Measuring the Azimuthal Distribution of Atmospheric Neutrinos in DUNE

Lisa Fantini, Glenn VanWinkle, Jeremy Wolcott, Hugh Gallagher

Tufts University

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OUTLINE:
1) Why study the azimuthal distribution?
2) Plans for our study
3) Azimuthal angle resolution
4) Next Steps

DEEP UNDERGROUND NEUTRINO EXPERIMENT

Motivation

DUNE CDR, Volume 2

Unique strength of DUNE compared to previous atmospheric neutrino detectors is its excellent resolution of neutrino direction.

Provide an early *in situ* measurement that demonstrates that we understand our resolution and that it is as good as advertised.

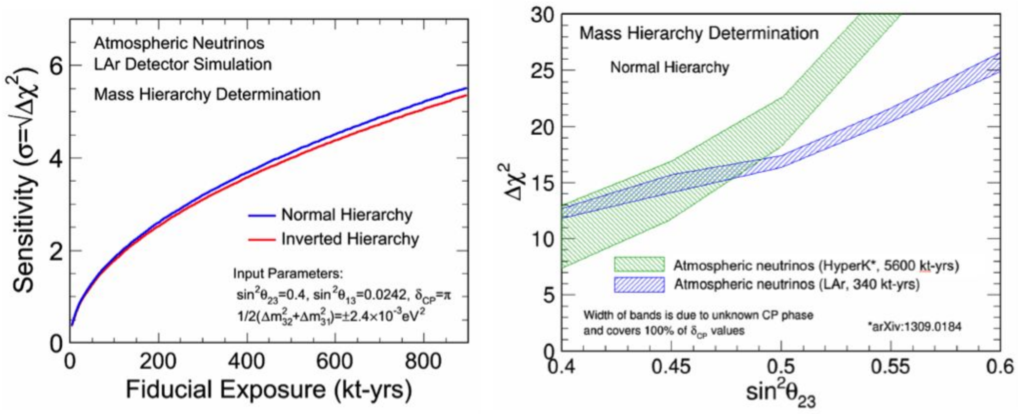
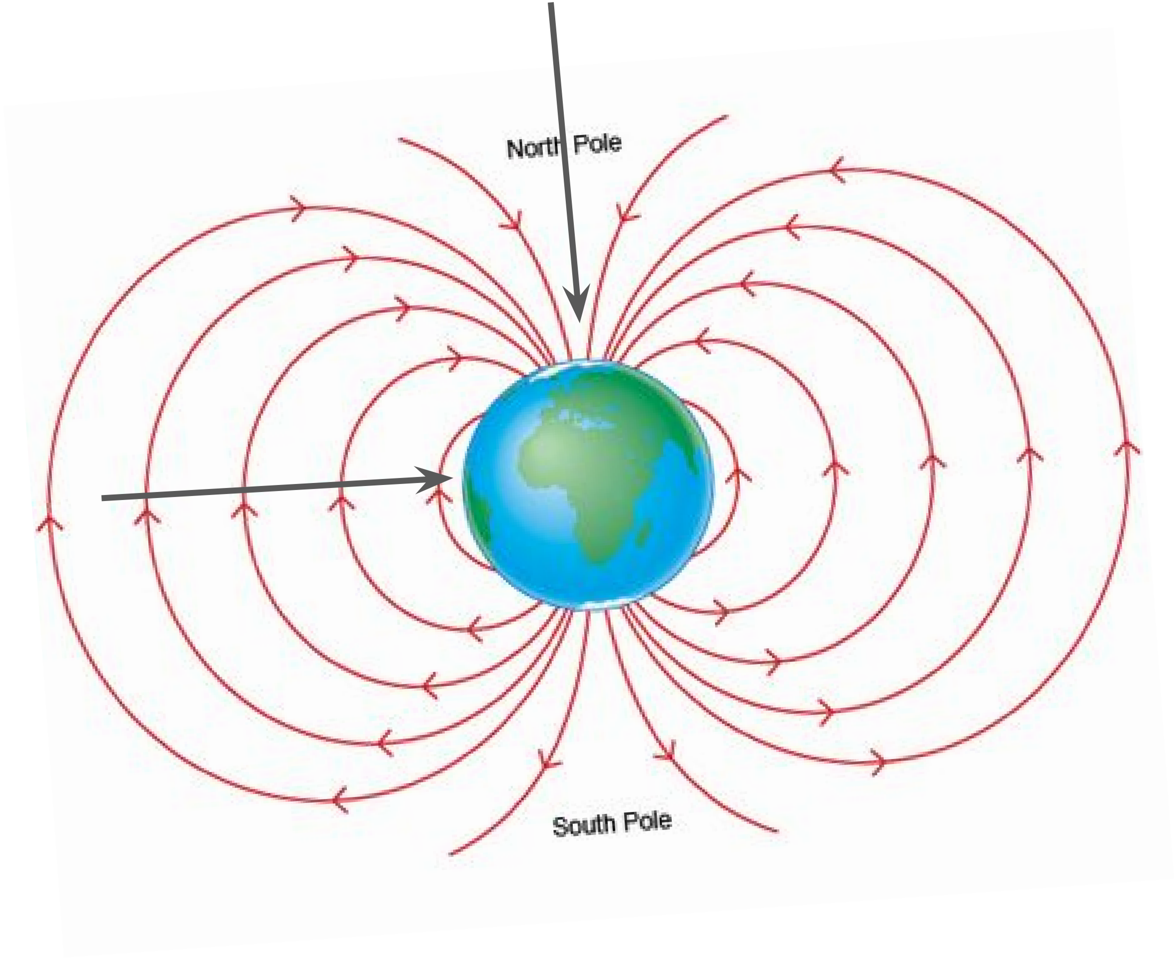


Figure 4.7: Sensitivity to mass hierarchy using atmospheric neutrinos as a function of fiducial exposure in a liquid argon detector (left), and as a function of the true value of θ_{23} (right). For comparison, Hyper-K sensitivities are also shown [101].

