Development of an EAS type identification method based on an artificial neural network for the TAIGA experiment

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- The main aim of this study is to check the perspectives of mashine learning method for investigation of the mass composition of CR and identification of gamma/hadron induced EASs. The results are very preliminary. The authors recognize the simplicity of the model and further need of the detail study.

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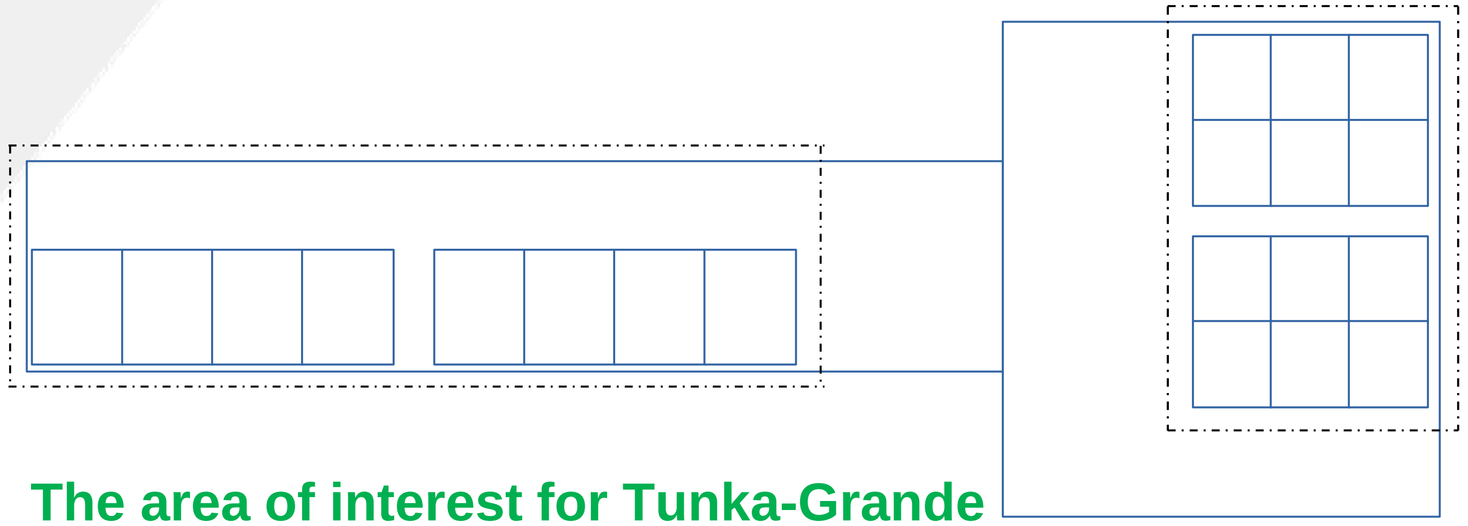
The simulation model divided into three parts:

- simulation of the EASs - CORSIKA package
- selection of the secondary particles – program based COAST library
- simulation of the detector response – GEANT4 package



The area of interest for Tunka-Grande

CORSIKA-77401, using standard electromagnetic interaction model EGS4 (Electron Gamma Shower)

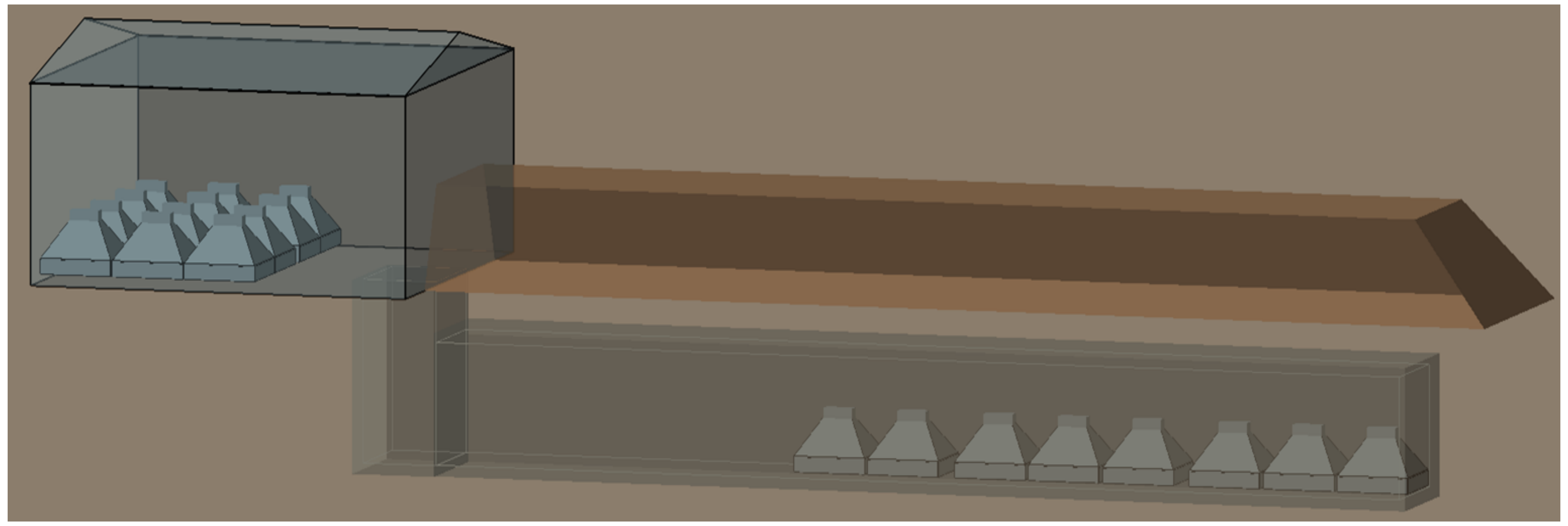
Libraries used for shower creation:

- High energy hadronic interaction model - QGSJET-II-04 (quark gluon string model)
- Low energy hadronic interaction model - FLUKA-2020 (fluctuating kascade)

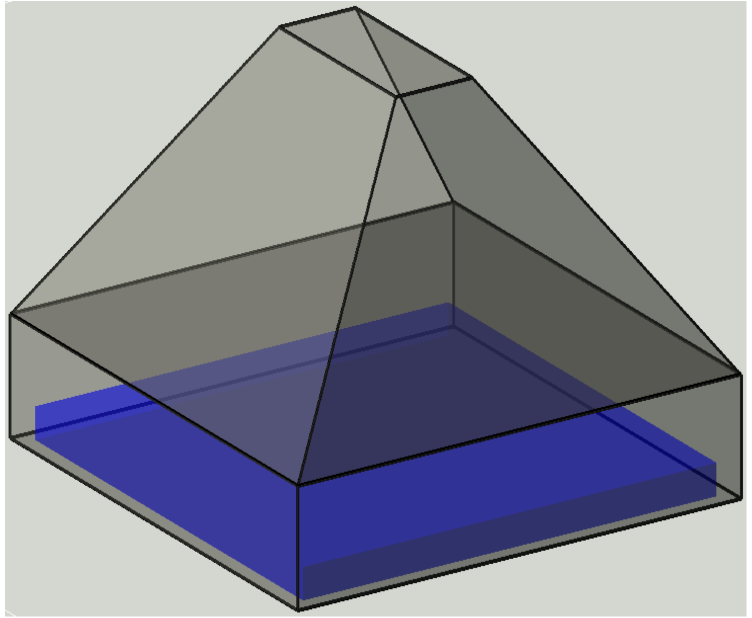
Secondary particles which could hit the ‘area of interest’ where selected for simulation in the Geant4.

