$n \to \bar{n}$ and $p \to K^+\bar{\nu}$ Atmospheric ν Backgrounds

Update

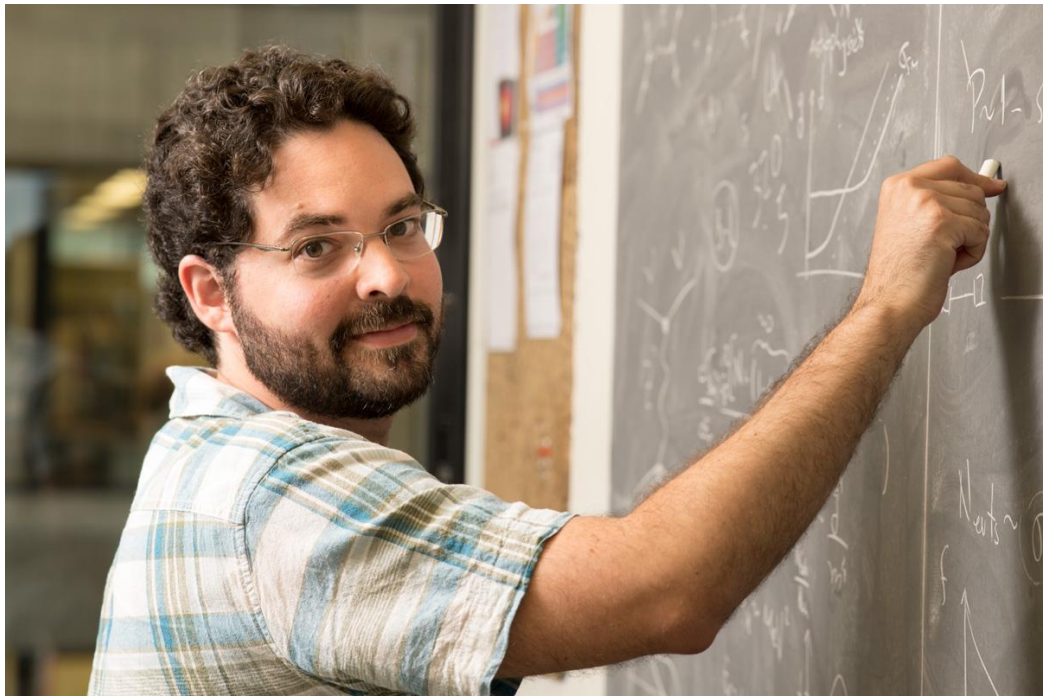
BY J. L BARROW, JBARROW3@VOLS.UTK.EDU

DOE SCGSR PROGRAM FELLOW, FNAL

SEPTEMBER 4TH, 2019

This material is based upon JB's work supported by the U.S. Department of Energy, Office of Science, Office of Workforce Development for Teachers and Scientists, Office of Science Graduate Student Research (SCGSR) program. The SCGSR program is administered by the Oak Ridge Institute for Science and Education for the DOE under contract number DE-SC0014664.

Collaborators—see their recent atm. ν PRL



Pedro Machado

Ivan Martinez-Soler

Goals for “the” atmospheric samples

Goals:

- To generate a set of oscillated atmospheric samples across nuclear model configurations to serve as background for rare event searches such as $n \to \bar{n}$ and $p \to K^+\bar{\nu}$
  - Oscillations provide a portal for ν_τ appearance, and can particularly give rise to ***CC backgrounds*** to $n \to \bar{n}$ due to multipionic decays, though NC backgrounds are still expected to dominate for $n \to \bar{n}$
  - These samples are being generated to study the effect of nuclear model configuration iteration on the separability of signal and background, not themselves to be used for oscillation studies
  - Will use “nominal” oscillation parameters from world data best fits, but can be editable if you like
- $2 \times 6 \times 100{,}000$ samples will be generated (and reconstructed)
  - Six nuclear model configurations: $\{\mathrm{hN2018}, \mathrm{hA2018}\} \otimes \{\mathrm{BR}, \mathrm{LFG}, \mathrm{ESF}\}$
  1. For $n \to \bar{n}$ using out of the box GENIE cross sections and generators, as dictated by tunes
  2. For $p \to K^+\nu$ using a new additional K^+ production channel, recommended by Marco Roda
  - Plan to have all of these available through the FNAL gpvm machines

