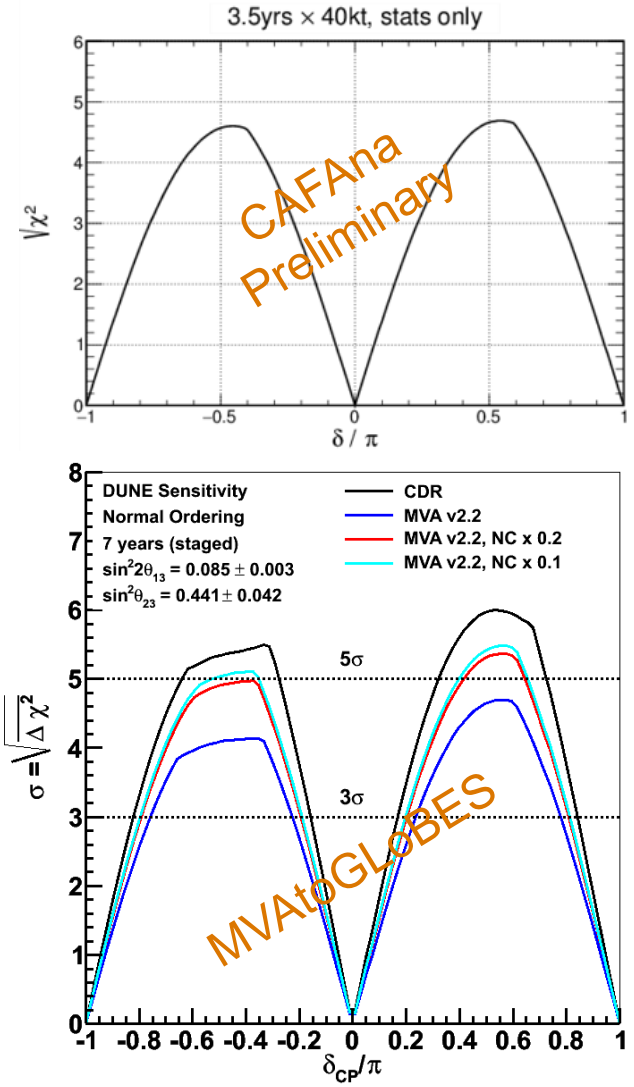
Long-Baseline: Updated Plots

- Updated sensitivity plots
  - CDR-era inputs
  - Optimized beam only
  - NuFit 2016 oscillation parameters
  - Many plots quote exposures in staged years
  - Where possible, show sensitivity for true $\delta_{CP} = -\pi/2$
  - Full suite of plots with captions in approved plots page
- Provided collaboration with details on staging scenario, sensitivity calculations, and a sample talk presenting long-baseline sensitivity: DocDB 2329



Long-Baseline: Hack Days

- February 16-17 at Fermilab
- 10-15 participants, many new collaborators
- Primary efforts:
  - Fitting: LOAF tutorial; porting CAFAna framework from NOvA; converting MVA selection (LArSoft-based) to GLoBES configurations
  - New collaborators learning to work with GLoBES
  - Documentation of LBL tools (Redmine wiki)
- Inaugural use of LBL slack channel
  - Inspired/facilitated effort to sync sensitivity results across multiple fitting procedures including GLoBES, VALOR, LOAF, CAFAna
- Very productive!



