Carpet-3 detection of a photon-like air shower with estimated primary energy above 100 TeV in a spatial and temporal coincidence with GRB 221009A.

The 5th International Symposium on Cosmic Rays and Astrophysics (ISCRA-2025)

Carpet-3 caloboration

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- Gamma-ray burst GRB221009A, registration and observation chronology
- Analysis of the event associated with GRB221009A at the Carpet-2 facility
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- Interpretation of the event

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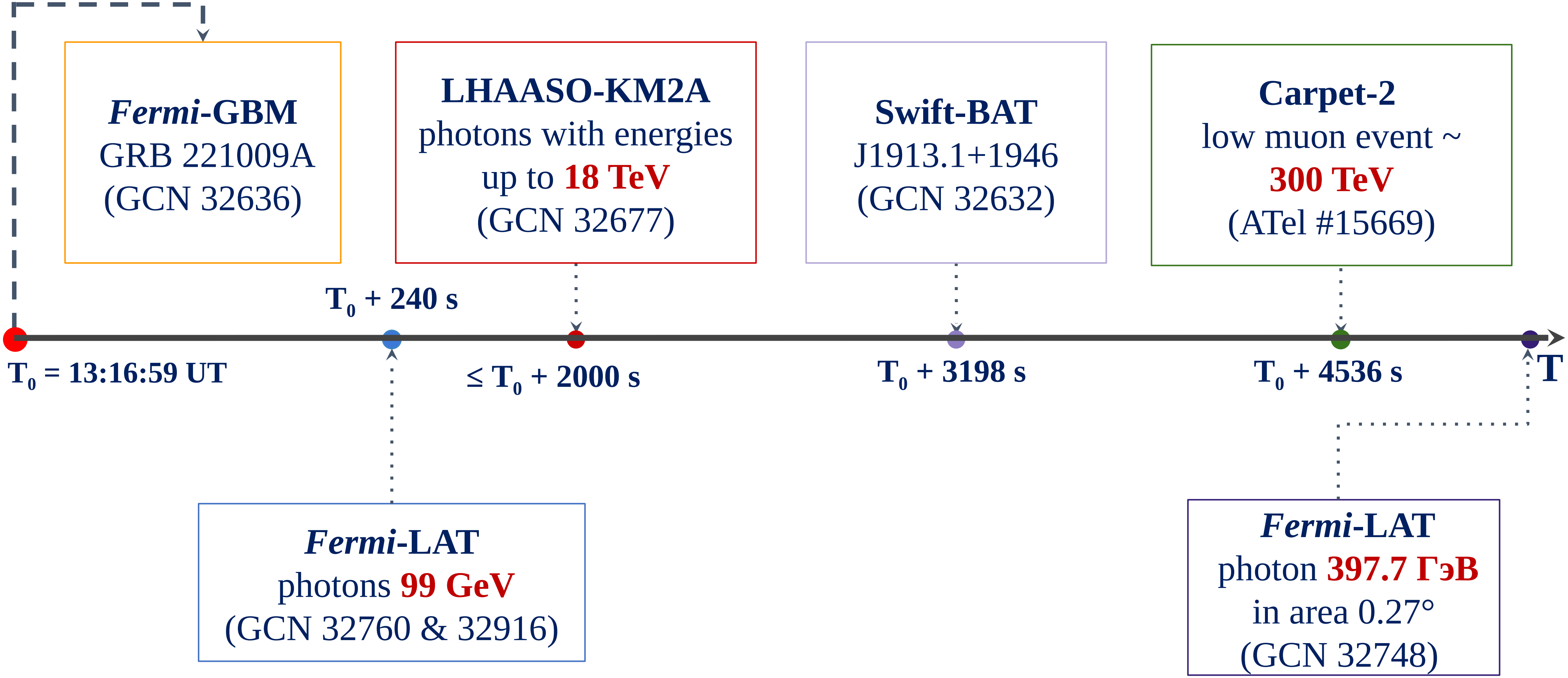
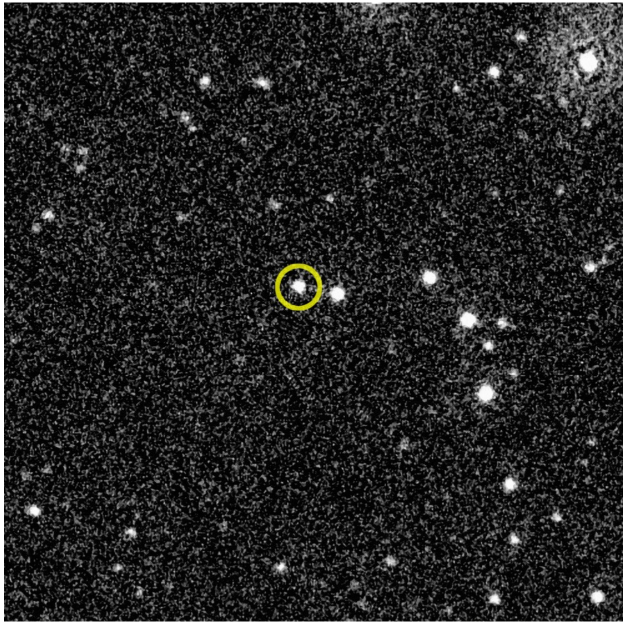
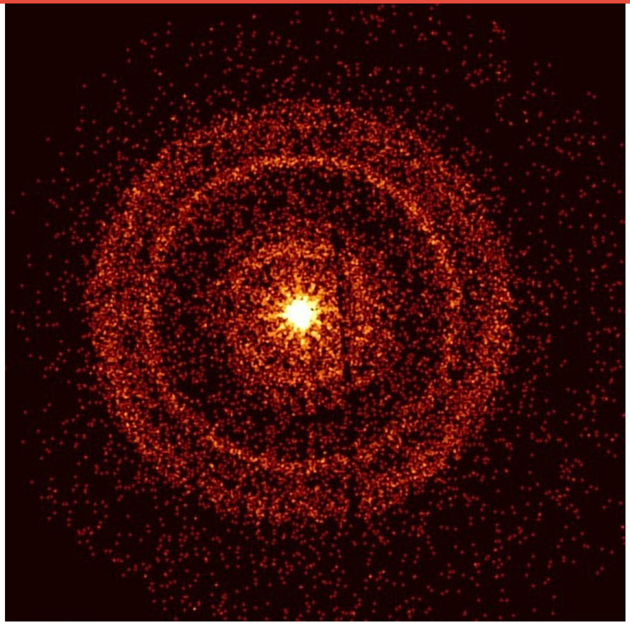
GRB221009A: Timeline of Key Observations



