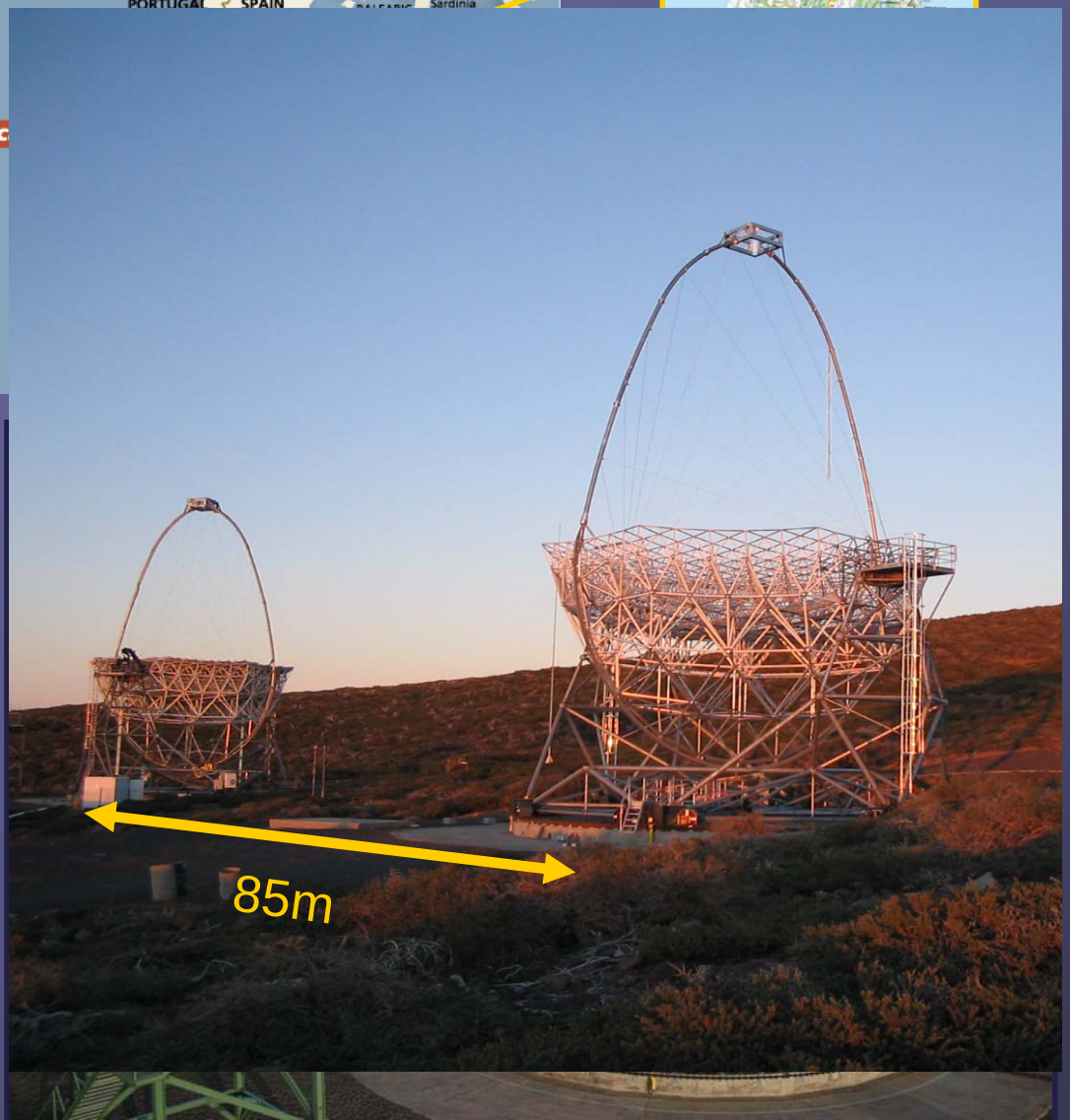
Photo-detectors for Gamma-Astronomy (IACT)

Mehr Licht!

M. Teshima

Max-Planck-Institute für Physik, München

MAGIC Telescope



New technologies to lower the threshold energy

17m diameter world largest cherenkov tel.
0.1°High resolution camera
Hemispherical PMT with enhanced QE
Analogue signal fiber transmission

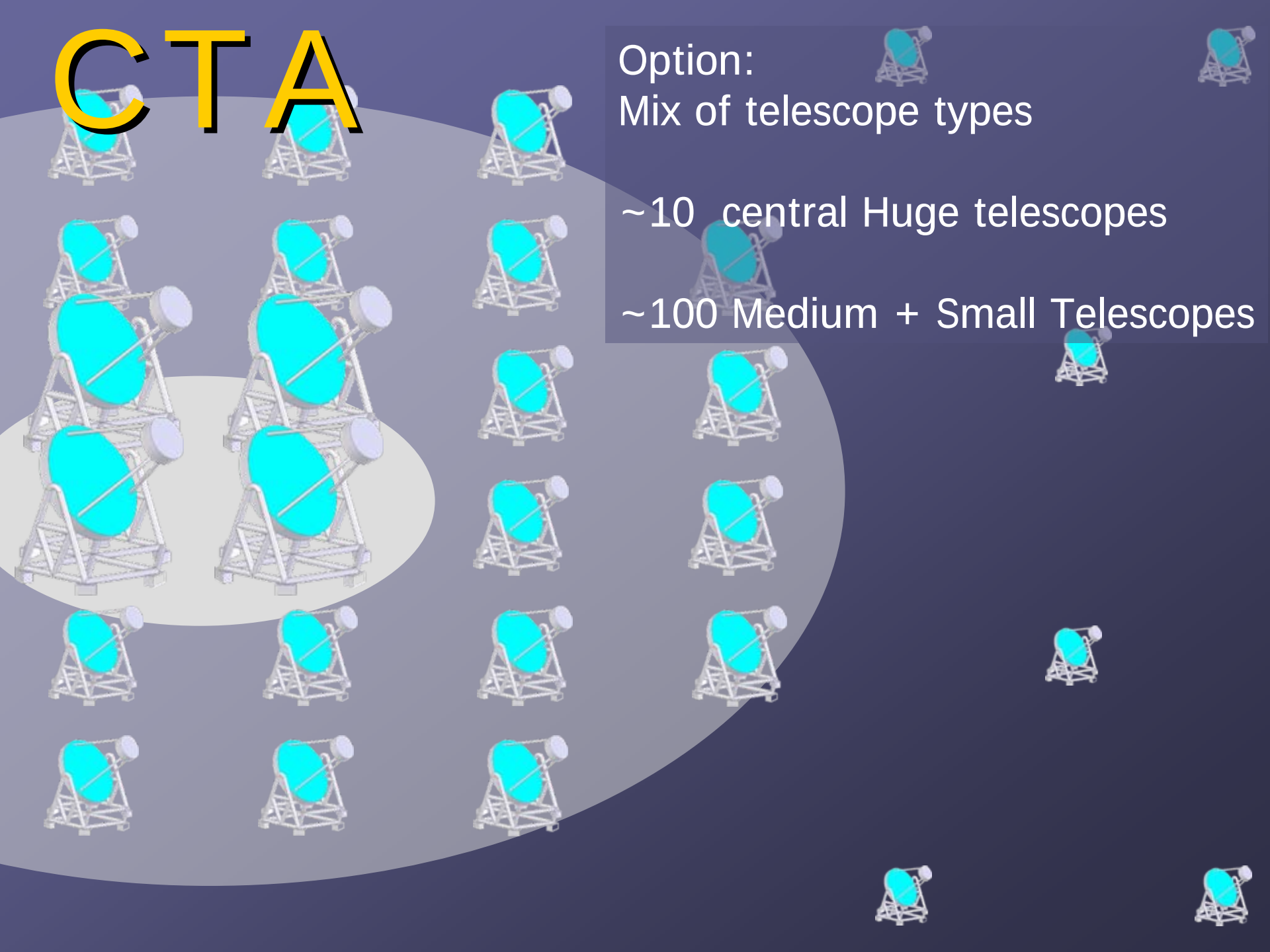
Current MAGIC-I Performance

Fast rotation for GRB < 40secs
Trigger threshold ~50GeV
Sensitivity ~2.0% of Crab (50hrs)
Angular resolution ~0.1 degrees
Energy Resolution 20-30%

