Calibration results of Liulin-5 charged particle telescope obtained in ICCHIBAN-7 experiment. New instrumentation for radiation monitoring on interplanetary missions

J. Semkova (1), R. Koleva (1) , St. Maltchev (1), G. Todorova (1), Ts. Dachev (1), V. Benghin (2), V. Shurshakov (2), V. Petrov (2)

(1) Solar-Terrestrial Influences Laboratory, Bulgarian Academy of Sciences, jepero@stil.acad.bg

(2) Institute of Biomedical Problems, Russian Academy of Sciences

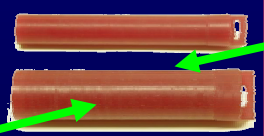
11th WRMISS, September 6th – 8th, 2006, Oxford, UK

OUTLINE

- Current status of the particle telescope Liulin-5 for investigation of the radiation environment dynamics in the spherical human phantom on ISS;
- Calibration results of Liulin-5, obtained in ICHIBAN project;
- Future projects;
- Discussion and Conclusion.

SPHERICAL TISSUE–EQUIVALENT PHANTOM *[V.Shurshakov et all., 2006]*

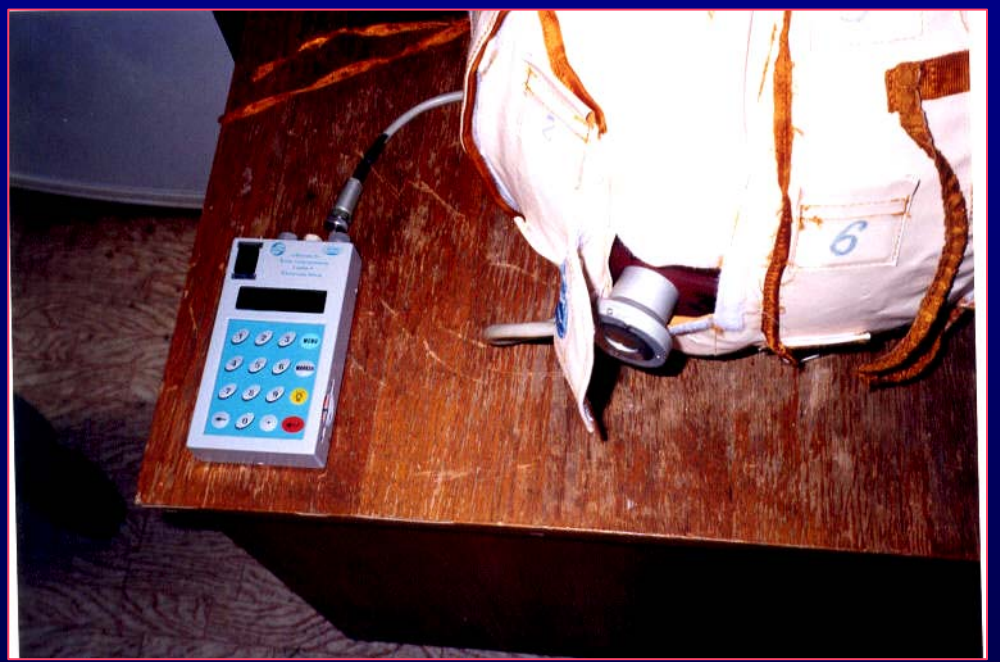
- Size: 370x370x390 mm; mass: 32kg;
- 13 tissue–equivalent slices;
- The slices, beside the central, have cylindrical openings, where passive dosimeters are placed;
- The central slice has 4 perpendicular radial channels.
- Jacket of the phantom: 32 outside pockets for Passive detectors;
- Containers for passive detectors inside the phantom;
- In a radial channel will be placed Liulin-5 detector module.



LIULIN-5 DESCRIPTION

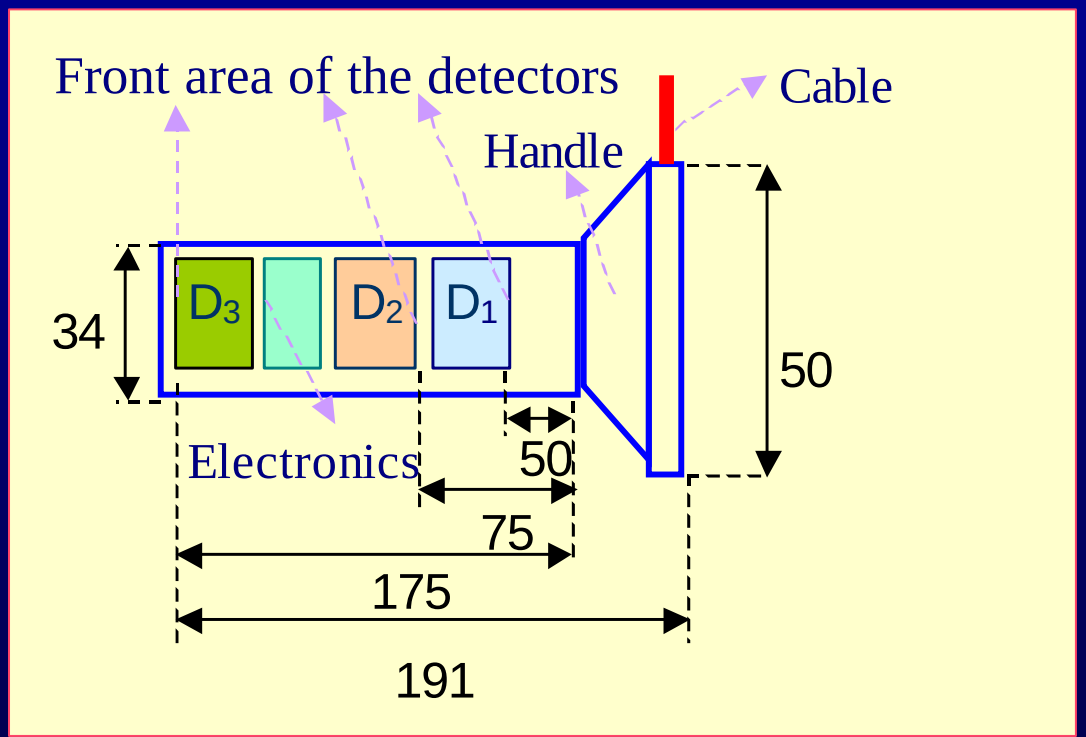
Two units: a detector module in the phantom channel and an electronic block outside it. Weight = 0,8 kg; Power consumption 1 W. Data are stored on smart media card.

