

Observation of Ultra High Energy Cosmic Rays in cloudy conditions by the JEM-EUSO Space Observatory

G. Sáez-Cano¹, J. A. Morales de los Ríos¹, Kenji Shinozaki^{2,1}, F. Fenu^{3,2}, H. Prieto¹, L. del Peral¹, N. Pacheco⁴, J.H-Carretero¹, A. Santangelo³ and M. D. Rodríguez Frías¹ for JEM-EUSO collaboration

(1) *SPace and AStroparticle Group, University of Alcalá, Spain*

(2) *Computational Astrophysics Laboratory, RIKEN 2-1 Hirosawa, Wako 351-0198, Japan*

(3) *Institut für Astronomie und Astrophysik, Eberhard Karls Universität Tübingen, Sand 1, D-72076 Tübingen, Germany*

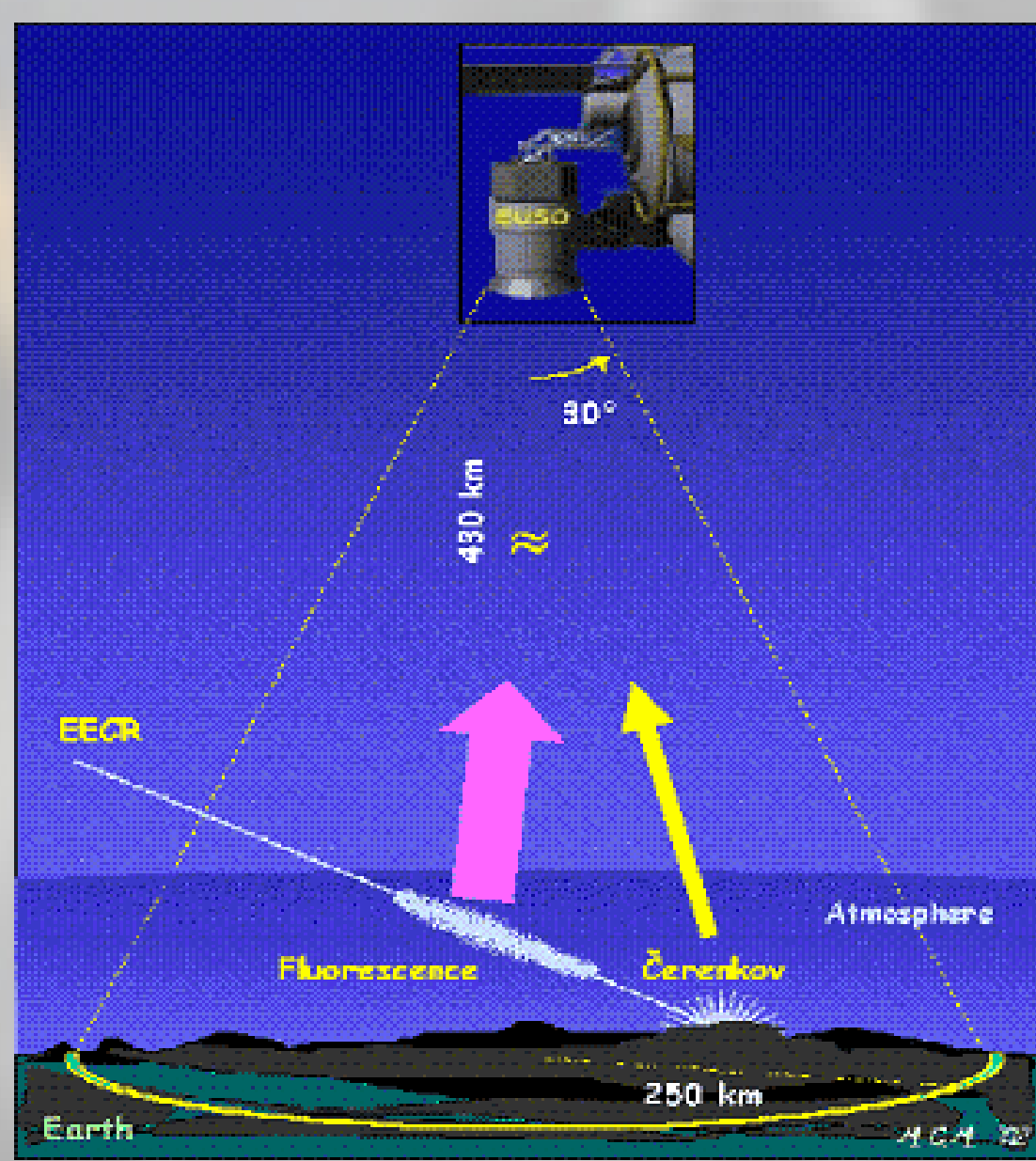
(4) *Instituto de Física Teórica (IFT), Universidad Autónoma de Madrid, Spain*



