Research activities of Neutrino physics and astrophysics in Taiwan

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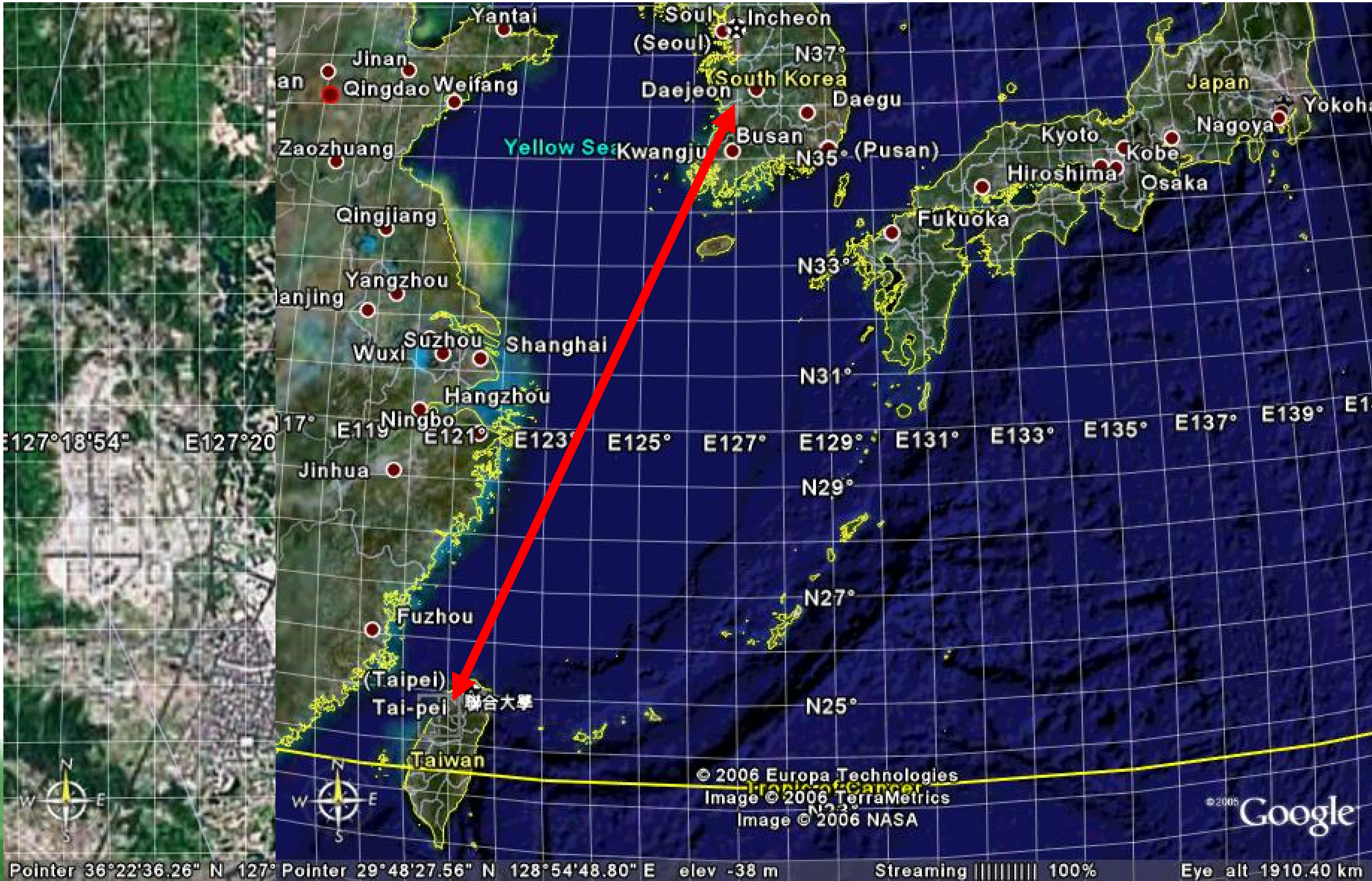
Where are we?


Yantai
Soul
(Seoul)
Incheon
N37°
Jinan
Qingdao
Weifang
South Korea
Daejeon
Daegu
Japan
Yokoha
Nagoya
Zaozhuang
Yellow Sea
Kwangju
Busan
N35°
(Pusan)
Kyoto
Kobe
Hiroshima
Osaka
Qingjiang
Fukuoka
N33°
Yangzhou
Nanjing
Suzhou
Wuxi
Shanghai
N31°
Hangzhou
Ningbo
E127°18'54"
E127°20'
E117°
E119°
E121°
E123°
E125°
E127°
E129°
E131°
E133°
E135°
E137°
E139°
Jinhua
N29°
N27°
Fuzhou
(Taipei)
Tai-pei
聯合大學
N25°
Taiwan
Tropic of Cancer
© 2006 Europa Technologies
Image © 2006 TerraMetrics
Image © 2006 NASA
Google
Pointer 36°22'36.26" N 127°
Pointer 29°48'27.56" N 128°54'48.80" E elev -38 m
Streaming |||||||||| 100%
Eye alt 1910.40 km

Contents

- Experimental
  - TEXONO: reactor neutrino experiment, H.P. Ge detector R&D
  - NuTel: Earth skimming-neutrino telescope R&D
- Theoretical
  - H. Athar, K. Cheung, G.L. Lin, et al. : atmospheric prompt tau neutrino, galactic tau neutrino, …
  - M.A. Huang, G.L. Lin, et al. : tau neutrino interacting with Earth
    - Major part of this talk

Propagation, interaction of high energy neutrino in Earth

TEXONO

Provided by

Henry T. Wong / 王子敬

Academia Sinica / 中央研究院

TEXONO Collaboration

Taiwan EXperiment On NeutrinO

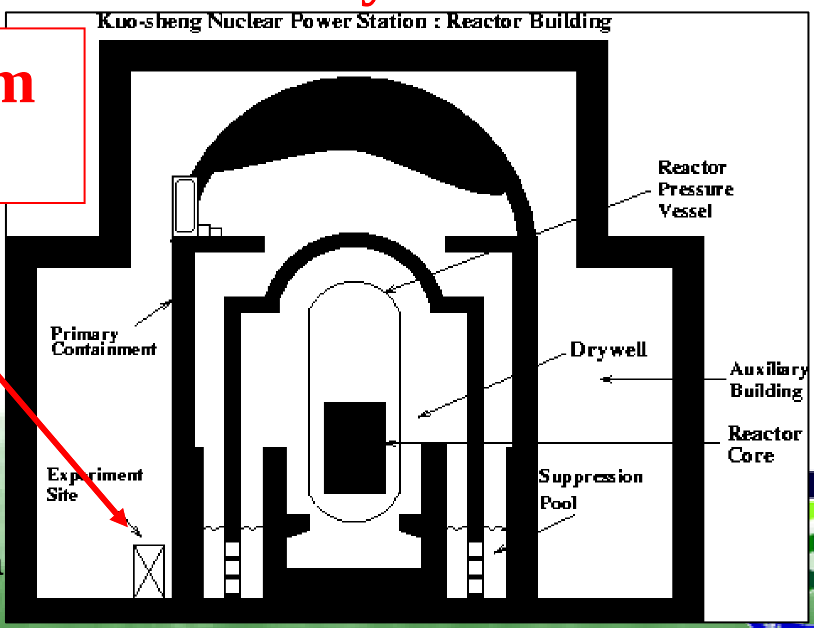
Collaboration : **Taiwan (AS, INER, KSNPS, NTU) ; China (IHEP, CIAE, THU, NJU) ; Turkey (METU) ; USA (UMD)**

Program: **Low Energy Neutrino & Astroparticle Physics**

- **Kuo-Sheng (KS) Reactor Neutrino Laboratory**

KS NPS-II ：
2 cores × 2.9 GW

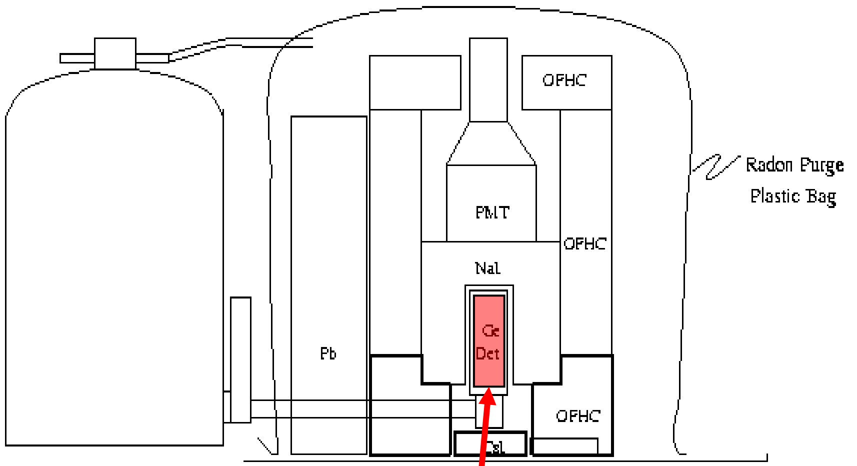
KS ν Lab: 28 m
from core#1



Magnetic Moment Searches @ KS

- simple compact *all-solid* design : HPGe (mass 1 kg) enclosed by active NaI/CsI anti-Compton, further by passive shieldings & cosmic veto
- TEXONO data (4712/1250 hours ON/OFF) [PRL 90, 2003]
  - background comparable to underground CDM experiment :
    - ~ 1 day-1keV-1kg-1 (cpd)
  - Limit: $\mu_\nu(\nu_e) < 1.0 \times 10^{-10}\ \mu_B$ (90% CL)

Kuo-Sheng Experiment : HPGe Detector

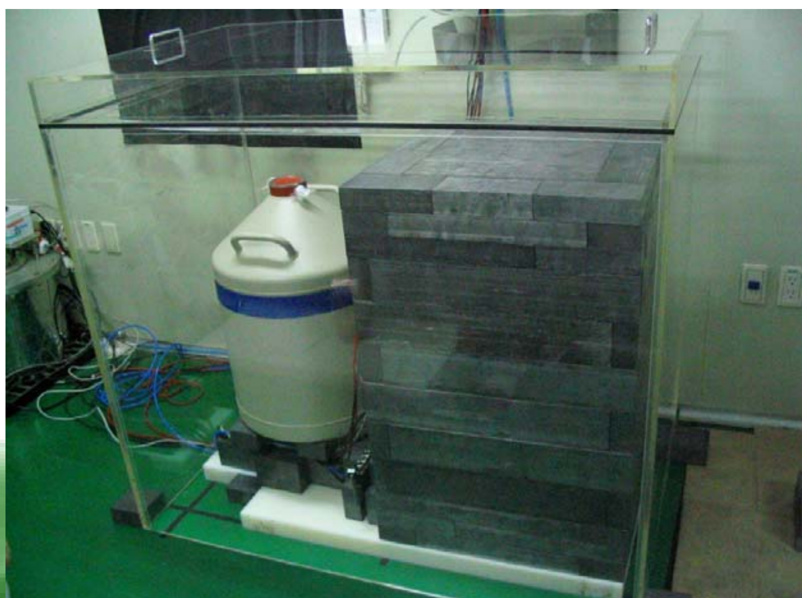


"Ultra-Low-Energy" HPGe Prototype

- **ULEGe – developed for soft X-rays detection ; easy & inexpensive & robust operation**
- **Prototype : (I) 5 g ; (II) 4 X 5 g ; (III) 10 g ; (IV) segmented 20 g**
- **threshold <100 eV after modest PSD** *[lowest achieved for bulk radiation detectors]*
- **study feasibilities for 1-kg-ish detector for νN coherent scattering and Dark Matter searches** *[μ_ν search a by-product]*

