Applied Cosmic ray physics

for Earth planetary science and hazard prevention

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In the 1990s…

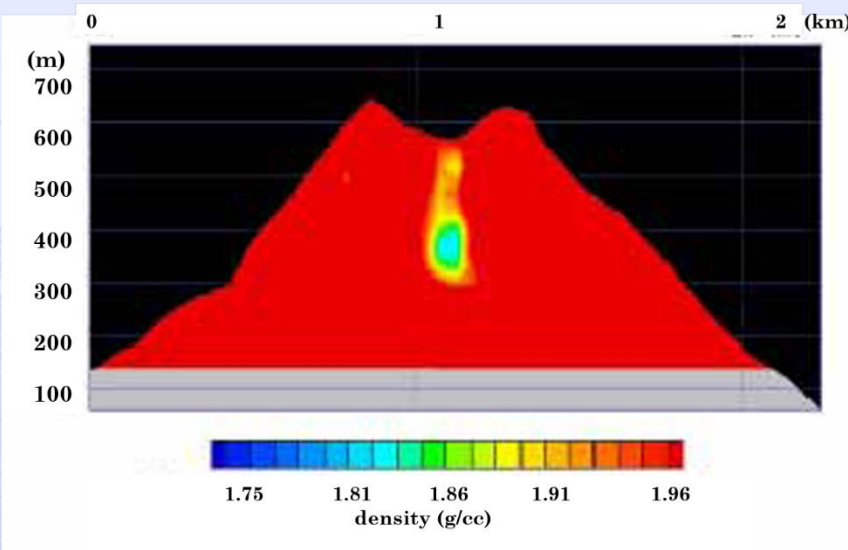
Q What is your research useful for ?
A1 It's not useful for you…
(honest person's answer)
A2 It would be useful in the future
(your answer)

In the 2010s…

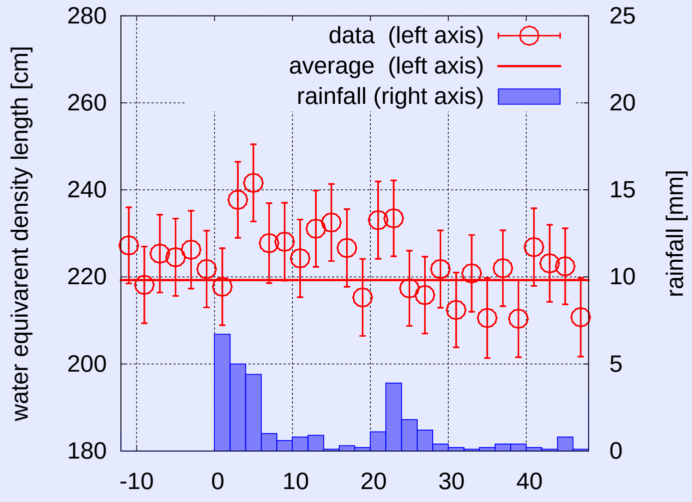
As you know…

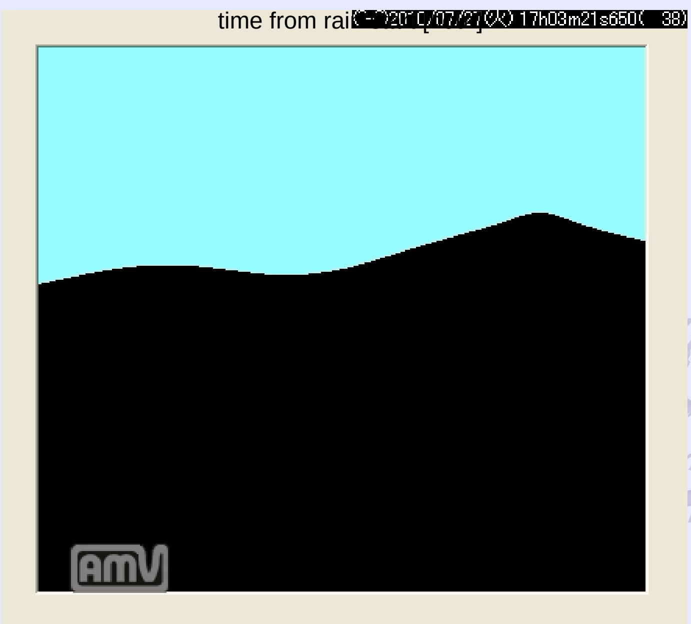
Cosmic ray is useful !

- Volcanology using hard component



- Hydrology using soft and hard component



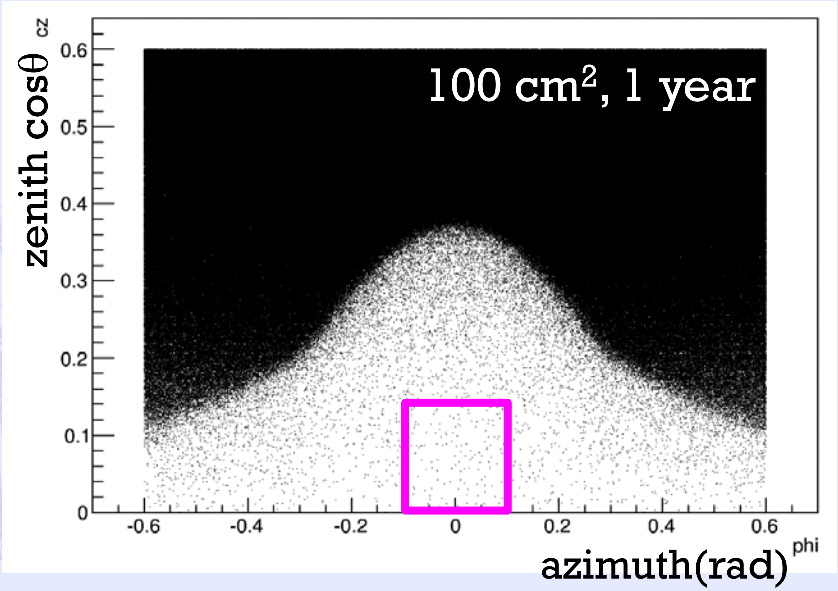


- Earth tomography using very hard component (absorption/oscillation)
- Seismic fault zone tomography using using hard component
- Planetary science (pion and hard component)
- Civil engineering

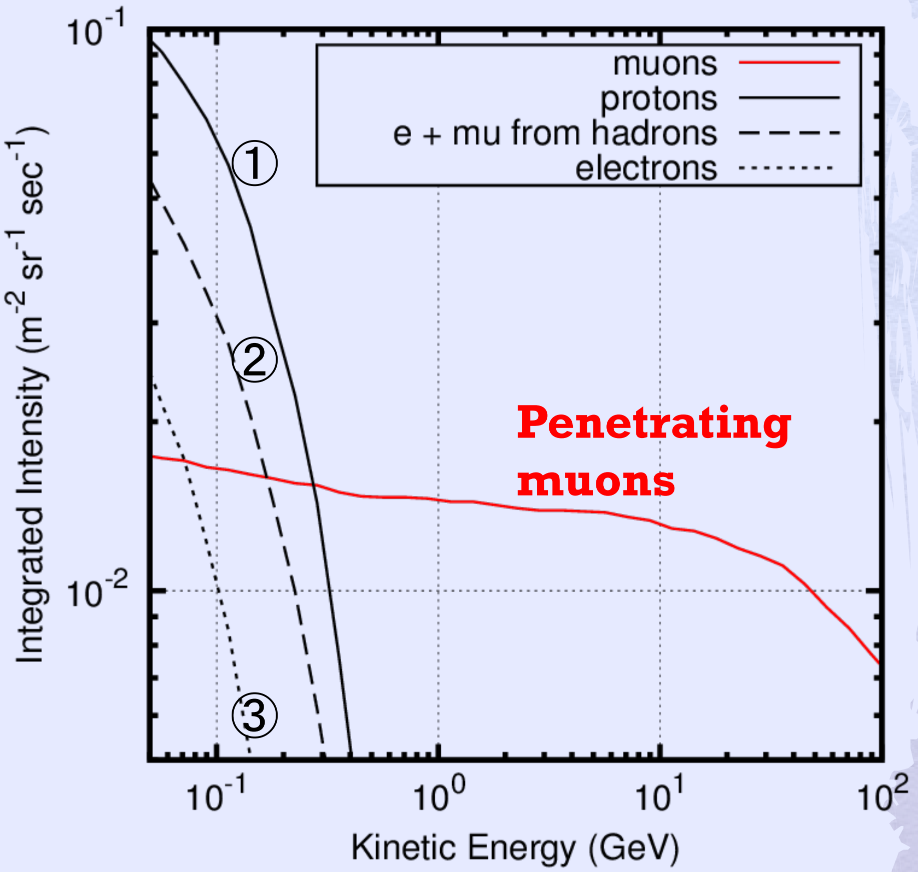
I appreciate your work, especially

- Hadronic interaction model development
  - Hydrology using EM component
    - AS production
  - Muon tomography
    - Background estimation
  - Neutrino tomography
    - Atmospheric neutrino production
    - Inelastic cross section
- Primary cosmic ray spectrum measurement
  - Signal to noise ratio
  - Pion tomography of the astronomical body

MC simulation of volcano (2km w.eq.)



