Performance of the gamma-ray camera based on scintillator array and PSPMT with an ASIC readout system

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IWORID9 July 24, 2007@Erlangen, Germany

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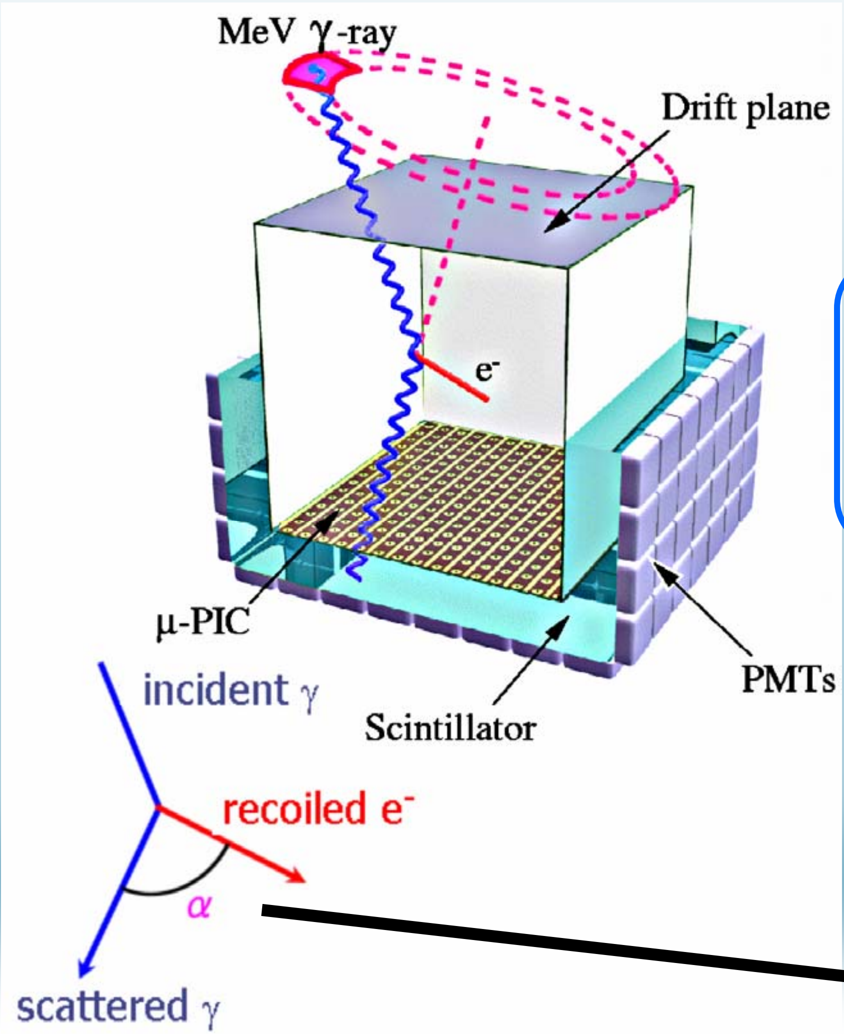
Gamma-ray Imaging Detector

Sub MeV ~ MeV gamma-ray imaging for…

- Astronomy (balloon experiment, SMILE)
- Application → Medical Imaging

Advanced Compton Camera



◆ gaseous TPC

(Time projection chamber based on μ-PIC as readout system)

→ Track and energy of recoil electron

◆ Scintillation camera

(Multi Anode PMT+Pixelated Scintillator Aray)

→ position and energy of scattered gamma-ray

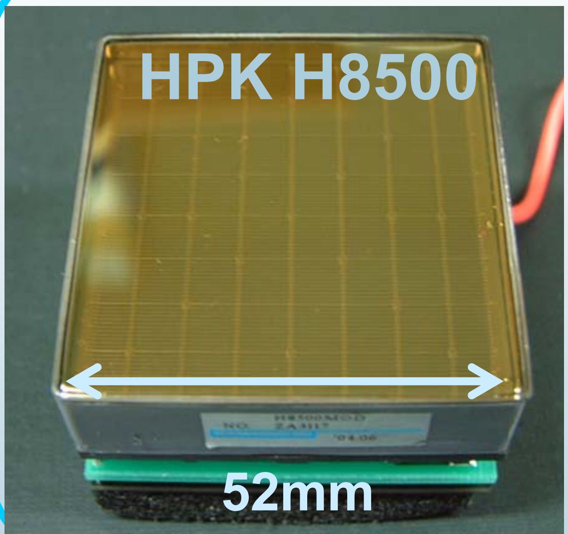
Reconstruct incident gamma-ray event by event

- 1 photon ⇒ direction + energy
- Large FOV (~3str)
- Kinematical background rejection

Scintillation Camera

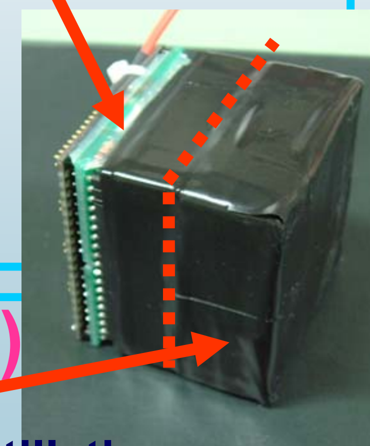
The camera consists of PSPMT and PSA (Pixel Scintillator Array).

← Considering *large sensitive area and *good position resolution

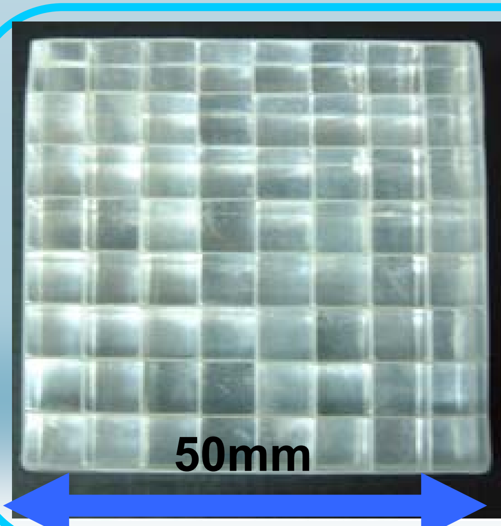


FlatPanel PMT H8500 (HPK)

- 8 x 8 multianode
- 6mm pixel pitches
- 12 stage metal channel dynode
- Gain ~10^6@-1000V
- Size: 52mm x 52mm
  (Photo Cathode Coverage ~89%)
- Anode uniformity: min:max~1:3



Scintillation camera



PSA(Pixel Scintillator Array)

- GSO (Ce) crystal
- 6mm x 6mm x 13mm pixel
- 8 x 8 array fits to anodes of H8500
- Pixels are optically isolated by the ESR(3M)
- Glued to H8500 with OKEN-6262A grease

