



Reconstruction of the characteristics of a high-energy event detected by the Carpet-2 array in association with the GRB 221009A gamma-ray burst

Carpet-2 collaboration

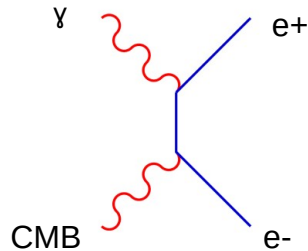
D. D. Dzhappuev, Yu. Z. Afashokov, I. M. Dzaparova, T. A. Dzhatdov, E. A. Gorbacheva, I. S. Karpikov, M. M. Khadzhiev, N. F. Klimenko, A. U. Kudzhaev, A. N. Kurennya, A. S. Lidvansky, O. I. Mikhailova, V. B. Petkov, E. I. Podlesnyi, N. A. Pozdnukhov, V. S. Romanenko, G. I. Rubtsov, S. V. Troitsky, I. B. Unatlov, I. A. Vaiman, A. F. Yanin, K. V. Zhuravleva (Carpet-2 group, INR RAS)



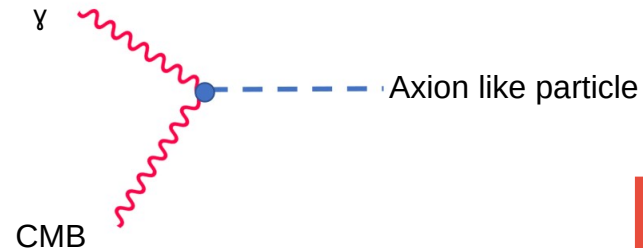
Introduction and motivation

- High-energy gamma ray from galactic sources may shed light on the origin of cosmic rays
- The presence of sources of high-energy gamma ray outside our galaxy may indicate the manifestation of new physics
- Swift and Fermi LAT observed the most energetic photons from **GRB 221009A distance: redshift $z=0.151$**
- LHAASO: photons up to 18 TeV
- **Carpet-2: 251 TeV photon-like event**
- Perhaps in order to explain these high-energy gamma quanta from a distant source, it is necessary to involve new physics: **axions** or **Lorentz violation**

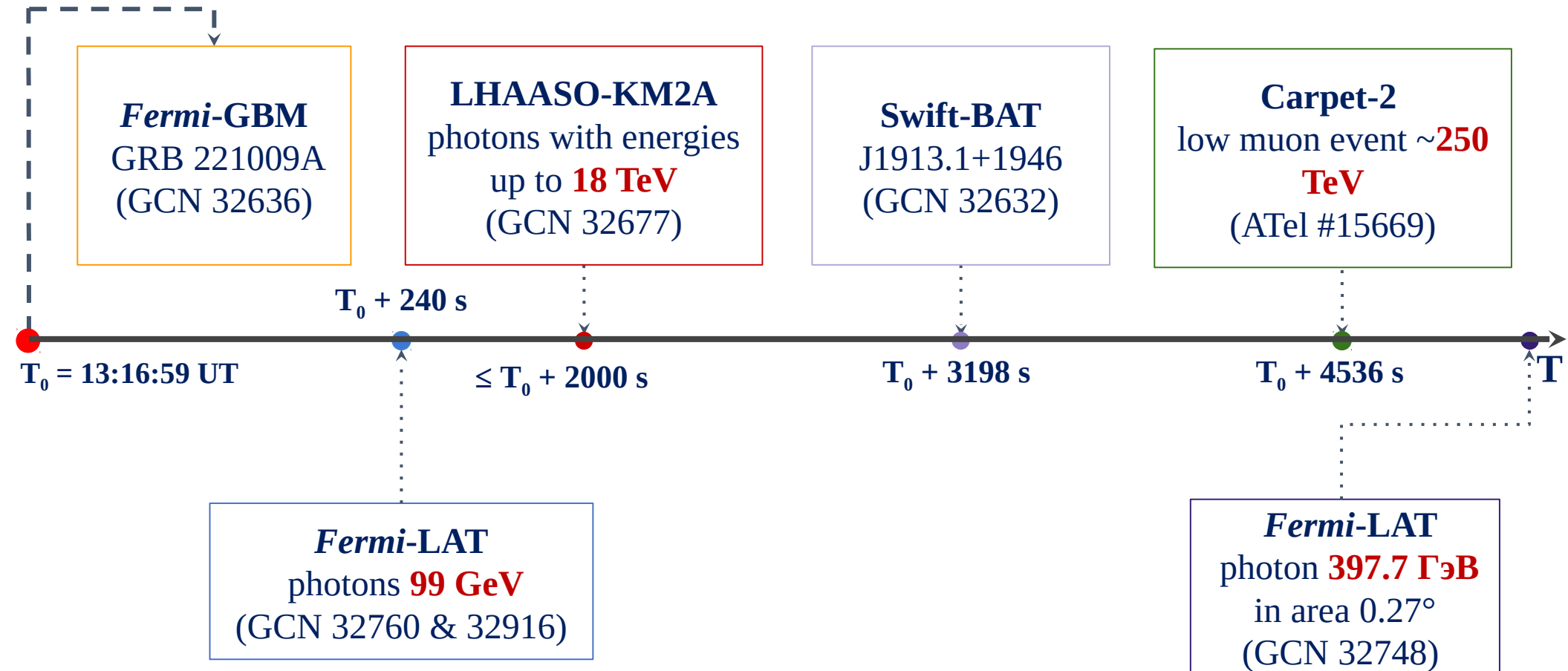
no production of electron-positron pairs
or pair production threshold shift



