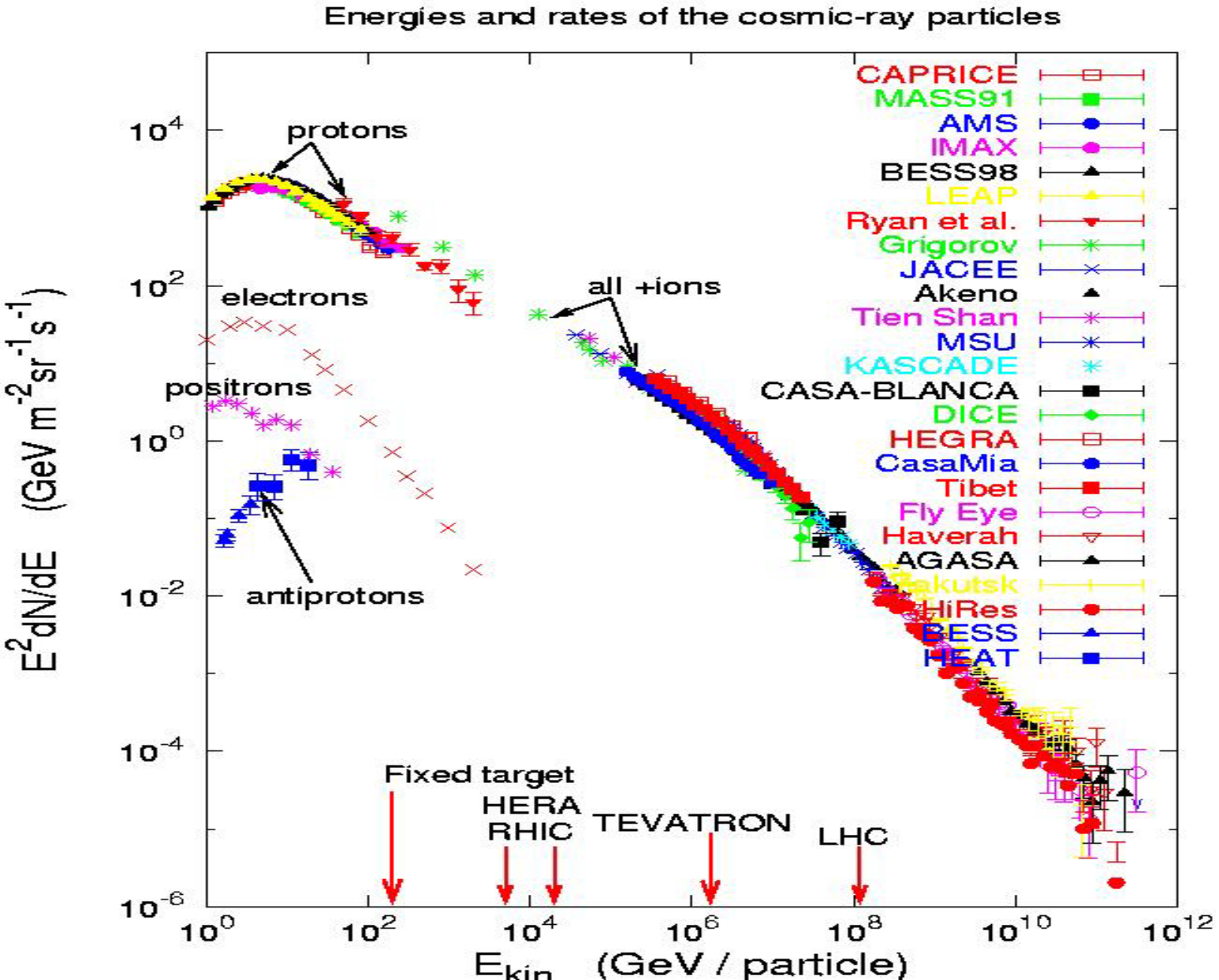
Jaroslav Urbar, AXRO 2009

Radiation IMAGING DETECTORs MEDIPIX/TIMEPIX on STRATOSPHERIC BALLOON CAMPAIGNS of the ESA - BEXUS

Cosmic Ray Induced Ionization atmospheric measurements, calibrations and image pattern recognition by using the Medipix detectors

Results of the first experiments using a MEDIPIX-type detectors for cosmic ray imaging in stratospheric environment are presented. The original detecting device was based on hybrid pixel detector of Medipix2-type developed at CERN with USB interface developed at Institute of Experimental and Applied Physics of Czech Technical University in Prague. The detector was used in its tracking mode allowing it to operate as an "active nuclear emulsion" as the first step to evaluate its feasibility to work as X-ray detector with focusing optics in space environment. Two flights (BEXUS-7 Oct08, BEXUS-8 Oct09) took about 4 hours each, with 2 hours at stable floating altitude of 26km. The flight opportunity was provided by Education dept. of European Space Agency (ESA).

Cosmic Ray primaries: Energy spectra composition



Cosmic Ray Extensive Airshowers (CR EAS)

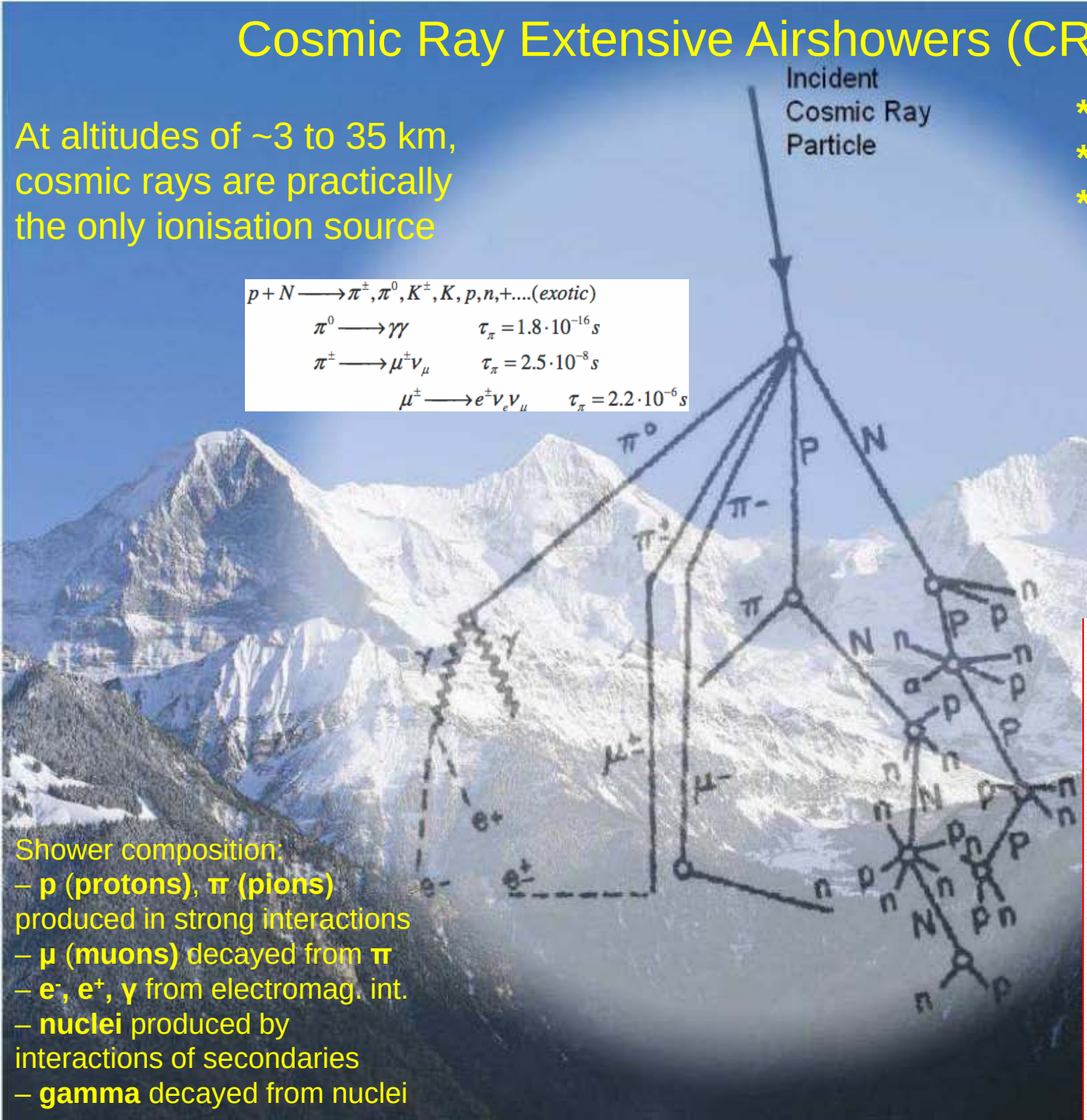
At altitudes of ~3 to 35 km, cosmic rays are practically the only ionisation source

$$p + N \longrightarrow \pi^{\pm}, \pi^{0}, K^{\pm}, K, p, n, + \ldots . (exotic)$$

$$\pi^{0} \longrightarrow \gamma\gamma \qquad \tau_{\pi} = 1.8 \cdot 10^{-16} s$$

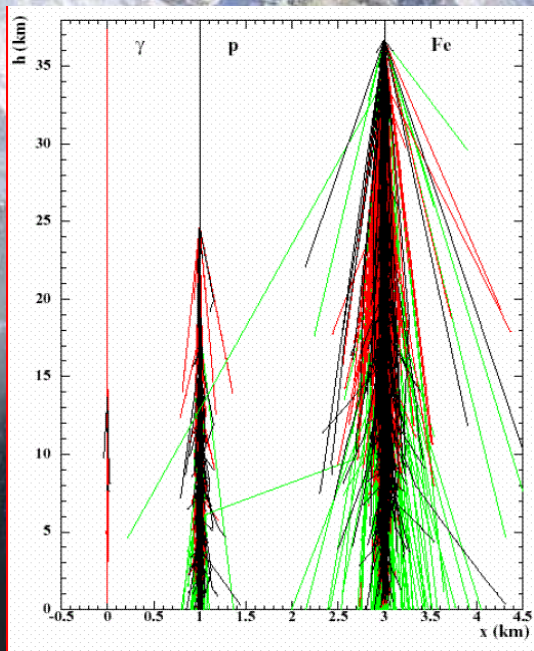
$$\pi^{\pm} \longrightarrow \mu^{\pm} \nu_{\mu} \qquad \tau_{\pi} = 2.5 \cdot 10^{-8} s$$

$$\mu^{\pm} \longrightarrow e^{\pm} \nu_{e} \nu_{\mu} \qquad \tau_{\pi} = 2.2 \cdot 10^{-6} s$$

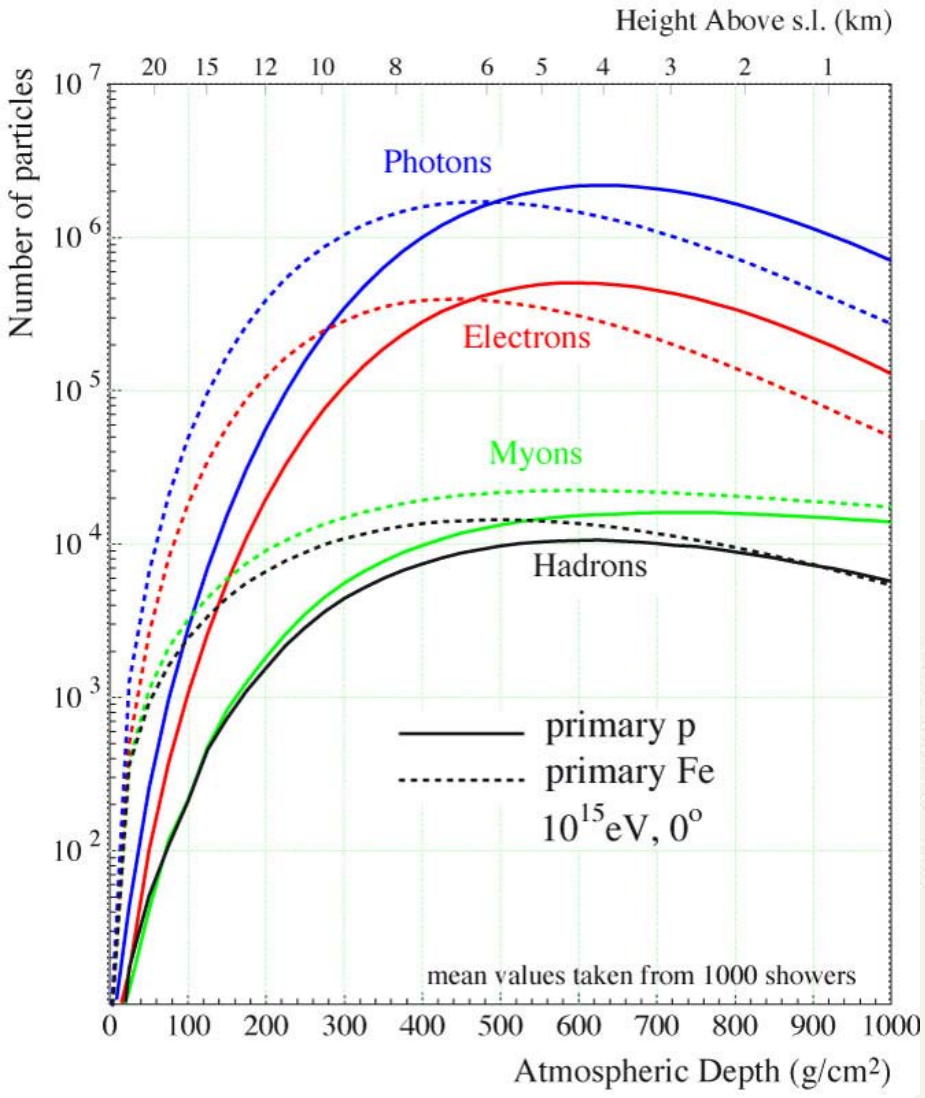


Shower composition:
– **p** (**protons**), **π** (**pions**) produced in strong interactions
– **μ** (**muons**) decayed from **π**
– **e⁻**, **e⁺**, **γ** from electromag. int.
– **nuclei** produced by interactions of secondaries
– **gamma** decayed from nuclei

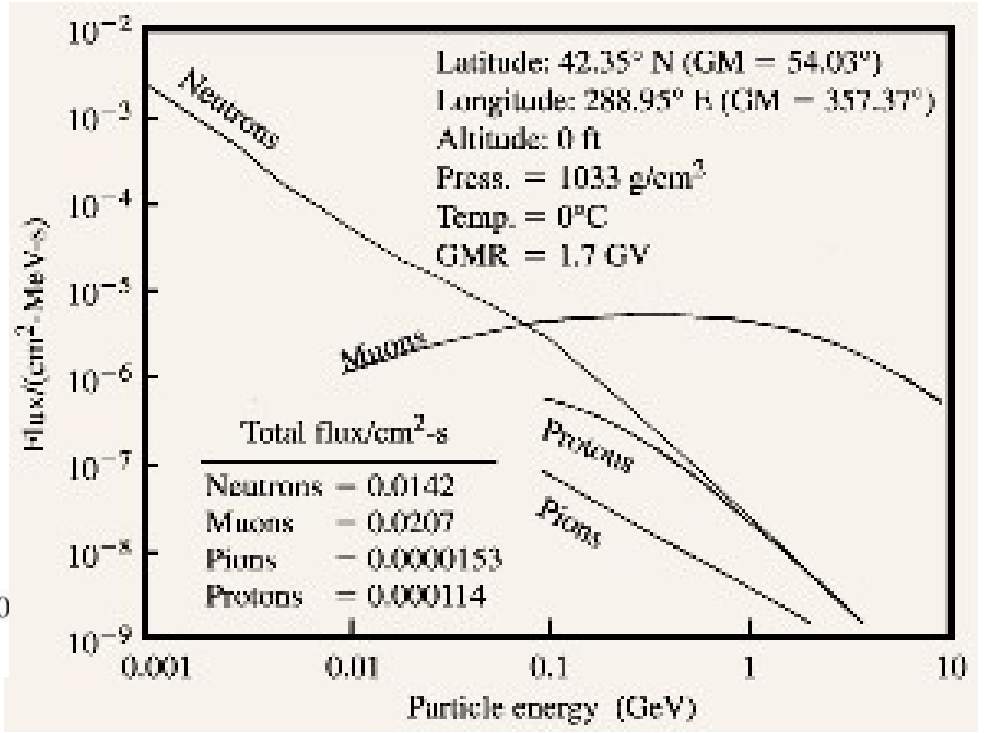
*** Ionisation Rate**
*** Ion Concentration**
*** Global Electric Circuit**
- Commmunication
- E-Fields,
- Lightnings,
- Thunderclouds
- Air Conductivity



CR fluxes in the Earths' atmosphere



particle	mass (MeV), lifetime		atm.abs.length
pion	134	26 ns	115 g/cm²
muon	106	2 μs	260 g/cm²
neutron	932	12 min	140 g/cm²
proton	938	stable	110 g/cm²
electron	0.511	stable	100 g/cm²
photon	stable		

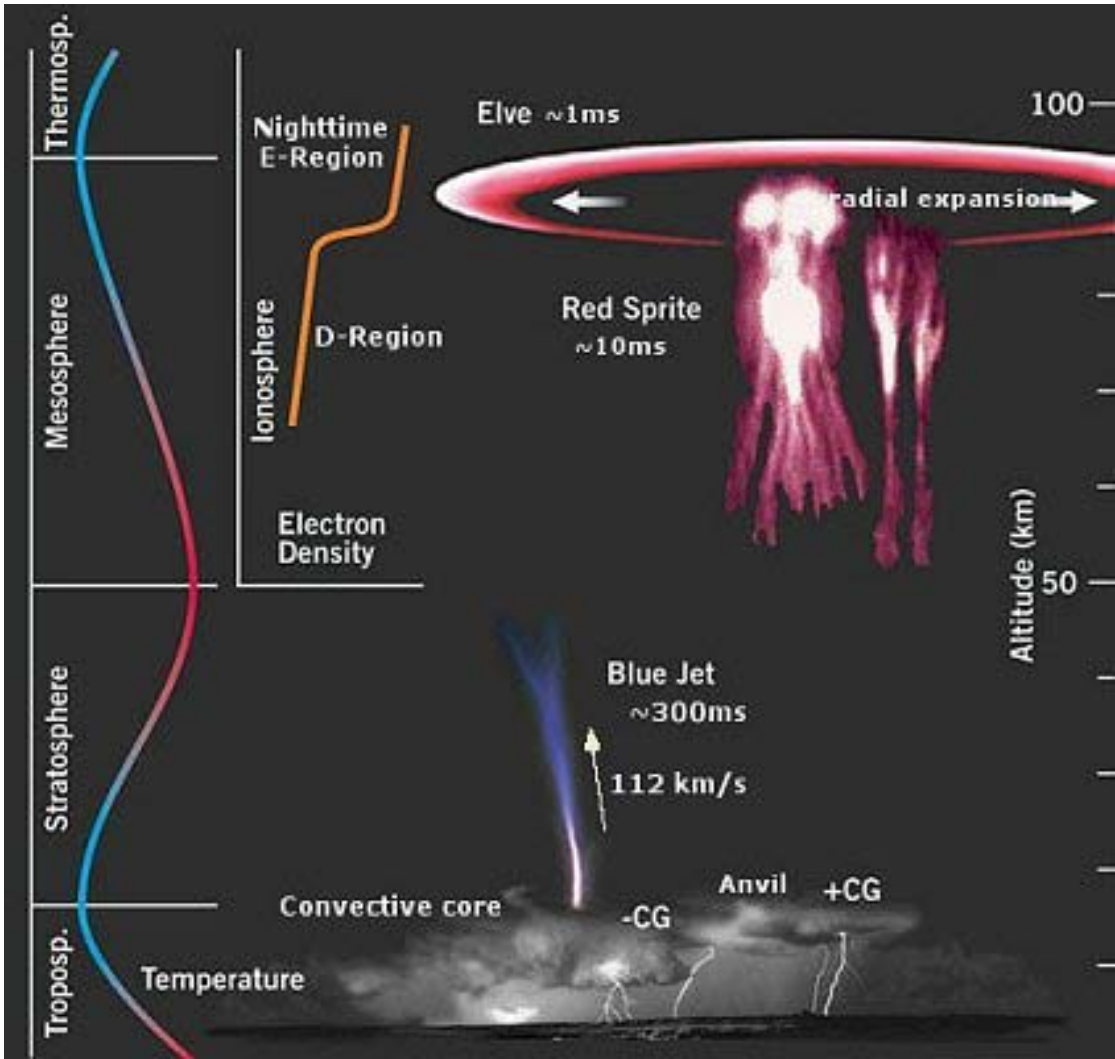


Imaging atmospheric phenomena with X-ray optics

TLEs, TIPPs: Sprite, Elve, Blue jet, Thunderstorm GRBs

Motivation:

- Both X-ray and gamma emissions are present
- Events are frequent also in polar atmosphere
- Phenomena are extended, structured
- Best observed in-situ or close-by (attenuation)
- S/C project TARANIS