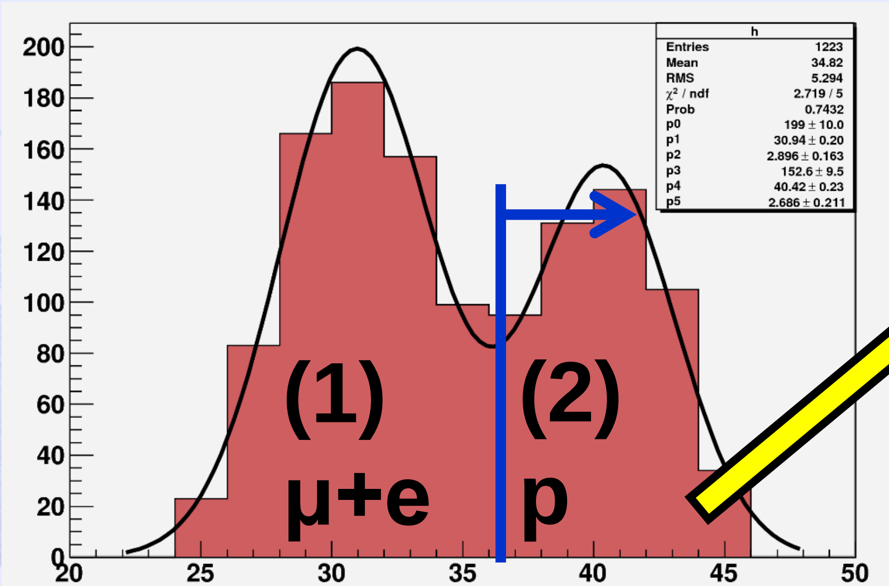
① proton
② hadron induced e and mu
③ upward going particles



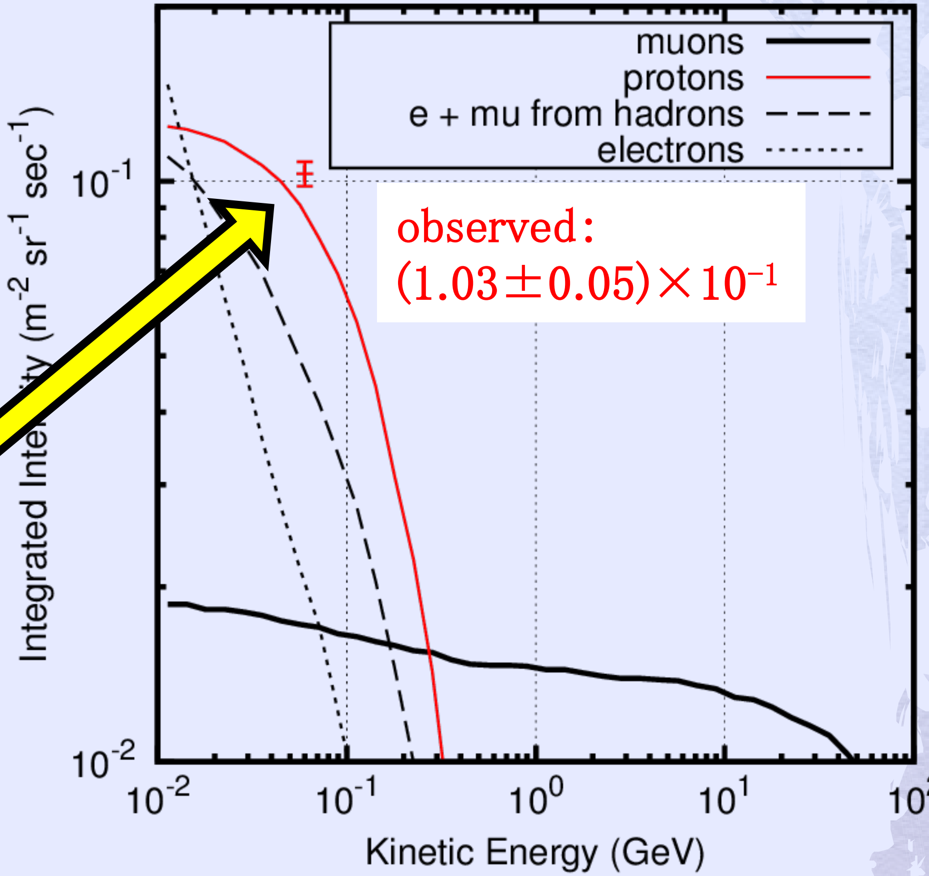
At low momentum (< 1 GeV), background particles dominate

Observed proton flux by Emulsion chamber

Grain density



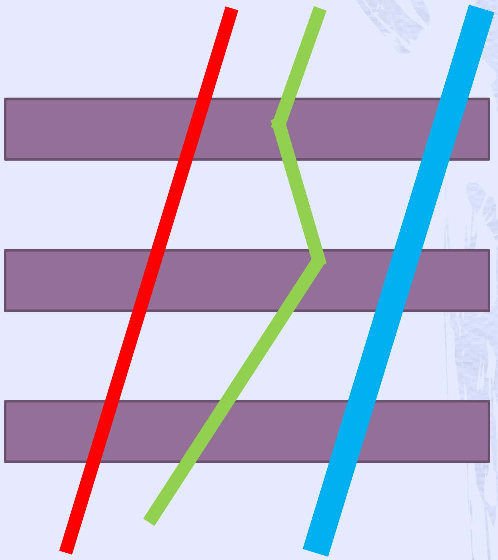
Grain density /100 μm～ dE/dx



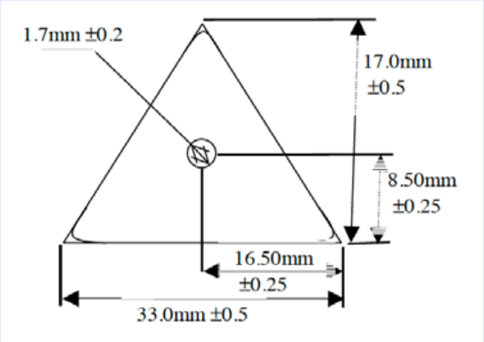
Observed proton-like flux was agreed within systematic uncertainty (50%)

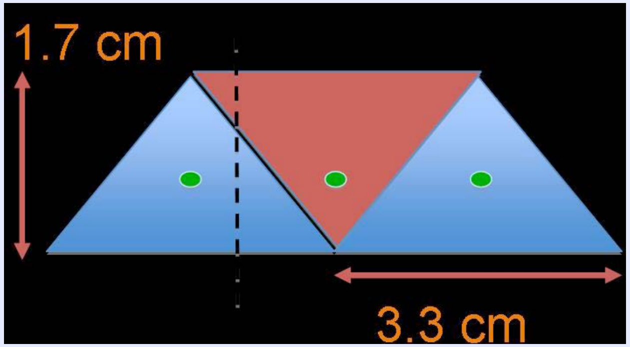
If we have accurate and reliable MC, we can subtract BG flux from data, and BG contaminated data become available !

Principle of our PID method



- Scattering and dE/dX
  - Not absorption
  - For mobility
- Muon： Linear track
- Electron：Polygonal track
- Proton： large dE/dX
- Already well established and used in the field
  - Scintillator + WLSF + MPPC (MINERvA etc)
  - Multi wire proportional chamber (ATLAS etc)
  - Emulsion chamber (OPERA etc)



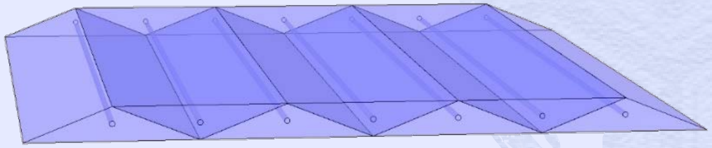


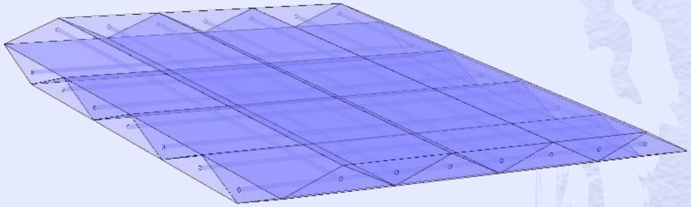
Is it useful for cosmic ray physics ?

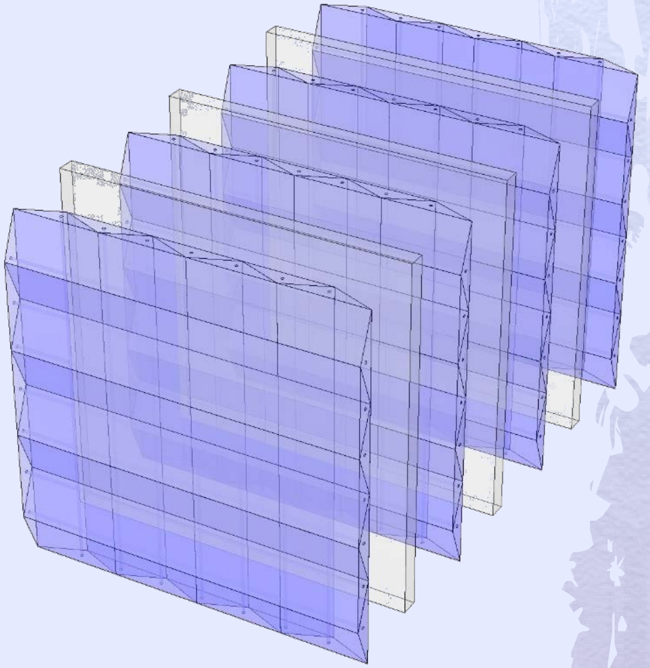
- Basically yes, but···
  - Emulsion chamber and MWPC do not have good timing resolution
    - nano second is not possible
  - Scintillator based tracker can be used but···
    - Very expensive for Air shower array
    - Cannot treat multiple particle
- We are developing the next generation particle tracker for applied CR physics
  - Portable
  - Cost effective
  - Low power consumption

Basic design

- Triangular scintillator bar + WLSF + MPPC/SiPM + thin absorber
  - Good position/timing resolution
  - Solid type detector
- FADC + TDC readout
  - Both ends readout
  - Good timing resolution
- Discriminate muon and other particles using scattering
  - Need careful detector parameter optimization
- Key points
  - Reducing number of channels
  - Reducing the power consumption
  - Easy manufacturing/maintainance