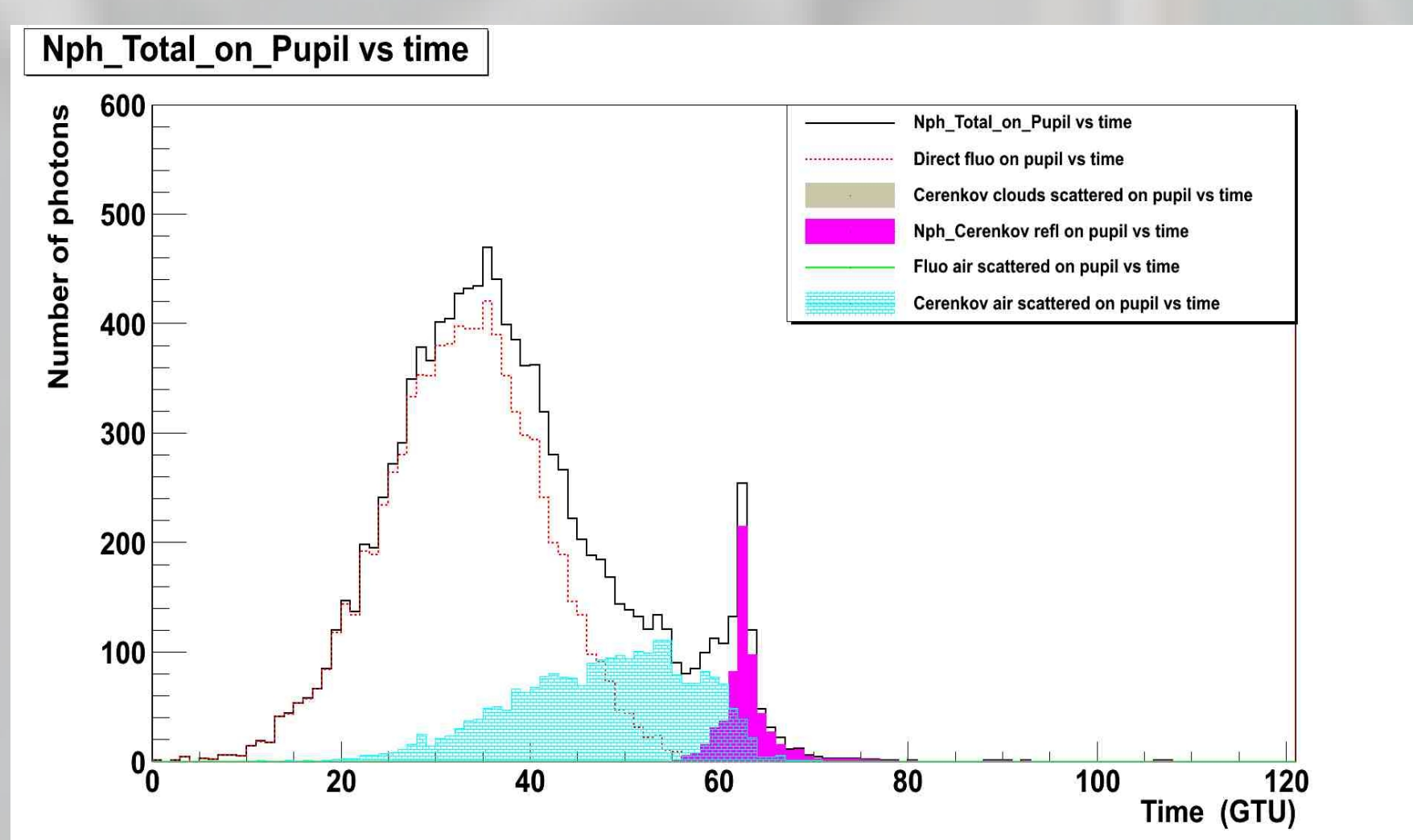
Abstract: JEM-EUSO (Extreme Universe Space Observatory on Japanese Experiment Module) is a space-based experiment that will be located at the International Space Station aiming to identify origin sources by detecting UHECRs at large statistics. It will use the atmosphere as a huge detector. Therefore, it is important to study how the presence of clouds will affect the detected signal of those UHECR. In the present work we simulated the EAS observation by the JEM-EUSO telescope to evaluate the impact of the clouds in EAS.

