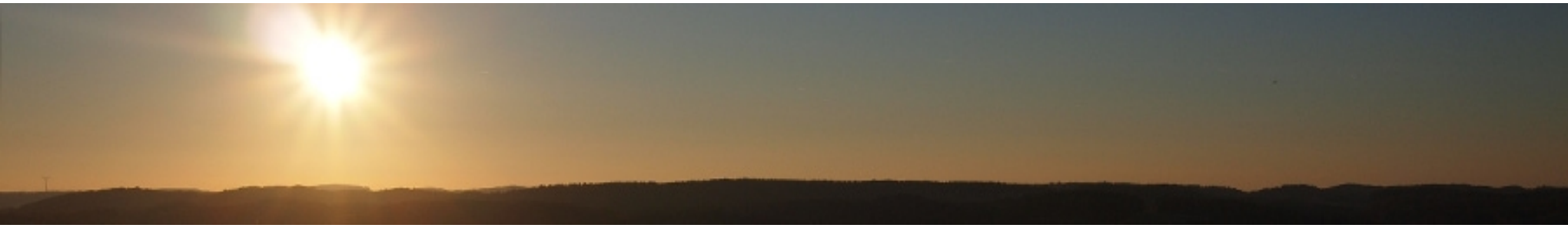
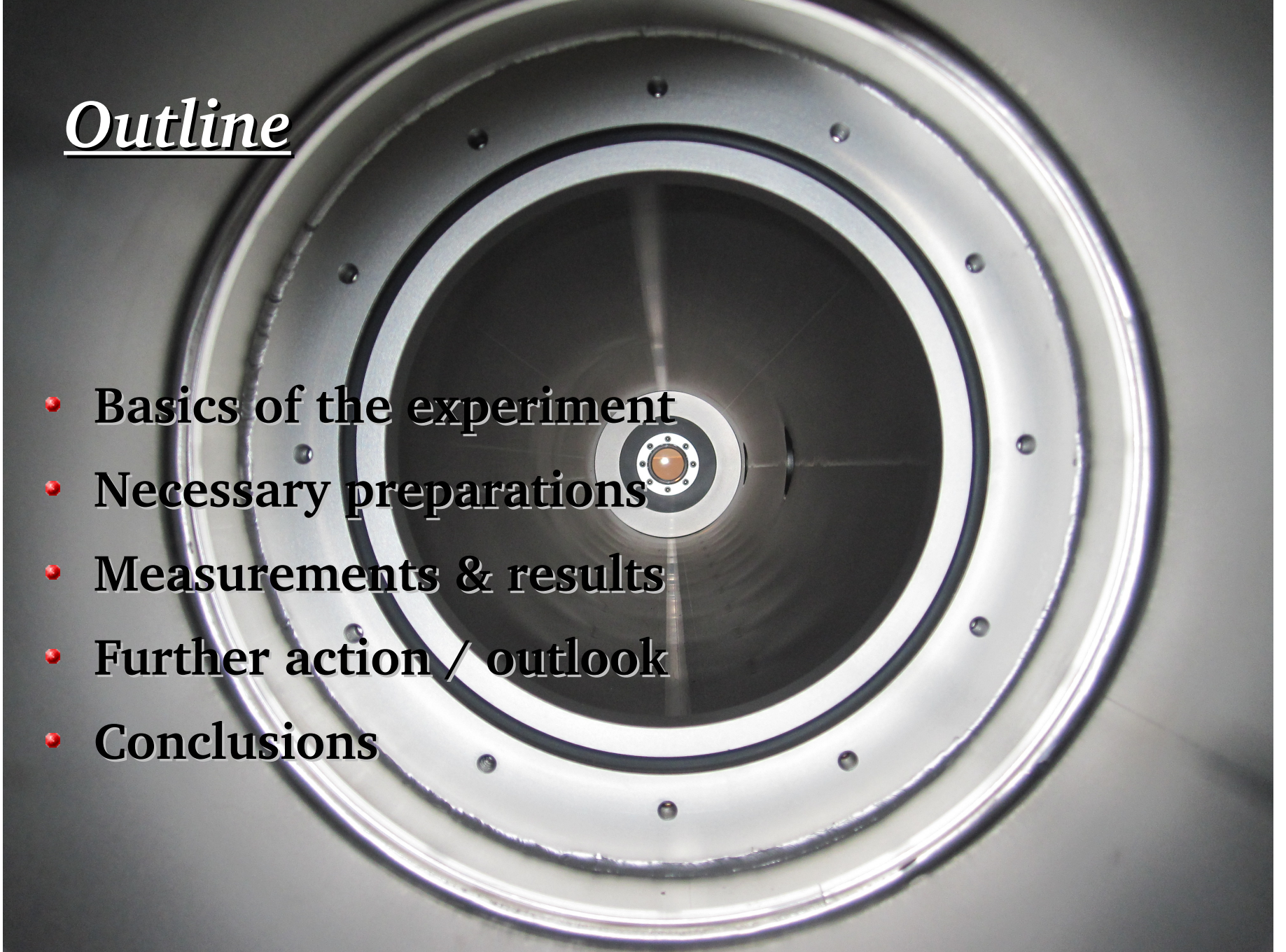


SHIPS

Solar Hidden Photon Search

Matthias Schwarz

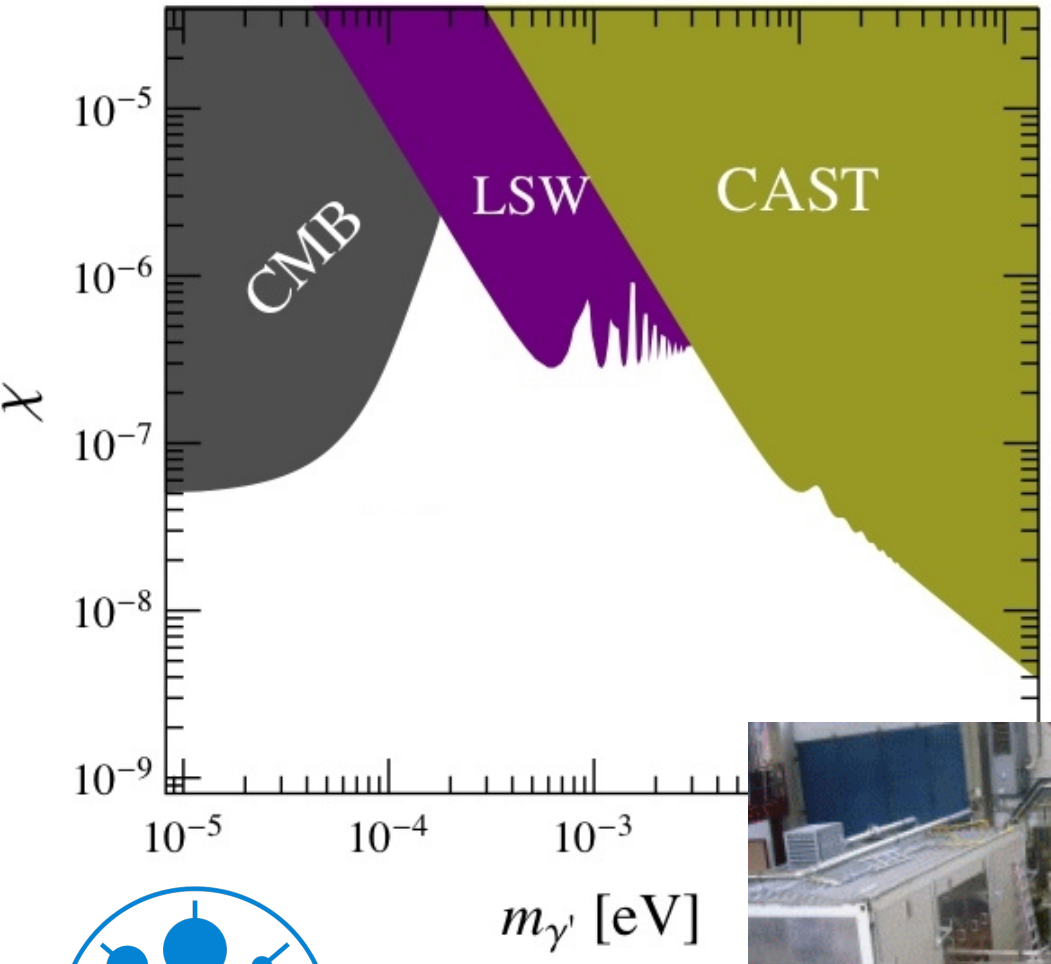
A. Ringwald, G. Wiedemann, J. Redondo, A. Lindner, M. Schneide,
J. Susol, E.-A. Knabbe, C. Martens,
E.-O. Saemann



Outline

- Basics of the experiment
- Necessary preparations
- Measurements & results
- Further action / outlook
- Conclusions

SHIPS - Offspring of ALPS family

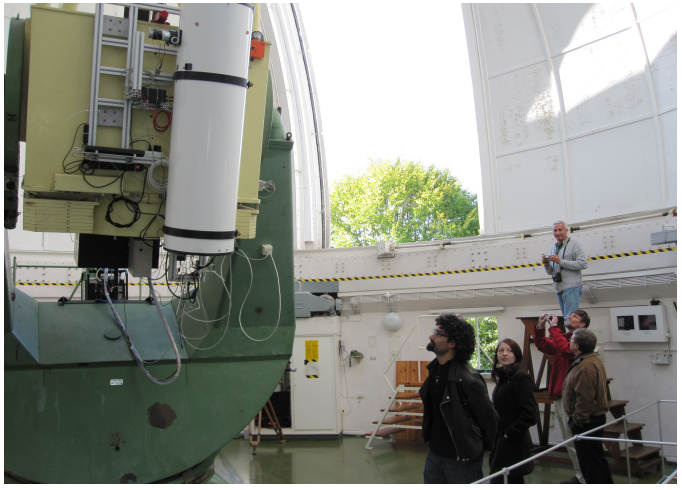


Idea:

Exploit the sun as huge natural source of Hidden Photons

DESY

First steps



Preluding meeting in October 2010

and tour of the telescope site

Particles, Strings,
and the Early Universe
Collaborative Research Center SFB 676

Some details about SHIPS

- Generation of a vast number of Hidden Photons in the Sun's interior and atmosphere
- (Re-) conversion into ordinary photons via flavor oscillation
- 'Hidden Photon Signal' (just) according to the reconverted ordinary photons

  → Helioscope has to be totally light-shielded
- No involved magnetic fields (unlike the laboratory experiments ALPS and ALPS II)
- Low pressure increases reconversion probability

  → vaccum pressures with at most 10^{-4} *mbar*
- Precise sun tracking is required

Tracing hidden photons

$$N_{\gamma'} = \int \frac{d\Phi_{\gamma'}}{d\omega} \cdot A \cdot T \cdot P_{(\gamma' \to \gamma)}(\chi, m_{\gamma'}, \omega, L, \Delta n) d\omega$$

with m = hp mass, L = path length, ω = photon energy,

$\Delta n = n - 1$, n: index of refraction of the medium

Tracing hidden photons

$$N_{\gamma'} = \int \frac{d\Phi_{\gamma'}}{d\omega} \cdot A \cdot T \cdot P_{(\gamma' \to \gamma)}(\chi, m_{\gamma'}, \omega, L, \Delta n)\, d\omega$$

with m = hp mass, L = path length, ω = photon energy,

$\Delta n = n - 1$, n: index of refraction of the medium

Photon - hidden photon oscillations

- The probability of photon - hp oscillations is given by:

$$P(\gamma \rightarrow \gamma') = \frac{\sin^2 2\chi}{\left(cos2\chi + \frac{2\omega^2 \Delta n}{m_{\gamma'}^2}\right)^2 + \sin^2 2\chi} \sin^2 \frac{m_{\gamma'}^2 \cdot L \cdot \sqrt{\left(cos2\chi + \frac{2\omega^2 \Delta n}{m_{\gamma'}^2}\right)^2 + \sin^2 2\chi}}{4\omega}$$

with m = hp mass, L = path length, ω = photon energy,

$\Delta n = n - 1$, n: index of refraction of the medium

- Oscillations are significantly smaller when $\Delta n > 0$
- For visible light a pressure below 10^{-4} mbar ensures that oscillations will not be damped

Photon - hidden photon oscillations

- The probability of photon - hp oscillations is given by:

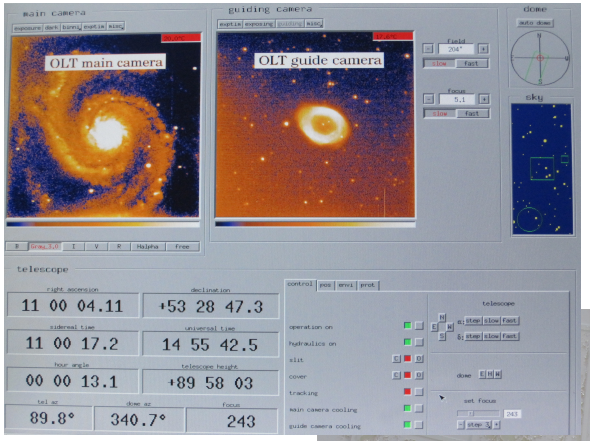
$$P(\gamma \rightarrow \gamma') = \frac{\sin^2 2\chi}{\left(cos2\chi + \frac{2\omega^2 \Delta n}{m_{\gamma'}^2}\right)^2 + \sin^2 2\chi} \sin^2 \frac{m_{\gamma'}^2 \cdot L \cdot \sqrt{\left(cos2\chi + \frac{2\omega^2 \Delta n}{m_{\gamma'}^2}\right)^2 + \sin^2 2\chi}}{4\omega}$$

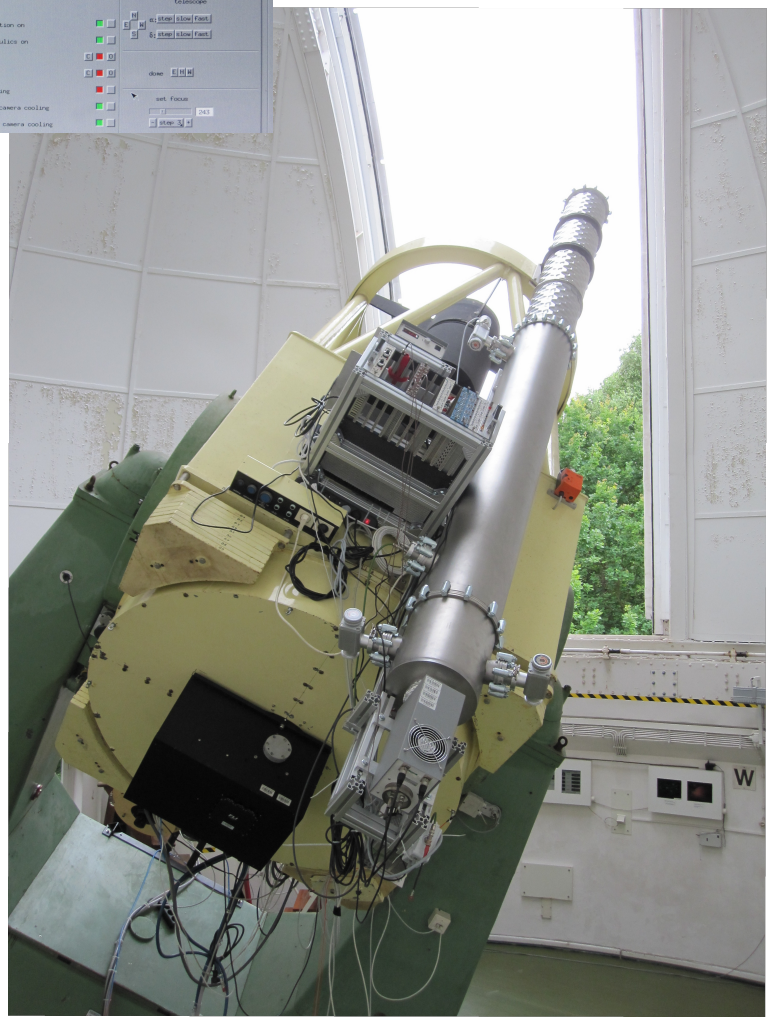
with m = hp mass, L = path length, ω = photon energy,

