Combined analysis of muon and neutron results from Ny Ålesund: preliminary results

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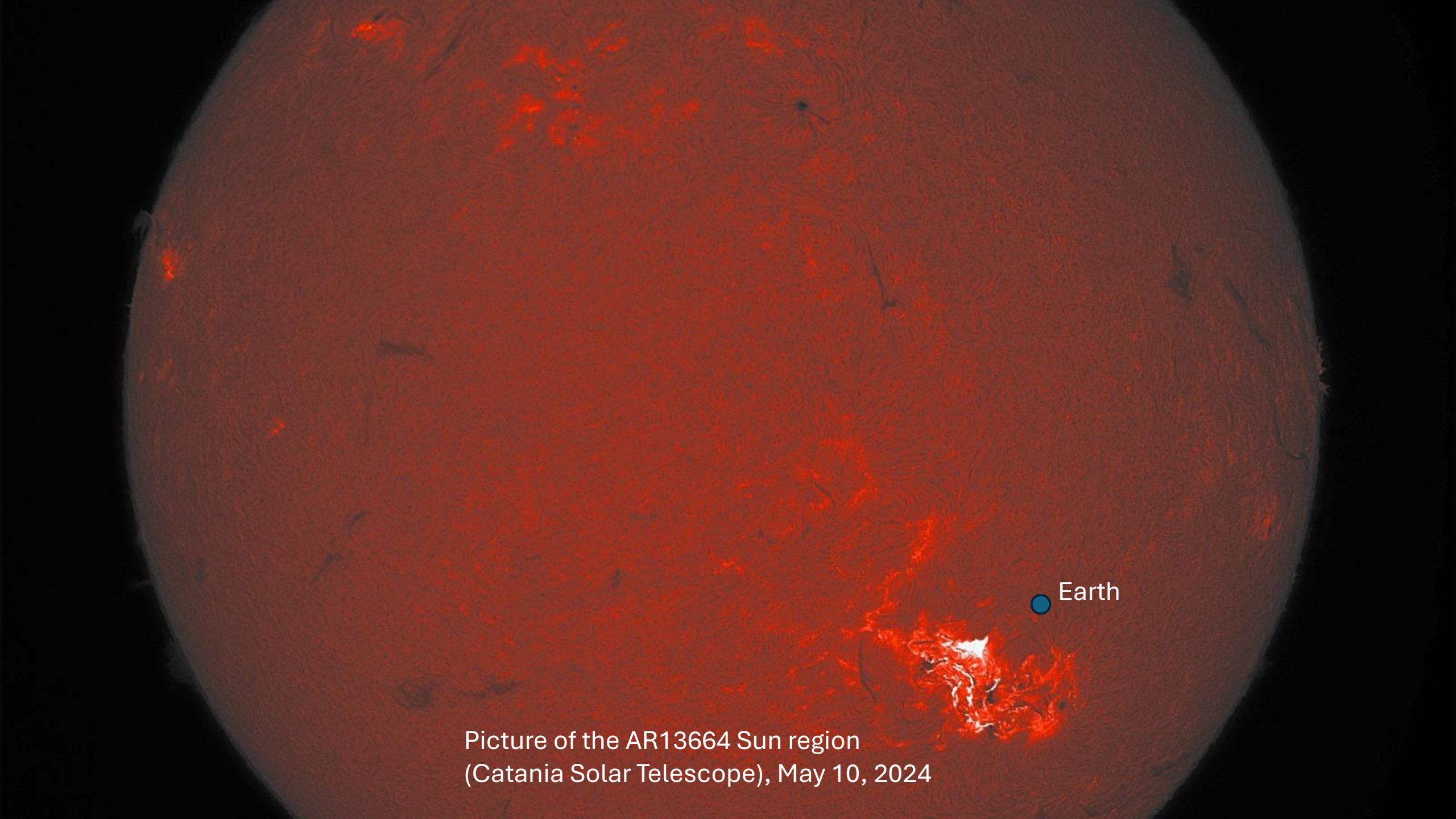
in collaboration with L.Hertle & M.Schrön (Leipzig)

A series of intense events, with solar flares and geomagnetic storms occurred since May 10, 2024

This was the largest in the last 20 years

NB: A new large solar flares just occurred on October 5

Precursor of the event: Sun region AR13664, with huge dimension (200,000 km, 15 times the Earth), producing several intense flares



Picture of the AR13664 Sun region
(Catania Solar Telescope), May 10, 2024

Solar flares during mid-May 2024: complex evolution after the first event

Km/s hours

ID	GOES peak time	GOES class	Location	CME speed	Travel time*	Arrival time*
1	2024-05-08 05:09	X1.0	S22 W11	511	82:08	05-11 15:17
2	2024-05-08 21:40	X1.0	S20W17	947	44:19	05-10 17:00
3	2024-05-09 09:13	X2.2	S20 W24	1226	34:14	05-10 19:27
4	2024-05-09 17:44	X1.1	S17 W28	1019	41:11	05-11 10:53
5	2024-05-10 06:54	X3.9	S17 W34	1006	41:43	05-12 00:37
6	2024-05-11 01:23	X5.8	S17 W44	1512	27:45	05-12 05:08
7	2024-05-11 11:44	X1.5	S19 W60	No CME	--	--
8	2024-05-12 16:26	X1.0	S20 W75	No CME	--	--
9	2024-05-14 02:09	X1.7	S17 WL	929	--	--
10	2024-05-14 12:55	X1.2	S17 WL	792	--	--
11	2024-05-14 16:51	X8.7	S18 WL	1988	--	--
12	2024-05-15 08:37	X3.4	S18 WL	1724	--	--

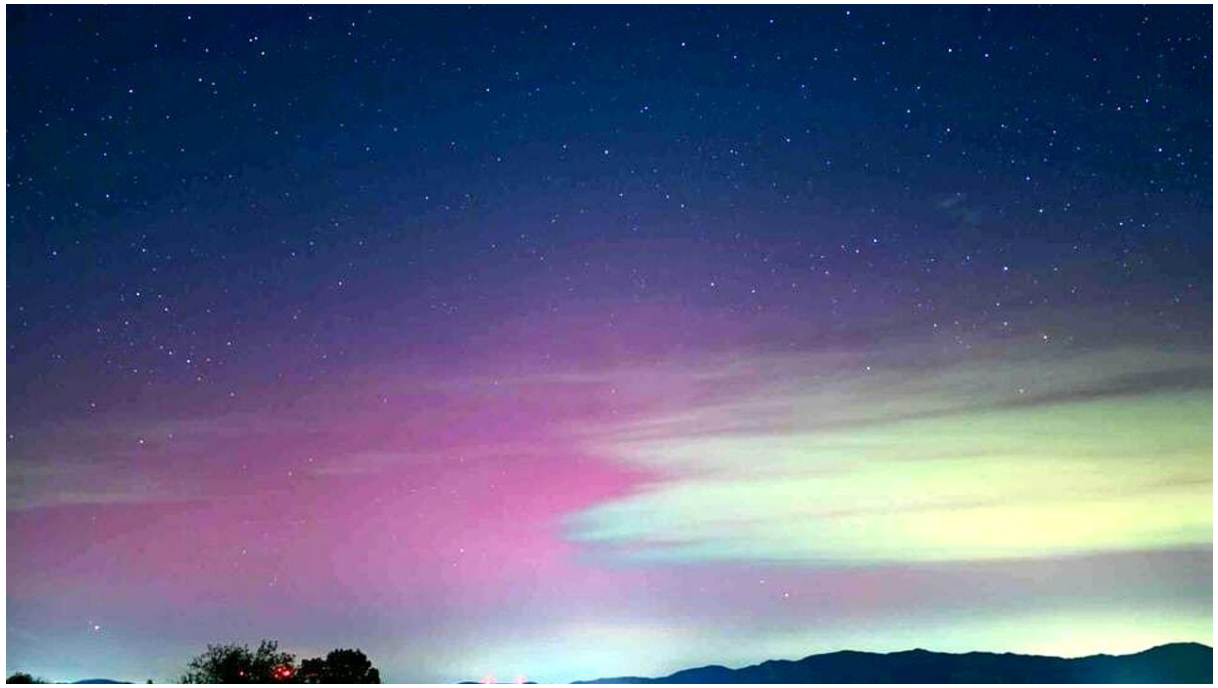
Major effects:

- Negative impact on ground-based broadcasting and radio shortwave communications
- GPS navigation was also affected in a few cases
- Some weather satellites stopped transmitting data.
- Starlink fleet of low-orbiting satellites, some degradation in their performance

and also

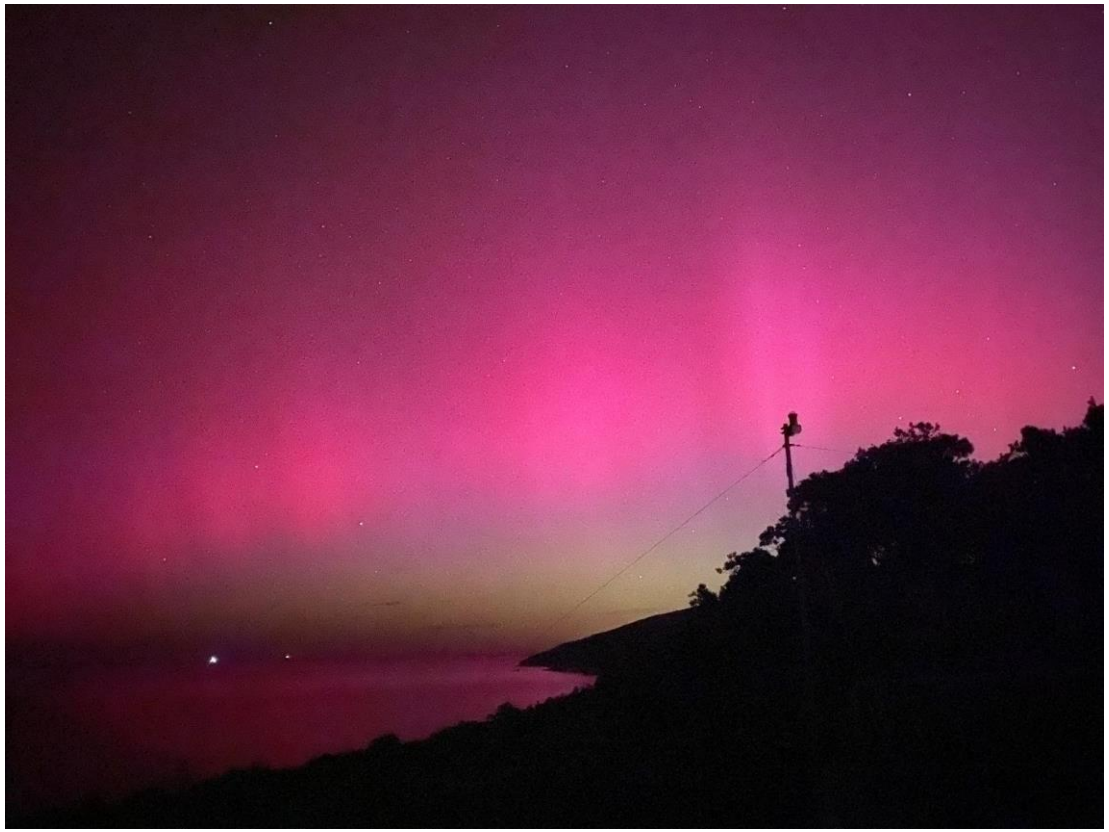
- Aurorae borealis (Northern lights)
- Forbush decrease in cosmic ray flux at ground

Aurorae borealis seen even at small latitudes over the world



Aurora borealis on Mt.Etna (Lat. 37° N)

Aurora borealis in Tuscany



And now, our main task: to investigate the Forbush variation in cosmic ray flux at high latitudes

Possibility to include in this analysis

- **Muon data from POLA-R detectors in Ny-Ålesund**
- **Neutron data from the Barentsburg Neutron Monitor, very close to Ny-Ålesund**
- **Neutron data from the Bonner Sphere Spectrometer in Ny-Ålesund**
- **Epithermal/thermal neutron data from additional sensors in the same area**

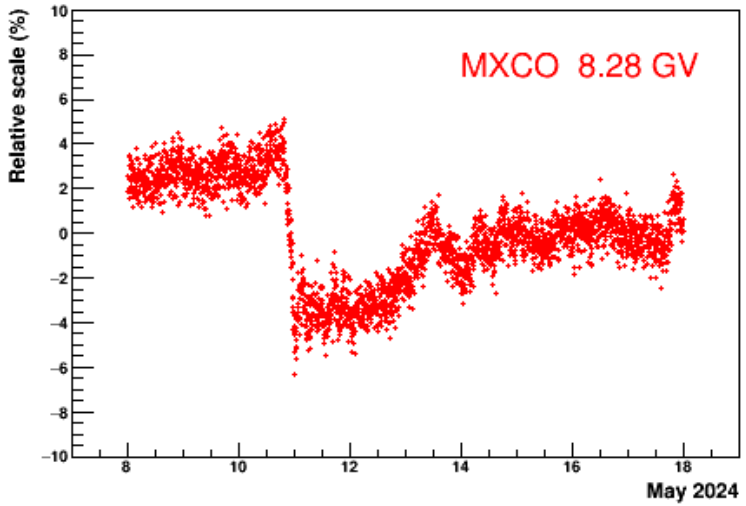
Last two datasets come from a close collaboration with L.Hertle and M.Schrön (Leipzig)

