On the Variability of the VHE γ-ray Emission From the Crab Nebula and Pulsar

Wojciech Idec[1]

[1]Department of Astrophysics, University of Łódź, Poland

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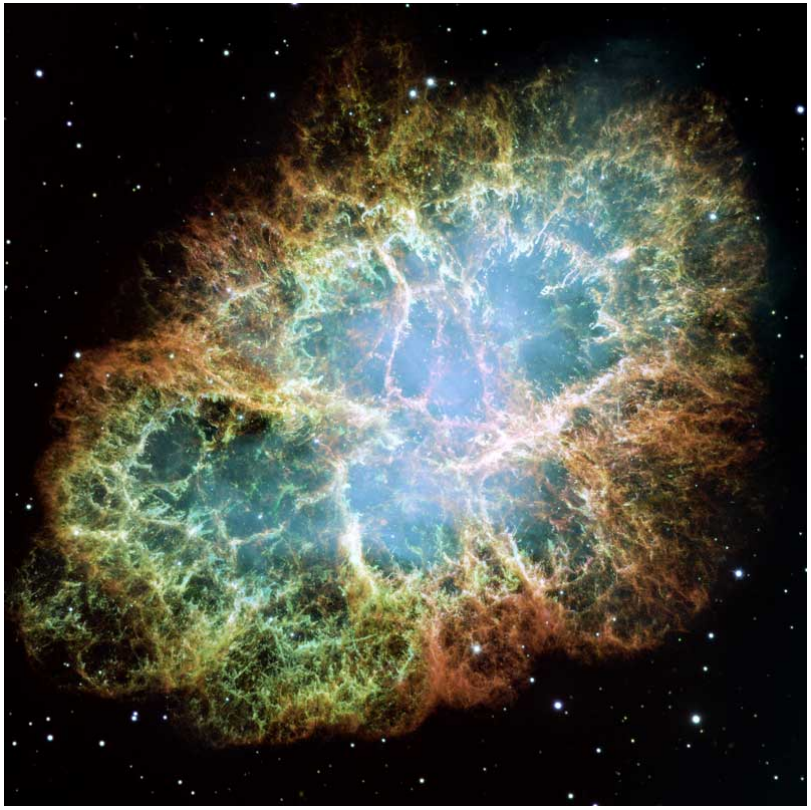
Crab Nebula



Outline

1. Day-scale variability of the Crab Nebula
   - A theoretical explanation of observed *gamma*-ray flares
   - Numerical calculations of the synchrotron and IC spectra of γ-rays emited by the Nebula
2. Searching for the Crab Pulsar month-scale variability with MAGIC telescopes

Motivation

- Crab Nebula as a γ-ray standard candle.
- 2-component (synchrotron and IC) γ-ray spectrum.
- Hypotetical flickering of the spectral tails due to the nonstationary acceleration of leptons at the pulsar wind shock.
- Observed flaring in GeV energies (e.g. Fermi-LAT) – higher flux, different spectral index.

Model

Possible scenarios for variable emission from Crab Nebula

1. Small region of the wind shock is excited
   - Extension of wisps biger than variability timescale $\longrightarrow$ reject
2. Emission region is moving relativisticaly towards the observer
   - Pulsar wind magnetic field reconnection may occur.
   - Good conditions for particle acceleration $\longrightarrow$ consider

See also:

- *Komissarov, Lyutikov, 2011, MNRAS, 414, 2017*
- *Cerutti, Uzdensky, Begelman, 2012, ApJ, 746, 148*

Schema of the Crab Nebula

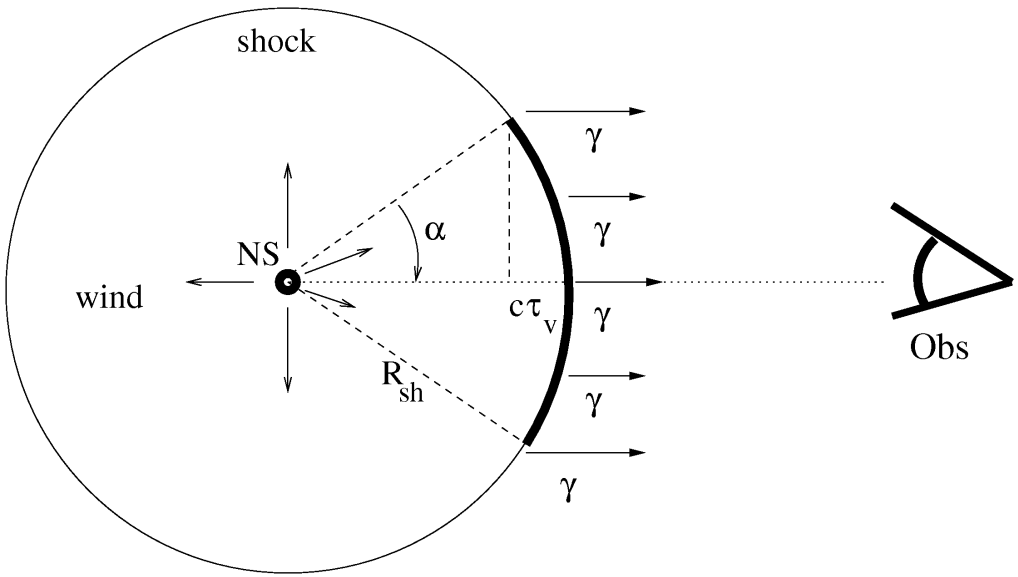
Shock moving relativisticaly outwards with γ_{sh}.

