"Hardware and software complex for control and synchronization of the SPI equipment"

for

"XXth Workshop on High Energy Spin Physics"

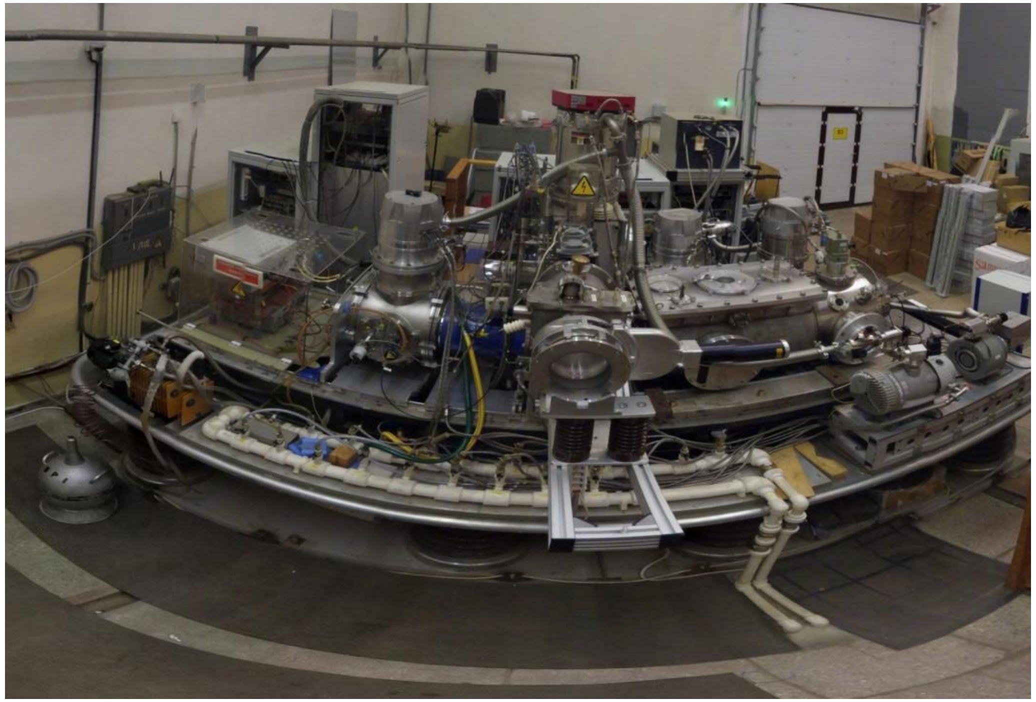
N.V. Dunin, V.V. Fimushkin, K.A. Ivshin, M.K. Kulikov, A.N. Solovev
Joint Institute for Nuclear Research, Dubna, Russia

A.N. Zelenski, Yu.N. Filatov
Moscow Institute of Physics and Technology, MIPT,
Dolgoprudnyi

08.09.2026

Main goal and tasks

Goal: a single hardware–software solutions for control, monitoring and automation of the critical infrastructure of the Source of Polarized Ions (SPI).



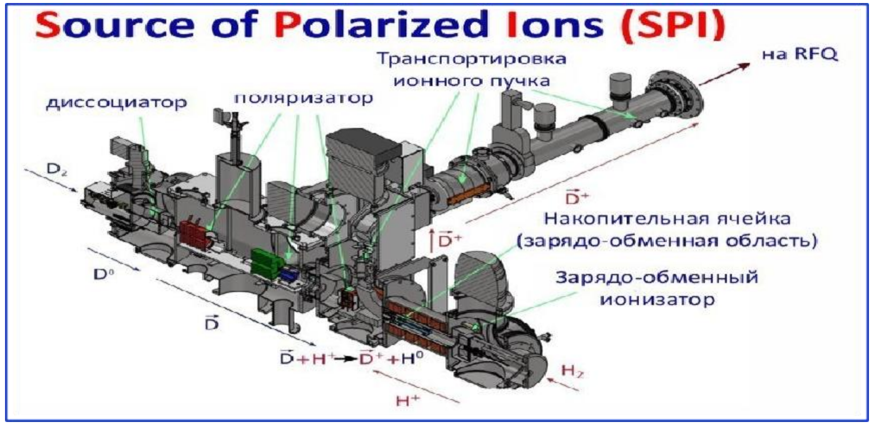
In practice, for the SPI setup:

1. Transfer of the 12 polarization tags.
2. Integration of lab equipment over SCPI (supplies, generators, counters).
3. Voltage / current measurement (ADC, PLC).
4. Temperature and water-flow monitoring of cooled parts.

Main tasks

- Power-supply management for the polarization cells.
- Control of the signal generators (spin modes & polarization marks).
- Control and monitoring of multi-range DC power supplies.
- Feedback control via ADC/DAC crate modules (STM32).

Cooling parameters and temperatures via a PLC.



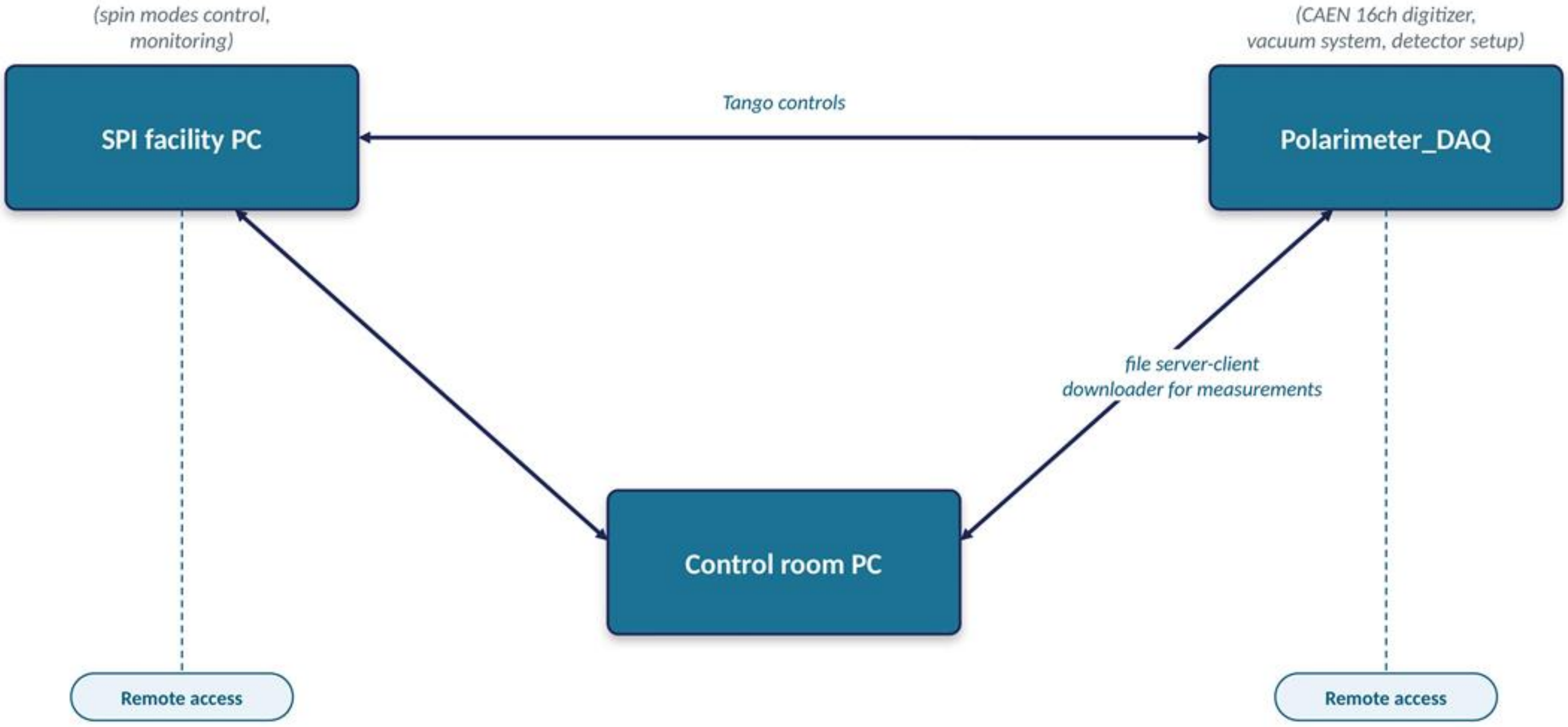
Integrated Equipment :

Siemens PLC

Pulse generator

CAEN VX1730 DIG.

