Upward μ Issues in Super-K

(with an eye towards a MINOS analysis)

Alec Habig
Univ. of Minnesota Duluth

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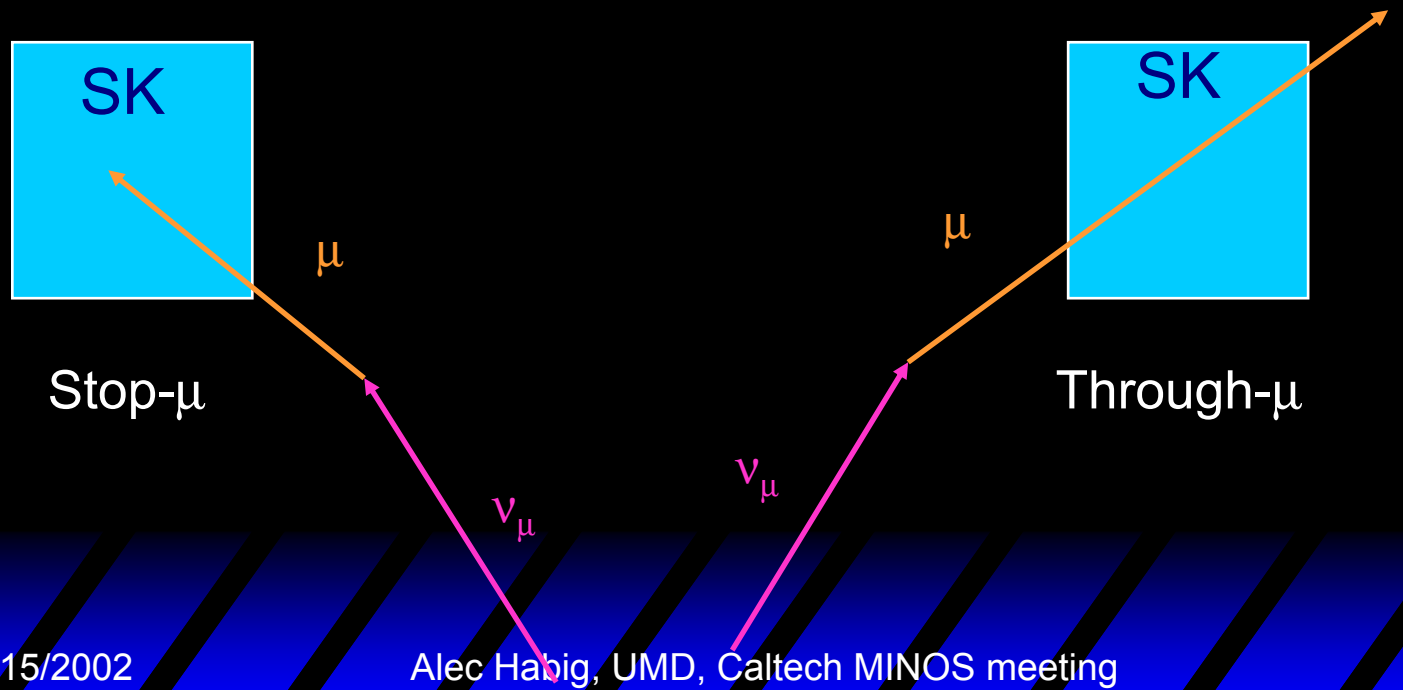
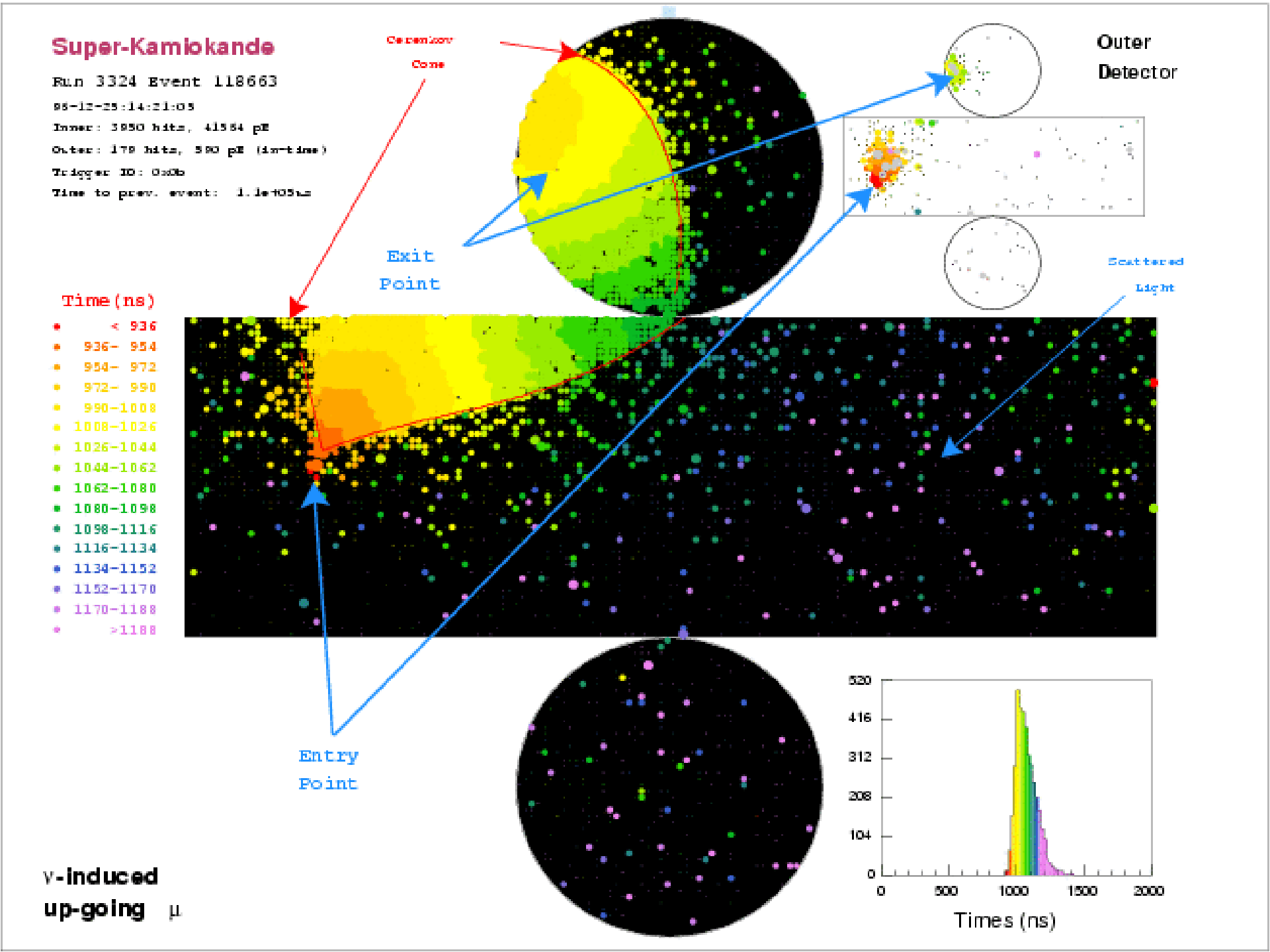
What are up-μ's?

