



# TA-muon

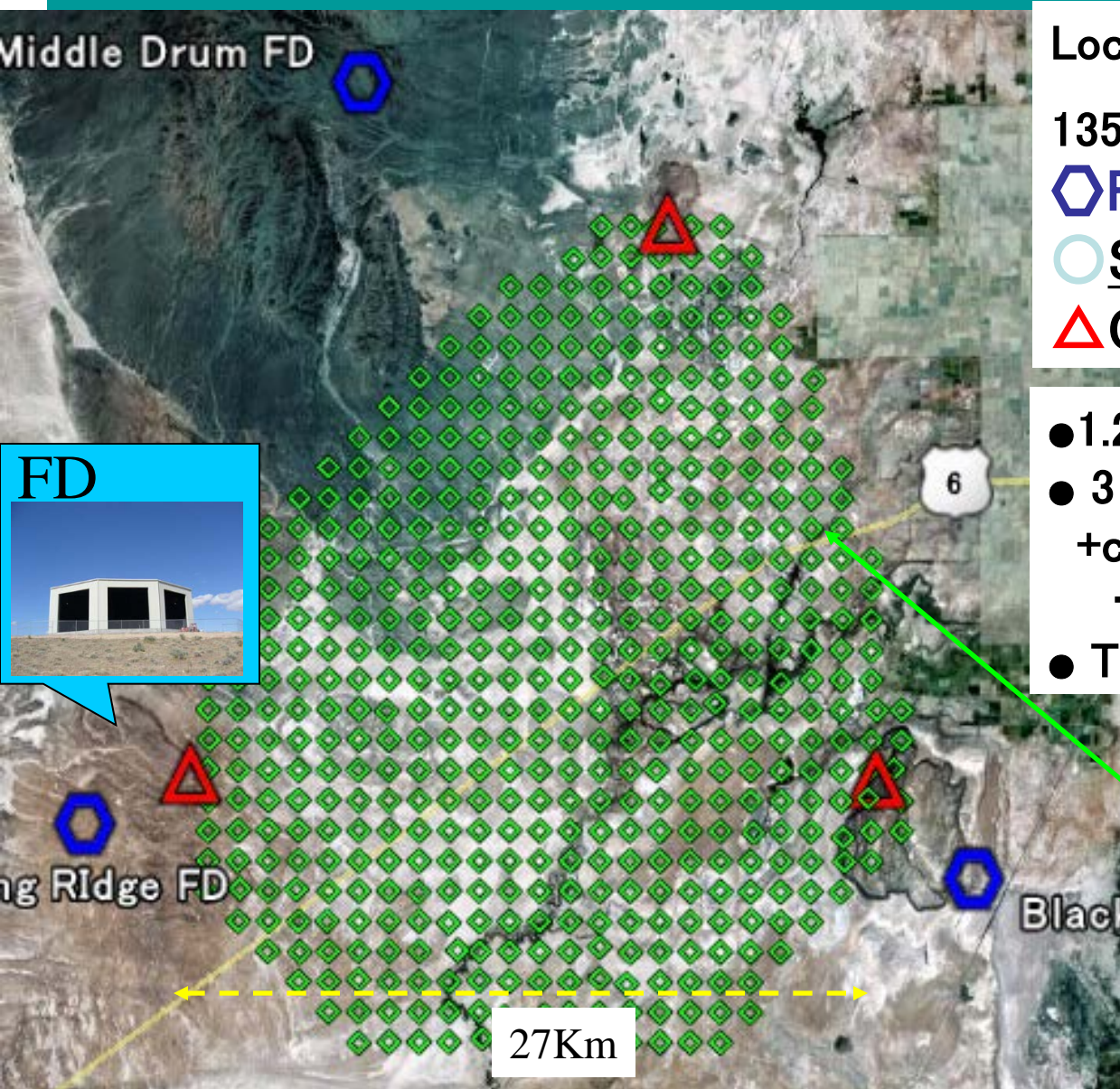
**Toshiyuki Nonaka**

**Institute for cosmic ray research university of Tokyo  
for Telescope Array Collaboration**

## Outline

- T ASD / concept of TA muon detector
- Design performance study
- status of construction of detectors
- Test output from TA Lead Burger.
- Summary · Future

# Telescope Array Experiment



Location: N39.3° W112.9°

1350–1500m asl

⬡ FD station (× 3station)

○ Surface Array (507 SD)

△ Communication tower

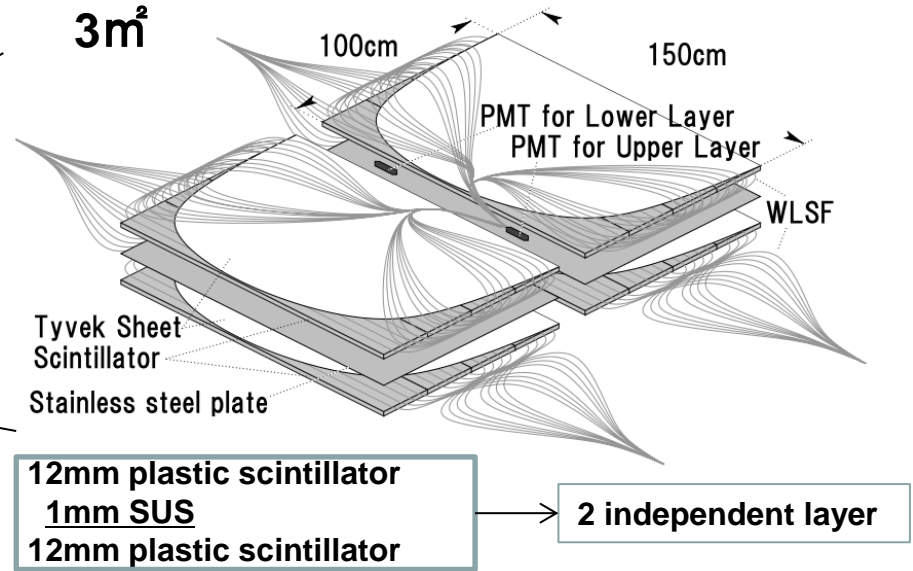
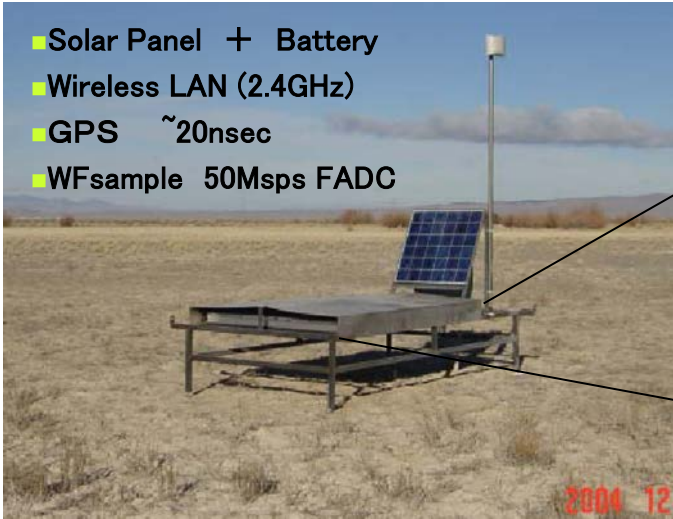
- 1.2 km grid SD (3m<sup>2</sup>)
- 3 sub array :  
+cross boundary trigger  
→ Total **507** SD
- Total detection area **~700km<sup>2</sup>**

SD



# TA Surface Detector

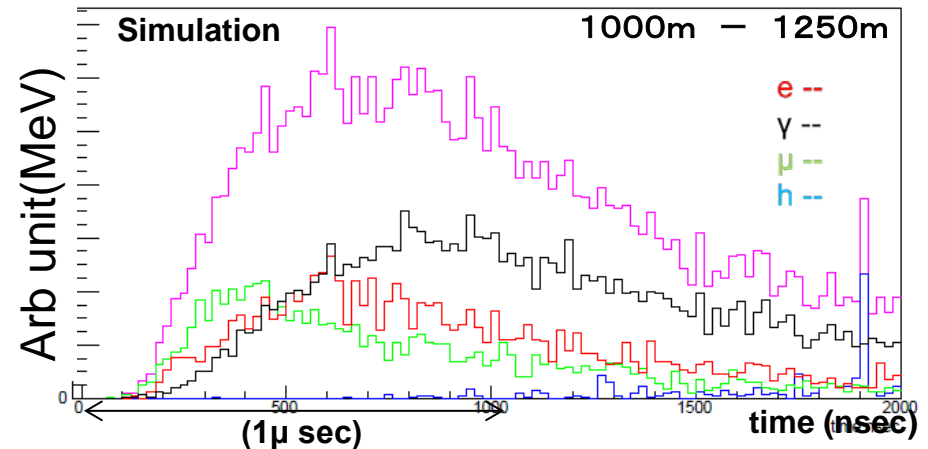
- Solar Panel + Battery
- Wireless LAN (2.4GHz)
- GPS ~20nsec
- WFsample 50Mps FADC



**TASD:**  
 Signal from 1.2cm scintillator .  
 → Low threshold  
 → sensitive to em component.

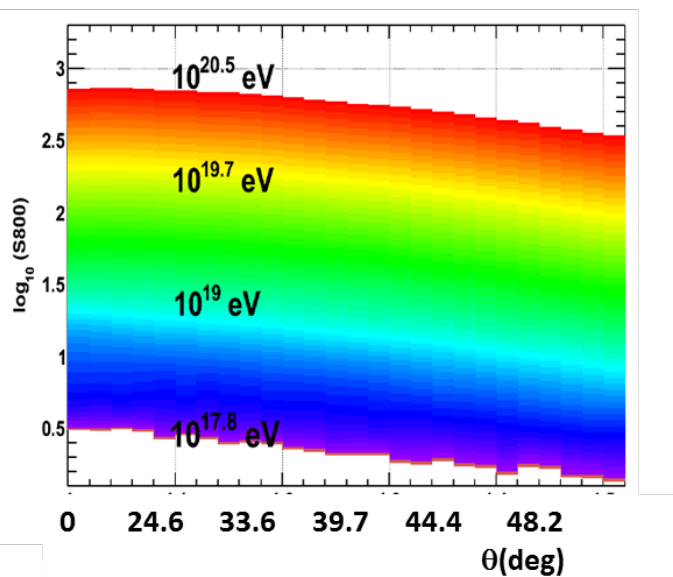
WLS Fiber (475nm) x5m → PMT ETL9124SA

$10^{19}$ eV Proton shower (stacked energy deposit)

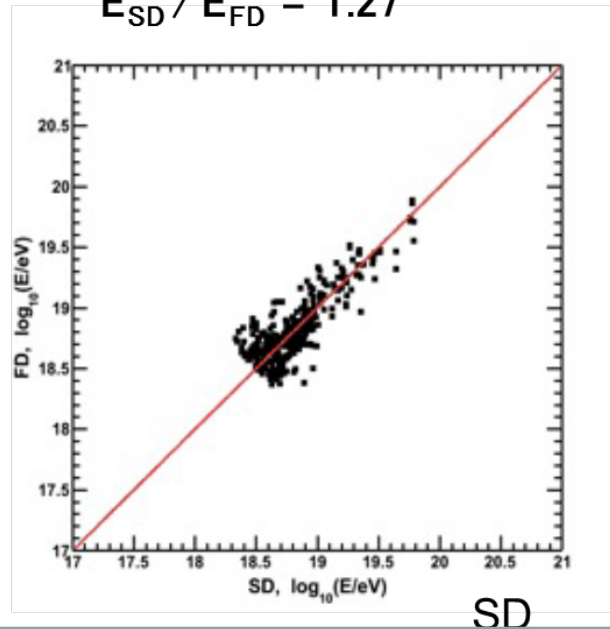


# Motivation

$S_{800}$ -Energy table by MC



$$E_{SD} / E_{FD} = 1.27$$



**Current status :**

-- Energy calibration with FD.

$$TASD \quad E_{sdmc} / E_{fd} = 1.27$$

→ ?