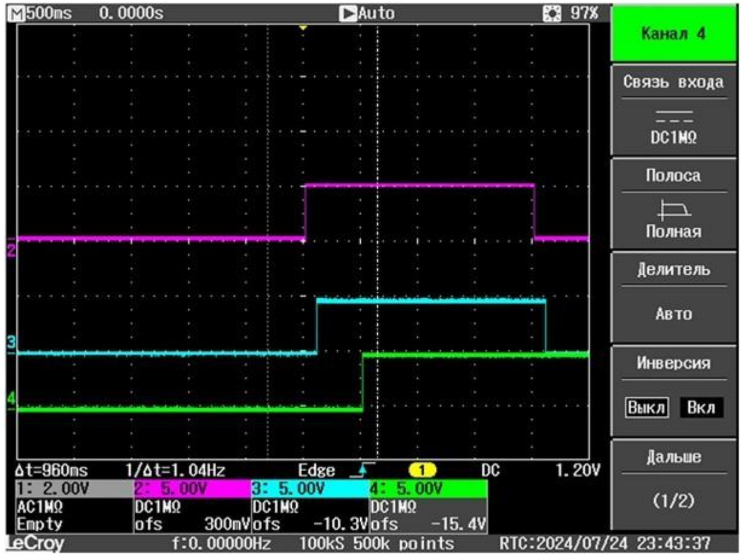
SPI facility connection diagram



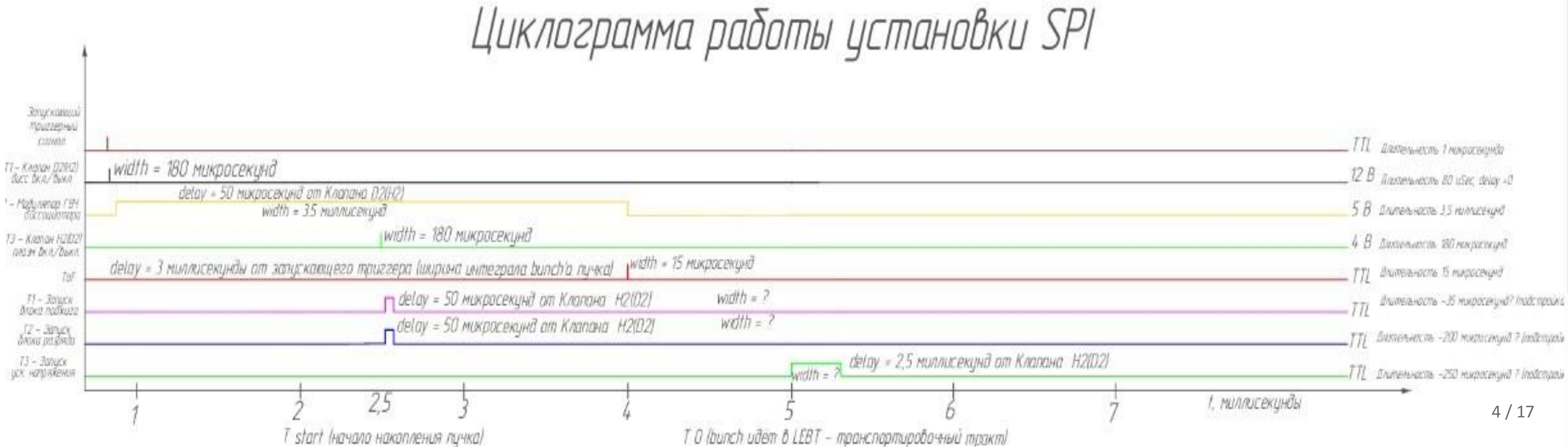
Example configuration of a Quantum Composer 9520 digital signal generator

How digital signal generator delays work:

- Pink = 1 millisecond;
- Blue = 100 milliseconds;
- Green = 500 milliseconds



- 2ch Wait pink;
- 3ch Wait blue;
- 4ch Wait green.



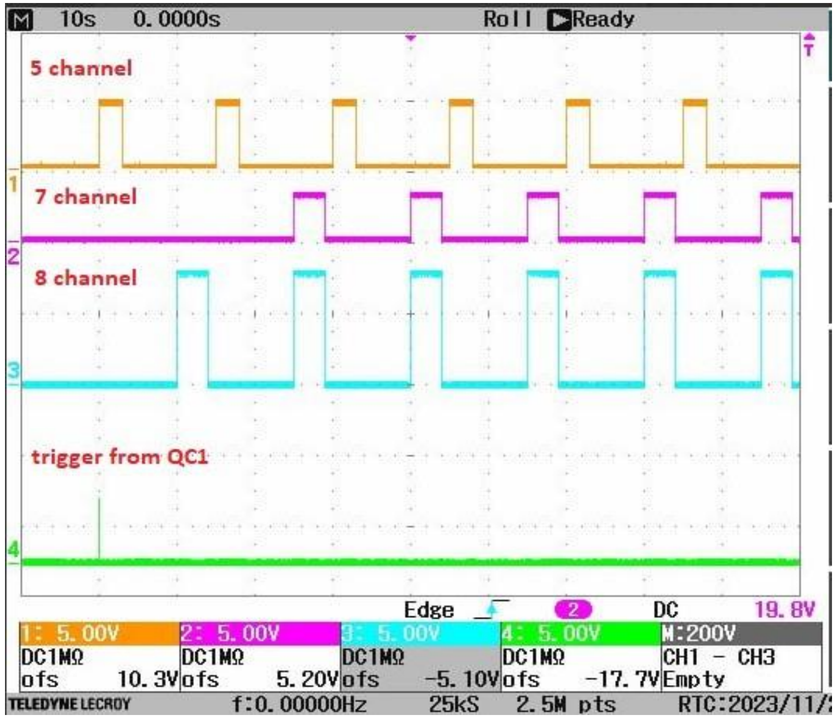
Required spin modes for the SPI

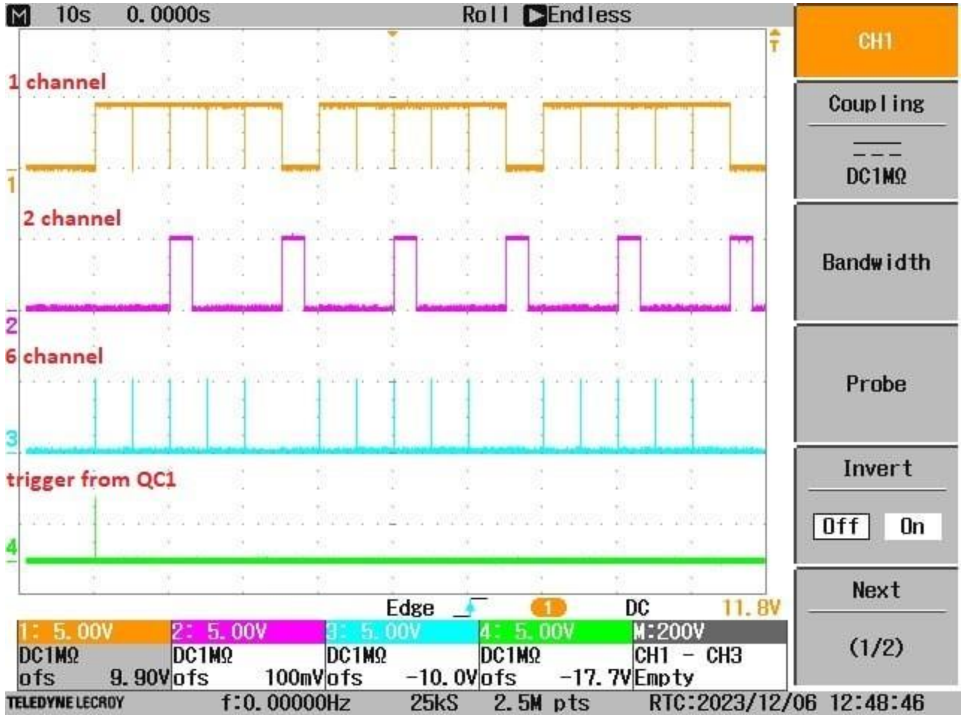
#	MFT	SFT	WFT	Pz	Pzz	I/I_0	Code
1	Off	2→6	off	+1/3	+1	1	0001
2	Off	3→5	off	+1/3	−1	1	0010
3	Off	3→6	off	+2/3	0	1	0011
4	Off	off	1→4	−2/3	0	1	0100
5	3→4	2→6	off	+1	+1	2/3	0101
6	3→4	off	1,2→3,4	−1	+1	2/3	0110
7	1→4	2→6	off	0	+1	2/3	0111
8	1→4	3→5	off	0	−2	2/3	1000
9	1→4	off	off	−1/2	−1/2	2/3	1001
10	3→4	off	off	+1/2	−1/2	2/3	1010
11	off	off	off	0	0	1	1011
12	*False Mode*						1111

Each mode combines MFT / SFT / WFT radio-frequency transitions → defined vector (Pz) and tensor (Pzz) polarization; 4-bit code tags the mode in the data. Mode 12 = "False mode" (sync-error flag).

Output signals for polarizations cells control (QC2)

5channel	7channel	8channel	1channel	2^{nd} ch	6^{th} ch	Trigger from QC1
Polarization tag – is ON: RF WFT is on dcycle delay 0 s width 3 s On cycle 1 Off cycle 2 Wait cycle 0 Amp 4.35 V	SFT 0.5 A (2->6) is ON: dcycle delay 5 s width 4 s On cycle 1 Off cycle 2 Wait cycle 4 Amp 3.05 V	SFT 1.75 A (3->5) is ON: dcycle delay 5 s width 4 s On cycle 1 Off cycle 2 Wait cycle 1 Amp 3.05 V	Polarization tag + is ON: Dcycle delay 0.009 s width 4.9902 s On cycle 5 Off cycle 1 Wait cycle 0 Amp 4.35 V	Polarization tag is 0 dcycle delay 0 s width 3 s On cycle 1 Off cycle 2 Wait cycle 2 Amp 4.95 V	RF SFT is ON dcycle delay 0.003 s width 0.01 s On cycle 5 Off cycle 1 Wait cycle 0 Amp 4.95 V	Trigger QC2 delay 0 s width 0.00004 s Amp 5 V



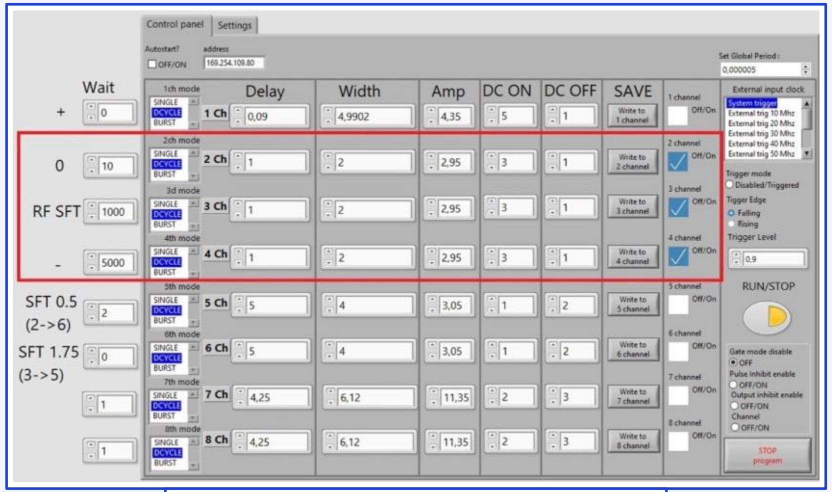


Signals for polarizations tags (Duty cycle , On cycle , Off cycle, Wait cycle examples)