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.

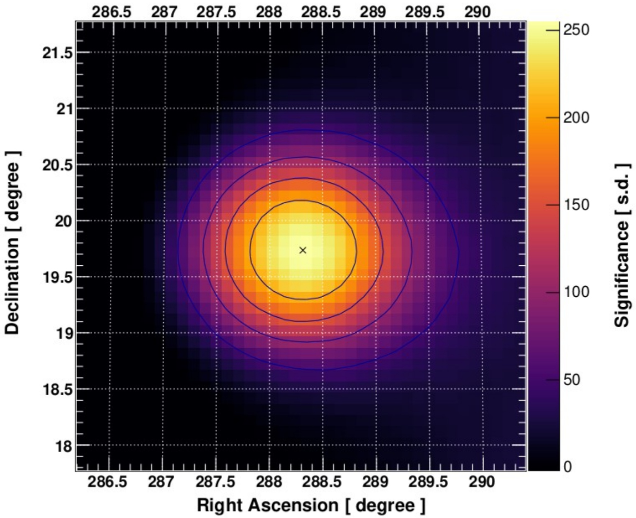


Swift's X-ray image of GRB 221009A shows circular rings around the gamma-ray burst. Dust in the Milky Way scattered the x-ray emission of the gamma-ray burst, creating the rings.

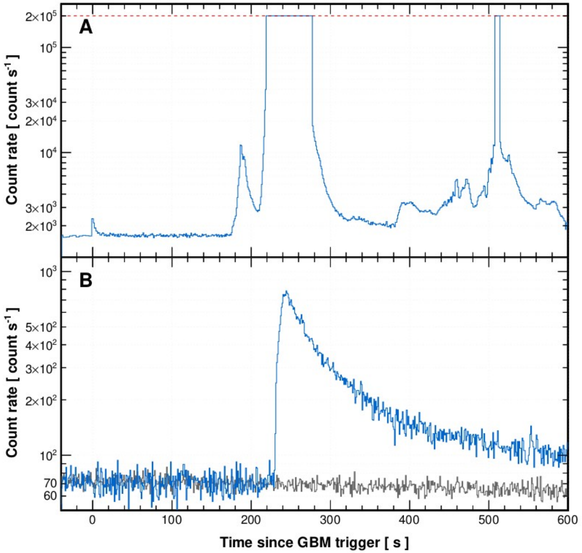
Image size is about 4 arc minutes.

the distance is large - red shift z=0.151

Observation of photons with energies of about 18 TeV by the LHAASO



LHAASO-WCDA significance map of detected gamma-burst-related events.



