РОСАТОМ

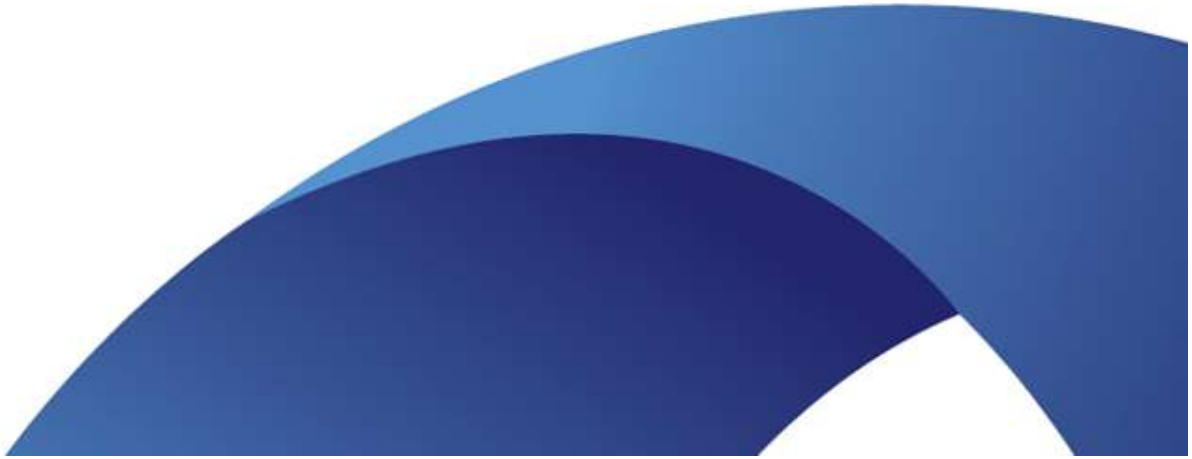
РФЯЦ ВНИИЭФ

ИЯРФ

ГОСУДАРСТВЕННАЯ КОРПОРАЦИЯ ПО АТОМНОЙ ЭНЕРГИИ «РОСАТОМ»

RFNC-VNIIEF's contribution to the construction of the PHOS Spectrometer: mechanical design, cooling system and temperature control

D. Budnikov
S. Filchagin

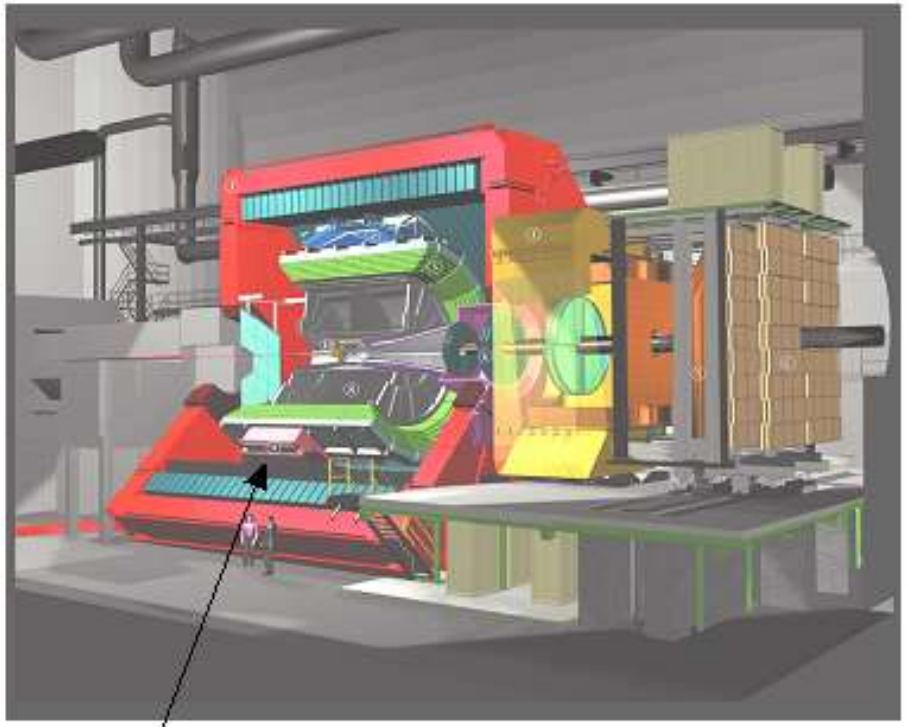


General information

PHOS spectrometer

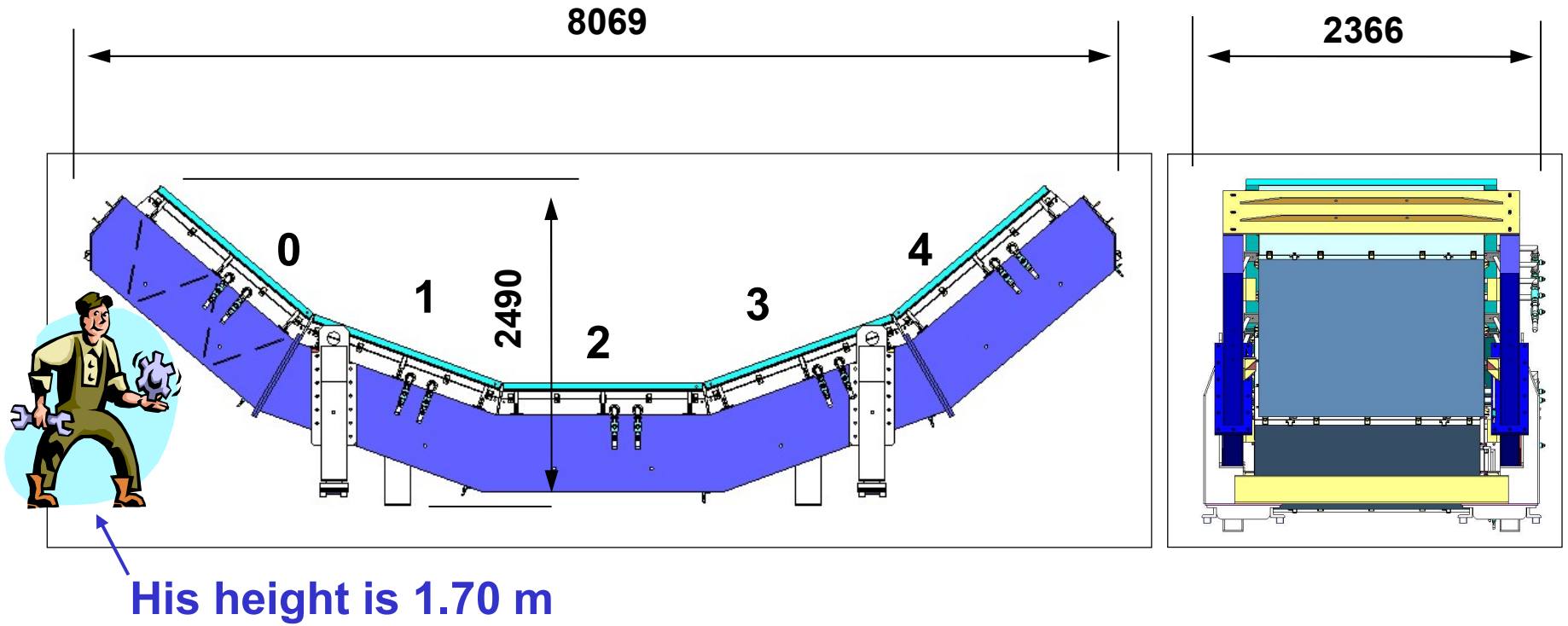
Technical data:

lead-tungstate crystals ($PbWO_4$)	17920
modularity	5
area of a crystals sensitive surface	8.67 m^2
total crystal weight	12.927 t
operating temperature	-25°C



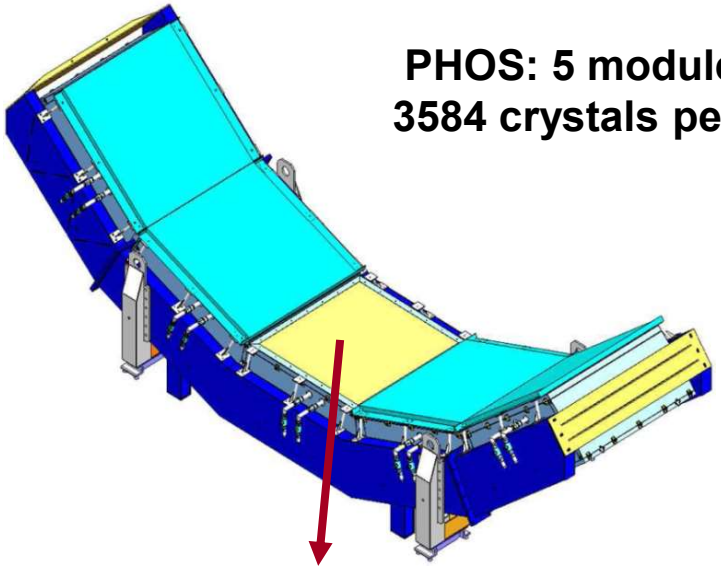
PHOS (PHOton Spectrometer) is a high resolution electromagnetic calorimeter consisting of 17920 detection channels based on lead-tungstate crystals(PWO).

PHOS spectrometer overall dimensions

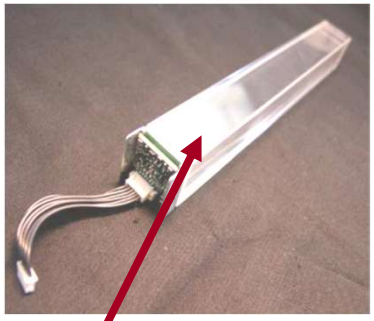


The total weight is around of 24.5 tons

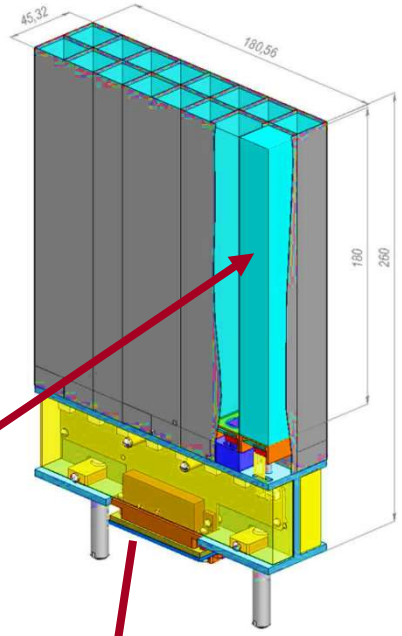
The main mechanical parts of the PHOS spectrometer

