NUCLEON

Satellite Mission. Present status.

a) Skobeltsyn Institute of Nuclear Physics, Moscow State University
b) DB ARSENAL, Sankt-Peterburg, Russia
c) Joint Institute for Nuclear Research, Dubna, Russia
d) HORIZONT, Ekaterinburg, Russia
e) Research Institute of Material Science and Technology, Russia
f) Moscow Engineering Physics Institute (State University), Russia

Background picture: SN 1987a in Magellanic clouds - 16 yeas after an explosion

Workshop on the Russian - Italian Cooperation, Moscow, 17-20 October 2005

D. Podorozhny for NUCLEON collaboration

The project has started in 2001

2001-2003

Phase 1 (R&D stage)

It has been worked and done : the exploring method , first prototype of the device, prototype beam tests at SPS CERN. It has been found out a vehicle for launching

2004-2008

Phase 2 (construction stage)

2004 - draft of the engineering design (beginning), adapting device for vehicle,

2005 - draft of the engineering design (ending), pre-production models, first step of an elaboration of working documentation,

2006 - elaboration of working documentation, production of a dimension-weight prototype of the NUCLEON device, production of a computer prototype of the NUCLEON device, production of a technological prototype of the NUCLEON device (beginning), tests,

2007 – manufacturing a technological prototype of the NUCLEON device (ending), production of a launching NUCLEON device (beginning), tests,

2008 – production of a launching NUCLEON device (ending), launch of NUCLEON device, tests.

2008 (end) - 2012 (?)

Phase 3 (Data taking and physical analysis stage)

Experiment NUVCLEON aimed to the direct measurements of the elemental energy spectra of high-energy (10^{12}-10^{15} eV) cosmic rays (CR) during 5 years (2008-2012) abroad the Russian regular satellite.

The main goal is to clarify:

- the Cosmic Rays origin.

differences in slopes of different nuclear components

(changing the type of sources in this region?)

- propagation of CR in Galaxy

secondary to primary ratio

(D~E?)

- CR anisotropy

time and space variation of different nuclear components

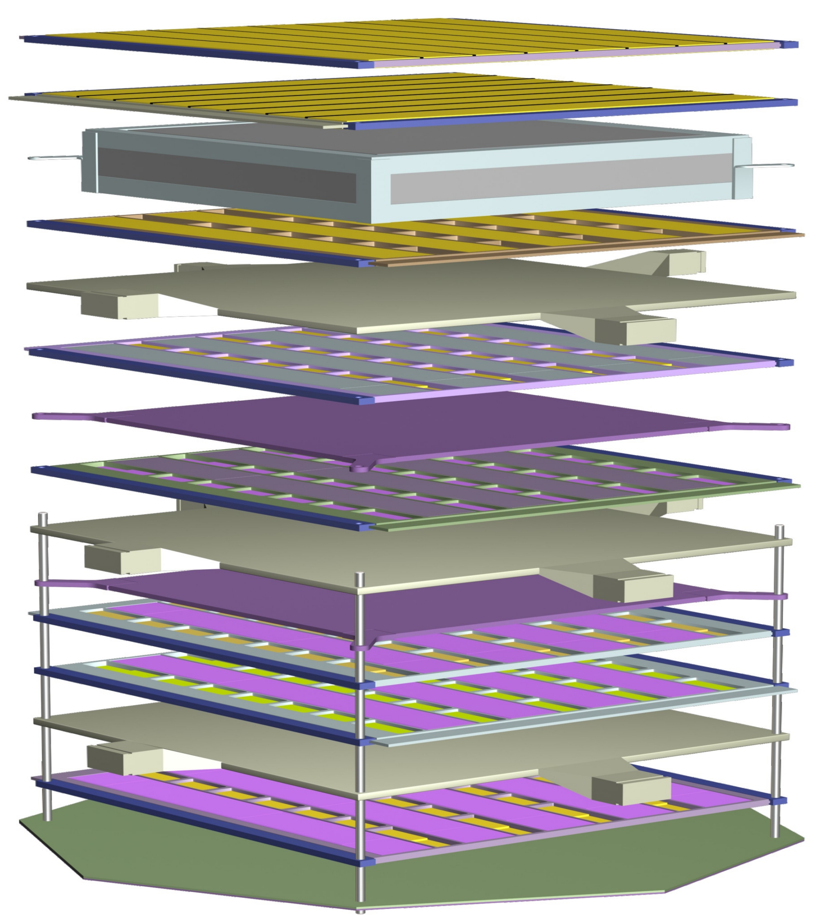
(nearby source ?)

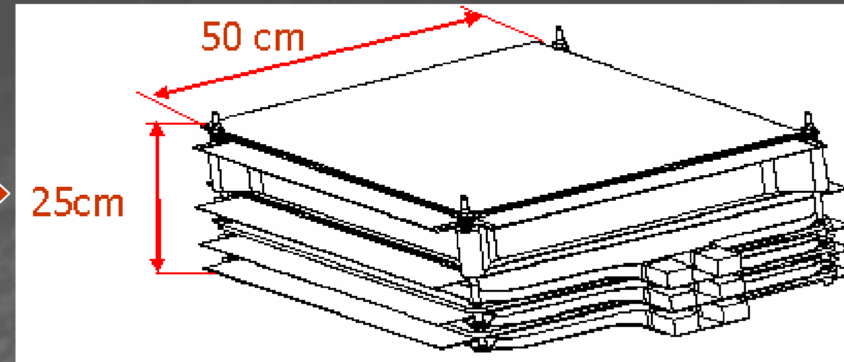
The main problem of direct high energy CR measurements is the high weight of planned devices (2-3 t) that needs the special space craft

Device concept

- A main idea of this project – to develop the method and to design a scientific instrument with large aperture being able to measure elemental spectra of cosmic rays in a wide energy range 10^{12}-10^{15} eV with the high charge resolution.
- At the same time the principal condition is that this instrument should have a relatively light weight (<200 кг) and size (<1.0 м3) to be of use on regular serial Russian satellites, that makes possible long duration (5 years) regular flights and it provides the rather low price of the project.

Is it possible to design a such type of a device?





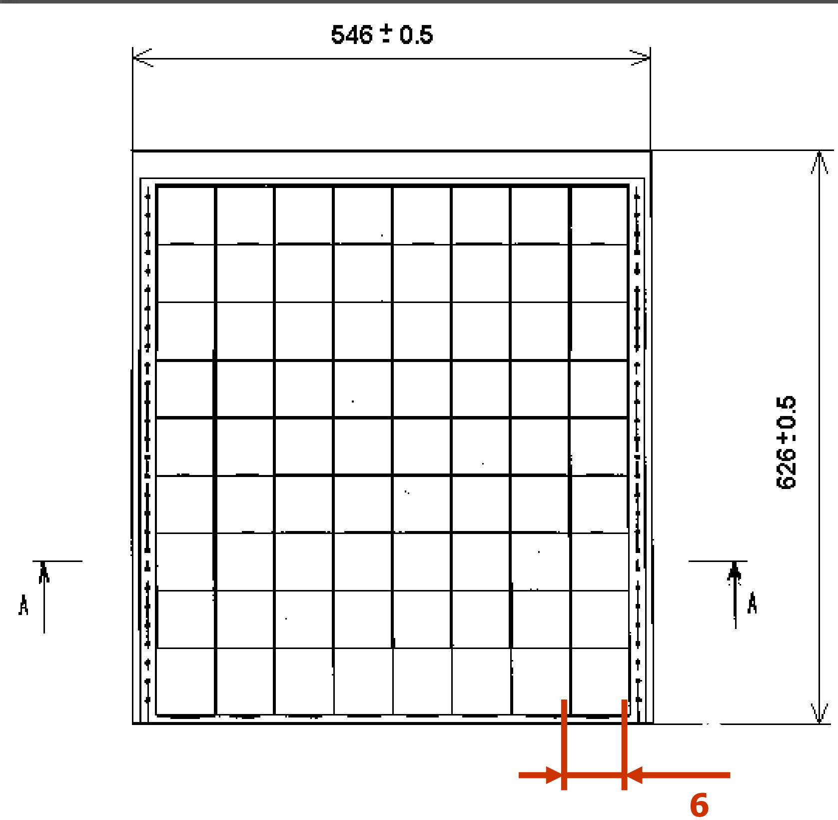
The NUCLEON device includes charge measuring system, tracker and energy measuring system, the trigger system, control electronics.

The charge measuring system consists of 4 silicon detectors layers.