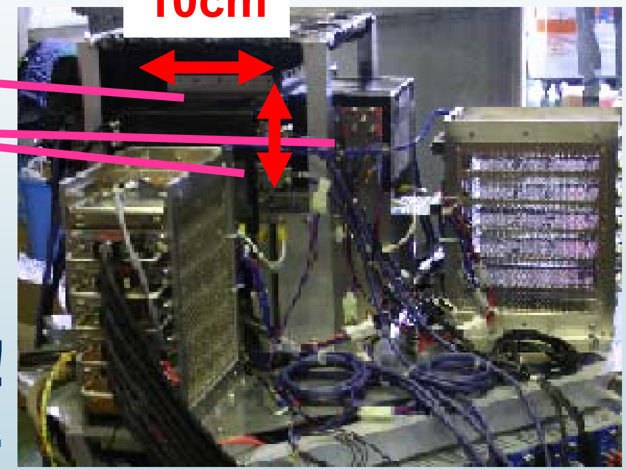
SMILE *Sub-MeV gamma-ray Imaging Loaded-on-balloon Experiment*

SMILE-1 (10cm)^3 Camera @ Sanriku, Japan

1st September 2006 launch

Gaseous TPC

33 Scintillation cameras



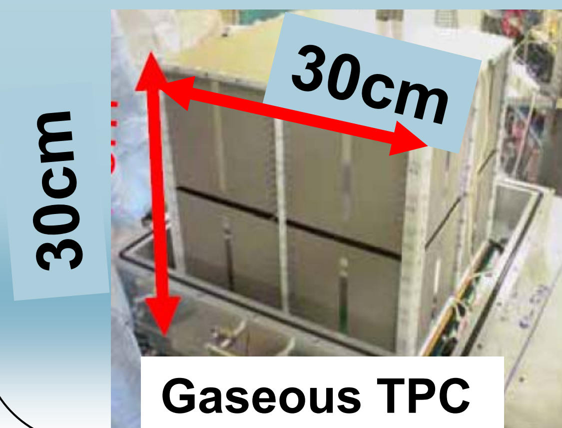
- Operation test of our Compton Camera @ 35km
- Diffuse cosmic and atmospheric gamma-ray measurement

SMILE-1 has been successful!

A.Takada Doctoral thesis, 2007, Kyoto University.

SMILE-2 (30cm)^3 Camera @Japan (2009)

- Observation of Crab and Cyg X-1



Gaseous TPC

Scintillation Camera

We need 108 scintillation cameras in order to surround large gaseous TPC.

We are developing larger detector !!

Requirements for scintillation camera

We should consider the following things for the balloon experiment.

- ●Position resolution / ●Energy resolution — Affect the angular resolution of Compton Camera → **PSA < 6mm**
- ●Dynamic range — Affect the dynamic range of Compton Camera
- ●Radiation Hardness — Scintillator is activated with cosmic ray in the sky. → **GSO**
- ●**Power consumption** — Power is limited in the sky.

	Number of PSPMT	Power Consumption [W/64pixels]	Energy Resolution (FWHM)@662keV	Dynamic Range [keV]
Requirements	**108**	**< 1.5**	**~ 11.0%**	**80-800**

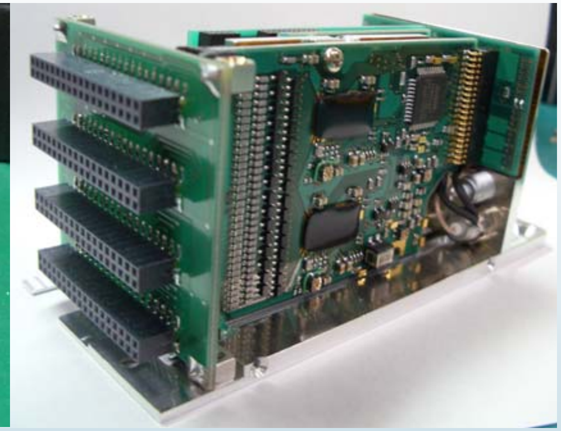
In order to satisfy these requirements…

We have studied and improved the readout system of Scintillation Camera

- ●With ASIC(IDEAS VA/TA)
- ●With ASIC and the board we developed

Every 64ch read-out with ASICs

We adopted the low power ASIC readout system.



H8500

15cm

Head Amp+FADC module CP80068
(by Clear Pulse Co. Ltd.)

32ch CMOS ASICs (by IDEAS ASA)

VA32_HDR11

PreAmp (Dynamic Range ~35pC)
shaper (Gain 118mV/pC, peaking time 0.7μs)
sample & hold
multiplexer

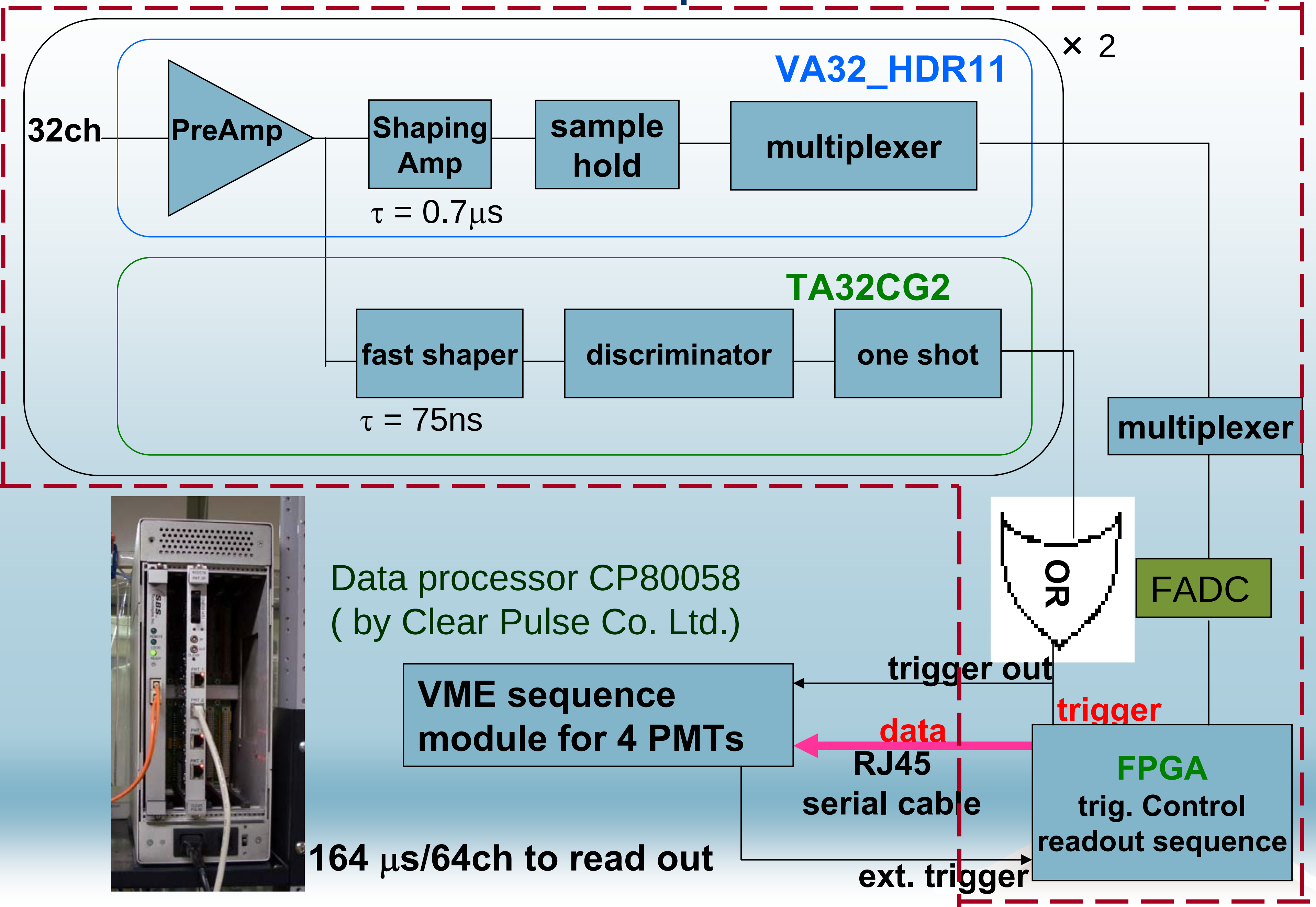
We should operate PMT with low gain of ~ 10^5.

