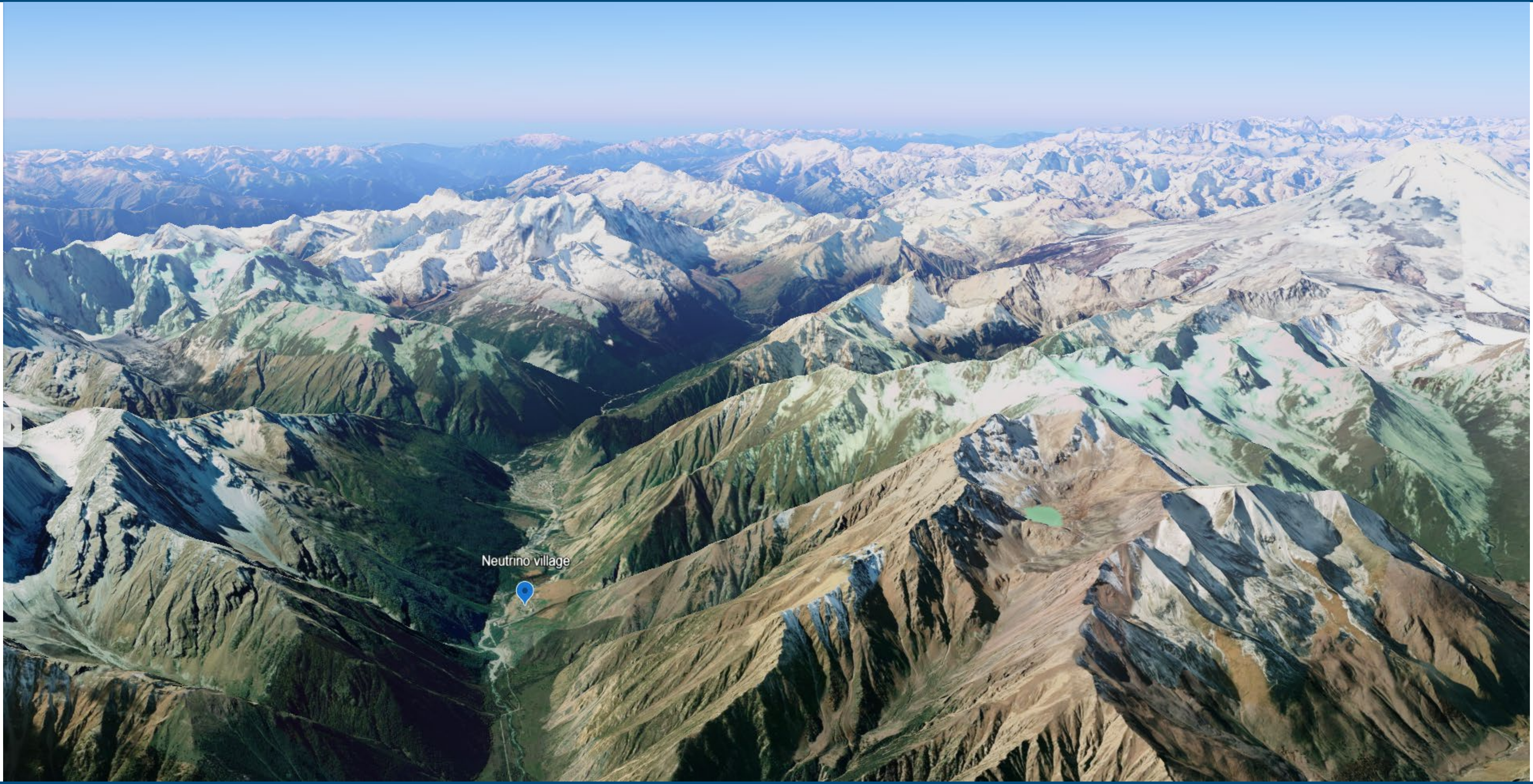
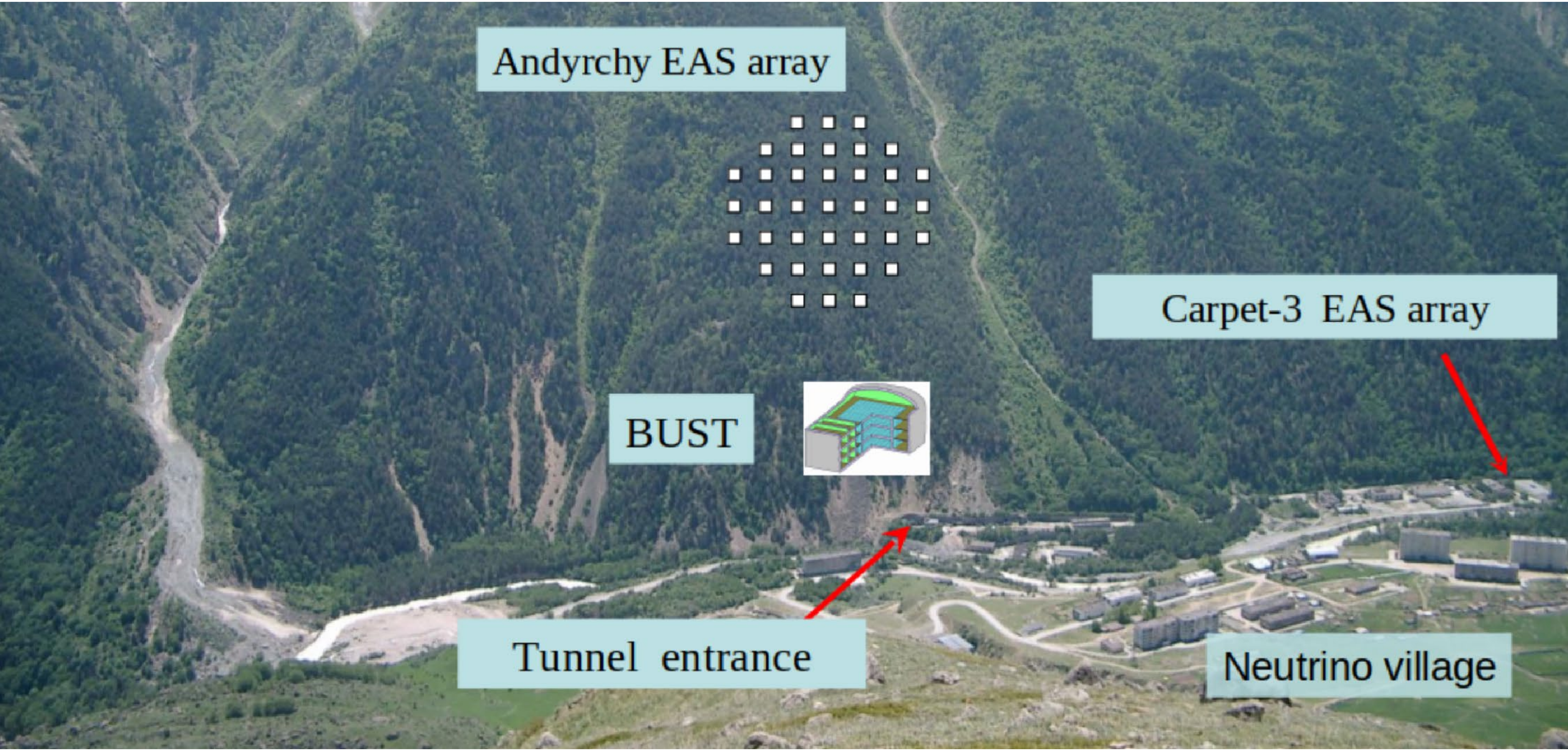
Recent results of the Carpet-3 collaboration

