TAIGA: HYBRID METHOD IN VHE GAMMA-RAY ASTRONOMY (FIRST RESULTS AND PERSPECTIVES

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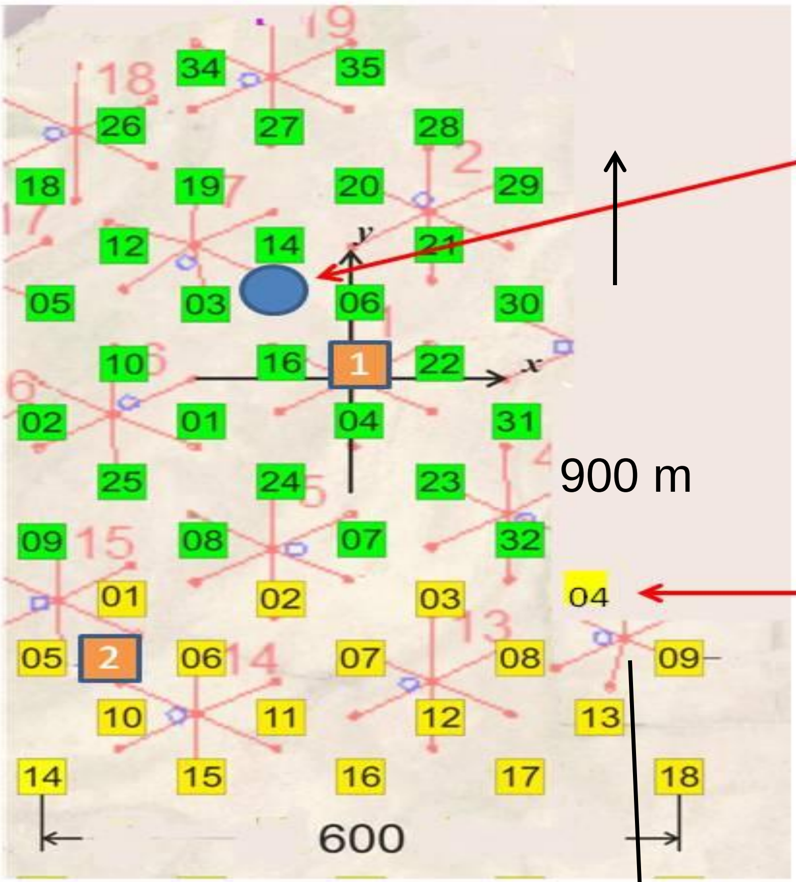
TAIGA (Tunka Advanced Instrument for cosmic rays and Gamma-Astronomy)

SEASON 2017-2018 LAYOUT



42 detectors , 106 m distance,
S~0.5 km2 , effective S ~ 0.3 km2

IACT:
S of mirrors = 8.5 m2
Focus 4.75m2
FOV 9.5º
Accuracy
of tracking 0.05º

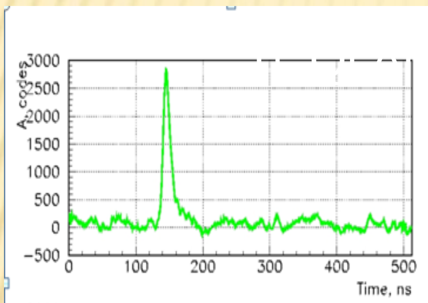
HiSCORE station:
"Tilting" to South by 25º to cover CRAB

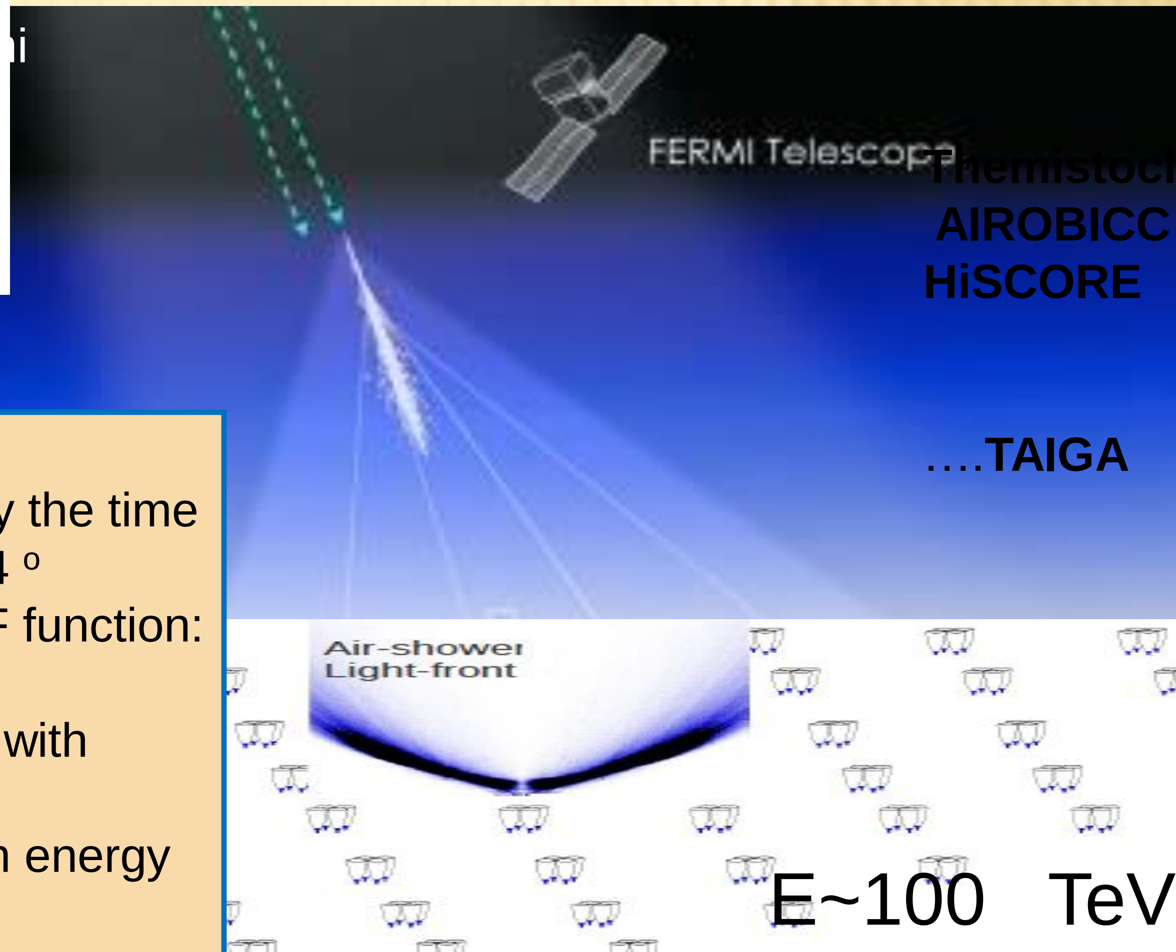
Sub-ns array-wide time synchronization

4 of 8'' PMTs with Winston cones light collection 0.5 m2 and FoV ~0.6 sr

NON IACT METHOD (TIMING ARRAY)

Non IACT technique **was developed in Tunka-25 and 133 array for cosmic rays detection and was optimized for PeV -100 PeV energy. To move to sub TeV region high sensitive detectors were developed to reach low energy 100 TeV.**





Themistocle
AIROBICC
HiSCORE

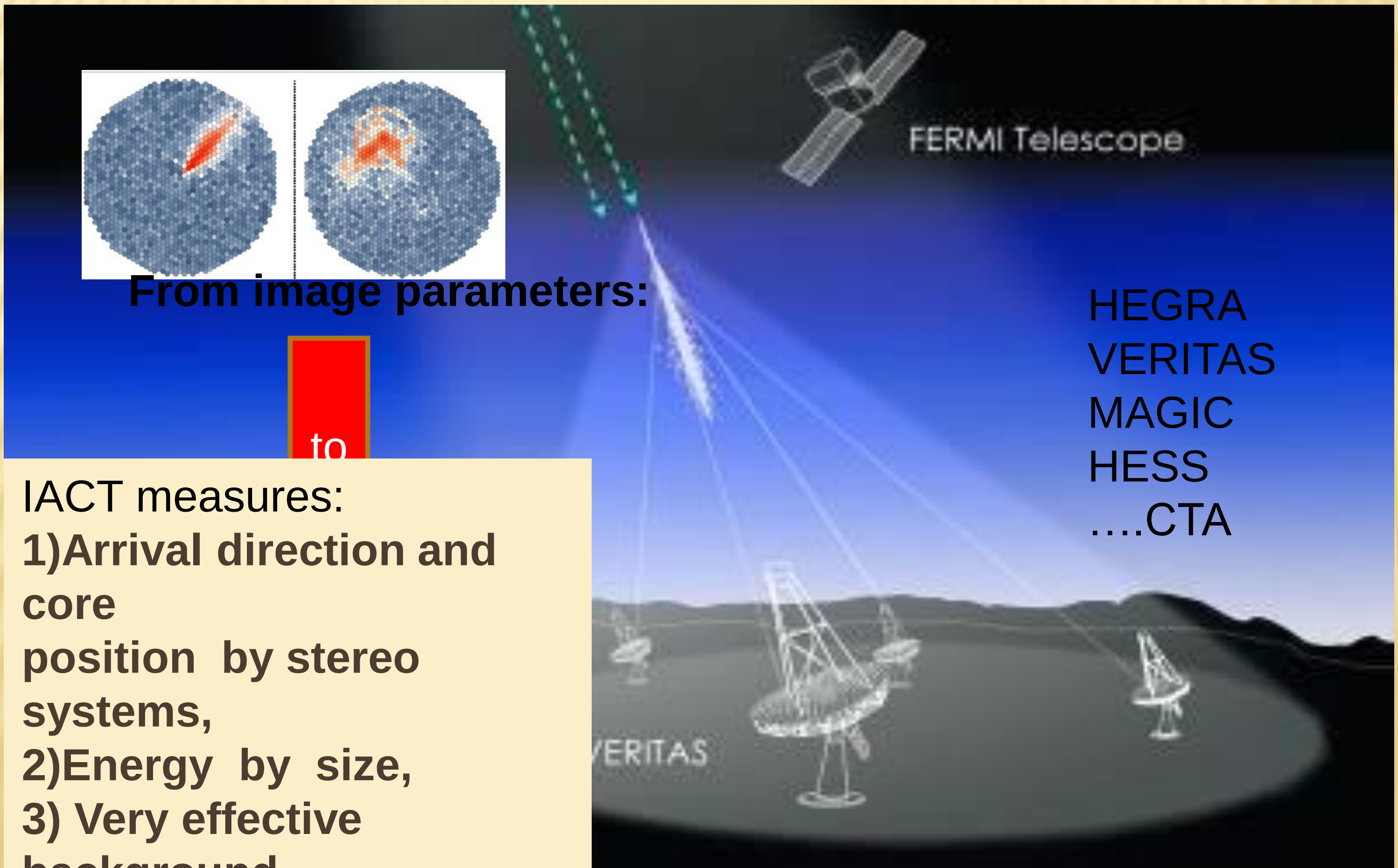
….**TAIGA**

What we measure:
1)The arrival direction – by the time delay : accuracy 0.1- 0.4 ^{o}
2The core position by LDF function: With accuracy 5m – 30m
3) energy by Q at 200m with accuracy 20-40%
3) Type of particles for high energy

E~100 TeV

METHOD OF IMAGING ATMOSPHERIC CHERENKOV TELESCOPES .

