NuPRISM Overview

Mike Wilking

NuPRISM Meeting

1-Feb-2015

NuPRISM LOI Submitted to J-PARC PAC

- Submitted 11/4
  - Now available at arXiv:1412.3086
- PAC meeting was 12/3-12/5
- Letters of Intent do not receive a talk at the PAC meeting
  - But PAC members receive a copy to read, and can make comments
- NuPRISM seminars are being given at the institutions of both American J-PARC PAC members
  - Bill Louis, LANL (11/4/2014)
  - Ed Blucher, U. of Chicago (1/12/2015)
- For the next J-PARC PAC meeting, we should submit a full proposal

Letter of Intent to Construct a nuPRISM Detector in the J-PARC Neutrino Beamline

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(Dated: December 13, 2014)

As long-baseline neutrino experiments enter the precision era, the difficulties associated with understanding neutrino interaction cross sections on atomic nuclei are expected to limit experimental sensitivities to neutrino oscillation parameters. In particular, the ability to relate experimental observables to the incident neutrino energy in all previous experiments has relied solely on theoretical models of neutrino-nucleus interactions, which currently suffer from very large theoretical uncertainties.

By observing charged current ν_μ interactions over a continuous range of off-axis angles from 1° to 4°, the nuPRISM water Cherenkov detector can provide a direct measurement of the far detector lepton kinematics for any given set of oscillation parameters, which largely removes neutrino interaction modeling uncertainties from T2K oscillation measurements. This naturally provides a direct constraint on the relationship between lepton kinematics and neutrino energy. In addition, nuPRISM is a sensitive probe of sterile neutrino oscillations with multiple energy spectra, which provides unique constraints on possible background-related explanations of the MiniBooNE anomaly. Finally, high-precision measurements of neutrino cross sections on water are possible, including electron neutrino measurements and the first ever measurements of neutral current interactions as a function of neutrino energy.

The nuPRISM detector also provides significant benefits to the proposed Hyper-Kamiokande project. A demonstration that neutrino interaction uncertainties can be controlled will be important to understanding the physics reach of Hyper-K. In addition, nuPRISM will provide an easily accessible prototype detector for many of the new hardware components currently under consideration for Hyper-K. The following document presents the configuration, physics impact, and preliminary cost estimates for a nuPRISM detector in the J-PARC neutrino beamline.

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Toward a Full NuPRISM Proposal

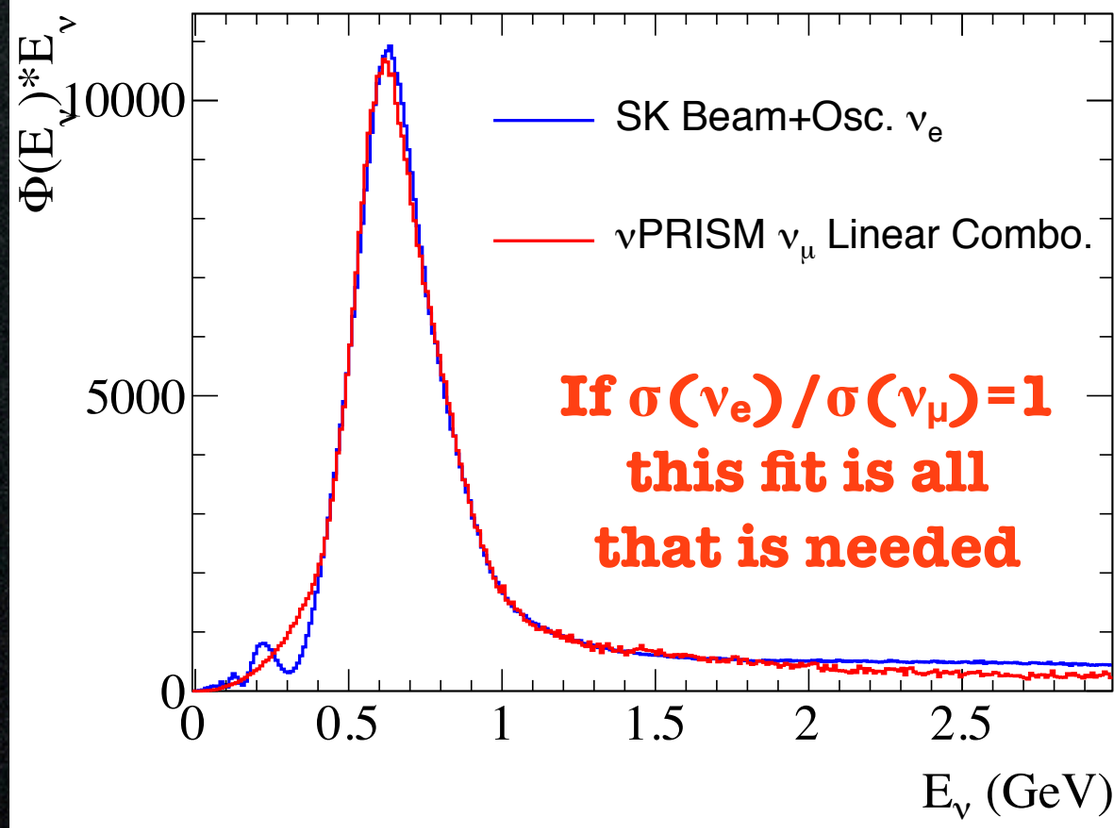
- Our current LOI shows that a T2K+nuPRISM ν_μ disappearance analysis is insensitive to cross section modeling at the 1% level
  - However, we need to include some discussion about all systematic errors, and the feasibility of reaching a total error at the ~3% level
    - See talk from Mark Scott later today
- All other physics analyses still need to be completed:
  - CP violation
    - ν_e appearance
    - ν_e/ν_μ cross section constraint
    - anti-neutrino measurements
  - Sterile neutrinos
    - A rough estimate is needed for how well we might ultimately do
  - Cross section physics (also feeds back into above measurements)
- Other topics that could use more development:
  - Detector calibration
  - Detector engineering
    - Incorporating scintillator panels into the design

