Study of the MPPC for the GLD Calorimeter readout

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for the GLD Calorimeter Group

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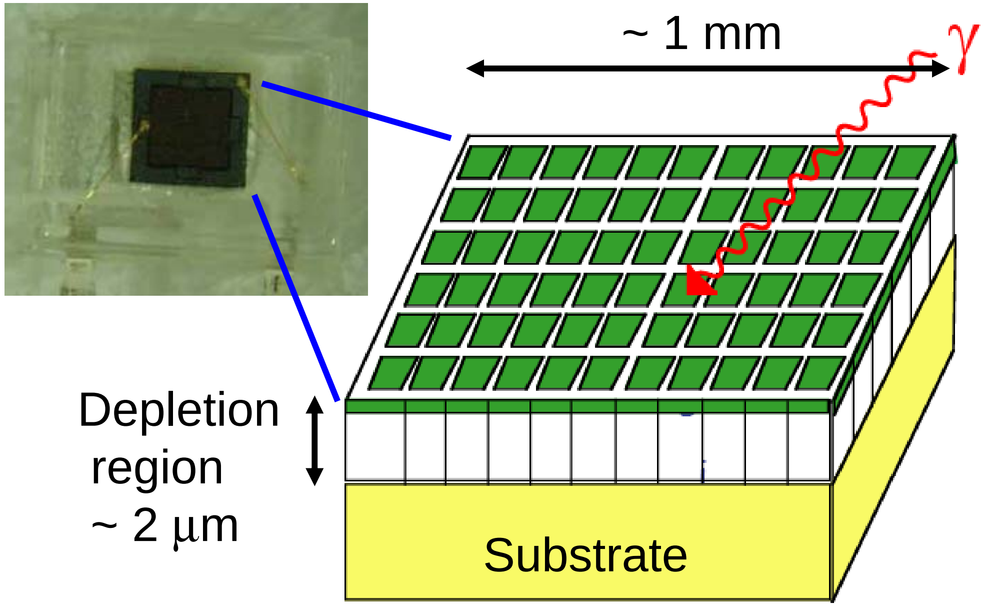
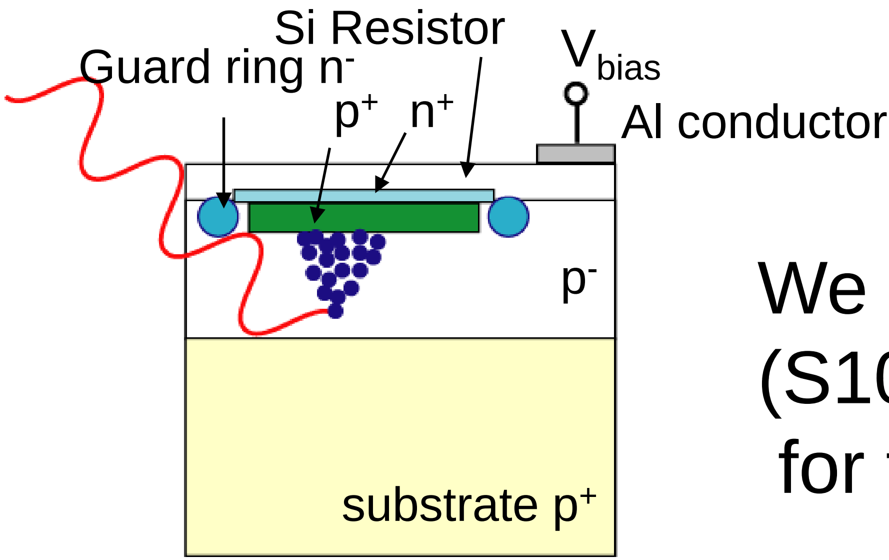
- Introduction
- Basic performances and Variation among 800 MPPCs
- Response curve & Recovery time
- Summary & Plans

The Multi Pixel Photon Counter (MPPC)

- A Geiger-mode avalanche photo-diode -





- High Gain (10^5~10^6)
- Good Photon Detection Efficiency (~15% with 1600 pixel)
- Compact (package size ~ a few mm)
- Low Cost
- Insensitive to magnetic field
- High dark noise (order of 100 kHz)
- Input vs output is non-linear

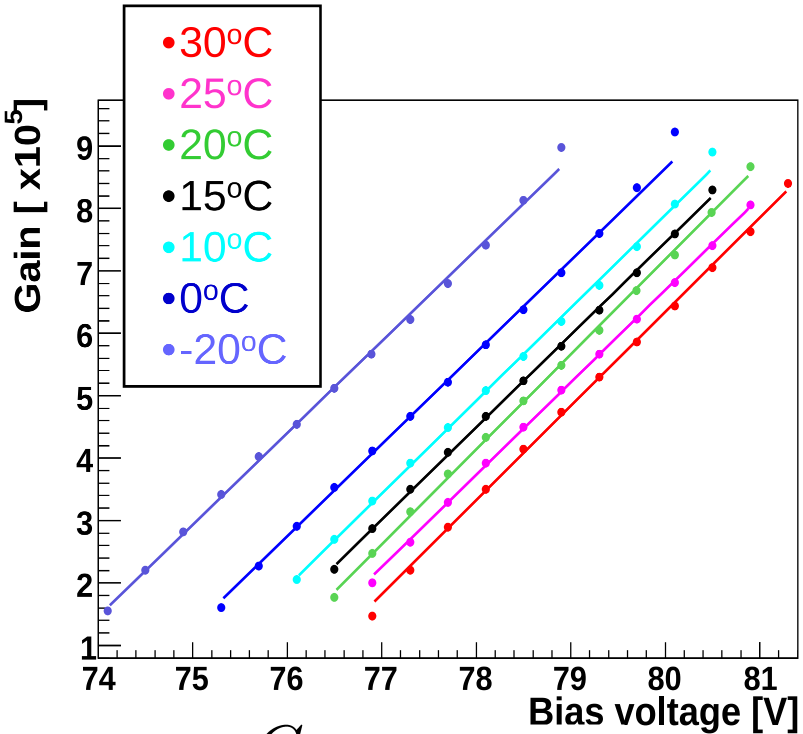
We are testing 1600 pixel MPPC (S10362-11-025MK) for the Scintillator-ECAL readout.

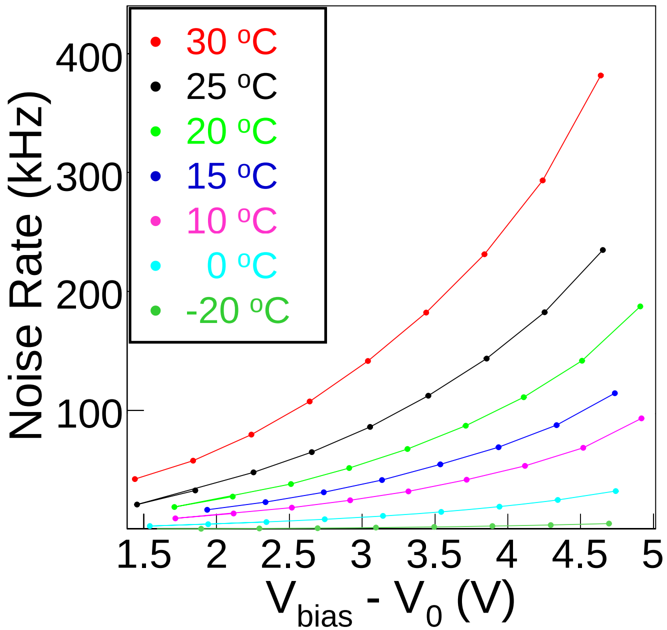
Required performance for the Calorimeter

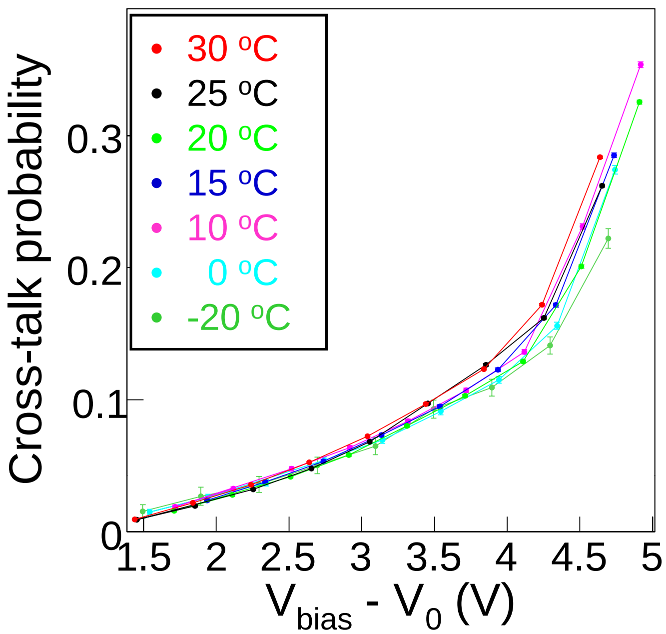
- Gain: ~ Best to have 10^6 , at least 10^5
- Dynamic range: capable to measure ~1000 p.e.
  - MPPC is non-linear device
  - Number of pixels and shape of response curve are important
- Photon detection efficiency enough to distinguish MIP signal
- Dark noise rate : < 1 MHz

