NGen (sounds like “Engine”): A Generalized Neutrino Event Generator

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What is NGen?

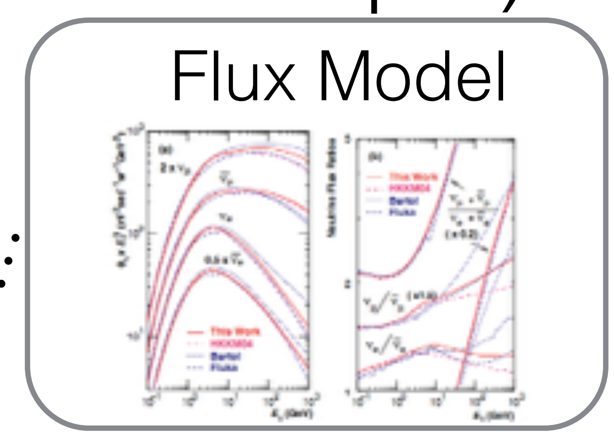
- This talk will be about NGen, a software tool I have been writing to produce simulated neutrino event vectors.

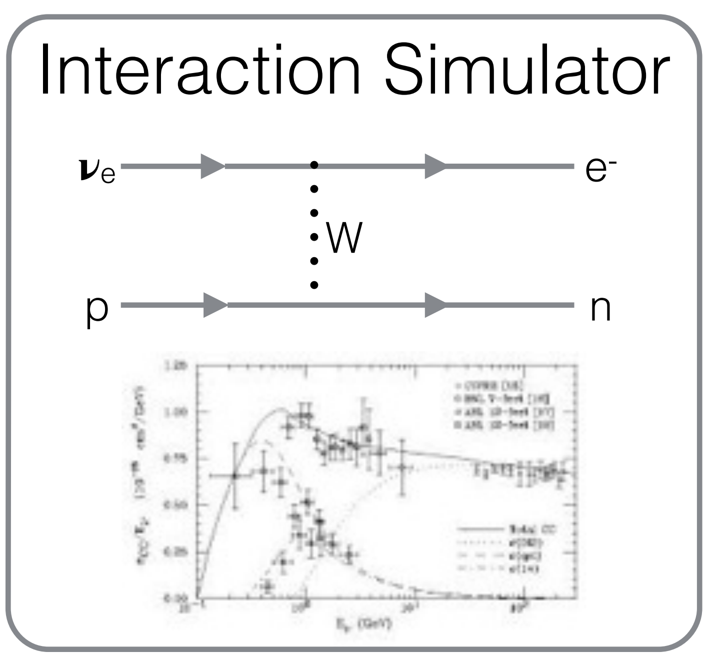
- I initially wrote NGen to produce atmospheric neutrino events and am validating with atmospheric flux, so much of this talk will lean in that direction.

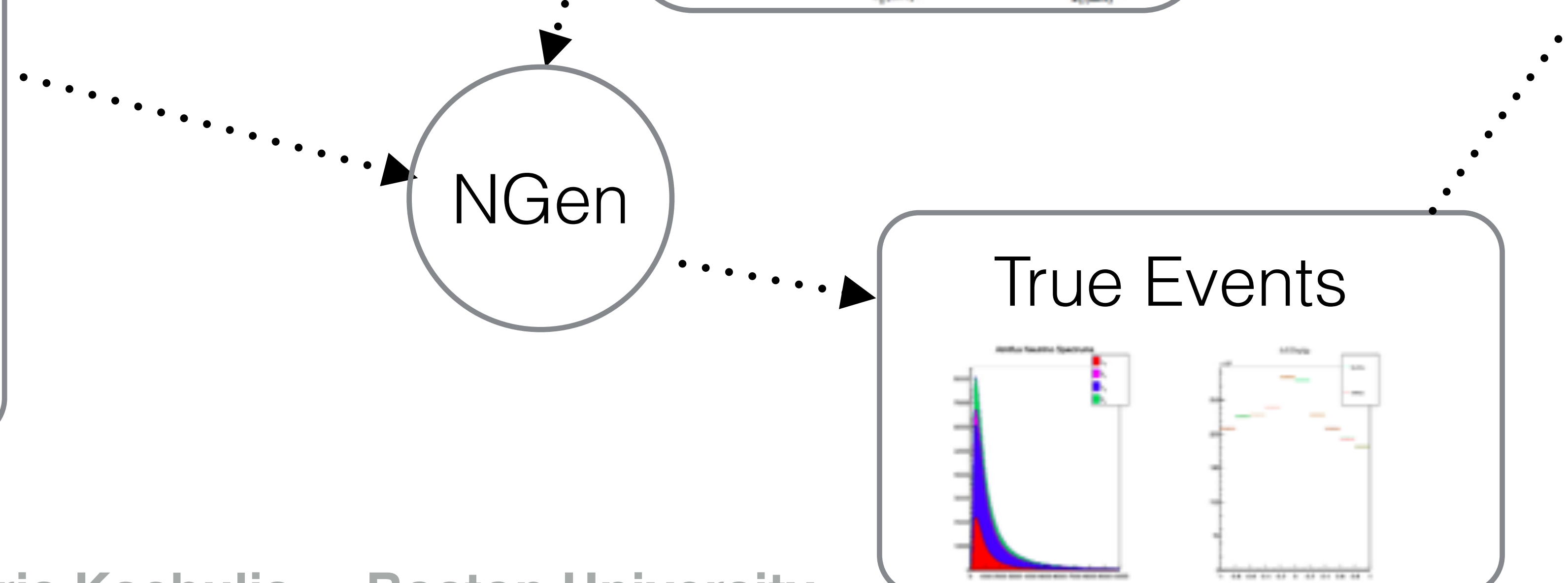
- However, NGen is written with the flexibility to handle many different types of neutrino fluxes. So, I will also discuss this flexibility and plans to implement non-atmospheric fluxes (examples: solar, supernova, beam …)

Atmospheric Neutrino Simulation

- To produce atmospheric Monte Carlo, we must first combine an atmospheric neutrino flux model (Honda flux, for example) with a neutrino-nuclear interaction simulator (NEUT, for example) to generate events.







To
Detector
Simulation

Currently @ SK

- In Super K, we currently use a piece of software called "Neutflux" to perform this task.
- Neutflux is very good at what it does, but it is a bit rigid, and a bit messy under the hood.
- Additionally some aspects of Neutflux are less desirable now than they were when Neutflux was first written.

Neutflux: Aspects we want to move away from

- Rigidity: Neutflux is written to work only with Neut, and only with the Super K detector. Only works with atmospheric neutrinos.

- (Lack of) portability: Neutflux uses a file input scheme called “rflist”, which is proprietary software from Fujitsu, and requires SK libraries. Thus, not very portable.

- ZBS Bound: Neutflux uses (and requires!) ZBS output formats. ZBS is not intended to be the data format of HK. Requirement of ZBS libraries additionally reduces Neutflux’s portability.

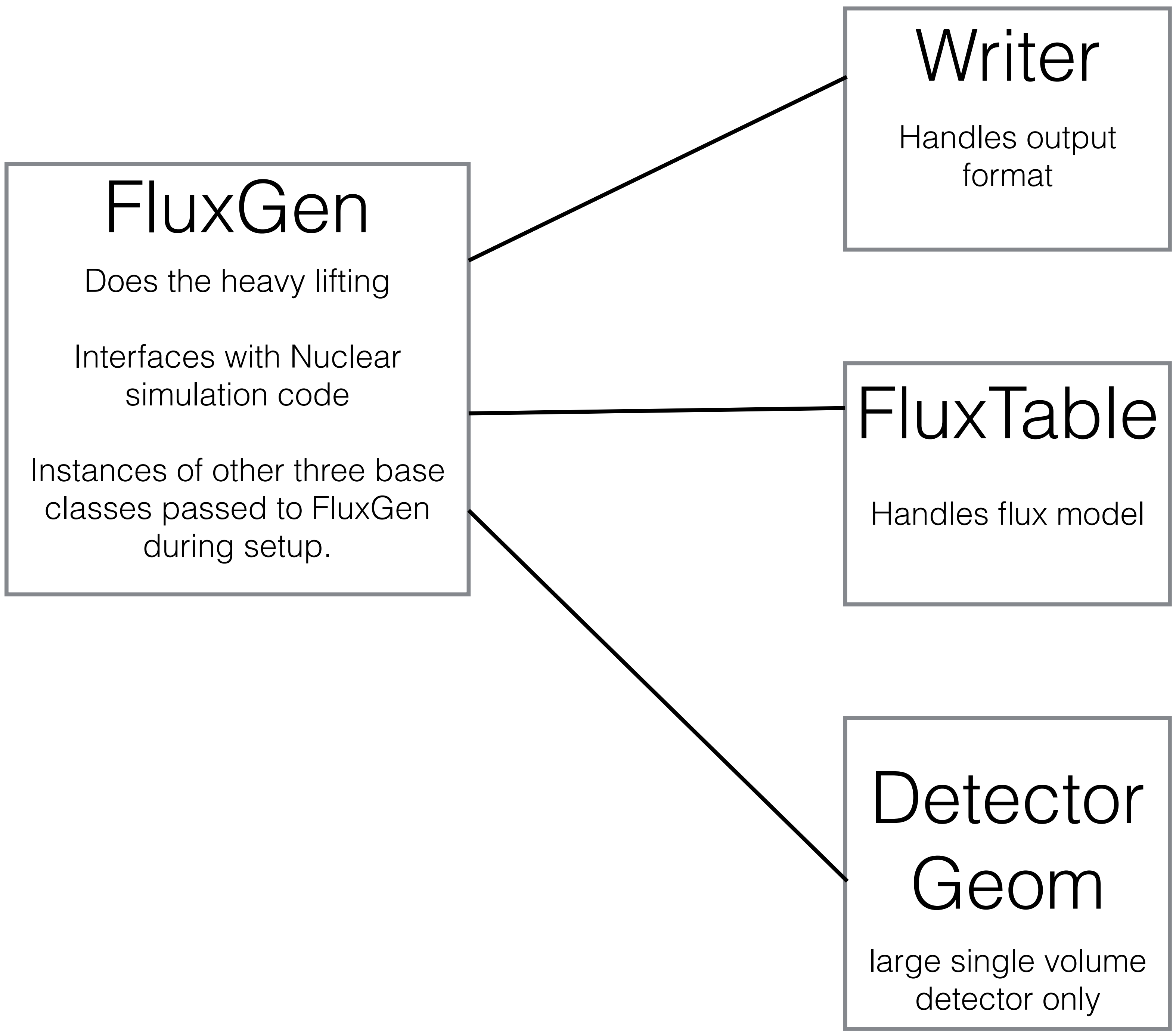
- All of these issues could be improved upon in Neutflux.
- But… better to create a more modern replacement software instead.
- So I’ve been working on creating a replacement, with very helpful oversight and guidance from Roger Wendell (Thanks Roger!)
- Intended for use at HK, SK, or any large single volume neutrino detector.

NGen: Overview

- written in C++, class based. Open source.
- Modular: Easily interchange different detector geometries, flux models, nuclear interactions simulators, output formats (can output multiple formats to different files simultaneously) through inheritance of abstract base classes.
- Dependencies: ROOT, Boost(optional), NO SK LIBRARIES.
- Uses random number generator TRandom3 from ROOT (based on Mersenne Twister). Seed can be set by hand for batch mode.
- Currently written with atmospheric neutrinos in mind, but flexibility will allow implementation of neutrino beam, supernova, solar, PDK, etc. —> One tool to do many fluxes, as opposed to separate tools for each flux.
- You can get NGen at: https://github.com/ckachulis/NGen.git (will be moved to a more official repository soon).

