Practical application of the new 'knee-like' approximation of Cherenkov light Lateral Distribution produced by EAS in the Earth atmosphere.

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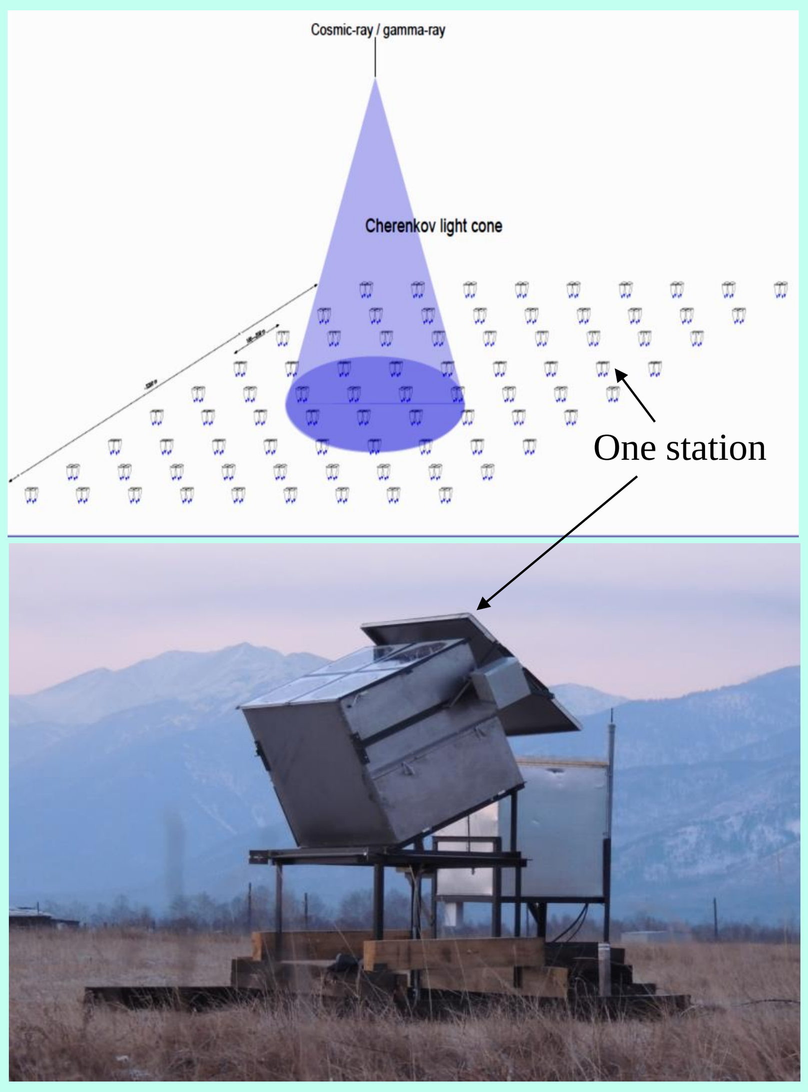
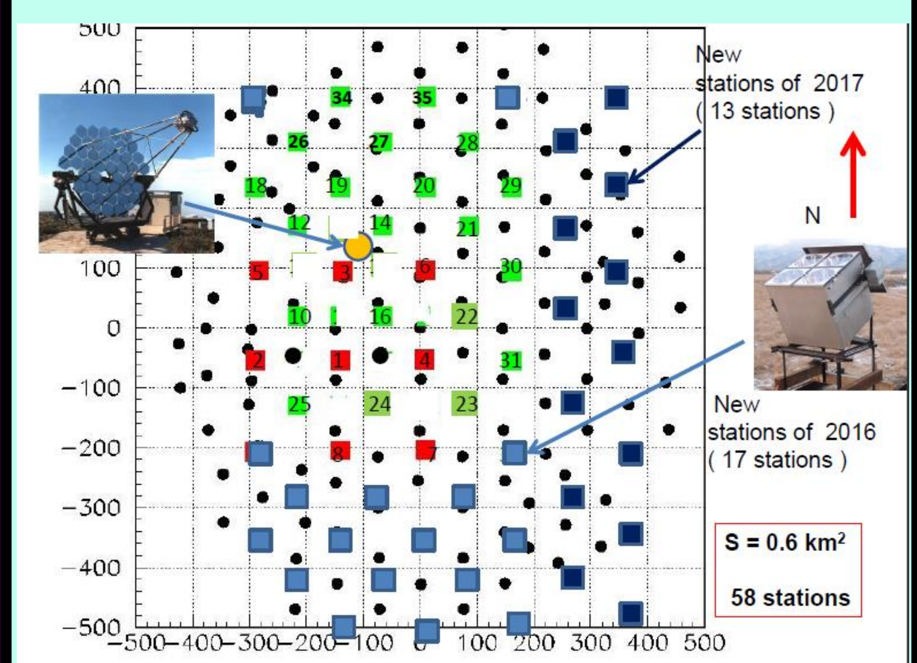
Introduction

