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

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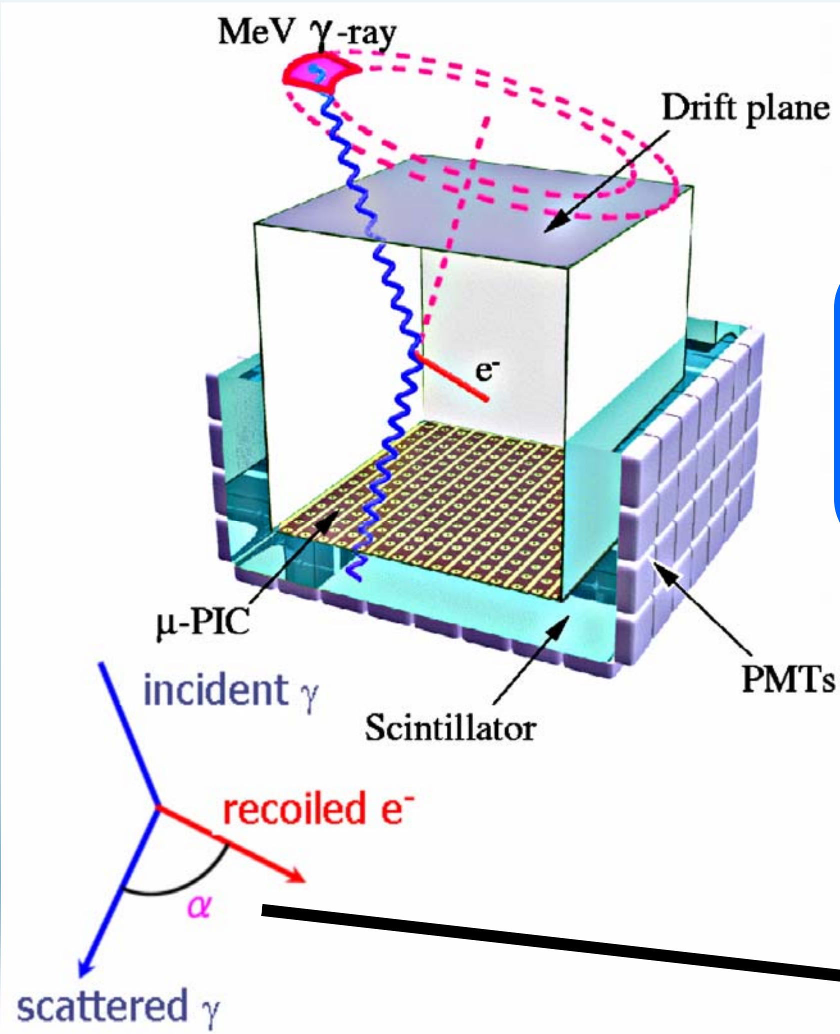
Gamma-ray Imaging Detector

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

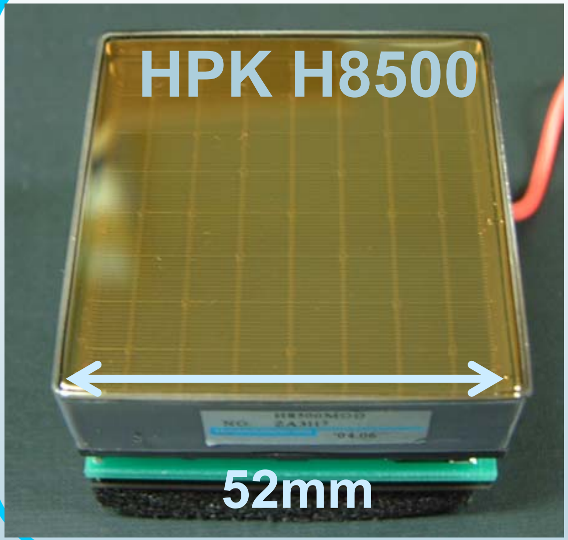
Reconstruct incident gamma-ray event by event

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

Scintillation Camera

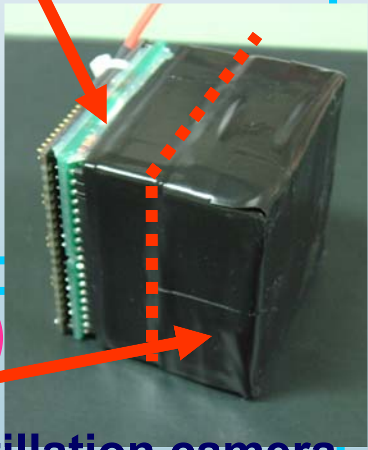
The camera consists of PSPMT and PSA (Pixel Scintillator Array).

← Considering *large sensitive area and *good position resolution

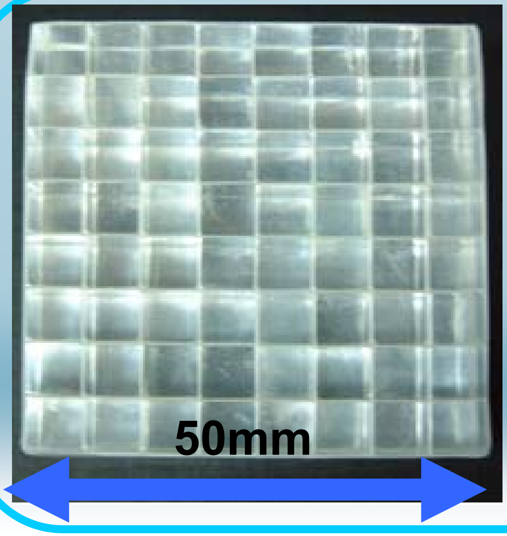


FlatPanel PMT H8500 (HPK)

- 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



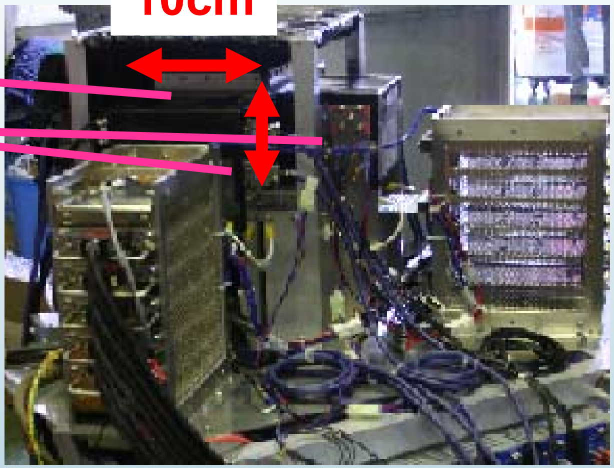
PSA(Pixel Scintillator Array)

- 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



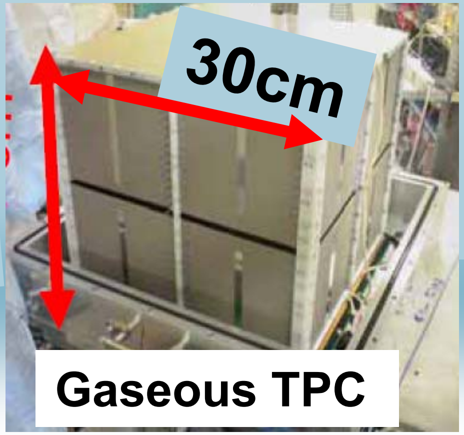
- Operation test of our Compton Camera @ 35km
- Diffuse cosmic and atmospheric gamma-ray measurement

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**

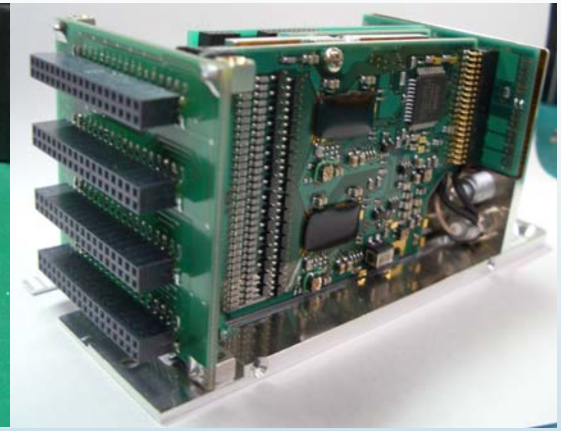
In order to satisfy these requirements…

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

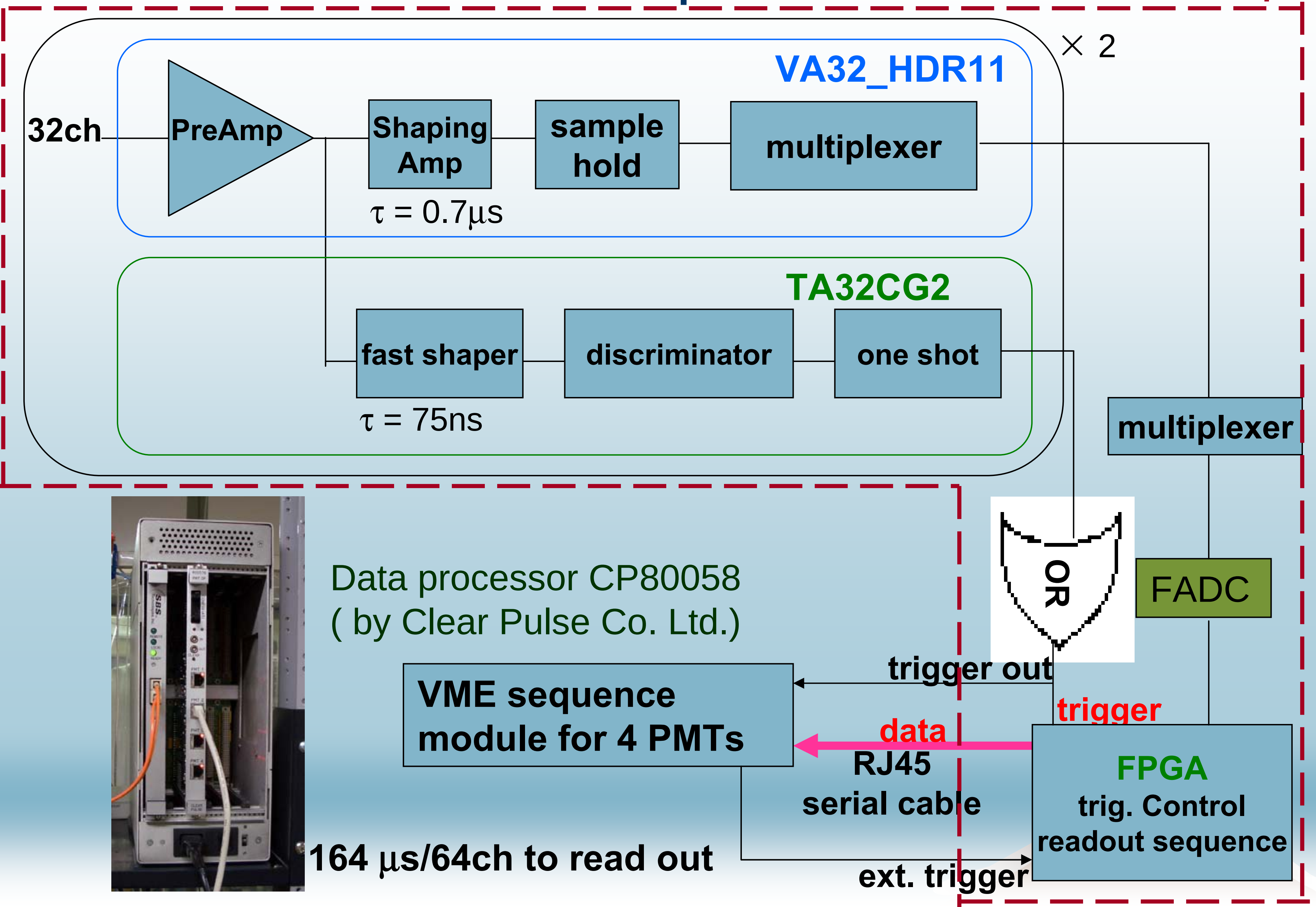
We should operate PMT with low gain of ~ 10^5.

TA32CG2

Fast shaper (peaking time 75 ns)
discriminator

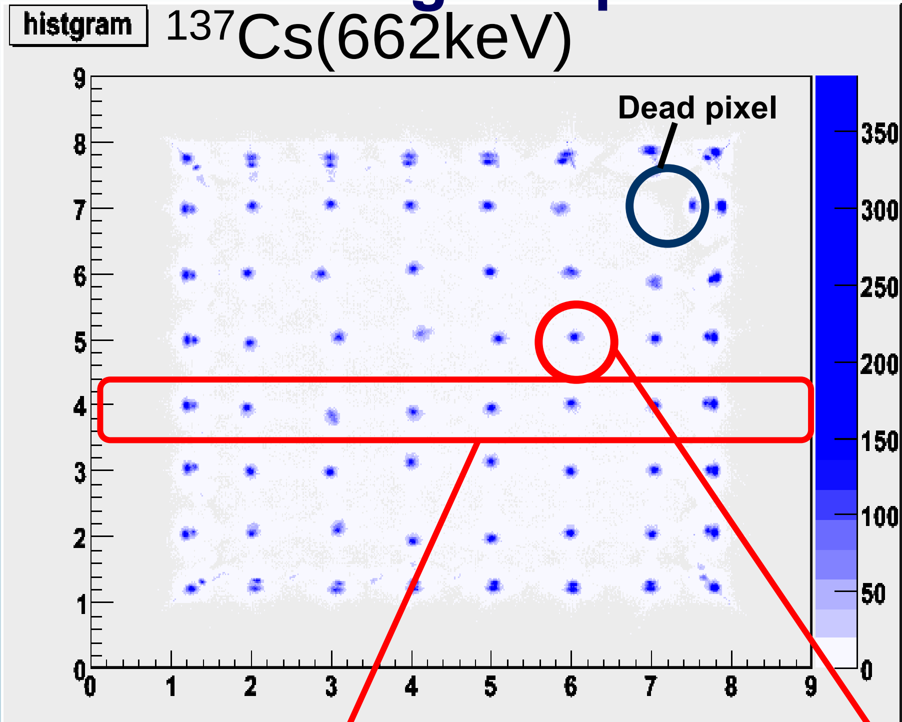
Power Consumption:
~1.3W/64pixels

Data Acquisition



VA 64ch read-out

Position image map



Input dynamic range: small

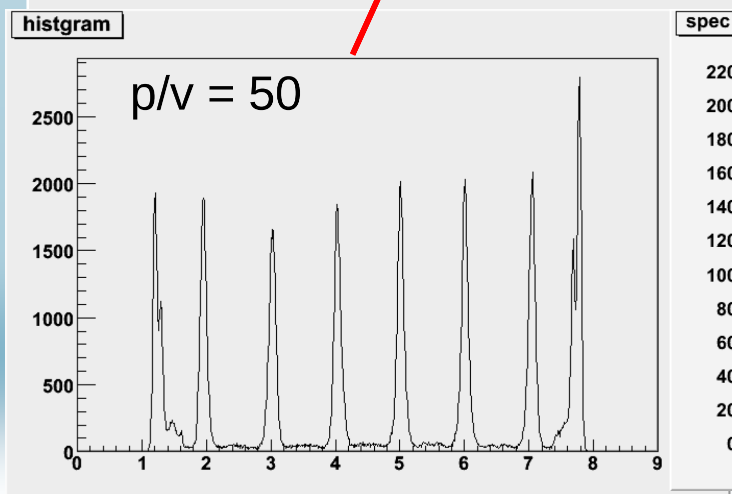
→ **PMT Gain~10^5**

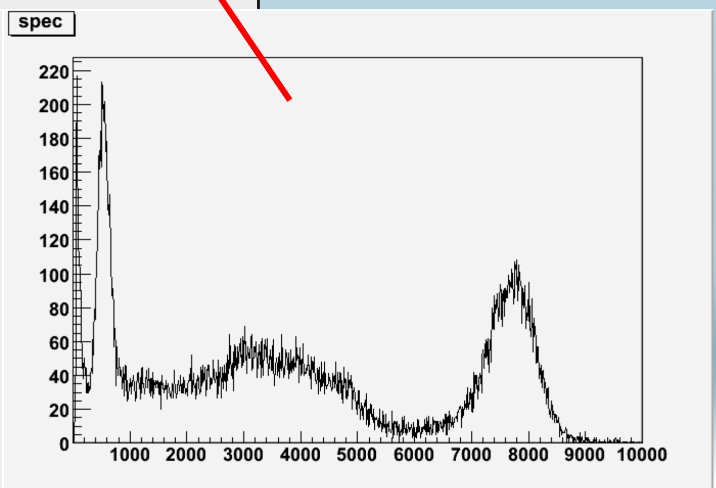
$$P_i = \text{ADC output of } i\text{th ch}$$