- ν_μ interacts in rock, resulting μ is seen
  - Entering events
  - Can't sort out from down-going CR μ
  - But μ coming up can only be ν-induced




Super-Kamiokande
Run 3324 Event 118663
98-12-25:14:21:05
Inner: 3950 hits, 41584 pE
Outer: 178 hits, 590 pE (in-time)
Trigger ID: 0x0b
Time to prev. event: 1.1e+05s
Cherenkov
Cone
Outer
Detector
Exit
Point
Scattered
Light
Time(ns)
< 936
936- 954
954- 972
972- 990
990-1008
1008-1026
1026-1044
1044-1062
1062-1080
1080-1098
1098-1116
1116-1134
1134-1152
1152-1170
1170-1188
>1188
Entry
Point
520
416
312
208
104
0
0
500
1000
1500
2000
Times (ns)
ν-induced
up-going μ

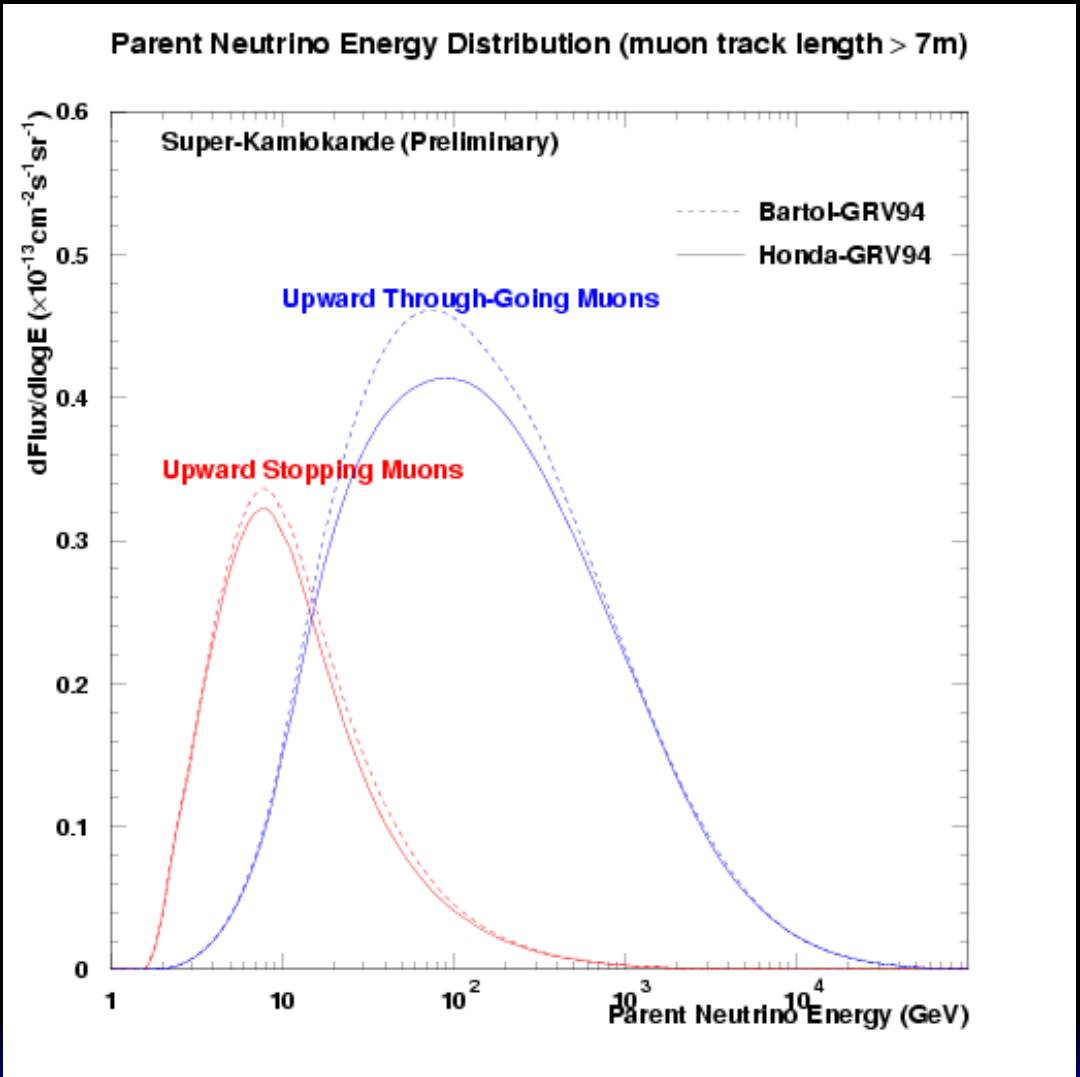
Backgrounds

- Near Horizon, down-going CR scatter slightly up (or fit resolution pulls in)