Process for atmospheric oscillation calculations

```
/*////////////////////////////////////////////////////////////////
Originally written by Ivan Martinez-Soler (Northwestern, FNAL)
PLEASE GIVE CREDIT WHERE CREDIT IS DUE!!!

Provided to Joshua Barrow (UTK, FNAL) for use by the DUNE NDK HEP
Working Group for atmospheric background studies using Honda flux
files. This code produces a new atmospheric flux file containing
6 neutrino flavors/type (nu_tau/nu_taubar) of similar structure to
the nominal 4-flavor/type files; it is intended that these files
interface with a new GENIE Honda flux driver to create a standard
set of oscillated atmospheric neutrino background samples. In
general, this code could also be used for more intense atmospheric
studies, but this is left to other future users.

This file requires a build of GNU GSL to run.
////////////////////////////////////////////////////////////////*/
```

AtmFlxOsc.cpp

by Ivan Martinez-Soler

- After discussions, was given modified code by Ivan using GSL libraries
  - Calculates oscillation probabilities and total event numbers from given Honda flux file structures for any site in average ν_ℓ/yr from $0.1 - 10{,}000$ GeV
    - Assumes the normal hierarchy
    - Includes density changes in the earth's geological makeup (as concentric shells)
    - Averages over angular bins
    - Treats atmosphere as vacuum, with ν production height set at 15 km (this is a parameter)
    - $\theta_{12} = 33.48°, \theta_{13} = 8.5°, \theta_{23} = 45°, \Delta m^2_{21} = 7.5 \times 10^{-5}\ eV^2, \Delta m^2_{31} = 2.5 \times 10^{-3} eV^2, \delta_{CP} = 90°$
  - All parameters can be easily changed, and it is all scriptable

```
average flux in [cosZ = 0.90 --  1.00, phi_Az =   0 --  30]
 Enu(GeV)    NuMu        NuMubar     NuE         NuEbar   (m^2 sec sr GeV)^-1
 1.0000E-01 9.8672E+03 1.0020E+04 4.8979E+03 4.5842E+03
 1.1220E-01 8.8940E+03 8.9868E+03 4.4193E+03 4.0866E+03
 1.2589E-01 7.9442E+03 8.0068E+03 3.9200E+03 3.5941E+03
 1.4125E-01 7.0265E+03 7.0725E+03 3.4317E+03 3.1152E+03
 1.5849E-01 6.1272E+03 6.1404E+03 2.9803E+03 2.6778E+03
 1.7783E-01 5.2653E+03 5.2489E+03 2.5622E+03 2.2779E+03
 1.9953E-01 4.4671E+03 4.4417E+03 2.1739E+03 1.9119E+03
```