The ‘area of interest’ -> The actual detection area is stretched out of 25 cm from the edges of the detector station (RMS of the transverse deviation due to multiple scattering is ~10 cm, the Moliere radius of electromagnetic cascade in the soil is ~5 cm)

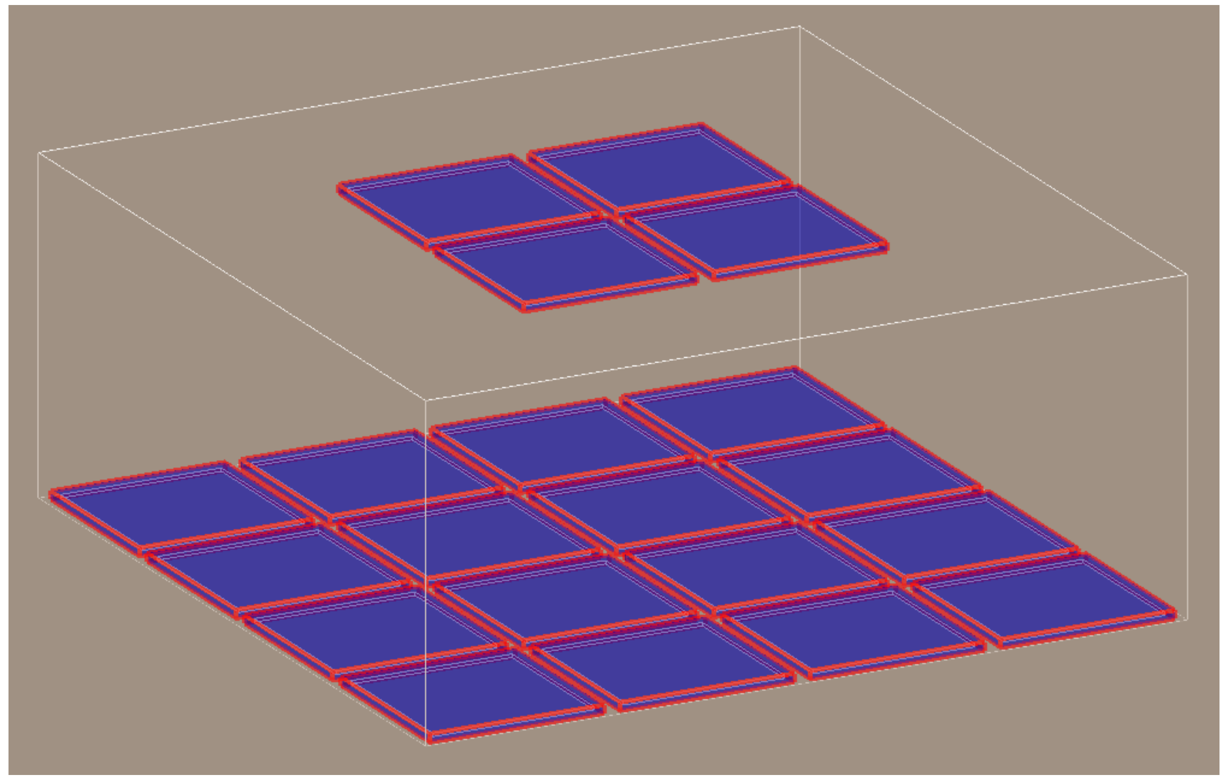
TAIGA

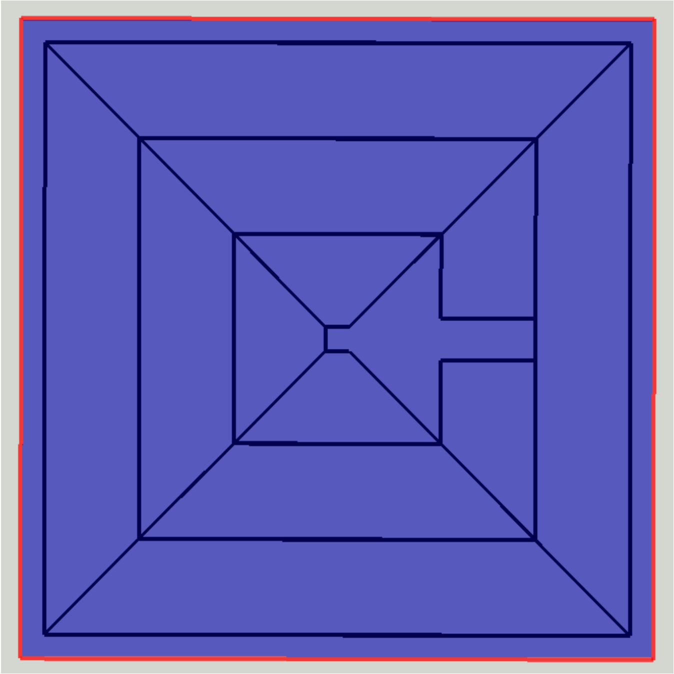


GEANT4 model of Tunka-Grande station



Grande counter - 0.64 m^2





Taiga-Muon counter - 0.94 m^2

TAIGA-Muon station for identification study

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Simulation model

In this study we chose 62 Hiscore stations located near to the Tunka-Grande stations

