30th International Scientific Conference of Young Scientists and Specialists

Influence of Optical Fiber Polishing Quality on Light Collection in the SPD Beam-Beam Counter Prototype

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Spin Physics Detector

AYSS-2026

The Spin Physics Detector (SPD) is an **experiment at the NICA collider** (JINR, Dubna) designed to study the **spin structure of the proton and deuteron** and other spin phenomena. It will exploit the unique opportunity to use **polarized proton and deuteron beams** at collision energies of up to 27 GeV and luminosities of up to 10^{32} cm^{-2} s^{-1}.

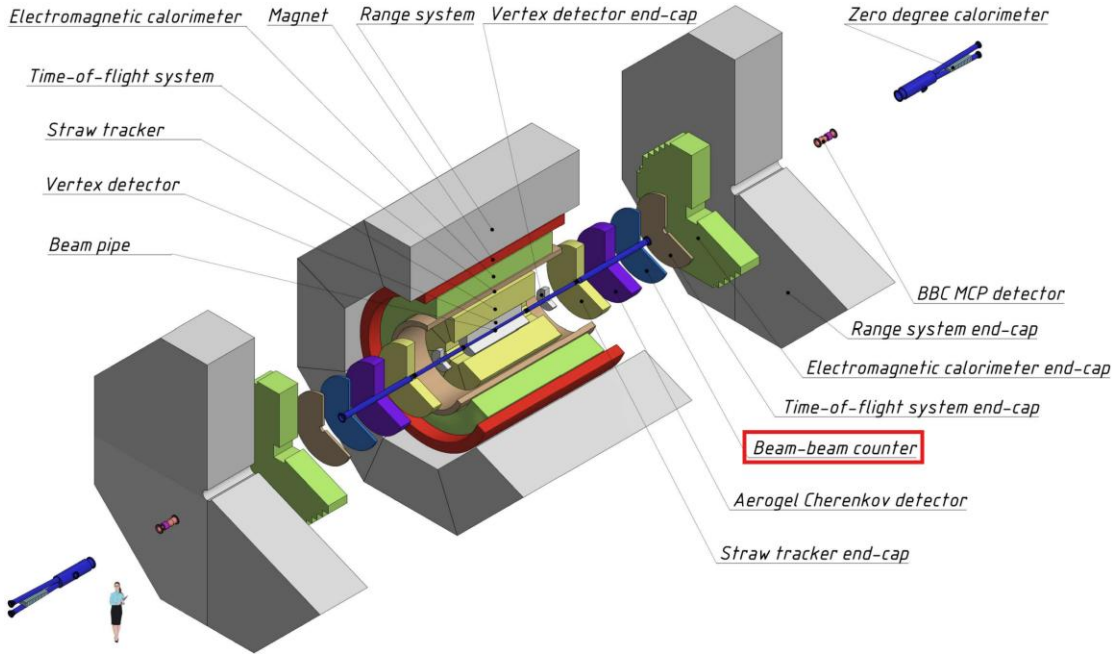


Fig. 1 – SPD scheme

In polarized proton–proton collisions, **SPD will bridge the kinematic gap** between low-energy measurements at ANKE-COSY and SATURNE and high-energy measurements at RHIC.

Two endcap wheels of scintillation counters, forming the Beam-Beam Counters (**BBC**s), are planned to be installed in front of the SPD time-of-flight (TOF) system, symmetrically with respect to the interaction point.

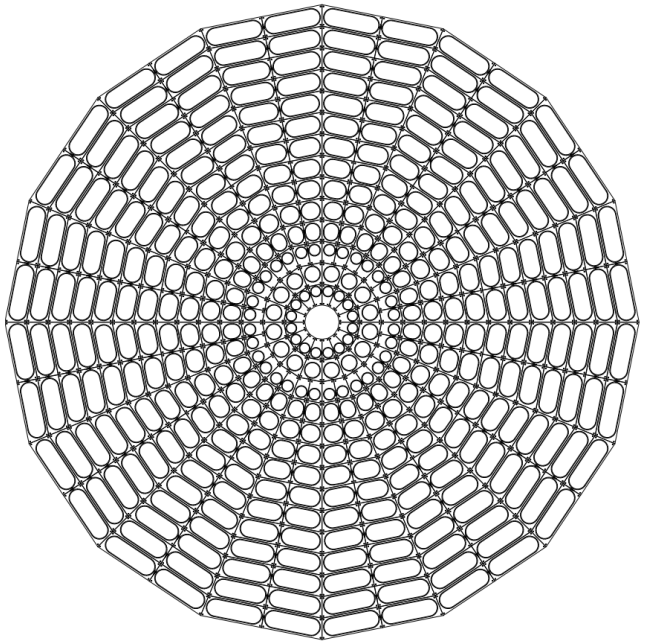


Fig. 2 – BBC wheel scheme

The main goals of the Beam-Beam Counters are:

- **Local polarimetry** based on measurements of azimuthal asymmetries in charged-particle production;
- **Luminosity monitoring** and beam-collision diagnostics;
- **Event-plane reconstruction** for heavy-ion collision studies.