$\Delta n = n - 1$, n: index of refraction of the medium

- Oscillations are significantly smaller when $\Delta n > 0$
- For visible light a pressure below 10^{-4} mbar ensures that oscillations will not be damped

TSHIPS in operation

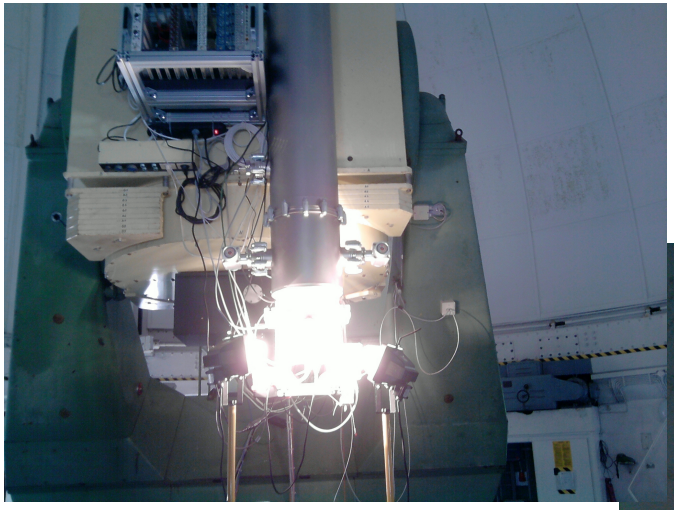


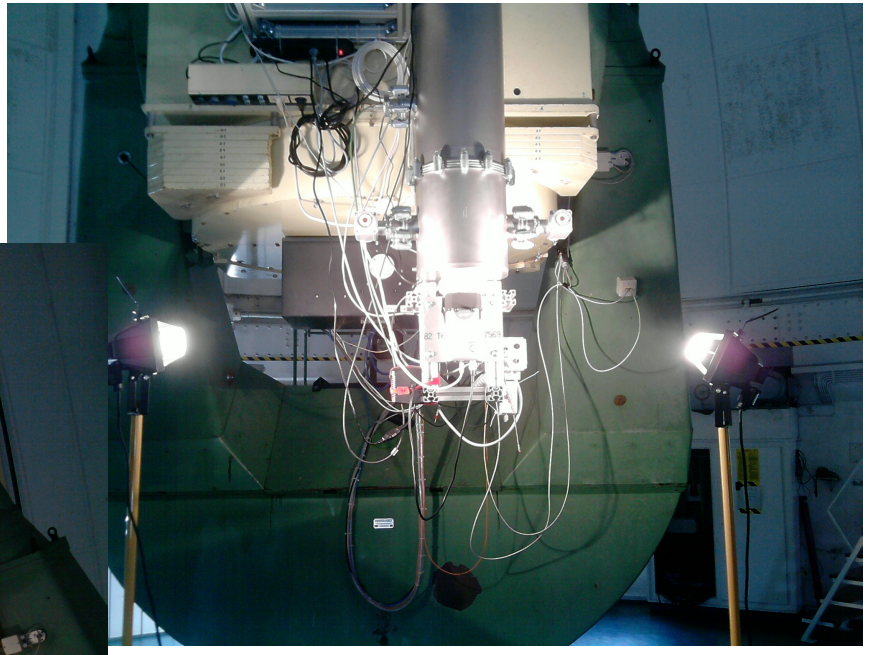


- Fully remote controllable
- Effective length: 4.15 m
- Diameter: 0.25 m
- First 'vacuum telescope' in more than 100 years at HS
- 'Piggyback operation'

  A 1.2 m Ritchey–Chrétien telescope serves as mount for TSHIPS1
- Full azimuth range (24 h)
- Altitudes: 10 to 90°

Light tightness checks



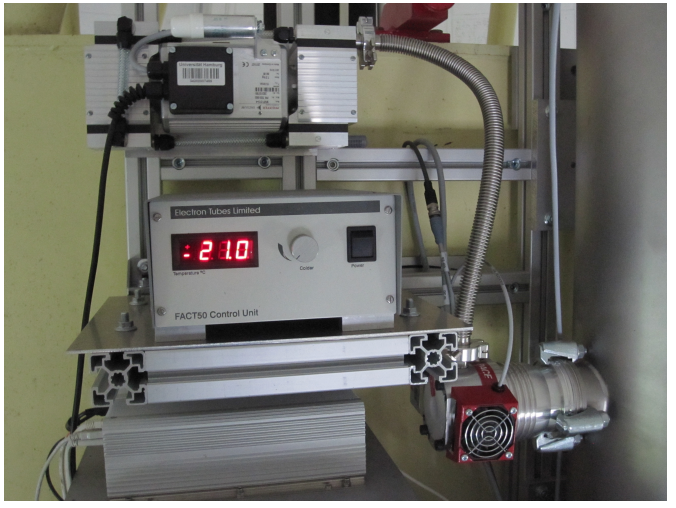


- The whole set-up with all flanges, junctions, etc. was checked extensively for light leakage.

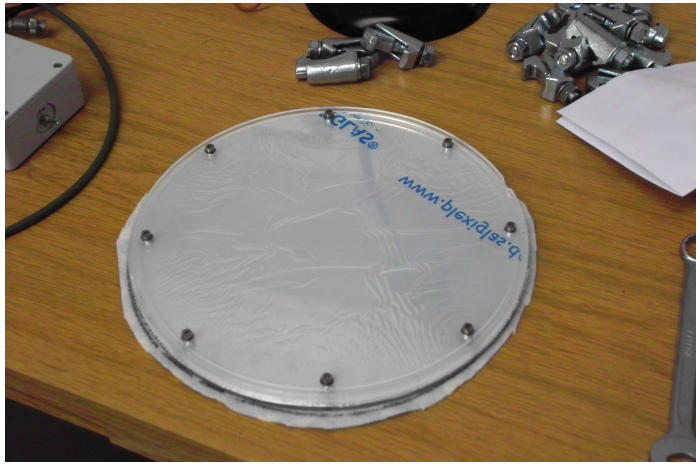
→ No interfering light left

Pressure at most 10^{-4} mbar

- Pressures of less than 10^{-5} mbar achieved within minutes
- Regularly checked by pressure gauge
- NO FAST TSHIPS MOVEMENTS

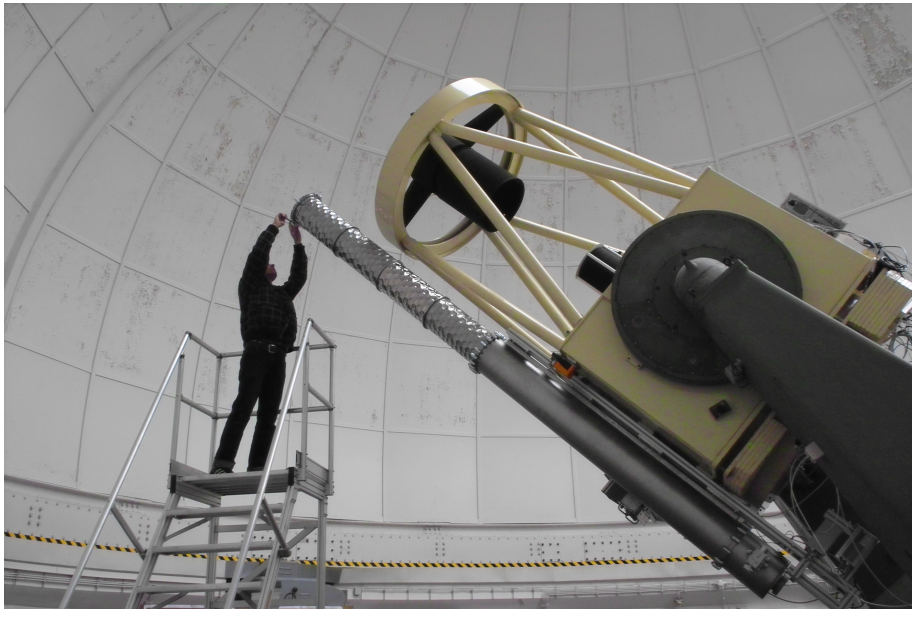


Pointing and tracking accuracy



← Solar filter (10^{-5}) fixed by two acrylic glass discs

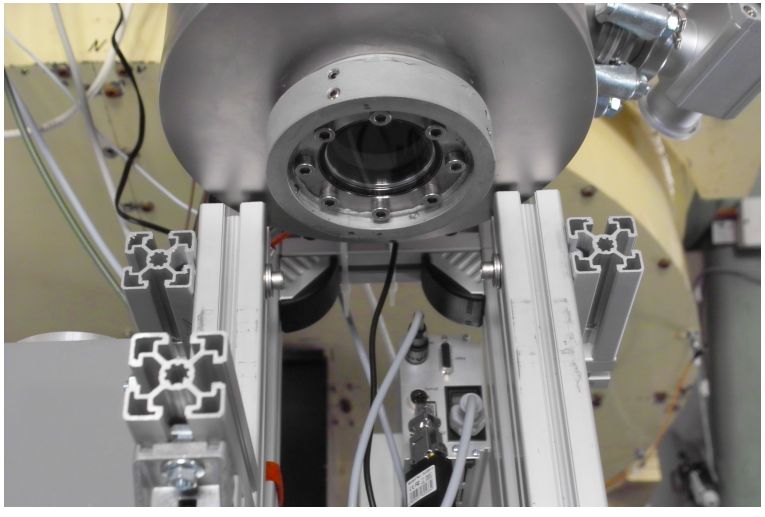
Then mounted to the top of TSHIPS ↓



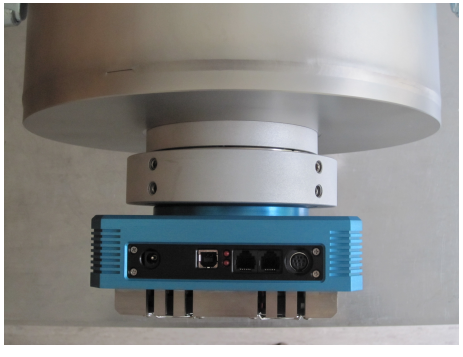
- Precisely positioned counterweight
- Direct sun observations (filter) for accurate TSHIPS1 pointing and the proper longterm tracking check

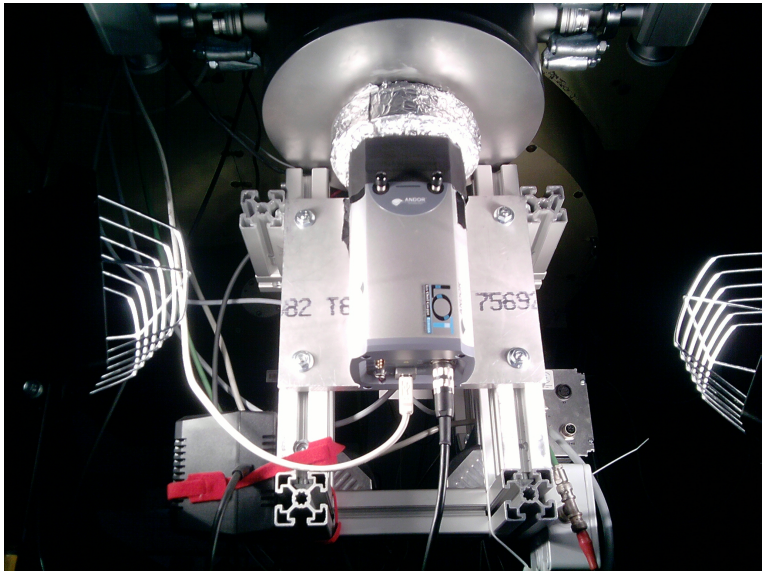
  → Position of the sun's image on chip varied a fraction of pixel number within hours.
- A proper sun tracking is guaranteed

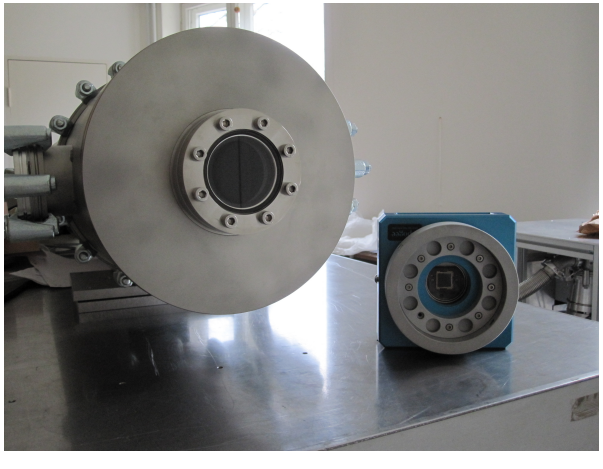
Detector interface

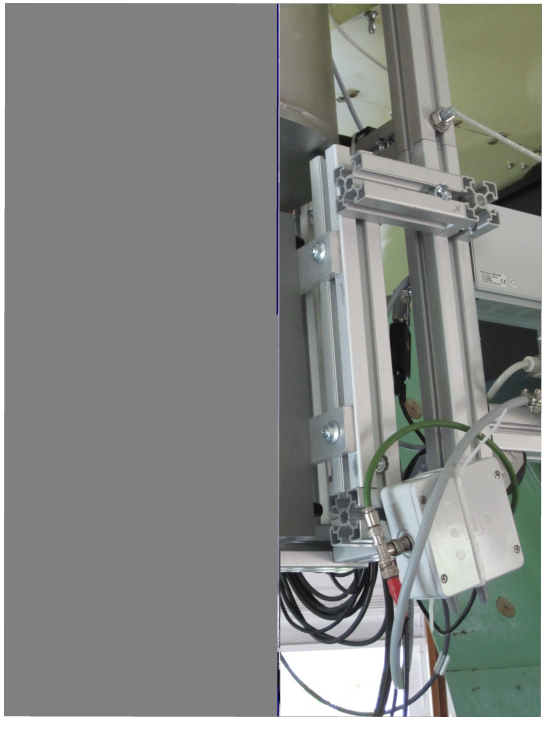


- Flexible and easily adapted detector interface allows an uncomplicated variation of different detectors (CCDs and PMT cooler housing)

