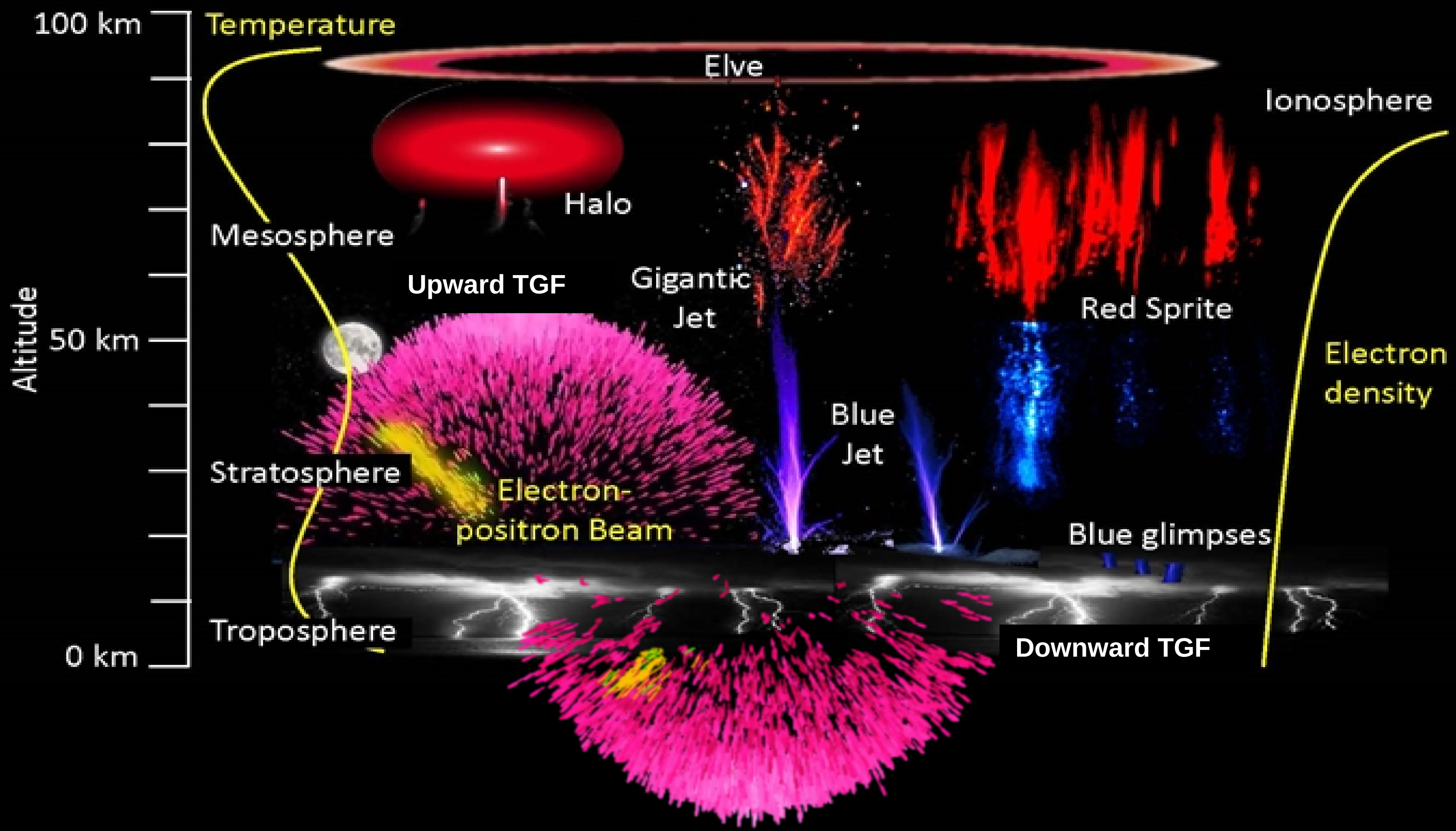
Status on TGF observations at the Pierre Auger Observatory

Roberta Colalillo[1] for the Pierre Auger Collaboration,
John Ortberg[3], Joseph Dwyer[2], David M. Smith[3]

1. Università degli Studi di Napoli “Federico II” and INFN, Sezione di Napoli, Italy
2. Department of Physics and Space Science Center (EOS), University of New Hampshire, USA
3. Physics Department and Santa Cruz Institute for Particle Physics, University of California, USA

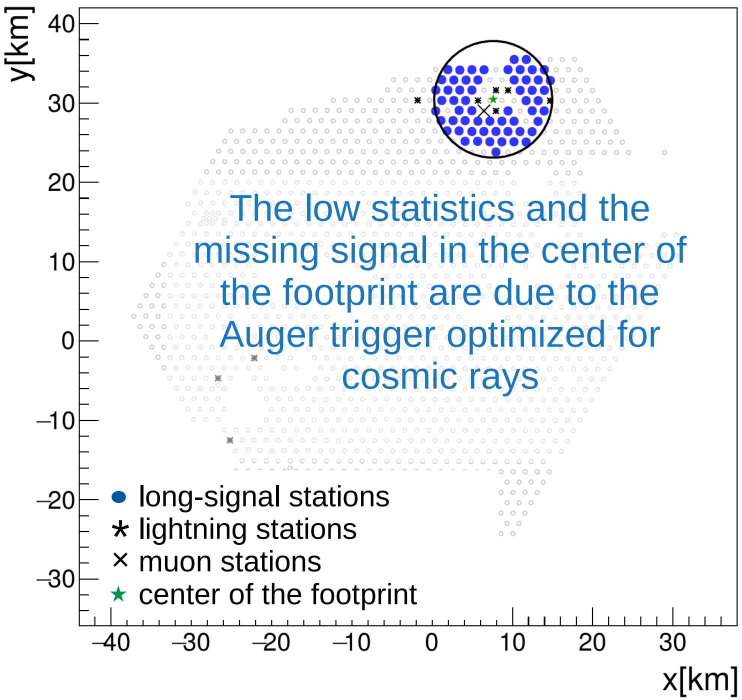
Meeting Auger Italia, Torino, 04/01/2025

Bright events produced by lightning

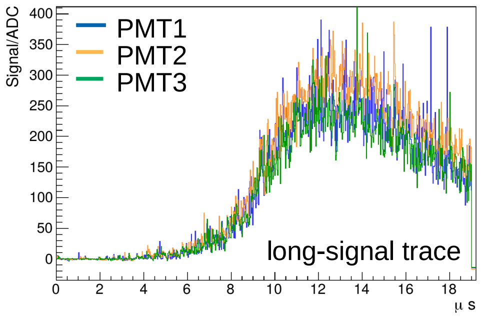


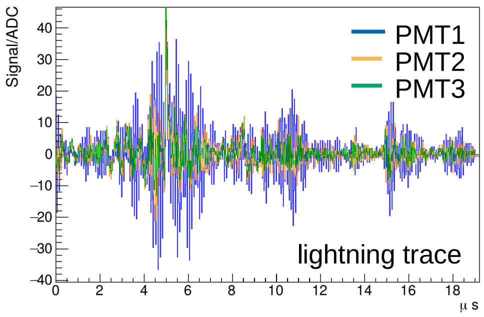
“TGF events”

23 peculiar events collected from 2005 to 2017 (change in the SD trigger).