-- Auger SD  $N_{\mu} \sim 1.8x(N_{\mu} \text{ MC})$

→ suggest possibility of modification of Hadron Interaction model ..

◇ We are not understand the cause of this 27% yet.

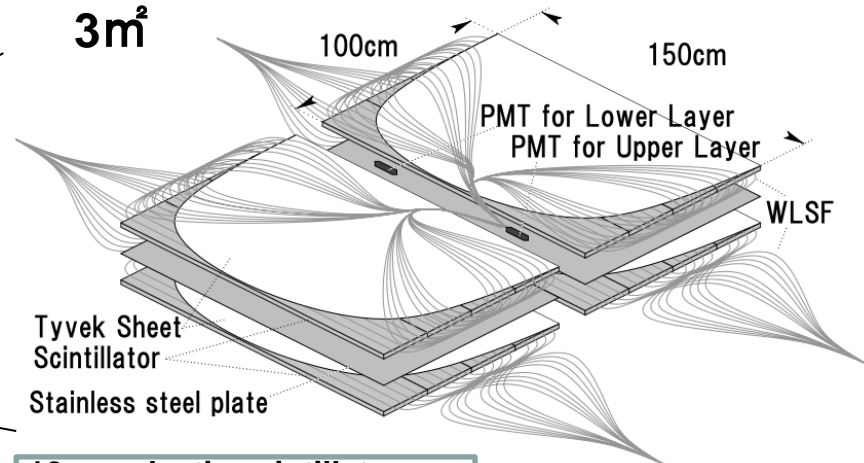
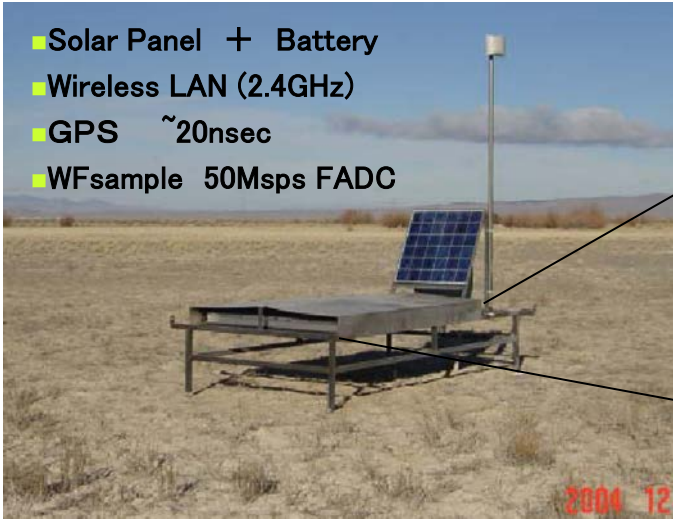
◇ Muon enhancement reported by Auger group + FD energy scale can explain the 27%?

◇ Need study about what parts of shower are different from MC.

(Not only the muon but EM component also) : Target Energy  $> \sim 10^{18.5}$  eV.

# TA Surface Detector

- Solar Panel + Battery
- Wireless LAN (2.4GHz)
- GPS ~20nsec
- WFsample 50Mps FADC



12mm plastic scintillator  
1mm SUS  
 12mm plastic scintillator

2 independent layer

WLS fiber (475nm) x5m → PMT ETL9124SA

**TASD:**

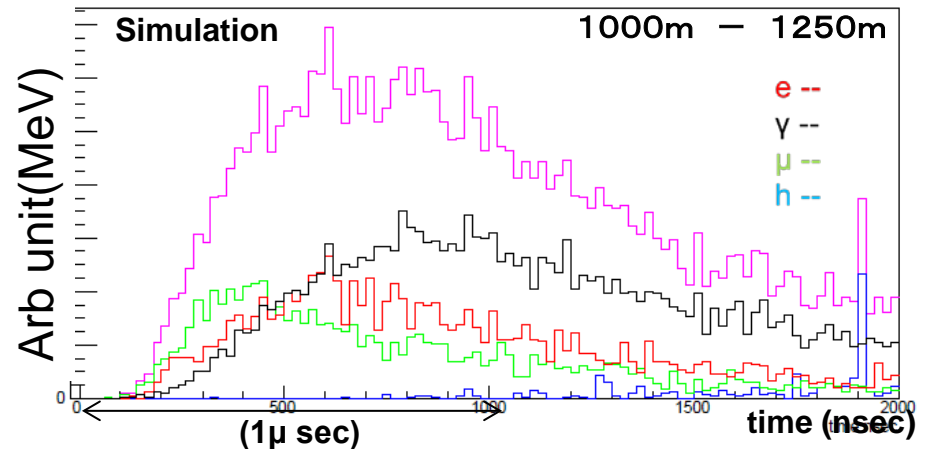
- Signal from 1.2cm scintillator .
- Low threshold
- em component sensitive.



**Concept:**

Using different thickness of detectors,  
 observe response to shower particles.

$10^{19}$ eV Proton shower (stacked energy deposit)

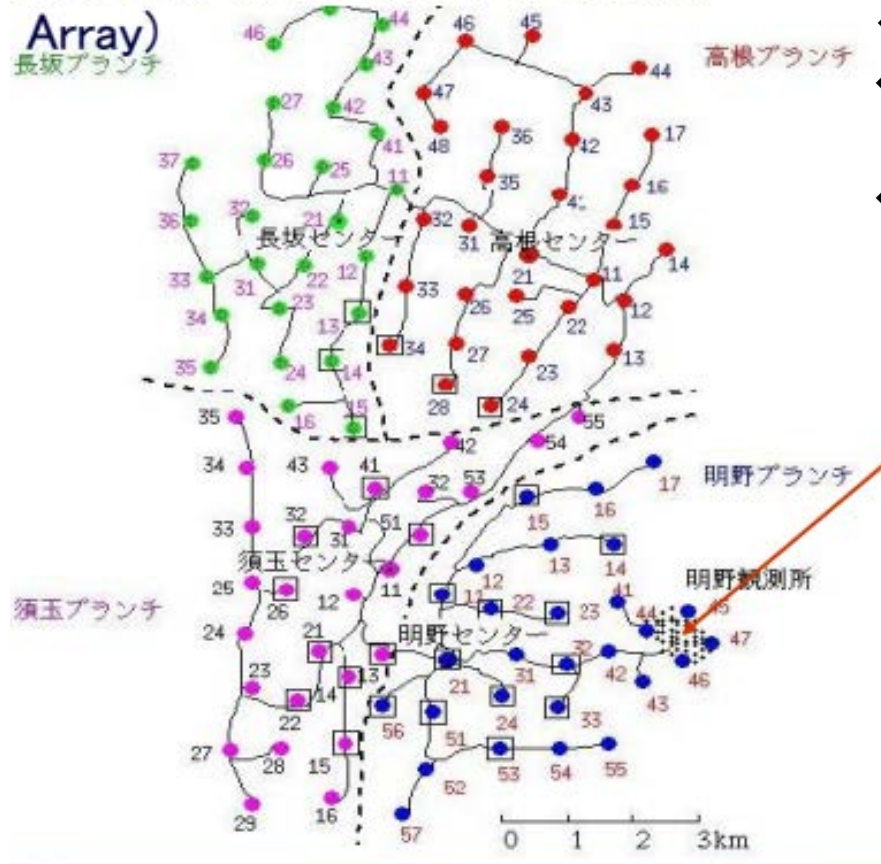


# Lead Burger Detector (AGASA)

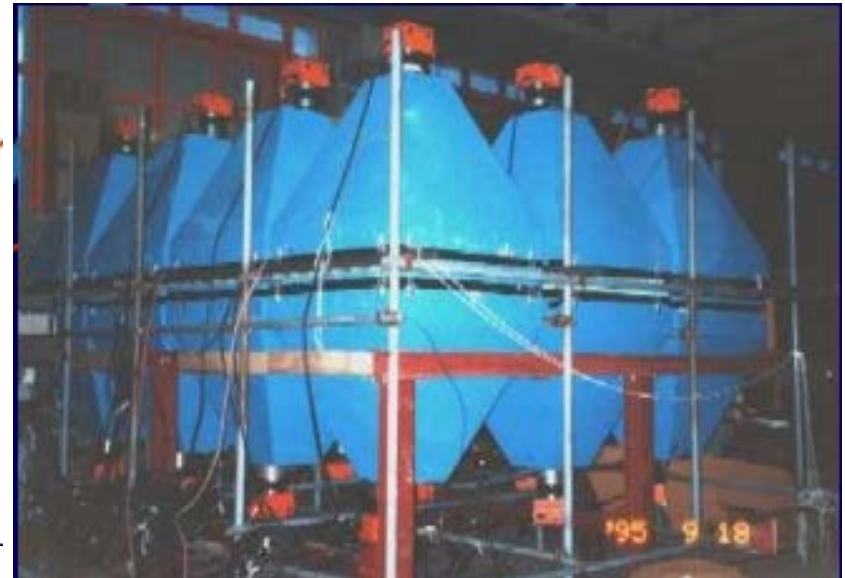
(we know an example existed in AGASA experiment.)