MAGIC-II is under construction and will be completed at the end of this year

Improve sensitivity by a factor of three
Effectively lower the threshold energy

CTA



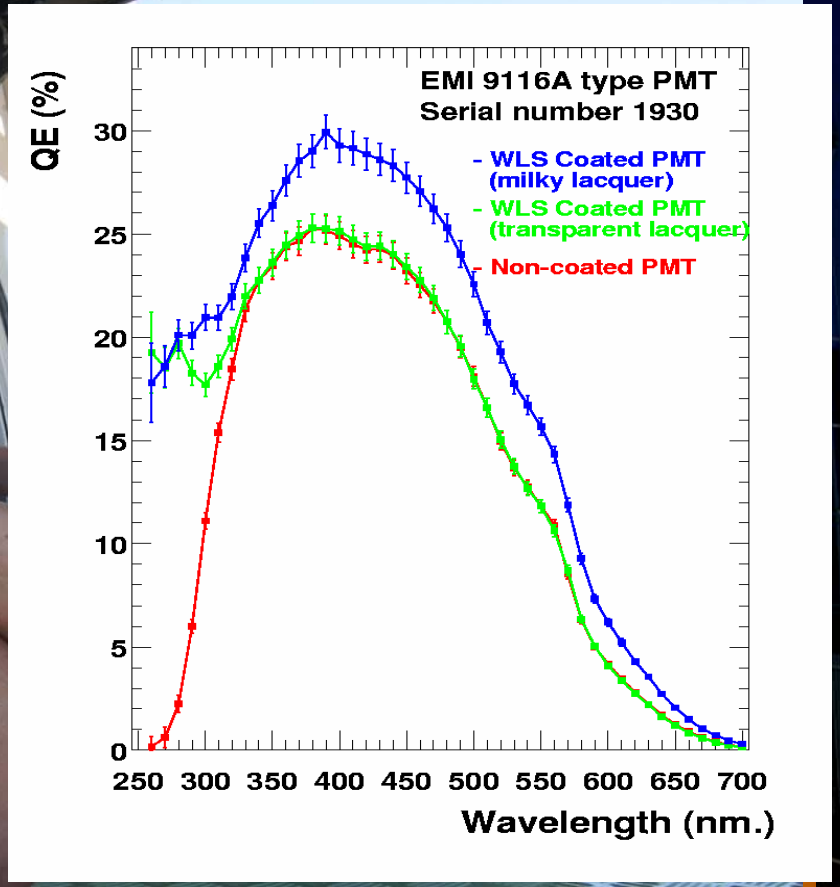
Option:
Mix of telescope types

~10 central Huge telescopes

~100 Medium + Small Telescopes

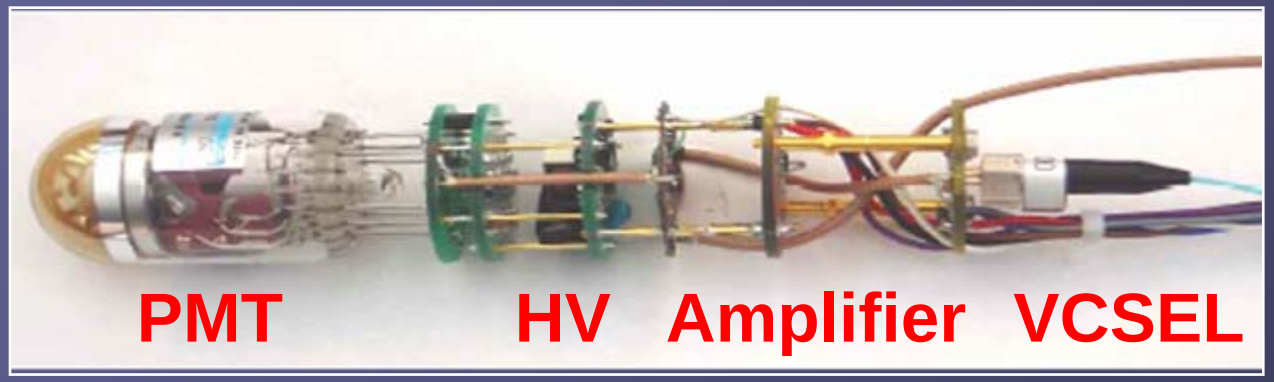
PMTs

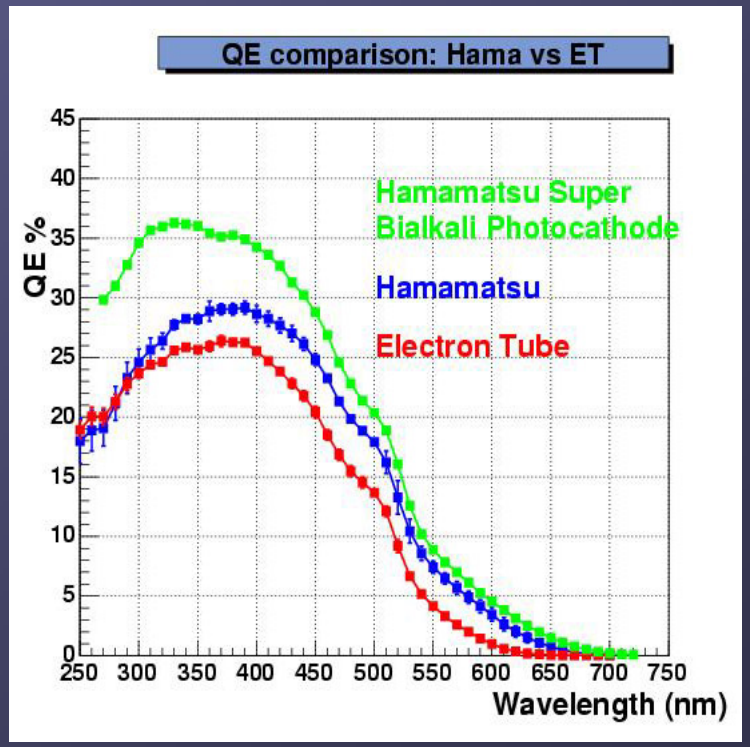
MAGIC-I Camera 3.5°576pixels



MAGIC-II Camera and pixel

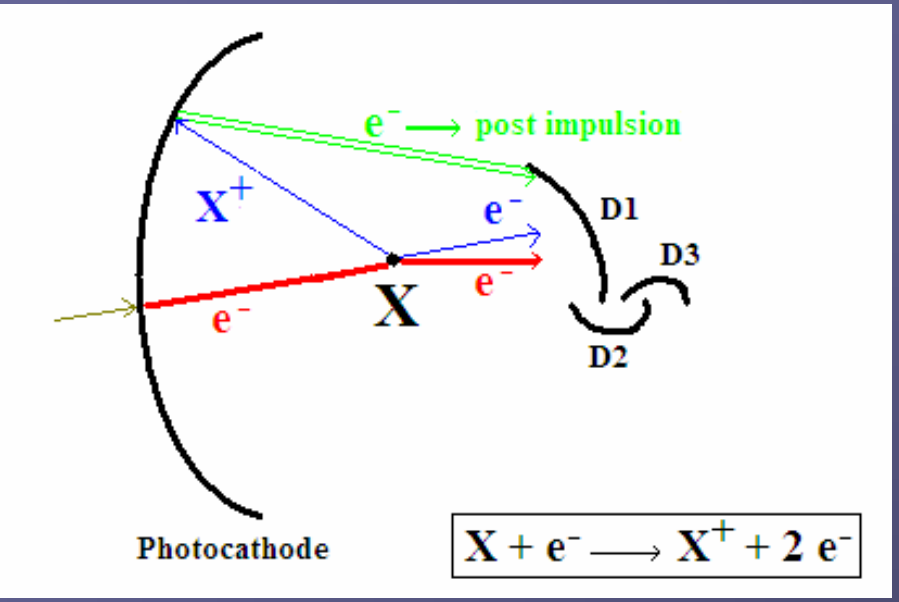
Hamamatsu
R10408Mod SBA-PMT

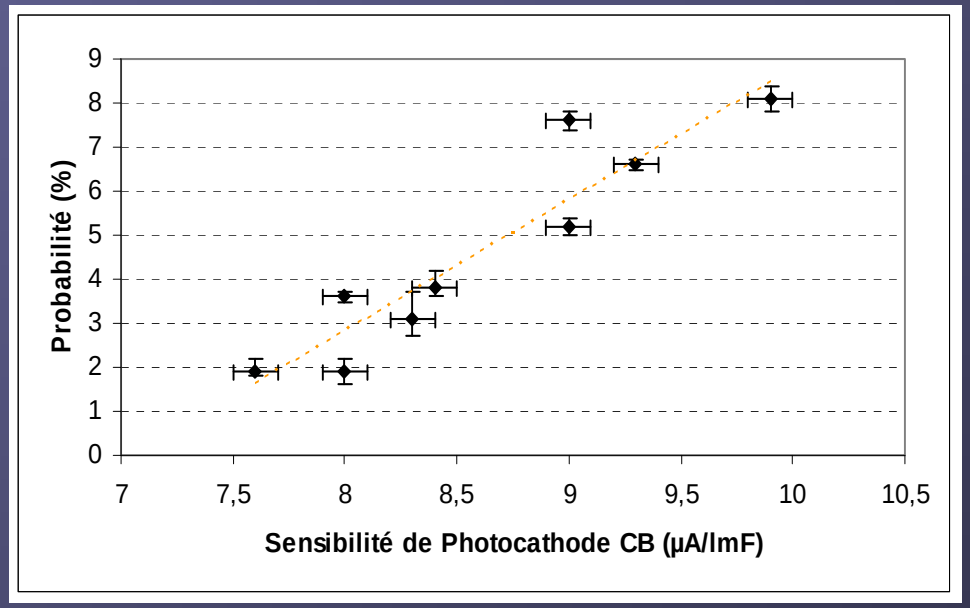




~35% Q.E.

After pulse rate of large PMT
by Damien Dornic (IPN, Orsay)





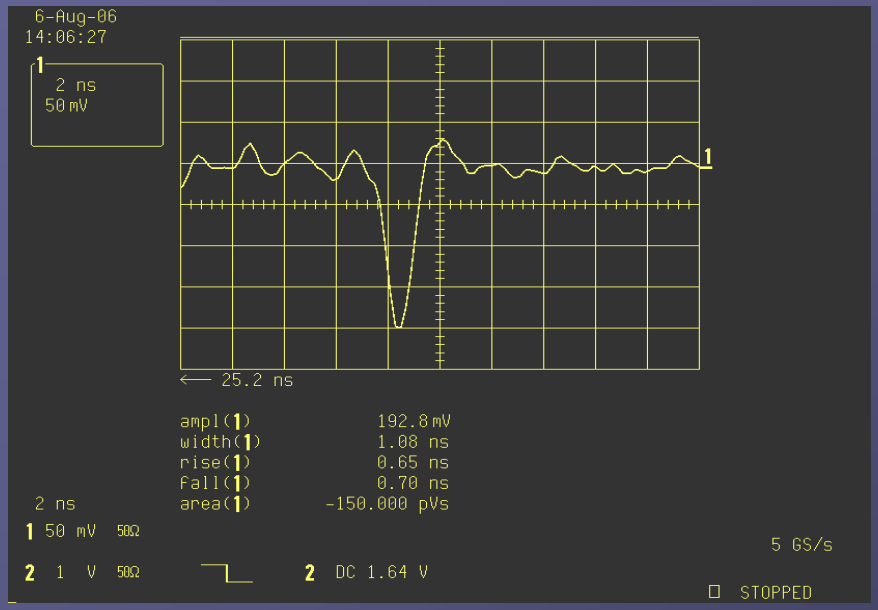
High after pulse rate will make the low trigger threshold difficult!!

Courtesy of Damien Dornic (IPN, Orsay)
Afterpulse rate as a function of the photocathode sensitivity. The measurements were made for 3 XP1803 (5 inches), 4 XP1806 (8”) and 2 XP1804 (10”).

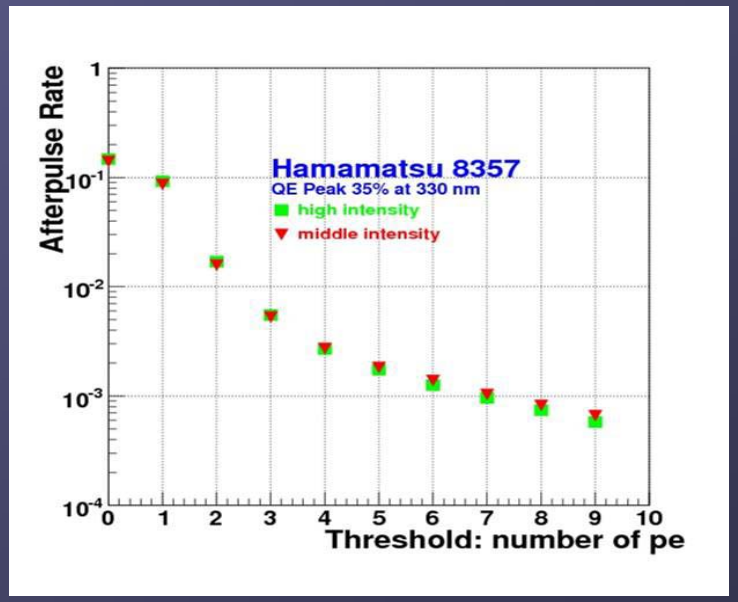
Must be examined for other tubes!!
Correlation between QE and after pulse rate

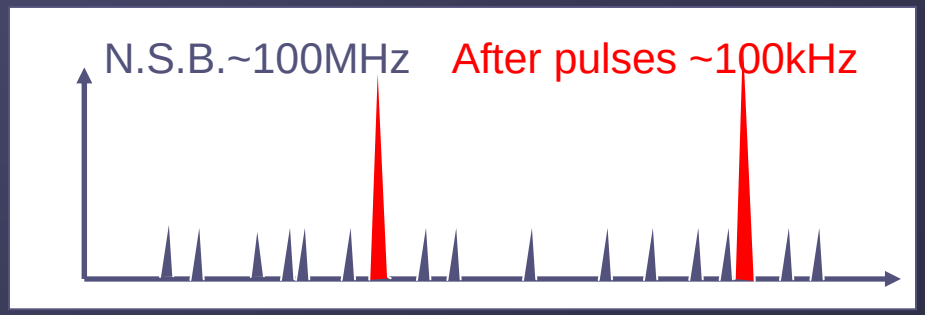
MAGIC-II New SBA PMTs from Hamamatsu

Very fast Response
FWHM =1.1 nsec
Rise T = 0.7 nsec

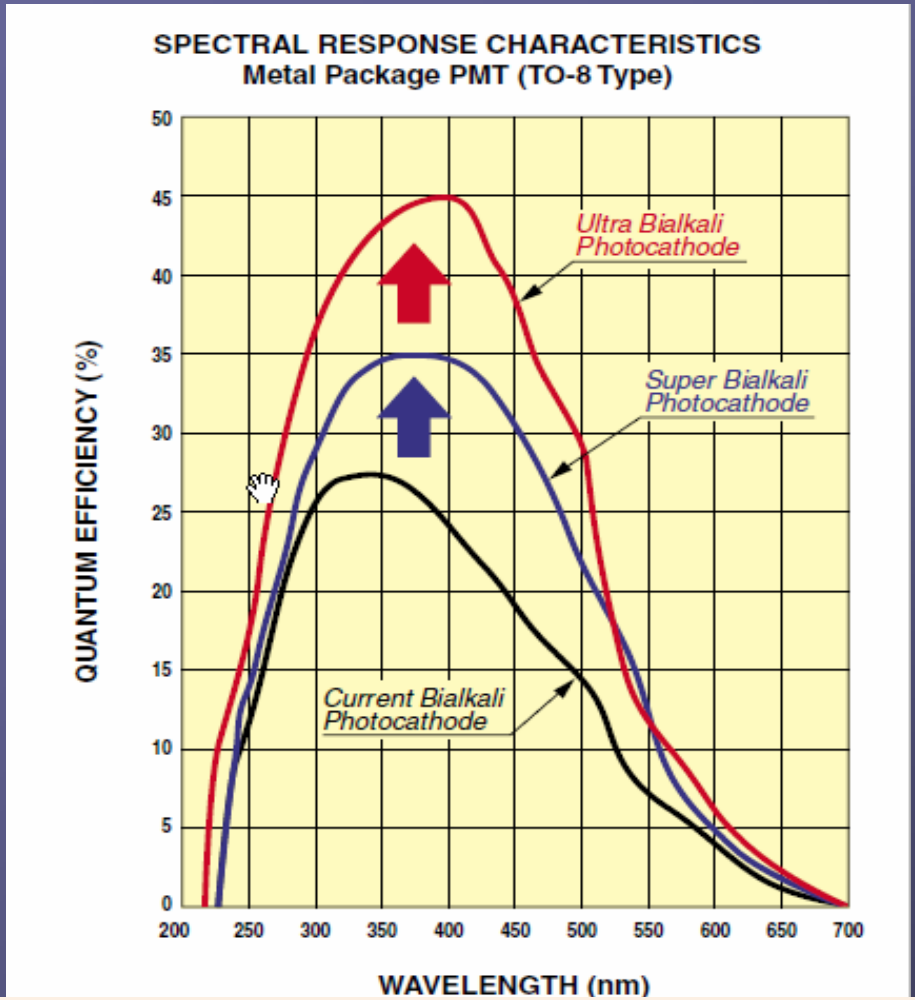


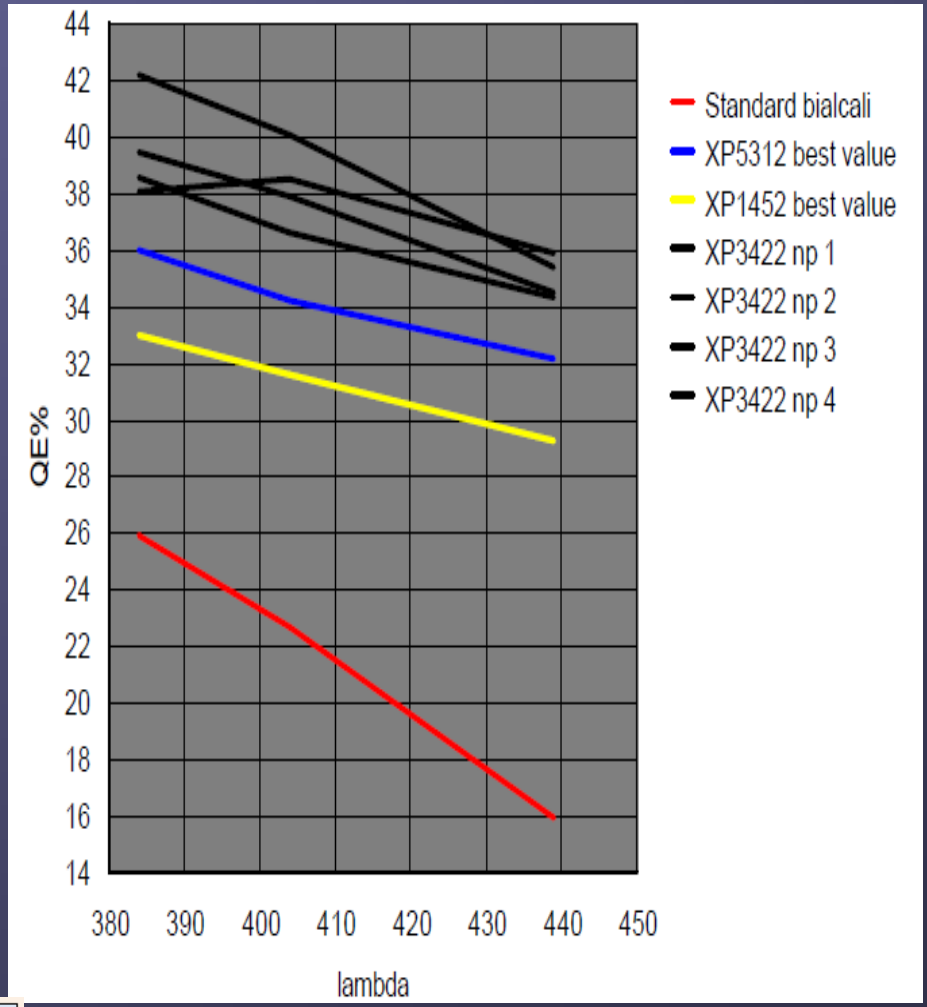
Low after pulse rate
<0.2% after pulse rate >5p.e.





