Low Background laboratory for Nuclear Physics

Institute of Physics, University of Belgrade

Study on 2021 November 4 Forbush decrease with ***Belgrade muon station***

Maletić Dimitrije, Veselinović Nikola, Savić Mihailo,
Dragić Aleksandar, Banjanac Radomir, Joković Dejan,
Knezević David, Travar Miloš, Udovičić Vladimir

V Meeting on Astrophysical Spectroscopy - A&M DATA, Palić, 14.09.2023.

Outline

- About the Low background Laboratory
- Cosmic rays
- Software and analysis tools
- results
- conclusions

Past and present activities in our laboratory

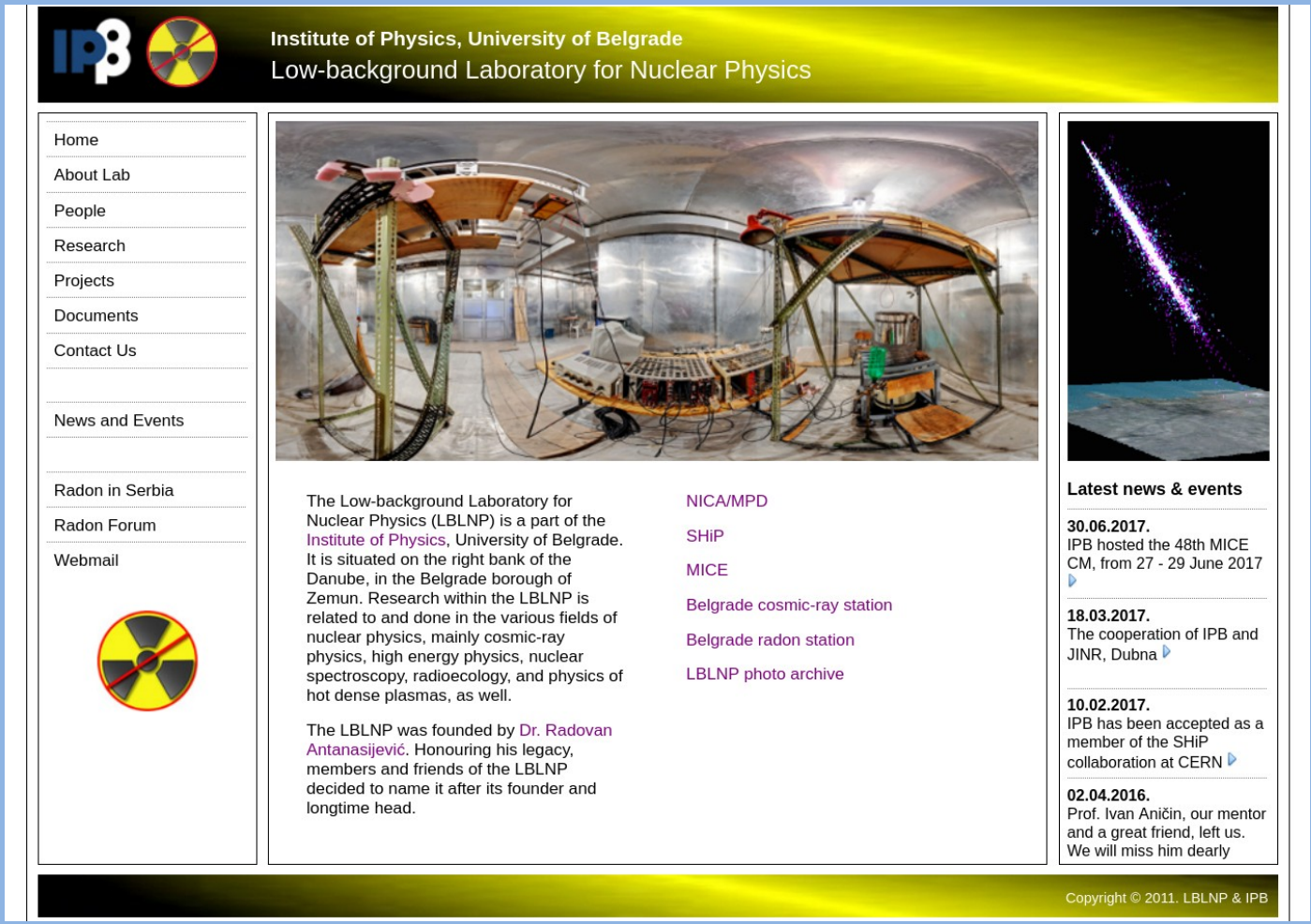
- **Expertise in low-level gamma-ray spectroscopy**
  - coincidence and anti-coincidence methods for fundamental and applied research
  - material radio-purity tests in low background laboratories environment, which includes the usage of plastic scintillator veto detectors.

- **Studying rare nuclear and particle processes**
  - low-probability decay modes
  - neutrinoless double beta decay
- **Comprehensive studies of all components of background in high sensitivity experiments**
- **Cosmic ray muon induced signatures in low-energy detectors**
- **continuous monitoring of Cosmic ray muon intensity**
- **Radon studies**
- **Neutron induced nuclear reaction**

- Software development, multivariate analysis, MC simulation, detectors, international collaborations in nuclear and particle physics
- etc

Laboratory

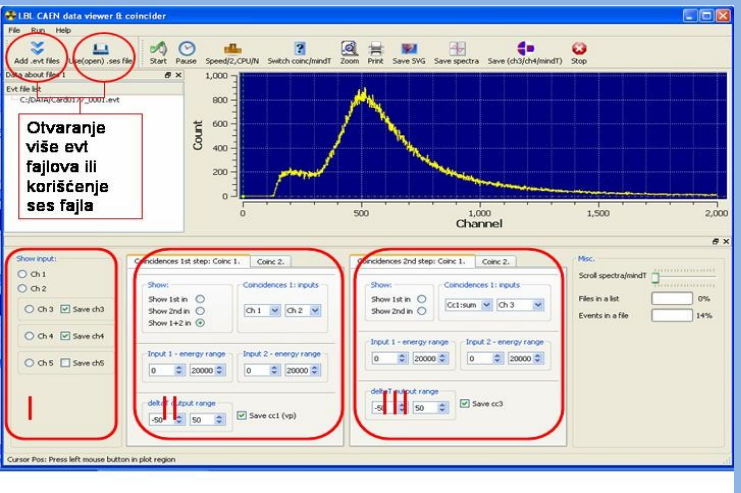
www.cosmic.ipb.ac.rs

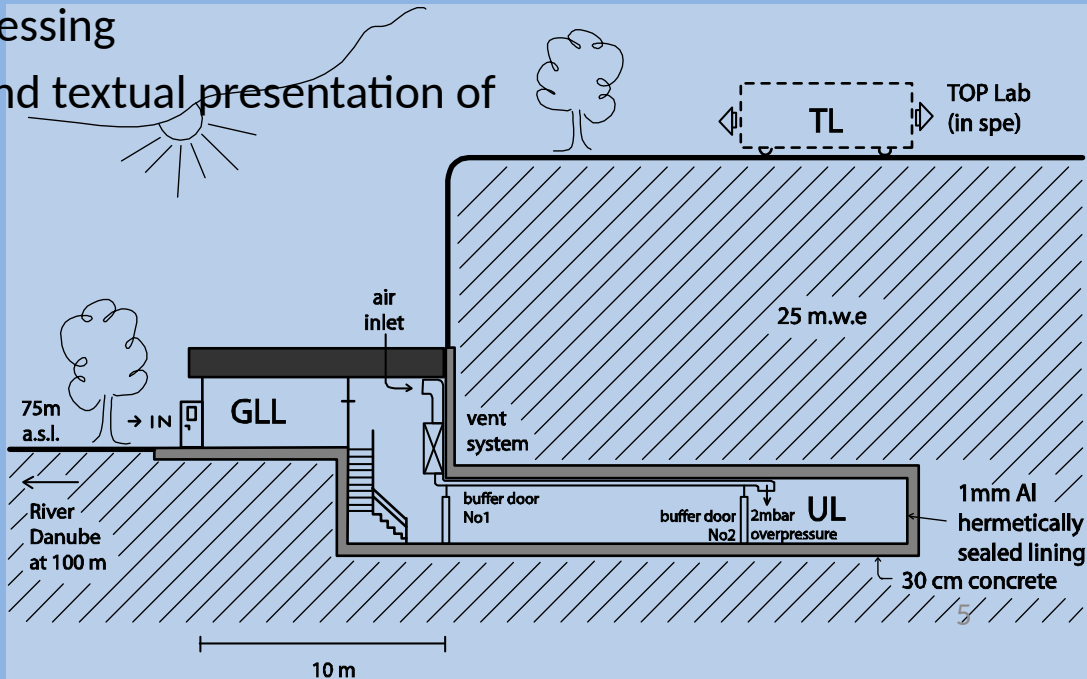


Second pick, right after wikipedia, at Google when „cosmic ray experiments “ is searched for
https://www.mpi-hd.mpg.de/hfm/CosmicRay/CosmicRaySites.html
Has our laboratory:
Miscellaneous sites of cosmic-ray and astroparticle research (sorted by region)
Serbia Belgrade: Low-Background Laboratory for Nuclear Physics at the Institute of Physics

Laboratory – cosmic rays

- Measurement of the flux of cosmic radiation on the surface and 12m underground
- Underground laboratory (UL) hermetically sealed and over-pressurized against radon intrusion (~10 Bq/m^3) - aluminum shielded - the largest tin can in the Balkans. A ventilation system. Air filters. The lowest background.
- Measurements using 1mx1m plastic scintillators. Data collection using CAEN fast digital ADC converters.
- Each event is recorded with all parameters, allowing for later Off-line analysis (list mode).
- The developed software for data processing
- Automatic processing and graphical and textual presentation of information on the Web.