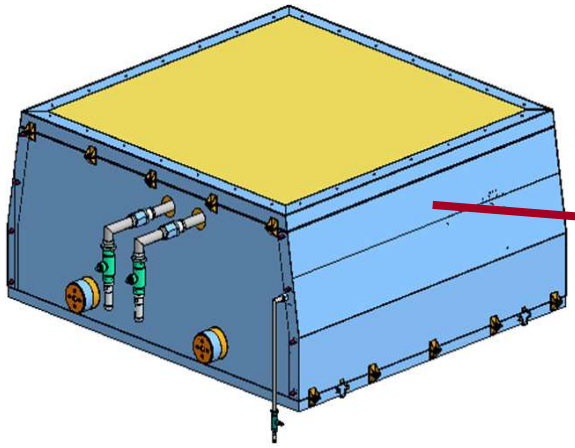


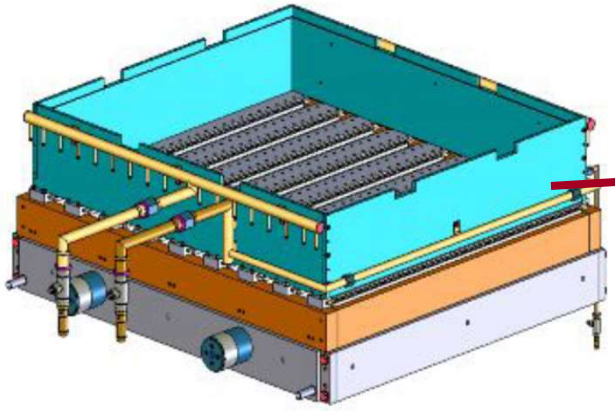
PHOS: 5 modules (plan)
3584 crystals per module

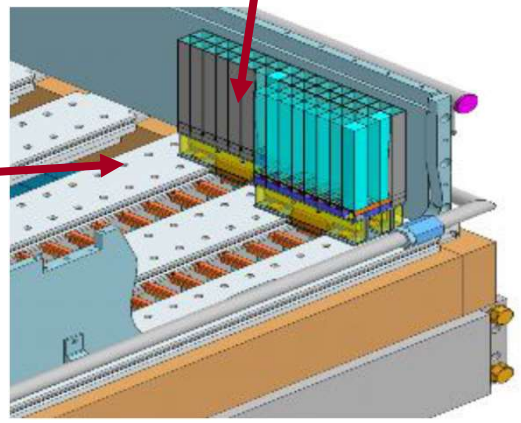


Crystal: $PbWO_4$
$PbWO_4$ volume: 0.94 м^3
Total crystal weight: 7.75 t
Strip unit 8×2
Working temperature: minus 25°C









PHOS module installation

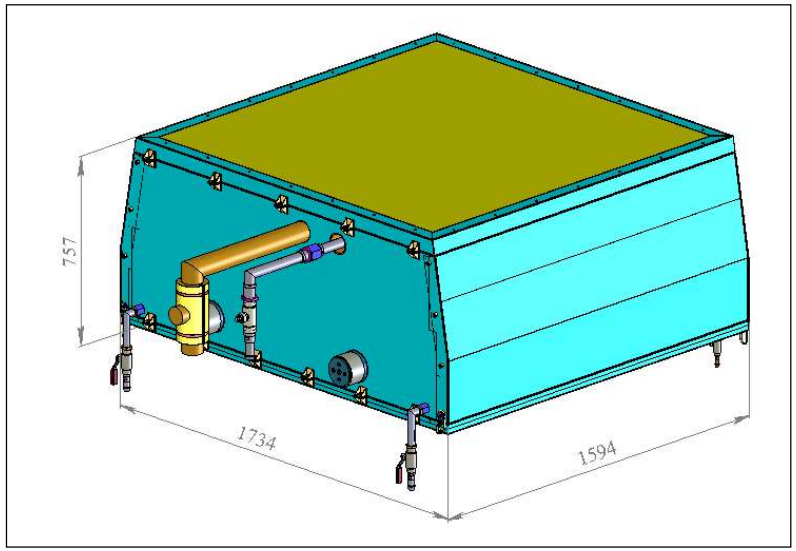
There are 4 modules in the PHOS spectrometer .
One of the modules (#1) has half of the crystals matrix (3584/2 = 1792).
The total crystal quantity is12544 in the PHOS spectrometer

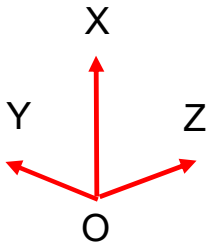
PHOS module

Module

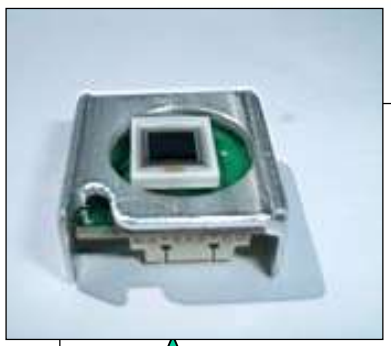
The PHOS spectrometer module consists of 3584 single detection channels forming a matrix of 64×56 crystals, so that 64 crystals are placed along the axis OX with a step of 22.6 mm, and 56 crystals – along the axis OY with a step of 22.7 mm.

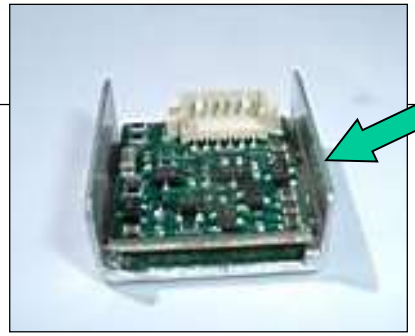
Its overall dimensions are 1734×1594×757 mm





Single registration channel





Preamplifier board

APD-preamplifier

PbWO4 crystals

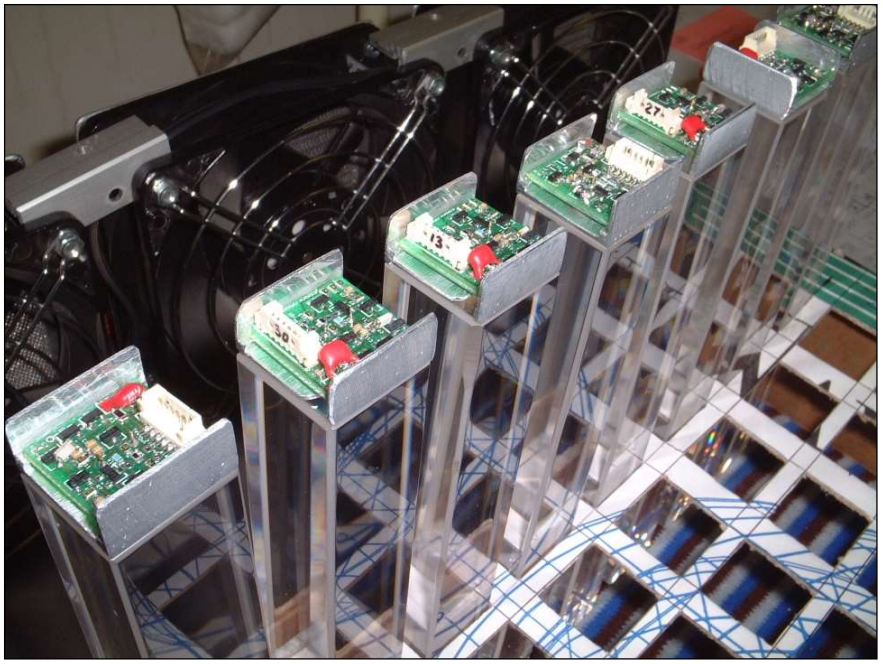
The module consists of the set of crystals $PbWO_4$, the 22×22 mm crystal front facing the direction of photons emitted from the LHC beam interaction point.

The density of crystals material is ρ=8.28 g/cm^3. The weight of one crystal is 0.721 kg.

The crystal manufacturer was the stock-company “Severnyje Kristally”, Apatity, RUSSIA.

Crystal matrix

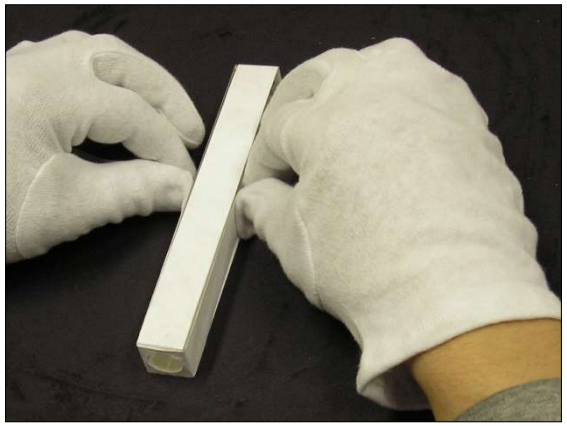
Front view of crystal matrix as seen from the interaction point

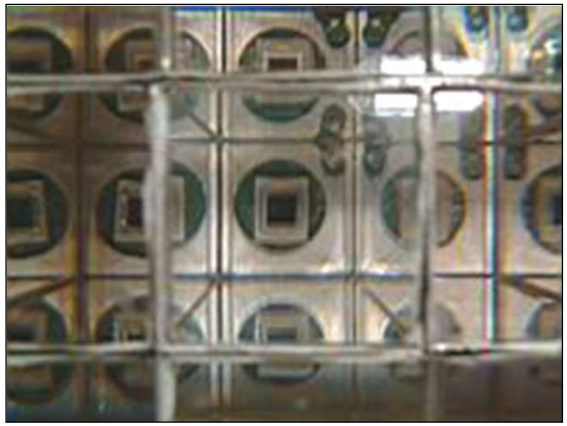


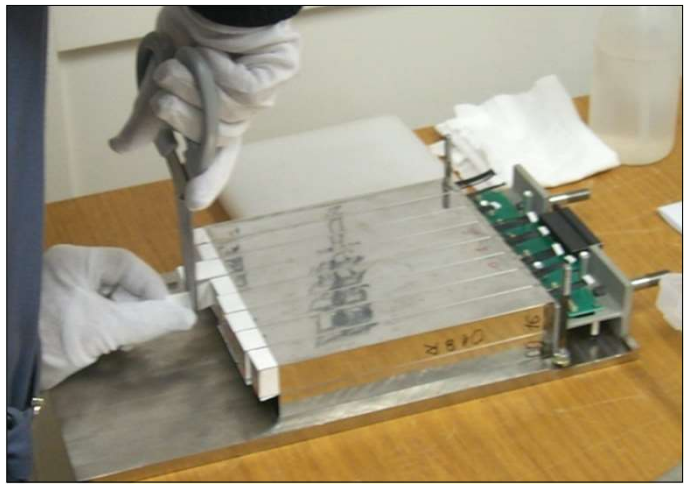
The detection channels with installed APD-photodiodes and preamplifier boards

The thickness of glue seal between the crystal end and the surface of photodiode is 0.05… 0.25 mm. The presence of the air inclusions inside the seal is not allowed. The optically transparent glue “Melt-Mount Quick-Stick”, Cargille Laboratories, USA is used.

