<u>**C2CR, Sep11, 2005**</u>

The Shower Event Rates of Ultrahigh Energy Tau Neutrinos in the Rock Salt

G.-L. Lin

National Chiao-Tung University

Taiwan

Work done with
Y.-L. Hong, A. Huang and C.-H. Iong

Outline

- Introduction
- The procedures for event rate simulations
- Tau neutrino event rates in the rock salt—due to standard model particle physics and TeV scale gravity respectively
- Concluding remarks

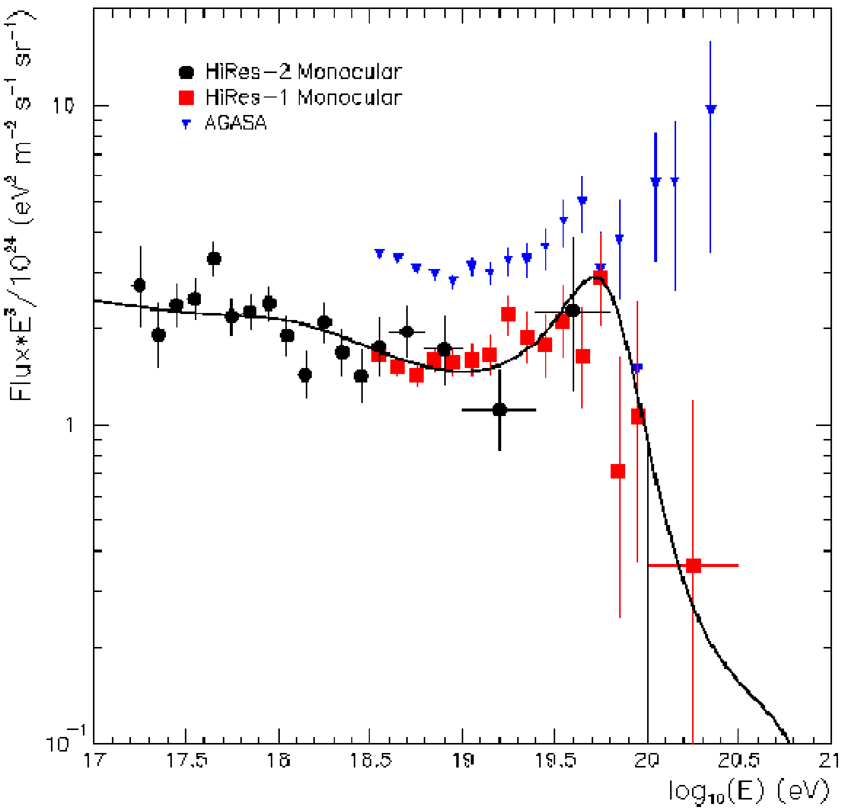
Introduction

- **Why are we interested in detecting high energy astrophysical neutrinos?**

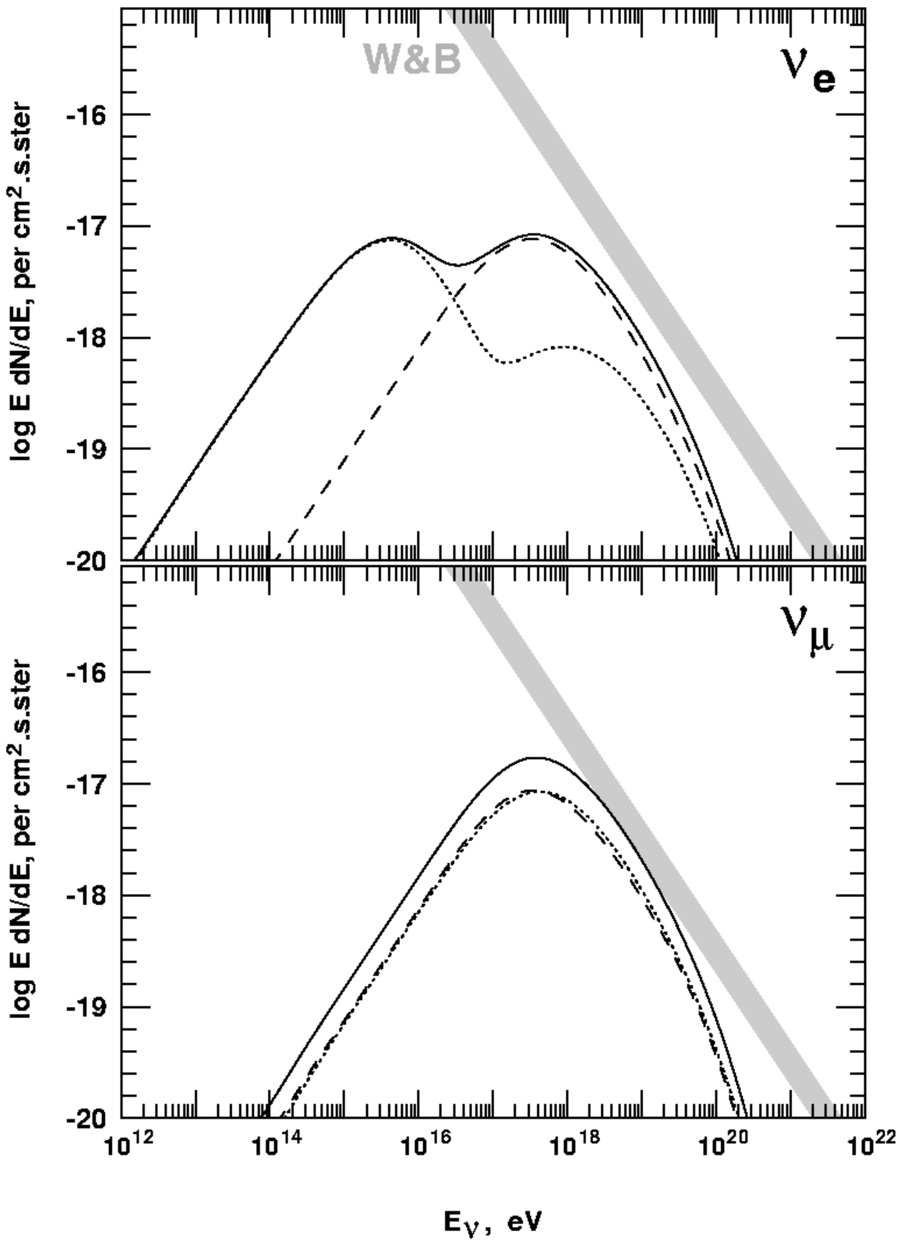
  (a) The neutrino is weak interacting. Its arrival direction points back to the powerful source in the universe.

  (b) The detection might help to unveil the mystery of cosmic ray flux beyond GZK cutoff.

Discrepancy yet to be resolved!



$P+\gamma_{\mathbf{CMB}} \rightarrow \Delta \rightarrow N\pi$, π **decays produce neutrino!**



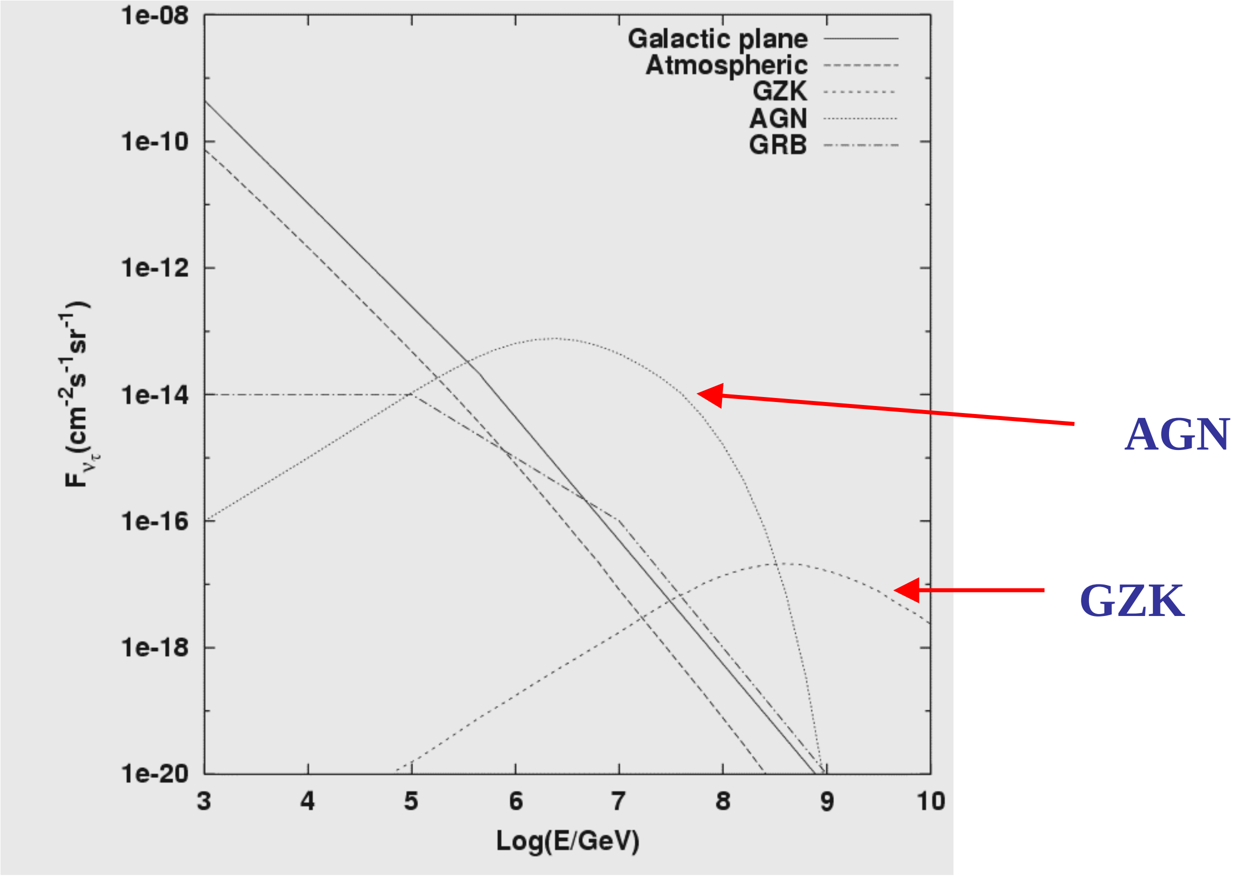
R. Engel, D. Seckel and T. Stanev, 01

ν_e:ν_μ: ν_τ=1:1:1 due to oscillations!

