# Development of Large area Gamma-ray Camera with GSO(Ce) Scintillator Arrays and PSPMTs
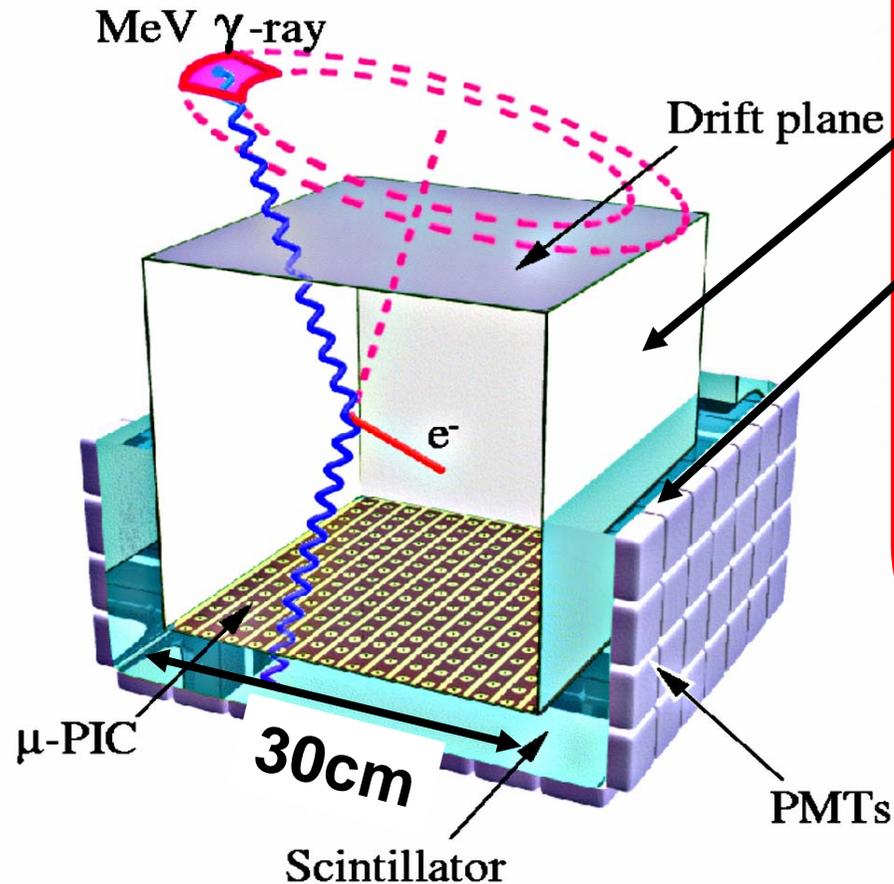
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1. The Advanced Compton Camera
2. GSO scintillator study
3. Large area gamma camera with GSO(Ce) and PSPMT
4. Conclusion

# The Advanced Compton camera with micro-TPC and scintillation camera

Observation of
  Gamma-ray (100 keV-10 MeV)
Angular resolution : ～5°
Field of View: ～4str

MeV γ-ray

Drift plane

e⁻

μ-PIC

**30cm**

Scintillator

PMTs

**Micro-TPC（gas）:**

**Detect 3-D track and energy of recoiled electron.**

⇒Tomorrow Hattori' talk

**Scintillation camera :**

**Detect direction and energy of scattered gamma-ray**

・Position resolution
・Energy resolution
・Large area
・high stopping power

・radiation hardness

**Perfect reconstruction of Compton event !!**

# Scintillator for Gamma Camera

| | Density （g/cm³） | Absorption coefficient (cm⁻¹) | Decay time constant （ns） | Light output (Relative) | Hydroscopic | Radiation Hardness |
|---|---|---|---|---|---|---|
| NaI(Tl) | 3.67 | 0.34 | 230 | 1 | Strong | very weak |
| CsI(Tl) | *Classical* 4.53 | 0.44 | 1050 | 0.85 | Weak | very weak |
| BGO | 7.13 | 0.92 large | 300 | 0.07-0.12 | No | weak |
| LSO | 7.4 | 0.87 large | 40 fast | 0.4-0.75 | No | strong |
| YSO | 4.45 | 0.38 | 40 fast | 0.3-0.45 | No | strong |
| CWO | 7.9 | 0.92 large | 5000 | 0.3-0.4 | No | weak |
| GSO | 6.71 | 0.70 large | ~60 fast | 0.18 | No | very strong |

# Factors of GSO(Ce)Pixel

1 ,**<u>Size</u>** :

the pitch of photo device $\Rightarrow$ area of bottom = $6 \times 6 mm^2$

absorption coefficient $\Rightarrow$ Height =13mm

$\Rightarrow$ **$6 \times 6 \times 13 mm^3$**

*Fixed!!*

**2,Surface polishing**

- **chemical etching or mechanical polishing**

**3,Concentration of Ce**

What is best?