Beam-Beam Counters prototype

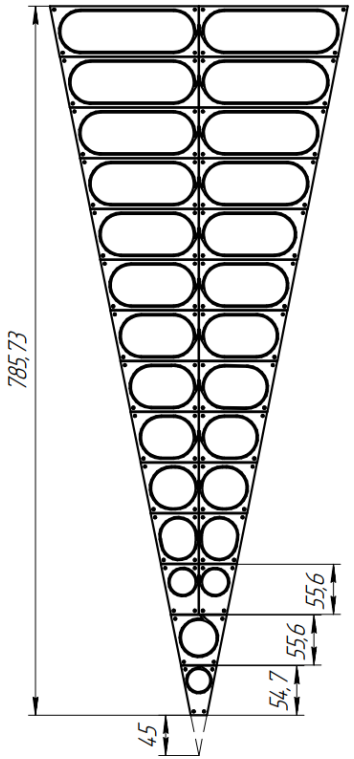
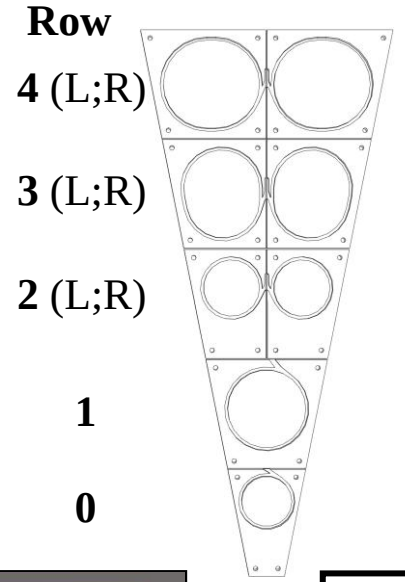


Fig. 3 – BBC sector

- Each SPD BBC wheel will consist of **16 sectors, with 24 scintillation tiles per sector**. Each tile is read out individually: the scintillation light is collected by a wavelength-shifting (WLS) fiber and transmitted through a clear optical fiber to a silicon photomultiplier (SiPM).
- One possible option for the front-end electronics (FEE) is the **CAEN DT-5202** readout system used in this work, which was specifically designed for large detector arrays.

- Wavelength-shifting (WLS) fiber shifts scintillation short-length light to the green region of the spectrum.
- Clear fiber has a long attenuation length.



In our prototype we use:

- Matted cover
- Saint-Gobain Crystals BCF92 wavelength-shifting (WLS) fibers, Kuraray Clear-PS (Non-S type) clear fiber
- Optical cement CKTN B
- Custom onsemi & Hamamatsu SiPM boards

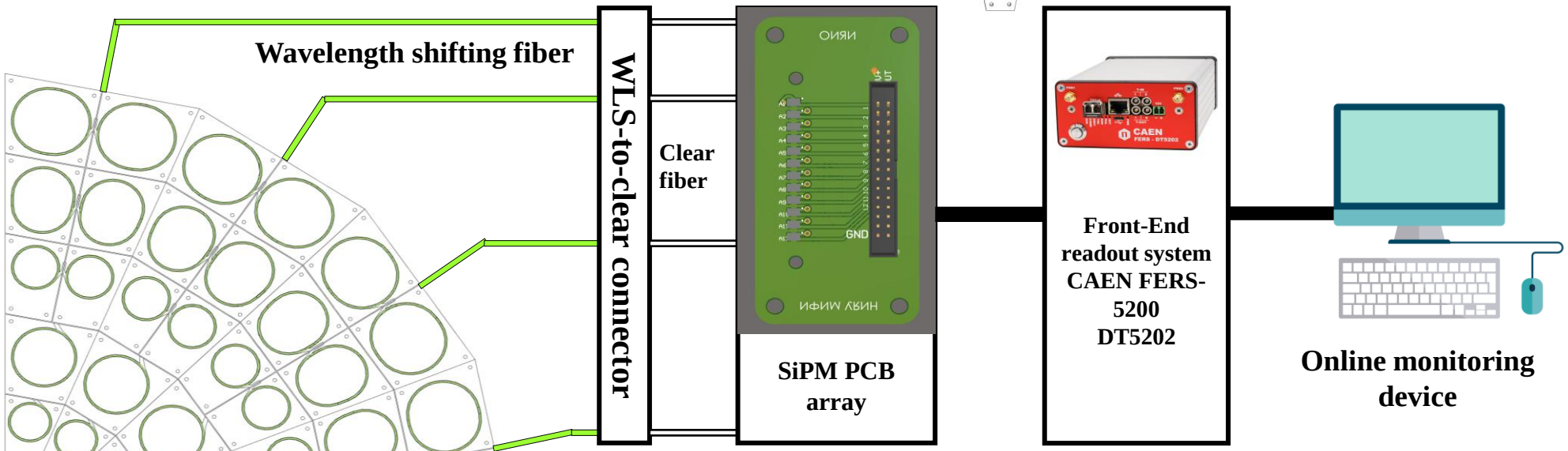


Fig. 4 – BBC prototype scheme

Surface polish necessity

1 **Remote readout**

Optical fibers allow SiPMs and FEE to be placed outside the active detector region.

2 **Lower transport losses**

Use clear fiber for the long transport section.

Fiber	Attenuation length
Kuraray Y-11(200) [1]	**>3.5 m**
(Saint-Gobain BCF-92 [2])	**(>3.5 m)**
Clear: Kuraray Clear-PS (Non-S type) [3]	**>10 m**

3 **Better optical coupling**

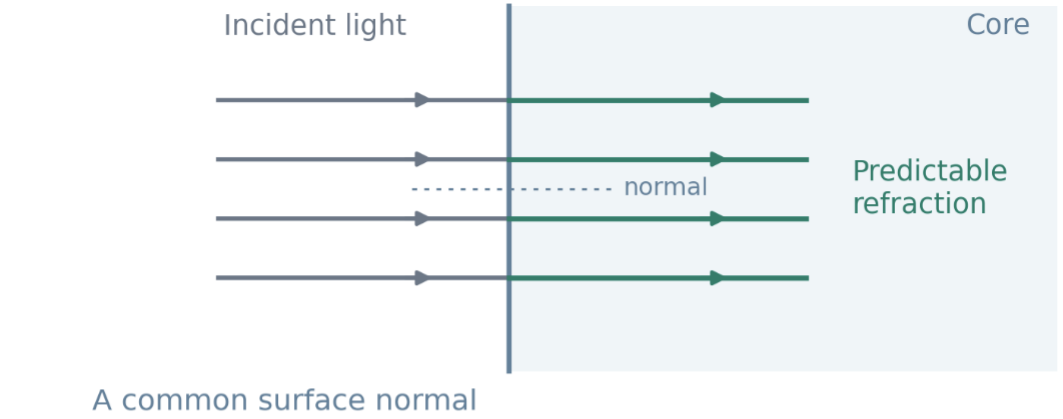
Polish the fiber ends at both interfaces:

WLS fiber → clear fiber → SiPM

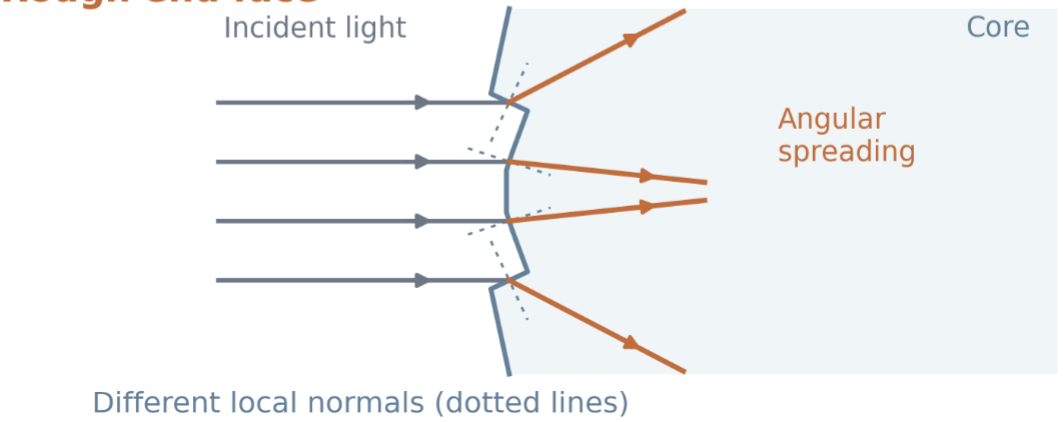
Improve optical contact and reduce surface-scattering losses.

End-face quality

Smooth end face



Rough end face



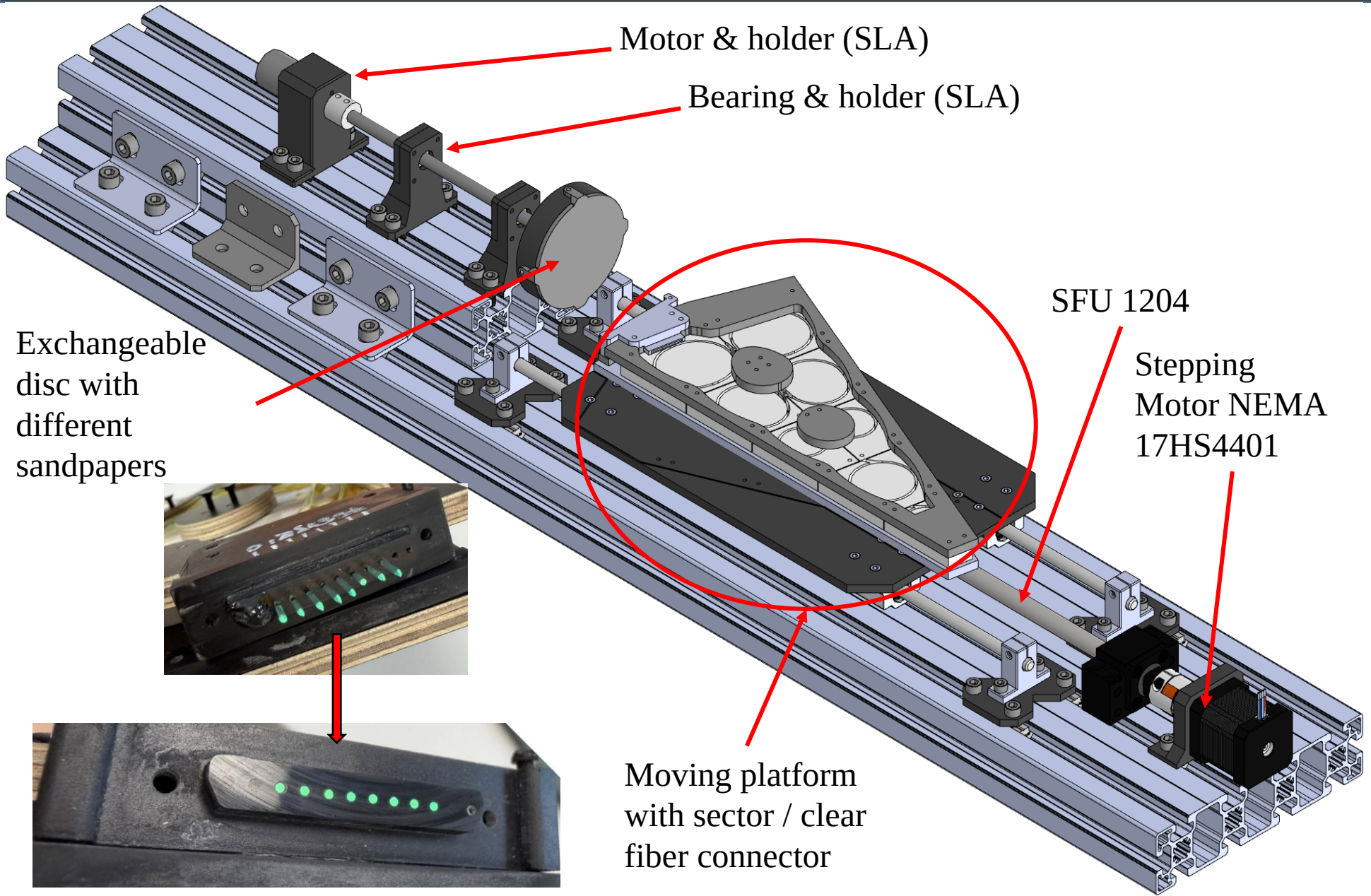
The core–cladding critical angle is unchanged.

Schematic; roughness exaggerated; reflections omitted.