High Q.E. PMTs materials from companies

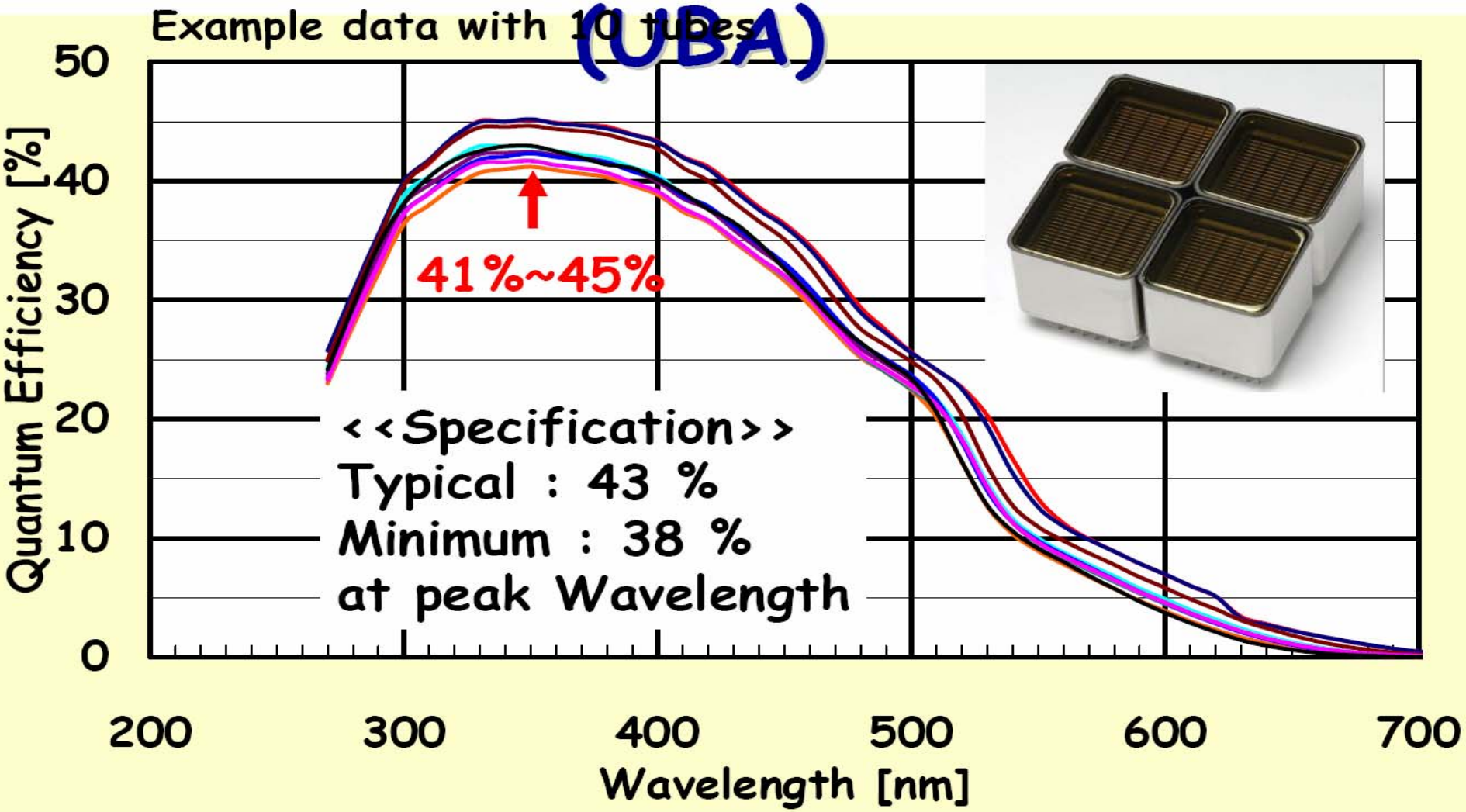




Photocathode	QE at peak wavelength		Type Availability
	Min.	Typ.	
Ultra Bialkali (UBA)	38 %	43 %	Metal Package PMT (TO-8 Type, □28 mm Type PMT)
Super Bialkali (SBA)	32 %	35 %	Metal Package PMT (TO-8 Type, □28 mm Type PMT) ϕ28 mm to ϕ76 mm Head-on PMT (Glass Bulb Type)

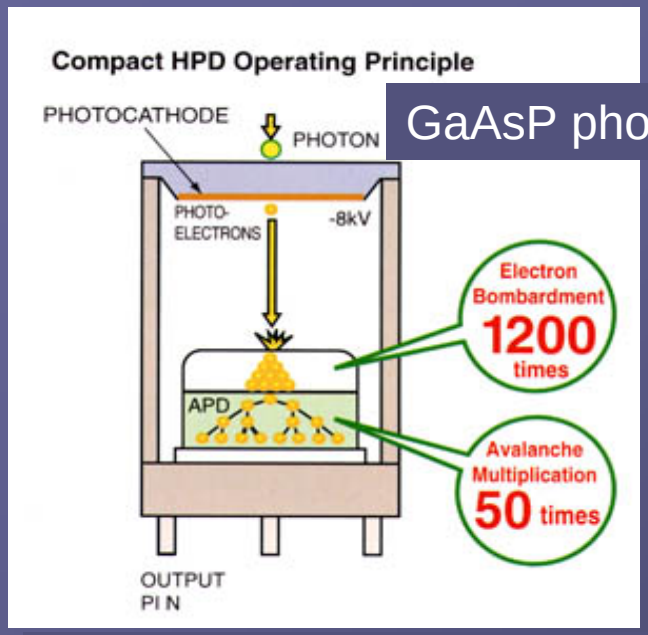
Hamamatsu UBA MAPMT

Latest Data of R7600-200 (UBA)

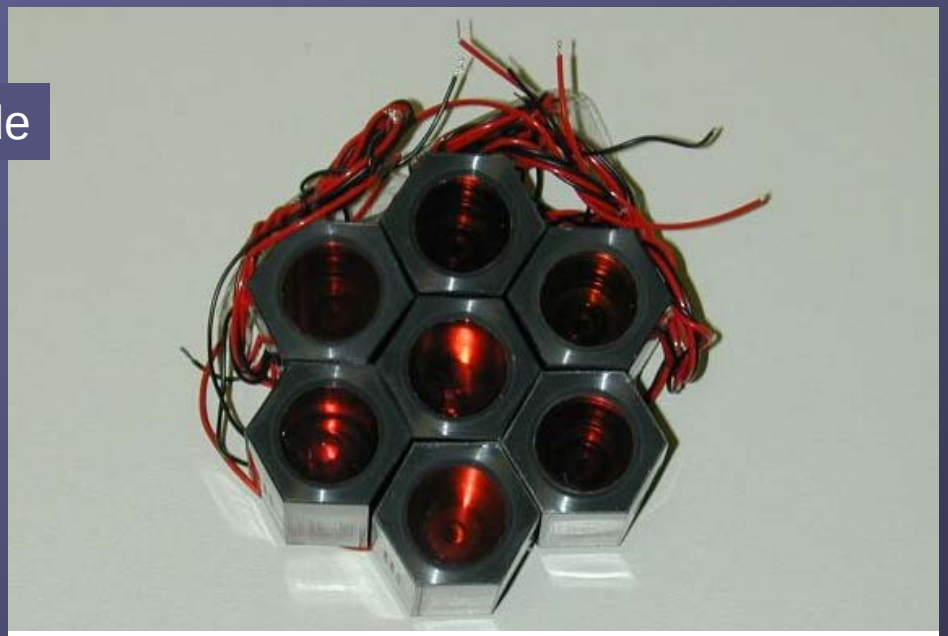


HPD

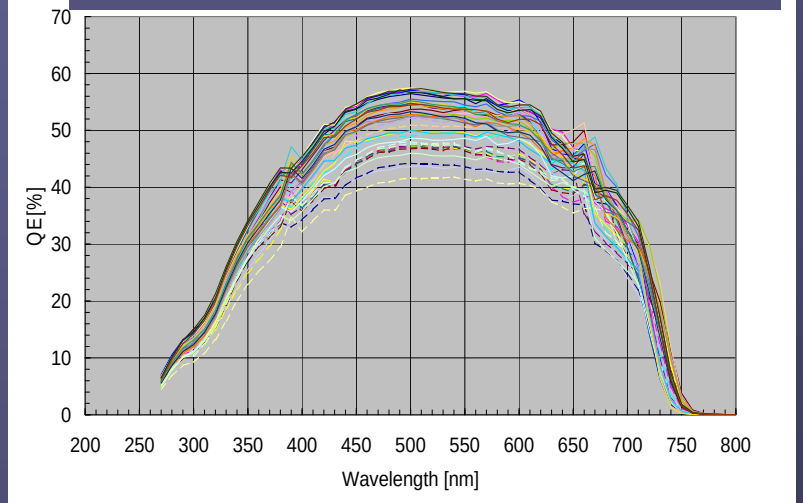
HPD R9792U-40 18mm GaAsP HPD by MPI & Hamamatsu

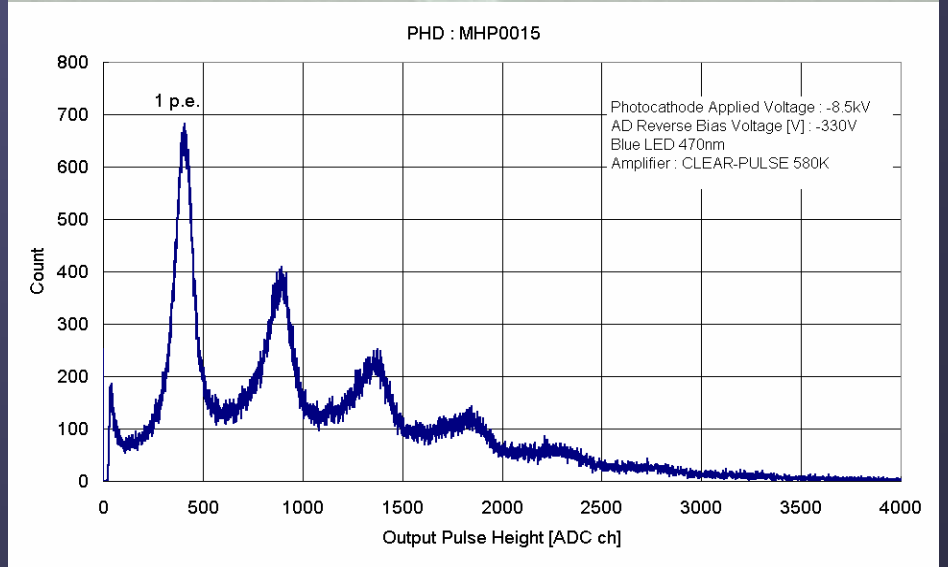


GaAsP photocathode



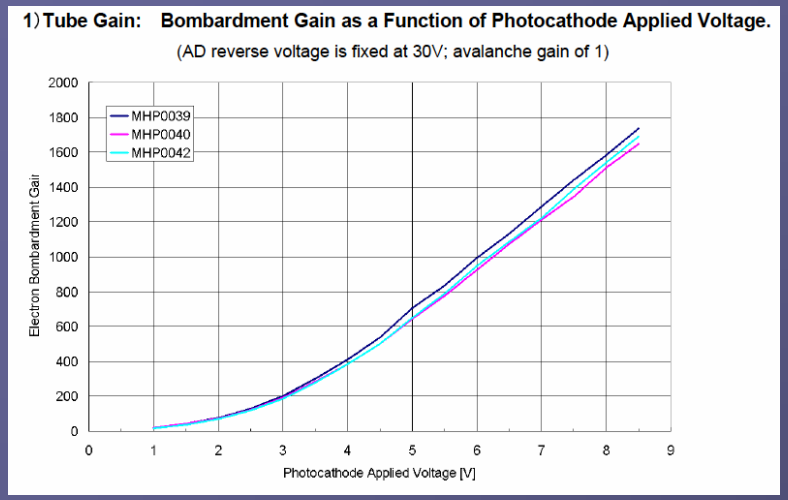
+ High Photoelectron collection eff.



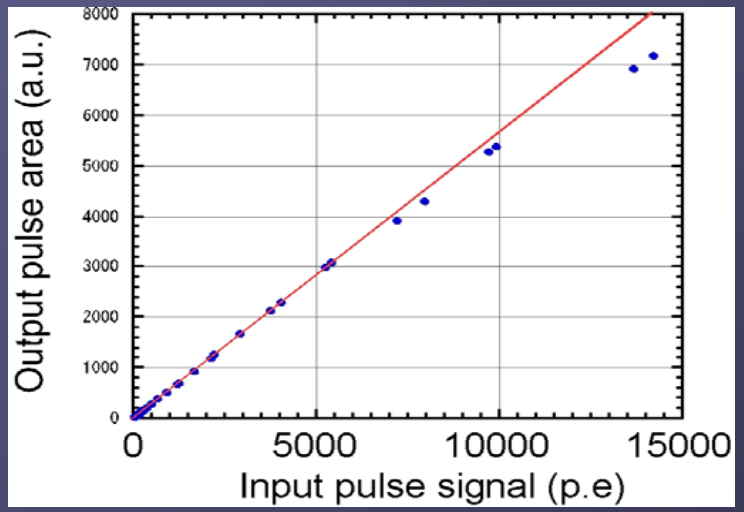


GaAsP HPD Gains, Dynamic range and time response

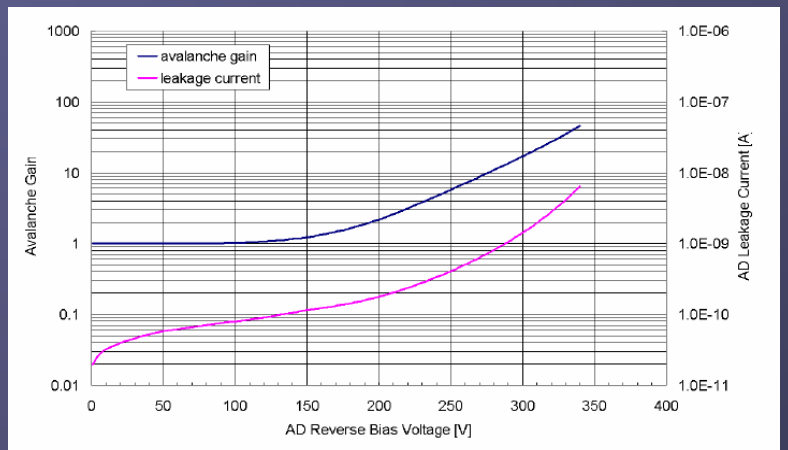
Electron Bombardment Gain



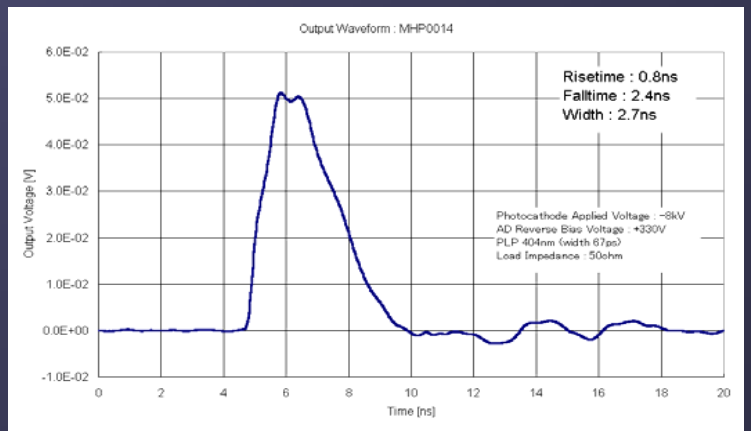
Dynamic range, 1pe ~5000 p.e.