TA32CG2

Fast shaper (peaking time 75 ns)
discriminator

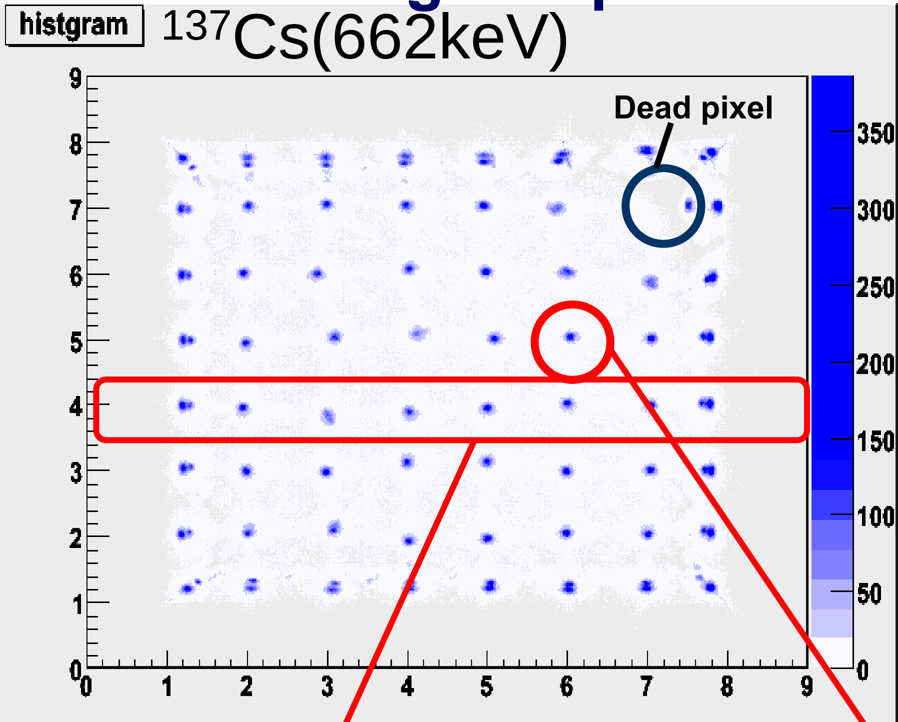
Power Consumption:
~1.3W/64pixels

Data Acquisition



VA 64ch read-out

Position image map



Input dynamic range: small

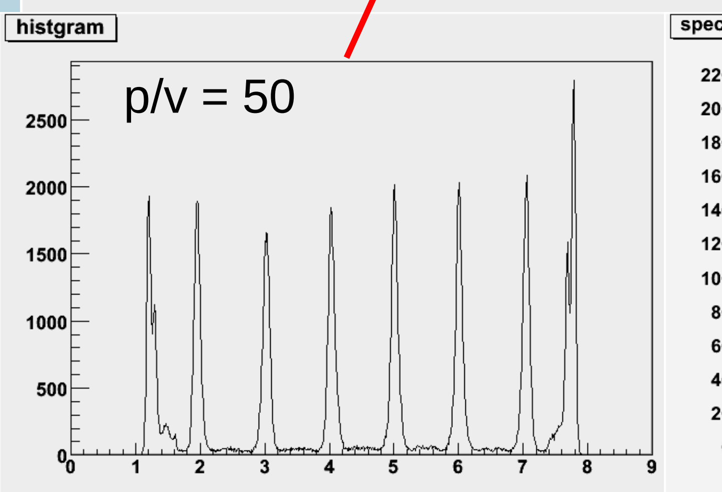
→ **PMT Gain~10^5**

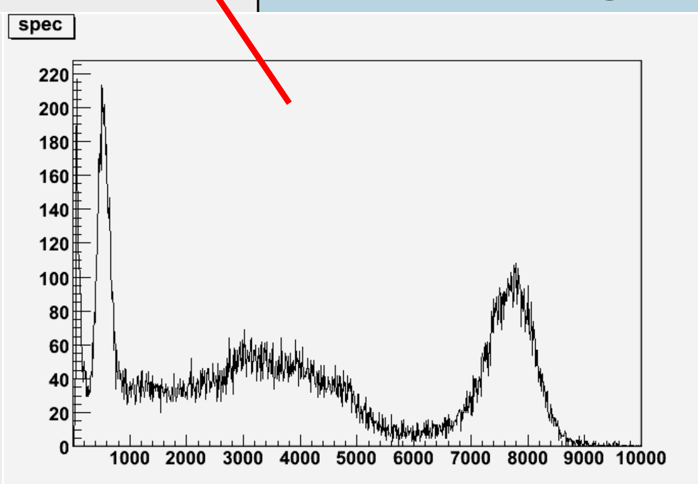
$$P_i = \text{ADC output of } i\text{th ch}$$