Long-Baseline: Reconstruction & Event Selection

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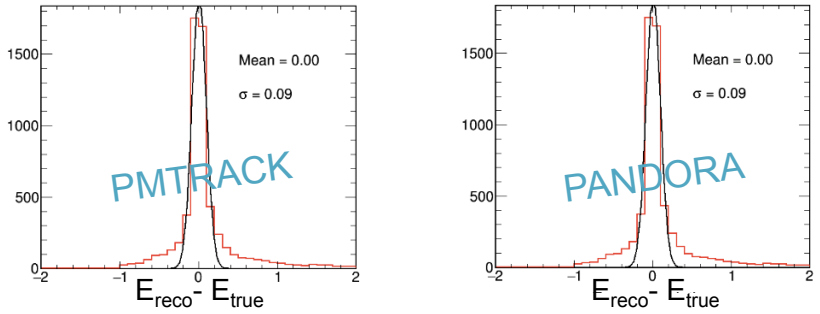
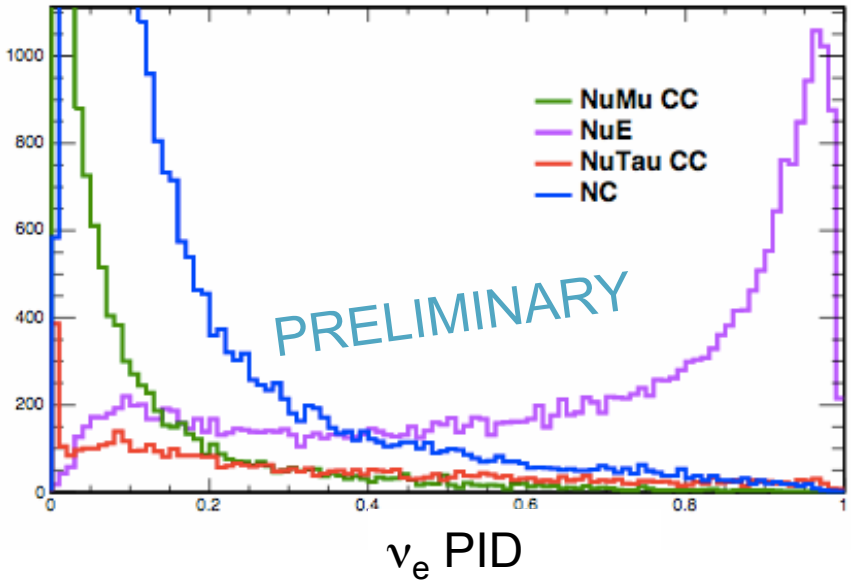
- Neutrino energy reconstruction
  - Module in LArSoft
  - Correction applied for bias in reconstructed hadronic energy
  - EM shower resolution ~9%
  - Neutrino energy resolution 10-20% depending on interaction type
- MVA-based event selection
  - Module in LArSoft
  - Investigating improvements to reconstruction and MVA algorithm
  - Investigating analysis optimization techniques
- CVN event classification
  - Initial module developed in DUNE framework and showing promise

Shower Energy:



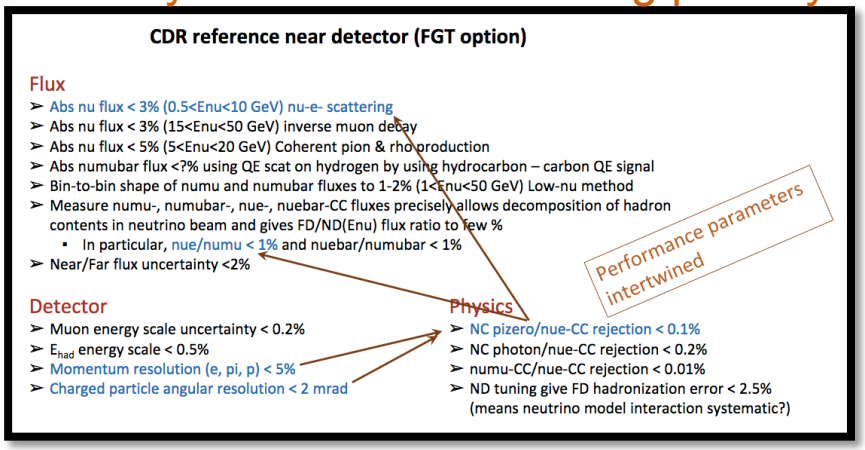
CVN Event Classification:



Near Detector

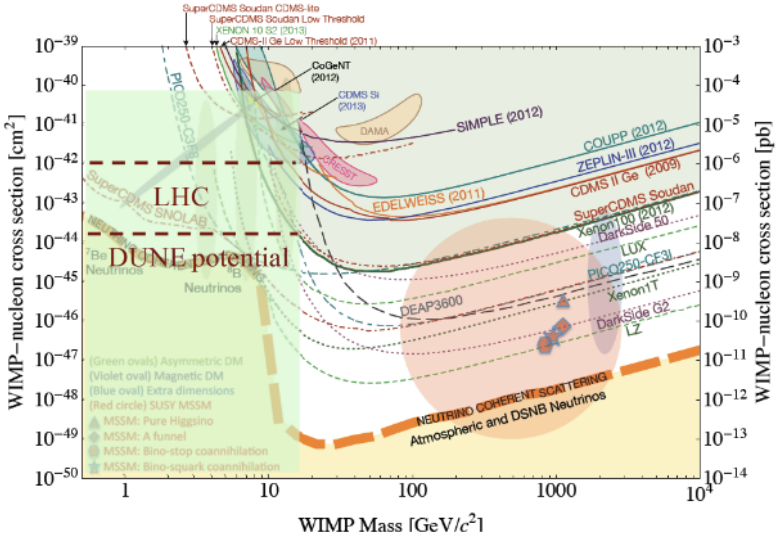
- Primary focus for near/medium term is choice and development of ND design concept
- Detailed review of performance requirements and assumptions presented in CDR
  - What are true requirements?
  - How achievable are assumed performance parameters for different design choices?
  - What metrics should be used to evaluate different design choices?
- Organization of ND workshop: March 27-29
- Close collaboration with LBPWG conveners in contributing to ND Design Study convened by K-B Luk
  - Strategy different from NDTF
- ND sim/reco group is a subgroup of the NDPWG

