Status and R&D of ASHIPH option for PID

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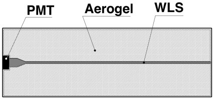
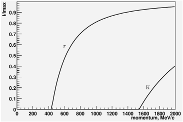
ASHIPH method for particle identification





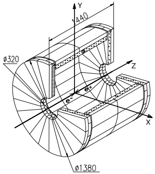
$$P_{thr} = \frac{mc}{\sqrt{n^2 - 1}}$$

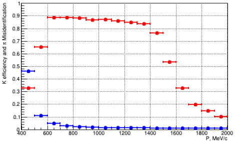
ASHIPH (Aerogel, SHifter, PHotomultiplier) method of light collection was suggested in 1992 (A. Onuchin et al. NIM A315, 1992, 517-520). Cherenkov light from particle in aerogel is collected by the wavelength shifter (WLS) placed in the middle of the counter and transported by WLS like a lightguide to photomultiplier (PMT):

- PMMA light guide doped with BBQ dye is used as WLS
- This method helped us significantly to decrease the PMT photocathode area (cost of the system)

ASHIPH systems at BINP (Novosibirsk):

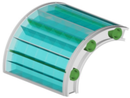
KEDR detector at VEPP-4M e^+e^- collider (2E=2÷10 GeV)

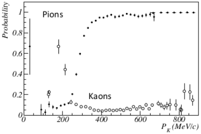




- 160 counters (2 layers)
- n=1.05 (1000 l)
- MCP PMT ⌀PC=18 mm
- $0.97\times4\pi$

SND detector at VEPP-2000 e^+e^- collider (2E=0.3÷2 GeV)

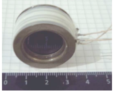


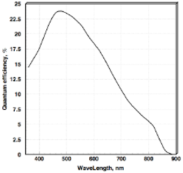


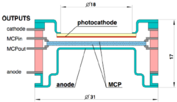
- 9 counters (1 layer)
- n=1.13 (9 l)
- Thickness ∼30 mm
- MCP PMT ⌀PC=18 mm
- $0.6\times4\pi$

ASHIPH upgrade: MCP PMT → SiPMs as photodetector

MCP PMT

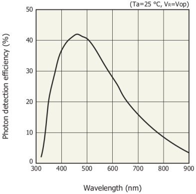






- Manufacturer: "Ekran FEP"(Novosibirsk)
- Borosilikate glass window
- Multialkali (Sb-Na-K-Cs) photocathode
- MCPs with channel diametr of 7 μm
- Maximum QE=23% at λ=500 nm
- Photoelectron collection coefficient ~0.6
- PDE=QE*CE=23*0.6≃14%
- Axial magnetic field
- Power supply 2÷4 kV

MPPC (Multi-Pixel Photon Counter) S13363-3050NE-16

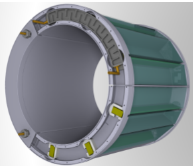


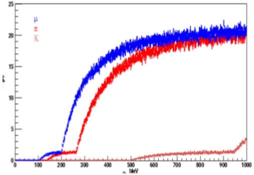
- Manufacturer: "Hamamatsu"
- Effective photosensitive area/channel 3×3 mm
- Number of pixels/channel 3584
- PDE=40% at λ=500 nm
- Any direction magnetic field
- Power supply <100 V (V_{BR}=53 V typ.)
- High level of DCR (0.5 Mcps)

Move to SiPMs must increase detected number of photoelectrons.
8÷10⇒20÷30 ph.e.

ASHIPH-SiPM proposals for BINP colliding beam experiments

ASHIPH for SND (VEPP-2000)

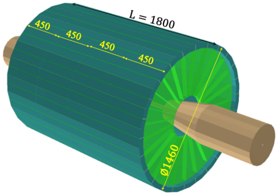


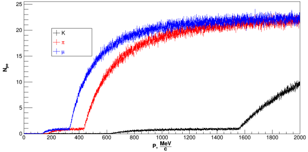


N_{pe} from parametric simulation

- Aerogel: 3cm & n=1.13
- $N_{pe}^{\sum}(\beta = 1) \approx 20$
- 9 counters $26\times10\times3$ cm^3 in 1 layer
- WLS(BBQ) $260\times17\times3$ mm^3
- $5\times9=45$ SiPMs 3×3 mm^2
- π/K-separation
  - $\geq4\sigma$ – 0.3÷1 GeV/c (thr. ∼5ph.e.)

