Measuring Cosmic Ray and Atmospheric Neutrinos in the Sudbury Neutrino Observatory

neutrino.lbl.gov/∼snoman/currat/talks/

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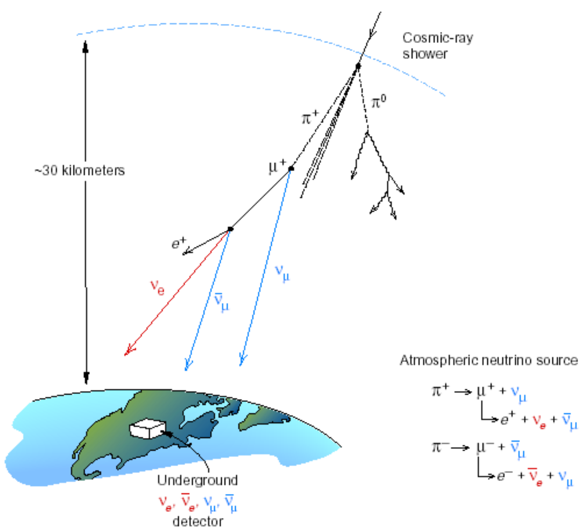
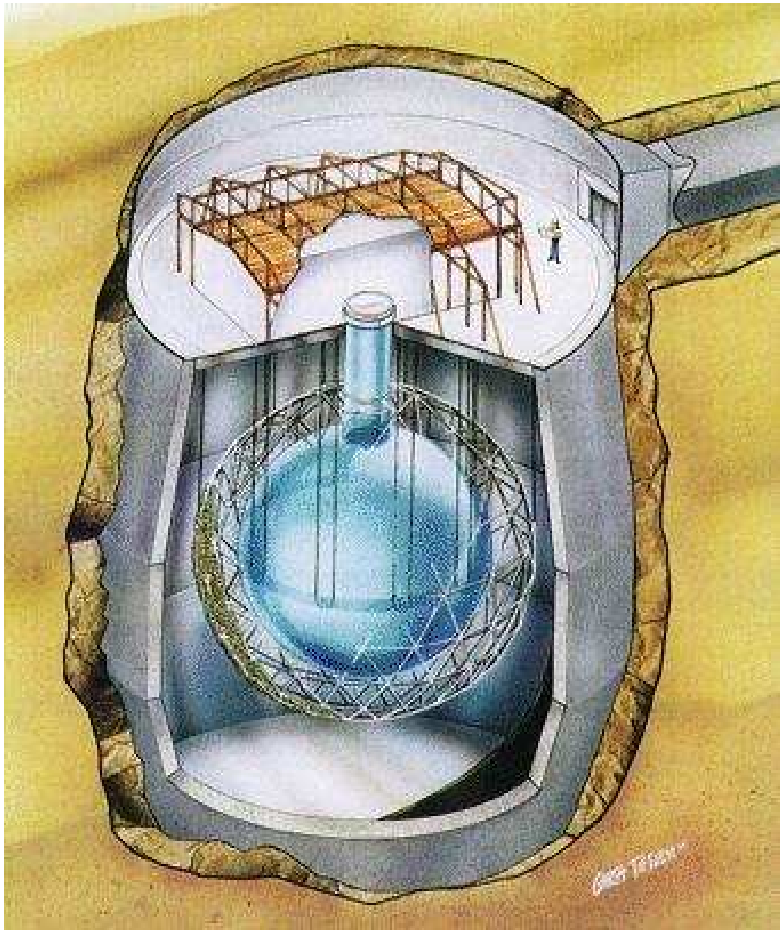
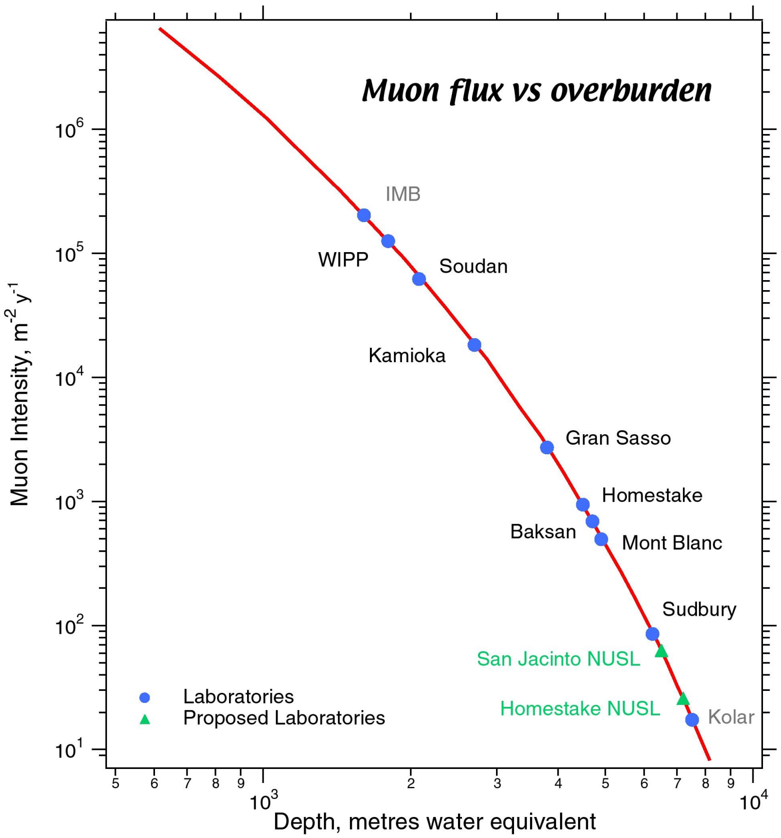


