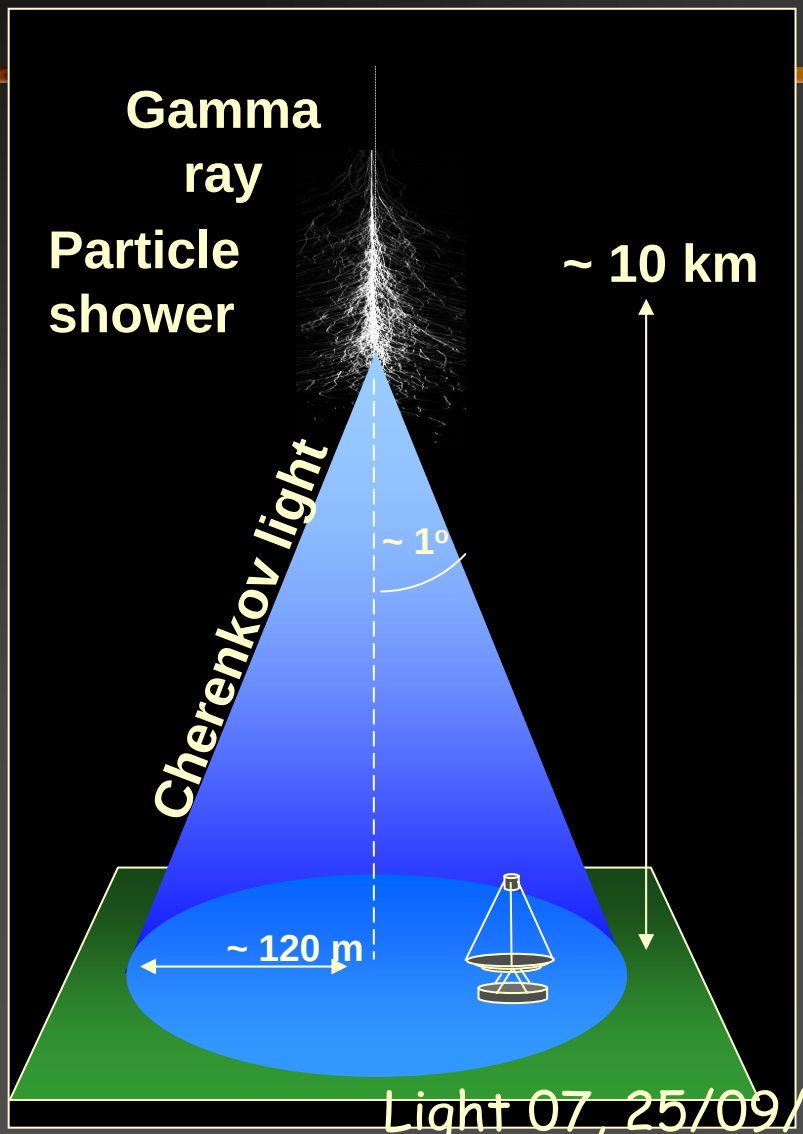
HPDs with GaAsP Photocathode for the MAGIC Project

Max Planck Institute for Physics

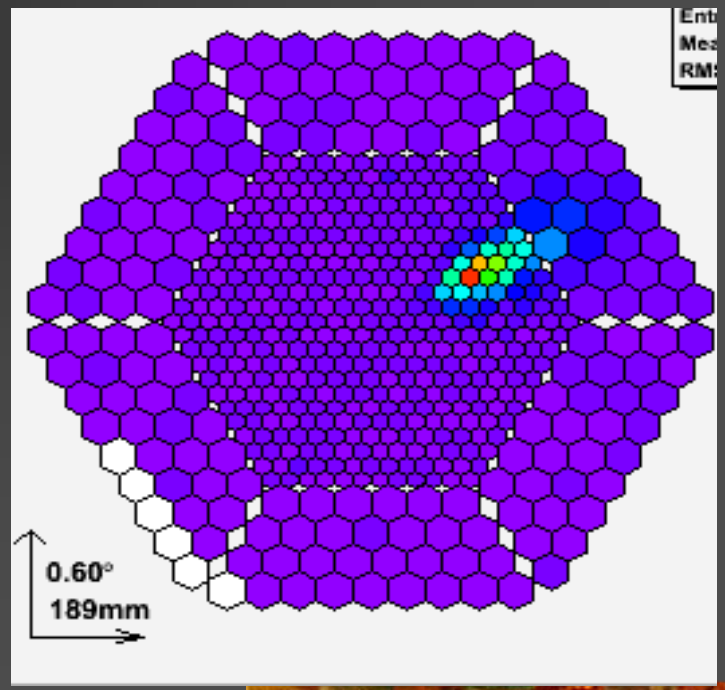
Takayuki Saito

HPD R9792U-40
MPI & Hamamatsu

Imaging Atmospheric Cherenkov Telescope (IACT)



- Detect Cherenkov light from air shower



MAGIC Telescope

17m Φ The Largest Telescope
Lowest energy threshold

Trigger Threshold ~60 GeV

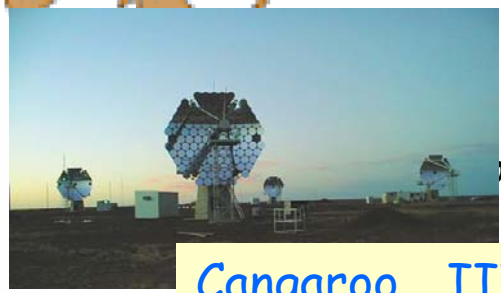
PMT Camera

MAGIC

Veritas

MAGIC-II

HESS

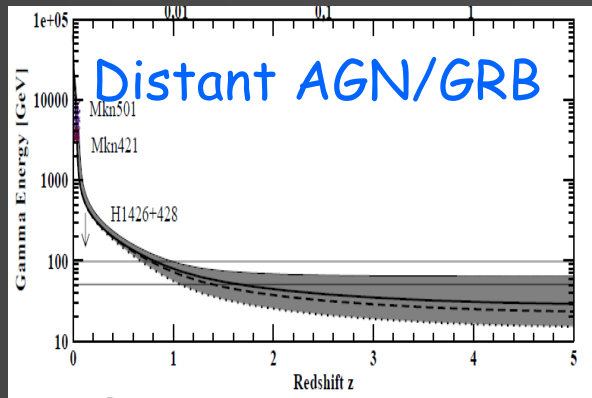


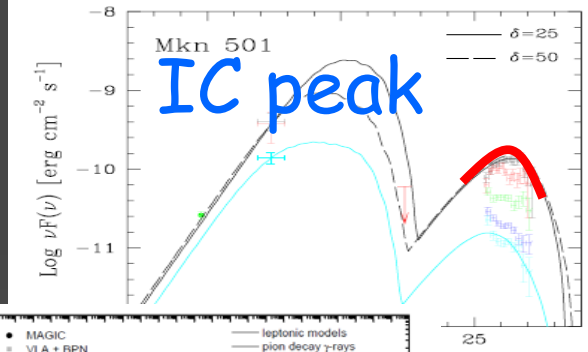
Cangaroo III

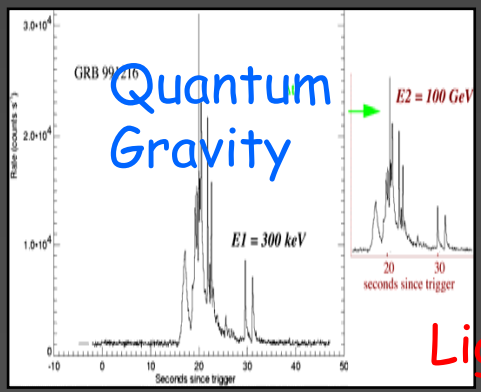
Lower Energy to 30GeV

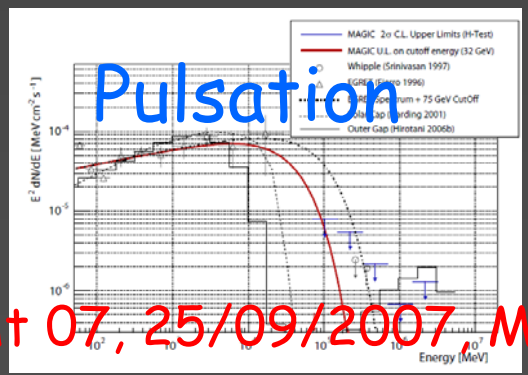
Energy range from 10 GeV to 100 GeV has not yet been investigated well.

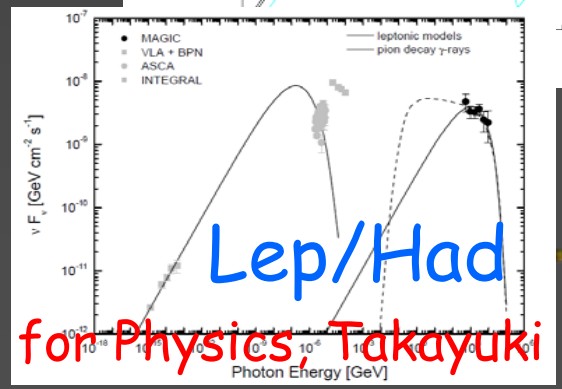
* More sources
  - Distant (z ~3) AGN, GRBs
* Emission Mechanism
  - IC peak, Lep/Had, etc
* Pulsation from Pulsars
* LBL, Quantum gravity etc…







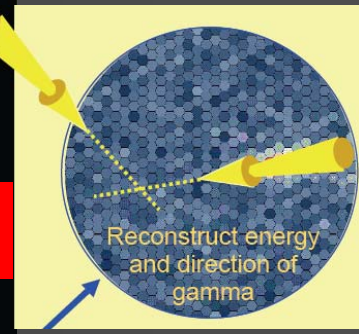




Toward Lower Energy
--- 3 approaches ---

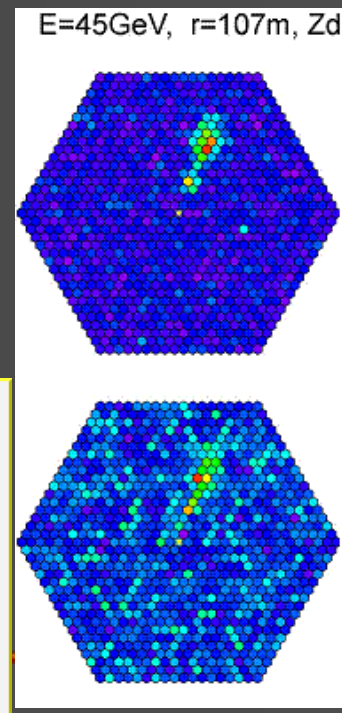
1. Stereoscopic Observation
-> More BG rejection