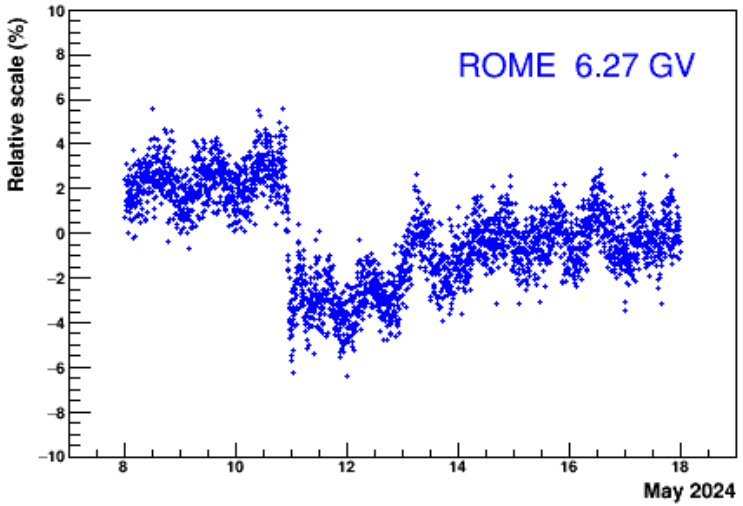
18 NM-64 detectors (proportional counters surrounded by moderator and lead (sensitive to CR 0.5-20 GeV)

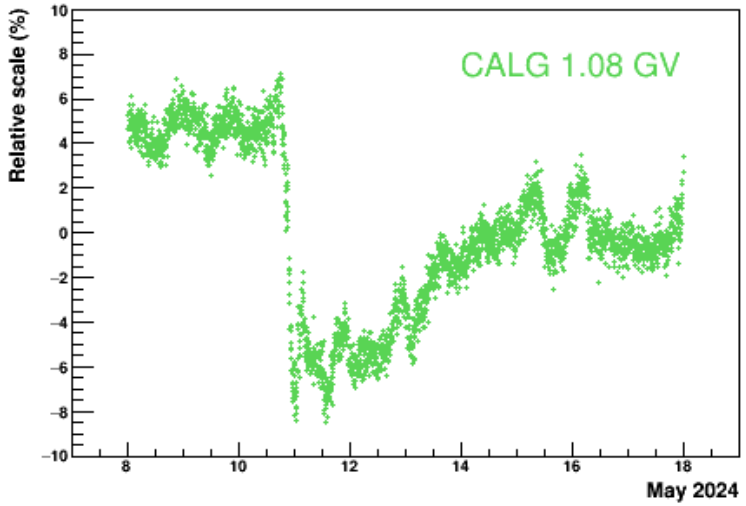
Location of Barentsburg with respect to Ny Ålesund

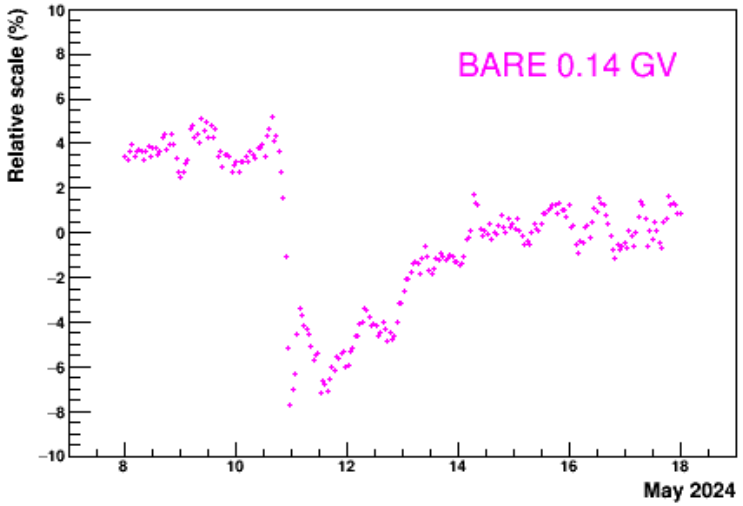
Neutron monitors distributed over the world are usually employed to investigate variations in the cosmic ray flux due to solar events

The amplitude of the decrease also depends on the geomagnetic cutoff of the site.



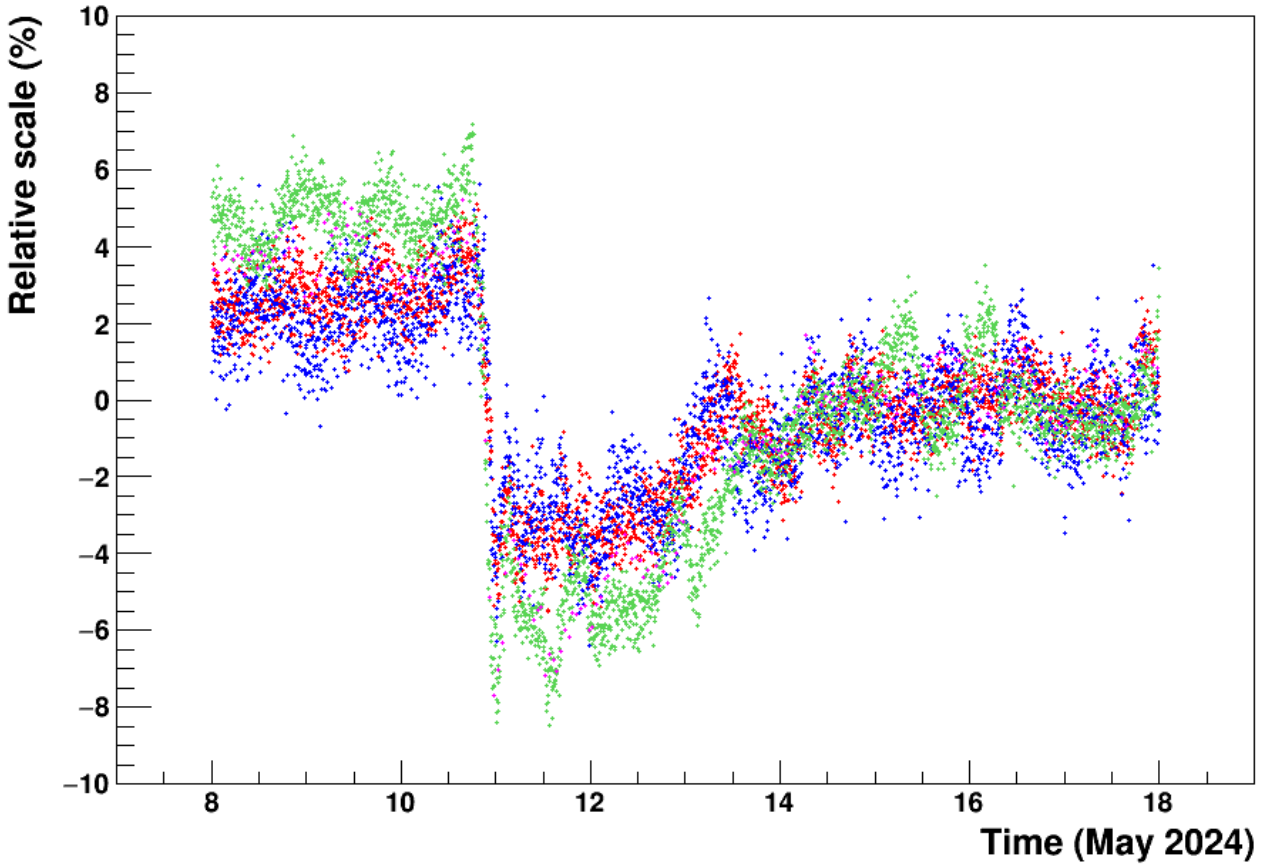






4 different NM stations with different geomagnetic cutoff

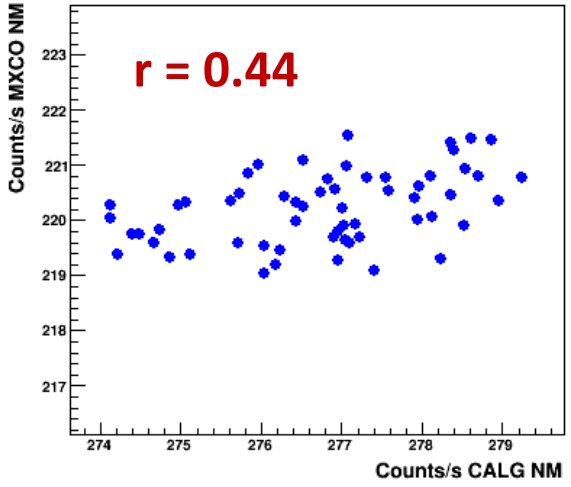
Similar trend, with different amplitudes observed in the various stations

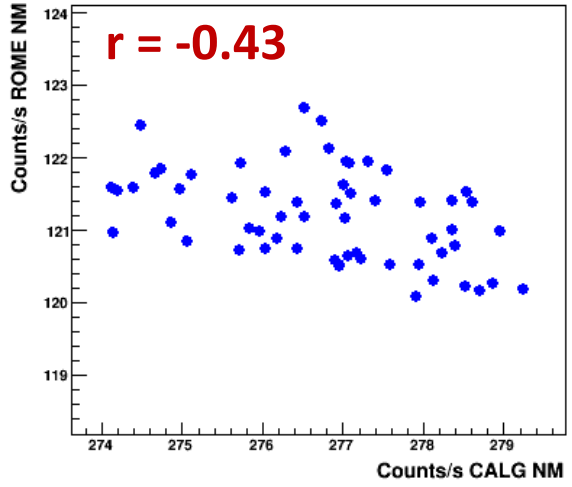


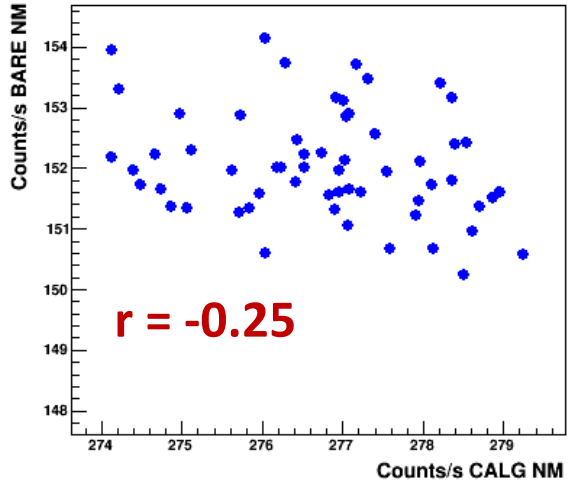
Correlation between the 4 NM detectors (6 pairs) studied in the pre-Forbush and during the Forbush periods

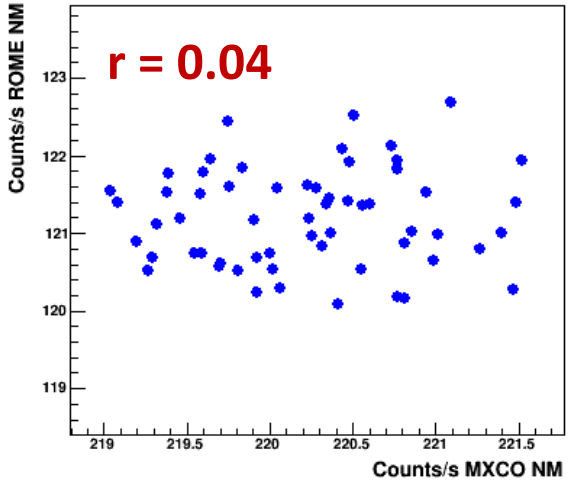
Pre-Forbush period (still to be better defined)

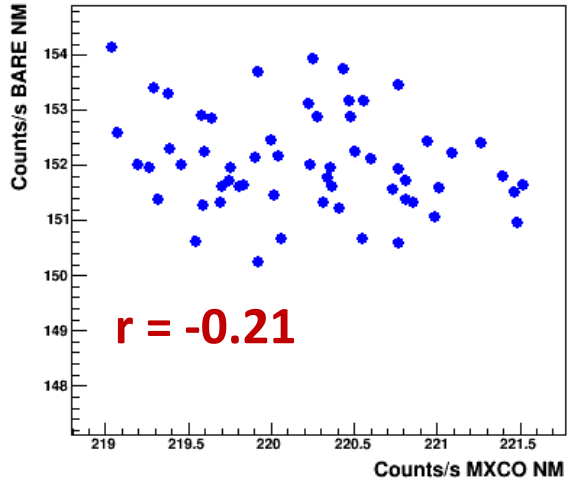
Correlation is not so good in the pre-Forbush period, with large dispersion of correlation coefficients (sometimes even negative…)