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

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

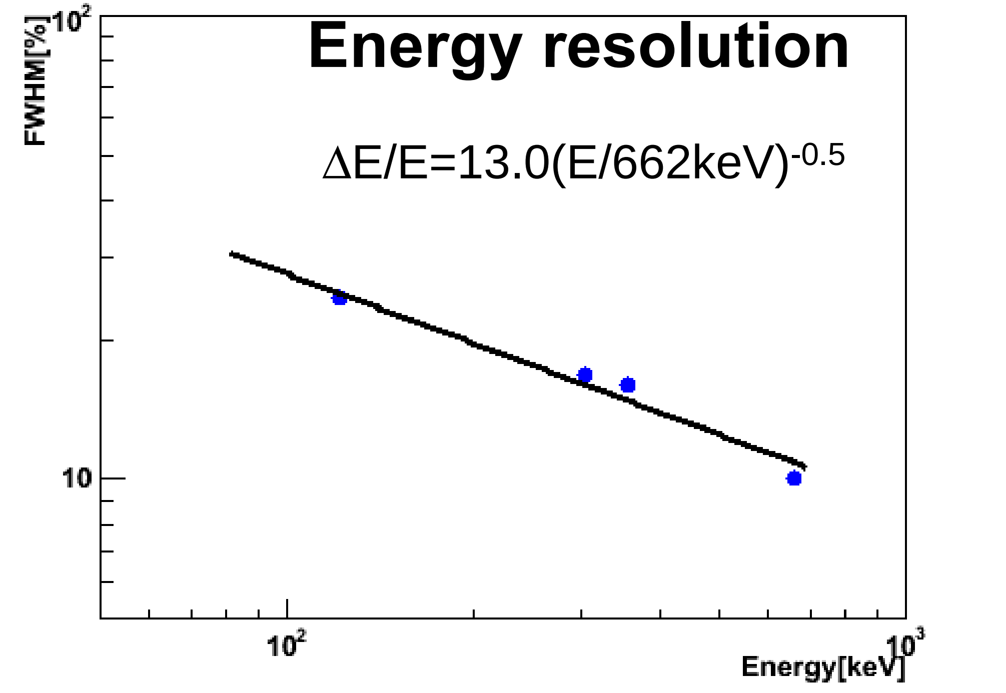
Each 64 pixel is resolved.
However, there are some split pixels.
The cause is the operation with low gain of H8500.





Energy res.(avr.): ～13%(FWHM)

Energy res.



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

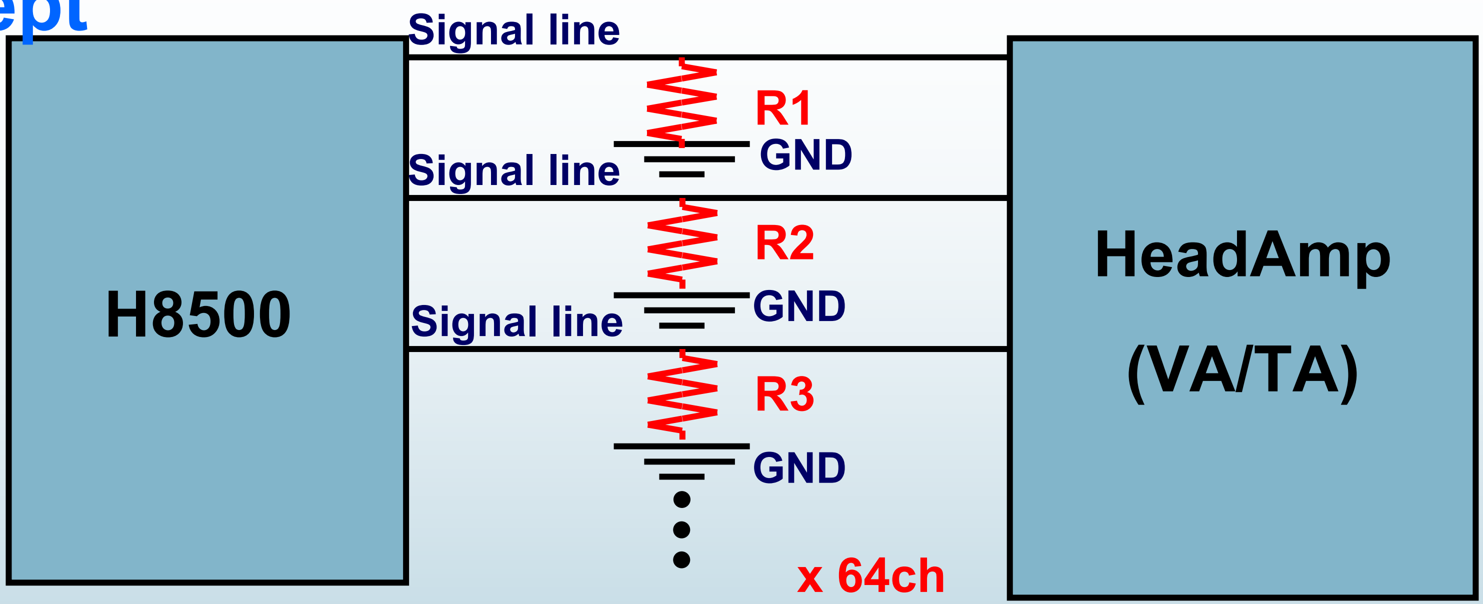
In order to achieve the motive, we made following improvements to VA readout system.

- 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.

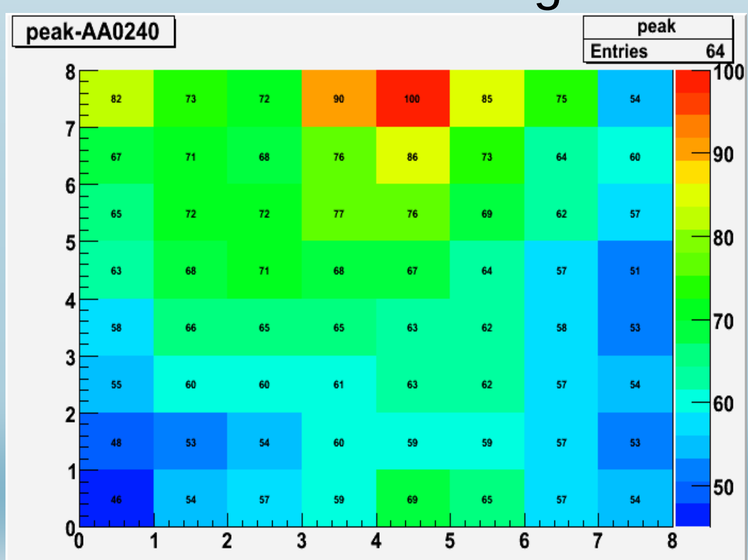
⇒ **We Developed an attenuator board which satisfies these requirements.**

Attenuator board

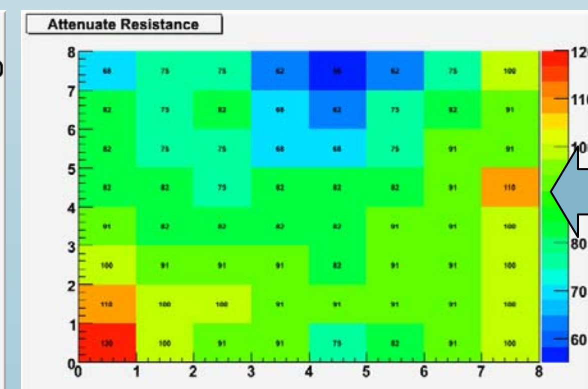
concept



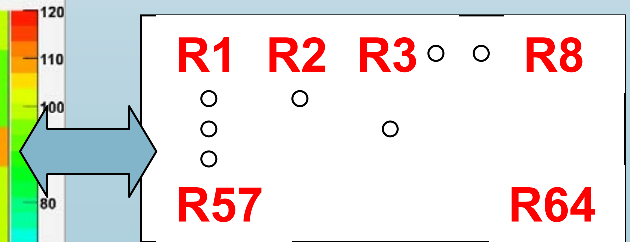
Attenuate signals to ~ 1/10 and uniform anodes gain variation



Anode gain map (S/N GA0240)