- **Why are we interested in tau neutrinos?**
  There are not direct detections of astrophysical tau neutrinos so far.

- **What are the current suggestions for astrophysical tau neutrino fluxes?**

Tau neutrino fluxes



AGN ν_τ inferred from Kalashev, Kuzmin, Semikoz, and Sigl, 02
GZK ν_τ inferred from R. Engel, D. Seckel and T. Stanev, 01

H. Athar, J.-J. Tseng and G.-L. Lin, ICRC 03

- **Various strategies to detect high energy tau neutrinos or other types of neutrinos:**

(a) with large underground water Cherenkov detectors---AMANDA, BAIKAL,IceCube, NEMO…

(b) with air-shower detectors (Fluorescence or Cherenkov)---Auger, Ashra-NuTel…

(c) with radio wave detectors---ANITA, SalSA

I will mainly focus on (c)

Radio array in salt dome

- **Radio signal from the showers**
  - **Cherenkov angle is large ~66º!**
- **Underground salt dome.**
  - **Higher density than water/ice**
  - **Good transparency to radio signal**

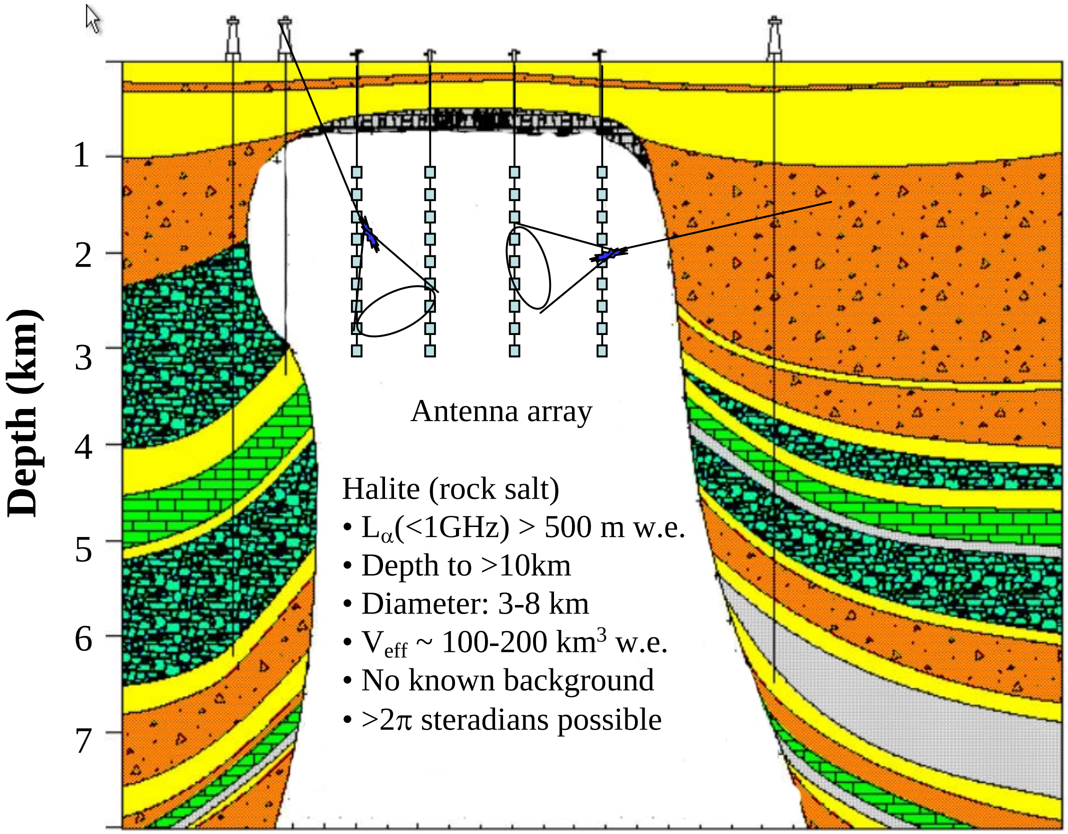
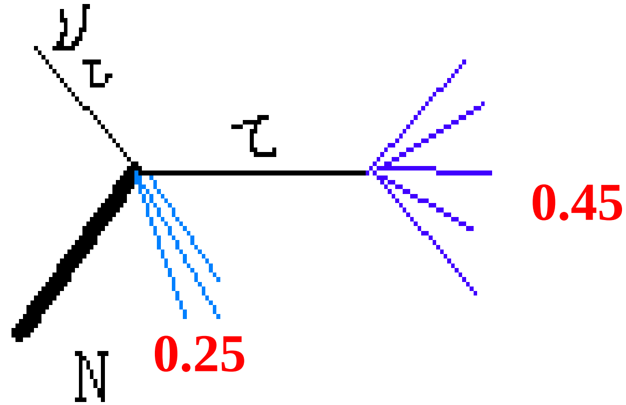


Figure comes from Peter Gorham, talk in SLAC SalSA workshop, Feb 2005.

The signature of high energy ν_τ



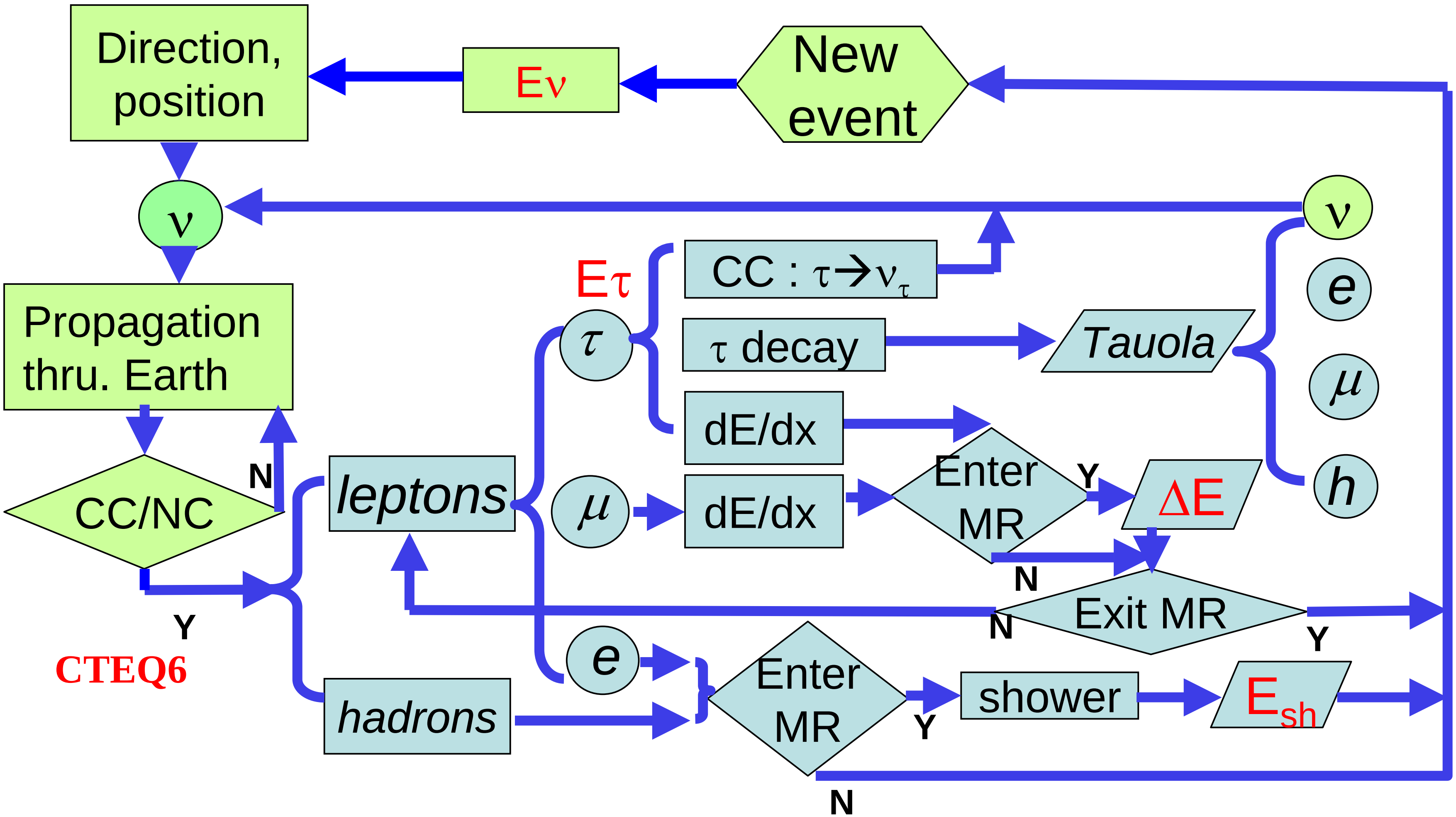
<u>1st shower</u>: neutrino-nucleon scattering, this shower carries 0.25 of neutrino energy.

<u>2nd shower</u>: τ decays into hadrons, this shower carries 0.75*0.6=0.45 of neutrino energy

2 showers separated by roughly $50\times(E_\tau/10^6$ GeV) m

Learned & Pakvasa, 1995; Athar, Parente, and Zas, 2000.