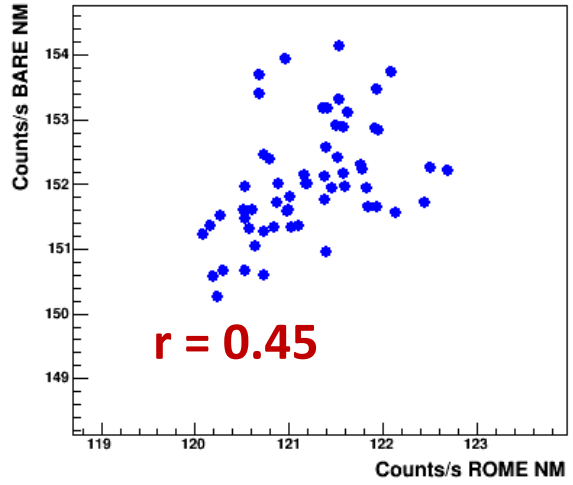










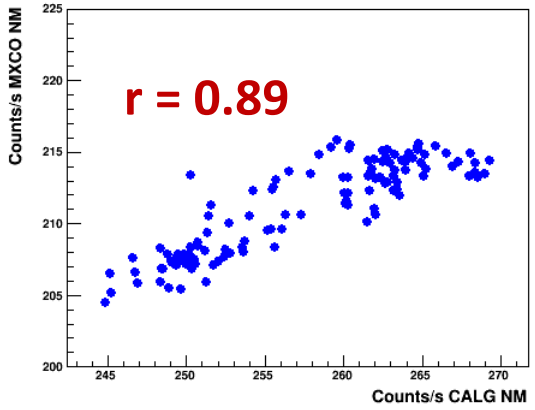


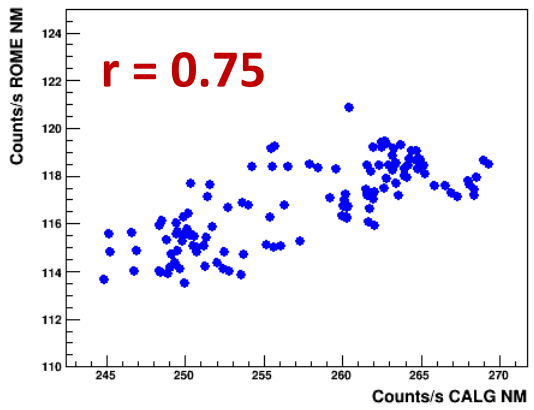
But is very good (coefficients 0.75-0.90) during the Forbush event.

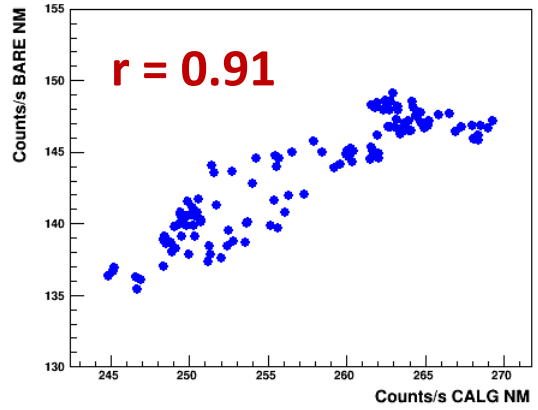
Forbush period (May 10-15)

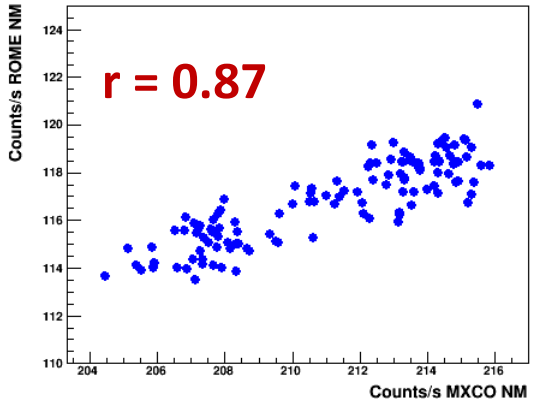
Here, the common origin of the flux variation in different detectors dominate over the statistical fluctuations.

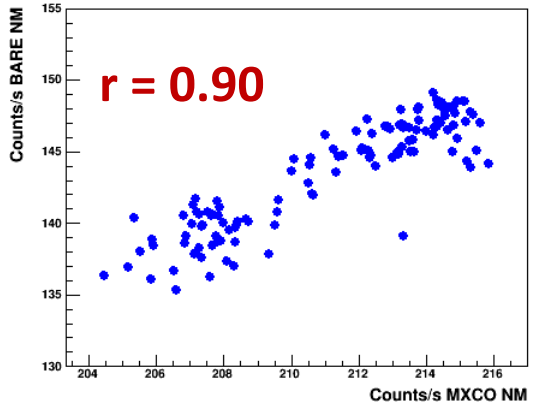
This suggested a method for investigate even muon-neutron correlations

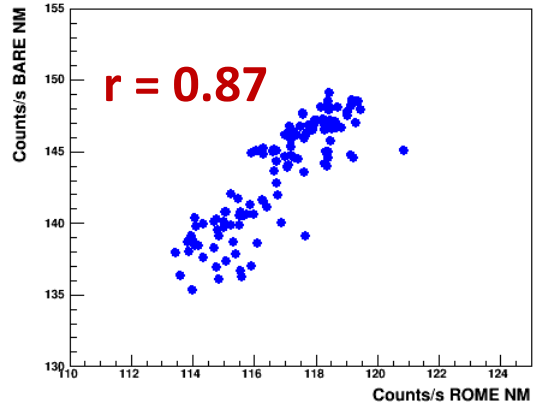




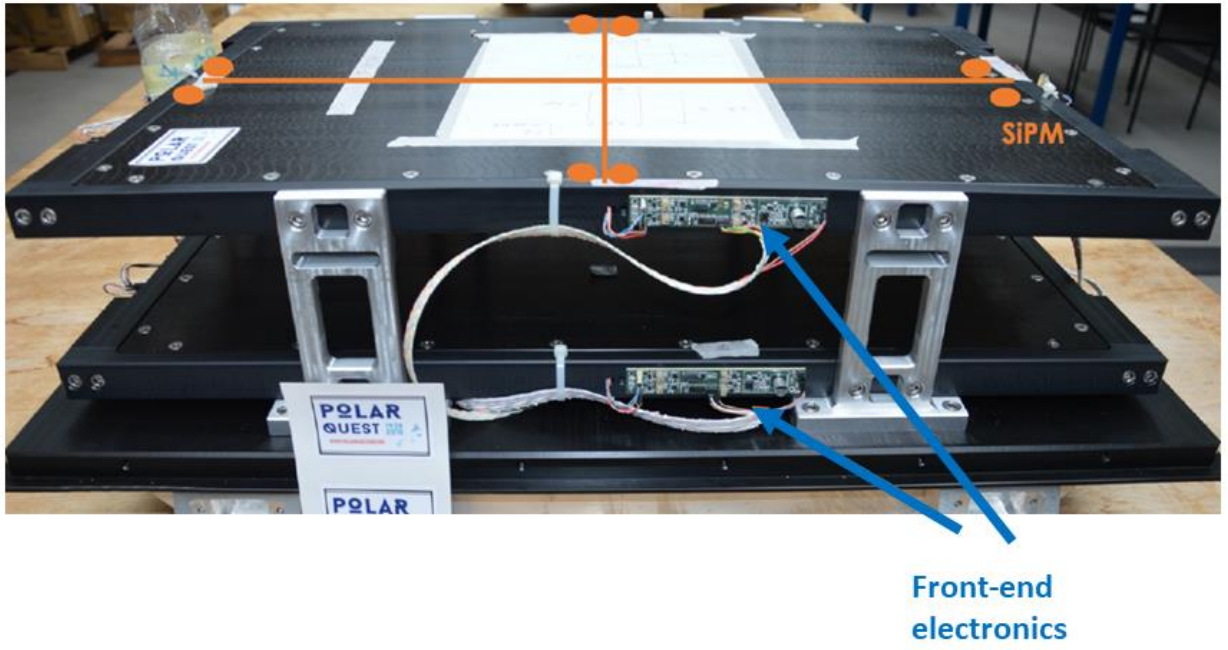






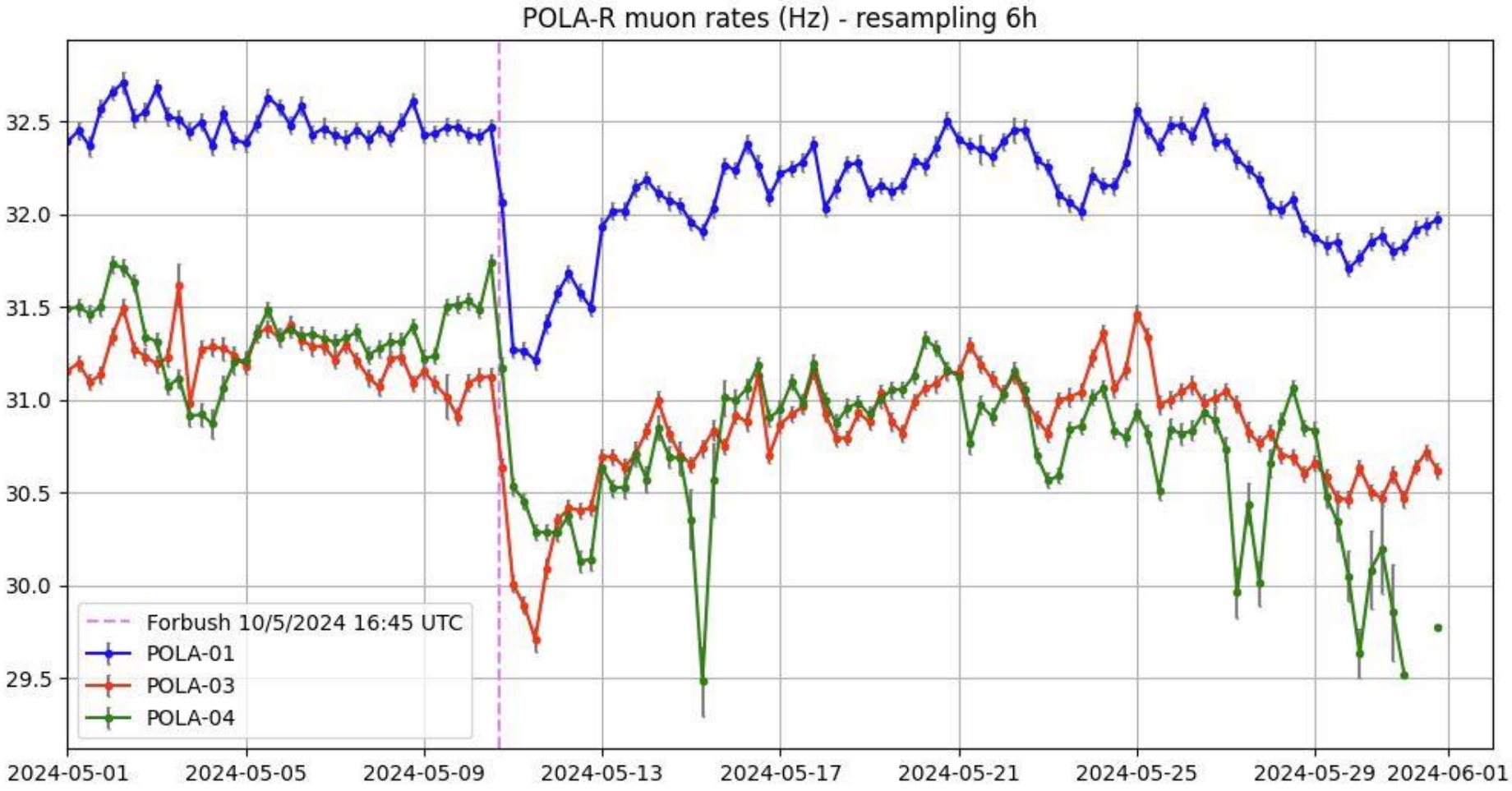


POLA-R detectors made by two segmented (2x2) scintillator planes
3 similar detectors taking data in Ny Ålesund since 5 years
On going analyses of annual periodicity
Detection of extensive air showers by GPS-tagged coincidence events



