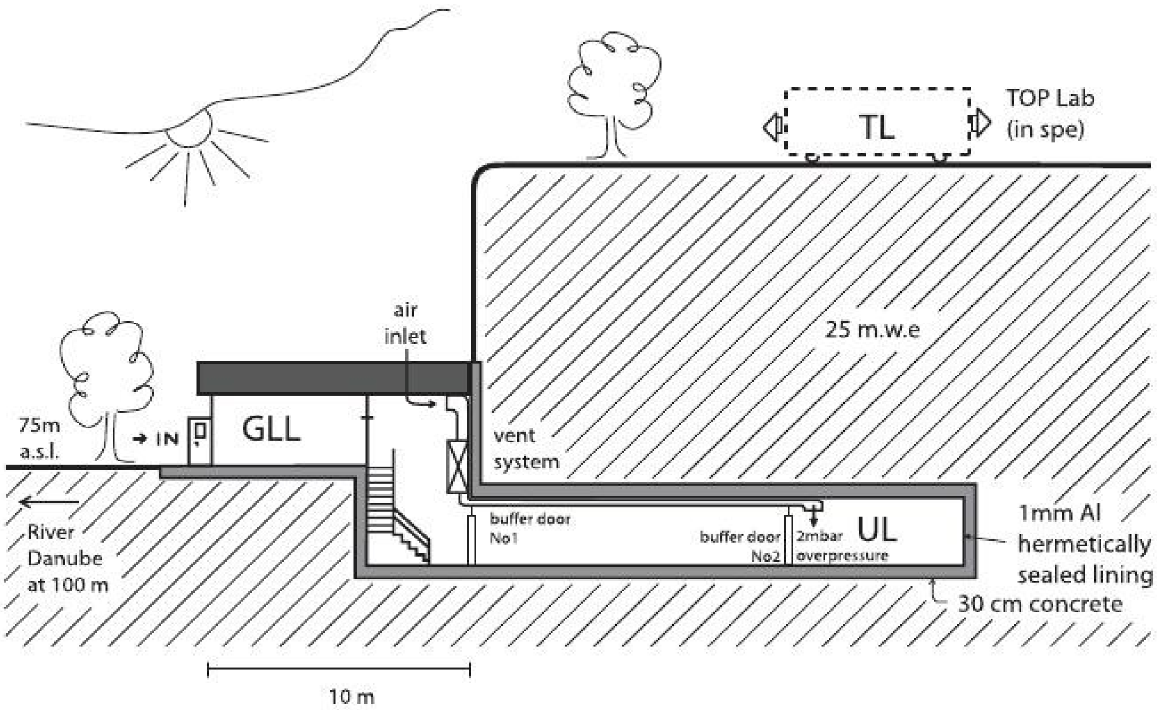
Effect of pressure and temperature corrections on muon flux variability at ground level and underground

Mihailo Savić, Institute of Physics Belgrade

LBL layout

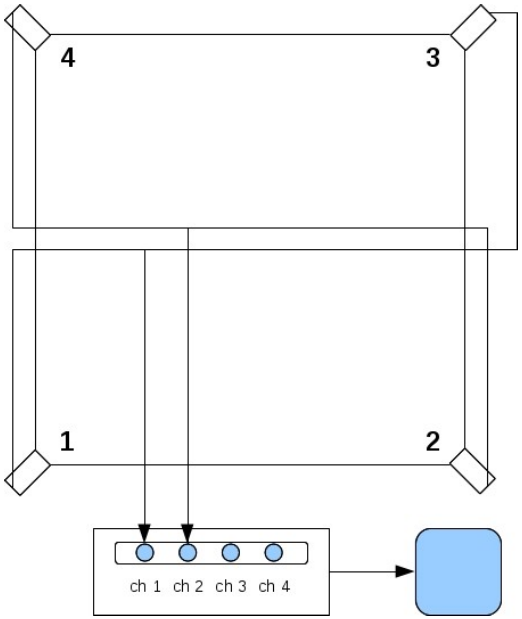
- Belgrade Low Background Laboratory (LBL) is located at Institute of Physics and consists of two interconnected spaces, a ground level laboratory (GLL) and a shallow underground one (UL), at 25 meters of water equivalent. Geographic latitude for the site is 44.86° and longitude is 20.39° while geomagnetic rigidity cutoff is 5.3 GeV.