- good uniformity, small cross-talk
- Timing Resolution ~ 1 nsec
  - Necessary for bunch ID, slow neutron separation
- Stable against bias voltage / temperature / time
- No influence with 3 T magnetic field
- Radiation hardness

Gain, Dark Noise Rate, Cross-talk







$$\text{Gain} = \frac{C}{e}\underbrace{(V_{bias} - V_0)}_{\textbf{Over-voltage}}$$

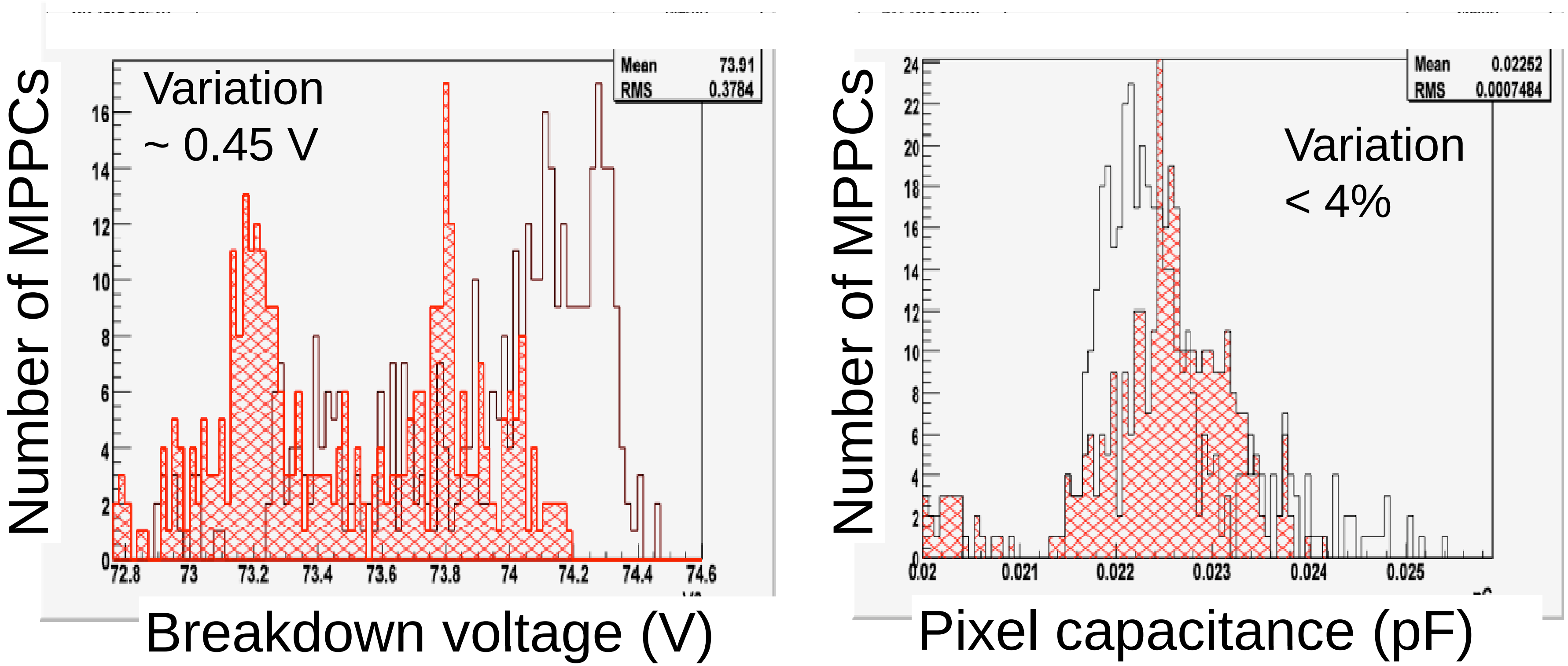
- C ... Pixel capacity
- V_0 ... Breakdown voltage

- Basic performances are almost OK.
- Further improvements is still ongoing.

Variation of Gain over 800 MPPCs

800 MPPCs have been measured.

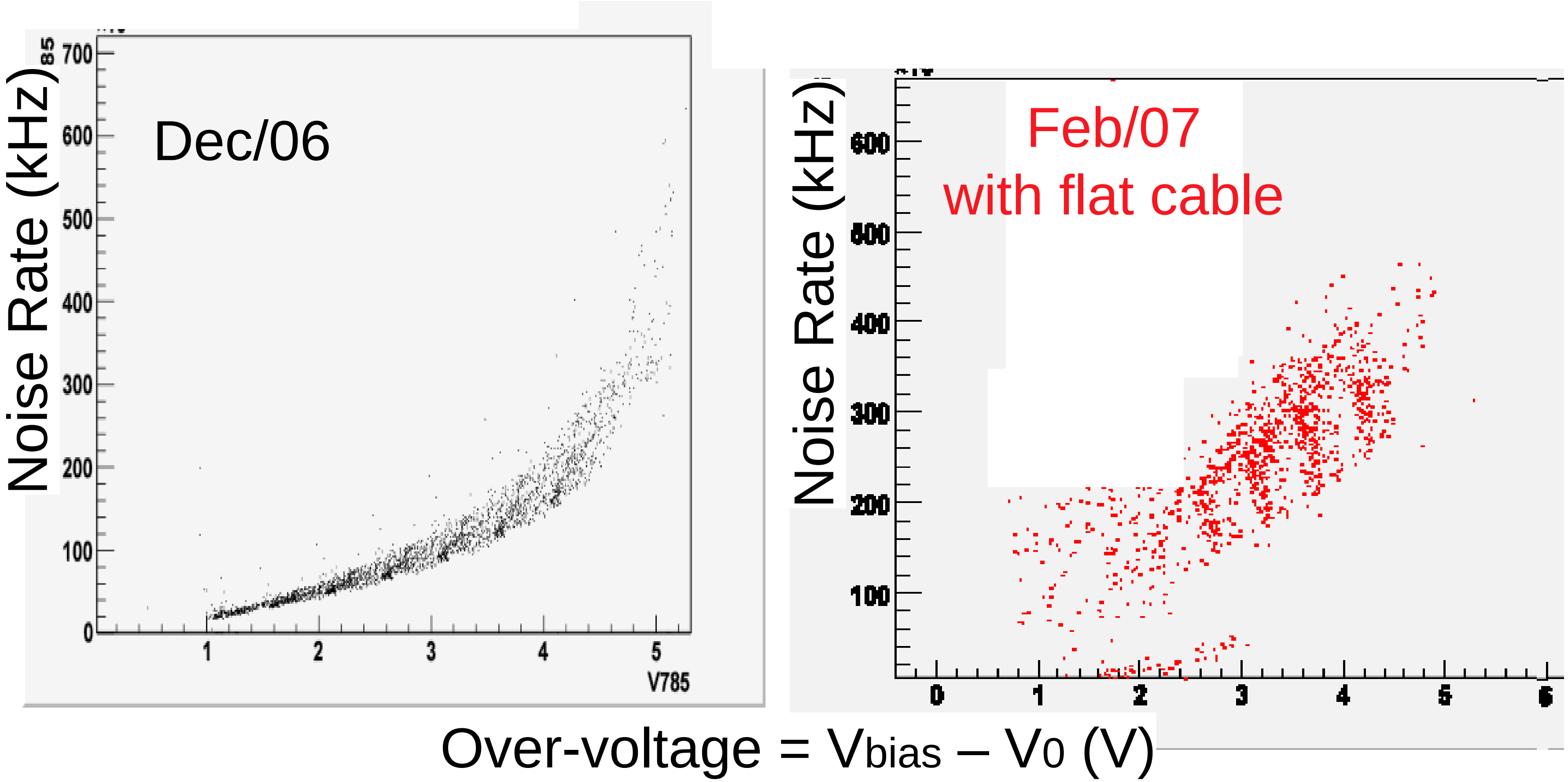
- 451 MPPCs : Dec-28 2006 ... All measured.
- 351 MPPCs : Feb-8 2007 … Measured after soldered to flat cable.



- Device-by-device variation is less than a few %.

→ No need for further selection or categorization on massive use !
Just need a small tuning of operation voltages.