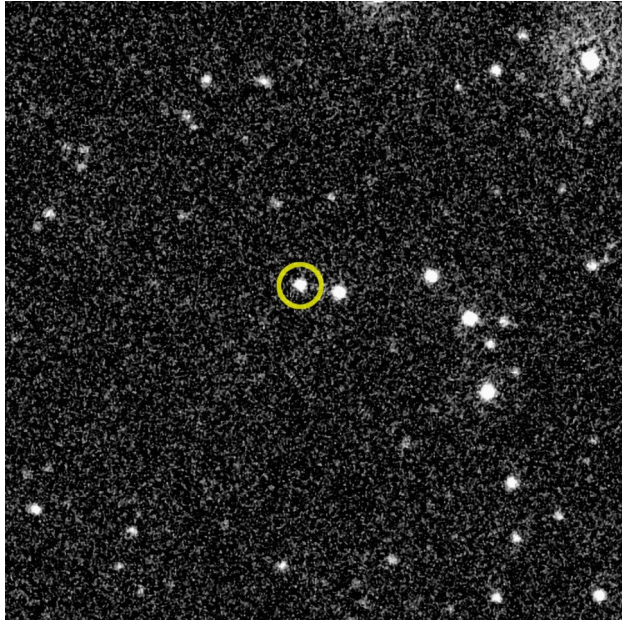
ALP-photon oscillations



GRB221009A: chronology of main observation

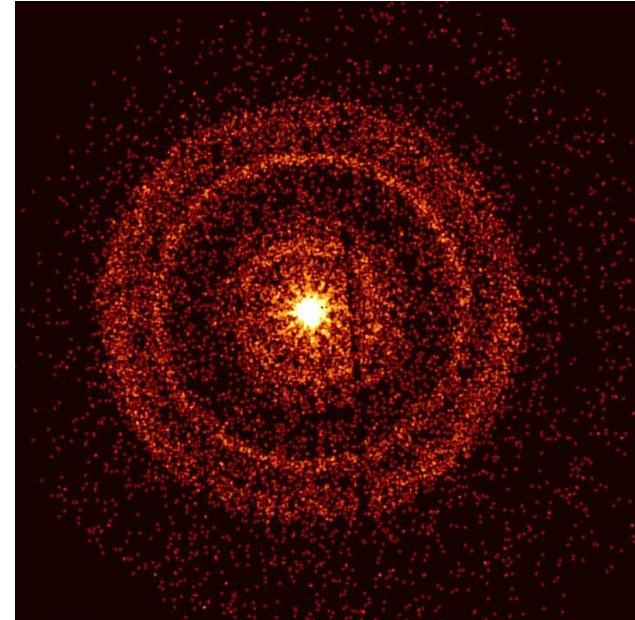


Gamma burst GRB 221009A, Swift



Visible light images of the *Swift Ultraviolet/Optical Telescope* show how the afterglow of **GRB 221009A** (circled) faded over the course of about 10 hours.

Image size is about 4 arc minutes..