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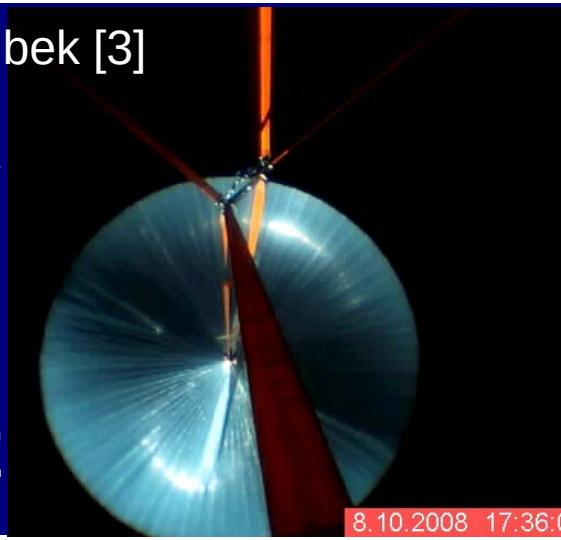
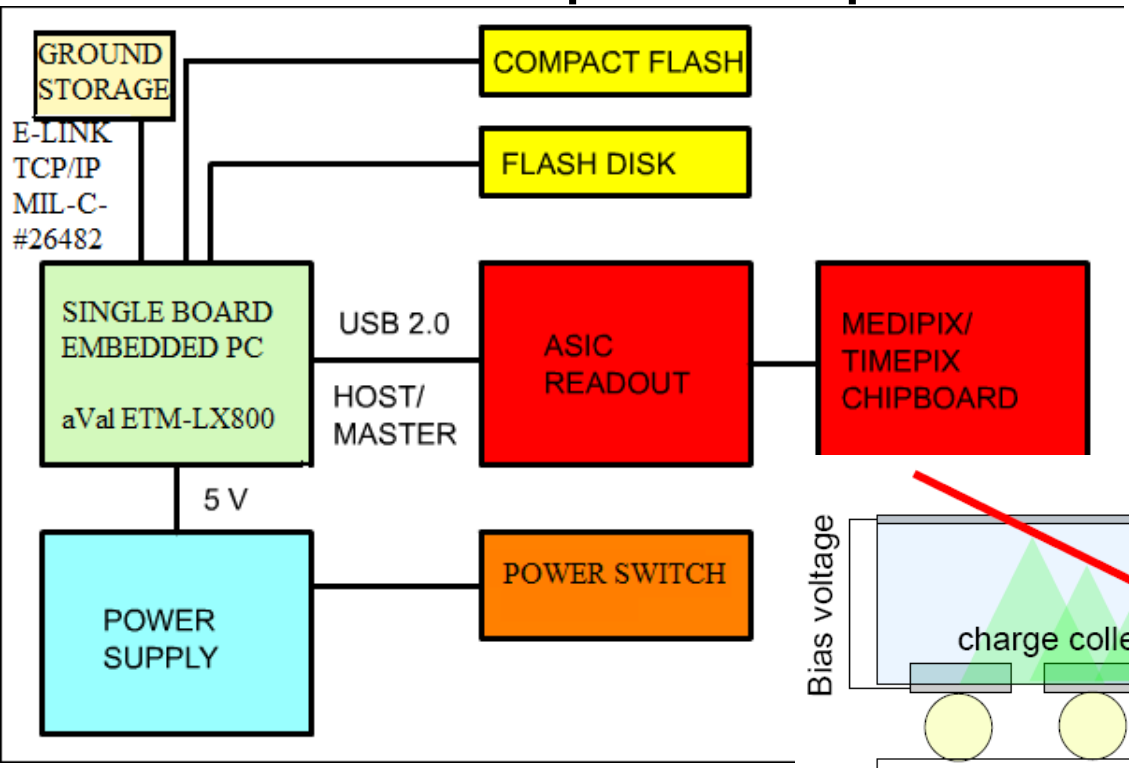
MEDIPIX
CR tracking device flown on ESA BEXUS-7 stratospheric balloon flight



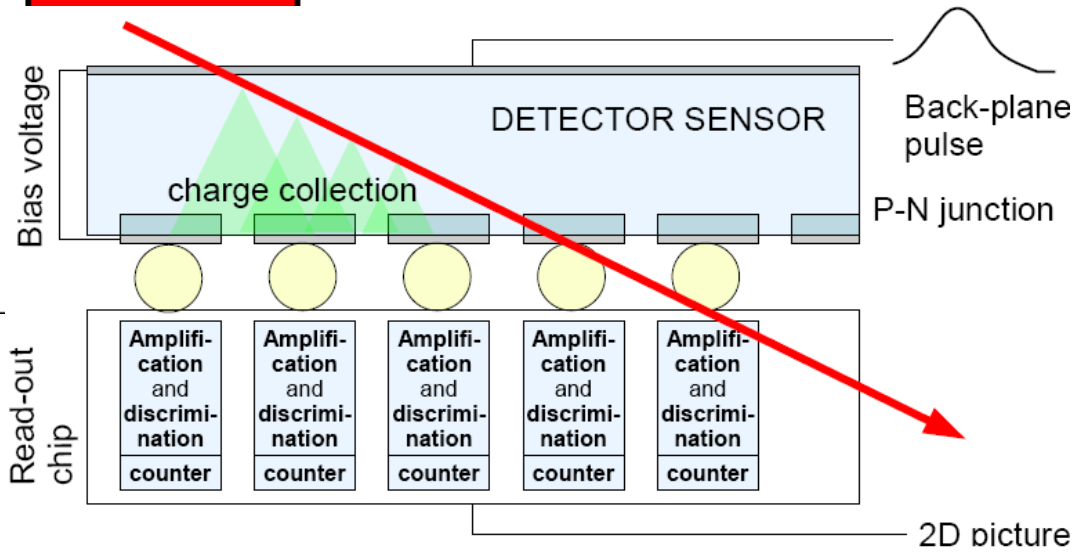
Abstract:

Results of the first experiment using a MEDIPIX-type detector for cosmic ray imaging in stratospheric environment are presented. The detector was used in its tracking mode allowing it to operate as an "active nuclear emulsion". The actual flight time was over 4 hours, with 2 hours at stable floating altitude of 26km. Different types of cosmic ray particles were acquired in the stratospheric radiation environment, sorted and analyzed. Detector performance is evaluated for further design implications of advanced concept focusing on Cosmic Ray Induced Ionization measurement.

TimePiX@Space experiment System overview



- Single Board computer AMD Geode 500MHz
- Ethernet Interface
- Solid State HDD (Compact Flash)
- Medipix2 Detector



Particle detectors are based on:
Energy deposited in the active material of the detector is transformed into charge (by ionization in gaseous detectors/ by excitation of electron-hole pairs in semiconductor ones). The charge is then collected by read-out electronics.

Solid State imaging detector Medipix2

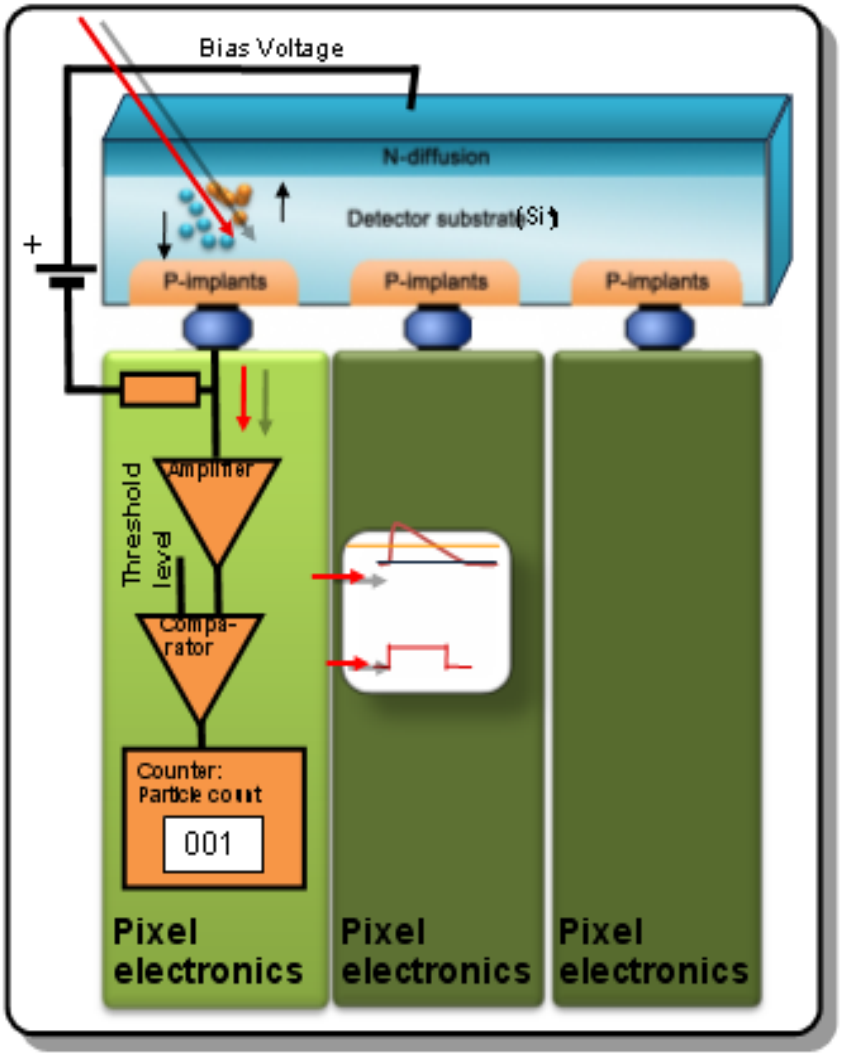
developed at CERN with USB interface developed at IEAP CTU in Prague

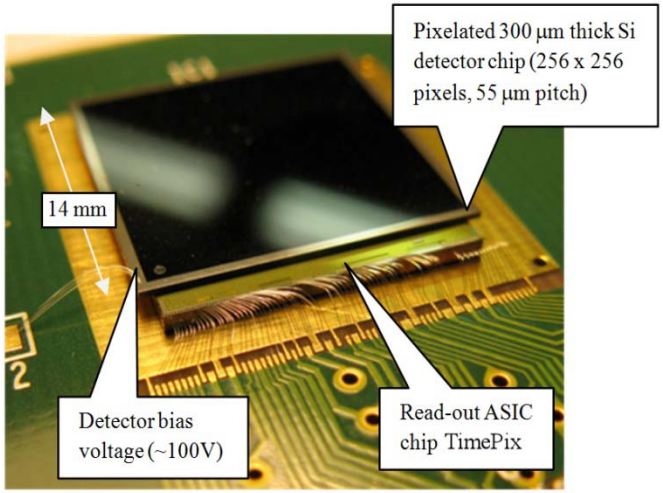
Planar pixel detector (700μm Si) bump-bond to read-out chip

Ionizing particle creates a charge in a sensitive volume

The charge is amplified and compared with threshold

Digital counter is incremented.

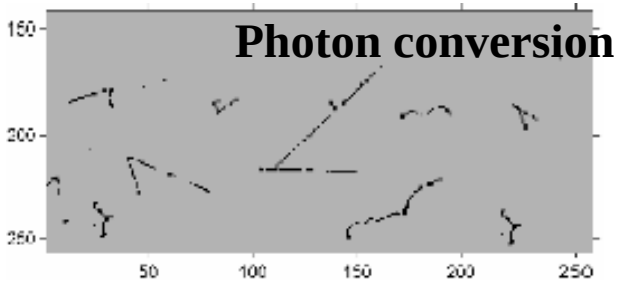


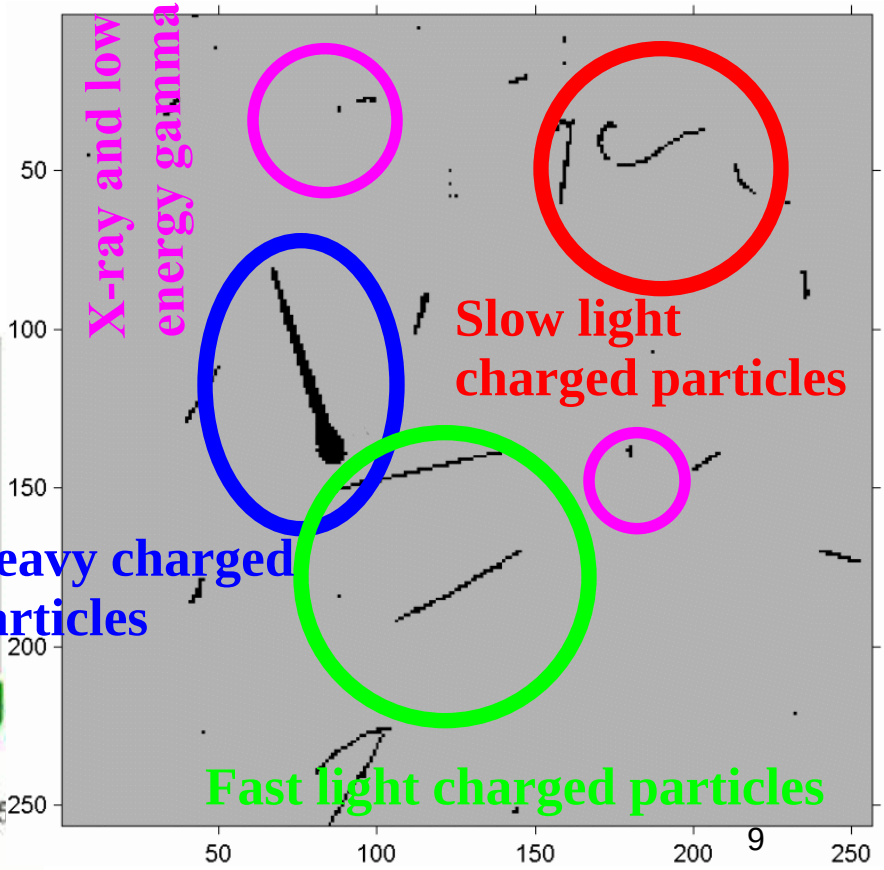


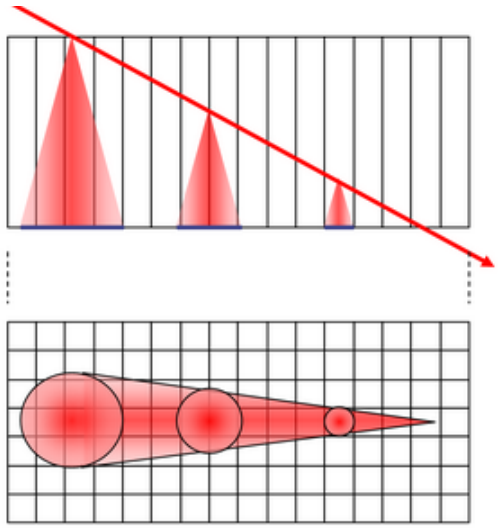
Unique tracking data for particle type identification

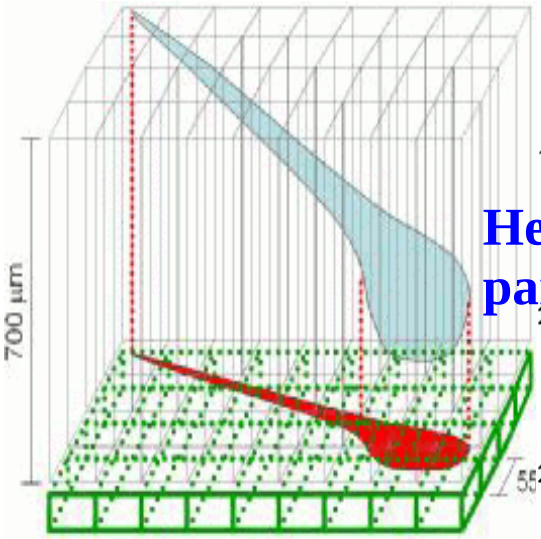
Identification criteria:

- track shape (pattern recognition algorithms: cluster area, linear dimensions, complexity)
- total energy deposited in the sensor (from the amplitude of the back-plane pulse MEDIPIX2)

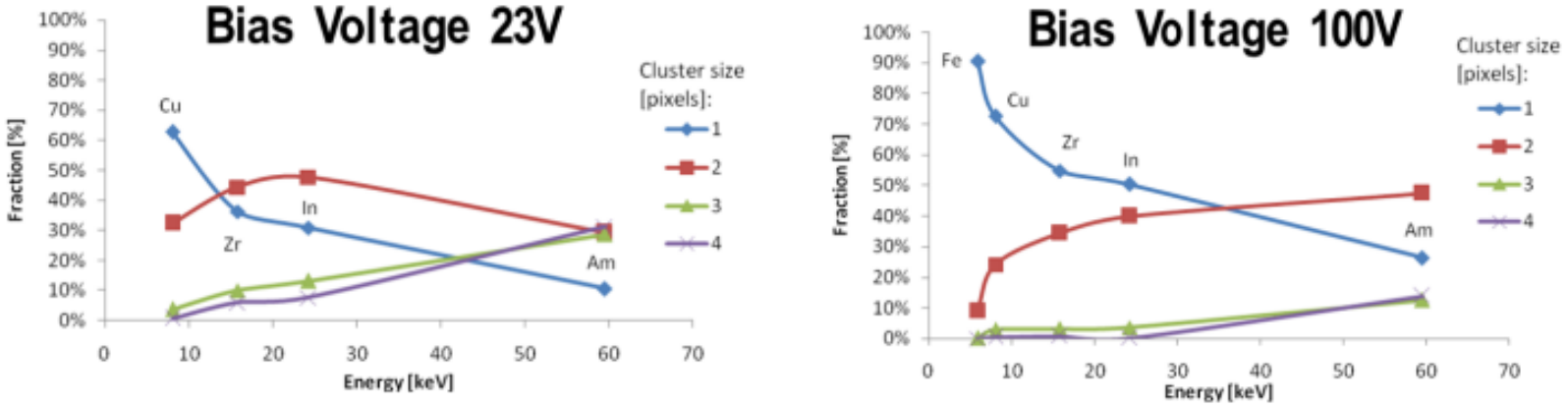




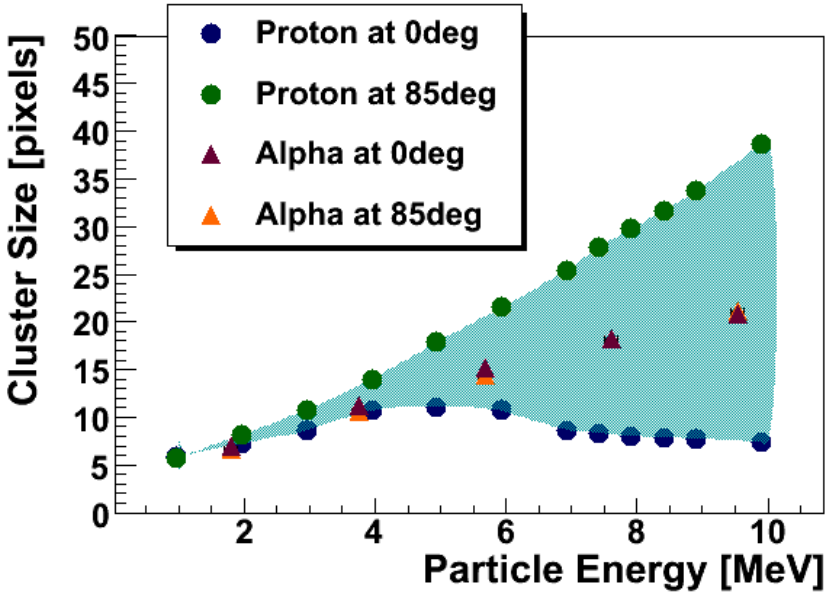




Charge sharing effect – cluster pattern analysis



Bias voltage cluster size and particle type dependences



→from 0 to 6 V: Increase of the cluster size could be explained by the term of diffusion.
→from 6 to 11V: Funneling effect (first decrease in cluster size)
→from 11 to 20V: Lateral diffusion.
→beyond 20V: Second decrease in cluster size. The increase of the longitudinal electric field increases the velocity of the charge carriers and the lateral spread decreases.

Proton and alpha cluster size at low threshold Medipix2 at 8keV

Mixed field radioisotope clusterananalysis tests:

Radiation calibration sources used:

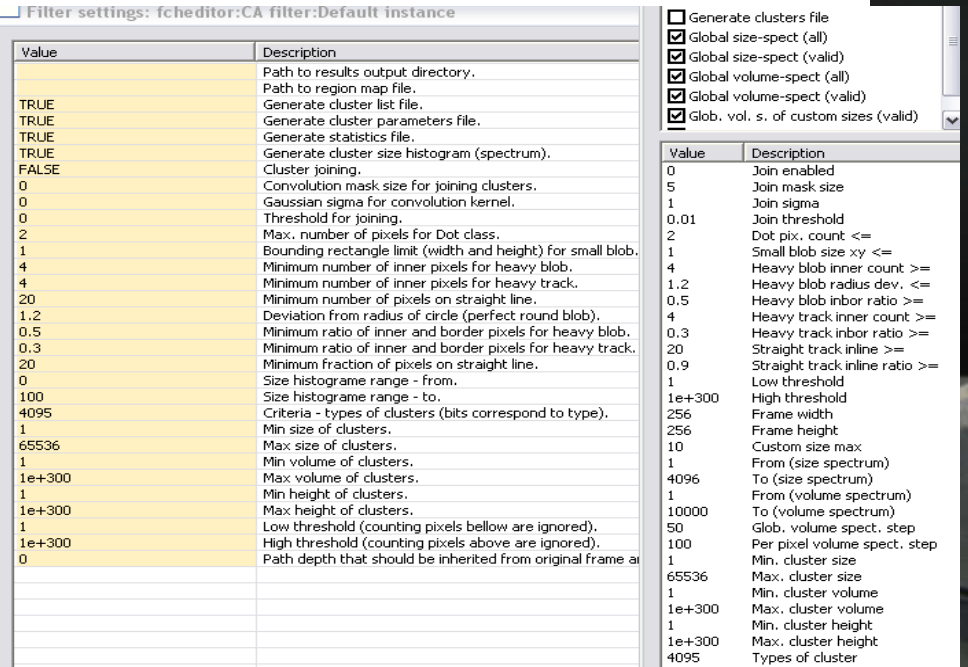
^{241}Am (Alpha spread spectrum) 12.7.04 of activity 8.779kBq

^{60}Co (Beta->X-rays 316keV, 1189keV by Compton scatter) 20.6.07 of 12.65kBq

$^{90}Sr^{90}Y$ (Beta) 1.7.92 of activity 55,76kBq

XRF^{241}Am (X-ray 59,5keV & Alpha) of activity 541MBq! and XRF^{55}Fe (X-ray 5.89keV)

The toy models were validated on 600 acquisitions of short 0.1s duration (here the dead time was no problem because of no restrictions on real acquisition lengths) to ensure the uniqueness of tracks for good analysis.