hms-ally-20-12-solmax.d

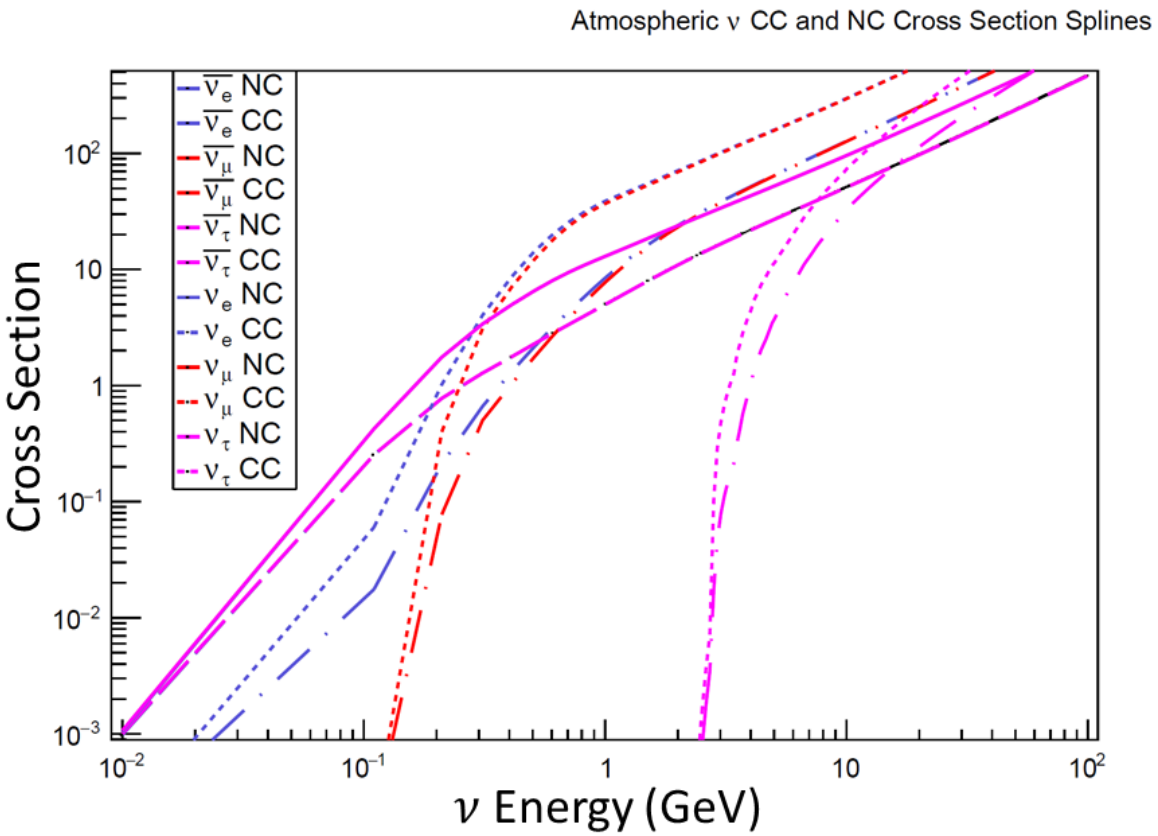
See Honda group site and associated article

```
g++ -o flux AtmFlxOsc.cpp -lgsl -lgslcblas
./flux hms-ally-20-12-solmax.d > hms-ally-20-12-solmax_3FlavOsc.d
```

```
average flux in [cosZ = 0.90 --  1.00, phi_Az =   0 --  30]
Enu(GeV)    NuMu        NuMubar     NuE         NuEbar      NuTau       NuTaubar   (m^2 sec sr GeV)^-1
1.0000e-01  3.2243e+03  2.5527e+03  4.3507e+03  5.5255e+03  7.1901e+03  6.5260e+03
1.1220e-01  4.6411e+03  4.2804e+03  4.0232e+03  4.5436e+03  4.6490e+03  4.2493e+03
1.2589e-01  3.5965e+03  3.8676e+03  4.2707e+03  3.4236e+03  3.9970e+03  4.3097e+03
1.4125e-01  2.3155e+03  2.5628e+03  3.8968e+03  3.0621e+03  4.2459e+03  4.5628e+03
1.5849e-01  5.5881e+03  5.6154e+03  3.0665e+03  2.7240e+03  4.5285e+02  4.7885e+02
1.7783e-01  3.1063e+03  3.1578e+03  2.6391e+03  2.2205e+03  2.0821e+03  2.1485e+03
1.9953e-01  1.6847e+03  1.8388e+03  2.4418e+03  1.8112e+03  2.5145e+03  2.7036e+03
```

hms-ally-20-12-solmax_3FlavOsc.d

GENIE changes and sample production



Quite simple changes were made to GENIE's src/Tools/Flux/GAtmoFlux.cxx and GHAKKMAtmoFlux.cxx flux drivers to allow for six ν types to be read in from newly calculated oscillated Honda flux files

- These are available in my personal geniegpvm repository, but will not be pushed to git for now (soon), but I doubt that GENIE has an interest in integrating them into their build
- See /genie/app/users/jbarrow/genie-v3/Generator

Six new nuclear model configuration tunes were constructed

Splines are being generated across all ν types for all nuclear model configurations

- Can have marginal differences on how cross sections are calculated due to momentum distributions

