Study of the MPPC for the GLD Calorimeter readout

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- Introduction
- Basic performances
- Future improvements
- Summary

The GLD Calorimeter

- Sampling calorimeter with Pb/W - scintillator sandwich structure with WLSF readout
- Particle Flow Algorithm (PFA) needs particle separation in the calorimeter

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- Fine granularity with strip/tile scintillator

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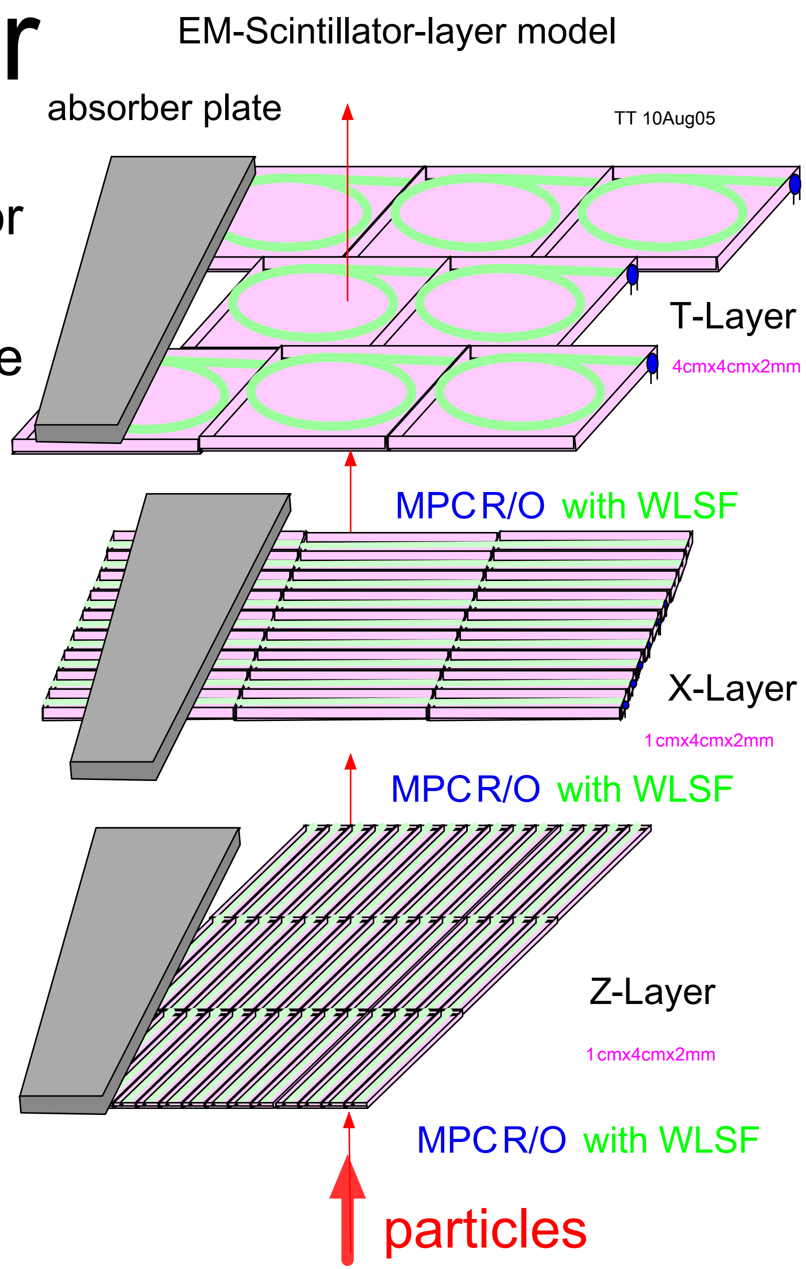
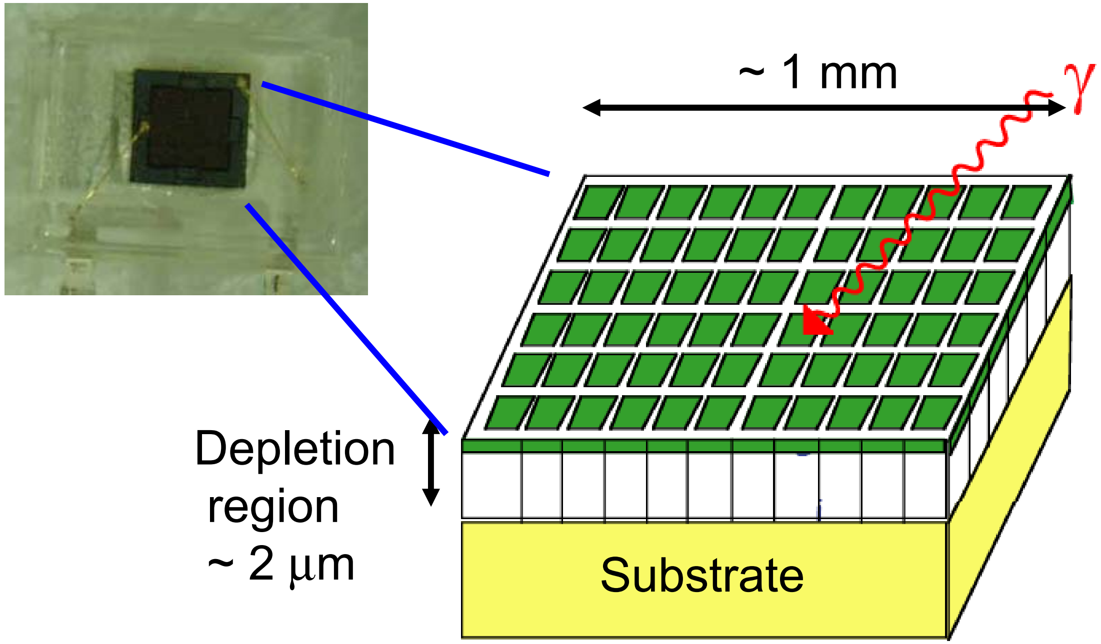
- Huge number of readout channels
  - ~10M (ECAL) + 4M (HCAL) !
  - 10K for muon detector
- Used inside 3 Tesla solenoid

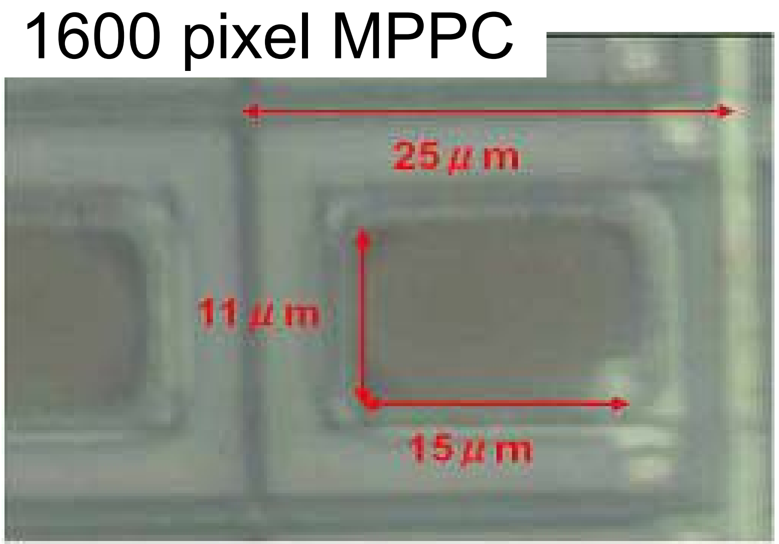


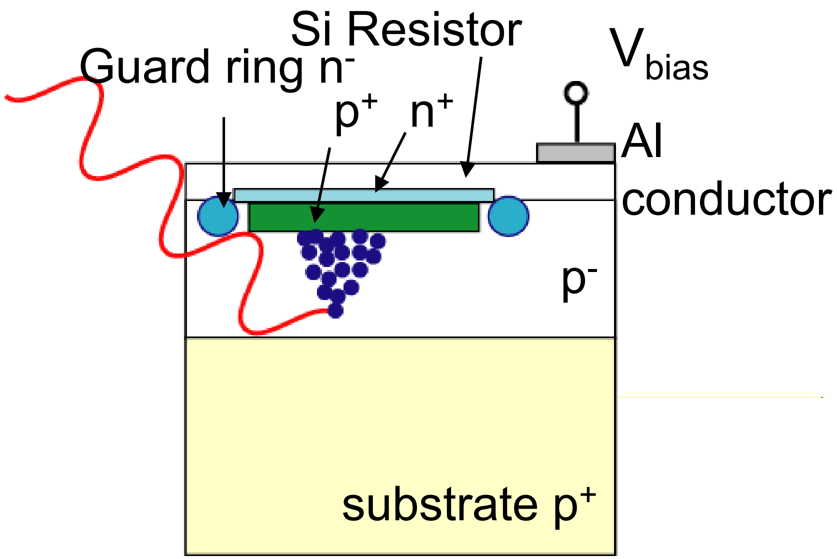
Need a new photon sensor which is compact and low-cost, and has enough performance.