January collaboration meeting plenary



BSM/Exotic

- Topics include long-baseline and ND-only analyses
- Five subgroups with individual coordinators
  - Low-mass dark matter
    - Additional detector required
  - Light sterile neutrinos and large extra dimensions
  - Non-standard interactions
  - Heavy neutrinos
  - Simulations and software
- Identify detector/beam enhancements/optimizations that increase sensitivity to BSM physics
- Produce sensitivity studies for TDR based on parameterized simulations



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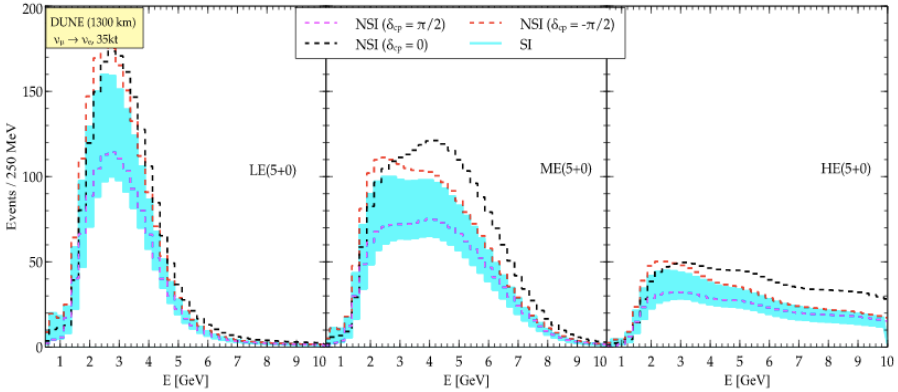
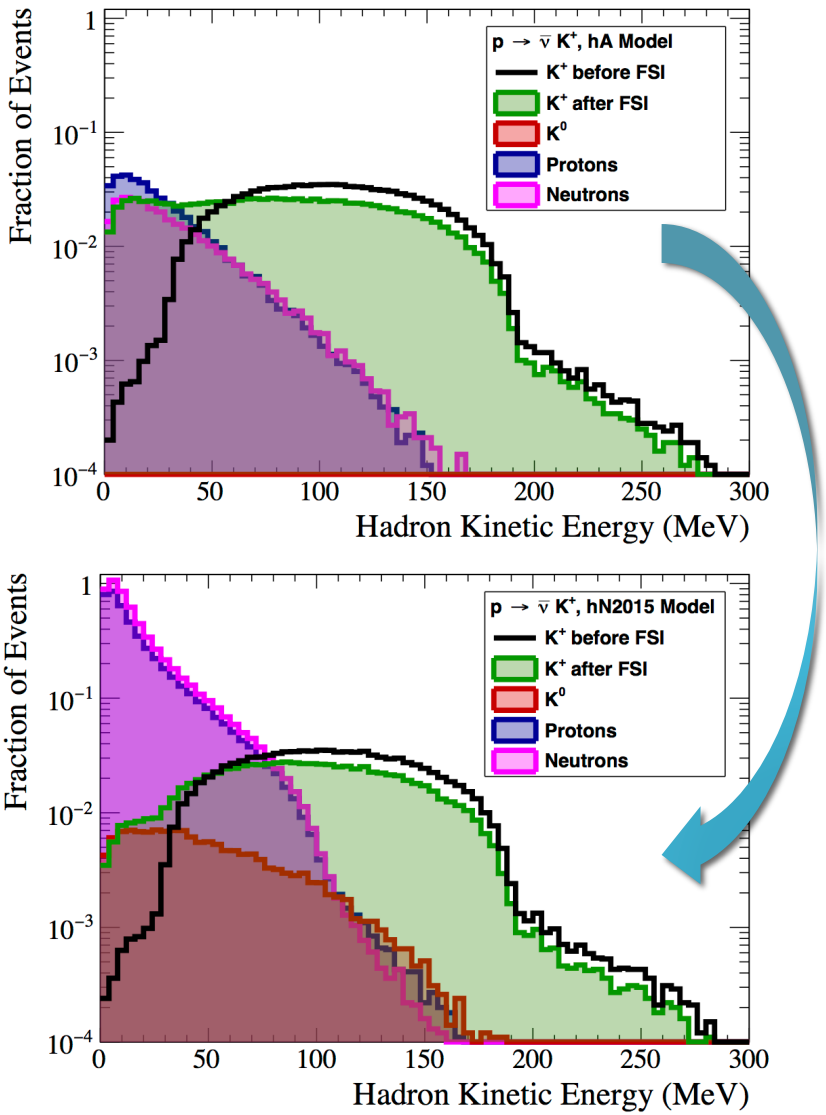