Filter settings: fcheditor:CA filter:Default instance

Value	Description
	Path to results output directory.
	Path to region map file.
TRUE	Generate cluster list file.
TRUE	Generate cluster parameters file.
TRUE	Generate statistics file.
TRUE	Generate cluster size histogram (spectrum).
FALSE	Cluster joining.
0	Convolution mask size for joining clusters.
0	Gaussian sigma for convolution kernel.
0	Threshold for joining.
2	Max. number of pixels for Dot class.
1	Bounding rectangle limit (width and height) for small blob.
4	Minimum number of inner pixels for heavy blob.
4	Minimum number of inner pixels for heavy track.
20	Minimum number of pixels on straight line.
1.2	Deviation from radius of circle (perfect round blob).
0.5	Minimum ratio of inner and border pixels for heavy blob.
0.3	Minimum ratio of inner and border pixels for heavy track.
20	Minimum fraction of pixels on straight line.
0	Size histograme range - from.
100	Size histograme range - to.
4095	Criteria - types of clusters (bits correspond to type).
1	Min size of clusters.
65536	Max size of clusters.
1	Min volume of clusters.
1e+300	Max volume of clusters.
1	Min height of clusters.
1e+300	Max height of clusters.
1	Low threshold (counting pixels bellow are ignored).
1e+300	High threshold (counting pixels above are ignored).
0	Path depth that should be inherited from original frame a

- ☐ Generate clusters file
- ☑ Global size-spect (all)
- ☑ Global size-spect (valid)
- ☑ Global volume-spect (all)
- ☑ Global volume-spect (valid)
- ☑ Glob. vol. s. of custom sizes (valid)

Value	Description
0	Join enabled
5	Join mask size
1	Join sigma
0.01	Join threshold
2	Dot pix. count <=
1	Small blob size xy <=
4	Heavy blob inner count >=
1.2	Heavy blob radius dev. <=
0.5	Heavy blob inbor ratio >=
4	Heavy track inner count >=
0.3	Heavy track inbor ratio >=
20	Straight track inline >=
0.9	Straight track inline ratio >=
1	Low threshold
1e+300	High threshold
256	Frame width
256	Frame height
10	Custom size max
1	From (size spectrum)
4096	To (size spectrum)
1	From (volume spectrum)
10000	To (volume spectrum)
50	Glob. volume spect. step
100	Per pixel volume spect. step
1	Min. cluster size
65536	Max. cluster size
1	Min. cluster volume
1e+300	Max. cluster volume
1	Min. cluster height
1e+300	Max. cluster height
4095	Types of cluster

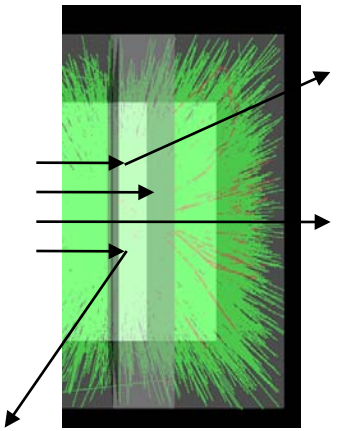
Photon passage through box wall by GEANT4

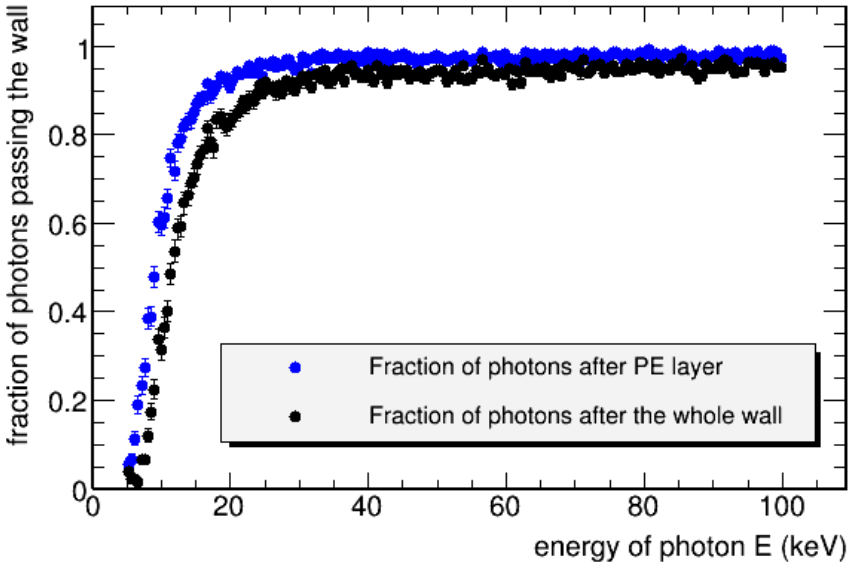
Photons are absorbed or reflected by box wall.
At 20 keV, 80% photons will pass through.
Effects are:

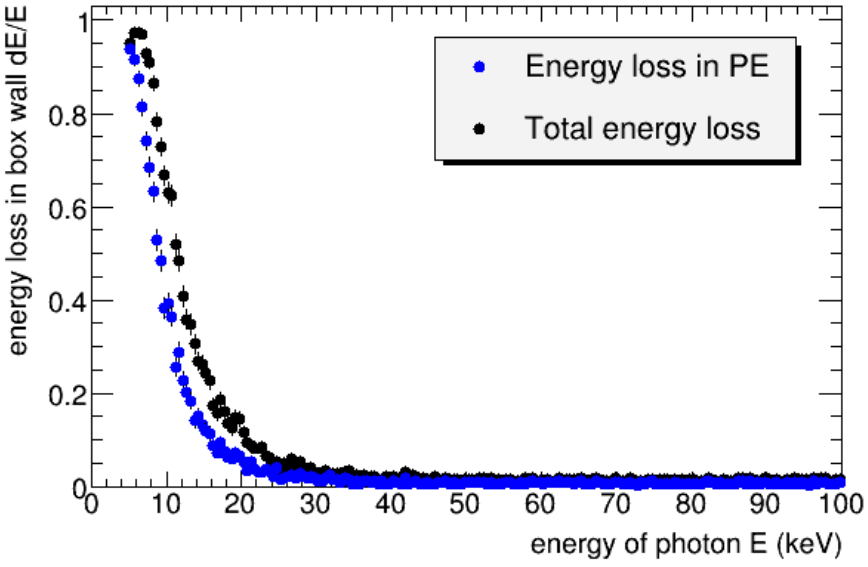
→ **Compton scattering:** elastic interactions with electron shell of atoms. Photon loose only part of its energy

→ **Photo-effect:** photon is absorbed by electron shell passing on its whole energy to the electron

→ **Conversion:** photons with energy above ~1 MeV can convert to pairs of e+e- (in electromagnetic fields of atoms)

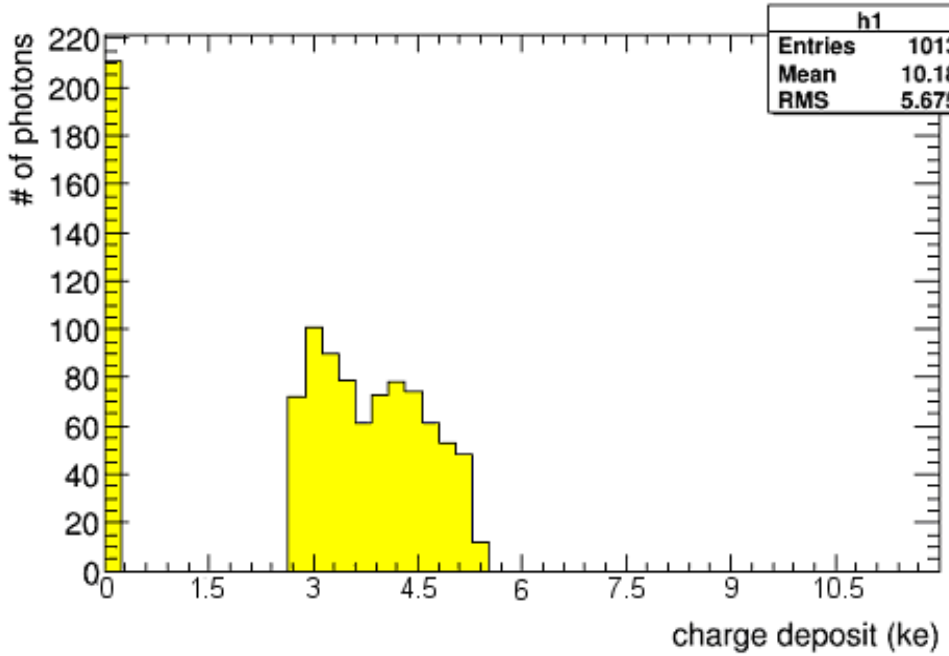




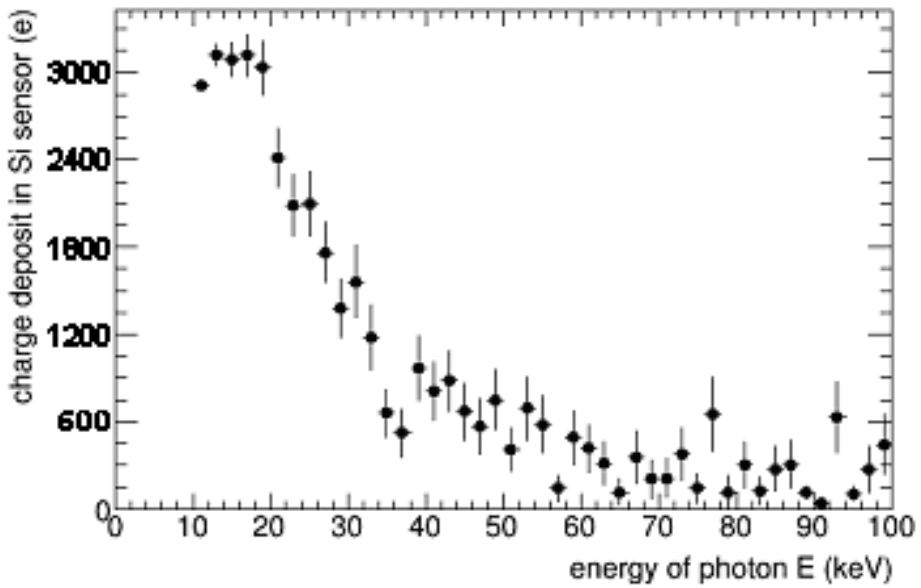


Charge deposit by photons in Si pixellated sensor

Threshold on collected charge is applied on every pixel for correction of specific deposited charge effect of e-h pair creation (3.65 eV) therefore: $q = E_{deposit} / 3.65\text{eV}$



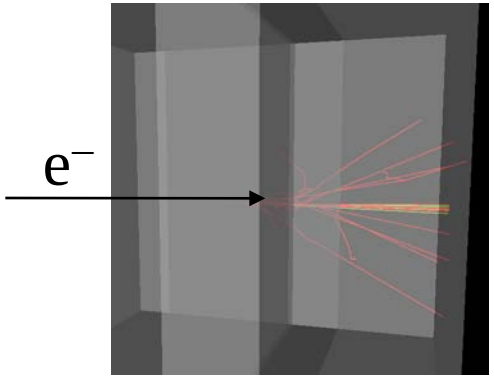
Mean deposited charge in Si wafer
(for photon energy 10keV<*E*<20keV)

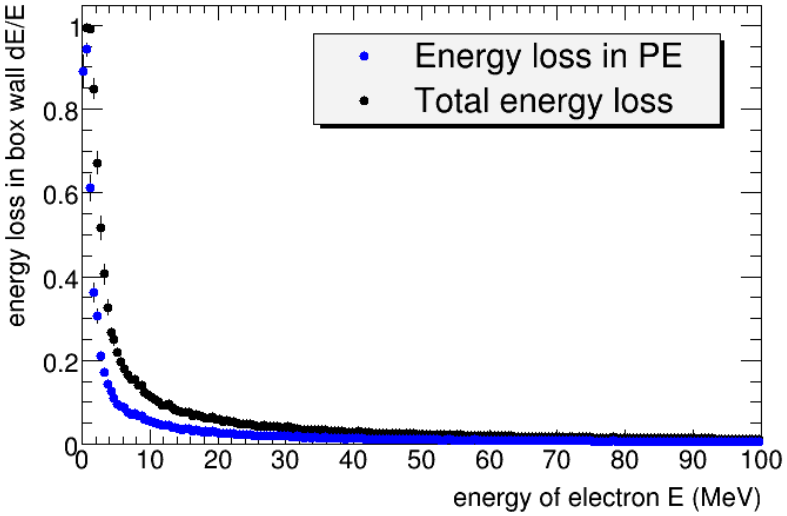


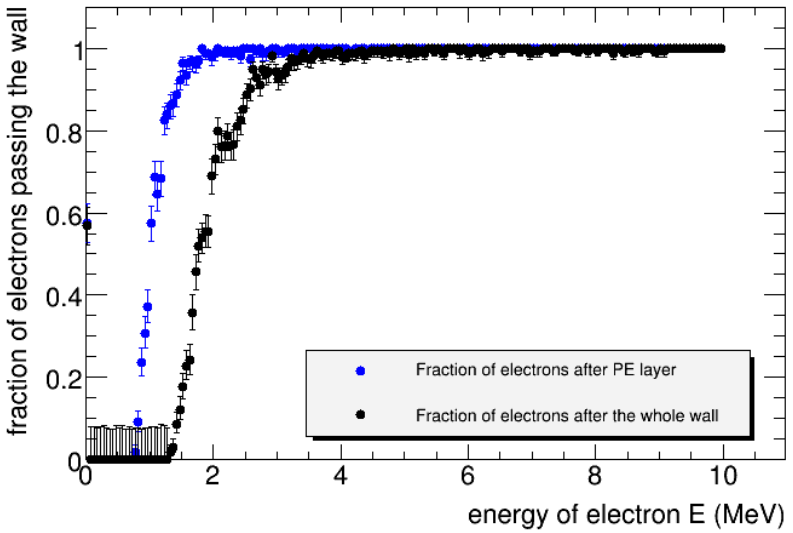
Distribution of deposited charge

Electron passage through box wall by GEANT4

Electrons loose much more energy than photons since they have a charge. From this reason about 50% electrons of 2 MeV will be absorbed in the wall as the simulations demonstrate.

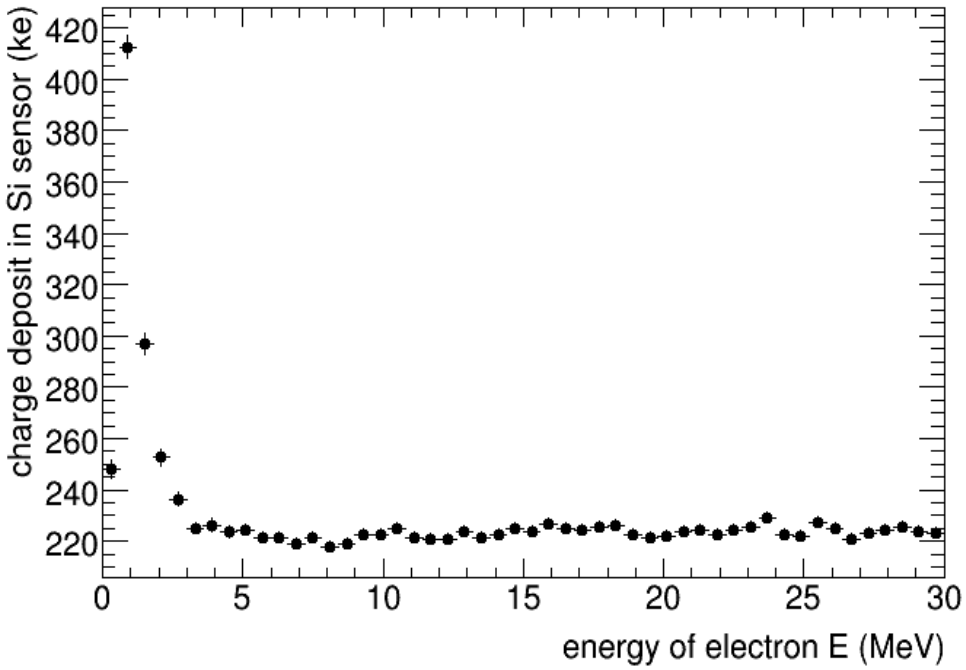




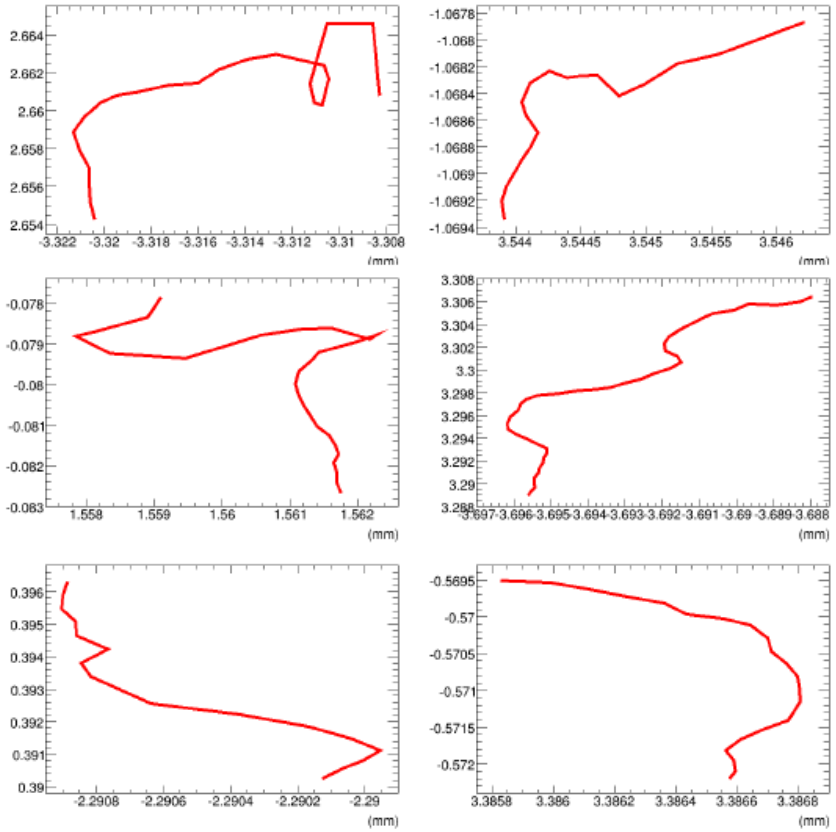


Charge deposit by electrons in Si pixellated sensor

PE box enclosing the main detector enables registration of electrons in the MeV range, while converting them to lower energies. Only then they can leave charge passing the detector efficiently enough. Overall charge deposited by electrons sensor >10x larger compared to photons.



Mean deposited charge by electrons



Simulated tracks of low-energetic electrons in silicon wafer (700 µm)

Ion energy loss and attenuation in ALU: effects

$$\frac{dE}{dx} = -\frac{4e^4 z^2 N_A Z}{mv^2 A} B_i$$

z : ion charge number

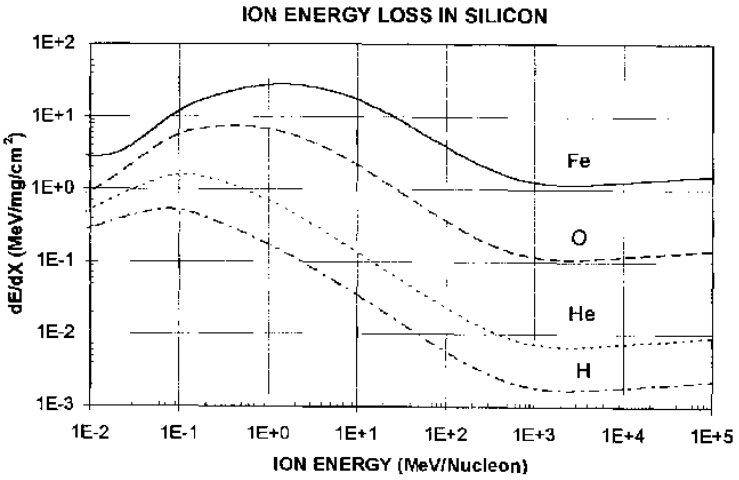
Z : material charge number;

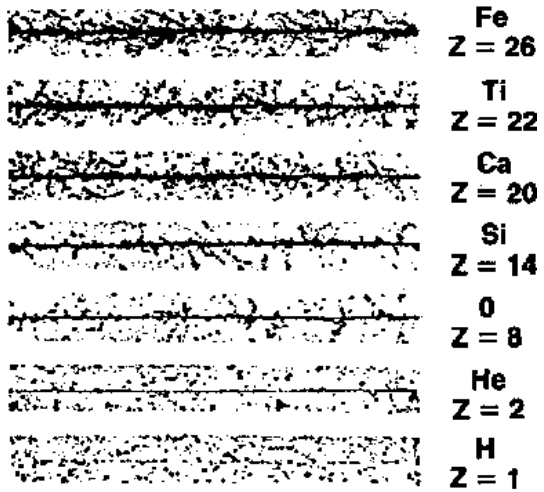
N_A : Avogadro's number;

A : Material atomic number

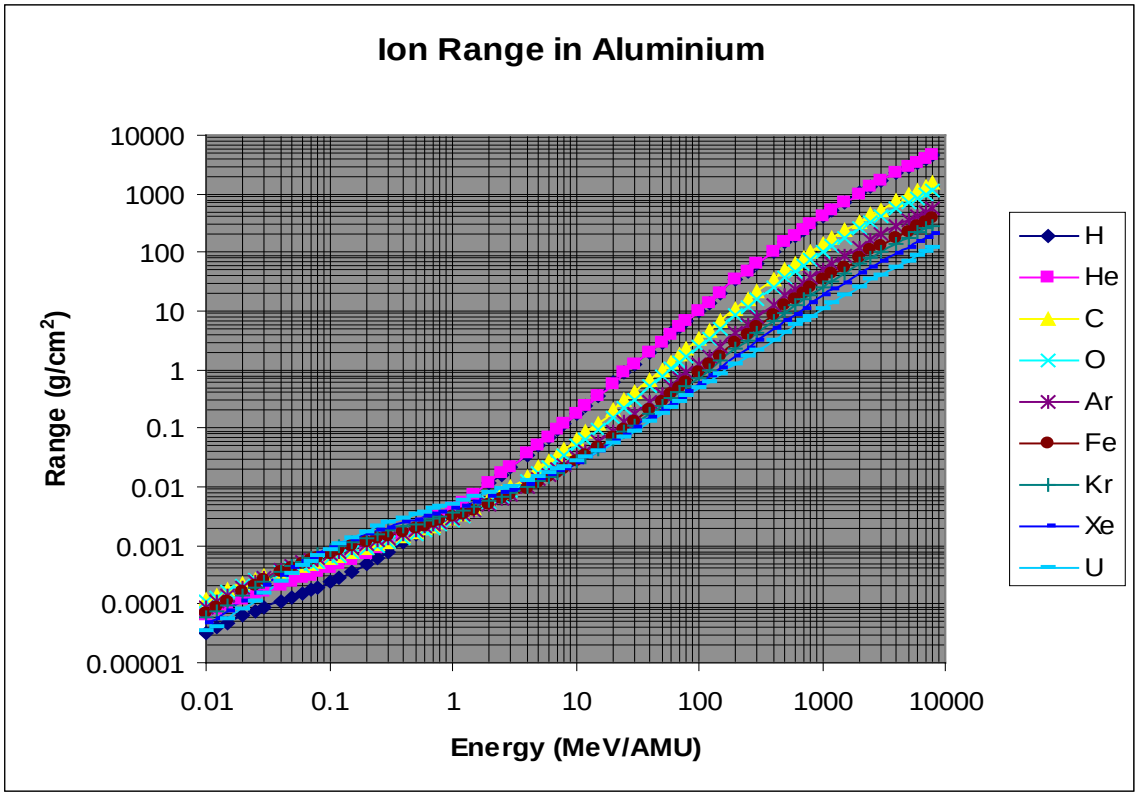
B_i : material dependent correction

Governed by Bethe-Bloch formula for energy transfer:

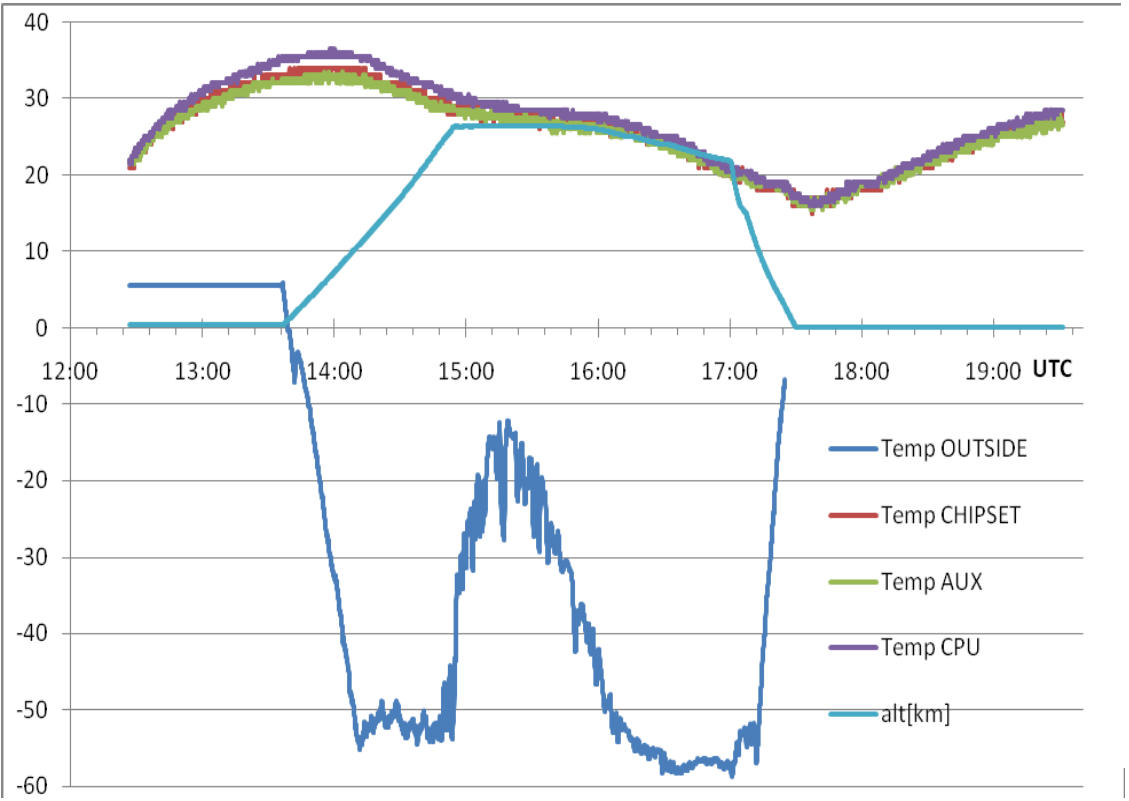


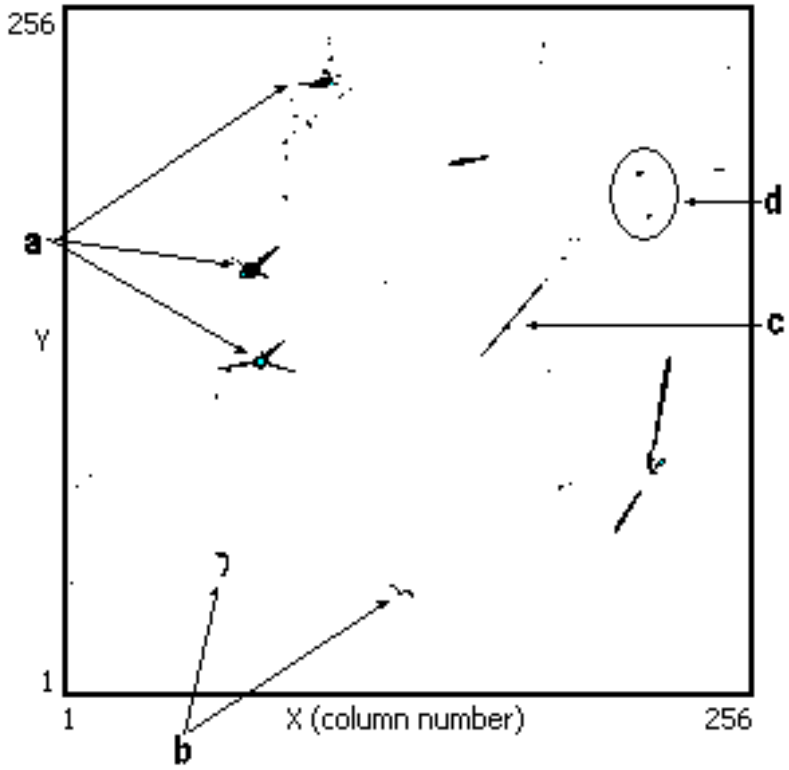


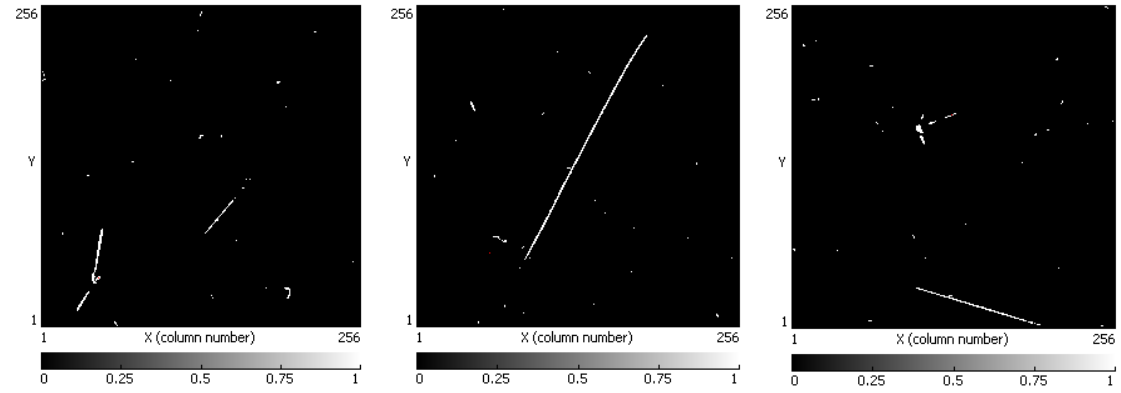
Cosmic ray ion tracks in a photographic emulsion.



Medipix systems' flight performance

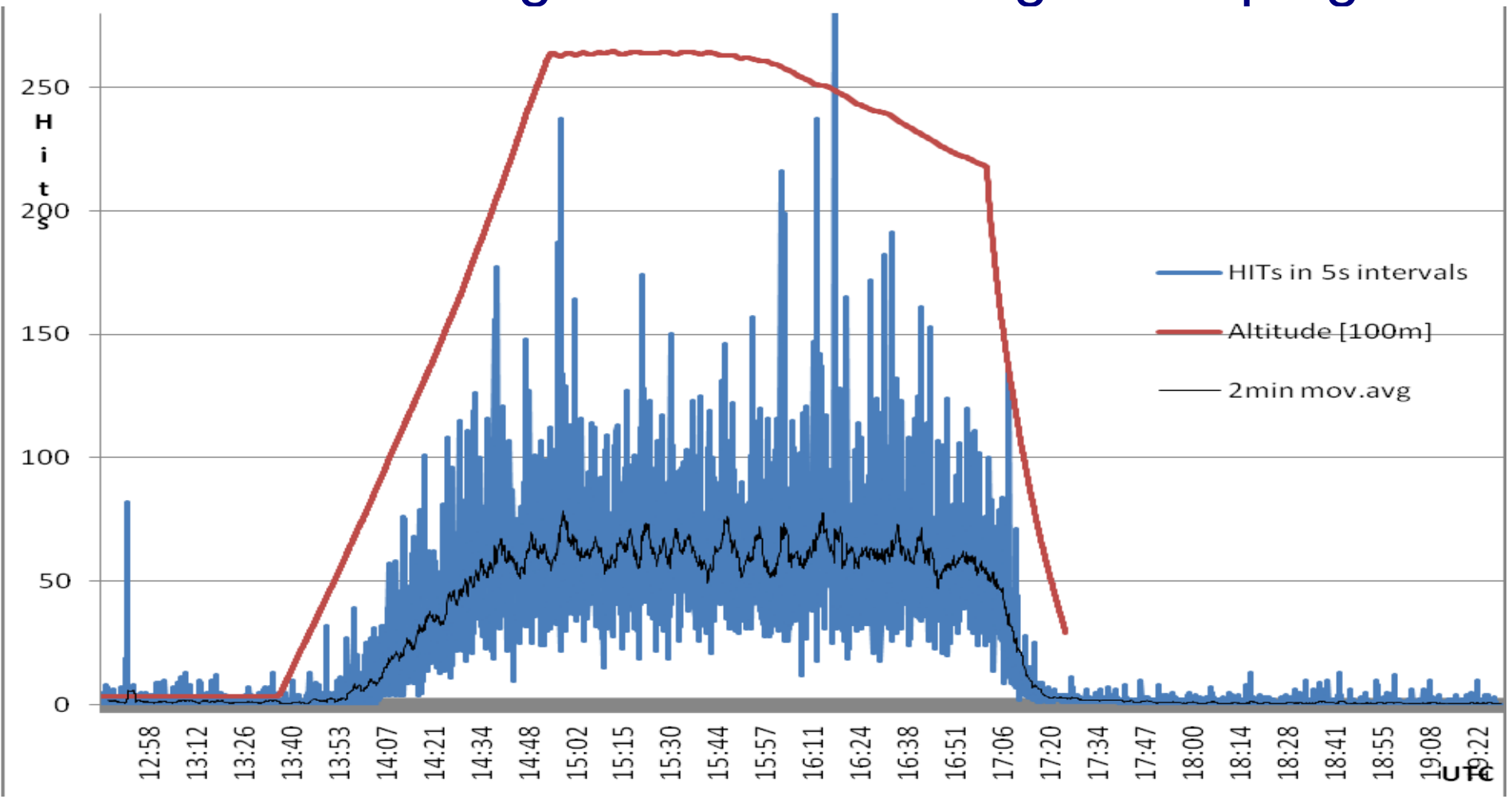






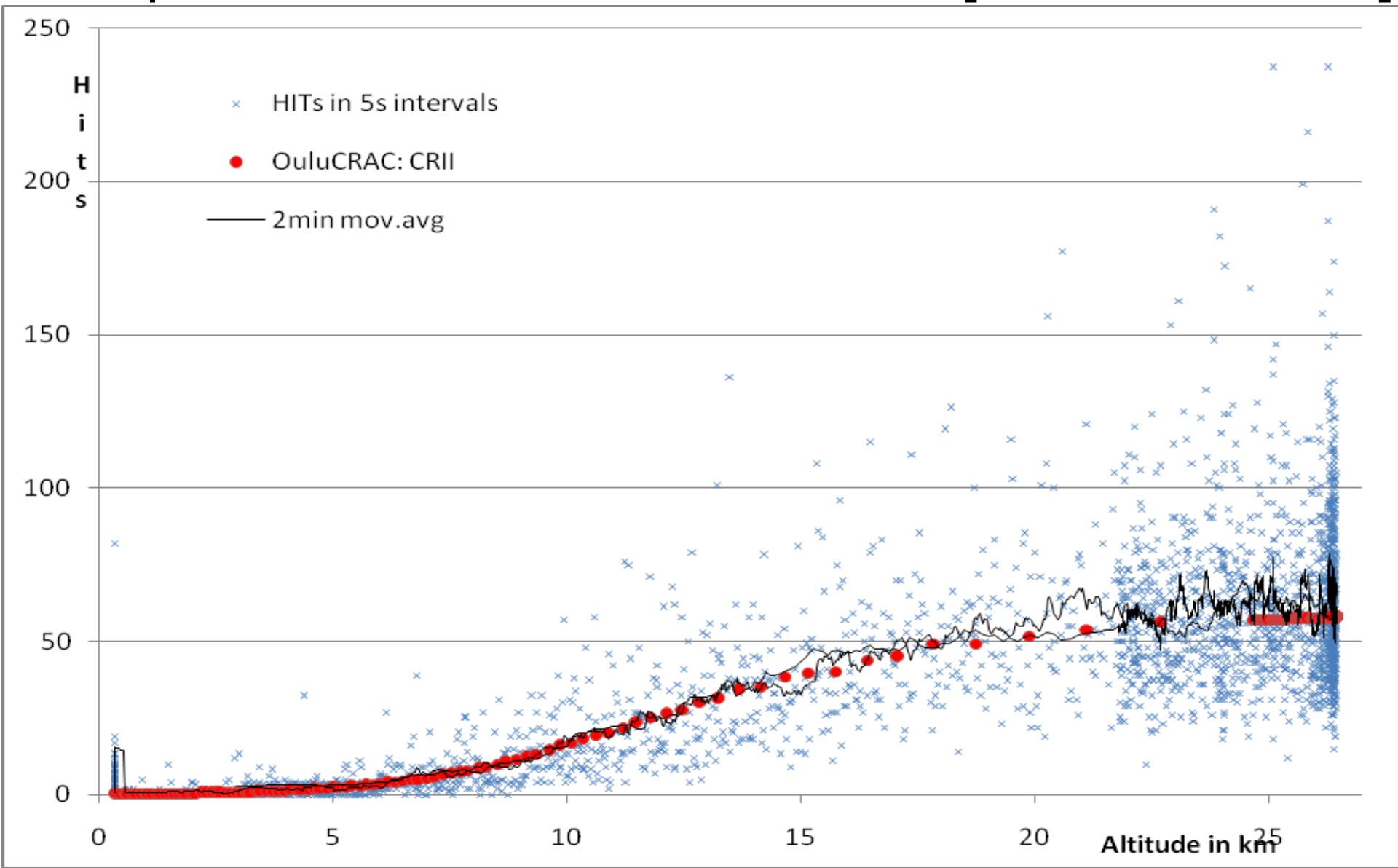
Ionizing radiation tracks acquired in stratosphere, particle pattern identification-by-track concept:
a- Heavy charged particles,
b- Slow light charged particles,
c- Fast light charged particles,
d- X-rays, low energy gamma

Flight profile HITs (pixels with signal in 5sec) as measured during the BEXUS-7 flight campaign



Experiment took place in arctic stratosphere, associated with high-geomagnetic latitude, corresponding to geomagnetic cut-off rigidity of 280 MV. That, along with ongoing Solar MINima, providing relat. high CR flux WITH *PARTICLE TYPES* AND *ENERGY* data.

Altitude dependent ionization yield in Medipix-2 compared: CRII from OuluCRAC 10[$cm^{-3}.sec^{-1}.atm^{-1}$]



CRindIons team

Novel concept of parallel in-situ measurement of the CosmicRay Induced Ionization rate by SSD with precise ionization yield evaluation

Formation of ions in Earth Atmosphere

SUCCESSFUL STUDENT experiment launched on BEXUS9 11 Oct 2009

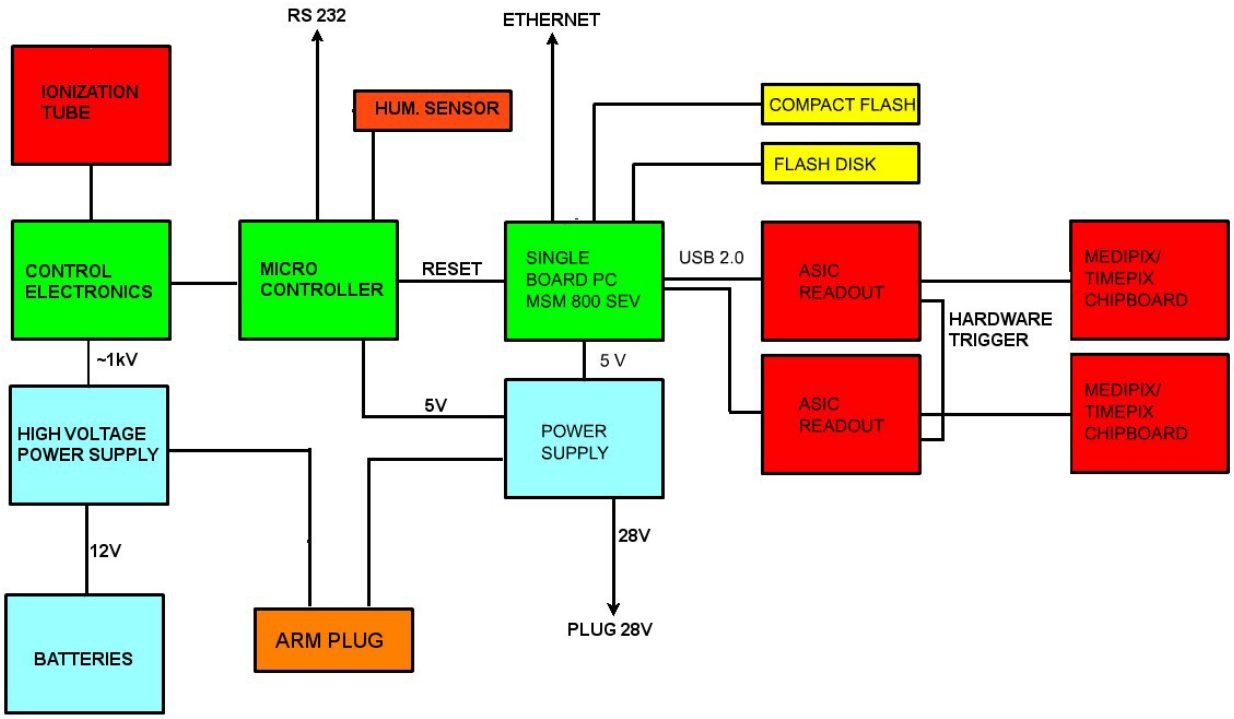
Czech Technical University in Prague,
Charles University in Prague, Czech Republic

CRIndIons: advanced project objectives

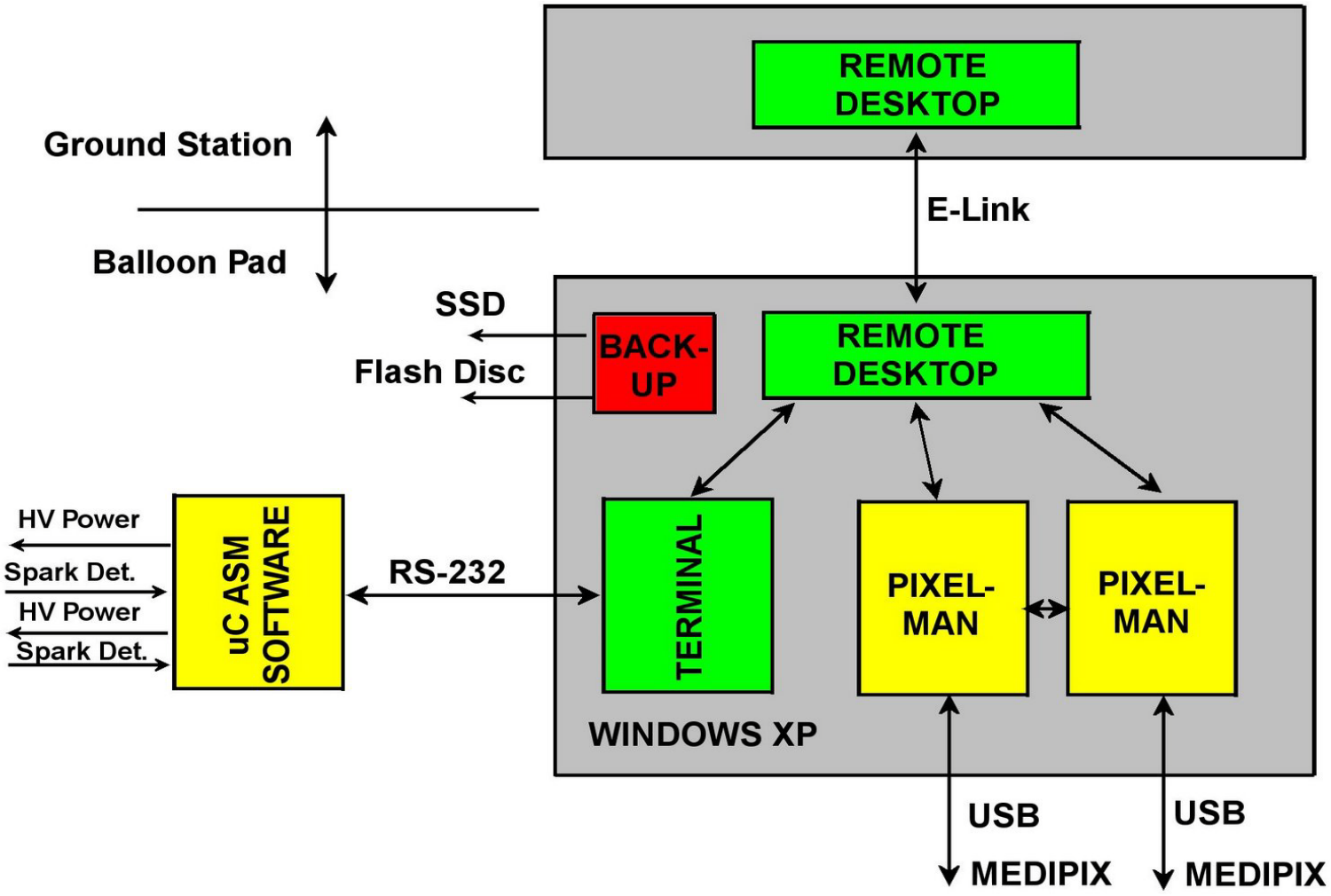
- In-flight comparison between Medipix2 and Timepix detectors – added neutron converter (ATLAS-MPX)
- Intercalibration of multiple SSDs – MPX-2, TPX with standard RAS LPI ST-6 gas discharge Geiger tubes
- Ionization yield measurement ~ Medipix2 pixel HITs
- Particle energy estimate from backside pulse - MPX
- Particle energy from calibrated Timepix(TOT mode)
- Time&space Coincidence⇔shower arrival direction
- 2 Sts-6 tubes⇔telescope&GCR vs. radiation envir.
- Aerosol conditions (estimate by ESRANGE LIDAR)