Control signal generator

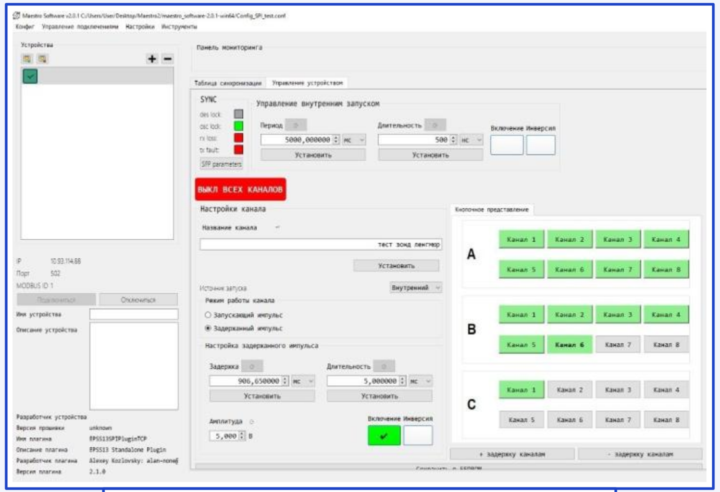
Used to control the ignition, discharge, and accelerating-voltage units, as well as the H_2/D_2 and D_2/H_2 valves of the SPI (Source of Polarized Ions) setup.

Previous solution — Quantum Composer 9520



LabVIEW SCPI client (TCP/IP) + 8-channel pulse generator

Current solution — Custom 28-channel generator



Altera Cyclone IV FPGA unit + software client (Modbus)

Инженерка
Международная инженерная школа

Communication protocol (Modbus, request – response)

- Input registers (read-only): temperature, voltage, power; link status; error counters.
- Holding registers (read/write): per channel (24) — start source, delay, pulse width, amplitude 0–12 V.
- Pulses formed from the 10 MHz and 40 MHz system clocks.

Request example

```
01 06 00 0A 70 0C F8 0C → Delay 907.15 ms
01 06 00 0C 4E 20 E8 0C → Width 500 µs
01 06 00 0E 00 11 F8 0C → Output ON
```

Инженерка
Международная инженерная школа

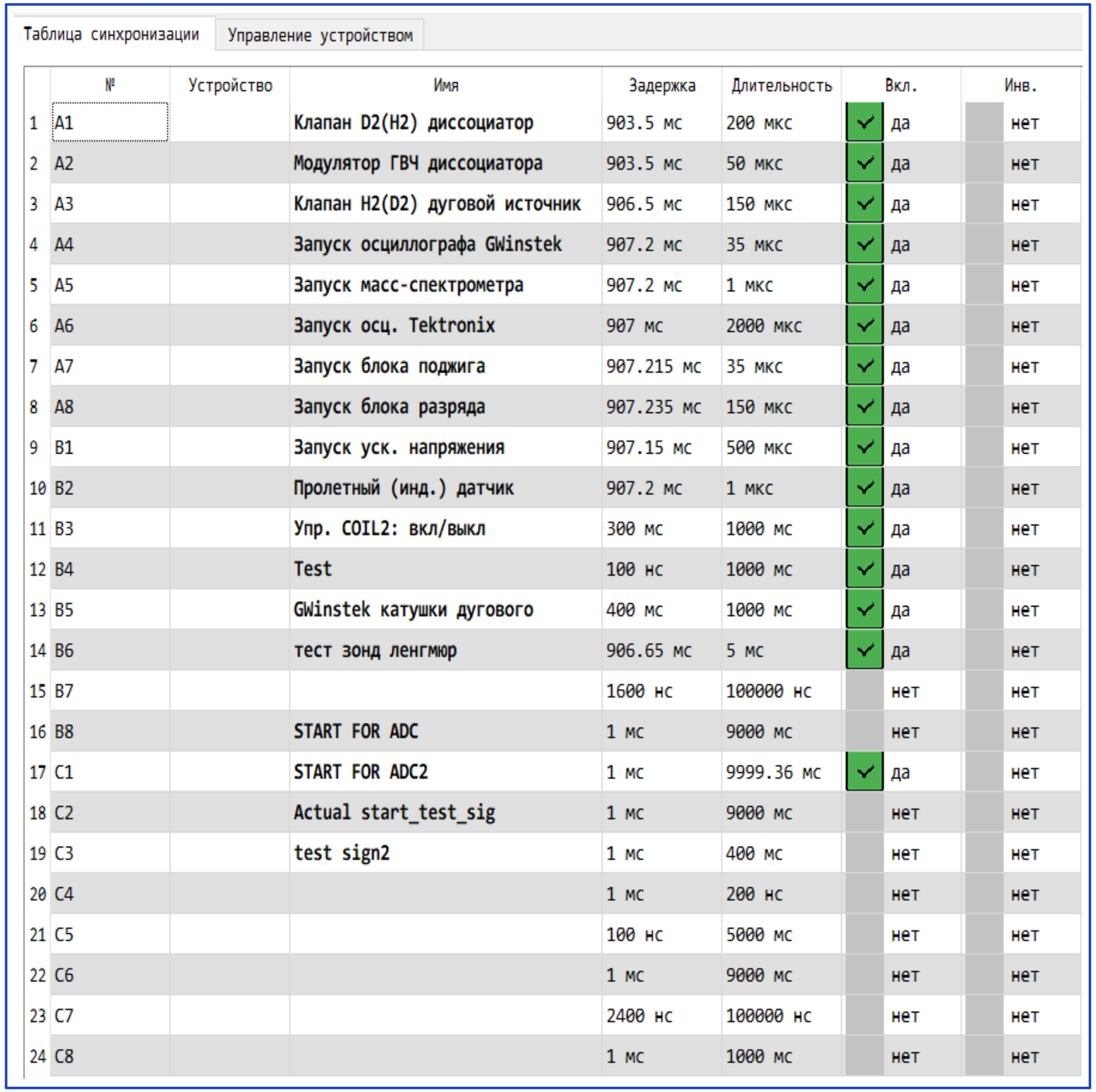
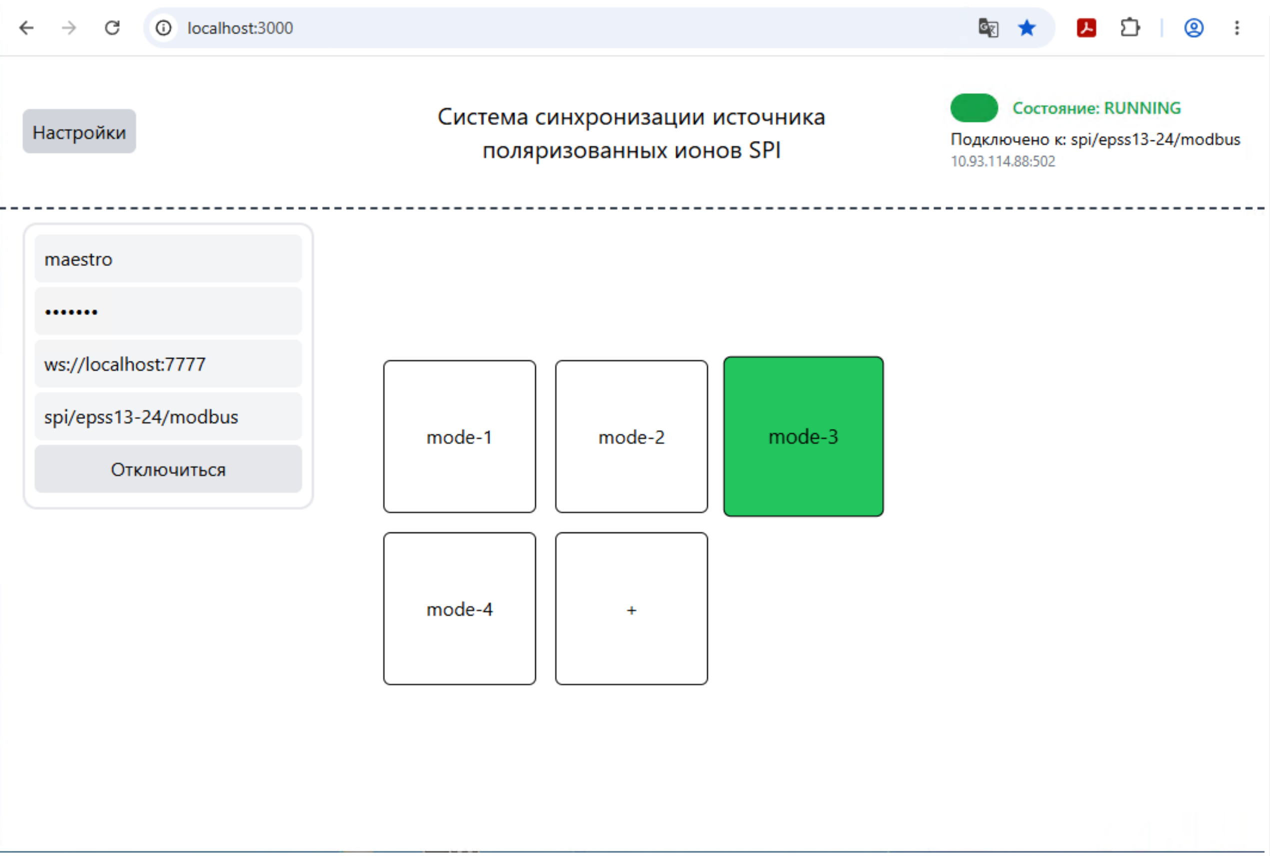