- The scintillation detector station includes 19 Tunka-Grande stations and 10 (future) Taiga-Muon stations
- The Taiga-Muon station consist of 20 counters (4 surface and 16 underground)
- The soil thickness in TAIGA-Muon station is 2m
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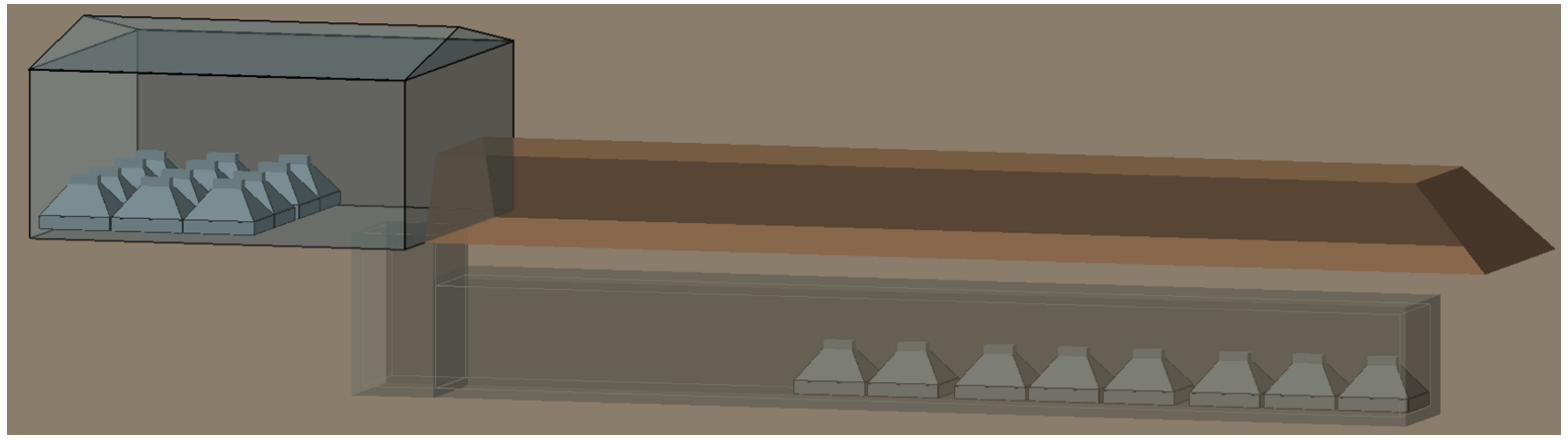
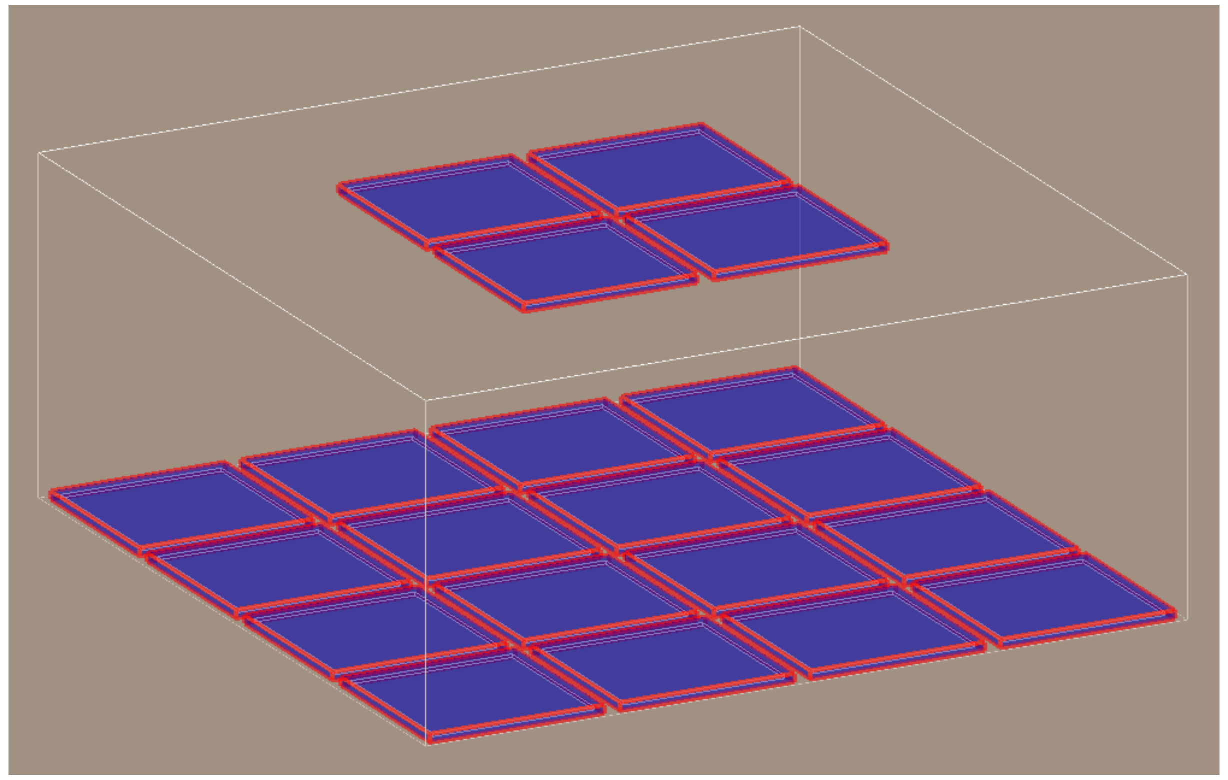
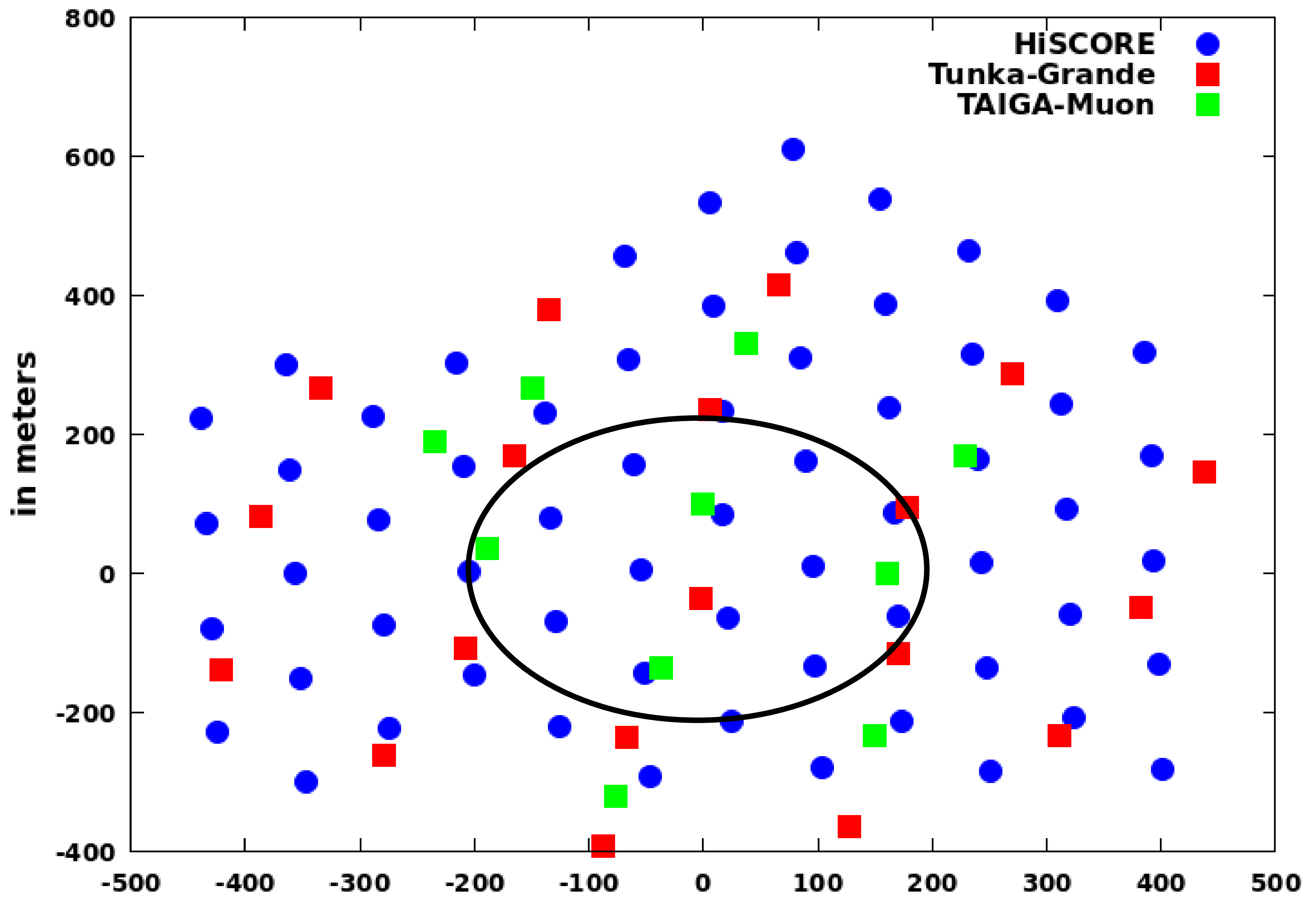




