Hybrid photon detectors

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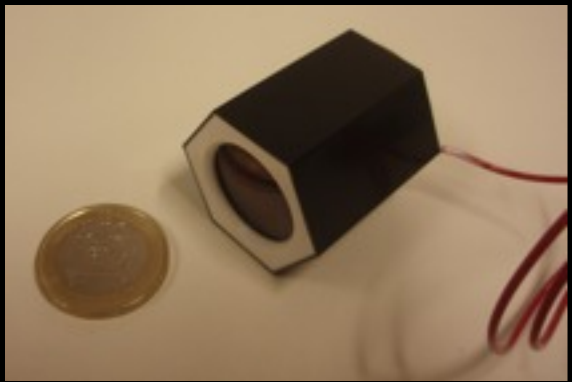
LIGHT 11



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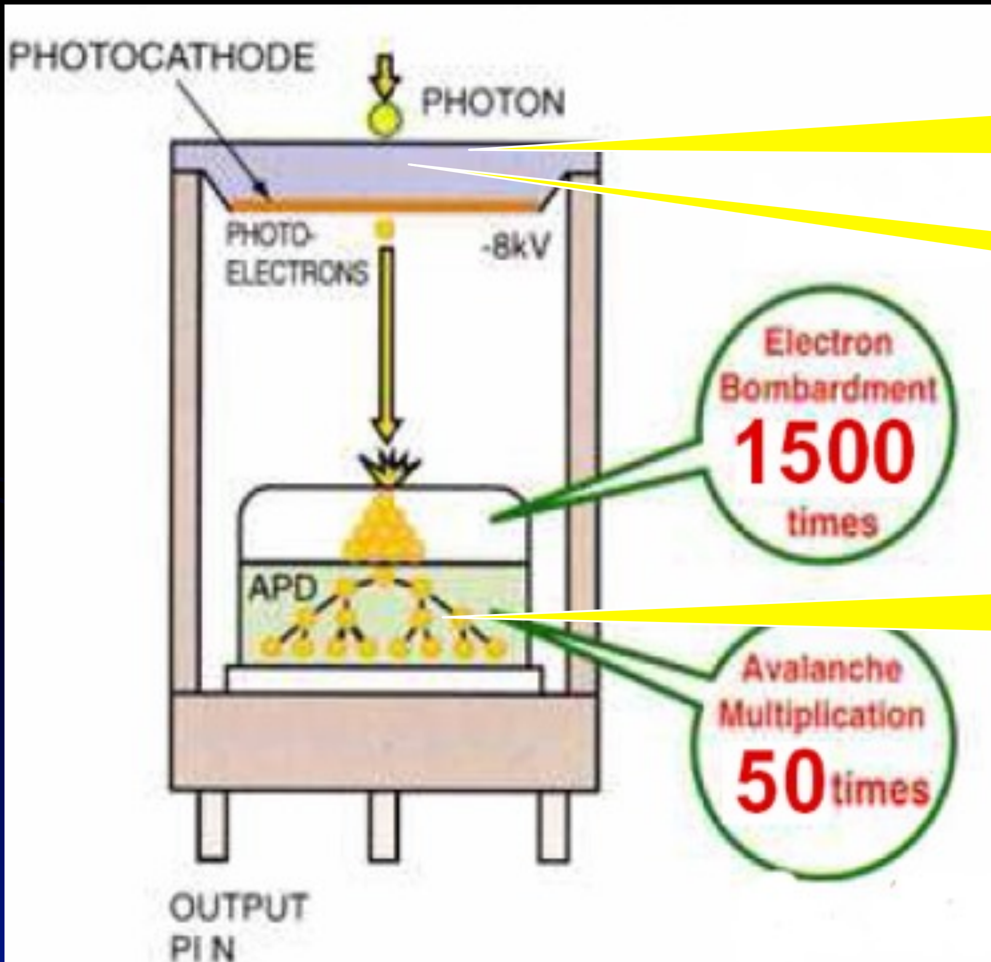
2) Properties of the Hamamatsu R9792U-40 HPD
3) Safe operation of HPD for Air shower experiments
4) HPDs in MAGIC

Principle of HPD

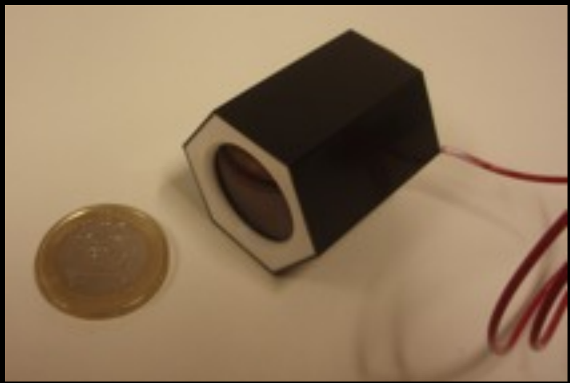


GaAsP
Photocathode

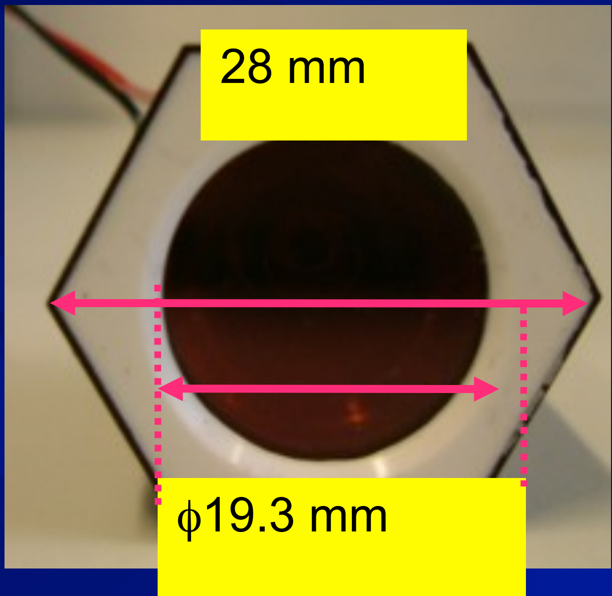
-8kV HV

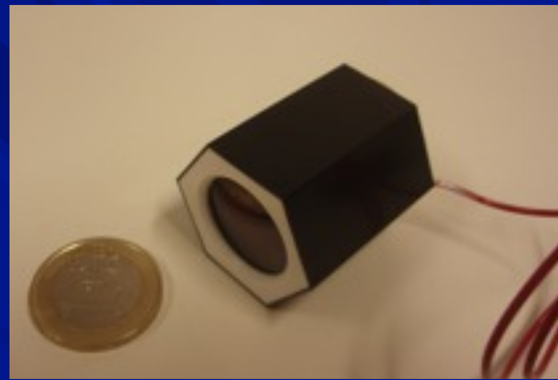
APD
~400V Bias

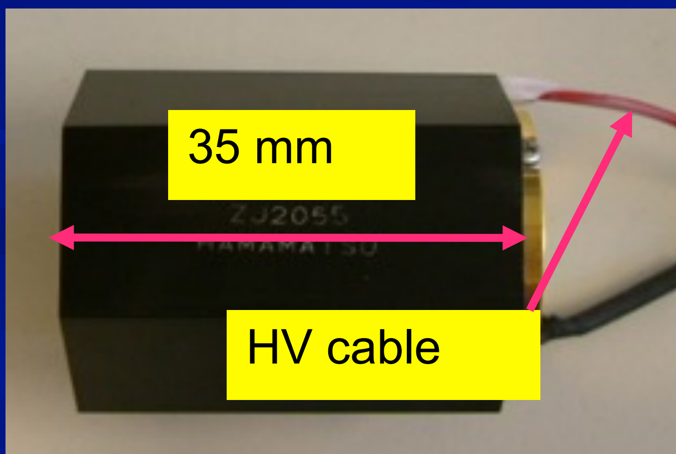
Properties of the Hamamatsu R9792U-40

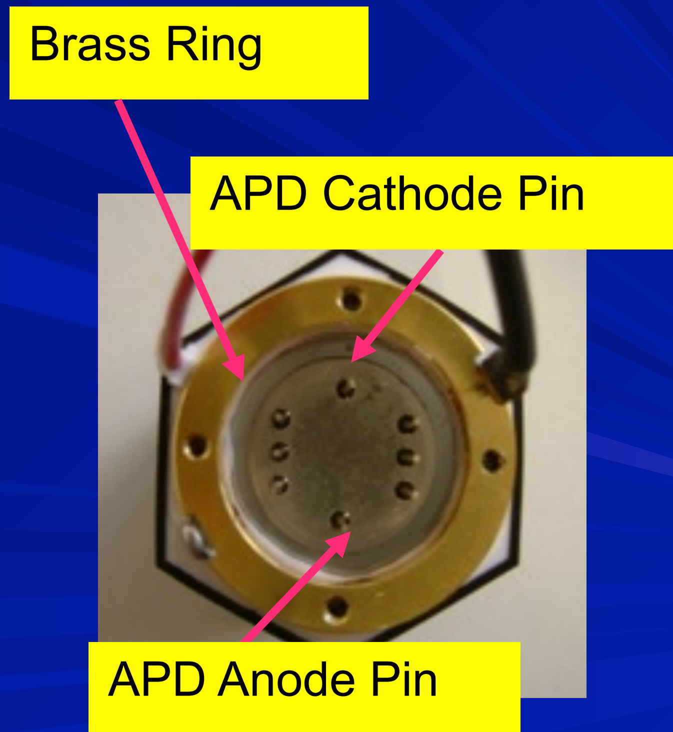


HPD Hamamatsu R9792U-40

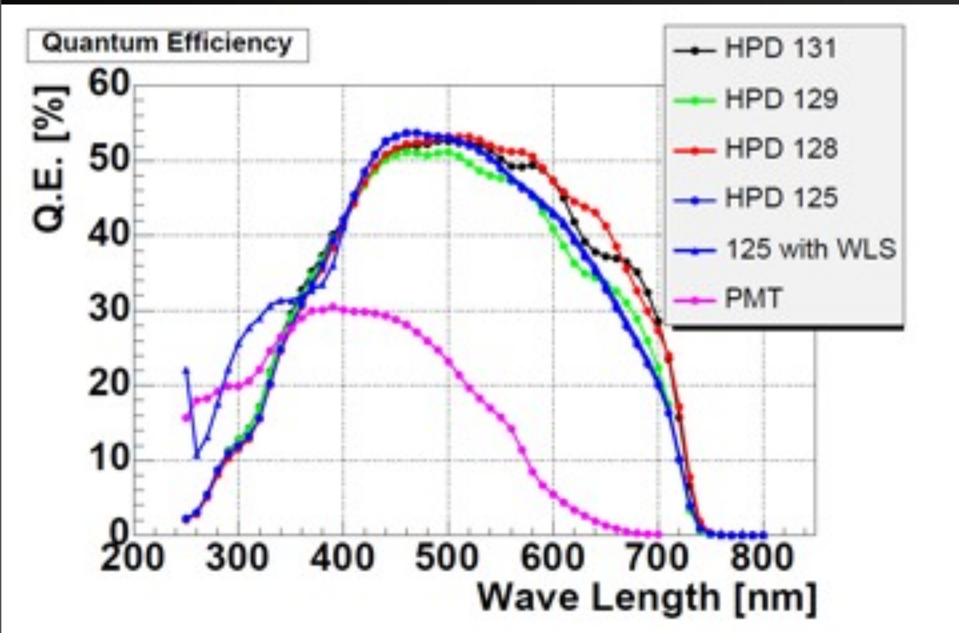






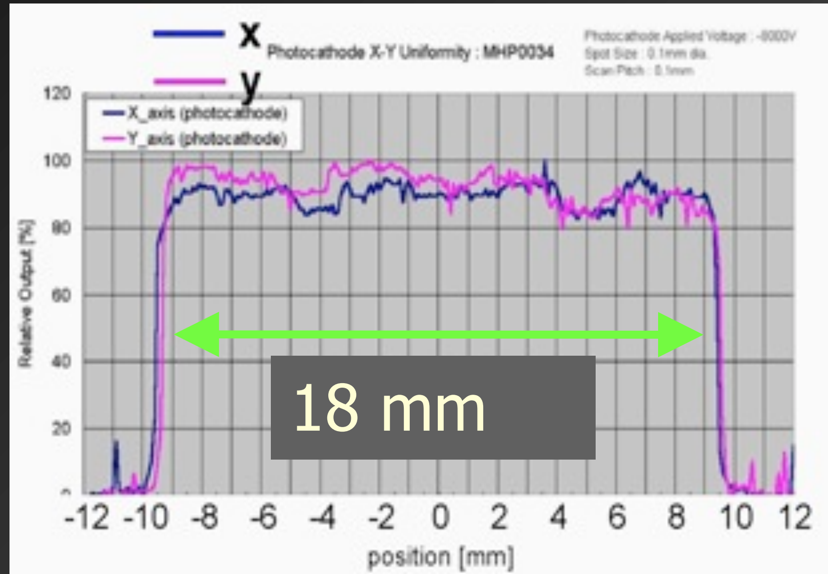


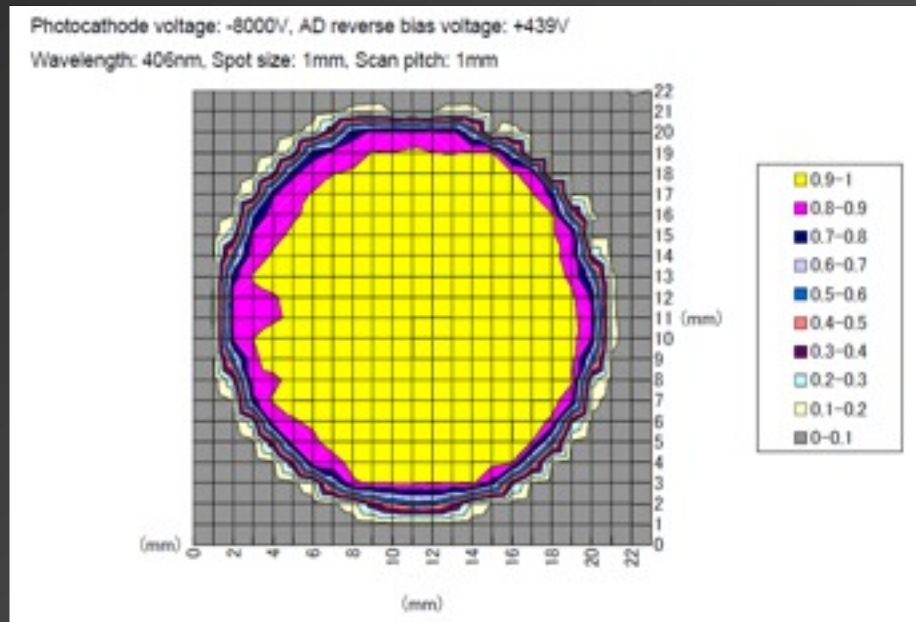
QE and uniformity



QE exceeds 50% at 450 nm

Two times more photon detection

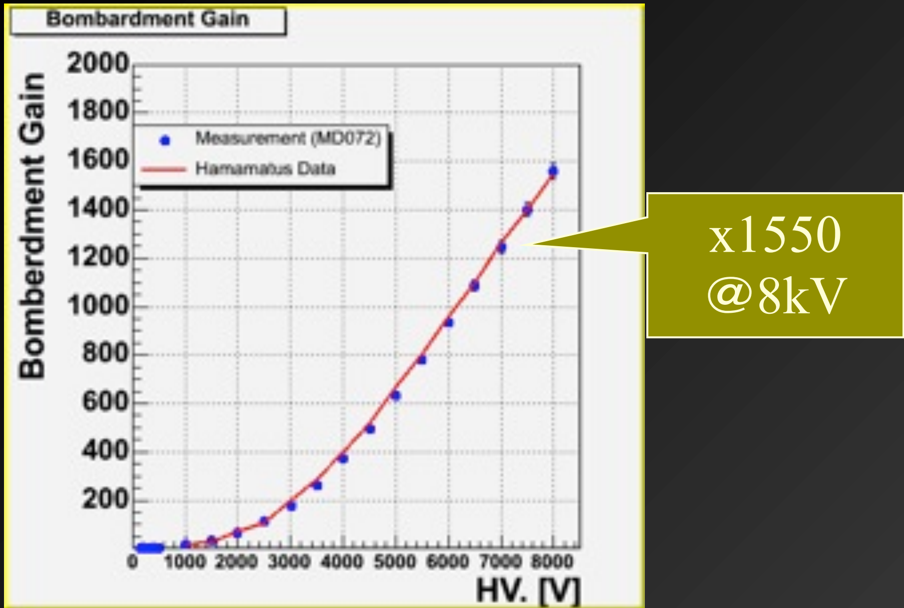




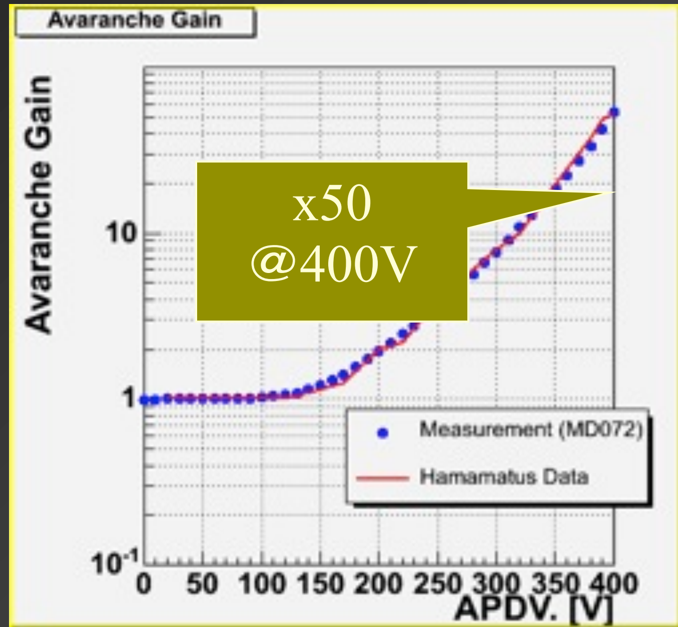
Good Uniformity. 18mm diameter

Within 10%.

Gain and Pulse Shape



< Bombardment Gain >



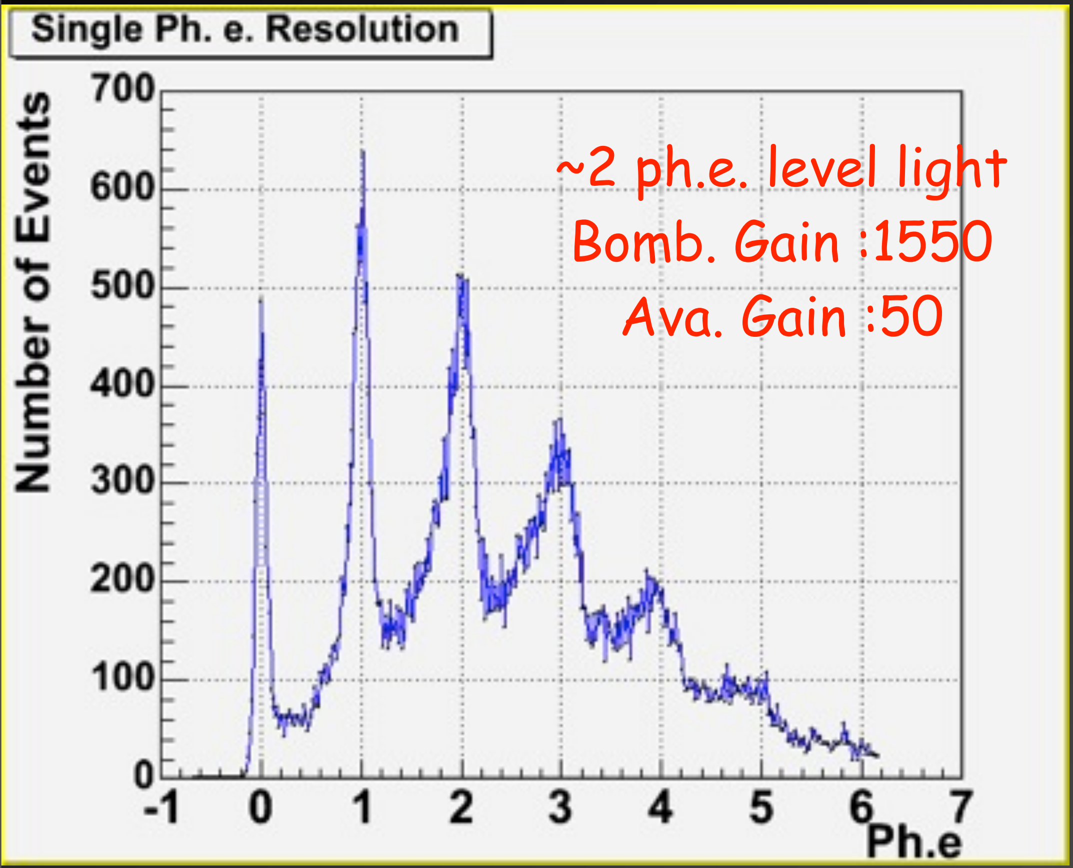
< APD Gain >

< Pulse Shape >

Width ~**2.2 ns** (FWHM)

