February 1999
Venice Nt99

New Atmospheric Neutrino Experiments

Jaap Panman

CERN

- Available Measurements
- Atmospheric versus Accelerator
- Open Questions
- How to Answer
- Existing Experiments
- New Experiments
- Conclusions

Special Thanks

J. Brunner (Antares)

P. Litchfield (Soudan-2)

A. Para (MINOS)

R. Santacesaria (Calculations)

P. Zucchelli (NOW98 review)

Other sources:

Now98 transparencies (Moscoso, Cavanna, ..)
SuperK transparencies (Mercier, Suzuki)
Picchi, Pietropaolo (CERN/scan9710037)
Battistoni, Lipari (Vulcano workshop)
SPSC M615, M621

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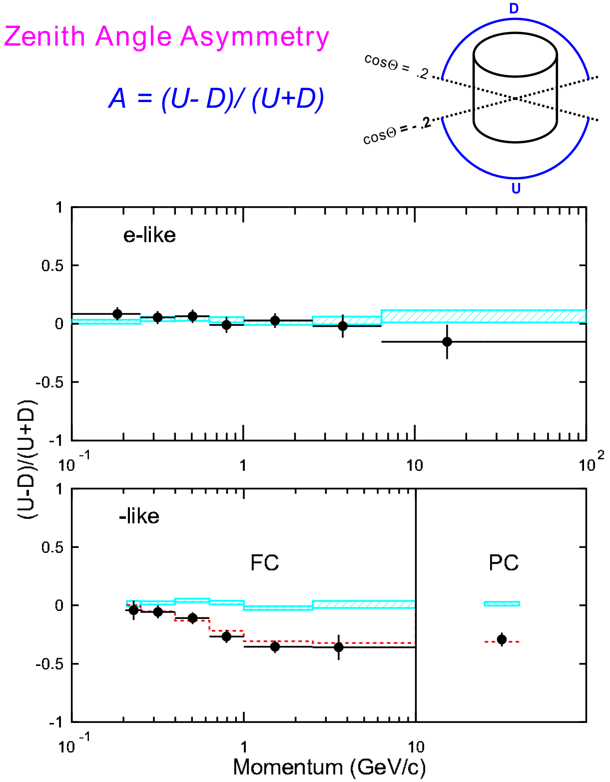
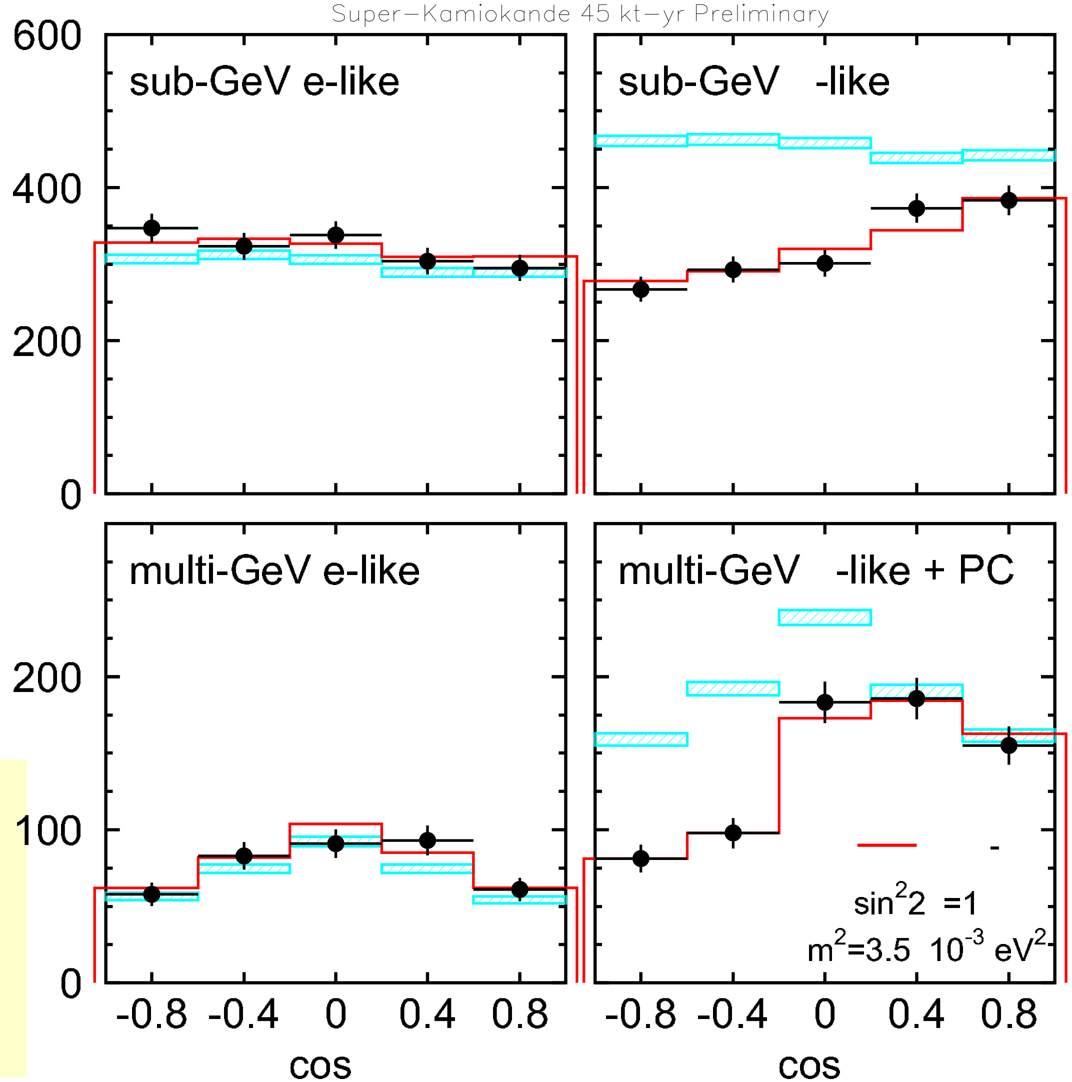
SuperK

Zenith Angle Asymmetry

A = (U- D)/ (U+D)





SuperK

R(e-mu)