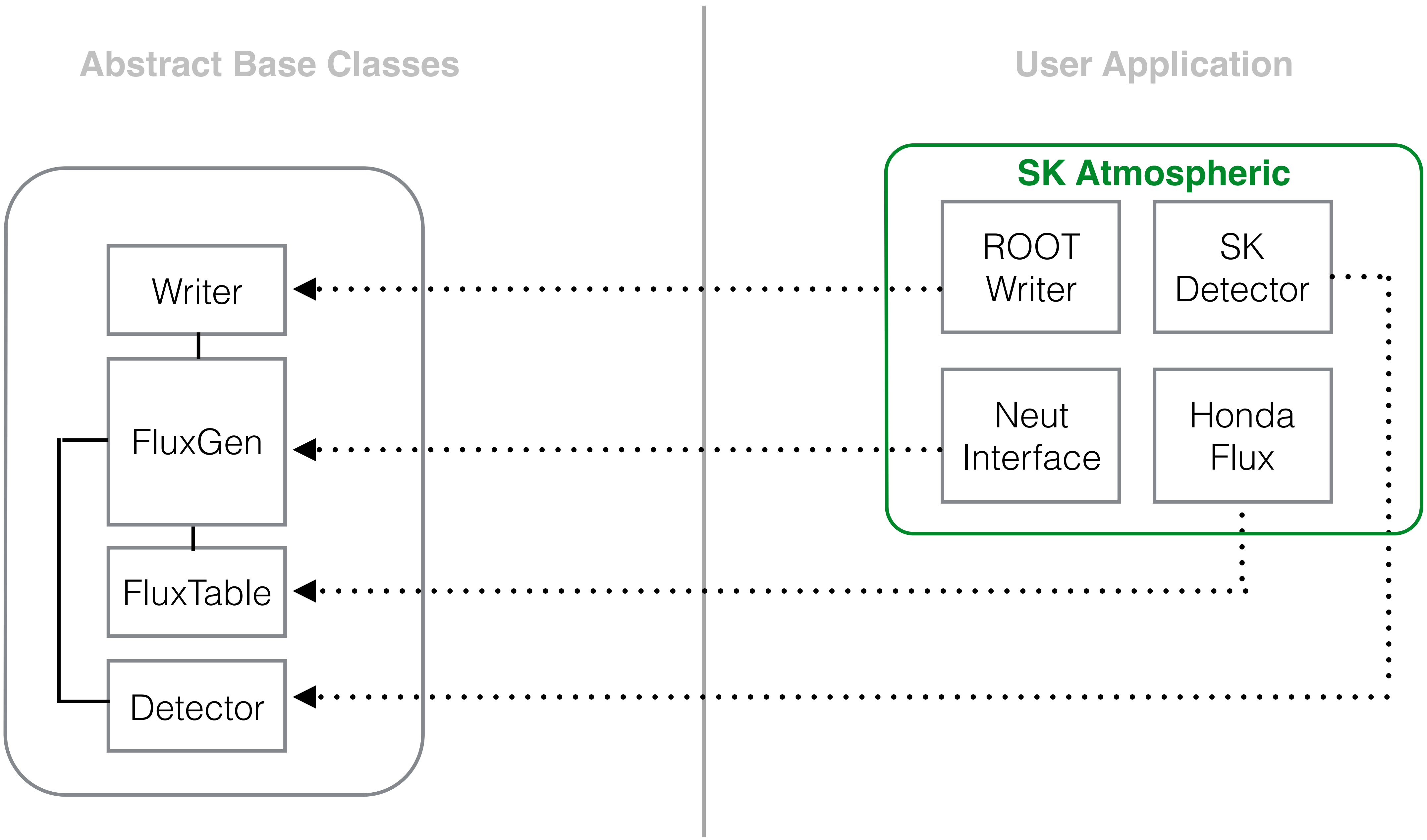
How It Works

Built around 4 abstract base classes



How It Works

User inherits abstract base classes to create application



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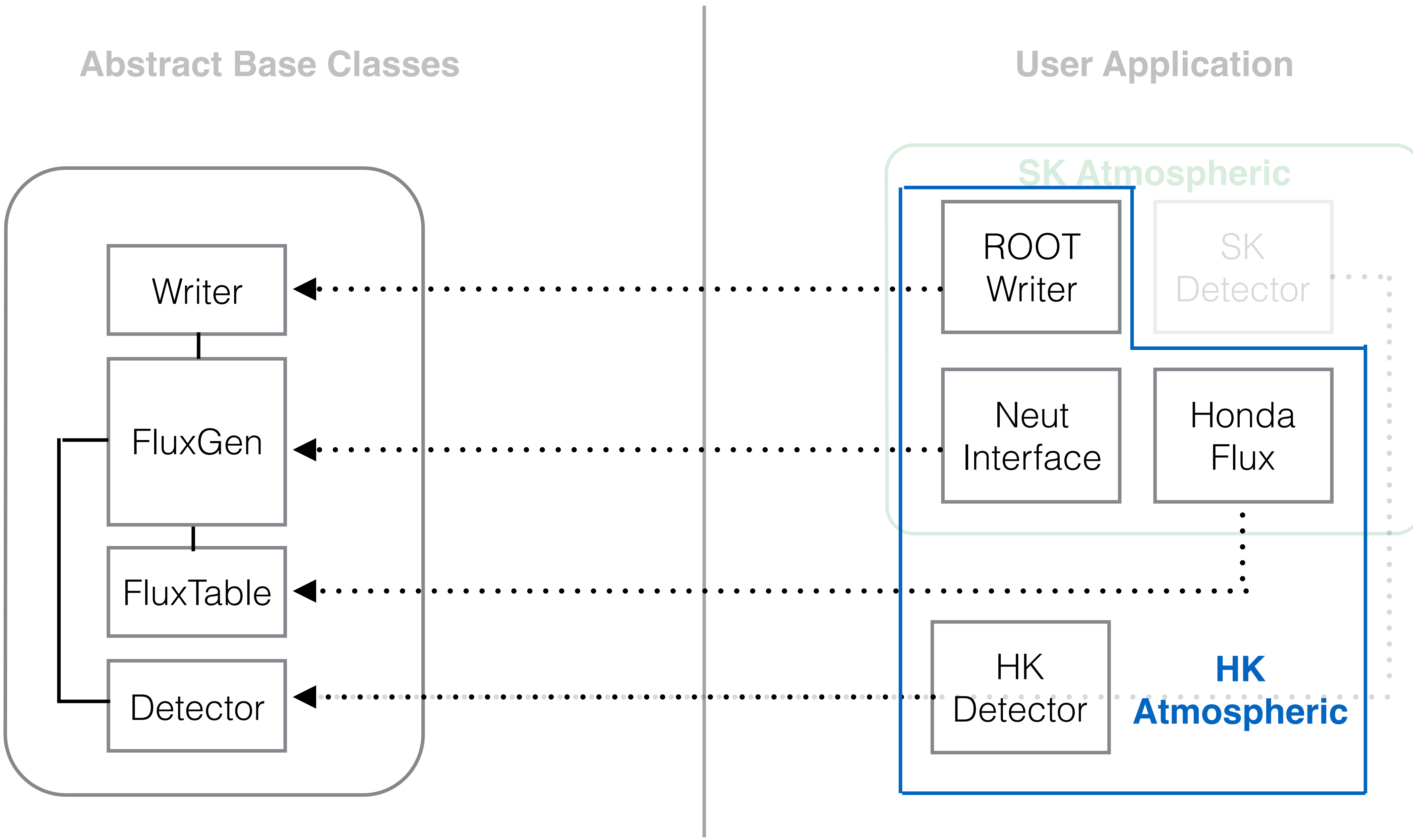
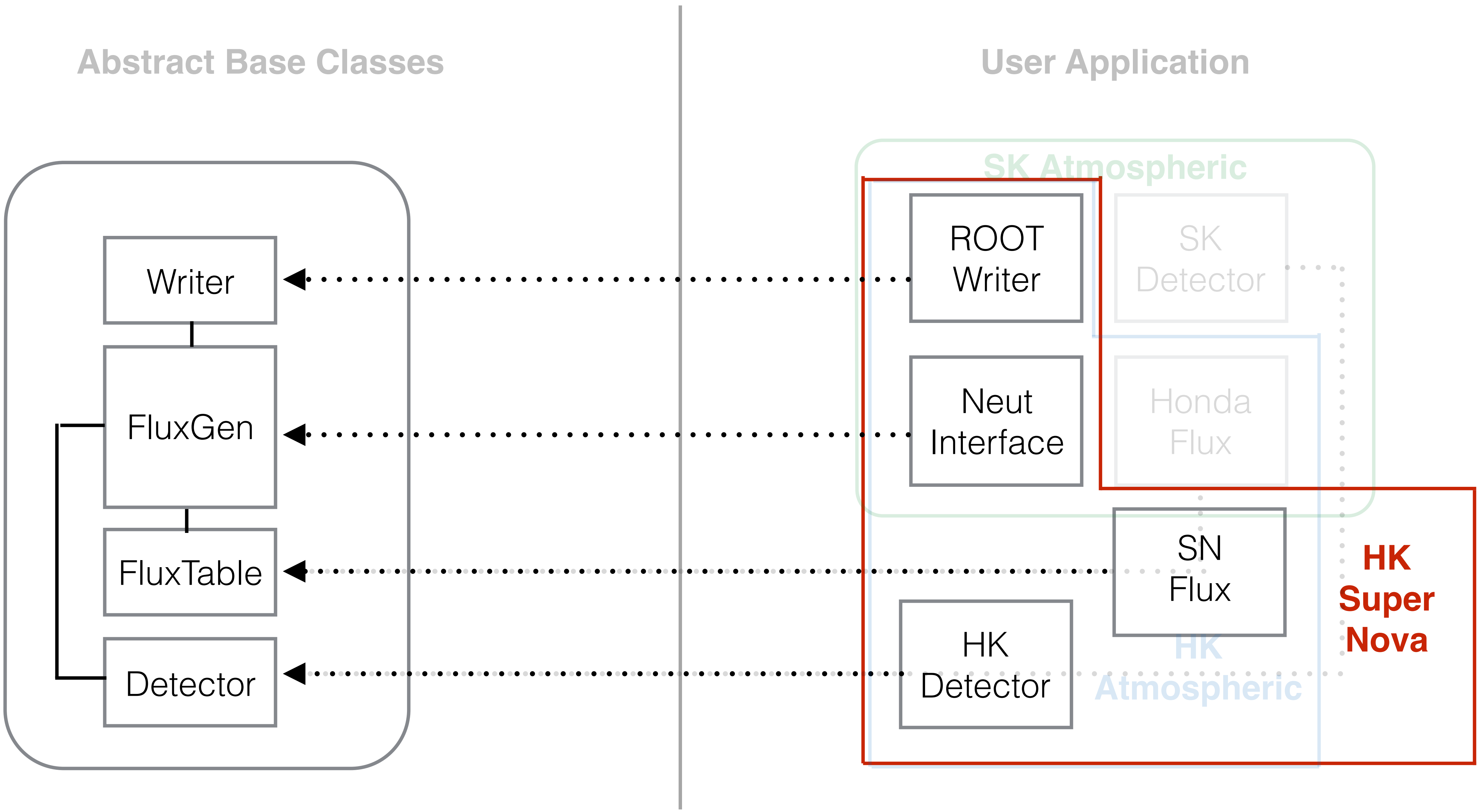


Modularity comes from changing single child class

In this example, ROOT Writer, Neut Interface, and Honda Flux are the same as in SK Atmospheric. Only change is SK Detector —> HK Detector

How It Works

User inherits abstract base classes to create application

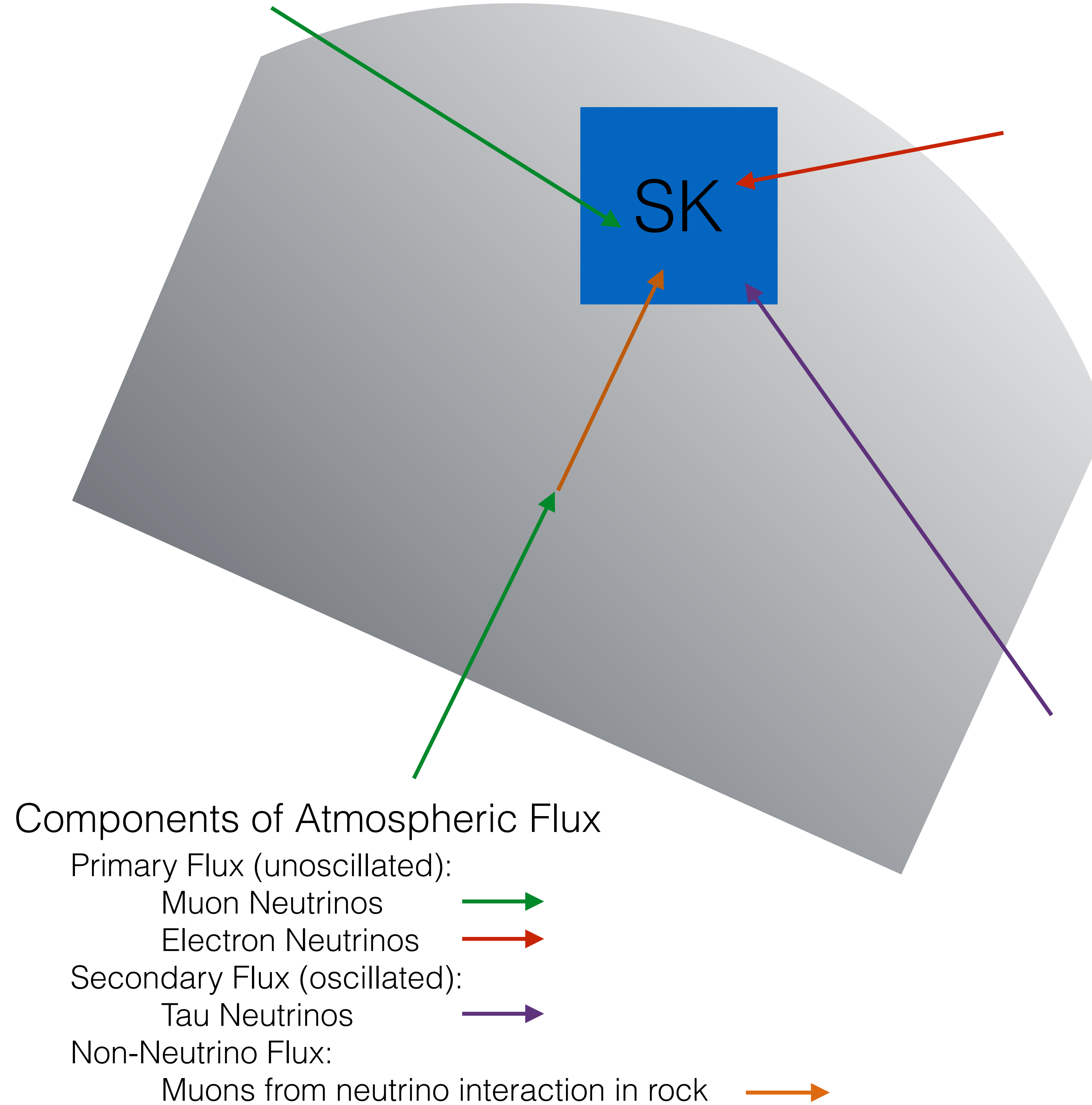


Modularity comes from changing single child class

In this example, ROOT Writer, Neut Interface, and HK Detector are the same as in HK Atmospheric. Only change is Honda Flux —> SN Flux