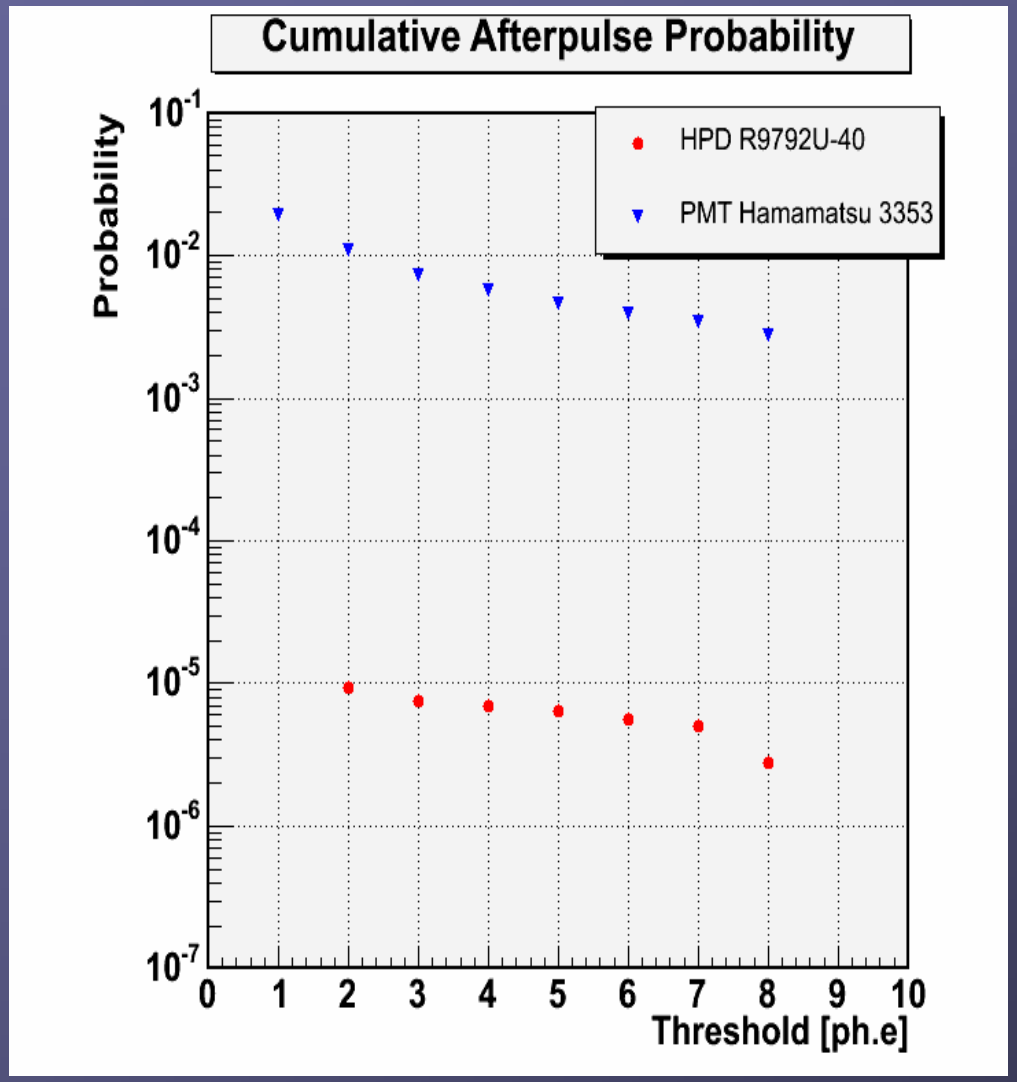
APD Gain and Dark current



Time response FWHM ~2.7nsec



Comparison of after pulse rates between PMT and HPD

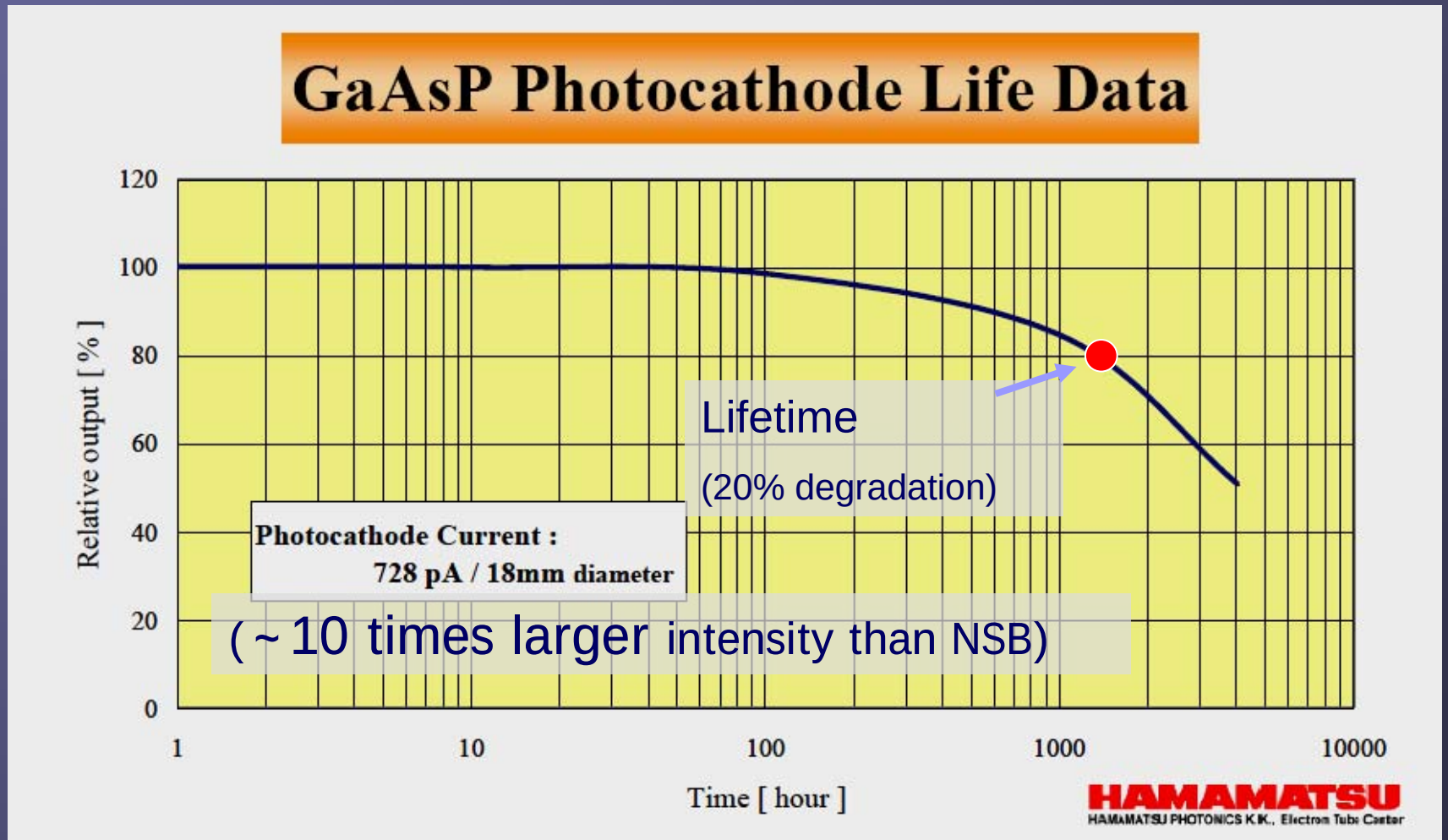


At least, HPDs has different

1) High vacuum
2) Ion feedback protection
help to reduce the after pulse rate

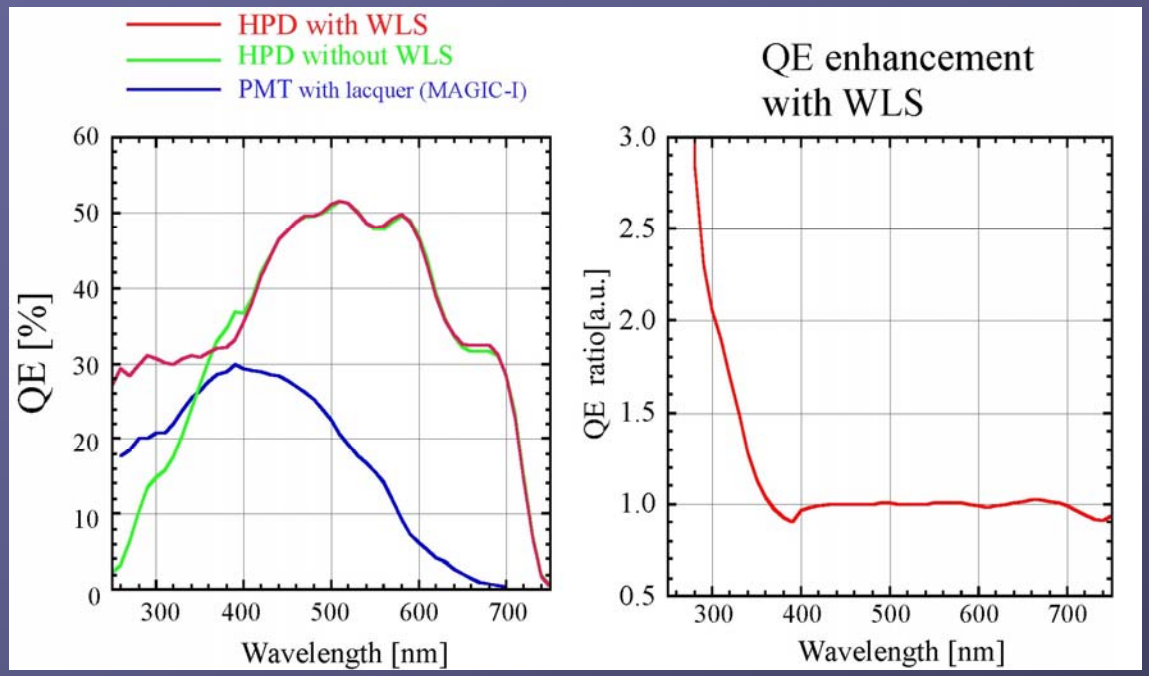
GaAsP HPD life time

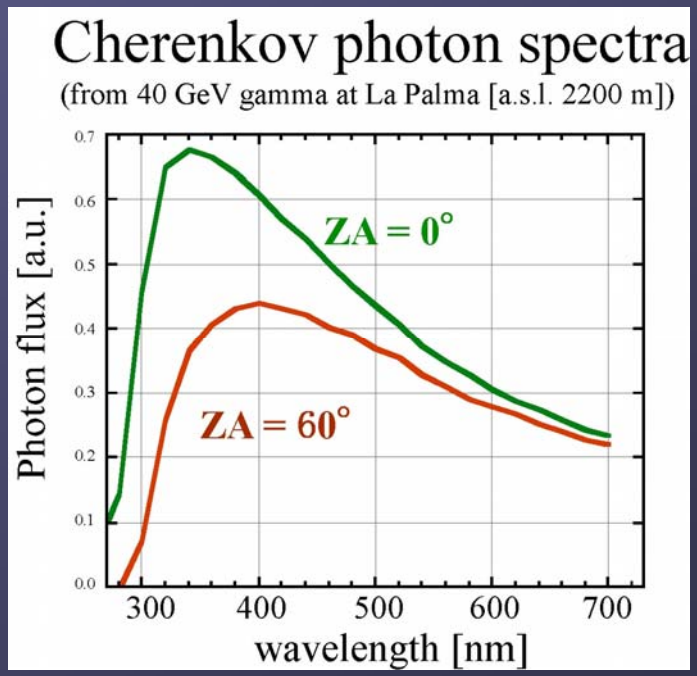
- Total charge; 3.5 mC in Photocathode (ca. 100 C in APD output @ gain 30000])



GaAsP HPD First Test with Wavelength Shifter (WLS)

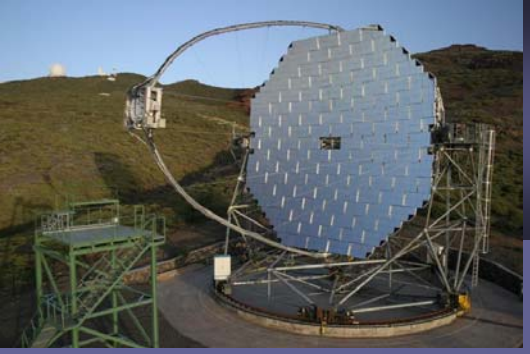
Equivalent to increase the mirror diameter from 17m to 24m!!





In comparison with the current PMTs With milky coating

ZA	0°	25°	45°	60°
No WLS	1.90	1.92	2.00	2.14
With WLS	**1.99**	**2.00**	**2.07**	**2.17**



γ Shower Events

(by MC simulation)

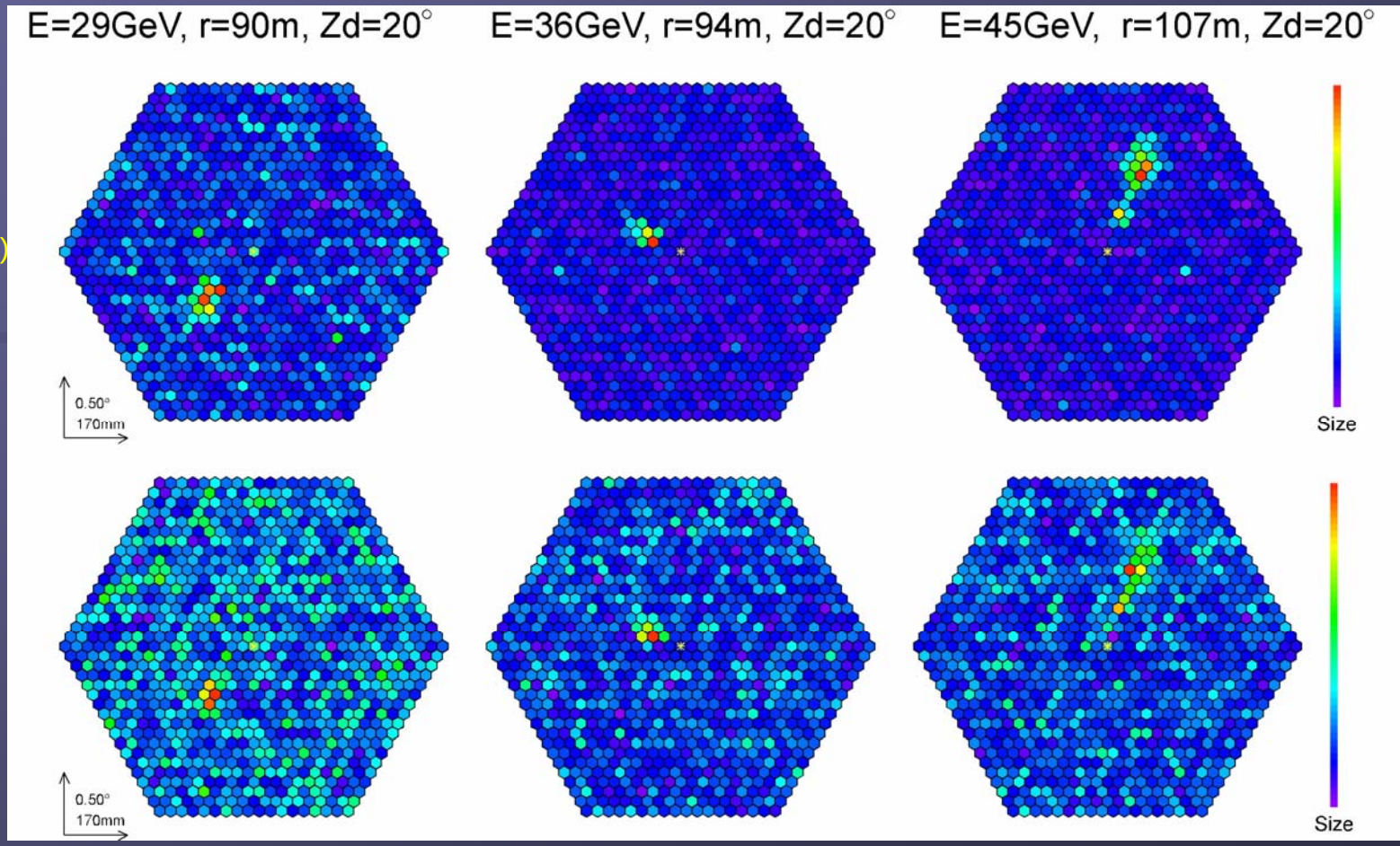
17m telescope becomes equivalent with 24m telescope