CRIndIons System Overview

- Medipix-2 with neutron converter (ATLAS-MPX)
- Gas-discharge module (STS-6) LPI RAS
- Single Board Industrial Computer AMD 500MHz
- Single-chip Micro controller (STS-6 flux and coincid. measurements)
- Ethernet, RS 232 (MIL-C)
- Solid State HDD (CF) backup flash memory

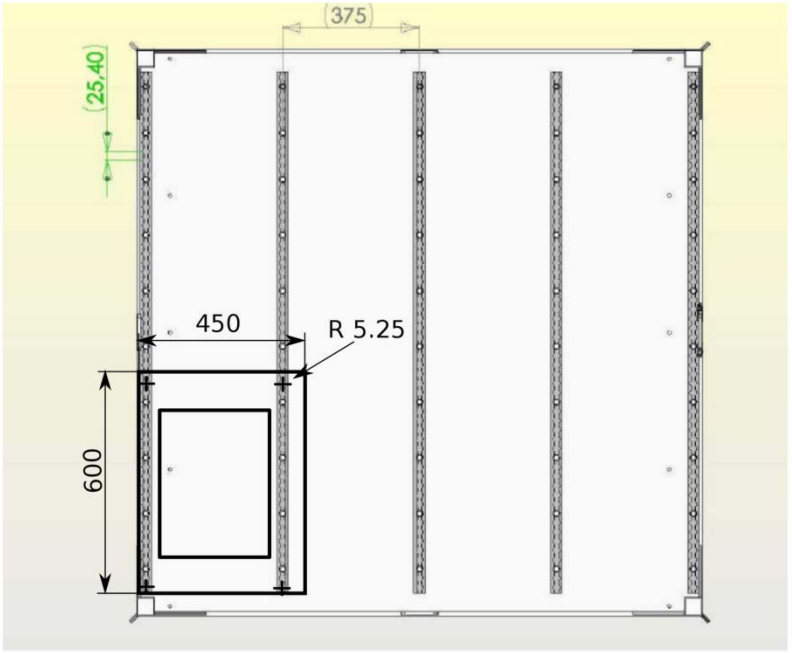


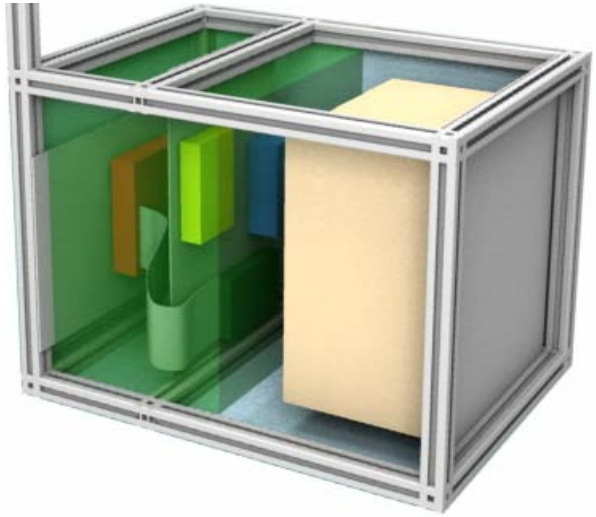
Software


REMOTE DESKTOP
Ground Station
Balloon Pad
E-Link
SSD
Flash Disc
BACK-UP
REMOTE DESKTOP
HV Power
Spark Det.
HV Power
Spark Det.
uC ASM SOFTWARE
RS-232
TERMINAL
PIXEL-MAN
PIXEL-MAN
WINDOWS XP
USB
MEDIPIX
USB
MEDIPIX

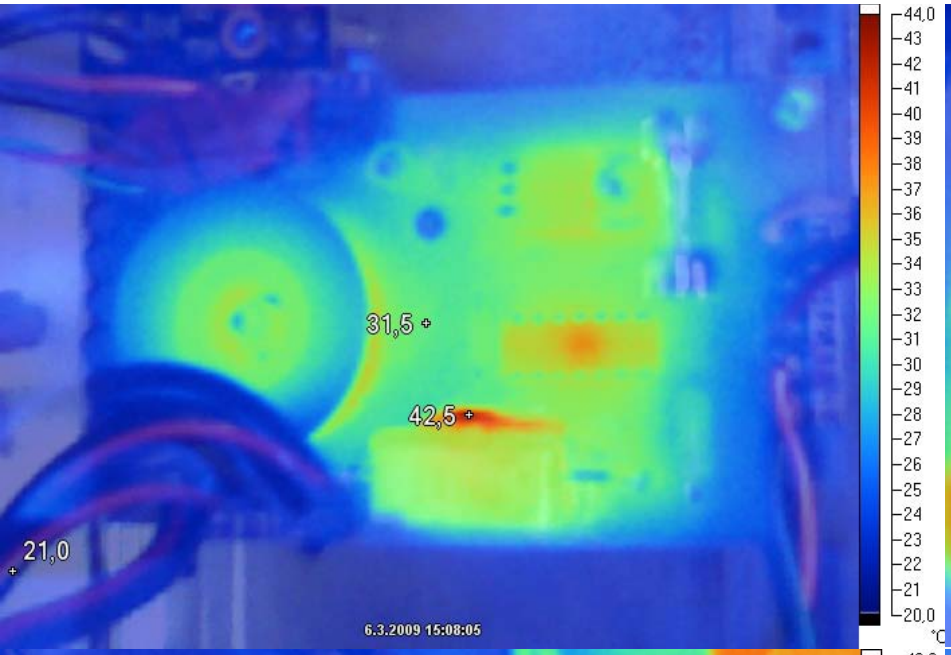
Mechanical design

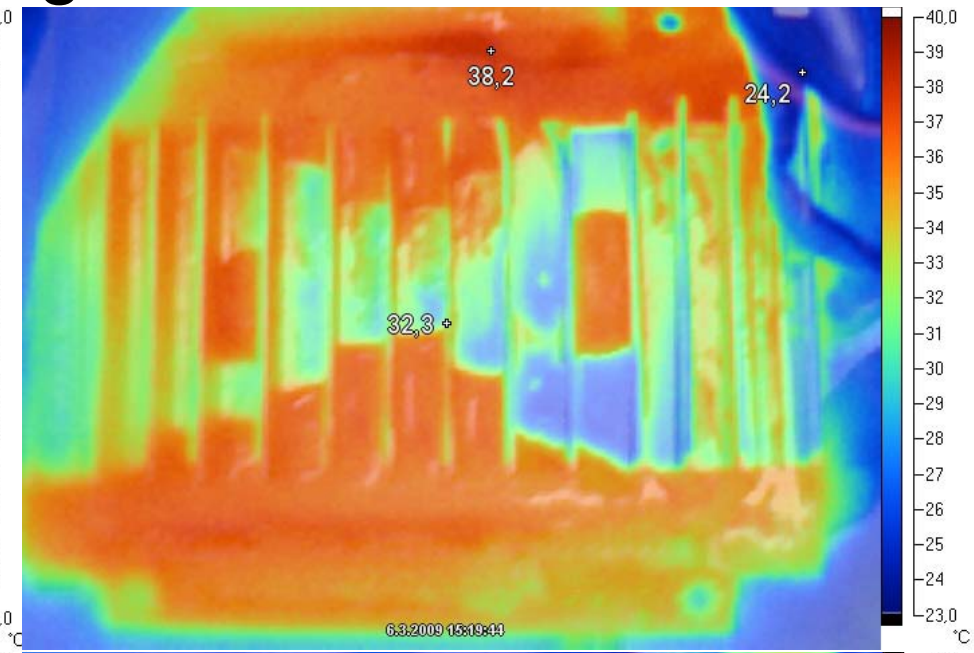
- Versatile and easy mounting main frame
- High & low voltage chambers separated
- Built of aluminum profiles
- Enclosed by fiberglass with metalized surface (cuprexite)
- Inner surface covered by pyrofoam thermal insulation

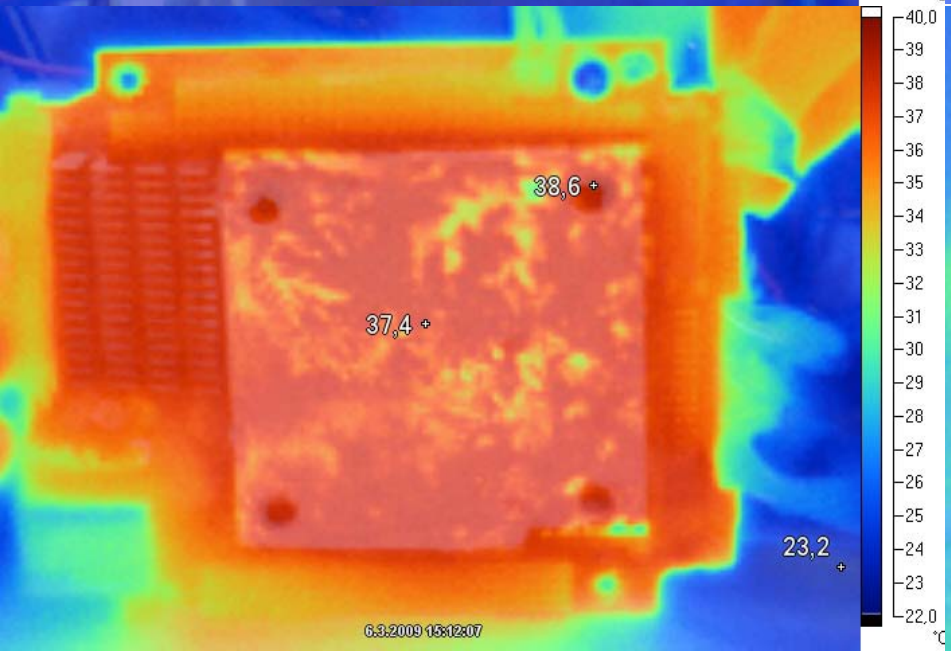


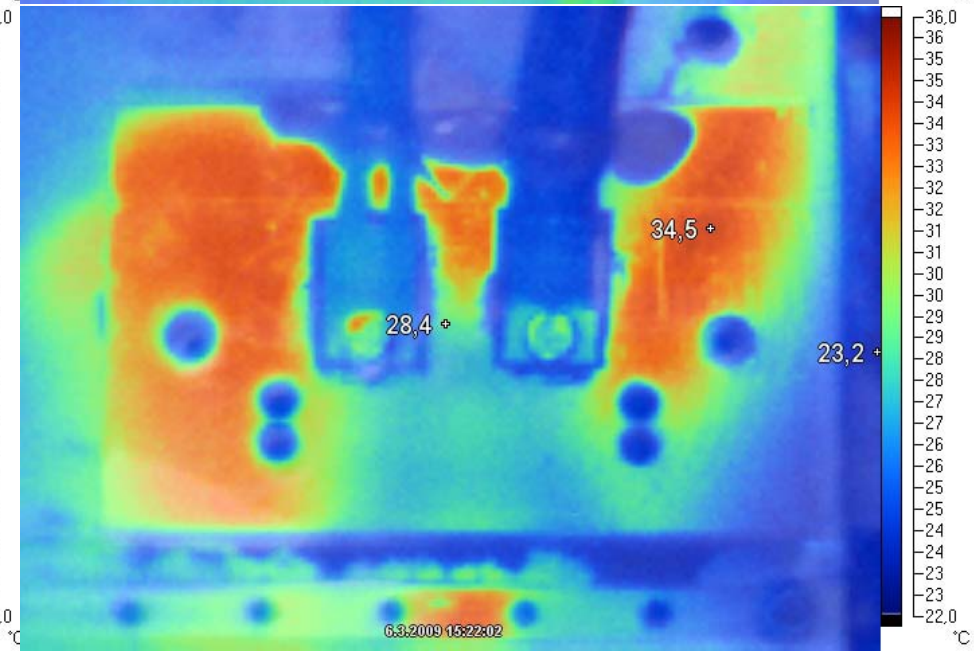


Thermal design validation



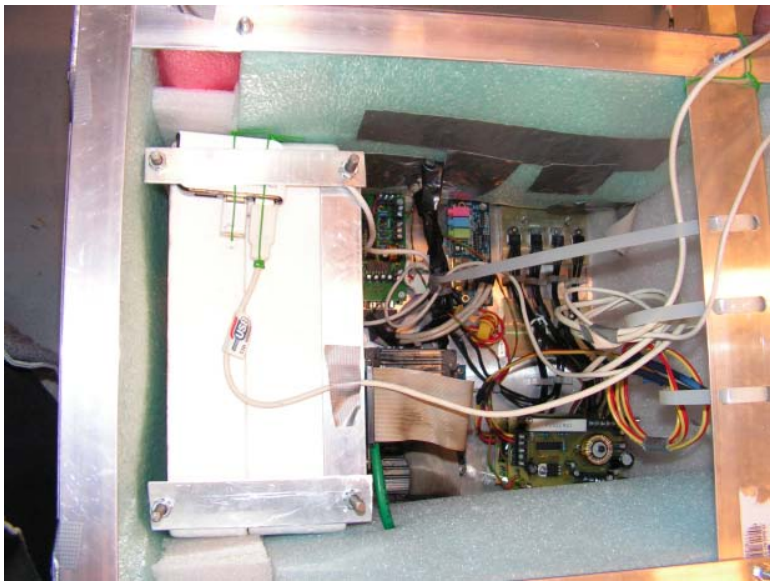




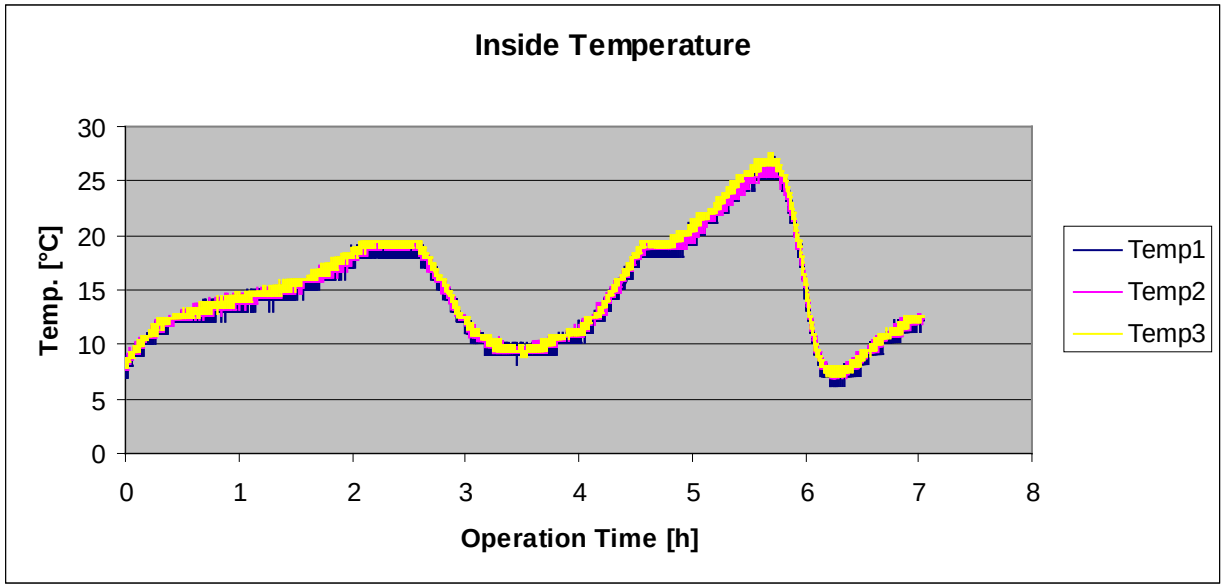


BEXUS-9 flight performance

- No damage or failure was found after recovery
- Experiment is still fully functional
- No mechanical problem (no screw or nut was loosed)
- Outer surface was wet, but the wetness didn't get into the experiment or detector's box
- Data was downloaded
- Temperature profile in the experiment
  - + 7 to + 27 °C
  - Passive design OK

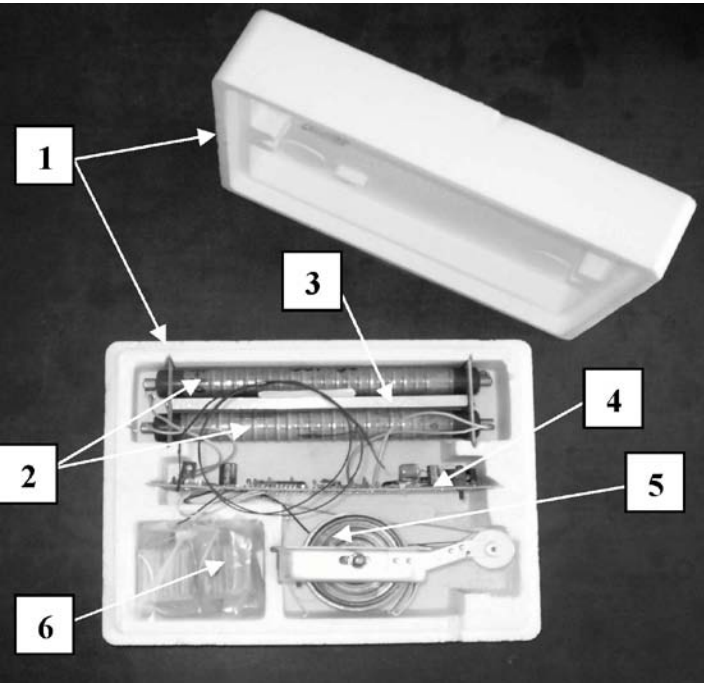


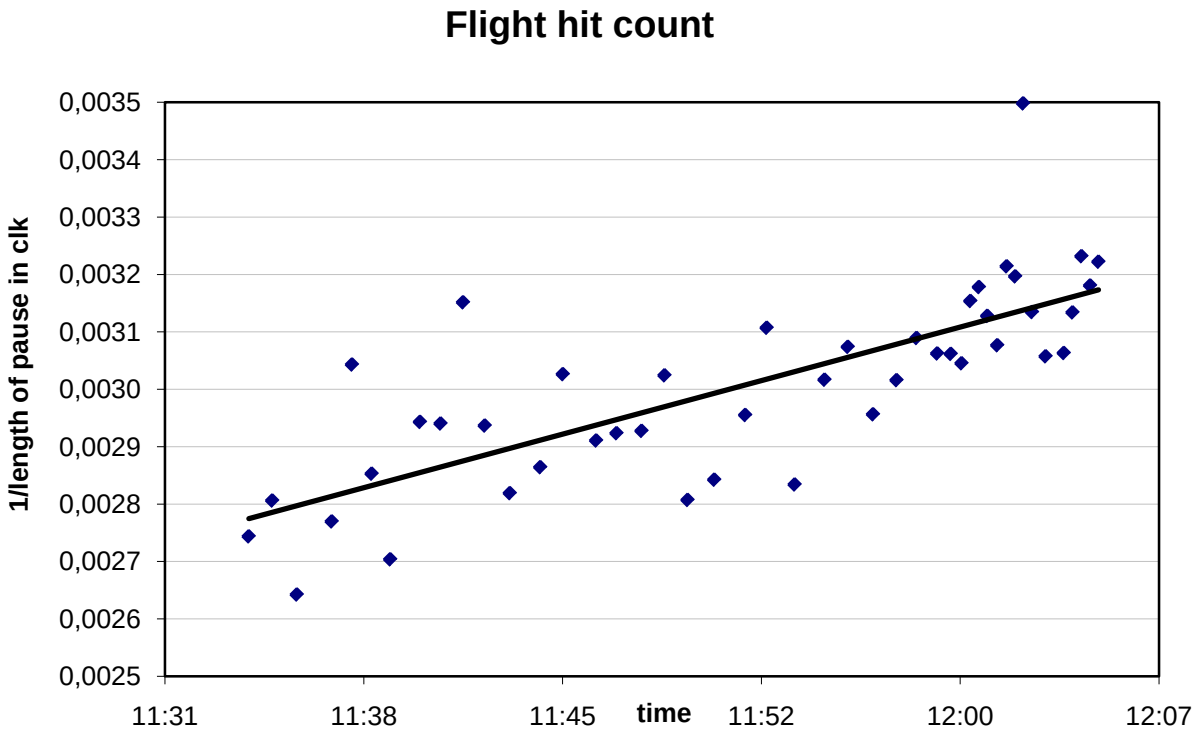
Experiment after recovery



Detectors after recovery

Standard radiosonde for cosmic ray flux: With custom built uC logging program





1 – a foamed plastic box

2 – detector of charged particles (gas-discharged counters)