  - Background subtracted from horizon bin
  - Soudan shallow so more of them – but flat overburden helps counter this
- Photo-produced π from near-miss CR's
  - In SK, thick veto counter plus 7m pathlength cut (E_μ>1.6 GeV threshold) eliminates these
  - In MINOS, short pathlength cut in iron would also eliminate

Oscillation probe

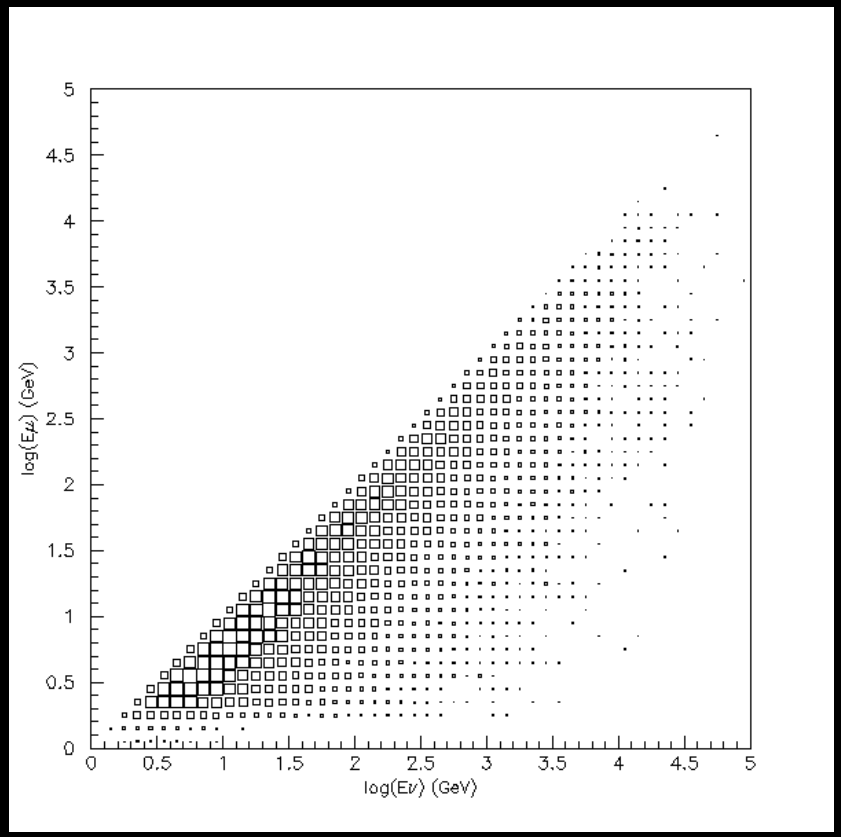
- The usual atmospheric ν game is played
  - look at flux as a function of zenith angle (and thus baseline) and energy
- Problem – can't tell parent ν energy very well:
  - No way to tell how much rock the μ has already penetrated (losing E all the way) before detector
  - For through-μ, μ continues unknown distance past detector (MINOS B-field could still find E_μ)

