Studies of Hadron Calorimeter

Zhigang Wang
Institute of High Energy Physics

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Outline

1,The Dark Matter Calorimeter

2,The Hadron Calorimeter(HCAL)

3, Summary

1，Dark Matter Calorimeter

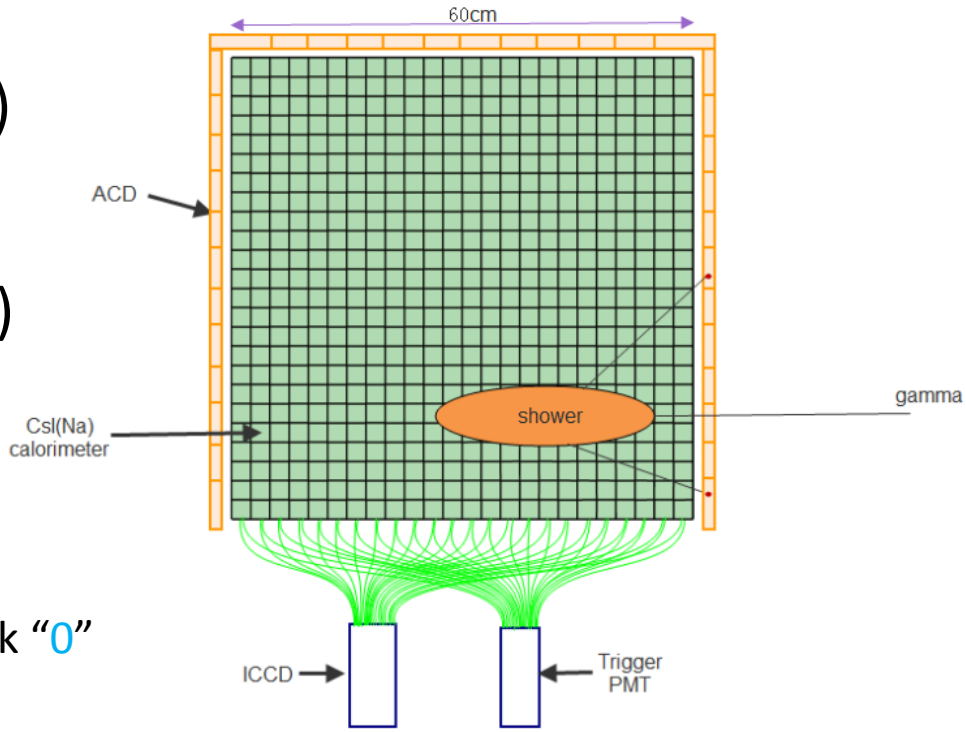
Two components:

Anti-Coincidence Detector(ACD)

mark incident charged particles,
distinguish γ and charged paricles.

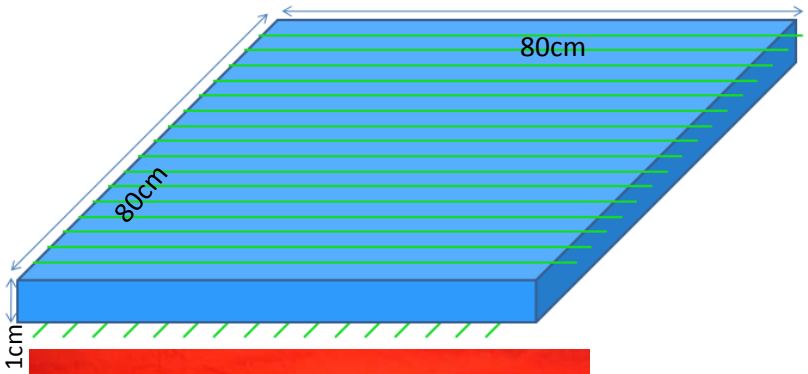
Digital Imaging Calorimeter(DIC)

measure incident particle
energy ,distinguish e γ and p
determine incident paricle's direction

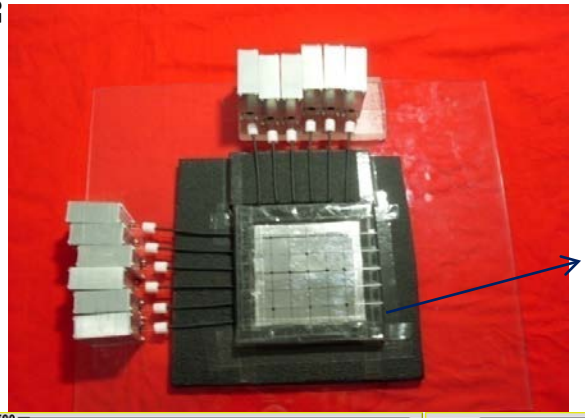


"Digital" means Hit mark "1", Non-Hit mark "0"
All of "0,1" describe the shower image.
Different energy and different particle has different "0,1" distribution.
We can get particle energy, particle type information through "0,1" analysis

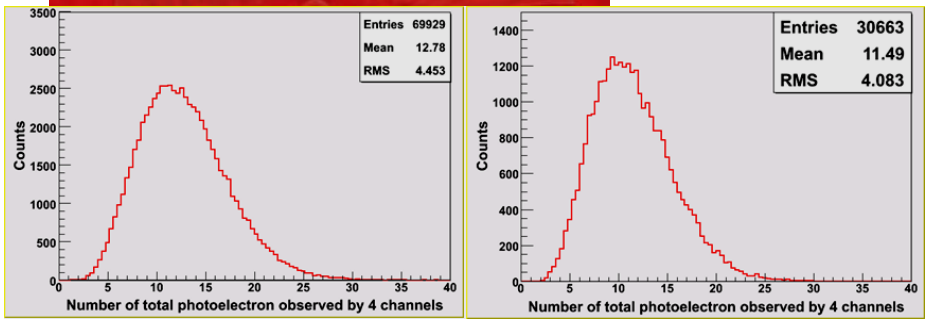
Anti-Coincidence Detector(ACD)

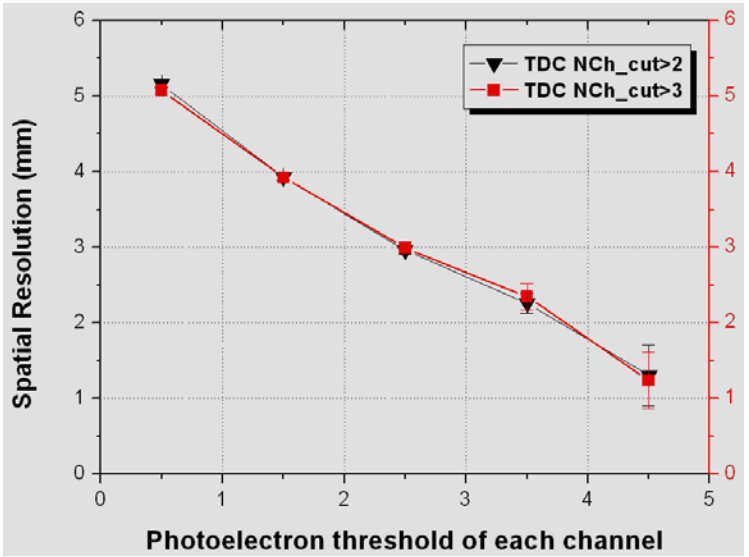


ACD is composed of a 80x80x1cm plastic scintillator and two layer WLS fiber arranged in the x and y direction embed in grooves on two surface of the scintillator.
Read out device is SiPM or *Multi-Anode PMT*.



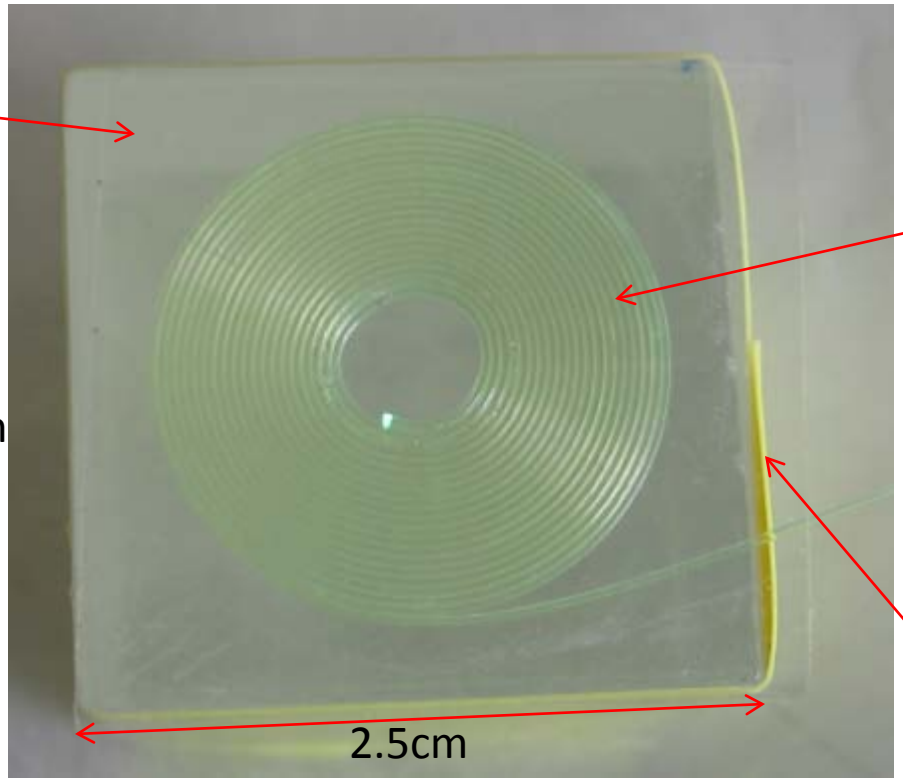
Fiber interval 1.2cm





Digital Imaging Calorimeter unit

CsI(Na) emission property:
Wave length: 420 nm
Decay time:
short 550 ns
long 4 us
Radiation length: 1.85 cm
Density: 4.51 g/cm^3
Hygroscopic : weak

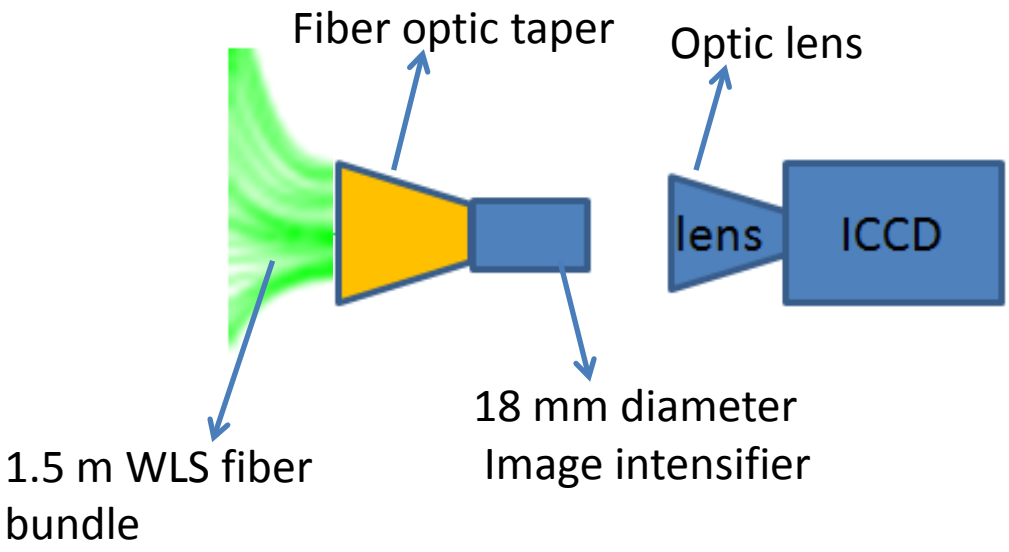


Wave length shifting fiber
(WLS fiber):
BCF-91A, BICRON
shift blue to green
Emission peak: 494 nm
Decay time: 12 ns

ESR reflector package
reflectivity >99%

The scintillation light of crystals is absorbed by a 300 um diameter wavelength shifting(WLS)fiber that is attached to the surface of the scintillator with a spiral structure.

Read out system of the detector

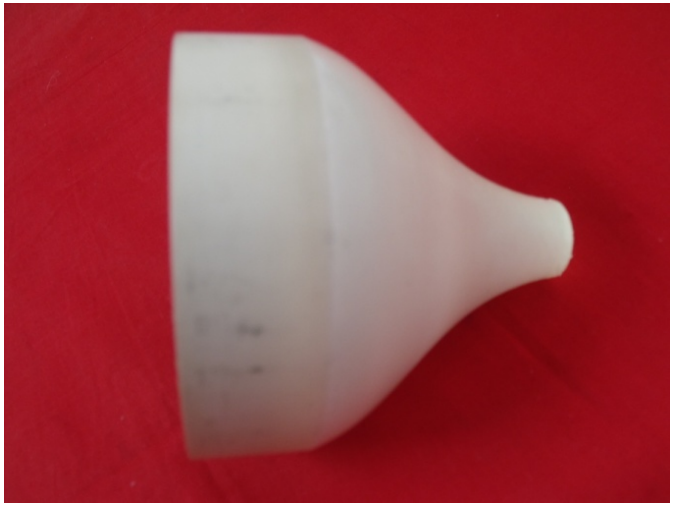


The fiber bundle is coupled to fiber optic taper directly and than coupled to the input-window of image intensifier. The shower development profile in the detector is transformed in the output image.

An intensified CCD camera system is used for read-out of the first image intensifier output .