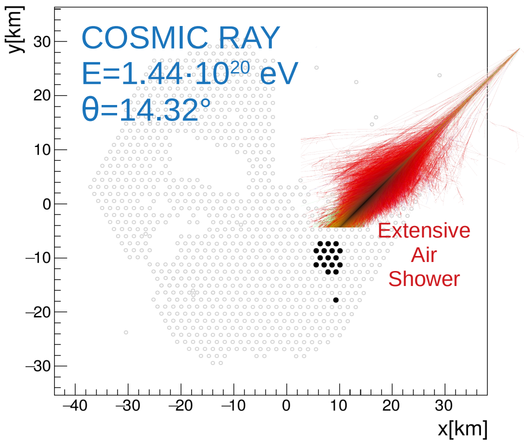
The low statistics and the missing signal in the center of the footprint are due to the Auger trigger optimized for cosmic rays

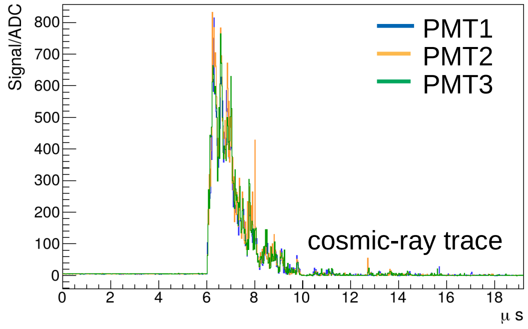


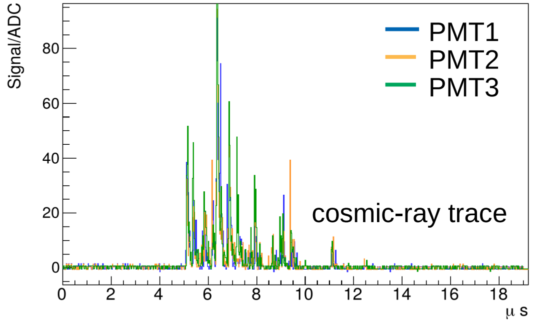


A dedicated trigger for TGF events was designed and installed.

Other work is necessary because the Pierre Auger Observatory was upgraded and the TGF algorithm needs to be optimized according to the new electronics.