Monte-Carlo simulation of neutrino interaction inside the Earth

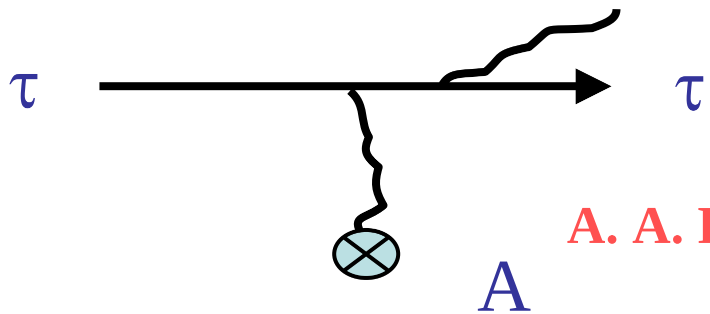


M. A. Huang, C.-H. Iong and G.-L. Lin, ICRC 05

The tau lepton loses its energy in the medium through 4 kinds of interactions:

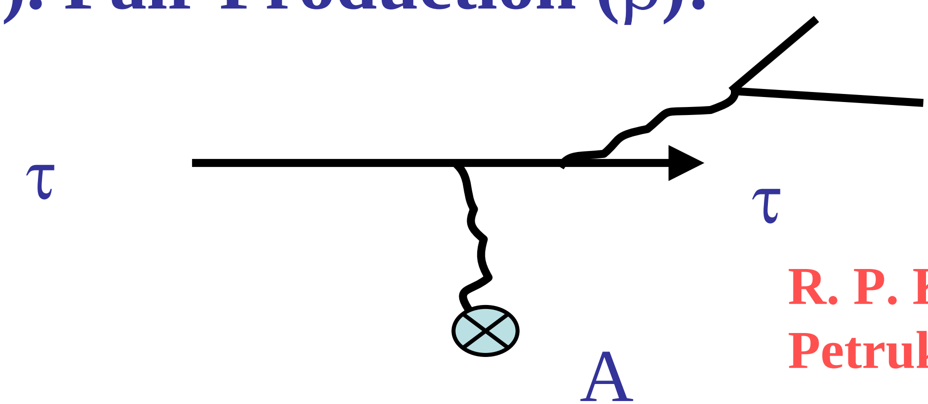
(1). Ionization (α): the tau lepton excites the atomic electrons. **H. A. Bethe 1934**

(2). Bremsstrahlung (β):



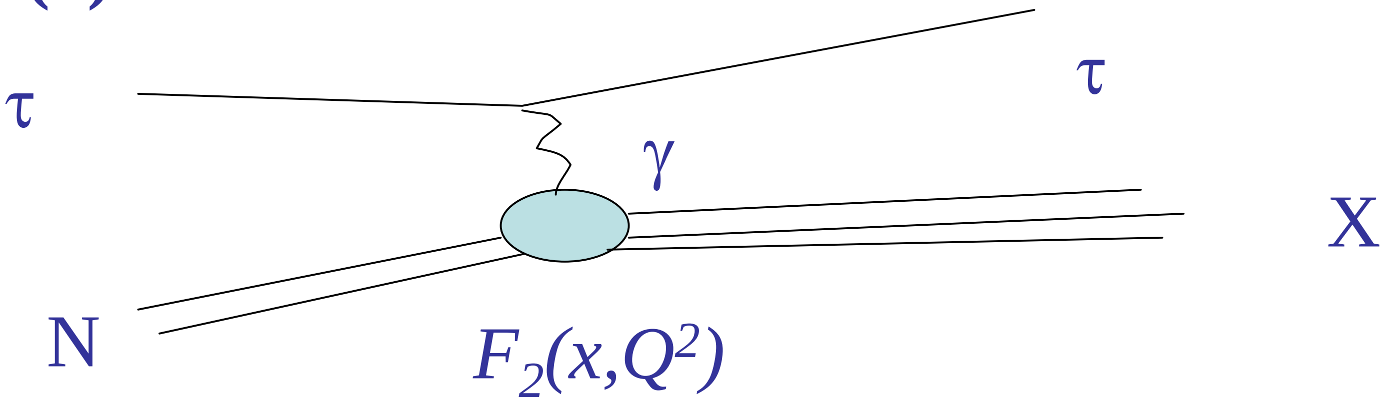
A. A. Petrukhin &V.V. Shestakov, 1968

(3). Pair Production (β):



R. P. Kokoulin & A. A. Petrukhin, 1971

(4). Photo-nuclear interaction:



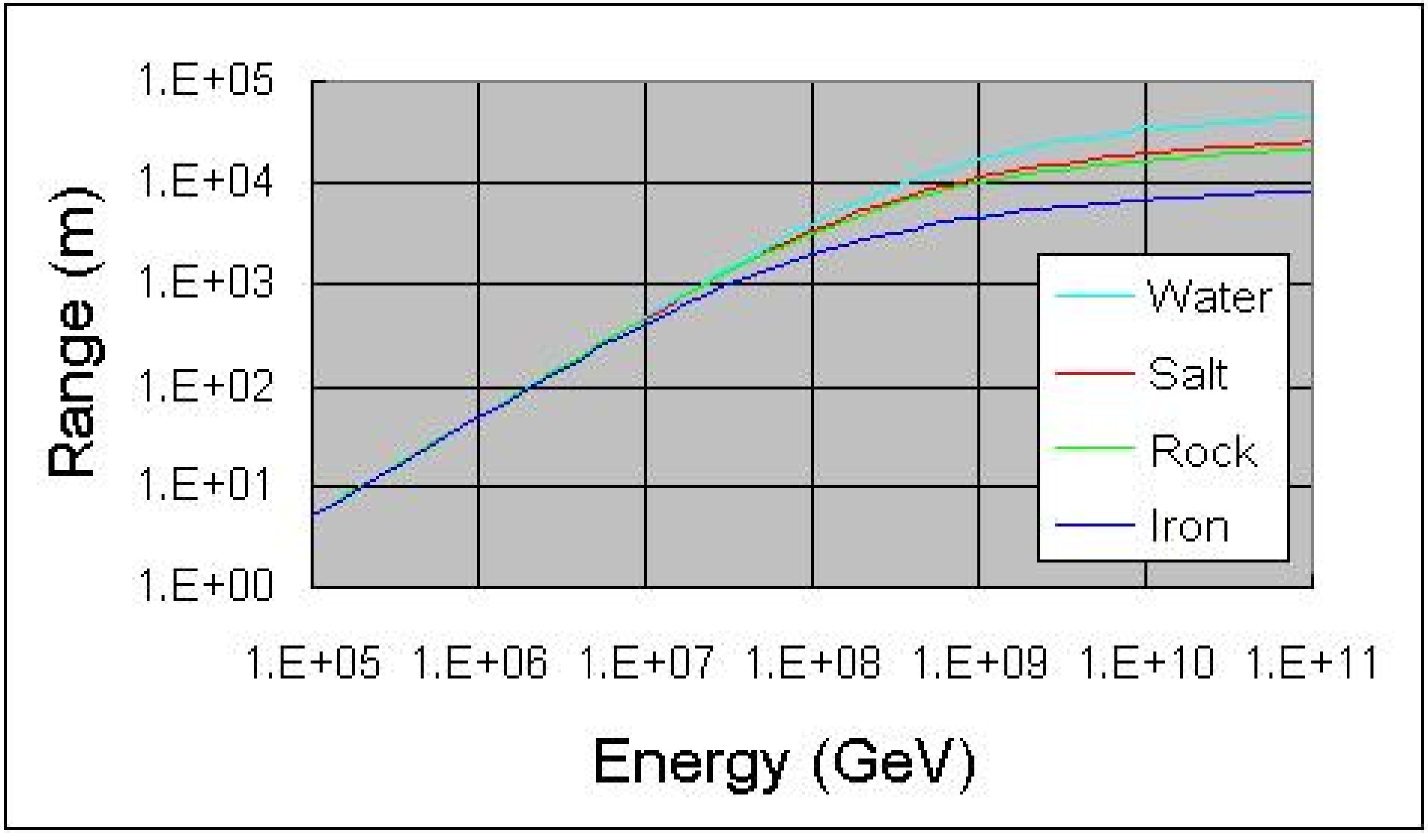
Basic component

The nucleus shadowing effect is considered:

