30th International Cosmic Ray Conference

Simulation of Double-Bang Event Induced by Tau-Neutrino in the Atmosphere

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Origin of the Flavors

$$pp \quad \to \quad \pi^{\pm}(\to \mu\, \nu_\mu) + X$$
$$\hookrightarrow e\, \nu_e\, \nu_\mu$$

$$pp \quad \to \quad D_s^{\pm}(\to \tau\, \nu_\tau) + X$$
$$\hookrightarrow \nu_\tau + Y$$

6.4%

Flavor Ratio at the Sources

$$\frac{\sigma[p(\gamma,p) \to D_S^{\pm} X]}{\sigma[p(\gamma,p) \to \pi^{\pm} X]} \leq \mathcal{O}(10^{-3} - 10^{-4})$$

$$R^0_{e/e} : R^0_{\mu/e} : R^0_{\tau/e} \propto 1 : 2 : 3 \times 10^{-5}$$

$$R^0_{\alpha/\beta} = F^0_{\nu_\alpha} / F^0_{\nu_\beta},$$

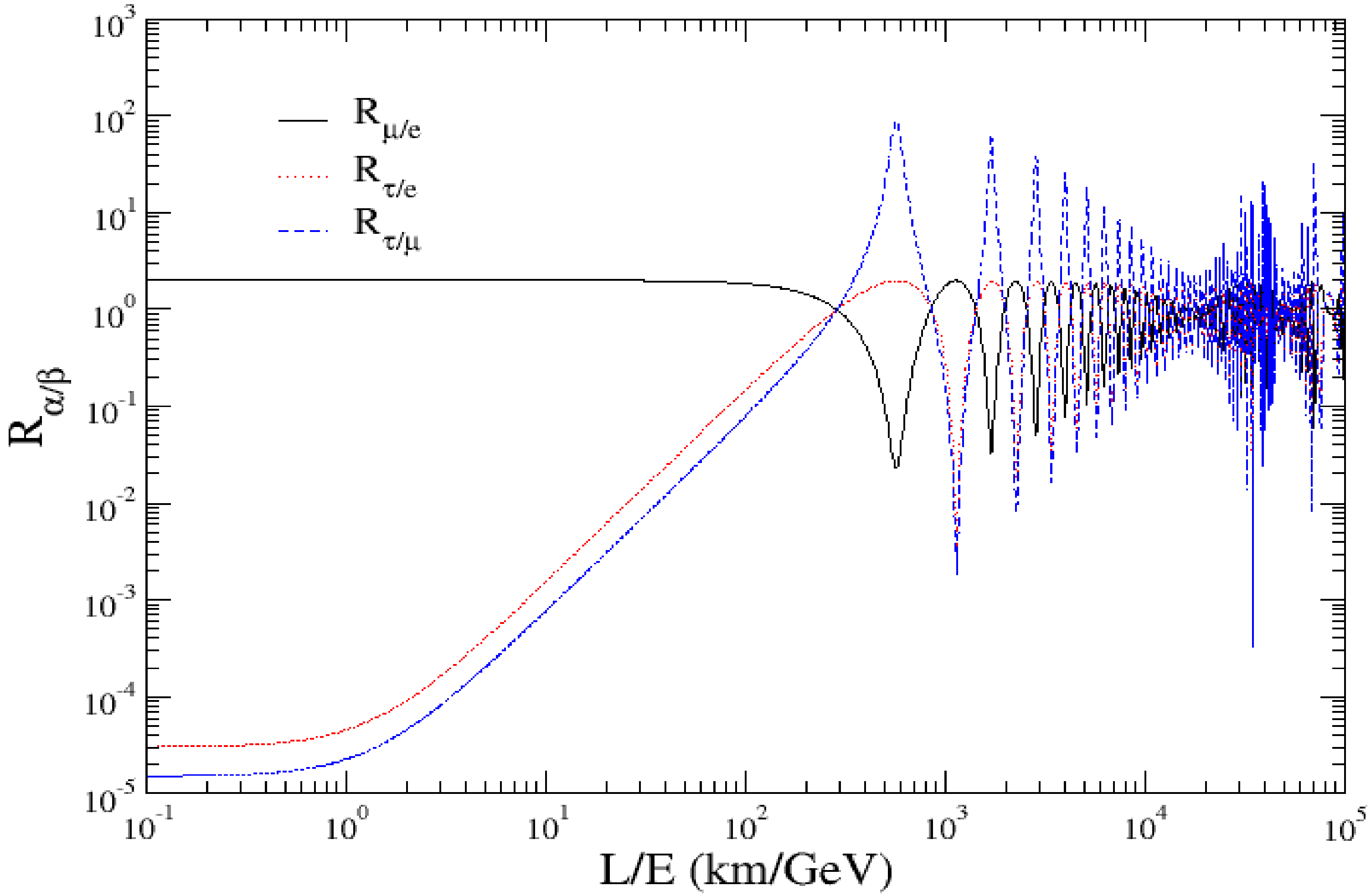
Flavor Ratio at Earth

$$P(\nu_\alpha \to \nu_\beta) = \delta_{\alpha\beta} - 4\sum_{i>j} U_{\alpha i} U_{\beta i} U_{\alpha j} U_{\beta j} \sin^2 \left[1.27 \Delta m^2_{ij} (L/E)\right]$$

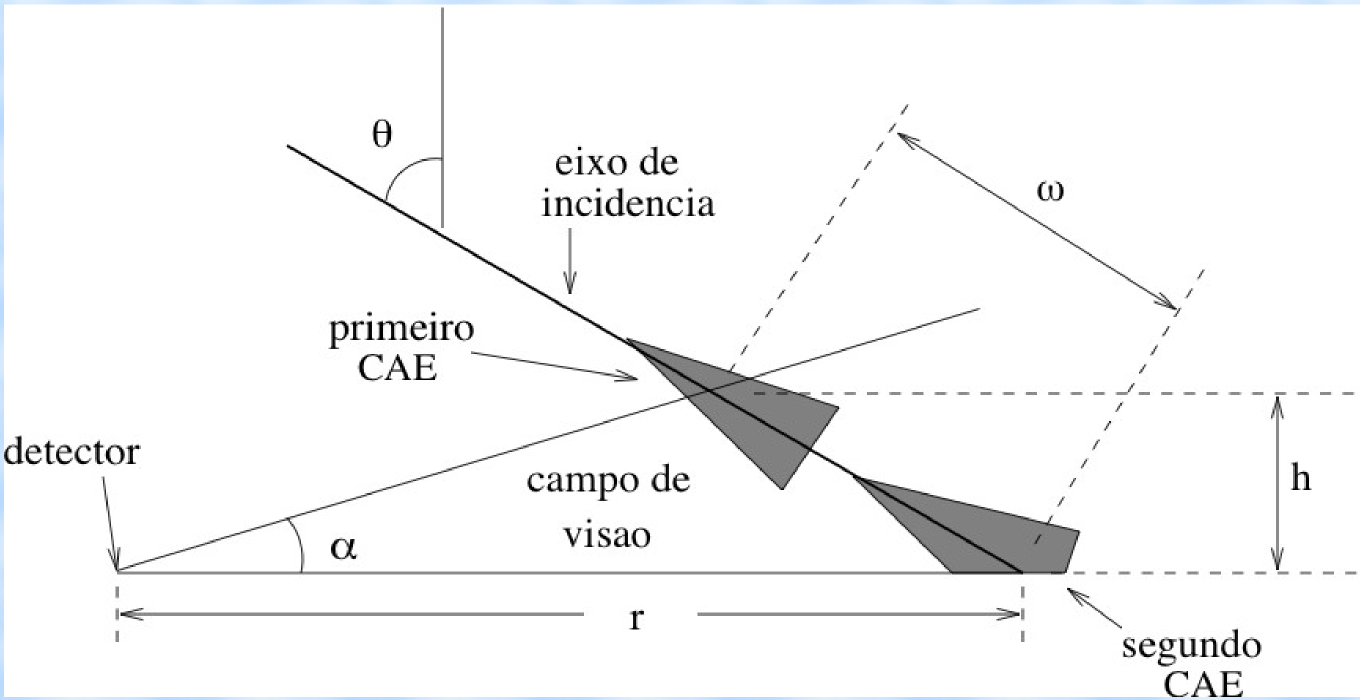
$$F_{\nu_\beta}(L,E) = \sum_\alpha P_{\alpha\beta}(L,E) F^0_{\nu_\alpha}$$