- ◇ Measure EM component + Muon component separately by classify waveform  
E-like , G-like , M-like signal.
- ◇ total area  $12\text{m}^2$  with segment size  $1\text{m}^2$

## AGASA(Akeno Giant Air Shower Array)



- ◇ 1cm Lead between up and lower layer
- ◇ Measure arrival time structure and fraction of each component of particles
- ◇ Installed in AGASA experiment  
Phys. Rev. D **56**, 3833 (1997) ..



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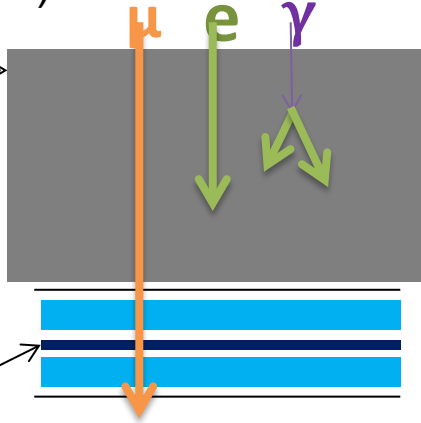
## Detector and estimation of performance

# Detector

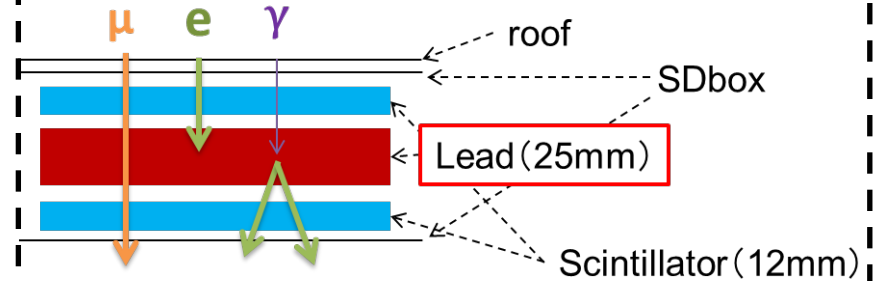
(Concrete shield)

Concrete (1.2m)

TASD



(Lead)



(Water Tank)

Auger North SD

New

SD for RDA in Colorado  
(1PMT)



- ◇ Concrete shield detector  
Measure high energy muon
- ◇ Lead inserted detector  
Measure low energy muon and Em component
- + Auger North,(south) detector (new)  
Compare response to same shower with TASD,  $N_{\mu}$

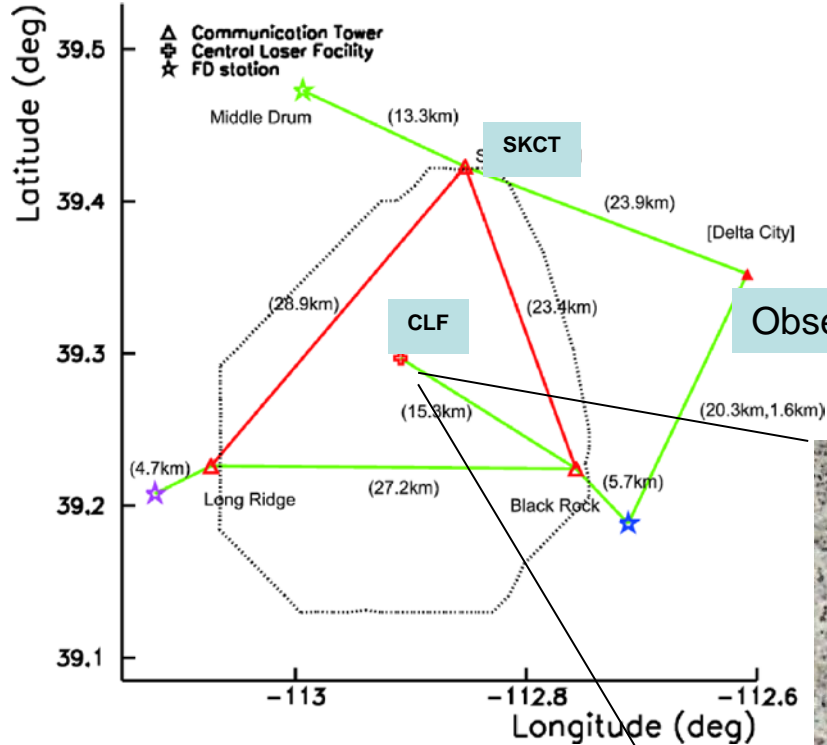
	$E_{th}$	**
Concrete(1.2m)	600MeV	~100% mu
Lead (25mm)	(70MeV)	Sensitive to EM , $\mu$
WT(120cm)(new)	(~300MeV)	Sensitive to $\mu$ (Em)



# TA Muon Detector site

Central Laser facility (CLF)

— Long distance network



Site :

CLFsite (center of TA FDs)

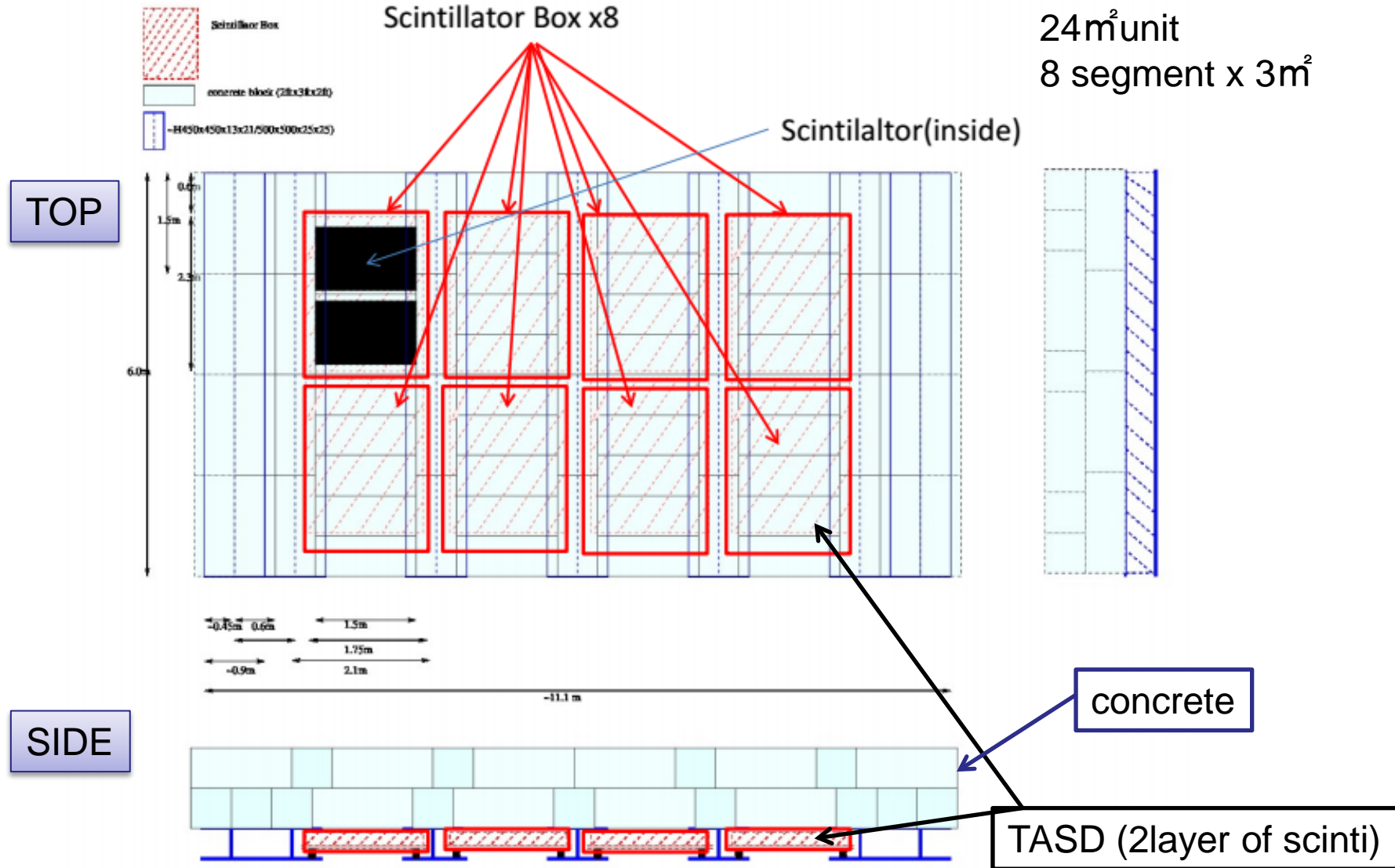
DAQ - Trigger :

TASD Level-2 air shower trigger.  
((Central trigger process) → CLF )

Same trigger will be provided to Auger Tanks

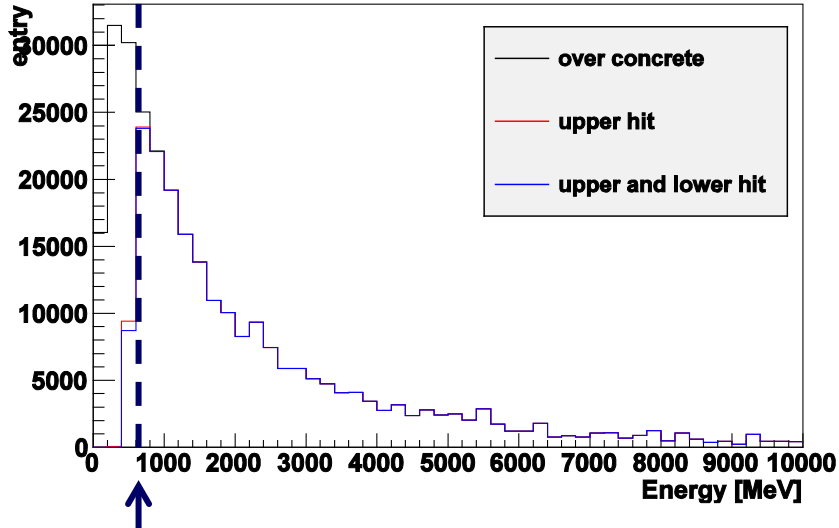


# Concrete shield detector



# Muons observed under shield

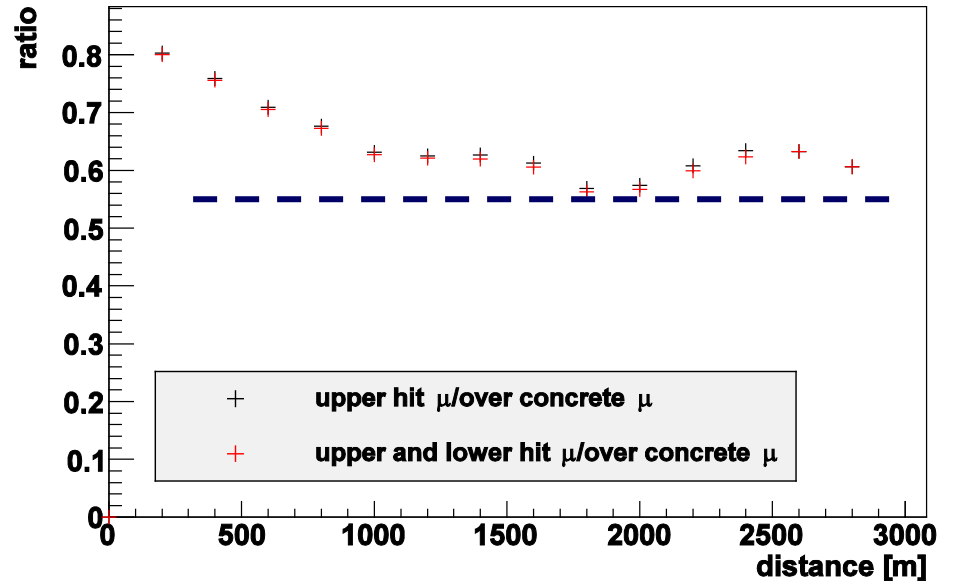
Muon energy distribution (E19.0Proton)