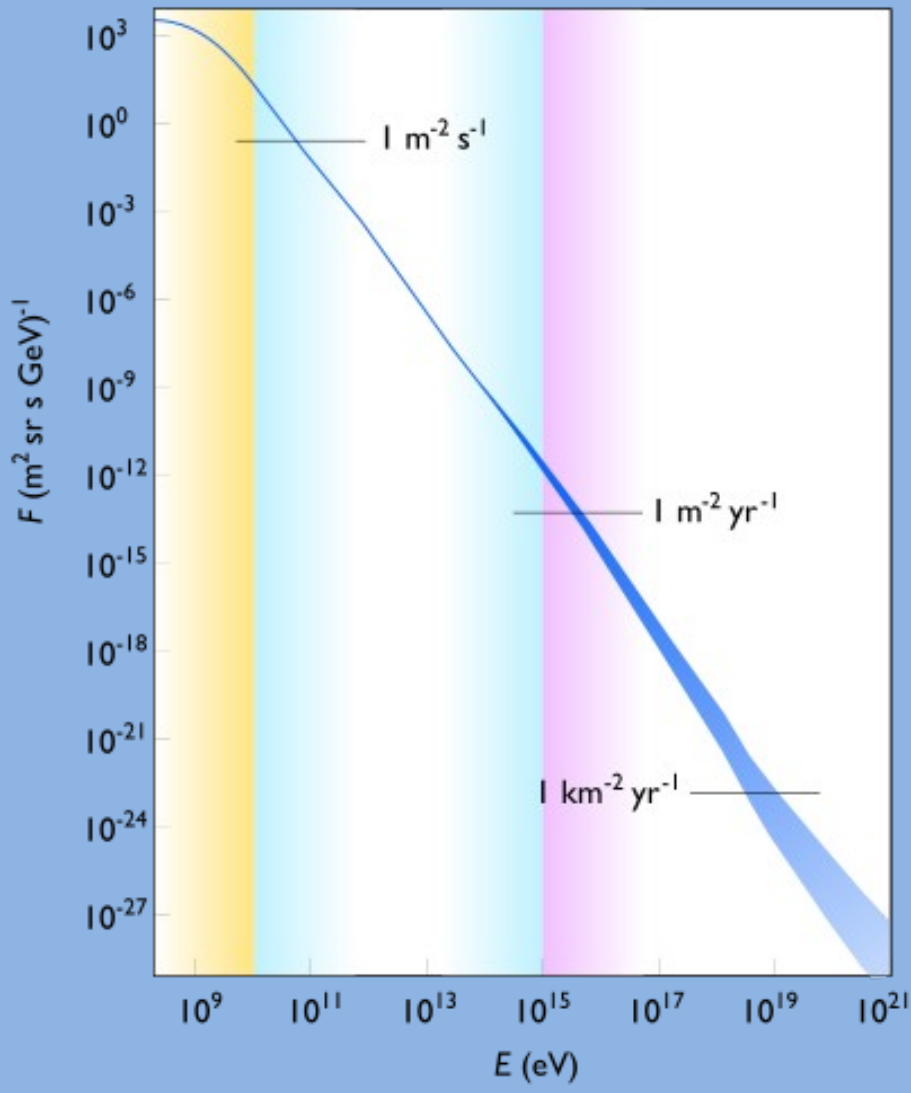


Cosmic rays

- Cosmic rays are high-energy particles that enter into the earth's atmosphere and mostly come from sources outside the solar system. This radiation is called the **primary cosmic radiation**.

- The composition of the radiation falling on the Earth's atmosphere (primary cosmic radiation) consists of about 90% protons, 9% of alpha particles (helium nuclei) and 1% are more massive nuclei.

- Particles enter the atmosphere and collide with the atoms of the atmosphere. Particles which are formed in these collisions are called **secondary cosmic radiation**.



A cosmic ray flux dependence of energy. Flux lowest energy (yellow zone) come mainly from the Sun, medium energy (blue zone) Galactic cosmic rays, the most energetic (purple zone) sources outside our galaxy.

