Investigation of the diurnal variation of cosmic rays at large latitudes by EEE detectors

An update report

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&

Centro Fermi

EEE Analysis Meeting, Nov 27, 2025

A brief recall of previous report: Cosmic Ray variations

Periodic variations:

- Long term variations (11 / 22 years, solar cycle)
- Short term variations (27 days, average Sun rotation period)
- Diurnal modulations

The diurnal variation of CR flux measured at ground is an important – although with small amplitude – feature of the data collected by a CR detector.

Both charged particles and neutrons undergo these variations.

Periodic variations occurring within a day (diurnal variations) are associated to changing conditions in the Interplanetary Magnetic Field (IMF) and Earth's magnetosphere.

Features of diurnal variations

Diurnal variations have been observed since a long time.

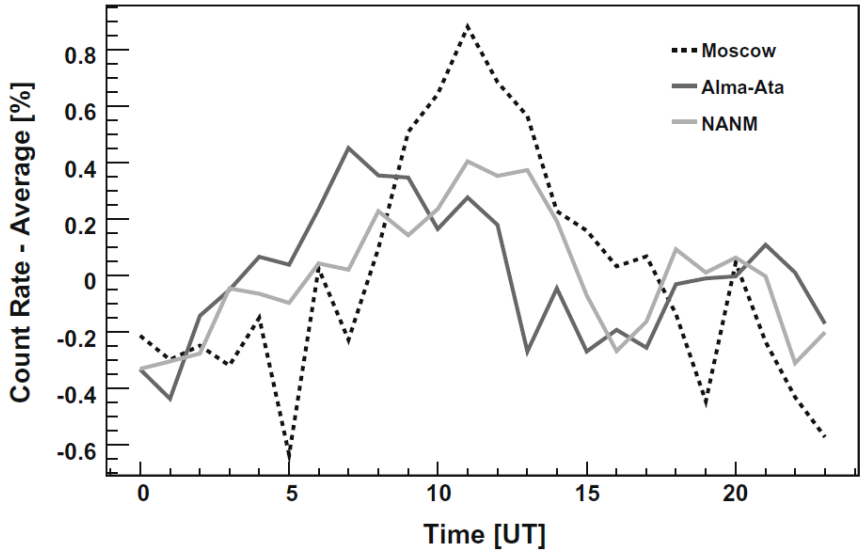
Observed amplitudes of the order of 0.1-0.3 %.

Phase (local time for the maximum) around 12h-14h local time, with large dispersion around it.

Although largely studied, diurnal variations are still an important topic for CR investigations, even today.

Detailed features depend on

- Coordinates of the observation site (especially latitude)
- Solar cycle, year (long term trends)
- Sun magnetic polarity
- Secondary particles being detected (neutrons, muons)



Maylian, Advances in Space Research(2010)

Analysis of cosmic rays diurnal variations in EEE

Due to the small expected effect (0.1 % or less) a stable and long dataset is required

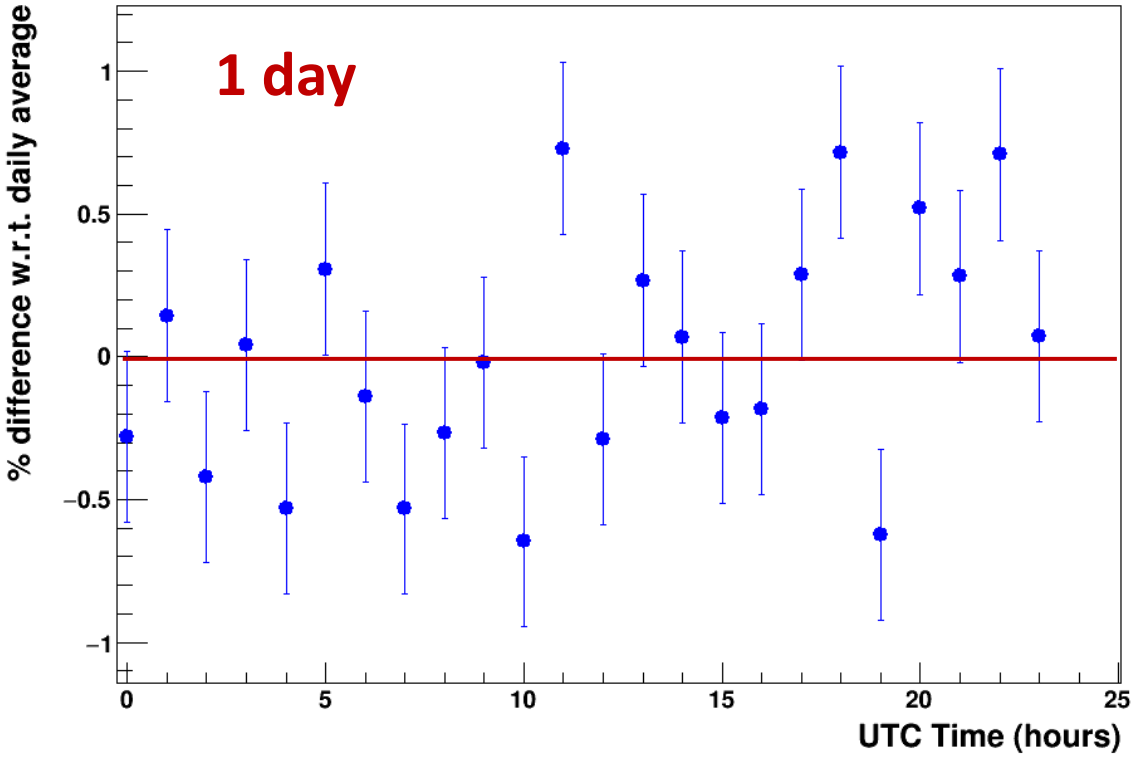
Good candidate: POLA-R detectors

- Relatively stable for long periods
- Three independent detectors in the same site
- Good counting rate (of the order of 30 events/s)
- Peculiar location at high latitude
- About six years of data available

- Preliminary results on this analysis presented during last meeting
- Comments and suggestions taken into account to update and complete the analysis

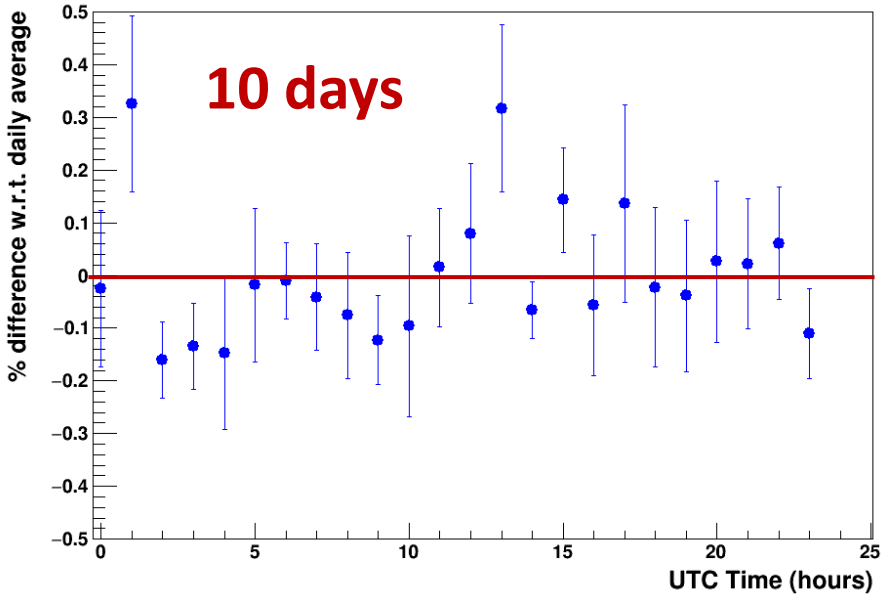
Analysis strategy

- Daily averages considered, with selection of full-coverage days
- Evaluate the hourly difference w.r.t. average

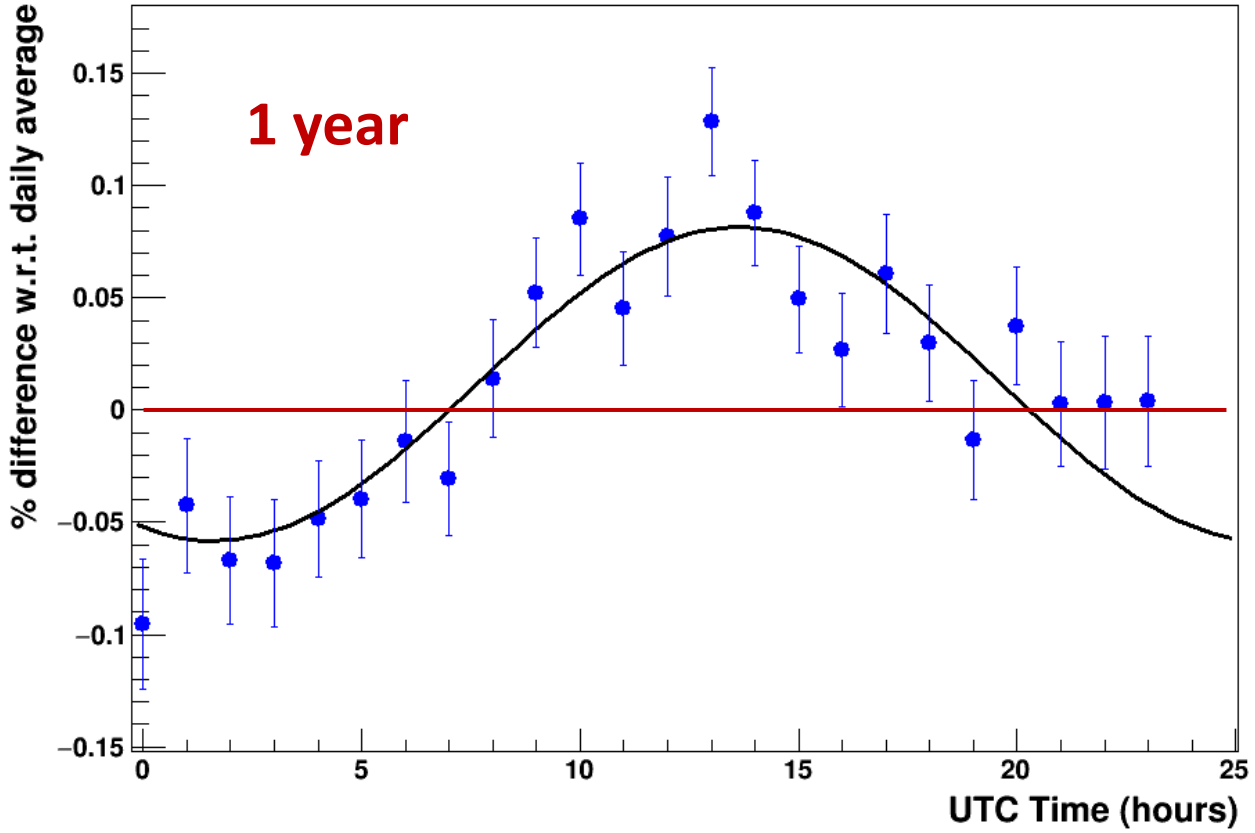


- Statistical fluctuations in each point of the order of 0.3-0.5 % (about 100k events collected in 1 hour).
- No defined trend seen in a single day, due to the small expected effect (0.1% or less).
- Increase statistics over many days