Таблица синхронизации | Управление устройством

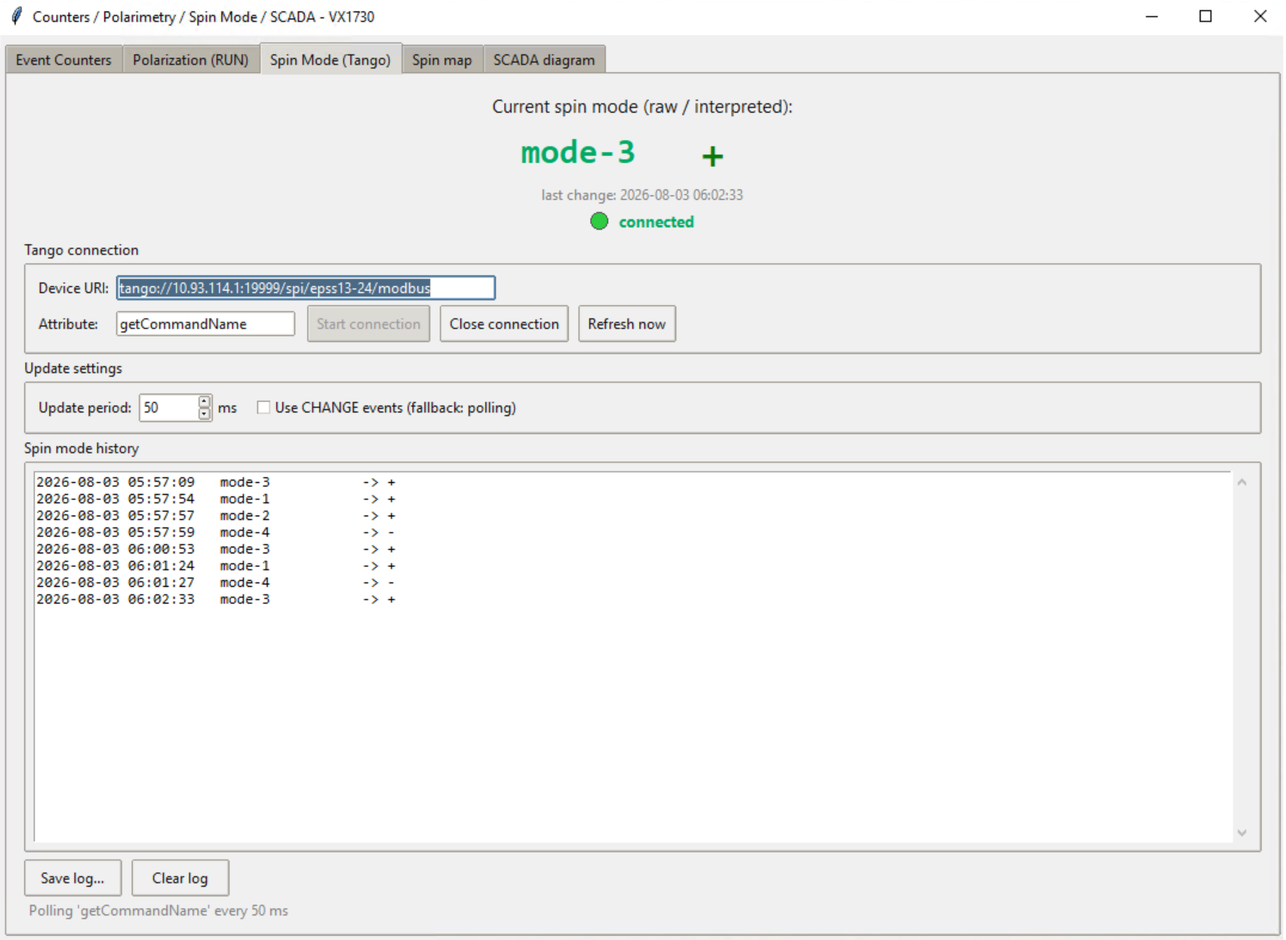
	№	Устройство	Имя	Задержка	Длительность	Вкл.	Инв.
1	A1		Клапан D2(H2) диссоциатор	903.5 мс	200 мкс	да	нет
2	A2		Модулятор ГВЧ диссоциатора	903.5 мс	50 мкс	да	нет
3	A3		Клапан H2(D2) дуговой источник	906.5 мс	150 мкс	да	нет
4	A4		Запуск осциллографа GWinstek	907.2 мс	35 мкс	да	нет
5	A5		Запуск масс-спектрометра	907.2 мс	1 мкс	да	нет
6	A6		Запуск осц. Tektronix	907 мс	2000 мкс	да	нет
7	A7		Запуск блока поджига	907.215 мс	35 мкс	да	нет
8	A8		Запуск блока разряда	907.235 мс	150 мкс	да	нет
9	B1		Запуск уск. напряжения	907.15 мс	500 мкс	да	нет
10	B2		Пролетный (инд.) датчик	907.2 мс	1 мкс	да	нет
11	B3		Упр. COIL2: вкл/выкл	300 мс	1000 мс	да	нет
12	B4		Test	100 нс	1000 мс	да	нет
13	B5		GWinstek катушки дугового	400 мс	1000 мс	да	нет
14	B6		тест зонд ленгмюр	906.65 мс	5 мс	да	нет
15	B7			1600 нс	100000 нс	нет	нет
16	B8		START FOR ADC	1 мс	9000 мс	нет	нет
17	C1		START FOR ADC2	1 мс	9999.36 мс	да	нет
18	C2		Actual start_test_sig	1 мс	9000 мс	нет	нет
19	C3		test sign2	1 мс	400 мс	нет	нет
20	C4			1 мс	200 нс	нет	нет
21	C5			100 нс	5000 мс	нет	нет
22	C6			1 мс	9000 мс	нет	нет
23	C7			2400 нс	100000 нс	нет	нет
24	C8			1 мс	1000 мс	нет	нет