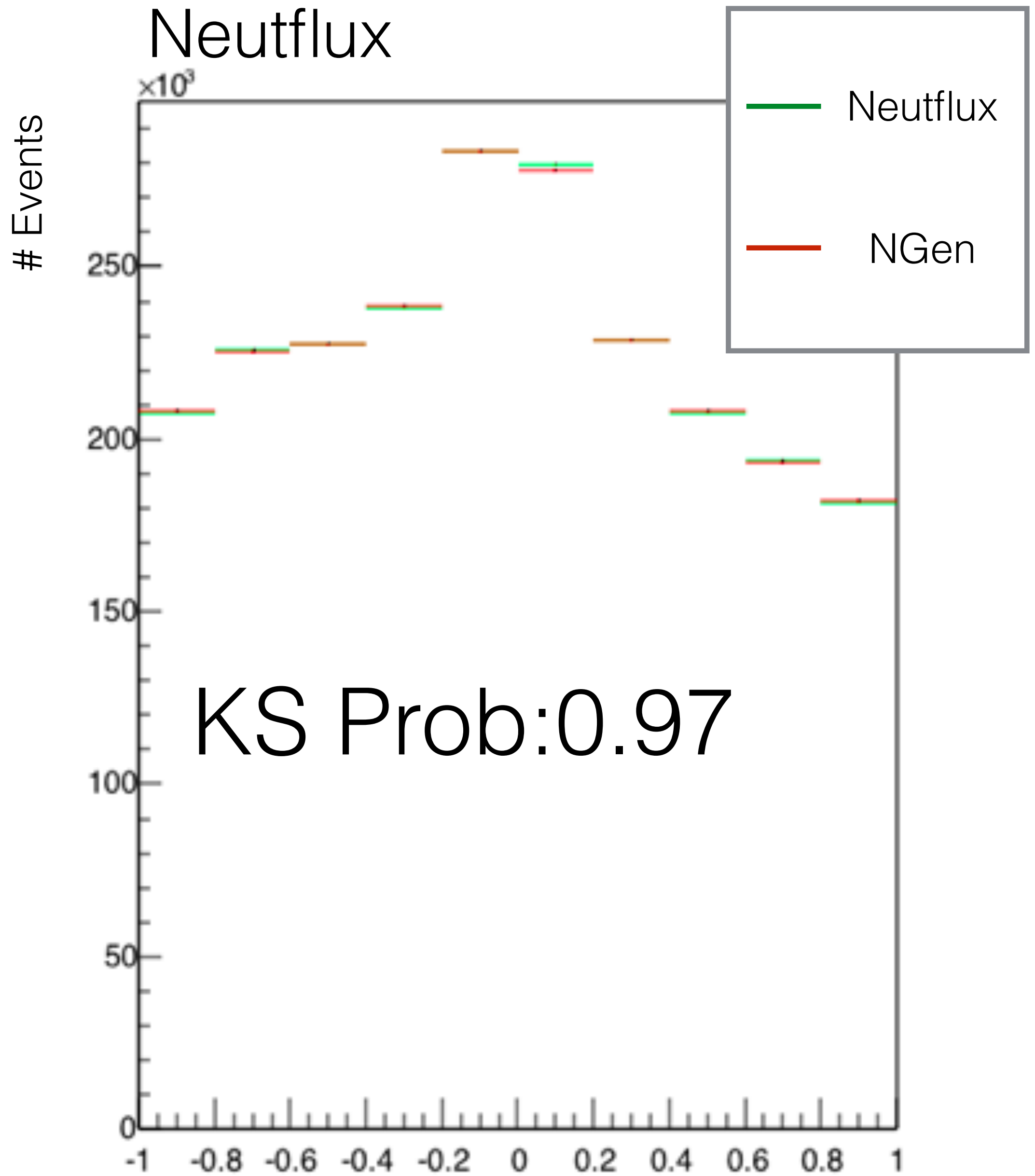
Current Status

- I currently have written applications for HK and SK atmospheric neutrinos using Honda Flux and Neut, with ZBS, Nuance and ROOT outputs. Nuance format feeds into WCSim, has been tested successfully.
- Currently validating for SK by comparison to Neutflux. Nu_mu and Nu_e are fully validated, working on Nu_tau currently, then Muons from rock.
- Because of modularity, validation for SK ≈ validation for HK
  - only difference is SK detector —> HK detector

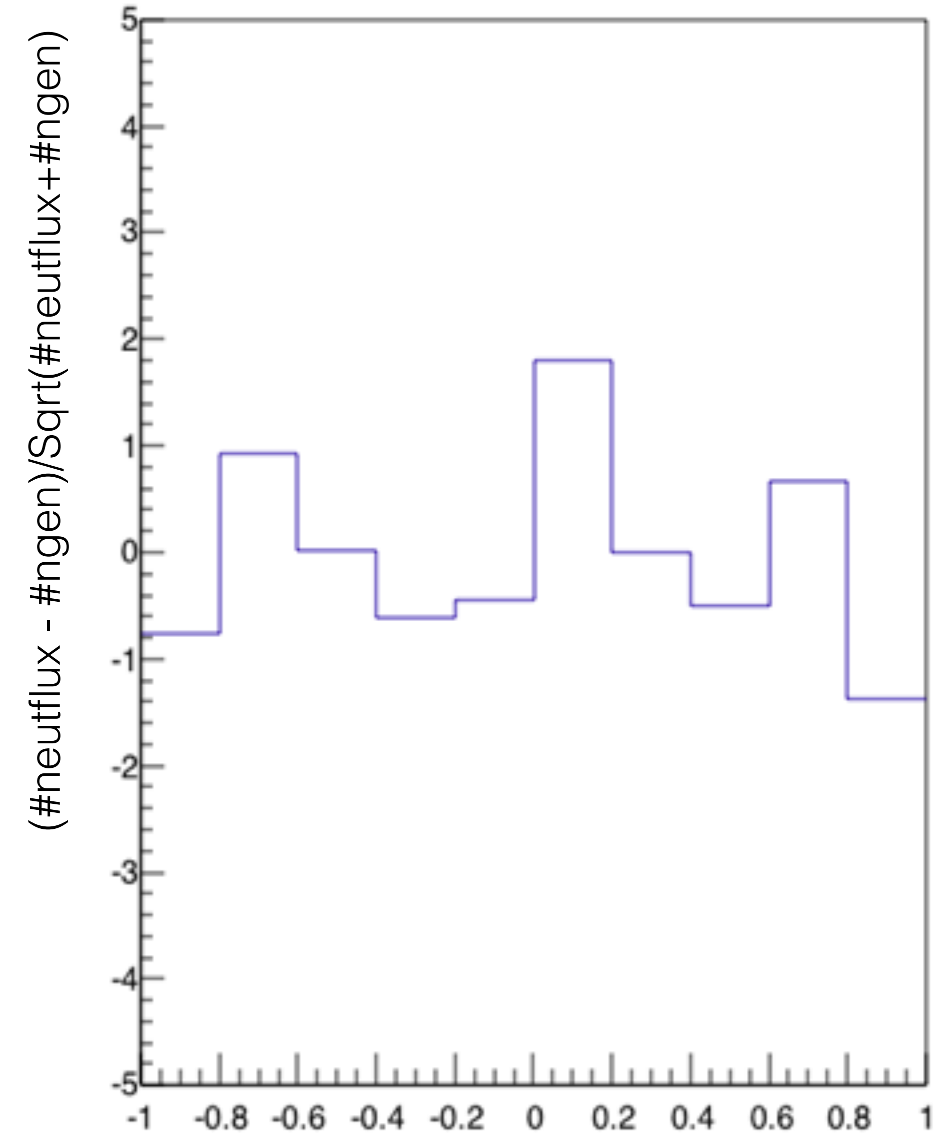


Validation Example

- 200 yrs atmospheric SK MC
- Nu_mu + Nu_e
- Comparing NGen to Neutflux
- KS prob is P value from unbinned KS Test
- Many more plots and tables in backup