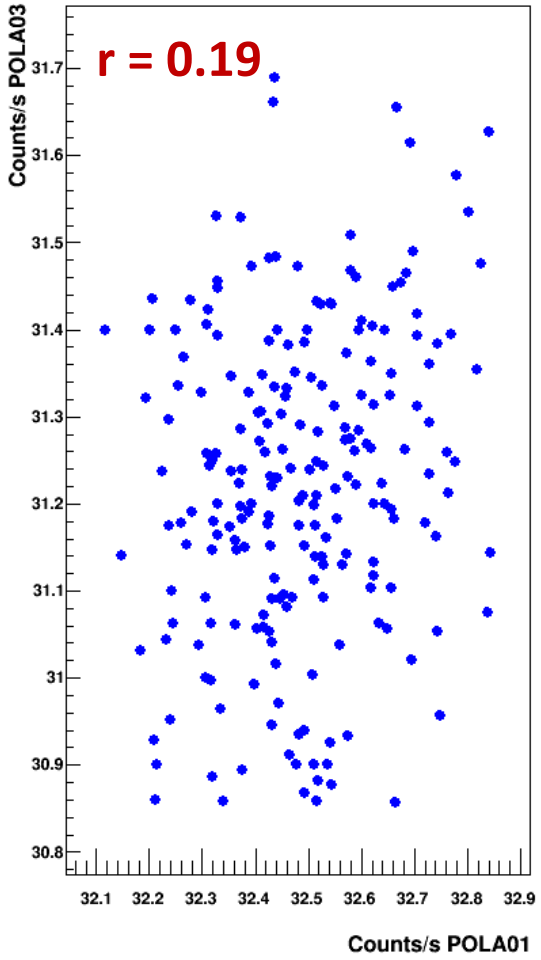
Data from our POLA-R detectors during May 2024 (corrected by pressure variation)

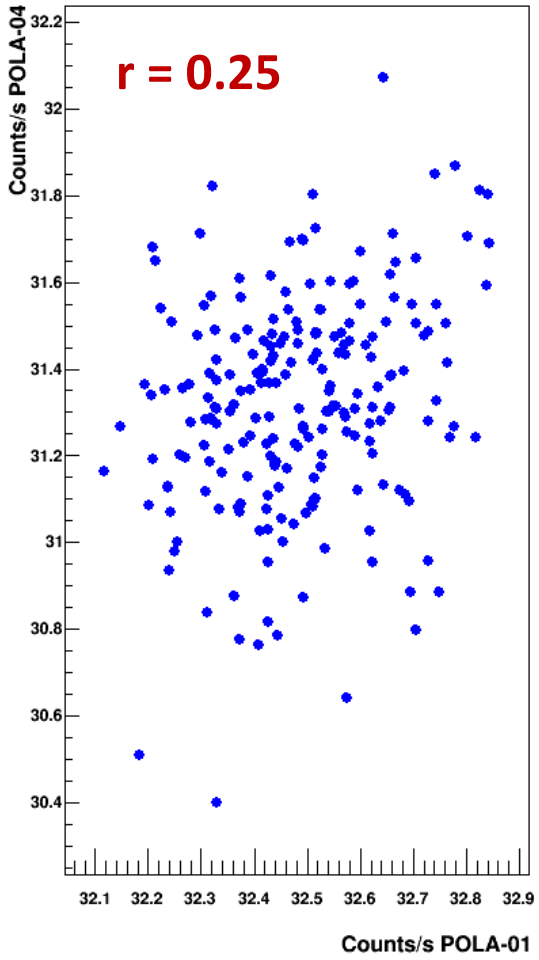
Strong similarity between the three detectors
Some spike in POLA-04 still being checked

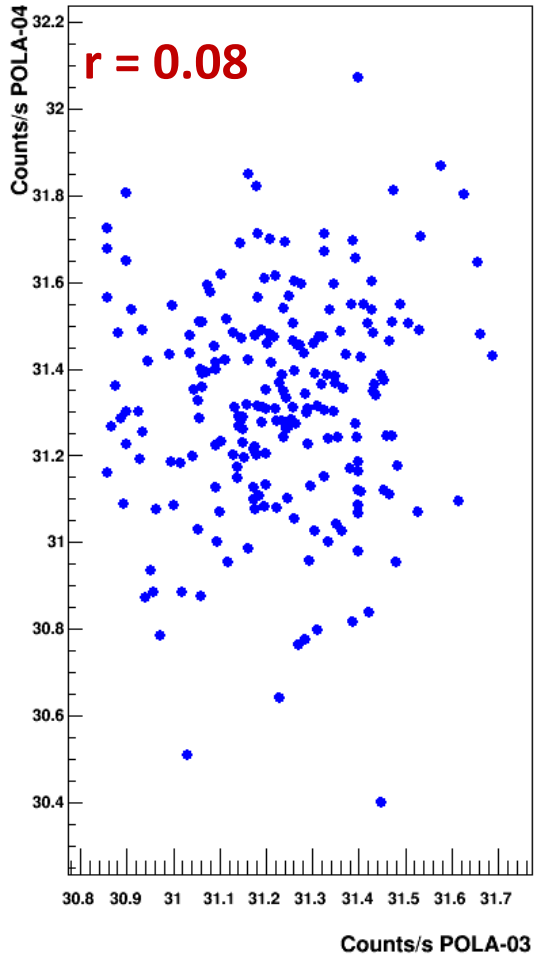


Correlation between the data from POLA-01, -03 and -04 detectors studied in the pre-Forbush period and during the Forbush (1-hour step)

Pre-Forbush period (April 30- May 9)

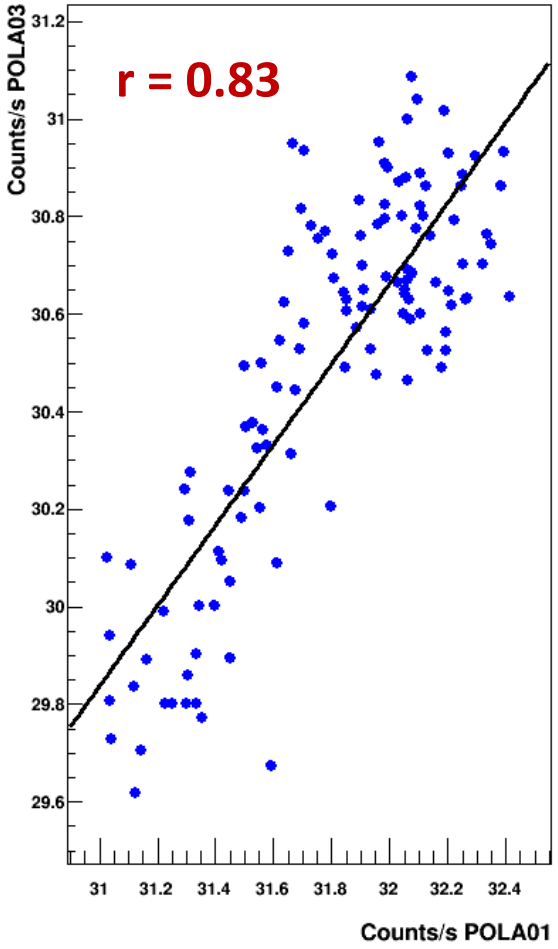


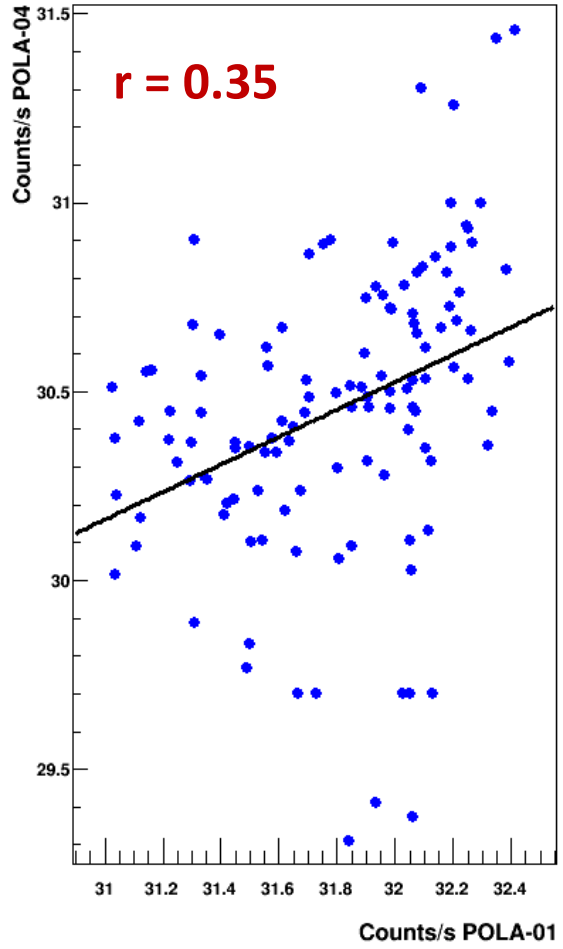


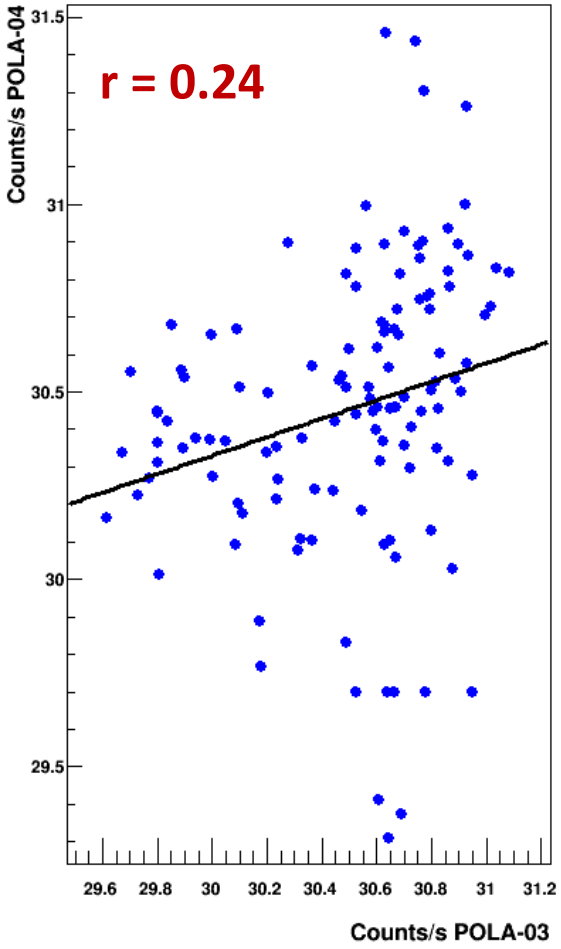


Correlation coefficients are larger during the Forbush period (similar to Neutron Monitors data)

Forbush period (May 10-15)



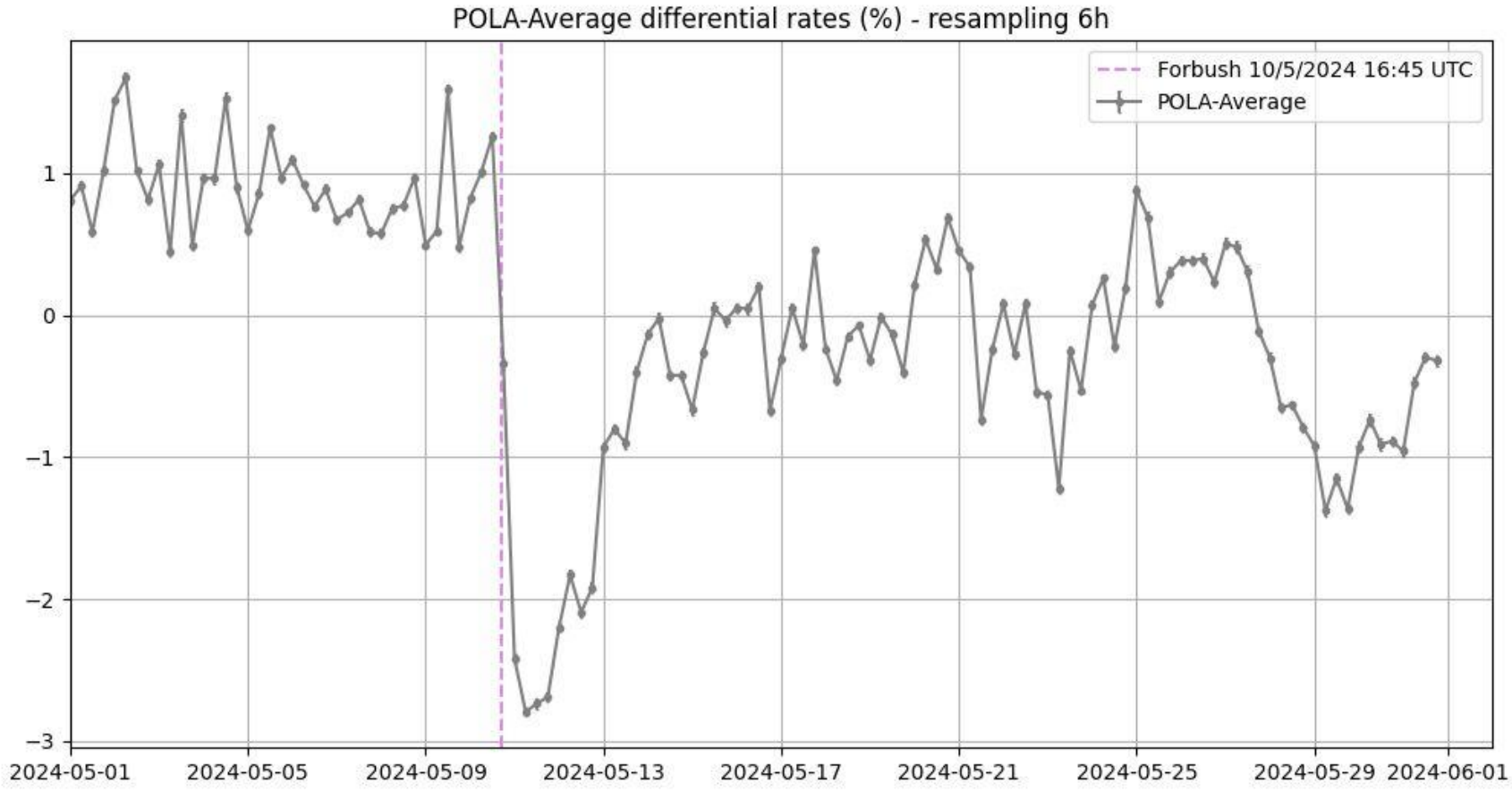




Due to uniformity in the response of the three POLA-R detectors, we may employ their average also to look for correlations to other detectors.

