NuTel, Ashra-1, and NTA

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II. NuTel and Ashra-1

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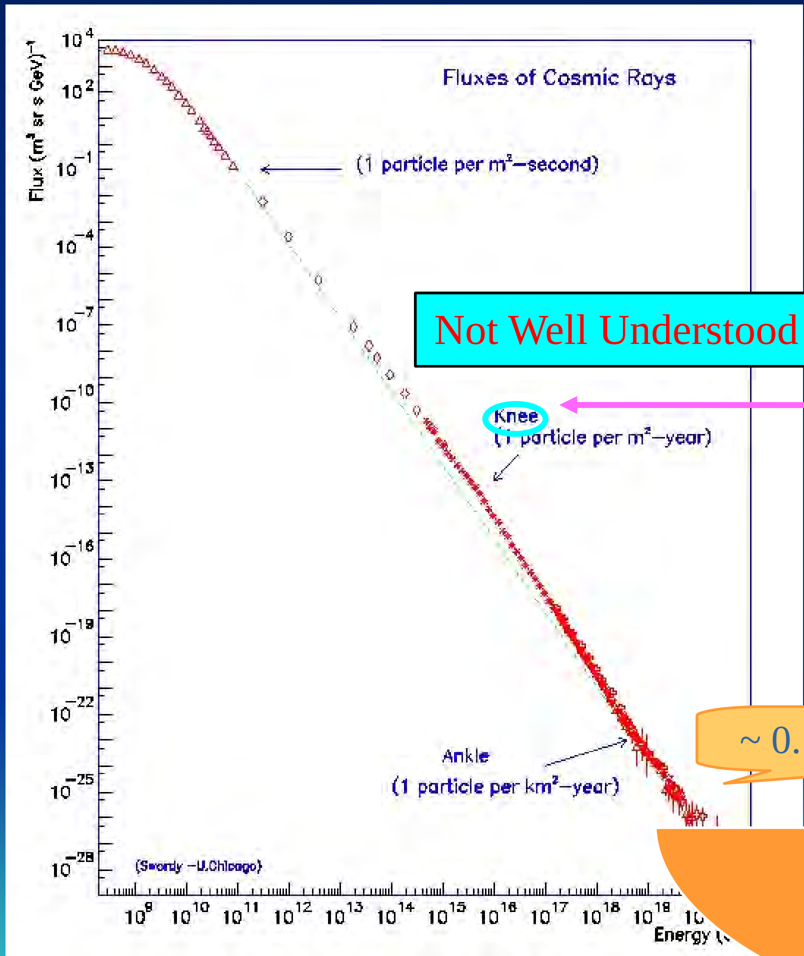
IV. Conclusion and Discussion

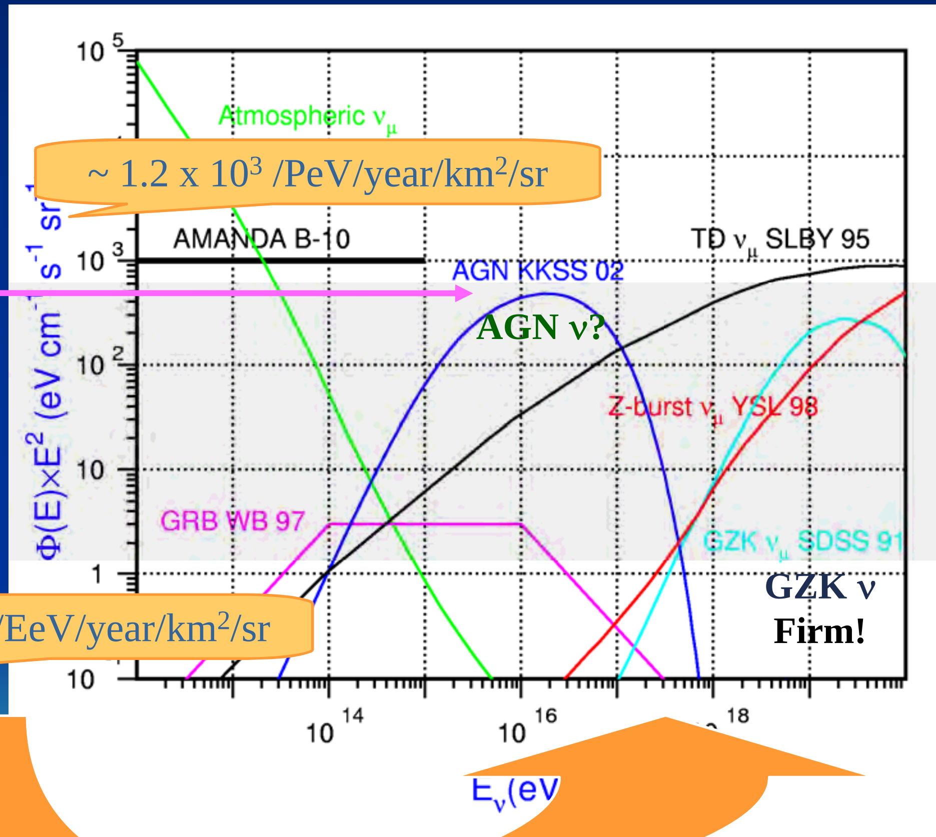
Cosmic Rays and Neutrinos

Cosmic Ray Spectrum



Not Well Understood

$CR + X \rightarrow \pi^{\pm} \rightarrow e^{\pm} + 2\nu_{\mu} + \nu_e$



~ 1.2 x 10^3 /PeV/year/km^2/sr

AGN ν?

~ 0.1 /EeV/year/km^2/sr

GZK ν
Firm!

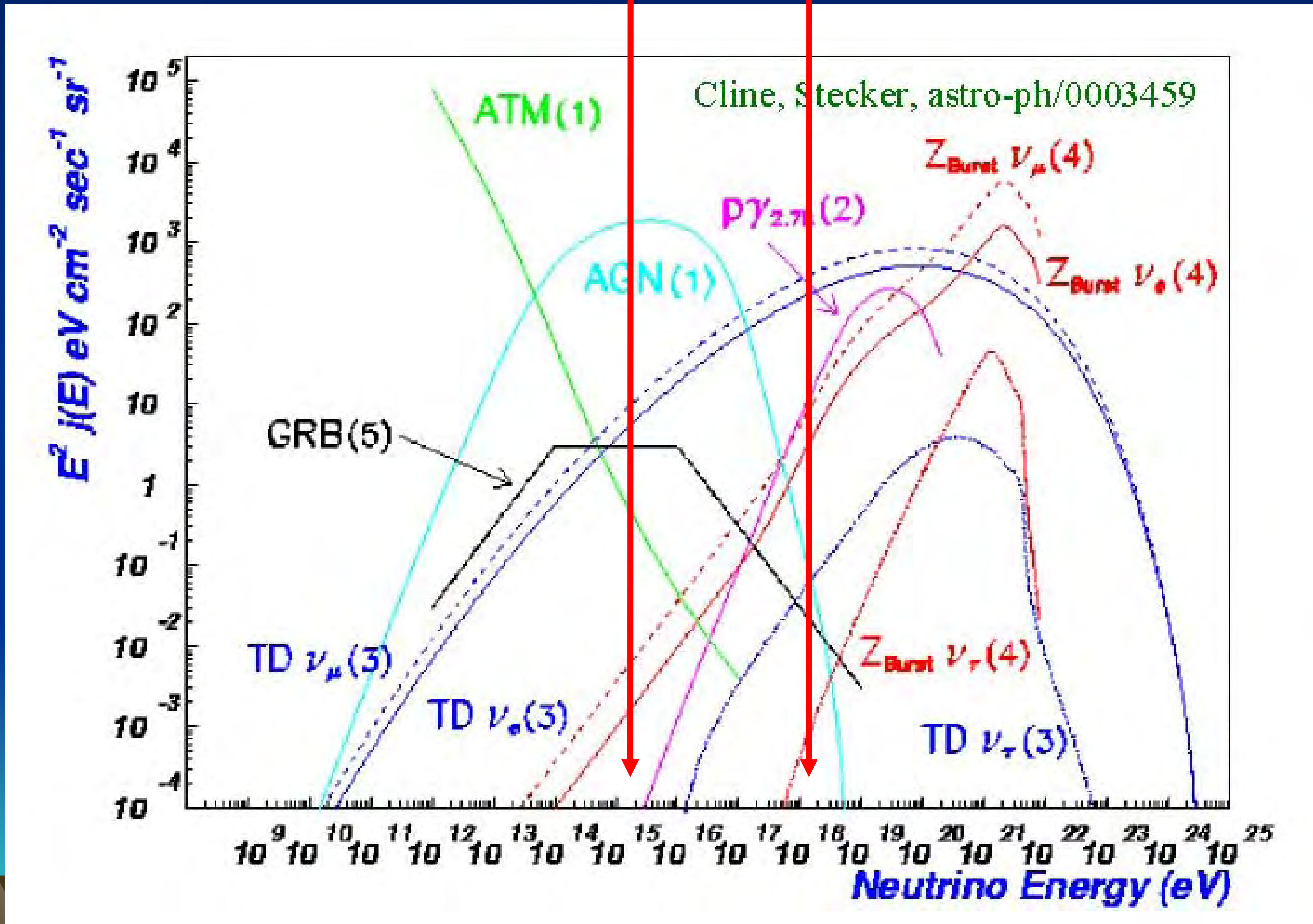
$UHECR + \gamma_{CMB} \rightarrow N + \pi \rightarrow GZK\ \nu$

Window of Opportunity

Conventional ν Detector

?

UHECR ν Detector

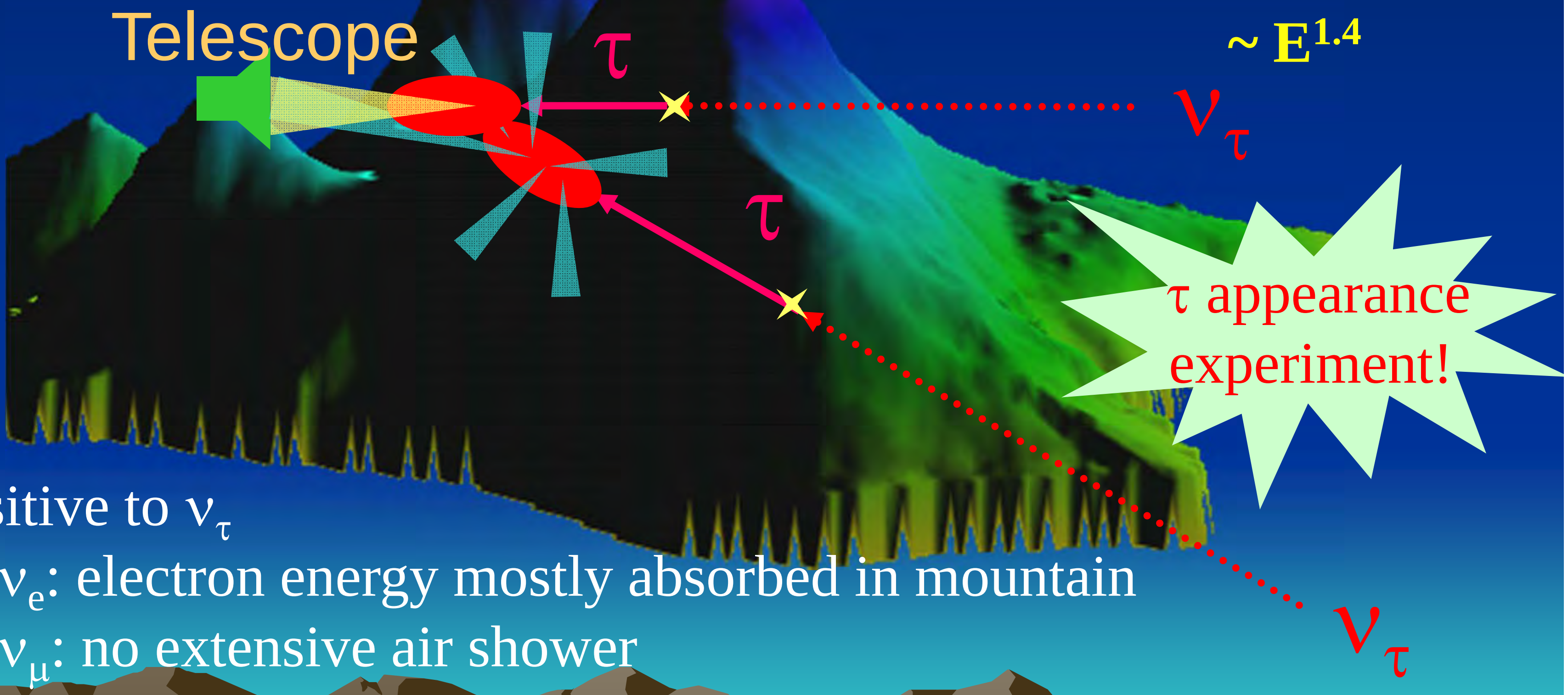


Earth Skimming

Earth Skimming + Mountain Penetrating

Cherenkov vs. fluorescence

Cross Section $\sim E^{1.4}$

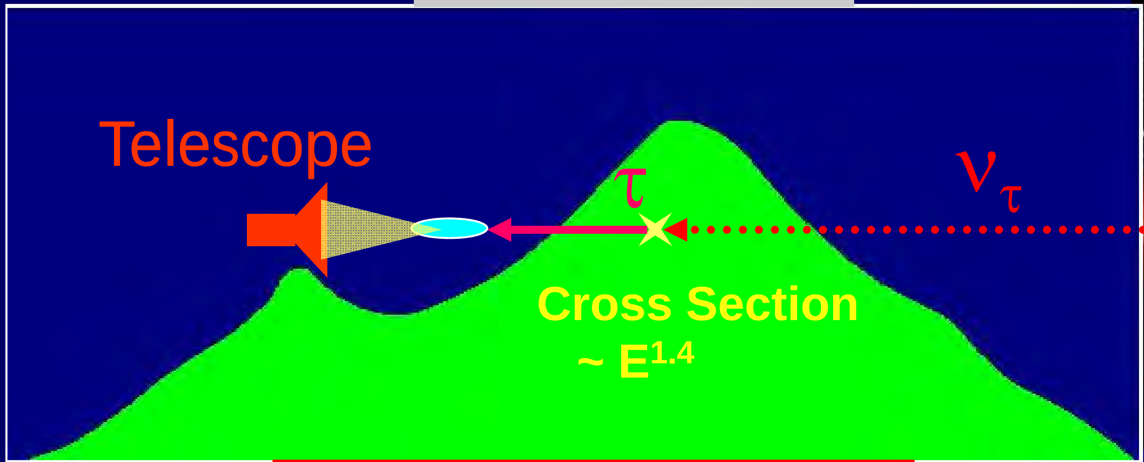


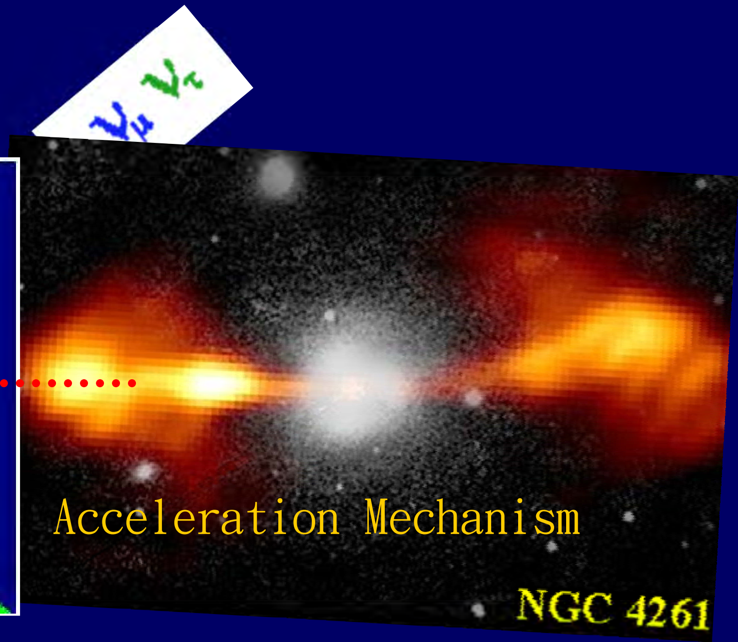
Sensitive to ν_τ

- ν_e: electron energy mostly absorbed in mountain
- ν_μ: no extensive air shower

Detection Mechanism

τ Appearance!





τ *Decay*: Air Shower
→ ns Cherenkov

What I learned 8/2001
▸ Vannucci Visit to NTU

- Earth Center Opaque for E > 10^{14} eV ν *!?*
- Mountain-Valley ν_τ Detection Concept

I asked whether he already had funding …
after - checking literature (e.g. Fargion)
- passing it thru NTUHEP PIs

I hired Alfred Huang in Fall (start simulations)

(had to convince him …)

Hawaii Site also came out from Vannucci visit …

Hawaii Big Island as Site: happened as *gotcha*

- Courtesy visit to CosPA-1
  [Fred Lo]
  - Hawaii is known good Astro Site
  - Stood together in front of Hawaii map
  - *Snap*: Big Mountains w/ 40 km sep.
- Mt. Hualalai: M. Alfred Huang

Good view of Mauna Loa

Situated at dryer west side

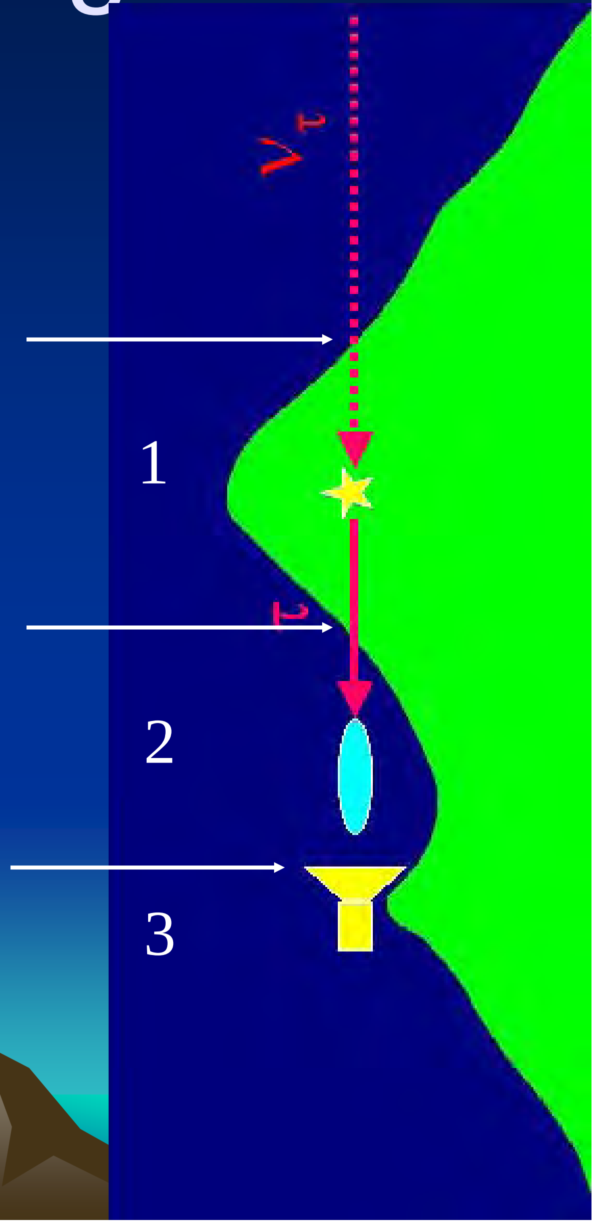
Mauna Loa provide long base line

~ 90 km wide and 4 km high

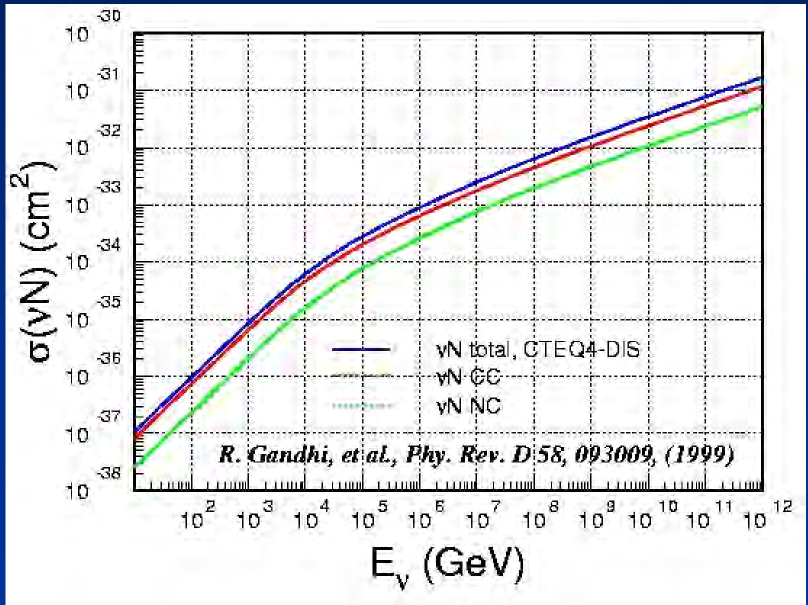
GWS Hou & MA Huang, astro-ph/0204145
P Yeh et al., MPLA 19 (2004) 1117 [CosPA 2003 WS]

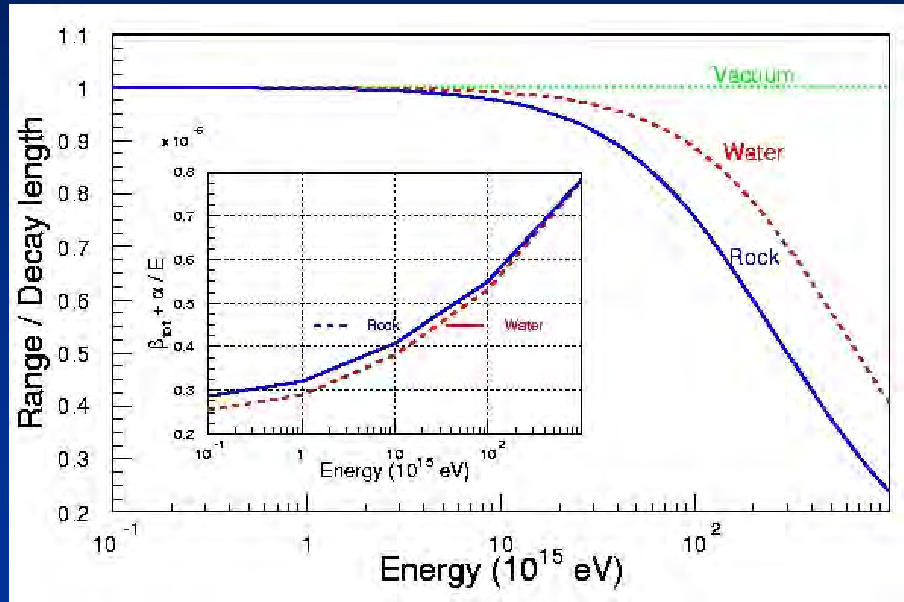
Three simulation stages

1. Mountain simulation: $\nu_\tau \rightarrow \tau$
   - ν+N cross-section
   - – inelasticity
   - – energy loss of tau
2. Air shower simulation:
   $\tau \rightarrow$ Cherenkov photons
   - – τ decay mode
   - – CORSIKA detailed air shower simulation
     vs. fast simulation
3. Detector performance simulation
   - – light propagation + Q.E.
   - – pixelization for triggers
   - – reconstruction



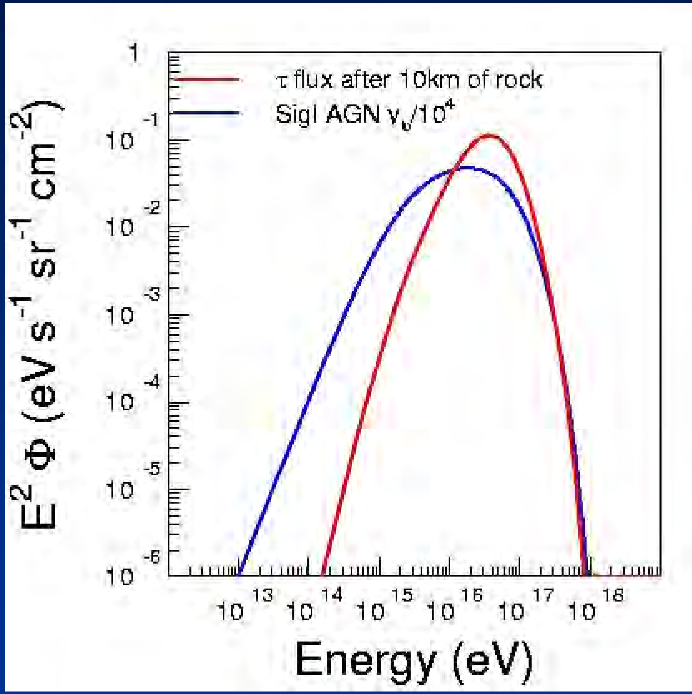
$\nu_\tau \to \tau$ inside mountain

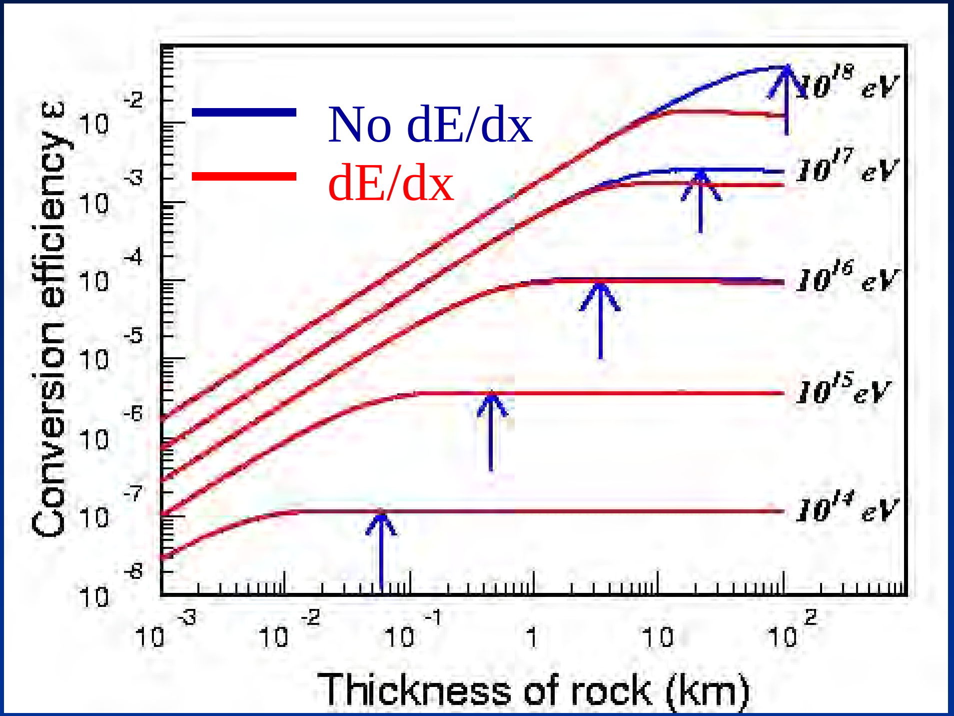




- SM CC ν+N cross-section
- Inelasticity & energy loss calculated by G.L. Lin, J.J. Tseng, T.W. Yeh, F.F. Lee of NCTU
- Range (distance when survival prob = e^{-1}) calculated by M.A. Huang

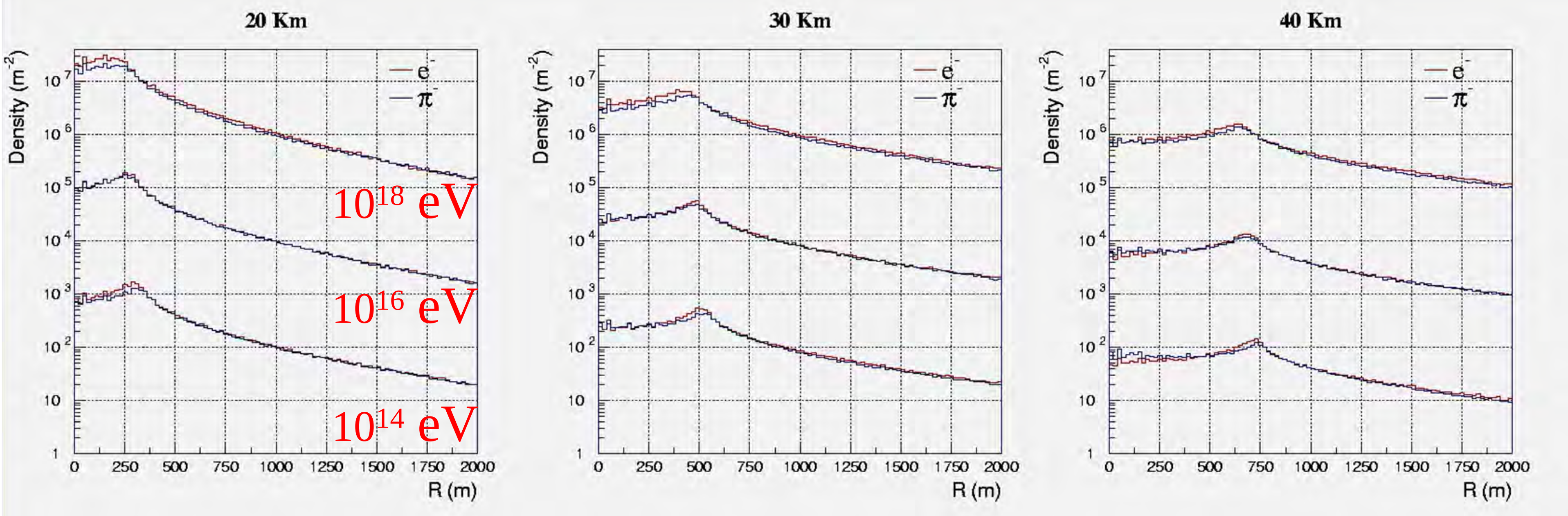
Tau flux





- Tau flux:
  - Fast simulation: single interaction inside target
  - Full transport eq.: Consider multiple interactions $\nu_\tau \rightarrow \tau \rightarrow \nu_\tau \rightarrow \tau$ ...
- Conversion efficiency:
  - optimal thickness ~ several times of λ_τ
  - Energy loss decrease conversion efficiency