Fiber optic taper

2:1 fiber optic taper

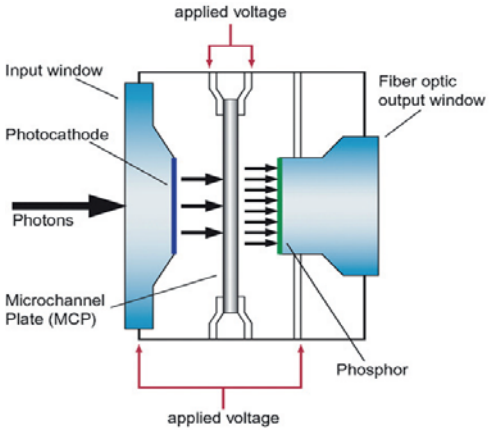


5:1 fiber optic taper

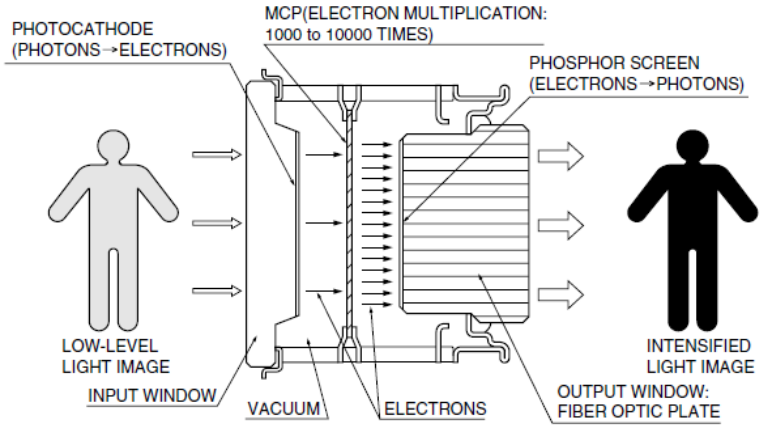
Produced by a company of China
Magnification:2:1, 5:1
Transmission :45% ,25% respectively
(measured in our lab)

Fiber optic taper is used to expand read out capacity of image intensifier
For ϕ300 um WLS fiber with 100 um interval:
18 mm diameter image intensifier: 1600
2:1 fiber optic taper: 6400
5:1 fiber optic taper: 40000

Image Intensifier



Overview of Image Intensifier construction



Photocathode spectral sensitivity

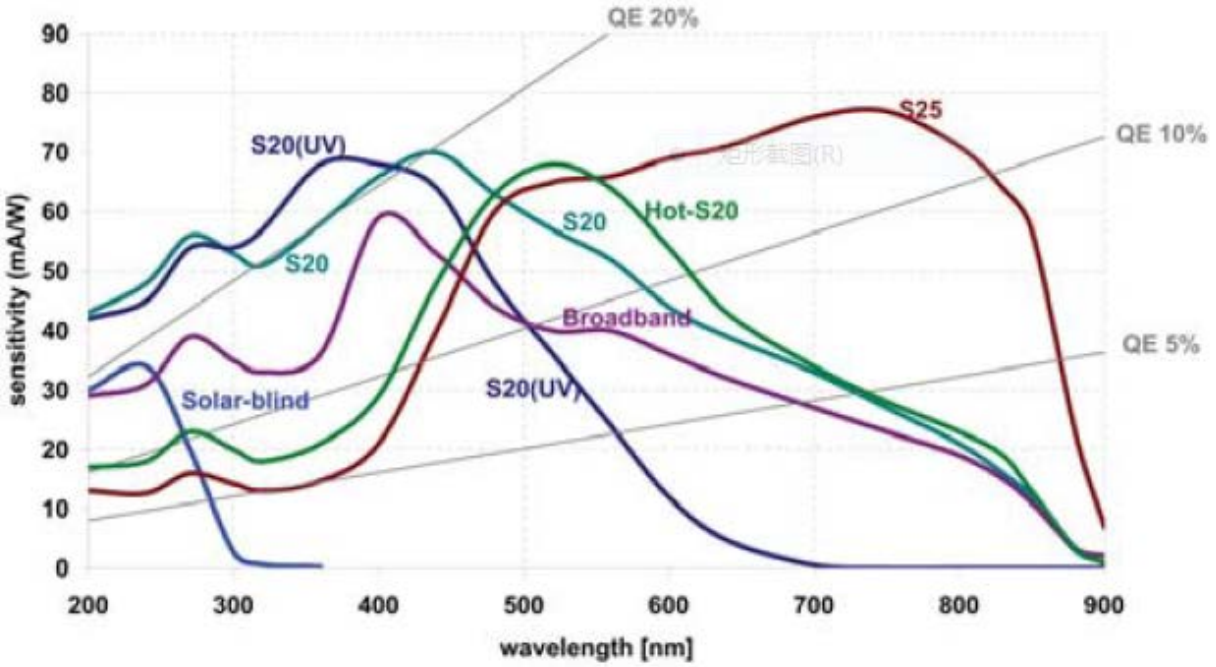
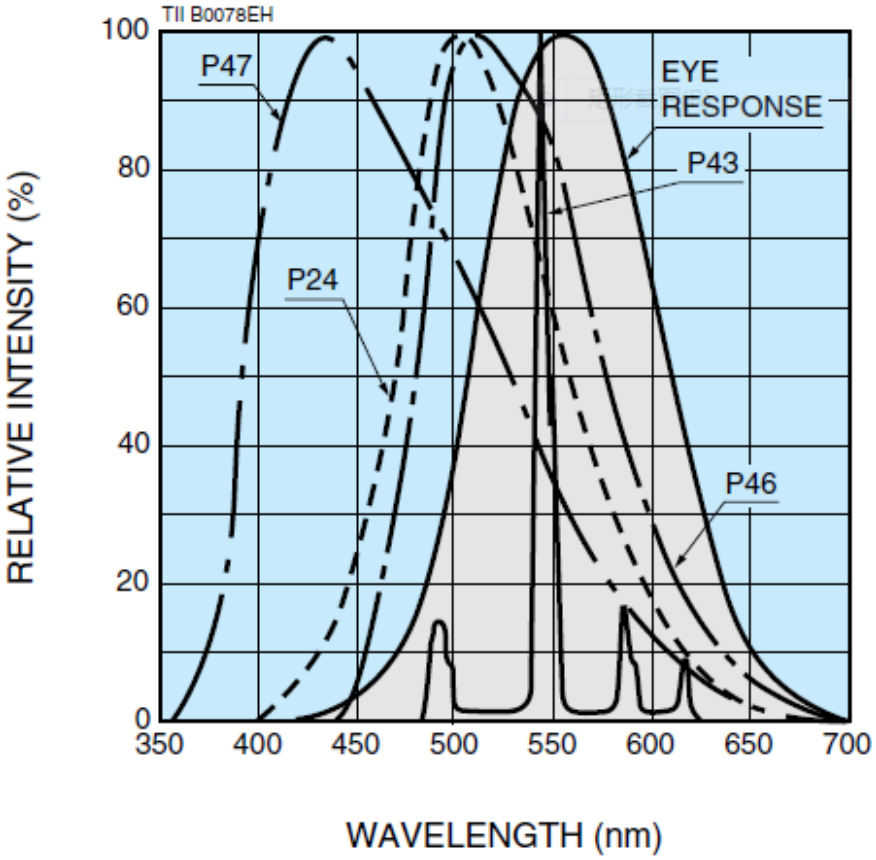


Fig. 1: Photocathode Spectral Sensitivity curves (deposited on glass) Photocathodes deposited on Fibre optic window are ~20% less sensitive and cut at 400nm

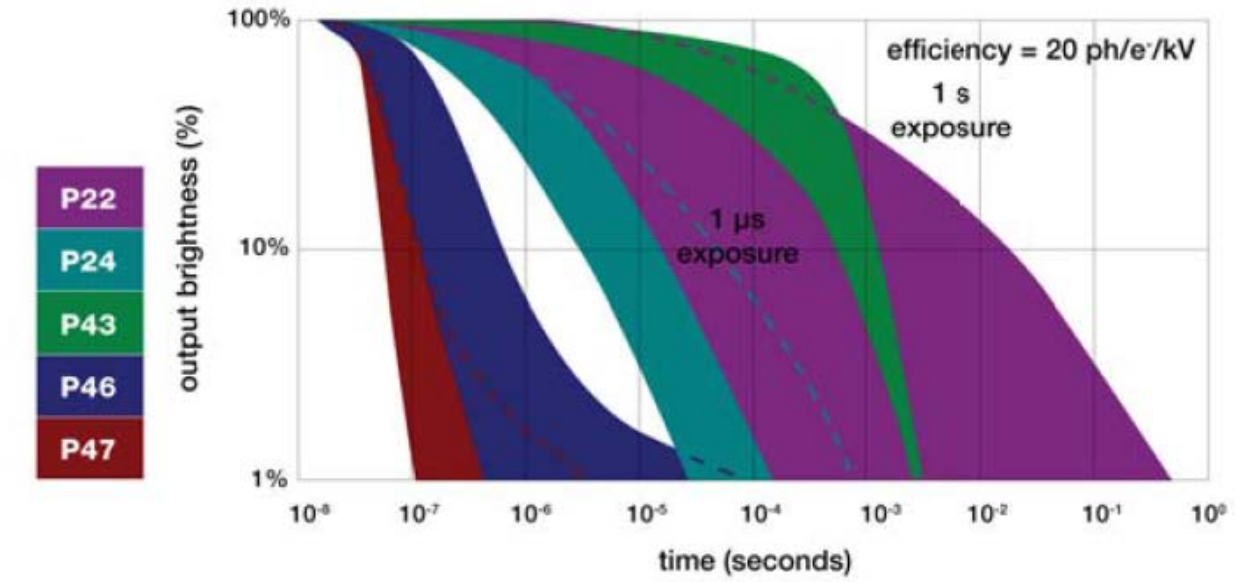
S20 is used in our detector

Phosphor spectral Emission

Figure 5: Typical Phosphor Spectral Emission Characteristics



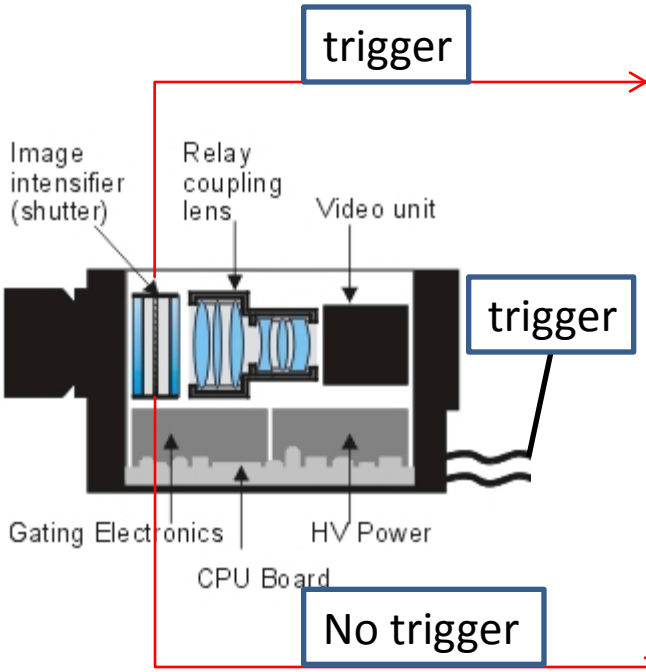
Phosphor Screen decay time



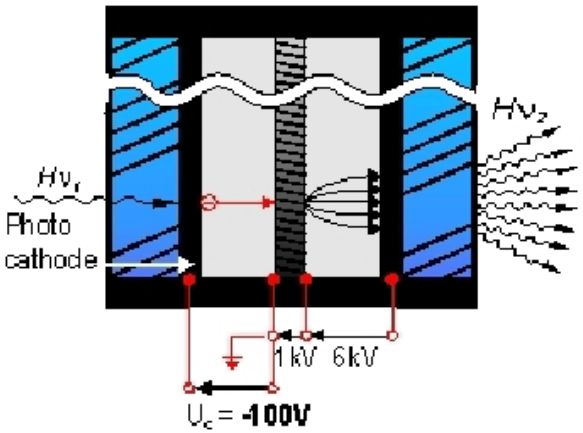
Phosphor Type	Peak Emission Wavelength [nm]	10 % Decay Time
P24	500	3 µs to 40 µs
P43	545	1 ms
P46	510	0.2 µs to 0.4 µs
P47	430	0.11 µs

ICCD system

Gating:
a crucial feature of high speed ICCD cameras

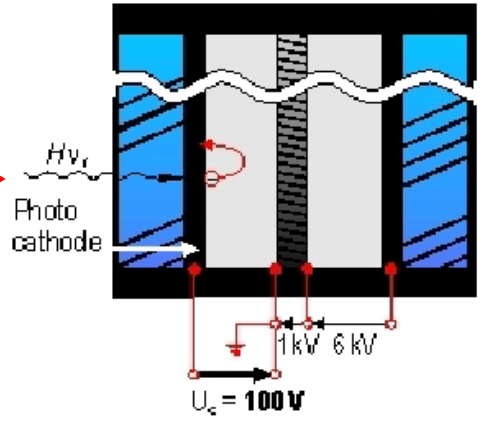


shutter is open



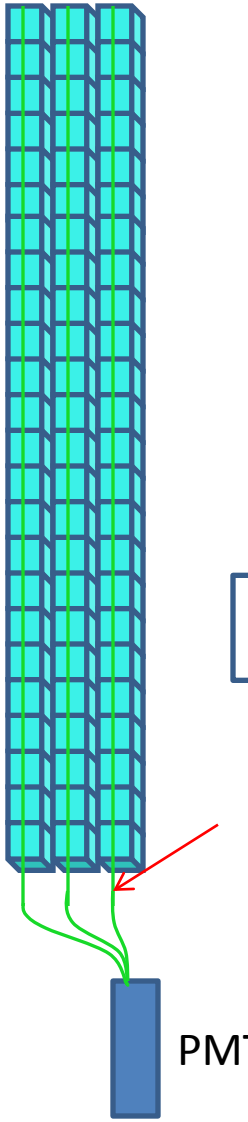
If the voltage U_C between photocathode and multichannel plate is negative, the photoelectrons are accelarated towards the multi channel plate. This means that the shutter is open.

