The study on quantum gravity theory through polarization measurements of high energy gamma rays from GRBs

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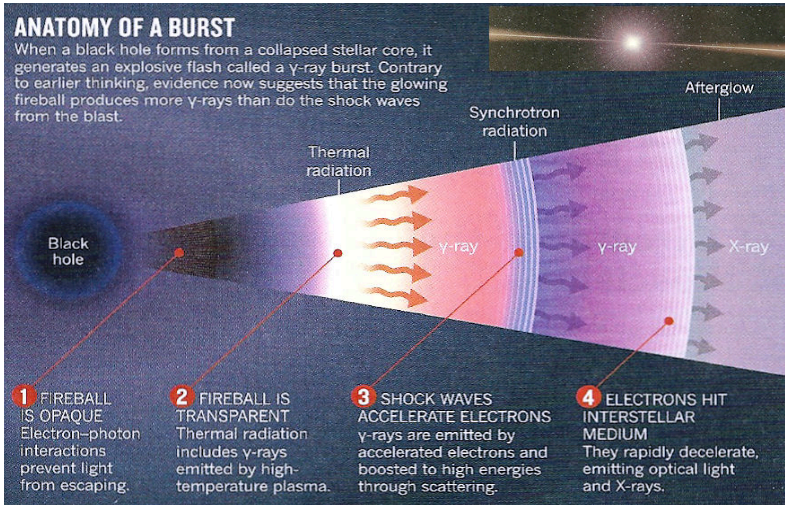
1.Motivation

Gamma ray bursts (GRBs) are the most energetic phenomena on the universe. The red shift of the most distant observed GRB is 9.4.
In some cases, they emit photons from radio to hight energy gamma rays.



http://universe-review.ca/I08-08-GRB.jpg

Because the photons from GRBs travel very long distance in the space, they can be used to investigate nature of space.

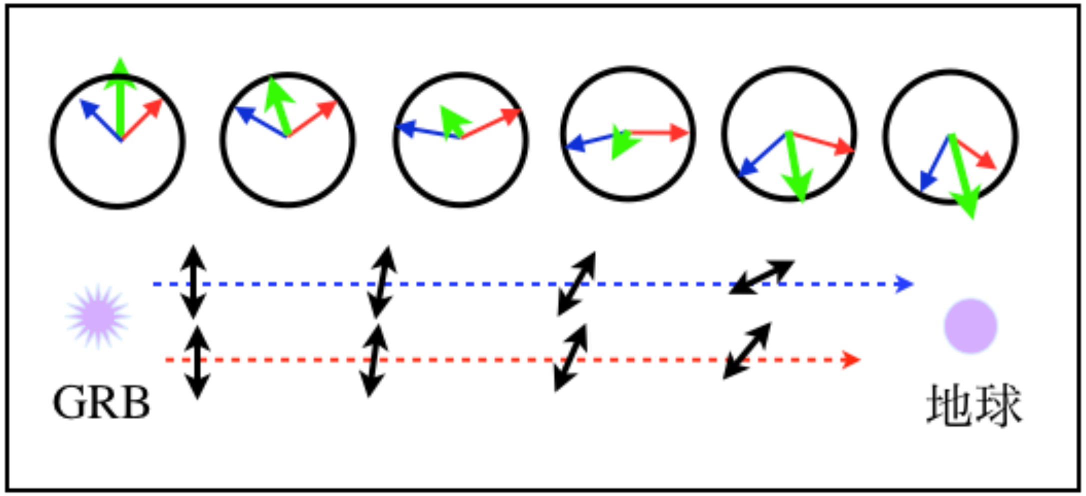
For example, according to some theories of quantum gravity, the polarization direction of the photons can rotate on the propagation even in vacuum.