$$a(A,x,Q^2) = \frac{F_2^A(x,Q^2)}{AF_2^N(x,Q^2)}$$

Brodsky & Lu, 1990; Mueller & Qiu 1986;
E665 Collab. Adams et al., 1992

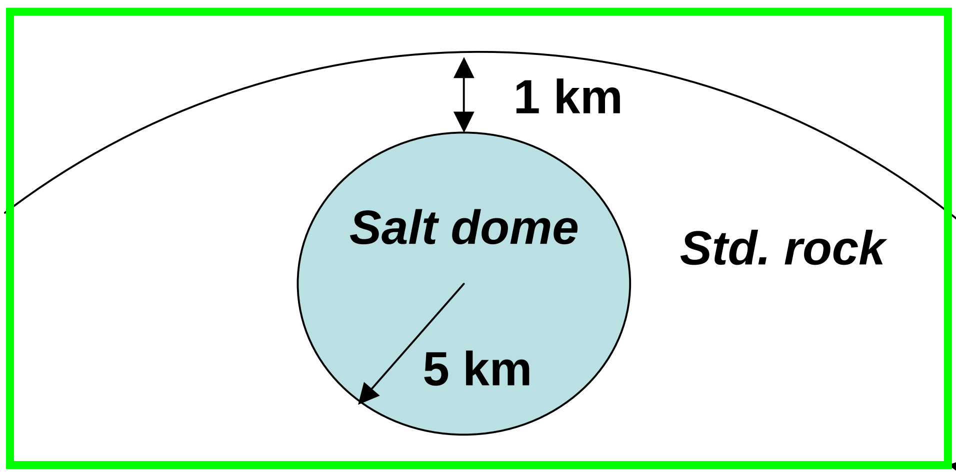
Tau lepton ranges

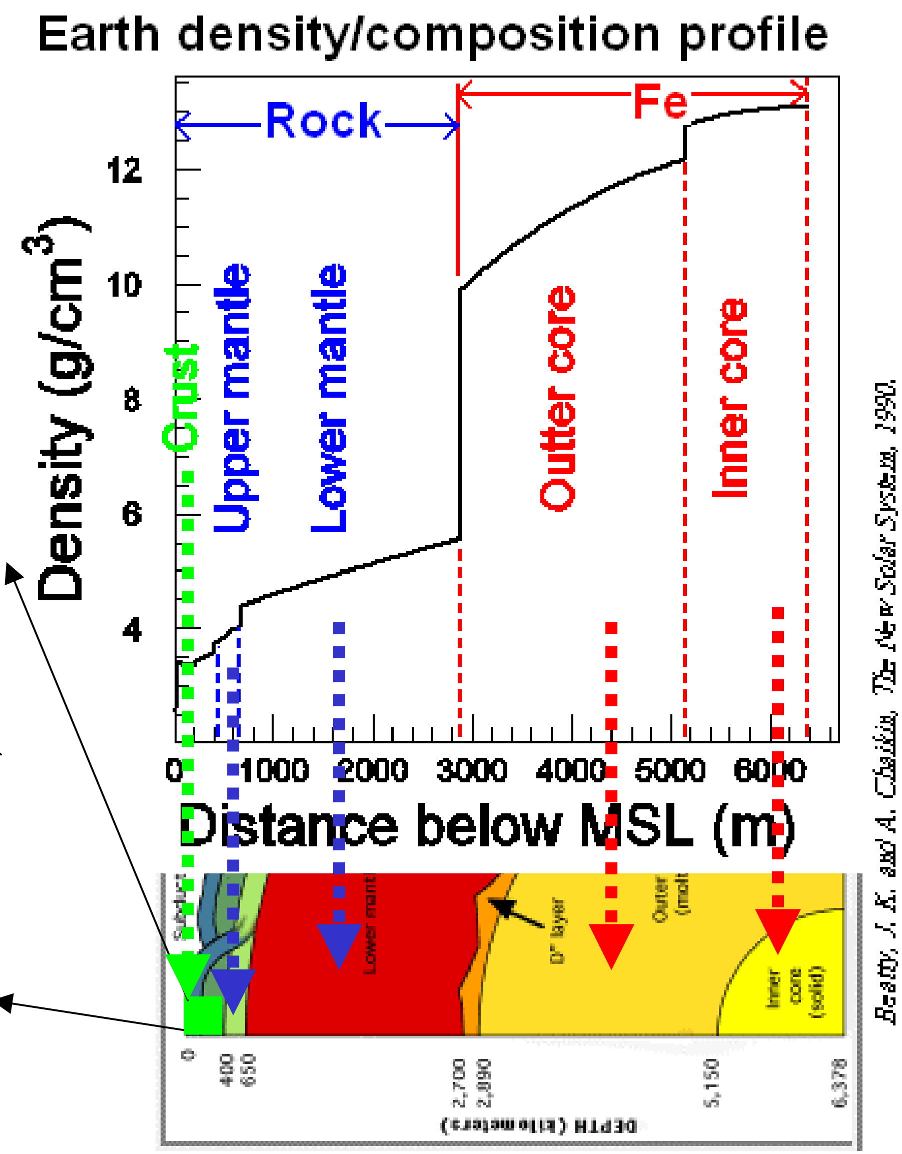


Tau lepton energy loss is treated as stochastic, as opposed to $-dE/dX=\alpha+\beta E$.

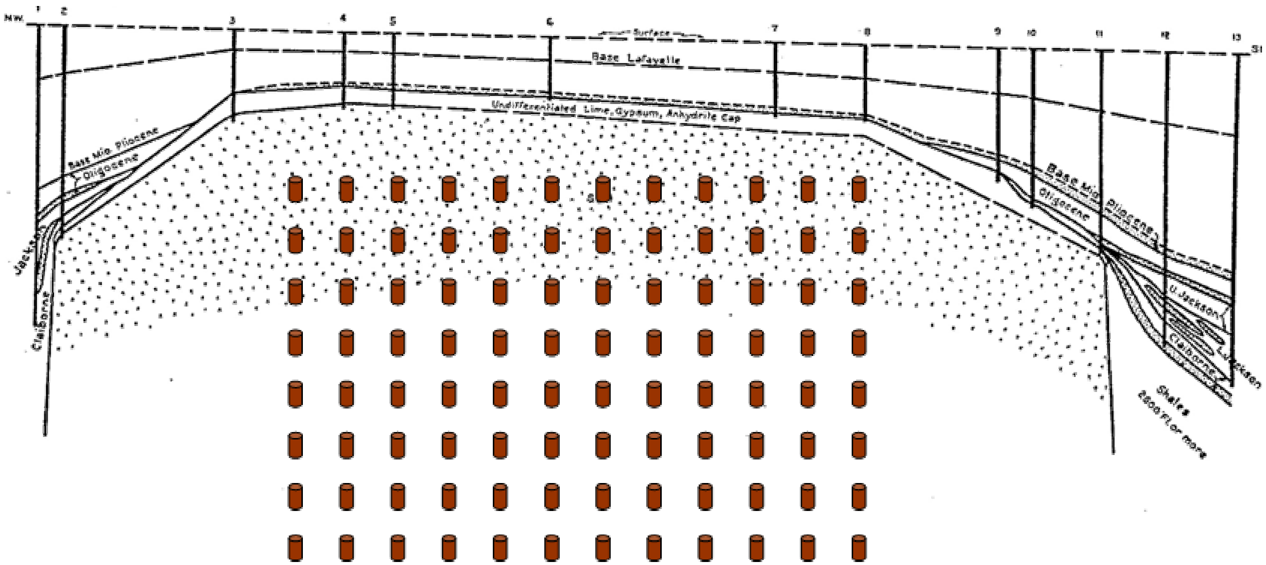
MR

- MR: Medium Region
  - Sphere of 5 km radius, under 1km of rock.





The Detector (inside MR)



- The detector array: 12 x 12 strings on each surface, 12 nodes per string (8 shown), 225 m spacing.
  - Total volume $(2.475\text{km})^3 = 15.16\ \text{km}^3 = 32.83\ \text{km}^3$ of w.e.
  - Figure and specification come from Peter Gorham, talk in SLAC SalSA workshop, Feb. 2005.

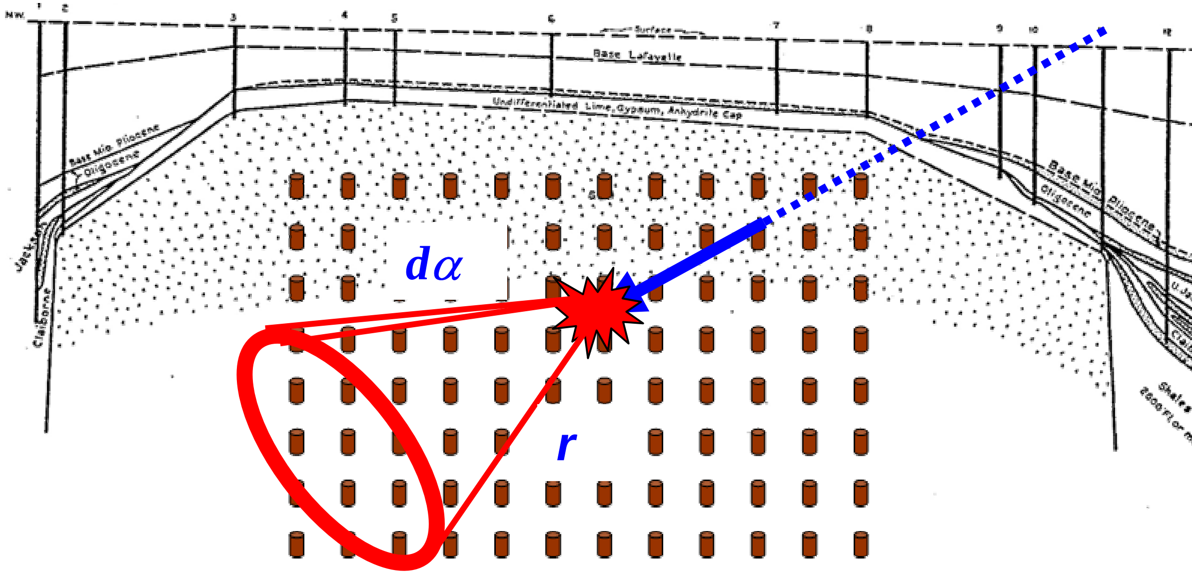
Toy model for detector simulation

- Shower energy distributed over Cherenkov cone and suffers from attenuation.
  - Assume λ=300 m, 600 m, and 900 m respectively
  - λ is between 250 m and 900 m. Gorham et al., 04
- Antenna trigger
  - $dE_{hit}/da > dE_{min}/da$
- Array trigger
  - 6 antennas triggered.

$$\frac{dE_{hit}}{da} = \frac{E_{sh}}{2\pi r^2 \sin\alpha\Delta\alpha} e^{-r/\lambda}$$

