Opportunities for Involvement in the DUNE Scientific Program

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Neutrino – Latin America Workshop

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Introduction

- Previous talks give a flavor for the range and nature of work within the various DUNE Physics Working Groups
  - Many examples of specific opportunities
- As current DUNE Physics WG Coordinator, my job here is to:
  - Convey the Physics WG **charge, organization & interconnections**
  - Describe **how** groups from South & Central America can become involved
  - Reinforce **key point**: DUNE needs strong participation from these groups:
    - Groups historically participating in FNAL physics (& neutrino) program
    - Newer groups willing to dive in

DUNE Physics Working Groups

- **Charge**

  1) **Extend our understanding of scientific capabilities of DUNE with the detector and beam line configurations being developed.**

     "Extend" → at progressively more realistic levels, driving toward full sim+reco.

     → close attention to tools, analysis strategies, systematics, backgrounds

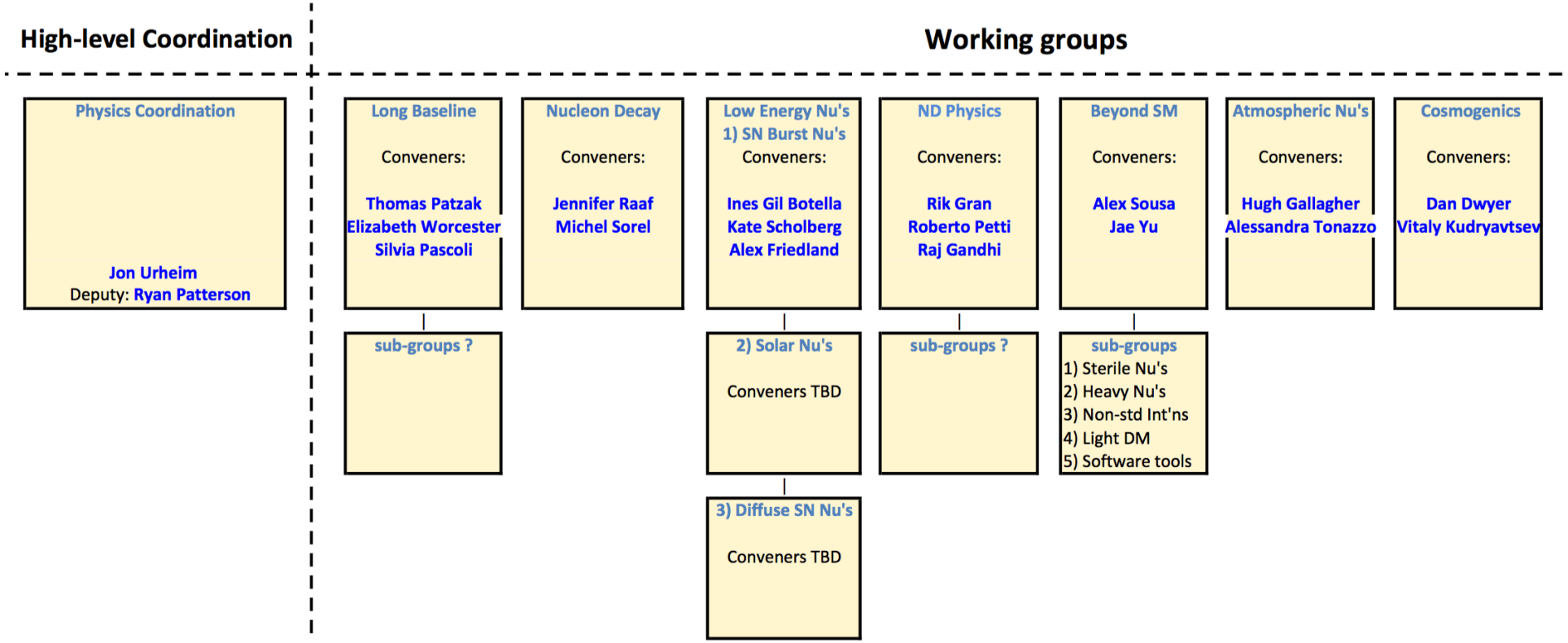
     → attention to the evolving experimental landscape

  2) **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**

- **Notes:**
  - Executing charge is essential for articulating our physics case!!
  - Note that emphasis is on physics!
  - Not present in charge: beam/detector optimization → **Task Forces!**

Overview of DUNE Physics Working Groups

- **Seven "high-level" WG's**
  - Most conveners in place since August; nominally 1-yr terms
    - Some WG's have a convener from the theory/phenomenology community.
  - All WG's have been meeting regularly (bi-weekly) since September.



Task Forces: short-term structures that cut across physics + detector + beam line + software WG's

- LBNF/DUNE is poised at a critical point
  - Racing toward development of the Technical Design

    aiming toward CD-2 + CD-3b/3c in CY 2019.

  - A Technical Design requires that main configuration choices be made
    - Beam Line configuration → sets the range of beam ν spectra/intensity
    - Detector Design → sets performance characteristics

  - Not all the tools are in hand / sufficiently integrated to carry out the necessary optimization studies at the desired level of realism.

  - Collaboration has established lightweight task forces lead optimizations
    - Beam Line TF
    - Near Detector TF
    - Far Detector TF

General Physics WG Issues in parallel with TF efforts

- WGs must address: what are the physics-driven requirements?
  - i.e., precision, sensitivity may be limited by detector performance, so…

    …what physics gets lost with degraded (or captured w/ enhanced) performance?

    …how critical is a given loss or gain of sensitivity?