External view of Liulin-5



Liulin-5 in the spherical phantom

Liulin-5 detector module.



- Detectors are placed in an Al tube. Thickness of the tube is 7.5mm;
- Three Si detectors arranged as a telescope;
- D1 and D2 detectors operate in coincidence mode. FOV is 98^0;
- Thickness of the detectors 400μm-passport data;
- Sensitive thickness of the detectors 300μm-passport data;
- Diameter of detectors < 19,2 mm – no exact passport data;

Liulin – 5 experiment

Goals

Liulin-5 will measure simultaneously in real time at 3 different depths of the radial channel of the spherical phantom:

- **Energy Deposition Spectra – then Dose Rate and Particle flux - then Absorbed Dose D;**

- **Measurement of the Linear Energy Transfer (LET) Spectra in Si – then assessment of LET in water = LET(Si) x 1,2/2,34- then assessment Q=f(LET) and Dose Equivalent H; H=DxQ.**

Parameters to be measured

- **Absorbed dose rate** in the range 0.04 x10^{-6} Gy/h - 0.04 Gy/h;
- **Intensity of the particle flux** in the range 0 - 4x10^{2}. part/(cm^{2}.sec);
- **Energy loss spectra:**
- in D1 and D2 detectors: **Two sub-ranges** :

LLET range 0.3 –9 MeV; HLET range 9–80 MeV;

- in D3 detector: **Two sub-ranges:**

LLET range 0.05 – 1.7 MeV; HLET range 1.7 – 10 MeV;

- **Coincidences D1& D2 spectra - LET spectrum** in the range 0.17 –130 keV.μm^{-1} in water.
- All **HLET events, exceeding the upper energy limit** are considered as **LETmax.**

Measurement modes

- **Standard** - Dose and flux rates measurement every 90 s, energy loss spectra and LET spectra – 90 min;

- **Fast** - for SPE and SAA. Dose and flux rate measurement every 20 s, energy loss and LET spectra -15 min;

- **Calibration** - for ground–based tests.

Status of Liulin-5 instrument

- Flight Model Qualification Tests in Bulgaria and Russia Done: November 2005 – June 2006;

- Expected Beginning of the Experiments with Liulin-5 in the Spherical Phantom on ISS – 2007.

LIULIN – 5 CALIBRATION

EXPERIMENTS

- Liulin-5 was exposed to 400 MeV/n ^{16}O and 300 MeV/n ^{56}Fe beams in the ICCHIBAN - 7 experiment *[Y.Uchihori et all., 2005]* at the HIMAC – Japan in September 2005. Liulin-5 was placed on a rotating X-Z stage.

- The active area of the detectors is smaller than was the beam area.

- Dose and flux rates, energy loss spectra and LET spectra had time resolution of 20 s.

Tests with oxygen ions

Beam [ICCHIBAN WG]:

Energy - 400 MeV/n;

Diameter ~ 20 mm;

LET-19.4 keV/μm in water;

Intensity ~ 200 pps.

Spill – 300 ms every 3.3 s.

Exposure to oxygen ions - exposure conditions of Liulin-5 *[ICCHIBAN WG]:*

	Incident angle	Position	Absorber	Time [min]	Total Events
Run 01	0 deg.	Centre (Xc, Yc)	No	30	74 538
Run 02	30 deg	Centre (Xc, Yc)	No	15	36 000
Run 03	0 deg	Centre (X+5mm, Yc)	No	15	39 000
Run 04	0 deg	Centre (Xc, Yc)	Al (20mm)	30	
Run 05	60 deg	Centre (Xc, Yc)	No	15	36 217