Absolute muon flux in Belgrade

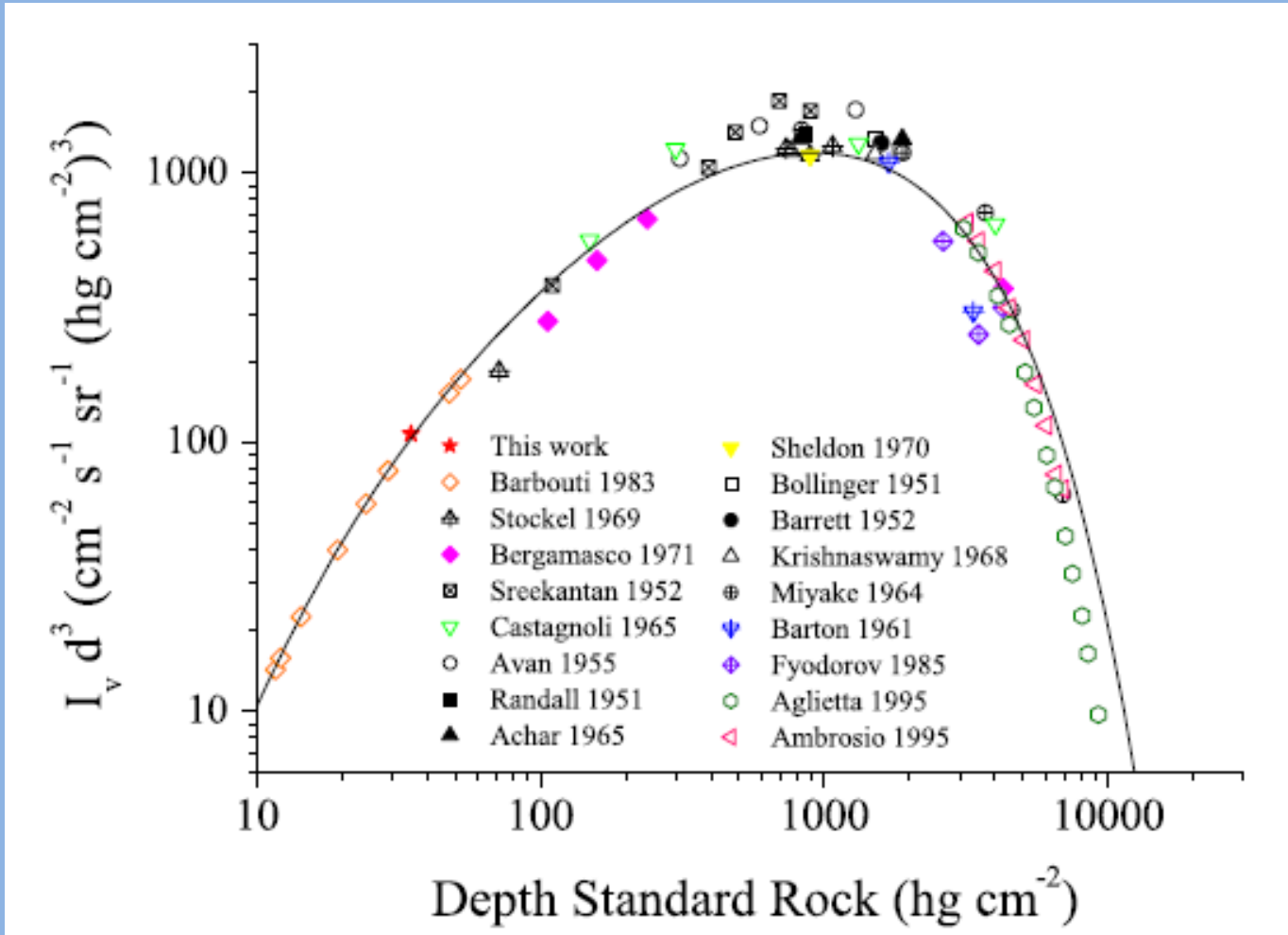
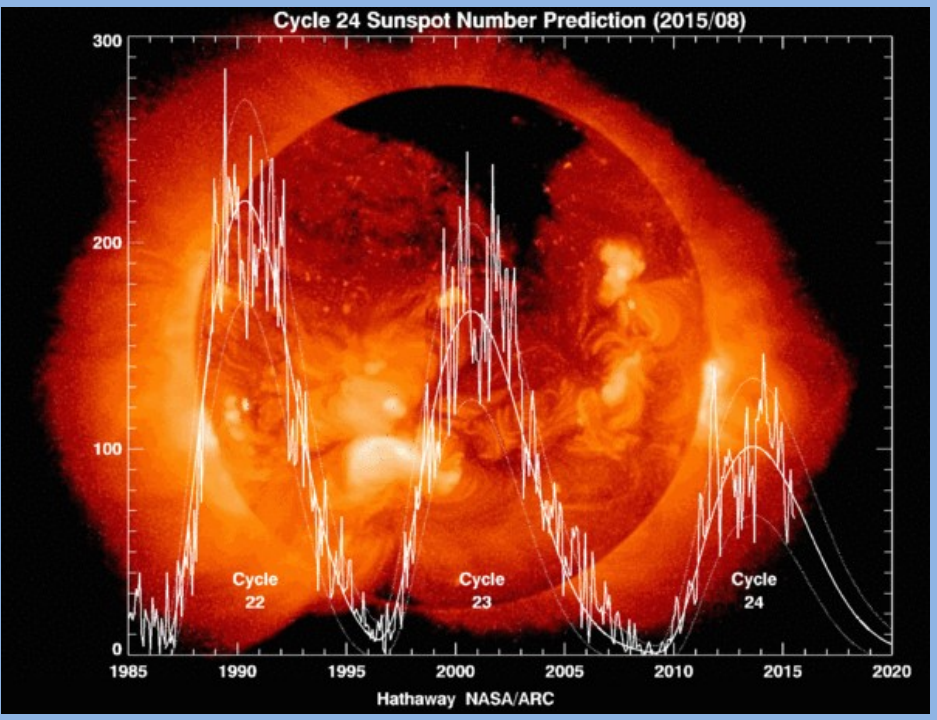
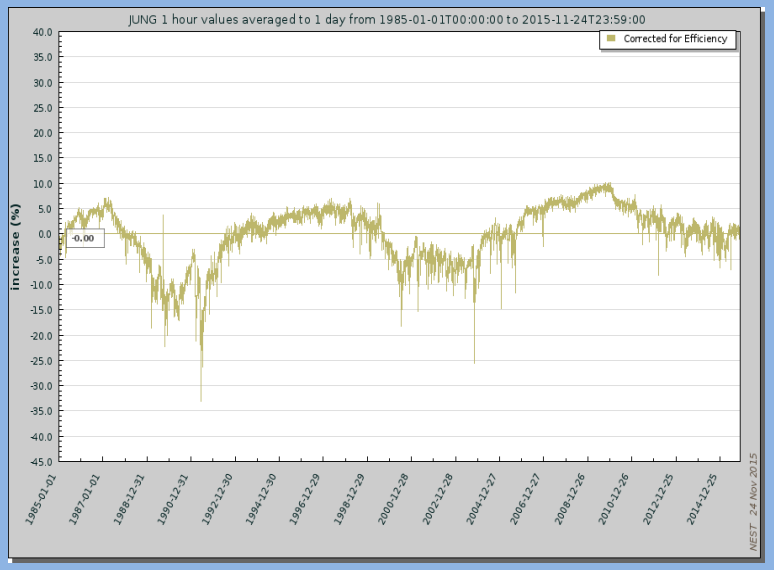


Fig. 4. Absolute vertical muon intensity vs. depth measured from the top of the atmosphere. The result of present measurement is indicated.

The activity of the Sun and cosmic rays





- The solar cycle (number of sunspots)
- Coronal Mass Ejection (CME) - creates a shock wave that affects the Earth's magnetosphere. Then part of the cosmic rays that would normally fall to the earth, they are directed outward direction of the Earth, resulting in the emergence of Forbush Decease (FD), or a significant reduction in the flux of cosmic radiation. This phenomenon is detected for several days.
- Ground Level Enhancement (GLE). While solar particle events typically involve solar energetic particles at 10–100 MeV, GLEs involve particles with significantly higher energies of >500 MeV. GLEs are associated with intense solar flares.

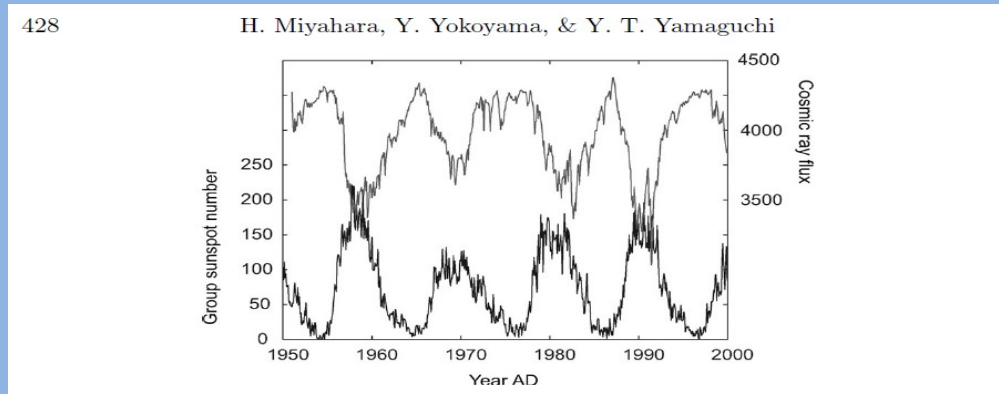


Figure 1. Monthly variation of the cosmic ray intensity observed by the Climax neutron monitor (upper gray line) and the group sunspot numbers (Hoyt & Schatten, 1998) (lower black line).

Low Background Laboratory for Nuclear Physics

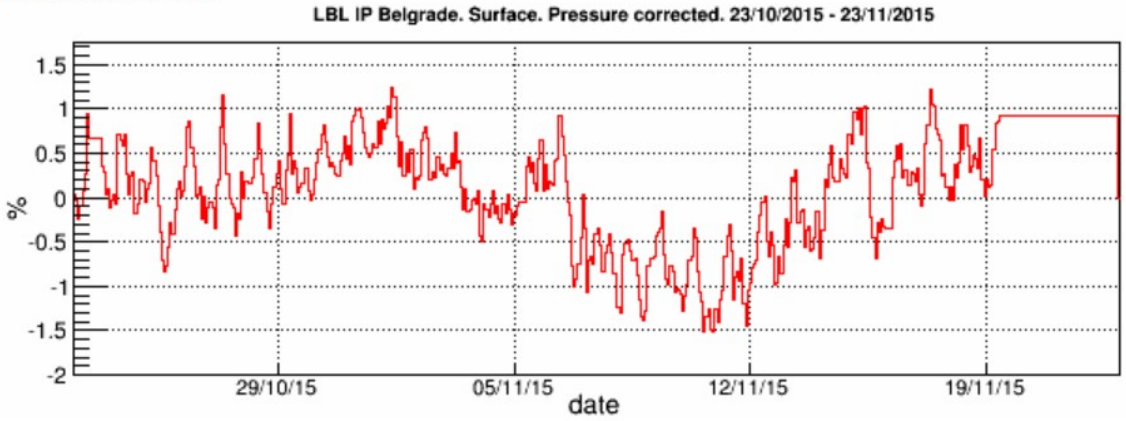
BELGRADE COSMIC RAY STATION

- Muon monitoring -

Institute of Physics Belgrade

Last 30 days. Ground level. Pressure corrected.*

Ground level pressure corrected txt data



* Preliminary results. The results are not normalised. There are occurance of artificial shift in counts when there are change in runs. This change comes from eventual change in detector gain.

ground_level ground_level_press_corr. undergro

A.Dragic, V.Udovicic, R.Banjanac, D.Jokovic, D.Maletic, N.Veseli
The new set-up in the Belgrade low-level and cosmic-ray laborator
Nucl. Technol. Radiat. 26 (2011) 181-192.