- Muon that have **over 600 MeV** can reach SD (R=1500m) (about **55%~** of all muon MC)

Number of muon fraction comes under Concrete shield

num of  $\mu$  under concrete / over concrete E19.0Proton



density:  $2.4\text{g/cm}^3$   
Z average: 12.26  
A average: 24.59

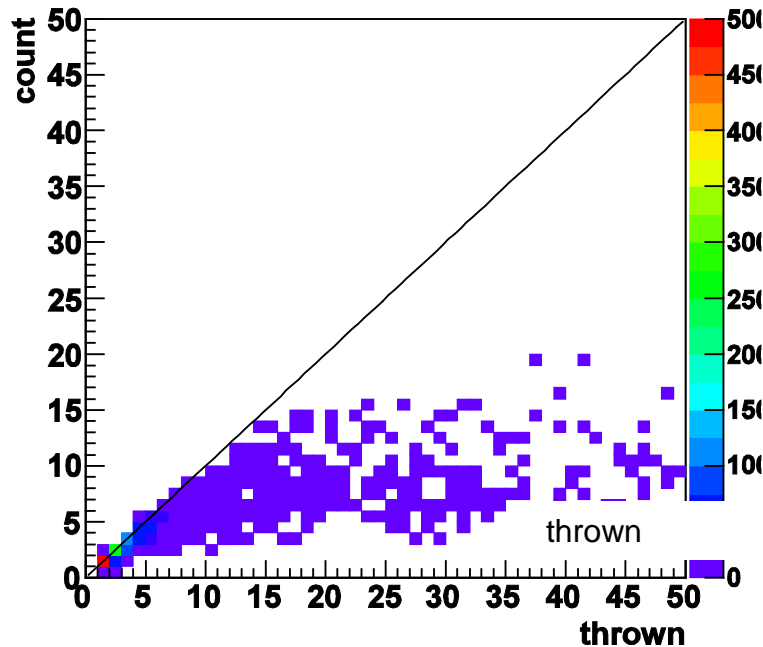
# Muon counting

## Thrown vs count : study of counting accuracy with simulation.

“Thrown” is number of muon thrown in 3m<sup>2</sup> segment

①

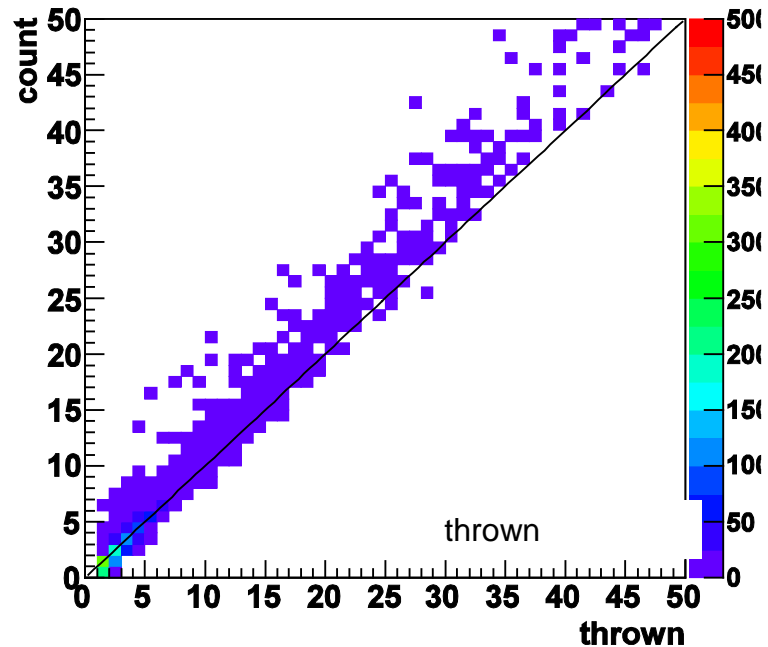
Count by the coincidence of rising edge in waveform



Good accuracy while small number of muon.

②

Count by charge output



Linearity up to large number of muon.

# Lead detector (1TA Lead Burger)

Solar panel

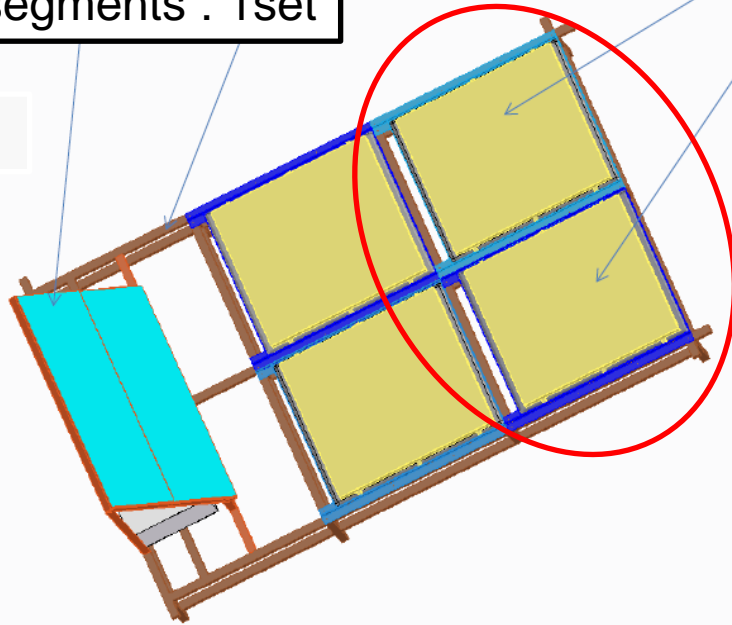
((150 × 67 × 6cm) × 2 parts)

Segmented SD Box

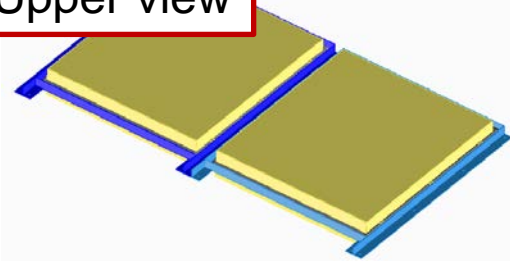
(100 × 110 × 6.5cm)

Steel base

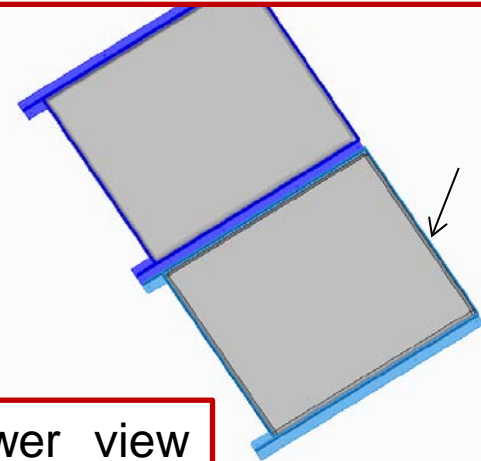
4 segments : 1set



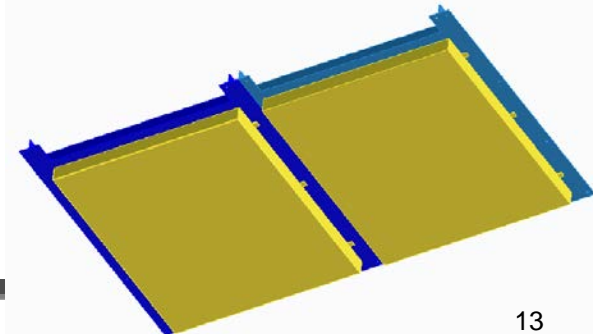
Upper view



Segmented palette + lead

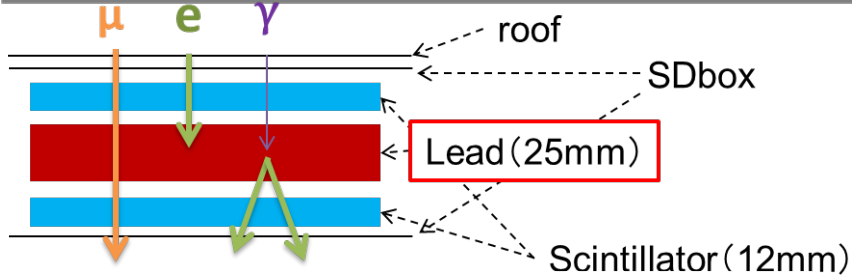


Lower view

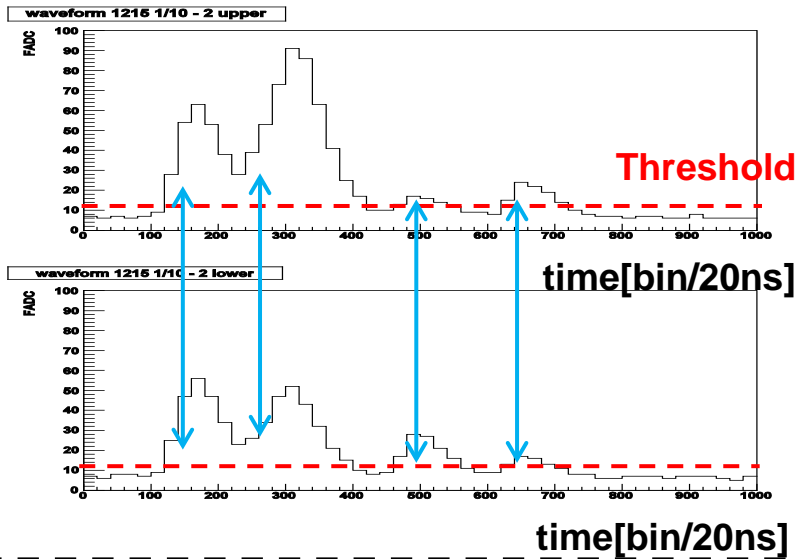


- ◇ 1 unit = 4 segments
- ◇ Box of 1 segment is 100 x 110 x 6.5cm
- ◇ This can be disassembled by 2-3 of person and possible to move to other places.