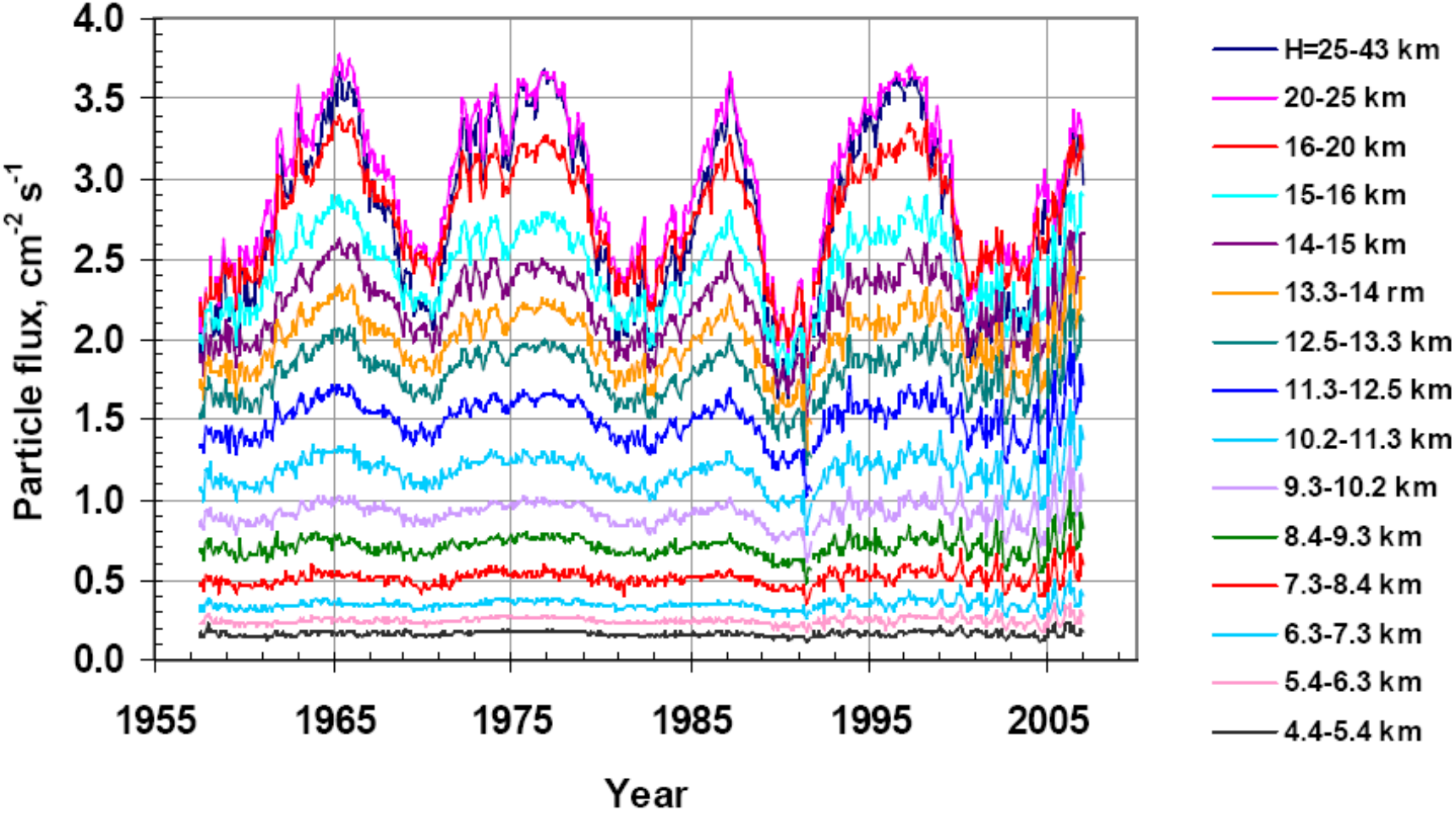
3 – 7mm aluminum plate

4 – high voltage power

5 – atmospheric pressure sensor

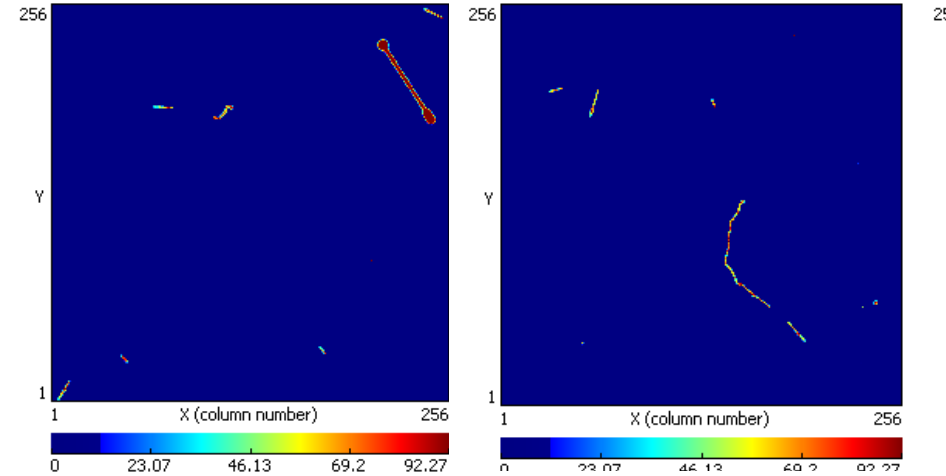
6 – chemical batteries

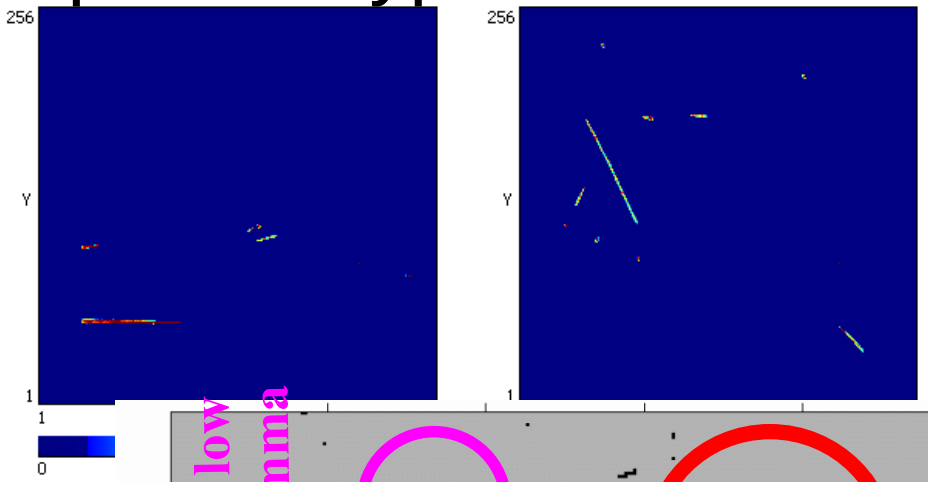
Ionizing particle FLUXes – BUT w/o particle types...

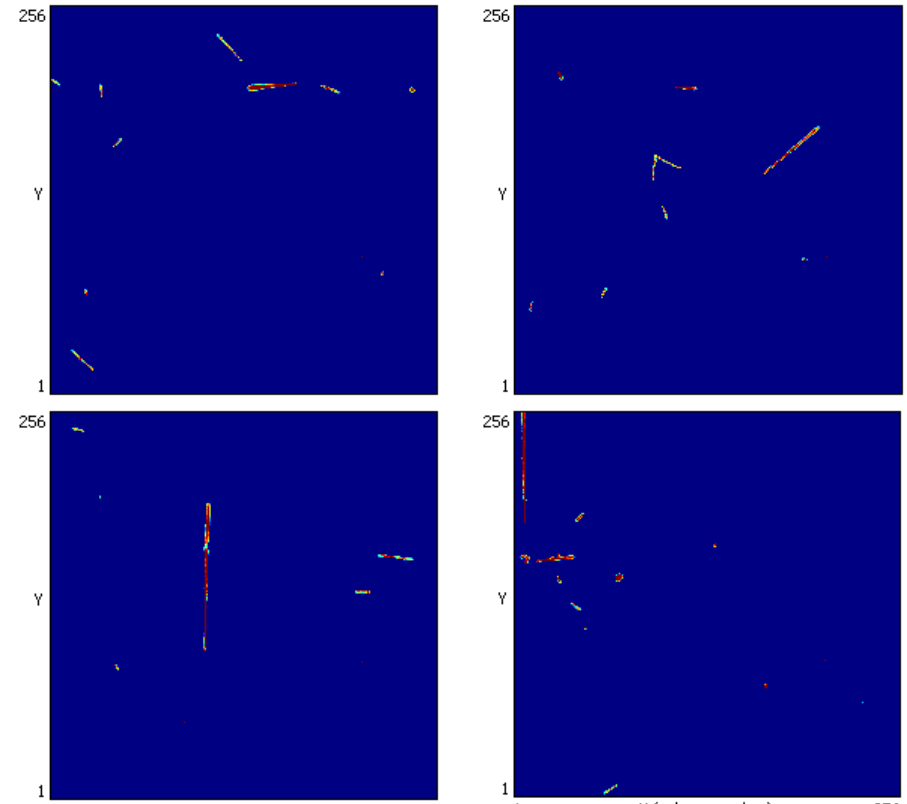


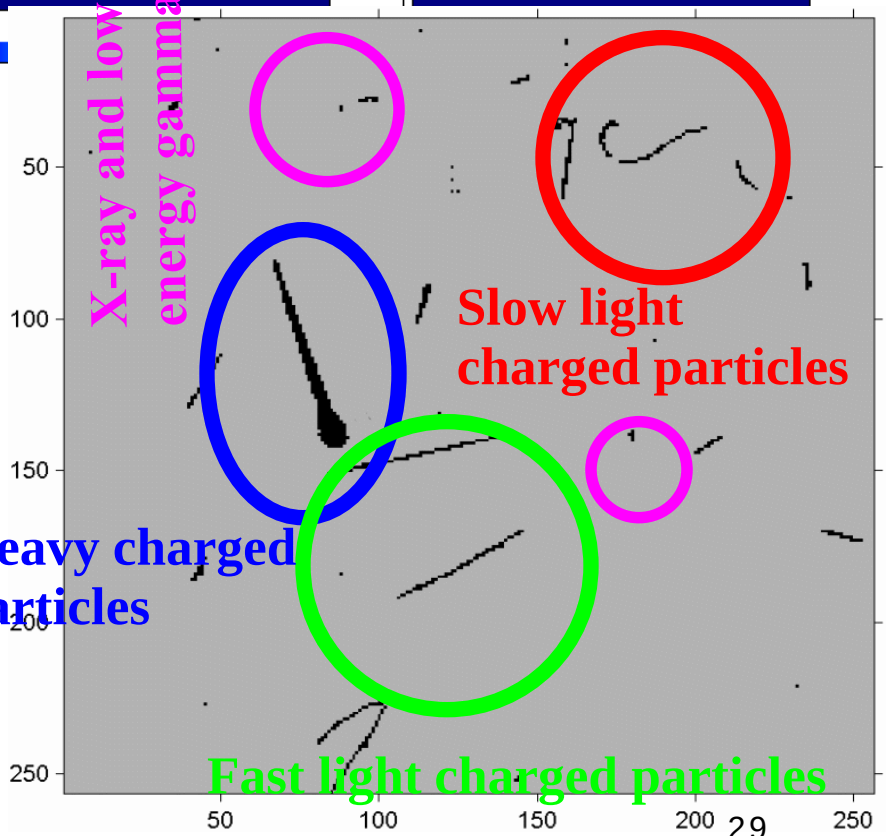
Monthly averaged fluxes of ionizing particles in the atmosphere over Murmansk region as measured by omnidir. Geiger counter (Bazilevskaya, 2007)

Unique tracking data for particle type identification



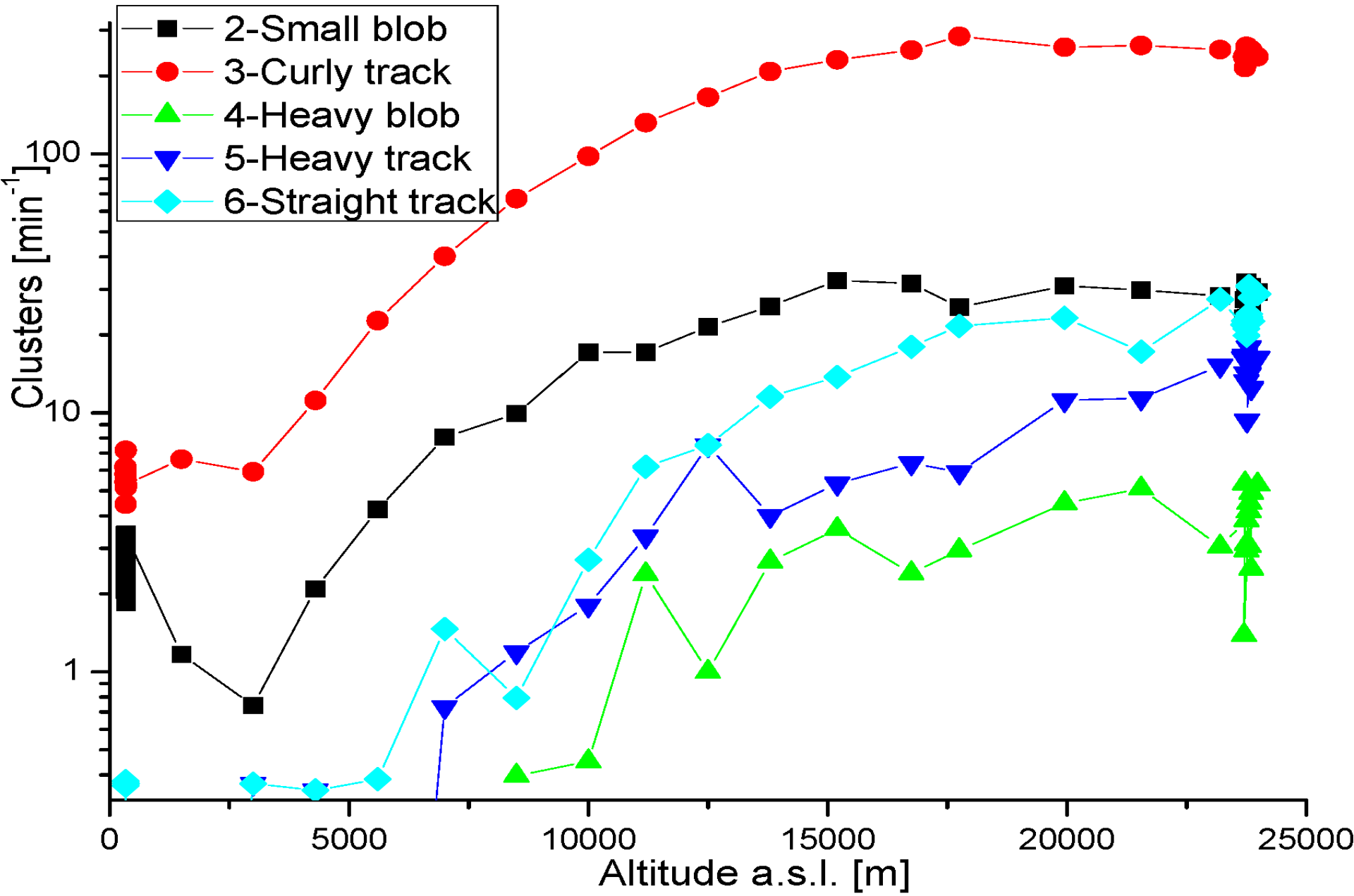


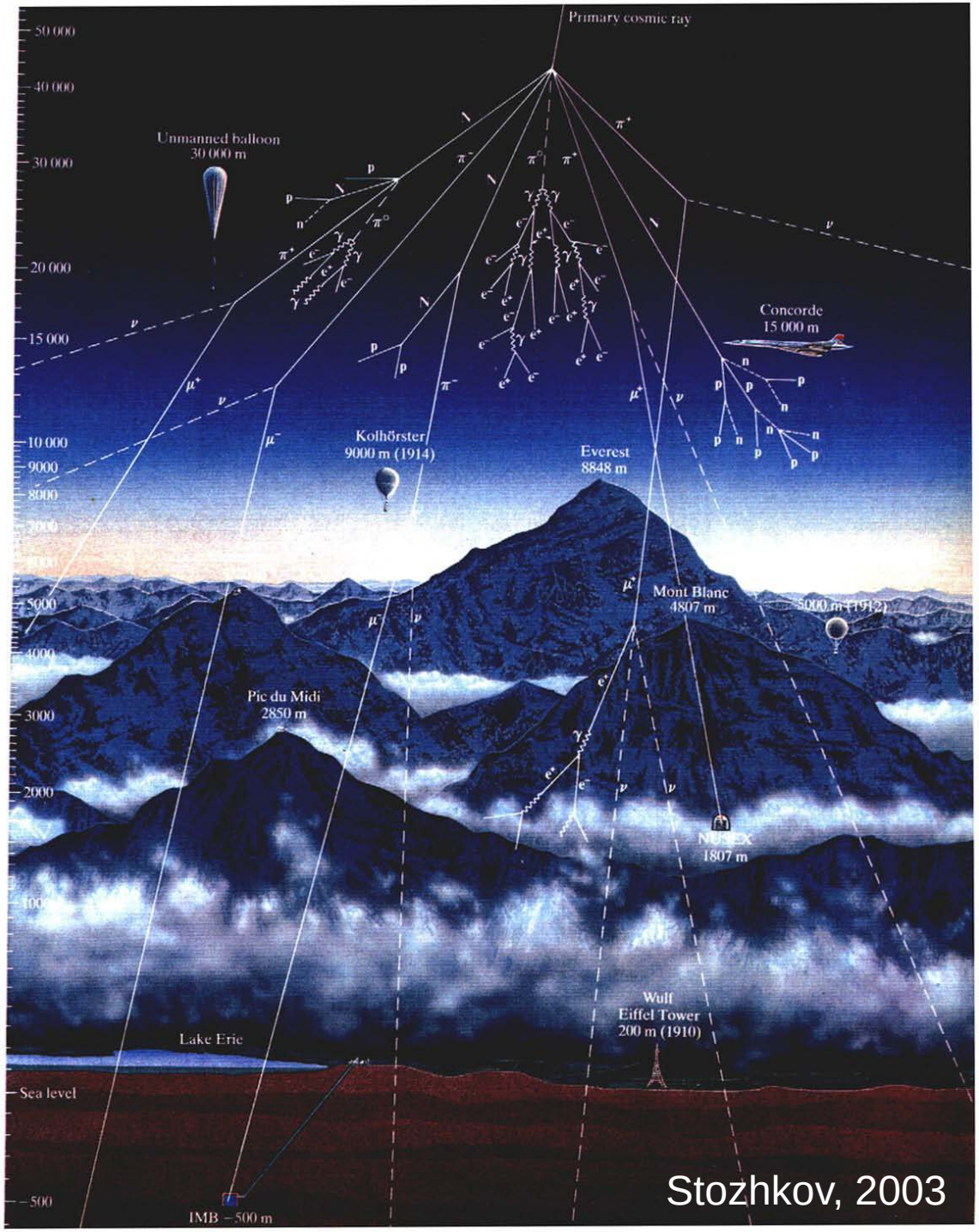




&track shape, total deposited energy

Our results from Timepix on BEXUS-9





Cosmic ray-induced Ion Production rate and Ion Concentration in the Earth's Atmosphere

At altitudes of ~3 to 35 km, cosmic rays are practically the only ionisation source