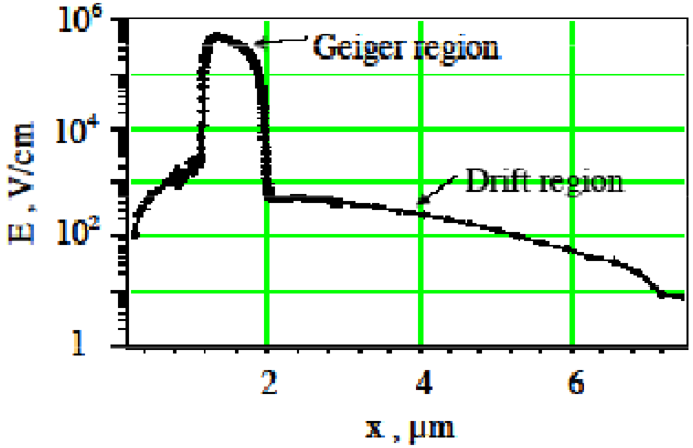
The Multi Pixel Photon Counter (MPPC)

- A novel semiconductor photon sensor -

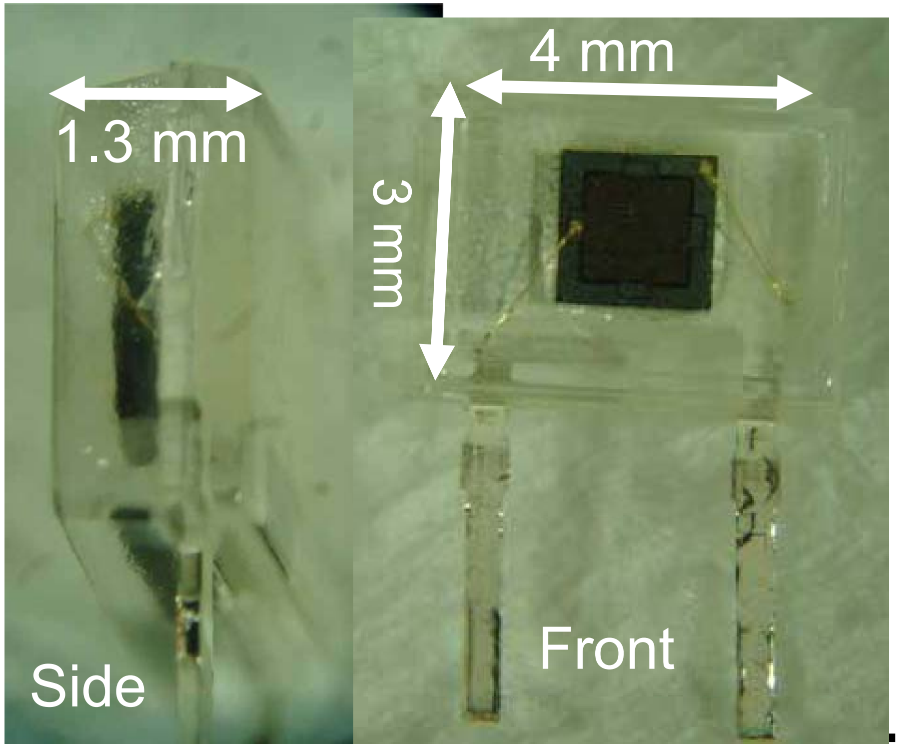


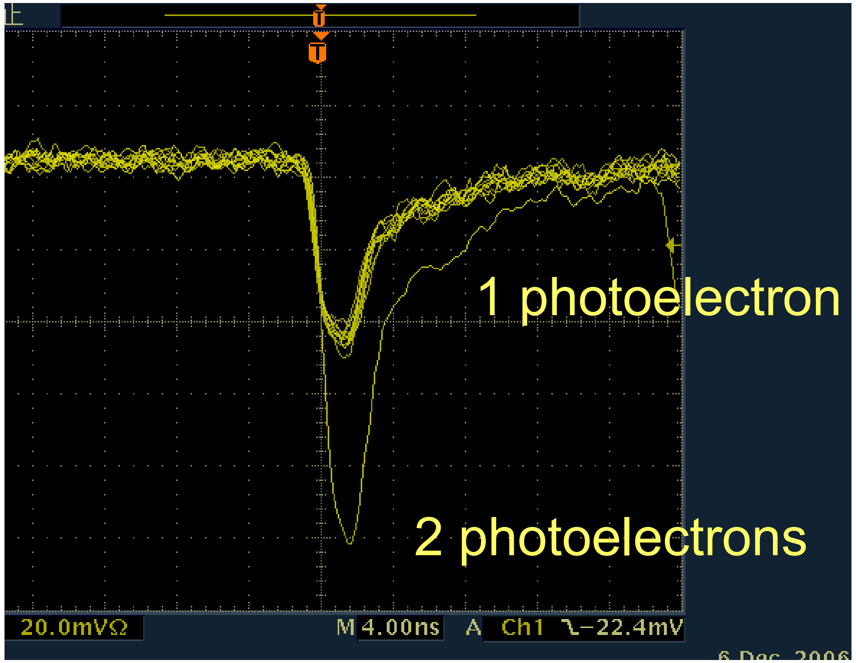


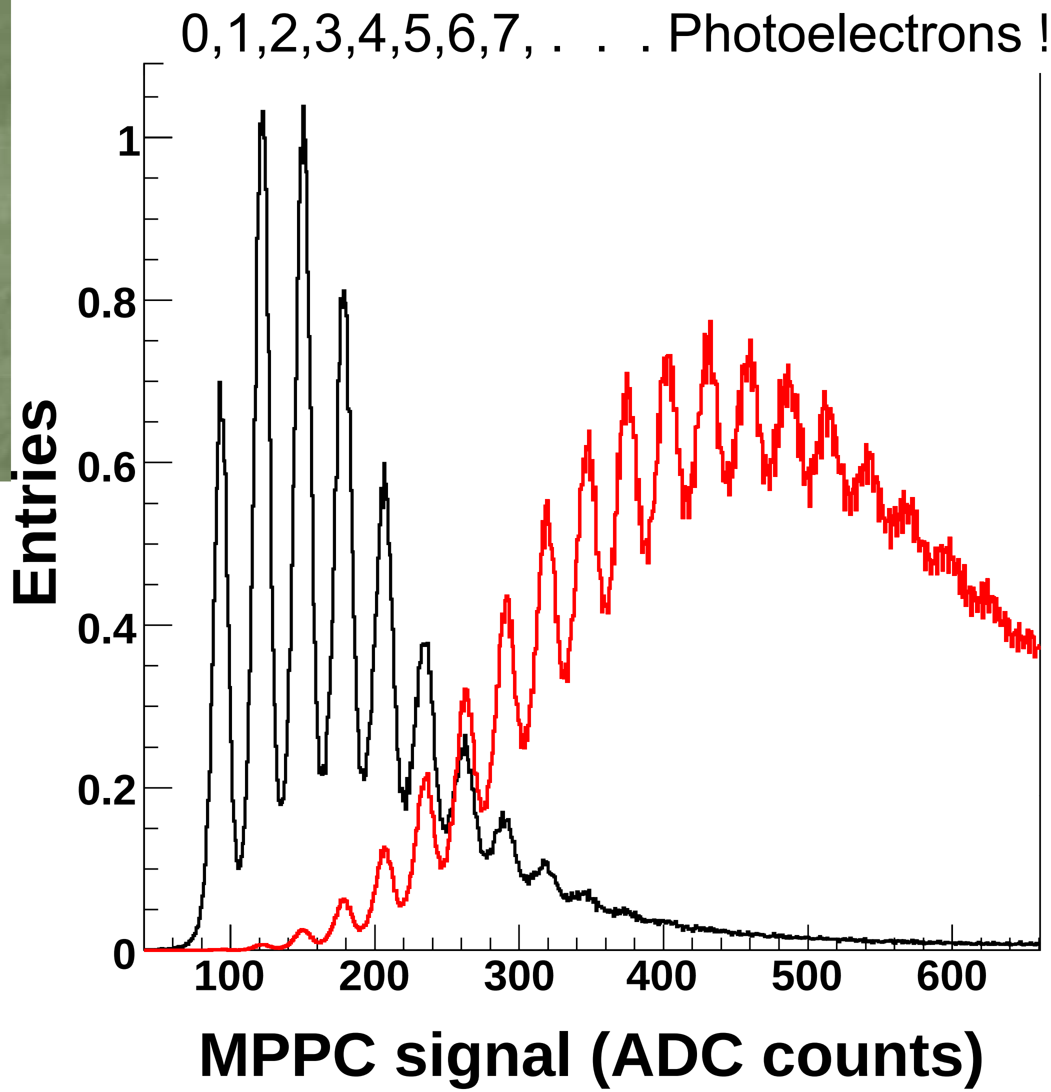




Excellent photon counting ability







The MPPC has lots of advantages

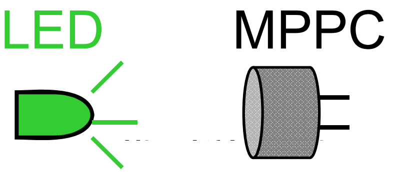
	Photomultiplier	MPPC
Gain	~10^6	10^5~10^6
Photon Detection Eff.	0.1 ~ 0.2	~0.2 for 1600 pix. MPPC
Response	fast	fast
Photon counting	Yes	Great
Bias voltage	~ 1000 V	~ 70 V
Size	Small	Compact
B field	Sensitive	Insensitive
Cost	Very expensive !	Not very expensive
Dynamic range	Good	Determined by # of pixels
Long-term Stability	Good	Unknown
Robustness	decent	**Unknown, presumably good**
Noise (fake signal by thermions)	Quiet	Noisy (order of 100 kHz)

The MPPC is a promising photon sensor,
and feasible for the GLD Calorimeter readout !