Differential rate with respect to the average over 1-31 May

Amplitude variation around 3%



The topology of the recovery phase is complex in this event, due to the many solar flares and CMEs after May 10th

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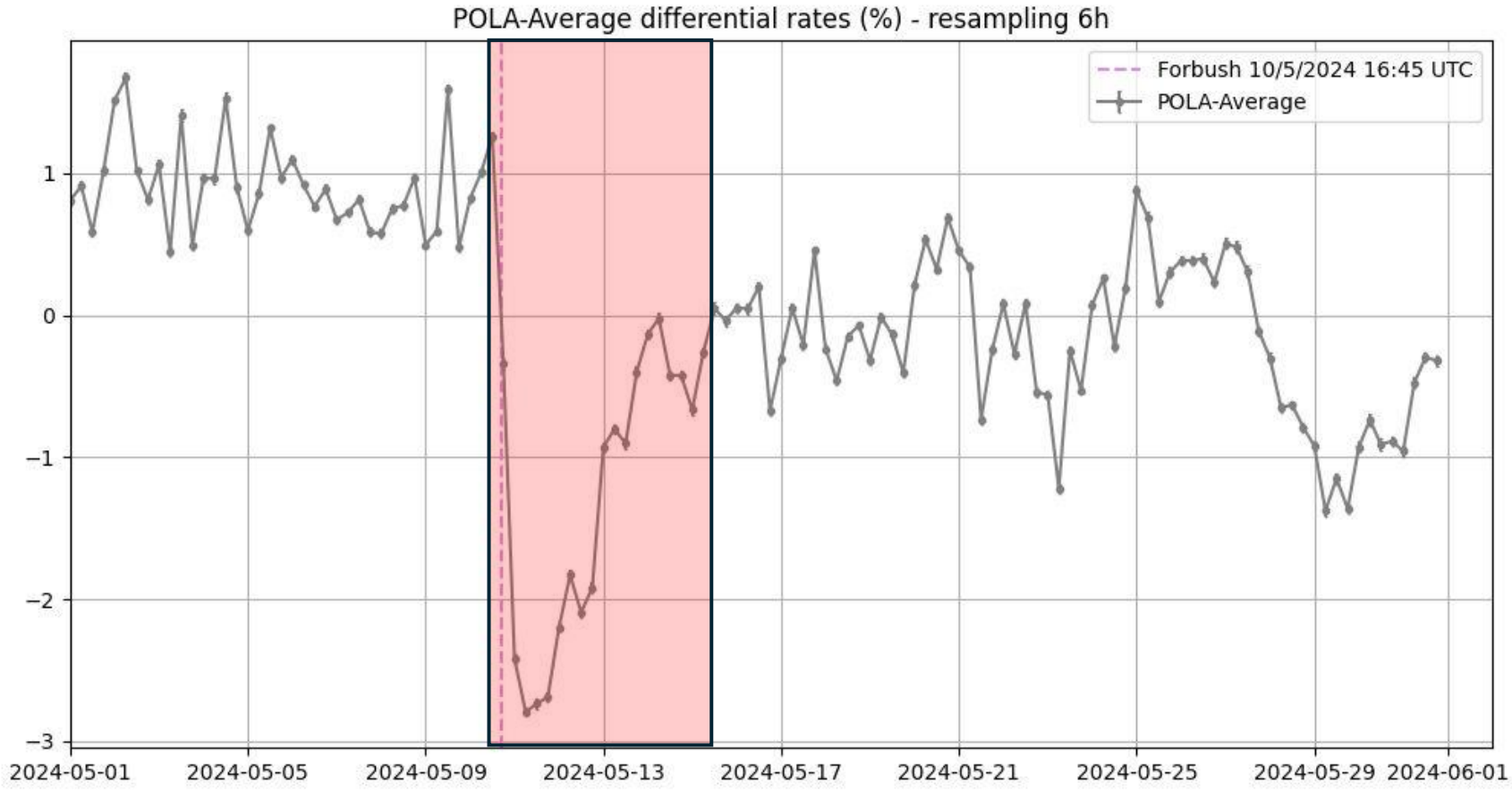

To compare correlation results from different detector combinations we are defining two or more windows for the «quiet» behaviour (pre-Forbush period) and for the Forbush period

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Differential rate with respect to the average over 1-31 May

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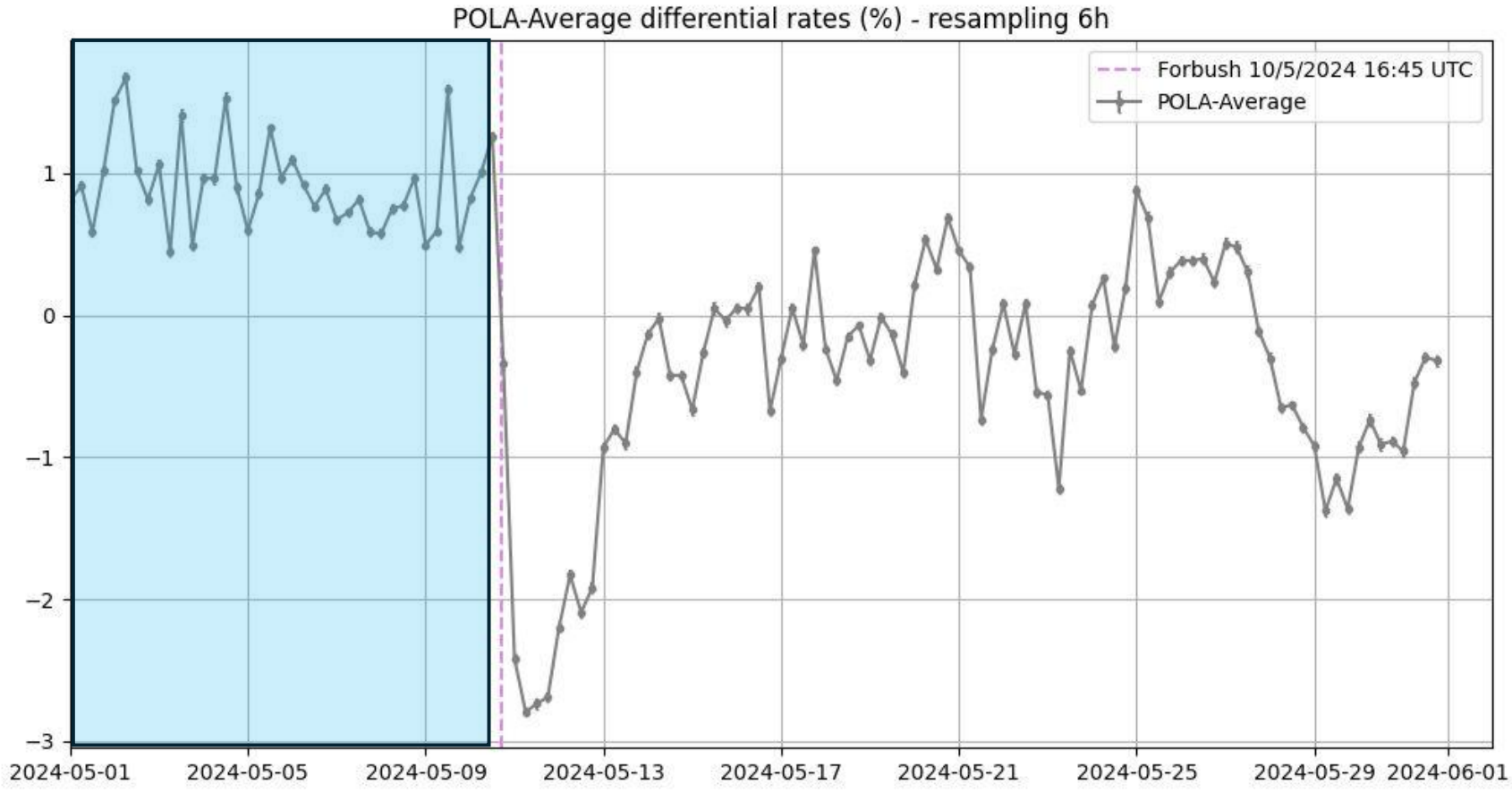
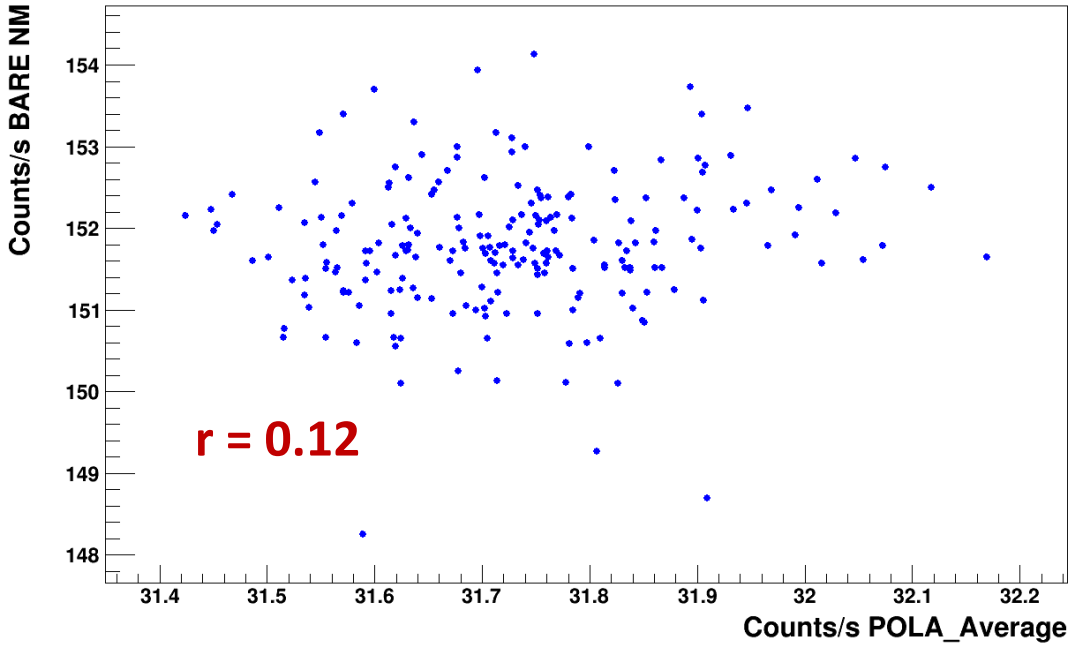


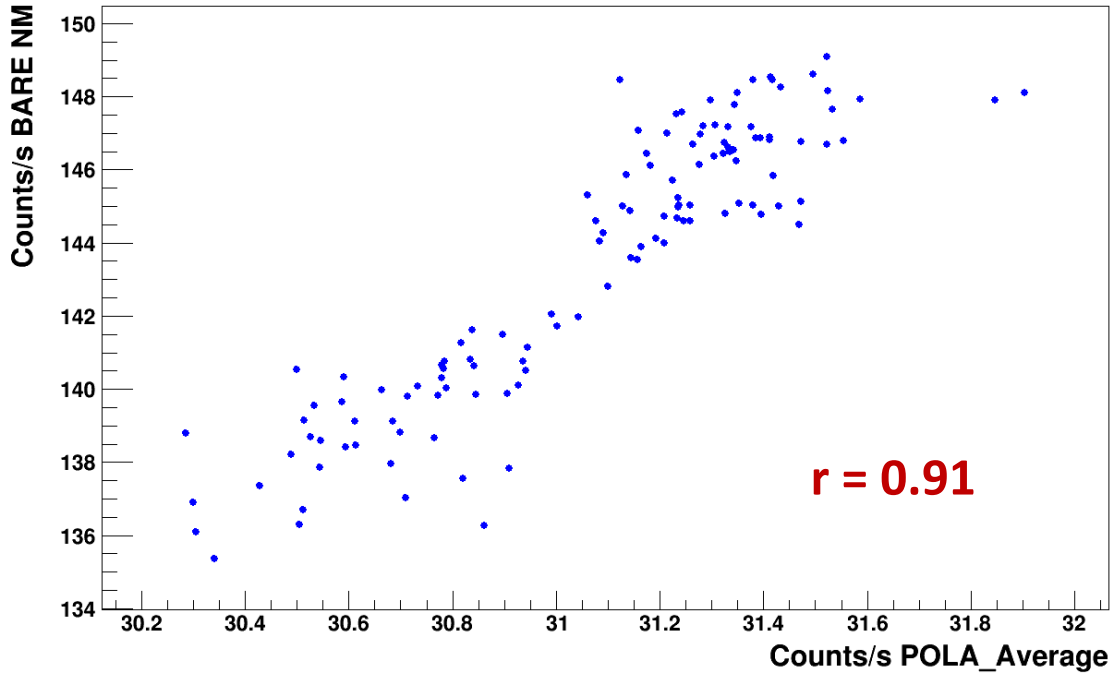
To compare correlation results from different detector combinations we are defining two or more windows for the «quiet» behaviour (pre-Forbush period) and for the Forbush period