The Sudbury Neutrino Observatory

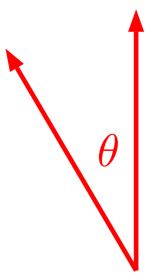
- SNO uses 1 kton heavy water + 1.7 kton water. Cherenkov light gathered by 9456 PMTs mounted on 17.8 m geodesic sphere.
- SNO located at a depth of 2092 meters under a flat overburden of 6010 mwe
  ⇨ cosmic muons ~ 80 events/day

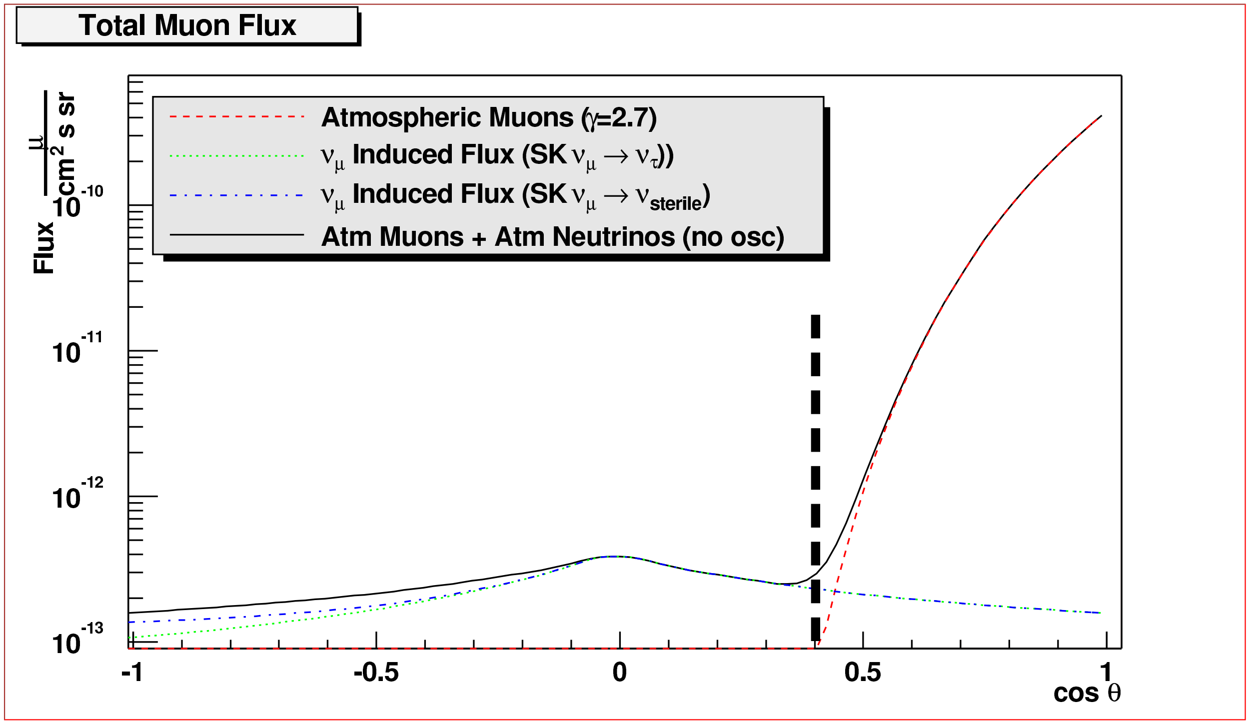




Atmospheric neutrinos in SNO 1/2

- SNO is of modest size ➪ cannot perform contained events analysis, e-like/μ-like ➪ zenith angle distribution of muons (up vs down)
- For zenith angles $\theta_{\text{zenith}} < 66^\circ$ $(\cos\theta > 0.4)$, muons from cosmic-rays
- For $\theta_{\text{zenith}} > 66^\circ$ ➪ muons generated in neutrino interactions in the rock