ASHIPH for VEPP-6

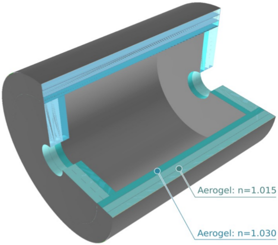


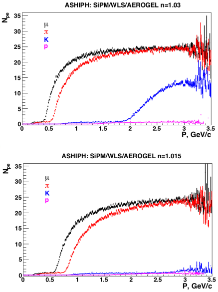


- Aerogel: 8[см]/1.05
  - $N_{pe}^{\sum}(\beta = 1) \approx 20$
  - 300 counters $45\times17\times4$ cm^3 in two layers
  - WLS – BBQ $45\times20\times3$ mm^3
  - $(6\div12)\times300=1800\div3600$ SiPMs 3×3 mm^2
- π/K-separation:
  - $\geq4\sigma$ – 0.5÷1.5 GeV/c (thr. 5 ph.e.)
  - $\geq2.5\sigma$ – 1.5÷2.0 GeV/c (thr 10 ph.e.)

ASHIPH-SiPM proposals for non BINP colliding beam experiments

ASHIPH for Super Charm-Tau Factory (Sarov)



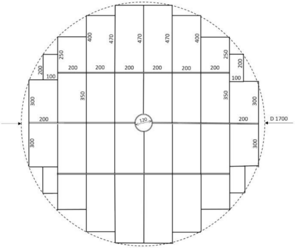


N_{pe} from parametric simulation

- Preliminary design:
  - Aerogel in three layers (6000 l): n=1.03 (8 cm) and n=1.015 (8+8 cm)
  - 1400 counter with sizes $\sim$18$\times$30$\times$8 cm^3
  - Amount of material $\sim$15%X_0
  - Light collection – WLS(BBQ) and 28000 SiPMs 3$\times$3 mm^2
- π/K-separation: 0.5÷2 GeV/c
- μ/π-separation: 0.4÷0.9 GeV/c

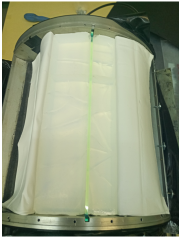
EPJ Web of Conferences 212, 01012 (2019), A.Yu. Barnyakov et al 2020 JINST 15 C04032

ASHIPH for SPD (NICA, Dubna)



- Aerogel: 8cm+8cm & n=1.02
- $N_{pe}^{\Sigma}(\beta = 1) \approx 16$
- 128 counters 47$\times$20$\times$8 cm^3 in 2 layers in 2 endcaps
- WLS – BBQ 470$\times$14$\times$3 mm^3
- (4)$\times$5$\times$128=2560 SIPMs 6$\times$6 mm^2
- π/K-separation:
  - $\geq 4\sigma$ – 0.7÷2.5 GeV/c (thr. 3 ph.e.)

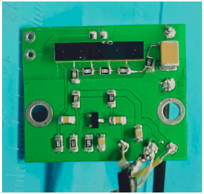
ASHIPH counter prototype & electronics



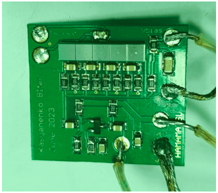
- The segment of ASHIPH system the SND detector are used
- The segment consist of 3 separate counters (only 1 counter is used)
- Cylindrical shape: R=105÷141 mm, length 260 mm, width 80 mm
- WLS position: displayed by $\sim 5^{\circ}$ from counter center
- Aerogel cover: teflon with a refractivity of R$\sim$98%
- Aerogel with $n = 1.12$, thickness 25 mm:
  - 4 tiles with sizes: $160\times50\times25$ mm^3, $70\times50\times25$ mm^3, $160\times30\times25$ mm^3, $70\times30\times25$ mm^3
  - counter not fully filled up to 30 mm
- A line of 5 SiPMs allows cover a WLS with sizes 17x3 mm^2