TEXONO ⊕ KIMS @ Y2L

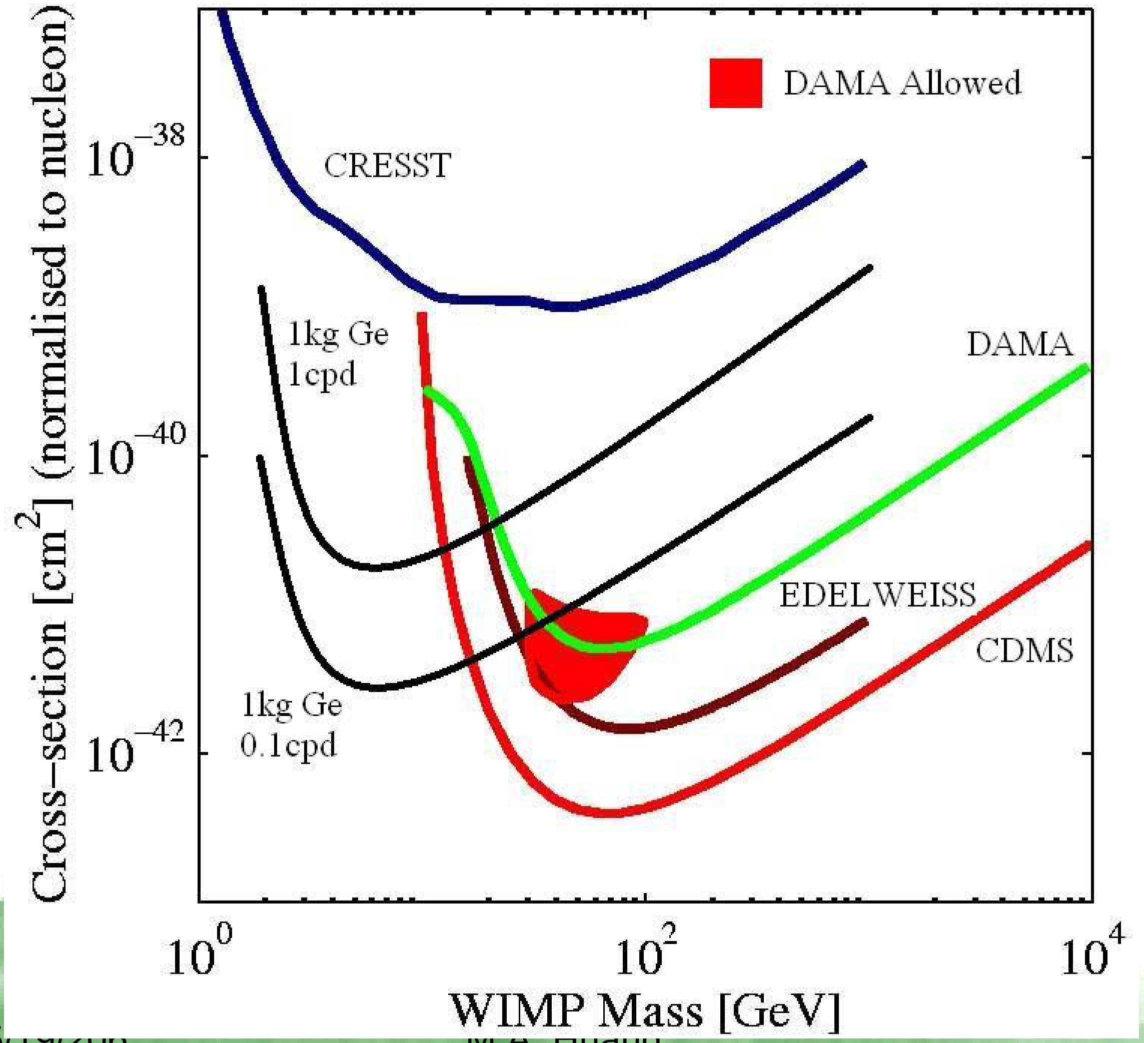
- China-Korea-Taiwan collaborations
- Install 5 g ULB-ULEGe at Y2L on January 2005
- Study background and feasibility for CDM searches
- may evolve into a full-scale (1 kg) CDM experiment



A. Hua

Yangyang（襄陽）Lab (Y2L)
min. 700 m of rock overburden

Sensitivity Plot for CDM-WIMP search with 1 kg ULEGe at 100 eV threshold ……..

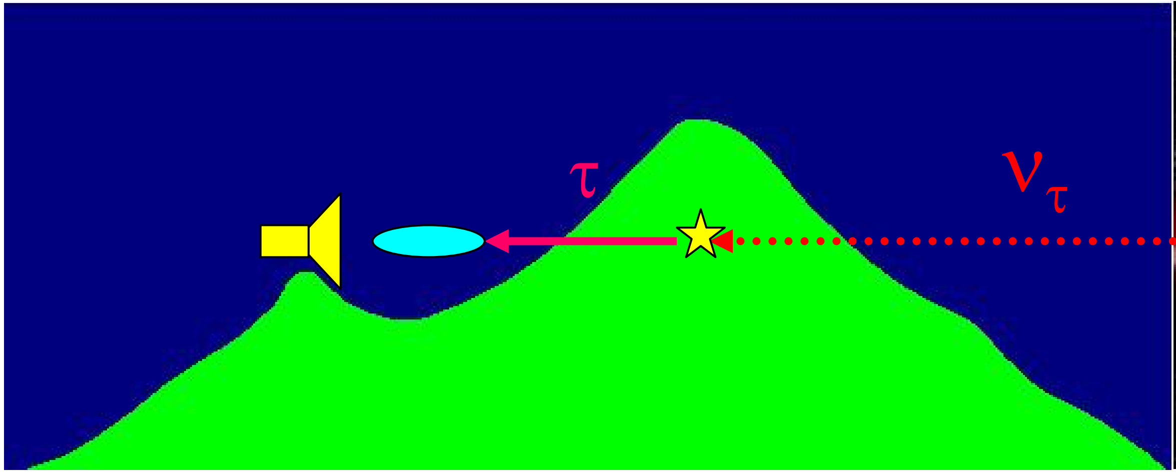


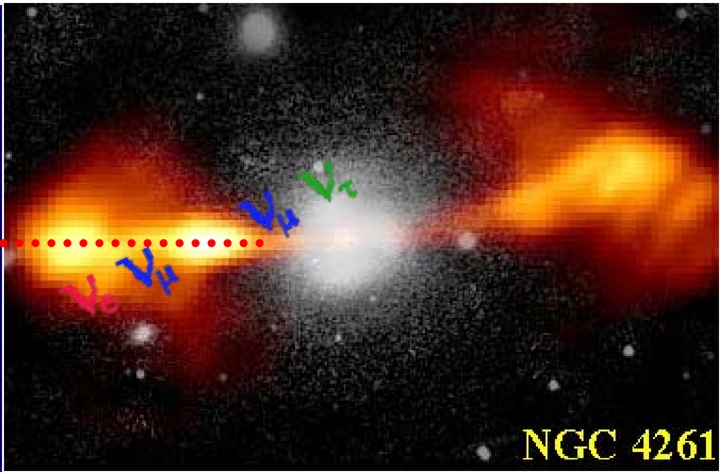
NuTel: NeUtrino TELescope

Provided by
NuTel

HEP, Dept. of Physic, National Taiwan University,
&
General Education center / Dept. of Physic, National United University

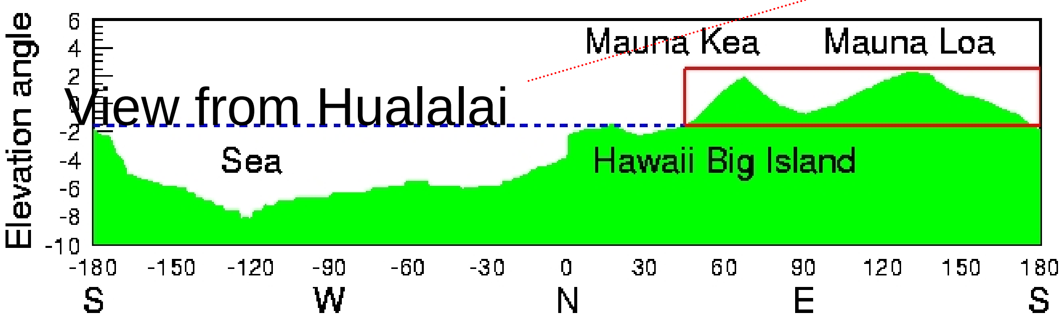
Detecting Earth-skimming Neutrinos

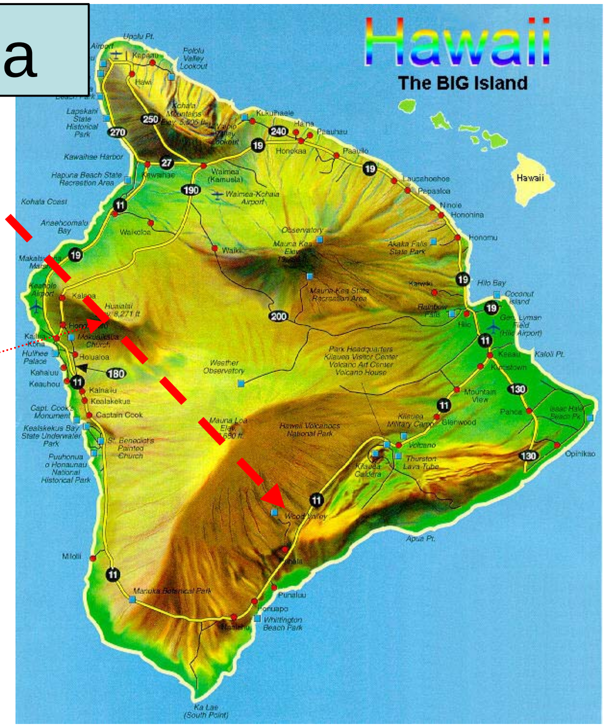




- High energy ν interact inside mountain, produce lepton via charge current interaction. $\nu + X \rightarrow e/\mu/\tau + X'$
  - e will shower in very short distance,
  - μ will pass through valley without interaction
  - τ could decay in the valley, produce shower and being detected.
- **Detector similar to γ-ray imaging Chrenkov telescope.**

W.S. Hou and M.A. Huang, (12/6-9/2001), *Proc. of the First NCTS Workshop on Astroparticle Physics*, Kenting, Taiwan. **astro-ph/0204145**



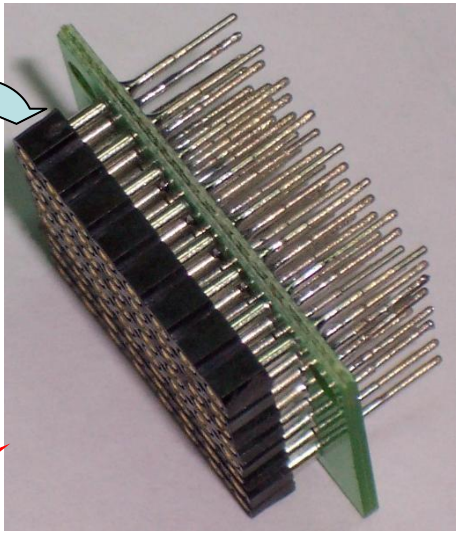


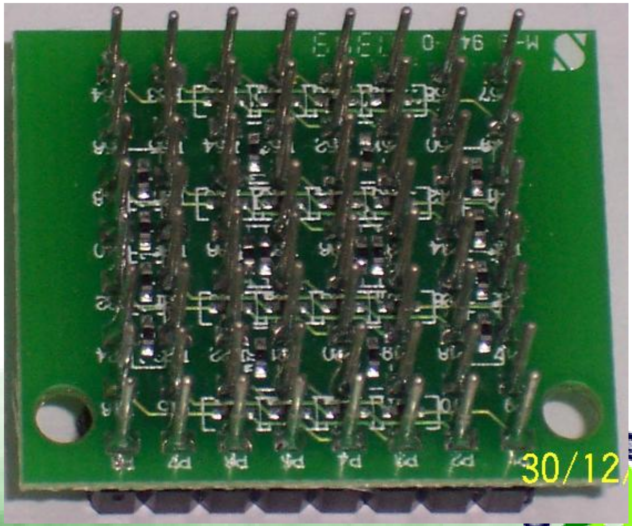
Target: Mauna Loa, Hawaii Big Island, USA

http://hep1.phys.ntu.edu.tw/nutel/

- M.A. Huang, (5/25-30/2002)**,** *Proc. of ν-2002* at Munich, German, Nucl. Phys. B Proc. Suppl. **118,** 516, (2003)
- P. Yeh, et al., Modern Physics Lett. **A.19,** 1117-1124, (2004).