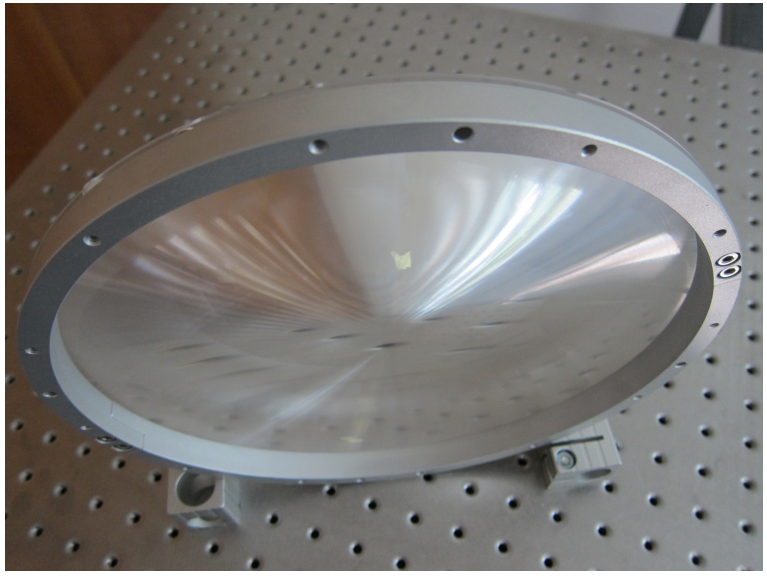


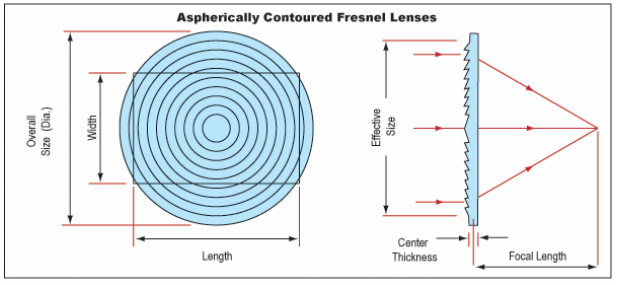


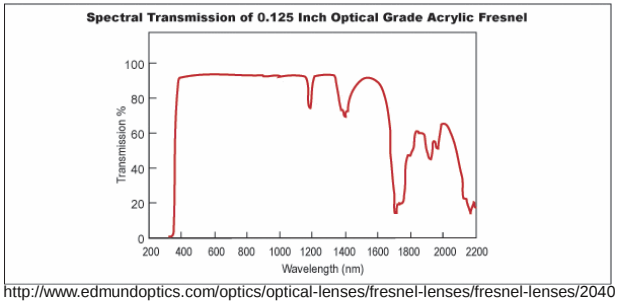




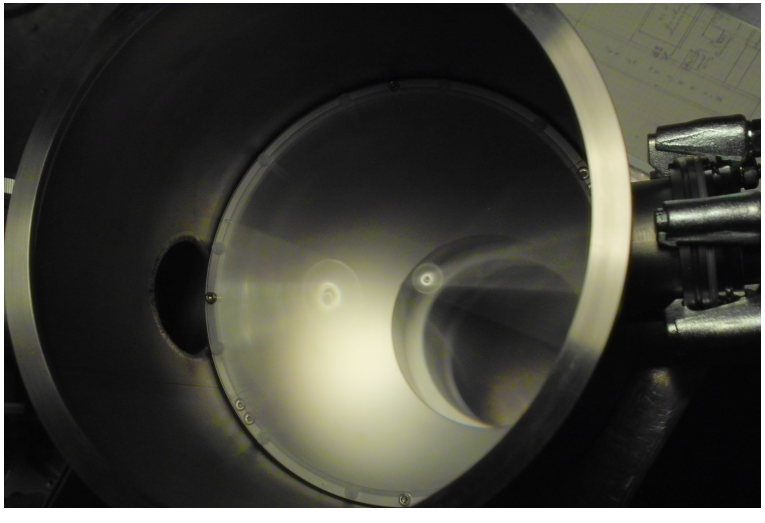
Optics

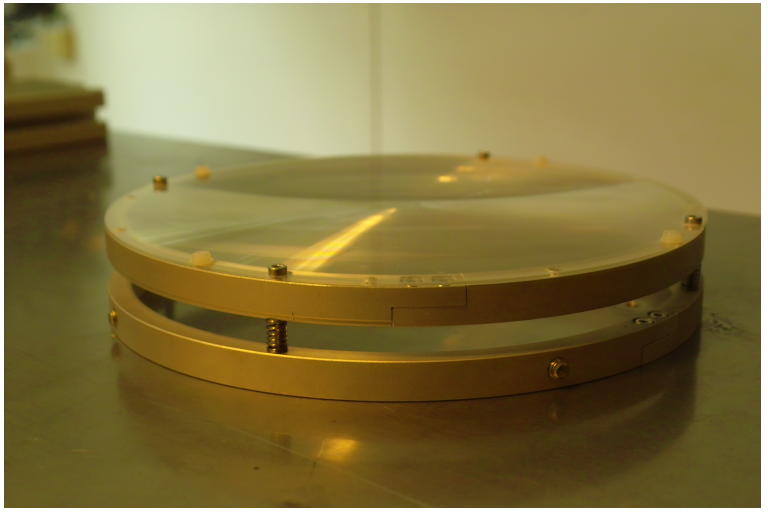






http://www.edmundoptics.com/optics/optical-lenses/fresnel-lenses/fresnel-lenses/2040





Fresnel lenses ...

- ensure a stable high trans-mission and image quality in the optical and near-infrared spectral range
- provides (here) a short focal length of 20 cm

Optical fresnel astronomy

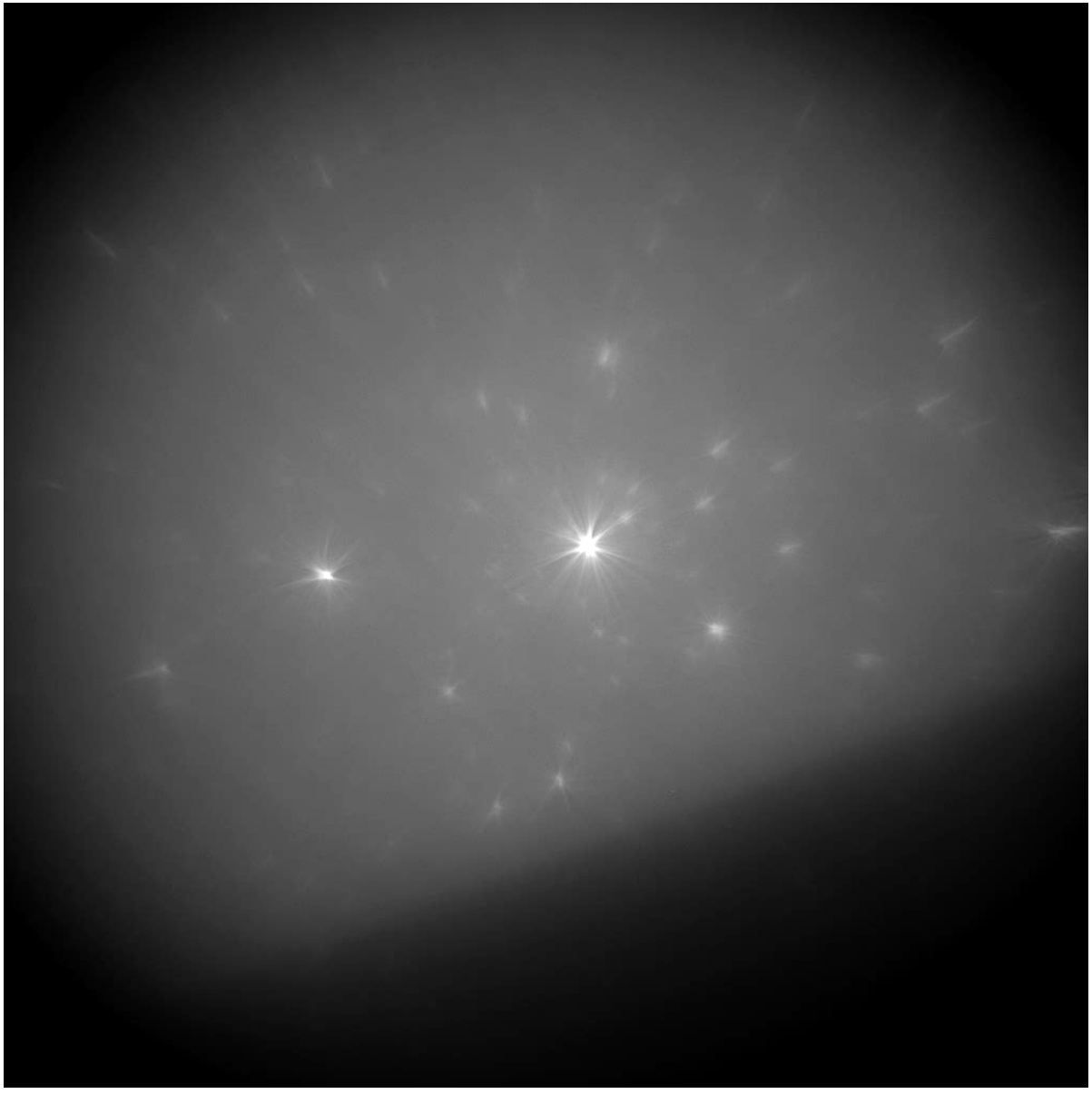
- HIP113622

by TSHIPS

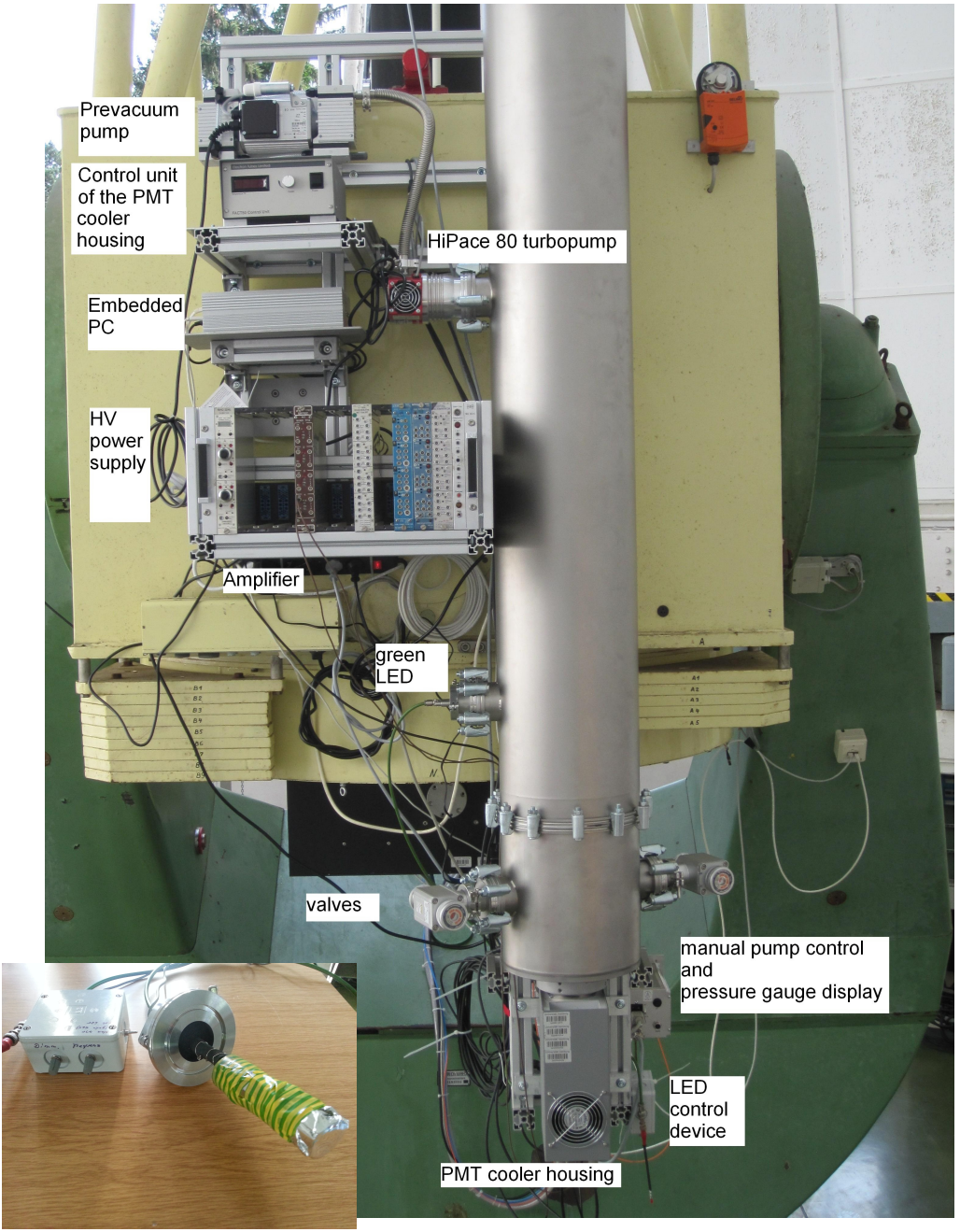
fresnel lens

FL 20 cm

iKon-M



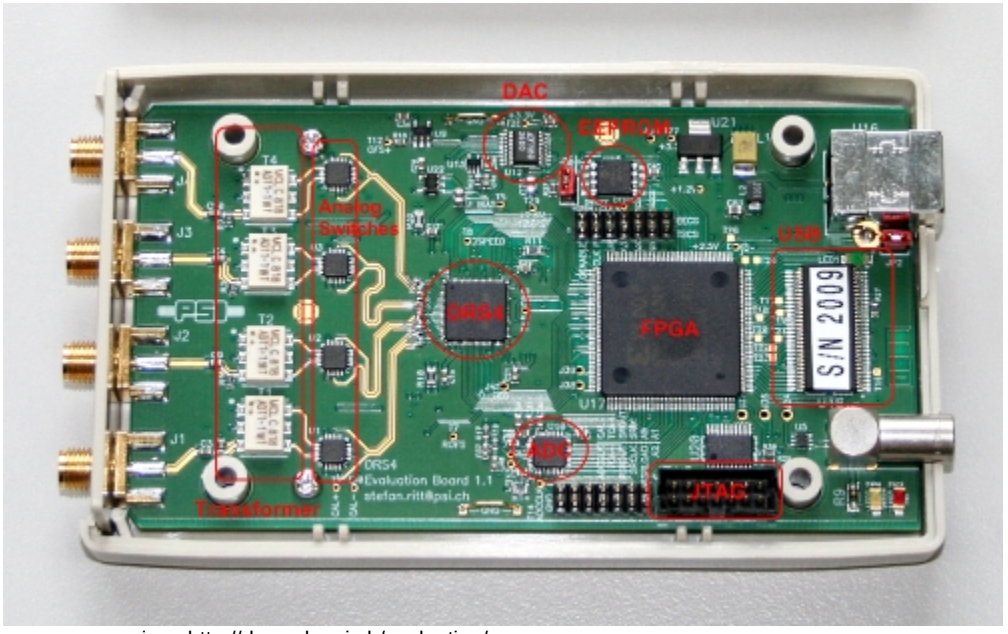
Setup of the helioscope



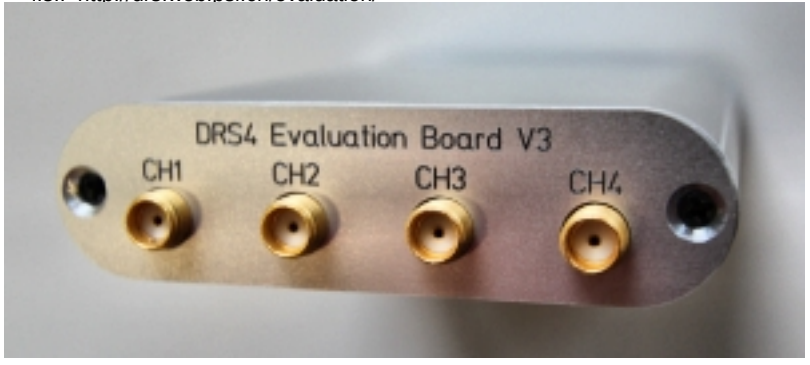
- Blue and red LEDs for artificial photon flux/signal
- Valves for further devices
- Pressure gauge
- Power supply
- PC
- Vacuum and prevacuum pumps
- Control units

All environment data like air humidity, temperatures, time, etc. is recorded!

