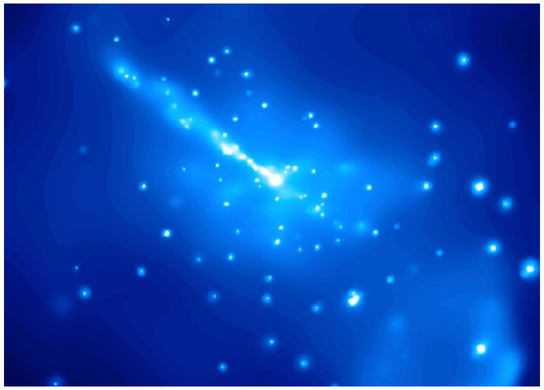
Neutrino astronomy and telescopes


INTERNATIONAL JOURNAL OF HIGH-ENERGY PHYSICS

CERN COURIER

VOLUME 43 NUMBER 5 JUNE 2003


Crab nebula


Cen A

Overview

- Neutrinos and their properties (done)
- Neutrino astronomy and connections to Cosmic rays and gamma-astronomy
- Neutrino sources and neutrino production

  SN collapse and nutrino burst
- Neutrino telescopes and detection technique
- Search Methods
- Current experimental scenario

Suggested references

- **Halzen and Hooper, Rept.Prog.Phys.65:1025-1078,2002**
- Learned and Mannheim,

  Ann.Rev.Nucl.Part.Sci.50:679-749,2000
- **Burgio, Bednarek, TM, New Astron. Rev. 49, 2005 (galactic point sources)**
- http://arxiv.org/PS_cache/astro-ph/pdf/0405/0405503.pdf (GRBs)
- Books: Longair, High Energy Astrophysics Berezinski, Neutrino Astrophysics 1995
- For all neutrino related information always look in

  http://www.nu.to.infn.it/

These transparencies:

http://www.icecube.wisc.edu/~tmontaruli/801.html

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The idea

νs are weekly interacting ⇒ require large target mass and conversion into charged particle Markov/ Greisen idea (1960)

Target is surrounding matter

$M = \rho R_\mu S$ (E_μ = 1 TeV : R_μ = 2.5 km)

Events are upgoing

$$\overset{(-)}{\nu}_{\mu} + N \longrightarrow \mu^{\pm} + X$$

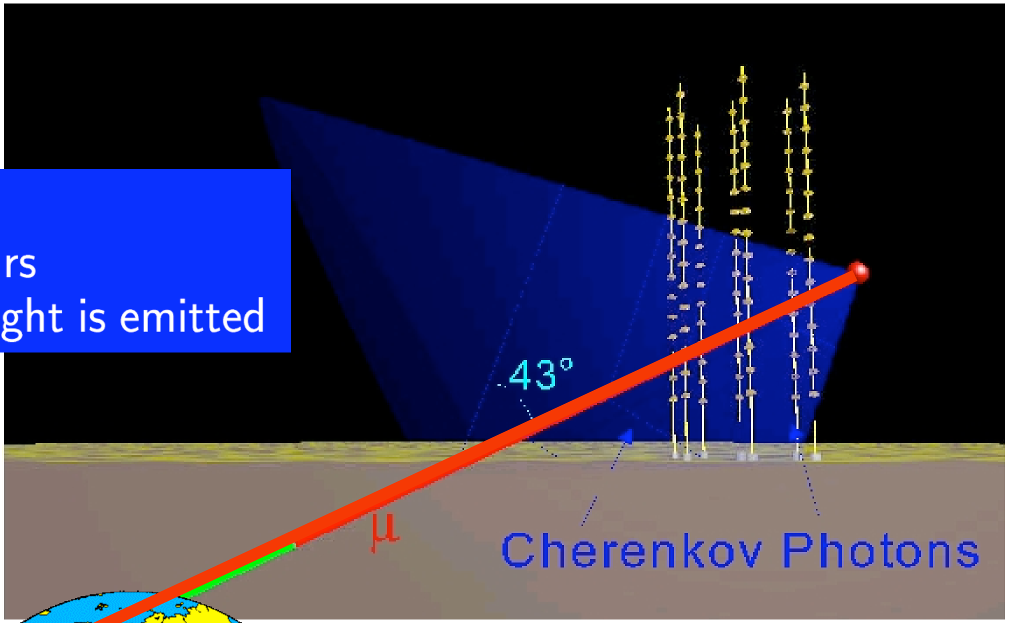
M.Markov (1960): idea to construct large deep underwater Cherenkov detectors for neutrino astrophysics using water masses of natural basins.

Era of underwater neutrino telescopes started

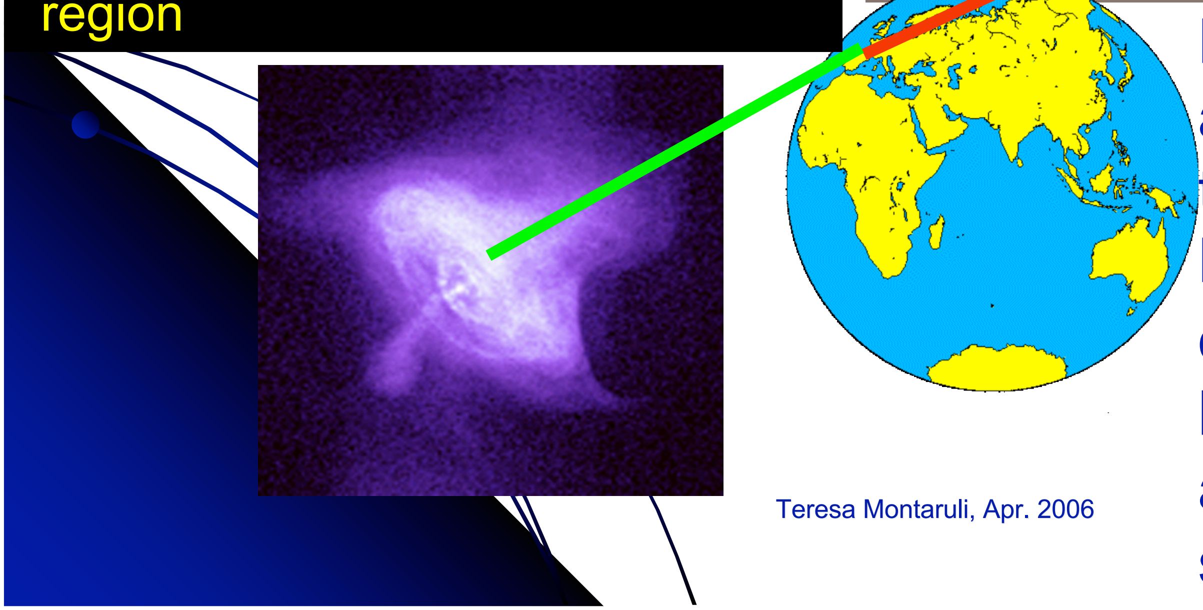
Neutrino Detection Principle

Water/ice used as:

- ■ shield to protect of atmospheric muons
- ■ target in which neutrino interaction occurs
- ■ detecting medium where the Cherenkov light is emitted



Upgoing muons: much larger interaction volume than what is in the instrumented region



Muon neutrinos are the only topology to allow source pointing
But since νs oscillate other topologies should be considered that allow to observe upper sky

Energy losses

Ionization and atomic excitation: interactions with electrons in the media continuous process mip: particles at the minimum of ionization 2 MeV/g/cm^2