- **0.5 mol% or 1.0 mol%**

Ce colors crystal and decrease the transmittance

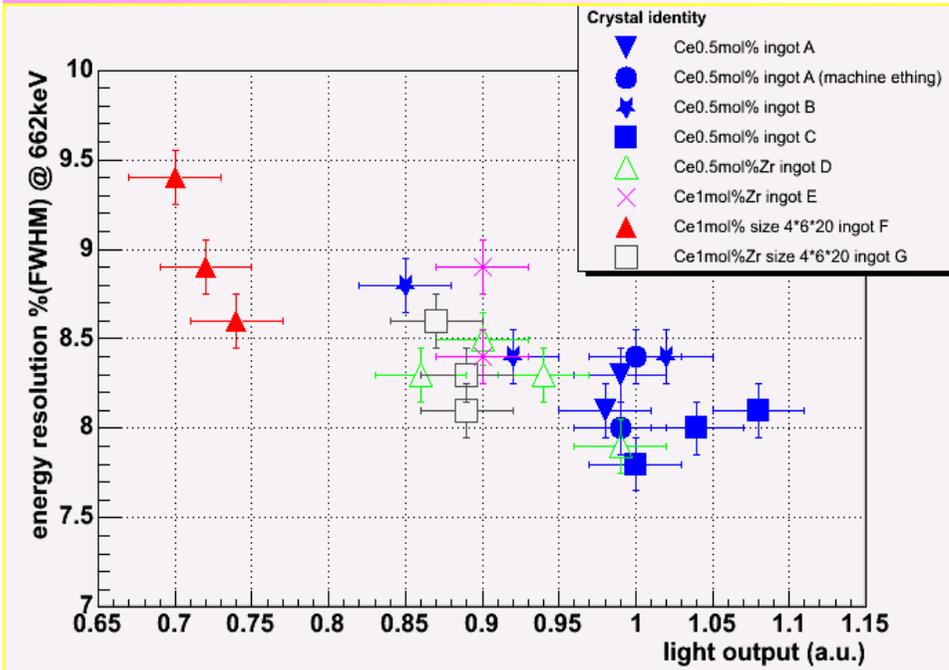**4,Zr-doped**

- **doped or not**

Zr makes crystal not to be colored

Measured these factors

Next $\Rightarrow$

# Measurement of sample pixel

**Crystal identity**
- ▼ Ce0.5mol% ingot A
- ● Ce0.5mol% ingot A (machine ething)
- ★ Ce0.5mol% ingot B
- ■ Ce0.5mol% ingot C
- △ Ce0.5mol%Zr ingot D
- ✕ Ce1mol%Zr ingot E
- ▲ Ce1mol% size 4*6*20 ingot F
- □ Ce1mol%Zr size 4*6*20 ingot G

*(plot: energy resolution %(FWHM) @ 662keV vs light output (a.u.))*

**reflector：Goatex**
**PMT：R6231（ＨＰＫ）**
**PreAmp:time constant 6 $\mu$ s**
**ShaperAmp:time constant 1 $\mu$ s**

### 6×6×13 pixel

- ▲ Ingot A Ce 0.5mol%
- ● ingot A (mechanical etching)
- ★ ingot B Ce 0.5mol%
- ■ ingot C Ce 0.5mol%
- ✕ ingot D Ce 0.5mol%+Zr(200ppm)
- △ ingot E Ce 1mol%+Zr (200ppm)

### 4×6×20 pixel

- □ Ingot F Ce 1mol%
- ▲ ingot G Ce 1mol%+Zr(200ppm)

**No significant relation**
performance of crystal
⇔polish,dopant(Ce,Zr)
in case of 6×6×13 pixel

**Cost Risk** ➡ **Ce 0.5mol% non-Zr chemical etching**

**Fixed!!**

# Construct Pixel Scintillator Array

- **Pixel Size** $6 \times 6 \times 13$ mm$^3$
- **Ce 0.5mol%**
- **Chemical etching**
- **$8 \times 8$ pixels ～5 cm**
- **Reflector ： ESR （３M）**



～5cm

A GSO array with 64 pixel

a) Folds written by LASER

ESR (Multilayer polymer Mirror)

b)

c)

GSO crystal

Bottom ESR

Side ESR

Separate ESR

6mm square crystal

（Naoko Inadama et al.IEEE NSS & MIC,M6-27,2002）

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# PSPMT（Hamamatsu H8500）

## FlatPanel PMT H8500 （HPK）

- 8×8 multi-anodes with 6mm pitch
- 12 stage metal channel dynode
- Gain ～$10^6$
- 52×52 mm² (Effective are is 49×49 mm²)
- Anode uniformity Min:Max 1:3 in one PMT(Typ.)