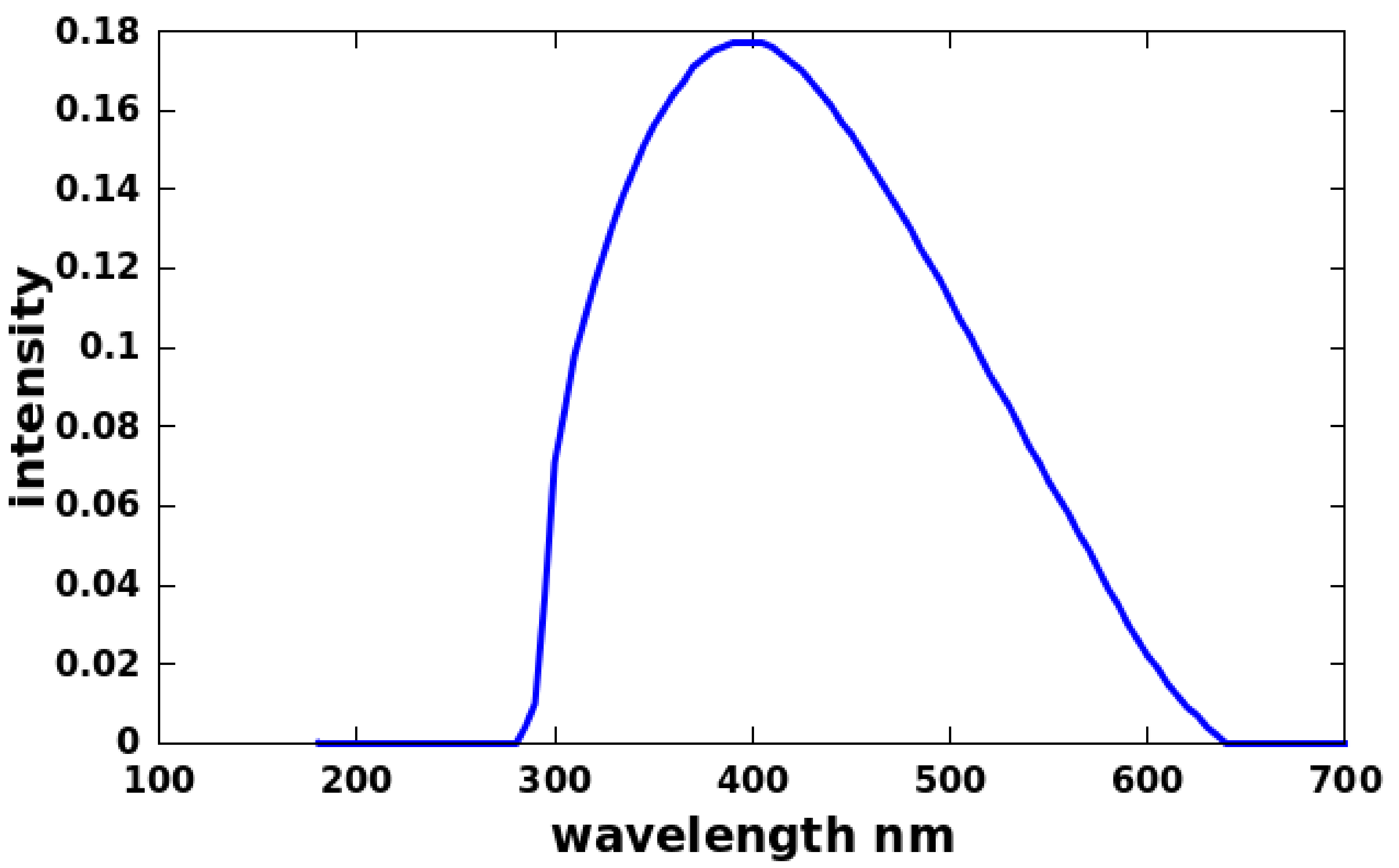


The shower core is randomised 200m
In corsika minimum energy cut was imposed
for gamma, e+/- -- 0.5MeV

for hadrons -- 50MeV

for muons -- 10MeV

The bunch size of Cherenkov photon was fixed as 30



The quantam efficiency of PMT was added in Corsika simulation
The HiSCORE station is considered as small telescope having radius of sphere 53cm

Simulation of the Tunka-Grande, TAIGA-Muon and TAIGA-HiSCORE arrays for a search of astrophysical gamma quanta with energy above 100 TeV, M Ternovoy et al 2021 J. Phys.: Conf. Ser. 1847 012047

- The study conducted in three steps

1. Priliminary study of energy determination systematic for different nuclei

1. Study with fixed energy ->

Determination of the contributions from different systems

1. Study with spread energy

2.gamma-proton seperation in a certain energy range

1.identification of mass composition in a energy range

In this study we have simulated EASs from p, He, C, N, O, Si, Ca, Fe and gamma for energies about 1 and 3 PeV

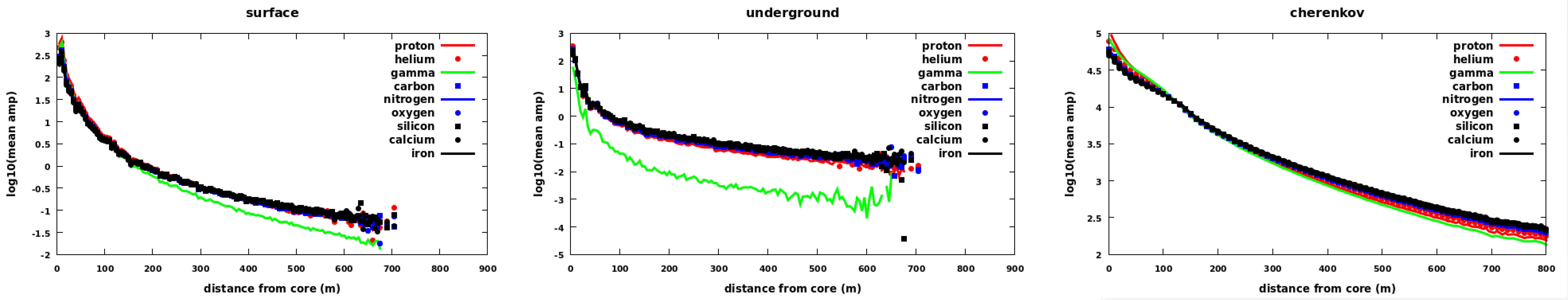
Overlapping point of energy

	proton	gamma	helium	carbon	nitrogen	oxygen	silicon	calcium	iron
0-15	1000	717.778	1102.692	1216.342	1227.227	1235.342	1322.594	1369.49	1431.49
	3000	2189.064	3270.504	3584.879	3602.51	3641.435	3890.572	3987.927	4187.544
15-30	1000	718.027	1107.541	1228.526	1239.331	1261.904	1328.522	1384.236	1465.1
	3000	2183.492	3312.78	3655.236	3662.336	3760.291	3953.753	4103.991	4343.062
30-45	1000	726.268	1119.321	1245.214	1269.734	1290.184	1345.378	1433.099	1505.148
	3000	2157.941	3323.195	3700.47	3754.425	3843.089	3975.696	4242.468	4441.71

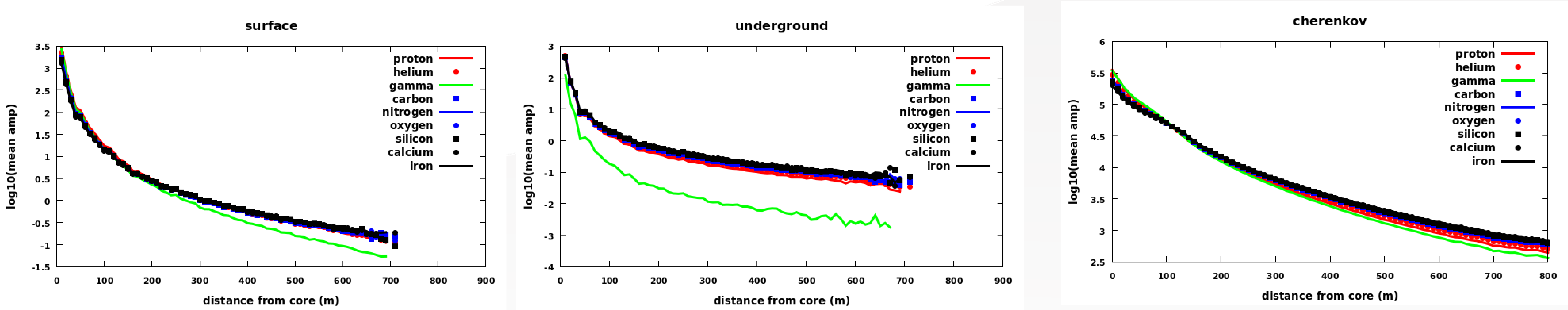
The energy of elements having similar cherenkov amplitude between 100-200m distance from shower core was calculated.

The overlapping energy of elements have similar cherenkov amplitude to the proton-induced event at 1PeV and 3PeV

Verification of amplitude distribution



~1PeV -- 0-15



~3PeV -- 0-15

Identification of elements

The simulation result was verified with random forest method

In the first stage proton, gamma, nitrogen, and iron was trained.

The detector response from scintillation array and optical detectors were verified separately.
Later combination of elements was trained: Proton-Helium (7:3), CNO (1:1:1), and iron

Then gamma identification study was conducted separately.