The IACT technique was developed and optimized for energies around 1 TeV.
A typical design consists 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) .



From image parameters:

to

HEGRA
VERITAS
MAGIC
HESS
….CTA

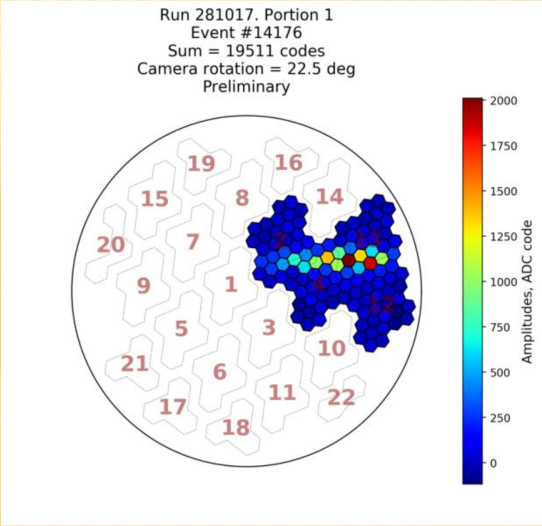
IACT measures:
1)Arrival direction and core position by stereo systems,
2)Energy by size,
3) Very effective background

OUTLINES

- Experimental sample of hybrid events 2017-2018 year
- Comparison with full Monte-Carlo simulations obtained with a new TAIGA-Optic program
- Search for gamma excess from Crab in the high energy range
- Outlooks

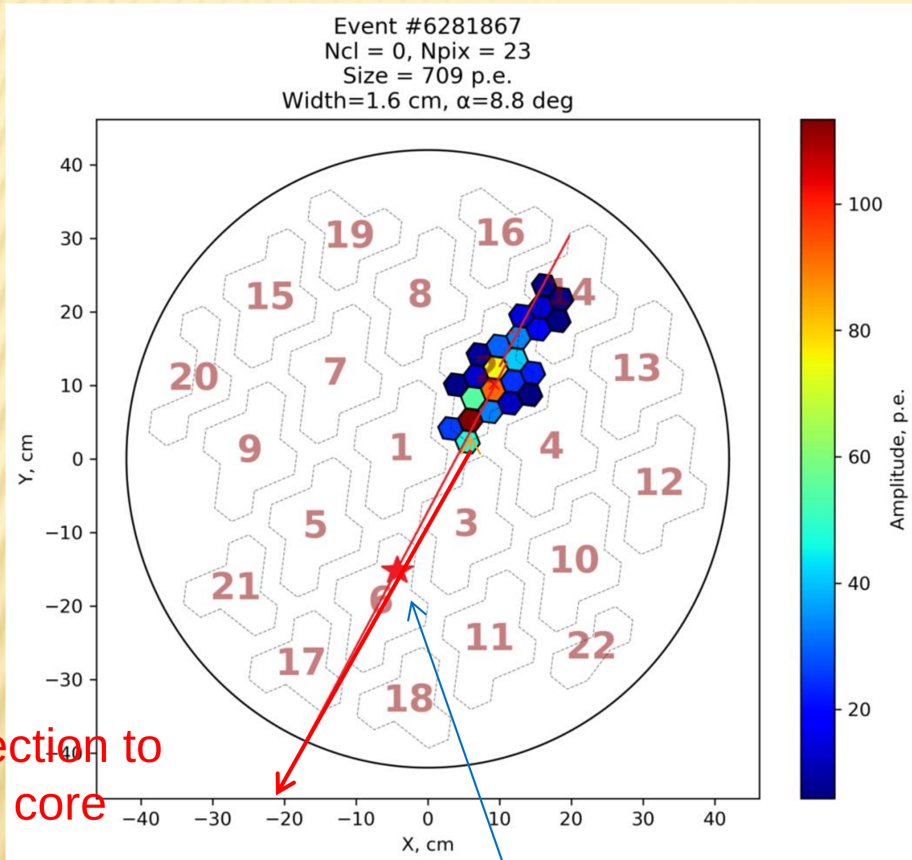
STEPS OF DATA PROCESSING OF IACT

- **1 step: Summarize different clusters and subtract pedestals.**
- **2 step: Codes →to ph.el., corrections to PMT sensitivity**
- **4 step: Current analysis:**
- **b) remove bad pixels**
- **c) remove star tracks**
- **6) Cleaning and visual analysis of images**
- **9) Calculate of Hillass's parameters**



- **10) Search for joint events in time window of 1.5 µs from the IACT and HiSCORE banks of events.**

INFORMATION WE HAVE ABOUT EVERY EVENT FROM IACT AND HISCORE



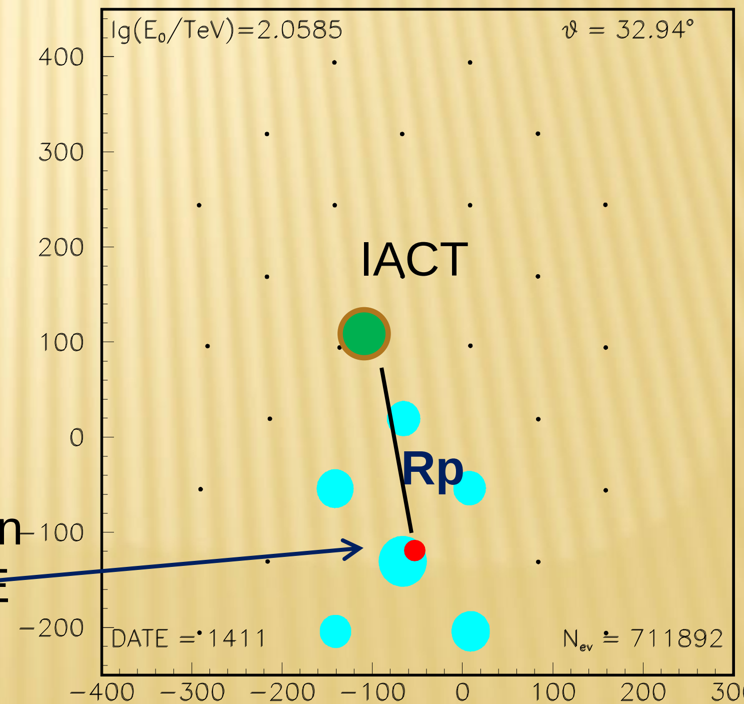
Direction to the core

Core position in IACT after introduction of scaling factor Rp' = Rp/1500

"Gamma-like"

HiSCORE detectors
E = 50 TeV Width = 0.19°

tet = 32.9 Fi = 33. 58



Core position In HiSCORE

PARAMETERS OF IMAGE

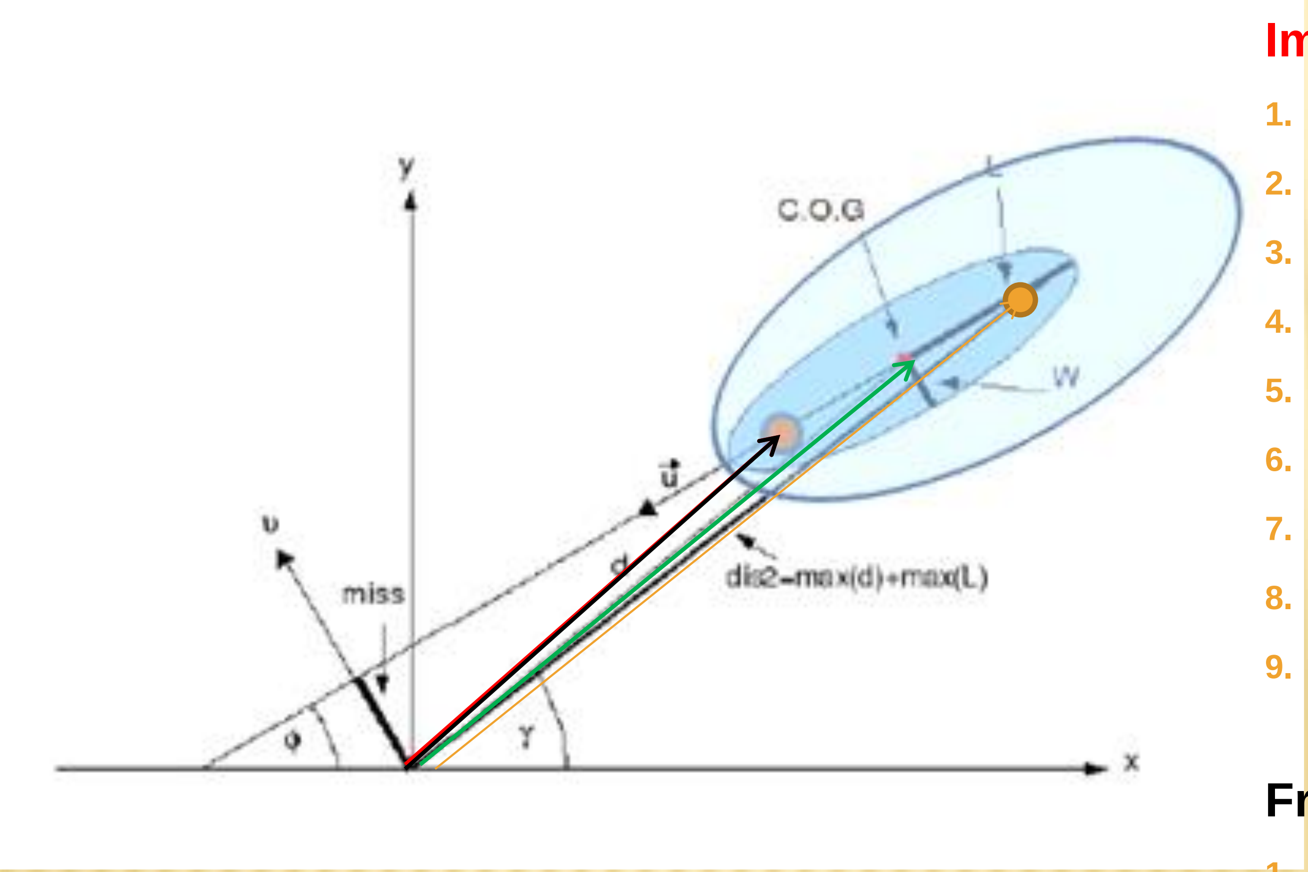


Image parameters

1. **Size, Npix**
2. **DIST, Rc**
3. **WIDTH**
4. **LENGTH**
5. **ALFA**
6. **Assimmetry**
7. **Concentration**
8. **Amiss**
9. **Peak(Max) Intensity**

From HiSCORE

1. **Energy**
2. **Rtel =Rcore-RIACT**
3. **Ψ - angle between shower direction and source direction**

Width, length,
Major axis directed to sources position,
Peak pixel shows the direction to sources
Miss - perpendicular distance from the major axis to the center of the camera, is equivalent to Ψ ,