Nikita Vasiliev
from the name of the «Carpet-3» collaboration

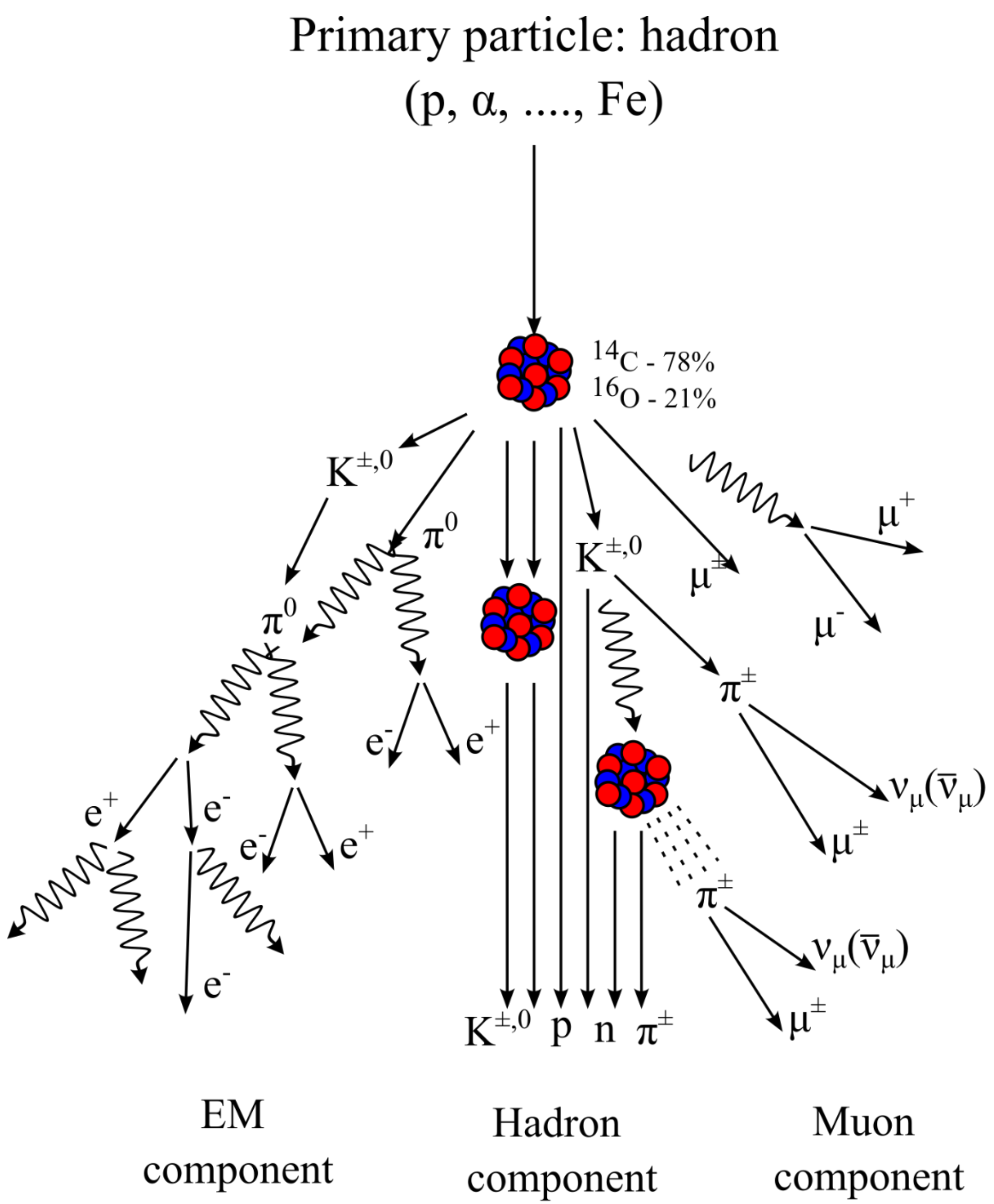
Baksan Neutrino Observatory, Neutrino village

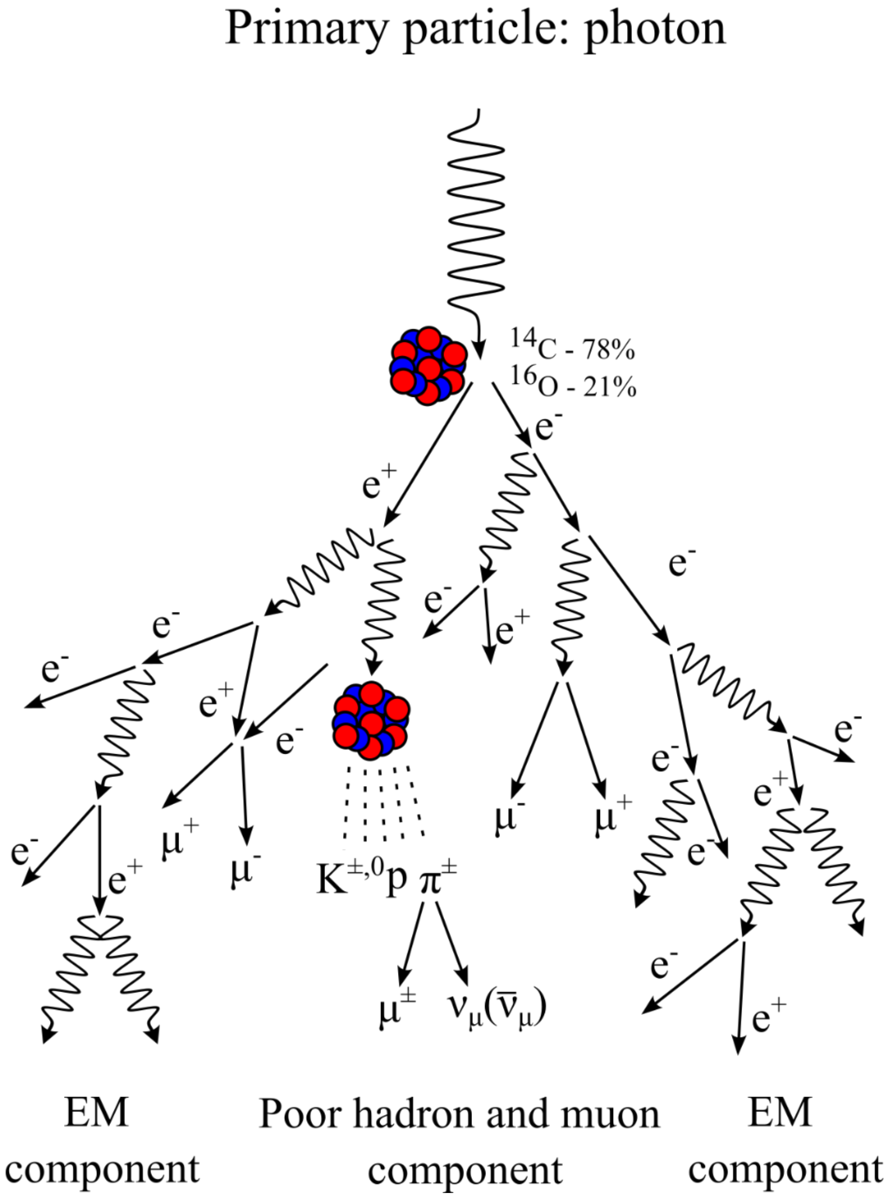


Baksan Neutrino Observatory detector complexes

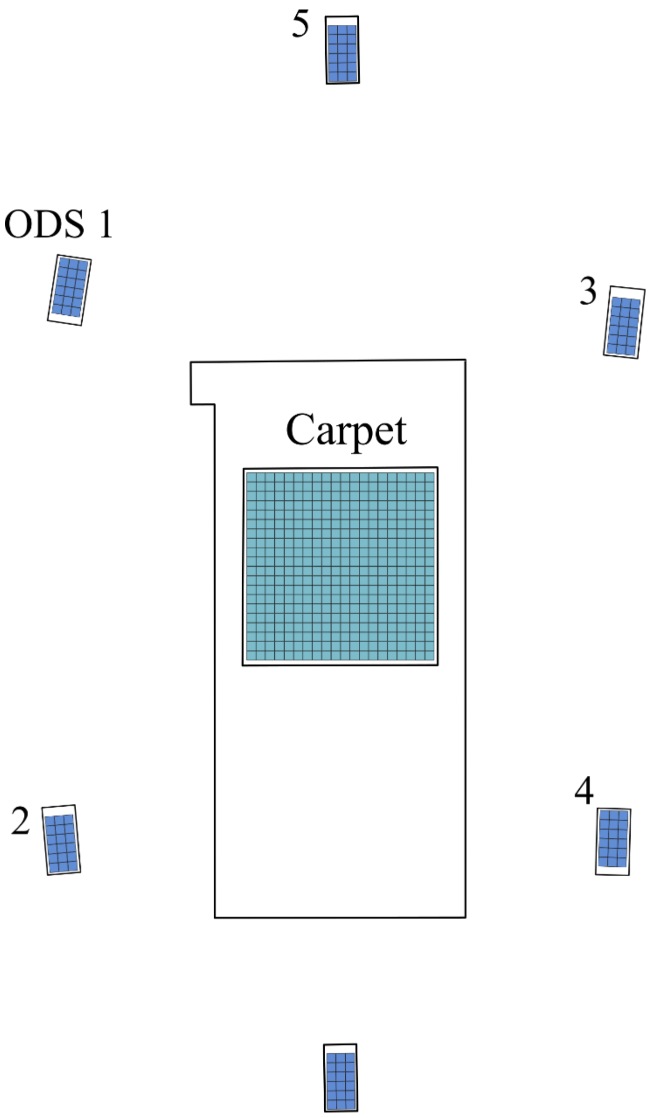


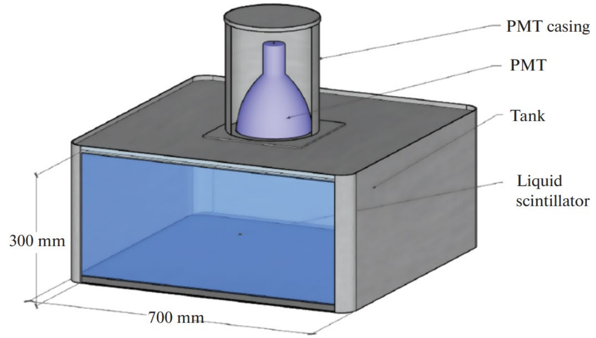
Extensive Air Showers (EAS)