Ion production rate q

$$\mathbf{q = I \rho \sigma / M}$$

I = I (h, R_c, Φ) cosmic ray flux

ρ air density

σ eff. ionisation cross section

≈ 2 x 10^{-18} cm^2 at h ≤ 20 km

M average mass of air atom

Ion concentration n

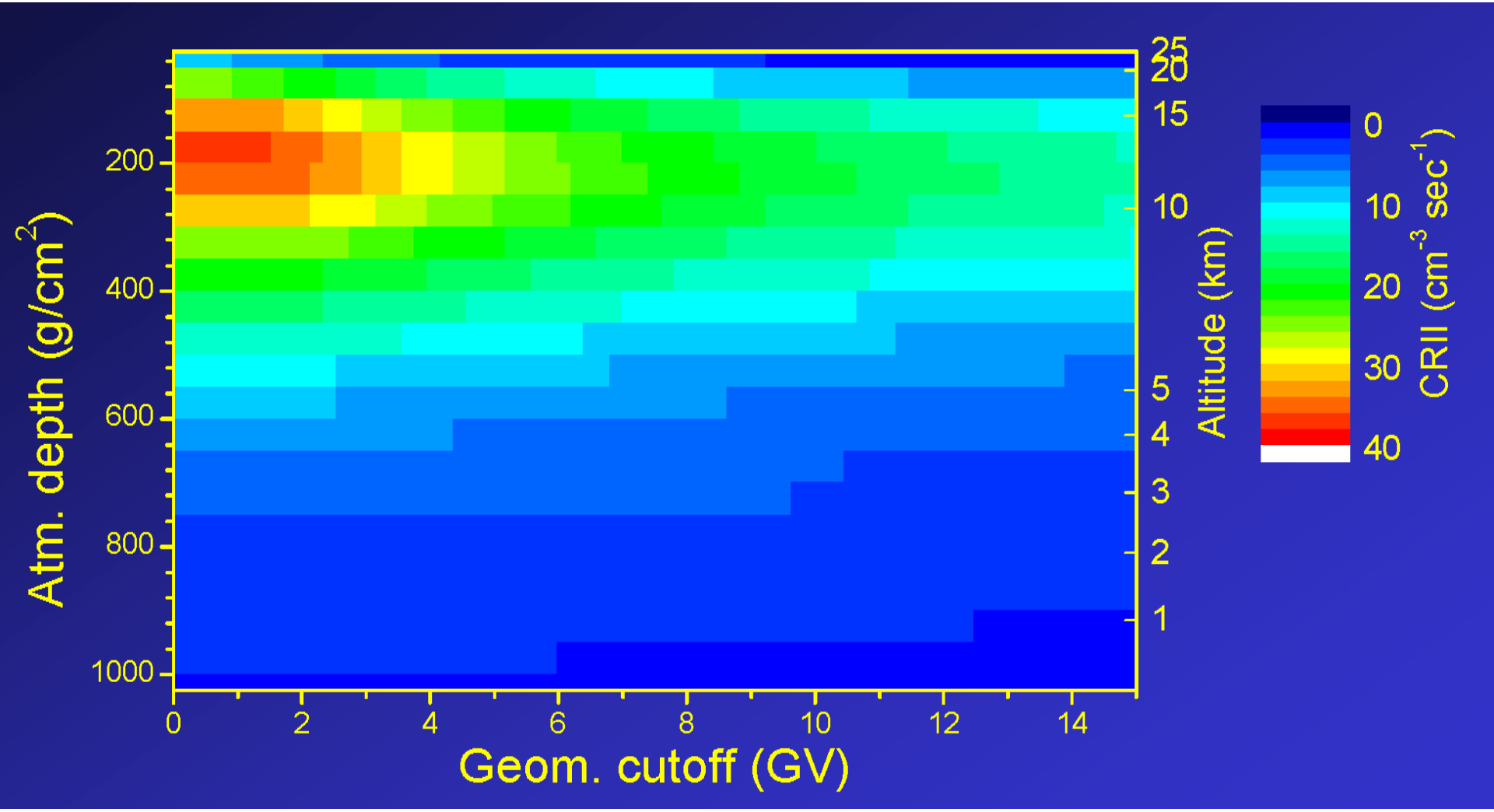
$$q = \alpha n^2$$

α 3D recombination coefficient

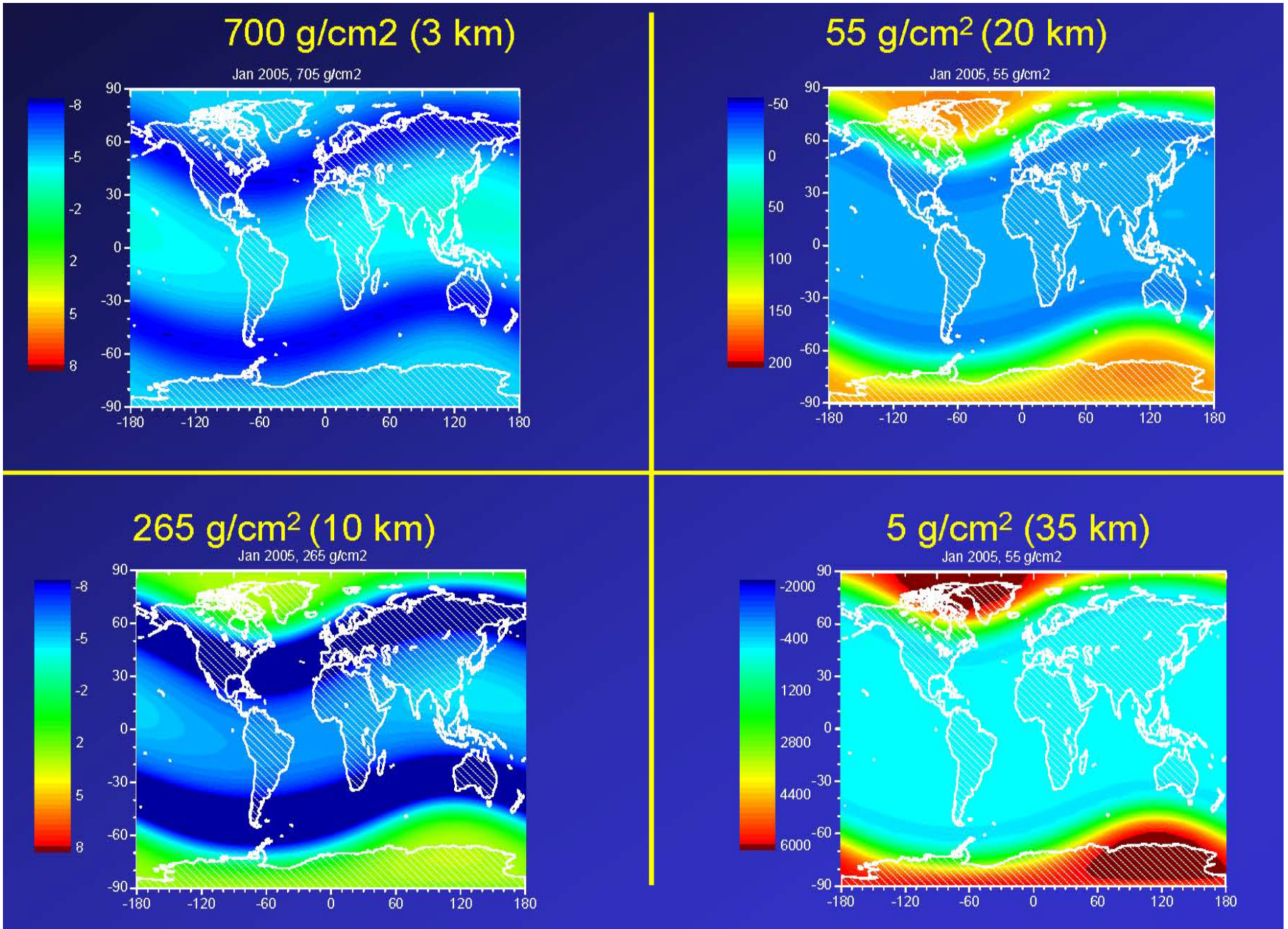
$$\mathbf{q(h) = \beta(h)\, n(h)}$$

β(h) linear recombination coeff

OuluCRAC model for Cosmic Ray Induced Ionization: Altitude on geomag. latitude dependence (Usoskin,2004)

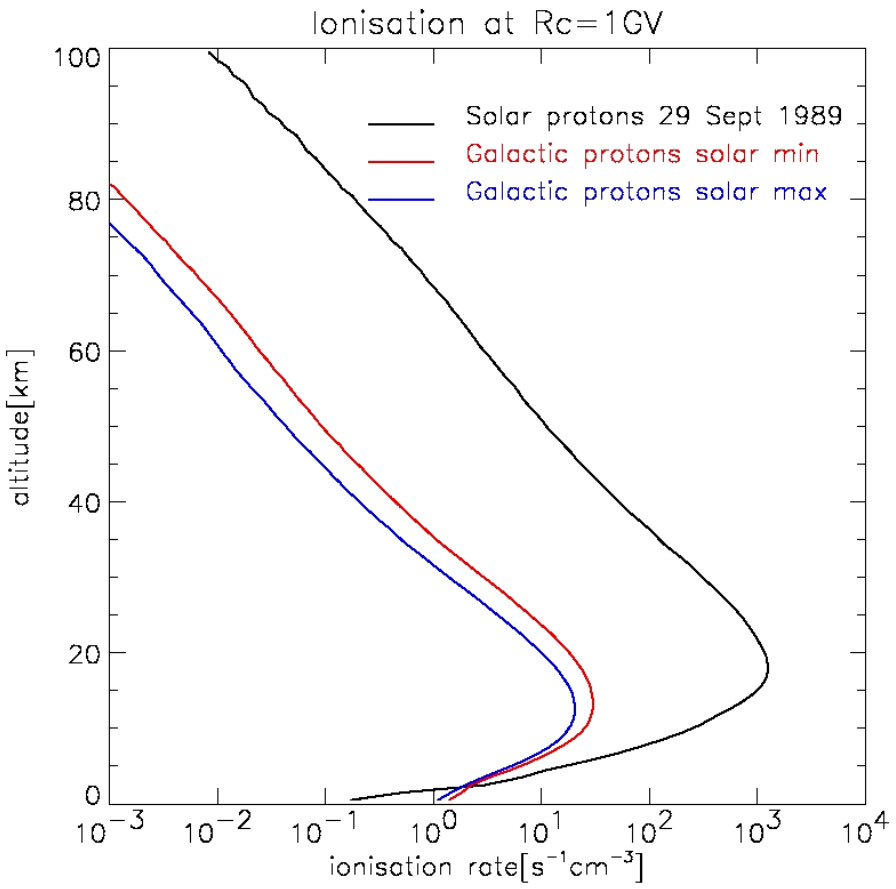


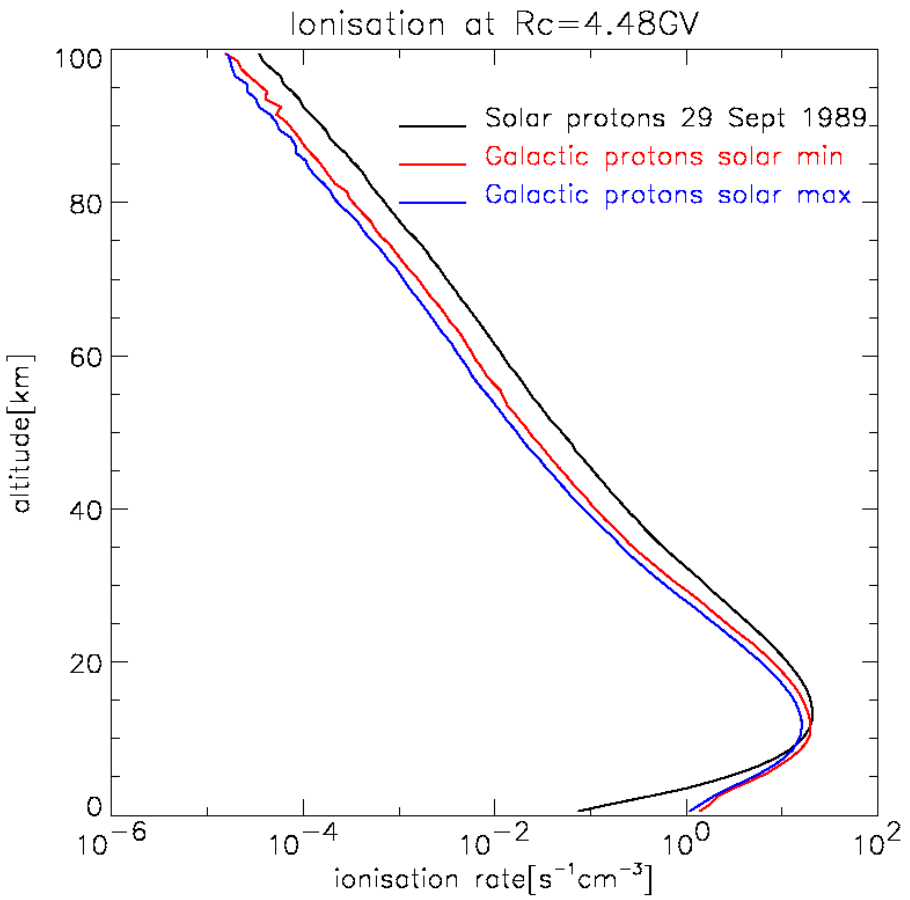
Modeled combined ionization effect of GCR (Usoskin, 2007)



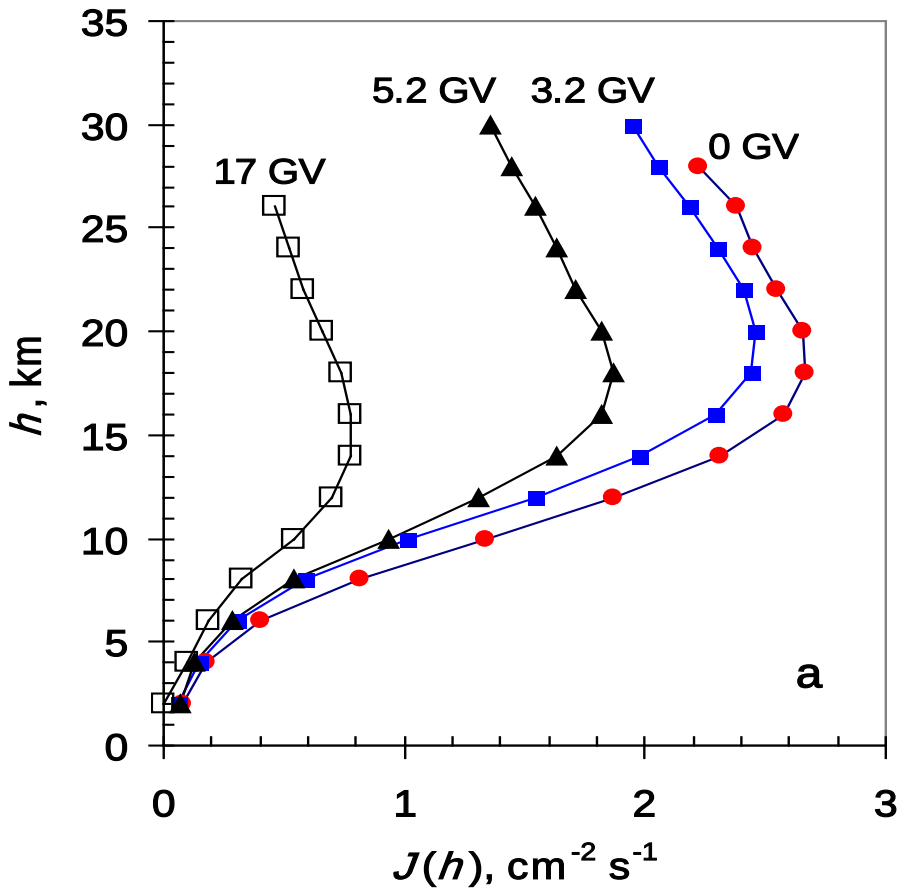
Ionization by GCR & SCR as simulated by PLANETOCOSMICS

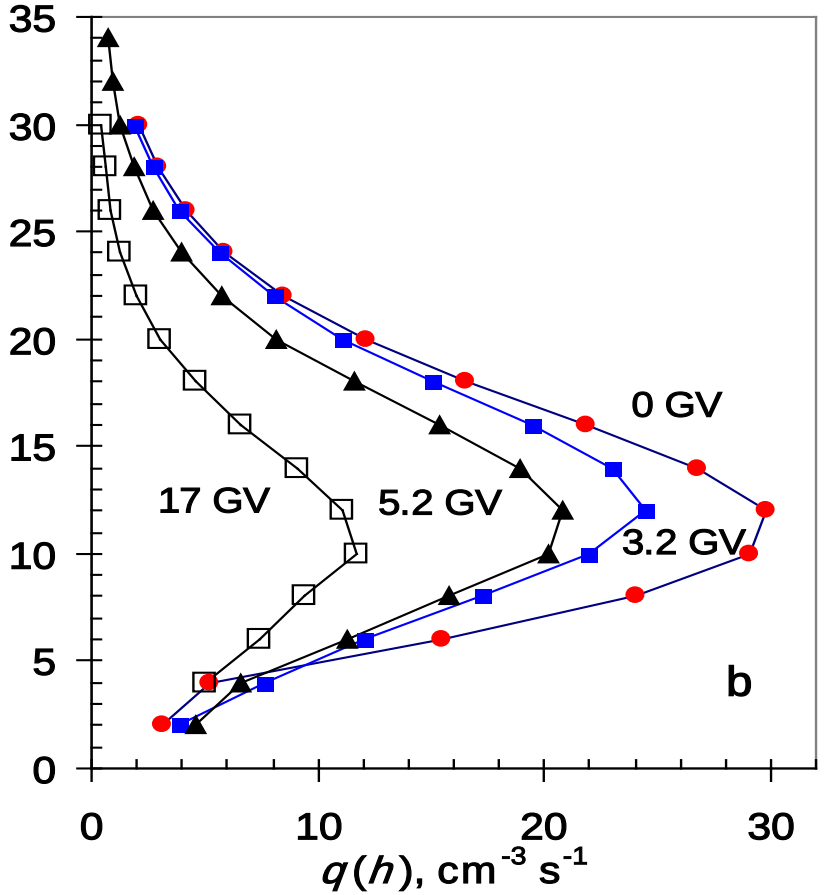
Bern Model, using GEANT4 CERN MC package:
http://cosray.unibe.ch/~laurent/planetocosmics
(Desorgher et al., AOGS 2004)





Modeled CR fluxes vs. Ion production rates (Stozhkov, 2008)

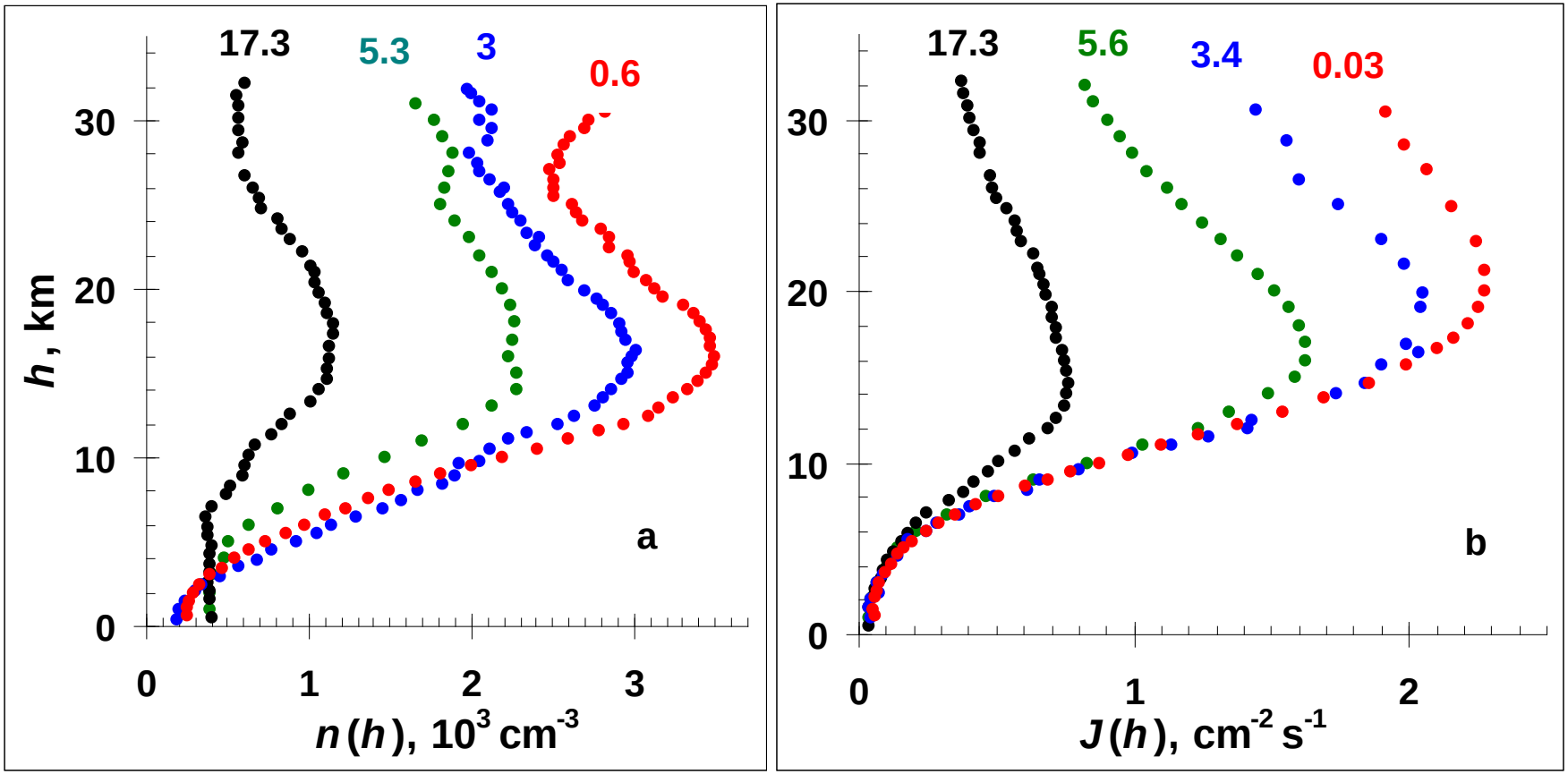




Left: altitudinal profiles of CR fluxes *J*(*h*), Right: ion production rate q(*h*)

The values of *J*(*h*) and *q*(*h*) were measured and calculated at the latitudes with different values of R_c (shown near each curve) and correspond to the period of high solar activity level (Stozkhov, 2008)

MEASURED Ion concentrat. vs. CR FLUXes (Stozhkov, 2008)



Left: Altitudinal profiles of light ion concentrations $n(h)$

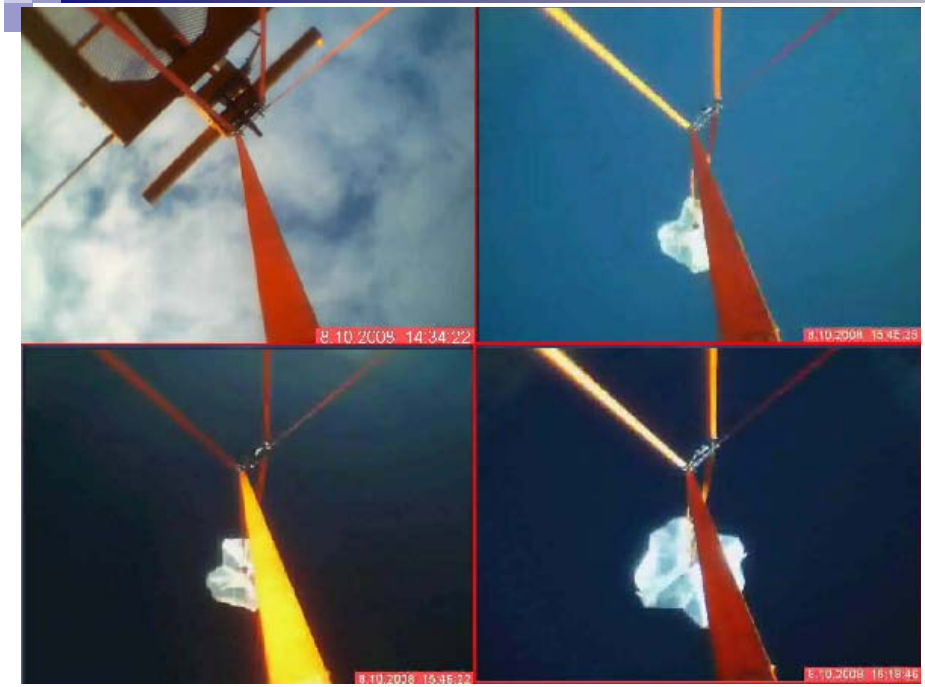
Right: Altitudinal profiles of CR fluxes $J(h)$

