Using UV-pass filters for bright Moon observations with MAGIC

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Outline

The MAGIC Telescopes

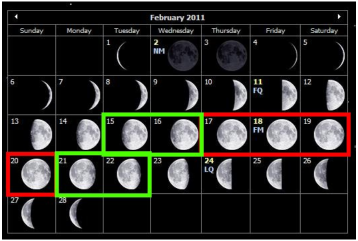
MAGIC: Major Atmospheric Gamma-ray Imaging Cherenkov
At *Roque de los Muchachos* Observatory, La Palma ($28.8°N$, $17.9°W$, 2200 m a.s.l)

- Two 17 m diameter mirrors
- Focus the light in a camera with 1039 PMTs
- FOV: $\sim 3.5°$
- Angular resolution $\lesssim 0.07°$ above 200 GeV
- Designed to observe VHE gamma-rays ($\gtrsim 50$ GeV)
- Use the Atmosphere as a calorimeter

Why filters?

1 Extend the duty cycle

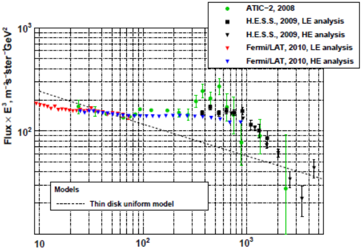
- MAGIC can work only up to a certain brightness
- Not operated on the 3-4 nights around Full Moon (FM period)
- Operation severely limited in the 2 nights before and after FM period

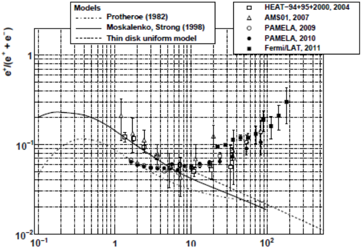


2 The Moon shadow project

The MAGIC Moon Shadow Project

GOAL: Observe the shadowing of CR e^- by the Moon



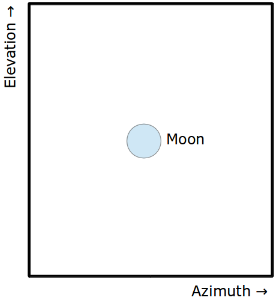


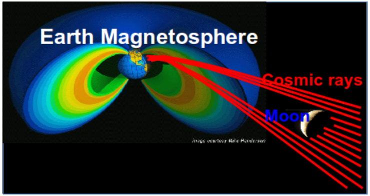
All-electron spectrum $(e^- + e^+)$ on the left and positron fraction $(e^+/(e^- + e^+))$ on the right. Data are from H.E.S.S., ATIC, PAMELA and Fermi-LAT (Figure from A. Panov, 2013).

Challenge: Measure the electron spectrum at 0.3-1 TeV to help solving the anomaly

Observation Strategy: The Moon Shadow Project

- The Magnetosphere deviates charged particles
- The Moon blocks a fraction of the incoming CRs





- Deviation depends on q, E
- There is a defect on the electron flux because of the Moon! (Moon Shadow)

GOAL

Detect the electron Moon Shadow

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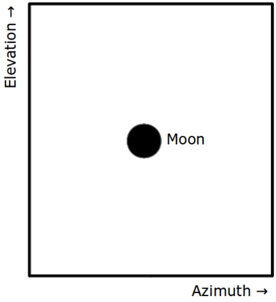

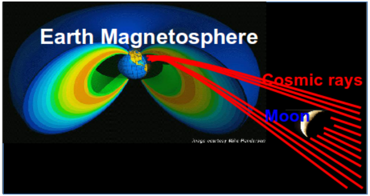

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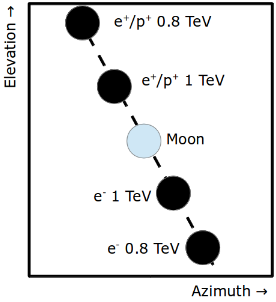