- Serial connection of 5 SiPMs for power supply and serial connection of 5 SiPMs for signal - does not work
- Parallel connection of 5 SiPMs for power supply and serial connection of 5 SiPMs for signal. The idea for the circuit is taken from the article NIMA 925 (2019) 148–155

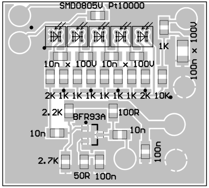
Version 1

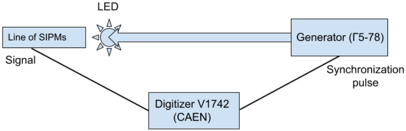


Version 2



Scheme version 2



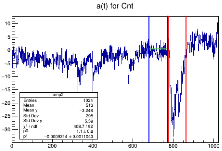


The number of photoelectrons is described by the Poisson distribution for small LED level:

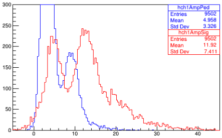
$$p(n) = \frac{e^{-\mu}}{n!}\mu^n,$$

$$\mu = -ln\frac{N_0}{N_{all}},$$

where n – number of photoelectrons, μ – average number of photoelectrons, N_{all} – total number of events, N_0 – number of events with zero amplitude (number of events in the pedestal).

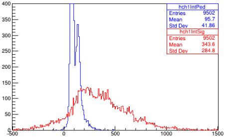


U=56 В, 1.09 ф.э.



Search the maximum pulse amplitude on waveforms

U=56 В, 1.05 ф.э.

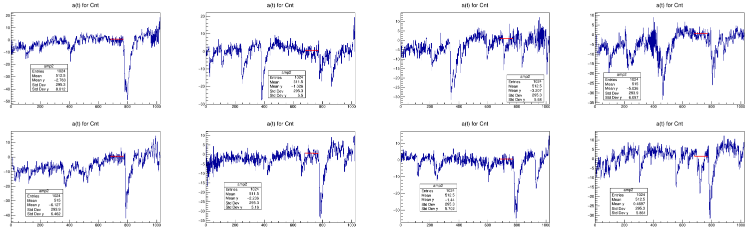


Integration the pulse on waveforms

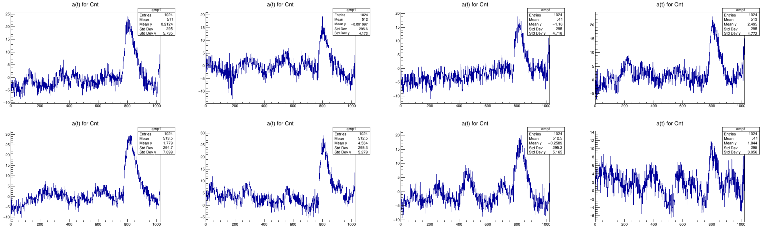
$$A_{1ph.e.} = (A_{sig} - Aped)/N^{cal}_{ph.e.}$$

Typical signals (Time(ns):Digitizer channels)