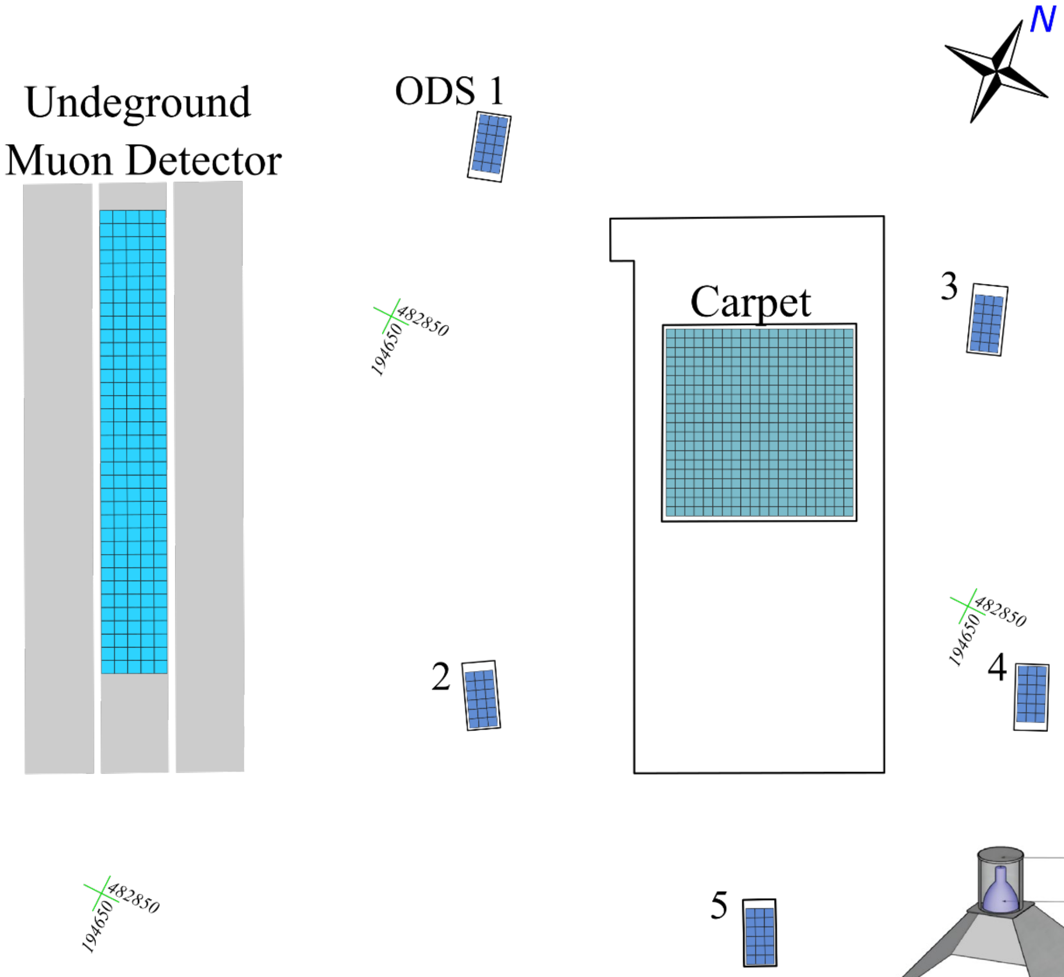


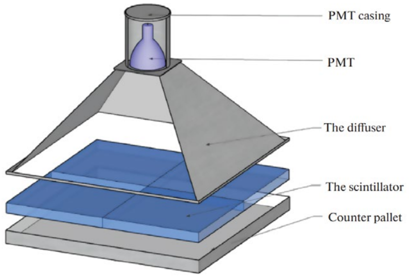
Carpet EAS array since ~1973





First modernization (Addition of the Muon Detector 175 m^2)





Carpet-3 facility (Current state)

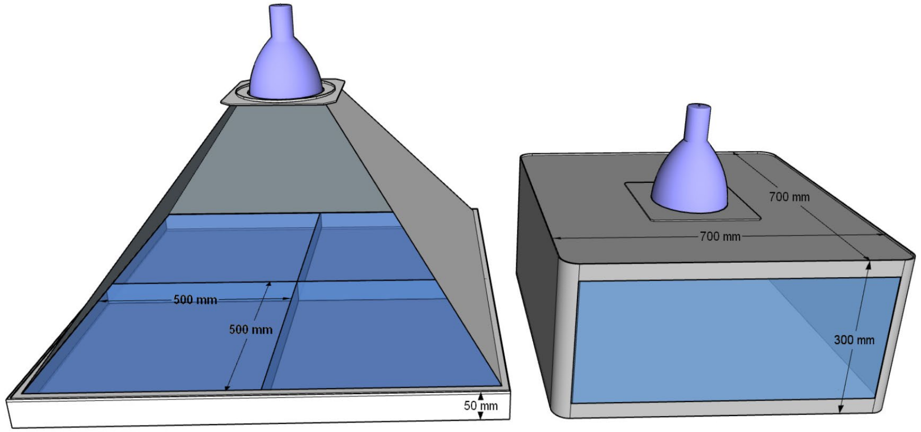
A – Carpet detector array;

B – outer detector stations (**ODS**);

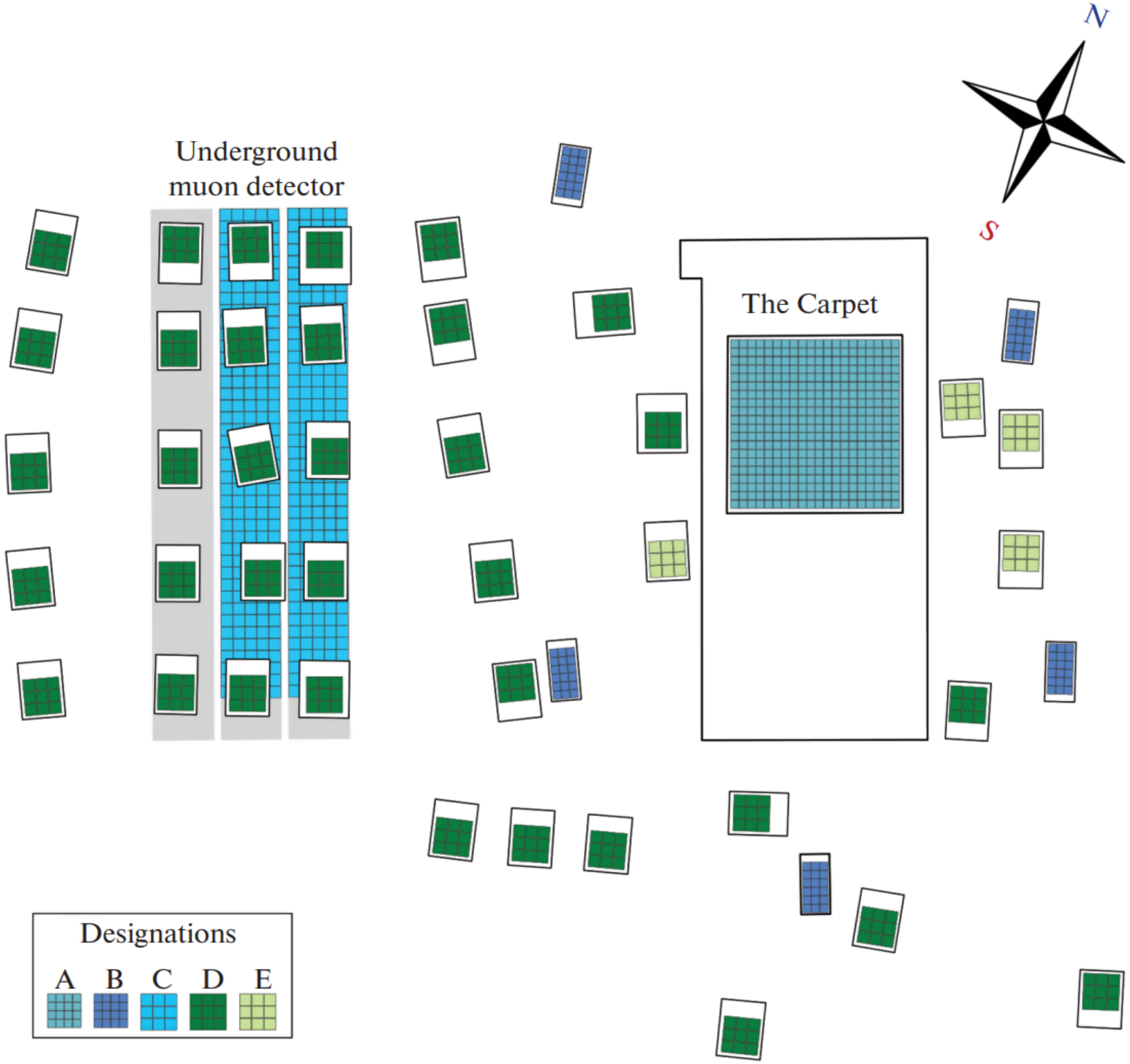
C – Underground muon detector (**MD**);

D – new ODS (plastic scintillator);

E – unfinished ODS;



1 r.p. ~ 10 MeV **1 r.p. ~ 50 MeV**



r.p. (relativistic particle) – most probable energy deposition in the scintillator created by relativistic muons.