Parent ν Energy

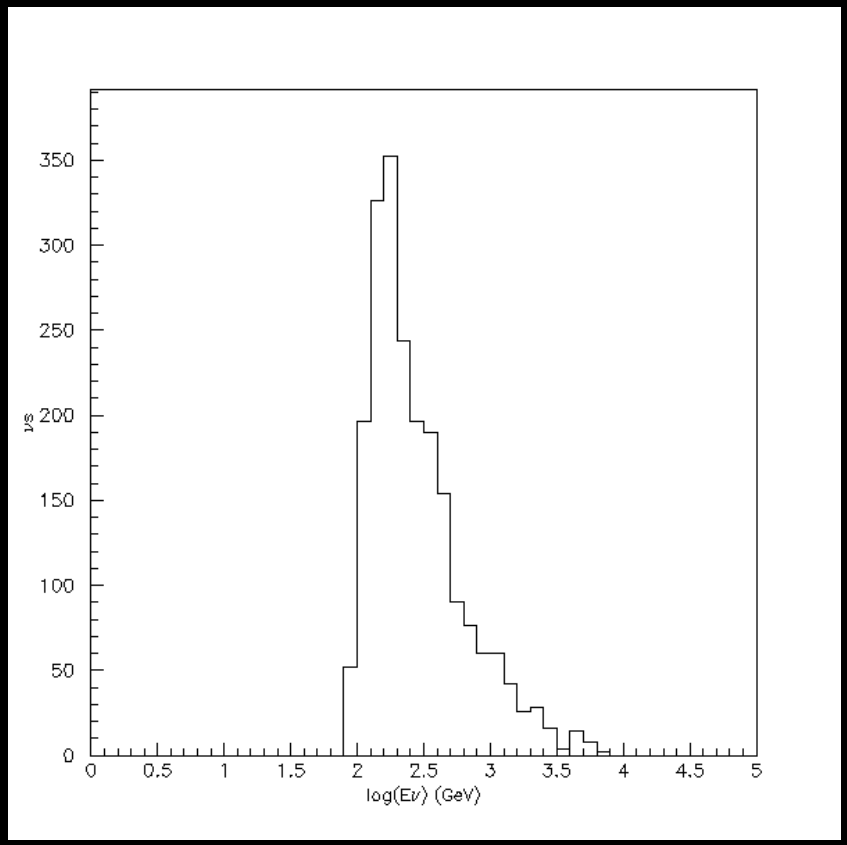


- Through-going μ from ~100 GeV ν
- Stopping-μ from ~10 GeV ν
- Pathlength cuts provide little additional discrimination