These studies may impact detector design!
(Inner detector diameter may need to be increased)

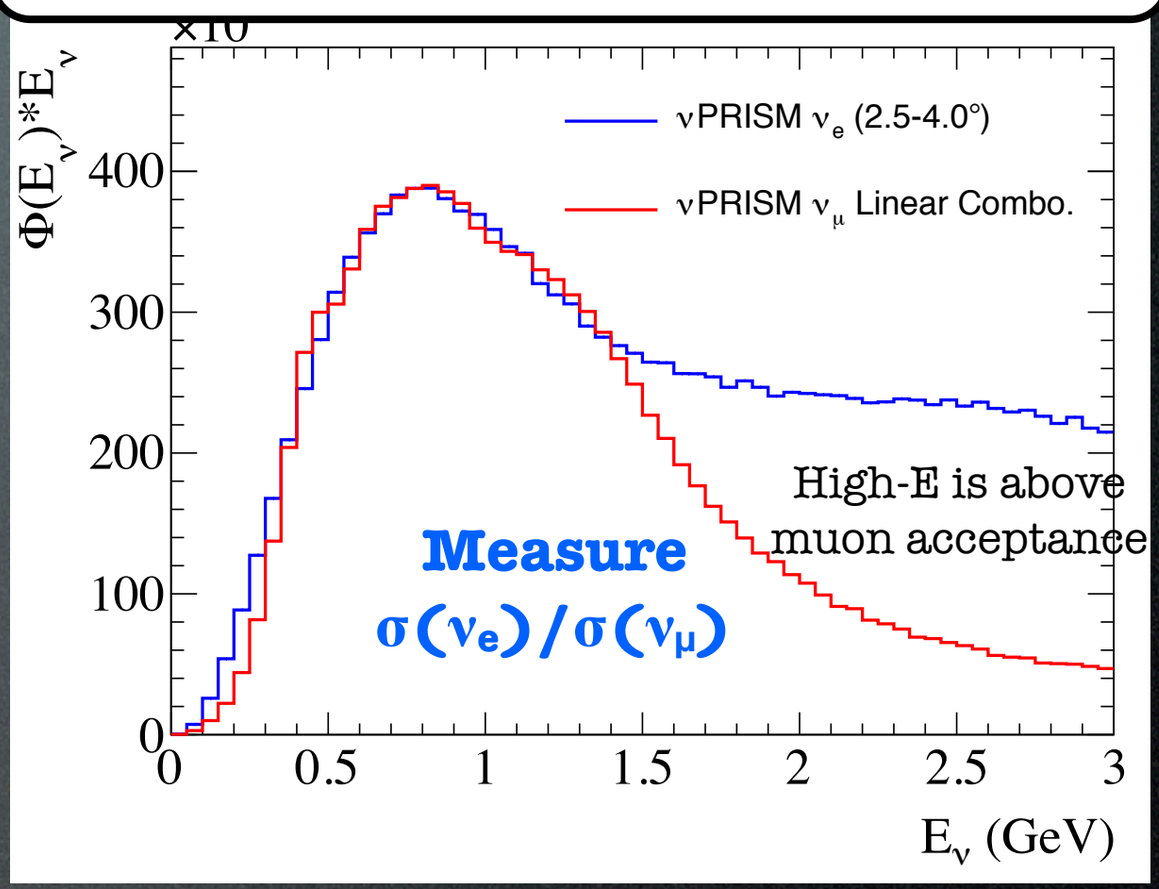
nuPRISM ν_e Appearance

2 step approach:

Step 1: Measure **Super-K** ν_e response with nuPRISM ν_μ



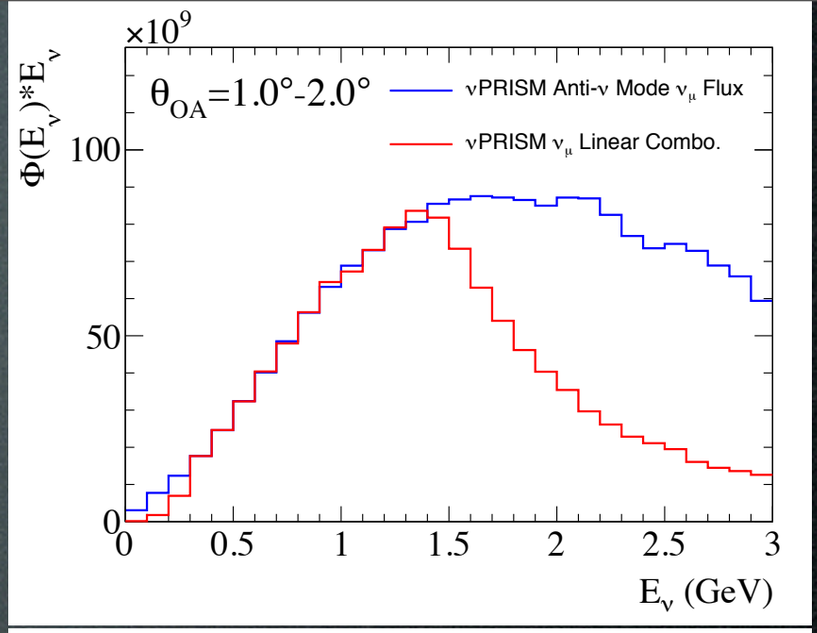
Step 2: Measure **nuPRISM** ν_e response with nuPRISM ν_μ