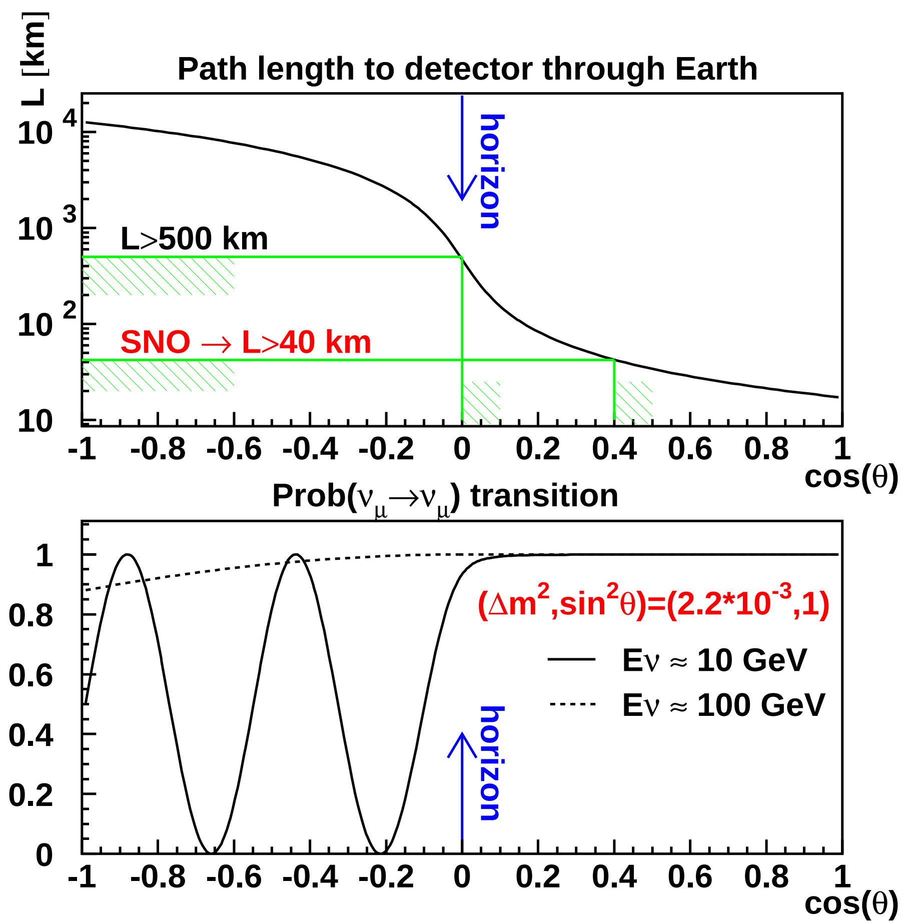




☞ Deep location permits direct measurement of absolute neutrino flux ➪ horizon is clear (no model-dependent shape correction)

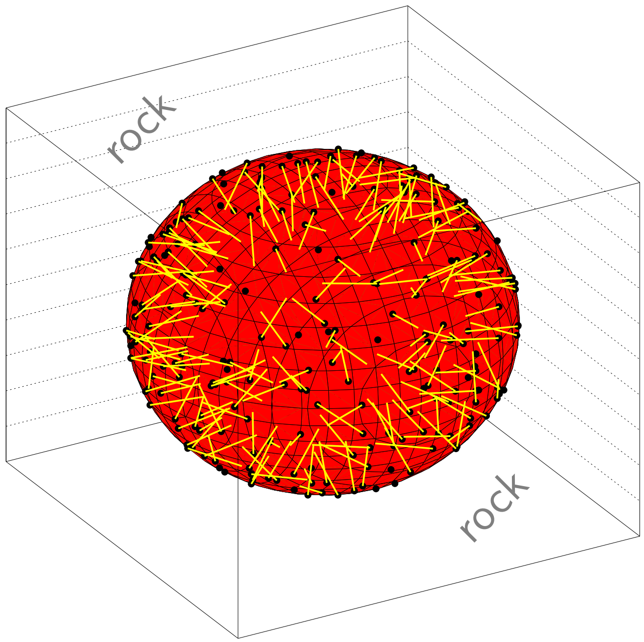
Atmospheric neutrinos in SNO 2/2

- By studying muon flux as $f(\theta_{zenith})$ it is also possible to study neutrino oscillations
- Only events coming from below the horizon may oscillate ➪ distortion in angular distribution shape



Muon simulation 1/2

- Simulation of neutrino-induced upward-going muons using `Nuance` (package for simulating neutrino propagation and interactions) according to Bartol flux up to detector's edge
- Interfaced with collaboration software for detailed simulation