The rotation angle depends on the energy of photons.

$$\theta(k, z) \approx \xi \frac{k^2 F(z)}{M_{PI} H_0}$$

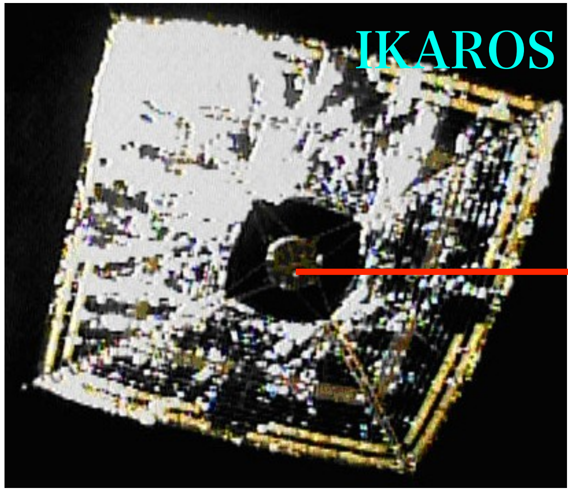
$$E_{\pm}^2 = p^2 \pm 2 \frac{\xi}{M_{PI}} p^3$$

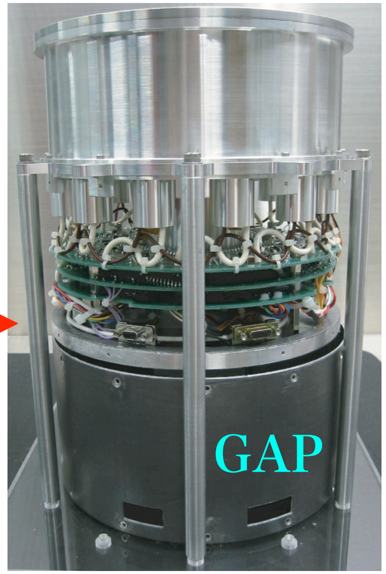
(Toma et al. PRL 2012)



We have developed GRB polarimeter sensitive to the hard X-rays.
It measured the polarization of some GRBs. We measured the difference of the polarization direction with two energy band.

$$\theta_{high}(100 \sim 300keV) - \theta_{low}(70 \sim 100keV)$$
$$\approx \xi \frac{F(z)}{M_{PI} H_0} \times \underline{(1.5 \times 10^{-8})}$$





The difference of the energy band was not large. The upper limit of ξ was <10^{-15}.

(Toma et al. PRL 2012)

↓

If we can compare polarization direction of the X rays with that of high energy gamma rays from a GRB afterglow, the difference of the rotation angle will be 10 billion times larger than that in the GAP case. So the upper limit for ξ will be constrained to 10 billion times smaller.

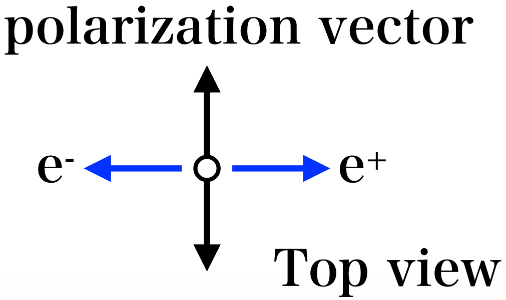
$$\theta_{high}(20GeV) - \theta_{low}(Xray) \approx \xi \frac{F(z)}{M_{PI} H_0} \times (\underline{4 \times 10^2})$$

↓

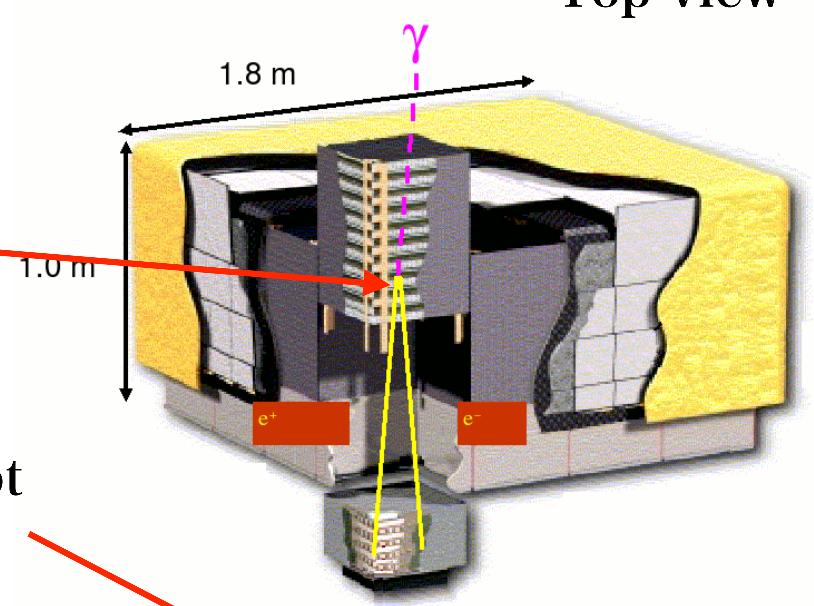
The polarization of X rays can be measured recently.
The polarization measurement for high energy gamma rays has never been carried out. We are studying the method of measurement.

