Future projects on atmospheric neutrinos

Neutrino 2002 Munich

- Physics issues
- Detectors
- Sensitivity forecast
- Summary

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Physics issues with atmospheric ν's

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- Explicit observation of the oscillation pattern in ν_μ disappearance
  - Test of the disappearance dynamics (proof of oscillations)
  - Precision measurement of $\Delta m^2_{\otimes}$ and $\sin^2 2\theta_{23}$
- Search for subdominant effects
  - Matter effects in scenarios with three (or more) neutrinos
    - $\sin^2\theta_{13}$, sign of Δm^2, …
  - Non statndard interactions (FCNC, VLI, VEP, …)
- Explicit detection of ν_τ appearance

Beam properties

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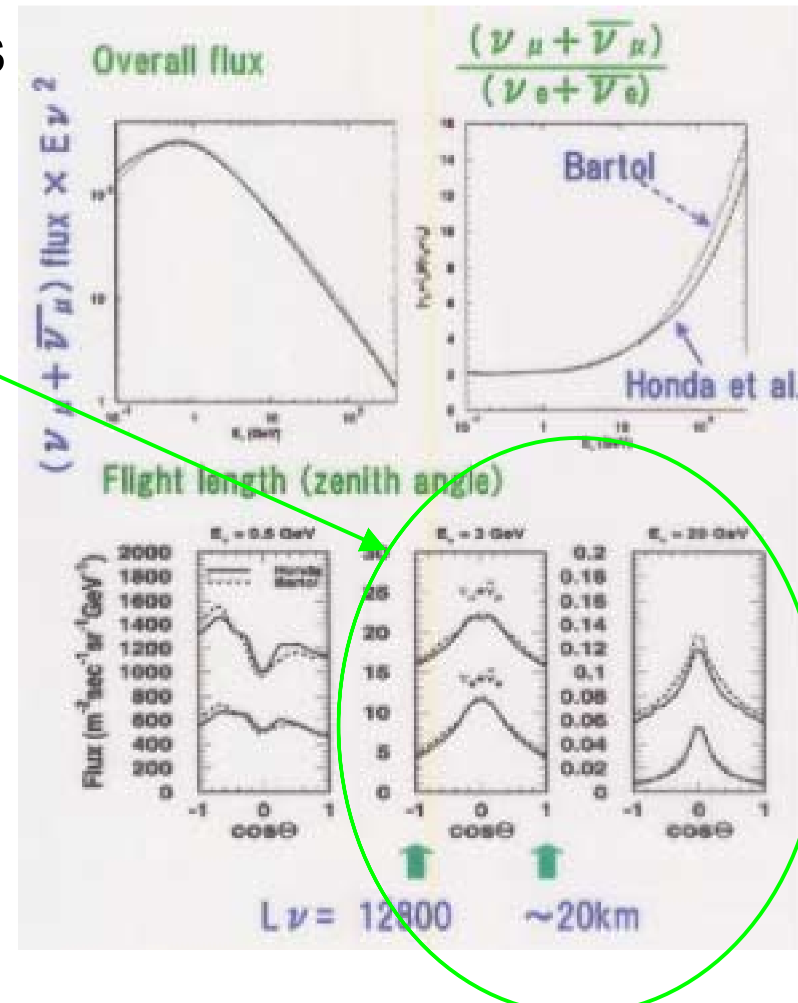
- Wide L/E range with very long baselines
  - Sensitivity to oscillations down to small Δm^2
  - Possibility to test earth-induced matter effects
- Up/down symmetry above ≈ 1 GeV
  - For $\Delta m^2 < 10^{-2}$ eV^2 and $E_\nu > 1.5$ GeV, downgoing neutrinos unaffected by oscillations → **Reference source**
- Almost democratic flavour composition
- Low intensity (≈100 evts/kty)

  → **massive detectors**

- The beam is on!

- Improving knowledge of fluxes (see T.Gaisser talk)

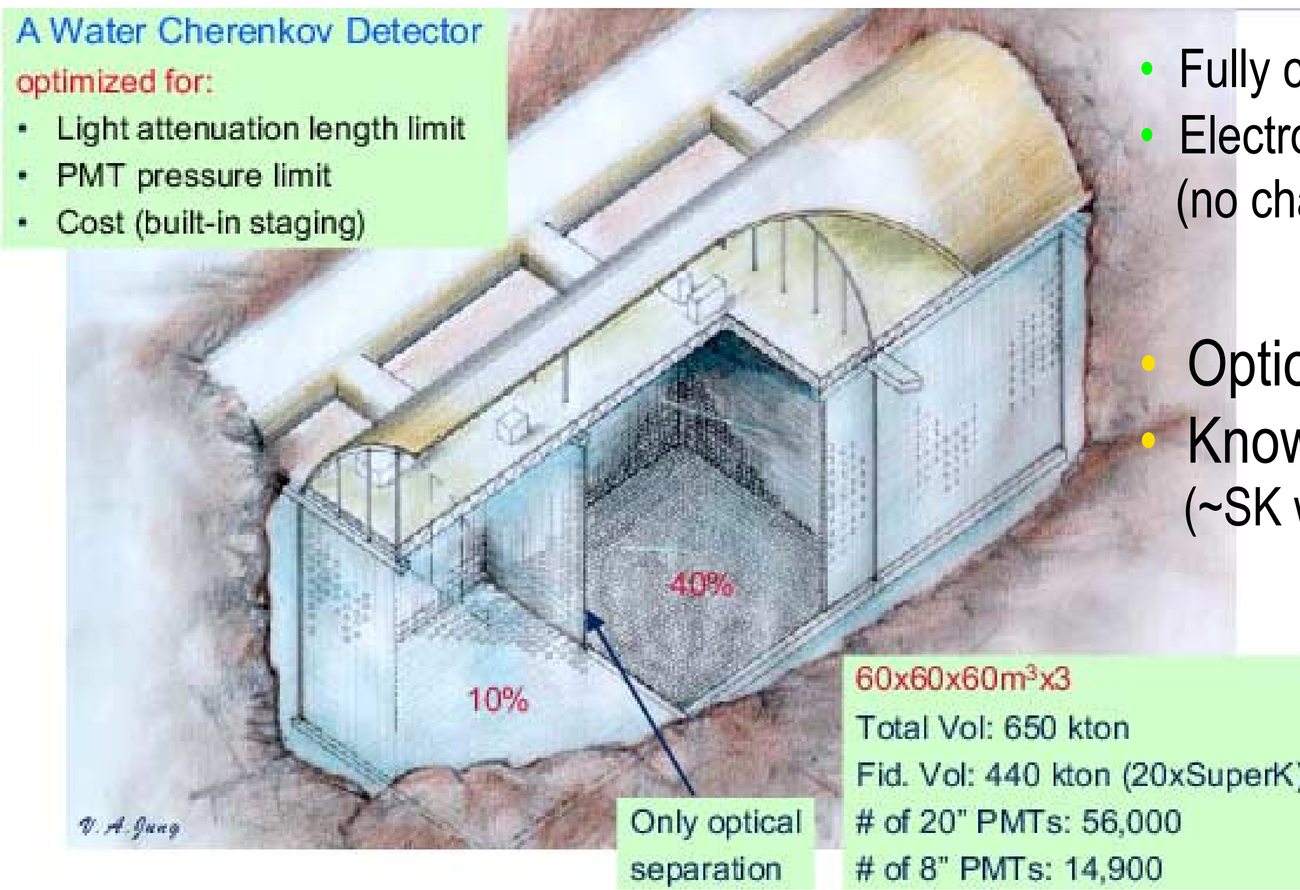


Detectors

	Mass	Status	Physics start
Reference			
Super-K	50/22 kt	idle	*2003 (restart)*
Large Water Cherenkov			
UNO	650/450 kt,	discussed	*201?*
Hyper-K	1.0 Mt	discussed	*201?*
Aqua-RICH	1.0 Mt	R&D	*??*
Magnetised Iron Neutrino Detectors			
Minos	5.4/3.3 kt	construction	*2003*
MONOLITH	34/27 kt	not approved by INFN	*??*
Generic 50 kt	?/50 kt	discussed for ν-factories	*201?*
Liquid Argon TPC			
ICARUS T600	0.6/0.5 kt	approved	*2003*
ICARUS	3.0/2.5 kt	proposed for CNGS	*2006 (?)*