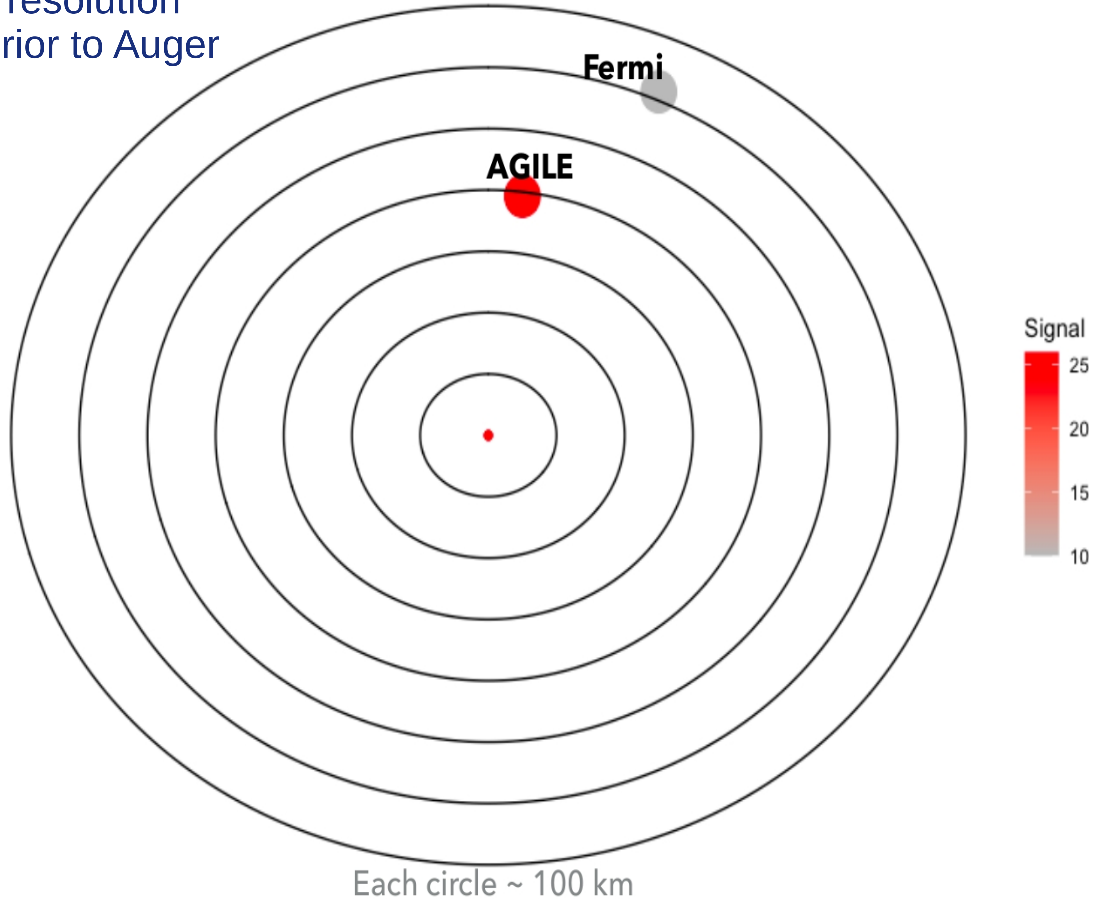


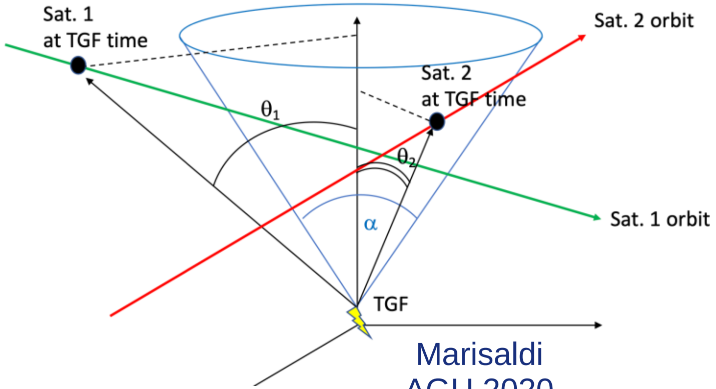




Advantages of a ground array

Greatest spatial resolution prior to Auger

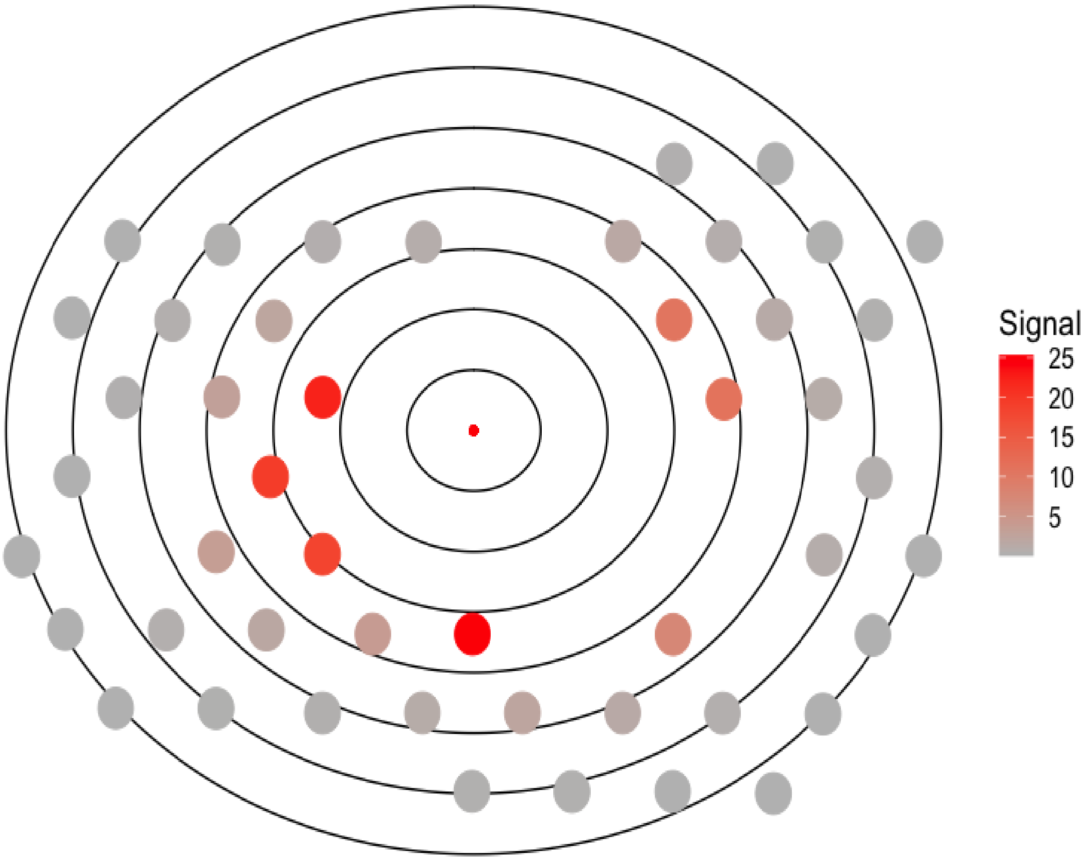




Marisaldi AGU 2020

Advantages of a ground array

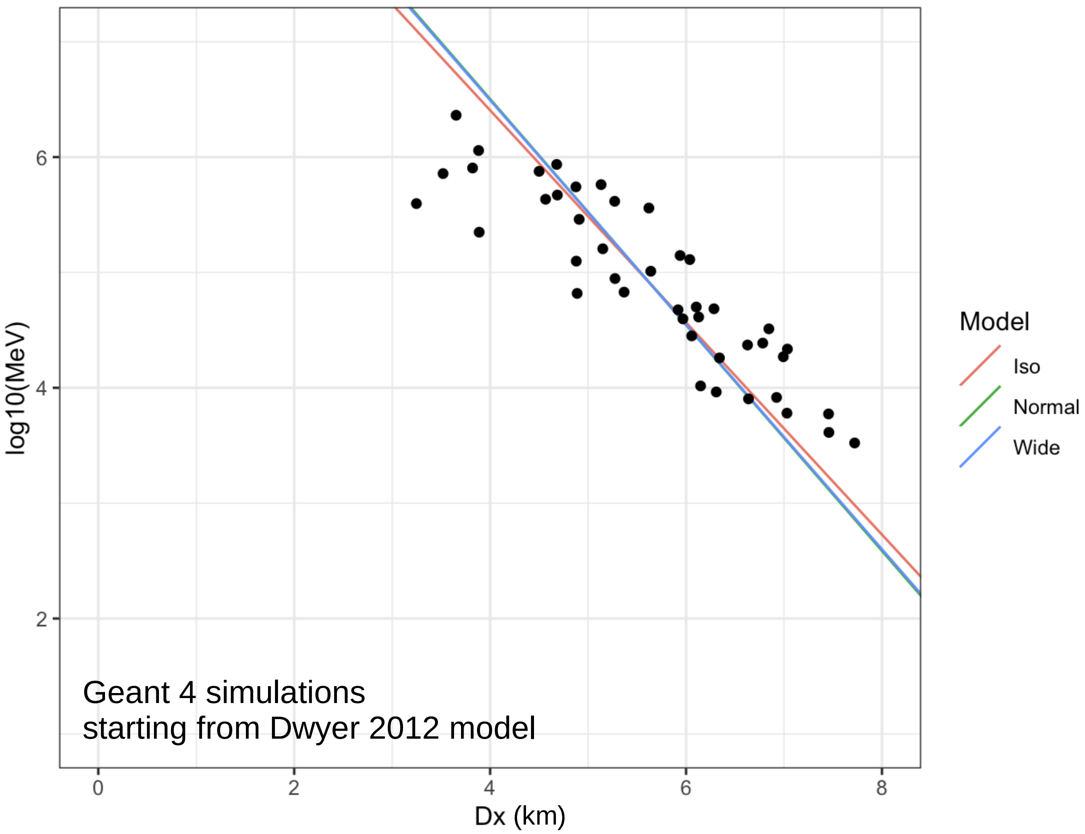
@Auger



Each circle ~ 1 km

- Reconstruction of the source position (few km above the ground)
- Sampling of the cone
  → study of the signal distribution
- Very detailed signal
  → Cherenkov detectors sensitive to gammas > 1 MeV
  → smooth time profile with 25 ns time resolution

