Future Atmospheric Neutrino Detectors

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Neutrino '2000, Sudbury, CDN, 17. 6. 2000

Why new atmospheric ν detectors ?

- measure ν_μ reappearance (oscillation pattern)
  $\Rightarrow$ prove oscillation hypothesis !
- search for matter effects in 3ν or $\geq 4\nu$ oscillations
  - ν vs. $\bar{\nu}$ $\rightarrow$ sign of δm^2 ?
  - test ν_τ/ν_s hybrid models
- cover low Δm^2 region poorly accessible to long baseline
- better understanding of atm. ν spectrum
  $\rightarrow$ talk P. Lipari

Future atm. ν detectors

*) also/mainly beam
→ see corresponding talks

reference:	mass total / fid.	status	physics start
• Super-Kamiokande	50/22 kt	running	

magnetised tracking calorimeters

	mass total / fid.	status	physics start
• MINOS*) atm.	5.4/3.3 kt	approved	2003
• ICANOE*) atm.	3.2/? kt	proposed	2003 ?
• MONOLITH	34/27 kt	proposed	2004 ?
• generic 50 kt detector (e.g. for ν-factory) MONOLITH-like	?/50 kt	discussed	?

measure μ charge → separate $\nu_\mu / \bar{\nu}_\mu$
measure E_{had} and $\vec{p}$ of noncontained μ's
→ good resolution at high E_ν

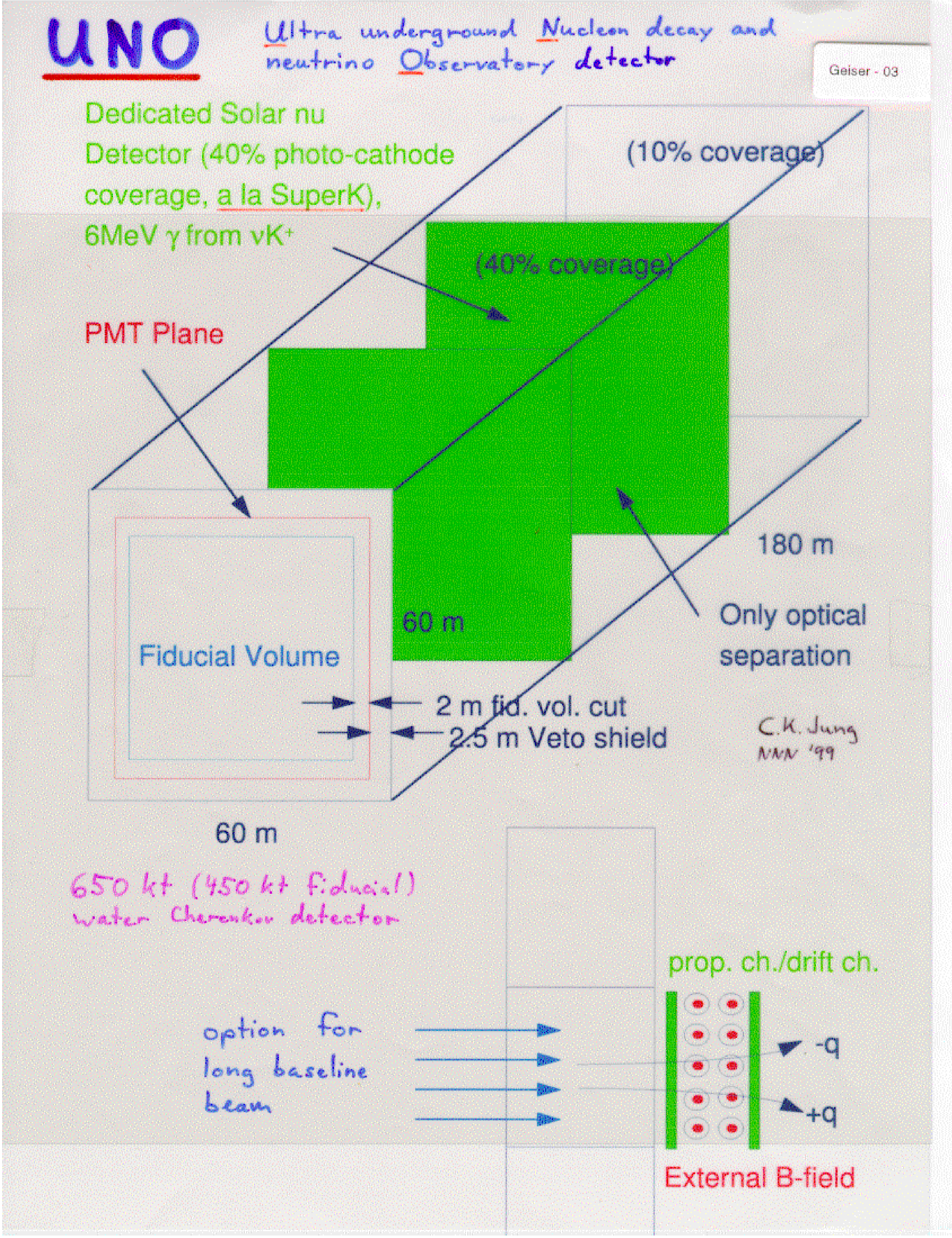
liquid argon TPC's*)

	mass total / fid.	status	physics start
• ICARUS T600	0.6/0.54 kt	approved	2001
• ICANOE*) atm.	7.6/5.6 kt	proposed	2003 ?
• Super-ICARUS	30/? kt	discussed	2015 ??

measure recoil nucleon + individual hadrons
→ high resolution down to low E_ν
separate ν_μ, ν_e, ν_τ

mega-ton water Cherenkov detectors

	mass total / fid.	status	physics start
• UNO	650/450 kt	discussed	2010 ??
• AQUA-RICH	1 Mt	R&D	?