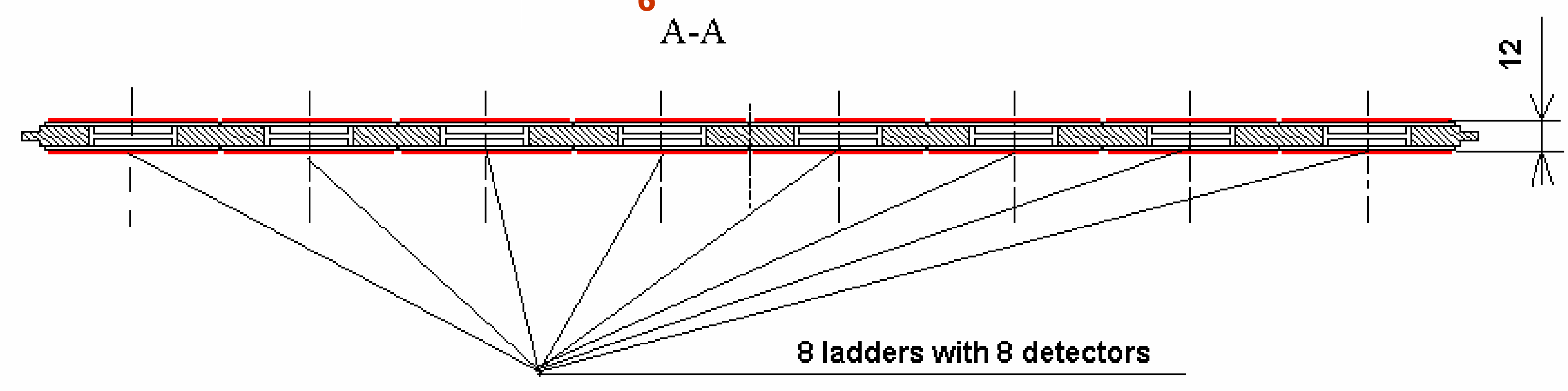
The tracker and energy measuring system consists of: the carbon block with the size 50×50×9 cm3 served as a target, 6 identical layers of micro-strip silicon detectors, 2 identical tungsten layers with the size 50×50×0.7 cm^3 served as a gamma-converter.

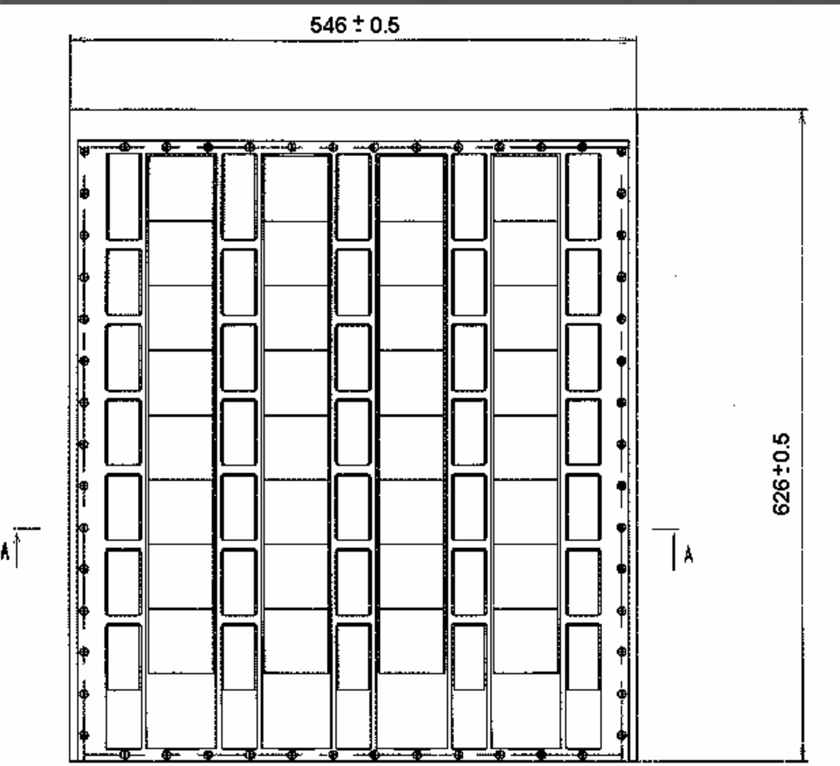
The trigger system (SC1-SC6) consists of three double layer 16-strip scintillator detectors (size ~ 500×30×0.5 mm^3) with a few 1 mm WLS fibers.

Control electronics are placed at the bottom of the device on the base plate.

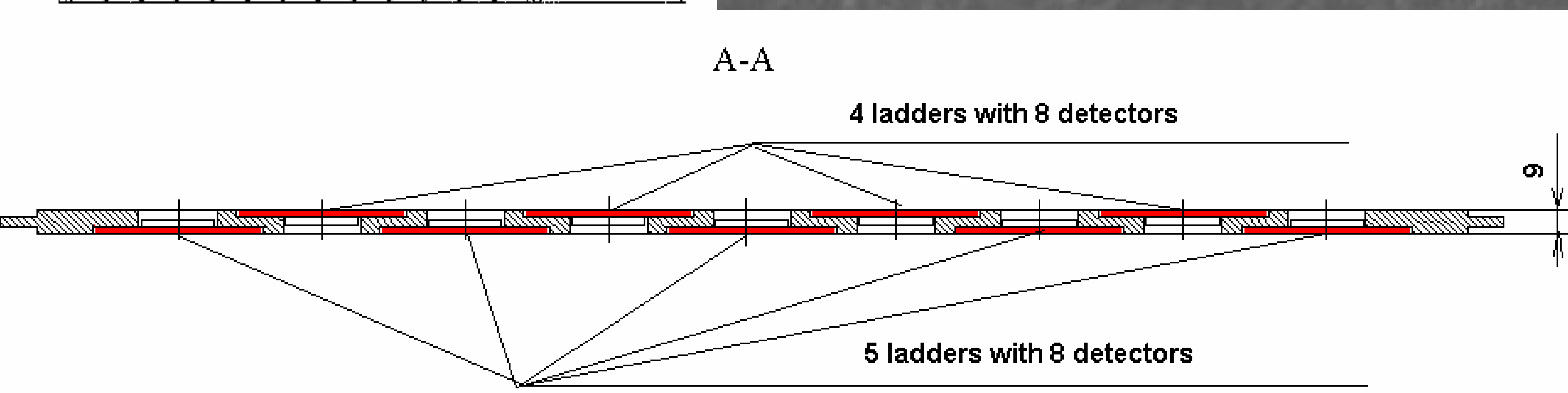


The charge measuring system consists of 4 silicon detectors layers placed on two identical mechanical plates. Every silicon detectors layer arranged in 8 ladders . Every ledder contains 8 detectors 6.2x6.2x0.3 см^3, every of which is divided by 16 pads with the size ~ 2.4 см^2 , in all 4096 channels.

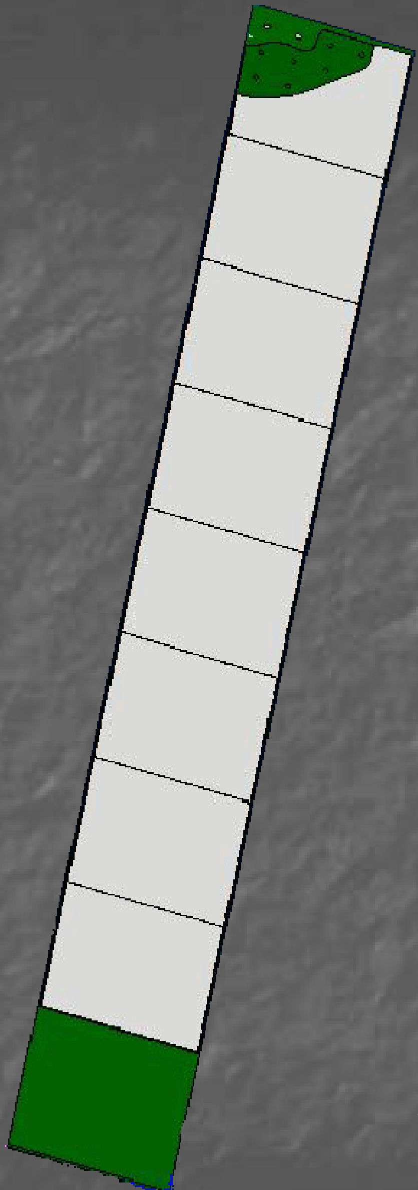




The tracker and energy measuring system. Every layer of silicon micro-strip detectors placed on mechanical plate. Every silicon micro-strip layer contains 72 detectors with the size 6.2x6.2x0.3 см3, arranged in 9 ladders with 8 detectors linked in series. A micro-strip pitch optimization has been done, and pitch size was reduced to 0.46 mm, to reduce a power consumption of the device. In all 6912 channels.