Identification efficiency of different detector systems (fixed energy)

~1PeV -- 0-15	Hiscore (62 stations)			
	proton	gamma	nitrogen	iron
proton	44.59	32.5	21.9	1
gamma	15.19	81.32	3.49	0
helium	30.22	19.34	45.9	4.54
carbon	11.8	3.42	64.37	20.41
nitrogen	9.2	2.45	65.13	23.23
oxygen	9.98	3.06	69.34	17.62
silicon	2.38	0.79	52.3	44.53
calcium	0.16	0	26.34	73.5
iron	0.1	0	16.08	83.82

~1PeV -- 0-15	Tunka-Grande (19 stations)			
	proton	gamma	nitrogen	iron
proton	31.68	24.3	21.08	22.95
gamma	11.02	81.2	5.21	2.57
helium	27.29	18.91	24.04	29.76
carbon	21.58	15.8	25.56	37.06
nitrogen	21.16	15.35	25.59	37.9
oxygen	20.96	14.25	26.34	38.45
silicon	19.08	12.33	26.29	42.3
calcium	16.29	11.44	26.1	46.17
iron	15.03	9.57	25.97	49.43

~1PeV -- 0-15	Hiscore (62 stations) + Tunka-Grande (19 stations)			
	proton	gamma	nitrogen	iron
proton	61.33	17	20.67	1
gamma	10.42	87.77	1.8	0.01
helium	43.9	7.16	44.56	4.38
carbon	15.02	1.01	63.19	20.78
nitrogen	11.43	0.84	64.35	23.39
oxygen	13.53	0.86	67.92	17.7
silicon	3.24	0.11	51.19	45.46
calcium	0.2	0	25.47	74.32
iron	0.12	0	15.46	84.43

~1PeV -- 0-15	Grande (19 stations) + Muon (10 stations)			
	proton	gamma	nitrogen	iron
proton	50.75	9.33	22.54	17.38
gamma	10.19	89.02	0.7	0.1
helium	41.71	5.31	27.1	25.88
carbon	30.08	2.64	29.65	37.63
nitrogen	28.67	2.95	29.3	39.09
oxygen	28.25	2.34	29.25	40.17
silicon	23.29	1.53	28.65	46.53
calcium	18.71	1.41	27.79	52.09
iron	15.56	0.93	26.83	56.68

Verification of identification efficiency

1PeV range	0-15			0-15		
	proton	nitrogen	iron	p-h	cno	i
proton	80.28	18.91	0.81	80.92	18.16	0.92
helium	51.57	44.19	4.25	51.67	43.78	4.56
carbon	16.36	63.43	20.21	22.93	58.06	19
nitrogen	12.33	65.38	22.29	16.4	62.14	21.46
oxygen	14.4	68.25	17.35	19.13	62.69	18.19
silicon	3.29	52.24	44.48	4.5	49.71	45.79
calcium	0.2	26.1	73.71	0.43	24.46	75.11
iron	0.09	15.57	84.34	0.09	12.38	87.54

The identification efficiency was calculated for elements with fixed energy

The network was trained with two different data set:

In the first set individual proton, nitrogen, and iron was trained
In the second set combination of elements was trained

The change of identification efficiency is not large so the combination of data set has been used for training in further analysis.

1PeV range	15-30			15-30		
	proton	nitrogen	iron	p-h	cno	i
proton	76.63	20.13	3.25	79.1	17.22	3.69
helium	51.58	41.36	7.06	51.14	40.92	7.94
carbon	18.94	57.88	23.18	24.58	54.7	20.72
nitrogen	16.1	58.53	25.37	22.54	54.63	22.84
oxygen	13.25	58.62	28.13	17.78	54.49	27.73
silicon	7.11	56.6	36.29	10.35	53.63	36.02
calcium	1.6	37.93	60.48	2.63	37.12	60.26
iron	0.34	19.25	80.42	0.39	17.28	82.33

1PeV range	30-45			30-45		
	proton	nitrogen	iron	p-h	cno	i
proton	77.76	18.58	3.66	78.7	17.82	3.48
helium	51.18	37.16	11.66	54.89	33.44	11.67
carbon	26.63	47.36	26	32.53	41.88	25.59
nitrogen	19.31	49.69	31	23.78	47.33	28.9
oxygen	19.66	47.96	32.38	23.35	46.01	30.63
silicon	15.2	49.45	35.35	18.45	45.74	35.8
calcium	3.69	33.79	62.52	5.26	31.5	63.24
iron	2.19	22.26	75.55	3.15	18.3	78.55

Identification efficiency at energies 1 and 3 PeV

	~1PeV -- 0-15			~3PeV -- 0-15		
	p-h	cno	i	p-h	cno	i
proton	80.92	18.16	0.92	90.81	9.01	0.18
helium	51.67	43.78	4.56	60.27	38.11	1.62
carbon	22.93	58.06	19	15.11	68.23	16.67
nitrogen	16.4	62.14	21.46	14.4	74.98	10.62
oxygen	19.13	62.69	18.19	10.42	77.25	12.33
silicon	4.5	49.71	45.79	0.33	54.94	44.73
calcium	0.43	24.46	75.11	0.03	32.76	67.21
iron	0.09	12.38	87.54	0	5.38	94.61

	~1PeV -- 15-30			~3PeV -- 15-30		
	p-h	cno	i	p-h	cno	i
proton	79.1	17.22	3.69	89.83	9.87	0.3
helium	51.14	40.92	7.94	59.02	39.92	1.06
carbon	24.58	54.7	20.72	16.35	68.11	15.54
nitrogen	22.54	54.63	22.84	17.27	73.73	9
oxygen	17.78	54.49	27.73	8.36	69.7	21.95
silicon	10.35	53.63	36.02	2.03	61.34	36.63
calcium	2.63	37.12	60.26	0.33	37.83	61.85
iron	0.39	17.28	82.33	0	7.78	92.21

At the overlapping condition of energy (1PeV and 3PeV energy range)

the identification efficiency was calculated

	~1PeV -- 30-45			~3PeV -- 30-45		
	p-h	cno	i	p-h	cno	i
proton	78.7	17.82	3.48	84.04	15.28	0.68
helium	54.89	33.44	11.67	64.07	34.42	1.51
carbon	32.53	41.88	25.59	27.98	59.27	12.75
nitrogen	23.78	47.33	28.9	19.87	63.03	17.1
oxygen	23.35	46.01	30.63	9.65	64.89	25.46
silicon	18.45	45.74	35.8	6.44	66.77	26.79
calcium	5.26	31.5	63.24	1.21	34.38	64.41
iron	3.15	18.3	78.55	1.22	13.73	85.05

Identification efficiency taking into account uncertainty in energy determination

1PeV range	0-15			15-30			30-45		
	p-h	cno	i	p-h	cno	i	p-h	cno	i
proton	79.55	18.03	2.42	74.02	19.48	6.5	68.41	21.44	10.15
helium	67.26	26.43	6.31	59.74	28.4	11.87	55.23	27.81	16.95
carbon	29.81	43.23	26.96	29.81	36.65	33.54	30.65	33.29	36.06
nitrogen	27.45	45.73	26.82	28.47	36.15	35.38	31.28	32.73	35.99
oxygen	27.33	45.73	26.94	30.14	39.6	30.26	32.4	32.65	34.95
silicon	9.6	41.04	49.36	16.27	36.64	47.09	20.97	33.41	45.62
calcium	2.86	29.45	67.69	7.37	33.35	59.28	14.88	32.18	52.94
iron	1.52	20.06	78.43	2.03	20.72	77.25	6.28	25.78	67.94

The energy resolution of HiSCORE system is ~20%

The overlapping energy of all element was spread ± 20%

The identification efficiency was calculated in the ~1PeV energy range.