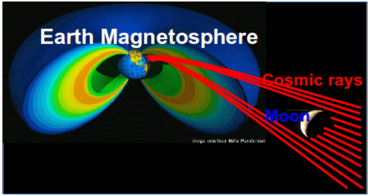

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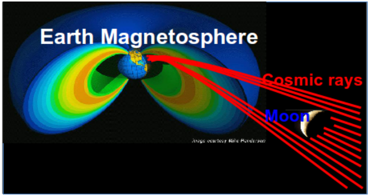

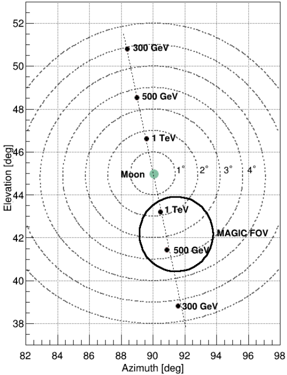

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GOAL

Detect the electron Moon Shadow

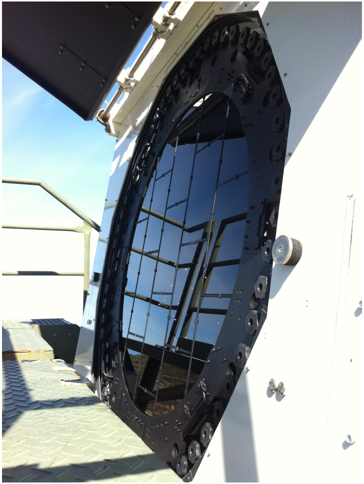
A timing problem...

MAGIC not designed to work with high background light

- Moon phase should be $< 50\%$
- Moon $Zd < 50^{\circ}$
- Only ~ 15 hr available per year

And more than 200 hs might be needed to detect the e^{-} shadow...

Solution: Installing UV filters



- Inexpensive filter tiles of 20×30 cm^2
- Outer Al ring, screwed to the camera
- Steel 6×6 mm^2 section ribs between filter tiles
- Plastic pieces to fix filters to the ribs
- Space between filters and ribs sealed with silicon
- Fast and easy mounting in the cameras

Solution: Installing UV filters

- Since October we have UV filters in both telescopes
- Crab observations were taken to characterize the performance of the telescopes when the filters are set
- First Moon Shadow observations with filters were taken
- Special filters-adapted Monte Carlo simulations are being produced to analyse the data taken

General features

- Measured Cherenkov light transmission: $\sim 45\%$
- Estimated Moonlight transmission: $\sim 20\%$
- We are able to point at 5° from the Moon during Full Moon.
- Even closer with lower Moon phases

$\Rightarrow$ Between 100 and 200 extra hours per year **could** be gained for the Moon Shadow project with the use of UV filters

UV filters performance

But are all those hours really useful?

Energy threshold and sensitivity might strongly depend on background light intensity.

Reference: No moonlight, No filters, low Zenith

- Energy threshold : ~ 70 GeV
- Sensitivity: $\sim 0.66\%$ C.U.

→ During full Moon the sky can be 200 times brighter than this!

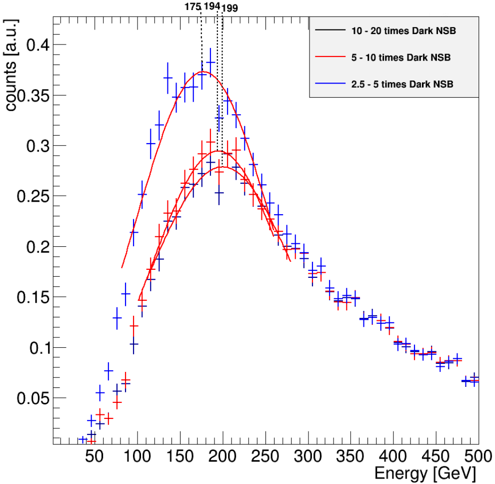
⇒ Filters performance must be characterized

- Crab observations with filters
- Monte Carlo simulations

Preliminary performance

Energy threshold

Energy threshold inferred from MC simulations, for events that went through the image cleaning and for a source with and assumed spectral index of -2.6.