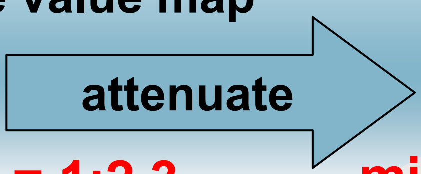


Resistance value map



Gain ~ 10^6

min : max = 1:2.3

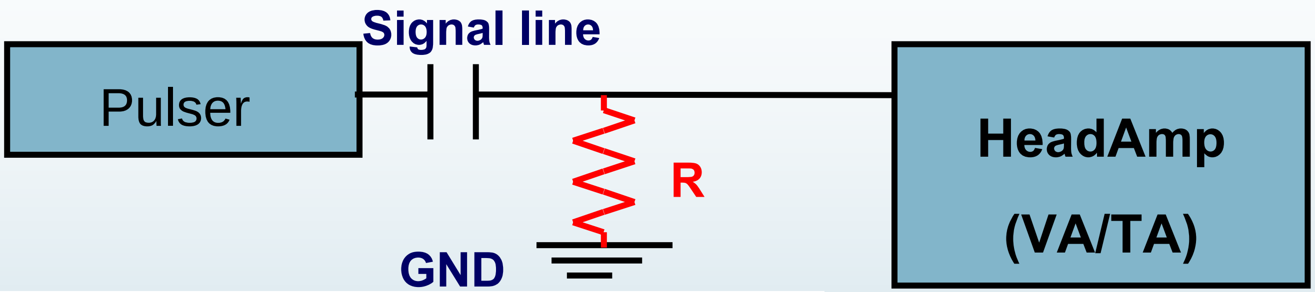


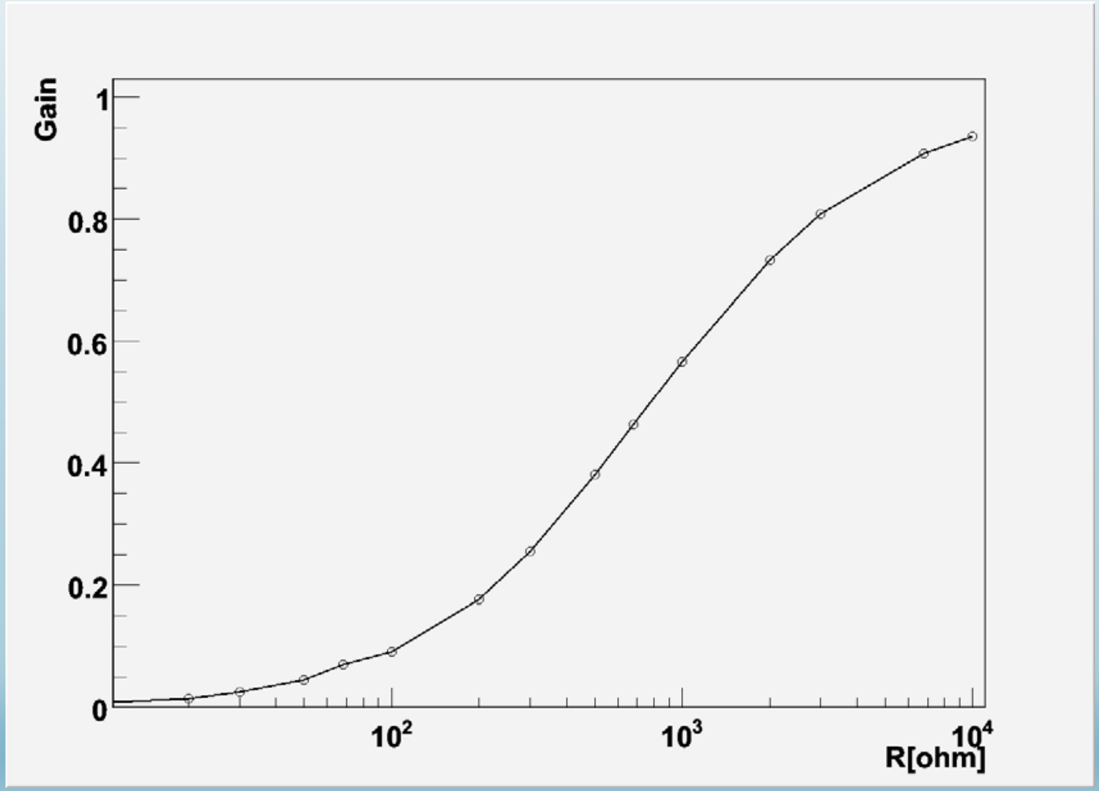
Gain ~ 10^5

min : max ~ 1 : 1.1

Attenuation factor

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





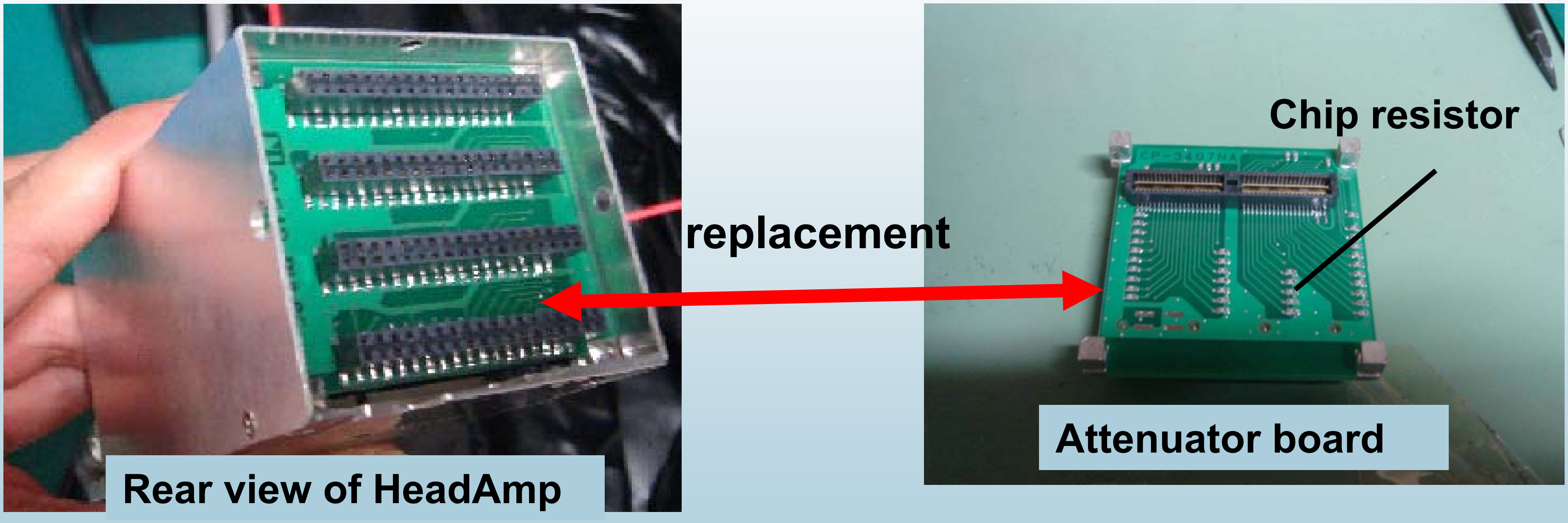
All 64ch attenuate almost the same rate.

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

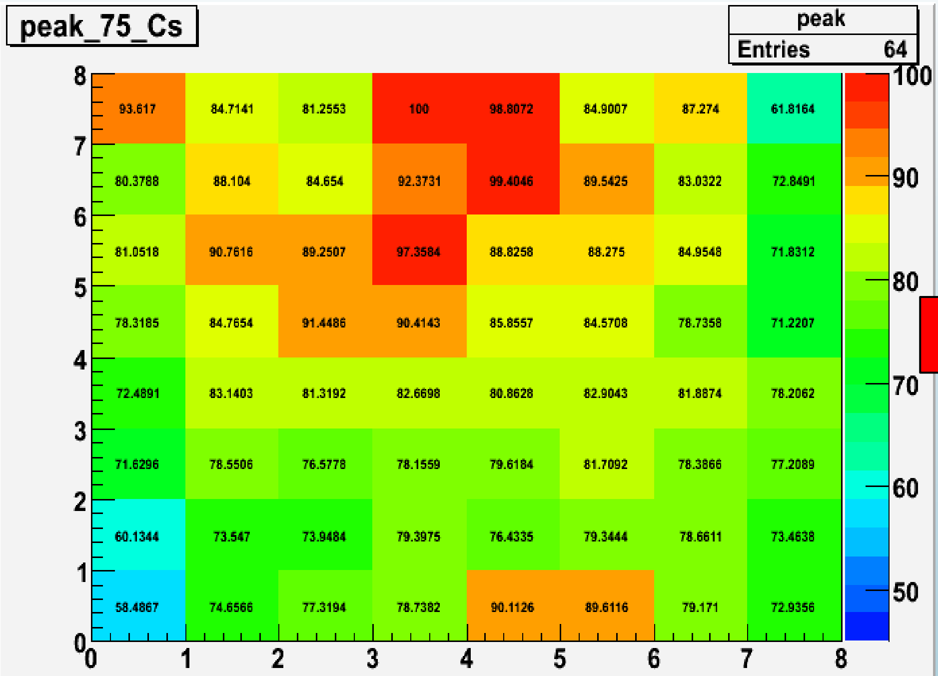


The size of HeadAmp + attenuator board + H8500 does not change because we only replace the readout board of HeadAmp by the attenuator board.

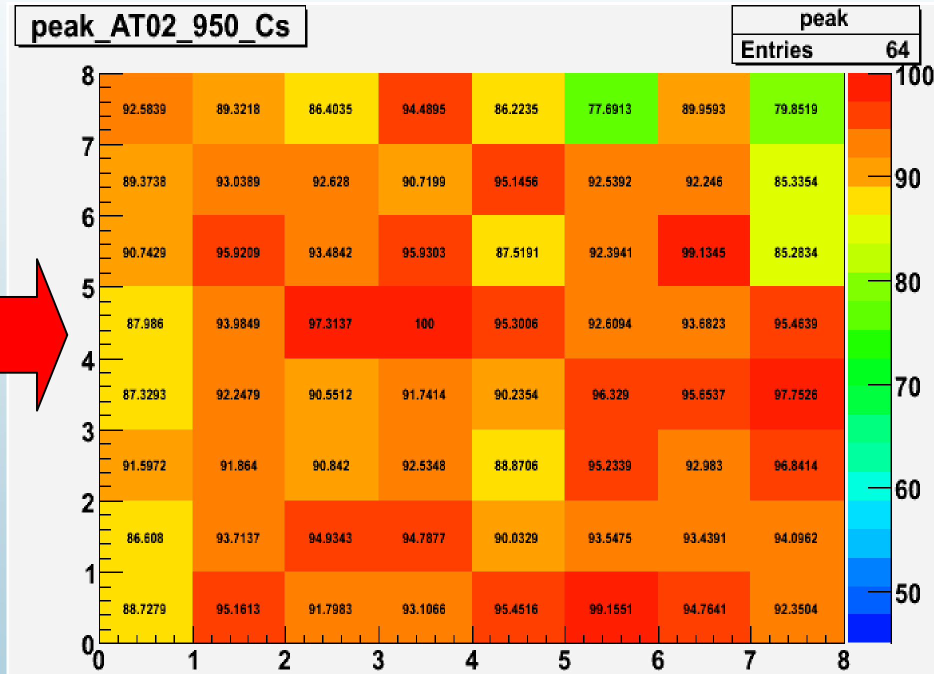
Uniformity

^{137}Cs(662keV)

Peak value of each 64ch



Not use the attenuator board



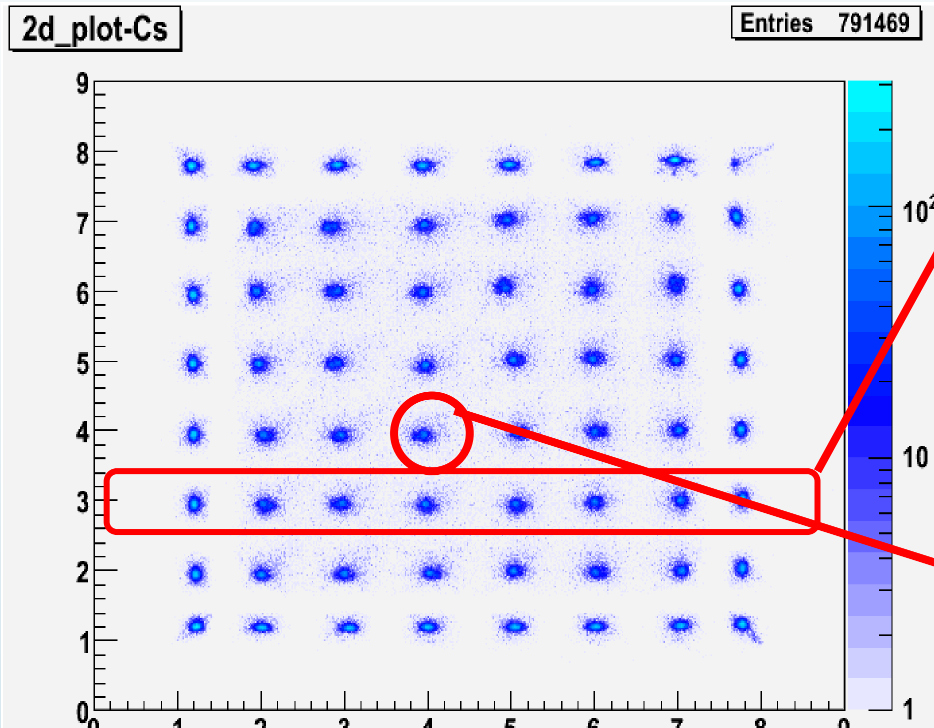
Use the attenuator board

min : max 1 : 2.3 → **1 : 1.2**

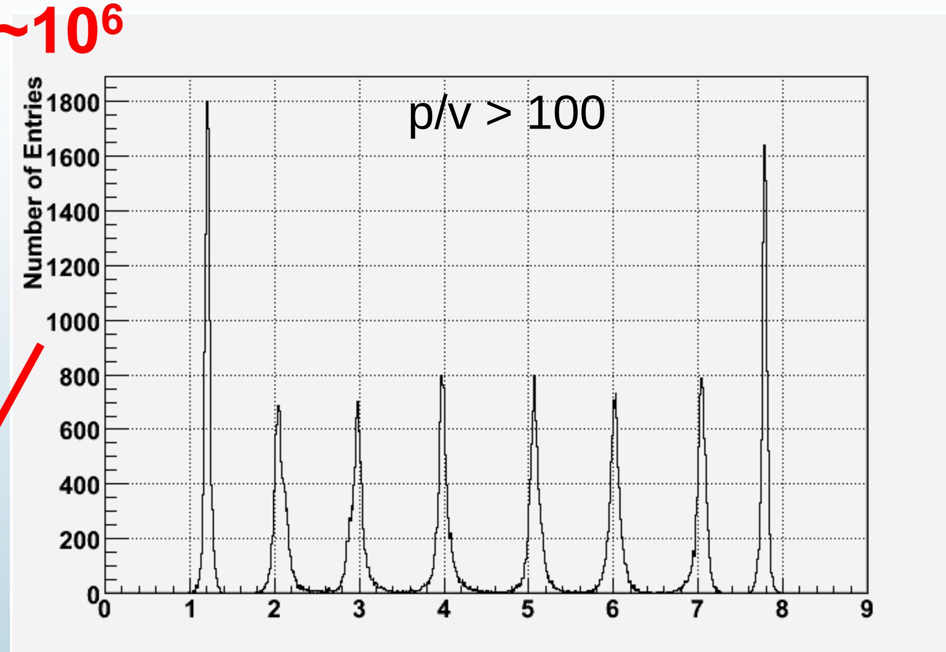
VA64ch read-out with an attenuator board

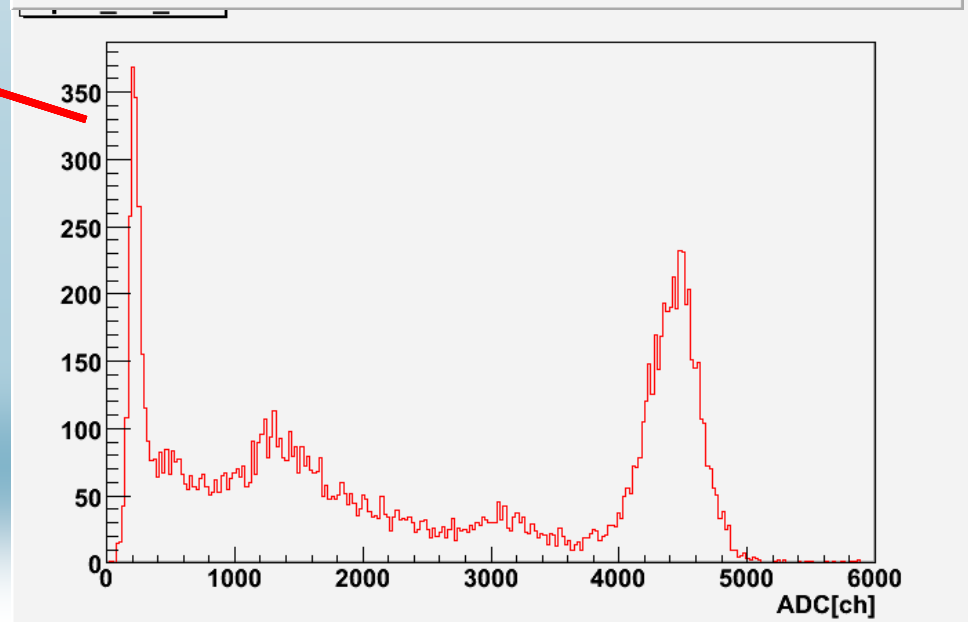
position image map **PMT Gain~10^6**

^{137}Cs(662keV)



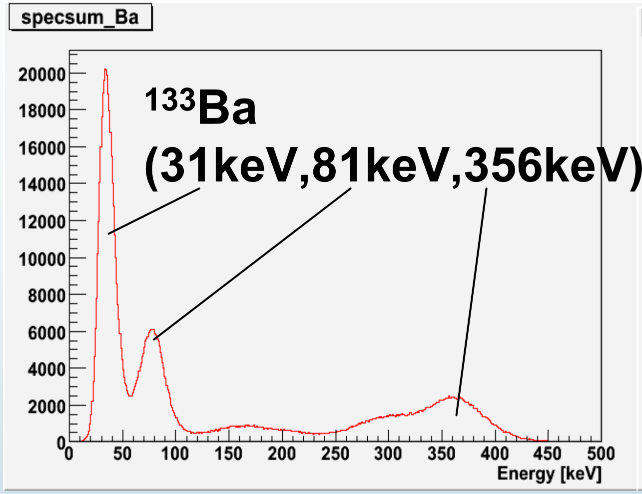
Each 64 pixel is clearly resolved!