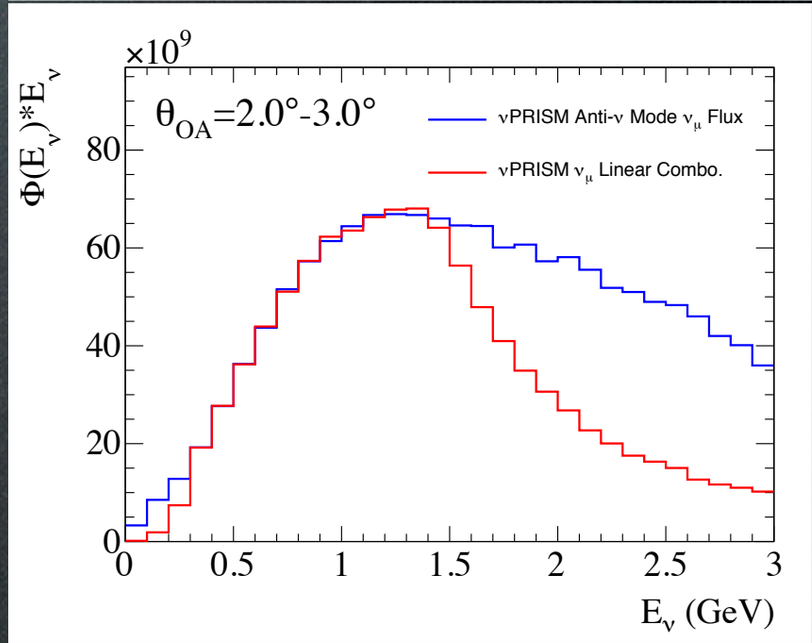


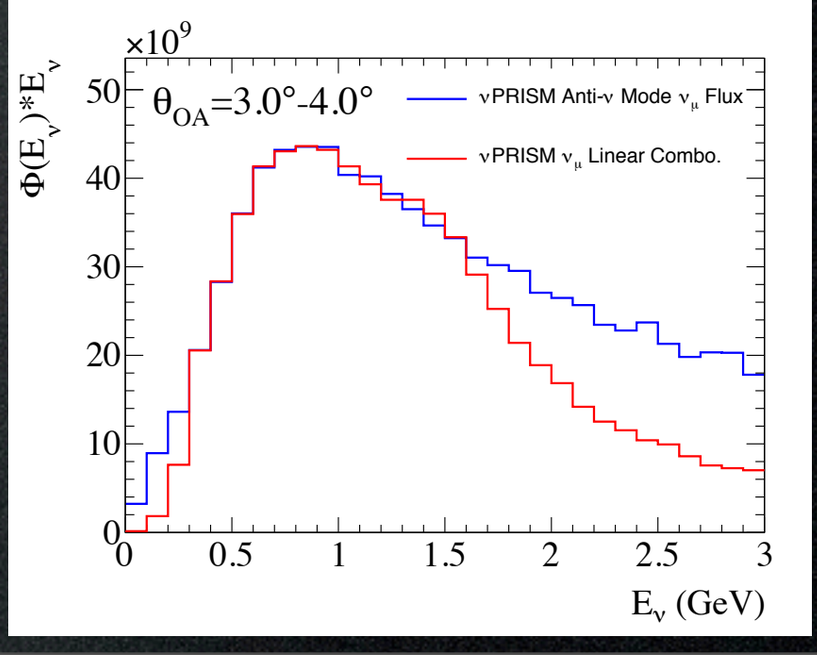
- Step 1 is the ν_e version of the ν_μ disappearance analysis
- Step 2 uses only nuPRISM to measure $\sigma(\nu_e)/\sigma(\nu_\mu)$
  - High energy disagreement is above muon acceptance
  - These plots show flux*E_ν, so difference is 1-ring μ events is smaller
- We need a quantitative evaluation of how well this strategy works!

Anti-neutrinos

- T2K can switch between ν-mode and anti-ν-mode running by switching the beam focusing
- Anti-ν-mode analysis is the same as for neutrinos
  - Except with a much larger neutrino contamination
- With what precision can we use ν-mode ν_μ data to subtract the ν_μ background in the anti-ν-mode anti-ν_μ data?
- Since nuPRISM has no sign selection, this question is very important!