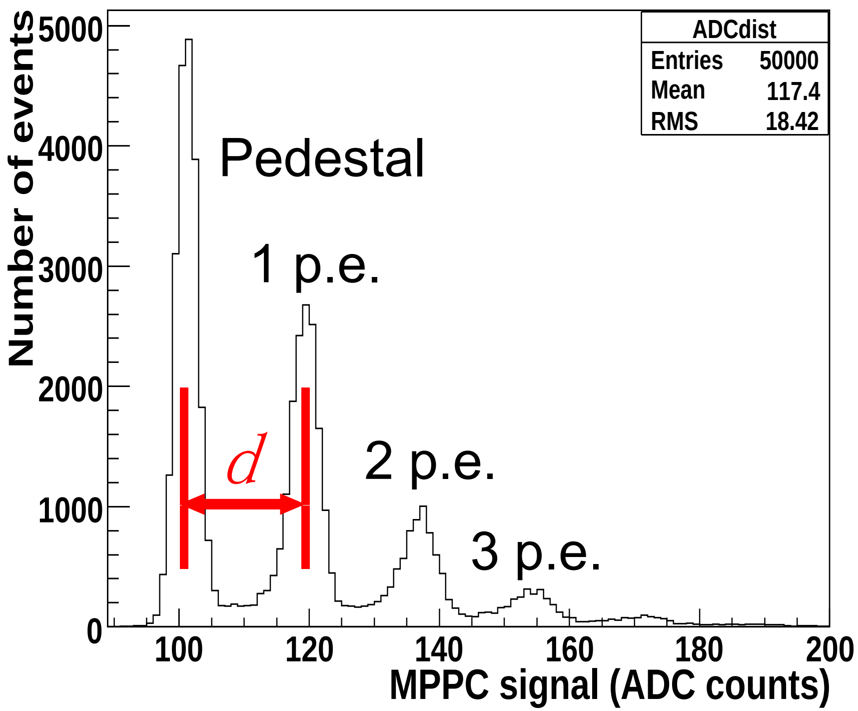
Basic performance

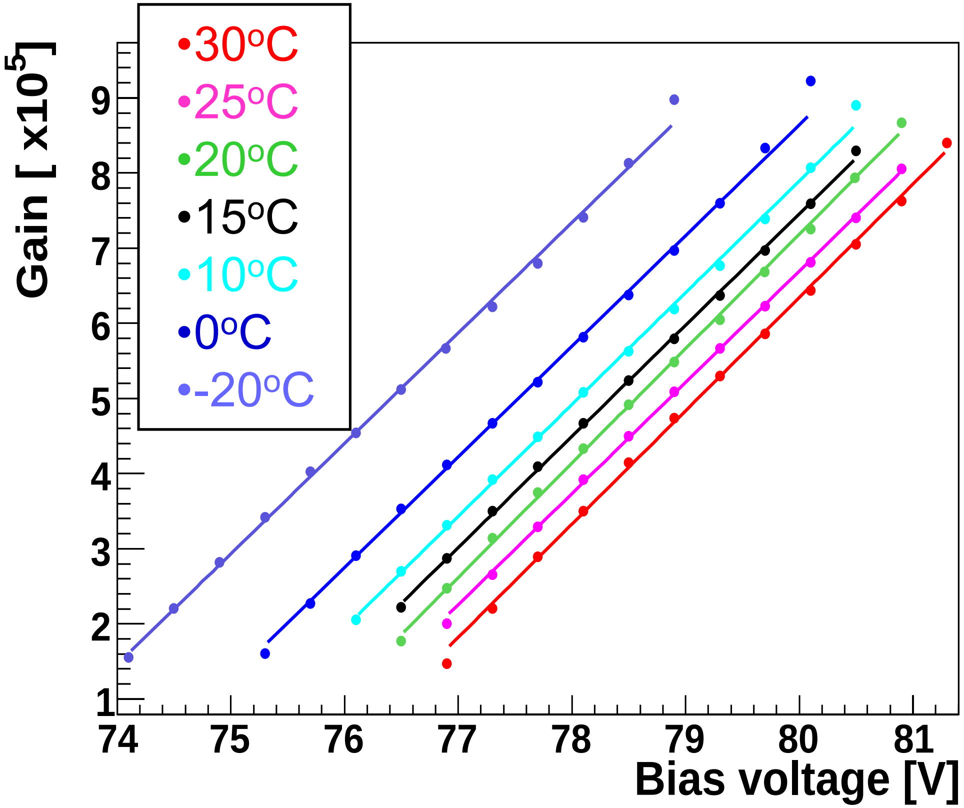
- Gain and its variation over 400 MPPCs
- Dark Noise Rate
- Cross-talk
- Photon Detection Efficiency

The MPPC Gain



$$\text{Gain} = \frac{\text{Corresponding charge to } ``d"}{e(= 1.6 \times 10^{-19})}$$





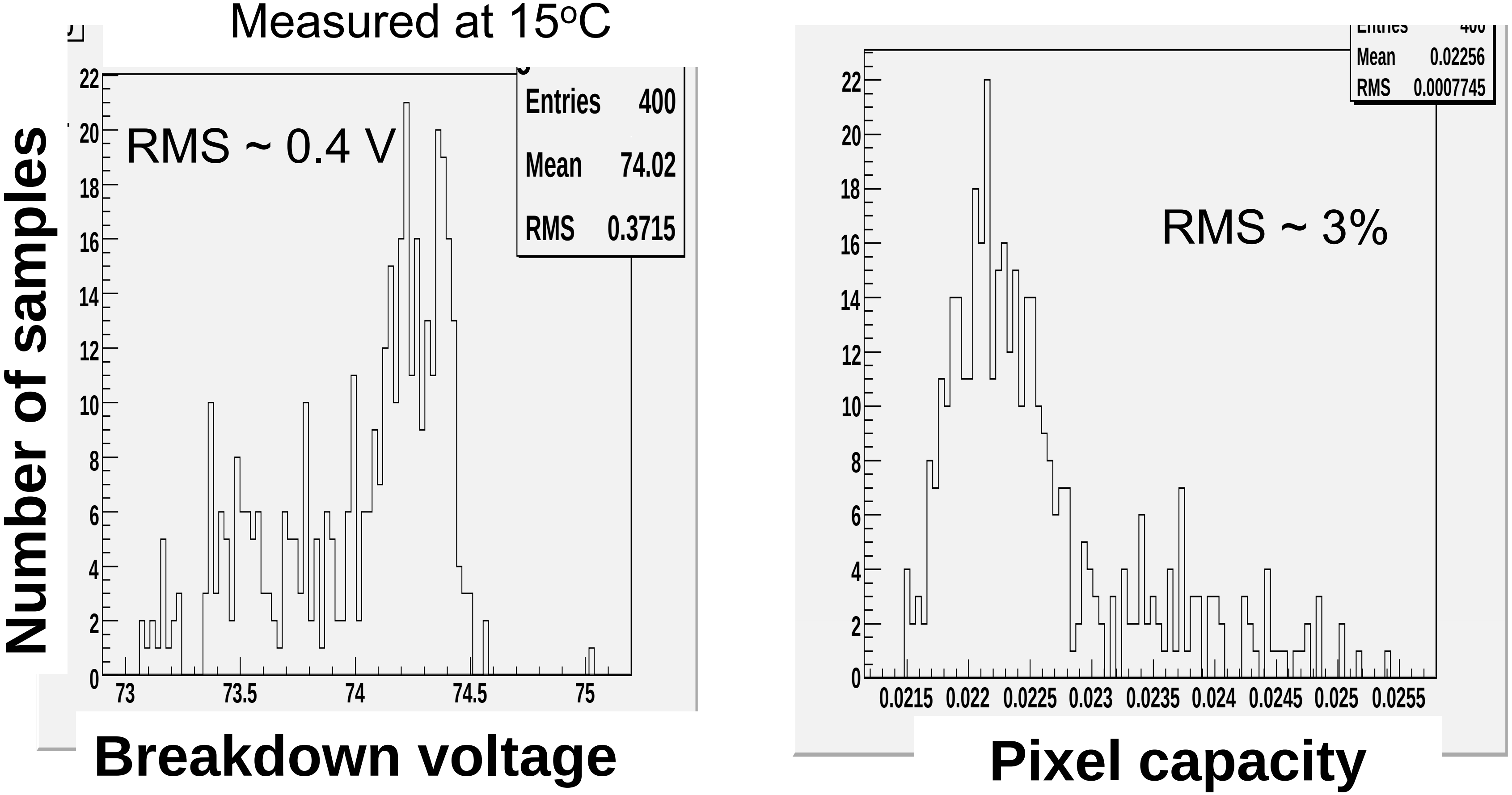
$$\text{Gain} = \frac{C}{e}\underline{(V_{bias} - V_0)}$$