The UNO detector

- Proton decay, supernova, solar and atmospheric neutrinos



- Fully contain $E_\mu \approx 35$ GeV
- Electron and muon identification (no charge id)

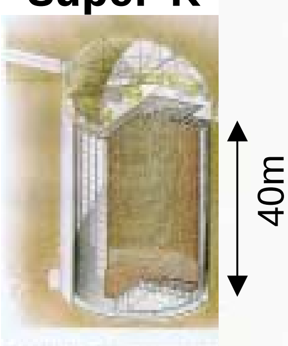
- Option for LBL beam
- Known technique (~SK with lower PM coverage)

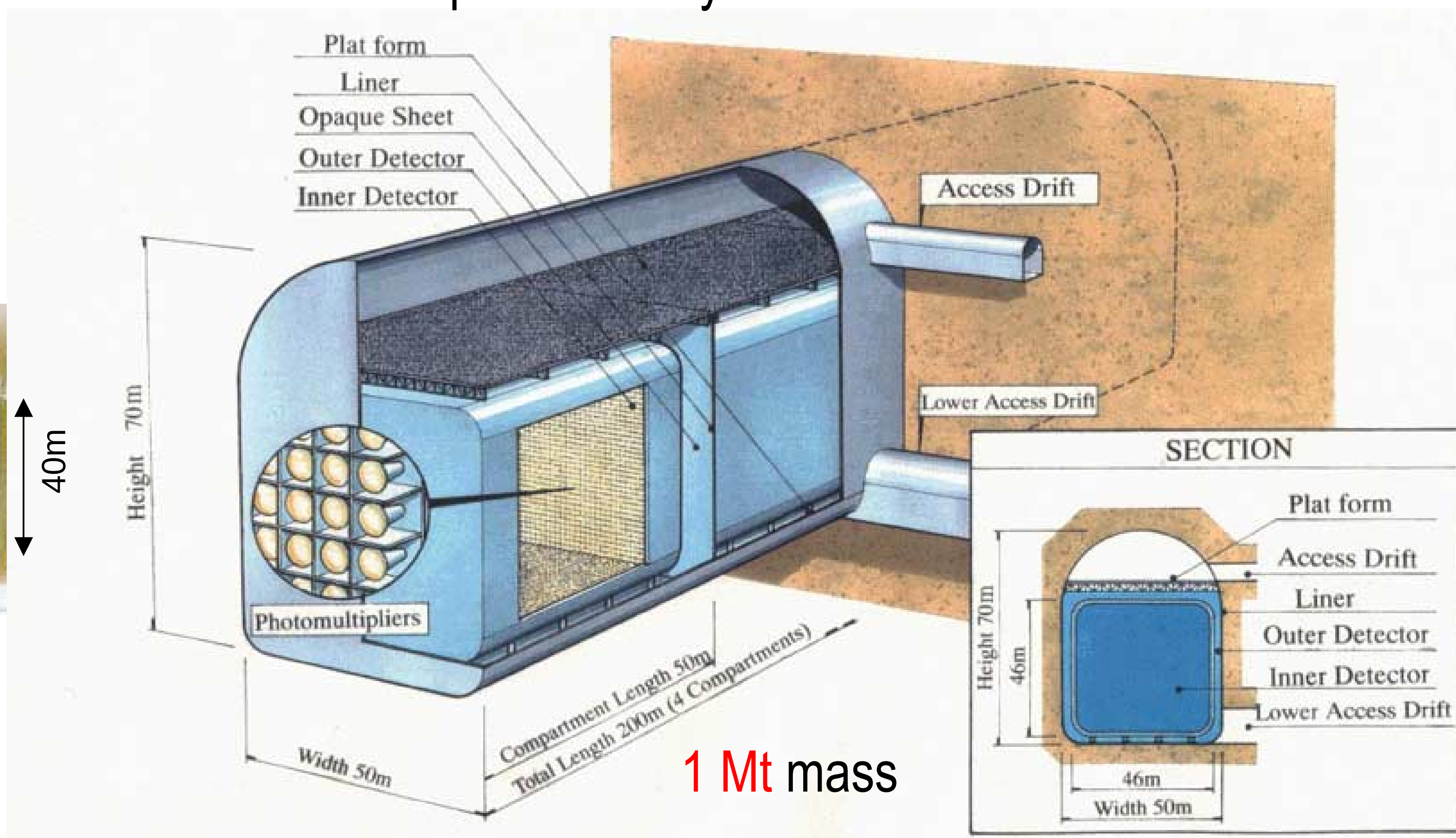
- Low unit cost (0.5 M€/kt + 0.5 M€/kt for excavation)

Hyper-Kamiokande

- Super-K successor for Supernova, solar, atmospheric and JHF beam neutrinos and proton decay

Super-K



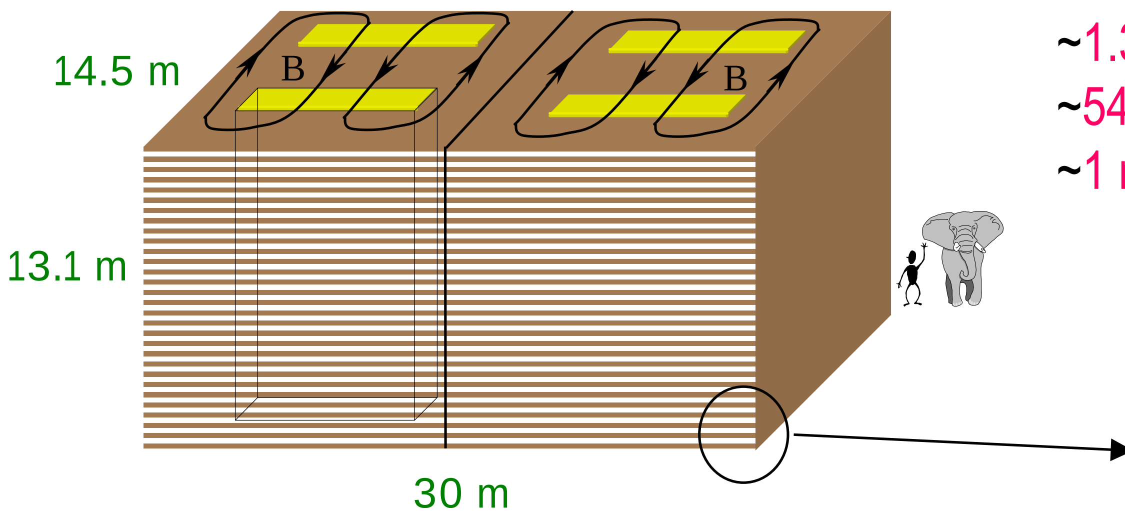


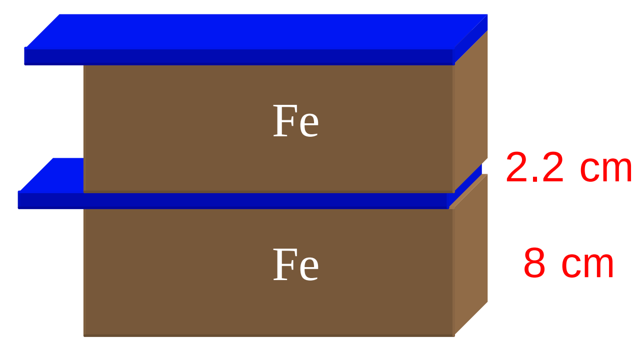
1 Mt mass

A beautiful MIND (MONOLITH)

- Main focus on atmospheric muon neutrinos
  - Acceptance at high energies → good resolution on ν energy and angle
  - $\nu_\mu/\bar{\nu}_\mu$ separation (muon charge)