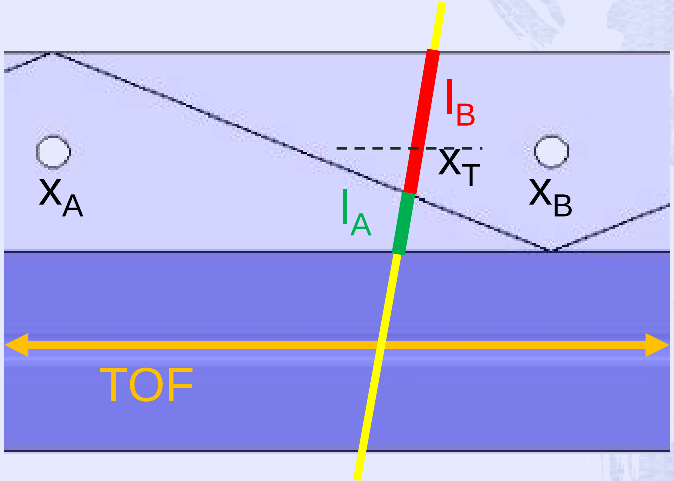


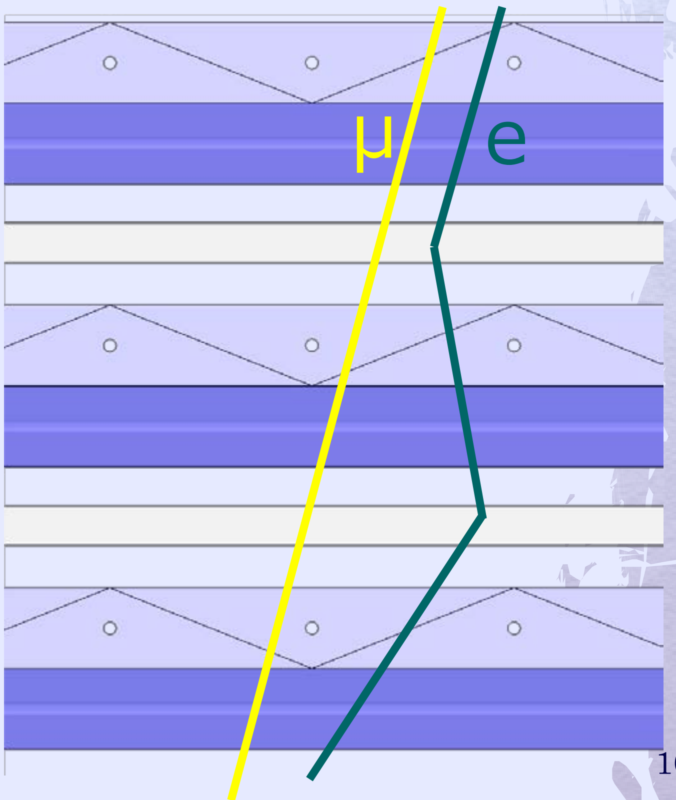


How does it work ?

- Position resolution < d_f
  - Output charge is proportional to track length in sci.
    - $Q_A \propto l_A$, $Q_B \propto l_B$
  - $X_T=(X_AQ_A+X_BQ_B)/(Q_A+Q_B)$
  - TOF can be used
    - Cross calibration
  - 2mm resolution @d_f=h_s= 1.7cm
- Particle ID
  - Scattered particle

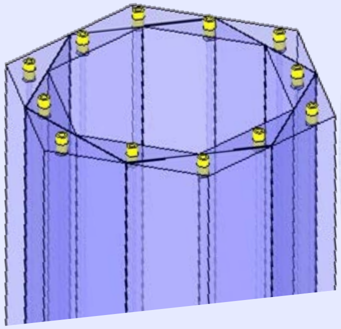
  → electron / low momentum
  - High dE/dX → proton or nuclei
  - Slow particle → proton or nuclei
- Particle direction
  - Using TOF information





Applications of new detector

- Muography on ground(of course)
- Muography from borehole
  - Seismic fault zone
- Cosmic Electron radiography
  - Hydrological observation
  - Hybrid radiography by EM+muon for buildings
- Air Shower Array
  - Muon / EM ratio
  - Mass composition
  - Cross section (first interaction point)

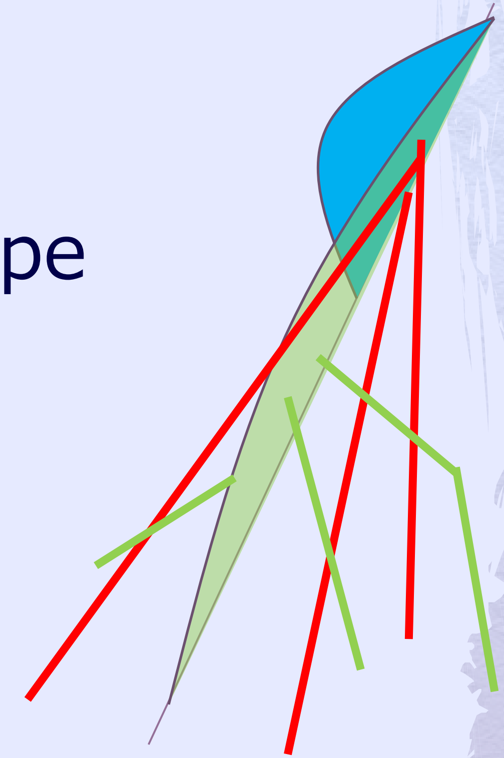


Questions (Motivations)

- Is electron Xmax distribution measurement by FT enough for mass composition measurement?
  - Hadronic interaction models are agreed well, but there is still some discrepancy
  - Is systematic uncertainty of each interaction model small enough ?
  - Why don't we add additional physical quantities ? (like NICHE)
  - Confirmation using different method is always very important
- Energy discrepancy between ASA and FT is ~ 30%
  - From muon excess ?
  - Can we neglect it ?
  - Of course FT is more reliable way to measure the energy
  - Is air shower phenomenology understood completely ?
- Can we detect GZK gamma rays (if it exist) ?

Air Shower Tracker Array

- Target energy range : 10PeV – 10EeV
  - 10km^2 array
  - 2000-4000 a.s.l
  - 250-1000 m detector spacing
- Hybrid experiment using single type detector
  - Lateral distribution of muon and EM
    - Muon excess problem
  - Muon arrival direction
    - Better angular resolution
      - Muons come from shower axis
    - Hadron Xmax and cross section
  - Highest energy gamma ray search

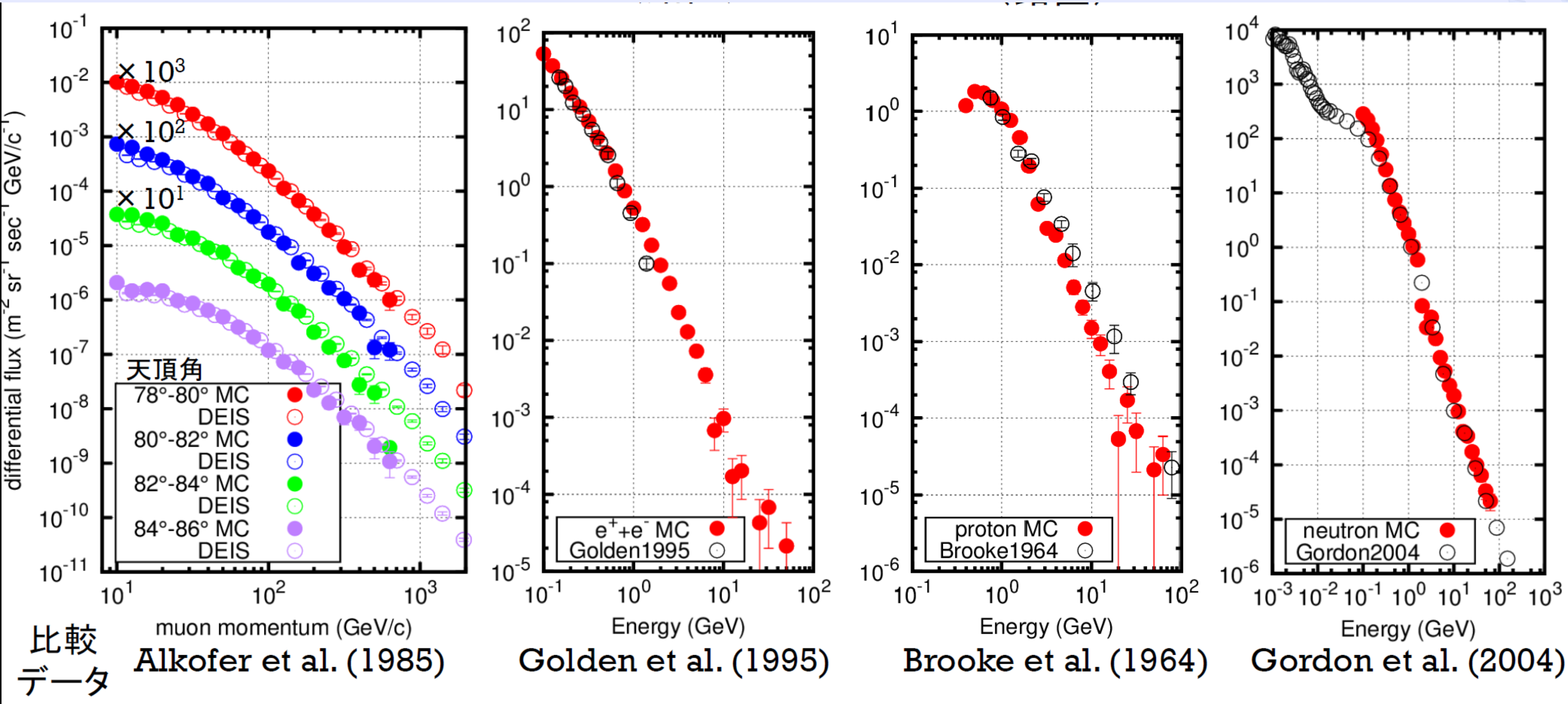


Conclusion and TODO

- Detailed measurement of air shower particle should be important
  - to deepen our understanding of cosmic ray physics
- The detector for geophysics can contribute to cosmic ray physics
  - reimportation
- Cost estimation
  - less than 3M$ for 100 detectors (2.5m^2)
- Cost reduction
  - Fiber spacing is the key issue
  - Without reducing the number of p.e.
  - Optimum scintillator shape and detector arrangement