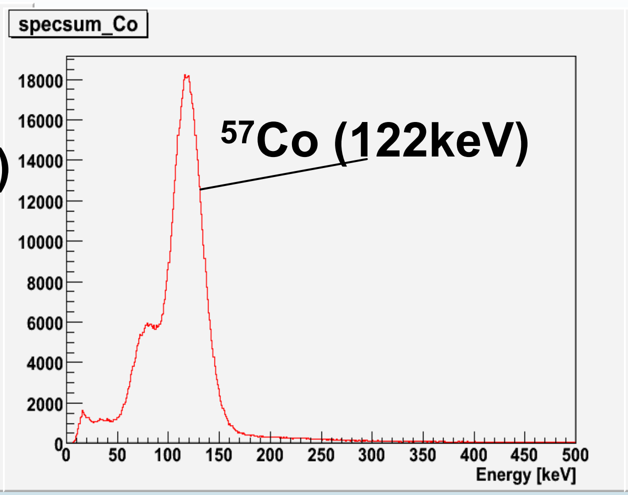


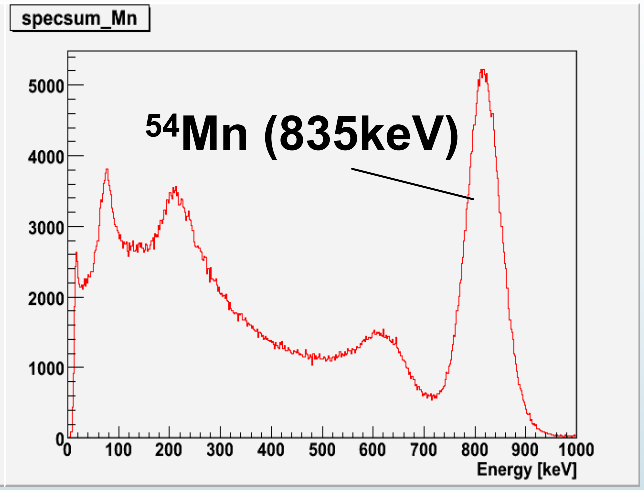


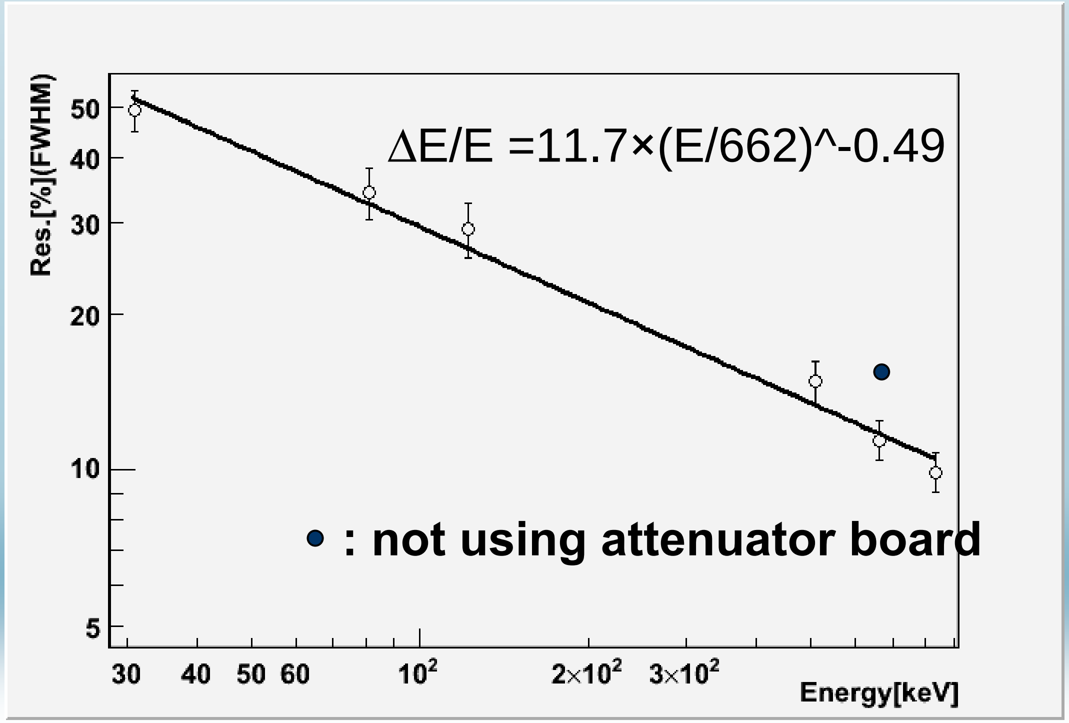
Energy res.(avr.):
～11.7%(FWHM)

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.

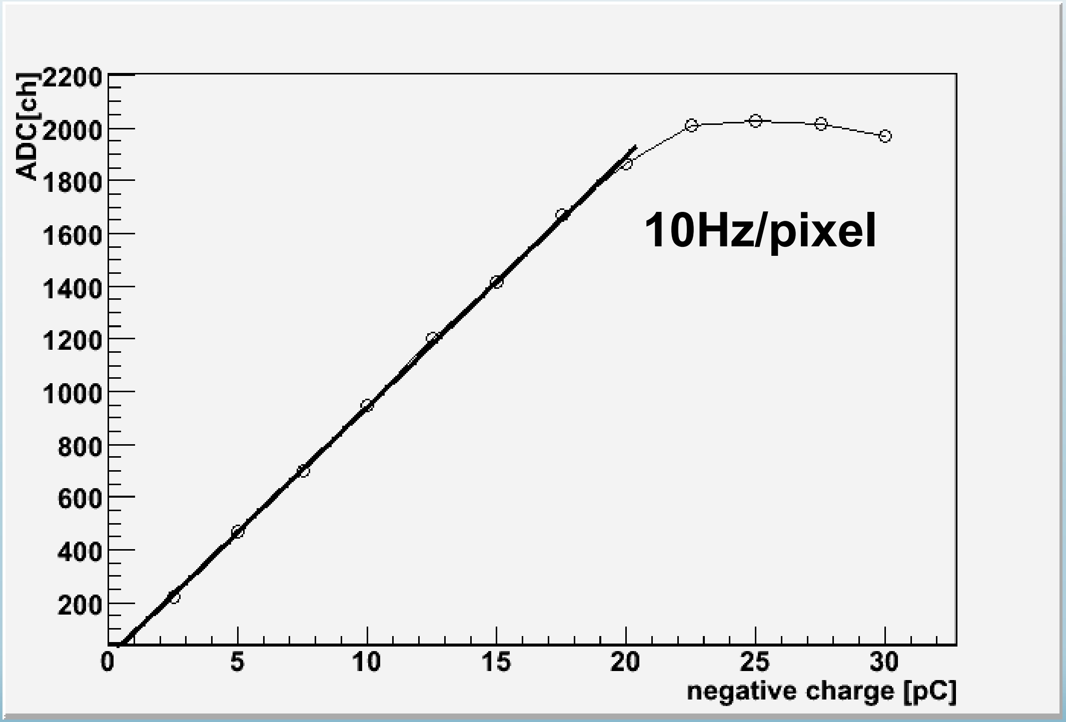
- Enlargement of the camera for the balloon experiment

Thank you !

Linearity

We tested the linearity of VA.

- Input some test charge into HeadAmp



Effectively, linearity is kept to ~-20pC

It is a little small to our needs.

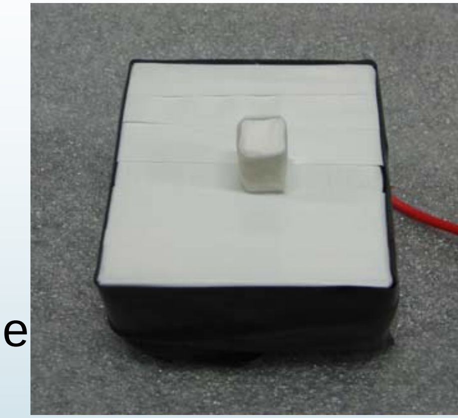
(It corresponds to the gain of 10^5 in H8500)

Now, we test the rate dependence.

The system stands up to a few kHz/all pixels.

Optical Cross talk

One GSO pixel is attached to anode 37 area by hand.
Others are masked.

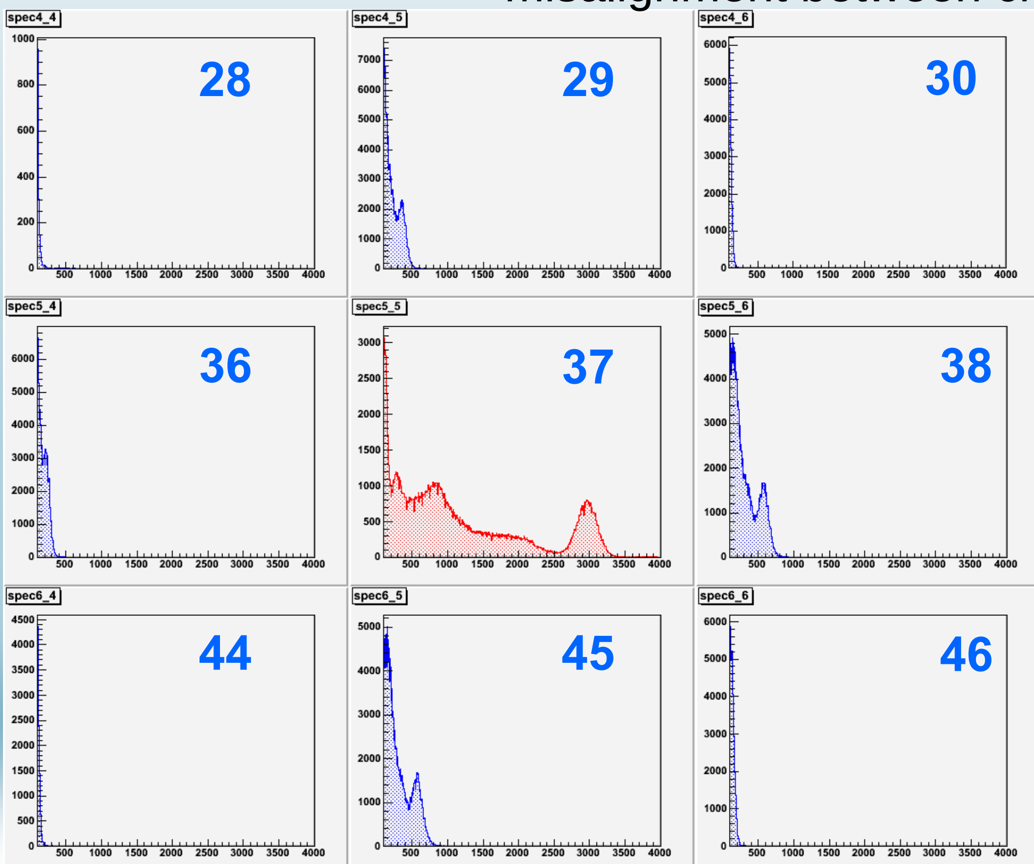


We observed the response of neighbor anodes when 662keV gamma-rays are uniformly irradiated to the array.

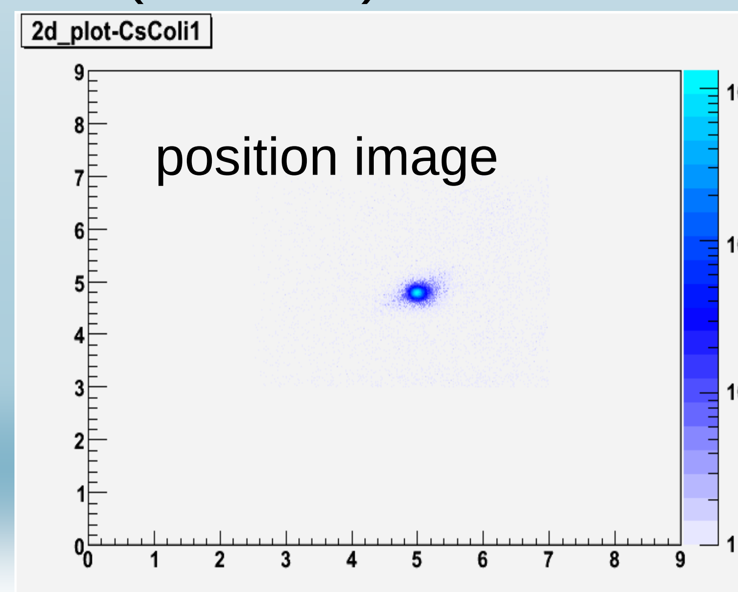
~ 40% cross talk

*1.5mm thick glass window

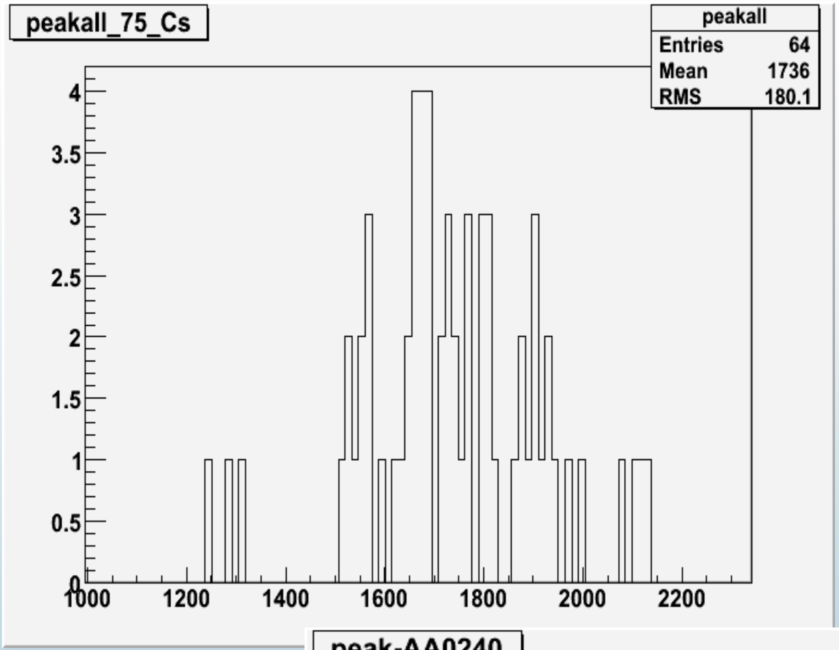
*misalignment between crystal and 1st dynode