Increase statistical significance

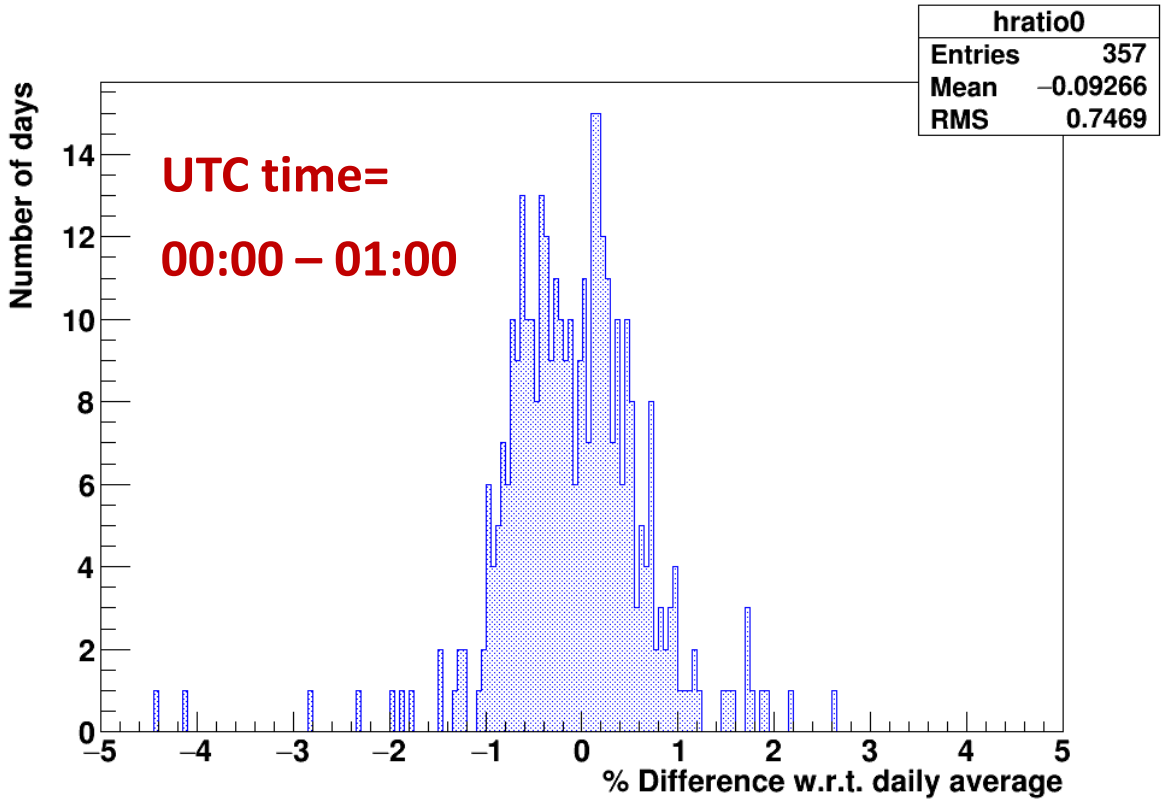


POLA-01 data 2024



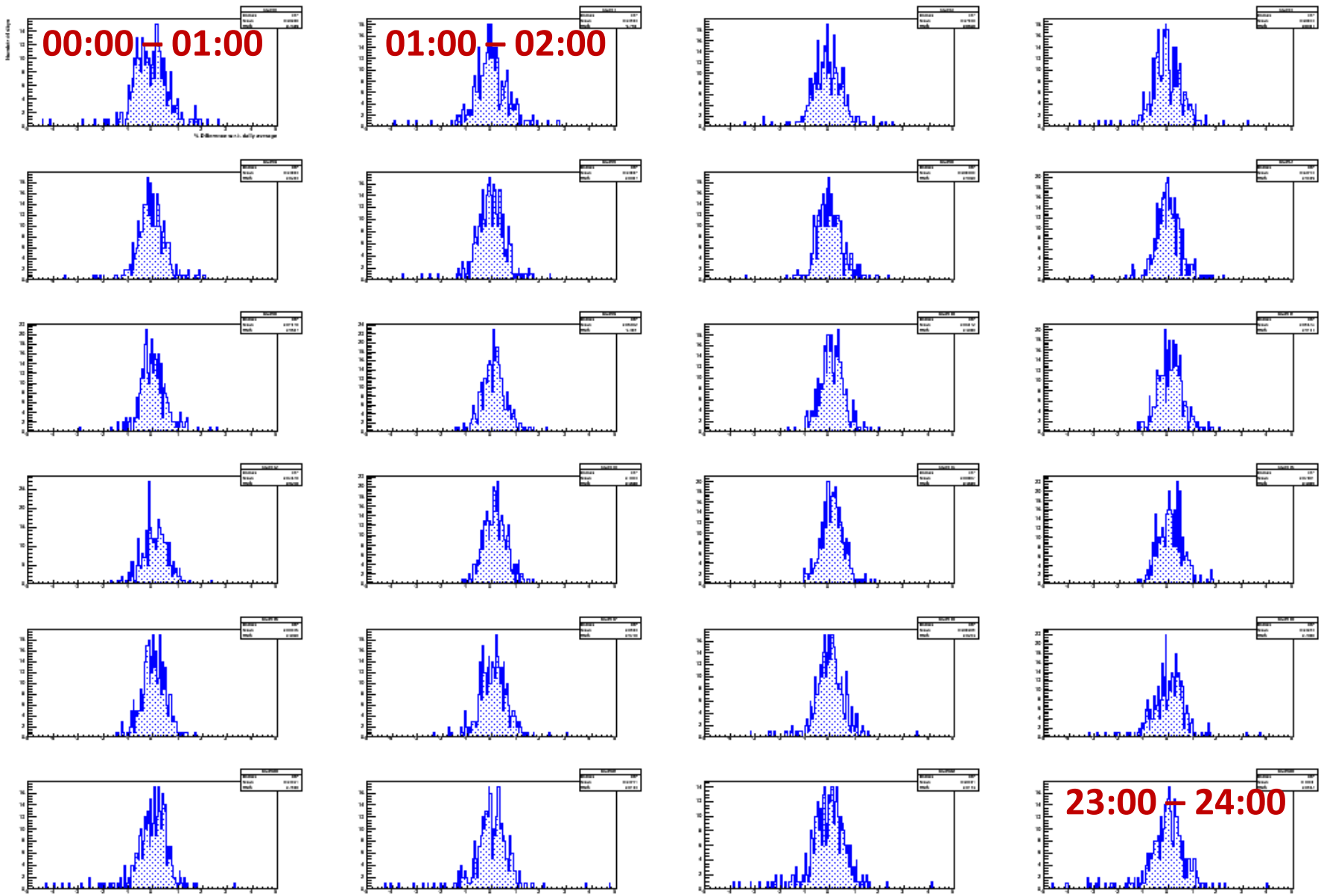
Mean and Error estimate

- For each of the 24 hourly interval (0-24), distribution of the differences w.r.t. daily average evaluated day-by-day.
- Cut within (-1.5 %, +1.5%), about 3 σ
- Extract centroid and its error RMS/$\sqrt{N_{entries}}$



Error estimate

Procedure replicated for all 24 1-h intervals and for each day



Amplitude and phase extraction

Amplitude and phase extracted by a single harmonic fit

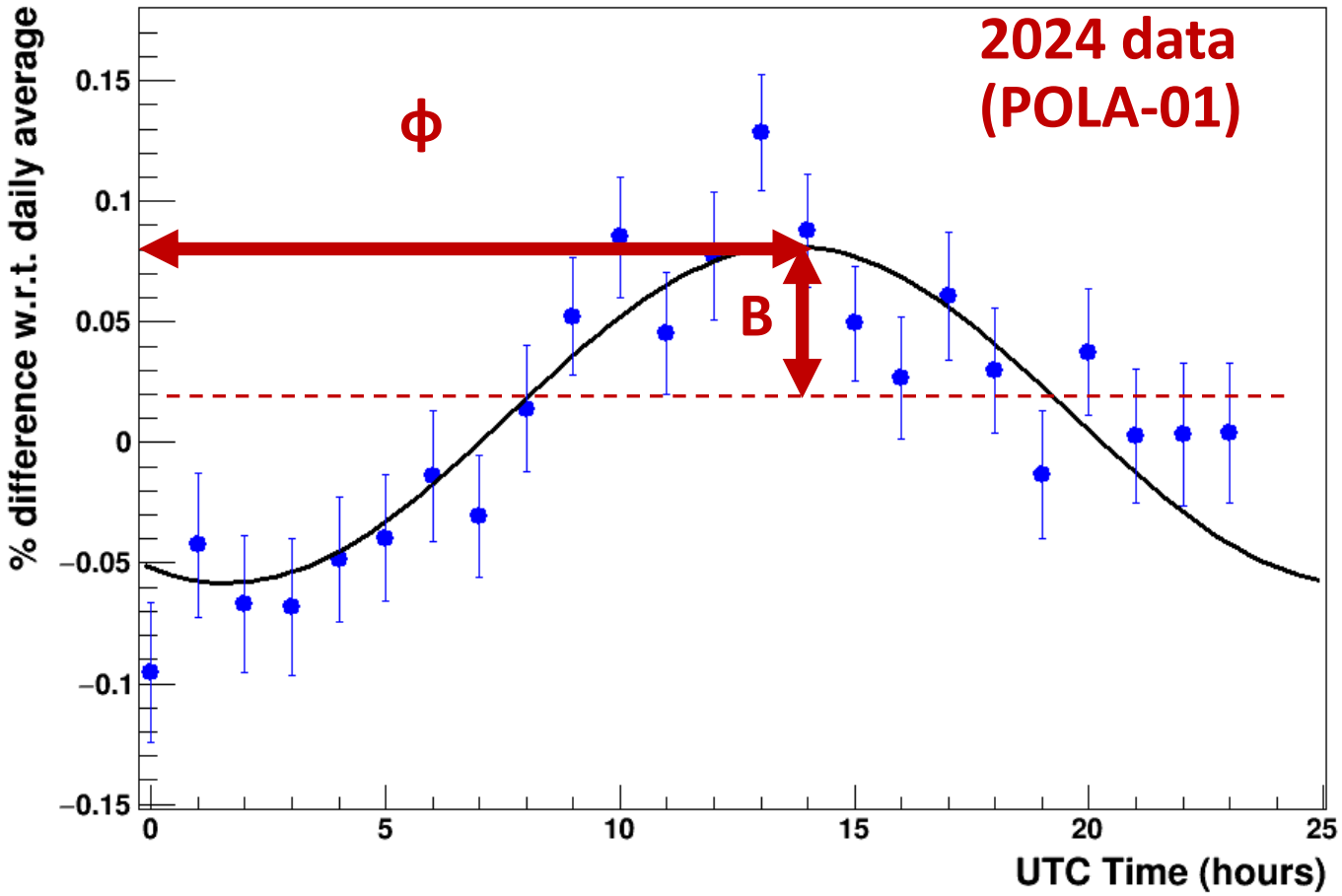
$F(t) = A + B \cos (\omega (t - \phi))$

$\omega = 2 \pi /24$, ϕ in hours

Amplitude B = (0.070 ± 0.007) %

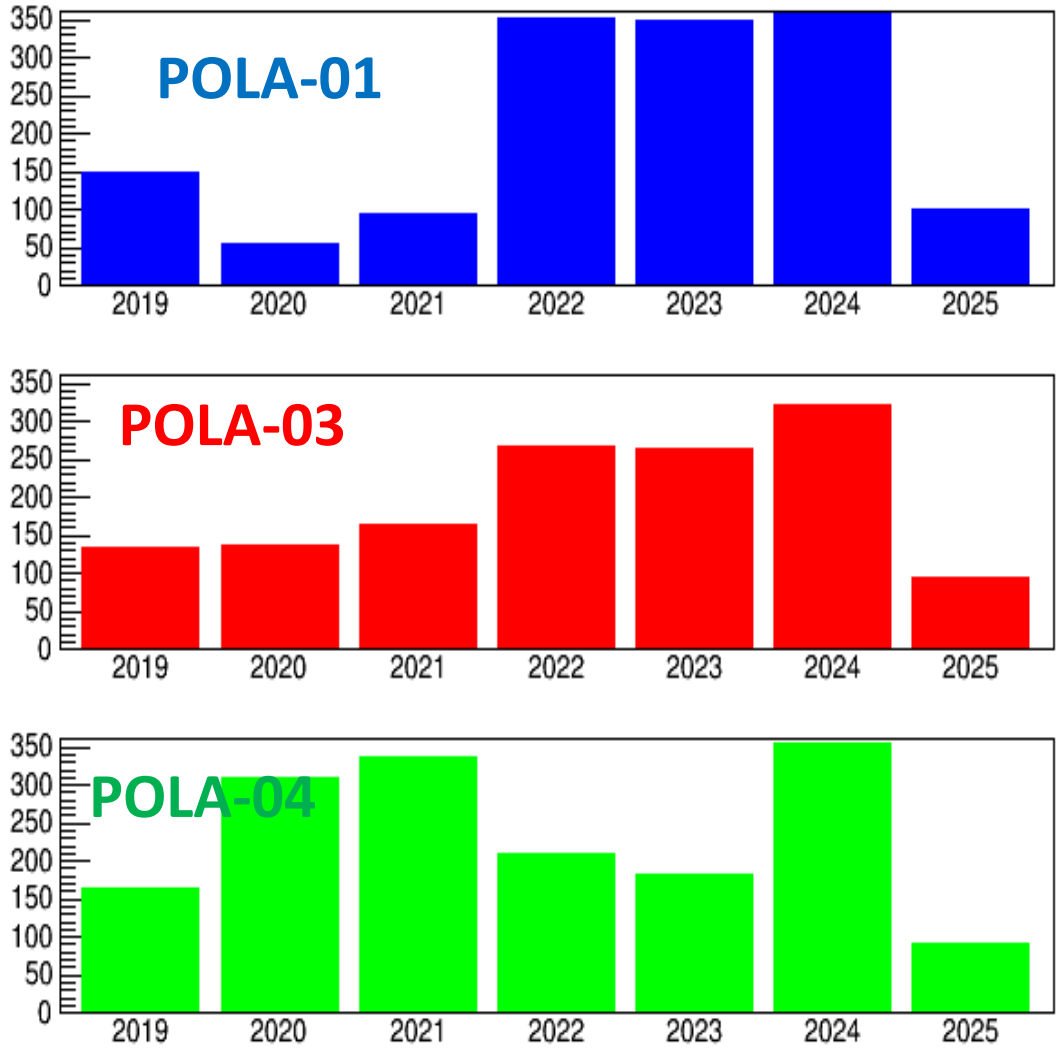
Phase ϕ = (13.6 ± 0.4) UTC time

Local Time ~ 14h 25’