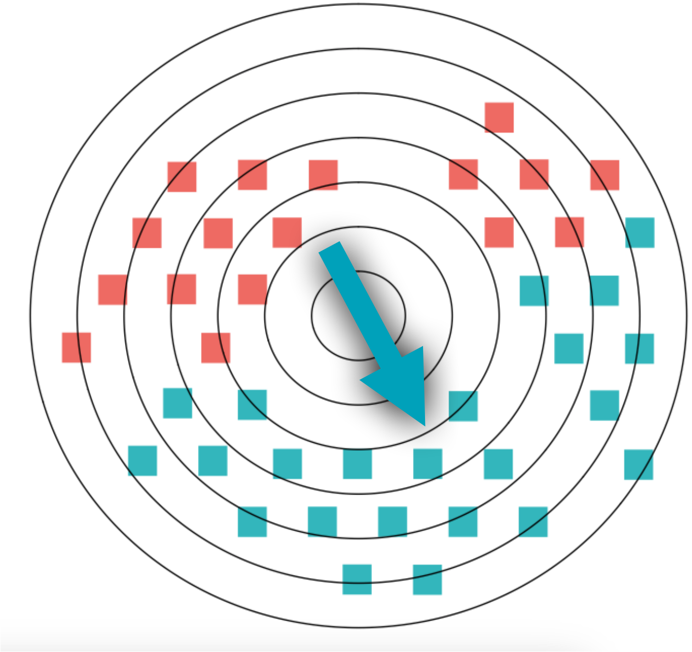
Comparison with standard TGF simulations

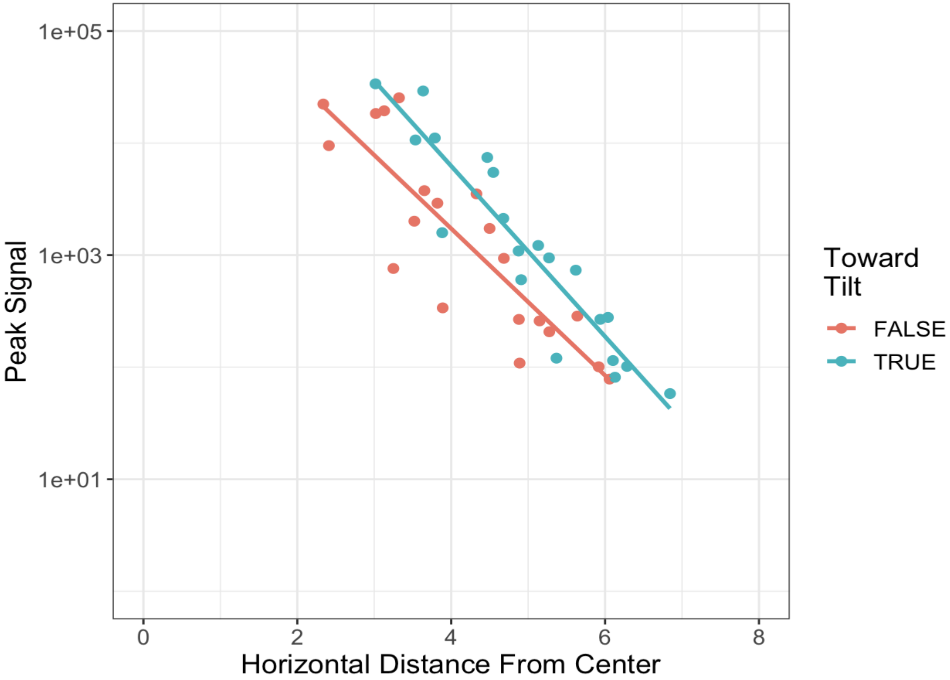


☺ Auger TGFs show a brightness similar to TGFs seen from space (10^{17}-10^{18} photons)

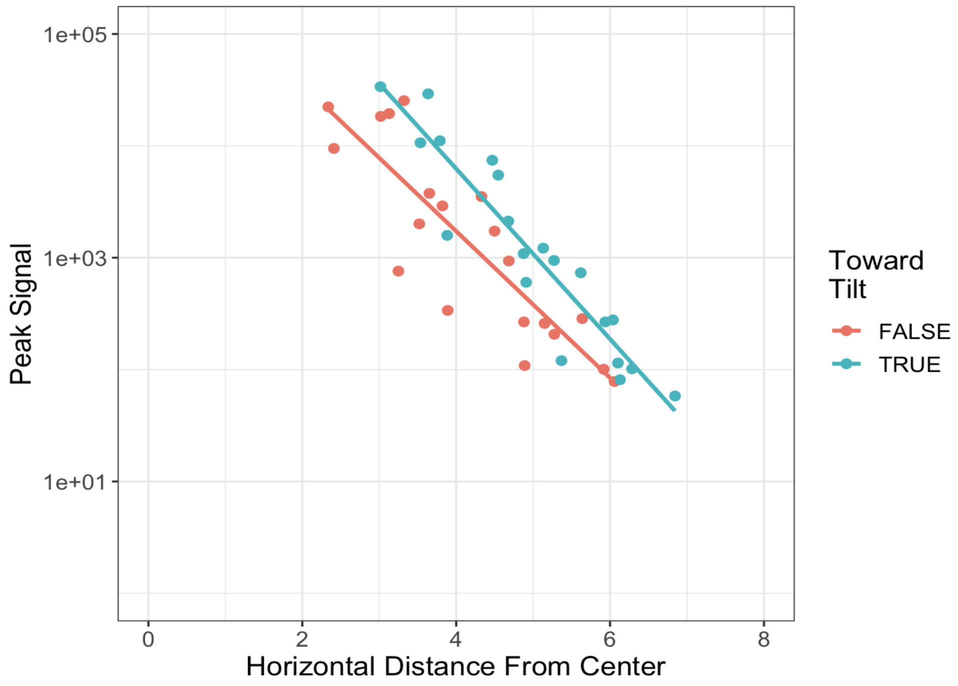
☹ The slope is not very well reproduced by standard TGF models