DRS4 Evaluation Board



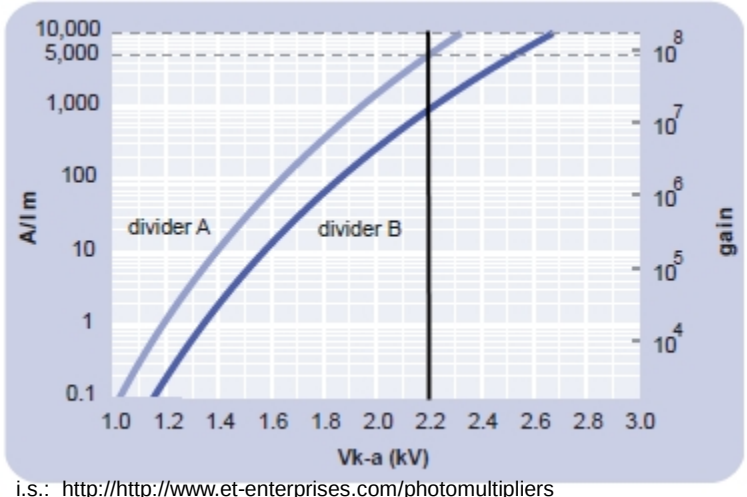
i.s.: http://drs.web.psi.ch/evaluation/



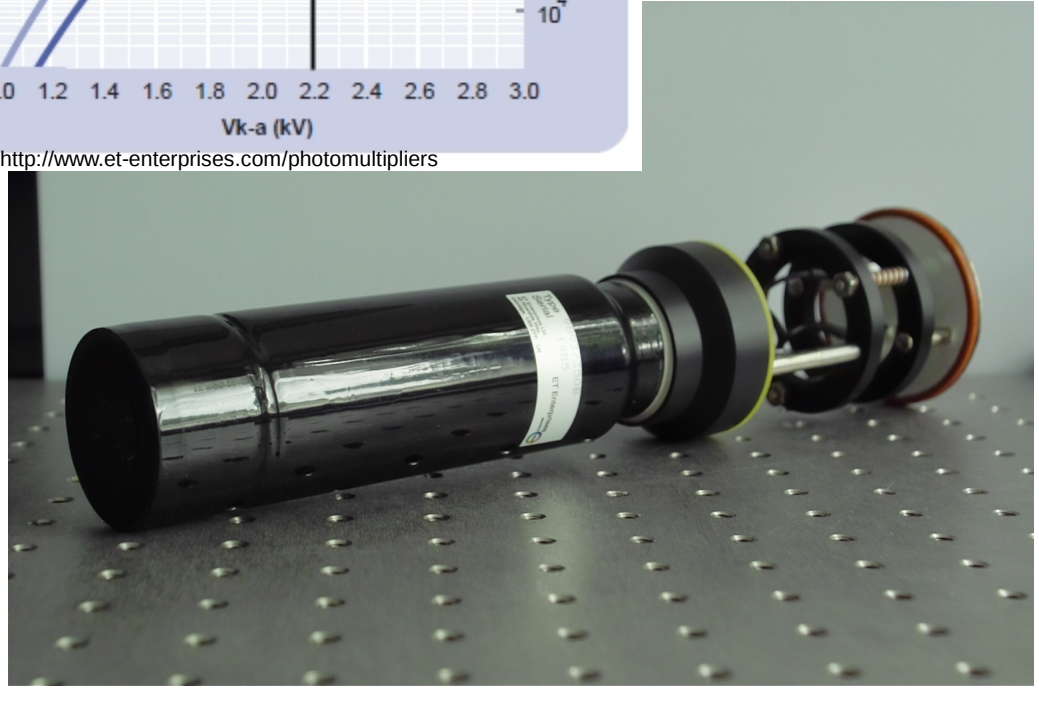
- Used for the analyses of the PMT signals
- Counting and detailed recording of every electron/photon event
- Very stable and accurate performance
- Easy longterm measurements
- Switched Capacitor Array digitizing 8 channels at sampling speed up to 5 GSPS.
- Equivalent to a four channel 5 GSPS digital oscilloscope

Detector for SHIPS

Photomultiplier 9893/350B



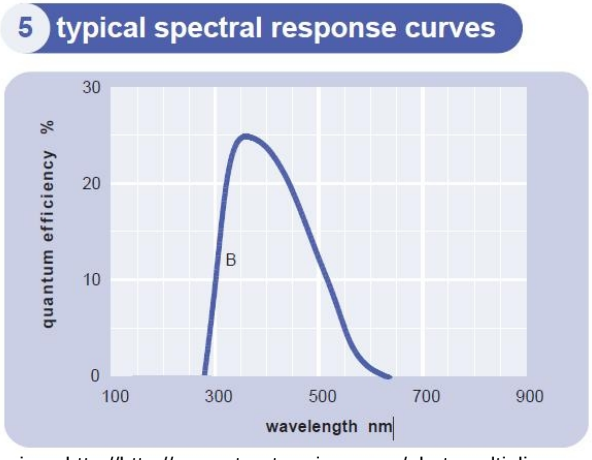
i.s.: http://http://www.et-enterprises.com/photomultipliers



ET Enterprises
9893/350B:

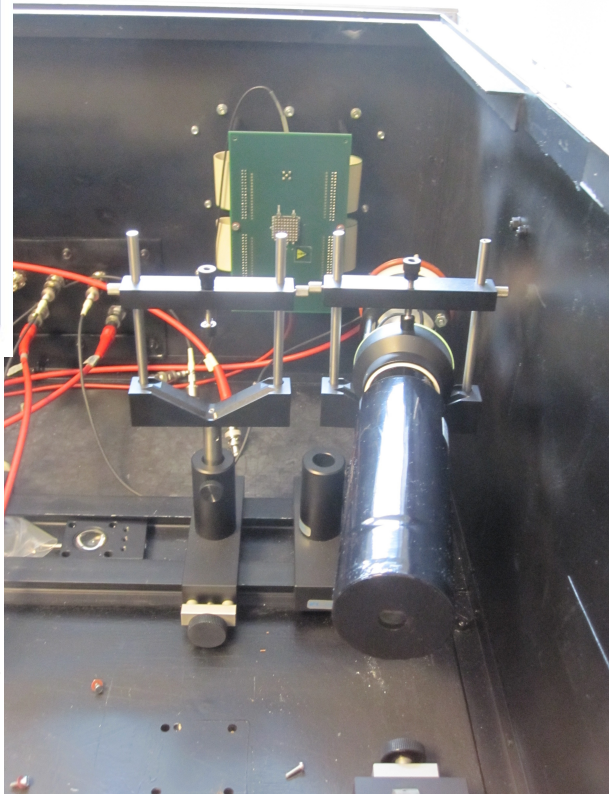
- Low noise: dark current 0.46 Hz
- Single Photon Counting
- Operated at -21°C
- Operating voltage: 2.2 kV
- Active diameter 9 mm
- Quantum efficiency at peak 25%
- Blue-green sensitive photocathode

Detector for SHIPS
Photomultiplier 9893/350B



i.s.: http://http://www.et-enterprises.com/photomultipliers

- Extensive lab testing,
  here in a black box with a blue LED and several filters
  → PMT was finally replaced



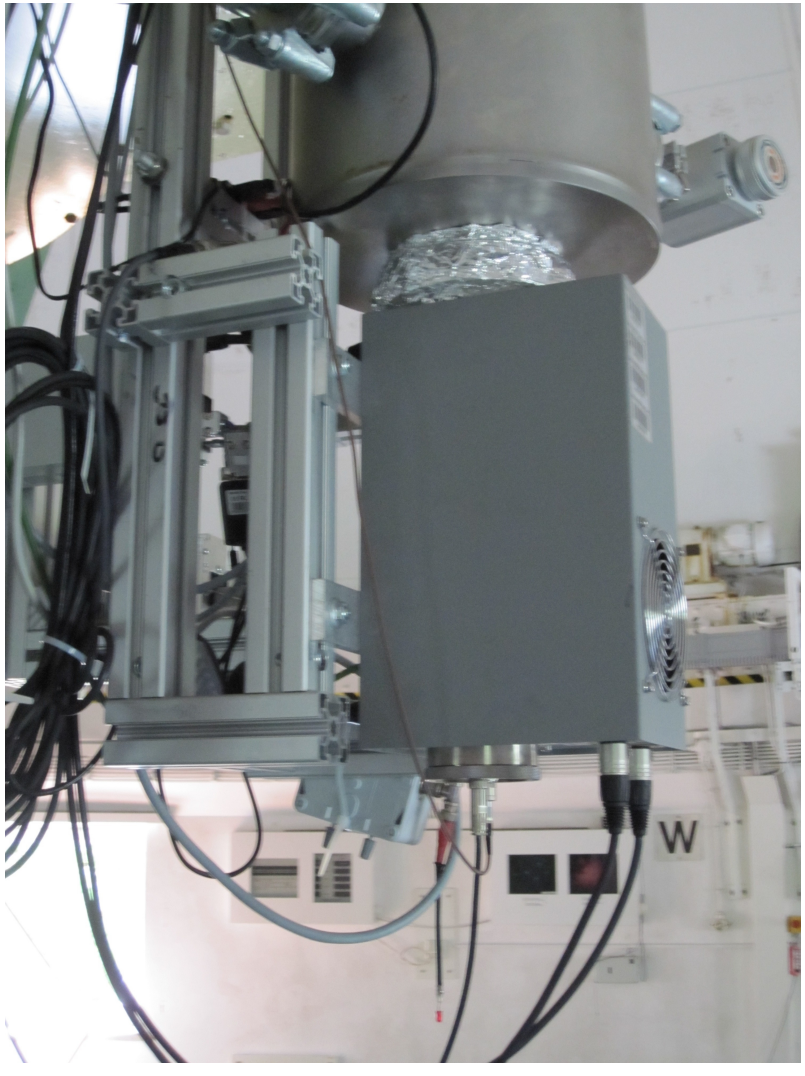
ET Enterprises
9893/350B:

- Low noise: dark current 0.46 Hz
- Single Photon Counting
- Operated at -21°C
- Operating voltage: 2.2 kV
- Active diameter 9 mm
- Quantum efficiency at peak 25%
- Blue-green sensitive photocathode

Detector for SHIPS

ET Enterprises Fact50 cooler housing

- Continuous uninterrupted voltage supply
  → no errors in voltage regulation
  → enormous increase of the stability of Dark Noise Rate
  → thus large reduction of a mayor systematic error

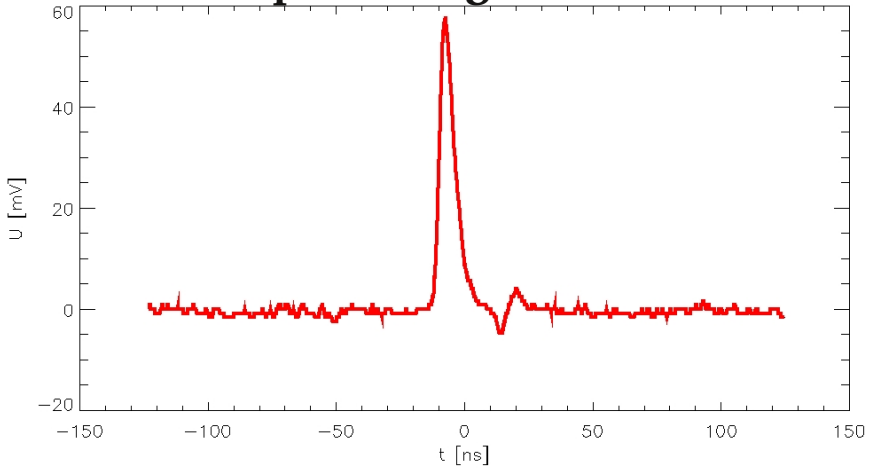


ET Enterprises Fact50 - cooler housing:

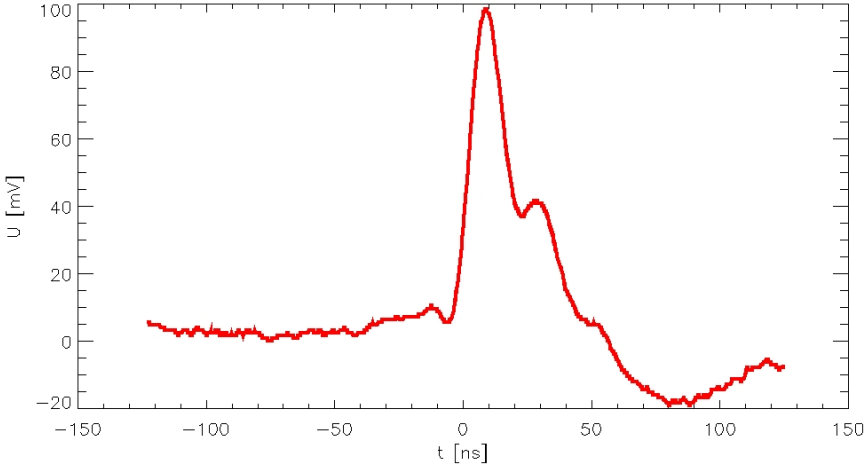
- Internal temperature sensor
  → Solid self-adjusting temperature of -21°C
- Relieved a light tight detector connection to TSHIPS
- Slight extra shielding for background impacts: cosmic rays, radioactivity