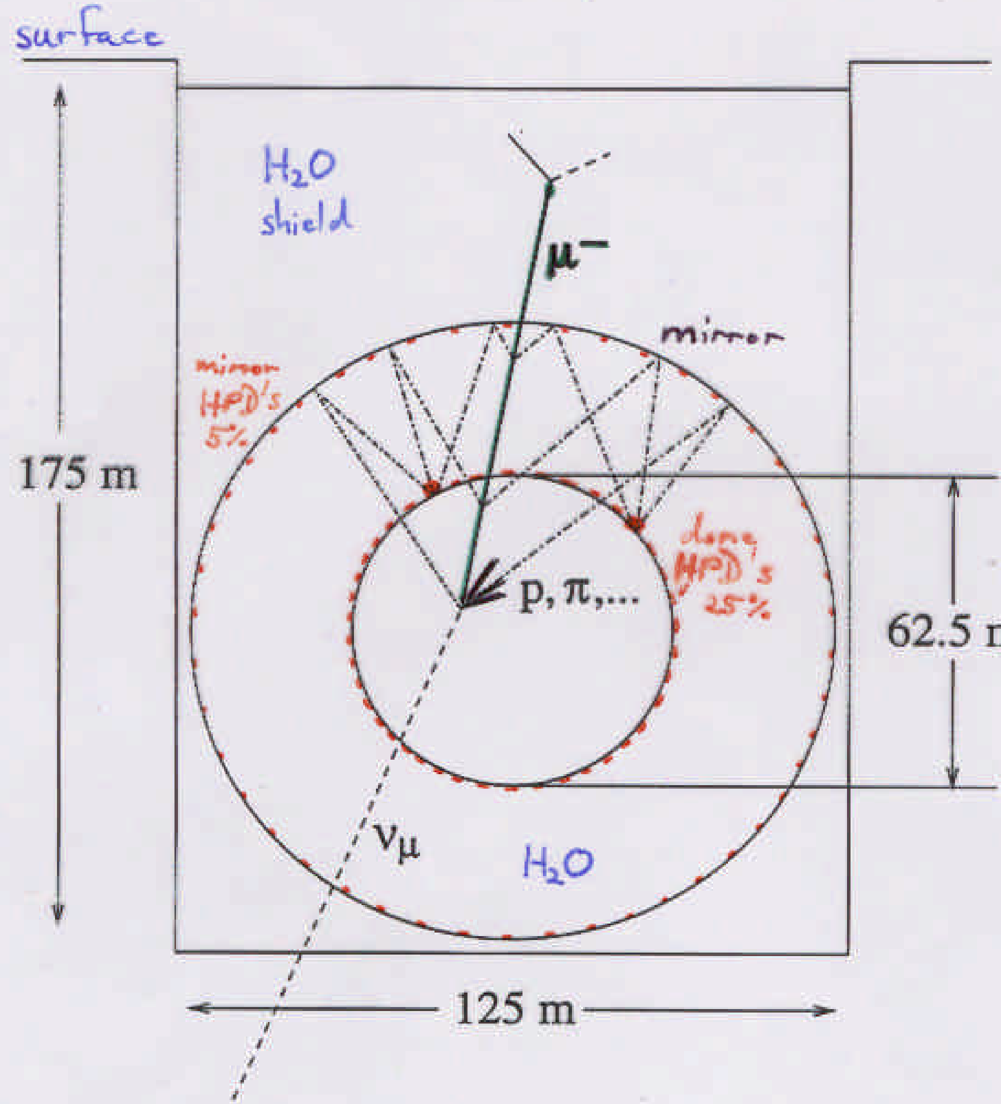

UNO
Ultra underground Nucleon decay and neutrino Observatory detector
Geiser - 03
Dedicated Solar nu Detector (40% photo-cathode coverage, a la SuperK), 6MeV γ from νK+
(10% coverage)
(40% coverage)
PMT Plane
180 m
60 m
Only optical separation
Fiducial Volume
2 m fid. vol. cut
2.5 m Veto shield
C.K. Jung
NNN '99
60 m
650 kt (450 kt fiducial)
water Cherenkov detector
prop. ch./drift ch.
option for long baseline beam
-q
+q
External B-field

AQUA - RICH

K. Zuber
contributed paper C57

Geiser - 04

1 Mt Ring Image CHerenkov det.



1 m HPD's being tested at CERN

mirror HPD's : vertex, direction

dome HPD's : Ring Image
momentum from multiple scattering

$\frac{\Delta p}{p} \sim 7\%$ at 20 GeV (GEANT simulation)

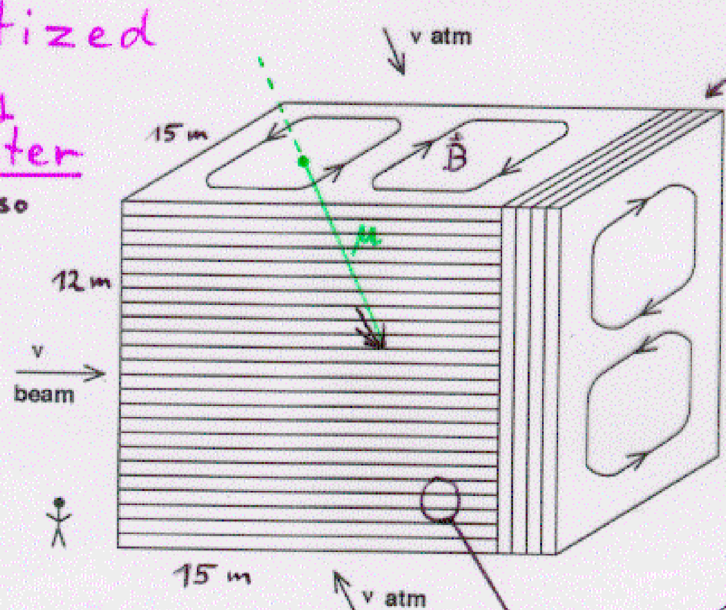
contrib. paper C58

proposal this summer

data ≥ 2004

magnetized tracking calorimeter
@ Gran Sasso

module:



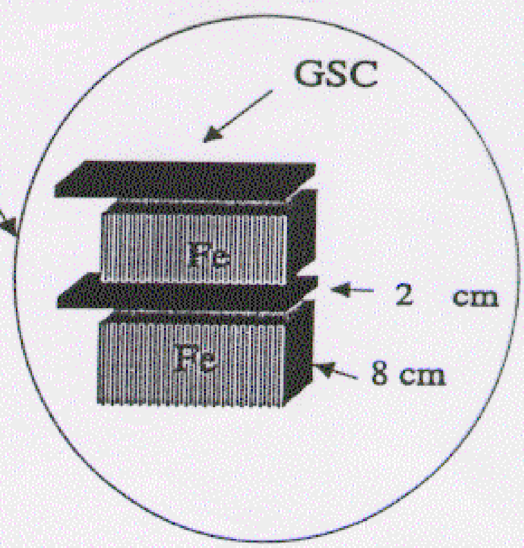
end cap option

external veto

B = 1.3 T

120 8 cm Fe plates
+ Glass Spark Counters
(RPC's)

2 modules
⇒ 34 kt



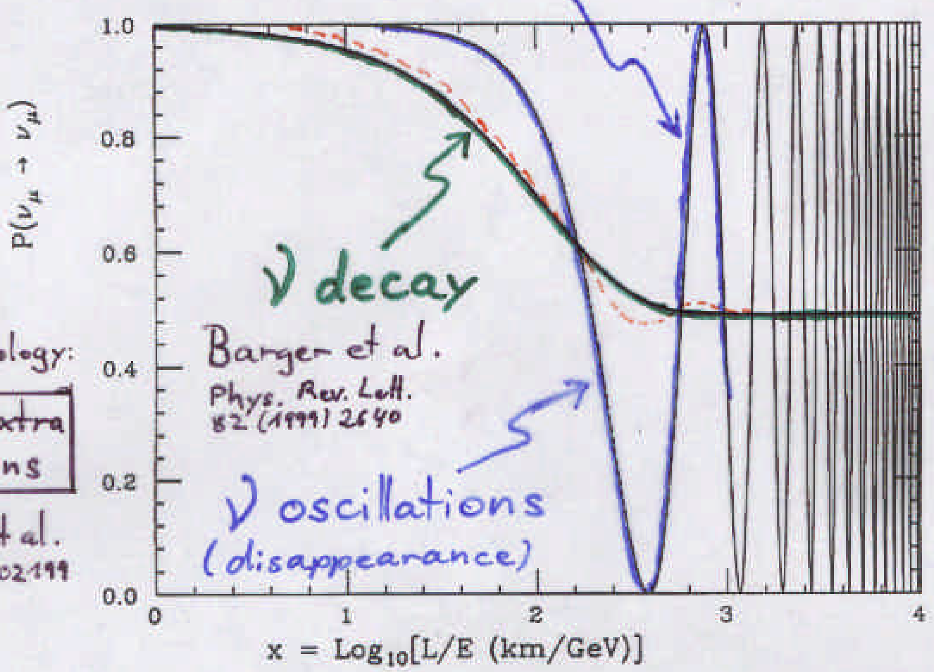
- measure $\vec{p}_\mu$ and charge for all μ's (p_μ > 1 GeV)
- measure E_{had}