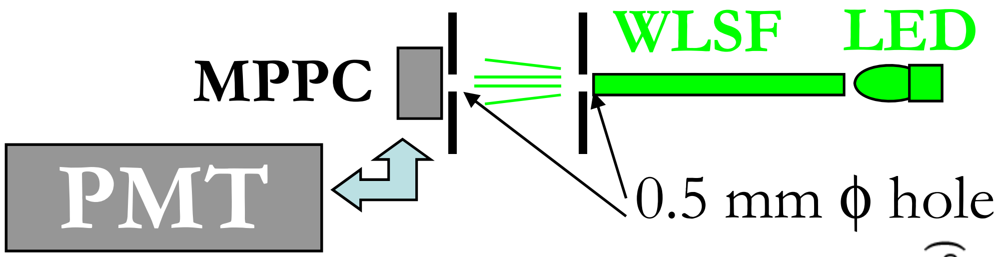
Variation of Dark Noise over 800 MPPCs



- Noise rate is far less than 1 MHz with all the samples.
- Device-by-device variation is order of ~10 %.

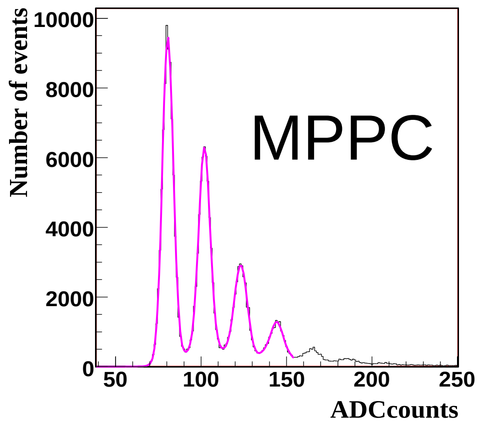
Photon Detection Efficiency

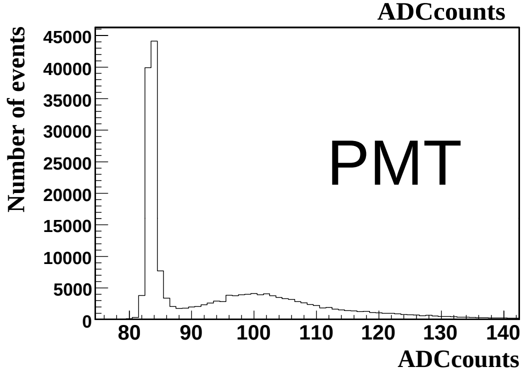
Measured by njecting same light pulse into both MPPC and PMT, and comparing light yield.

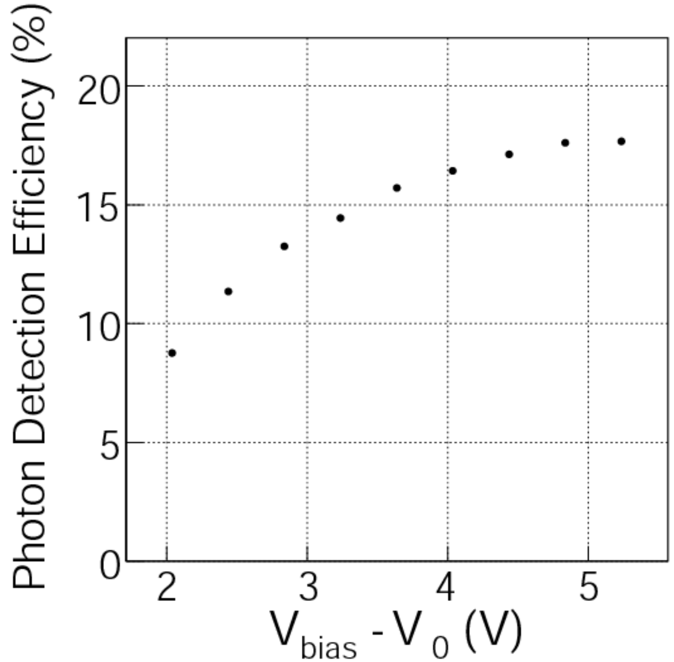


$$PDE_{MPPC} = \frac{N_{p.e.}^{MPPC}}{N_{p.e.}^{PMT}} \boxed{PDE_{PMT}}$$

~ 16 %

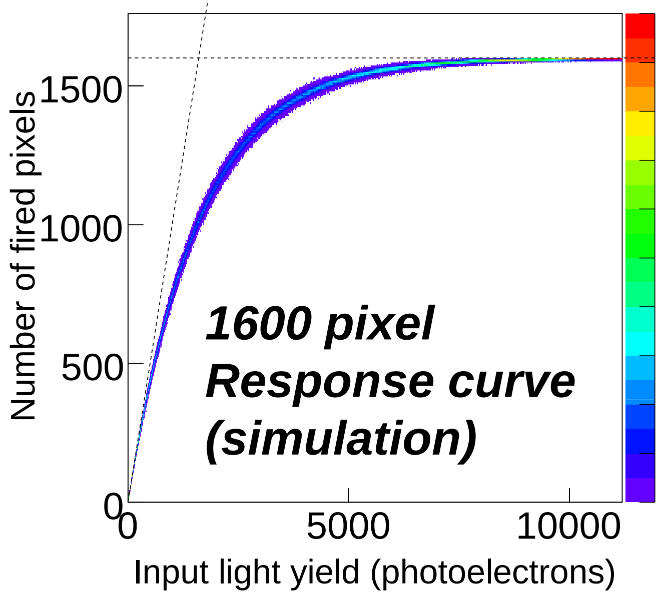


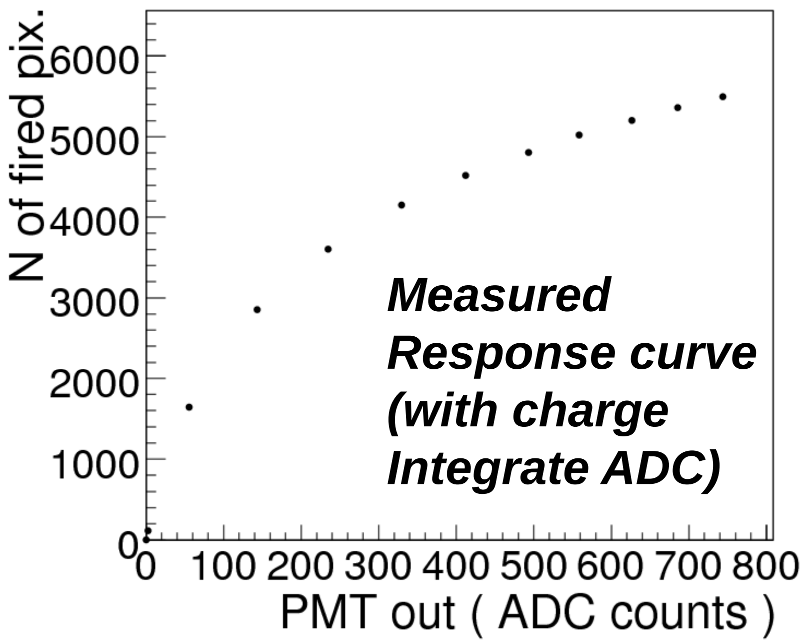




The 1600-pixel MPPC has comparable P.D.E. with normal photomultipliers (15~20%).

Saturation effect

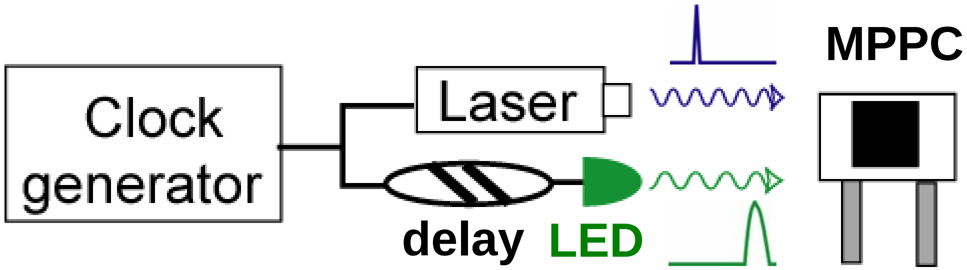




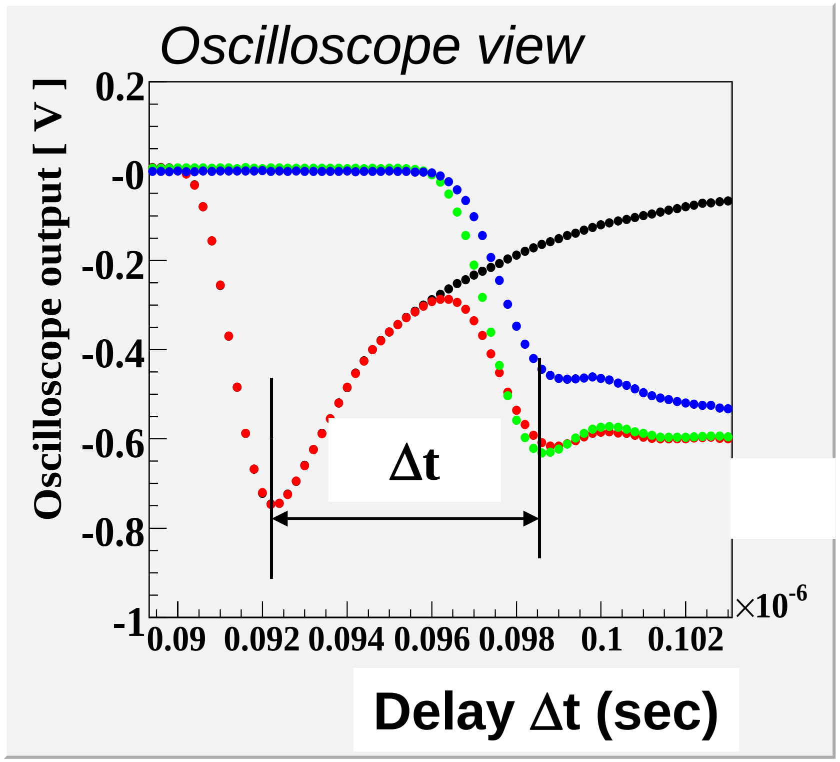
- The MPPC is a non-linear device.
- Response to input light can be theoretically calculated as :