8×8 MAPMT

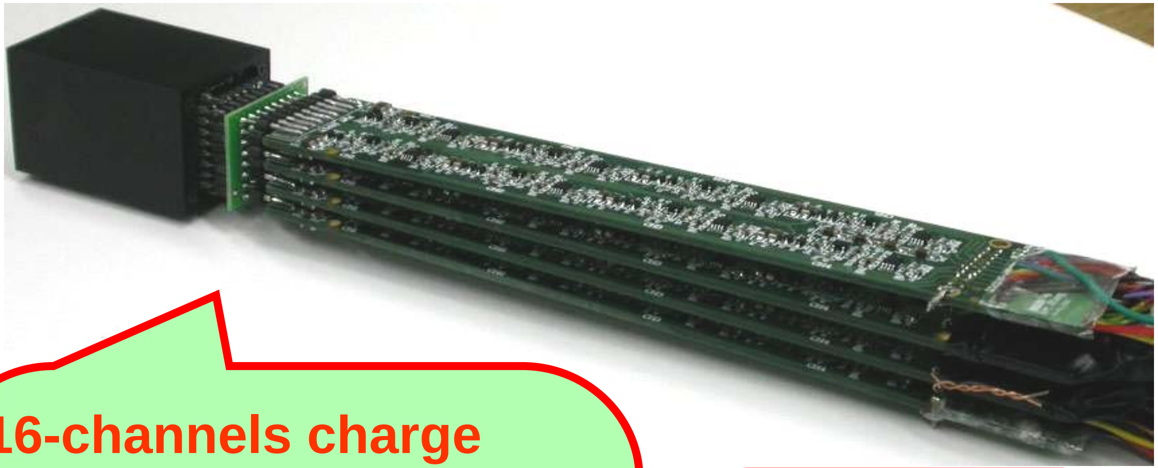


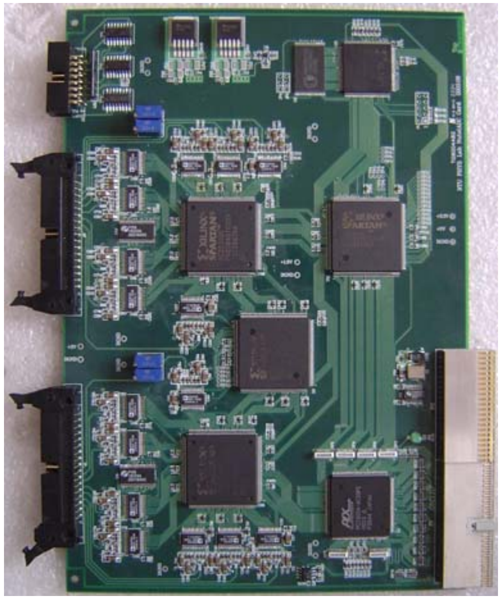


Multi-anode PMT (MAPMT) "H7546" of 8x8 pixels is used as photon-sensitive device

Signal-sharing plate is used for increasing dynamic range of the system in factor of about 10-20 times

Compact Electronics



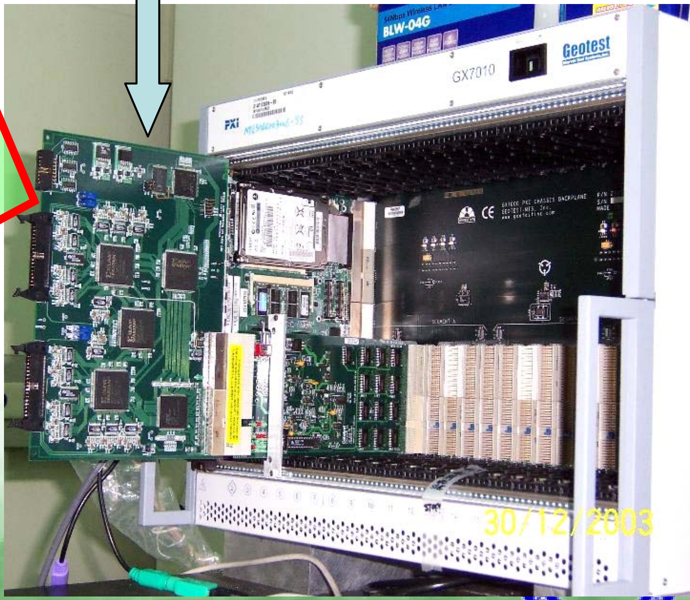


16-channels charge sensitive preamplifier transforms charge into voltage for digitising by pipelined ADC

4 preamplifier boards and signal- sharing plate are connected to one MAPMT

32-channels Data Collection module in cPCI (PXI)

16 DCM boards (512 channels) inside one PXI chassis

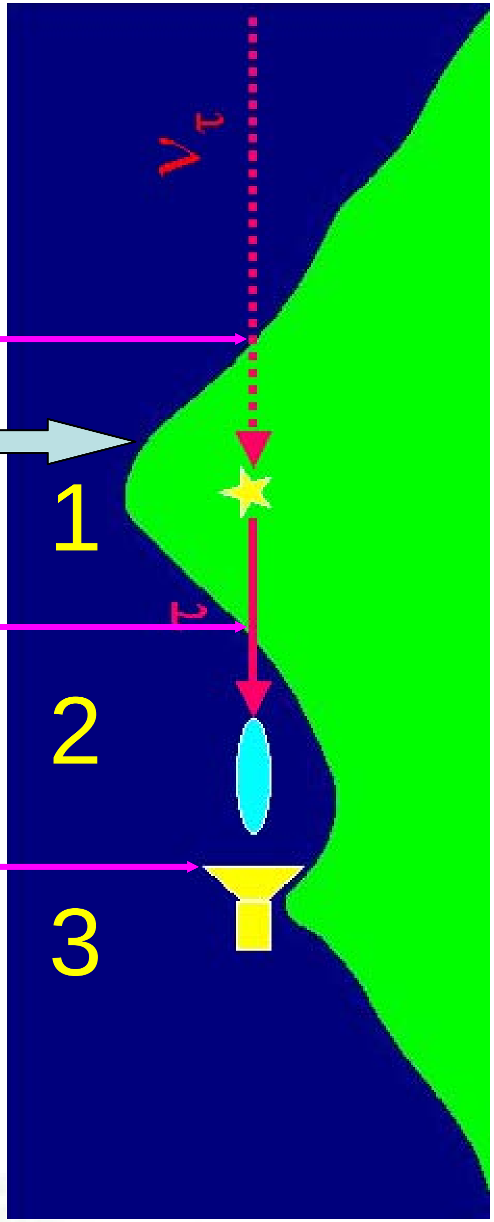


Three stage simulation

1 Front end: $\nu_\tau \rightarrow \tau$ inside mountain and Earth
- Simulation code "SHINIE"
- Paper in preparation

2 Air shower: $\tau \rightarrow$ Cerenkov photons
- M.A. Huang, C.C. Hsu, and P. Yeh (7/31- 8/7, 2003) ***Monte-Carlo simulation of horizontal air shower,*** Proc. of the 28th ICRC, Tsukuba, Japan, p.583 - 586

3 Detector simulation
- P. Yeh, et al., (2004), ***PeV cosmic neutrinos from mountain,*** Proceeding of CosPA 2003, Modern Physics Lett. **A.19**:1117-1124



Current status of NuTel

- Feasibility phase ends in 2003, no extension.
- Continuing working on electronics while try to form collaboration with ASHRA
  - Collaboration ends in 2004.
- Now working on designing a wide-field of view optical system.
  - Try to revive by a new budget sources.

Theoretical Studies

- Works by group of
  - NCTS: H. Athar, K. Cheug,
  - NCTU: G.L. Lin, T.W. Yeh, F.F. Lee, J.J. Tseng, C.H. Iong
  - NUU: M.A. Huang
- Focus on tau neutrino production, propagation, and interaction
  - Atmospheric neutrinos
  - Neutrinos from galactic disk
  - Earth-skimming neutrinos

Prompt tau neutrino

- Typical neutrinos flavor from hadronic interactions are ν_μ & ν_e, which comes from decay of π / k.
  - ν_τ comes from oscillation
- At higher energy, ν_τ could also be produced from D_s^*

(A) Via D_s mesons

$$pp \to c\bar{c}; \qquad c/\bar{c} \xrightarrow{had.} D_s; \qquad D_s \to \nu_\tau + X$$

Two approaches:

(1) use either NLO or LO with a K factor PQCD calculation:

$$gg, q\bar{q} \to c\bar{c}; \quad \sigma = \sum_{gg,q\bar{q}} \int\int dx_1\, dx_2\, f_{i/p}(x_1)\, f_{j/p}(x_2)\, \hat{\sigma}(ij \to c\bar{c})$$

$$D_{c\to D_s}(z) = N\, \frac{z(1-z)^2}{[(1-z)^2+\epsilon\, z]^2}; \quad \text{Use } \epsilon = 0.029 \pm 0.005; \quad f_{c\to D_s, D_s^*} = 0.19$$

(2) use the Quark Gluon String Model.

$$\frac{d\sigma^{D_s}(s,x)}{dx} \approx \frac{1}{x^2 + x_\perp^2} \sum_{n=1}^{\infty} \sigma_n^{pp}(s)\, \phi_n^{D_s}(s,x)\ ,$$

$x = 2p_\parallel/\sqrt{s}, \qquad x_\perp = 2\sqrt{(m_{D_s}^2 + p_\perp^2)/s}.$

$\sigma_n^{pp}(s)$ is the nth pomeron exchange cross section.

$\phi_n^{D_s}(s,x)$ consists of products of structure and fragmentation functions.

(B) Via b hadrons

$$pp \to b\bar{b}; \quad b/\bar{b} \xrightarrow{had.} b\text{–hadron}; \quad b_h \to \nu_\tau + X$$

Use PQCD calculation and Peterson FF with $\epsilon = 0.0047$, $B(b_h \to \nu_\tau + X) = 0.026$.

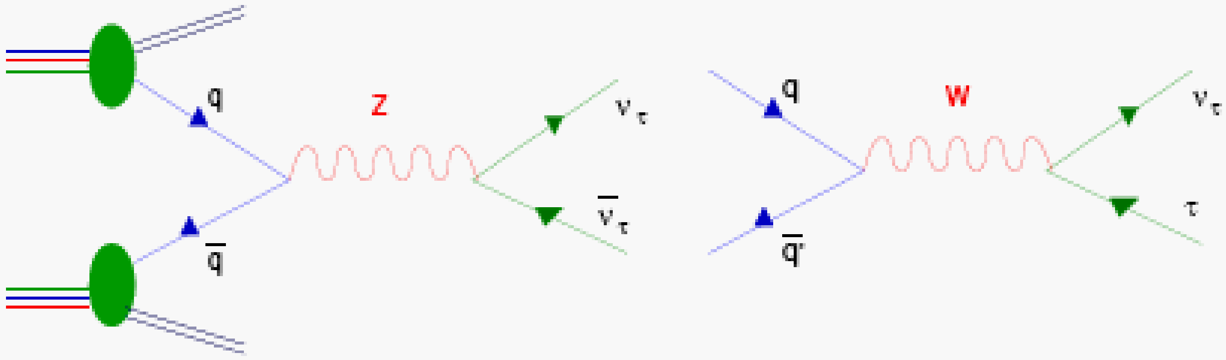
(C) Via $t\bar{t}$

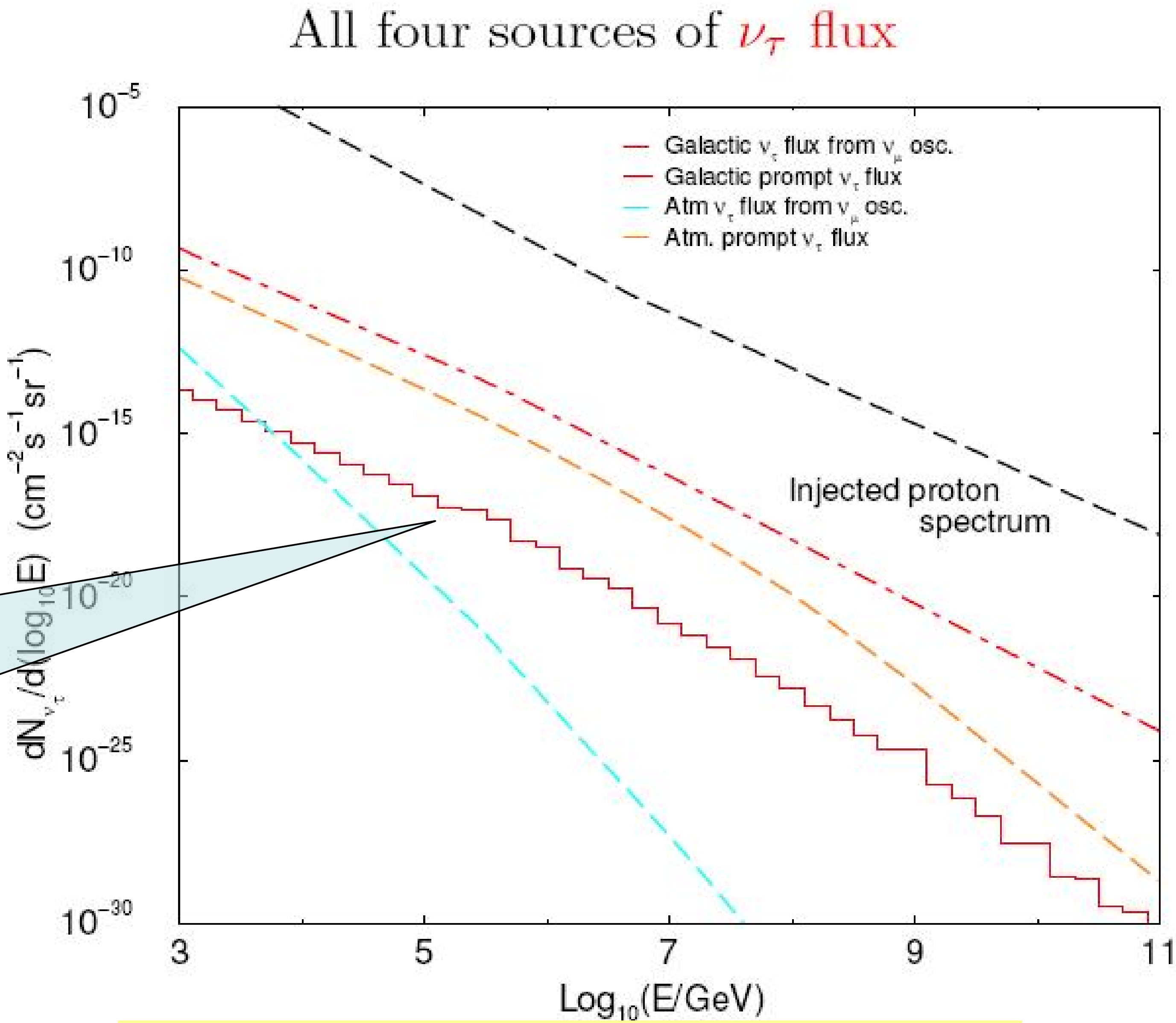
$$pp \to t\bar{t}; \quad t/\bar{t} \to bW; \quad W \to \nu_\tau \tau$$

Use PQCD calculation and $B(t \to bW) = 1$, and $B(W \to \nu_\tau \tau) = 1/9$.