Second Telescope under construction

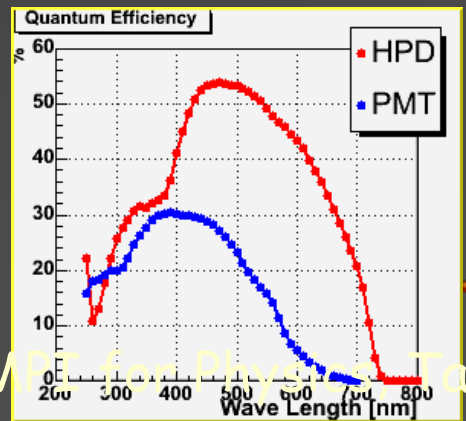


2. High Q.E.
-> More photons

HPD Camera under development

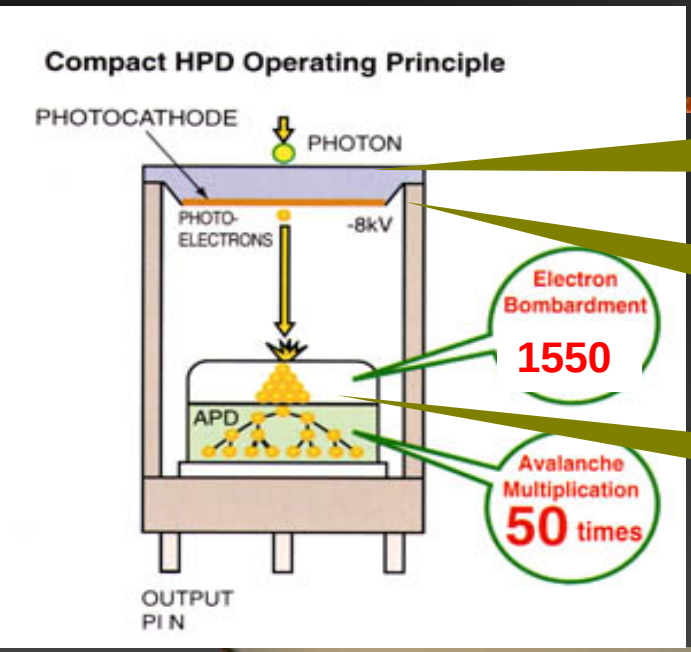


3. Higher Frequency (2GHz) FADC
-> Lower DAQ Noise
-> Timing information for more BG rejection



Installed!! Light 07, 25/09/2007, MPI for Physics, Takayuki Saito

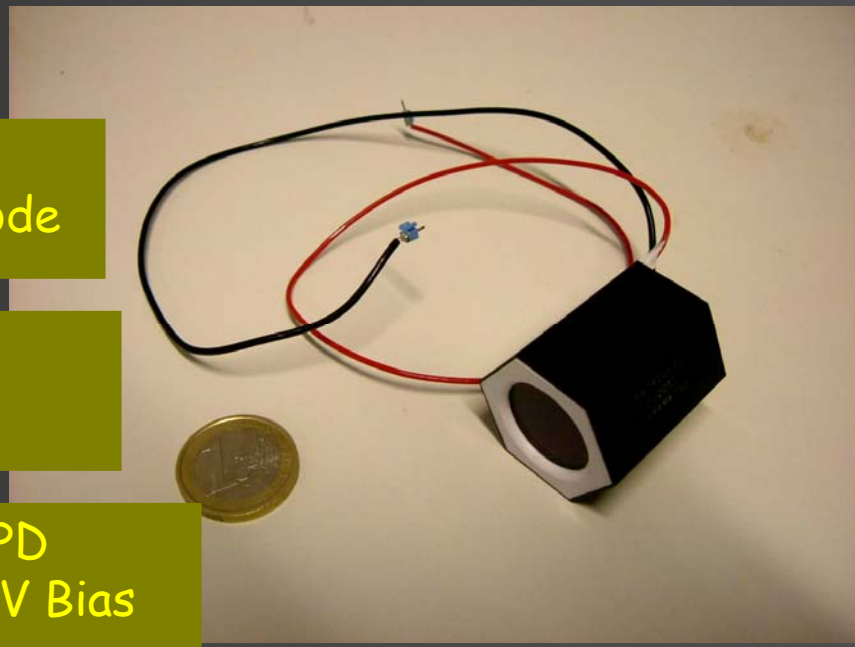
HPD R9792U-40

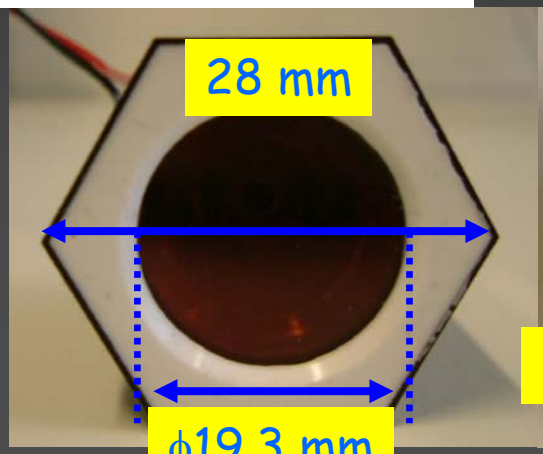


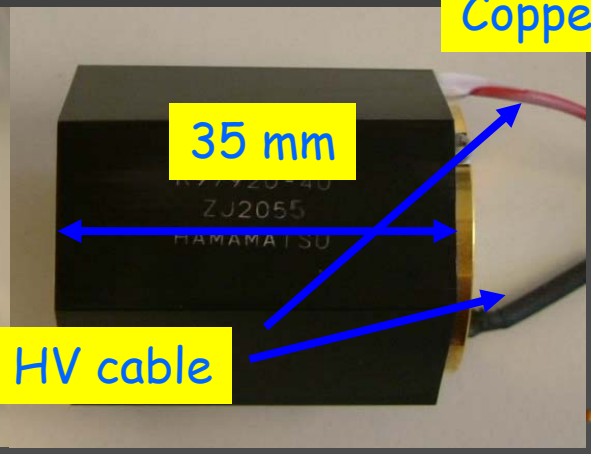
GaAsP PhotoCathode

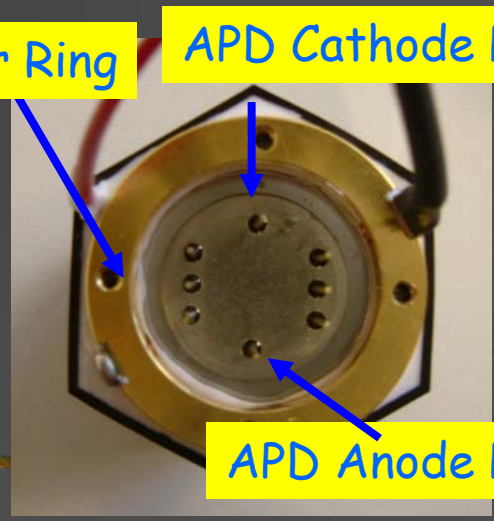
-8 kV HV

APD ~400 V Bias

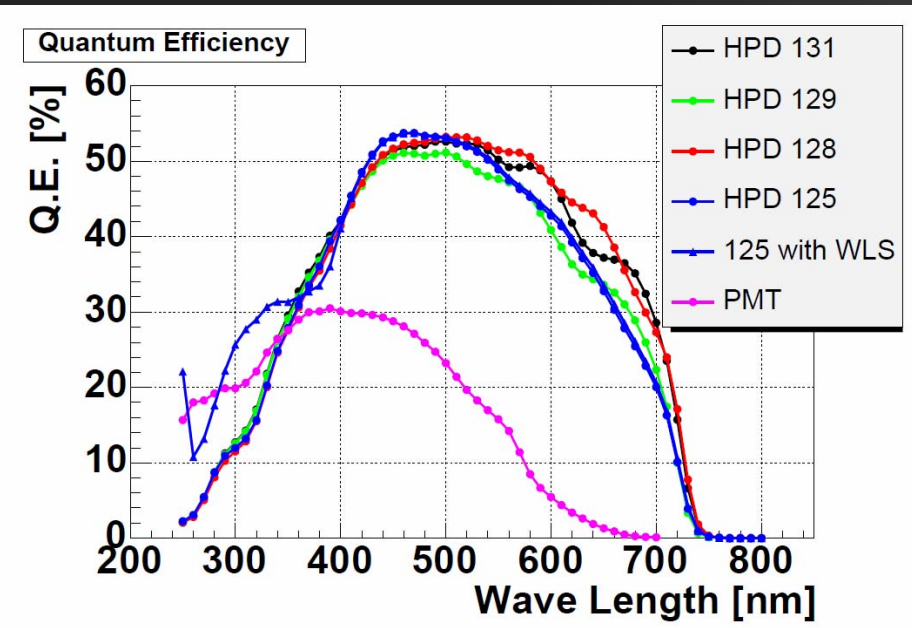




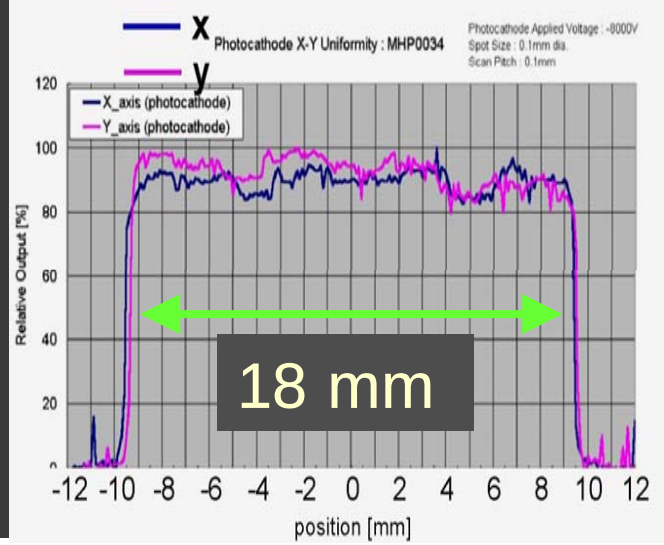


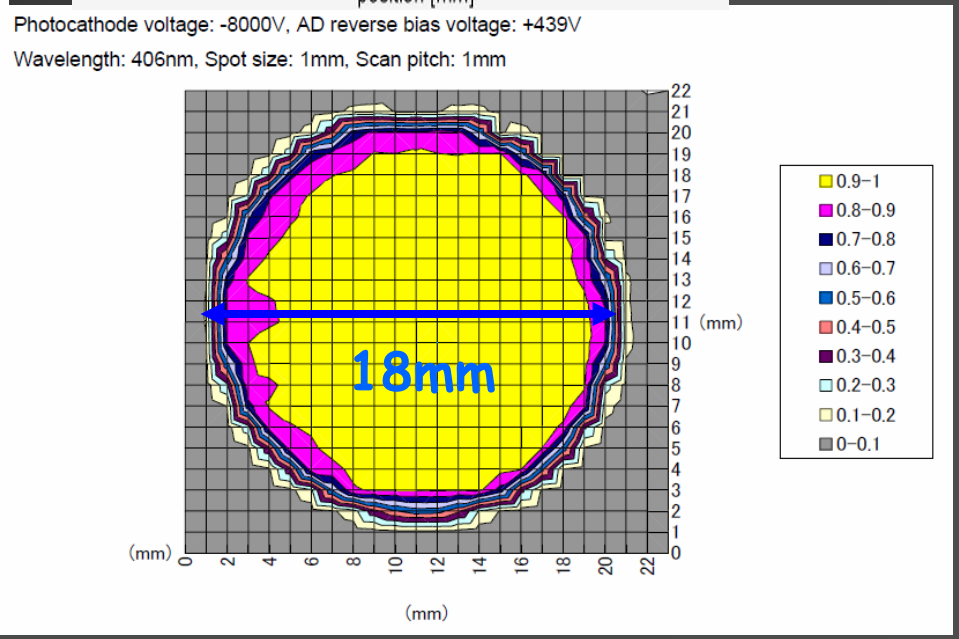


Q.E.



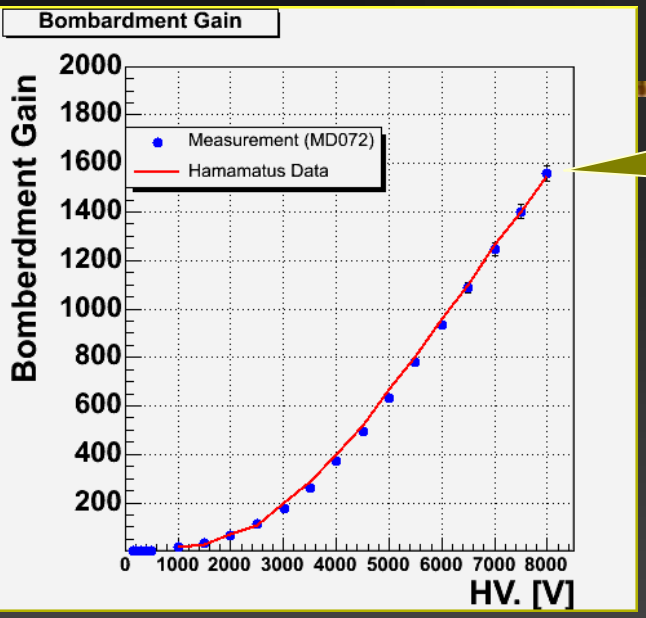
QE exceeds 50% at 450 nm
Two times more photon detection



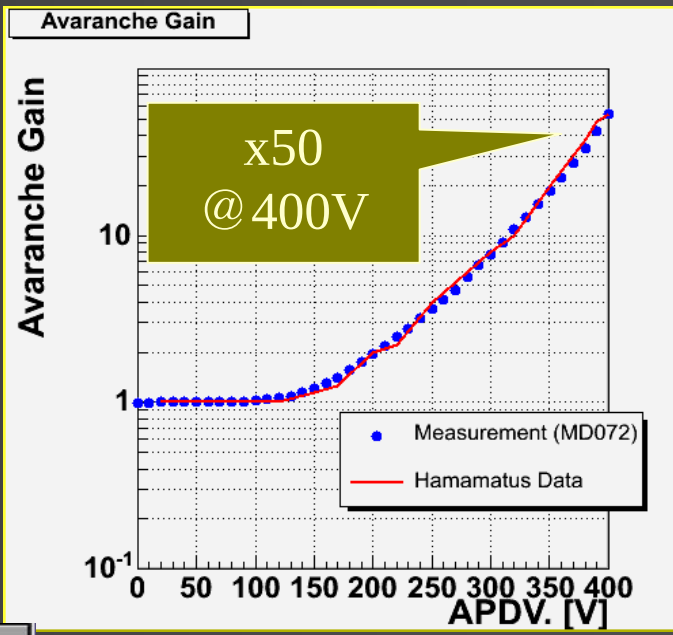


Good Uniformity. 18mm diameter
Within 10%.

Gain and Pulse Shape



x1550
@8kV



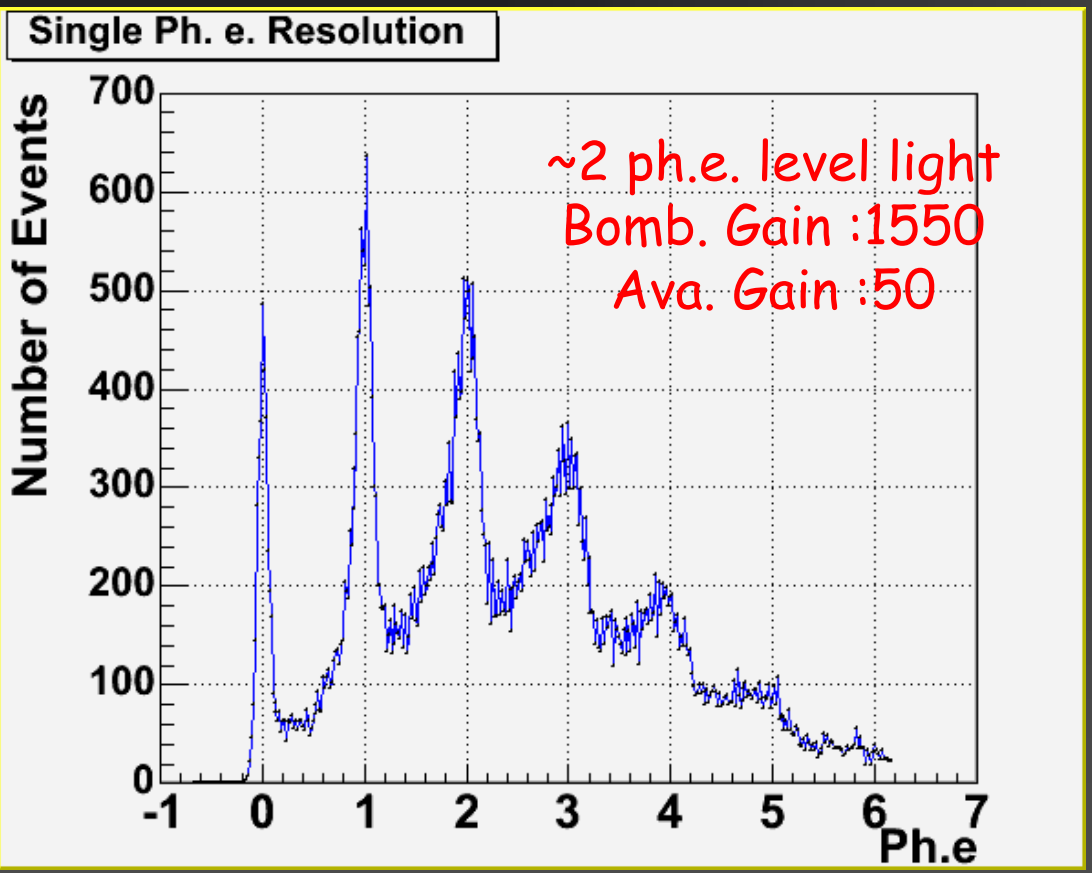
< Bombardment (

< Ava. Gain >

Width ~**2.2 ns** (FWHM)

Rise; 0.7 ns, Fall; 2.6 ns

Single ph.e. resolution



Useful for Absolute intensity Calib.