Nucleon Decay: $p \longrightarrow \bar{\nu} K^+$

- Proper simulation of kaon FSI implemented in GENIE
  - Default model (hA) does not simulate K^+ charge exchange or any other K^+ absorption. Elastic scattering model is approximate. Improved model (hN2015) includes these effects, tuned to experimental K^+ data
  - After FSI, softer kaon spectrum and increase in secondary neutrons make reconstruction and event selection more challenging and significantly different from CDR assumptions.
- Kaon selection efficiency with current reconstruction is ~80% for kaons with kinetic energy above 60 MeV but rapidly decreasing for lower energy
  - Algorithm development ongoing



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  - Impact is softer kaon spectrum and increase in secondary neutrons which make reconstruction and event selection more challenging and significantly different from CDR assumptions.
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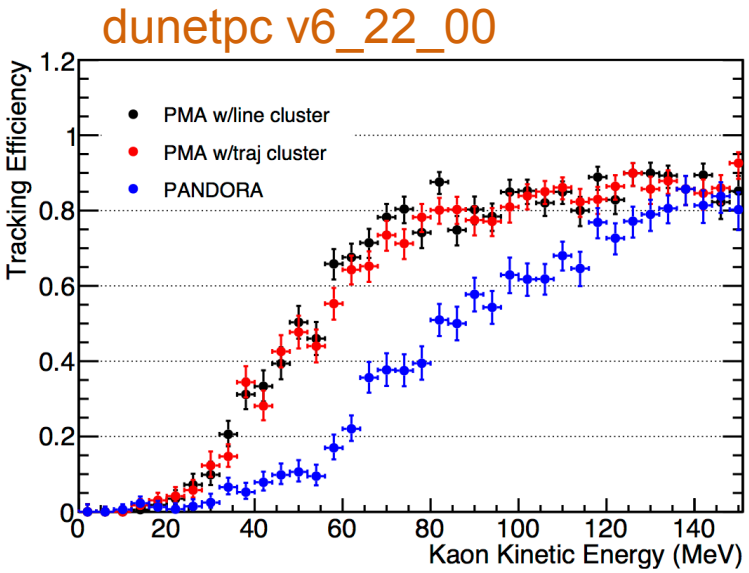


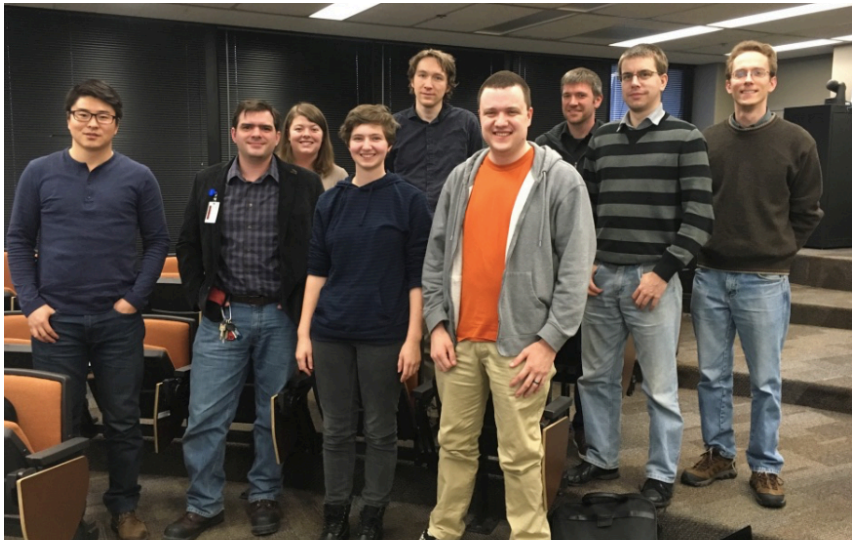
Note: PANDORA not yet tuned for the DUNE FD