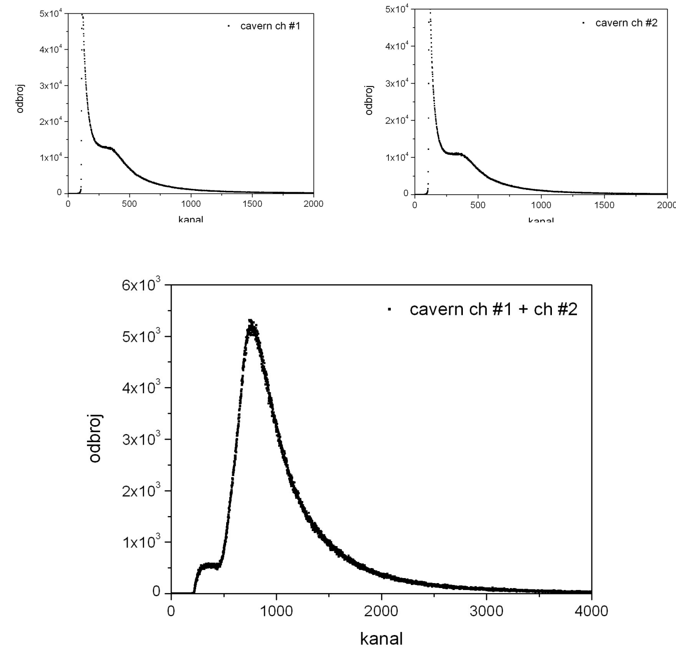
Layout of the Low Background Laboratory

Experimental setup

- Experimental setup consists of two identical sets of detectors and read out electronics, one situated in GLL and the other in UL.
- Each setup utilizes a plastic scintillator detector with dimensions 100cm x 100cm x 5cm equipped with 4 PMT directly coupled to the corners. Flash ADC with 10ns sampling is used for read out.



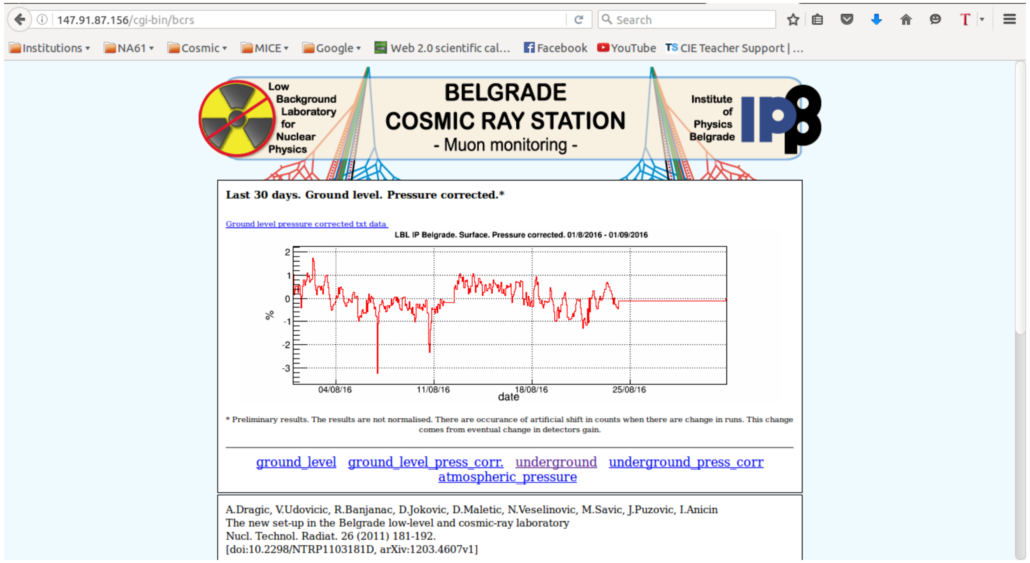
Experimental setup scheme



Single summed diagonal and coincidence spectra

Significance of meteorological effects

- Meteorological effects on muon component of secondary cosmic rays are well known, with pressure and temperature effect being most dominant.
- Correcting for these effects noticeably increases data usefulness, especially increasing sensitivity to periodic and aperiodic variations of non-atmospheric origin (variations of primary cosmic rays, different heliospheric processes, etc.)
- In Belgrade Low Background Laboratory continual measurements utilizing described setup started in April of 2008 for the GLL and in November of 2008 for the UL, and with some interruptions are still ongoing. Base time resolution for integrated count is 5 minutes but time resolution of 1 hour is also often used in analysis. Link to Belgrade cosmic ray station can be found on the following address: *http://www.cosmic.ipb.ac.rs/*