$$x = \frac{\sum_{i=1}^{64} P_i(i \bmod 8)}{\sum_{i=1}^{64} P_i}$$

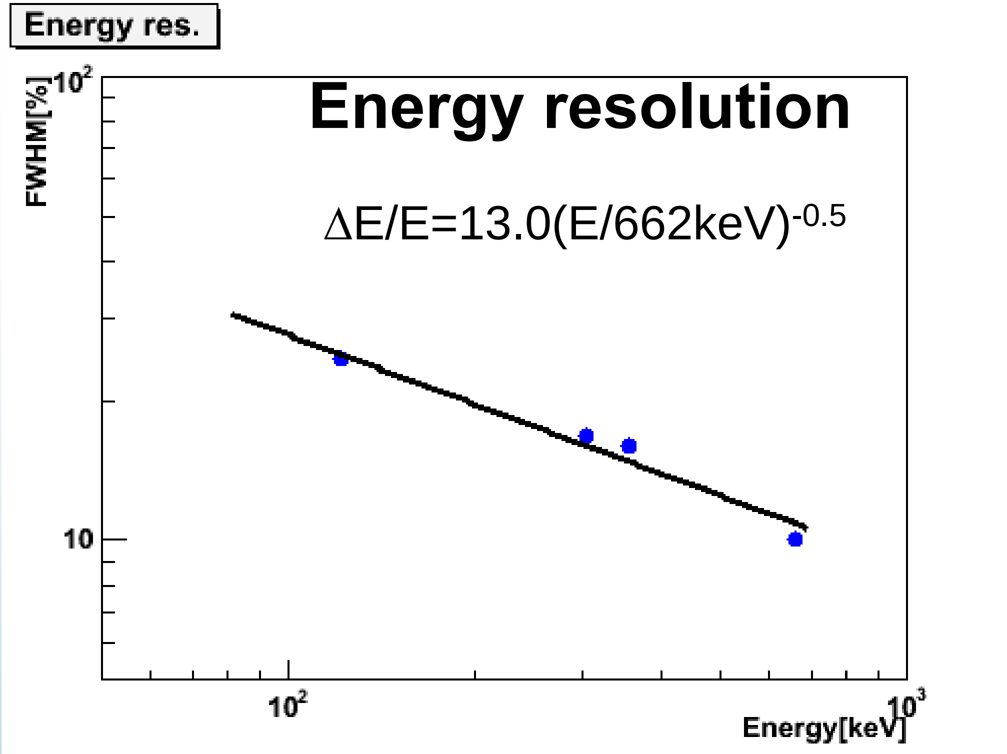
$$y = \frac{\sum_{i=1}^{64} P_i(i \,\mathrm{div}\, 8)}{\sum_{i=1}^{64} P_i}$$

Each 64 pixel is resolved.
However, there are some split pixels.
The cause is the operation with low gain of H8500.





Energy res.(avr.): ~13%(FWHM)



Dynamic range:
100-700keV

	Power Consumption	Energy Resolution	Dynamic Range	P/V
VA	O 1.3W/64pixels	× 13.0%@662keV	× 100-700keV	50
requirements	<1.5W/64pixels	~ 11% @ 662keV	80-800keV	

The dynamic range of VA system is narrower than that of requirement.

Also, VA system has the worse energy resolution than requirement.

We improved the VA system to obtain the performance such as requirements.

Improvement

In order to achieve the motive, we made following improvements to VA readout system.

- Energy resolution
  - H8500 had to be operated with the low gain of ~ 10^5.

    → We want to get the gain of about 10^6 in H8500.
- Dynamic range
  - HeadAmp has the narrow dynamic range.

    → We want to keep the charge within the dynamic range of HeadAmp.
  - H8500 has the anodes gain variation.

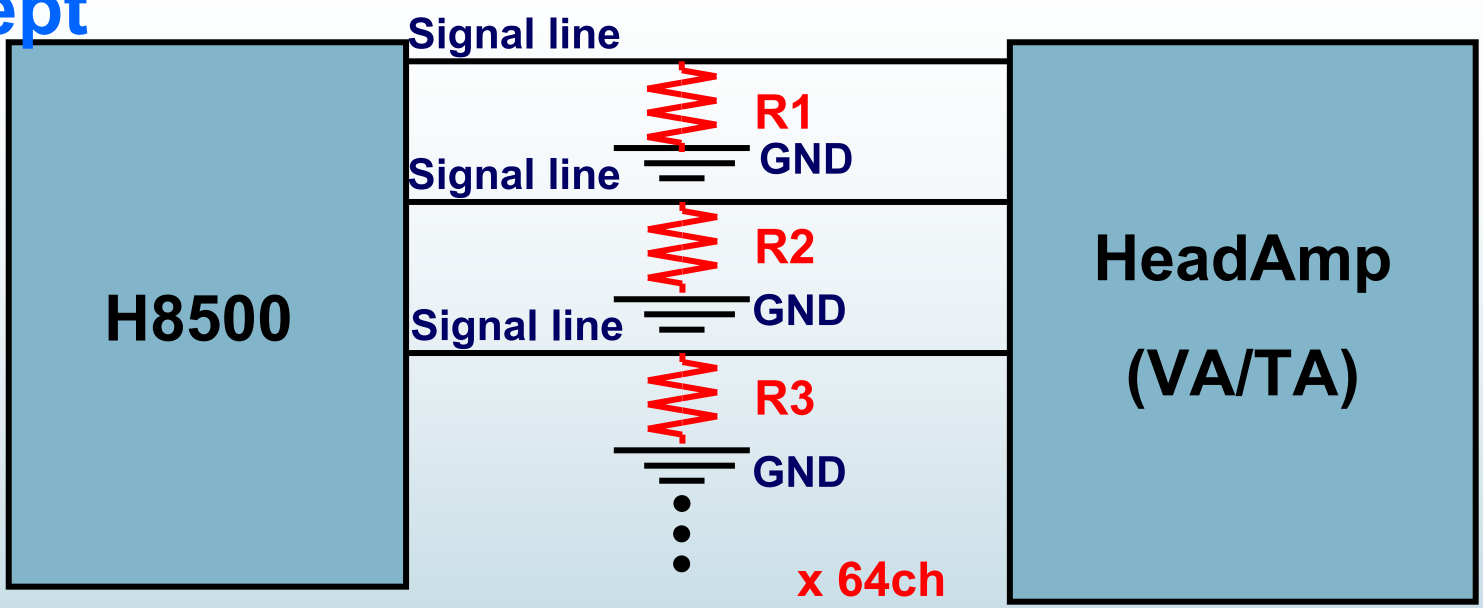
    There were some pixels which are able to observe 80keV or 800keV.

    → We want to uniform the gain variation before HeadAmp.