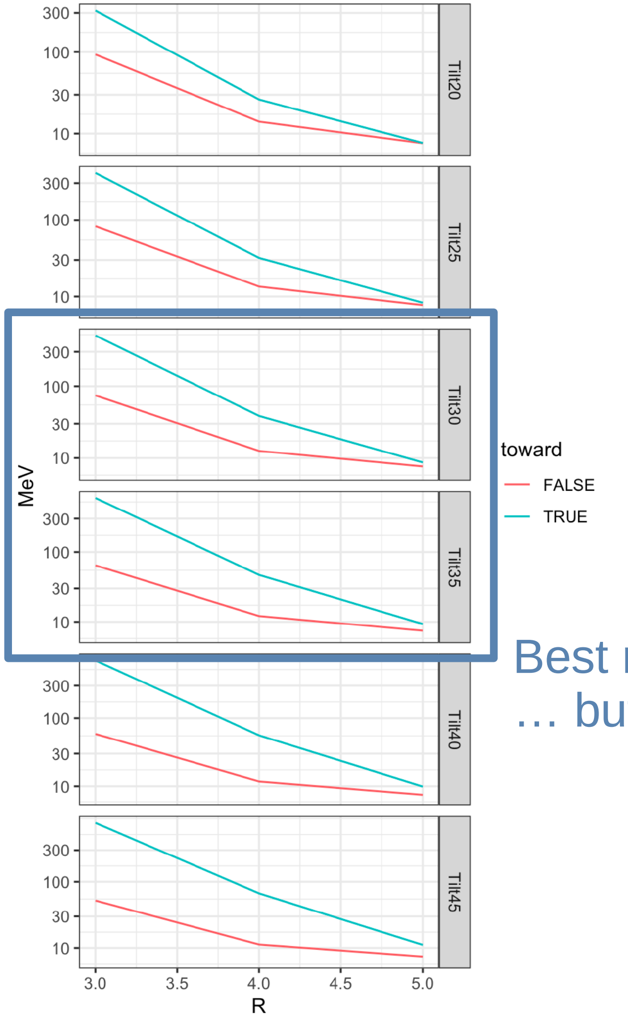
Studying the signal distribution





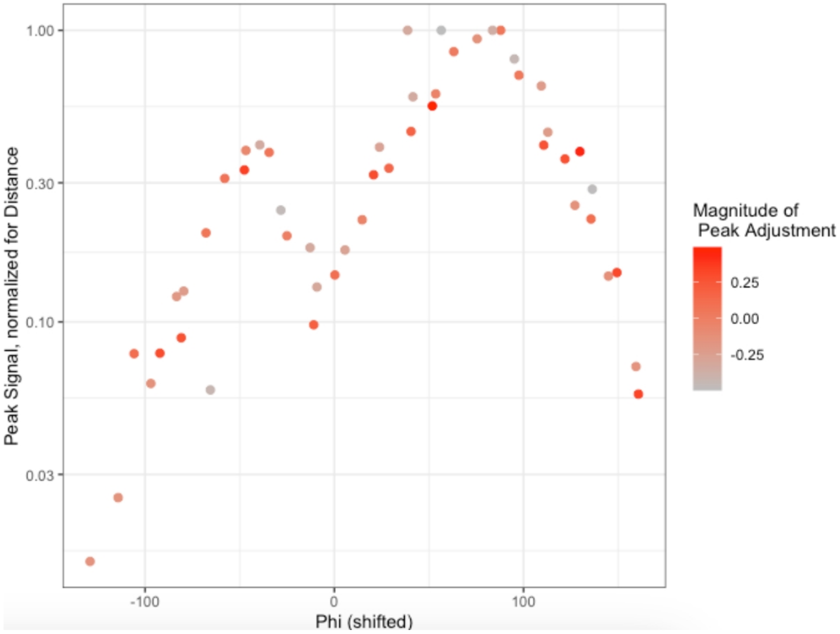
Studying the signal distribution

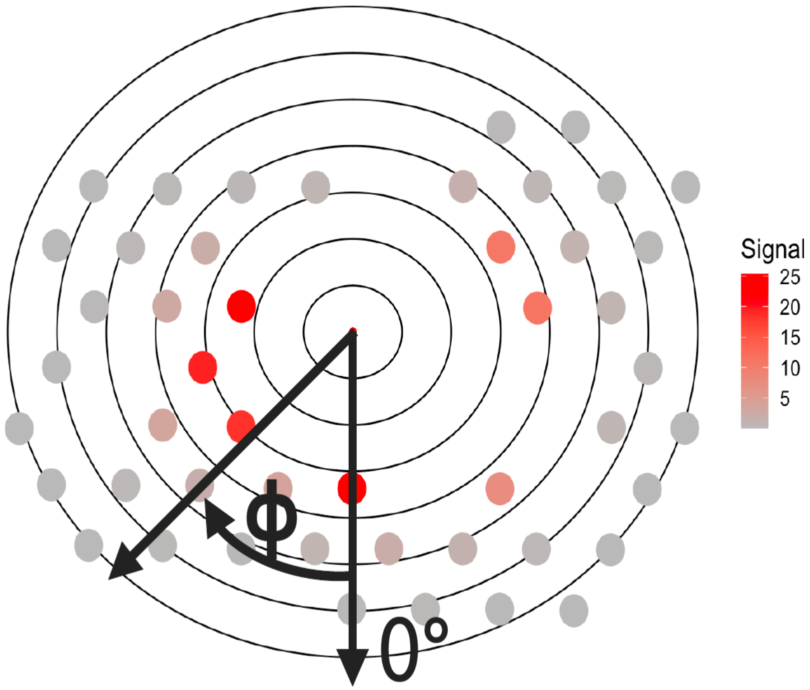




Best match
… but

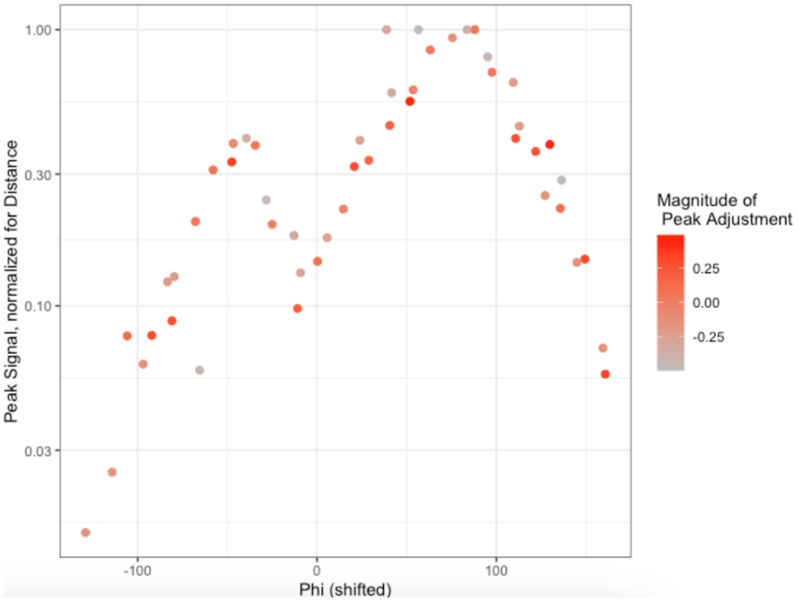
First evidence of an asymmetric TGF

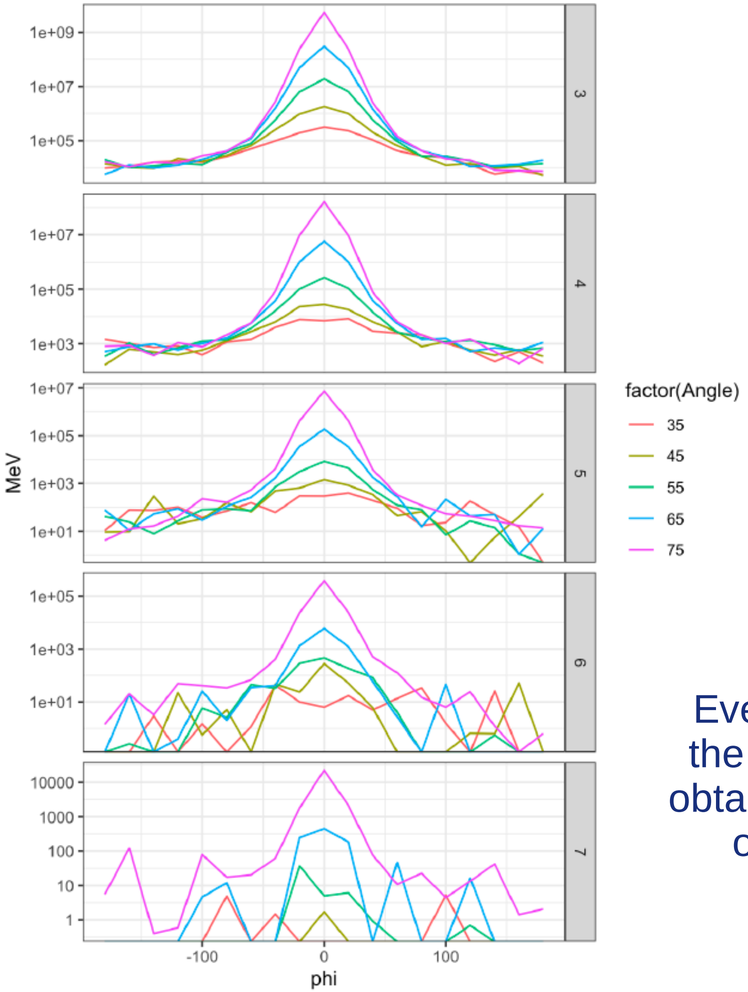




Could it depend on the inclination?

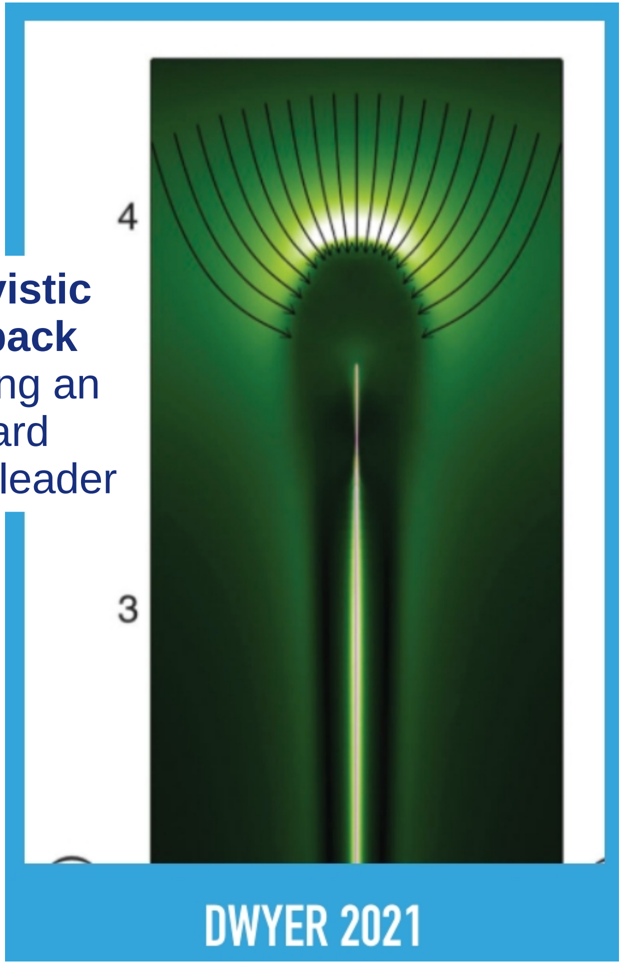