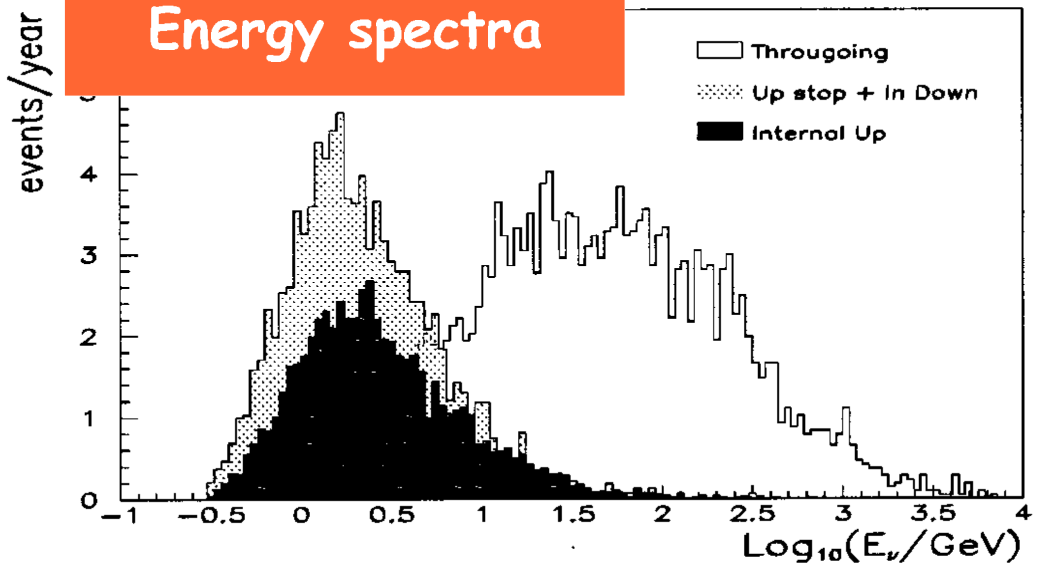
Upgoing muons

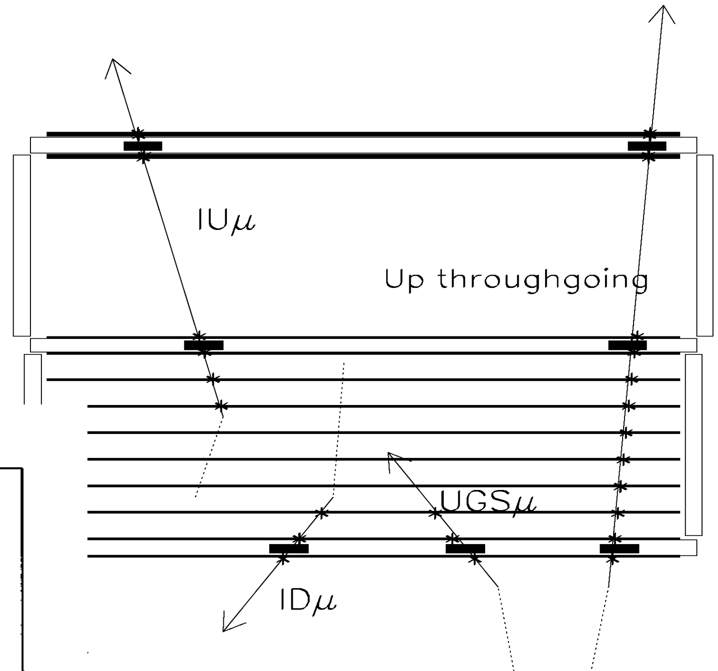
Zenith Angle Distributions

Macro

MACRO Upgoing muons

Energy spectra





Event topologies

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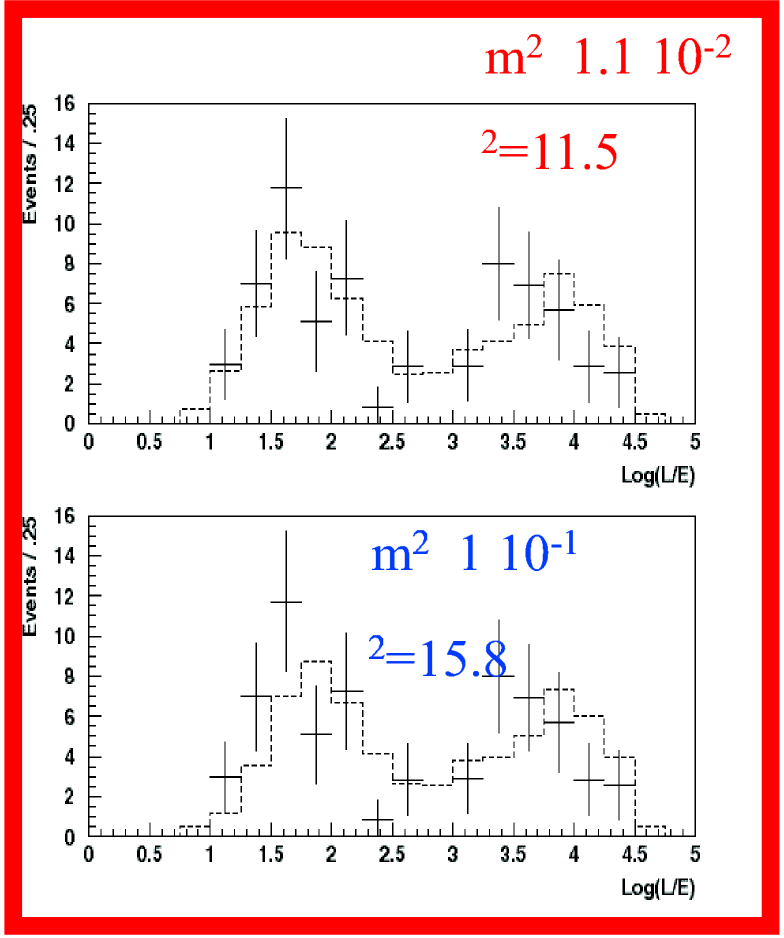
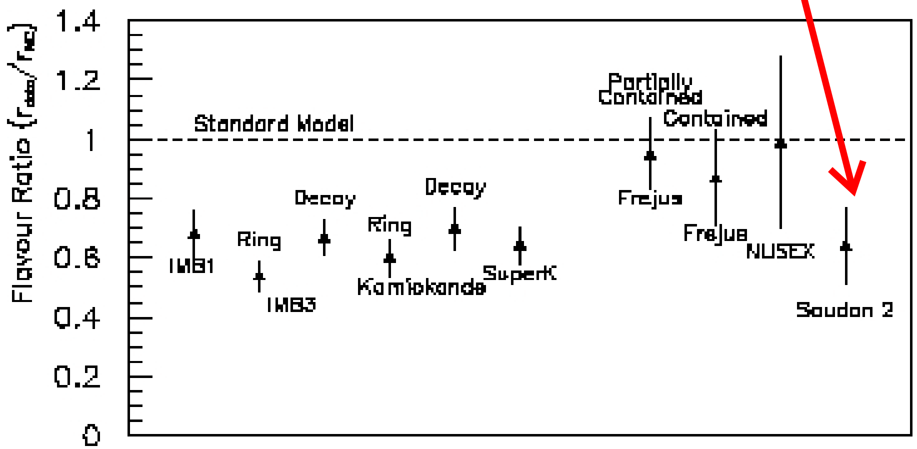
Soudan-2

Preliminary



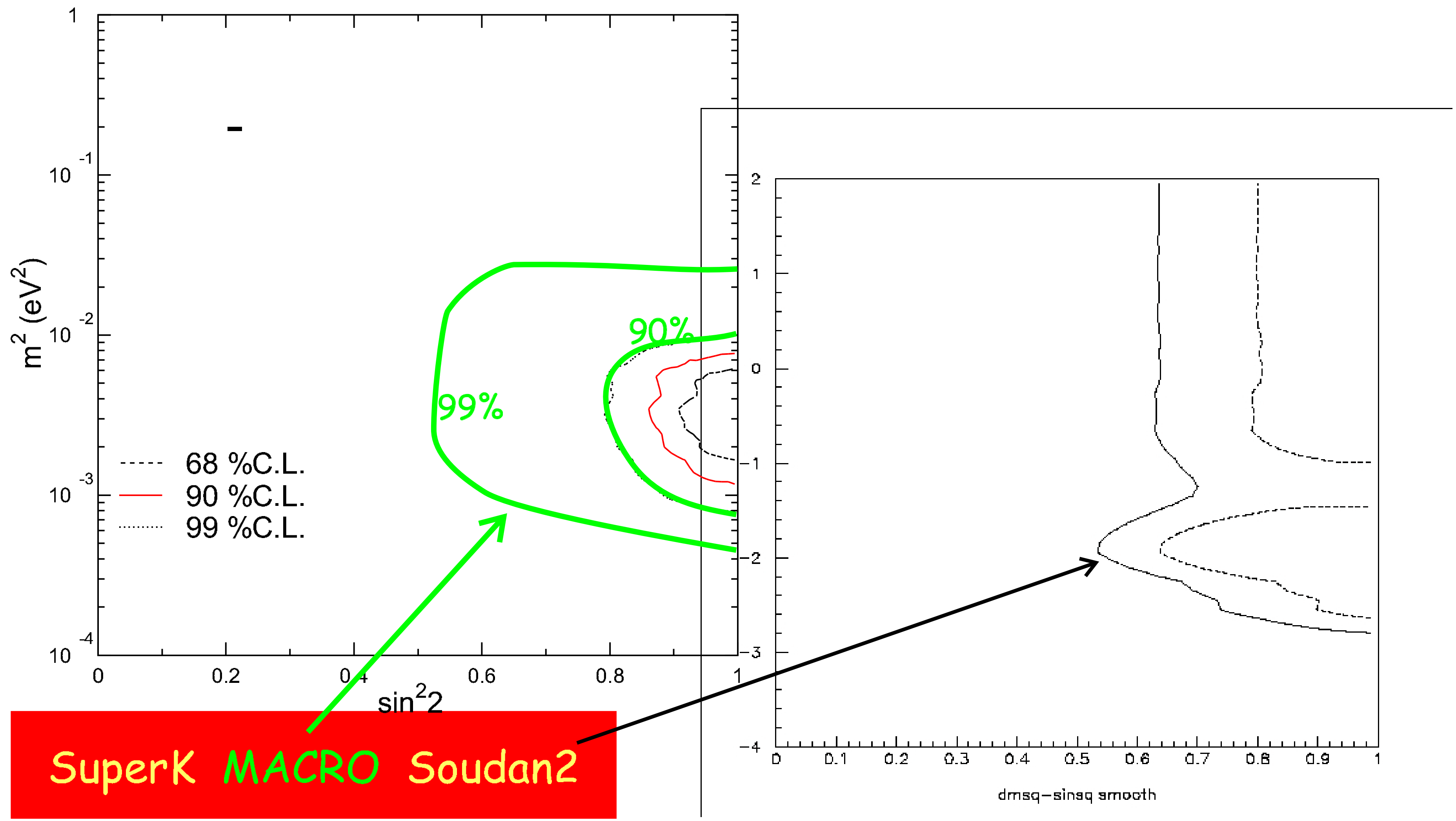
Soudan2
Zenith Angle Distributions
R(e-mu)