$$R_{\alpha/\beta}(L,E) = \frac{\sum_\delta P_{\delta\alpha}(L,E) F^0_{\nu_\delta}}{\sum_\delta P_{\delta\beta}(L,E) F^0_{\nu_\delta}} = \sum_\delta \frac{P_{\delta\alpha}(L,E) R^0_{\delta/e}}{P_{\delta\beta}(L,E) R^0_{\delta/e}}$$

Flavor Ratio at Earth



Double-Bang Produced by Tau-Neutrino in the Atmosphere



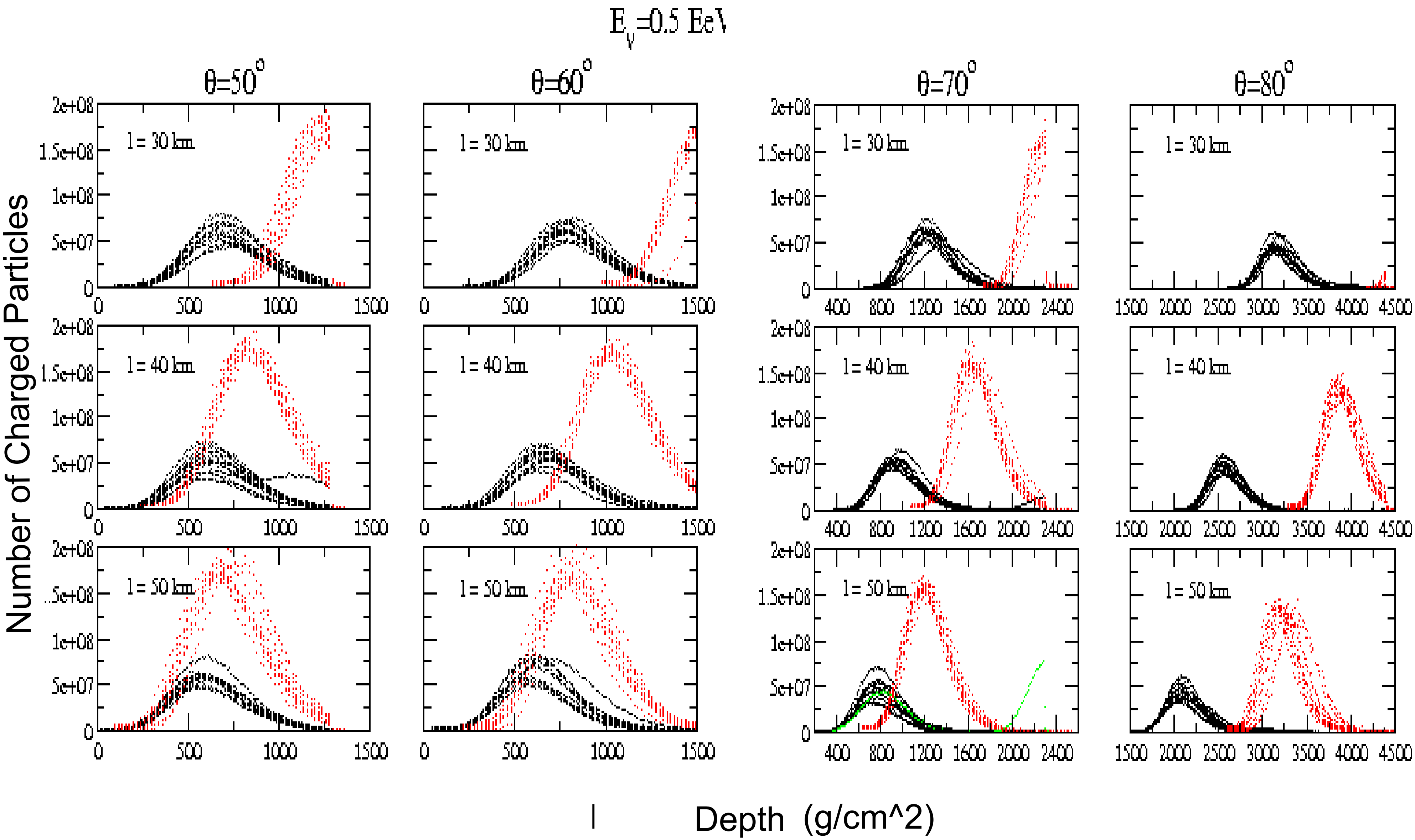
$$L \simeq \frac{E_\tau}{[\text{EeV}]} \times 49 \text{ km}$$
$$\simeq (1-y)\frac{E_\nu}{[\text{EeV}]} \times 49 \text{ km}$$