1PeV range	0-15 (thr_{ph} = 0.3, thr_{cno} = 0.3)			15-30 (thr_{ph} = 0.26, thr_{cno} = 0.29)			30-45 (thr_{ph} = 0.28, thr_{cno} = 0.32)		
	p-h	cno	i	p-h	cno	i	p-h	cno	i
proton	91.59	8	0.41	91.37	7.7	0.93	88.53	9.04	2.43
helium	83.45	15.52	1.03	83.71	13.82	2.48	76.79	18.92	4.29
carbon	50.19	41.83	7.98	58.61	33.2	8.18	56.14	29.94	13.93
nitrogen	48.38	46.11	5.52	55.49	35.93	8.58	55.09	31.73	13.18
oxygen	47.38	46.53	6.1	60.1	32.3	7.6	56.69	30.63	12.68
silicon	24.2	59.24	16.56	41.92	45.4	12.68	45.92	37.13	16.96
calcium	10.45	66.33	23.22	29.26	53.2	17.54	36.45	41.98	21.57
iron	5.67	53.51	40.82	13.66	53.54	32.8	21.31	45.76	32.93

The threshold point was fixed by considering the identification efficiency of iron and CNO

The identification efficiency of iron and CNO was maintained at least 30%

Gamma-proton separation

The previously gamma proton separation studied only using scintillation array
The binary cross entropy method has been utilised to verify the joint study
The backgound airshower events are trained the NN
only with proton
with mixture of few elements
(proton-helium - 85%, CNO - 10%, iron – 5%)

Gamma-proton seperation at different condition

	angle	threshold	gamma	Proton or mix
Previous result	0-15	0.25	54.7	88.4
	15-30	0.25	53.2	86.5
	30-45	0.25	48.2	87.2
Joint study proton-gamma	0-15	0.02	58.167	99.8059
	15-30	0.01	50.8078	99.8249
	30-45	0.03	50.9599	99.6895
Joint study mixture-gamma	0-15	0.01	64.25	99.84
	15-30	0.01	61.3	99.79
	30-45	0.01	73.27	99.51

~1PeV (fixed energy) -- 0-15

	angle	threshold	gamma	Proton or mix
Previous result	0-15	0.15	61.8	93.7
	15-30	0.15	52	94.3
	30-45	0.15	49.1	91
Joint study proton-gamma	0-15	0.01	79.7748	99.4714
	15-30	0.01	72.5906	99.7401
	30-45	0.01	69.6745	99.8999
Joint study mixture-gamma	0-15	0.03	83.66	99.81
	15-30	0.02	81.89	99.77
	30-45	0.01	87.84	99.85

~3PeV (fixed energy) -- 0-15

The gamma-proton seperation was studied with scintillation array and HiSCORE station response.

The EAS having 1PeV energy range and 3PeV energy range shown here separatly.

The simulation result shows suppression factor in the order of 10^3.

Zenith angle	~1 PeV			~3 PeV		
	threshold	gamma	mixture	threshold	gamma	mixture
0-15	0.005	50.5316	99.8997	0.003	49.1091	99.9791
15-30	0.005	49.3917	99.8924	0.001	48.4768	99.9414
30-45	0.002	51.2042	99.9085	0.001	74.4384	99.9253

The overlapping energy ±20% widen at 1PeV energy range

The identification efficiency was calculated for gamma

Zenith angle	1 PeV range		
	threshold	gamma	mixture
0-15	0.003	50.0270	99.9499
15-30	0.010	50.9082	99.7781
30-45	0.040	49.6833	99.8490

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Conclusion

There is an increase in identification efficiency because of 10 TAIGA-Muon stations

In the combined study gives better result than identification study using individual detector systems.

In the combined study of gamma-proton seperation gives third order suppresion factor while having 50% of gamma identification efficiency.

THANKS!

ANY QUESTIONS?

Questions to
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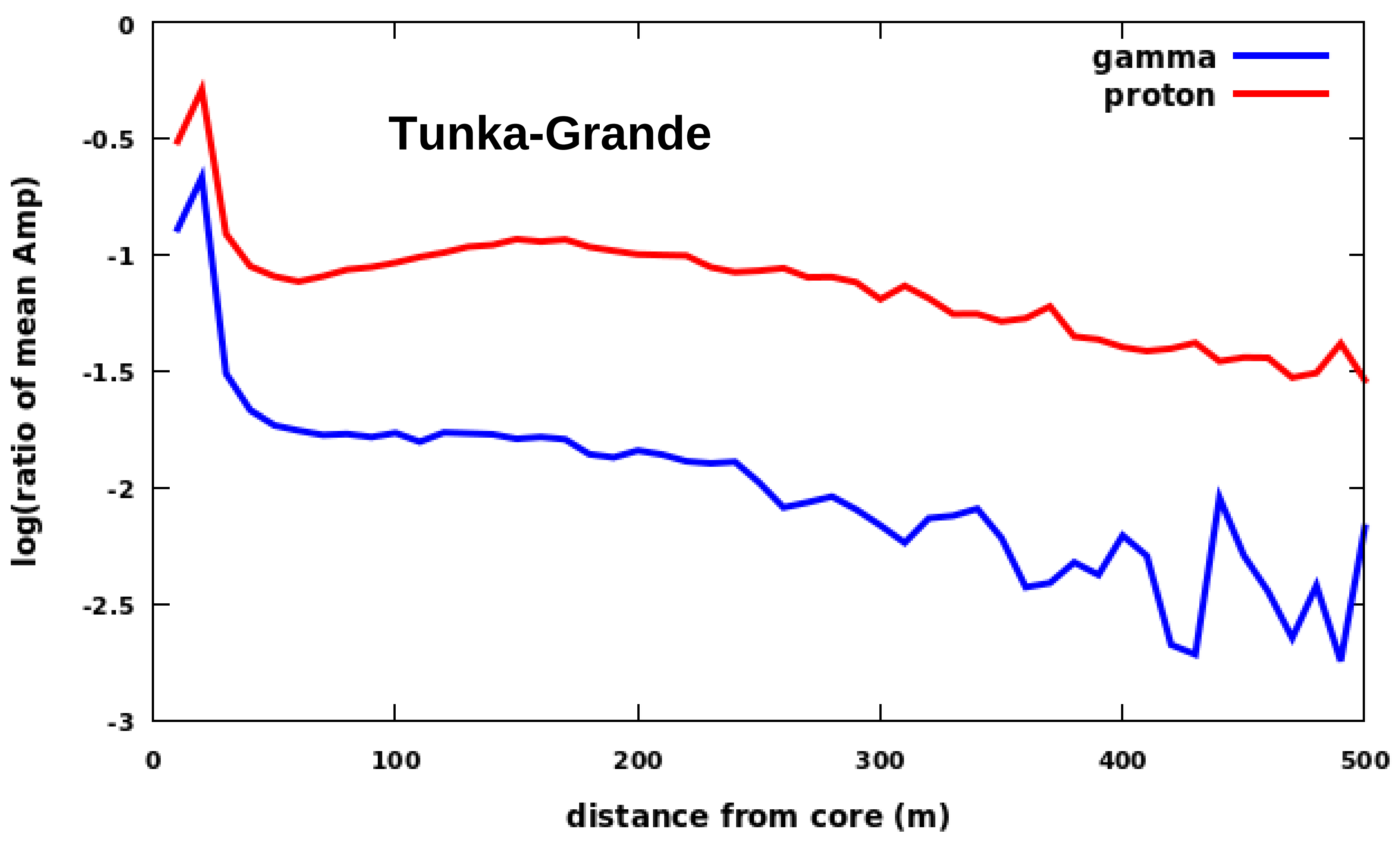