  - Leads to discussion of "requirements" and "desirements"…

    …& distinction between "exploratory" vs "programmatic" measurements
    - looking for interesting features in SN ν spectrum is example of the former,
    - measuring mass hierarchy is an example of the latter.

  - This aspect of the DUNE science program requires coordination w/ Detector & Beam WG's, i.e., FD Detector Performance WG
    - FD Detector Perf. WG asks us "How important to meet some specification?"
    - We ask them, "What is cost/technical impact of extending some capability?"

Other General Physics WG Issues

- Physics WGs must also address:
  - How to effectively engage theory community? (more on this later)
    - Raises questions about process for joint expt'l/theory publications
    - And how much / how to make internal DUNE tools / software configurations available to those outside the collaboration.
  - How to capitalize on & provide guidance for the ProtoDUNE program?
  - How much standardization on high level tools, analysis frameworks, etc
    - Want to take a long view, without imposing on short-term goals
    - Really the discussion on this is just starting
  - How to identify new manpower…

High-level Summary of Opportunities within Physics WG's

- **All** Physics WG's need additional personnel
  - See appended slides for condensed summaries from WG conveners
    - These list some of the high-priority tasks & show the status
    - Also show one or two highlights
  - Opportunities focused on main Physics WG charge items (slide 3)
  - Opportunities focused on needs of Task Forces / Experiment Design issues
  - Plenty of room for novel ideas !!

Opportunities for Members of Theory/Phenomenology Community

- **Theorists have a special role to play – especially NOW !!**
  - **Experiment Design is driven by Physics first and foremost!**
  - **The DUNE Collaboration desires to make it possible for contributions to be made at different levels of integration**
    - We are aware of issues involving publication and authorship
    - The collaboration counts a number of theorists among its numbers; some are already in leadership positions (e.g., WG conveners) → theorists have a voice
  - **DUNE is trying to facilitate participation at all levels:**
    - Theory Members of DUNE are authors on DUNE publications
    - Theorists may publish predominantly theoretical work
      - With subset of DUNE as co-authors if internal DUNE activities provided key input
      - Independently, if only publicly available DUNE information is utilized

Summary

- Many opportunities to engage with the scientific program of DUNE
  - Physics Working Groups are a natural entry point:

    Physics WG's naturally lead to other activities (Detectors, Beam, Software, Computing, protoDUNE's)

- **The challenges are immense**
  - The scope is broad
  - The schedule is insane
  - The number of people currently working in any single area is very small

Additional Slides

Long-Baseline Physics Working Group

- Conveners:
  - Silvia Pascoli (Durham)
  - Thomas Patzak (Paris Diderot)
  - Elizabeth Worcester (BNL)



- Charge:
  - Extend understanding of DUNE physics reach
  - Build & defend scientific case for DUNE
  - Develop analysis strategies for oscillation analyses
  - Contribute to/facilitate work of task forces
    - Produce far detector analyses and sensitivity calculations for all three TFs

- Bi-weekly phone meetings
  - Typically 15-20 participants; ~15 people currently taking on LBPWG tasks
  - Topics include organization of effort, discussion/approval of publications and public presentations, phenomenology (eg: effect of long-range force on long-baseline oscillations), analysis tools (eg: automated sensitivity calculations, Fast MC, analysis frameworks, fitters), simulation and reconstruction, analysis results (eg: event selection), systematic uncertainty (eg: studies of detector effects, updates on neutrino interaction models)

Long-baseline Physics WG – High Priority Tasks

- **Theme: Many high priority tasks factorize / others not listed here**

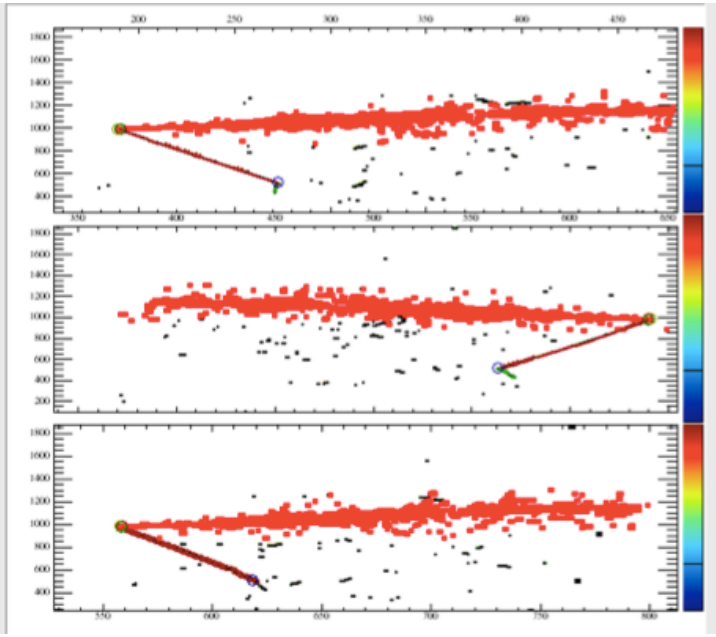
1) Calculate official DUNE sensitivities
2) Fast MC development
3) Systematics studies
4) Interactions expert
5) LArSoft studies to evaluate detector performance
6) DUNE Fitter
7) DUNE analysis algorithms for LArSoft MC