Nucleon Decay: Other Progress

- Assessment of backgrounds from atmospheric neutrinos and cosmogenics
  - Current estimate is <1 cosmogenic background event per 200 kt-years for $p \longrightarrow \nu K^+$
  - Atmospheric background evaluation in progress
- Validation of nucleon decay modes in GENIE 2.12
  - Each 2-body and 3-body PDK nucleon mode validated using H_2O and Ar targets
  - nnbar oscillation also included
- nnbar oscillation feasibility studies
  - MC truth studies exist, MC reconstruction-based studies in progress

Low-E/SNν: Hack Days

- Successful model for other physics working groups
  - 1st hack days July 2016
  - 2nd hack days January 2017
  - Will continue twice yearly
- Jan 9-11 at Fermilab
  - 10 participants
  - 9 analysis topics

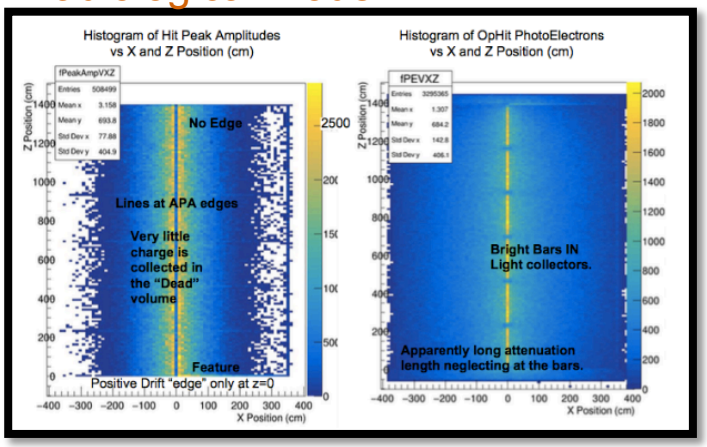


Name	Institution	Task
Kate Scholberg	Duke	New more realistic smearing file for SNOwGLoBES
Erin Conley	Duke	Brems vs deexcitations
AJ Roeth	Duke/U. of Oklahoma	10 MeV NC channel
Kirk Bays	Caltech	DSNB
Steven Gardiner	UC Davis	MARLEY time sampling
Michael Baird	Sussex	DAQ sim and triggering
Jingbo Wang	UC Davis	Angular distributions
Jason Stock	SDSMT	
Chris Backhouse	Caltech	Photon matching/energy resolution/SN reco
Ivan Lepetic	IIT	LArIAT/ArgoNEUT gammas

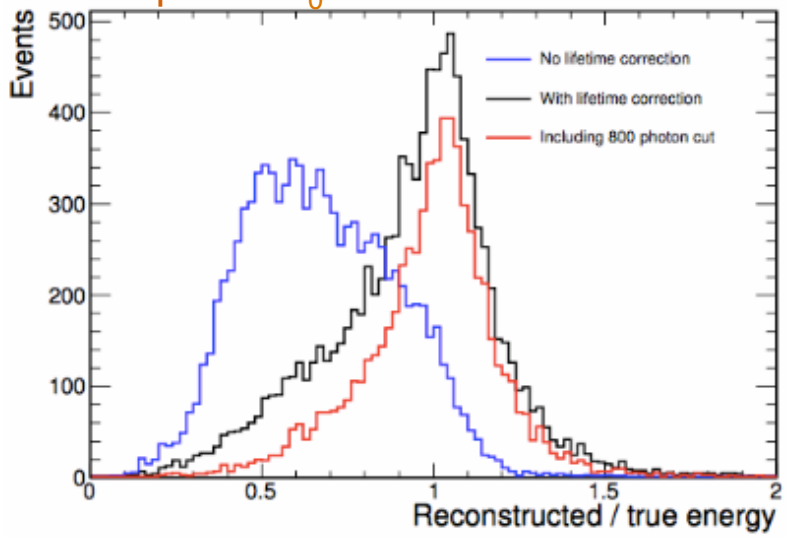
Low-E/SNν: Recent Progress

- Reconstruction tools working for events below 20 MeV
  - As of May 2016 collaboration meeting
  - Improvements ongoing
- Realistic SN neutrino event generation
  - De-excitation γ and nucleons (MARLEY) integrated into LArSoft
  - Time profile simulation (work in progress)
- Tagging algorithms
  - NC-induced γ, de-excitation γ (work in progress)
- Radiological backgrounds
  - ^{39}Ar rate studies
  - Full radiological simulation available
- Photon detectors
  - Attenuation correction, reconstruction contribution (work in progress)