Some exposure positions for Liulin-5

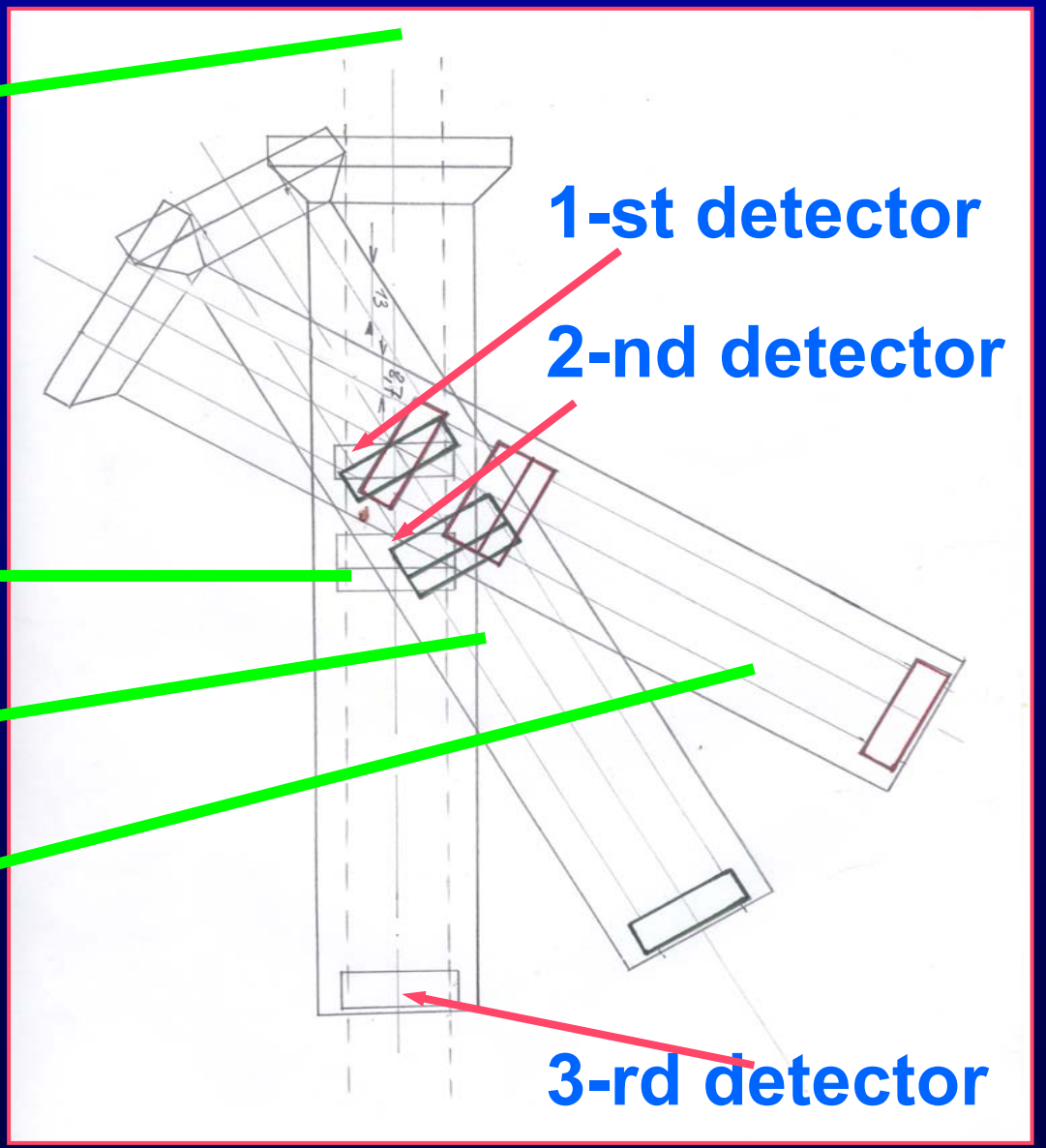
Incident beam

Inclination
(rotation around the centre of 1-st detector):