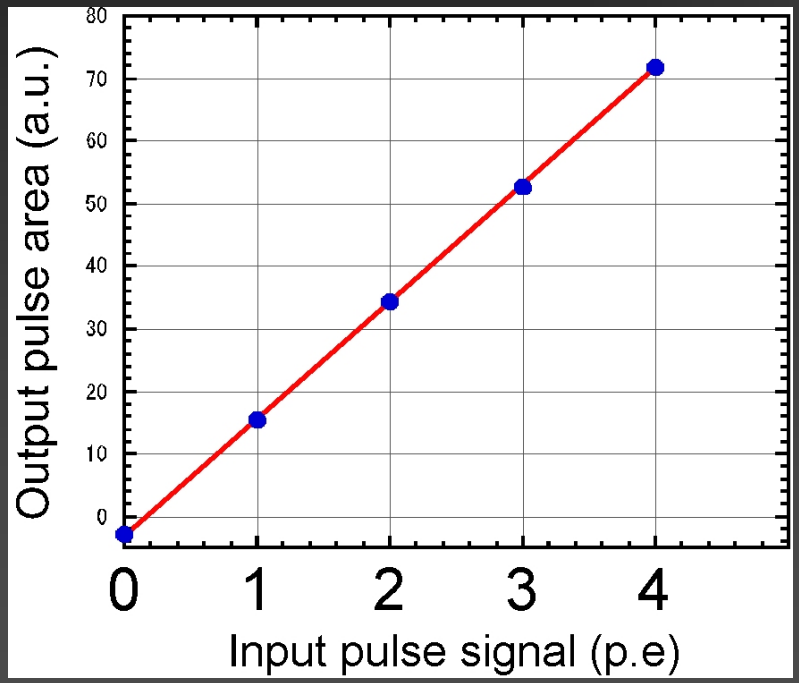
Useful for Gain Calibration

Dynamic Range

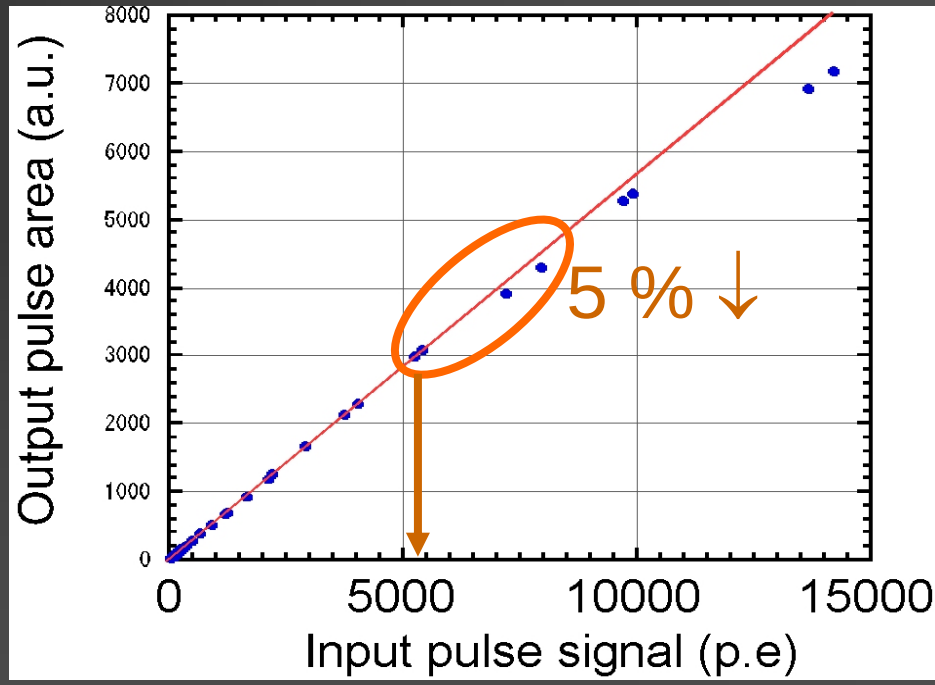
- ~ 5000

  (condition –8 kV, 395V)

  - Measured by pulse area

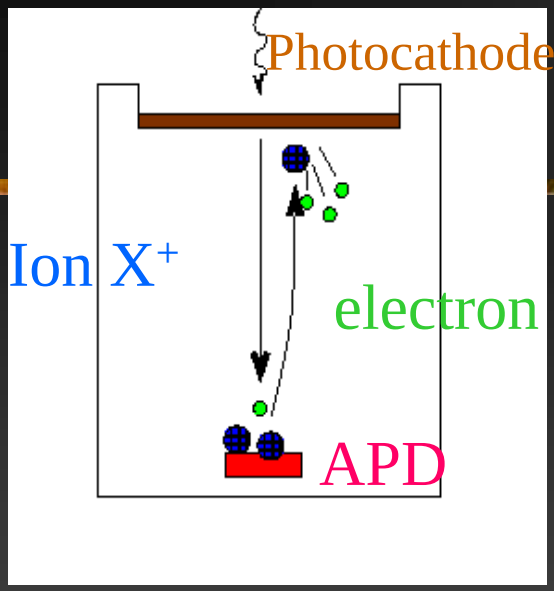


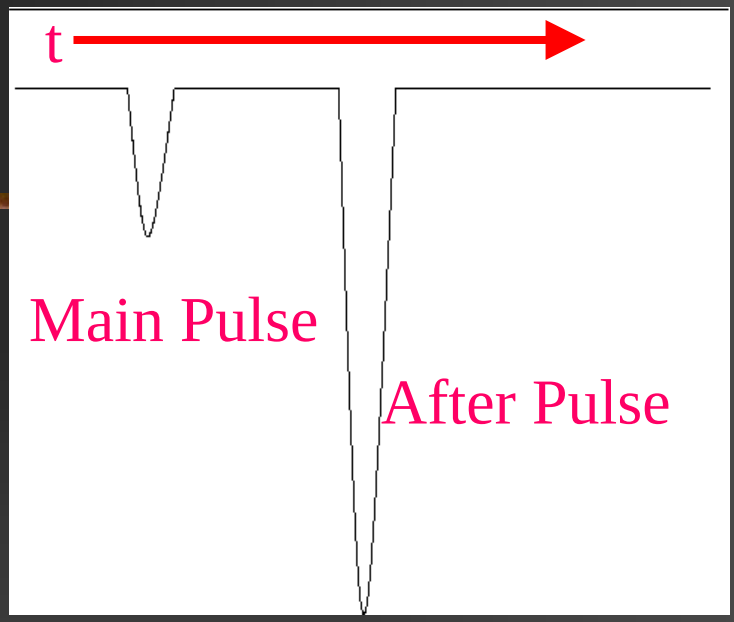
<Small signal >



<Large signal>

Afterpulsing





100 MHz NSB photons
(very small pulse)

⇓

Ion feedback

⇓

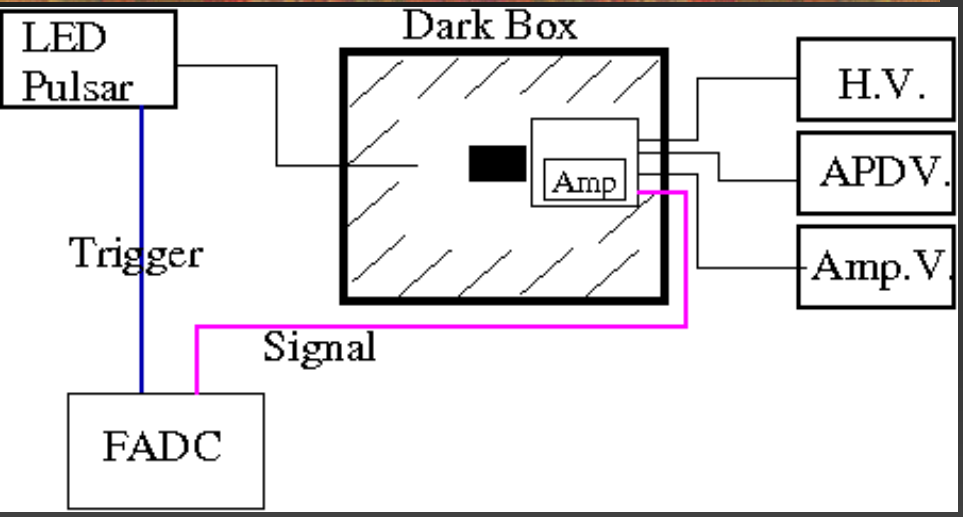
Big Fake Signal!!

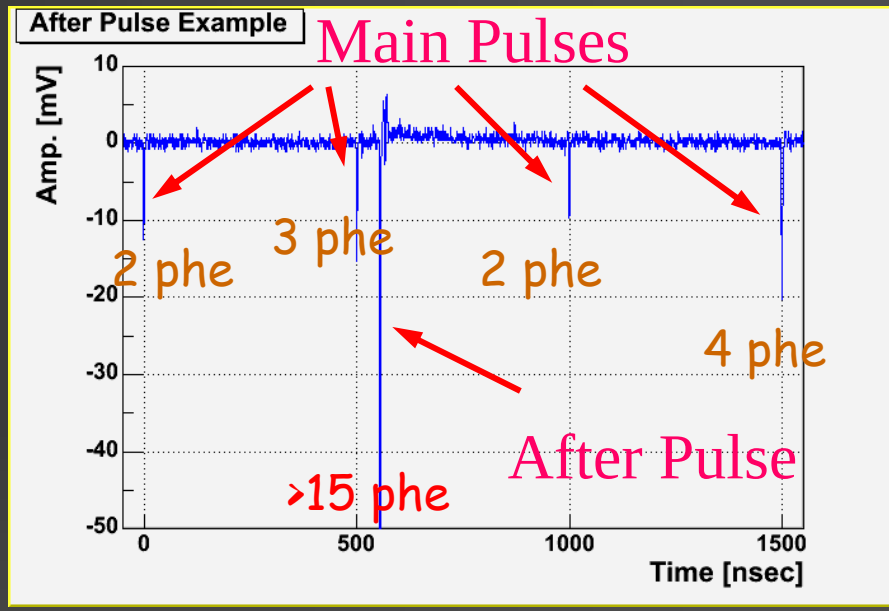
Damage Photocathode

⇓

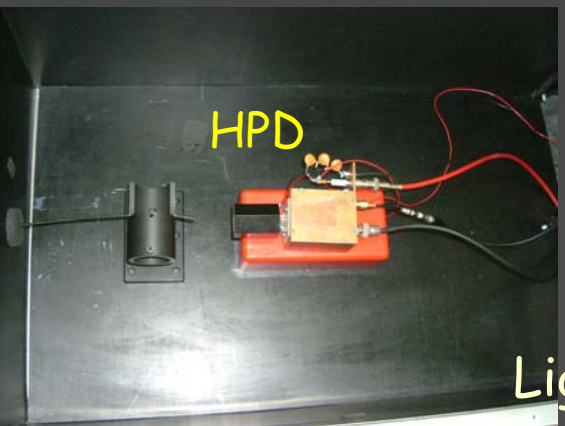
Q.E. Degrade !!

Method





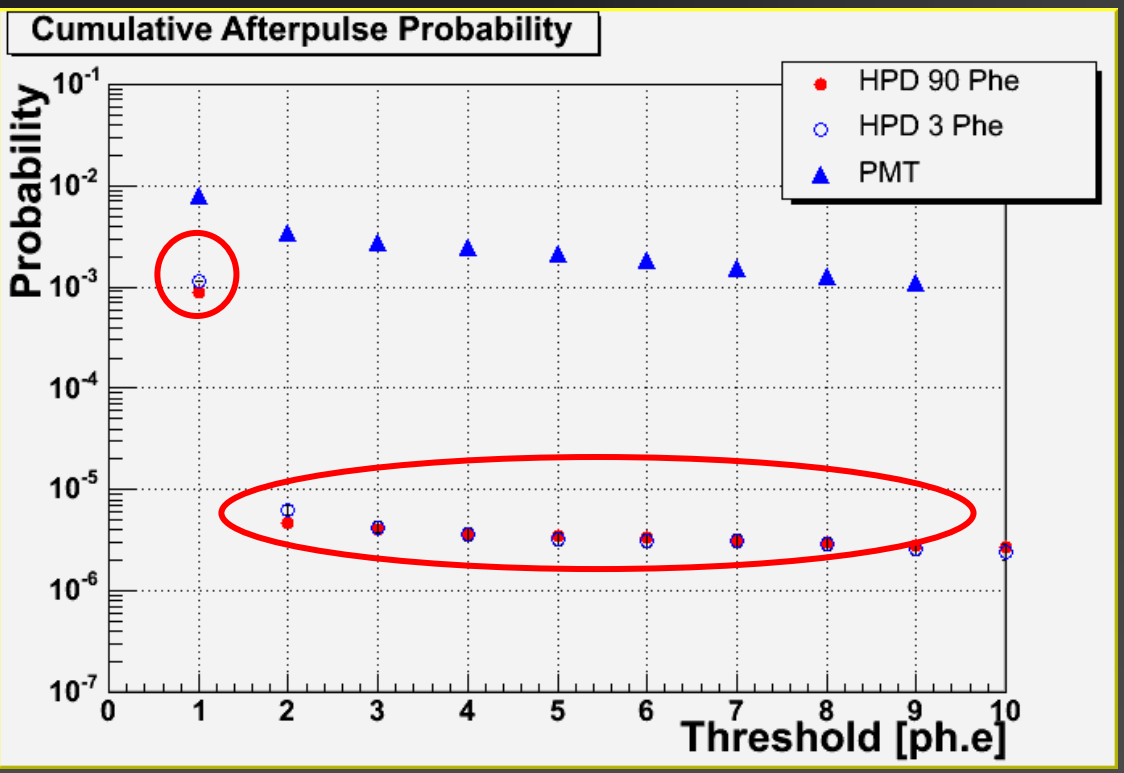
2 different light levels (3 and 90 ph.e.)