Comparisons: E_ν

SUPER-KAMIOKANDE

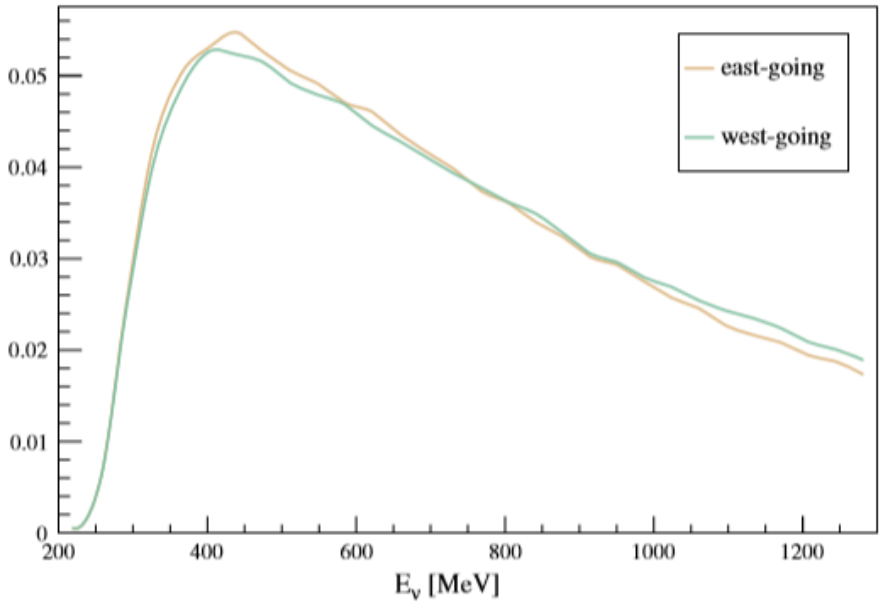