⇒ improved acceptance and resolution at high E_ν
(good L resolution)

⇒ **improved L/E resolution + ν/ν̄ separation** for multi-GeV ν_μ

to prove oscillations:

measure ν_μ-reappearance



--- osc.
+ detector resolution

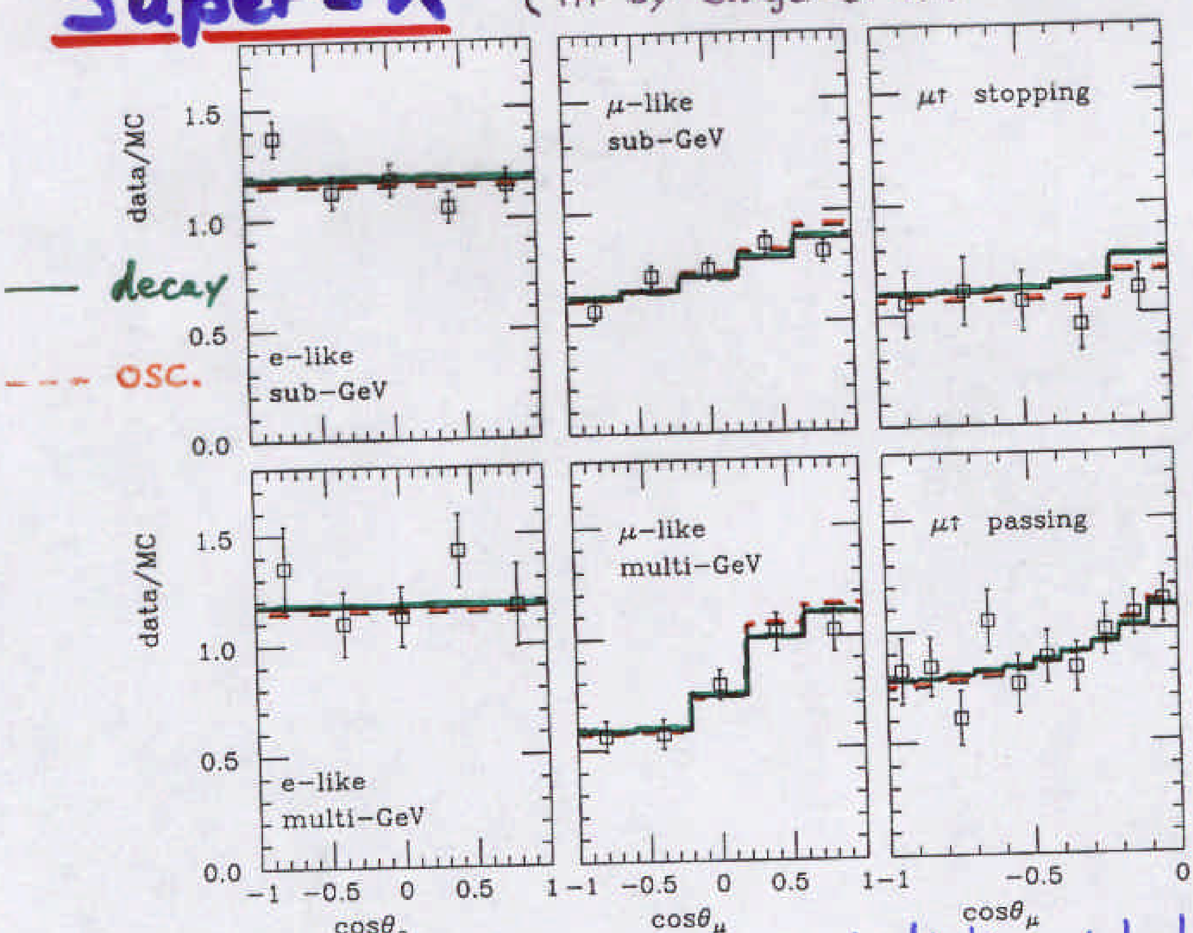
similar phenomenology:

Large extra dimensions

Barbieri et al. hep-ph/0002199

Super-K

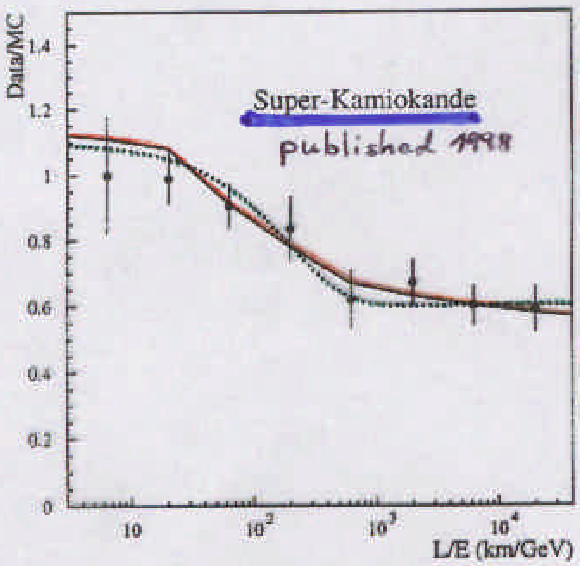
(fit by Barger et al.)

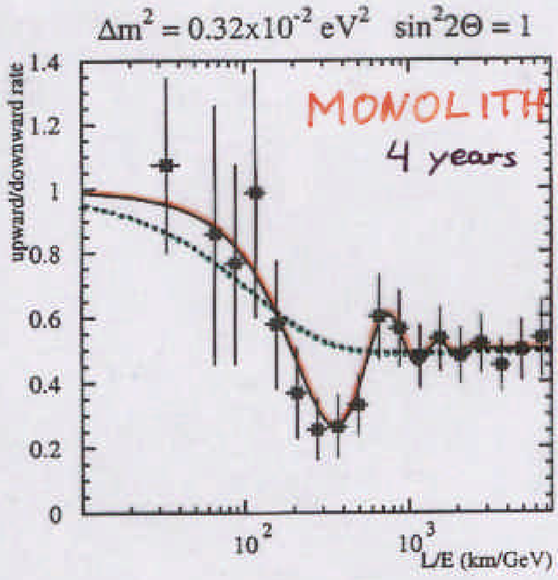


indistinguishable!