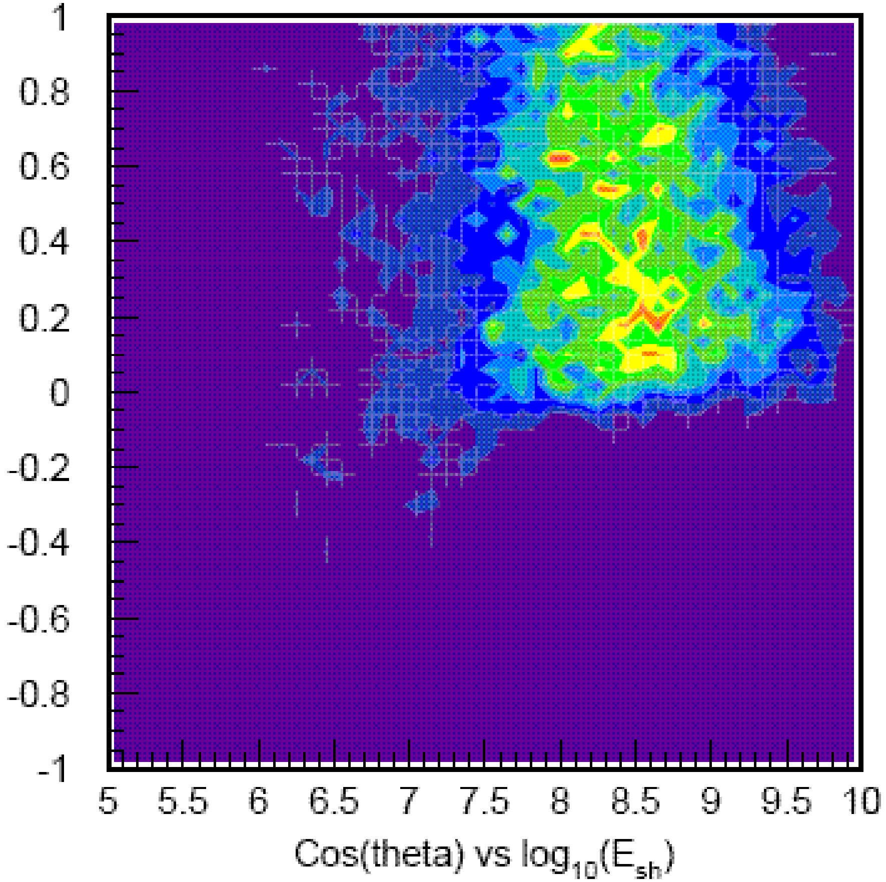
$$\frac{dE_{\min}}{da} = \frac{E_{th}}{2\pi\lambda^2 \sin\alpha\Delta\alpha} e^{-1}$$

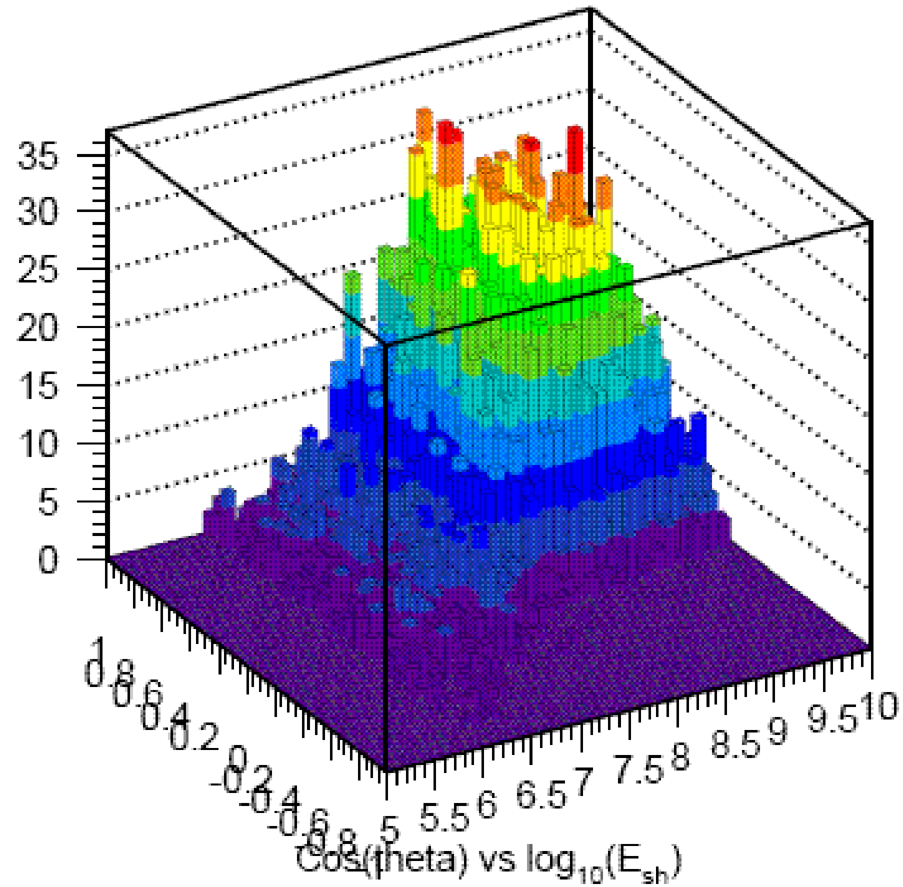
$$\alpha = 66^{\circ}, d\alpha = 5^{\circ}$$