STATISTIC 2017-2018

Crab tracking: 78 days, 197hr

Θ <40º with HiSCORE : 20 days, 70 hr,
Good quality of data : 20 days , 25 hours

Without technical problems with camera and with good tracking

Expectation:
CRAB 130 hr effective time in Hiscore aperture

37 days of HiSCORE & 20 days of IACT : 16days HiSCORE + IAC

IACT only: 20 days, effective time 25 hr, Size>60, Npix>4 : 95000 events

HiSCORE only Ndet>4, 50 m from edge 1.33 mln events

IACT + HiSCORE (1and 2 clusters all joint showers 37000

MONTE-CARLO DATA STATISTICS
46 HISCORE STATIONS, 1+2 CLUSTER UP TO R=600M

Primary	Eth	Slope	Ntot	Detected by IACT	By HiSCORE	Joint		Ntot HiScore 50pe	TM-C hours
Protons	70 TeV	-2.6	122000	8864	20222	5090		104000	
Helium	70 TeV	-2.6	110000	8137	10365	2615		86000	
Gamma	35 TeV	-2.6	40000	7396	4135	1216		33018	

1) Shower development in the air was simulated by CORSIKA;

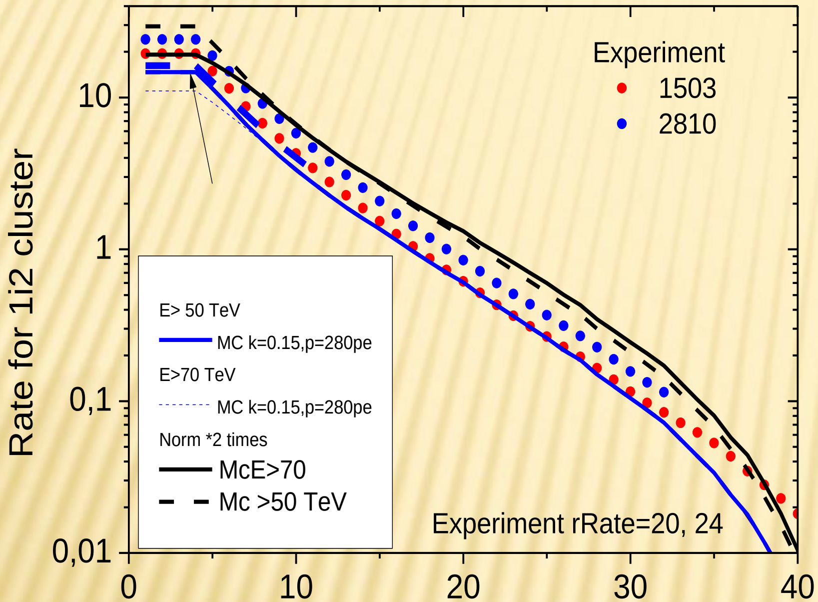
2) Cherenkov photons of the shower were traced through the optical system of the IACT and optical system of every station of HiSCORE, TAIGA OPTICA,

3) Trigger conditions were included in simulations,

4) The methods of shower arrival direction, energy and core position reconstruction used in experiments were implemented in program.

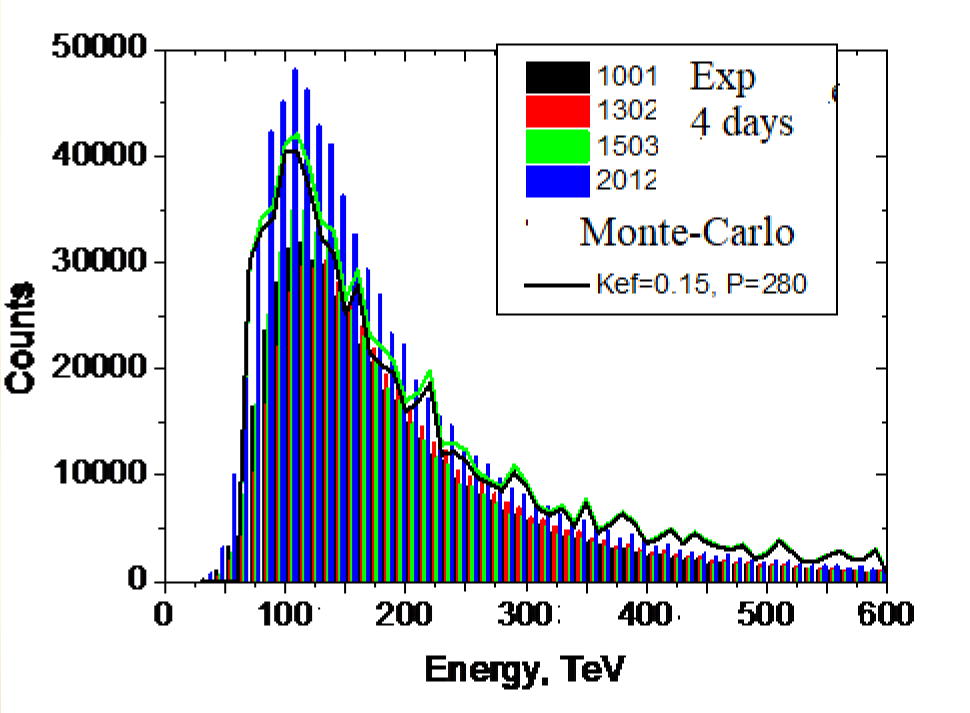
HISCORE DATA: EXPERIMENT & MC

Counting rate of hit stations, sec-1



Number of hit stations

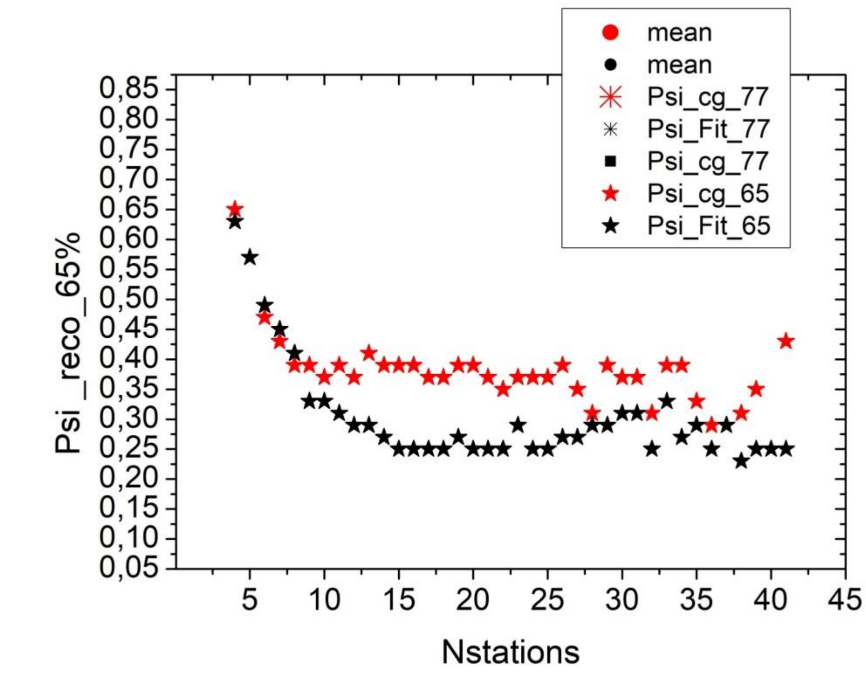
Differential spectra obtained in HiSCORE

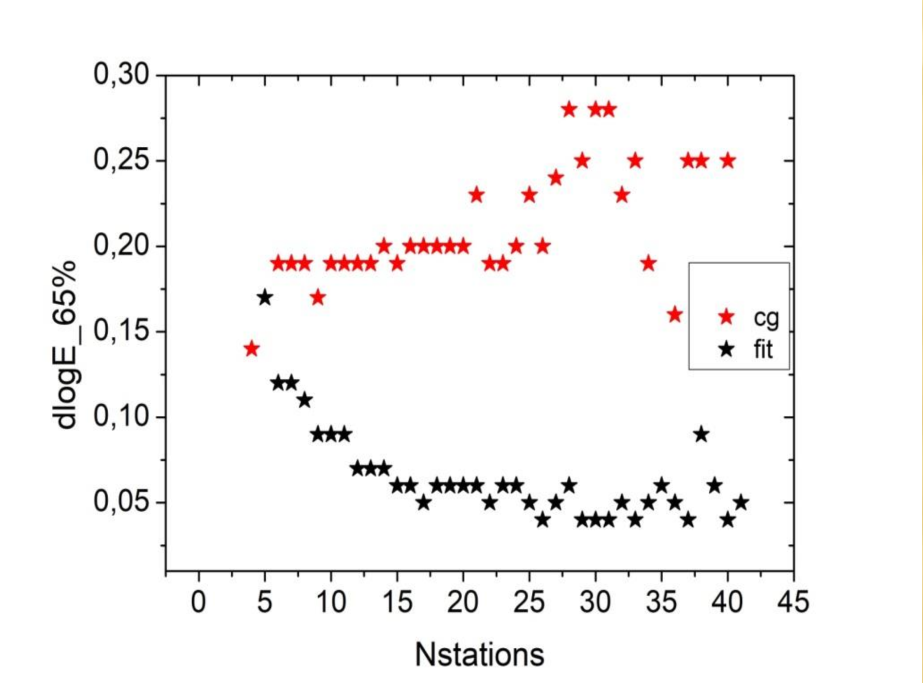


Primary spectrum and mass composition (Hoerandel,2001);

Min number of photoelectrons per station ,Qhreshold~280 ph.el., 70% efficiency provides an agreement with experiment, and gives ~ 100 TeV peak energy

IMPLEMENTATION OF THE RECONSTRUCTION METHOD (CG & FIT) INTO THE MC SIMULATION





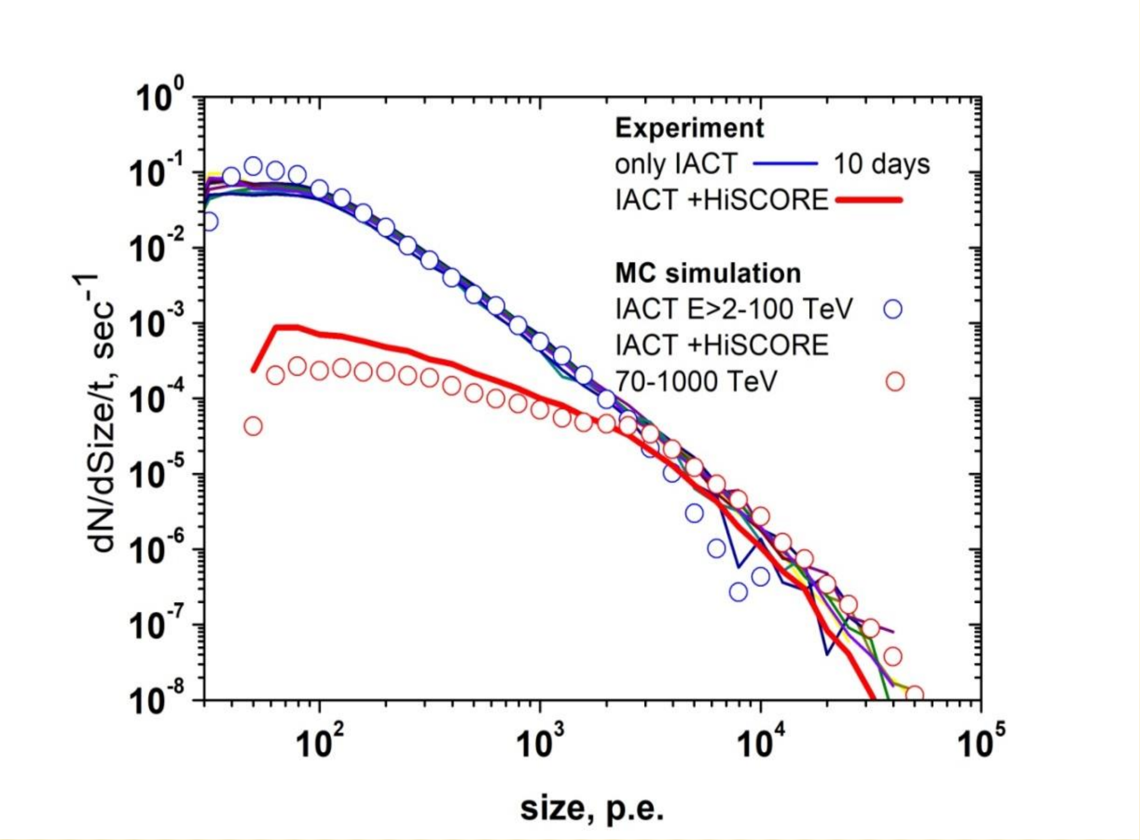
Accuracy of arrival direction reconstruction