Over-voltage

- C … Pixel capacity
- V_0 … Breakdown voltage

Variation of C and V_0 over 400 MPPCs

Measured at 15^{o}C

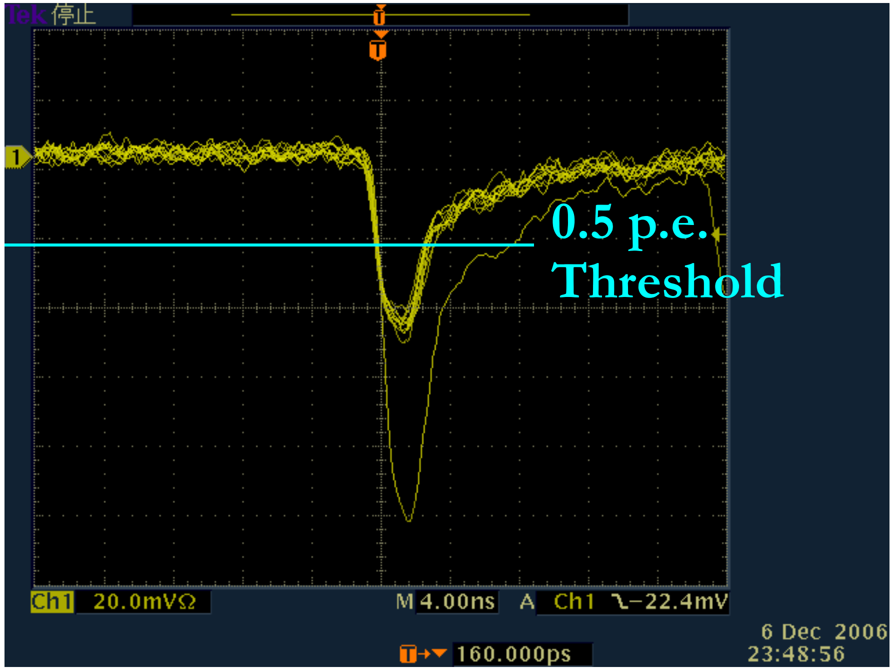


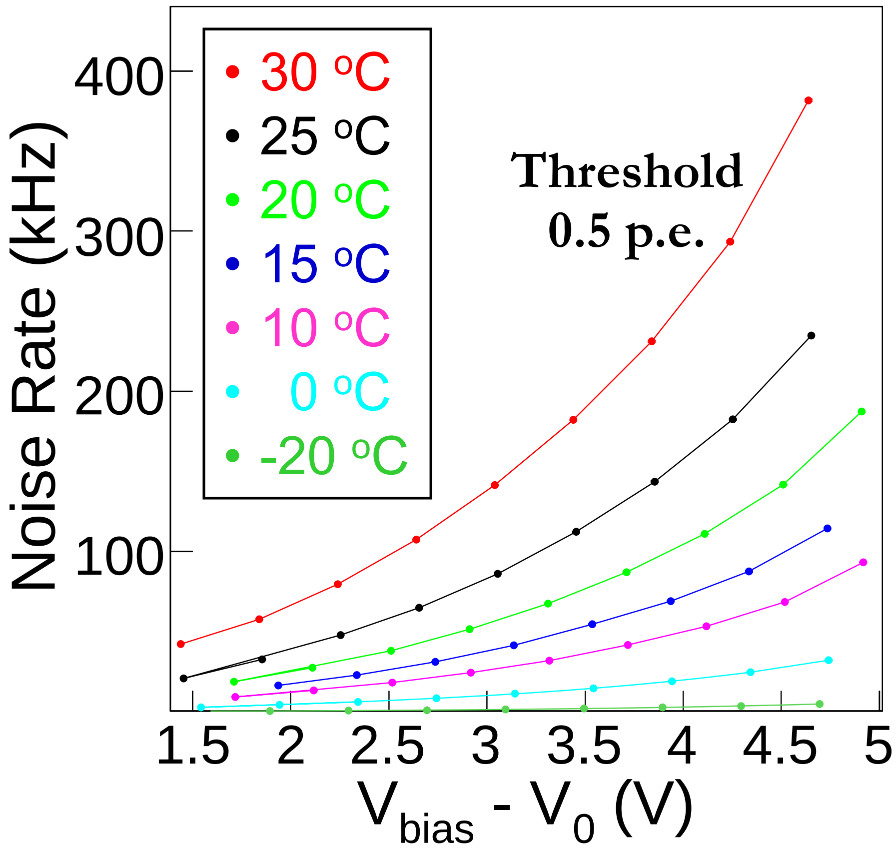
- 400 MPPCs have been delivered for a coming ECAL beamtest, and we have measured all of them.
- Obserbed variation of breakdown voltage is small enough and acceptable.

Rate of Dark Noise

Dark noise :

Avalanche signal caused by thermal electrons

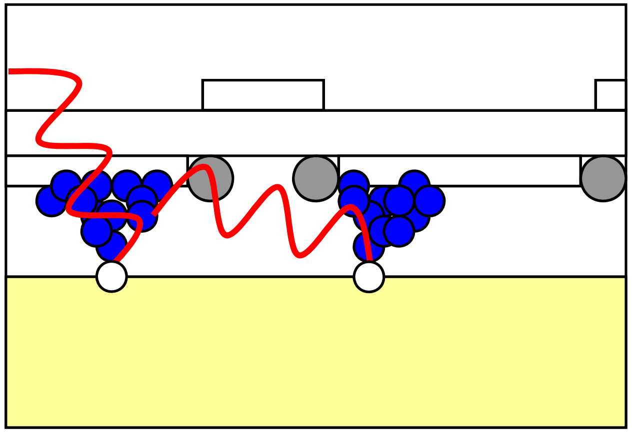




- Dark noise rate increases with over-voltage.
- It is also affected by temperature.
- Typical noise rate is order of 100 kHz with 1600 pixel MPPC.

Cross-talk

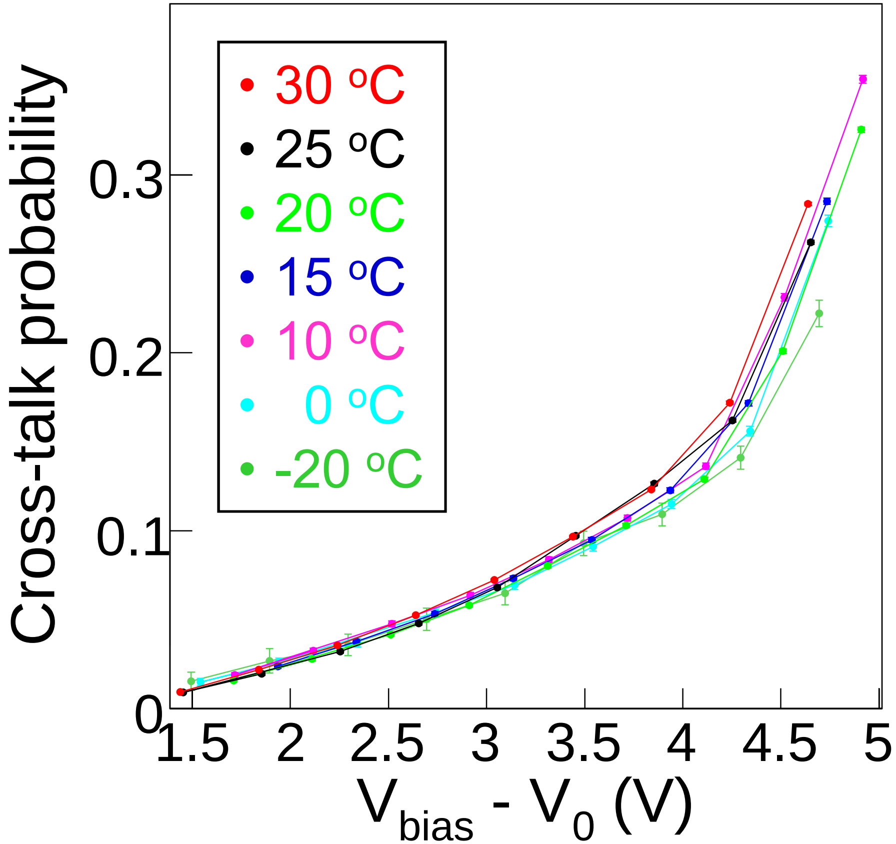
The inter-pixel cross-talk to adjacent pixels is caused by photons created in an avalanche.



Method to measure:

2 pixels fired signals in dark noise is caused by the cross-talk effect.

$$P_{crosstalk} = \frac{\text{Noise Rate(>1.5 p.e.)}}{\text{Noise Rate(>0.5 p.e.)}}$$



Cross-talk prob. increases with over-voltage, but not affected by temperature.