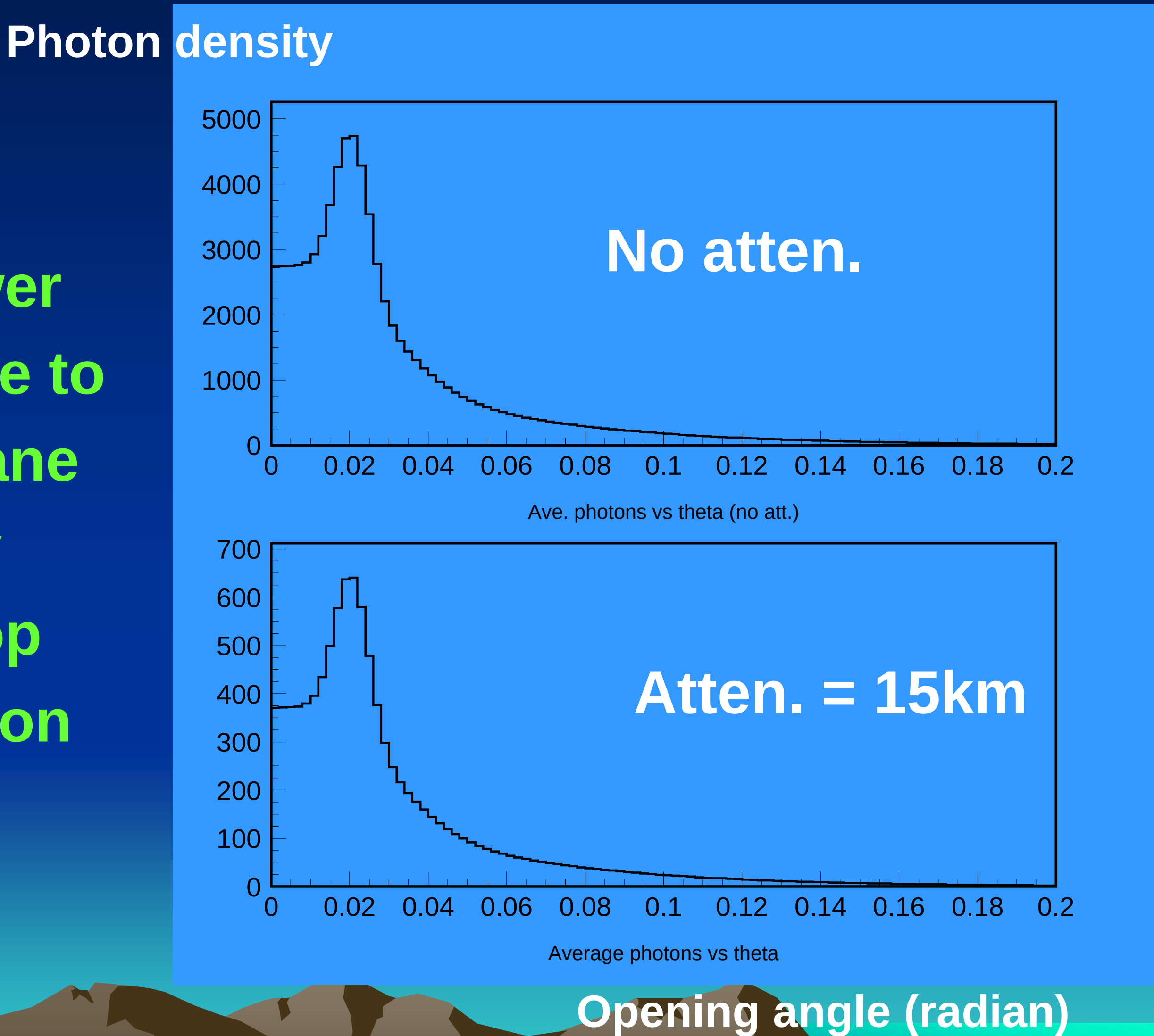
Lateral profile of Cherenkov photons for horizontal shower (CORSIKA)



- Similar profile for showers produced by e^- and π^-
- Cherenkov ring distance ~ $(L\text{-}R_{max})\times\text{Tan}\ \theta_c$
- Outside ring, photon density ~ exponential decay
- Detector can trigger far away from Cherenkov ring

Photons numbers vs opening angle

- 1 PeV shower
- Shower core to detector plane 30 km away
- Serious drop w/ attenuation



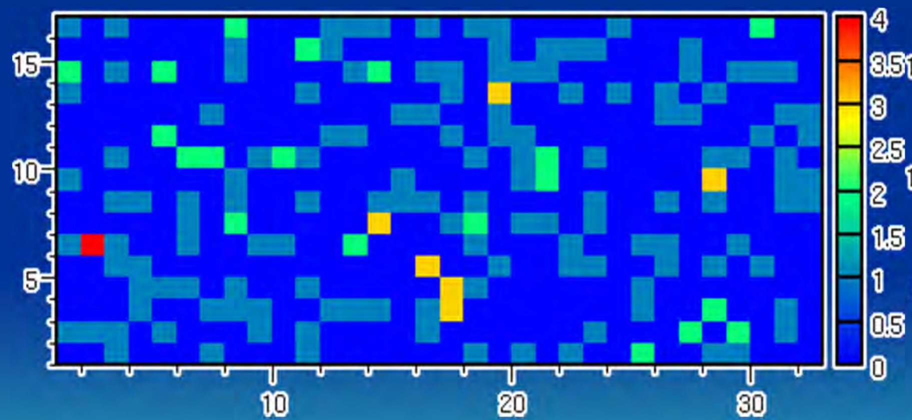
The Signal and Background Pattern

Cherenkov: ns pulse, angular span ~ 1.5 degrees
Night Sky Background (mean)

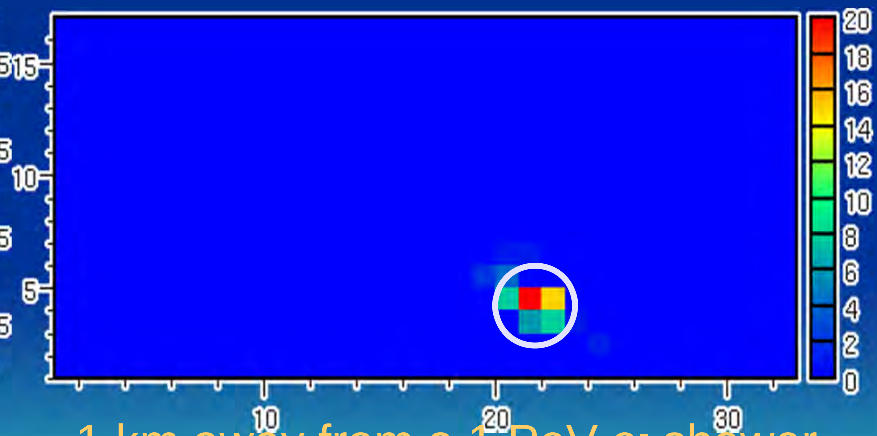
Measured at Lulin observatory: 2.0 x10^3 ph/ns/m^2/sr

A magnitude 0 star gives 7.6 ph/m^2/ns in (290,390) nm

Cosmic Ray background very small
Cluster-based trigger algorithm



Random Background with NSB flux



1 km away from a 1 PeV e^- shower

Trigger Configuration

- Single Pixel Trigger: One pixel pass energy threshold H

H

- Duo Trigger: Two neighbouring pixels pass threshold H

H	H

- H-L Trigger: Two neighbouring pixels with one passes high threshold H and the other one passes low threshold L

H	L

- Sum Trigger: 1. (3x3) trigger cell
  2. Central pixel pass high threshold H
  Neighbour Npe Sum pass threshold A=n1+n2+…+n8

n1	n2	n3
n8	H	n4
n7	n6	n5

Night Sky Background:

- Npe Follows Poisson distribution: $\mathrm{Prob}(n;\mu) = e^{-\mu}\,\mu^n/n!$,

  $\mu = \langle Npe \rangle \quad \Phi\, t_g\, A\, FOV\, \varepsilon_A\, \varepsilon_q$,

  $\Phi = 200/\mathrm{ns/m^2/sr}$ $A=1\mathrm{m}^2$ $FOV=0.5^o \mathrm{x} 0.5^o$ $\varepsilon_A = 0.5$ $\varepsilon_q = 0.2$

  $\mu = 0.039$ tg=25ns ; $\mu = 0.076$ tg=50ns

Range < 0.5 km: Majority of photon arrives within 25 ns

Most photons arrives within 50 ns

Trigger Efficiency for Electron Shower

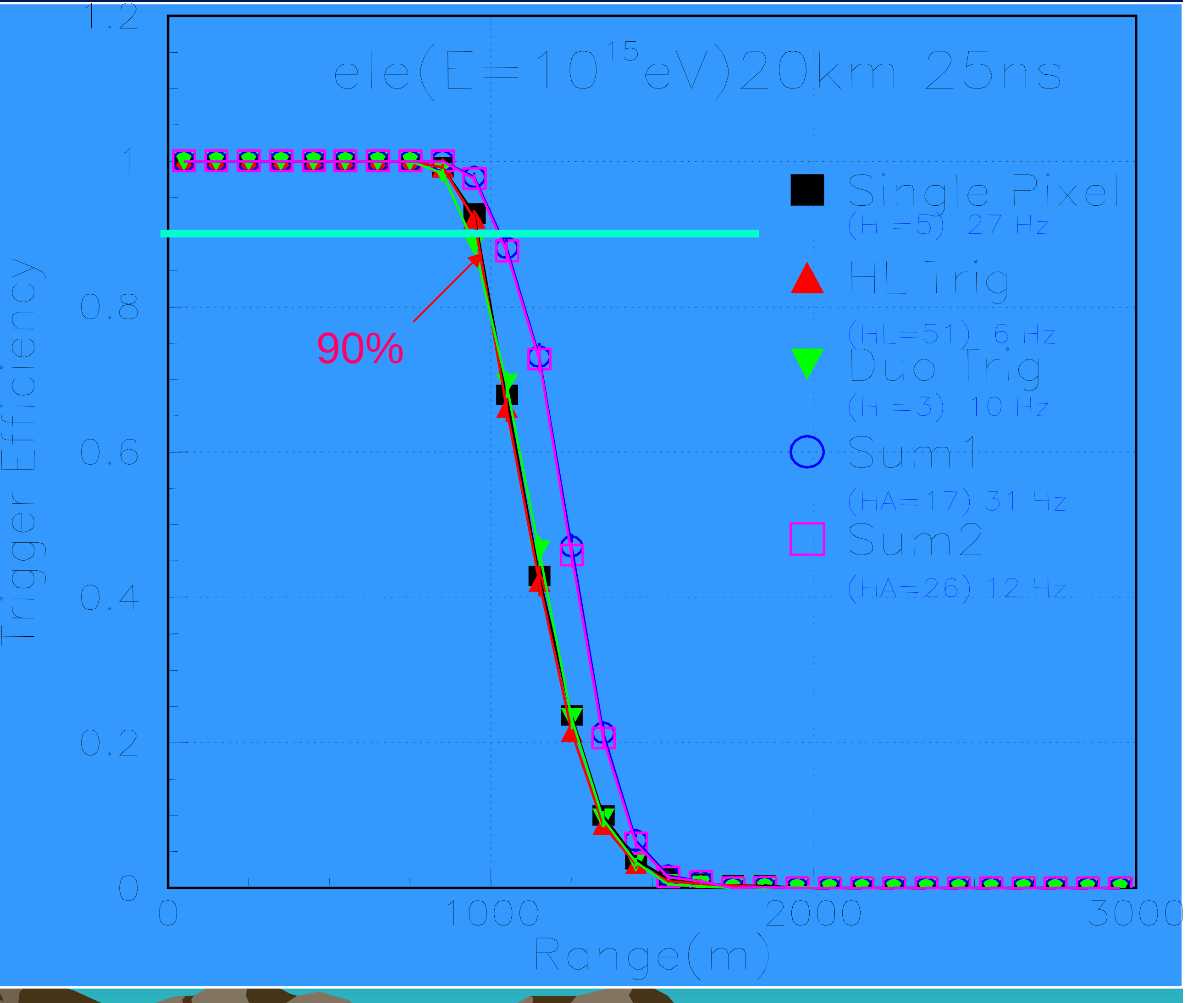
Sum Trigger gives largest range

1.1 km for ε_{trig} = 90%

Sum 2 trigger similar

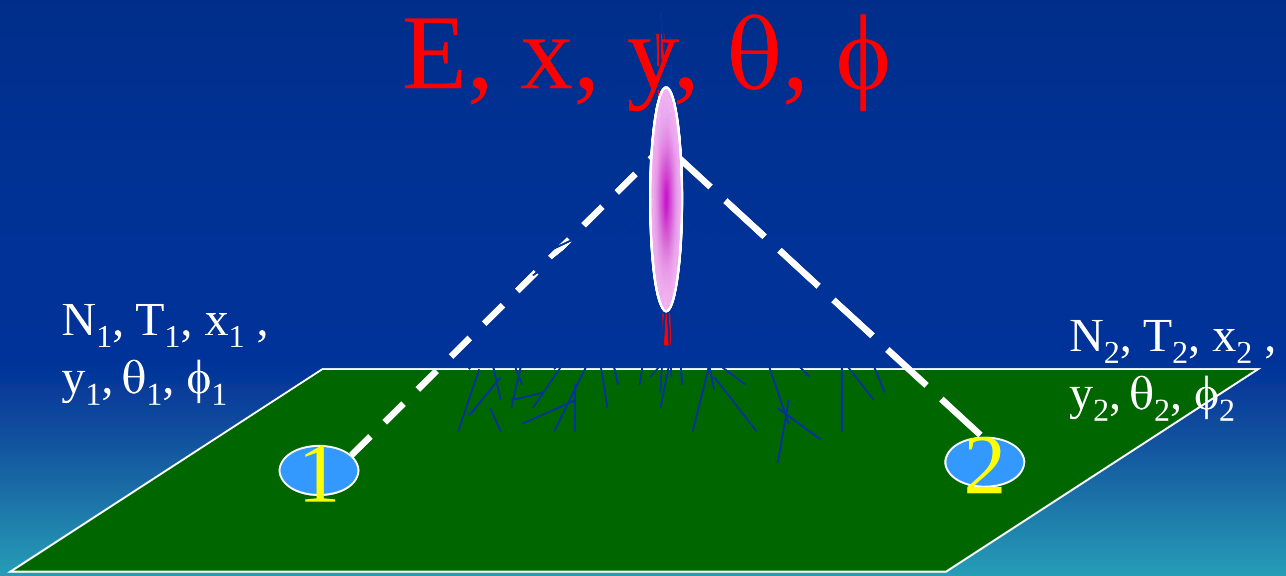
Other three triggers Similar to each other

Conservative estimate: 200 γ needed



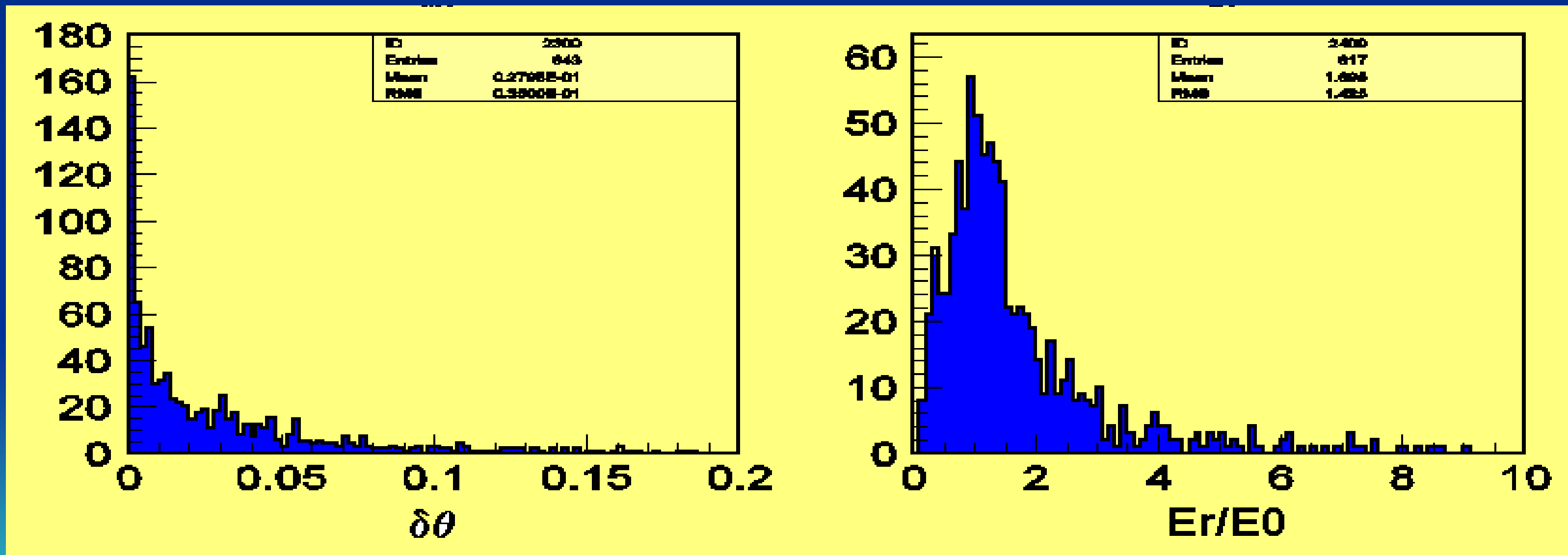
Preliminary Reconstruction

- Reconstruction: Minimize χ^2 for x, y, θ, ϕ, and E
  - <u>Two Detectors</u> Separated by ~ 100 m



Possibility for Reconstruction

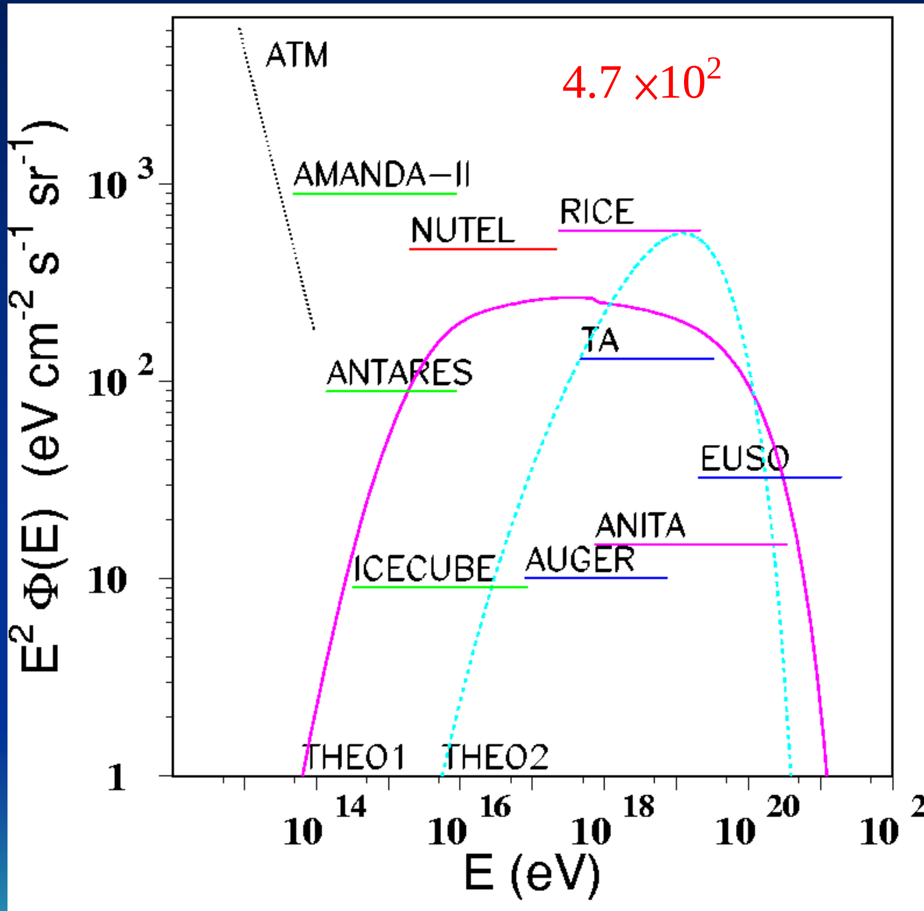
- – Angular Error within 1°
- – Energy Error ~ 40%
- – Reconstruction Efficiency > 90% if triggered



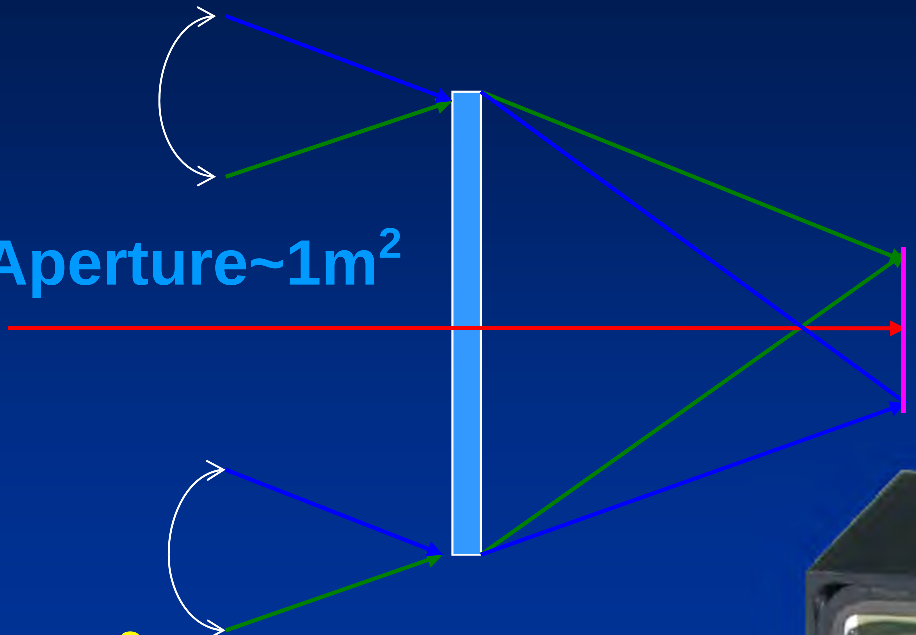
Sensitivity

- Defined as reachable upper limit of flux
- Assume $F(En) = F0\ En^{-2}$
- Assume no signal in 2 years of observation
- Feldman-Cousin method for upper limits:
  - 2.44 signal events
- Theo1: ~ 0.5 events/year

diffuse



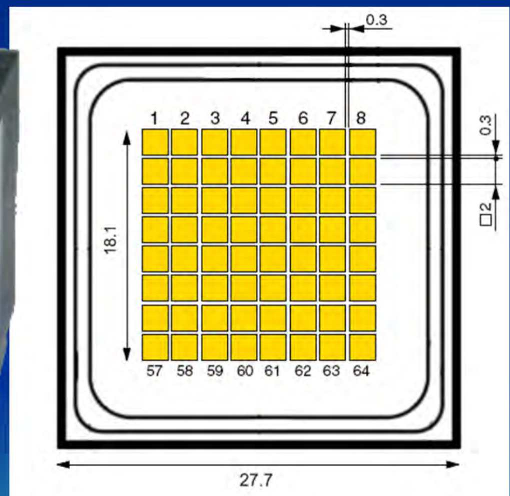
Demands of Optical system



Aperture~1m^2

Photo sensor:
8 x 8 MAPMTs with 512 pixels

FOV: 16^o horizontally
8^o vertically

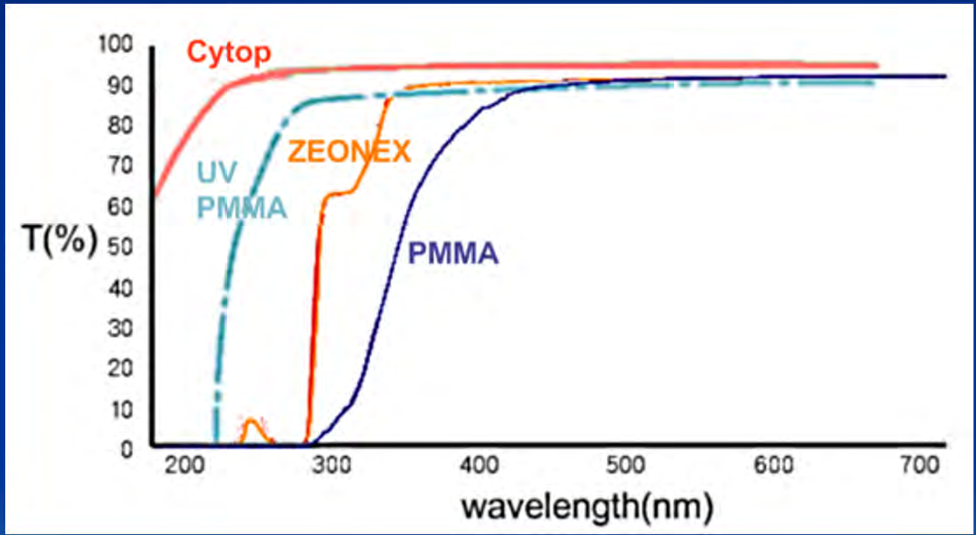


- Smaller image size is better.
- Smaller spot size is better.
- Wavelength: UV region, because it has more Cherenkov light as $1/\lambda^2$.

Fresnel lens system not good enough

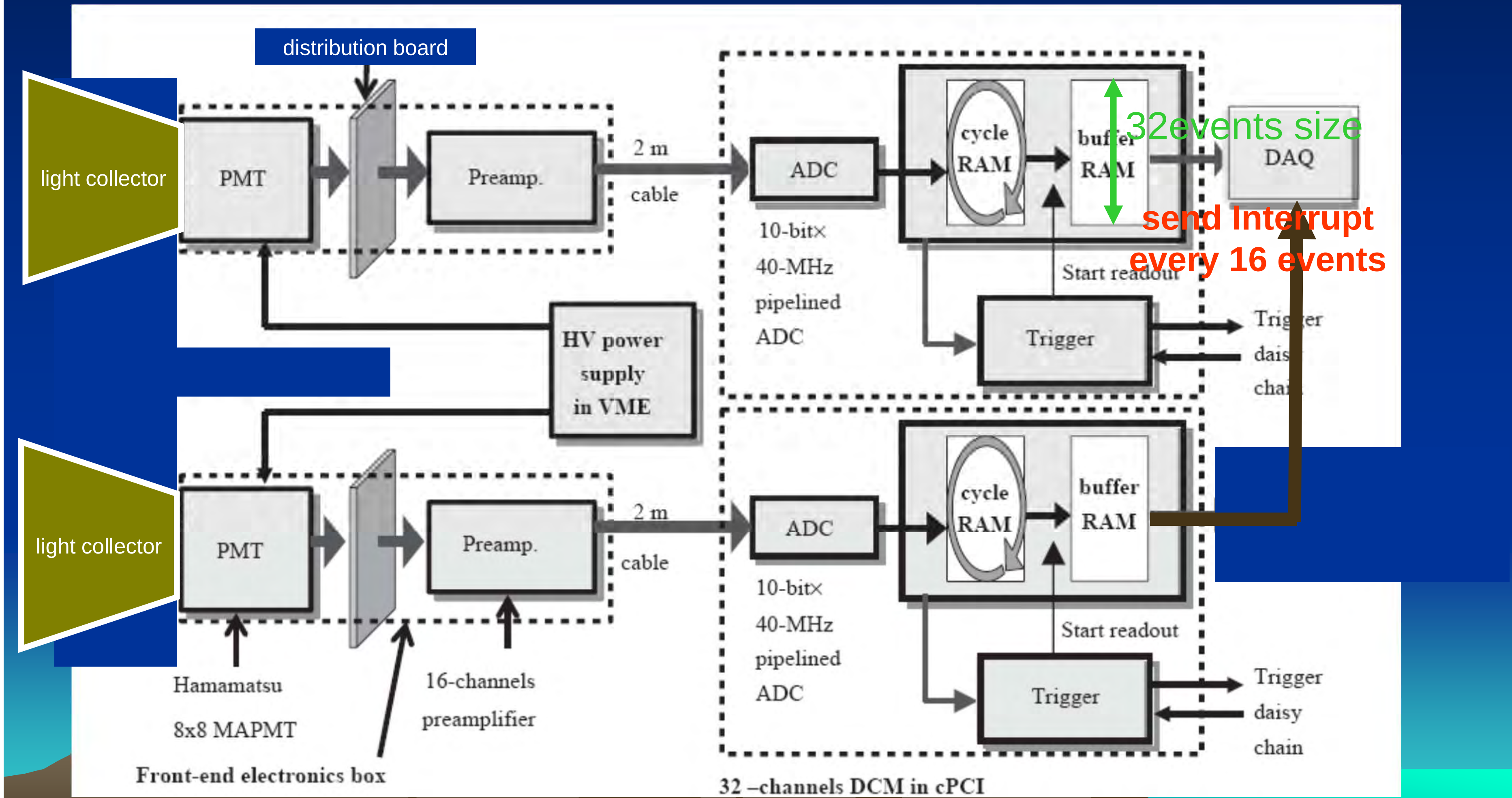
- The spot all isn't small, ~ 5mm. This is Chromatic issue.
  Spot with multi-wavelength is 2~3 times spot with single wavelength.
- The main way to lower the chromatic aberration is to use different material. However there are very few UV transparent material.
- Cytop is the best to eliminate dispersion (high Abbe no.), also high T(%) its spot size ~3mm, but it is expensive and lens will become fatter due to low index.