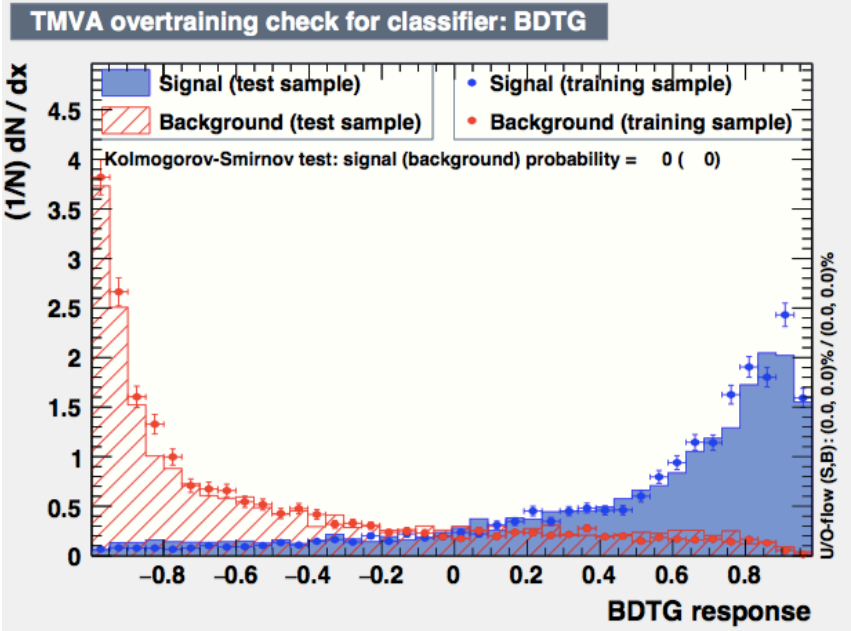
Long-Baseline Physics WG – Status of Task List

4	LBPWG	Calculate Official DUNE sensitivities	M	Q1 2016	ongoing	0.5	Jeremy Hewes
5	LBPWG	Fast MC code development	H	Q1 2016	6	1	Dan Cherdack/Sam Kohn
6	LBPWG	LArSoft detector performance studies for Fast MC input	H	Q1 2016	6	1	David Adams/X
7	LBPWG/SimReco	LArSoft detector performance studies as f(E)	M	Q3 2016	36	1.5	David Adams/Michel Sorel/X
8	LBPWG	DUNE Fitter	H	Q1 2016	6	1	Dan Cherdack/X
9	LBPWG	AnaTree Initial Analysis	H	Q1 2016	6	1	h Worcester/Dan Cherdack/Tingj
10	LBPWG/SimReco	AnaTree Development	H	Q1 2016	12	1	Tingjun Yang/X
11	LBPWG	Evaluate sensitivity for ND/FD TF studies	H	Q2 2016	6	1	lizabeth Worcester/Dan Cherdack
12	LBPWG	Systematics studies	M	Q1 2016	36	1	Elizabeth Worcester/X
13	LBPWG	Interactions expert	M	Q1 2016	ongoing	0.5	Steve Manly
14	LBPWG	Define physics sensitivity requirements	M	Q1 2016	6	0.5	Silvia Pascoli/Ye-Ling Zhou
15	LBPWG	NC physics analysis	L	Q3 2016	12	1	X
16	LBPWG	nu_tau appearance physics analysis	L	Q3 2016	24	0.5	X
17	LBPWG	beyond 3-flavor physics analysis	L	Q3 2016	36	1	Jorge Diaz/Fernando Torres/X
18	LBPWG	Impact of SBN sterile	L	Q1 2017	12	1	X
19	LBPWG	Model independent MH/CPV analysis	L	Q1 2017	12	1	X

Highlight: First ν_e Event Selection

- T. Yang (FNAL)
- ν_e event selection performed on simulated neutrino interact'ns w/ realistic flux
  - LArSoft simulation of DUNE FD (4 APA workspace geometry)
  - Fully automated reconstruction algorithms in LArSoft
  - Boosted Decision Tree event selection using 24 input variables
- First pass achieves significant (>80%) reduction for both NC and CC background for 80% signal selection efficiency
  - Reconstruction in development: expect improvement in background rejection as these algorithms are refined





Supernova Burst / Low-Energy Neutrino WG – Overview

- **Purpose:**
  - Evaluate and demonstrate the experimental sensitivity of DUNE to supernova physics, and other low-energy signatures such as those due to solar neutrinos
- **WG Conveners:**
  - Inés Gil Botella (CIEMAT), Kate Scholberg (Duke), Alex Friedland (SLAC)
- **DUNE Collaborators:**
  - Broad collection not just of people, but also groups with specific interests, i.e.,…
    - Modeling of ν-Ar interactions to exclusive final states (w/ de-ex gammas)
    - How to exploit capabilities of FD photon detection system
    - Implications of SNB for DAQ/Computing

SNB / Low-Energy Neutrino WG – High Priority Tasks

- **Theme: Large number of diverse tasks;** note solar/DSNB are “med” priority

- **High priority:**
  1) Simple SN event generator w/ de-ex γ’s (almost done)
  2) Inputs relevant for photon system requirements (coord w/ photon WG)
  3) Ar-39 background study in TPC / for photons
  4) Preliminary reconstruction / tagging algorithms

- **Medium-High priority:**
  1) Impact of additional channels, esp. NC
  2) Study of trigger/DAQ requirements (coord w/ DAQ group)
  3) Impact of cosmogenics/radiologicals (coord w/ cosmo, cleanliness WGs)
  4) More refined de-excitation γ simulation (Marley group)
  5) Physics studies w/ improved sim/reco tools