Importance of MC for muon radiography

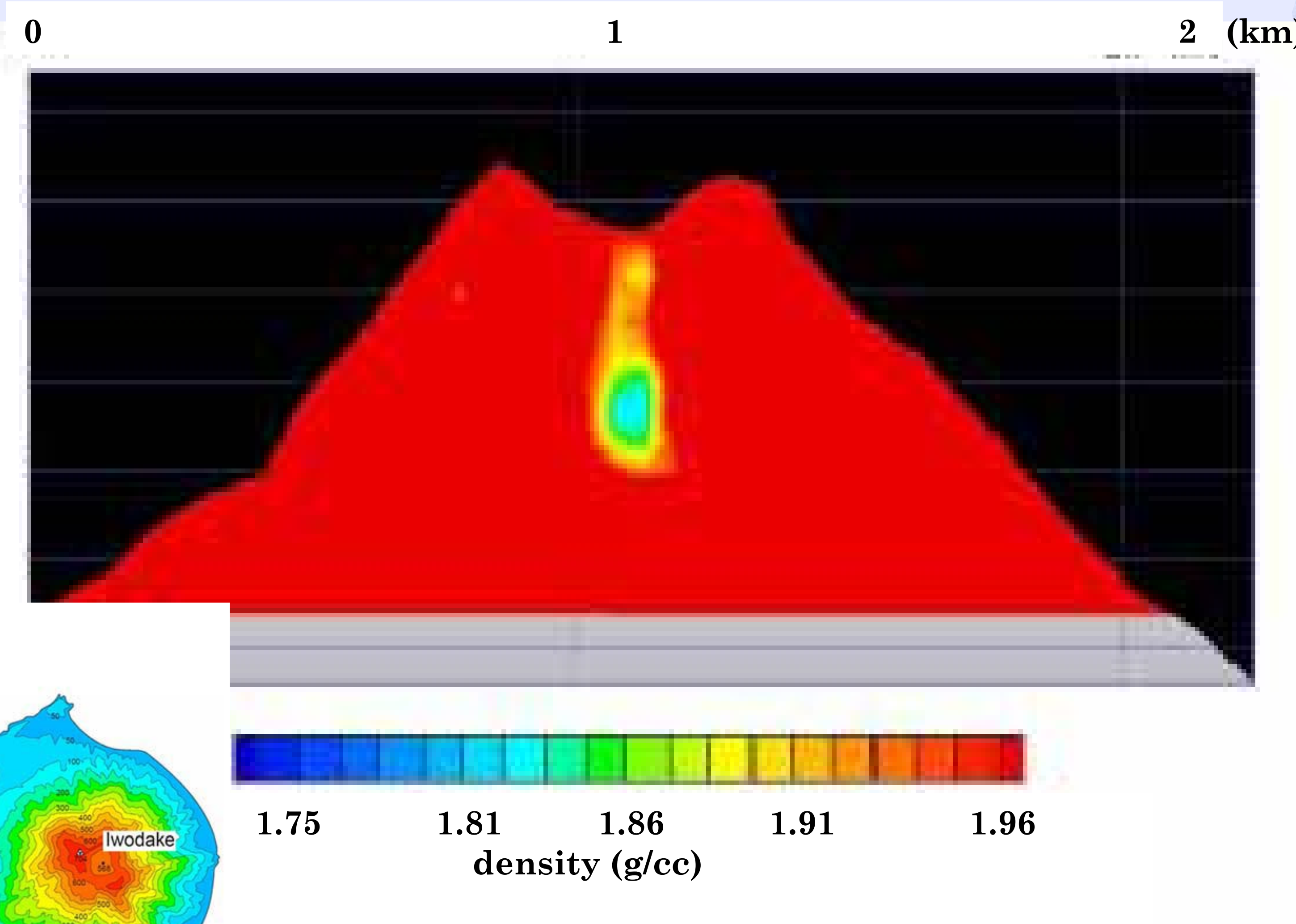
Muon electron proton neutron

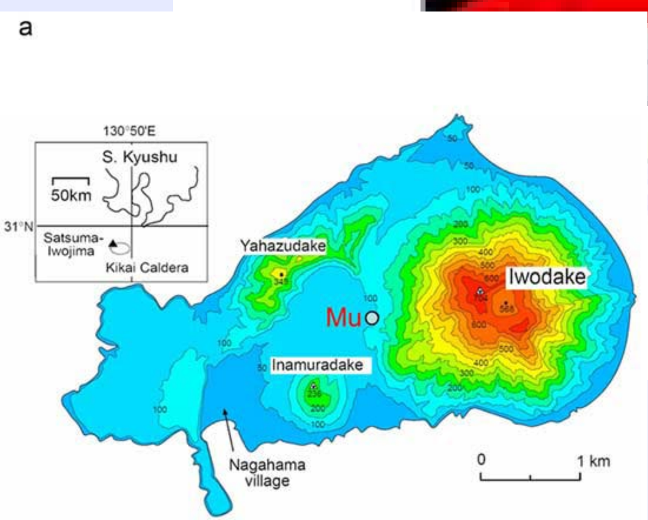


Muon and electron : agreed within 5%

Neutron and proton : agreed within 30%

Mt. Satsuma Iwo Jima





Seismic fault zone

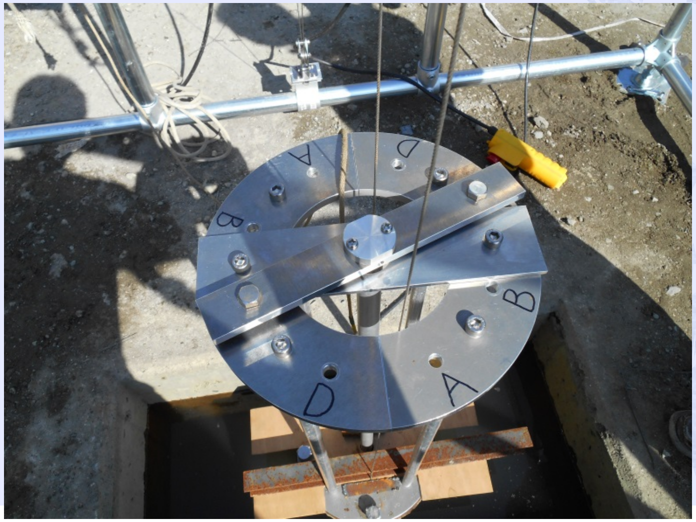
Fault crop

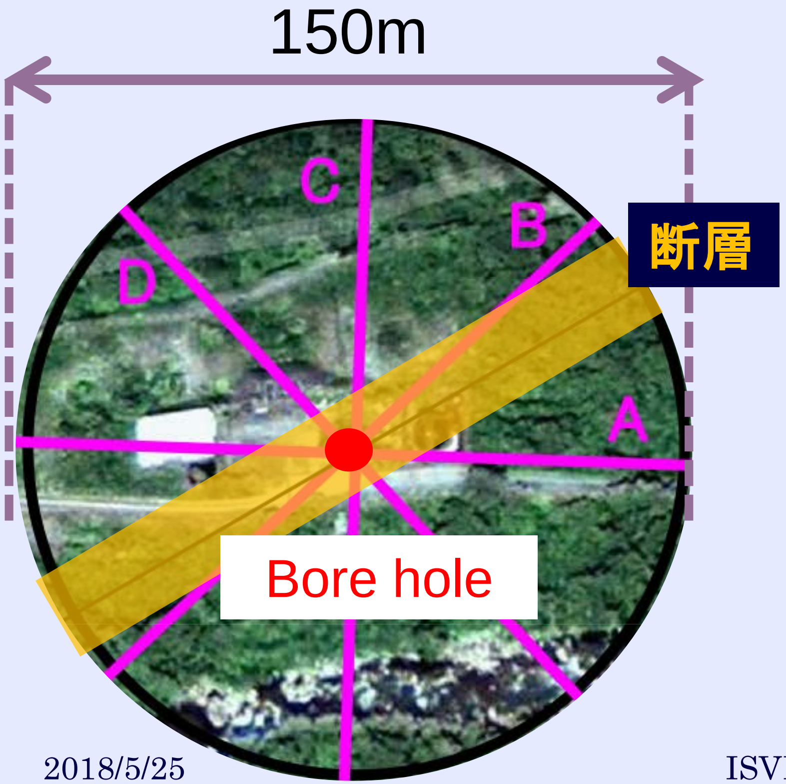
Fracture
Zone

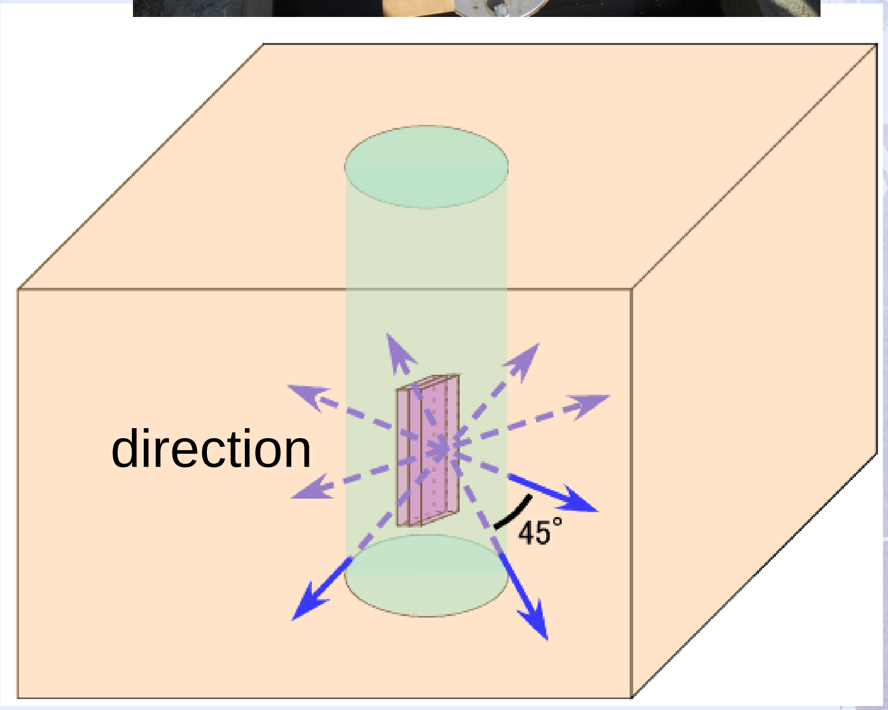

(¯-¯)2010/07/27(火) 17h03m21s650(38)

Outline of the observation

Period : Oct. 2013 ~ Dec. 2013
Depth : 10m ~ 100m (9 point)
Direction : 45 degree step