	Cytop	PMMA
Refraction index (n_d)	1.34	1.49
Abbe's number	90	55

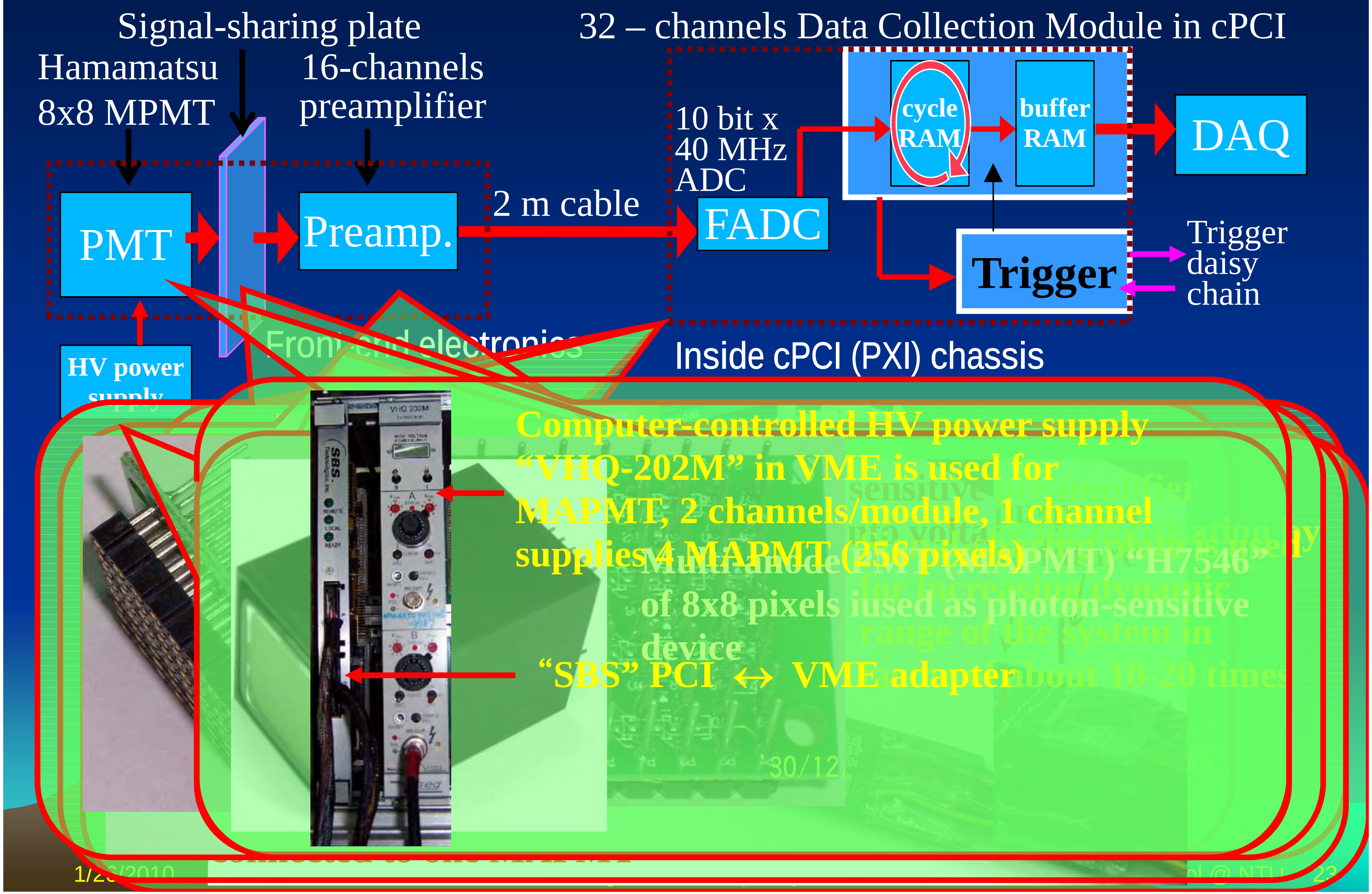


- To sum up, all spot size are less than the channel size of MAPMTs, it meets the threshold but not good enough. Any possible errors can make spots larger. So we changed to other design.

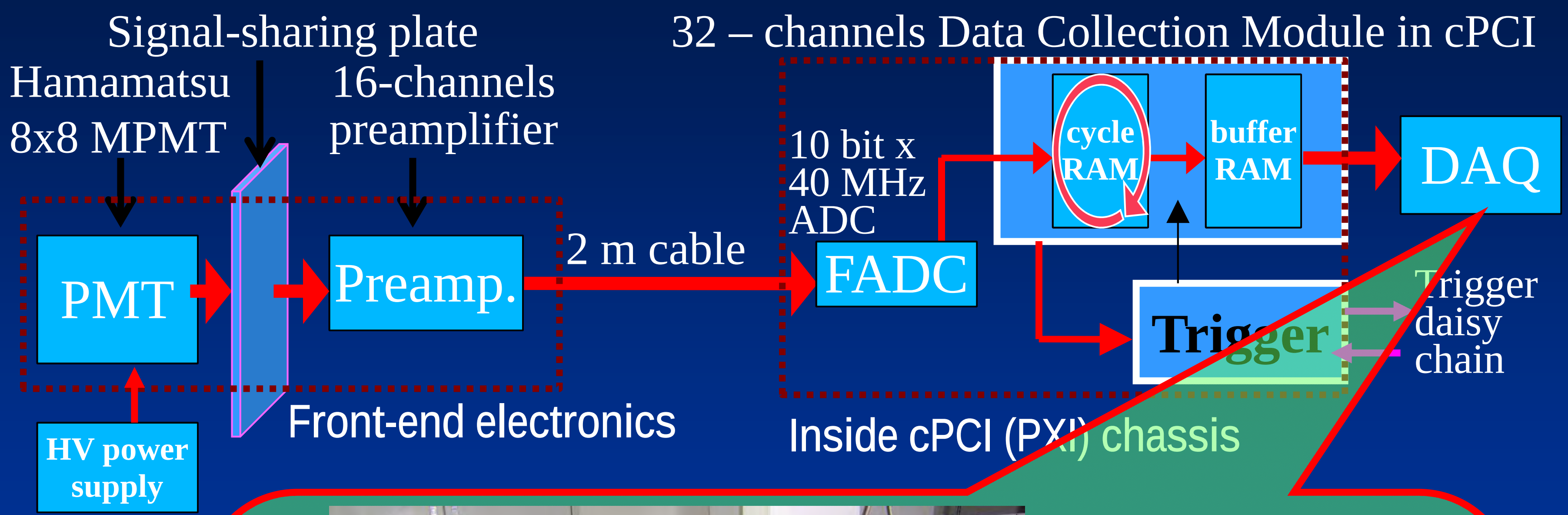
Electronics Device of NuTel (schematic)



Schematics of electronics



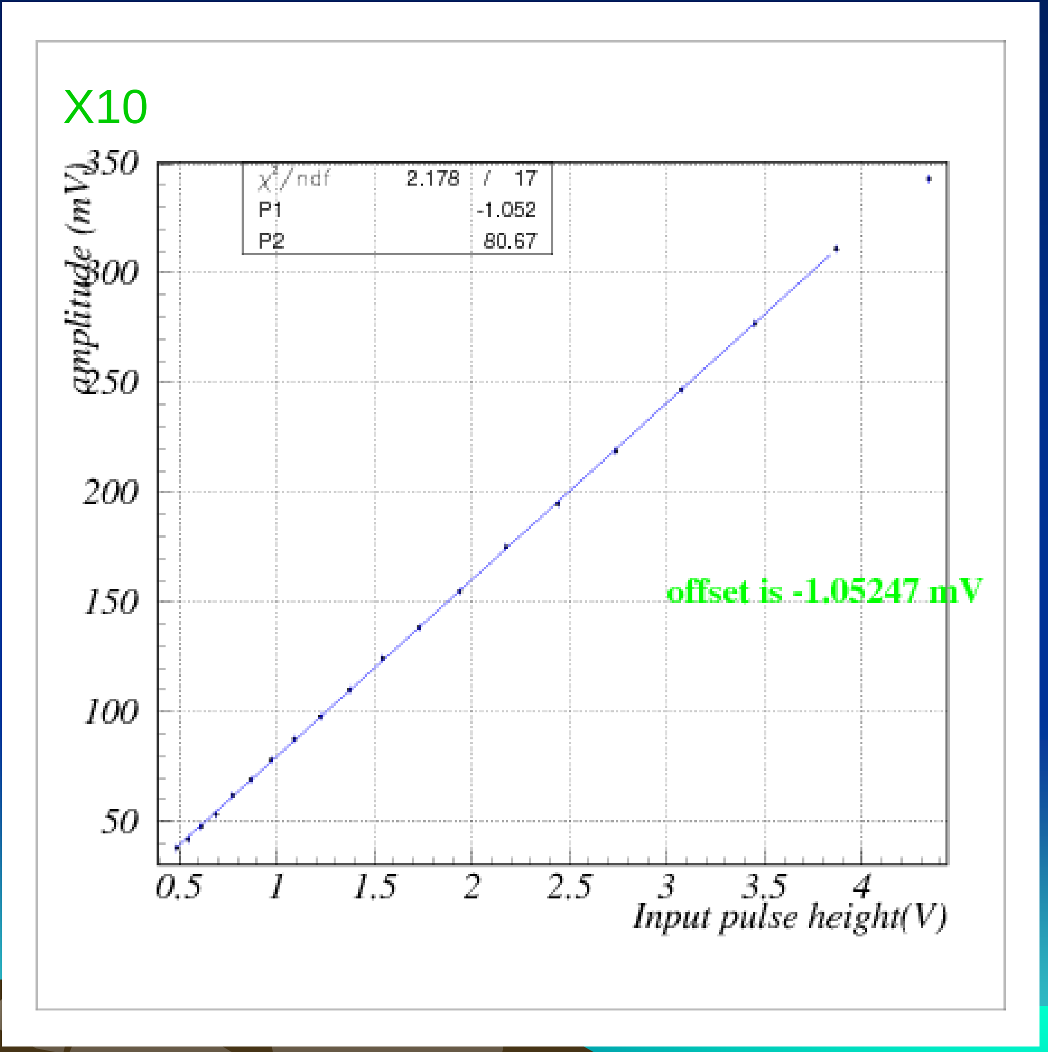
Schematics of electronics



DAQ – in Linux, inside cPCI (PXI) CPU card

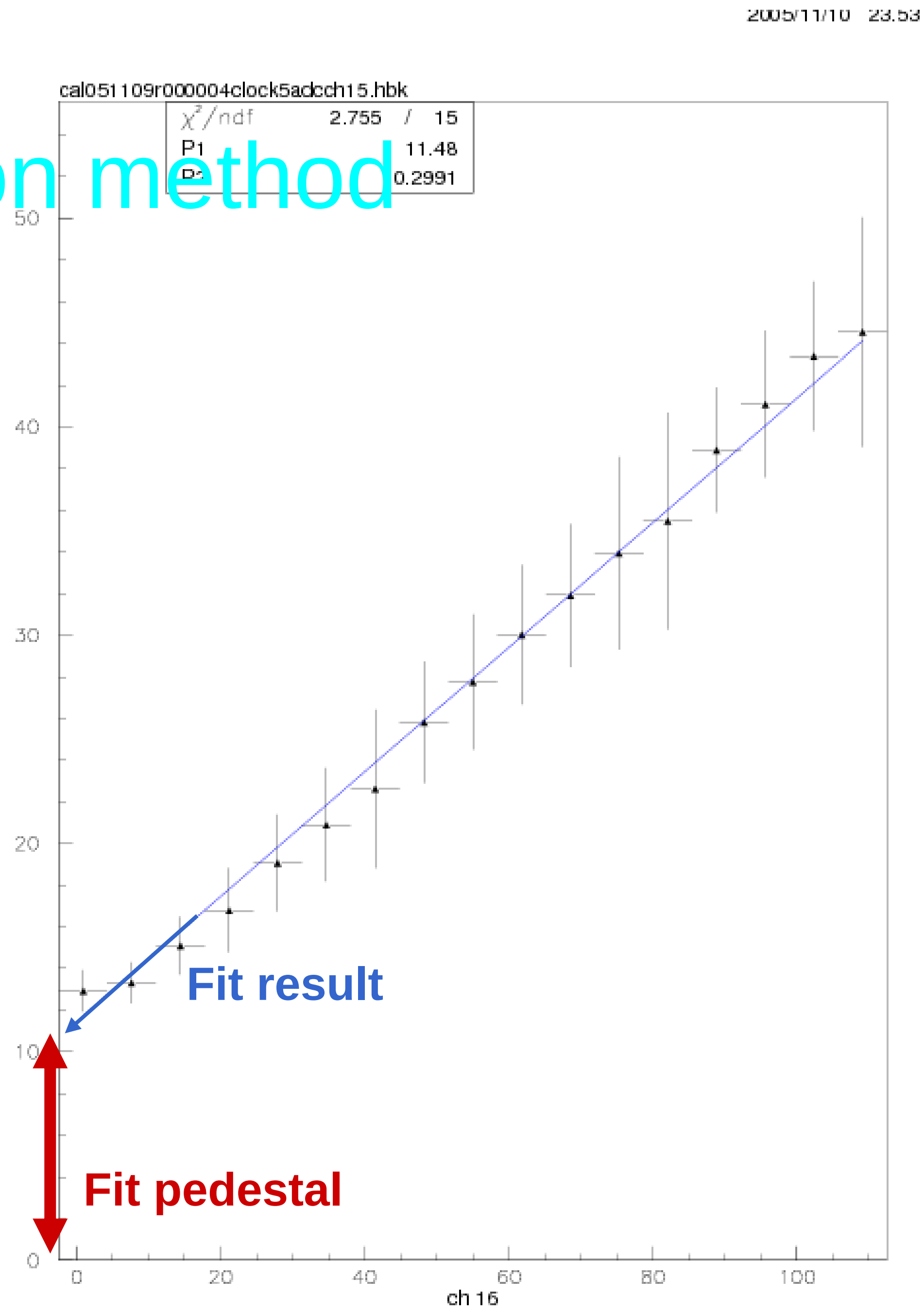
Pre-amp. linearity

- Use attenuation to send decreasing pulses in height.
- Intercept with y axis is 1.025mV.

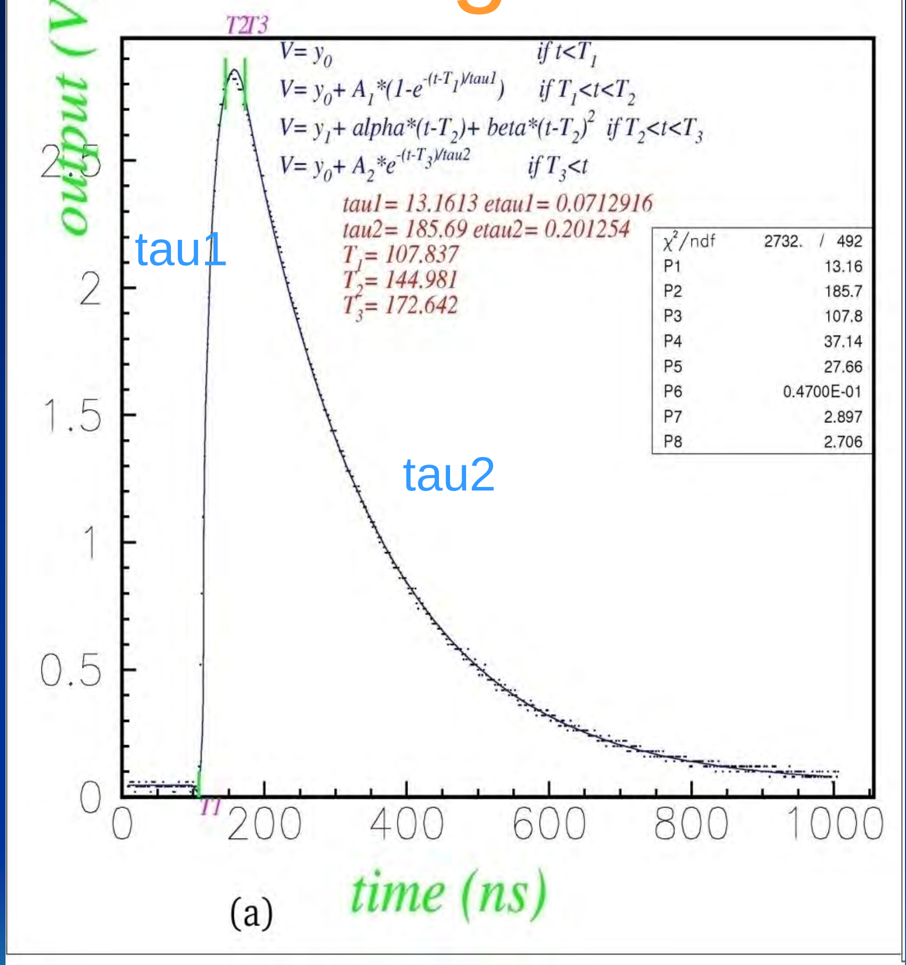


Calibration method

- Every step taking 96 events. Take peak clock value (usually 5th clock). Calculate every step's mean and rms.
- Error = rms/ square(N)
- Use first order fn (line) to fit.
- intercept with y-axis is pedestal.



Single Pulse into Pre-amp



(a)

$$V = y_0 \qquad \text{if } t<T_1$$
$$V = y_0 + A_1 * (1 - e^{-(t-T_1)/tau1}) \qquad \text{if } T_1<t<T_2$$
$$V = y_1 + alpha*(t-T_2) + beta*(t-T_2)^2 \qquad \text{if } T_2<t<T_3$$
$$V = y_0 + A_2 * e^{-(t-T_3)/tau2} \qquad \text{if } T_3<t$$

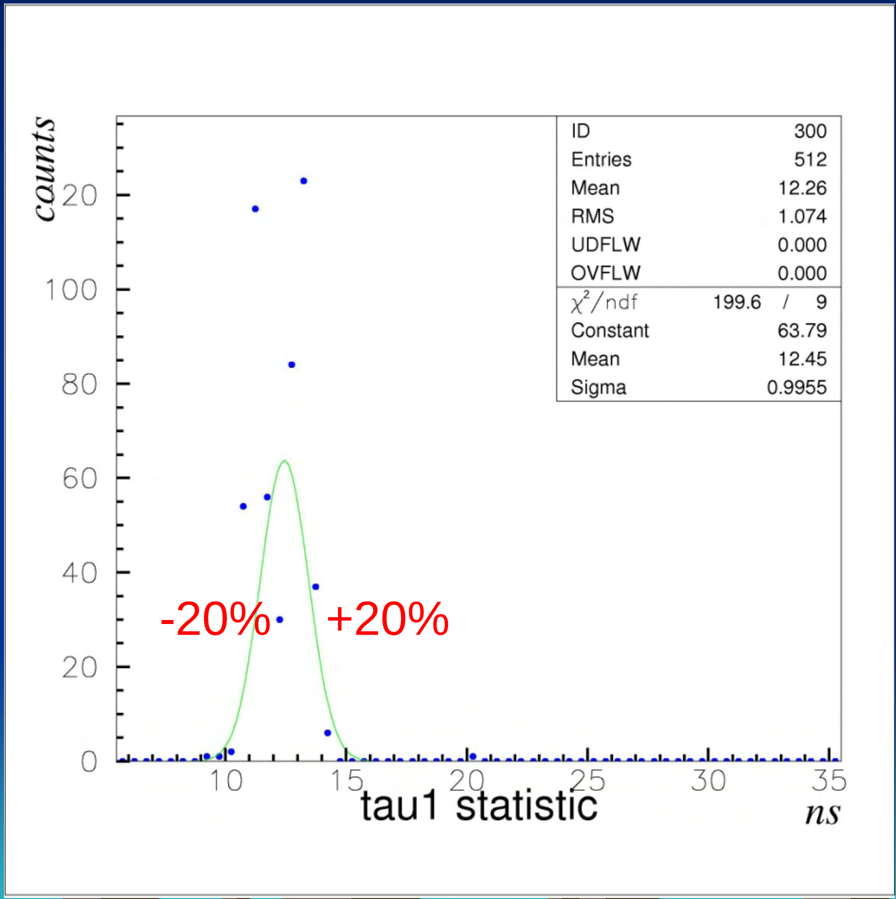
(b)

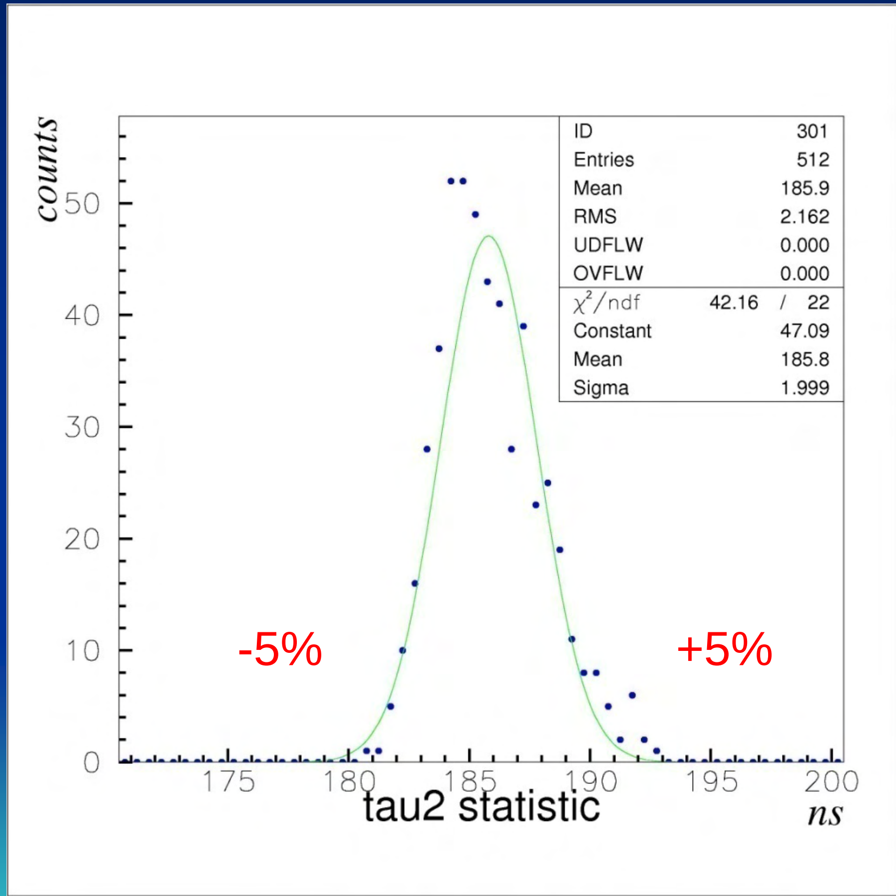
- Output with paw fit, divide by 3 regions.

  (a) Pre-amp.#37 ch.2

  (b) fitting function

tau1 and tau2 over 512 channels



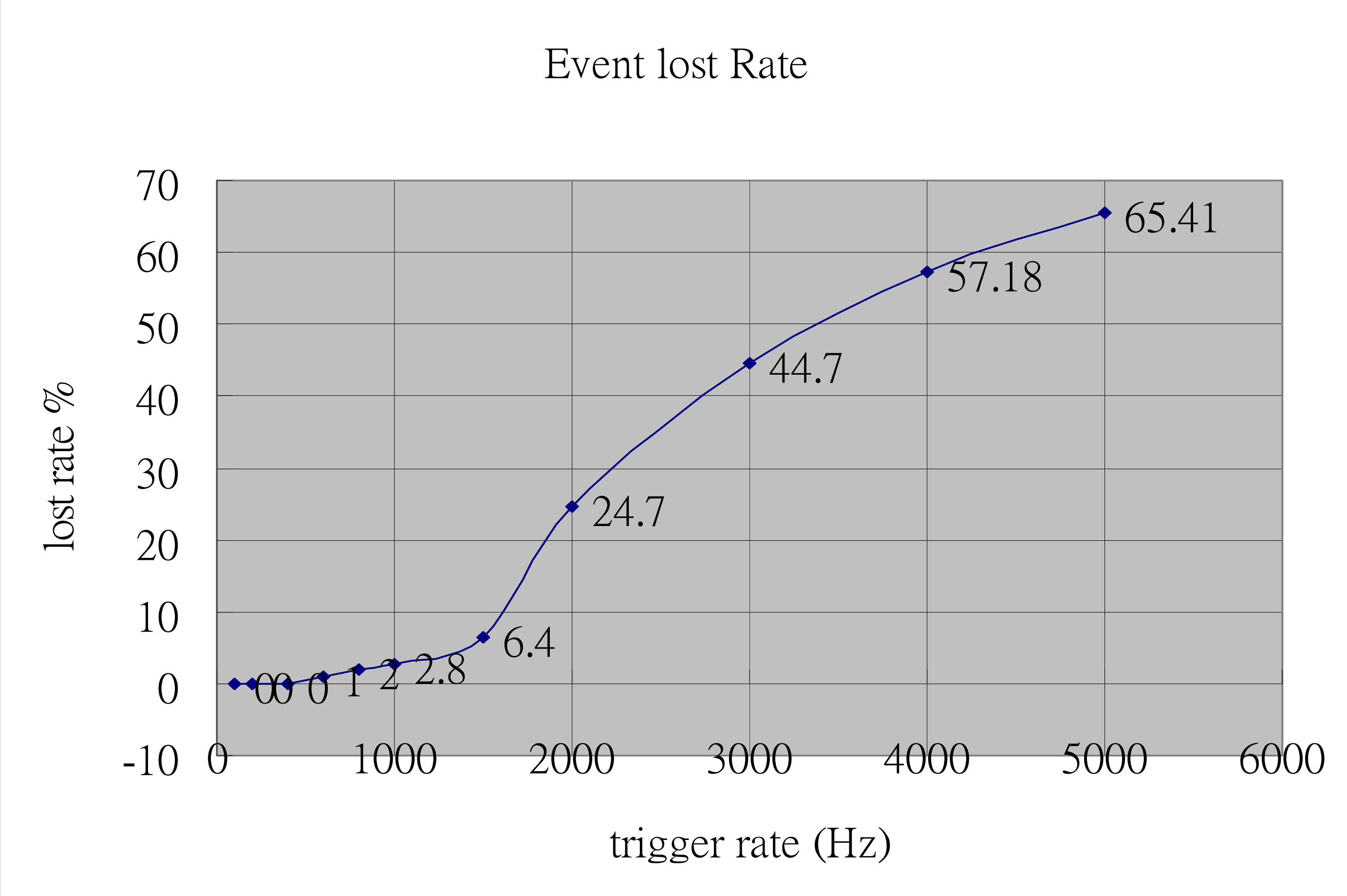


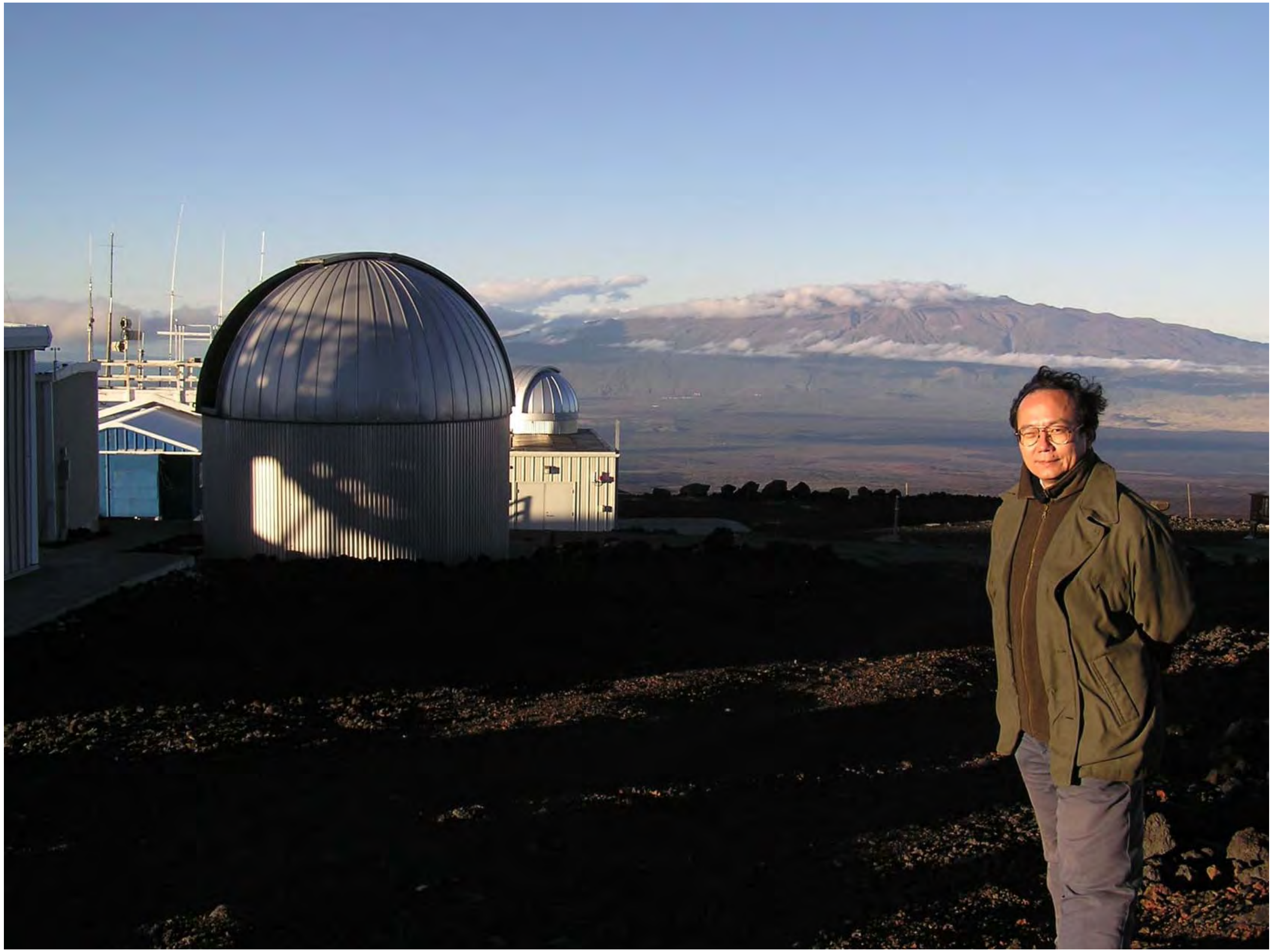
mean value of tau1=12.26ns

mean value of tau2=185.9ns

DAQ Test

- Event lost rate =
  total lost event / (50000+total lost event)





1/2004 up Mauna Loa

NuTel

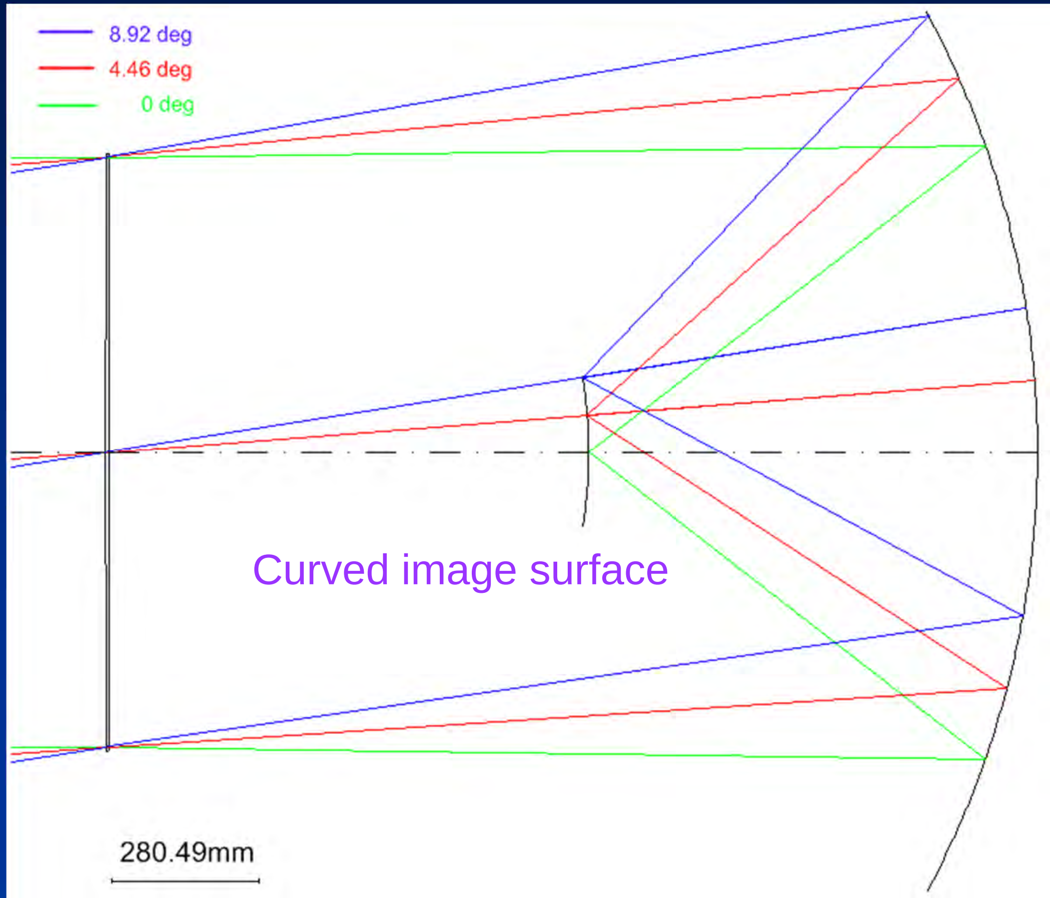
- NuTel is the first experiment *dedicated* to earth skimming for τ appearance
- PeV cosmic ν_τ rate is ~ 0.5 event/year
- First set of two telescopes ready
- VHECR observation in Taiwan: prototype deployment in 2009 indicates high light background at Mei-Fong
- But it got cut out in CosPA II in Spring 2004 ...

  and we could not restore it, after several tries ...

  so I continued it on a shoestring ...