Comparison of light curves measured by Fermi/GBM and LHAASO-WCDA

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

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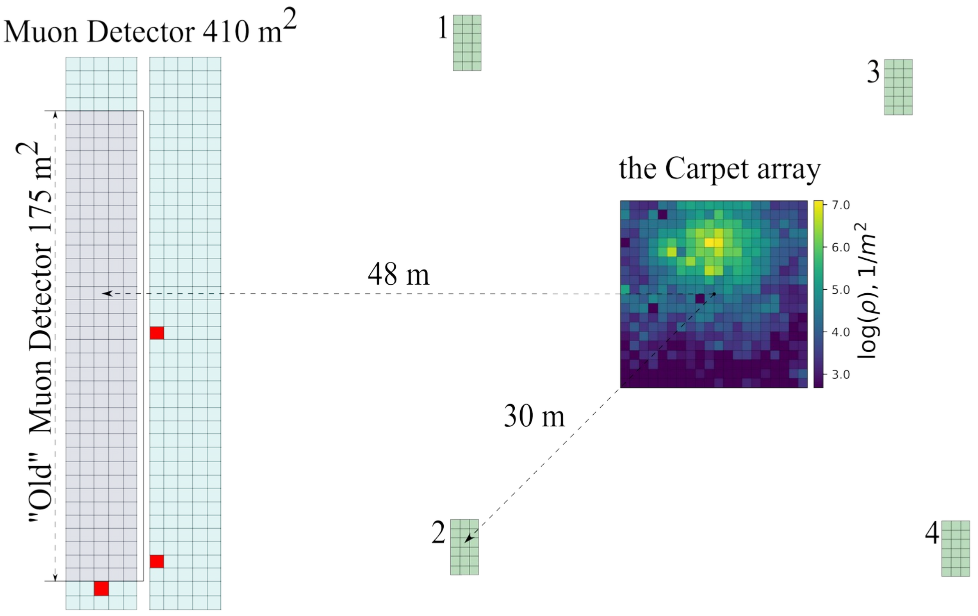
Carpet-2 instalation

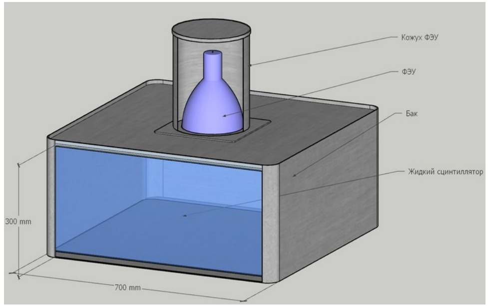
Ground part of the installation

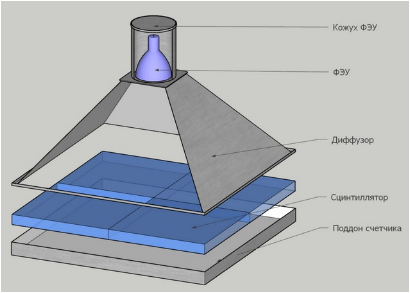
- "Carpet" - 400 counters based on a liquid scintillator, with a total area of 196 m².
- 5 remote registration points, 18 counters in each, based on a liquid scintillator, area 9 m².
- angular resolution 4.7^0

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





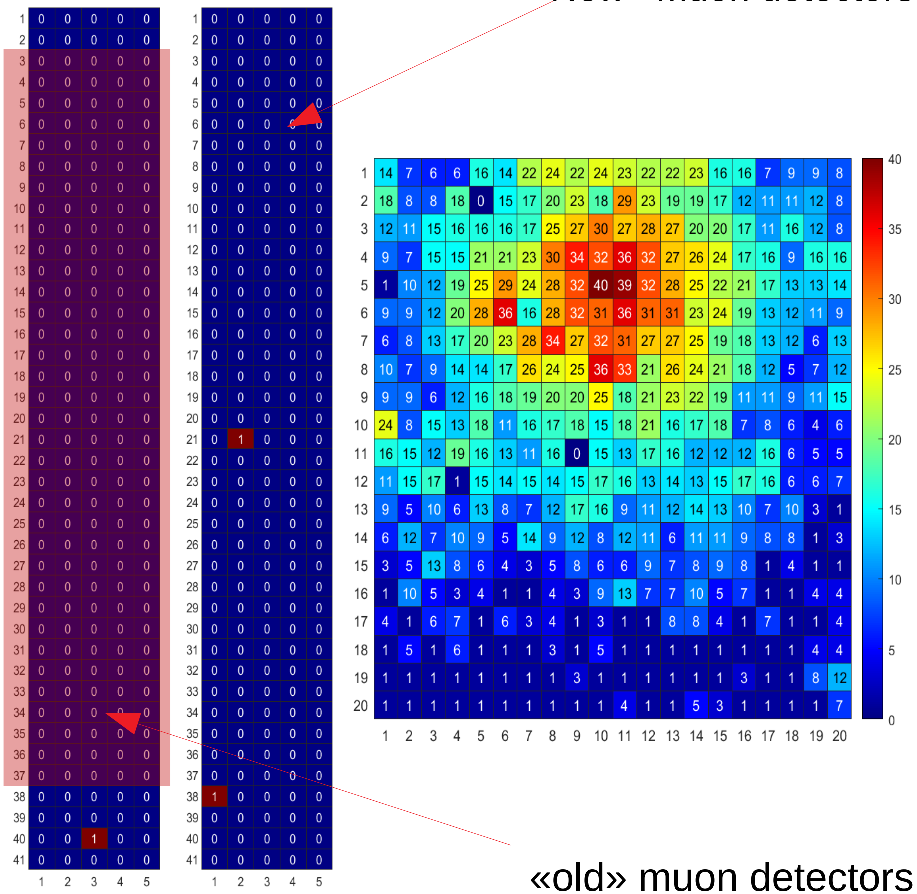


Carpet-2 instalation

Carpet

Muon detector

"Carpet 2", a photon-like event associated with the gamma-ray burst GRB221009A



- Carpet-2: ~230 TeV photon-like event 4536 sec after T0
- N_e=36400 (~300 TeV)
- 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 410 m² detector