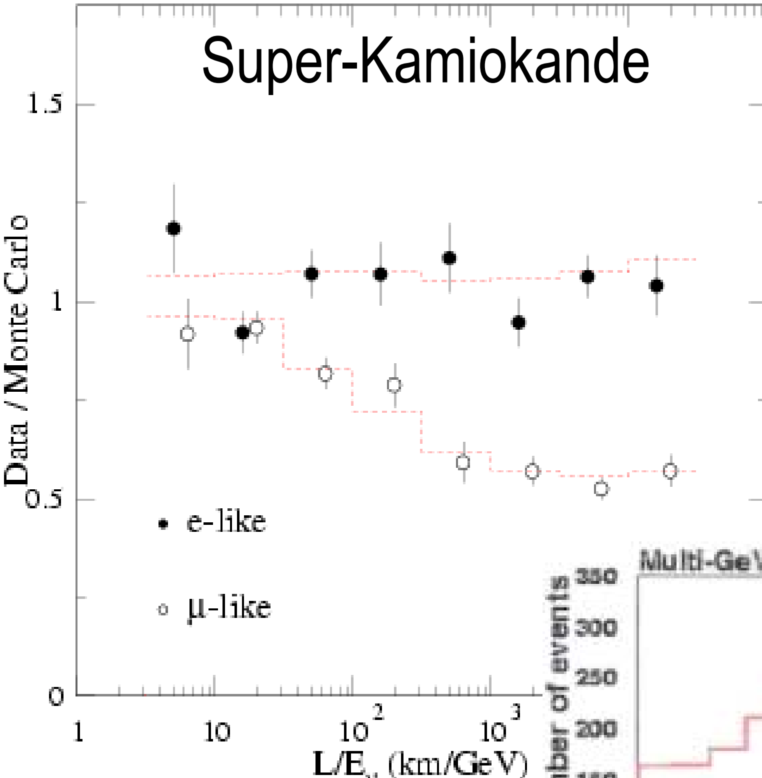
34 kt mass (two modules)
~1.3 T magnetic induction
~54000 m^2 of Glass Spark Counters
~1 ns timing resolution

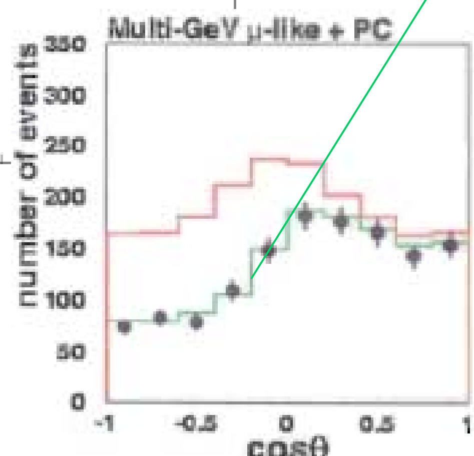




- Option (reuseable) for ν-factory beams
- Supernova watch with neutral currents (à la OMNIS) ?
- Low unit cost (1 M€/kt)

Explicit detection of oscillations





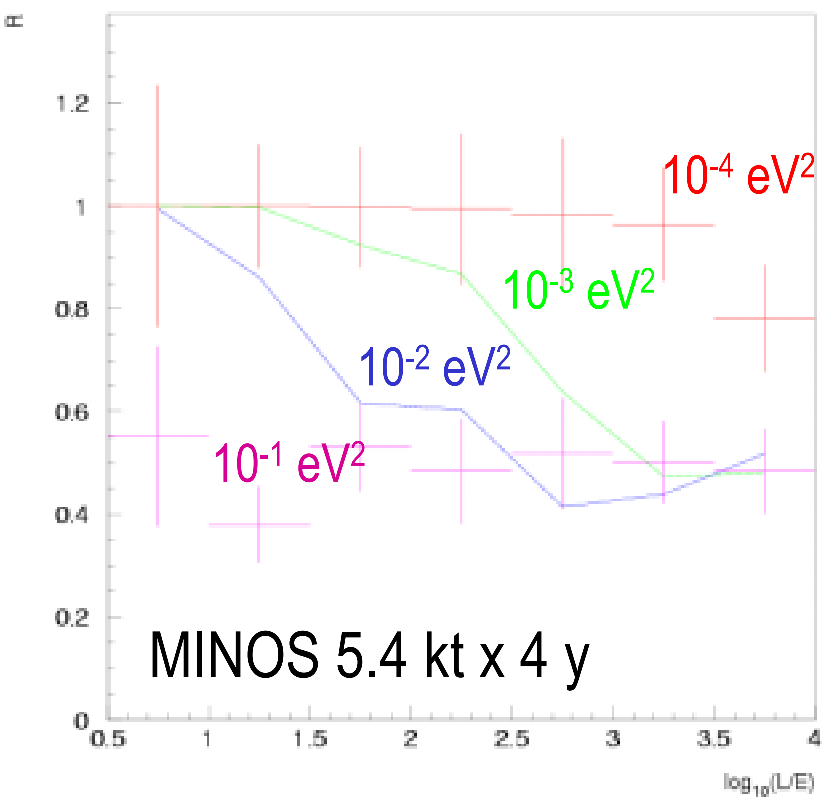
up/down=0.54 ±0.04±0.004

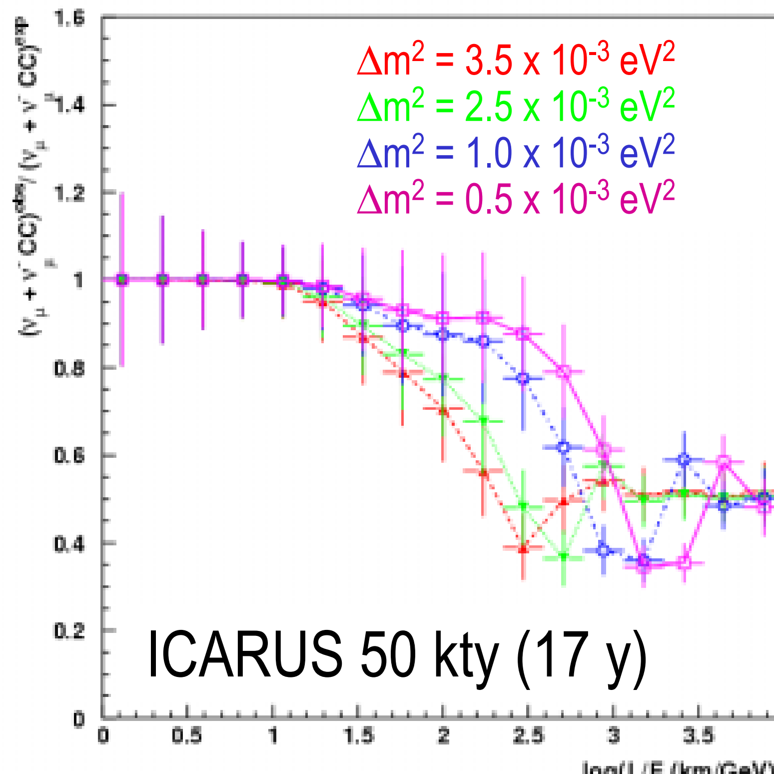
- Poor L/E resolution
  - Limited acceptance to high energy μ's (E_{cont} < 10 GeV)
  - Disappearance occurs about the horizon ($\sigma_L/L \approx \tan\theta\,\sigma_\theta$)
- Limited precision on Δm^2
- Direct proof of oscillation still outstanding

- The up/down asymmetry of multi-GeV muons fixes the mixing with little systematic uncertainty
- Precision on $\sin^2 2\theta_{23} \div (\text{exposure})^{1/2}$