Unified ladder for charge and energy measurement systems



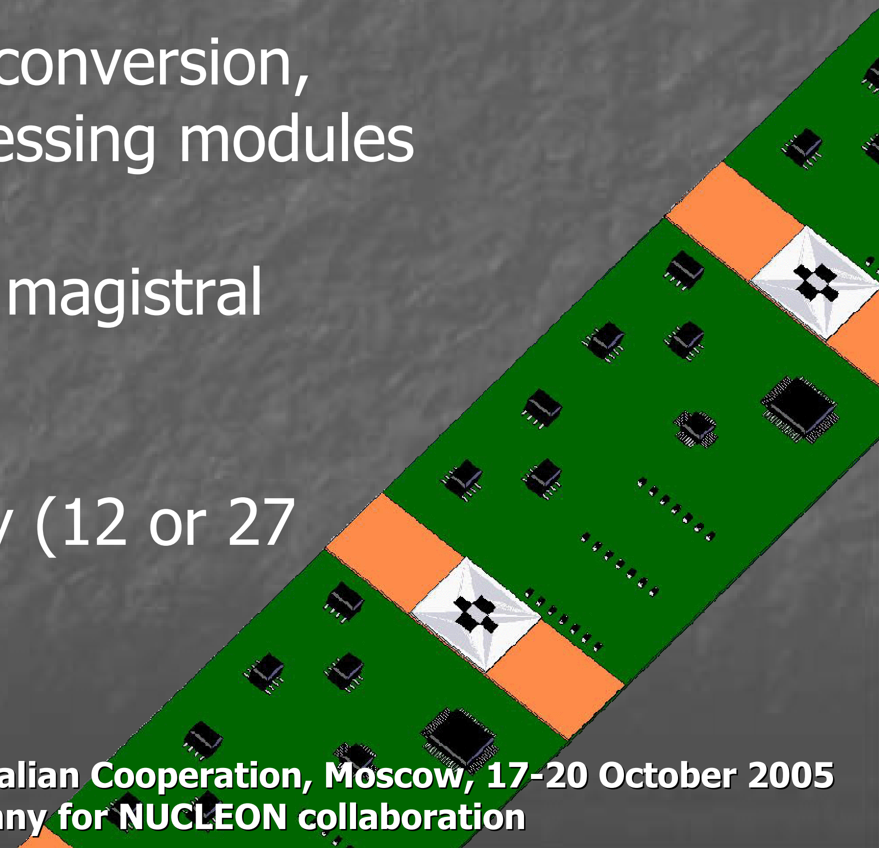
- 8 pad or microstrip silicon detectors ~60*60 mm size (128 channels)

- 4 VA32hdr14 readout ASIC’s

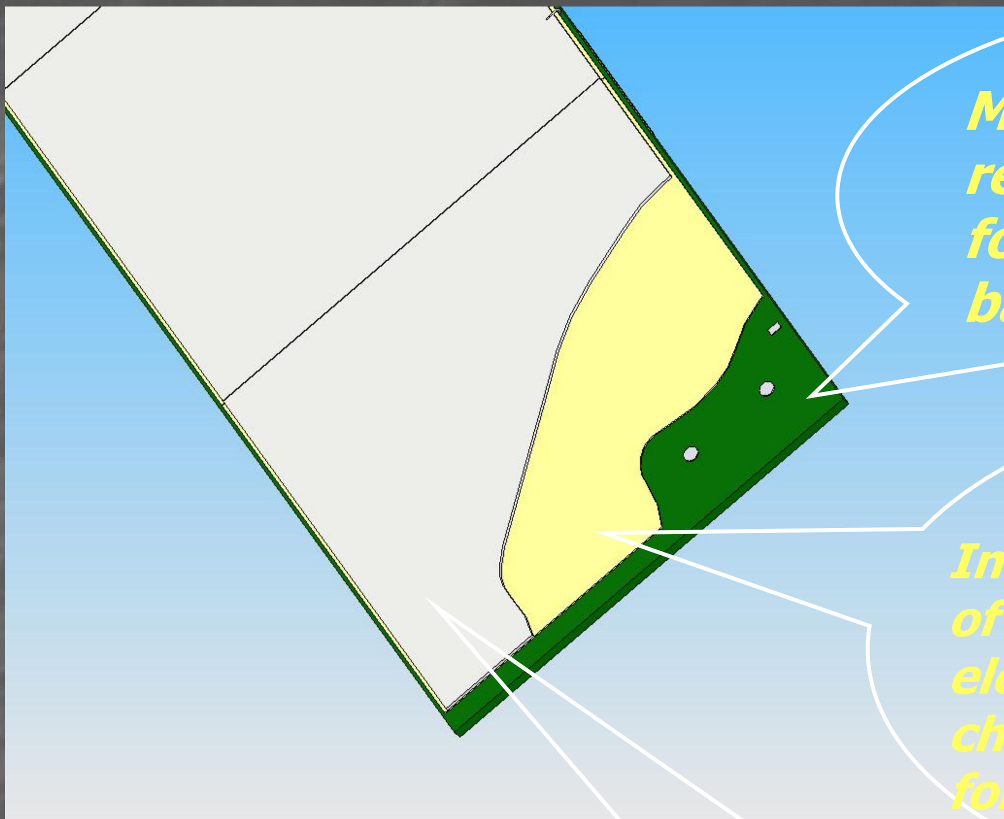
- 4 analog-to-digital conversion, storage and preprocessing modules

- code output (serial magistral communication line)

- single power supply (12 or 27 Volts)



Ladder Mechanical Design



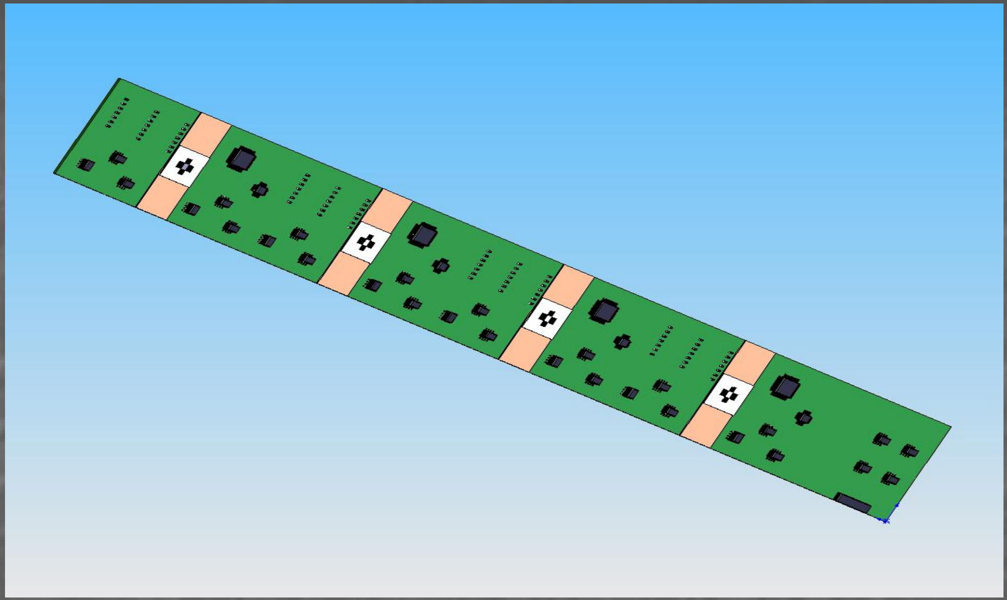
Multilayer (8) PCB for readout electronics unified for all systems and it is a base of the ladder

Intermediate PCB for a connection of silicon detectors with readout electronics : one-layer PCB for pad charge detectors and 4-layer PCB for strip detectors

Silicon Detector (pads or microstrips)

Ladder Electronic Design

Ladder electronics consists of 4 similar readout modules



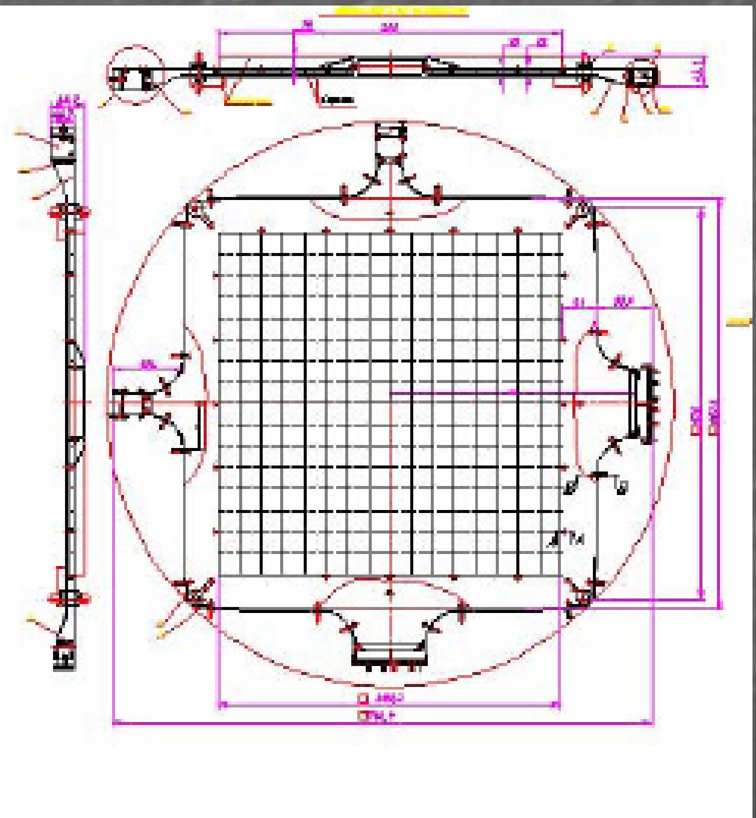
Every module includes:

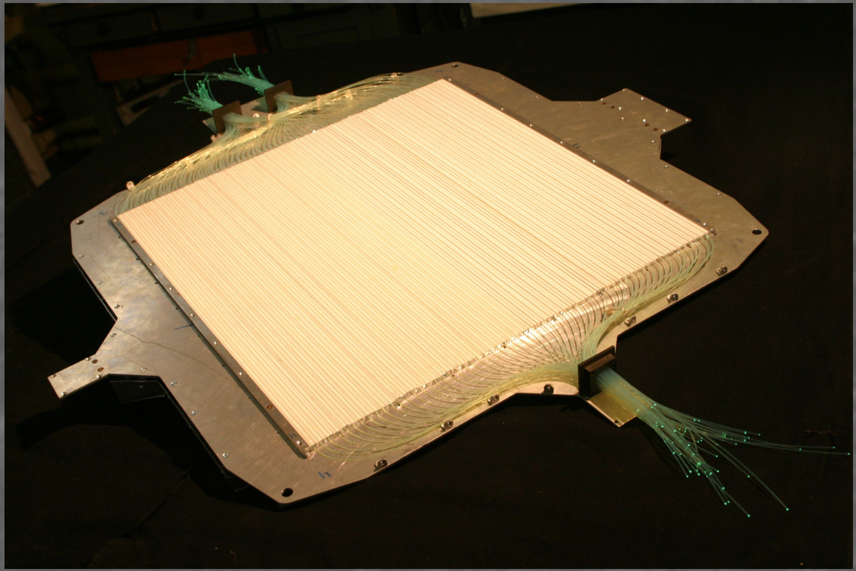
- **VA32hdr14 ASIC**
- **AD7687 analog-to-digital converter**
- **MSP430 microprocessor**
- **track/hold delay driver**
- **double communication code line driver**
- **detector and electronics power sources**

All-in-one signal processing solution :

- **charge sensitive amplifier**
- **analog-to-digital converter**
- **front-end microprocessor with buffer memory**
- **power-supply system**
- **code communication**

The trigger system consists of three double layer 16-strip scintillator detectors (size ~ 500x30x0.5 mm3) with a few 1 mm multicladding WLS KURARAY Y-11 fibers. Light signals are detected from an opposite side of each strip by 1 and 16-channel PMTs . Signals at the level of ~10 photoelectrons are obtained from MIP particles. Two systems of 1-channel PMTs is used to get the total amplitude signal from every scintillator plane in production of during 50 ns.





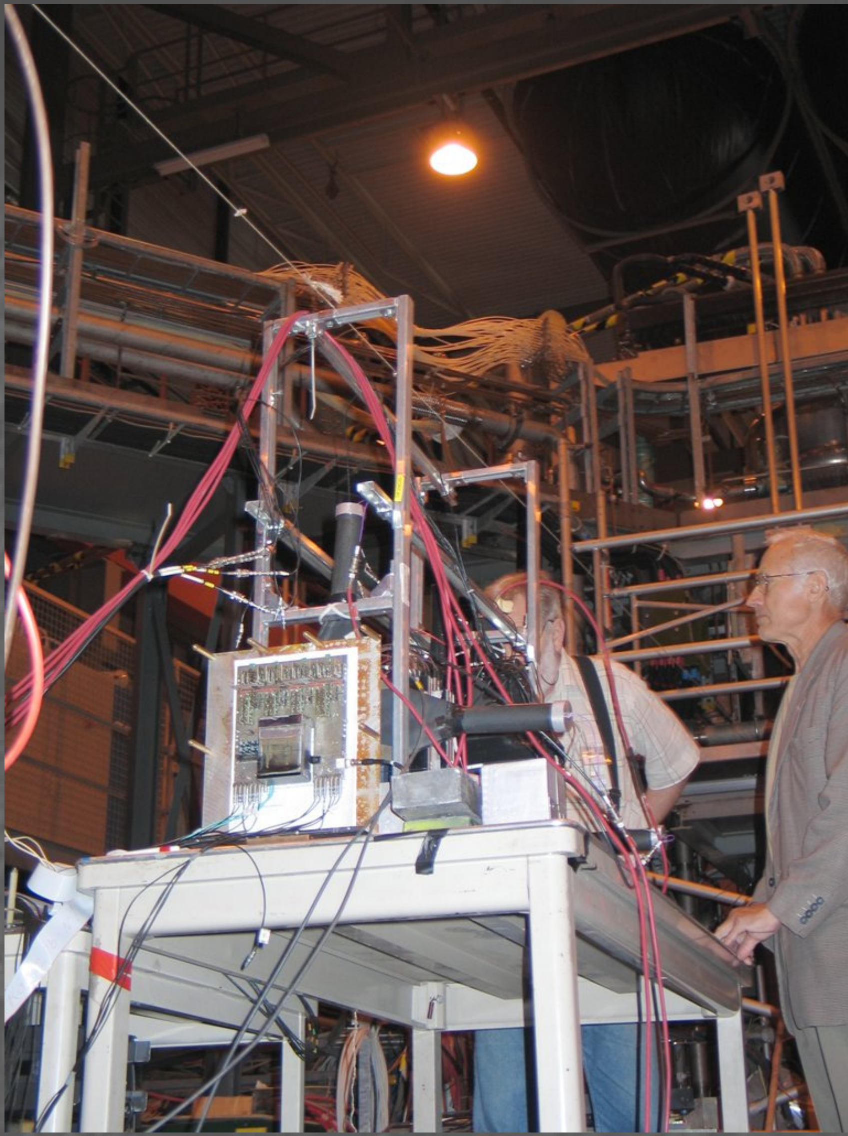
Accelerator tests

There were 3 beam tests. The little prototypes of the NUCLEON device were used.

2001. π. 180 GeV. The brief experiment confirmed adaptability of microstripe silicon detectors for our aims.

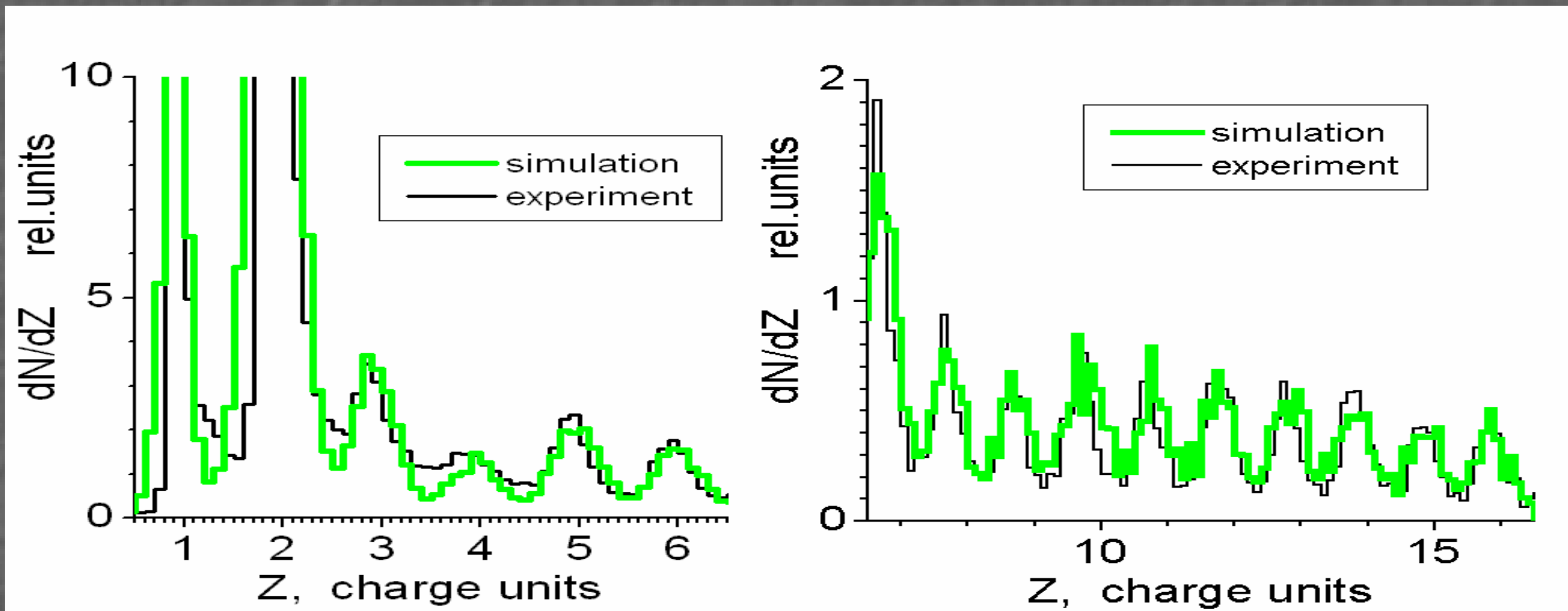
2003. Nuclei. 158 Gev/n. The charge measuring system was tested.