Correlation between POLA-R detectors (average) and Barentsburg Neutron Monitor

Pre-Forbush



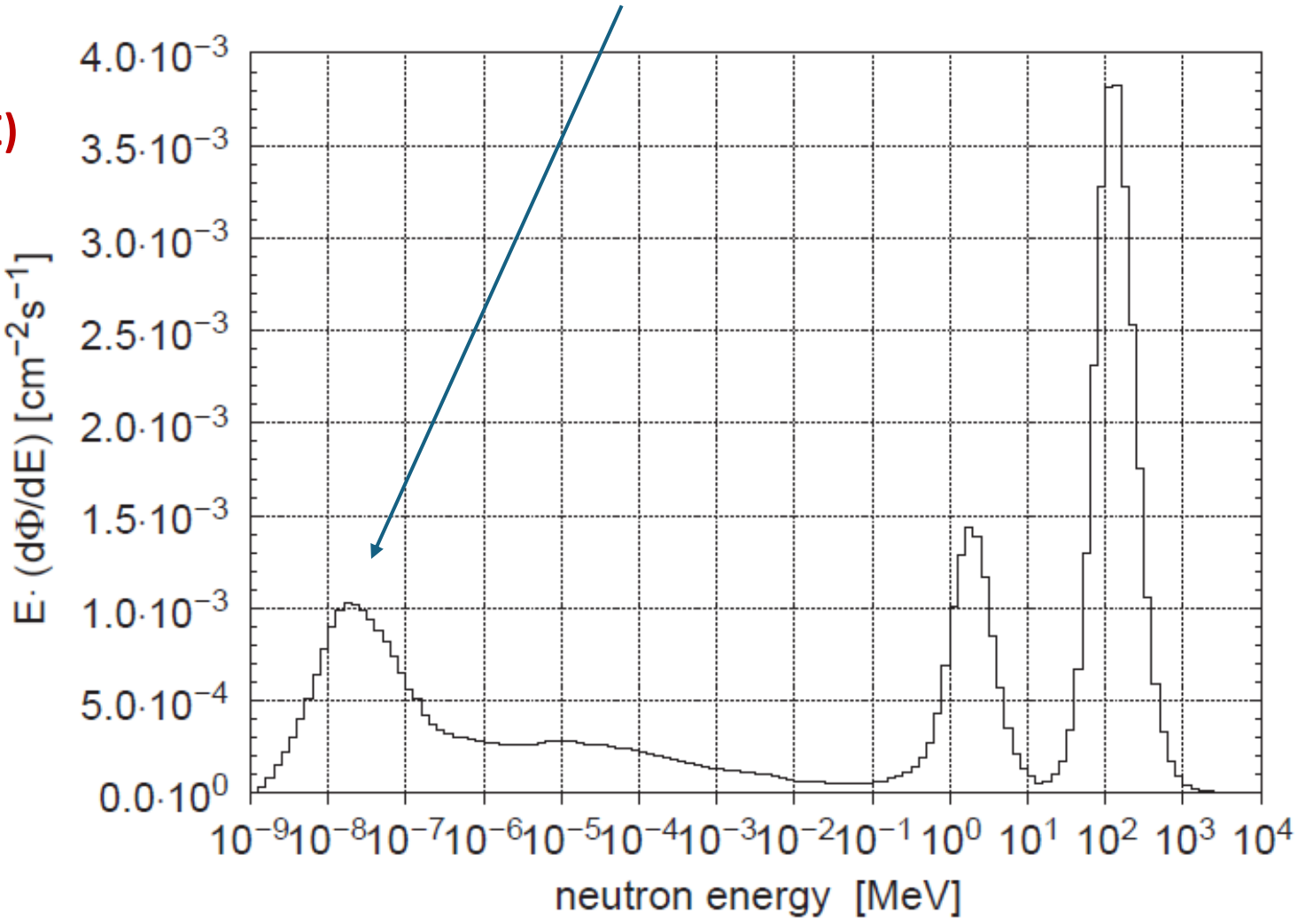
Forbush



Thermal peak (E<0.1 eV)

Neutrons thermalized, resulting from elastic collisions with materials surrounding the detector (floor, environment), with a Maxwell-Boltzmann distribution

Lethargy
E (dϕ/dE)

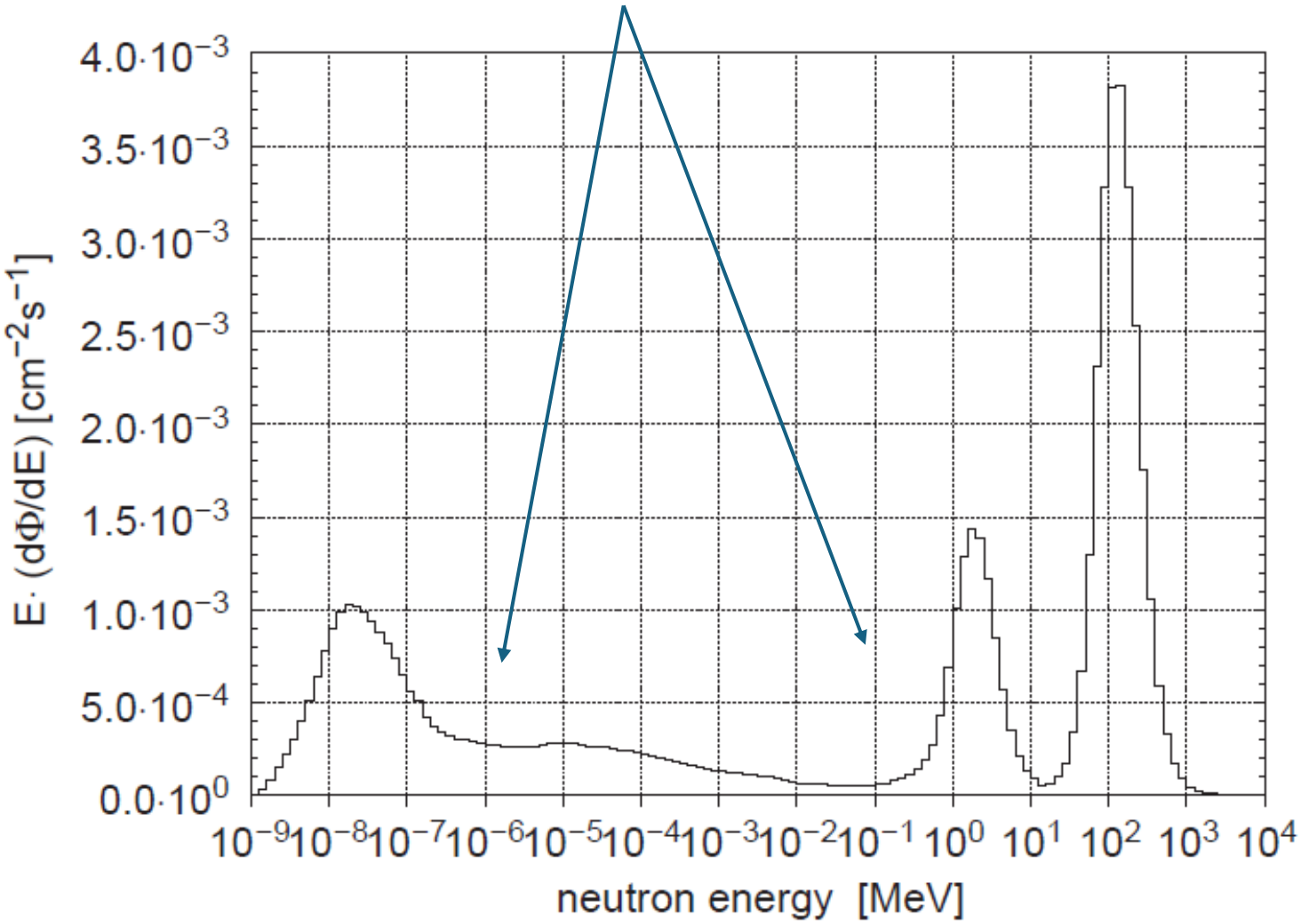


Typical cosmic neutron spectrum

Epithermal region (E< 100 keV)

Neutrons dominated by elastic collisions

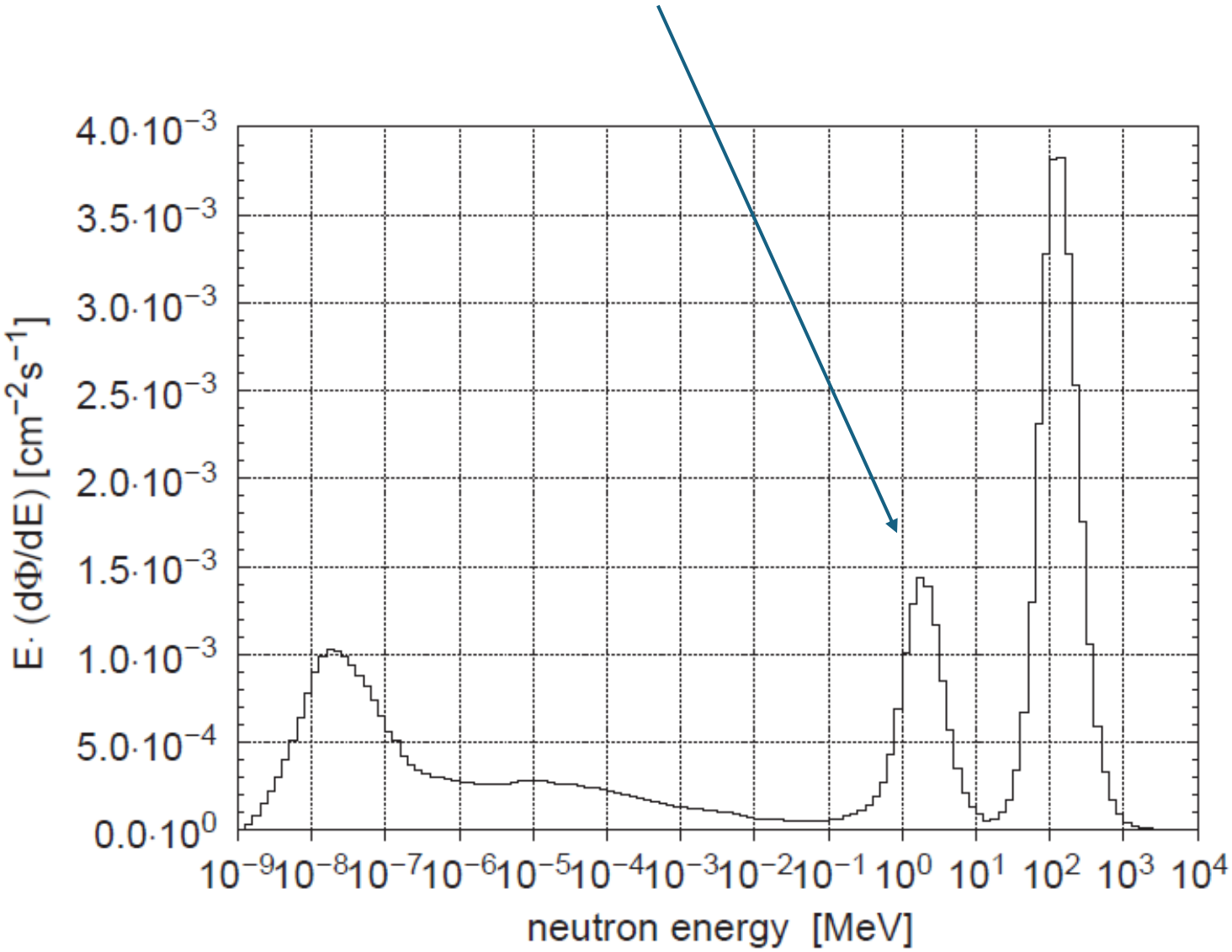
(~1/E energy dependence)



Typical cosmic neutron spectrum

Fast neutrons peak (E=1-2 MeV)