measurement of oscillation pattern

ν_μ disappearance

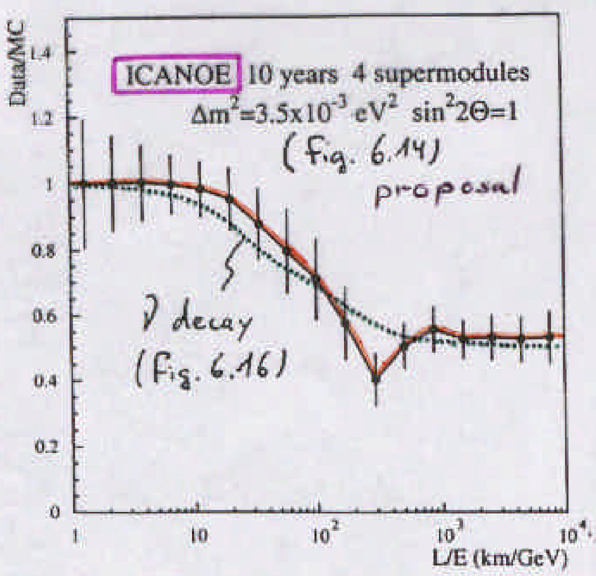


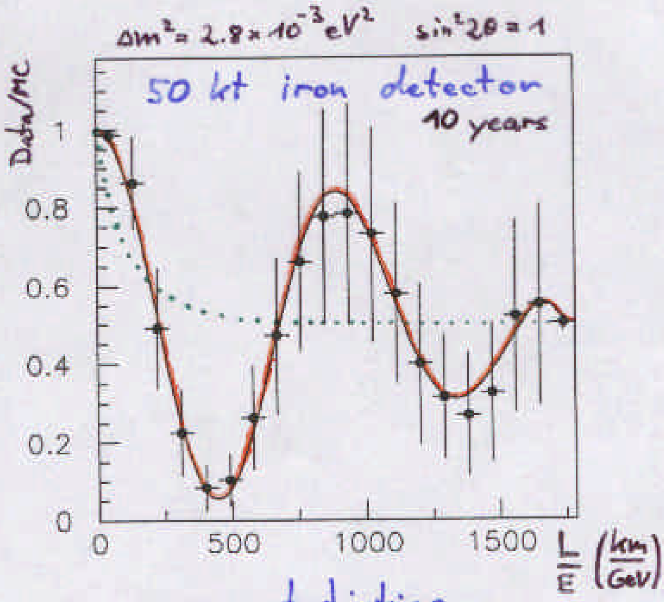


contr. paper C58

—— oscillations

······· decay



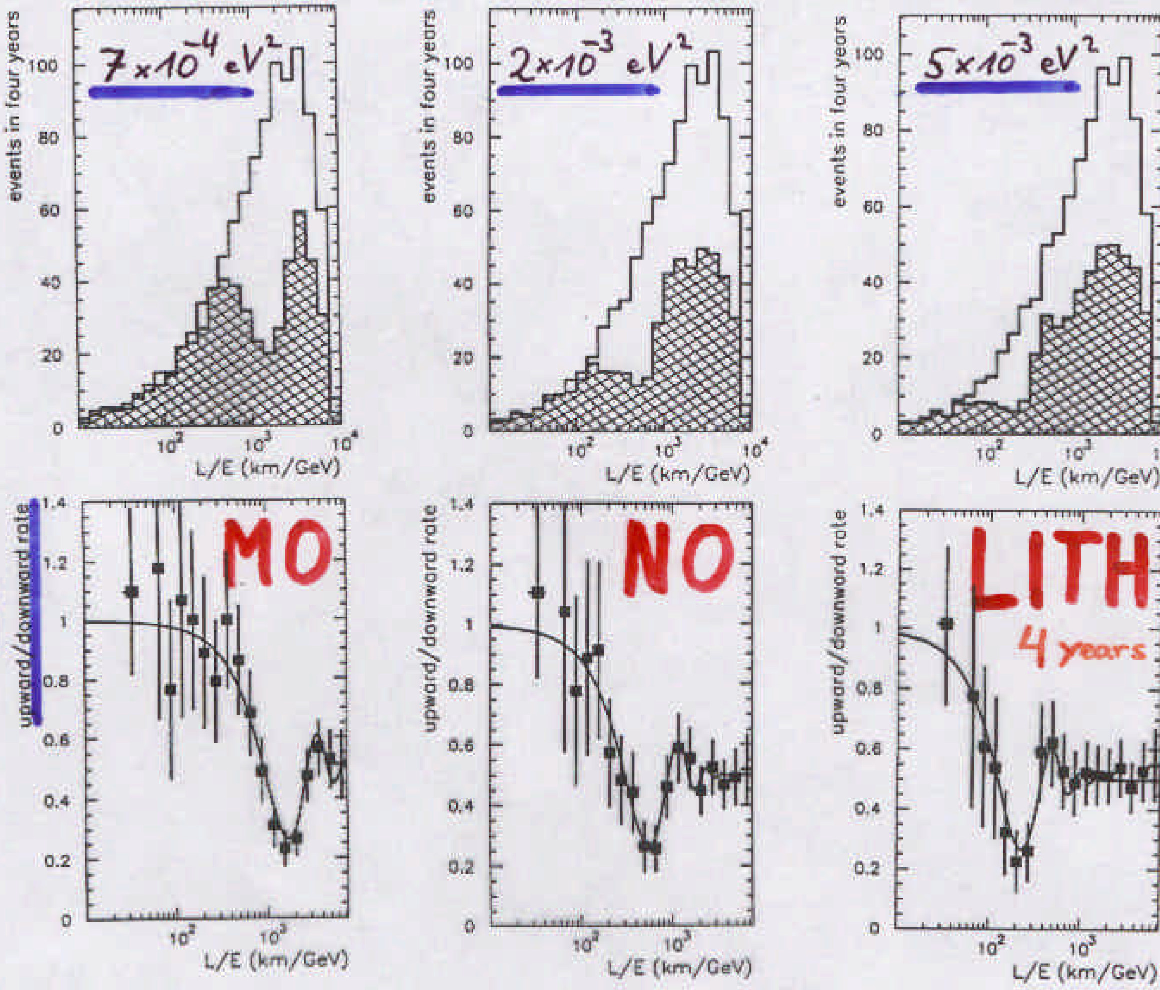


more statistics → harder cuts:

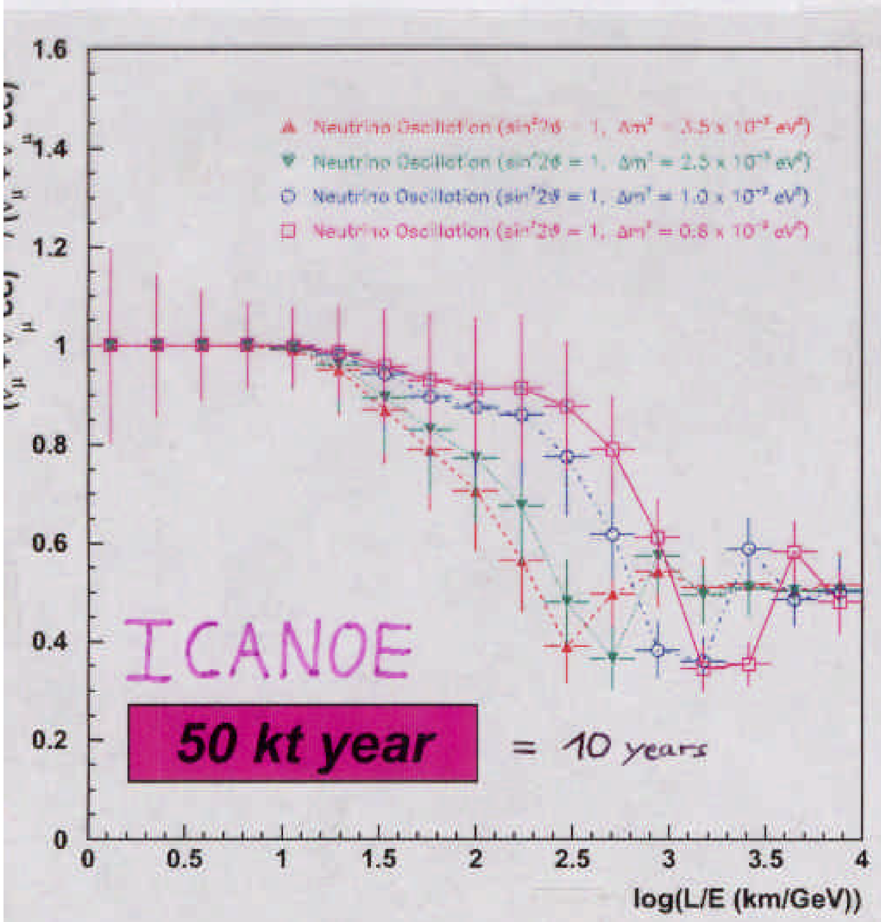
$$\frac{\Delta\left(\frac{L}{E}\right)}{\left(\frac{L}{E}\right)} < 20\%$$