Hamamatsu H8500

**52mm**

**Effective area of making 10cm² Camera**

Max. **89%**       Min. **49%**

H8500          R7600(old model )

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# Read out with circuit resistive chain

Back plane of PMT

**resister**

**anodes**

64ch FlatPanel PMT

$l_1$ $r_1$

**64ch Anode**

$l_2$ $r_2$

$l_3$ $r_3$

$l_4$ $r_4$ **Y**

PMT＋resistive chain

$l_5$ $r_5$

$l_6$ $r_6$

**16ch**

$l_7$ $r_7$

Sum Amp

$l_8$ $r_8$

PreAmp
×16ch

**X**

ShaperAmp
×16ch

**position calculation**

Discriminator
＆Gate

y : mass of center
x : charge division
law

**16chADC**

$$P_i = l_i + r_i$$

$$y = \frac{\sum_i P_i \cdot i}{\sum_i P_i}$$

$$x = \frac{l_i}{P_i}$$

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# Performance of 64 pixel Scintillation camera with GSO:Ce

FlatPanelPMT

$6 \times 6 \times 13mm^3$  **GSO**  $8 \times 8$

**energy resolution**

**9.8%@662keV(FWHM)**

**10%(Typ.)**

**In flood field of gamma-ray of $^{137}$Cs**

hh

Y

X

**x-projection**

# 16cm × 16cm scintillation camera with 9 flat-panel PMTs

**1)Put 3 of 5 cm unit on**

**1unit = 5 × 5cm²**

**3)Put 3 sets of 3 PMTs in box like this.**

**16cm**

**2)Connect 24 anodes with resistive chain over 3 PMTs**

192ch scintillation camera with 3 PMTs

64ch FlatPanelPMT

Anode

8ch PreAmpBoard

◆16cm Scintillation Camera
◆effective area ～80 %
◆6 mm 576 pixel
◆48 ch readout by resistive chain

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In field flood of radiation of $^{137}$Cs （662keV）



16 c m

576pixel
is resolved !!

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# Energy resolution and dynamic range

**The gain map: light out put at each pixel**

- **Energy resolution（typ.）10.5%(FWHM）@662keV**

gainmap

relative light output

Good
9.7%

Bad
13.0%

Energy resolution (%)

- Good pixel
- typical pixel
- bad pixel

Energy (keV)

**Good Pixel**

**bad Pixel    Typical Pixel**

**Energy resolution of each point at 122keV-1333keV**

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# Now constructing

**Scintillation camera for 10cm TPC**



**Scintillation camera for 30cm TPC**



5×3PMTs

25cm



TPC

# 3mm pitch scintillation camera

- 3mm pixel scintillator array+H8500

**3mm pixel array**

**6mm pixel array**

hh

Almost of pixel is resolved.

**energy resolution:**
**Typ 12%(FWHM)@662keV**

spec

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# Summary

· Scintillation camera for advanced compton camera

· Study of Pixelated GSO scintillator
    with size of 6×6×13 mm³

· Large area scintillation camera with size of
  160×160mm²
(ＧＳＯ pixel scintillator array and H8500 with 6mm pitch anodes)
−Image of 576 Pixel are resolved clearly ～6mm pitch
-energy resolution  9～13% @662keV(FWHM)  Typ.10.5%
−Dynamic range  from 100keV to 1MeV (Typ.)
· Now developing
  −Expanding to large area.
  −3mm Pixel GSO + H8500 −  position resolved
        energy resolution @662keV(FWHM) Typ.12%

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# 3mmピッチＰＳＡカメラ
## 〜位置分解能を求めて〜