Fast rise: 0.7 ns; Fall: 2.6 ns

Single ph.e. resolution



Good single PhE resolution

But: strong backscattering about 12%

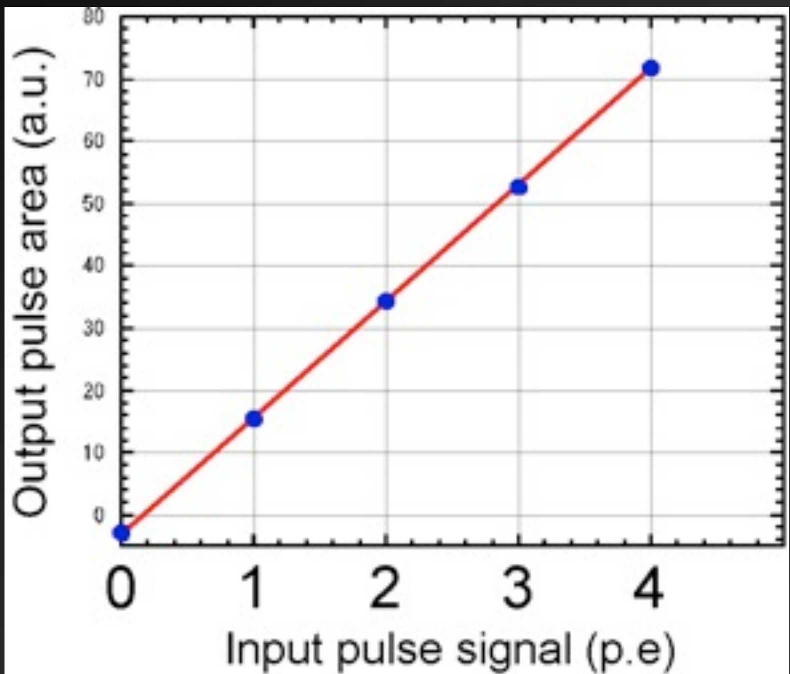
Makes absolute flux measurements difficult, need model for backreflection or

a) Only count pedestal

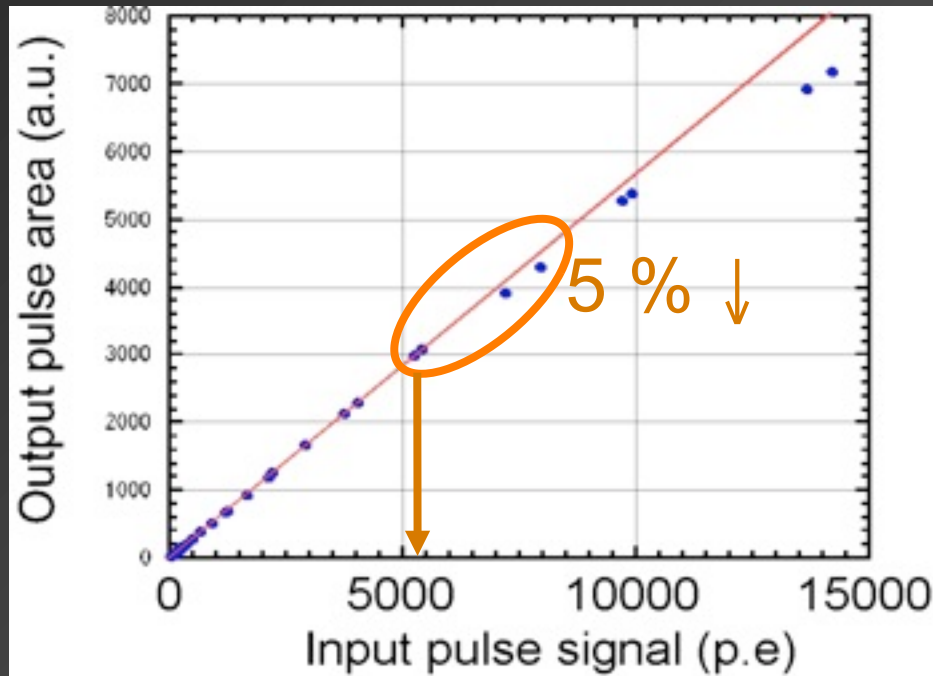
b) Use mean of distribution + 12%

Dynamic Range

- up to 5000 possible
  (condition –8 kV, 395V)
  - Measured by pulse area

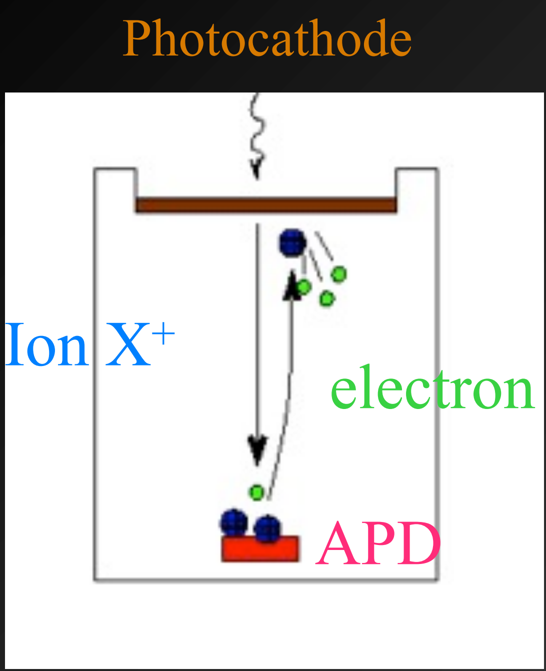


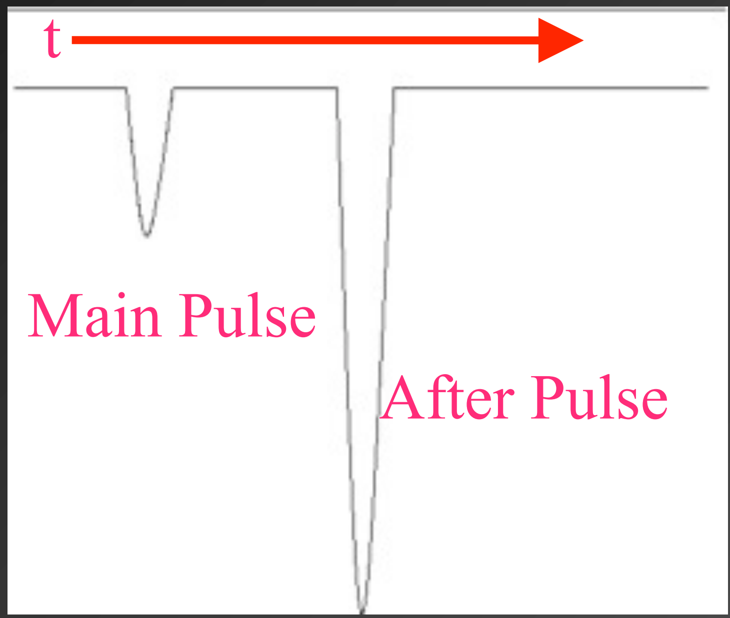
<Small signal >



<Large signal>

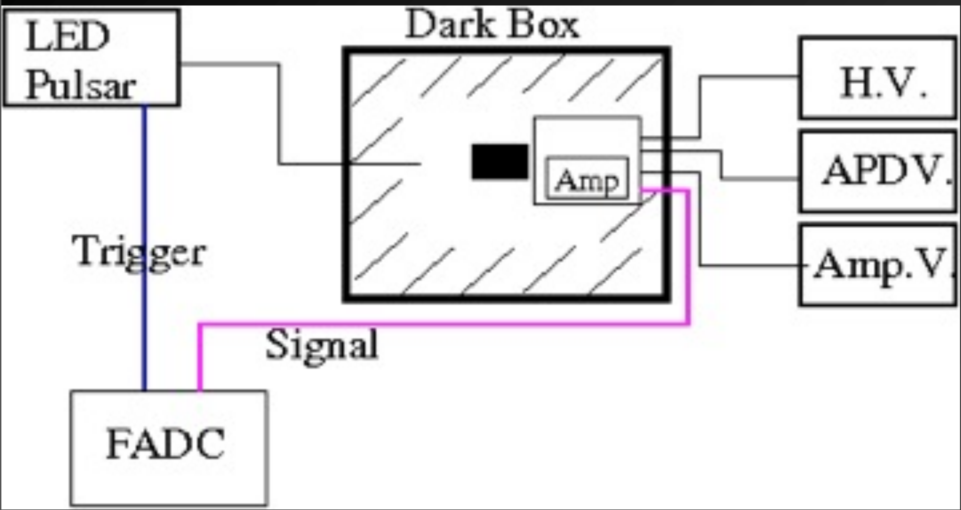
Afterpulsing: What is it ?



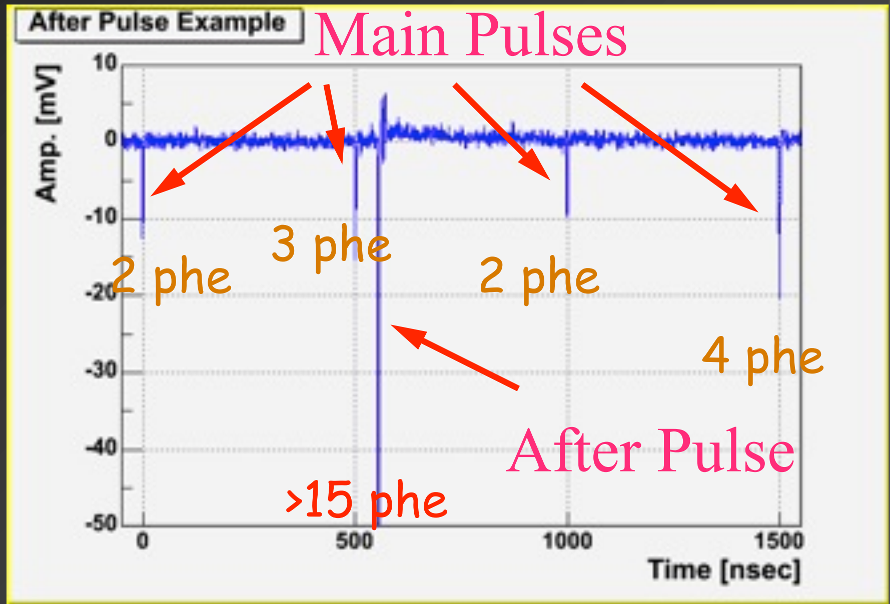


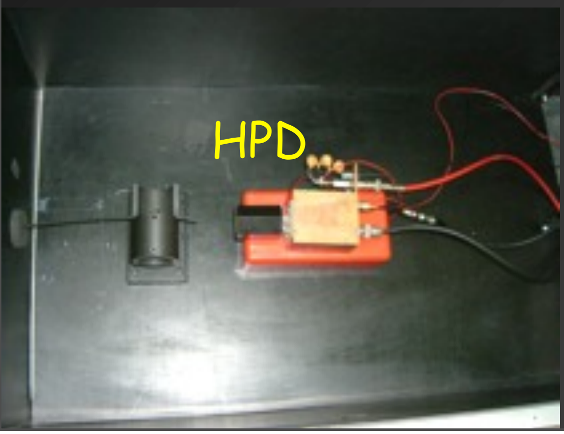
- Electrons hitting the APD release positive ions.
- They accelerate back to the photocathode
- They damage the photocathode (QE degrades !!)

Measure the afterpulse probability



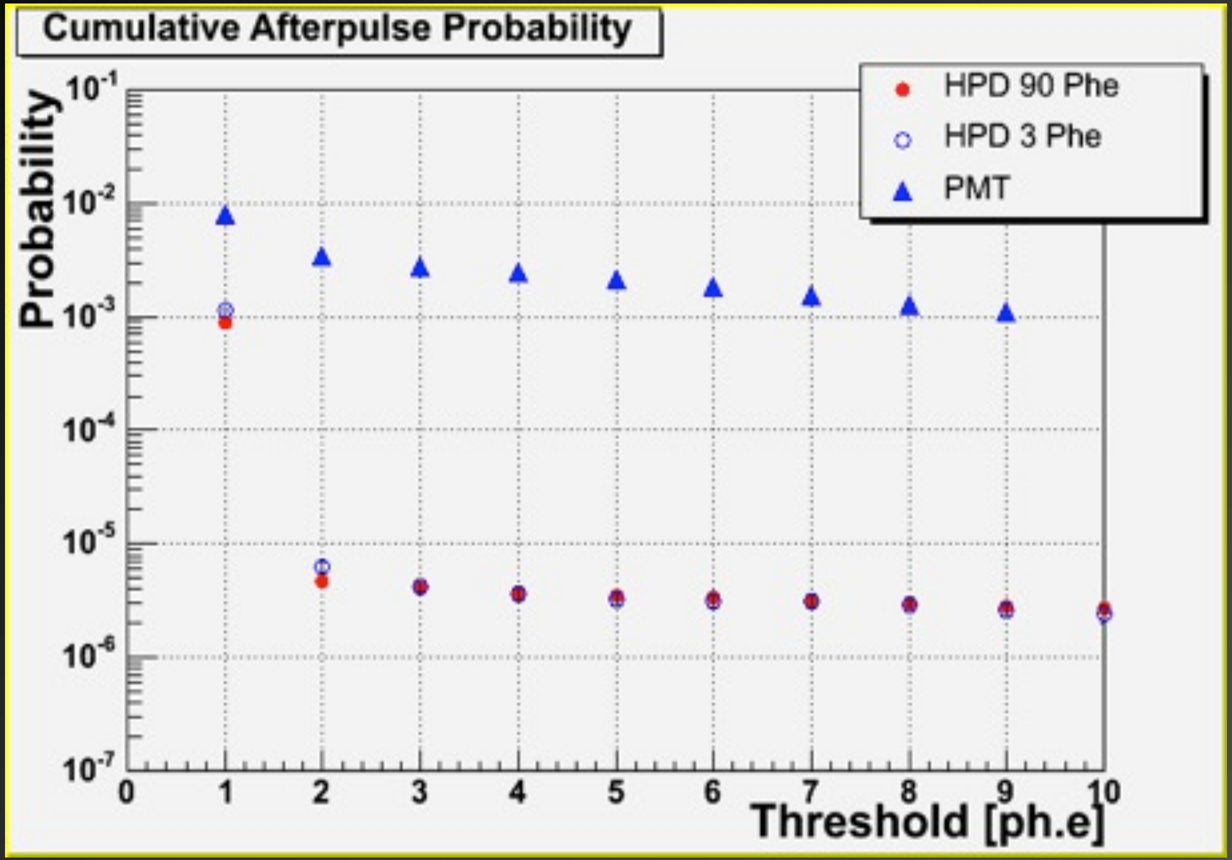
2 different light levels (3 and 90 ph.e.)



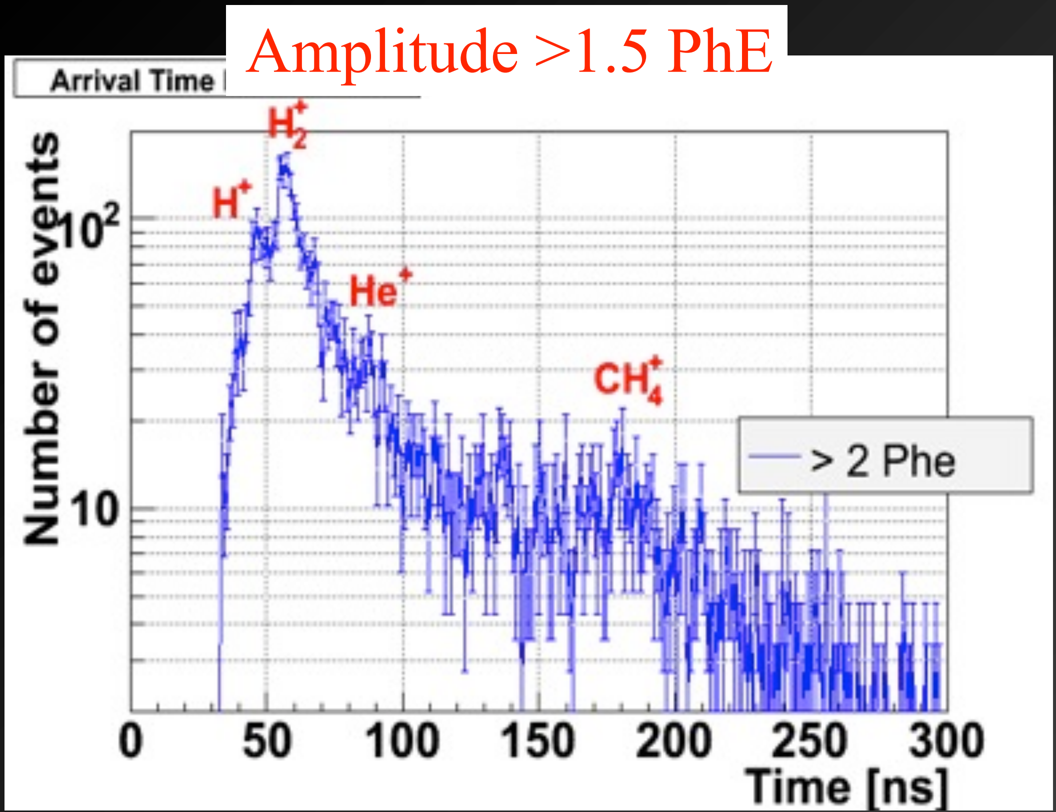


Search between 33 nsec and 450 nsec

HPD afterpulse probability in comparison with PMT



2.5 – 3 orders of magnitude lower than for PMTs!!