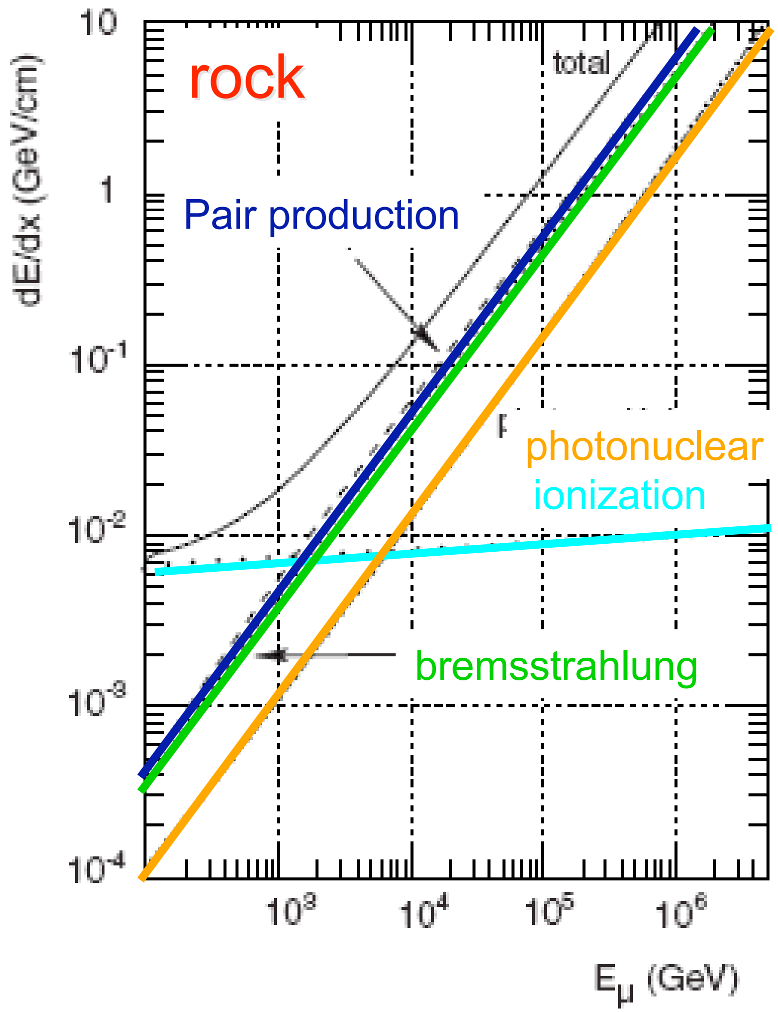
Radiative: discrete process and stochastic

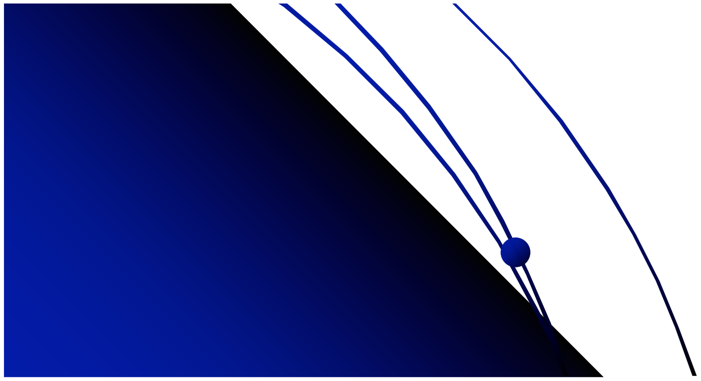
Bremmsstrahlung: radiation emitted by ar accelerated or decelerated particle throug the field of an atomic nuclei

Energy emitted $\propto 1/m^2$

Pair production: $\mu + N \rightarrow e^+e^-$

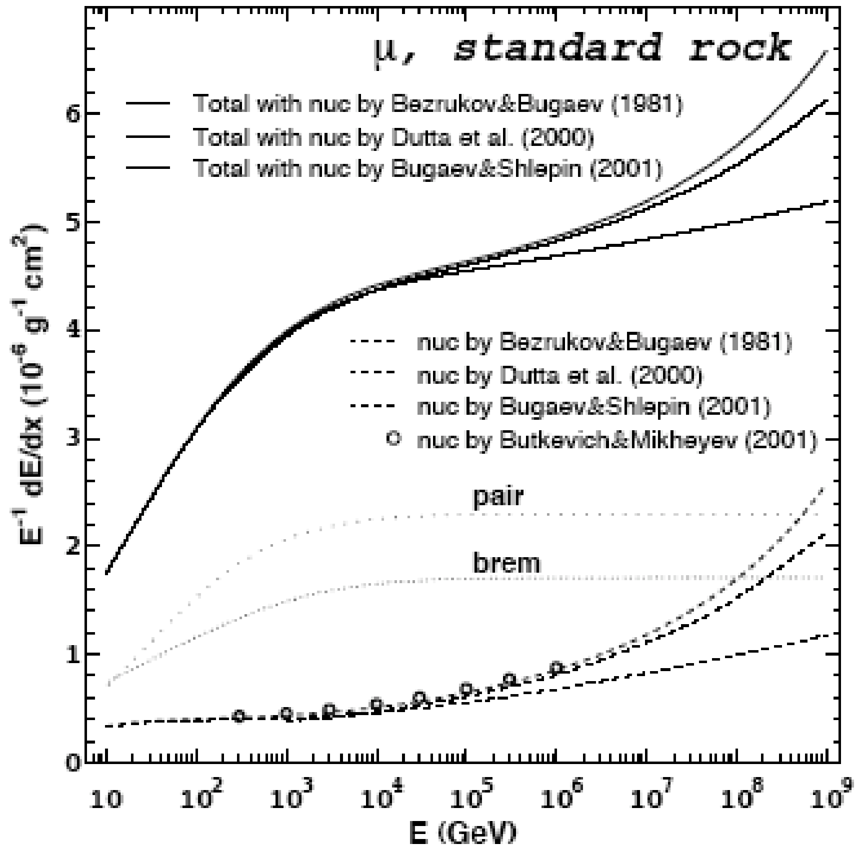
Photonuclear : inelastic interaction of muons with nuclei, produces hadronic showers