2004. π. 200 & 350 GeV. The method of energy measurements was tested.



Charge detector test

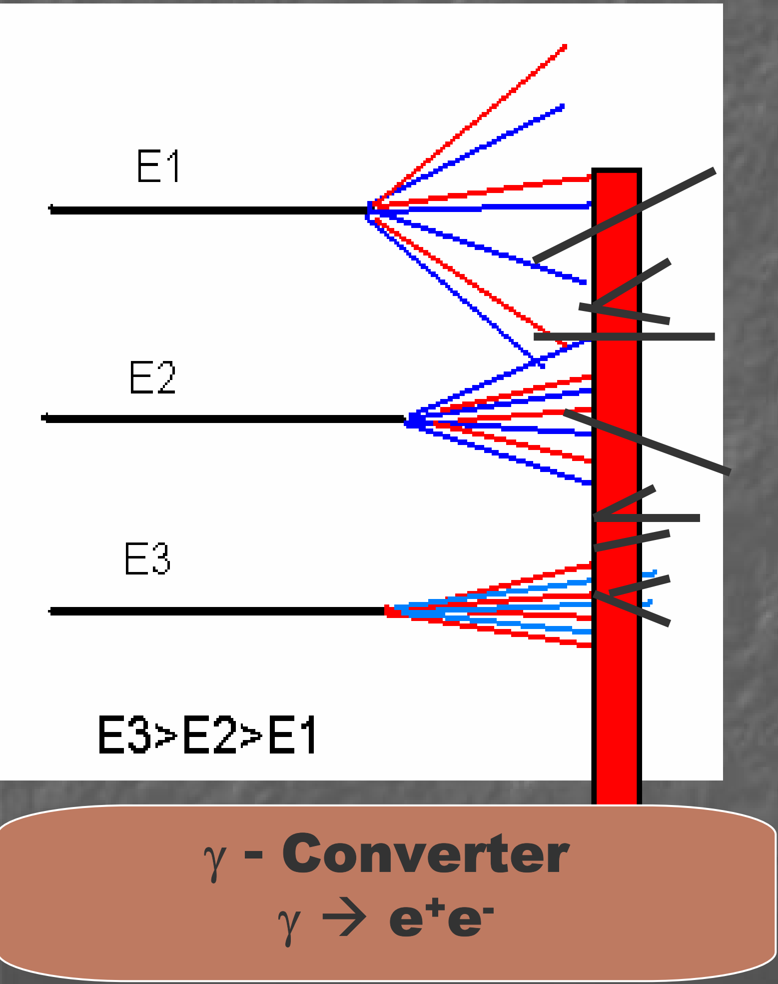
The prototype of charge detector was tested by ion. Different nuclei are produced in processes of indium beam fragmentation at interaction in beryllium target and then are sorted by magnetic rigidity. The charge detector consists of 4 pad silicon detectors layers.



There is a satisfactory agreement of experimental and simulation results. Small difference for light nuclei can be explained by simultaneous registration of a few particles. The charge detector resolution allows to separate different elements. Thus we can measure fluxes of different nuclei.

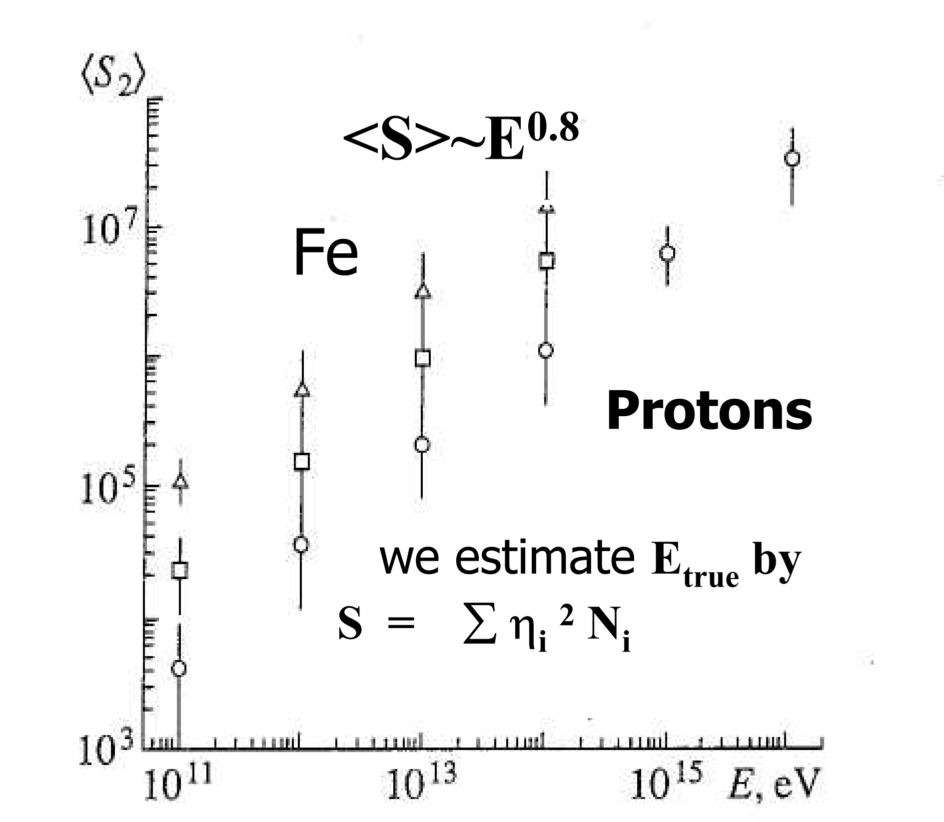
Kinematic Lightweight Energy Method (KLEM)

For the energy measurements we use KLEM method. In this method – main idea to use spatial density of secondary particles which are sensitive to Lorents factor of primary particles This is not pure Castagnoly method, but a combination of ultrathin calorimeter with kinematics.



Pseudorapidities

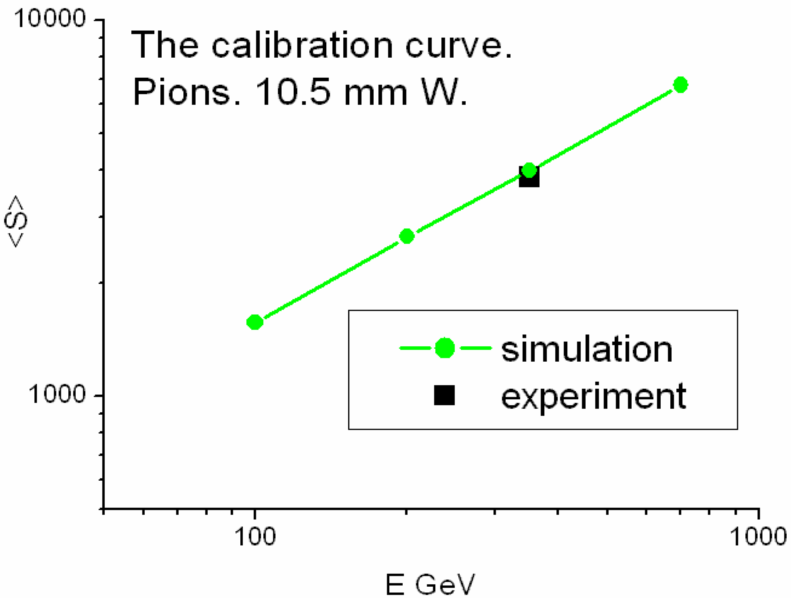
$$\eta_i = -\ln \mathrm{tg}\,(\theta^i/2)$$