(D) Via W^*, Z^*

$$pp \to W^* \to \tau \nu_\tau; \quad pp \to Z^* \to \nu_\tau \bar{\nu}_\tau$$





Prompt tau neutrino exceed oscillated tau neutrino at above 10^{13} eV

H. Athar, K. Cheung, G.-L. Lin, and J.-J. Tseng, Astropart. Phys. **18**, 581 ~2003

Tau propagation

Study ν_τ and τ propagation through standard rock.

- ν_τ -N & τ-N interaction: CC/NC
- Tau decay produces "regenerated ν_τ"
- Tau energy loss

$$\frac{\partial \phi_{\nu_\tau}(E,X)}{\partial X} = -\frac{\phi_{\nu_\tau}(E,X)}{\lambda_{\nu_\tau}(E)} + \int_E^\infty dE' \left(\frac{\phi_{\nu_\tau}(E',X)}{\lambda_{\nu_\tau}(E')}\right) \frac{dn}{dE}(\nu_\tau N \to \nu_\tau X; E', E)$$
$$+ \int_E^\infty dE' \left(\frac{\phi_\tau(E',X)}{\rho_\tau^{\rm dec}(E')}\right) \frac{dn}{dE}(\tau \to \nu_\tau X; E', E)$$
$$+ \int_E^\infty dE' \left(\frac{\phi_\tau(E',X)}{\lambda_\tau(E')}\right) \frac{dn}{dE}(\tau N \to \nu_\tau X; E', E)$$

$$\frac{\partial \phi_\tau(E,X)}{\partial X} = -\frac{\phi_\tau(E,X)}{\lambda_\tau(E)} - \frac{\phi_\tau(E,X)}{\rho_\tau^{\rm dec}(E)}$$
$$+ \int_E^\infty dE' \left(\frac{\phi_{\nu_\tau}(E',X)}{\lambda_{\nu_\tau}(E')}\right) \frac{dn}{dE}(\nu_\tau N \to \tau X; E', E)$$
$$+ \int_E^\infty dE' \left(\frac{\phi_\tau(E',X)}{\lambda_\tau(E')}\right) \frac{dn}{dE}(\tau N \to \tau X; E', E)$$

$$\lambda_{\nu_\tau} = 1/(N_A \sigma_{\nu N}^{\rm tot})$$

J.-J. Tseng, *et al.,* Phy. Rev. **D68:** 063003, (2003); astro-ph/0305507.

Signature of neutrino sources

- If detectors can detect Eν spectrum from 10^{16} to 10^{18} eV, it may be possible to identify sources of neutrinos by fraction of fluxes.

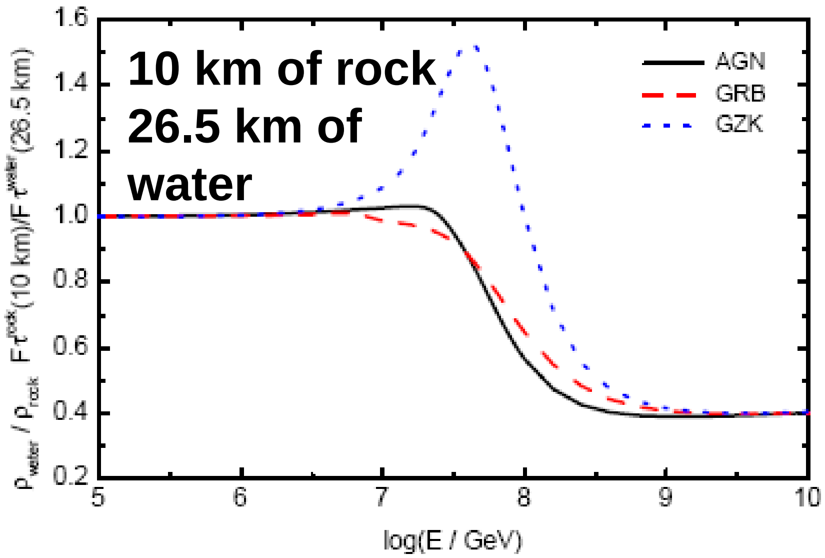


FIG. 5. The ratio of F_τ in rock and water induced by the AGN, the GRB, and the GZK neutrinos for $X = 2.65 \times 10^6$ g/cm^2.

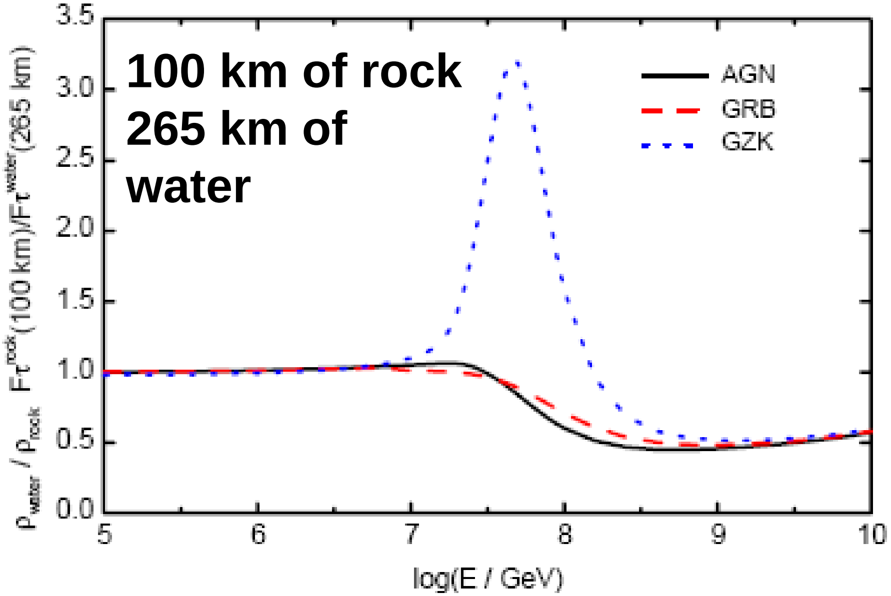


FIG. 6. The ratio of F_τ in rock and water induced by the AGN, the GRB, and the GZK neutrinos for $X = 2.65 \times 10^7$ g/cm^2.

J.-J. Tseng, *et al.,* Phy. Rev. D68: 063003, (2003); astro-ph/0305507.

Simulation on neutrino interacting with the Earth

NCTU:

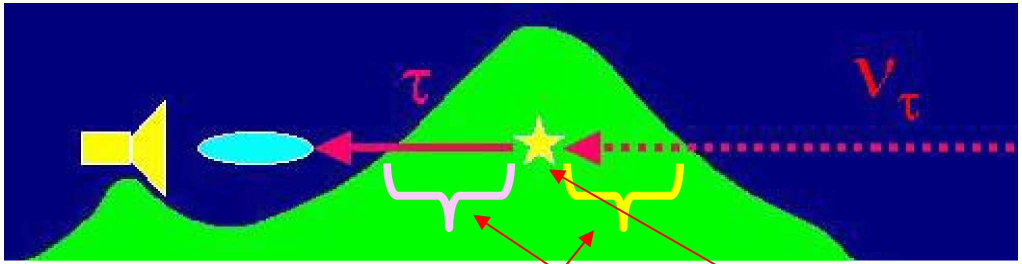
G.L. Lin, F.F. Lee, J.J. Tseng, C.H. Iong

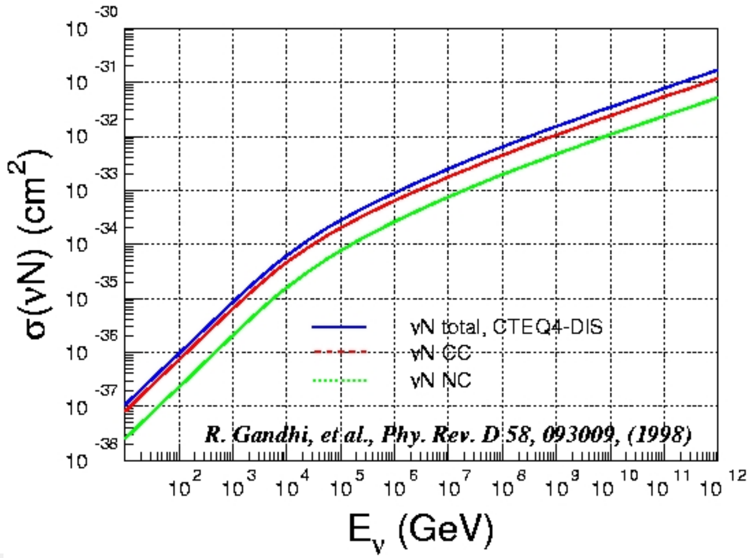
NUU:

M.A. Huang

First version

- ❖ Single interaction, no energy loss for tau lepton
  - λ_ν : neutrino interaction length
    - ν-N CC/NC cross-section from R. Gandhi et al.(1998)
  - λ_τ : tau lepton decay length
  - Material : std. rock



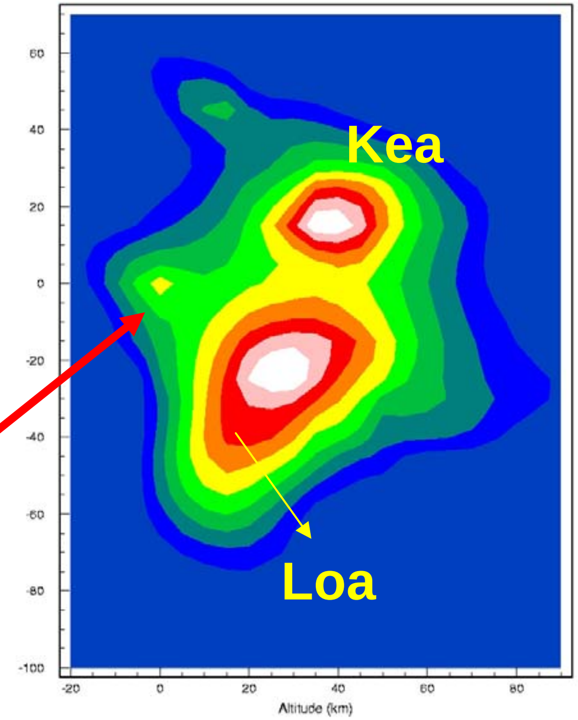


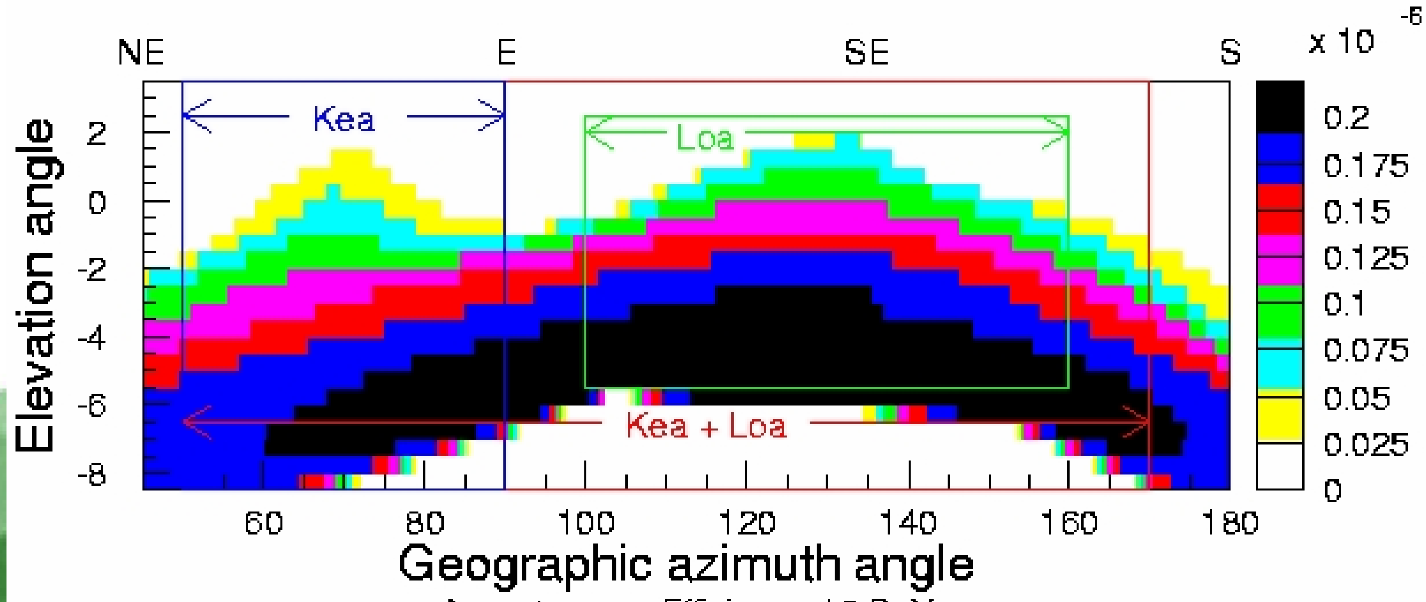
$$\varepsilon = \int_0^L e^{-x/\lambda_\nu} e^{-(L-x)/\lambda_\tau} \frac{dx}{\lambda_\nu} = \frac{\lambda_\tau}{\lambda_\nu - \lambda_\tau}\left(e^{-L/\lambda_\nu} - e^{-L/\lambda_\tau}\right)$$