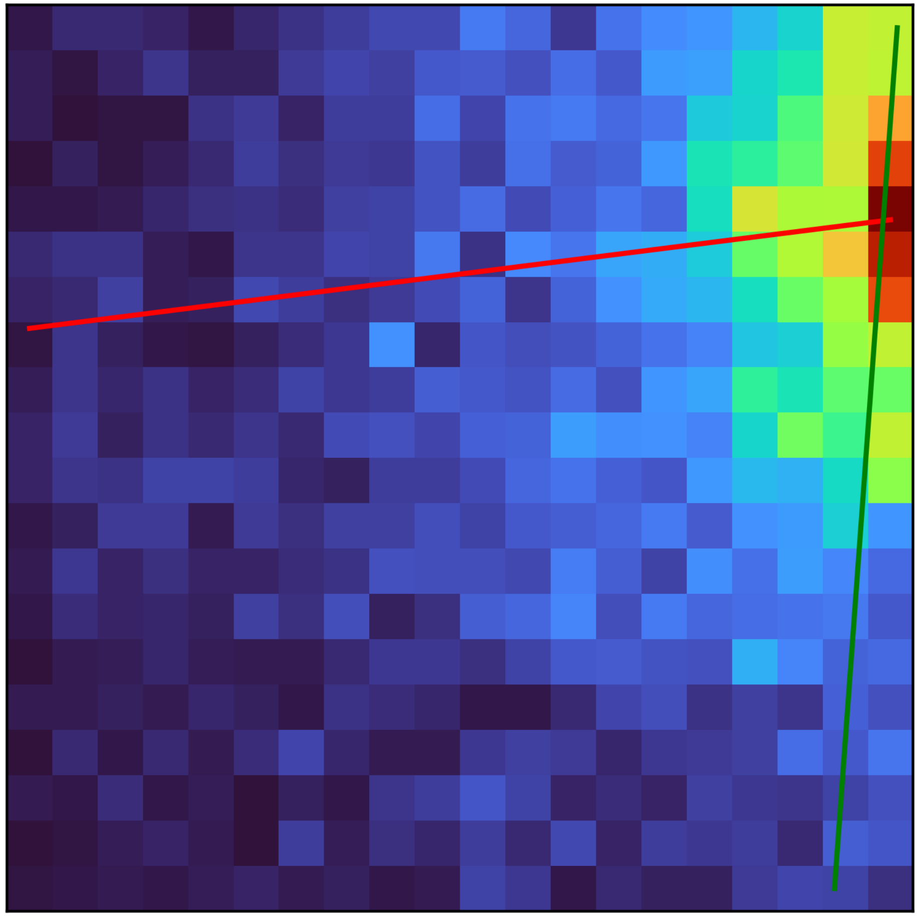
Reconstruction methodology

- ❖EAS arrival direction (θ, φ) is reconstructed by relative time lags of 4 main ODS with flat shower front approximation.
- ❖Shower size Ne and age s is reconstructed by fitting particle density spatial distribution with NKG function:

$$\rho_e(r,s,N_e) = \left(\frac{N_e}{r_M^2}\right)\frac{\Gamma(4,5-s_N)}{2\pi\Gamma(s_N)\Gamma(4,5-2s_N)}\left(\frac{r}{r_M}\right)^{s_N-2}\left(1+\frac{r}{r_M}\right)^{s_N-4,5}$$

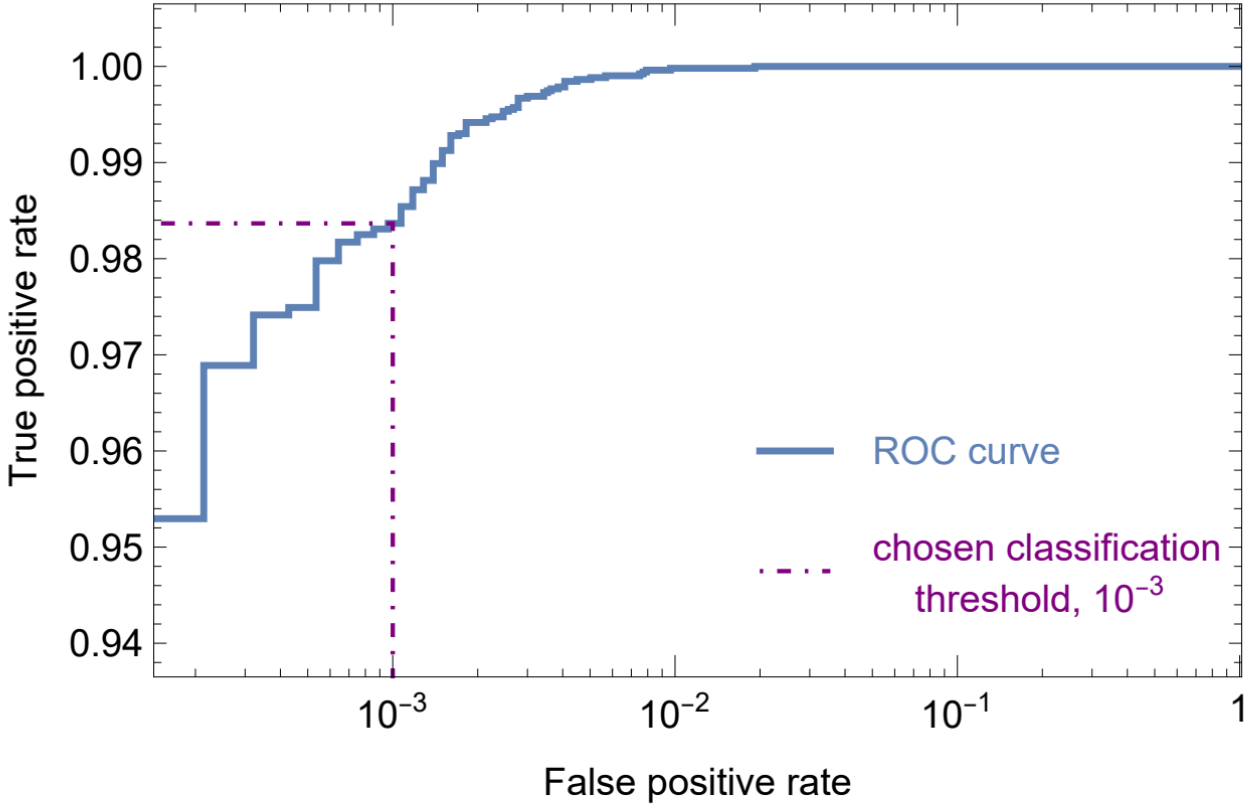
Shower core position reconstruction

- **Identify the position of the detector with maximum energy deposition in each of the 20 central array rows/columns.**
- **Assign a weight equal to the total energy deposition in the row/column.**
- **Fit straight lines to the weighted points via LSM.**
- **The intersection of the lines defines the shower axis.**

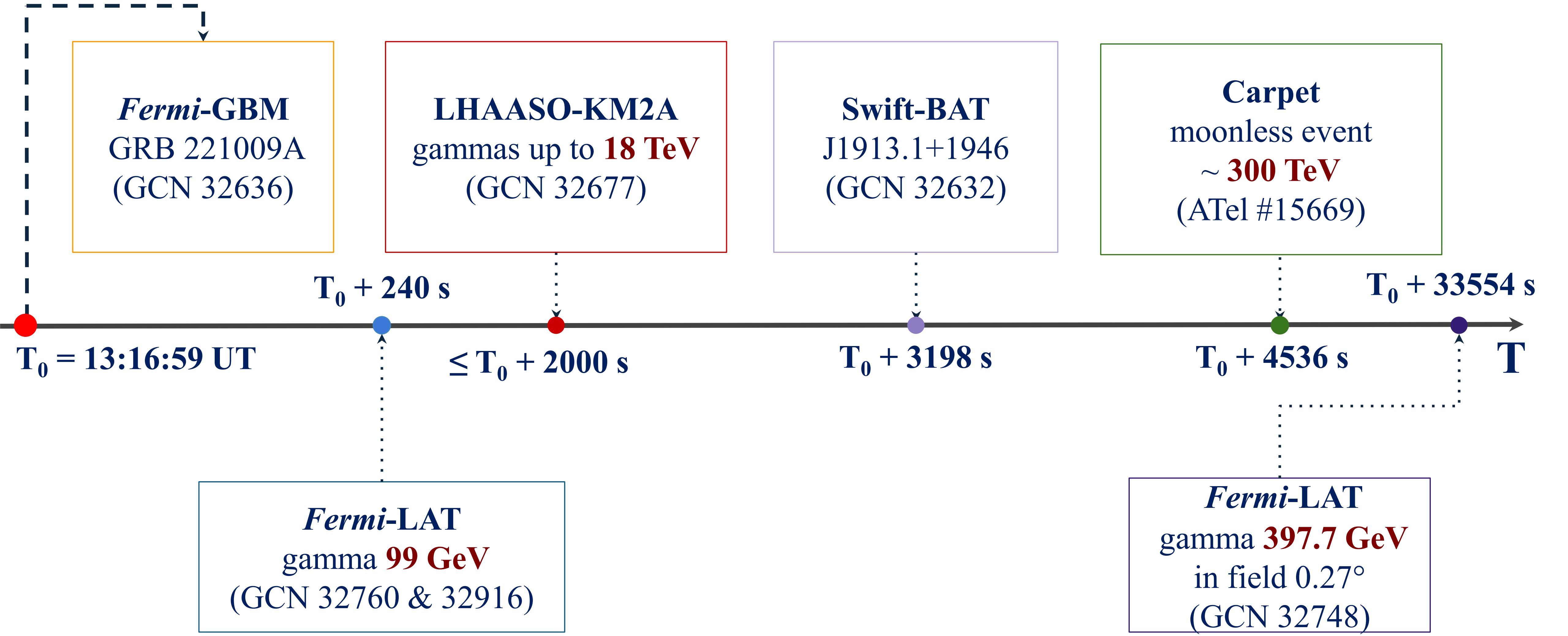


Neural network gamma-ray classification

- We estimate the type of primary particle using a neural network classifier trained on the MC event set (80609 events).
- The network is trained to distinguish between events with proton and photon primary particles.