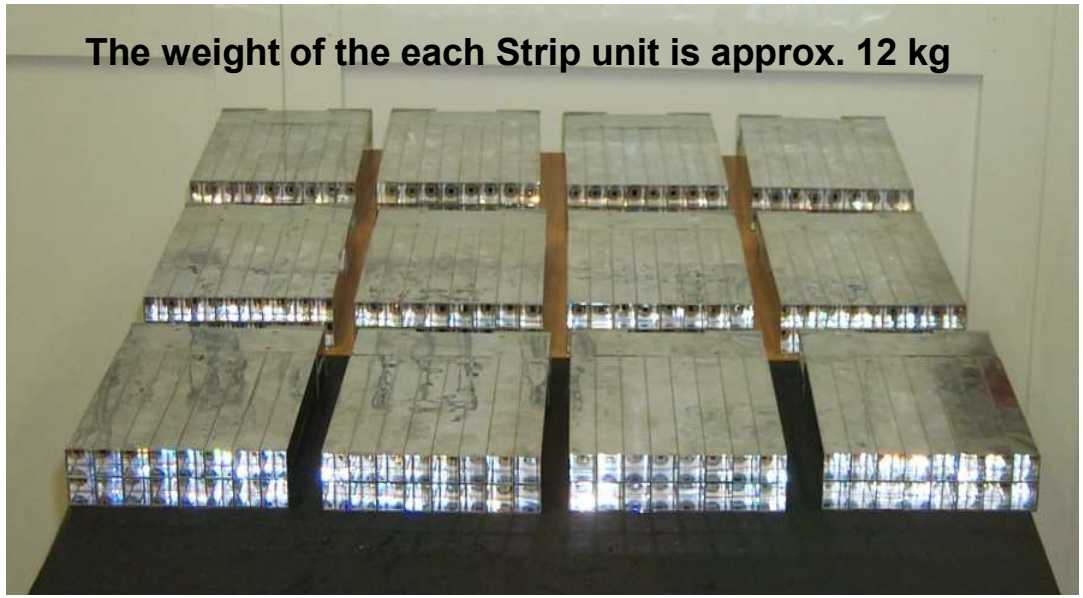
Process of assembling the Strip unit





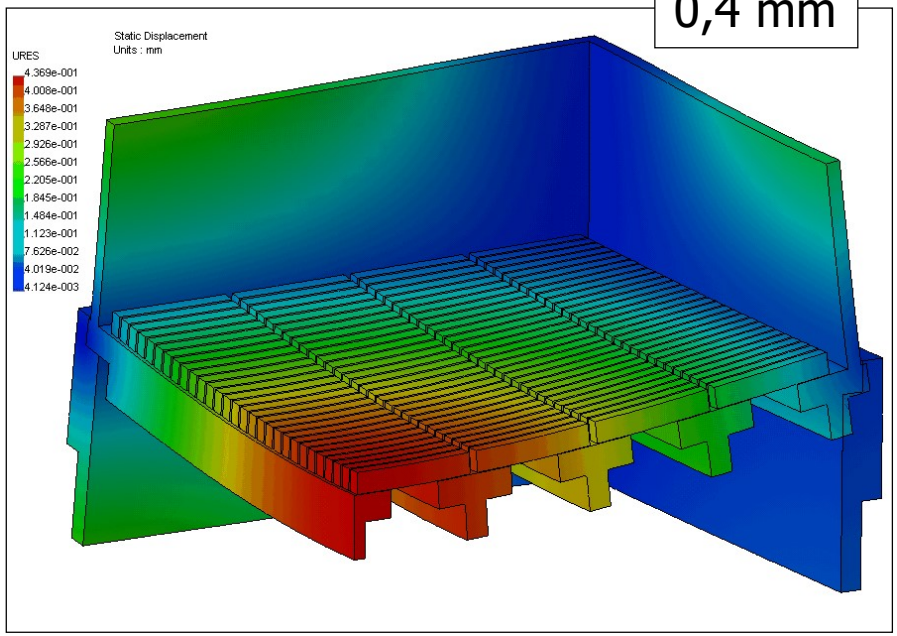


Crystals are packed mechanically into groups of 2x8, referred to as Strip units



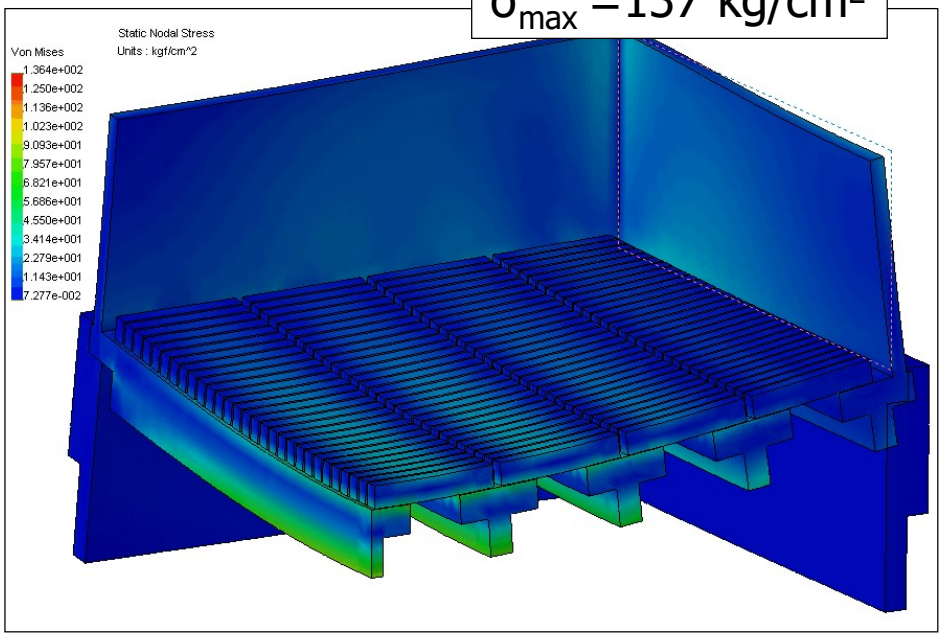
Calculation of the main module frame

0,4 mm



Displacements

σ_{max} =137 kg/cm^2



Stresses

Results of the mechanics-and-strength calculation of the glass-cloth-base laminate body and cooling panels with T-section at their horizontal position under crystals' loading during 0.5g starting acceleration

PHOS mechanical design: summary

1. The mechanical design of the detector is very stable over more then 10 years of operation.
2. The mechanical design of the module provides all conditions to reach a temperature of minus 25°C for the crystal matrix.
3. In future we plan to divide the module into two parts, named “cold” part with crystals and “warm” one with electronics to have a possibility to service the electronics at any time (when there is no a beam)

Temperature & cooling: requirements

Physical factors:

1. PWO light yield strongly depends on temperature (≈ 2% per 1ºC)
2. APD gain strongly depends on temperature (≈ 5% per 1ºC)
3. We have to avoid water in FEE zone (warm volume) (dew point ≈ 12ºC)
4. We have to remove heat from electronics

Therefore to achieve 1% energy resolution:

1. High precision temperature measurements in PWO matrix required
2. High cooling stability required
3. Warm volume Temp. control & cooling
4. FEE water cooling required

PHOS requirements:
T operation -25 ºC,
T stability ± 0.1 ºC,
T precision ± 0.05 ºC

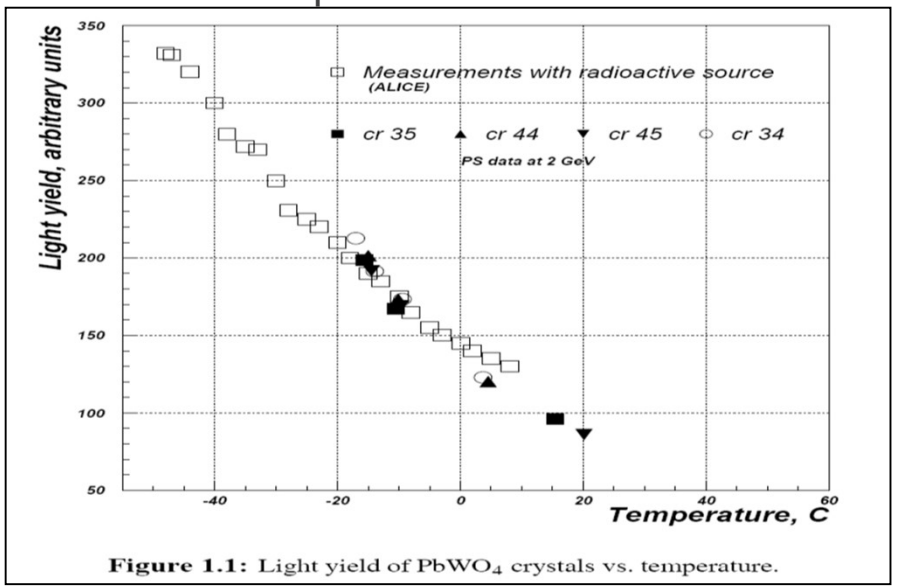
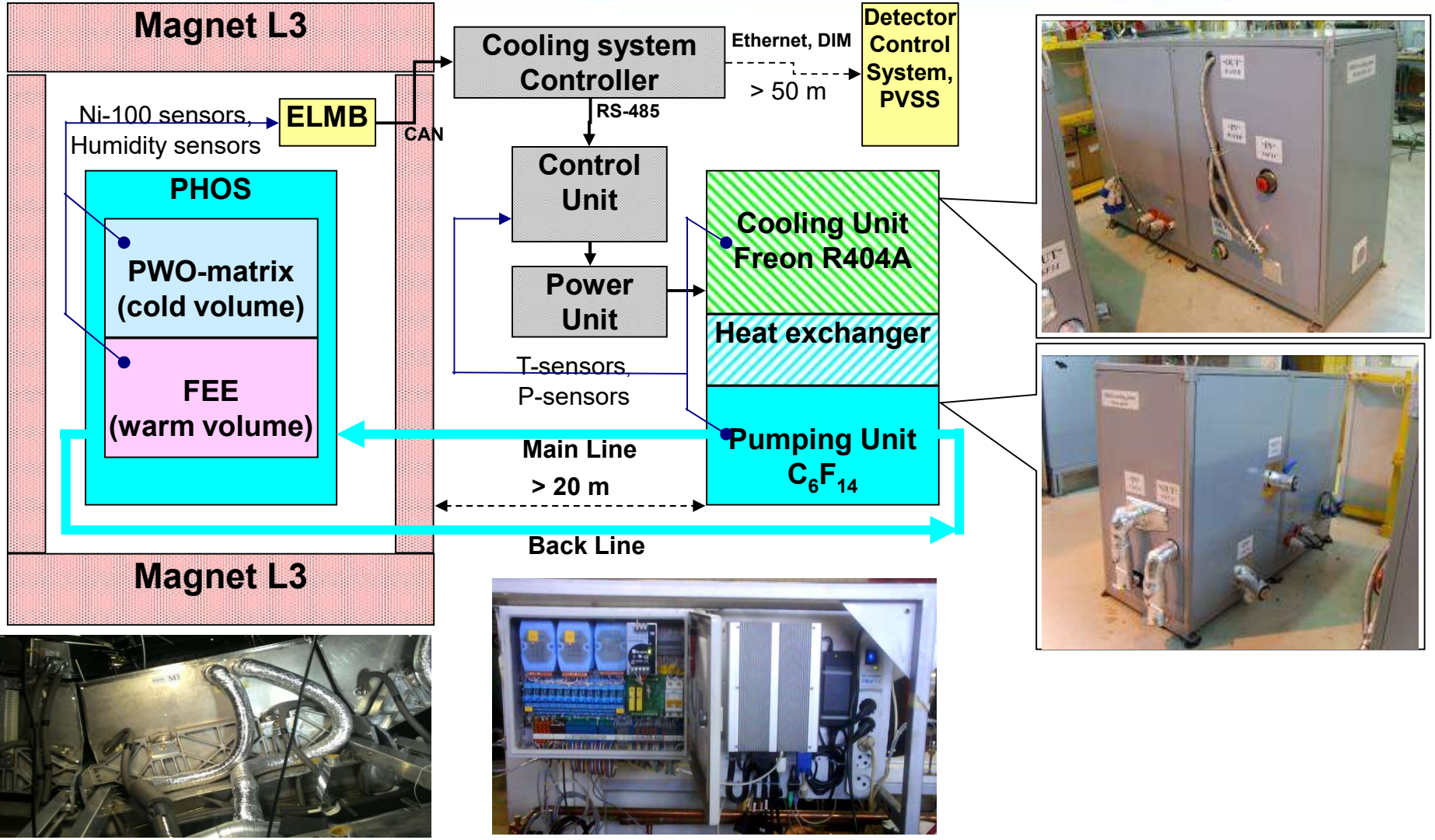
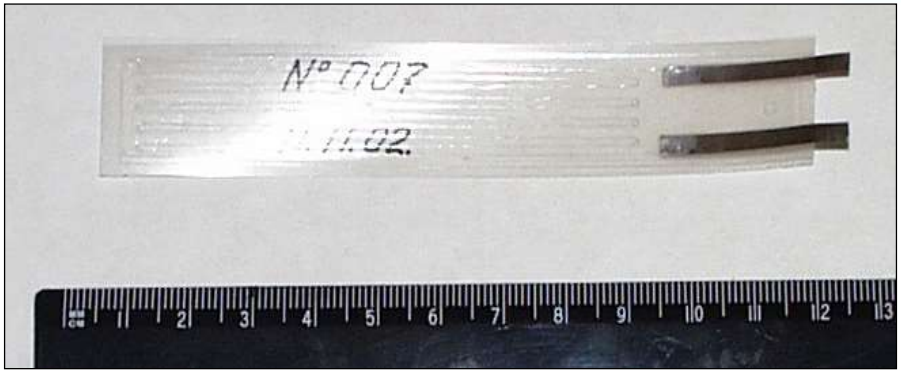