This work is performed in the frame of the TAIGA experiment:
Part of TAIGA: TAIGA - HiSCORE
(High Sensitivity Cosmic Origin Explorer).
Non-imaging air Cherenkov HiSCORE array: 28 optical stations placed with the step 100 m and covering the area 0.25 km2 now and in future 1km^2, that detect Cherenkov light from EAS with the threshold about 30 -50 TeV.



The IACT technique was developed and optimized for energies around 1 TeV.
A typical design consists of a system of Cherenkov telescopes with a mirror, a camera with a field of view of the order of 4 degrees.
To move to higher energy it requires a larger effective area and a large number of telescopes (CTA) .



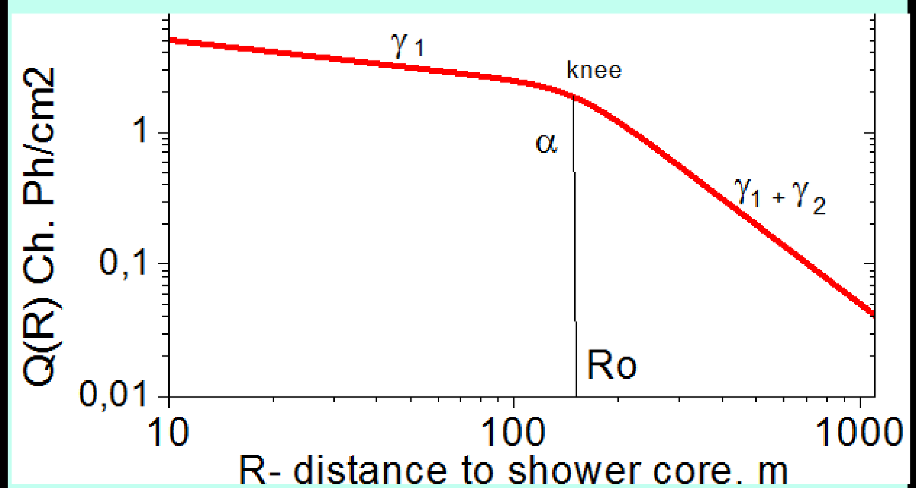
The Tunka fitting function depends only on 2 parameters a and bxy, the first one is a normalization factor, the second one characterizes the steepness of the whole LDF. The Tunka approximation well describes all the LDFs for primary cosmic rays in the energy interval 10^{14}-10^{18} eV, while the LDFs of gamma rays, incident at large angles, have a positive value of the slope of the LDF before the knee, which the Tunka fitting function cannot reproduce.