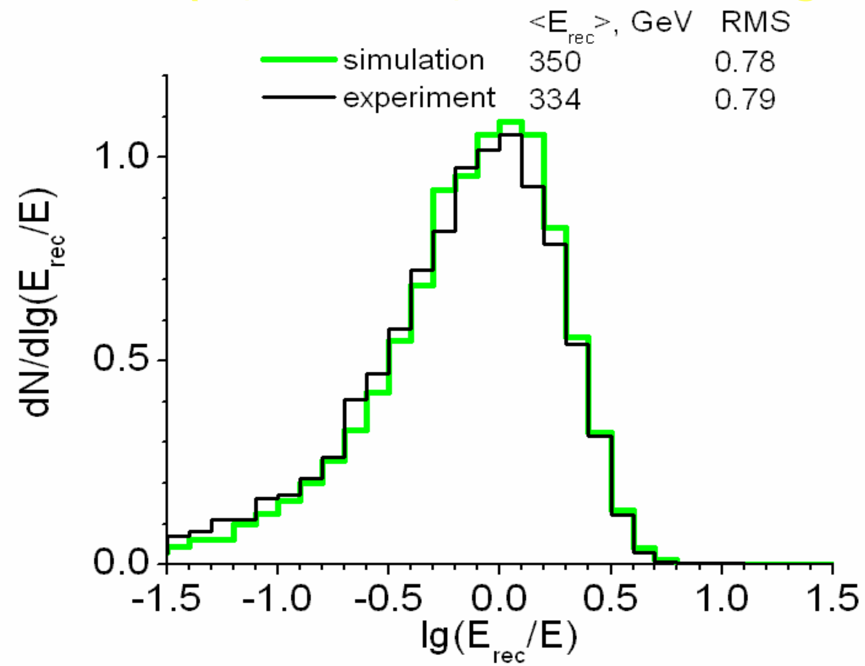


Energy reconstruction in beam tests

The experiments in CERN were performed to test our simulation results. Different variants of the NUCLEON device construction were exposed with the pion beams of energy 200 and 350 GeV in 2004.

The examples of Reconstructed energy distributions (π-, 350 GeV, 1.05 cm of tungsten)



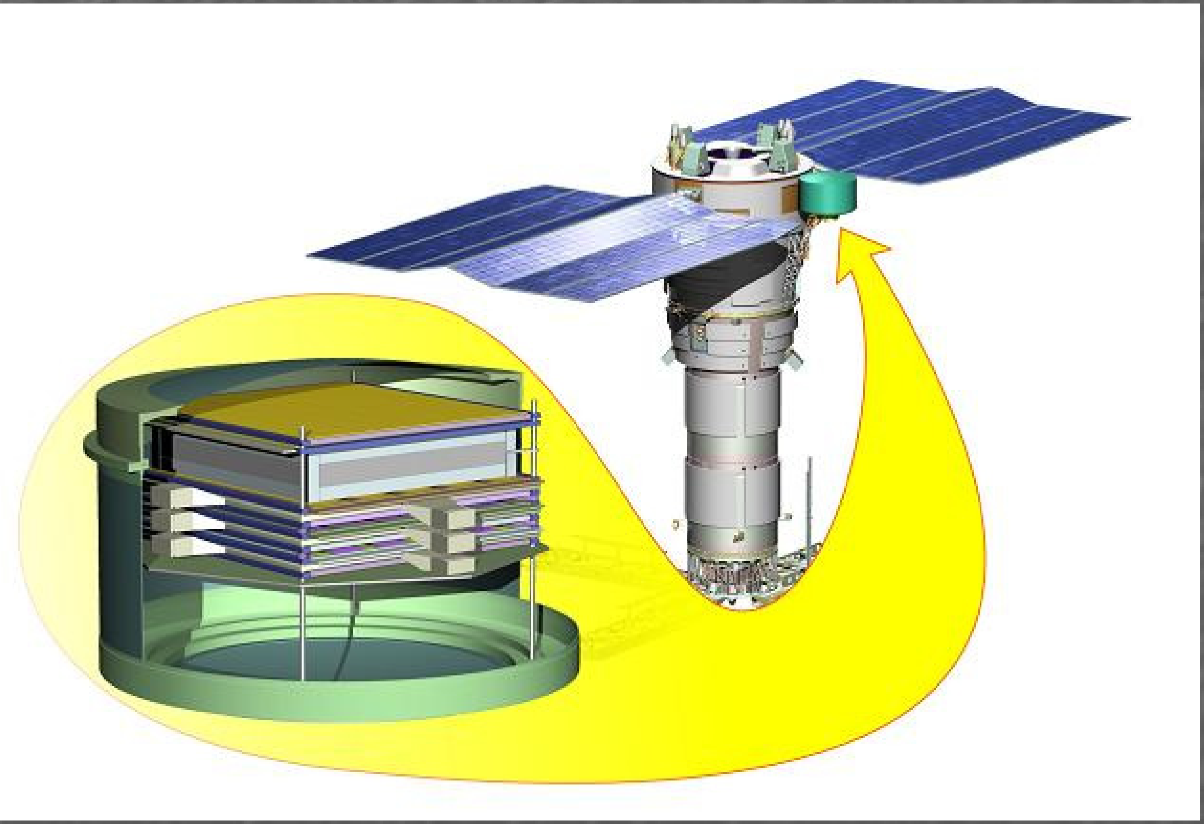


Calibration curves and reconstructed energy distributions are satisfactory agreement of experimental and simulation results. The results of this analysis confirmed our suggestion about the opportunity of the NUCLEON device to measure energy of particle

Accuracy of energy determination is around 70-80%, which is enough for our project tasks.

The NUCLEONE scientific module consist of:

- The NUCLEONE device as the monoblock in the own pressurized container;
- Additional remote control system with its own pressurized container;
- Antenna-feeder system;
- Configuration items intended for installation of the instrumentation in space.



The general NUCLEON modul characteristics are:

- Weight of the modul <265 kg (for scientific device <165 kg);
- Power consumption <150 W (for scientific device <120 W);
- The nominal telemetry rates are expected to be 270 MB per day.;
- Exposure orbit time $\geqslant$5 years;