# Lead detector (TA Lead Burger)



## Count coincidence (U/L layer)

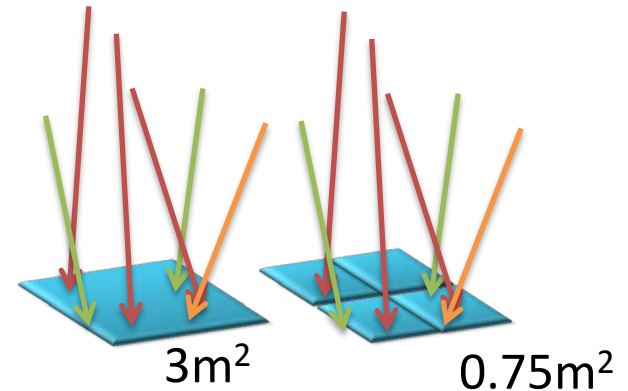


- 25mm Lead between Upper/Lower scinti
- Count  $\mu$ -like signal by rising edge of FADC
- “Segmented SD” 1 segment  $0.75\text{m}^2 \rightarrow$
- Shaper output time width  $\times 1/3 \rightarrow$

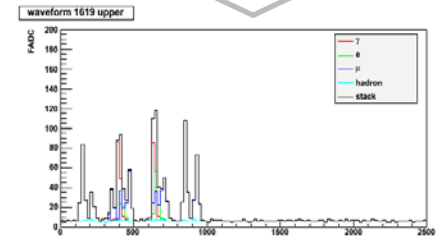
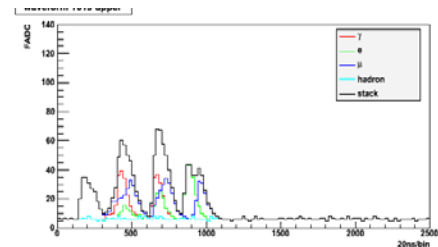
## Divide detector 1/4

TASD

TALB

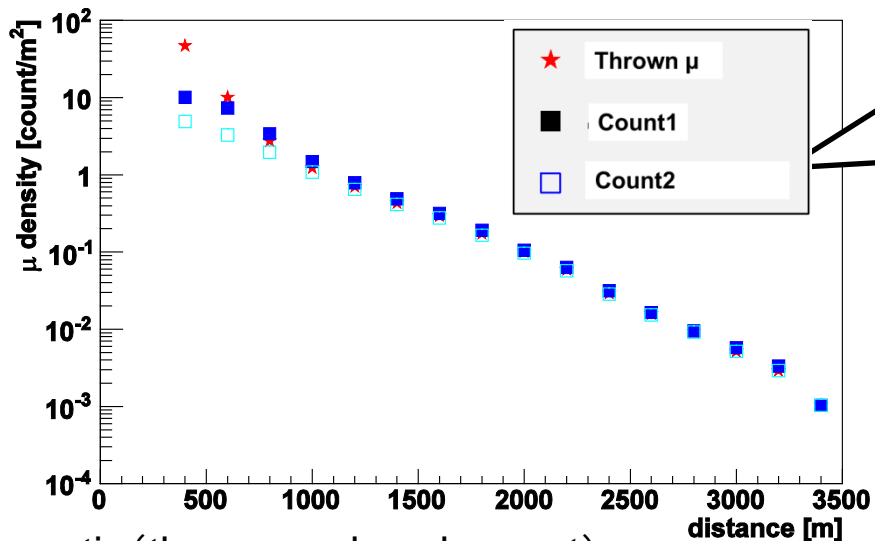


## Time constant 1/3



# Estimate $N_\mu$ with $\mu$ -like signal

E19.0 Proton shower

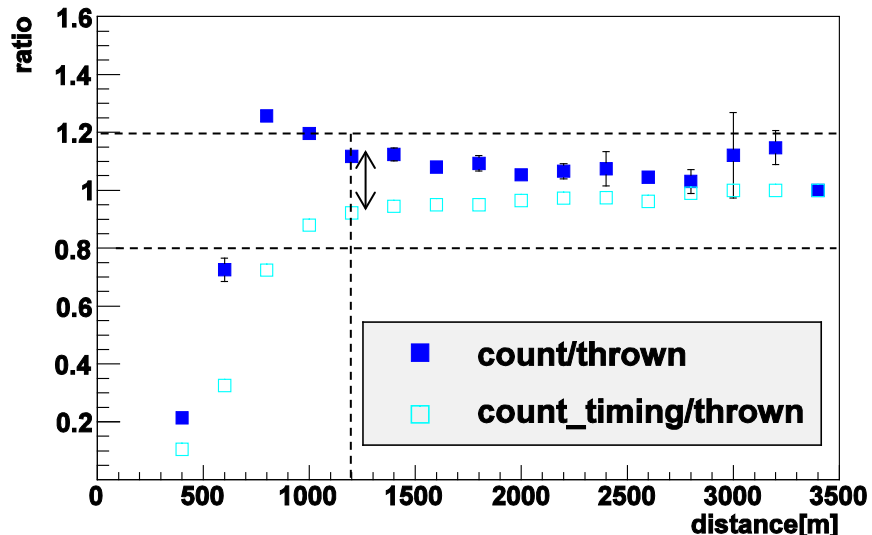


**thrown**: the number of muon, input to Geant4  
**count1**: the number of the coincidence of rising edge in waveform  
**count2**: number of the case succeeded to count the muon.

$N_{\mu\text{-like}} / \text{thrown} < 20\%$   
 Purity  $> 80\%$  accuracy

$\log_{10}$ (Energy/eV)	4 division + shaper time 1/3	
	Proton	Iron
17.7	800	800
18.0	1000	1000
18.4	1000	1000
18.7	1200	1200
19.0	1200	1200
19.4	1400	1400

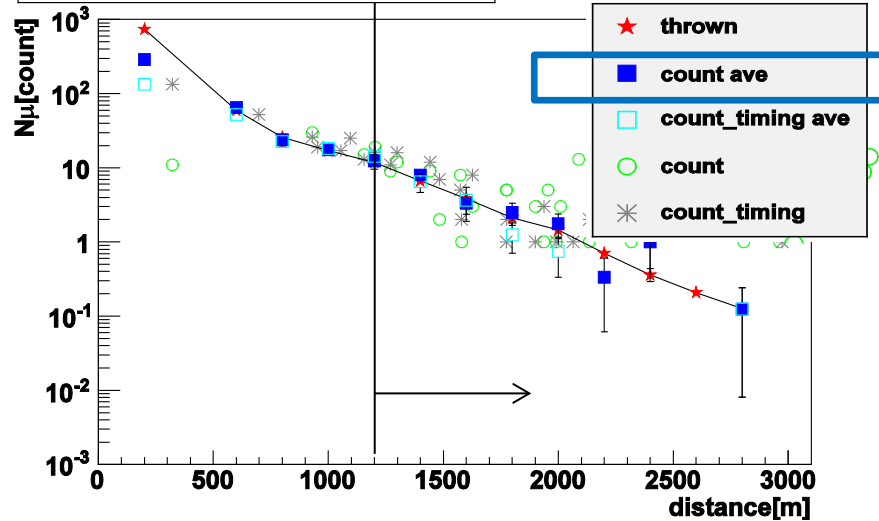
ratio (thrown and each count)



Avg .  $\sim 10\%$  over count constantly.  
 We can count muon in 20% accuracy at core distance above.

# 30m<sup>2</sup> x 2Year Observation

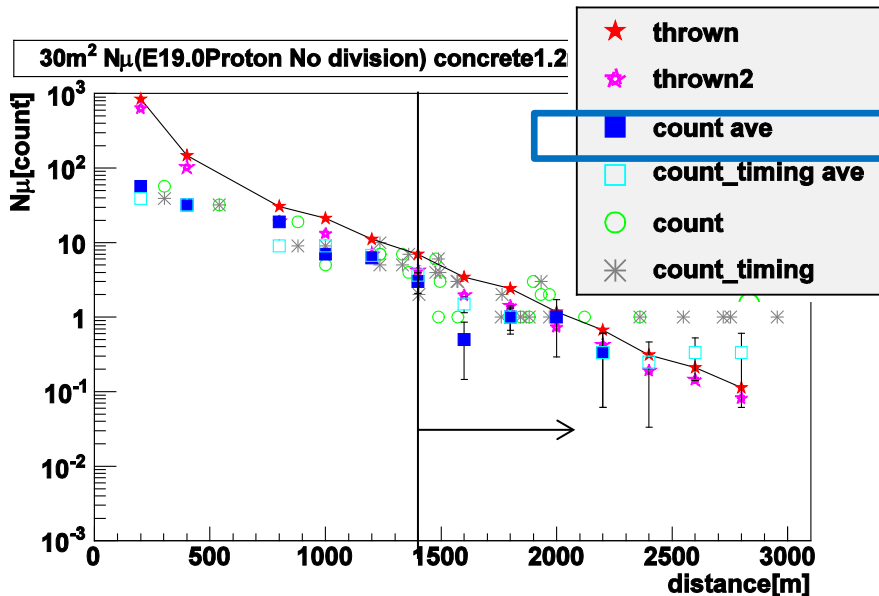
◇ Simple estimation of average muon lateral count  $E > 10^{19.0} \text{eV}$