Synchronization table — software client

Spin-modes control and monitoring using TANGO controls

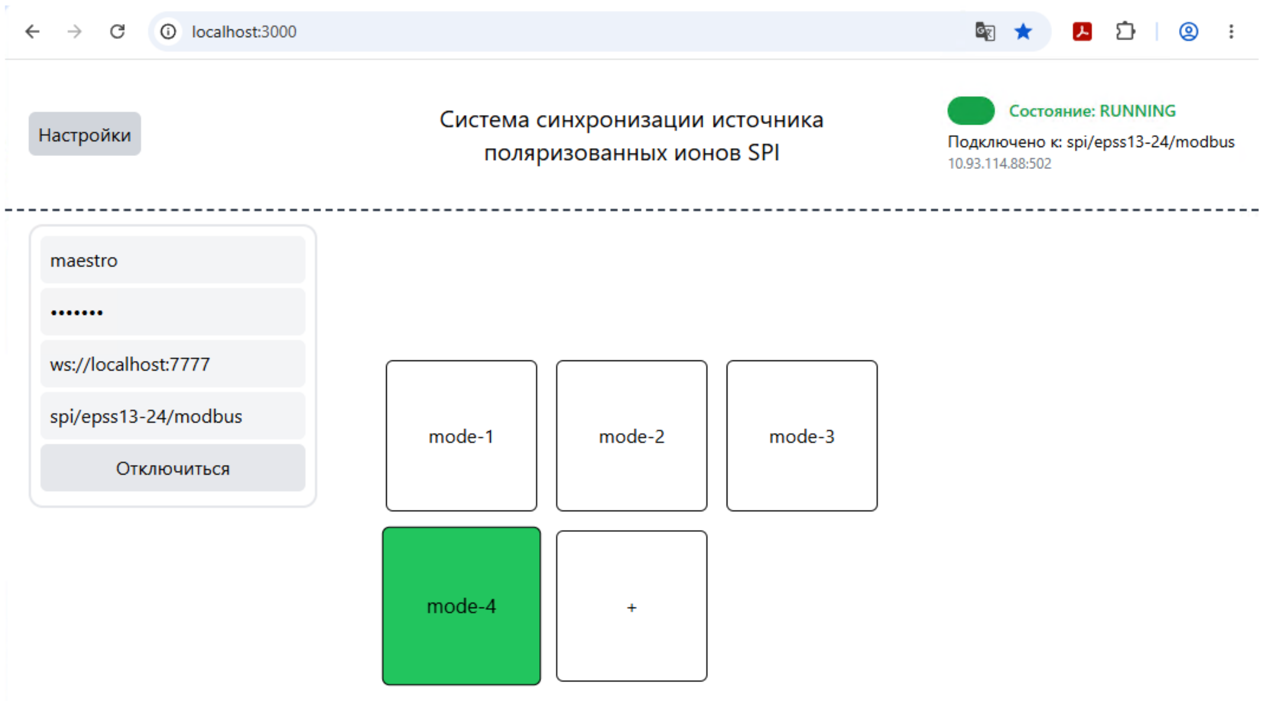


High-level Frontend control panel

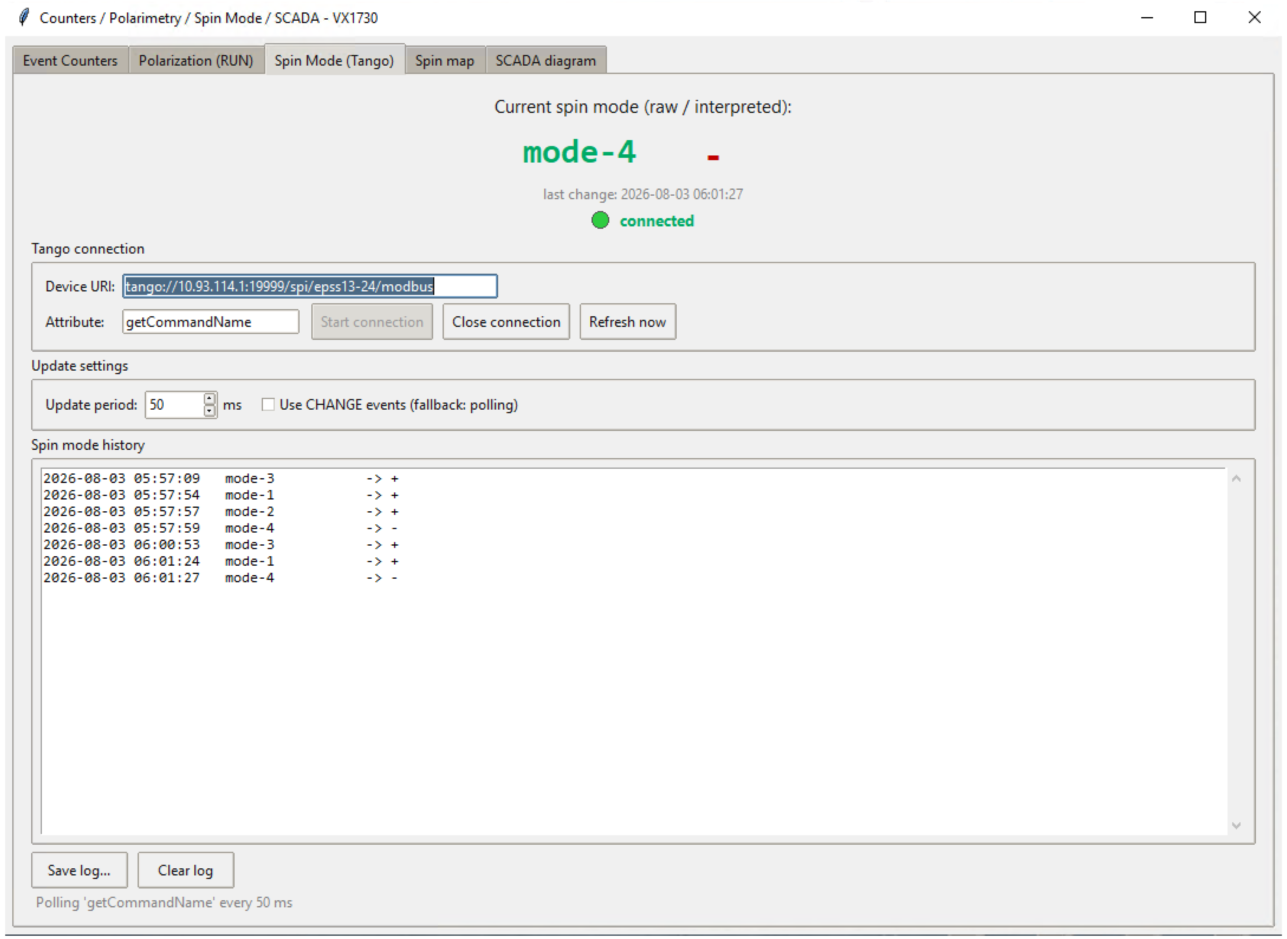


Client side for current spin mode monitoring

Spin-modes control and monitoring using TANGO controls



High-level Frontend control panel



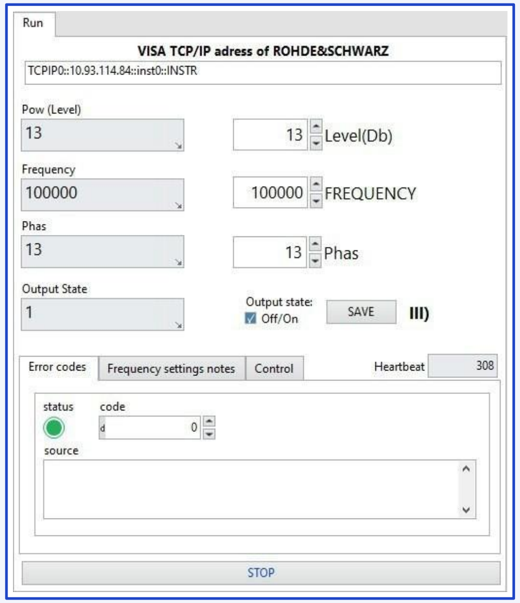
Client side for current spin mode monitoring

Power supplies for the polarization cells

MFT & WFT — GW Instek PSB-1400M (0–160 V, 0–10 A)

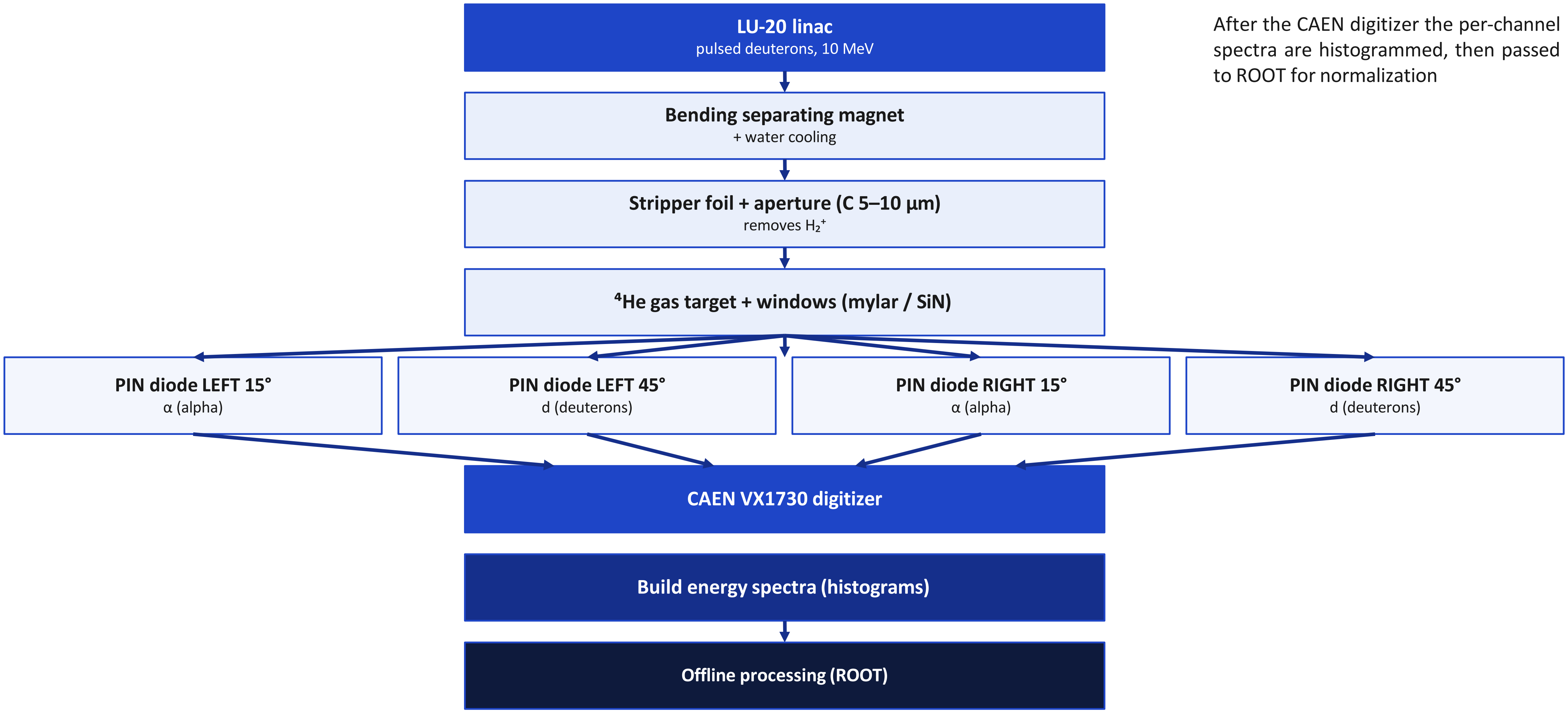
LabVIEW client (TCP/IP with device library)

SFT — Rohde & Schwarz SMB100A (RF)



LabVIEW client (TCP/IP +SCPI requests)

Polarization measurement algorithm



After the CAEN digitizer the per-channel spectra are histogrammed, then passed to ROOT for normalization

