Development in PMTs for advanced Fluorescence Telescopes

Sven Querchfeld, Karl-Heinz Kampert, Daniel Kruppke-Hansen, Julian Rautenberg

BERGISCHE UNIVERSITÄT WUPPERTAL

PIERRE AUGER OBSERVATORY

HAP Workshop Advanced Technologies

January 24^{th} 2013

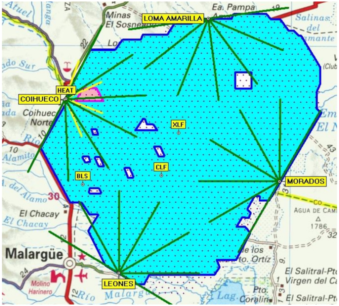
bmb+f - Förderschwerpunkt Astroteilchenphysik
Großgeräte der physikalischen Grundlagenforschung

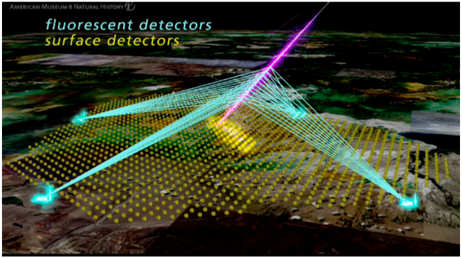
HELMHOLTZ ASSOCIATION
Alliance for Astroparticle Physics

s.querchfeld@uni-wuppertal.de

The Pierre Auger Observatory

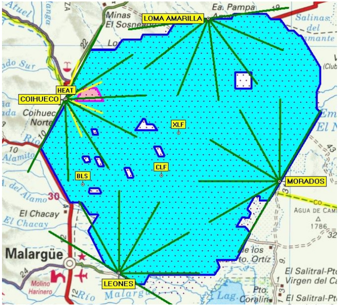
- largest experiment to detect cosmic rays at highest energies
- 3000 km^2, hybrid detector
  - 1660 surface detectors
  - 24 fluorescence telescopes
  - +3 HEAT tel.
  - radio array
  - muon detectors





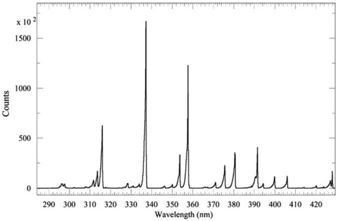
The Pierre Auger Observatory

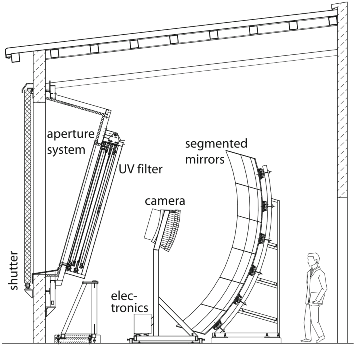
- largest experiment to detect cosmic rays at highest energies
- $3000\,\text{km}^2$, hybrid detector
  - 1660 surface detectors
  - 24 fluorescence telescopes
  - +3 HEAT tel.
  - radio array
  - muon detectors

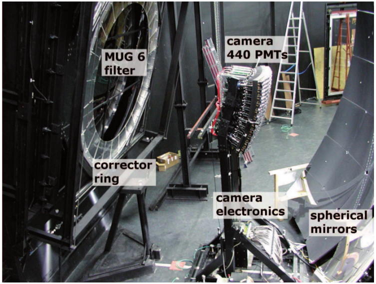


Fluorescence Telescopes

- optimized for fluorescence light between 300 nm and 400 nm
- camera: 440 photomultiplier (PMT)
- transition between PMTs is covered by light guides

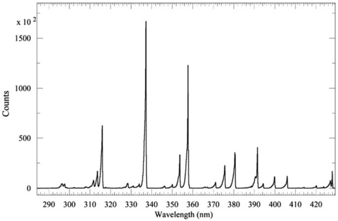


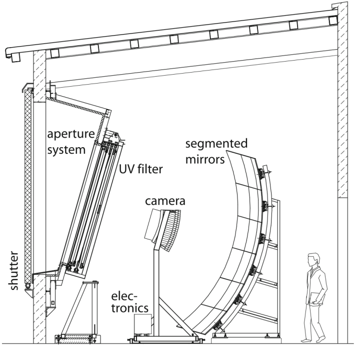


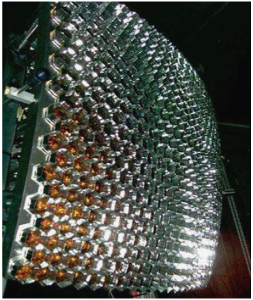


Fluorescence Telescopes

- optimized for fluorescence light between 300 nm and 400 nm
- camera: 440 photomultiplier (PMT)
- transition between PMTs is covered by light guides