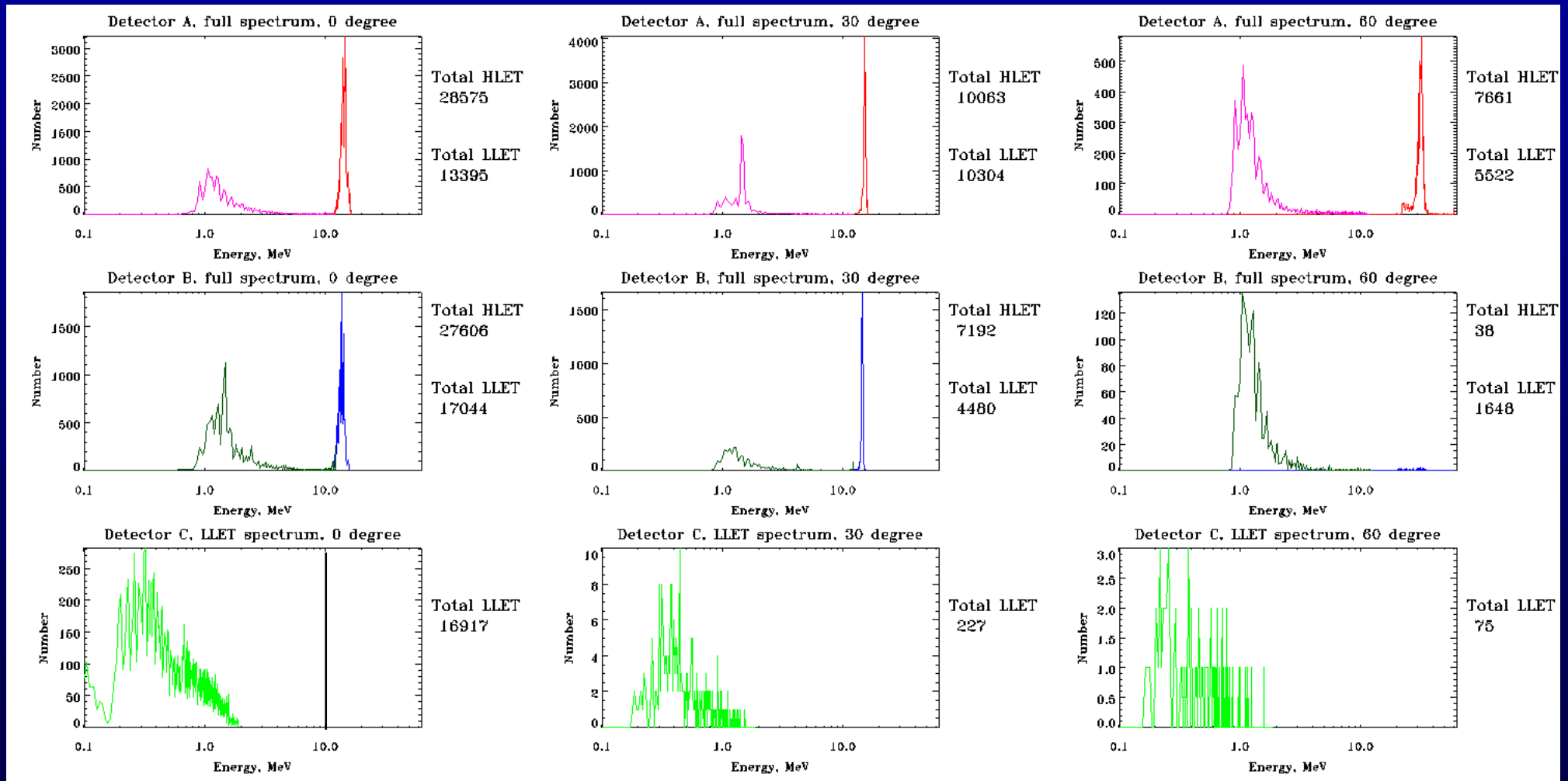
0 degree

30 degree

60 degree

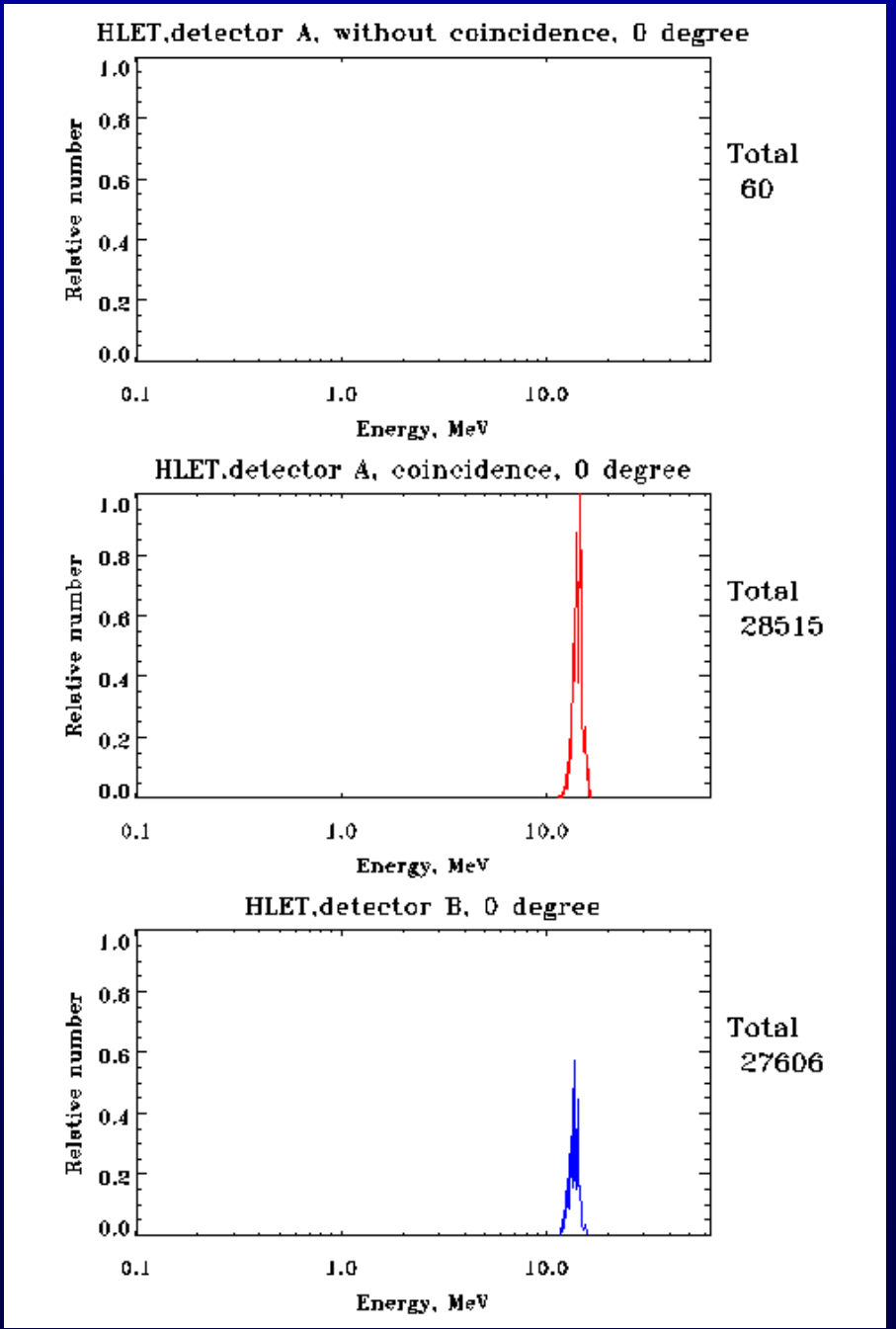


Total deposited energy spectra in the detectors at 0, 30 and 60 degree



HLET spectra in 1-st and 2-nd detectors – 0^0

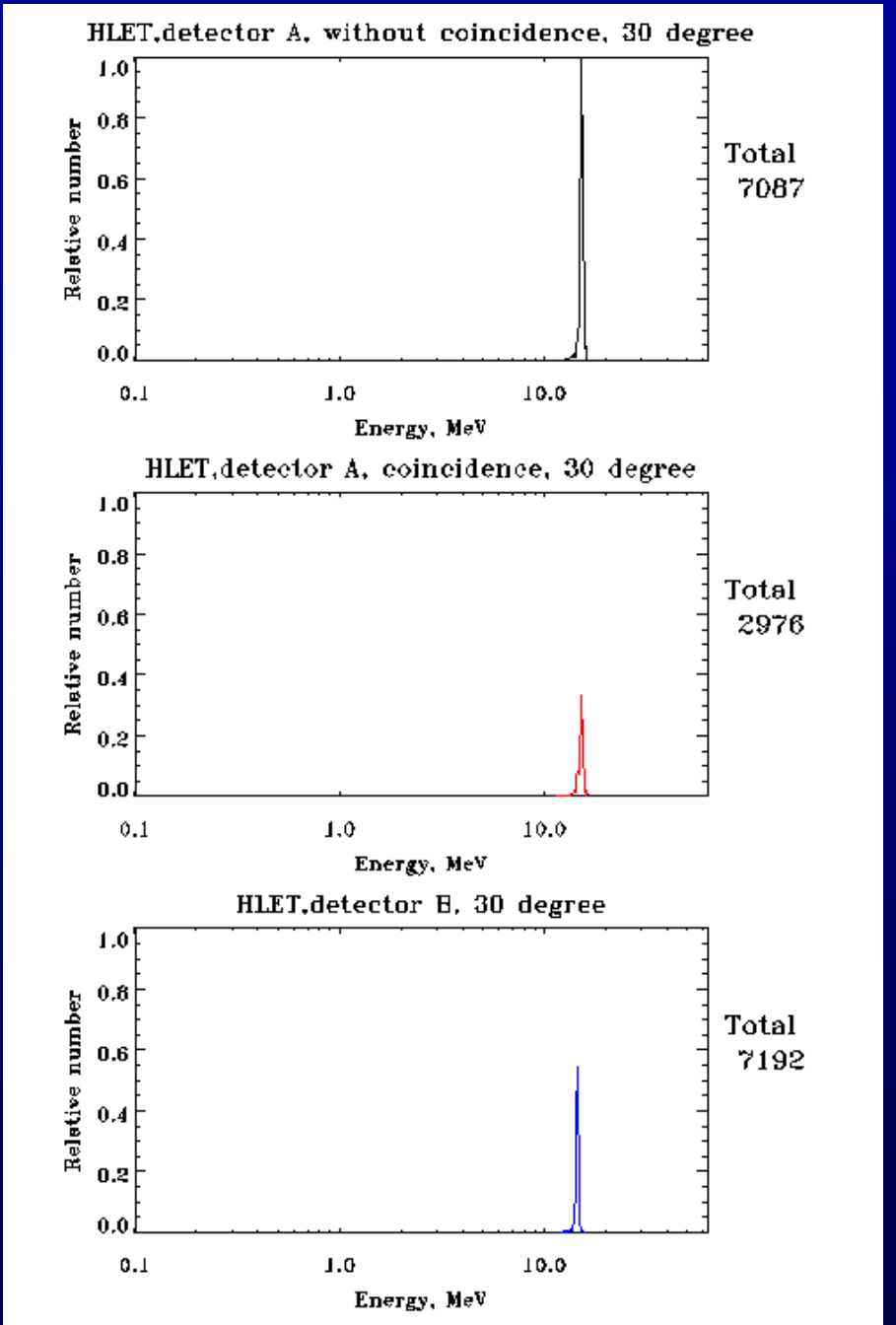