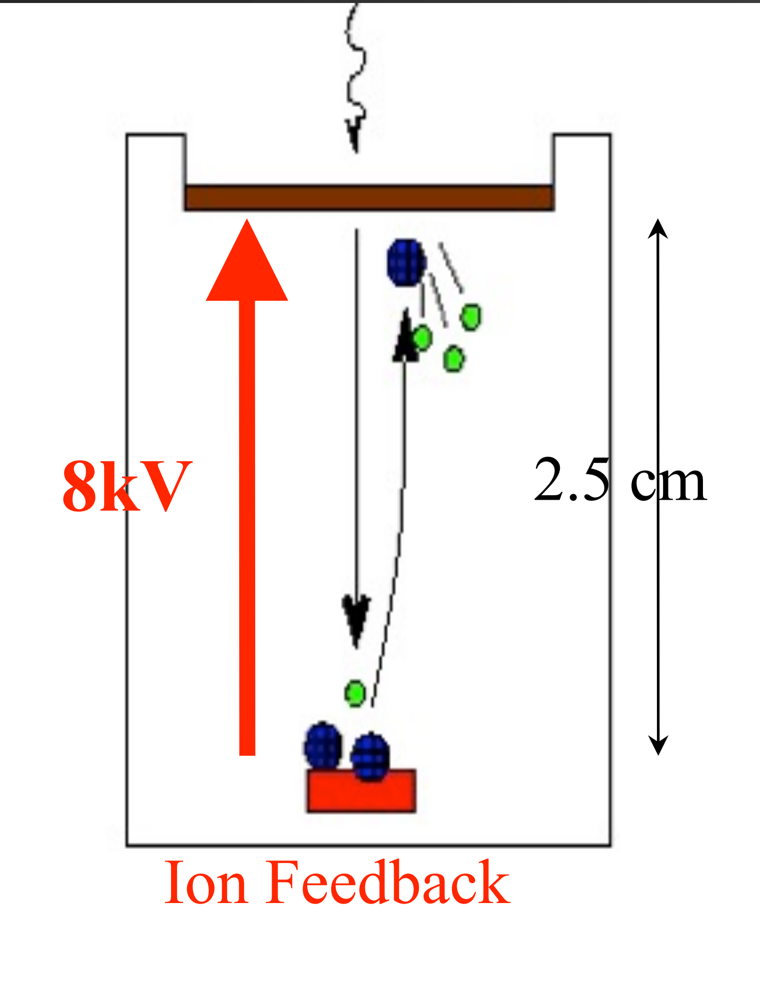


$$d = \frac{1}{2} a t^2$$

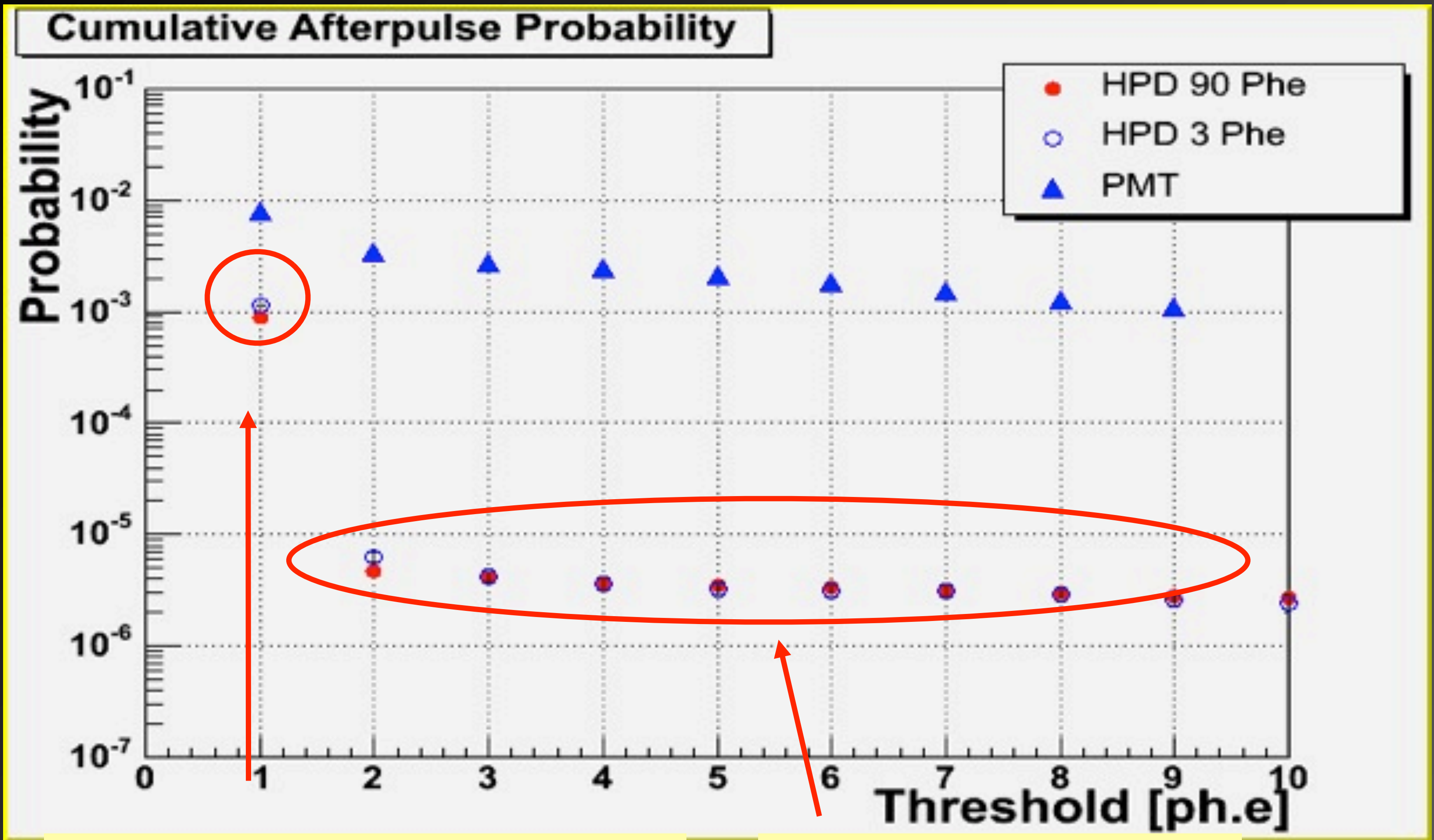
$$a = \frac{f}{M} = \frac{eV}{Md}$$

$$t = \sqrt{\frac{2Md^2}{ZeV}}$$

$$\cong 40\sqrt{\frac{M/M_p}{Z}}\, n\sec$$

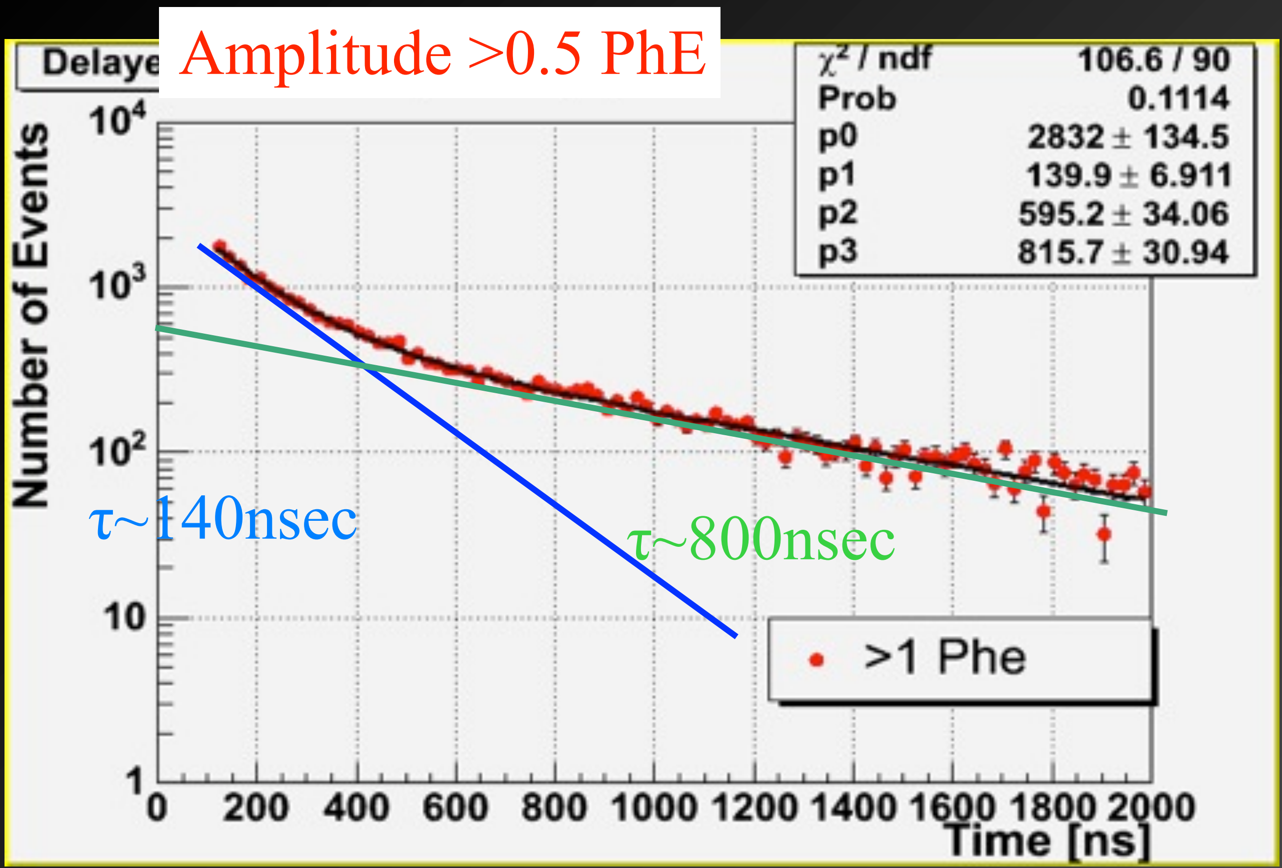


Photon feedback ?

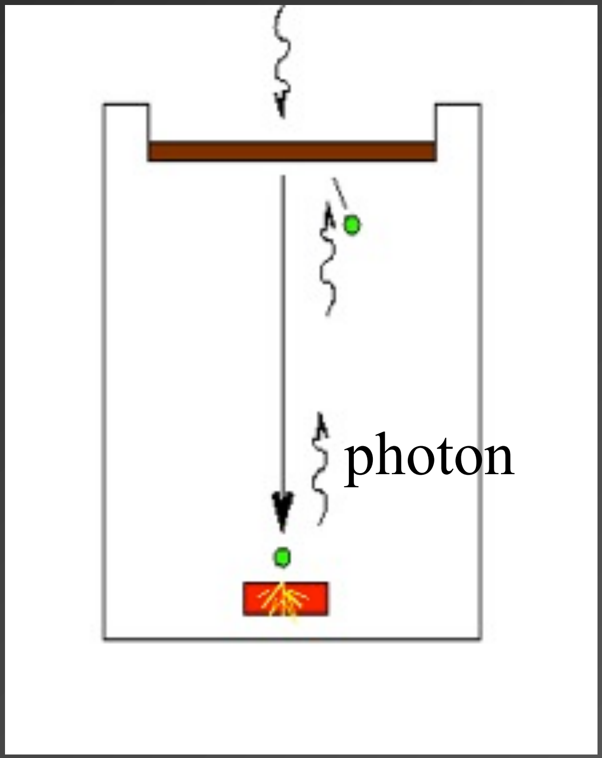


Photon Feedback?

Ion Feedback

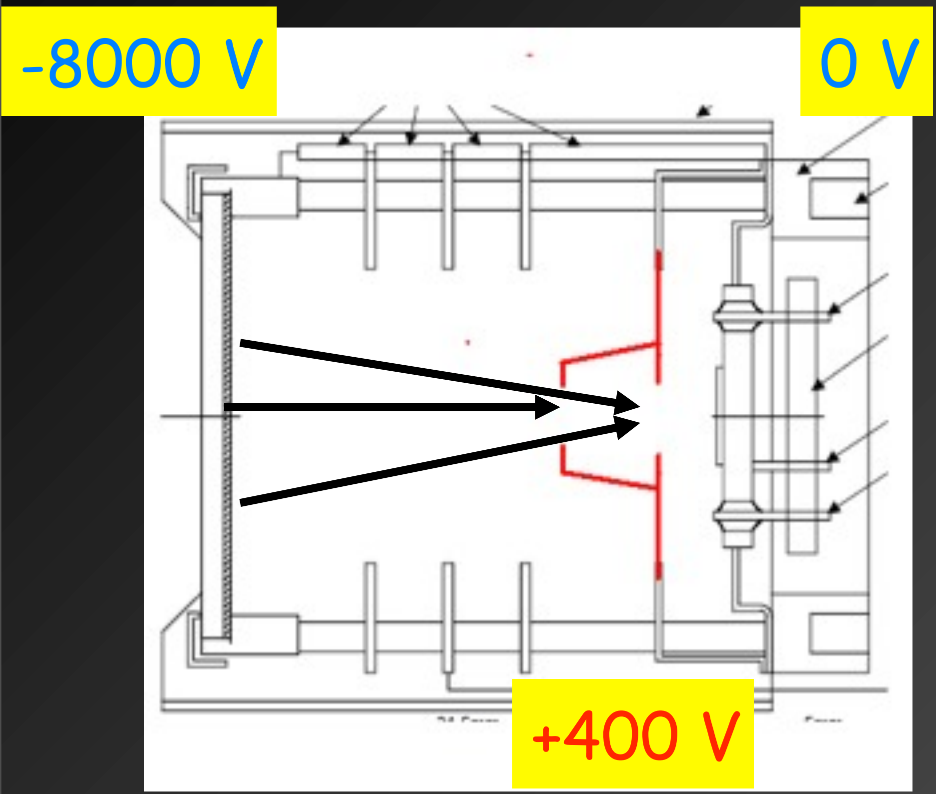


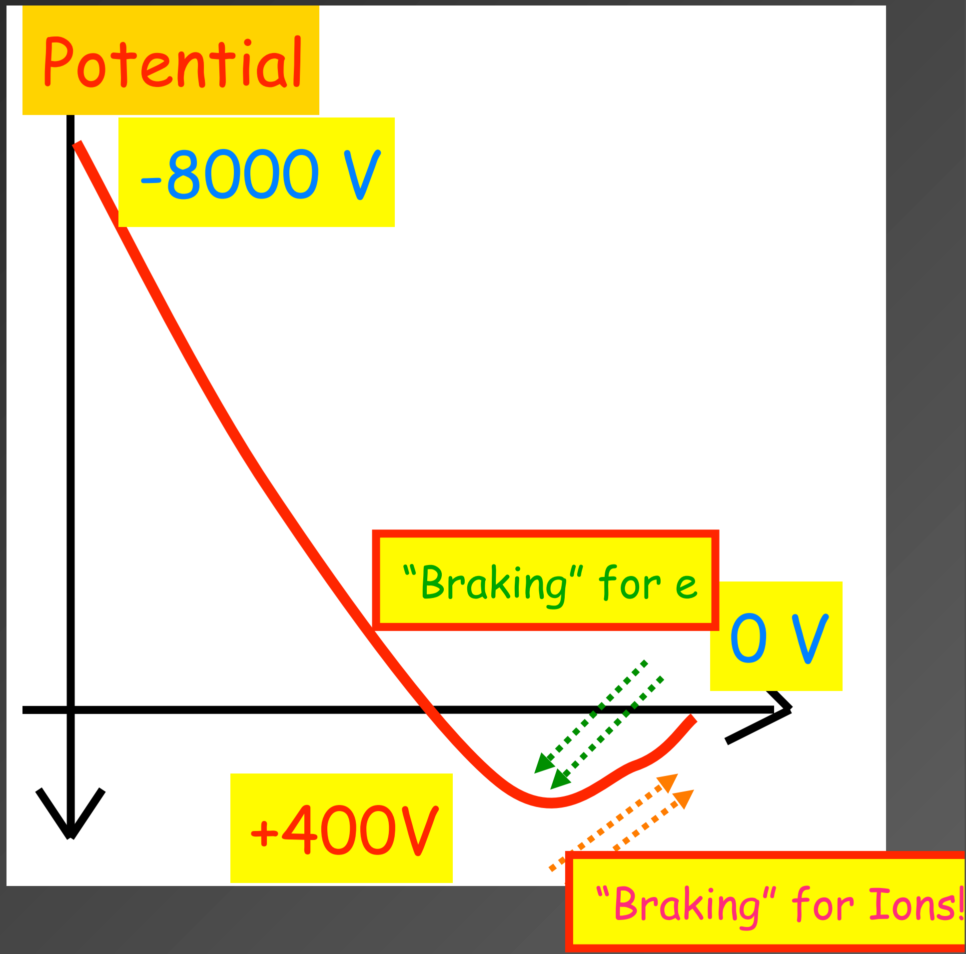
Photon Feedback



Why is Ion feedback Rate so Low?

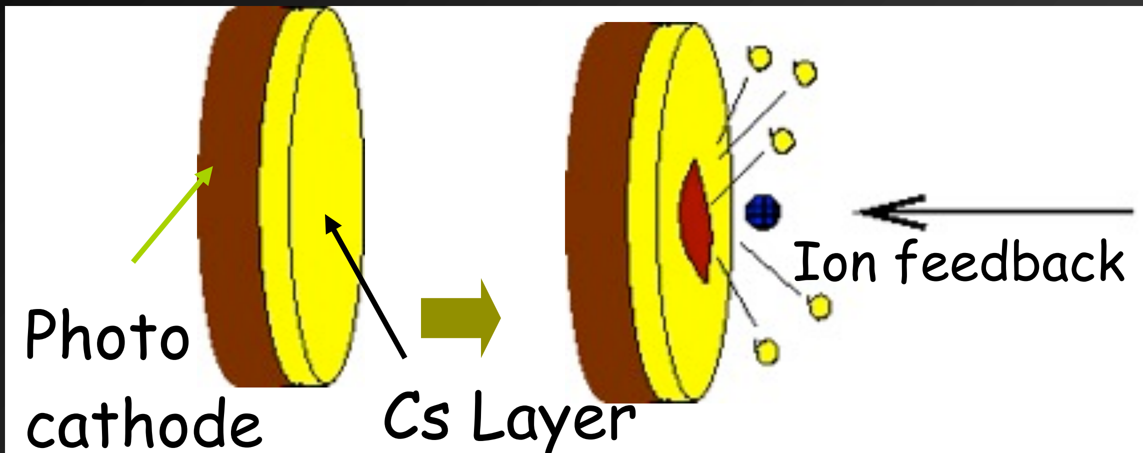
- One reason is higher vacuum compared to PMT.
- Another is due to special electric field configuration

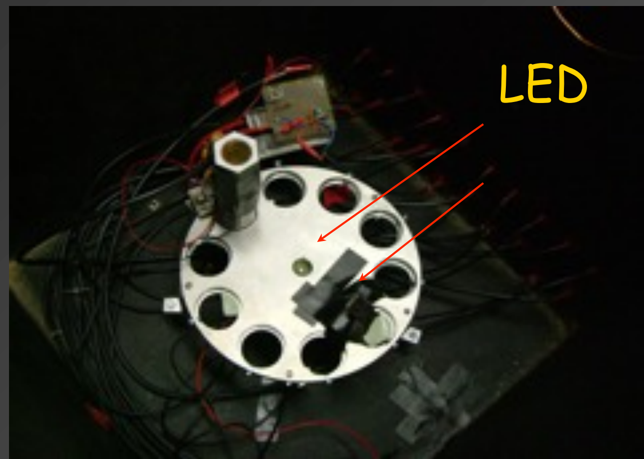




Lifetime measurement

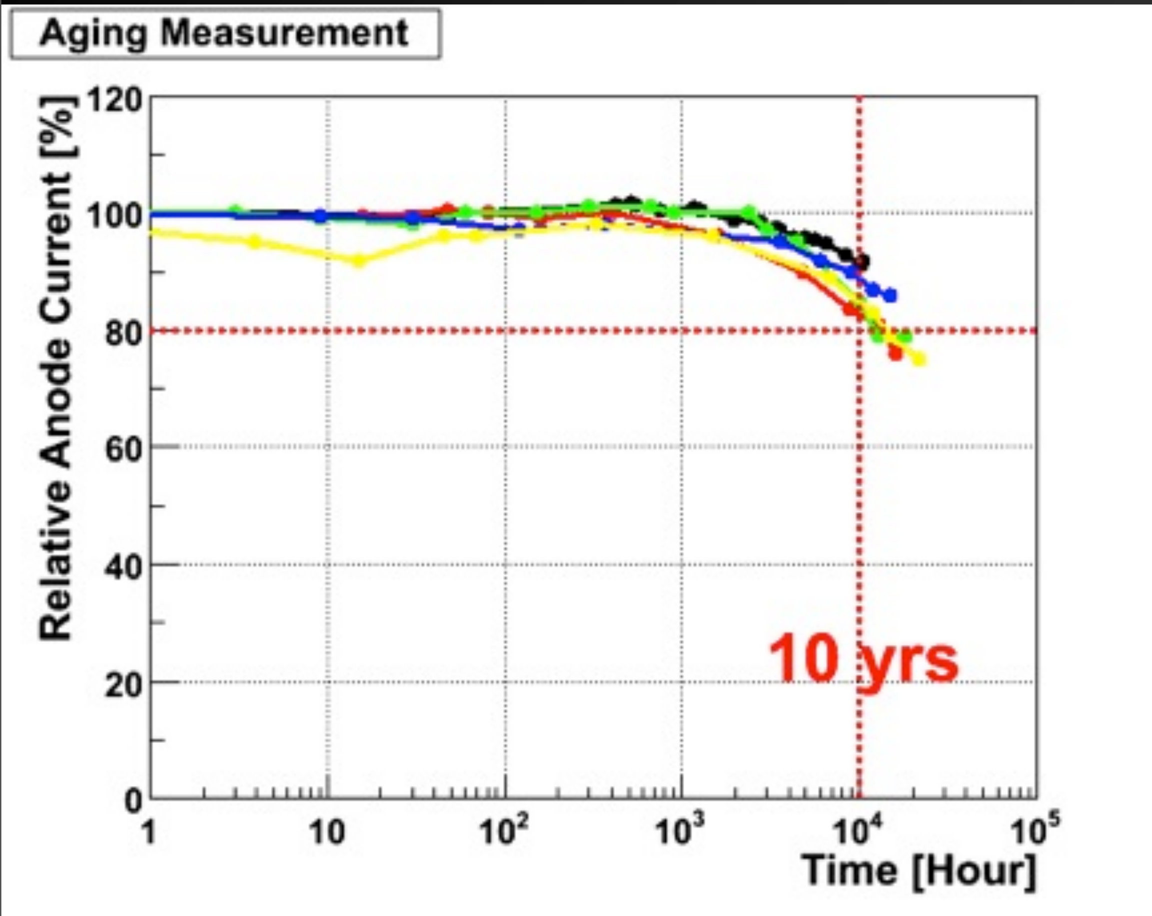
It is widely known that a GaAsP photocathode has higher QE but shorter Life Time because mono atomic Cs layer can be easily damaged by afterpulses.





Accelerated Lifetime measurements were done with continuous light for 5 HPDs.

Life Time: 10 000h >80% --> 10 years for gamma ray experiments



1 yr = 1000h operation
Exposed to 300 MHz
constant photon rate.

Lifetime : 20% reduction of Q.E.

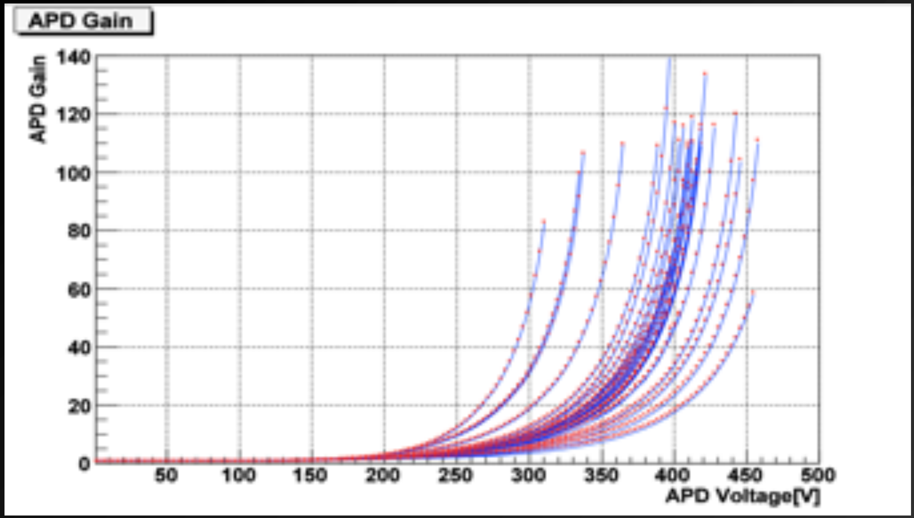
Lifetime > 10years !!

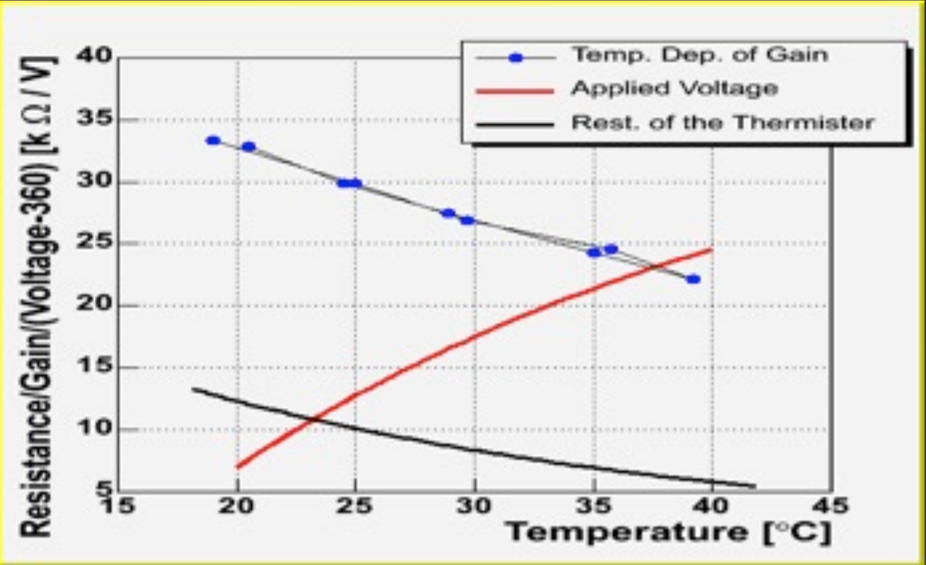
Strange pulses

- With low rate huge pulses appear
- Different from HPD to HPD
- Muons ? or Sparks ?