Photon Detection Efficiency (P.D.E)

$$\varepsilon_{MPPC} = Q.E. \times \varepsilon_{Geiger} \times \varepsilon_{geom}$$

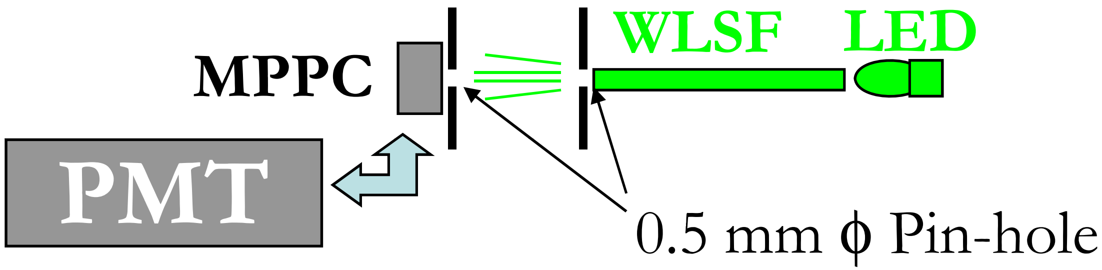
- **Q.E. : Probability of electron-hole production by single photon**
- **ε_{Geiger} : Probability that a photoelectron induces an avalanche**
- **ε_{geom} : Fraction of sensitive region in a sensor (Geometrical Efficiency)**

<u>Measurement method</u>

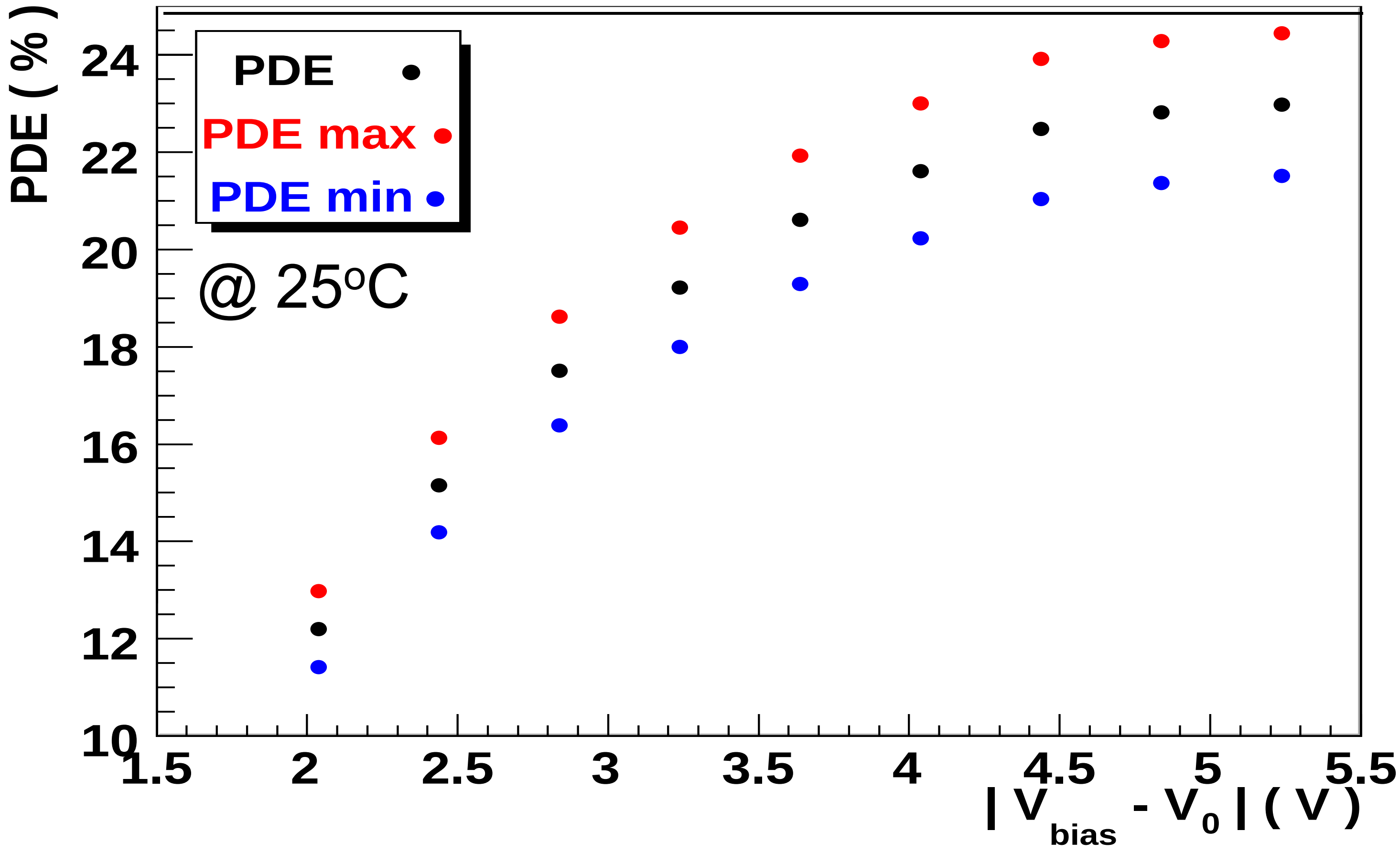
- **Inject same light pulse into both MPPC and PMT, and compare light yield measurede by MPPC and PMT.**

$$\varepsilon_{MPPC} = \frac{N_{p.e.}^{MPPC}}{N_{p.e.}^{PMT}} \boxed{\varepsilon_{PMT}}$$

~ 16 %



Photon Detection Efficiency



- P.D.E of the MPPC is ~20%, which is comparable to PMT (for 1600 pixel).
- Dominant uncertainty comes from uncertainty of PMT's P.D.E.

So the MPPC is satisfactory for the GLD calorimeter readout?

Requirements for the GLDCAL readout

- Gain: ~ at least 10^5
- Dynamic range: satisfactory to measure EM shower maximum
  - need ~5000 pixels
- Photon Detection Efficiency should be comparable to PMT to distinguish MIP signal
- Noise rate : < 1 MHz (threshold = 0.5 or 1.5 p.e)
- Small package suitable to attach to the scintillator strips
- good uniformity, small cross-talk
- Timing Resolution ~ 1 nsec
  - Necessary for bunch ID, slow neutron separation
- Should be stable against bias voltage / temperature / time
- Price !

The MPPC is feasible for the GLD calorimeter, but still need more improvements.

Improvement is ongoing

We are improving the MPPC collaborating with Hamamatsu photonics.

Evaluate performance of the MPPC prototypes

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Provide feedback, requirements and suggestions to HPK

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Improved samples from HPK

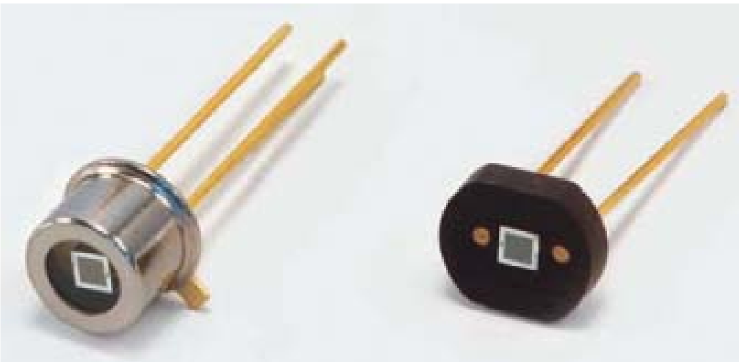
We are still improving performance of the MPPC.

In some future we will have the MPPC with sufficient performance for our requirements.

If you are interested in the MPPC …
Yes, now you can buy it !