For a bin of neutrino flavor/energy/zenith angle, oscillation effects are the same at all azimuthal angles.

SuperK studies: arXiv:1510.08127 (20 yrs data)



Generic features of 3-d flux calculations:

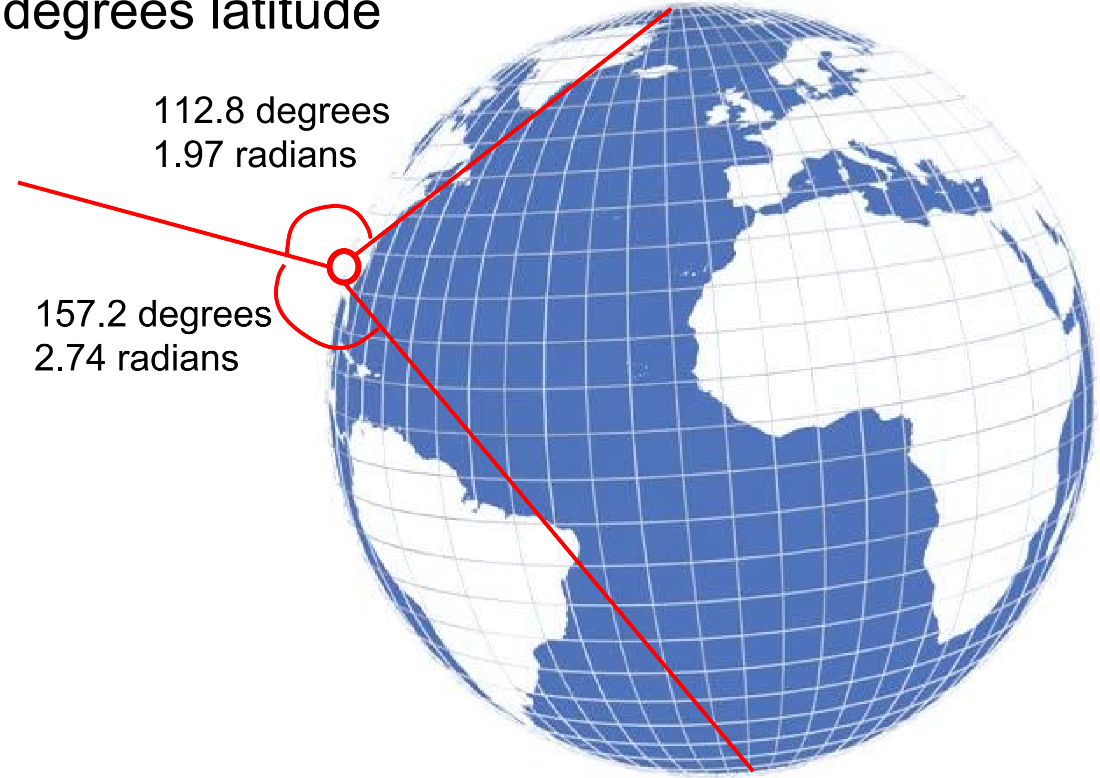
Geometric effect: increase in flux of neutrinos at horizon.

Geomagnetic effects: high particle rigidity requirement at equator relative to poles results in increased fluxes for directions that point back to the magnetic pole regions (affected by site latitude).

East/west asymmetry due to trajectories of positively charged cosmic rays.

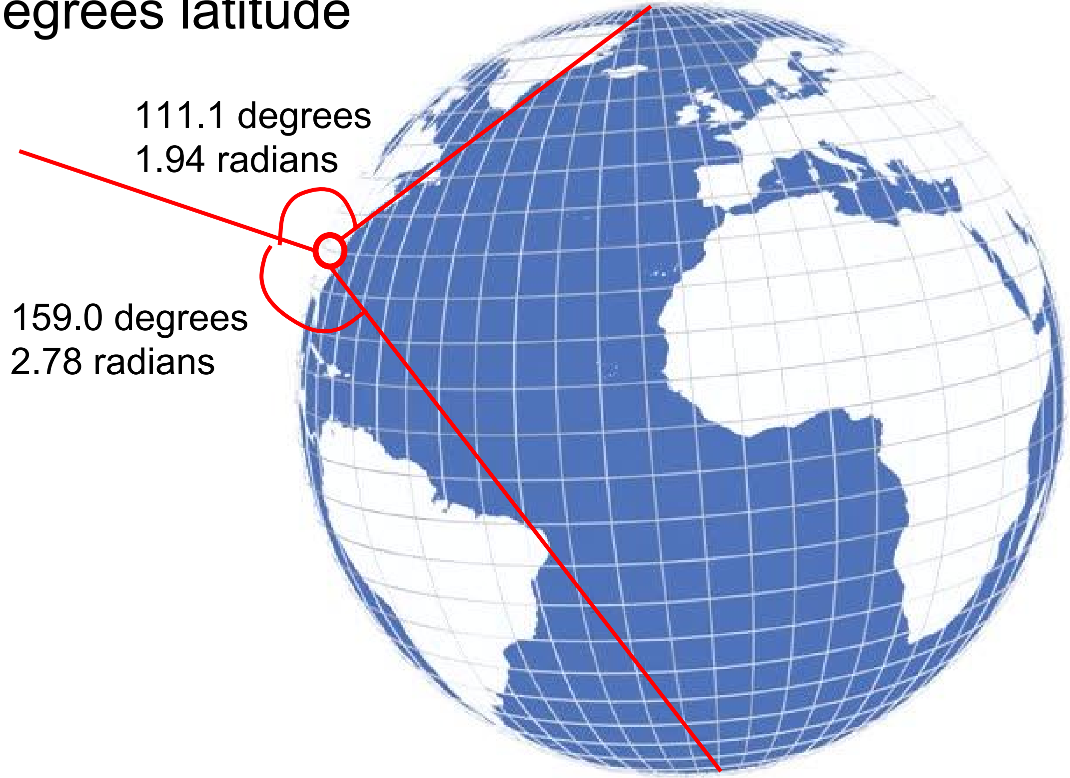
https://www.tes.com/lessons/HL9HRDdDBHbtvQ/earth-s-magnetic-field