Observed emission region limited by α:

$$\sin\alpha \approx \sqrt{(c\tau_\nu/R_{sh})^2 + 2(c\tau_\nu/R_{sh})} \quad (1)$$

Lorentz factor connected to α:

$$\gamma_{sh} \sim 1/\alpha \approx \sqrt{R_{sh}/(2c\tau_\nu)} \quad (2)$$



Calculations of the synchrotron and IC spectra

Spectra calculated using formulae from *Blumenthal, Gould, 1970, Rev. Mod. Phys., 42, 237*

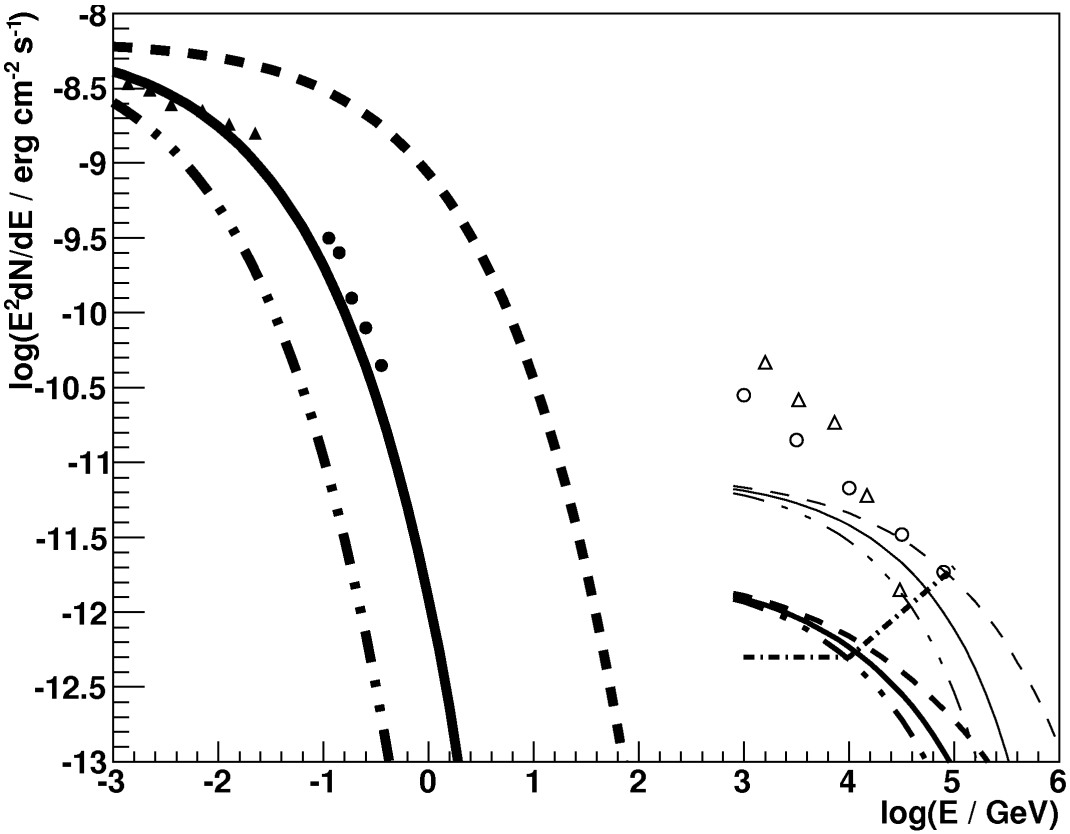
- Synchrotron spectra
- Inverse Compton spectra

In Inverse Compton spectra only well-definned soft photon targets taken into account:

- microwave background radiation (MBR)
- synchrotron radiation from the nebula

Calculations of the synchrotron and IC spectra – results

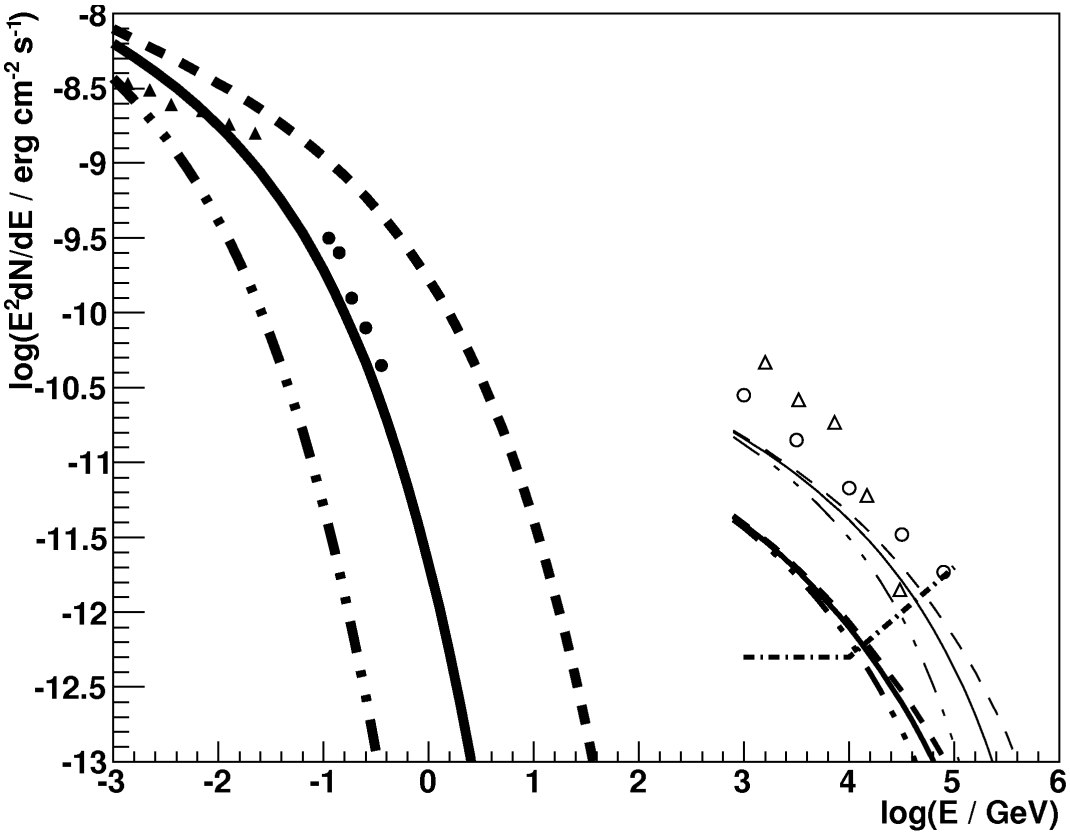
- $B_{sh} = 2 \times 10^{-3} G$
- $\beta = 3$
- $\gamma_e^q = 7 \times 10^8$
- $\gamma_e^f = 3 \times 10^9$
- $\gamma_e^{sq} = 2.3 \times 10^8$



β – index of electron spectrum

Calculations of the synchrotron and IC spectra – results

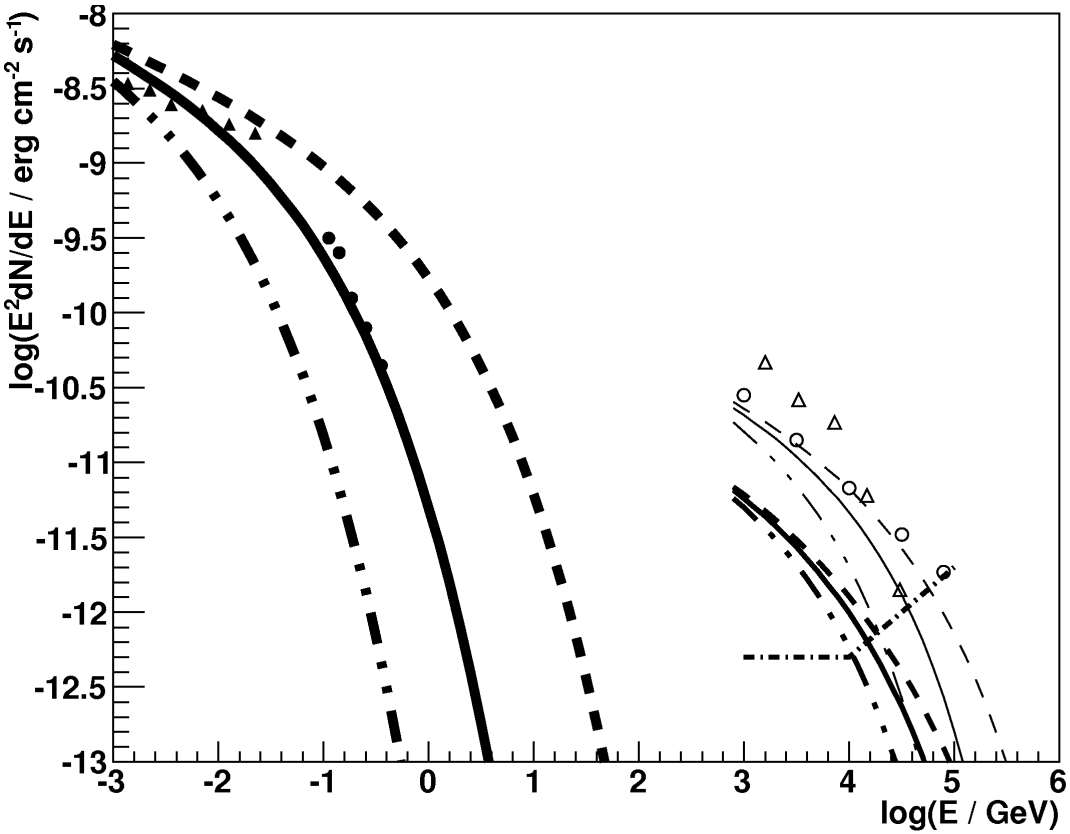
- $B_{sh} = 2 \times 10^{-3} G$
- $\beta = 3.6$
- $\gamma_e^q = 7 \times 10^8$
- $\gamma_e^f = 3 \times 10^9$
- $\gamma_e^{sq} = 2.3 \times 10^8$