HPD

with 10ns gate
(2 Gsamples/s FADC)

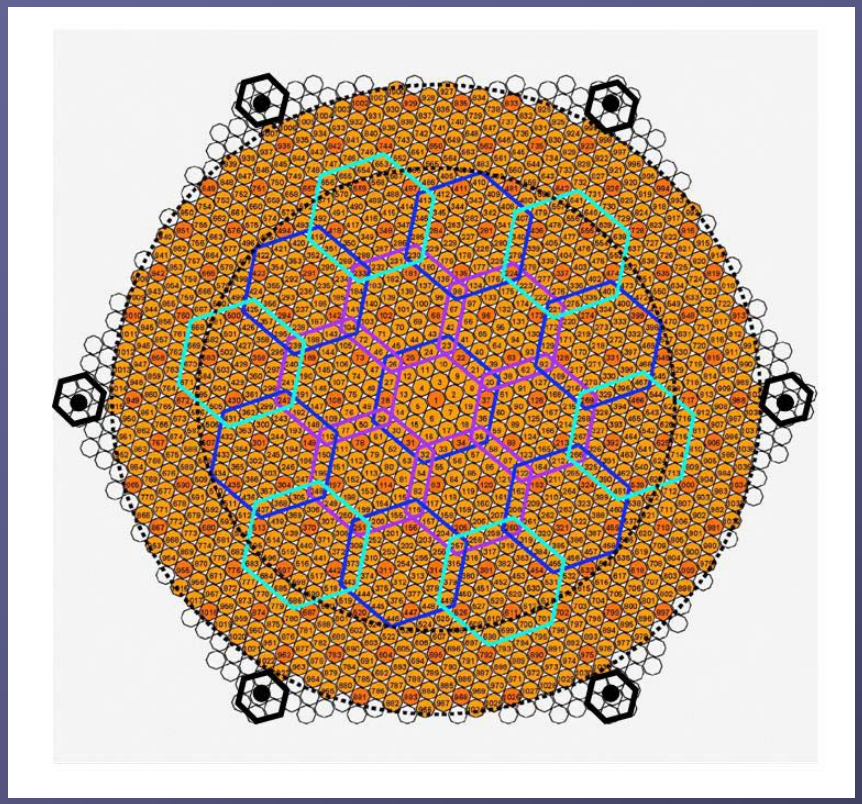
PMT

with 20ns gate
(300Msamples/s FADC)

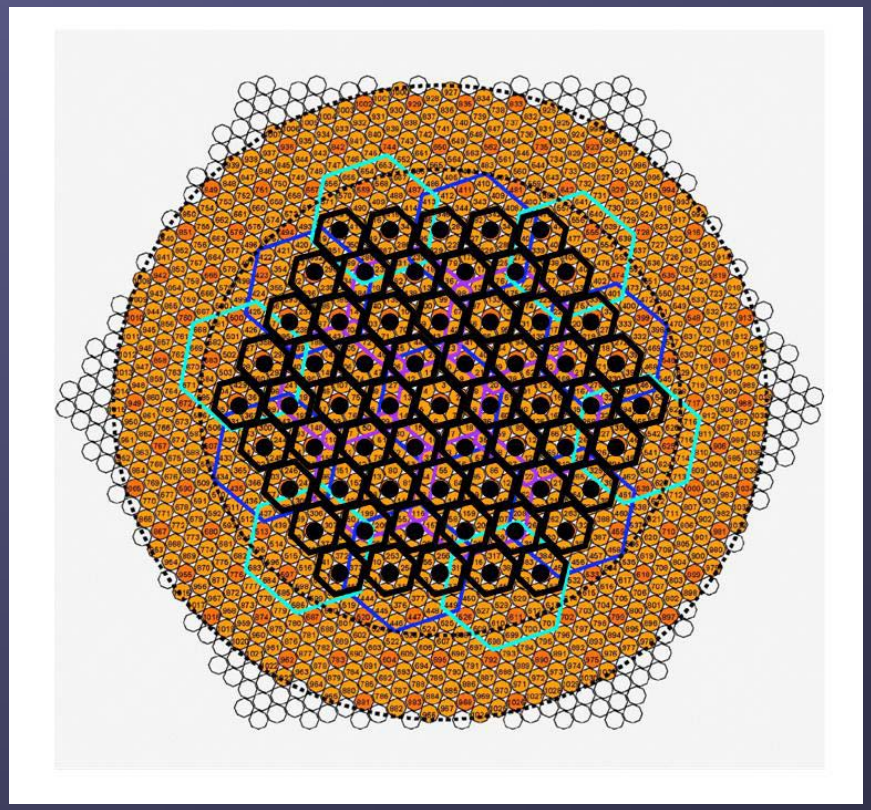


Upgrade of MAGIC-II Camera with HPD

First phase
6 clusters 42HPDs

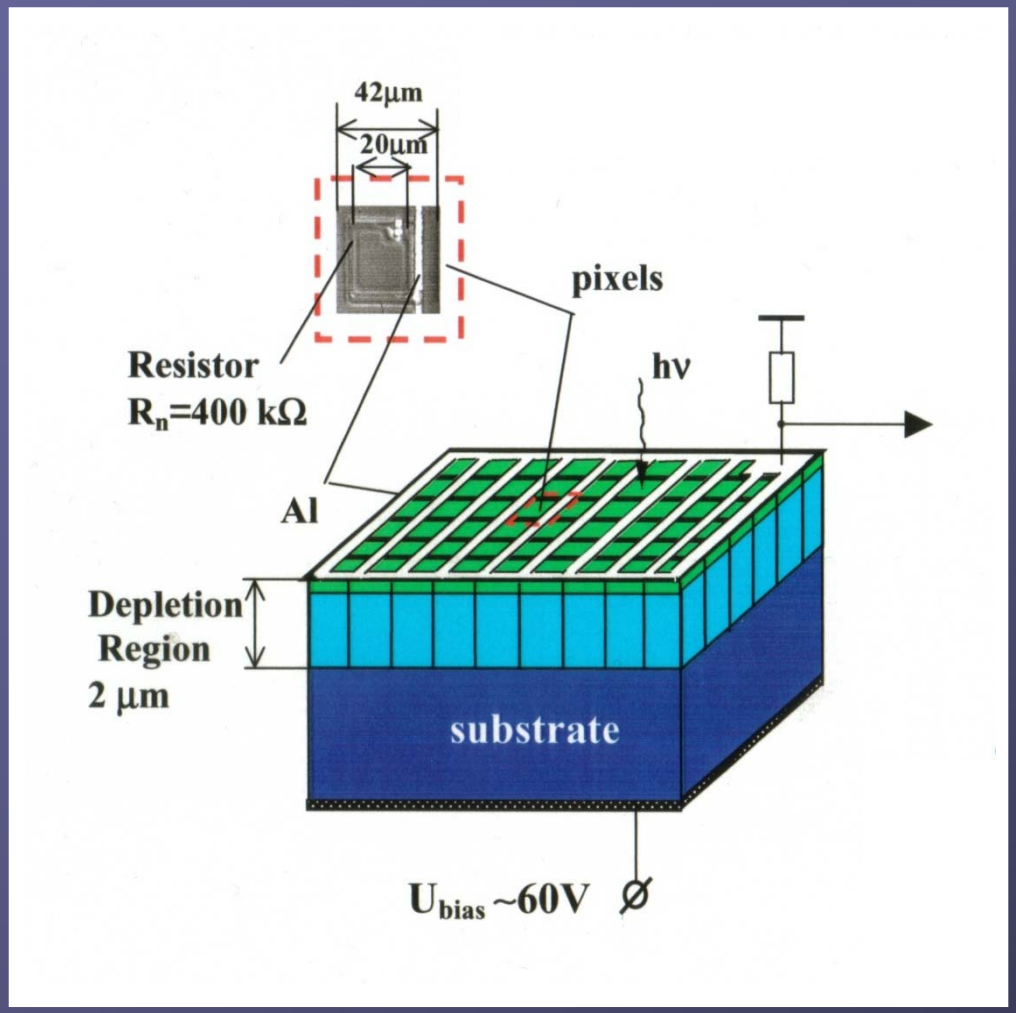


Second phase
61 clusters 427HPDs
±1.3 degrees

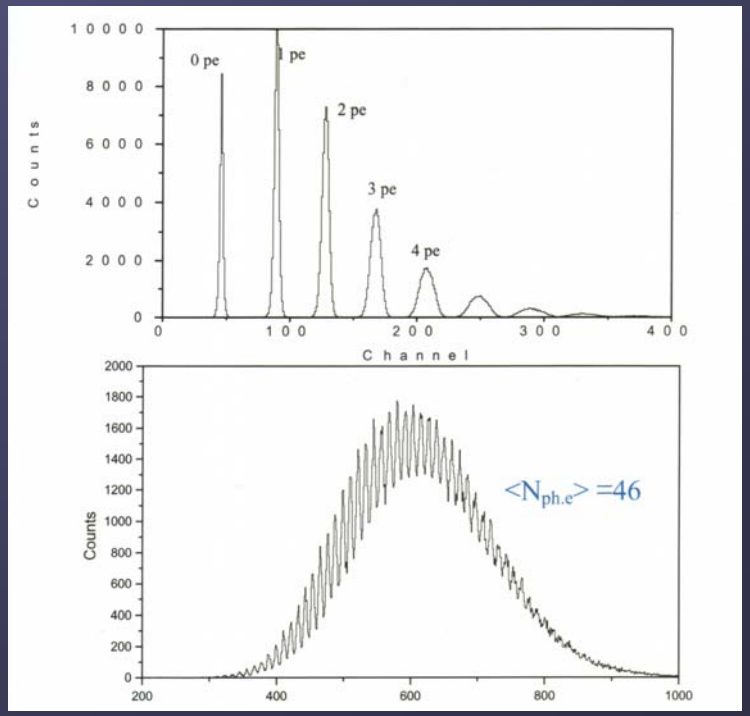


SIPM/SPM/MPPC/G-APD

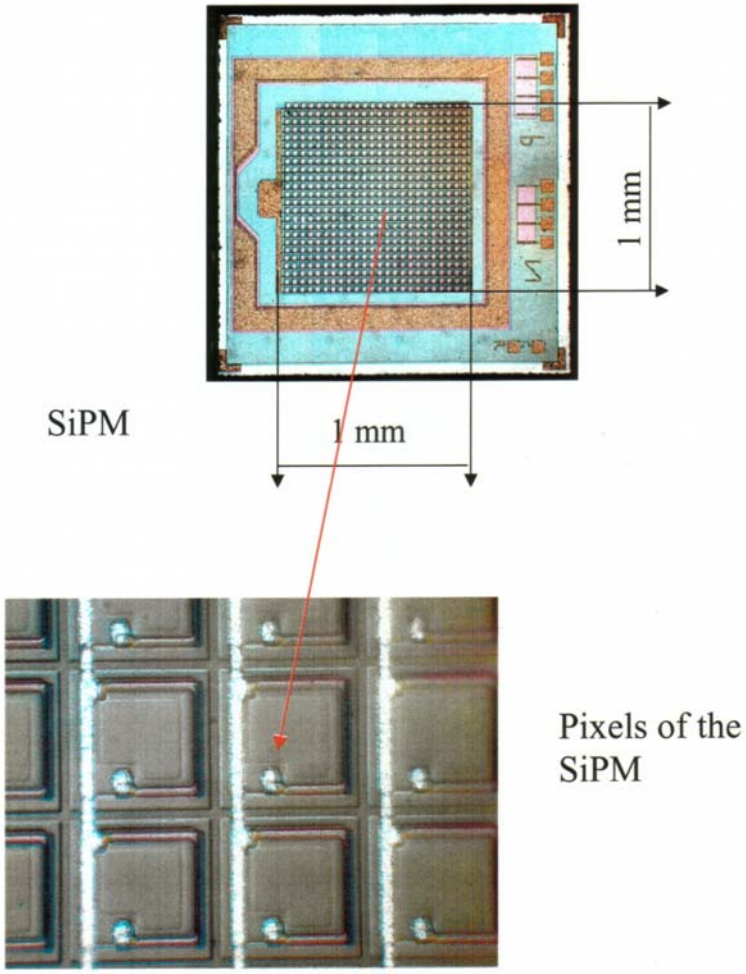
SiPM for TESLA
by Dolgoshein et al. MEPhI

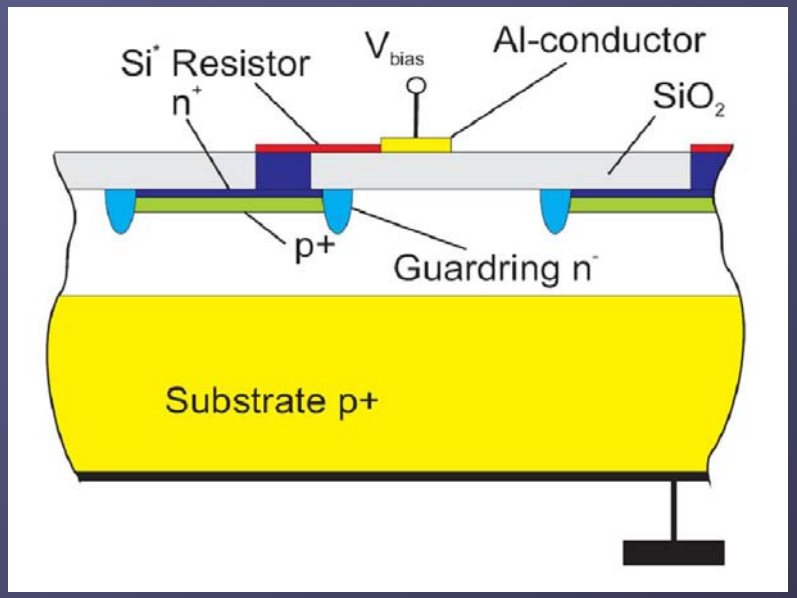


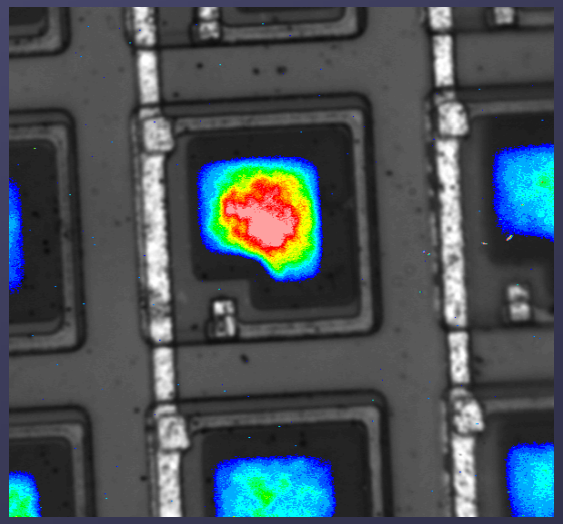
- Single photoelectron measurement
- Gain ~10^6
- Ubias = 30~60
- P = 50μW/mm2
- Npixel ~ 1000
- Insensitive to Magnetic field