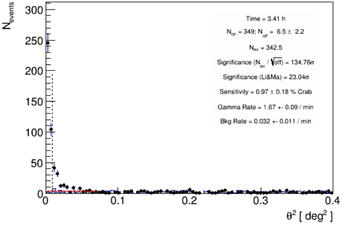
- Energy threshold from ~ 170 GeV to ~ 200 GeV in the three ranges obtained.

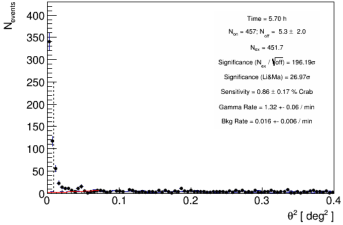
- Still to be done for higher NSBs

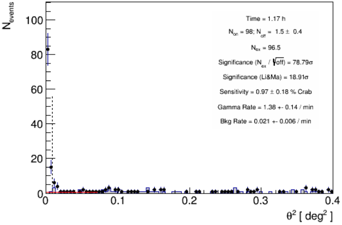
Reference → Dark NSB: No filters, low Zenith, no moonlight. Energy threshold: ~ 70 GeV

Sensitivity (from Crab observations)

θ^2 plots for Crab observations: Sensitivity $\sim 0.9\%$ C.U.
Reference $\rightarrow$ Dark NSB: No filters, low Zenith, no moonlight. Sensitivity: $\sim 0.66\%$ C.U.







- **Upper left.** Darkest situation: from 2.5 to 5 times the dark NSB
- **Lower left.** from 5 to 10 times the dark NSB
- **Upper right.** from 10 to 20 times the dark NSB

Highlights

- Filters installed, tested and operational
- Observations with filters are feasible almost in any position of the sky, every night!
  → Including pointing at 5° from the Moon during Full Moon
- With the filters we can observe sources in situations otherwise telescopes would not be operational
  → Energy threshold $\sim 170 - 200$ GeV
  → Energy threshold $\sim 0.9\%$ C.U.
  → Duty cycle significantly boosted

⇒ Performance known for almost any 'non Moon Shadow' source!

New time slots available!

As the duty cycle of MAGIC increases thanks to the UV filters, a new window of opportunities arises for the observation of other sources

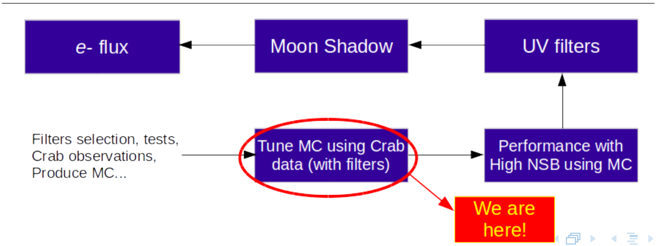
What about Moon Shadow?

During Full Moon and pointing at 5° from the Moon the NSB can be up to 10 times brighter than what has been analysed.

Next Steps:

- Produce MC with higher NSBs to evaluate the performance in brighter conditions
- Evaluate when Moon Shadow observations are meaningful
- Re-evaluate the feasibility of this project

Roadmap



Enjoy Pizza!

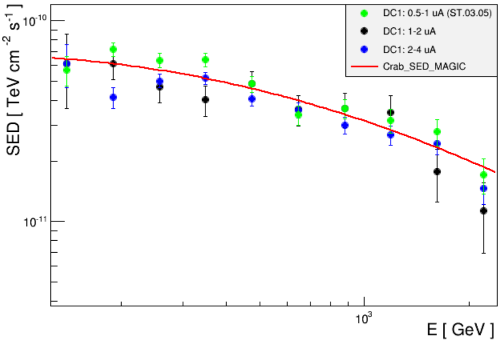
“La buena pizza necesita tiempo. Su paladar agradecerá la espera”

Pizzería ’El Cuartito’, Buenos Aires.