Attenuation lengths: manufacturer reference values for 1 mm fibers; test conditions differ.

[1] Kuraray, Wavelength Conversion Fiber. [2] Bicron / Saint-Gobain, Standard Plastic Fibers. [3] Kuraray — Clear Fiber, official specifications.

Polishing device setup



- To control the torque and pressure, a feedback mechanism has been implemented.
- The polishing-disc motor current is used as an indirect indicator of the contact load. As the connector presses against the rotating disc, the motor experiences increased resistance, resulting in higher current consumption.
- A preset current threshold is used to limit the contact load during polishing.
- SFU and 17HS motor provides ~1.25 µm per step for softer and precise movement
- Polishing motor provide up to 1360 rpm

Polishing test device setup

Tektronix Source Measure Unit (SMU) **Keithley 2400**

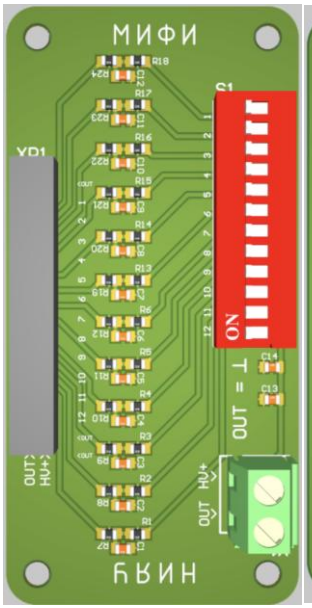


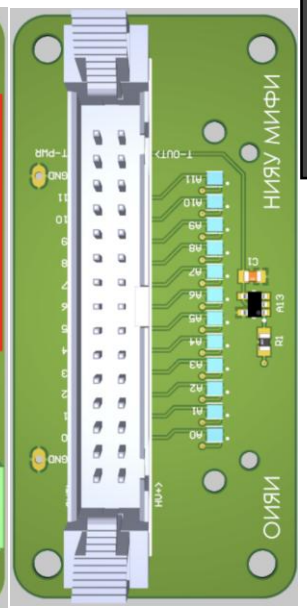


Power Supply AKTAKOM **ATH2031**

I/O switches

x12 channels

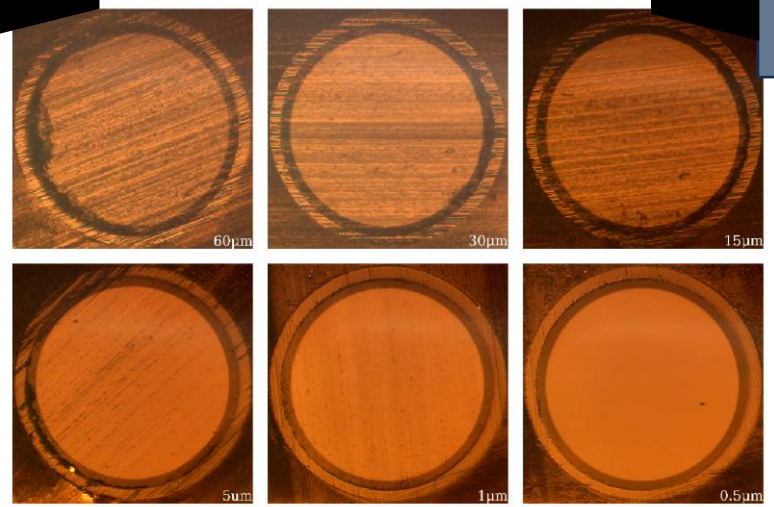




SiPM PCB

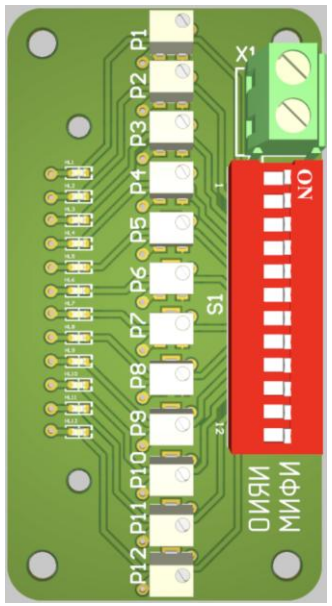
Connector

Fiber under test



Connector

LED PCB



I/O switches

x12 channels

Key features of the test setup

1. Channel-by-channel measurements

Independent selection of LED and corresponding SiPM channels.
Individual measurements of light transmission through optical fibers.

2. Custom-designed SiPM boards

Developed specifically for the SPD BBC detector.
Will also be used in the upcoming testbeam.