Summary table from the report of Y.SEO, presented at 29 ICRC

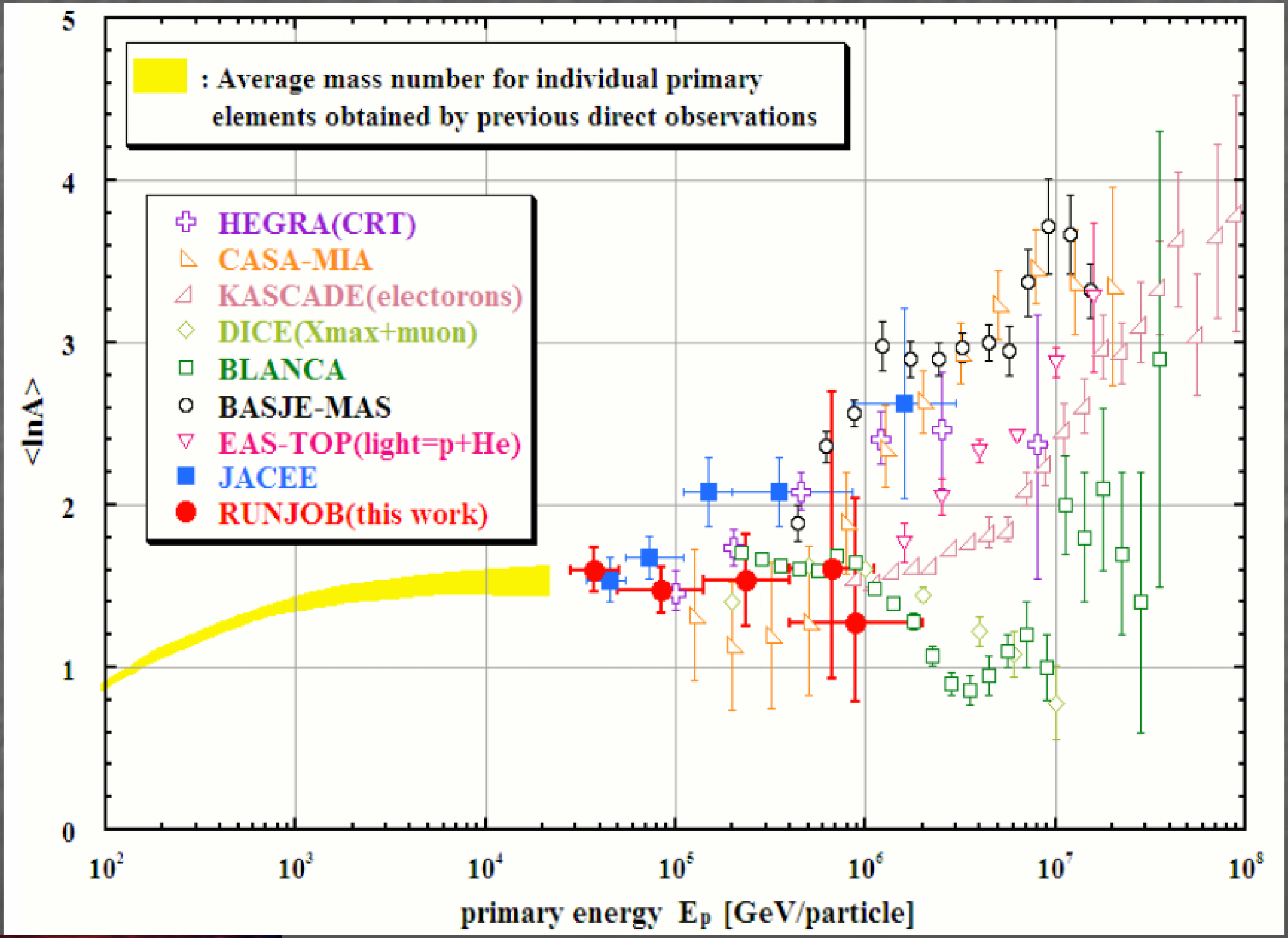
W	Experiment	Species	Technique	Energy/nucleus (eV)	Instr. Effective Geometry Factor (m^2sr)	Exposure Factor (m^2sr-days)
B	TRACER	5 • Z • 28	TRD	$10^{11} – 10^{14}$	5	50
B	RUNJOB	1 • Z • 26 (element groups)	Emulsion chamber	10^{13} - 3 x 10^{14}	1.6	70
B	JACEE	1 • Z • 26 (element groups)	Emulsion chamber	10^{12} - 5 x 10^{14}	2 - 5	80
B	CREAM	4 • Z • 28 1 • Z • 28	TRD Calorimeter	$10^{11} – 10^{14}$ $10^{10} – 10^{14}$	1.3 0.3	50 12
B	ATIC	1 • Z • 28	Calorimeter	$10^{10} – 10^{14}$	0.23	7
S	SOKOL	1 • Z • 26 (element groups)	Calorimeter	3 x 10^{12} - 10^{14}	0.04	1.2
S	SEZ - Proton	All particle	Calorimeter	10^{11} - 5 x 10^{15}	0.3	500
S	HEAO-3 - French-Danish	4 • Z < 28	Cherenkov	3 x 10^{10} - 2 x 10^{12}	0.14	33
S	HEAO-3-HNE	16 • Z • 28	Ioniz.-Cherenkov	3 x 10^{10} - 10^{13}	1.2	370
S	CRN	5 • Z < 26	TRD	7 x 10^{11} - 3 x 10^{13}	0.1- 0.5 (low Z) 0.5- 0.9 (high Z)	0.3 to 3
	Nucleon	**1<Z<30**	**KLEM**	**10^{13}-10^{15}**	**0.09 (p) 0.24 (Fe)**	**170 460**

Expected statistics

Z	>0.1TeV	>1TeV	>10TeV	>100	>1000
All	1,19E8	2,6E6	57700	1300	29,9
1	3,02E7	588000	11500	224	4,36
2	2,51E7	576000	13200	302	6,92
3	892000	25700	742	21,4	0,617
4	301000	5350	95,2	1,69	0,0301
5	844000	9470	106	1,19	0,0134
6	6,16E6	135000	2950	64,5	1,41
7	1,58E6	30000	572	10,9	0,208
8	1,02E7	213000	4440	92,8	1,94
9	221000	4500	91,9	1,88	0,0383
10	2,95E6	67600	1550	35,5	0,813
11	4,81E6	105000	2300	50,4	1,1
12	5,37E6	123000	2820	64,6	1,48
13	930000	20300	445	9,74	0,213
14	6,74E6	120000	2130	37,9	0,674
15	234000	4770	97,4	1,99	0,0406
16	124000	3490	98,5	2,77	0,0782
17	238000	4970	104	2,17	0,0453
18	608000	13900	319	7,3	0,167
19	384000	8600	192	4,31	0,0965
20	1,09E6	21800	435	8,69	0,173
21	234000	5360	123	2,81	0,0645
22	973000	23900	587	14,4	0,353
23	473000	11100	260	6,09	0,143
24	1,1E6	23600	503	10,8	0,23
25	786000	27300	945	32,8	1,14
26	1,58E7	406000	10400	268	6,89

Z	>0.1TeV	>1TeV	>10TeV	>100	>1000
27	71100	1350	25,8	0,492	0,00937
28	66000	20600	636	19,7	0,607
29	15700	421	11,3	0,305	0,00821
30	11800	325	8,95	0,247	0,00679
31	2500	70,3	1,98	0,0559	0,00157
32	2920	84,2	2,43	0,0701	0,00202
33	734	21,2	0,61	0,0176	5,08E-4
34	1460	43	1,27	0,0375	0,00111
35	934	28,2	0,852	0,0257	7,77E-4

It is critically important to obtain Direct data on the all-particle spectrum as a sum of different nuclear CR species around 1013–1015 eV/particle to see how the different nuclear CR species “go into” the knee.