First evidence of an asymmetric TGF



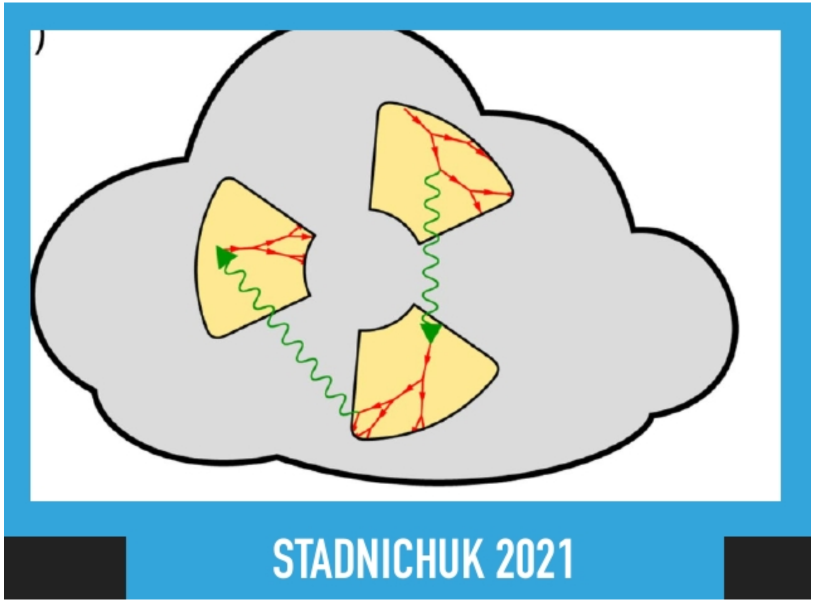


NO!
Even by increasing the tilting angle, the obtained signals have only one peak.

Indication for different sources?



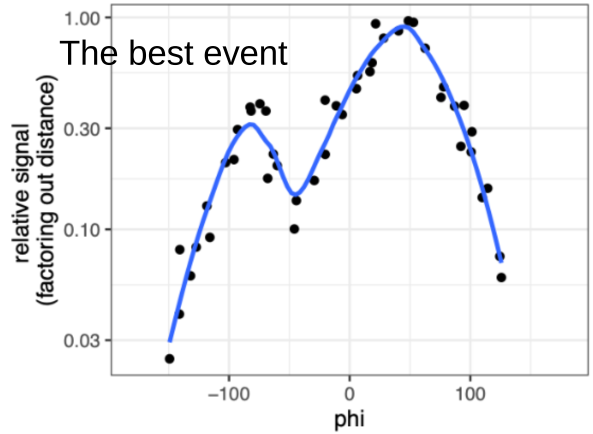
Relativistic Feedback
assuming an upward positive leader



Reactor Feedback
exchange of high-energy particles between different accelerating regions