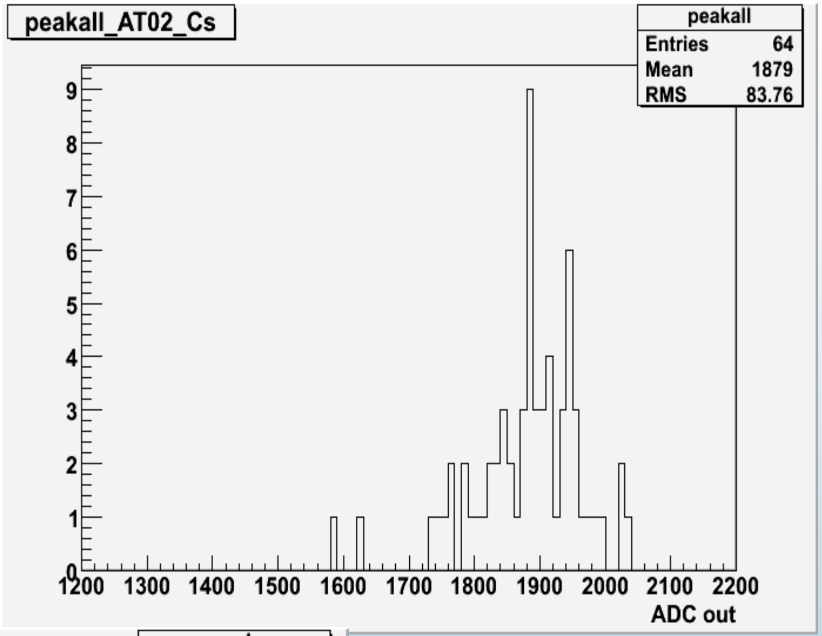


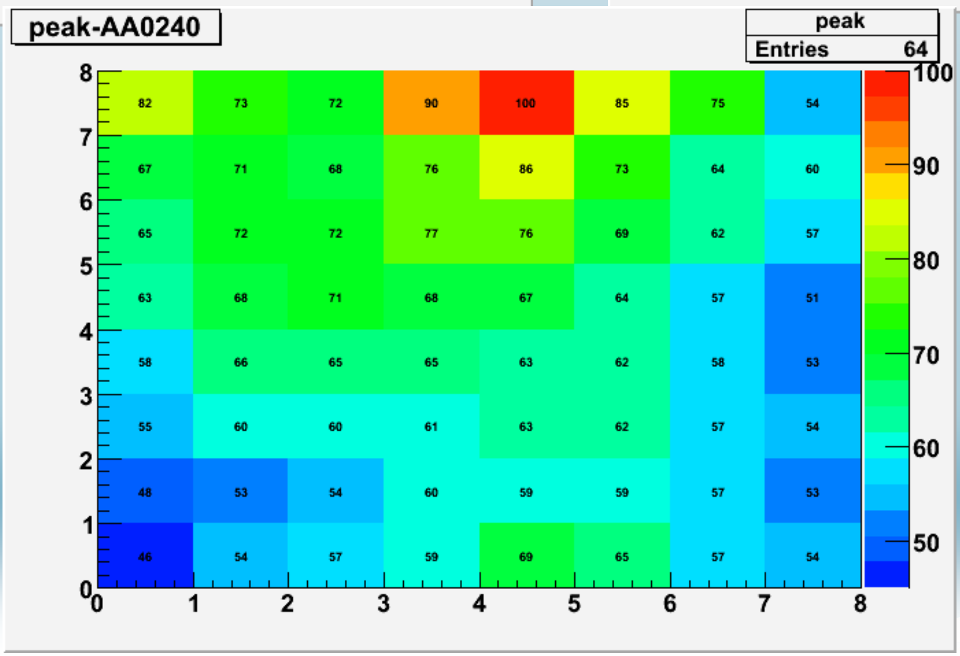
^{137}Cs(662keV)



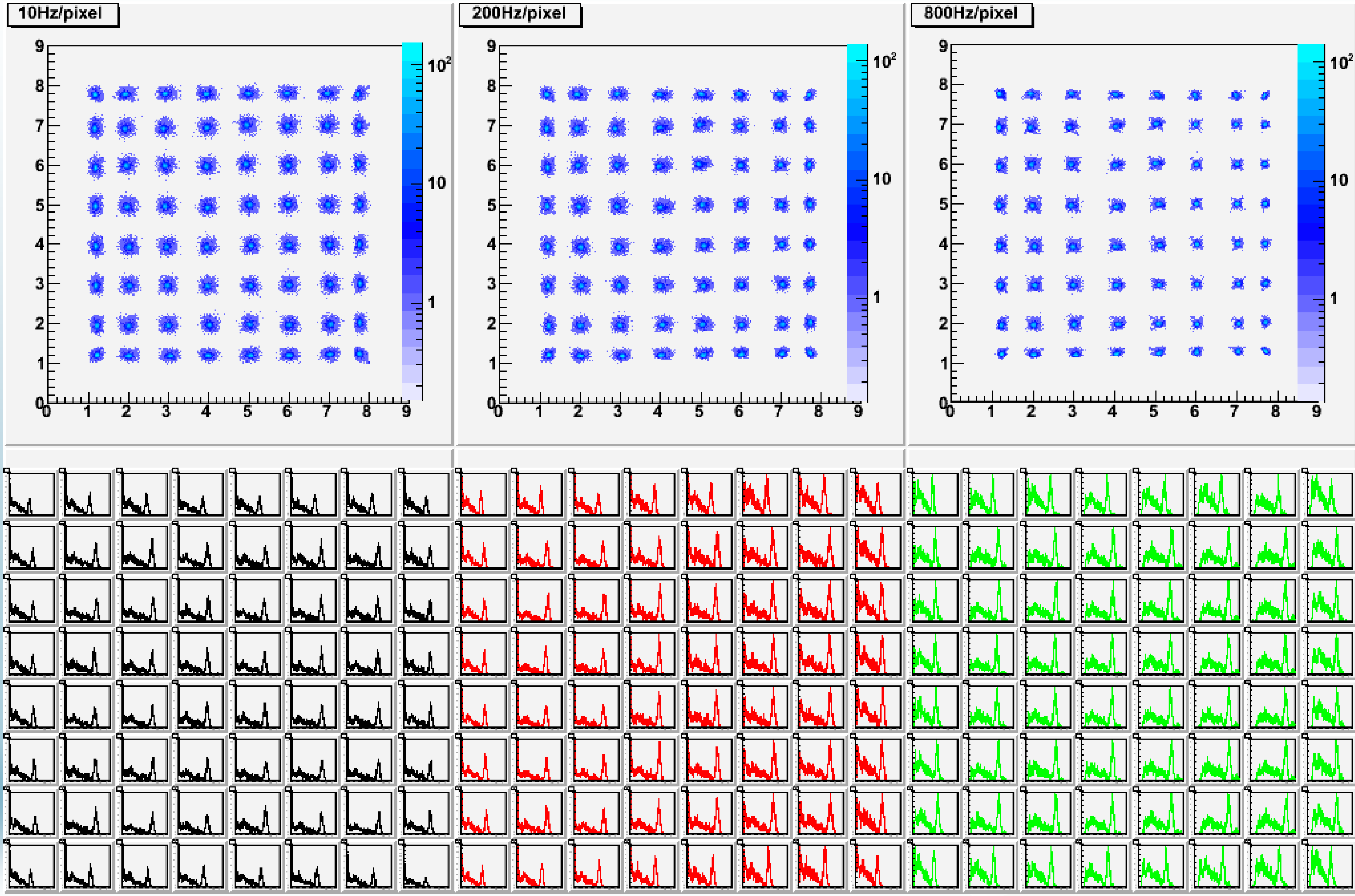
uniformity

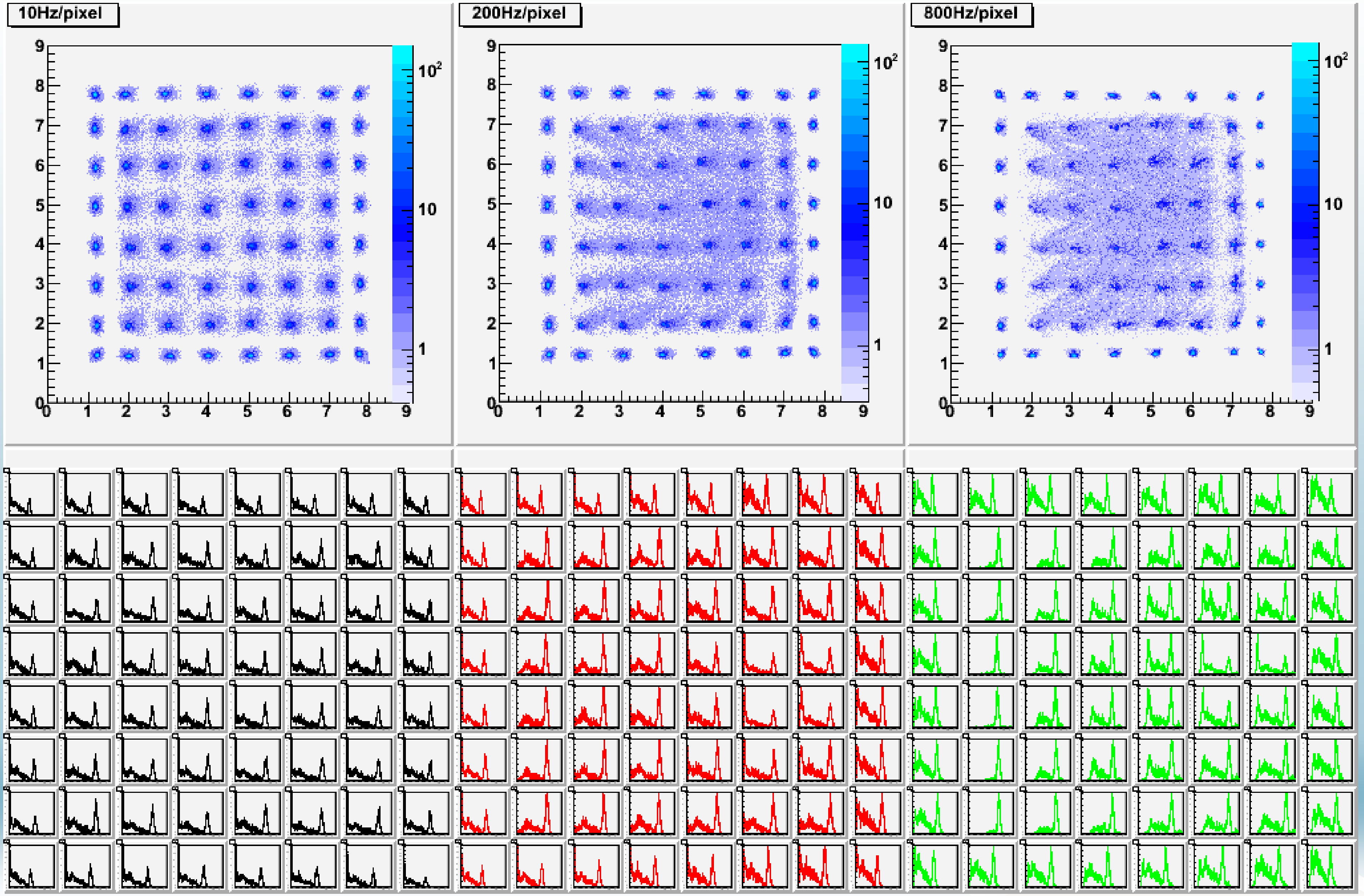

peakall_75_Cs
peakall
Entries 64
Mean 1736
RMS 180.1
0
0.5
1
1.5
2
2.5
3
3.5
4
1000
1200
1400
1600
1800
2000
2200


peakall_AT02_Cs
peakall
Entries 64
Mean 1879
RMS 83.76
0
1
2
3
4
5
6
7
8
9
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
ADC out


peak-AA0240
peak
Entries 64
82 73 72 90 100 85 75 54
67 71 68 76 86 73 64 60
65 72 72 77 76 69 62 57
63 68 71 68 67 64 57 51
58 66 65 65 63 62 58 53
55 60 60 61 63 62 57 54
48 53 54 60 59 59 57 53
46 54 57 59 69 65 57 54
0
1
2
3
4
5
6
7
8
50
60
70
80
90
100

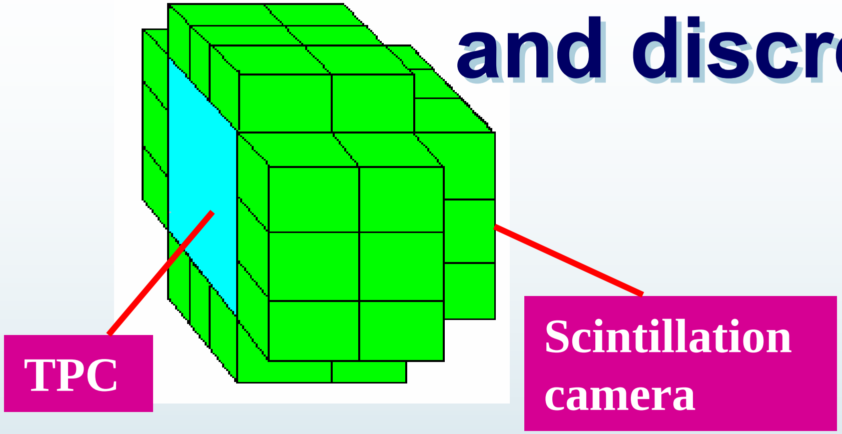
10Hz(7Hz) 200Hz(70Hz) 800Hz(100Hz)





10Hz/pixel
200Hz/pixel
800Hz/pixel

Readout system with chained resistor and discrete parts



For SMILE-1

The TPC needs to be surrounded with the 33 scintillation cameras in order to increase the efficiency.

As the readout system of scintillation camera, we want to use the system which is easy to deal with.

If we use the discrete parts to all channels, the power consumption of this system is **~130W/64pixels!**

It is too large!!

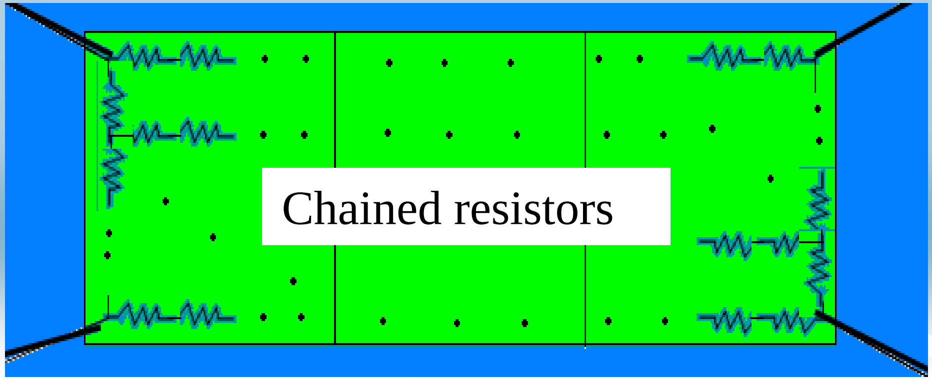
Saving power consumption

Connect the anodes in horizontal row and both edges of those chains with 100Ω resistor for 3 cameras.