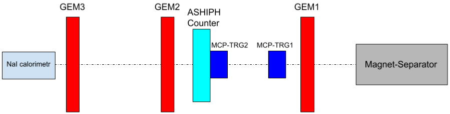
- Electronic version 1

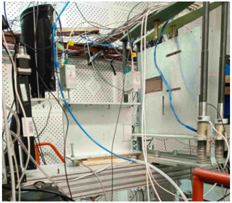


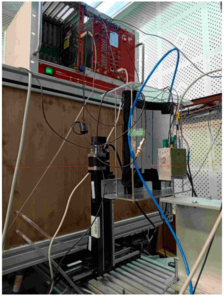
- Electronic version 2



Scheme of the experiment on beam test facilities at BINP







- Electron energy – 2.5 GeV;
- Tracking based on 3 coordinate GEM detectors ($\sigma_x \sim 70$ μm and $\sigma_y \sim 200$ μm) and NaI calorimeter;
- Trigger formed from MCP-TRG1 and MCP-TRG2 coincidence (⌀PC=18 mm), and VETO from GEMs "BUSY"-signals summarised as "OR";
- Signal MCP-TRG1,2 and from prototype are digitized by V1742 (CAEN, 12-bit, 5 GSample/s), operated in "Fast TRG"mode, saved waveforms;
- ∼50 kevents were collected for each geometrical area on counter prototype and at different bias voltages on the SIPMs
- The external temperature during data acquisition was 24^{o}C
- Data taking with electronic version 1 (June 2023) – results are presented
- Data taking with electronic version 2 (December 2023) – data under processing

Test beam results

Cards with the resulting $N_{ph.e.} = (A_{sig} - Aped)/A_{1ph.e.}$ at various geometric points

- 1 method – Search the maximum pulse amplitude on waveforms

Point	U=53 V	U=54 V	U=55 V	U=56 V
p1	5.16±0.10	10.86±0.16	11.06±0.17	11.28±0.18
p2	6.94±0.13	15.20±0.24	14.93±0.23	16.30±0.29
p3	7.22±0.12	12.76±0.18	14.48±0.22	16.03±0.27
p4		10.64±0.17		
p5		13.92±0.23		
p6		13.82±0.21		
p7	5.09±0.67	8.97±0.15	10.26±0.26	11.08±0.28
p8	6.45±0.18	11.43±0.20	13.93±0.36	14.59±0.48
p9		13.10±0.21		

- 2 method – Integration the pulse on waveforms

Point	U=53 V	U=54 V	U=55 V	U=56 V
p1	5.55±0.10	10.53±0.16	11.56±0.17	11.85±0.18
p2	7.64±0.13	15.05±0.22	15.63±0.22	16.23±0.23
p3	7.77±0.12	12.62±0.17	15.15±0.22	16.28±0.22
p4		10.55±0.16		
p5		14.00±0.22		
p6		13.91±0.21		
p7	5.74±0.67	8.96±0.14	10.95±0.27	11.78±0.30
p8	7.05±0.18	11.43±0.18	14.77±0.37	14.75±0.34
p9		13.20±0.20		

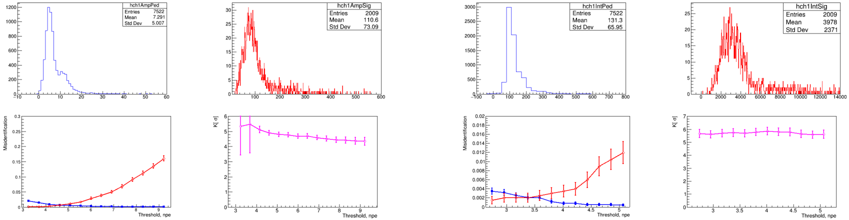
- Inhomogeneity of light collection is ~30% over the counter
- The difference between results the two methods is not more than 1 ph.e.

- the underthreshold efficiency mainly determined by its own DCR

56 V, point 2, T≃24°C, DCR≃3MHz

1 method — Noise spectrum, Signal spectrum

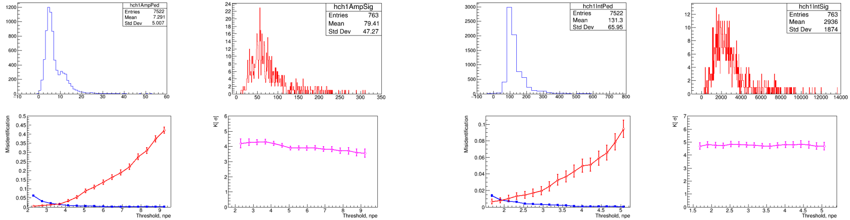
2 method — Noise spectrum, Signal spectrum



$$K[\sigma] = \sqrt{2} * \mathrm{erf}^{-1}(1 - 2\varepsilon_K) + \mathrm{erf}^{-1}(1 - 2 * (1 - \varepsilon_\pi))$$