Results -1

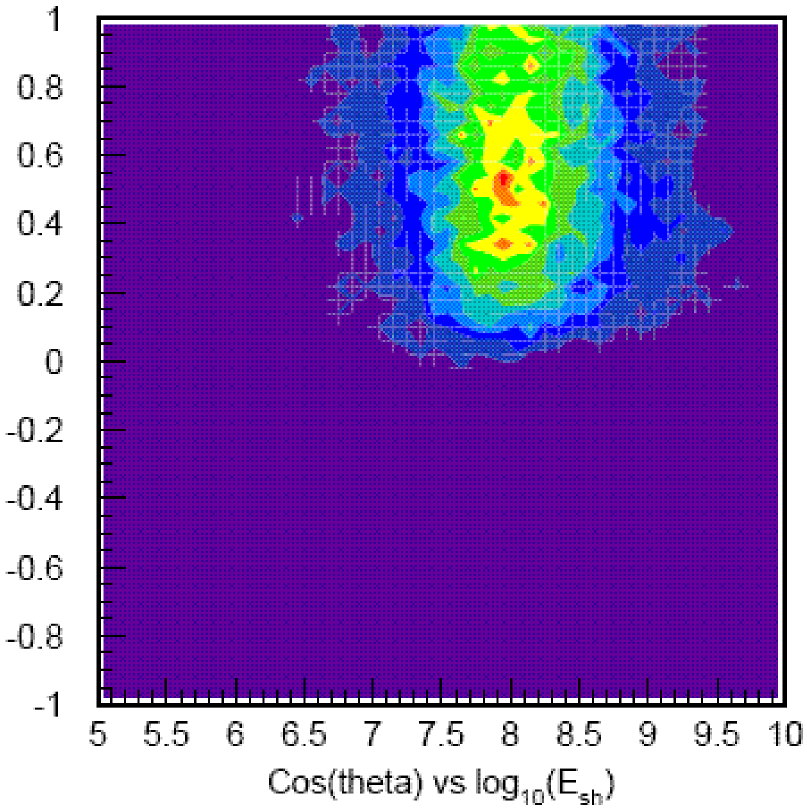
- cosθ vs. shower energy: all events

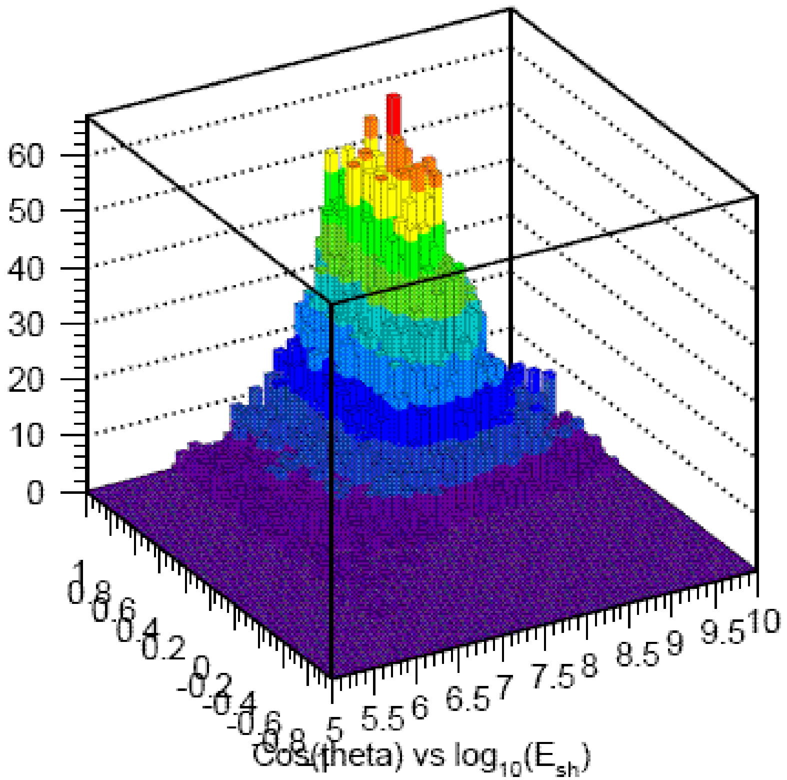




Results –BH-1

- cosθ vs. shower energy: all events



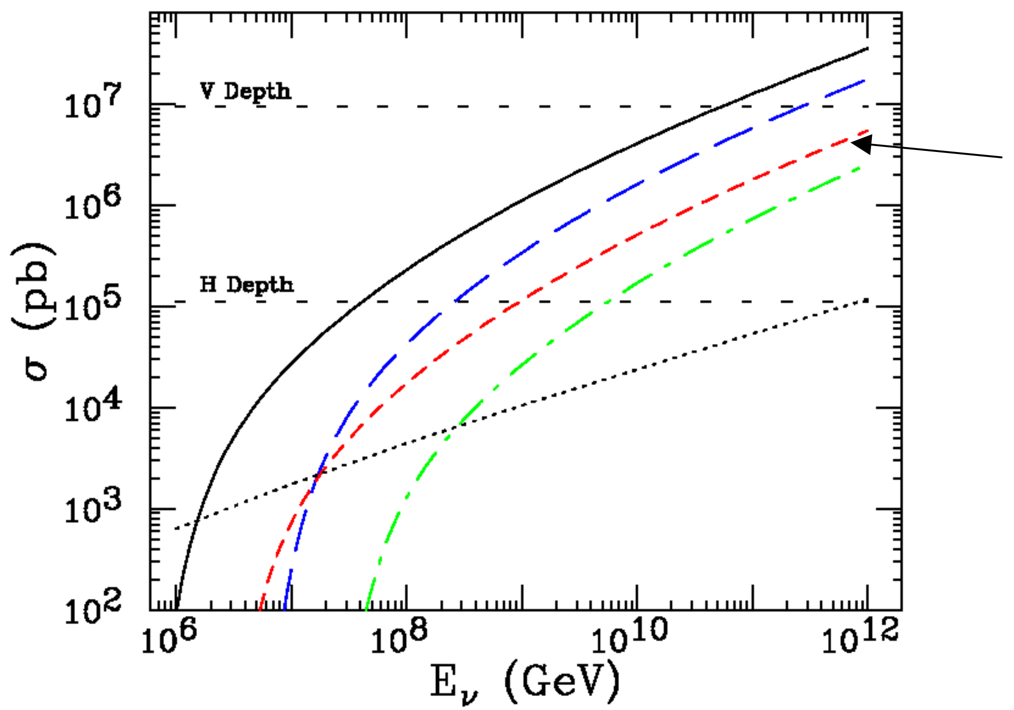


J. L. Feng and A. D. Shapere 02

- J. Alvarez-Muniz et al. 02

L. A. Anchordoqui et al. 03

4+n dimensions of space-time



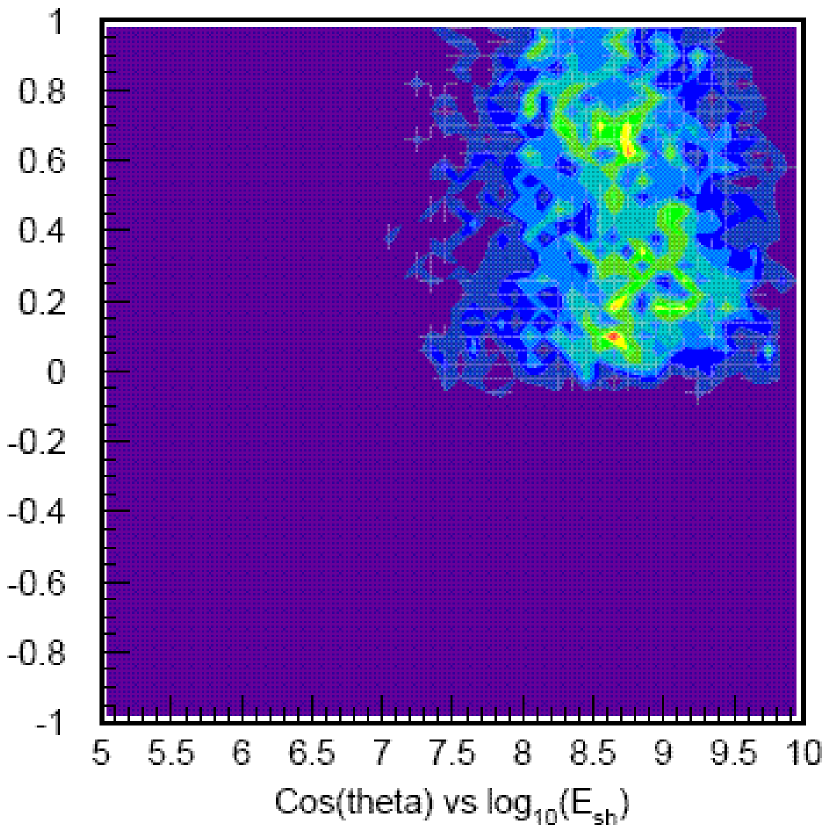
ν+N → micro black holes → τ

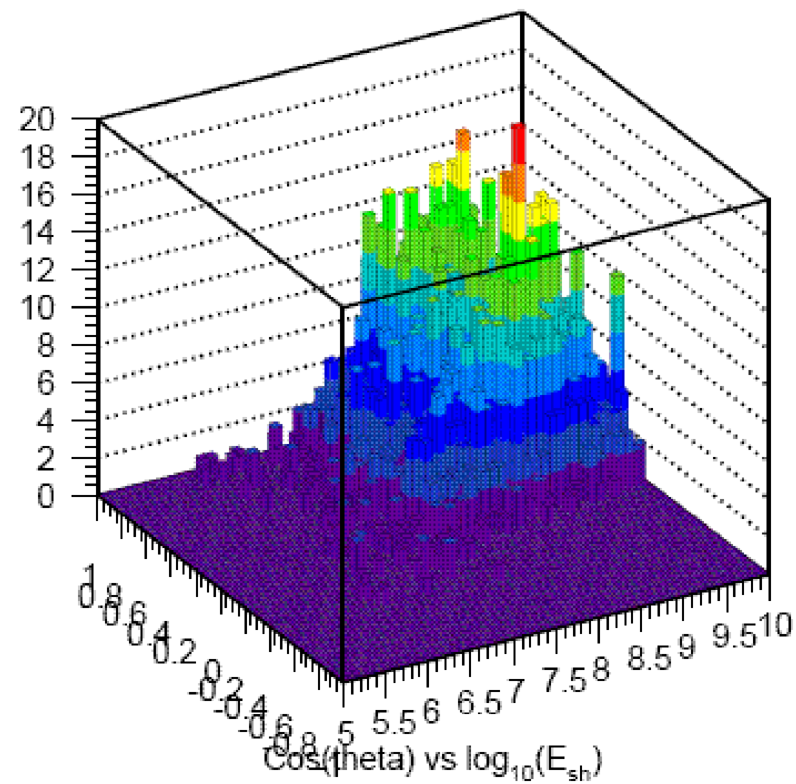
~4 particles at 10^8 GeV
~6 particles at 10^9 GeV

Take n=6, M_D=2 TeV for simulations

Results -2

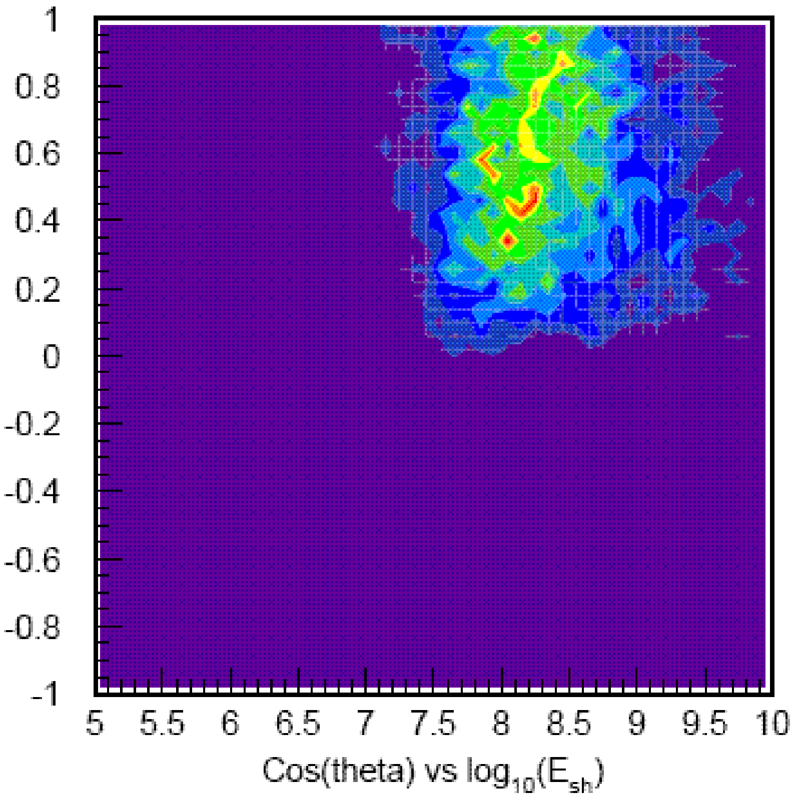
- cosθ vs. shower energy: $E_{th}=10^6$ GeV, λ=900 m