Almost all HLET events measured in detectors A and B are coincident.



HLET spectra in 1-st and 2-nd detectors – 30^0

Al (13mm) in front of detector A and a part of detector B;

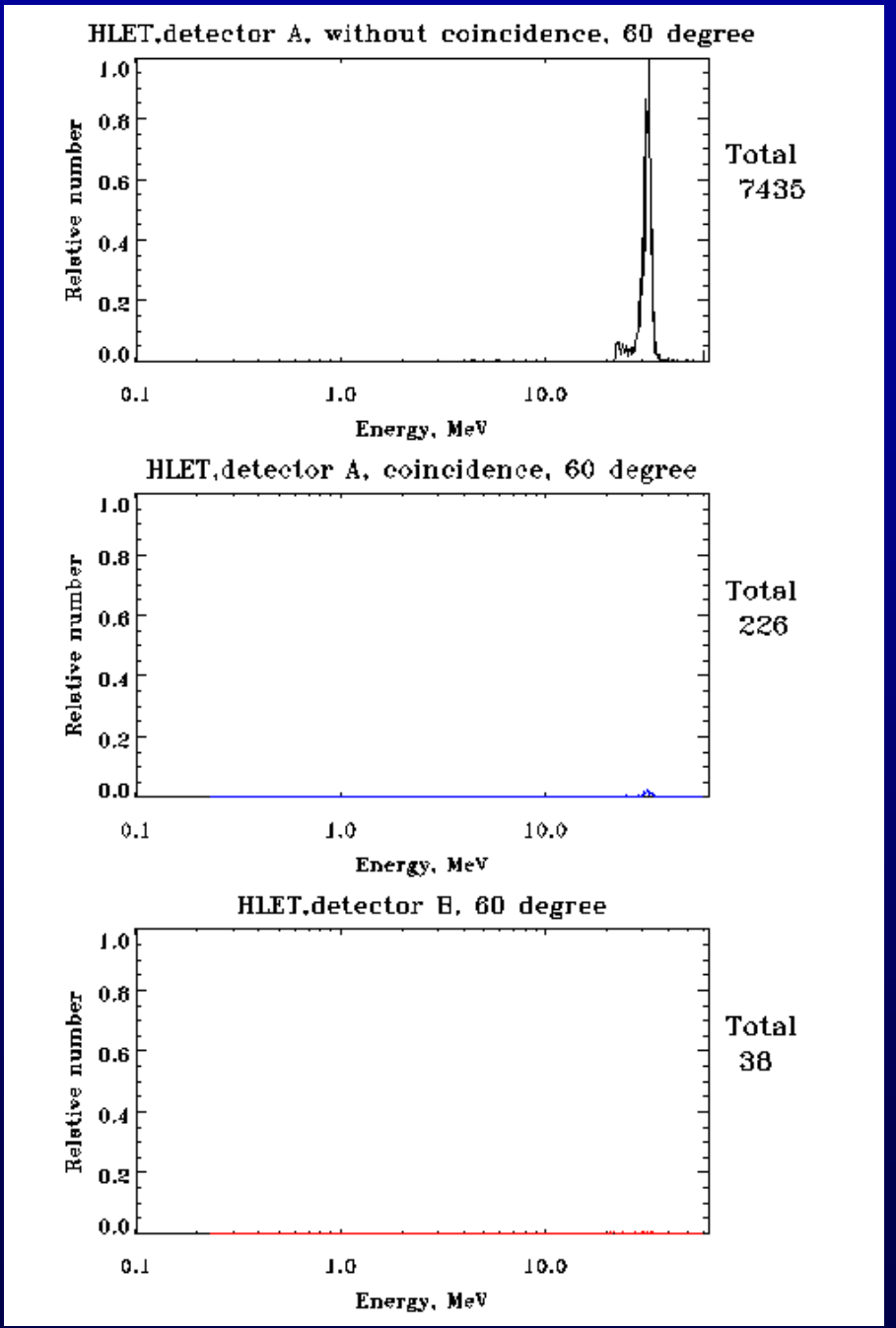
Total HLET events measured in :
Detector A -10043;
Detector B – 7192;
Coincident events – 2976;