Schmidt Mirror System

Aspherical Corrector Lens mainly eliminate spherical aberration.

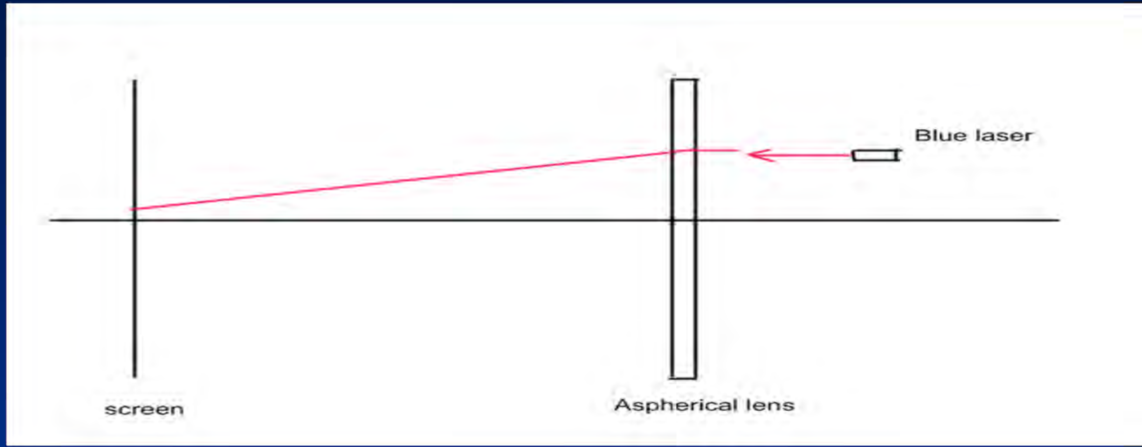


D:1.6 m, finally we made 1.8 m

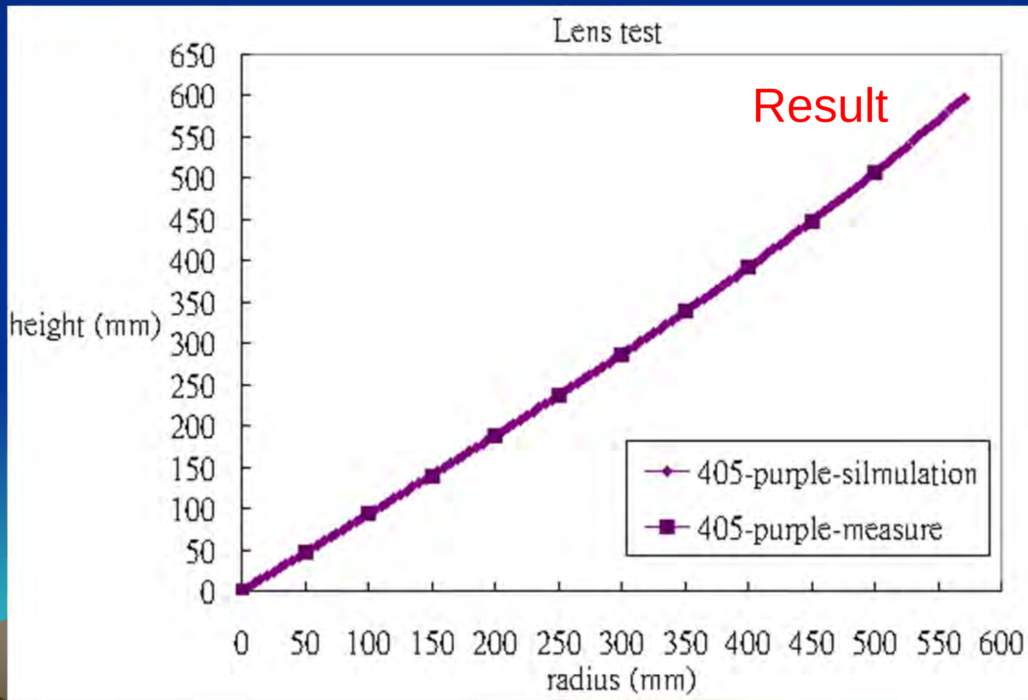
Surface #	Surface Name	Surface Type	Y Radius	Thickness	Glass	Refract Mode	Y Semi-Aperture
Object		Sphere	Infinity	Infinity		Refract	O
Stop		Asphere	14277.1987 V	8.0000	491755.573	Refract	570.0000 O
2		Sphere	Infinity	1797.4128 V		Refract	571.0183 O
3		Sphere	-1800.0000	-869.0192 V		Reflect	842.9845 O
Image		Sphere	-914.3269 V	0.0000		Refract	144.9557 O

	conic const (k)	4th order	6th order	8th order
surf 1(Stop) aspherical parameters	0	-7.033e-011	-2.904e-017	-2.607e-023

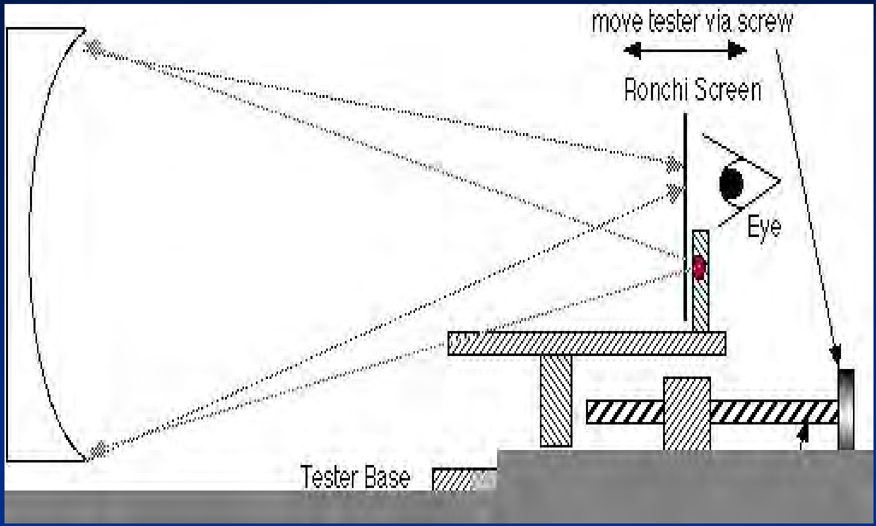
Measurement of the Aspherical Lens at KEK

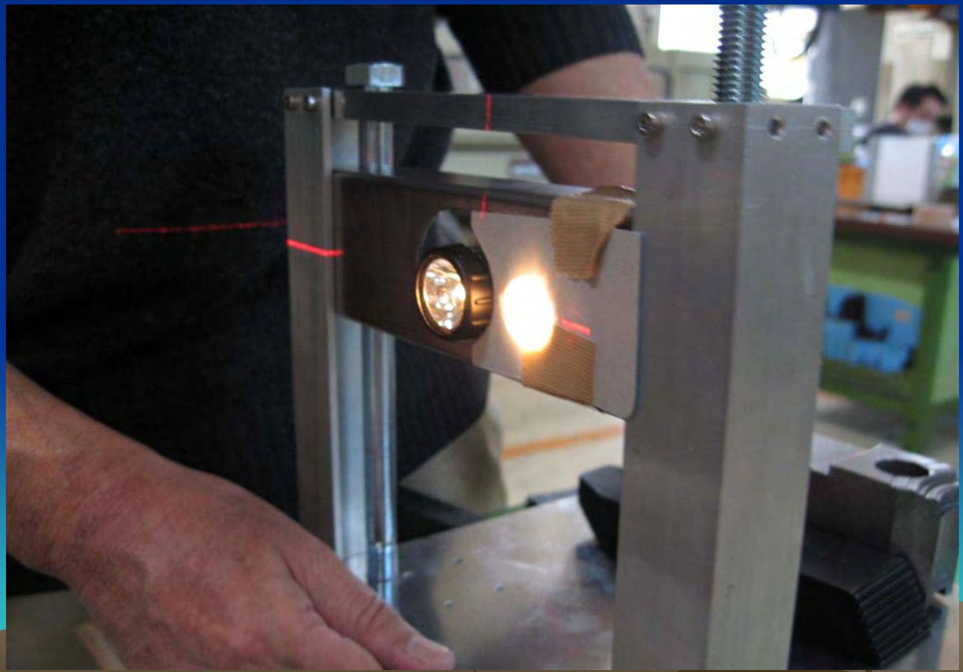


- An image of a blue laser through the lens is measured on the screen.
- Compare with design curve



Foucault test at KEK

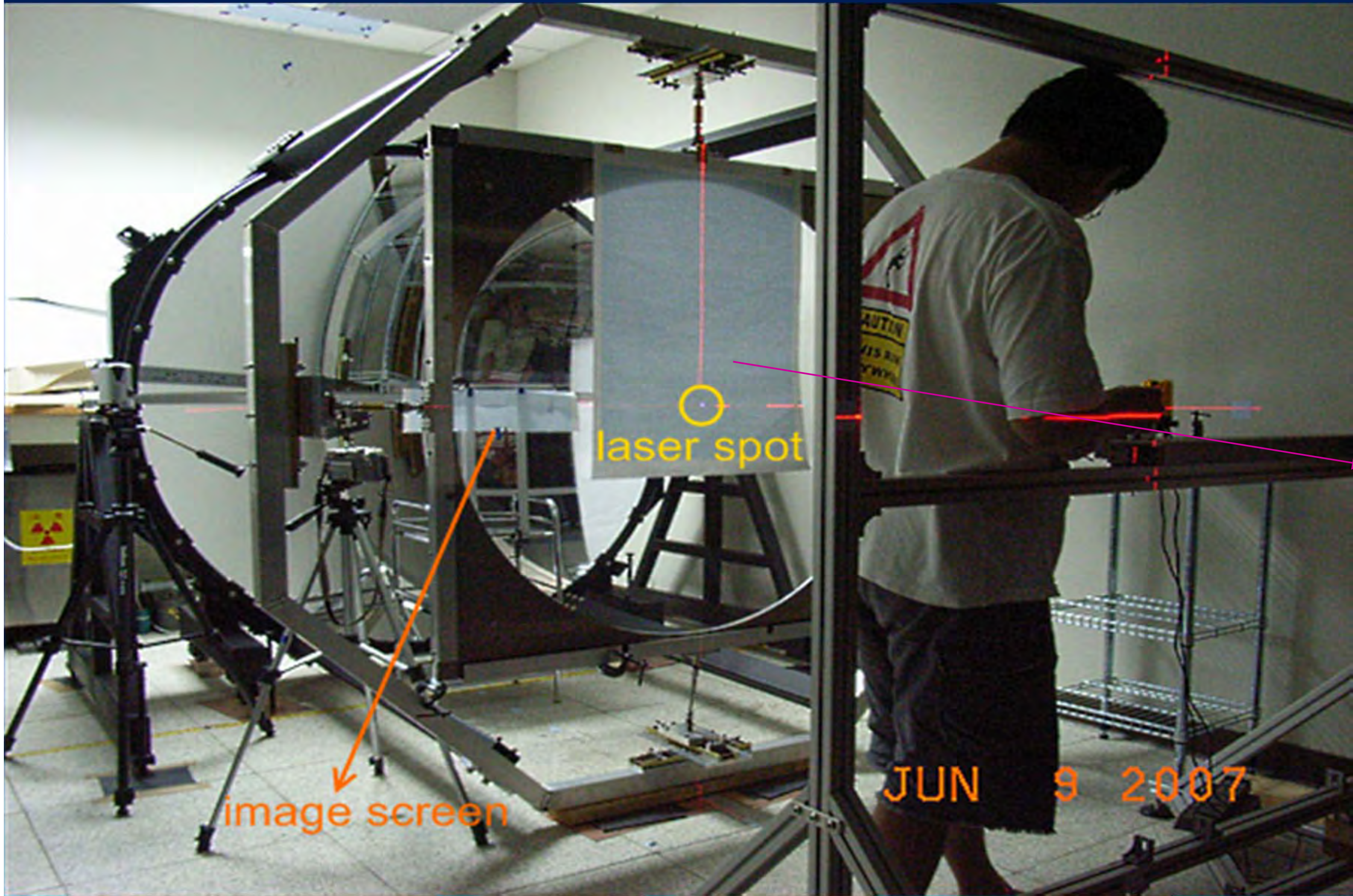




RESULT: 1801±2mm

Design value: 1800mm

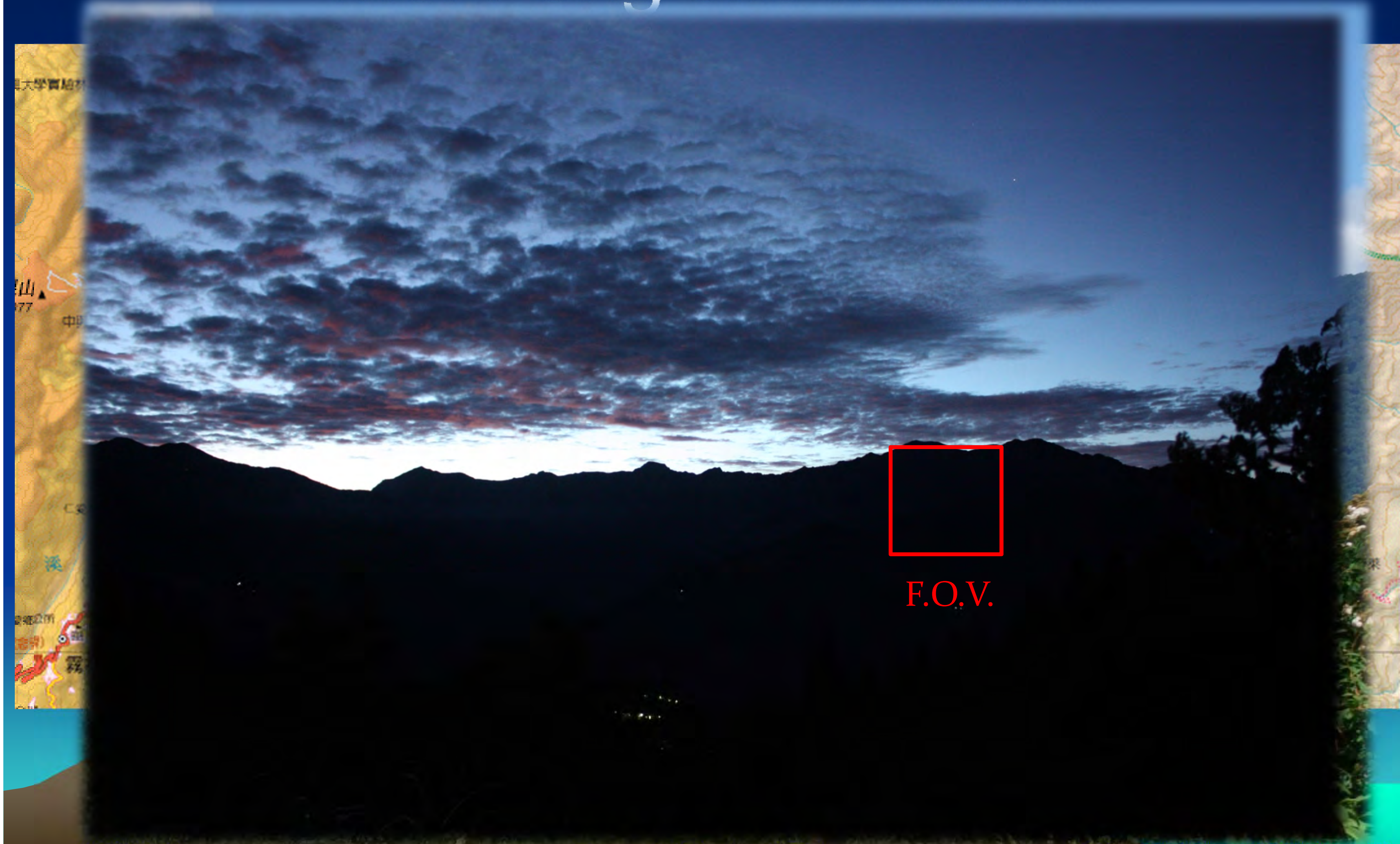
Spot size measurement



Origin of optical system.

z y
x

Mei-Fong site location



First NuTel Field Test at Mei-Fong

7/15-7/27

Set-up of Observational Tent

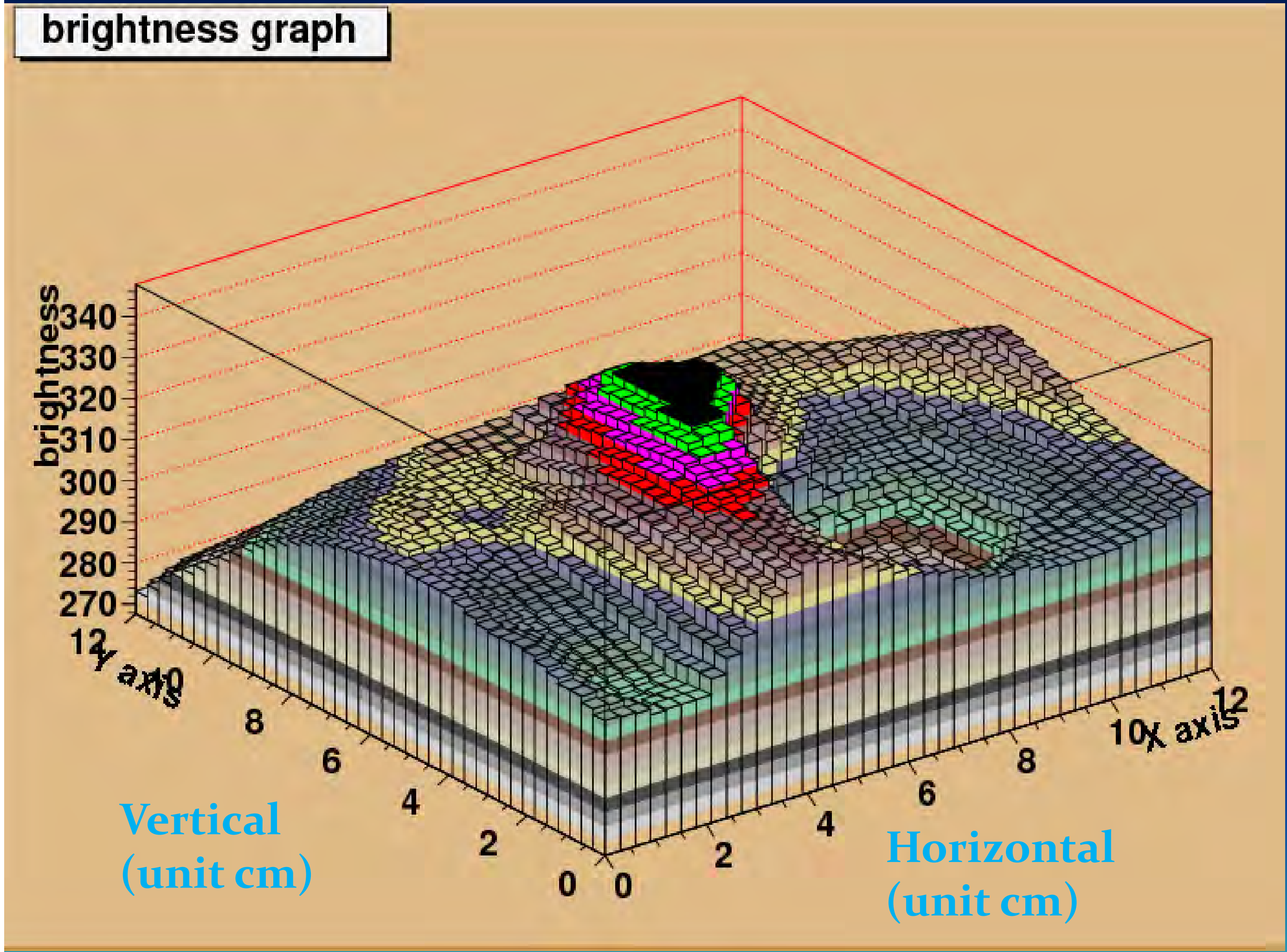
Image around the focal plane

Waiting for sunrise before leaving

Photon Flux Calculation

$$\phi_{photon} = \frac{N_{P.E.}}{t} \times \frac{1}{E_{MAPMT}} \times \frac{1}{E_{opt}} \times \frac{1}{T_{BG3}} \times \frac{1}{T_{ND}} \times \frac{1}{A_{opt}} \times \frac{1}{\Omega_{pixel}}$$

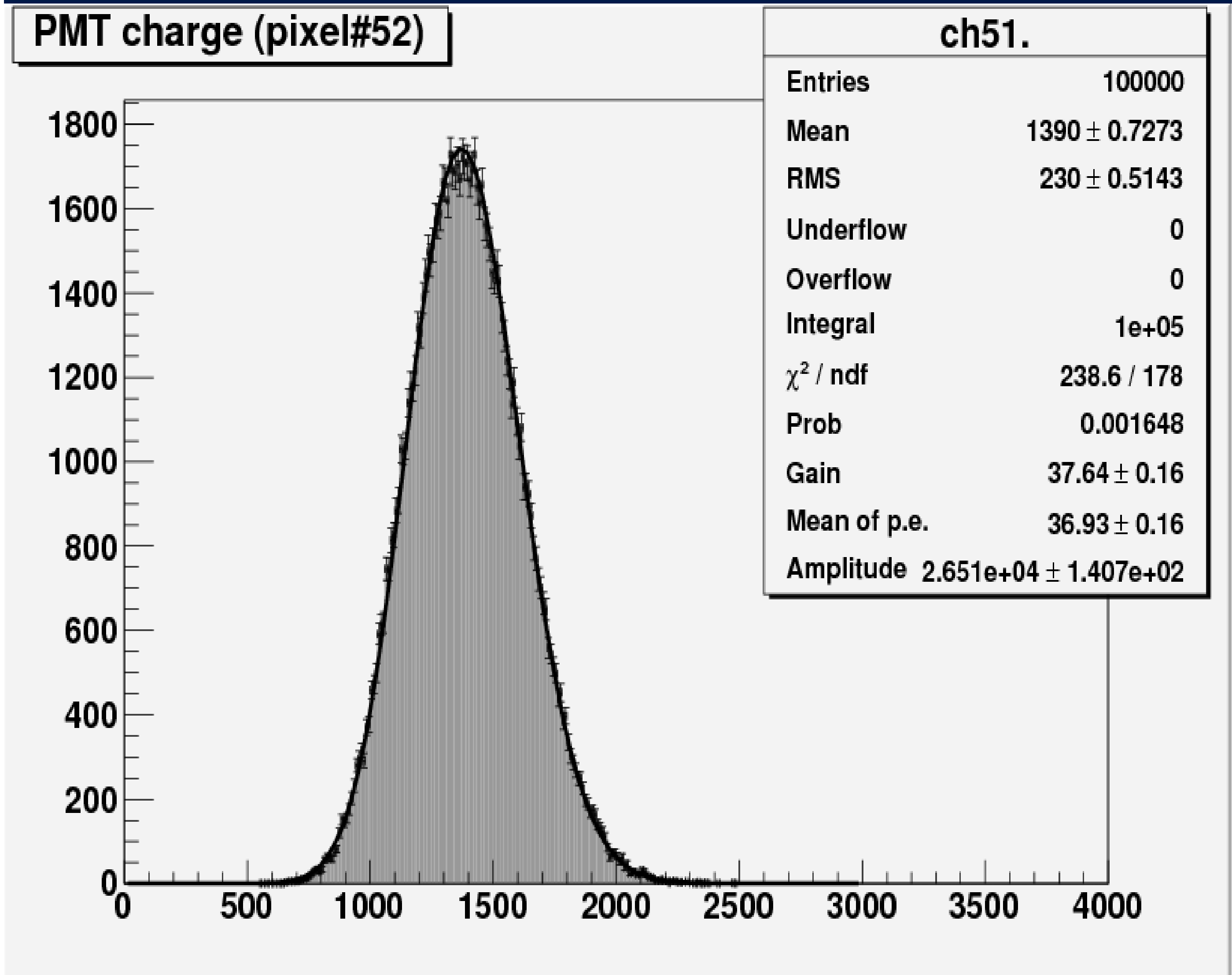
- Φ_{photon}: photon flux
- $N_{P.E.}$: number of photoelectron
- t : time of measurement (sec)
- T_{BG3}: transmittance of BG3, about 80%.
- T_{ND}: transmittance of ND filters
- A_{opt}: optical receive area, about $0.56^2\pi$ (m^2)
- Ω_{pixel}: solid angle of each pixel, about $(0.5°)^2$



Calibration of MAPMT gain

We use purple-UV led to shine on MAPMT in black box.

And we use a photo-diode to check the brightness distribution in MAPMT front window plane.



$$P(\mu) = A \times \frac{\mu^N \times e^{-\mu}}{N!} = A \times \frac{\mu^{\frac{q}{g}} \times e^{-\mu}}{\Gamma(\frac{q}{g}+1)}$$

q is measured charge(mV) for each event
g is gain(mV/p.e.) , denoted by P1
μ is mean number of photoelectrons , denoted by P2

A is a scaled factor(probability→ entries) , denoted by P3

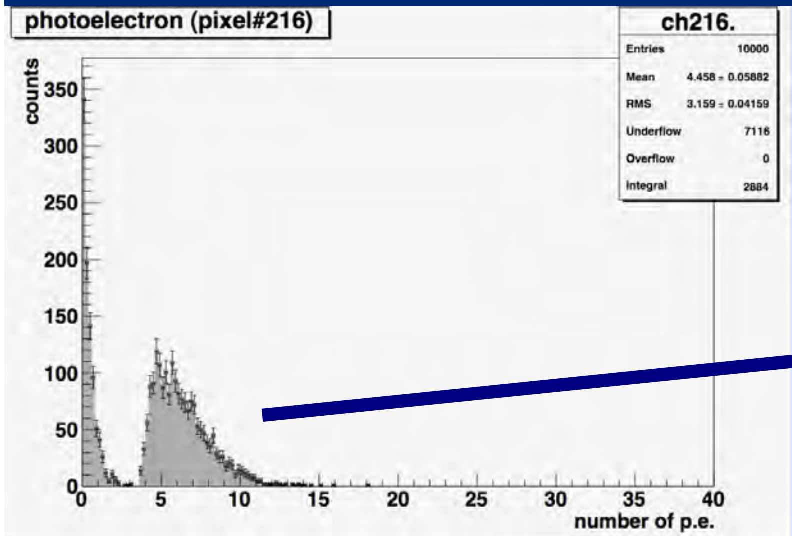
Calibration of MAPMT gain

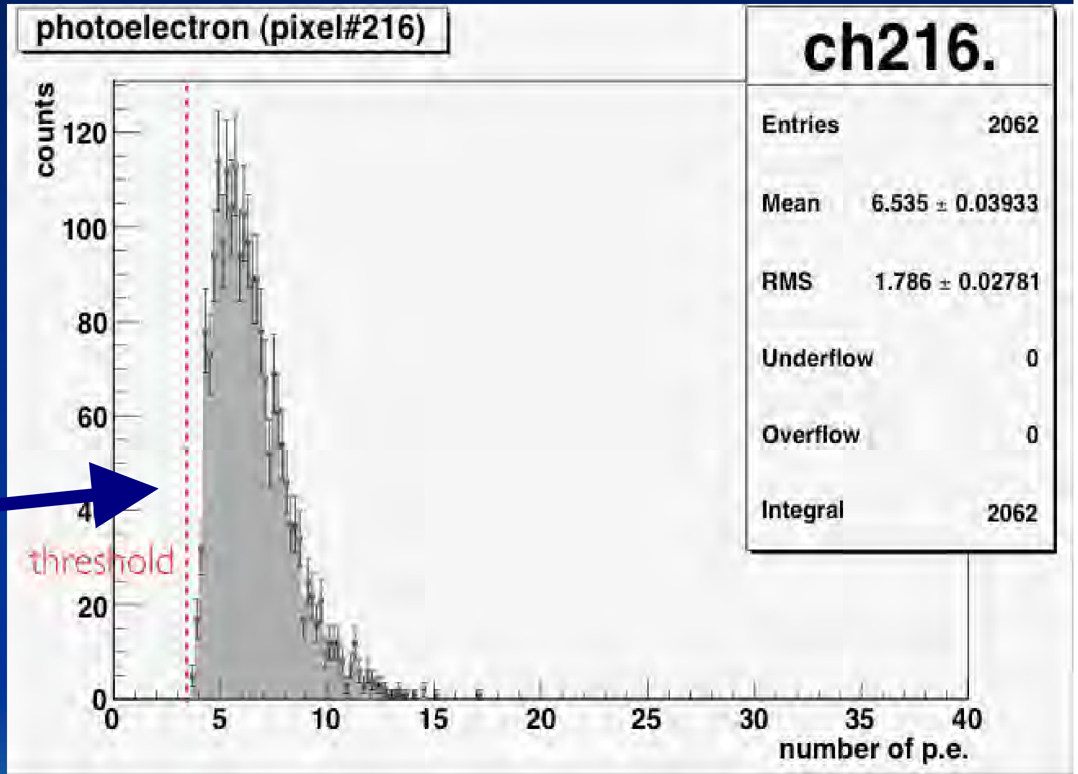
We use purple-UV led to shine on MAPMT in black box.

Left graph shows input charge histogram.

The fitting results shows mean # of photoelectron and gain.

