Photo-detectors for Gamma-Astronomy (IACT) 
Mehr Licht!

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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
Option:
Mix of telescope types

~10 central Huge telescopes
~100 Medium + Small Telescopes
PMTs
MAGIC-I Camera 3.5° 576 pixels

EMI 9116A type PMT
Serial number 1930

- WLS Coated PMT (milky lacquer)
- WLS Coated PMT (transparent lacquer)
- Non-coated PMT

QE (%) vs. Wavelength (nm.)
MAGIC-II Camera and pixel

Hamamatsu R10408Mod SBA-PMT

~35% Q.E.
High after pulse rate will make the low trigger threshold difficult!!

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.

N.S.B. ~ 100 MHz
After pulses ~ 100 kHz
# High Q.E. PMTs

materials from companies

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### Spectral Response Characteristics

#### Metal Package PMT (TO-8 Type)

<table>
<thead>
<tr>
<th>Photocathode</th>
<th>QE at peak wavelength</th>
<th>Type Availability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultra Bialkali (UBA)</td>
<td>38 %</td>
<td>Metal Package PMT (TO-8 Type, □28 mm Type PMT)</td>
</tr>
<tr>
<td>Super Bialkali (SBA)</td>
<td>32 %</td>
<td>Metal Package PMT (TO-8 Type, □28 mm Type PMT) □28 mm to □76 mm Head-on PMT (Glass Bulb Type)</td>
</tr>
</tbody>
</table>

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**Graphs:**

- **Left Graph:** Spectral response characteristics showing the quantum efficiency (%)
  - Ultra Bialkali Photocathode
  - Super Bialkali Photocathode
  - Current Bialkali Photocathode

- **Right Graph:** QE% as a function of lambda (nm)
  - Standard bialkali
  - XP5312 best value
  - XP1452 best value
  - XP3422 np 1
  - XP3422 np 2
  - XP3422 np 3
  - XP3422 np 4
Hamamatsu UBA MAPMT

Latest Data of R7600-200

(UBA)

Example data with 10 tubes

Quantum Efficiency [%]

41% ~ 45%

<<Specification>>
Typical: 43 %
Minimum: 38 %

at peak Wavelength

Wavelength [nm]
HPD
HPD R9792U-40 18mm GaAsP HPD by MPI & Hamamatsu

Compact HPD Operating Principle
- Photocathode
- Photon
- Electron Bombardment
  1200 times
- Avalanche Multiplication
  50 times

+ High Photoelectron collection eff.

GaAsP photocathode

![Graph showing QE vs. Wavelength](image)

<table>
<thead>
<tr>
<th>Wavelength [nm]</th>
<th>QE [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>10</td>
</tr>
<tr>
<td>250</td>
<td>20</td>
</tr>
<tr>
<td>300</td>
<td>30</td>
</tr>
<tr>
<td>350</td>
<td>40</td>
</tr>
<tr>
<td>400</td>
<td>50</td>
</tr>
<tr>
<td>450</td>
<td>60</td>
</tr>
<tr>
<td>500</td>
<td>70</td>
</tr>
</tbody>
</table>

![Graph showing Output Pulse Height vs. ADC ch](image)

PHD: MHP001G
- Photocathode Applied Voltage: -6.5kV
- AD Reverse Bias Voltage: V -330V
- Bias LED: 471nm
- Amplifier: CLEAR-PULSE 560K

Graph parameters:
- Output Pulse Height [ADC ch] vs. Count
- 1 p.e.
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)

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GaAsP Photocathode Life Data

- Photocathode Current: 728 pA / 18mm diameter
- Lifetime: (20% degradation)
- (~ 10 times larger intensity than NSB)
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

<table>
<thead>
<tr>
<th>ZA</th>
<th>0°</th>
<th>25°</th>
<th>45°</th>
<th>60°</th>
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</thead>
<tbody>
<tr>
<td>No WLS</td>
<td>1.90</td>
<td>1.92</td>
<td>2.00</td>
<td>2.14</td>
</tr>
<tr>
<td>With WLS</td>
<td>1.99</td>
<td>2.00</td>
<td>2.07</td>
<td>2.17</td>
</tr>
</tbody>
</table>
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 for TESLA
by Dolgoshein et al. MEPhI

- Single photoelectron measurement
- Gain ~10^6
- U_{bias} = 30~60
- P = 50\mu W/mm^2
- N_{pixel} \sim 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°C ~ -15°C)
- 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

Without optical crosstalk suppression

Suppression by optical barrier 0.11 \( N_{\text{dd}} \)

Suppression by optical barrier and second p-n junction 0.026 \( N_{\text{dd}} \)

Time difference (pix1-pix2), ns

Optical crosstalk between two separate pixels

B. Dolgoshein, SiPM review
Reduction of cross talk between micro pixels

Usual SiPMs, E.N.F. = 1.6

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

1mmx1mm size

5mmx 5mm size

Gain 3x10**6

Gain 3x10**7
Photodetection efficiency

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

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

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

4 SiPMs 5x5 mm²
Peltier element

23-28 of October 2007

VI Int. Workshop LIGHT 2007
Elena Popova Cooled SiPM matrixes module
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

Sub-module
Top view

Side view
Cooling plate 0 ~ -15 degrees

DAQ board

Top view
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