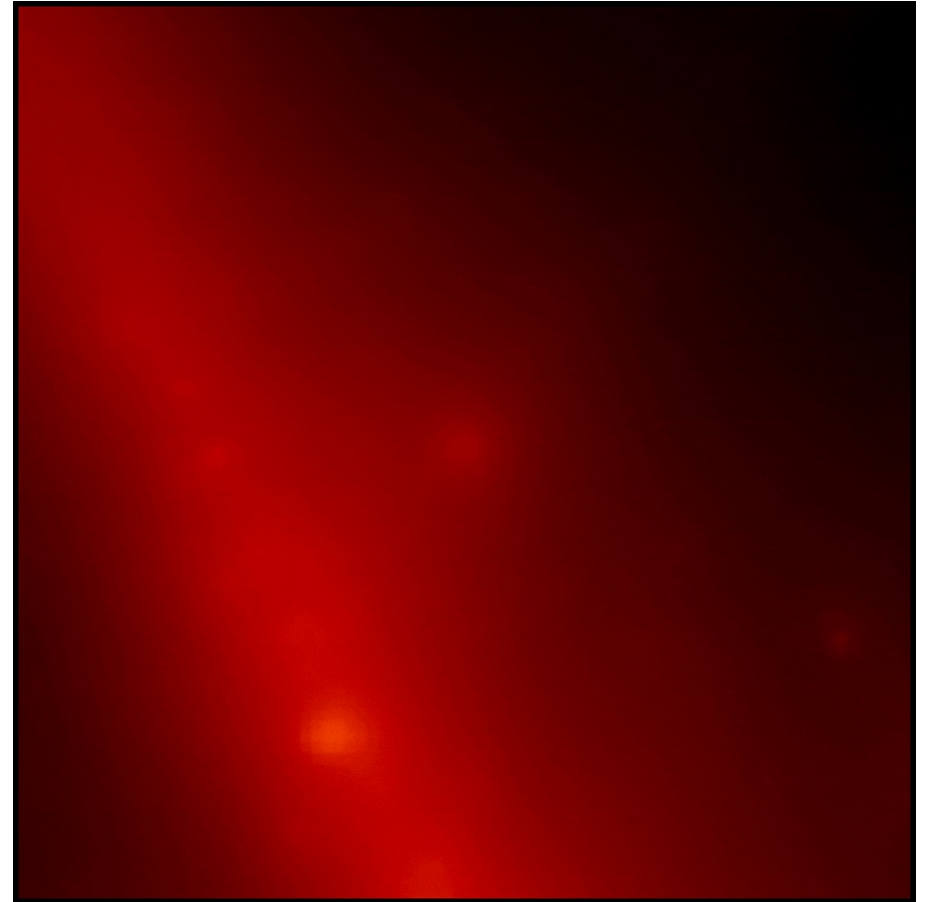
Swift's X-ray image of GRB 221009A shows circular rings around the gamma-ray burst. Dust in the Milky Way scattered the x-ray emission of the gamma-ray burst, creating the rings.

Gamma burst GRB 221009A, Fermi-LAT

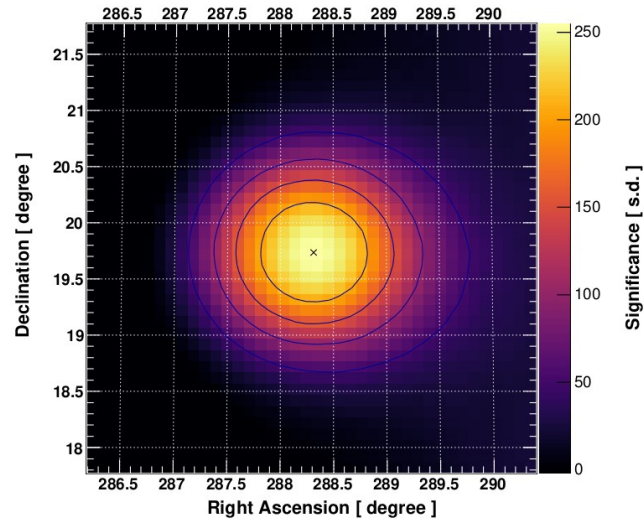
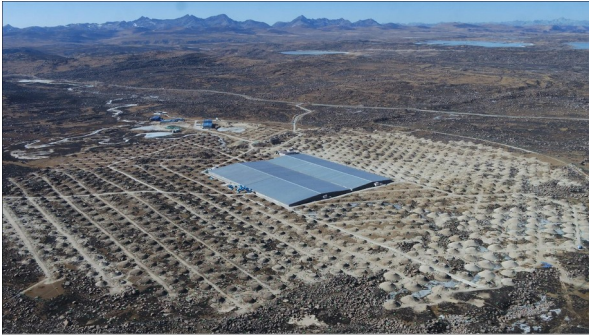
Images built from 10 hours of *Fermi-LAT* data show a gamma-ray sky centered on the localization region of **GRB 221009A**.

Each frame shows gamma rays with energy over **100 MeV**.