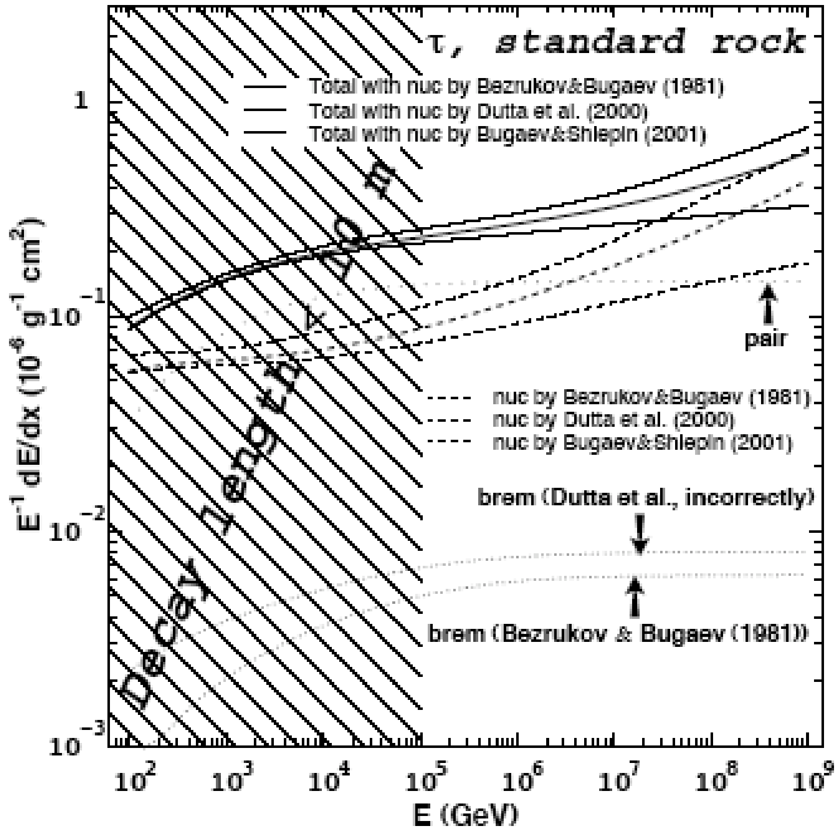




Muons and Taus

- Bremsstrahlung $\propto 1/m^2$ << important than photonuclear for taus





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The target mass

$$-dE/dx = a(E) + b(E)\,E$$

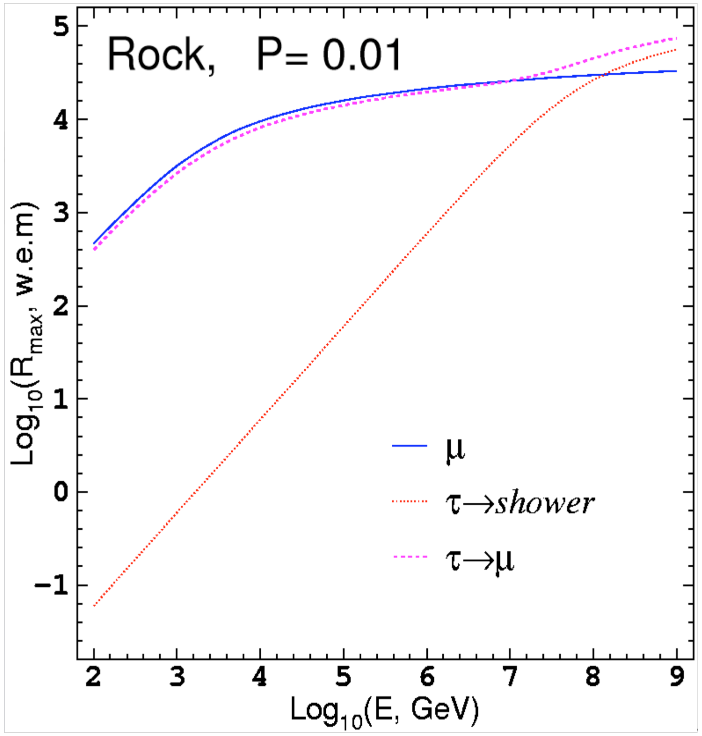
Ionization Stochastic losses

~2 MeV/g/cm^2 (dominate > 1TeV)

$$R_{max}(E_l,E_l^{min}) = \int dX\ P_{surv}(E_l,E_l^{min},X)$$

$$R_\mu = \int_0^E \frac{dx}{dE}\,dE \approx \int_0^E \frac{1}{a+bE}\,dE = \frac{1}{b}\log(1+E/E_c)$$

$$E_c = a/b$$



	τ	μ
m (GeV)	1.777	0.105
τ_{dec} (sec)	2.9×10^{-13}	2.2×10^{-6}
l_{dec} (m)	4.9×10^{-5} ×(E/GeV)	6568 ×(E/GeV)

- $\tau \rightarrow \mu\ \nu_\mu\ \nu_\tau$ BR=17.36%
- $\tau \rightarrow e\ \nu_e\ \nu_\tau$ BR=17.84%
- τ →sciami BR=82.64%

Neutrino interactions on nucleons

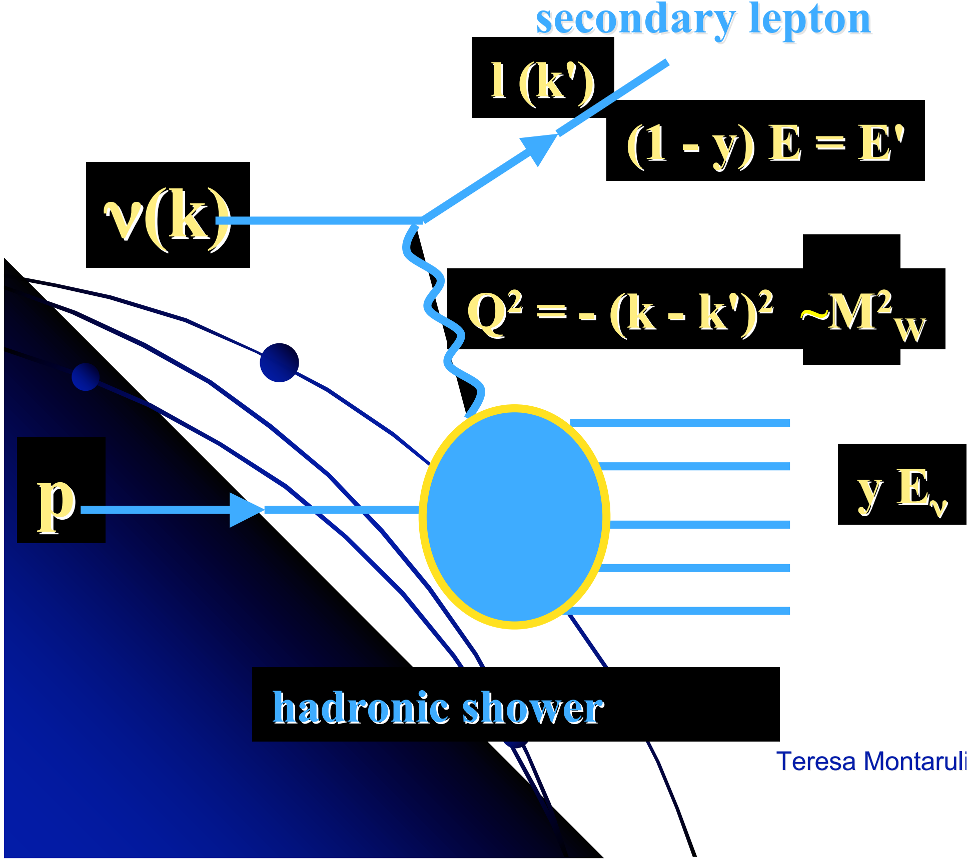
$$\frac{d^2\sigma}{dxdy} = \frac{2G_F^2 M E_\nu}{\pi}\left(\frac{M_W^2}{Q^2+M_W^2}\right)^2\left[xq(x,Q^2)+x\overline{q}(x,Q^2)(1-y)^2\right]$$

q parton distribution functions

$$Q^2 = 2ME_\nu xy \qquad y=\nu/E_\nu \qquad \nu = E_\nu - E_\mu$$

For antineutrinos q↔q and above 10^5 GeV cross sections are equal since the interactions on sea quarks dominate over valence ones