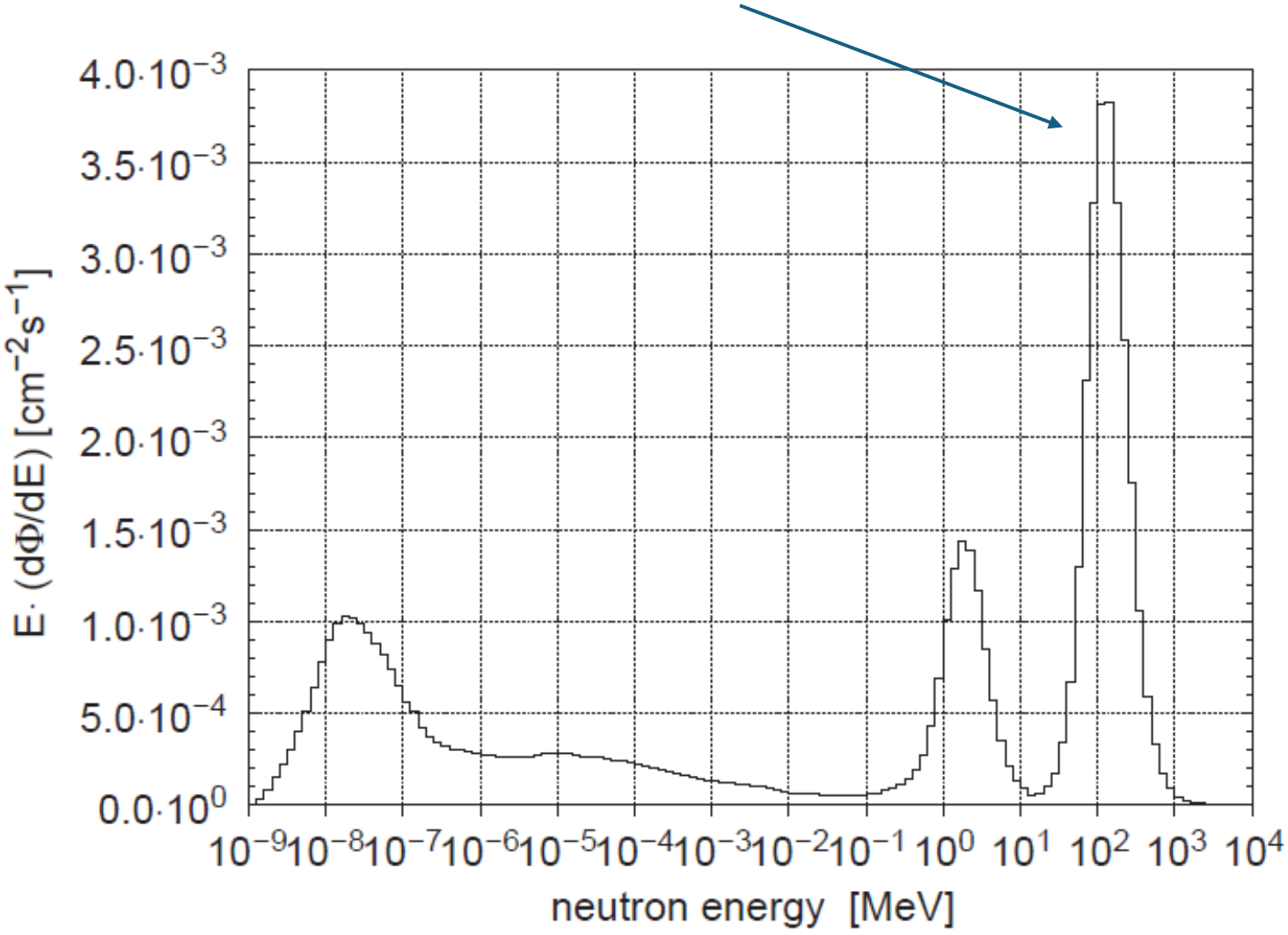
Neutrons evaporated by excited residual nuclei



Typical cosmic neutron spectrum

Cascade peak (E=100-200 MeV)

Neutrons with a small interaction cross section with air, hence able to traverse a large air thickness



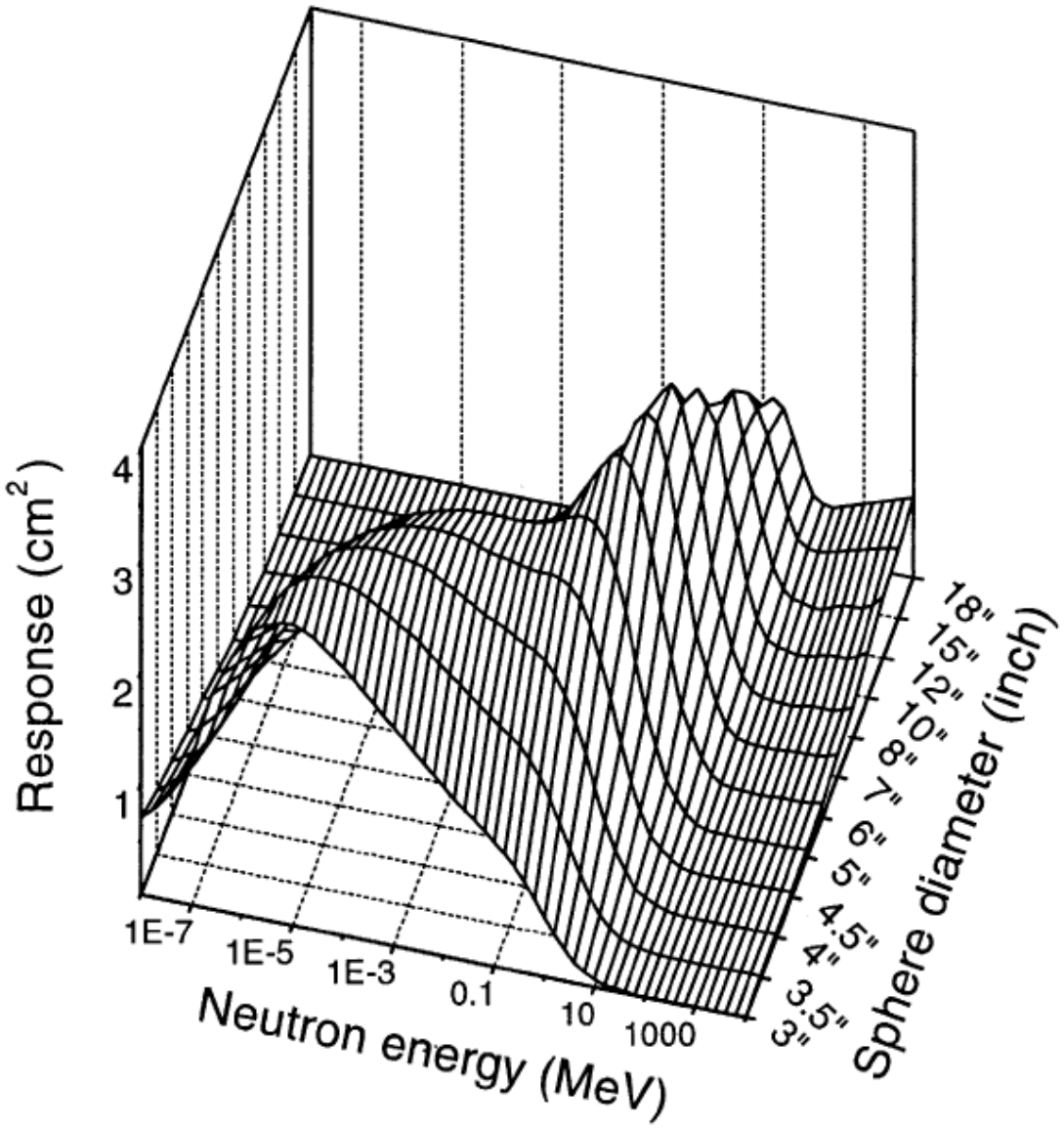
Typical cosmic neutron spectrum

BSS installation in Ny-Alesund

BSS detector in Ny-Alesund

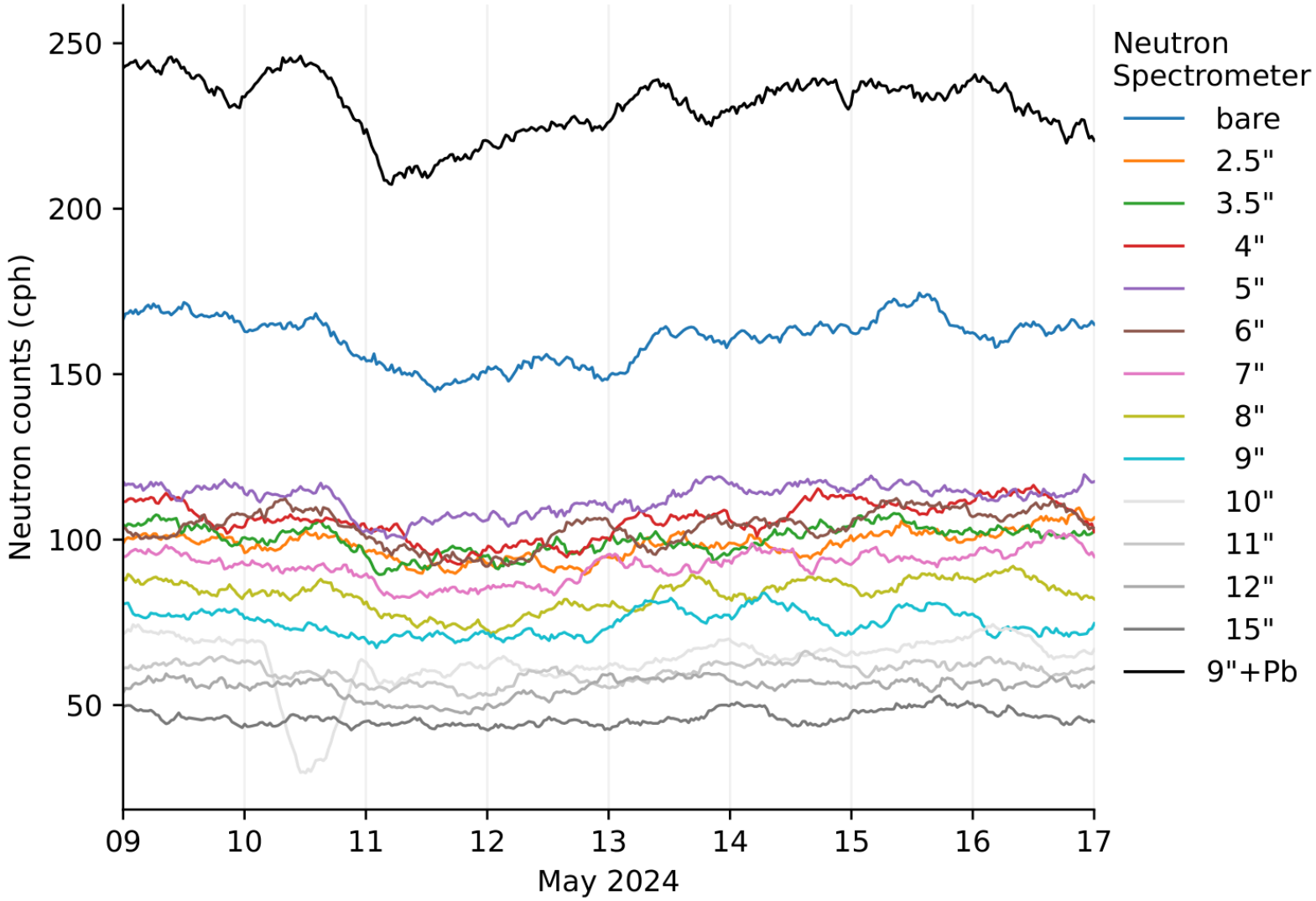
Channel	Diameter
01	bare detector
02	2.5" Sphere
03	3.5" Sphere
04	4" Sphere
05	5" Sphere
06	6" Sphere
07	7" Sphere
08	8" Sphere
09	9" Sphere
10	10" Sphere
11	11" Sphere
12	12" Sphere
13	15" Sphere
14	9" Sphere with 1" lead

Typical response of a Bonner Sphere Spectrometer to different neutron energies



Data trend for the Bonner Sphere Spectrometer around mid-May

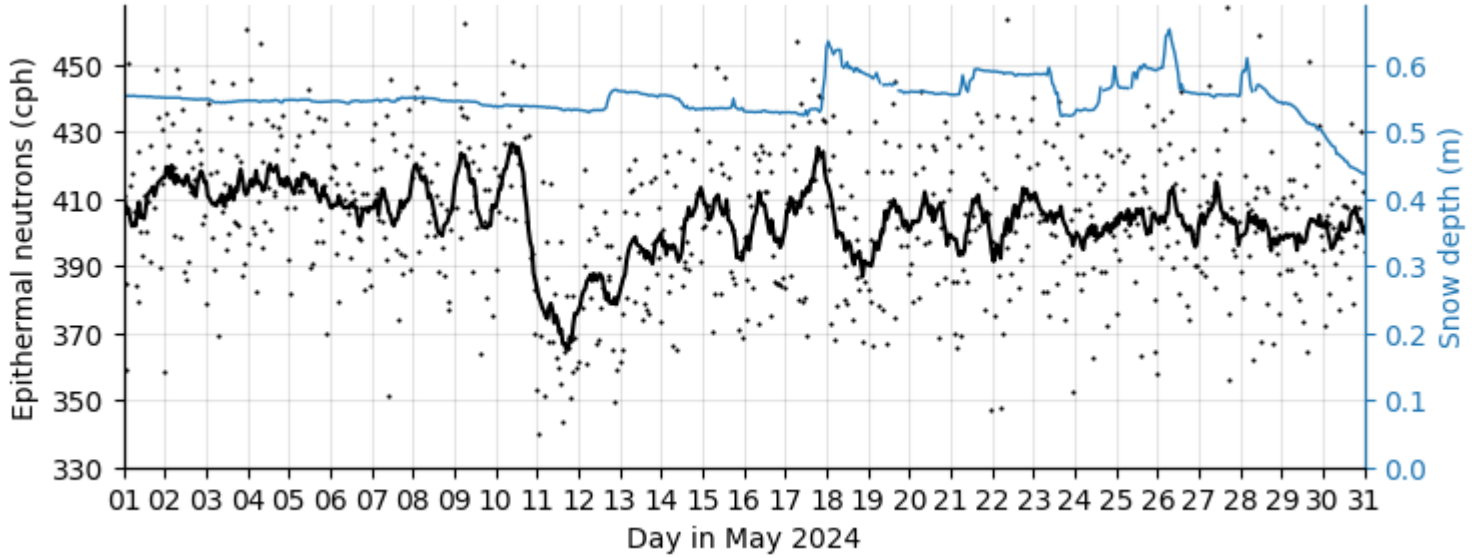
Different channels correspond to moderator spheres with a different diameter, hence sensitive to different ranges of neutron energies