Introduction

JEM-EUSO (Extreme Universe Space Observatory on Japanese Experiment Module) is the space-based Ultra-High Energy Cosmic Ray (UHECR) observatory to detect extensive air showers (EASs) monitoring night atmosphere. Apart from postanalysis using Atmospheric Monitoring System on the telescope, the EECR observation is continuously operated throughout various atmospheric conditions including the presence of clouds. Unlike ground-base experiment, signals from EAS through such conditions are observable thanks to unique location of the observatory on the orbit. In the present work, we studied the effect of clouds to EAS signals and to the aperture for UHECR observation.



Clear sky



Observation principle of JEM-EUSO

The principle of the space-based observation is based on the measurement of fluorescence light and in part Cherenkov light reflected from the Earth's surface (left panel). The light curve (time profile of arrival photon to telescope pupil) for the typical EAS (10^{20} eV from 60 degrees zenith angle) is shown in the right panel in unit of GTU (gate time unit = 2.5 microseconds). The main part of light curve is constructed with direct fluorescence photons and is followed by the reflected Cherenkov light. In this example, the clear sky case is assumed and therefore the latter represents the reflection signal from the Earth's surface

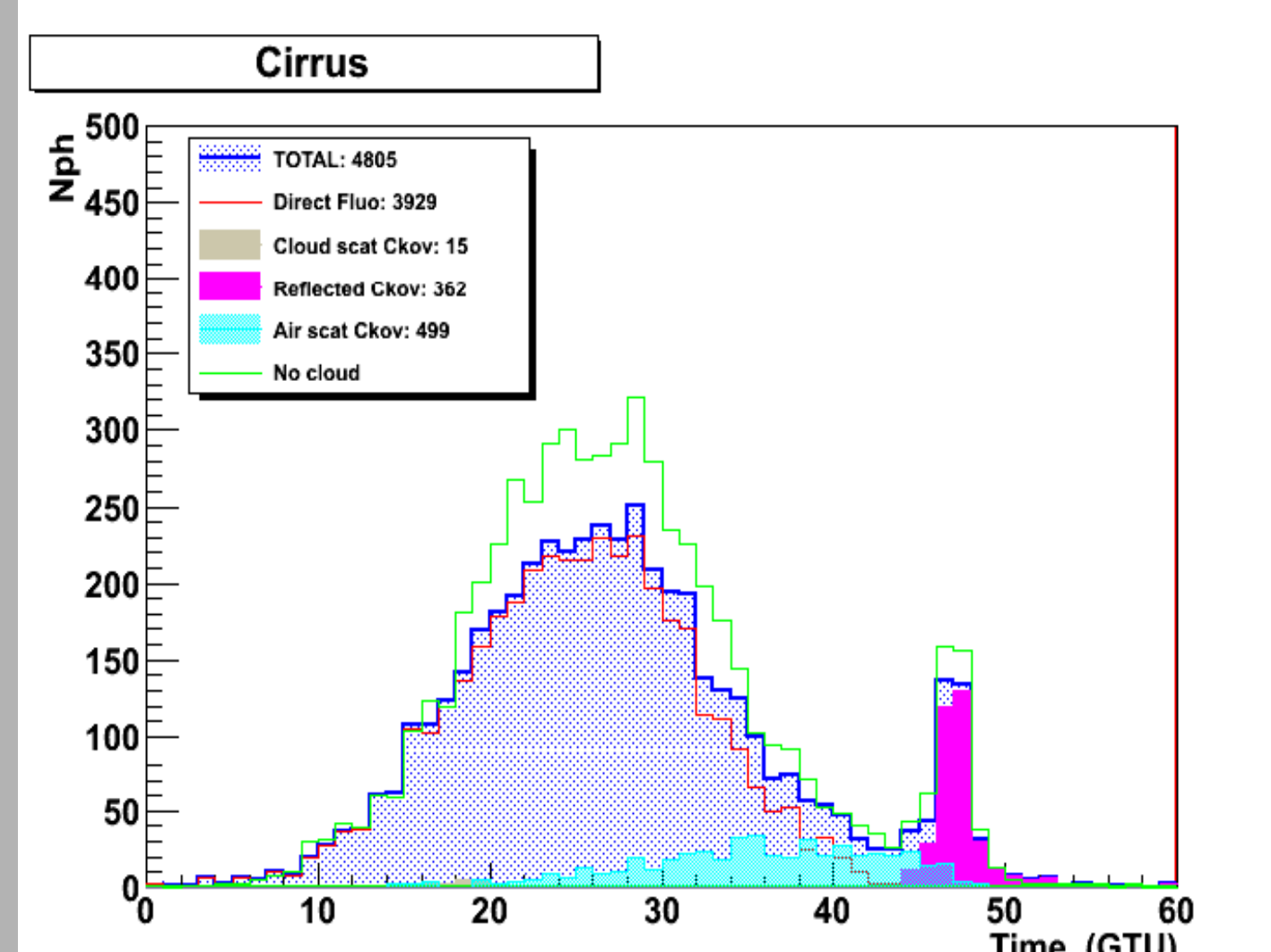
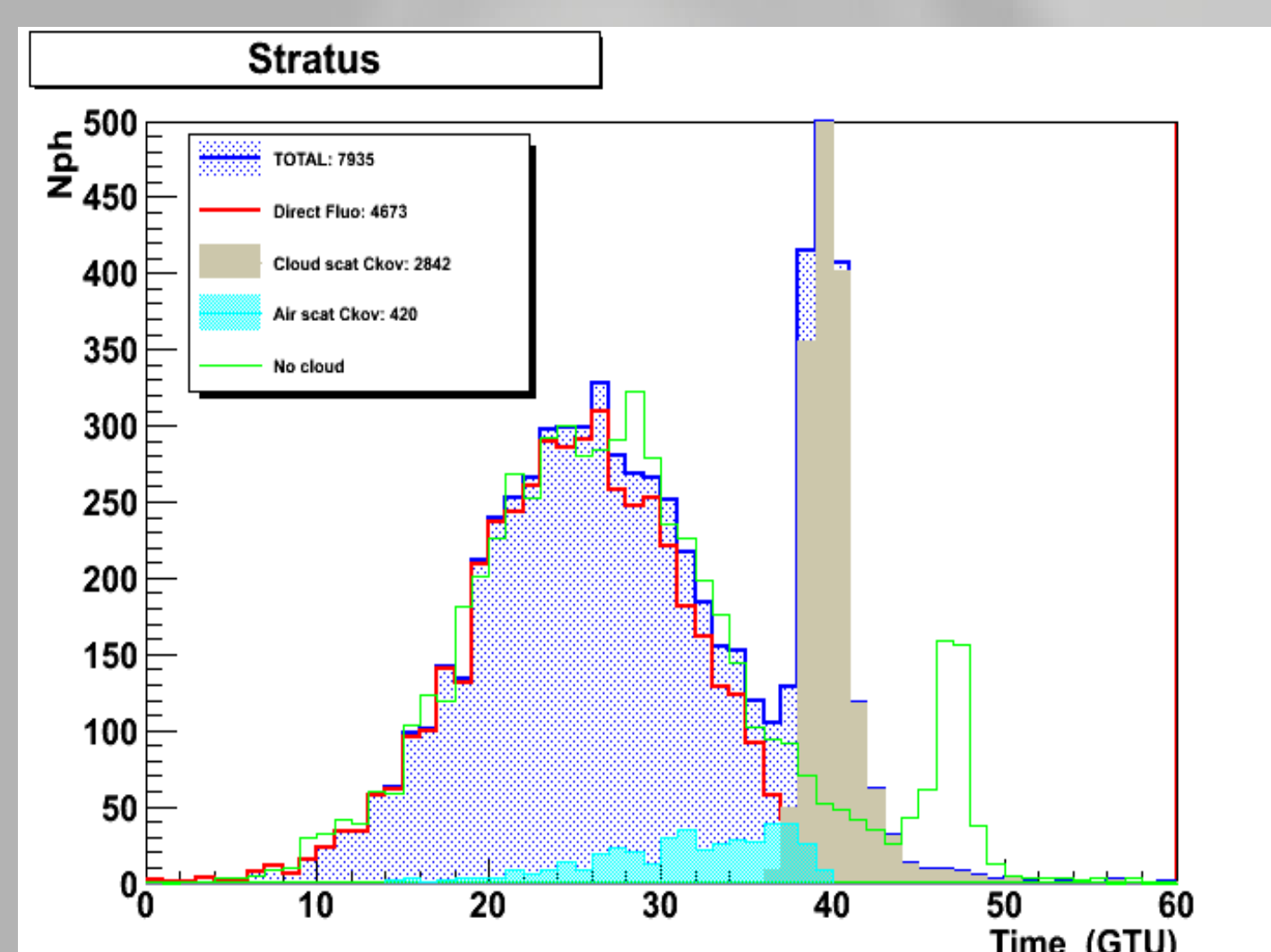
Simulation for EAS profile in cloudy condition