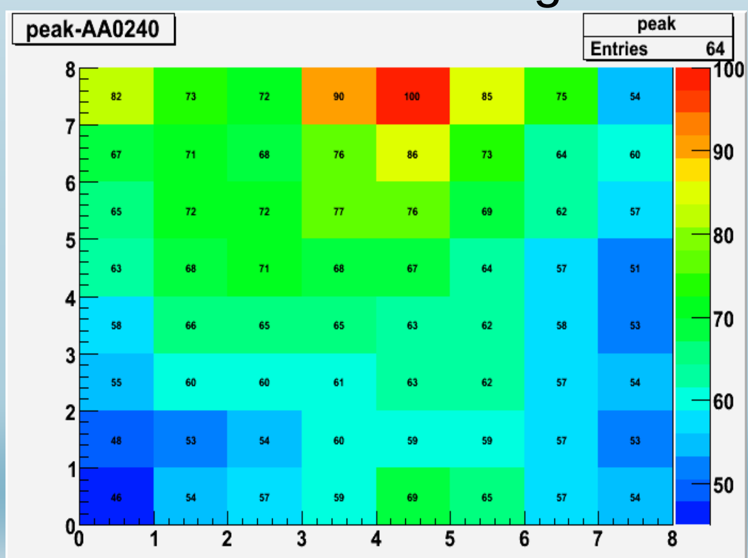
⇒ **We Developed an attenuator board which satisfies these requirements.**

Attenuator board

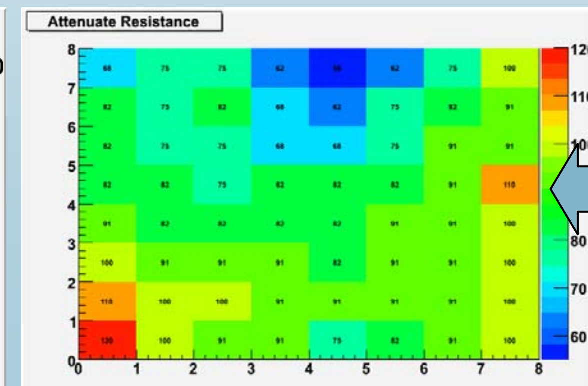
concept



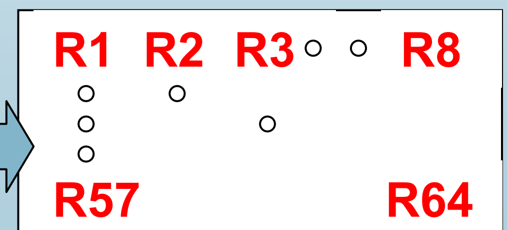
Attenuate signals to ~ 1/10 and uniform anodes gain variation



Anode gain map (S/N GA0240)



Resistance value map



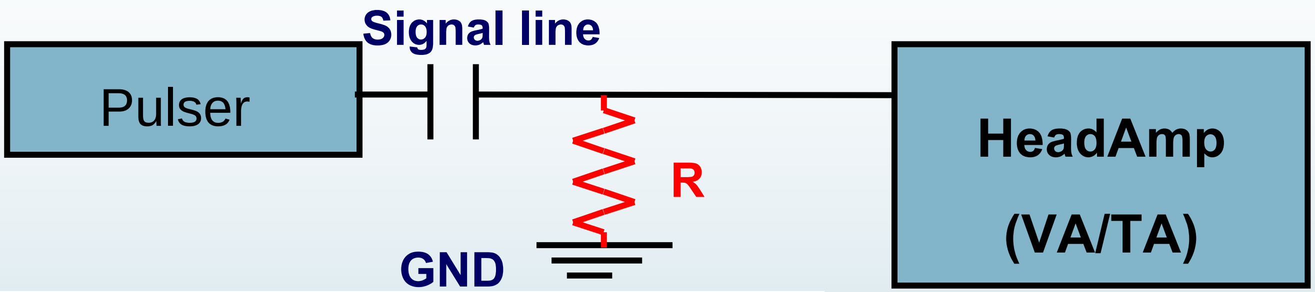
Gain ~ 10^6
min : max = 1:2.3

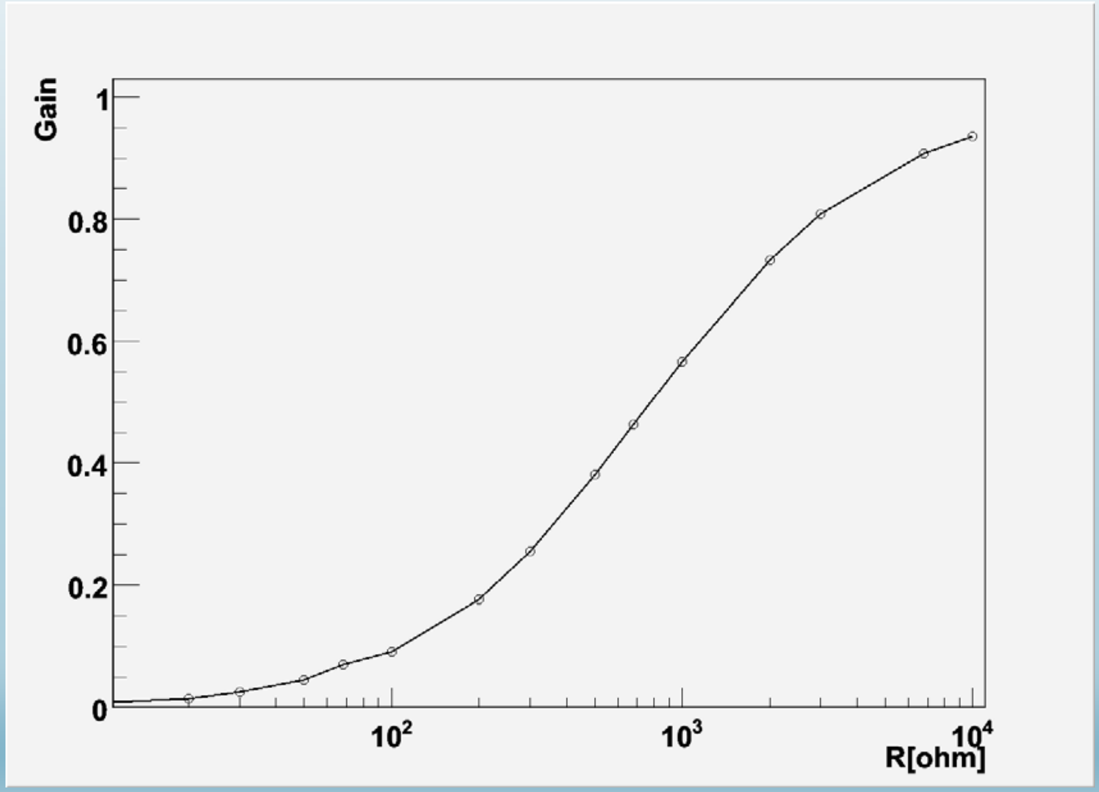
attenuate

Gain ~ 10^5
min : max ~ 1 : 1.1

Attenuation factor

We investigated the attenuation factor to some resistors with using test pulse.