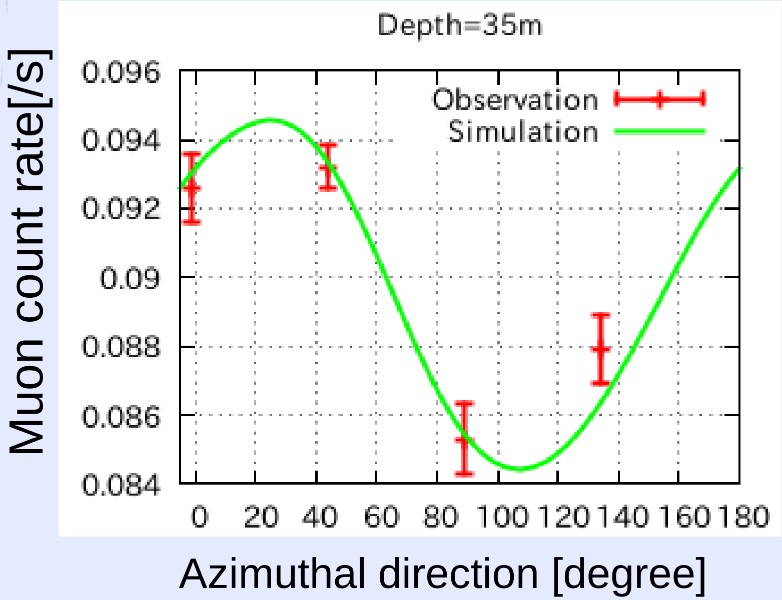




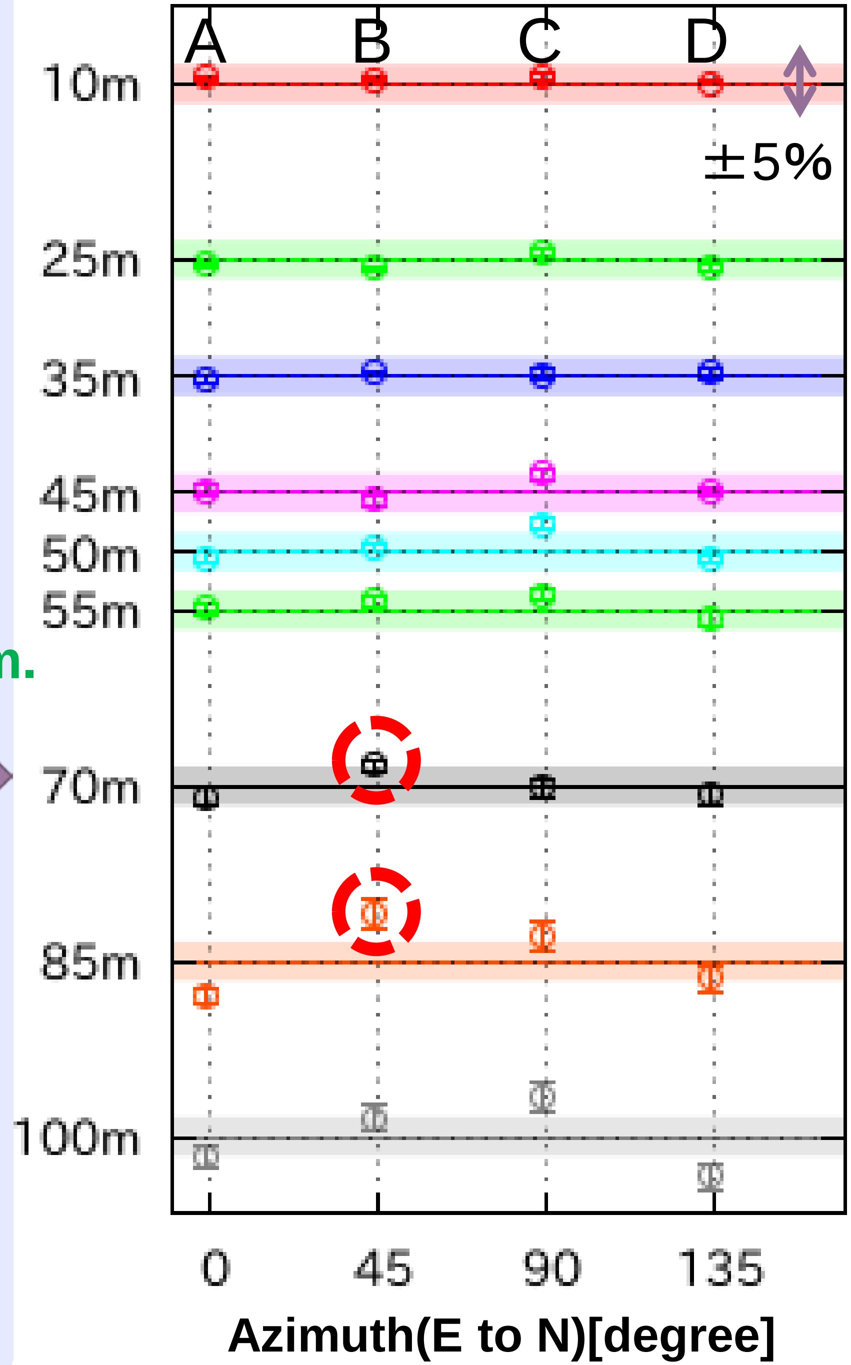


Result

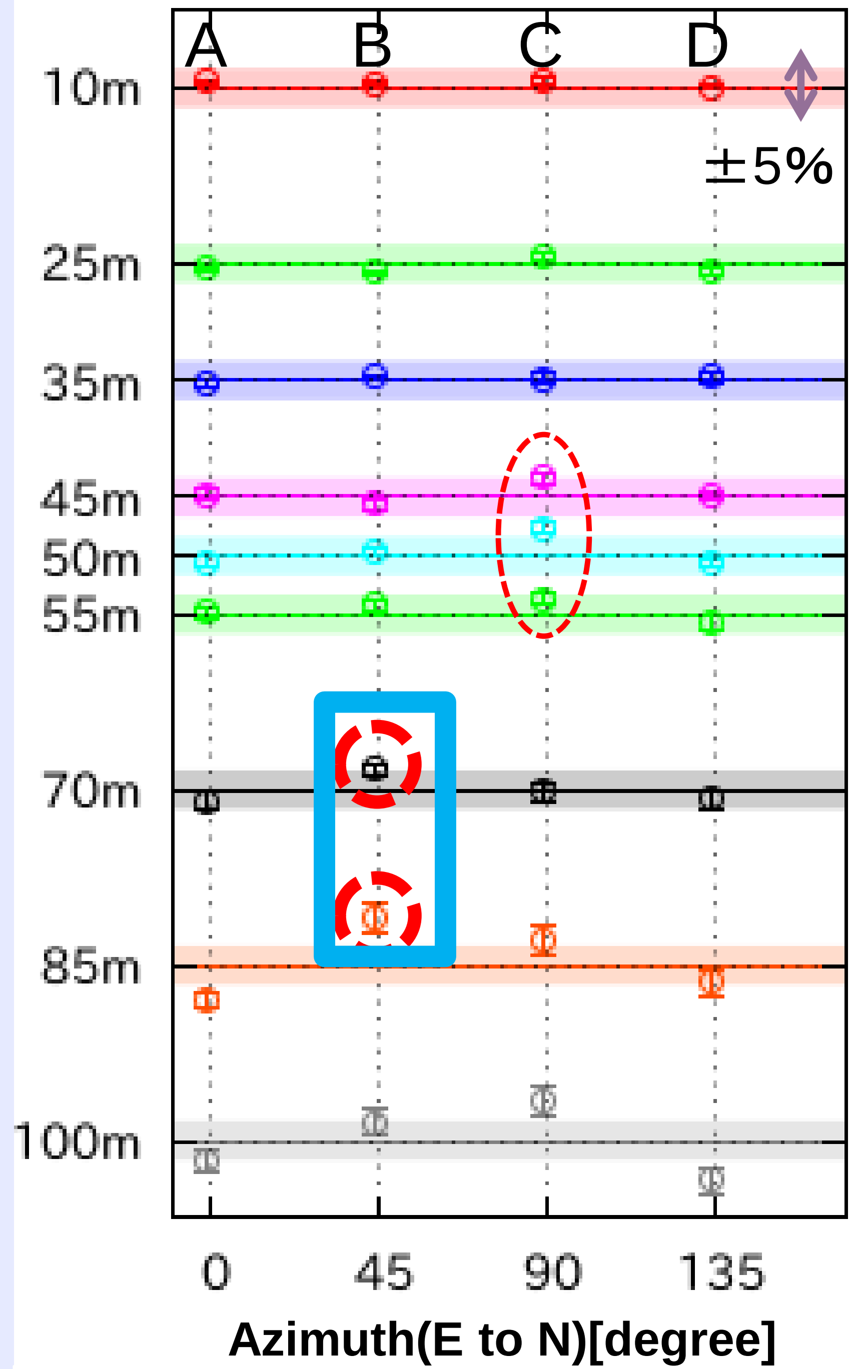
Muon flux and elevation map
Average density by muon :
2.403 ± 0.002 g/cc
Average density by sampling :
2.45± 0.1 g/cc



Obs./Sim.