**Geometry: vertical shower, 40event**  
**Energy=10<sup>19.0</sup>eV**  
**Events in 3km**

Note: In real event analysis, energy and Geometry is given by FD+SD obs

**Assuming 30m<sup>2</sup> Detector and 2year Observation.**  
**Integrate the counted number in lateral direction.**



**Evaluate uncertainty from collected Muon number**



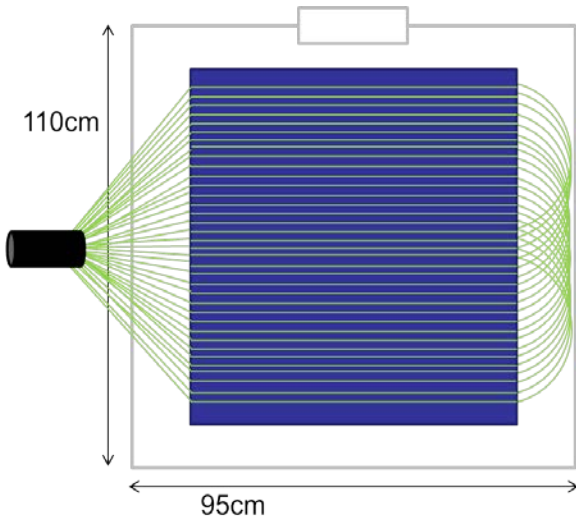
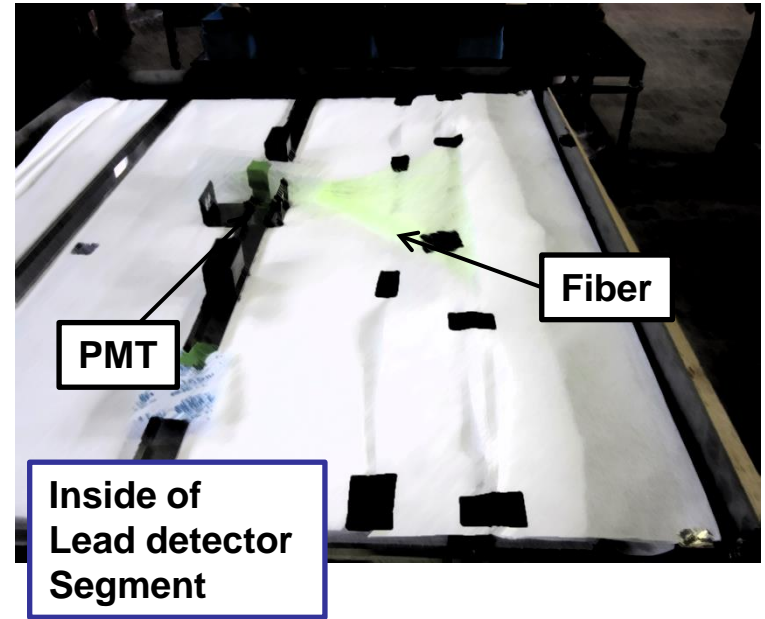
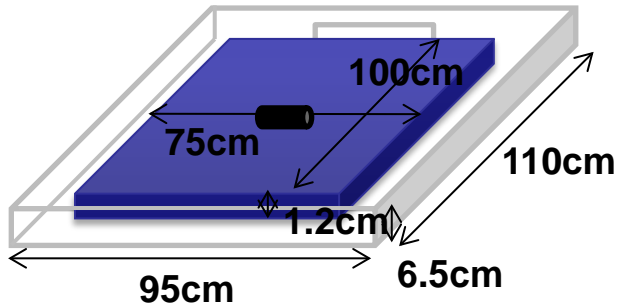
	$\sigma_{N_\mu}/N_\mu$			
	Lead (30m <sup>2</sup> )		UG (concrete)	
E [eV]	Fe	P	Fe	P
10 <sup>18.7</sup>	9.5%	11.6%	14.5%	15.2%
10 <sup>19.0</sup>	9.6%	11.7%	14.4%	18.2%



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## Detector assembly (TA Lead Burger)

# One segment of lead detector



## Misc value

	TASD	Lead SD
surface	3m <sup>2</sup>	0.75m <sup>2</sup>
Length of fiber	5m × 104	3.4m × 26
Fiber layout	1 fiber read 1 straight groove. Readout at both end	1 fiber read 2 straight groove. Readout at both end
PMT	Side of scintillator (ETL9124SA)	On the scintillator (ETL9124SA)
Box	2 layer in one box	2 layer in separate box.

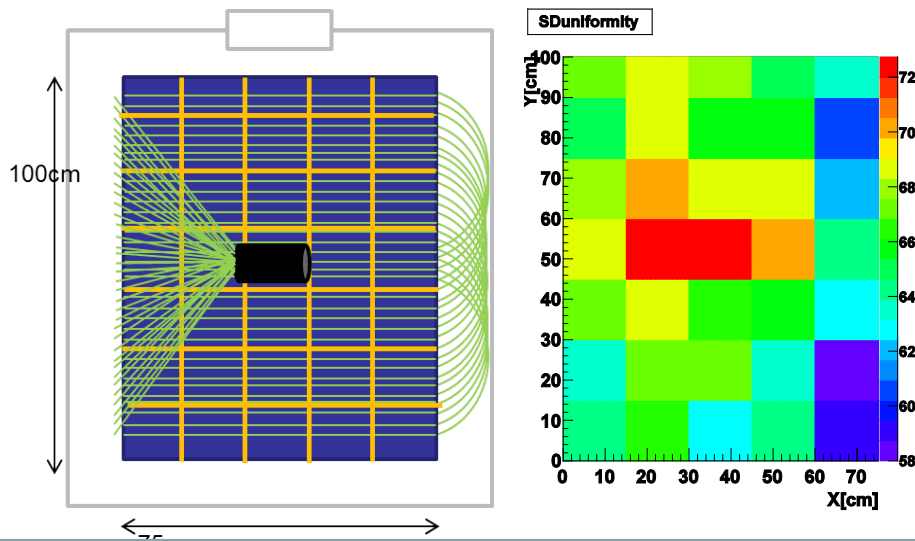
◇ different fiber layout  
→ (table)

◇ PMT is on top of scintillator.

◇ (small, easy to handle.)

# Detector response

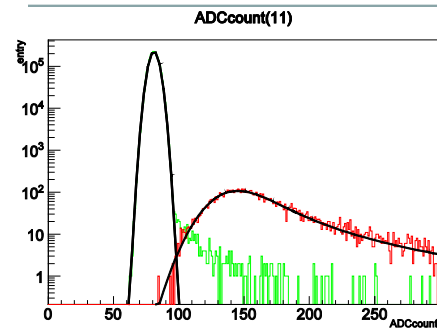
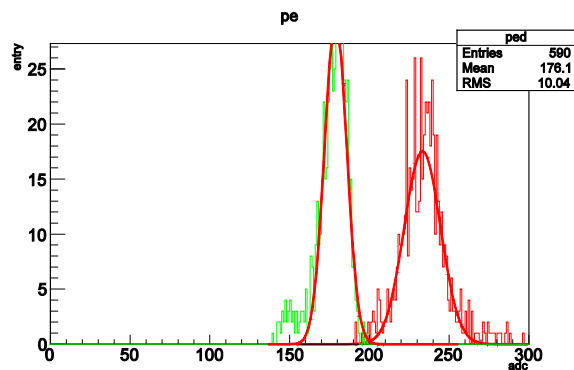
**Uniformity:** measure 1MIP in 35 points using 15cm × 15cm probe



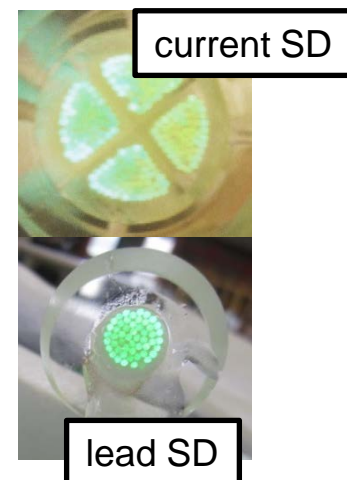
1MIP =  $66.07 \pm 3.27$  FADCcount  
( $\pm 4.97\%$ )

✖ current SD : 5~10%

**Light output from scintillator + fiber**



1p.e. =  $3.62 \pm 0.02$  FADC count  
1MIP = 66.07 FADC ~ 18.25 p.e. /MIP  
\* average of current SD 24p.e.



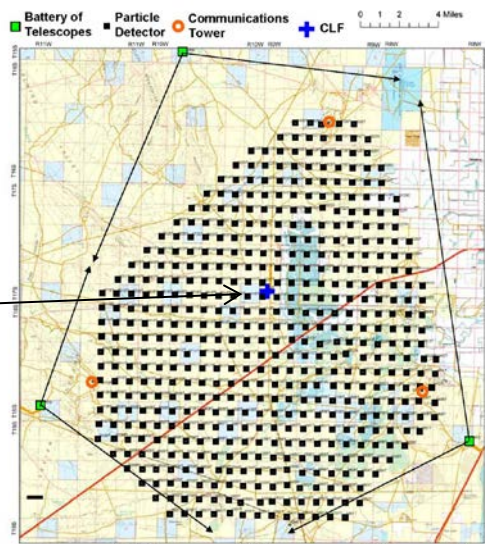
triggered waveform: 590/1664421

# Summary of construction status

- 2013
- ~Mar ▪ Simulation study for counting accuracy → decide design
  - Aug ▪ Lead det. 12 segment (9m<sup>2</sup>) Assembly
  - SD (TASD) x 8 (24m<sup>2</sup>) Assembly
  - Oct-Nov Shipment → PMT assembly @site Check.
  - Dec ▪ 1st Lead Detector deploy
  - Start observation (with TAElec)
- 2014
- < (winter + wait for permission )
- Permission of land use (2014/06)
  - (Arrival of Auger SD x 8)
  - Start construction of Concrete structure (2014/08/16-)
- Detector construction

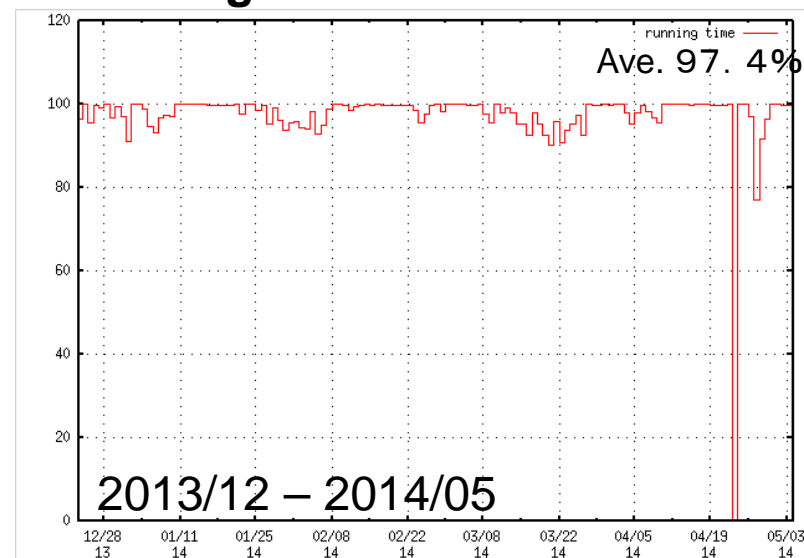
**Auger tank assembly is planned (2014/10/17-)**  
**We hope to learn how to operate/maintain detector.**