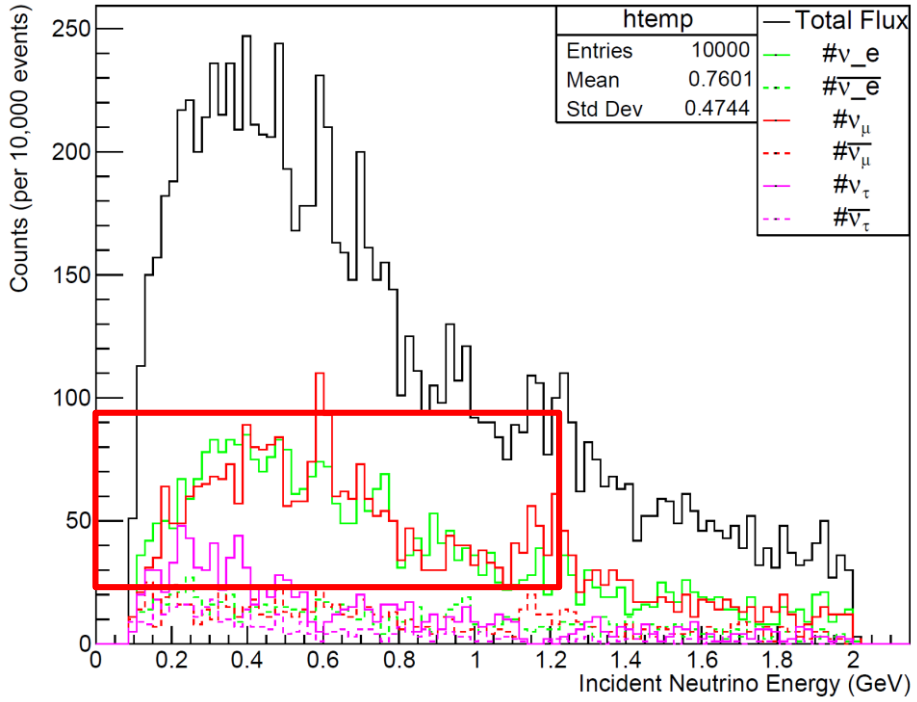
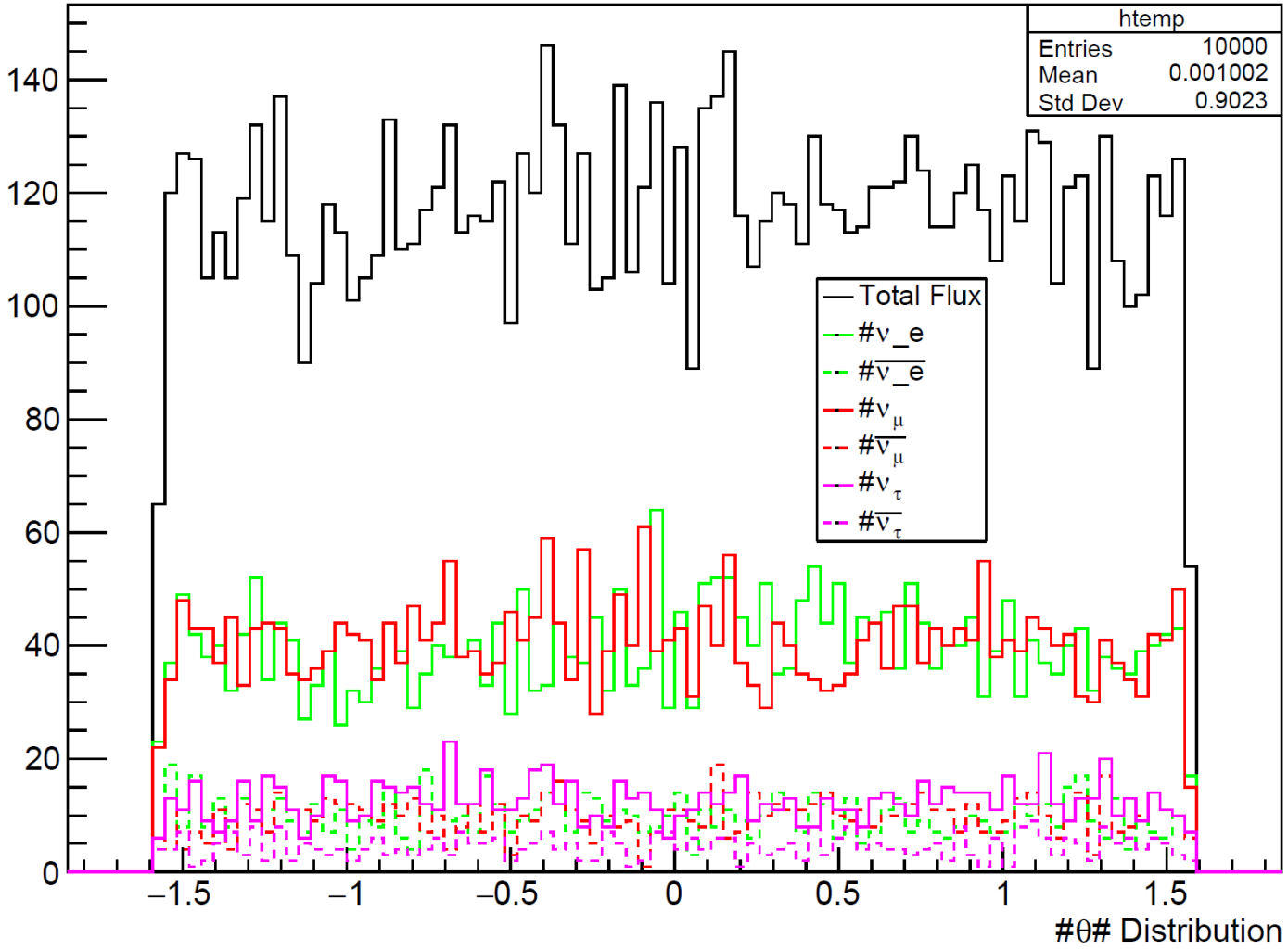