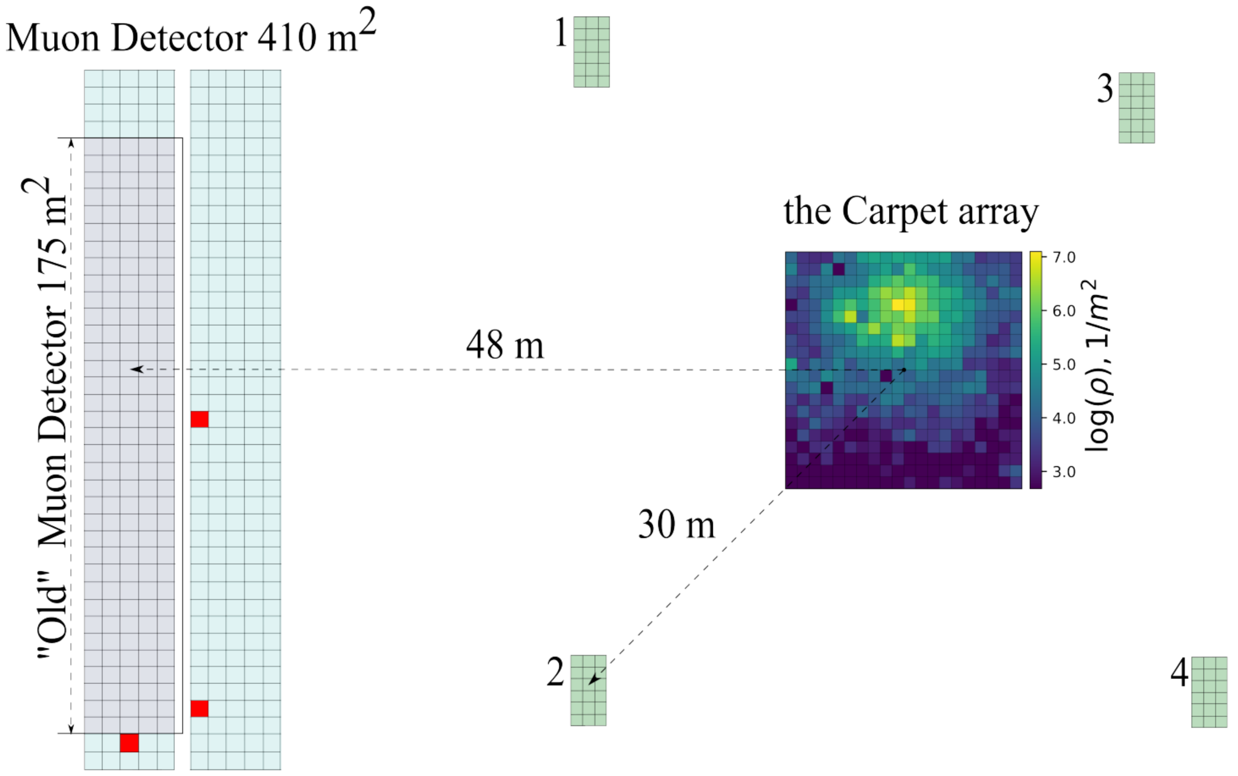


UHE γ-astronomy at the BNO (GRB221009A)

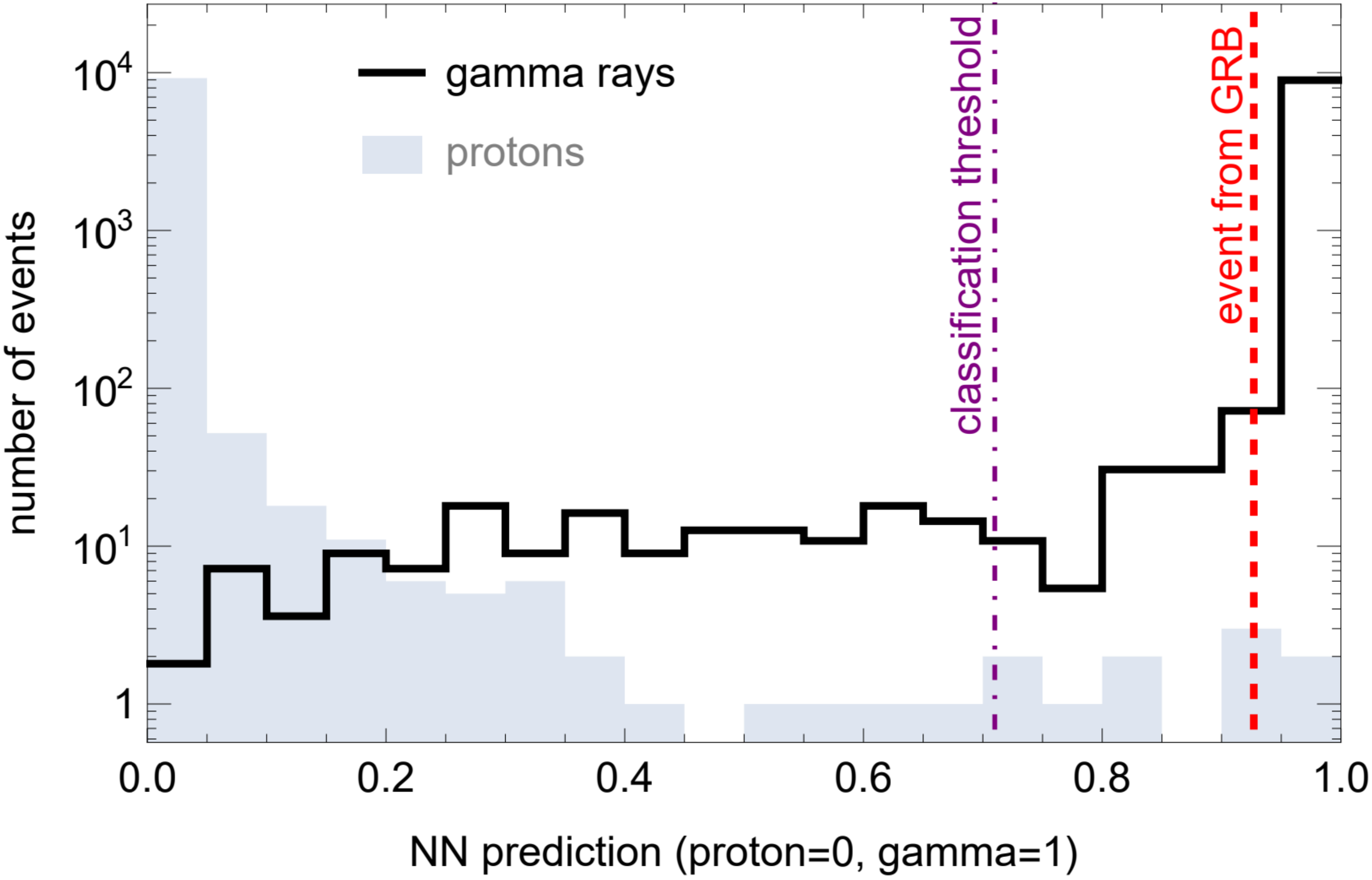


The event associated with GRB 221009A

- Estimated energy of the primary particle (E=300 ± 40 TeV).
- Air Shower is photon-like (probability of a hadronic primary is 0,03 %).
- The event is coincident with the GRB in its arrival direction and time (chance probability ~ 0,9 %).