Supernova Burst / Low Energy Neutrino WG – Status of Task List

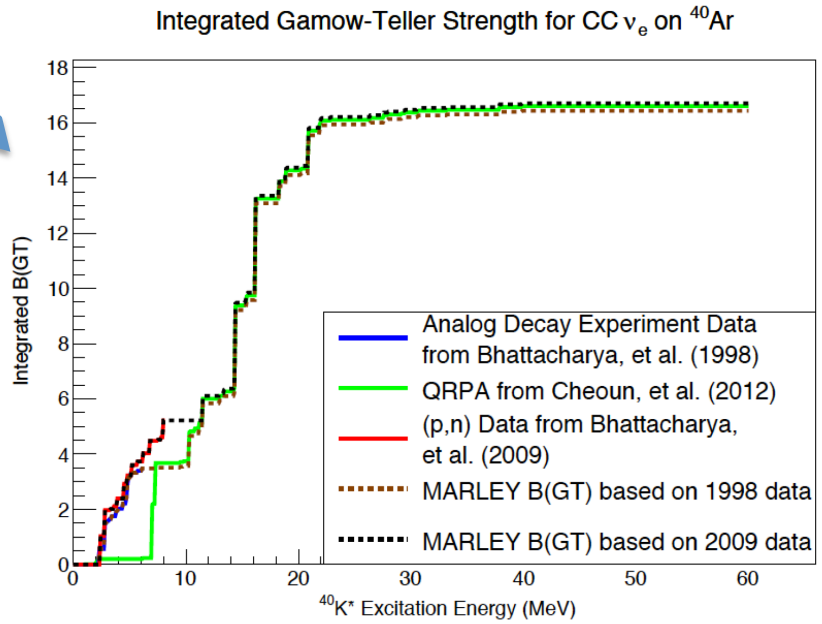
49	LowE/SNB	Simple SN event generator	H	Q1 2016	1	0.1	Scholberg/Sinev
50	LowE/SNB	Photon system requirements	H	Q1 2016	3	0.5	Photon group?
51	LowE/SNB	Ar-39 background study	H	Q1 2016	2	0.3	Sinev
52	LowE/SNB	Preliminary recon/tagging	H	Q1 2016	6	0.5	X
53	LowE/SNB	Identification and evaluation of physics signatures	M/H	Q1 2016	12	0.2	Friedland
54	LowE/SNB	Impact of additional interaction channels	M/H	Q1 2016	2	0.5	X
55	LowE/SNB	Study of trigger/DAQ requirements	M/H	Q1 2016	12	0.2	Weinstein/DAQ group
56	LowE/SNB	Impact of cosmogenic/radiologicals	M/H	Q1 2016	6	0.5	X/Cosmogenics group/Mouton
57	LowE/SNB	Refined de-excitation gamma sim (MARLEY)	M/H	Q1 2016	6	1	Davis group
58	LowE/SNB	Physics studies with basic sim/recon	M/H	Q2 2016	6	0.5	X
59	LowE/SNB	Improved recon/tagging	M	Q2 2016	6	0.5	X
60	LowE/SNB	Directionality studies	M	Q2 2016	3	0.5	Torres/X
61	LowE/SNB	Single/dual-phase comparison	M	Q2 2016	6	1	X
62	LowE/SNB	Solar neutrinos	M/L	Q3 2016	3	0.5	Lunardini
63	LowE/SNB	DSNB studies	M/L	Q3 2016	3	0.5	Lunardini

SNB / Low-Energy Neutrino WG – Highlights

- **November 2015, SN Theory Workshop**
  - Two-day workshop held at SLAC, organized by Bob Svoboda & Alex Friedland
  - Brought together ~10 prominent SN theorists, plus conveners from relevant DUNE WGs
  - Aim is a written report providing a list of key features of SN physics program that bear on DUNE Far Detector capabilities.

- **Release of MARLEY low-E ν-Ar Event Generator (UC Davis Group):**
  - incorporates exclusive nuclear final states for CC interactions & (partial) knowledge of gamma cascades

- **Studies of Radiological BGs**
  - Starting w/ incorporation of ^{39}Ar (Sinev, Junk) in DUNE G4 simulations & Look at photon detector response



Nucleon Decay WG – Overview

- **Purpose:**
  - Evaluate and demonstrate the experimental sensitivity of DUNE to various nucleon decay modes and other baryon number violating processes
- **WG Conveners:** Jen Raaf (FNAL), Michel Sorel (IFC, Valencia)
- **DUNE Collaborators:**
  - F. Blaszczyk, E. Church, M. Goodman, E. Gramellini, J. Hewes, Y. Kamishkov, L. Lin, M. Robinson, G. Santucci
- **Status:**
  - Joint meetings w/ Atmospheric Neutrino WG
  - Limited coverage of High Priority Tasks

Nucleon Decay WG – High Priority Tasks

- **Theme: understanding sensitivities for key channels**
  - Tasks shown are examples of high priority tasks, but not all needed right away
  - See actual Task List generated by WG Conveners (next slide).