σ Residuals



Cos Zenith Incoming Neutrino

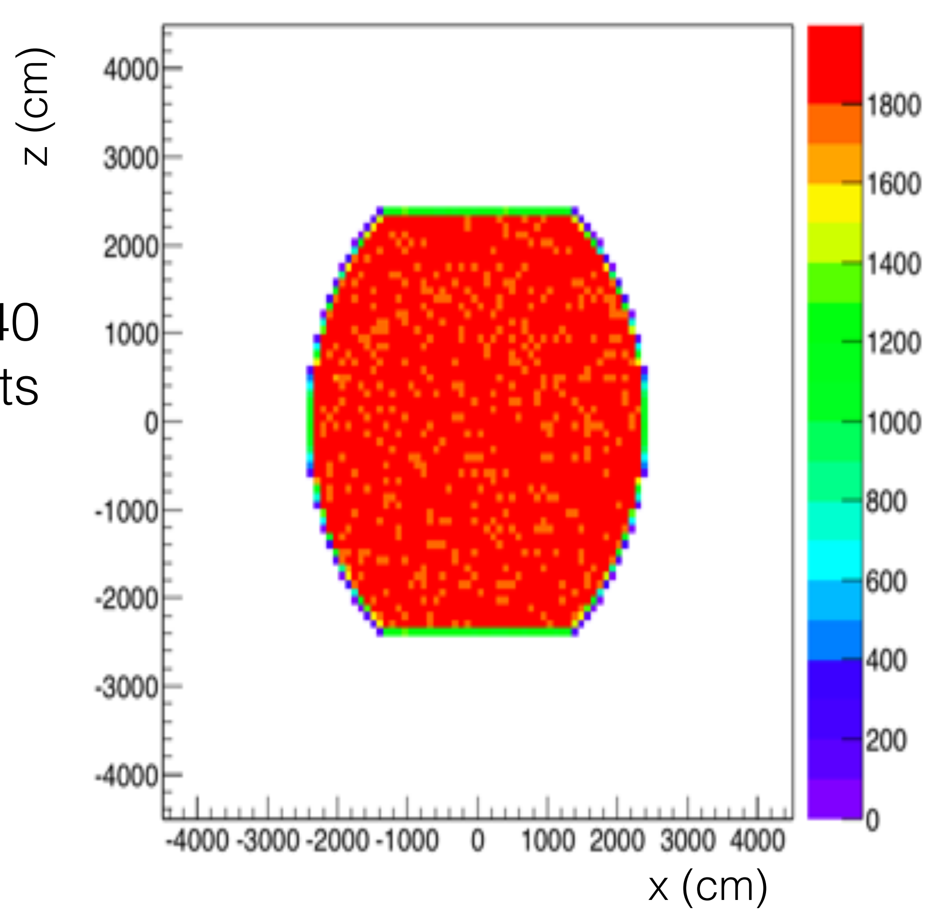
HK Production

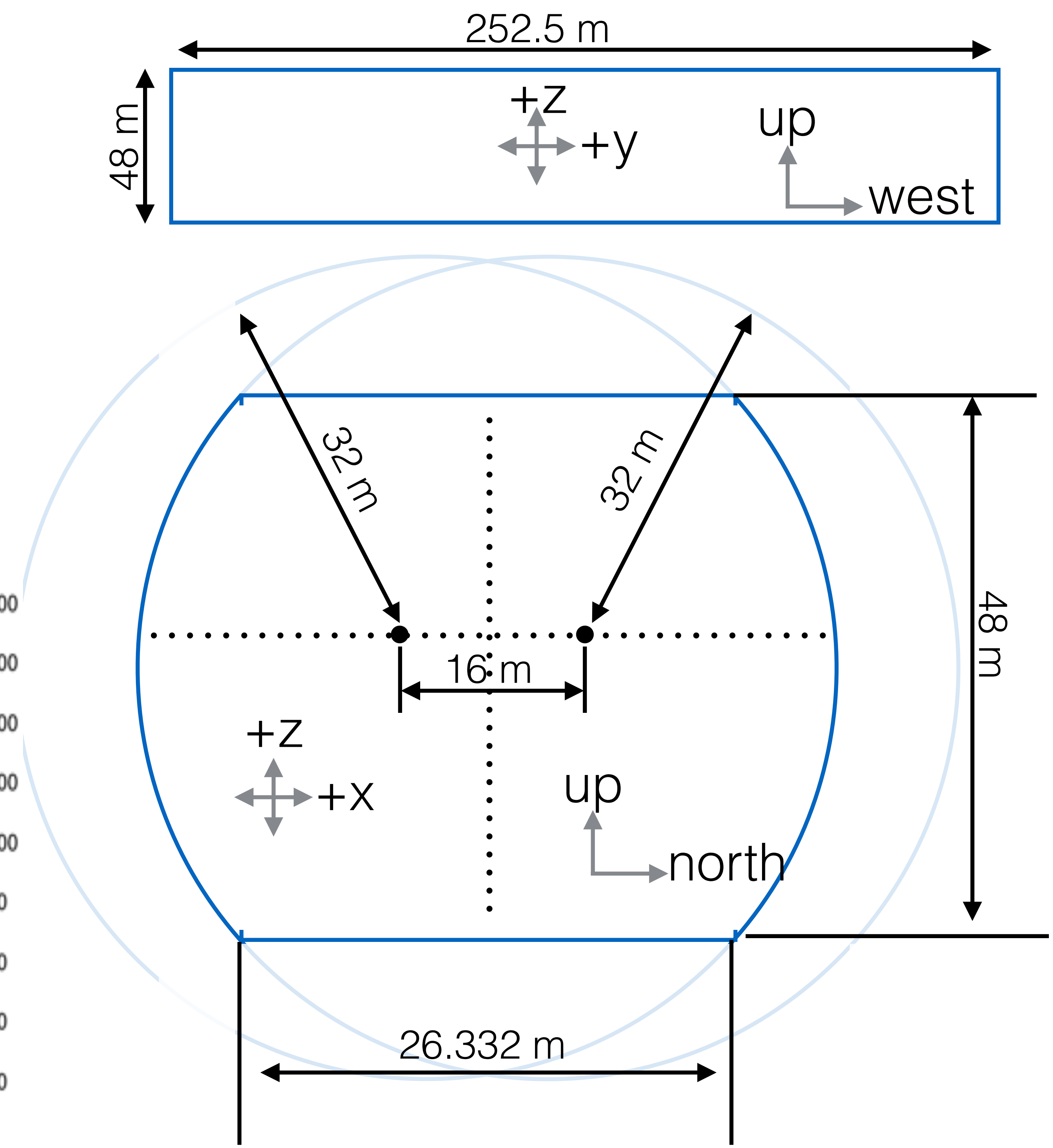
This is the HK geometry I currently have implemented

Because of modularity, adjusting, rotating and moving this geometry is very simple and quick. Good for optimization.

Can also easily replace with other geometries, again good for optimization

cross sectional position for 40 Yrs HK events (~500 kT)





Summary and Future

- NGen is a neutrino event generator with flexibility to be used with many different types of neutrino flux, detectors geometries, nuclear simulation models.
- Atmospheric Application: Finish validation for SK, run validation for HK (basically just geometry validation).
- Implementation of other types of fluxes (SN, beam, solar, PDK…). Will require time dependent flux capability, currently fluxes assumed to be constant in time.
- More to come soon!

Supplemental

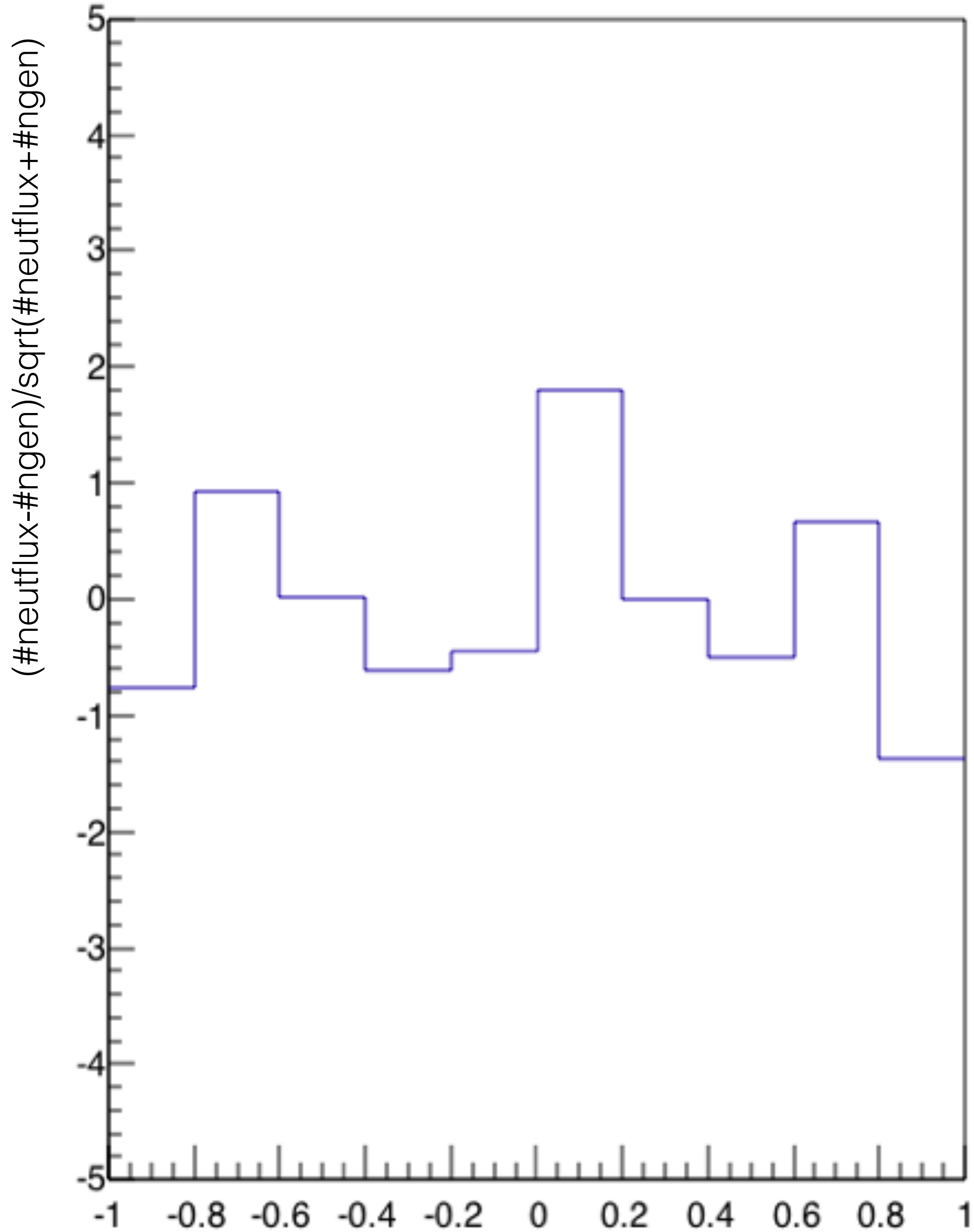
Validation Plots (Nu_mu + Nu_e)

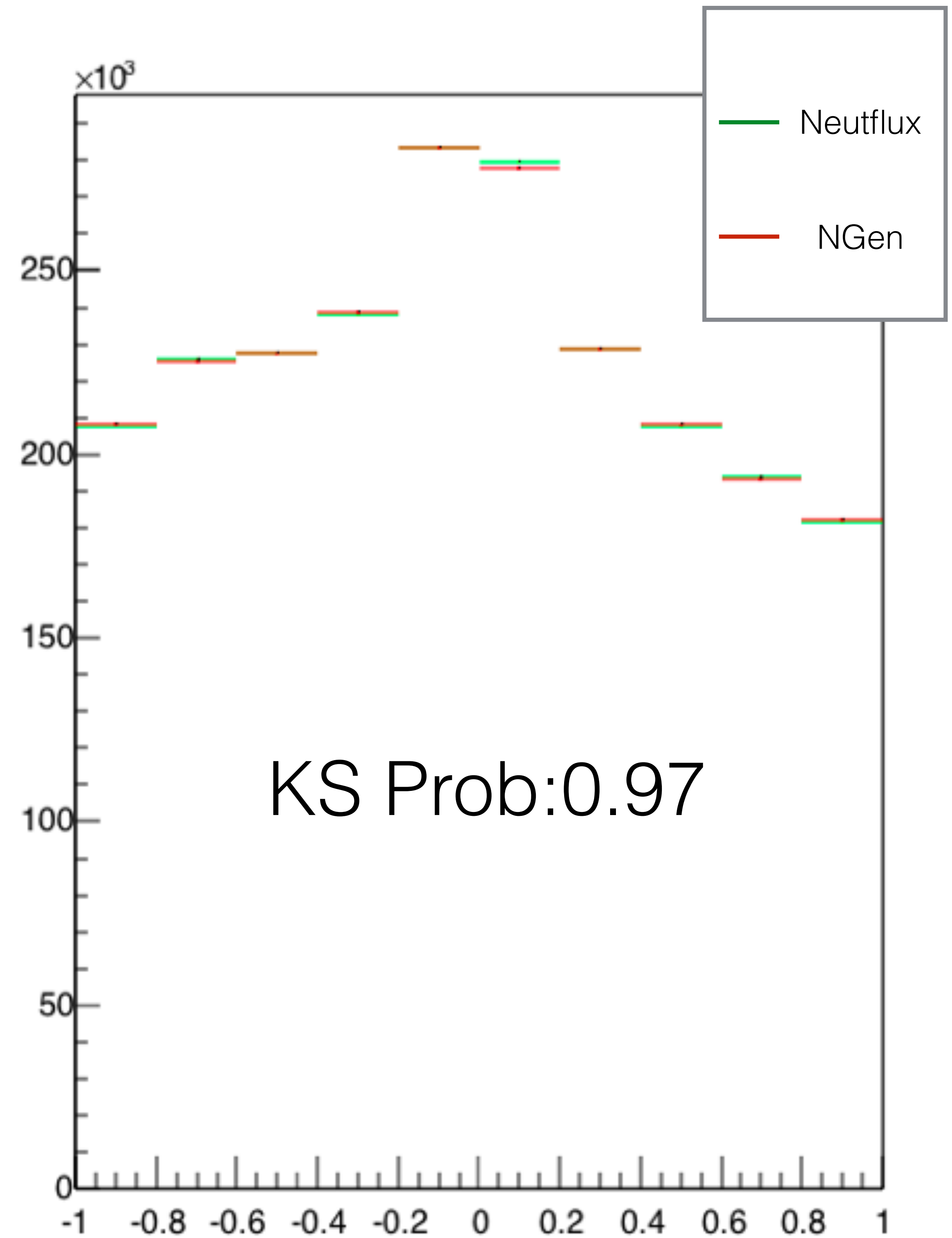
- 200 years MC, using Neut 5.3.2 and hkkm06mt, honda96low. Comparing to Neutflux.

- Using unbinned KS test to compare CosZ, Azimuth, Energy spectrum.

- Using Chi2 to compare “Number of particles” and “Interaction mode” (since KS test not valid for these non continuous distributions).