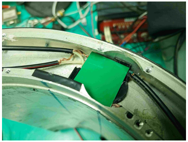
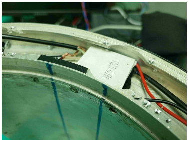
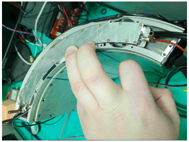
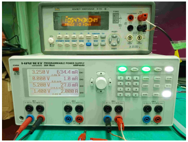
56 V, point 7

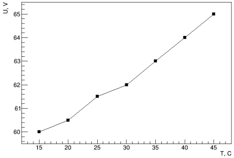
Noise spectrum, Signal spectrum, Noise spectrum, Signal spectrum



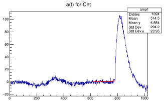
Separation power is better than 4σ at a threshold of 4.5 ph.e.

- One of the main limitations to the use SiPMs in detectors is the need to create a cooling system due to the high DCR level which depends on temperature.
- The thermal stabilization system version was created for tests:
  - Platinum board mount temperature sensor with programmable multimeter (B7-78/2) for control
  - Thermoelectrical Peltier module (SnowBall-71, 30×30 mm, 3.6 A, 36 W) with programmable power supply (HAMEG)
  - Air aluminum radiator

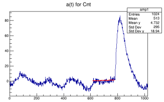







SiPM V_{op}&T°C



T=25°C, U=61 V



T=45°C, U=65 V

- Imitation from LED (16 ph.e., T=45°C, electronic version 2) give separation power is better than 4σ (thr. 4.5 ph.e.)
- TB data taking with thermal stabilization system (for T=45°C) and electronic version 2 performed (December 2023) – data under processing

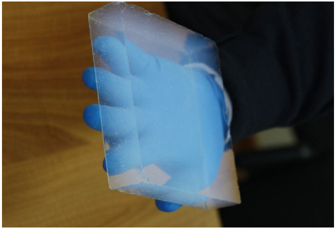
Summary

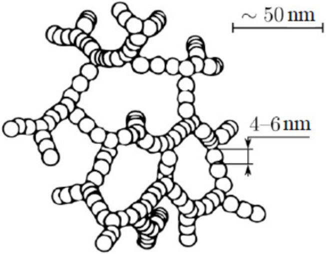
- The ASHIPH technique of Cherenkov light collection was developed in BINP
- ASHIPH-SiPM proposals for colliding beam experiments are presented
- ASHIPH-SiPM counter prototype constructed for tests
- Tests with ASHIPH-SiPM counter prototype on beam test facility at BINP are performed:
  - Average amplitude is around 14 ph.e. over the counter
  - Inhomogeneity of light collection is ∼30% over the counter
  - Estimated separation power is better than 4σ at a threshold of 4.5 ph.e. (bias voltage of 56 V) at T=24°C
- Thermal stabilization system for SiPMs inside ASHIPH prototype counter for tests is designed
- $N_{ph.e.}$ can be compared for ASHIPH-SiPM & ASHIPH-MCP PMT since used same SND (VEPP-2000) counter
  - ASHIPH-MCP PMT:
    - Aerogel – n=1.13, 30 mm
    - $N_{ph.e.} = 8$ (start experiment)
  - ASHIPH-SiPM:
    - Aerogel – n=1.12, 25 mm
    - $N_{ph.e.} \approx 14 \times 1.3 \approx 18.2$
  - $N_{ph.e.}(ASHIPH - SiPM)/N_{ph.e.}(ASHIPH - MCPPMT) \approx 2.2$
    - agrees with PDE ratio for SiPM to MCP PMT

BACKUP

Aerogel

S.S.Kistler, "Coherent Expanded Aerogels and Jellies“, Nature, 1931,vol. 127, p. 741.