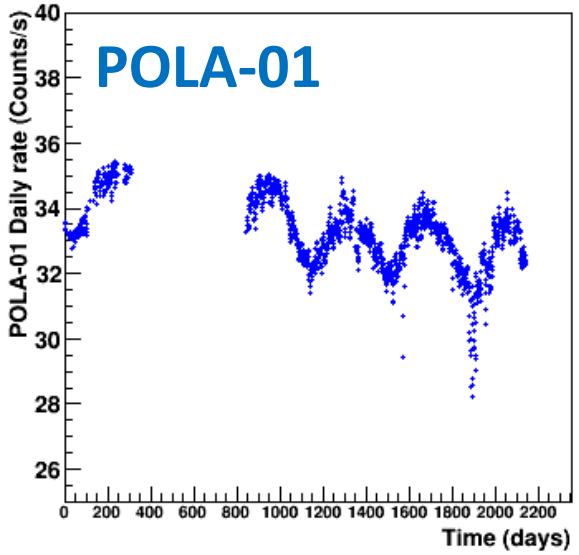


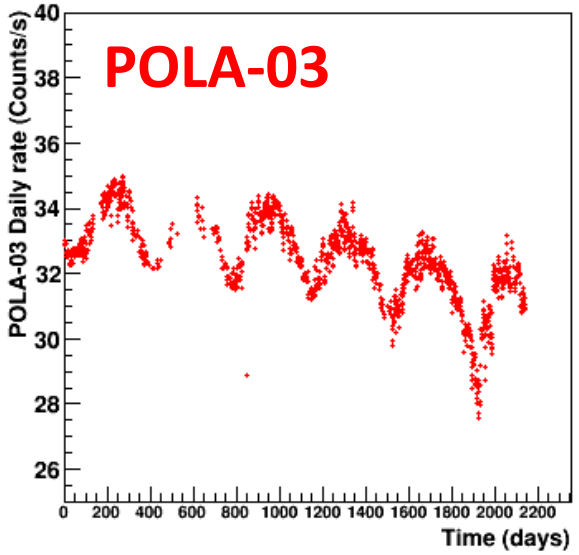
Available days for analysis

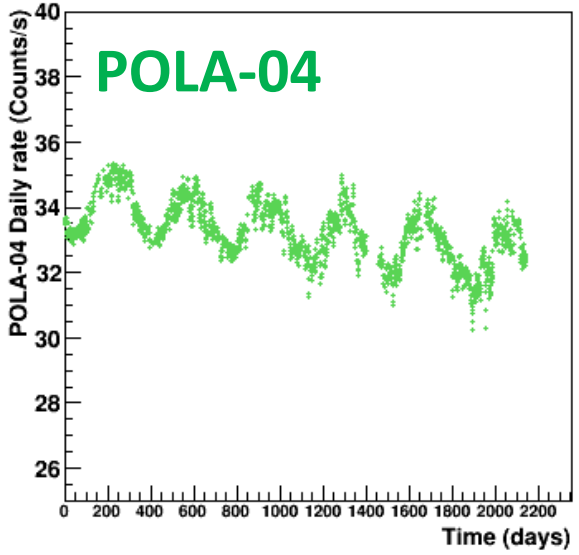
- June 2019 – April 2025, about 6-years
- Data corrected for pressure variations
- Only days with full 24-hours coverage selected, for a proper evaluation of daily averages

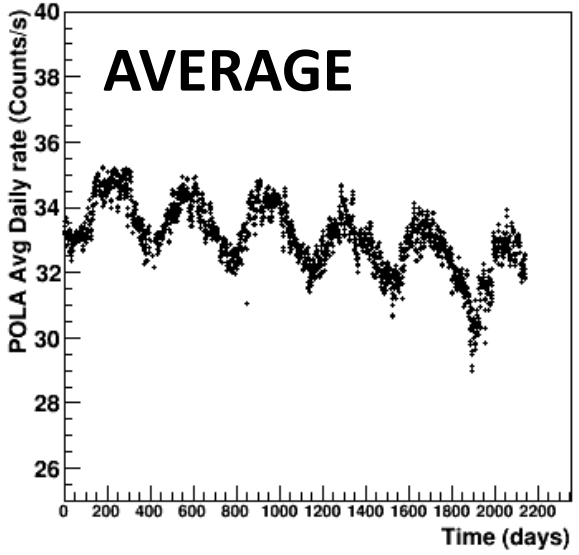


Daily average rates





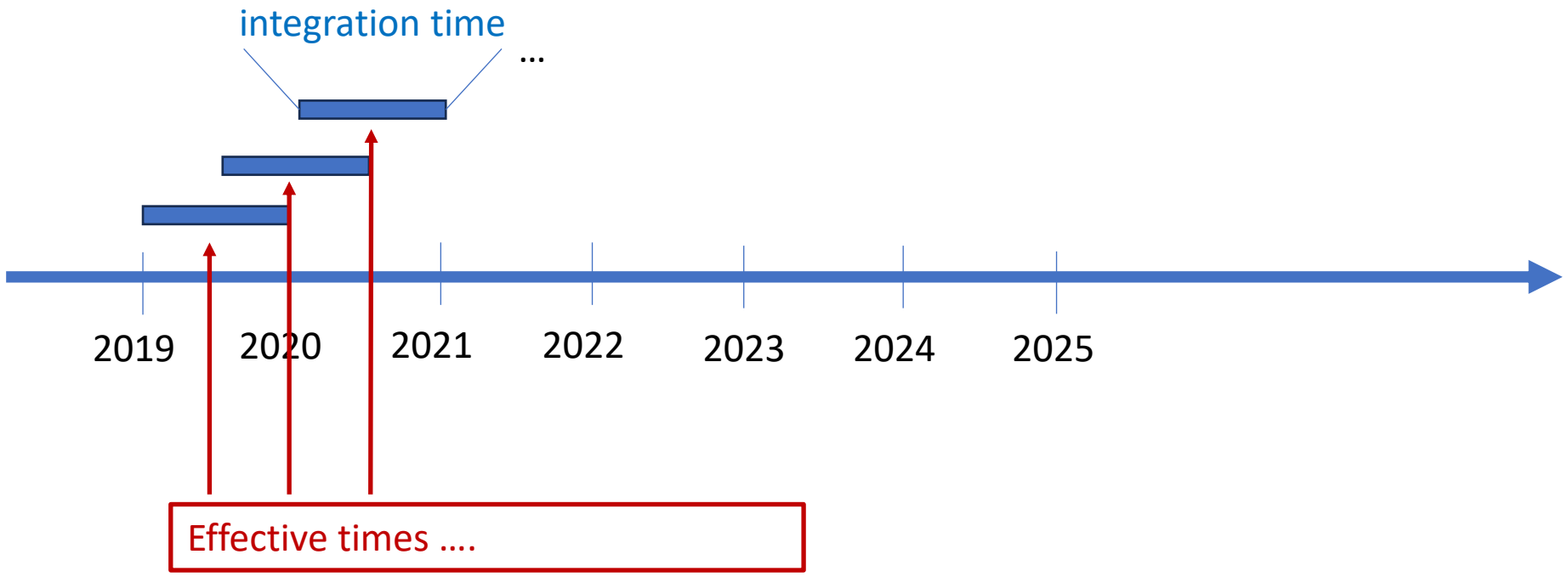




- Diurnal variations with respect to these daily averages investigated along the 6-years period
- Preliminary analysis had been carried out for the separate years 2019, 2020,… 2025

POLA-R results over the years: Running average

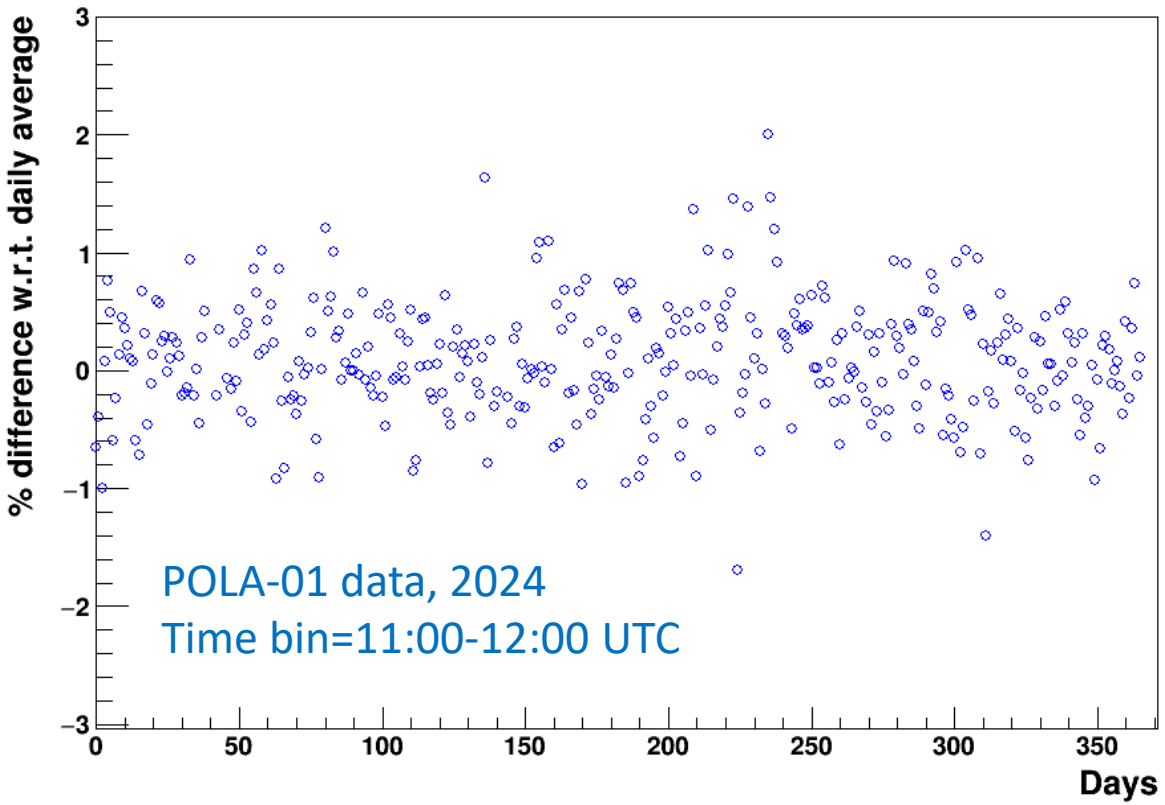
- New analysis carried out for all years with a running average (1-year integration time, 6-months steps)
- Effective time evaluated taking into account missing days



POLA-R results vs time

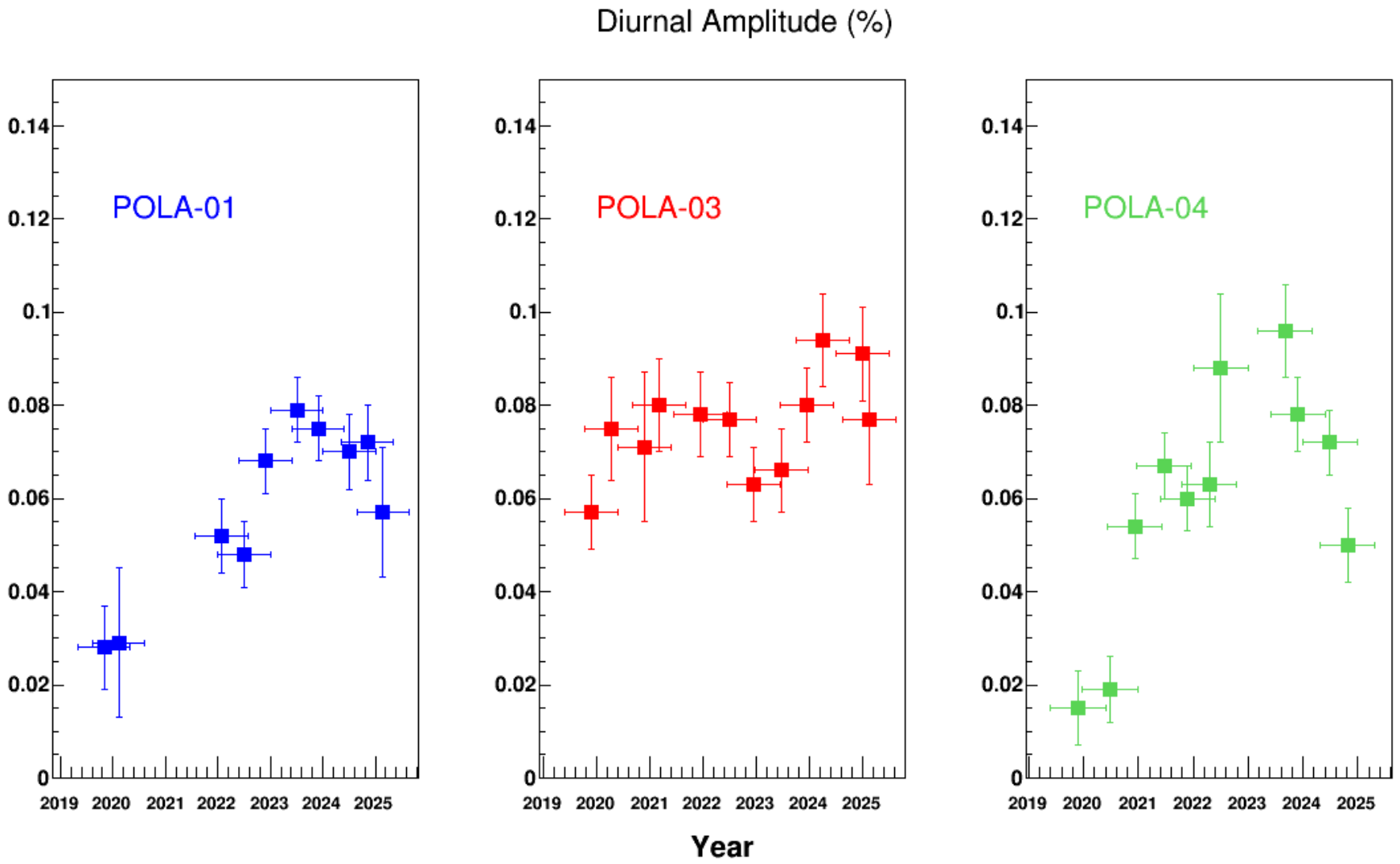
- Is there any variation of amplitude and phase along the time?