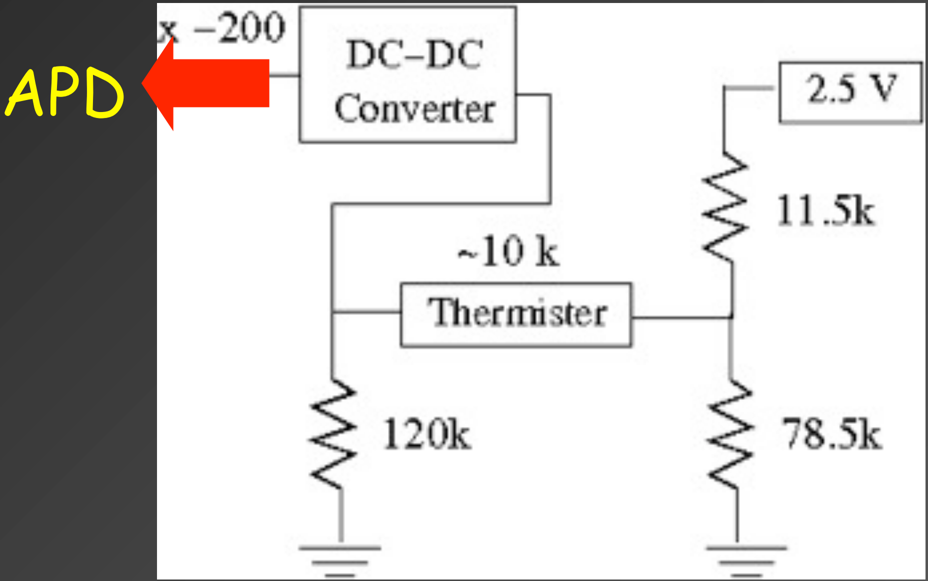
Operation of HPD in Air Cherenkov experiments

Temperature Dependence of APD Gain





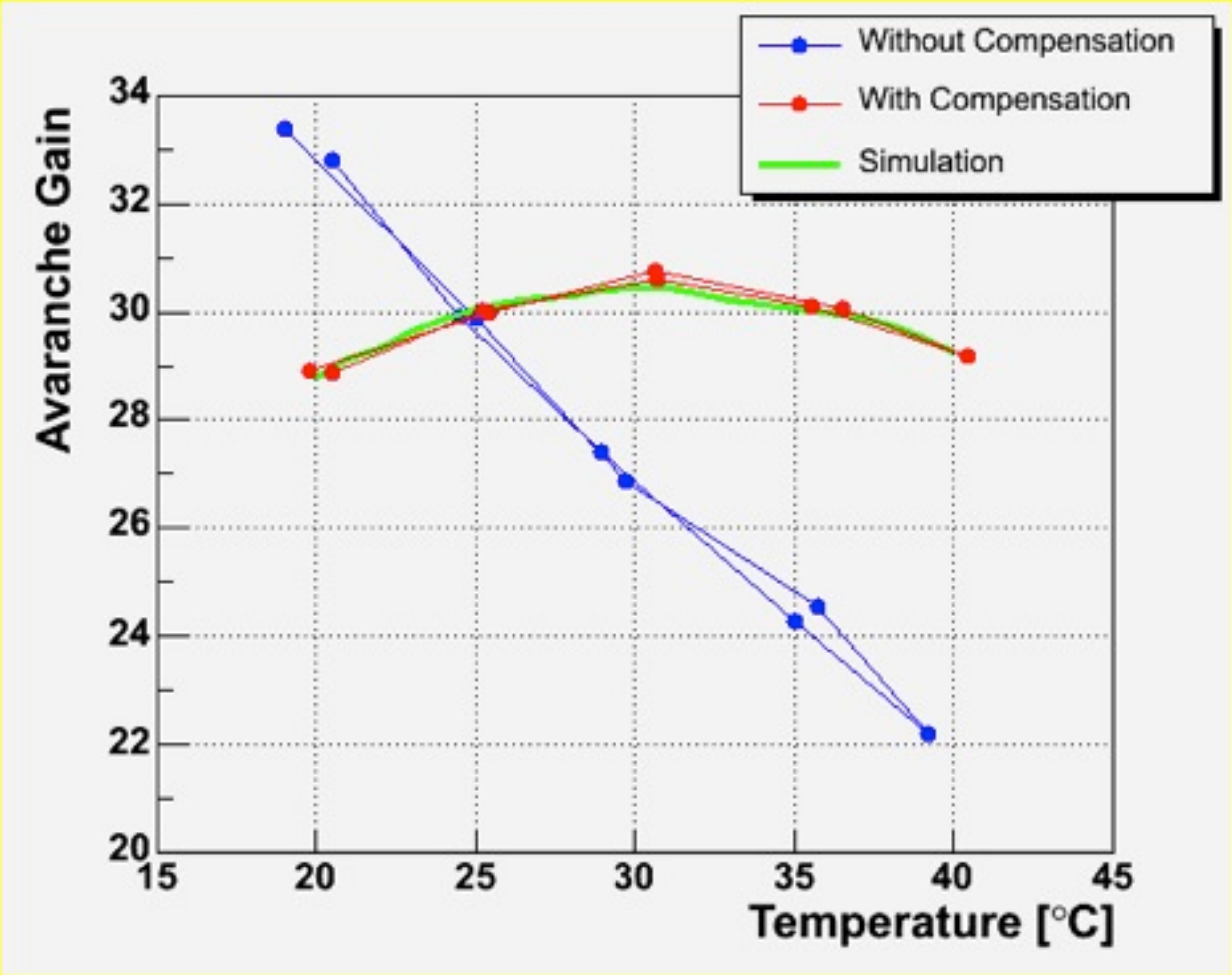
Temperature Compensation Circuit



(103AT-2,ishizuka)

Strong temperature dependence of -2 % / ℃ !!
(~0.2%/ ℃ for PMTs)

Passive compensation with thermistor



2% / ℃

0.3% / ℃

(25℃~35℃)

and

0.5% / ℃

(20℃25℃,

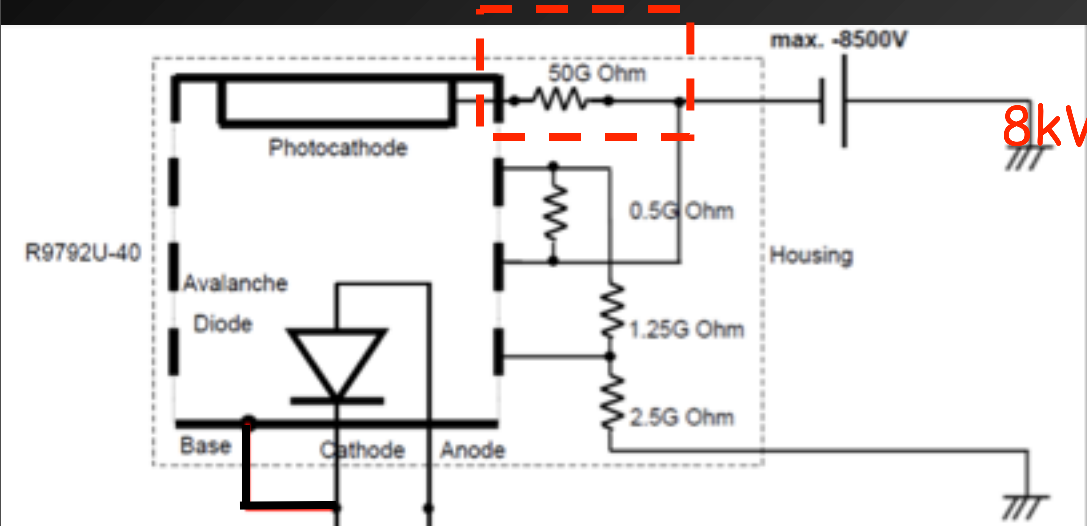
35℃~40℃)

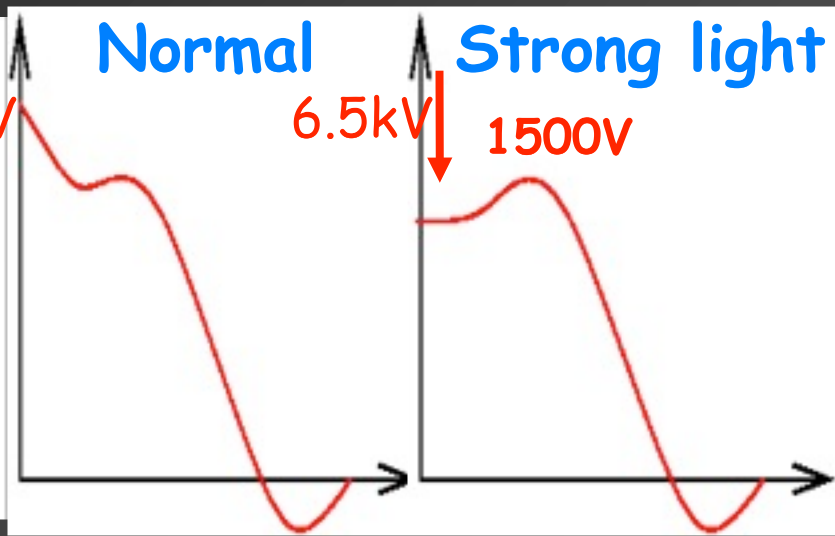
Position of Peak depends on the choice of the resistors

How to protect HPD from strong light?

Introduction of 50 GOhm resistor to photocathode, limiting the photocurrent

30nA x 50 GOhm = 1500V drop



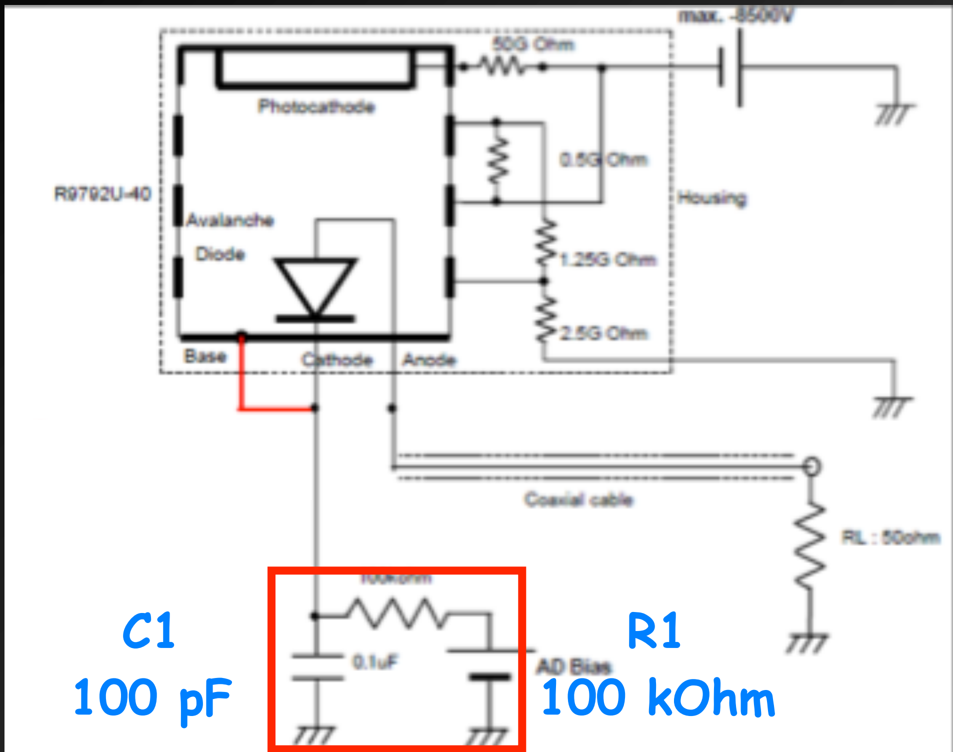


30nA (= 500 x NSB) of photocathode current will provide a voltage drop of 1500 V

-> Stops electron flow to APD.

How to protect APD from strong light (II)?

2) Fast light flashes flash are a problem

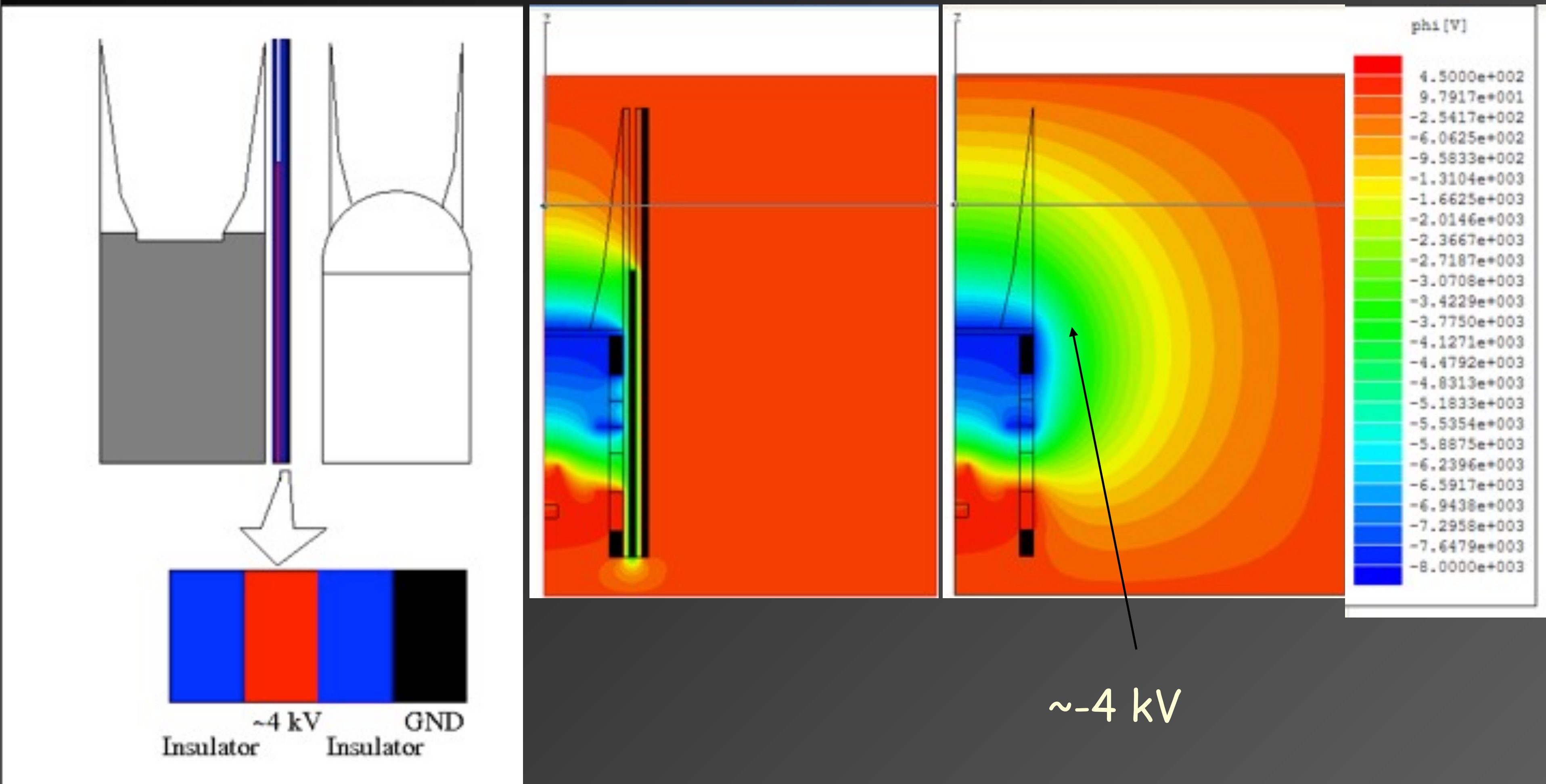


- Photocathode has a Capacitance of ~10pF .
- 8000V x 10pF = 80 nC on the photocathode is available.
- Flash 10 ns:
  APD current-->8A x Gain

--> 50 GOhm protection resister will not help in case of fast flash

--> Maximum current flow must be limited by 'feeding' capacitance and charging resistance.

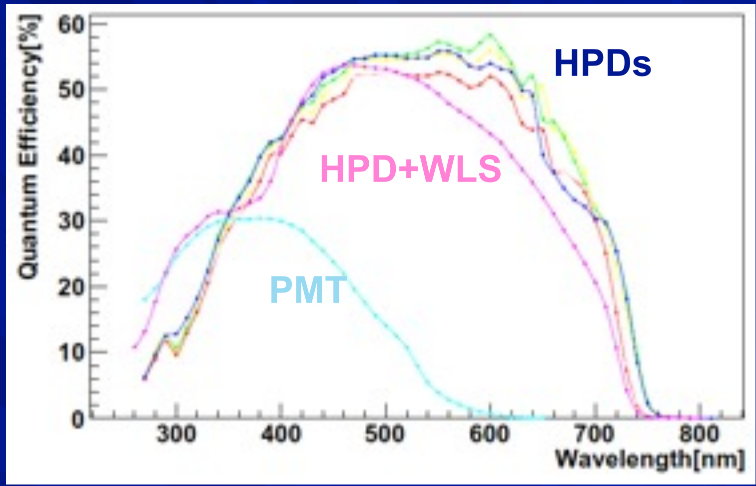
Electric field around HPD, shielding distorts electric field

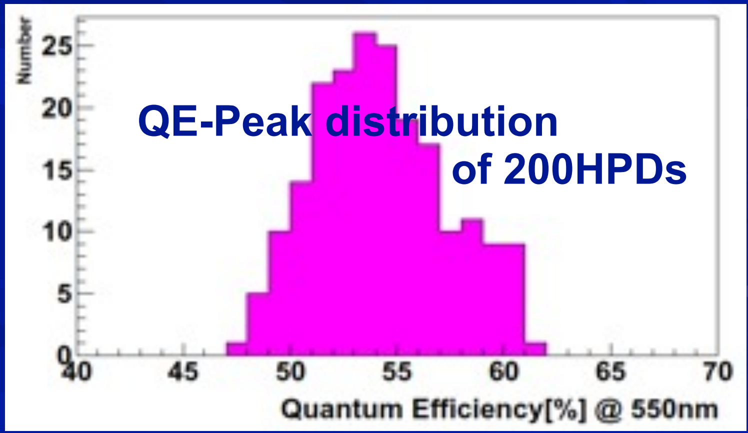


MPI , Takayuki Saito

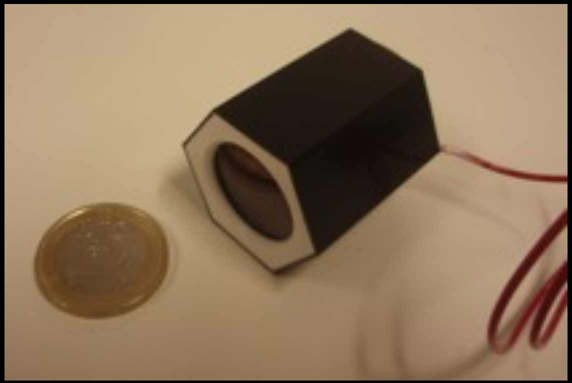
HPD R9792U-40 Properties

- Higher Q.E. than PMT(>50%@peak)
- Higher collection eff. than PMT
- Good single ph.e. resolution
- 300 times less afterpulses than PMT
- Fast pulse shape ~2.3ns(FWHM)
- Lifetime > 10 years
- Gain stability can be provided (temperature compensation)
- Implementation of protection circuit for strong light