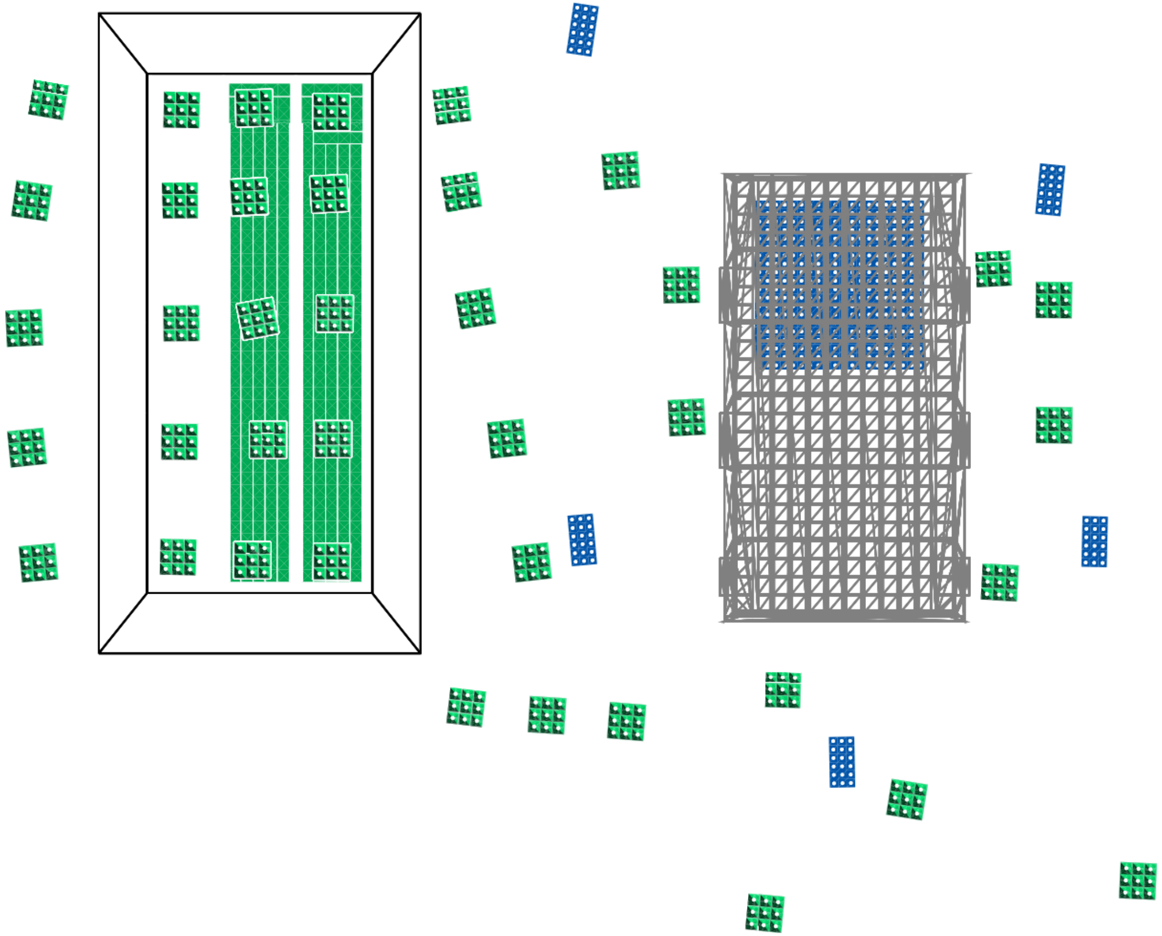


GRB event classification



Carpet-3 model in Geant4

- ❖ Includes 1251 scintillation detectors.
- ❖ Passive geometry taken into account (central Carpet building and muon detector embankment).
- ❖ The response of each detector is calculated by simulating scintillation photons reaching the PMT photocathode.



Record and reconstruction triggers

- Total energy deposition in the central Carpet exceeds 15 r.p.
- At least four ODS exceed the 0.5 r.p. threshold.

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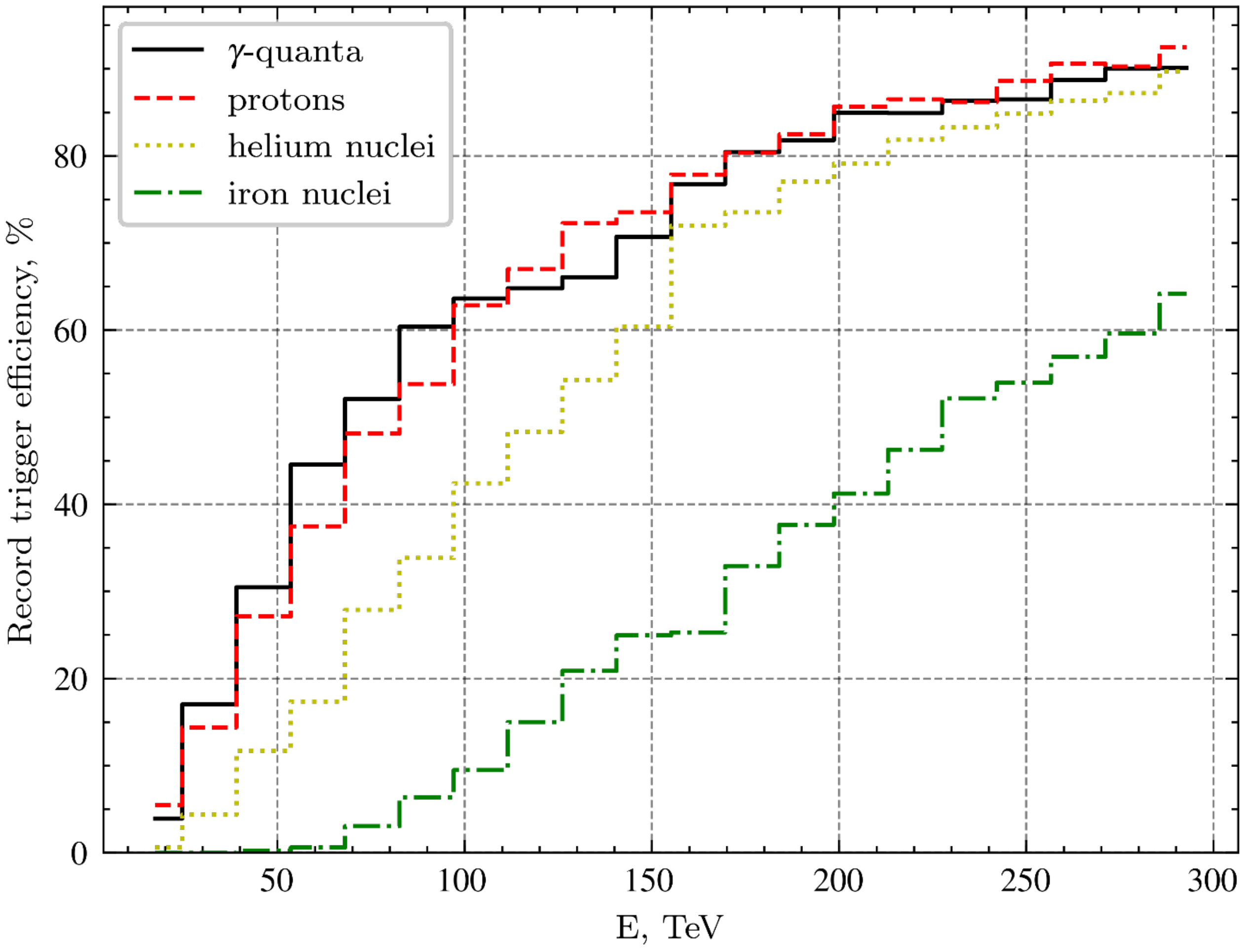
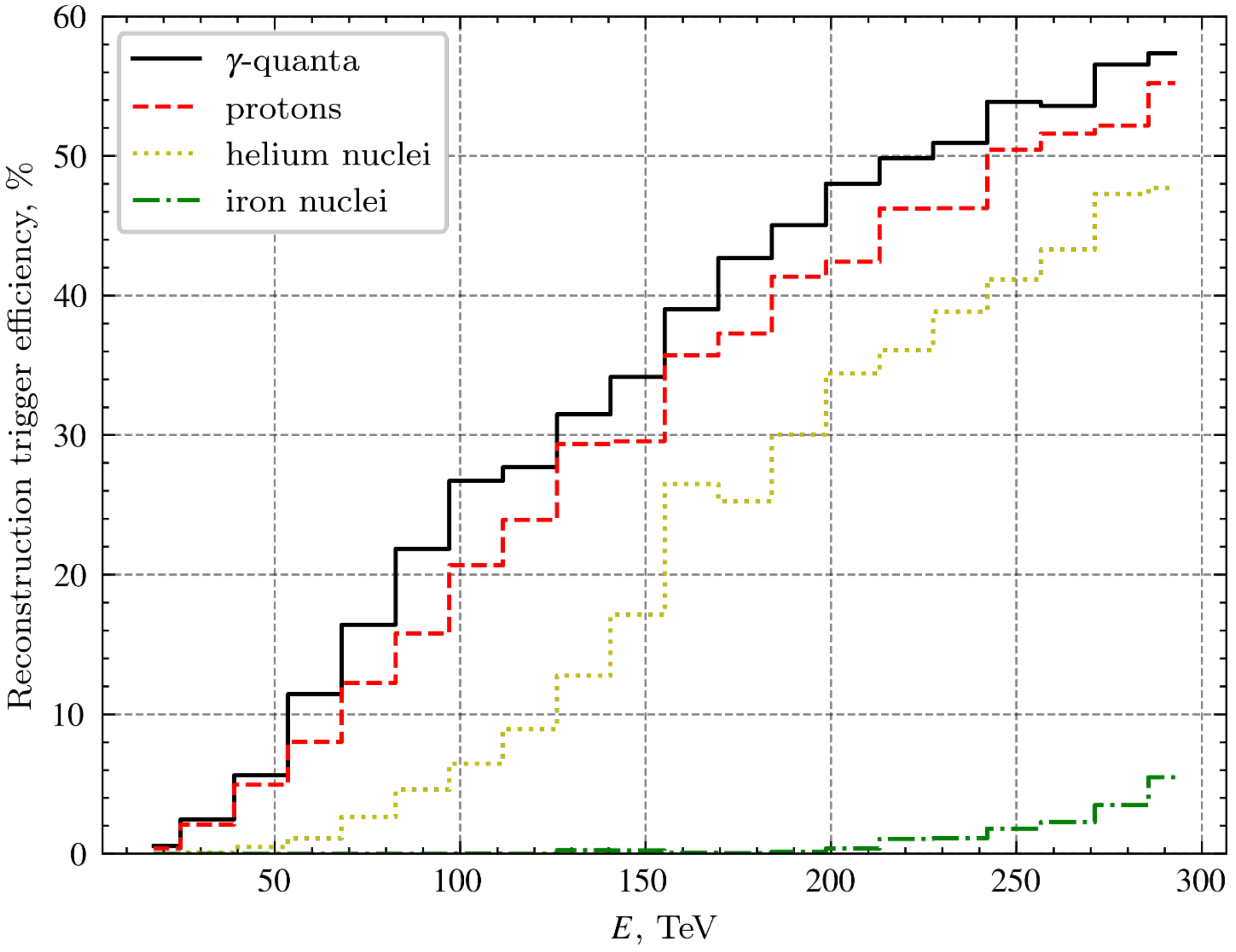
- At least four ODS exceed the 0.5 r.p. threshold.
- At least 8 r.p. in 50 central cells
- Reconstructed axis must lie within the central 12.6×12.6 m^2 area.
- Reconstructed zenith angle $\theta \leq 40$.