FlatPanelPMT H9500（HPK）
・16×16マルチアノード
51mm角　256ch



H9500 アノードゲインのばらつき（HPK）



Min:Max=1:4.5

3mmピッチPSA

- 3mm角GSO
- 16×16
- ESR反射材

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hosei_map

137Cs（662keV） の全面照射

Good 9.7%

Bad 13.0%

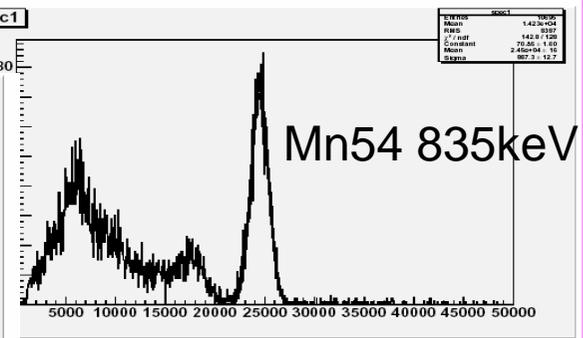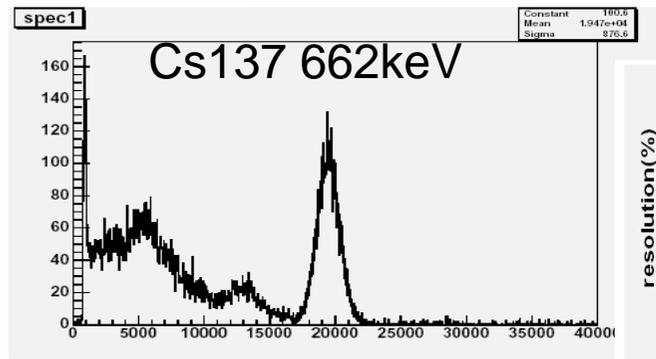gainmap

一分解能（**typ.**）

**～10%(FWHM） ＠662keV**

# ダイナミックレンジ



中央部で
80keV〜1.4MeV
周辺部でも
100keV〜1.0MeV

Co57 122keV

Ba133 356keV

Cs137 662keV

Mn54 835keV

Na22
511,1275 keV

Co60 1173,1333keV

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# GSO vs CsI(Tl)

20mm

13 mm

gso
密度大
吸収断面積大
⇒小さくていい
⇒コンプトン成分小

速い！

CsI(Tl) 20mm厚アレイ
GSO  13mm厚アレイ

コンプトン小

662 keV

2 μ sec

200nsec

光量はCsI(Tl)：GSO＝0.46：1

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# Monte Carlo study with Geant4

ＡＲＭのシンチカメラ位置分解能依存性

ピクセルサイズ：20，15，10，5，2，1（mm）

ARM（RMS，deg）

5.7° @500keV

3.3° @500keV

Incident Gamma-Ray Energy（keV）

シンチカメラのエネルギー分解能、位置分解能、共にＡＲＭに効いてくる

要請値

位置分解能：2.5mm（FWHM）

エネルギー分解能 ：7.5%@662keV

再構成γ線のＡＲＭ 分解能

5.3° @300keV, 3.4° @1MeV（RMS）

Fidutial, Kinematicalカット依存

# Monte Carlo study with Geant4

～30cm

入射γ

TPC

散乱γ'

反跳e-

ジオメトリ
TPC:　　30cm立方，Xe 1.5atm
ピクセルシンチ:
　　　2.5cm厚CsI(Tl) 、側面高さ
15cm

片端読み出し

SPD

γ

φ

ARM

e

散乱γ'

ＡＲＭのシンチカメラエネルギー分解能依存性

エネルギー分解能
11%, 9%, 7%, 5%@662keV

3.7° @500keV
2.3° @500keV

ARM [deg, RMS]

10
8
6
4
2
0

0  100  200  300  400  500  600  700  800  900  1000

Incident Gamma-Energy

# 抵抗chain　4 ch

γ

**4 terminal**

137Cs（662keV） の全面照射

実際のサイズに較正

real y [ mm ]