Single event peaks recorded by a digital oscilloscope

Not amplified signal

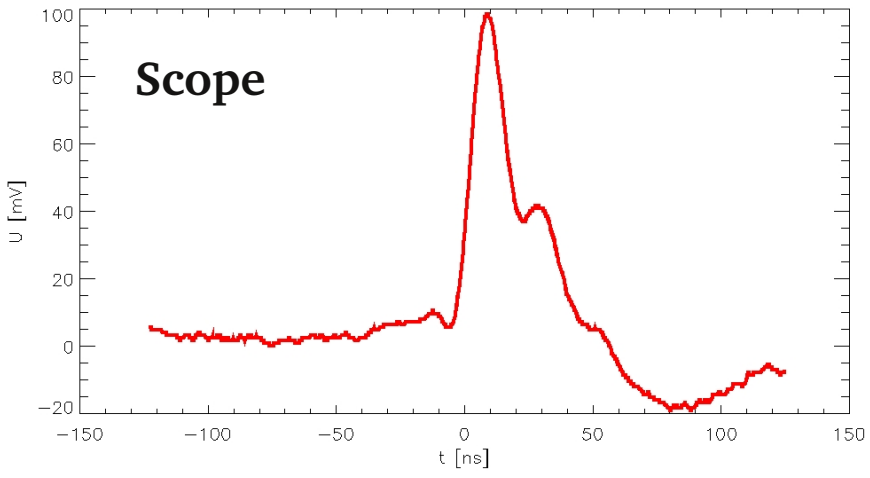


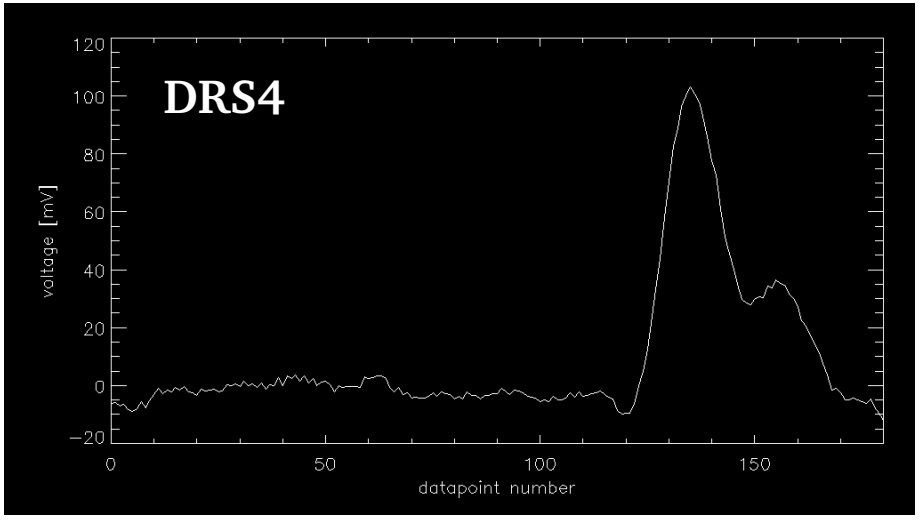
Amplified signal



- Rather high unamplified signal and typical amplified signal pulses
- Slight changes in the shape of the peak caused by the amplifier
- Triggering on the positive flanks performs equally accurate in both cases
- Trigger level can be set to a more comfortable level above the ground noise level

Typical data event peak recorded by scope and DRS4

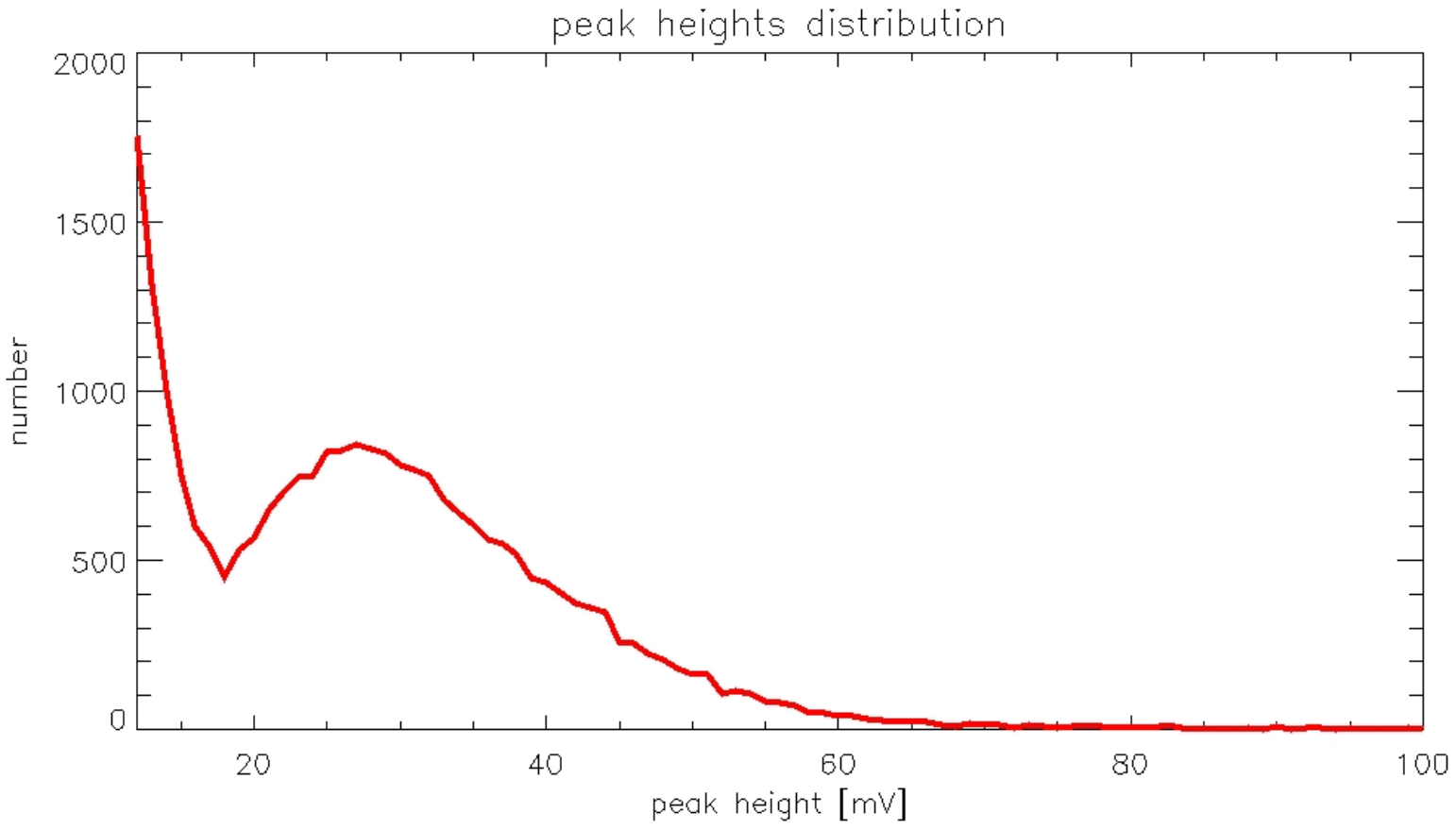




- Every event is digitally recorded and saved (1024 datapoints) with the DRS4 Evaluation Board. **Whole SHIPS raw data is available at any time.**
- The ”real photon” events can not be distinguished from ordinary background events by the shape of the event peak.
- The pulses heights are correlated with the deposited energy

  → Low energy thermal electrons and high energy cosmics can be excluded

9893/350B Single Pulse Height Distribution (PHD)



- ET 9893/359 B at -21°C and 2.2 kV – recorded with DRS4
- The typical shape of a photomultiplier tube PHD is very easy to recognize

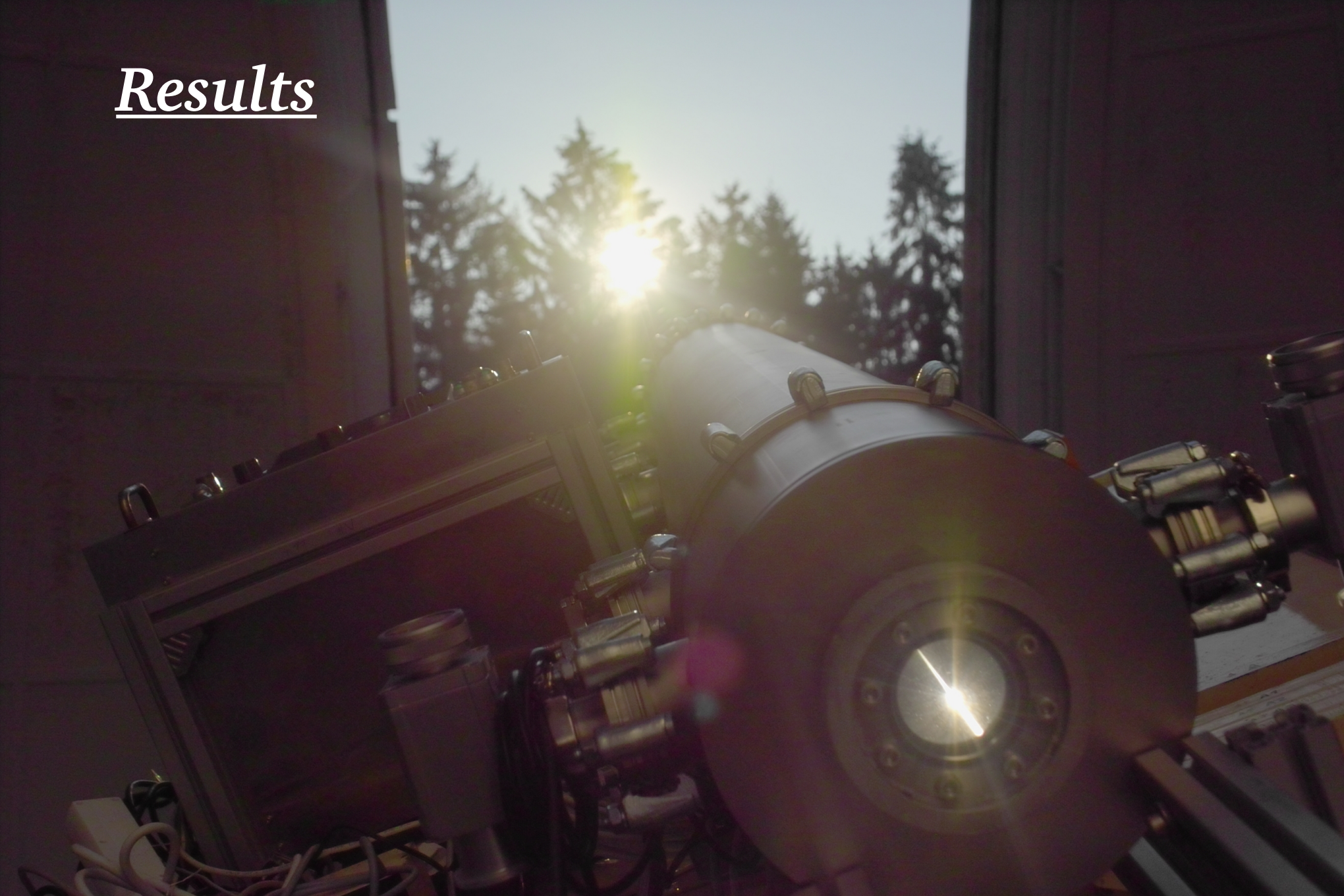
Final phase of data taking

- Results gained only from the optimized last measurement phase started at 18th March and ended at 7th May
- Fraction of the background correlated with altitude

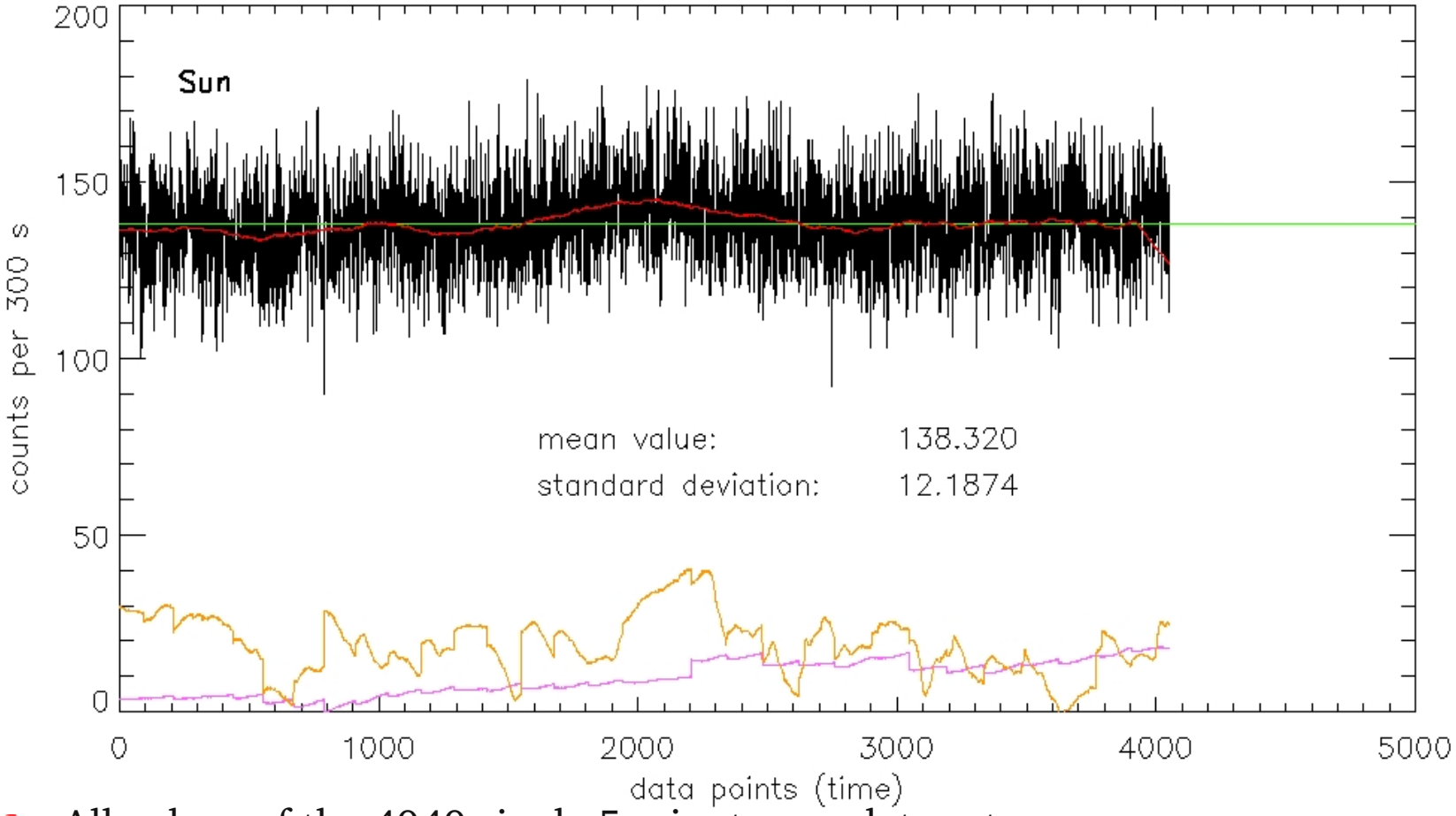
  → The sun and comparative measurements are taken with the exact same measurement time per degree.