Deep inelastic scattering: νs probe the internal structure of nucleons



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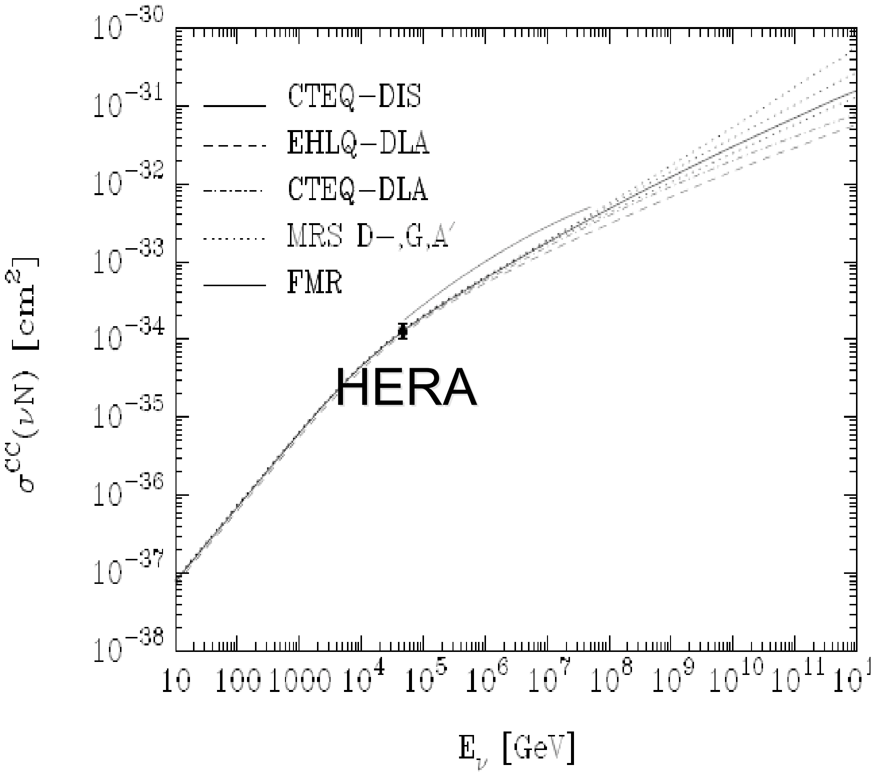


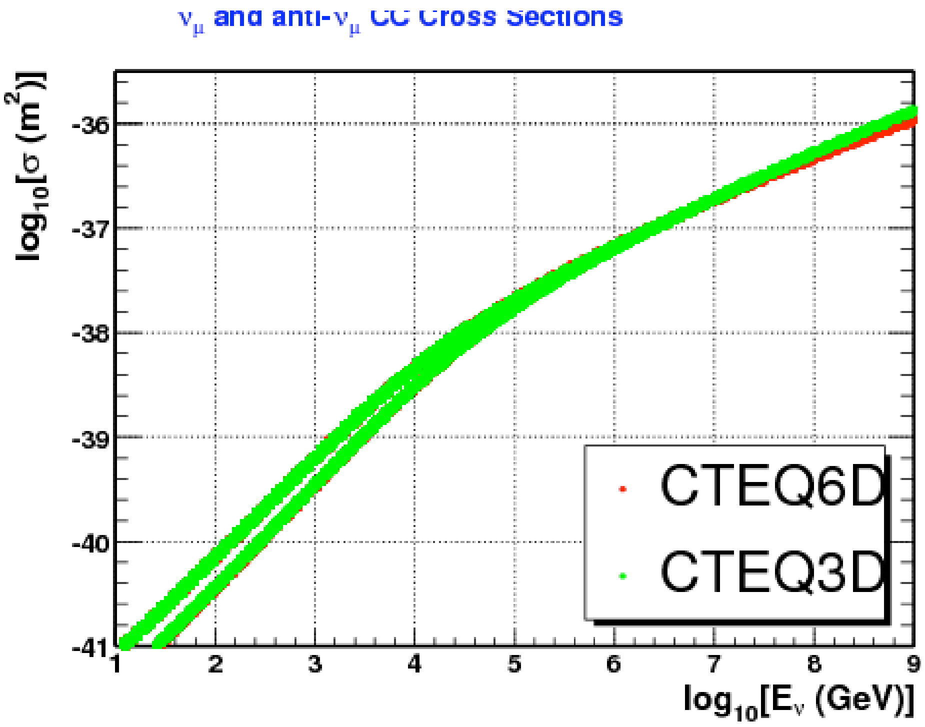
The DIS total cross section

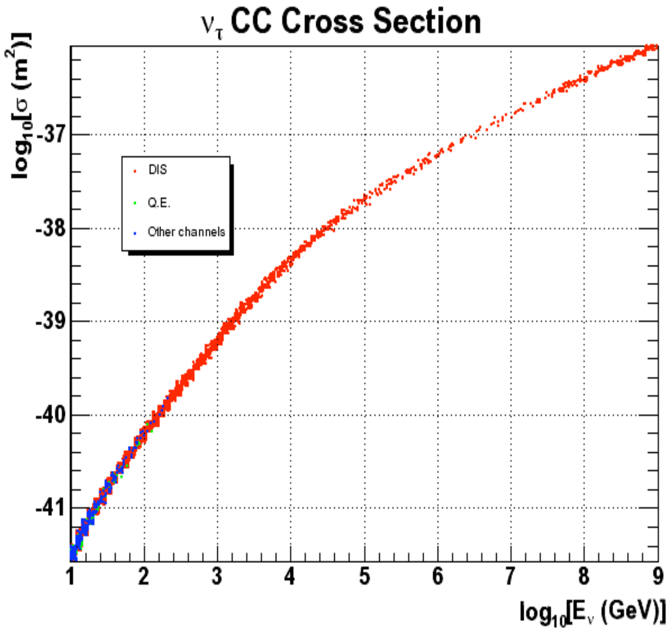
For antineutrinos q↔q and above 10^5 GeV cross sections are equal since the interactions on sea quarks dominate over valence ones

$$\frac{d^2\sigma}{dxdy} = \frac{2G_F^2 M E_\nu}{\pi}\left(\frac{M_W^2}{Q^2+M_W^2}\right)^2\left[xq(x,Q^2) + x\overline{q}(x,Q^2)(1-y)^2\right]$$

$$q(x,Q^2) = \frac{u_v(x,Q^2)+d_v(x,Q^2)}{2} + \frac{u_s(x,Q^2)+d_s(x,Q^2)}{2} + s_s(x,Q^2) + b_s(x,Q^2)$$