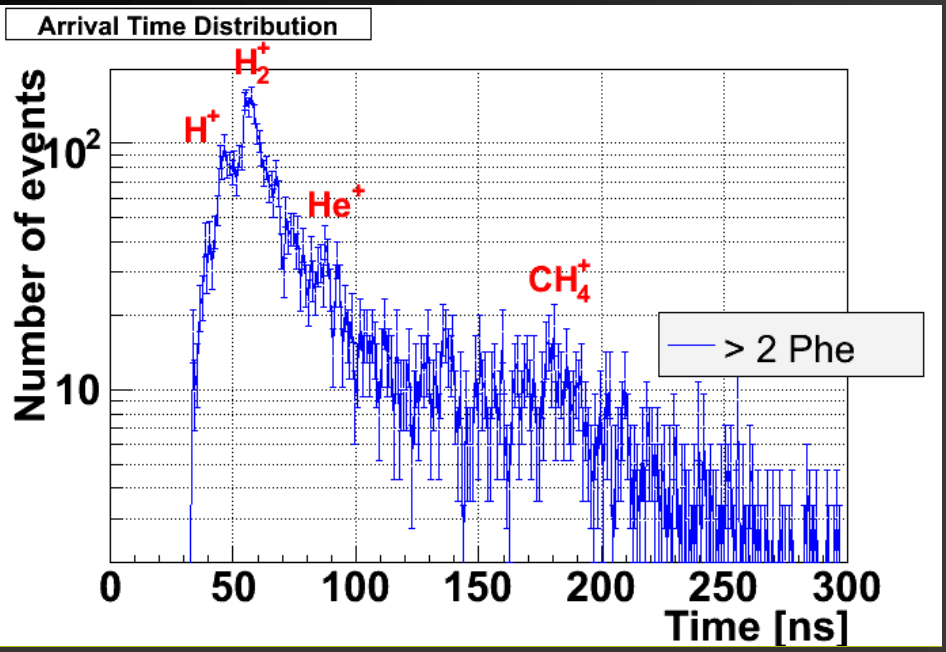
Search between 33 nsec and 450 nsec

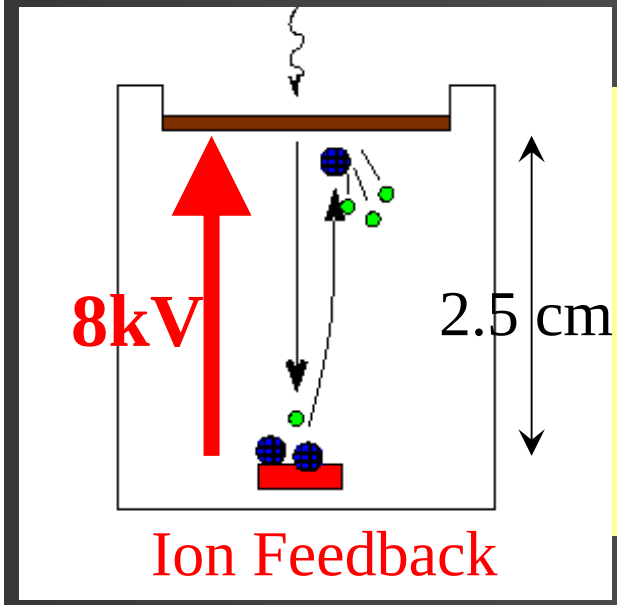
Results

Afterpulse Prob. = $N_{\_afterpulse} / \{N_{\_main\text{-}pulses} \times M_{\_ph.e./pulse}\}$



Order of 2.5 – 3 lower than the current PMTs!!





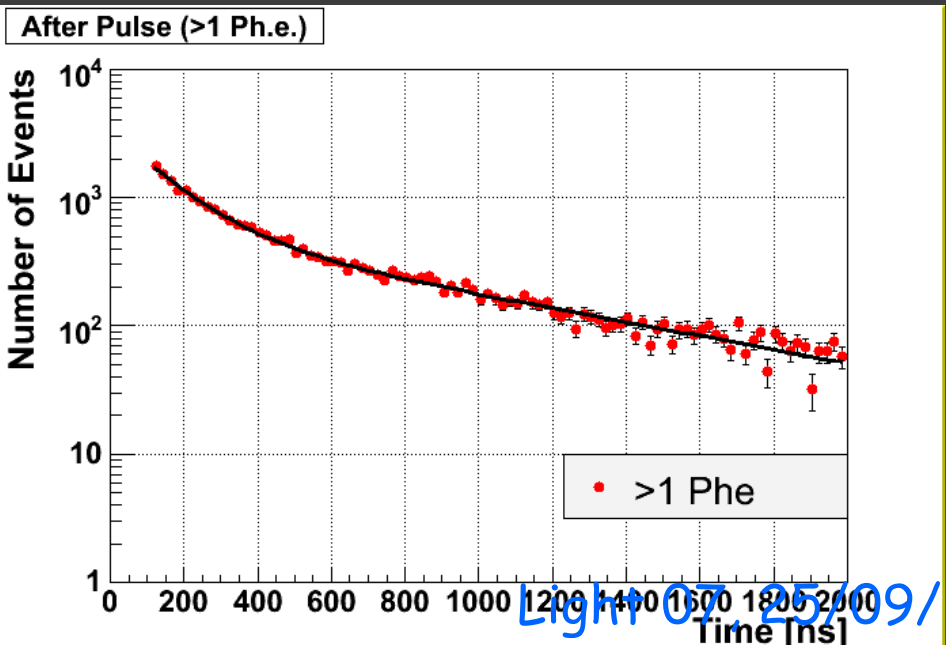
Ion Feedback

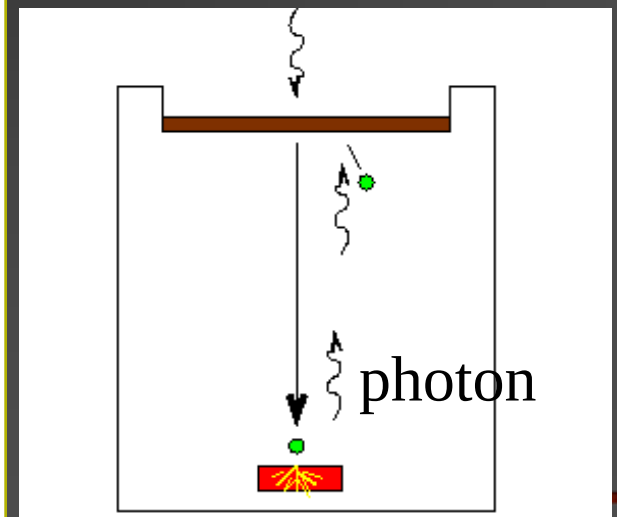
$$d = \tfrac{1}{2} a t^2$$

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

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

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

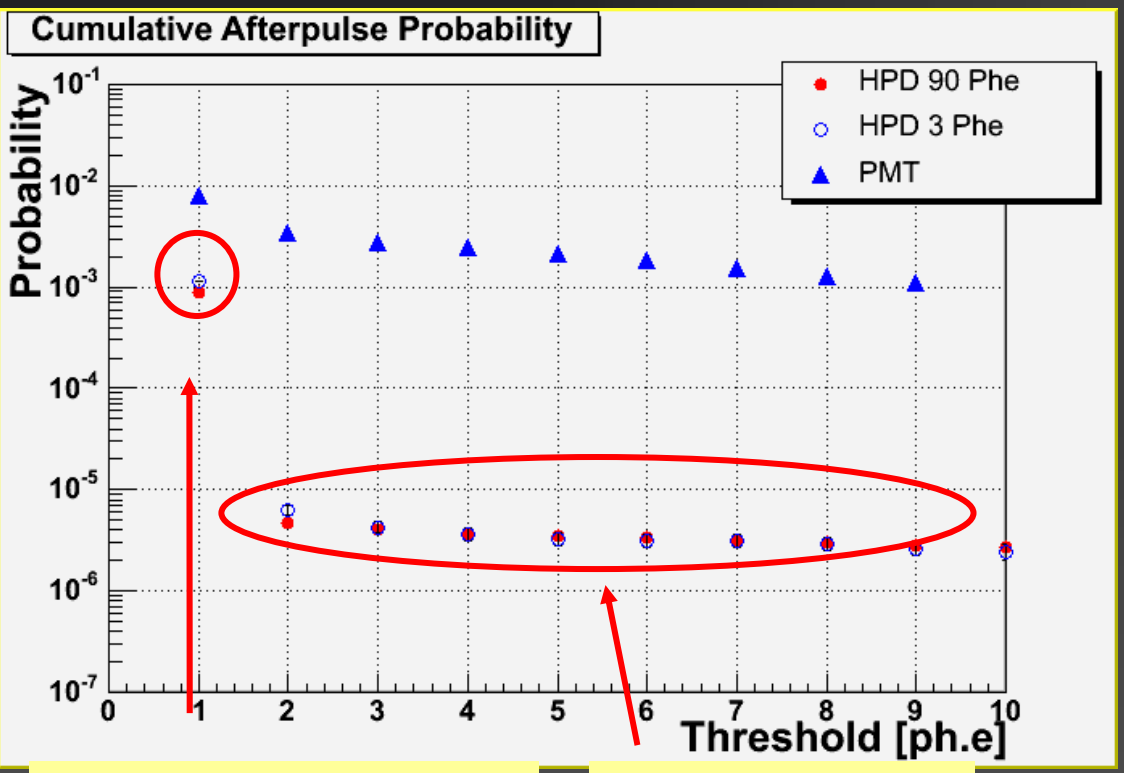




Photon Feedback

Results

Afterpulse Prob. = $N_{\_afterpulse} / \{N_{\_main\text{-}pulses} \times M_{\_ph.e./pulse}\}$



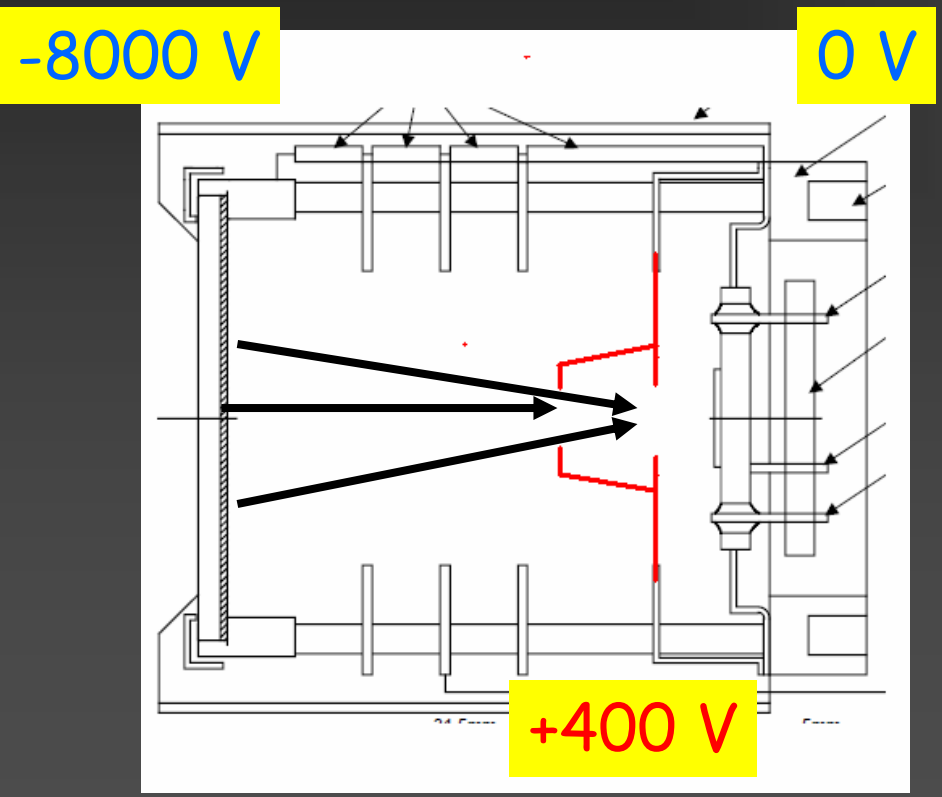
Order of 2.5 – 3 lower than the current PMTs!!