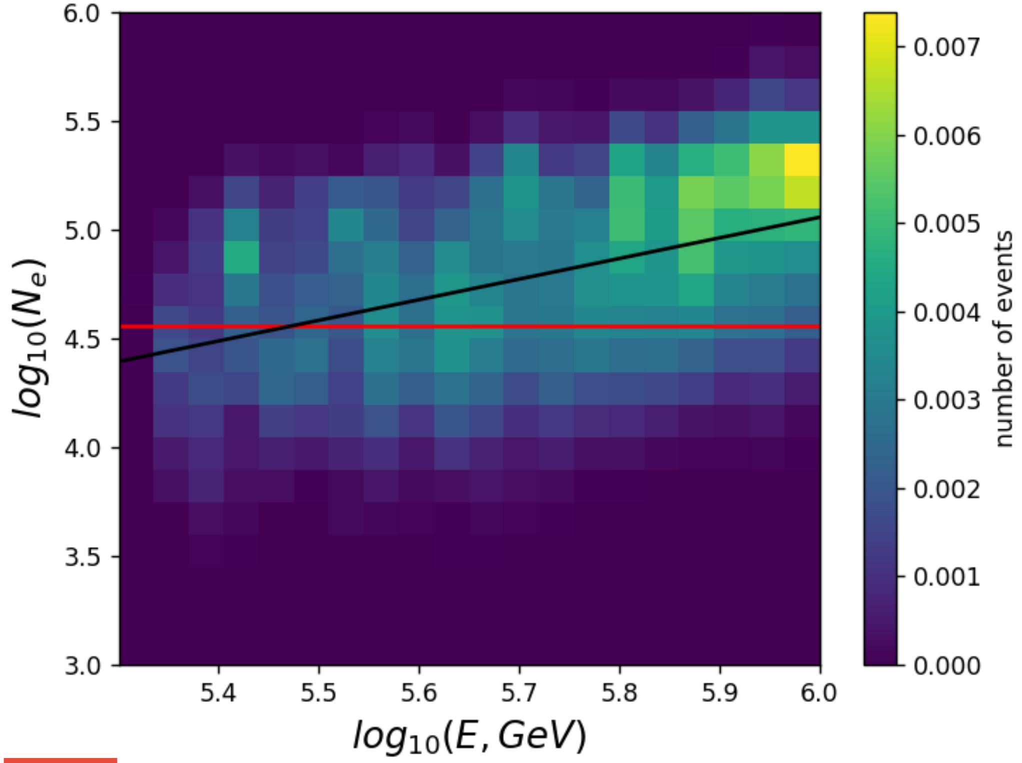
Poisson probability of a random coincidence of

410m^2: $9.0\cdot10^{-3}$ (667 work day, 6 events N_μ<=3 with N_e>36400)

175m^2: $4.3\cdot10^{-3}$ (1676 work day, 7 muonless events, N_e>36400)

Estimation of the primary energy of a gamma-ray burst event

Dependence of the number of particles Ne on the primary energy of a photon shower