Number of pixels	100	400	1600
Sensor size	$1 \times 1\ mm^2$		
Nominal Bias Volt.	70 ±10 V		77±10 V
Gain ($\times 10^5$)	24.0	7.5	2.75
Noise Rate (kHz)	400	270	100
Photon Detection Efficiency	65 %	50 %	25 %
Temperature dependence ($\Delta V_0/\Delta T$)	50 mV / °C		

(Numbers from HPK catalog)



- Hamamatsu is starting to deliver the MPPC. See following page for more information:

http://www.hamamatsu.com/news/2006/2006_10_26.html

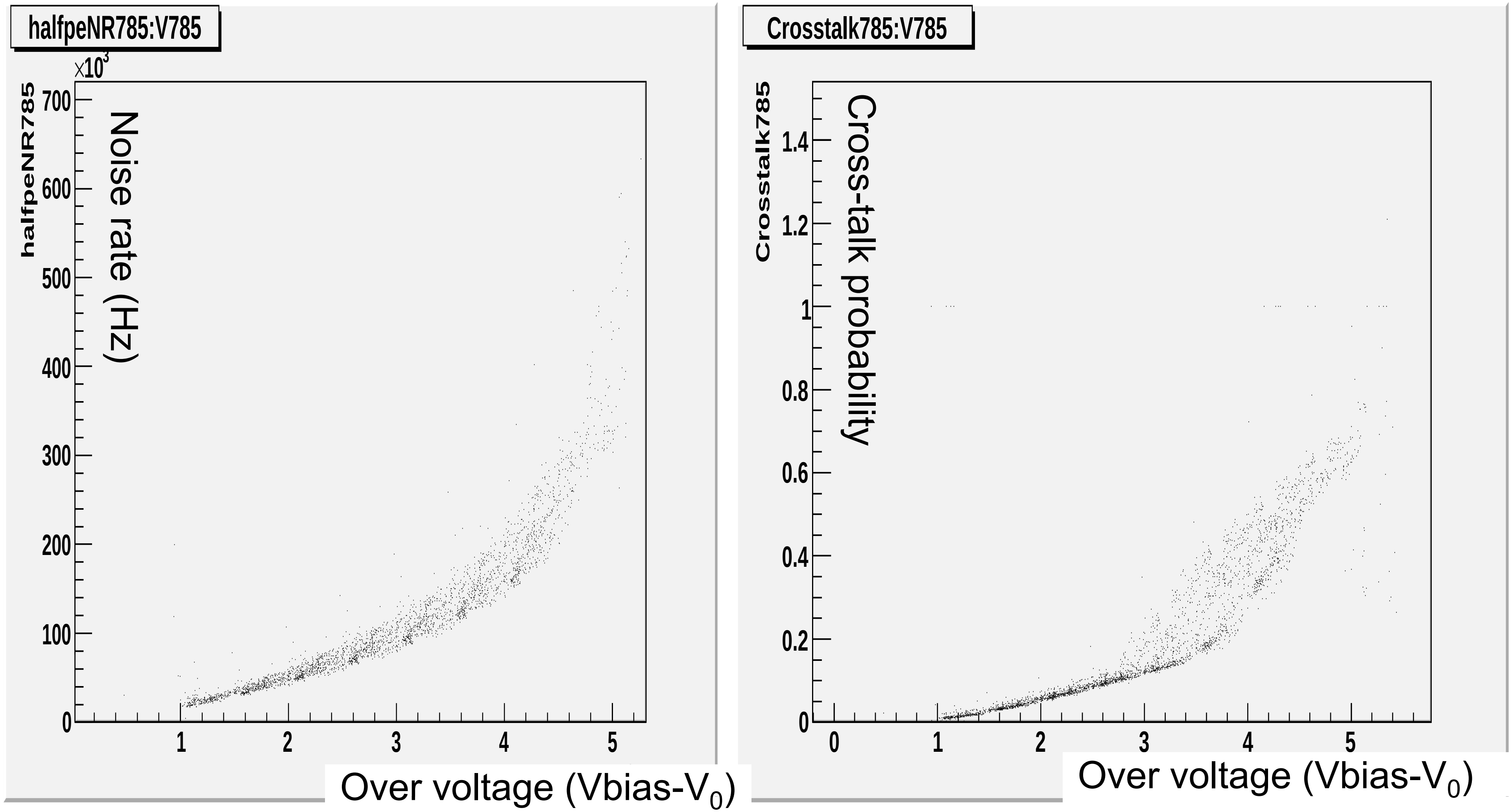
Summary

- The Multi Pixel Photon Counter is a new and promising photon sensor.
- It has many advantages comparing with photomultiplier and suitable for the GLD calorimeter readout.
- However there are still some points necessary to be improved (dynamic range, temperature dependence, etc..)
- We are improving these points with Hamamatsu photonics and we will have a sufficient performance in future.

Plans

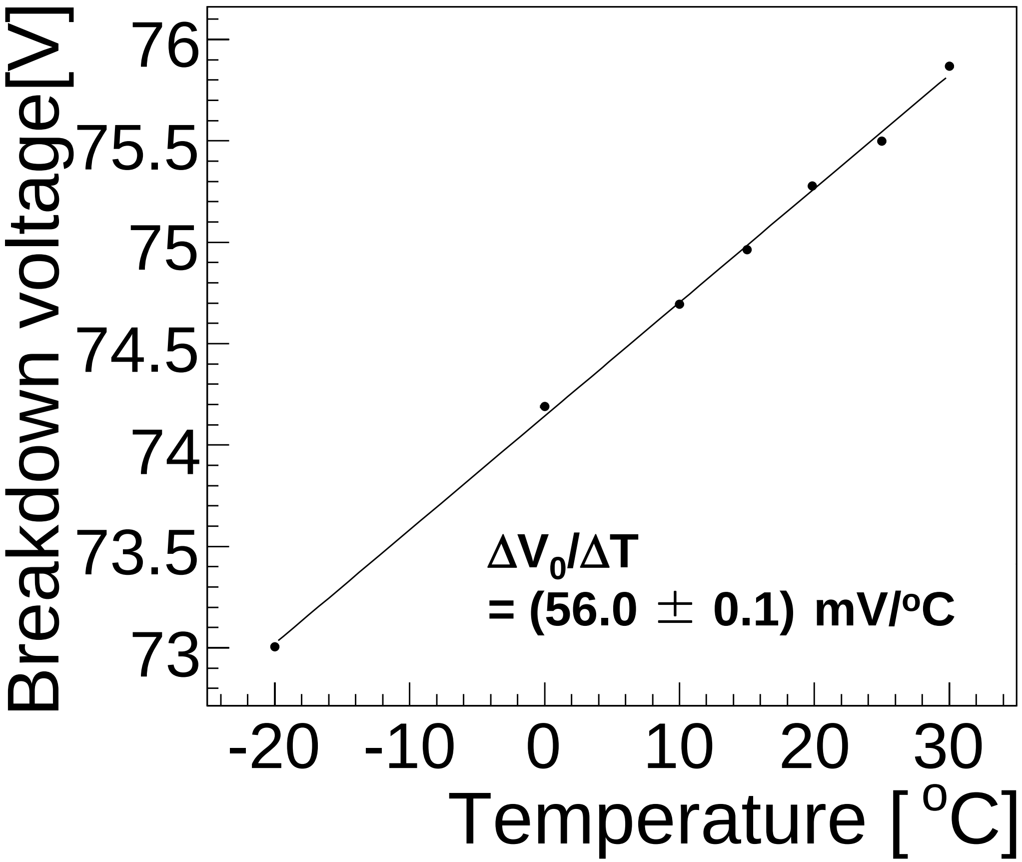
- Perform a ECAL beam test with full MPPC readout (→ next talk).
- After the beam test, we will study robustness, long-term stability, radiation hardness, magnetic field tolerance, timing resolution.
- Of course we will continue to improve the MPPC performance collaborating with Hamamatsu.

Backups



halfpeNR785:V785
×10^3
halfpeNR785
Noise rate (Hz)
700
600
500
400
300
200
100
0
1
2
3
4
5
Over voltage (Vbias-V0)
Crosstalk785:V785
Crosstalk785
Cross-talk probability
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
1
2
3
4
5
Over voltage (Vbias-V0)

Temperature dependence of V_0



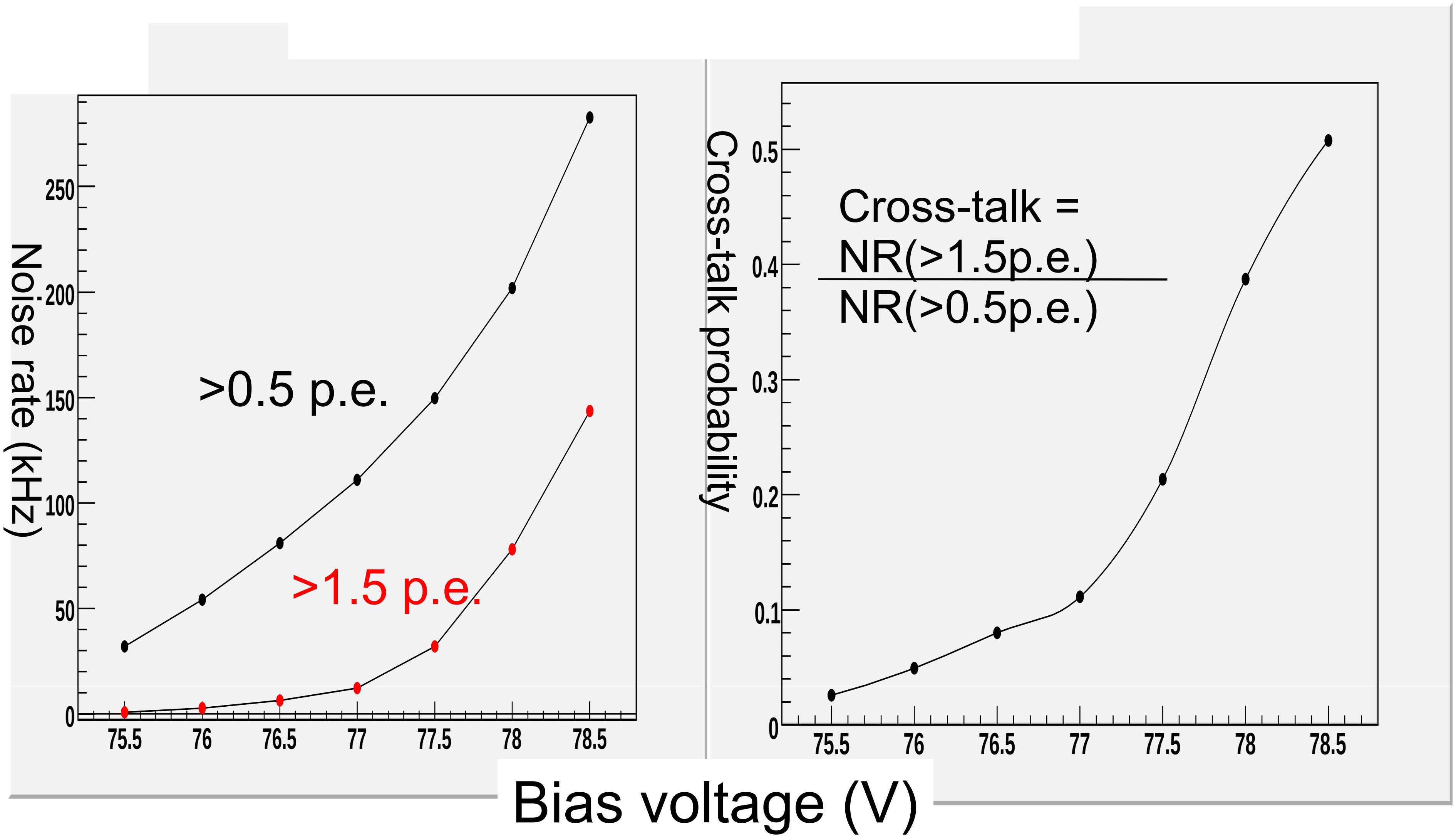
KEK Detector Technology Project Photon Sensor Group