2. Detector

The high energy gamma rays interact with detectors via pair creation. The azimuthal emission direction of electron and positron has the polarization information.

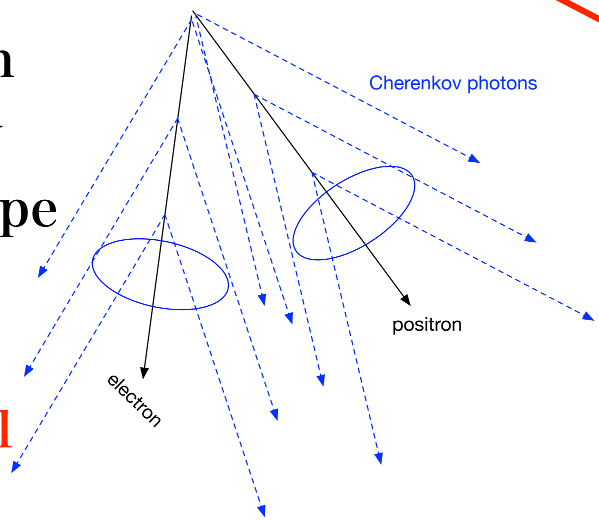


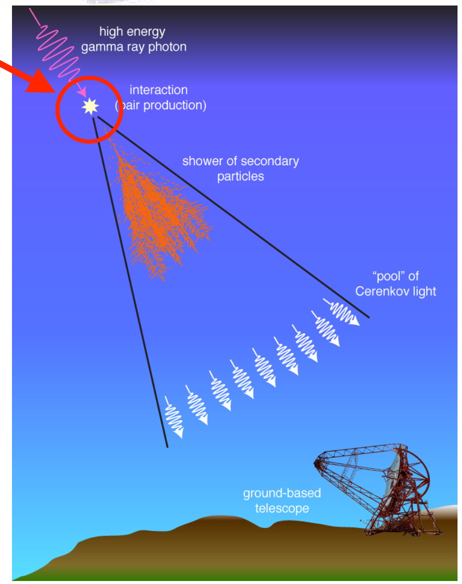
However, the Fermi LAT can not measure the correct direction due to the coulomb multiple scattering in the detector.



Cherenkov telescope is a good candidate, because the detector is thin air and then it does not strongly scatter high energy electron and positron.

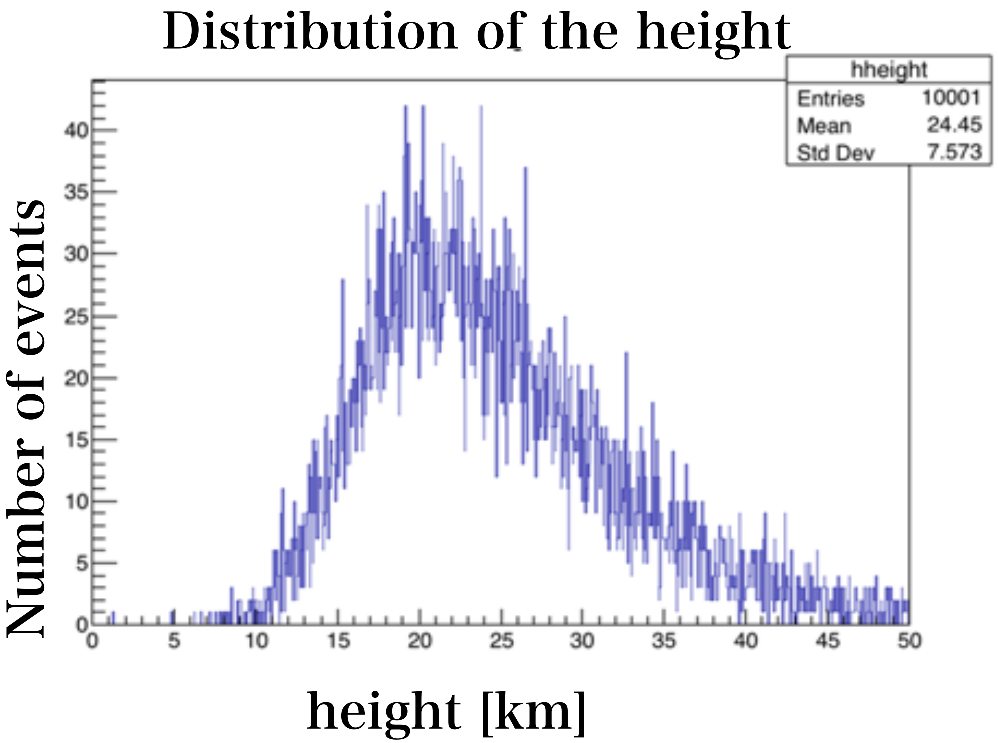
Because two particles run faster than the light speed in the air, Cherenkov photons are emitted in a conical shape of which the axis is the traveling direction of each particle.
The Cherenkov photons of the initial pairs has polarization information.