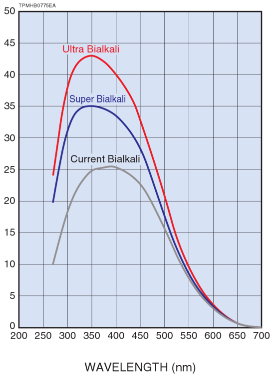






Motivation

- 'Auger-Next'
  - new observatory ($>10\,000\,\mathrm{km}^2$)
  - new fluorescence detectors/design
- new PMTs with higher quantum efficiency (QE) available
- Photonis stopped PMT-production and delivery before HEAT was equipped (re-opened by HZC Photonics in Dec. 2012)

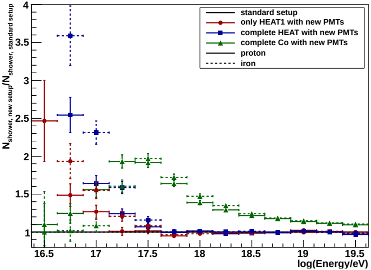


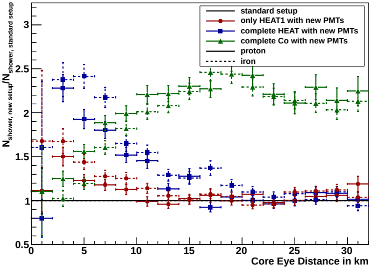
Telescope Simulation

Detector simulation of proton and iron showers with enhanced QE PMTs:

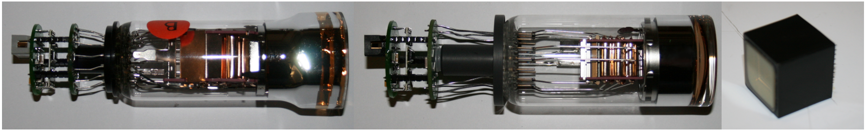
- simulation show increased performance for fd telescopes
  - HEAT: below $\sim 10^{17}\,\mathrm{eV}$ already for one upgraded HEAT camera
  - CO: higher energies
- telescopes see further away

Region which most benefits from HEAT upgrade is exactly where most enhancements are located (AERA, AMBER, AMIGA, Infill)





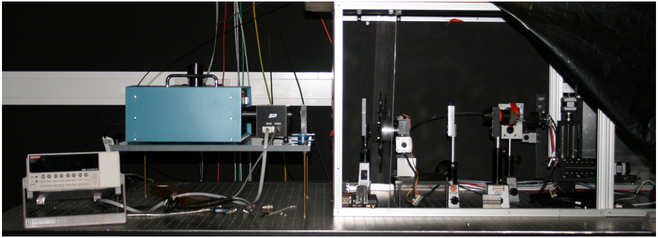
Photomultiplier

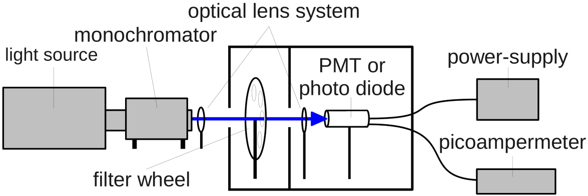


	XP3062	Ham. R9420-100	Ham. R8900-100
Faceplate	hexagonal	round	square
Photocathode	bialkali	super-bialkali	super-bialkali
Window	lime glass	borosilicate	borosilicate
Dynode structure/stages	lin. focused/ 8	lin. focused/ 8	metal channel/ 10
Gain	2.6×10^5	3.7×10^5	1×10^6
Supply Voltage [V] typ.	1100	1300	800
max.	1300	1500	900
Dark current [nA] typ.	1	10	2
max.	20	100	20
Cathode sens. [mA/W]	90	110	110
Q.E.$_{\text{at peak wavelength}}$	27%	35%	35%
Rise Time [ns]	3	1.6	1.8