FIG. 17. Energy spectra between eastgoing and westgoing events, showing the MC true energy spectrum of events reconstructed as single-ring sub-GeV μ-like events. The area under both curves is normalized to unity.

HOMESTAKE SITE, GENIE PRODUCTION

(0.1 – 2.0 GEV, 10,000 EVENTS)



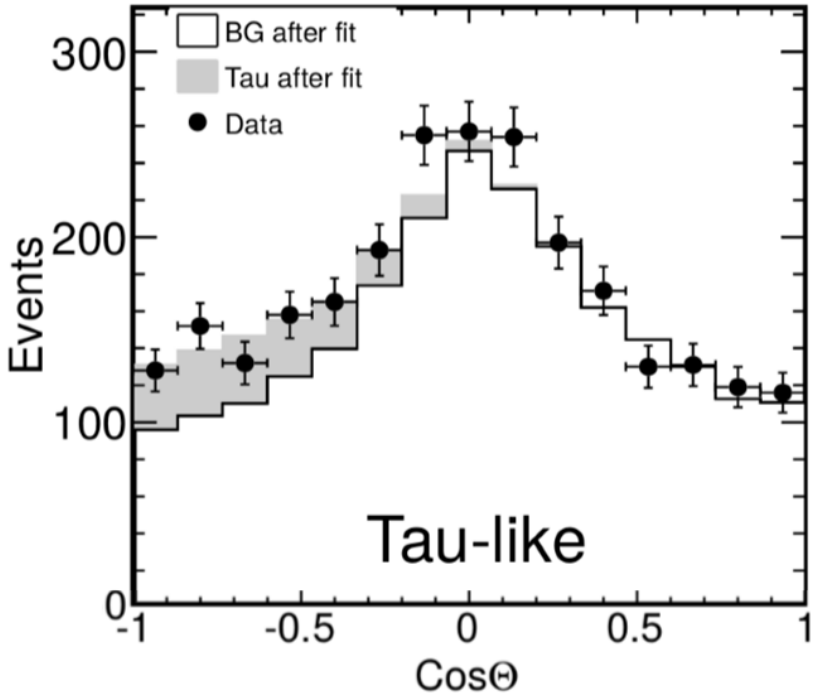


Azimuthal angle θ

Comparisons: ν_τ counts by $\cos(\theta)$

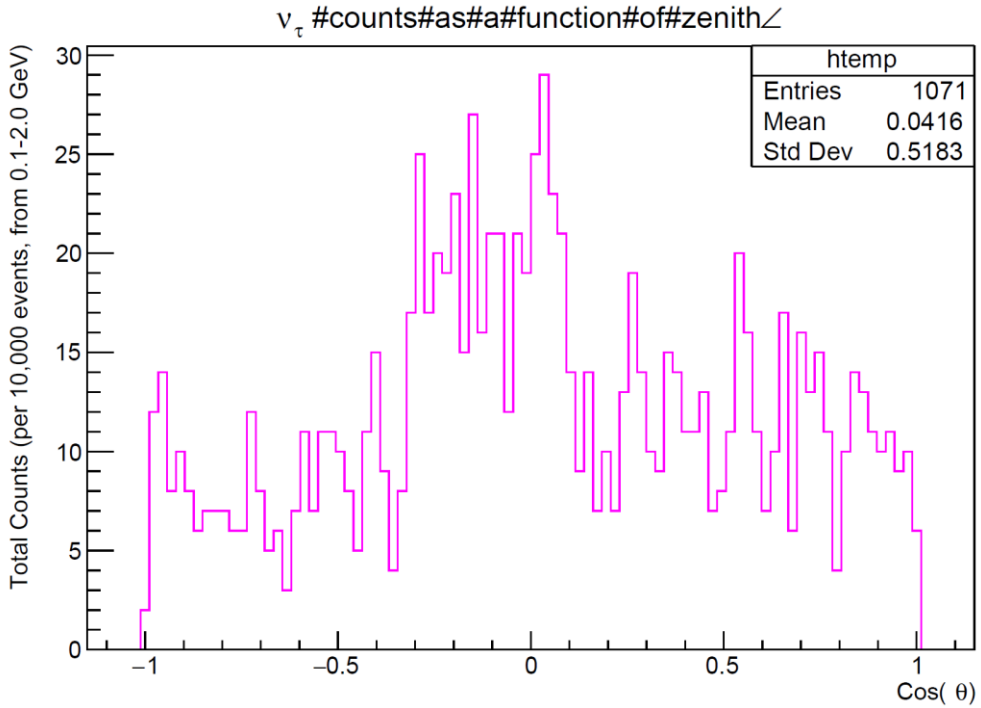
SUPER-KAMIOKANDE

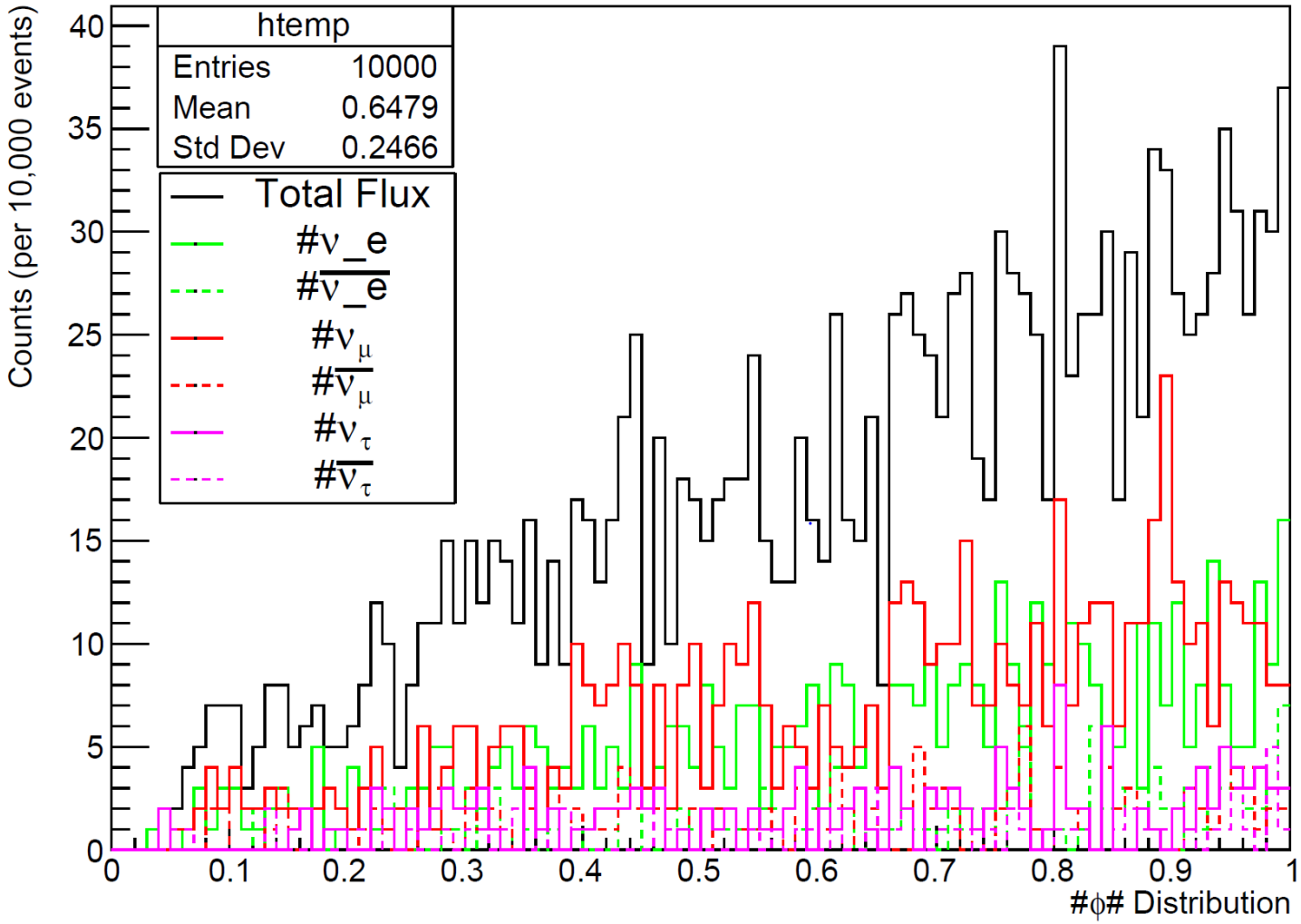
(5326 DAYS, CC, $>$ 1.3 GEV VISIBLE ENERGY)