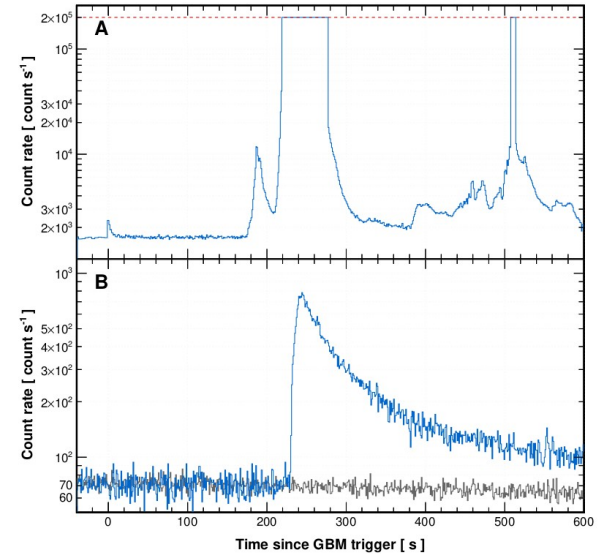
Brighter colors indicate a stronger gamma signal.



LHAASO: events associated with GRB221009A



Significance map of the GRB emissions detected by LHAASO-WCDA.



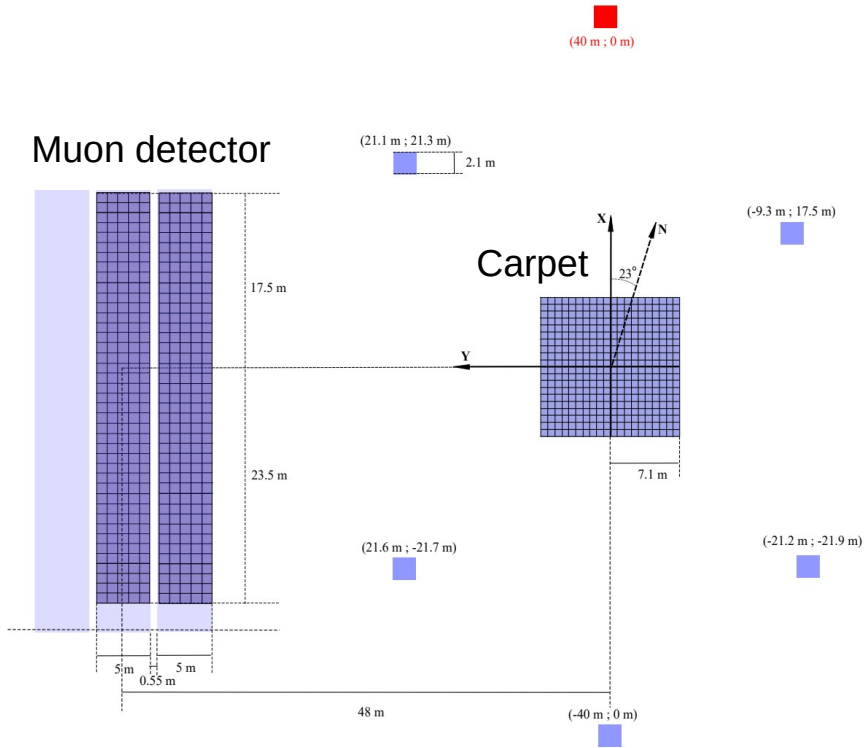
Comparison between the keV–MeV light curve measured by Fermi/GBM and the TeV light curve measured by LHAASO-WCDA

Within 2000 seconds after the Fermi GBM trigger, LHAASO observed more than 5000 high-energy photons with an energy of about 18 TeV

Carpet-2 installation

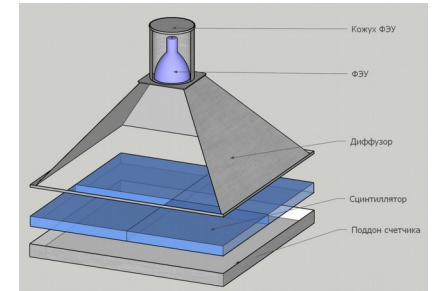
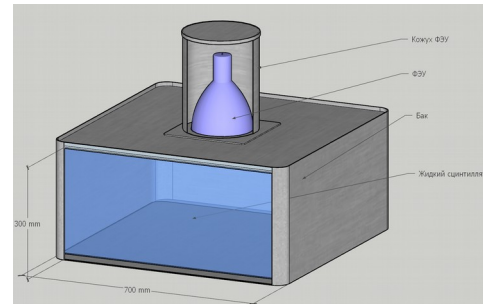
Ground part of the installation

- "Carpet" - 400 counters based on a liquid scintillator, with a total area of 196 m².
- 5 remote registration points, 18 counters in each, based on a liquid scintillator, area 9 m².