Up-μ and parent ν Energies

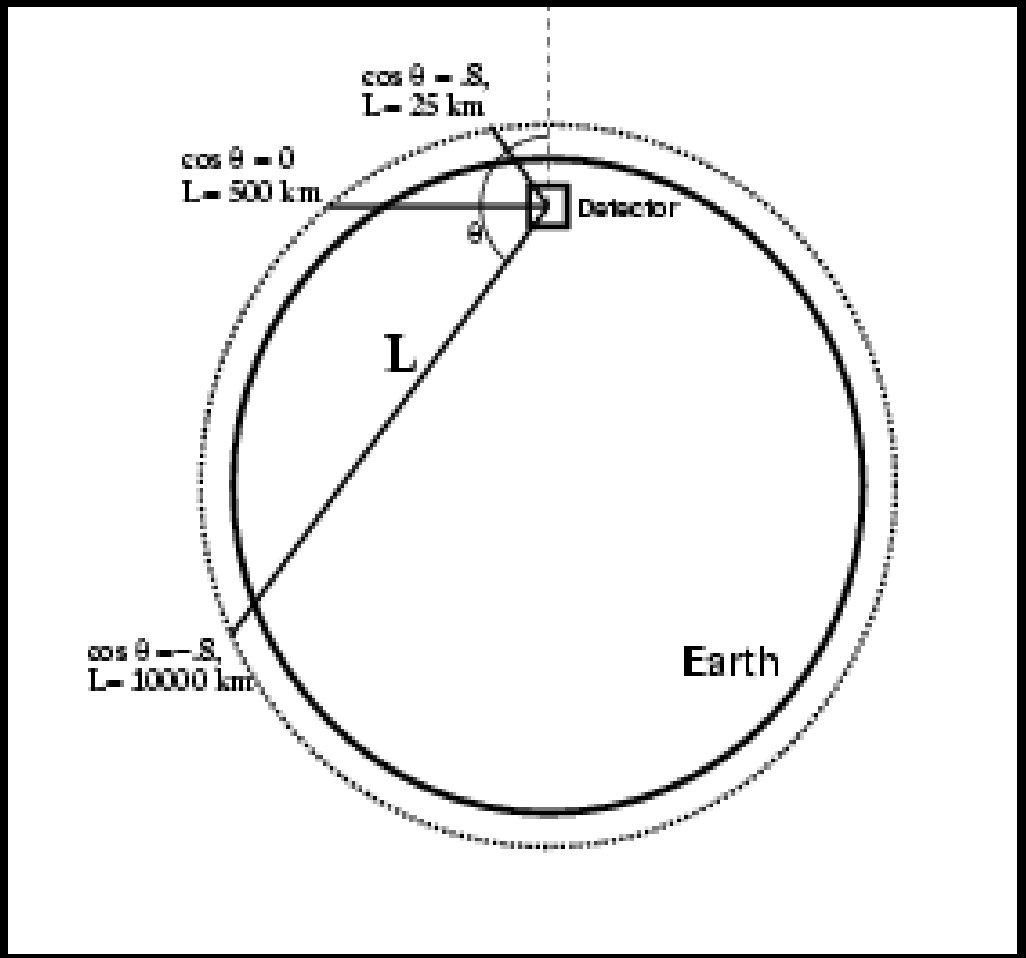


log(Eν) (GeV)



log(Eν) for 100 GeV up-μ's

Pathlength from θ

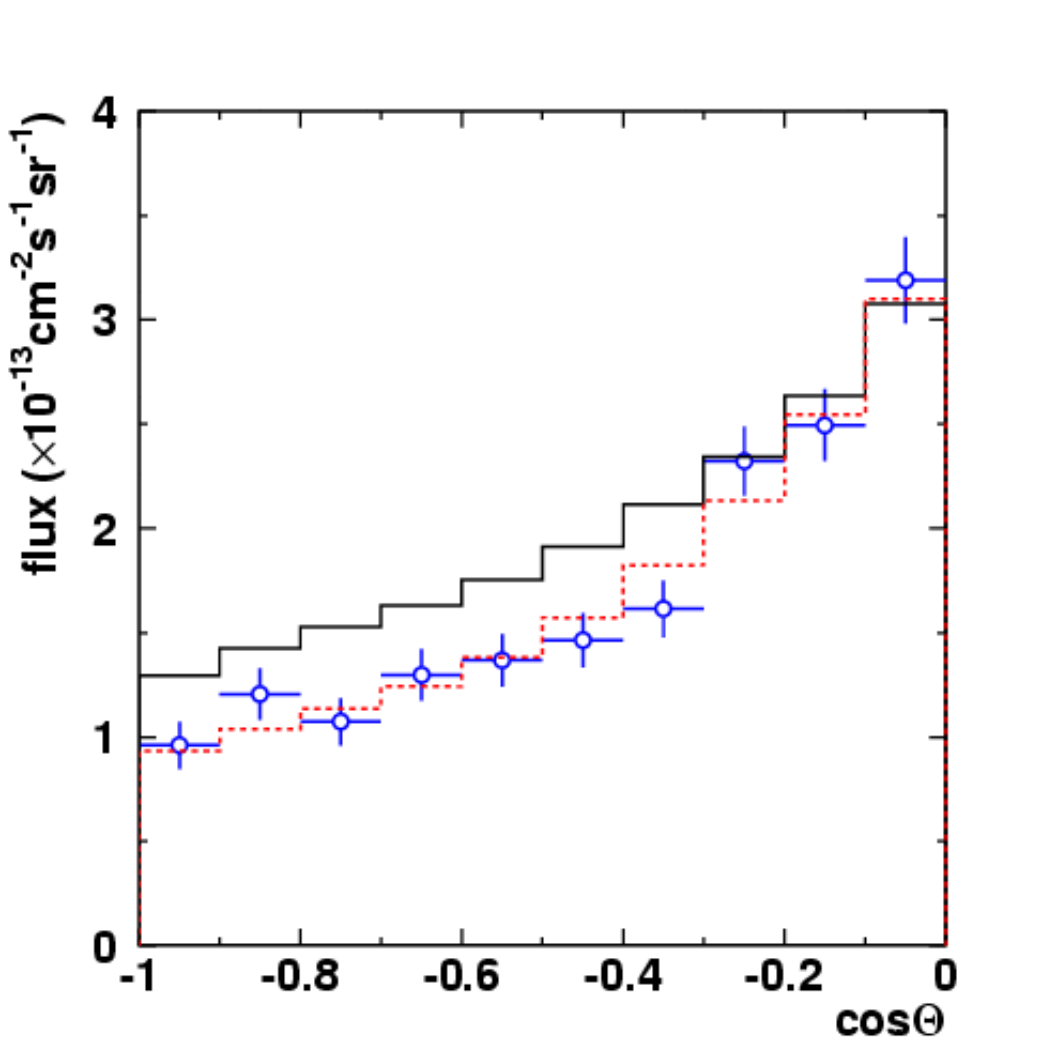


- ν has traveled a distance which depends upon zenith angle θ
- Only angles below the horizon accessible to this analysis (cos θ < 0)