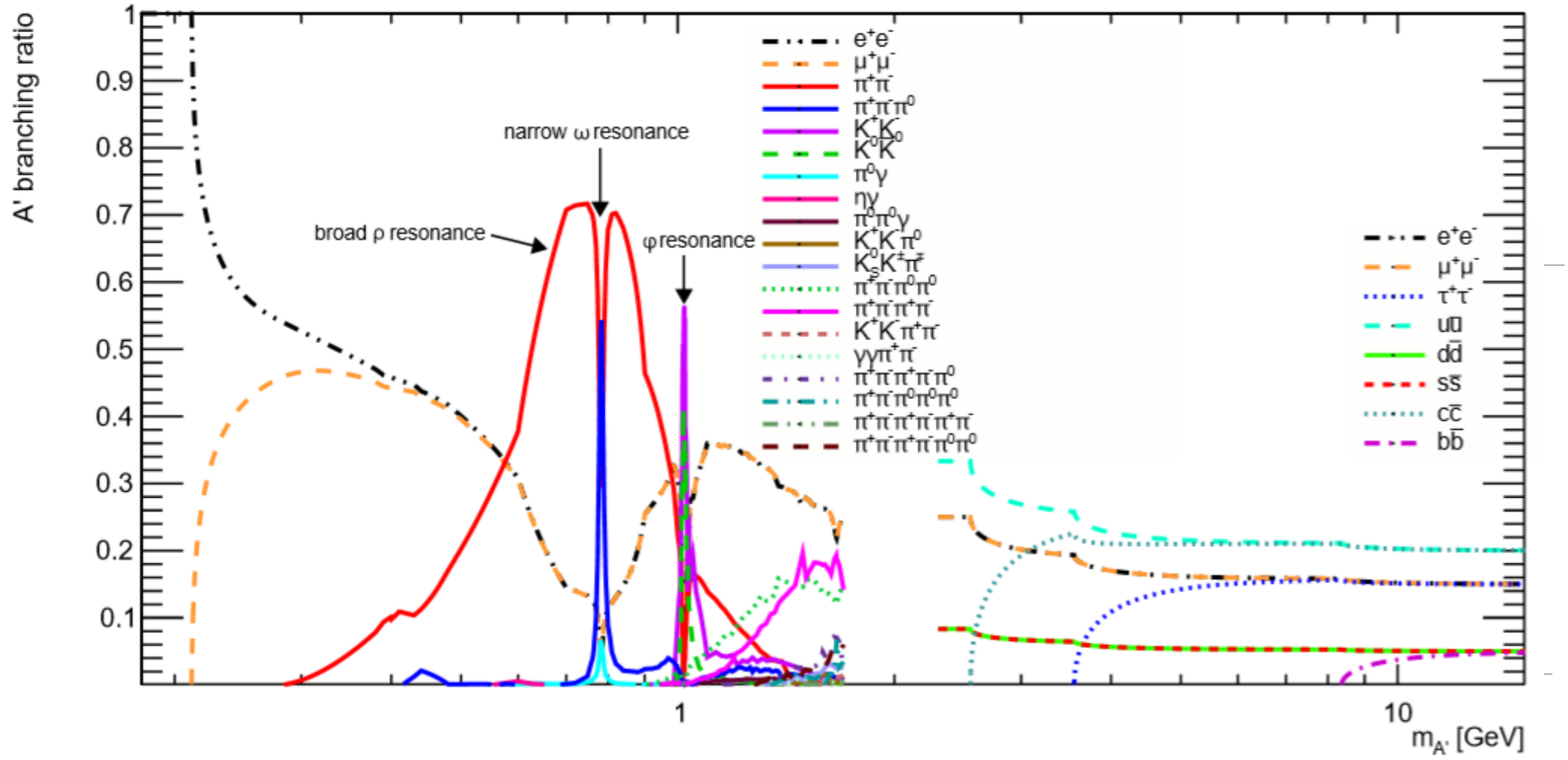
HOMESTAKE SITE, GENIE PRODUCTION

(0.1 – 2.0 GEV, 10,000 EVENTS)





Polar/zenith angle



A word on other backgrounds…

…need to check that many rare SM branching channels are included in GENIE!