  → Each sun data set has an equivalent in the comparison data similar in altitude, orientation, time, etc.
- In the end the exact same time was used for off-target and sun measurements at equal telescope heights
- 5 minutes measurement duration for every data set
- We could obtain about 330 hours of sun data and again 330 h of comparison measurements with 4040 data sets each

Results

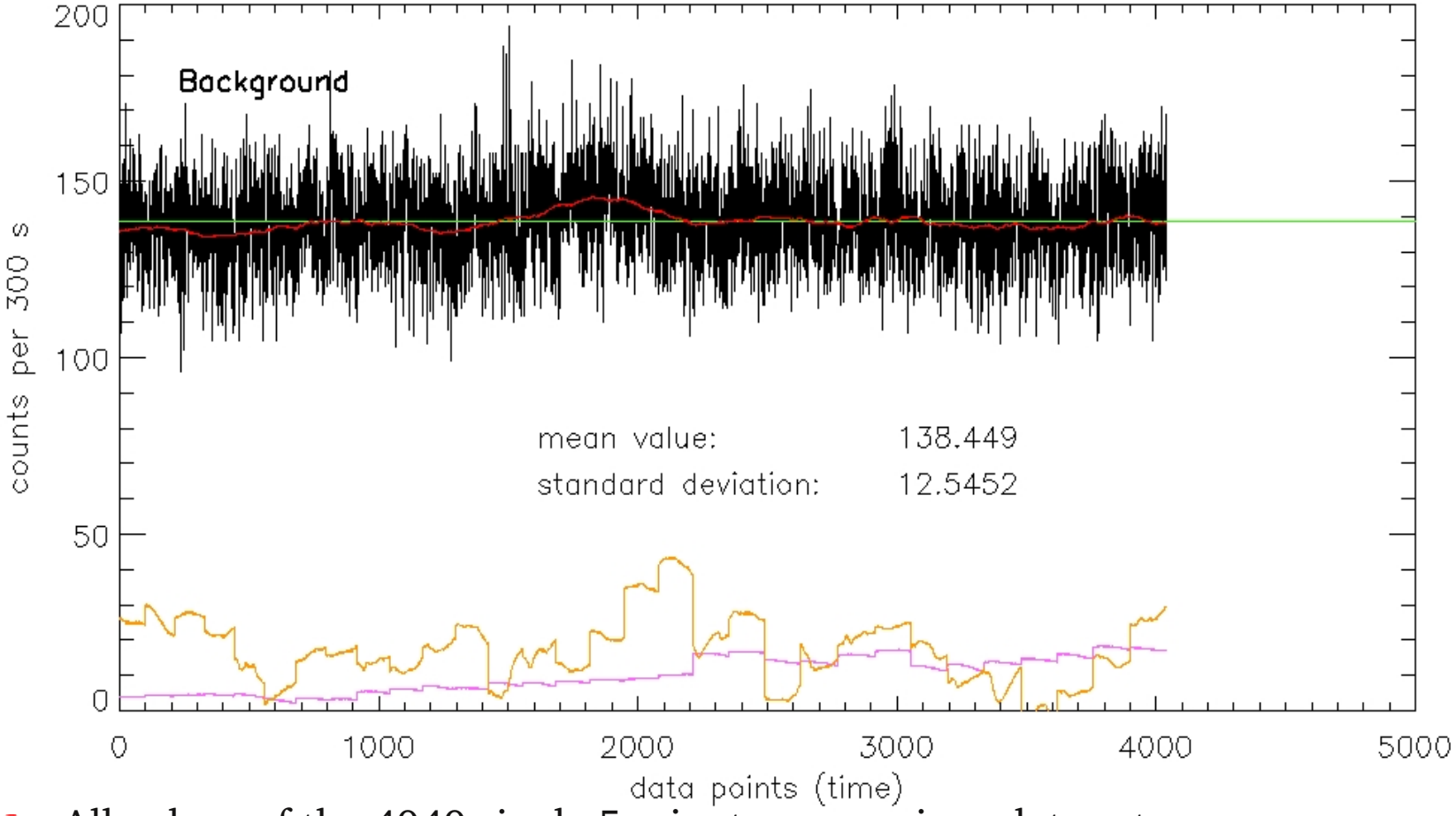


TSHIPS1 measured values



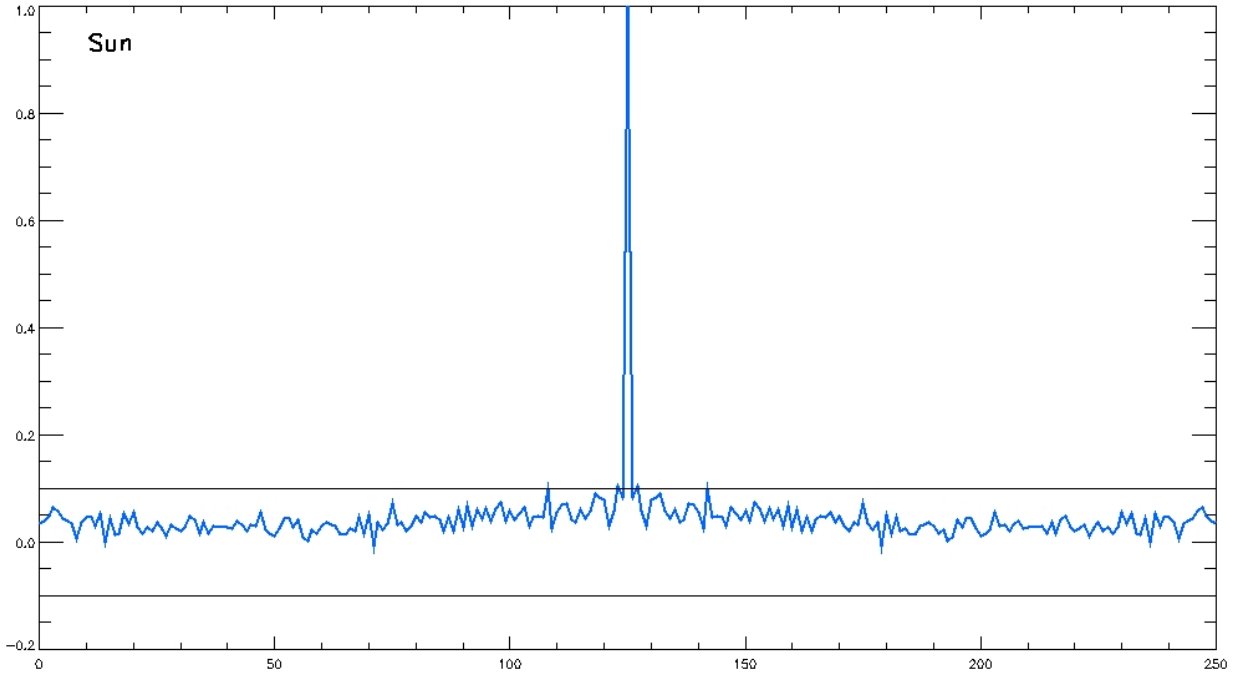
- All values of the 4040 single 5 minute sun data sets
- Standard variation: 12. 1874
- plus: correlated humidity (orange) and temperature (violet)

TSHIPS1 measured values



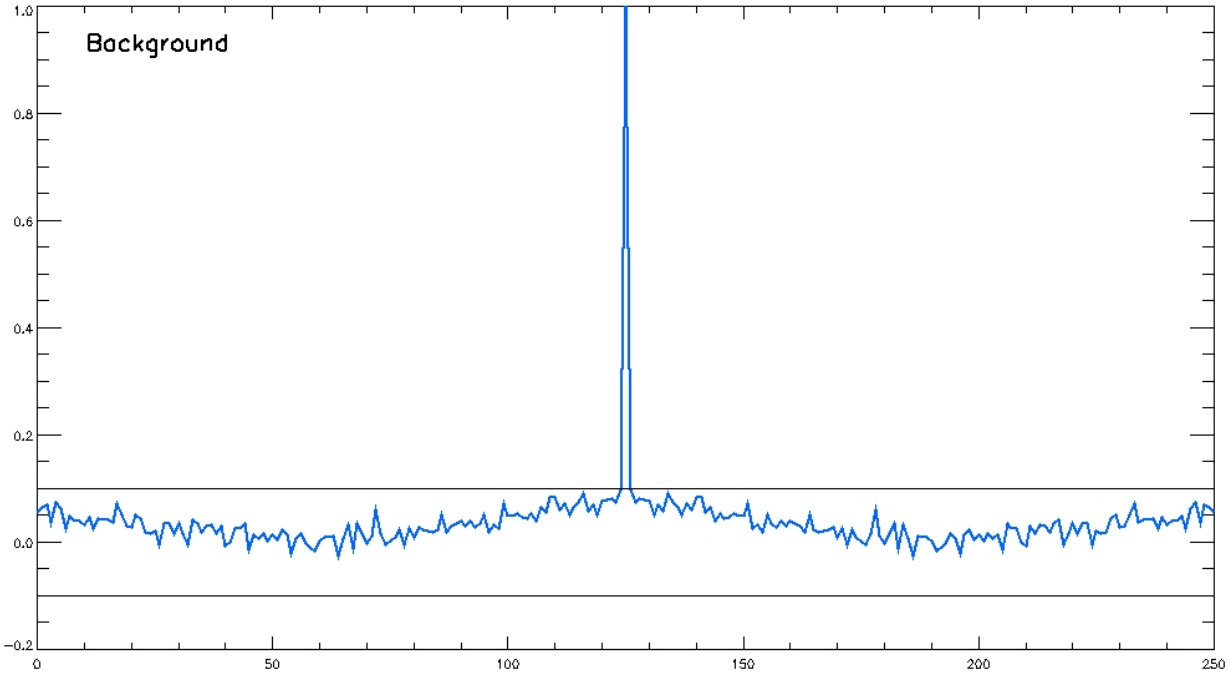
- All values of the 4040 single 5 minute comparison data sets
- Standard variation: 12. 5452
- plus: correlated humidity (orange) and temperature (violet)

TSHIPS1 sun data autocorrelation



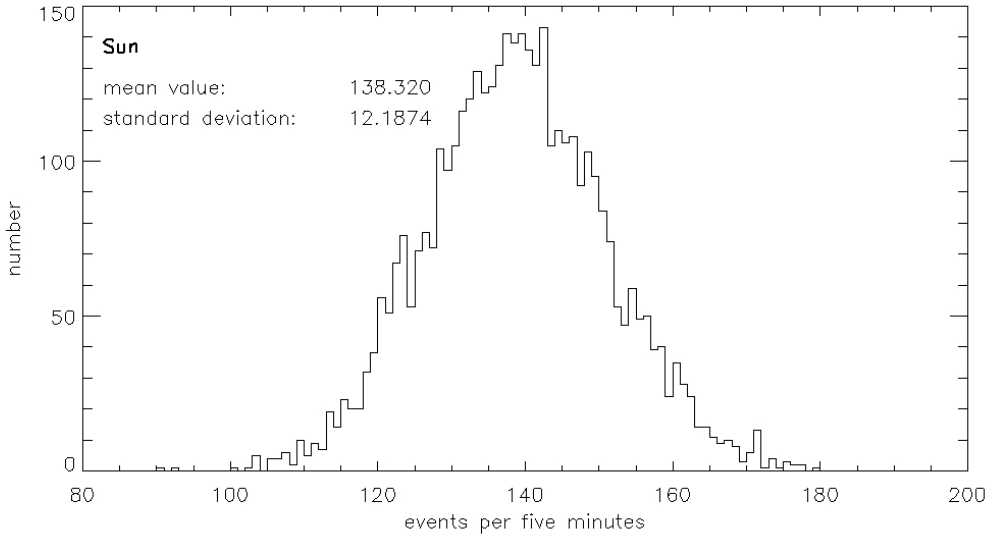
- The whole data was always checked for possible correlations. This would reveal several systematic errors in the data taking.
- There are no such correlations left as the autocorrelation plot verifies.
- The taken data is good and usable.

TSHIPS1 comparison data autocorrelation



- The whole data was always checked for possible correlations. This would reveal several systematic errors in the data taking.
- There are no such correlations left as the autocorrelation plot verifies.
- The taken data is good and usable.

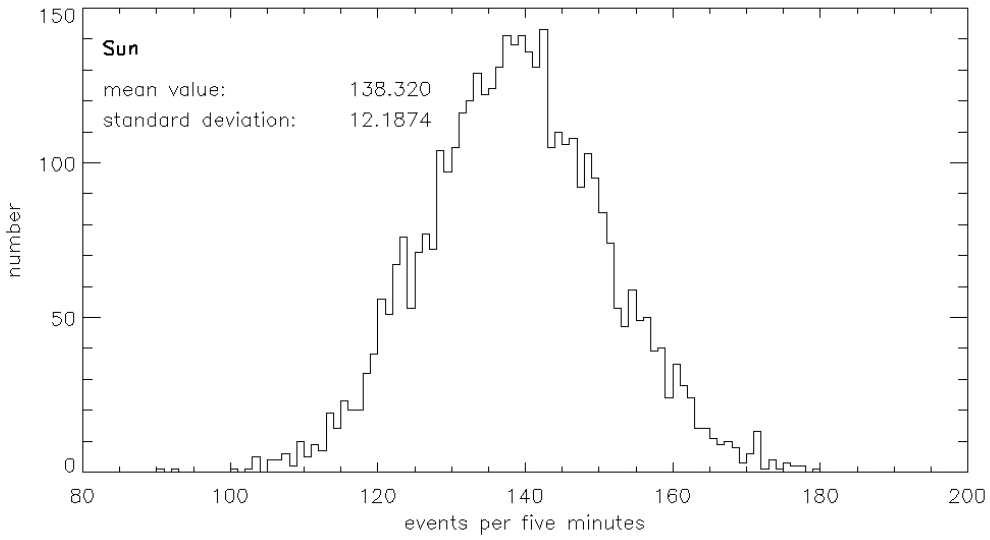
TSHIPS1 measured values histograms

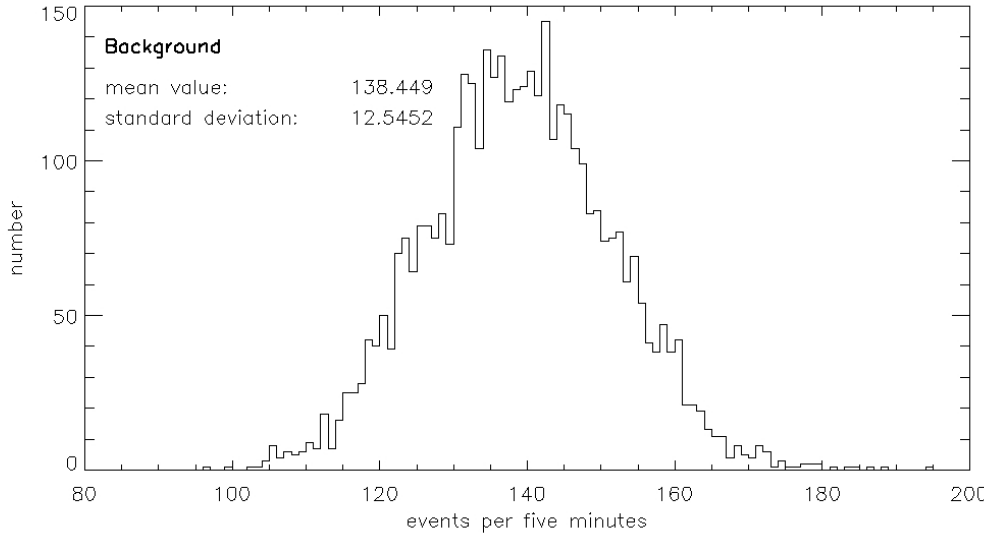


- Histogram of the single sun measurement values
- The whole process of measuring was improved for this last data taking period