ESAF (Euso Simulation and Analysis Framework) is used to estimate the efficiency of EAS observation and the behaviour of the signal produced by EAS in cloudy conditions. The Impact of the the cloud distribution has been taken into account as well. Simulations have been performed considering the cloud as a uniform layer, whose characteristics are optical depth τ and cloud-top altitude H_c . The physical thickness of the cloud has been considered to be 1km for every case. Also, background is considered as constant.

The right panels demonstrates the effect to observed EAS light curve in the presence of stratus (top) and cirrus (bottom). In the simulations, these clouds are modeled with combinations of τ and H_c as 5 and 2.5km and 0.05 and 10 km, respectively. In each case, the light curve expected for the clear sky is shown from comparison.

For stratus-like clouds with large τ at lower altitudes, most of signals from EAS are observed without attenuation when the altitude of the cloud is well below the altitude of EAS development, Such clouds also produce a very intense reflected Cherenkov signals and the detected signal is even better than that for the clear sky case. This will enhance the better capability of triggering and reconstruction for EAS geometry.

For cirrus-like cloud at higher altitudes, signals from EAS are attenuated according to the optical depth, while the shower image and its time evolution will allow the arrival direction analysis.

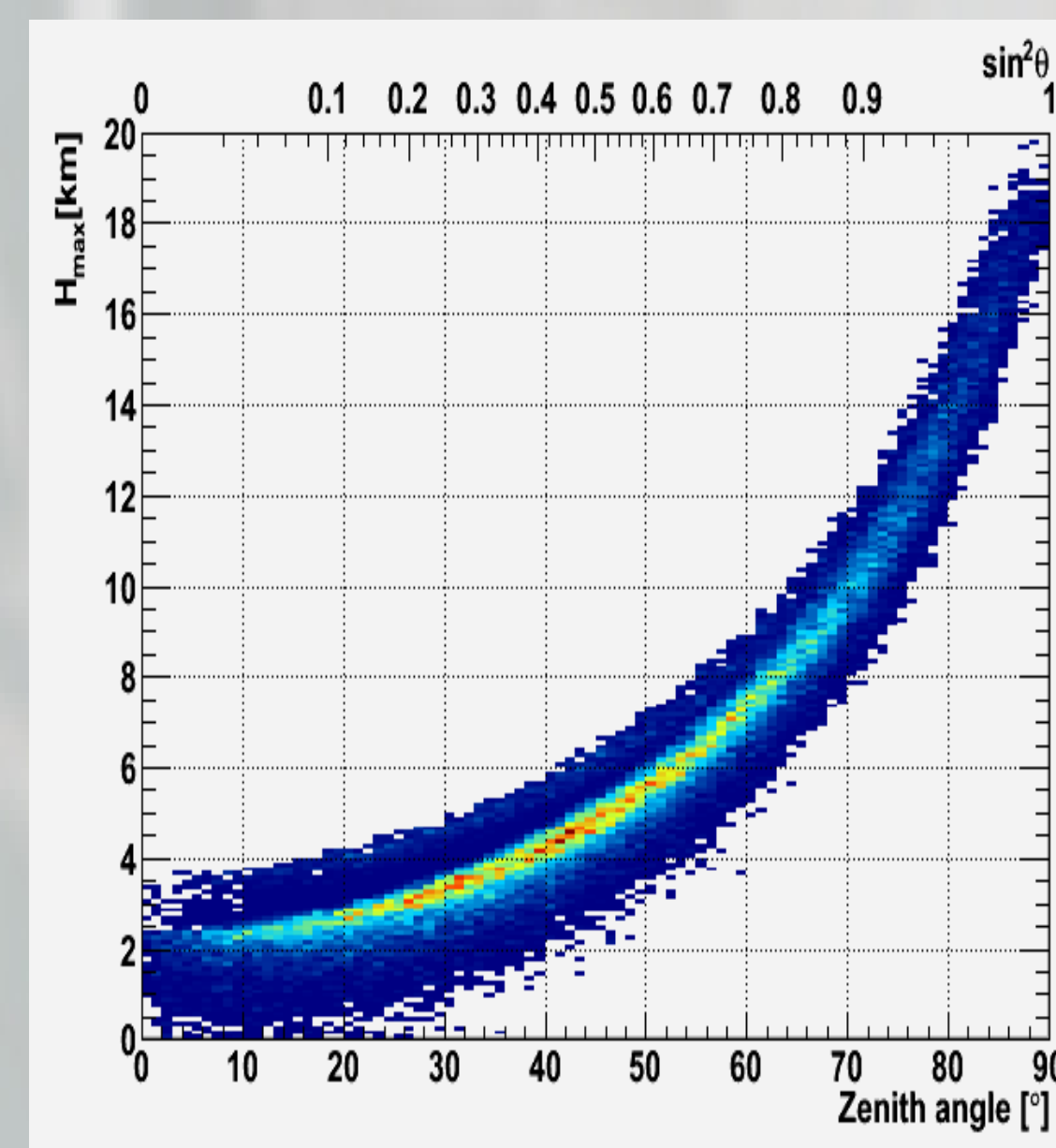


Impact on trigger efficiency

In order to evaluate the impact on the trigger efficiency (ratio of trigger aperture to saturated fiducial aperture for clear sky condition) due to the cloud presence, we simulated a large sample of EAS events on various cloud conditions. The set of key parameters is as follows:

- Primary UHECR: proton
- Primary energy [eV]: $3 \times 10^{19} - 10^{21}$
- Zenith angles: 0–90 degrees
- Optical depth: 0.05, 0.5, 1.5 and 5
- Cloud-top altitude: 2.5, 5, 7.5 and 10 km
- Physical cloud thickness: 1km
- JEM-EUSO altitude: 400 km
- Operation mode: Nadir mode

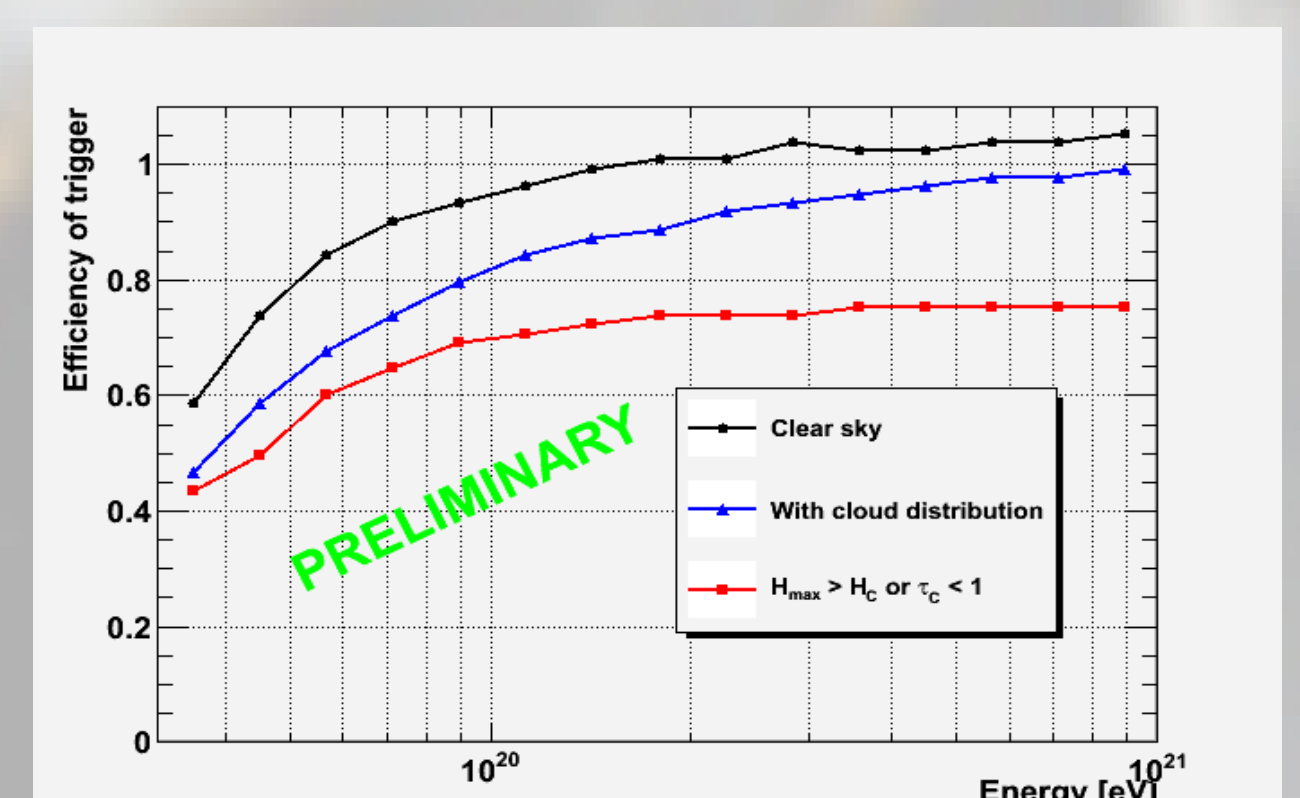
For each condition, 100,000 events were simulated with a spectrum of $dN/dE \propto E^{-1}$. The same simulation for clear sky case was also carried out for comparison.