1) **Identification of channels where DUNE impact is greatest**

2) **Detection Efficiency Studies** (i.e., for $p \rightarrow K \nu$)
   - Simulate, run/develop LArSoft-based reconstruction.
   - Acceptance studies: Kaon track position, orientation, energy dependence.
   - K-decay kink recognition; momentum resolution for decay muon.
   - Event Reconstruction, Kaon decay vertex, mass, collinearity, etc., distributions.
   - Nuclear physics effects

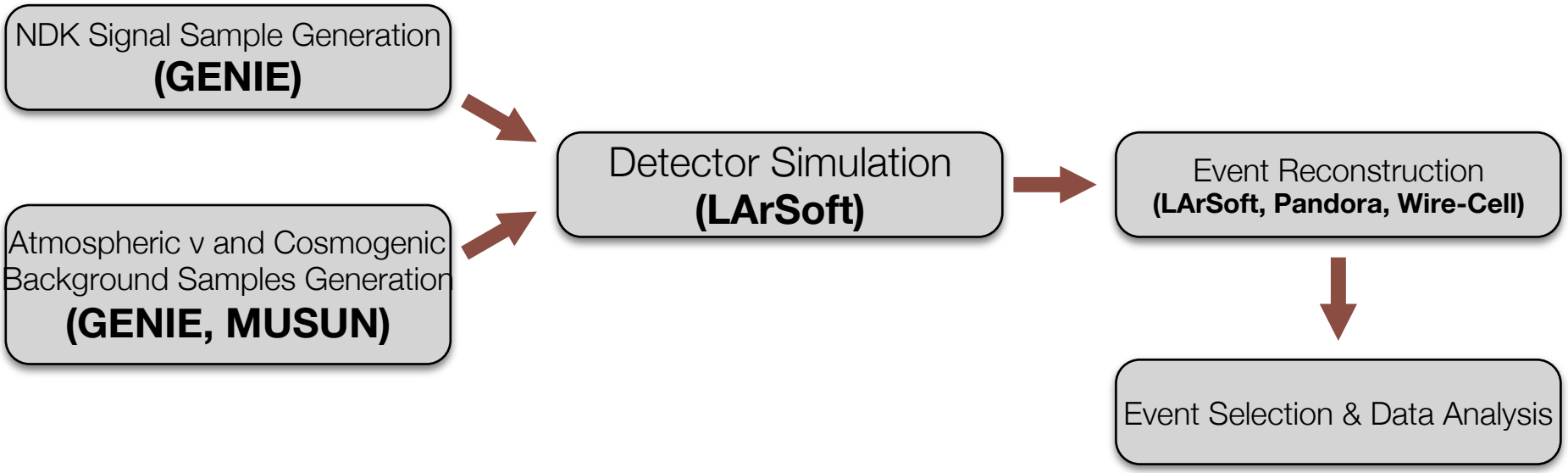
3) **Background Rejection/Evaluation Studies**
   - p/K/pi/mu separation via dE/dx
   - Rejection of accompanying particles in atmospheric nu background events
   - De-excitation gamma studies
   - Coordination w/ Atmospheric Nu & Cosmogenics WG efforts

Nucleon Decay WG – Status of Task List

28	NDK	Define comprehensive list of nucleon decay, di-nucleon decay and n-nbar o	H	already started	3	0.5	Maury Goodman/Lisa Lin
29	Sim/Reco + NDK	Re-evaluate GENIE/LArSoft interface for nucleon decay, di-nucleon decay, r	H	Q1 2016	3	0.5	Jeremy Hewes
30	NDK / Atmos. / FD P	Establish detector requirements quantities related to NDK	H	Q1 2016	3	0.5	X
31	Sim/Reco (for NDK)	Initial MC production of atmospheric neutrino sample for background studi	H	Q1 2016	3	0.5	X
32	Sim/Reco (for NDK)	Initial MC production of signal samples	H	Q1 2016	3	0.5	Gabriel Santucci
33	Sim/Reco (for NDK)	Validate high-level reconstruction algorithms	H	Q1 2016	3	0.5	Gabriel Santucci
34	NDK	Complete list of nucleon decay 2-body modes in GENIE	M	already started	1	0.5	Elena Gramellini
35	NDK	Add n-nbar oscillation (w/annihilation modes) in GENIE	M	already started	3	0.5	Jeremy Hewes
36	Sim/Reco (for NDK)	Initial MC production of cosmics/cosmogenics sample for background studi	M	Q2 2016	3	0.5	X
37	NDK	Preliminary signal selection & background rejection algorithms using LArSo	M	Q3 2016	6	0.5	X
38	NDK	Add nucleon decay 3-body modes in GENIE	L	Q3 2016	6	0.5	X
39	NDK	Add di-nucleon decay modes in GENIE	L	Q3 2016	6	0.5	X
40	NDK	Improve Kaon FSI model in GENIE	L	Q3 2016	6	0.5	X
41	FD + Atmos/NDK	Trigger definition for NDK	L	Q1 2017			
42	NDK	Trigger efficiency studies	L	Q2 2017			
43	Sim/Reco (for NDK)	Large-scale MC production of atmospheric neutrino sample for BG studies	L	Q2 2017			
44	Sim/Reco (for NDK)	Large-scale MC production of cosmics/cosmogenics sample for background	L	Q2 2017			
45	Sim/Reco (for NDK)	Large-scale MC production of signal samples	L	Q2 2017			
46	NDK	Extend sensitivity studies to other nucleon decay modes and other baryon	L	Q3 2017			
47	NDK	Initial evaluation of detector systematic uncertainties and impact on NDK s	L	Q3 2017			