  The histogram only contains data taken after the 18th March 2013.
- Each single data set takes 5 minutes

TSHIPS1 measured values histograms

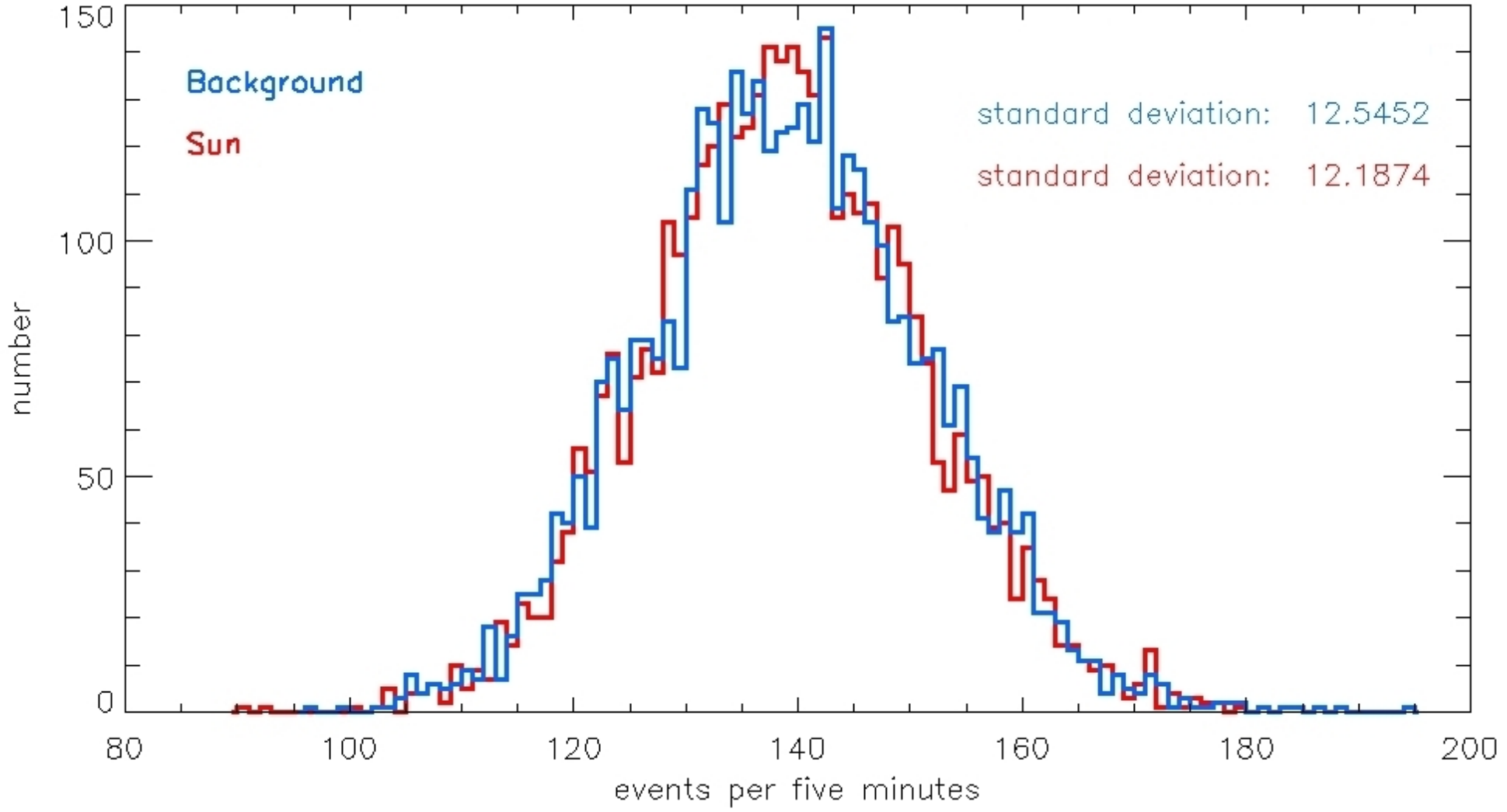




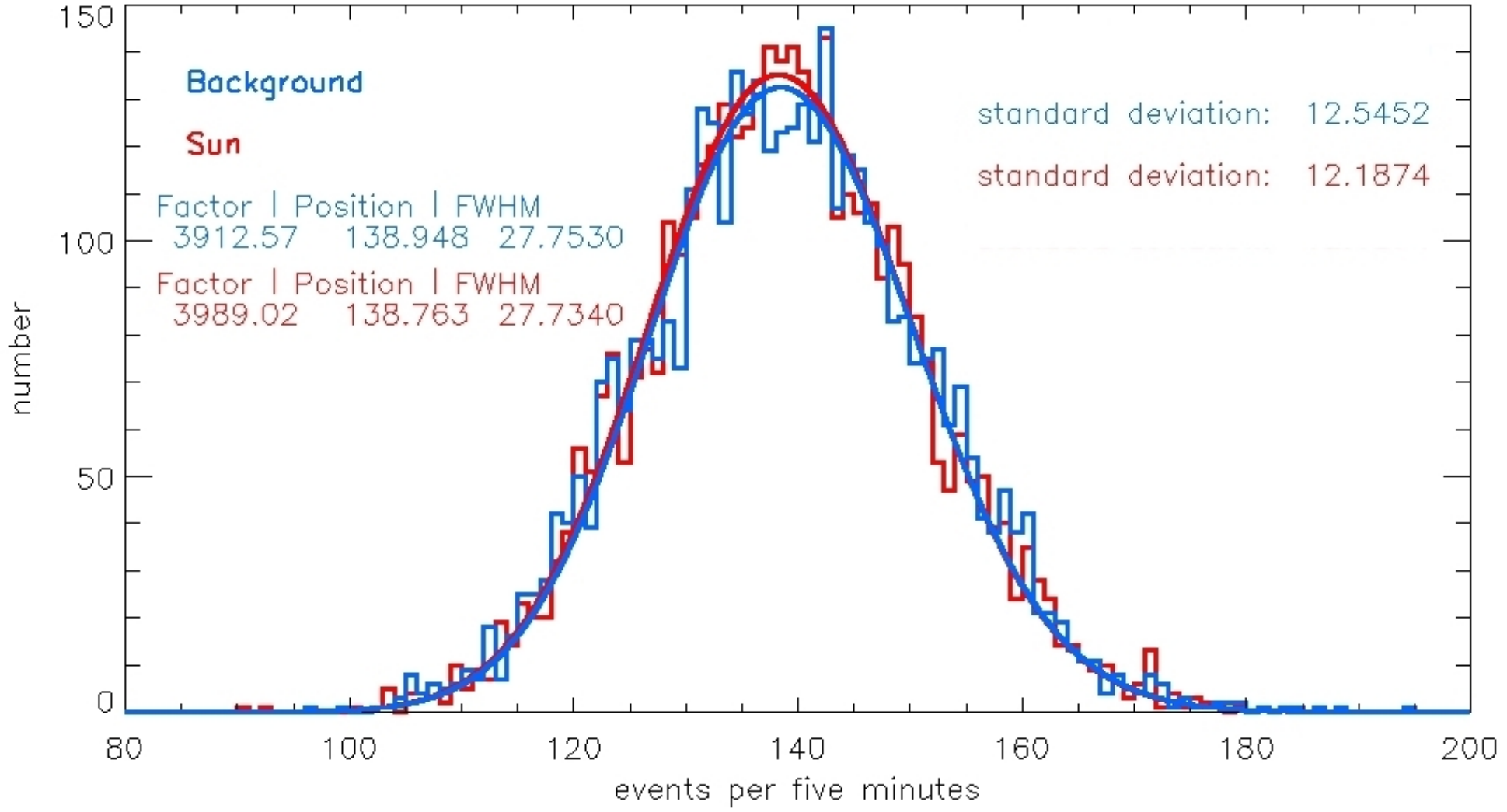
- Histograms of the single sun and comparative measurement values
- The whole process of measuring was improved for this last data taking period

  The histogram only contains data taken after the 18th March 2013.
- Each single data set takes 5 minutes