Underground muon detector

- 175 "old" and 235 "new" counters based on a plastic scintillator, with a total area of 410 m²
- 1 GeV is the threshold energy for vertical muons
- angular resolution 4.7°



Carpet-2 instalation



Carpet



Muon detector

Carpet-2: event associated with GRB221009A

- Carpet-2: ~ 250 TeV photon-like event 4356 sec after T0
- arrival direction: RA=289.51°, DEC=18.44°, 1.78° from GRB (angular resolution 4.7°)
- zenith angle 26°
- 0 muons in 175 m² detector and 3 muons in 235 m² detector

Poisson probability of a random coincidence of 1.2×10^{-4} (428 work day) which corresponds to 3.8 sigma (pre-trial)

New selection criteria

- energy release in a carpet of more than 5000 relativistic particles (was 10000)
- 200 triggered detectors (was 300)

Swift J1913.1+1946/GRB 221009A: detection of a 250-TeV photon-like air shower by Carpet-2

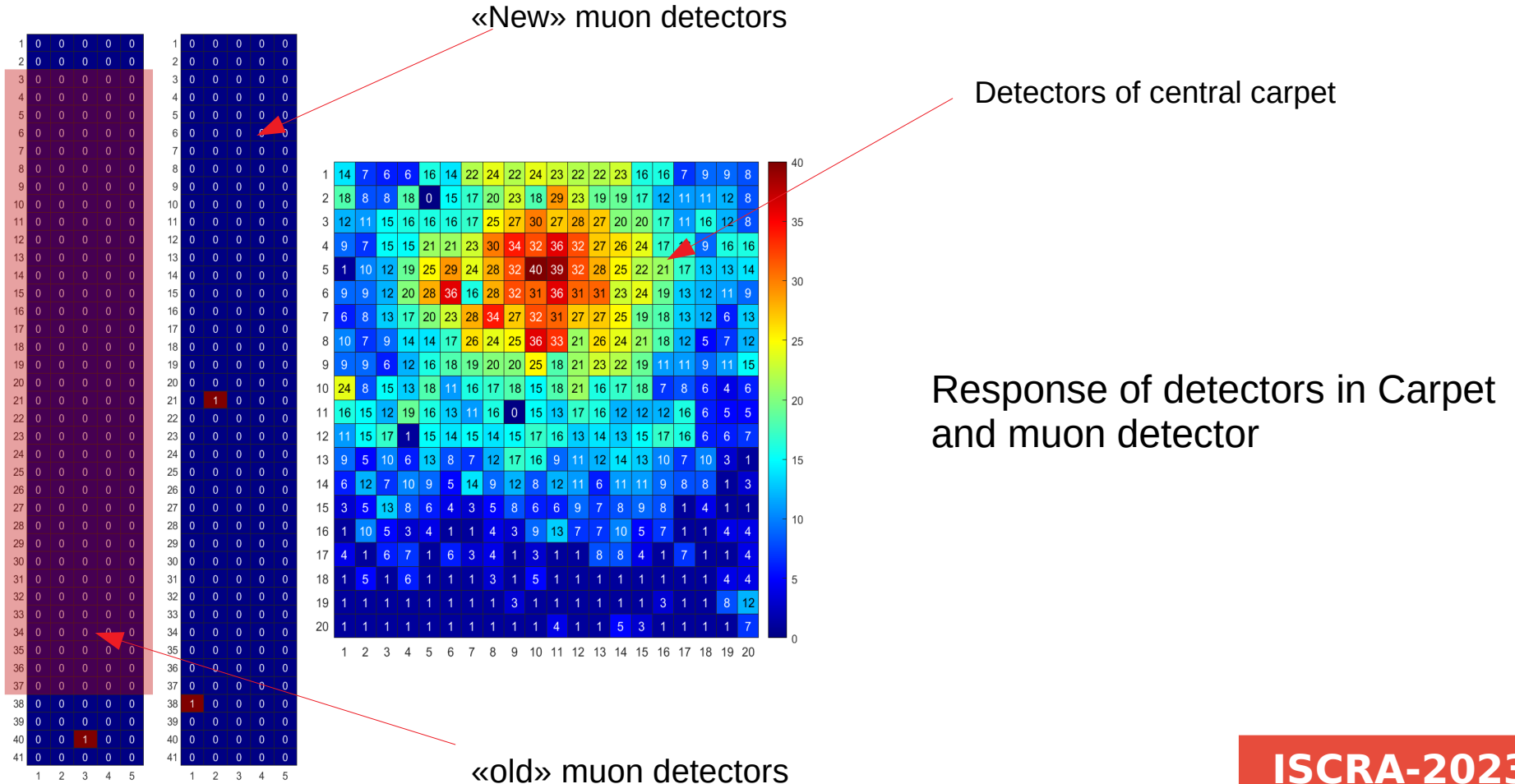
ATel #15669; D. D. Dzhappuev, Yu. Z. Afashokov, I. M. Dzaparova, T. A. Dzhatdoev, E. A. Gorbacheva, I. S. Karpikov, M. M. Khadzhiev, N. F. Klimenko, A. U. Kudzhaev, A. N. Kurenya, A. S. Lidvansky, O. I. Mikhailova, V. B. Petkov, E. I. Podlesnyi, N. A. Pozdnukhov, V. S. Romanenko, G. I. Rubtsov, S. V. Troitsky, I. B. Unatlokov, I. A. Vaiman, A. F. Yanin, K. V. Zhuravleva (Carpet-2 group, INR RAS)
on 12 Oct 2022; 13:56 UT