$$E_2 \approx 2E_\tau/3$$
$$\approx \frac{2}{3}(1-y)E_\nu$$

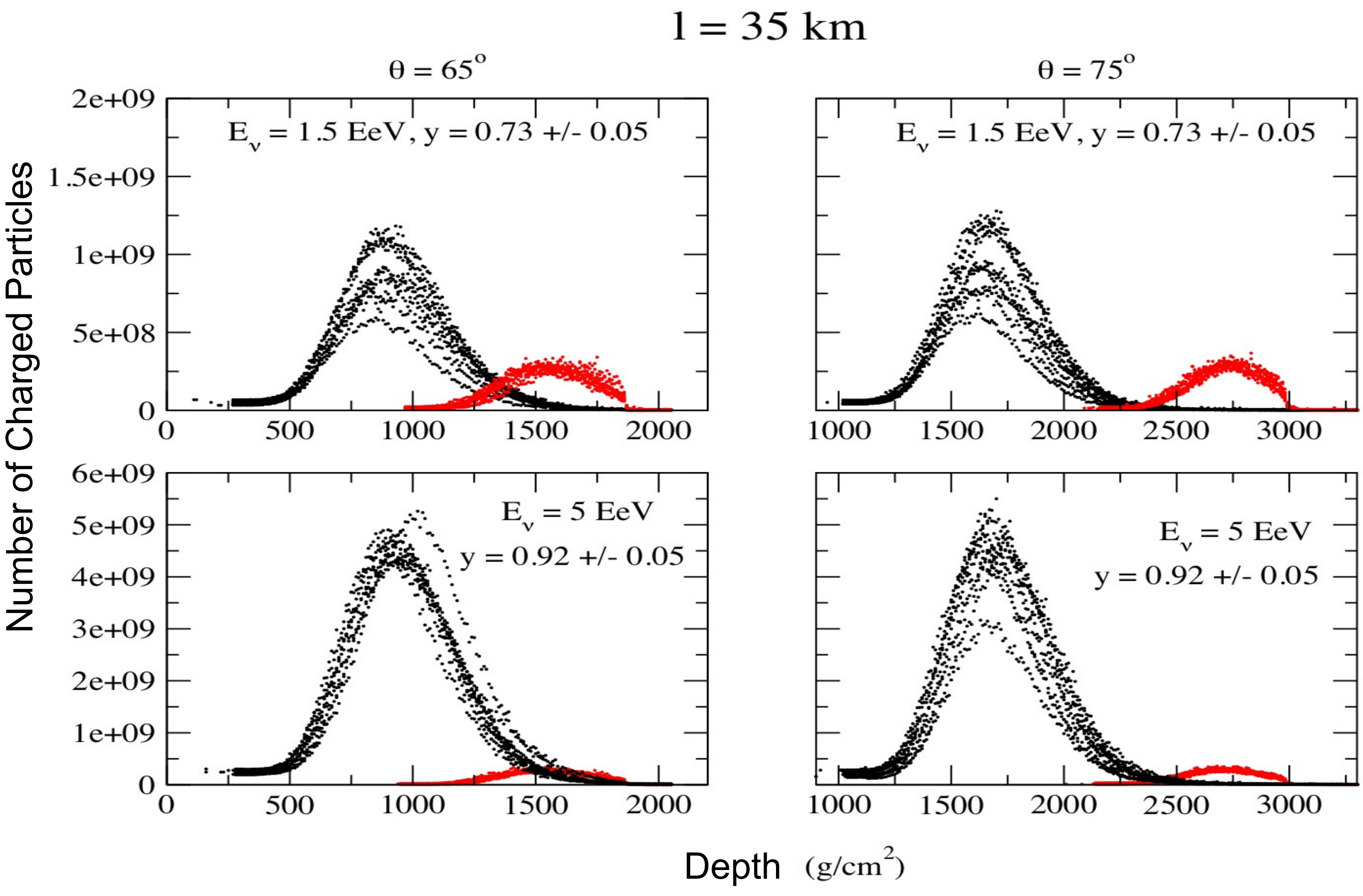
Inelasticity

$$
\begin{aligned}
E_\nu &= E_1 + E_l \\
y &= \frac{(E_\nu - E_l)}{E_\nu} \\
E_1 &= yE_\nu \\
E_l &= (1-y)E_\nu
\end{aligned}
$$

Double-Bang Simulations



Double-Bang Simulations



Event Rate Calculation

$$\frac{N_{eventos}}{\Delta t} = \int_{E_{th}}^{\infty} dE_\nu \; \Phi_\nu(E_\nu) \; \mathcal{A}(E_\nu)$$

$$\mathcal{A}(E_\nu) = \int_{\Omega, A} d\Omega \; dA \; P_{int}(E_\nu, \theta) \; F_{det}(E_\tau, r, \theta) \; \Sigma(E_1, r)$$

Interaction Probability

$$P_{int}(E_\nu, \theta) = \left[\sigma_{CC}^{\nu N}(E_\nu) + \sigma_{CC}^{\bar{\nu} N}(E_\nu)\right] \times N_T(\chi)$$

$$\sigma_{CC}^{\nu N} = 5.53 \times 10^{-36} \left(\frac{E_\nu}{[\mathrm{GeV}]}\right)^{0.363} \mathrm{cm}^2$$

$$\sigma_{CC}^{\bar{\nu} N} = 5.52 \times 10^{-36} \left(\frac{E_\nu}{[\mathrm{GeV}]}\right)^{0.363} \mathrm{cm}^2$$

$$N_T(\chi) = 2N_A \chi(\theta)$$

$$\chi(\theta, l) = \int_{\lambda=l}^{\infty} \rho(H = \lambda \cos\theta + \frac{1}{2}\frac{\lambda^2}{R}\sin^2\theta) d\lambda$$

Trigger and Efficiency

$$F_{det}(E_\tau, r, \theta) = P_{had}\, P_L\, \frac{\omega(r,\theta)}{L(E_\tau)}$$