HLET spectra in 1-st and 2-nd detectors – 60^0

Al (8,7mm) in front of detector A and a part of detector B;
B is outside the beam;

Total HLET events measured in :
Detector A -7661;
Detector B –36.
No coincident events.



Method of calculation of the dosimetric values

- Mean HLET absorbed energy ΔE for each detector calculated from HLET deposited energy spectra.
- Deduced dE/dX of 400 MeV/n ^{16}O in Si = 160 [MeV/g∗cm^2]; Deduced dE/dX behind absorbers.
- Calculation of detector's thickness h = ΔE x cosα /(dE/dX x ρ); α – angle to the incident beam; ρ (density) of Si.
- Calculation of absorbed dose per a particle.
- LET(Si) values deduced from absorbed energy ΔE in detector A in coincidence mode: LET (Si) = ΔE x cosα/hA → LET(H_2O) = LET (Si) x1.2/2.34.

Summary of results of Liulin-5 exposure to oxygen ions in ICCHIBAN-7

Run/Detector	Run 01/ A	Run 02/A -no coincidence	Run 02/ A [coincidence]	Run 03/ A	Run 04/ A	Run 01/ B	Run 02/ B	Run 03/ B	Run 04/ B	Run 05/ A
Angle α/position/ absorber	0	30, Al 13mm	30, Al 13mm	0, Xc+5mm	0, Al 20mm	0	30	0, Xc+5mm	0, Al 20mm	60, Al 8,7mm
Total HLET events	27957	6861	2860	13863	19088	27154	7124	13593	18899	7661
Total events	41970	20370		19916	29174	44650	11672	21634	30145	13183
Sum Ni*Ei	388822,5	105165,5	43165,19	192782,6	279988,7	361421,2	102300,6	180973,4	264559,5	
Average HLET absorbed Energy [MeV]	13,908	15,328	15,093	13,906	14,668	13,310	14,360	13,314	13,999	28,47
HLET de/dX [MeV/g*cm^2]	160	168,4	168,4	160	176	160	160	160	176	165,6
Average thickness h [cm]	0,0373	0,0374	0,0369	0,0373	0,0358	0,0357	0,0352	0,0357	0,0375	
LET in water [keV/μm]	19,12		18,7	19,12	21,63					
Average HLET absorbed dose [nGy/particle] 1proton/[cm2]	25,82	28,47	28,04	25,82	27,24	24,73	26,68	24,73	26,01	52,9

