THE MAGIC TELESCOPE
E. LORENZ, for the MAGIC COLLABORATION

17 mtr
MAGIC

* A NEW GENERATION IMAGING AIR CHERENKOV TELESCOPE

* USE OF NEW TECHNOLOGIES TO PAVE WAY TO LOWER THE THRESHOLD DOWN TO \( \approx 30 \text{ GEV (PHASE I)} \) AND \( 15 \text{ GEV (PHASE II)} \) TO ALLOW FOR RAPID RESPONSE IN CASE OF GRB ALERTS

* DEVELOPMENT OF COST CUTTING ELEMENTS AND PERFORMANCE IMPROVEMENT CONFIGURATIONS (AMC..)

* CONSTRUCTION OF A SINGLE TELESCOPE AND ONLY AFTER VALIDATION OF NEW TECHNOLOGIES: BUILD MULTIPLE TELESCOPE OBSERVATORY

* MAIN PHYSICS GOALS:
  - STUDY OF HIGH RED SHIFT AGNS UP TO \( z=2-3 \)
  - GRBS
  - PULSARS
  - STUDY OF FUNDAMENTAL PHYSICS QUESTIONS (DARK MATTER, QUANTUM GRAVITY…)
  - SNRS, BINARIES, UNIDENTIFIED EGRET SOURCES….
SOME KEY MAGIC PARAMETERS:

• MIRROR AREA 242 m²  \[ f/D = 1 \]  MIRROR Ø: 17 m  MIRROR PROFILE: PARABOLIC (ISOCHRONOUS)

• MAIN MIRROR COMPOSED OF 940 ELEMENTS,

• ALL ALUMINIUM SANDWICH UNITS, DIAMOND TURNED, LIGHTWEIGHT, HEATEABLE

• ACTIVE MIRROR CONTROL TO COUNTERACT SMALL DISH DEFORMATIONS

• 574 PIXEL CAMERA, 3.5° Ø, INNER PIXELS 0.1°Ø, OUTER PIXELS 0.2° Ø, SPECIAL LIGHT CATCHERS

• HEMISPHERICAL PMTS (ET 9116,9117, 6 STAGES) TREATED FOR ENHANCED QE (30-34% AT PEAK \( \lambda \))

• LOW LOSS, HIGH BW (> 250 MHz) SIGNAL TRANSMISSION BY OPTICAL FIBER SYSTEM

• THREE LEVEL TRIGGER (REJECTS ALREADY A FRACTION OF HADRONS ON TRIGGER LEVEL)

• TRIGGER AREA \( \approx \) 2° Ø, TRIGGER RATE 250-300 Hz (TECHNICAL LIMIT 1 KHz)

• SIGNAL DIGITISATION: DUAL RANGE FADC (\( \approx \) 58 dB DYN. RANGE), DIGITISATION FREQUENCY 300 MHz

• MAX ROTATION SPEED: 23(20) sec FOR 180° TURN -> FOR RAPID RESPONSE TO GRBS
SOME KEY MAGIC PARAMETERS II:

TRACKING PRECISION ≈ 0.02 (WITHOUT STARGUIDER CAMERA)
EXPECT TO REACH 0.005 WITH STAR GUIDER CAMERA

PSF: 0.03°
EXPECT TO REACH 0.02° FOR OPTIMISED AMC

CURRENT THRESHOLD: AROUND 50 GeV (TRIGGER AND ANALYSIS NOT OPTIMIZED) -> 30 GeV
->24 GEV FOR SPECIAL PULSAR TRIGGER

CURRENT SENSITIVITY: STILL ABOUT FACTOR 2-3 WORSE THAN PREDICTED (USE OF CLASSICAL IMAGE ANALYSIS NOT SO EFFICIENT < 150 GeV)

EXPECTED CRAB RATE (CLOSE TO CULMINATION) ≈ 1 Hz
(+ ≈ 1-2 HZ BG IN RELEVANT α REGION)
AFTER OPTIMISED SELECTION
THE MIRROR

COMPOSED OF 940 ELEMENT
ALL ALUMINIUM CONSTRUCTION
MANY DIFFERENT RADII (PARABOLIC PROFILE)

Mirrors quartz coated
THE ACTIVE MIRROR CONTROL COUNTERACTS SOME SMALL DEFORMATIONS OF MIRROR SUPPORT FRAME

EXAMPLE OF MIRROR FOCUSSED TO A LIGHT SOURCE 1000mtr AWAY

PSF 0.03° AFTER MANUAL ADJUSTMENT (0.02° POSSIBLE) WILL DEGRADE DURING RUNS IF NOT FREQUENTLY READJUSTED
FAST PM SIGNAL TRANSMISSION BY OPTICAL FIBER SYSTEM WORKING IN ANALOG MODE

PM, 6 DYNODES

PREAMP

VCSEL

OPTICAL FIBER 160 mtr

PIN PHOTODIODE

TO TRIGGER LOGIC

TO FADC

AMPL.