Neutrino CosZ

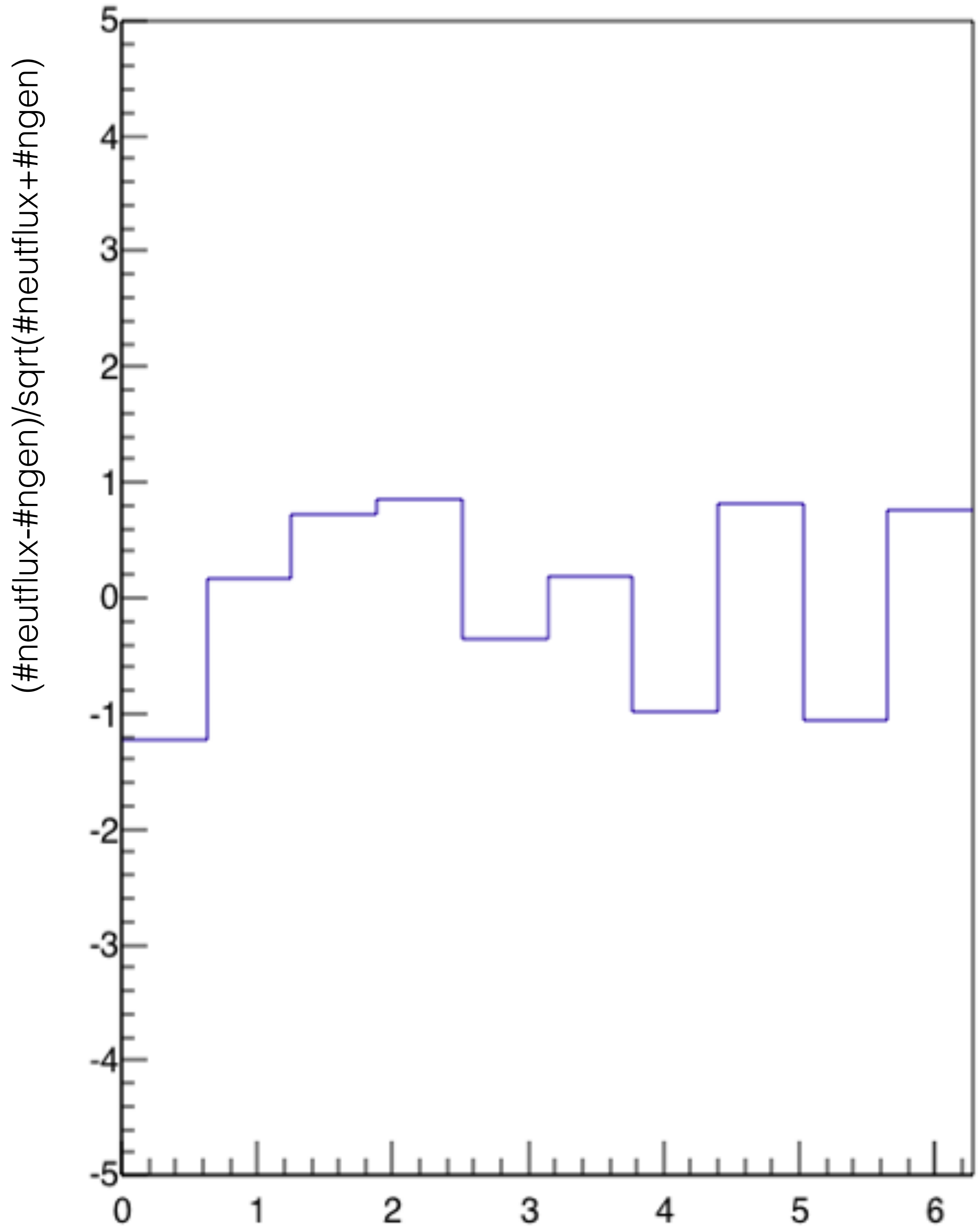


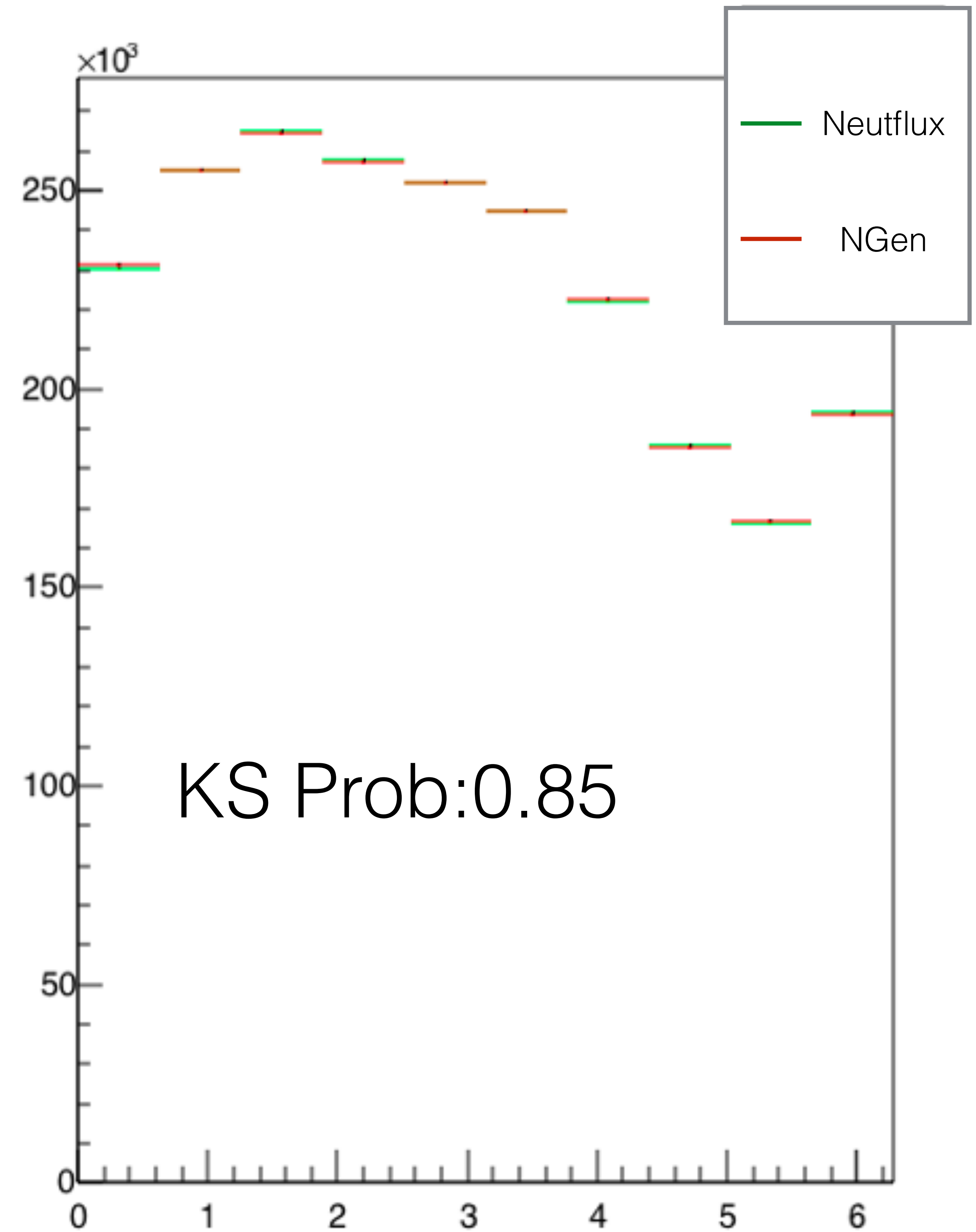


CosZ

ν

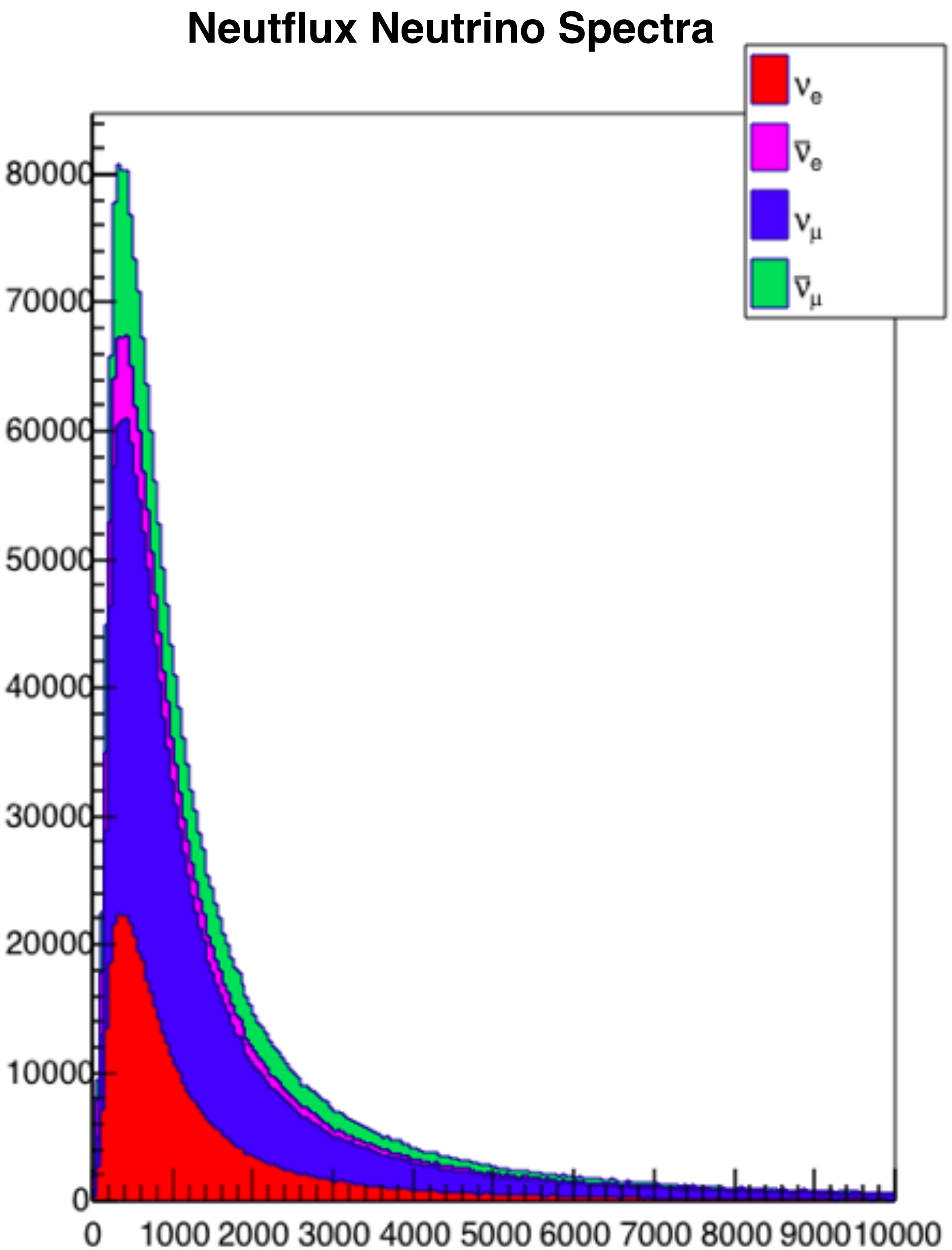
Neutrino Azimuth