4ch readout to 192 pixels

⇨ **~ 2.7W/64pixels**

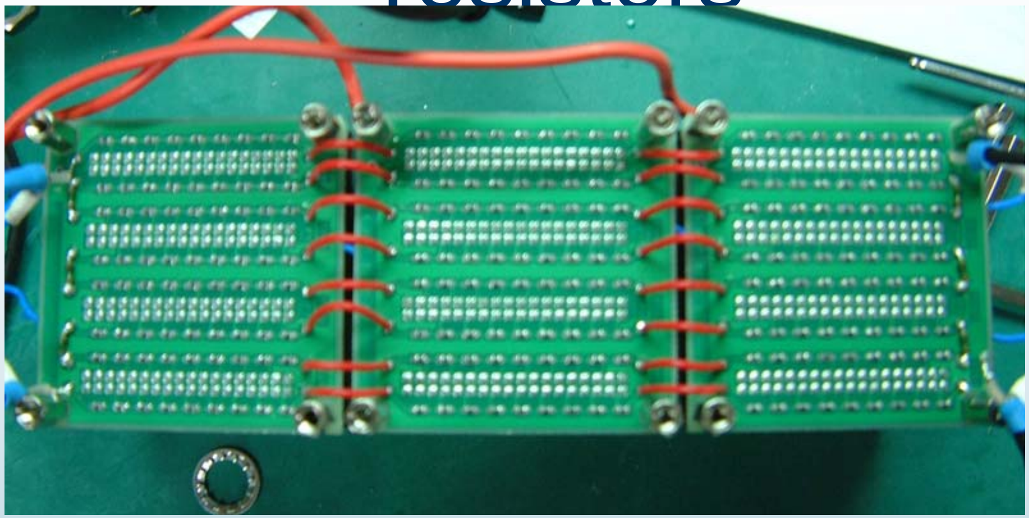
It satisfies our needs.



Reduce to 4ch read-out with chained resistors

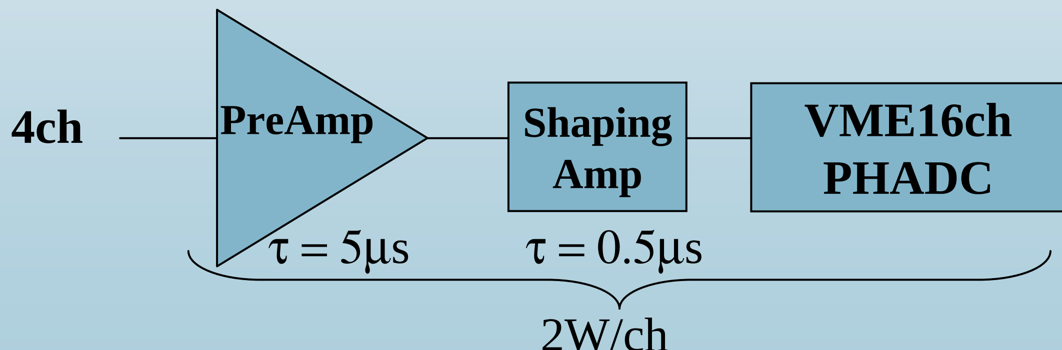
a

b



c

d



Obtained 4ch data are pre-amplified, shaped, held, and digitized by discrete modules.

Power Consumption: ~2.7W/64pixels

Position reconstruction

Simply calculate the center of gravity of the 4 outputs

$$x = \frac{c+d}{a+b+c+d}$$

$$y = \frac{b+d}{a+b+c+d}$$

Position reconstruction

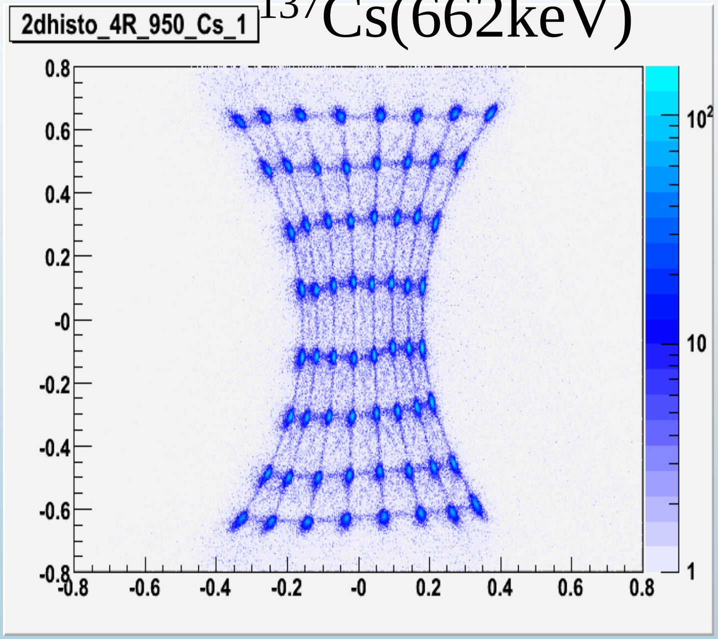
Simply calculate the center of gravity of the 4 outputs

$$x = \frac{c+d}{a+b+c+d}$$

$$y = \frac{b+d}{a+b+c+d}$$

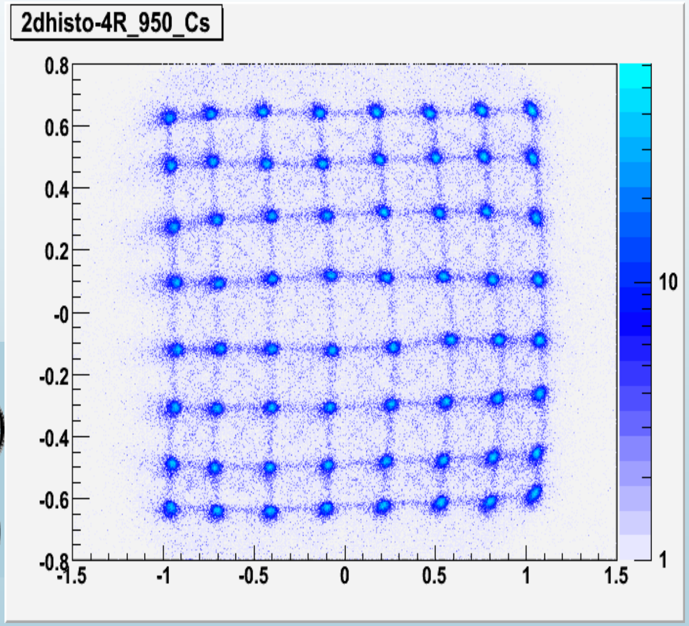
662keV gamma-rays are uniformly irradiated to the array.

^{137}Cs(662keV)



$$\text{real } x = f(x,y)$$

$$\text{real } y = g(x,y)$$



Distort correction

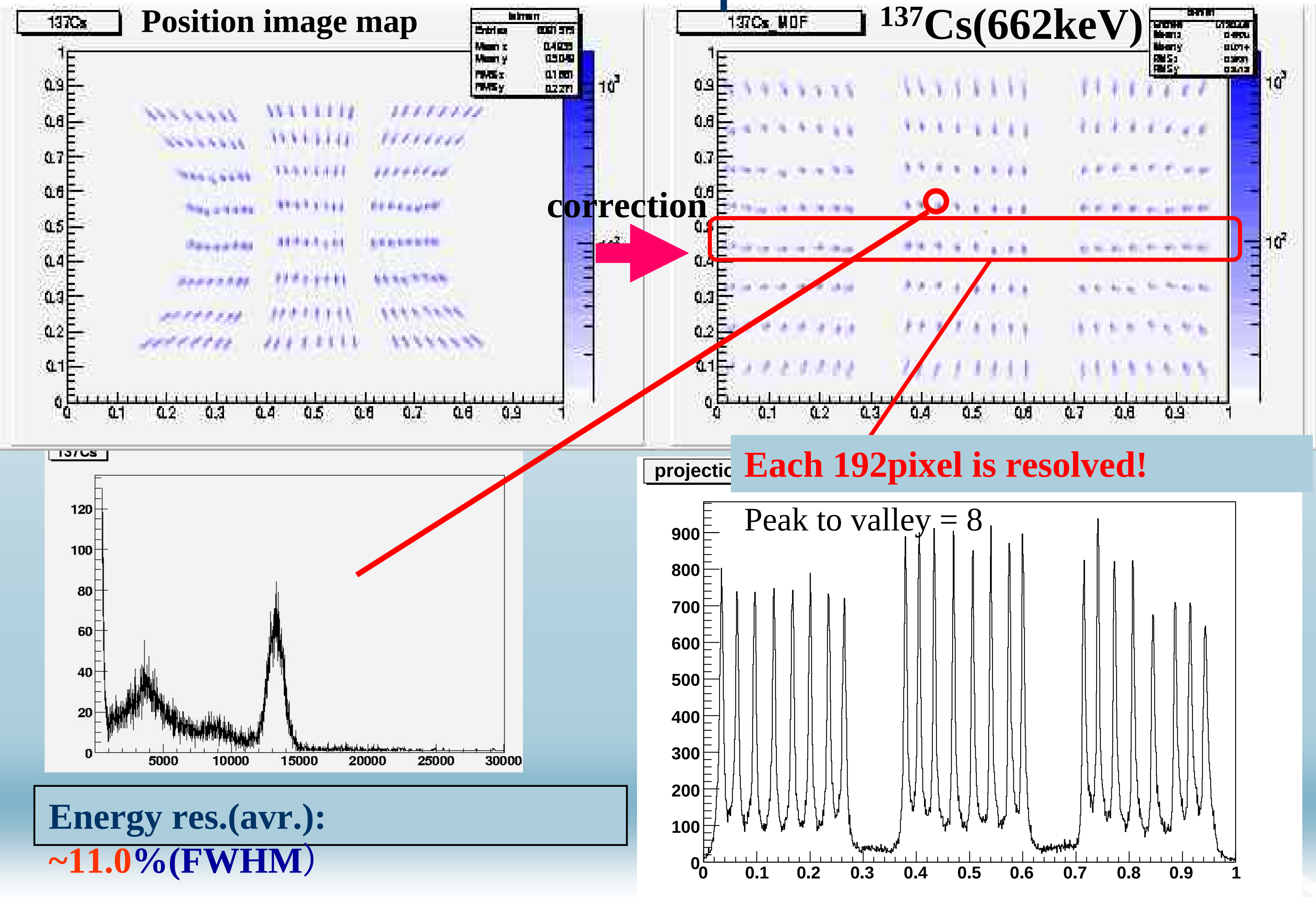
Correct the distorting effect of resistor on image by fitting raw 64 points into real 64 points with polynomials

$$f(x,y) = \sum_{i=0}^{n} (a_i x^i + b_i y^i)$$

$$g(x,y) = \sum_{i=0}^{n} (c_i x^i + d_i y^i)$$

4ch read-out to 192 pixels

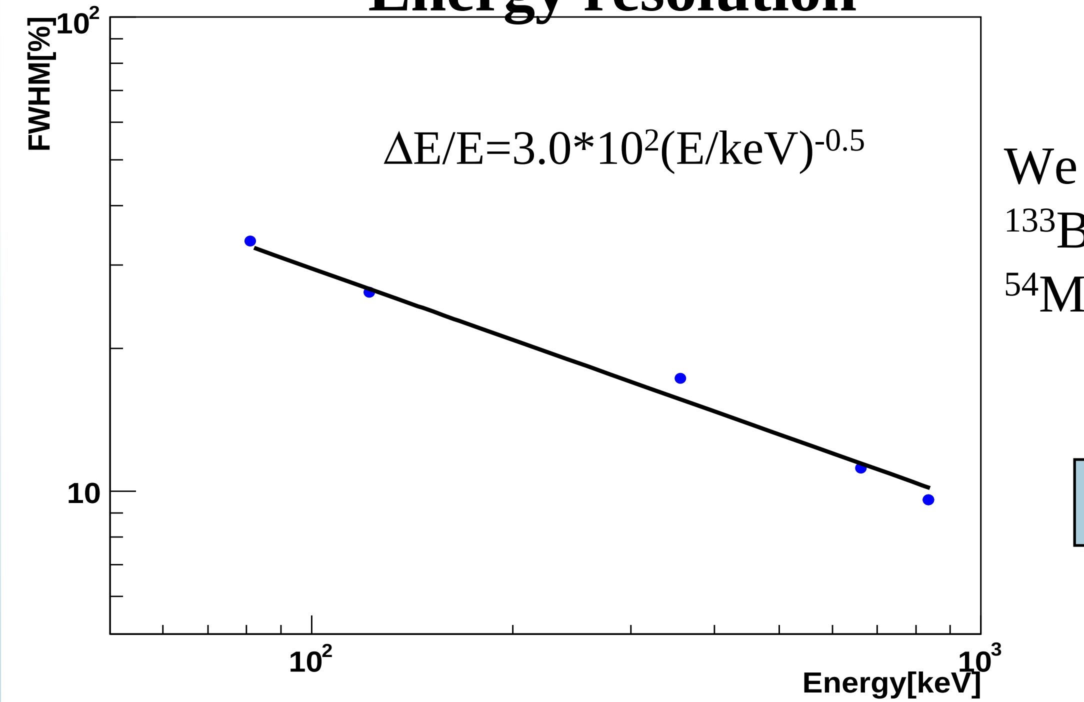
PMT Gain~10^6



Energy res.(avr.): ~11.0%(FWHM)

Energy res.

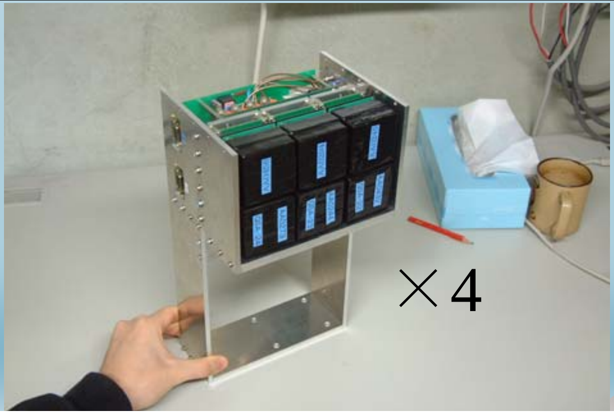
Energy resolution



We also obtained the data from ^{133}Ba(81,356keV), ^{57}Co(122keV), and ^{54}Mn(835keV)

Dynamic range: 80-800keV

	Power Consumption	Energy Resolution	Dynamic Range
chained resistor	○ 2.7W/64pixels	○ 11.0%@662keV	○ 80-800keV



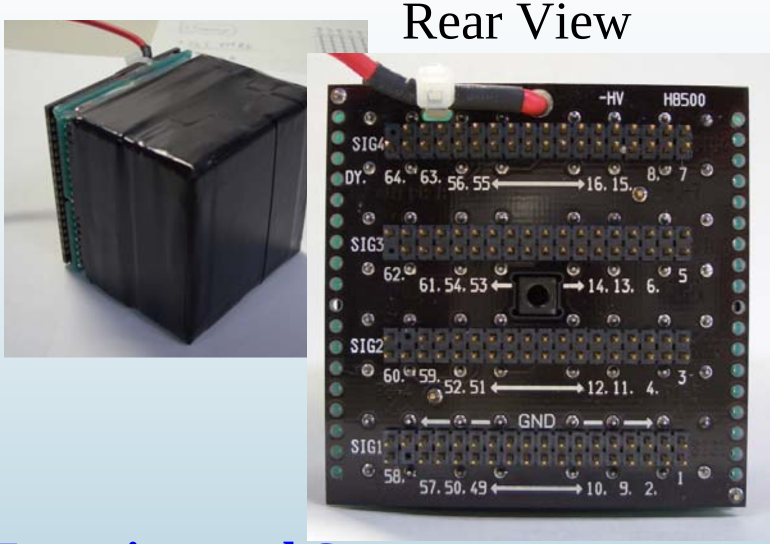
We made the scintillation camera for SMILE-1 using the system.