Pressure effect

- Barometric effect is defined by the following equation: $\left(\frac{\delta I}{I}\right)_P = \beta \cdot \delta P$

  where $\delta I/I$ is the normalized variation of muon flux intensity, β is barometric coefficient and δP is pressure variation. Pressure variation is calculated as $\delta P = P - P_B$, where P is current pressure and P_B is base pressure value.

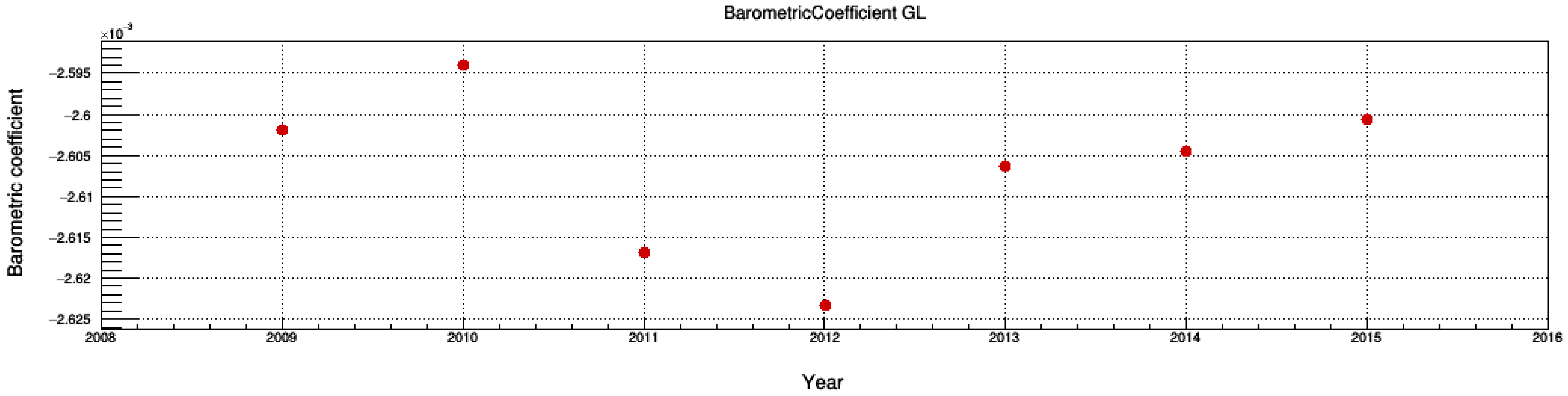
- Since no in situ pressure measurement was performed prior to 2015, current pressure values have mostly been acquired from official meteorological measurements performed by Republic Hydrometeorological Service of Serbia as well as from Belgrade airport meteorological measurements. In all, data from 5 different stations was used. All pressure data was normalized to Belgrade main meteorological station.