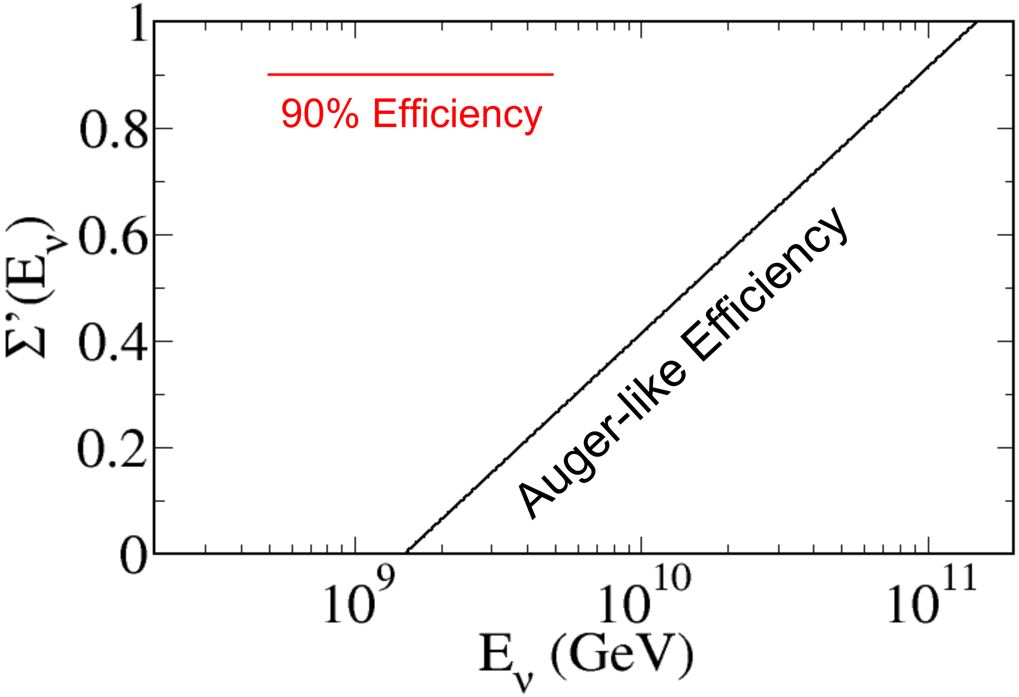
$$P_{had} \simeq 0.64$$

$$P_L \simeq 0.63$$

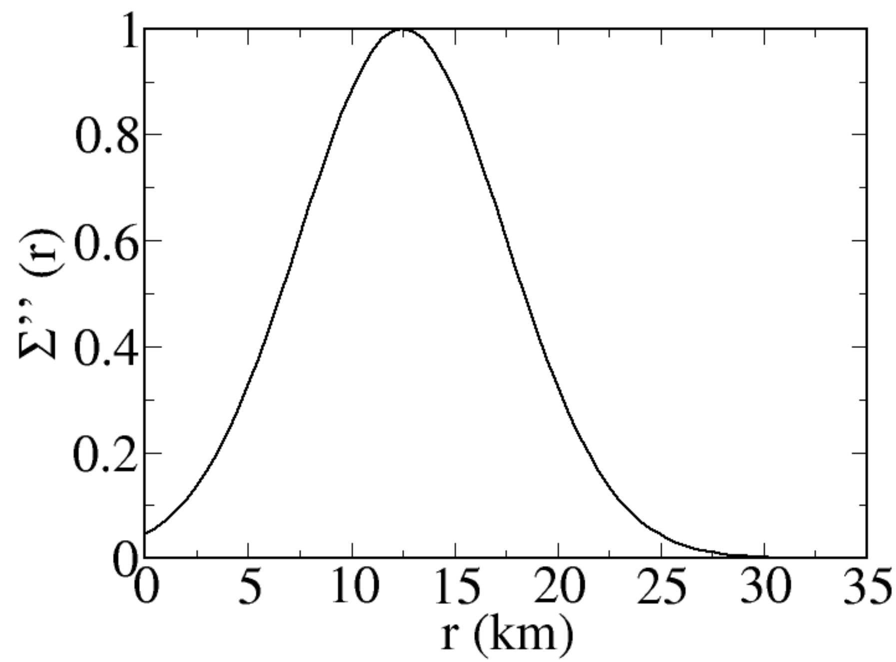
$$\Sigma(E_1, r) = \Upsilon\, \Sigma'(E_1)\, \Sigma''(r)$$