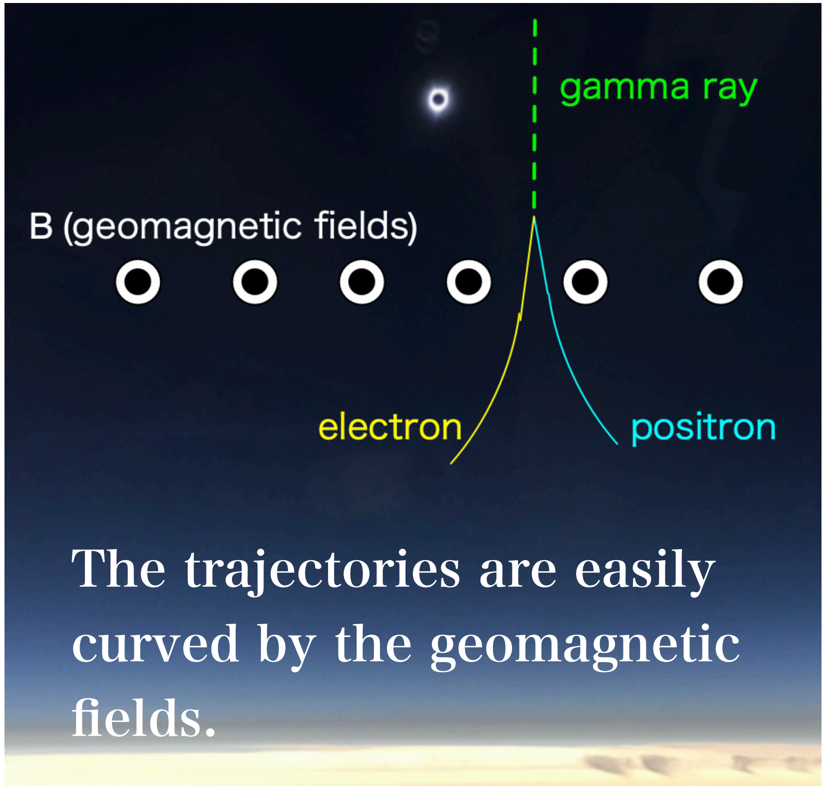




3. Basic Simulation

I have developed the simulation code and investigated the basic characteristics of the air shower.





The height of the pair creation is not constant but diverse.

Within ~100 m, the direction change is saved within several degrees.