  $N_{\text{fired}} = N_{\text{pix}}(1 - e^{-N_{\text{pe}}/N_{\text{pix}}})$
- However observed response curve has quite different shape.
- One pixel fire the signal twice due to quick recovery ?

Recovery Time Measurement



- Inject strong laser (width=52 ps) into the MPPC
- After delay of Δt, inject strong LED light pulse and measure MPPC pulse height.
- Compare the MPPC output for the LED pulse between with and without the first laser pulse.



Black … MPPC output for Laser pulse

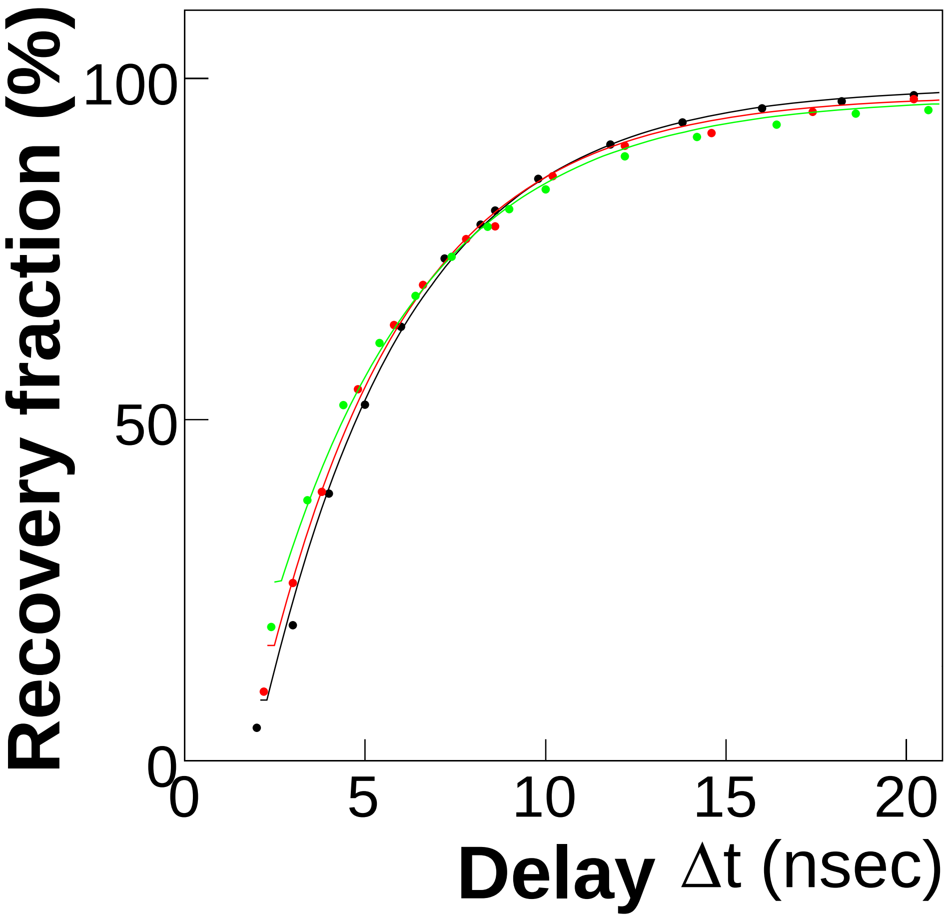
Green … MPPC output for LED pulse

Red … Laser + LED

Blue … (Laser+LED) - Laser

Ratio of Blue / Green shows recovery fraction.

Recovery Time Result



The curve is fit with a function

$$f(\Delta t) = A(1 - e^{-(\Delta t - t_D)/\tau})$$

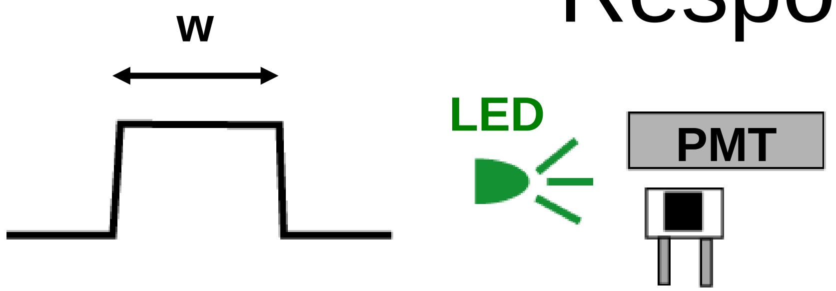
t_D : dead time

τ : recovery time

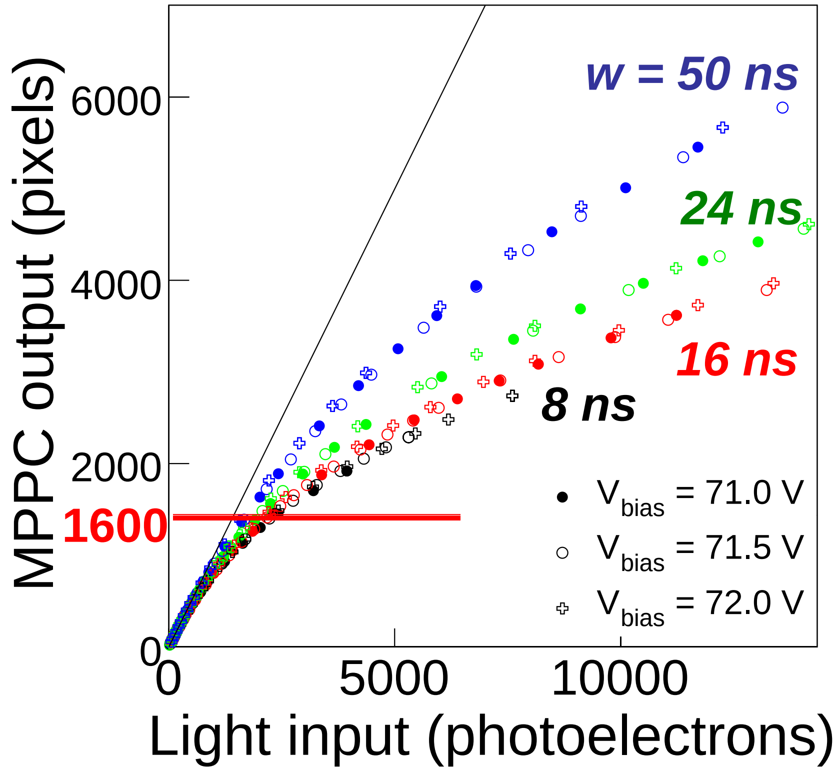
V_{bias} (V)	τ (nsec)	t_D (nsec)
71.0	4.1 ± 0.1	1.9 ± 0.1
71.5	4.0 ± 0.1	1.7 ± 0.1
72.0	4.2 ± 0.1	1.3 ± 0.1

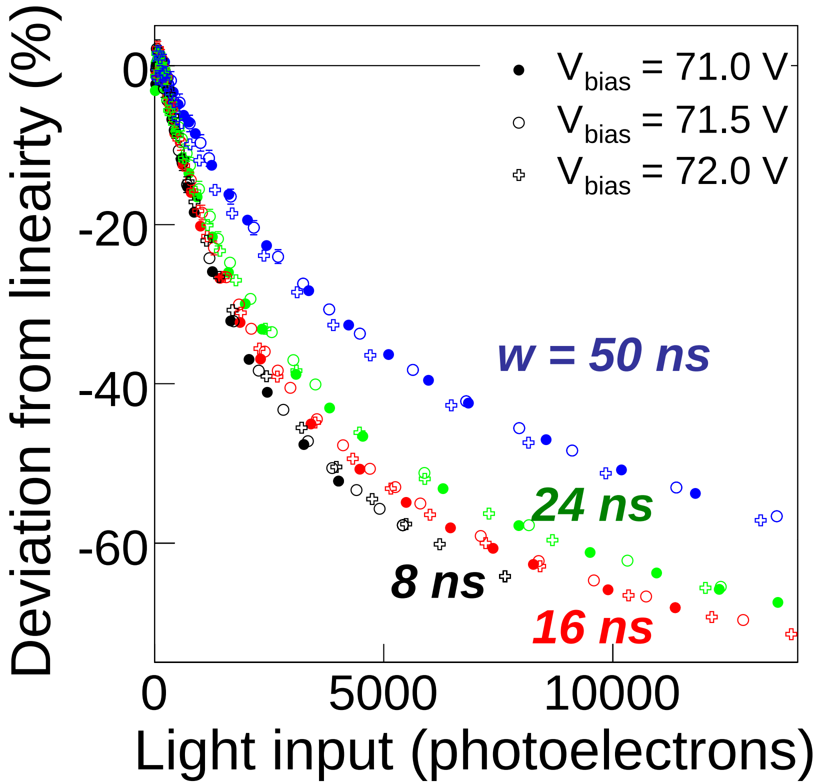
- Recovery time of the 1600-pixel MPPC is measured to be 4 ns.
- Shape does not depend on bias voltage.