Accuracy of energy reconstruction

CG method: only 4 central detectors are used for parameters reconstruction: red stars

Fit method: all hit stations are used for LDF reconstruction : black stars

EXPERIMENTAL DIFFERENTIAL SIZE SPECTRA: EXP & MC



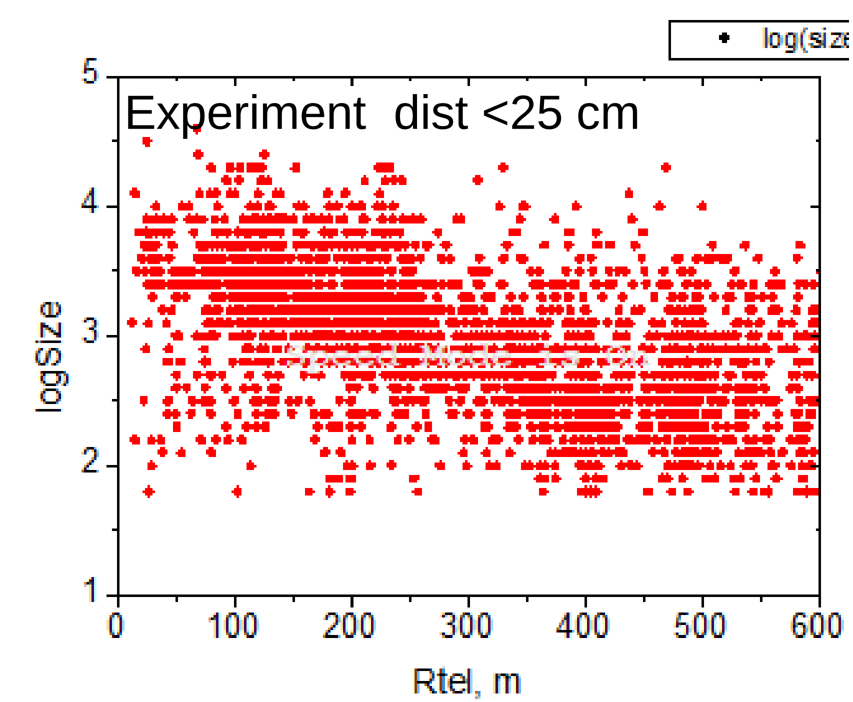
Assumed primary spectrum
For Pr+HE and Nuclears
Close to spectra of Hoerandel,200

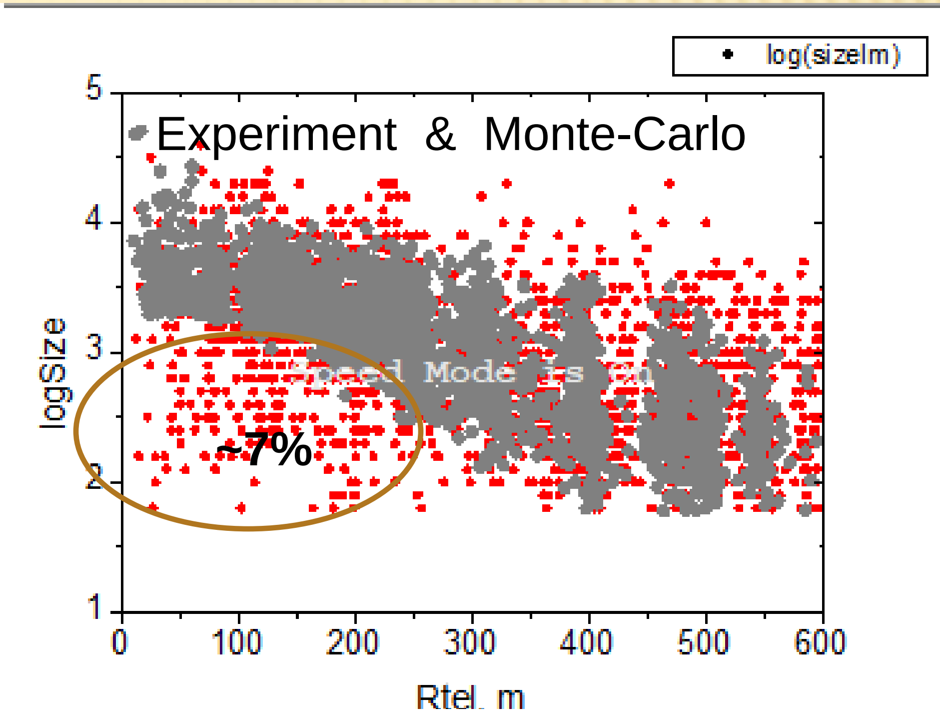
MC describes experimental spectra: low energy range 2-100 TeV and 70-1000 TeV
In the region near the threshold in both samples we have some discrepancies, requiring the understanding

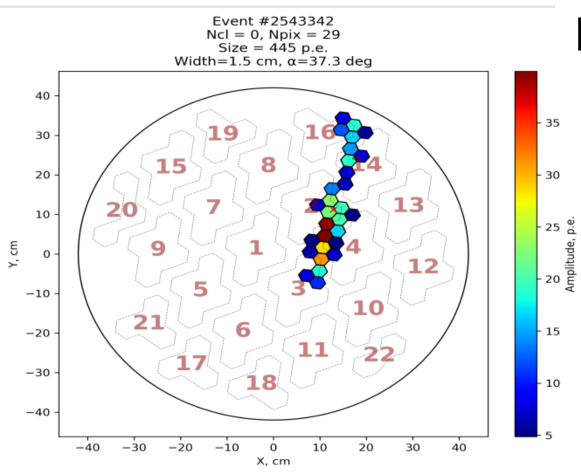
COUNTING RATES STATISTIC: EXPERIMENT& MC

	Experiments	M-Carlo
N	25 hr	HAWC
37500		
Rate of HiSCORE 4 stations	**20-25 Hz**	**~24 Hz**
Rate of IACT	**13-20 Hz**	**~20 Hz**
16900		
Rate of joint events	**0.35 Hz**	**0.7 Hz**
7615		