β – index of electron spectrum

Calculations of the synchrotron and IC spectra – results

- $B_{sh} = 4 \times 10^{-2} G$
- $\beta = 3.6$
- $\gamma_e^q = 2 \times 10^8$
- $\gamma_e^f = 8 \times 10^8$
- $\gamma_e^{sq} = 7 \times 10^7$



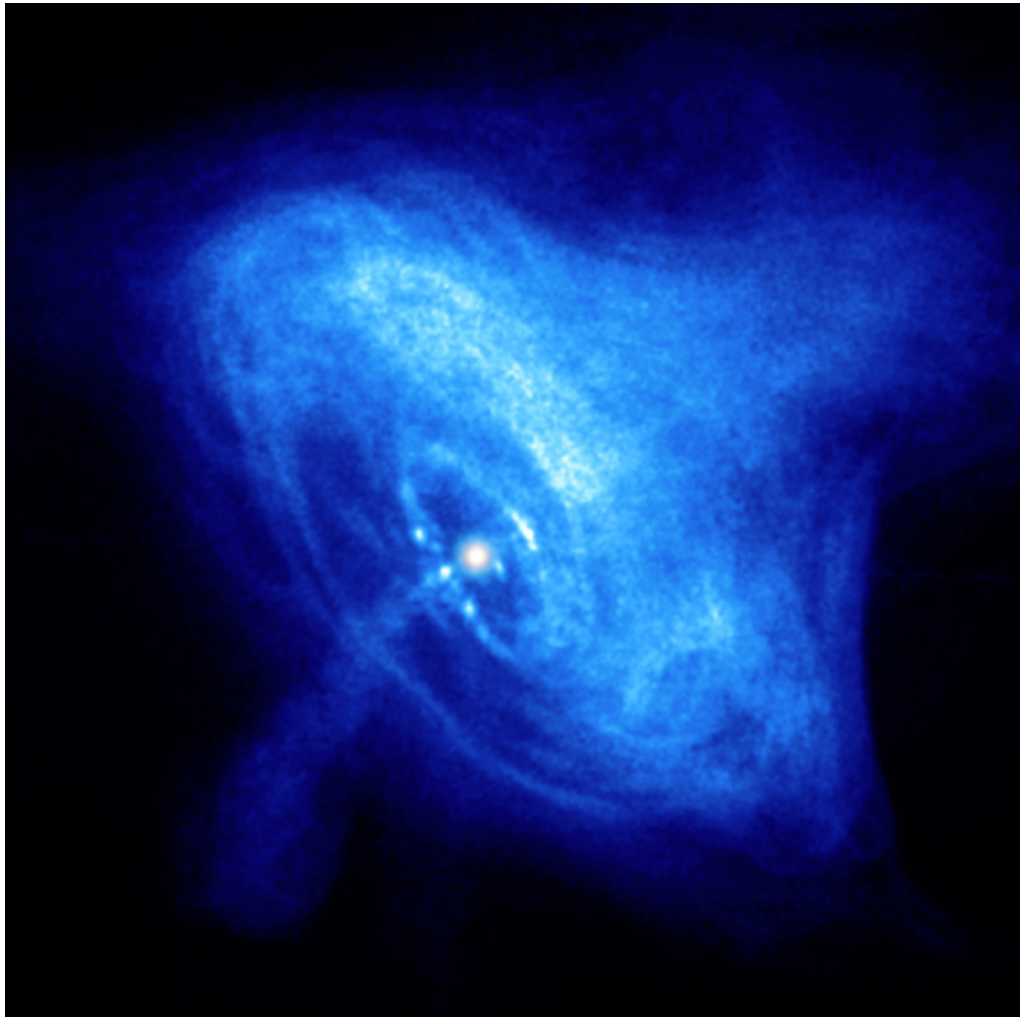
β – index of electron spectrum

Conclusions I

1. Day-scale variable emission from the Crab Nebula can be explained by moving emission region.
2. γ-ray emission may come from the region just behind the shock in the pulsar wind.
3. Electrons may be accelerated during the reconnection of magnetic field and emit HE synchrotron radiation, as well as IC VHE γ-rays by scattering of the MBR and LE synchrotron radiation.
4. Results may be verified by future CTA experiment.
5. Numerical calculations for the newest observed flare ongoing.
6. More to be found in *W. Bednarek, W. Idec, 2011, MNRAS, 414, 2229* (+ references)