Response Curve



Response curves taken with various width of LED light pulses





- Linearity is not limited by number of pixels thanks to quick recovery !
- No significant influence from changing bias voltage.
- Time structure of the light pulse gives large effects in non-linear region.
- Knowing time structure of input light is important.

Summary

- We are testing the 1600-pixel MPPC for the GLD calorimeter .
- Measured performance is almost sufficient for the requirement
  - Comparable gain / P.D.E. with photomultipliers.
  - Low noise rate (~100kHz) comparing with SiPMs.
- Variation of gain and noise rate among 800 samples are small enough (<10%).
- We already entered to a stage of practical application (see SCECAL beam test talk by Daniel)
- Study of the response curve is currently underway.

Plans

- Establish method to correct for saturation effect with strip scintillators.
- Study robustness, long-term stability, radiation hardness, magnetic field tolerance, timing resolution.
- Continue to improve the MPPC (temperature dependence, cross-talk, etc…) collaborating with Hamamatsu.

Backups

The GLD Calorimeter

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

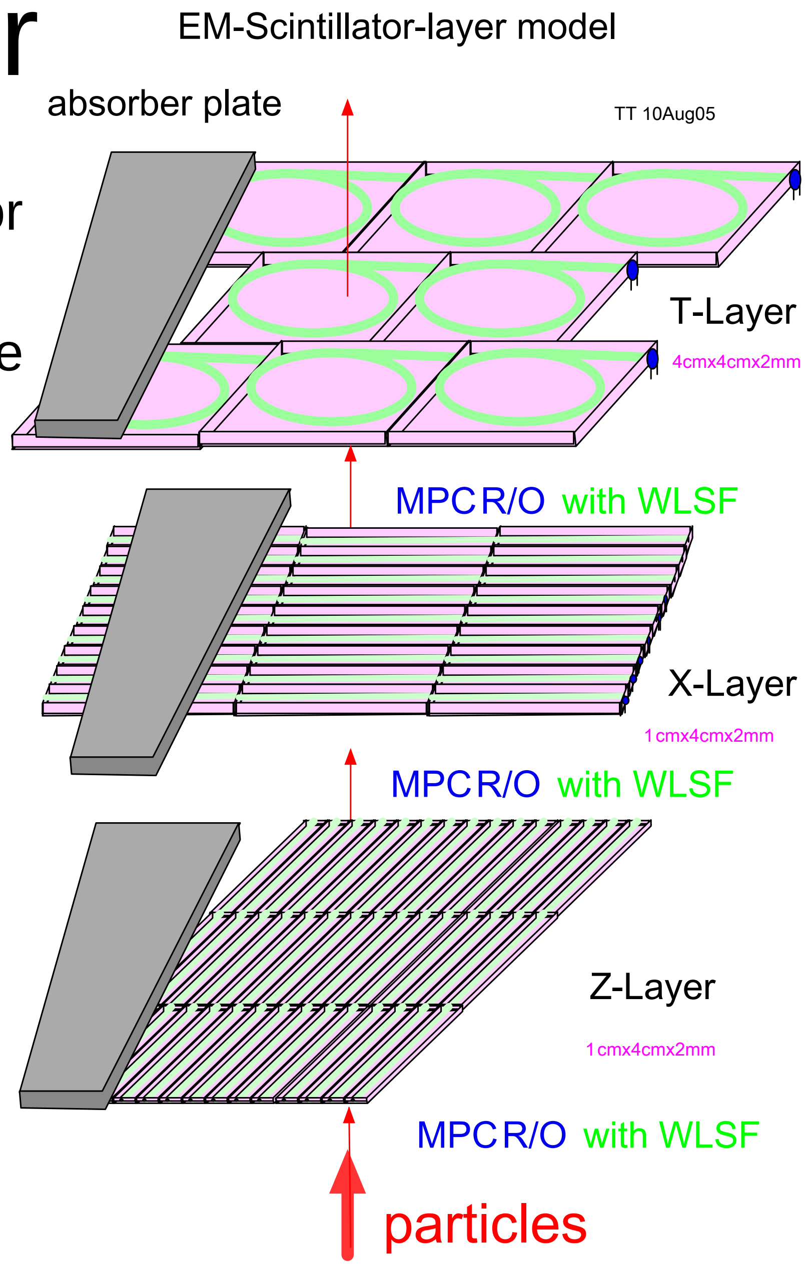
↓

- Fine granularity with strip/tile scintillator

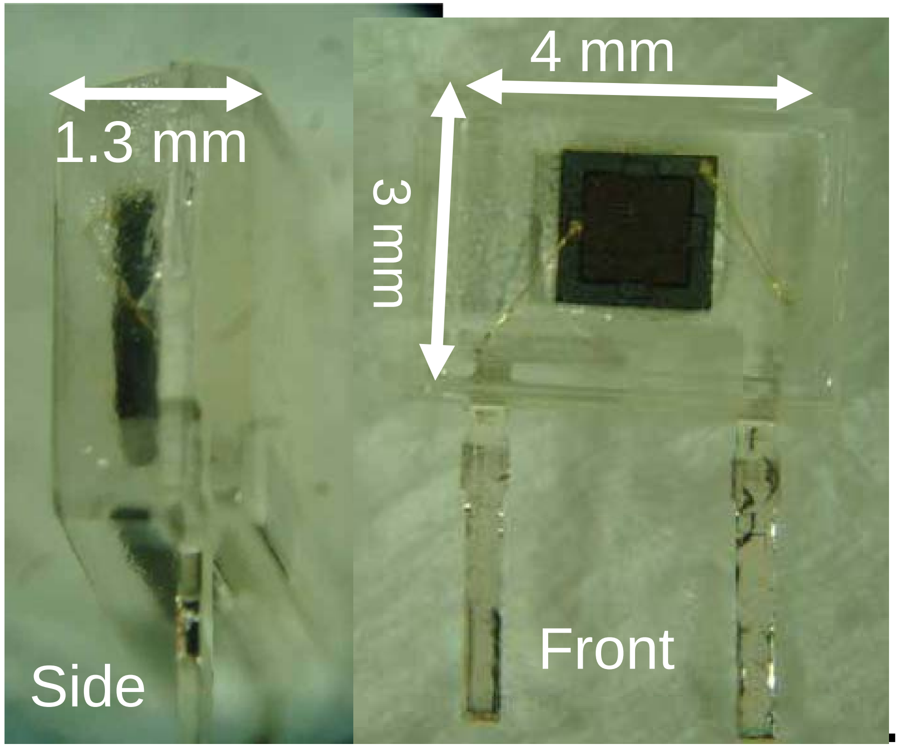
↓

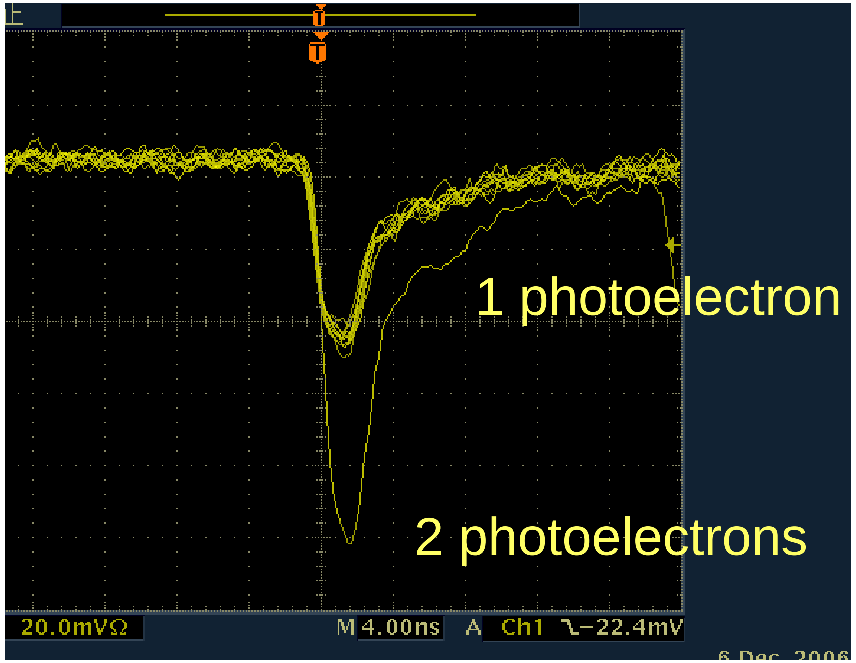
- Huge number of readout channels
  - ~10M (ECAL) + 4M (HCAL) !
  - 10K for muon detector
- Used inside 3 Tesla solenoid