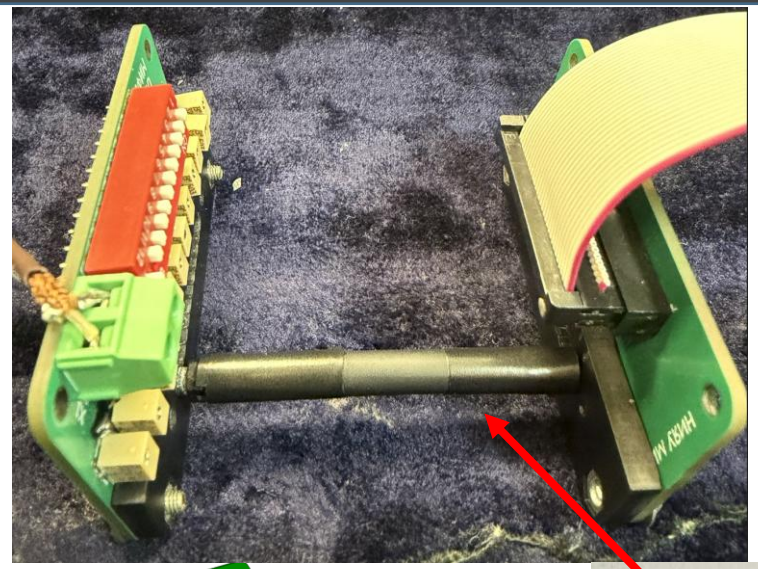
3. SiPM protection

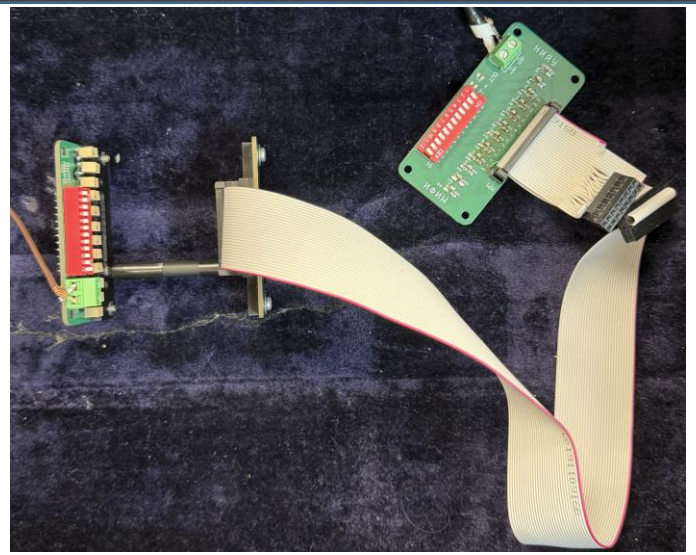
Current-limiting resistors installed on a separate interface board.
Allow continuous operations without switching off SiPMs even under ambient light.

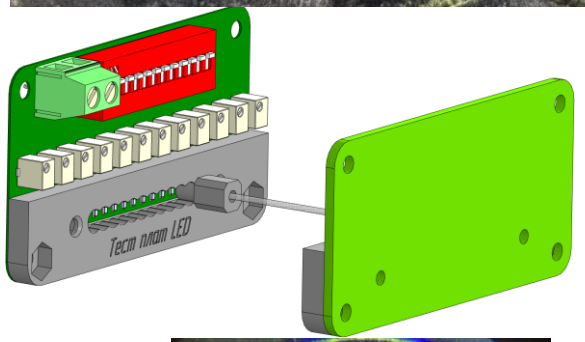
4. Adjustable LED brightness

Potentiometers on the LED board allow individual adjustment of LED supply voltage and light intensity.

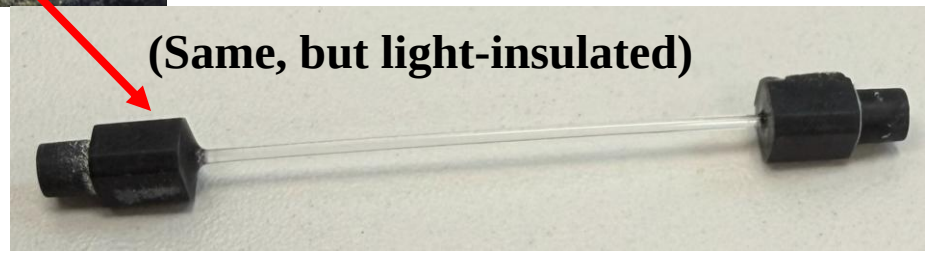
Polishing test device calibration

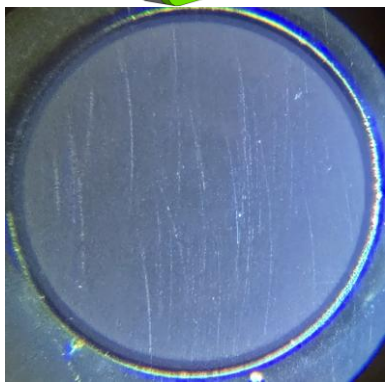






(Same, but light-insulated)





1 Light-tight enclosure

Both boards were placed inside a light-tight box.

2 Reference fiber

A single fiber with a high-quality polished end face was used as a reference.

3 Channel-by-channel scan

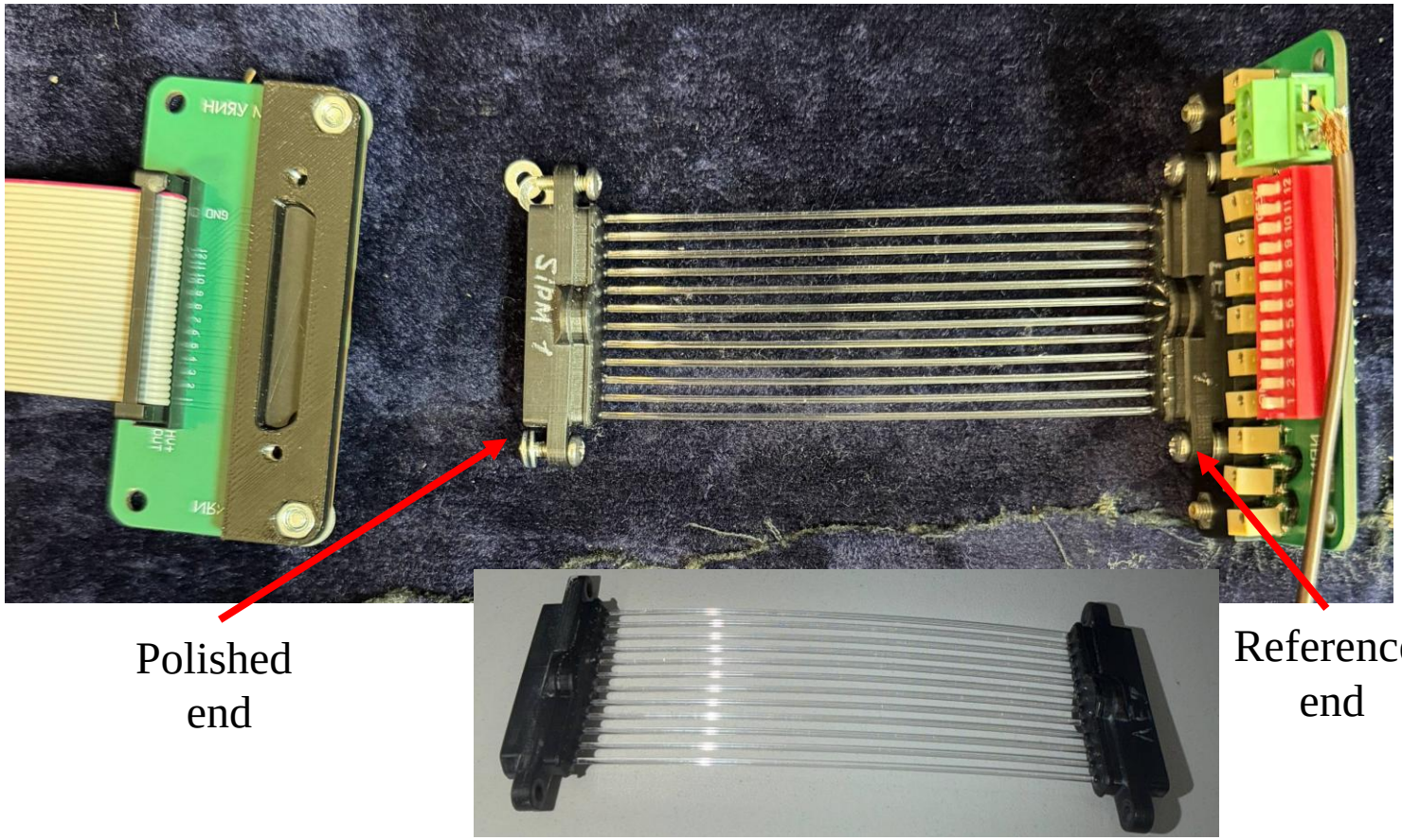
Each LED was paired with its corresponding SiPM; the SiPM current was measured for each channel.