'Knee-like Cherenkov light LDF approximation'

For parameterization of simulated Cherenkov light Lateral Distribution Function Q(R)
we used the function that we called ('knee- like approximation'), which was used earlier by J.Horandel for description of the knee in the CR spectrum. It was a function of energy at that time, but we make it a function of the distance R from the shower axis. It depends on five parameters a, γ_1 , γ_2 , R_0 and α.

$$F_{theoretical} = a(R^{\gamma_1}(1+(R/R_o)^{\alpha})^{\gamma_2/\alpha}) \quad \textbf{Eq. (1)}$$

Knee-like approximation function and the meaning of parameters



R is the distance from the shower axis;
a, γ_1, γ_2, R_0 and α are the parameters of the Cherenkov light LDF
R_0 : the knee position
γ_1: the slope of the LDF before the knee
$\gamma_2+\gamma_1$: the slope of the LDF after the knee
Parameter α characterizes the sharpness of the knee

Items for this work

Previously we performed our investigation on CORSIKA-simulated data of the number of Cherenkov photons, Q $_{ph.\ cm^{-2}}$, emitted by showers in the atmosphere. This year we start processing experimental high energy data.

1-We apply our fitting function to experimental data to show how our approximation fit this experimental events.

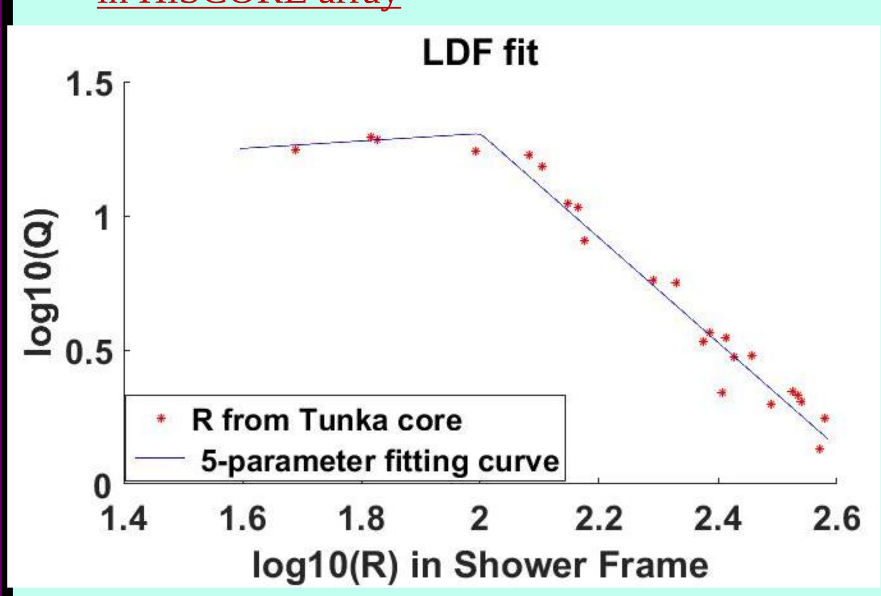
2-Estimation of the accuracy of the Cherenkov light density measurement

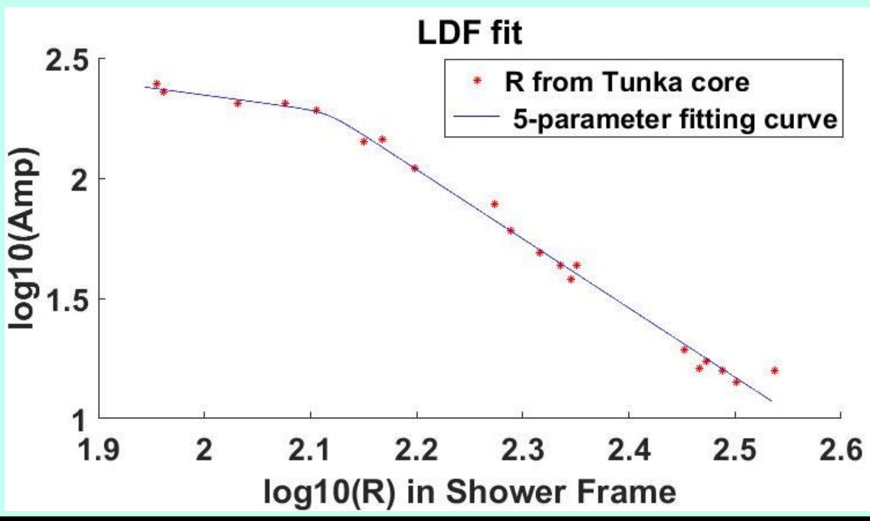
3-Estimation of the Cherenkov density Qtel in the site of the IACT telescope using our knee-like fit for the HiSCORE experimental data , and comparison with the Cherenkov density measured with the IACT.