Searching for the Crab Pulsar variability

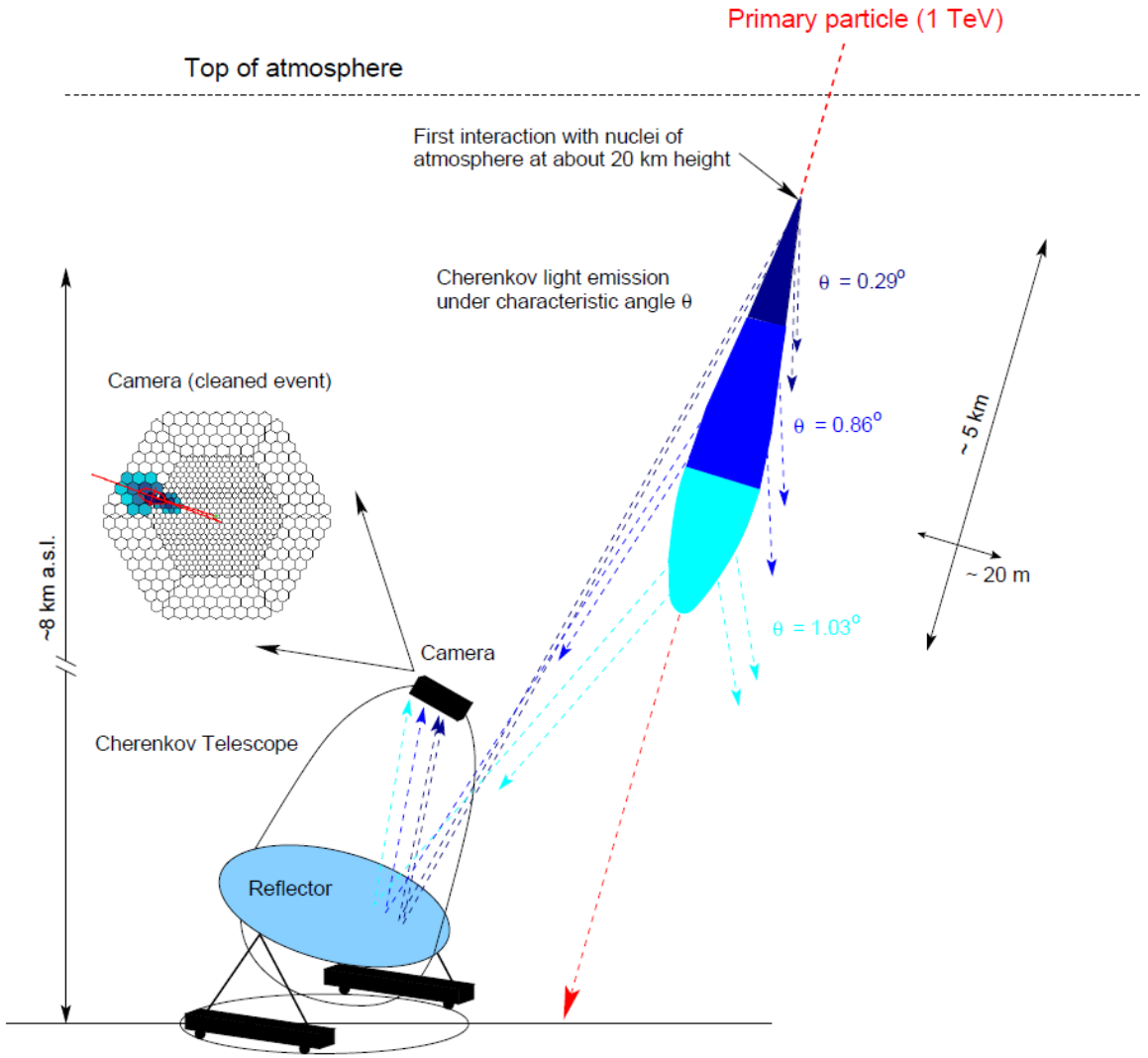
Motivation – Thomas Schweizer's (MPI für Physik, Munich) idea



Searching for the Crab Pulsar variability

Introduction – IACT technique

1. γ-rays: HE, VHE, (PeV)
2. Absorbed by atmosphere
3. El-mag cascades
4. Observed from the ground