- Nearly constant trend, however detailed analysis for the 6-years period shows some trend..



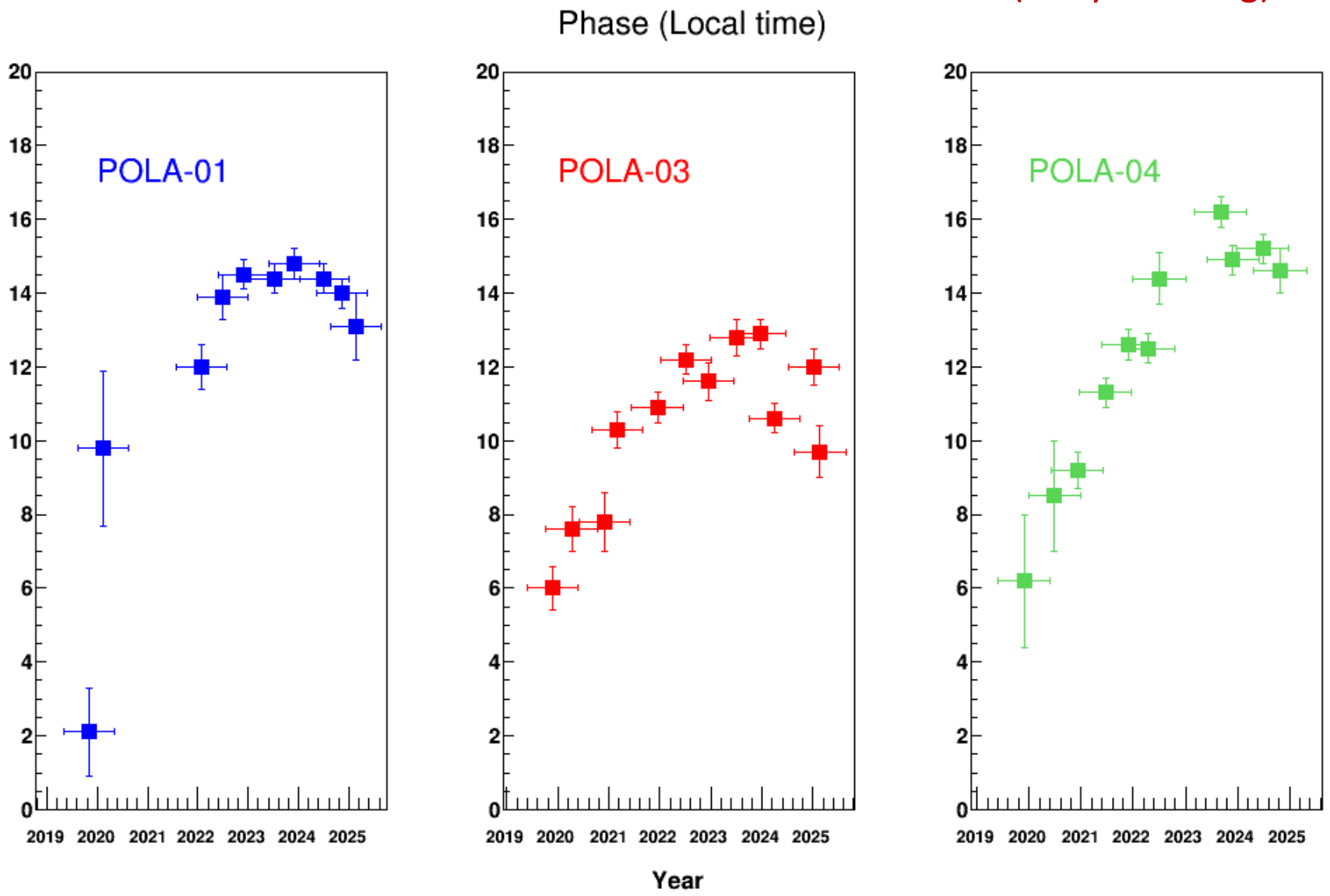
POLA-R results over the years: Amplitude

Increasing trend generally observed, from 2019-2020 (as low as 0.02) to 2025 (0.08-0.10)



POLA-R results over the years: Phase

Clear shift of the phase observed, from 2019-2020 (early morning) to 2024 (early afternoon)



Comparison with neutrons at high latitudes

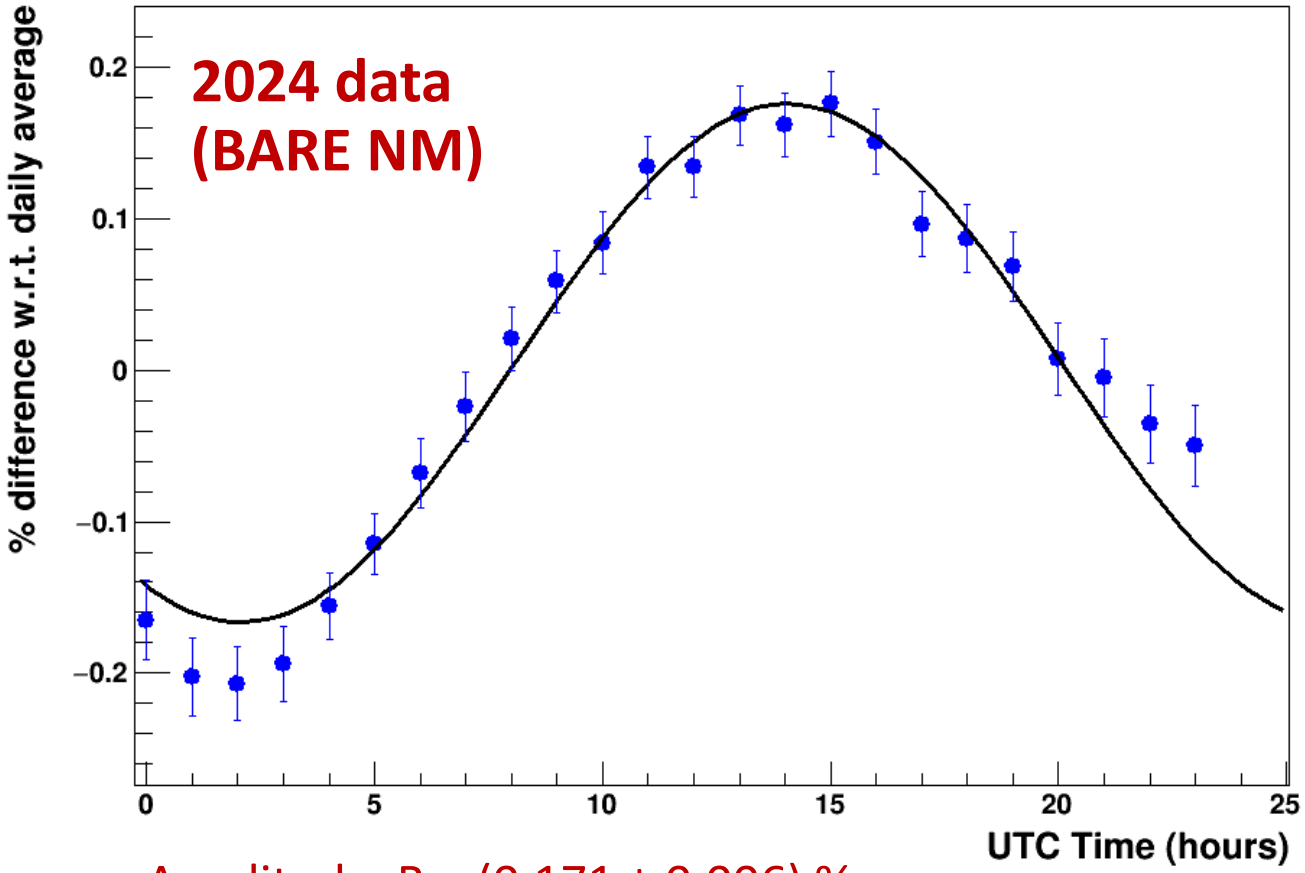
Barentsburg Neutron Monitor

(not far from POLA-R detectors)

Same analysis strategy applied

A long (22-years) period considered

To compare muon and neutron results, the average from the 3 POLA-R detectors considered



Amplitude B = (0.171 ± 0.006) %

Phase = (14.1 ± 0.2) UTC time

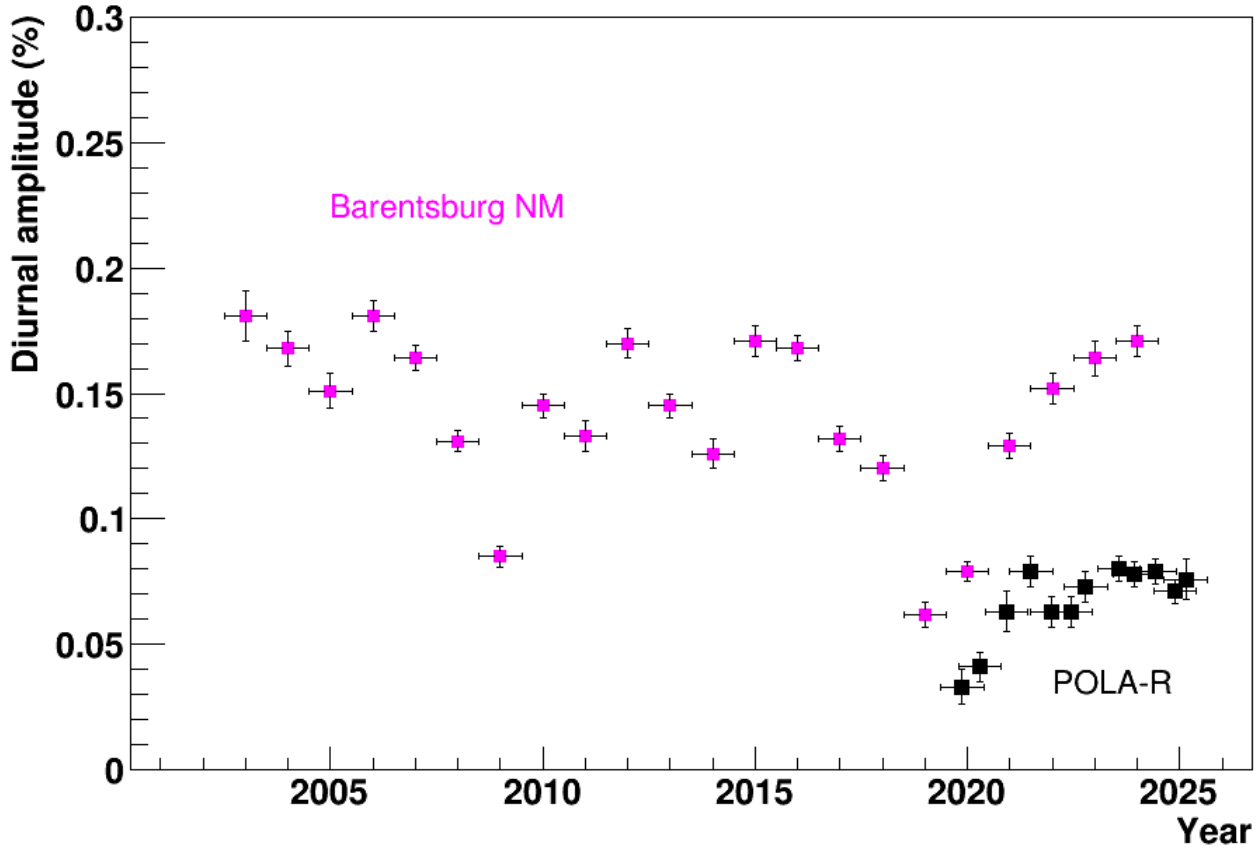
Local Time ~ 15h 10’

Neutron and muon comparison

- Amplitudes for neutrons are generally higher (0.1-0.2 %) than for muons (0.05-0.1 %)