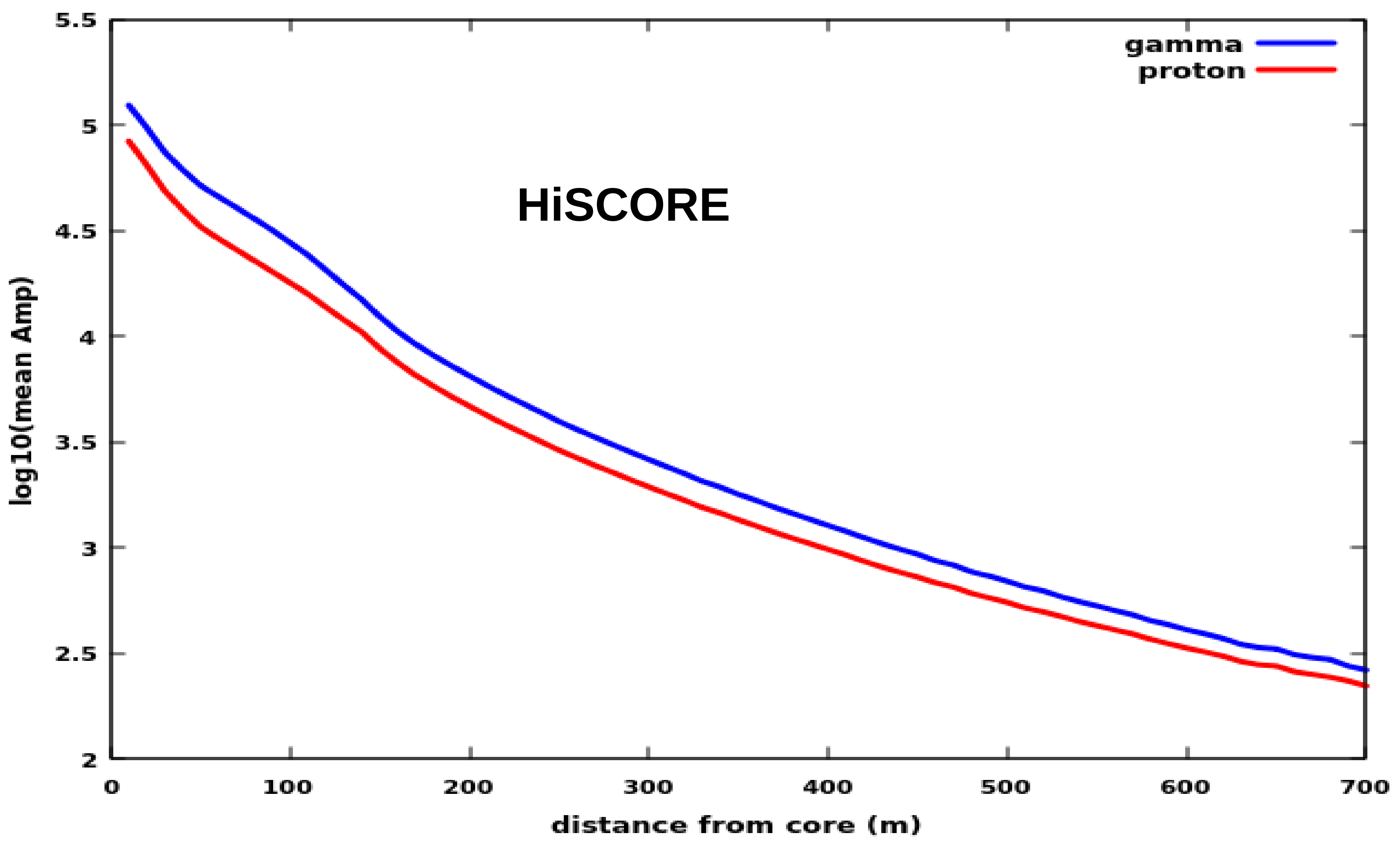

The gamma and proton induced EAS with energy **1PeV and zenith angle 0º** were simulated

At the same energy, Cherenkov component is larger and muonic component is lesser

Thus overlapping point of energy in HiSCORE will be less than proton induced EAS

The detector response of scintillation array contributes for gamma identification