Noisy environment ?





$$\phi_{0ND} = \frac{6.535}{200ns} \times \frac{1}{0.24} \times \frac{1}{0.766} \times \frac{1}{0.8} \times \frac{1}{1} \times \frac{1}{0.56^2 \pi} \times \frac{1}{(0.5 \times \frac{\pi}{180})^2}$$

$$= 2961 m^{-2} sr^{-1} ns^{-1}$$

NuTel

- NuTel is the first experiment *dedicated* to earth skimming for τ appearance
- PeV cosmic ν_τ rate is ~ 0.5 event/year
- First set of two telescopes ready
- VHECR observation in Taiwan: prototype deployment in 2009 indicates high light background at Mei-Fong
- We learned challenge of mountain operation
  - ➔ Tried pair up with CRTNT ... they evolved ...

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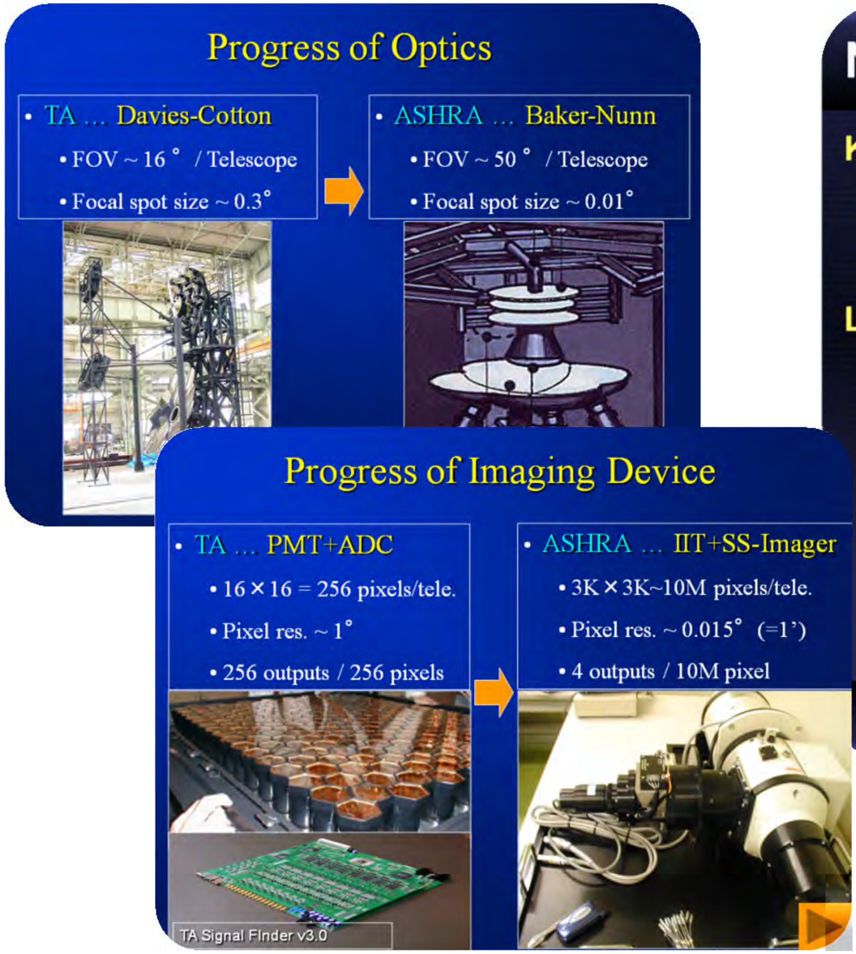
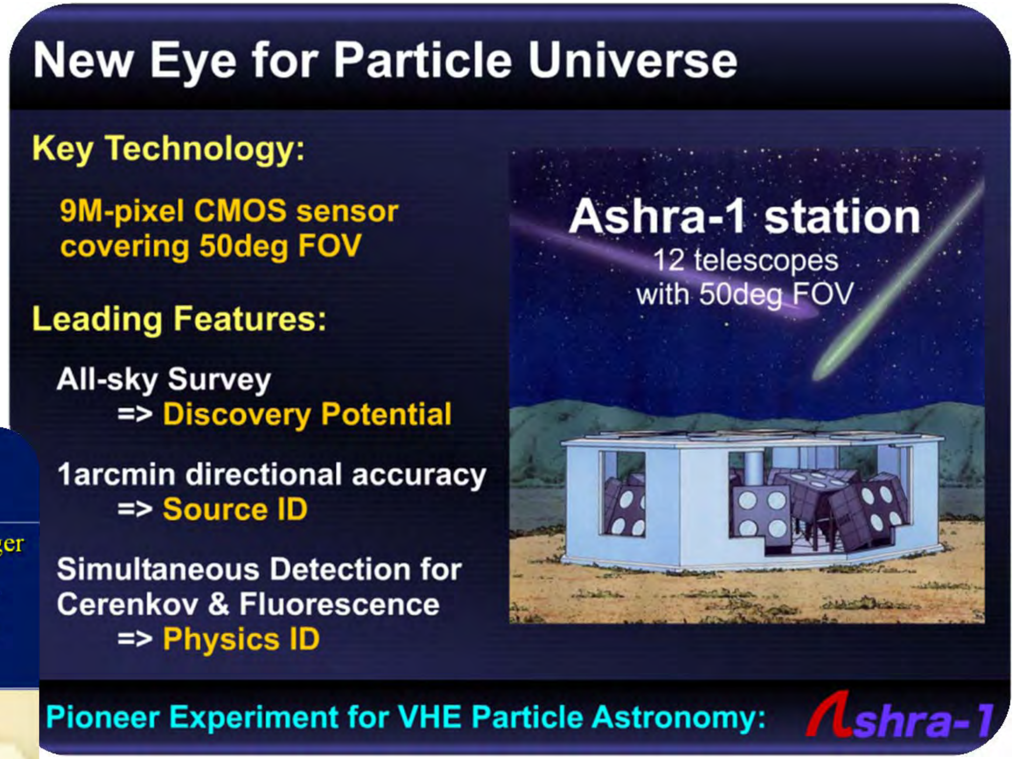
- First set of two telescopes ready
- VHECR observation in Taiwan: prototype deployment in 2009 indicates high light background at Mei-Fong
- We learned challenge of mountain operation

  ➙ Tried pair up with CRTNT ... they evolved ...
- Pair up with Ashra-1 (M.Sasaki) at ICRR ➙ NTA

Ashra-1

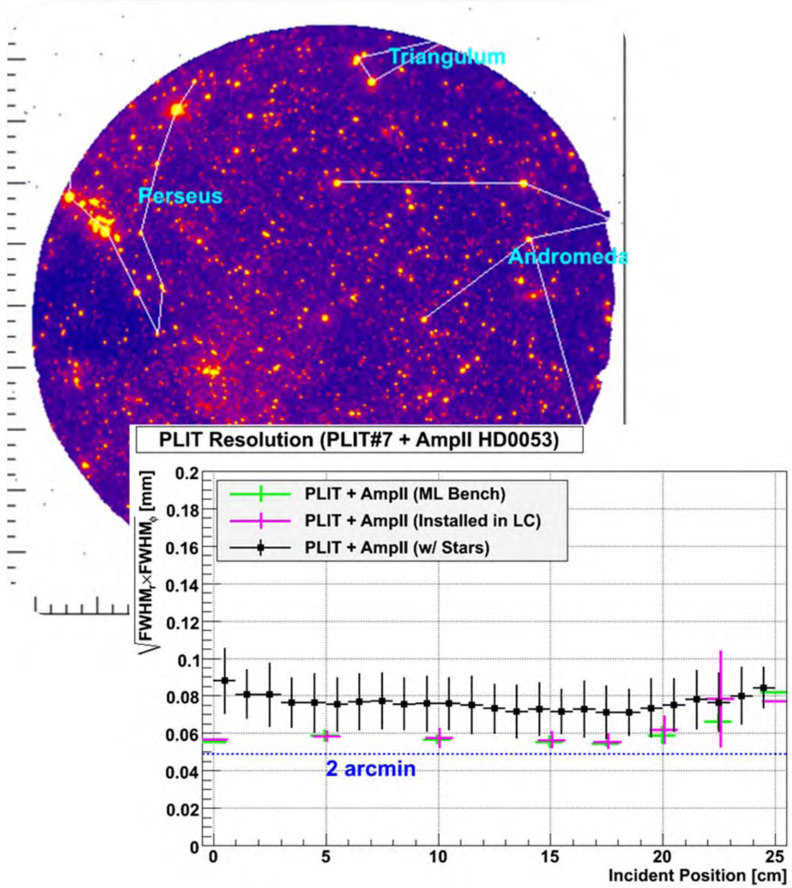
- Ashra-1 succeeded in demonstrating powerfulness of Earth-Skimming for τ appearance.





[Sasaki's Presentation @ CosPA 2003-NTU]

Ashra-1 Light Collector

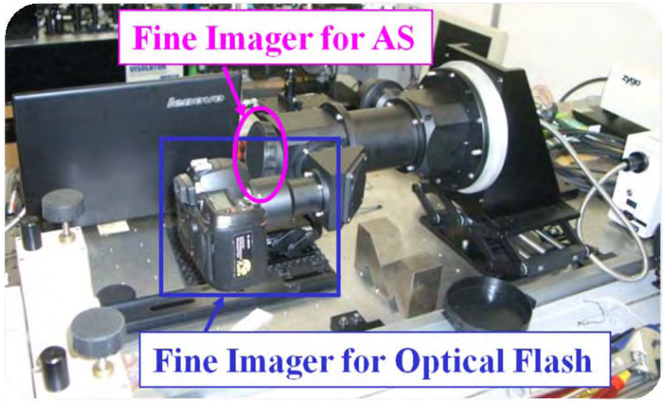


Total Resolution: ~3 arcmin image in 42 deg FOV

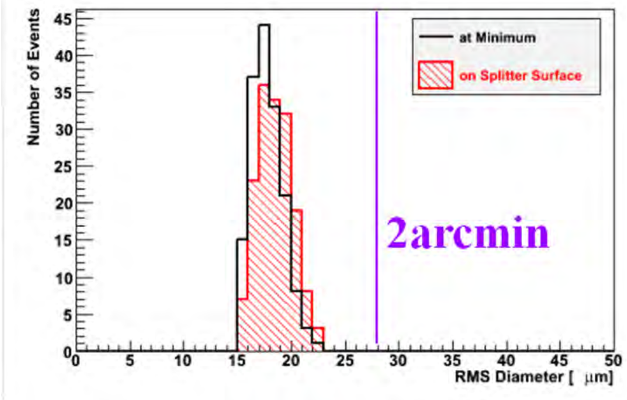
Can Cover Mauna Kea Surface at 35 km Distant

Ashra-1

PIP & PLI Installation @Mauna Loa



Test of PIP

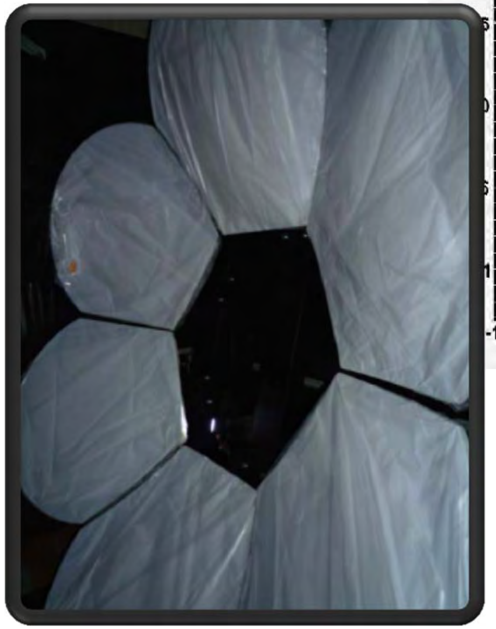


Installation of PLIs

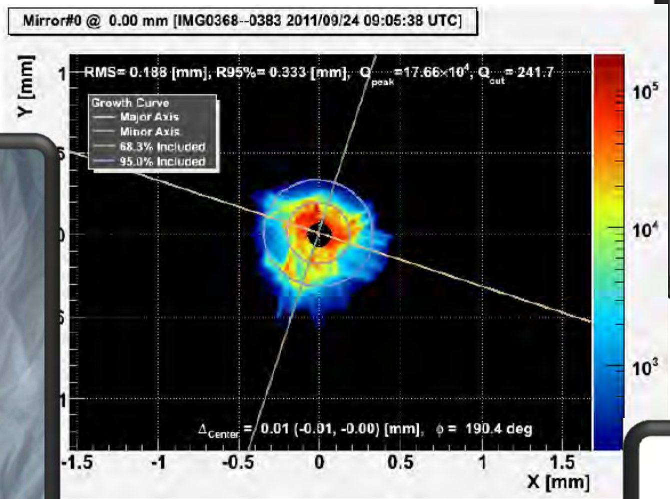
20-in Photoelectric Lens Image Intensifier (PLI)
[Y.Asaoka, M.Sasaki NIM, A647:34-38,2011]

Ashra-1

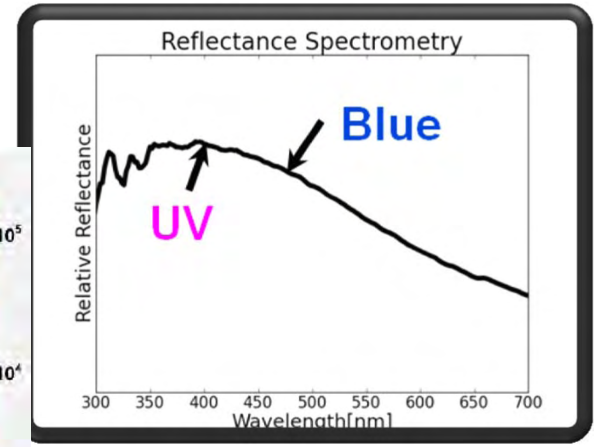
Segment Mirror Installation @ Mauna Loa



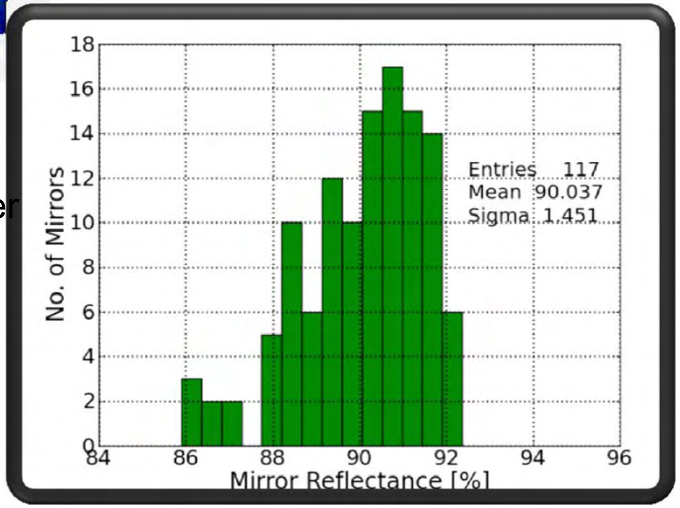
Mount Seg.Mirrors



Spot Size RML 0.19mm
Corresponds to 0.46 arcmin after adjusting all segments



$Al+Al_2O_3$-coat:
Blue = UV -3%



Reflection >85%

All Light Collector Optical System on ML Ready

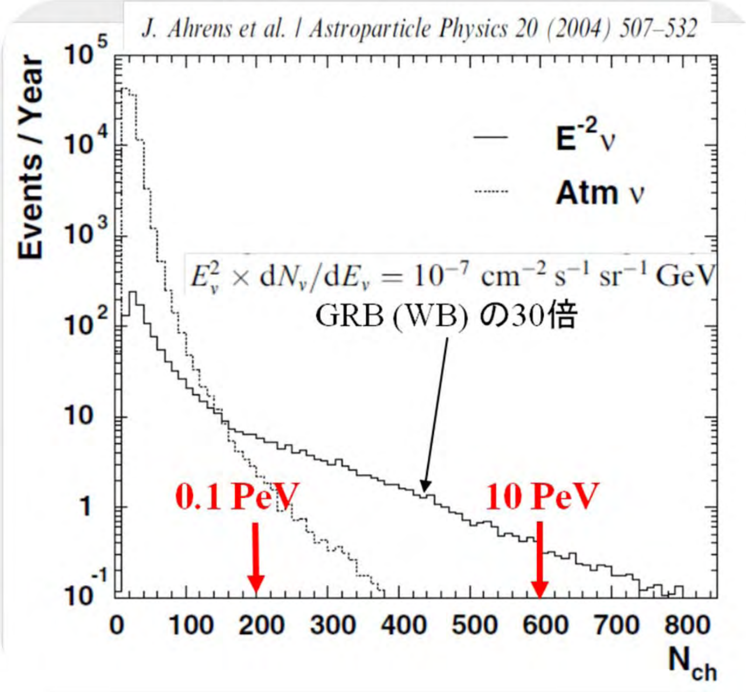
Ashra-1

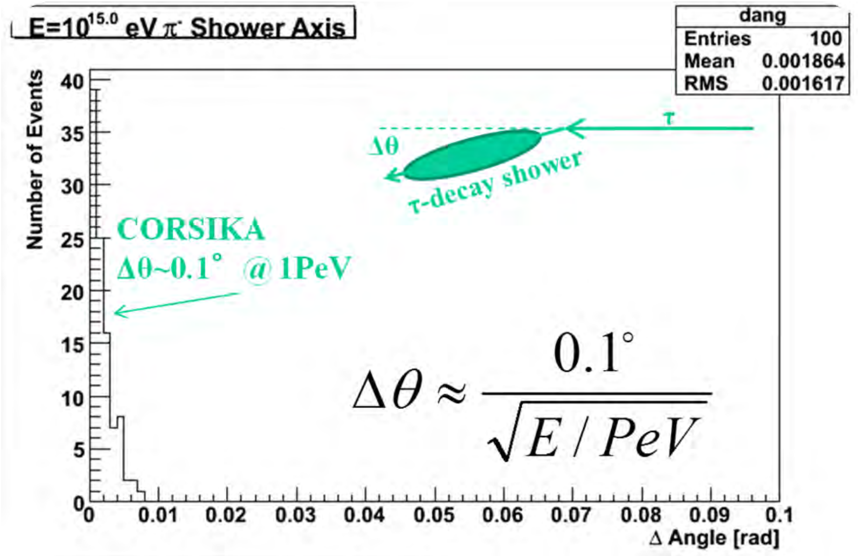
Ashra Observational Site: Mauna Loa

3,300 m a.s.l. 35 km from MK   77% mono. 27% stereo.   2~3 arcmin image

Nice Coverage and Precision as Particle Monitor

Advantages of ES Tau Neutrino Detection



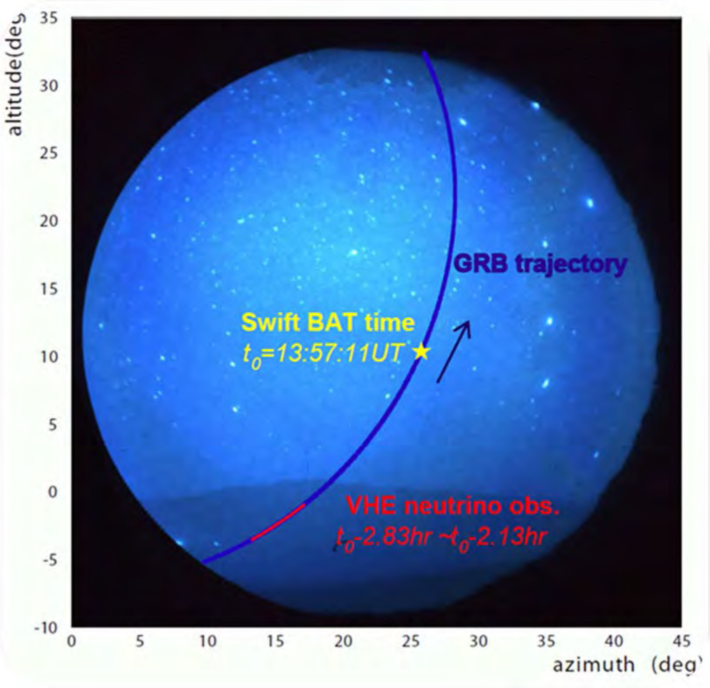


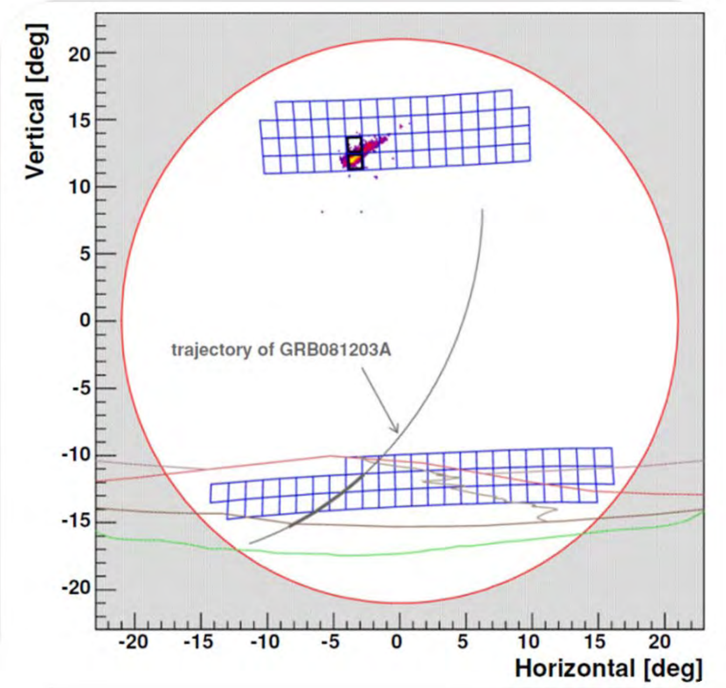
Possible Point ν < 0.1 deg

Atm-ν & CR BG Free

Image A Fine Tau Shower → Open up Multi-Particle Astronomy

GRB081209A



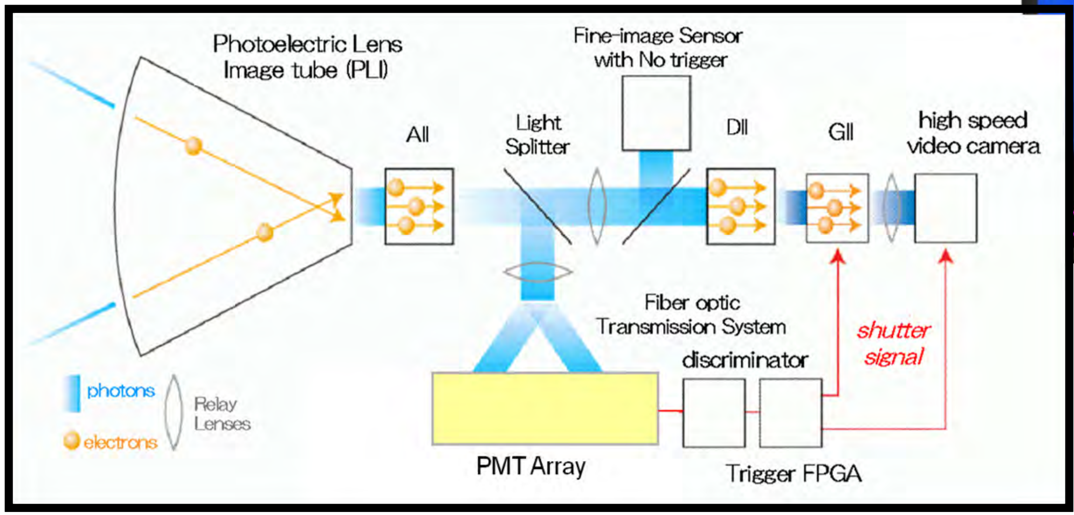


Swift GRB Alert during Commissioning

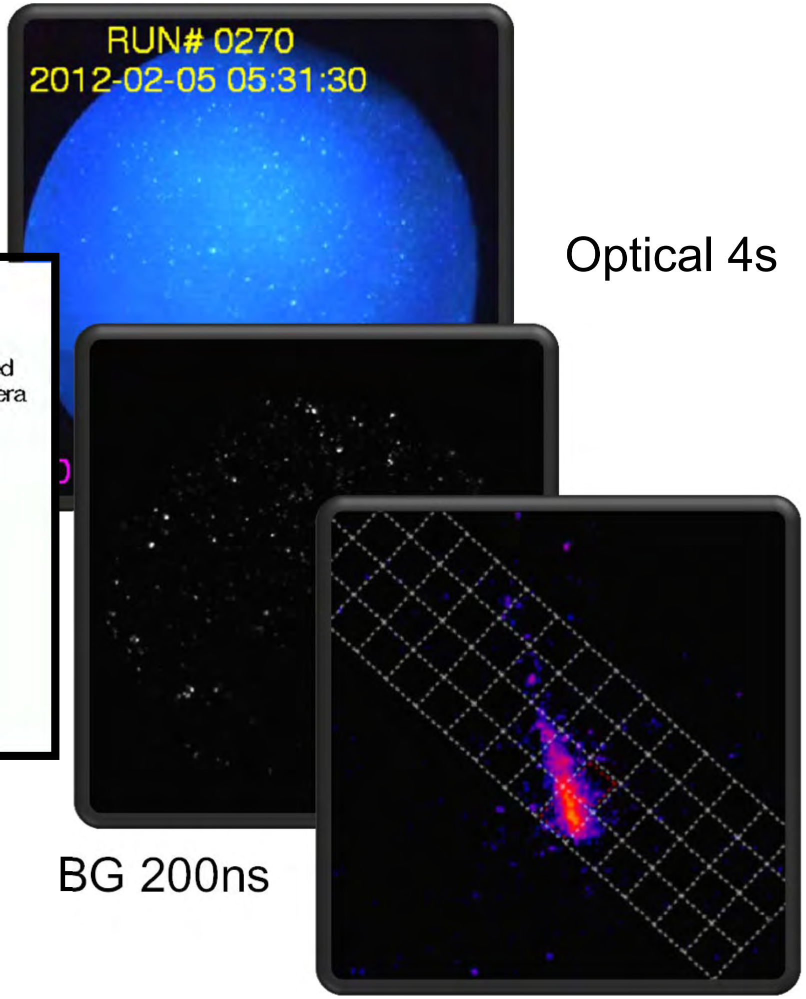
First Check for PeV-EeV Tau Neutrino from a GRB

Ashra-1

Ashra Pipeline Trigger & Readout



Same Fine Image to Multiple Triggers



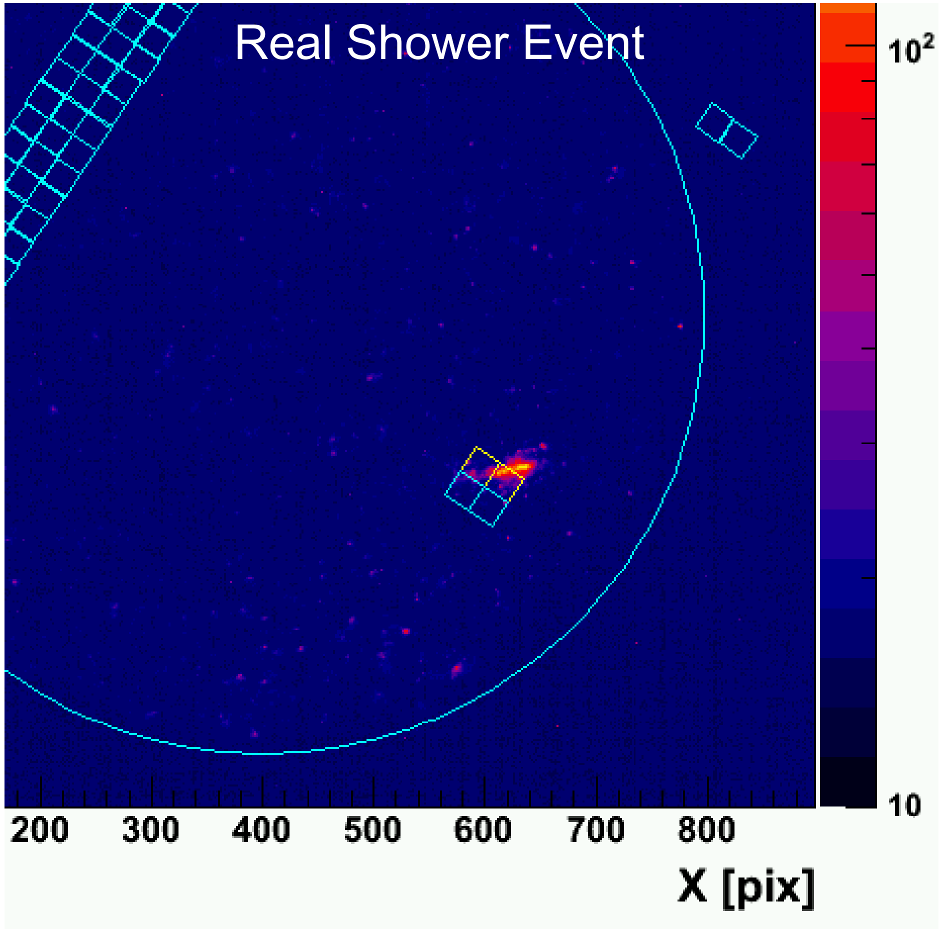
Optical 4s

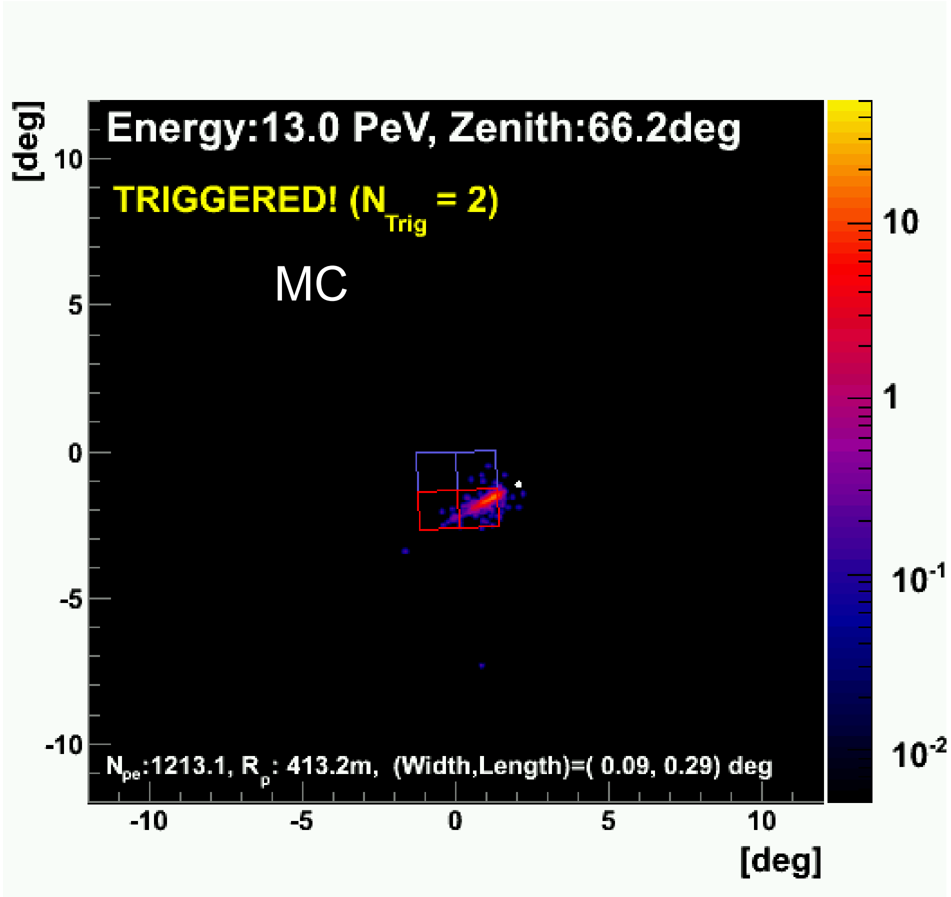
BG 200ns

CR 200ns

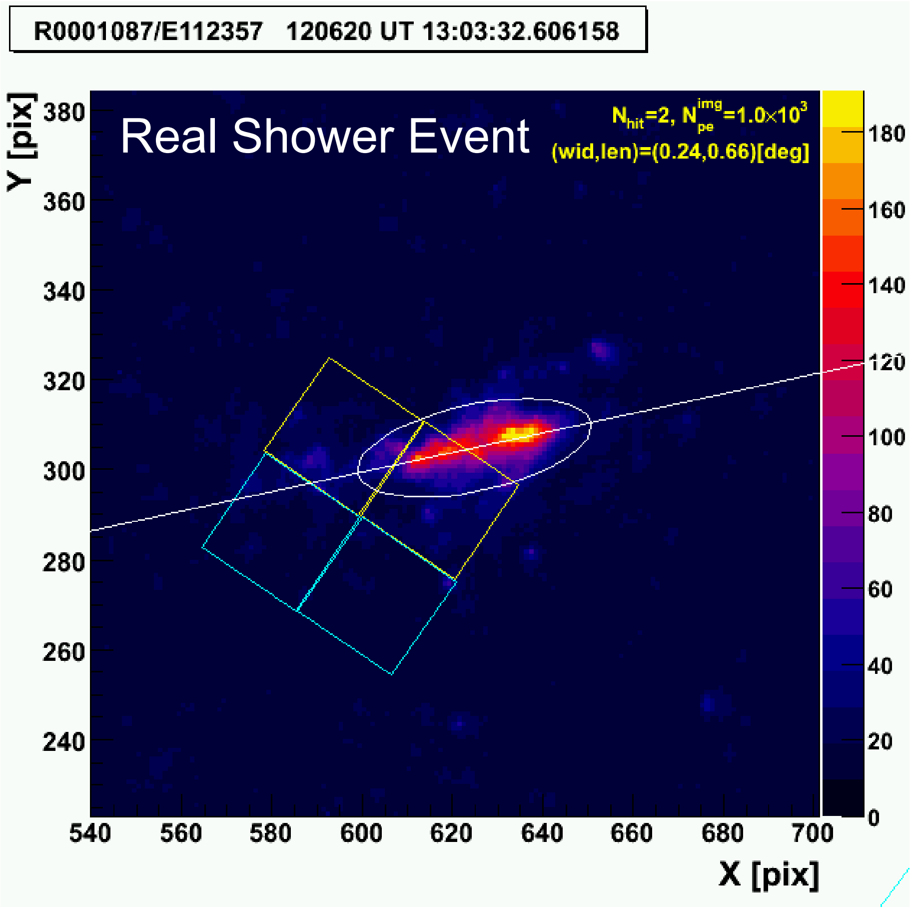
Multi Messenger Approach with One Detector System