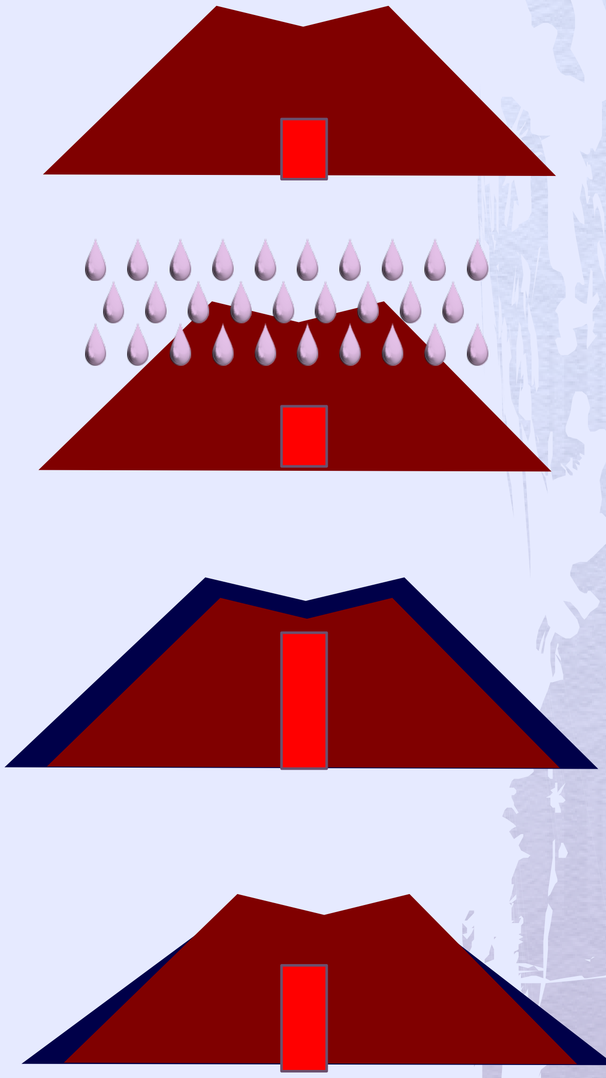


Consistent with seismic fault zone

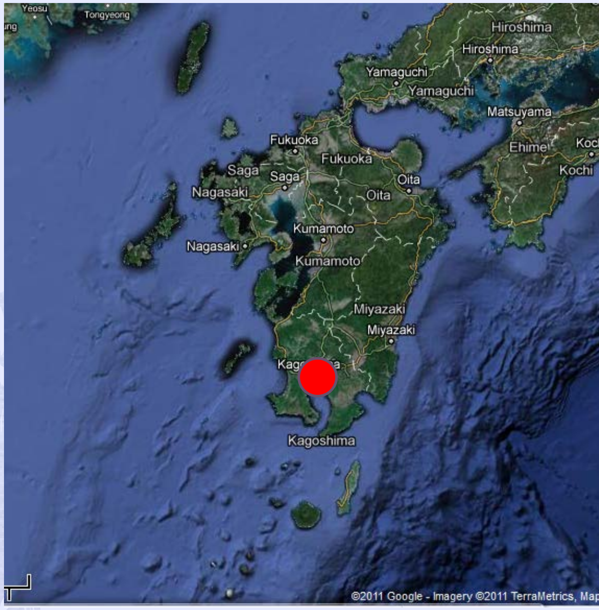


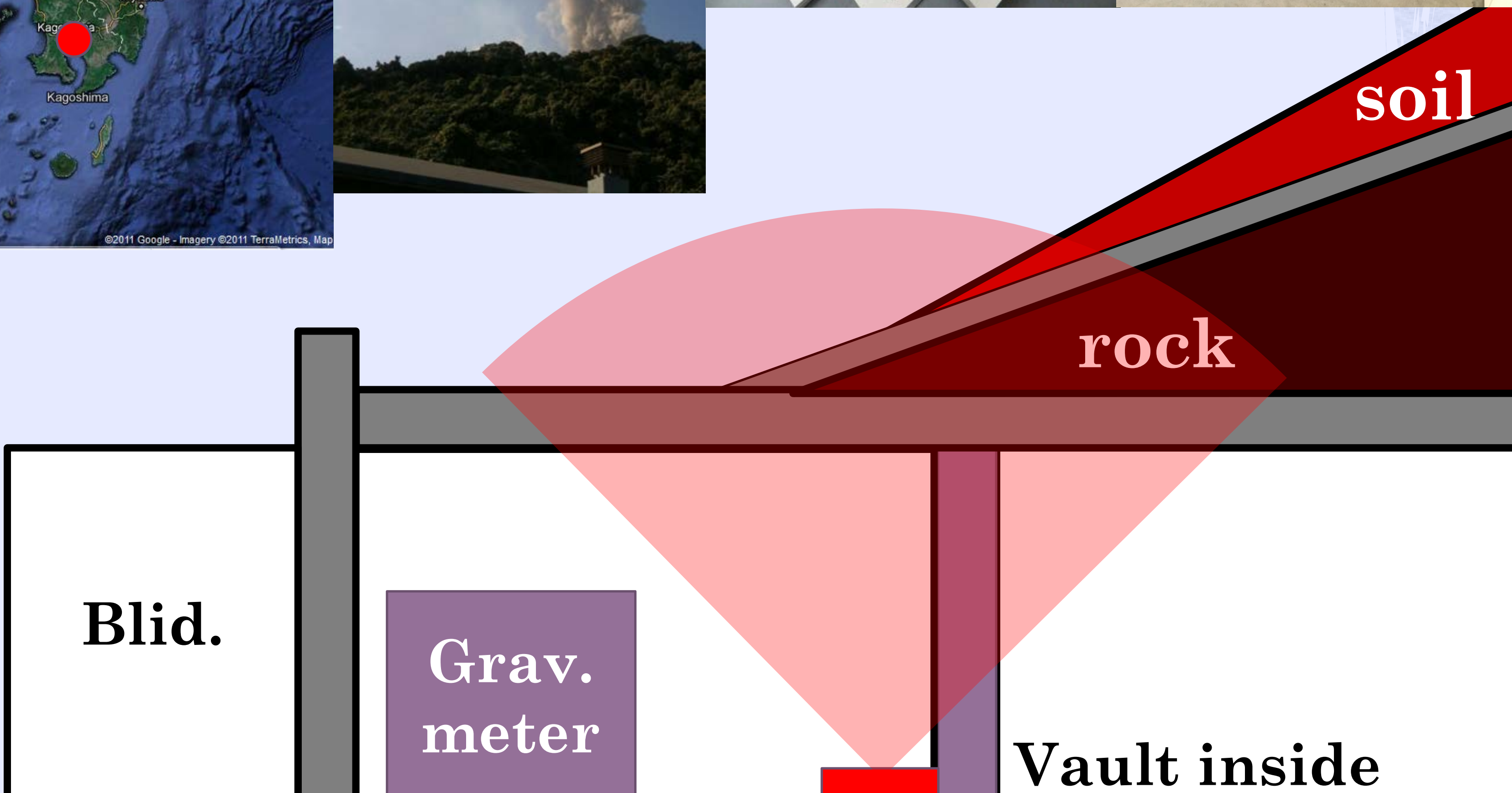
Air shower radiography : remote sensing of water

- Developed for water level indicator
  - Water level in the building
- Groundwater stream
  - Essential for eruption prediction
  - Magma movement is measured by gravitymeter
  - Gravitymeter is disturbed by water stream