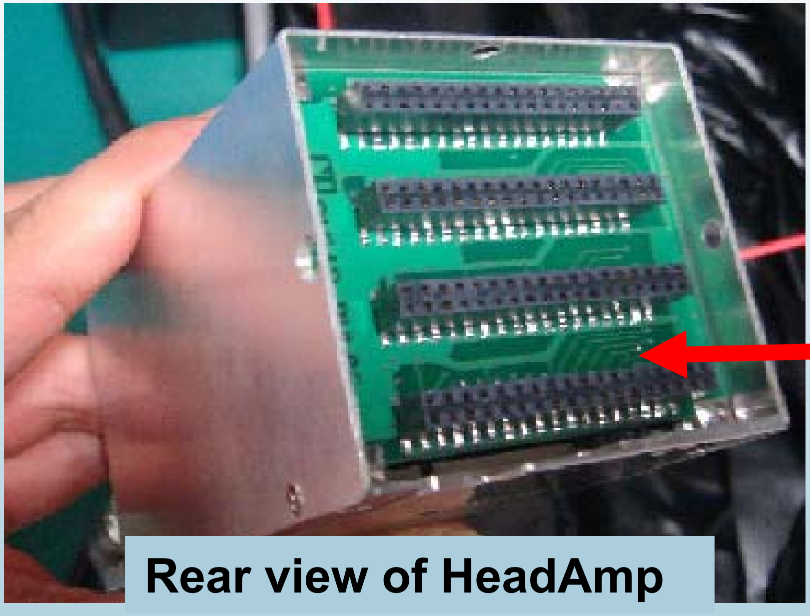
All 64ch attenuate almost the same rate.

Also, some VA chips have the same attenuating rate.

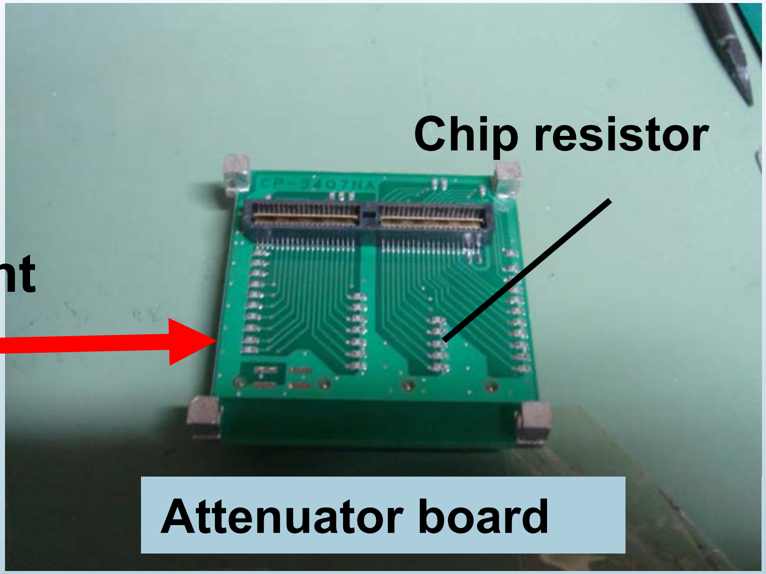
On the basis of this result, we made the following board.

When the attenuating resistor is not set, gain is 1.

Attenuator board



replacement

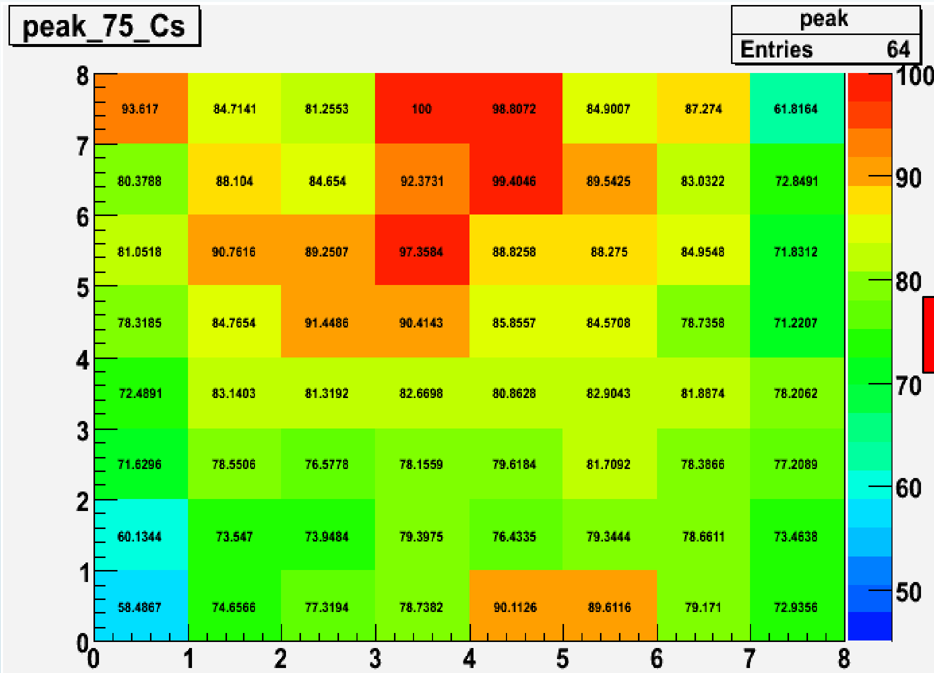


The size of HeadAmp + attenuator board + H8500 does not change because we only replace the readout board of HeadAmp by the attenuator board.

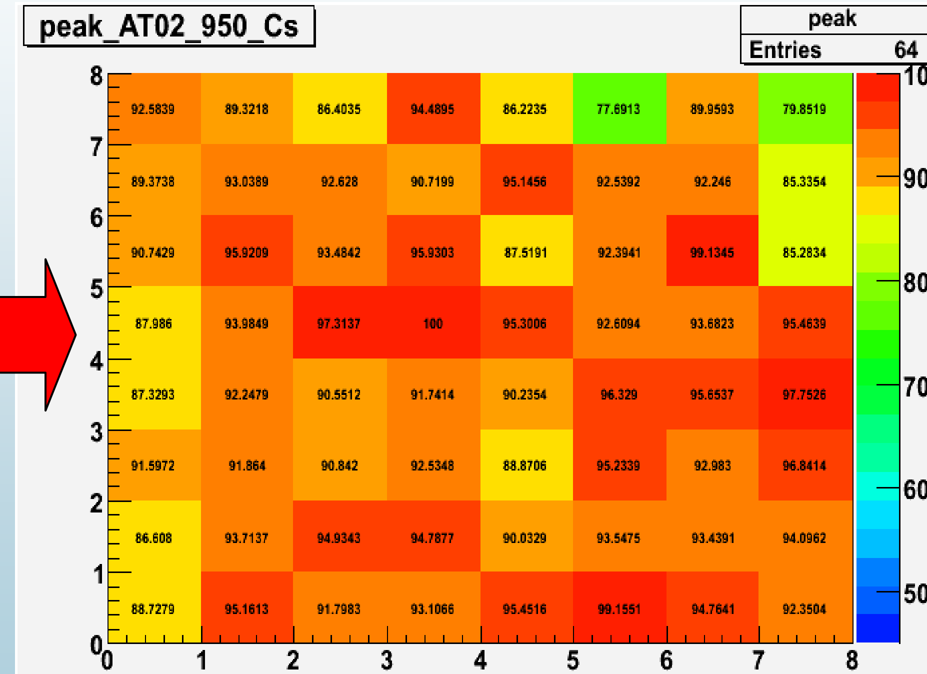
Uniformity

^{137}Cs(662keV)