DAQ software development for CAEN VX1730 digitizer

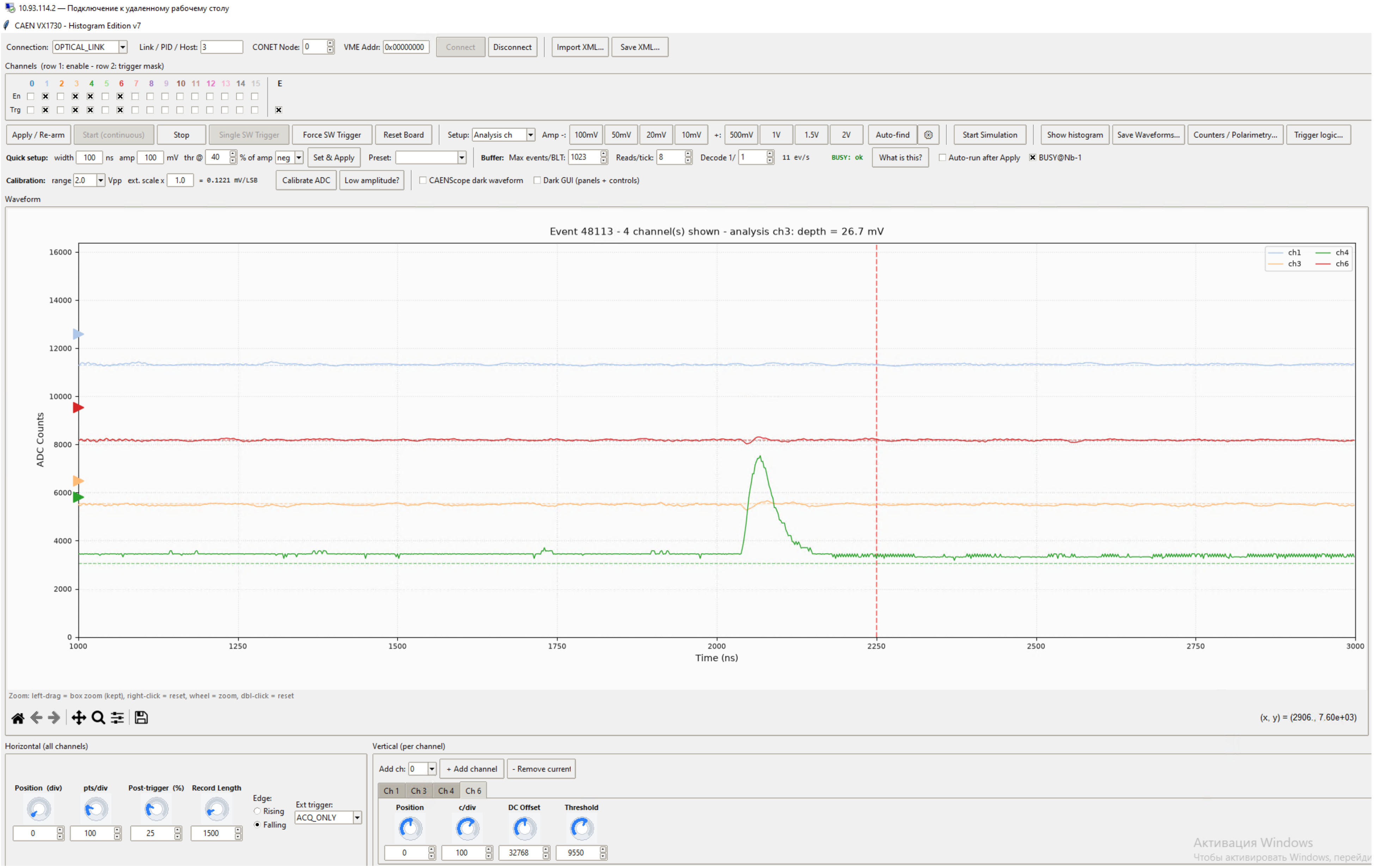
Key result

100 mV / 100 ns

resolved at input rates up to **20 MHz**

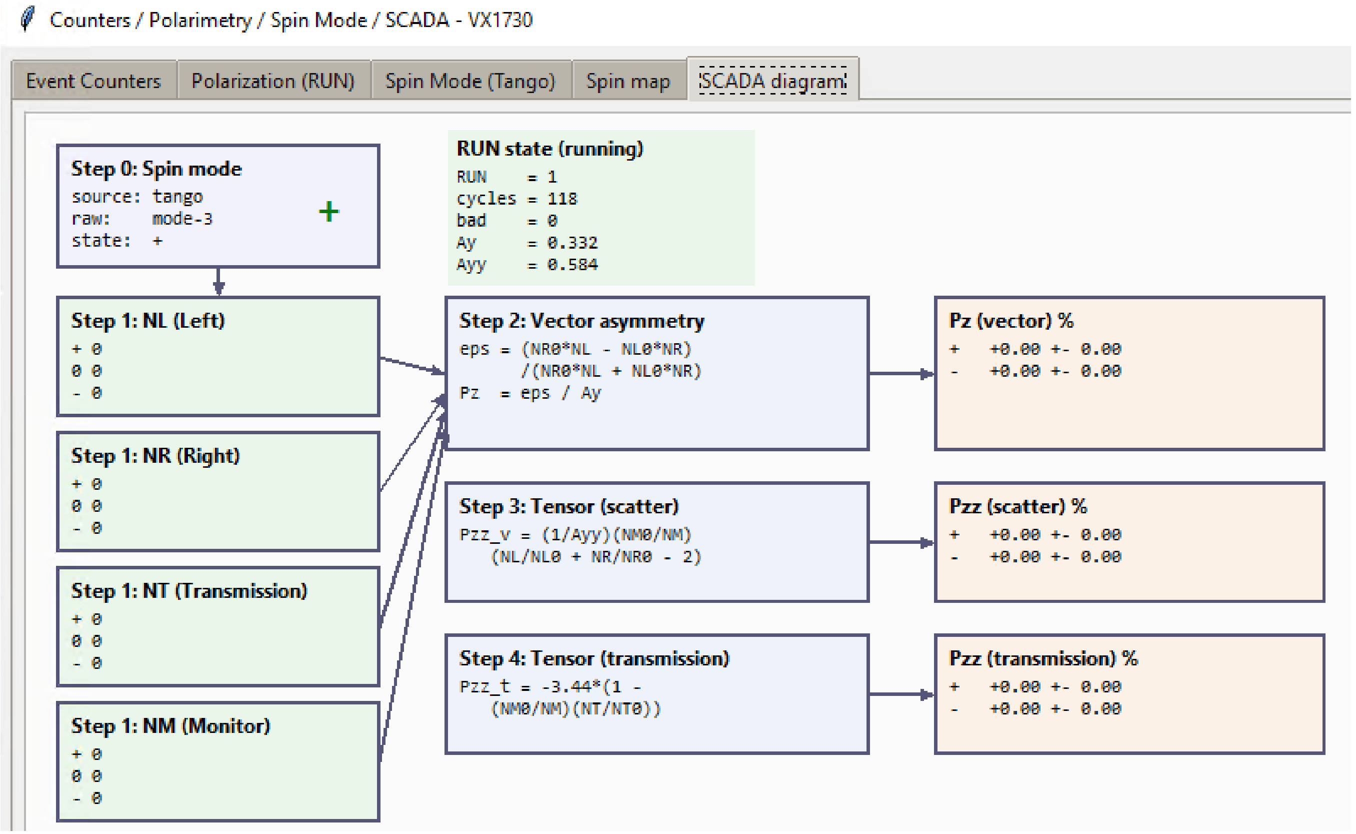
- 1000 mV , 100ns , 1 Mhz, Duty Cycle
- 50%
- Pulse waveform
- (Up to 20Mhz Frequency).
- Record length 630 ns window
- No external trigger,
- Vertical: c/div 5 , Horizontal pts/div 100
  Optical link connection

CAEN VX1730 digitizer



Histogram / waveform DAQ — test pulses from a Rigol DG1022 (1000 mV, 100 ns, 630 ns window, optical link)

Beam polarization — definitions and counting algorithm



Polarization calculations steps

Counting algorithm

4 PIN-diode channels run in counter mode; for every spin tag (+, 0, −) the counts N_+, N_0, N_- are accumulated, then combined by the formulas at left.

Spin tag	m_i	Counter	pz	p_zz
+	+1	N_+	+	+
0	0	N_0	0	–
–	−1	N_-	–	+

In what way polarization is measured with the CAEN system

1 · Calibration & setup

Fill ^{4}He target (0.1–0.2 bar), open gate valve, weak beam (1–10 nA), align on detector max, record background.

2 · Sign switching

Set + spin mode, record C^+ L, C^+_R over fixed pulses;

Switch to − spin mode, record C^-_L , C^-_R ; repeat ≥ 10×.

3 · Online

Per cycle compute the asymmetry ε and check it is stable cycle-to-cycle.

4 · Offline

Normalize to beam charge (**Faraday cup**), subtract background, compute r and t_{11}.

Vector polarization (Polarimeter Work Plan)

$$\varepsilon = \frac{(C_L^+/C_R^+) - (C_L^-/C_R^-)}{(C_L^+/C_R^+) + (C_L^-/C_R^-)}$$