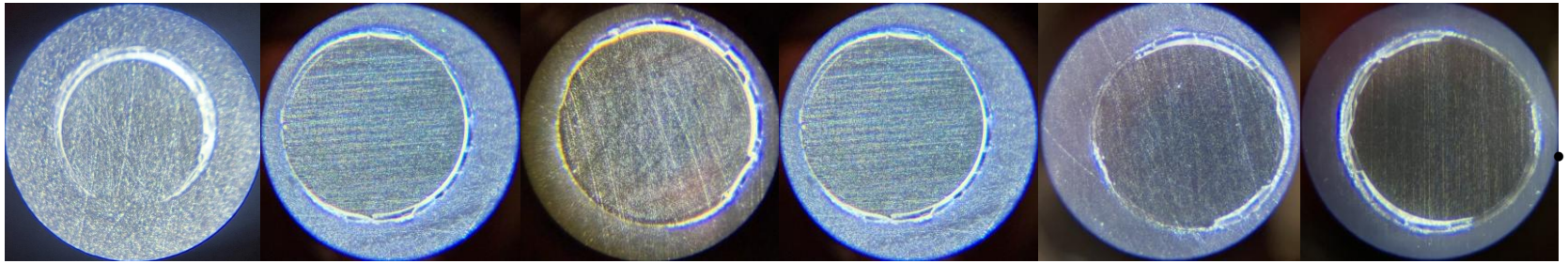
4 LED intensity adjustment

The supply was kept at 7 V. The LED operating voltage was adjusted using board-mounted potentiometers to control the LED brightness.

Channel number	12	11	10	9	8	7	6	5	4	3	2	1
SiPM current, µA	-	34.5	34.3	34.6	34.0	36.7	35.9	35.5	35.7	34.9	36.9	35.6