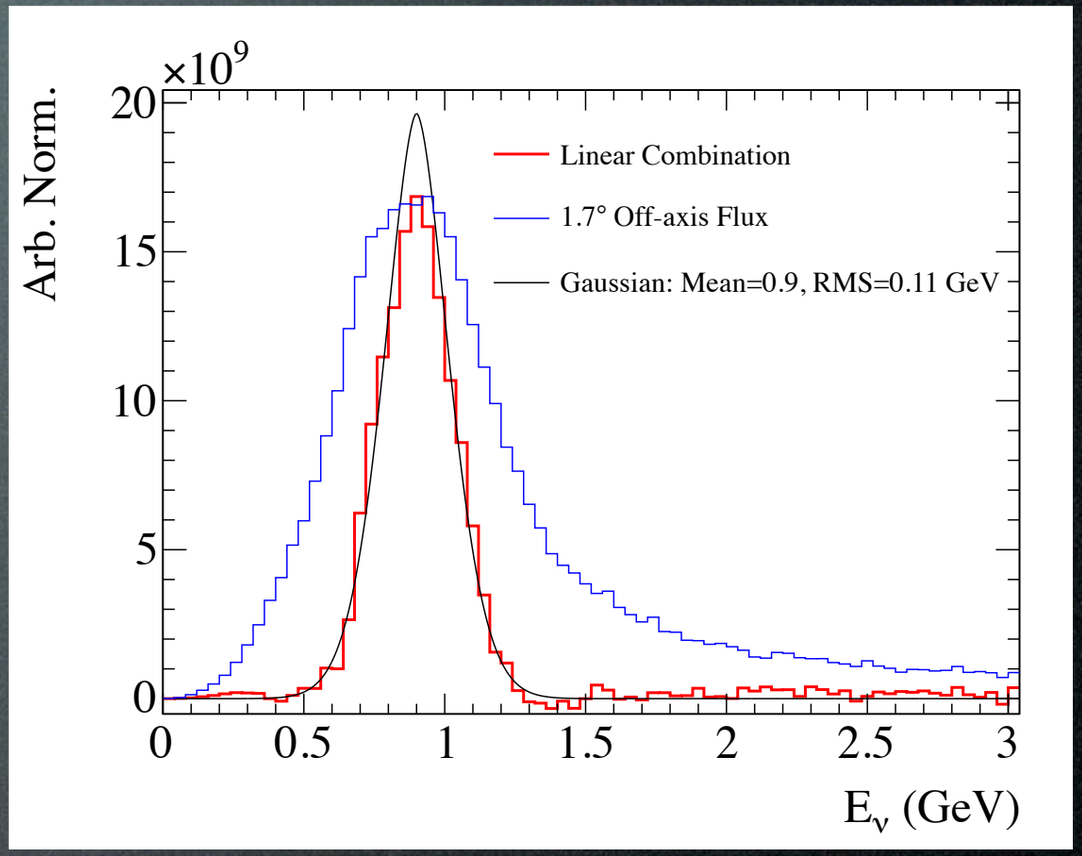


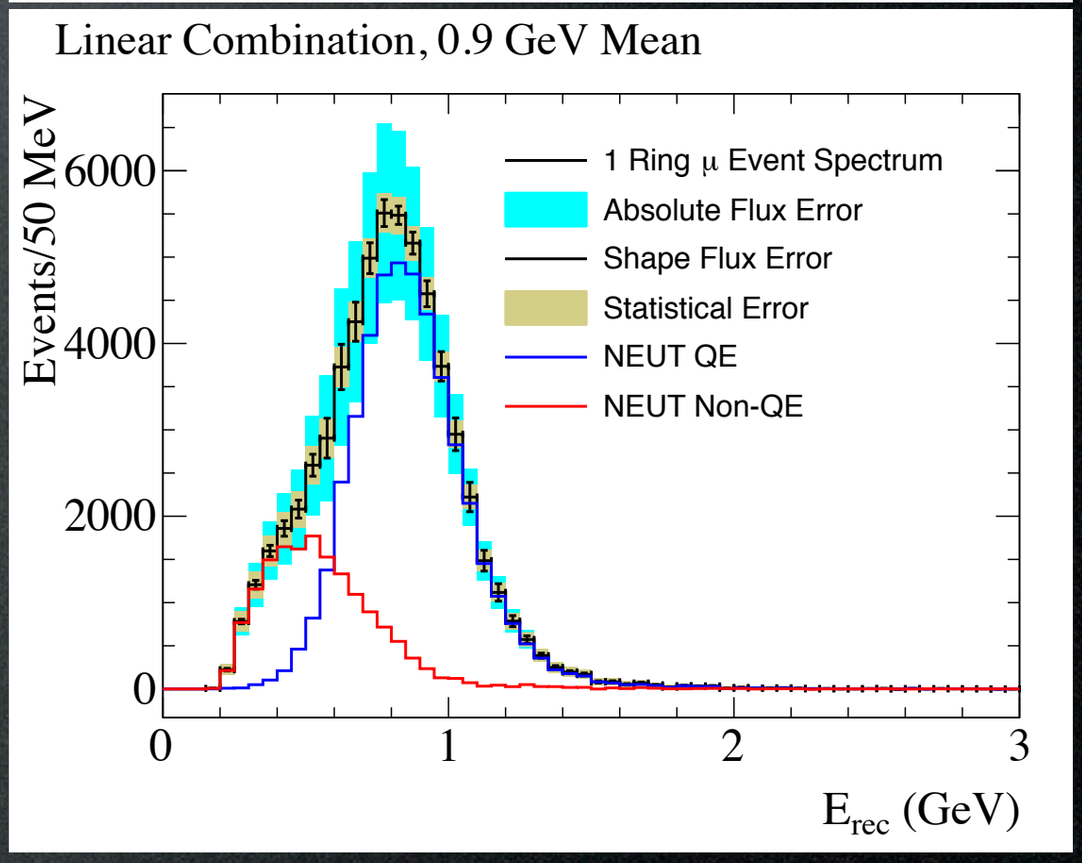




Cross Section Measurements

- Monoenergetic beams are now available for study
  - First ever measurements of NC events with E_ν
  - First ever "correct" measurements of CC events with E_ν
    - Do not rely on final state for E_ν
- How precisely can we measure various final states?
  - e.g. using fiTQun μ/π separation
- Of critical importance are the background processes for the ν_e selections
- Lots of room for people to participate!
  - Many processes to study!



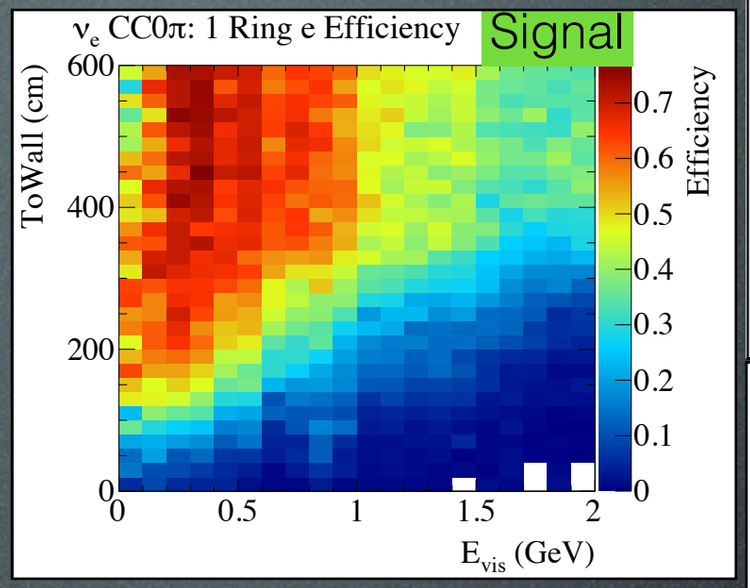


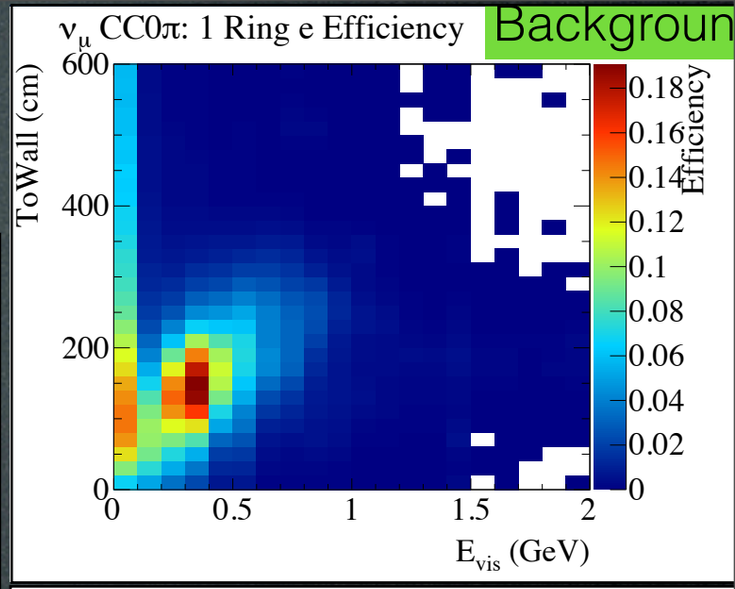
Sterile Analysis

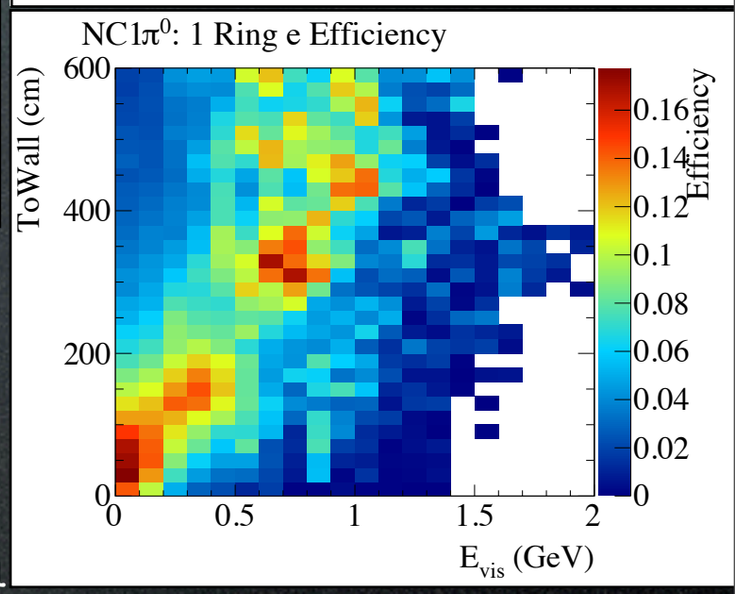
- More from Stefania today
- So far, we have taken a conservative approach of reporting how well we know we can do
- It would also be very useful to produce a rough estimate of how well we might do with a full nuPRISM analysis
  - ND280 constraint
  - Estimated constraints on background processes
  - Full ν_e + ν_μ fit
  - Using efficiencies & resolutions from new simulation (next slide)
- If we can show that it may be possible for NuPRISM to produce a very sensitive sterile neutrino measurement, it greatly enhances the case for the experiment
- We need to know soon whether this analysis may eventually be statistics limited, as it may affect detector design (ID diameter)