Solar X-rays: NORMAL geomagnetic conditions QUIET From n3kl.org

Time series with selective time range

Starting date: 5 1 2015 stoping date: 6 1 2015 Time resolution: 1h

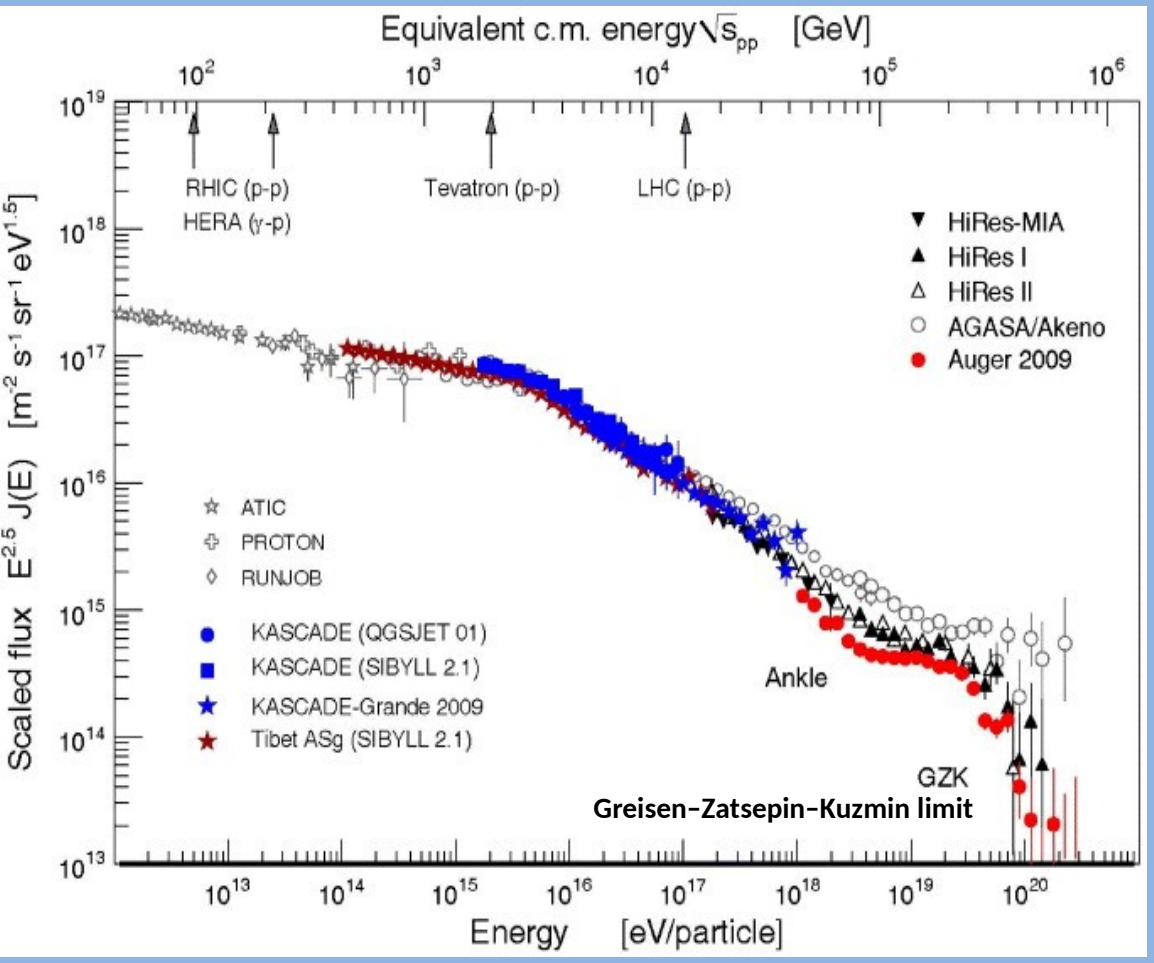
Surface surface P corr. surface TP corr.
Underground underground P corr. underground TP corr.
atmospheric pressure.

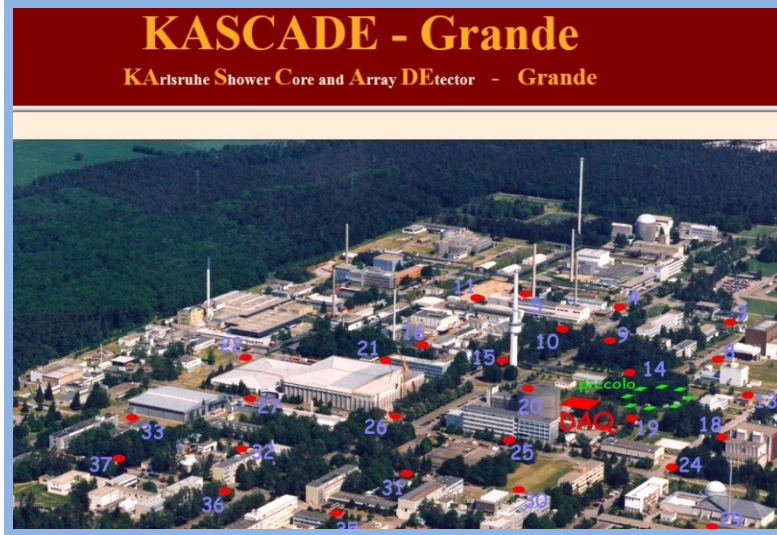
create_plots

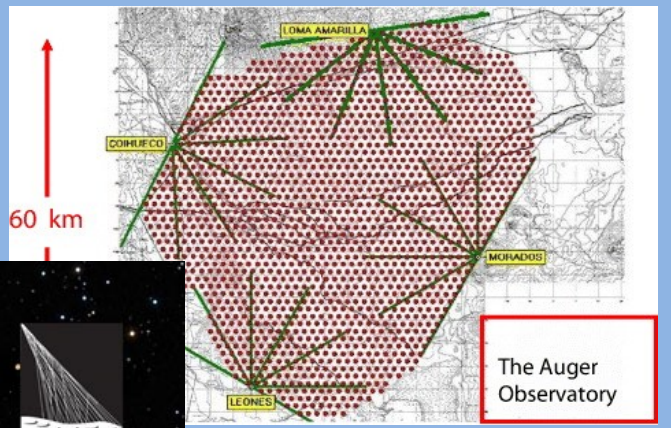
Page of the automatic muon station, with the ability to preview the entire base with 1hour and 5min resolutions

Top cosmic ray experiments

Pierre Auger Project, and **KASCADE,** where the CORSIKA software was first developed