$R=0.66\pm0.11$ 0.06



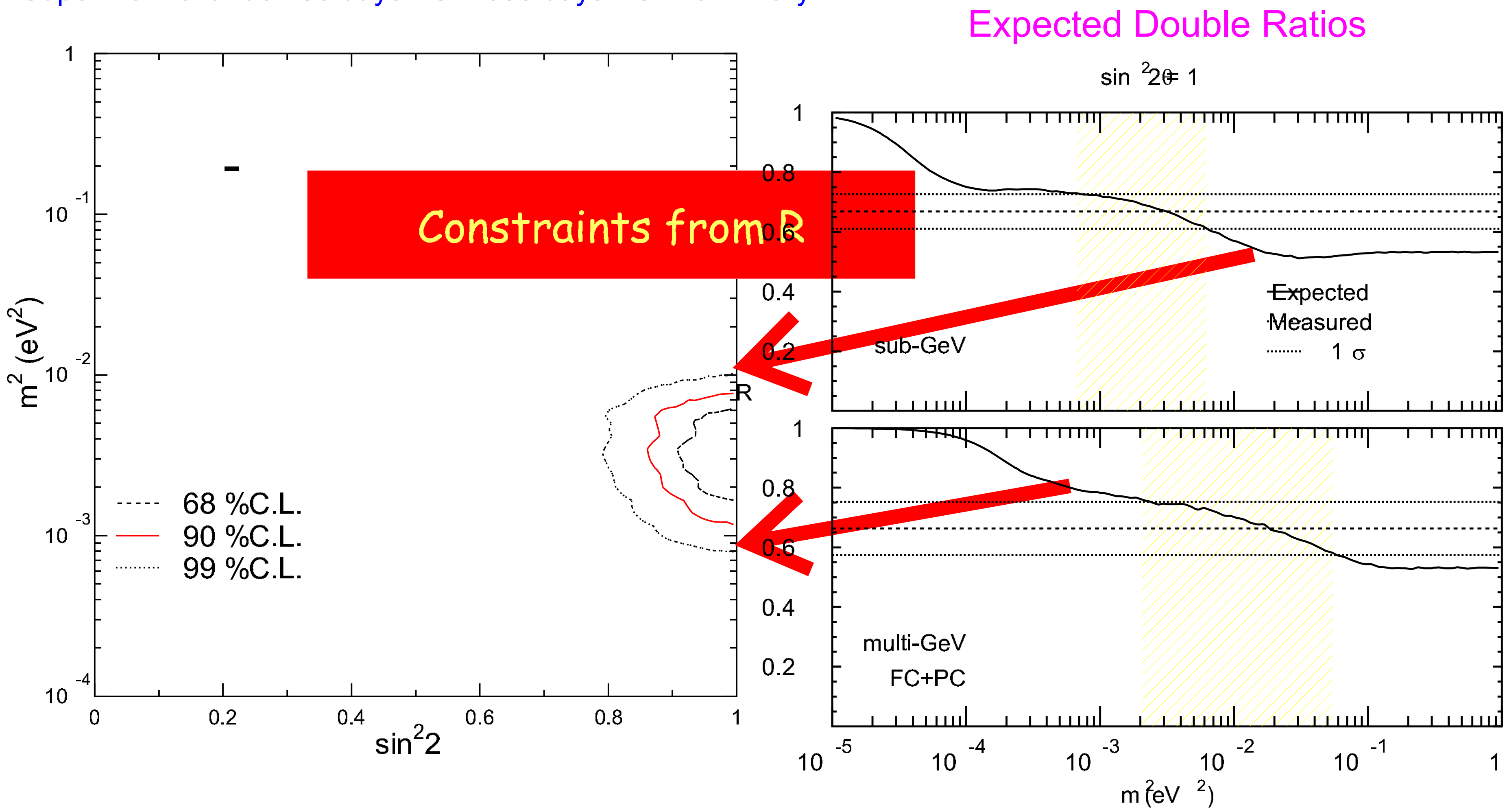
Parameter space

Super-Kamiokande 736 days FC + 685 days PC Preliminary



SuperK Interpretation

Super-Kamiokande 736 days FC + 685 days PC Preliminary



SuperK Interpretation

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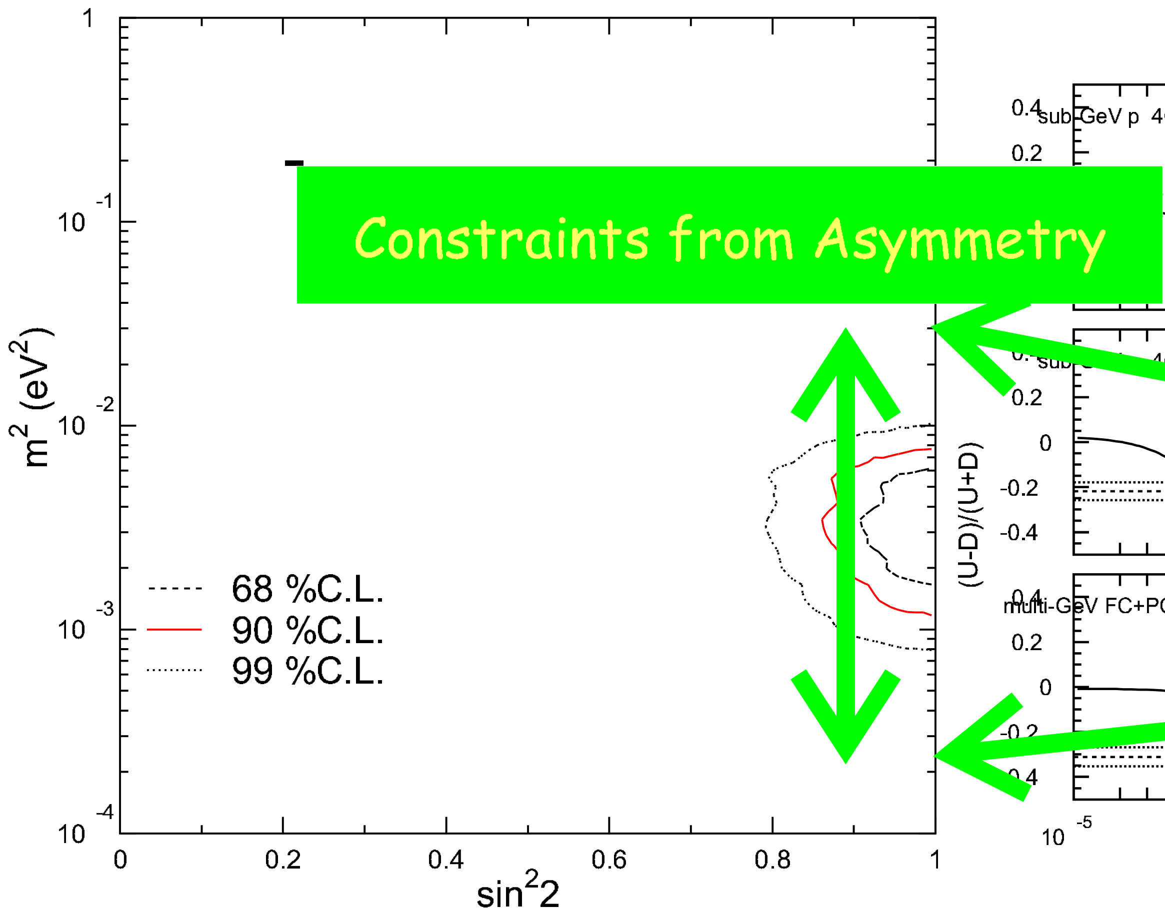
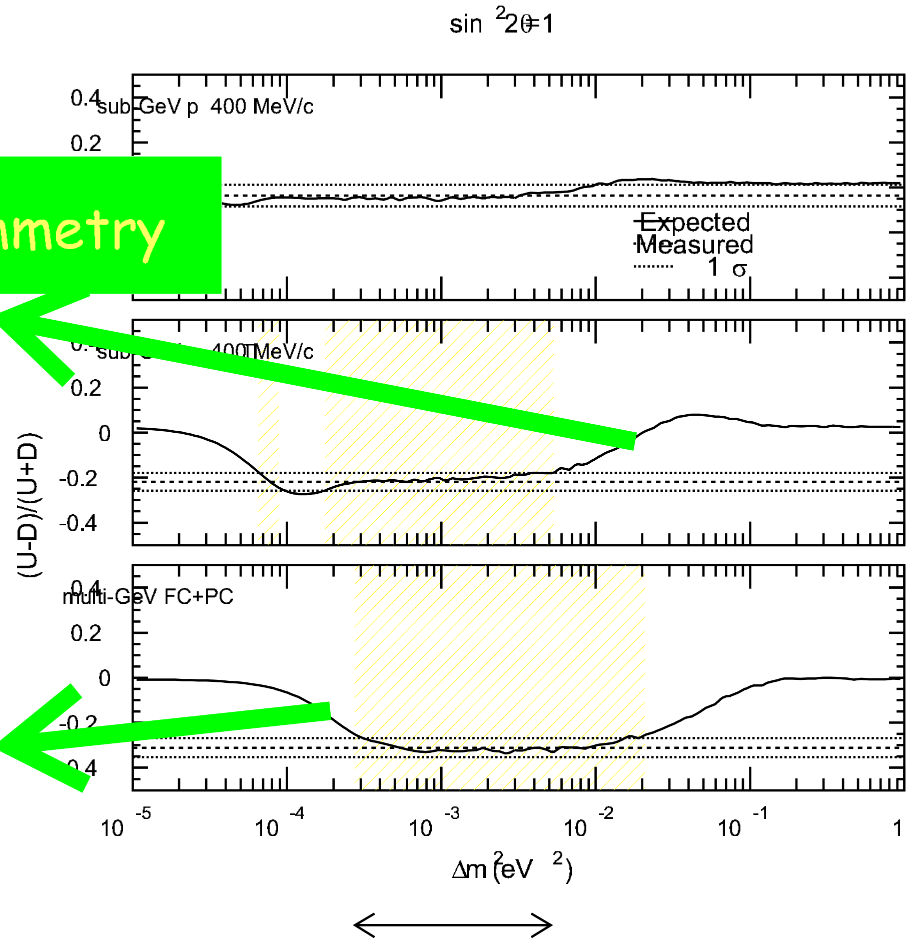
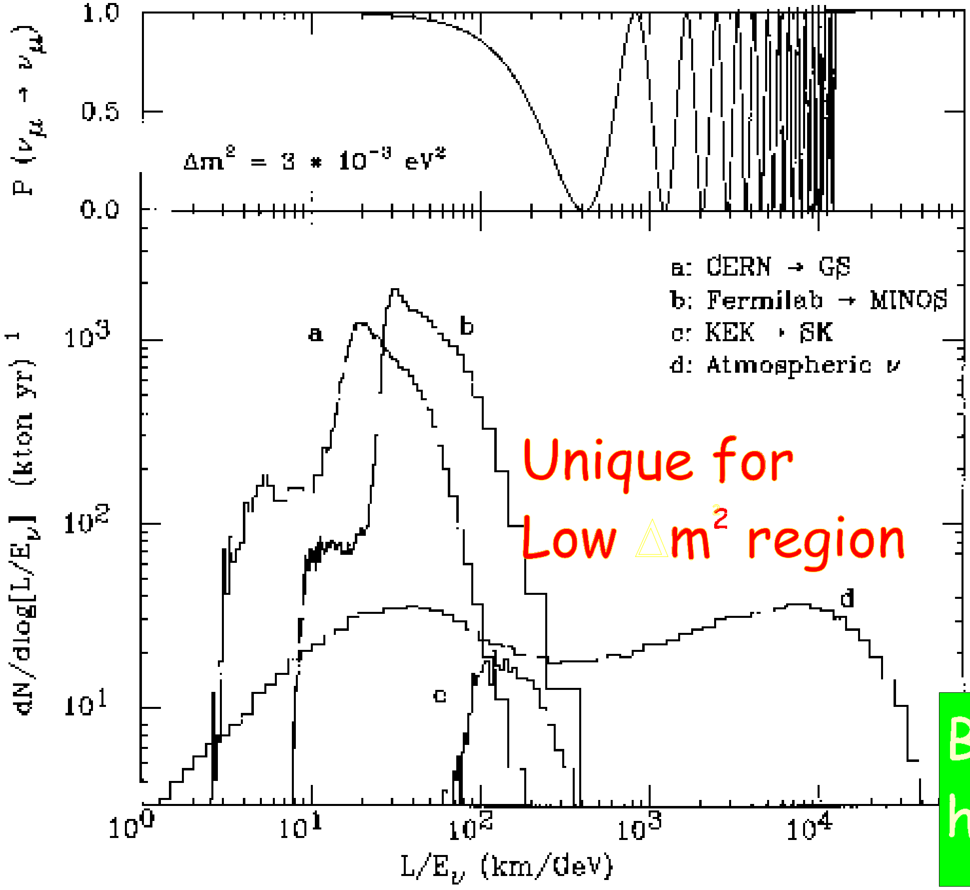


Expected Zenith Angle Asymmetries

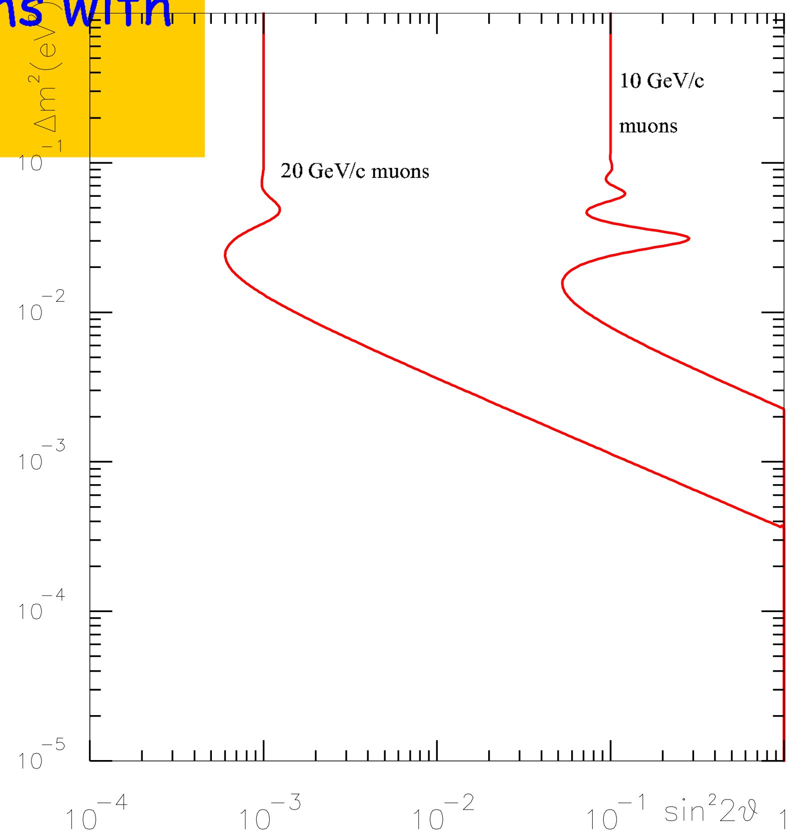


Experimental Reach

Compare L/E reach of accelerator beams with atmospheric neutrino flux



Unique for
Low Δm^2 region



Beams from Muon Storage Rings have also great potential

Open Questions

m^2 and $sin^2 2$

-> ?

Oscillation to tau-neutrinos?

Sterile neutrinos?

How To Answer?