ν_e Event Selection

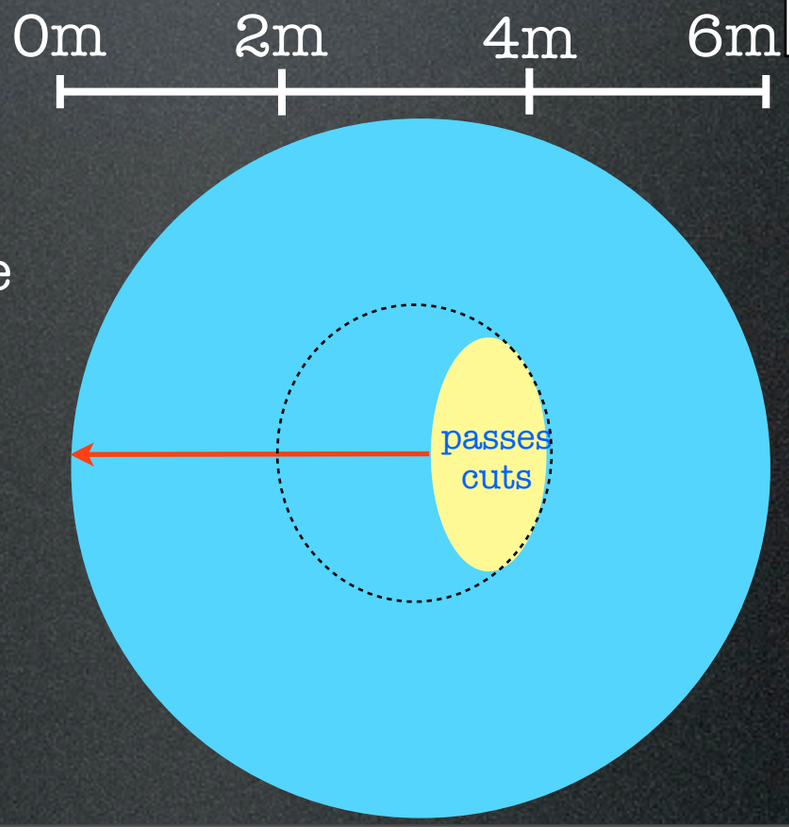
- ν_e's are more sensitive to the tank diameter than ν_μ's
- Large ν_μ background requires good PID
  - PID degrades as particles approach the tank wall
- 6m diameter already seems too small
  - 8m diameter has been studied only in the sterile analysis so far
    - And it has a big impact
- We expect the acceptance near the wall to increase with 8" PMTs
- ν_e's are a crucially important part of the NuPRISM physics program
  - Reconstruction studies are urgently needed







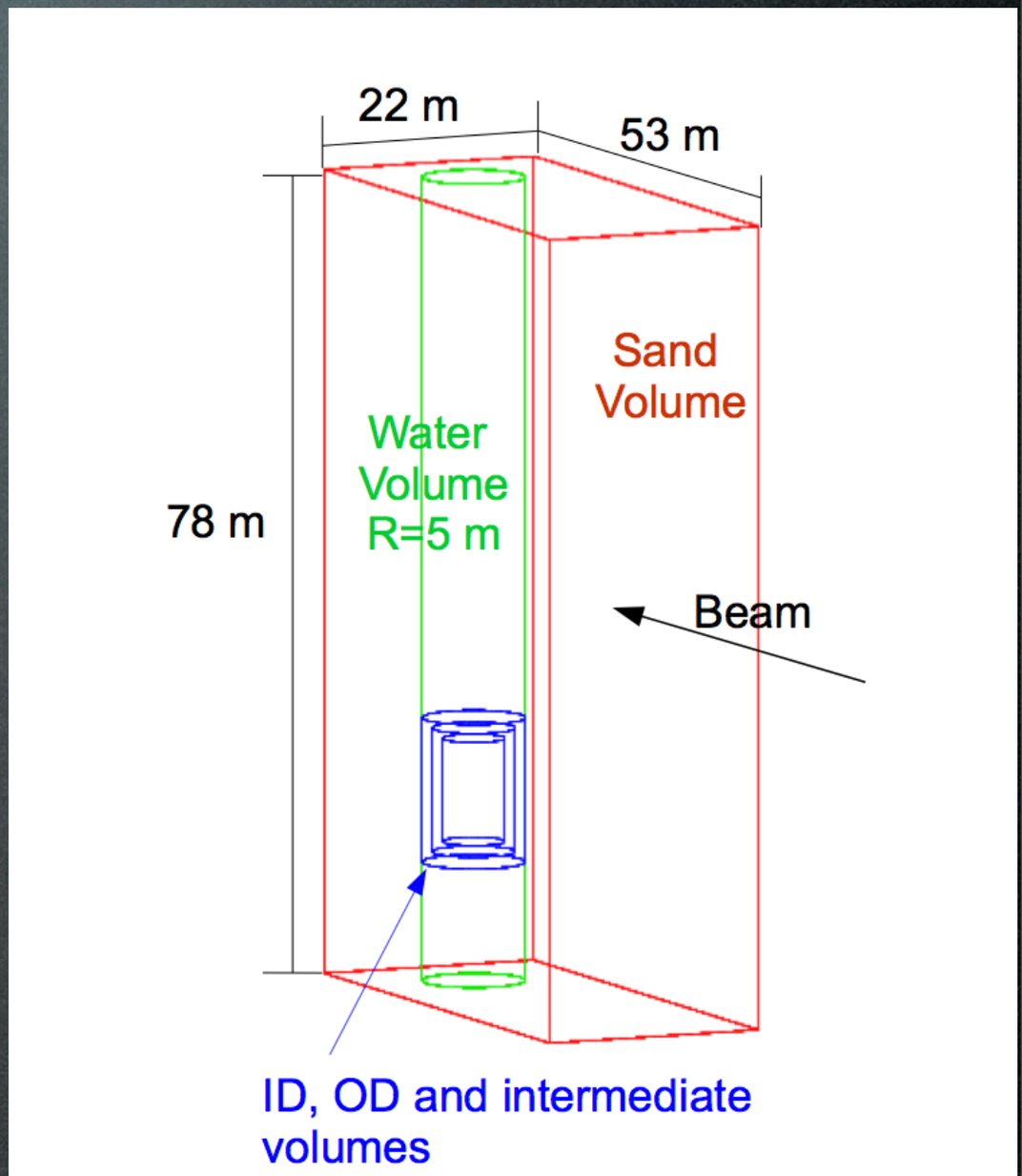
1 Ring e selection:
E_{vis}>200 MeV
DWall>200 cm
ToWall>320 cm