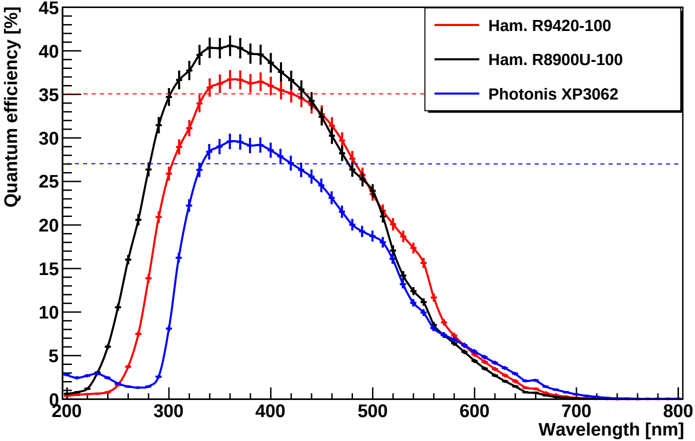
QE Test Setup in Wuppertal

$$QE_{PMT}(\lambda) = QE_{Ref}(\lambda) \cdot \frac{|I_{PMT}| - |I_{ped,PMT}|}{|I_{Ref}| - |I_{ped,Ref}|}$$



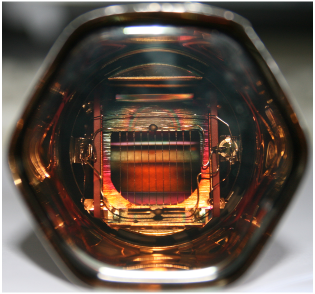


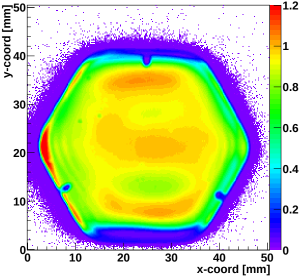
QE Measurement

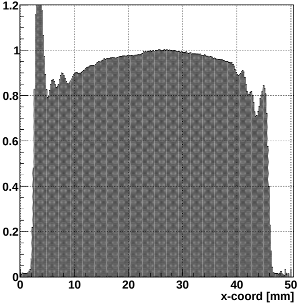


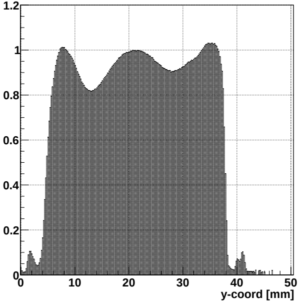
- measurement in reference to calibrated photodiode
- higher QE verified