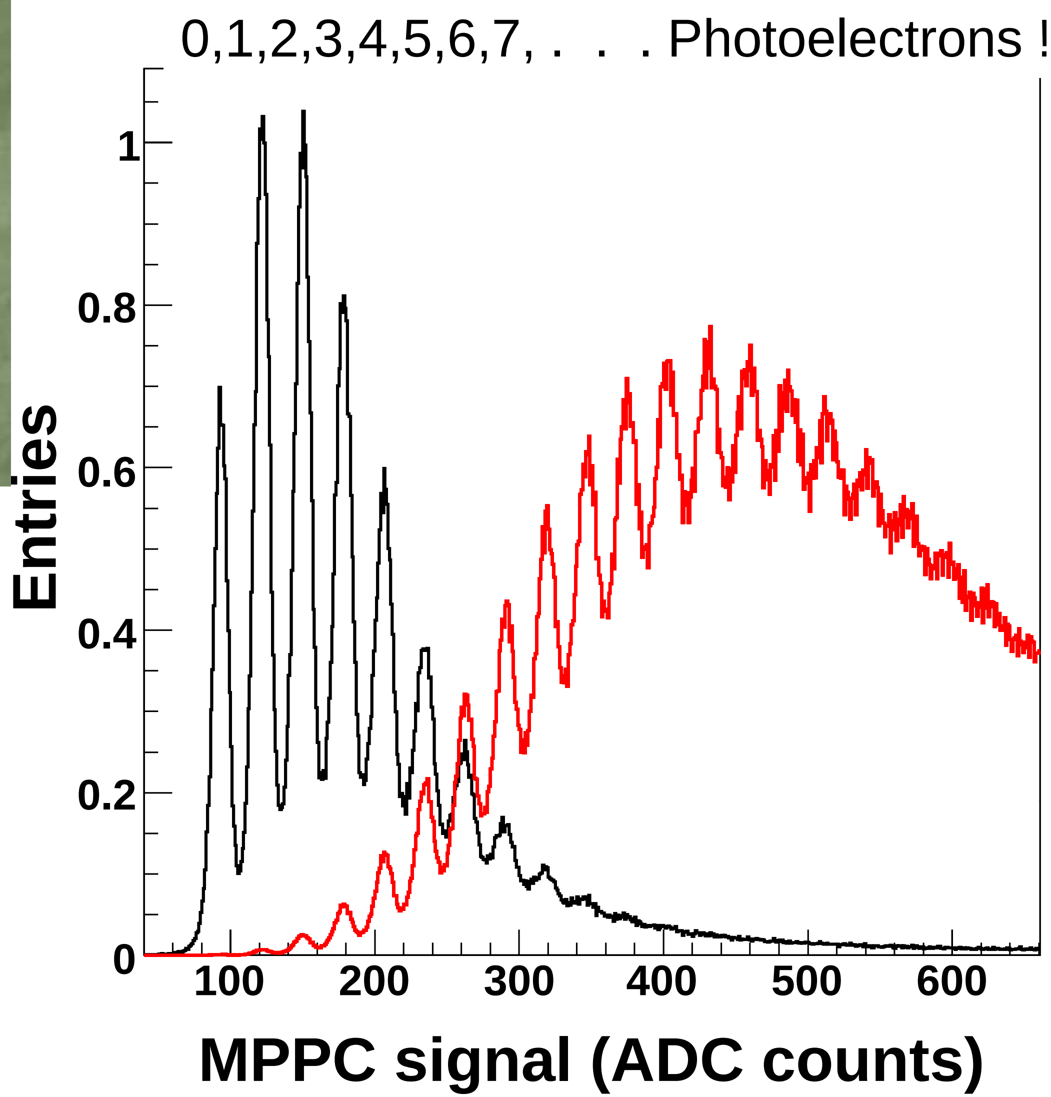
Need a new photon sensor which is compact and low-cost, and has enough performance.



Excellent photon counting ability







The MPPC has lots of advantages

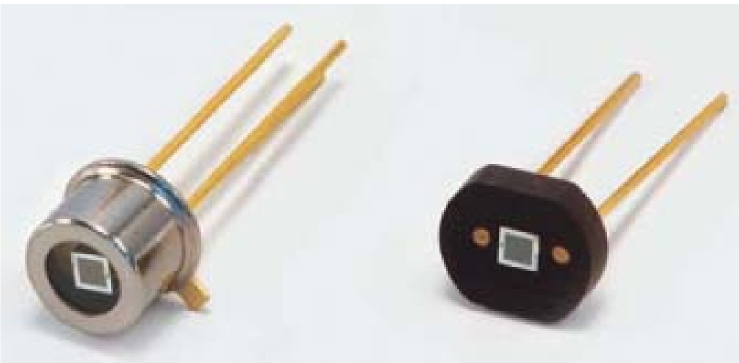
	Photomultiplier	MPPC
Gain	~10^6	10^5~10^6
Photon Detection Eff.	0.1 ~ 0.2	~0.2 for 1600 pix. MPPC
Response	fast	fast
Photon counting	Yes	Great
Bias voltage	~ 1000 V	~ 70 V
Size	Small	Compact
B field	Sensitive	Insensitive
Cost	Very expensive !	Not very expensive
Dynamic range	Good	Determined by # of pixels
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 !

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

Number of pixels	100	400	1600
Sensor size	1 x 1 mm^2		
Nominal Bias Volt.	70 ±10 V		77±10 V
Gain (x 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 / ^{o}C		

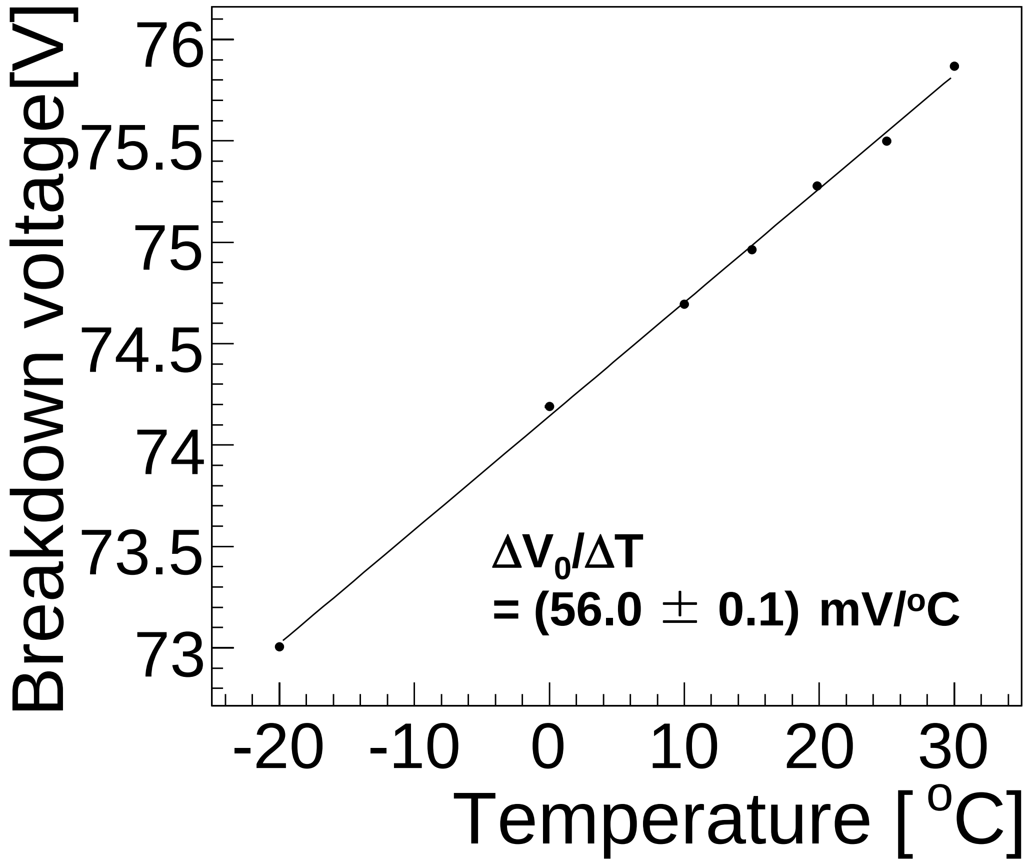
(Numbers from HPK catalog)