Forthcoming experiments

- Check of Super-K
- Not for precision measurements *(with atmospheric ν's!)*





- Low mass and limited acceptance at high energies

A high resolution thought experiment

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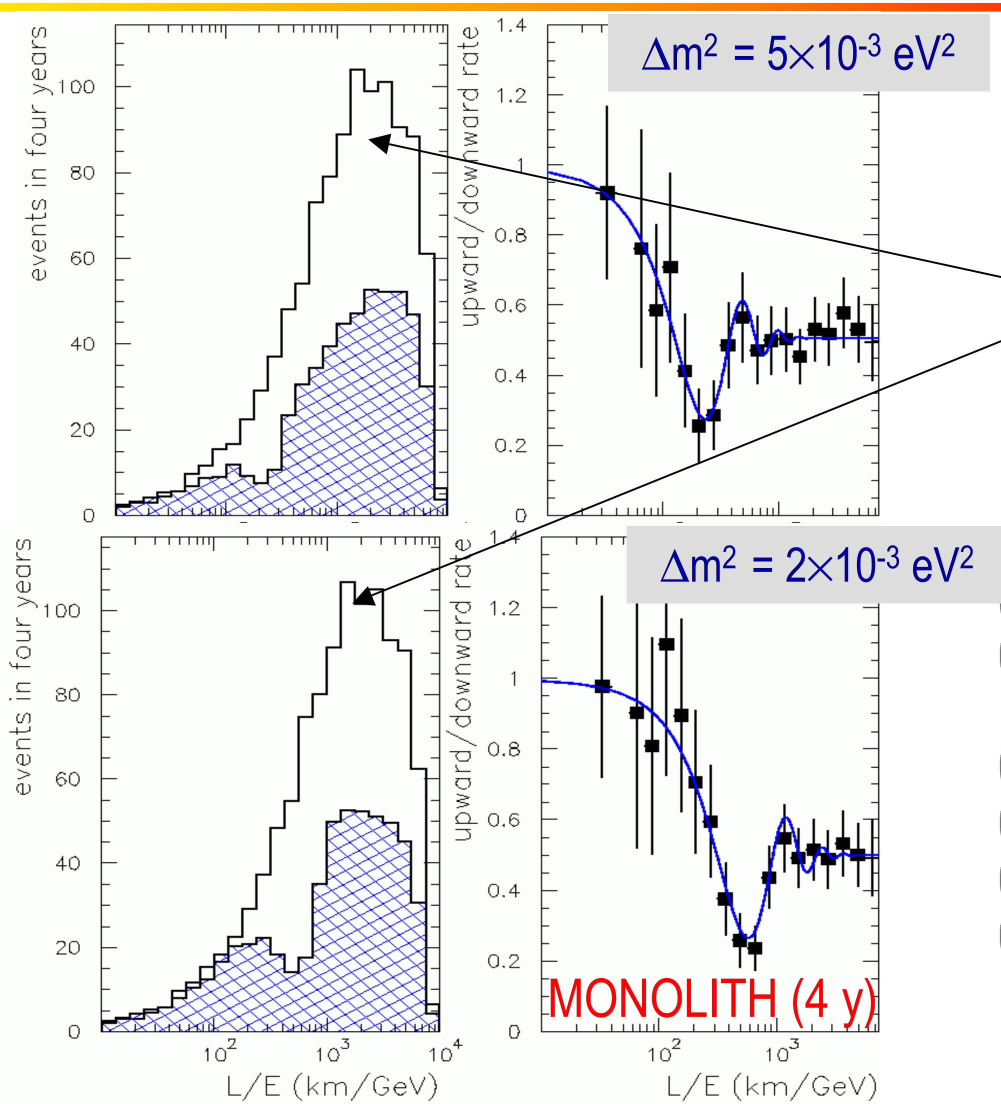
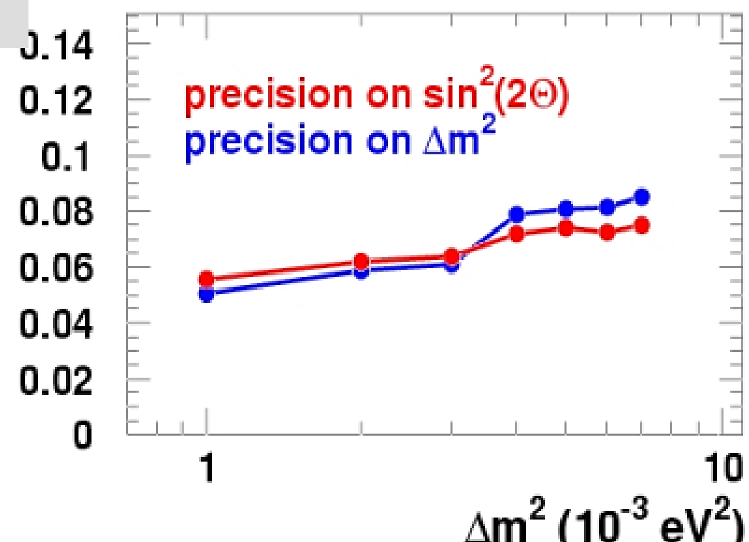
Not approved



- Flux independent analysis
  - Only multi-GeV μ's
  - Reference source of downgoing neutrinos
- Precision on parameters limited by statistics



Atmospheric versus beam

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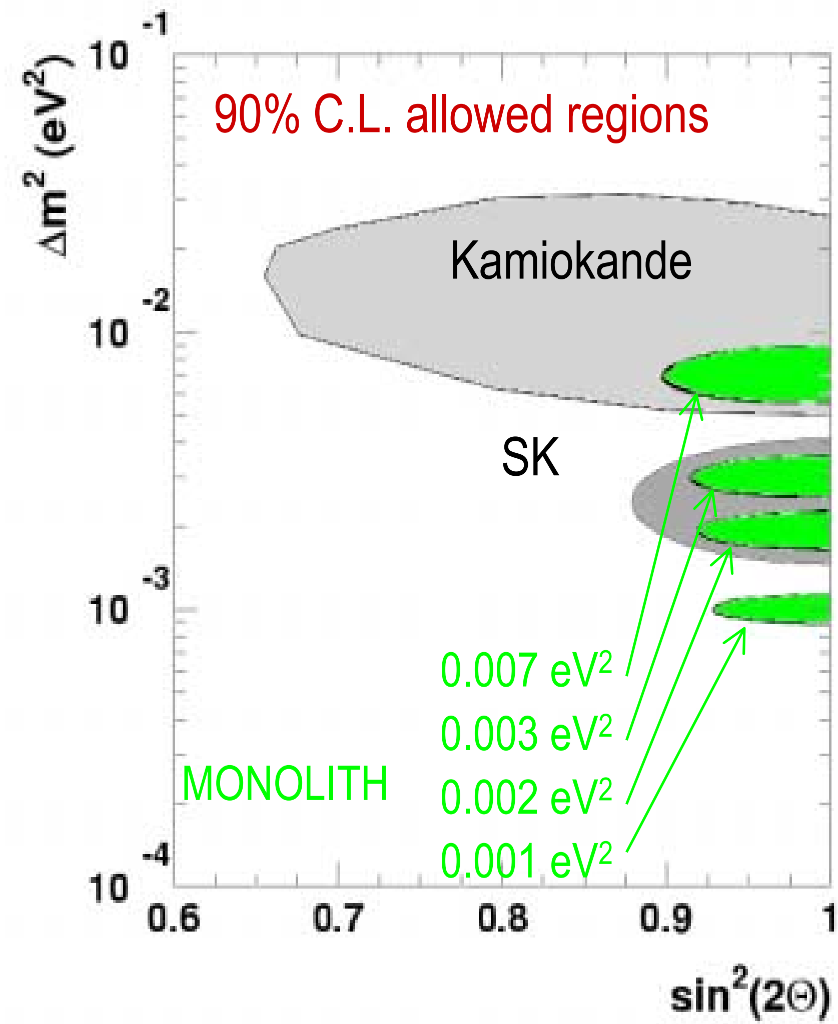

