Oscillation Physics at nuSTORM

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Outline

Available ν Physics with a Muon Storage Ring

Boosted decays; $\mu^+ \to e^+ \nu_e \bar{\nu}_\mu$ and $\mu^- \to e^- \bar{\nu}_e \nu_\mu$

	Store μ^+	Store μ^-
Golden Channel	$\nu_e \to \nu_\mu$	$\bar{\nu}_e \to \bar{\nu}_\mu$
ν_e Disappearance Channel	$\nu_e \to \nu_e$	$\bar{\nu}_e \to \bar{\nu}_e$
Silver Channel	$\nu_e \to \nu_\tau$	$\bar{\nu}_e \to \bar{\nu}_\tau$
Platinum Channel	$\bar{\nu}_\mu \to \bar{\nu}_e$	$\nu_\mu \to \nu_e$
ν_μ Disappearance Channel	$\bar{\nu}_\mu \to \bar{\nu}_\mu$	$\nu_\mu \to \nu_\mu$
Dominant Oscillation	$\bar{\nu}_\mu \to \bar{\nu}_\tau$	$\nu_\mu \to \nu_\tau$

Available ν Physics with a Muon Storage Ring

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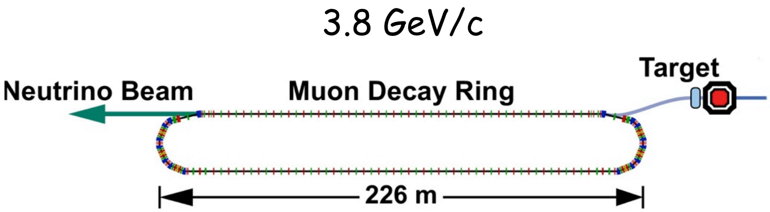


Neutrino Oscillation Program at νSTORM

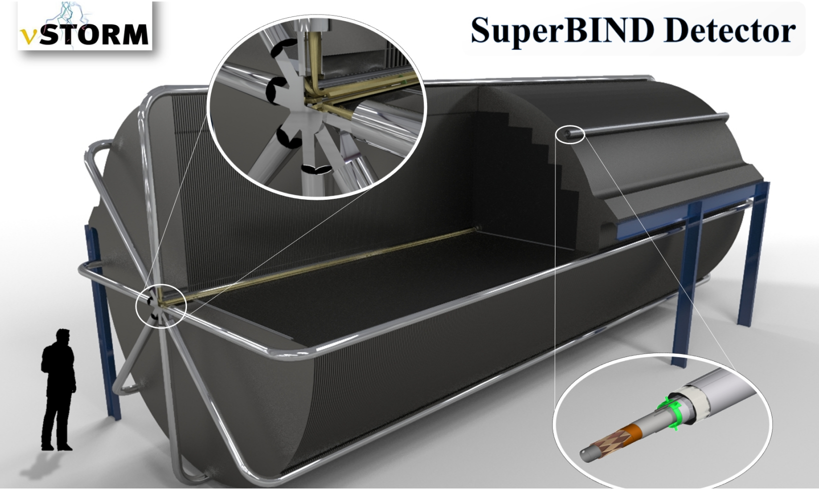
- νSTORM accepts muons of a single charge μ^+ in the ring.
- Requires two detectors: Eg. 200 Ton at 50 m, 1.3 kTon at 2 km.

Oscillation Channels for Stored μ^+ with 10^{21} POT

Channel	Osc.	S	B	$(S-B)/\sqrt{S+B}$
ν_μ Appearance	$\nu_e \rightarrow \nu_\mu$	332	0	18.2
$\bar{\nu}_\mu$ Disappearance	$\bar{\nu}_\mu \rightarrow \bar{\nu}_\mu$	122322	128433	-12.2
ν_e Disappearance	$\nu_e \rightarrow \nu_e$	216657	230766	-21.1
NC Disappearance	$\bar{\nu}_\mu \rightarrow \bar{\nu}_\mu$ NC	47679	50073	-7.7
NC Disappearance	$\nu_e \rightarrow \nu_e$ NC	73941	78805	-12.4

- All channels will be available (ν_e appearance not shown).
- Muons are easy to detect and identify by charge.
- Appearance has a clean signal relative to disappearance.
- Focus has been on ν_μ appearance.

A Potential Magnetized Iron Neutrino Detector



- 1.5 cm steel planes
- 1.5 cm thick sci. planes

SuperBIND Simulation and Reconstruction

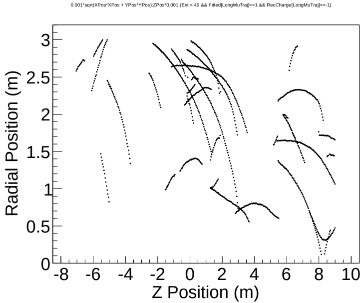
Simulation

- ν events Simulated in GENIE
- Particles tracked using GEANT4 simulation of detector.