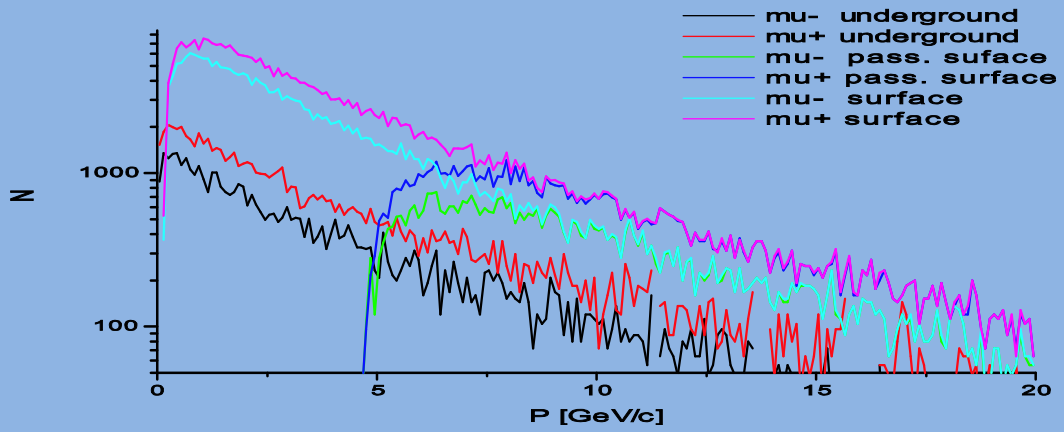


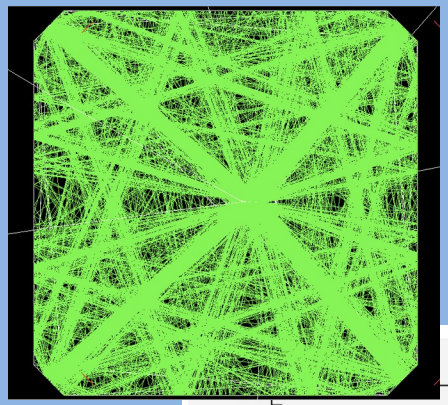


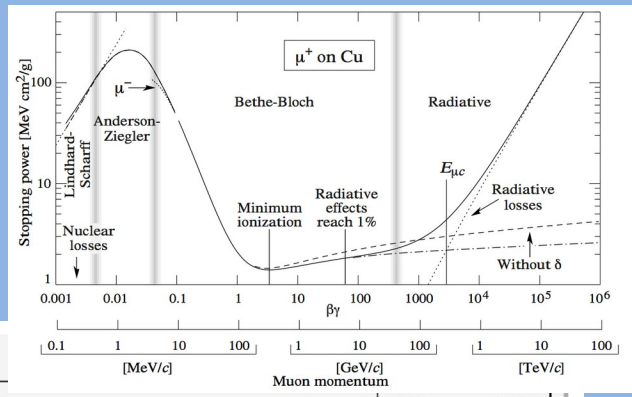


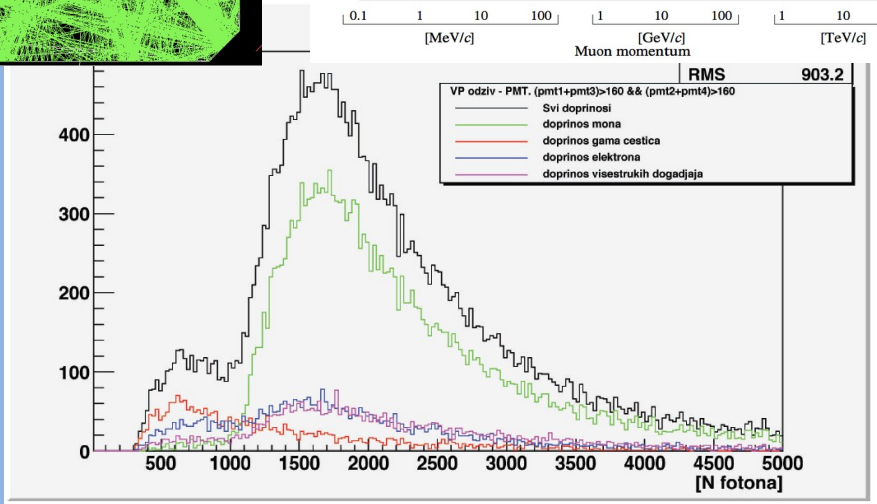
MC simulations of Cosmic rays

- Simulations are inevitable and necessary tool in research.
- For the simulation of cosmic radiation the CORSIKA software package developed for the experiment KASCADE was used.
- Geant4 software package, developed for particle physics, and simulates the interaction of particles with matter, is a very good tool to simulate the response of detectors used in the experiment.
- Combining of these two software packages we can simulate cosmic rays from primary cosmic radiation that is entering in the atmosphere and follow the creation of the cascade through the atmosphere, and finally detects using plastic scintillators at the Earth's surface or in the underground laboratory.









March 2012 FD candidate

Correlation Matrix (signal)

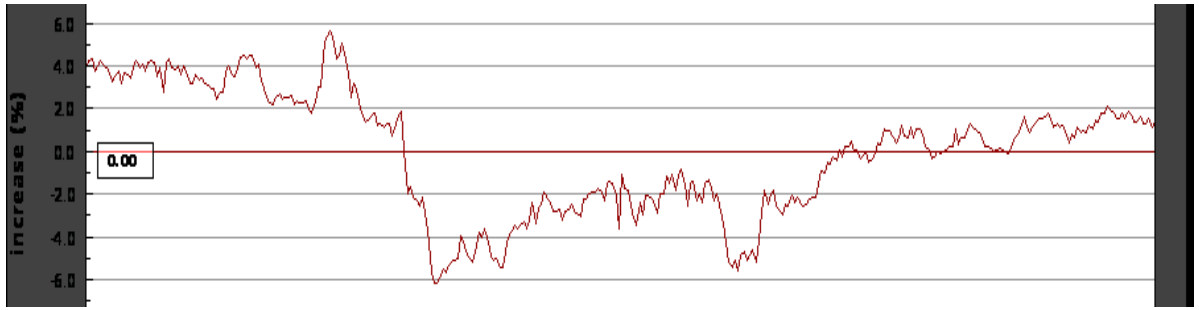
Linear correlation coefficients in %

	AATB	APTY	ATHN	BKSN	FSMT	IRKT	JUNG	KERG	KIEL	LOMS	MCMU	NAIN	OULU	PWNK	ROME	TERRA	THUL	TXBY	SURF_RAW	SURF_PC	SURF_TPC	UNDGR_RAW	UNDGR_PC	UNDGR_TPC
UNDGR_TPC	76	78	78	78	71	73	76	74	76	71	73	71	77	72	79	73	74	77	68	75	79	81	95	100
UNDGR_PC	78	78	79	76	75	77	79	77	79	74	77	76	79	75	81	77	76	79	66	78	69	82	100	95
UNDGR_RAW	67	68	64	61	69	68	68	66	71	65	68	68	70	68	68	68	69	71	89	48	45	100	82	81
SURF_TPC	82	85	85	88	74	78	81	81	79	79	78	75	81	77	84	76	78	78	57	90	100	45	69	79
SURF_PC	90	90	90	91	83	87	91	89	89	88	88	85	89	85	92	87	85	86	58	100	90	48	78	75
SURF_RAW	78	80	74	73	79	79	78	77	81	78	79	78	80	78	78	79	79	80	100	58	57	89	66	68

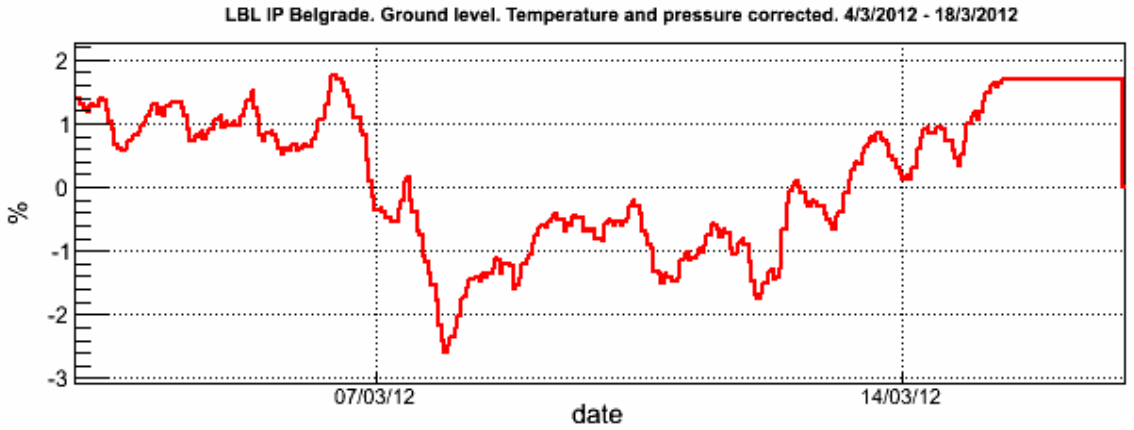
100 80 60

Baksan NM, Detector 6NM64 , Geographic latitude 43.28° N , Geographic longitude 42.69° E , Altitude 1700m asl , Effective vertical cutoff rigidity (1965) 5.6 GV