Figure 1.1: Light yield of $PbWO_4$ crystals vs. temperature.

Cooling system - scheme

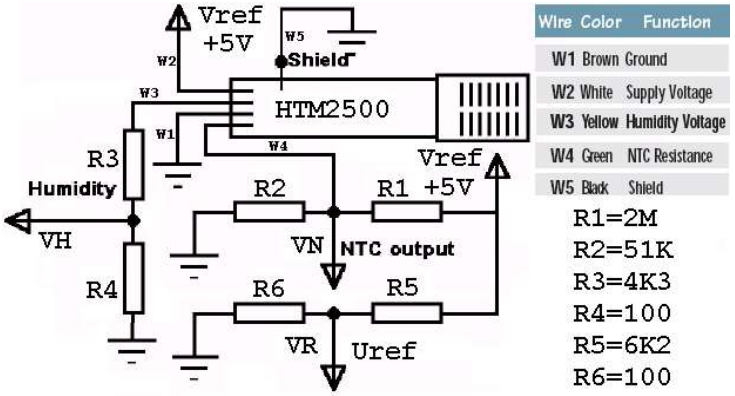


Temperature & humidity measurement



Technical parameters

Precision of measurement	± 0.05°C;
Thickness	0.1 mm;
Working temperature range	–30…+30°C



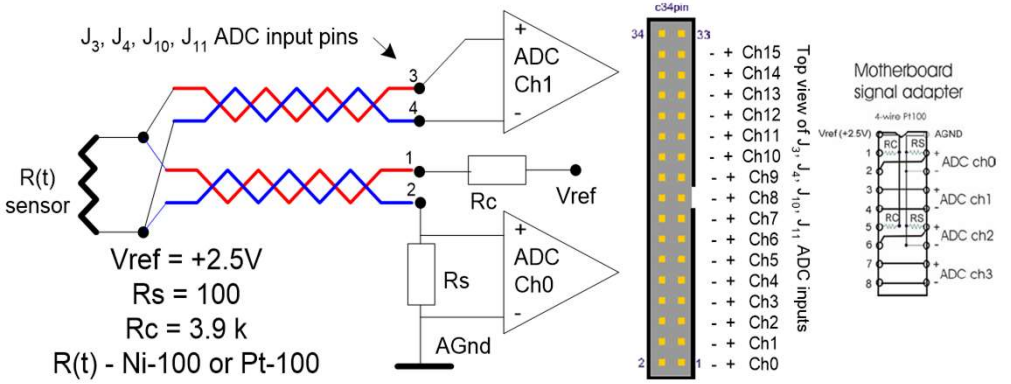
Wire	Color	Function
W1	Brown	Ground
W2	White	Supply Voltage
W3	Yellow	Humidity Voltage
W4	Green	NTC Resistance
W5	Black	Shield

R1=2M
R2=51K
R3=4K3
R4=100
R5=6K2
R6=100

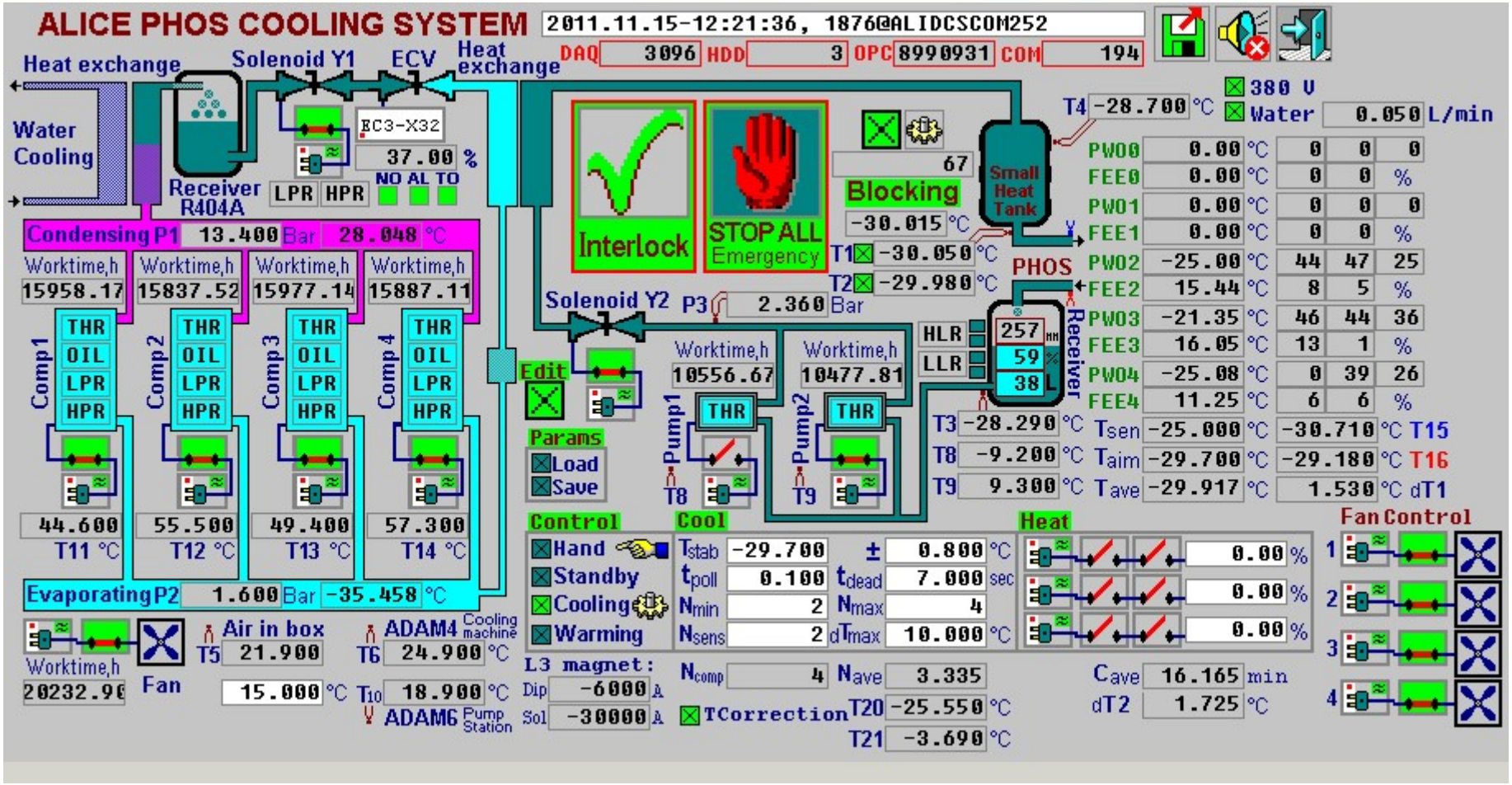
Ni-100 temperature sensors (made in RFNC-VNIIEF) are mounted between the crystals and have a thickness less than 100 μm to not enlarge gaps between them.