$$\Upsilon \simeq 0.1$$

Efficiency vs. Energy



Efficiency vs. Distance



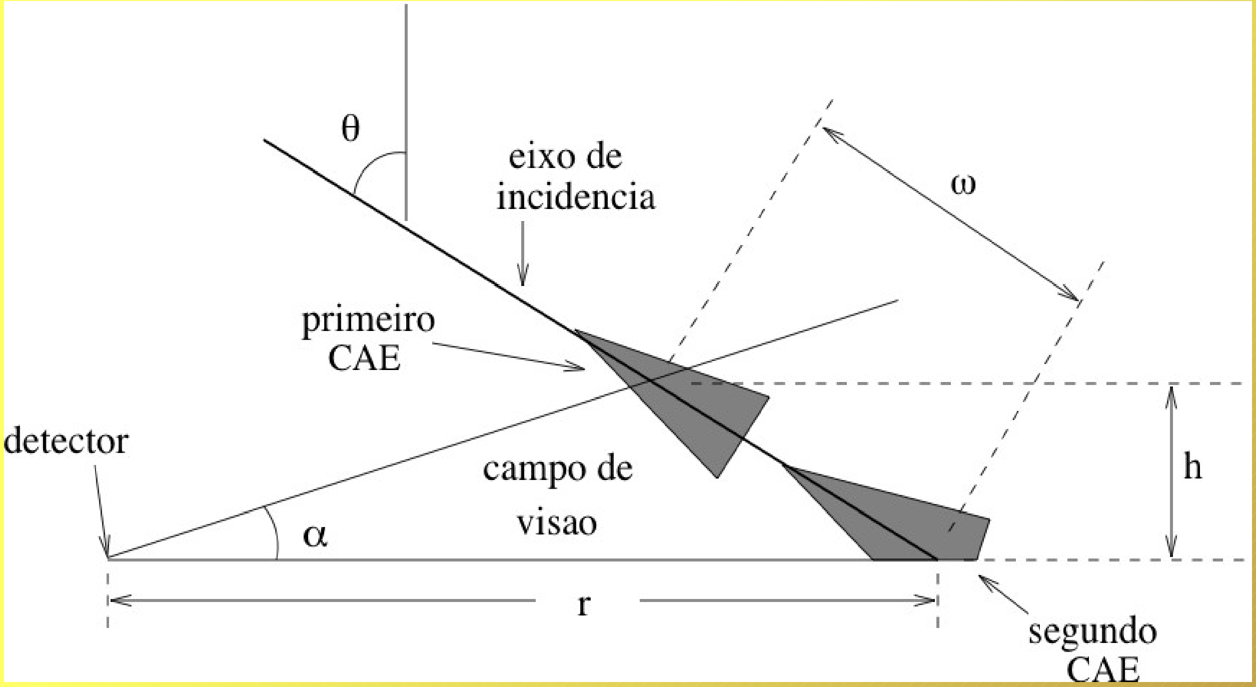
Results: Number of Events per Year for "Auger" and Last Column for Future Detector

	E > 1 EeV	E > 10 EeV	E > 100 EeV	0.5 EeV > E > 5 EeV
TD-92(0)	1,83	0,46	0,03	118
TD-92(0.5)	0,03	0,01	0,001	1,46
MPR	0,005	9,00E-004	3,70E-005	0,48
TD-92(1.0)	0,004	0,002	3,20E-004	0,093
TD-92(1.5)	0,002	7,10E-004	1,30E-004	0,037
AGN-95J	6,10E-004	1,10E-004	4,70E-006	0,06
WB	1,10E-004	2,00E-005	8,40E-007	0,011
TD-96	4.70E-008	4.80E-009	8.30E-011	9.00E-006

Sumary

$$R^0_{e/e} : R^0_{\mu/e} : R^0_{\tau/e} \quad \propto \quad 1:2:3\times 10^{-5}$$

$$R_{e/e} : R_{\mu/e} : R_{\tau/e} \quad \propto \quad 1:1:1$$



$$\frac{N_{eventos}}{\Delta t} = \int_{E_{th}}^{\infty} dE_\nu \; \Phi_\nu(E_\nu) \; \mathcal{A}(E_\nu) \approx \mathcal{O}(0.01 - 100)$$