Peak value of each 64ch



Not use the attenuator board



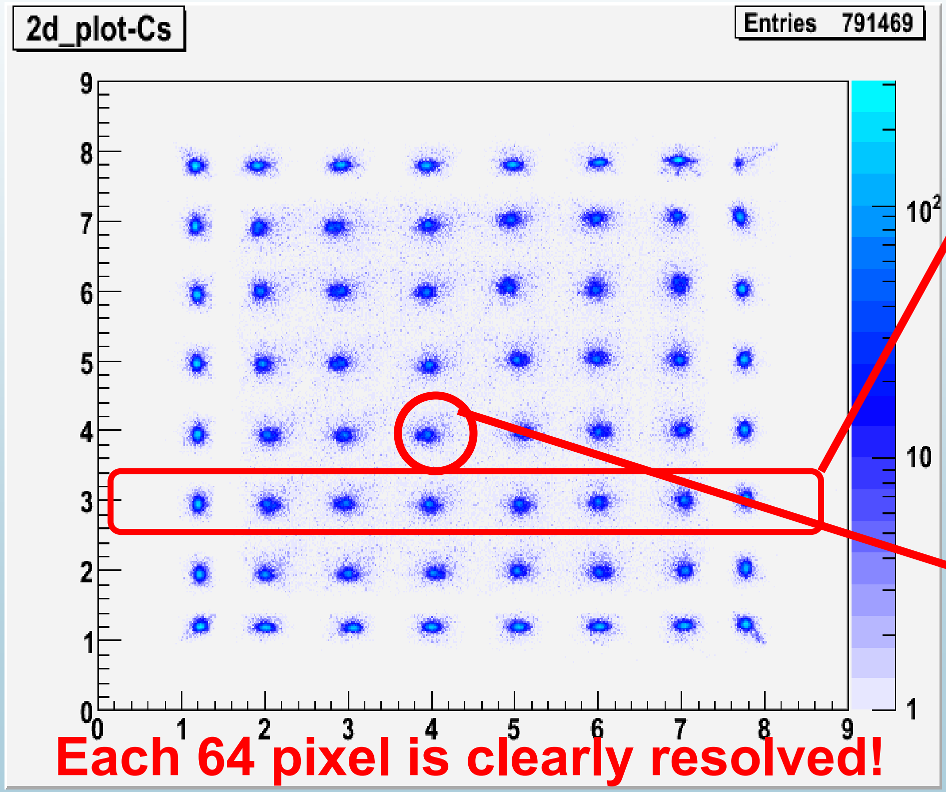
Use the attenuator board

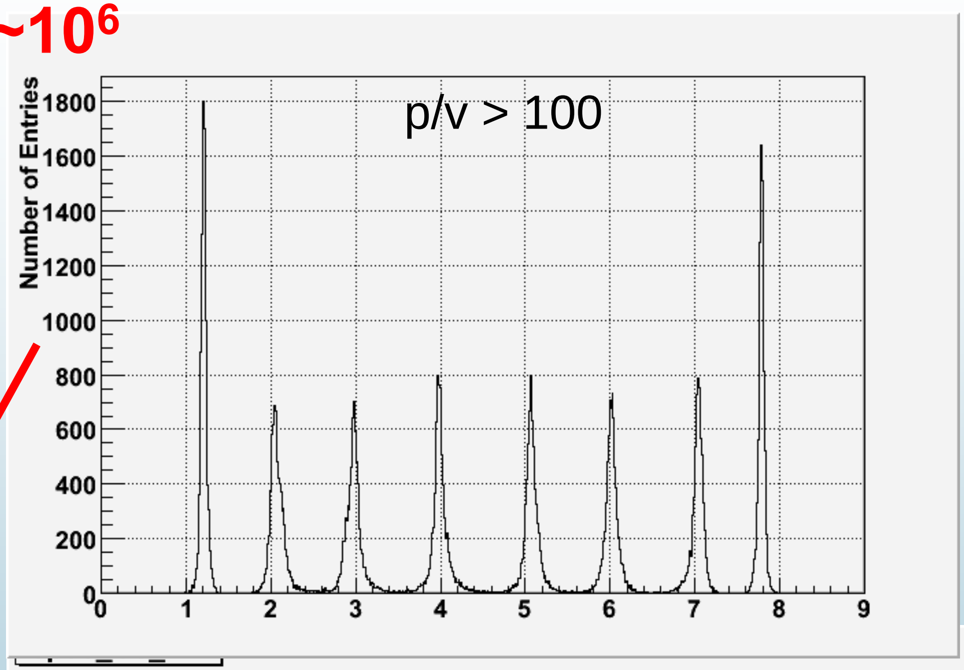
min : max 1 : 2.3 → **1 : 1.2**

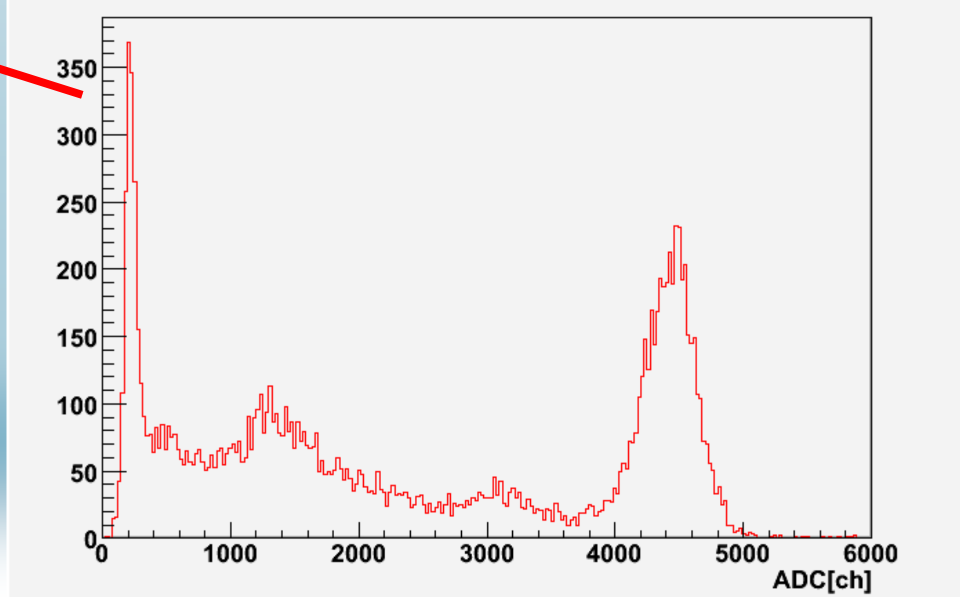
VA64ch read-out with an attenuator board

position image map **PMT Gain~10^6**

^{137}Cs(662keV)