Nuance to Snoman kinIO v3

- N.B.: given the size of SNO detector, most of the muons are through-going

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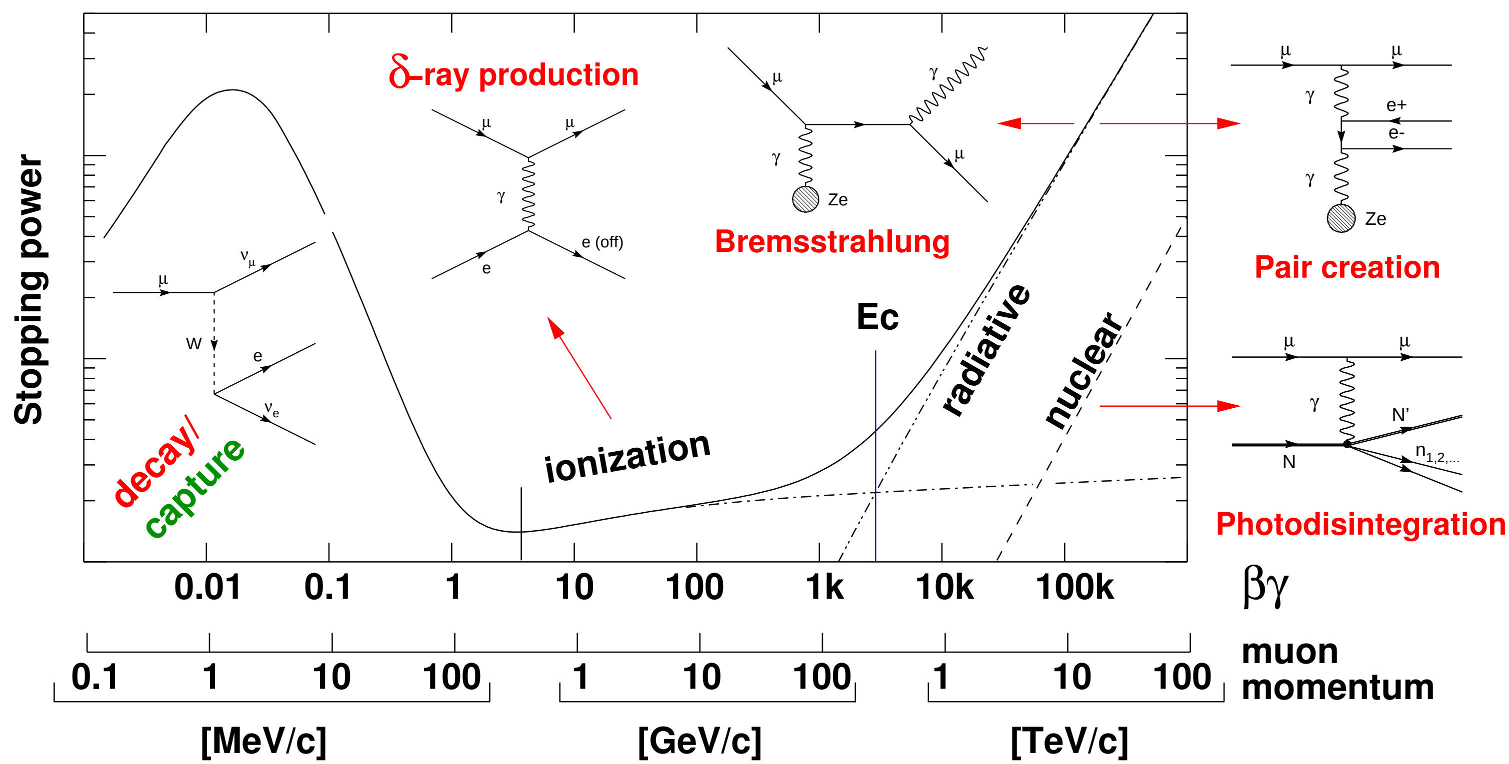

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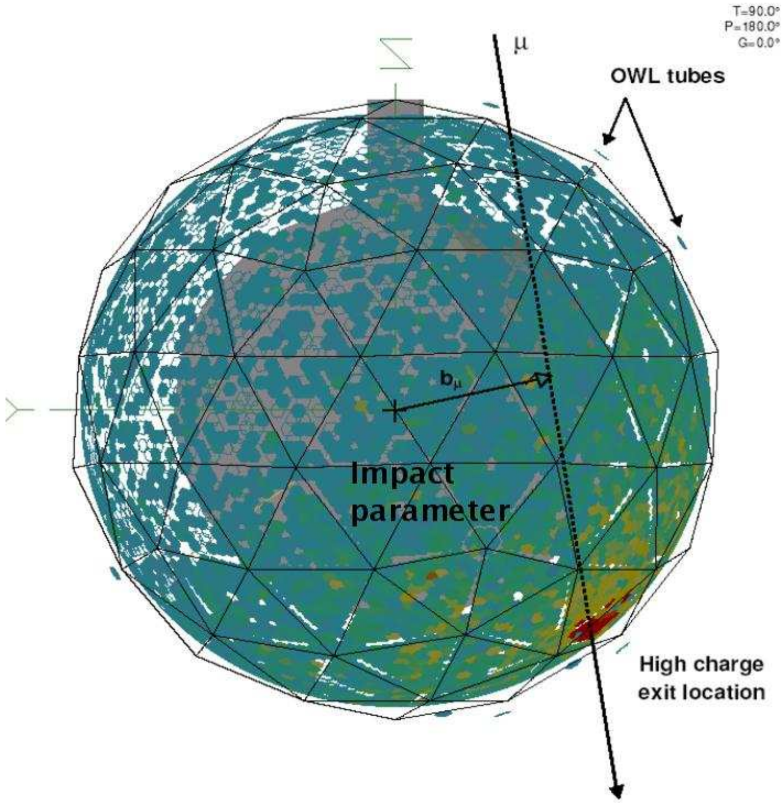
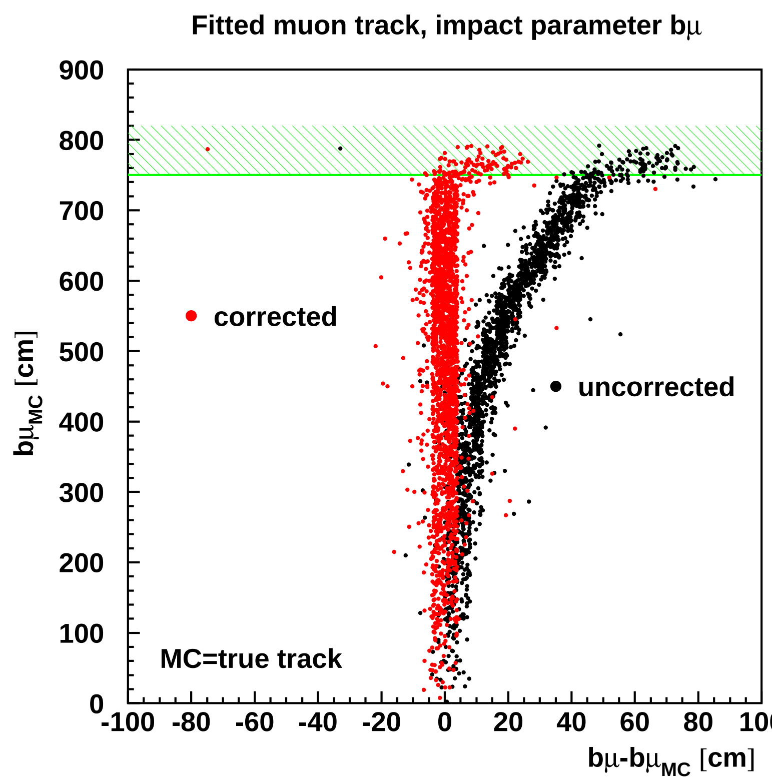
Muon measurement