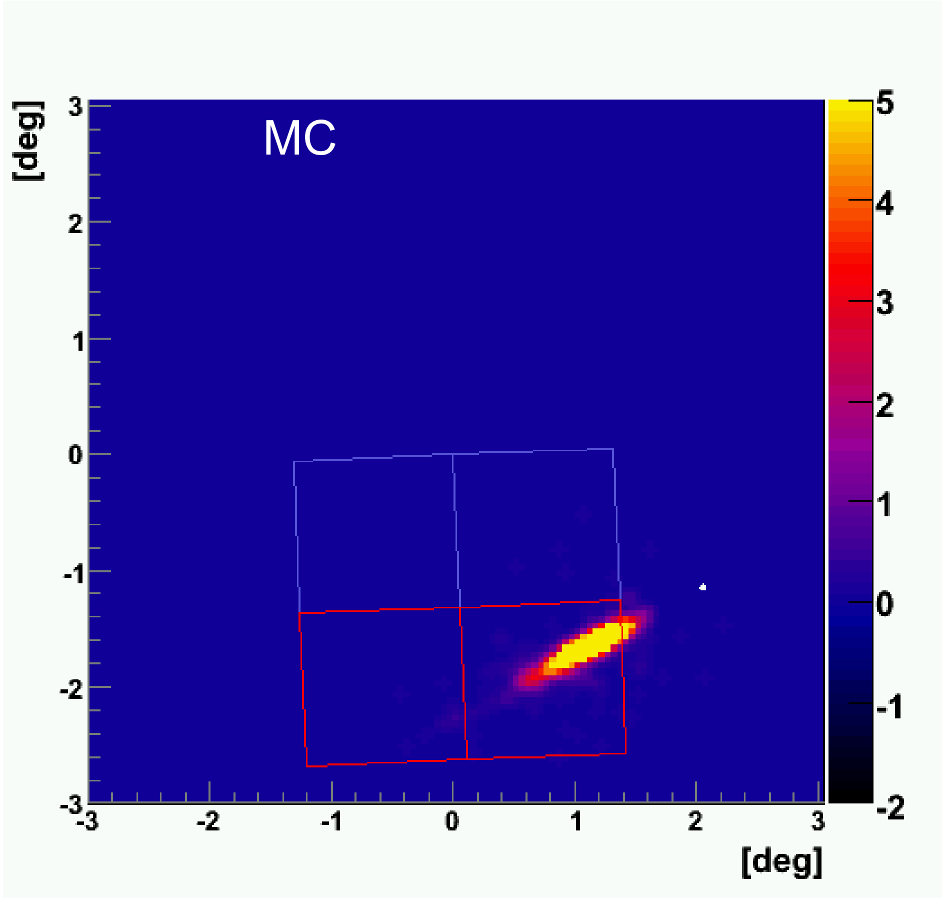
Ashra-1 R0000941/E115513 Triggered Real Shower Event vs MC





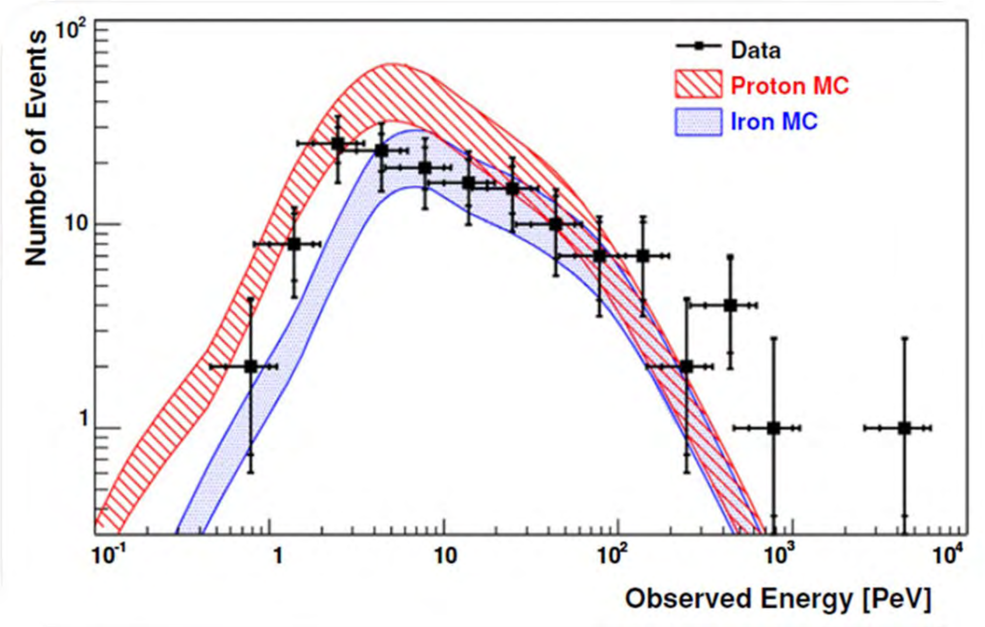
Ashra-1 R0000941/E115513 Triggered Real Shower Event vs MC





MC reproduce real event

Observed CR Spectrum

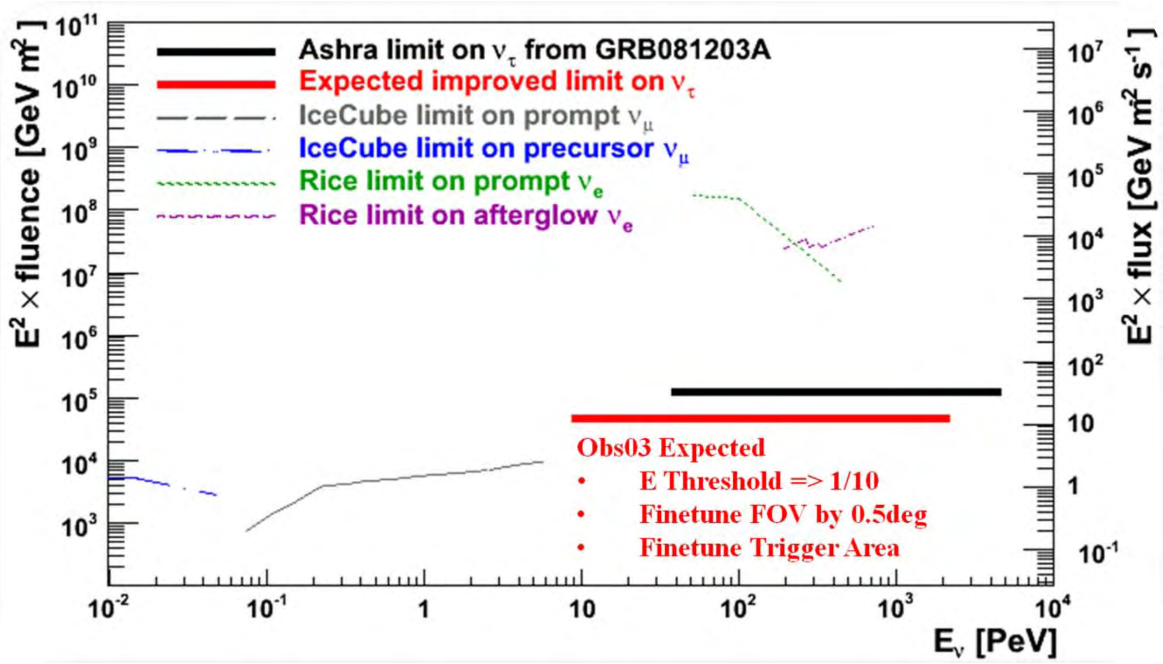


Validation of Sensitivity and Reconstruction

Some Hint for Composition

Ashra-1

PeV-EeV Tau Neutrino Search Limit

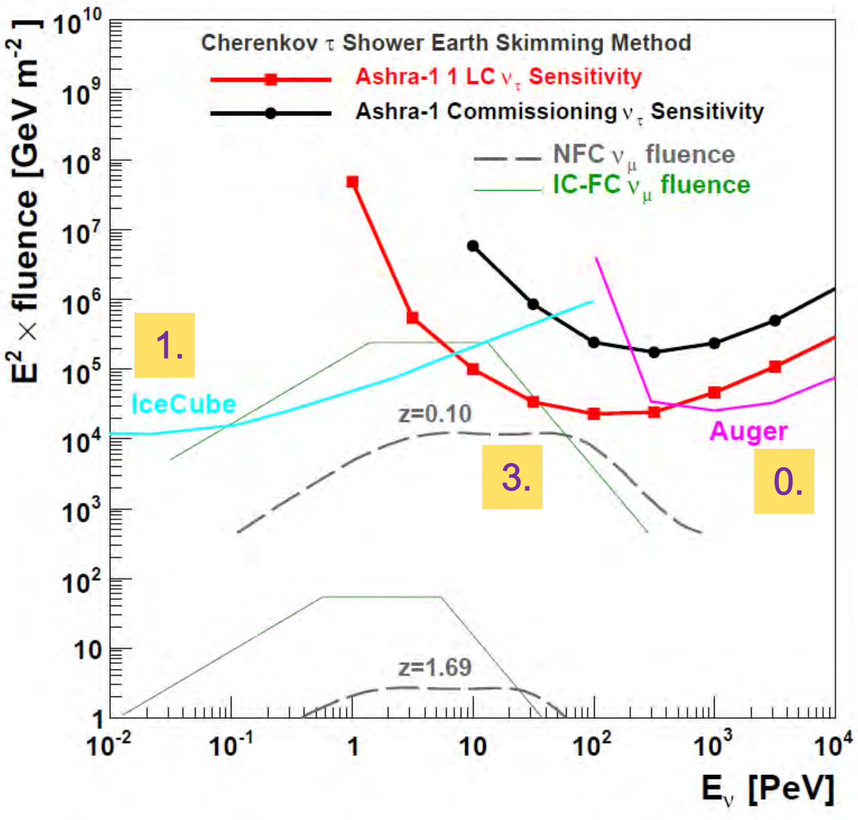


Even Commisioning 100x Better than Rice

Started Obs03 Runs Approaching to IceCube Area

Ashra-1

GRB Neutrino Search Comparison



0. Auger, PRD 79 (2009) 102001

Complement IceCube:
- Methodology
- Energy
- <u>Self-trigger for Tau Neutrino</u>

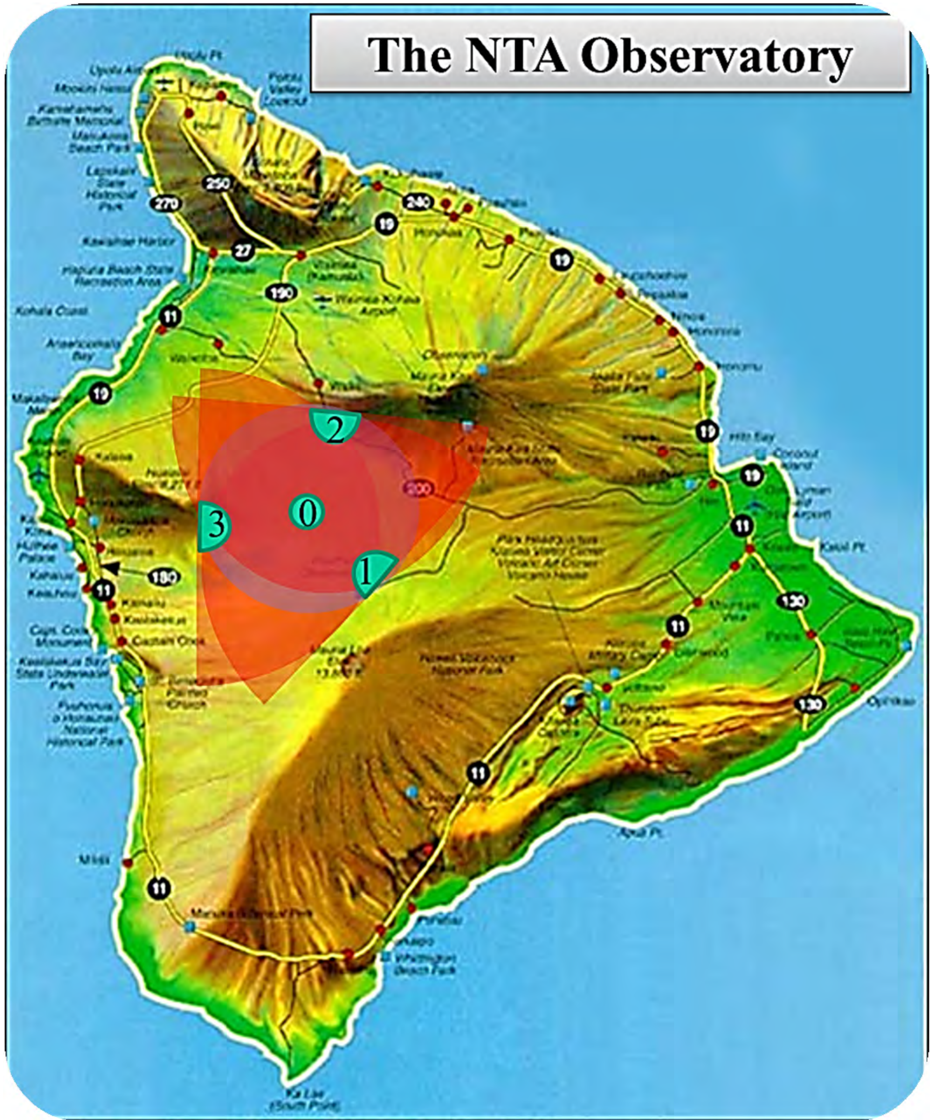
1. IceCube, Nature 484 (2012) 351
- IC40+IC59 stacked 117+181GRBs
- Very strong bias for time window (28s) around Satellite Triggers to suppress huge BG

2. Murase et al. ApJ 651 (2006) L5
- Nearby Low luminosity (LL) GRB (ex. GRB 060218/SN 2006aj) dominate total neutrino fluxes at Earth
- X or γ Satellites cannot detect

3. Hummer et al. PRL 108 (2012) 231101
- Recalculated neutrino flux => Ashra Energy Region more important

<u>Plausible: Ashra's Unbiased Search with BG-free</u>

Neutrino Telescope Array (NTA)



Conceptual Layout

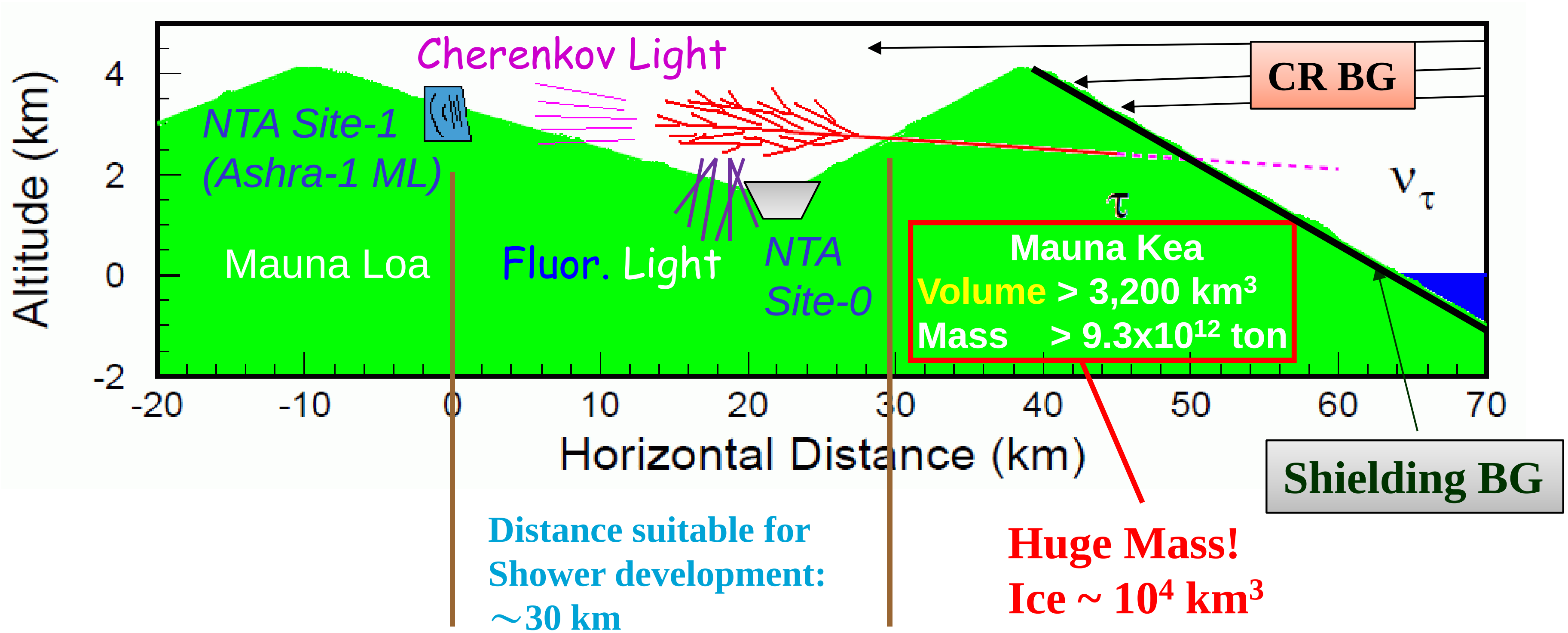
<u>Central Site</u> (Site-0)
<u>Peripheral Sites</u> (Site-1, 2, 3)
    25 km Triangle Grids

⇒ Huge Target Mass (>100 km^3-weq)
    Huge Atm. Mass (above area >1000 km^2)
    3 Mountains Shield BG

Compound Eyes watching the air from sides and beneath

The air in good weather condition between 3 mountains
Cherenkov & fluorescence images of tau appearance showers

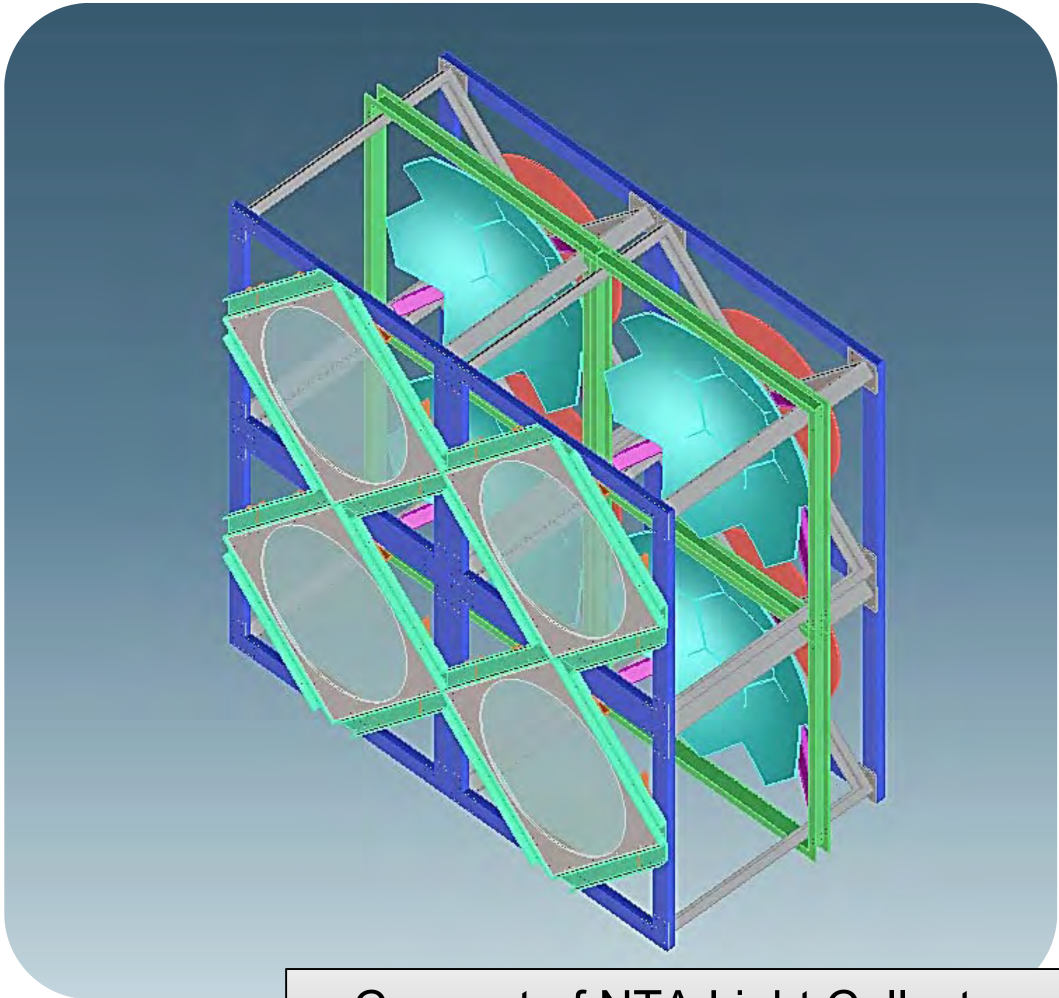
Earth-Skimming τ Shower Imaging Method



Ashra-1 really demonstrated this method！
(ApJ, 736 (2011) L12)

Neutrino Telescope Array (NTA)

NTA Light Collector (NTA-LC) mount baseline design (tentative)



Design Review
~ 1 yr in NTA collaboration
⇒ Technical Proposal

Light Collector (LC)
Schmidt Optics with ϕ1.5m pupil
FOV 28° = focal sphere ϕ50cm

Detector Unit (DU)
4 LCs watching same FOV
Superimposed 4 images
⇒ Effective pupil size = ϕ3m

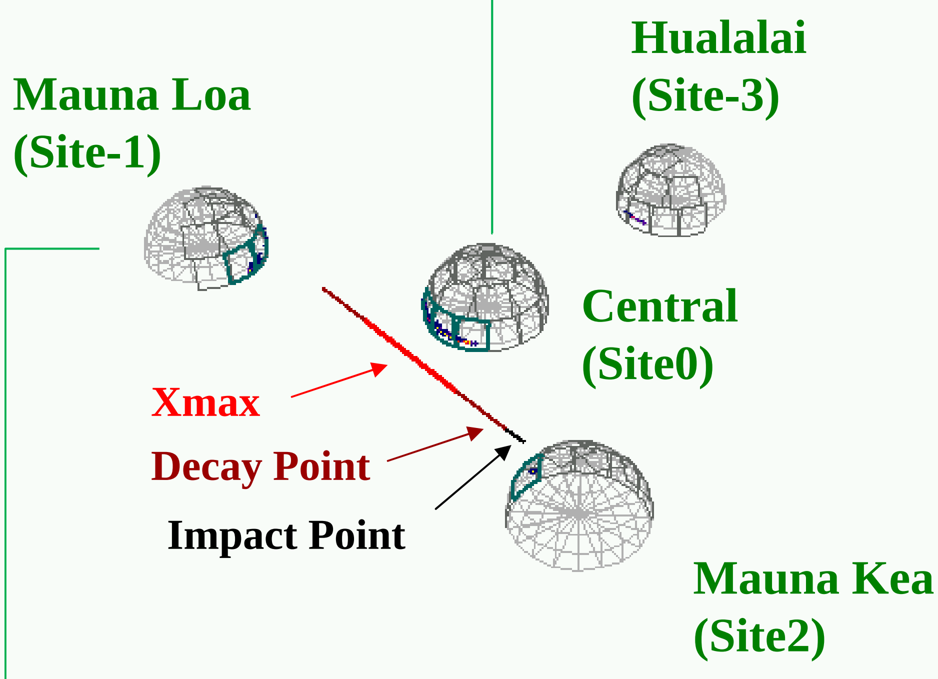
⇒ Concept of NTA Light Collector:
Ashra-1 x 1.5 scaled-up + same trigger & readout

Neutrino Telescope Array (NTA)

MC Event Sample (100PeV)

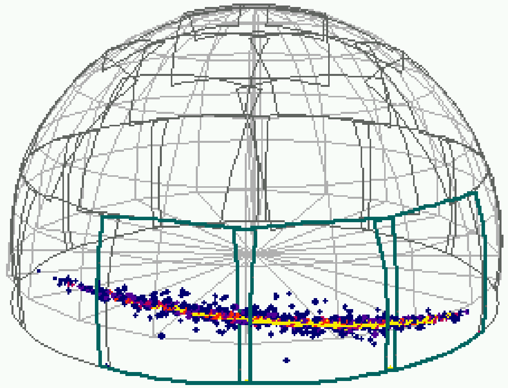
R00264/E00052: $E_\nu=10^{17.0}$eV, $E_\tau=10^{16.8}$eV, $E_{show}=10^{16.7}$eV

Elevation=-6.4°, Azimuth= 347.6°



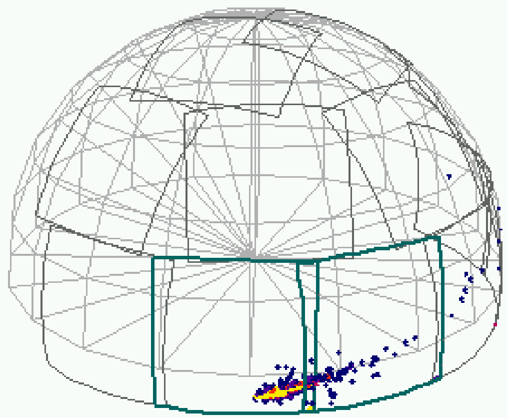
N_{pe}^{tot}=4035 (C:1363, F:2672), R_p^{min}=1.8km, R_x^{min}=5.4km