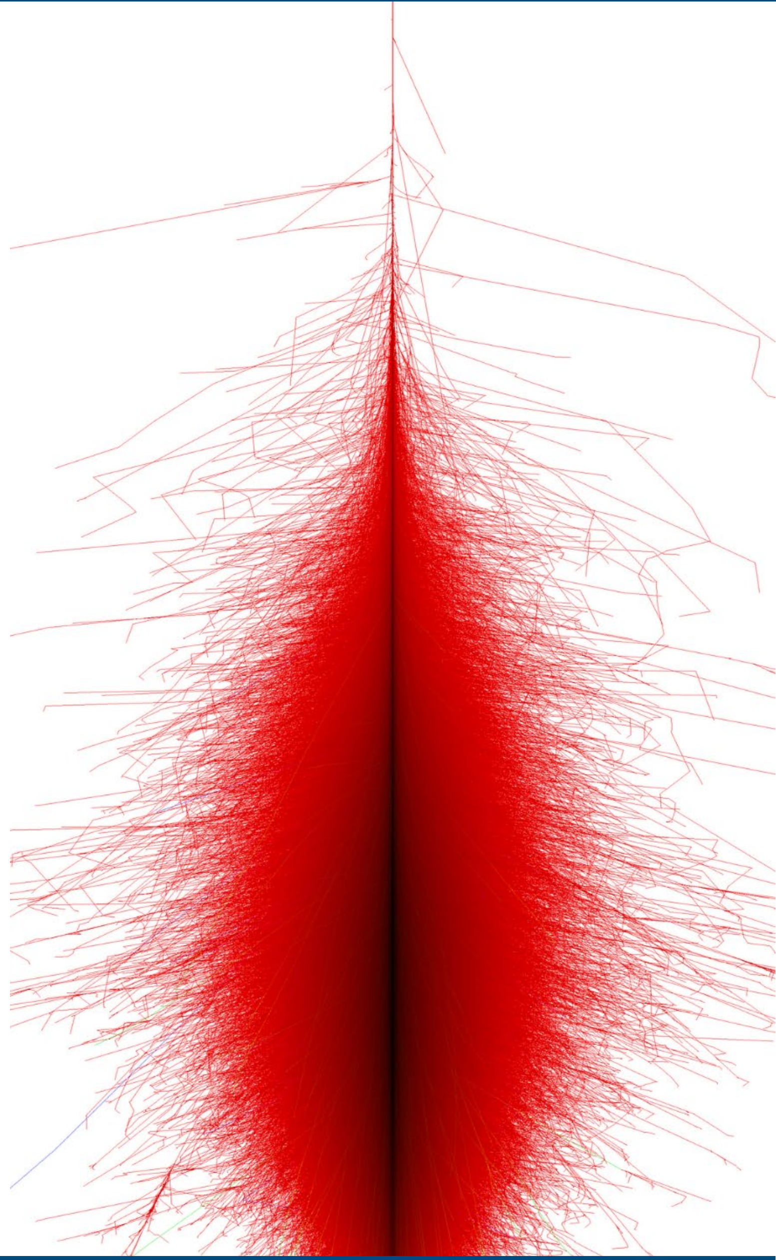
Trigger efficiency estimation





Conclusions

- A detailed description of the Carpet-3 detector array is introduced.
- A set of reconstruction algorithms of such parameters as EAS core position, arrival direction, age, size and primary type is presented.
- The developed methodology allowed us to estimate the efficiency of the detector array depending on the energy and the type of primary particle.
- Main goals for future research are developing more accurate reconstruction methods with the help of machine learning + testing the model precision on a large scale of energies.



Thank you for your attention!

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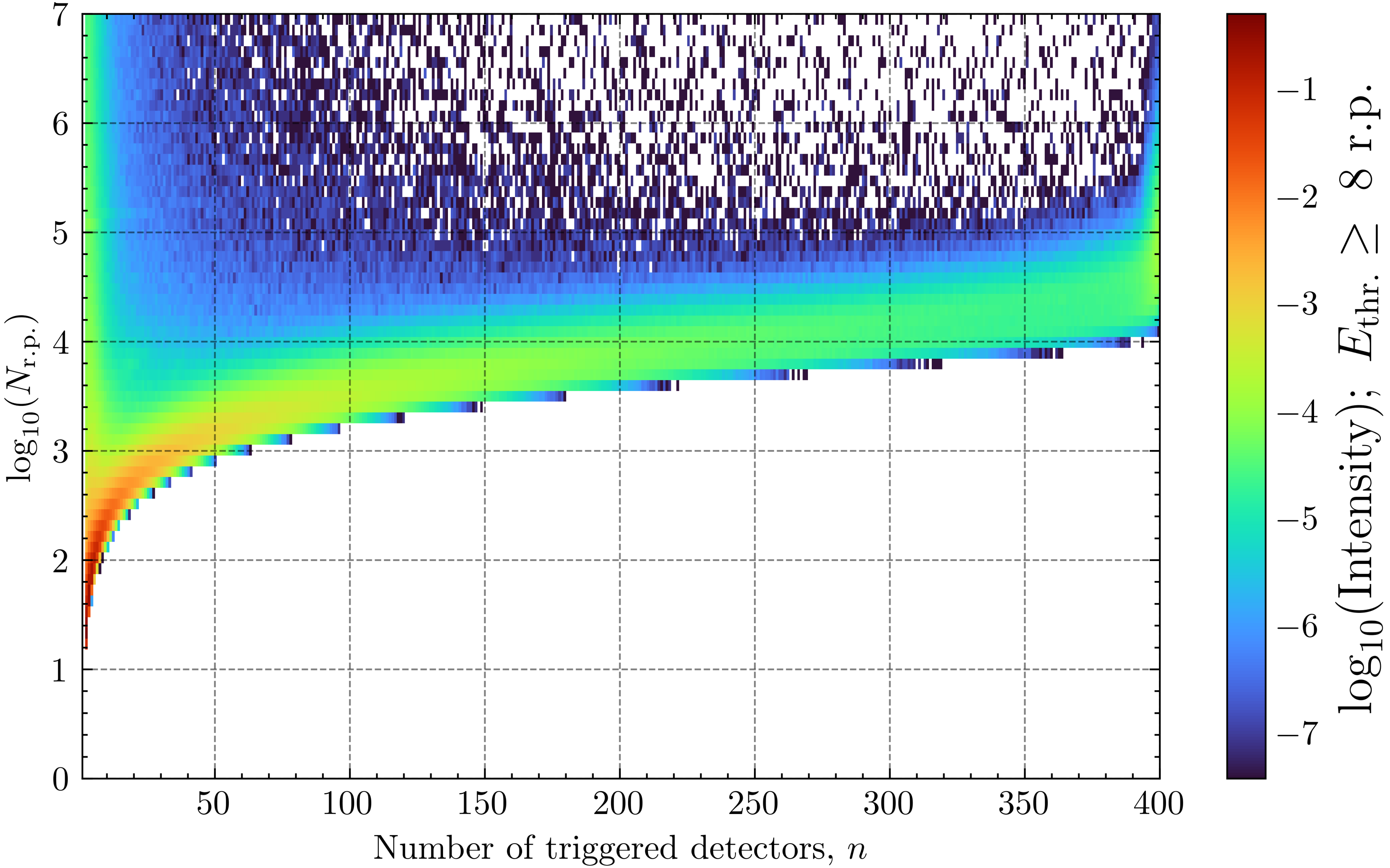
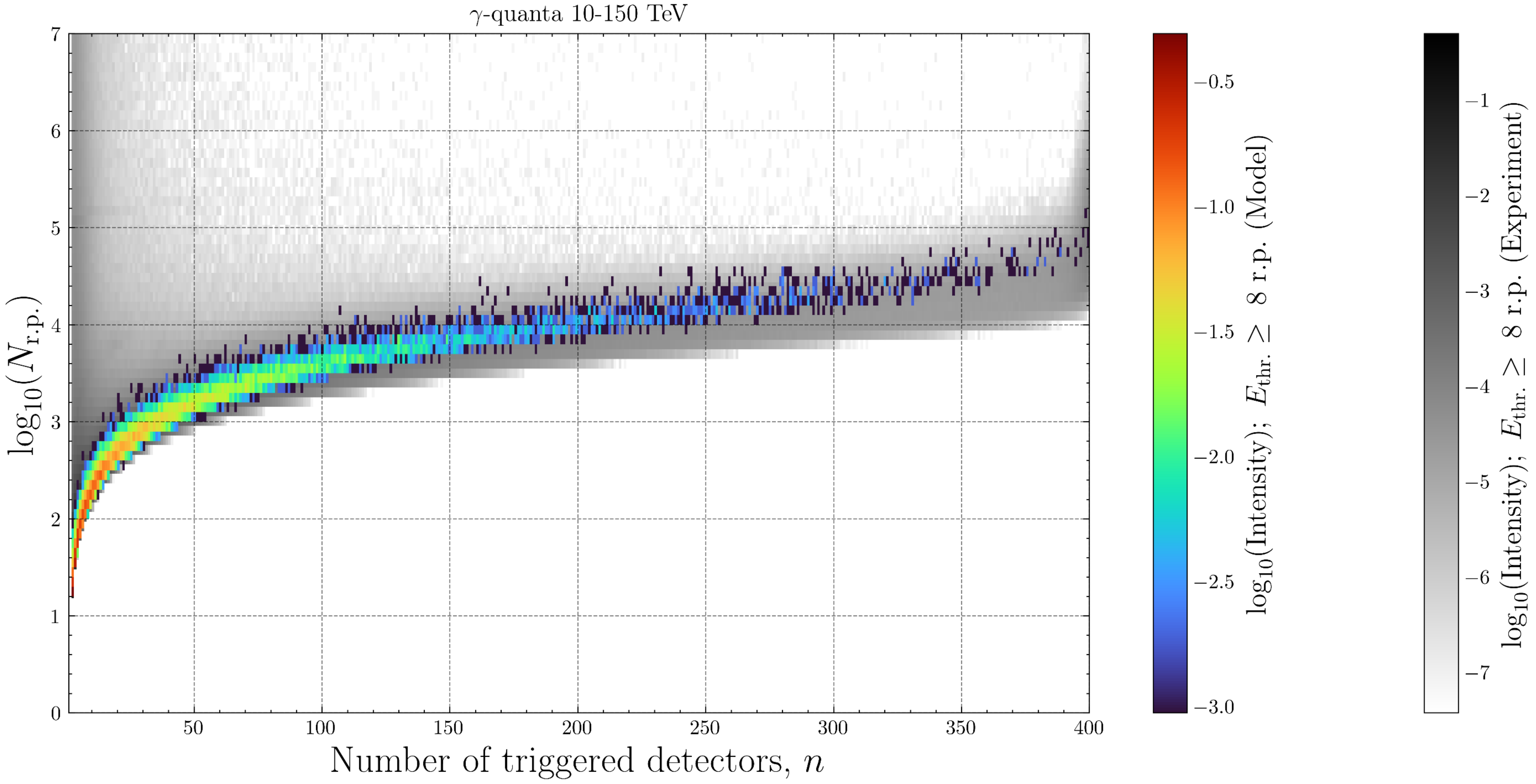
CORSIKA simulations