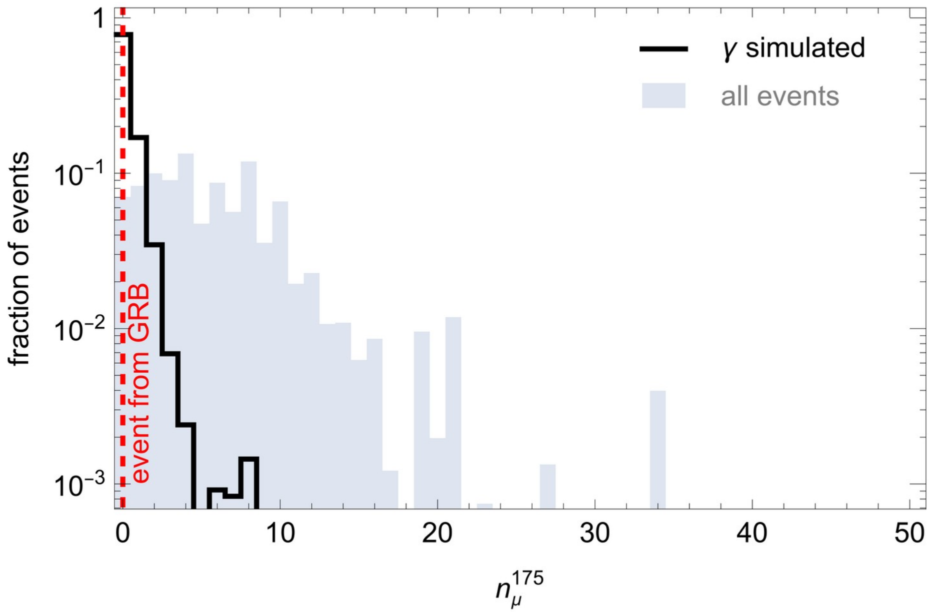


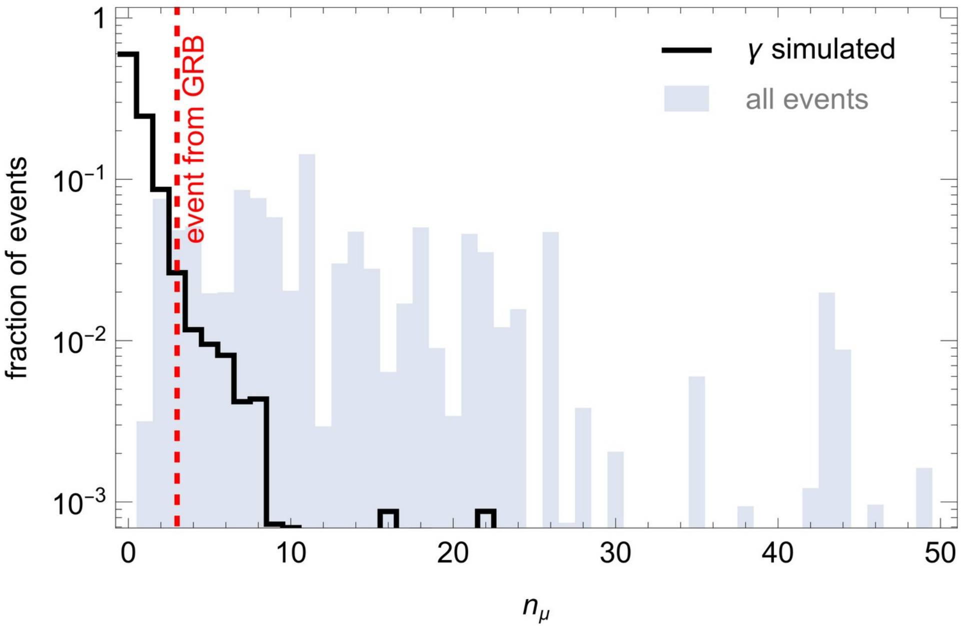
Red line: Ne = 36400 (Ne events)
Black line: fit

The Ne distribution is weighted by the photon spectrum slope -2
$dN/dE \sim N^{-2}$

E_γ = 300(+43/-38)TeV

Estimation of statistical significance of hadron background by muon component of shower



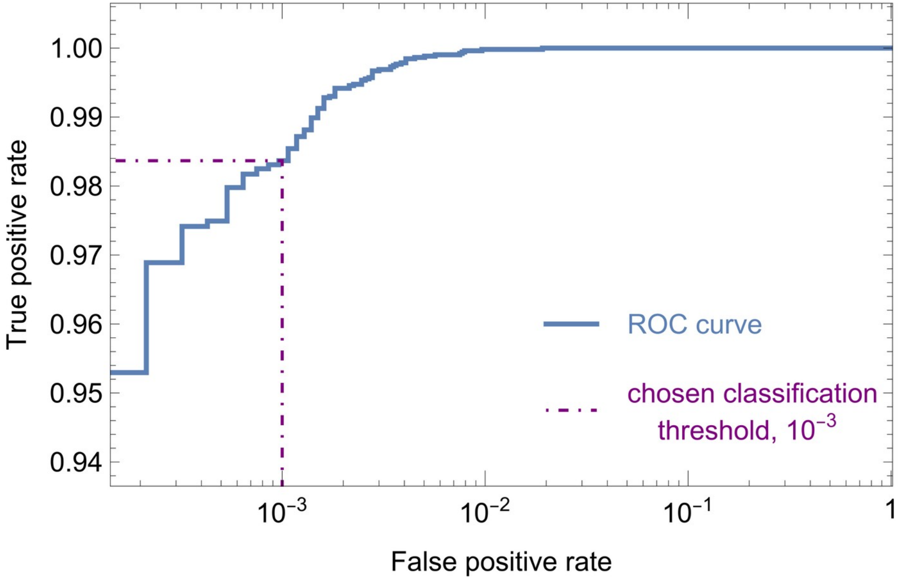


To estimate the hadron background, we used data selected from the same arrival direction (θ, φ) in which the gamma-ray burst is located. Then we weighted the events taking into account the log-normal distribution with the mean value corresponding to the N_e event. A double Gaussian distribution by arrival angles was also added. Taking these weights into account, we construct distributions of the selected events by the number of muons N_μ