Data Summary

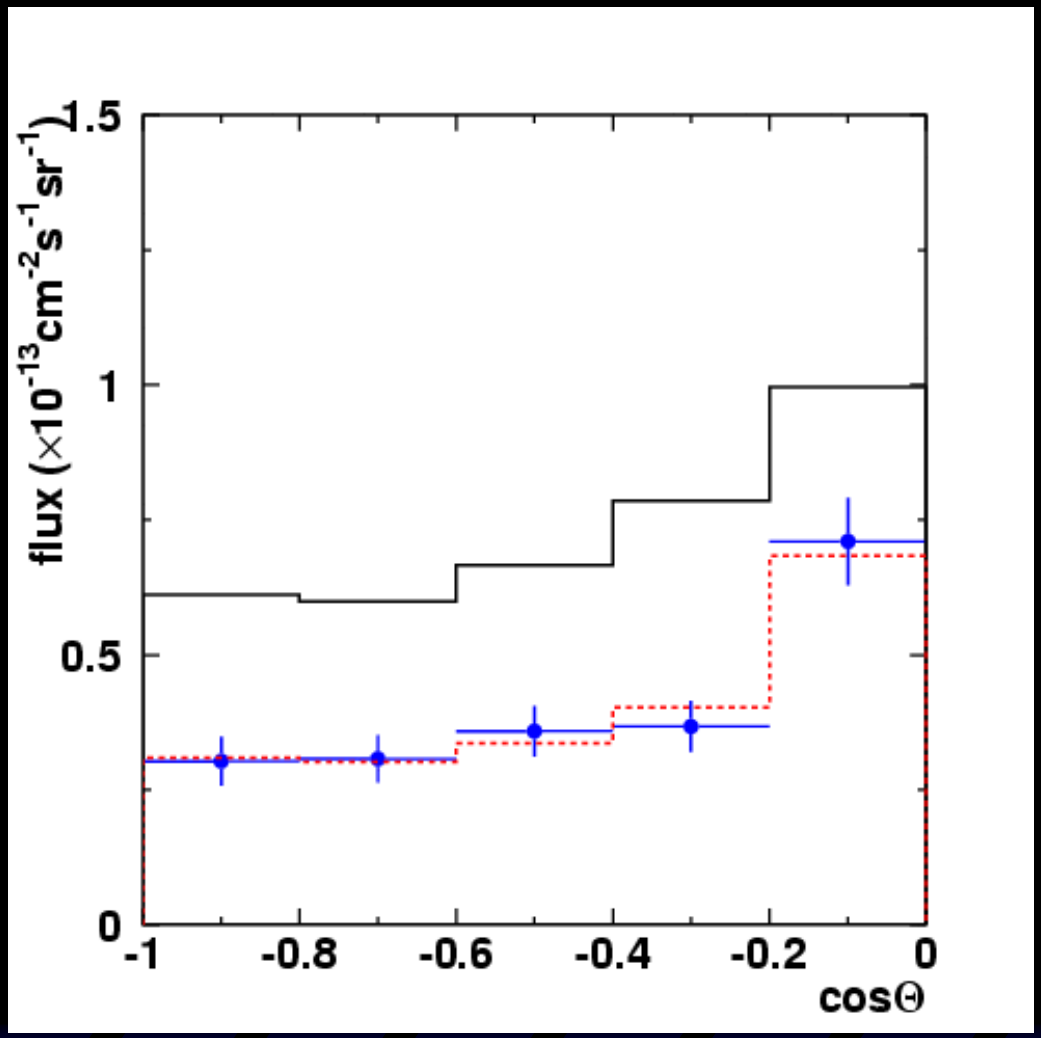
- For Super-K,
  - 1636 Thru-μ in 1481 days (1.68±0.04 x10^{-13} $cm^{-2}sr^{-1}s^{-1}$)
  - 403 Stop-μ in 1460 days (0.404±0.025 x10^{-13} $cm^{-2}sr^{-1}s^{-1}$)
  - (another ~6 months or so in the bag, also being reprocessed from start with new reduction software)
- Note units. Statistics proportional to time, size (*esp. for stoppers!*), and efficiency
  - SK, MACRO, AMANDA, Baksan already do better than MINOS will in several year run
  - Antares, Ice-Cube will soon crush all competitors