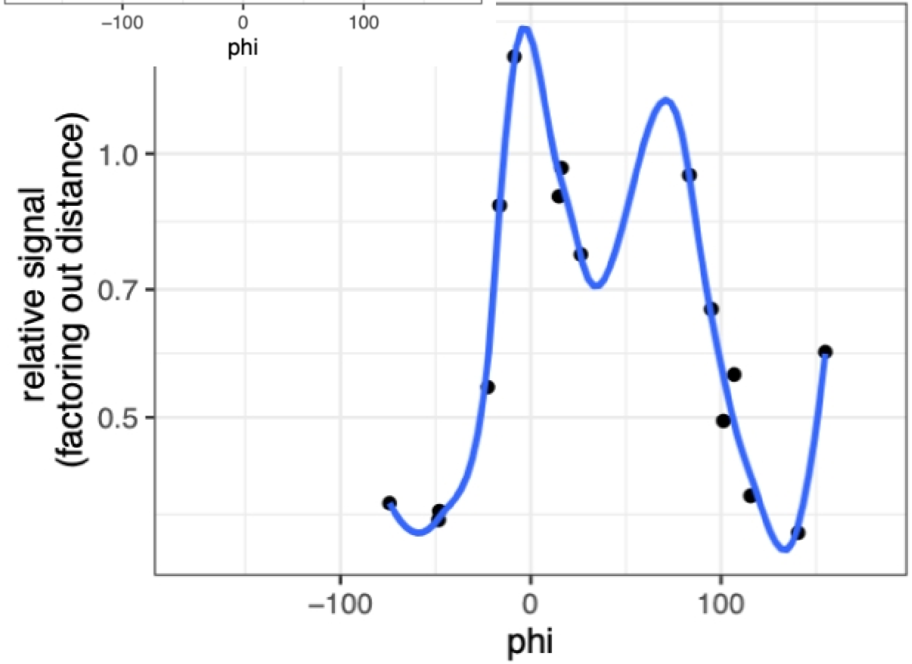
Auger TGFs

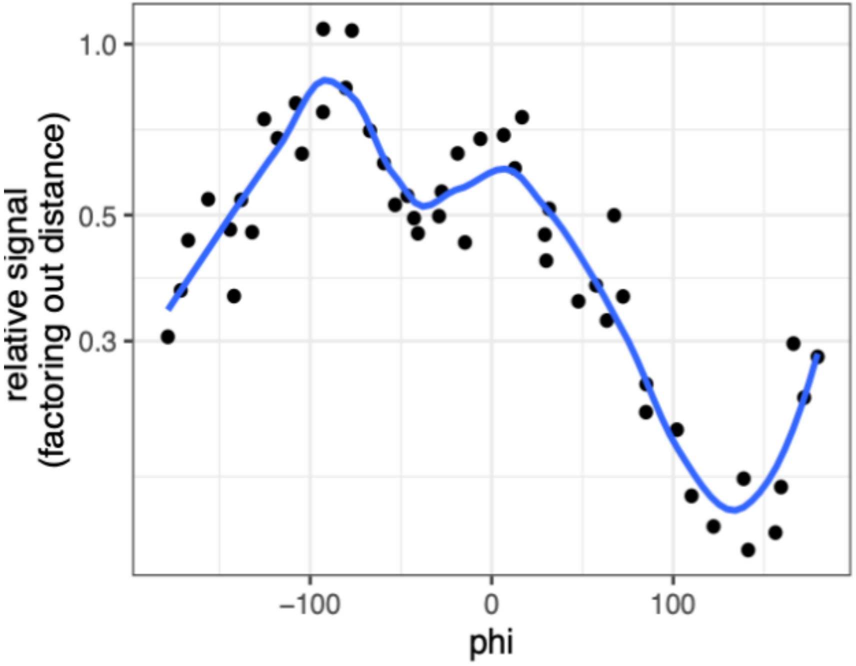
The best event



Signal = f(r)*g(phi)