For HONDA flux (calculated at SURF in Deadwood, South Dakota)
44.4 degrees latitude



https://openclipart.org/tags/globe

For BARTOL flux (calculated at Soudan, MN)
47.8 degrees latitude



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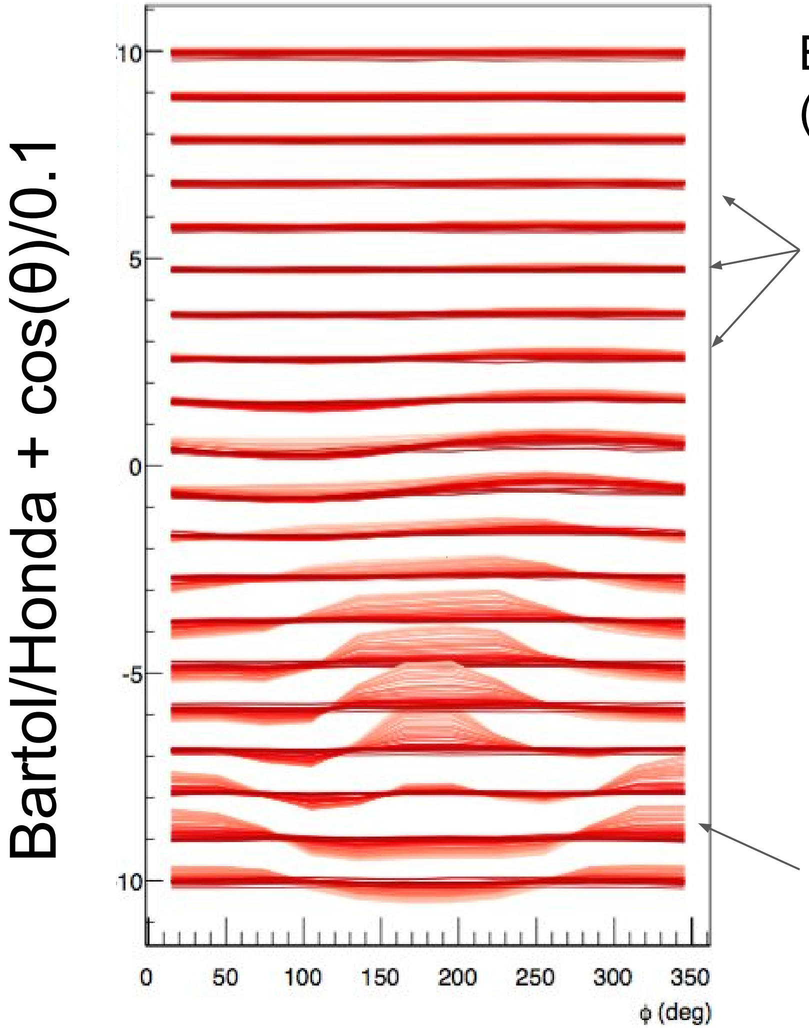
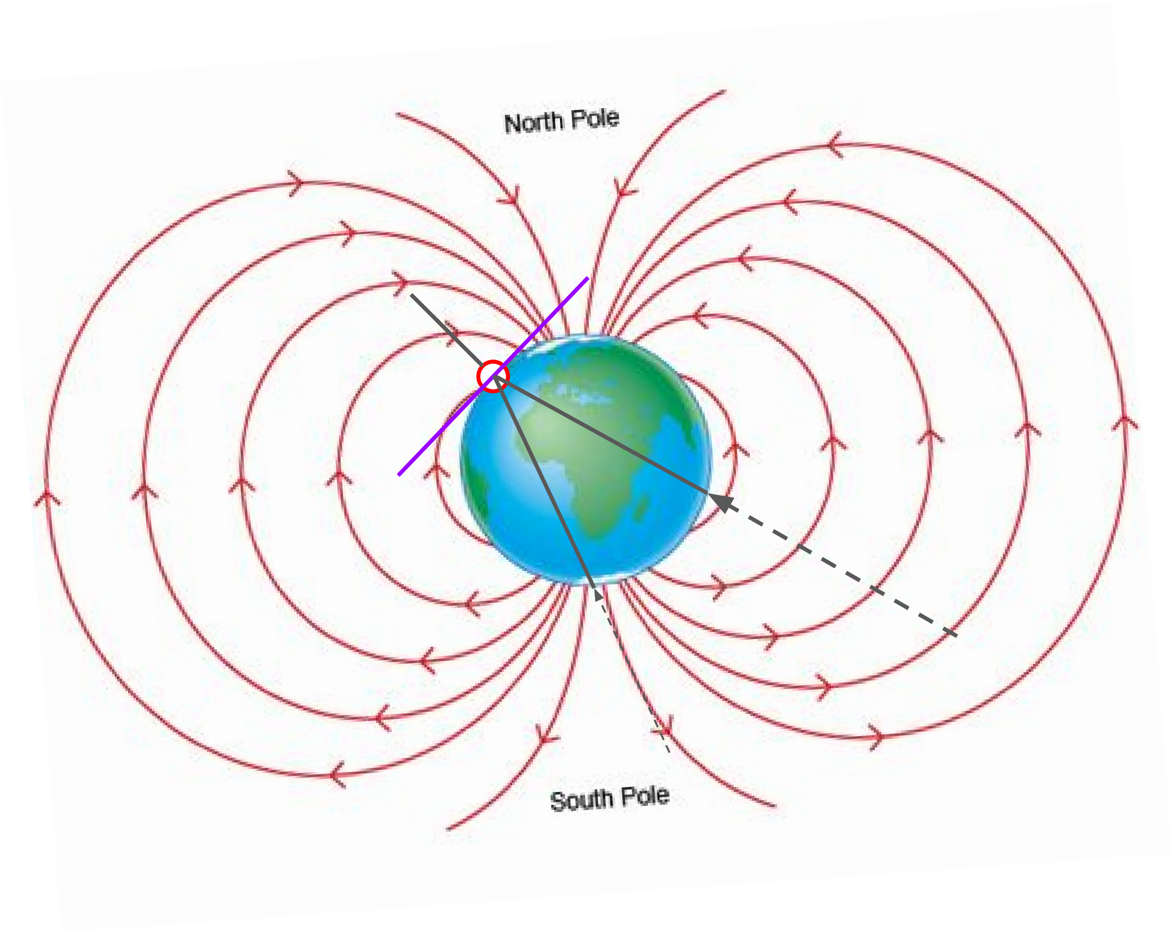
Bartol/Honda flux ratio for electron neutrinos (Here Bartol is averaged over azimuthal angle)