Up-Through μ flux



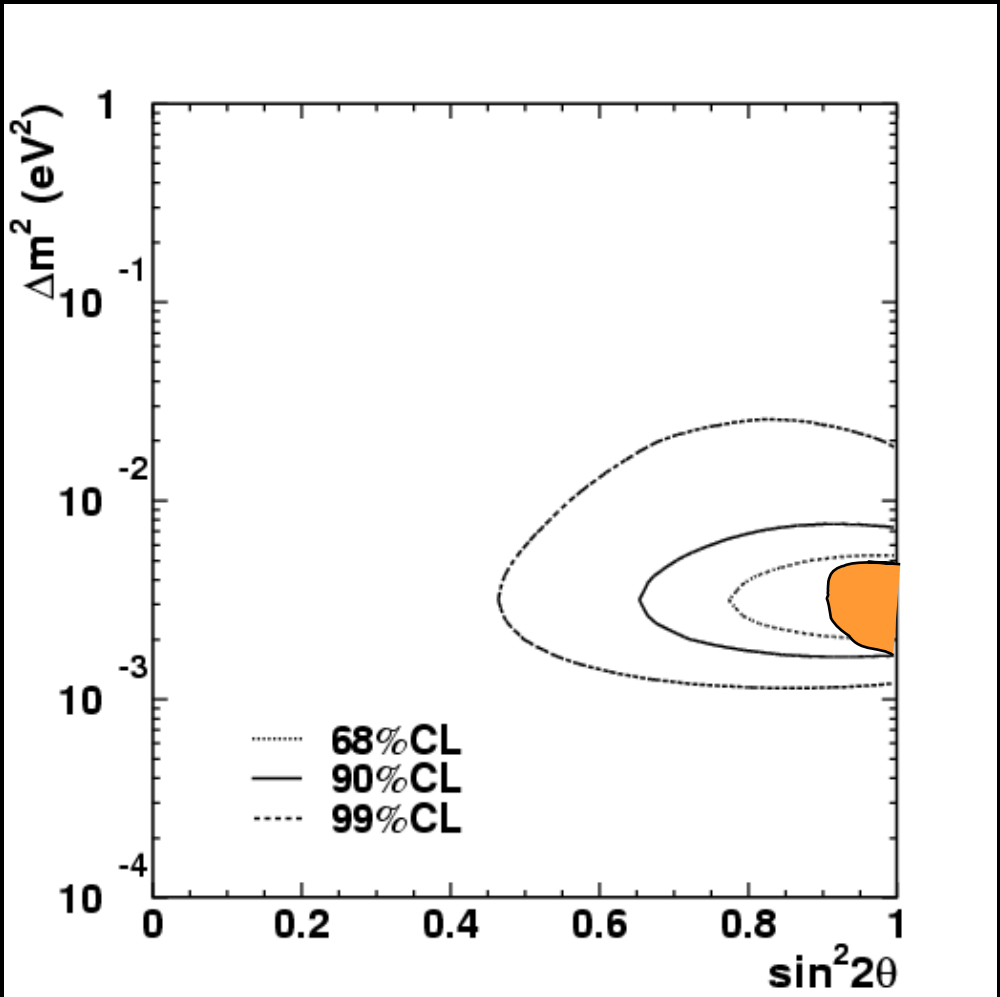
- Data - crosses
- Black - no-osc
- Red – ν_μ ✡ ν_τ osc, Δm^2=3.2x10^{-3} eV^2, sin^{2}2θ=1.0
- Note shape distortion due to osc
- High through-μ statistics sets overall flux normalization

Up-stop μ flux



- Data - crosses
- Black - no-osc
- Red - $\nu_\mu \leftrightarrow \nu_\tau$ osc, $\Delta m^2 = 3.2 \times 10^{-3}$ eV^2, $\sin^2 2\theta = 1.0$
- Stop-μ strongly oscillated
- Without Through-μ to set normalization, this suppression is within theory error

Oscillation results



- All up-μ used in fit
- ν_μ ✡ ν_τ in same range as contained SK ν's
- Most useful in conjunction with other atmospheric ν – shrinks allowed region
- Provides high-energy lever to investigate alternate theories, especially sterile ν

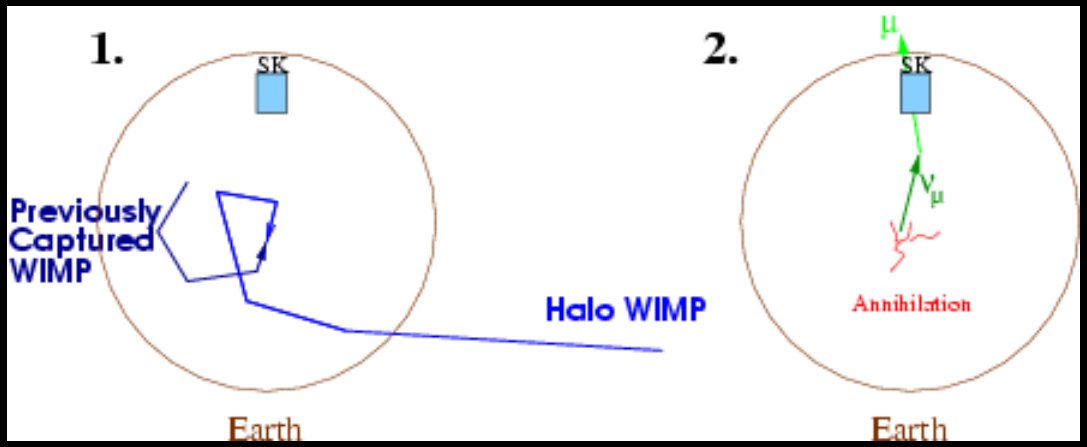
Other Up-μ Topics

- Up-μ are good high-energy ν probe due to using external rock as target
- Astrophysical high-energy ν sources (AGN's etc)
  - Nothing seen so far. Models suggest we need ~1 km^3 volume to have a prayer
- WIMP searches