In order to evaluate the impact on the trigger efficiency due to the cloud presence, the altitude of the maximum of EAS development (H_{max}) is shown as a function of zenith angle. Note that in energy range of interest the depth of EAS development (X_{max}) only varies by ~ 100 g/cm² and therefore the H_{max} is dominantly determined by the zenith angle. From this plot, for example, $H_{max} > \sim 7$ km for 60 degrees EAS.

For the simulated conditions of clouds, the average trigger efficiency is summarised in the following table for UHECR events above 5.5×10^{19} eV as a ratio of trigger efficiency to the clear sky case (*cloud impact*) and is $\sim 82\%$ very little dependant of spectrum (E^{-3} is assumed herein). The probability of the presence of various type of clouds have been studied in Garino et al in the present conference. The convolution of cloud presence probability and *cloud impact* yields the overall trigger efficiency as shown in the right panel. This panel also shows further requirement of H_{max} above optically thick cloud ($\tau > 1$) or clouds with $\tau < 1$. These conditions allow observation of the maximum of the shower. In this case, the cloud impact is $\sim 70\%$ independent of energy which is interpreted by the geometrical relations between H_{max} and typical cloud altitudes.

E > 5.5x10 ¹⁹ eV	Cloud-top altitude [km]			
	2.5	5	7.5	10
OD = 5	88%	66%	37%	18%
OD = 1.5	89%	69%	43%	26%
OD = 0.5	88%	82%	74%	70%
OD = 0.05	90%	89%	89%	90%



Conclusion

The effect of clouds to EAS observation by JEM-EUSO were studied using ESAF code. The presence of low-altitude stratus-like clouds may enhance capability of detection and reconstruction of EAS. Cirrus-like clouds reduce just slightly the signal from EAS. Considering all conditions according to the study of Garino et al., about 80% of the showers produced will be detected. For more than 70% of triggered EAS, cloud effect is limited as the maxima of EAS development are observable above optical thick clouds or through optically thin clouds.

References

- C. Berat et al. 2010, *Astropart. Phys.*, 33, 221.
- T. Ebisuzaki et al. 2011, in the present conference (ID120).
- F. Fenu et al. 2011, in the present conference (ID592)
- F. Garino et al. 2011, in the present conference (ID398)
- J.A. Morales de los Rios Pappa et al 2011, in the present conference
- A. Neronov et al. 2011, in the present conference (ID301)
- A. Santangelo et al. 2011, in the present conference (ID991)
- K. Shinozaki et al. 2011, in the present conference (ID979)
- Y. Takahashi et al. 2009, *New J. Phys.* 11, 065009.