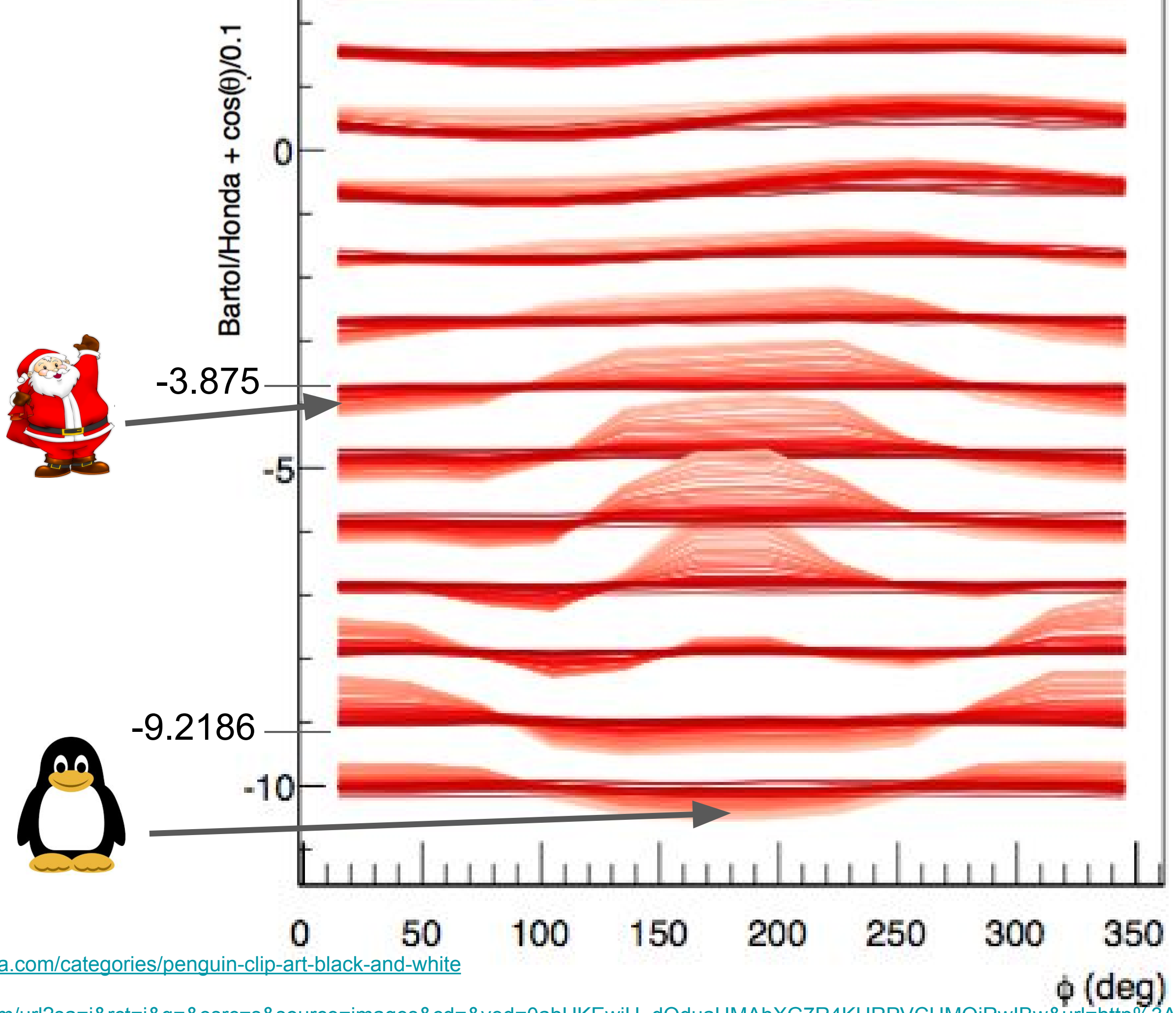


Bands correspond to different zenith angles.