$SiO_2 + H_2O(1 \div 5\%)$

$$n^2 = 1 + 0.438 \cdot \rho$$

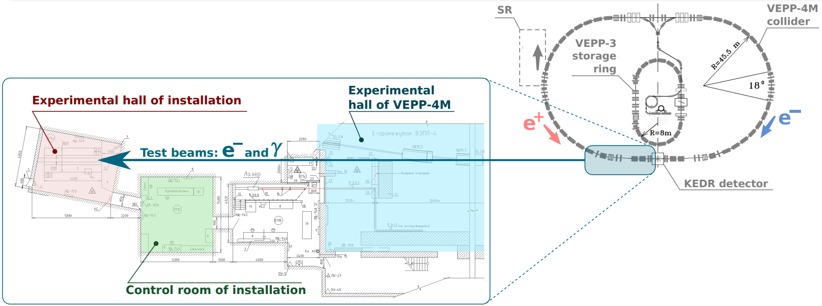
n=1.006...1.070 – synthesis
n=1.070...1.130 – sintering

Beam test facilities at BINP

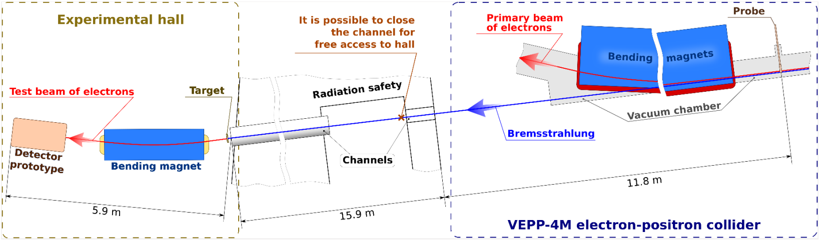
VEPP–4M electron–positron collider is used to provide γ- and electron- beams.

VEPP–4M main parameters:

- Perimeter 366 m;
- Beam energy 1÷5.5 GeV;
- Number of bunches 2×2;
- Luminosity 10^{30} cm$^{-2}\cdot$s^{-1} for E_{beam}=1.5 GeV.



Beam test facilities at BINP



- A special probe is moved into the halo of a primary electron beam of the VEPP–4M collider for generation of Bremsstrahlung gammas.
- These gammas are converted to electron – positron pairs on a lead target at the entrance to the experimental hall.
- Electrons with a certain momentum are selected using a bending magnet.

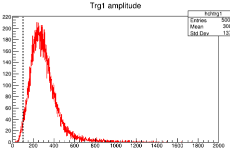
The beam parameters:

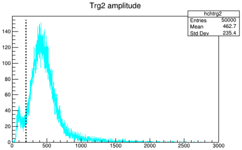
- Energy range 0.1÷3.5 GeV;
- Intensity 50÷100 Hz;
- Energy spread 7.8% for 0.1 GeV and 2.6% for 3.0 GeV.

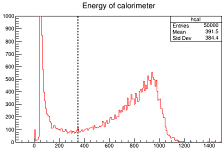
Some cuts for event selection.

- NaI-calorimeter and MCP PMTs amplitudes cuts are applied to select single particle events with straight tracks.

MCP PMT spectra

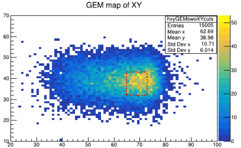






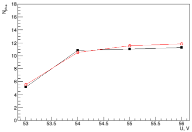
Events above the dashed lines are selected

- Center of the spot on GEM map is used to select events.