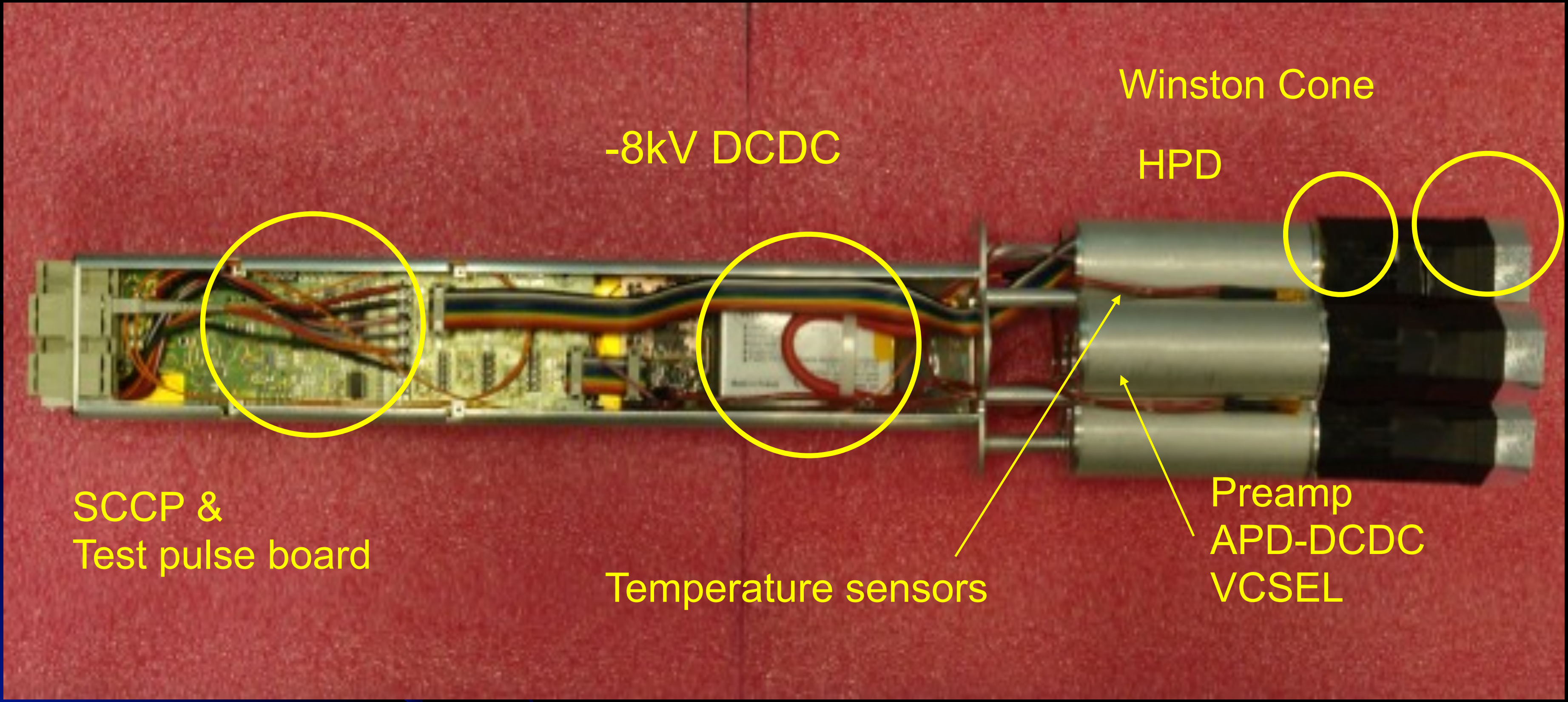


Field test in MAGIC experiment

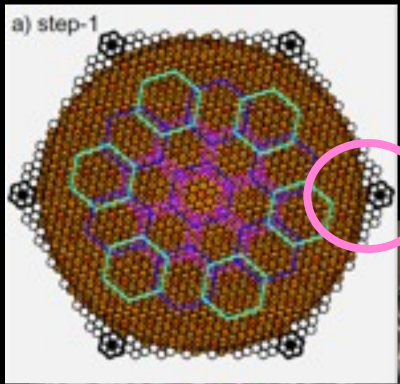


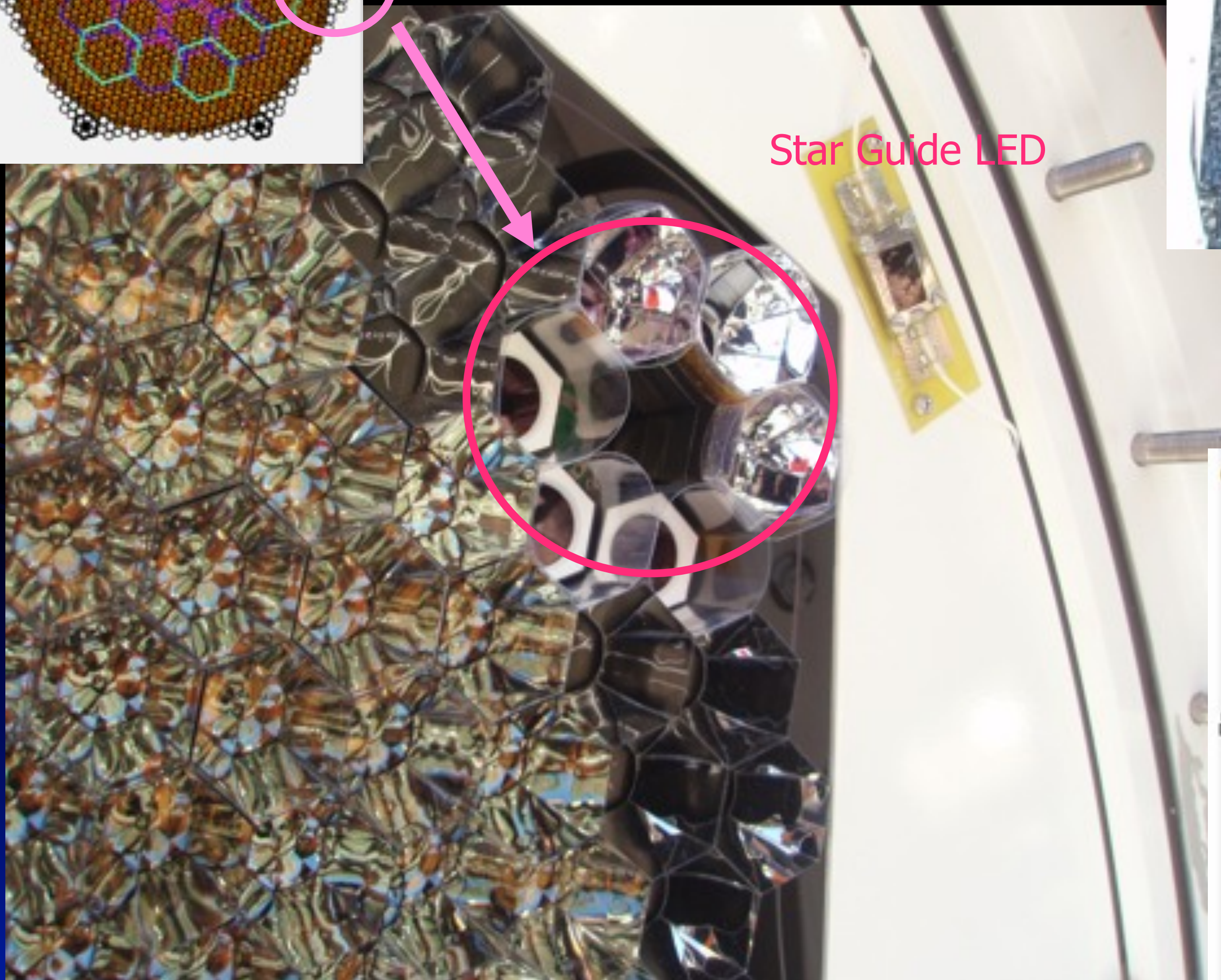
MAGIC HPD Cluster

With Winston Cone

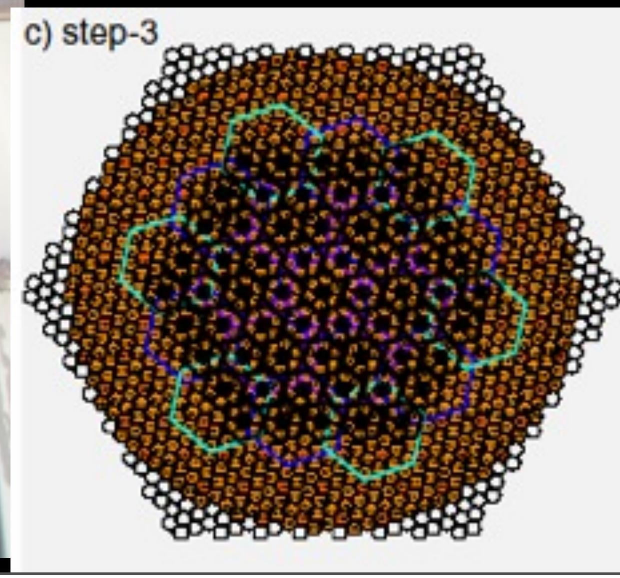


Installing in MAGIC-II Camera

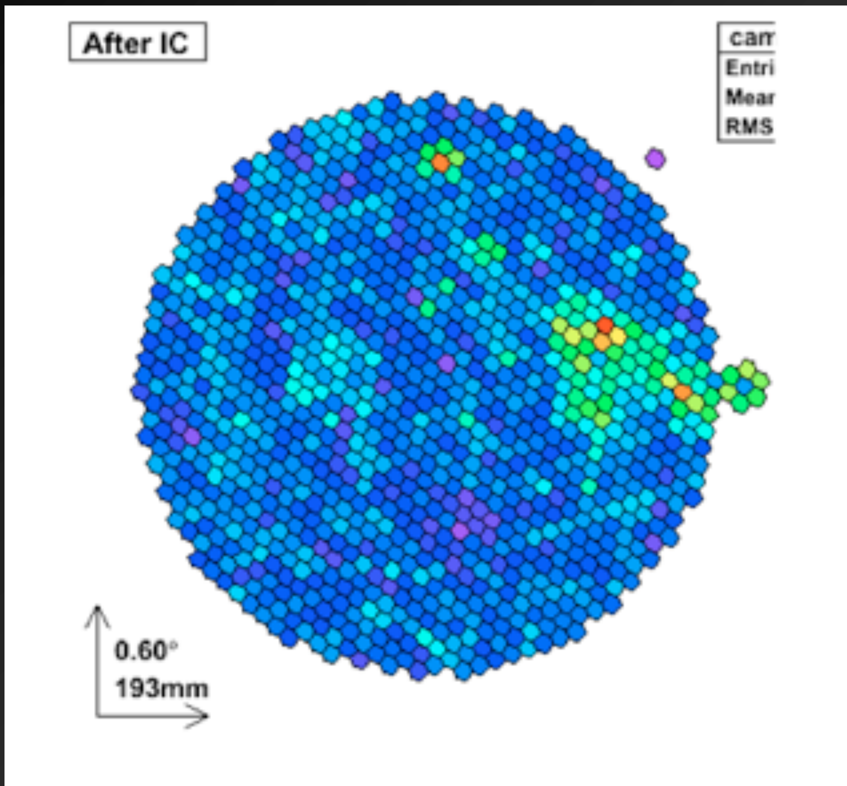


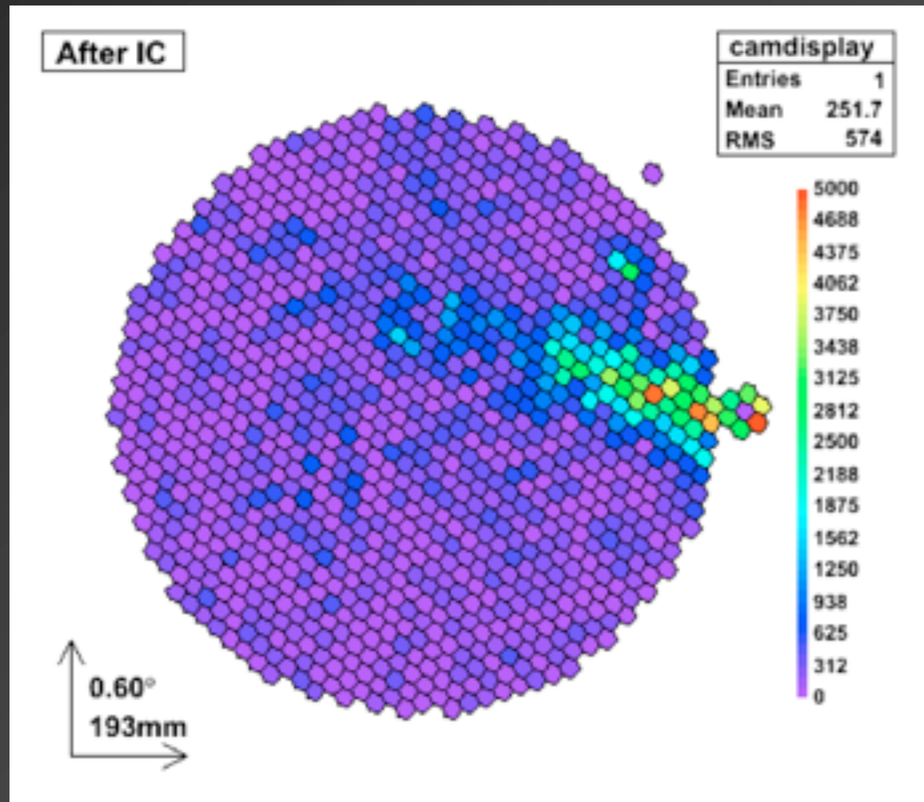


Future plan



Shower event in HPD cluster

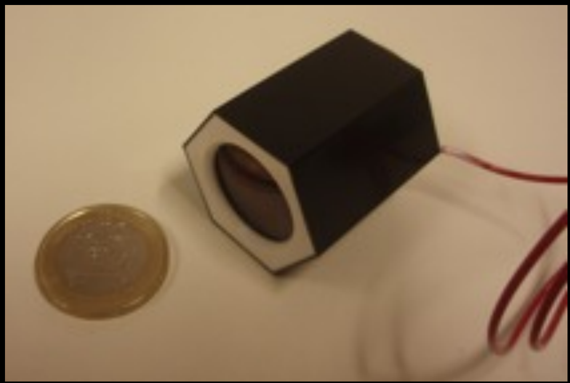




Summary

- The Hamamatsu HPD is a photon detector with nice properties and high QE
- It is fragile, sensitive, but it can be handled with appropriate protection circuitry
- It has been successfully operated during many months in the MAGIC experiment without damage, without degradation

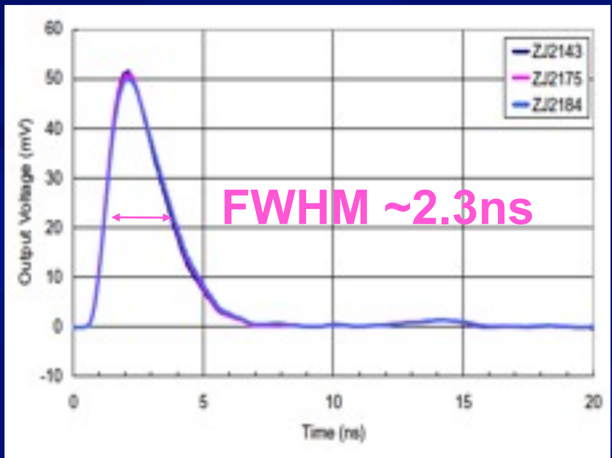
- The main disadvantage: High costs



The end

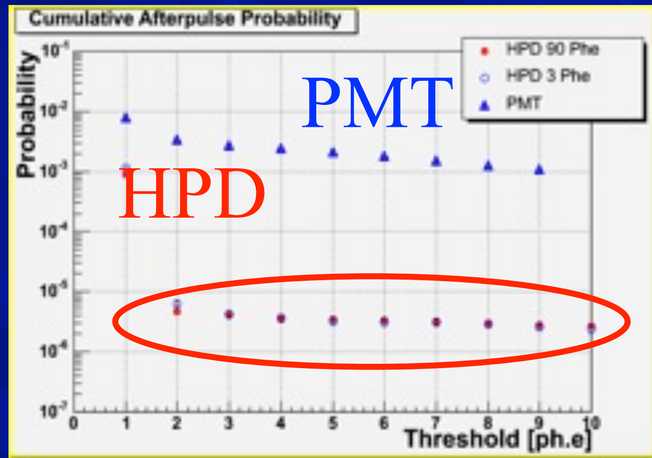
HPD R9792U-40 Specifications

Fast signal shape

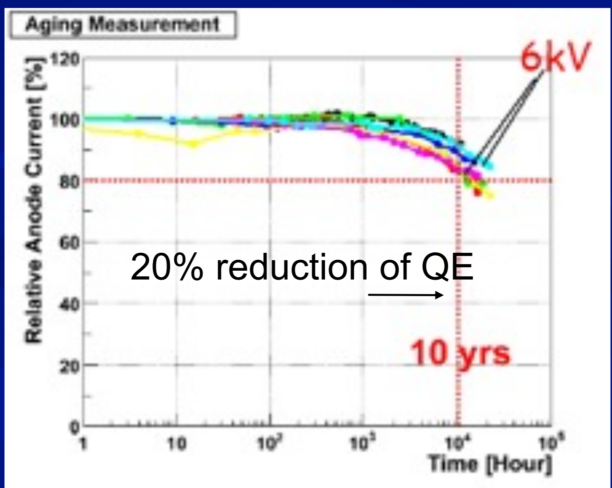


Good ph.e. resolution

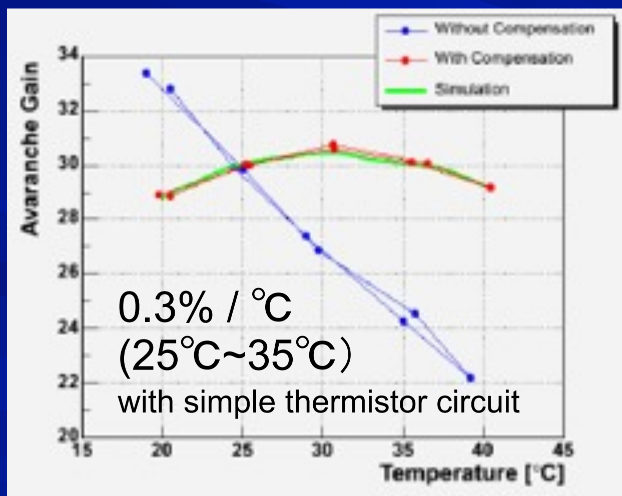
Very low after pulse rate



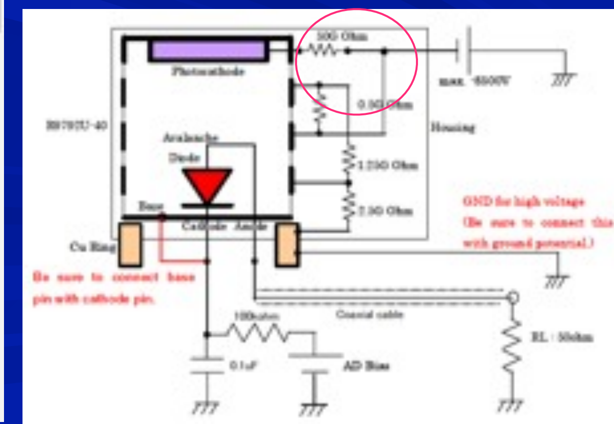
Life > 10 years



Temperature compensation



Protection circuits for strong light

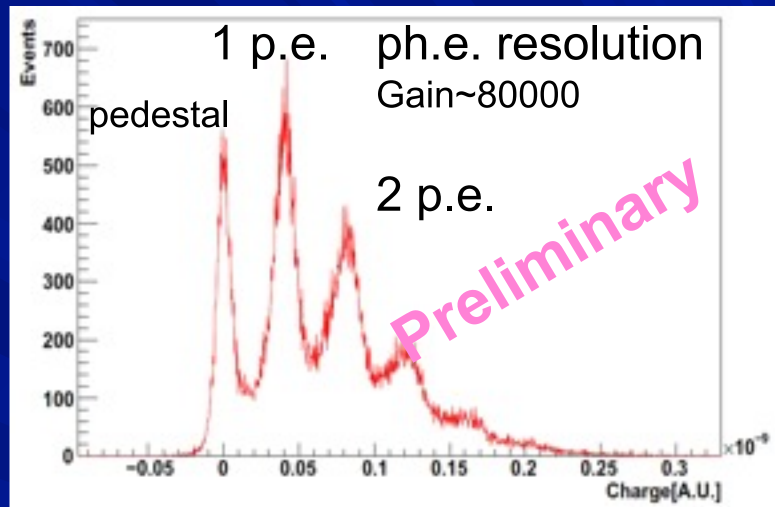


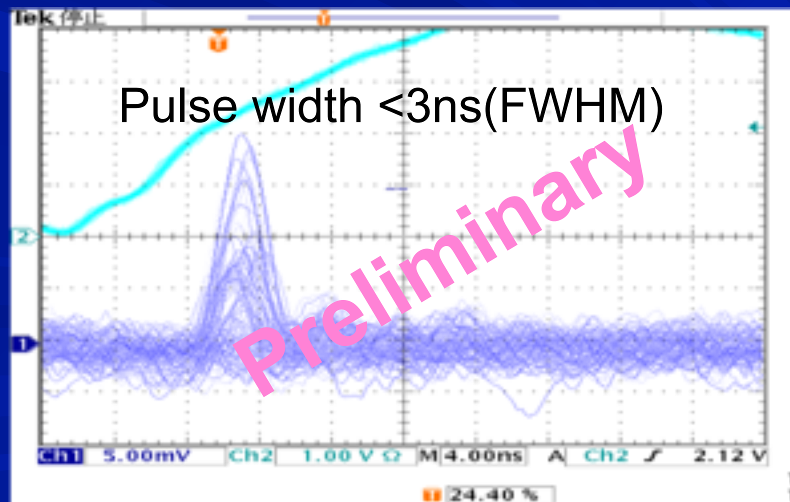
Monday, October 31, 2011

HPD Cluster Performance

Basic operation is OK.
Now checking ……

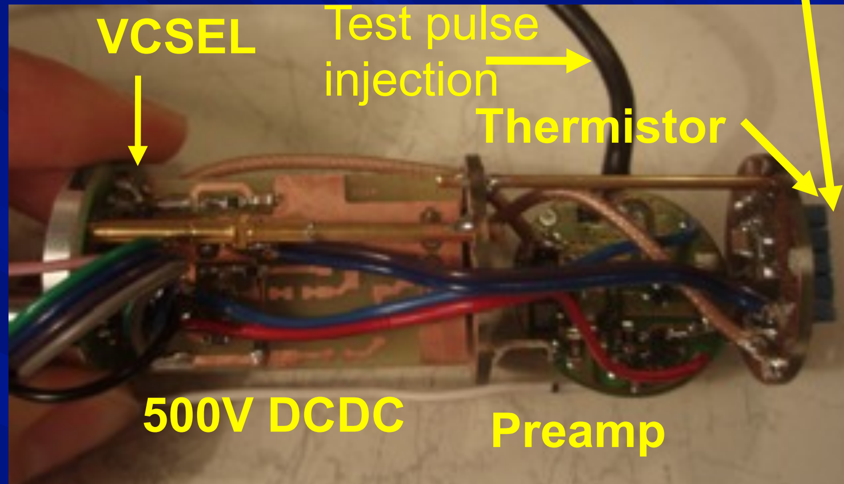
- Pulse shape
- Ph.e. resolution
- Gain stability, linearity, Cross talk, spark,,,,,,etc





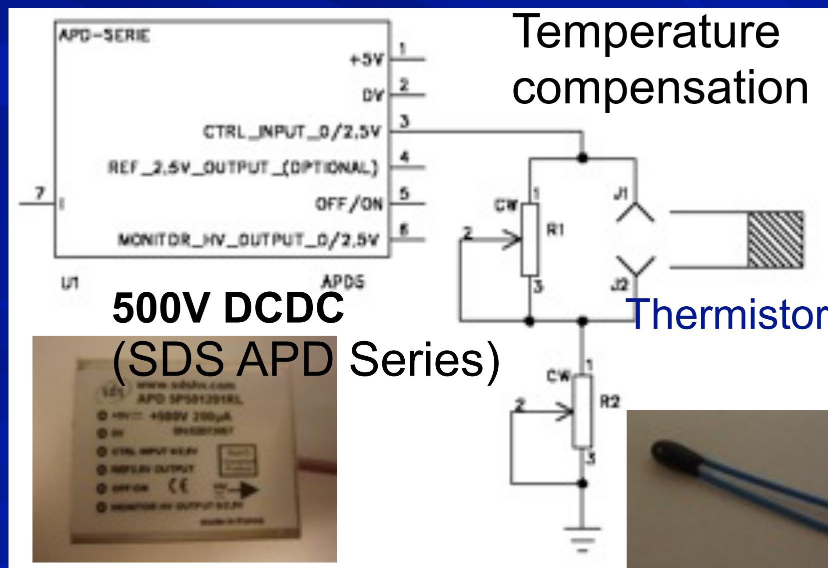
HPD Cluster Components

- HPD mounting board
- Preamp
- Thermistor
- DCDC(500V), DCDC(-8kV)
- VCSEL
- Temperature sensors
- SCCP(Control& Monitor)



-8kV DCDC (SDS HPD Series)