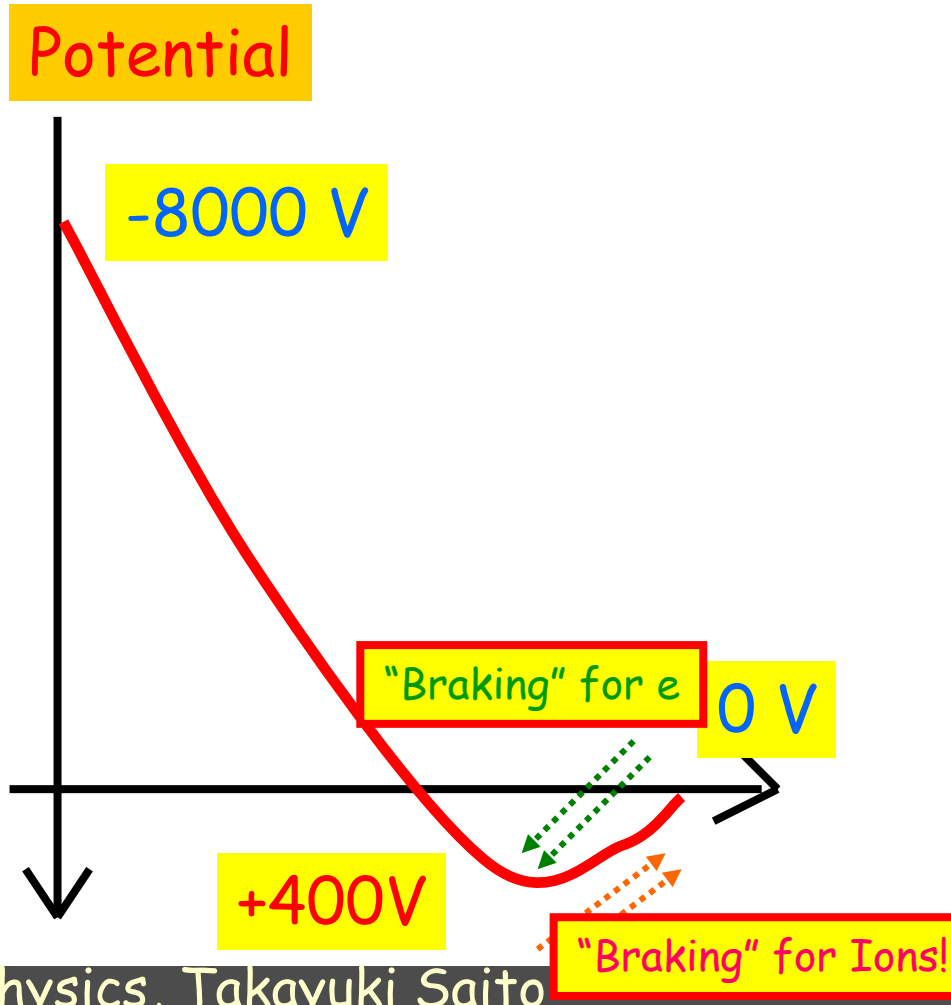
Photon Feedback?

Ion Feedback

Why is Ion feedback Rate so Low?

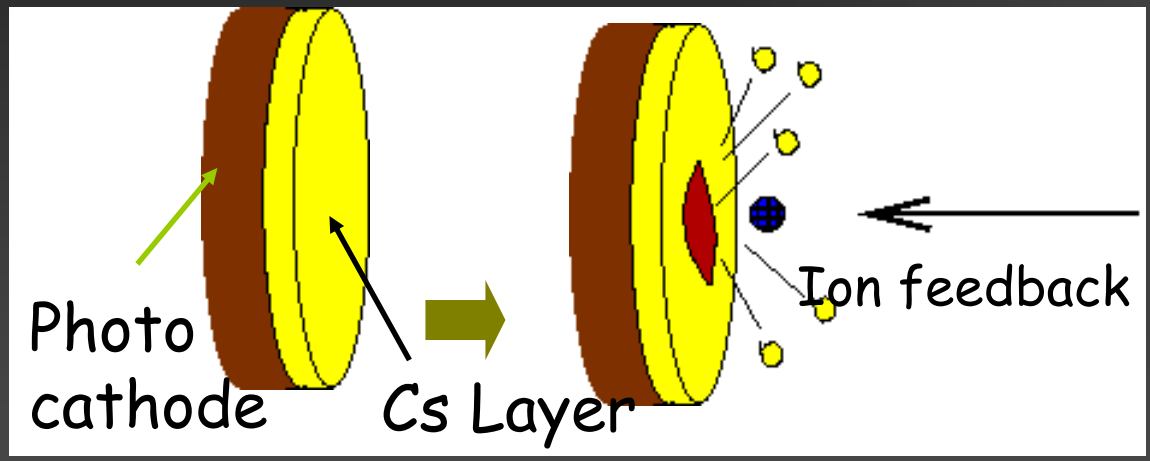
One reason is higher vacuum.
Another is special electric field.

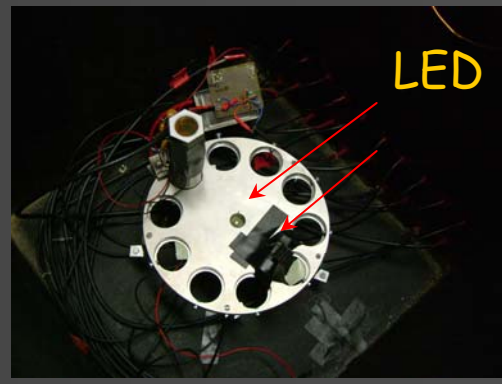




Lifetime measurement

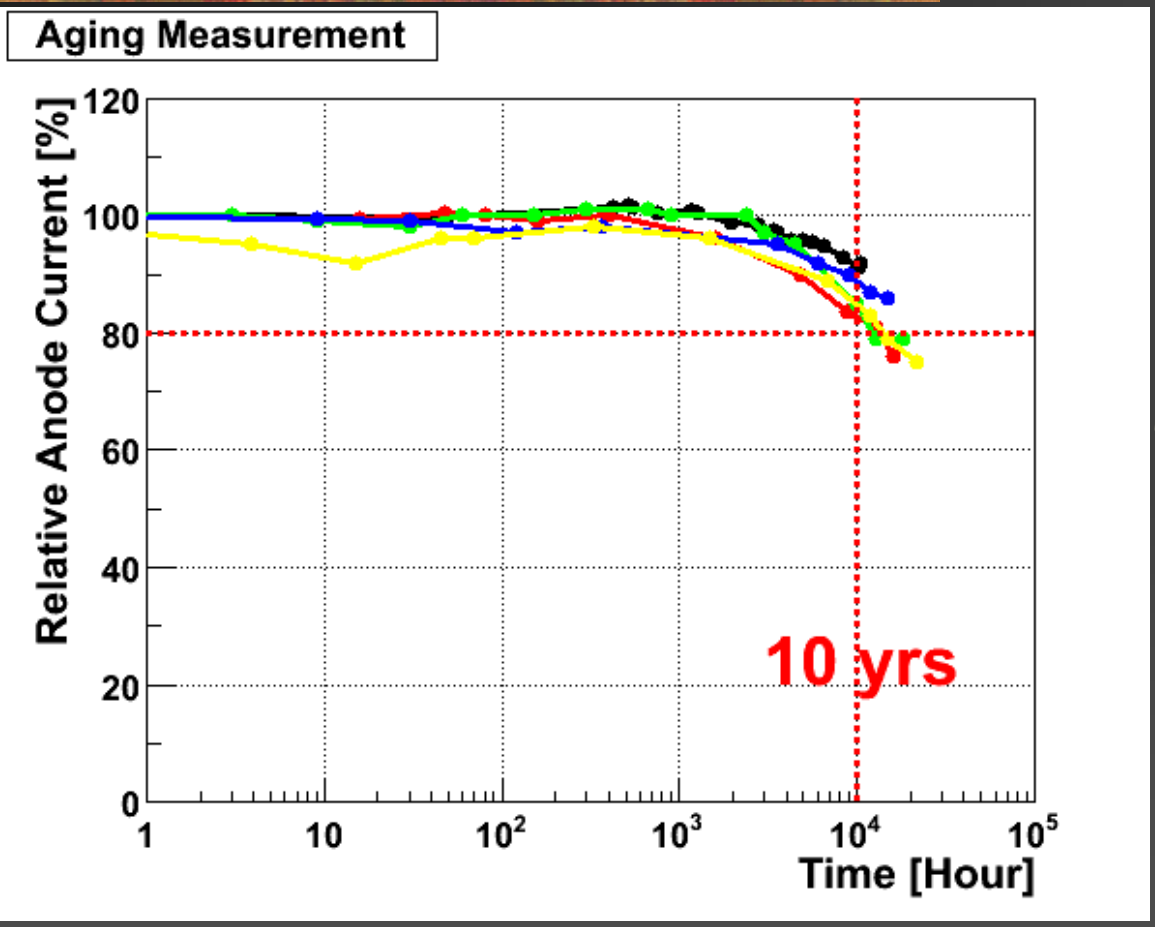
It is widely known that a GaAsP photocathode has higher QE but shorter Life Time because Cs layer is easily damaged.





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

Life Time

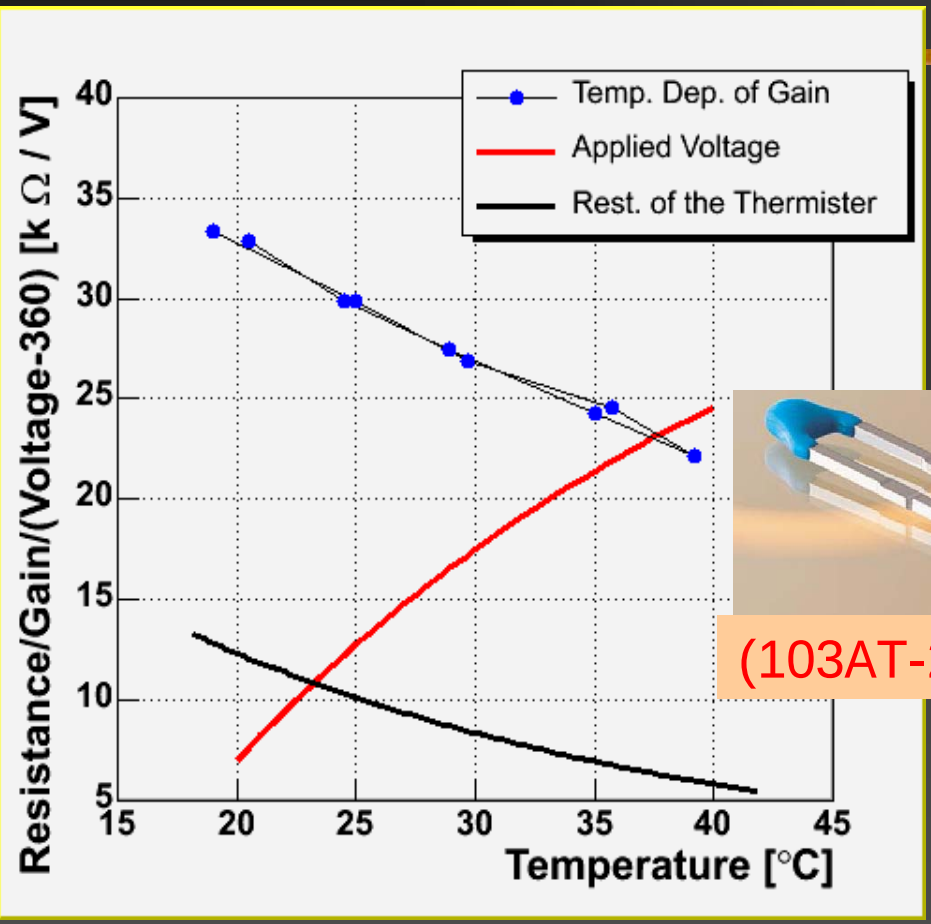


1 yr = 1000h operation
Under 300 MHz constant photon

Lifetime = 20% Q.E. degradation

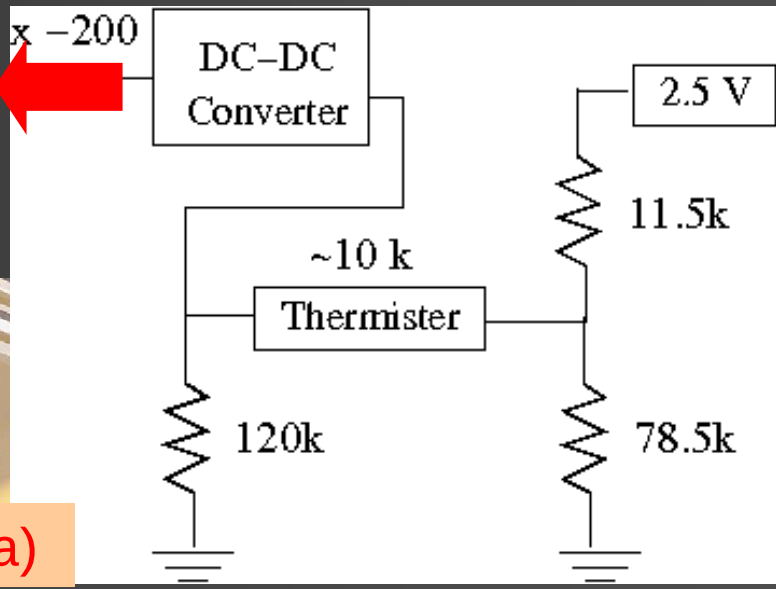
Lifetime > 10years !!