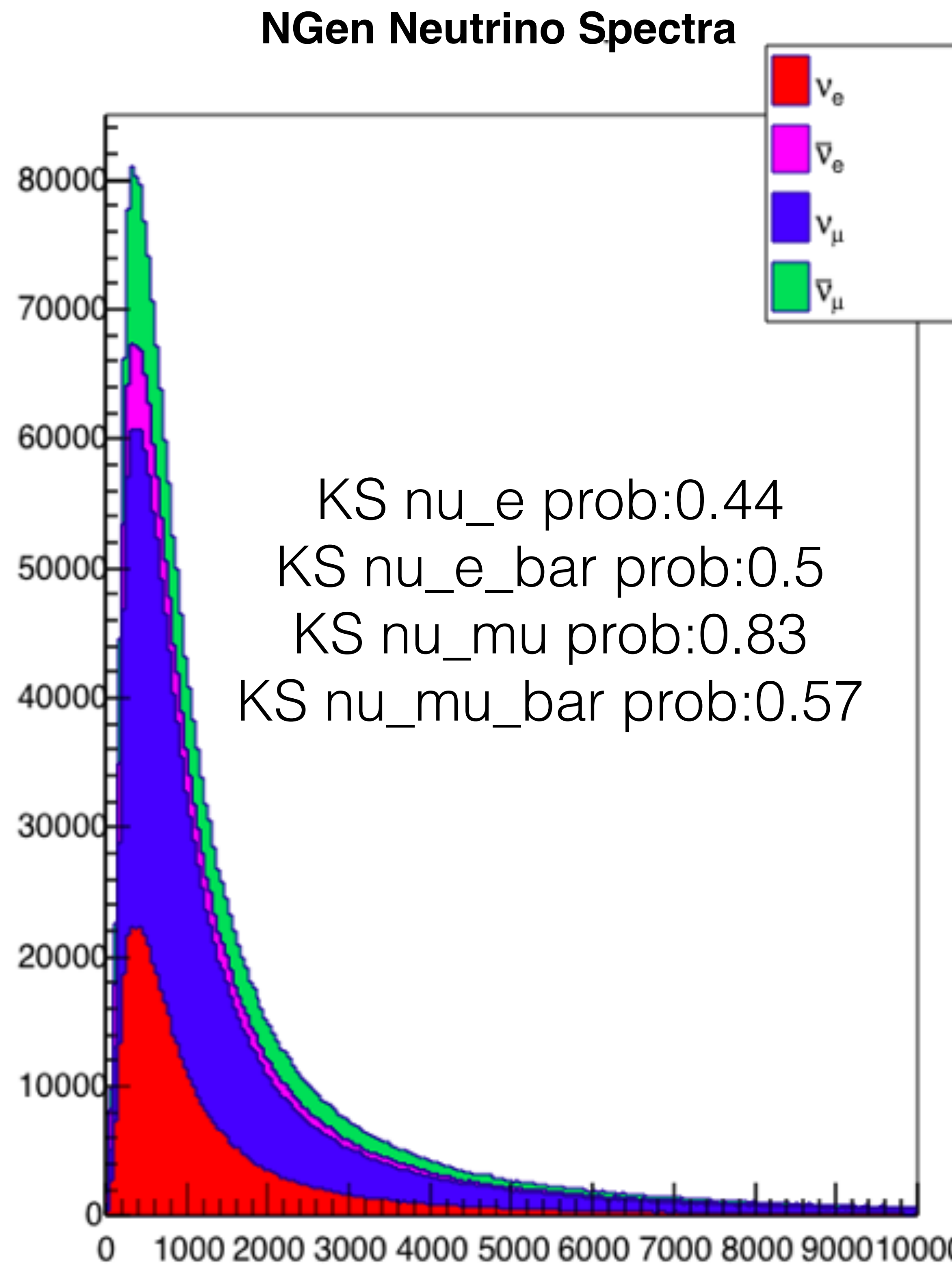




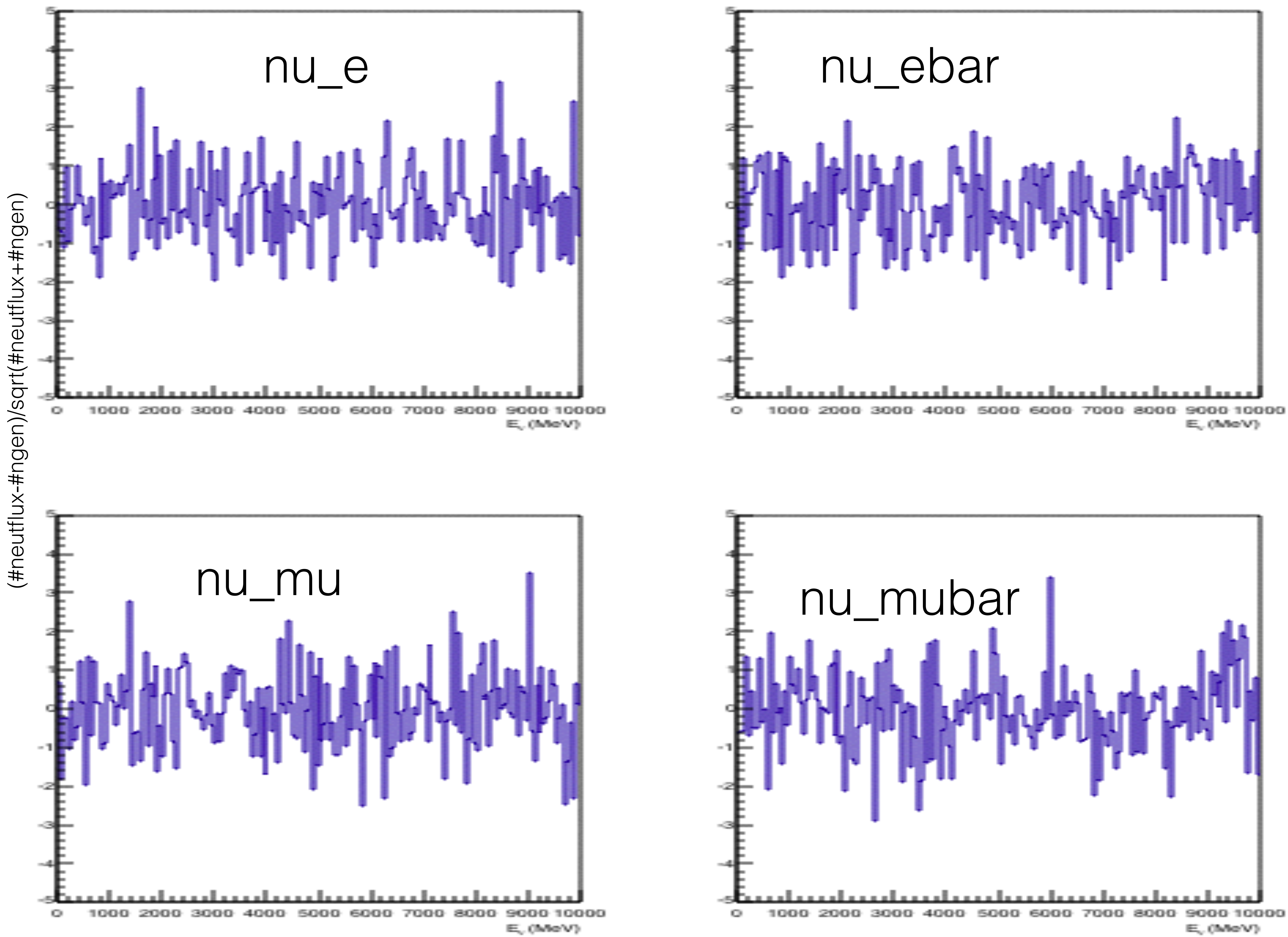
Phi

Neutrino Energy Spectra

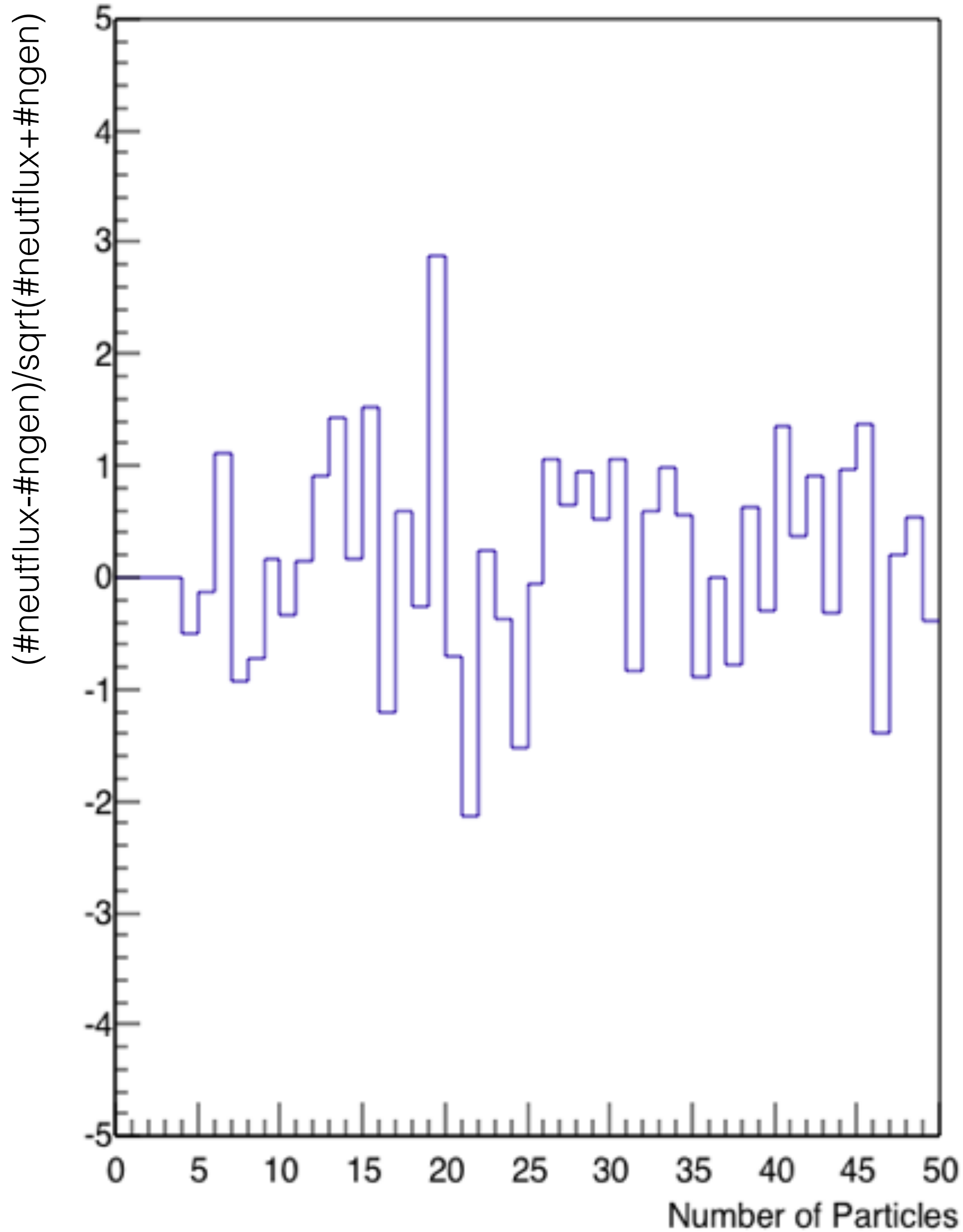


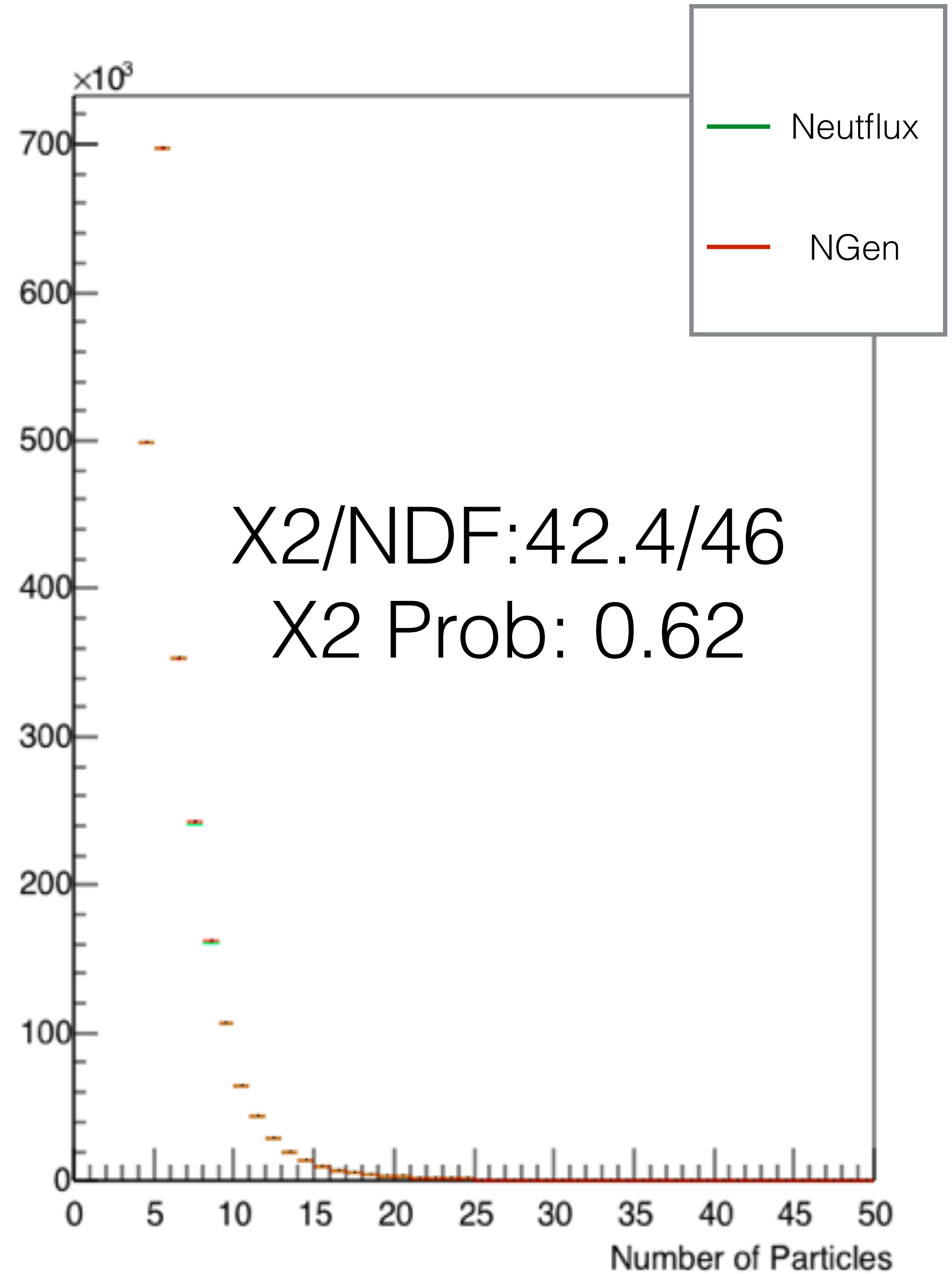


E_nu (MeV)