Uniformity

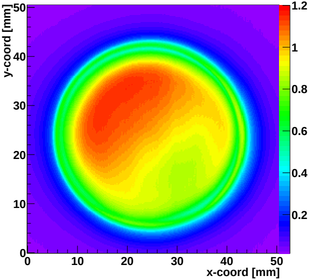


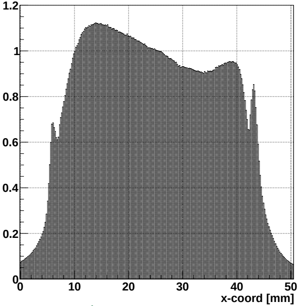


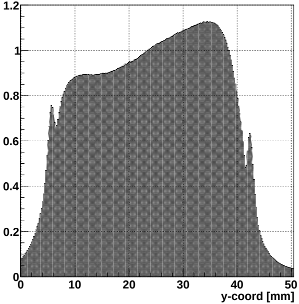




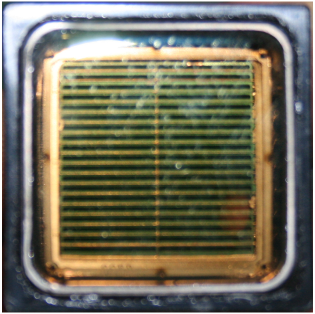
Uniformity

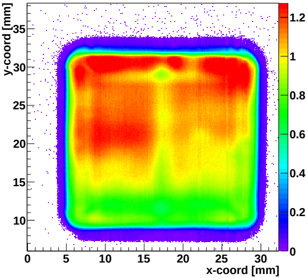

y-coord [mm]
x-coord [mm]
0
10
20
30
40
50
1.2
1
0.8
0.6
0.4
0.2

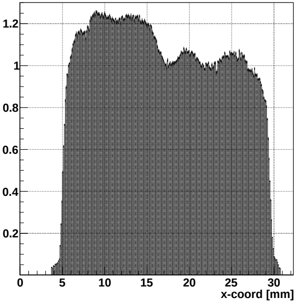

x-coord [mm]
0
10
20
30
40
50
0.2
0.4
0.6
0.8
1
1.2

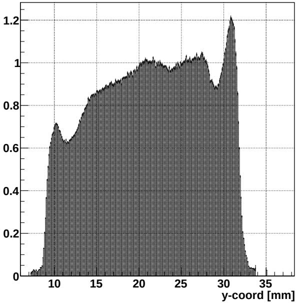

y-coord [mm]
0
10
20
30
40
50
0.2
0.4
0.6
0.8
1
1.2

Uniformity





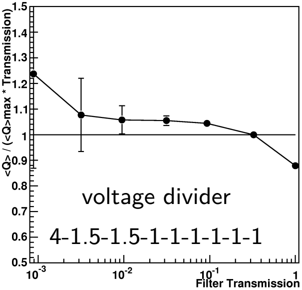


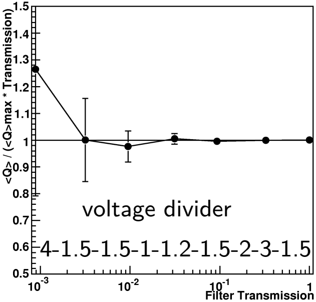


Linearity

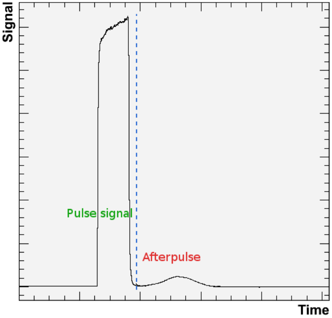
Linear relation between charge and light

- important for energy estimation
- depends on voltage divider
- measured with calibrated attenuation filters
  - resistor ratio optimized





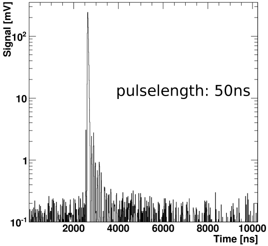
Afterpulses



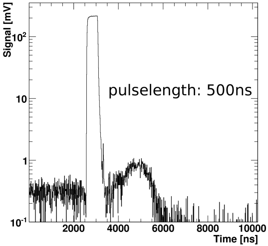
- occure due to luminous reactions & ionisation of residual gases
- transit time:
  - lum. reactions: after $20\,\mathrm{ns}$ to $100\,\mathrm{ns}$
  - ionisation: few $100\,\mathrm{ns}$ to several $\mu\mathrm{s}$
- problematic if large afterpulse can not be separated from signal
- measurement:
  - average over 1000 pulses
  - calculate ratio of charge in afterpulse to signal

Afterpulses

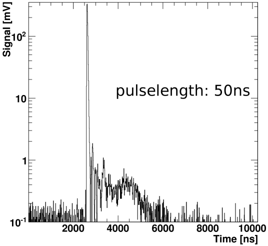
Photonis XP3062

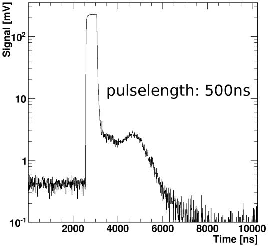


2%



Ham. R9420-100

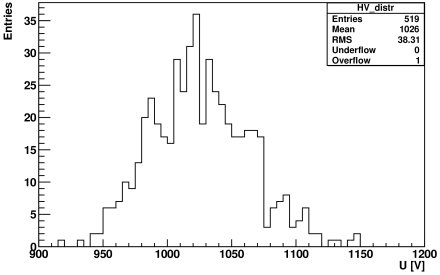


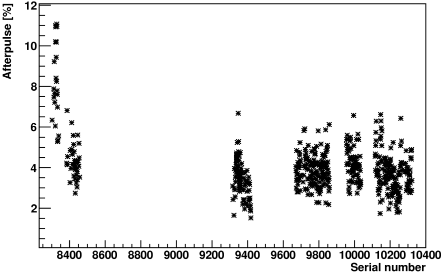


9.4%

Qualification Benchmark

- 500 PMTs ordered to equip a new camara
- gain classification (2×10^5)
  - 22 PMTs at same HV
- tested for linearity, afterpulse and spectral response
- delivered to Argentina in March 2011