Ratio of electron-like and muon-like events:

- **Statistically strong but least robust**

Through-going and stopping muons:

- Difficult to get parameters with precision

Zenith-angle distributions:

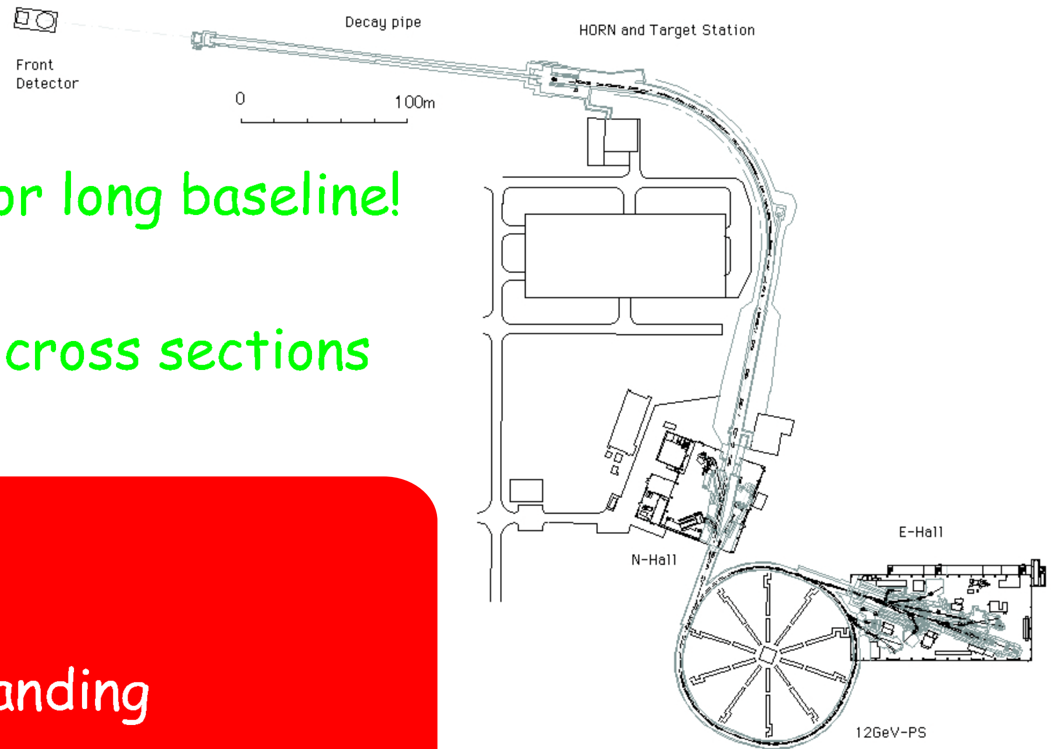
- Convincing measurement
- Problem with angular resolution at low energy

Active versus sterile neutrinos:

- Compare charged current with neutral current measurements
- Example: ^{0}'s or non-muon events

Existing Experiments

Macro, Soudan-2 and most significantly **SuperK**



K2K experiment. Not only for long baseline!

Calibration of rate for ^{0}

Measurements of low energy cross sections

SuperK

More statistics

Better understanding

What will be status in 2005?

Planned Experiments

MINOS

Presented at FNAL PAC

Use MINOS also to detect atmospheric events - muon range and shower measurements

Dedicated Designs

Gran Sasso

M615, M621 calorimeters

Icarus

(Mega-Icarus/Mega-Rich)

Water and Ice detectors:

Amanda

Baikal

Nestor

Antares

Modification of part of the detector with finer segmentation

Look for vertical upcoming muons

Presented at NOW98

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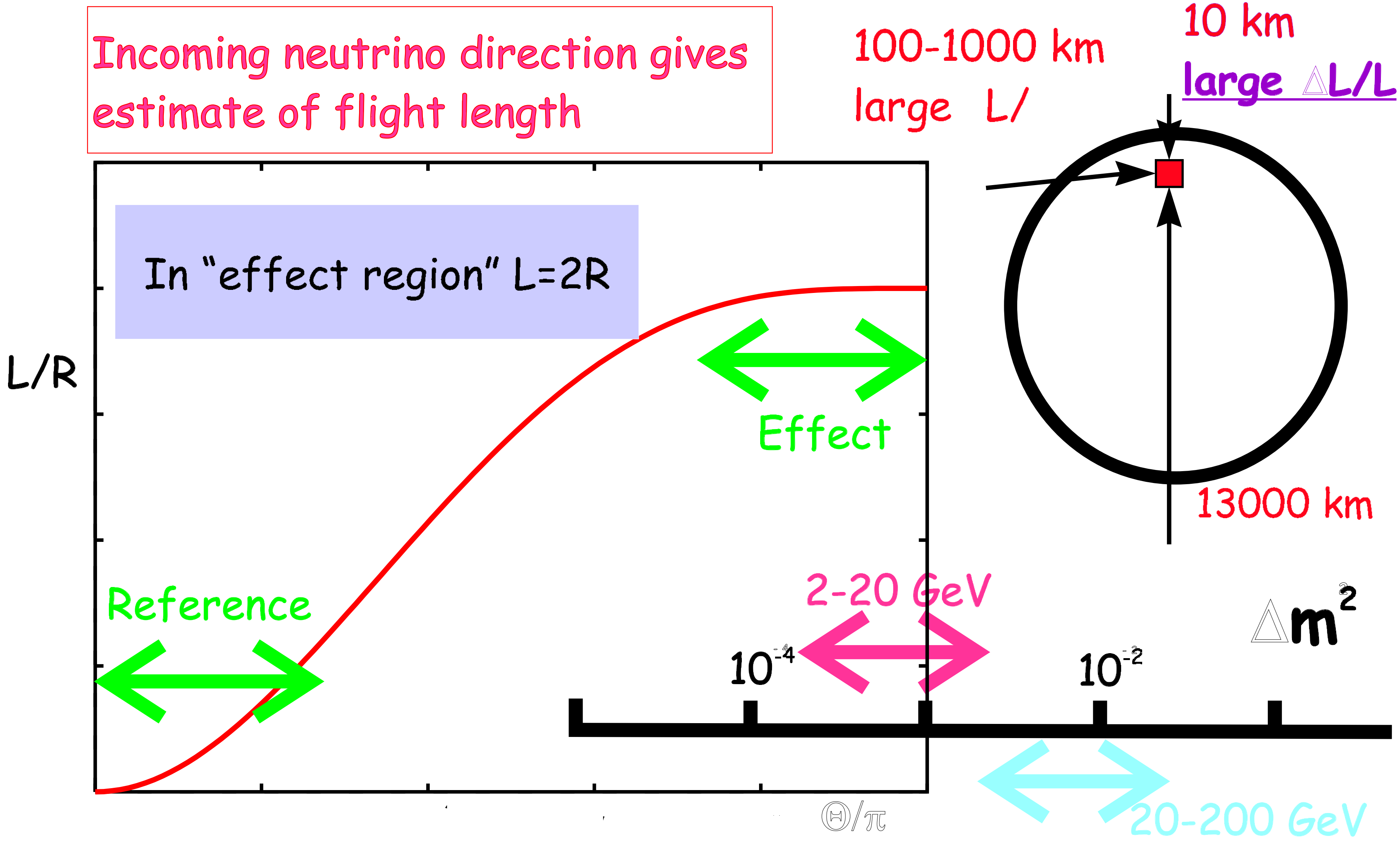
L/E method

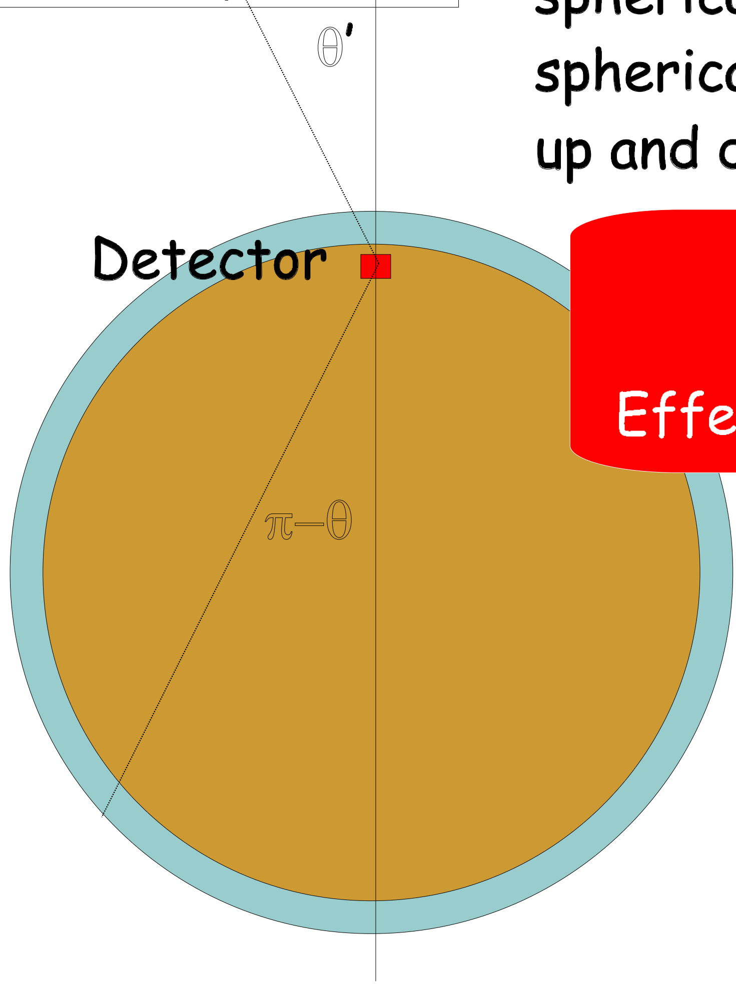
Incoming neutrino direction gives estimate of flight length



Method of reference angle

Picchi, Pietropaolo
CERN/scan-9710037

Simple consequence of **symmetry**:
spherically symmetric cosmic ray flux
spherical shape of earth
up and down going flux should be the same