There are 128 temperature sensors and 20 humidity sensors:

- Temperature monitoring in PWO matrix for each module - 24 sensors;
- Temperature monitoring in warm volume (FEE zone) for each module - 8 sensors;
- Humidity monitoring in warm volume (FEE zone) for each module - 5 sensors

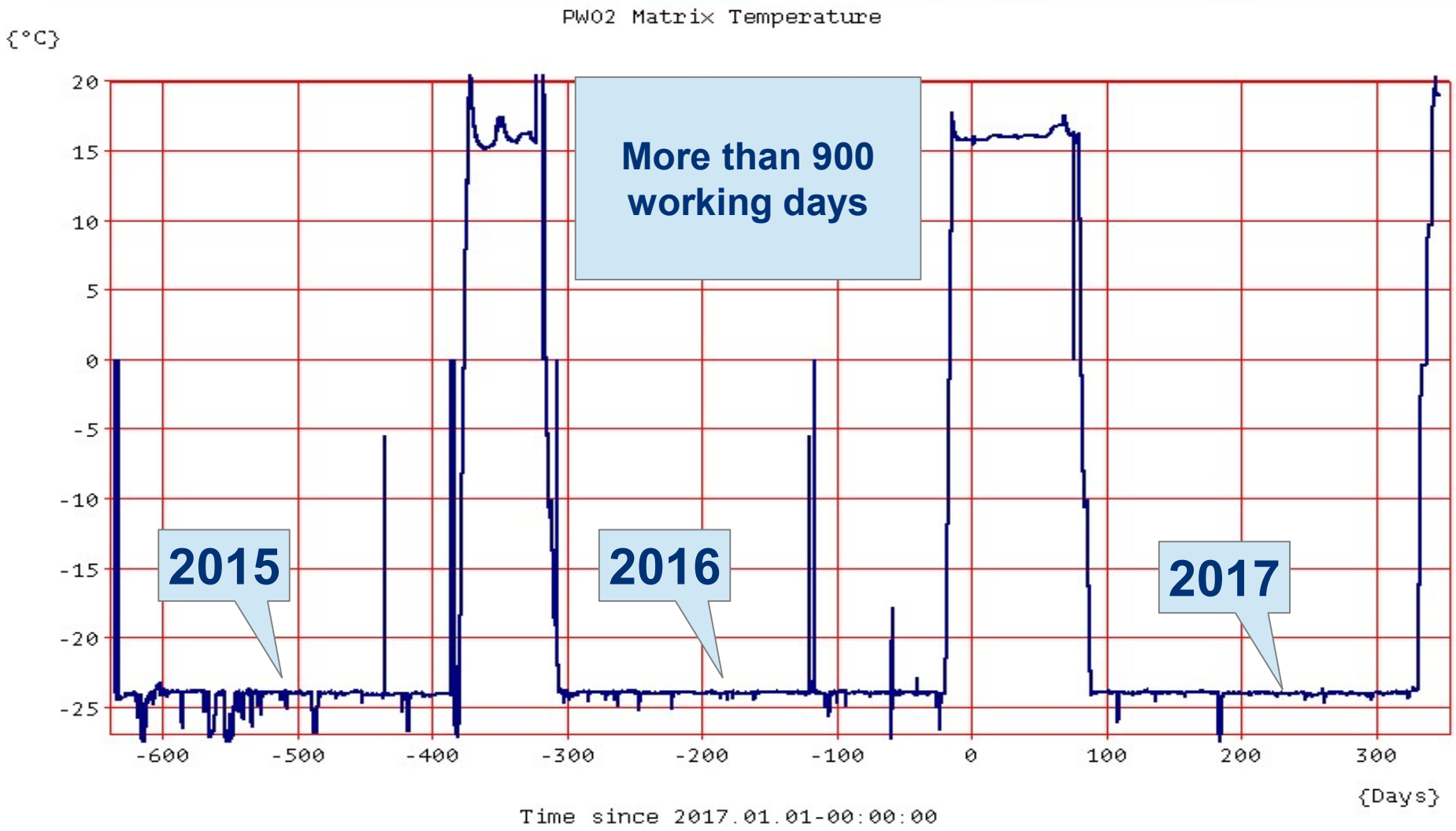


Cooling system software — AliPhosCool in Run 1, Run 2

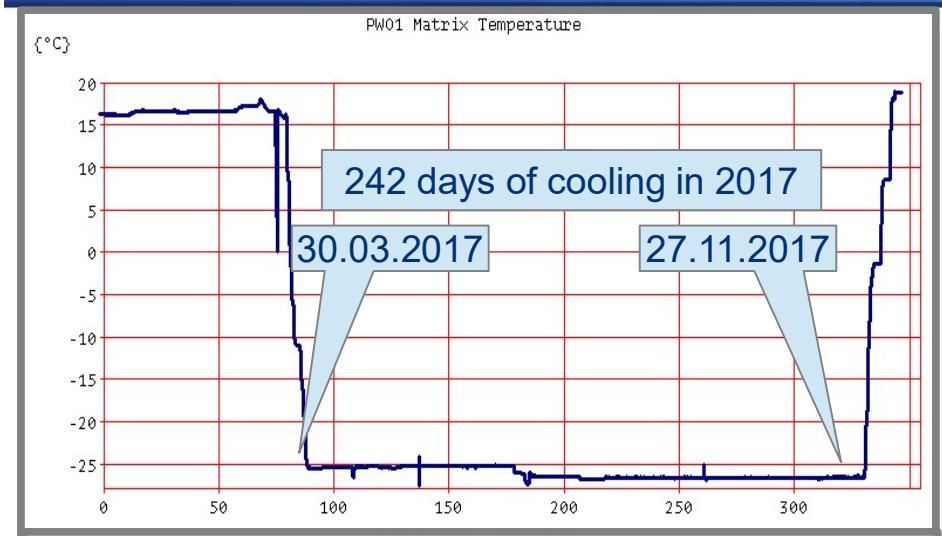


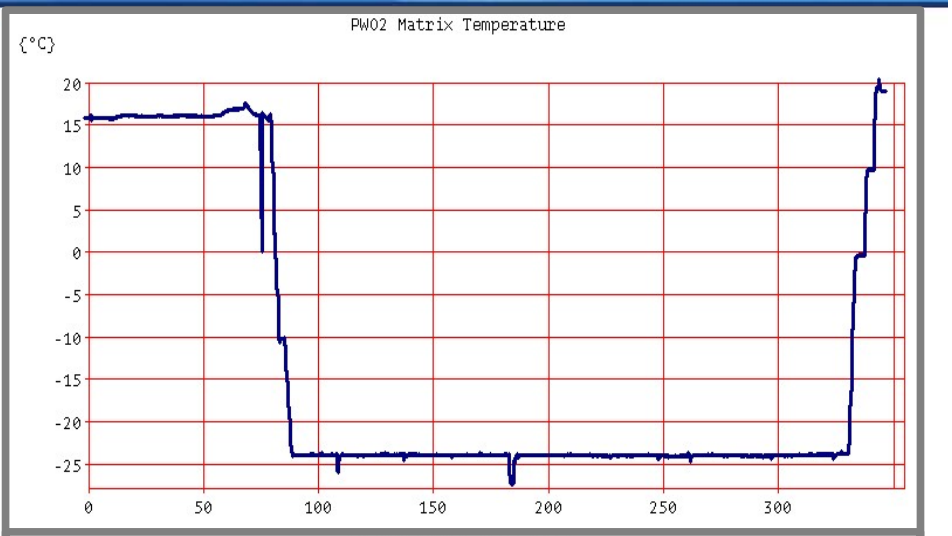
There was not any failure of cooling system due to software for 8 years of operation

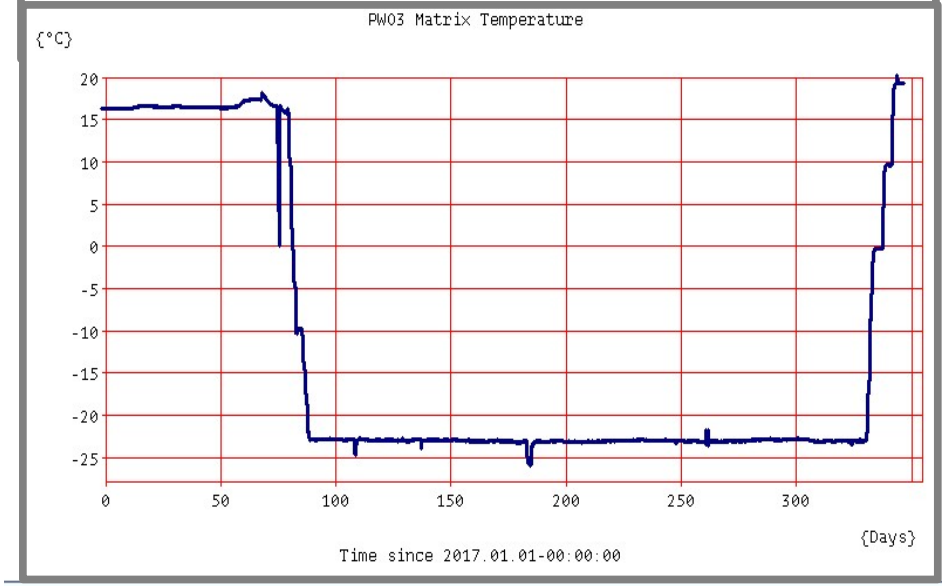
Results: PHOS-RUN2 $PbWO_4$ matrix temperature