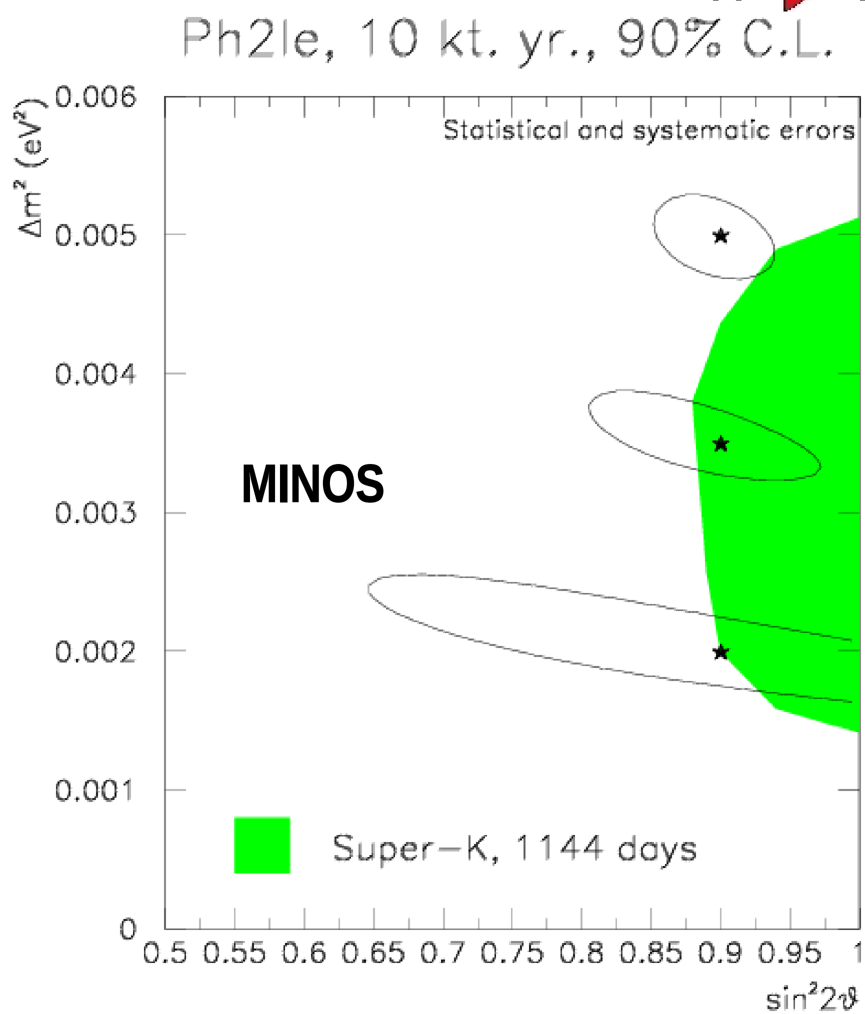

Large exposures

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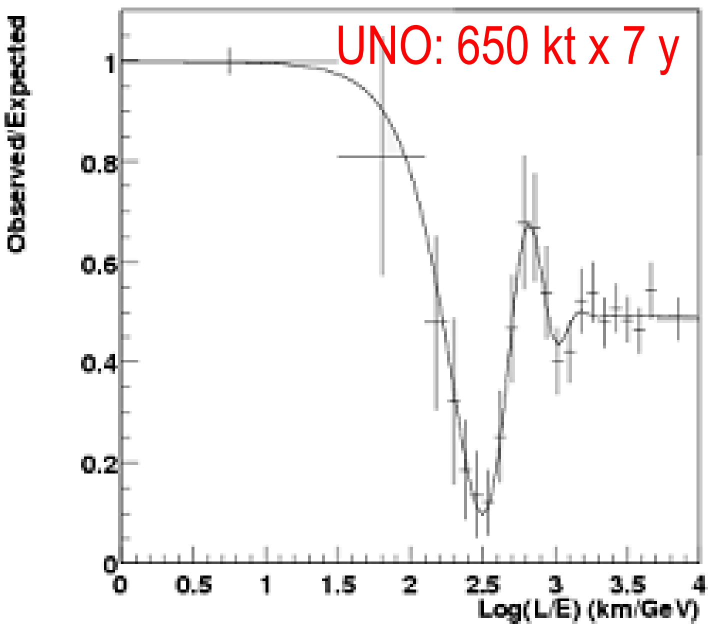
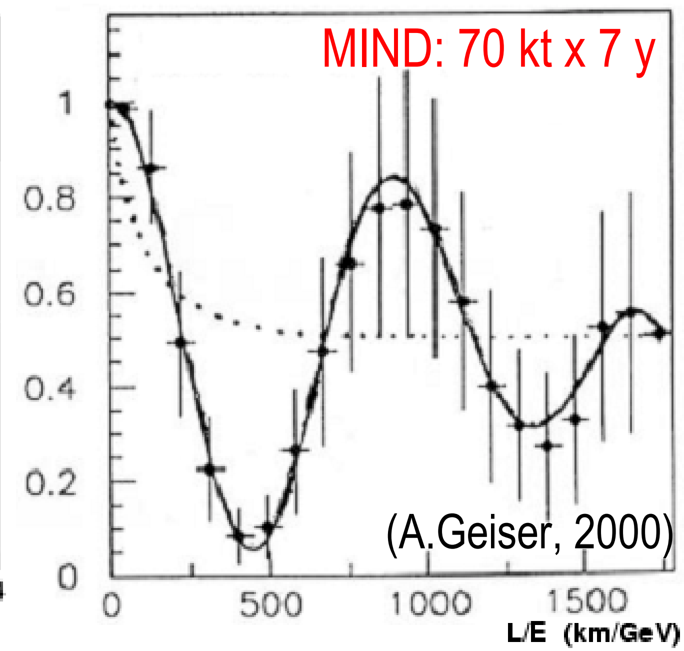


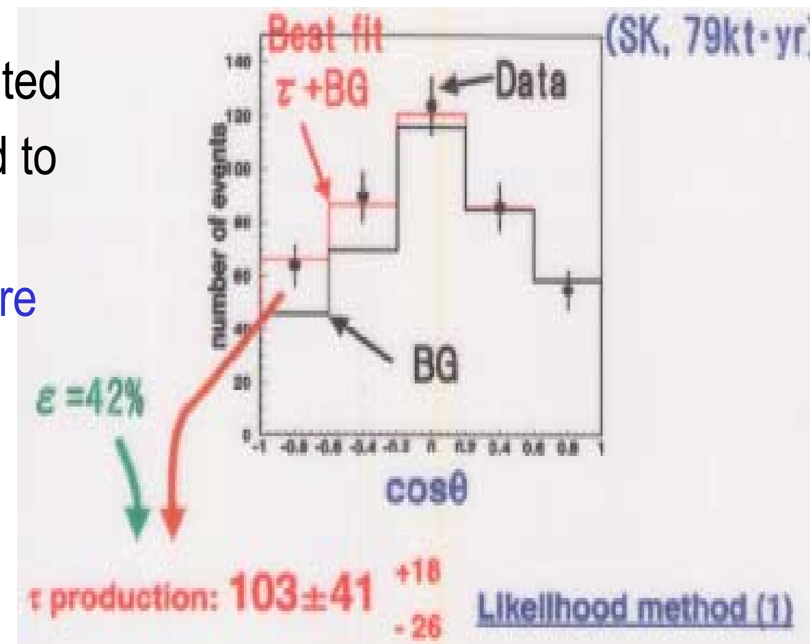


- Tighter selections
- High resolution sample

- O(1%) cent statistical precision on oscillation parameters
- Systematic limitations:
  - $\approx$ 1% on $\sin^2 2\Theta_{23}$ (Deviation from exact up/down symmetry)
  - O(1%) on Δm^2 (L/E scale and resolution function)

Explicit detection of ν_τ

- ν_τ appearance ↔ "NC-like" up/down (zenith angle dependence)
- S/N ≈ 1/100 before selections
  - SK result (≈ 2σ effect) statistically limited
  - Largest systematic error (16%) related to uncertain knowledge of Δm^2
  - Expect 3σ effect in 10 y of SK exposure
  - Achievable also with other techniques provided the mass is large enough
  - If needed: UNO ≈ 400 τ's/year



- Marginal compared to ν_τ detection from beam, but useful to test scenarios with sterile neutrinos