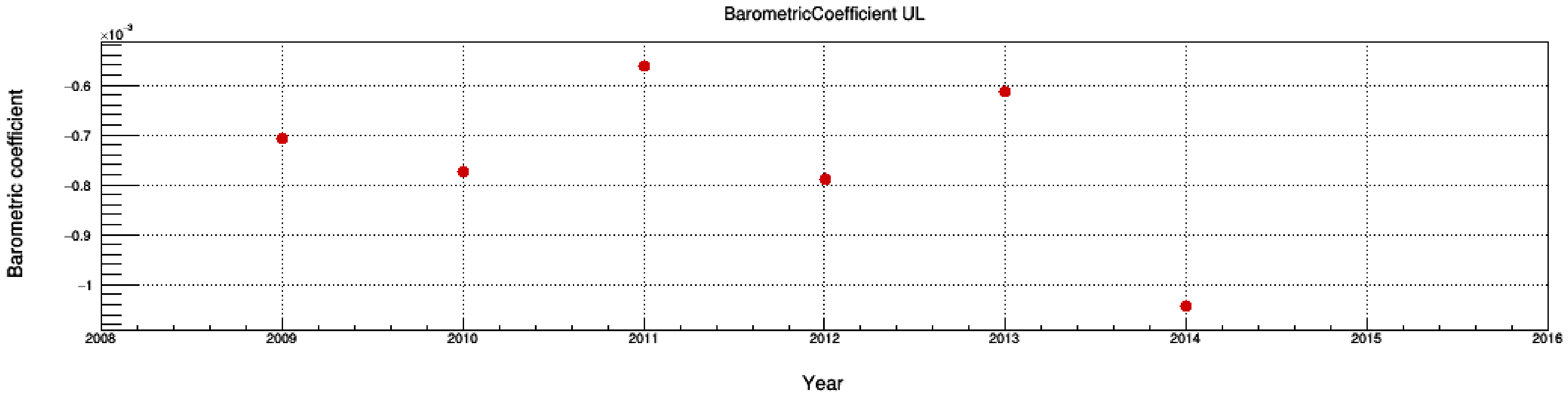
- Stations were sorted according to geographical proximity and consistence of data. Unique pressure time series was composed by using data from the first station with available pressure entries for a given hour. Linear interpolation was then performed and pressure values were sampled with 5 minute step.

- Normalized variation of muon flux intensity vs. pressure variation was plotted for each year. Only data for the 5 geomagnetically most quiet days of each month were taken into account (selected from International Quiet Days list). Barometric coefficient for each year was determined from linear fits of these plots.

Pressure effect

- Yearly values for barometric coefficients for Ground Level Laboratory and Underground Laboratory





Temperature effect

- Temperature effect on hard muons is well known and there are several methods developed to describe and correct for it. Method we used was integral method, where normalized variation of muon flux dependence on temperature variation is described as:

$$\left(\frac{\delta I}{I}\right)_T = \int_0^{h_0} \alpha(h) \cdot \delta T(h) \cdot dh$$

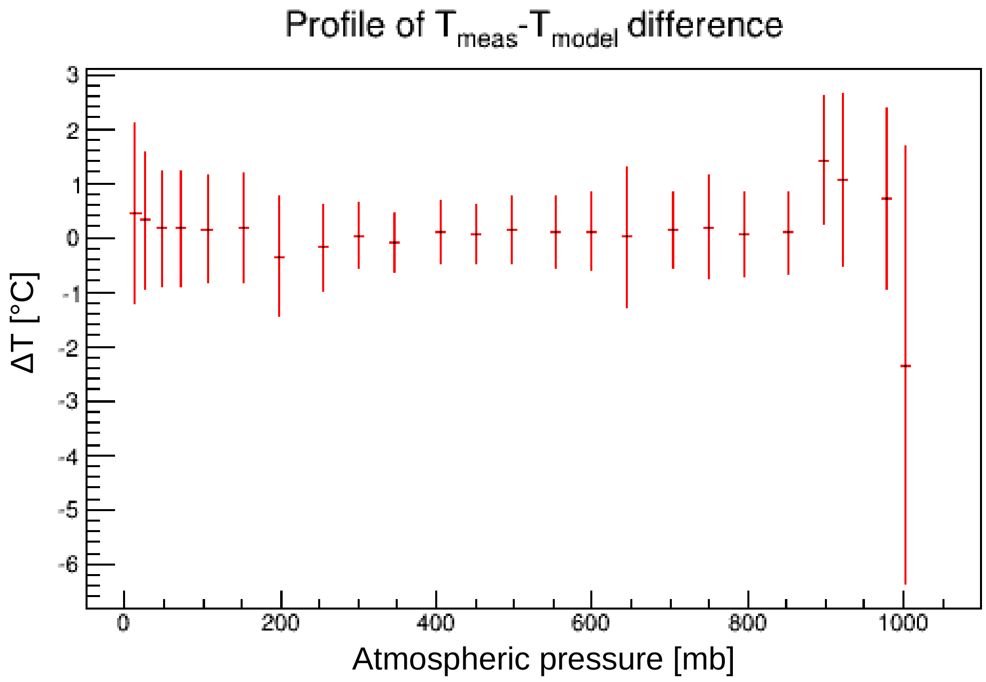
  α(h) being temperature coefficient density and temperature variation calculated as

  $\delta T = T - T_B$.