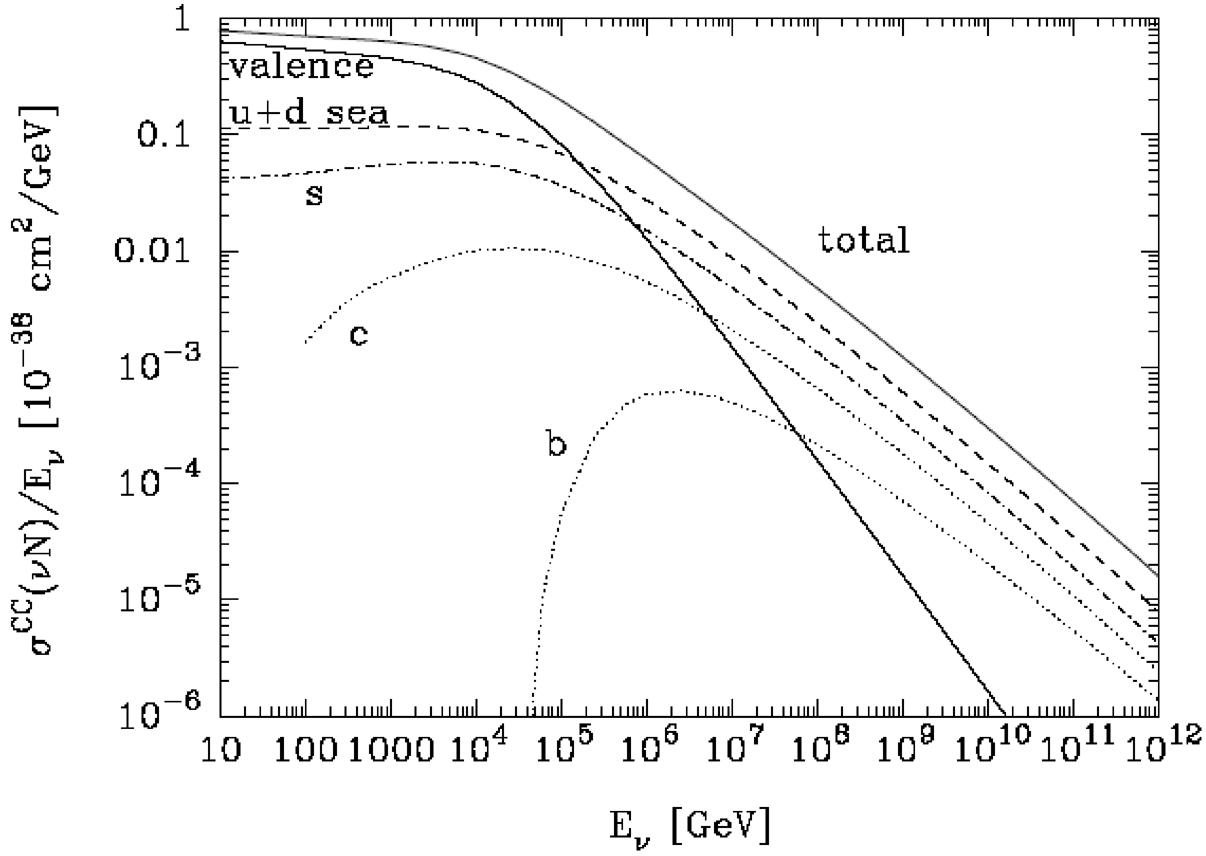
$$\overline{q}(x,Q^2) = \frac{u_s(x,Q^2)+d_s(x,Q^2)}{2} + c_s(x,Q^2) + t_s(x,Q^2),$$





Teresa Montaruli, Apr. 2006

Quark contribution

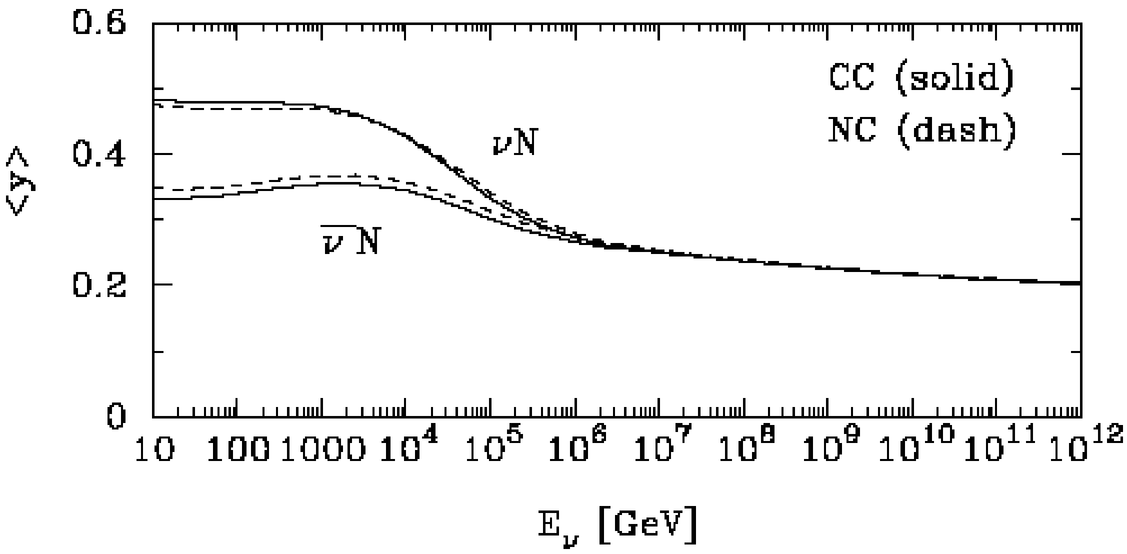


Ghandi et al, hep-ex/9512364

Inelasticity

$y = \nu / E_\nu$

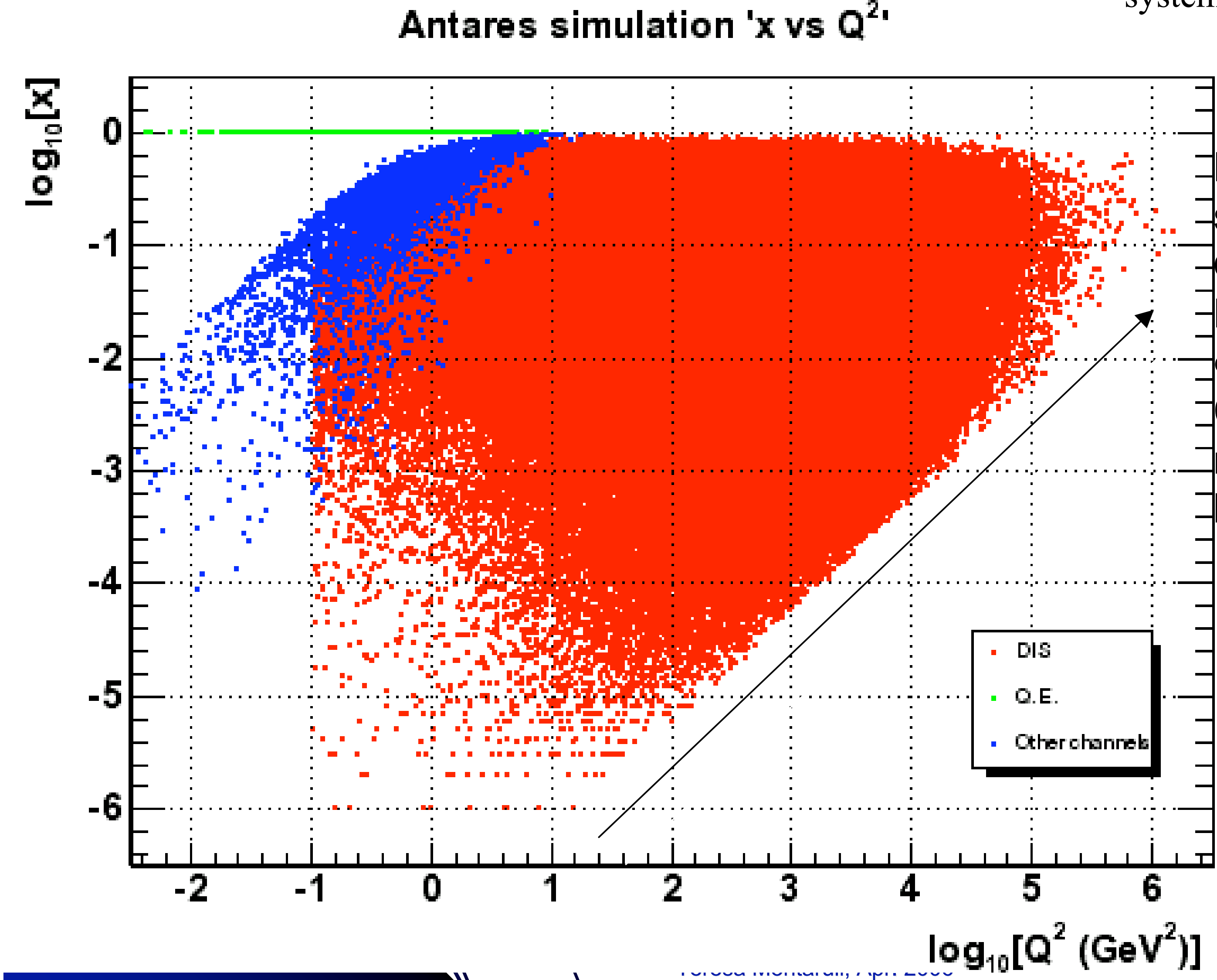
$\nu = E_\nu - E_\mu$



The parameter space

HERA x ~10^{-5}

cut on invariant mass of hadronic system $W^2 = Q^2/X$ 2-10^8 GeV^2



Double Asymptotic Scaling structure function depend only on a variable $\sigma(x,Q^2)$