Central (Site-0): Fluorescence



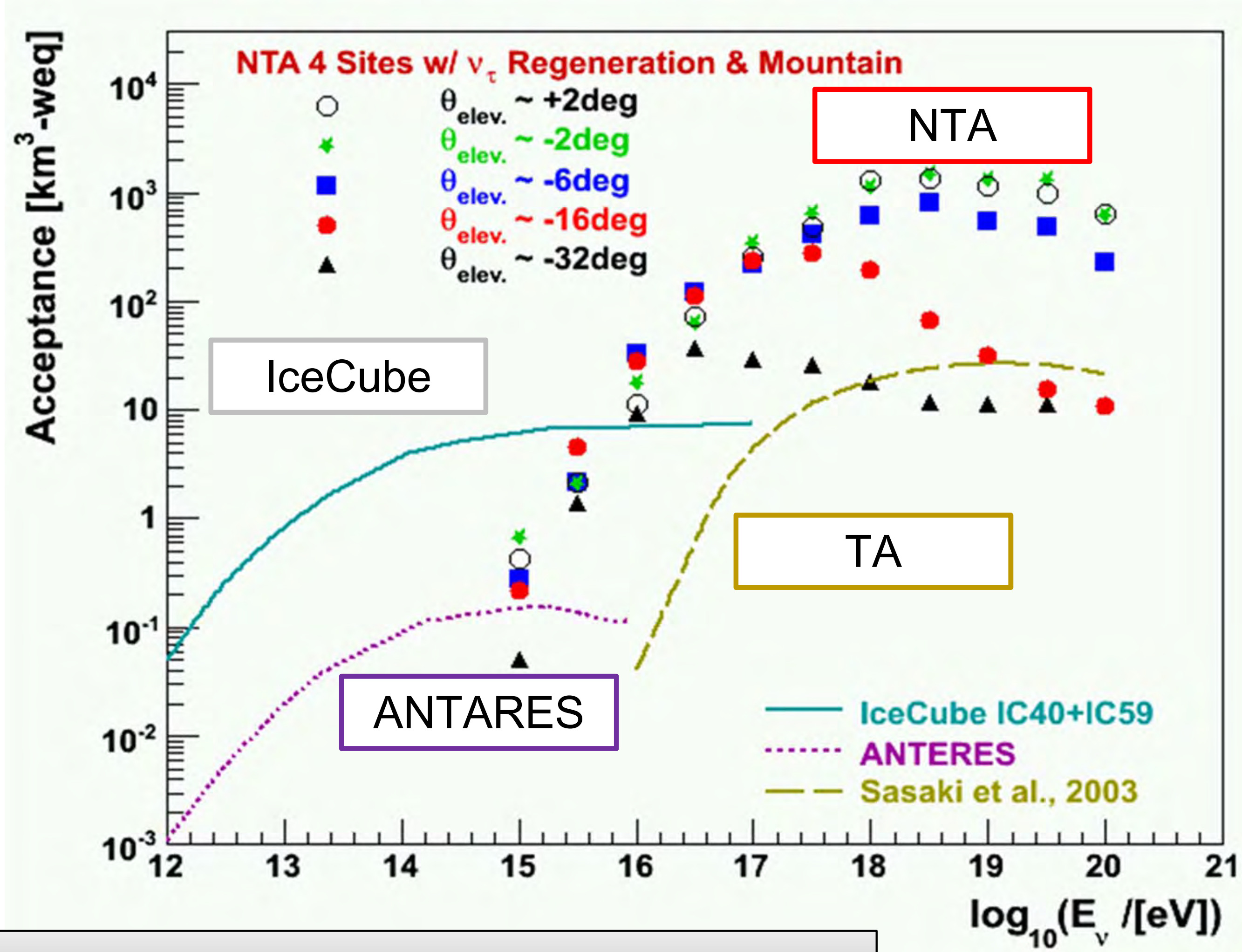
0.5° trigger pixel (yellow >5 pe)

Mauna Loa (Site-1): Cherenkov



Neutrino Telescope Array (NTA)

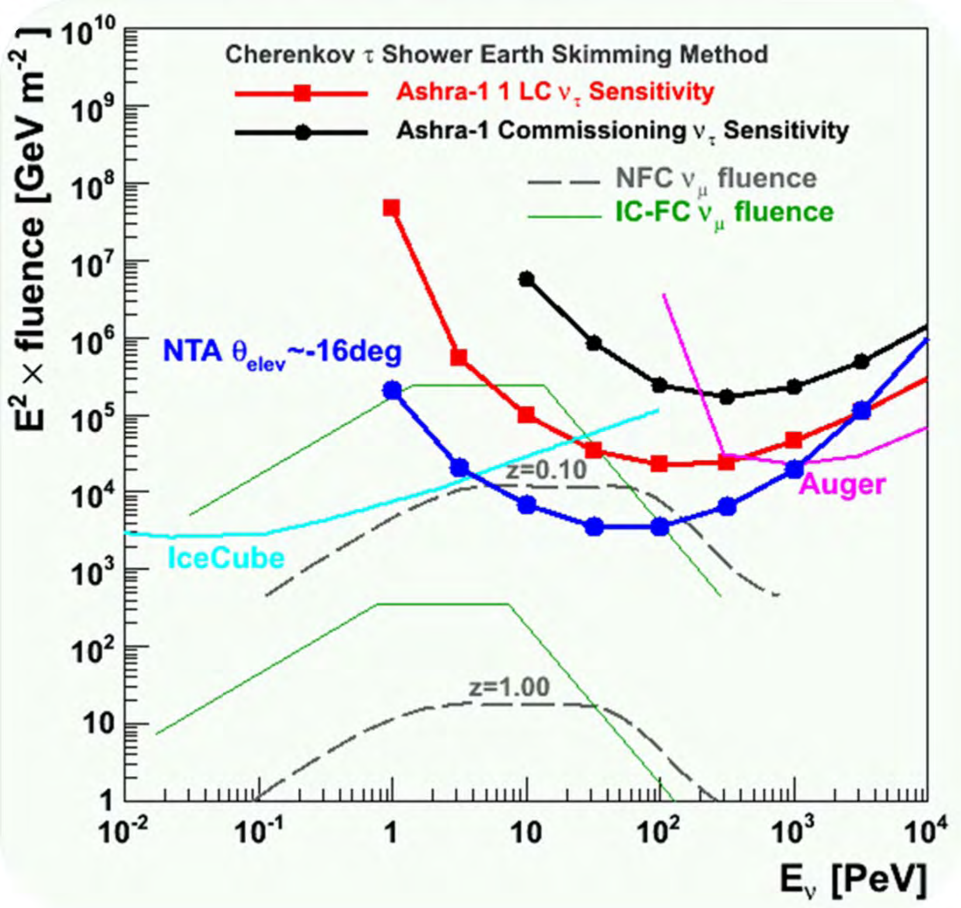
Acceptance with Water & Muon vs Air & Tau



⇒ ν_τ Detection in Wide Elevation ~30 deg

Neutrino Telescope Array (NTA)

GRB Neutrino Search Comparison



0. Auger, PRD 79 (2009) 102001

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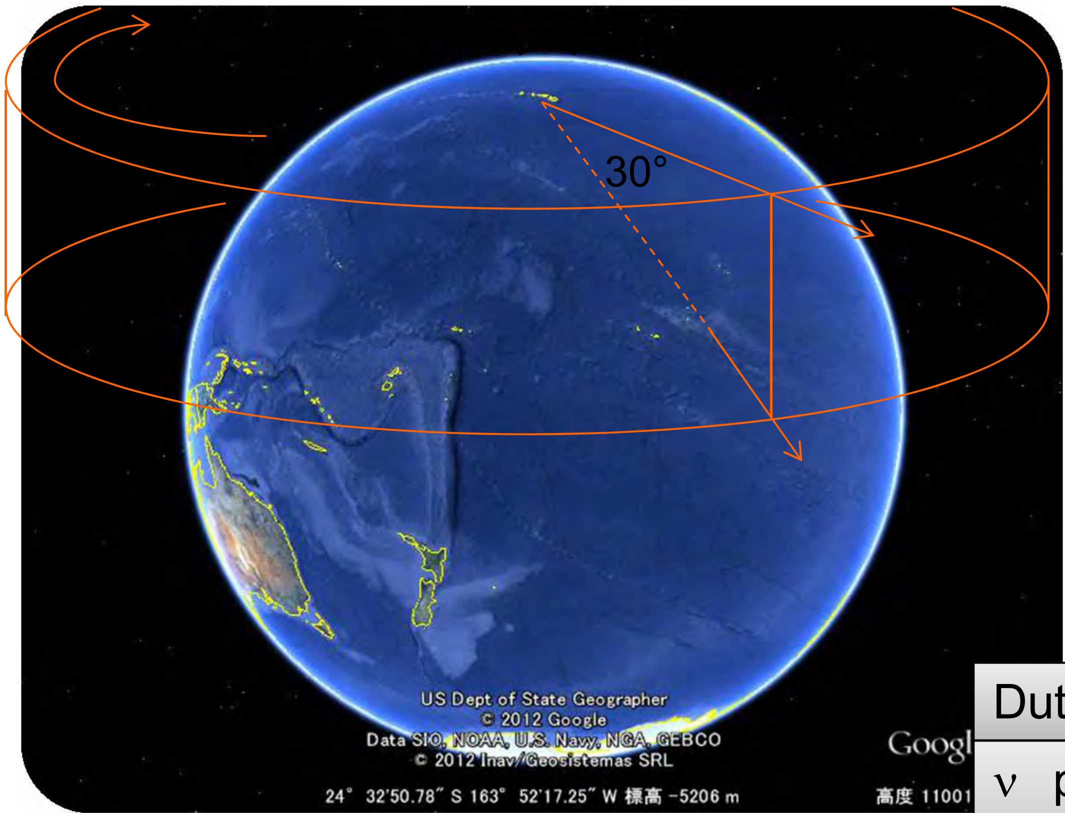
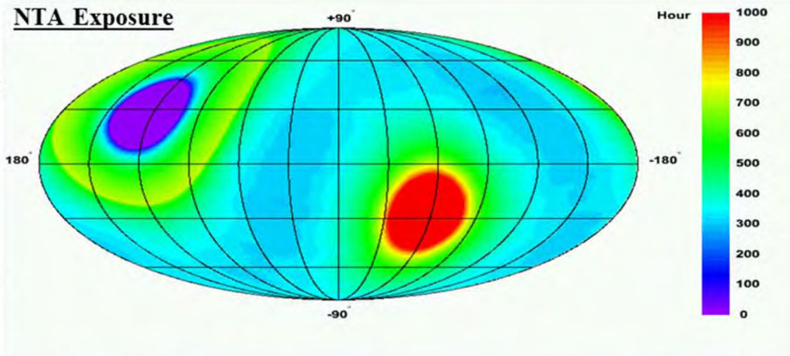
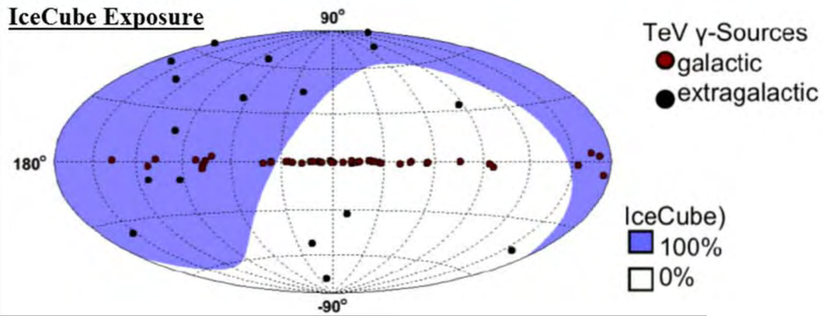
3. Hummer et al. PRL 108 (2012) 231101
- Recalculated neutrino flux => Ashra Energy Region more important

NTA Survey Depth: z ~ 0.15 (2 Glyr) for GRBν flux (by Hummer et al.)

Neutrino Telescope Array (NTA)





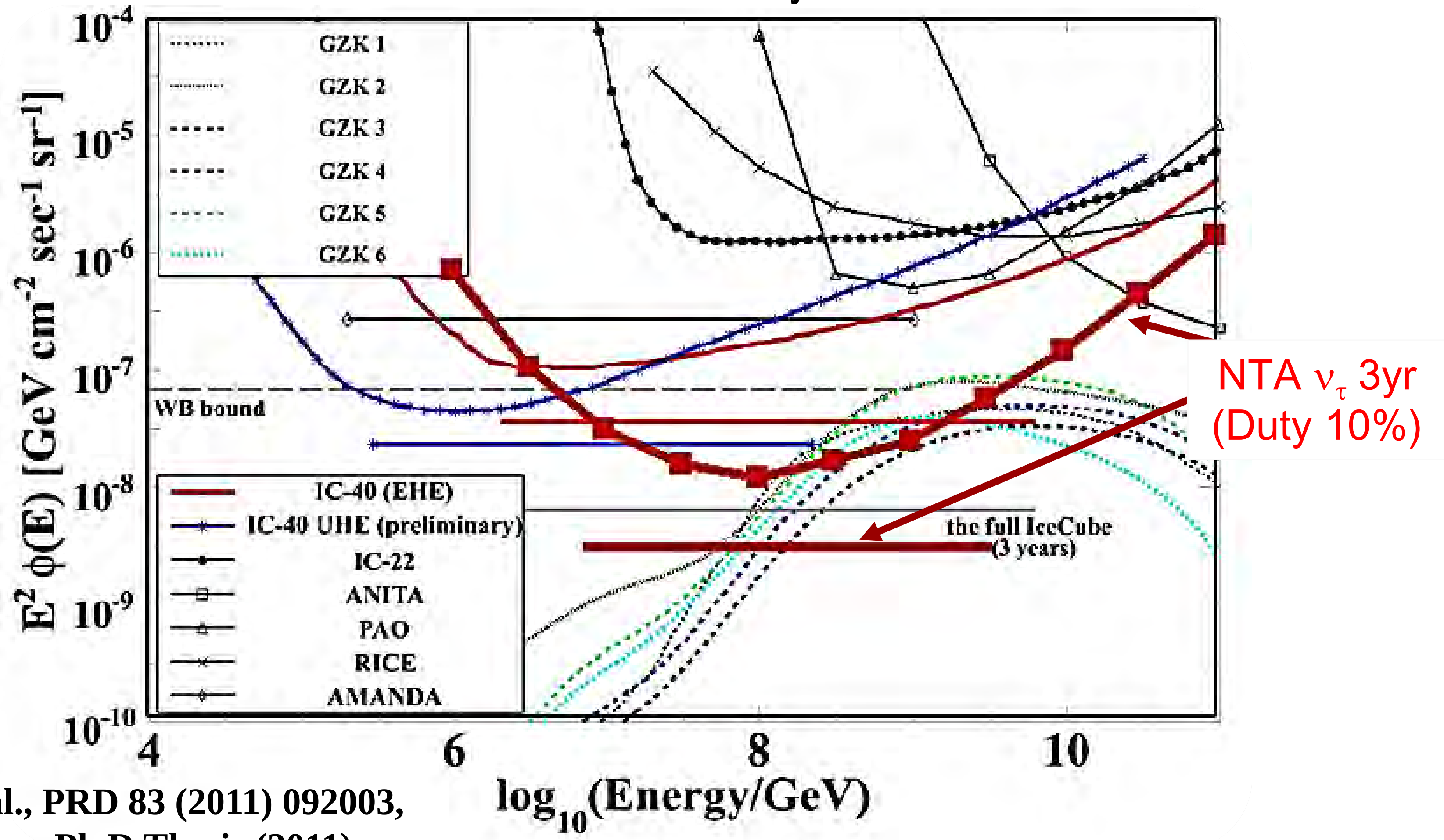


NTA ν Survey Performance

Duty 10-20% from Ashra-1
ν pointing accuracy < 0.2° (Cheren. mono)
FOV Elevation 30°× Azimuth 360°
For GRBν Survey Depth z < 0.15 (2 Glyr) ⇔ GW det. KAGRA (0.7 Glyr) x 3

Neutrino Telescope Array (NTA)

Diffuse-ν Sensitivity



Abassi et al., PRD 83 (2011) 092003,
H. Johansson Ph.D Thesis (2011)

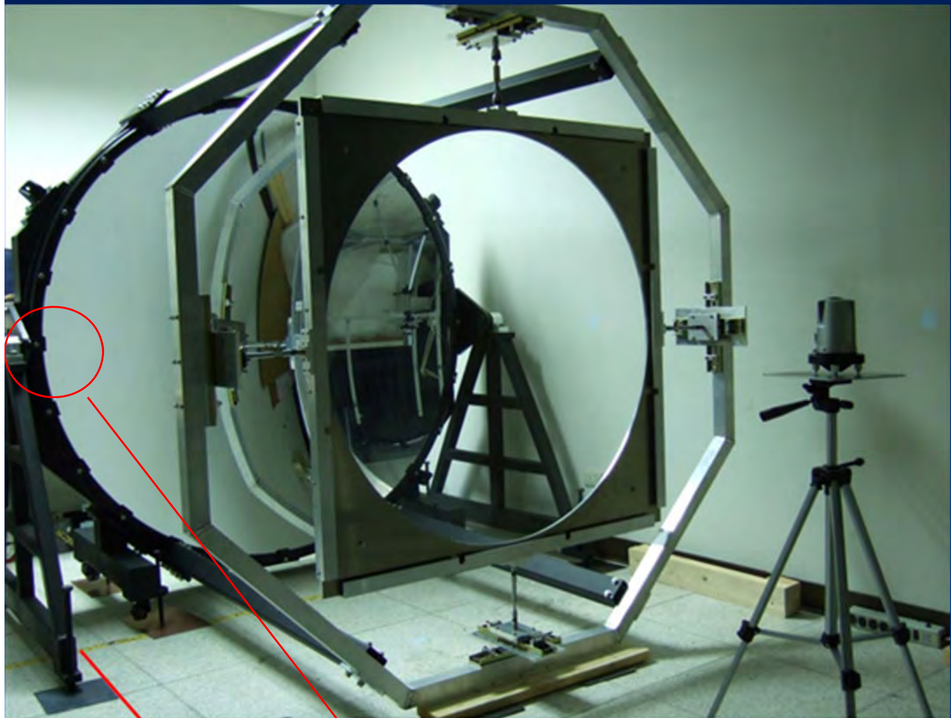
Diffuse ν case: Duty 10% × solid angle ratio 0.5 ⇒ competitive w/ IceCube

Conculsion

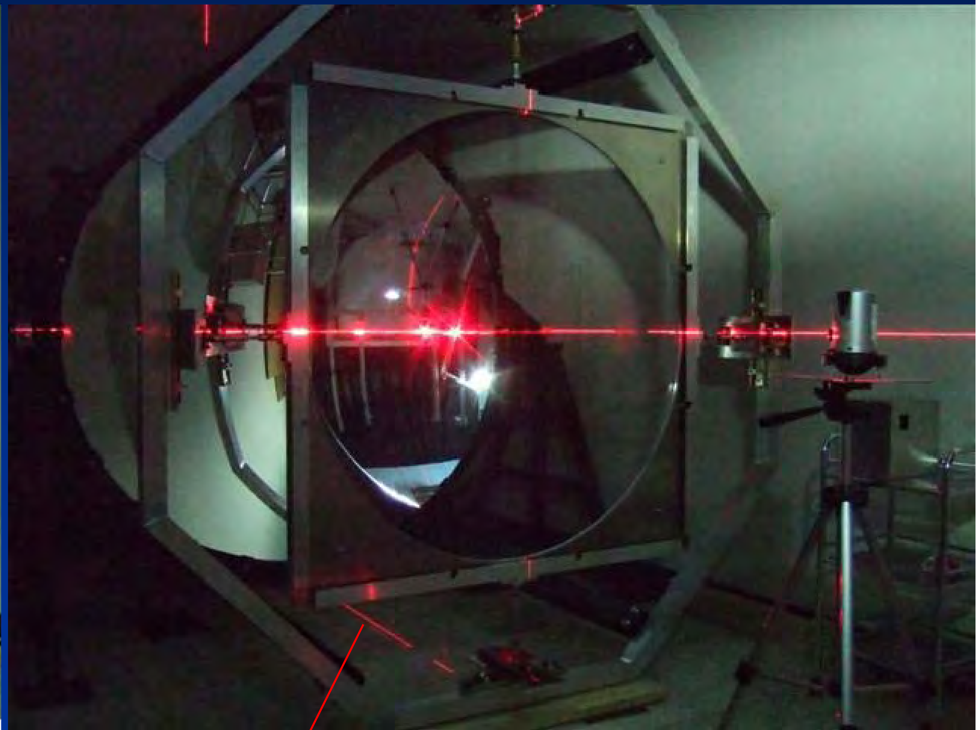
- Excellent detection sensitivity of Earth-Skimming (ES) τ Shower Imaging method in PeV-EeV region to search for ν's from hadron acceleration in astronomical objects, with good pointing accuracy and negligible BG from CR and atm-ν's.
- NuTel and Ashra-1 were developed to detect ν_τ with the ES method. The optical/electronic systems of NuTel were designed, built and tested at 2100 m on Mei-Fong Mountain in Taiwan, and is ready for physics observation. Ashra-1 succeeded in the first search for PeV-EeV ν_τ from GRBs with the best instantaneous sensitivity since 2008.
- New collaboration for next-gen. Neutrino Telescope Array (NTA) begin to form. The layout considers three site stations for 25 km-grid triangle and a single site station at the center with full-sky coverage, watching the total air mass surrounded by the 3 mountains on Hawaii Island. This configuration allows tremendous sensitivity (> 100 Gton weq.) and wide survey capability with Cherenkov-fluorescence observation for PeV-EeV ν's in essentially background-free conditions.

Backup

NuTel at NTU



Fix and let the main part of support easily leaving the floor to rotate vertically.



Gravity center, make rotation easier.

Trick of alignment of position & tilt: make incident and reflected light overlapped.

- Mei-Fong (2100 m)

- Site survey in summer 2008

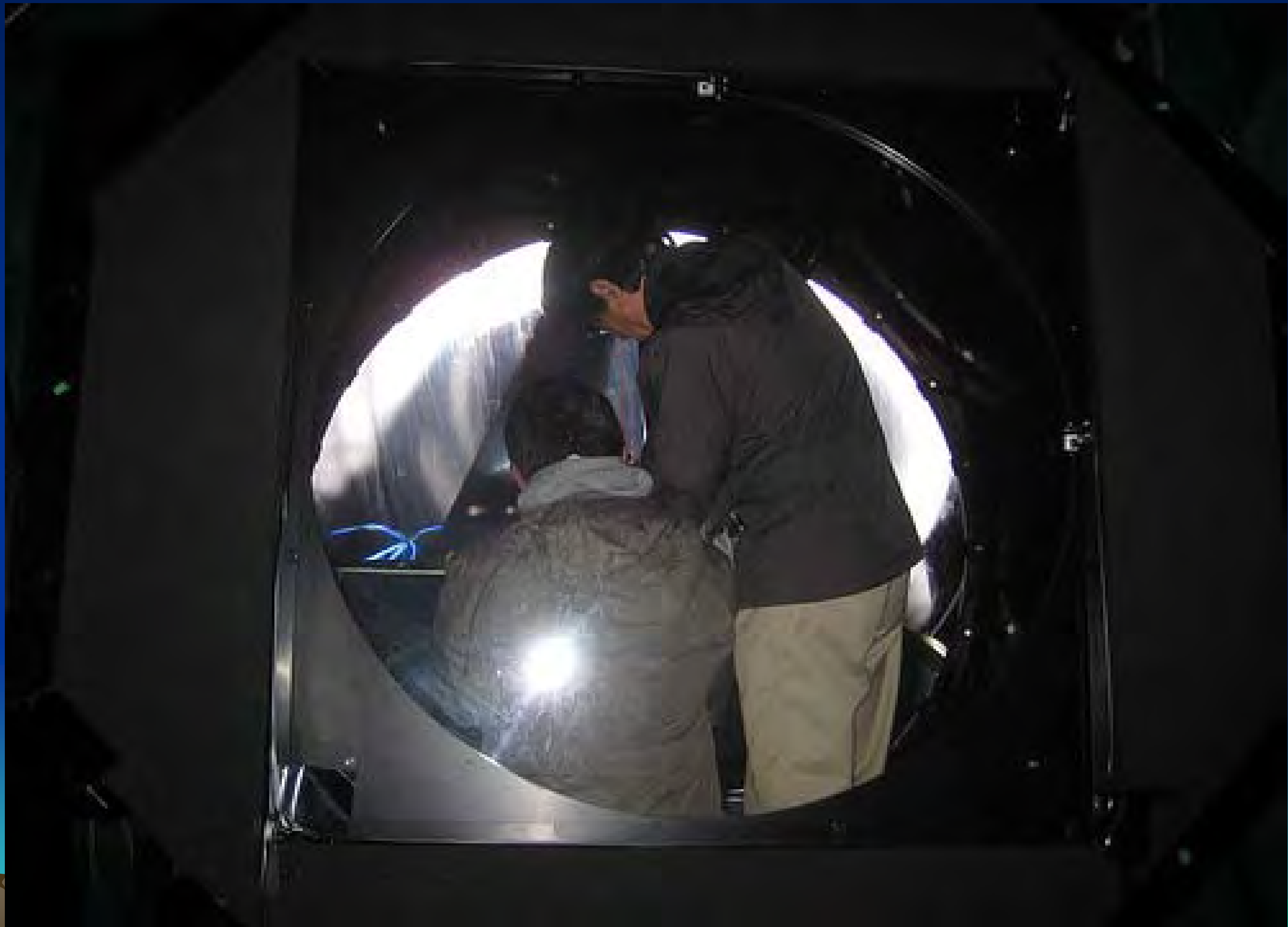
- Lu-Lin Zan Chung (2700 m)

- Kuan-young (3092 m)

Working in the observational Tent

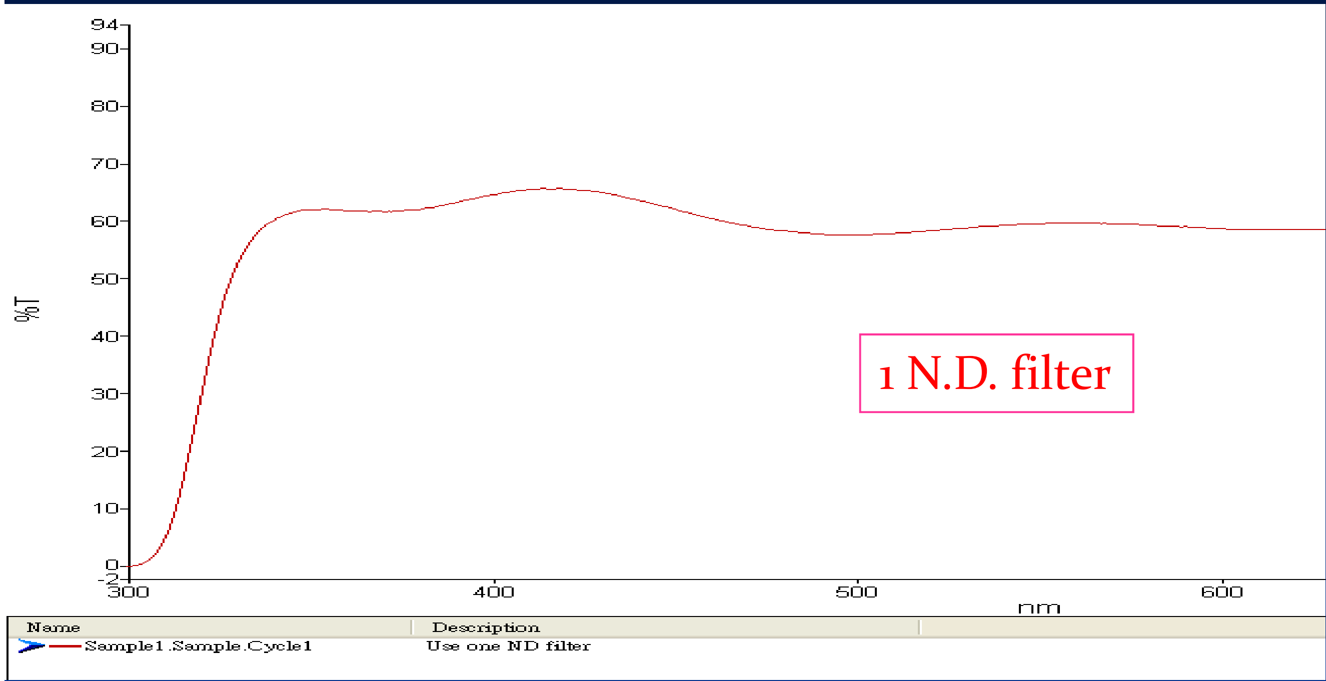
Installation of light sensor/readout

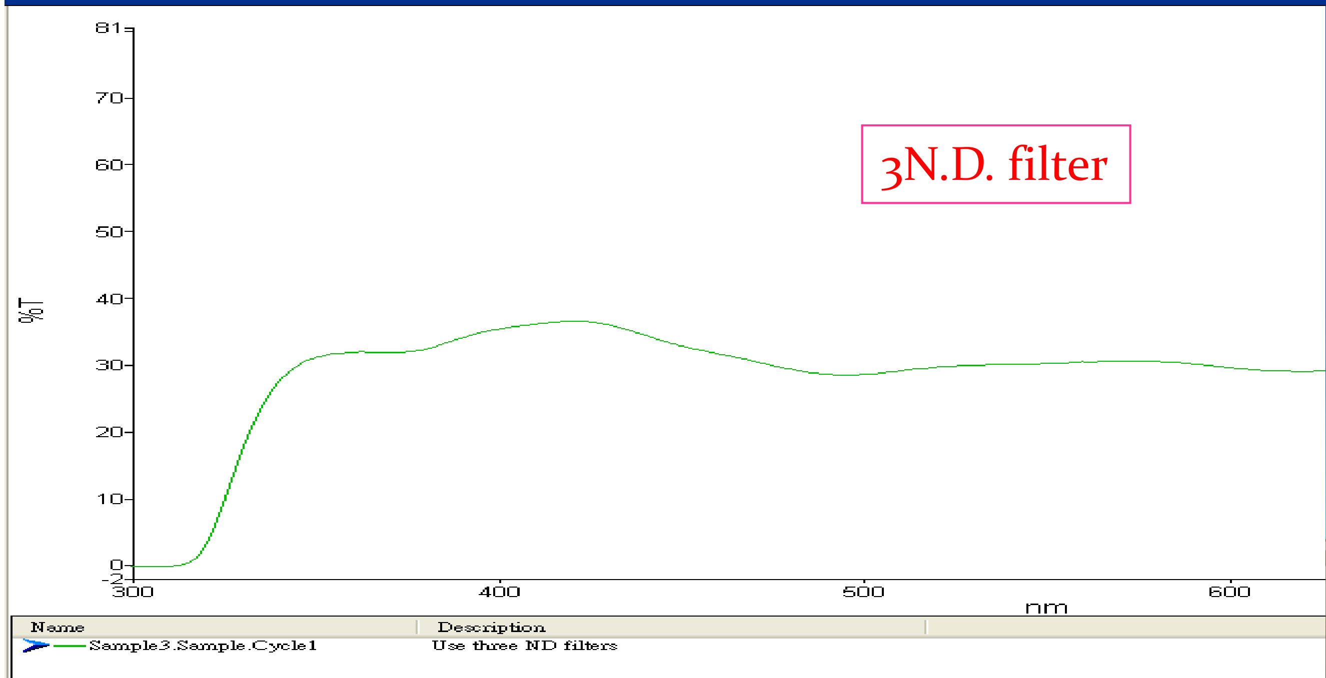
Final adjustment of optics



Taking shifts for online monitoring

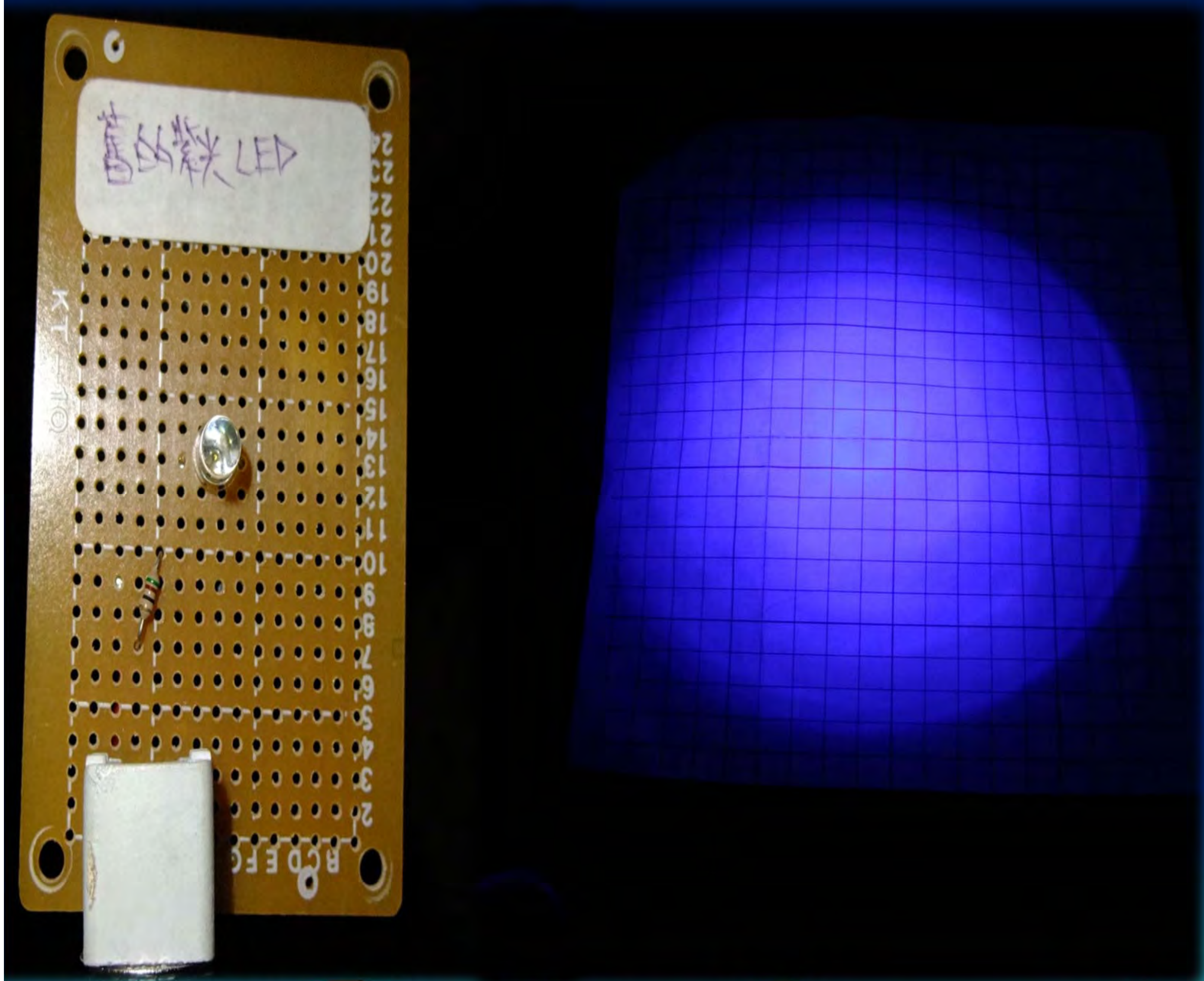
N.D. filter Transmit rate





By adding N.D. filter in front of window of MAPMT, we can decrease incident photons into MAPMT.