Colors within a band correspond to 10 bins of neutrino energy from 0-10 GeV (light to dark).



https://www.tes.com/lessons/HL9HRDdDBHbtvQ/earth-s-magnetic-field



http://www.clipartpanda.com/categories/penguin-clip-art-black-and-white

https://www.google.com/url?sa=i&rct=j&q=&esrc=s&source=images&cd=&ved=0ahUKEwiU_dOduaHMAhXG7R4KHRPVCUMQjRwIBw&url=http%3A%2F%2Fcroswell-library.com%2Fsanta-visit%2F&bvm=bv.119745492,d.dmo&psig=AFQjCNE6eRTy8DNEljH7nW_EwTy-czTFIA&ust=1461386386954463

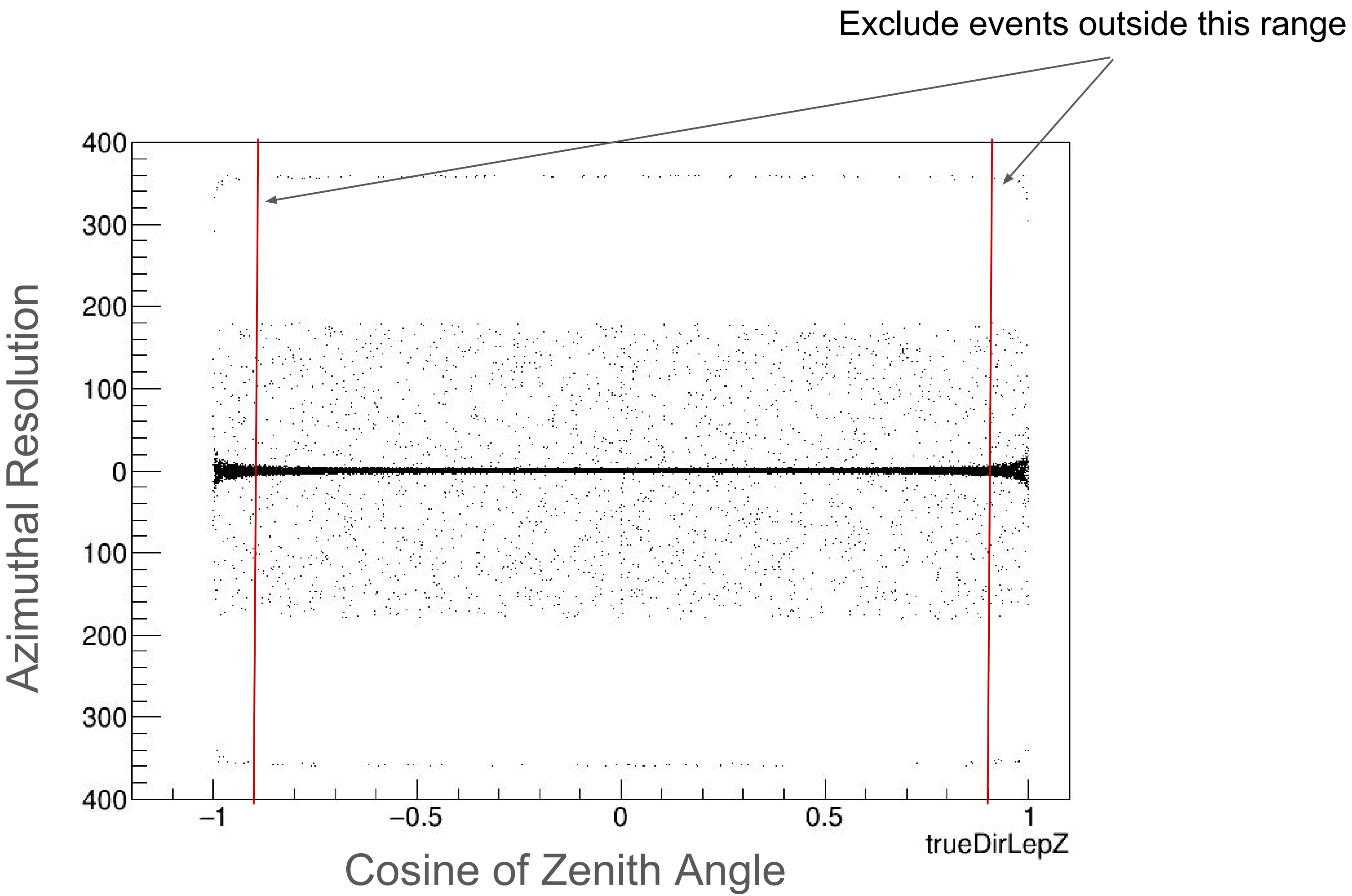
We are using unoscillated MC files generated for previous LBNE atmospheric sensitivity studies done by Andy Blake.

Use a set of detector performance assumptions (right) to smear truth-level MC quantities.

These simulations used the Bartol flux, calculated for Soudan, MN (PRD 70, 023006, 2004).

Implementation in GENIE at that time assumed isotropic azimuthal distributions.

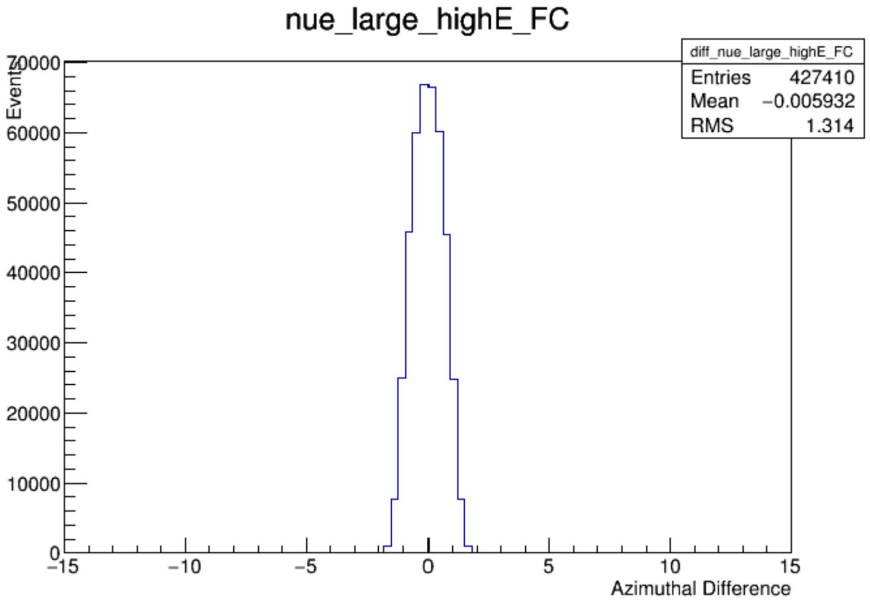
Angular Resolution	Electron	1°
	Muon	1°
	Hadronic system	10°
Energy Resolution	Stopping muon	3%
	Exiting muon	15%
	Electron	1%/√E + 1%
	Hadronic system	30%/√E
Signal Acceptance	Electrons	90%
	Muons	100%
Background Rejection	e-like (p^0, g)	95%
	m-like (p^+, p^-)	99%