$\sin^2 2\theta = 1$

$\Delta m^2 =$



syst. errors cancel



no strong Δm^2-dependence of sensitivity

best sensitivity at low Δm^2

K. Nakamura
NuFact '00

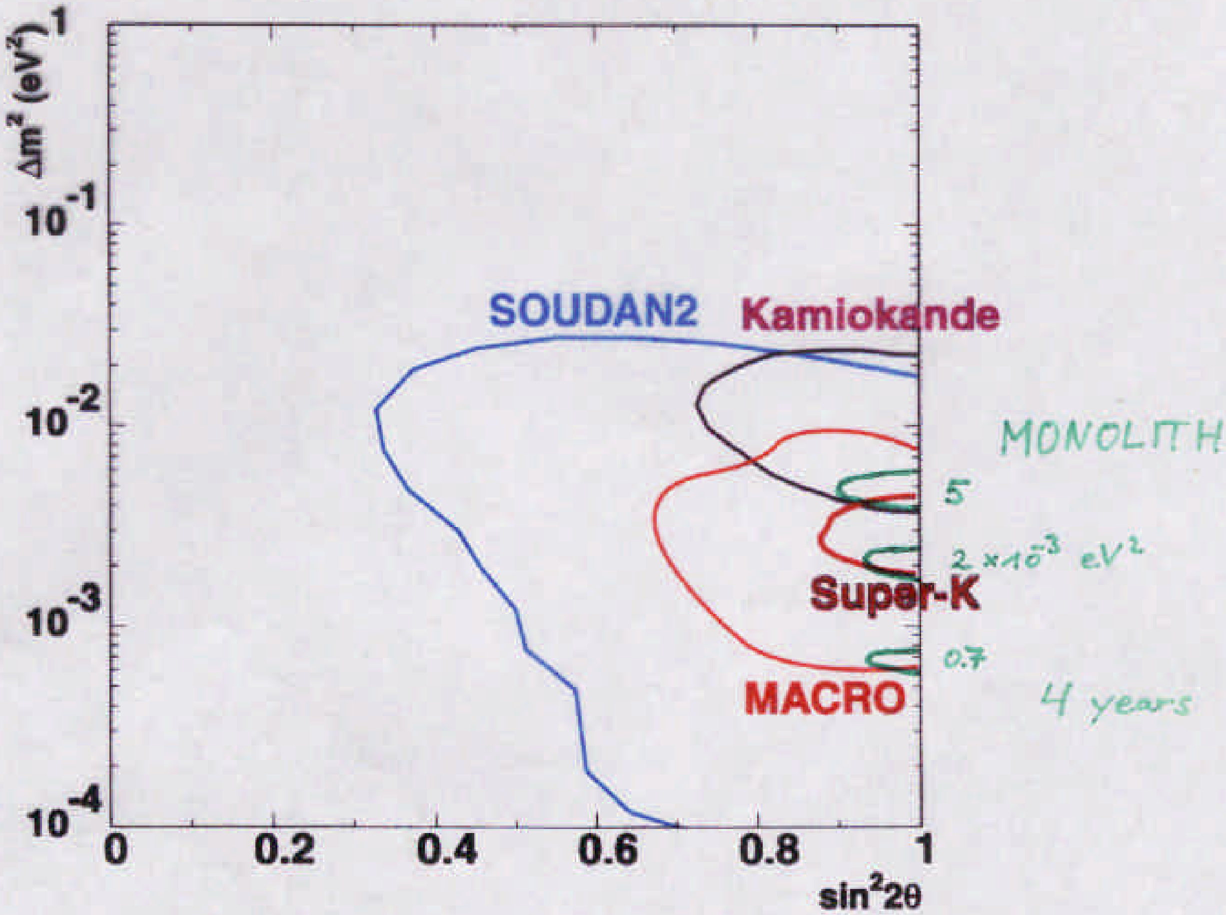
Geiser - 09

Comparison of allowed regions

Allowed regions

atmospheric neutrinos

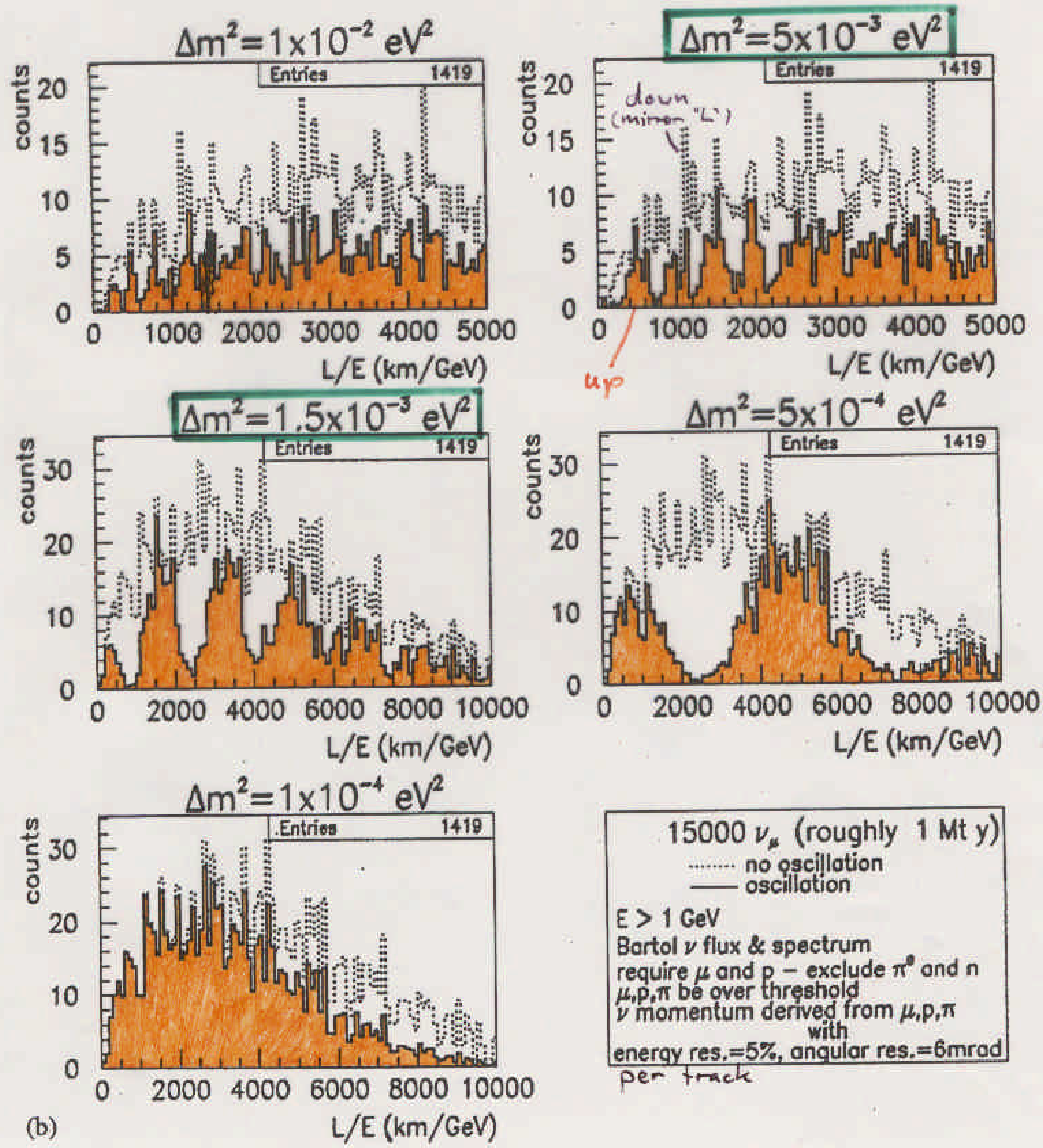
$\nu_\mu \rightarrow \nu_\tau$ 90% C.L.