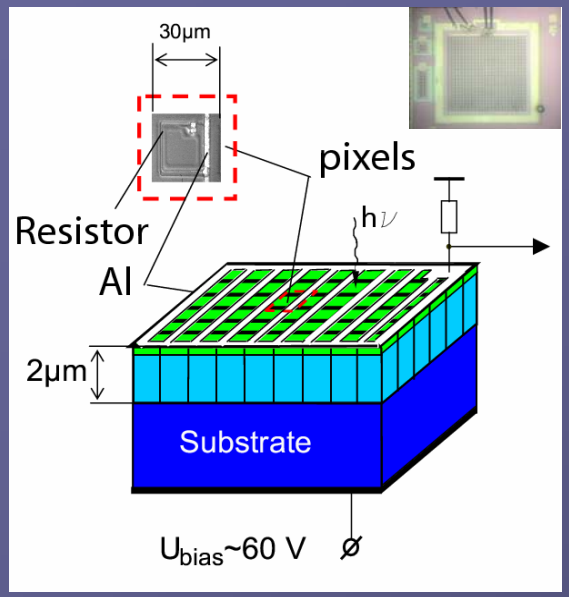
SiPM for TESLA
by Dolgoshein et al. MEPhI

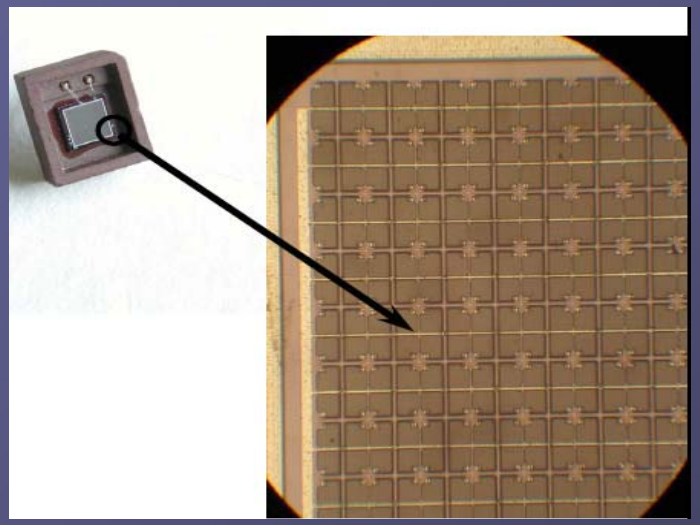


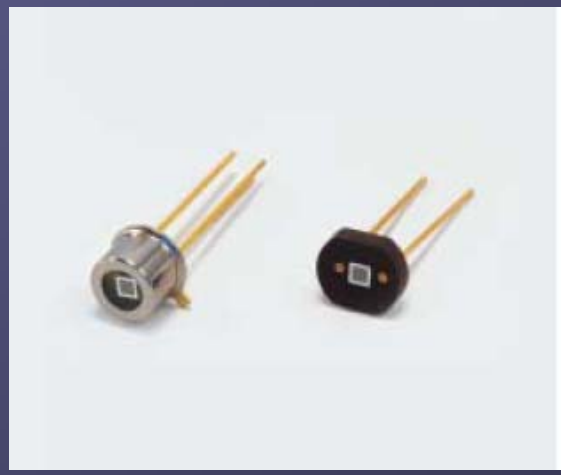


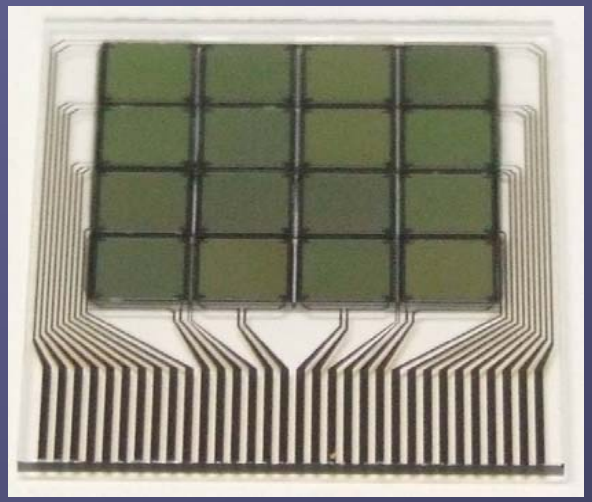


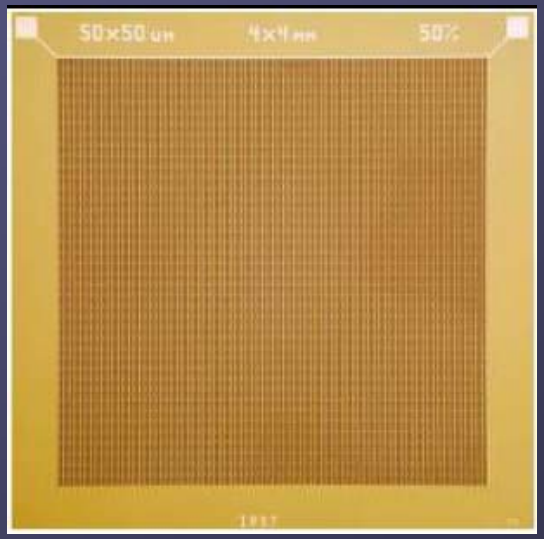
SiPM, SPM, MPPC, G-APD,,,

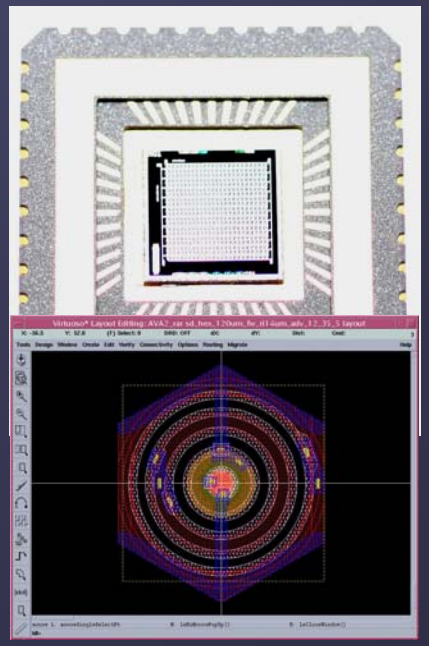








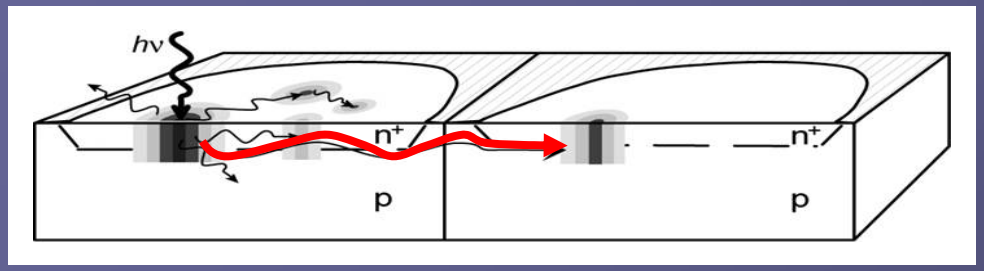




Several problems in SiPM

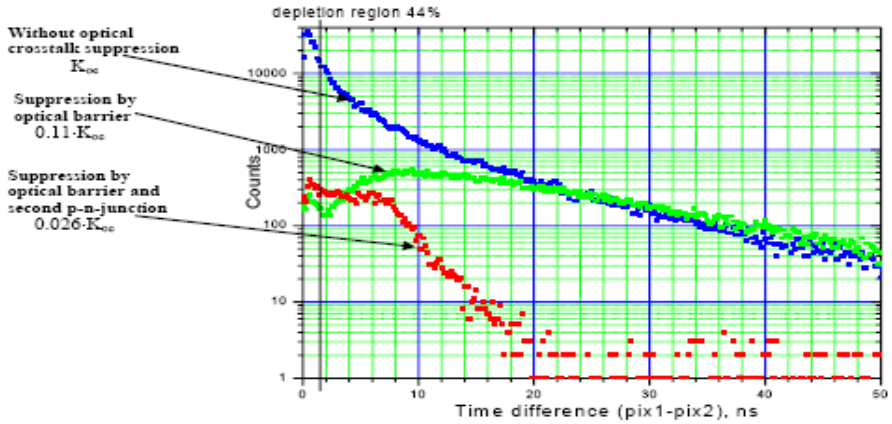
- Low filling factor (low aperture)
  - PDE = Transmittance x Fill factor x Q.E.x Geiger eff.
  - 25-50 μm → 100 μm
- Crosstalk between micro-pixels
  - Low amplification in Geiger gain ➔ may result in low PDE
  - Trench between pixels, double p-n structure
- Dark current
  - Low temperature operation(0℃ ~ -15℃)
- High temperature dependence 3~10%/deg
  - Temperature stabilization is necessary
- Small size (1mmx1mm)
  - 1mm x 1mm (2003) ➔ 3mm x 3mm (2004) ➔ 5mm x 5mm (2005) ➔ 8mm x 8mm (2007)
- Blue sensitivity is relatively low
  - Anti-reflection coat
  - Reverse the structure (p-on-n structure)

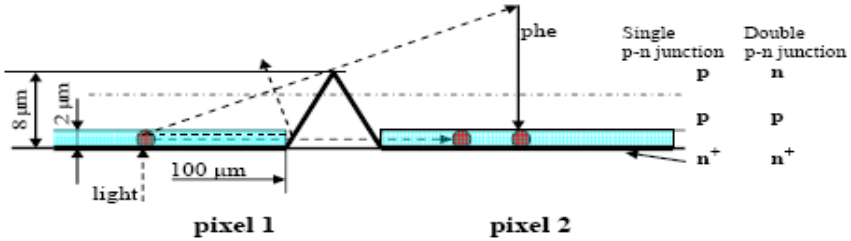
Optical Crosstalk suppression



Sketch from Cova et al. NIST 2003 Workshop on single photon detectors

Optical Crosstalk studies

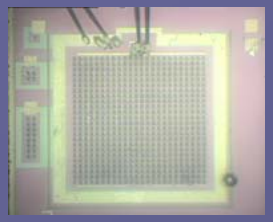




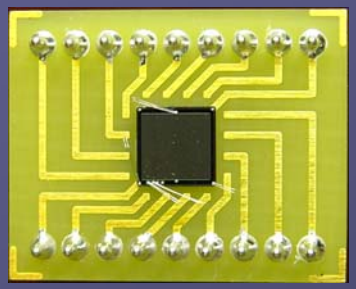
Optical crosstalk between two separate pixels

B.Dolgoshein,SiPM review

Reduction of cross talk between micro pixels



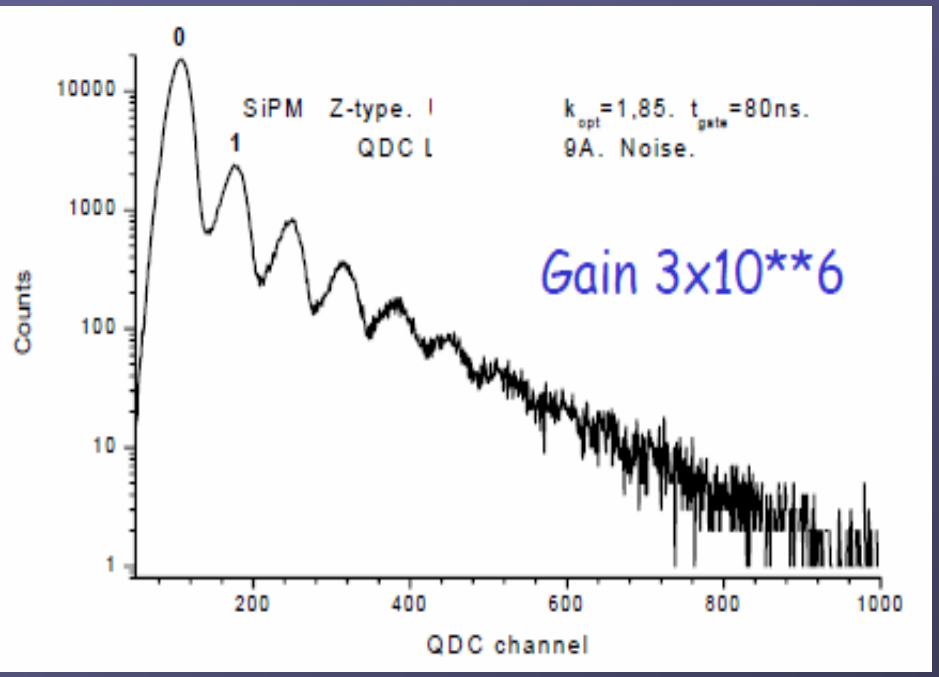
1mmx1mm size

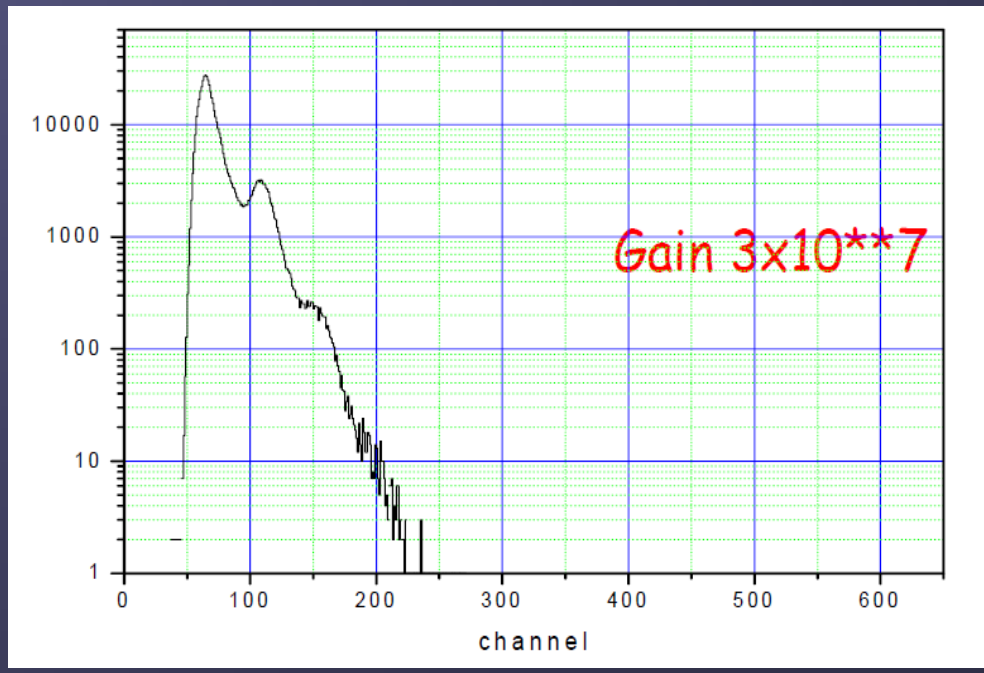


5mmx 5mm size

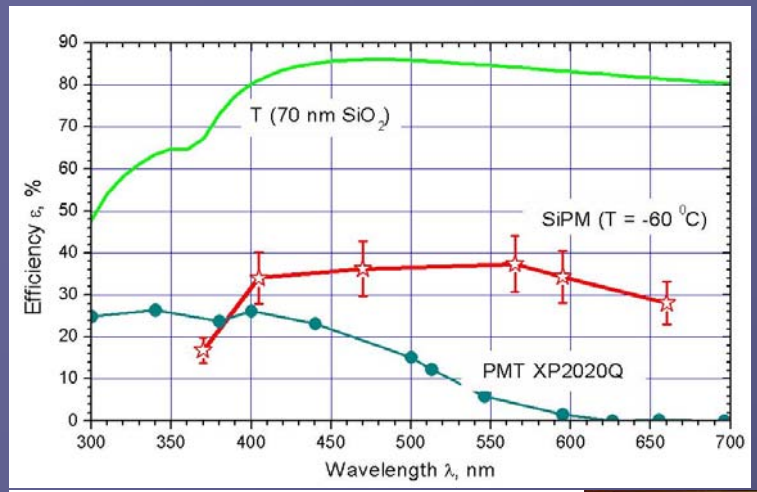
Usual SiPMs, E.N.F. = 1.6

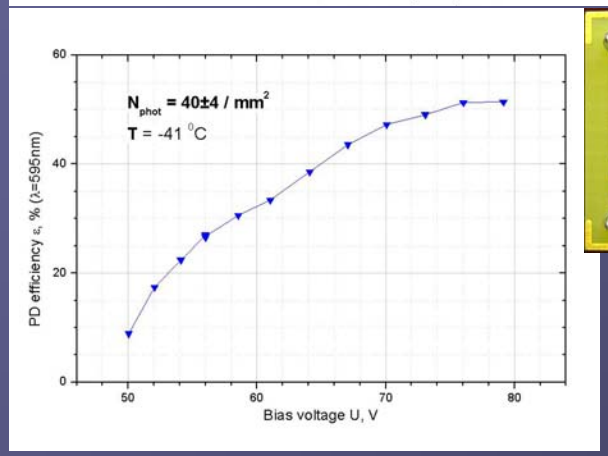
New type of SiPM developed
by MPI and MEPhI E.N.F. = 0.97±0.05