Slow Control Cluster Processor

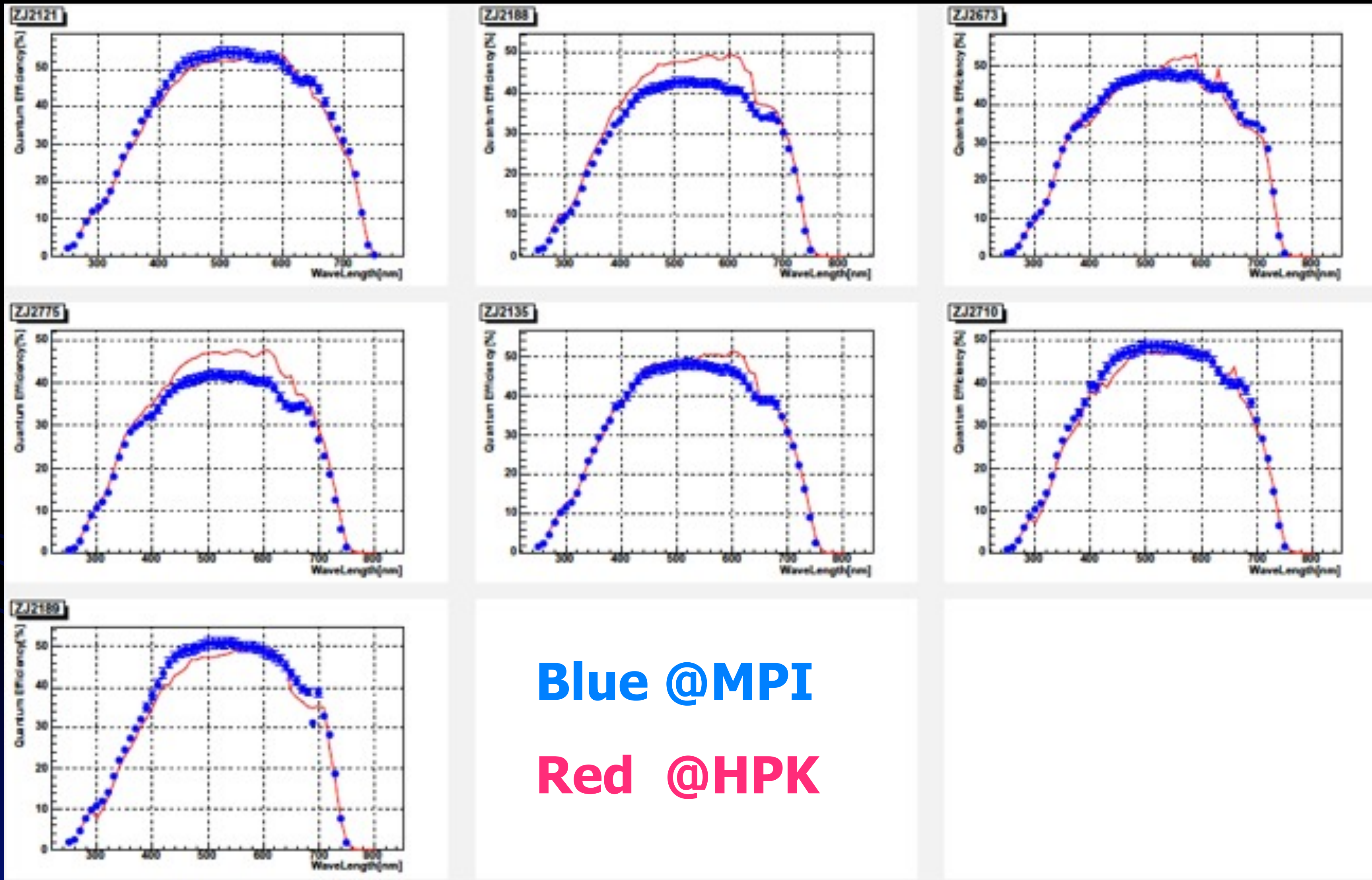


First Prototype Cluster

- 6 HPD channels (by mechanical reason)
- 3 channels with Winston-cone (non UV-reflective)

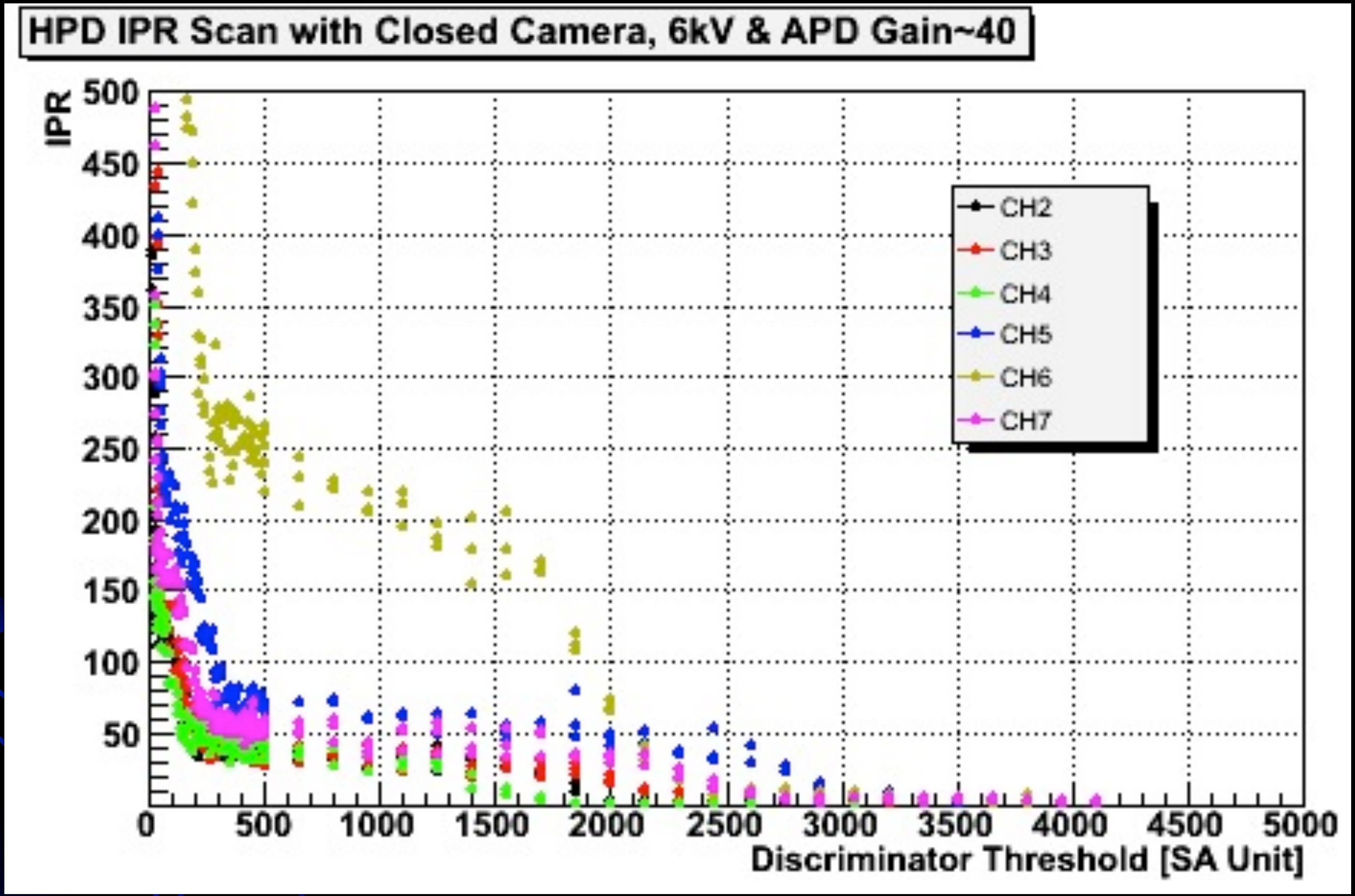
  3 channels without Winston-cone (with clear insulation film)
- Tested at MPI before installing

QE measurement before installing



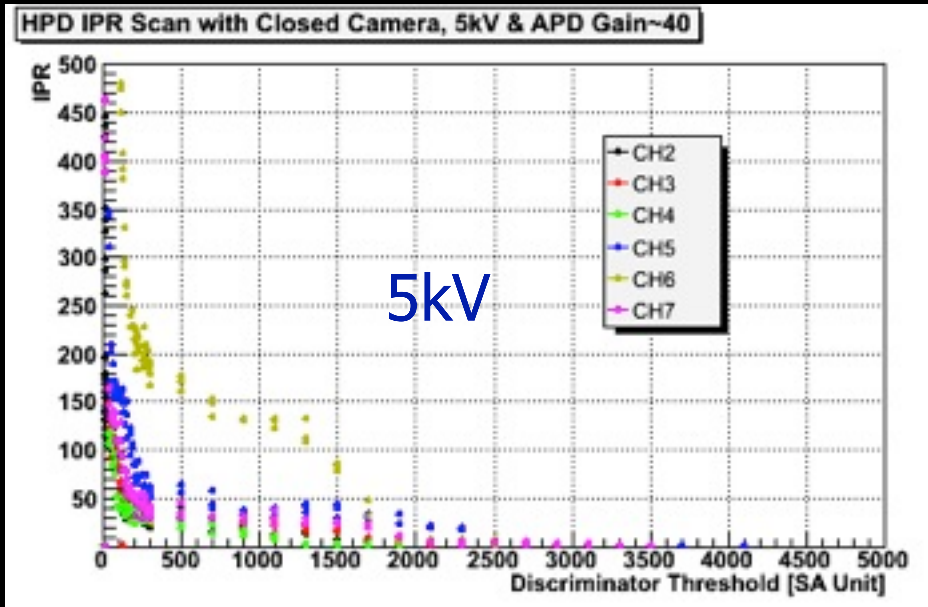
For the prototype cluster, low QE HPDs were selected.
We check QE again after the long-term operation on MAGIC-II.

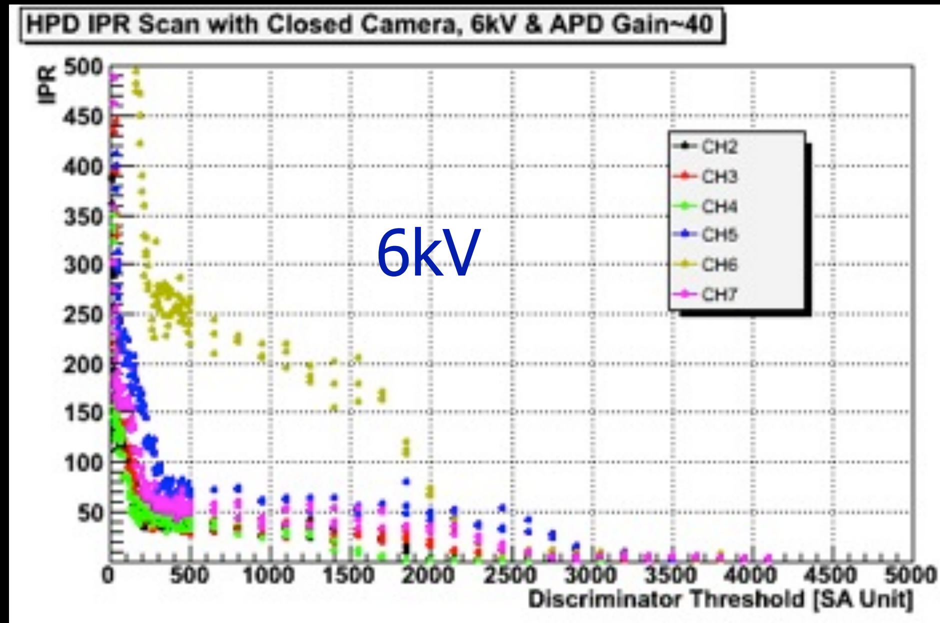
IPR Scan with Closed Camera

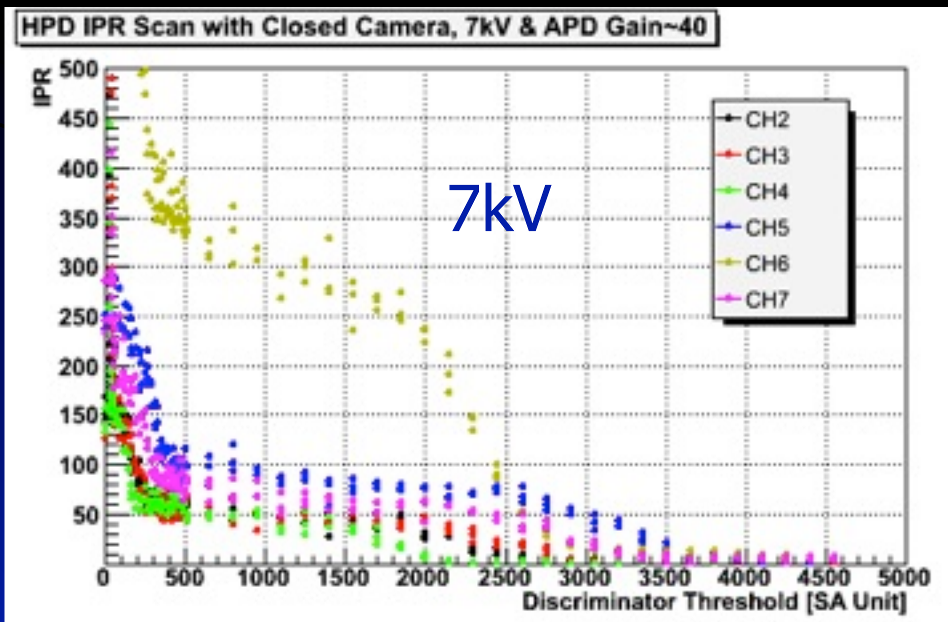


- Gain~36000

IPR Scan with Closed Camera

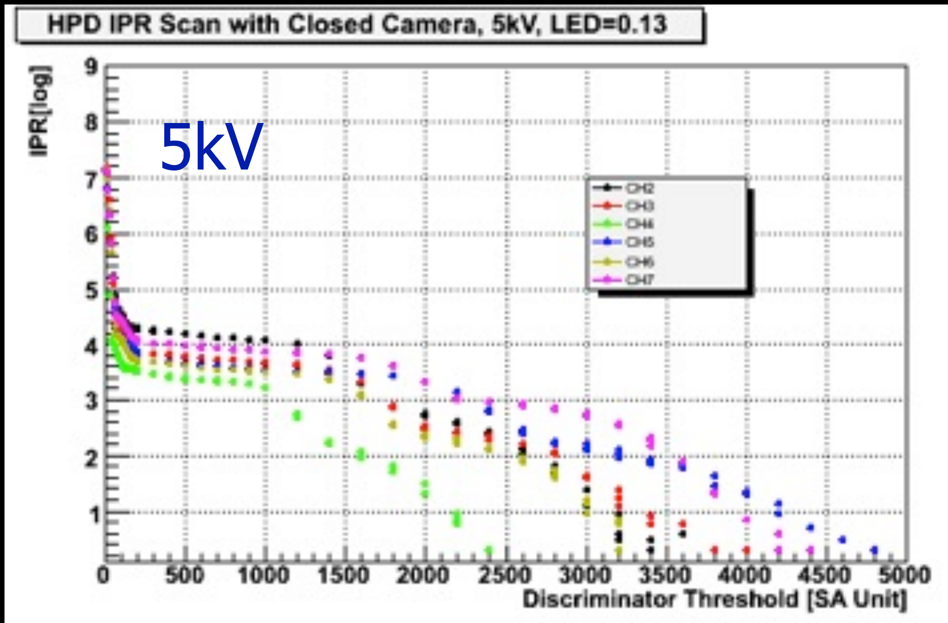


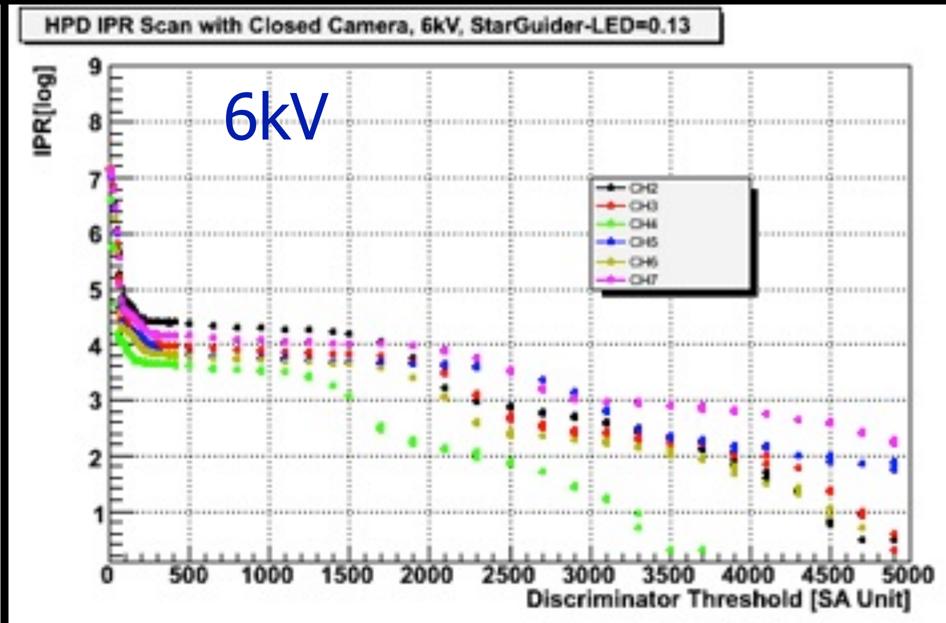


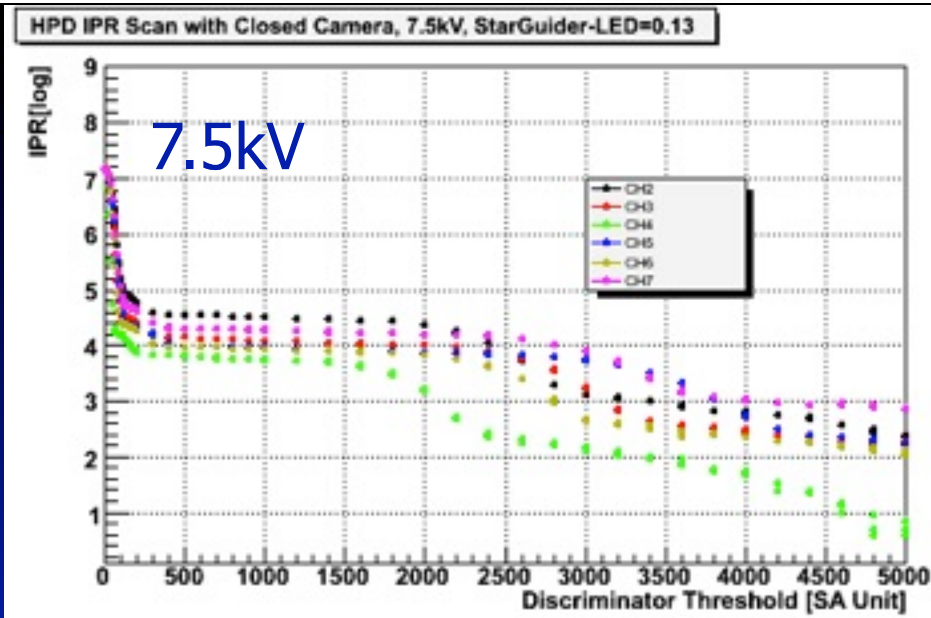


HPD X-ray rate increases with High Voltage

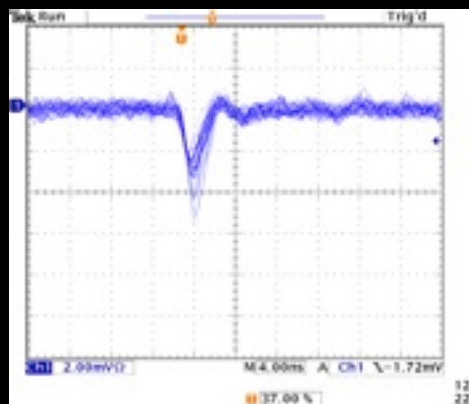
IPR Scan with Closed Camera (LED ON)