4- Test of the ability to separate heavy and light nuclei using fit parameters values.

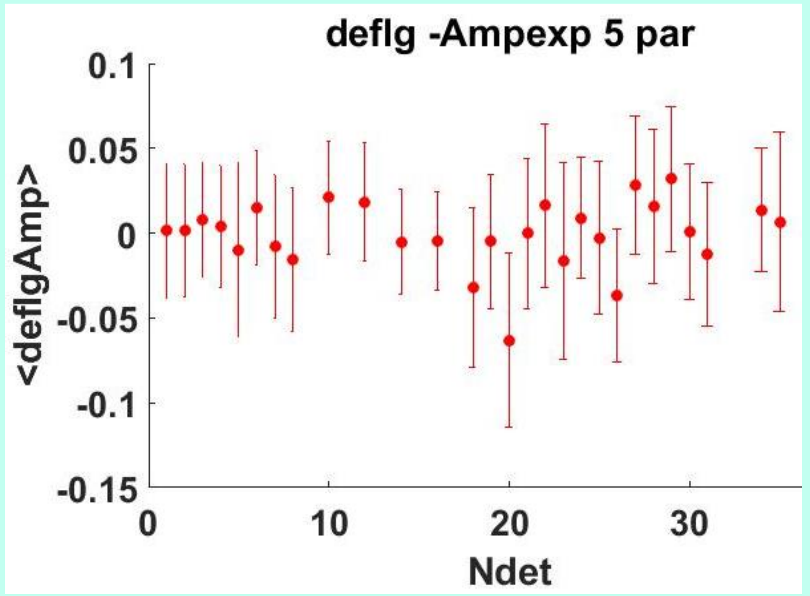
Item1- How our approximation fit this experimental events

- We applied our 5-parameter fitting function to the Experimental events obtained in Tunka-HiSCORE in 2016-17years. The 'knee-like' approximation of experimental data (detected by the HiSCORE array of TAIGA) demonstrates a very good fit quality for individual events.
- 2 examples of individual experimental events in HiSCORE array





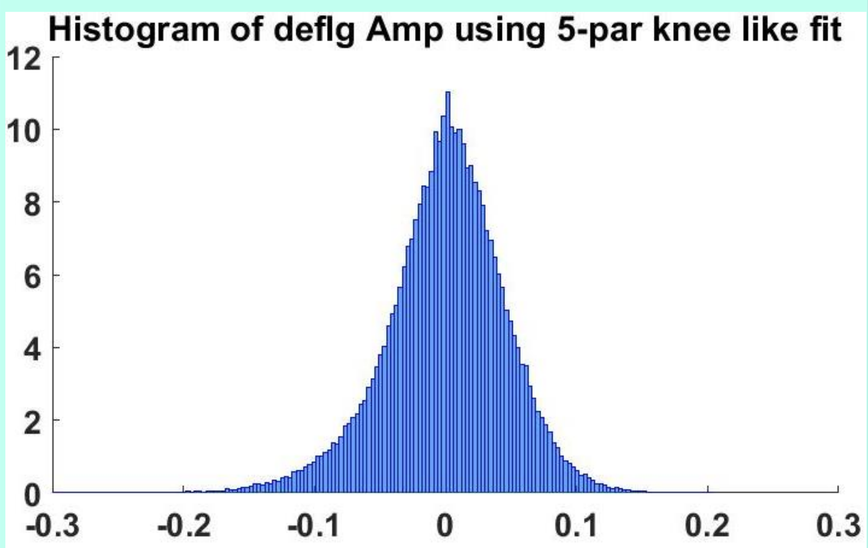
Item2-Estimation of the accuracy of the Cherenkov light density measurement