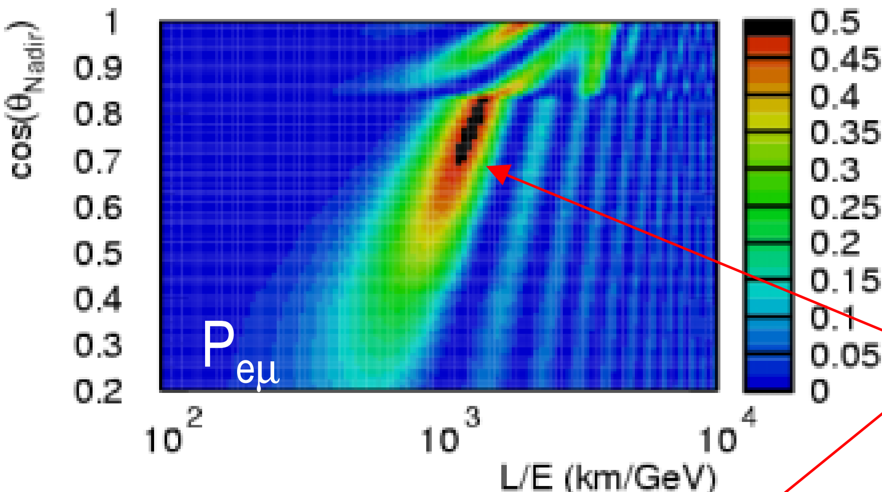
Subdominant effects?

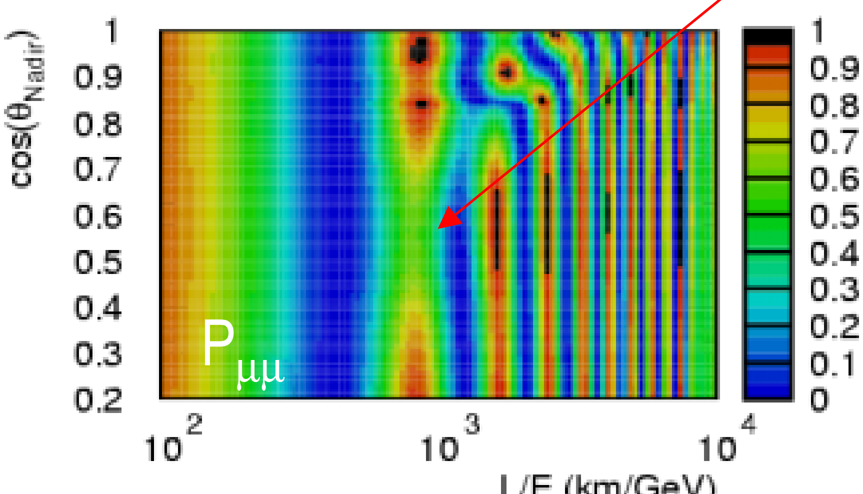
- Subdominant effects can perturb the L/E dependence of standard (pure) ν_μ - ν_τ oscillations
  - $[\nu_\mu - \nu_\tau]$ + $[\nu_\mu - \nu_e]$ → [L/E] + [MSW]
  - $[\nu_\mu - \nu_\tau]$ + $[\nu_\mu - \nu_s]$ → [L/E] + [MSW]
  - $[\nu_\mu - \nu_\tau]$ + [VEP,VLI] → [L/E] + [L E]
  - $[\nu_\mu - \nu_\tau]$ + [FCNC] → [L/E] + [L]

Matter effects

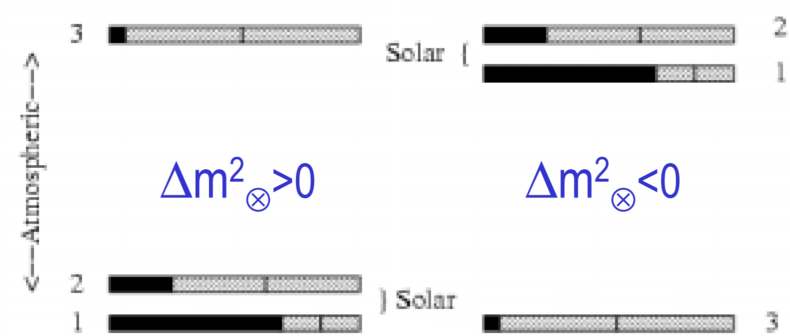
- Electron neutrino (three neutrino oscillations)
  - Solar LMA solution
  - Contribution of $\nu_e \leftrightarrow \nu_\mu$ to $\Delta m^2_\otimes$
- Sterile neutrino (2+2 and 1+3 scenarios)
  - Spectral distortions at high E_ν + upward muons (SK, MACRO-like analysis)
  - If non maximal mixing → additional handle from charge id (MIND)

Matter effects with three neutrinos





- "One mass scale dominance" scenario for atmospheric ν's: $\Delta m^2_{\otimes} = \Delta m^2_{23} >> \Delta m^2_{\odot} = \Delta m^2_{12}$
- Relevant parameters: Θ_{13}, Θ_{23} , $\Delta m^2_{\otimes}$
- Resonant $\nu_e \leftrightarrow \nu_\mu$ transition either on ν or on anti-ν depending on the sign of $\Delta m^2_{\otimes}$



- Largest effects in the earth's mantle ($E_R \approx 7$ GeV)

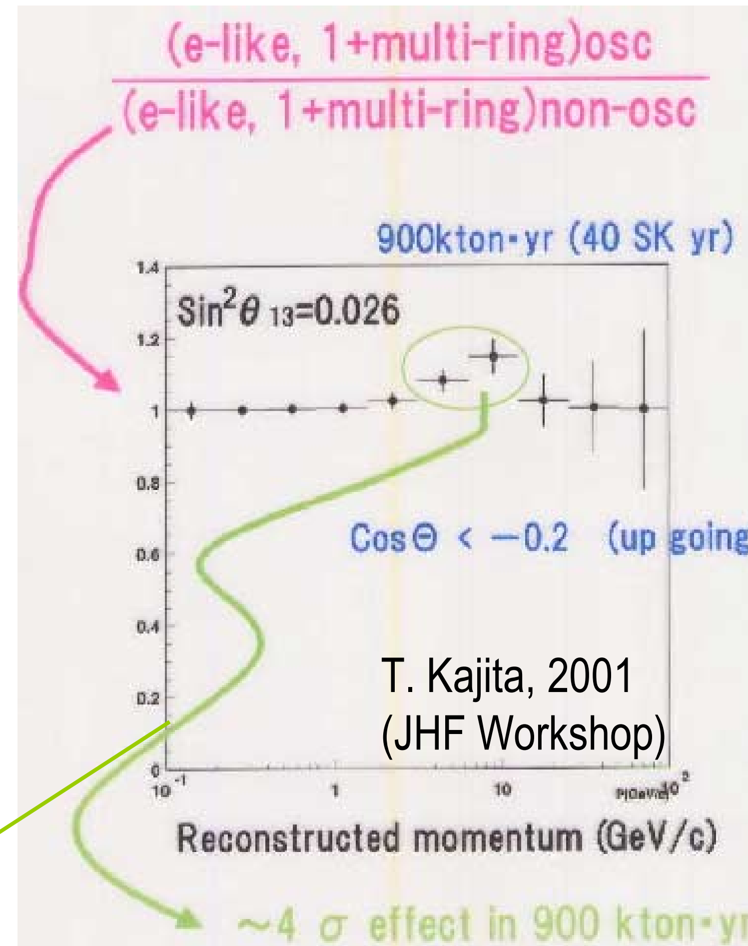
ν_e appearance

- $$\frac{\phi(e)_{obs}}{\phi(e)_{\exp}} = P_{ee} + \frac{\phi(\mu)}{\phi(e)} P_{e\mu}$$