W.S. Hou and M.A. Huang, (12/6-9/2001), *Proc. of the First NCTS Workshop on Astroparticle Physics*, Kenting, Taiwan. **astro-ph/0204145**

Relative efficiency in Field of View

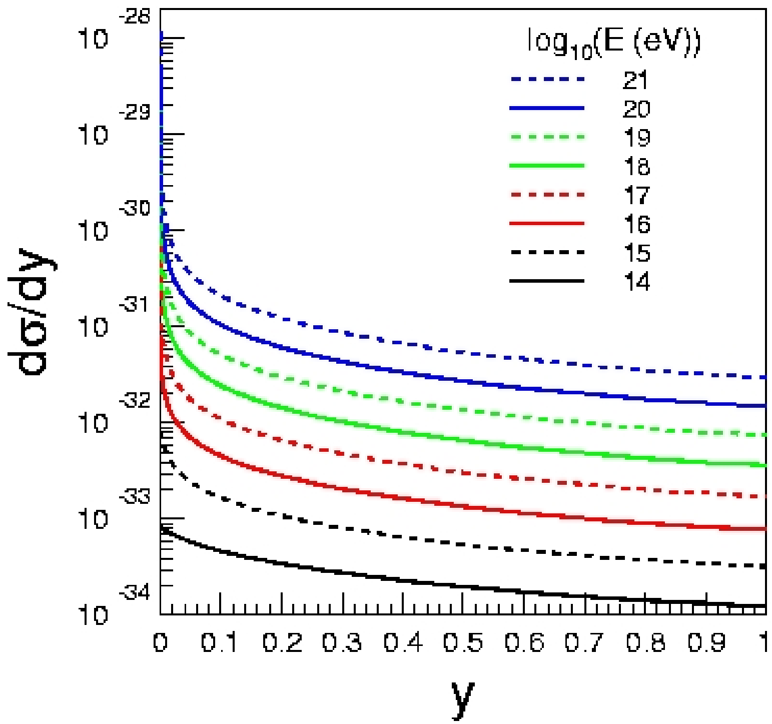
- Include conversion from ν_τ to τ, τ decay to shower, and shower detection efficiency.
  - Telescope on top of Mt. Hulalai in Hawaii Big Island.





Second version

- *Semi-Monte-Carlo* : Consider all physical processes, simulate everything except energy loss in Monte-Carlo simulation.
- dσ/dy calculated by CTEQ6 parton distribution function.
  - Inelasticity y and interaction cross-section σ



$$E_\tau = (1\text{-}y)\, E_\nu$$

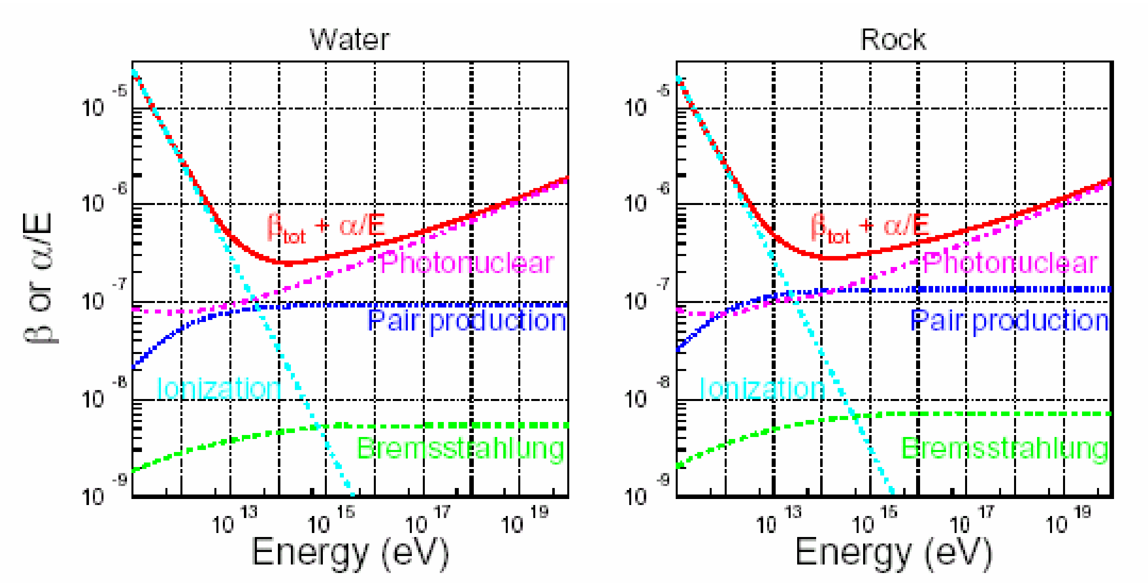
τ energy loss

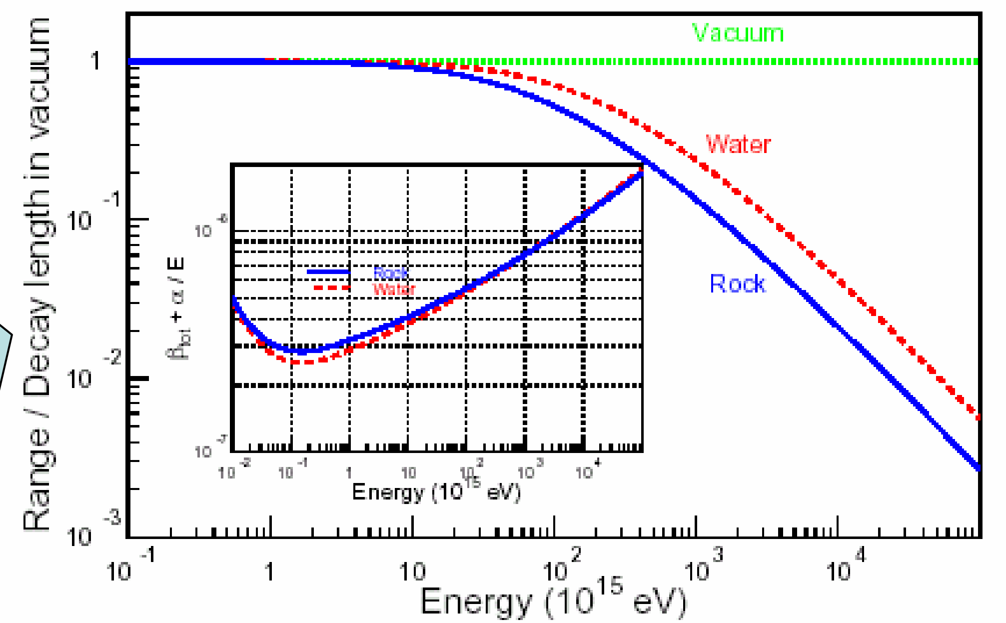
- Modeled energy loss of tau lepton by analytical form.

τ decay length = κE.

$$-\frac{dE}{dx} = \alpha + \beta E = \beta' E$$

$$\frac{dP}{P} = \frac{-dx}{\kappa E} = \frac{dE}{\kappa \beta' \rho E^2}$$



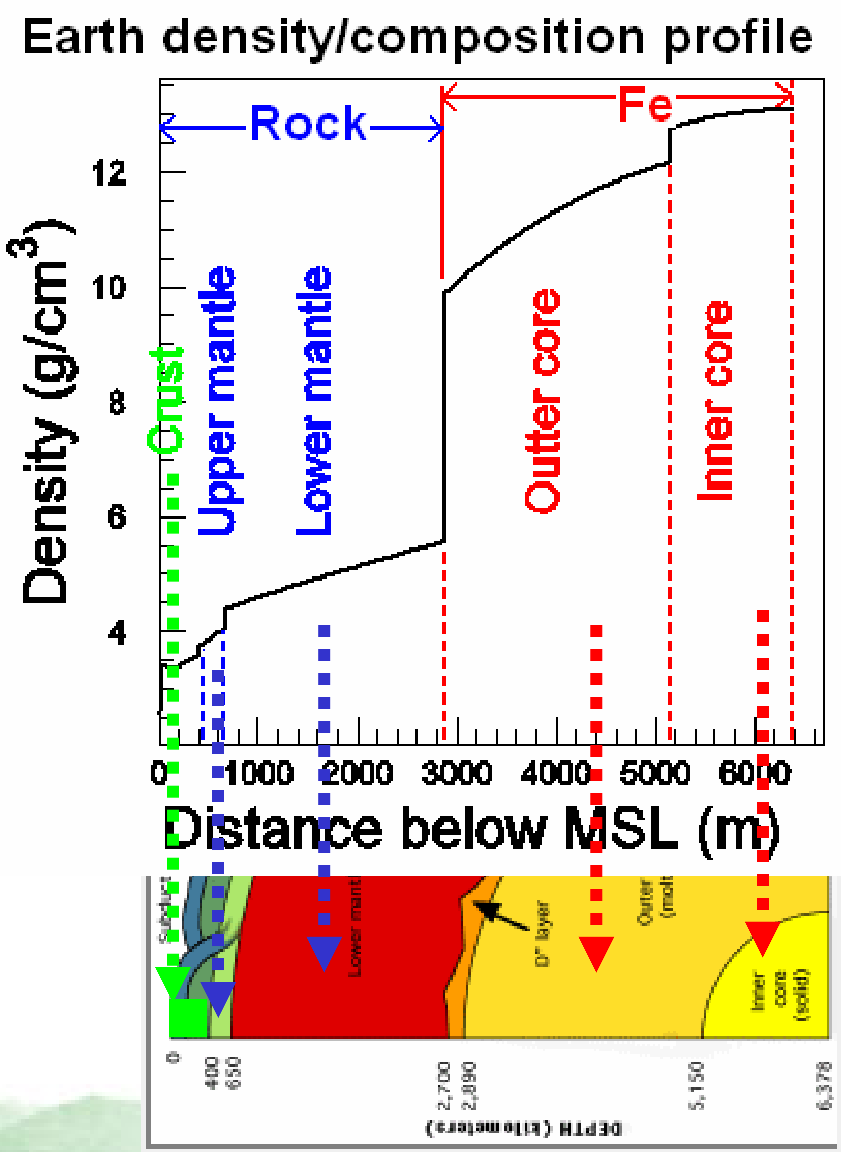


M.A. Huang, J.J. Tseng, and G.L. Lin (7/31- 8/7, 2003) Proc. of the 28th ICRC, Tsukuba, Japan, 1427-1430

Tau ranges are confirmed by S.I. Dutta, Y. Huang, M.H. Reno, Phys. Rev. D72:013005, 2005

Earth Model

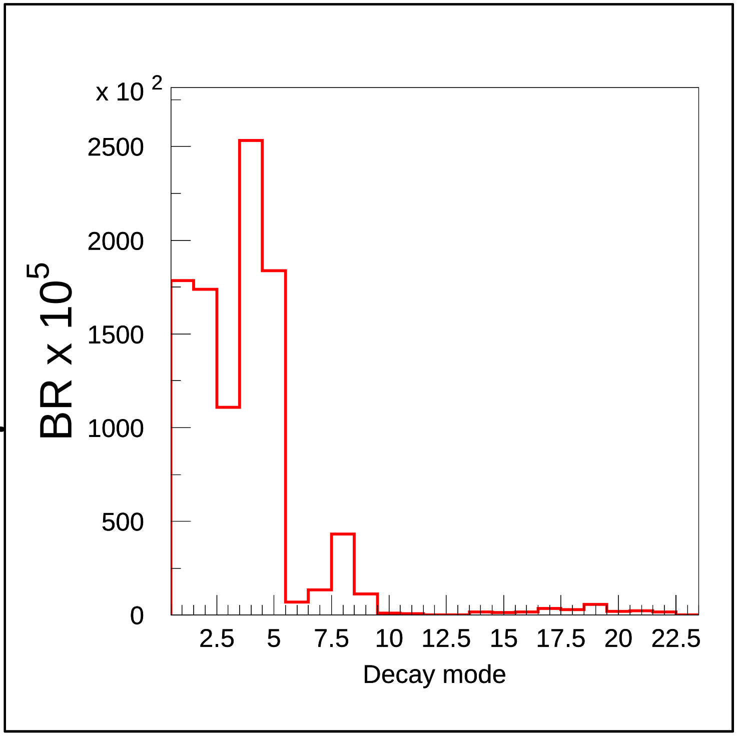
- Spherical Earth, $R_{\oplus}$ = 6371.2 Km
- Density/composition profile
- Material around detector can be selected from 4 materials.



Beatty, J. K. and A. Chaikin, The New Solar System, 1990.