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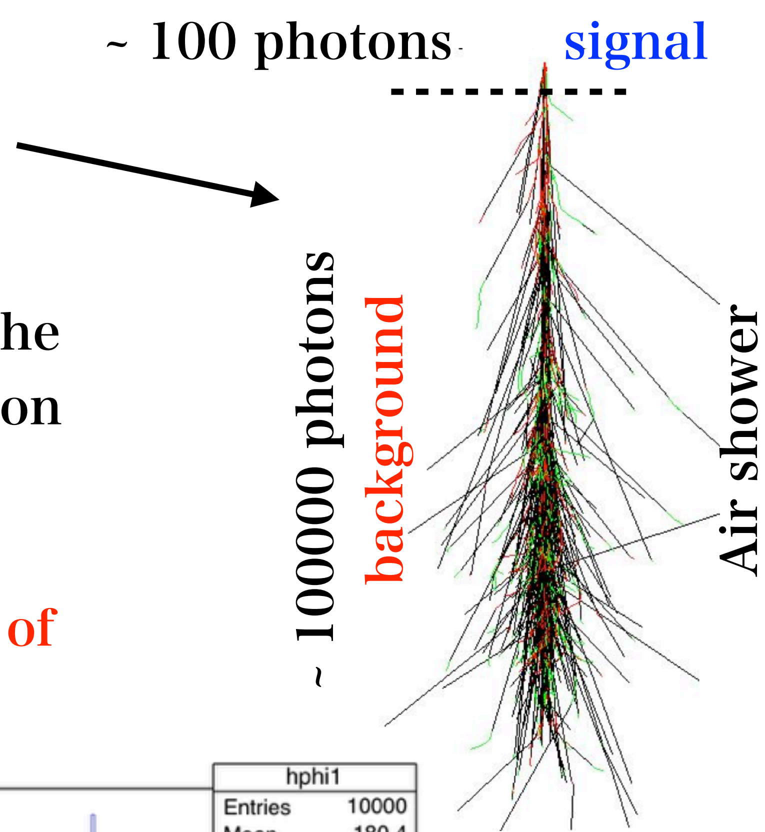
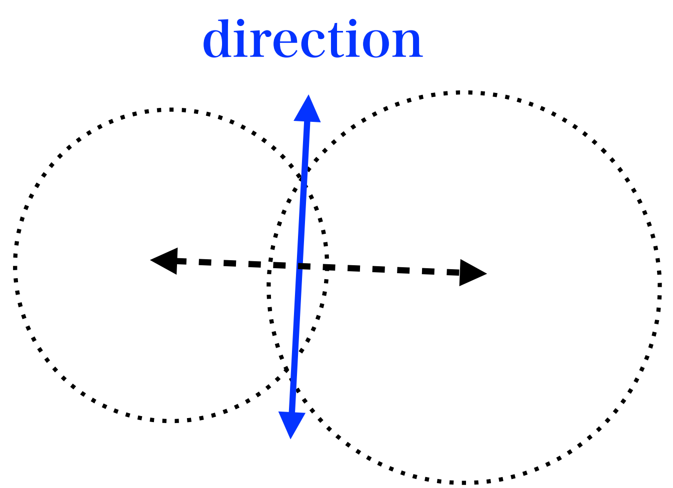
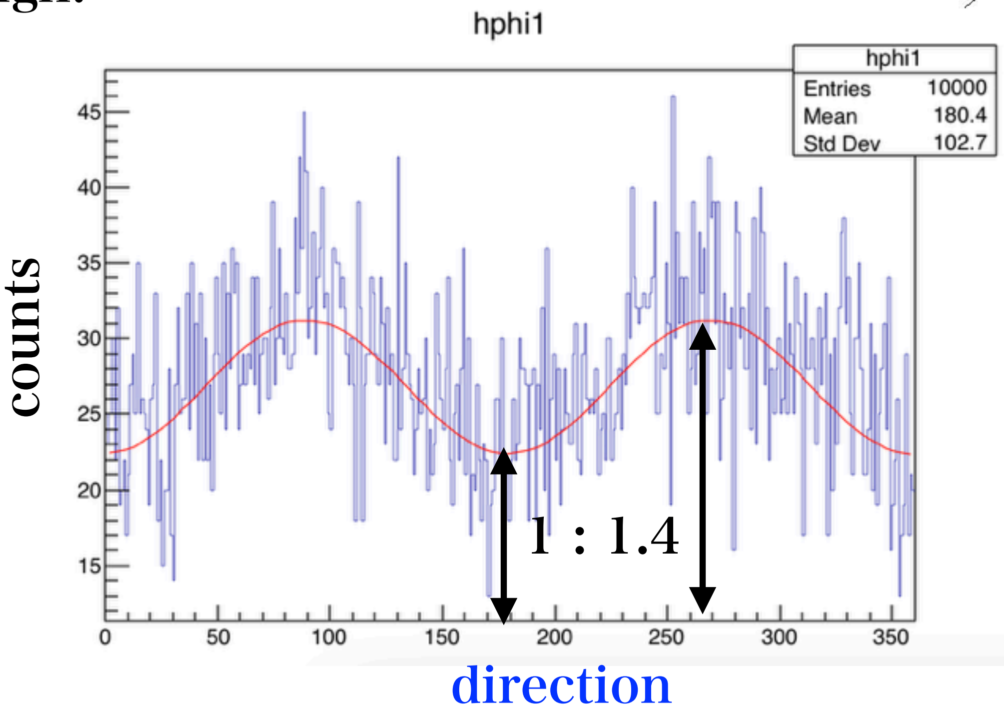
It is necessary to find the emitted photons within ~100 m from the first interaction point.