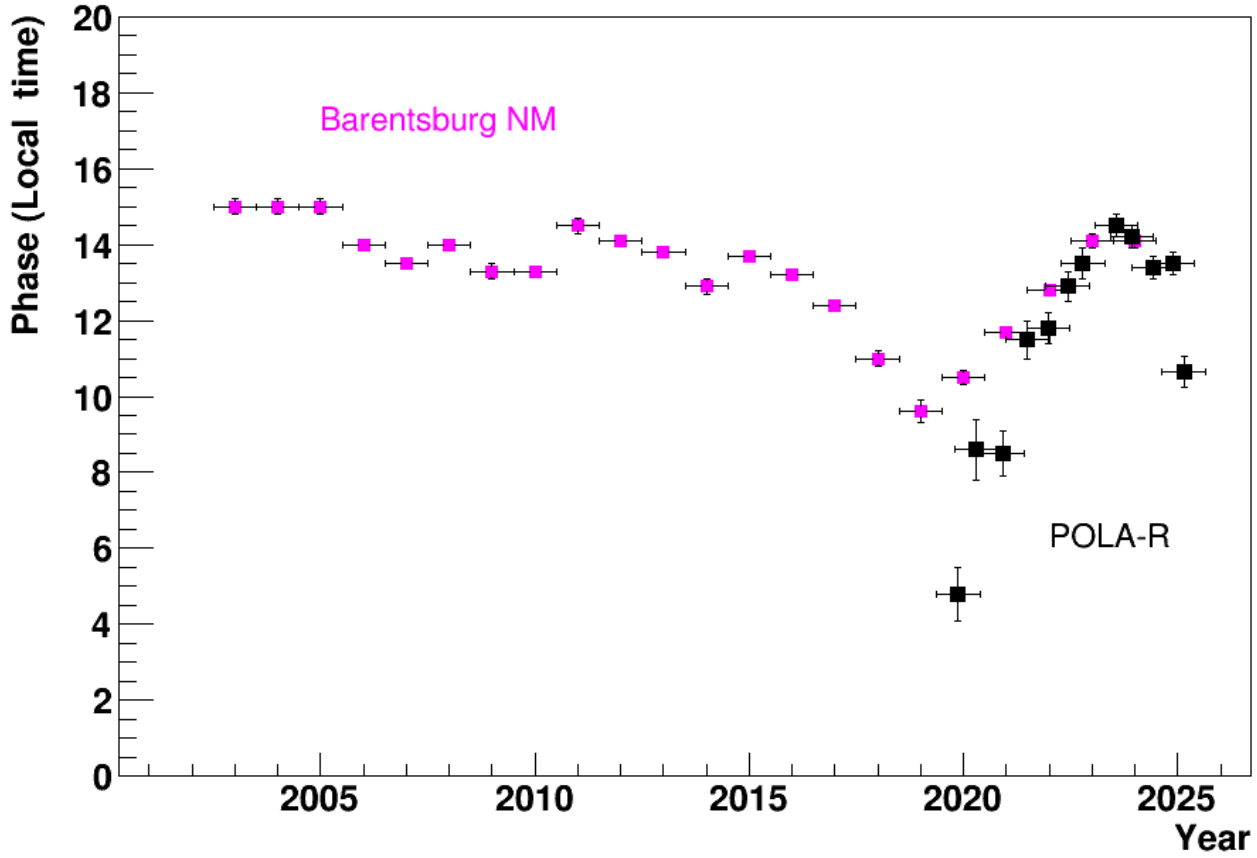
- Increasing trend of the amplitude over the last years (Solar Cycle 25) both for neutrons and muons

- Overall amplitude trend for neutrons consistent with an 11-years period (sunspot cycle)



Neutron and muon comparison

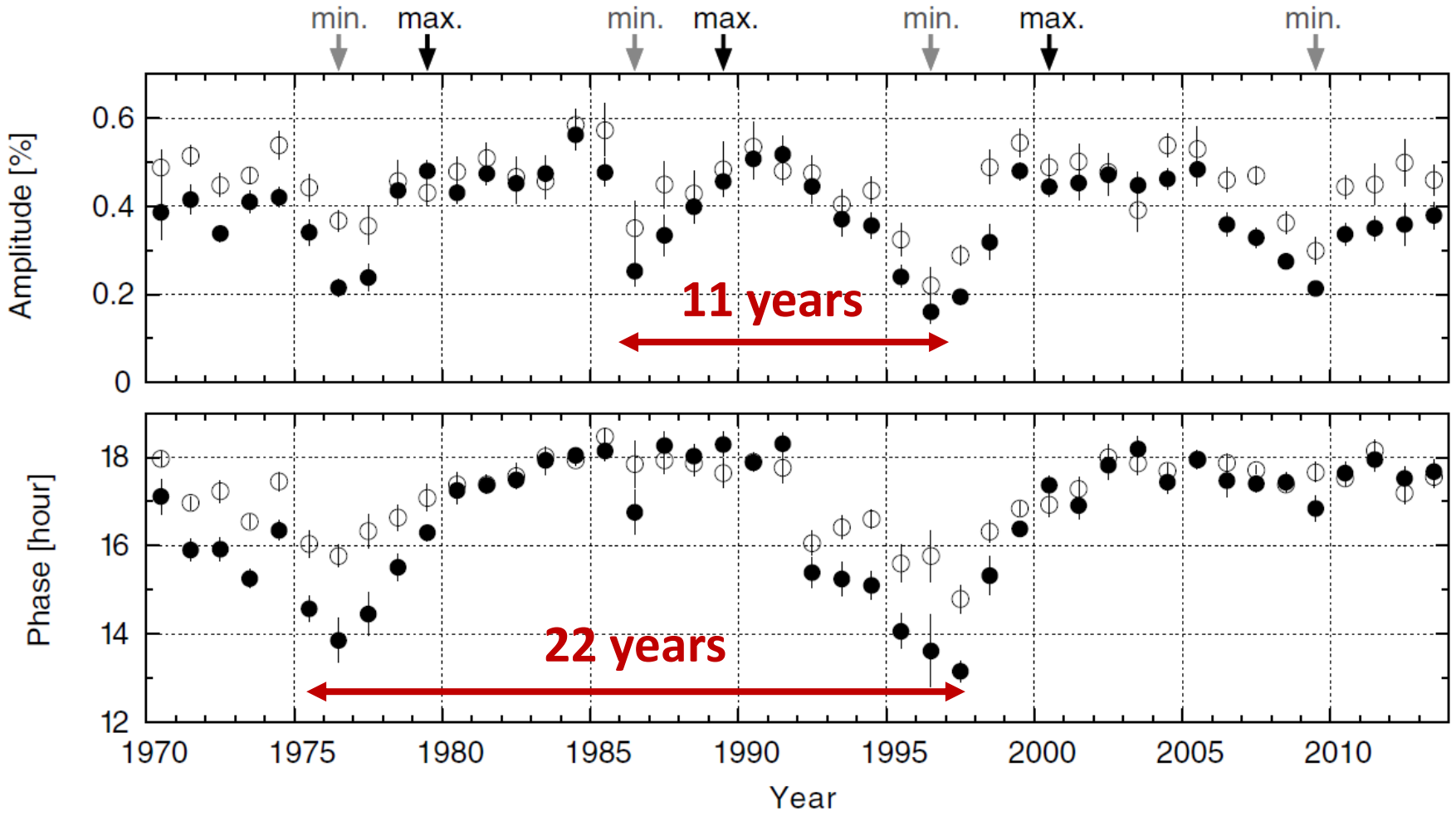
- A dip in the phase observed near 2019-2020, more pronounced for muons
- Overall phase trend consistent with a 22-years period (magnetic field cycle)



Findings about amplitude and phase trends in agreement with what observed by other authors

Neutron and muon comparison

- ● Nagoya Muon Telescope
- ○ Neutron Monitor

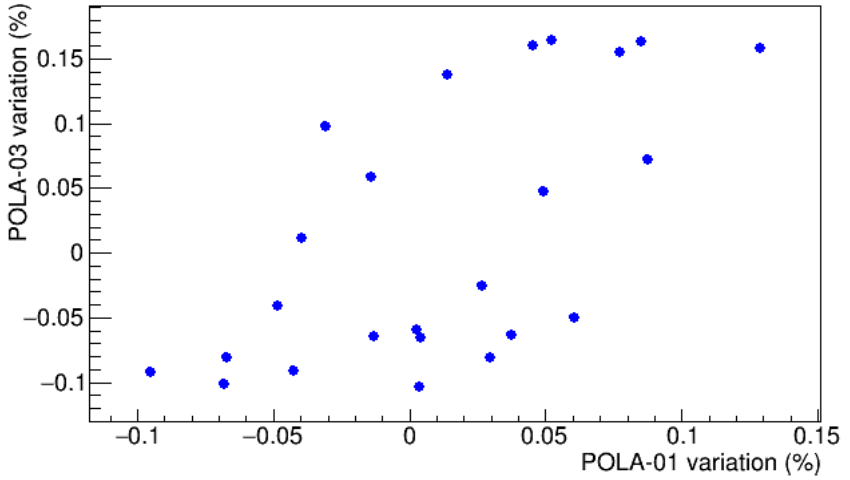


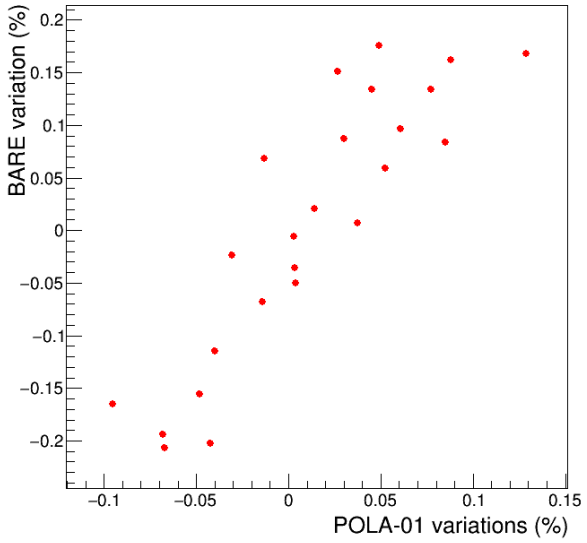
Munakata et al., ApJ 2014

Correlation among POLA-R detectors and with Barentsburg NM

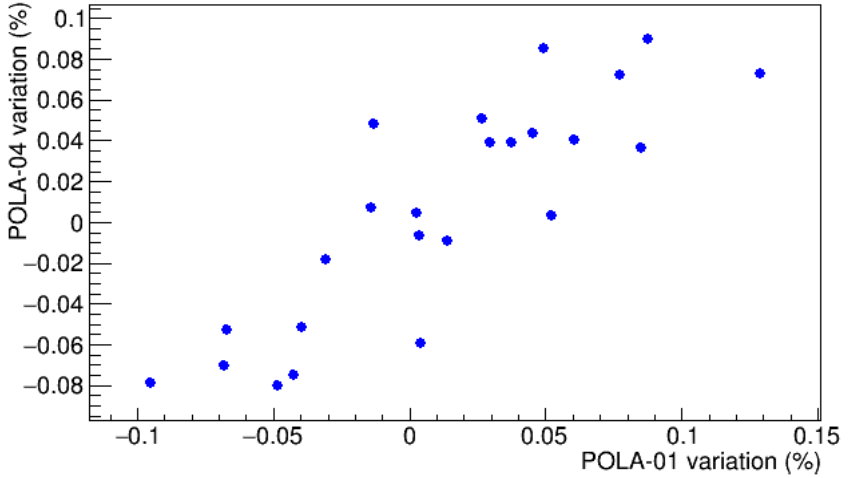
Diurnal variations in the three POLA-R detectors are reasonably correlated among them and with the Barentsburg NM

POLA1-POLA3: r=0.63+/-0.13
POLA1-POLA4: r=0.86+/-0.06
POLA3-POLA4: r=0.49+/-0.16





POLA1-BARE: r= 0.89 +/-0.05

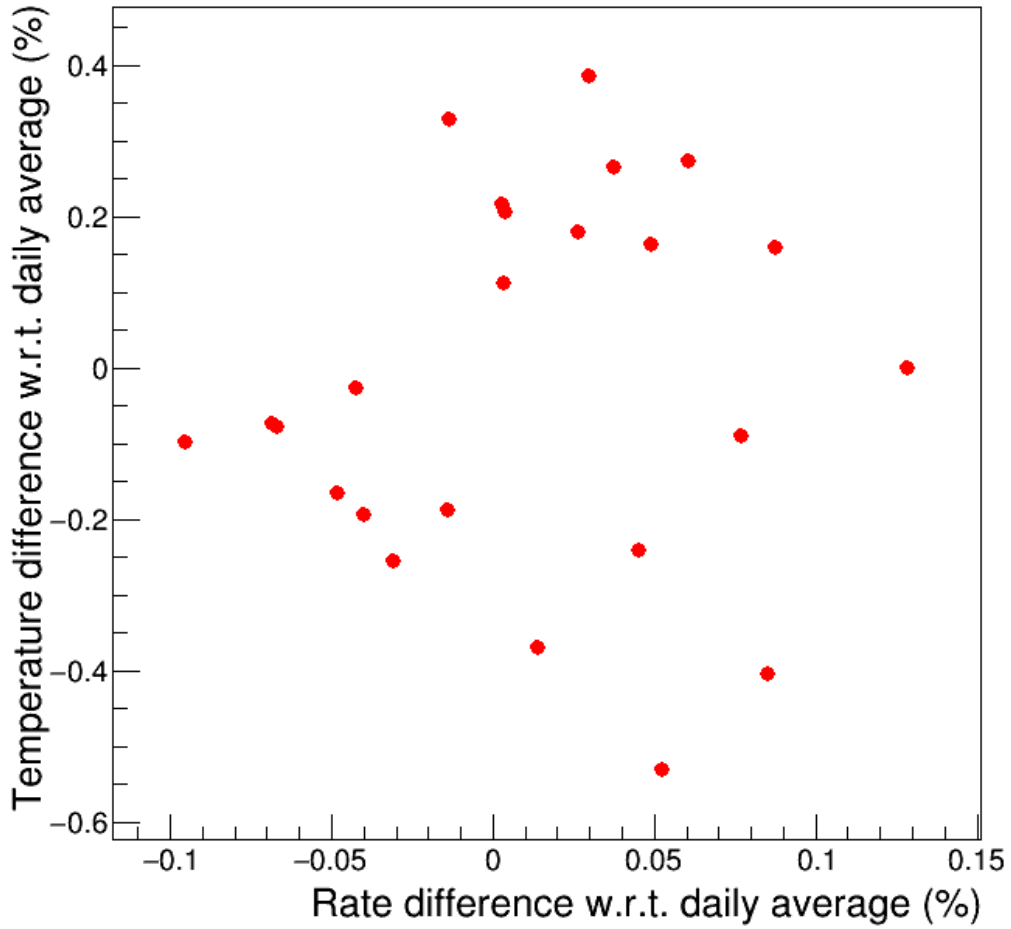


Checks of the temperature influence

To investigate possible influence of temperature variation along the day, a correlation analysis of the temperature-rate diurnal variation carried out, with the same analysis strategy

No apparent correlation is seen

Correlation factor= 0.09 +/-0.21



Draft preparation

If no major objections will come to this analysis, a paper draft is being finalized and will soon be circulated..