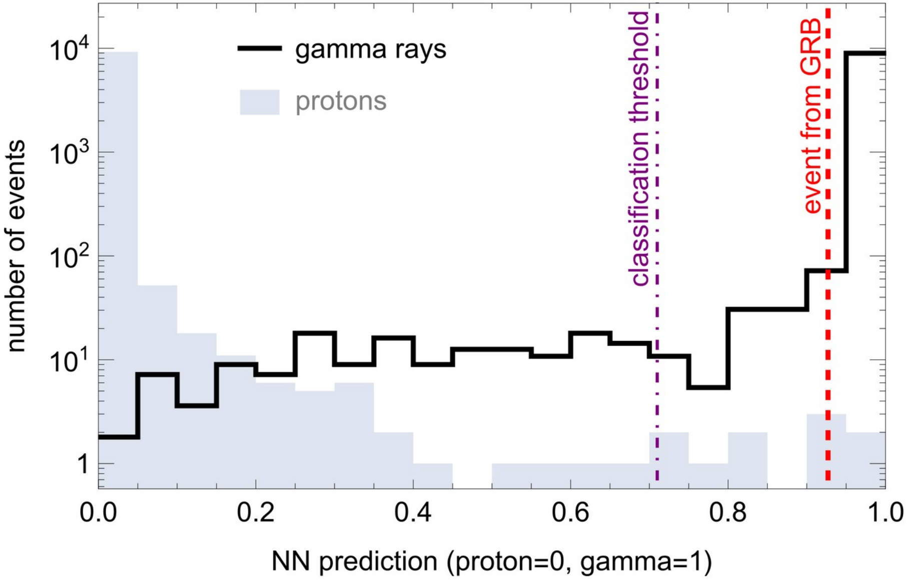
P-value = 0.127 - fraction of events with N_μ <=3 in muon detectorn data 410м^2

P-value = 0.070 - fraction of events with N_μ ==0 in muon detectorn data 175м^2

Neural network gamma-ray classification



ROC curve of the gamma-ray – proton classifying neural network, evaluated on the test set.
The chosen thresh-old is shown as a dot-dashed line

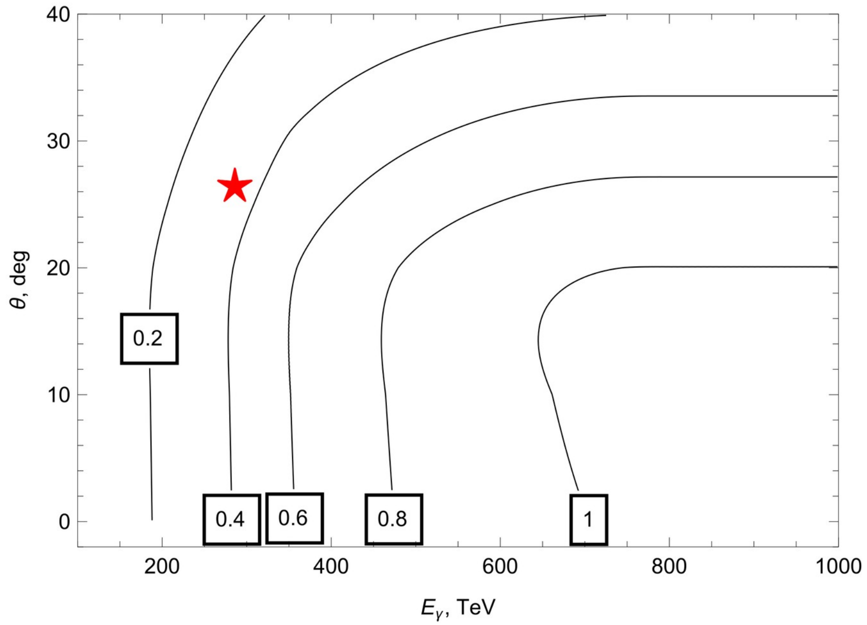


Predictions distribution of the gamma-ray – proton classifying neural network. The values of the classification threshold (0.71; dot-dashed line) and of the prediction for the event analyzed in this work (0.927; dashed line) are shown.

Based on simulations, the probability that this event is a misclassified hadron is $\approx 3 \cdot 10^{-4}$

Event Registration Efficiency

eff = proportion of events selected / proportion of showers thrown into the installation