Tank Diameter Strongly Impacts ν_e Fiducial Volume

Event Pileup at 1 km

- Full GEANT4 simulation of water and surrounding sand
  - Using T2K flux and neut cross section model
- 8 beam bunches per spill, separated by 670 ns with a width of 27 ns (FWHM)
- **41% chance of in-bunch OD activity during an ID-contained event**
  - Want to avoid vetoing only on OD light (i.e. using scintillator panels)
- **17% of bunches have ID activity from more than 1 interaction**
  - 10% of these have no OD activity
- **Careful reconstruction studies are needed to confirm reconstruction of pileup events**
  - Multi-ring reconstruction at Super-K works very well, but dedicated pileup reconstruction studies will not be completed in time for the proposal
- Need to consider what we will state in the proposal regarding loss of events due to pileup



Simulation & Reconstruction

- Basic MC (WCSim) and reconstruction (fiTQun) tools exist for physics analysis studies
  - However, further tuning of fiTQun is needed to handle new 8” PMTs (not 20” like Super-K)
- New effort is beginning on detailed fiTQun tuning for various WCSim configurations
  - A new undergraduate student and postdoc are beginning work on this project
- Goal is to produced a streamlined process for adapting fiTQun to new detector geometries or PMT types
  - This will also allow us to adapt fiTQun to a simulation using the new proposed detector electronics
    - Work to add this to the simulation can happen in parallel
- We need to transition to using real simulation and reconstruction as soon as possible
  - This will likely have a large impact on NuPRISM ν_e and sterile-ν sensitivities

Cost Estimates

- LOI had a very crude cost estimate of the entire project
- Cost drivers (PMTs and civil construction) were based on real numbers from companies
  - Although the civil construction depends on a geological survey of the eventual site
- Most of the remaining costs were taken from the T2K 2 km proposal
  - Exchange rate of 107 yen / $
  - 2005 prices assumed (i.e. flat Japanese inflation rate)
- We must decide which items need more precise cost estimates for the proposal

TABLE IV. Summary of nuPRISM project costs, excluding any contingency. Costs taken directly from the T2K 2 km proposal are labeled with *

Item	Cost (US M$)
Cavity Construction, Including HDPE Liner	6.00
*Surface Buildings	0.77
*Air-Conditioning, Water, and Services	0.50
*Power Facilities	0.68
*Cranes and Elevator	0.31
*PMT Support Structure	1.27
3,215 8-inch PMTs	4.30
PMT Electronics	1.45
*PMT Cables and Connectors	0.13
Scintillator Panels	0.36
Water System	0.35
Gd Water Option	0.15
*GPS System	0.04
Total	16.31

Collaboration Formation

- As we move toward a proposal, some initial decisions about collaboration organization are required
- Japanese host institutions for the experiment will likely be necessary
  - Host institutions assist in acquiring project approval and contribute to the experimental infrastructure
- Organizational structure should include:
  - An executive committee: One member from each region + one representative from each host institution + spokespeople
    - Decides issues that cannot be resolved by PI board, due to either time constraints or disagreements
  - PI Board: All grant eligible members
    - Responsible for approving collaboration bylaws (e.g. procedures for shifts, publications, conference speakers, etc.)
  - A Japanese project manager is needed to communicate with KEK/J-PARC
    - This is the same model used by Belle II (conceived of by Yamauchi-san)
- A draft document is will be distributed in advance of the Feb 1st face-to-face meeting