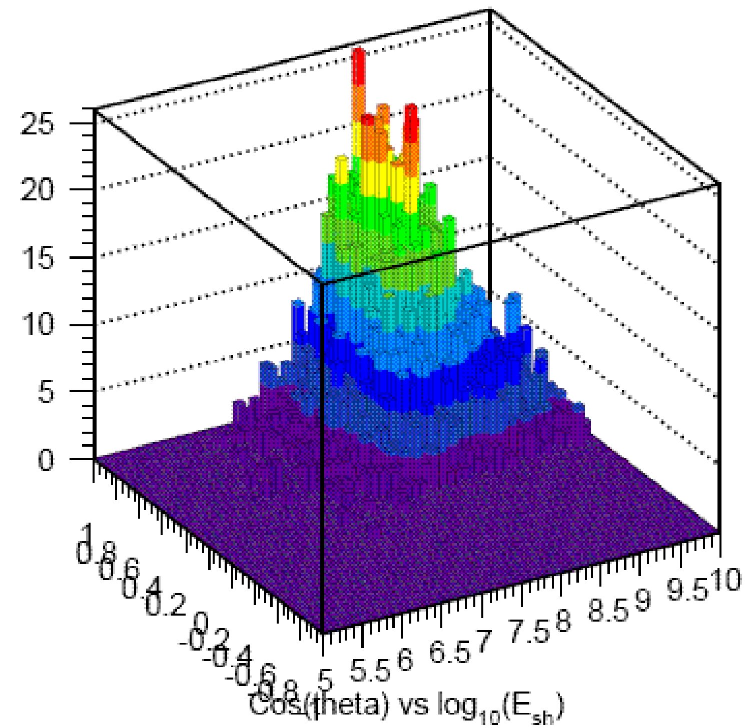




Results –BH-2

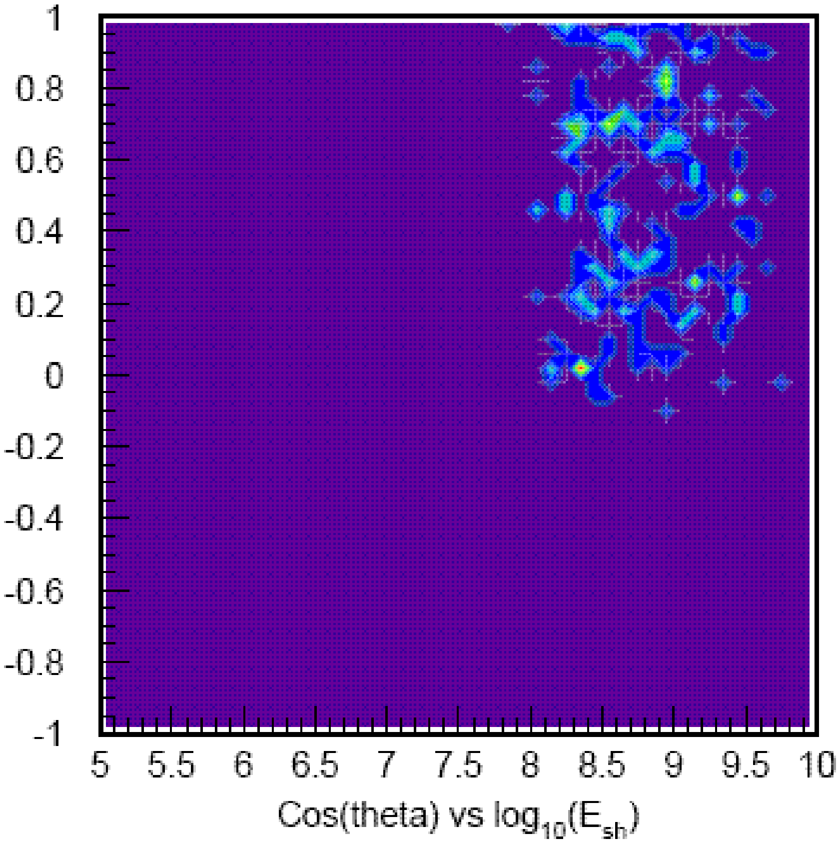
- cosθ vs. shower energy: $E_{th}=10^6$ GeV, λ=900 m

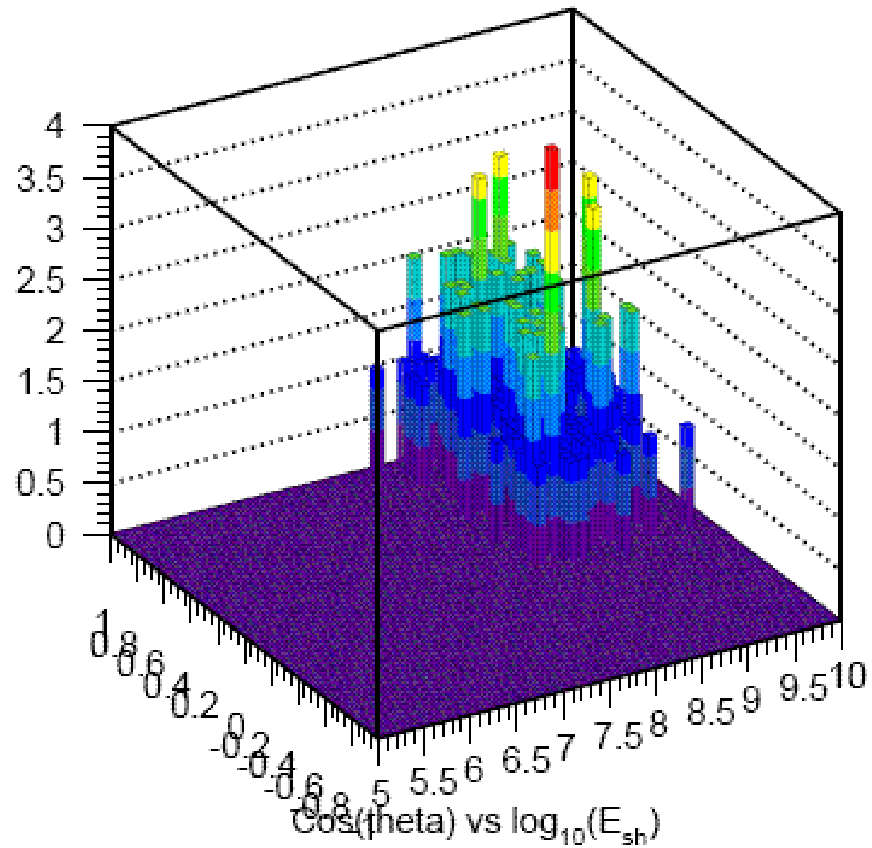




Results -3

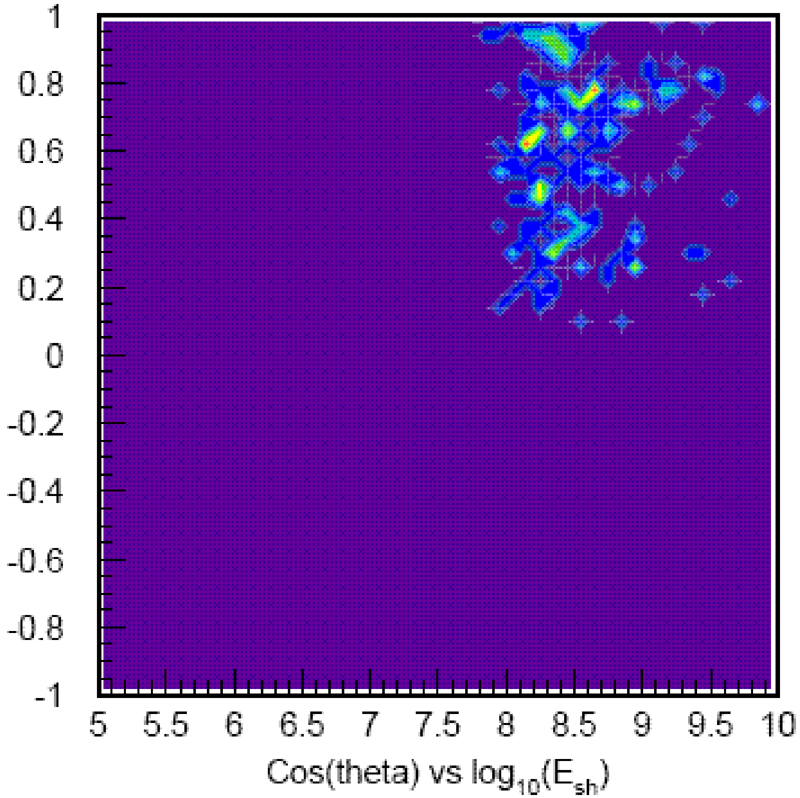
- cosθ vs. shower energy: $E_{th}=10^6$ GeV, $\lambda=300$ m