  $$\approx 1 + \left(\frac{\phi(\mu)}{\phi(e)} - 2 \right) P_{e\mu}$$

  Maximal (2,3) mixing

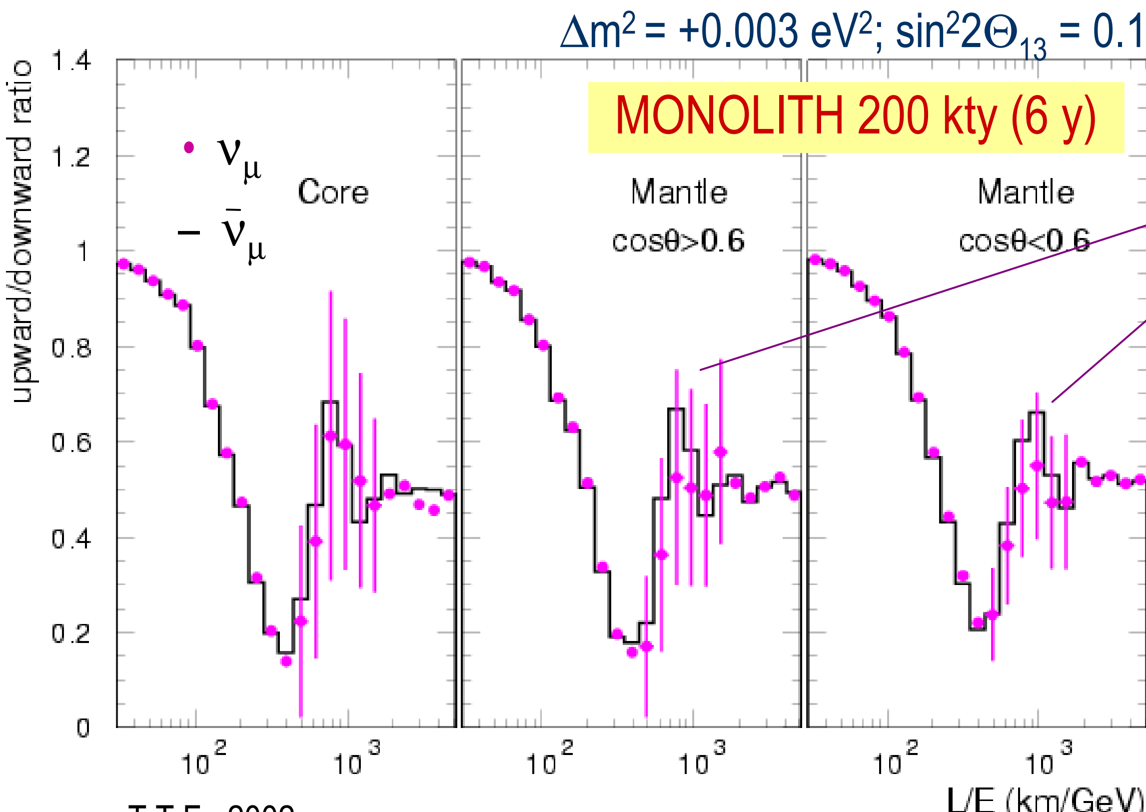
- Difference in resonance height for positive and negative Δm^2
  - Lower rate (cross-section) for anti-neutrinos than for neutrinos
  - $\approx 2\sigma$ separation for $\pm\Delta m^2$



For Θ_{13} at the CHOOZ limit!

ν_μ disappearance

- $$\frac{\phi(\mu)_{obs}}{\phi(\mu)_{\exp}} = P_{\mu\mu} + \frac{\phi(e)}{\phi(\mu)} P_{e\mu}$$



T.T.F., 2002

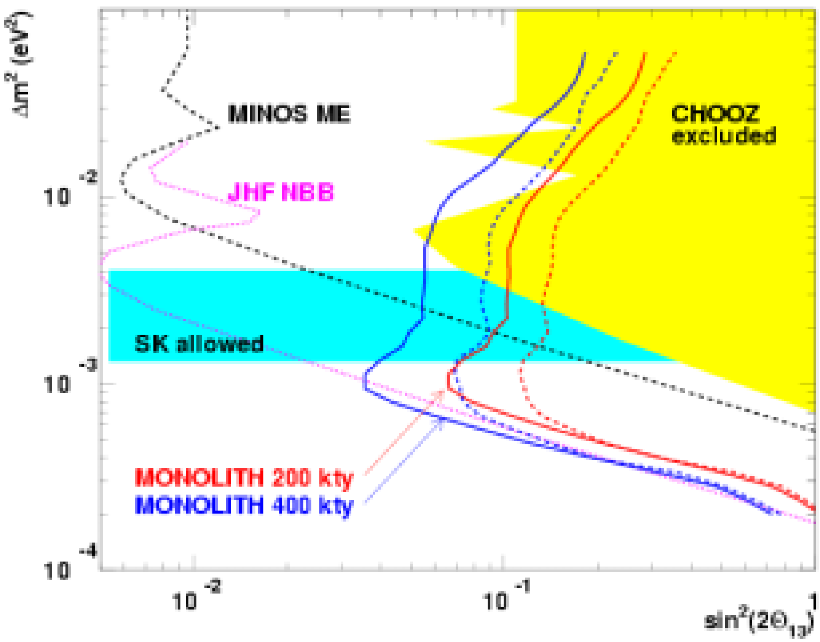
Charge Asymmetry

$$\frac{N(\mu^-) - N(\mu^+)}{N(\mu^-) + N(\mu^+)}$$

referred to downgoing events

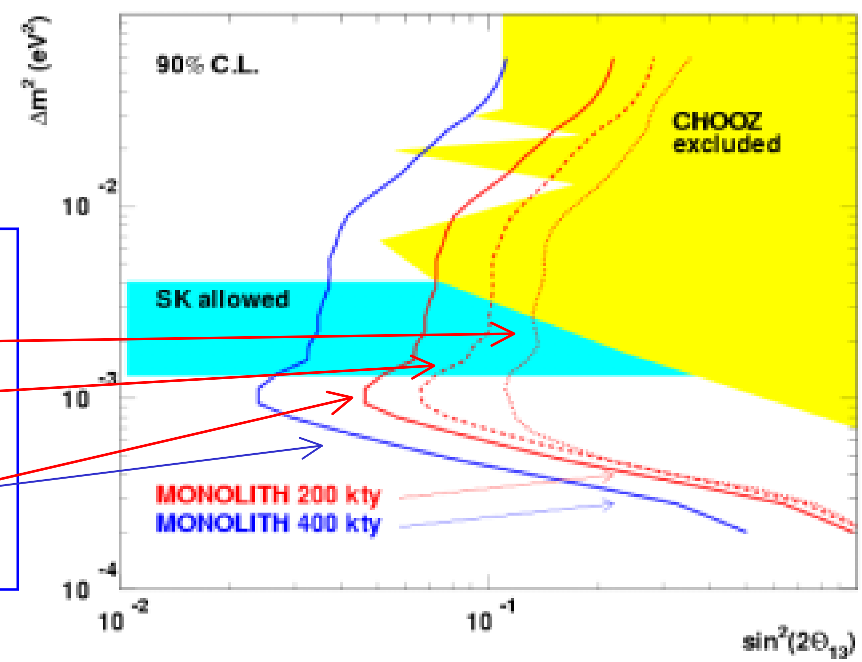
size and sign of the effect → Θ_{13} & sign(Δm^2)

Sensitivity plots (90% C.L.)



- Sensitivity to $\sin^2 2\Theta_{13}$ for
  - $\Delta m^2 > 0$ (continuous line)
  - $\Delta m^2 < 0$ (dashed line)

At variance with MINOS and JHF, if an effect is observed the sign Δm^2 of can be determined !