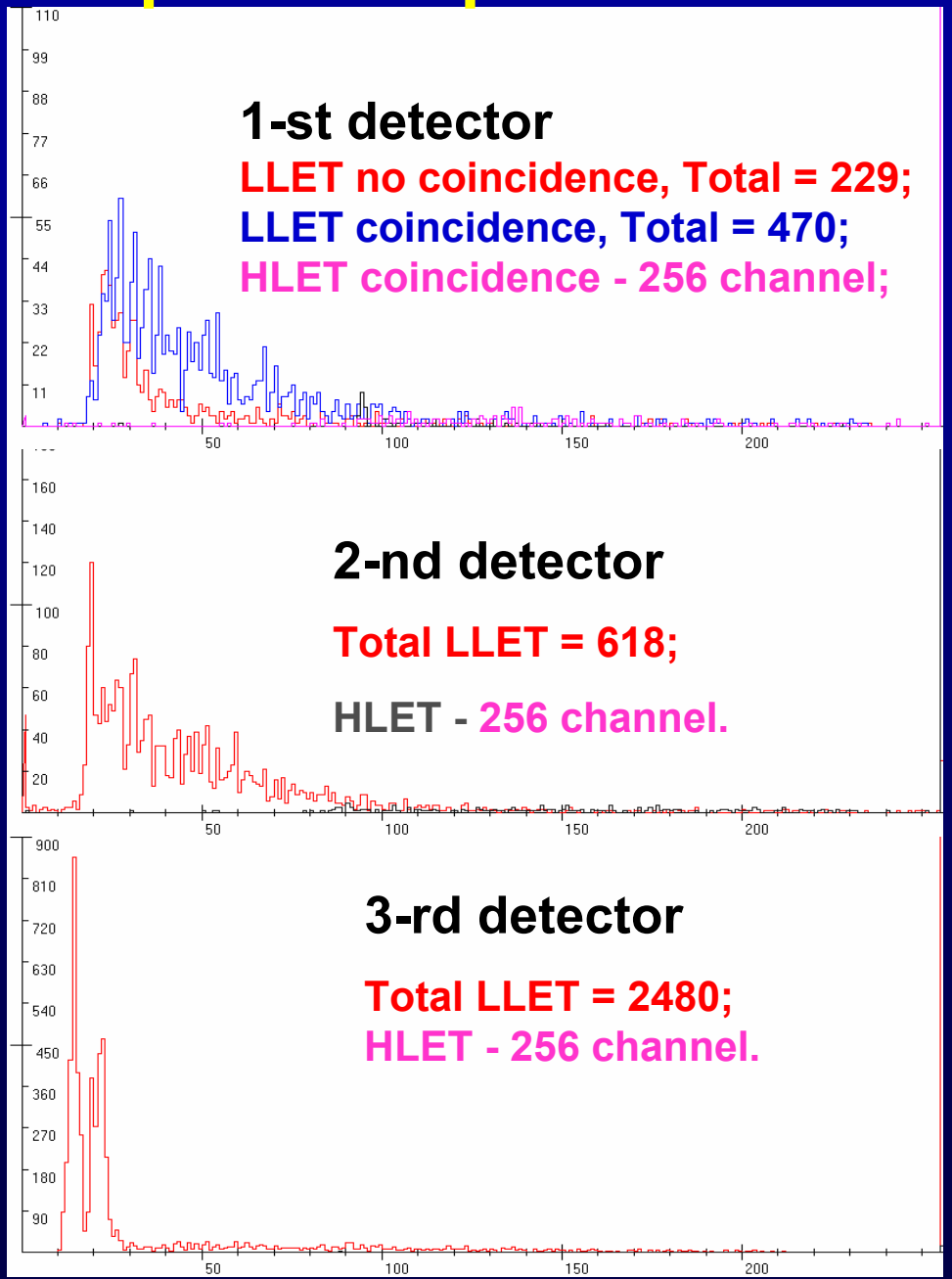
Exposure to Fe ions *[ICCHIBAN WG]:*

Beam: Fe – 300 MeV/n;

LET-234.4 keV/micron in water;

Energy loss of ^{56}Fe exceeds the upper energy limit of Liulin-5. LET of iron beam exceeds the upper LET limit of Liulin-5.

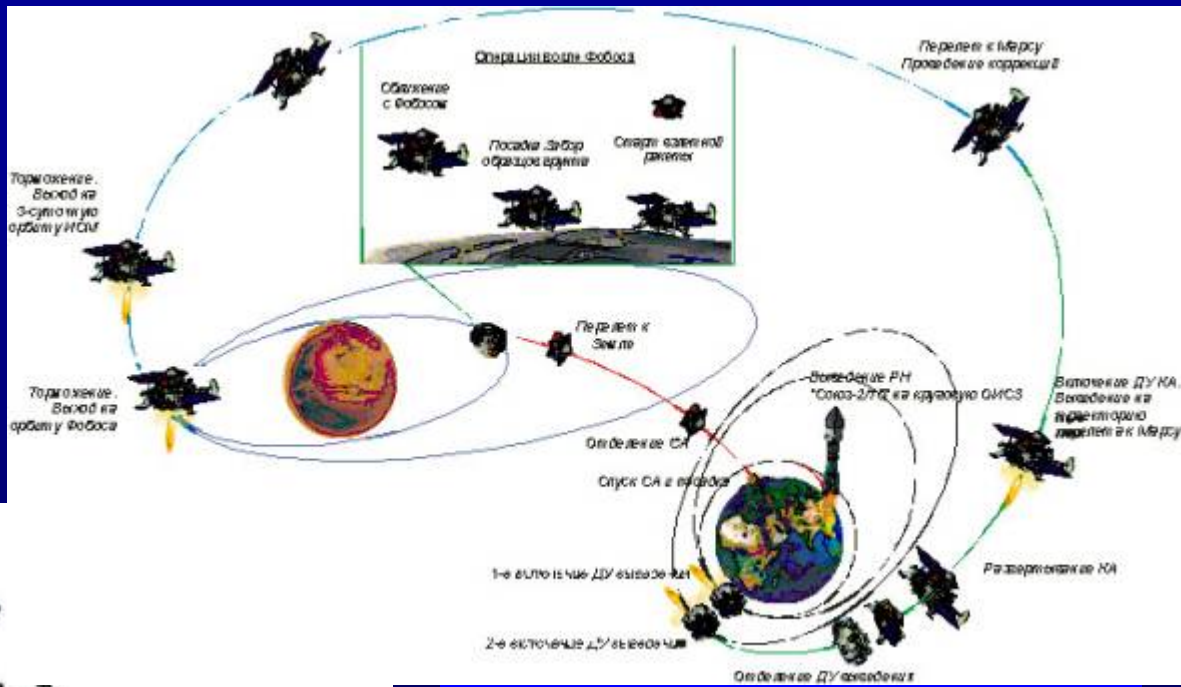
Deposited spectra at 0^0



Calibrations main results

- Calibrations of Liulin-5 with ^{16}O beam 400 MeV/n allow to define the sensitive thickness of the detectors.
- Using measurements at 30^0, the diameter of the detectors were calculated as 17,2 mm.
- Obtained values of absorbed HLET doses in detectors A&B (24,73-25,82 nGy/particle) in good agreement with calculated dose for 1proton/cm^2 in Si =25,4 nGy.
- The 300 MeV/n iron exposures were outside LET range of Liulin-5.

FUTURE PHOBOS-GRUNT PROJECT



Launch of the spacecraft is scheduled for 2009.

(Zelenyi, Zaharov, Pichadze, http://www.roscosmos.ru/science0615.asp)

LIULIN – F EXPERIMENT FOR FHOBOS - GRUNT MISSION

Collaboration:

- IMBP (Russia);
- NIH (Italy);
- NIRS (Japan);
- STIL (Bulgaria).

Current shedule:

2006 – Mass &Thermal Models;

2007 – Engineering Model;

2008 – Flight Model.