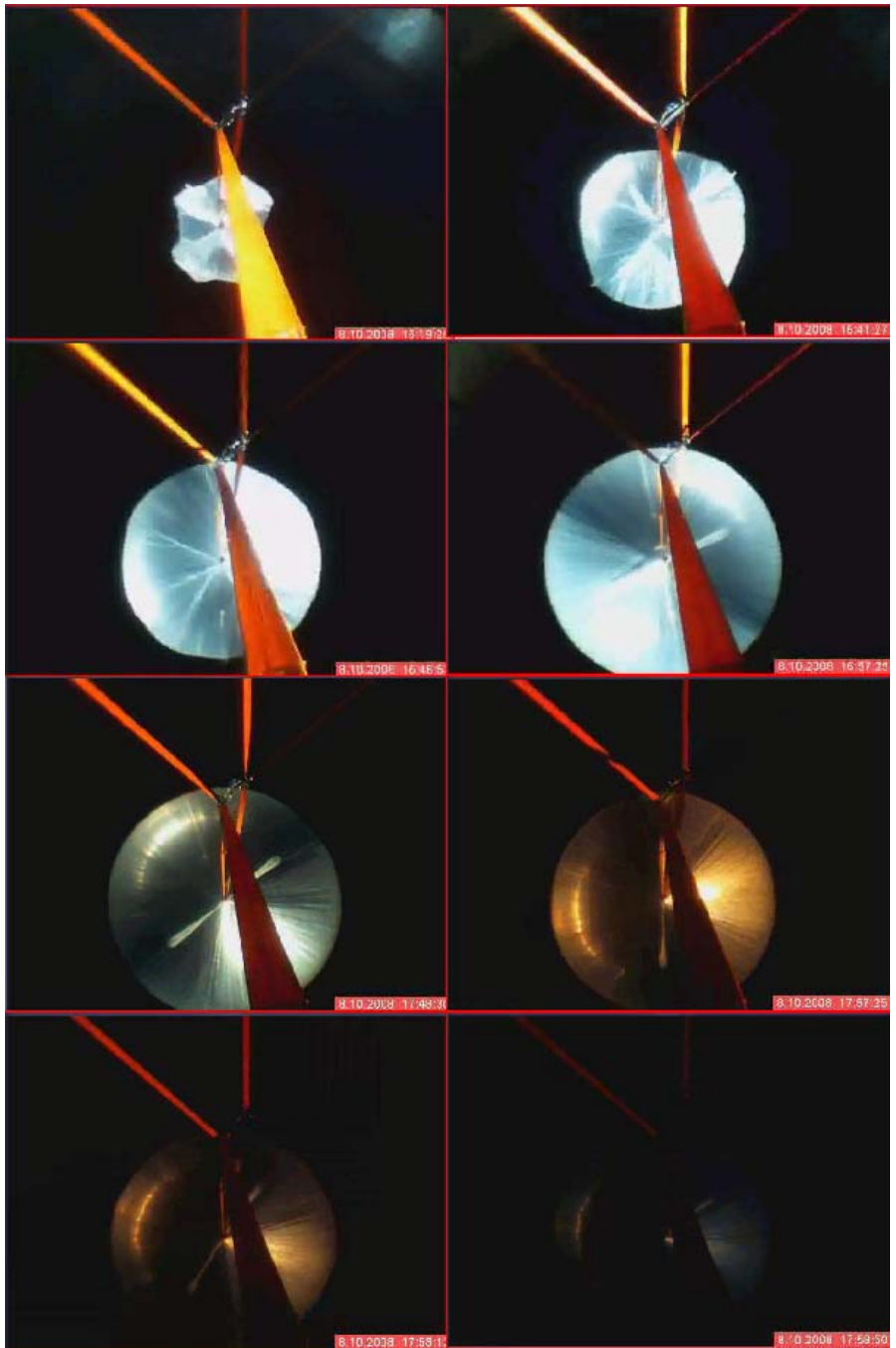
These data were obtained during solar activity maximum at the latitudes with different values of R_c (labels near curves) (by Stozkhov, 2008)

Acknowledgments

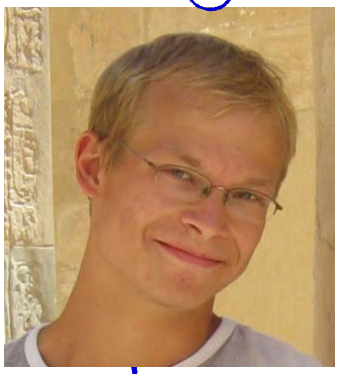
Detector providers

Launch opportunity





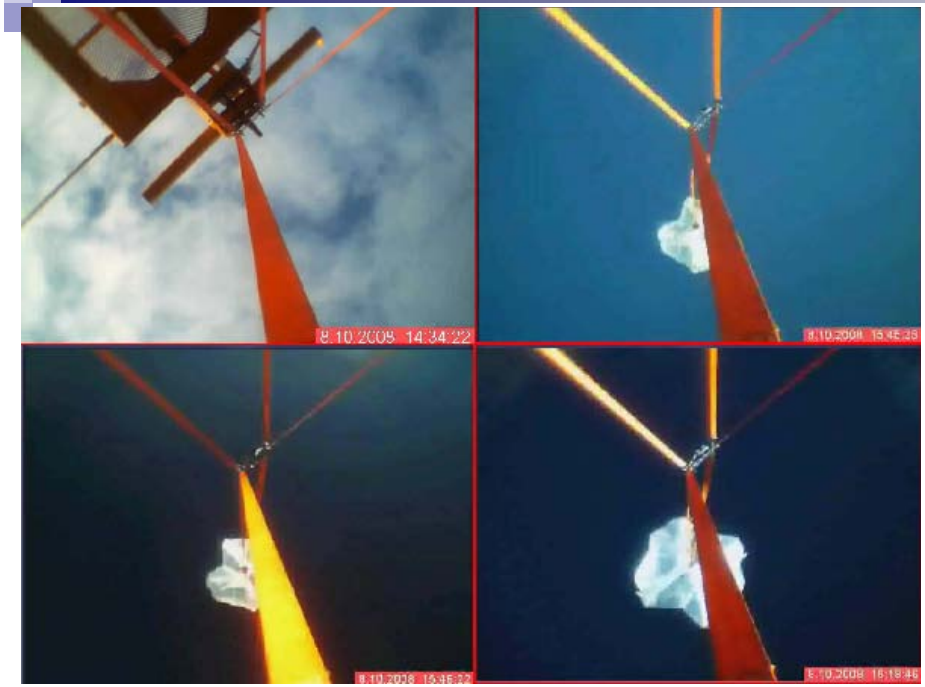
Any Suggestions?

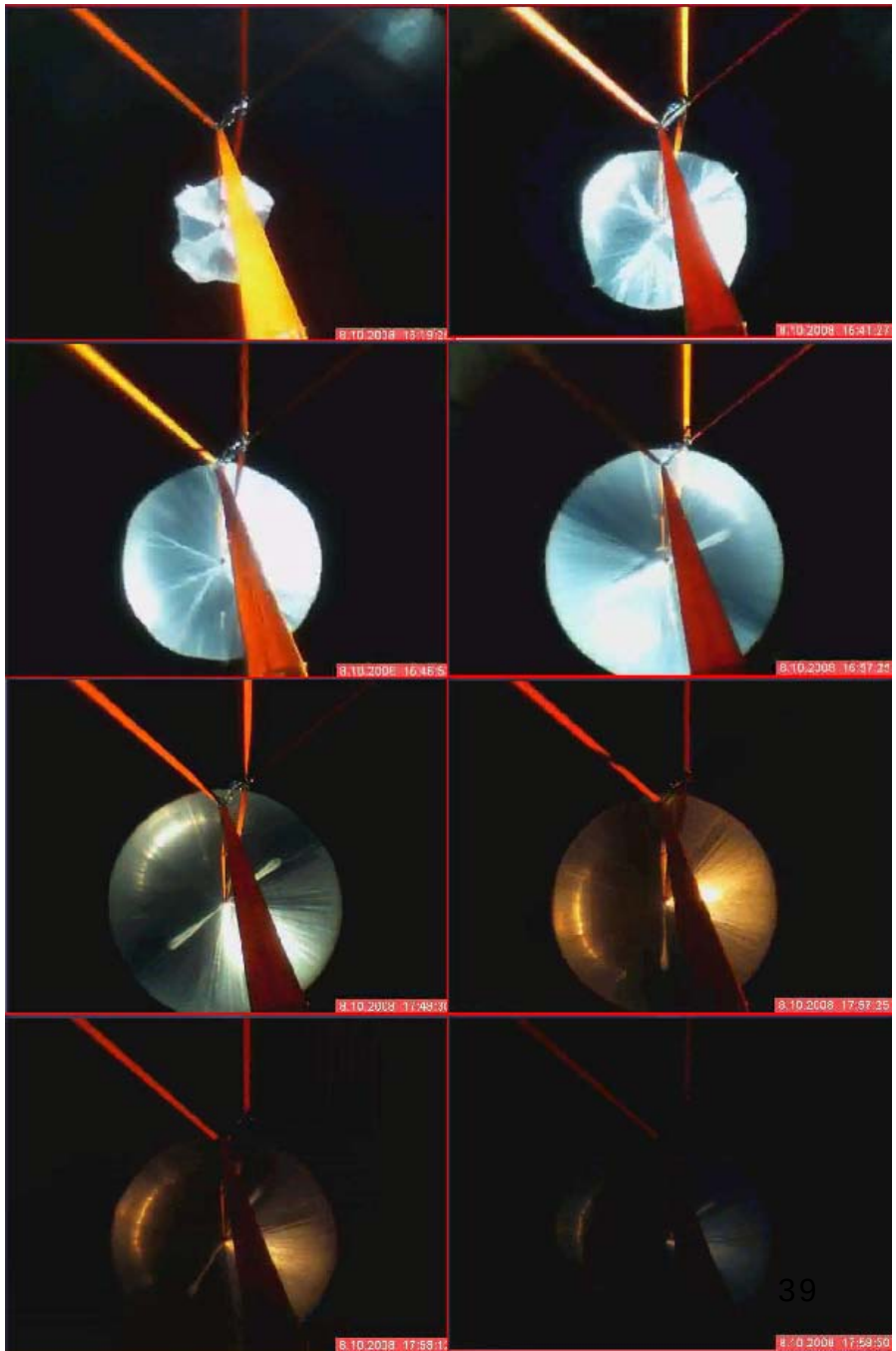


Please tell me:

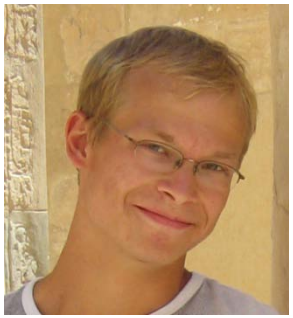
Jaroslav.urbar@mff.cuni.cz

Thank You!





Any Suggestions?

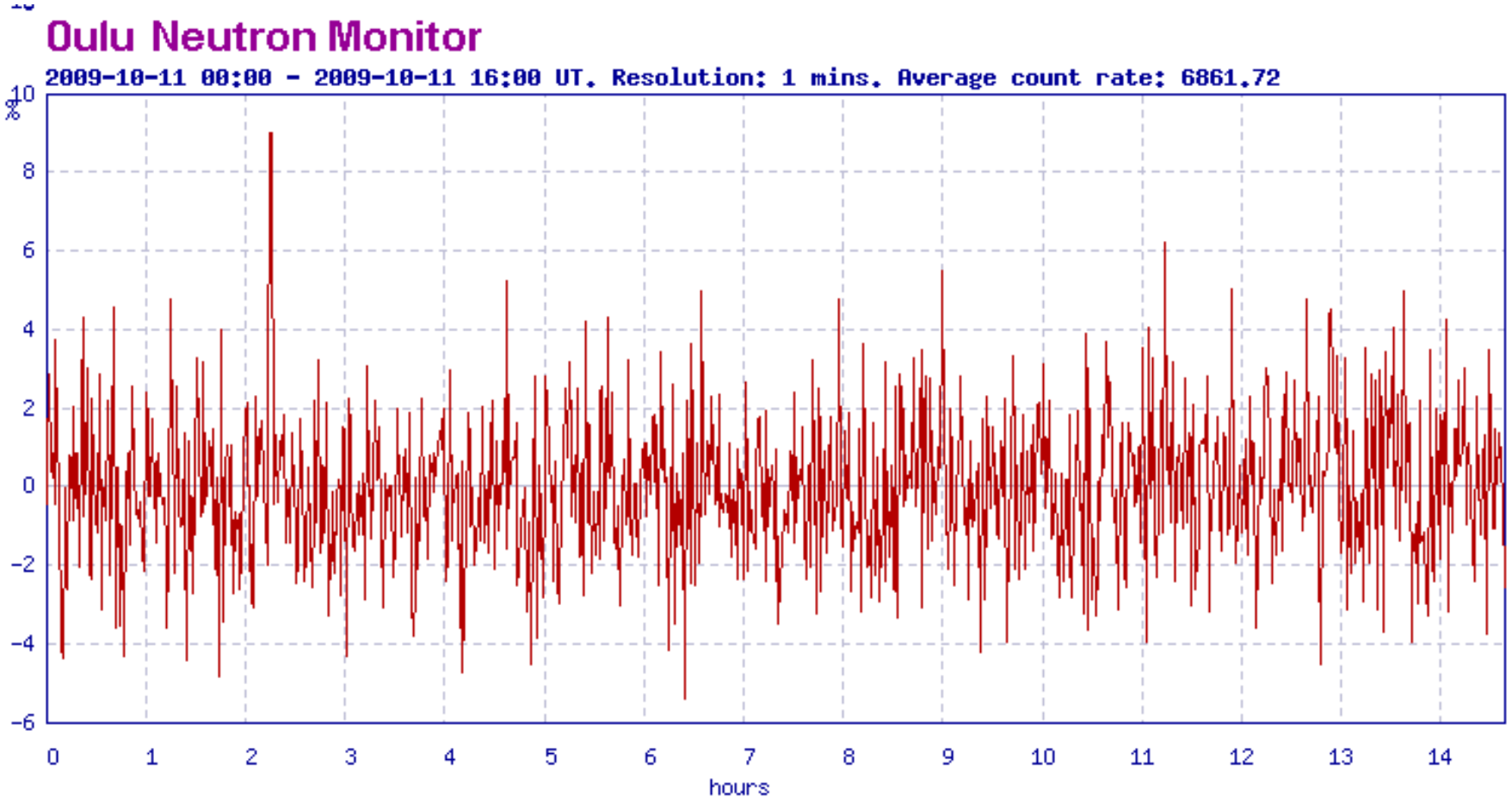


Please tell me here or later:

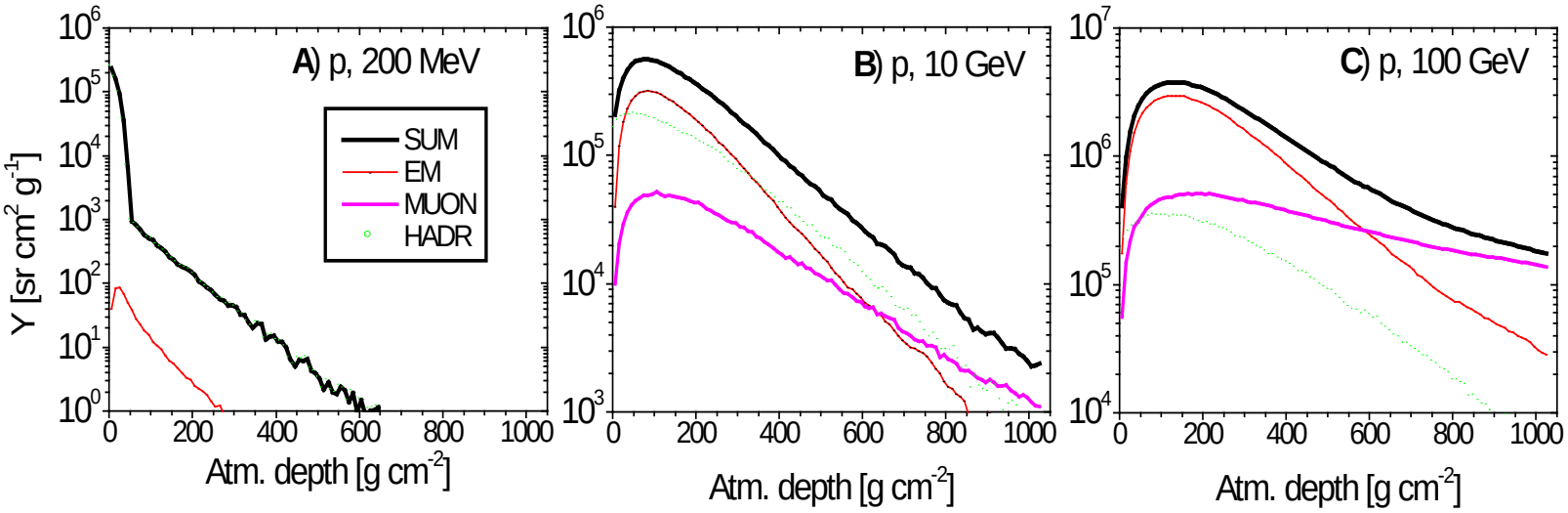
Jaroslav.urbar@gmail.com

Main focus of *student* CRIndIons project is to measure precisely in situ the Cosmic Ray Induced Ionization (CRII), its rate and ambient environment ion concentration along the atmospheric layers traversed during the balloon flight. There is still high ambiguity in specific ionization processes, impacting phenomenons in magnetospheric and atmospheric physics, concerning global atmospheric electric currents and cloud forming conditions. While the CRII is the main atmospheric ionization contributing process in altitudes of 3-35km, and we know relevant cosmic-ray fluxes well, we need more specific data on its ionization yields. Those depend on *particle types* and their *energies*. This still needs to be measured in more detail in situ as requested by scientific community.

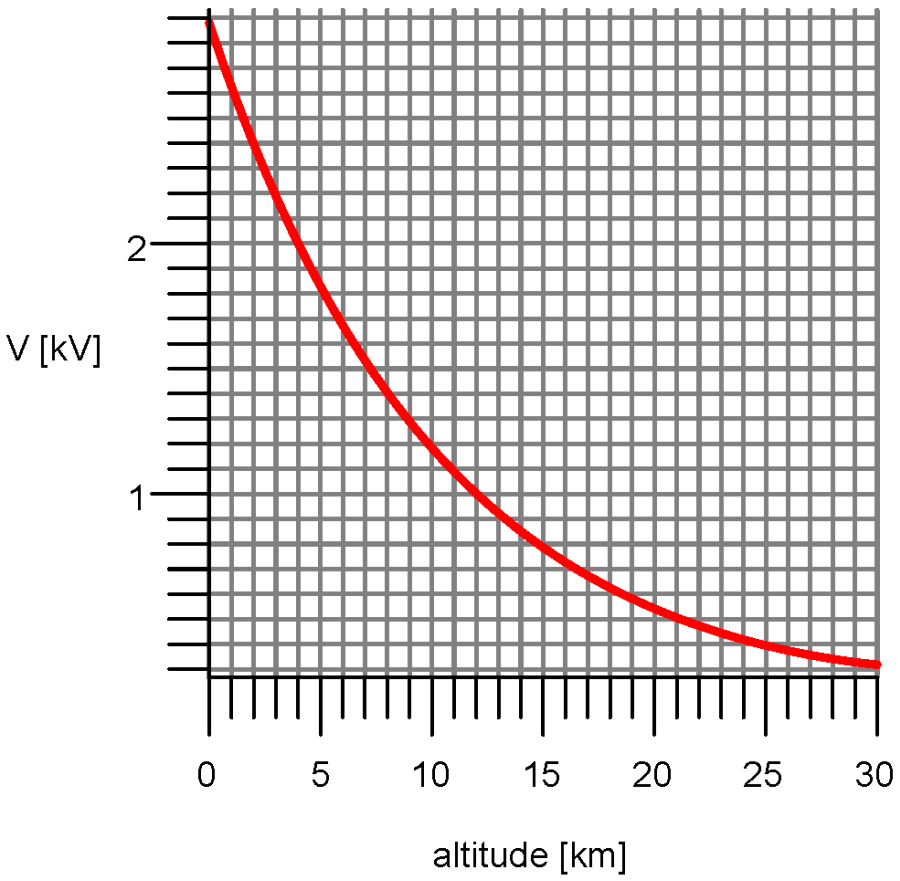
Flight conditions

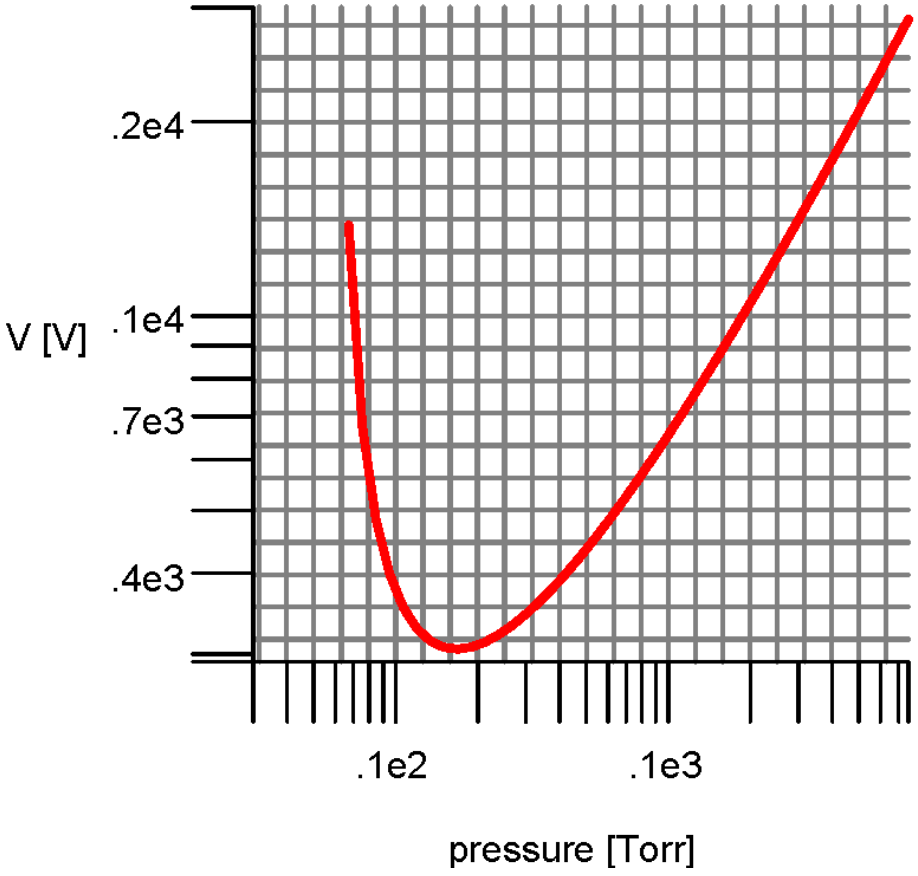


Ionization Yields from the shower components for specific particles, OuluCRAC



Breakdown voltage dependence on conditions





By using Paschen's law->
having available max 800V potential
designed optimal distance of 0.5mm
spark-plug electrodes to obtain best results

Power Consumption

Consumer	Source	Current	Power Drain
PC/104	5V PS	800mA	4W
TimePix/MediPix#1	5V PS	400mA	2W
TimePix/MediPix#2	5V PS	400mA	2W
uC unit	5V PS	14mA	70mW
Web Camera	5V PS	100mA	500mW
Humidity Sensor	5V PS	200uA	1mW
Total		1714mA	8.6W
Note: The 5V PS drains 400mA from 28V power plug after conversion with power lost 2.5W			
HW Source	12V Battery	200mA	2.4W
Spark Det. El.	12V Battery	5mA	600mW
Total		205mA	2.8W