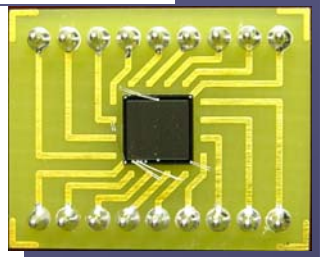


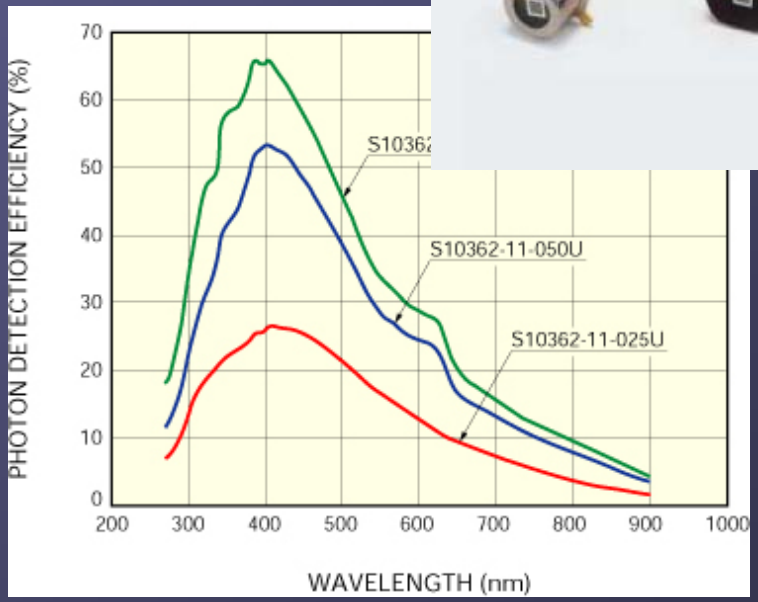


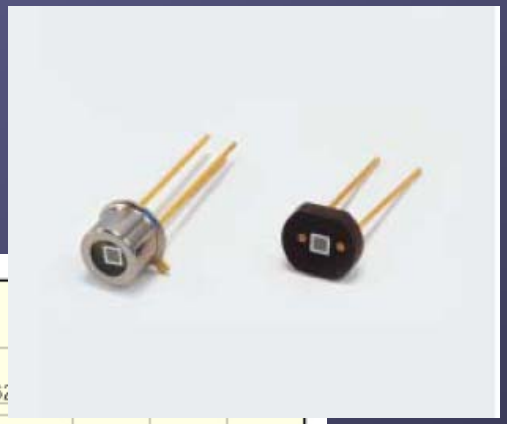
Photodetection efficiency









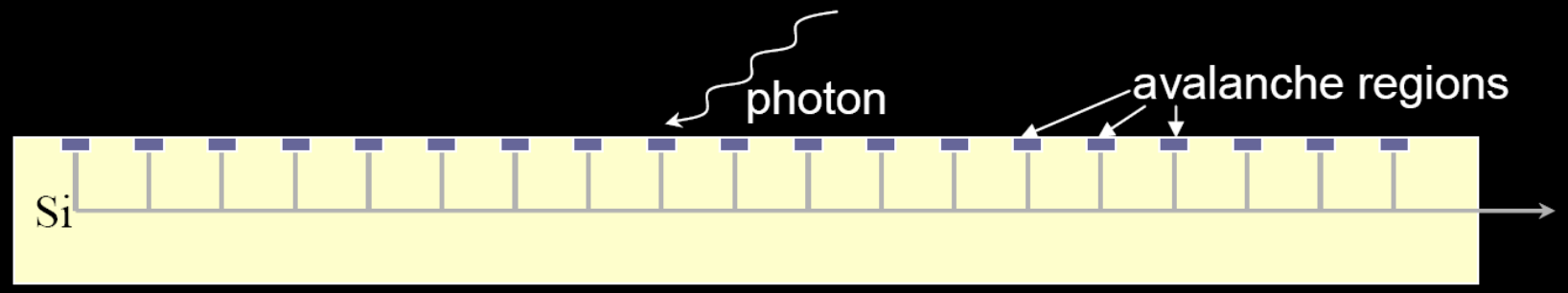


MPI+MEPhI SiPM
100μ pitch, n-on-p structure
33-38%(400-600nm)
➔ 50% at 550nm at high OV.

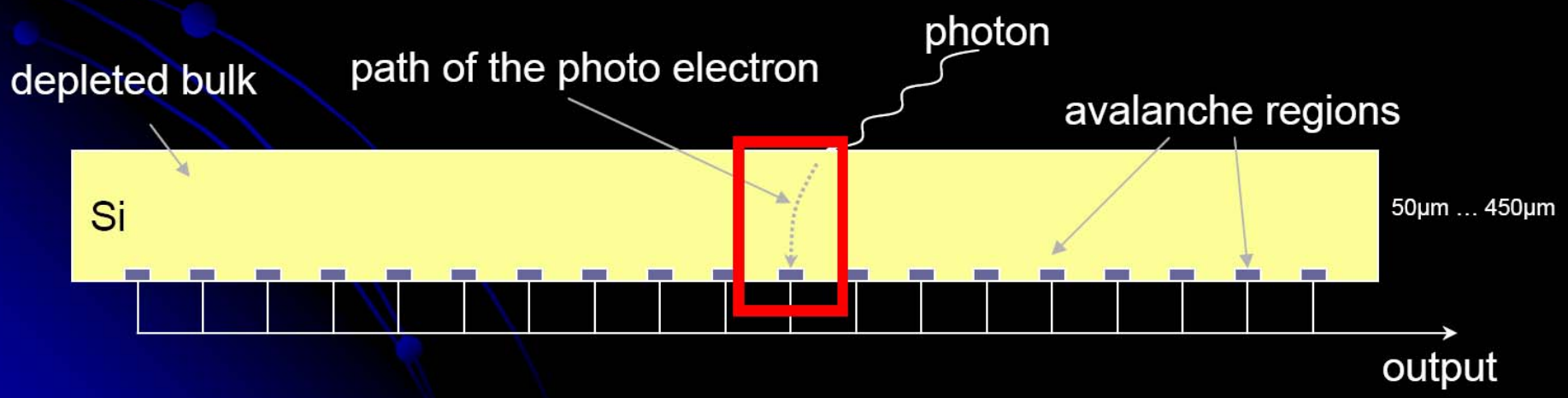
Hamamatsu SiPM
100μ pitch, p-on-n structure
35% (300nm) ~ 65% (400nm)
20% overestimated
28% (300nm) ~ 52% (400nm)

BID-SiPM

Conventional SiPM - an array of avalanche photo diodes operated in Geiger mode

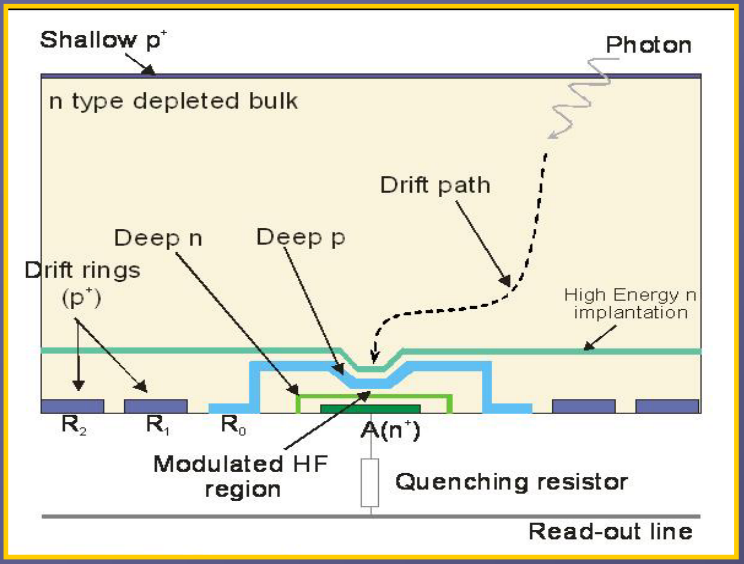


BID SiPM – combined principle of avalanche photodiode and drift diode



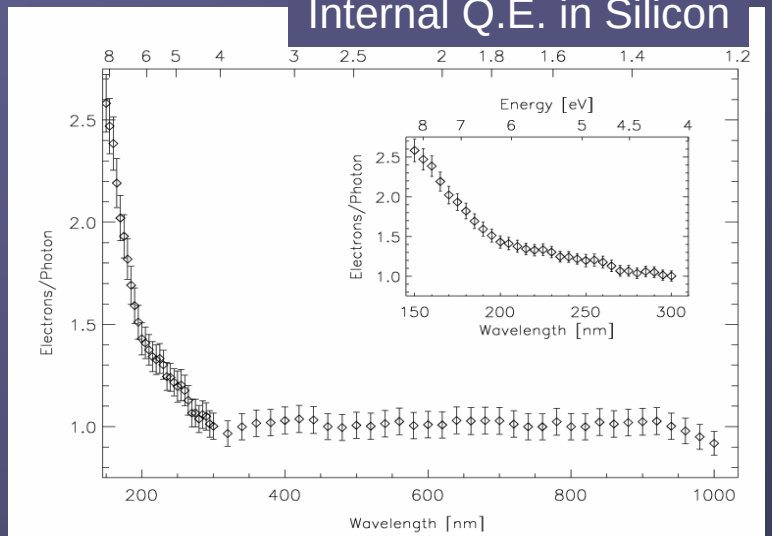
MPI-HLL Back illuminated Drift SiPM

Structure of Micro-Pixel

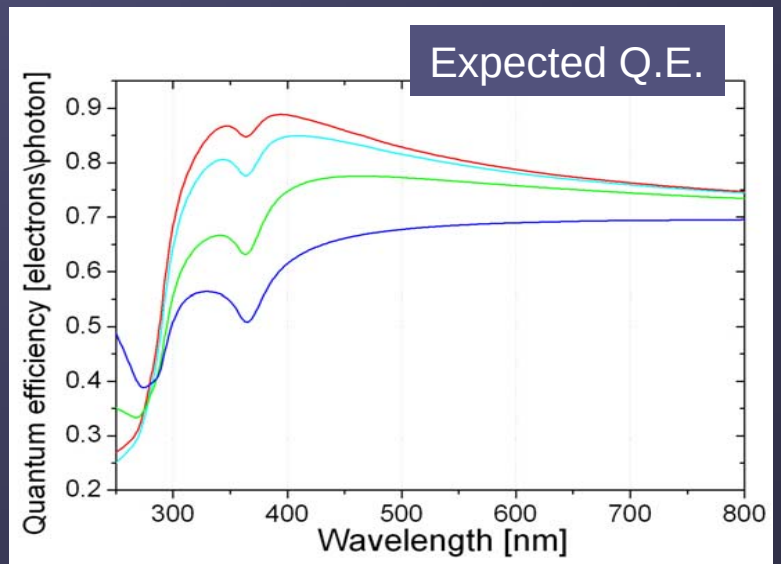


MPI-HLL Facility

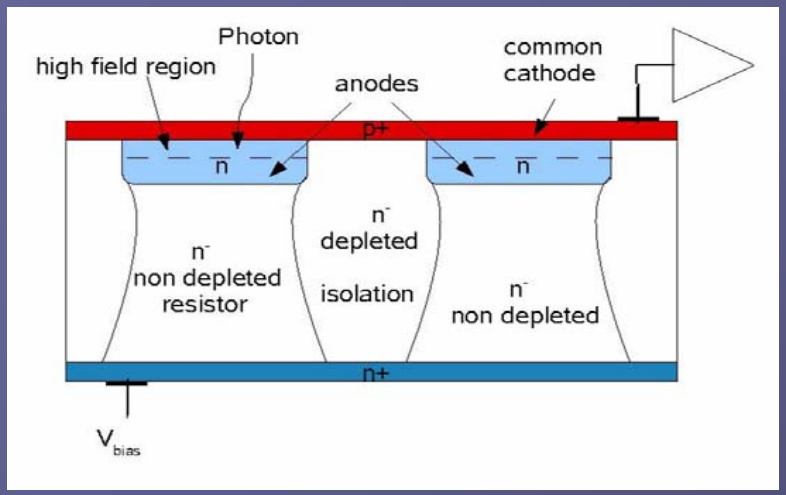
Internal Q.E. in Silicon

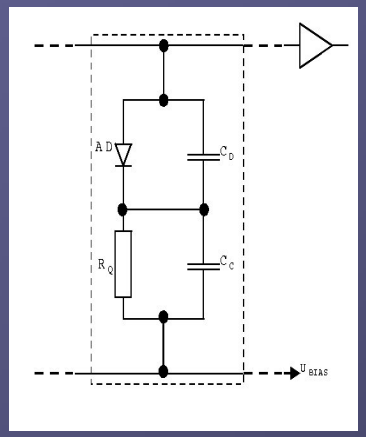


Expected Q.E.