Radiological Model



Impact of t_0 from PDS



Assessment Exercise

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Patterson, October LBNC Meeting

An explicit exercise now underway. ***Two pieces:***

1. Which assumptions (from CDR or latest state-of-the-art) absolutely **must be replaced** with something "better"? Which ones **could be defended** as they stand, in a pinch?
2. For each thrust of work (most already underway): **What is the risk** that it simply **won't deliver/demonstrate** the required performance in 12 to 16 months?

In essence, this acts as a **requirements and risks assessment** for the physics studies themselves, which are tied to a **hard project deadline** with our CD-2/3 review

- Working group conveners completed this exercise on schedule
  - Preliminary discussion of assessments at a series of conveners meetings in December and January
  - Final results presented to collaboration at January collaboration meeting
  - Primary benefit is to working group conveners: clarify task ahead

Assessment Exercise Examples

- NDK group identified a list of channels for which full analysis should be demonstrated:

  - Priorities toward full analysis, in addition to $p \rightarrow \bar{\nu} K^+$:

Analysis	Motivation
$p \rightarrow l^+ K^0$ (l = e, μ)	Different exp strategy (+ DUNE should do well)
$p \rightarrow e^+ \pi^0$	Different theory motivation (non-SUSY GUTs), different exp strategy
n-nbar	Different theory motivation (new physics at 10^3-10^5 GeV), different exp strategy

- SNν group identified a prioritized task list:

Approximate priority order

1. Low energy reconstruction of electrons and photons
2. Full simulation of realistic CC events
3. Trigger and DAQ of SN events
4. Simulation of other detection channels (NC, elastic)
5. Comparison between single and dual phase technologies
6. Impact of backgrounds in the detection threshold and energy resolution
7. Directionality
8. Solar neutrinos & DSNB estimations

Responses to Recommendations

- All recommendations for physics working groups have been closed. Additional recommendations for Sim/Reco will be addressed by T. Yang.
- **2016-25**: Attracting more collaborators remains the main issue and needs continued attention
  - Response: This is understood and has been a high priority. The collaboration will soon be 1000 members strong. Physics working groups are engaging new collaborators via prioritized task lists and "hack days" which are effective at bringing new people up to speed.
- **2016-26**: Prioritization of the task list as a function of time will be needed in the event that the required manpower for the full list is not available
  - Response: This has not been the highest priority. In addition, "projectizing" the scientific effort has not been met with enthusiasm within the collaboration. DUNE is not convinced that pursuing this approach is constructive at this time. However, individual physics working groups have engaged in some prioritization via the assessment exercise and are recruiting new effort to address these priorities.

Responses to Recommendations

- **2016-27**: Close interaction with reconstruction efforts should be maintained
  - Response: Reconstruction activities moved into relevant physics WGs. This tighter coupling of the reconstruction development and the physics goals has been effective.
- **2016-55**: Close interaction with reconstruction efforts should continue to be encouraged and maintained
  - Response: Reconstruction activities moved into relevant physics WGs. This tighter coupling of the reconstruction development and the physics goals has been effective.
- **2016-56**: The low-energy reconstruction efforts should continue to be a priority given their importance for informing the detector design
  - Response: The collaboration agrees and has taken action. Alex Himmel has recently been appointed as co-convener for the Sim/Reco physics working group and a PDS subgroup of the FDTF was formed. Low-energy reconstruction effort will follow the new model for all reconstruction effort; i.e., it will proceed as appropriate in either the Sim/Reco physics working group or in the topical physics working groups such as LowE/SNν.

Summary

- Physics working group organization working well
  - Integration of sim/reco into physics has been very successful
  - Physics working group conveners active and engaged
  - New subgroups and conveners being added as needed
- Significant technical progress from all physics groups
  - Full sim/reco/long-baseline analysis chain
  - Continual improvements to sim/reco in all physics working groups
  - Expanded workforce in many physics working groups, but progress is still effort limited for most groups
- Assessment exercise to prepare working groups for TDR successfully completed
- Near-term priorities:
  - Improvements/upgrades to sensitivity analyses for physics TDR
    - Both sim/reco improvements & analysis improvements
  - Detector performance studies for detector TDR
  - Near Detector Design Study