WIMP Search

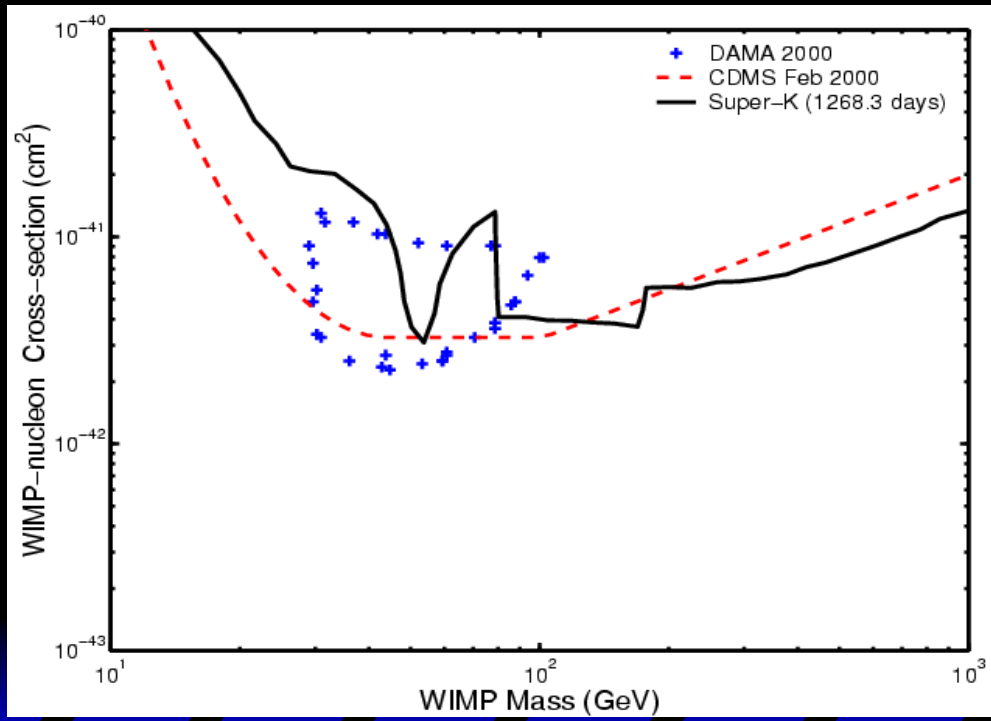
- WIMPs collect in core of Earth, Sun, Galaxy
- WIMPs annihilate, high energy ν's produced
- Look for up-μ excesses from directions of these cores
  - None seen, set limits, compare to direct-detection experiments

WIMP Results



WIMPs capture, Annhilate, make νs and up-μs

SK WIMP limits, compared to DAMA & CDMS



Hope for MINOS?

- MINOS can get μ energy, sign, decent stop-μ
  - but μ energy poor handle on ν energy, this helps less that one would like
  - μ sign currently done very approximately
    - Stop-μ decay/capture times
  - MINOS can contribute here – anything out of the ordinary would be extremely surprising
- MINOS too small, short term, & late to compete
  - only sparse results are accessible to begin with
  - plus layered detector not optimal
- Up-μ analysis in MINOS - "muons for nothin'"
  - More confirmation, crosschecks
  - Good student analysis project with actual ν's

Muons for Nothin'
(to the tune of Money for Nothin')

Look at them bozo's (that's the way you do it)
Build a big machine to catch a cosmic ray
That ain't background (beam gas is their signal)
Get your muons for nothing, get events all day

That ain't waitin' (beam is always comin')
Let me tell you, them guys ain't dumb
Maybe have some downtime to backup computers
Maybe take it down to change the run

We got to install microwave klystrons
Custom dipole assemblies
We got to run these accelerators
We got to run these cooler ring things

I should have learned to study cosmics
And neutrinos from the sun
No `expert en route to unquench the magnet'
Man, we could have some fun

And what's this? The run is goin'
But he's climbin' the detector like a chimpanzee
That ain't radiation (that's the way you do it)
Get your muons for nothing, get events for free

We got to install microwave klystrons
Custom dipole assemblies
We got to run these accelerators
We got to run these cooler ring things

I want my, I want my, I want my PhD…

By Bob Nolty, the last MACRO grad student, nolty_r@caltech.edu
Who graduated as of last week!