Searching for the Crab Pulsar variability

Idea

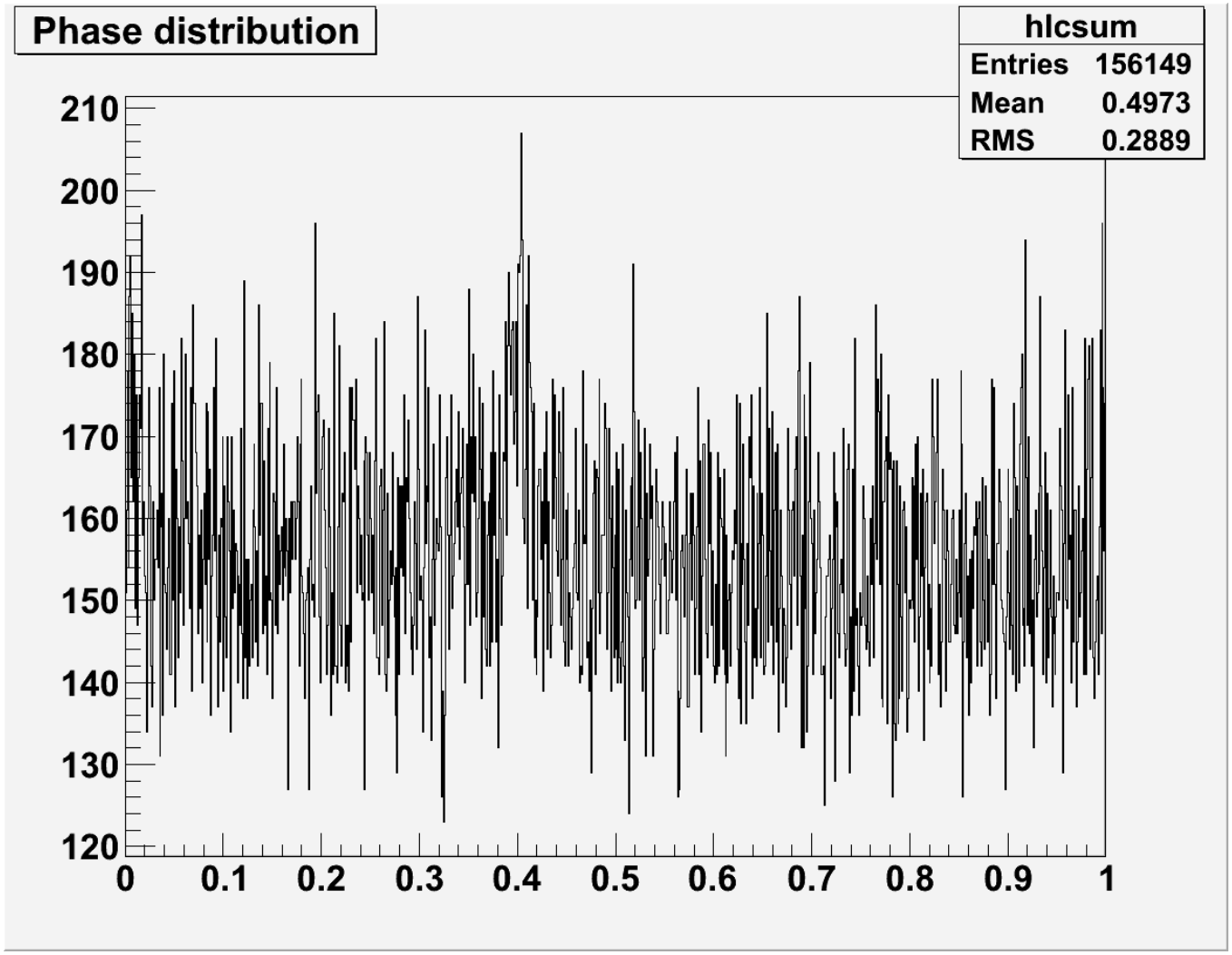
Produce a lightcurve of Crab Pulsar (ratio of the signal Pulsar/Nebula).

Initial assumptions

1. Using preprocessed data files
2. Using stereo data 10.2009 – 02.2011
3. Data grouped into 1-month bins

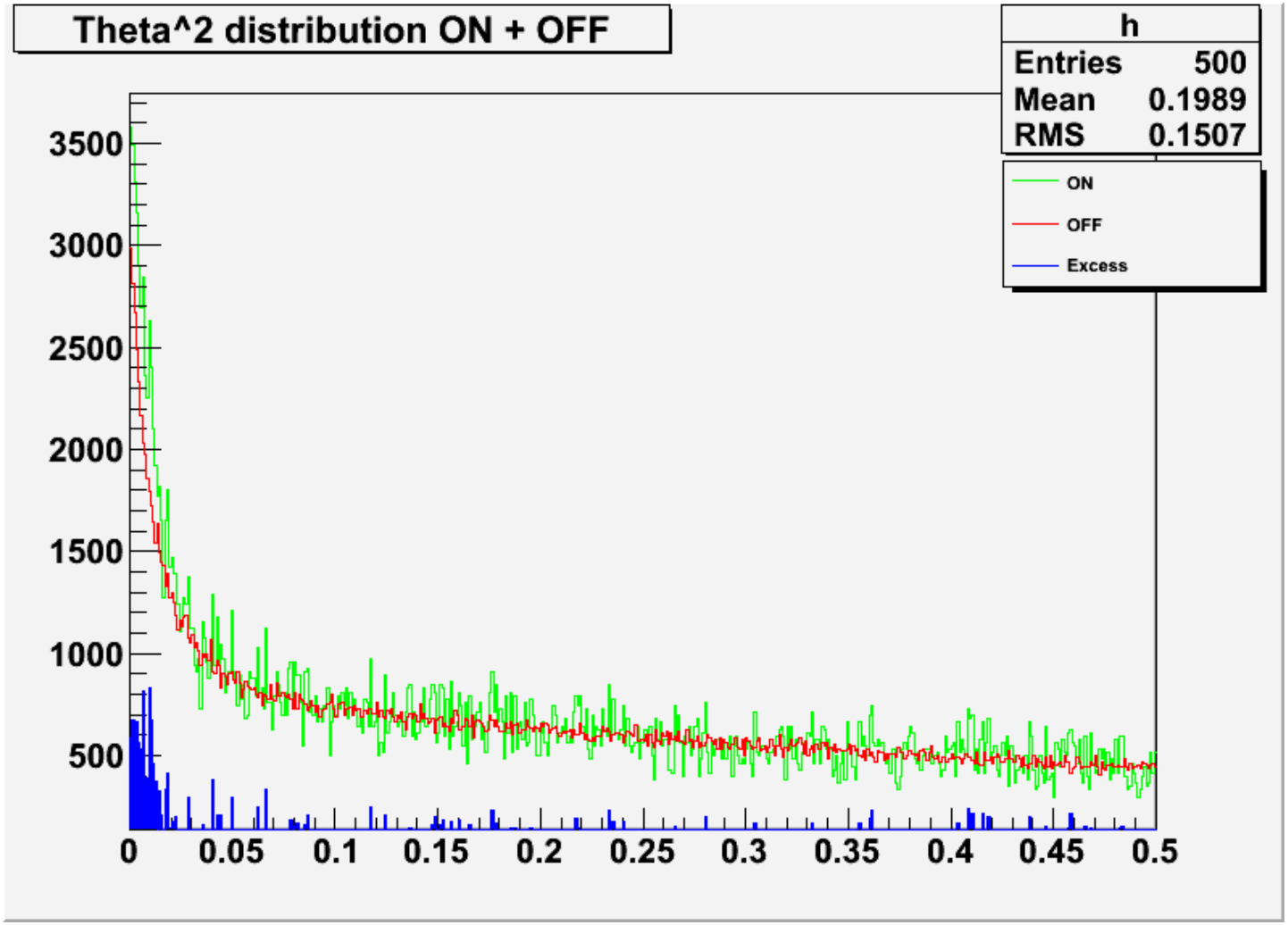
Searching for the Crab Pulsar variability