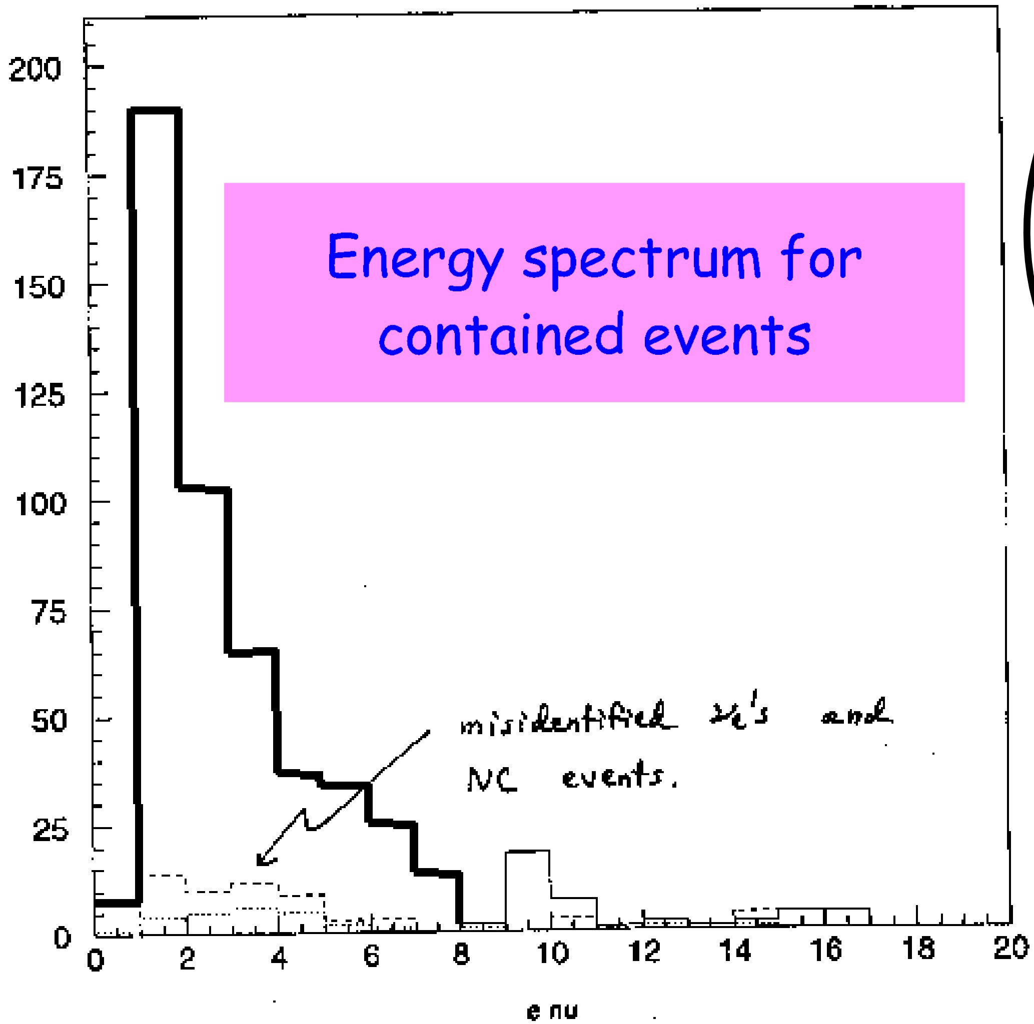


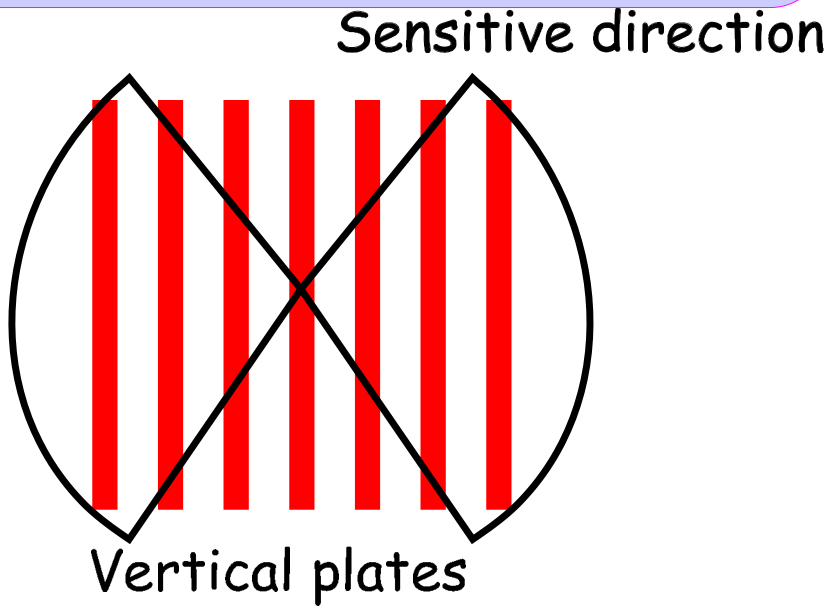
Spoiled by *geo-magnetic* field!
Effect is negligible at high energy

Angular measurement bad at low energies (kinematics)

Energy measurement depends on technique

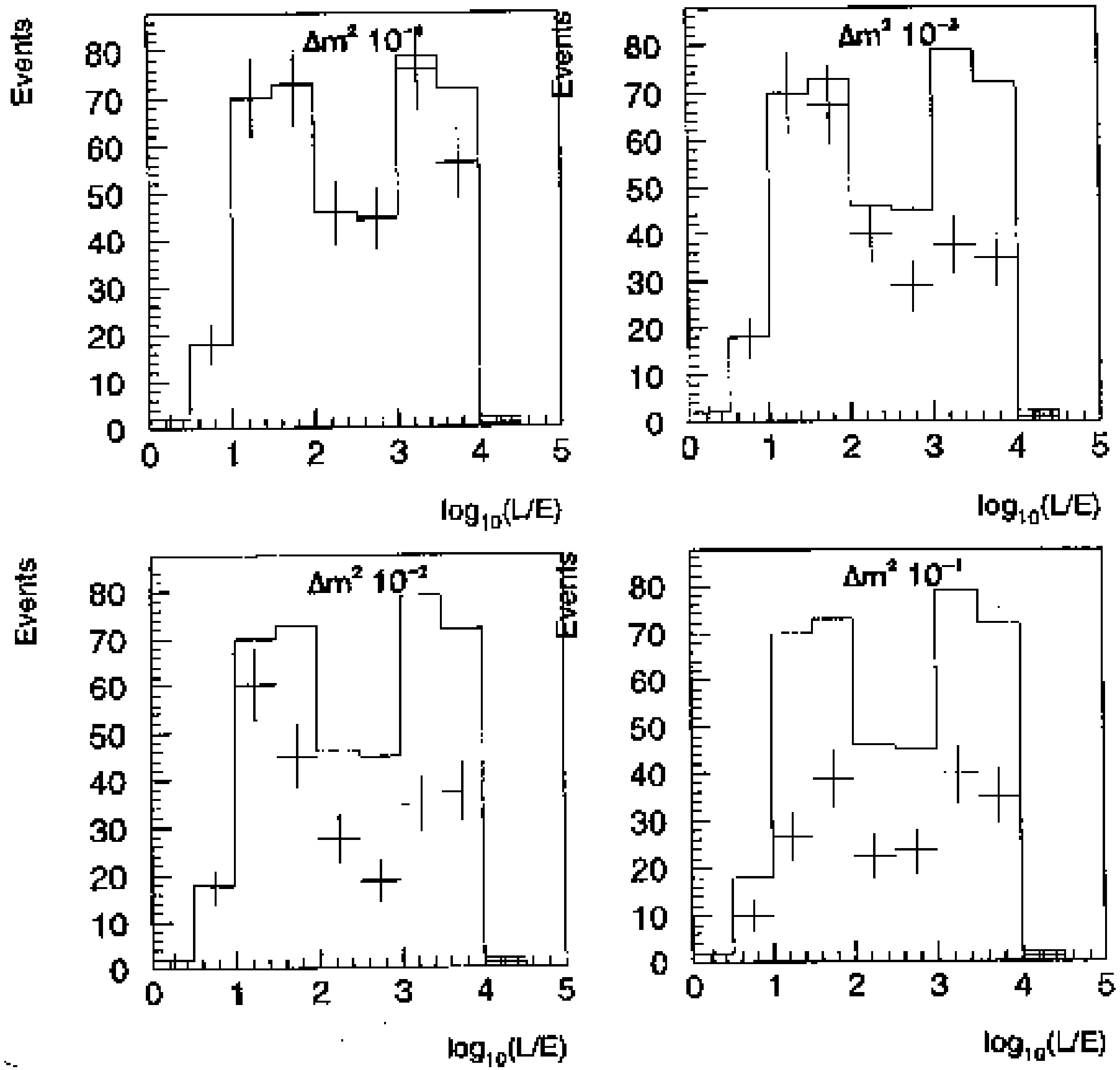
MINOS





Byproduct of LBL experiment
Most sensitive to horizontal neutrinos
Containment up to 8 GeV (peak at 1)

MINOS sensitivity



Sensitivity Range:

- Down to 10^{-4}
- Note: at high m^2 by R alone

Disadvantages:

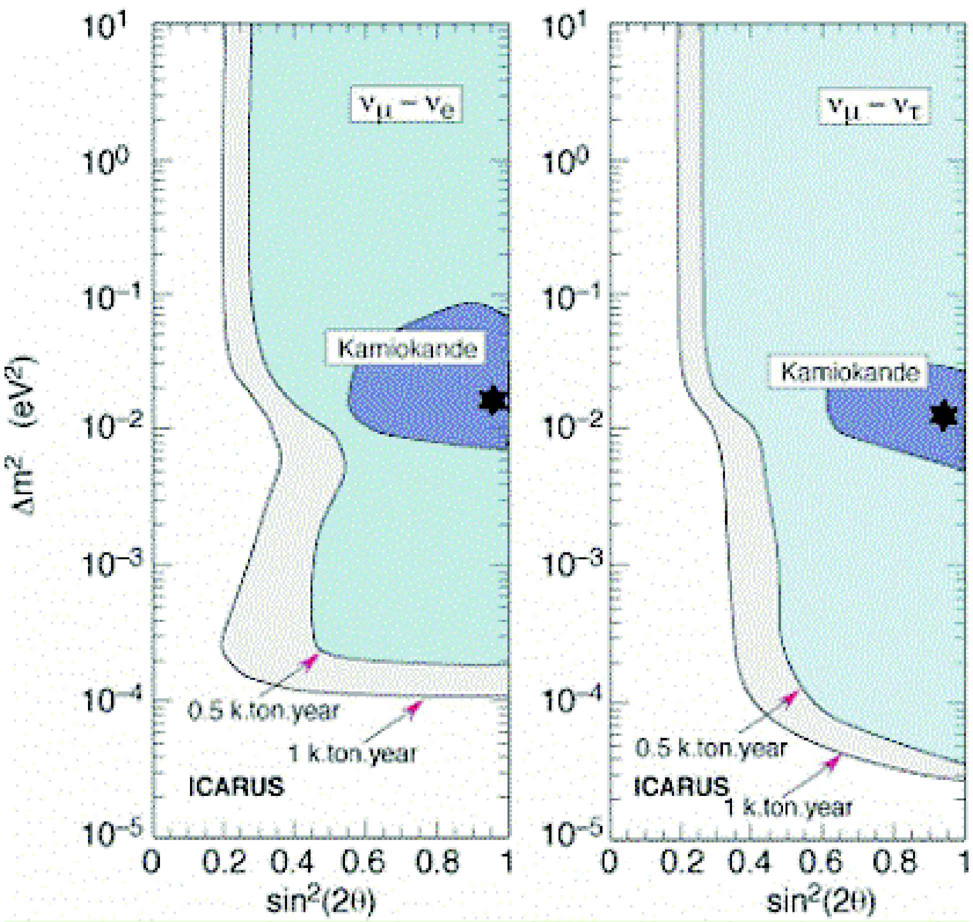
- Low energy
- Horizontal neutrinos (No reference sample)