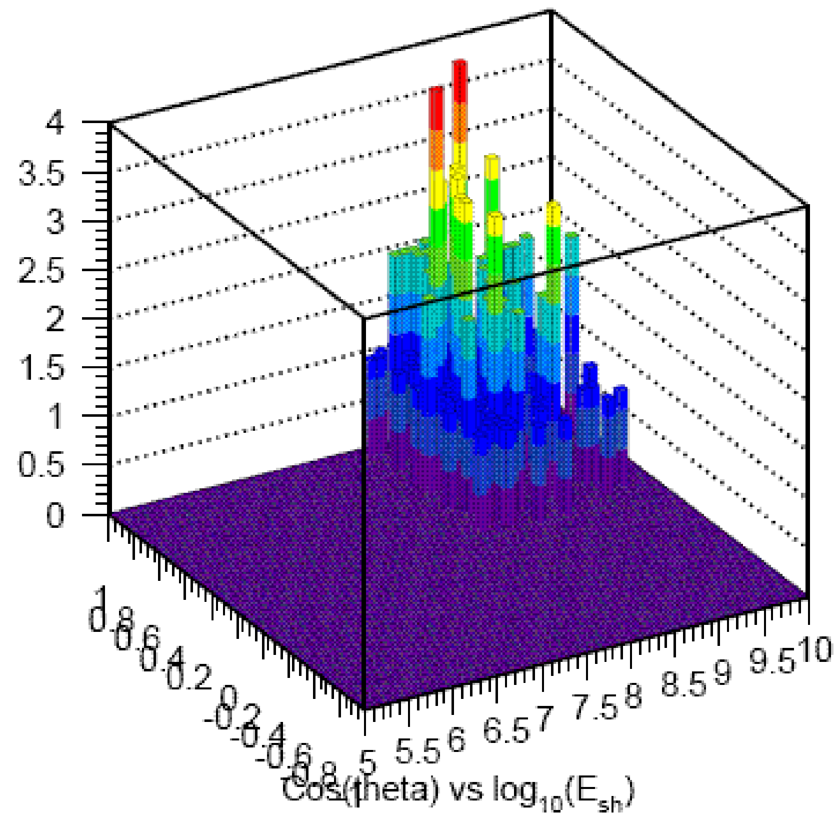


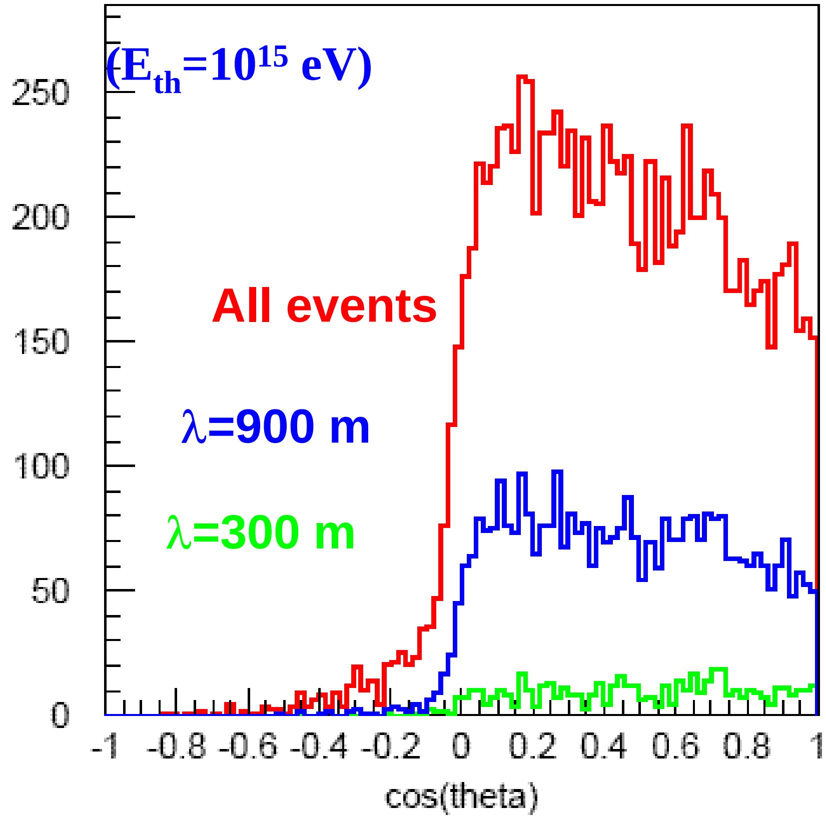


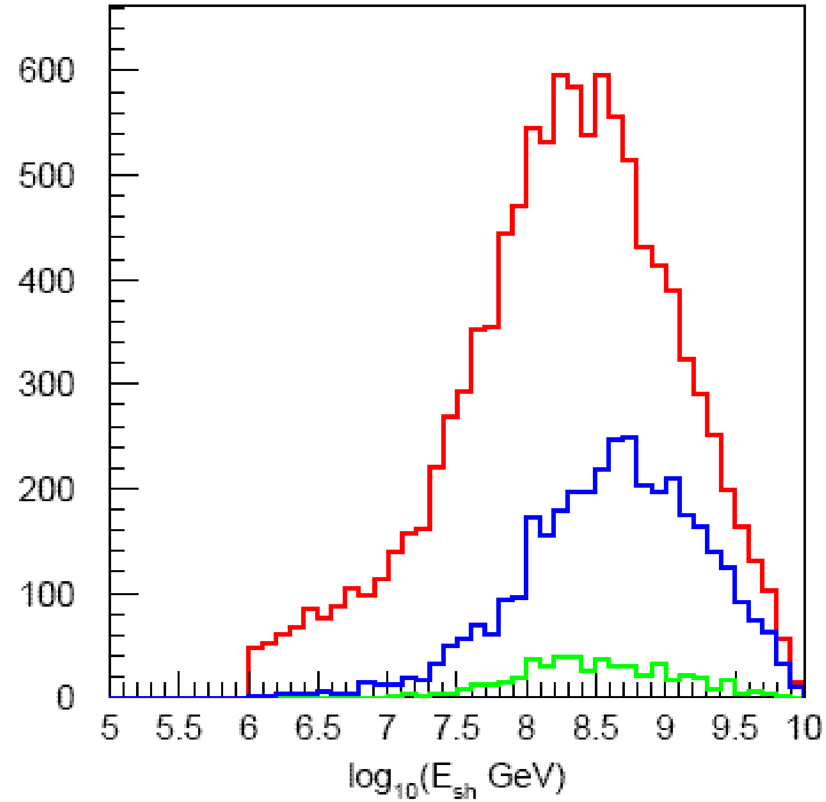
Results –BH-3

- cosθ vs. shower energy: $E_{th}=10^6$ GeV, λ=300m





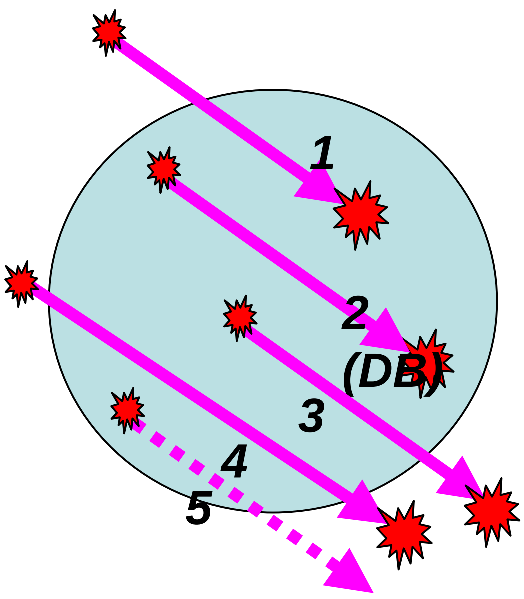




- Event numbers differ significantly between λ=300 m and λ=900 m.
- Vertical axis is in relative scale

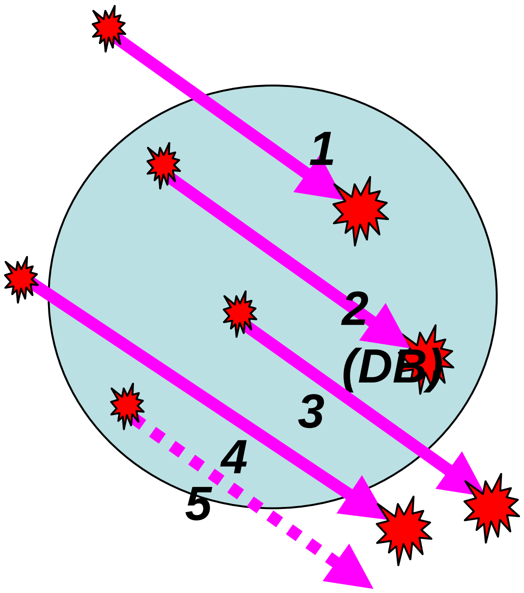
- Event numbers/yr at $E_{th} = 10^6$ GeV

$5/(2\oplus 3)=\sigma_{NC}/\sigma_{CC}$



Type	CC	τ decay	All events	λ		
				300 m	600 m	900 m
1	out	in	25.8±0.5	0.59±0.08	2.4±0.2	7.9±0.3
2	in	in	13.2±0.4	1.2±0.1	3.6±0.2	5.2±0.2
3	in	out	30.1±0.6	2.0±0.1	5.6±0.2	8.9±0.3
4	out	out	23.9±0.5	0.38±0.06	1.7±0.1	10.0±0.3
5	NC	x	17.9±0.4	0.96±0.10	3.1±0.2	5.3±0.2
Total			110.9±1.1	5.1±0.2	16.3±0.4	37.3±0.6

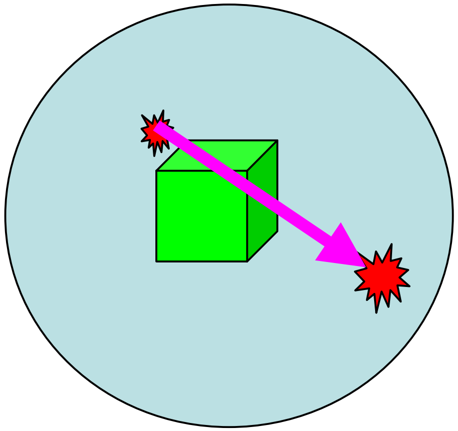
- Event numbers/yr, λ=600 m



Type	CC	τ decay	All events	E_{th}		
				10^6 GeV	3×10^6 GeV	10^7 GeV
1	out	in	25.8±0.5	2.4±0.2	1.3±0.1	0.8±0.1
2	in	in	13.2±0.4	3.6±0.2	2.7±0.2	1.9±0.1
3	in	out	30.1±0.6	5.6±0.2	4.4±0.2	3.1±0.2
4	out	out	23.9±0.5	1.7±0.1	0.9±0.1	0.6±0.1
5	NC	x	17.9±0.4	3.1±0.2	2.4±0.2	1.5±0.1
Total			110.9±1.1	16.3±0.4	11.6±0.3	7.8±0.3

Double Bang events

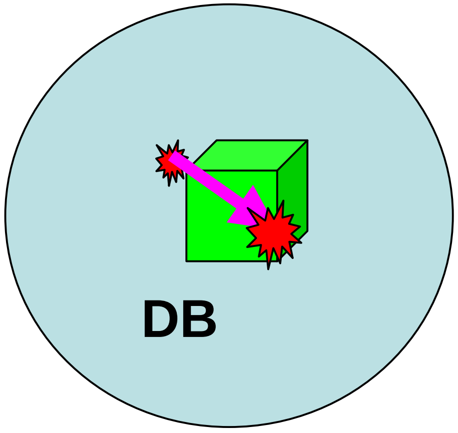
- Type 2 event are fully contained inside MR, but not both of the two showers could trigger the detector

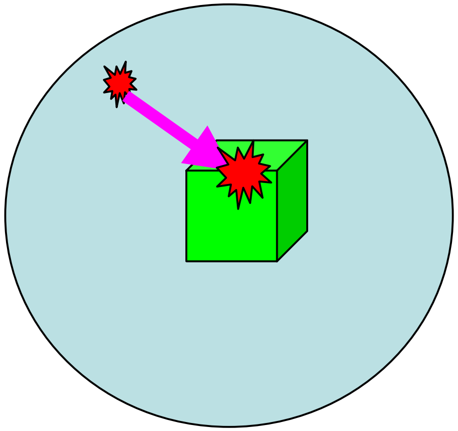


~0.1/yr for

λ=300 m,

$E_{th}=10^6$ GeV





Concluding Remarks

- I have presented the motivations for high energy tau neutrino astronomy.
- The tau neutrino shower event rates and their angular distributions in the rock salt are presented. The event rates vary by about one order of magnitude from λ=300 m to λ=900 m.
- The ν_τ and τ propagations inside the Earth are simulated in a full detail, while a toy model for the detector is used to obtain the event rates. However, one gets an idea on the geometric capacity of the SalSA detector.