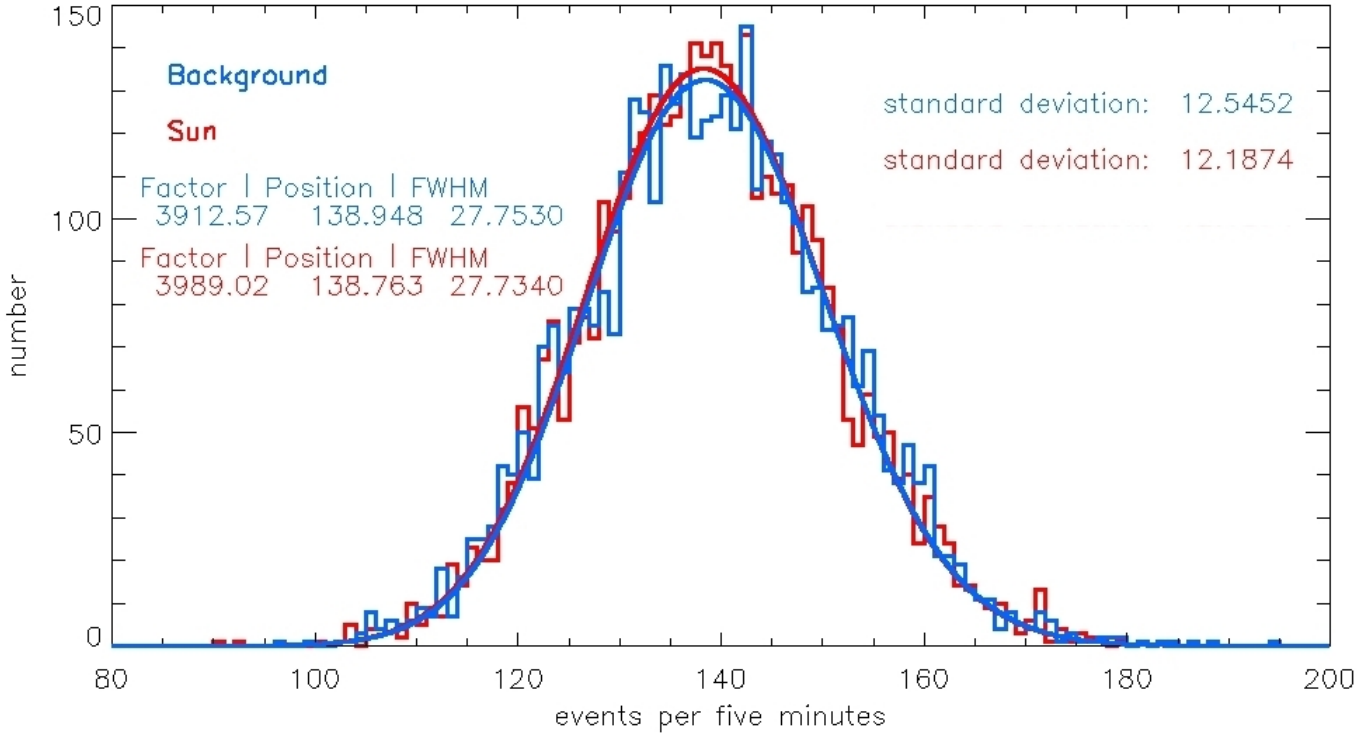
TSHIPS1 measured values histograms



TSHIPS1 measured values histograms

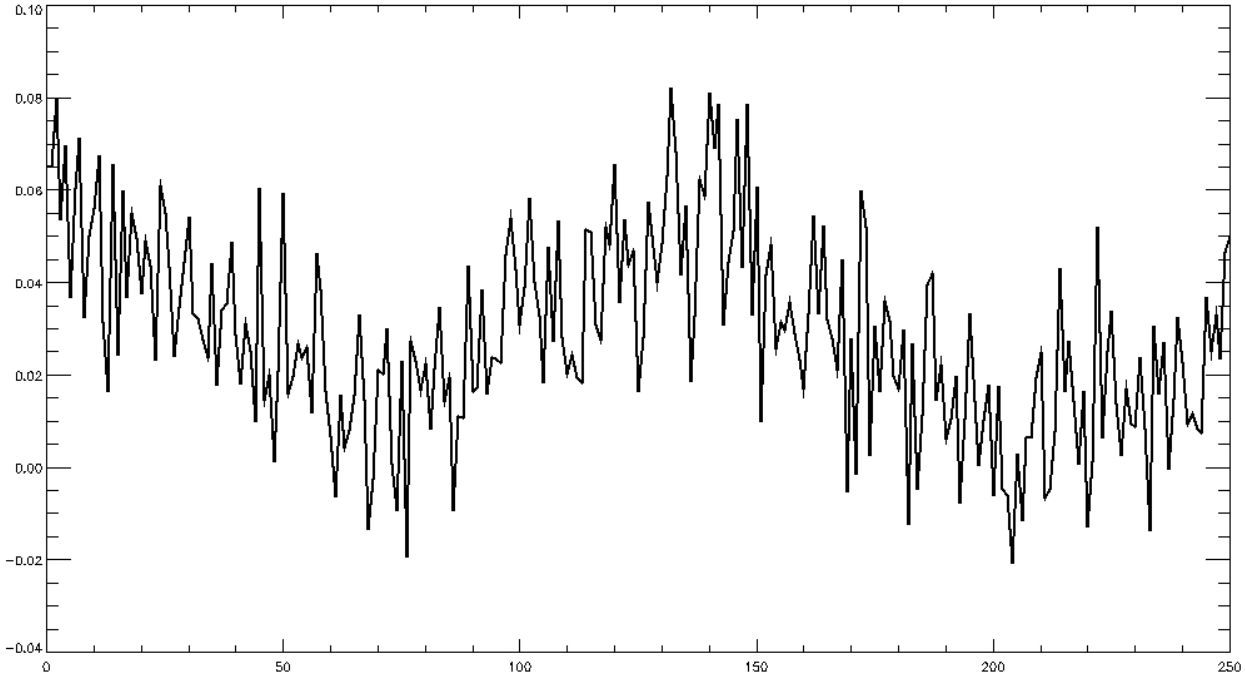


TSHIPS1 measured values fits



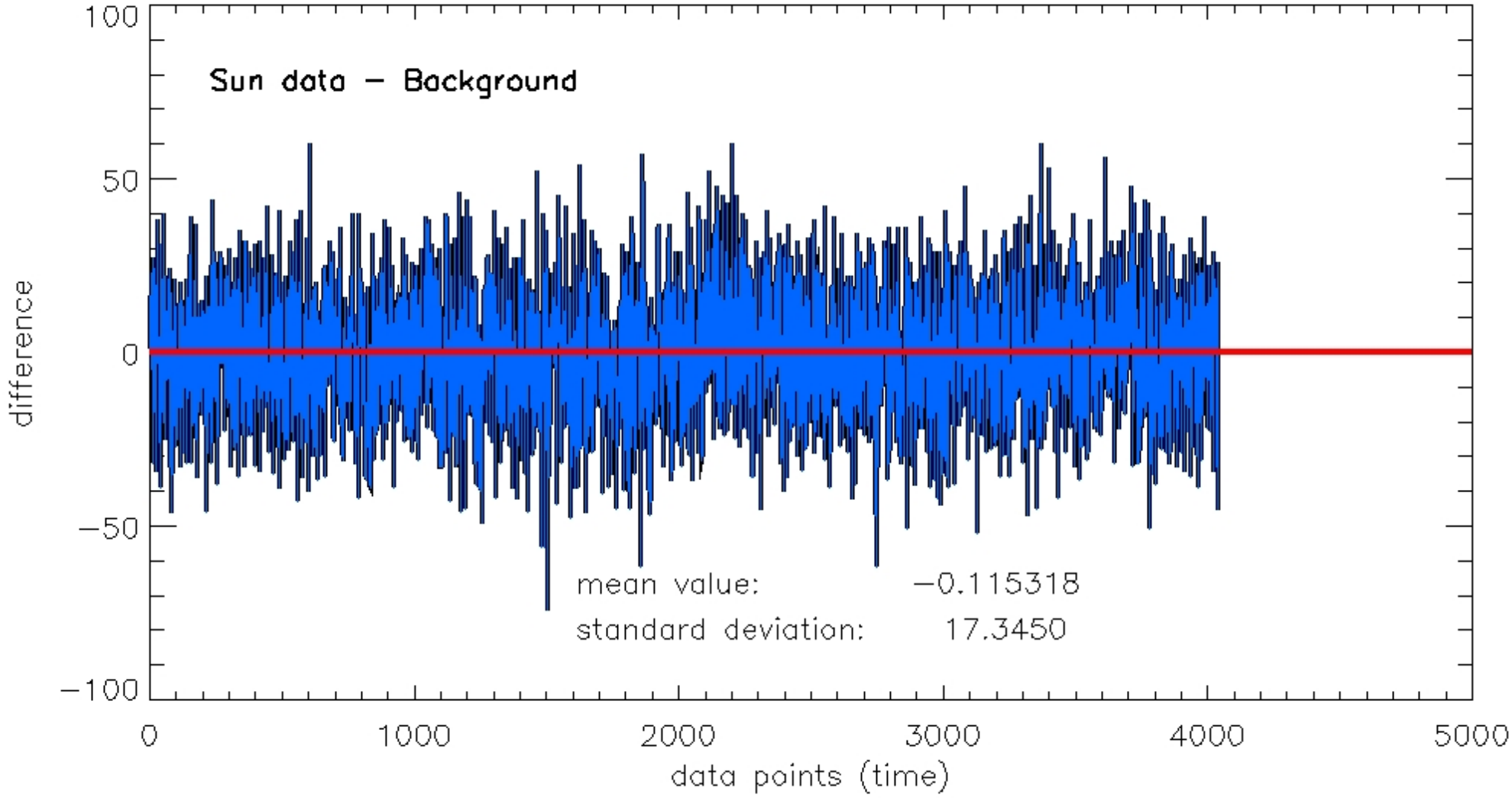
- Histograms of the PMT 5 min data sets follow a Poisson distribution
- The standard variation of an Poisson distribution with a mean of 138.8 would be $\sqrt{138.8} = 11.8$. The taken sun data varies just about 0.4 more.
- Achieved rate fluctuation is about 0.185 counts per five minutes and hence $6.17 \cdot 10^{-4}$ counts per second
- Systematic errors in the data taking could be reduced to a level just barely above the photon noise.

TSHIPS1 data cross correlations

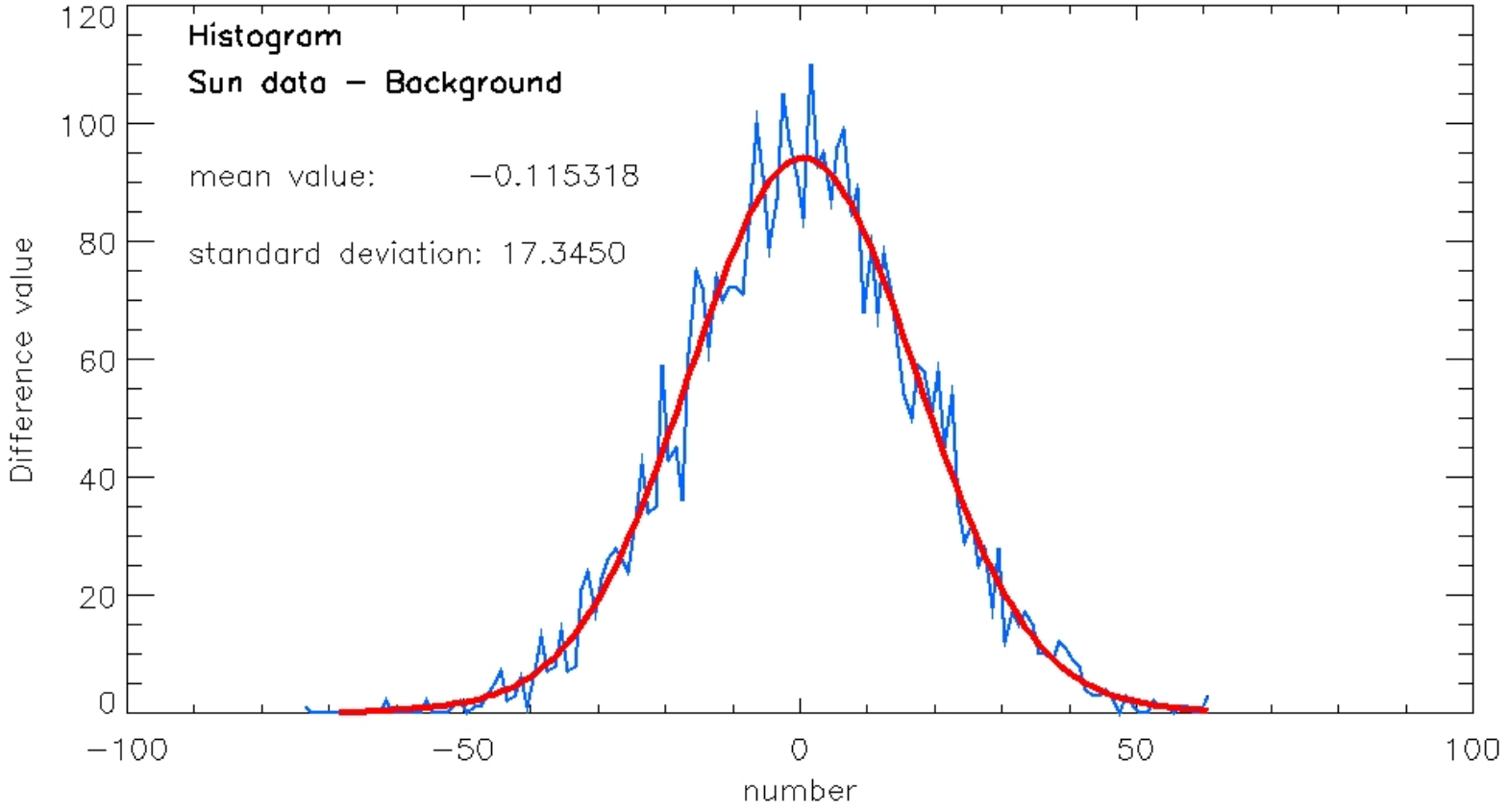


- No noteworthy cross correlation between both → no temporal correlation between both series of measurements
- The standard variation of an Poisson distribution with a mean of 138.8 would be $\sqrt{138.8} = 11.8$. The taken sun data varies just about 0.4 more.
- Achieved rate fluctuation is about 0.185 counts per five minutes and hence $6.17 \cdot 10^{-4}$ counts per second
- Systematic errors in the data taking could be reduced to a level just barely above the photon noise.

Difference between sun and background data sets



Histogram of the divergence values sun data minus background



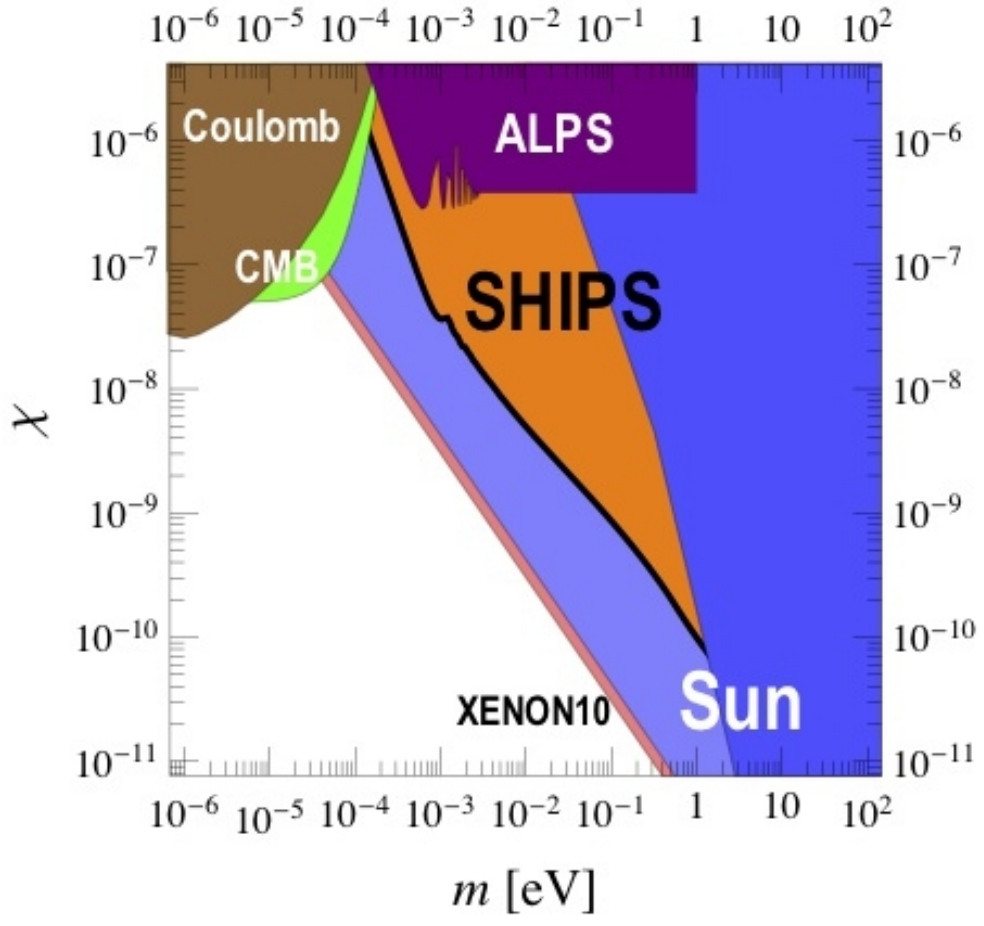
Outcome

- Achieved rate fluctuation is about 0.185 counts per five minutes and hence

$$6.17 \cdot 10^{-4} \pm 7.26 \cdot 10^{-4}$$

Counts per second

Hidden photon mass and coupling plane (preliminary)

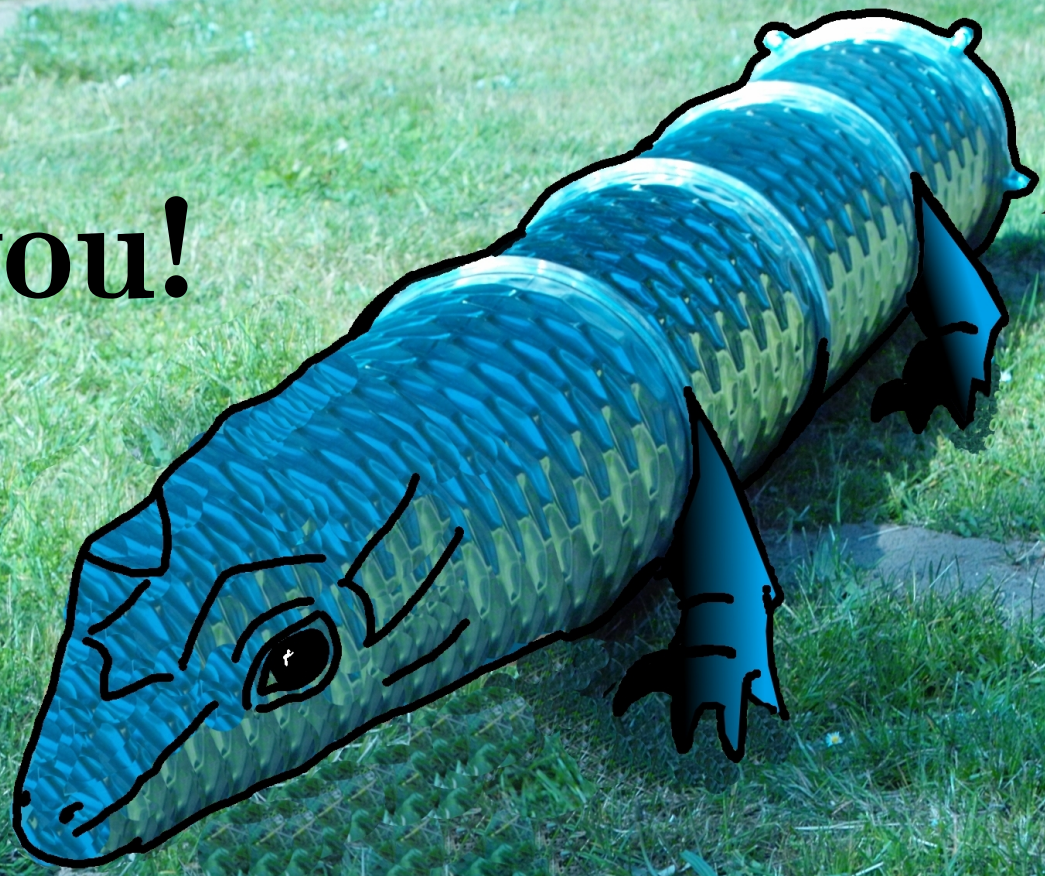


Conclusions

- SHIPS set-up provides clean and proper conditions for a sub-eV Hidden Photon detection
- Solar Hidden Photon Search was succesfully performed
- No evidence for HP (or other BSM physics)
- Achieved event rate fluctuation less than

  $6.17 \cdot 10^{-4} \pm 7.26 \cdot 10^{-4}$ counts per second
- Estimation of new constraints to hidden sector boson parameters
- Publication is in progress

Thank you!



WÖTAS* -Largest Reptile Species of the TSHIPS Family - in Action : Searching for Hidden Photons in Dark Matter

*WÖlbstrukturTeleskopfürAStroparticles