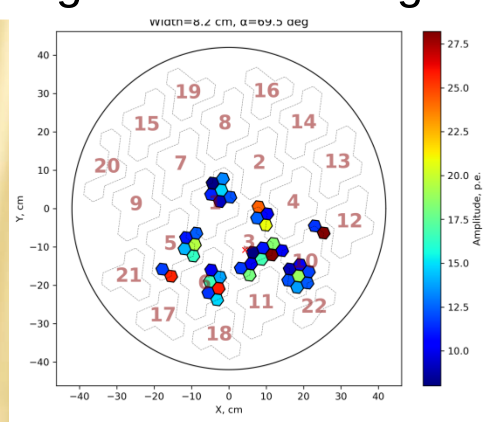
SIZE – DISTANCE FROM IACT TO CORE

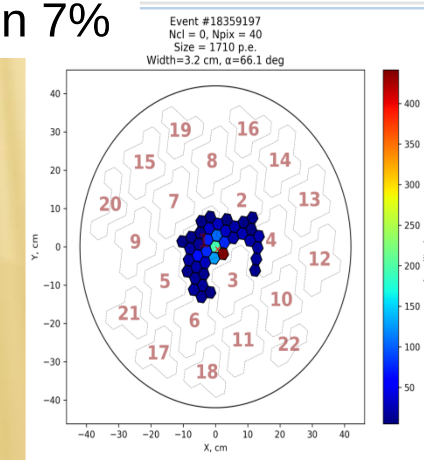






Many strange events among this region 7%

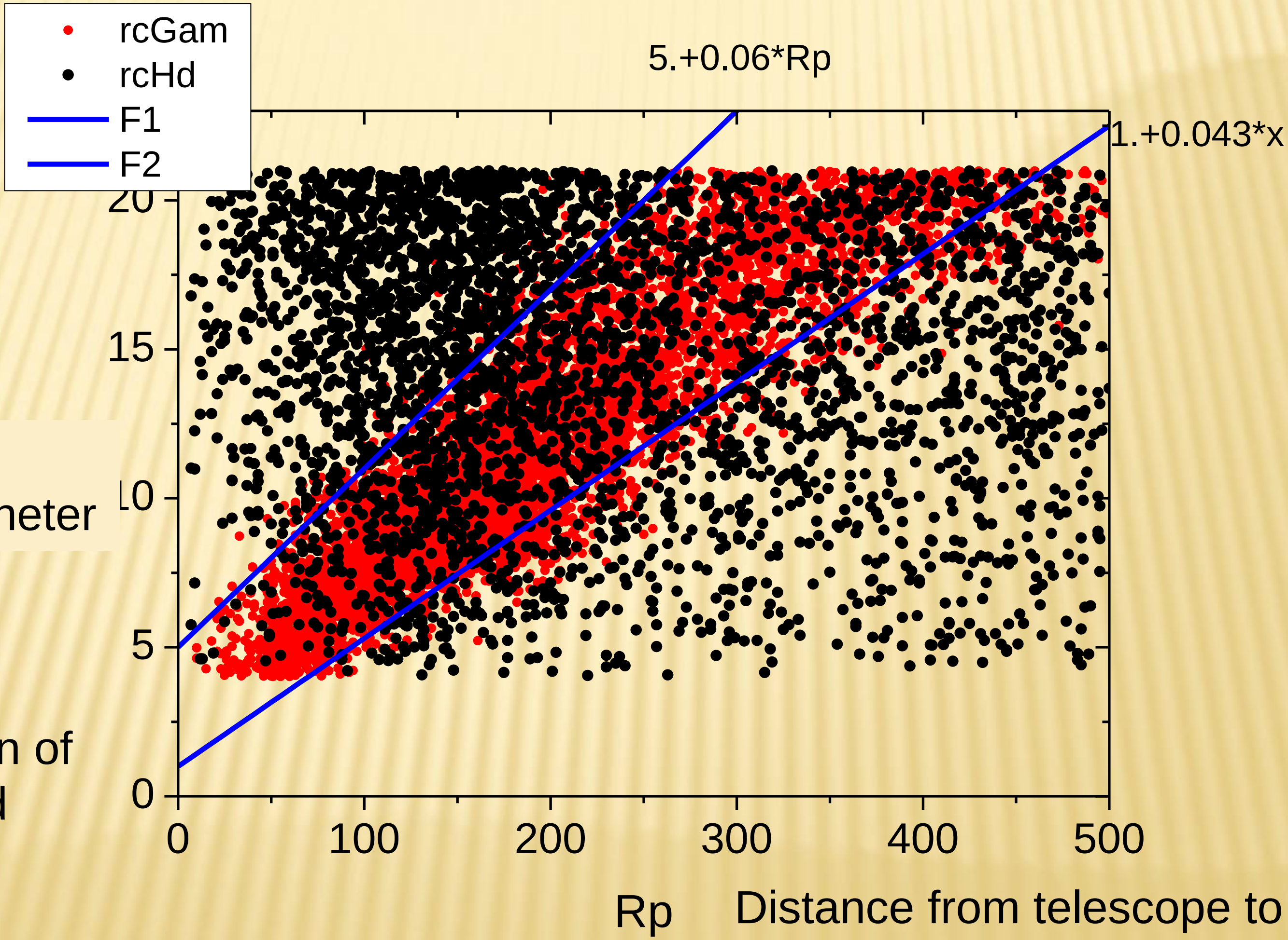




PARAMETERS USED FOR GAMMA RAY DISCRIMINATION

CUT : DIST- RTEL

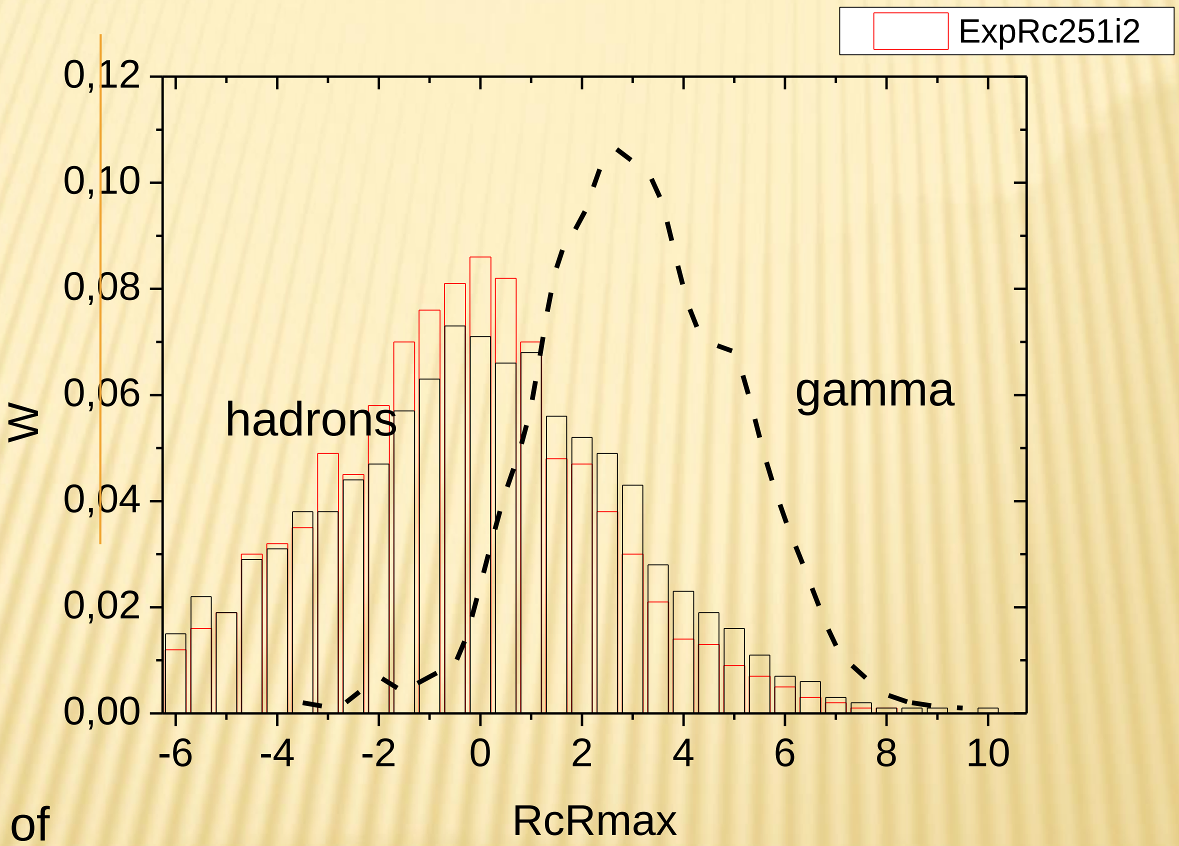
Distance to Weighted ceneter



Distance from telescope to EAS core

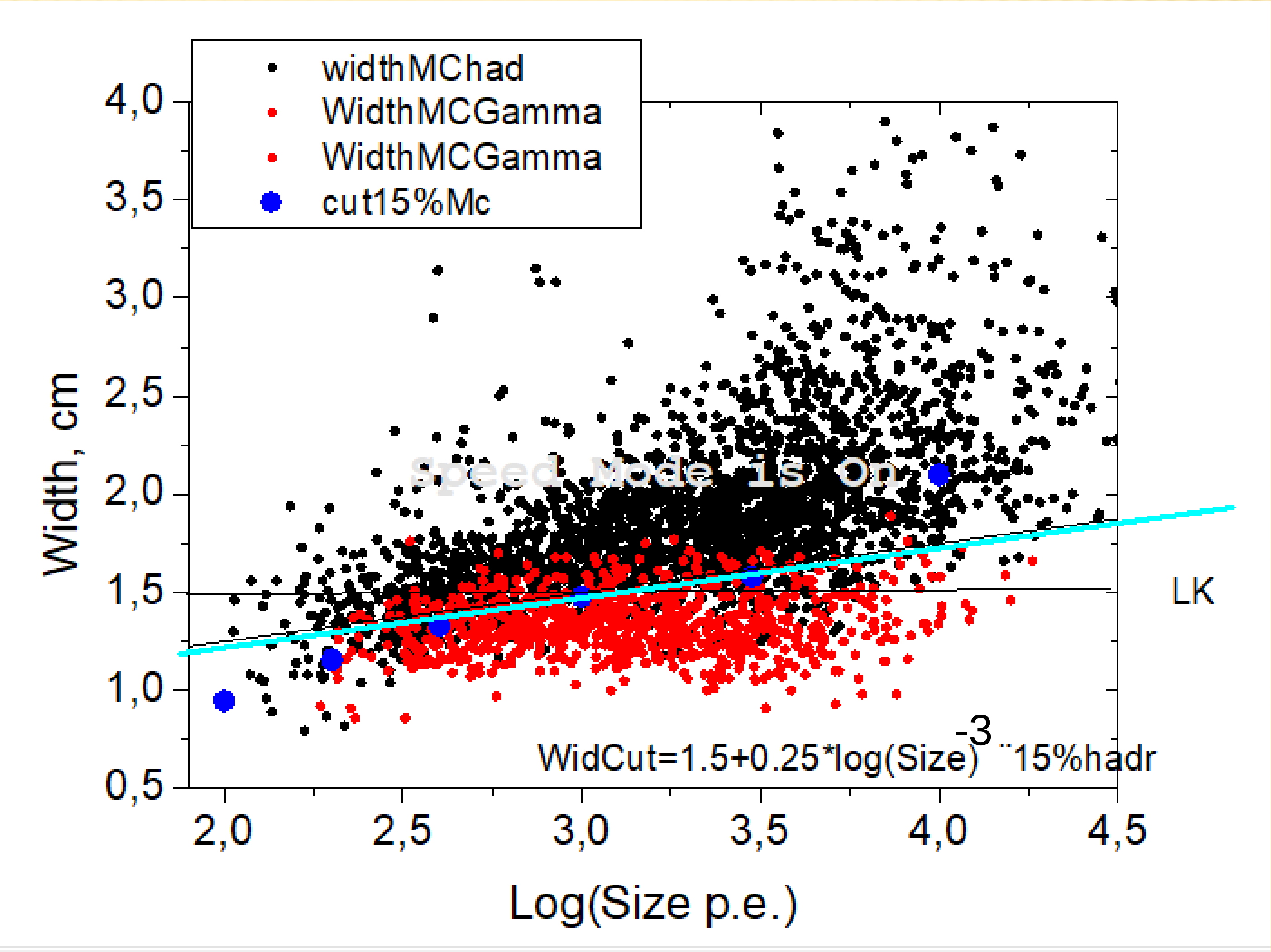
Suppression of bachground ~7 times

ASSYMMETRY



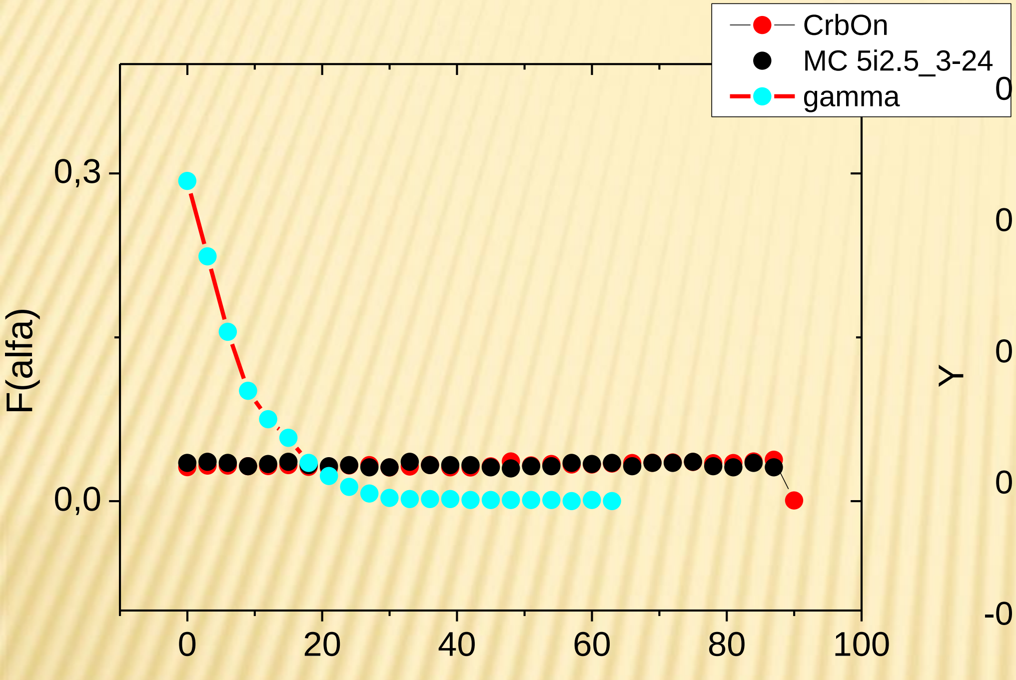
Suppression of background ~2.5 times

WIDTH(SIZE), CUTS

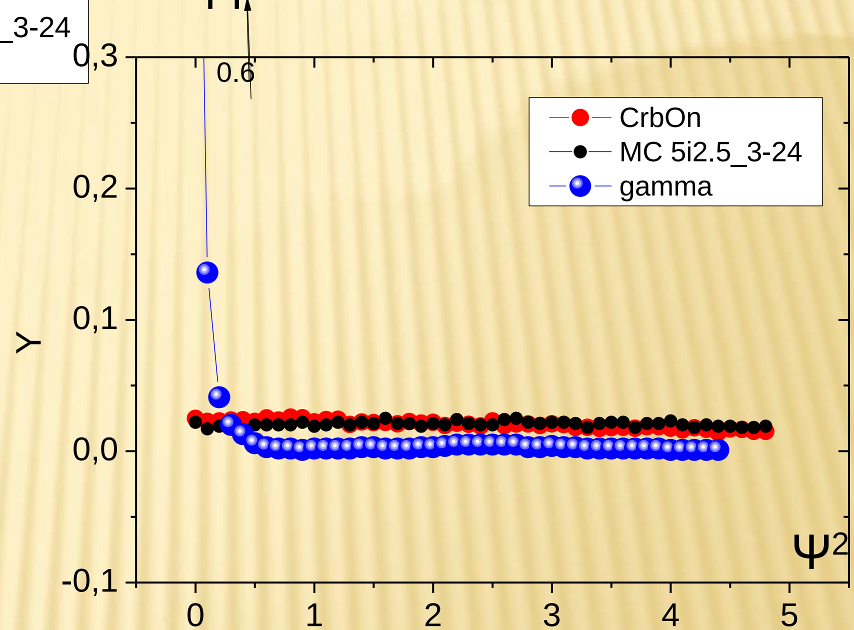


Suppression
~20 times

ALFA AND Ψ² DISTRIBUTIONS RECONSTRUCTED FROM DATA IN SIMULATIONS



Suppression factor ~7-9



ψ **- angle between shower direction and direction to source**