The N.D. filters are reflective type. The transmit rate verse wavelength show as left graphs.



Calibration of MAPMT gain

We use purple-UV led to shine on MAPMT in black box.

And left picture show the purple led and it shine on grid paper .

$\nu_\tau \rightarrow \tau \rightarrow \nu_\tau \rightarrow \tau \dashrightarrow$

CC 相互作用ごとに非弾性度分エネルギー損失しながら、レプトン変換を繰り返す

⇒　高いエネルギーの　ν_τ　を低いエネルギーの　ν_τ　に“変身”させて検出する。

⇒　高いエネルギーの　ν_τ　の地球による遮蔽を軽減できる。

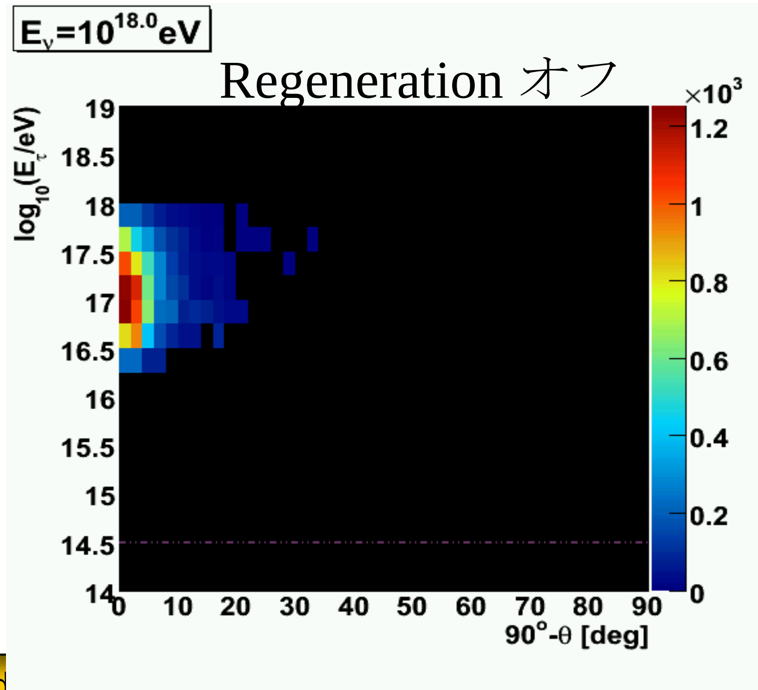
⇒　検出視野(俯角)を稼ぐことができる

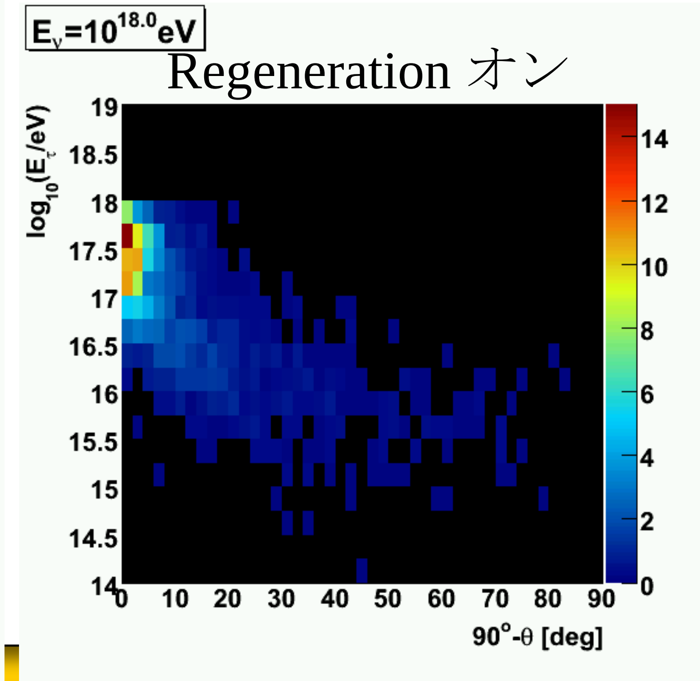
⇒　NTAによる探査範囲が広がる

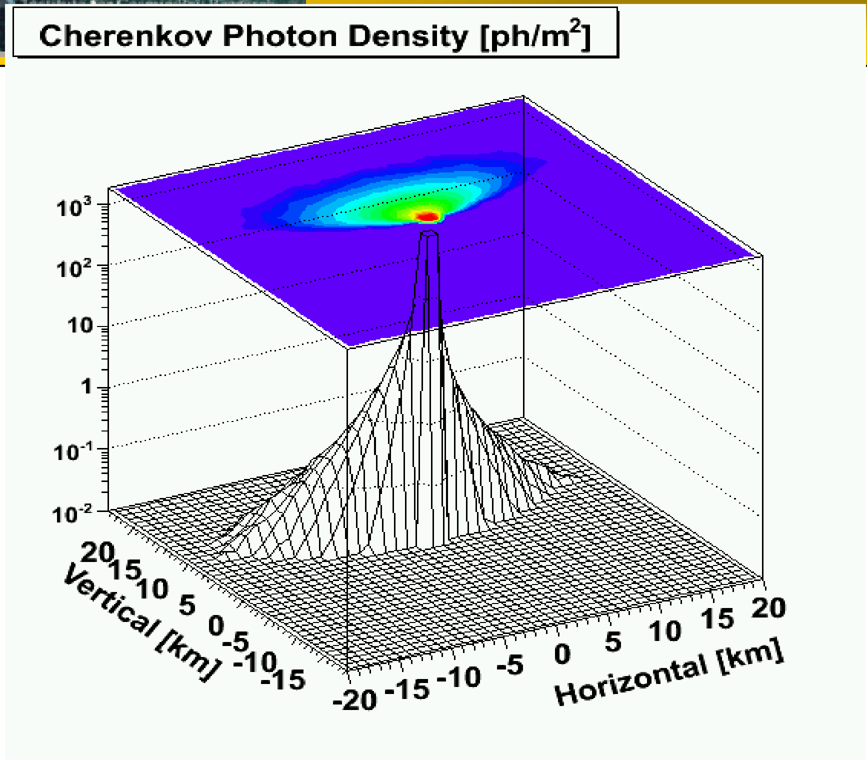
E_ν=1EeV

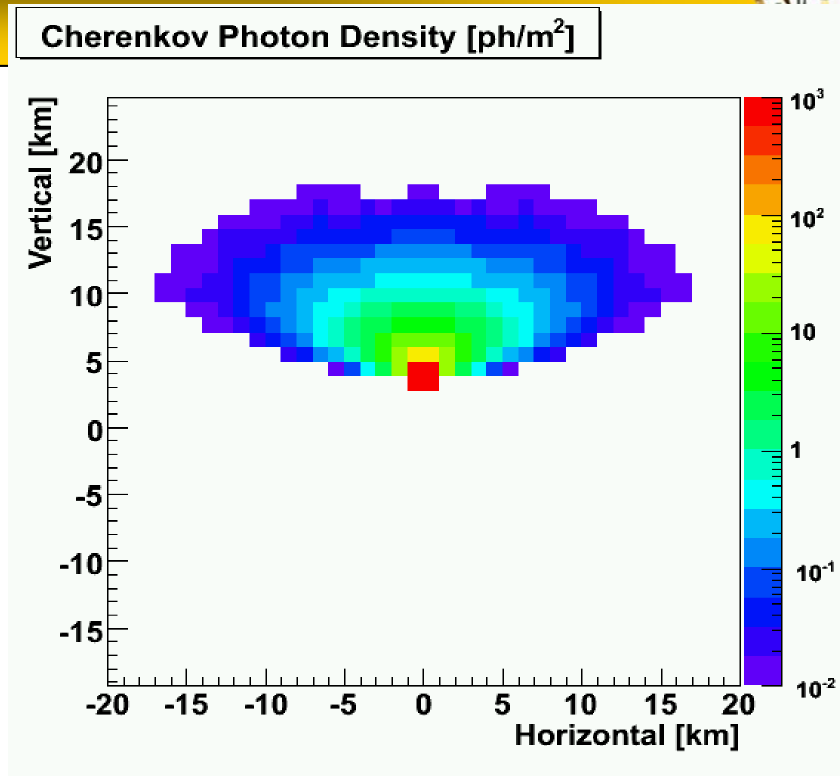
τ出現時の

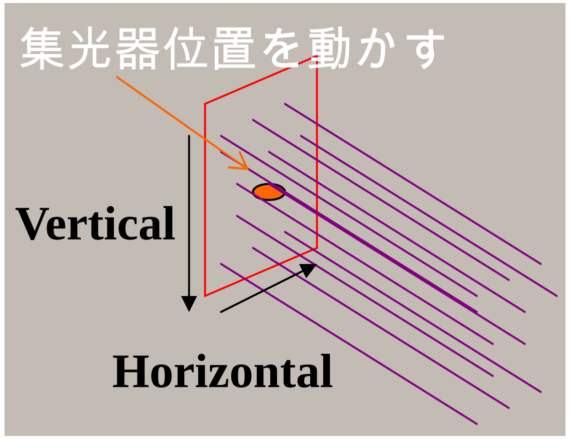
E_τ vs $-\theta_{elev}$











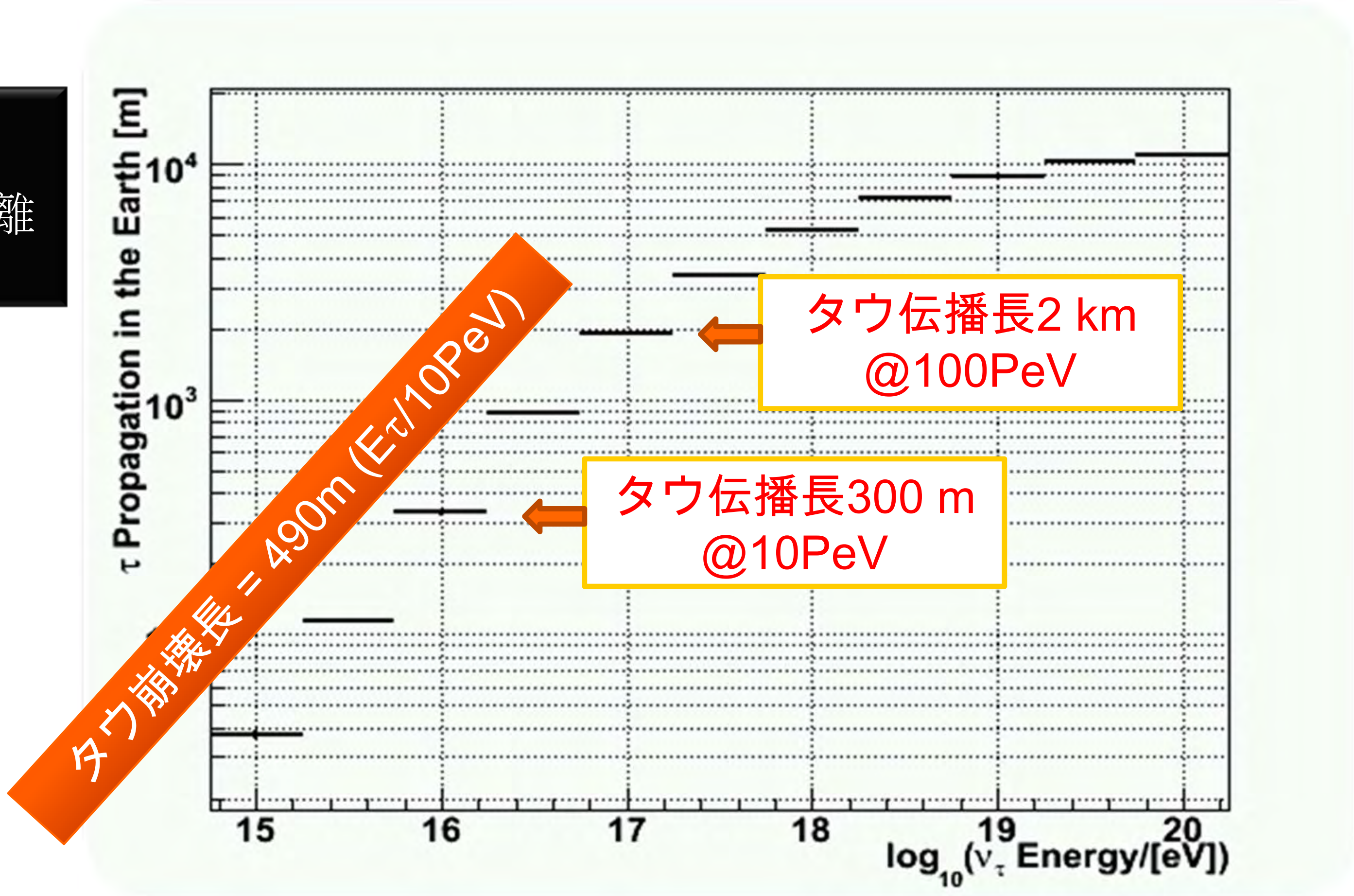
タウシャワー
10°吹上げ
シャワー開始
は地表面近く

水平シャワーからのチェレンコフ光は広範囲(~5km)で検出可能

1PeV < Eν < 10PeV では
チェレンコフ光が蛍光より優勢

Tau Propagation Length in Rock (MC study)

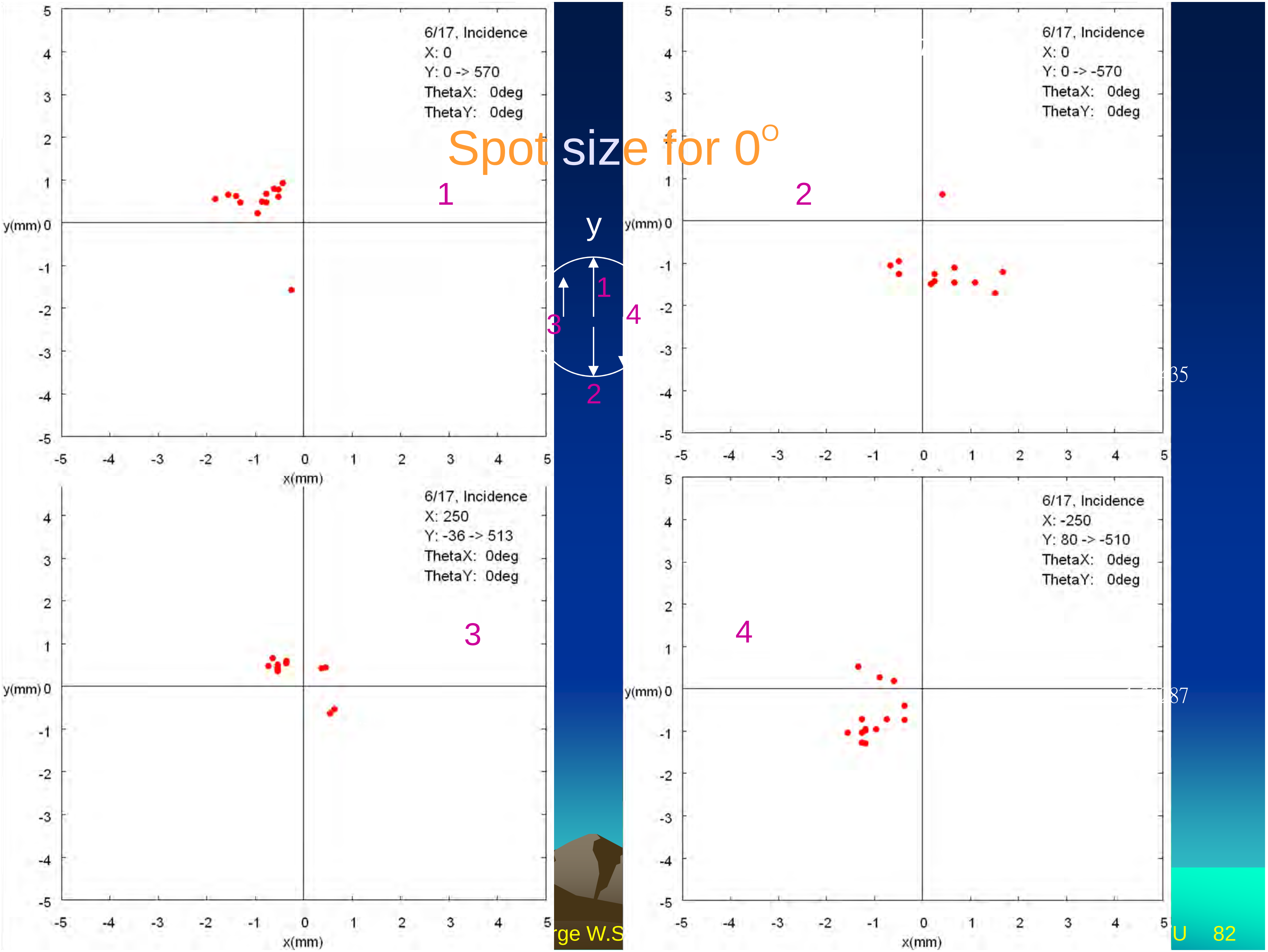
地表に現れたτ が
地中を走行した距離
のMC平均

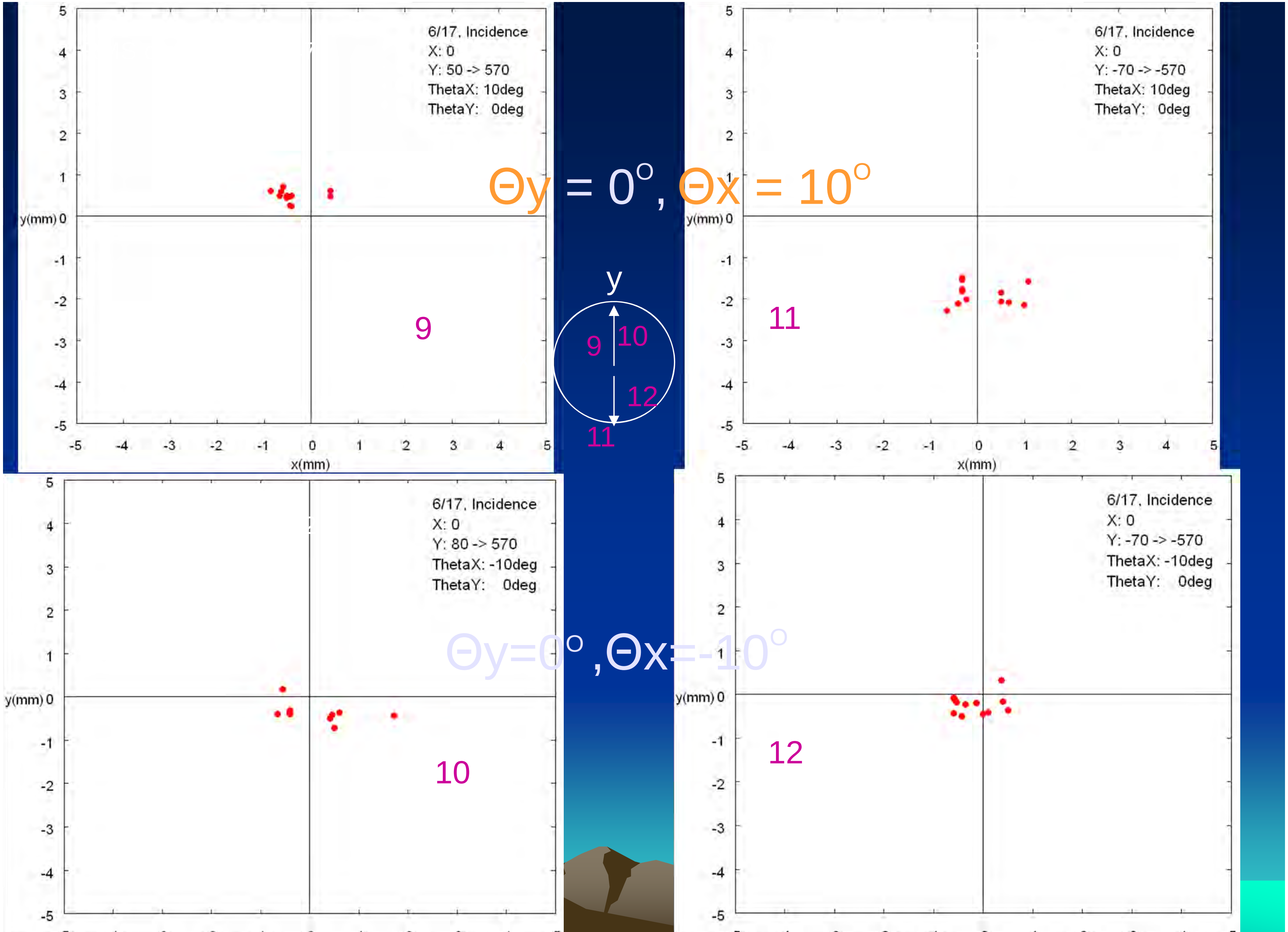


(横軸：ν_τエネルギー)

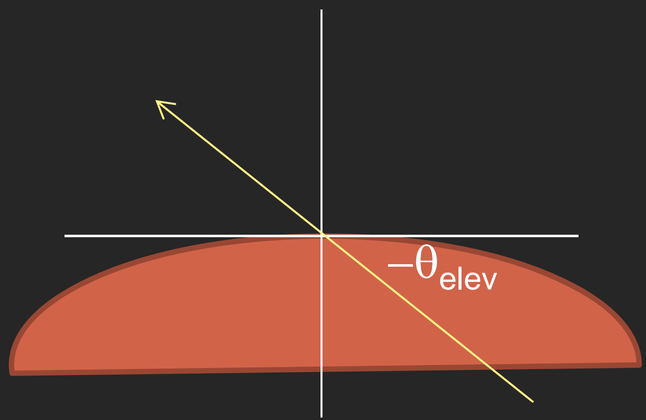
Forming International Collaboration

Spot size for 0^{o}




Θy = 0°, Θx = 10°
6/17, Incidence
X: 0
Y: 50 -> 570
ThetaX: 10deg
ThetaY: 0deg
9
6/17, Incidence
X: 0
Y: -70 -> -570
ThetaX: 10deg
ThetaY: 0deg
11
y
9
10
12
11
6/17, Incidence
X: 0
Y: 80 -> 570
ThetaX: -10deg
ThetaY: 0deg
10
Θy=0°,Θx=-10°
6/17, Incidence
X: 0
Y: -70 -> -570
ThetaX: -10deg
ThetaY: 0deg
12
x(mm)
y(mm)

地中におけるCC散乱長 (L_{CC}^{ν}) に相当する俯角 ($-\theta_{elev}$)



E_ν (PeV)	L_{CC}^{ν} (10^7g/cm^2)	$-\theta_{elev}$ (deg)
1	270	32
10	94	16
100	35	5.9
1000	14	2.3

[M.Sasaki et al., Astropart. Phys. 19 (2003) 37]

Regeneration ⇒ 低エネルギー化 ⇒ 検出立体角度の拡大

τシャワーの方向精度(検出方法起源)

Astropart. Phys. in press,
arXiv:1202.5656

- 伝播・反応過程での方向変化
  - 素粒子・宇宙線分野で広く用いられ定評ある シミュレーションプログラムにより評価

過程	評価方法	精度@PeV	注釈
ν_τ荷電相互作用	PYTHIA	< 0.3分角	Pt: W質量で制限
τ地中伝播	GEANT4 ALLM model	< 1分角	輻射プロセス重要 光核反応のみALLMモデルで評価した
τ崩壊	TAUOLA	< 1分角	Pt: τ質量で制限
空気シャワー	CORSIKA	0.1°	AS軸ずれ$\propto$ $E^{-1/2}$

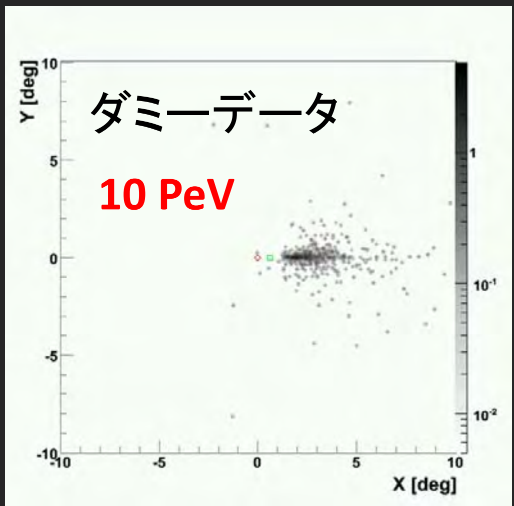
PeV-EeV領域では、τシャワーはν_τの方向を覚えている

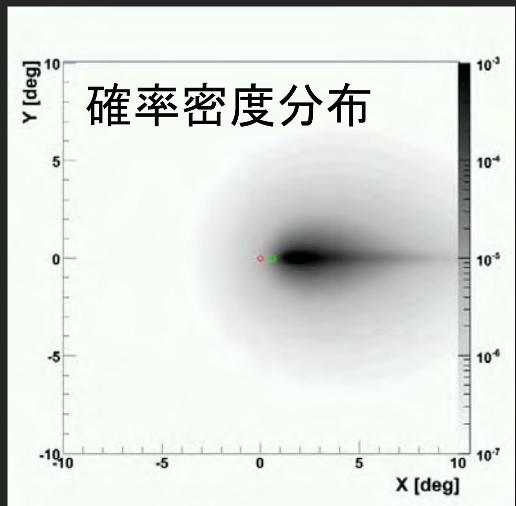
- 事象再構成
  - 到来方向決定精度 ⇒ 重要
    - 大天頂角宇宙線BG除去
    - 超高エネルギーニュートリノ源同定
  - Likelihood を用いた再構成精度評価
    - **$\sigma = 0.16^\circ$**

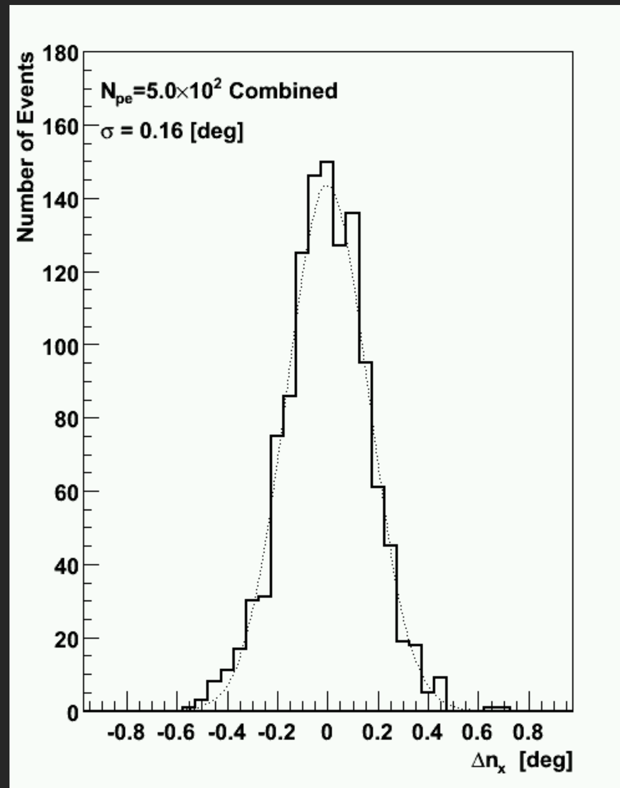
⇒ Cherenkov モノ観測でも 高精度方向決定が可能

(cf.) E>PeV τ シャワーの方向精度良好

$$L = \sum_i N_{\rm pe}^i \log(p_i).$$







宇宙線BG

- 支配的なバックグラウンド
  - 大天頂角からの宇宙線シャワー
- 期待されるBG量 (CORISKAにて推定)
  - Commissioning 観測
    - N_{BG} = 1.3x10^{-4} (197.1hr) ⇒ 無視可能
  - 本観測 (1LC)

山際からの距離	0.1°	0.3°	1.0°	3.0°
期待されるBG頻度	0.082/yr	0.55/yr	4.3/yr	39/yr