shutter is closed

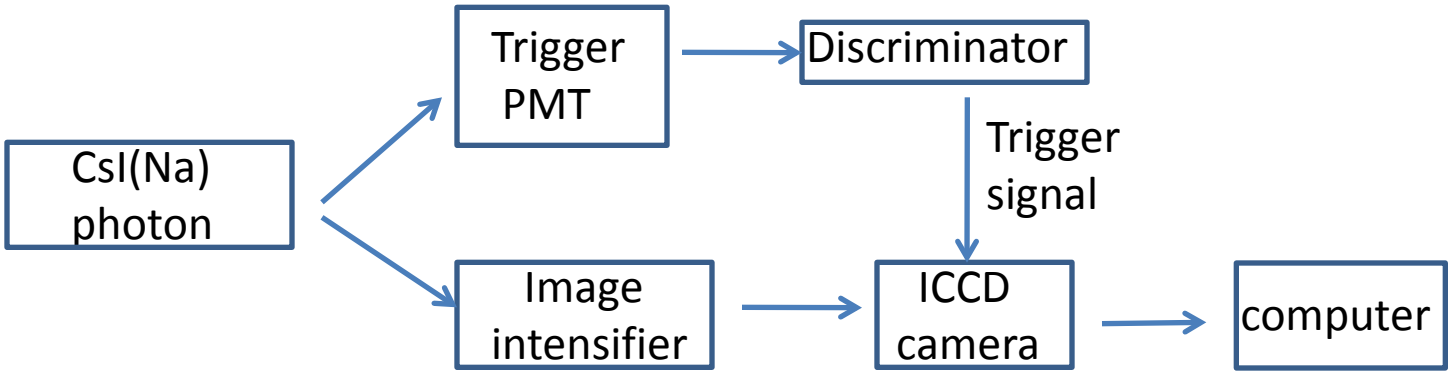


If the voltage U_C is positive, the photoelectrons are kept at the photoathode, thus the shutter is closed

Trigger structure



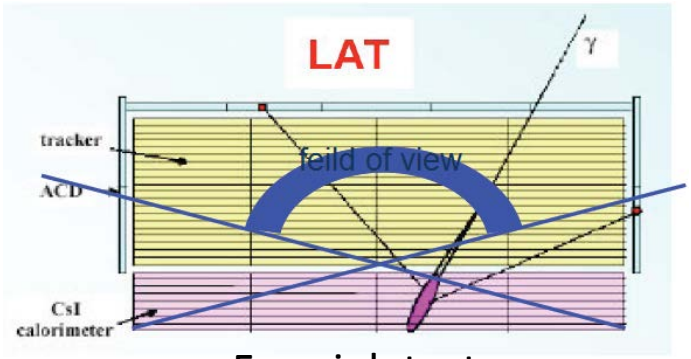
One WLS fiber attached to the surfaces of a row of crystals, total 24X24=576 fibers couple to one PMT
when a high energy particle incident, we can get a fast signal(<100 ns) from the PMT that proportional to the particle energy.
So a threshold can be set for trigger.



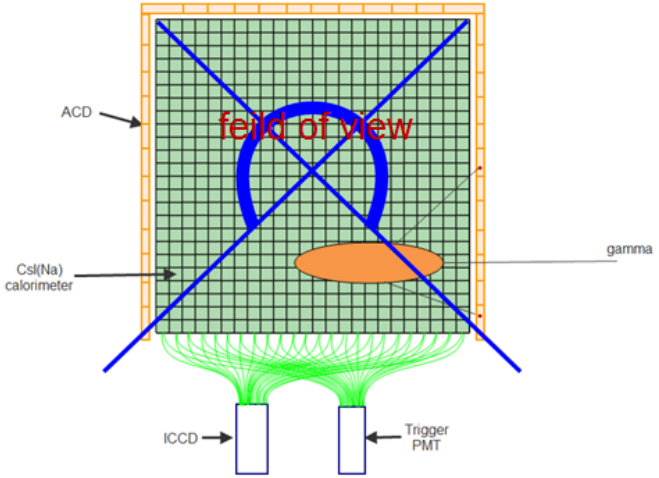
Delay photon signal to waite for ICCD to open

The trigger signal generates a gate with a width of 2 us to open the shuttle of the CCD.

Main feature of the digital imaging calorimter



Fermi detector



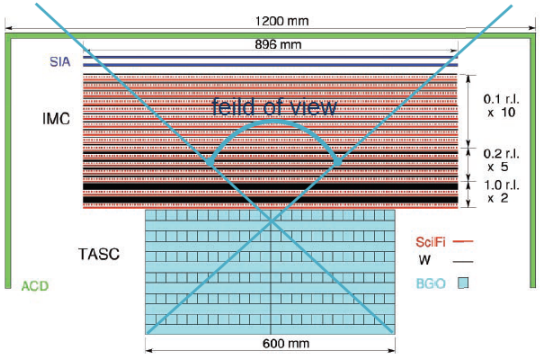


Fig. 9. A schematic side view of the CALET detector concept.

CALET detector

- Digital imaging - has no amplitude saturation problem
- 5 sensitive faces - has a large field of view
- High level of granularity - has Good particle identify power and Good angle resolution
- CCD read out -with low power ~10w

Simulation Study

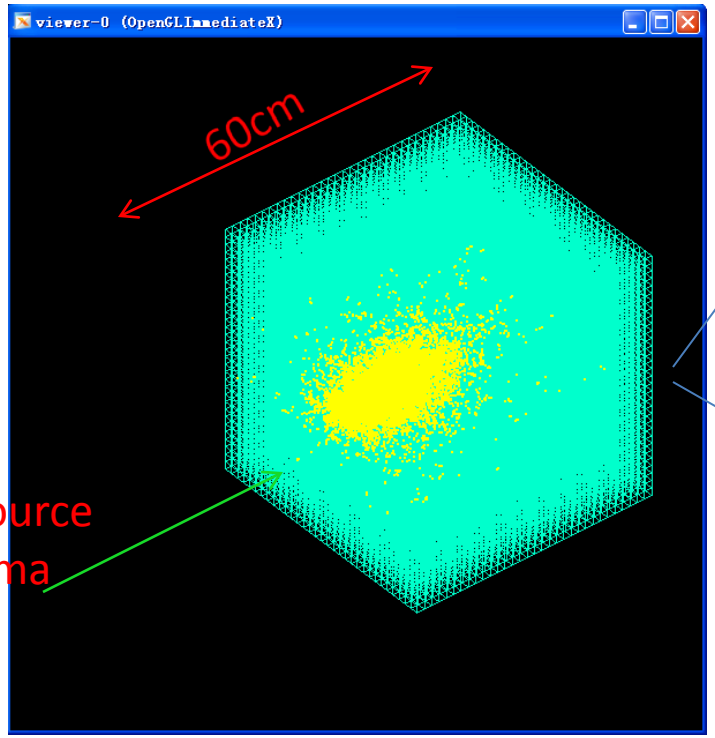
Energy linearity

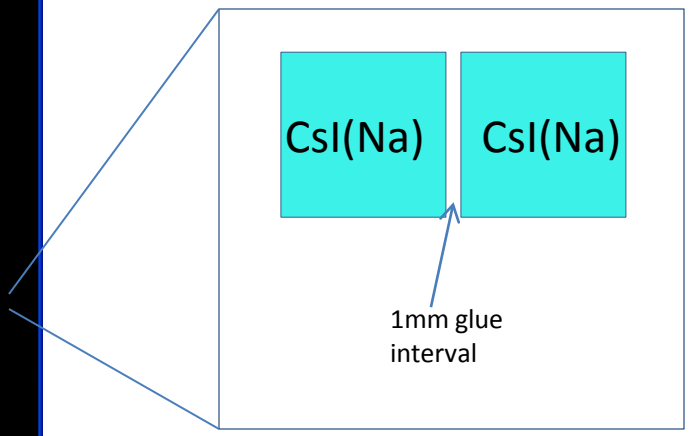
Energy resolution

Angular resolution

Particle Identification

Detector geometry



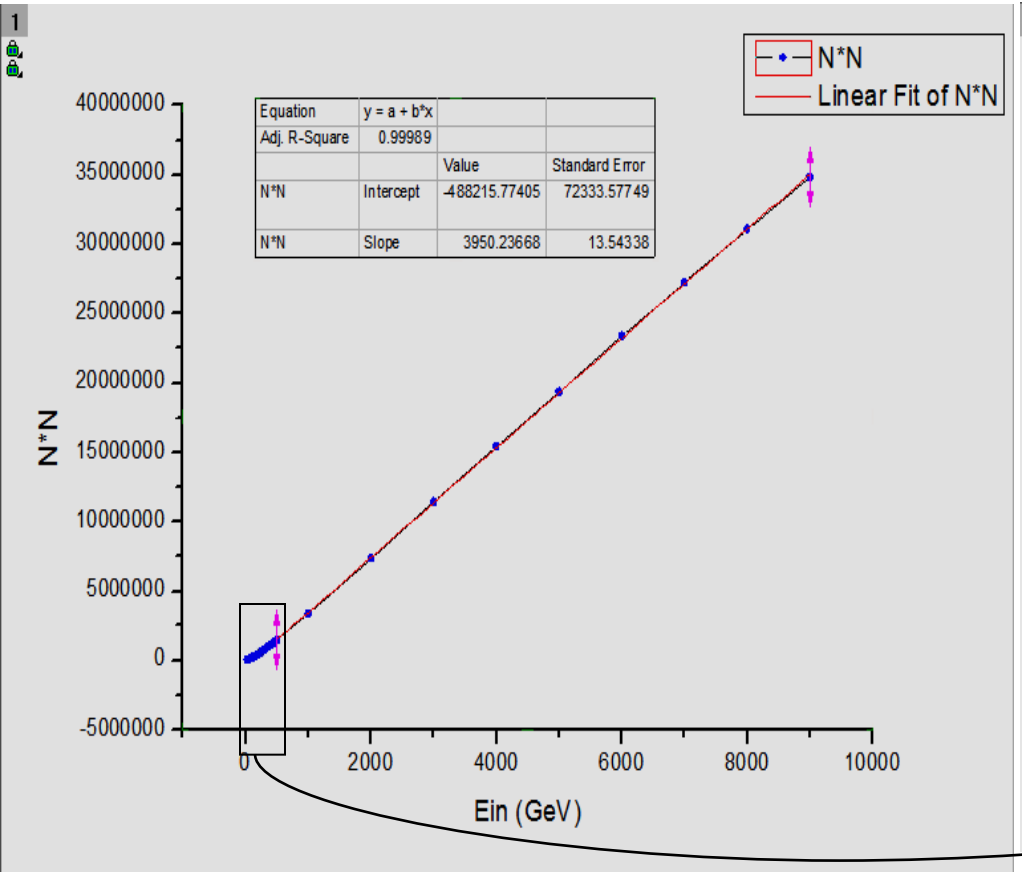


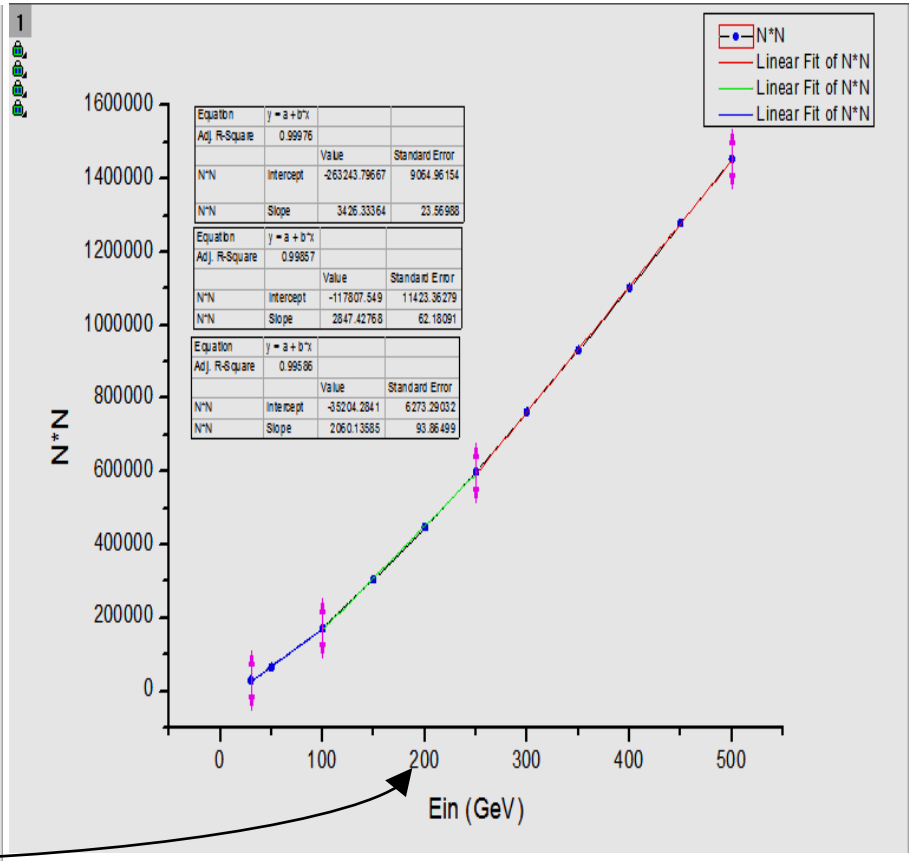
Total dimension: 60 cm × 60 cm × 60 cm
Crystal cell side length varied for 1.5 cm to 4.5 cm
radiation length: $32X_0$
Weight: 974 kg

Code: Geant4
Physics list: QGSP
Record deposited energy in each CsI(Na) unit if energy>cut(12 MeV) mark “1”
else mark “0”
12 MeV –MIP energy of cosmic muon in 2.5 cm CsI(Na)