- To correct for temperature effect using formula above it is necessary to have most complete information about atmospheric temperature profile for a given geographical location as well as to know temperature coefficient density function. Temperature profile measurements performed by local meteorological service are not done on consistent basis but more detailed information is available from meteorological models. One such model is GFS (Global Forecast System) that, among other data, provides temperatures for 25 isobaric levels for a given geographical location with latitude/longitude precision of 0.5 degrees.

Temperature effect

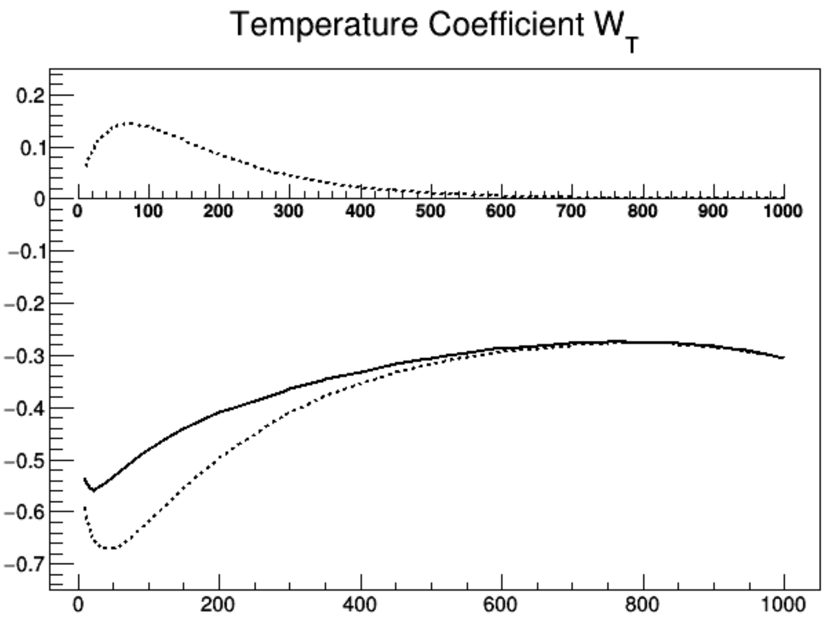
- Following plot shows distribution of difference between modeled and temperatures measured by meteorological balloons for Belgrade (where such data was available)



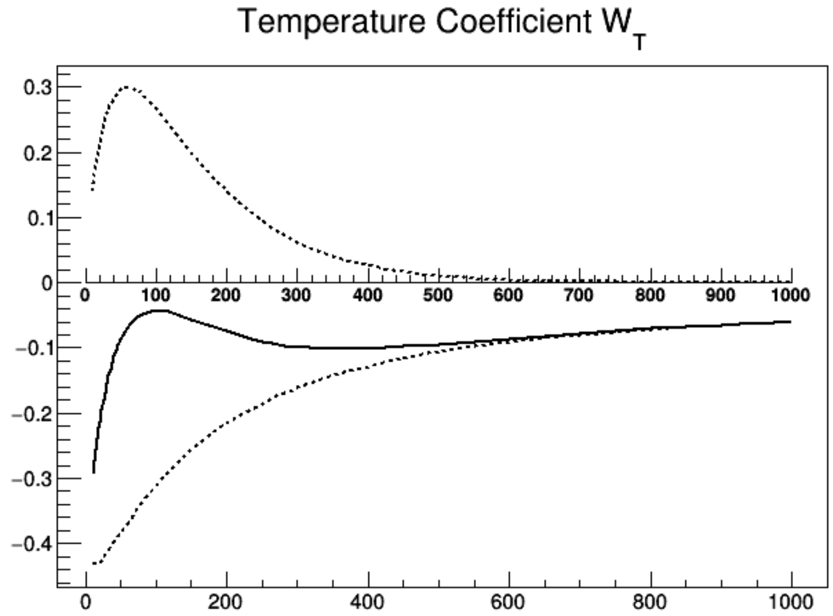
- Measured and modeled values seem to be in fairly good agreement except for the lowest isobaric level. That is why for this level temperature from local meteorological stations was used, treated in the same manner as described for local pressure data
- Time resolution for modeled temperatures is 6 hours so interpolation was performed using cubic spline and temperature values were sampled in 5 minute steps.