- ❖Over 200000 EAS events were generated for primary γ-quanta, protons, helium, and iron nuclei.
- ❖Zenith angles ranged from 0° to 40°.
- ❖Discrete uniform energy distribution from 10 to 300 TeV (1 TeV steps).
- ❖Observation level: 1700 m above sea level.

Experimental distribution of sum of r.p. vs number of triggered detectors



Comparison with the experiment



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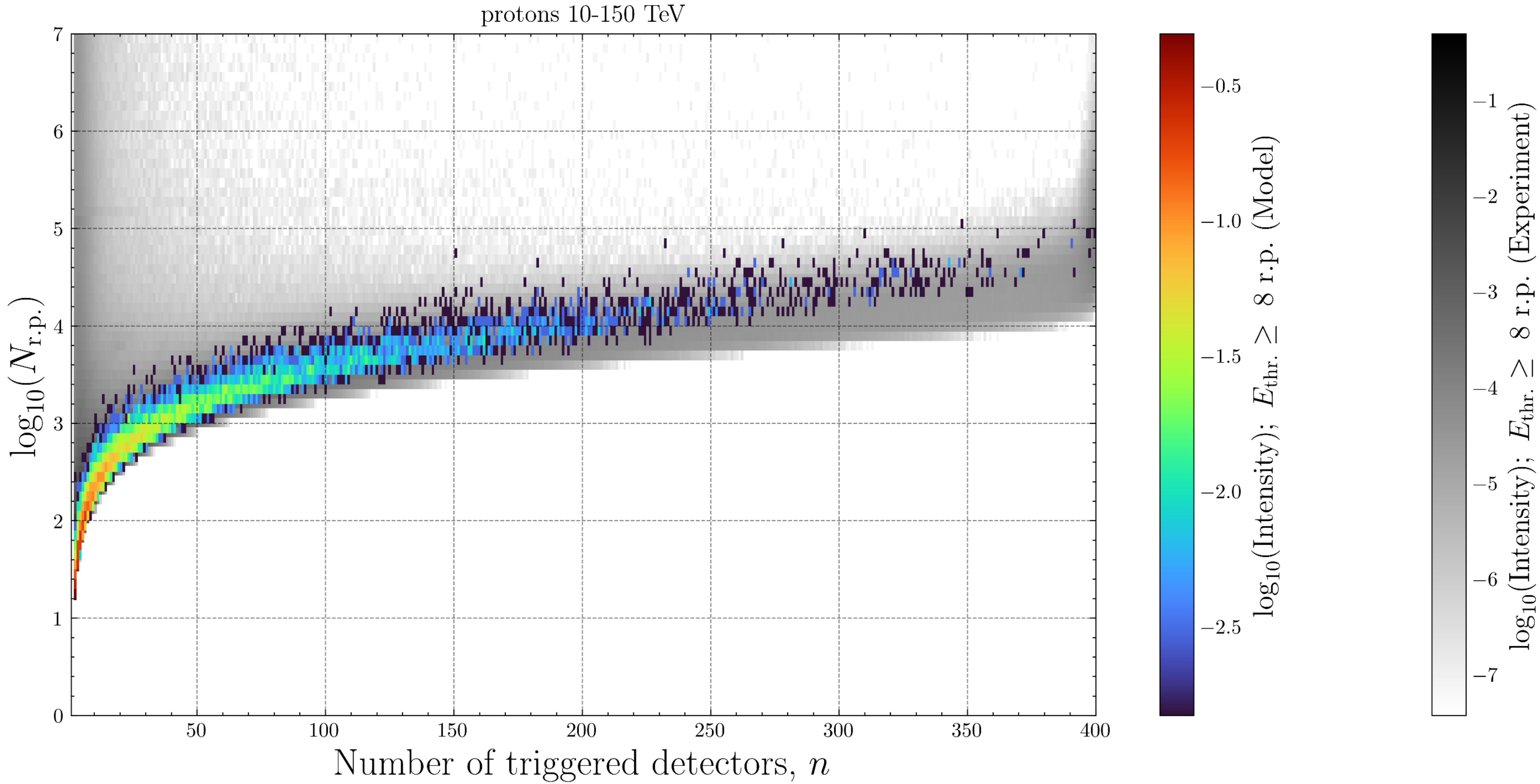
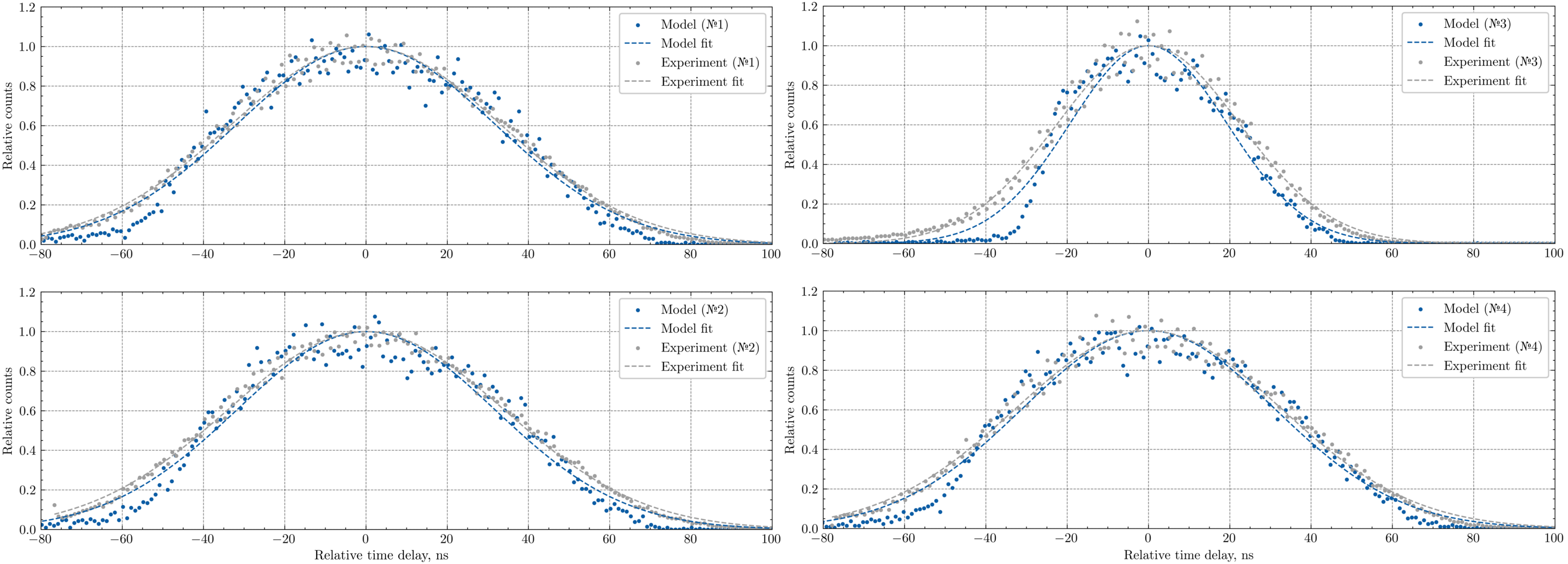


Time distributions of ODS triggers (0 equals central Carpet trigger time)



(x, y) and (ϑ, φ) reconstruction precision