Large Q^2 small x:

$\sigma \propto \ln(1/x)*\ln Q^2$

Calculations not possible for non perturbative region low x and small Q2

$Q^2 = 2MxyE_\nu$

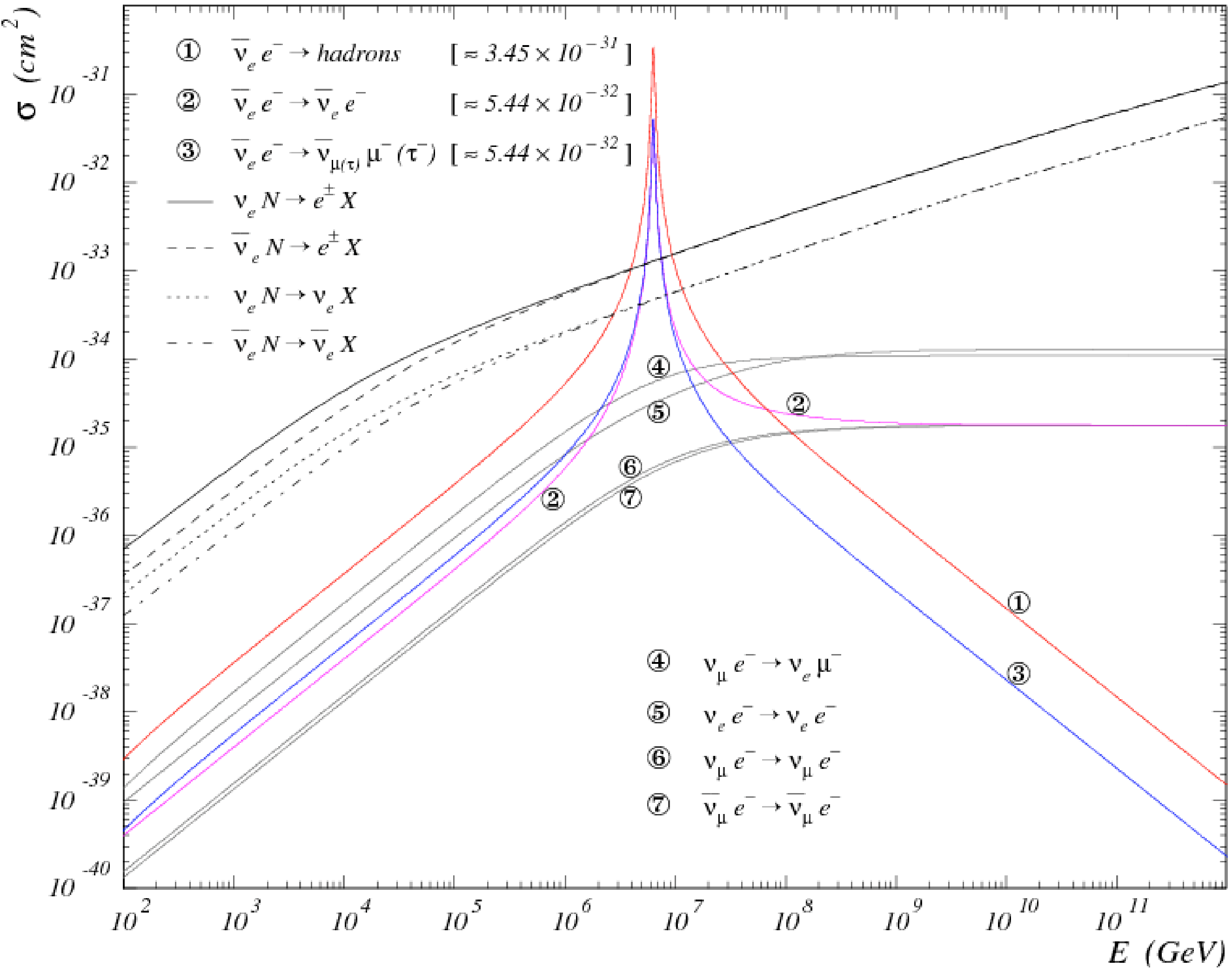
$x = Q^2/(2M\nu)$

$y = (E_\nu - E_l)/E_\nu = \nu/E_\nu$

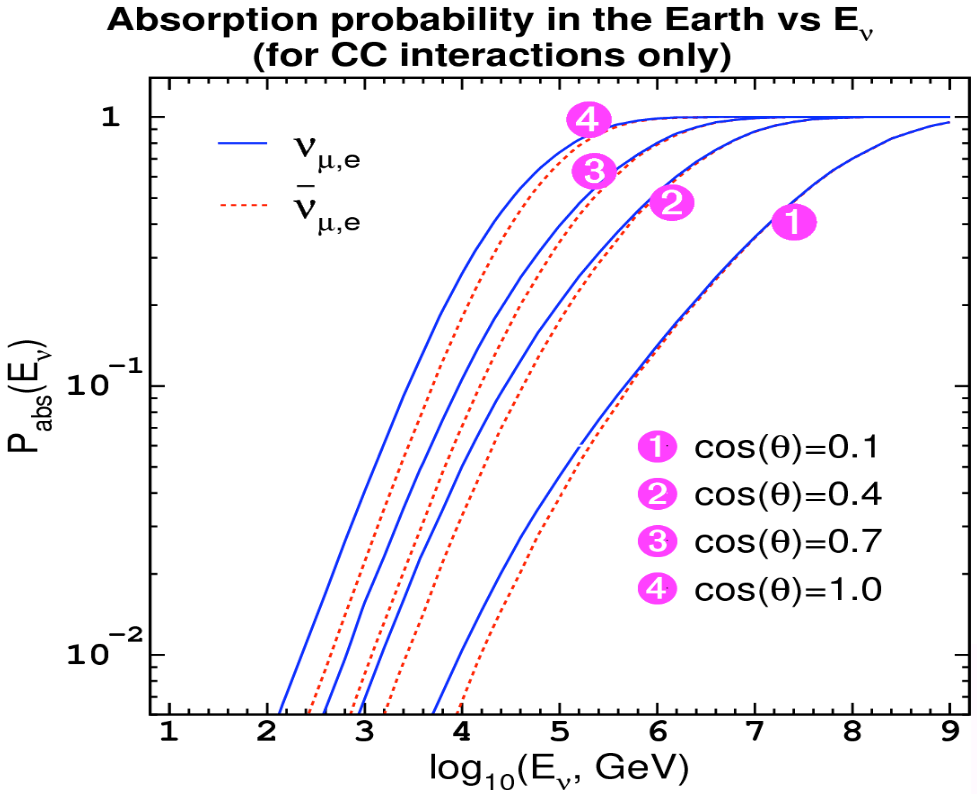
CTEQ6-D: $10^{-6} < x < 1$ $1.3 < Q < 10^4$ GeV