$A_{eff} = eff \times A_{geom}$

$A_{geom} = 12.82 \times 12.82 m^2$,

eff = 0.38,

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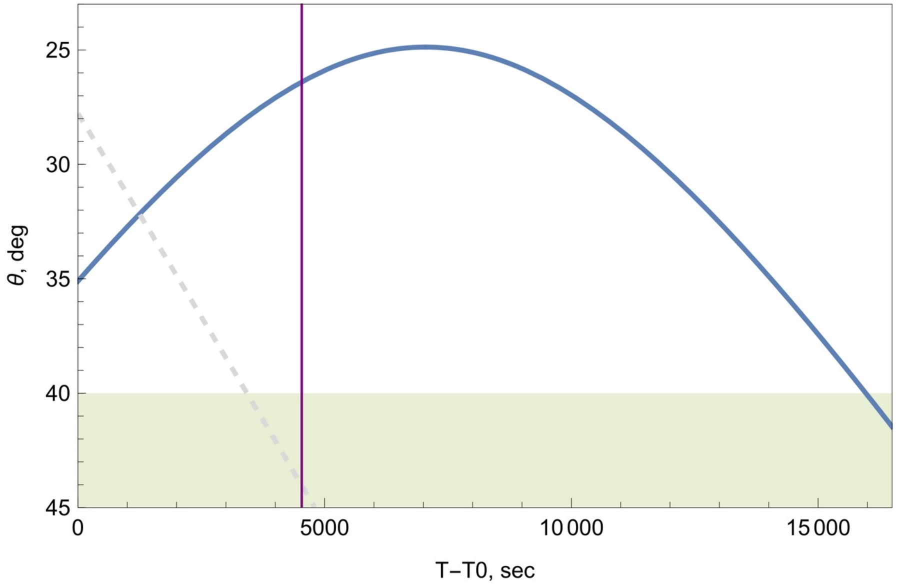
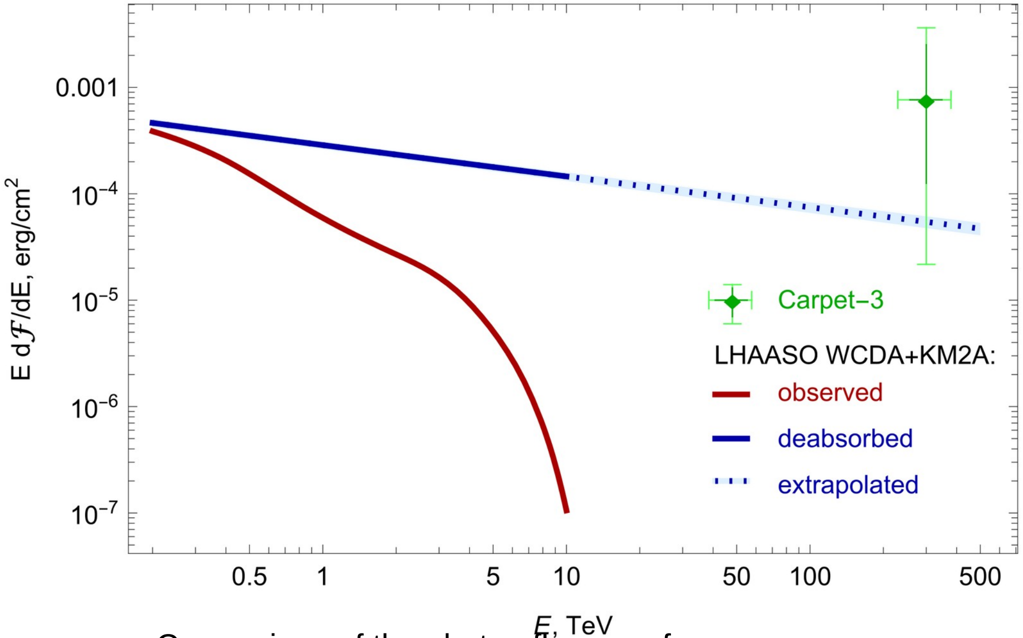
Comparison of photon fluence from gamma rays GRB221009A



Temporal dependence of the zenith angle of the GRB 221009A as seen by Carpet–3 (full blue line). The dashed gray line is the same dependence for LHAASO. The vertical maroon line indicates the Carpet–3 event arrival time. The shaded area at the bottom corresponds to zenith angles $\theta > 40^0$ excluded in the analysis.



Comparison of the photon fluence of GRB 221009A estimated from the Carpet–3 observation (dark green: 68% CL, light green: 95% CL errors) with the extrapolation of LHAASO results.

The estimated GRB 221009A fluence above 100 TeV is
$F \approx (1.1 \pm 0.9) \times 10^{-3}$ erg/cm^2 (68% CL),

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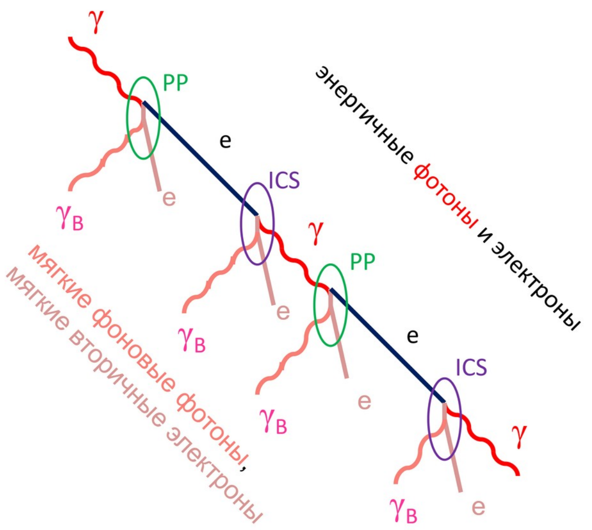
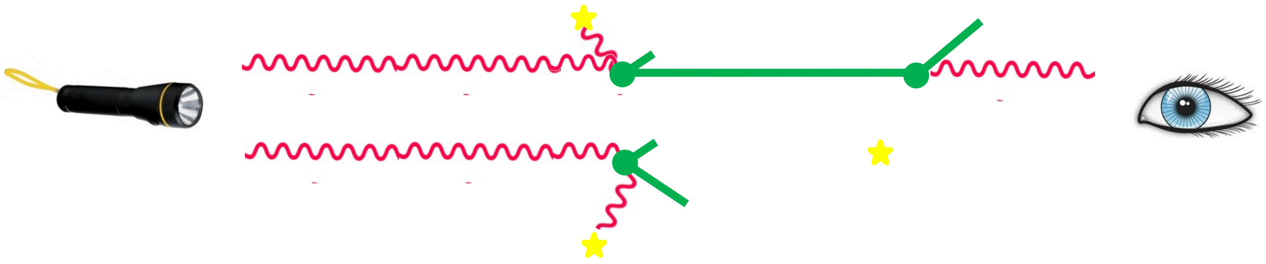
Interpretation of a gamma-ray burst event