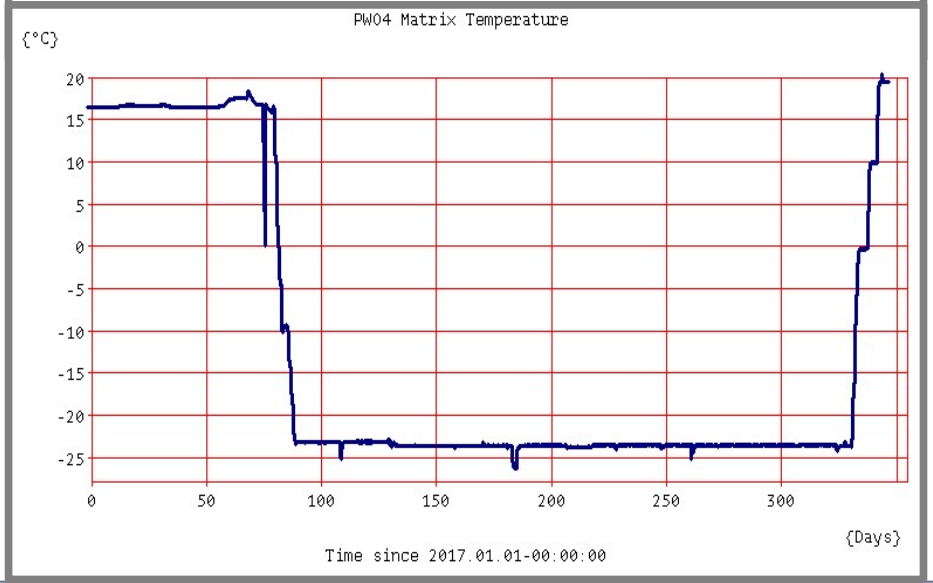


Results: PHOS-2017 temperature $PbWO_4$

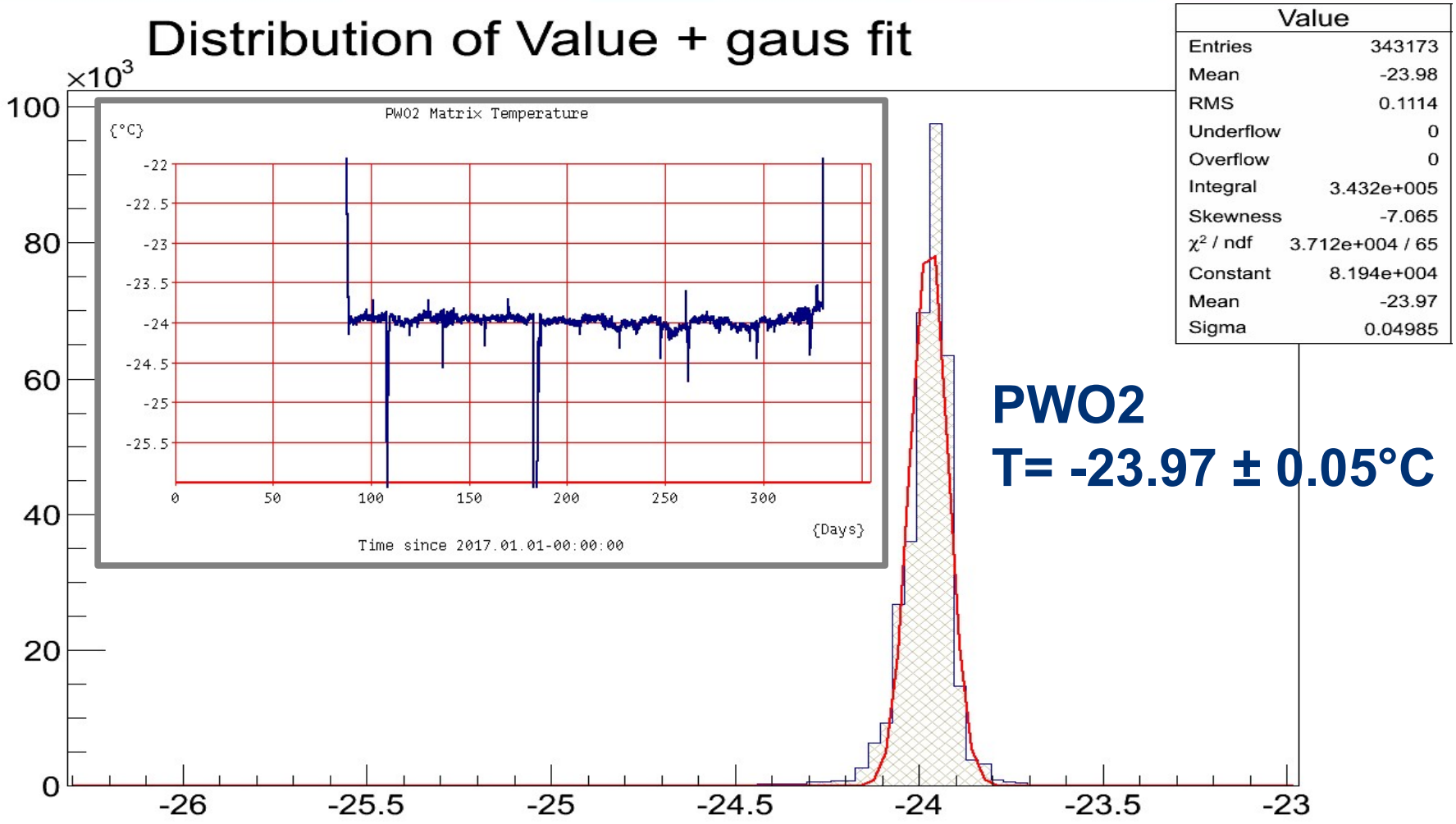




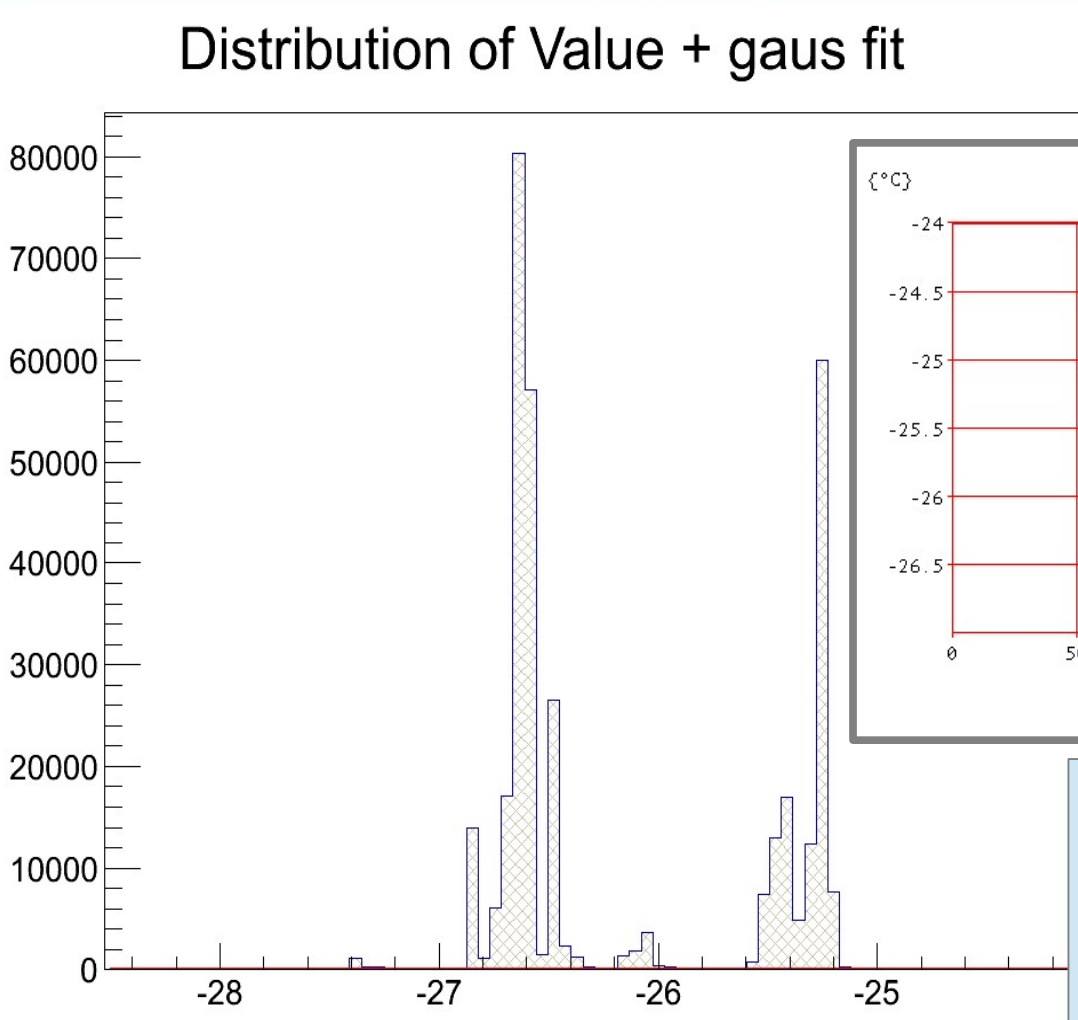




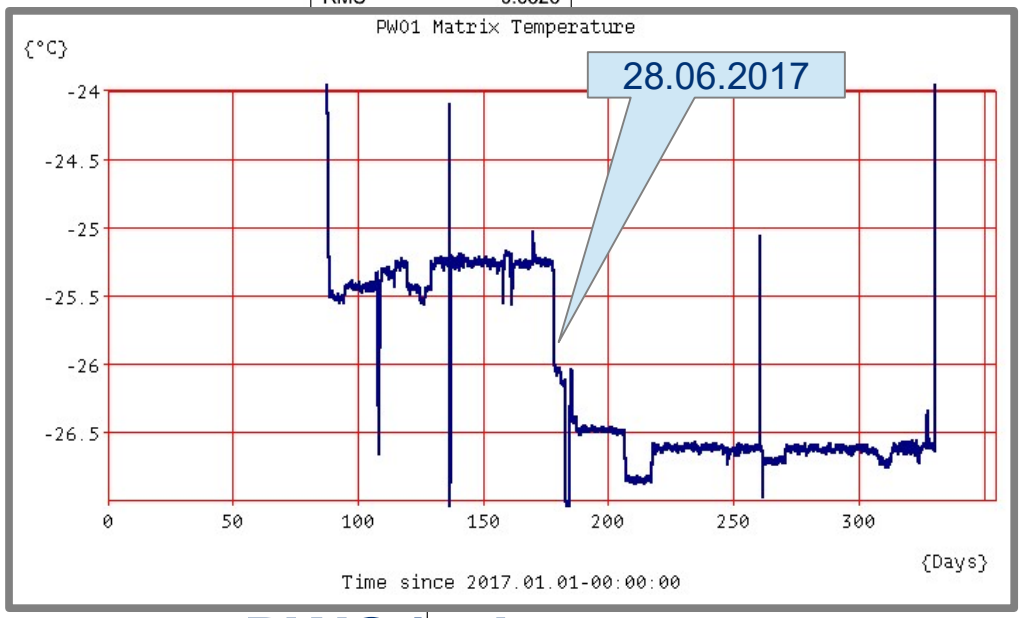
PHOS-2017: temperature distribution in PWO2