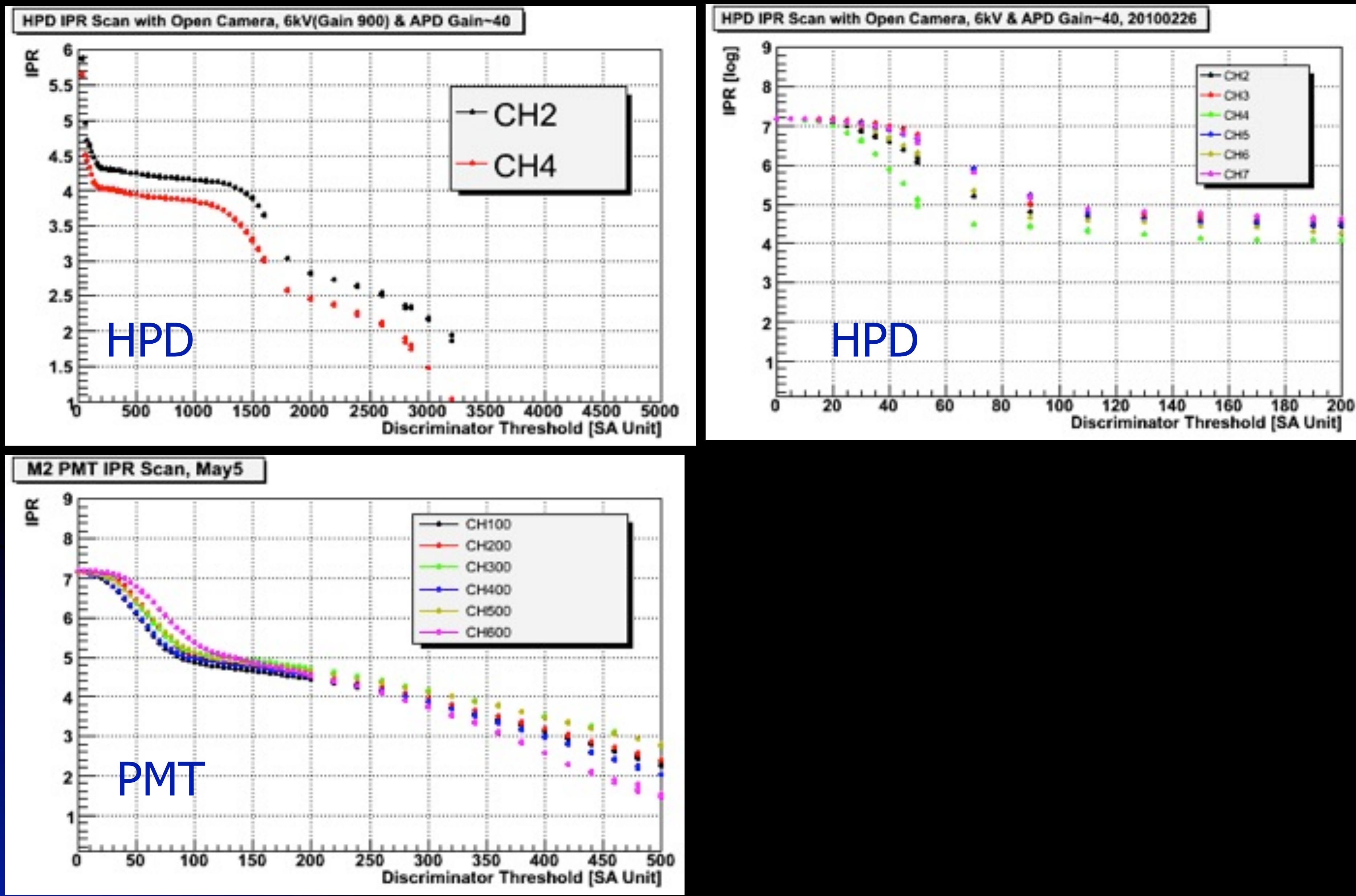


Star Guider LED ON

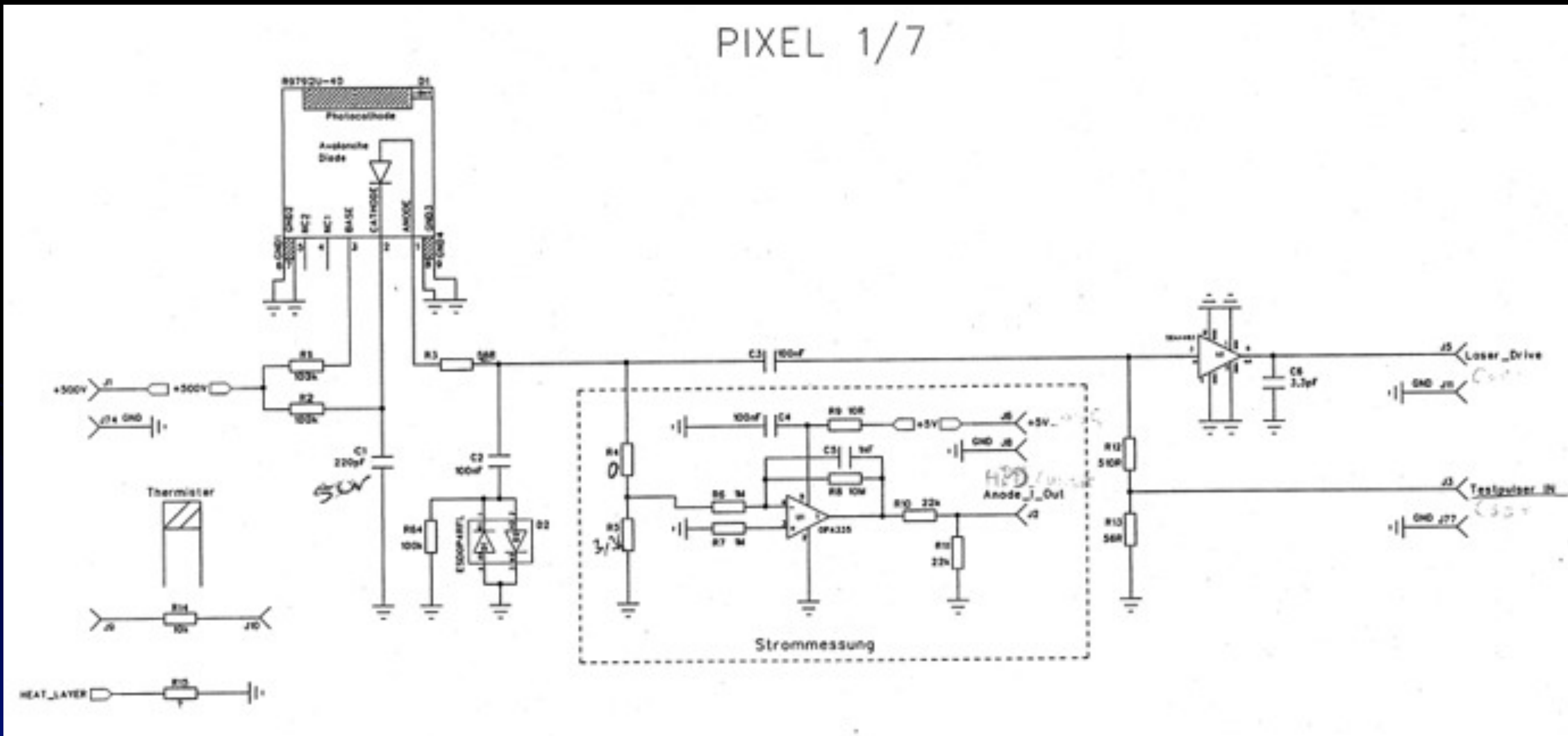


StarGuider LED light is not negligible for HPDs

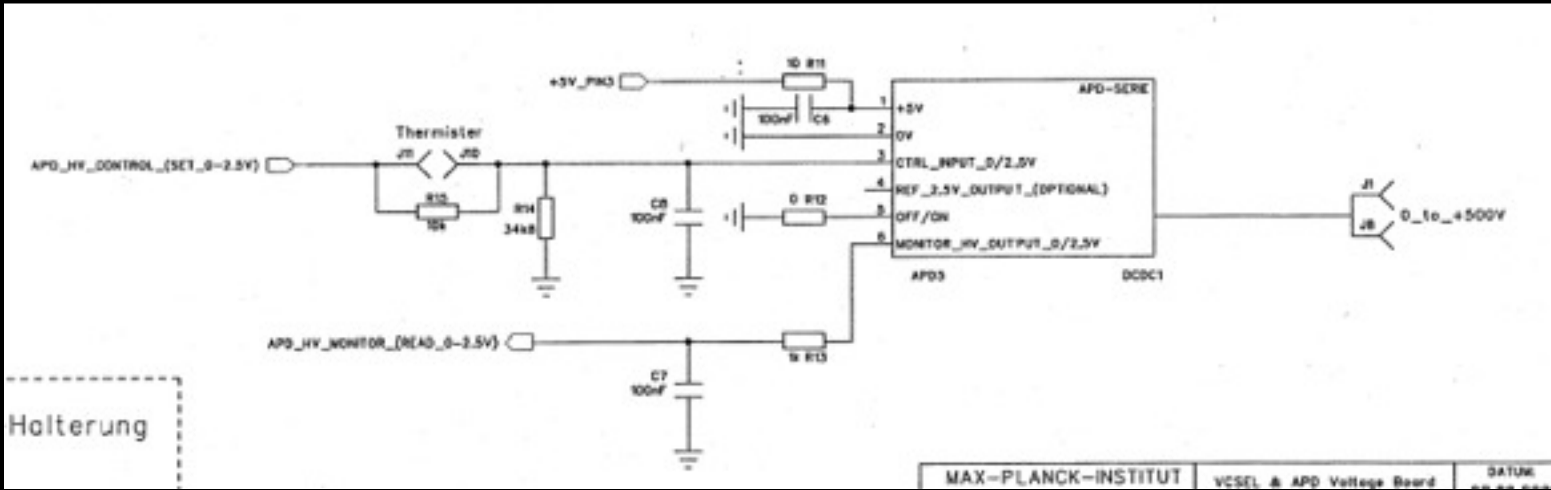
IPR Scan with Open Camera



Circuit Schematics

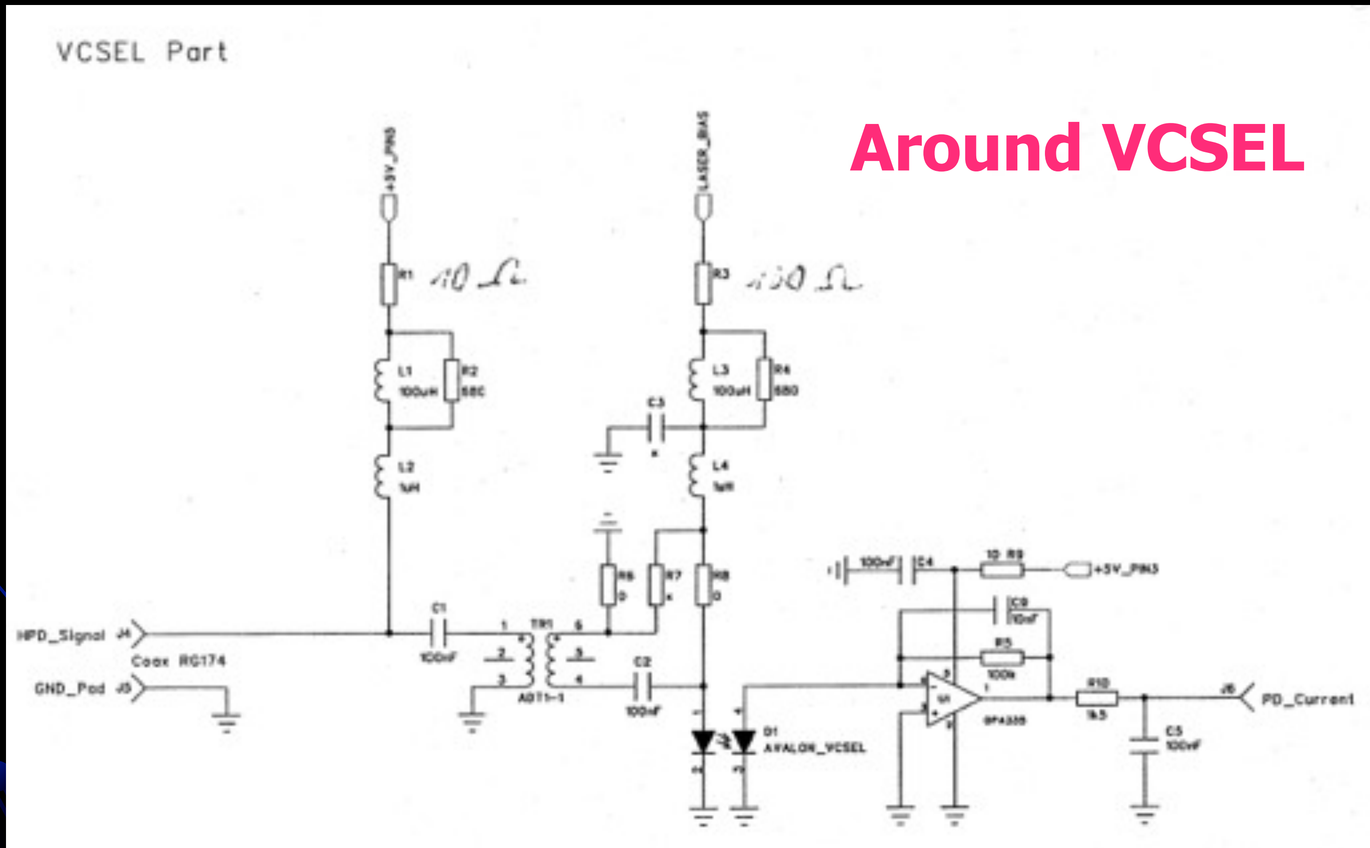


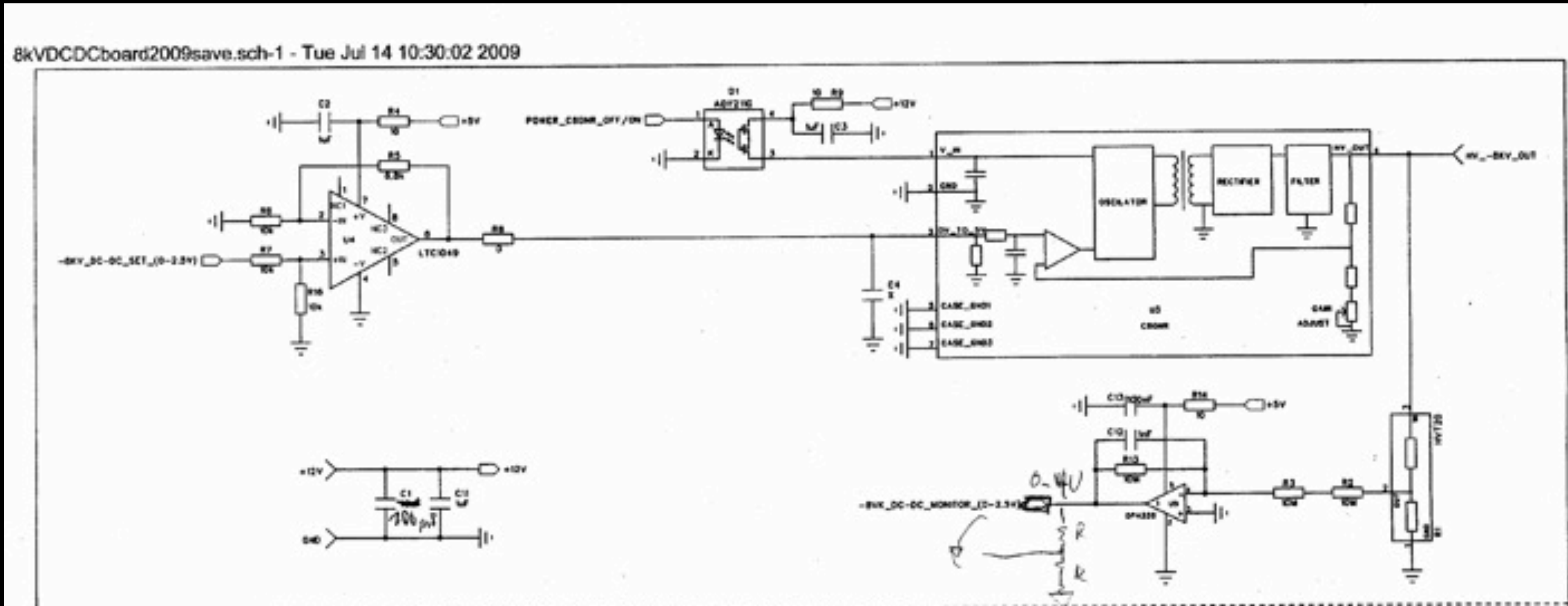
Around HPD



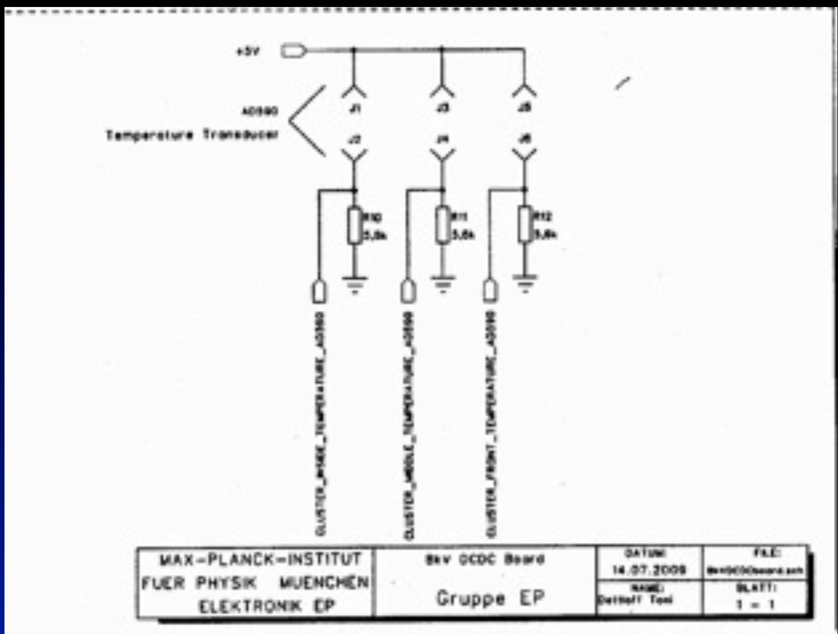
Around APD DCDC

Around VCSEL





Around 8kV DCDC



Temperature sensor

Cluster Components

- 400kV DCDC : SDS APD Series
- 8kV DCDC : EMCO C80N
- Thermistor : EPCOS B57540
- Winston Cone : Dielectric

Serial ID of Mounted HPD

- CH1 None
- CH2 ZJ2188 G_{40} =388V(Max 424V) QE 47%
- CH3 ZJ2775 G_{40} =385V(Max 418V) QE 47%
- CH4 ZJ2135 G_{40} =319V(Max 349V) QE 48.7%
- CH5 ZJ2248 G_{40} =316V(Max 333V) QE 50%
- CH6 ZJ2710 G_{40} =397V(Max 433V) QE 47.2%
- CH7 ZJ2121 G_{40} =400V(Max 406V) QE 52%

Test on MAGIC-II Camera

- Long Term Test : 6.5kV confirmed
- Spark Test1 (After Rain)

  Small spark at 7.5kV

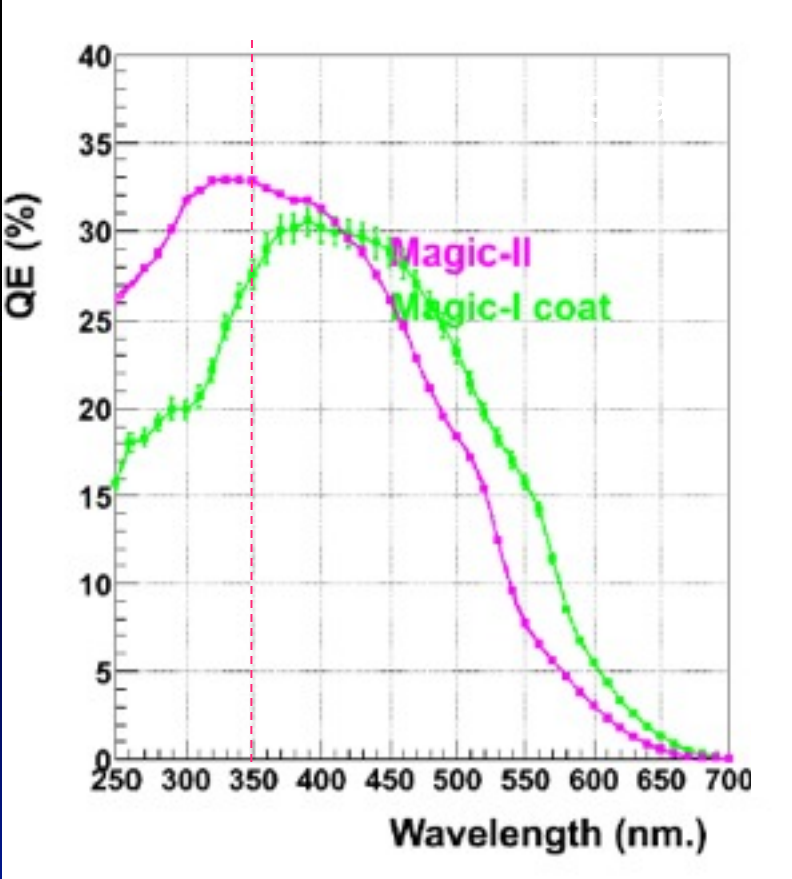
  Depending on channels(0.05~6Hz)
- Spark Test2 (After Camera Drying)

  At 8kV no spark except CH6(~0.6Hz spark-like event)

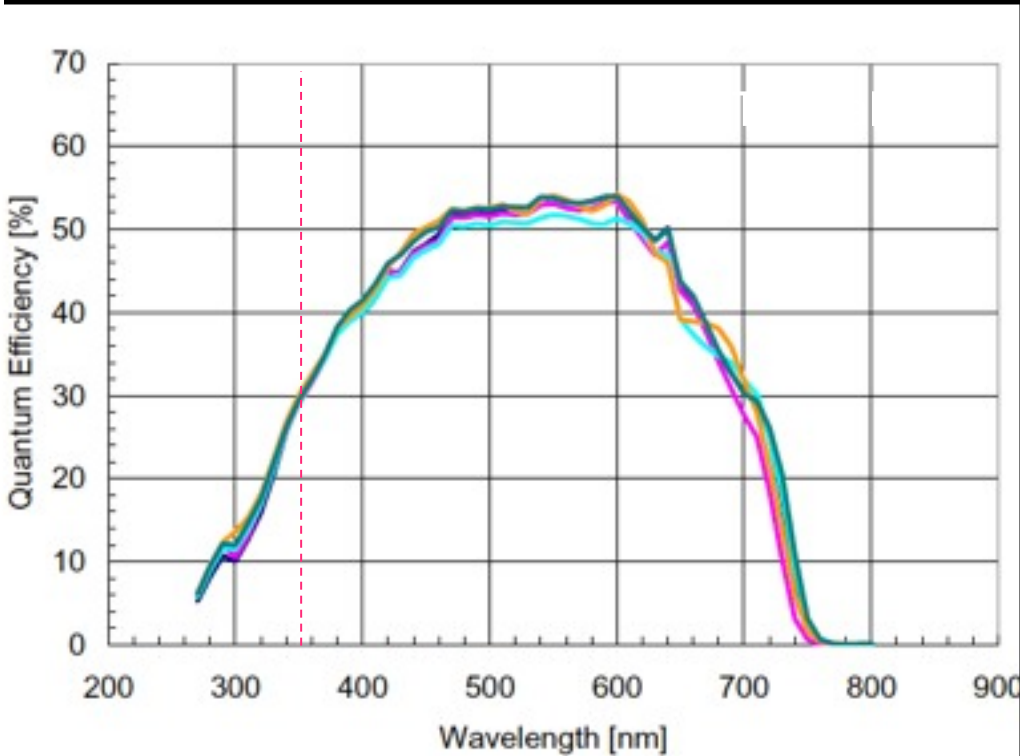
  Humidity average 42%, T_{in}=16deg, T_{out}=9deg

QE Comparison at 355nm (MAGIC-II Calibration Laser)

