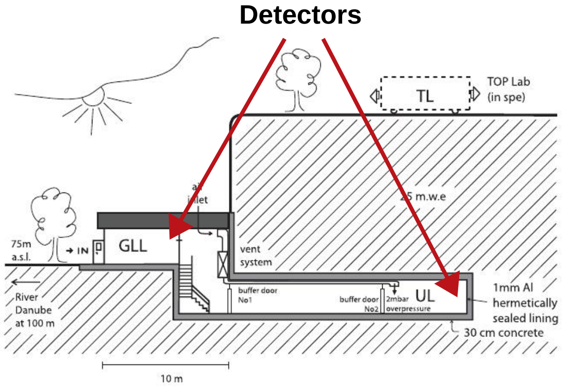
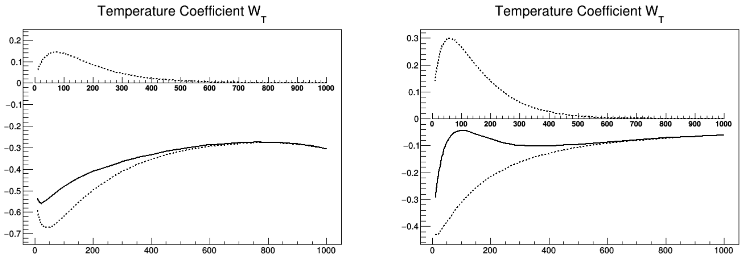
New empirical methods for correction of meteorological effects on cosmic ray muons

There are several well established and widely used methods for correction of atmospheric effects on cosmic ray muons:

- Method of effective level of generation
- Integral method
- Mass-average temperature method
- Effective temperature method



Why do we need to introduce another one?



Integral method is often used as a reference as it is based on the theory of meteorological effects.

Motivation for introduction of new methods:

- Improve on the existing empirical methods
- Universal and easy to use
- Not dependent on topology of terrain or laboratory infrastructure
- Potentially reveal effects not taken into account by theory
- Can be extended to include more atmospheric parameters

Tools:

Modern techniques used for decorrelation and dimensionality reduction of large, highly correlated data sets:

- Principal component analysis (PCA)
- Multivariate analysis utilizing machine learning (MVA)

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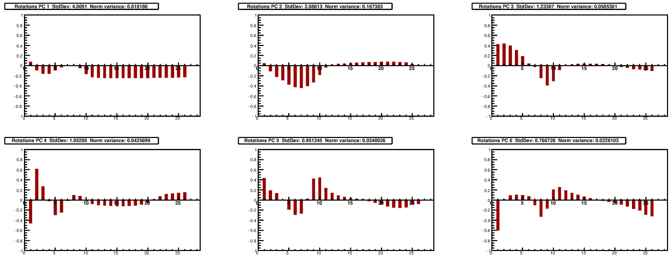


I. Principal component composition (first six components).

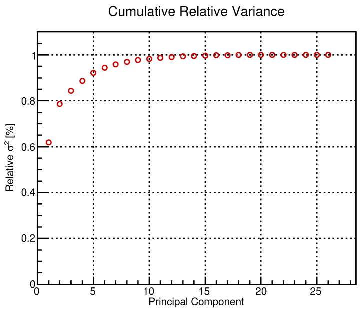
PCA method

I. Atmospheric pressure + 25 atmospheric temperatures → 26 principal components

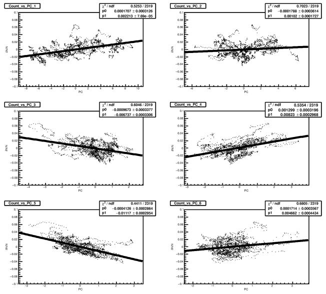
II. Set reduced to 6 (5) significant components

III. Muon count rate corrected using coefficients from linear regression

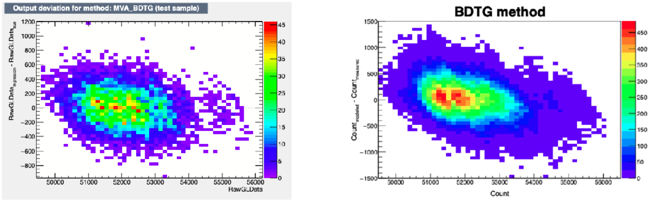
$$\boxed{N_\mu^{(corr)} = N_\mu - \langle N_\mu \rangle \sum_i k_i PC_i, \qquad i=1,3,4,5,6}$$



II. Cumulative relative variance.



III. Linear regression fits.



a)

b)

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

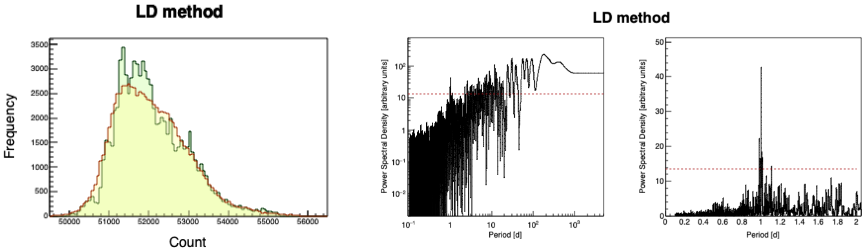
MVA method

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

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



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

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Effect of correction on periodic CR variations (annual variation)

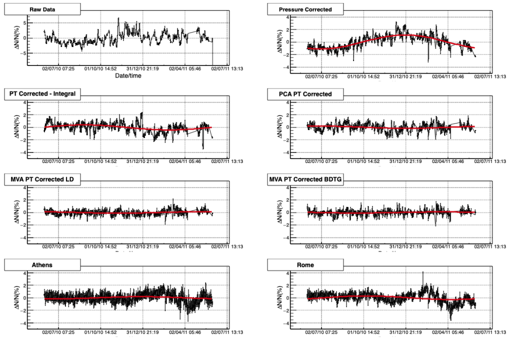

Figure: Time series for period of one year (01.06.2010-31.05.2011) for corrected muon data and reference neutron monitors.

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)

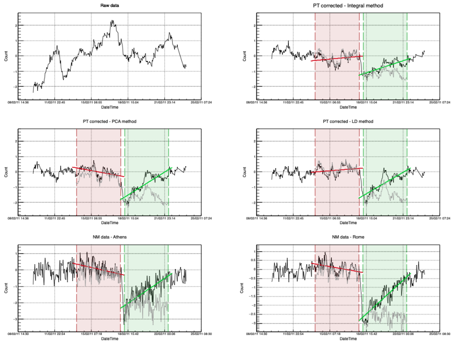

Figure: Time series around the Forbush decrease event in February 2011 for corrected muon data and reference neutron monitors.

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)