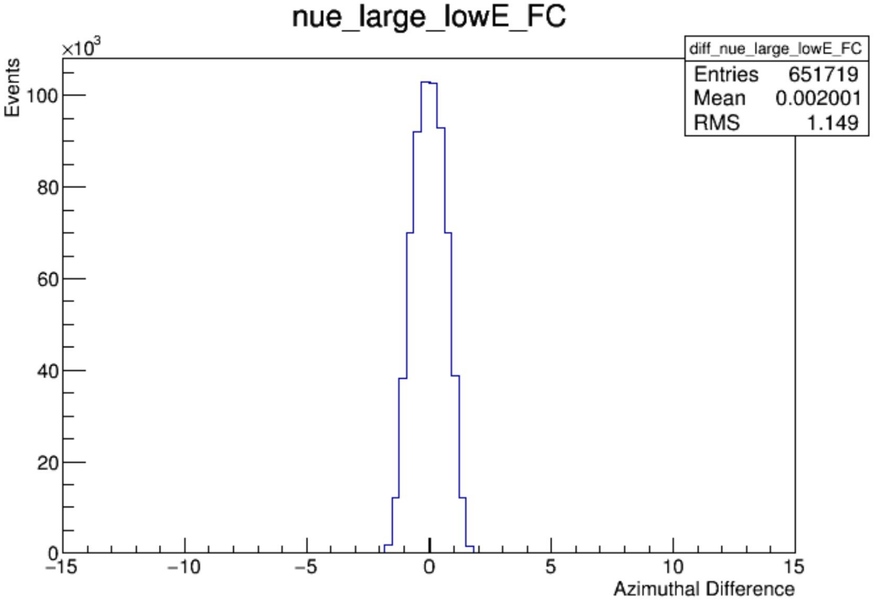

Exclude events outside this range
400
300
200
100
0
100
200
300
400
−1
−0.5
0
0.5
1
trueDirLepZ
Azimuthal Resolution
Cosine of Zenith Angle

Cuts made on charged current events:

- Partially contained vs. fully contained
    - Only muon like neutrinos can be partially contained
- Muon neutrino vs. electron neutrino
- Low energy (<1 GeV) vs. high energy (>1 GeV)