Energy linearity

$$N_{hit}^{2} \propto E_{incident}$$

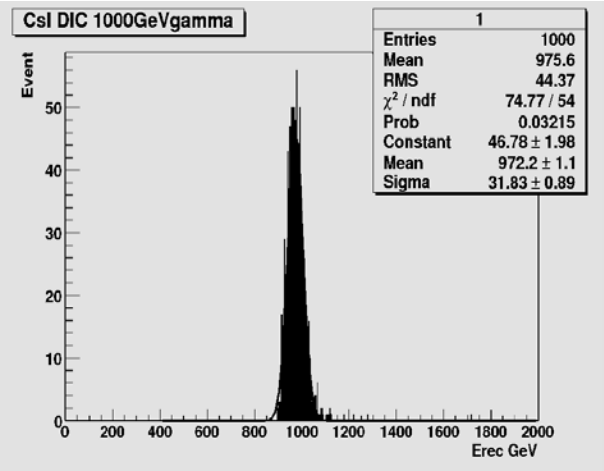




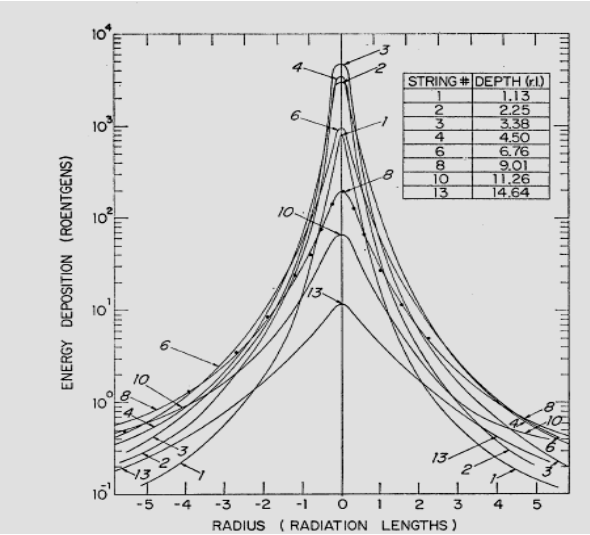
Incident energy(GeV)

Incident energy(GeV)

Energy resolution

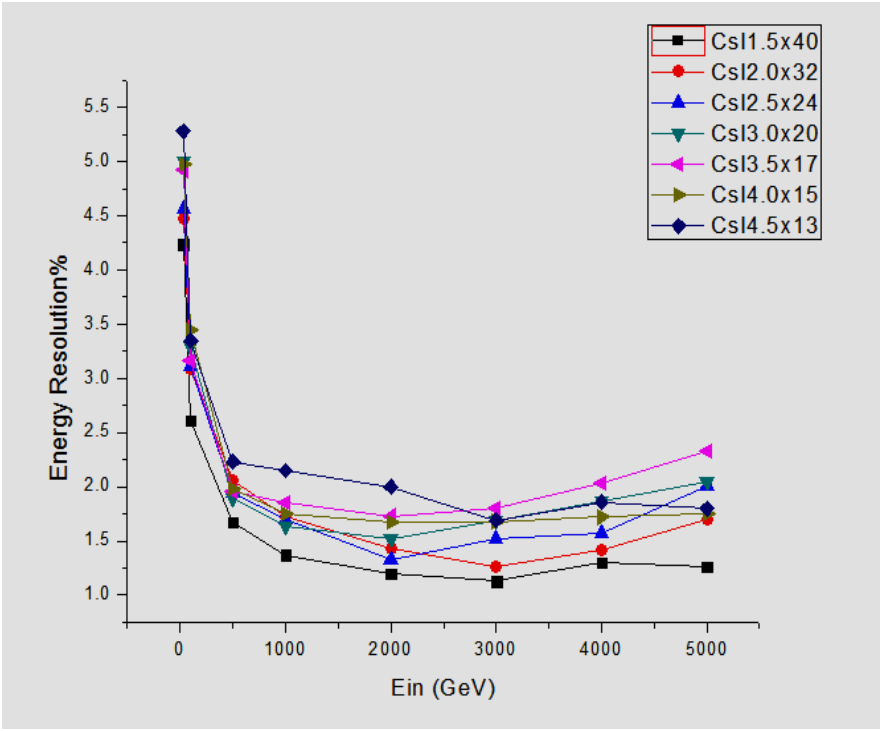


1 TeV gamma energy resolution is 3.27%



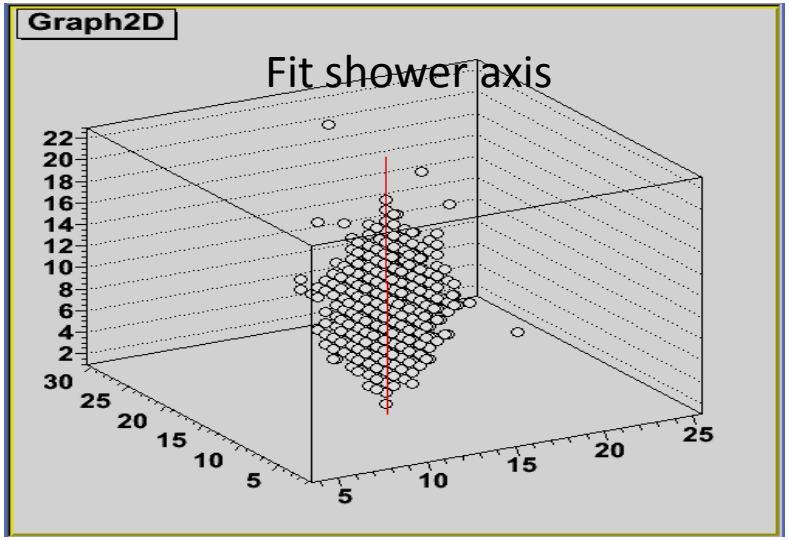
Transverse energy distribution

Different granularity
Energy resolution compare

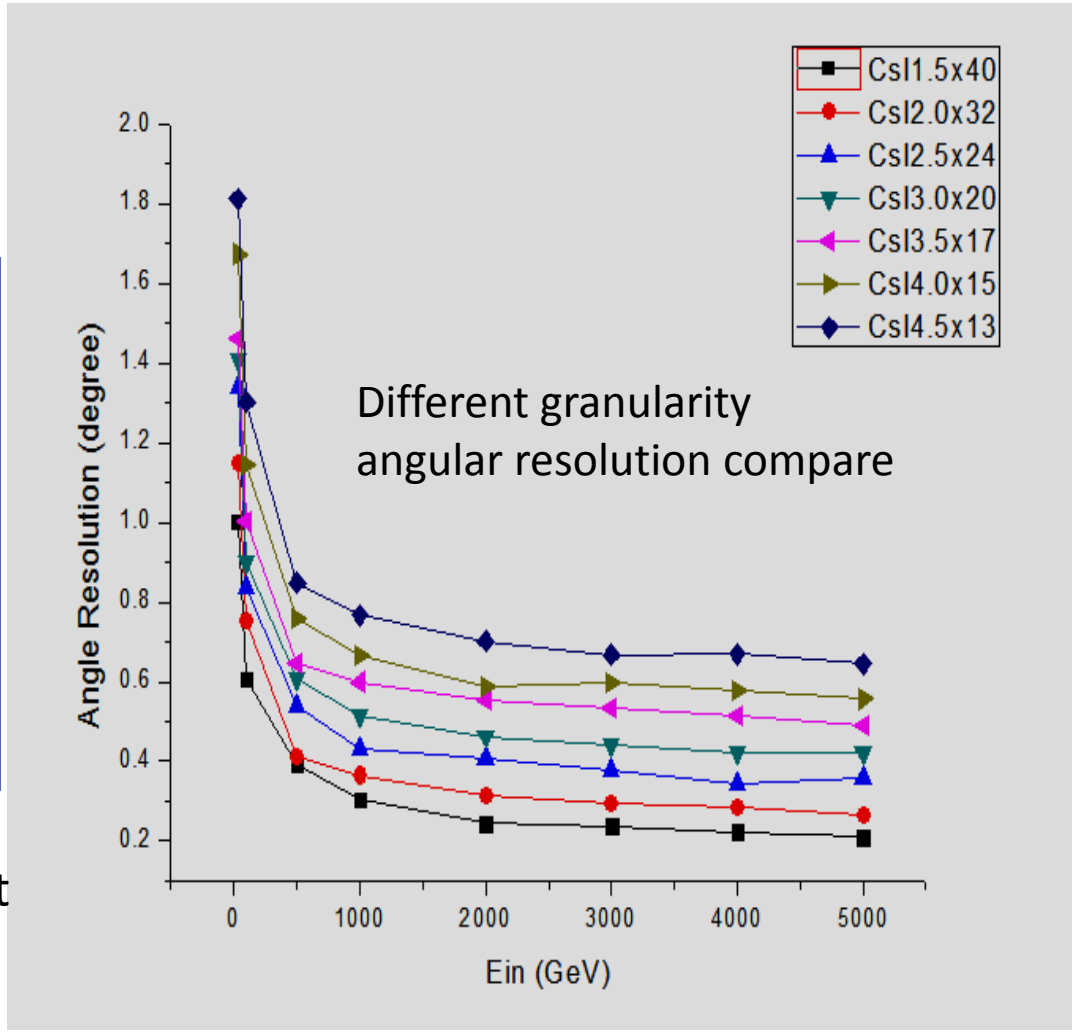


energy resolution after
transverse energy correction

Angular resolution

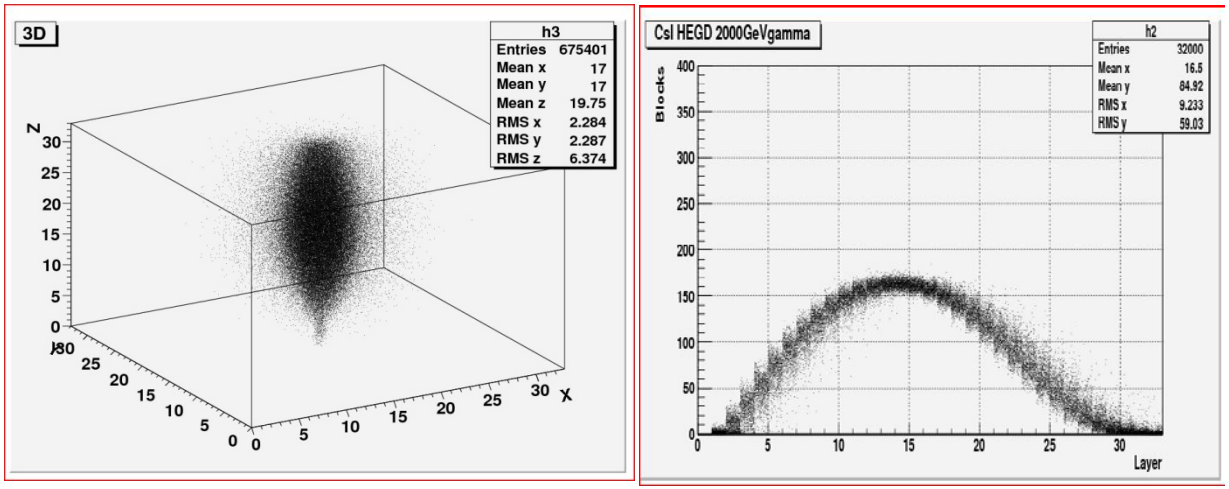


500 GeV gamma shower development shape

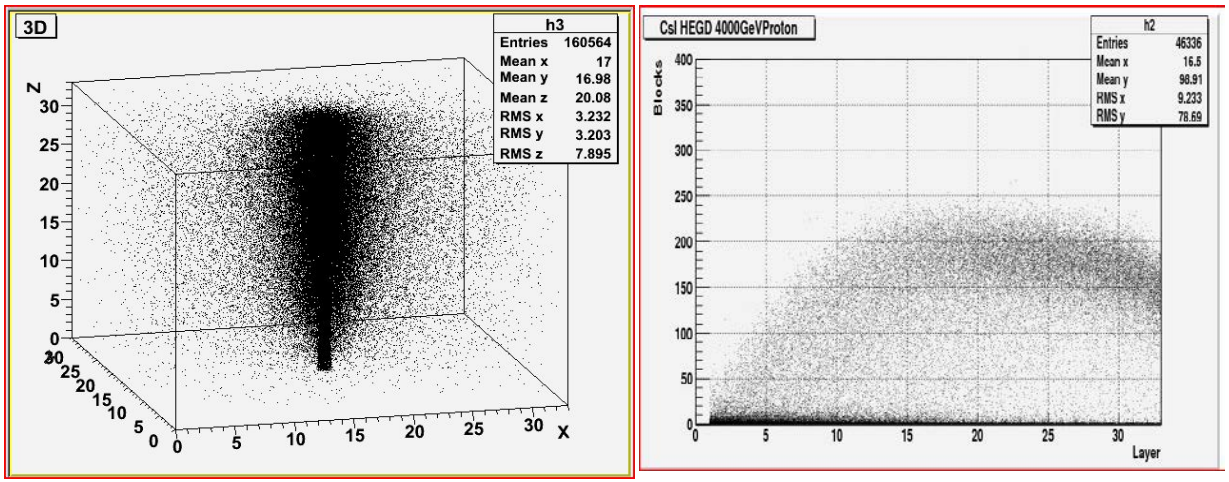


Angular resolution ~ 0.5 degree

Particle Identification(PID)