T2K and Super-K MOUs

- We are currently drafting MOU documents to facilitate coordination between both the T2K and Super-K collaborations
- The T2K MOU is most critical and includes:
  - Sharing of software tools
  - Author list procedures for joint analyses
    - This is somewhat delicate, since in the NuPRISM era, most T2K analyses will likely use NuPRISM
  - Sharing of shift-taking responsibilities
- We are seeking clarification regarding which items must be included in the Super-K MOU
  - e.g. neut? fiTQun? skdetsim?
- These MOUs should be established in time for the submission of the full proposal

Publication Plans

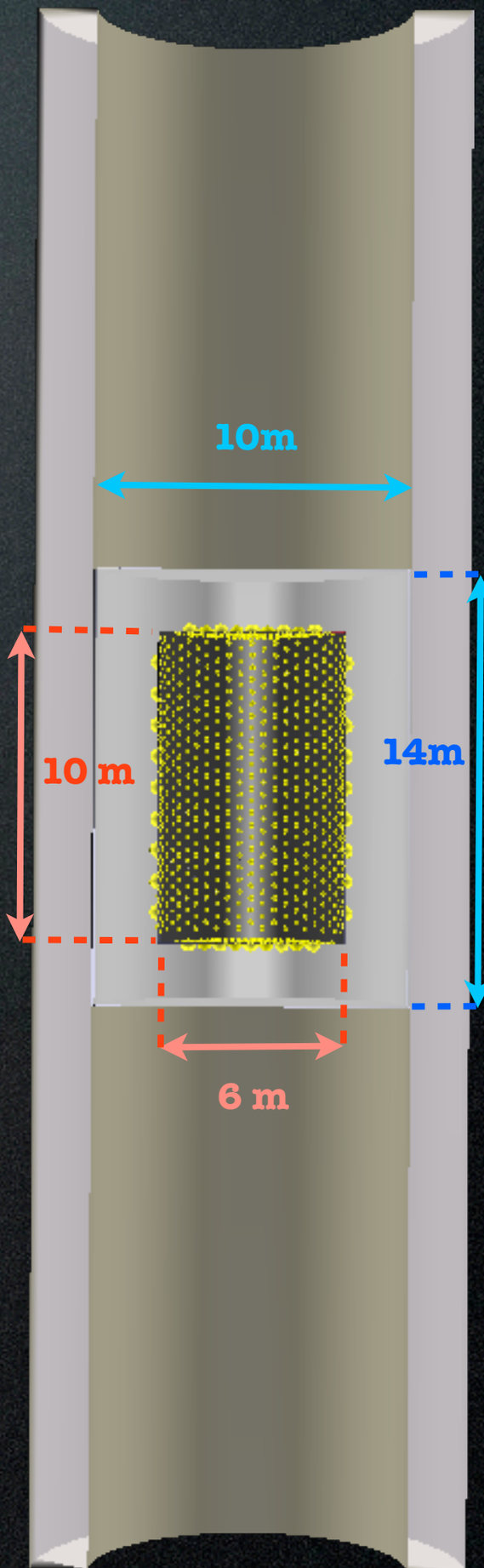
- First paper will be a nuPRISM concept paper
  - A partially completed template exists in the NuPRISM GitHub repository
- There are also plans for a detailed paper on the sterile neutrino analysis
  - This will be led by the Barcelona group
- Other papers can be prepared as analyses mature, e.g.
  - Oscillation physics sensitivities
  - ν_e/ν_μ cross section constraint
  - Cross section physics from monoenergetic beams

Manpower/Organization

- Much work needs to be accomplished in a relatively short time
  - More people will become available as the T2K analysis effort for producing spring results declines
- Several new people are joining
  - Expect rate of progress to increase significantly
  - However, there is still room for many more people to contribute
- We will hold a week-long workshop in March at IPMU
  - Intensive working time (very few talks)
- If you are interested in getting involved, we can help to get interested people started as soon as they are available
- We plan to hold weekly meetings beginning after the T2K meeting finishes next week
  - We will send a doodle poll later today to help select a time for these meetings

Need for NuPRISM

- NuPRISM is a necessity in the Hyper-K era
  - Otherwise most analyses will be systematics limited within a few years of running
  - Even T2K will be systematics limited without NuPRISM
- Very important to build the first version now
  - Need to gain familiarity with this new technique
  - Must demonstrate that Hyper-K can make use of 5+ years of beam time
- Provides an ideal environment for Hyper-K detector R&D
  - Detector can be lifted out of the water for maintenance or replacements
- Provides a mechanism to grow the Japanese neutrino physics community toward Hyper-K
  - Large, engaged, international user base will be needed
  - A lot of interesting physics to do on a 5 year timescale!



	Current	Transition Project	Future
Fermilab	NOvA	Short-baseline LAr	LBNF
J-PARC	T2K	**???** **NuPRISM?**	Hyper-K

Summary

- NuPRISM is critically important for the Japanese neutrino physics program
  - Very important to build the detector during the T2K era
- Much work is needed to prepare for a NuPRISM proposal to the J-PARC PAC
  - Submission in mid-June
- Some new effort is being devoted to project-critical items
  - However, much more effort is needed
  - Please consider getting involved, as the next few months will be critical to the NuPRISM proposal
- We will have an intensive analysis workshop March 16-20 in Kashiwa
- Please sign up for the mailing list if you haven't already: http://nngroup.physics.sunysb.edu/cgi-bin/mailman/listinfo/nuprism