PHOS-2017: temperature distribution in PWO1

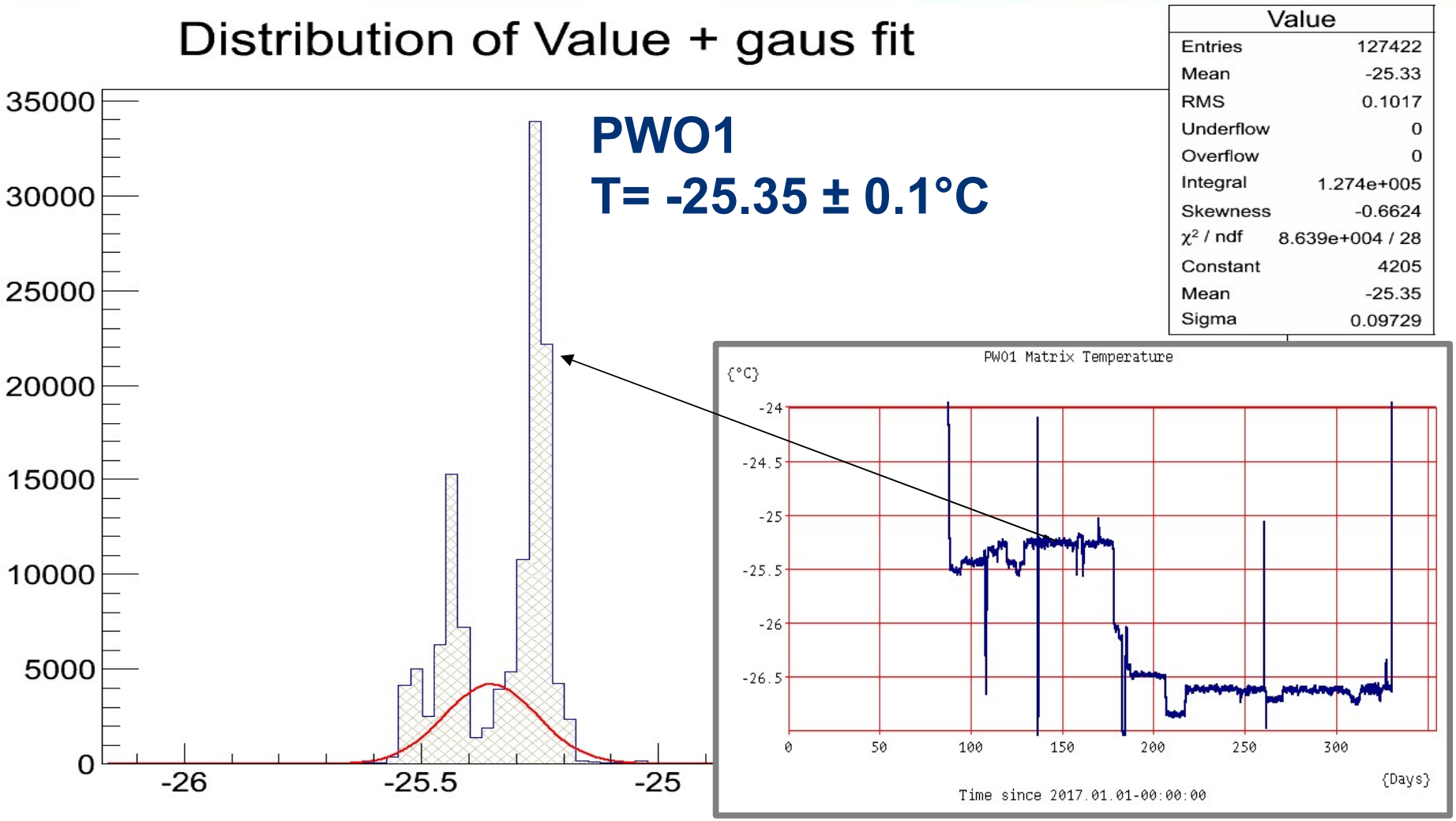


Value	
Entries	342104
Mean	-26.14
RMS	0.6326

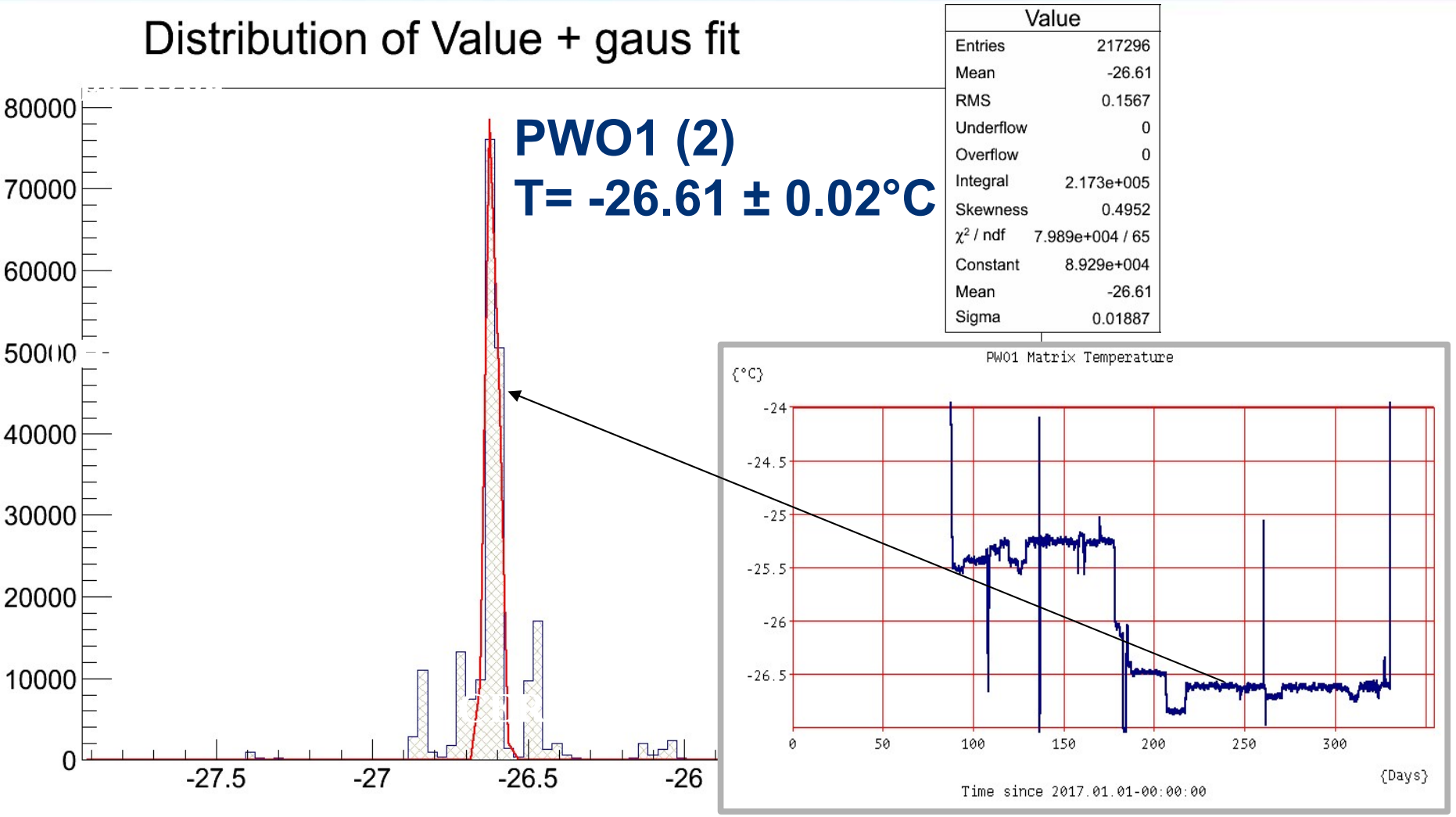


PWO1: there are two peaks
T1= -25.35 ± 0.1°C
T2=-26.61 ± 0.02°C

PHOS-2017: temperature distribution in PWO1 (peak 1)



PHOS-2017: temperature distribution in PWO1 (peak2)



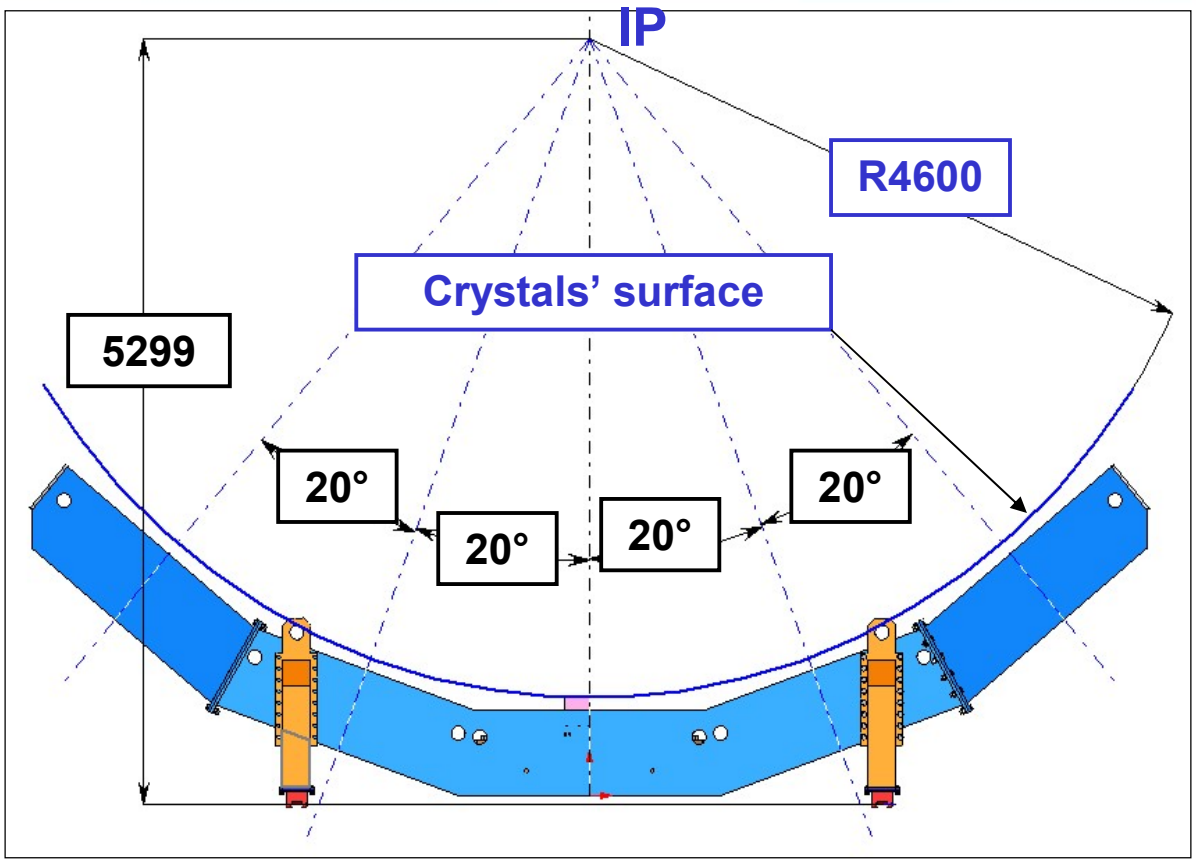
PHOS RUN2: Conclusions

1. The uninterrupted operation of the cooling system is provided in RUN 2.
2. The temperatures of
   PWO2=-23.97±0.05°C - satisfy
   PWO3=-23.02±0.10°C PHOS
   PWO4=-23.60±0.04°C requirements
2. PWO1 temperature has got two peaks
   T1=-25.35±0.1°C, T2=-26.61±0.02°C

   This was hapened due to the part of FEE disabling ≈ 28.06.2017
3. The cooling power is ≈45% of max.

Thanks!