- Sensitivity to the sign Δm^2 for $\sin^2 2\Theta_{13}$
  - unknown
  - unknown and $\Delta m^2 > 0$
  - known with 30% accuracy from LBL beam experiments

Large exposures

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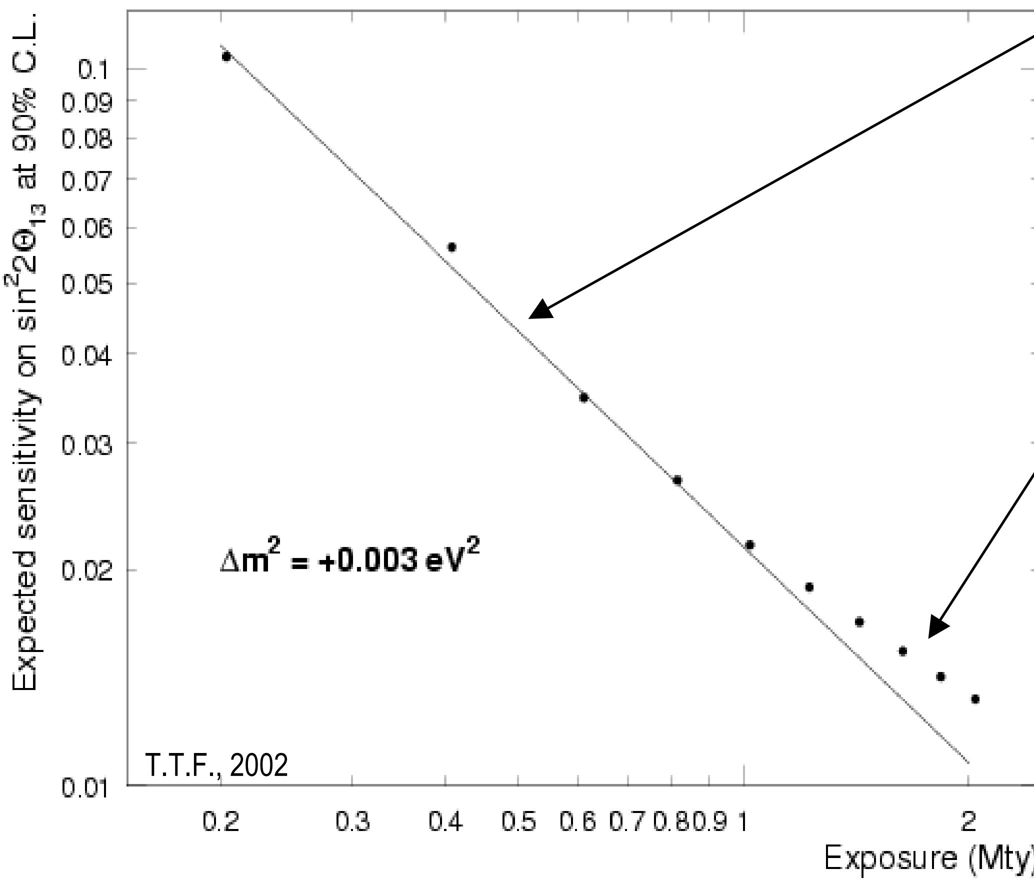
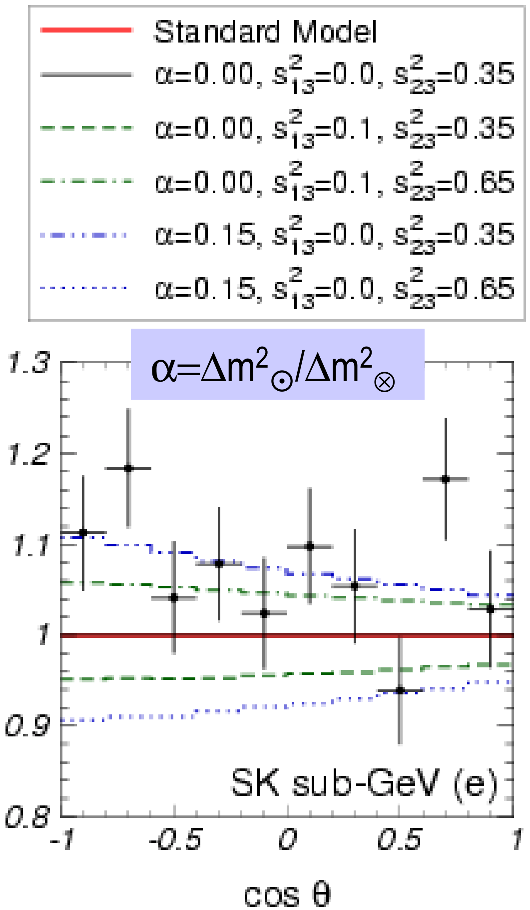


- Sensitivity statistically limited
  - Small uncertainty from the knowledge of the Earth's density profile

    (Earth's mantle is well known)
- Resonance width comparable to the experimental resolution
- Better resolution needed to further push the sensitivity below $\sin^2 2\Theta_{13} \approx 0.01$

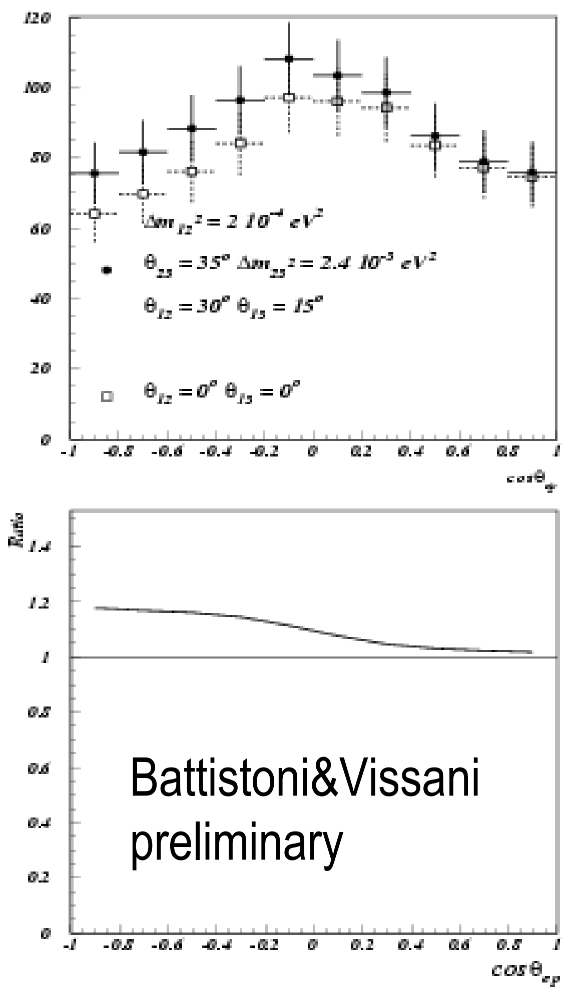
The LMA solution with high $\Delta m^2_\odot$



Gonzales-Garcia&Maltoni, 2002

- Suggested solution to the normalization problem of sub-GeV electrons in SK (Peres&Smirnov, 2001)
- A non zero effect requires either
  - (2,3) mixing not maximal
  - (1,3) mixing not vanishing
- Effects statistically visible in large water Cherenkov detectors
  - (zenith angle dependence smeared by resolution at low energy →need good knowlegde of flux normalization)

ICARUS (20 kty)



- Improved reconstruction of the neutrino direction at low energies
  - (resolution limited by Fermi motion and nuclear effects)

- With some luck a zenith angle dependence might be detectable

  (Some model dependence in the correction for the up/down asymmetry of low energy neutrino events)

- Key to Θ_{13} or non maximal Θ_{23}, if LMA parameters fixed elsewhere

- Precision measurement in SuperICARUS?

Summary

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- Short term (approved experiments)
  - Precision on $\sin^2 2\Theta_{23}$ and ν_τ appearance from SK ÷ (exposure)$^{1/2}$ (if operation conditions as before)
  - Other approved projects have limited sensitivity to atmospheric neutrinos
- Medium/Long term (?): Massive (magnetised) detector
  - precise reconstruction of the oscillation pattern
  - precision measurement of Δm^2 and $\sin^2 2\Theta_{23}$
    - Most probably covered by LBL beams (NuMI, JHF)
  - If $\sin^2 2\Theta_{13}$ not too small, window of opportunity to observe matter effects in 3ν oscillations and measure the sign of Δm^2
    - Requires Very-LBL (Super-Beams, Neutrino factories)