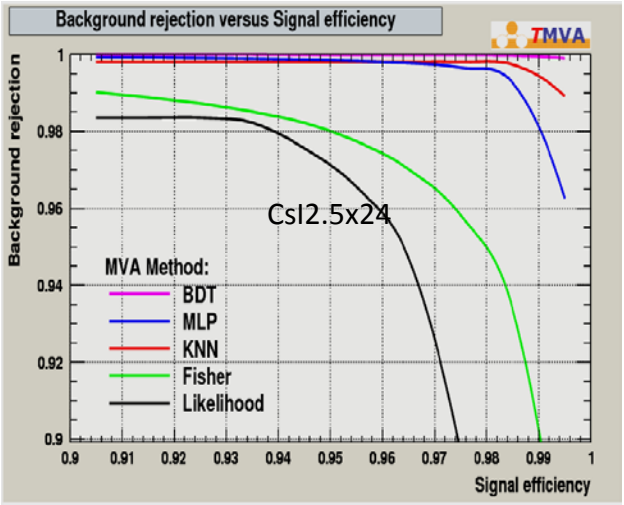


Shower distribution of 2 TeV proton



Shower distribution of 2 TeV gamma

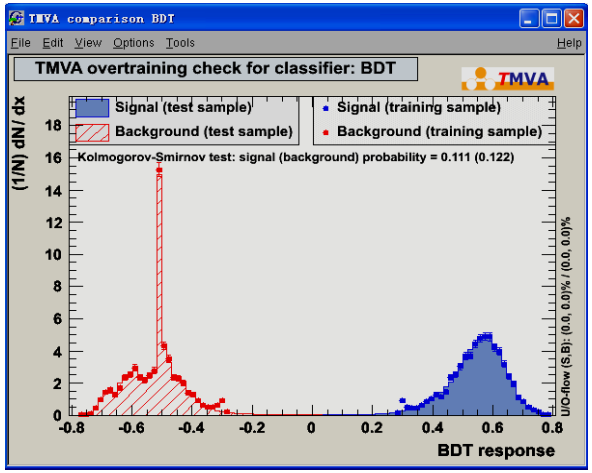
Gamma/proton separation

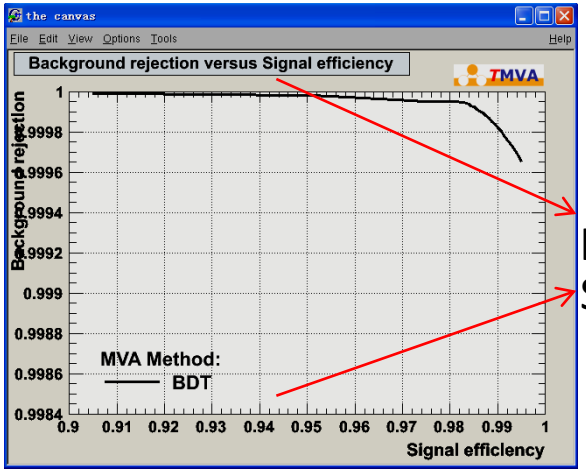


TMVA(Toolkit for Multivariate Analysis) package is used to do PID

Signal: gamma-ray 100 GeV
Background: proton 100 GeV—5000 GeV distribute as power law 2.7

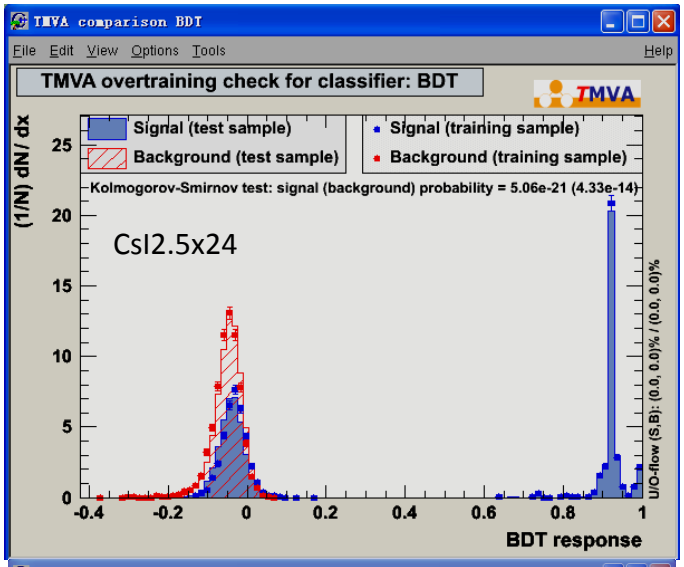
```
Collected:
    Signal     training entries: 40000
    Signal     testing  entries: 99662
    Background training entries: 40000
    Background testing  entries: 978821
```

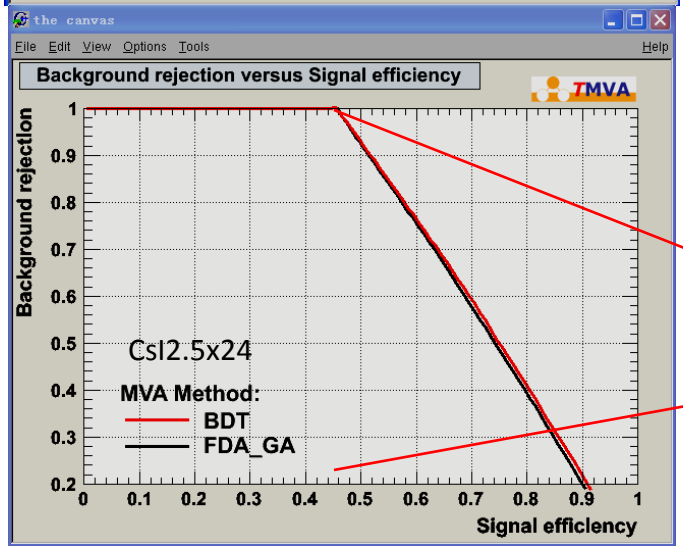




proton rejection power ~5×10^5
Signal efficiency 95%

Gamma/electron separation





Signal: gamma-ray 100 GeV
Background: electron 100 GeV

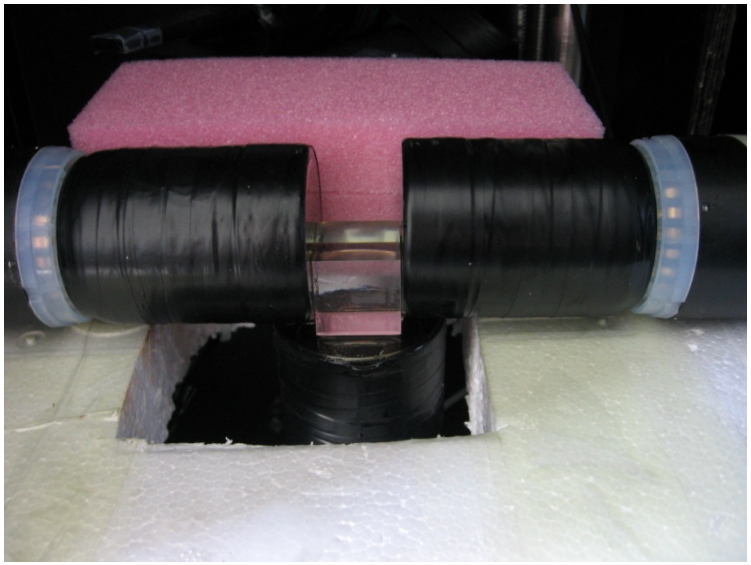
```
: Collected:
:     Signal     training entries: 5000
:     Signal     testing  entries: 134662
:     Background training entries: 5000
:     Background testing  entries: 154376
```

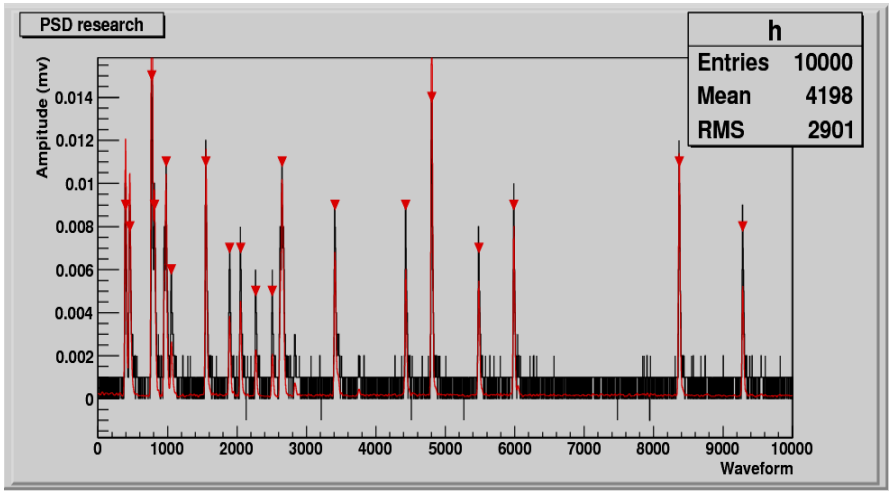
electron rejection power ~1×10^4
Signal efficiency 45%

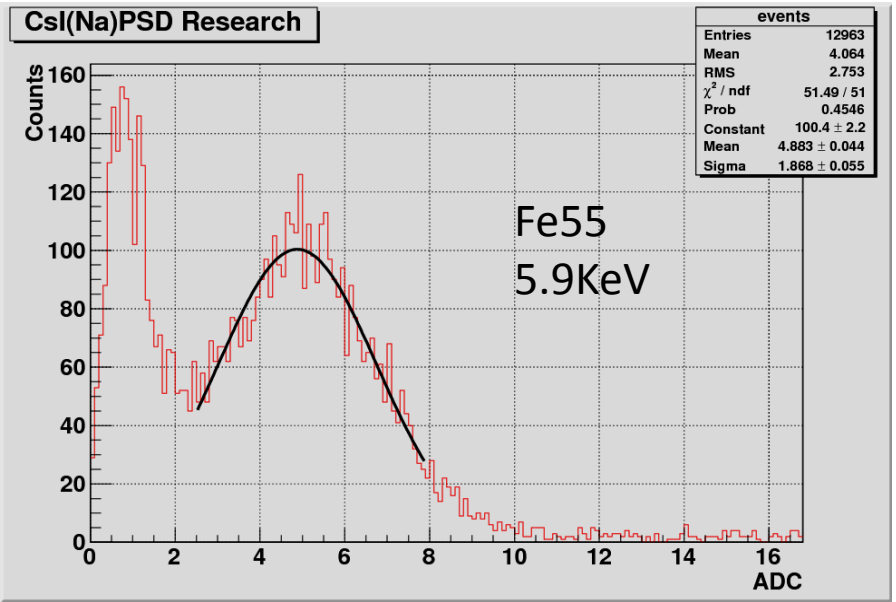
Experiment study

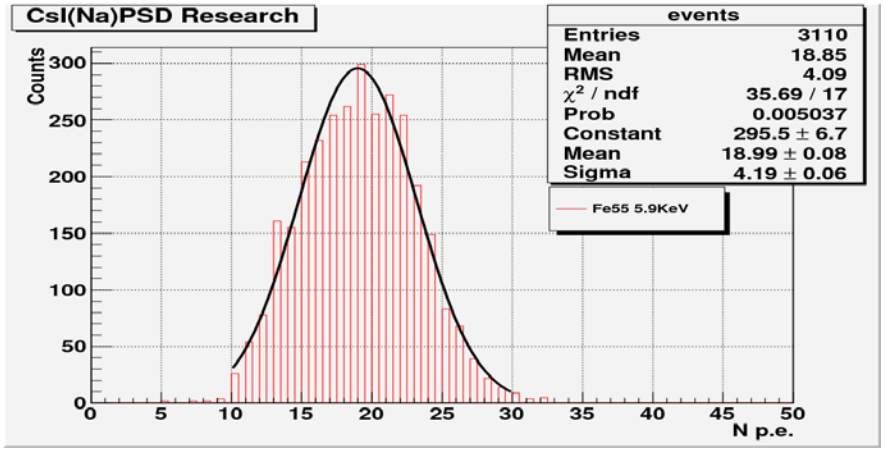
- CsI(Na) light yield
- Cosmic ray test

CsI(Na) light yield test



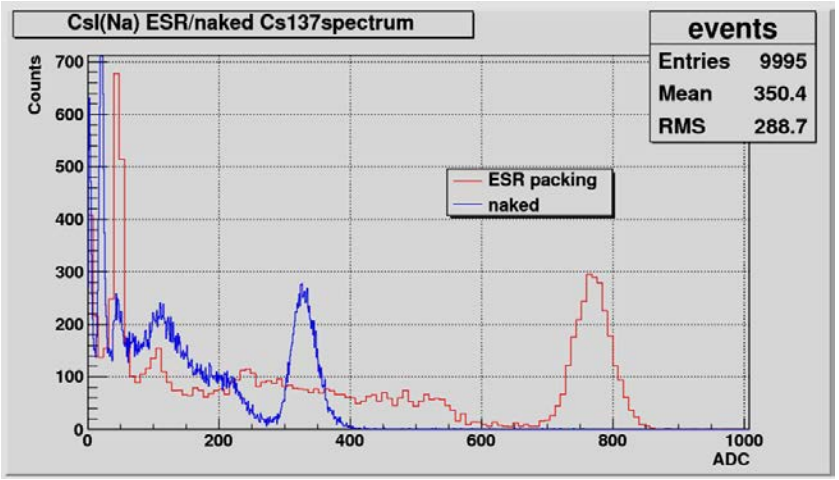


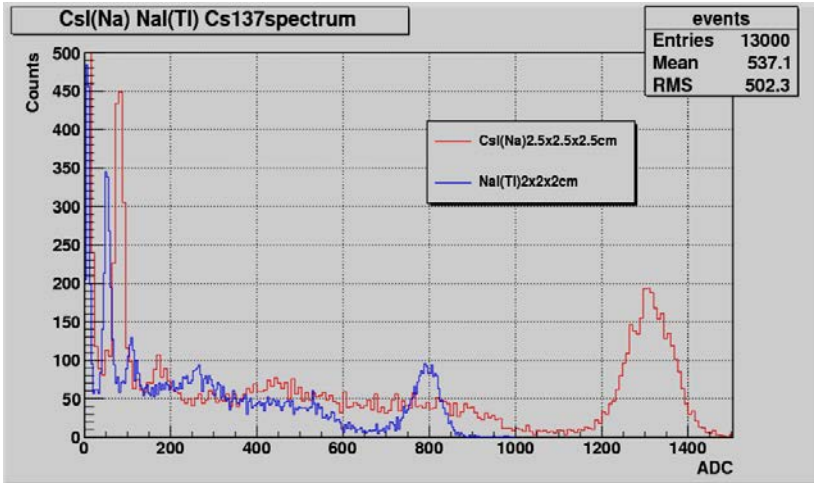




Light yield: 3.2 p.e./keV
@2 us integration time
(no ESR packaging)