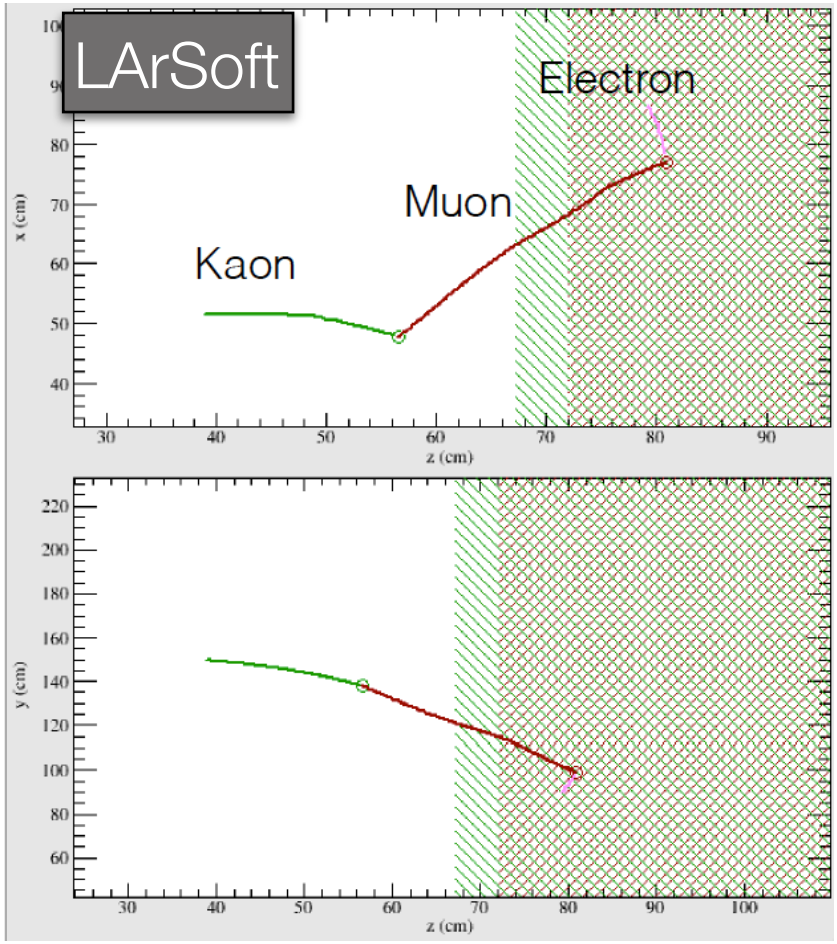
NDK Highlights

- **Milestone for 2016**: perform a first analysis of a promising NDK mode that uses an end-to-end simulation/reconstruction of signal and associated backgrounds



NDK Highlights (cont'd)

- A first NDK signal MC sample ($p \rightarrow \bar{\nu} + K^{+}$) has been produced
- Display shows a well reconstructed event using standard LArSoft reconstruction
- Simulation validation and evaluation of reconstruction performance has just started
- **Credit**: Gabriel Santucci, with help from FD Simulation & Reconstruction WG (Tingjun Yang, Xin Qian, Chao Zhang)



Cosmogenics & CR Physics WG – High Priority Tasks

- **Theme: Develop the WG program in all facets**

1) Evaluate effects of cosmogenic bg's, incl. neutrons, on nucleon decay (CD1 recommendation)
2) Impact of cosmogenic activation on SNB / Low-E nu physics
3) Cosmogenic bg for atmospheric nu's
4) Atmospheric nu bg for proton decay (w/ atmos nu WG)
5) Develop calibration procedures using CR mu's & secondaries for (e.g.) particle ID, dE/dx, etc.. (w/ FD calibration WG)
6) Identification of physics opportunities w/ CR muons, etc.

Cosmogenics

- Co-conveners: Dan Dwyer (LBL) and Vitaly Kudryavtsev (Sheffield).
- Tasks (non-identified manpower is in red):
  - Full implementation and testing of the MUSUN muon generator in LArSoft – Warburton, Robinson, completed – December 2015.
  - Simulation muon-induced background for proton decay – Robinson, Warburton + X (0.85 FTE for 21 months on average) – started in December 2015, expected end – December 2017. Depends strongly on reconstruction:
    - First stage: analysis of truth information for kaon modes without reconstruction – Robinson, Warburton (0.5 FTE for 12 months), 12/15-12/16, high priority (H)
    - Kaon modes with full reconstruction – 0.5 FTE for 12 months, 08/16-07/17 (H).
    - Muon background for PDK (other modes) – 0.5 FTE for 12 m, 10/16-09/16 (M).
  - Validation of reconstruction using muon events – 0.3 FTE for 24 m, 01/16-12/17 (H).
  - Simulation of cosmogenic activation for low-energy neutrino tasks (together with Supernova and Low energy neutrino WG) – Shirley Li, 02/16-01/17 (M).
  - Atmospheric neutrino background for proton decay – together with NDK/PDK and Atmospheric neutrinos WG – 0.5 FTE for 19 months, 06/16-12/17 (H).