τ decay

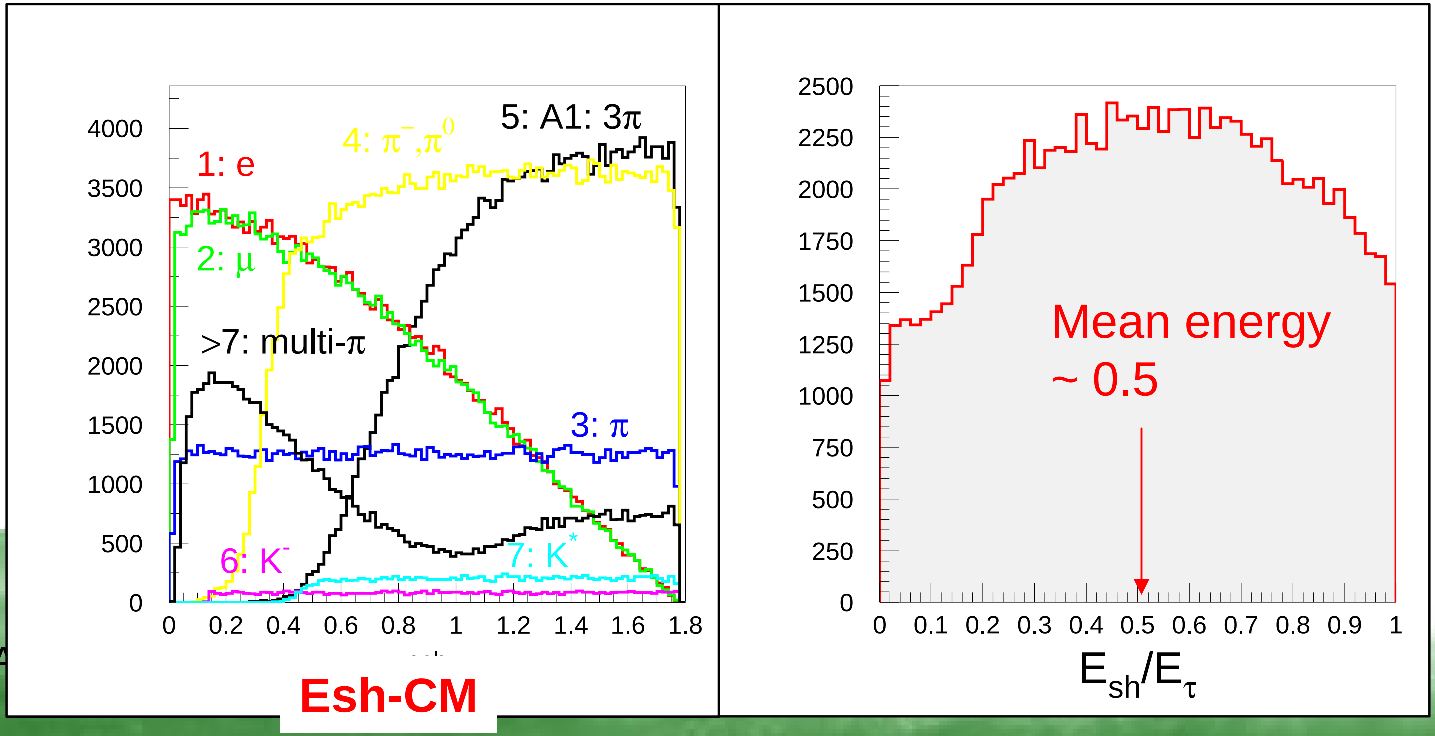
- τ decay simulated by
  - Randomly choose one event from a data bank of pre-simulated events
    - current version
  - Link to TAUOLA
    - in near future



- TAUOLA simulation
  - Fully polarized τ
    - Tauola have 22 decay modes, while PDB have 37 modes
- TAUOLA gives 4 momentum in CM of all decay particles
  - Define $E'_{cm} = P_{\|} + M_\tau$
  - Boost to lab by $\gamma = E_{\tau\text{-lab}} / M_\tau$
  - Secondary particle energy in lab frame $E'_{lab} = \gamma E'_{cm}$

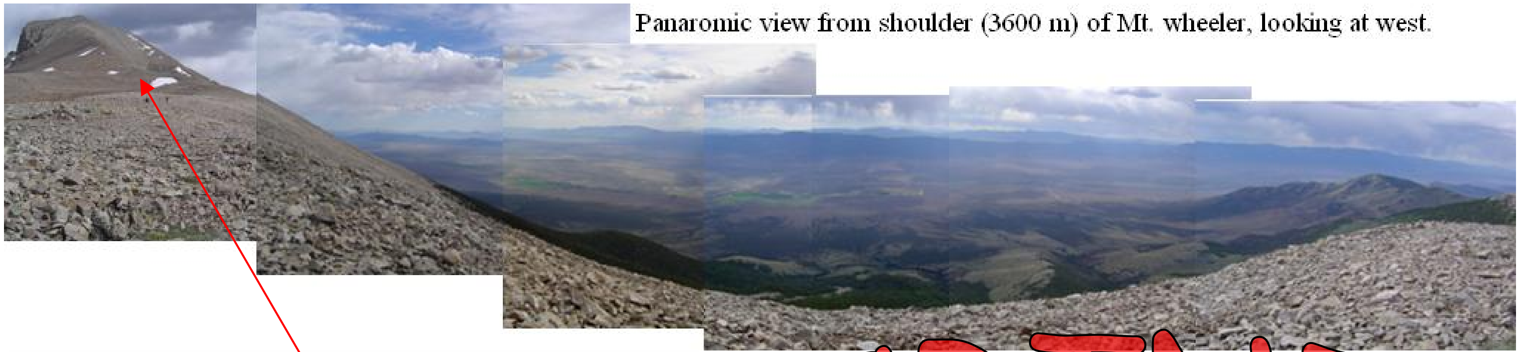
Shower energy

- If τ decay inside Earth, $E_{\nu\text{-lab}}$ is calculated and ν are re-propagated thru the rest of journey.
- If τ decay in atmosphere, shower energy E_{sh} is sum over E_{lab} of hadrons or electron / gamma.
  - The mean energy per particles is calculated by E_{sh}/M, where M is number of secondary particles which generate shower.

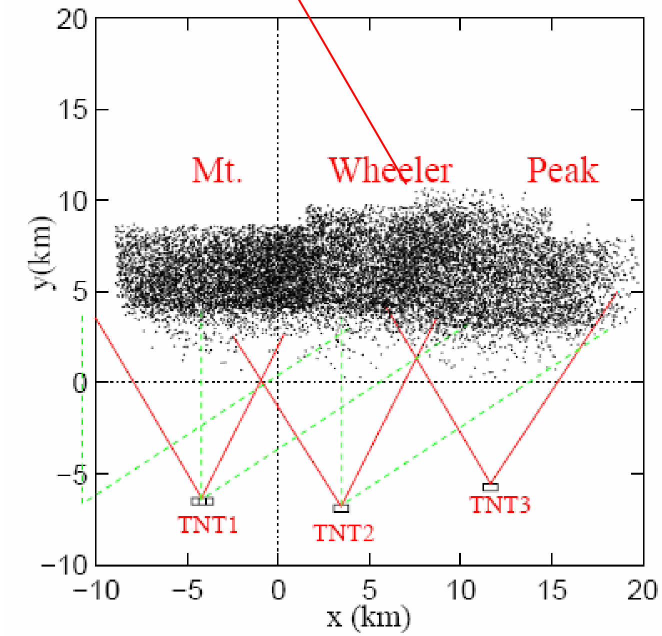


Publications based on semi-MC version

- Publications based on the semi-MC version:
  - M.A. Huang, J.J. Tseng, and G.L. Lin (7/31- 8/7, 2003) Proc. of the 28th ICRC, Tsukuba, Japan, p.1427, (2003)
  - M.A. Huang, Proc. of the 21th International Conference on Neutrino Physics and Astrophysics (ν -2004) at Paris, French, Nucl. Phys. B (Proc. Suppl.), 143, 546, (2005); astro-ph/0412642
  - P. Yeh, et al., Proc. of CosPA 2003, Modern Physics Lett. A.19, 1117-1124, (2004)
  - Z. Cao, M.A. Huang, P. Sokolsky, Y. Hu, J. Phys. G, 31, 571-582, (2005)



Panaromic view from shoulder (3600 m) of Mt. wheeler, looking at west.



CRTNT

Target: Mt. Wheeler, Nevada, USA.

(prototype in construction)

Z. Cao, M.A. Huang, P. Sokolsky, Y. Hu, *J. Phys.* ***G*, 31**, 571-582, (2005)

Highlight paper of the year 2005 by J. Phys. G

See talk by Zhen Cao

Are we there yet?

NO!

There are always rooms for improvement!

Radio detection of Neutrinos

- ∵ small ν-N cross-section, ∴ Need huge detection volume!
- Radio signal from EAS has large Cherenkov angle!
  - ANITA
  - SalSA
- Need simulation for these type of events

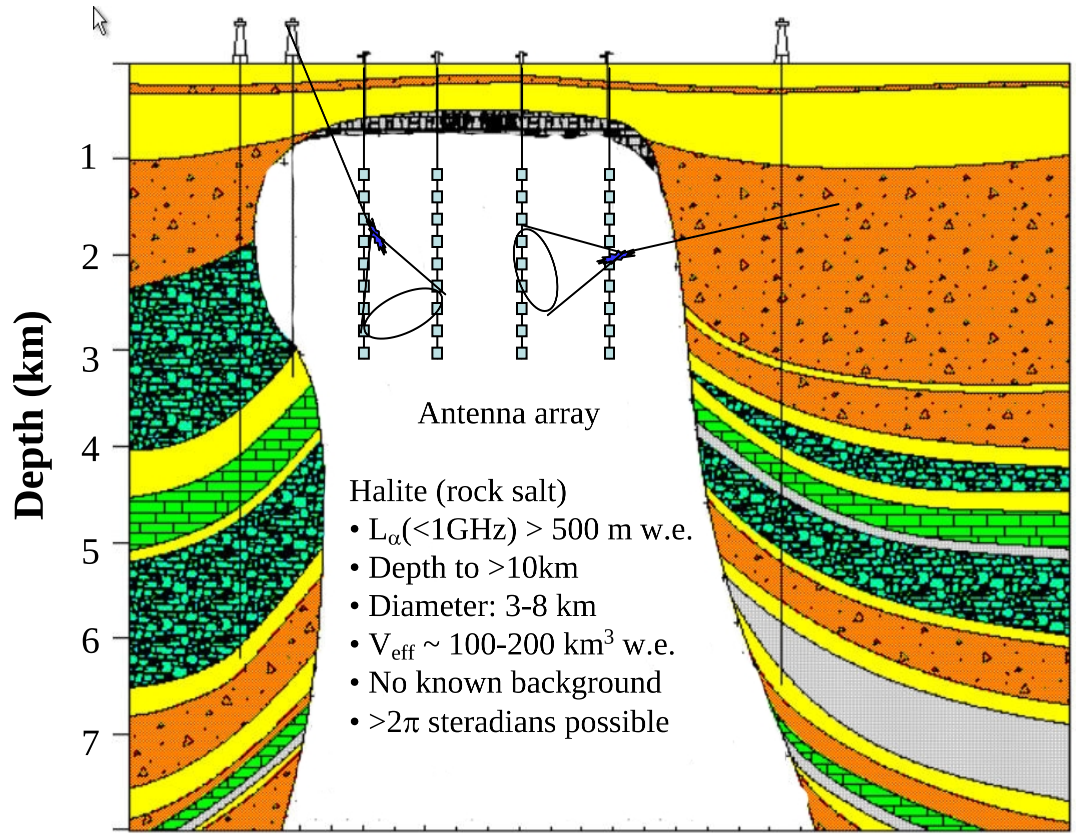


Figure comes from Peter Gorham, talk in SLAC SalSA workshop, 2005.