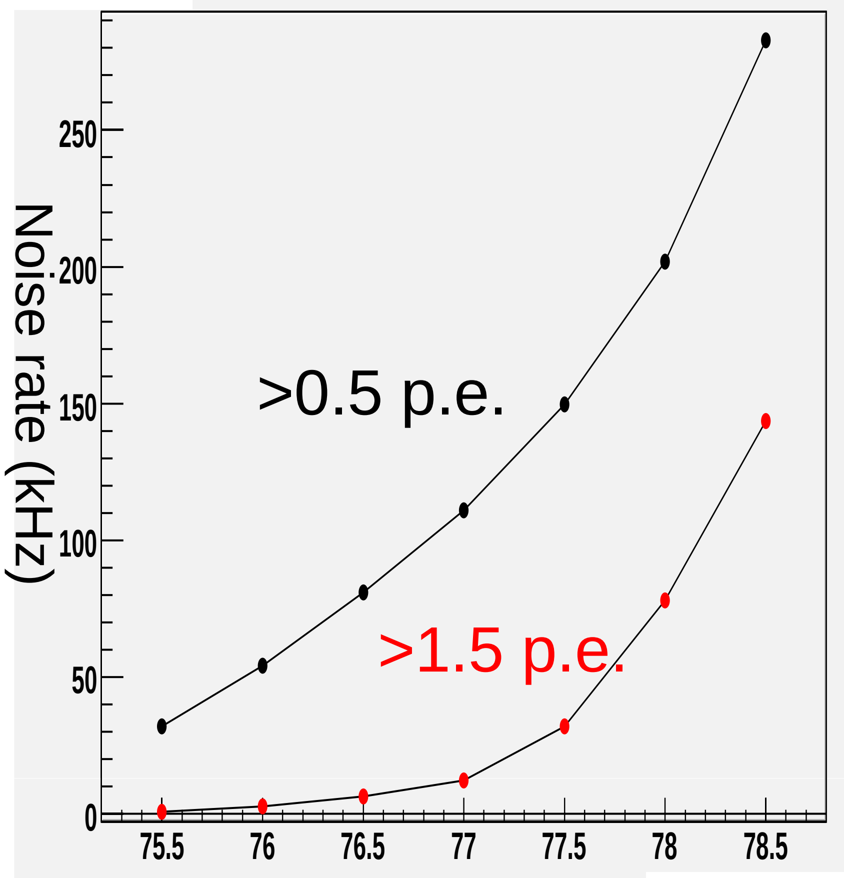
- Hamamatsu is starting to deliver the MPPC. See following page for more information:

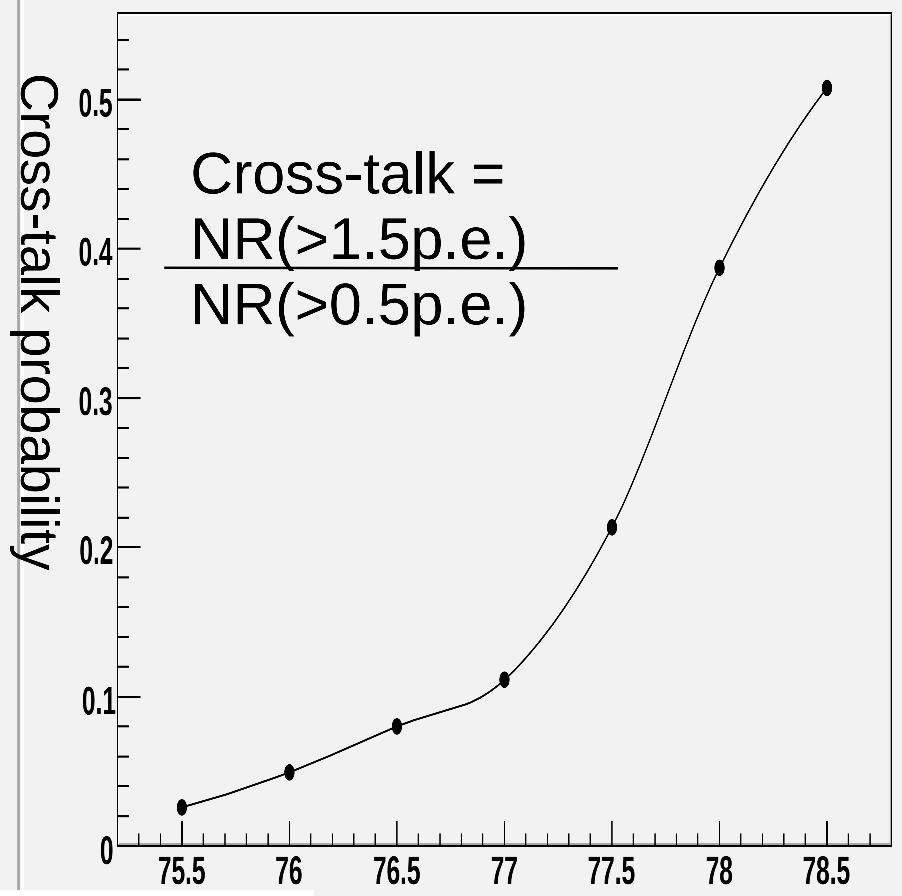
http://www.hamamatsu.com/news/2006/2006_10_26.html