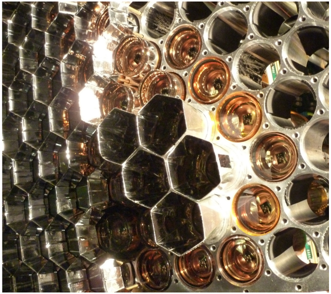
Winston Cones

To increase effective area gaps between PMTs have to be covered

Winston cone:

- geometry given by PMT radius and max. acceptance angel
- modification for transition of round to hexagonal
- since focal plane is on a sphere $\rightarrow$ difficult to produce

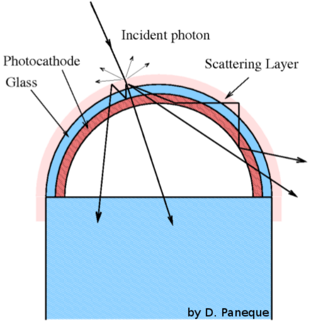
Test of KIT prototype at LosLeones

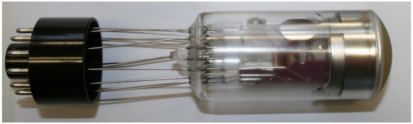


R9420-100 mod

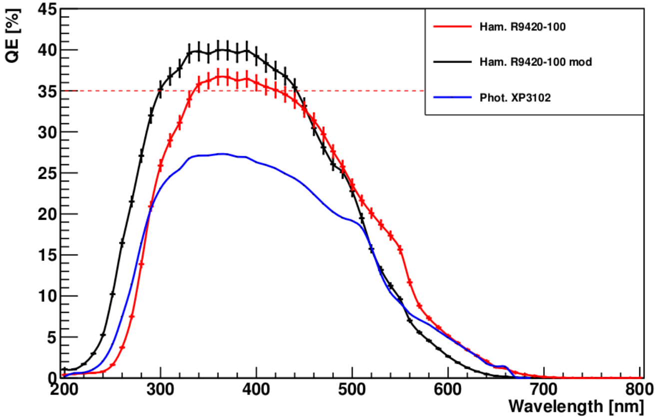
Further development of R9420-100 available and ongoing (coop. of Hamamatsu & CTA):

- 1.5" tube + SBA photocathode
- dynode structure from 1" PMT (R8619)
- frosted hemispherical window
  - + elongated way through cathode
  - + scattered photon can hit hemispherical cathode twice
  - + traped between two layers
  - – larger reflectivity than



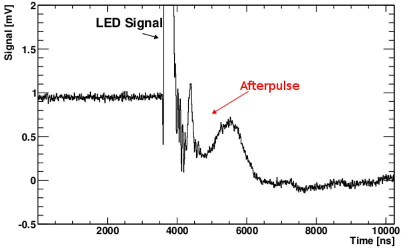


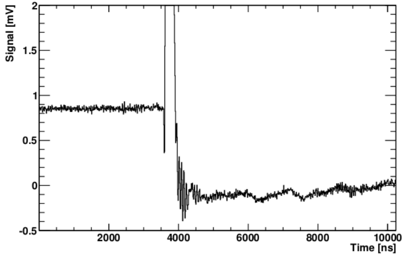
QE R9420-100 mod



- measurement in reference to calibrated photodiode
- single prototype: almost 40% QE