The Cherenkov photons due to the initial electron pair are a few thousand times smaller than those due to secondary particles (background).



If we succeed in extracting the signal, the image of the Cherenkov photons with two rings will be observed on the ground. By investigating the distribution of the direction for many gamma rays, the polarization direction can be measured. However, the amplitude of modulation curve is not so high.





This work is so hard.

4. Method for detection of polarization

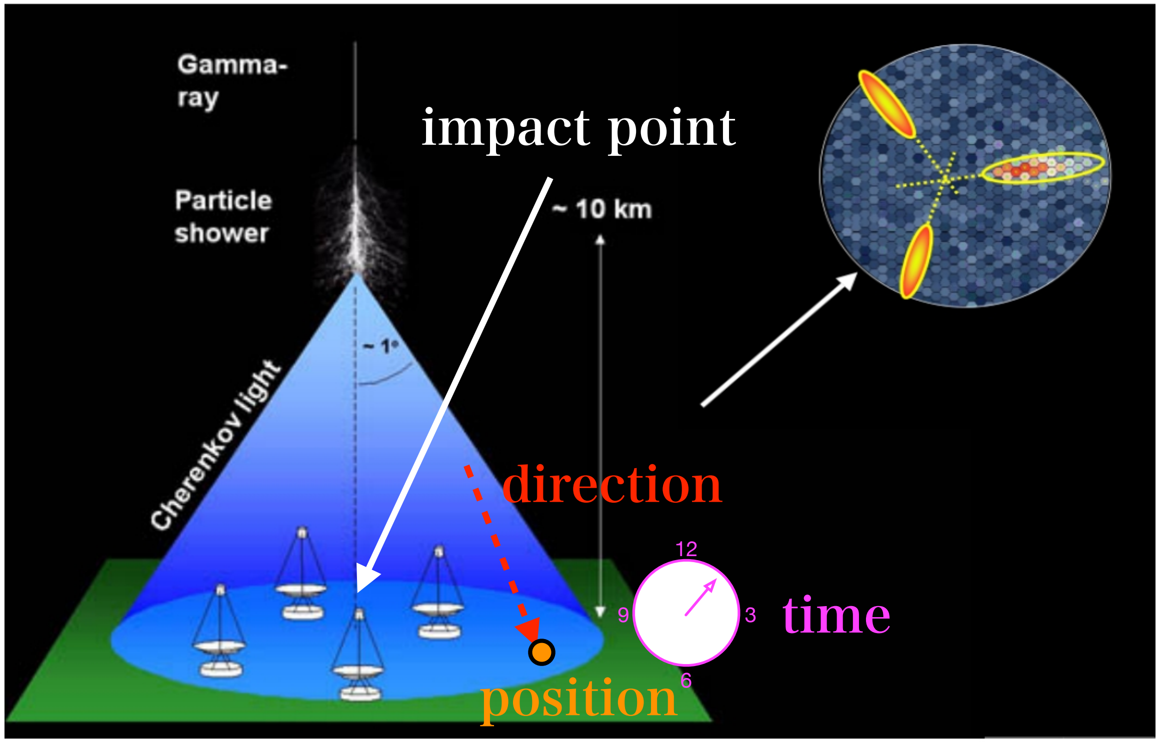
We must develop the analysis program to extract only the Cherenkov photons produced within ~100 m of the first interaction.
If the large number of small Cherenkov telescope would be constructed, we can use the three information for reached photons on the ground.