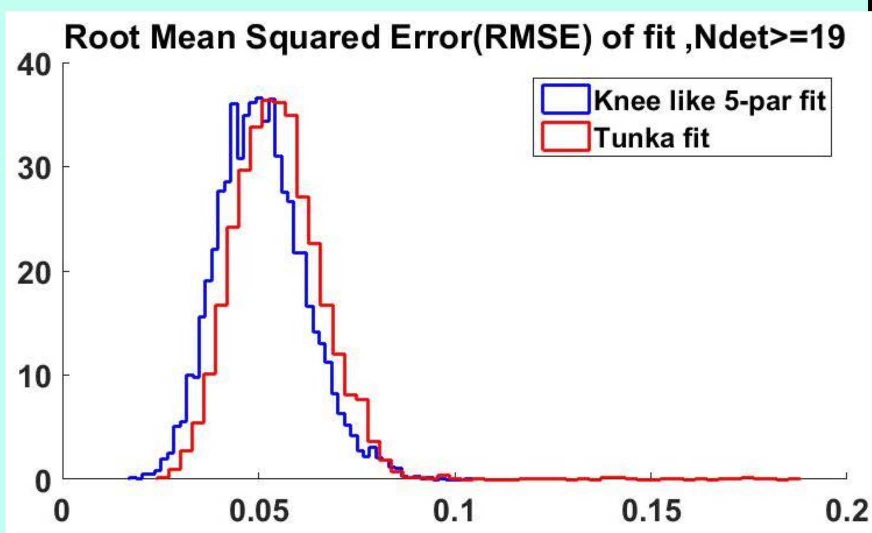
- This figure shows the relation between the number of stations and the mean deviation of the measured (Amp) and fitted value (Ampfit) of amplitude in every detector

deflg=log10(Amp)-log10(Ampfit)

We can see that some stations do not work well such as the stations number 18,20 and 26.



- This figure shows the distribution of the deviation for the amplitude using 5-par Knee-like fit , where we found that the RMS for Amp ~ 0.05 and for Q ~ 0.1