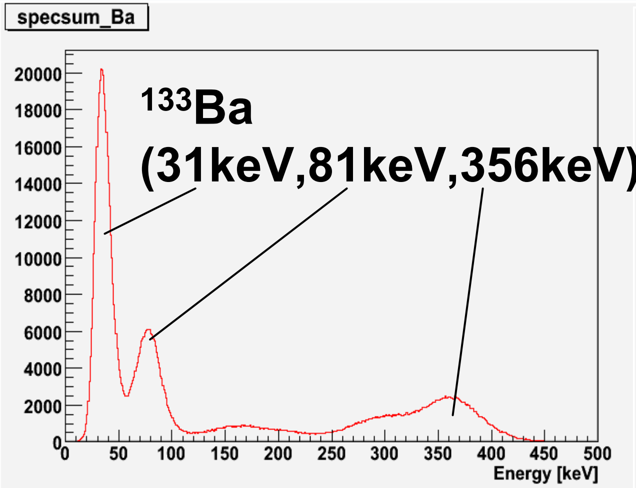


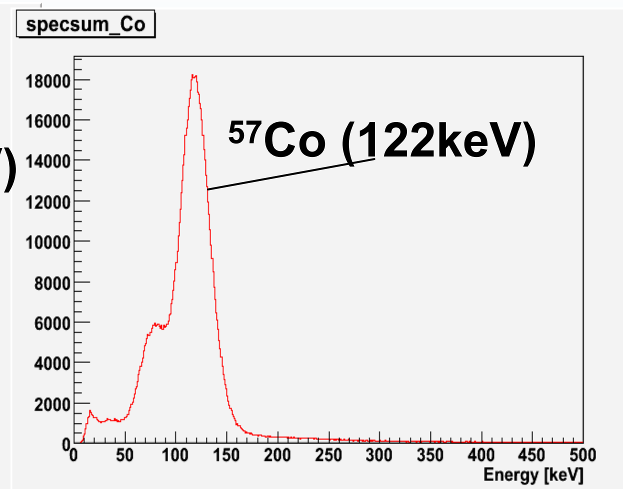


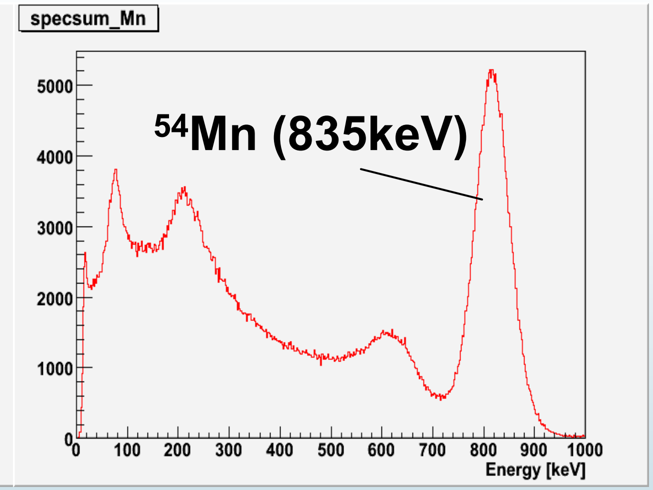


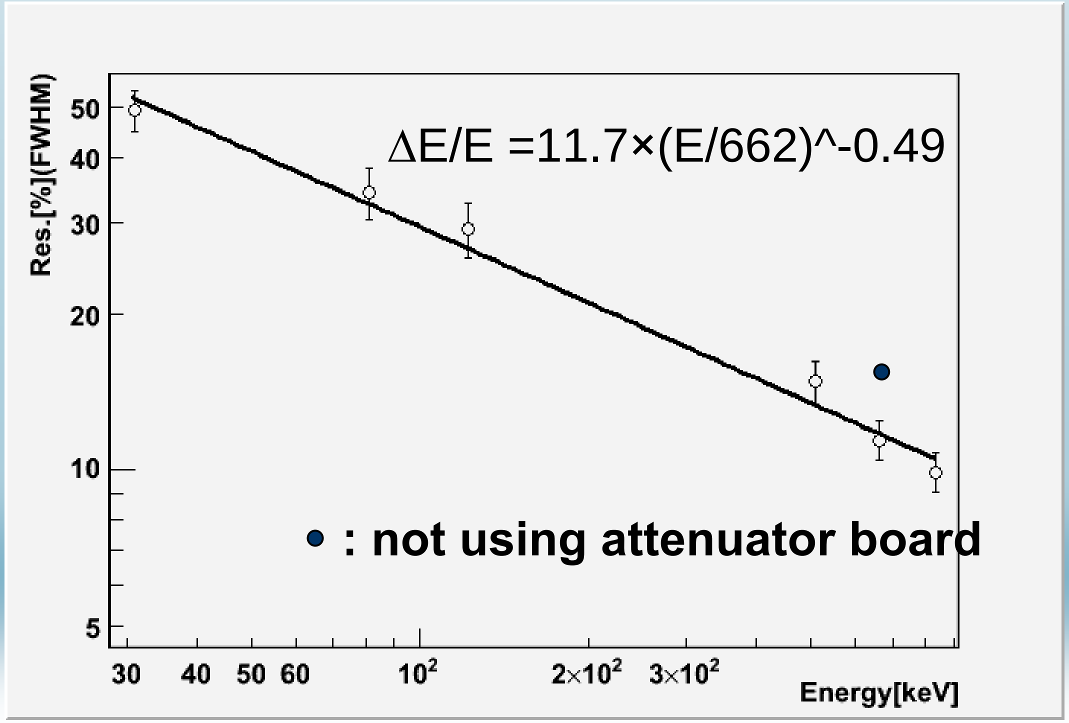
Energy res.(avr.): ~11.7%(FWHM)

spectra









Dynamic Range: 100-700keV

Not using attenuator board

Dynamic Range: 30-900keV

Summary and Future work

Summary

MeV gamma-ray imaging detector

We have developed the MeV gamma-ray imaging detector with using Compton scattering for the balloon experiment, SMILE.

Scintillation camera is the absorber of scattered gamma-ray.

SMILE-1 has been successful.

For the balloon experiment, SMILE-2, we need the readout system of scintillation camera with low power consumption.

Readout system of Scintillation camera

We adopted the system with ASIC and attenuator board we developed.

	Power Consumption	Energy Resolution	Dynamic Range	P/V
not using the boar	O 1.3W/64pixels	× 13.0%@662keV	× 100-700keV	50
using the board	O 1.3W/64pixels	O 11.7%@662keV	O 30-900keV	>100

As the result, those satisfy our requirements.

Future work

- Investigation of rate dependence of HeadAmp
- Improvement of position resolution

  We will advance developing 3mm pitch GSO scintillation camera.
- Enlargement of the camera for the balloon experiment

Thank you !