(http://rd.kek.jp/)

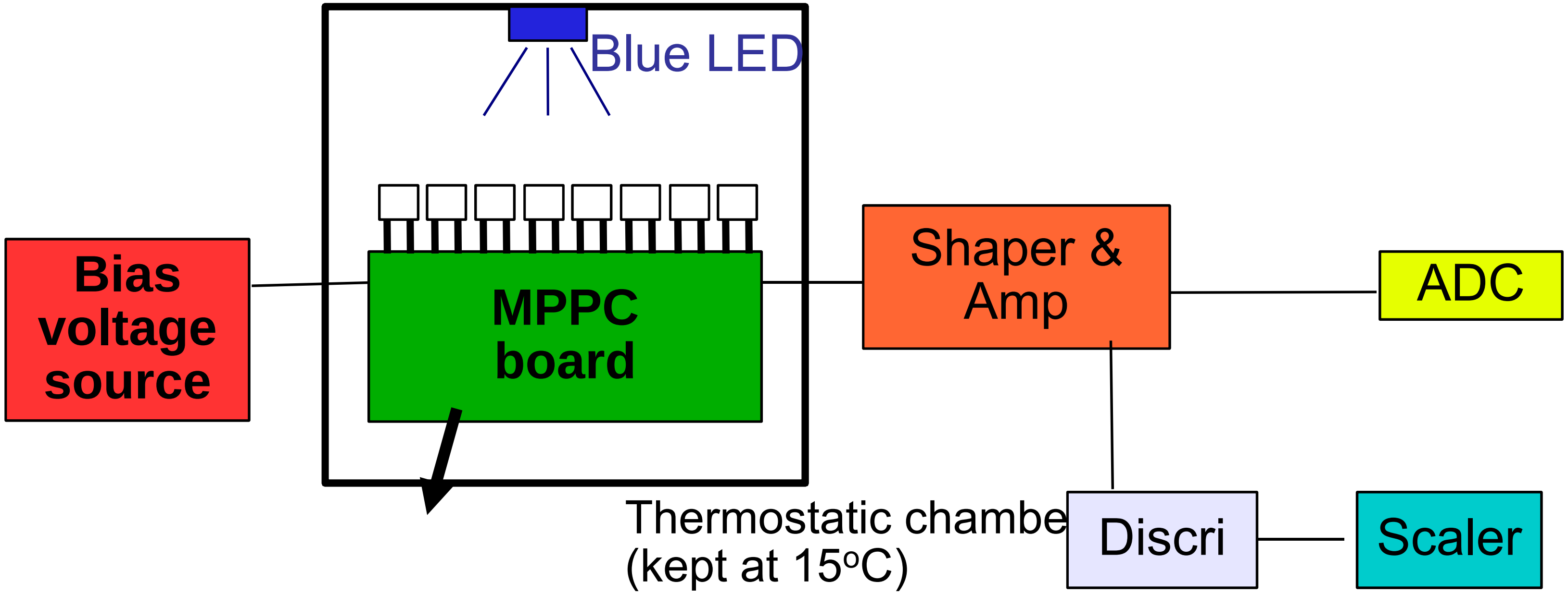
(KEK, Kobe, Kyoto, Nagoya, Nara-WU, NDA, Shinshu, Tokyo/ICEPP, Tsukuba)

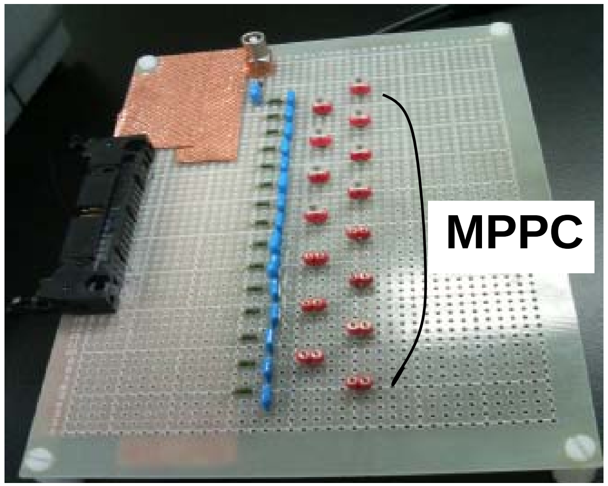
- Develop and study the MPPC with Hamamatsu
- Aiming to have satisfactory performance to use at :
  - GLD calorimeter
  - T2K near detector
  - Belle Aerogel Cerenkov Counter
- Provide important feedbacks to Hamamatsu for improvement of fundamental properties