Eur. Phys. J. C manuscript No.
(will be inserted by the editor)

Investigation of the diurnal variation of cosmic rays at large latitudes by the detectors of the Extreme Energy Events Project

M.Abbrescia[1,2], C.Avanzini[3,4], L.Baldini[3,4], R.Baldini Ferroli[5], G.Batignani[3,4], M.Battaglieri[6], S.Boi[7,8], E.Bossini[4], F.Carnesecchi[9], D.Cavazza[10], C. Cicalò[8], L.Cifarelli[10,11,12], F.Coccetti [12], E.Coccia[13], A.Corvaglia[14], D.De Gruttola[15,16,12], S.De Pasquale[15,16,12], L.Galante[17], M.Garbini[12,10], I.Gnesi[12,18], F.Gramegna[23], E.Gramstad[32], S.Grazzi[6,19], E.S.Haland[32], D.Hatzifotiadou[9,10], P.La Rocca[20,21,12], Z.Liu[22], G.Mandaglio[19,21], A.Margotti[10], G.Maron[23], M.N.Mazziotta[2], A.Mulliri[7,8], R.Nania[10,12], F.Noferini[10,12], F.Nozzoli[24], F.Ould-Saada[32], F.Palmonari[11,10], M.Panareo[25,14], M.P.Panetta[14], R.Paoletti[26,4], C.Pellegrino[27], L.Perasso[6], O.Pinazza[10,12,9], C.Pinto[9], S.Pisano[12,5], M.Rasà[20,21,12], F.Riggi[20,21,12,a], G.Righini[28], C.Ripoli[15,16,12], M.Rizzi[2], G.Sartorelli[11,10], E.Scapparone[10], M.Schioppa[29,18], G.Scioli[11,10], A.Scribano[26,4], M.Selvi[10], M.Taiuti[30,6], G.Terreni[4], A.Trifirò[19,21], M.Trimarchi[19,21], C.Vistoli[27], L.Votano[31], M.C.S.Williams[9,22], A.Zichichi[12,11,10,9,22], R.Zuyeuski[22,9]

Organization of the paper

+ 12 figures

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Fig. 1:

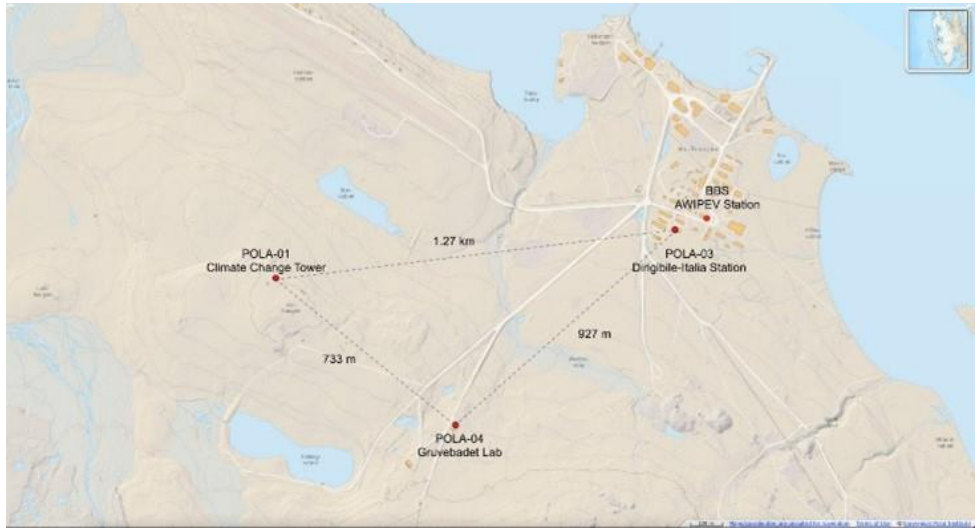

Fig. 2:

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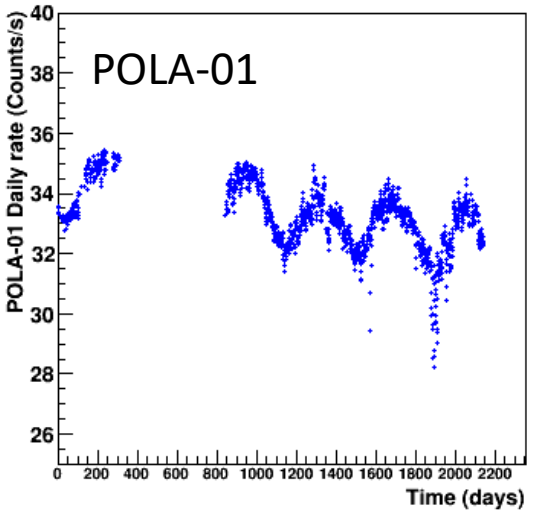

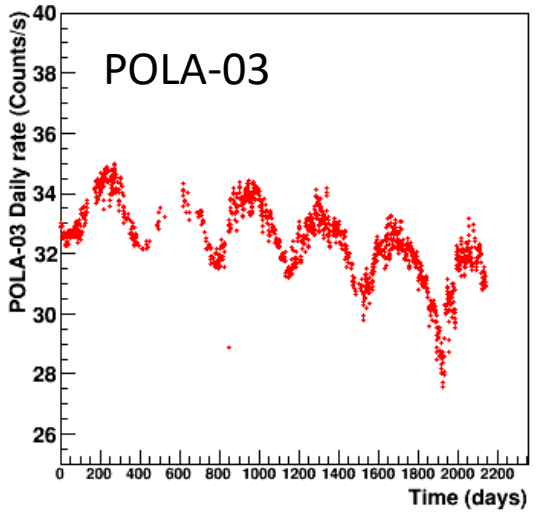

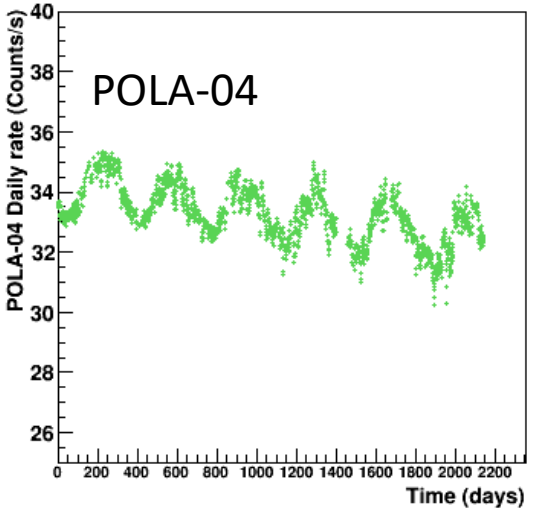

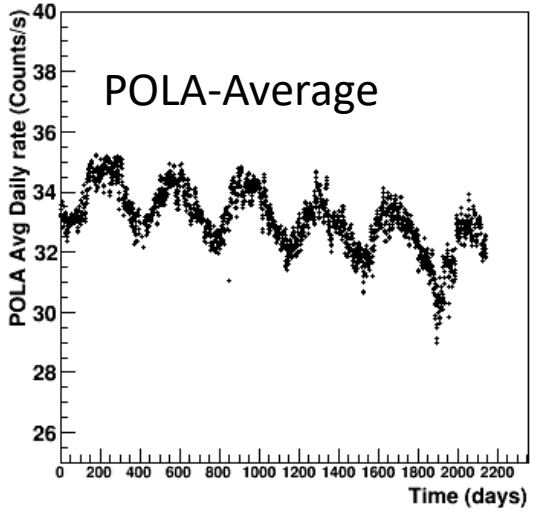

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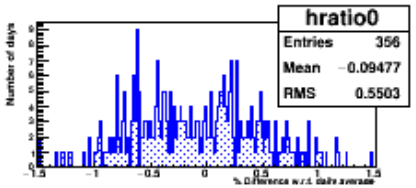