• VERY LOW FAILURE RATE AFTER ≈ 1 YEAR
• VERY LOW CROSSTALK, NO PICKUP
• LARGE DYNAMIC RANGE (>60 db)
• SOME NONLINEARITY
• SOME GAIN SHIFT AND MODE HOPPING
• NEEDED TO SELECT VCSELS

Input pulse ≈ 2.5 nsec
Output pulse at optical fiber system, 160mtr
Output pulse after RG 58C cable, 156 mtr
The camera

- Matrix of 577 PMTs
- Two sections:
  - Inner part: 0.1° PMTs
  - Outer part: 0.2° PMTs

Plate of Winston cones ⇒ Active camera area ~100%

INCREASE OF QE BY DIFFUSE LACQUER (LOADED WITH WLS)
MAGIC STATUS AND SOME ISSUES TO MENTION

* MAGIC INAUGURATION OCT. 10, 2004

* SINCE LATE WINTER: TIME USE: ≈50% OBSERVATIONS, ≈50% TELESCOPE STUDIES (CALIBRATIONS, DETERMINATION OF TELESCOPE PERFORMANCE, PARAMETER TUNING)

-> AN ULTRALARGE TELESCOPE REQUIRES MANY MORE ADJUSTMENTS AND TUNING COMPARED TO A 3-5 mtr CLASS TELESCOPE)

* COMPLETE THE COMMISSIONING IN OCTOBER FOR BASIC MODE OF OPERATION

* TYPICAL EFFICIENCY FOR DATA TAKING: CURRENTLY 70 (50-85)%; TRIGGER RATE ≈ 250-300 hz FOR ≈ 50 GEV THRESHOLD (WITHOUT LEVEL 2 TRIGGER PROCESSOR)

* FOR THE TIME BEING: WE USE A CONSERVATIVE APPROACH TO TRIGGER DISCRIMINATOR THRESHOLD SETTING AND ANALYSIS

* THRESHOLD (CONSERVATIVE THRESHOLD SETTING) ≈ 50 GEV (STILL LARGE SYSTEMATIC UNCERTAINTIES). IT WILL TAKE US ABOUT 1 MORE YEAR TO REACH 30 GEV THRESHOLD

* THE STANDARD IMAGE ANALYSIS DEGRADES RAPIDLY WHEN GOING DOWN IN ENERGY

* THE CURRENT SENSITIVITY IS STILL ≈2-3 TIMES WORSE THAN PREDICTED BUT WE HAVE NOT YET EXPLORED ALL ‘TOOLS’ FOR γ/hadron REJECTION

* MUONS ARE NOT THE MAIN PROBLEM (TRIGGER RATE HIGH, BUT REJECTION HIGH)

* THE MAIN BACKGROUND: FROM SINGLE ELECTROMAGNETIC SHOWER FROM HADRONIC REACTIONS: p + Nucleon -> p + n + charged mesons +p⁰ -> gg -> em shower

<--no Cherenkov light-->         C-light
difficult to discriminate,’ stereo’ does not help much
MUON ARC IMAGES

THE MAGIC TRIGGER SUPPRESSES FULL MUON RINGS (EX. CLOSE TO THRESHOLD)
LIGHT YIELD FROM MUON ARCS AGREES WITHIN 10% WITH OTHER METHODS (F-FACTOR ANALYSIS OF LIGHT PULSER SIGNAL)
FROM MC SIMULATION: RESIDUAL MUON BG ONLY A FRACTION OF HADRONIC BG.
IMPORTANT: MUONS DO NOT PEAK AT SMALL ALPHA AND DO NOT FAKE A SOURCE
EXAMPLE: MUON RING AFTER NEW FOCUSSING
EXAMPLE: CRAB OBSERVATION DURING COMMISSIONING (FEB 04)
PHASE WITH NONOPTIMISED CUTS. \( E_{\text{thr}} \cdot (\text{size } 2000) > 70 \text{ GeV} \cdot (\cos \theta)^{2.7} \)

1491k On, 1538k Off events
zenith angle 25-51 deg
size > 2000
766 excess above 1369 bkg (13 sigma)
140 min => 5.5 / min
Mkn421 April ’04, using old cuts of HEGRA, not optimized for MAGIC

Analysis in slices of the parameter size; in (red): most probable energy

- 800 - 1200 photons (75 GeV)
- 1200 - 2000 photons (102 GeV)
- 2000 - 4000 photons (160 GeV)