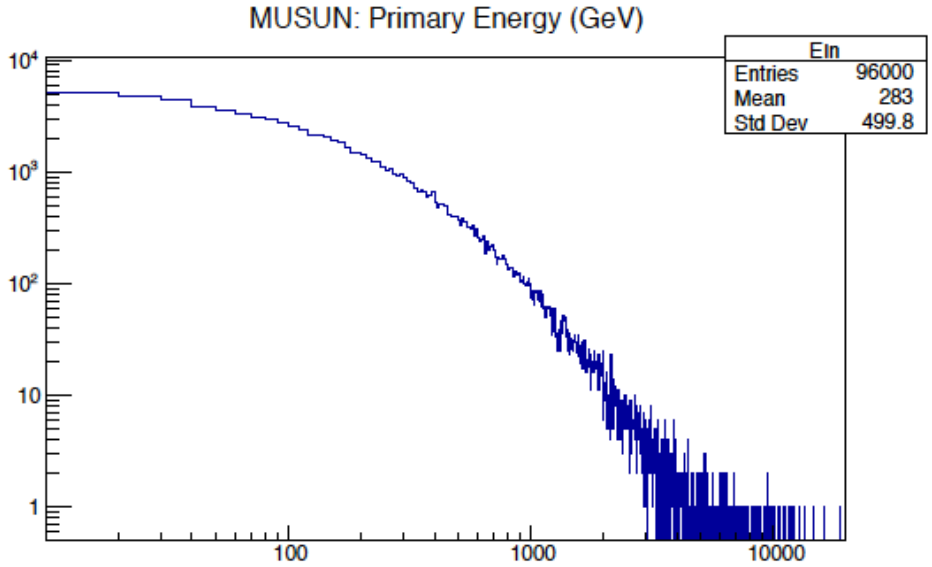
Cosmogenics

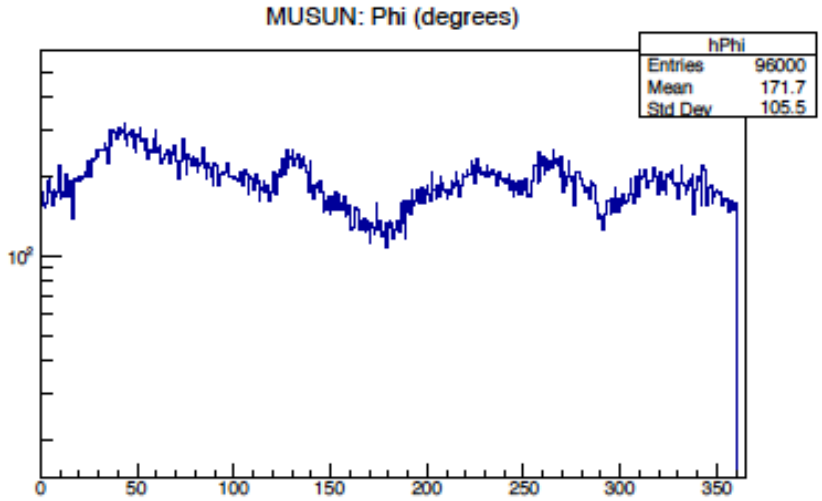
- More tasks:
  - Muon background for atmospheric neutrino measurements (together with Atmospheric neutrino WG) – 0.5 FTE for 12 months, 01/17-12/17 (M).
  - Developing a calibration procedure using cosmic rays (together with Calibration WG) – 0.75 FTE for 24 months, 04/16-03/18 (H).
  - Muon physics: muon-induced cascades, stopping muons etc – 0.5 FTE for 24 months, 01/17-12/18 (L).
- Work so far:
  - Muon generator: interface with LArSoft, tests and validation.
  - Muon background for proton decay (started)
  - Testing reconstruction of muon events – not there yet.
  - Cosmogenic activation: experience with Super-K for DUNE.
- Priorities for unidentified manpower:
  - Validation of reconstruction using muon events – 0.3 FTE for 24 months.
  - Calibration using cosmic-ray events – 0.75 FTE for 24 months.
  - Atmospheric neutrinos (background for PDK) – 0.5 FTE for 19 months.
  - Total: about 1.5 FTE for 24 months.

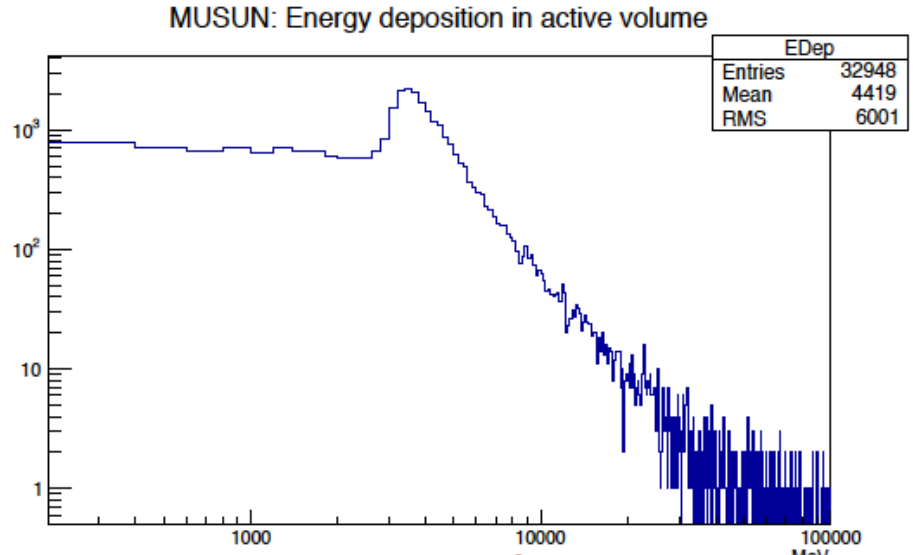
Cosmogenics and CR Muon WG – Status of Task List

65	Cosmogenics	Full implementation and testing of muon generator in LArSoft	H	Q3 2015	4	0.5	Warburton, Robinson
66	Cosmogenics	Simulation of muon-induced background for PDK (kaon modes)	H	Q4 2015	12	0.5	Robinson, Warburton + X
67	Cosmogenics	Muon-induced background for PDK (kaon modes) with reconstruction	H	Q3 2016	12	0.5	Robinson, Warburton + X
68	Cosmogenics	Validation of reconstruction using muon events	H	Q1 2016	24	0.3	X
69	Cosmogenics	Simulation of cosmogenic activation for low-energy neutrino	M	Q1 2016	12	0.5	Shirley Li
70	Cosmogenics	Atmospheric neutrino background for proton decay	H	Q2 2016	24	0.4	X
71	Cosmogenics	Develop a calibration procedure using cosmic rays	H	Q2 2016	24	0.75	X
72	Cosmogenics	Muon-induced background for PDK (other modes)	M	Q4 2016	12	0.5	Robinson +X
73	Cosmogenics	Muon background for atmospheric neutrino measurements	M	Q1 2017	12	0.5	X
74	Cosmogenics	Muon physics: cascades, stopping muons etc	M	Q1 2017	24	0.5	X

MUSUN: muon generator for DUNE







Surface profile at the DUNE site.