# Test detector operation (Lead @ CLF)

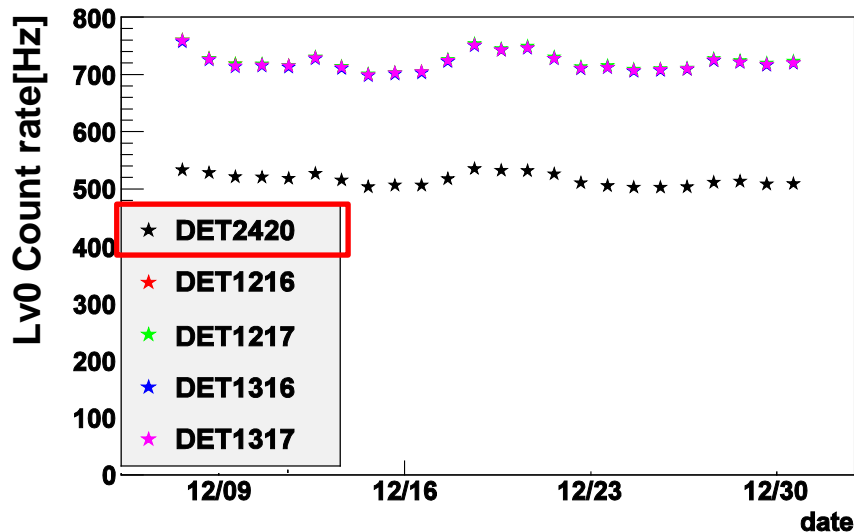


## Running time

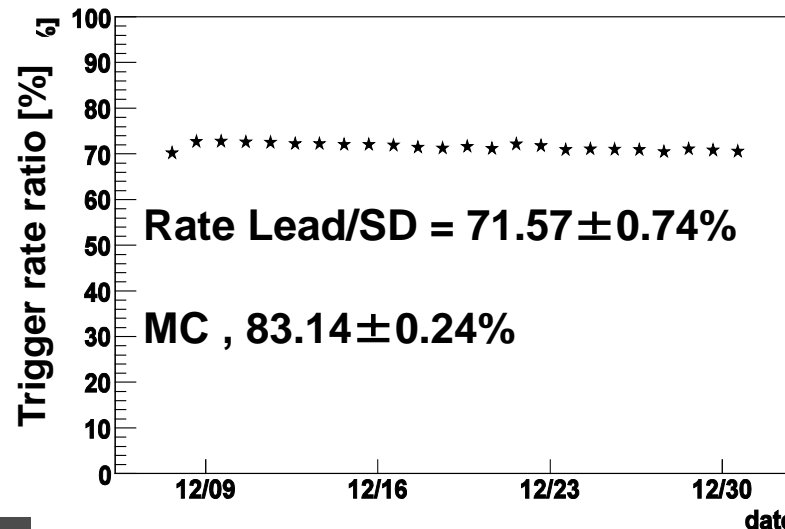
Live time/Run time



## Count rate:



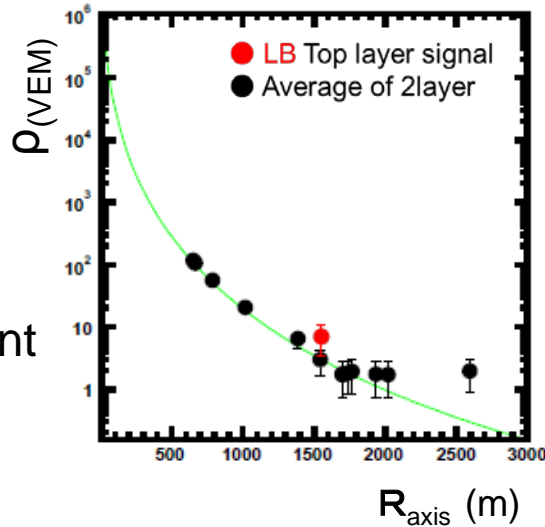
## Count rate ratio.



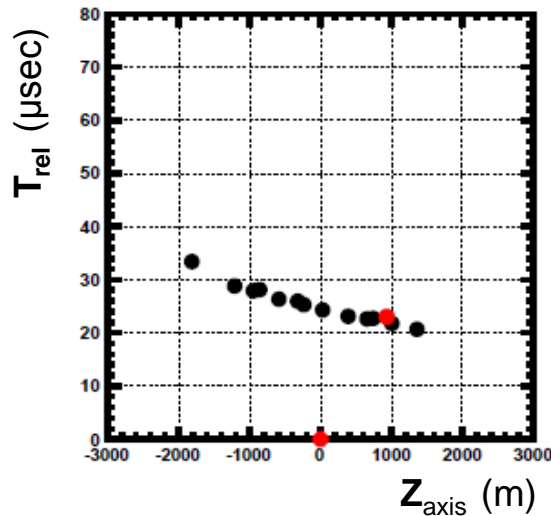
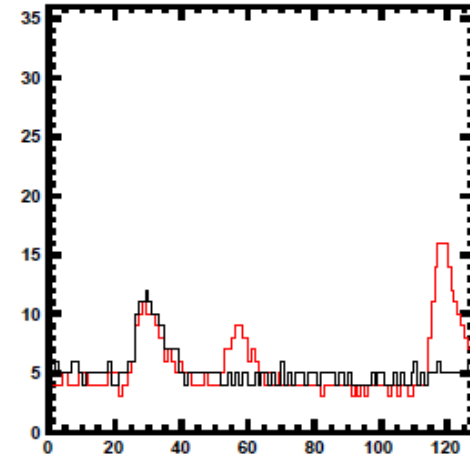
# Muon Detector event sample

2014/01/24 04:26:03

- Period: (0.5Yr)  
13/12/05-14/05/10
- zenith < 55
- R<3km (E>10<sup>18</sup>eV)  
total : 102 Event  
Detector hit 18 event



Wave form of TA Lead Burger



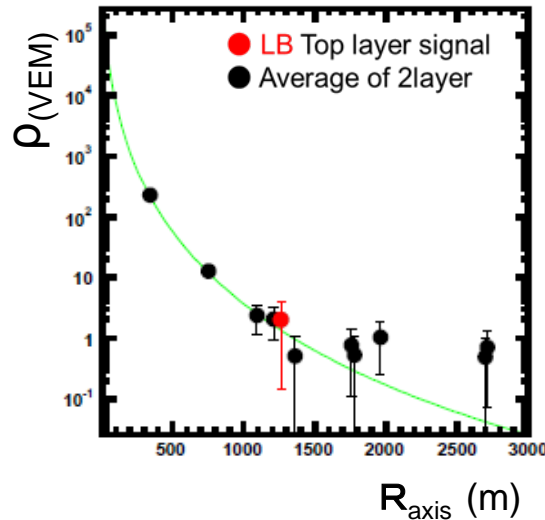
Largest energy event in test period  
E = 17EeV  
Zenith angle 37°  
Distance to shower axis 1550m

(left top) lateral distribution  
(left botm) Arrival timing.

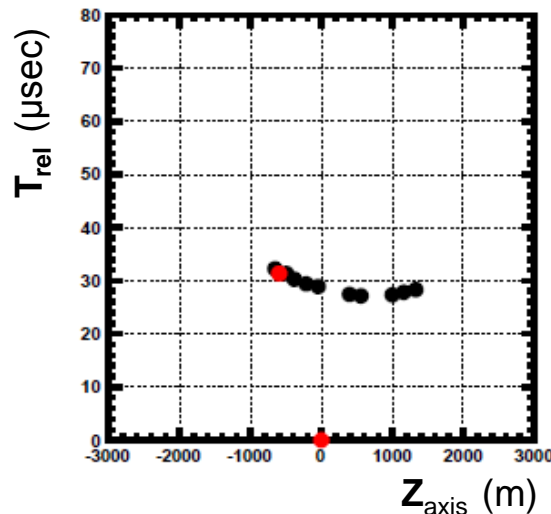
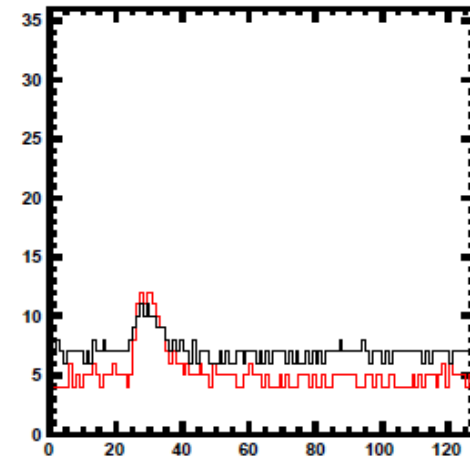
$N_{\mu}$ -like : (by Wf count) 1\_ptcl  
(by charge) 2.01VEM