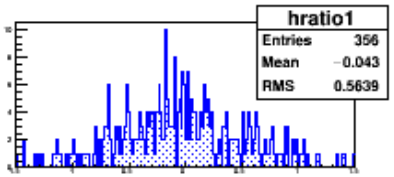

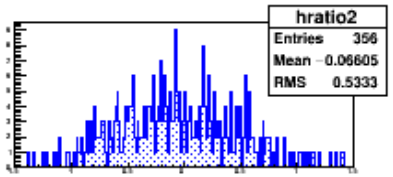

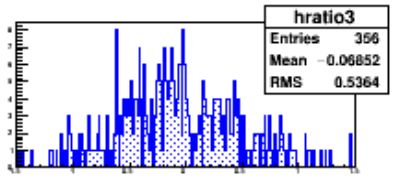

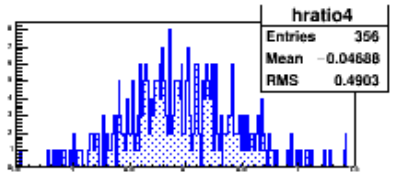

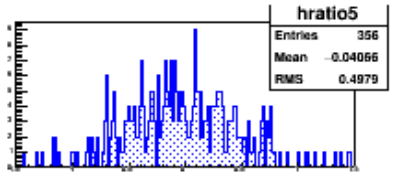

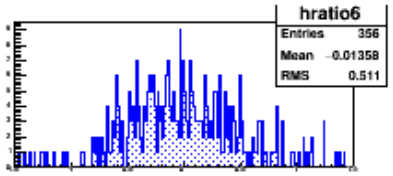

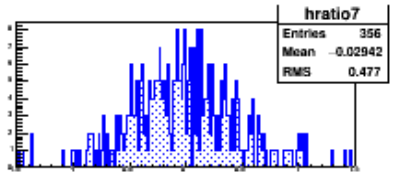

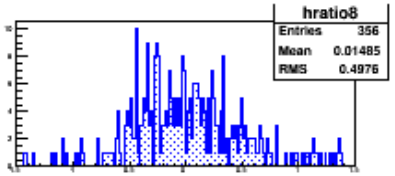

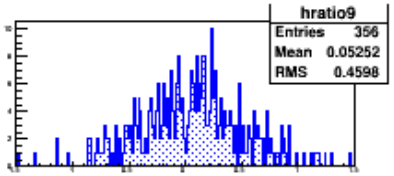

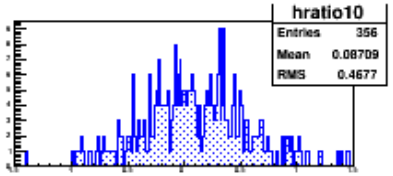

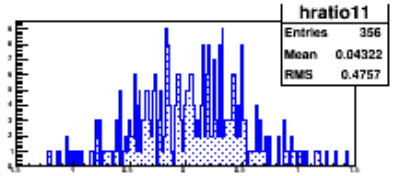

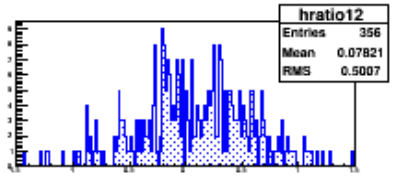

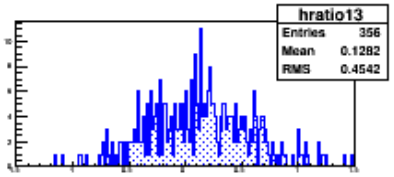

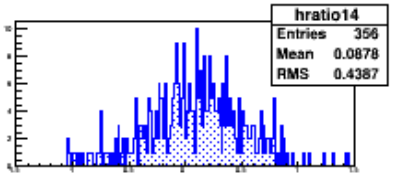

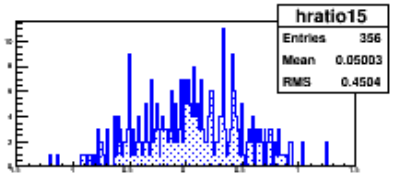

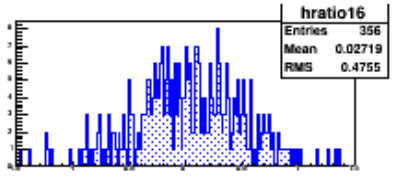

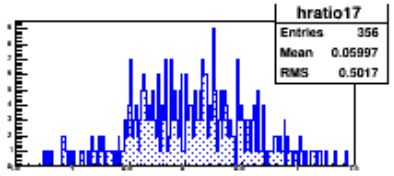

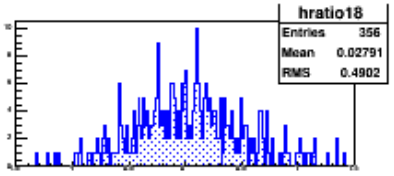

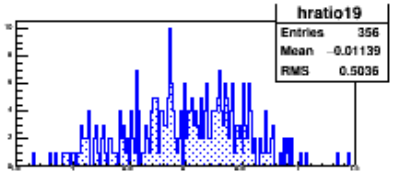

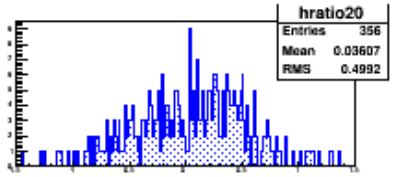

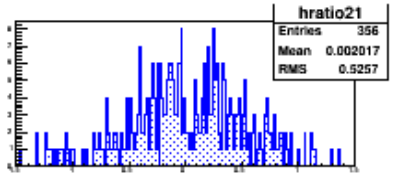

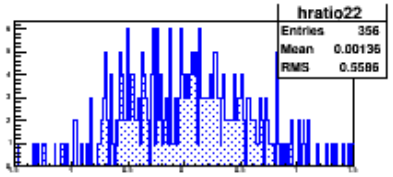

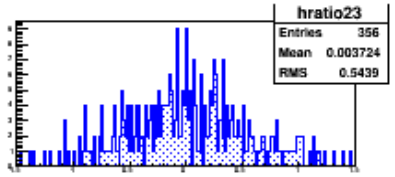

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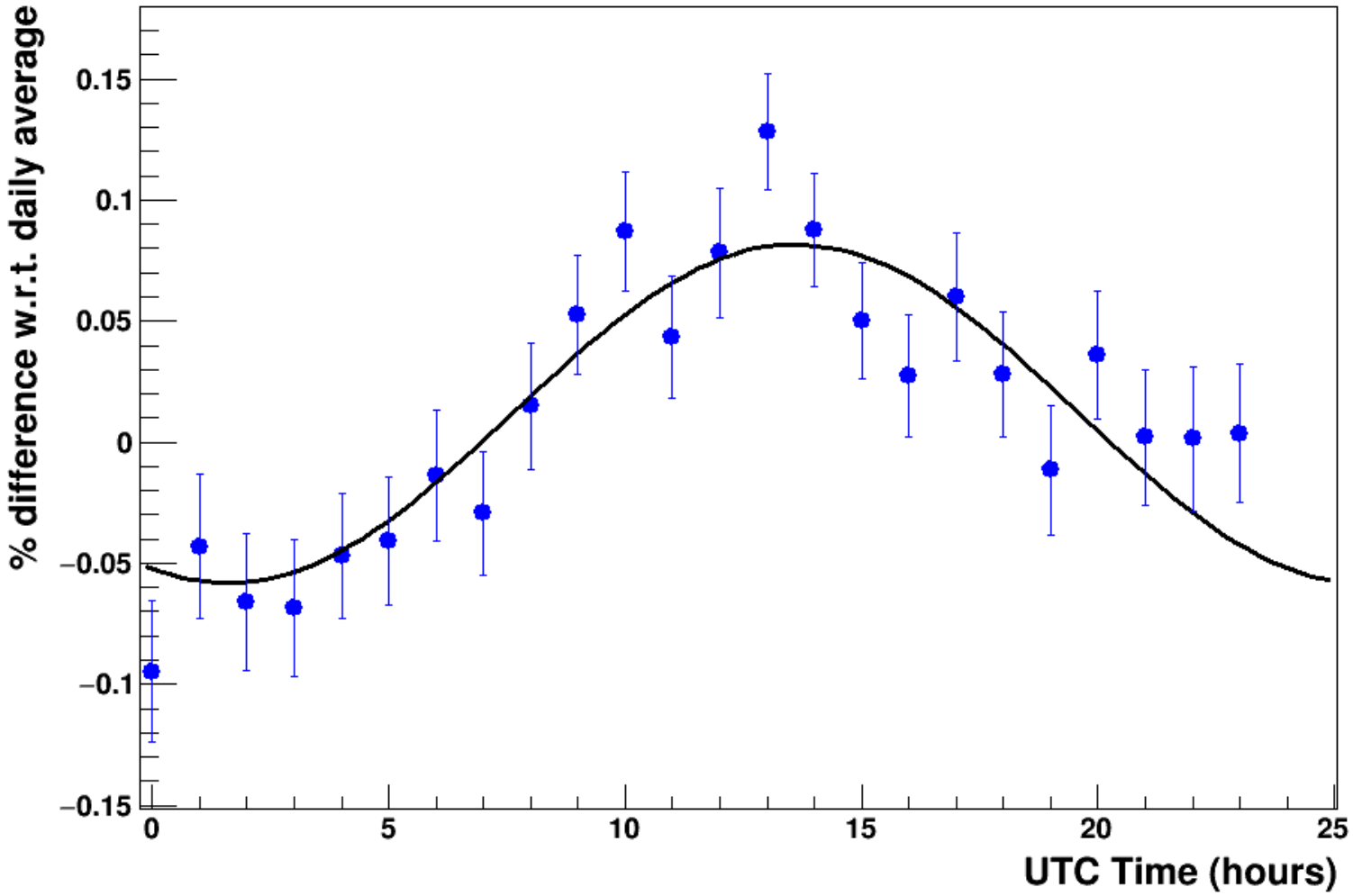

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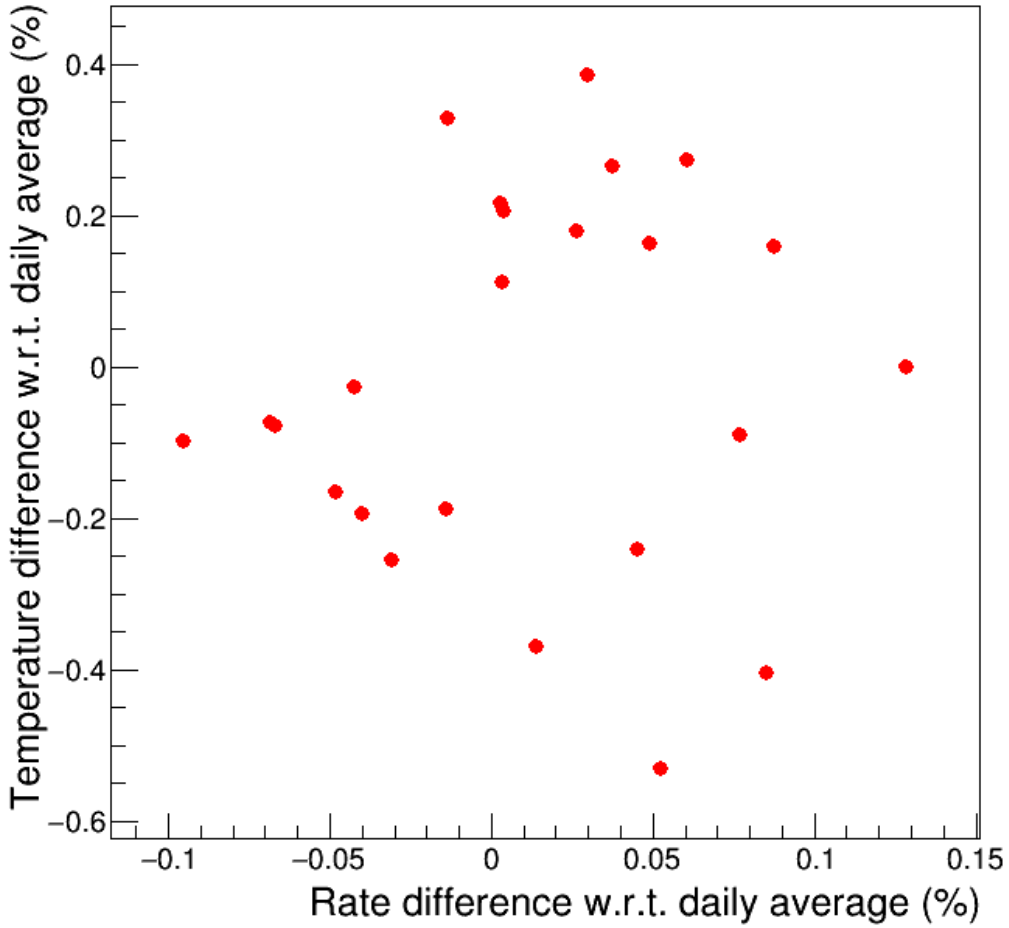

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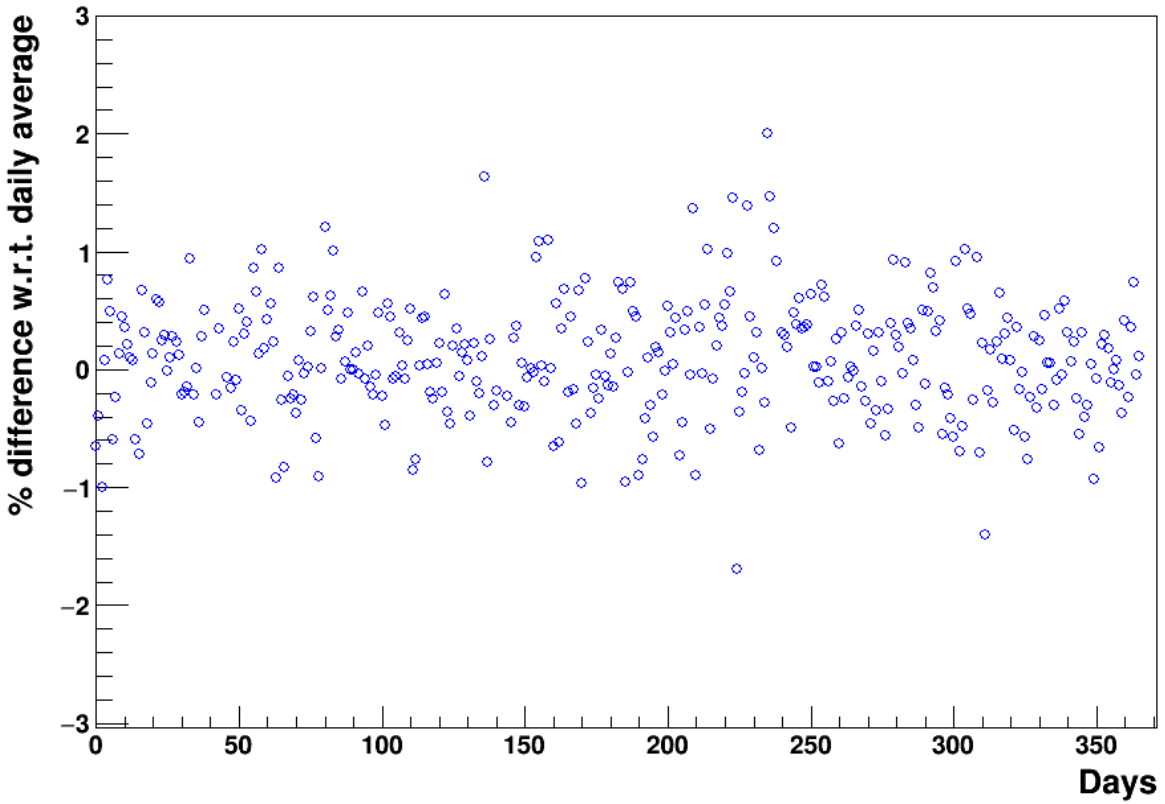