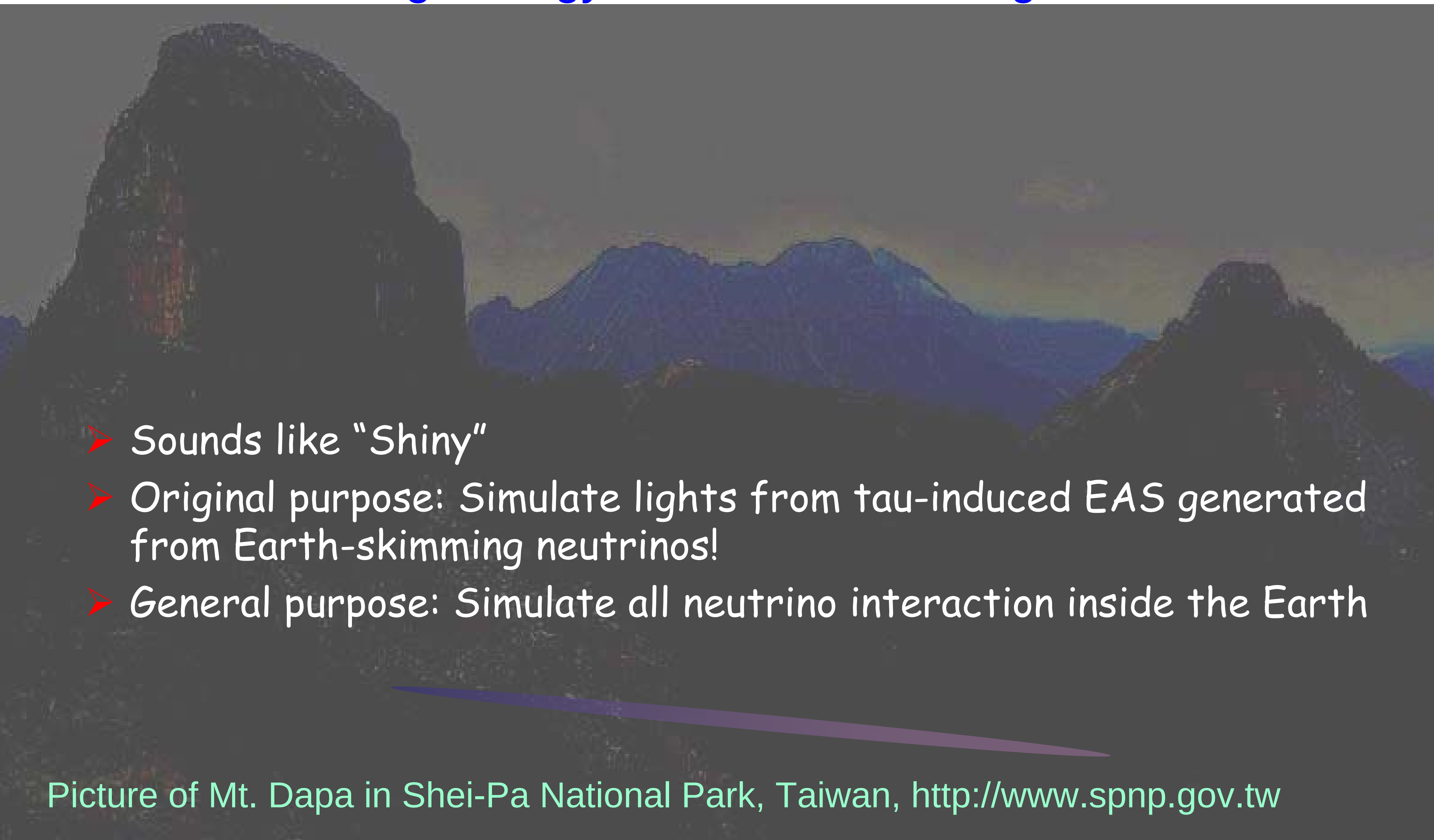
Updates in current version

- New materials and energy loss in these materials
  - Salt
  - Iron in Earth nucleus
- Include e/μ and ν_μ, ν_e
  - Both leptons and neutrinos can be injected to Earth for simulation
- Can simulate events for detectors above or under ground.
- Need a name!

Current version: SHINIE

Simulation of ***HI***ghenergy ***N***eutrino ***I***nteracting with the ***E***arth

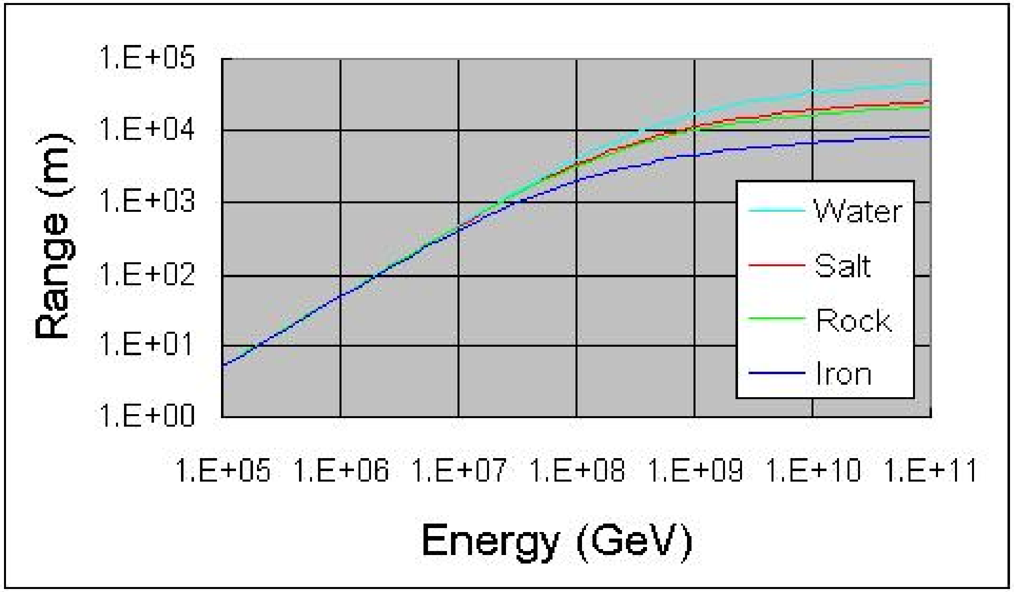
- Sounds like “Shiny”
- Original purpose: Simulate lights from tau-induced EAS generated from Earth-skimming neutrinos!
- General purpose: Simulate all neutrino interaction inside the Earth



Picture of Mt. Dapa in Shei-Pa National Park, Taiwan, http://www.spnp.gov.tw

Materials

- 4 materials: std. rock, water (ice), salt, iron
- Input particles:
  - e/ν_e , μ/ν_μ , τ/ν_τ
- Energy loss of μ and τ in 4 materials
  - Ionization (α).
  - Pair Production, Photo-Nuclear, Bressmstrlung
  - Soft energy loss cut at 0.003 (can be changed)



- Tau loss by

$$\tau + X \rightarrow \nu_\tau + X'$$

~ 0.16% at E > 2.5×10^{17} eV.

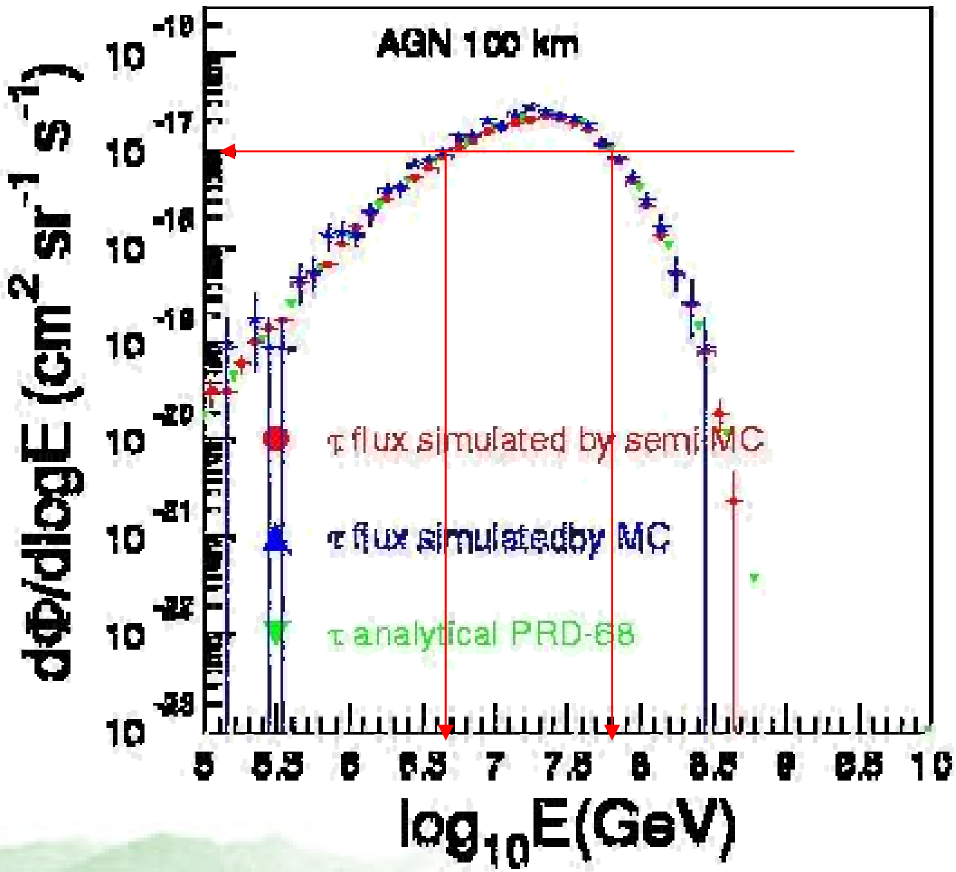
Consistence check

- Use several methods to calculate tau flux passing through 100km of standard rock for two different source spectrum (AGN and Cosmological).
  - Full MC: Use SHINIE,
    - M.A. Huang, et al., paper in preparation.
  - Semi-MC: MC in all processes except dE/dX
    - M.A. Huang, Proc. of ν -2004 at Paris, Nucl. Phys. **B**, **143**, 546, (2005)
  - Analytical calculation: Solve τ and ν_τ transport eq.
    - J.J. Tseng *et al*., Phys. Rev. **D 68**, 063003, (2003).
  - Source spectrum:
    - AGN: A. Neronov, *et al*., Phys. Rev. Lett., **89**, 051101 (2002)
    - Cosmological: R. Engel, D. Seckel and T. Stanev, Phys. Rev. **D 64**, 093010 (2001).

Typical Earth skimming event, θ=90.5°, cord length ~100 km.

AGN ν_τ

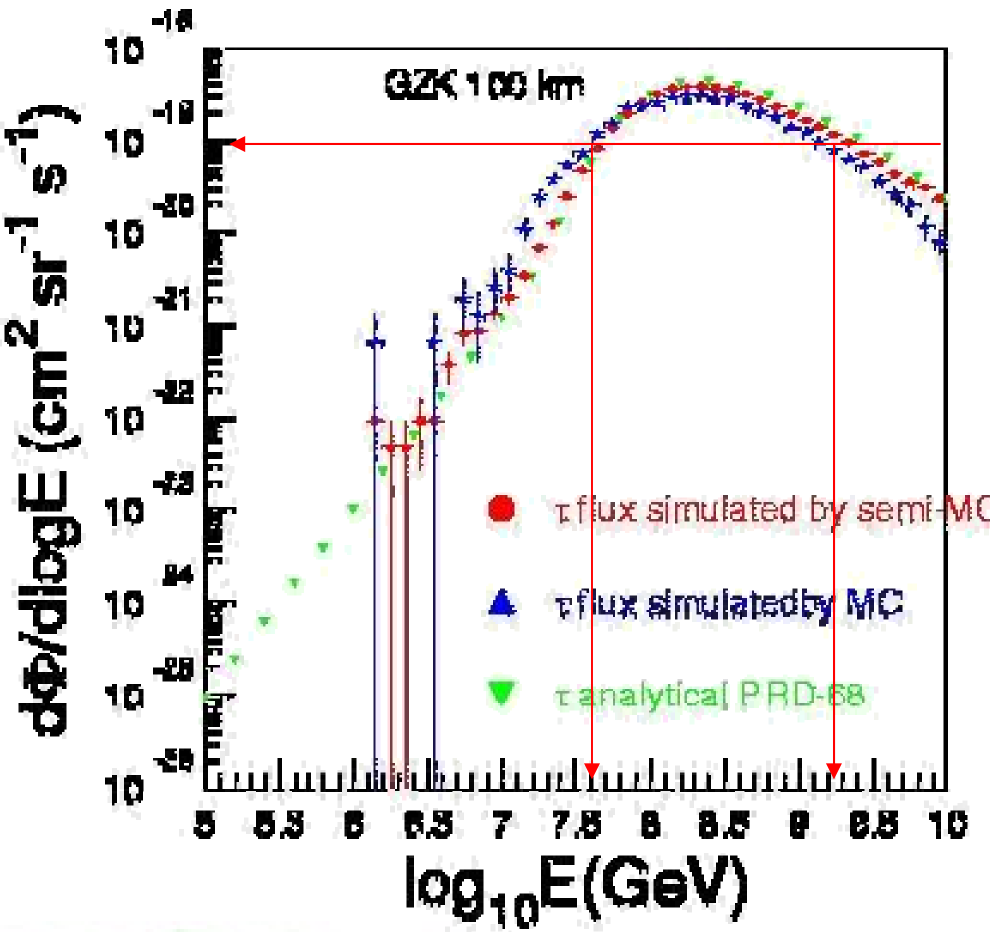
- MC method produce results similar to analytical method.
- Conditions used in MC:
  - 10^5 GeV < E < 10^{10} GeV
  - $N\nu=3\times10^7$
  - ~1.10 $\times10^{20}$ cm^{-2} s^{-1} sr^{-1}
  - $N\tau=2979$ (at E > 10^5 GeV)
  - Mean conversion efficiency 9.93×10^{-5}
- Total fluxes 2.7×10^{-17} $(cm^2\ sr\ s)^{-1}$; Equivalent to 8.5 events/(km^2 sr yr)
  - Should multiply trigger efficiency and acceptance to get event rate.
    - Both energy-dependent



τ energy peak at around 5~63 PeV, shower energy will peak around 10 PeV.