Temperature effect

- Temperature coefficient density functions for ground level and depth 25 m.w.e



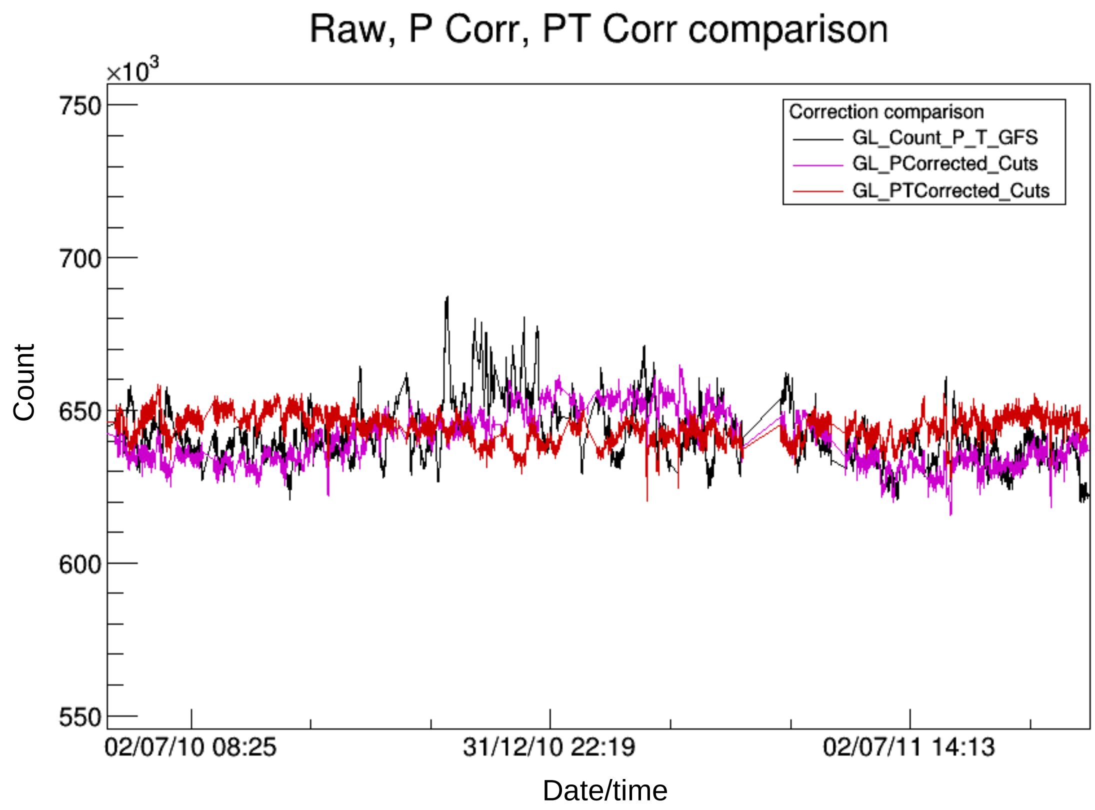
ground level



25 m.w.e

PT corrected time series

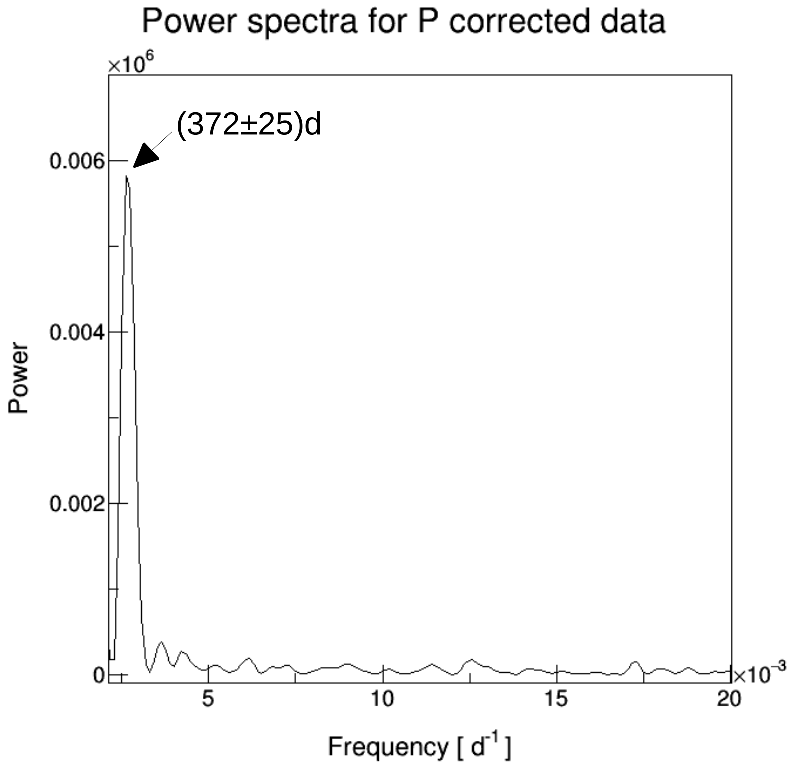
- Ground Level Laboratory raw (black), pressure corrected (magenta) and PT corrected (red) muon count time series for a selected period.



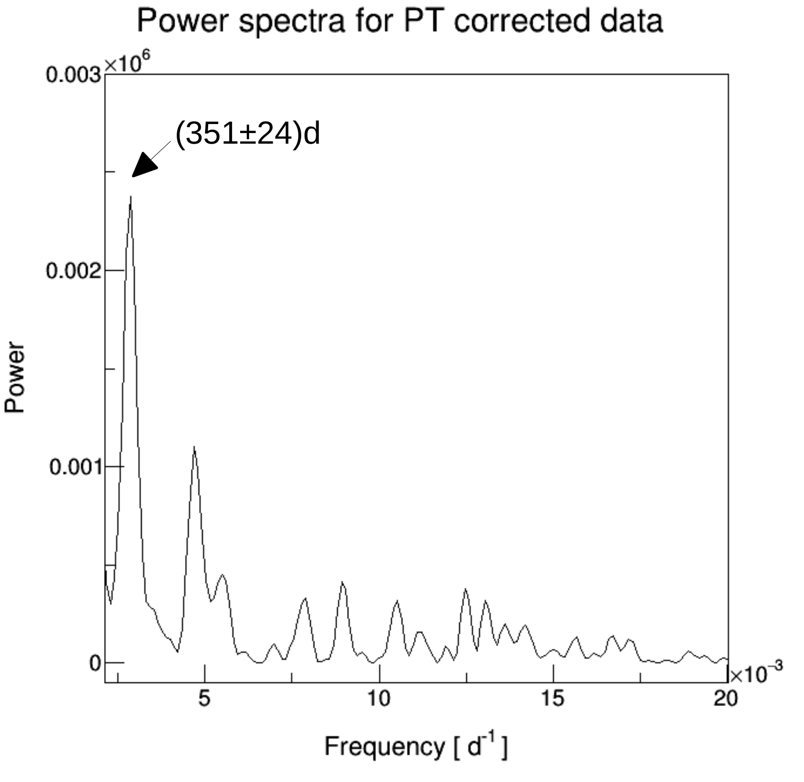
- It would seem that pressure correction successfully removes aperiodic pressure induced fluctuations while temperature correction most significantly affects annual variation induced by atmospheric temperature variations.

Spectral analysis

- Spectral analysis can give us further insight into effect of temperature correction on annual variation of muon count (presented for GLL data)