PMT



HPD



~30%@355nm

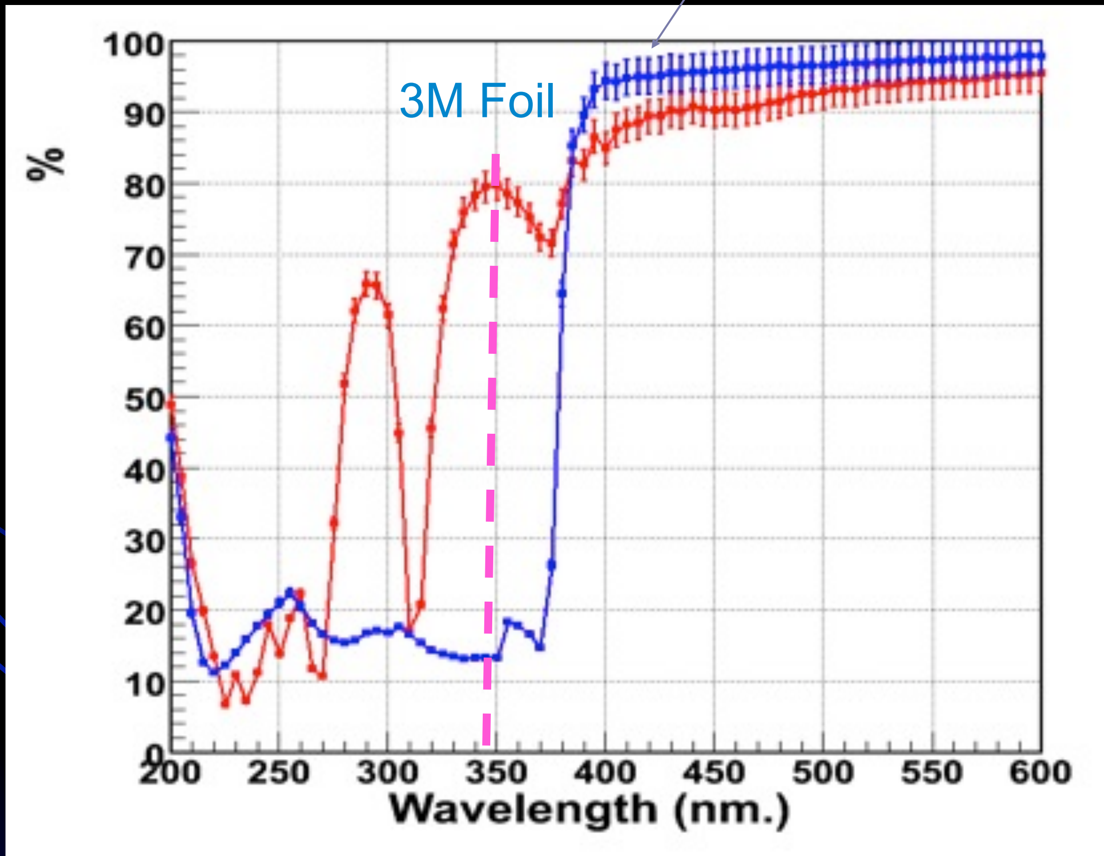
Without wavelength Shifter

Transmittance of Insulating Film

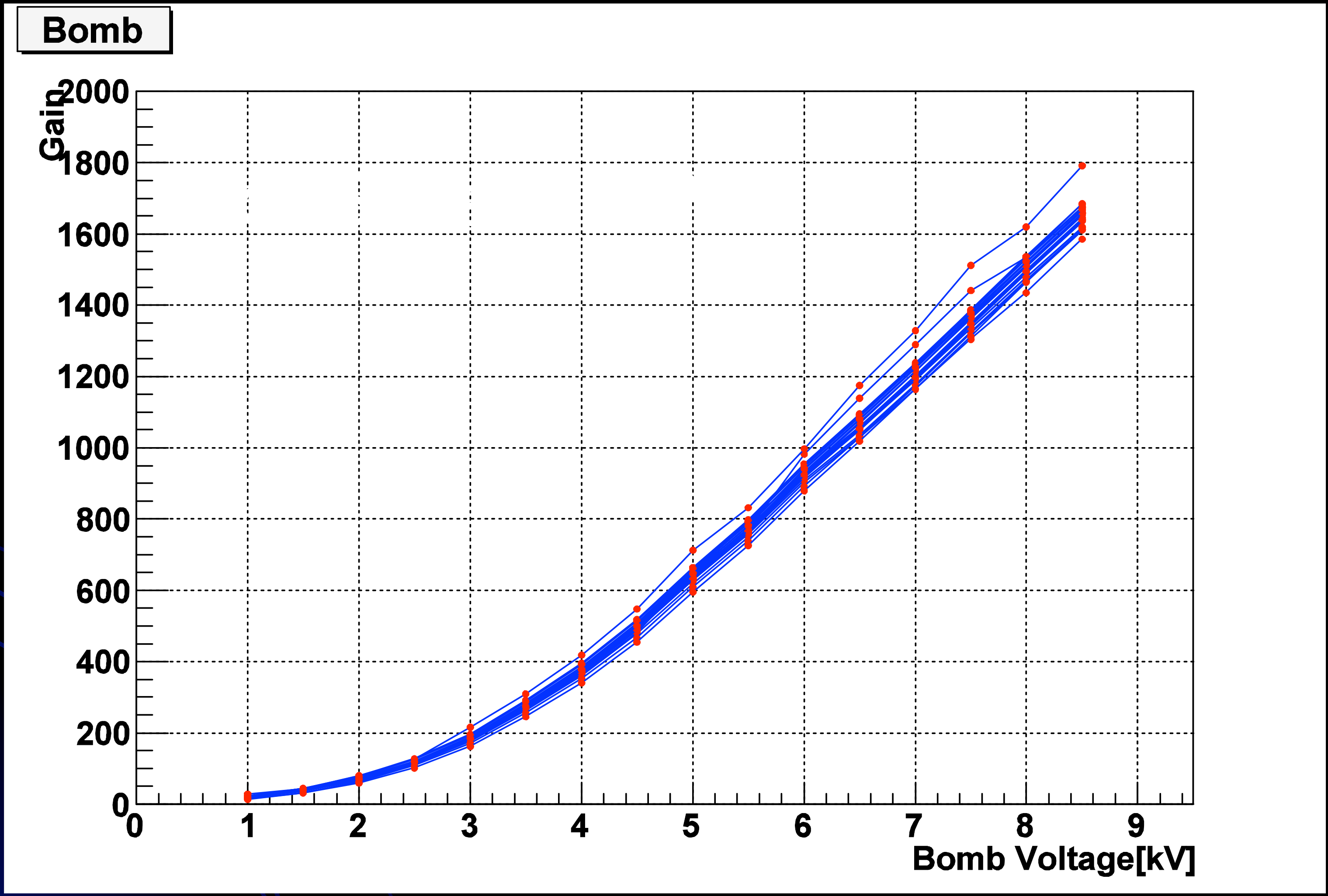
- Clear PTFE 127um (RS 536-3996)
  Dielectric Strength 260kV/mm

Transparency as a function of wavelength

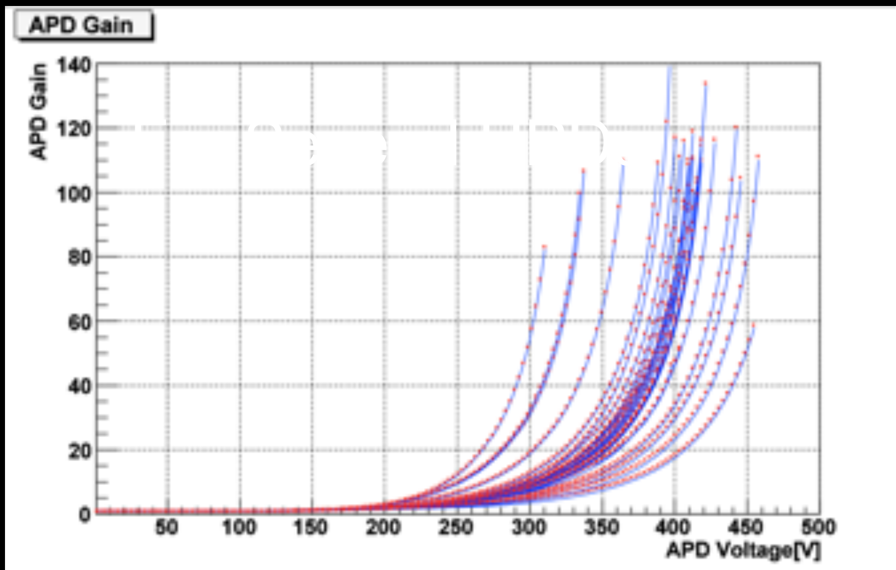
Reflectivity of Current dielectic WC Film (3M Foil)

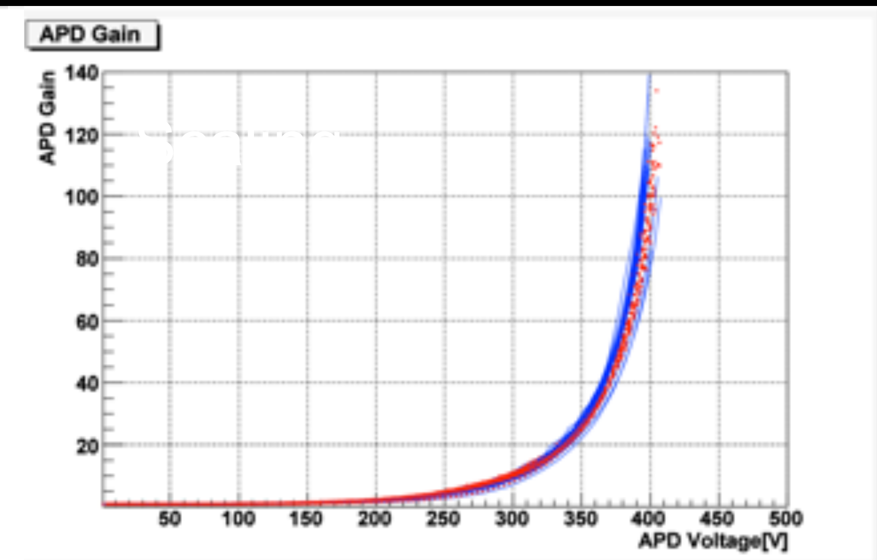


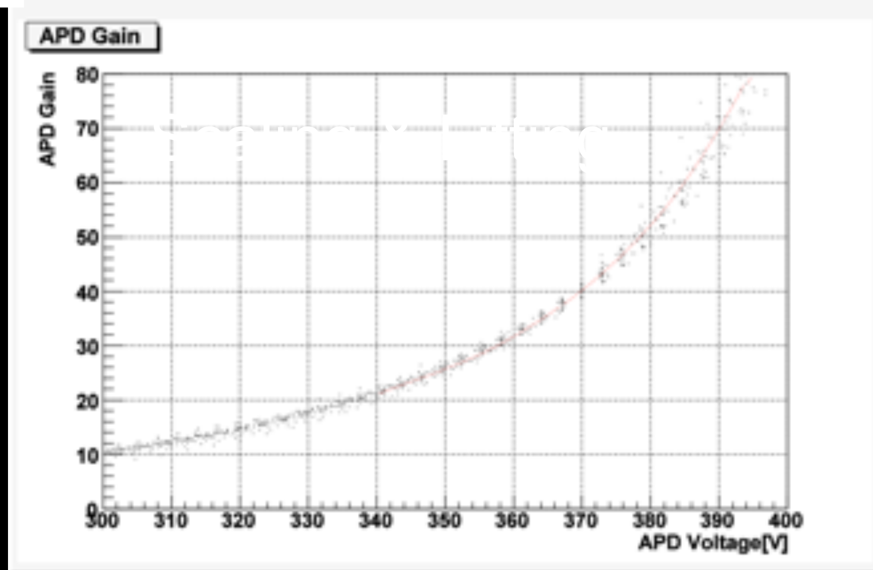
Ref: Bombardment Gain



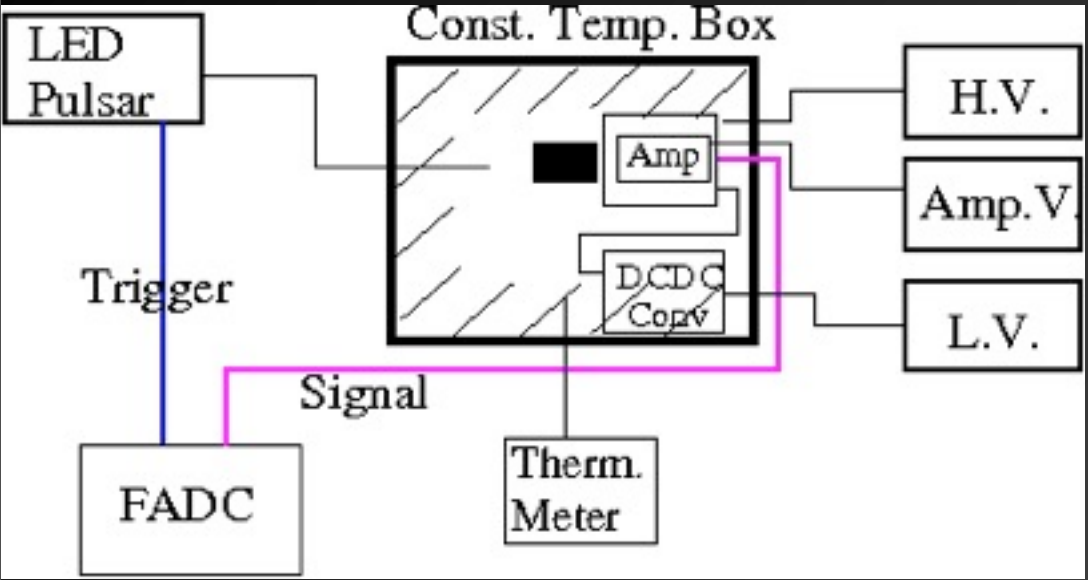
Ref: APD Gain calculation

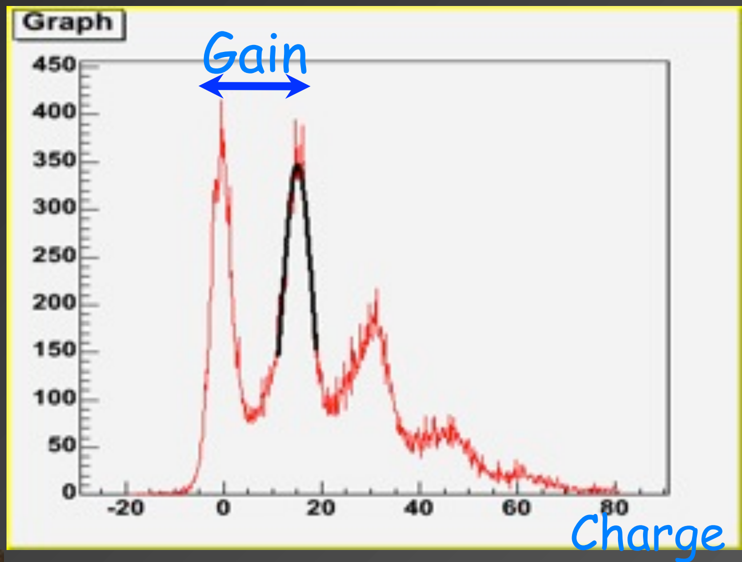




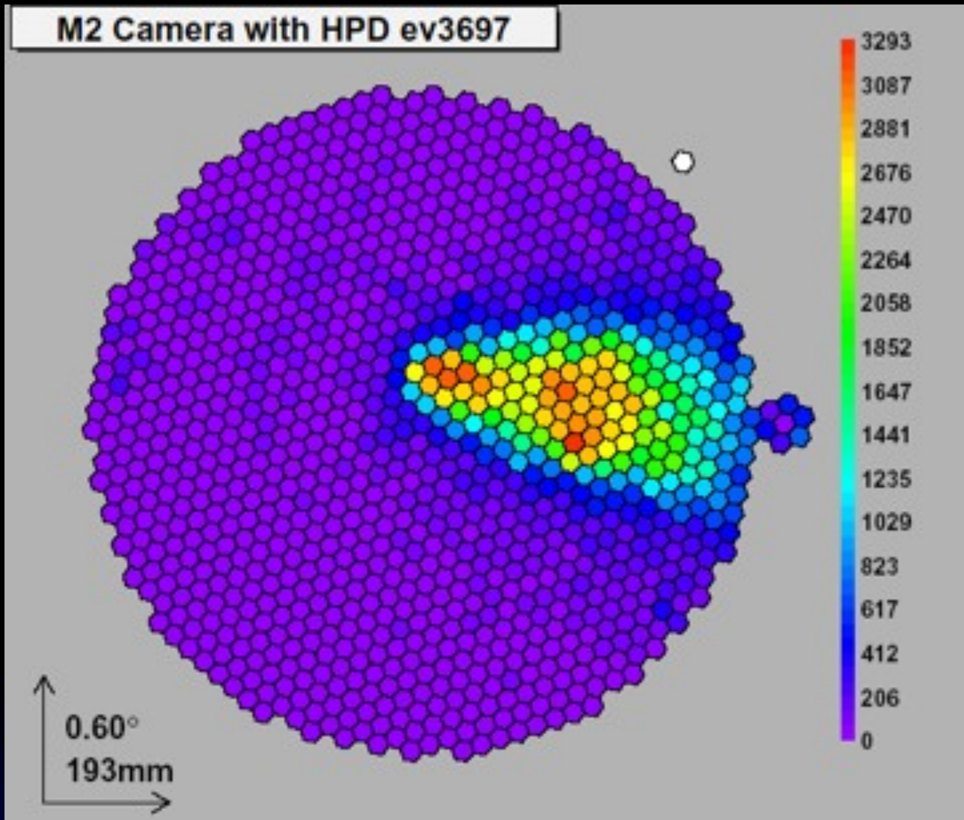


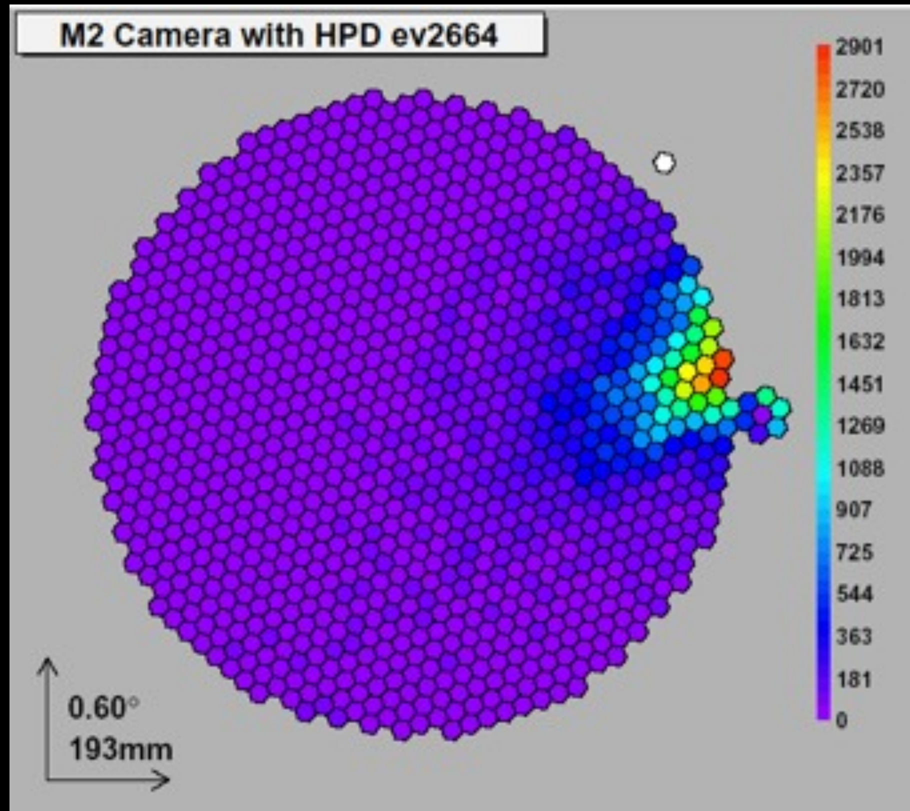
Check the variation of Av. Gain





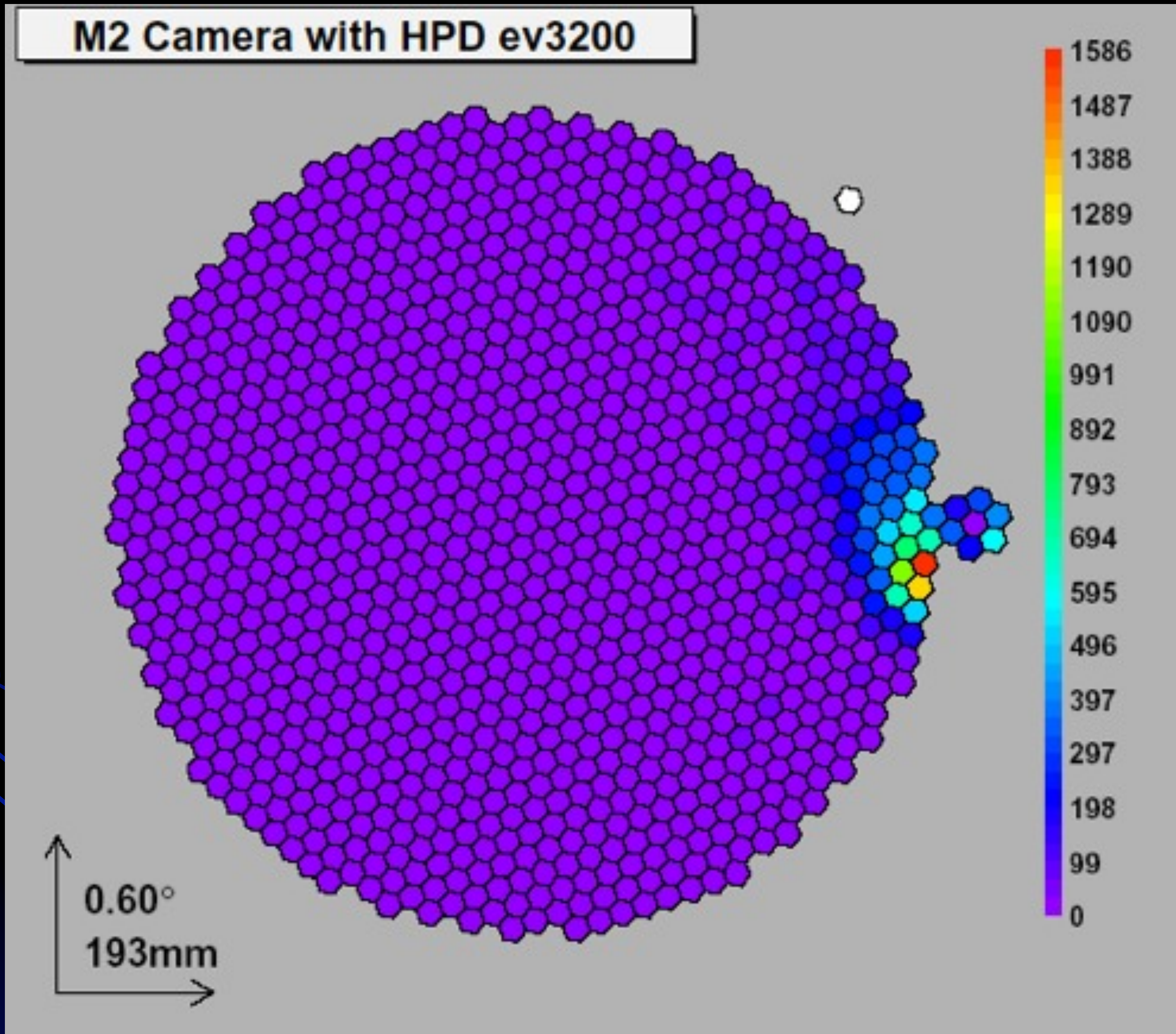
Shower Events





(Pulse height without Domino Calibration)

- Domino calibration coefficient should be calculated for HPD channels.
- Caco2 should be updated
  (Sometimes no signal because of wrong the HV setting….)


M2 Camera with HPD ev3200
1586
1487
1388
1289
1190
1090
991
892
793
694
595
496
397
297
198
99
0
0.60°
193mm