Temperature Dependence of Ava. Gain



(103AT-2,ishizuka)

APD

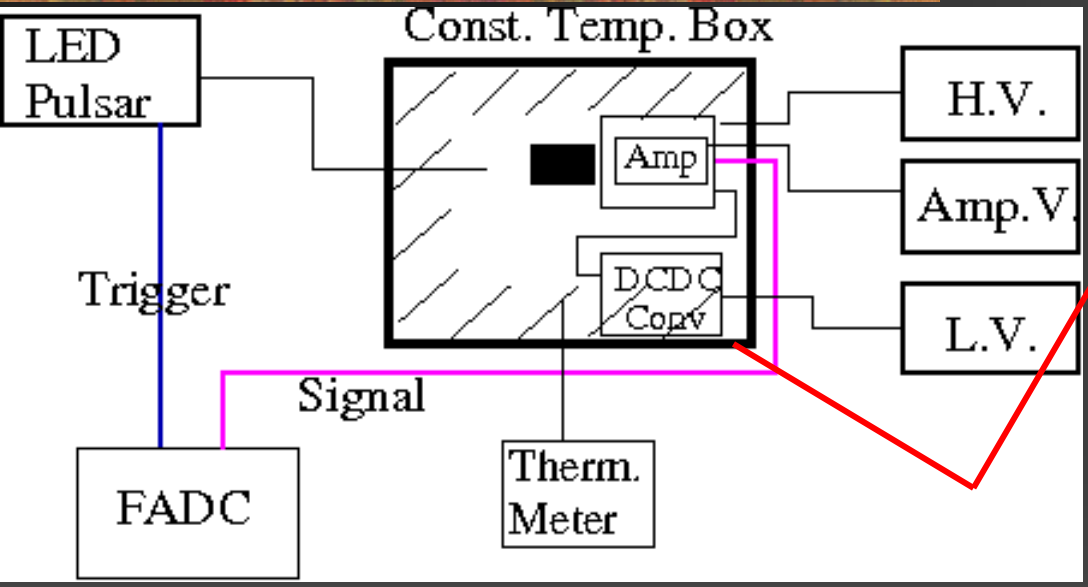


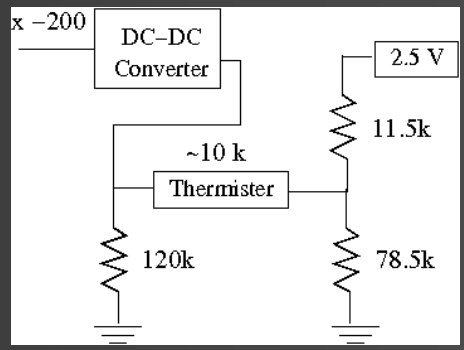
Temperature Compensation Circuit

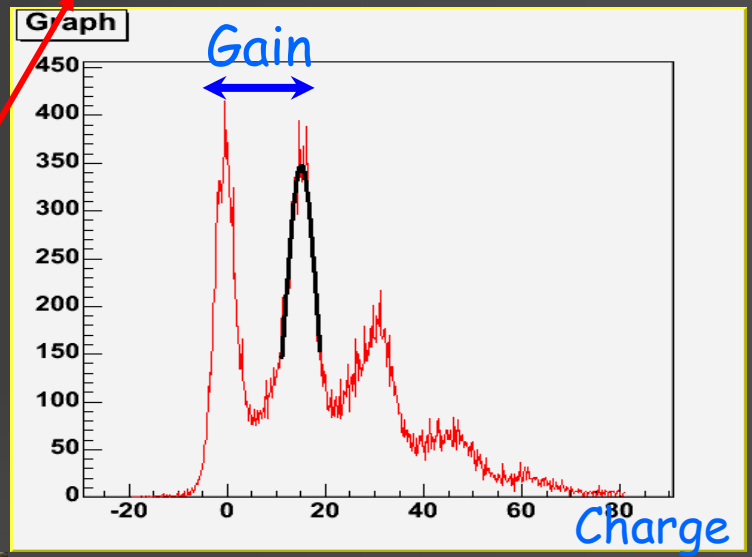
-2 % / ℃ !!

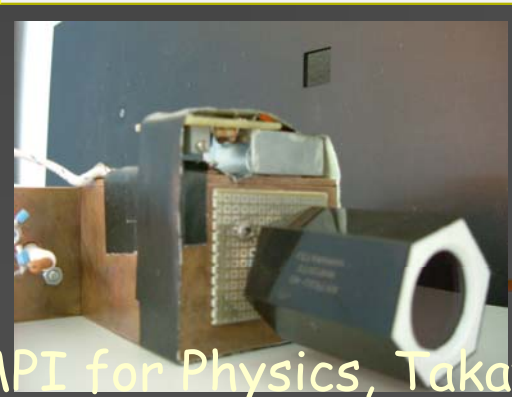
(~0.2%/ ℃ for PMTs)

Method

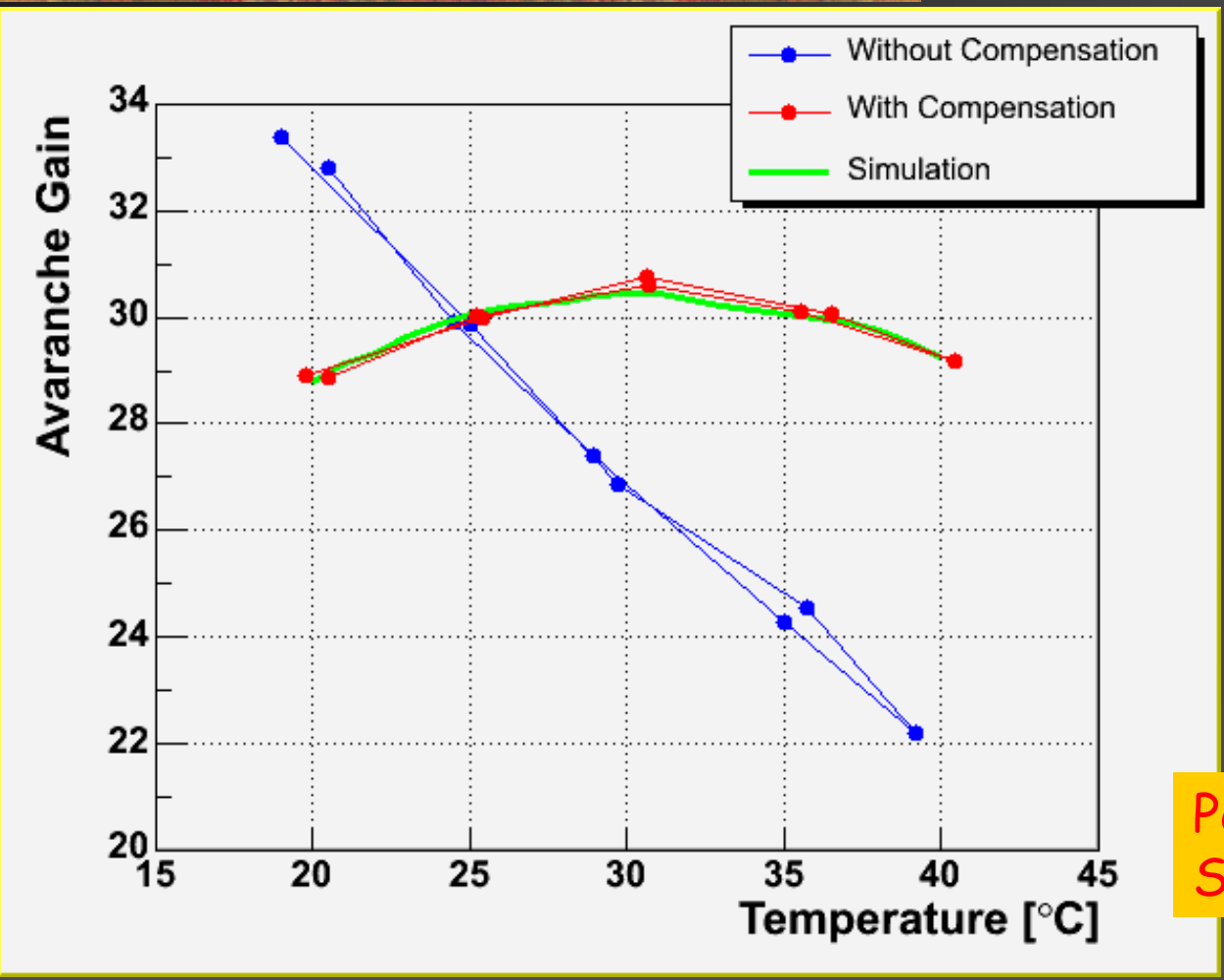

LED
Pulsar
Const. Temp. Box
Amp
DCDC
Conv
H.V.
Amp.V.
L.V.
Trigger
Signal
FADC
Therm.
Meter


x −200
DC–DC
Converter
2.5 V
11.5k
~10 k
Thermister
120k
78.5k


Graph
Gain
450
400
350
300
250
200
150
100
50
0
-20
0
20
40
60
80
Charge



Result



2% / ℃

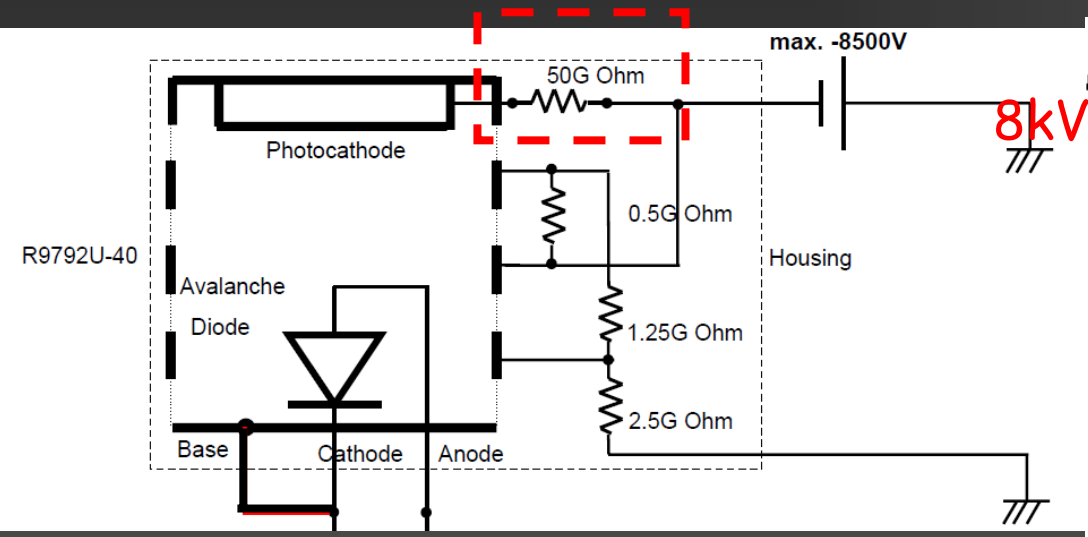
0.3% / ℃
(25℃~35℃)

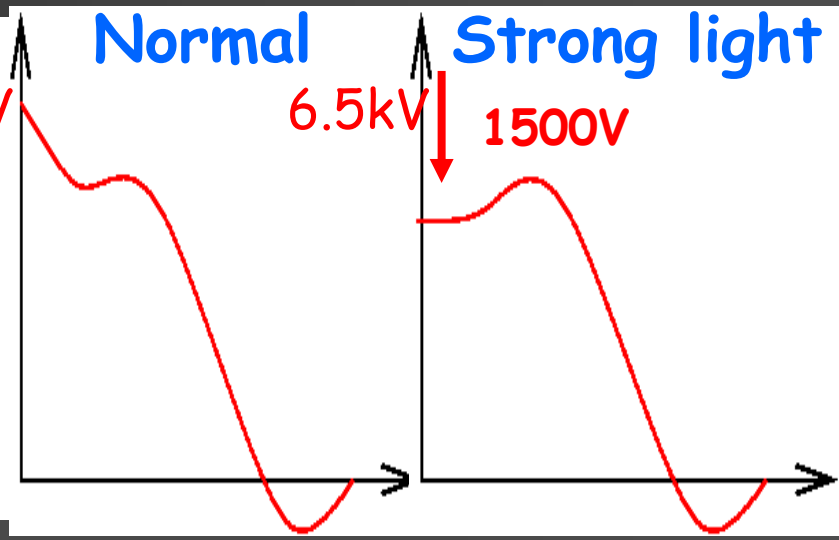
0.5% / ℃
(20℃25℃,
35℃~40℃)

Peak Can be shifted by
Small change of the circuit

How to protect APD from strong light?

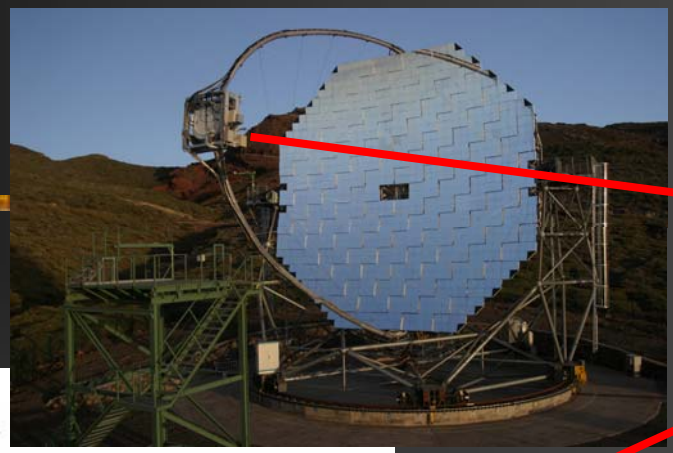
30nA x 50 Gohm = 1500V drop

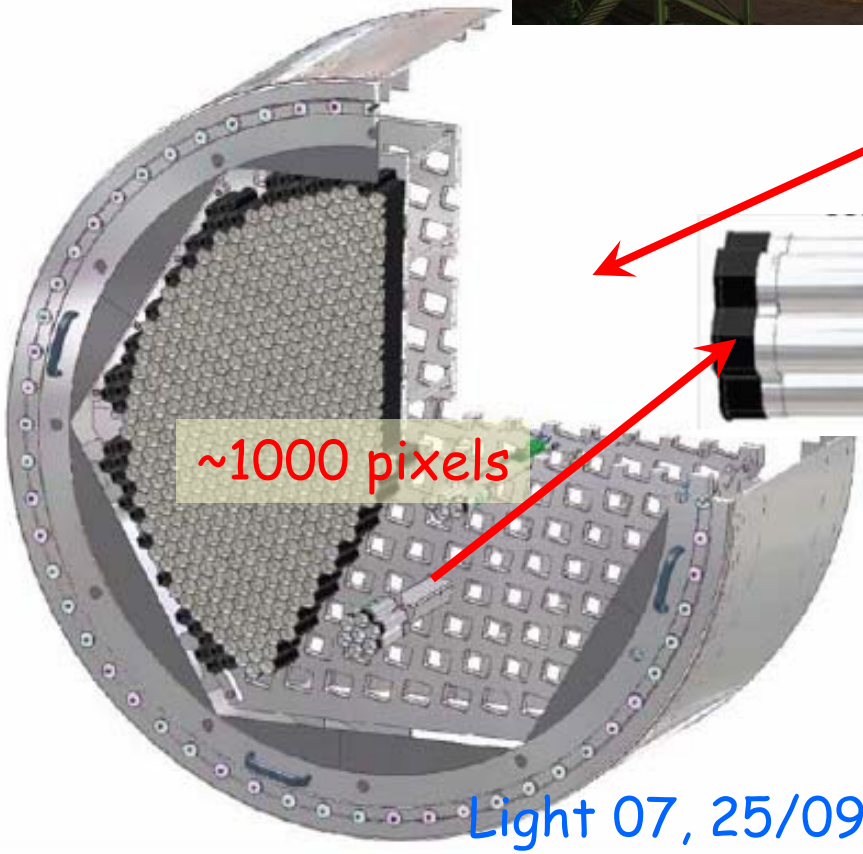


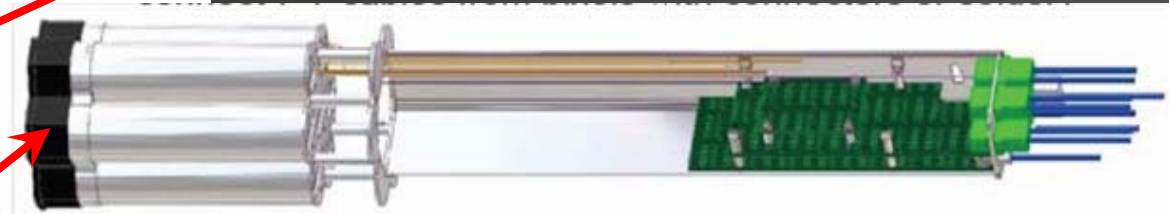


30nA (= 500 x NSB) of photocathode current drops voltage by 1500 V
-> NO Bombardment.