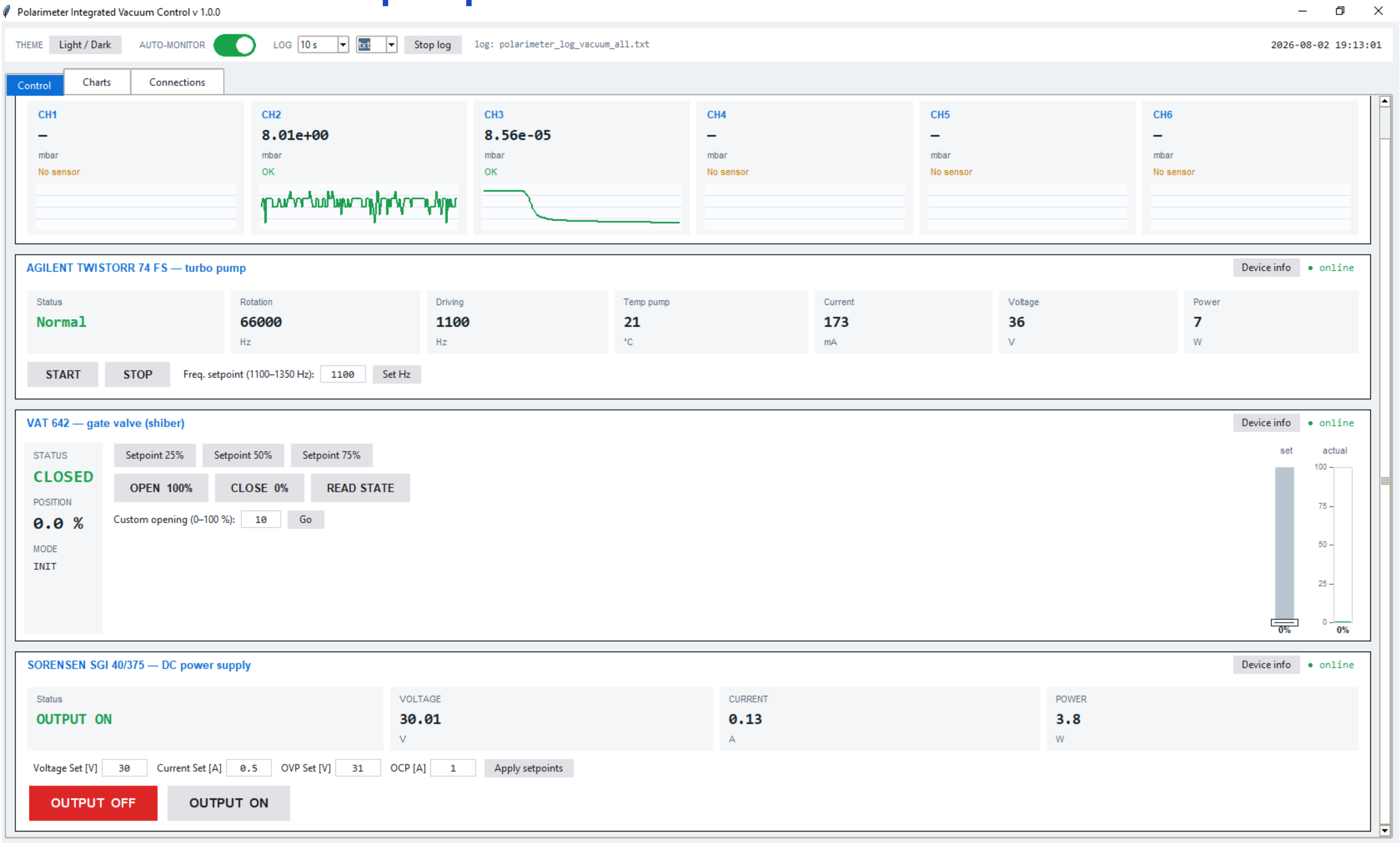
asymmetry

$$r = \left(\frac{C_L^+\,C_R^-}{C_L^-\,C_R^+}\right)^{1/2} \qquad t_{11} = \frac{1}{2\,iT_{11}} \cdot \frac{r-1}{r+1}$$

t_{11} = Vector polarization

iT_{11} — analyzing power of ^{4}He (, d)^{4}He at the given energy and angle (calibration constant).

Turbo pumps and vacuum control solution



Results and outlook

- A complete set of software modules in LabVIEW 2020 and Python/ PyQt covers control- the full and-monitoring cycle of the SPI.
- Tango controls integration with a high-level frontend web interface.
- Integration with heterogeneous equipment over standard interfaces: UART, TCP/IP, Modbus TCP/IP.
- Event-driven architecture for reliability.
- DAQ software for CAEN VX1730 16 channel Digitizer 1.0 generation.
  Energy Spectrum measurements feature implemented based on DRS4 evaluation board logic.

Present

In operation now on the SPI.
(Source of Polarized Ions).

Future

To test with a more number of channels;

To obtain energy spectra;

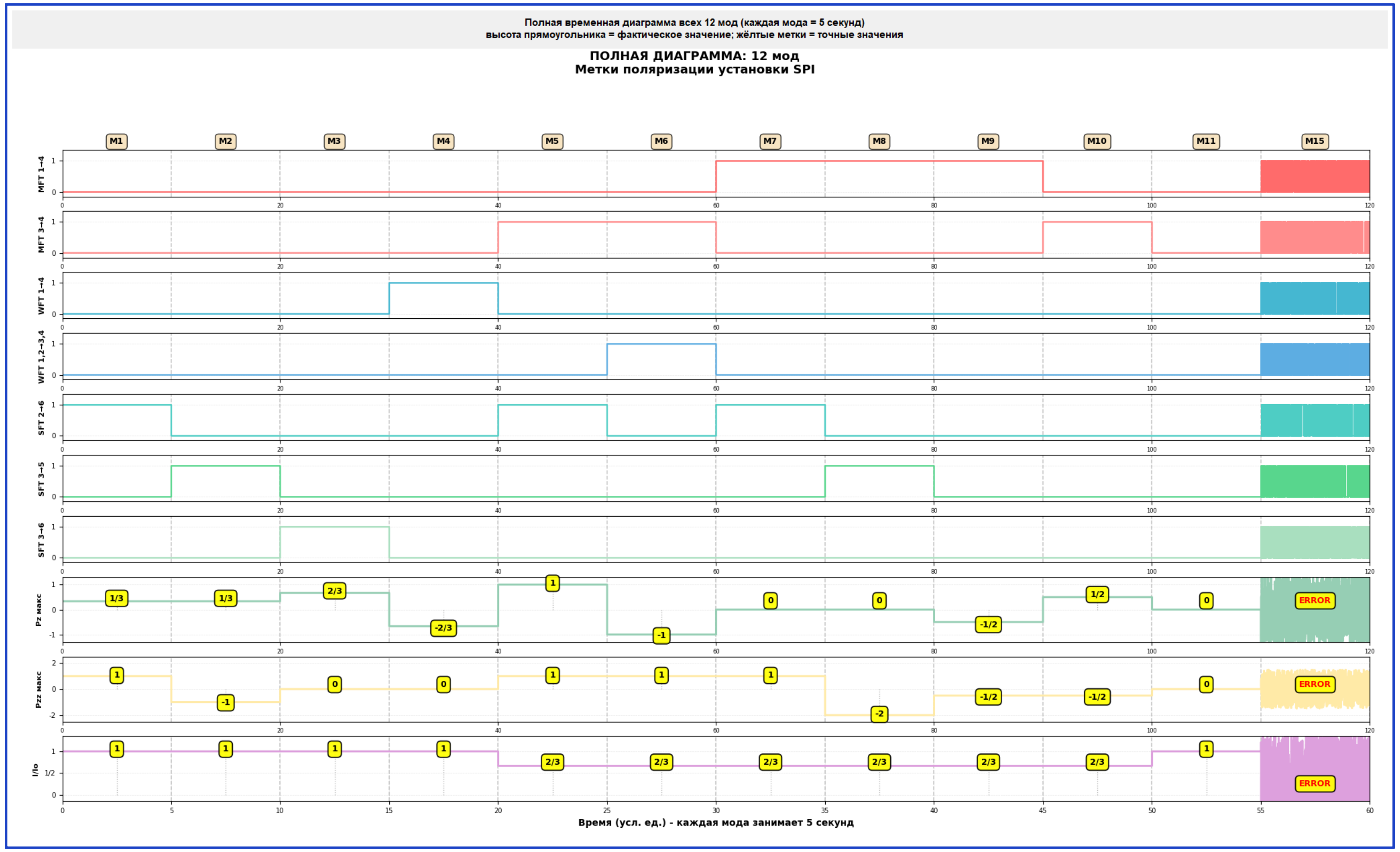
The study was supported by the Russian Science Foundation,

Grant No. 25-72-30005, https://rscf.ru/project/25/72/30005/.

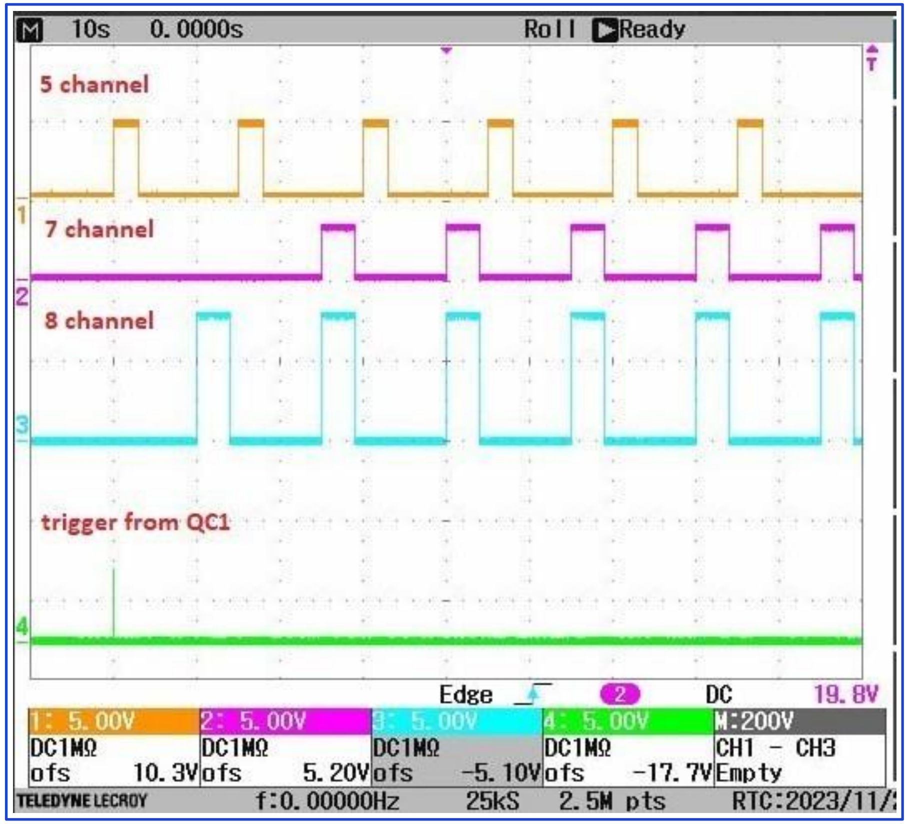
Thank you for your attention!