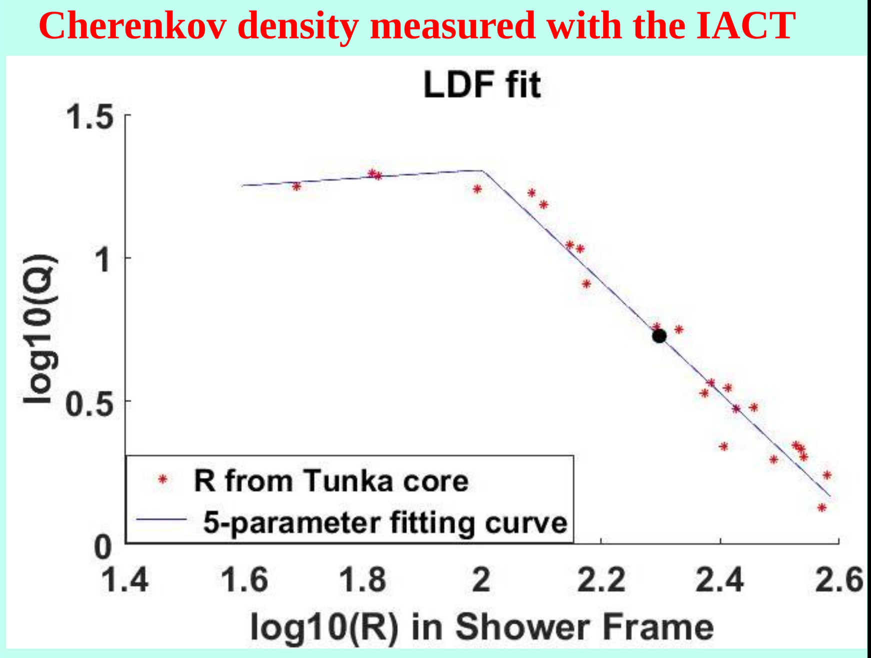


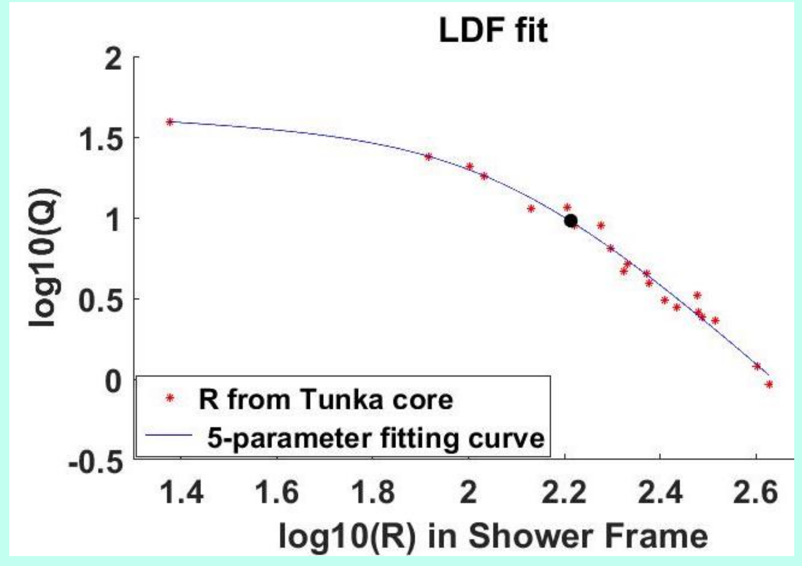
- This figure shows the Root-Mean-Squared Error (RMSE) which characterizes the accuracy of fitting for every event. It was calculated from these equations:

SSE=Sum((log10(Amp)-log 10(Amp fit).^2)
RMSE=Sqrt (SSE/(no of detectors - no of parameters))

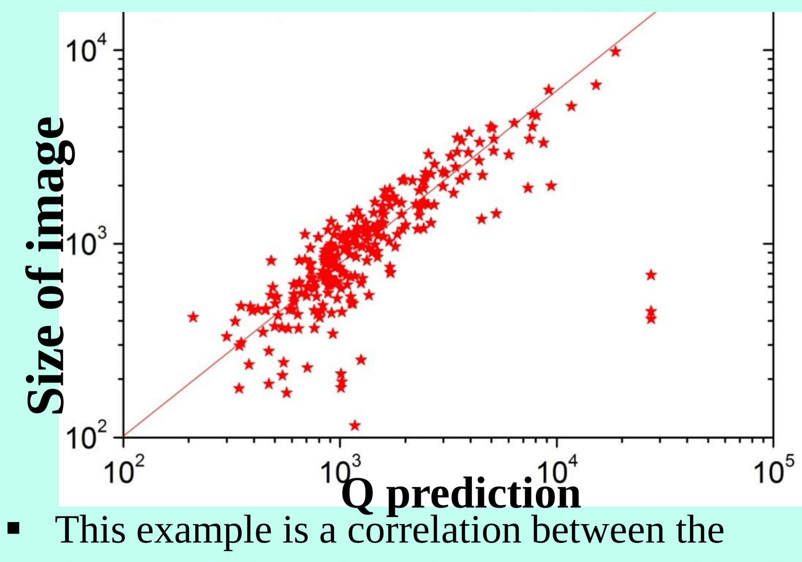
The blue histogram (with the small RMSE) which represents our Knee like fit is better than the red one which has a big tail and represent the Tunka fit.