**Energy resolution
8.6%@662keV(FWHM)**

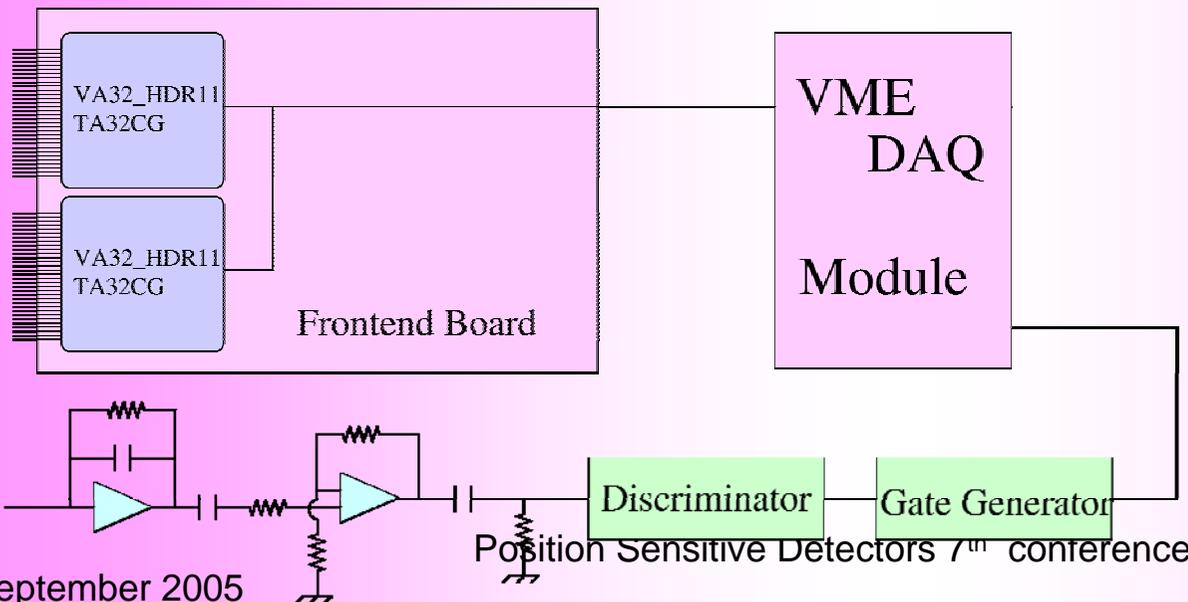Position Sensitive Detectors 7th conference

keV

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# VAを用いた64ch read out γ

VA

- ●シリコンストリップ用に開発されたASIC
- ●charge AMP・shaping AMP・sample & hold
- ●multiplexer によるシリアル化