Light yield compare

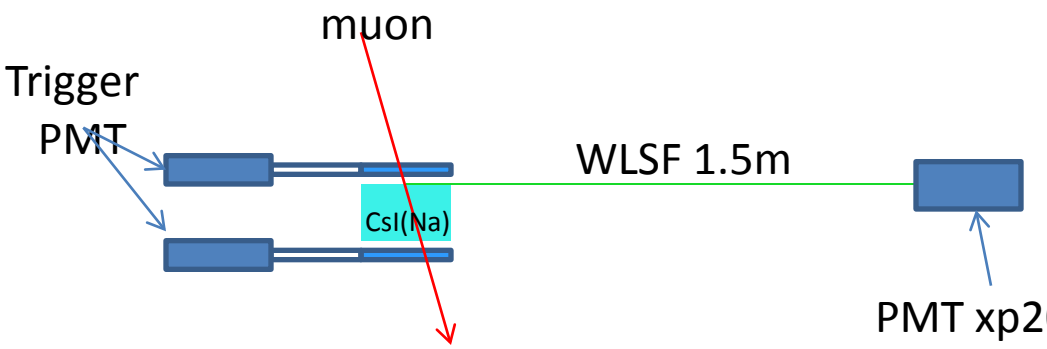


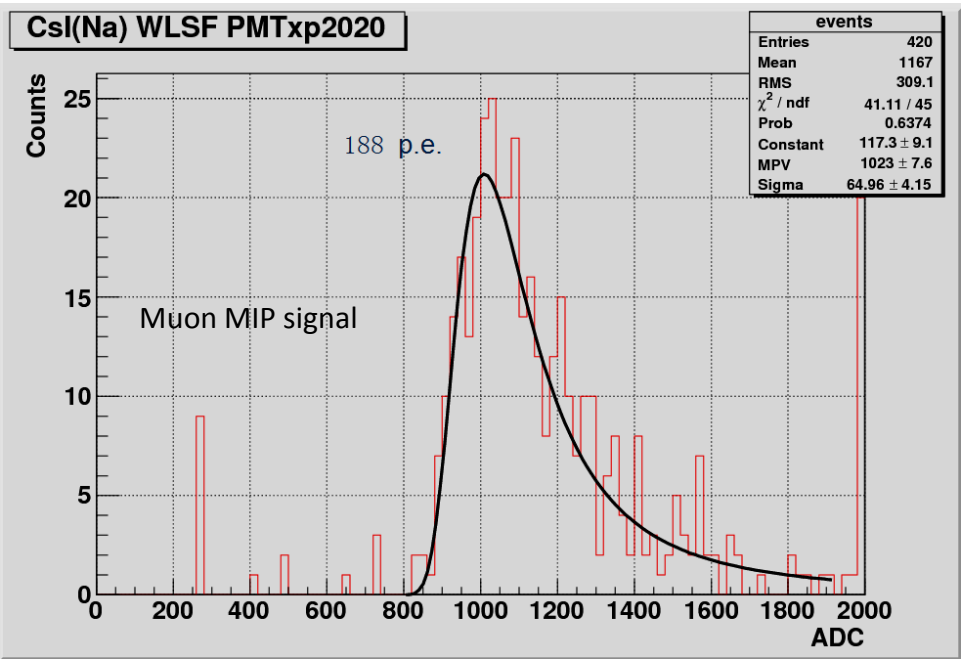


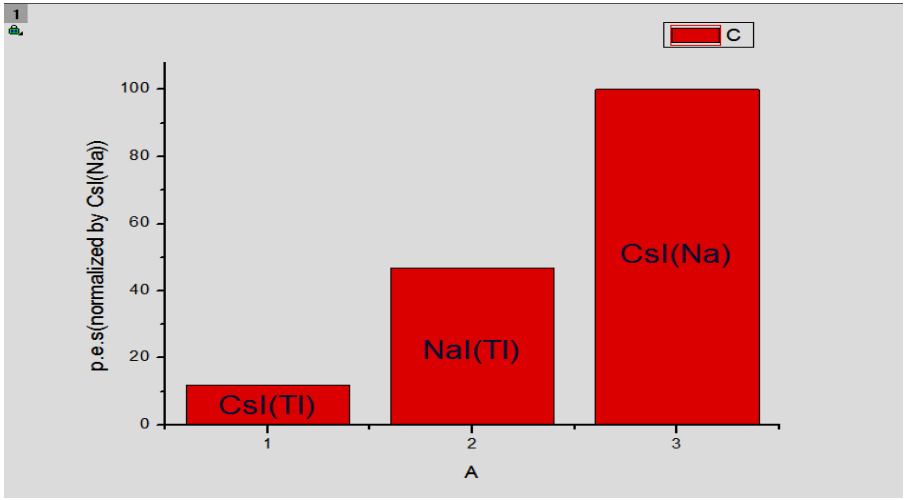
ESR packing:
Peak position:769 channels, resolution 3.51%
Naked:
Peak position: 330 channels,resolution 5.88%
ESR packing is 2.33 times larger than naked
ESR packing light yield: 7.4 p.e./KeV @2us integration time

Integration time: 20us
CsI(Na) 1.625 times larger than NaI(Tl)
Light yield: 12 p.e./KeV

Crystal+WLSF cosmic ray test with PMT



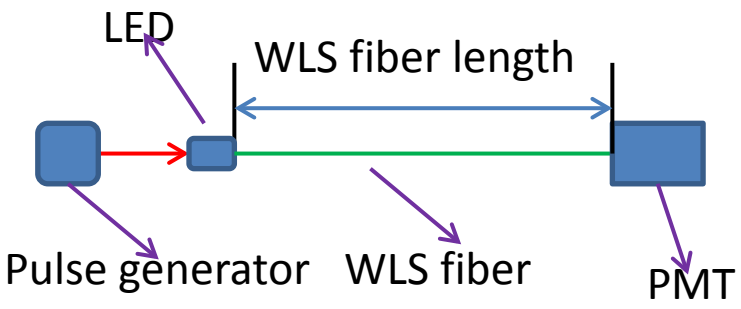




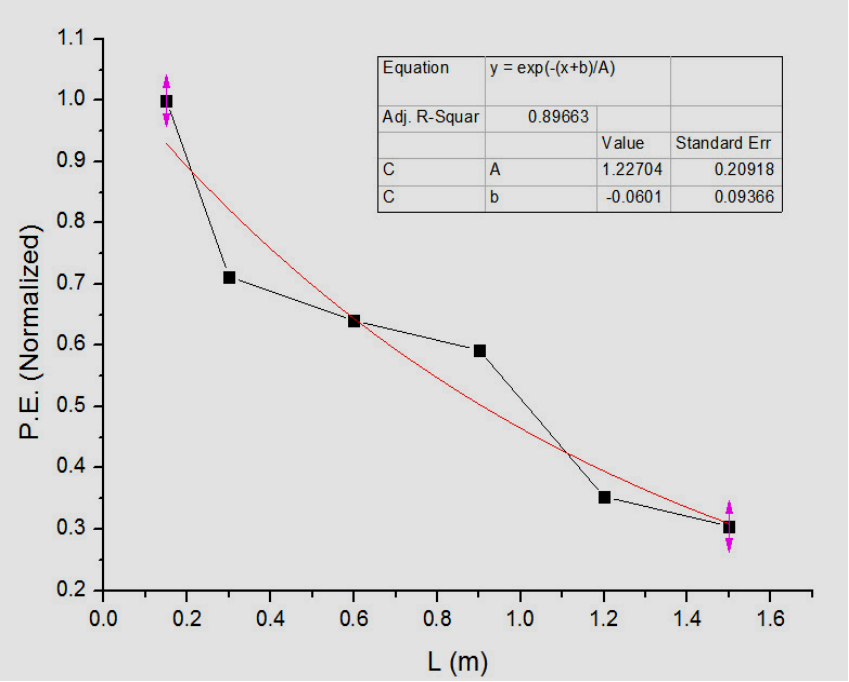
ϕ300um WLSF stretch 1.5m to PMT

3 different type crystals light output test results,
CsI(Na) has best performance

Light attenuation length of the WLS fiber

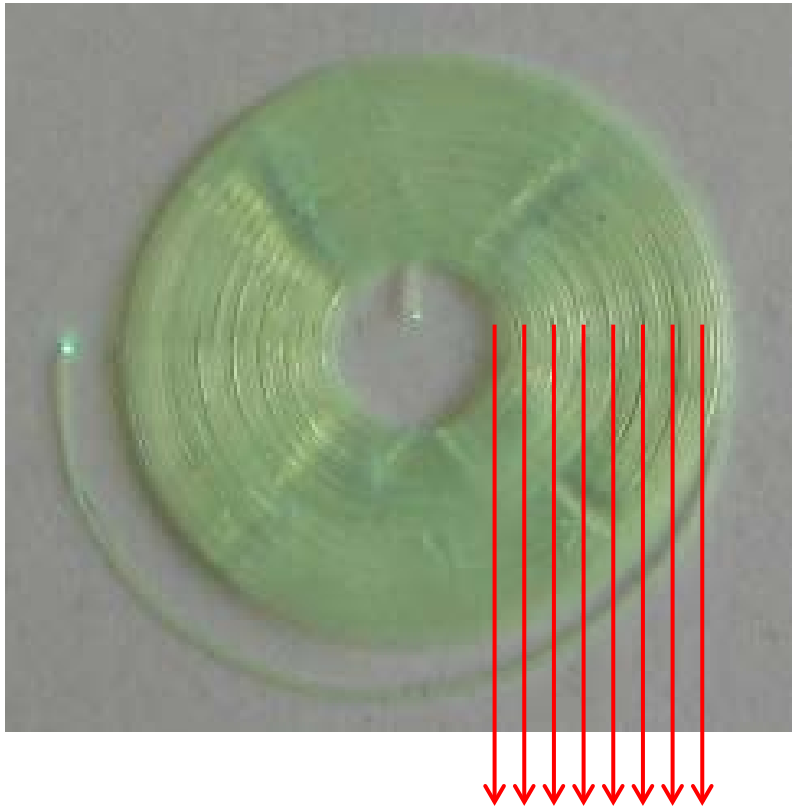


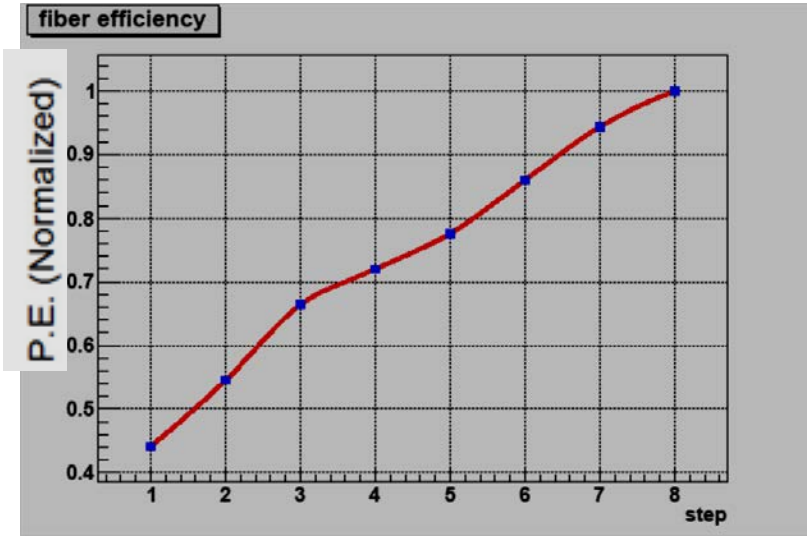
Setup of light attenuation length test of the fiber



Light attenuation length of the 300um diameter WLS fiber is 1.23 meter.