Advantages:

- Granularity
- Byproduct of LBL

Icarus

600t module sensitivity



Sensitivity Range:
- Down to 10^{-4}
- Note: at high m^2 by R alone

Disadvantages:
- Only low energy events contained

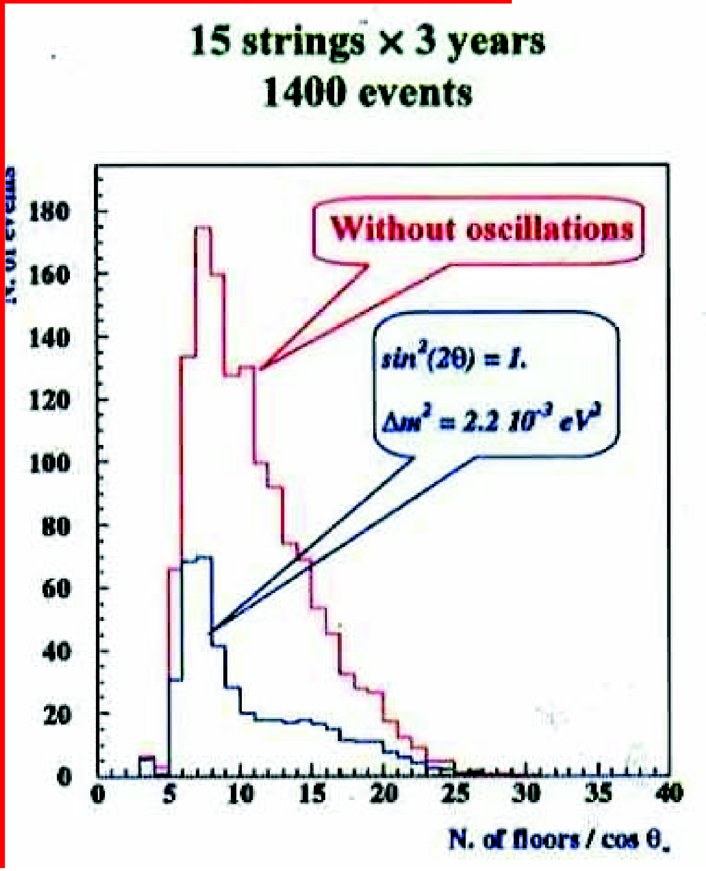
Advantages:
- Good energy and direction reconstruction for contained events
- Byproduct of other goals
- In principle isotropic

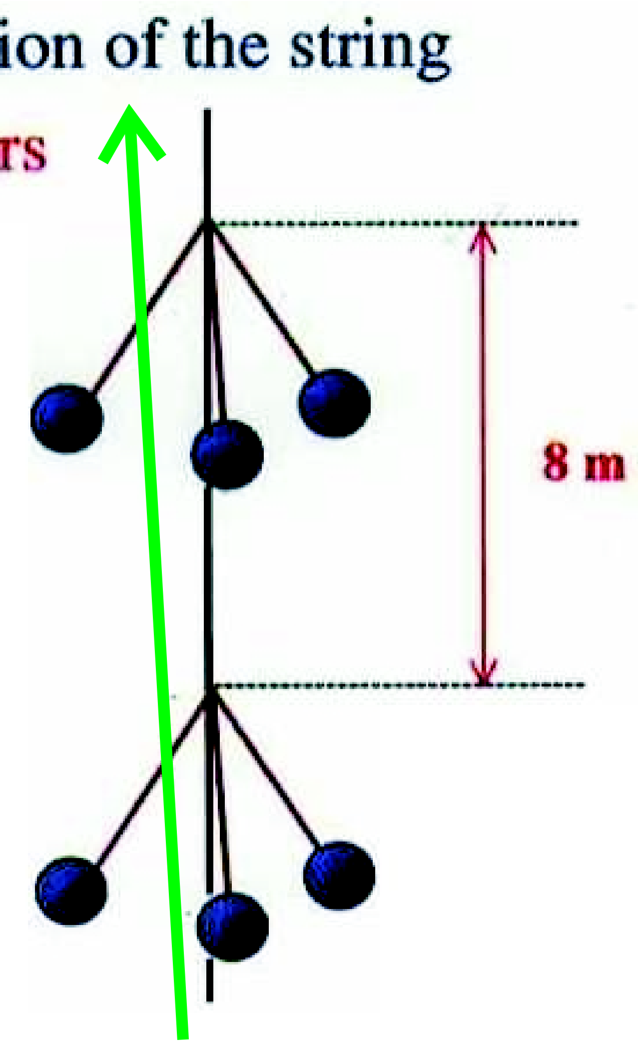
Antares principle

Equally valid for similar detectors (Amanda, Nestor, Baikal)
Re-optimize subset of strings with better granularity

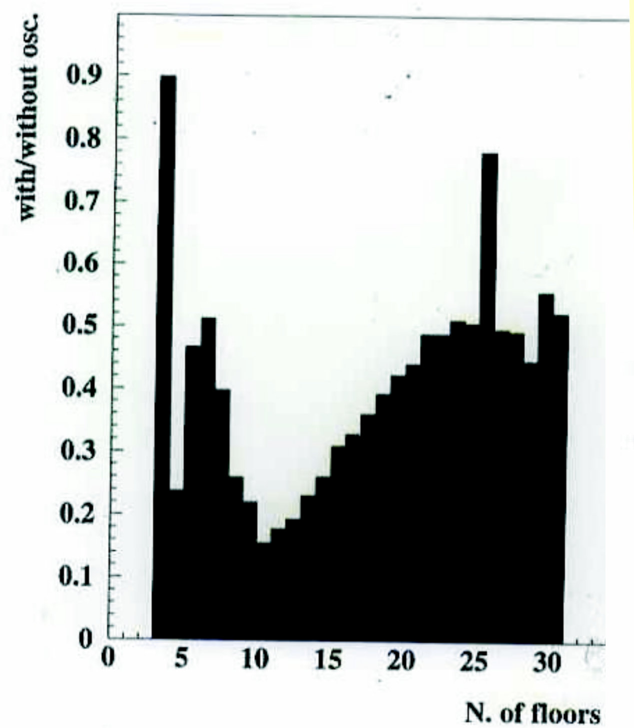
Muons have to be almost parallel to string

Momentum range 5-50 GeV (+/- 1.6Gev)

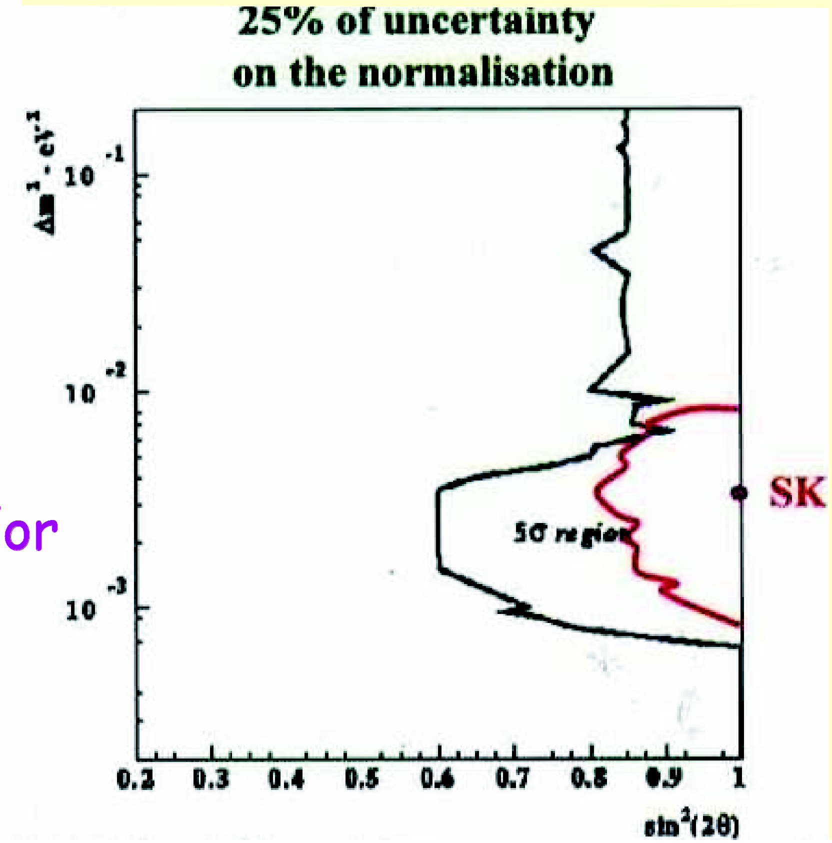




Antares Physics reach



Fixed baseline (vertical muons)
Estimate E/L with energy
range 260 < L/E < 2600 km/GeV