Past Work

Read-out Methods

Front View

Rear View

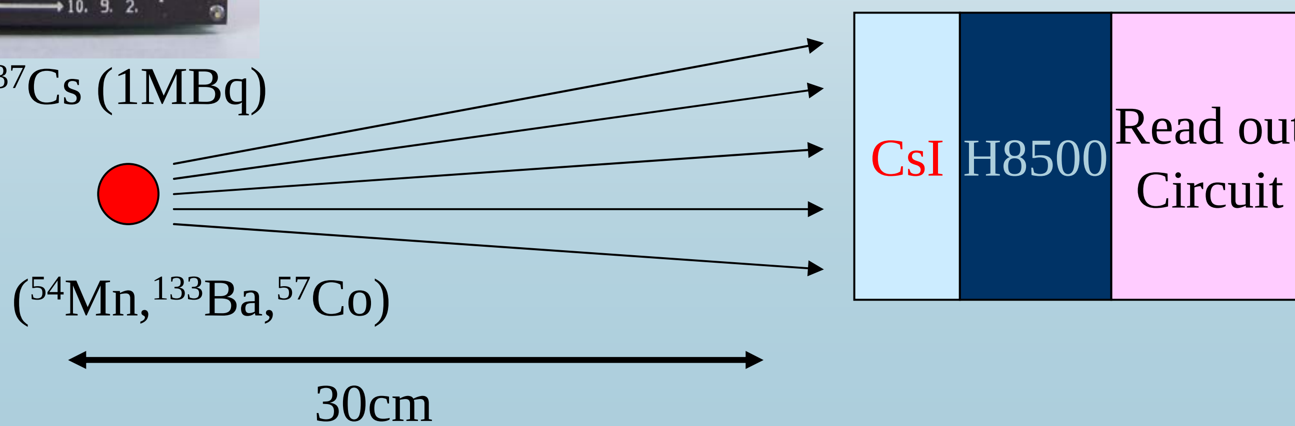


In order to deal with 64 anodes,
We have studied two different
types of read-out systems.

1. 64ch readout with ASIC
2. 4ch readout with chained resistor

Experimental Setup

662keV γ -rays are uniformly irradiated to the array.



	Power Consumption	Energy Resolution	Dynamic Range
type 1	○ 1.3W/64ch	△ 10%@662keV	× 300-700keV
type 2	× 8W/64ch	○ 8.7%@662keV	○ 80−800keV

This detail is in Sekiya et al. NIM A563 (2006) 49.

GSO(Ce) crystal

CsI(Tl)crystal → Absorption Coefficient: small

→ Problem of Activation (on flying object)

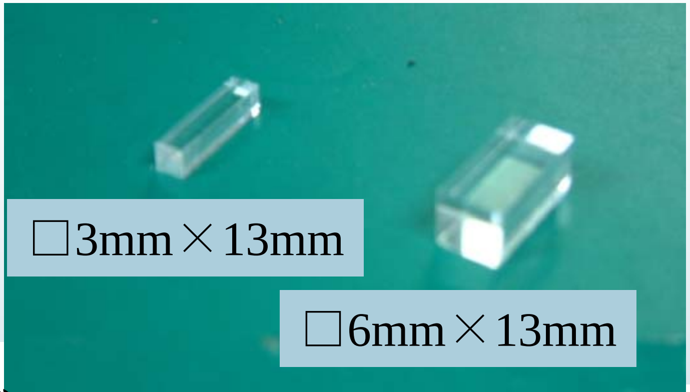
→ Adoption of **GSO** (**Gd_2SiO_5**)

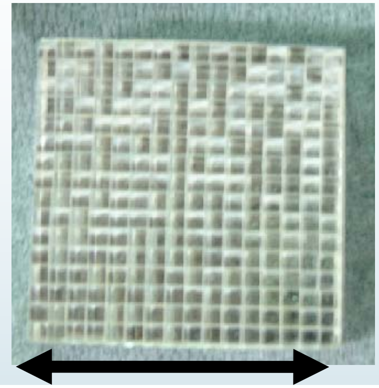
	Density(g/cm^3)	Absorption Coefficient (cm^{-1})(@511keV)	Decay time constant(ns)	Light Output (relative)
NaI(Tl) **Hydroscopic :Strong**	3.67	0.34	230	1
CsI(Tl) **Hydroscopic: Weak**	4.53	0.44	1050	0.85
GSO(Ce) **Hydroscopic: No**	6.71 **Large**	0.70 **Large**	**~60** **fast**	0.18

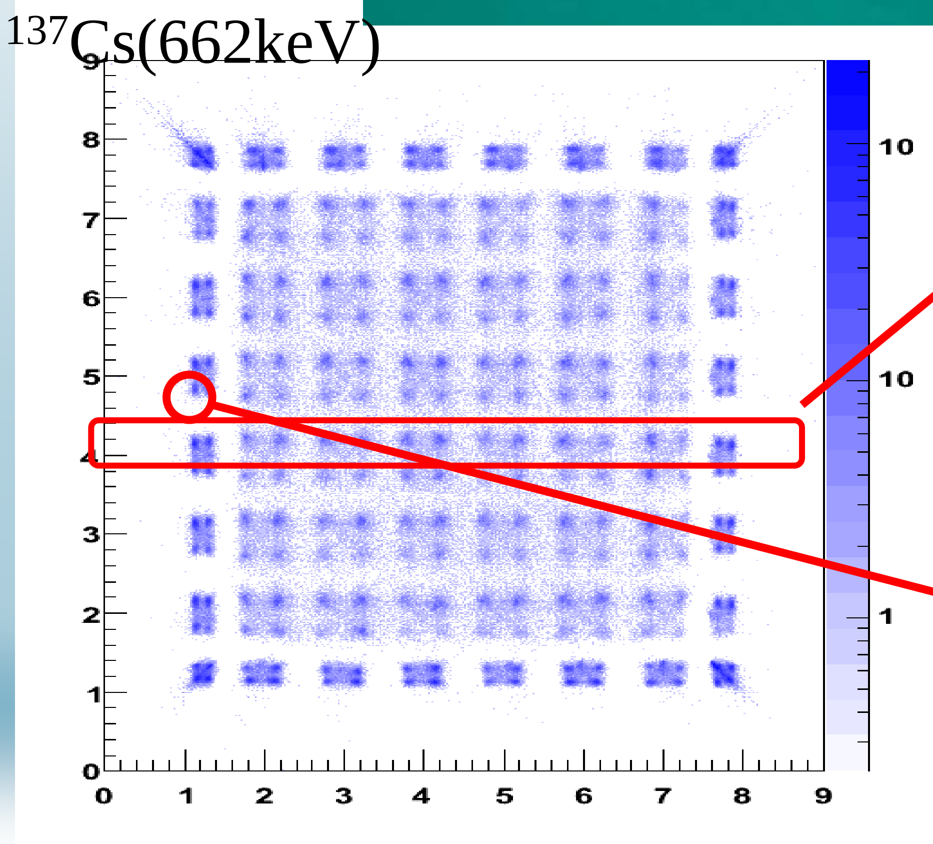
~Comparative Table~

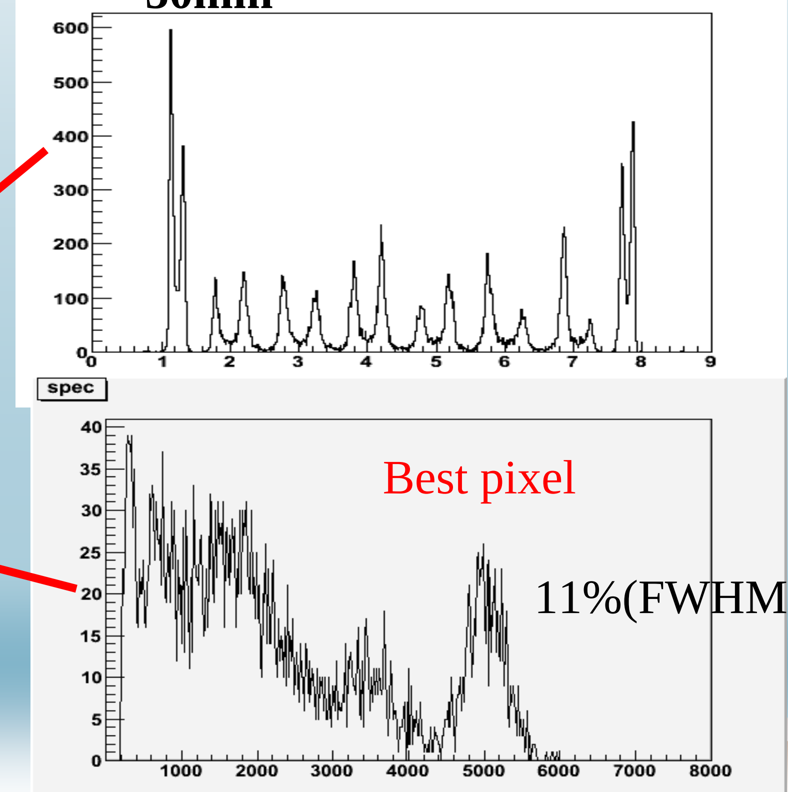
3mm pitch GSO PSA camera

~Hoping for an improvement of position resolution~





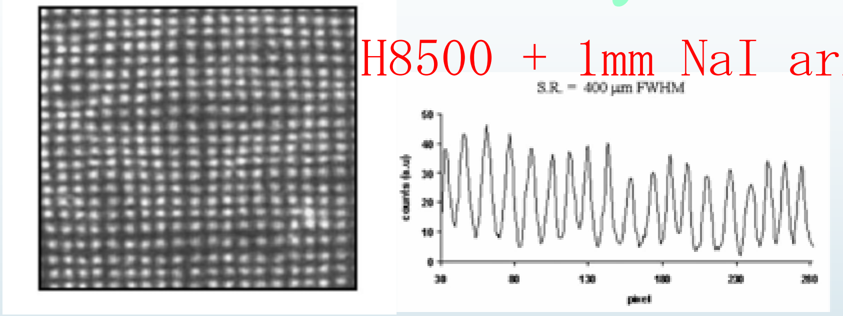


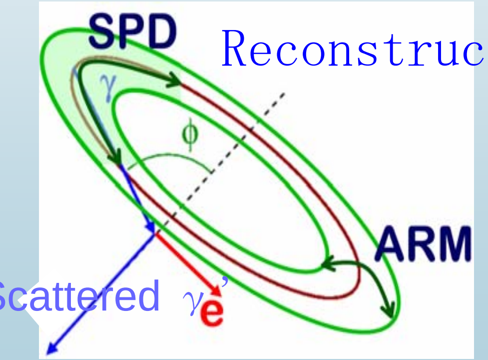


Motivation

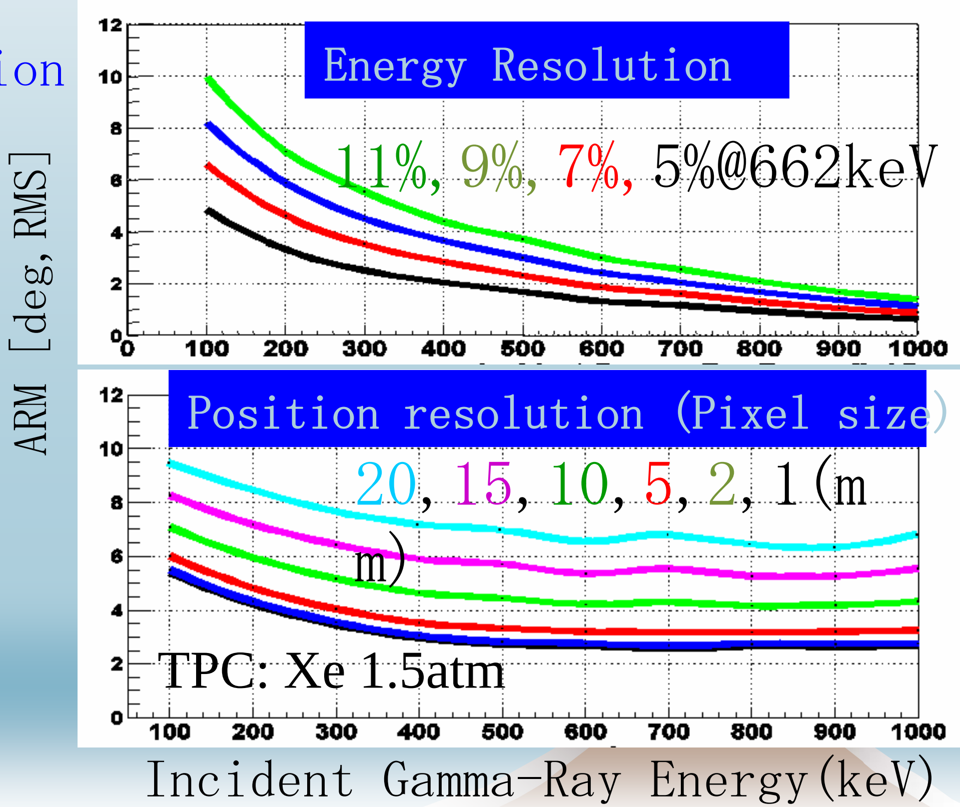
- Position resolution has been examined for PET applications.