Fiber spiral light transmission test





Step

Step: 1 2 3 4 5 6 7 8

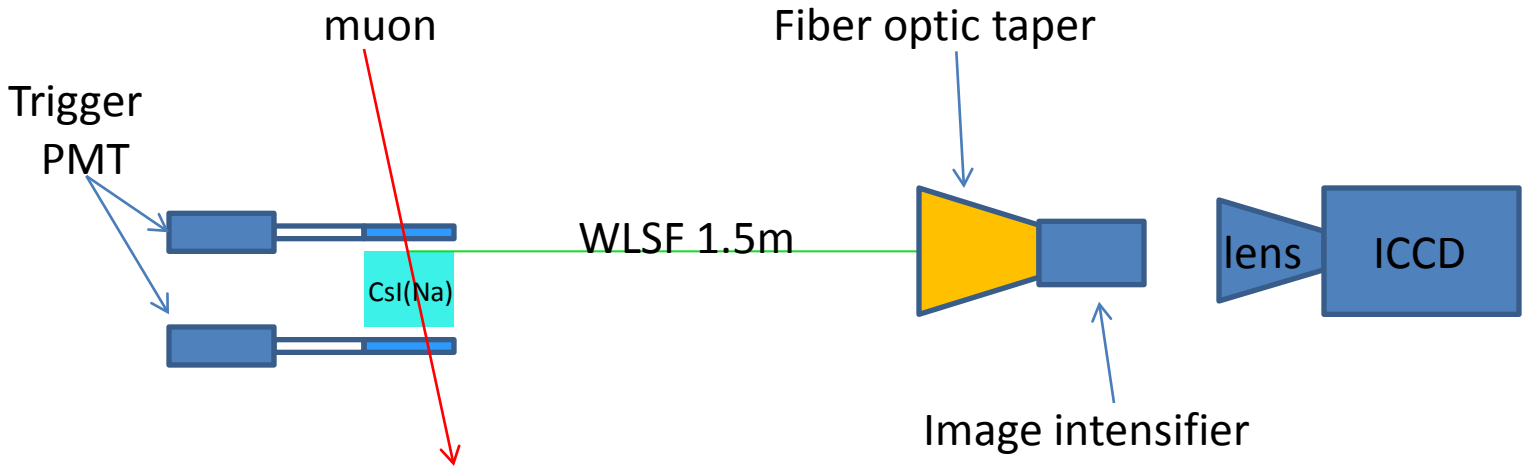
400 um diameter tube,
direct LED light to fiber

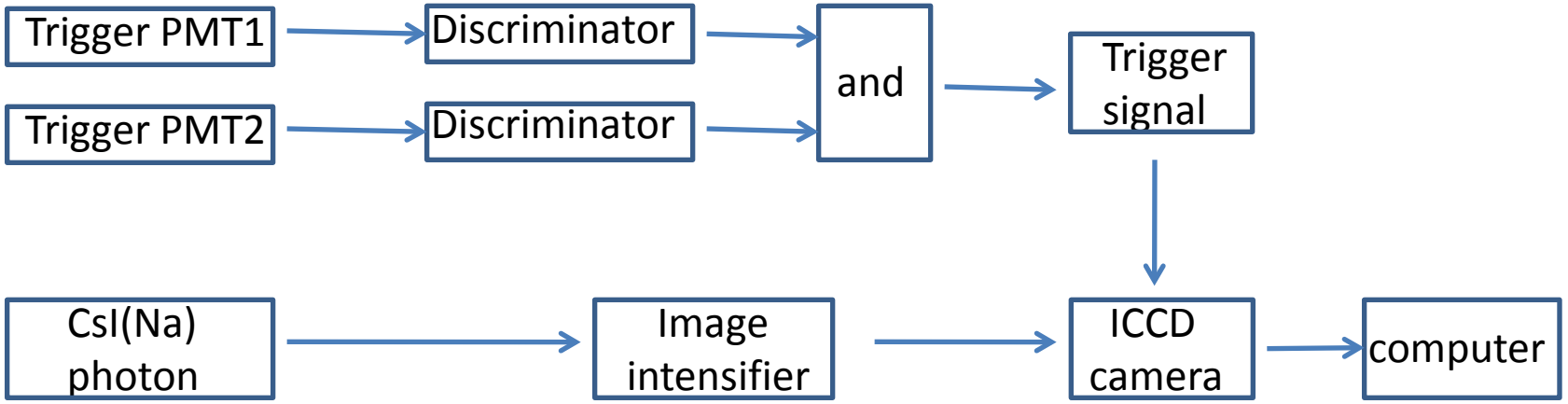
Step length : 1 cm

LED: 405-410 nm,
simulate the CsI(Na) crystal light

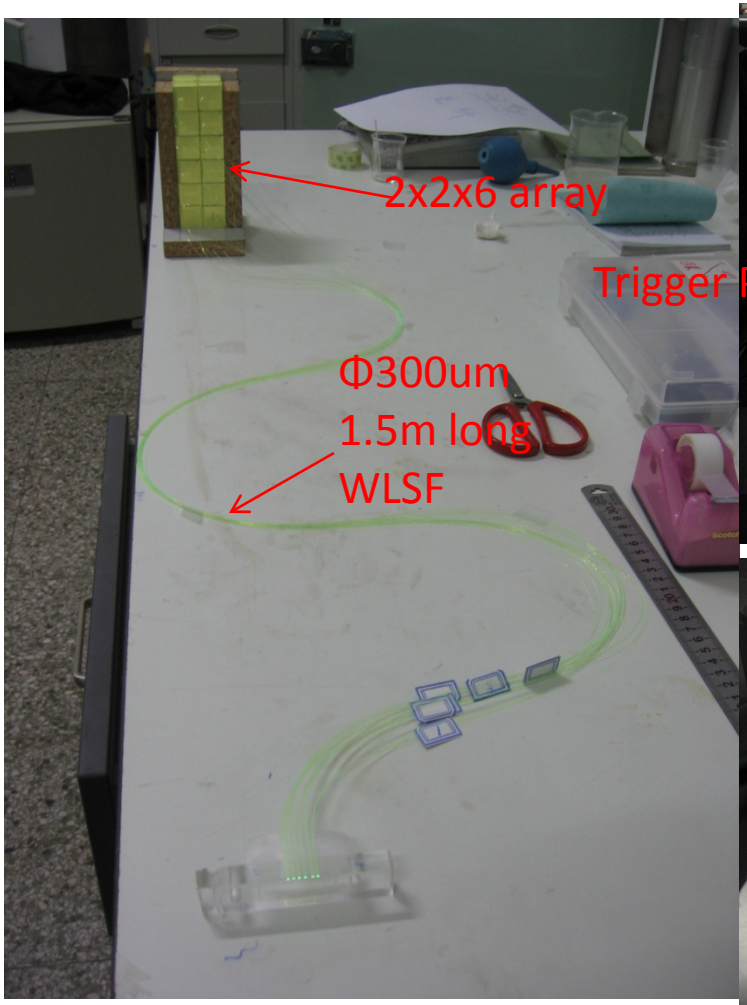
The light transmission of the innermost position is 42% to the outermost.