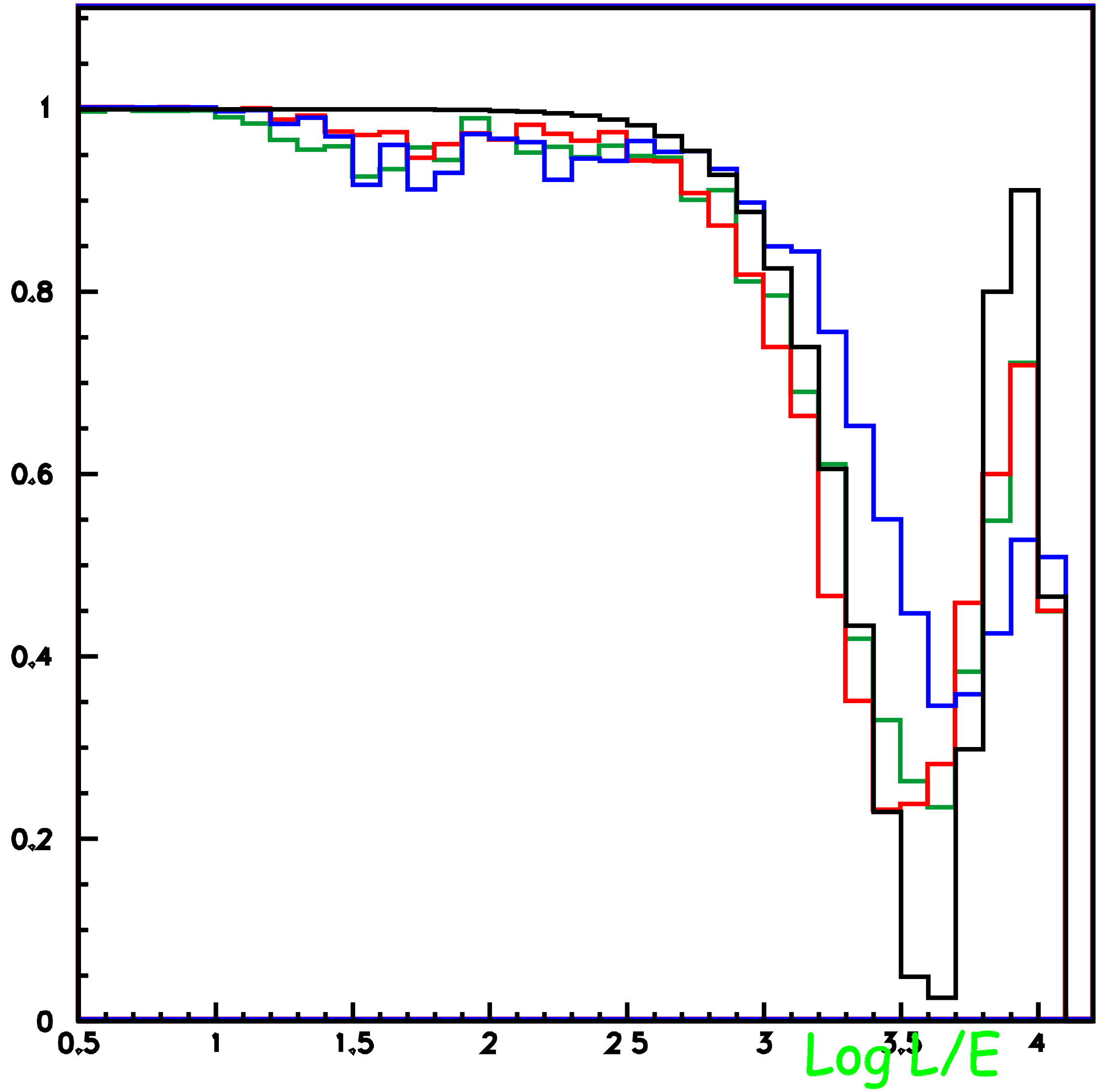


Extension to high m^2 depends on spectrum calculation

Note:
$10^{-3} <$ $m^2 < 10^{-2}$ EV^2

Ratio of L/E spectrum for meas/MC at 2 10^{-2}
No reference sample
(No down going muons!)

Visible Effect



Visible Effect for different measurement quality

All for $m^2 = 3\ 10^{-4}$

--- ideal

--- all reconstructed

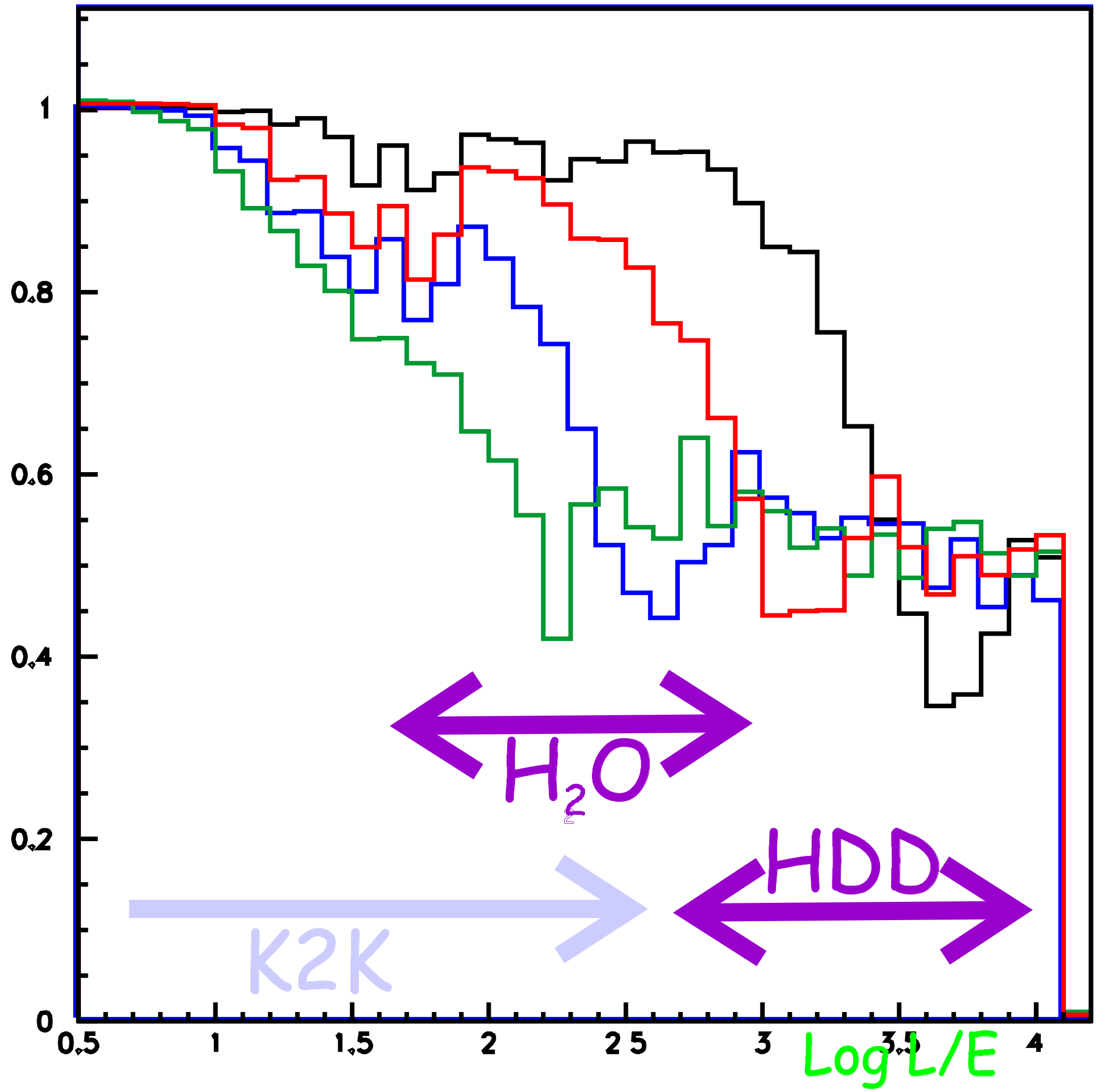
--- muon only

--- muon + E-hadron

Thanks to
R. Santacesaria

Jaap Panman NT99

Visible Effect different m^2



Visible Effect for
different values of m^2
(muon parameters only)