Muon track reconstruction proceeds in 2 steps: (1) high charge cluster to locate exit point / (2) use of PMTs timing to reconstruct track direction

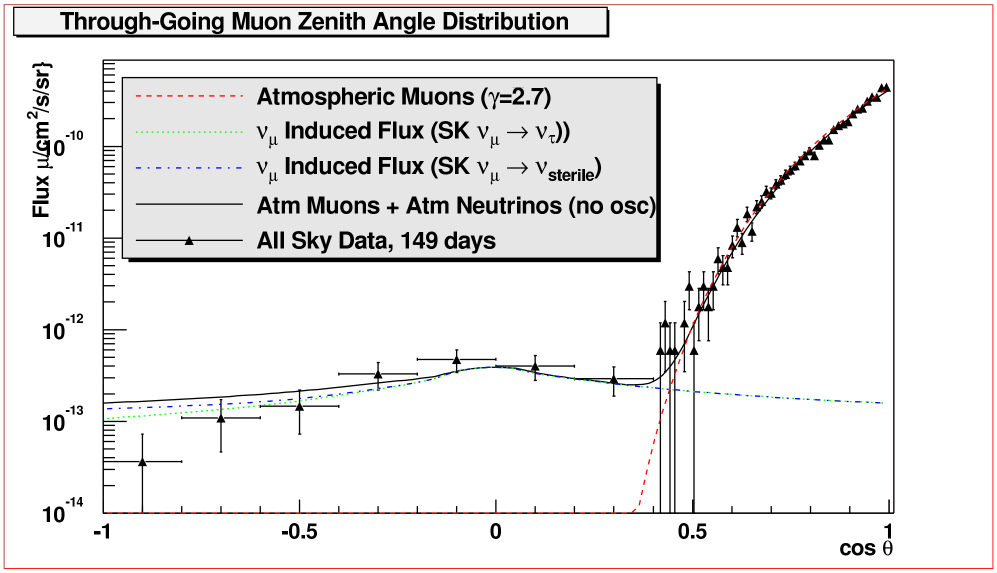
- typical error on impact parameter $\sigma_{b_\mu} \simeq 15$ cm
- typical error on direction $\sigma_\theta \simeq 1.5^\circ$
- systematic effects such as radial bias are corrected as f(impact parameter)