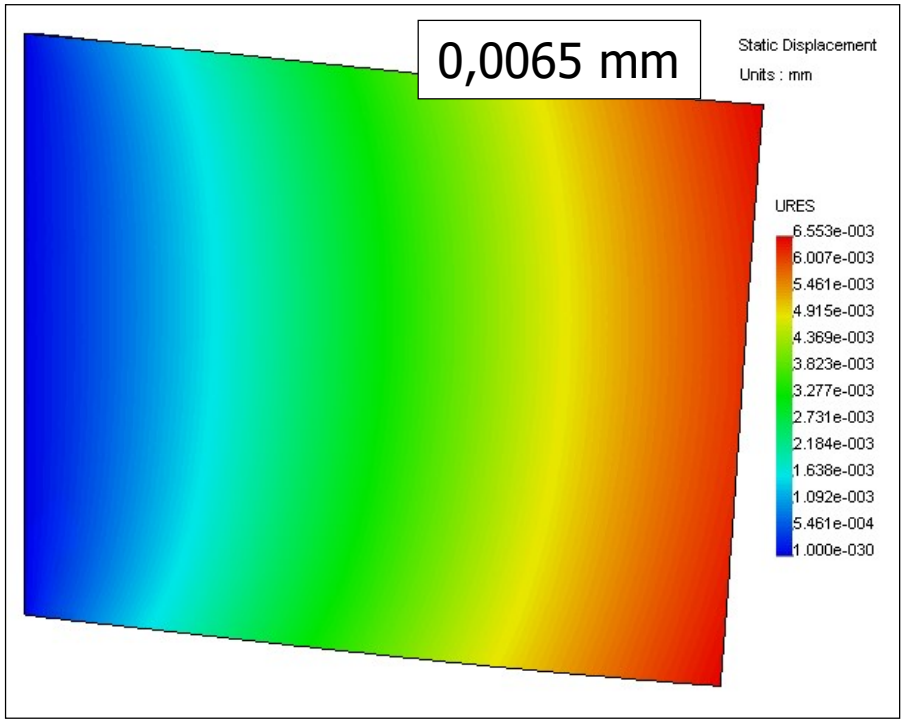
PHOS spectrometer location from IP



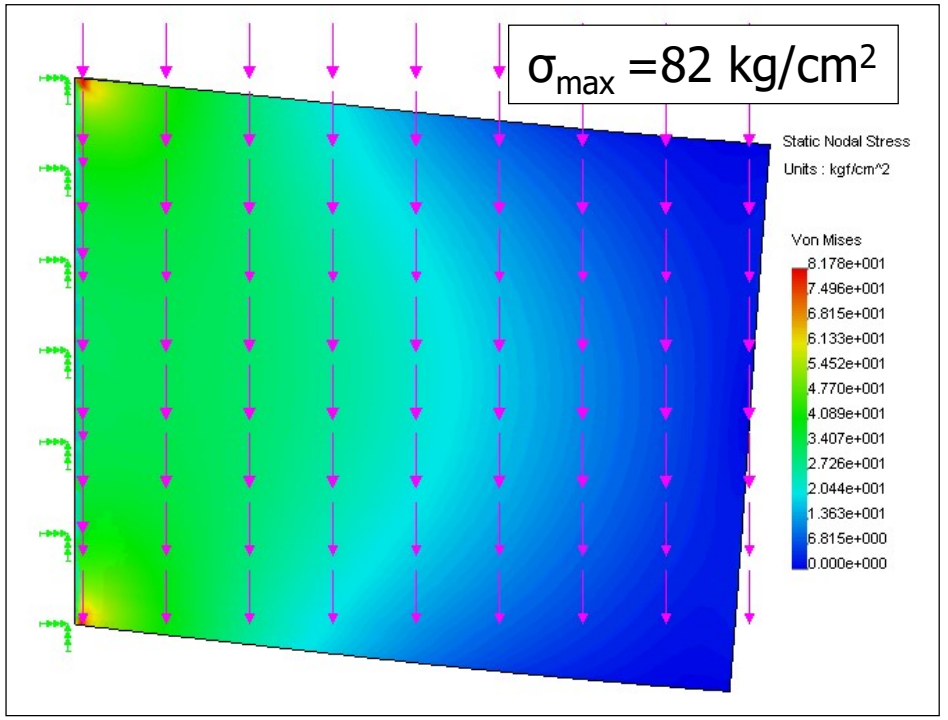
There are 5 modules in the PHOS spectrometer cradle. The weight of each is approx. 4.0 t.

The distance is 4600 mm from the IP up to the crystals' surface

Calculation of the cell cristal structure



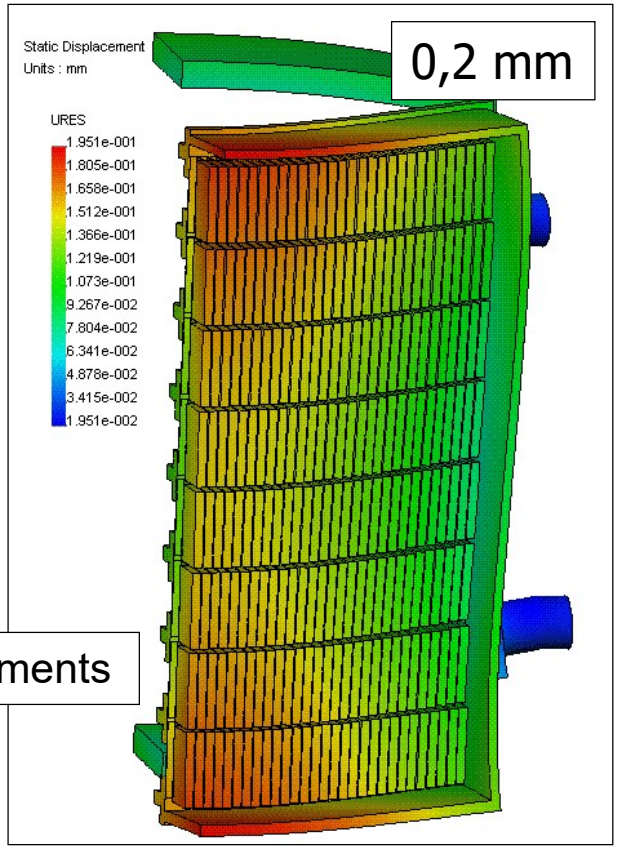
Displacements



Stresses

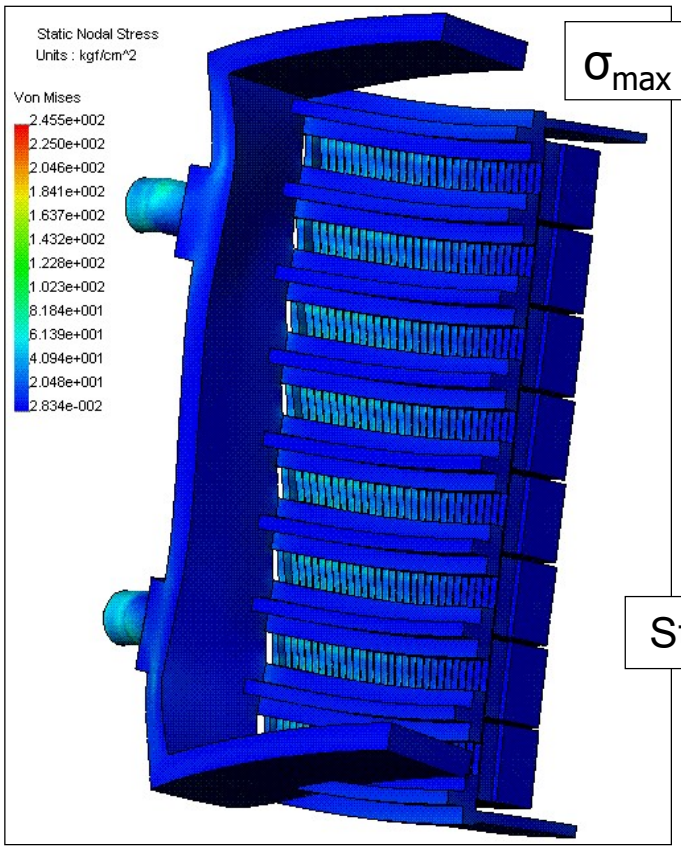
The maximum working loading onto the cellular structure is a weight of crystals at the horizontal position in the cells while calibration.

Calculation of the main module frame in the vertical position



0,2 mm

Displacements

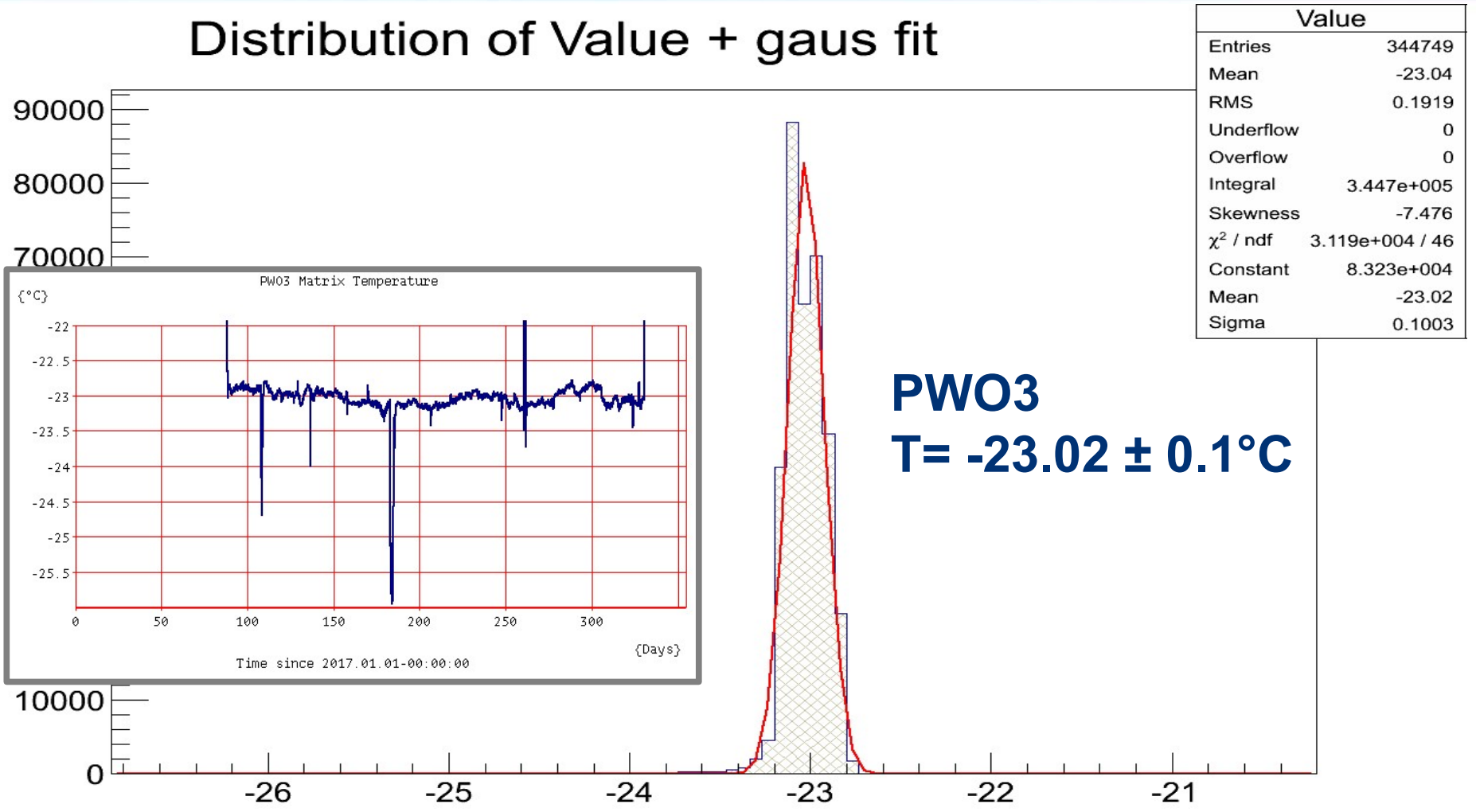


σ_{max} =246 kg/cm^2

Stresses

Results of the mechanics-and-strength calculation of the glass-cloth-base laminate body and cooling panels with T-section at their vertical position under crystals' loading

PHOS-2017: temperature distribution in PWO3



PHOS-2017: temperature distribution in PWO4