--- $3\ 10^{-4}$
--- 10^{-3}
--- $3\ 10^{-3}$
--- 10^{-2}

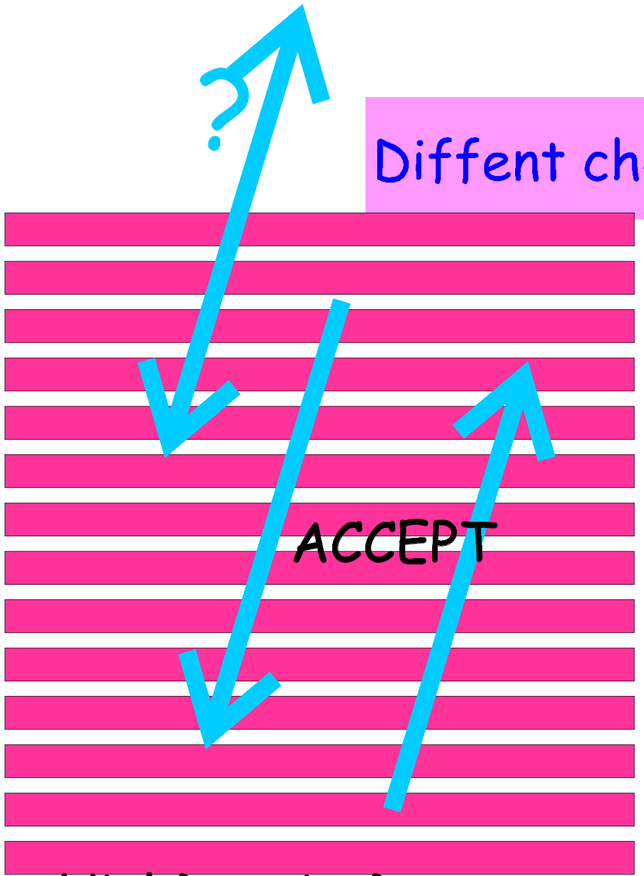
Thanks to
R. Santacesaria

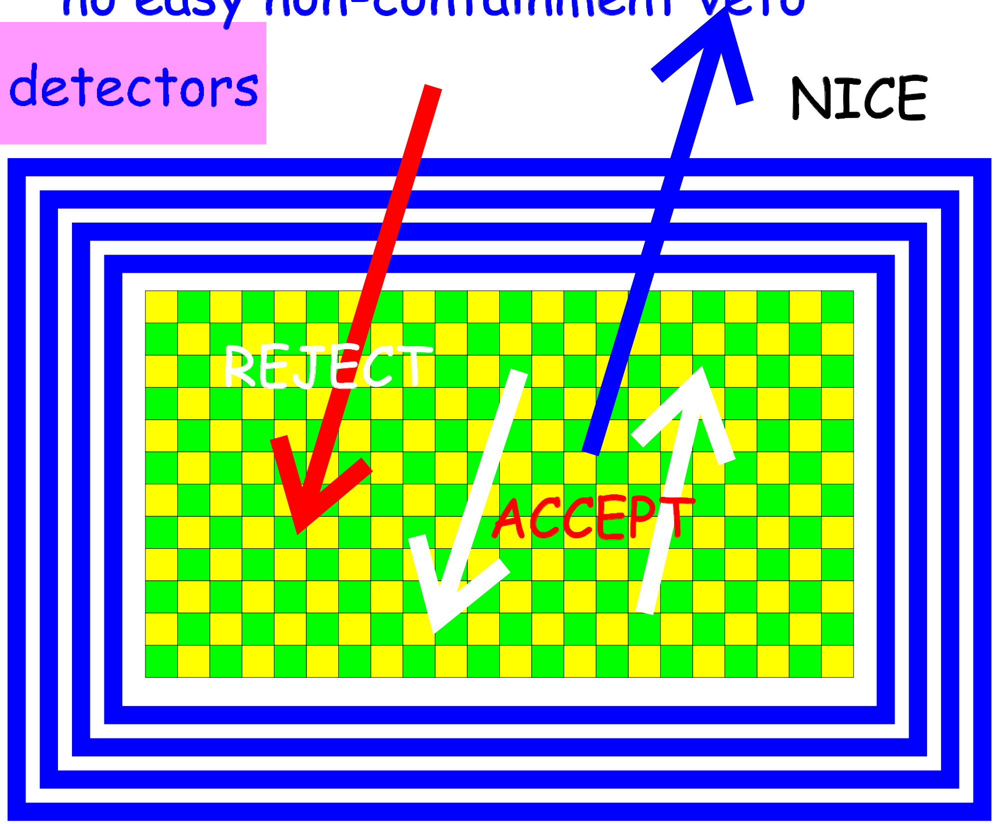
Dedicated Detector Choices

Veto non-contained tracks
Makes direction choice easier

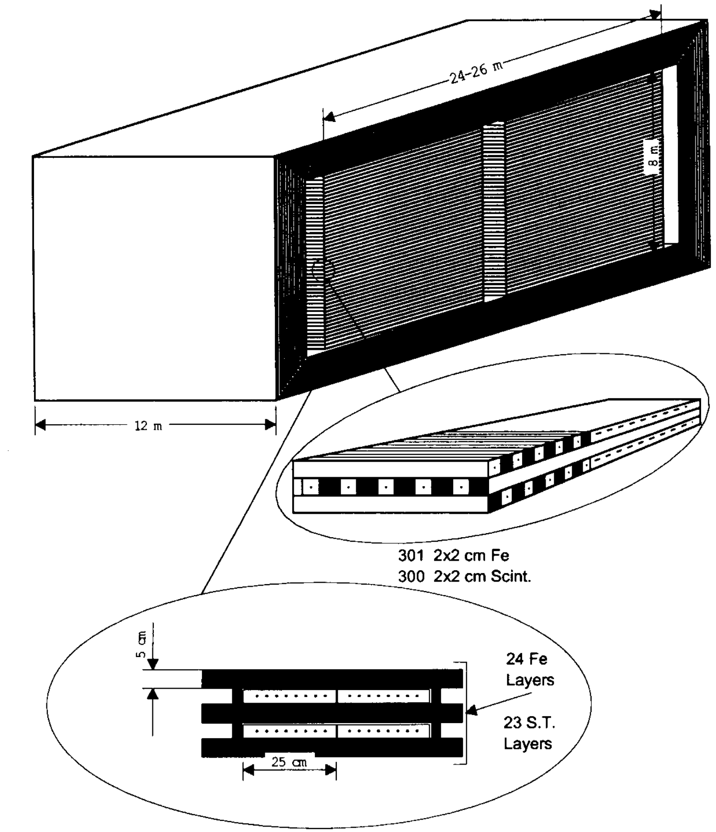
Try energy measurement with magnet
need good direction determination
no easy non-containment veto

Diffent choice of detectors





Design of Nice



Frame magnet around calorimeter
- Large mass (20 kt) magnet
- Smaller (10kt) calorimeter

Contained and exiting events
- Magnet used to get momentum
- Up/down critical (timing) - background rejection from above!

High energy muons
- Spectrum up/down symmetric
- Timing direction easier
- Direction of
- Reference sample exists

Use also shower energy/direction
- Difficult!

Compromise between LBL and atmospheric exposure
Complicated!

High Density Detector

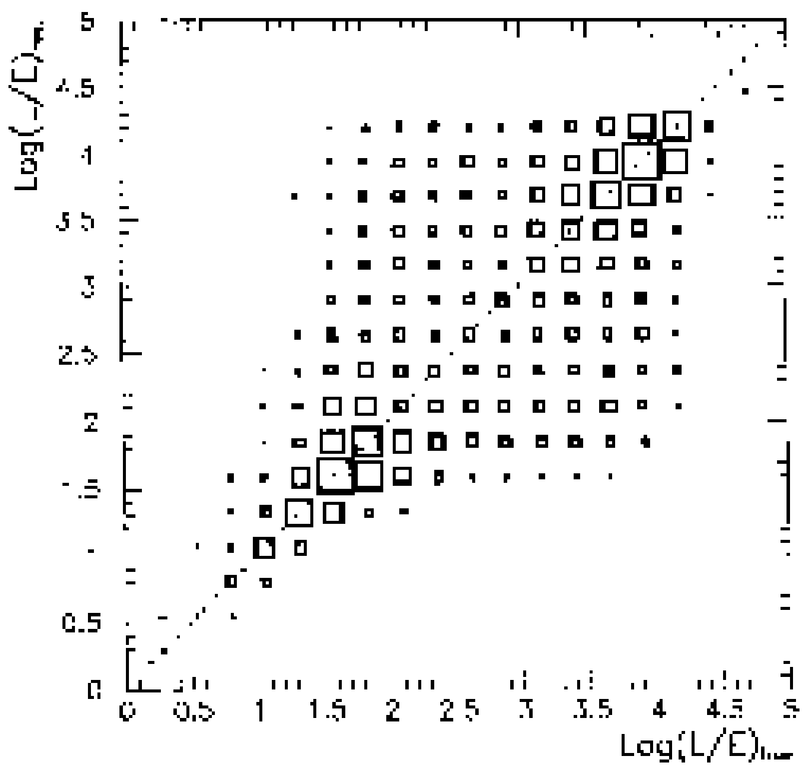
As simple as possible
- Large mass (30 kt), no magnet
- Fe(8cm) stack total 12 m
- Large surface RPCs

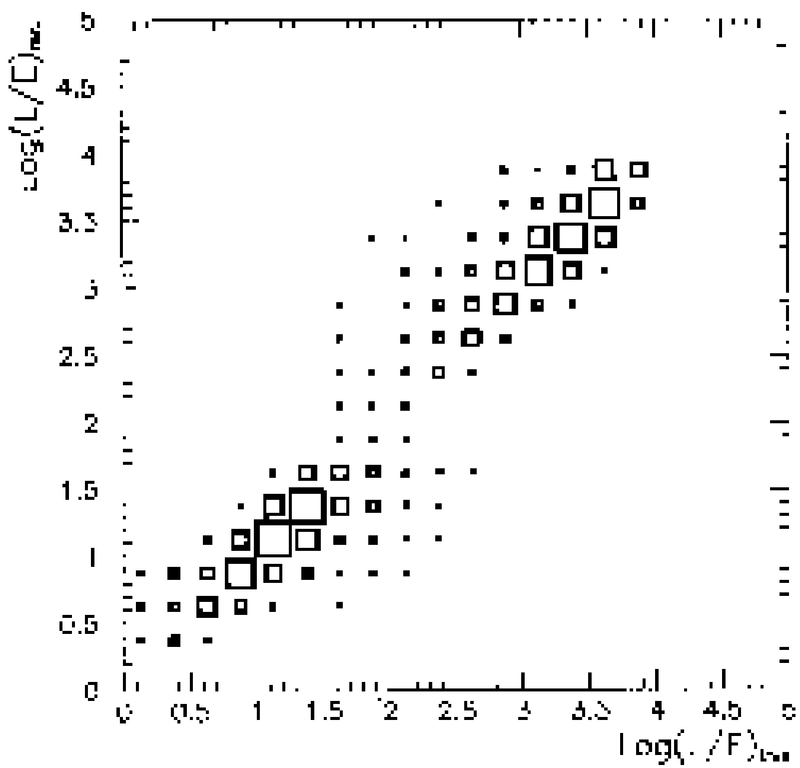
Only contained events
- Outer layer veto - crucial
- Up/down easier (timing)

High energy muons only (range)
- Spectrum up/down symmetric
- Timing direction easier
- Direction of
- Reference sample exists

Also attempt at active/sterile neutrino - difficult!

HDD L/E correlation





SuperK

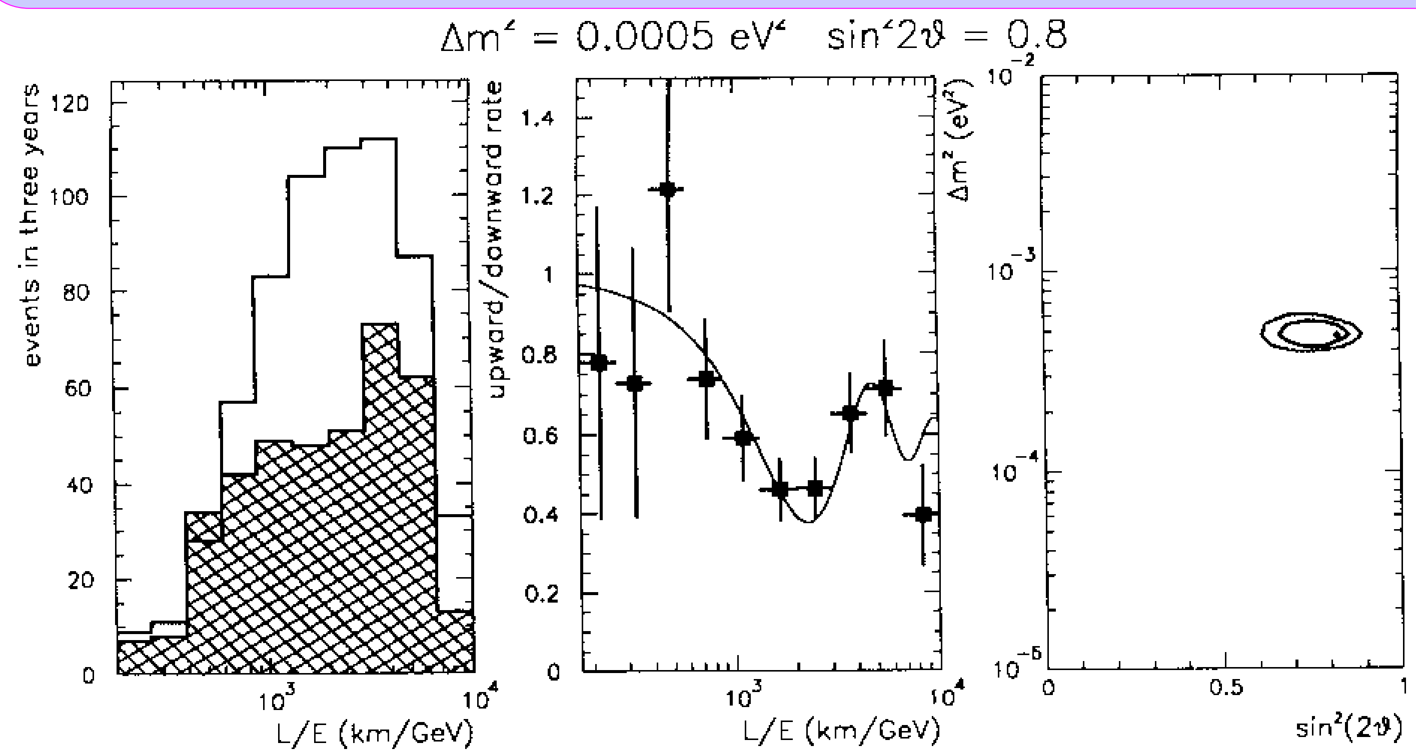
Low energy neutrinos

High Density Detector

Higher energy

Better correlation

Experimental Reach



3 year exposure

Example for $\Delta m^2 = 5\ 10^{-4}\ eV^2$

Measurement possible by modulation of upward going spectrum for

$10^{-4} < \Delta m^2 < 2\ 10^{-3}\ eV^2$

Downward going neutrinos sensitive above 10^{-2} (but K2K!)

Conclusions

Important task to pin down
- Δm^2 --- not yet clear!
- ν_μ -> ??? Channel

For atmospheric experiment most interesting task
- Low Δm^2 region
- (K2K will Δm^2 > 2 10^{-3} eV^2)

Important and difficult to know what will NOT be done by SuperKamiokande
- $_s$/ $_\mu$ within reach with K2K
- calibration of ^{0}
- Robust measurement of m^2 if > 10^{-3} eV^2?

Complementarity with LBL:
- Sub-10^{-3} only possible with new beams (muon storage rings)
- Appears to remain exclusive niche for atmospheric experiments

Design-in-principle for a new atmospheric experiment exists