Electron type, fully contained

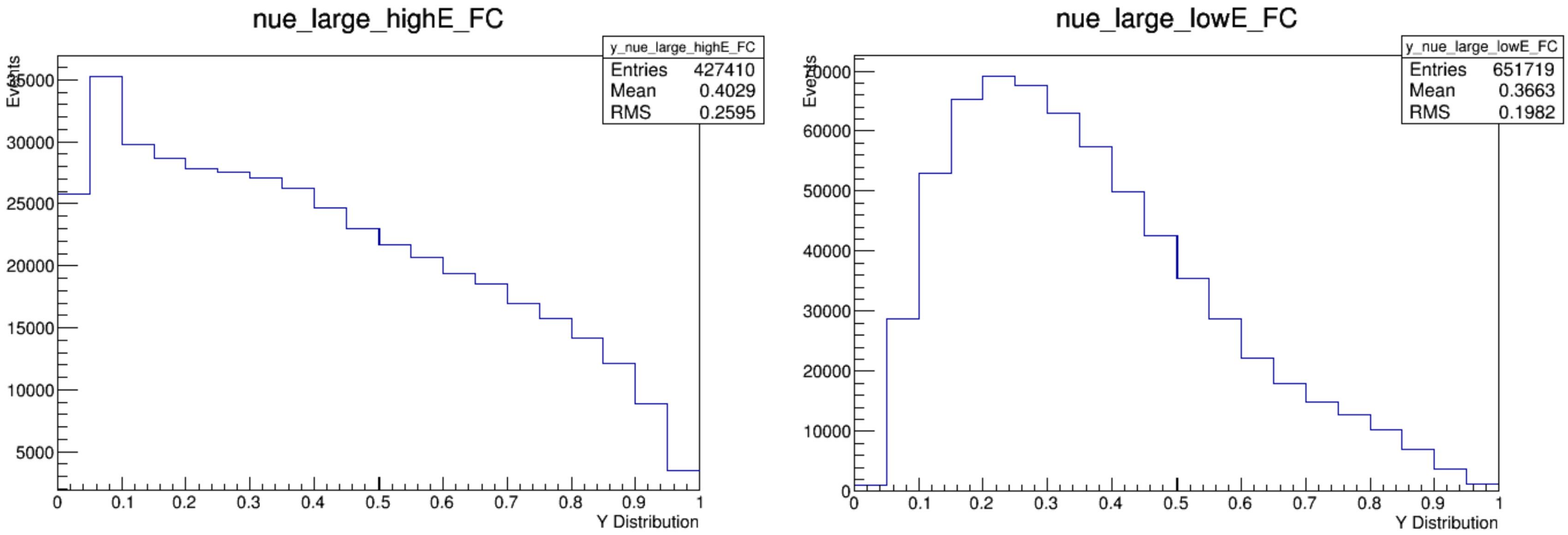




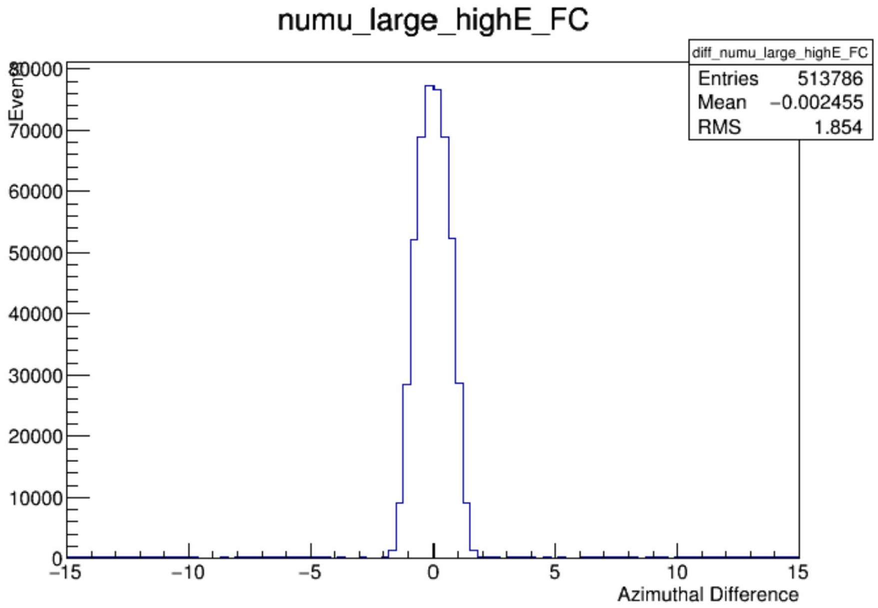
For this sample: <y>=0.
403

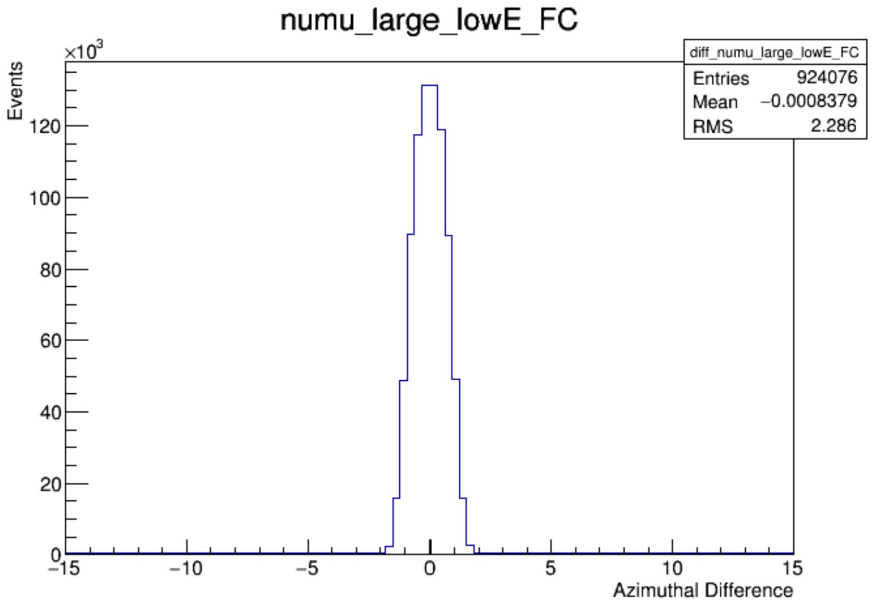
For this sample:
<y>=0.367

Electron type, fully contained



Muon type, fully contained

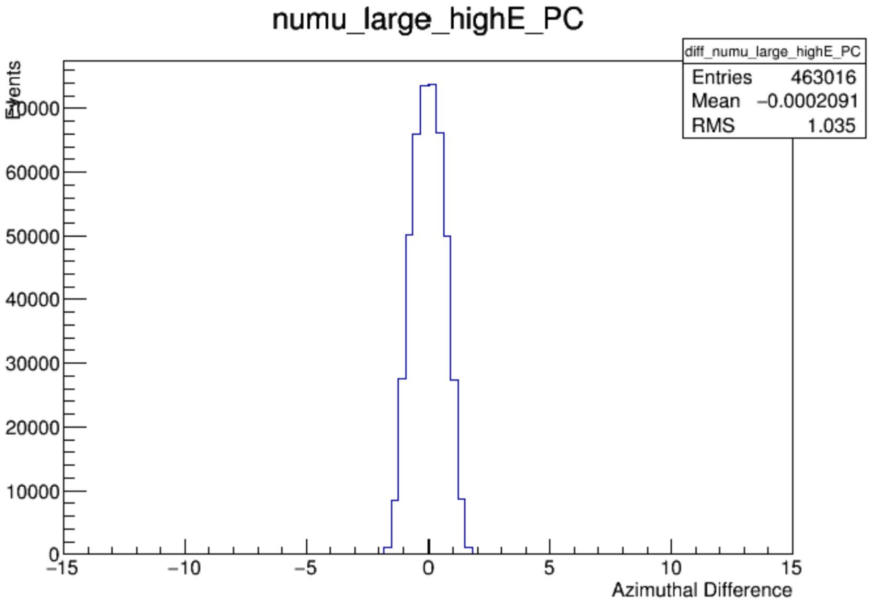




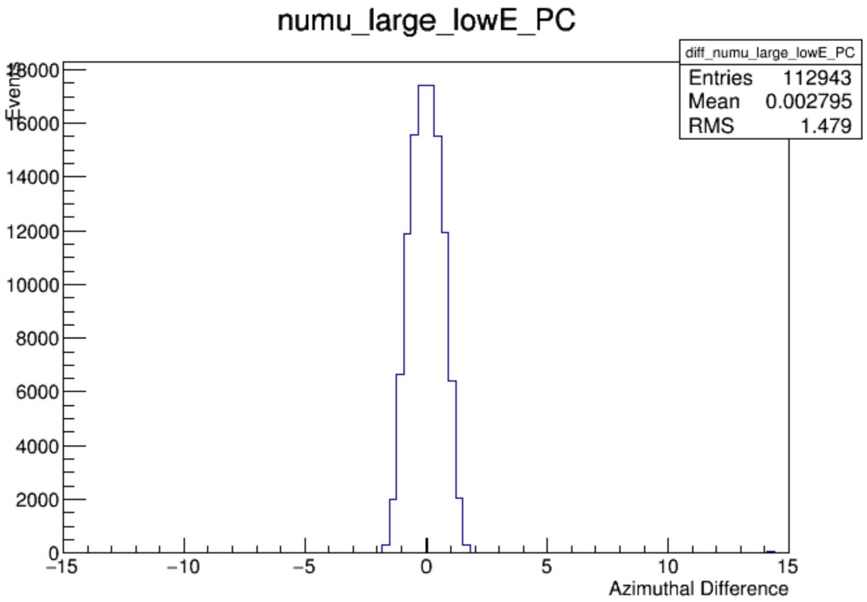
<y>=0.462

<y>=0.336

Muon type, partially contained



<y>=0.317



<y>=0.287

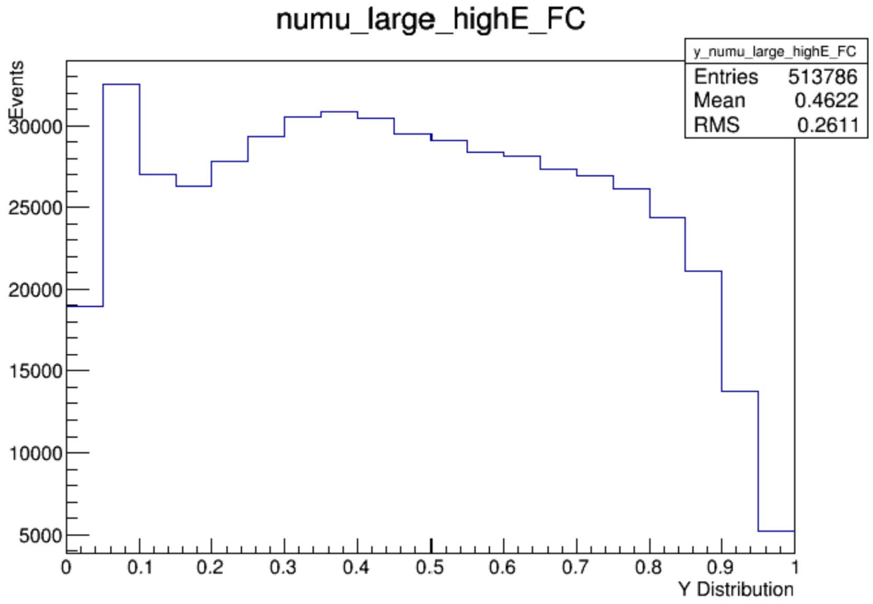
Next Steps

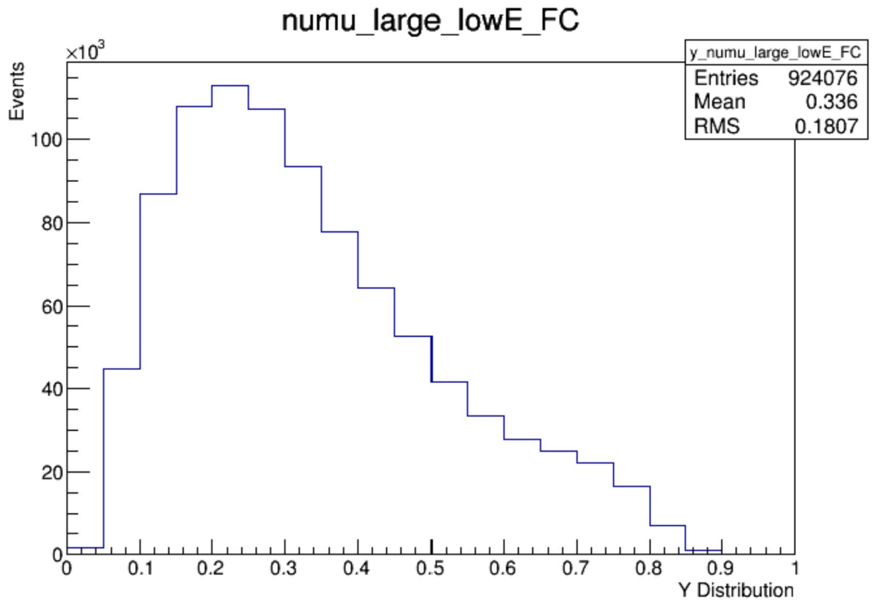
1) Including a realistic azimuthal distribution
    a) For now, reweight fluxes as a function of (flavor, energy, zenith, azimuth) using ratios previously shown.
    b) Will test out the new GENIE atmospheric flux driver when it is available.
2) Sensitivities
    a) How much data is required to observe a 2σ azimuthal isotropy in directions of poles?
    b) How much data is required to observe the east/west asymmetry at 2σ?
3) Related Questions
    a) What is the uncertainty on the expected size of these asymmetries?
    b) Compare different flux calculations, discuss with flux calculation experts.

Goal is to have some results to show and discuss at the May collaboration meeting.

BACKUP

Muon type, fully contained





Muon type, partially contained