Very preliminary
TELESCOPE FOCUSED FOR LARGE ZENITH ANGLE NON-OPTIMIZED CUTS

\[ E_{\text{thr}} \text{ (size 1000)} \approx 35 \text{ GeV/} (\cos \Theta)^{2.7} \]

-> FOR SMALL ZENITH ANGLES EXPECT \( \approx 1 \text{ GAMMA/SEC} \)
NEXT STEPS TOWARDS A MULTITELESCOPE CHEREKOV OBSERVATORY (ECO)

CONSTRUCTION OF MAGIC II

* BASICALLY A COPY OF MAGIC I WITH SOME IMPROVEMENTS
  - 1x1m² ALL ALUMINIUM SANDWICH MIRRORS
  - CONTINUOUS ACTIVE MIRROR CONTROL IN IR (NOT INTERFERING WITH CAMERA PMTS)
  - MORE COMPACT OPTICAL ANALOG SIGNAL TRANSMISSION -> SIMPLER CAMERA LAYOUT
  - 2 GHZ FADCS (MULTIPLEXED SYSTEM (TEST OK, FUNDS JUST RECEIVED),
    SWITCHED CAPACITOR SYSTEM OF PSI
  - DETAILED PHOTON ARRIVAL ANALYSIS (γ/μ, γ/h SEPARATION IMP.), LOW POWER, BETTER NSB REJECTION, MORE COMPACT ALSO LATER FOR MAGIC I
  - LATER A HIGH QE CAMERA (NO INTERRUPTION OF MAGIC I OBSERVATION PROGRAM)

* STATUS, PROVISIONAL TIME SCHEDULE
  - SITE AGREEMENT PROCEDURE COMPLETED
  - HARDWARE PRODUCTION ONGOING -> FIRST PARTS ALREADY ON LA PALMA
  - TELESCOPE MECHANICS ALREADY IN PRODUCTION AT COMPANY MERO
  - CONSTRUCTION OF FOUNDATION : SPRING 2005
  - DATE OF COMPLETION 2006 (TO BE READY WHEN GLAST IS LAUNCHED)

* MODE OF OPERATION
  A) AS STAND-ALONE TELESCOPE TO OBSERVE OTHER SOURCES IN PARALLEL TO MAGIC I
  B) STEREO OPERATION WITH MAGIC I FOR SPECIFIC STUDIES
     PROBLEM AT LOW ENERGIES DUE TO EARTH MAGNETIC FIELD
CAMERA IMPROVEMENTS FOR MAGIC I (PHASE II) AND MAGIC II

* **USE OF HIGH QE PHOTOSENSORS**

* **LARGE POTENTIAL TO IMPROVE TELESCOPE PERFORMANCE**
  - **LOWER THRESHOLD**, BETTER $\gamma/h$ SEPARATION AT HIGHER ENERGIES
  - SLIGHTLY IMPROVED ENERGY RESOLUTION

* **TWO DEVELOPMENT LINES ARE FOLLOWED:**
  A) **HIGH QE HYBRID PMTS** (GaAsP CATHODES+ ELECTRON BOMBARDED AVALANCHE DIODES, QE CLOSE TO 50%, WIDE SPECTRAL RANGE, VERY FAST PULSES)
  B) **SiPMs** (MULTICELL GEIGER-MODE APDs, QE HIGHER THAN CLASSICAL PMTS, ULTRAFAST, VERY ROBUST (-> NO DAMAGE WHEN EXPOSED TO DAYLIGHT UNDER FULL BIAS), LOW OPERATION VOLTAGE, NOISY -> MODEST COOLING)

* DEVELOPMENTS VERY DEMANDING AND COSTLY (HIGH QE HYBRID PMTS MORE ADVANCED, ALREADY GOOD PROTOTYPES)

* INITIAL OPERATION WILL BE COMPLEX
IN 2007 (WHEN GLAST IS OPERATIONAL)

2 MAGIC TELESCOPES OPERATIONAL WITH IMPROVED PERFORMANCE

EXPECT THAT WE REACH PREDICTED SENSITIVITY (ALREADY IN 2005)

VERY LIKELY ONE TELESCOPE WITH HIGH QE CAMERA (\( \Rightarrow \) THRESHOLD \( \approx 15 \) GeV ?)