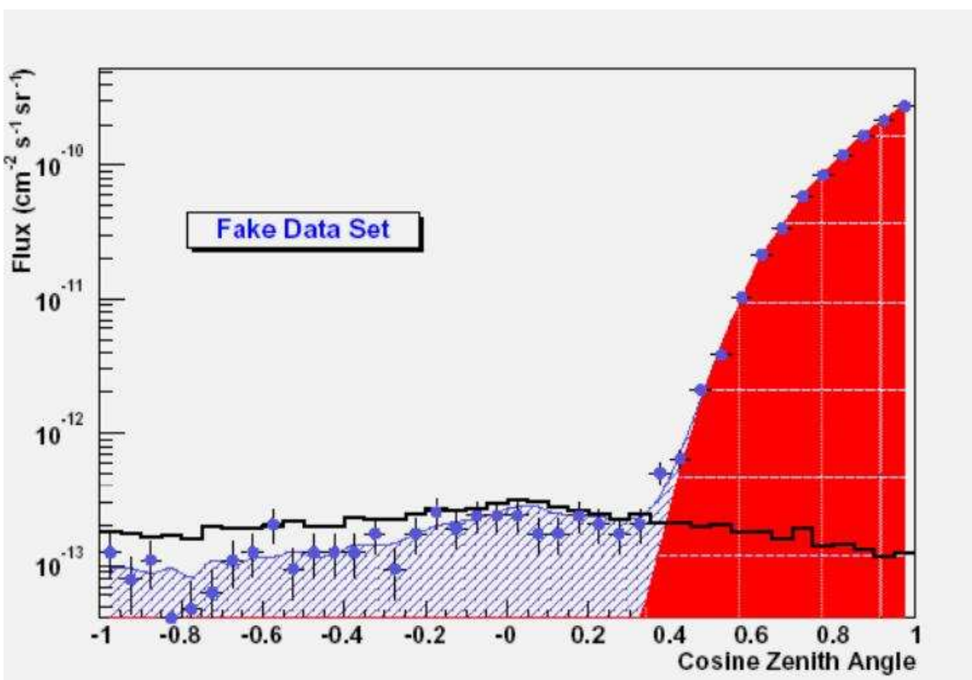


☞ Reconstruction efficiency $\epsilon \simeq 1$ for energies $E_\mu \gtrsim 4$ GeV (stopping range ~ detector size) and for $R < 7.5$ m ($R_{\text{MAX}} = 8.9$ m)

Preliminary analysis with 150 days of data carried out in 2001 (courtesy of N. Tagg)



Prospect at SNO with 730 days of data ☞ simulated data set



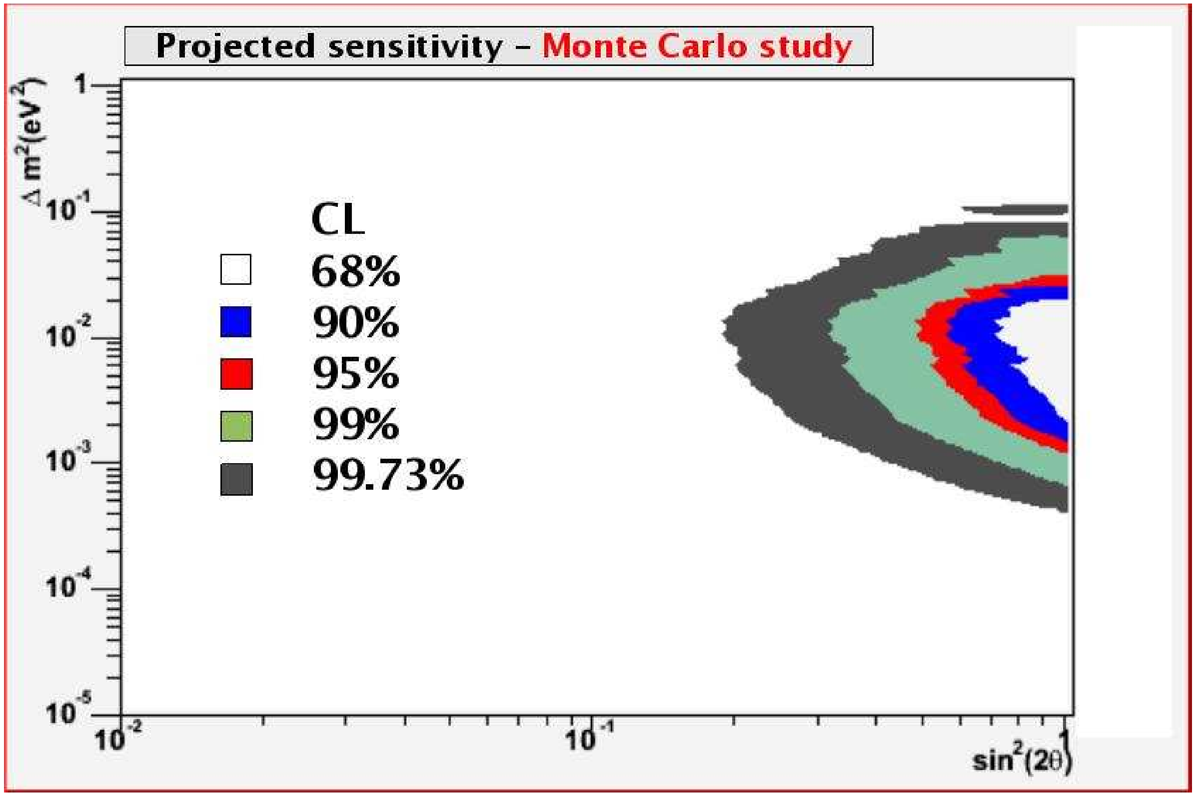
- ✦ data point $(\Delta m^2, \sin^2\theta) = (5 \times 10^{-3}\mathrm{eV}^2, 1)$

☞ stop/thru analysis under investigation (bin over horizon)

