Measurement of the neutrino-nucleon cross-section at multi-TeV energies with the IceCube Neutrino Detector

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Source: Muon neutrinos from cosmic rays
- Flux of atmospheric and astrophysical $\nu_\mu$
  - Isotropic cosmic rays interact with atmosphere [Gaisser, Elbert]
  - Resulting kaons and pions decay into conventional $\nu_\mu$ [Honda et al 2007]
- Charm atmospheric neutrino component ("prompt") [ERS 2008]
- "Astrophysical" neutrinos from the universe’s acceleration mechanisms
- Available flux is 98% conventional, 1.4% astrophysical, and 0.6% prompt.

Target: Earth
- Earth density model: Preliminary Reference Earth Model [PREM 1981]
  - Observe/measure neutrino absorption in the Earth
  - Differential density changes spectrum from surface to detector
  - Earth diameter $= interaction length at \approx 40$ TeV

Detector: IceCube Neutrino Detector
- Neutrino astrophysics with world’s largest neutrino telescope
  - Detects Čerenkov photons from charged particles
- Located at South Pole in deep clear glacial ice (1450 - 2450 m deep)
- 1 km$^3$ instrumented volume, or 1610 GigaTons
- 5160 optical sensors (digital optical modules, DOMs) deployed on 86 strings, 60 DOMs per string, 125-m grid, plus surface array IceTop
- Particle energy $\approx 10$ GeV $\rightarrow 1$ EeV (10$^{20}$ GeV)
- Muon neutrino direction $\approx \pm 1$ degree, muon energy $\pm 50\%$
- Average detector uptime 99.8% taking data year-round
- Collaboration of 300 members from 48 institutions in 12 countries

Cross section baseline
- Total cross section for NC and CC interactions for $\nu_\mu$ and $\bar{\nu}_\mu$
  - Assumes that NC and CC cross sections scale together
  - Result does not account for diffractive neutrinos [Seckel 1998]

Simulation
- Source simulation from NeutrinoGenerator (NuGen)
  - Monte Carlo that creates, propagates, and interacts up-going neutrinos
  - Can vary cross section models to generate expectations for fitter
- Background simulation from CORSIKA
  - Cosmic ray muon (down-going) events for background rejection
  - Signal to background $\approx 1:10^6$ events, final event selection purity 99.9%

Experimental fit
- Event selection yielded 10,784 muon neutrinos in 2010 data year
  - Muon energy determined by Truncated Energy method [IceCube 2013]
- Two-dimensional LLH fit in muon energy and zenith angle
  - Constrained by priors from other experiments
  - Astrophysical and prompt fluxes from IceCube [IceCube 2015]
  - Fit results given as multiple of SM expectation from CSMS 2011
  - Fit parameters included fluxes of conventional, astrophysical, prompt, $\nu_\mu$, $\bar{\nu}_\mu$, ratio, kaon-pion ratio, DOM efficiency
  - Systematics included ice model, Earth model, atmospheric temperature model, and choice of astrophysical and prompt flux priors

Results
- Total $\nu_\mu$-nucleon cross section $= 1.30 \pm 0.30 \pm 0.26 \text{(stat.)} \pm 0.32 \pm 0.40 \text{(syst.)}$ times CSMS 2011 expectation
  - Energy range 6.3 TeV to 980 TeV
  - In agreement with the Standard Model cross section at high energy
  - Plans for follow-up analysis using 5+ years of data

References
- Cosmic rays: Gaisser, Astropart. Phys. 35 (2012) 801-806
- Cosmic ray knee correction: Elbert, DUMAND Summer Workshop Vol 2 (1978)
- Neutrino model: Cooper-Sarkar, Mertsch, & Sarkar, JHEP 1108 (2011) 042

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