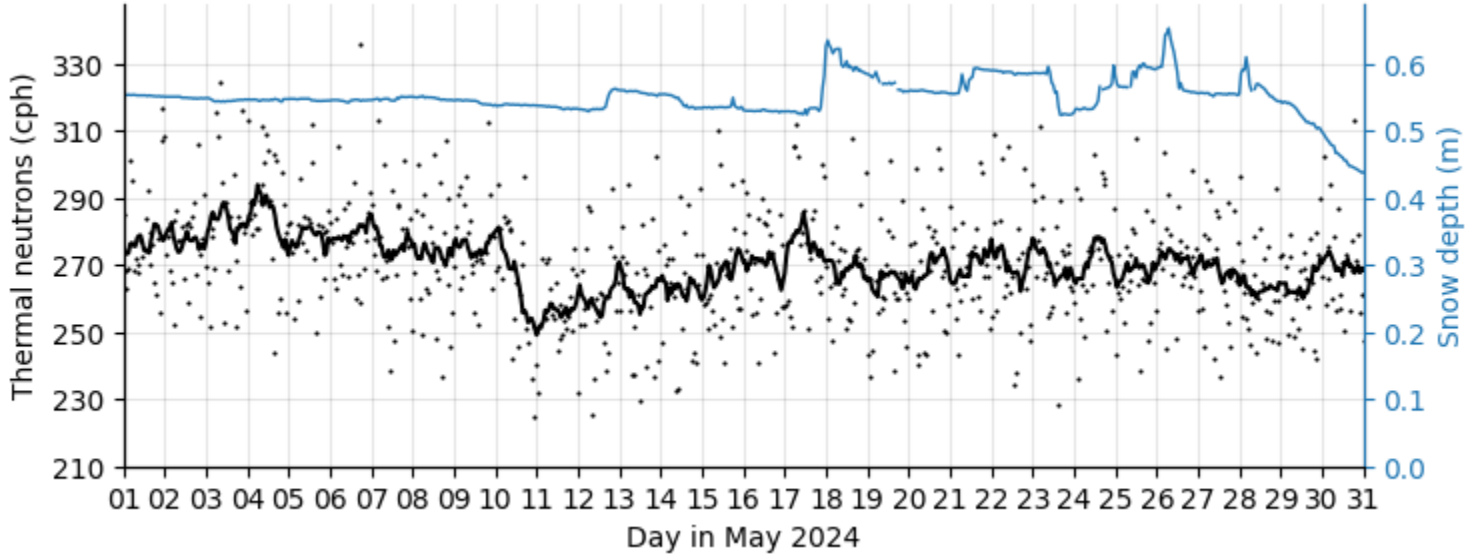
Thermal and epithermal neutrons are also measured by additional neutron sensors in Ny-Ålesund (SVEN)

Data need to be corrected for different weather parameters and presence of snow

Data trend for the epithermal



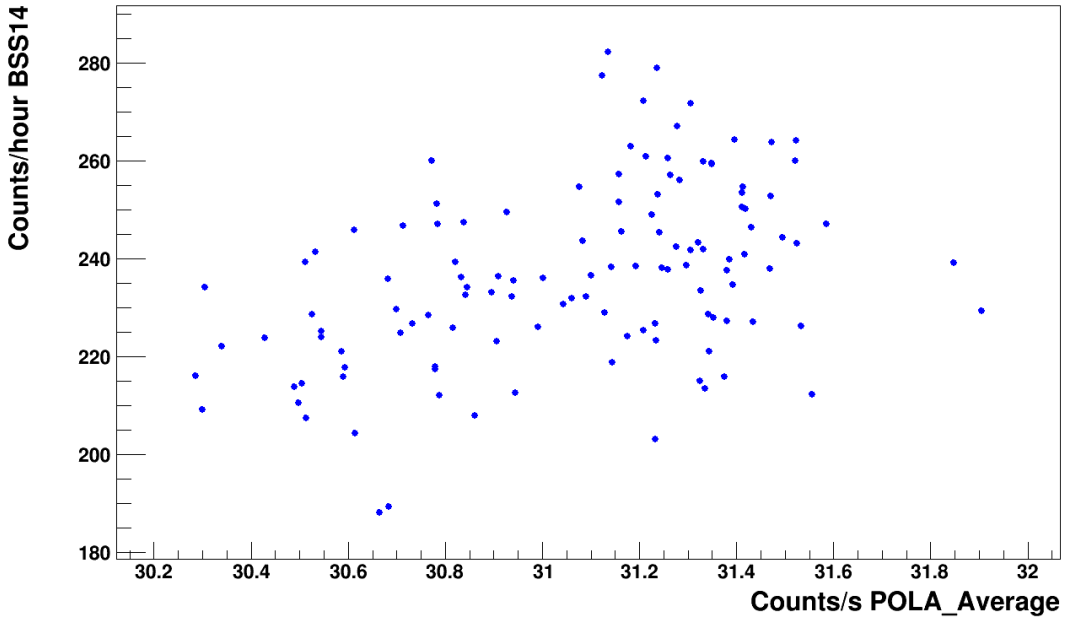
and thermal neutrons



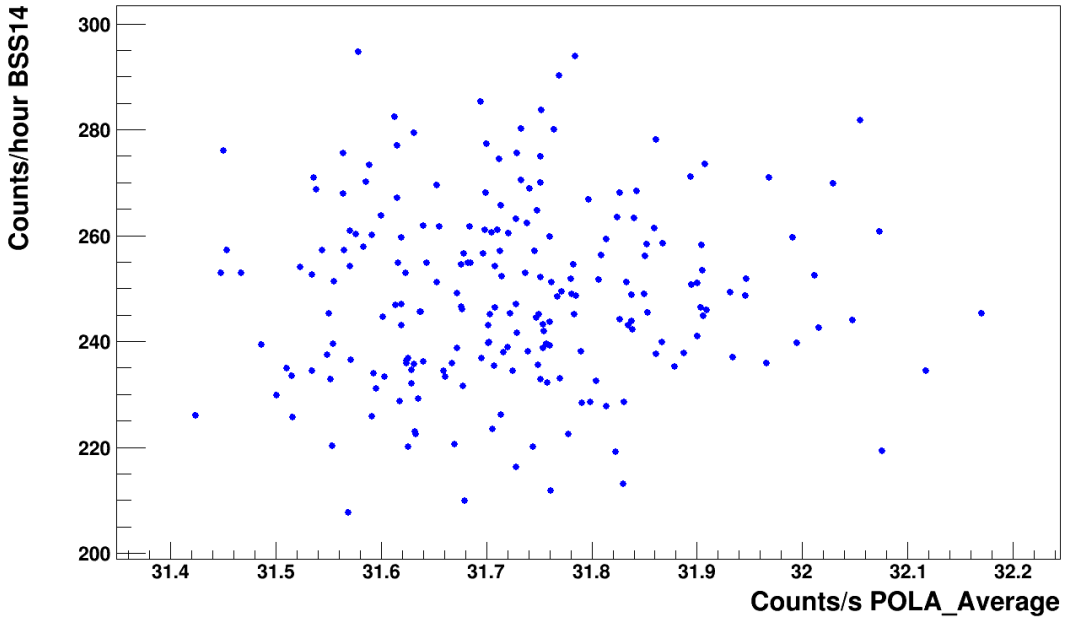
Preliminary correlation study between POLA-R and BSS (various channels)

BSS channel with 9’’ sphere + 1’’ lead

Forbush
r = 0.43 ± 0.07

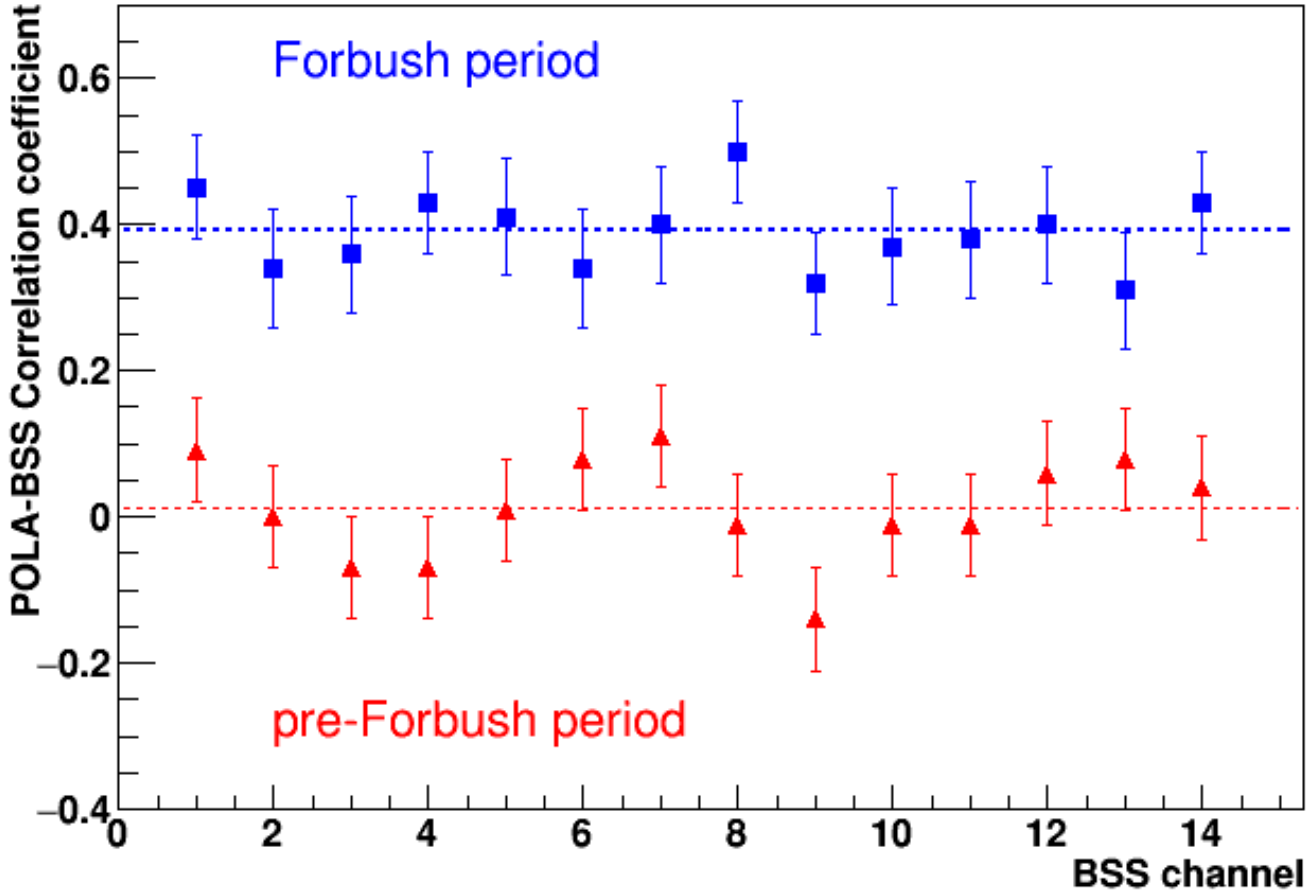


Pre-Forbush
r = 0.04 ± 0.07



Correlations between muons and neutrons from different BSS channels (different energy ranges)

- Correlation is certainly higher during Forbush
- Correlation is negligible during (short) quiet periods
- Apparently, no detailed trend of the correlation with neutron energy is seen



Work in progress

- **Set up uniform conditions for correlations studies (better define pre-Forbush and Forbush periods)**
- **Estimate sensitivity of the information to the selected period**
- **Explore different integration times**
- **Study the correlation of muons with epithermal/thermal neutrons**
- **Study the correlation between different neutron energies**
- **Estimate uncertainties (& p-values) on correlation coefficients**
- **Work on the draft of the paper (Several parts already written, shared Overleaf structure)**