- the position where the photons reach
- the incident direction of the photons
- the time when the photons reach

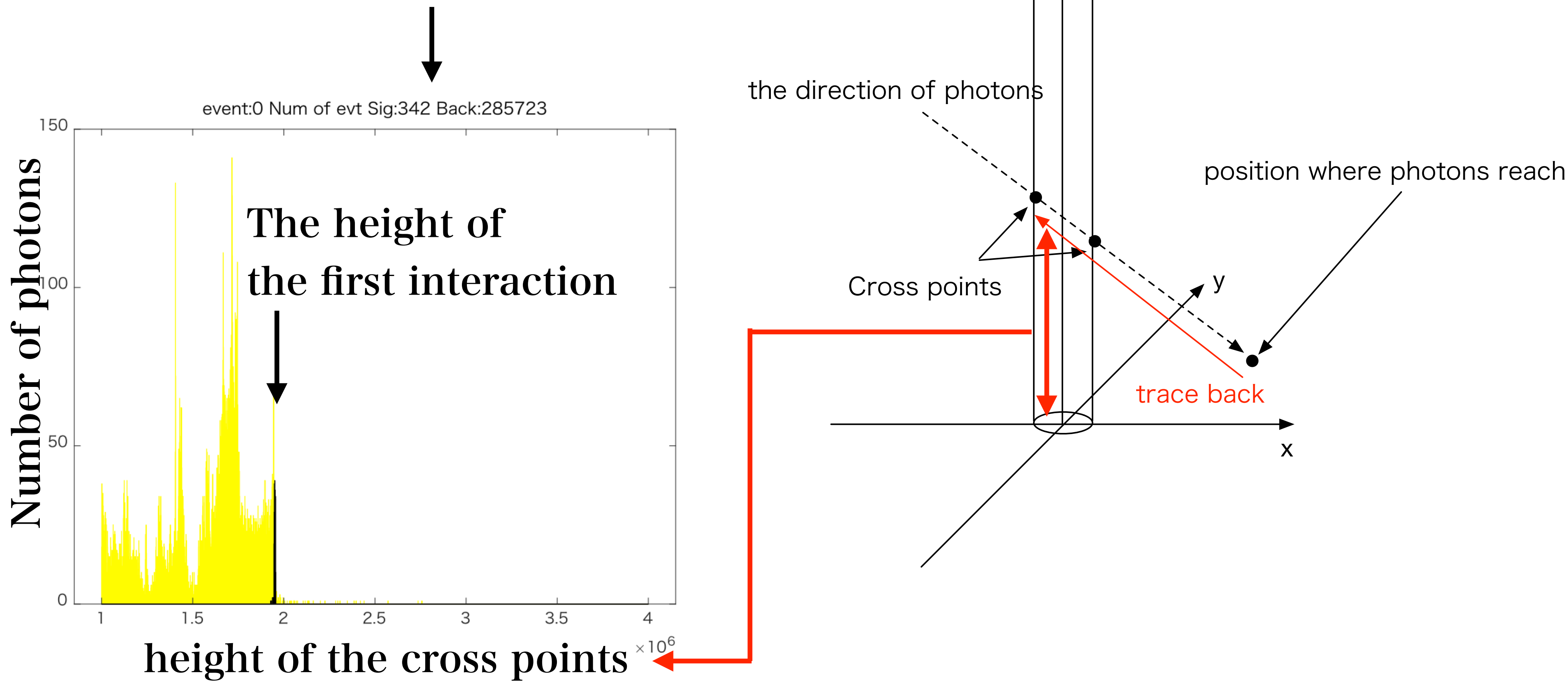
But it does not exist, yet.

The impact point and the direction for the incident high energy gamma rays can be identified with even a few of telescopes.

Using the impact point and the direction in addition to three information for each photon, the point of the first interaction can be identified by the following method.



From the position and the direction of each photon, the trajectory of the photon can be traced back and then the cross points with shower axis are identified. If there are cross points, the height is calculated and the value is put to the histogram.



The distribution of the yellow histogram disappears from the height of the first interaction! From this distribution, we can know the height of the first interaction.

We investigated the probability of the correct estimation.