Cosmological ν_τ

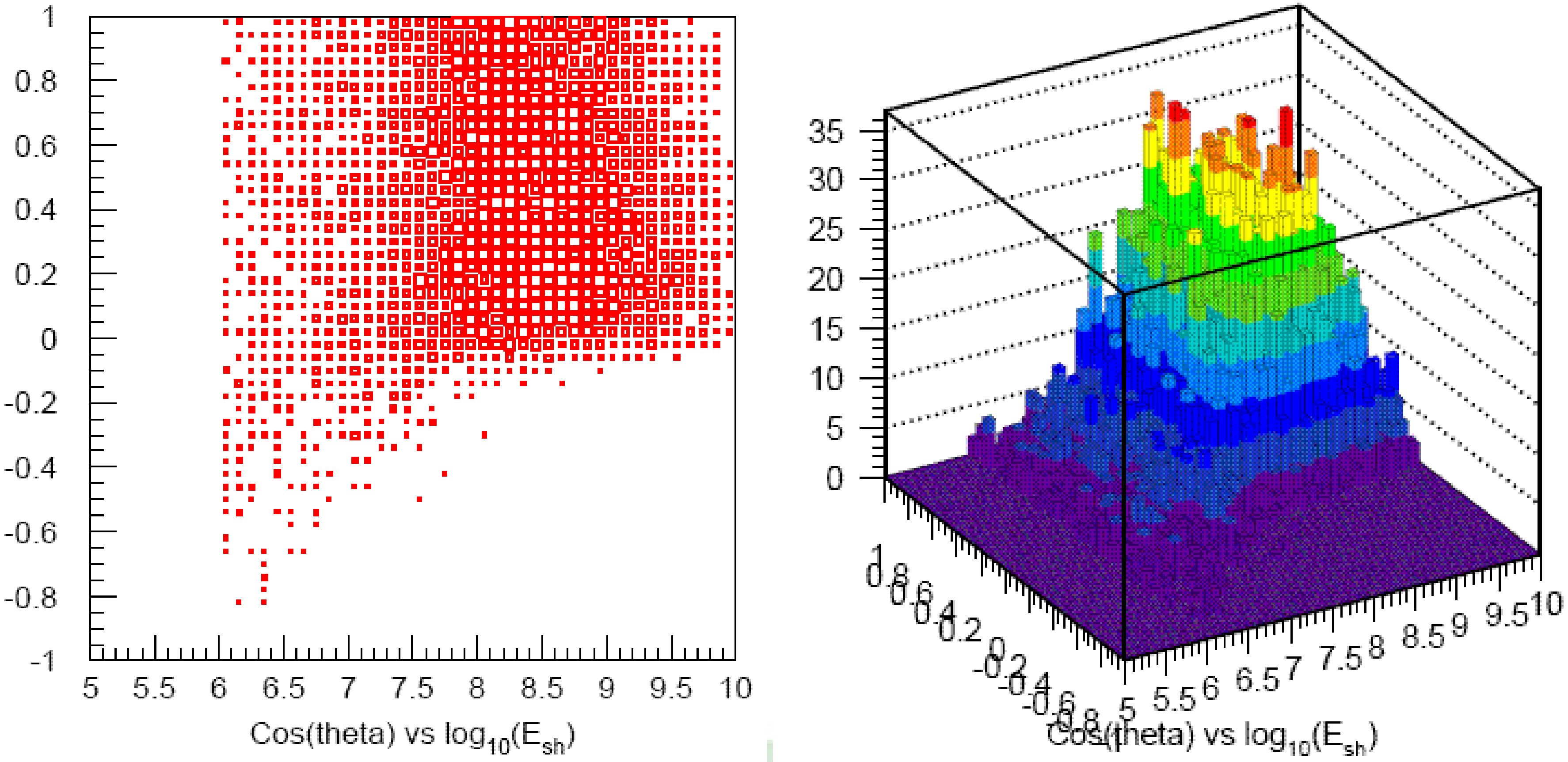
- For Cosmological neutrinos,
  - Slightly move to lower energy due to large energy loss.
- MC simulation conditions:
  - 10^5 GeV < E < 10^{12} GeV
  - $N\nu$=508294
  - ~1.52×10^{22} cm^{-2} s^{-1} sr^{-1}
  - $N\tau$=5969 (at E > 10^5 GeV)
  - Mean conversion efficiency 1.17×10^{-2}
- Total fluxes 3.9×10^{-19} (cm^2 sr s)$^{-1}$; Equivalent to 0.12 events/(km^2 sr yr)



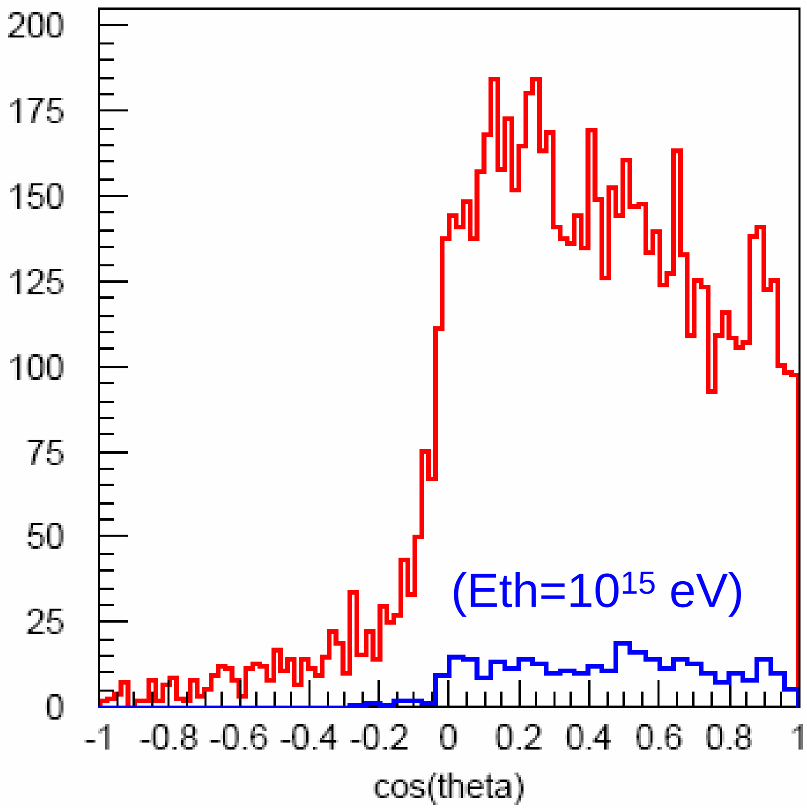
τ energy peak at around 0.04 PeV ~1.6 EeV, Shower energy will peak around 0.1 EeV.

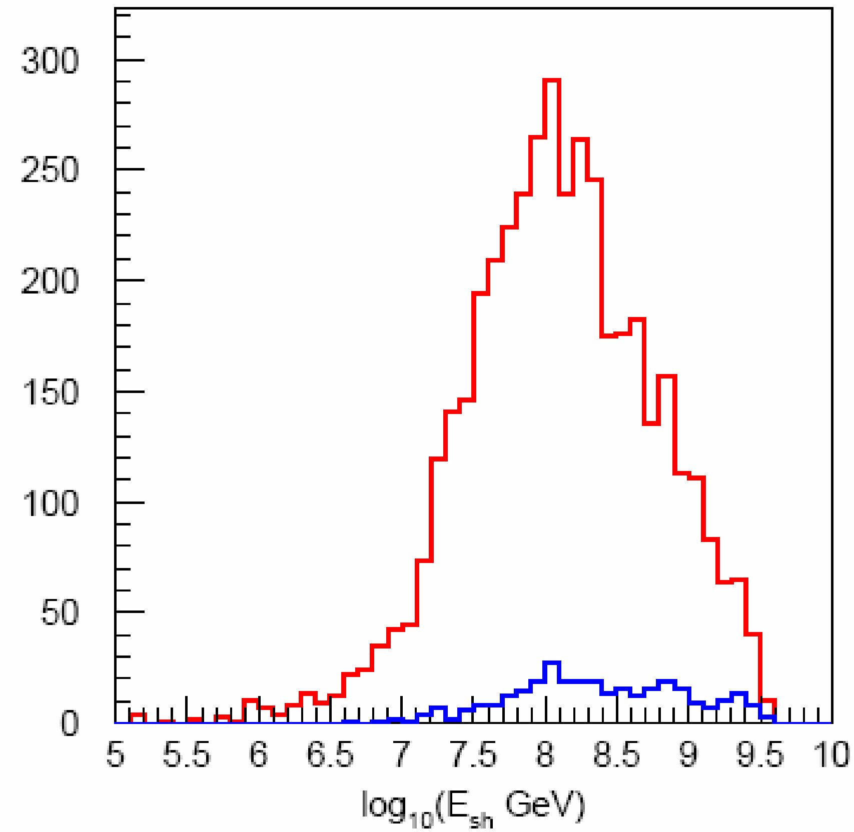
Cosmological ν_τ in salt dome

- cosθ vs. shower energy for detector above ground.



M.A. Huang, et al., paper in preparation



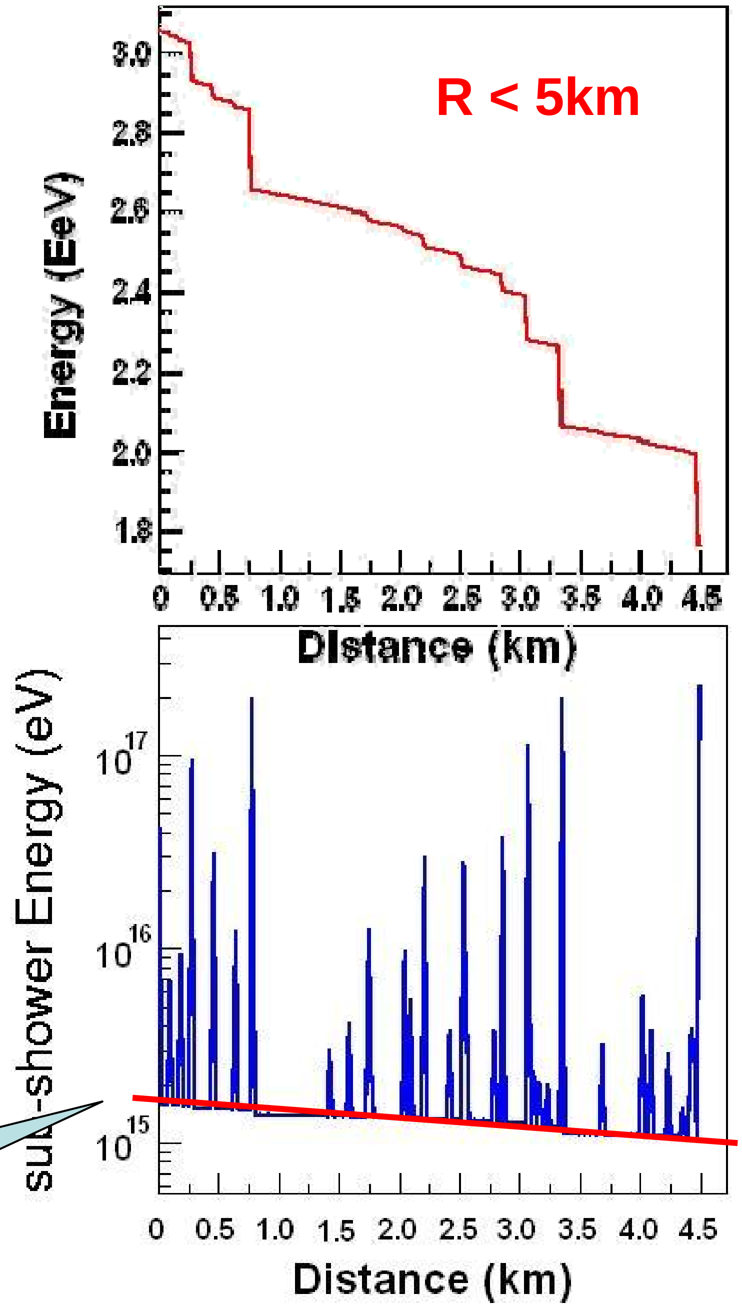


- FWHM of cosθ distribution: $-0.05 < \cos\theta < 1$, i.e. $0 < \theta < 93°$
- FWHM of Esh: $10^{16.5}$ eV $< E_{sh} < 10^{18}$ eV.

M.A. Huang, et al., paper in preparation

Not just double bang!

- Tau energy loss in stochastic process, produce some large energy loss, which produce sub-showers.
- Example: 3.5 EeV tau lepton entering salt dome.
  - #sub-showers depends on detector threshold,
  - > 200 sub-showers w. E > 1 PeV
    - Many of these comes from soft energy loss, which can be adjusted and lower down threshold.
  - 14 sub-showers w. E > 10 PeV
  - 4 sub-showers w. E > 100 PeV



Conclusion

- SHINIE simulation code is “almost” finish!
  - Still need some cosmetic works on user friendly I/O.
  - No manual or any documentation yet!
- For Earth skimming events:
  - AGN tau flux ~ 8.5 events/(km^2 sr yr), need detector ~ 1 km^2 sr
    - Shower spectrum peak around 10^{16} eV.
  - Cosmological tau flux ~ 0.12 events/(km^2 sr yr), need detector ~ 100 km^2 sr
    - Shower spectrum peak around 10^{17} eV.
- For underground detector such as SalSA:
  - Shower spectrum peak around 10^{17} eV.
  - $-0.1 < \cos\theta < 1$.

M.A. Huang, et al., paper in preparation

Acknowledgements

❖Thanks to conference organizer for invitation and assistantship.

❖Look forward for more international cooperation!