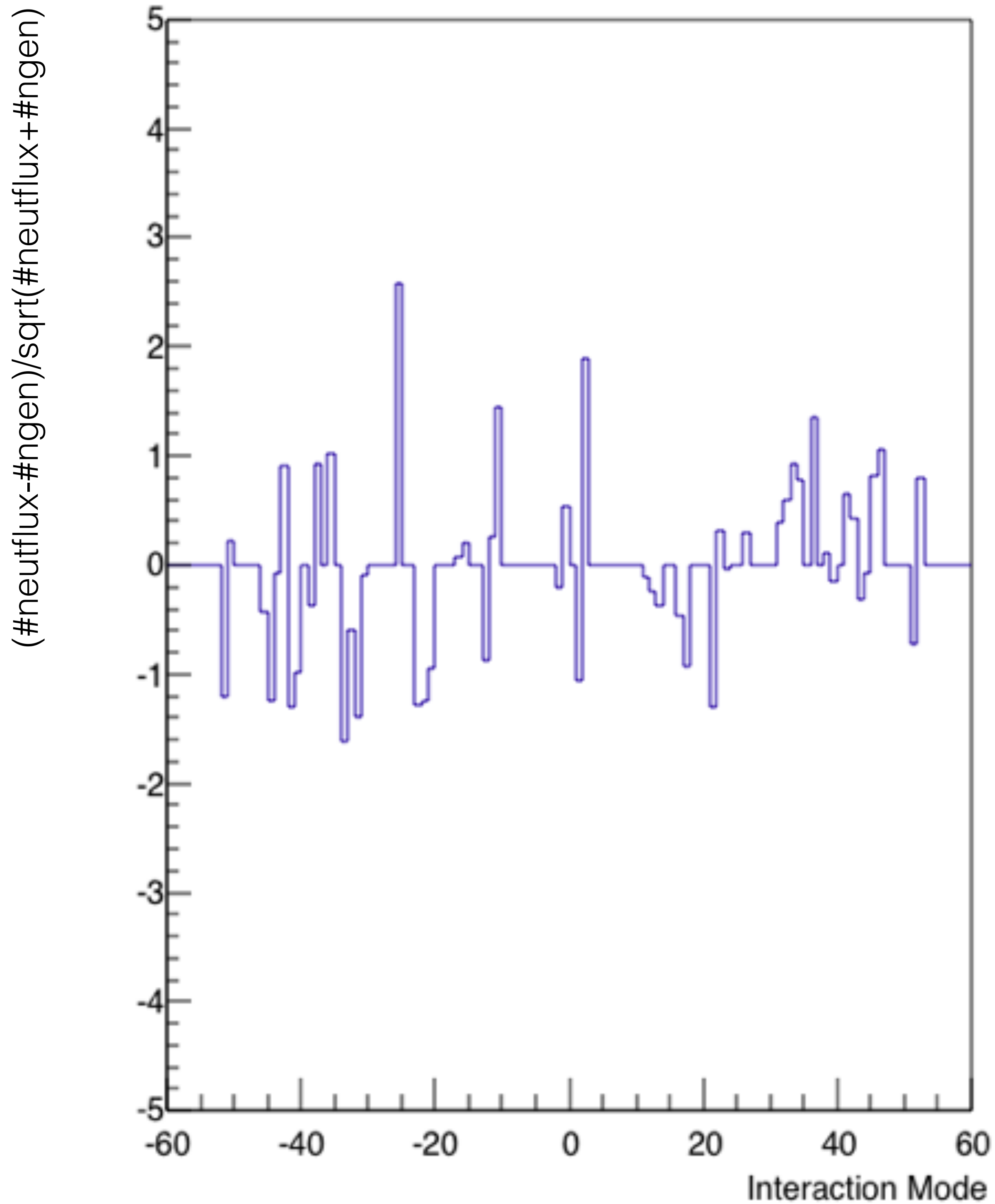

(#neutflux-#ngen)/sqrt(#neutflux+#ngen)
nu_e
nu_ebar
nu_mu
nu_mubar
0 1000 2000 3000 4000 5000 6000 7000 8000 9000 10000

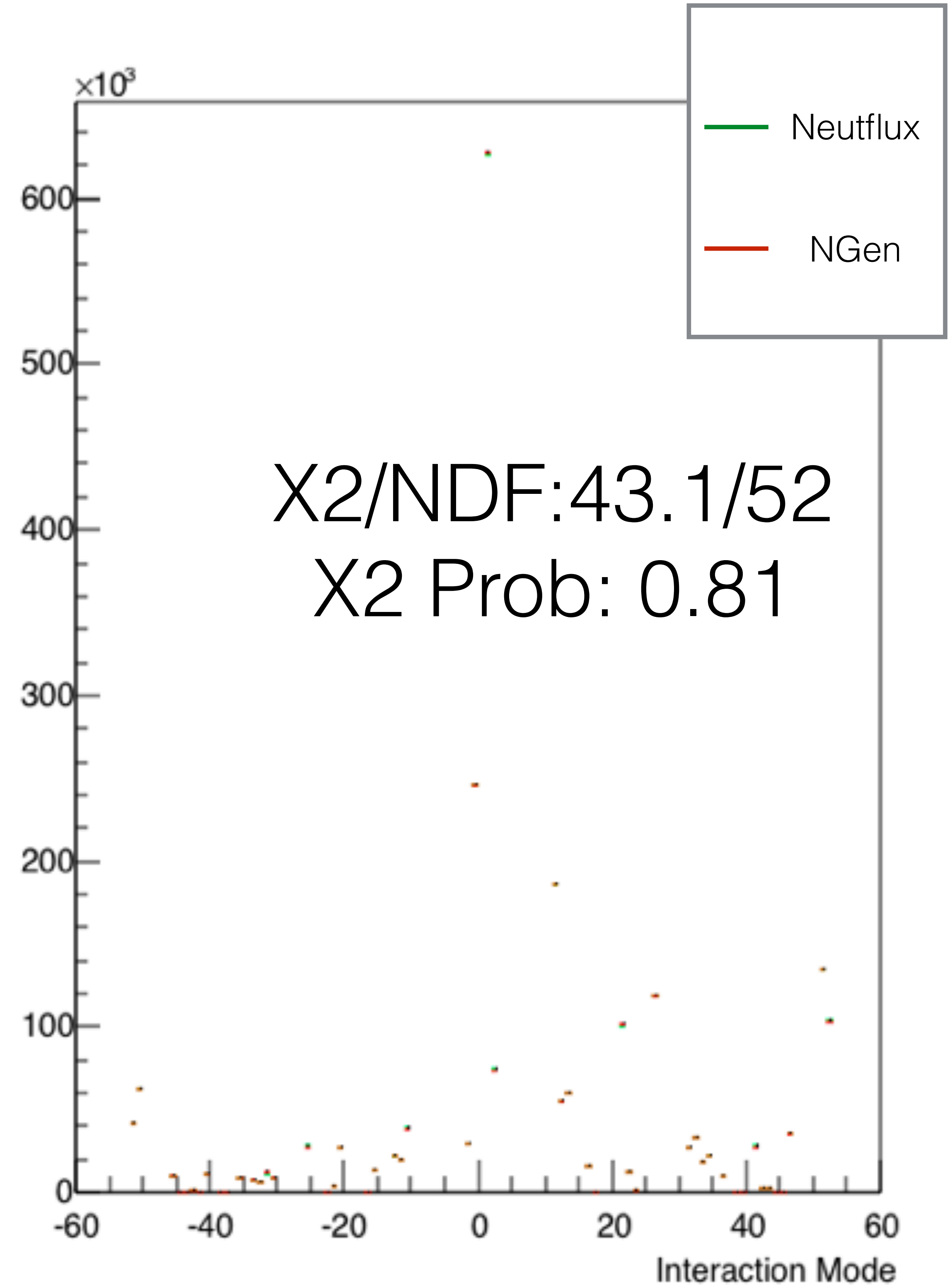
Number of Particles





Interaction Mode





Secondaries

- I also calculated KS probs for CosZ, Azimuth, and Energy Spectrum for all secondary particles. Values in table for these rows are "KS Prob".

- In tables on next two slides I'm counting only secondaries which are marked for tracking through detector simulation.

- σ diff =(#neutflux-#ngen)/sqrt(#neutflux+#ngen)

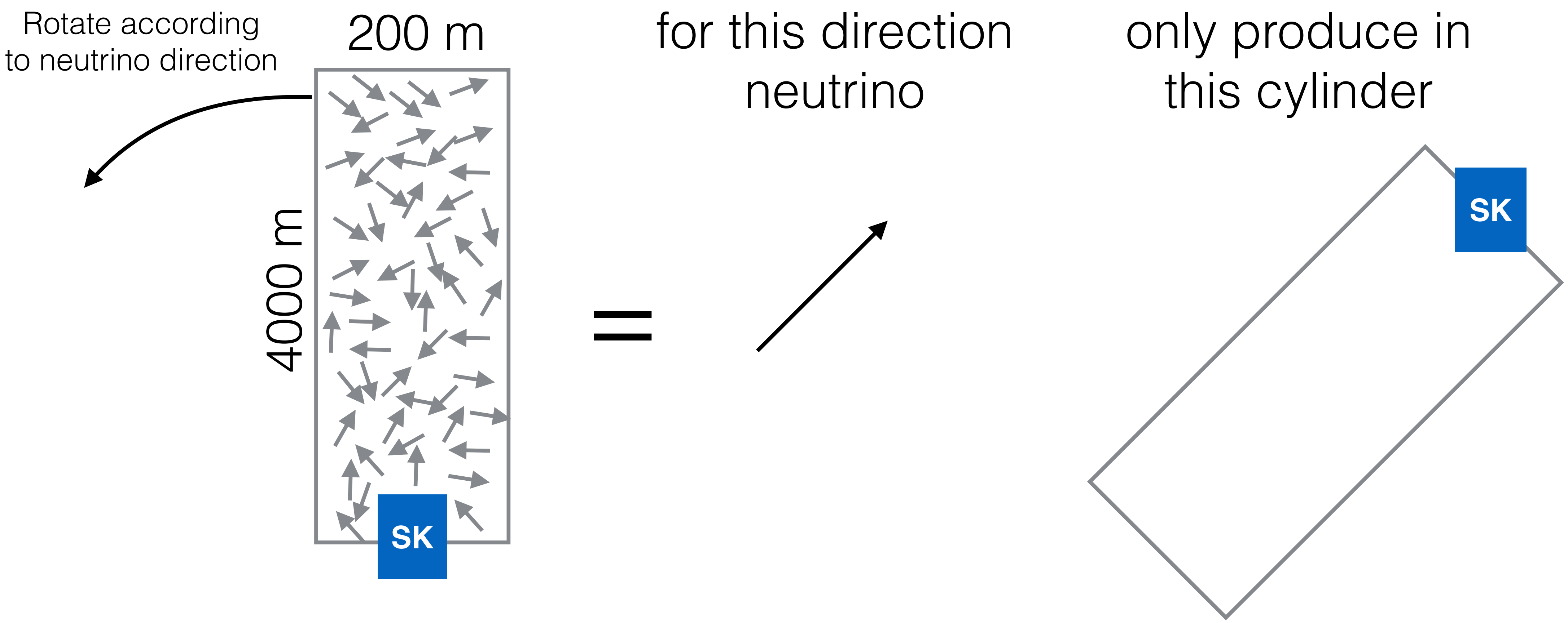
ν

	$\bar{p}$	$\bar{n}$	K-	π-	$\bar{\nu}_\tau$	$\bar{\nu}_\mu$	μ+	$\bar{\nu}_e$	e+
Theta	0.9	0.84	0.21	0.25	0.98	0.82	0.92	0.2	0.78
Phi	0.85	0.57	0.24	0.35	0.12	0.39	0.82	0.38	0.12
E_spec	0.24	0.74	0.75	0.80	0.34	0.77	0.53	0.33	0.8
# Neutflux	2418	2143	8619	335308	6	78830	293778	34694	133495
# Atmflux	2276	2148	8558	333574	3	79266	293000	34415	133449
σ Diff	2.07	-0.08	0.47	2.12	1	-1.10	1.02	1.06	0.09