Digitization

- Hits clustered into 1×1 cm^2 units.
- Energy smeared and attenuated.

40 Fitted Events; ν_μ CC sample



Pattern Recognition and Reconstruction

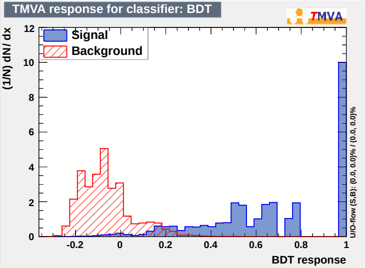
- Relies on Kalman filtering/fitting algorithm.
- Multiple tracks fit by program.
- Determines the charge and momentum of all tracks.
- Longest track is muon.

Analysis for SuperBIND

- Use multiple variables for signal discrimination.
- TMVA methods assumed to properly account for correlations.
- Reduces multiple variables into one classifier variable.

Variables for MVA

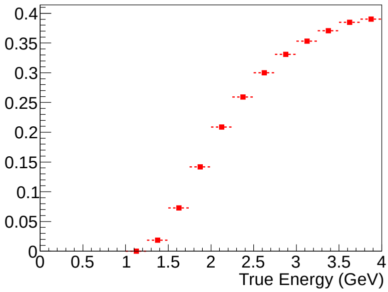
Variable	Description
Track Quality	$\sigma_{q/p}/(q/p)$, the error in the trajectory curvature scaled by the curvature
Hits in Trajectory	The number of hits in the trajectory
Mean Energy Deposition	Mean of energy deposition of hits in fit of the trajectory
Variation in Energy	$\sum_{i=0}^{N/2} \Delta E_i / \sum_{j=N/2}^{N} \Delta E_j$ where the energy deposited per hit $\Delta E_i < \Delta E_{i+1}$.
Q_t	Muon isolation $Q_t = p_\mu \sin^2 \theta_\mu$



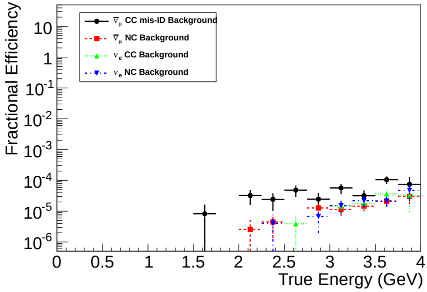
- Focussed on Boosted Decision Tree (and related) method.

Appearance Event Selection

Signal Efficiency



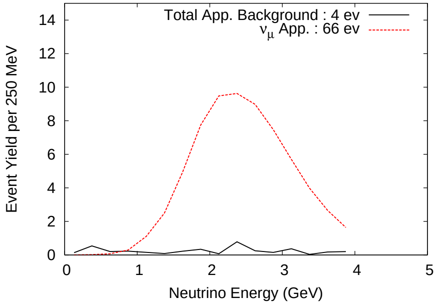
Background Efficiencies



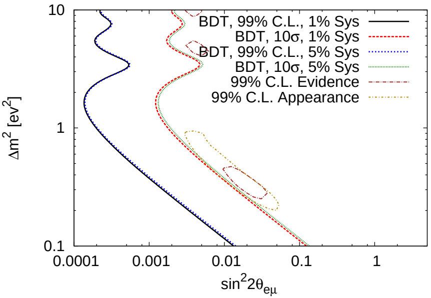
- Optimization completed with $S/\sqrt{S+B}$ FOM with BDT method.
- Restrictive signal selection set by sensitivity requirements.
- Ideal sensitivity results with background rejection of 10^{-4}.

nuSTORM Sensitivity to ν_μ Appearance

Expected Rates



Sensitivity Contours



- 1.6×10^{18} useful μ decays over 5 years.
- 1% signal and 10% background systematic uncertainties.

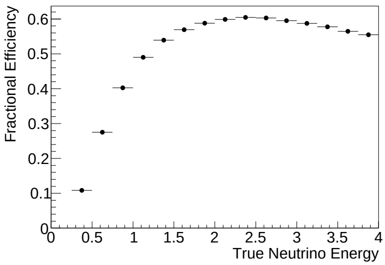
3+1 observation probability

$$P_{\nu_e\rightarrow\nu_\mu} = sin^2 2\theta_{e\mu} \sin^2 \frac{\Delta m^2_{14} L}{4E}$$

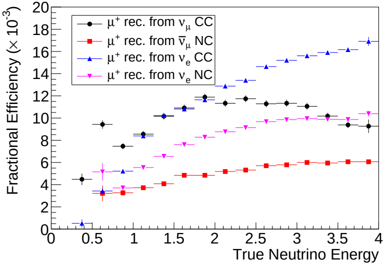
$$sin^2 2\theta_{e\mu} = 4|U_{e4}|^2|U_{\mu4}|^2$$