Credential Certification: Sergey Troitsky (st@ms2.inr.ac.ru)

Subjects: VHE, UHE, Gamma-Ray Burst, Transient

Referred to by ATel #: [15675](#)

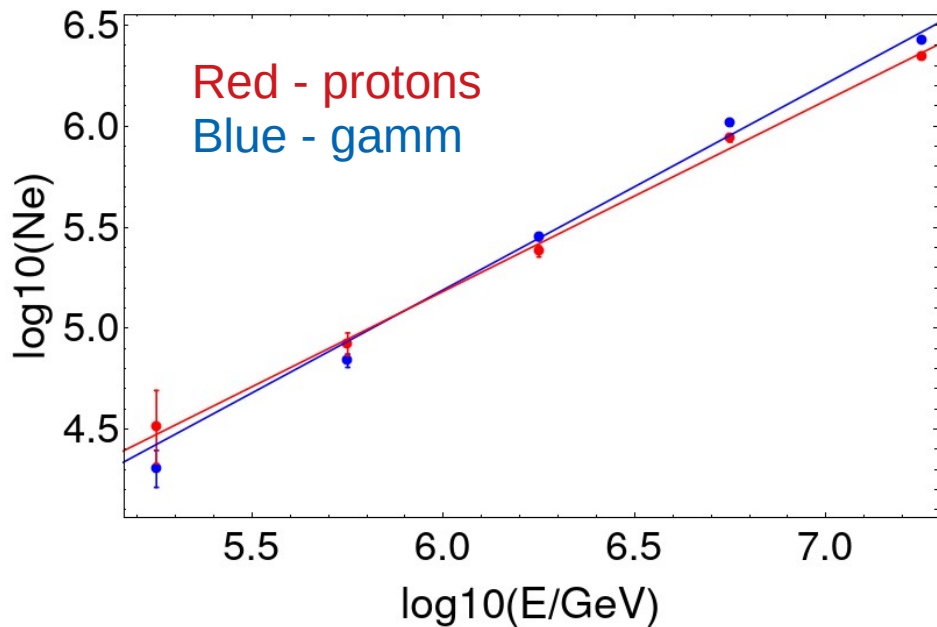
Image of the event 09/10/2022, according to the Carpet-2 installation + MD 410 m²