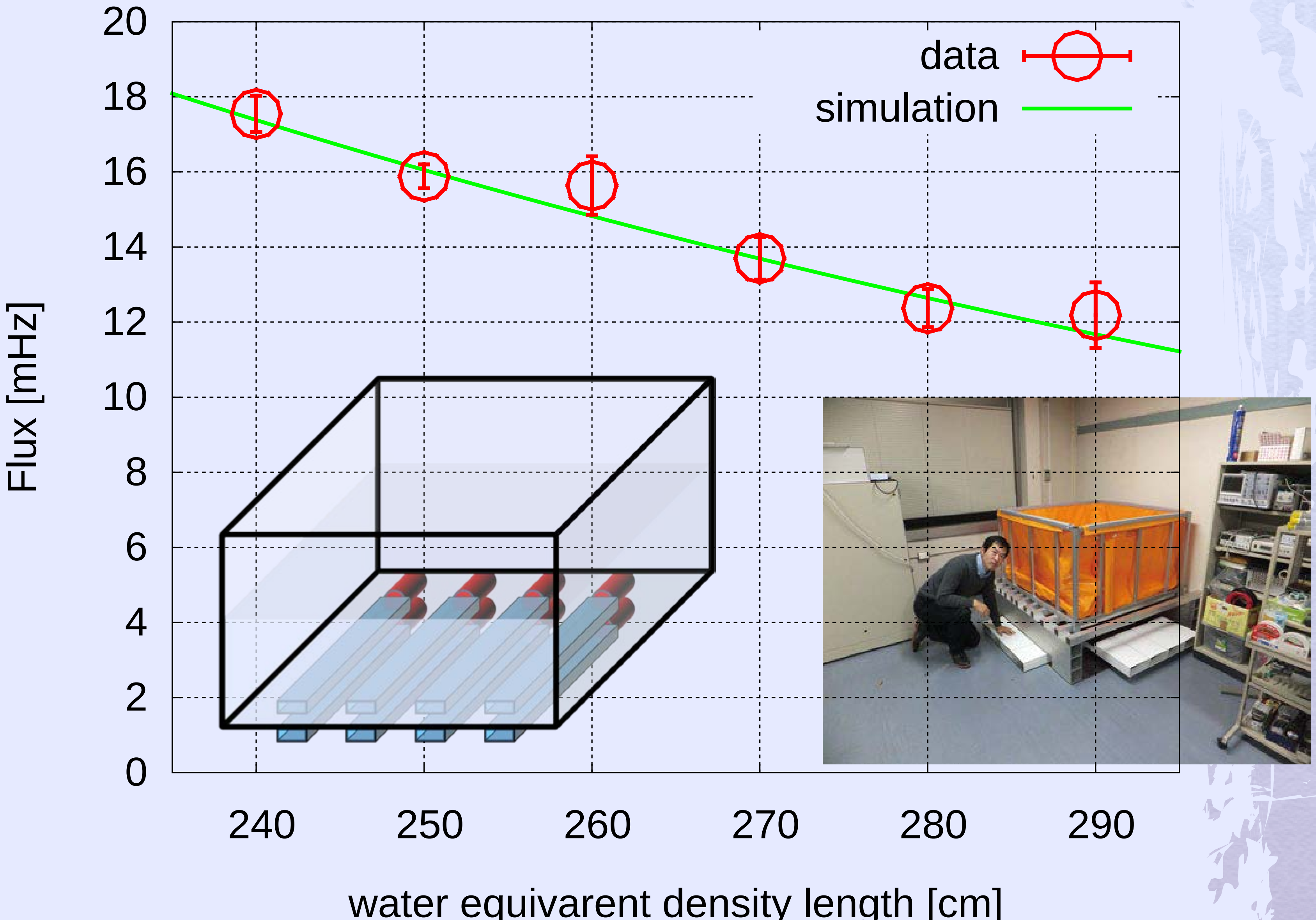


Mt Skurajima eruption prediction

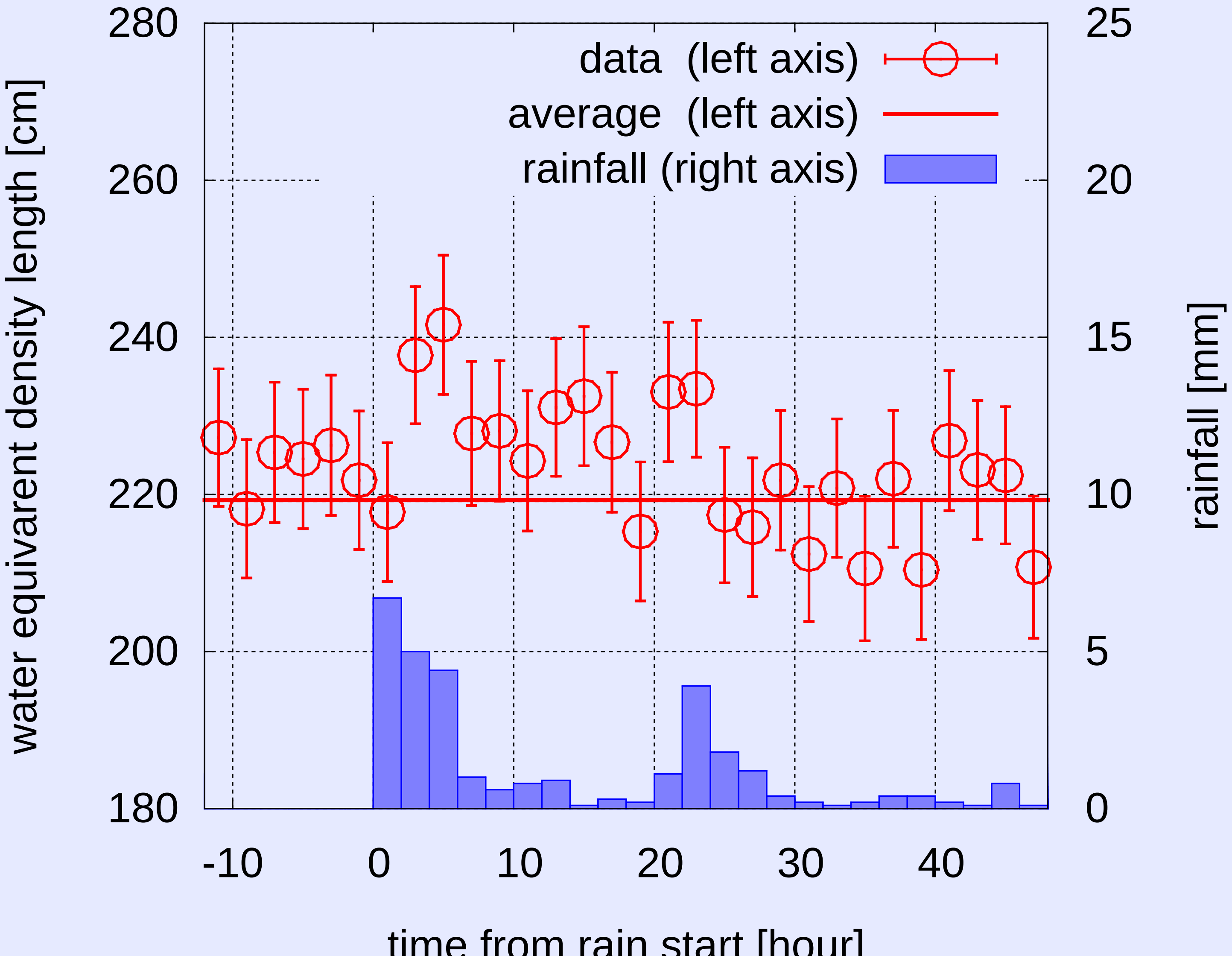


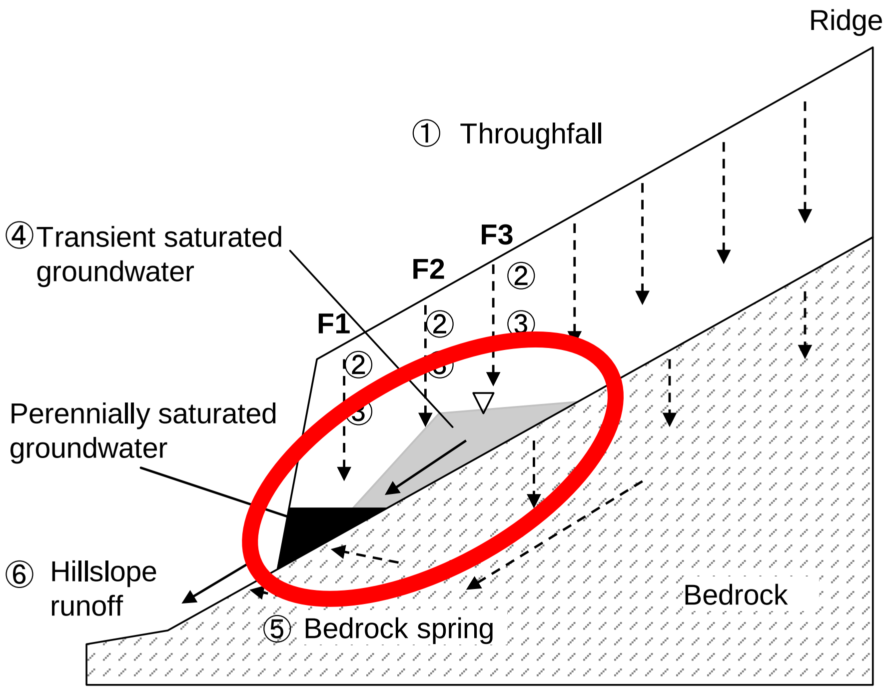


Water tank calibration



Density length and precipitation





宇宙線 噴火予知変える

マグマの様子 画像観測

■ミュー粒子　宇宙から飛来する放射線が大気に衝突してできる素粒子。電子の約200倍の質量がある。地上に届く多くの宇宙線は、ミュー粒子になっている。地表には手のひらくらいの面積に毎秒1個のミュー粒子が降り注いでいる。エックス線をはね返す巨大な岩盤も透過する。

マグマ噴火への移行が心配されているから、その予測に役立つかもしれない」と、田中教授は話す。

検出装置を山頂にずらりと並べ、内部の構造を精密にとらえる仕組みも構想している。富士山は山体が大きすぎてミュー粒子が透過せず、この方法は困難だ。

■水分を分析

マグマが地下水に触れて爆発する水蒸気爆発の予知は、ミュー粒子では難しい。マグマはとらえられても、水をとらえることはできないのだ。東大地震研の武多昭道助教は、ミュー粒子とは別の宇宙線の成分で、土壌の水分を分析する試みに着手している。

観測するのは電子やガンマ線で、水分が多いと、これらは弱くなる。昨年から桜島で始め、今年は装置を二台追加する。これによって、地中深いところの水分量を知り、マグマの動きの予測を精密にすることが可能になる。まだ基礎研究の段階だが、将来は水蒸気爆発の予知が可能になるかもしれない。土砂災害の防止につながるとの期待もある。「データを積み重ね、早く実用化につなげたい」と武多助教は話す。

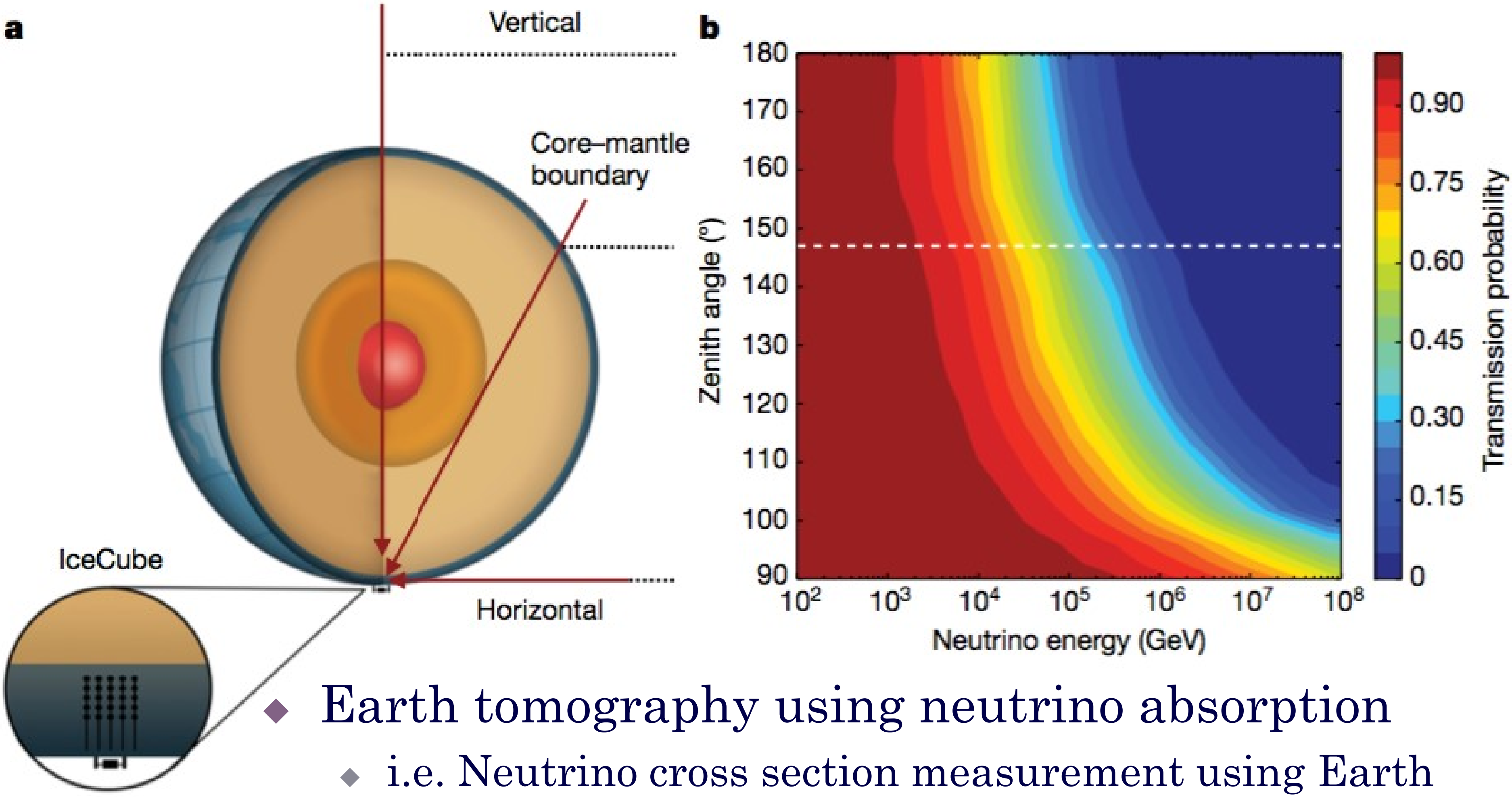
■遺跡の調査

ミュー粒子は、遺跡の調査にも使われ始めている。構造物を壊さずに内部を調べられるからだ。エジプトのピラミッドや奈良県の古墳の調査に実績がある。

田中教授は最近、インドネシア・ジャワ島の世界遺産・プランバナン寺院で、耐震性を調べた。今年は同じくジャワ島のボロブドゥール寺院で、三重大の佐里利一教授（地震工学）らと共同観測する。