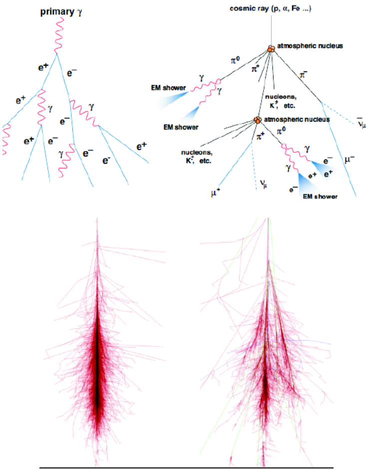
Backup

Flute output for three different NSB ranges:

- DC1: 0.5 - 1 μA (ST.03.05) $\Rightarrow$ 2.5 - 5 times Dark NSB
- DC1: 1 - 2 μA (ST.03.06) $\Rightarrow$ 5 - 10 times Dark NSB
- DC1: 2 - 4 μA (ST.03.06) $\Rightarrow$ 10 - 20 times Dark NSB



Detecting CR e^-



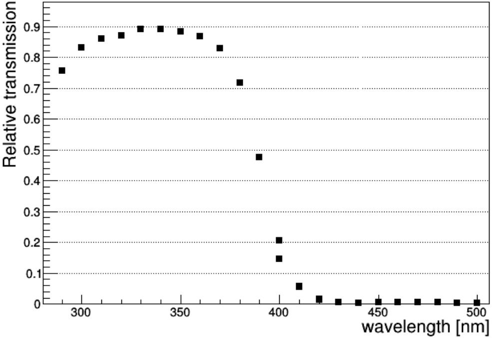
- CR interact with the atmosphere producing Extensive Atmospheric Showers (EAS). Height of first interaction $\sim 30km$
- Particles produced might emit Cherenkov light
- γ-ray and e^-/e^+ produce similar showers

Background discrimination

- Shower development is different (and so are the images recorded)
- Hadronness (h): A parameter calculated using a multivariate event classification algorithm (*Random Forest*)
  $h \to 0$ γ/e^- like shower
  $h \to 1$ hadron like shower

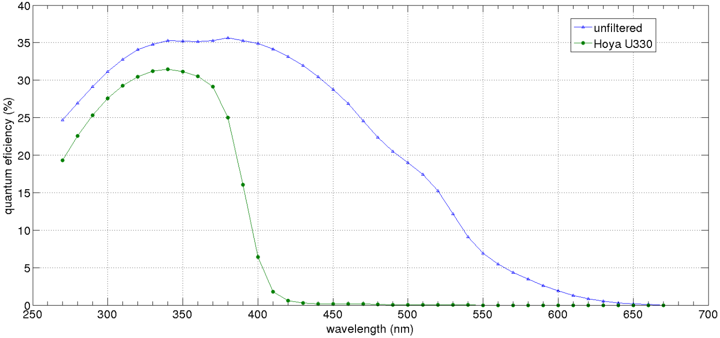
Filter transmission

Filter transmission measured at IFAE



Filter transmission

Quantum efficiency of a pixel before and after applying a filter



Cherenkov light and NSB spectrum

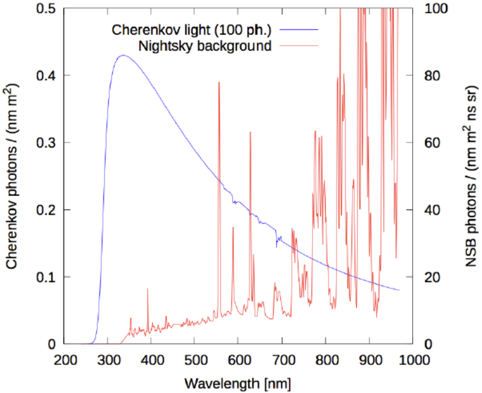


Figure 1: Cherenkov light spectrum is shown for 500 GeV γ-ray showers at 20° zenith angle and detected at 2000 m above sea level. The Cherenkov light is scaled to 100 photons/m2 in the wavelength range from 300-600 nm, a value typical for γ-ray showers of about 500 GeV at small core distances.