Required spin modes In accordance with the technical requirements

12 modes (5 seconds each);
each signal set by its duty cycle — ON / OFF / WAIT — all locked to a common trigger.



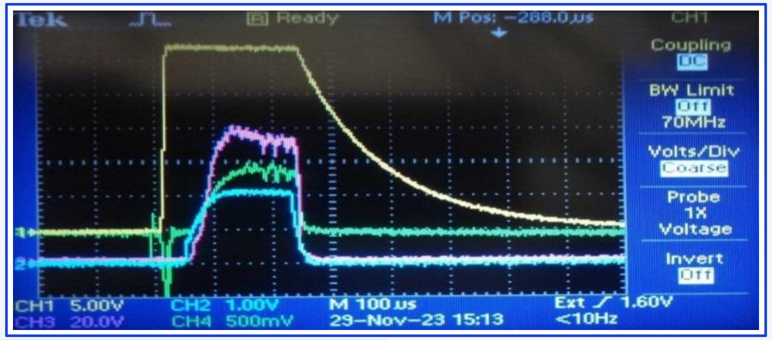
Full timing diagram of all 12 polarization modes (MFT / WFT / SFT, Pz, Pzz, I/I_0)

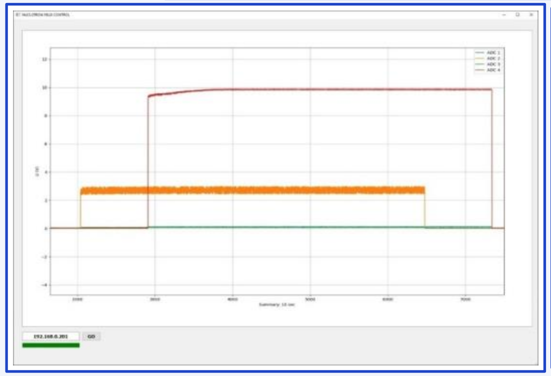


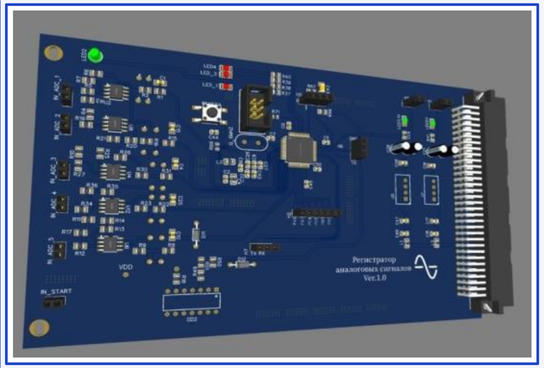
SPI facility timing sequence example

Feedback control and hardware interlocks

Feedback signals for polarization control (ADC, STM32)

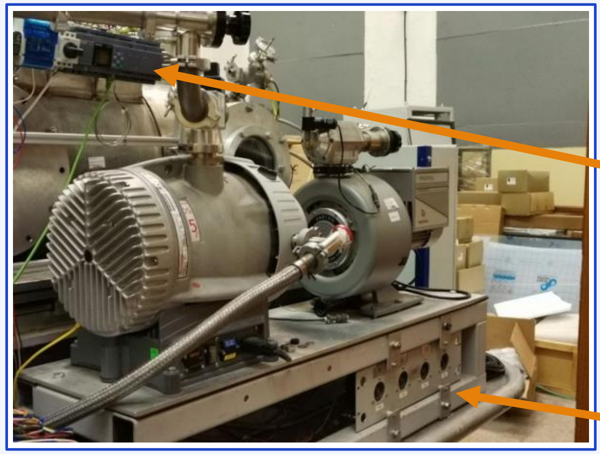






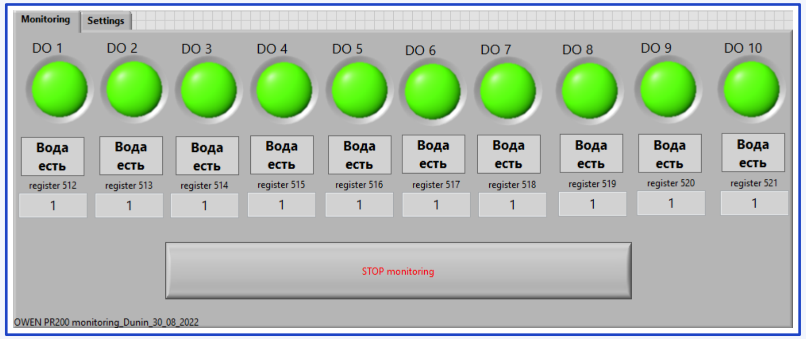
Diagnostic signals · Python (PyQt) ADC chart · registrator PCB

Hardware interlocks (Siemens PLC)



Siemens PLC
(24 V input)

Proteus 100 flow switch series



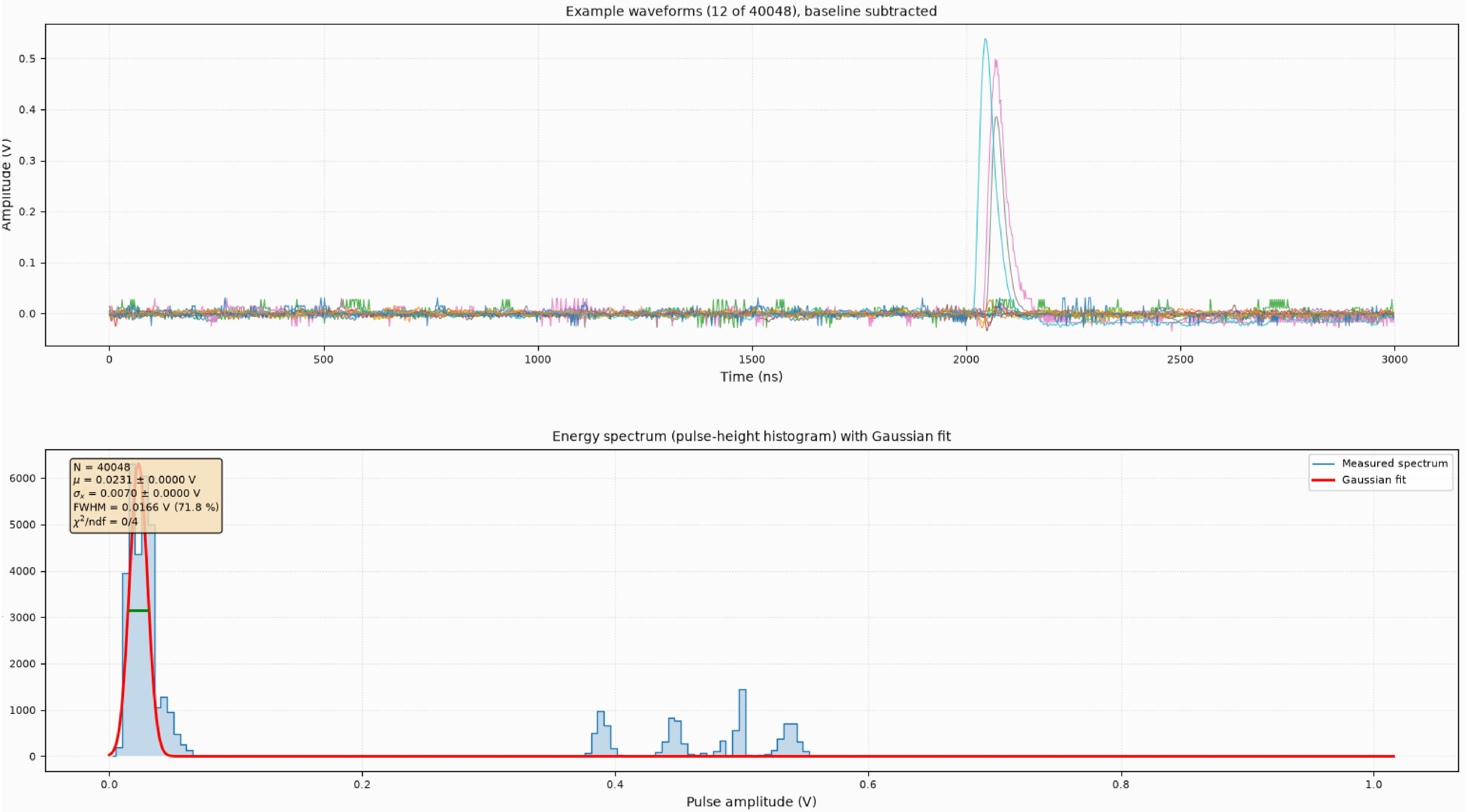
https://www.proteusind.com/product/100-series-flow-switch/

Varian turbopump (PLC 24 V) · LabVIEW water-input LEDs

Yellow – high voltage on the first electrode of the extraction system;

Pink – ion current signal on the corner collector (Faraday cup) after the bending magnet (and the separating magnet performs separation of the beam into components such as H_2^+ ...);

Green – current in the power supply circuit of the high-voltage source; Blue – plasma source current pulse; The oscillogram is used to assess the correct operation of the SPI, specifically for the absence of breakdowns


Example waveforms (12 of 40048), baseline subtracted
Amplitude (V)
Time (ns)
0
500
1000
1500
2000
2500
3000
0.0
0.1
0.2
0.3
0.4
0.5
Energy spectrum (pulse-height histogram) with Gaussian fit
N = 40048
μ = 0.0231 ± 0.0000 V
σx = 0.0070 ± 0.0000 V
FWHM = 0.0166 V (71.8 %)
χ2/ndf = 0/4
Measured spectrum
Gaussian fit
Pulse amplitude (V)
0.0
0.2
0.4
0.6
0.8
1.0
0
1000
2000
3000
4000
5000
6000