Internal Register type SiPM (GAPD) aim PDE~ 61%

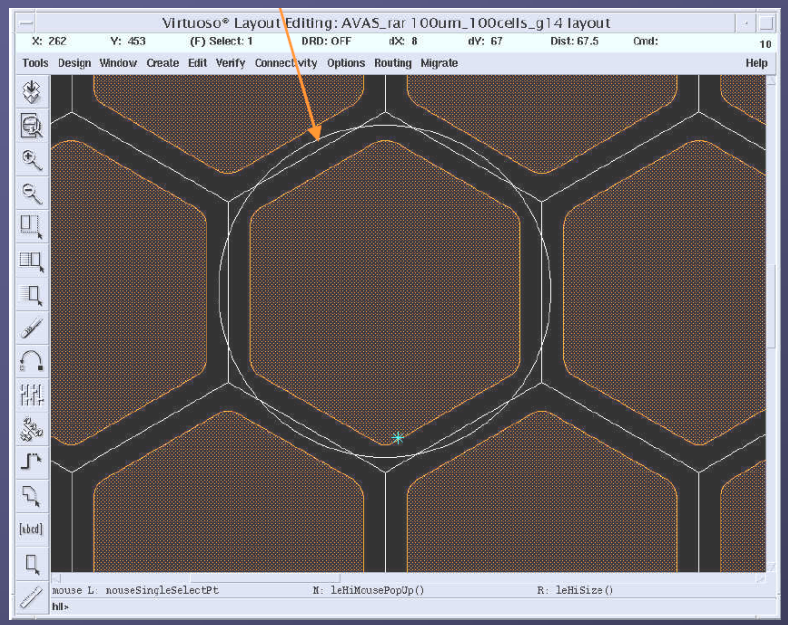


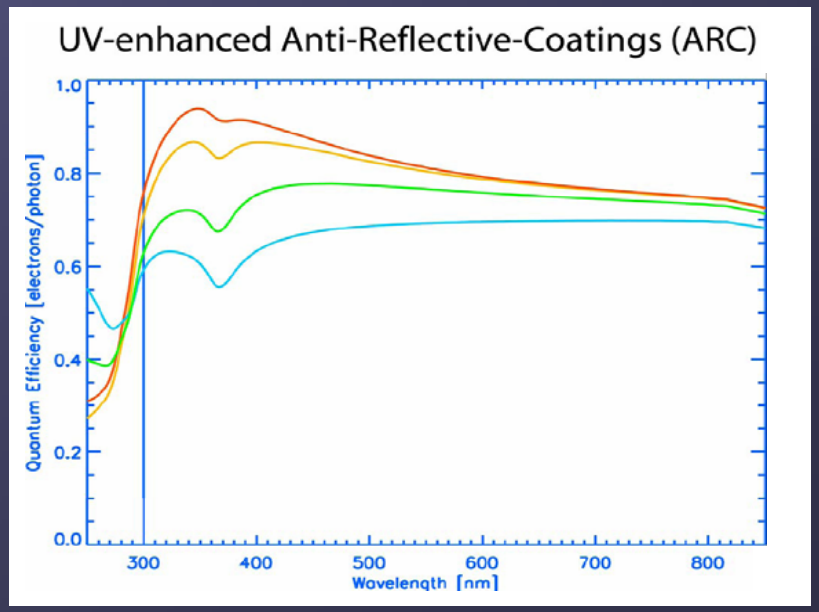


Filling factor 75%
150µm pitch
20µm isolation gap

Transmittance 90%
Geiger Efficiency 90%

Total PDE ~61%

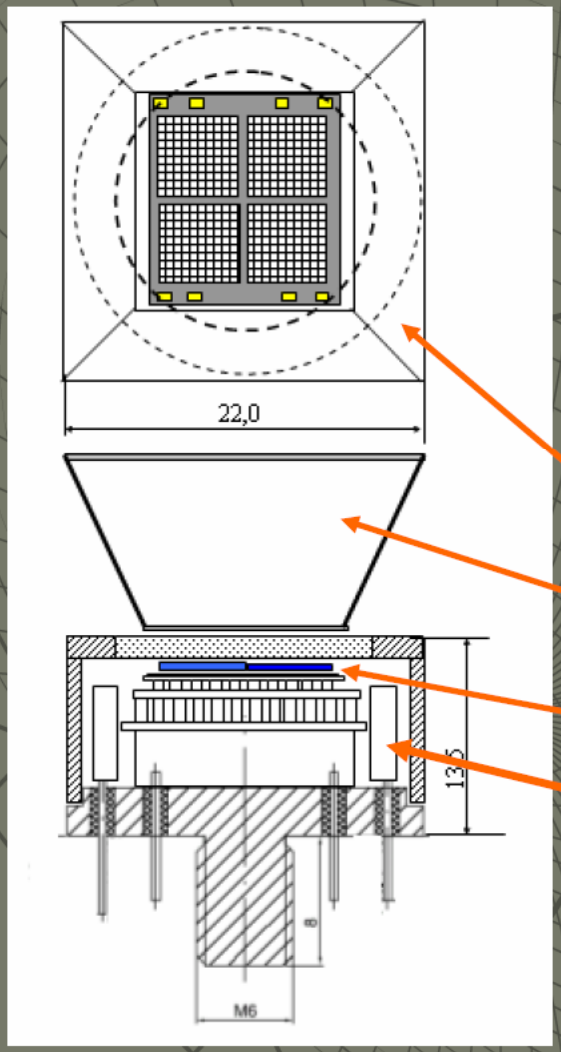


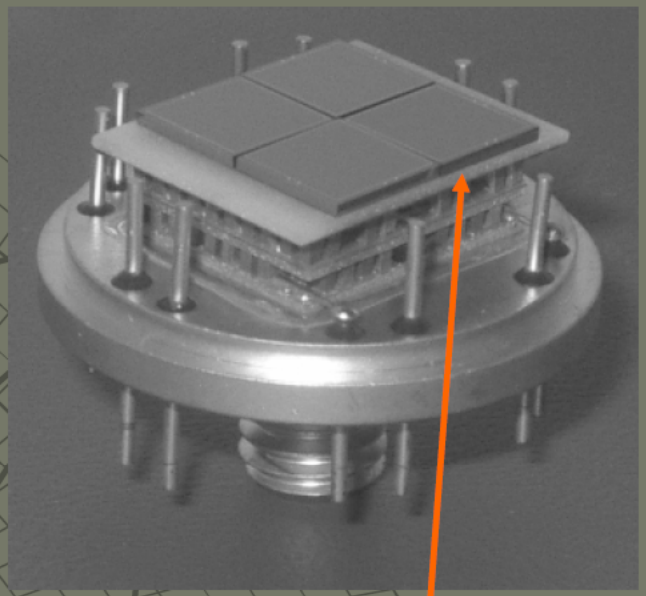


Packaging of SiPM

New module for Magic with adapted geometrical parameters

Submodule





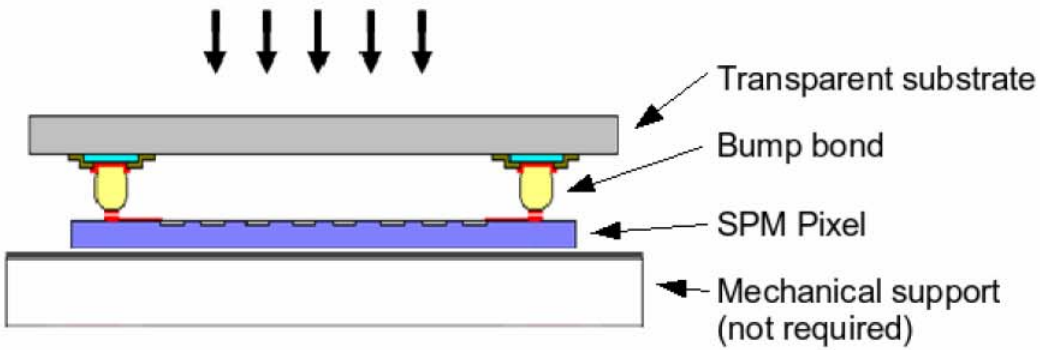
4 SiPMs
5x5 mm^2

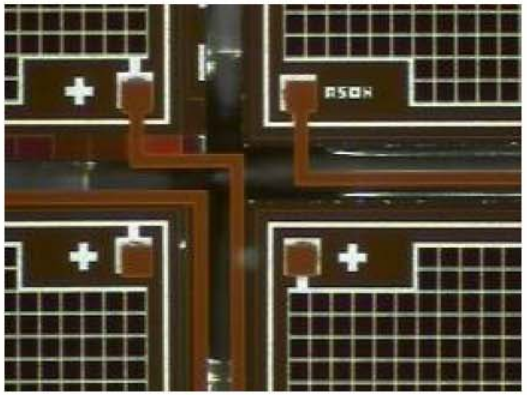
Peltier element

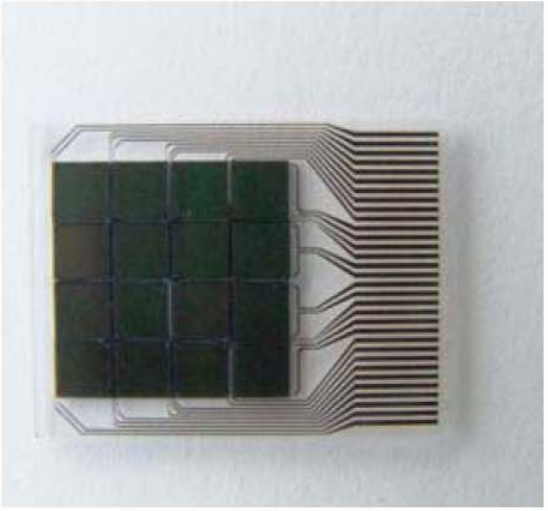
- Winstone cone
- New detectors (B.Dolgoshein talk)
- Improved electronics

Glass Arrays

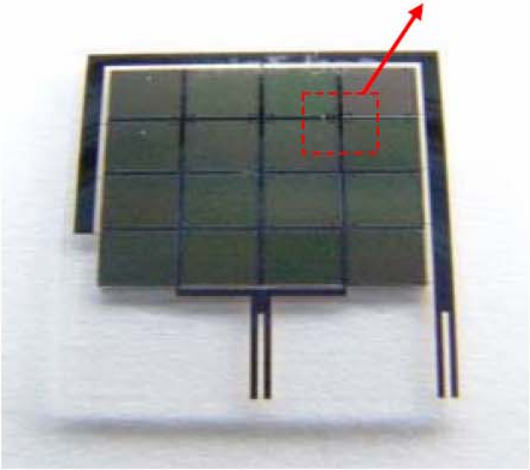
- **SPM flip-chip on glass**





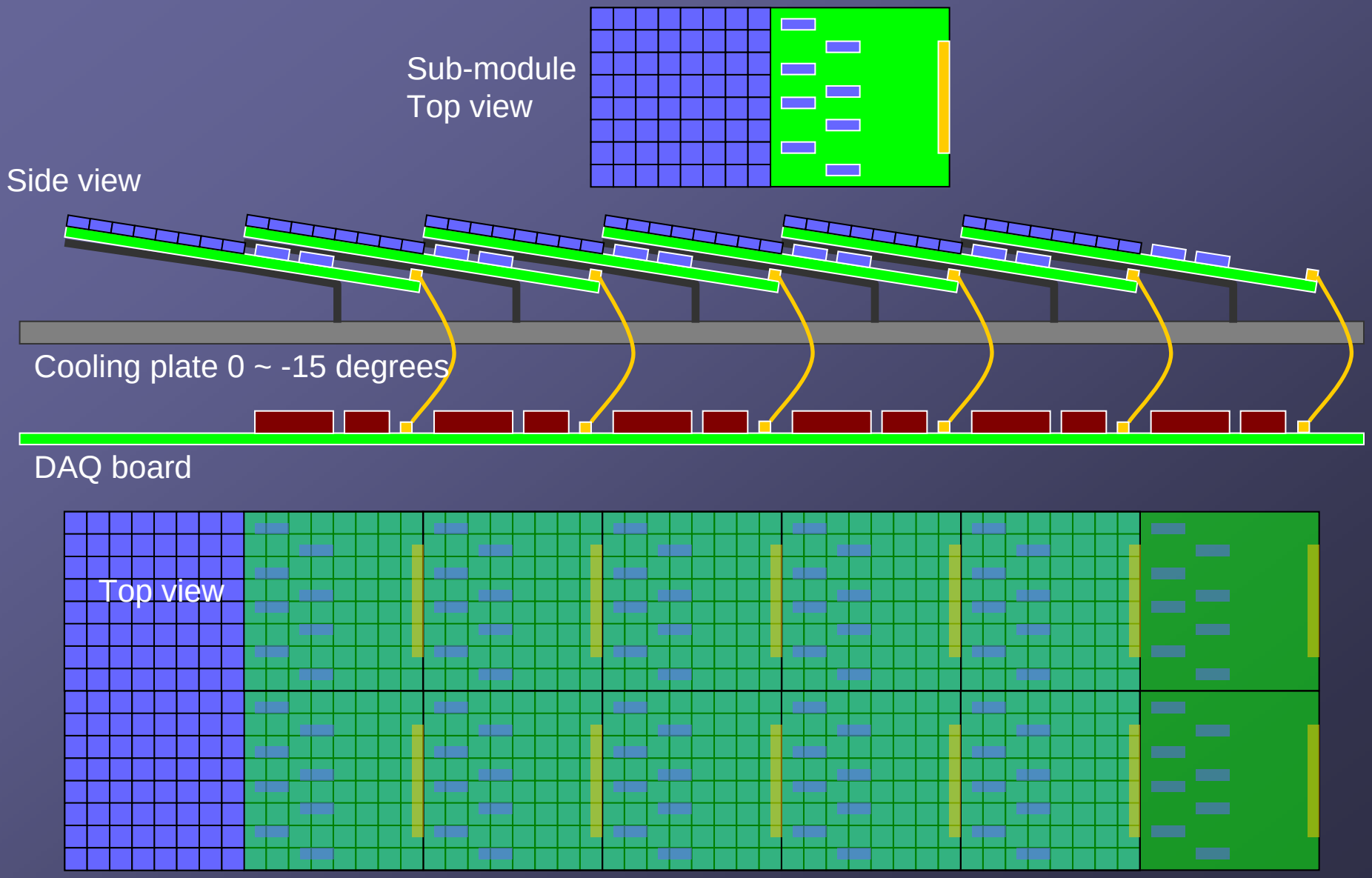


4x4 SPM Pixellated Output
"SPM Array"



4x4 SPM Summed Output
"SPM Plus"

Possible structure of Sub-module and the camera



Conclusion

- High Q.E. PMTs are certainly good candidates for the next generation IACT at present
  - Hamamatsu R10408-SBA will be used in MAGIC-II
  - Be careful to after pulsing rate for some type of PMTs!!
- GaAsP HPD also can be the candidate
  - Will be demonstrated on MAGIC-II / MAGIC-I
  - High Q.E. x High p.e. collection efficiency x very low after pulsing rate
  - but several times expensive than PMTs
- SiPM/SPM/MPPC/G-APD can be the good option in near future(2~3 years)
  - 60-70% P.D.E. will be achieved soon (70-80% could be the hard limit)
  - Several UV-sensitive SiPM will be available soon
  - Moderate cooling / Temperature stabilization are very important
  - Several types of SiPM Array will be available soon
  - Demonstration is highly recommended / required