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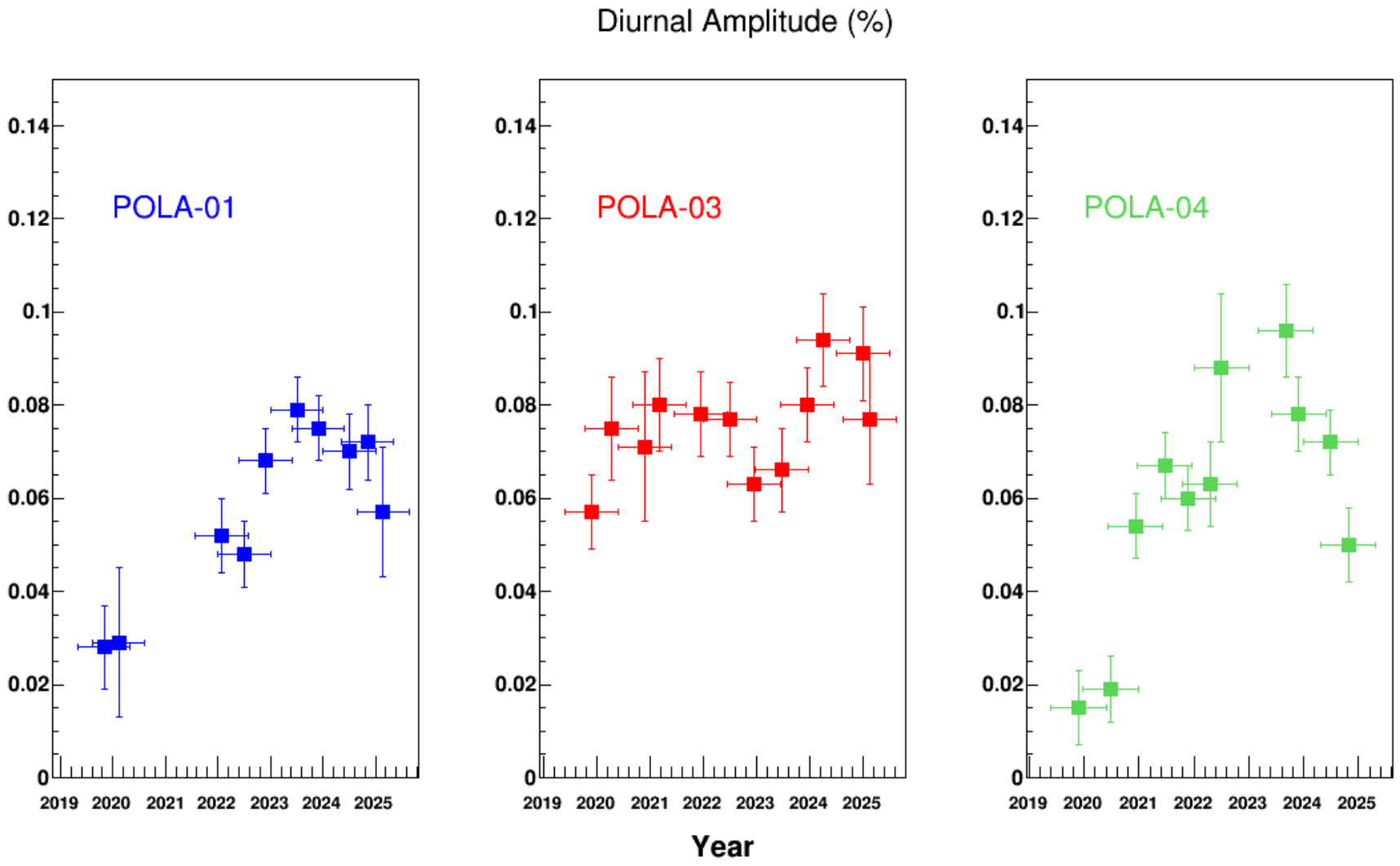

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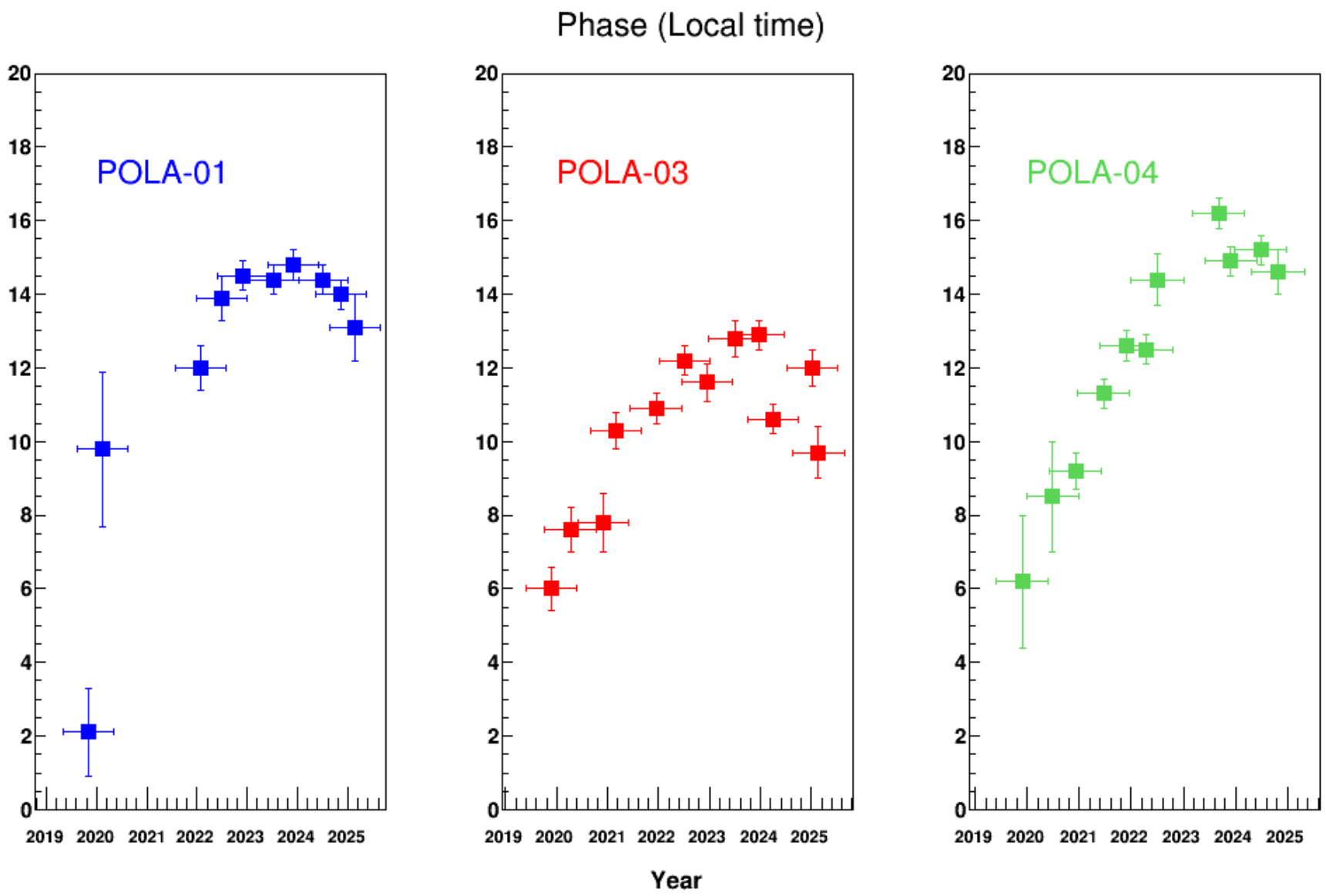

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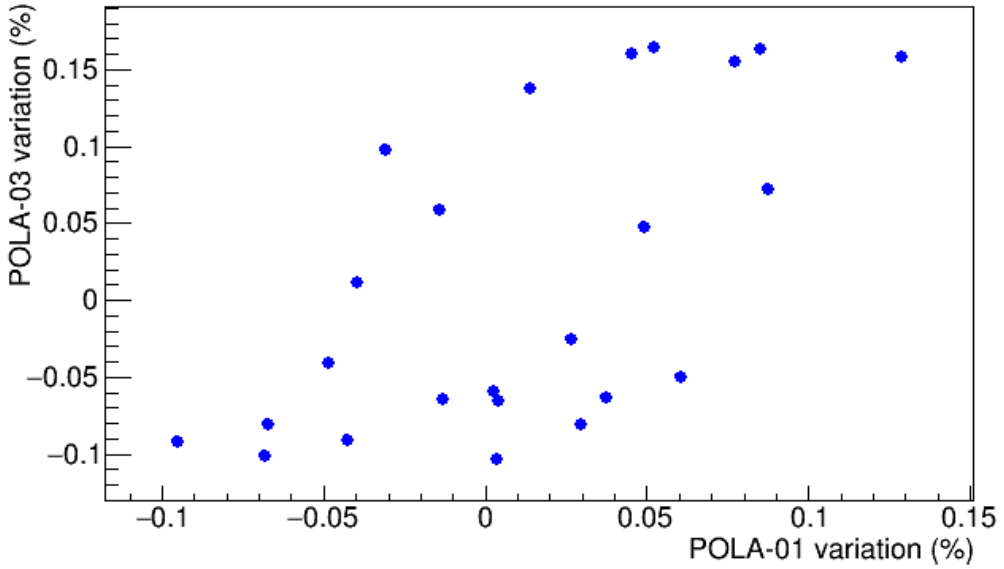

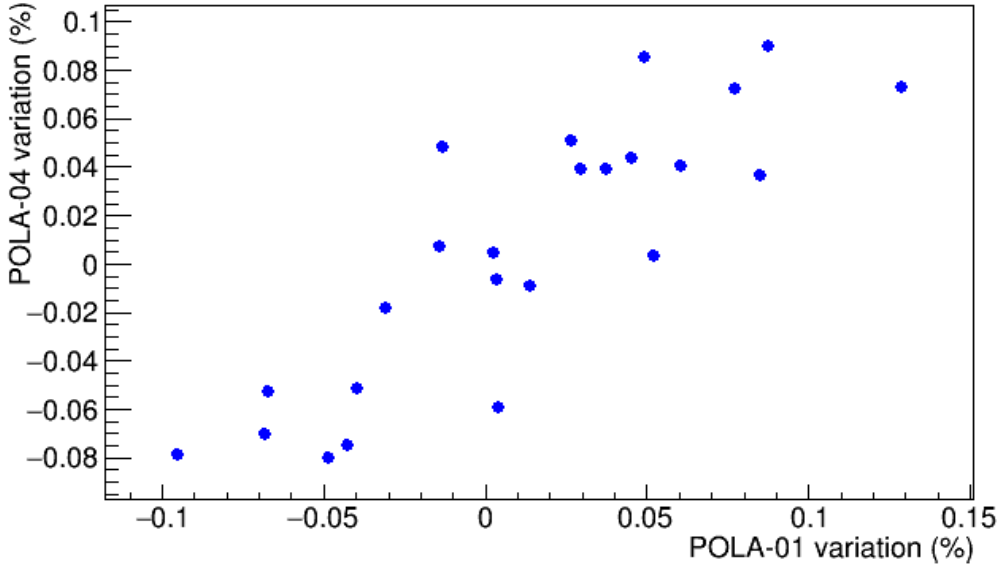

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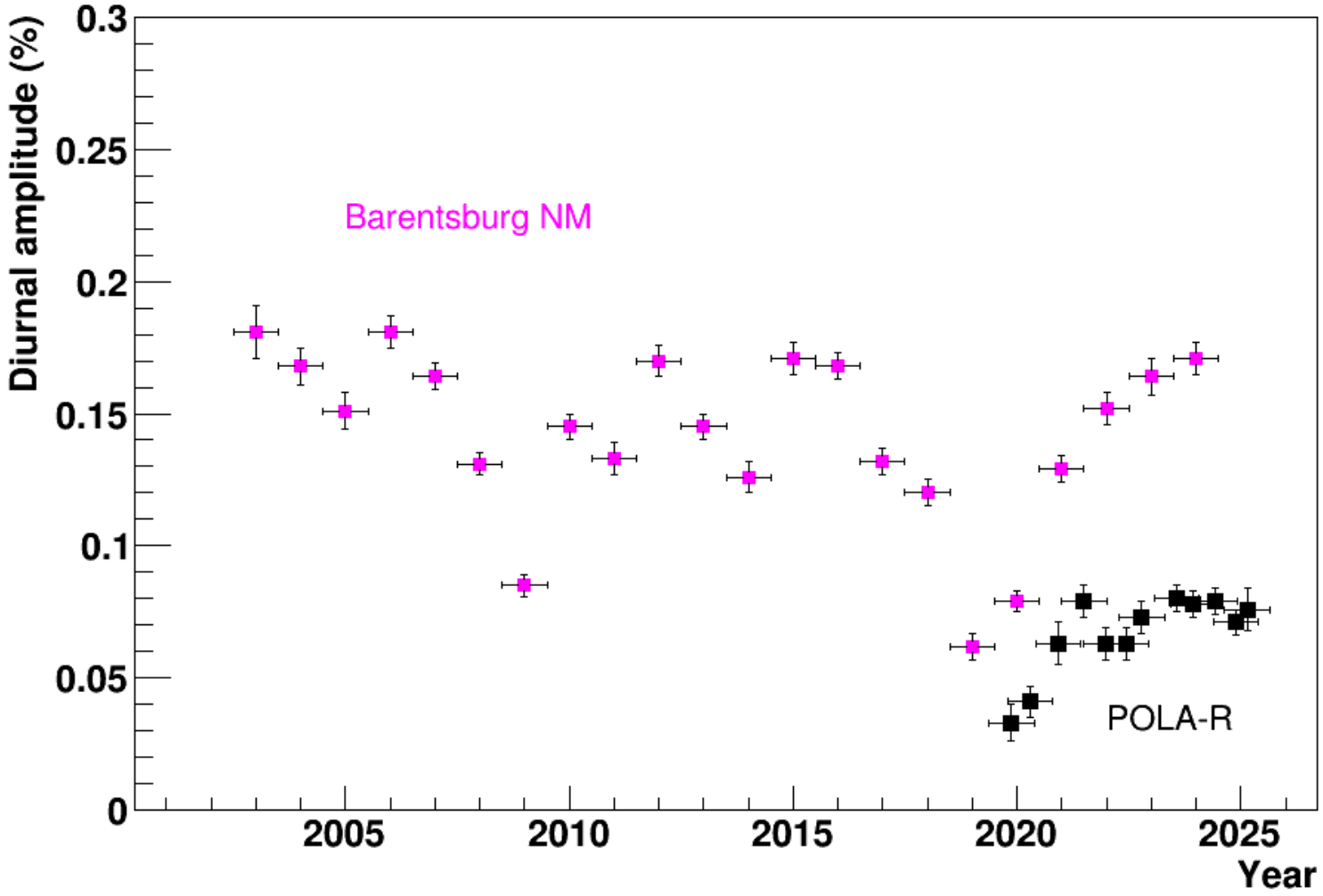

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