Projected sensitivity 2/2

Projected sensitivity to atmospheric neutrino-oscillation parameters at SNO

- ... with 730 days of data (as of Winter 2003)
- ... with flux constraint
- ... data point $(\Delta m^2, \sin^2\theta) = (5 \times 10^{-3}\text{eV}^2, 1)$
- ... MC study, statistical only



Possible muon calibration

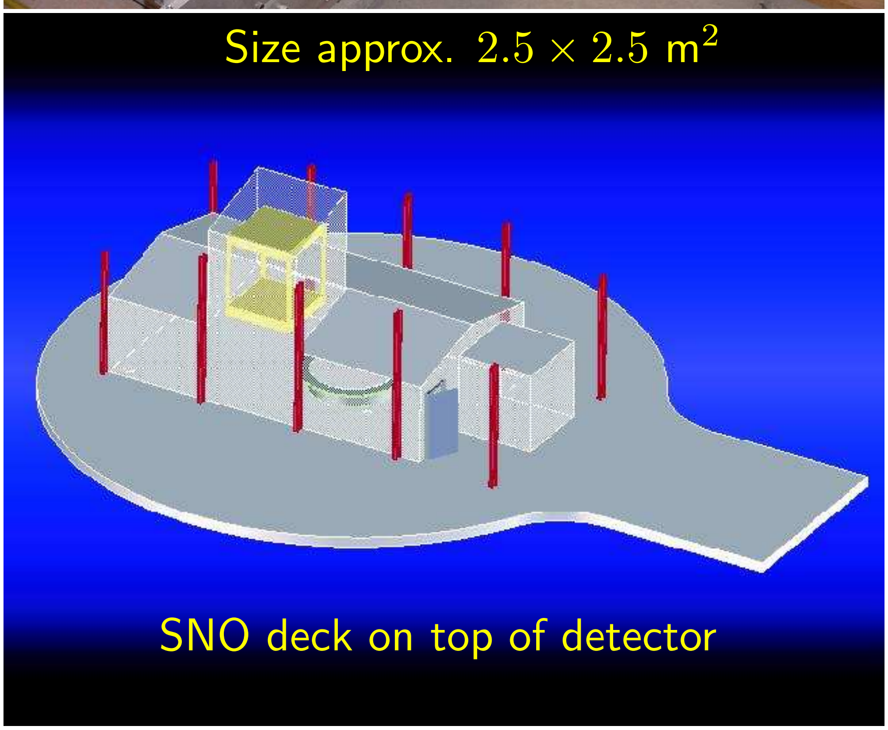
☞ Analysis in progress...

- ❖ Systematics (in track reconstruction) have strong impact on sensitivity studies
- ❖ Statistics really matter ➪ improved fitter acceptance at large impact parameters is welcome
- ❖ Simulation and reconstruction algorithm to be tuned on independent data

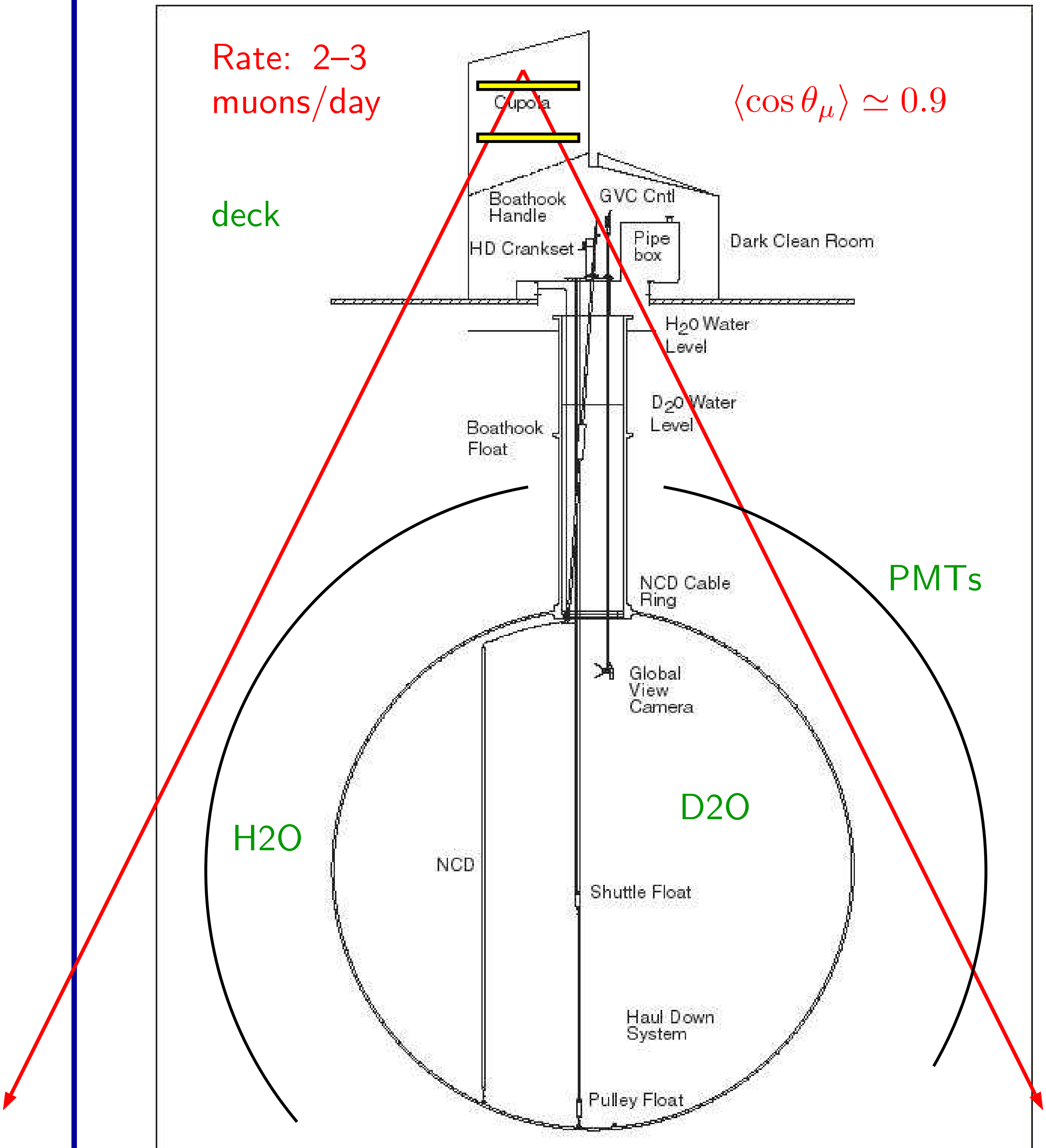
☞ Study feasibility of standalone muon tracker (with application at SNO) in progress