We applied a correction for distance dependence

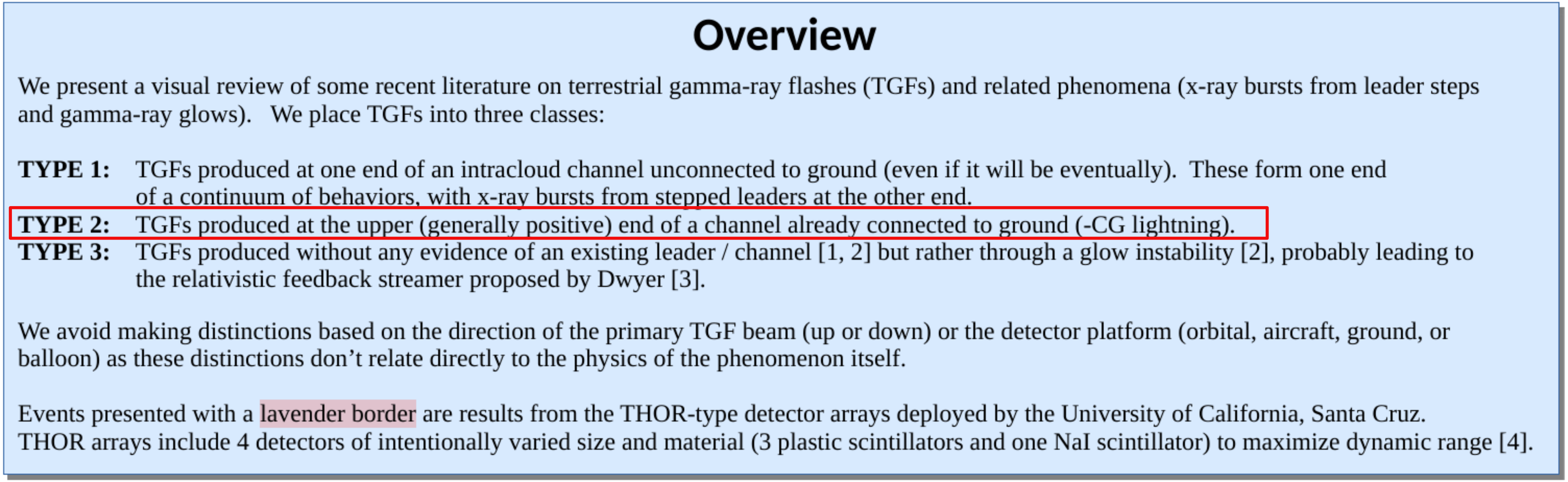




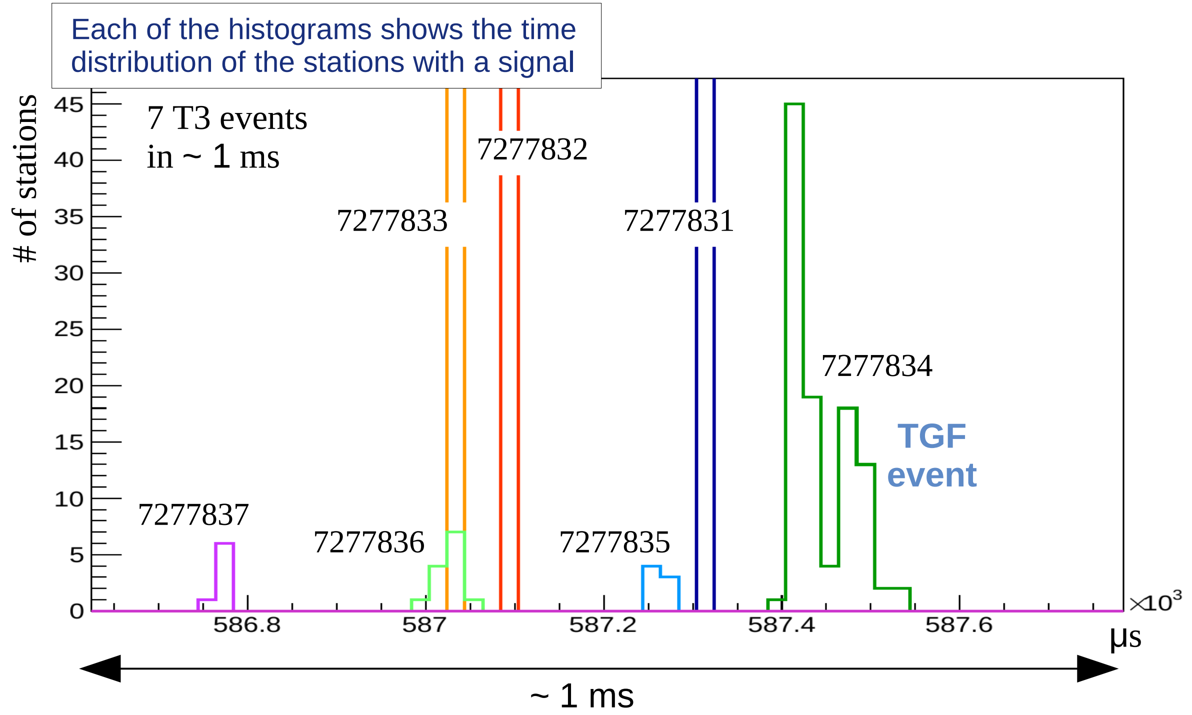
Also other events are showing two or more peaks

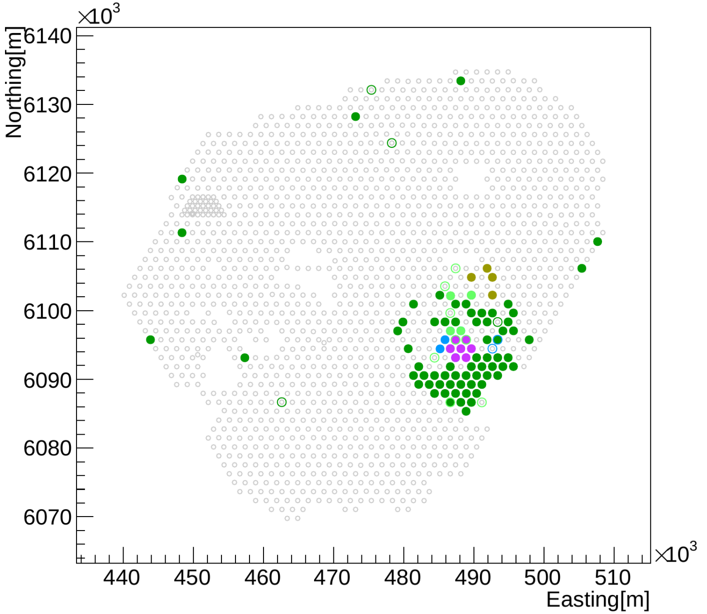
What TGF type are we observing?

David Smith @AGU 2025



What TGF type are we observing?





Behaviour similar to the events observed by the Santa Cruz group (J. Ortberg & D. Smith) in Japan and New Mexico: timing consistent with a stepped leader making a connection at that time → the upward return stroke enhances the field in the right direction for the avalanche to be aimed toward the ground with a strong horizontal component (**-CG** – negative cloud-to-ground).

Detailed lightning information not available at the time of our events…hoping for new events → see Matteo's talk

Papers

Observation of downward TGFs with the surface detector of the Pierre Auger Observatory*

Author† and Second Author‡
Authors' institution and/or address
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(Pierre Auger Collaboration)
(Dated: February 4, 2025)

An article usually includes an abstract, a concise summary of the work covered at length in the main body of the article.

Usage: Secondary publications and information retrieval purposes.

Structure: You may use the `description` environment to structure your abstract; use the optional argument of the `\item` command to give the category of each item.

I. INTRODUCTION

Since the start of the operation of the Pierre Auger Observatory[1], very peculiar events have been observed, during stormy days, with its surface detector, an array of water-Cherenkov detectors. The Observatory, located in the Argentinian Pampa Amarilla, was designed to detect extensive air showers produced in atmosphere by interactions of cosmic rays of ultra-high energy, namely above 10^{17} eV. While the footprint of a shower gener-

Wada et al. [7], while additional five TGFs were detected in the nearby area of Uchinada [8, 9]. Downward TGFs have also been observed with the Telescope Array [10], another large cosmic-ray observatory located in Utah.

In this paper, we report on TGF observations made with the Pierre Auger Observatory: although unexpected for an instrument optimised for the detection of cosmic rays, they illustrate its additional potential for the detection and characterisation of downward TGFs. We will show how the characteristics of the surface detec-

Papers

manuscript submitted to *JGR: Atmospheres*

A TGF with Azimuthal Substructure at the Pierre Auger Observatory

John Ortberg[1], David M. Smith[1], and Joseph Dwyer[2], for the Pierre Auger Collaboration[3]

[1]Physics Department and Santa Cruz Institute for Particle Physics, University of California, Santa Cruz, California, USA
[2]Department of Physics and Astronomy, University of New Hampshire, Durham, New Hampshire, USA
[3]Observatorio Pierre Auger, Av. San Martín Norte 304, 5613 Malargüe, Argentina

Abstract

The Pierre Auger Observatory, a 3000 km^2 detector array that sits 1.4 km above sea level in Argentina, has the unique ability to map the entire footprint of Terrestrial Gamma-ray Flashes (TGFs) incident on the ground. This is in stark contrast to the vast majority of TGF detections that only occur in a single point in space. In this paper we leverage this capability to perform two novel analyses on an event from the summer of 2007. First, we triangulate the source of the TGF to 2.1±0.3 km using the arrival time of the gamma rays themselves at the detector array , independently of any information regarding the lightning channel. With the source position has been established, we can analyze the spatial distribution of the TGF on the ground with respect to that center. Not only do we find that one side of the TGF shows significantly higher flux than the other, as one would expect if it were tilted with respect to its vertical axis, but we also find an asymmetric azimuthal structure consisting of two clear peaks in intensity offset by about 150° from each other. This azimuthal structure is not possible under the traditional uniform electric field model of a TGF. Thus we use Geant4 simulations to explore what possible asymmetric source regions would lead to the asymmetric footprint seen on the ground.