A full suppression factor of background (from MC and Experiment)

ε back~1/(600) .

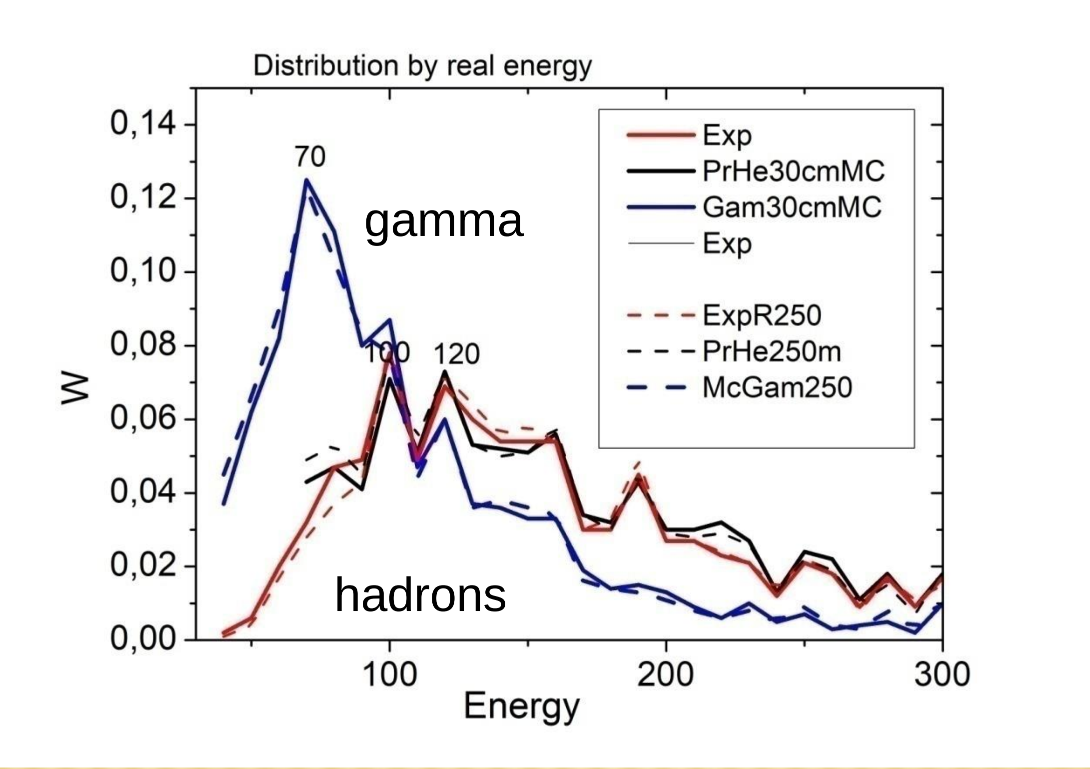
MC gamma- sample decreases by about 2 times,

ε back~1/(2) .

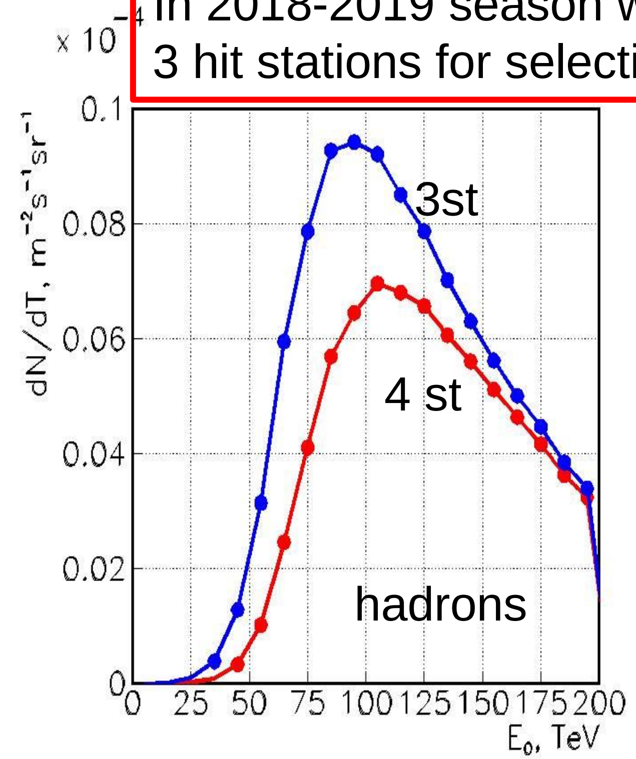
$$Q = \frac{\varepsilon_{gam}}{(\varepsilon_{back})} = 10$$

GAMMA RAY EXPECTATION

After all cuts we suppress gamma rays by about 65% and expect to detect ~3 -4 gamma rays with peak ~ 70 TeV over area 0.3 km2 during 25 effective hours

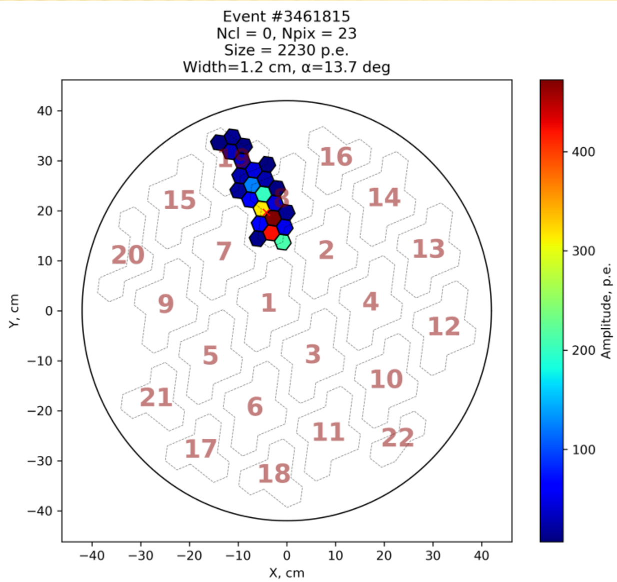


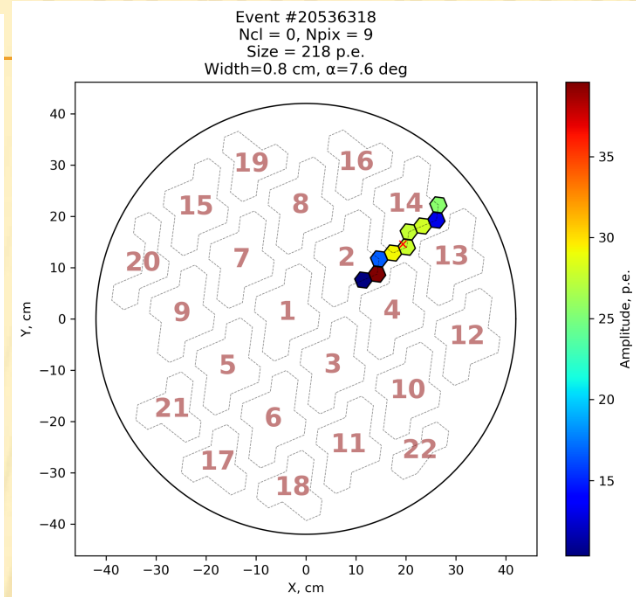
In 2018-2019 season we try 3 hit stations for selection

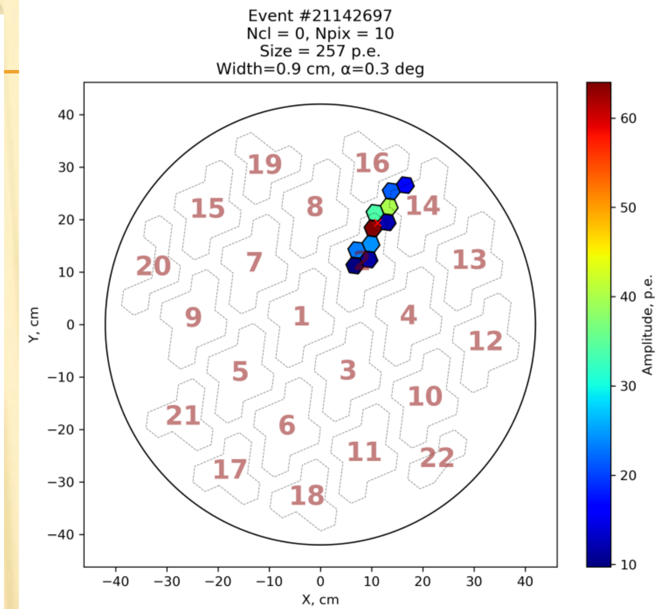


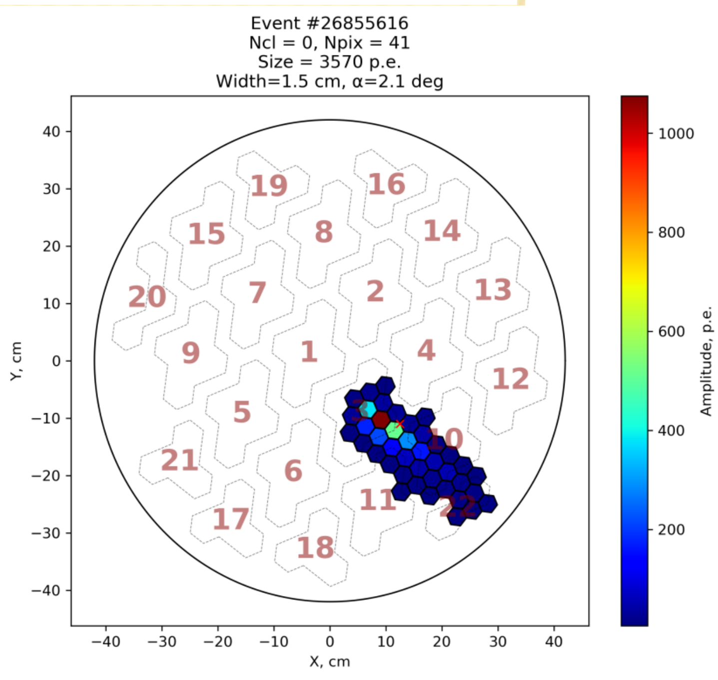
Distribution by energy for joint events for background and for gamma rays Experiment & MC