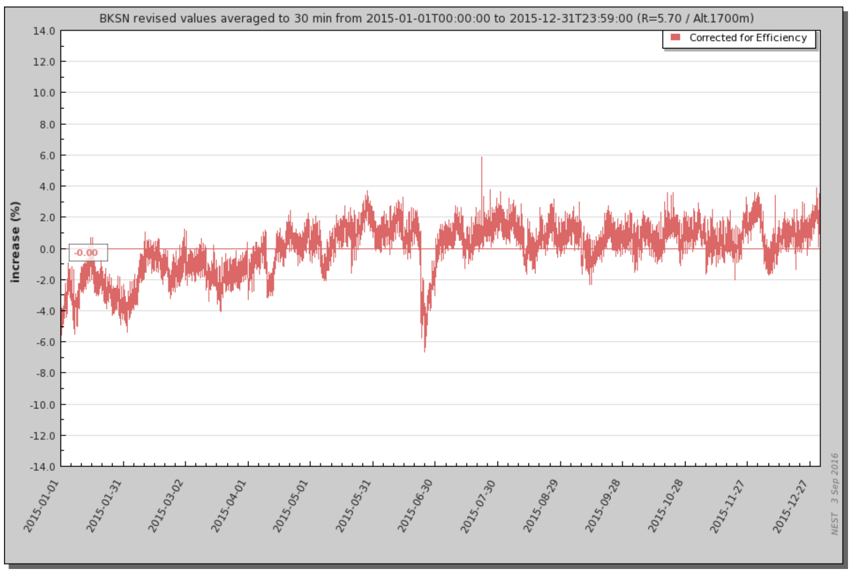
Pressure corrected data



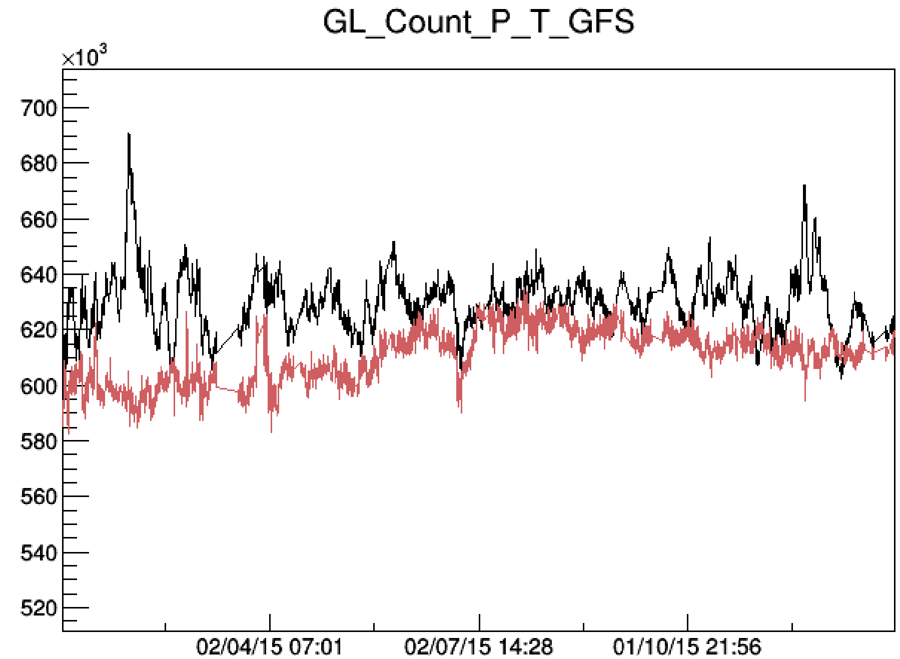
Pressure/temperature corrected data

Neutron monitor correlation

- Possible validation for correction procedure would be agreement of pressure/temperature corrected muon count time series with neutron monitor data. BAKSAN neutron monitor was selected as a possible reference. BAKSAN neutron monitor and GLL raw and PT corrected data comparison for year 2015 is shown bellow



BAKSAN neutron monitor data



GLL raw and PT corrected data

- More detailed correlation with neutron monitors to follow

Conclusion

- Corrections for temperature and pressure effect are essential for muon data gathered at Belgrade LBL.
- Atmospheric temperature profile for Belgrade seems to be adequately modeled by GFS.
- Temperature correction utilizing integral method seems to give acceptable results (while quality can still be further improved). Also, other methods could be applied and results compared.
- Muon flux data after pressure and temperature corrections has increased sensitivity to periodic and aperiodic effects of non-atmospheric origin.
- Preliminary comparison with neutron monitor data supports this claim with more detailed correlation analysis to follow in the future.

Acknowledgements

We are very grateful to late prof. Ivan Aničin. His enthusiastic contributions, deep insights, valuable advice and kind nature will be missed.