Simple power-like spectra with a slope

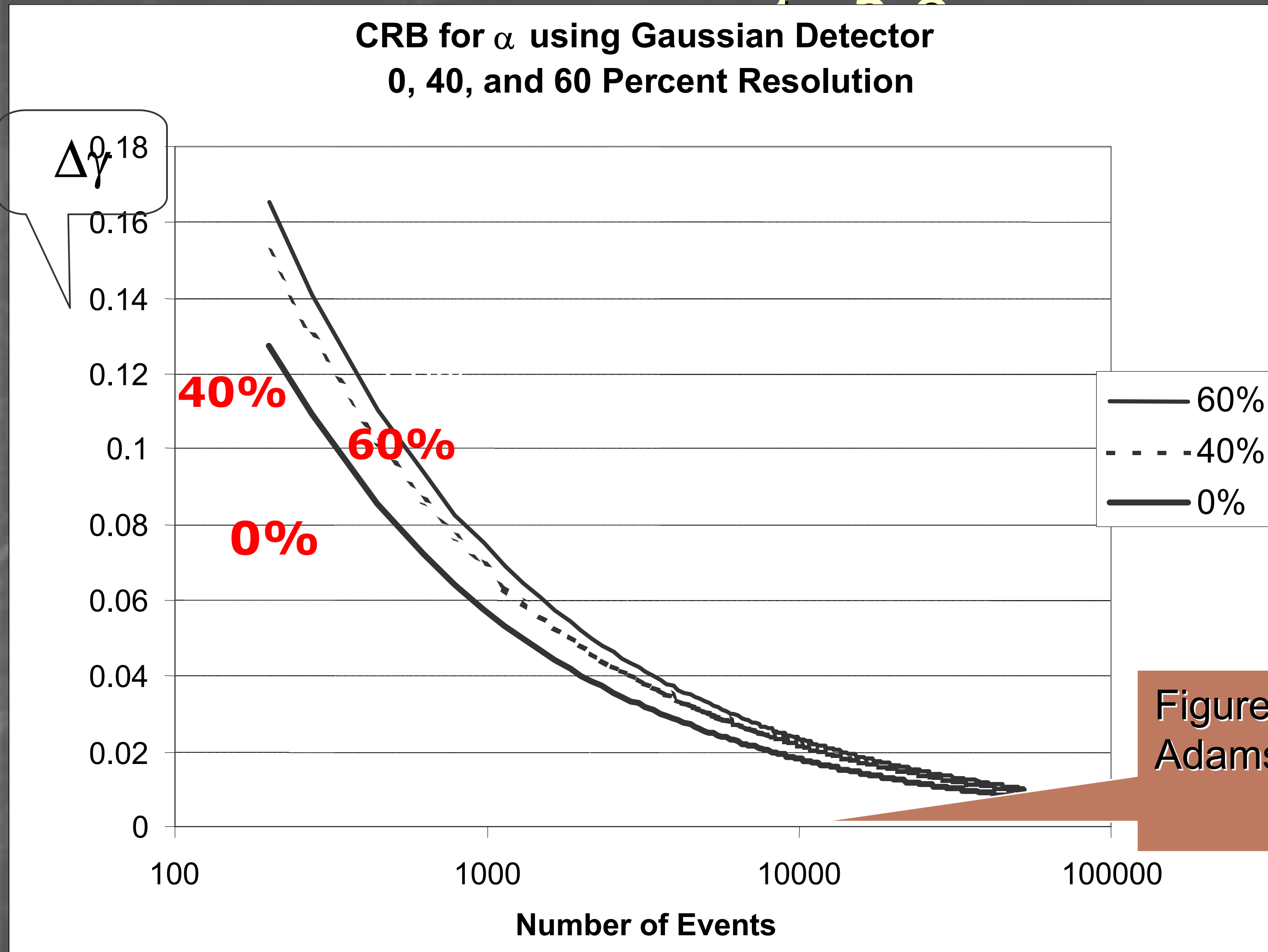
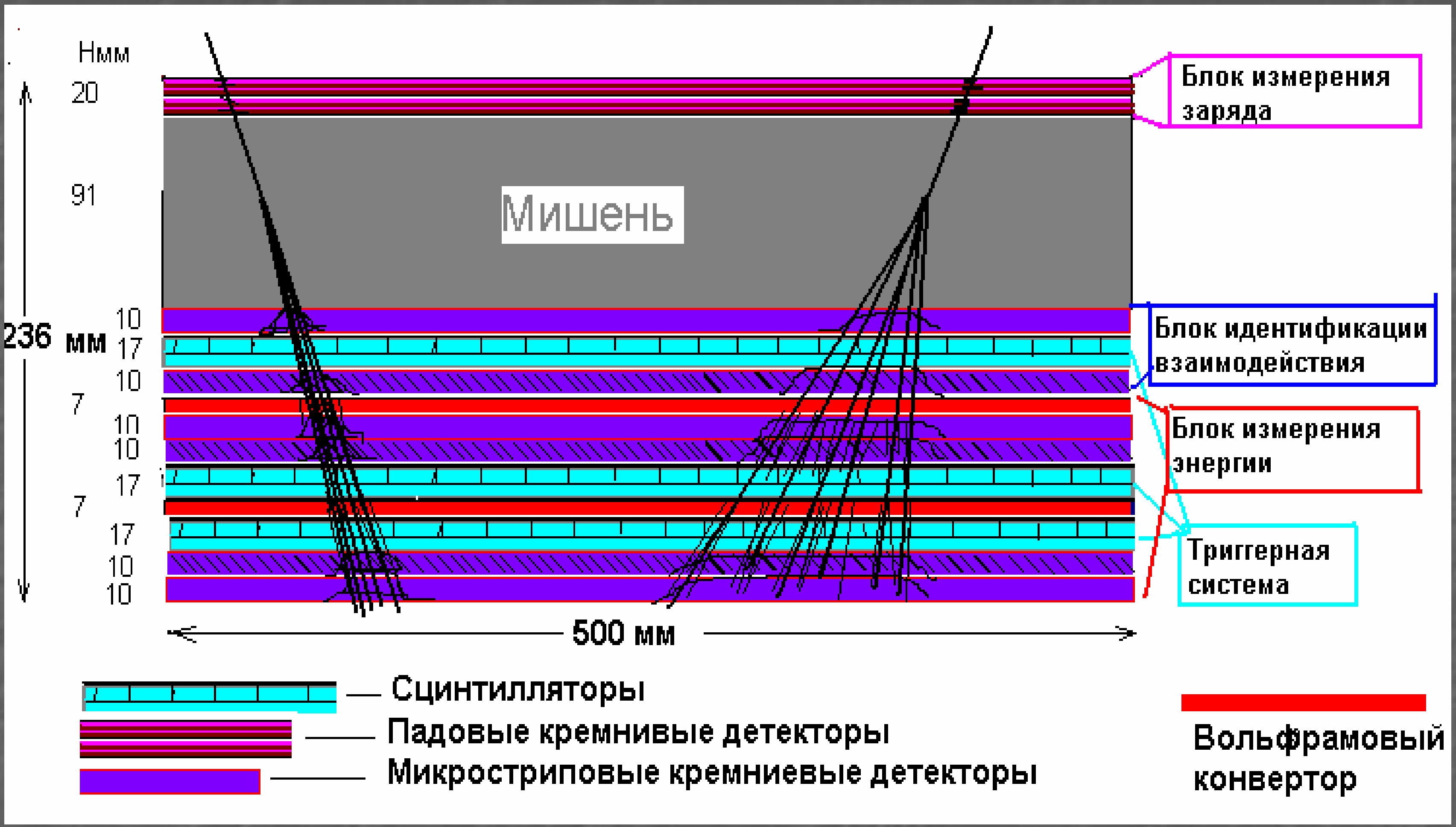
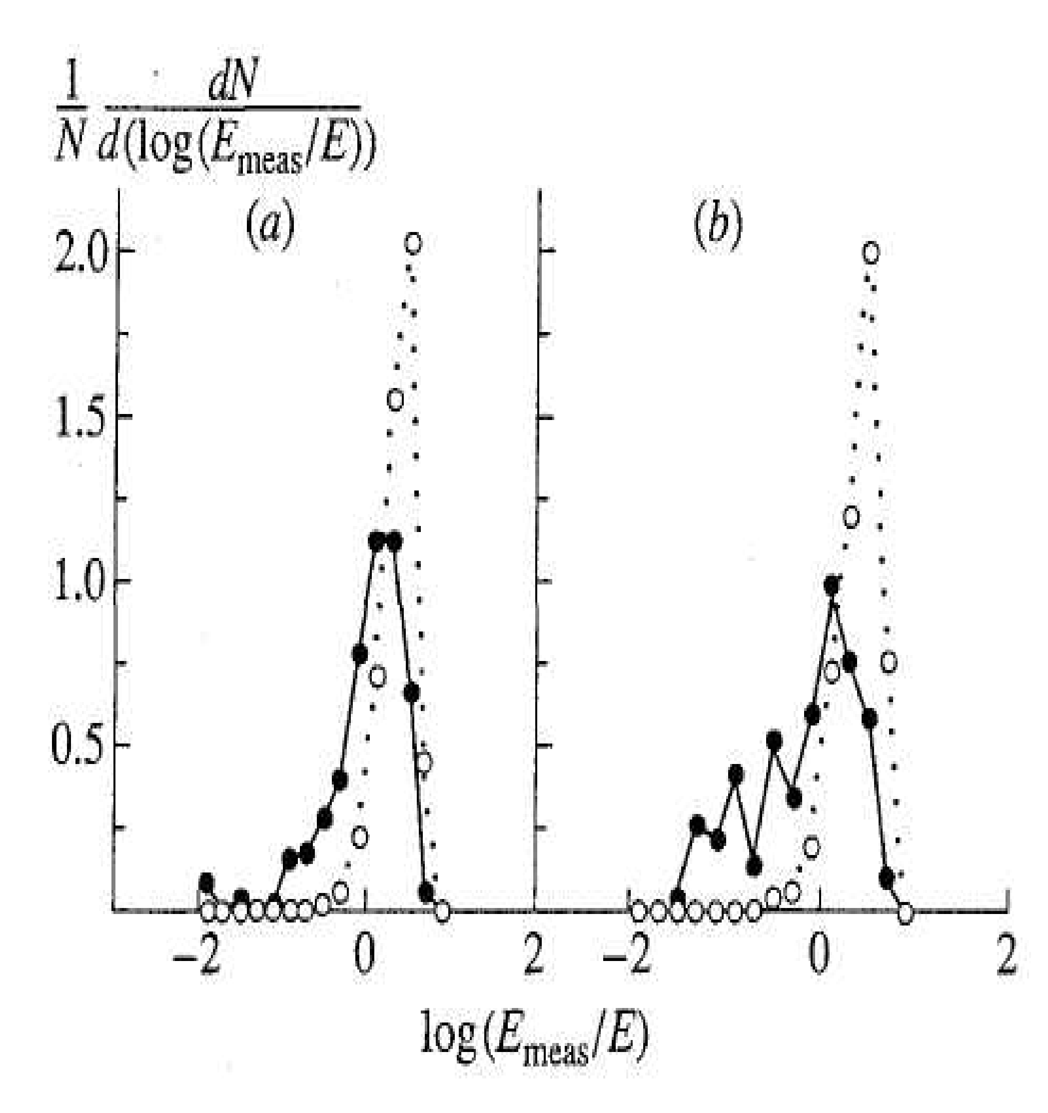


Figure from James Adams et al. project


Нмм
20
91
Мишень
236 мм
10
17
10
7
10
10
17
7
17
10
10
500 мм
Блок измерения заряда
Блок идентификации взаимодействия
Блок измерения энергии
Триггерная система
Сцинтилляторы
Падовые кремнивые детекторы
Микростриповые кремниевые детекторы
Вольфрамовый конвертор



(a) primary protons and *(b)* iron nuclei
the closed circles - *W,*
the open circles - *W**

σ*(lg(Emeas/E))*
0.22(protons),
0.23(Fe-nuclei)

Монохроматический пучок для сравнения:
σ*(lg(EmeasE))* =
0.46(p), 0.49(Fe)