Afterpulse R9420-100 mod



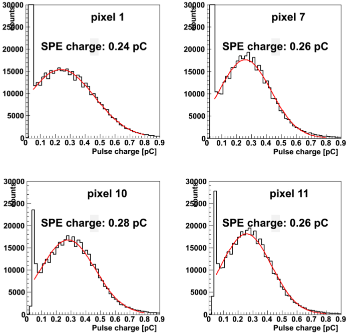


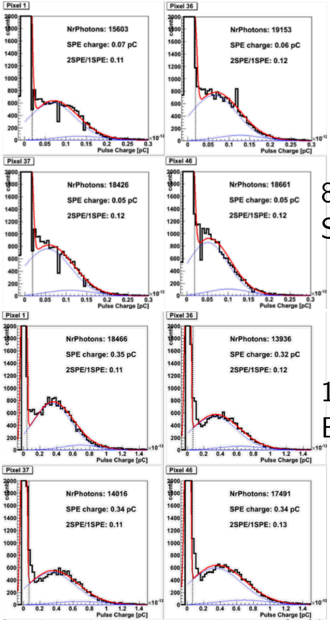
- reduced afterpulses due to smaller dynode structure
- singel prototype: almost no afterpulsing

Additional Measurements: MAPMTs

Further analysis of MAPMTs for different experiment/ new FD telescope design:

- single photon spectrum of 2" H8500 MAPMT compared to 1" R11265





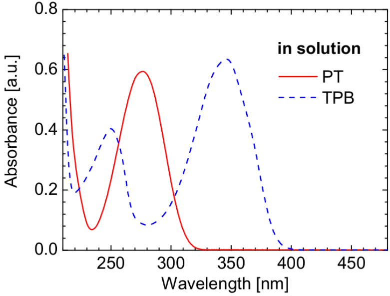
8stage SBA

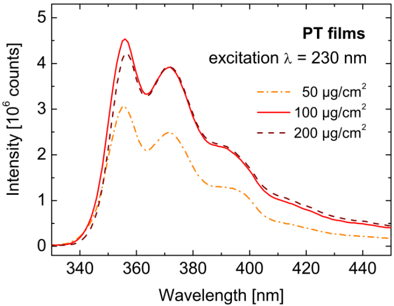
12stage BA

WLS

Enhance efficiency of RICH-detector with WLS p-terphenyl

- p-terphenyl dip-coating of PMTs (by Michael Dürr, HS Esslingen)
- absorption: $\sim 240\,\mathrm{nm}$ emission: $\sim 350\,\mathrm{nm}$
- gain in efficiency of 12% for specific mirrors and gas

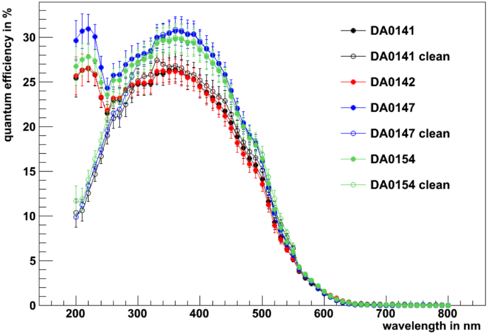




WLS

Enhance efficiency of RICH-detector with WLS p-terphenyl

- p-terphenyl dip-coating of PMTs (by Michael Dürr, HS Esslingen)
- absorption: $\sim 240\,\mathrm{nm}$ emission: $\sim 350\,\mathrm{nm}$
- gain in efficiency of 12% for specific mirrors and gas



Summary & Outlook

- new PMTs with higher QE available
- test setup for QE-scans build in Wuppertal
- R9420-100 ordered, benchmarked and delivered to Argentina
  $\rightarrow$ equip one camera
- further developments are ongoing (CTA & Hamamatsu)

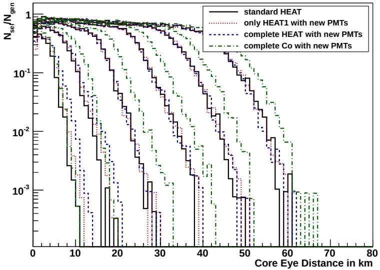
ToDo:

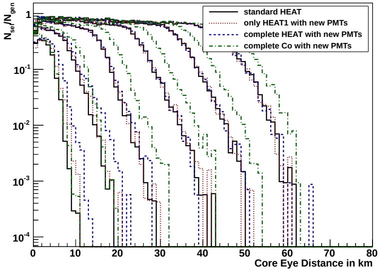
- Winston cones
- further tests of latest PMTs
- new design studies for future FD telescopes

BackUp Slides

Detector Simulation

Monte-Carlo sim. of proton and iron showers for energies from $1 \times 10^{17}\,\mathrm{eV}$ to $1 \times 10^{19.5}\,\mathrm{eV}$





Uniformity R9420-100 mod