Item3-Estimation of the Cherenkov density Qtel in the site of the IACT telescope using our knee-like fit for the HiSCORE experimental data, and comparison with the Cherenkov density measured with the IACT





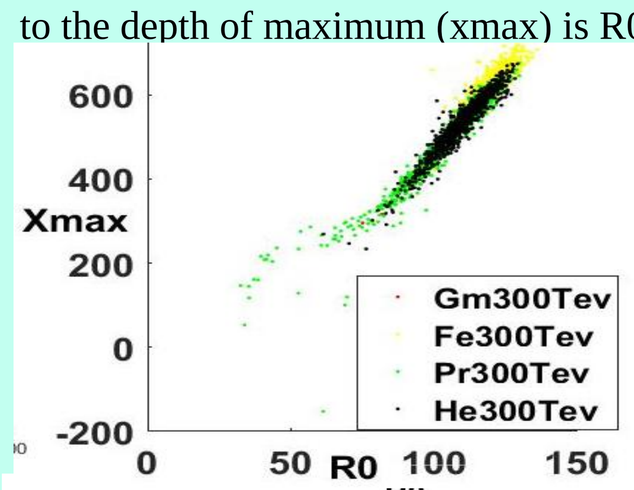
- We can see in these 2 examples that the black points represent the estimation of the Cherenkov density Qtel in the site of the IACT telescope using the knee-like fit for the HiSCORE data.

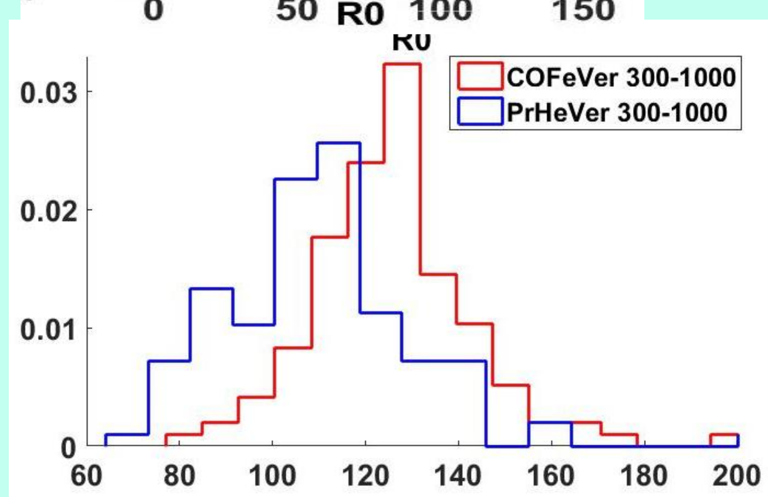


- This example is a correlation between the density of Cherenkov photons measured by the IACT (size of image) and the calculated predictions Qtel, obtained from HiSCORE data using the knee-like fit.

Item4- Investigate the ability to separate heavy and light nuclei using fit parameters values.

- We start this work using the simulated data and we have found that the most sensitive parameter to the depth of maximum (xmax) is R0





Distribution of the parameter R0 for proton-Helium (blue) and Carbon-Iron (Red) two samples for energy from 300-1000 Tev at angles 0-25.We can see that using R0 parameter we can separate between heavy and light nuclei with a good accuracy.

Conclusion

1- The "knee-like" approximation describes the average and individual LDF for gamma rays and different nuclei very well not only for simulated data but also for experimental events.
2. Using correlations of different parameters we have been able to decrease the number of parameters to 3 or 4, and made an algorithm of a core position determination with a good accuracy
3- Using the knee-like fit we obtained a good correlation between density of Cherenkov photons measured by the IACT (size of image) and the calculated Predictions Qtel.

4- The possibility of separating heavy and light nuclei has been studied using one parameter from our knee-like approximation (R0), this work will be complete in the future.