Neutrino interactions on electrons

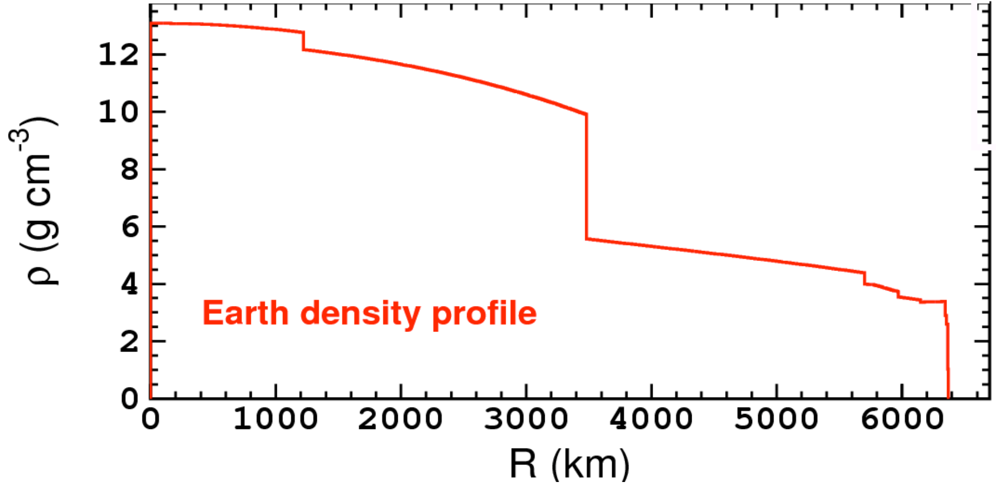
Glashow resonance 6.3 PeV



Neutrino absorption in the Earth



Absorption probability in the Earth vs E_ν
(for CC interactions only)



Earth density profile

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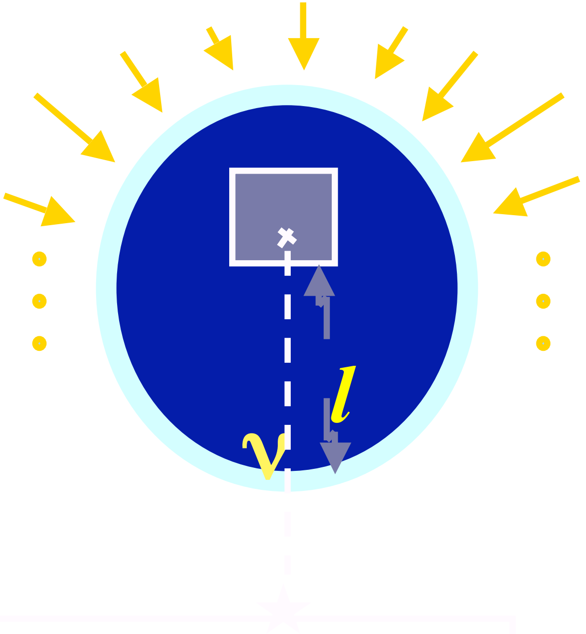
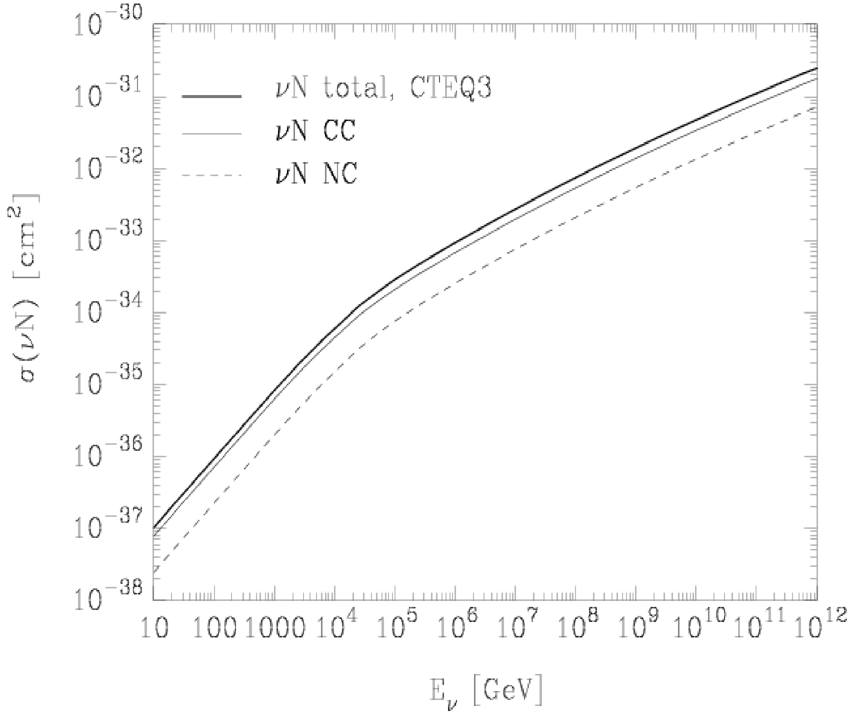


$$P_{survival} = \exp -(l/\lambda_\nu)$$

$$\lambda_\nu = 1/(\rho N_A \sigma_\nu (E_\nu))$$

NC interactions

$$\nu_\mu + N \to \nu_\mu + X$$



$\sigma_{CC} \sim 3\ \sigma_{NC}$

Similarly to ν_e and ν_τ CC, NCs for all flavors produce showers.

$$q^0(x,Q^2) = \left[\frac{u_v(x,Q^2)+d_v(x,Q^2)}{2} + \frac{u_s(x,Q^2)+d_s(x,Q^2)}{2}\right](L_u^2+L_d^2)$$
$$+ \left[\frac{u_s(x,Q^2)+d_s(x,Q^2)}{2}\right](R_u^2+R_d^2) + \qquad (11)$$
$$[s_s(x,Q^2)+b_s(x,Q^2)](L_d^2+R_d^2) + [c_s(x,Q^2)+t_s(x,Q^2)](L_u^2+R_u^2)$$

$$\overline{q}^0(x,Q^2) = \left[\frac{u_v(x,Q^2)+d_v(x,Q^2)}{2} + \frac{u_s(x,Q^2)+d_s(x,Q^2)}{2}\right](R_u^2+R_d^2)$$
$$+ \left[\frac{u_s(x,Q^2)+d_s(x,Q^2)}{2}\right](L_u^2+L_d^2) + \qquad (12)$$
$$[s_s(x,Q^2)+b_s(x,Q^2)](L_d^2+R_d^2) + [c_s(x,Q^2)+t_s(x,Q^2)](L_u^2+R_u^2),$$