OPERATION DURING MOON SHINE (\(< 70\%\) FULLY UNDER CONTROL
(30-50\% HIGHER THRESHOLD)
\( \Rightarrow \) EXPECT 1500-1800 h OBSERVATION TIME /YEAR

SOME DIFFERENCES COMPARED TO GLAST
ONLY OBSERVING NORTHERN SKY
LOWER DUTY CYCLE, ONLY NIGHTS, OFFSET TO VERITAS 6 H)
POORER ENERGY RESOLUTION BELOW \( \approx 150\text{GeV} \)
MUCH SMALLER FOV \( \Rightarrow \) 2-5 msterad (x2 telescopes)
BETTER angular resolution (0.05° ABOVE 150 GeV)
MUCH LARGER COLLECTION AREA \( 10^4-10^5 \) m²
\( \Rightarrow \) CAN DETECT FAST FLARES
\( \Rightarrow \) CAN MEASURE SPECTRA OVER WIDER ENERGY RANGE (AGNS, SPECTRAL HARDENING DURING FLARES…)
Sensitivity of γ-ray Experiments

MAGIC CURVE FOR HIGH QE PHOTO SENSORS

CURRENT MAGIC SENSITIVITY WITH NONOPTIMIZED CUTS
LONG-TERM PLAN TO ENLARGE THE EUROPEAN CHERENKOV OBSERVATORY BY AN ULTRALARGE IACT OR A WIDEANGLE AIR CHERENKOV TELESCOPE

* **PLAN FOR A 1000 m² IACT: ECO 1000**

- Main aim to lower the threshold to below 10 GeV
- Technology: extrapolation of the MAGIC concept
- Camera with high QE photo sensors
- Stand-alone or combined observation with MAGIC I.II
- Main problems: A) Earth magnetic field blows up showers
  B) Fluctuations in shower development increase
    - Worse angular, energy resolution, worse $\gamma/h$ separation
  C) Cosmic electron BG, $p + X \rightarrow \ldots +$ energetic $\pi^0 \rightarrow \gamma\gamma$
- On the other hand no more BG from low energy hadronic CRs

Price estimate: 12-20 M€, construction time estimate: $\approx 3$ y, developments $\approx 2-4$ y

* **WIDE ANGLE IACT WITH A THRESHOLD < 100GeV, FOV 15-20°**

- Limited all sky monitoring
- Very challenging design of the optics
- High QE photo sensors (multi-pixel sensors) a must
- Extensive development studies needed

* **DECISIONS DEPEND VERY MUCH ON THE PROGRESS IN THE FIELD OF GROUND-BASED GAMMA-ASTRONOMY**
STUDY OF A 1000 m² CHERENKOV TELESCOPE

ECO - 1000

MAGIC - Teleskop

34 m

17 m
SUMMARY

* MAGIC (PHASE I) COMPLETED, NOW RUNNING \( \approx 50\% \) OF TIME ON PHYSICS
  WILL REACH 80\% ‘OBSERVATION TIME’ END OF YEAR

* CURRENT THRESHOLD AROUND 50 GEV (LARGE UNCERTAINTIES)
  WILL REACH 30 GEV NOT BEFORE A YEAR FROM NOW

* NEW TECHNOLOGIES WORKING (ONLY THE USUAL STARTUP PROBLEMS)

* RUN-IN OF THE ULTRALARGE TELESCOPE MORE COMPLEX THAN ANTICIPATED

* MAGIC II: CONSTRUCTION HAS BEEN STARTED, READY 2006 (GLAST LAUNCH)

* LONGTERM ACTIVITY: HIGH QE CAMERA (THRESHOLD LOWERED BY \( \approx 2 \))

* LONGTERM VISION/PLANS: ADD ECO 1000 IACT (THRESHOLD: 5-10 GeV)
  ADD WIDEANGLE IACT (TECHNICALLY DEMANDING)
QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.
Zur Anzeige wird der QuickTime™ Dekompressor “Foto - JPEG” benötigt.

Cross section of a hybrid photomultiplier with avalanche diod

QUANTUM EFFICIENCY OF GaAsP CATHODES OF DIFFERENT DEVELOPMENT STEPS

Fig. 2: Photocathode Sensitivity (Quantum Efficiency)

Quantum Efficiency [

Wave Length [nm]

New-type
0 kV-type

Zur Anzeige wird der QuickTime™ Dekompressor “Foto - JPEG” benötigt.
Silicon photomultiplier (SiPM)

SiPM main features:
- Sensitive size 1x1 mm² on chip 1.5x1.5 mm²
- Gain 2x10⁶
- $U_{bias}$ ~ 50 V
- Recovery time ~ 100 ns/pixel
- Number of pixels: 576
- Nuclear counter effect: negligible (due to Geiger mode)
- Insensitive to magnetic field
- Dynamic range ~ 10⁵/mm²

For further details see:
«Advanced study of SiPM»
http://www.slac.stanford.edu/pubs/icfa/fall01.html

Single photoelectron (single pixel) spectra

SiPM:
- excellent single photoelectron resolution
- low ENC expected

More about pixel signal resolution:
tens of photoelectrons

SiPM consists of a large number of pixel photoelectron counters with binary readout for each pixel, working as analogue device
- signal uniformity from pixel to pixel is quite good