Disappearance Event Selection

Signal Efficiency



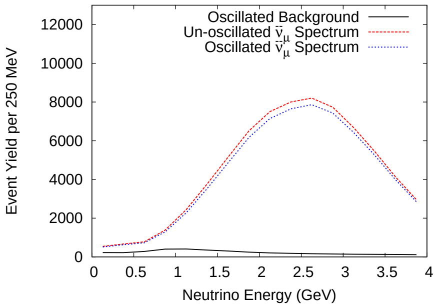
Background Efficiencies



- Optimized an MLP boosted neural network with a χ^2
  - Maximize difference between sterile and null hypotheses.
  - Spectral information used in optimization.
- Less restrictive selection allowed by greater signal significance.

nuSTORM Sensitivity to $\bar{\nu}_\mu$ Disappearance

Expected Rates



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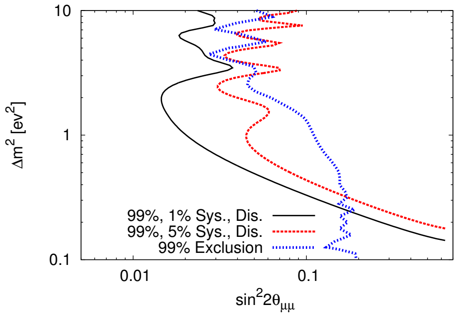

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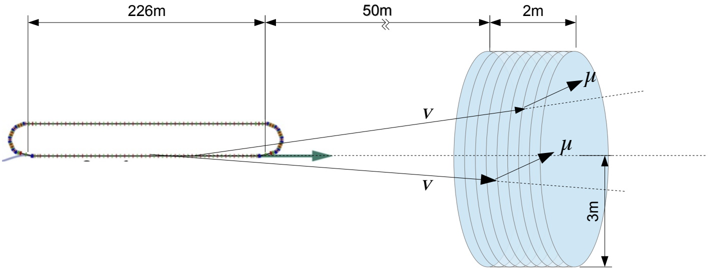
$$P_{\nu_\mu\rightarrow\nu_\mu} = \sin^2 2\theta_{\mu\mu}\sin^2\frac{\Delta m^2_{14}L}{4E}$$

$$\sin^2 2\theta_{\mu\mu} = 1-4|U_{\mu4}|^2(1-|U_{\mu4}|^2)$$

Near Detector Simulations

- Near detector not included in disappearance sensitivity.



- Detector subtends 0.022(0.119) rad from end(beginning) of straight.
- Beam spectrum not in current simulation.
- Requires neutrino interaction simulation in context.

Near-Far Extrapolation

- Different methods used for Near Detector predictions.

Simultaneous fit of Near and Far Detectors

- Used for reactor experiment fits.

Predict far detector rate N_{FD} from near detector rate:

$$N_{FD} = M_{FD} P_{osc}(\theta_{14}, \theta_{24}, \Delta m^2_{14}) M_{nOsc} M^{-1}_{ND} N_{ND}$$

- $M_{F(N)D}$: cross-section and response of far(near) detector.
- M_{nOsc}: relationship between near det. $\bar{\nu}_\mu$ flux and far det. $\bar{\nu}_\mu$ flux.
- $P_{osc}(\theta_{14}, \theta_{24}, \Delta m^2_{14})$: oscillation probability.
- N_{FD}: The measured near detector rate.

Analysis Requirements for Shower Events

- Some guidance provided by MINOS ν_e oscillation search.

Algorithm for Shower Identification

- Preselection excludes muon tracks.
  - Remove events with threshold number of track-like planes
  - Remove events with threshold number of planes
- Select events with showers
  - occupying a more than 5 contiguous planes
  - matching a particular energy loss profile.
- ν_e CC and NC pre-selection tuned differently.
- Further application of multi-variate or LEM methods to be determined.

- ν_e CC methods will be described in detail by David Adey

Summary

- Five potential channels for sterile oscillations are accessible at nuSTORM
  - Advanced ν_μ appearance analysis.
  - Work remains on a $\bar{\nu}_\mu$ disappearance analysis.
  - Early days for a ν_e disappearance analysis.
  - A $\bar{\nu}_e$ appearance analysis is not practical.
  - A neutral current oscillation analysis is under consideration.
- A more complete near detector simulation is in progress.
  - Inclusion of detector geometry and beam divergence in GENIE simulation required.
  - Essential for $\bar{\nu}_\mu$ CC and NC disappearance searches.
  - Not necessary for appearance analysis.
- New algorithms must be developed for shower reconstruction in context of SuperBIND for NC and ν_e CC disappearance.