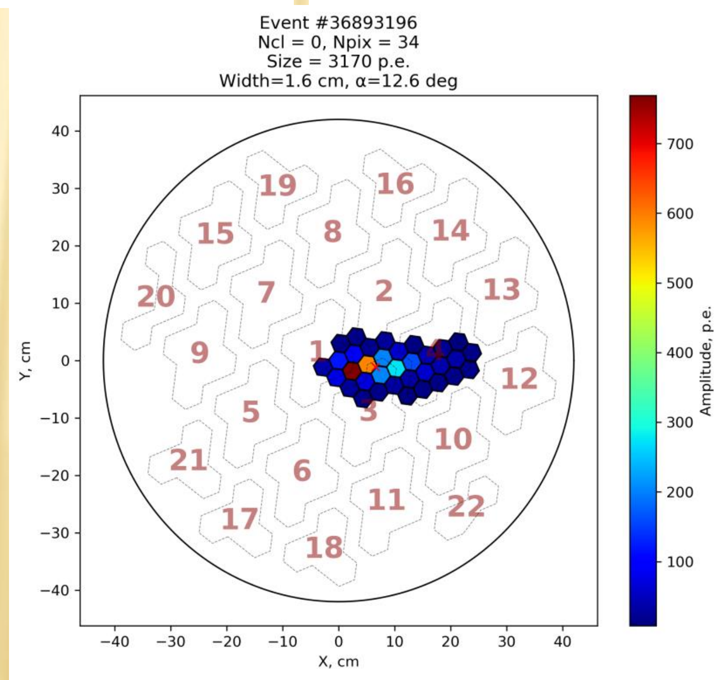
GAMMA-LIKE EVENTS AFTER ALL CUTS











OUTLOOK

We’ll put efforts to understand more accurately the hadron background in the threshold region.

In season 2018-2019   ‘wobble’ mode of IACT work is realized

In season 2018-2019 minimum 3 hit stations events are included in processing for decreasing a threshold

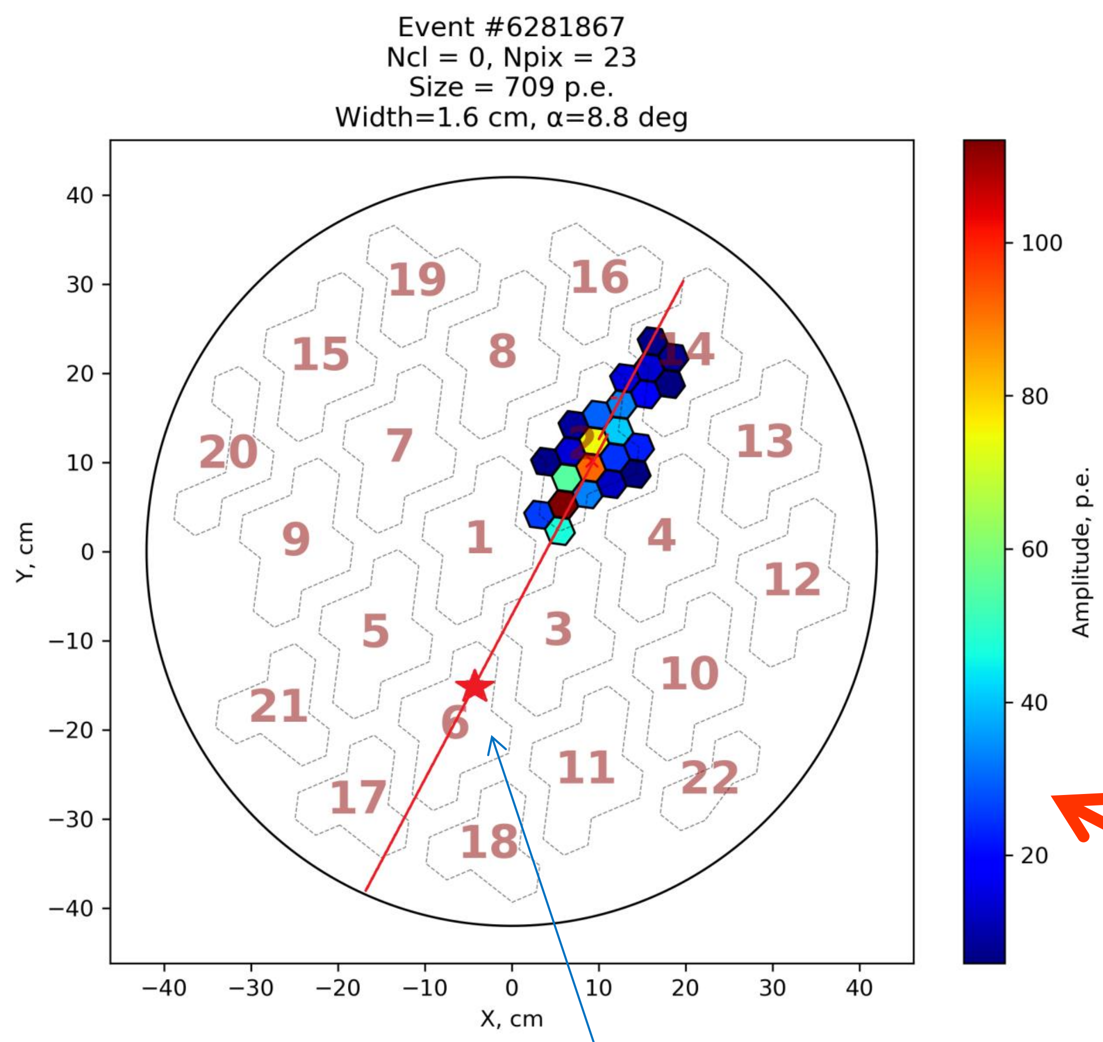
CONCLUSIONS.

1. For the first time the hybrid method of EAS registration and gamma/hadron separation in the region around tens-hundred of TeV was realized in the experiment TAIGA. About 37000 events, detected by HiSCORE wide-angle timing array and simultaneously by IACT in the direction to Crab Nebular were detected during 25 effective hours on the area ~ 0.3 km^2.

2. It was possible to agree spectra, counting rates, Hillas's parameters, obtained from both installations with MC simulations. Only threshold region requires the additional refinement and understanding. The Qfactor of gamma/hadron separation, estimated from MC simulation is ~ 10.

3. In the first season 2017-2018 of joint operation, the expected peak energy of gamma rays was enough high 70-75 TeV, that allows to expect ~ 3 gamma-like events versus 5-6 particles. In season 2018-2019 due to special efforts we decreased threshold of HiSCORE stations and expect lower threshold of gamma induced showers ~60 TeV.

THANK YOU !



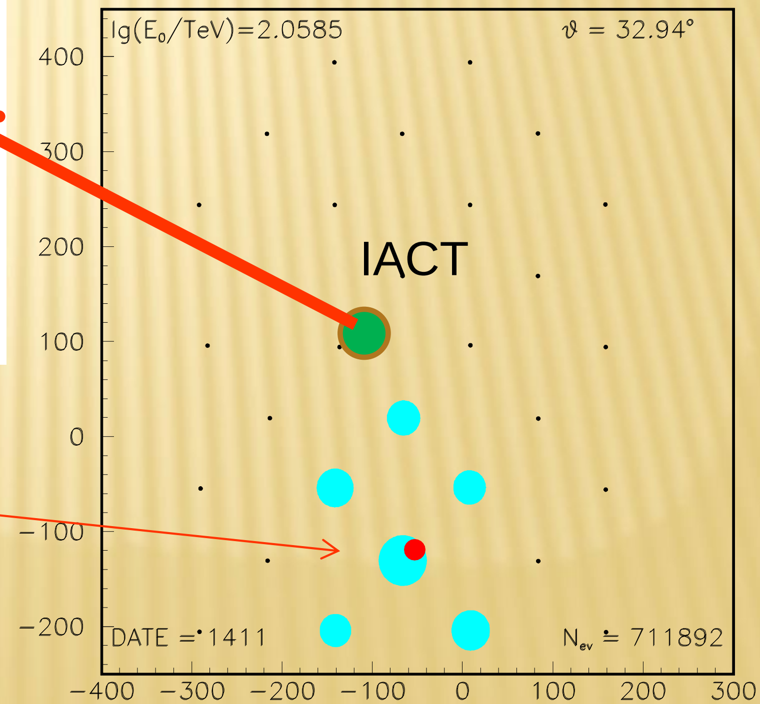
“Gamma-like”