## K2K SciBar用のboard＆VME＋DAQ

- ●IDEAS製VA32_HDR11+TA32CG２つで６４ch
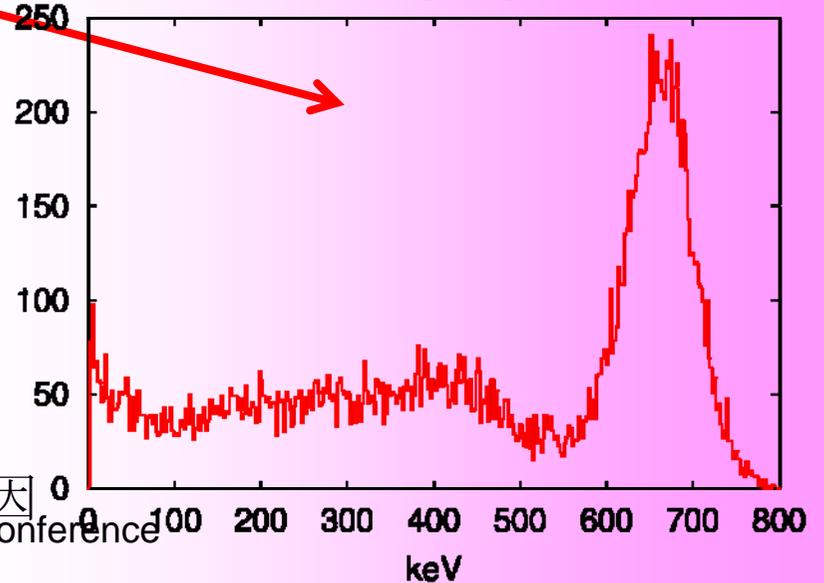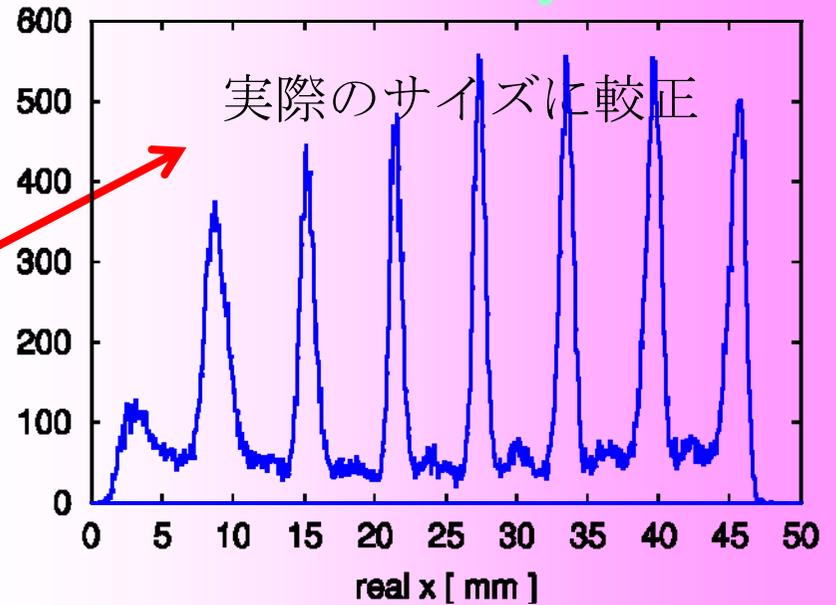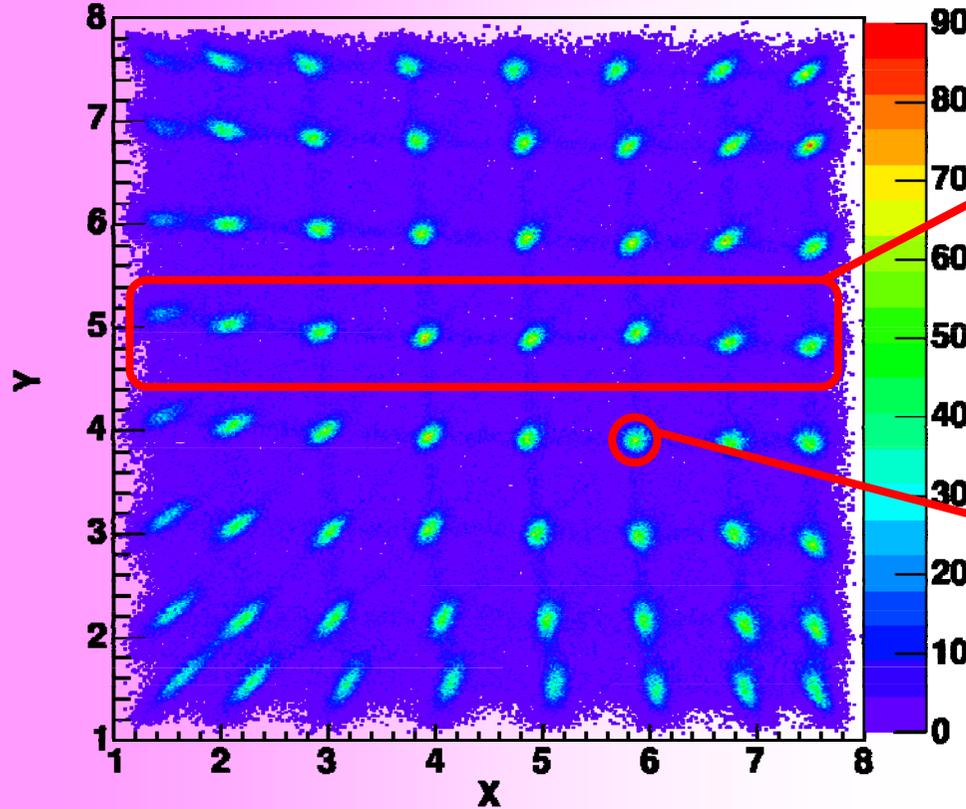- ●VA/TA読み出しシーケンス制御のためのVMEモジュール
- ●TA機能は使用せず

VA32_HDR11
TA32CG

VA32_HDR11
TA32CG

Frontend Board

VME
DAQ

Module

Discriminator    Gate Generator

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入力ダイナミックレンジ
〜-35pC

H8500を低ゲイン
１０⁴で動作

位置は全chの重心演算

# VA 64ch read out

$\gamma$



VA/TA read out

137Cs（662keV）の全面照射

実際のサイズに較正

**Energy resolution
12.9%@662keV(FWHM)**

低ゲインでのオペレーションが原因

# 各ピクセルのゲイン・発光量ばらつき

**GSO-PSA**の **662keV** に対する応答
（**ADC**値）



**Min:Max=1：2.4**

**PMT AnodeGain**のばらつき（**HPK**）



**Min:Max=1：2.3**

補正

発光量のばらつき



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**Min.:Max.=1：1.5**