Polish test setup





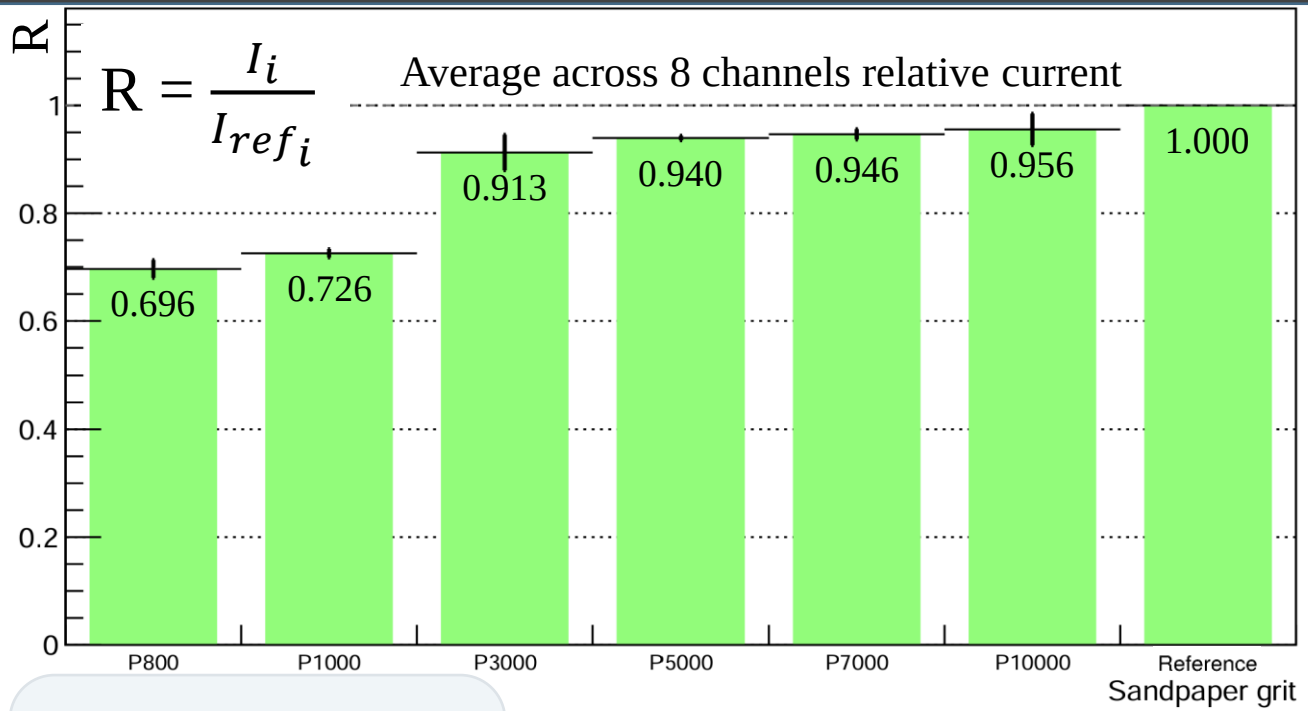
1000 2000 3000 5000 10000 Reference

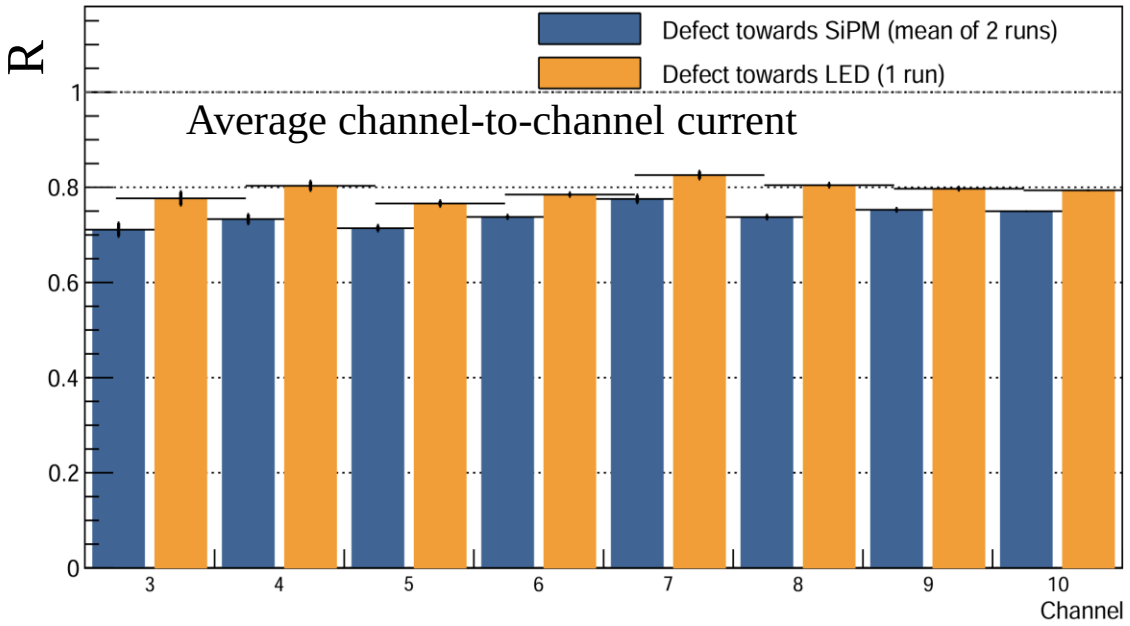
- A 12-channel fiber sample (10 cm long) was used. One end was reference-polished, while the opposite end was progressively polished using sandpaper from P800 to P10000 (including 3M machine polish 09376).
- The polished end was initially oriented towards the SiPMs, while the reference-polished end faced the LEDs.
- **To account for variations in optical coupling**, each measurement was repeated after disconnecting and reconnecting the fiber assembly.
- The uncertainty was estimated using the **half-range method**:

$$\left(\Delta R = \frac{R_{max} - R_{min}}{2}\right)$$

- **Additional test:** the fiber assembly was reversed to investigate the influence of the polished end-face orientation on light collection.

Polishing one fiber end





MEASURED RESPONSE

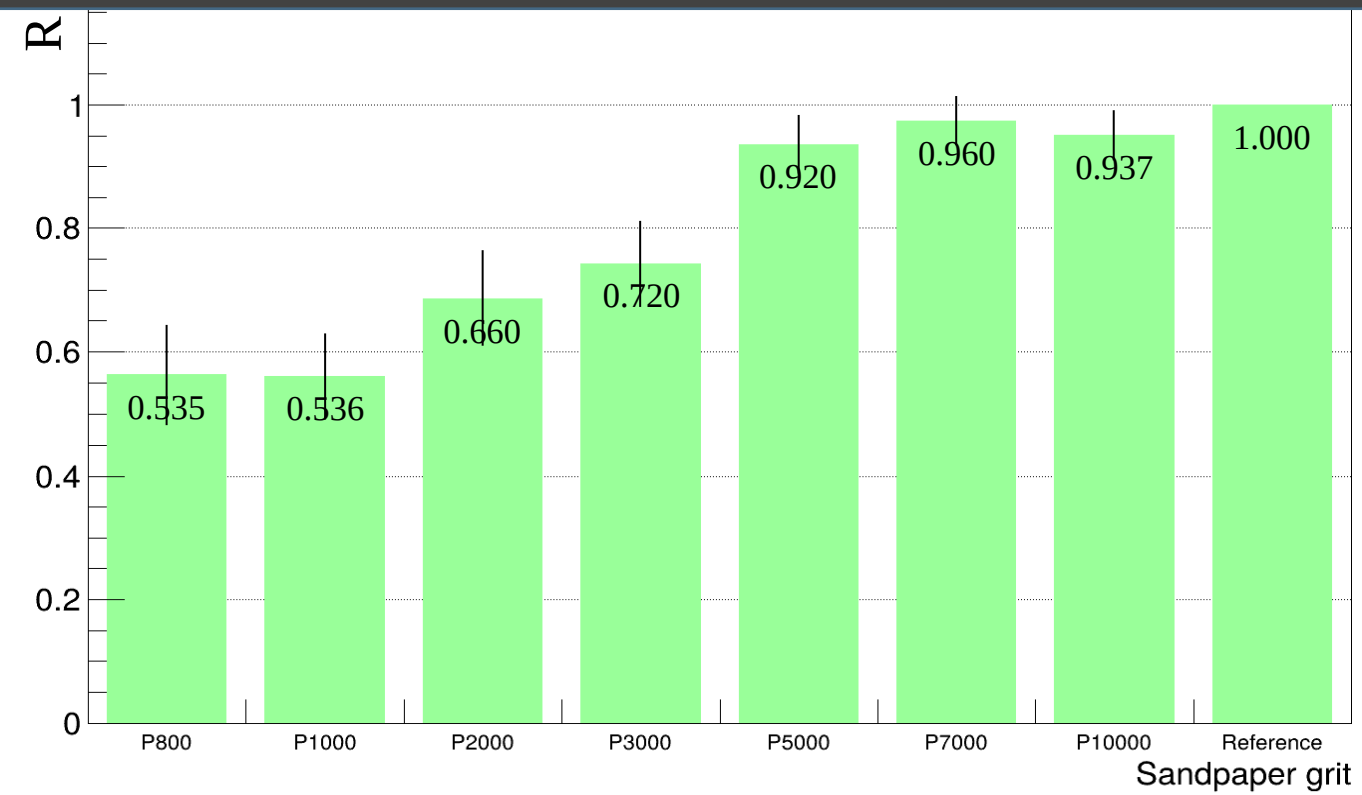
0.70 → 0.96
P800 → P10000
+25.9 percentage points