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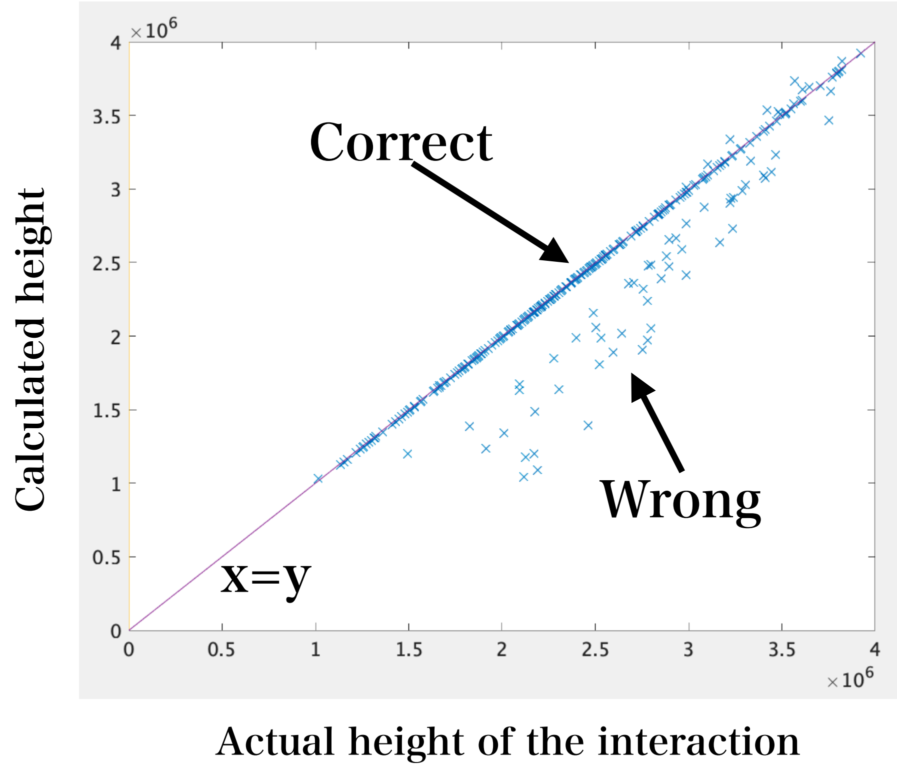
We confirmed that the interaction height can be correctly estimated at the 82% probability, now.



In the case of correct estimation, we can extract only the photons emitted within 100 m from the first interaction height. The image of these photons should be two rings on the ground.

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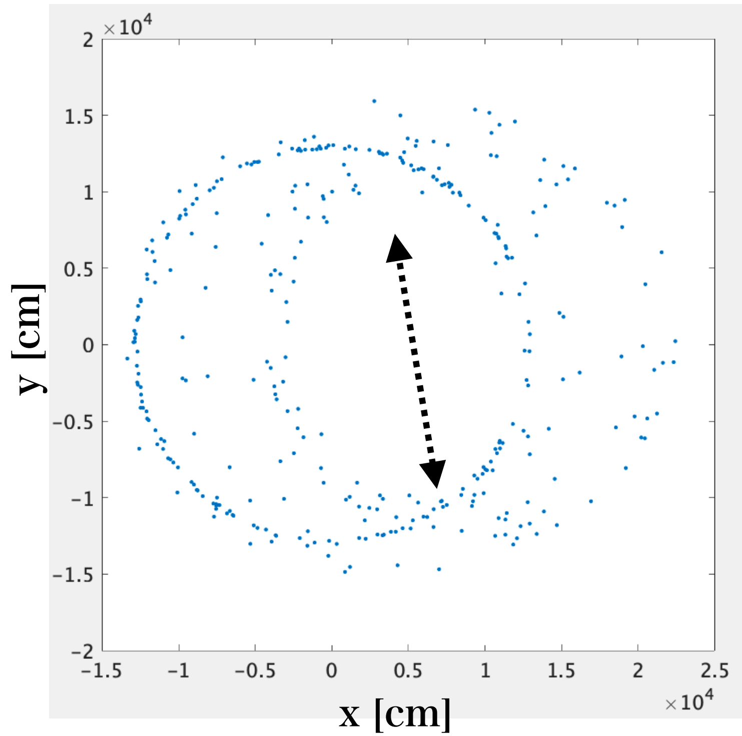
In this sample figure, two rings can be observed. Each ring corresponds to the Cherenkov photons by the initial electron and positron, respectively. From the image, the polarization information will be derived.



5. Conclusion and Future Work

・The polarization measurements of the photons over wide energy range from GRBs are useful for the experimental research of the quantum gravity.

・As it is important to measure the polarization of high energy gamma rays, I have developed the simulation code.

・ It was confirmed that it is very important for the measurement to identify the first interaction point of high energy gamma ray. So we have developed the method. According to the method, we have succeeded in the identification at the 82% probability.

We have lot of work to do.

・We want to improve the probability of the identification above ∼95%.

・We must make the program to identify the double rings, to determine the center positions, and to determine the polarization direction.

・We must design the actual Cherenkov telescopes to realize the study.

Thank you for the support to this research.