E = 50 TeV

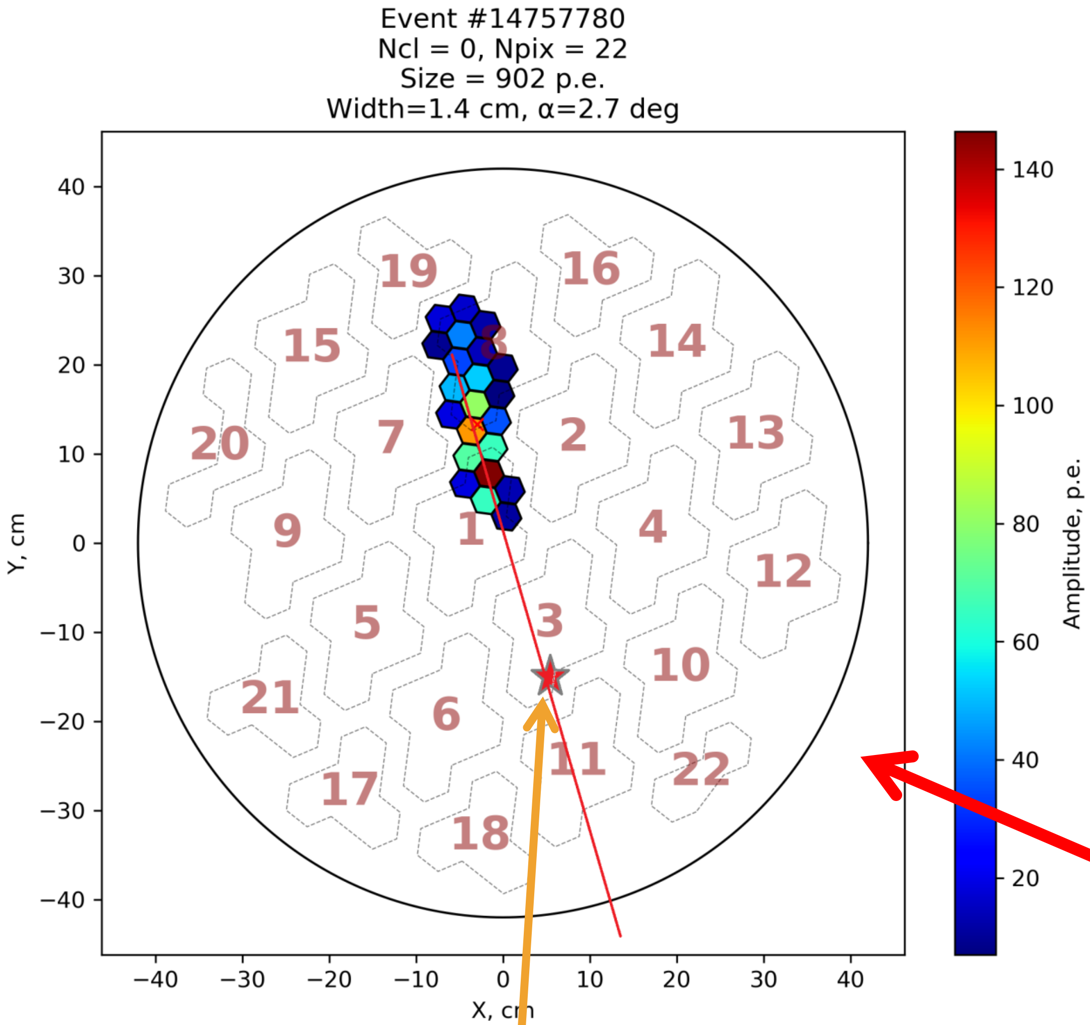
Width = 0.19°

tet = 32.9

Fi = 33. 58

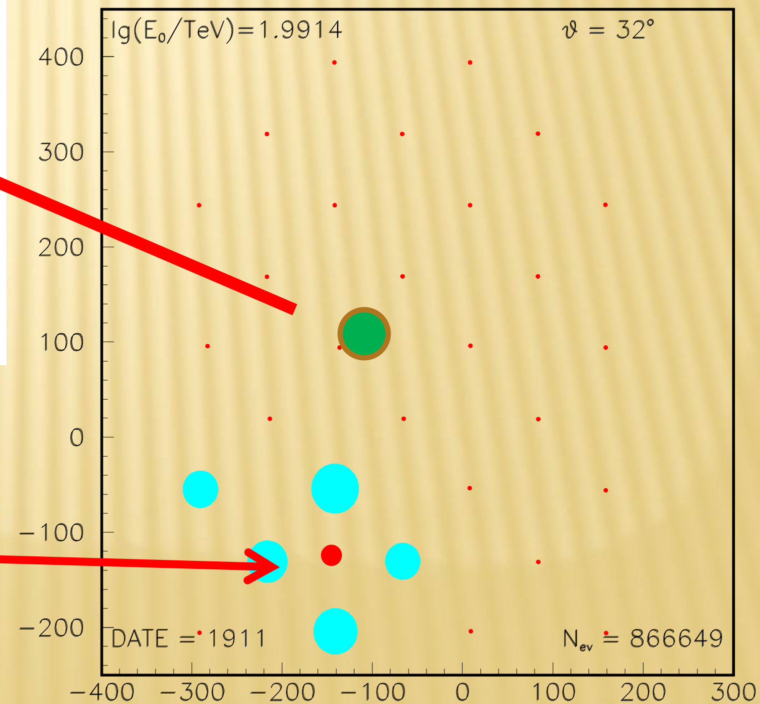


Core position



Gamma-like

E =50 TeV
tet = 37.0
Fi = 331. 12



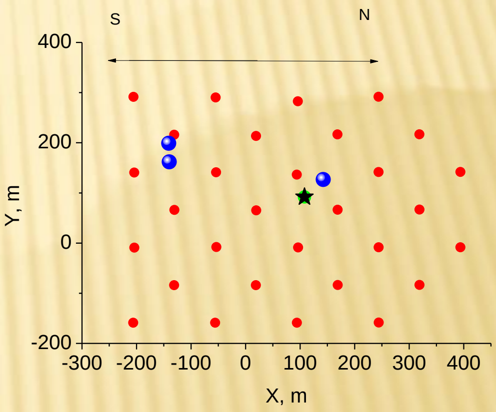
Core position

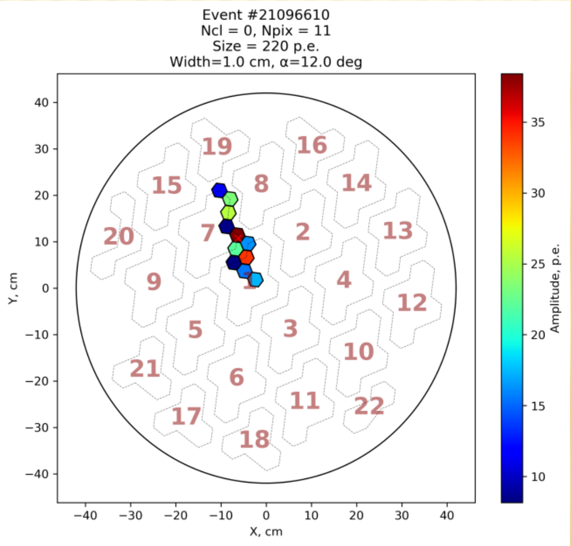
STATISTICS AND GAMMA-LIKE EVENTS

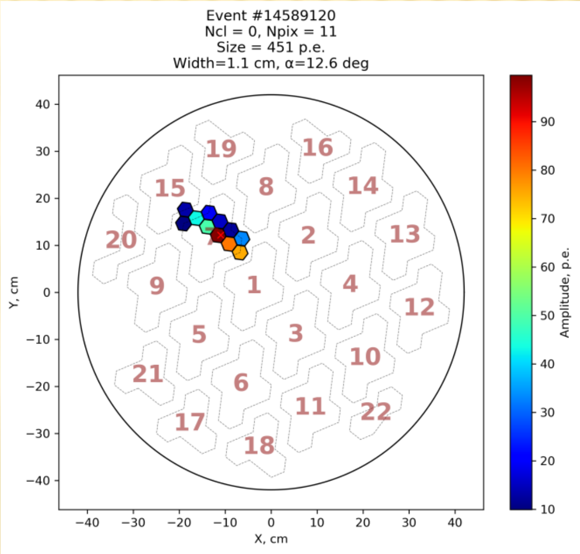
Gam- angle between direction on Crab and shower direction measured by HiSCO

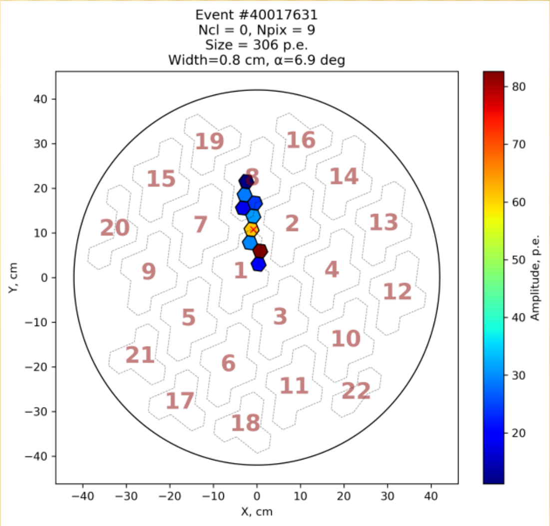
Effective Time -
Gam <1 degrees -   255 events
Selection criteria Gam<0.3o,   gam <1o,
alfa < 18,   Rc<27 cm   3 events

Energy ~ 50-70 TeV
Distance ~ 50m, 300m,   270m

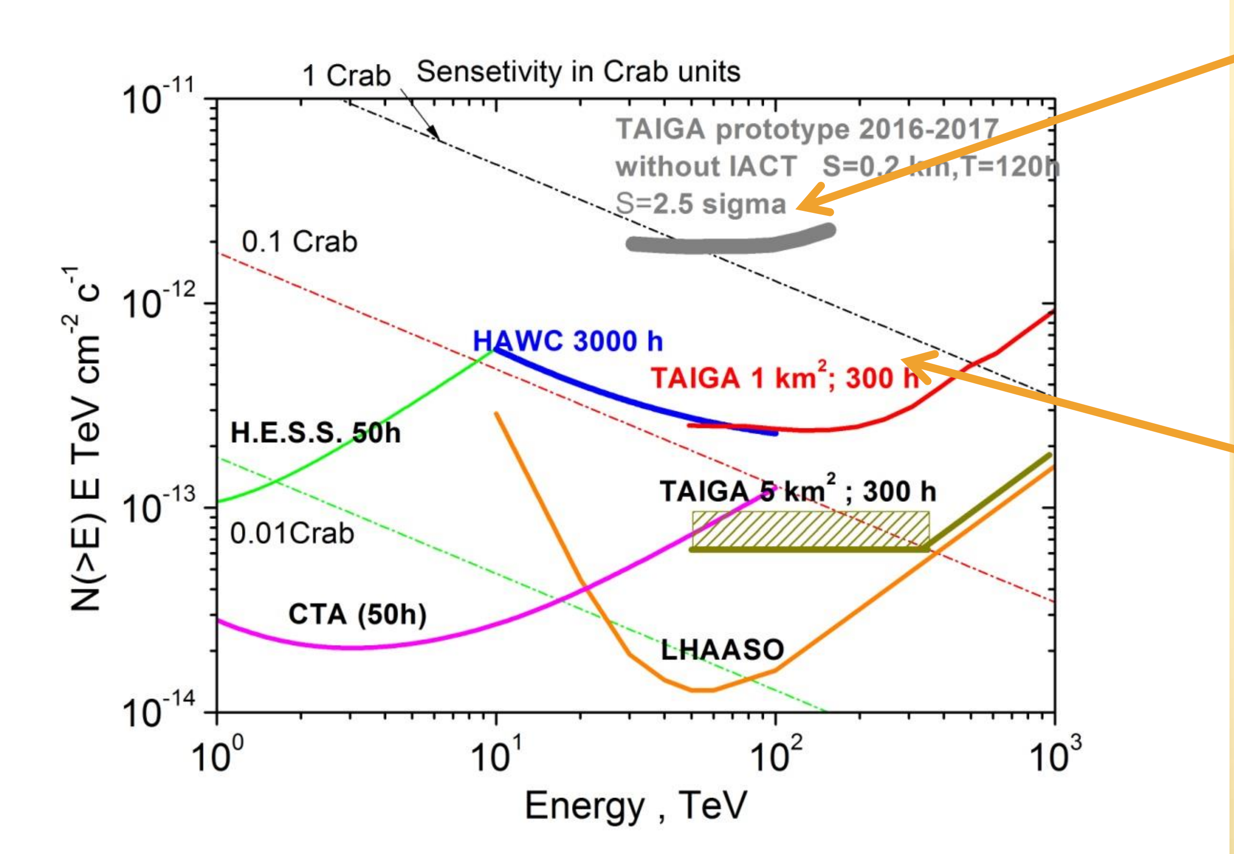








WHAT WE CAN EXPECT WITH CURRENT PROTOTYPE ?



Current array:
S=0.2 5km2,
T~120 hr
without IACT
Significance=
2.5 sigma

2019 : 1 km2 +3 IACT

Integral sensitivity