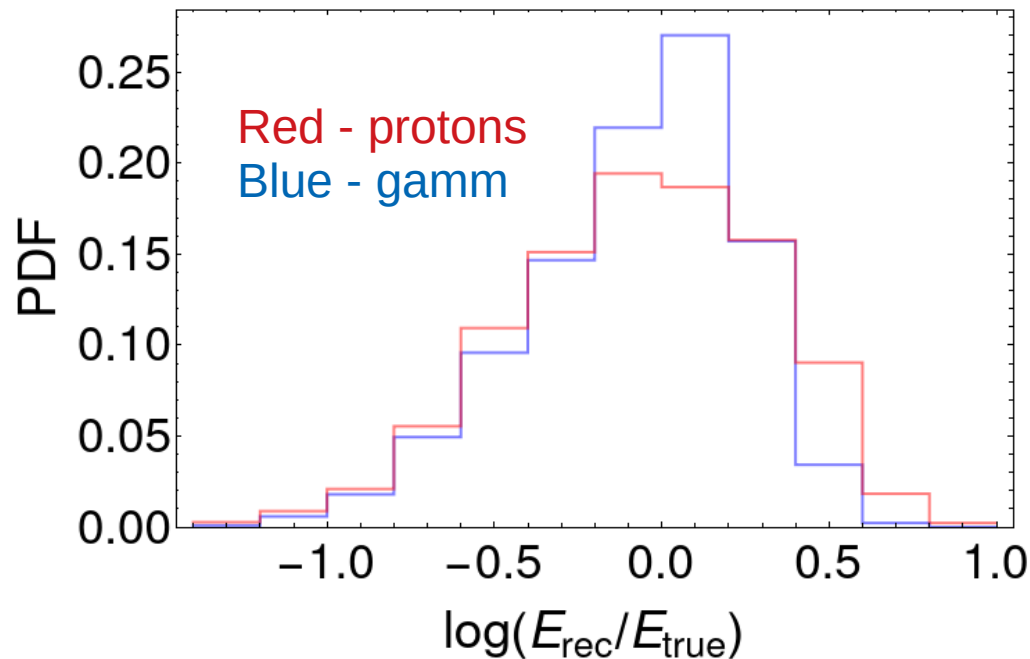
Carpet-2 Monte-Carlo for event 09/10/2022

- CORSIKA7.4001
- QGSJET-II-04 high-energy hadronic interaction models
- FLUKA2011.2c as the low-energy hadronic interaction models
- Primary differential energies spectrum is an $E^{-2.7}$ for proton and E^{-2} . For gamma
- energy range $100 \text{ GeV} < E < 500 \text{ GeV}$.
- average values $\Theta = 26.5^\circ$, $\varphi = 289.51^\circ$, (dispersion = 4.7°)
- we simulated 3000 showers for primary protons and the same number for primary gamma.

E vs N_e for gamma and protons



dependence of the N_e on energy
(mean N_e in energy bin)



The difference between restored
and true energy

But the energy is systematically increased by 5% and 24%
for photons and protons, respectively.

Event Energy Estimation

Energy expression between number of particles and energy:

$$\text{For gamma: } \log(N_e) = 0.95 \times (-0.934 + 1.020 \times \log(E/\text{GeV}))$$

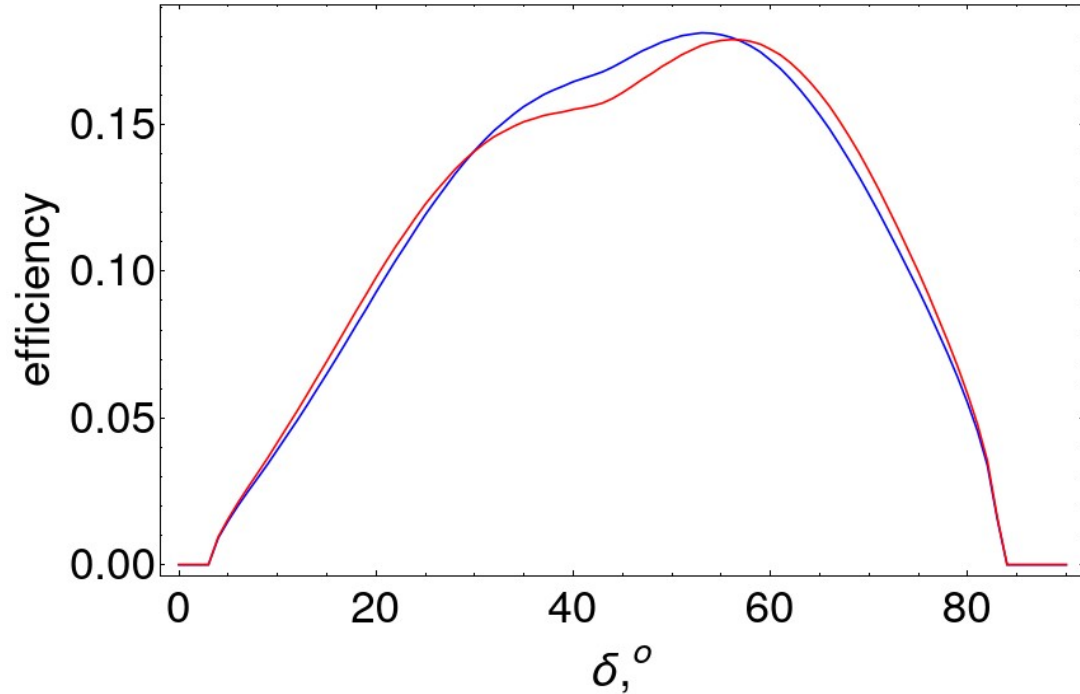
$$\text{For protons: } \log(N_e) = 0.76 \times (-0.484 + 0.944 \times \log(E/\text{GeV}))$$

$$E_{\text{event}} = 228.8 (+75/-70) \text{ TeV}$$

$$E_{\text{event}} = 166.2 (+110/-62) \text{ TeV}$$

Bias taken into account!!!