Accurate muon transport through rock.

Fully implemented in LarSoft.

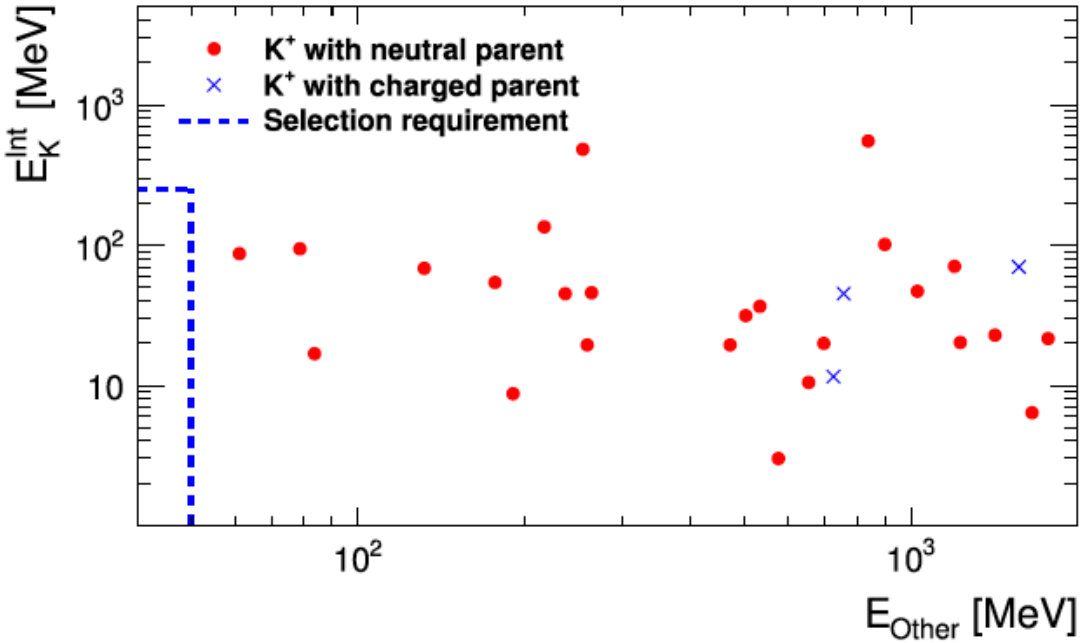
Mean muon energy 283 GeV.

Tested with DUNE geometry.

Peak in the energy deposition at 3.5 GeV.

Mean energy deposition: 4.4 GeV.

Preliminary studies of cosmic-ray background to proton decay search: $p \rightarrow K^+ \bar{\nu}$



Cylindrical geometry as for two-phase LAr.

4 km w. e. and flat surface.

20 kt of LAr within a single TPC (no cells, no gaps).

No reconstruction, only truth.

Smearing included.

Background for positive kaon modes only.

Statistics: 100 years (2 Mt year).

Cuts (Klinger et al. PLB 746 (1915) 44):

no muon and no energy depositin within 10 cm from the TPC walls;

kaon energy deposition (without kaon decay product) < 250 MeV;

total energy deposition (kaon, its secondaries and daughters) < 1 GeV;

energy deposition from other particles (not kaon or its daughters) < 50 MeV.

No event survived the cuts. Background event rate < 1.2 $(\text{Mt year})^{-1}$ at 90% CL.

For DUNE we need accurate geometry, detector response and reconstruction.

Atmospheric Neutrino WG – High Priority Tasks

- **Theme: focus on improving tools**
  - Tasks shown are examples of high priority tasks – see raw slides for medium priority

1) Distribution & documentation of LBNE atmos ν analysis package for near-term studies
2) Extension of analysis tools to incorporate detector specific systematics
   - i.e., differences in up-down acceptance.
3) Update / re-evaluate detector performance from full simulations
4) Improvements to GENIE flux drivers, inclusion of 3d fluxes
5) Interface w/ FD reconstruction WG on metrics for evaluating performance on atmos ν events
6) Evaluate cosmogenic bg mitigation strategies (w/ cosmogenics WG)
   - Includes studies of impact of a veto shield

Atmospheric Neutrino WG – Status of Task List

21	Atmospherics	Distribution/documentation of LBNE atmospheric neutrino analysis packag	H	Q1 2016	1	0.5	X
22	Atmospherics	Testing and improving the GENIE/Atmospherics model in LArSoft	H	Q1 2016	2	0.5	X
23	Atmospherics	Extension of analysis tools to incorporate detector-specific systematics	H	Q1 2016	6	0.5	X
24	Atmospherics	Updating / re-evaluation of detector performance characteristics as full sim	H	Q2 2016	18	0.3	X
25	Atmospherics	Interfacing with reconstruction group on appropriate metrics to evaluate p	H	Q1 2016	12	0.2	X
26	Atmospherics	Evaluate cosmogenic background mitigation strategies	H	Q3 2016	6	0.5	X
27							