Temperature dependence of V_0



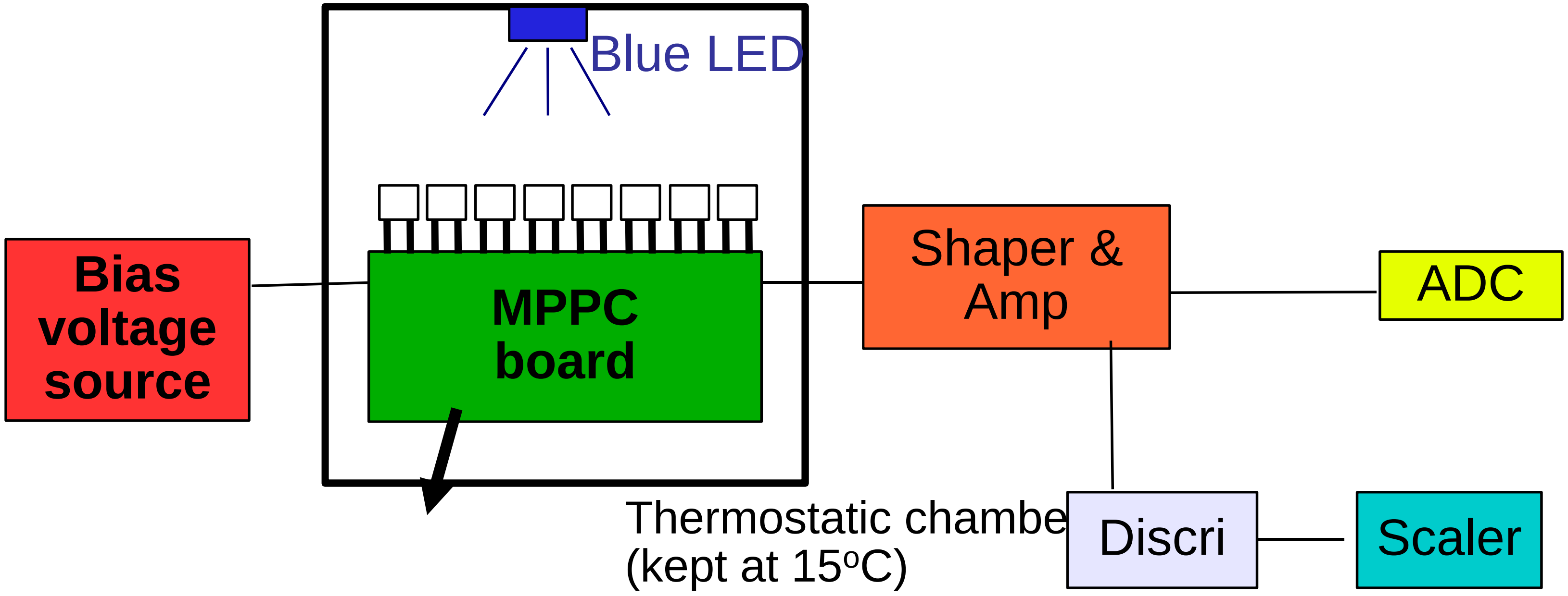
Noise Rate, Cross-talk

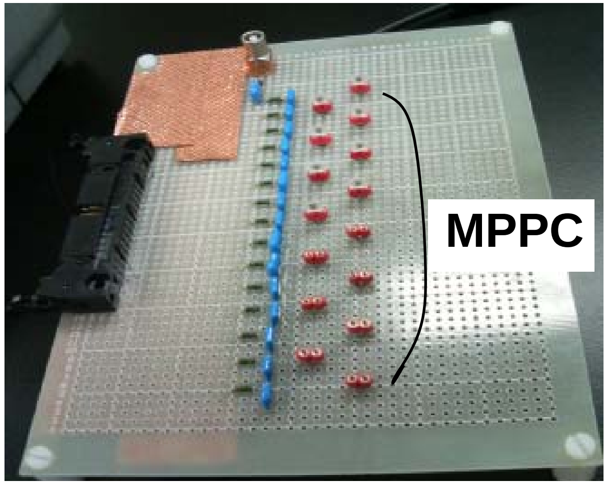




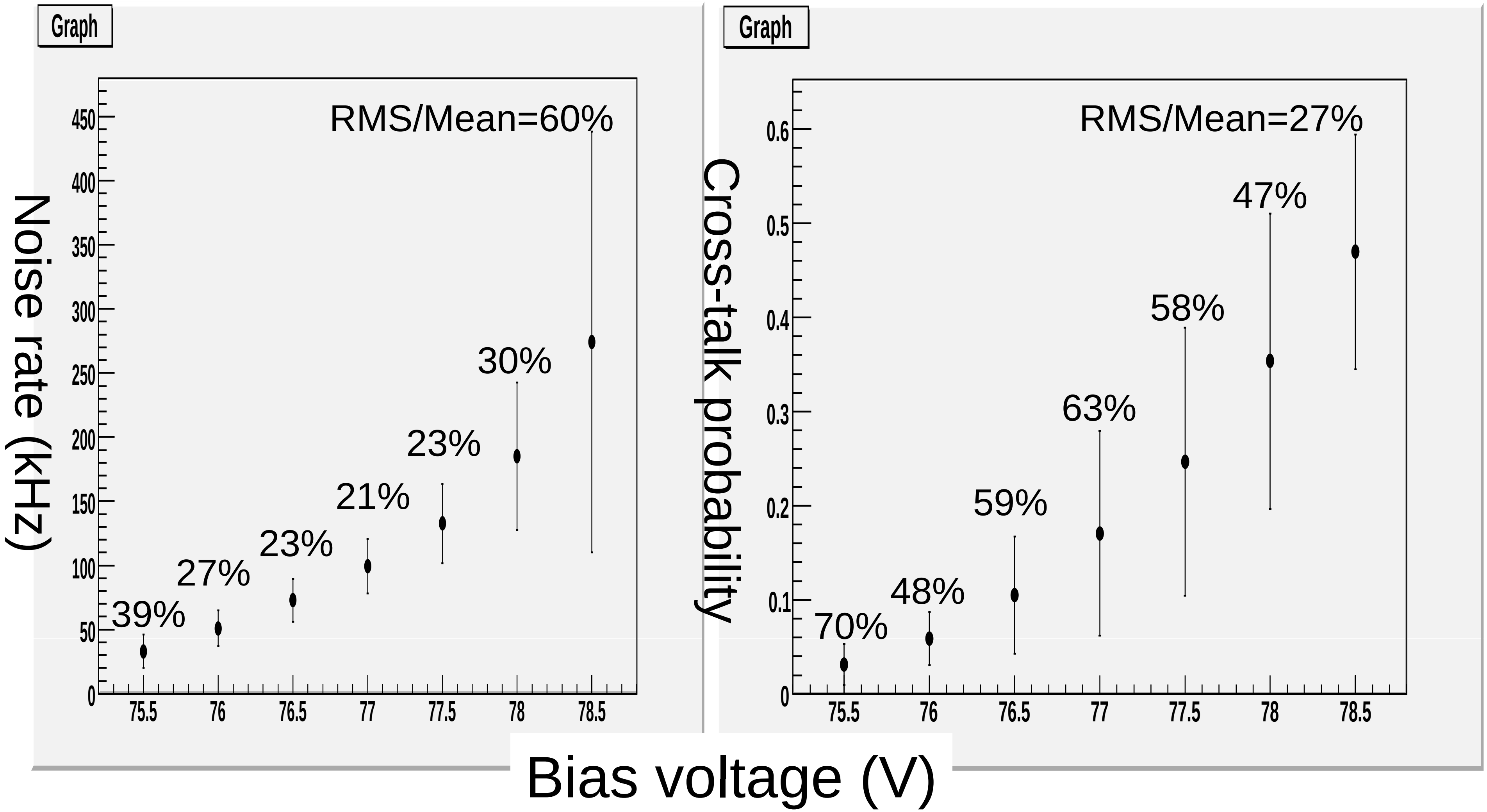
Bias voltage (V)

MPPC mass measurement



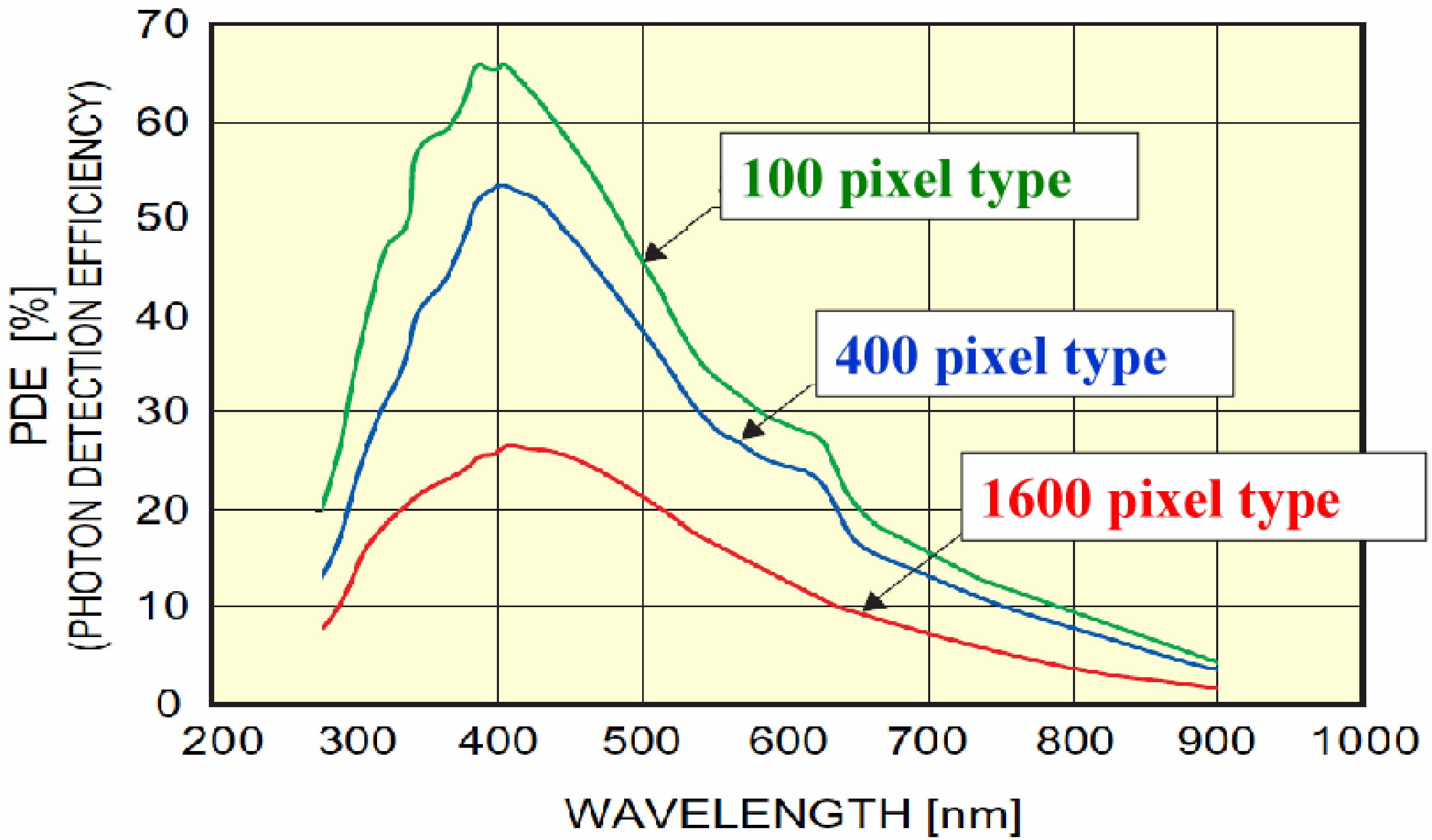


Variation of Noise Rate, Cross talk over 400 MPPCs



•Error bars mean variation (RMS) over 400 MPPCs

Photon Detection Efficiency by Hamamatsu



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