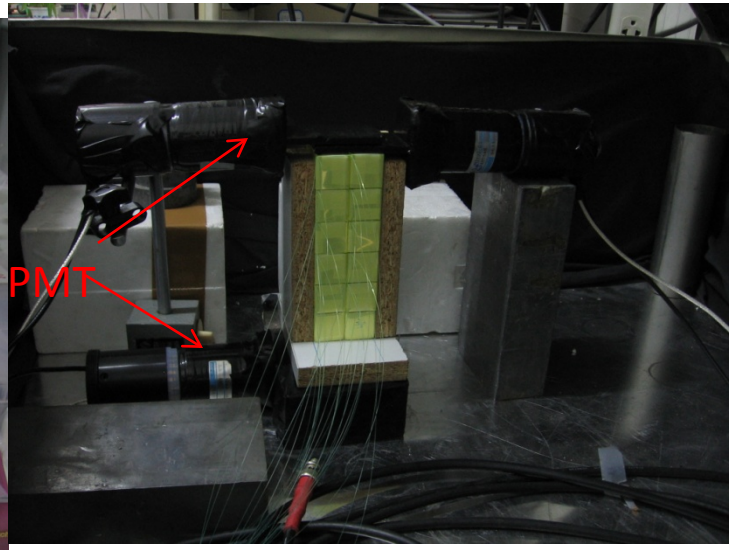
Crystal+WLSF cosmic ray test with ICCD

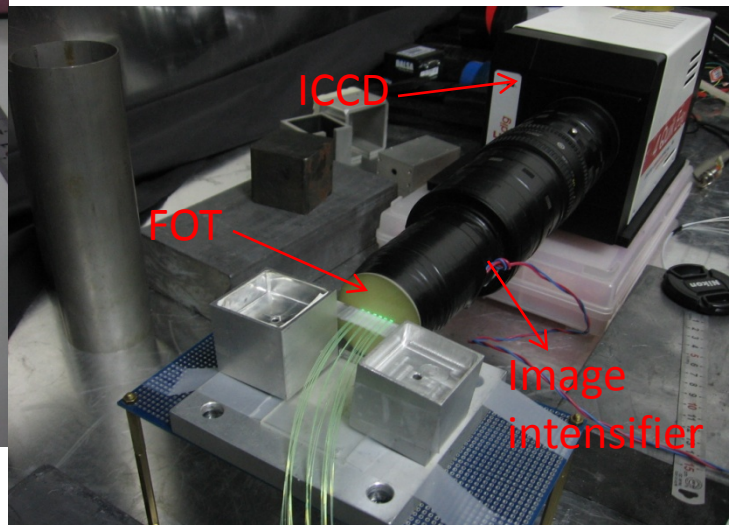




Prototype 2x2x6 array

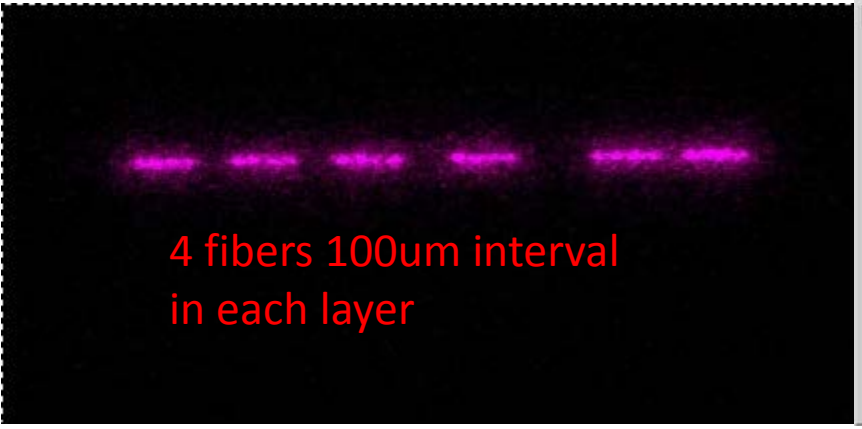


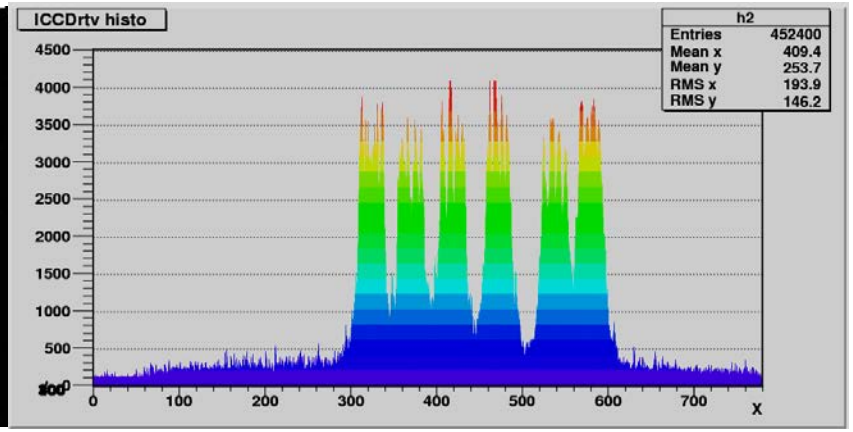




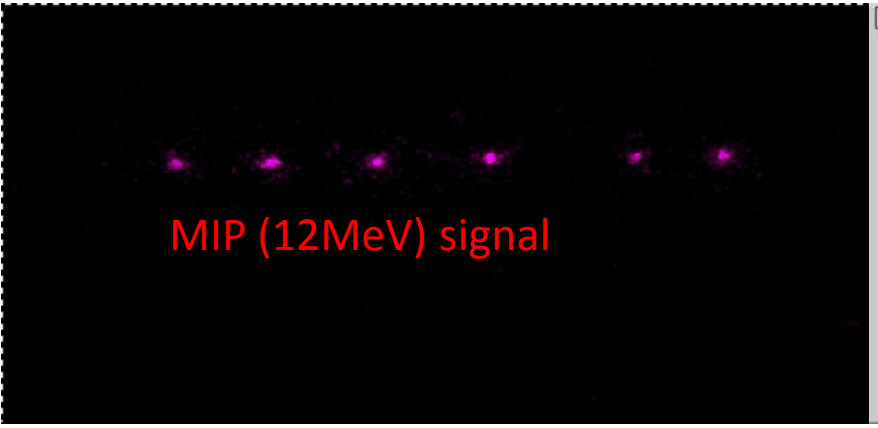
Cosmic ray test results

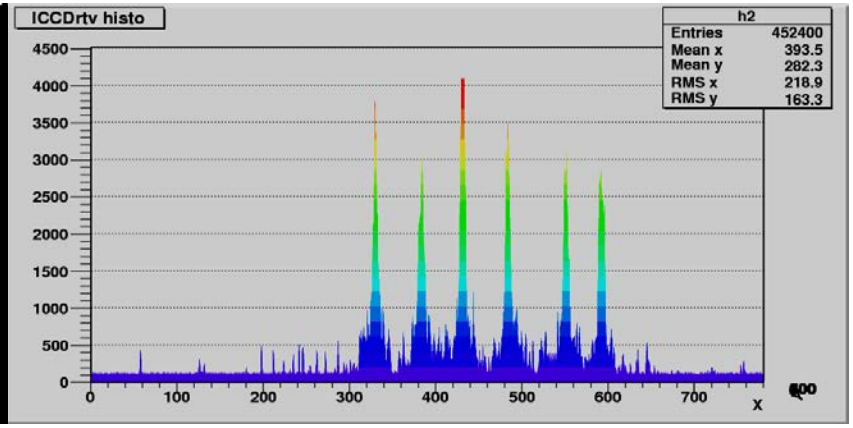
Fiber position calibration



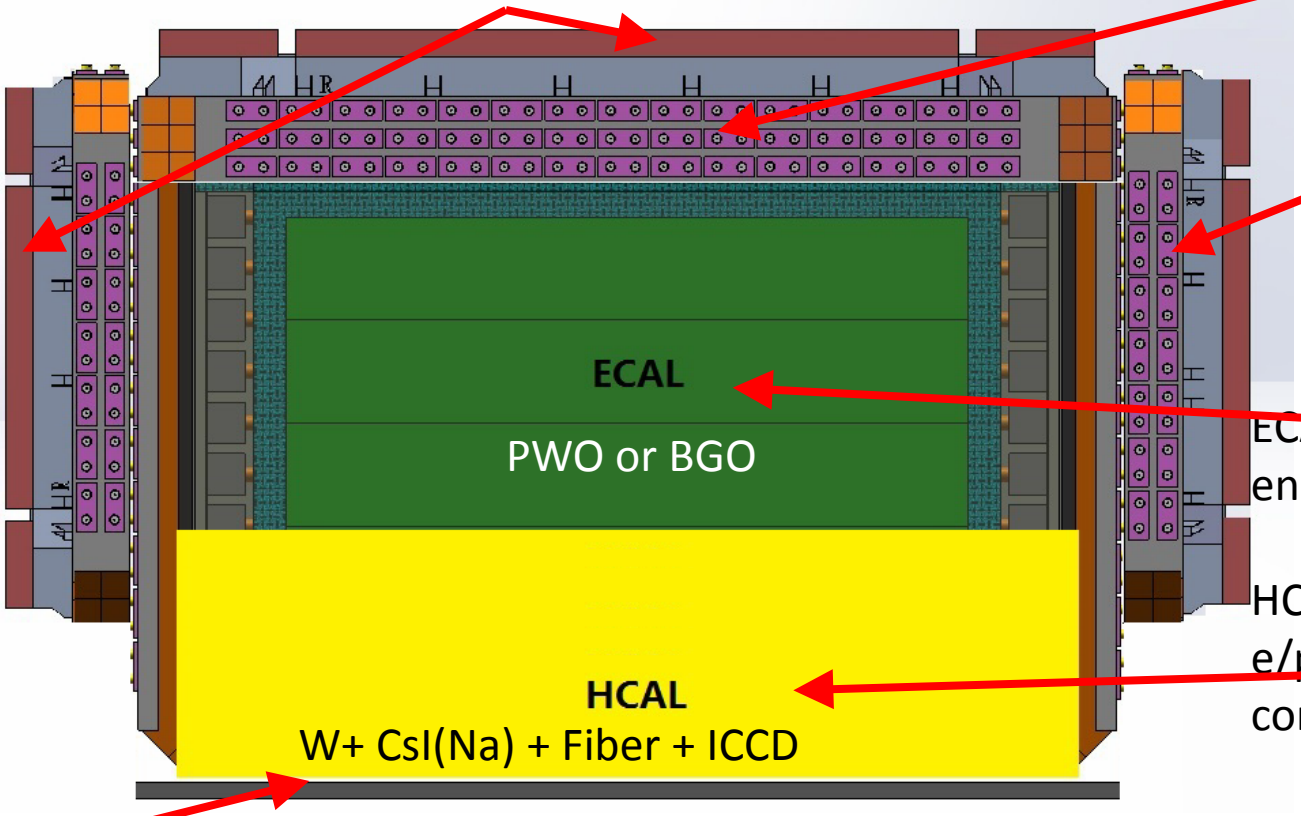


muon event display





2，High Energy cosmic Radiation Detection facility



Charge detector: 2-layered Si+PIN. Charge measurement

Shower Tracker: W+scintillation fibers

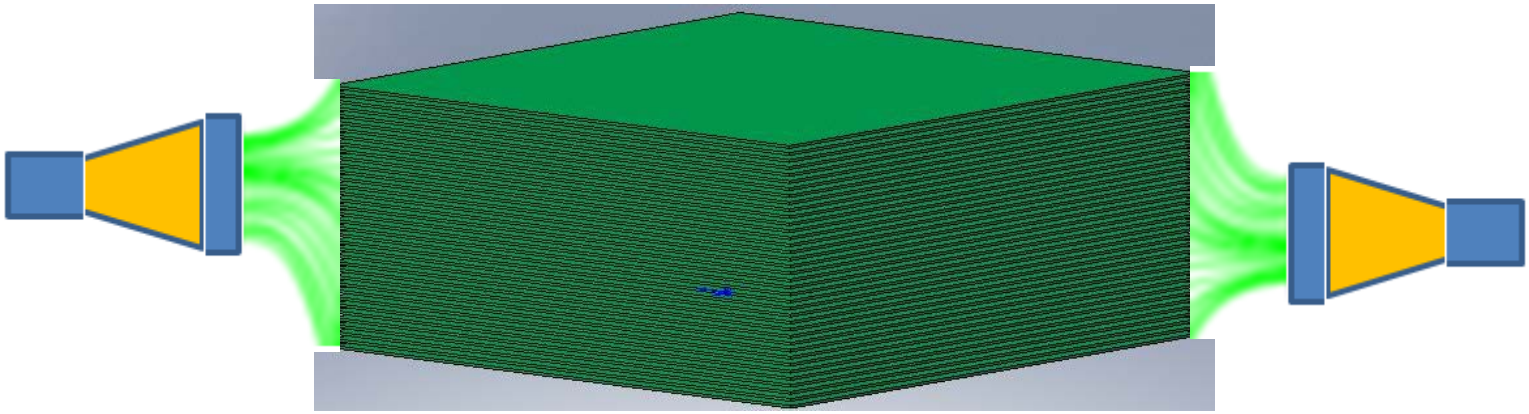
Nucleon Tracker: scintillation fibers.

ECAL: lepton calorimeter. e/γ energy.

HCAL: hadron calorimeter. e/p discrimination and CR composition measurement.

Neutron detector: B-doped plastic scintillator for delayed signals. Enhanced e/p discrimination.

Structure of the HCAL



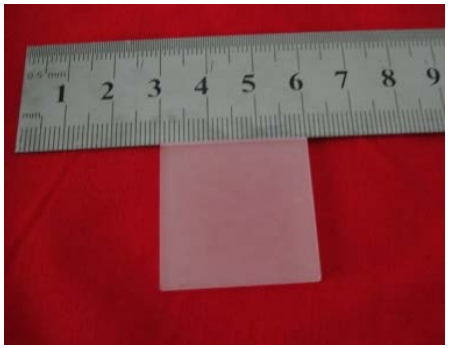
The hadron calorimeter(HCAL) is a sampling calorimeter made of CsI(Na)-scintillator tungsten sandwich structure, which function as active and passive material, respectively. Lateral dimension of the HCAL is 70 cm×70 cm. Each layer consists of 0.35 cm thick tungsten absorber plates and 0.2 cm thick CsI(Na)-scintillator tile , The tile size is 2.5 cm×2.5 cm。

The scintillation light of crystals is absorbed by a 300 um diameter wavelength shifiting(WLS)fiber that is attached to the surface of the scintillator with a spiral structure, and the readout system is similar to the digital imaging calorimeter.

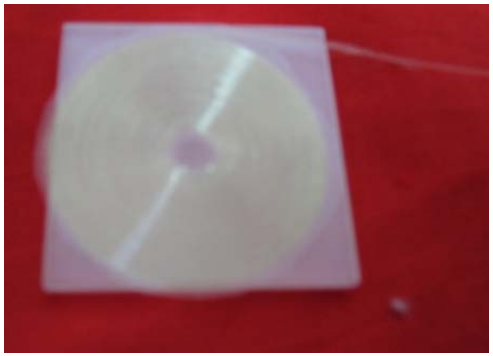
In total, the hadron calorimeter has 35 layers, amounting to a depth of 1.3 hadronic interaction lengths, with a total of 27440 scintillator cells.

Total weight of HCAL is 1000kg.

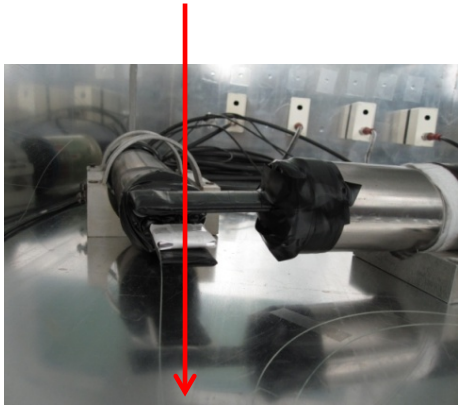
Light output test of the crystal-fiber unit



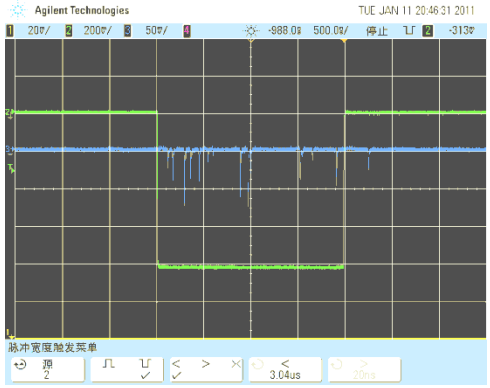
crystal 3 cm × 3 cm × 0.2 cm



crystal and WLS fiber spiral



Cosmic ray test



Waveform signal

Diameter 300μm WLS fiber output signal readout by PMT: average 15.4 p.e
If the number of the photoelectron can not meet the requirment of the ICCD, the thickness of the crystal can be increased to 0.3 cm or 0.4 cm.
The weight of crystals only account for 12.7% of the total detector.

Fabraction of WLS fiber spiral

mold

upper part and lower part of the mold

circle WLS fiber in the mold

hot air gun heat the mold and fiber to 100 degree for 5 minutes , then natural cooling to roo temperature(20miniutes).

open the upper part of the mold carefully and smear little epoxy glue on the surface of the fiber

At room temperature, the gule takes 3 hours to set , and then can separate the mold and fiber easily.

Furture work

1, order 2000 CsI(Na) crystal(2.5cm × 2.5cm × 0.2cm) to study the production process of the detector: package of crystals, fix of the crystals on the tungsten plates, layout of the fibers,….

2, beam test to study the performance of the HCAL.

Summary

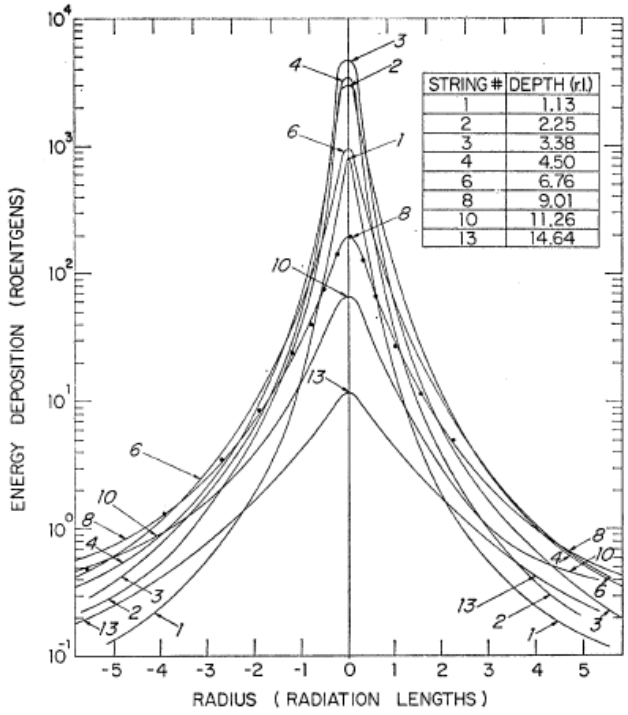
Hadron Calorimeter:

- Evolved from Digital Imaging Calorimeter
- 5 sensitive faces - large field of view
- High level of granularity - Good particle identify power and Good angle resolution
- ICCD read out -with low power ~10w
- More detailed work need to do

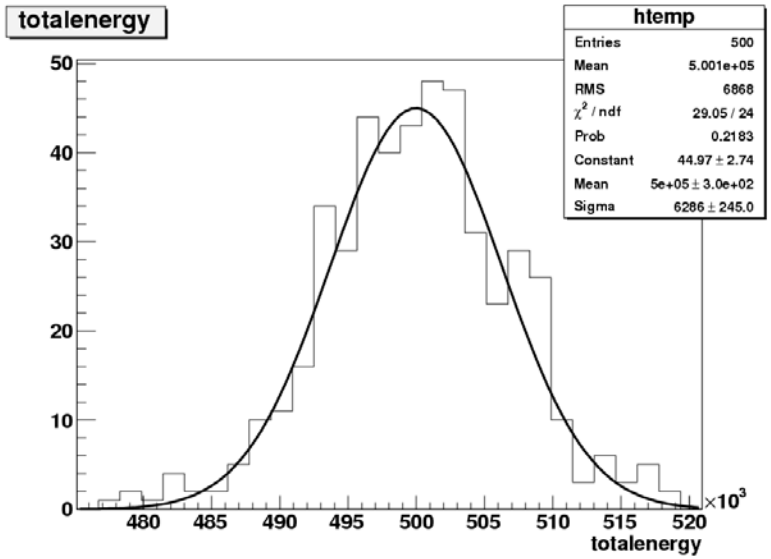
Thanks!

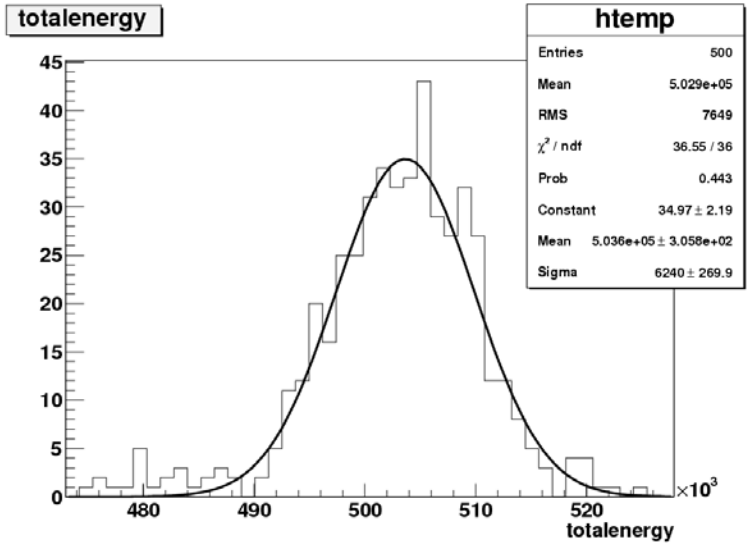
Back Up

Correction of energy resolution



500 GeV gamma energy resolution：





500GeV gamma energy resolution after correction：1.26%。

520GeV gamma energy resolution after correction：1.26% ： 1.24%，