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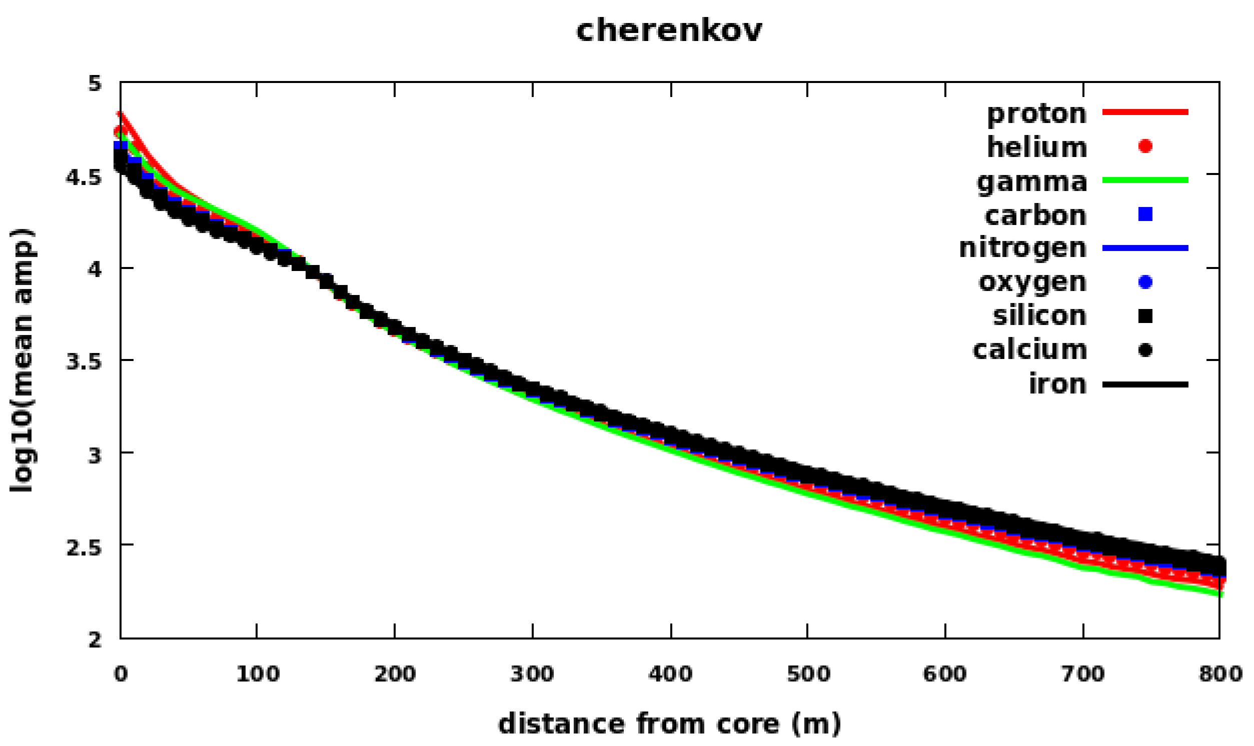
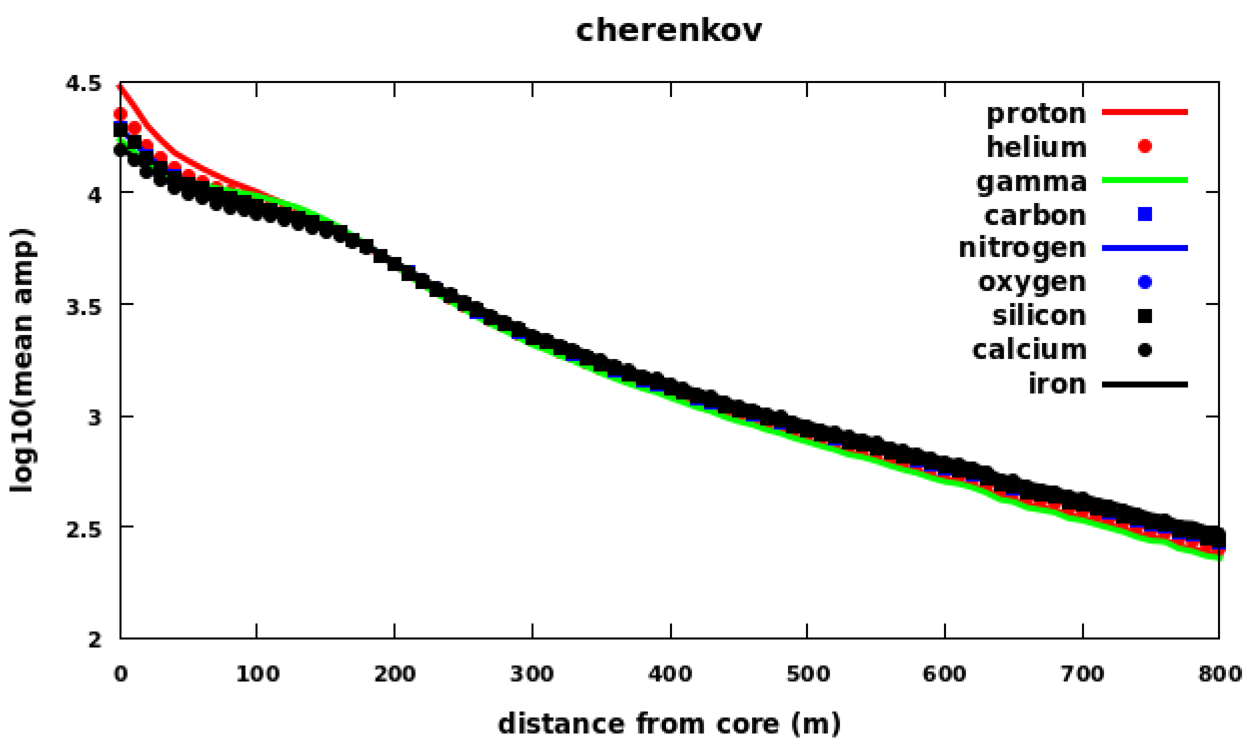
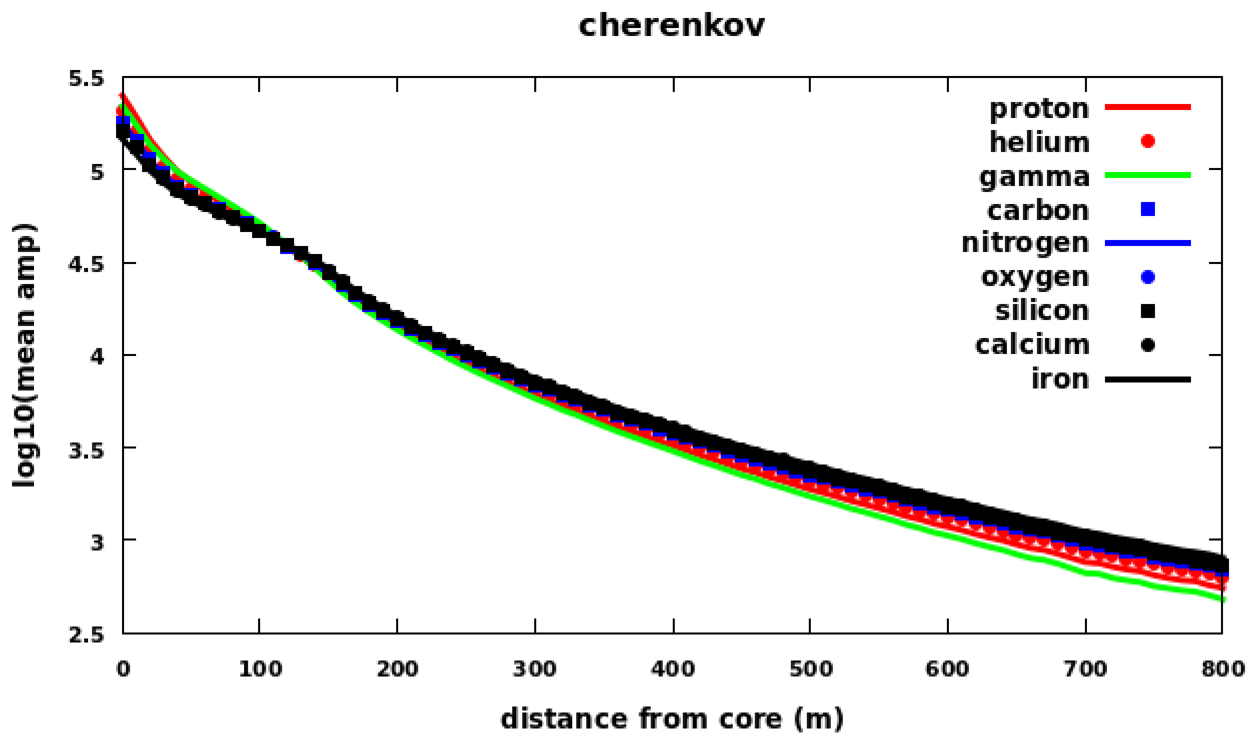


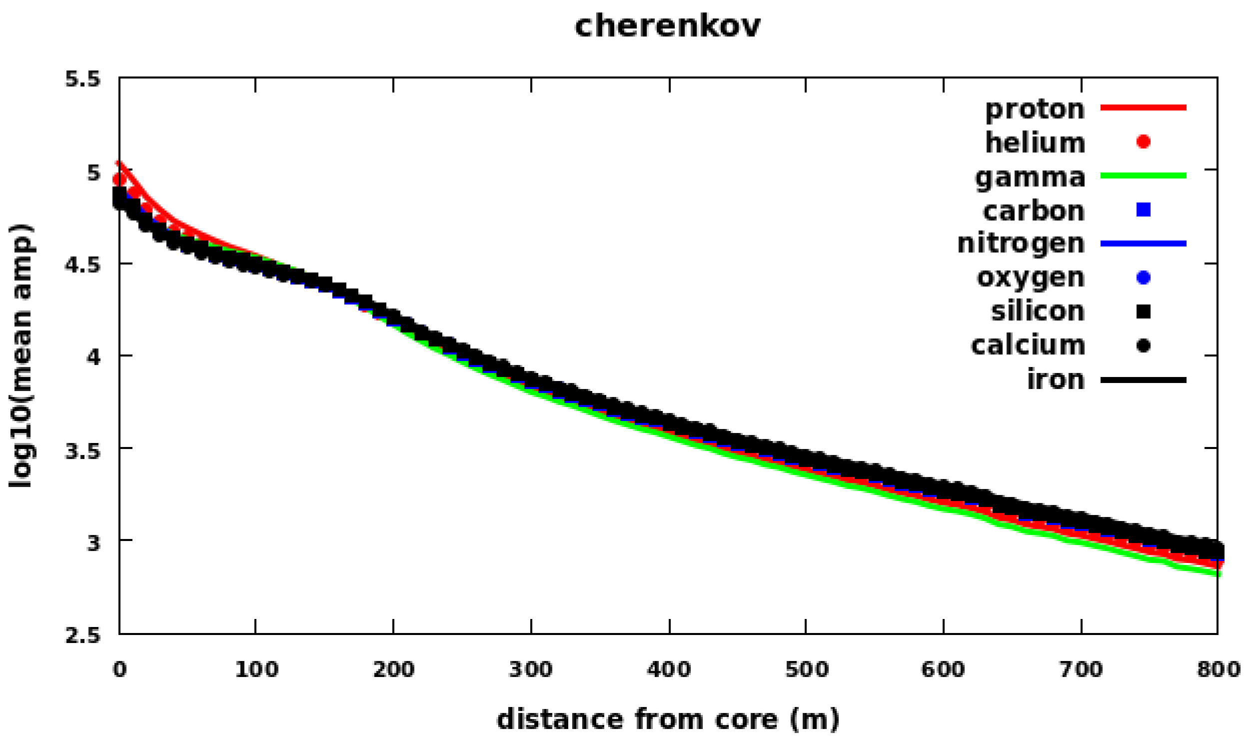
1PeV range -- 15-30



1PeV range -- 30-45



3PeV range -- 15-30



3PeV range -- 30-45

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