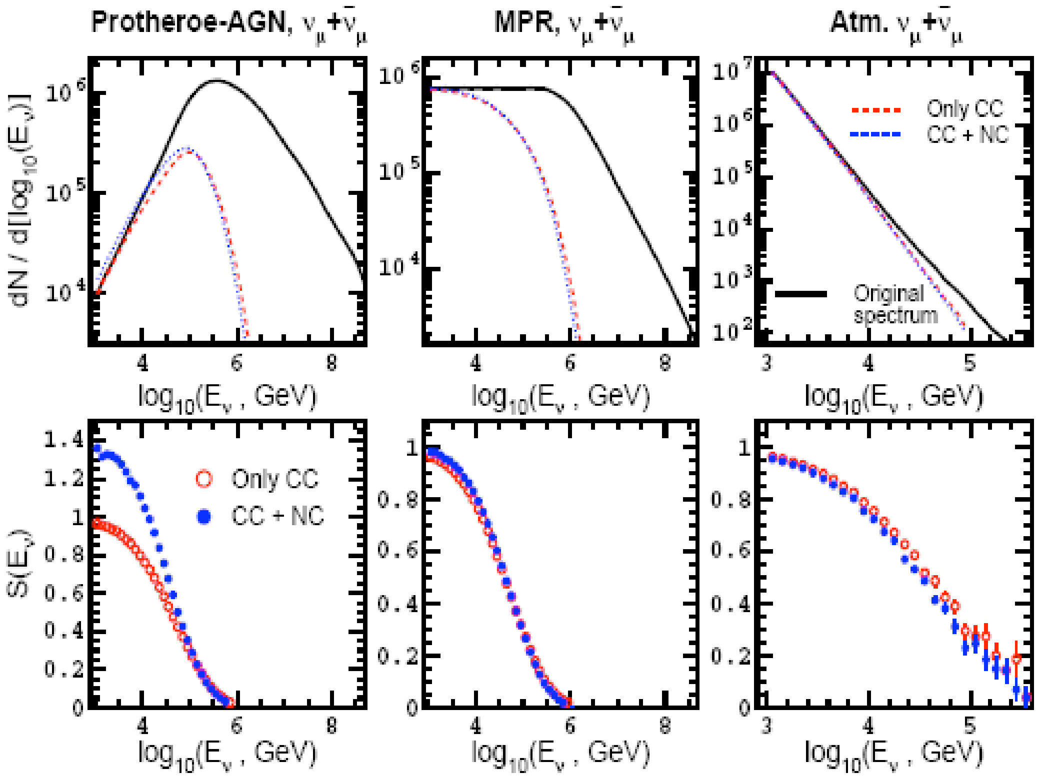
$$x_W = \sin^2\theta_W$$

$$L_u = 1 - \tfrac{4}{3}x_W \qquad L_d = -1 + \tfrac{2}{3}x_W$$
$$R_u = -\tfrac{4}{3}x_W \qquad R_d = \tfrac{2}{3}x_W$$

$$\frac{d^2\sigma}{dx\,dy} = \frac{G_F^2 M E_\nu}{2\pi}\left(\frac{M_Z^2}{Q^2+M_Z^2}\right)^2\left[xq^0(x,Q^2) + x\overline{q}^0(x,Q^2)(1-y)^2\right],$$

NC interactions

$\nu_\mu + N \rightarrow \nu_\mu + X$



Muon Neutrinos are not lost in the Earth after a NC unlike for CC (except for ν_τ)

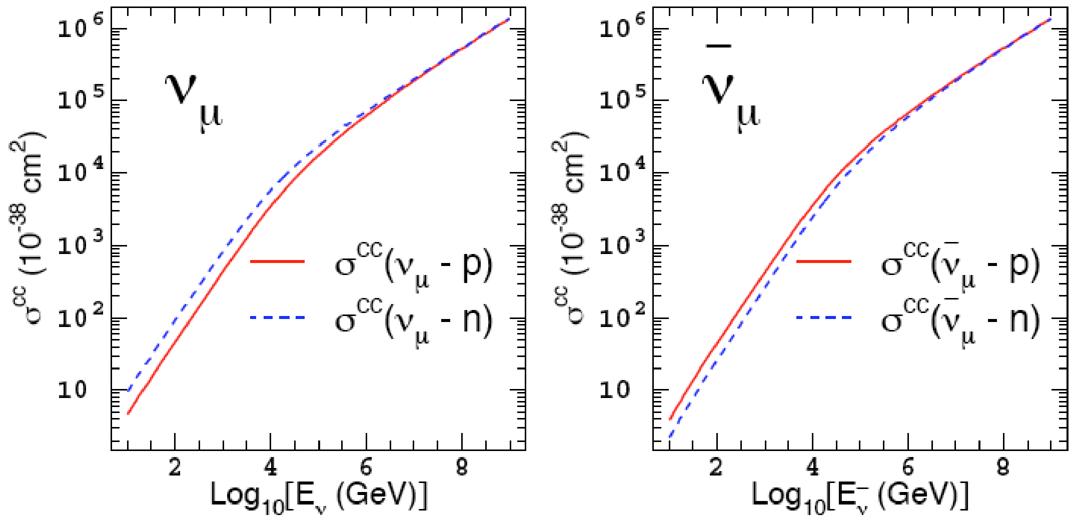
Astropart.Phys.23:57-63,2005

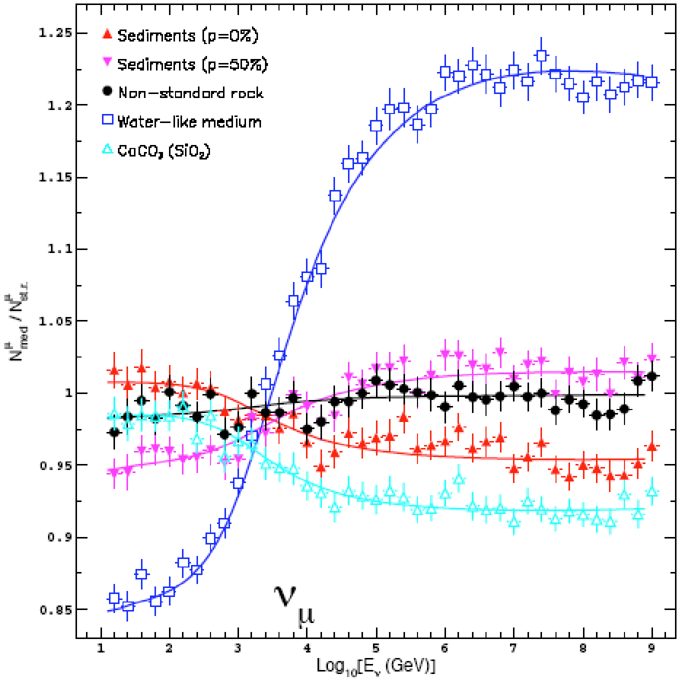
Most of neutrino telescopes cannot distinguish if they are hadronic (~20% more light) or em

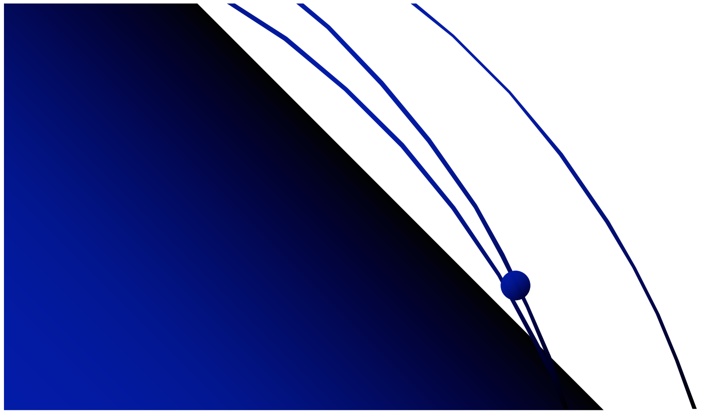
The dependence on the interaction media on event rates

$$N^{cc}(E_{\nu_\mu,\bar{\nu}_\mu}) \propto \rho \, N_A \left[\frac{Z}{A} \, \sigma_p^{cc}(E_{\nu_\mu,\bar{\nu}_\mu}) + \left(1 - \frac{Z}{A}\right) \sigma_n^{cc}(E_{\nu_\mu,\bar{\nu}_\mu}) \right] .$$

$$\sigma_{H_2O} = \frac{10}{18}\sigma_p + \frac{8}{18}\sigma_n = \frac{1}{2}(\sigma_p + \sigma_n) + \frac{1}{18}(\sigma_p - \sigma_n) = \sigma_{\rm iso} + \frac{1}{18}(\sigma_p - \sigma_n)$$







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