Liulin – F goals

Liulin-F will measure simultaneously at 2 perpendicular directions:

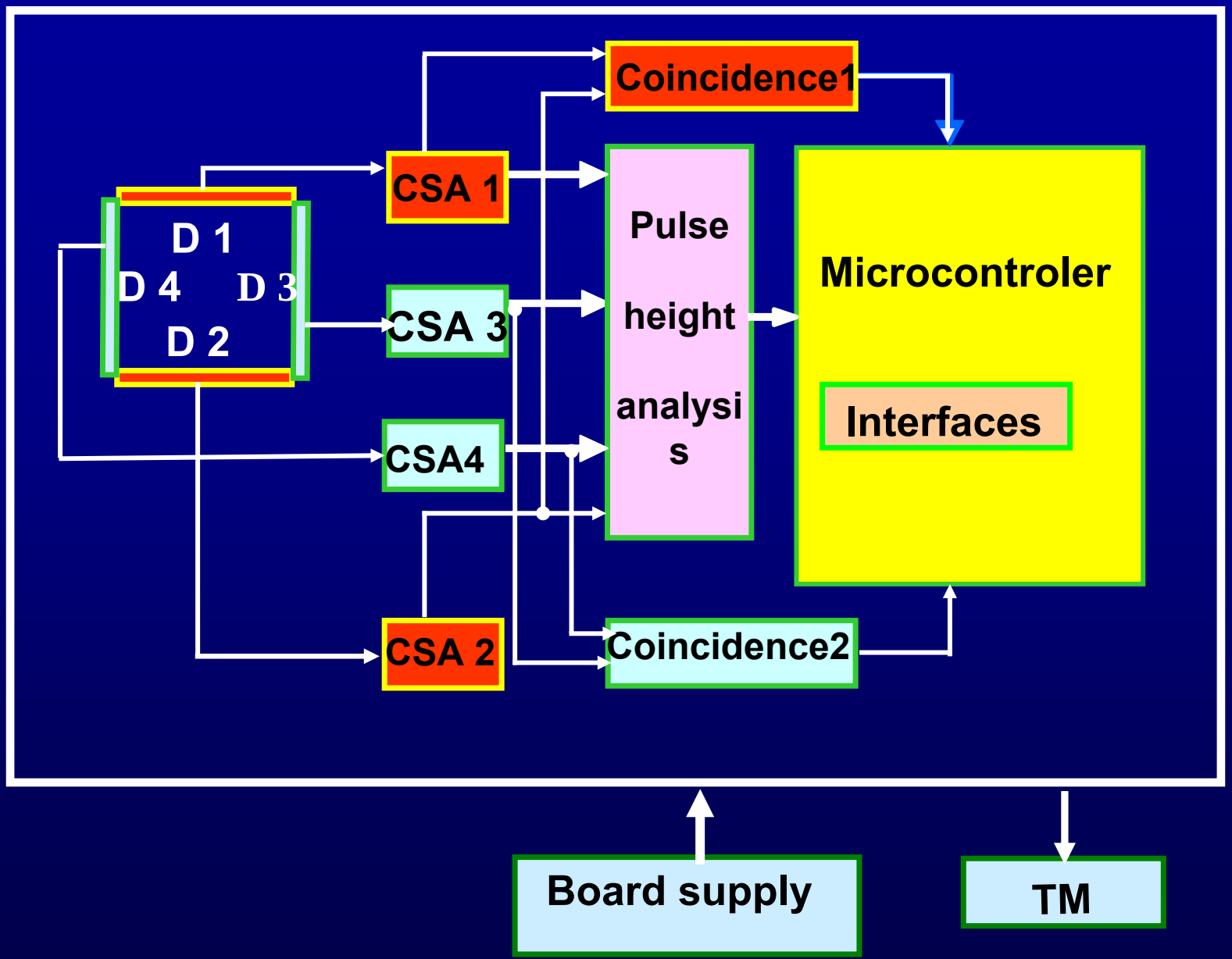
- Absorbed Dose Rate;
- Intensity of particles flux;
- Linear Energy Transfer (LET) Spectra;
- Dose equivalent rate;
- Individual contribution of electrons, protons, and HZE particles in the dose composition.

Liulin-F particle telescope description

(Preliminary)

- 2 dosimetric telescopes in perpendicular directions;
- Detectors – Si PIN Photodiodes (Hamamatsu)
- Weight 0,330 kg;
- Power consumption 0,3 W;
- Telemetry rate –160 kB/day

Prototype of proposed instrument is Liulin-5 charge-particle spectrometer developed for Matroshka-R experiment on ISS.



Block-diagram of Liulin-F

Parameters to be measured (preliminary)

- **Absorbed dose rate** in the range
  0.04 x10^{-6} Gy/h - 0.1 Gy/h;

- **Intensity of the particle flux** in the range
  0 - 10^{3} particle/(cm^2 sec);

- **Energy loss spectra** in the range 0.1-110 MeV, measured by each of detectors;

- **LET spectra** in the range : 0.17 –170 keV·μm^{-1}.

CONCLUSION

- A particle telescope Liulin-5 has been developed for investigation of the radiation environment dynamics within a human phantom on ISS .

- Space qualification and acceptance tests of the flight unit have been done.

- Calibrations of Liulin-5 in ICCHIBAN - 7 experiment with ^{16}O beam 400 MeV/n allow to define the sensitive volume of the detectors.

- Liulin-5 is planned to be flown on the ISS in 2006.

CONCLUSIONS (continuation)

- An experiment Liulin-F to study the radiation hazards during the Mars exploration through future Phobos-Grunt mission has been proposed.

- The instrumentation Liulin-F will characterize, in terms of dose rate and LET spectrum, the radiation environment in interplanetary and near-Mars space.

- Data obtained will be used for the evaluation of shielding requirements on future manned Mars mission.

CONCLUSION (continuation)

- The measurements will allow to verify and to improve methods for radiation detection and dosimetry for long-duration space flight as well as calculation models for particles transport and dose assessment.

- Prototypes of proposed instruments are dosemeters and charge-particle spectrometers developed for radiation measurements on ISS.

ACKNOWLEDGEMENTS

- Agreement between RAS and BAS on space research, grant "Infrastructure" from the Bulgarian Ministry of Education and Science.

- NIRS-Chiba, Japan and ICCHIBAN WG for the opportunity to participate the ICCHIBAN Project.

Thank you for your attention!