Noise Rate, Cross-talk

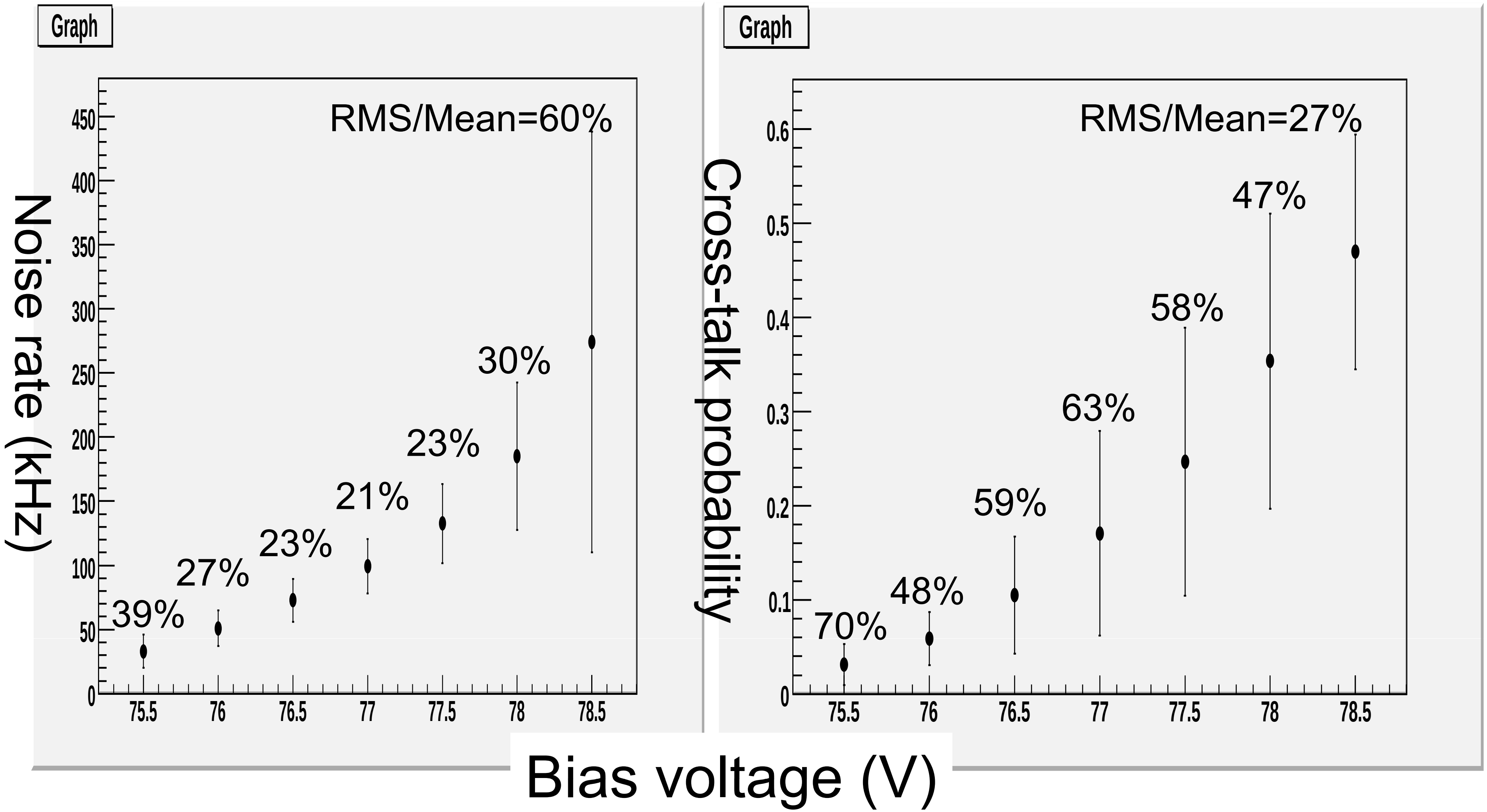


MPPC mass measurement



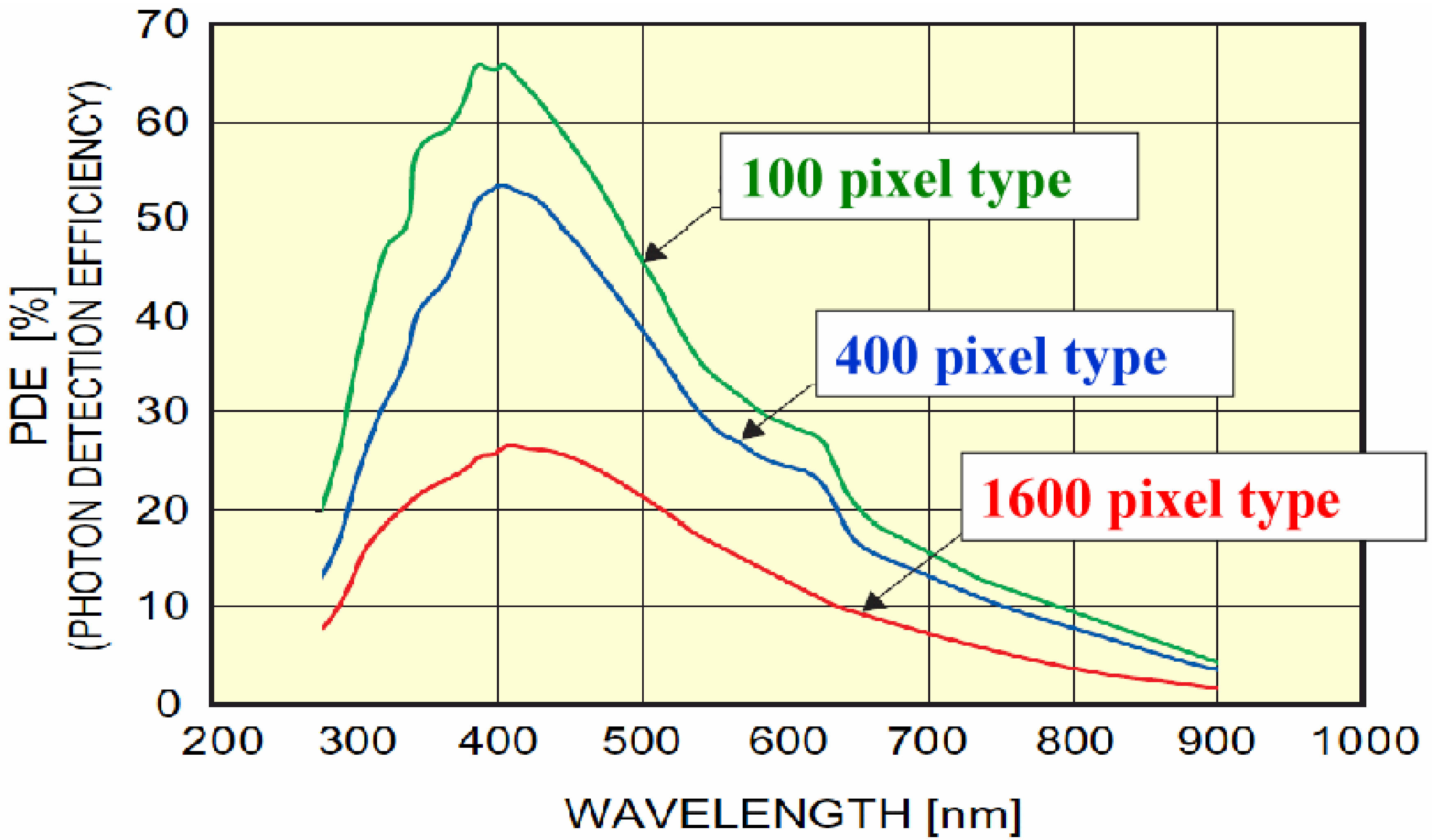


Variation of Noise Rate, Cross talk over 400 MPPCs



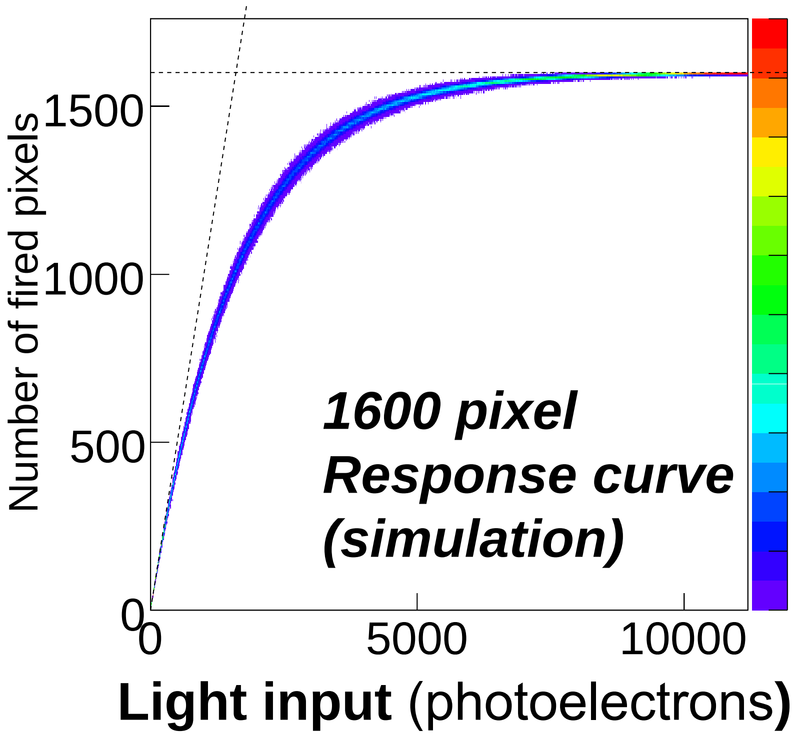
•Error bars mean variation (RMS) over 400 MPPCs

Photon Detection Efficiency by Hamamatsu



=400nm, including the cross-talk and after pulse

Need More Dynamic Range !



- The MPPC is a non-linear device.
- One pixel can count only one photon, even if there are 2 or more photons injected.
- Need to increase number of pixels to improve the dynamic range. (currently 1600 pixels is maximum)

About 5000 pixels is necessary to measure high energy electromagnetic shower maximum

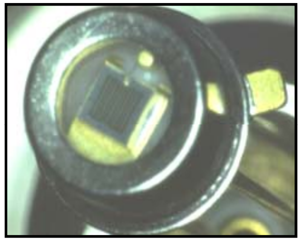
The MPPC is drastically evolving …

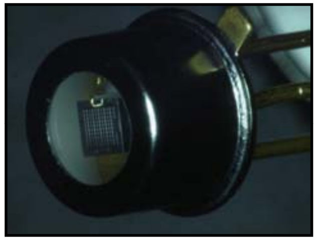
Mar. 2005
- 100/400 pixels
- First sample from Hamamatsu

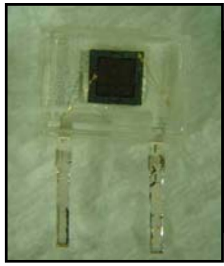
Jan. 2006
- 100/400/1600 pixels
- Smaller pixel size results in more number of pixels

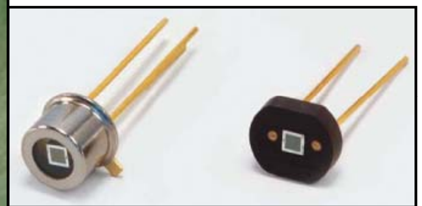
Oct. 2006
- 100/400/1600 pixels commercialized
- Improved Gain and dark noise

Sometime in future
- Larger sensor area
- More number of pixels
- And perhaps more…









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