Muon tracker project

Recycling chambers used for HEP test beams (FNAL/IUCF/JLab). Some engineering work required for SNO needs (scintillator pads for trigger, support structure).



Location & coverage



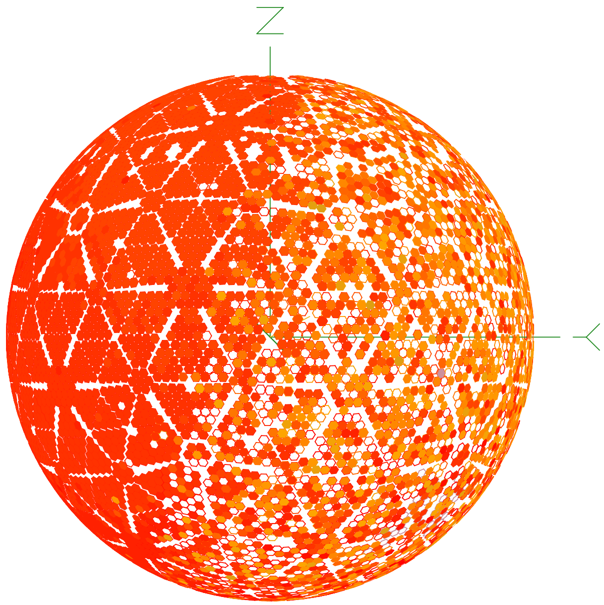
Summary

- SNO is the deepest underground laboratory currently in operation and benefits from a flat overburden
- Muon flux as a function of zenith angle ➩ neutrino oscillations ("shape")
- Muon flux as a function of zenith angle ➩ absolute atmospheric neutrino flux ("rate")
- ... model-independent measurement
- Muon simulation and reconstruction are robust but further refinements/improvements would require independent calibrated data

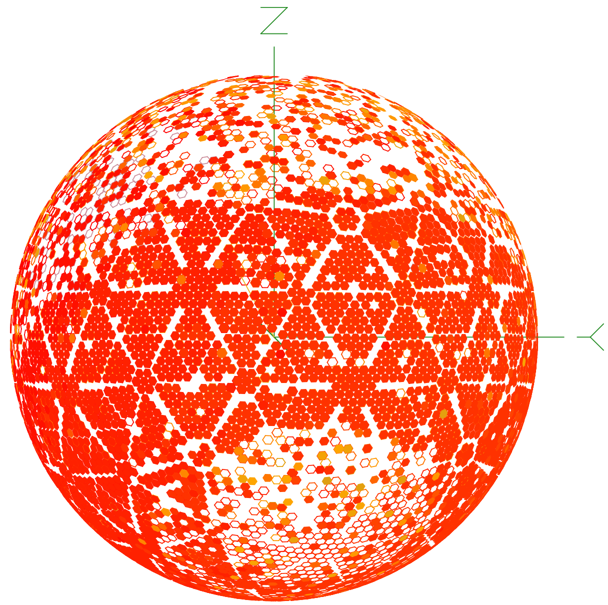
- Muon tracker being setup for possible use at SNO
- Good number of present and future underground labs ➩ portable muon flux monitoring device is appealing

☞ Stopping muons: very few muons stop in the detector (range is 18 m for $E_\mu = 4$ GeV). About 13% of the upward-going muons do.

$E_\mu \simeq 150$ GeV



$E_\mu \simeq 2$ GeV — stopping



☞ Multiple muons: approx. 3% of all muons, 90% of which are double muons.