AQUARICH

~ 1 Mt year after selection cuts

Antonioli et al. / Nuclear Instruments and Methods in Physics Research A 433 (1999) 104–120

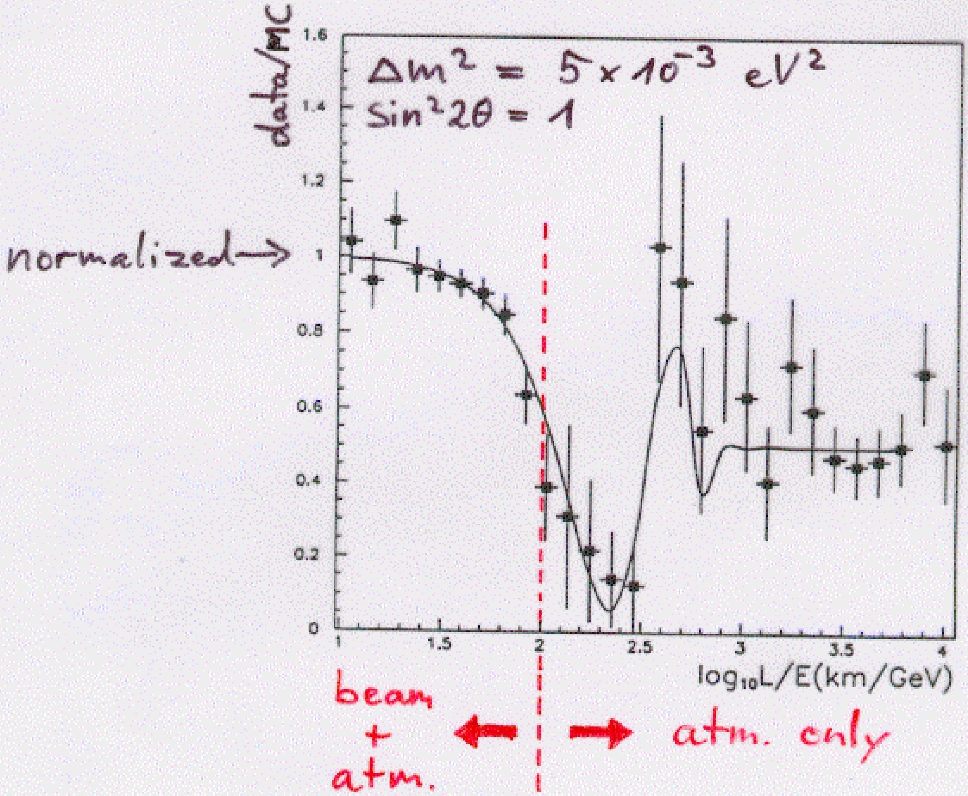


complementarity of atmospheric ν's + beam ν's

CERN/Gran Sasso beam ≥ 2005

example:

MONOLITH 2 years atm. + 1 year beam



caveat:

beam systematics?

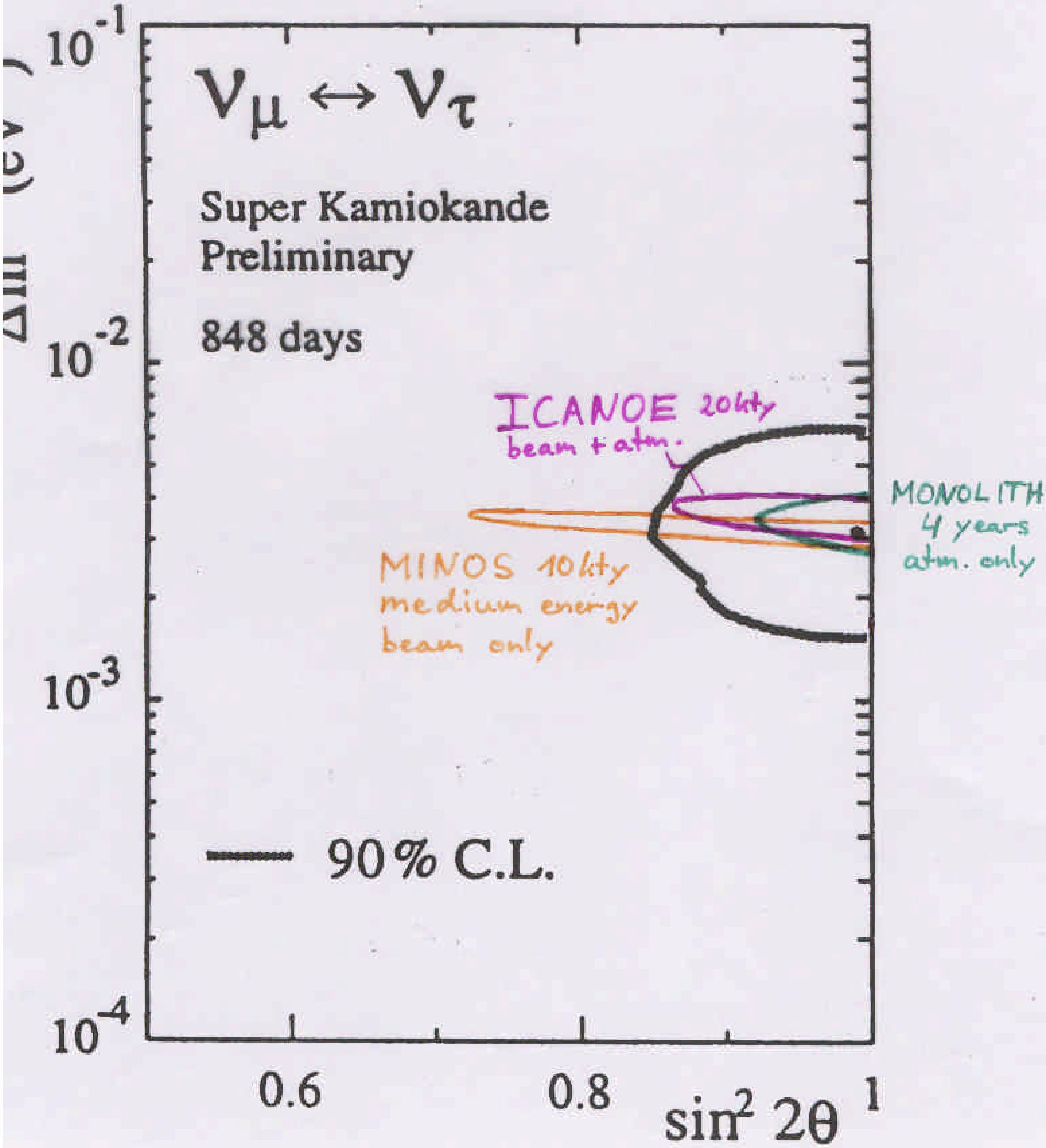
ICANOE:

beam analysis (see talk A. Rubbia)
(bin-to-bin syst. error: 30%)