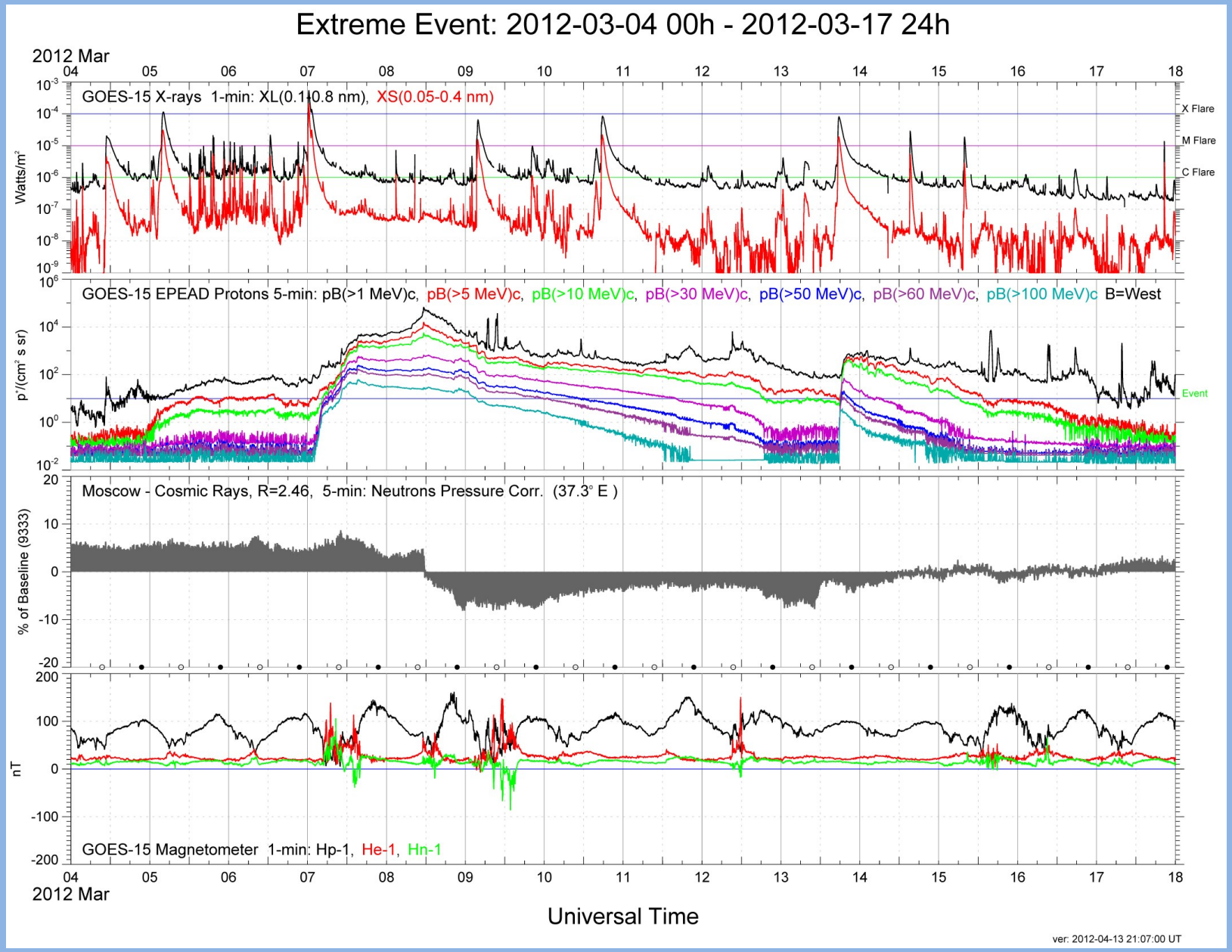
Baksan



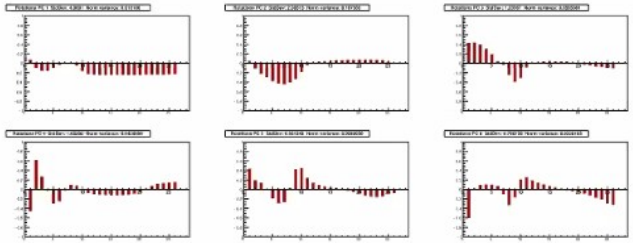
Belgrade



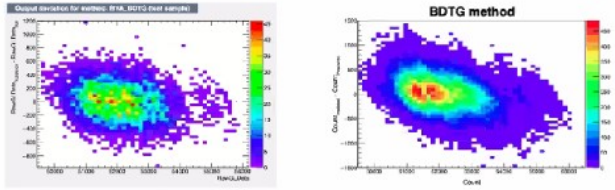
March 2012 FD candidate



New empirical methods for correction of meteorological effects on cosmic ray muons



I. Principal component composition (first six components).

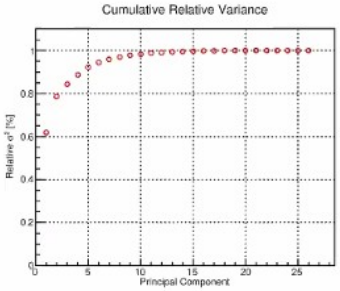


I. Deviation of modeled vs measured muon count for test data set (a) and full data set (b) for BDTG algorithm.

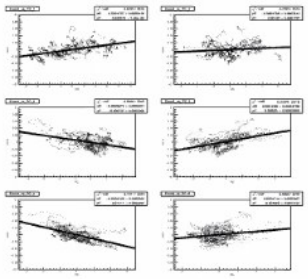
PCA method

I. Atmospheric pressure + 25 atmospheric temperatures → 26 principal components
II. Set reduced to 6 (5) significant components
III. Muon count rate corrected using coefficients from linear regression

$$N_\mu^{(corr)} = N_\mu - \langle N_\mu \rangle \sum_i k_i PC_i, \quad i = 1,3,4,5,6$$



II. Cumulative relative variance.

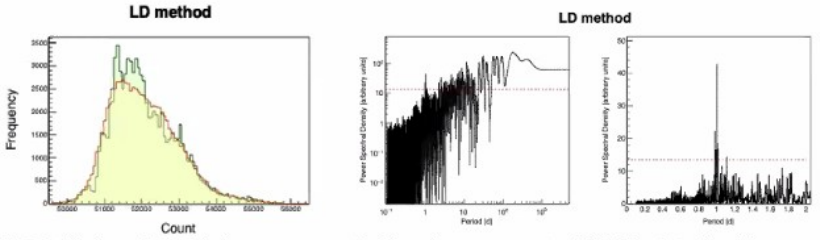


III. Linear regression fits.

MVA method

I. TMVA regression algorithms trained on a train/test subset of data, applied to the whole data set
II. Predicted output target distributions were tested for consistency (deviation distribution, count distribution, spectral analysis, relative count variation). Best performing algorithms selected (LD, BDTG)
III. Muon count rate corrected assuming modeled target value contains all the variations due to atmospheric effects

$$N_\mu^{(corr)} = \Delta N_\mu + \langle N_\mu \rangle, \quad (\Delta N_\mu = N_\mu^{(mod)} - N_\mu)$$



II. Distribution of modeled vs raw count (left) and power spectra (right) for LD algorithm.

New empirical methods for correction of meteorological effects on cosmic ray muons

Effect of correction on periodic CR variations (annual variation)

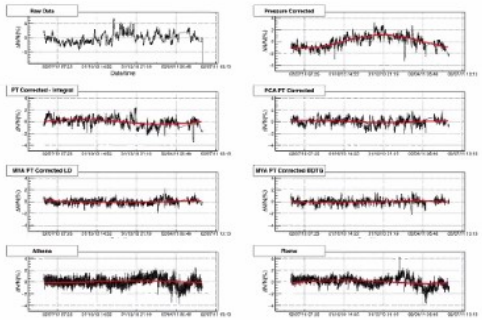


Figure: Time series for period of one year (01.06.2010-31.05.2011) for corrected muon data and reference neutron monitors.

Table: Annual variation amplitude (from sine function fits) and reduction of annual variation relative to pressure corrected data.

Method	P_{corr}	Int.	PCA	LD	BDTG	Ath.	Rome
Amplitude [%]	1.11(9)	0.40(3)	0.18(5)	0.11(3)	0.09(1)	0.17(5)	0.29(1)
Relative reduction [%]	-	64(10)	84(28)	90(30)	92(17)	-	-

Effect of correction on aperiodic CR variations (Forbush decrease)

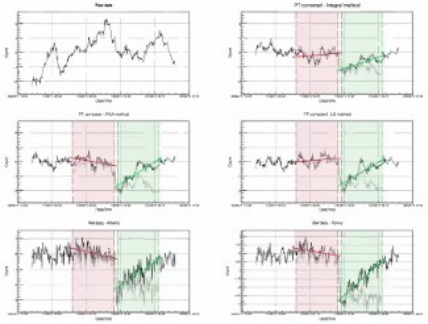


Figure: Time series around the Forbush decrease event in February 2011 for corrected muon data and reference neutron monitors.