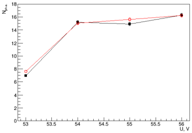


Dependences of the number of photoelectrons on the bias voltage SIPM at various points of the counter (1 method - black line, 2 method - red line)

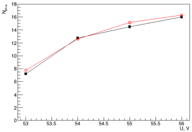
Point 1



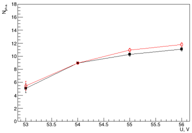
Point 2



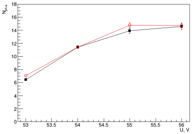
Point 3



Point 7

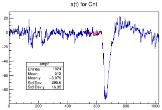


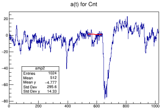
Point 8

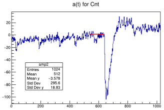


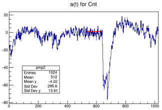
Typical signals (Time(ns):Digitizer channels)

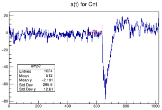
- Electronic version 1

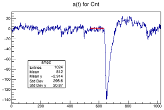


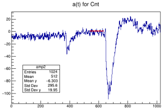


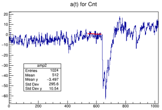


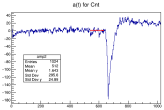


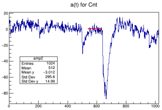


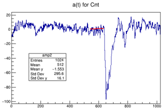


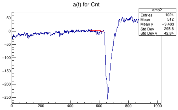


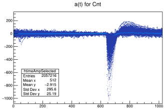








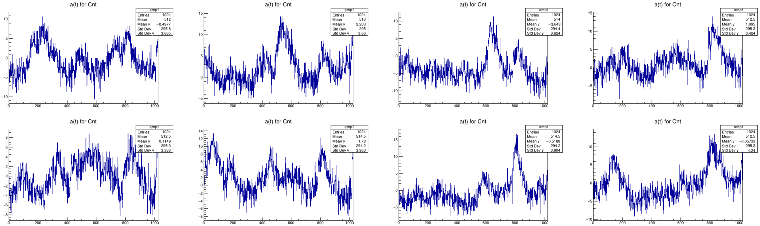




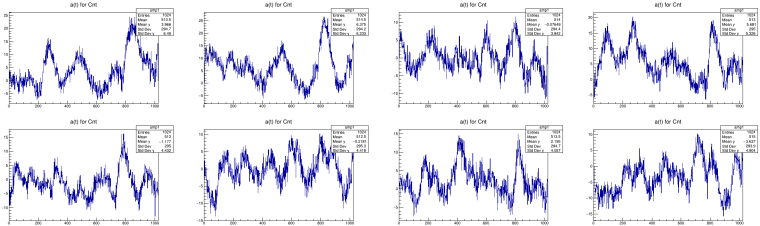
Temperature tests

Typical signals (Time(ns):Digitizer channels) with small LED light level

- **T=25°C, U=61 V**



- **T=45°C, U=65 V**

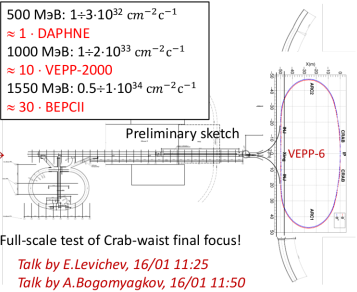


From plenary talk by I.Logashenko (15.01.2024)

Under consideration: VEPP-6

- e^+e^- collider
  - Beam energy from <0.5 to 1.6 GeV (J/ψ) (2.0 GeV)
  - Luminosity $\mathcal{L} \approx 10^{34}\ cm^{-2}c^{-1}$ @ 1.6 GeV
- General purpose detector
  - Tracking
  - Calorimetry
  - Particle ID
- Physics
  - J/ψ decays
  - Baryon thresholds
  - Measurement of R
  - … Complementary to SCTF

500 МэВ: 1÷3·$10^{32}\ cm^{-2}c^{-1}$
≈ 1 · DAPHNE
1000 МэВ: 1÷2·$10^{33}\ cm^{-2}c^{-1}$
≈ 10 · VEPP-2000
1550 МэВ: 0.5÷1·$10^{34}\ cm^{-2}c^{-1}$
≈ 30 · BEPCII



Full-scale test of Crab-waist final focus!

Talk by E.Levichev, 16/01 11:25
Talk by A.Bogomyagkov, 16/01 11:50