Application



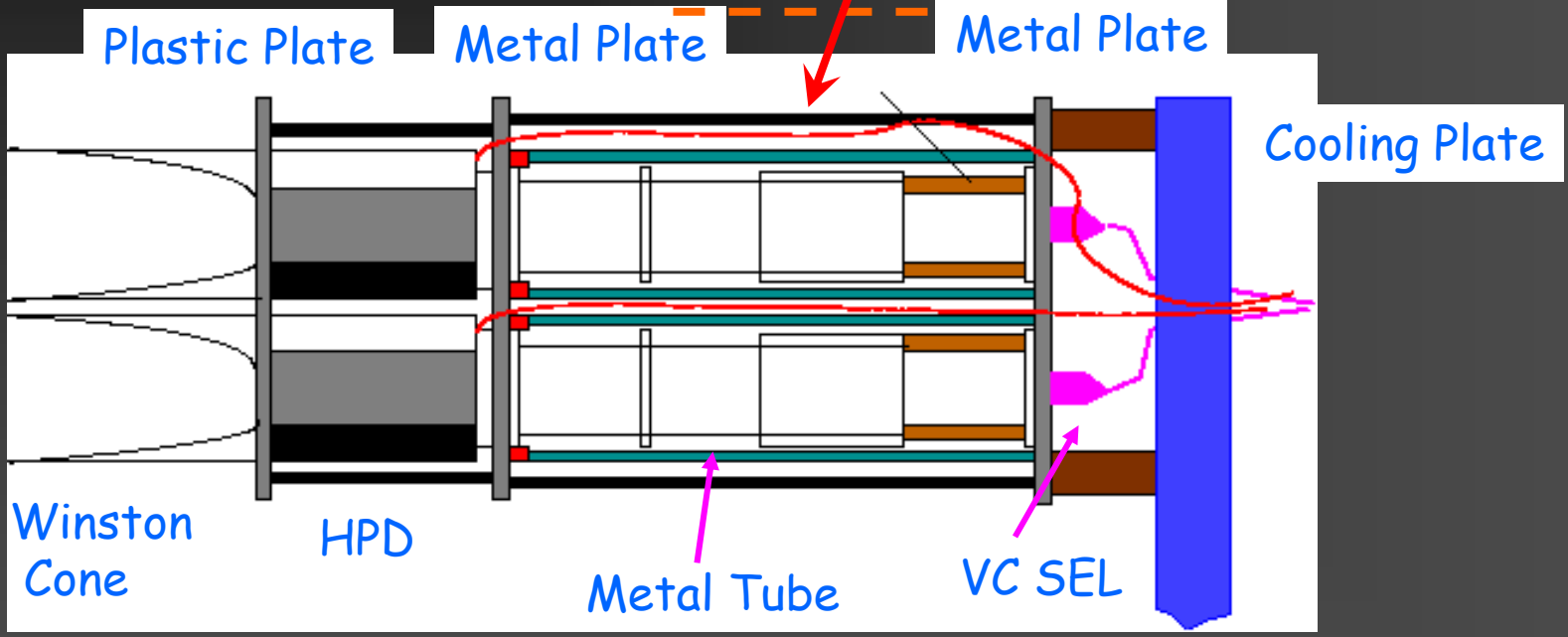




~1000 pixels

7-pixel cluster

Application (Preliminary Design)



1st Stage
* Coax. for Signal
* Thermal Sensor
* Thermistor
* etc

2nd Stage
* Pre Amp.
* AC/DC decouple
* DC monitor
* Test Pulse injection

3rd Stage
•DC/DC converter for Bias Voltage

4th Stage
* VCSEL

Future

April 2008, 7 clusters (49 HPDs) will be installed as shown in Fig. A.

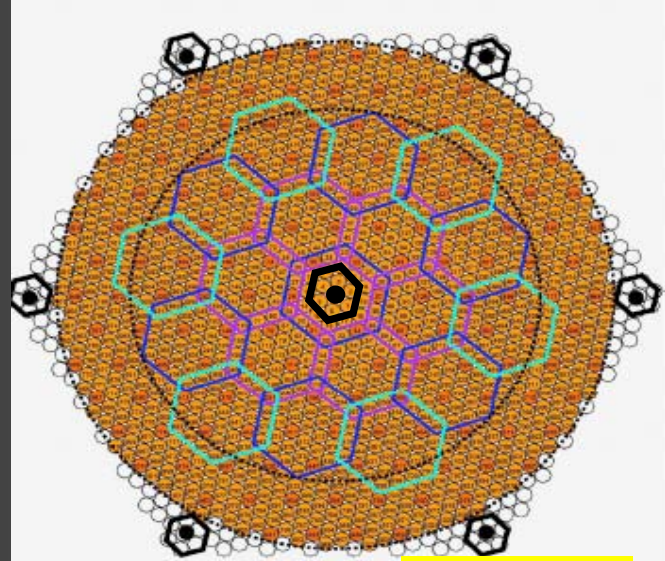


Fig. A

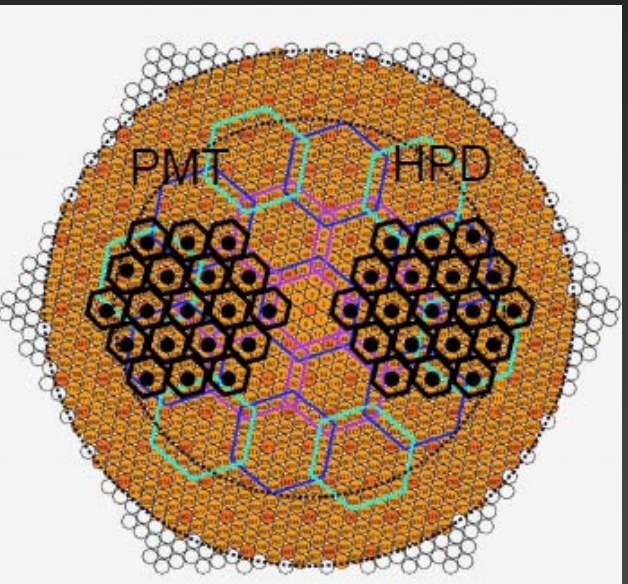


Fig. B

If there is no problem, 19 Clusters (133 HPDs) will be installed to see the sensitivity improvement.

Finally, we are planning to install 61 clusters (427 HPDs) to the inner region of the Camera.

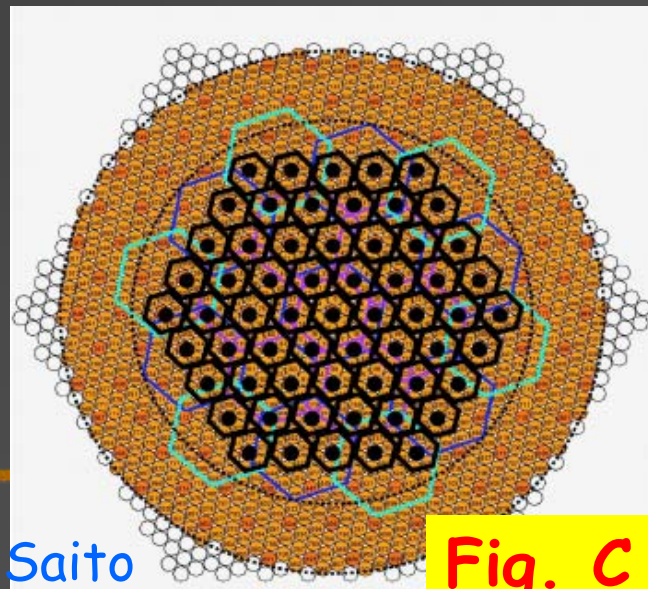


Fig. C

Summary

- HPD R9792U-40 has 2 times more Q.E. and 300 times lower ion feedback rate than PMT.
- All parameters (photocathode uniformity, pulse shape, linearity, gain etc) are fine for the MAGIC telescope.
- Lifetime is also long enough for 10 year operation, because of low ion feedback rate.
- Temperature compensation can easily be done by a simple circuit with a thermistor
- First field test will start in April 2008

Backup

γ Shower Events

(by MC simulation)

HPD

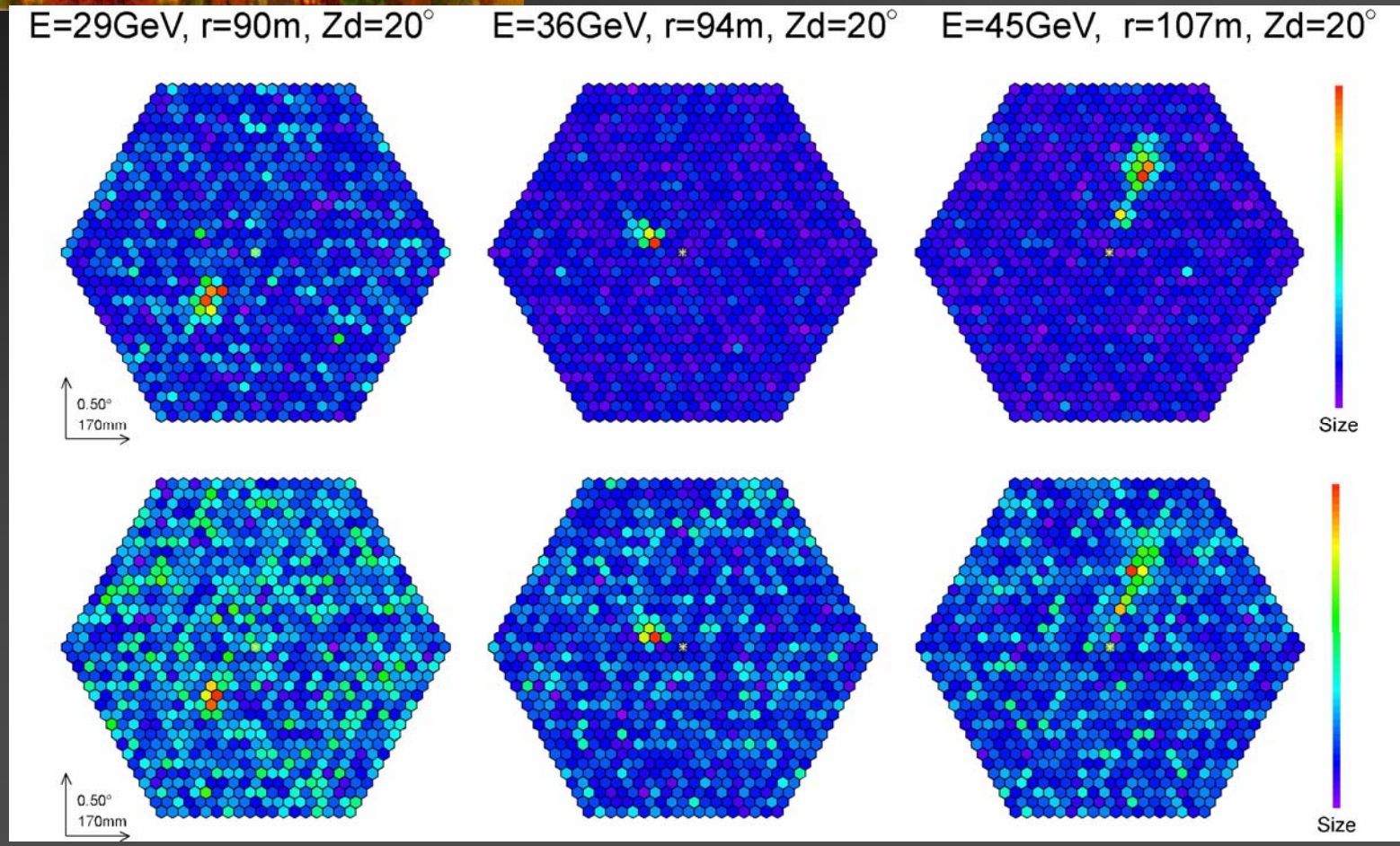
with 10ns gate

(2.5 Gsample/s FADC)