R. Pani et. al.,
NIM A527(2004) 54





Reconstructed gamma direction are affected by both position and energy resolution of the scintillator

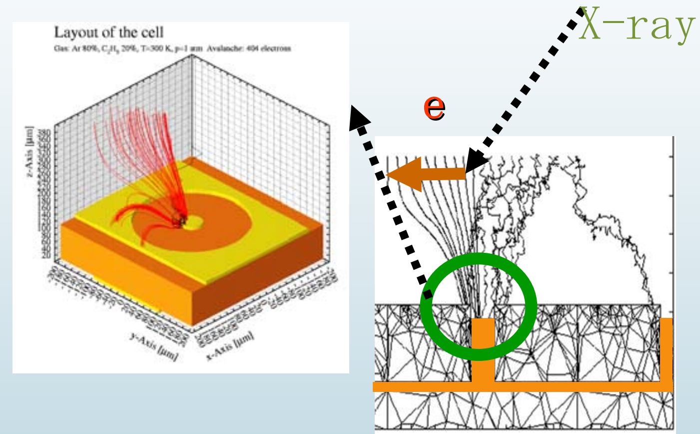


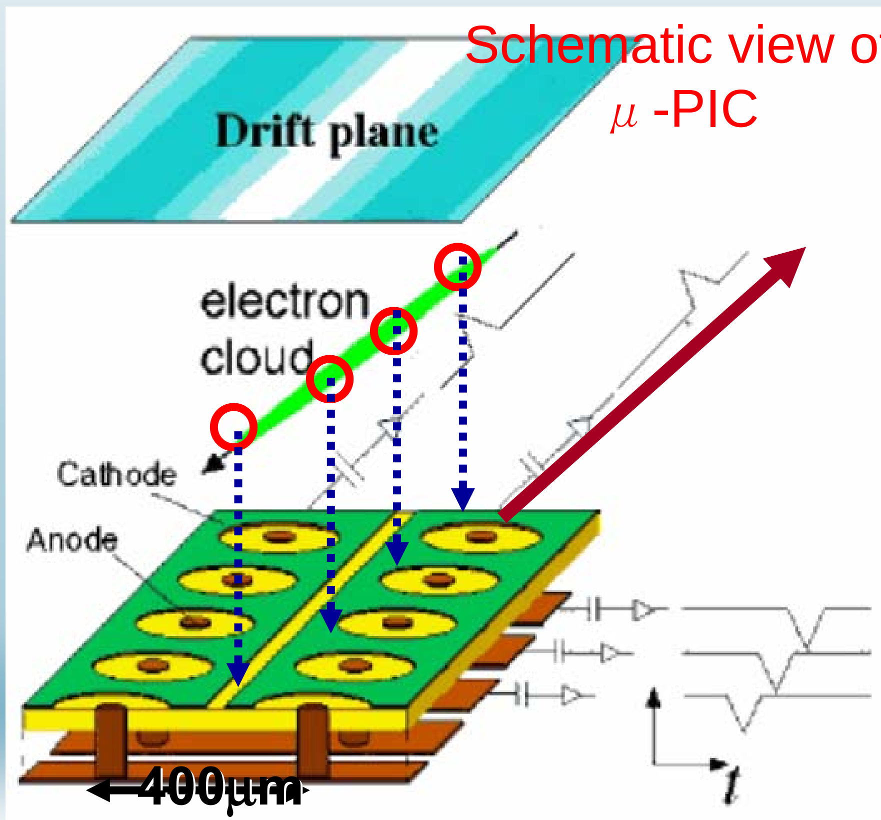
- We have examined not only position resolution but also dynamic range (100keV-1MeV) and energy resolution.

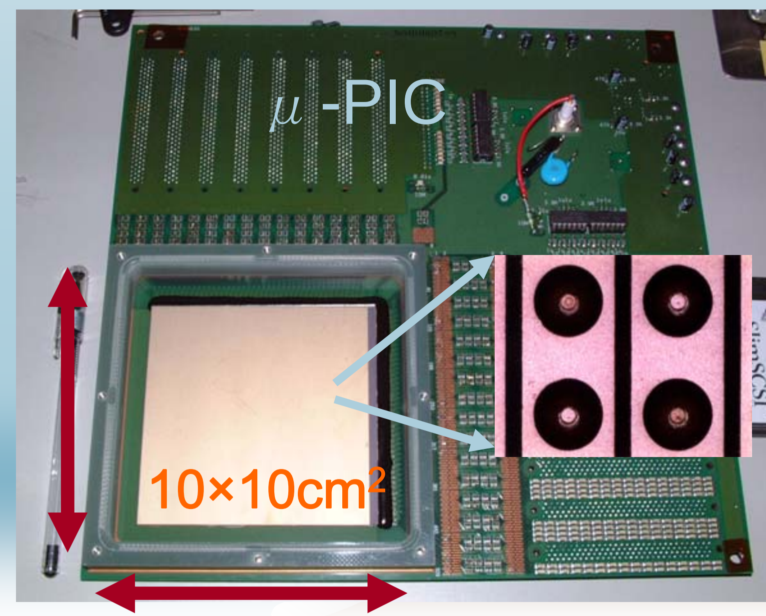
Micro Pixel Chamber（μ -PIC）

- good position res. (100μm)
- High gain (~10000)
- robust for discharge
- Large detector 30cm square possible
- `Printed board technology (cheap cost)

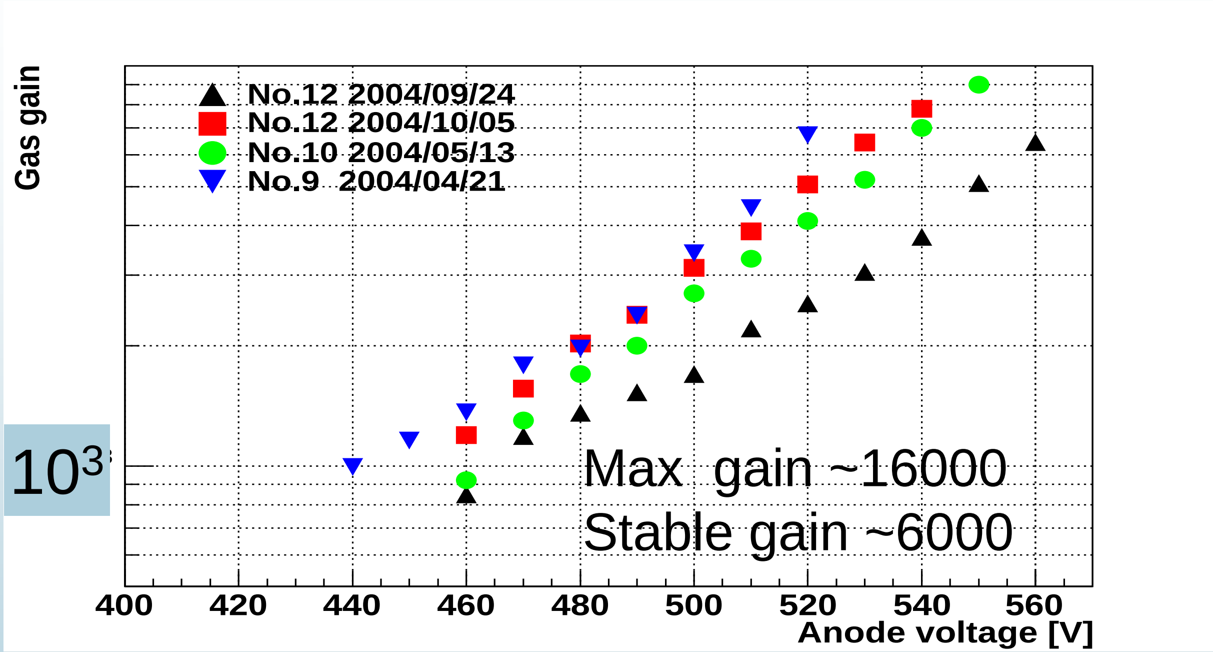
Design base on3D simulation

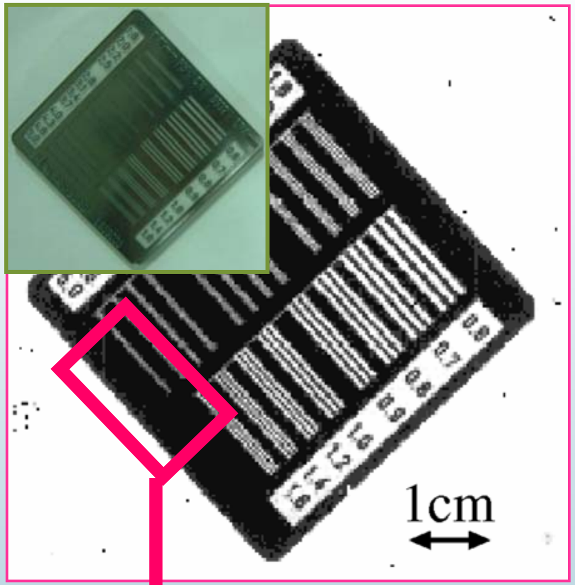




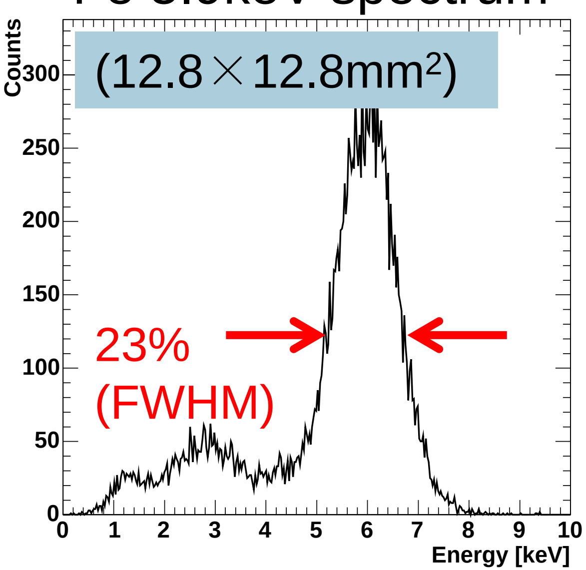


Performances of the μ–PIC

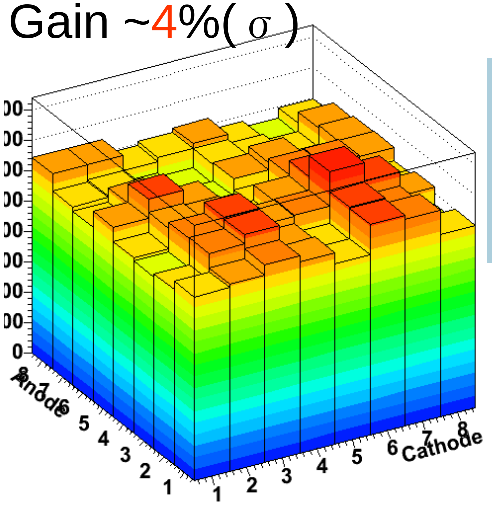


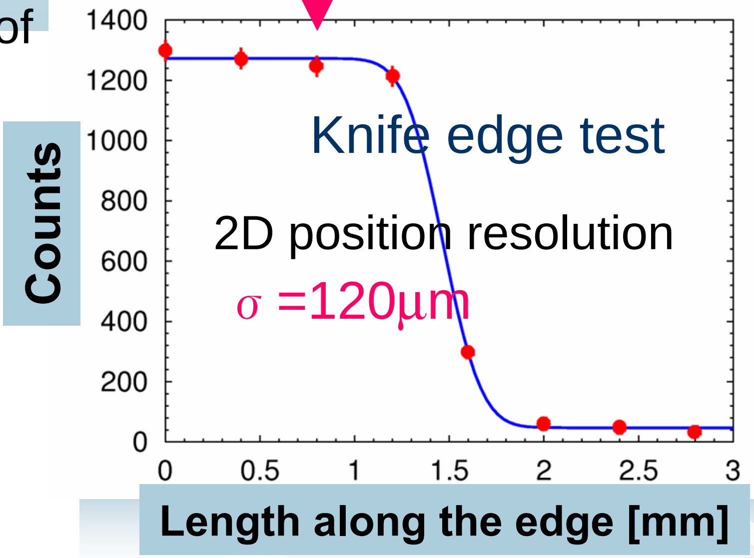


^{55}Fe 5.9keV spectrum



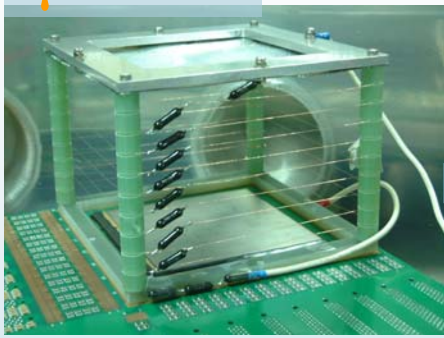
Position Dependence of Gain ~4%(σ)





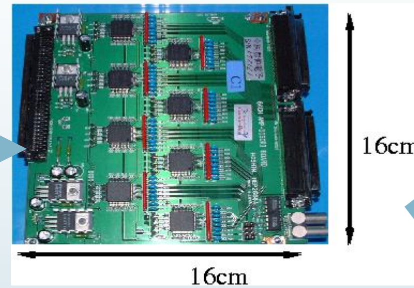
DAQ system

μ-TPC



512ch

ASD



512ch
digital

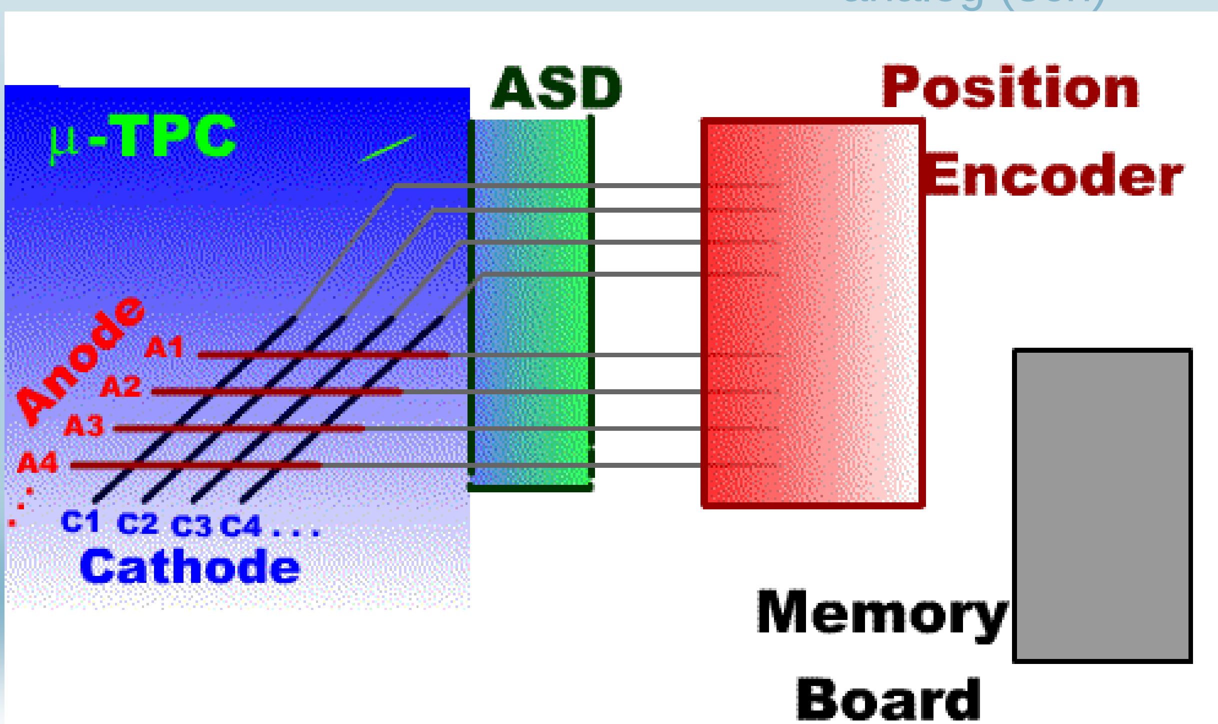
Encoder

32bit

VME
Memory Board

summed
analog (8ch)

VME FADC
100MHz 8ch



MeV-γ imaging (Energy unknown)

^{137}Cs : 662keV, 0.89MBq

^{54}Mn: 835keV, 0.65MBq