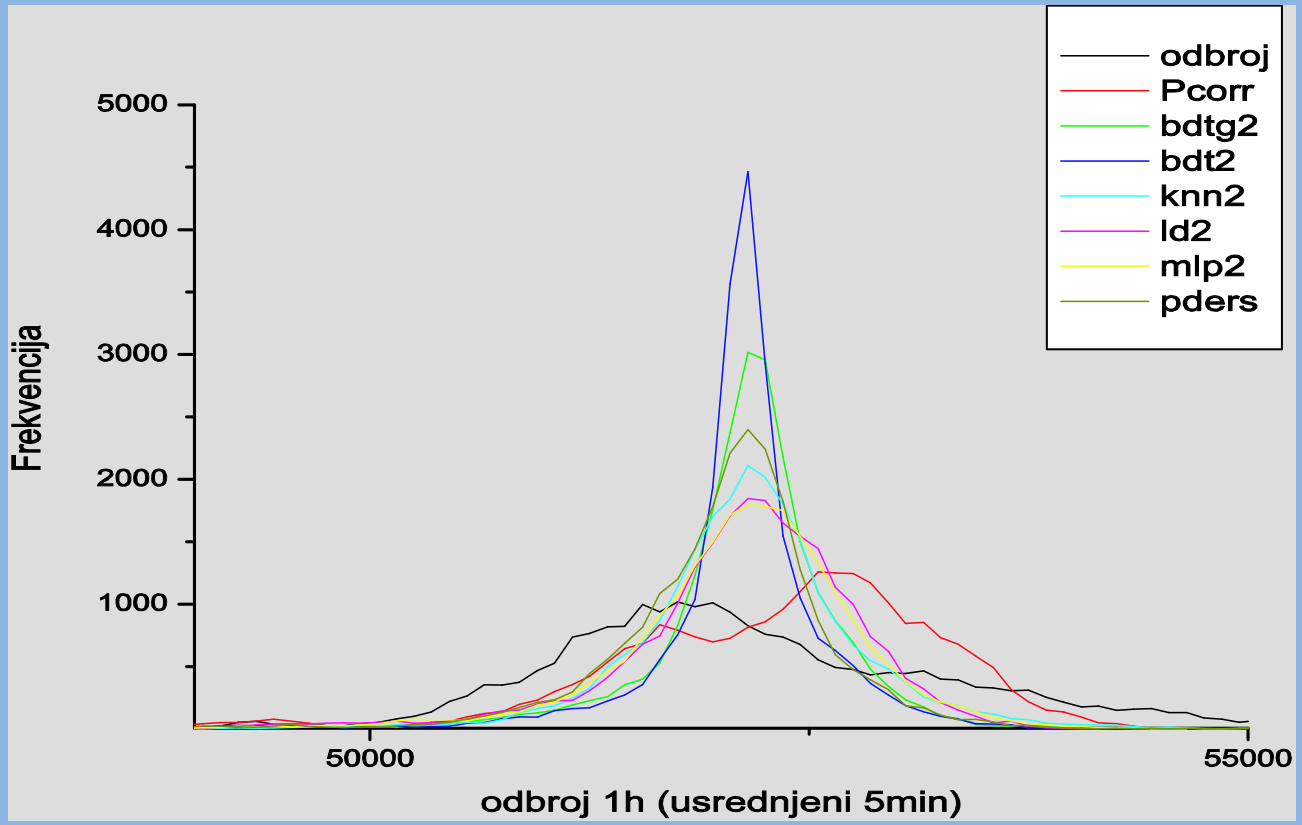
Table: Forbush decrease amplitude (determined from above plots) and amplitude relative to the standard deviation of data leading up to decrease.

Method/ NM	Int.	PCA	LD	BDTG	Ath.	Rome
FD Amplitude [%]	1.38(14)	1.52(21)	1.96(18)	1.10(13)	1.97(15)	2.68(15)
Relative FD Amplitude	4.31(44)	4.90(66)	7.09(65)	4.78(56)	5.30(40)	8.65(48)

Using Multivariate analysis for cosmic ray flux corrections

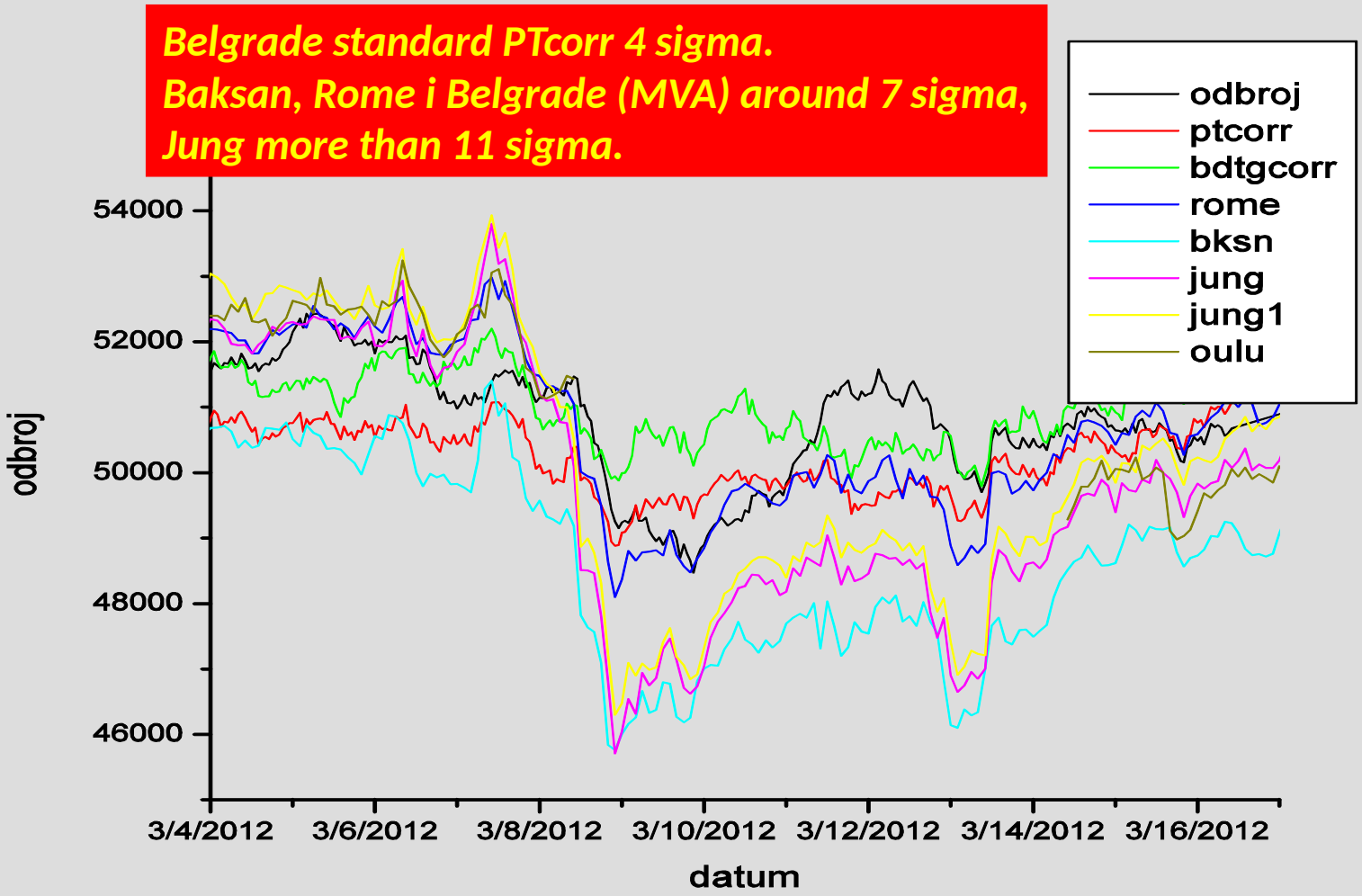
Value of sigma in distribution

raw	950
Pcorr	860
Oulu	670
PTcorr	505
mlp	495
ld	490
knn	440
pders	390
bdtg	285
bdt	175



Comparable sensitivity to some Neutron monitors!

March 2012 FD candidate



1mx1m plastic scintillator ~ 5k EUR, Neutron monitor ~ 250K EUR

Low Background Laboratory for Nuclear Physics

BELGRADE COSMIC RAY STATION

- Muon monitoring -

Institute of Physics Belgrade

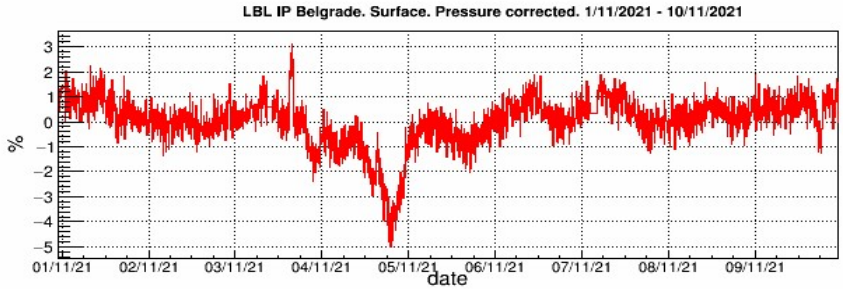
Time series with selective time range

Start date: 1 11 2021 stop date: 10 11 2021 Time resolution: 5m

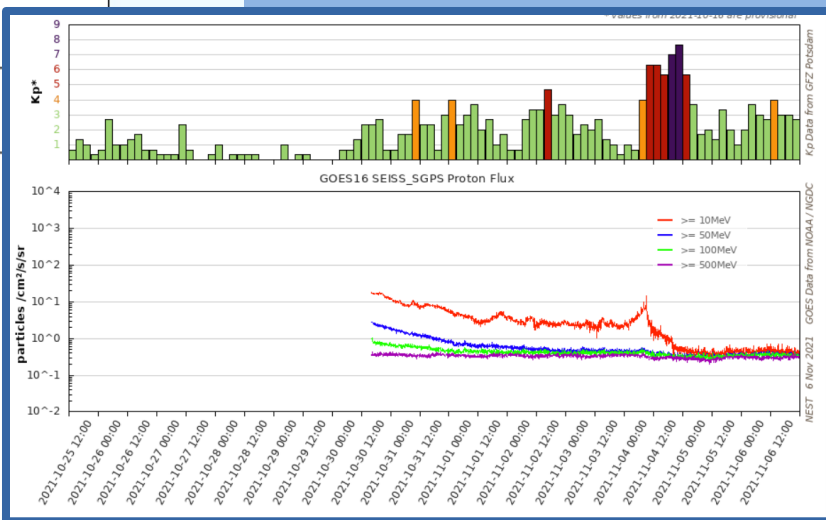
☐ Surface ☑ surface P corr. ☐ surface TP corr.
☐ Underground ☐ underground P corr. ☐ underground TP corr.
☐ atmospheric pressure.