PMT

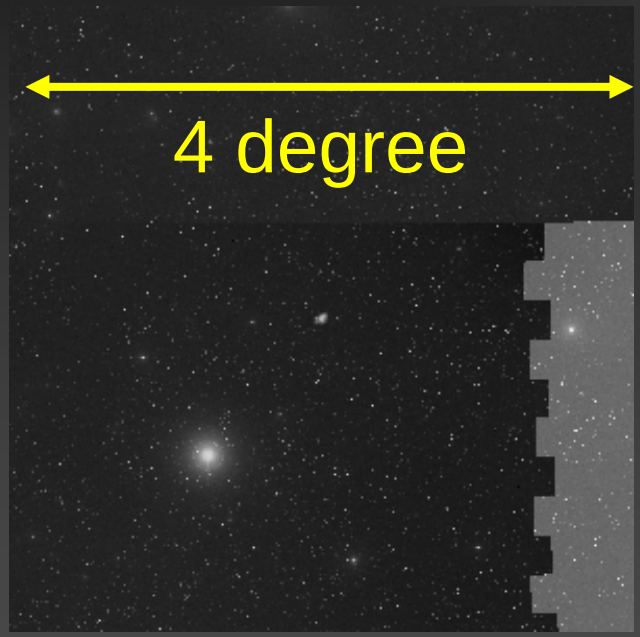
with 20ns gate

(300Msample/s FADC)



Star Light and NSB Simulation

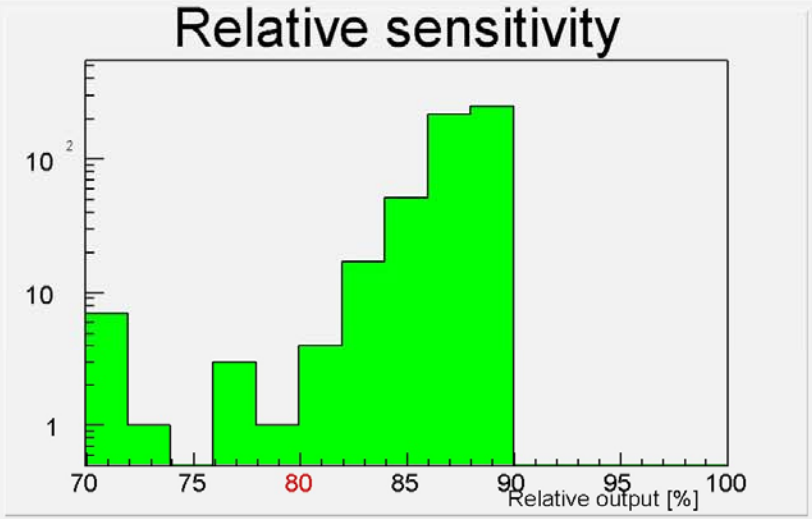
<star field (Crab nebula)>

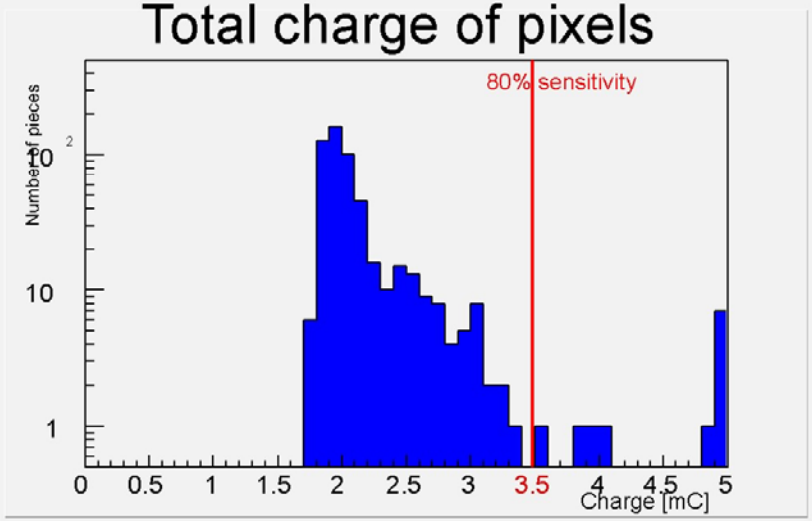


# Objects	# stars <11mag	Brightest star[mag]
10	228	3.02

- 10 typical TeV sources
- Brighter than 11.0 mag stars
- Observation time
  100 h/yr for each
  (Total: **1000h /yr**)
- Star rotation on Camera

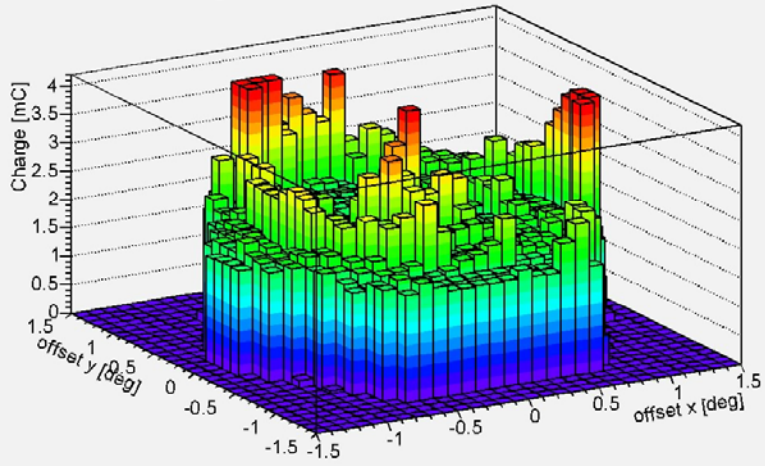
Simulation Results of the Stars and Night Sky





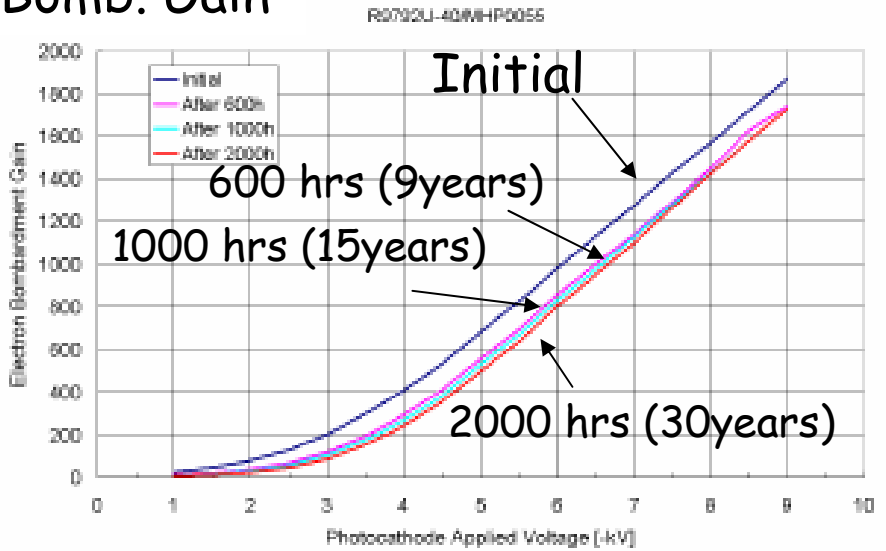
After 10year operation

The charge distribution on the camera



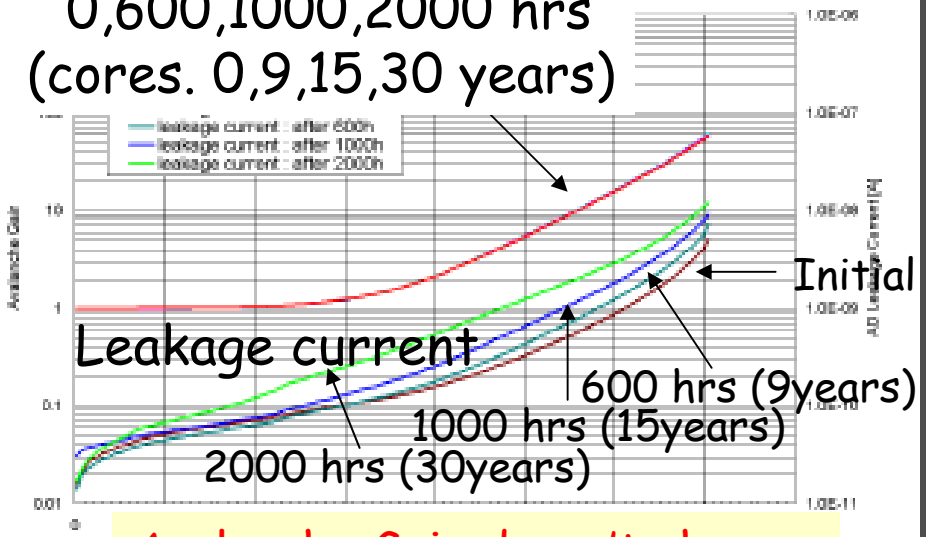
After intense aging test……

Bomb. Gain

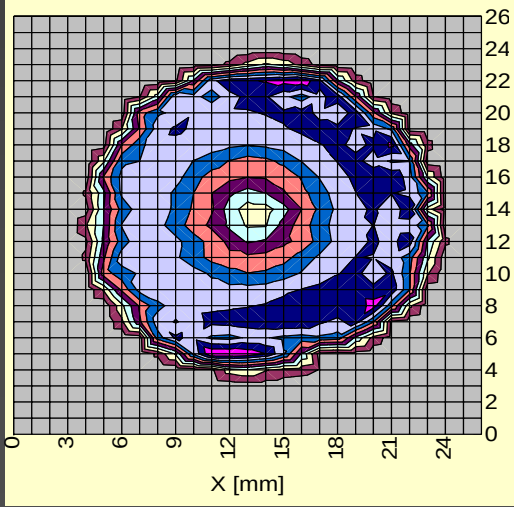


Bombardment Gain degrades by 10%
After 9 year operation!

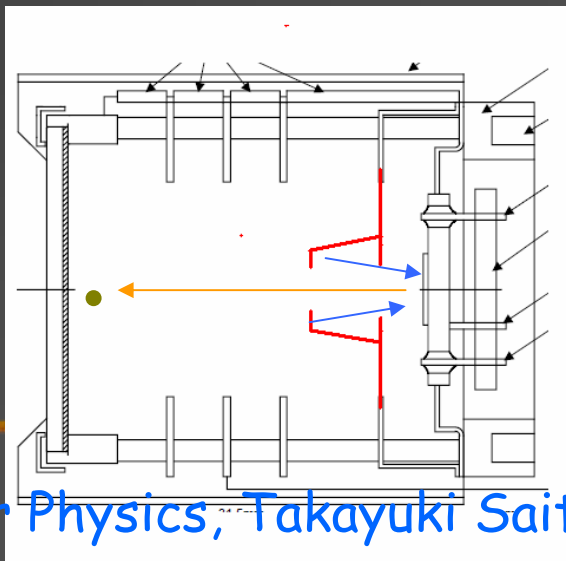
Ava. Gain after 0,600,1000,2000 hrs (cores. 0,9,15,30 years)



Avalanche Gain doesn't change.
Leakage Current rises by 30 %
After 9 year operation.

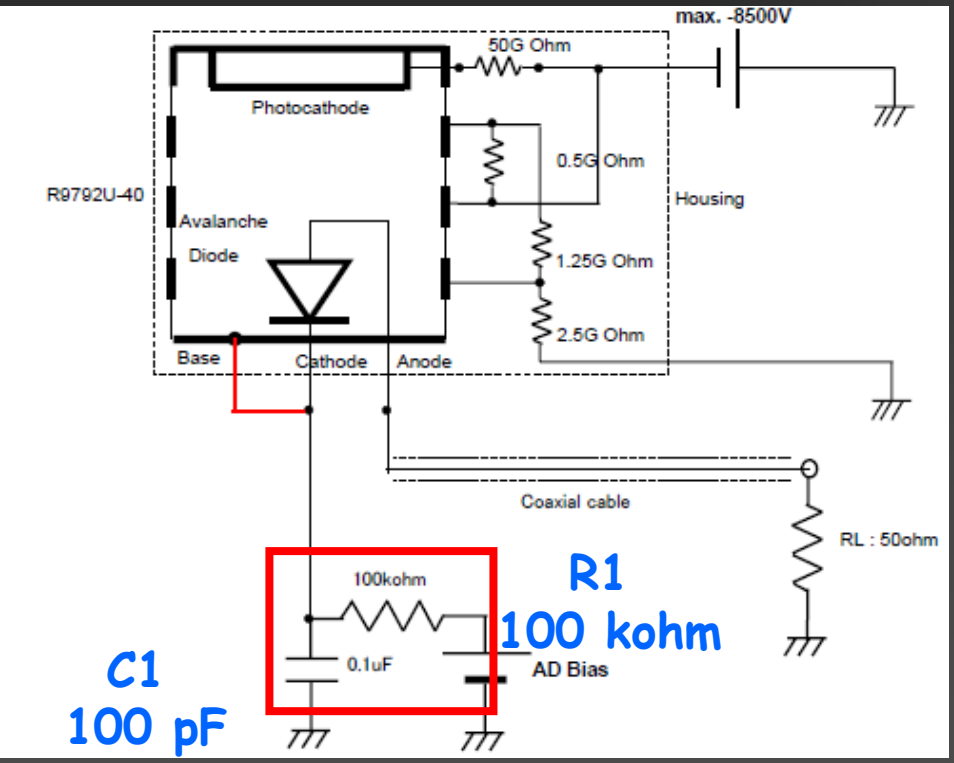


Q.E. degrade more at the center



How to protect APD from strong light?

2) For Fast flash -> Feeding capacitance



Photocathode to GND has a Capacitance of ~1pF .
1500V x 1pF = 1.5 nC on the photocathode is available.
(50 Gohm protection resister doesn't help at all!)

Maximum current flow must be limited by feeding capacitance and resistance.

400V x 100 pF = 40 nC