Explanation by classical physics:

1. The event came from a galactic source - galactic latitude 4° - close to the plane of the Milky Way.
   In the same area of the celestial sphere is the source observed by the HAWK installation.
   But such an event from this direction came once in 1442/484 days and coincided with a gamma burs
   p ~ 0.003 (3 sigma).

2. Secondary photons produced during the electromagnetic cascade or GZK cutoff reach us,
   during which the proton produces π0 decaying into photons. But the distances for these processes are large.





Interpretation of a gamma-ray burst event

Explanation with new physics:

1. Pair production due to gamma-ray scattering on relic photons is suppressed by Lorentz invariance violation
2. Decay of heavy, sterile neutrinos.
3. Axion-like particles - the "light through the wall" mechanism

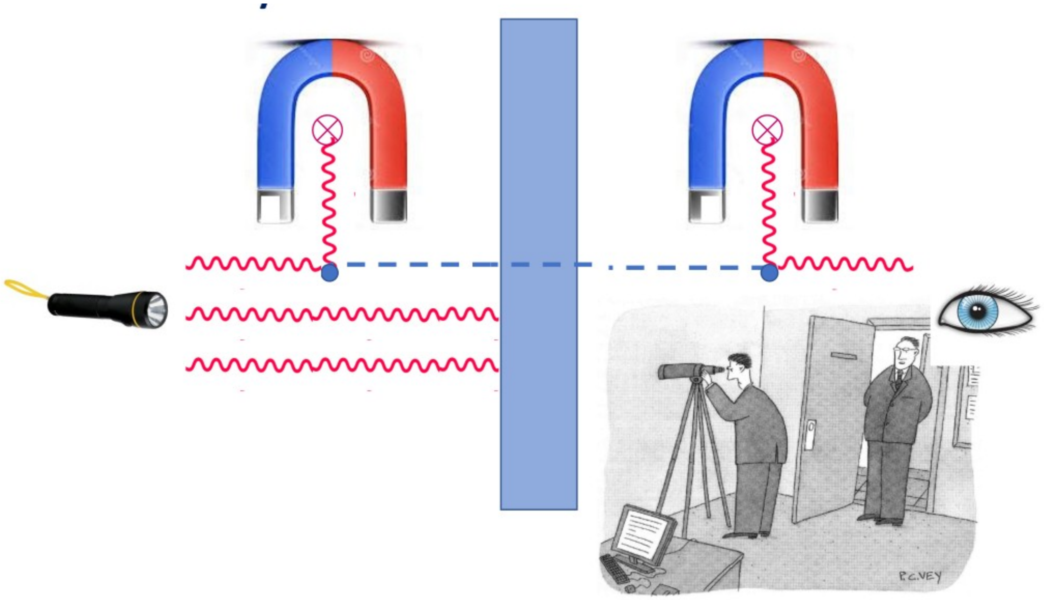
изменение дисперсионных соотношений

$$\boxed{E_a^2 - p_a^2 = m_a^2 \pm |\delta_{a,n}| p_a^{n+2}}$$

$$\Downarrow$$

$$\boxed{E^{\mathrm{th}}_{\gamma_{\mathrm{b}}} = \frac{m_{\mathrm{e}}^2}{E_\gamma} - \frac{1}{4}\delta_{\gamma,n}\, E_\gamma^{n+1}}$$

сдвиг пороговой энергии рождения пар



Заключение и выводы

- GRB 221009A – a record gamma-ray burst in brightness and photon energy
- the distance is large - red shift z=0.151
- LHAASO photons (до 18 ТэВ)
- photon-like event, Carpet-3 (~300 ТэВ)
- due to the creation of pairs in background radiation, photons of such energies should not reach us
- photons from the Galaxy? Cascades? Axion-like particles???

Even with large installations like LHAASO, small ones like Carpet, located far away in geographic longitude, can yield important results

Thank you for your attention!