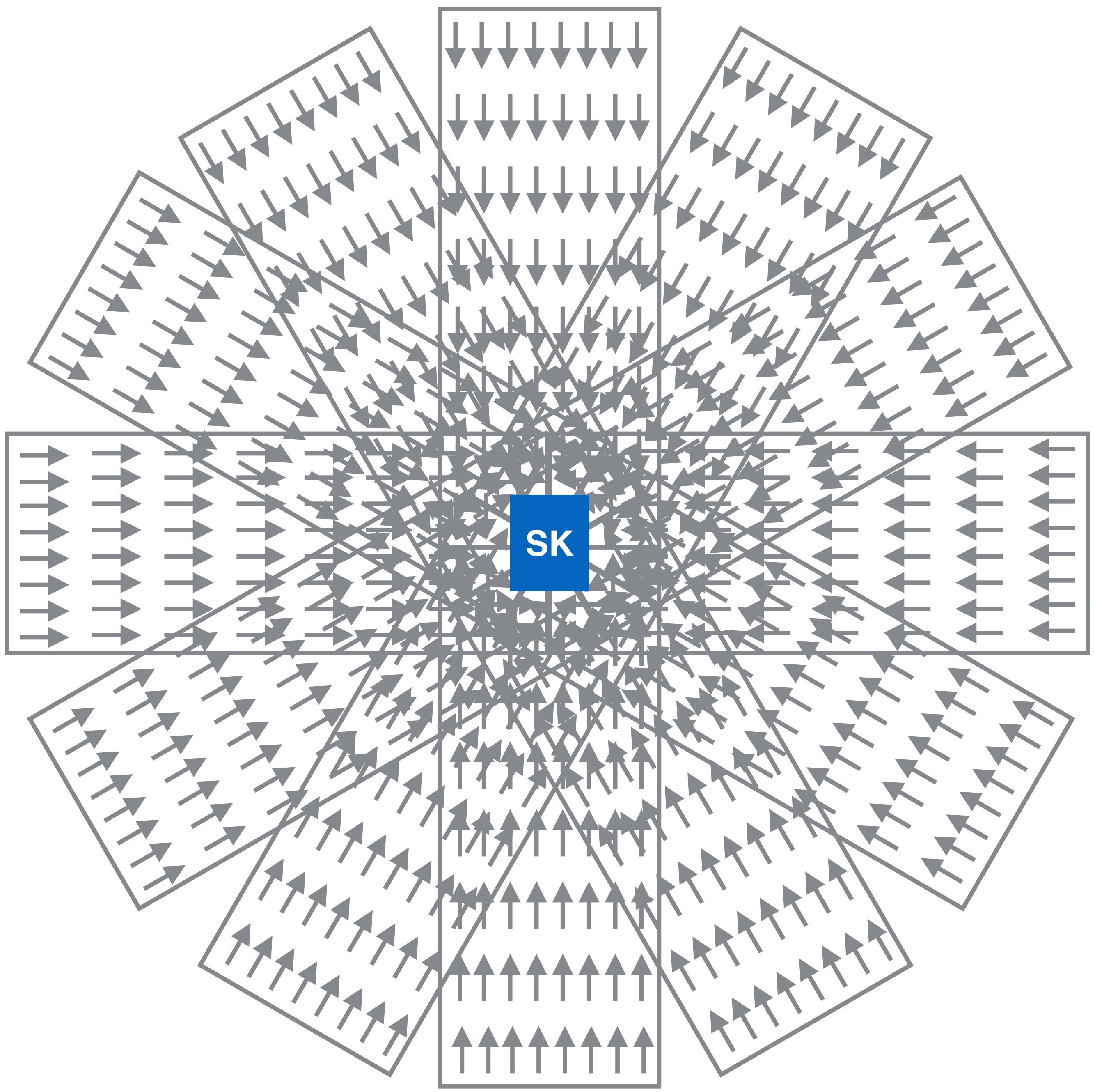
ν

	e-	ν_e	μ-	ν_μ	γ	π^0	K^0_L	K^0_S	π+	η	K+	n	p	Λ
Theta	0.95	0.16	0.6	0.54	0.71	0.16	0.1	0.67	0.6	0.11	0.38	0.93	0.89	0.44
Phi	0.31	0.08	0.03	0.63	0.73	0.43	0.57	0.43	0.46	0.71	0.85	0.44	0.51	0.12
E_spec	0.67	0.96	0.52	0.18	0.62	0.08	0.53	0.17	0.8	0.38	0.69	0.93	0.45	0.012
# Neut flux	426,586	83,099	817,856	164,917	840,856	466,514	11,787	11,809	580,860	45,038	20,021	1,578,644	2,336,375	3,628
# Atmflux	426,936	83,115	818,106	164,721	841,773	466,104	11,642	11,718	580,653	45,211	19,802	1,577,392	2,335,480	3,676
σ Diff	-0.38	-0.04	-0.2	0.34	-0.7	0.42	0.95	0.6	0.19	-0.58	1.1	0.7	0.41	-0.56

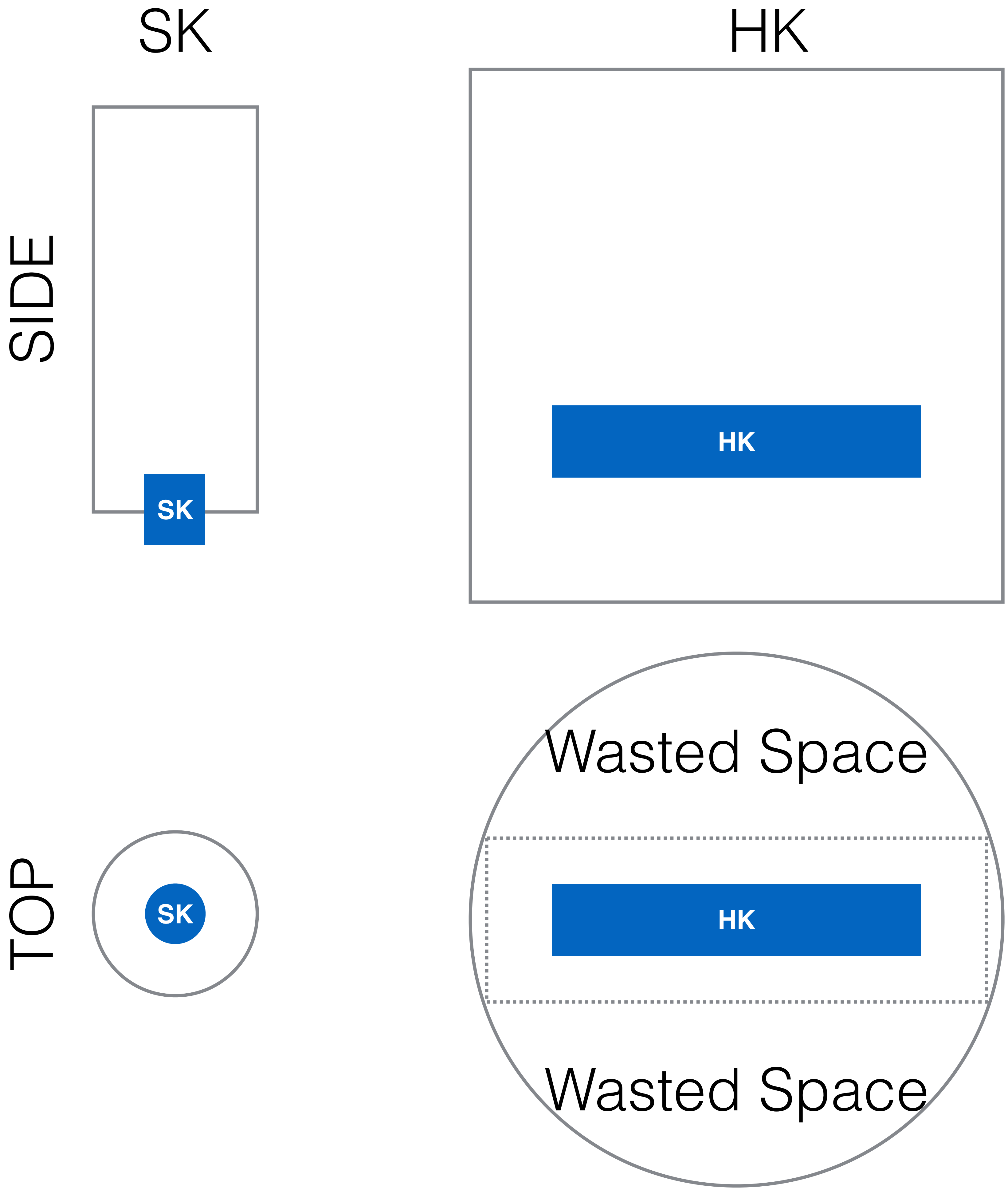
UpMu: Neutflux Trick



- Instead of proposing events in full sphere around detector, only propose in large cylinder extending above detector
- Then for each event, rotate position so that neutrino momentum point along rotated cylinder to detector



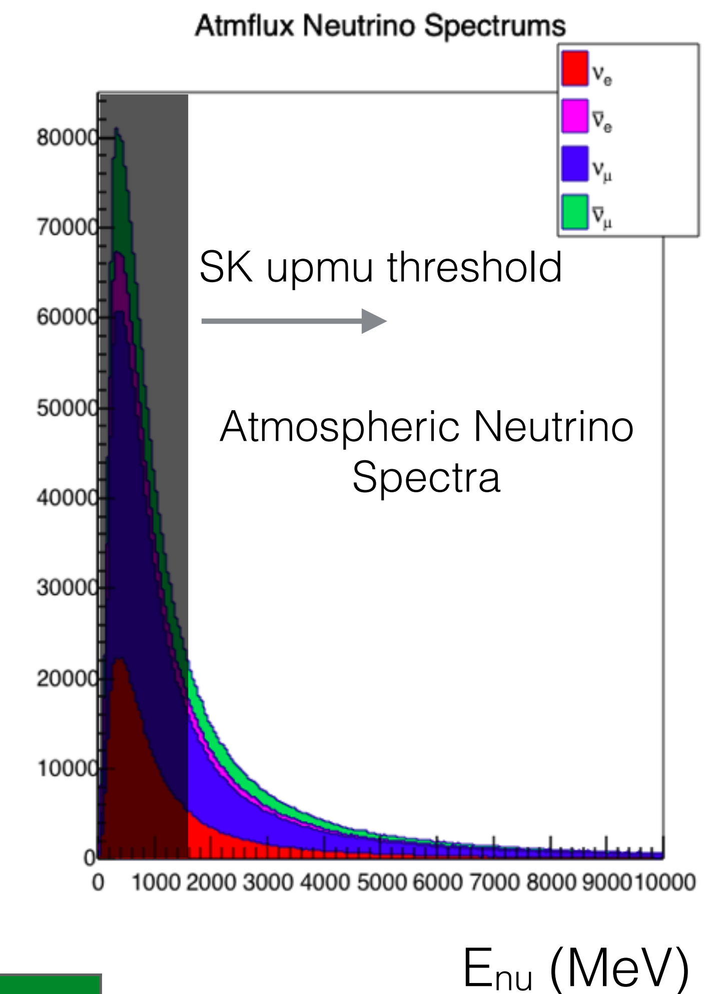
- This means we are only proposing those events which point roughly toward the detector.
- Significantly fewer events now. Ratio of events is $4/3\ R^3_{sphere}/(R_{sphere}\ R^2_{cyl})$
- For SK Neutflux this is a factor of 2133
- Massive speedup



- HK might not have SK's helpful "spherical symmetry"
- Lot more wasted space if we use a cylinder
- Switch to "large box". Rotations become slightly more complex (requires third euler rotation), but still can be done.

Additional Time Saving: Russian Dolls

- Neutrino event spectrum falls sharply with energy. Vast majority of events come from neutrino with energy below 10 GeV.
- 10 GeV muon has range in rock ~20 m. However we simulate a 4 km sphere! Extremely inefficient.
- In fact more than 98% of the time, a proposed energy-position pair is immediately tossed out because resulting muon would have no chance of reaching detector. More efficient to not propose these pairs to begin with.
- Solution: “Russian Dolls”, perform simulation of energy steps. For each energy chunk use different radius, dependent on highest energy.
- Leads to roughly factor of 2 speedup for SK. Not yet tested on HK



Example

Energy	Radius
1 -10 GeV	60 m
10- 100 GeV	450 m
100 GeV - 90 TeV	4000 m