Efficiency of registration event 10/09/2022



Dependence of efficiency on declination

overall effectiveness
for the event 09.10.2022

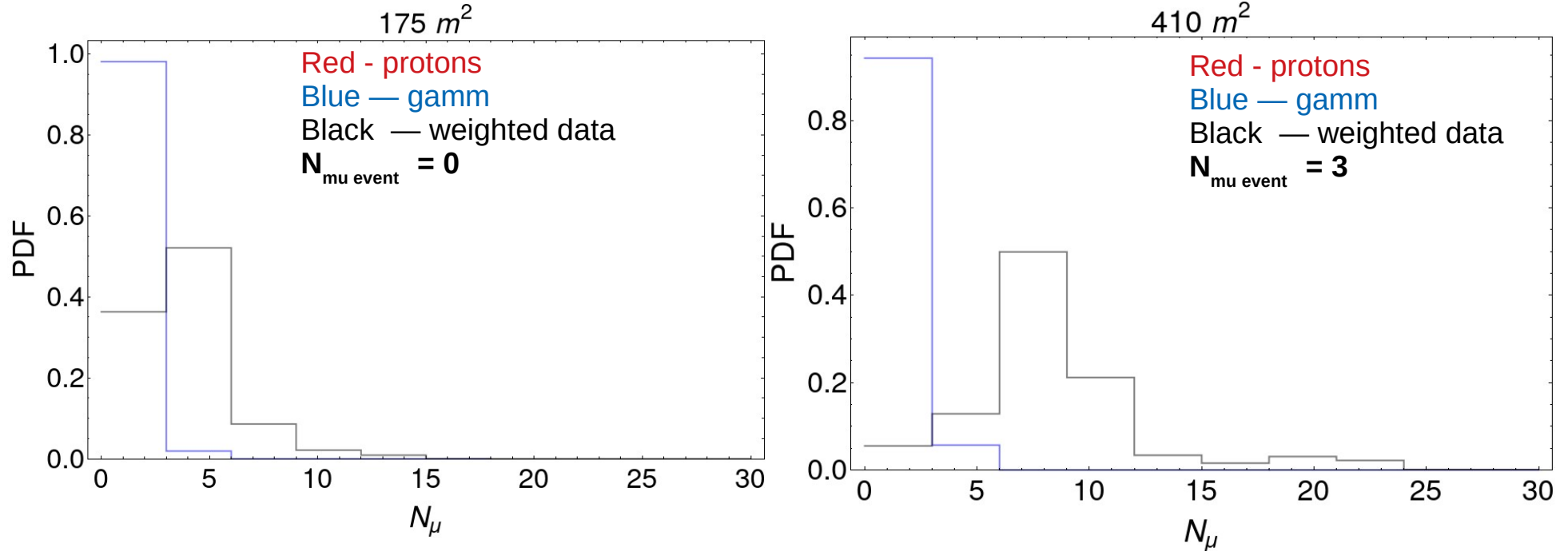
Gamma Eff = 0.32638

Protons Eff = 0.468995

Gamma Eff($\delta = 19.495$) = 0.086

Protons Eff($\delta = 19.495$) = 0.094

Number of muons in the detector 175 and 410 m²



For **175 m²** **p-value** that we observe the primary hadron is **7.99%**
(fraction of proton MC events with $N_{\text{mu}} == 0.0$)

For **410 m²** **p-value** that we observe the primary hadron is **7.86%**
(fraction of proton MC events with $N_{\text{mu}} \leq 3$)

CONCLUSIONS

- **GRB 221009A - a record gamma-ray burst in brightness and photon energy**
- **distance is large - redshift $z=0.151$**
- **photons LHAASO (up to 18 TeV)**
- **Poisson probability of a random coincidence in 4536 seconds of 1.2×10^{-4} , that is to the 3.8 sigma pre-trial significance**
- **photon-like event, Carpet-2 (228 TeV, p-value = 92%)**

Thank you for your attention!