Determine the best ON and OFF phase regions



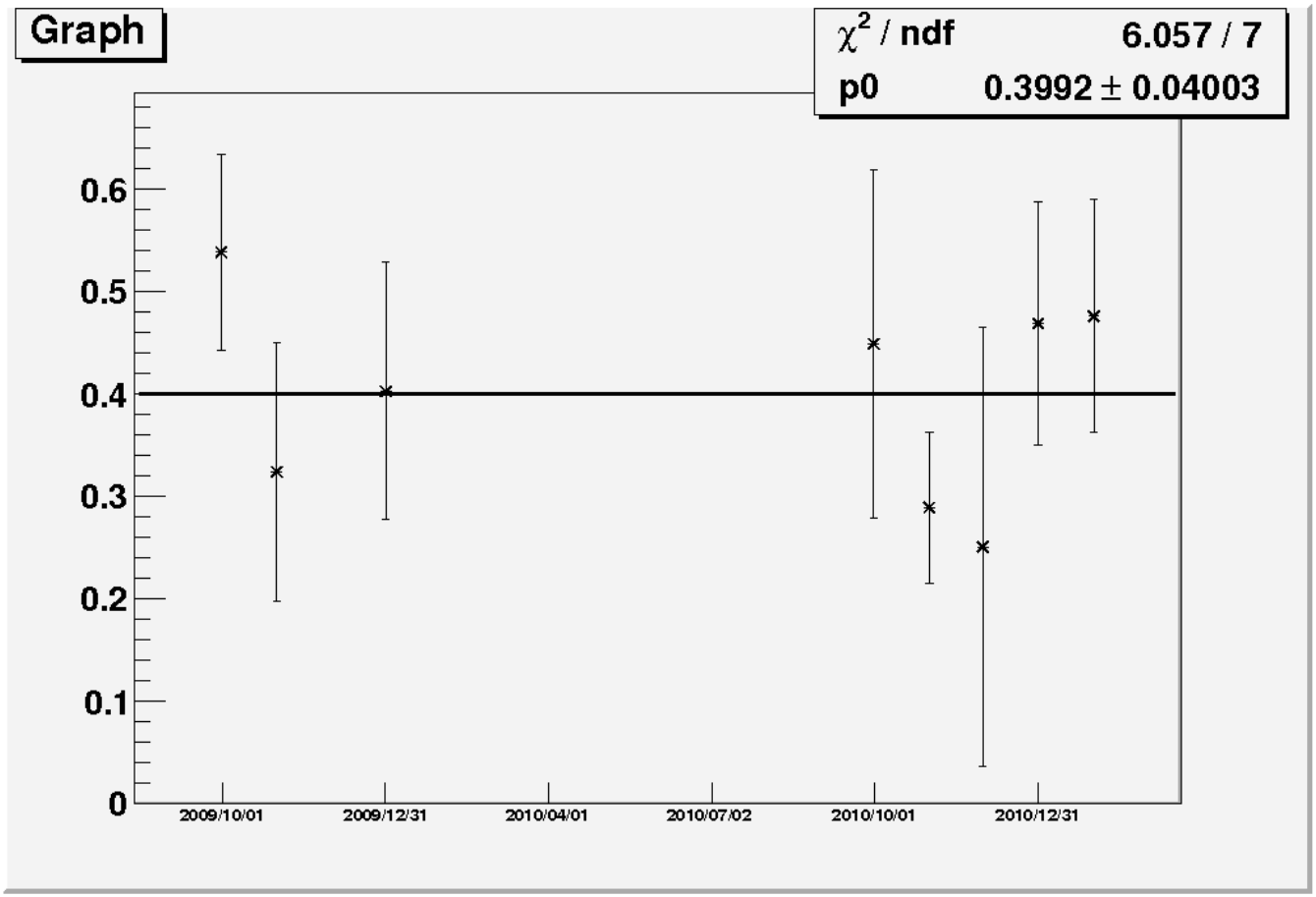
Searching for the Crab Pulsar variability