# Muon Detector event sample

2014/01/24 04:26:03



Wave form of TA Lead Burger



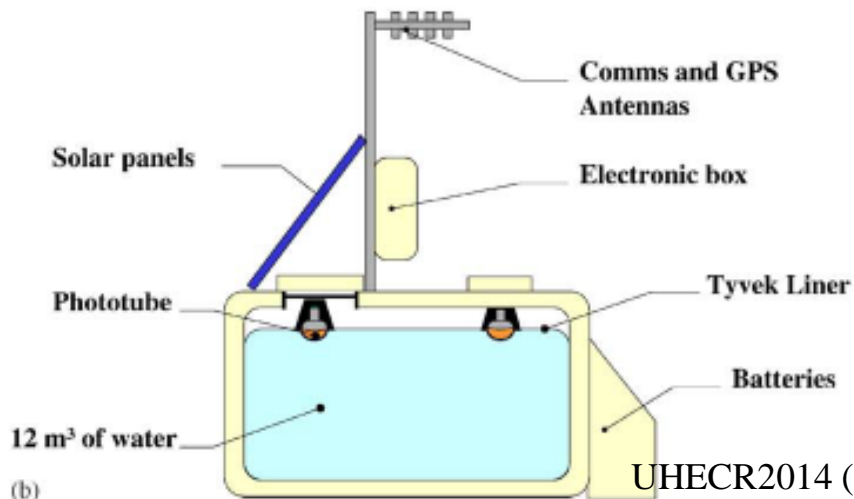
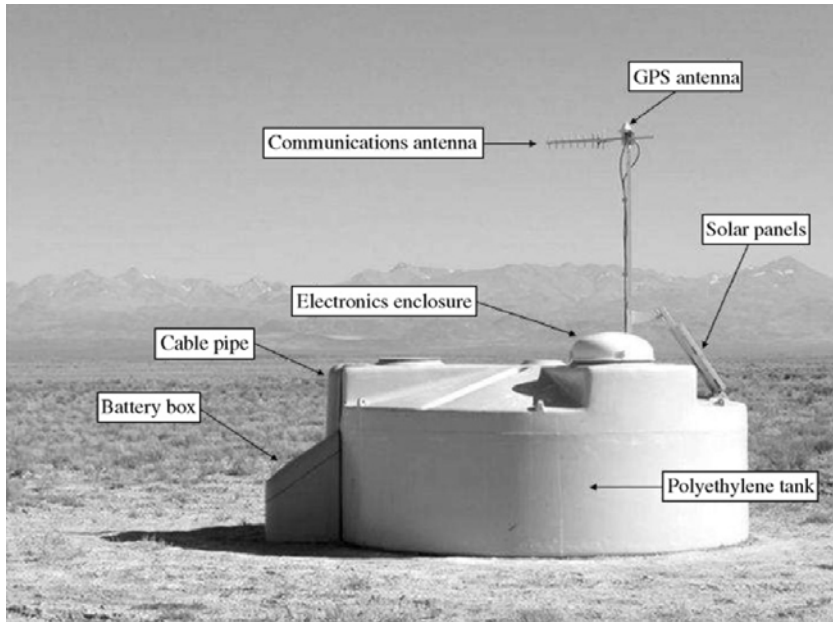
Smallest energy event in period  
 $E = 2EeV$   
Zenith angle  $32^\circ$   
Distance to shower axis 1264m

(left top) lateral distribution  
(left botm) Arrival timing.

$N_\mu$ -like : (by Wf count) 1 ptcl  
(by charge) 1.17 VEM

# Auger South SD

(3PMT)



# Auger North SD

SD for RDA in Colorado  
(1PMT)



UHECR2014 (Springdale Utah)

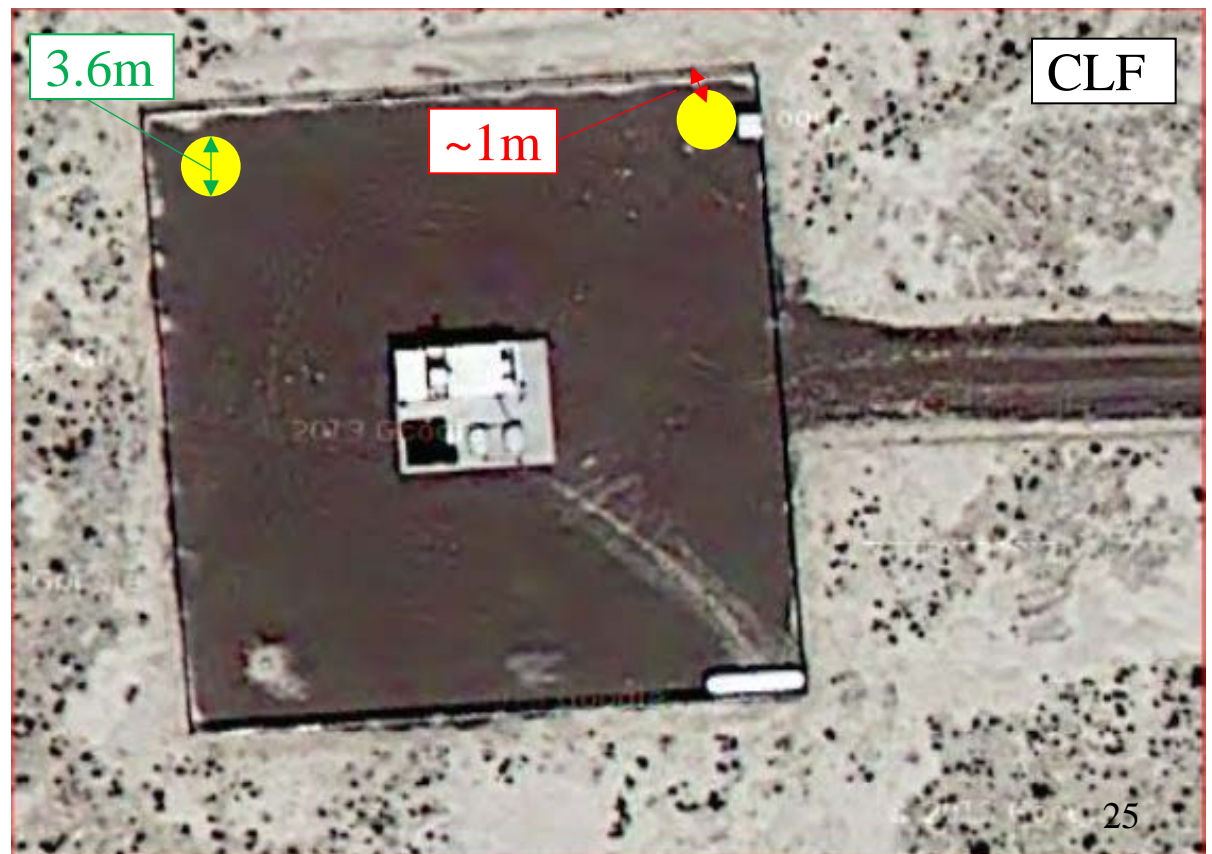
T. Nonaka

Pierre Auger Collaboration (2003)



# Deployment 1: CLF

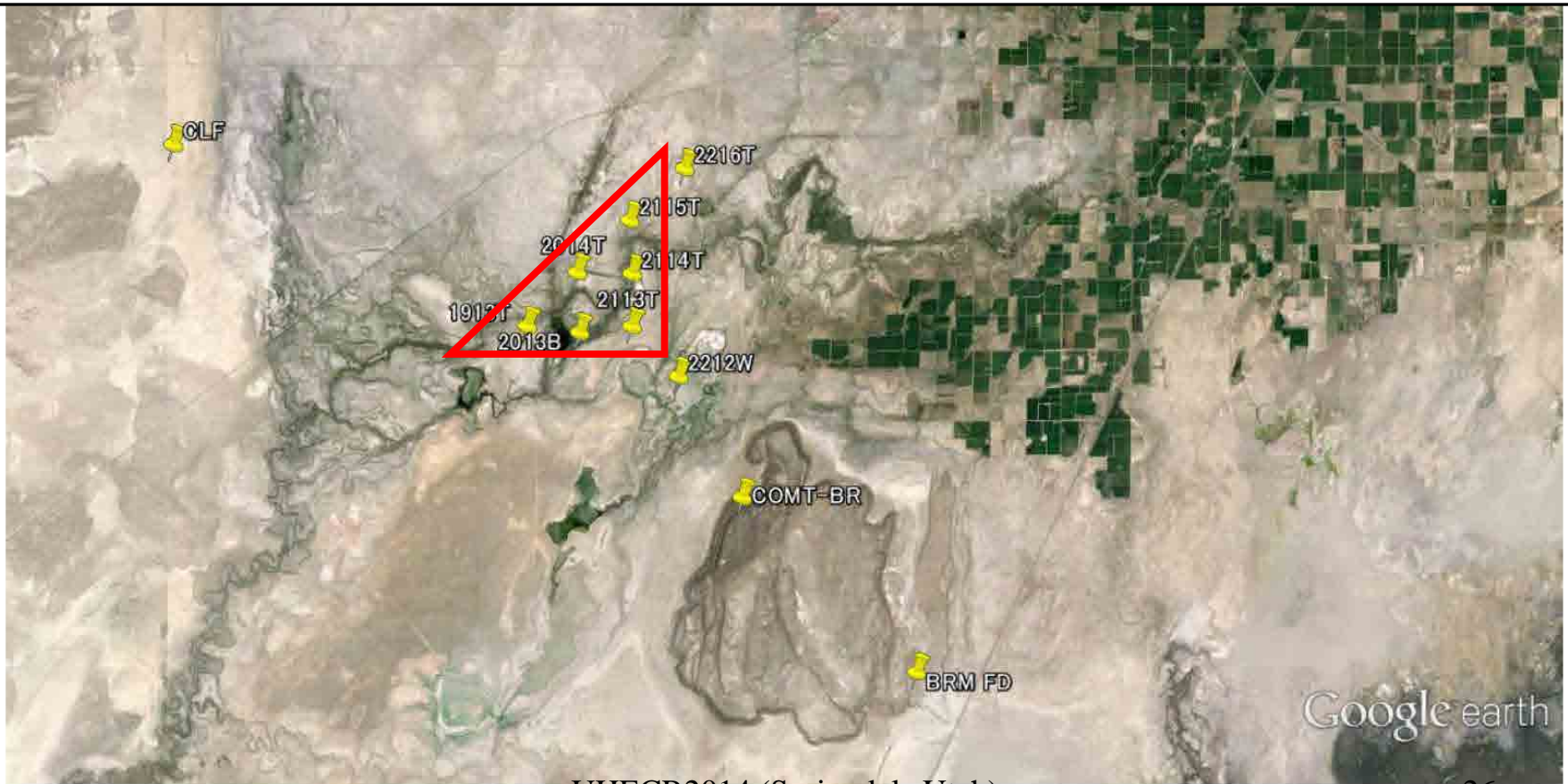
- Observe the same shower with TA muon detectors
- 1 South SD and 1 North SD



# Deployment 2:

## Proposal of Auger SDs in the field

- Observe the same shower by Auger SDs
- 6 North SDs near TA SDs, with array configuration



UHECR2014 (Springdale Utah)

# Summary

- ◇ Motivation: Need study about what aspect of shower is different from MC. (Not only the muon but EM component also)
- ◇ We designed Concrete shield muon detector and TA Lead Burger.  
→ Estimated performance was reported.
- ◇ Construction is just started. (a lot effort by Utah staffs)
  - Looked signal from shower taken by 1<sup>st</sup> Lead Burger detector. (very small)
  - Analyzing  $\mu$ -like signal and Em component development upper between lower
  - hopefully, we compare data with MC with more statistics.

## Current work )

- 2<sup>nd</sup> deployment of Muon Detector is starting.
  - 24m<sup>2</sup> (Shield detector)
  - 9m<sup>2</sup> (TA Lead Burger)
- + with Auger SDs
  - 2 tanks will be put same place with TA-Muons
- 6 tanks are proposed to be deployed near by T ASD in array.



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# Back up