宇宙線を用いた透視に、火山学者の関心は高い。早川由紀夫群馬大教授は「噴火予知にすぐ使えるとは思えないけれども、火山内部が透視できるのは、科学的にとても興味深い。技術として発展させることが大事だろう」と話している。

Neutrino absorption measured by IC

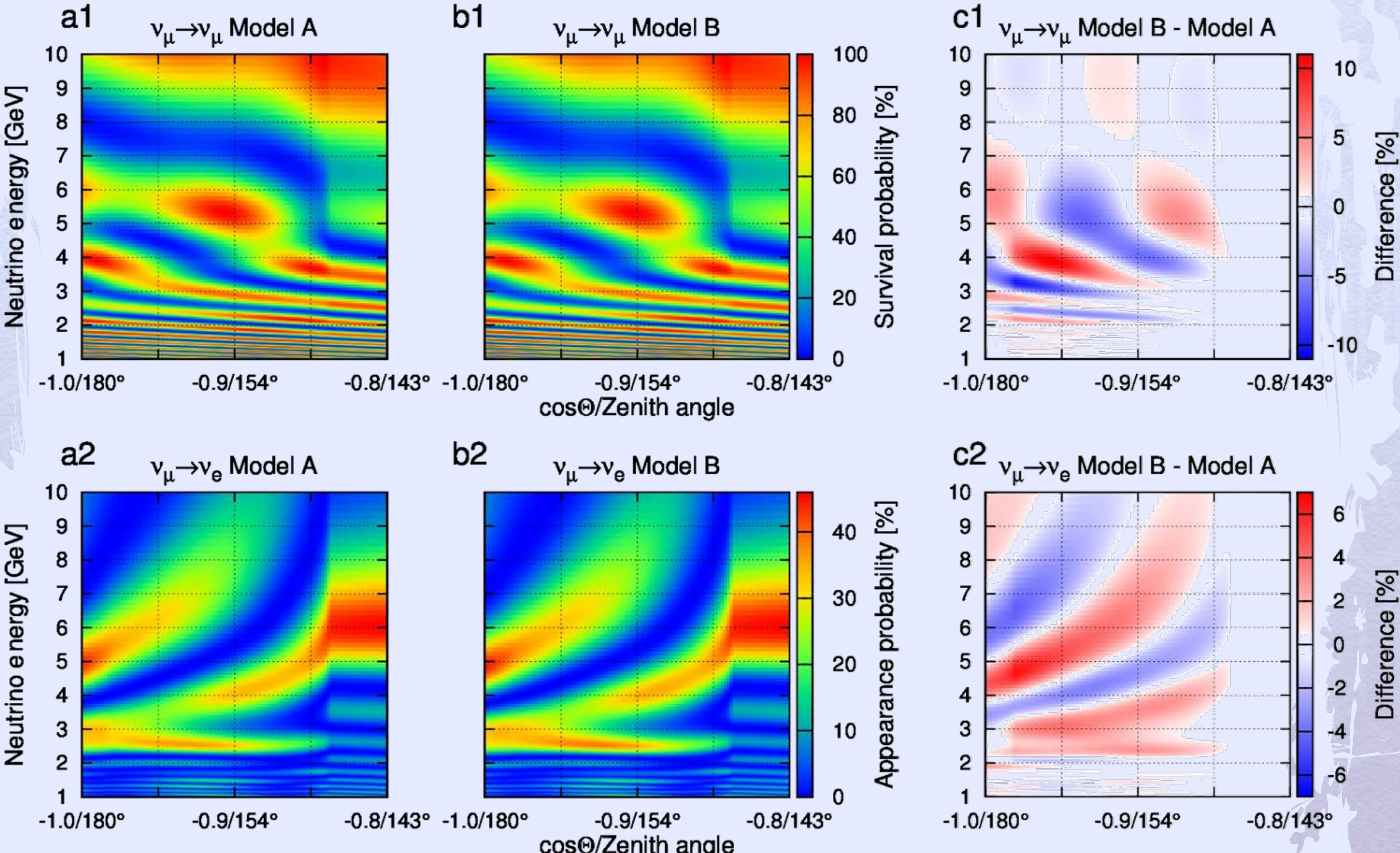


- Earth tomography using neutrino absorption
  - i.e. Neutrino cross section measurement using Earth

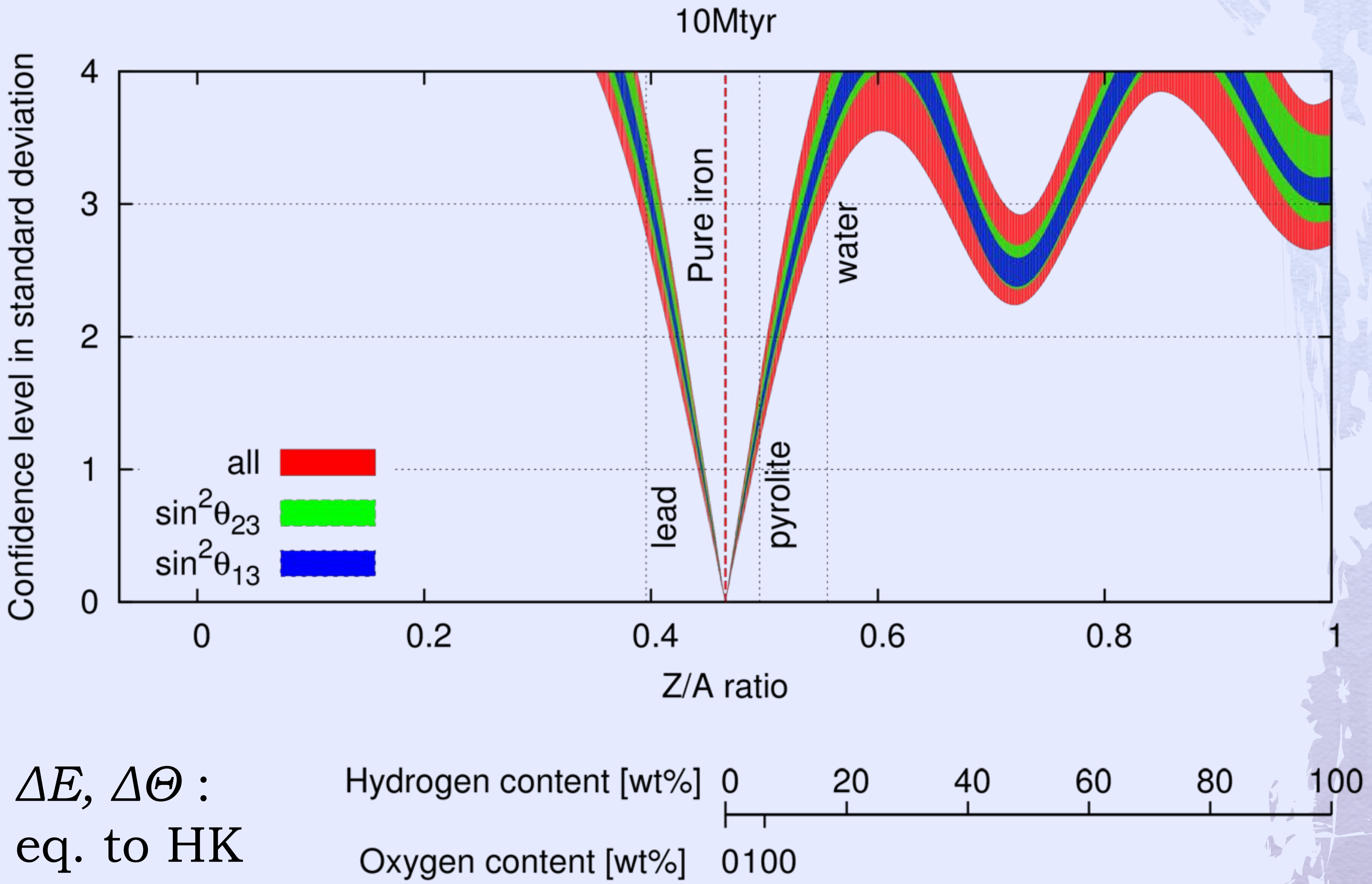
Geophysical application of ν osc.

- Neutrino oscillation probability depend on **electron density**, not matter density
- By using neutrino oscillation, we can measure the electron density of the medium
  - If we knew the neutrino property very well
  - And had sensitive(=very large) detector
- We have the precise matter density profile of the earth
  - From seismic wave tomography and free oscillation
- Combining matter density and electron density, **we can measure the average chemical composition of the deep earth !**
  - Ratio of atomic number to mass number (Z/A)

Oscillograms (Fe vs Fe+2wt%)



Outer Core composition by HK



ΔE, ΔΘ :
eq. to HK