+ atmospheric analysis "à la Super-K"

⇒ combined fit

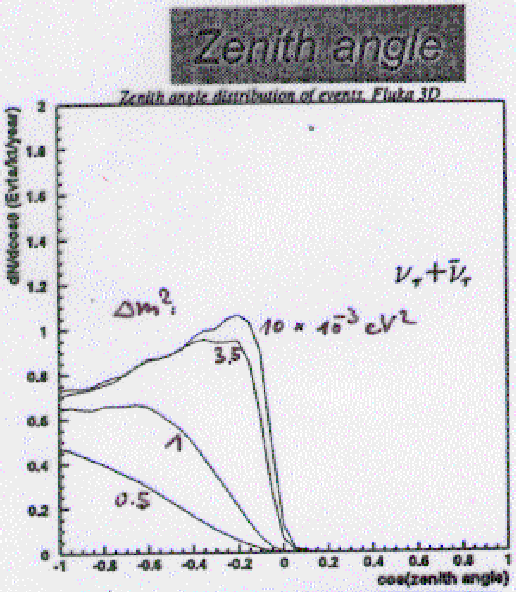
sensitivity contours for $\Delta m^2 \sim 3 \times 10^{-3}\ eV^2$



ν_τ "appearance" ↔ "NC" up/down

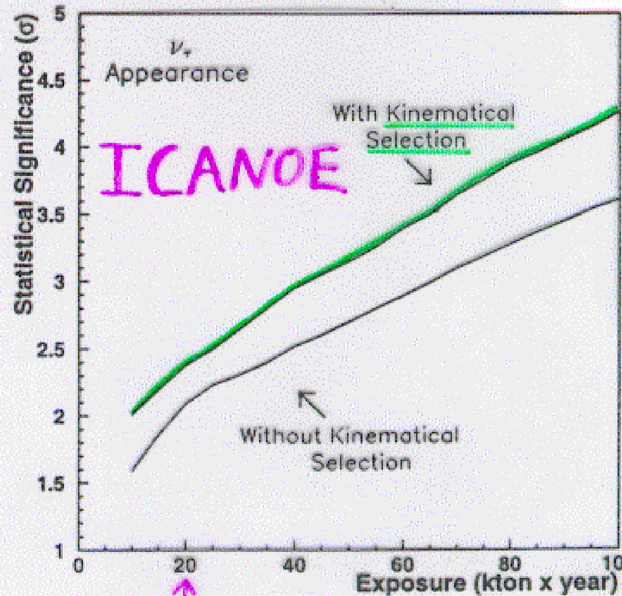
$\tau \to$ hadrons

at high E_{vis}



up down

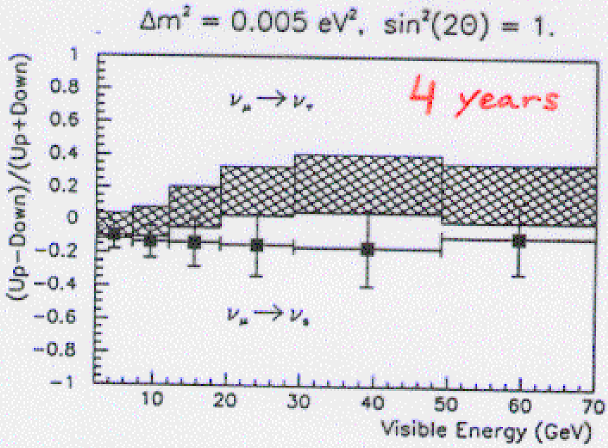
~ 1τ/kty

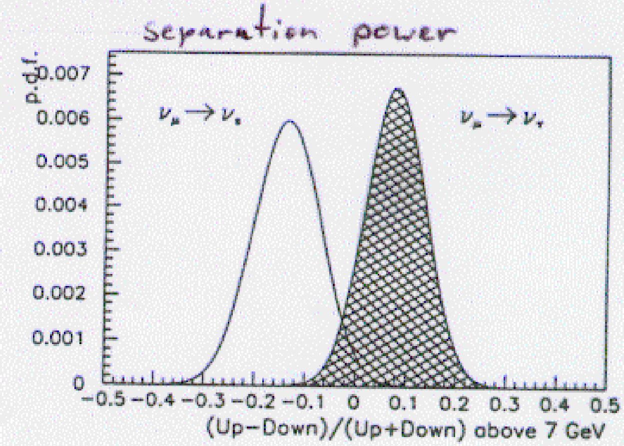


↑ 4 years

Super-ICARUS?

MONOLITH





- marginal compared to ν_τ detection from beam
- potentially useful to test complicated ν_μ/ν_s hybrid models

if needed:

UNO: ~ 400 τ's / year

matter effects

- occur for $\nu_\mu \leftrightarrow \nu_e$ and $\nu_\mu \leftrightarrow \nu_s$ ($L \gtrsim 1000$ km)
- do not occur for $\nu_\mu \leftrightarrow \nu_\tau$ (to 1st order)

ν_τ / ν_s discrimination

- spectral distortions at high E_ν + upward μ's
  $\Rightarrow$ SK-like analysis
- non-maximal mixing
  $\Rightarrow$ additional handle : difference $\nu/\bar{\nu}$

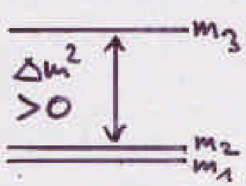
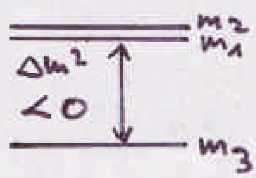
e.g. MONOLITH:

- additional 99% c.l. sensitivity for $\delta m^2 = 2 \times 10^{-3}\, eV^2$, $\sin^2 2\theta = 0.8$
- test allowed ν_τ/ν_s hybrid solutions (O. Yasuda)

solar LMA solution

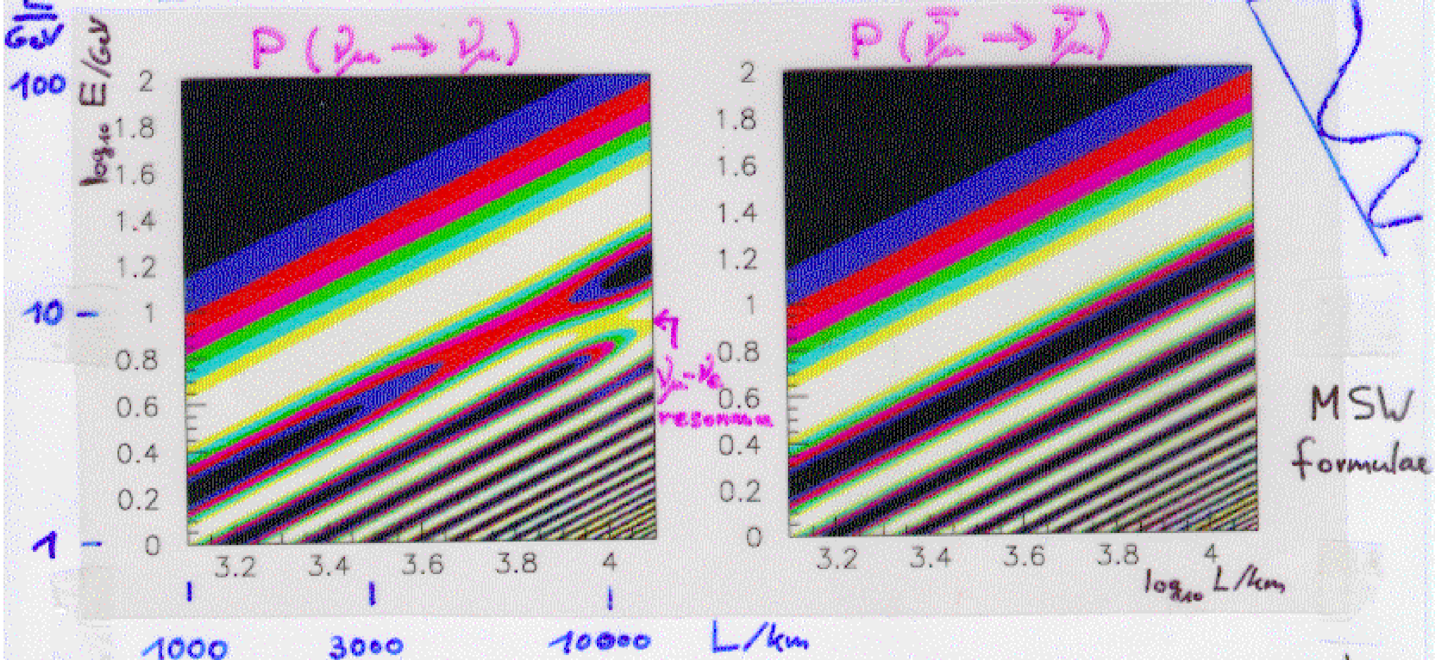
- ICANOE:
  - test matter affected ν_e appearance at low E_ν

$\nu_\mu \leftrightarrow \nu_e$ contr. to atm. Δm^2

distinguish  from  ?

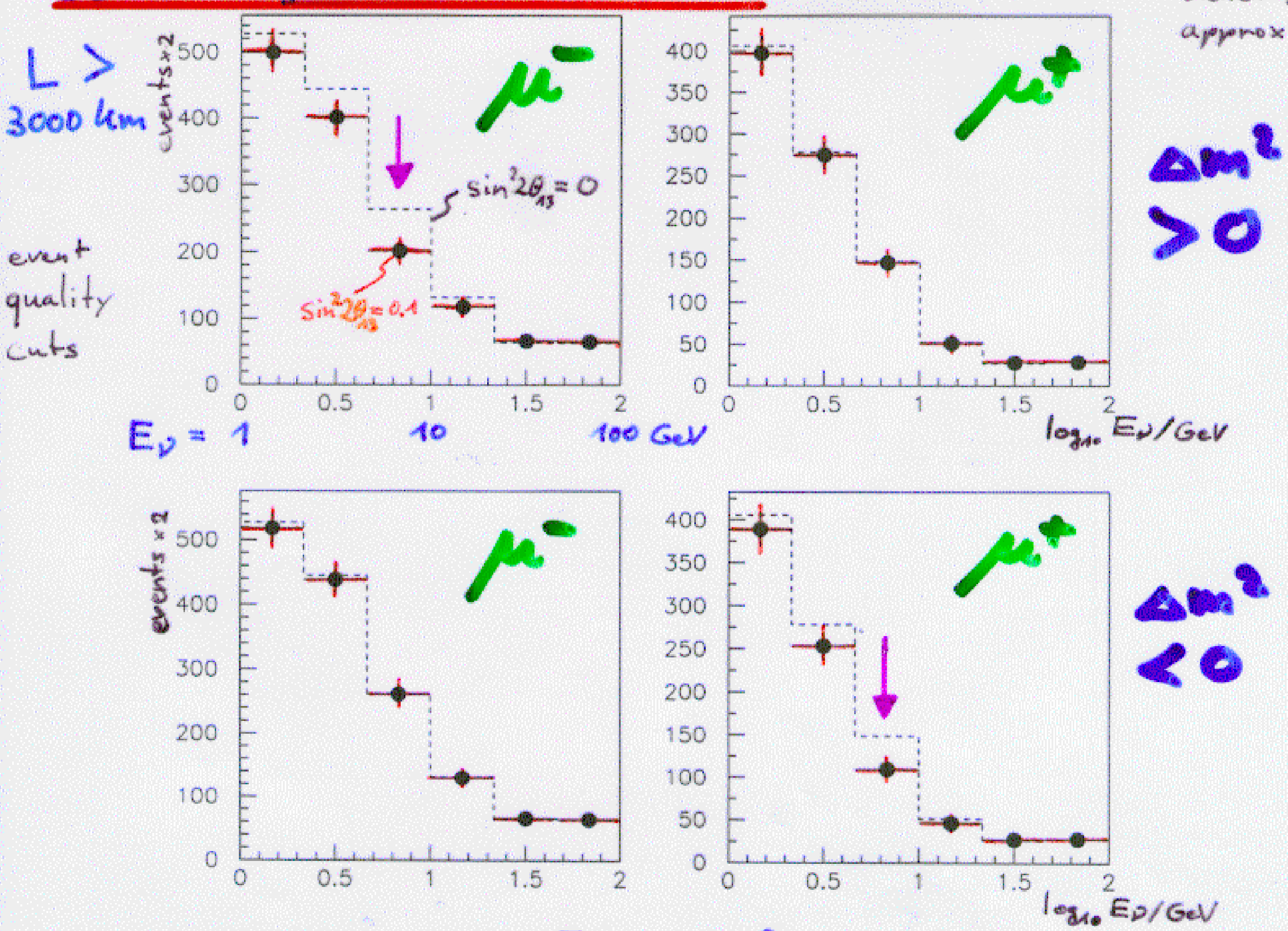
3 flavour oscillations

$\Delta m^2 = 2.8 \times 10^{-3}\,eV^2$ $\sin^2 2\theta_{23} = 1$ $\sin^2 2\theta_{13} = 0.1$



50 kt magnetised iron detector 5 years

constant density approx.



systematics of ν_μ, $\bar{\nu}_\mu$ spectra?

Conclusions

- new atmospheric neutrino experiments in preparation

- measure ν_μ reappearance
  ⇒ prove oscillations !
  - unique if Δm^2 low
  - complementary to long baseline beams if Δm^2 high

- matter effects accessible (large L)
  ⇒ with some luck:
  window of opportunity to measure sign of Δm^2? (mass hierarchy)
  systematics needs further study

- detectors (detector concepts) reuseable for ν-factories
  → talk H. Schellman