Produce the θ^2 plots for ON & OFF



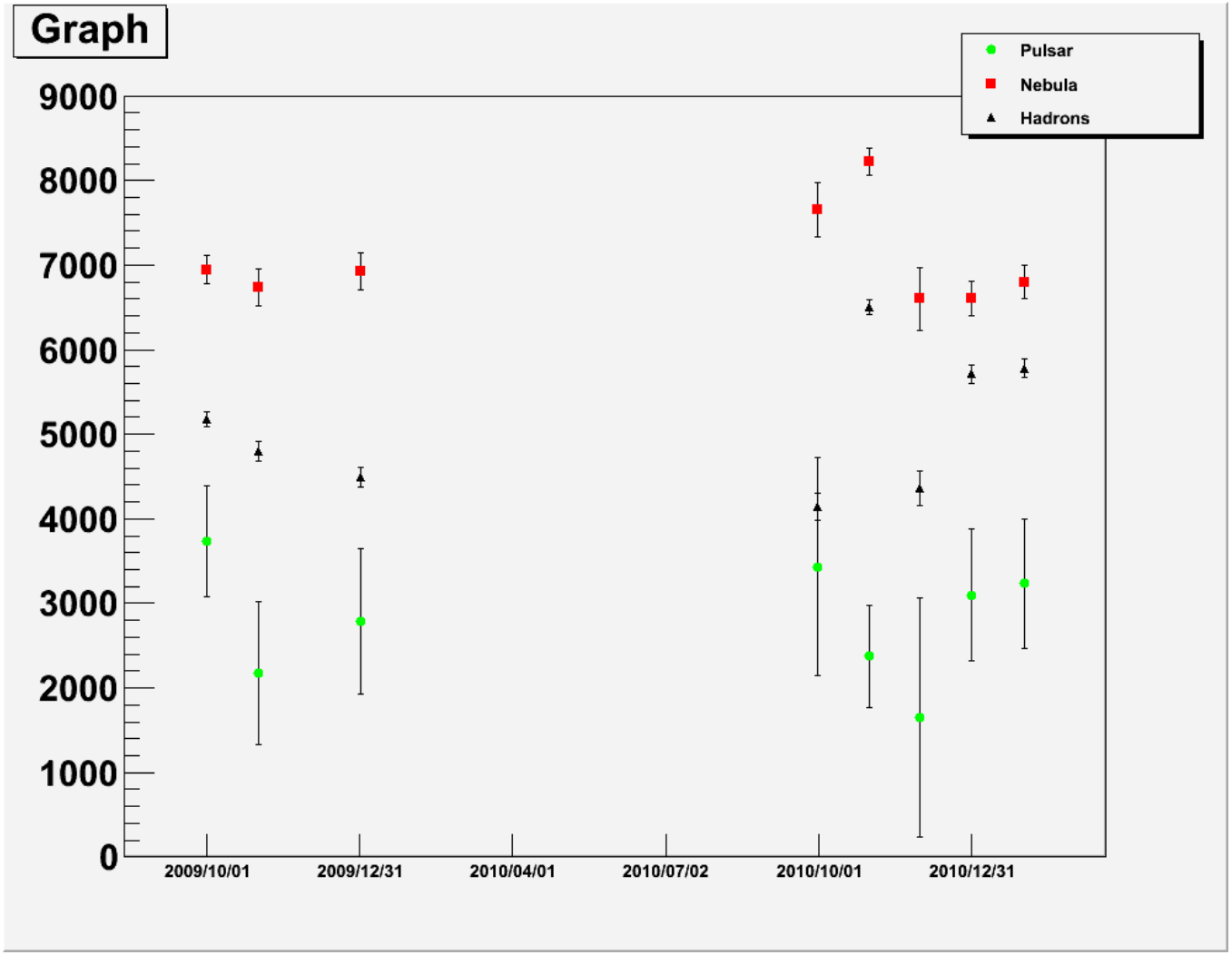
Searching for the Crab Pulsar variability

Pulsar/Nebula ((ON-OFF)/(OFF-Had)) lightcurve



Searching for the Crab Pulsar variability

Pulsar, Nebula and Hadron rates



Searching for the Crab Pulsar variability

Conclusions II

- Crab Pulsar is stable. . .
- . . . or we need more statistics
- Crab Nebula is variable (it is indeed)

Future

- Calculations of the spectra for the parameters of the newest observed flare in Crab Nebula.
- Optimization of the data analysis from the MAGIC telescopes in order to gain more statistics.
- Producing long-time-scale lightcurve for Crab Nebula from the MAGIC data.

Thank you.