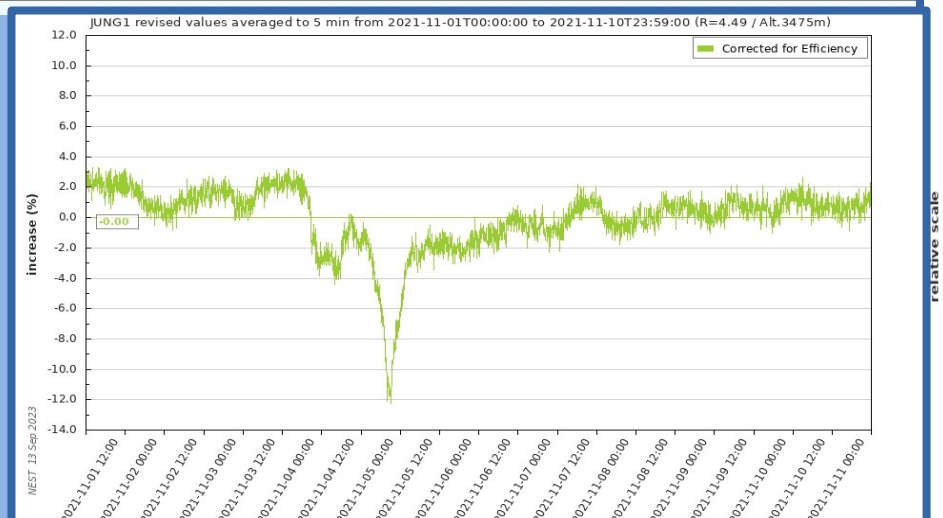
create_plots

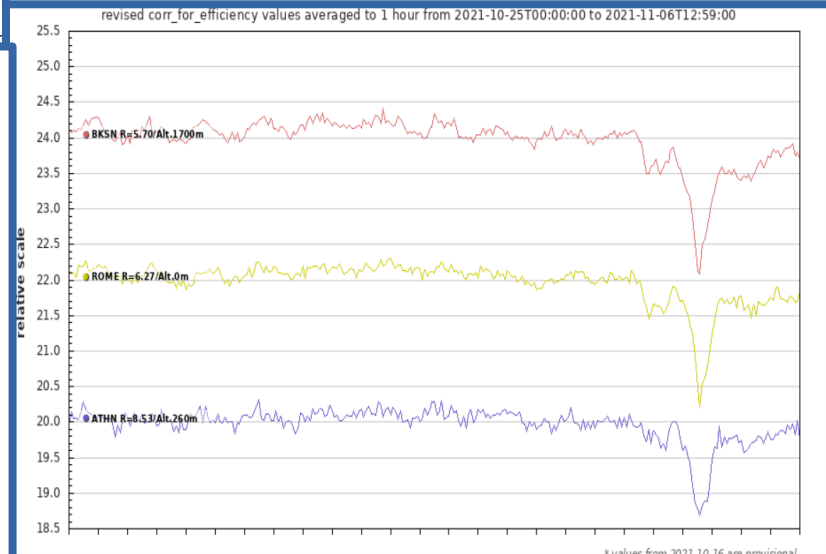
Sufrace, pressure corrected



serija_Surface_5m_pc.txt







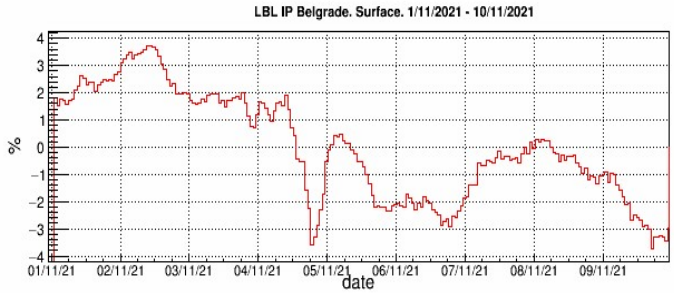
BELGRADE COSMIC RAY STATION
- Muon monitoring -

Low Background Laboratory for Nuclear Physics

Institute of Physics Belgrade

1h resolution

Surface, raw

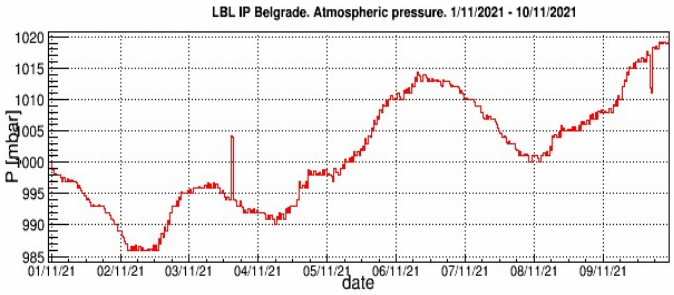


serija_Surface_1h.txt

Sufrace, pressure corrected

serija_Surface_1h_pc.txt

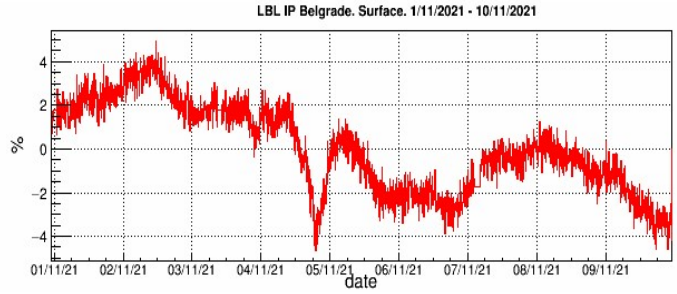
Atmospheric pressure, Belgrade



serija_P_satni.txt

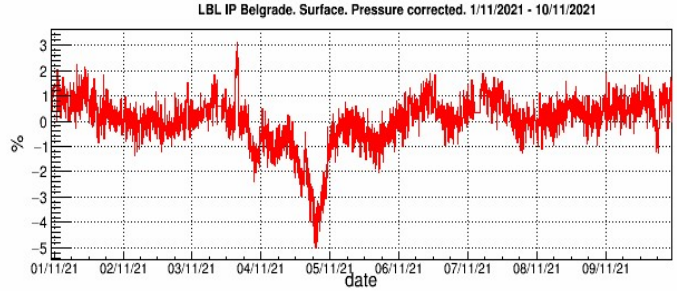
5m resolution

Surface, raw



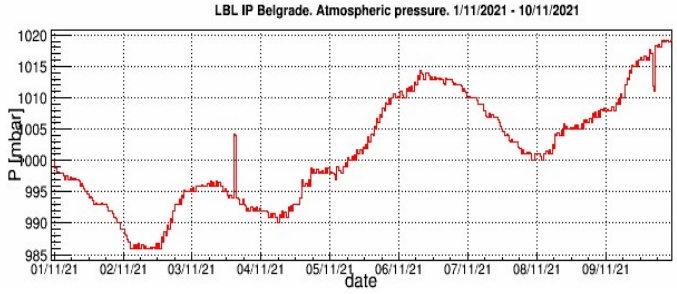
serija_Surface_5m.txt

Sufrace, pressure corrected



serija_Surface_5m_pc.txt

Atmospheric pressure, Belgrade



serija_P_satni.txt

Conclusions

- Low background laboratory continuously measures cosmic muon flux for more than 15 years

- The number of aperiodic events we recorded is not big

- New software and tools for data acquisition and analysis was developed during the years and applied

- Results are comparable to some better equipped laboratories

Thank you for your attention!