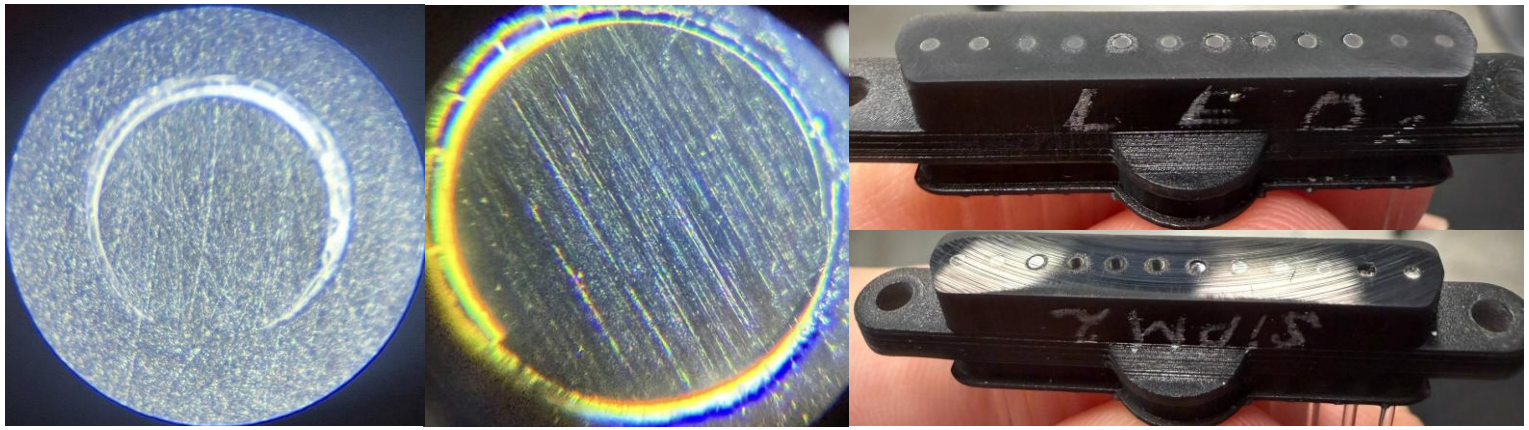
0.940 → 0.956
P5000 → P10000
+1.7% relative gain

The final polishing stage still improves light collection.

- The uniformity was evaluated using the standard deviation of the normalized SiPM response across **8 channels (3–10)**.
- The channel-to-channel SD(R) ranged from **0.57 to 1.66**% and is comparable to the uncertainty associated with optical reconnection.
- The results indicate generally uniform optical response across channels, although variations in optical coupling may contribute to the observed spread.
- **At P800, orienting the rough end towards the LED increased the mean SiPM current by approximately 7.4% (from 35.04 to 37.64 µA), compared with the rough end facing the SiPM.**

Polishing both fiber ends





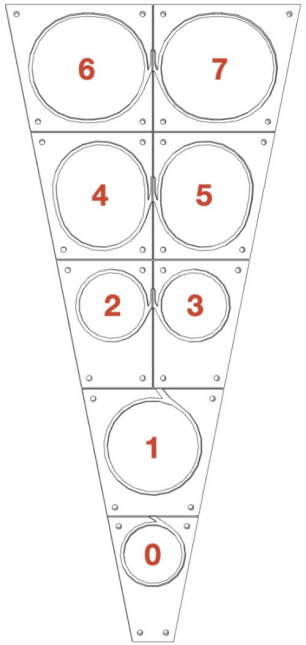
Manual and machine polish

- Both fiber ends were polished using the same sandpaper grit.
- At P1000, machine polishing produced an **83.9% higher mean SiPM current** compared with manual polishing.
- Despite visible differences in surface quality, the machine-polished fibers exhibited a mean current only **1.1% below the reference value**.
- The channel-to-channel standard deviation was **0.97–1.73% of the reference response** for P5000–P10000, indicating relatively uniform optical response.
- Similar DC photocurrents do not necessarily imply identical end-face quality, highlighting the need for further development of the optical quality-control method.

Sector telescope setup

- The telescope consists of three reduced BBC sectors;
- The distance between reduced sectors is approximately 1,8 cm;
- Wavelength-shifting fibers were machine-polished using the procedure described above;
- Custom SiPM Hamamatsu readout boards were used.





BBC wheel prototype and reduced sector model including tile numbering.

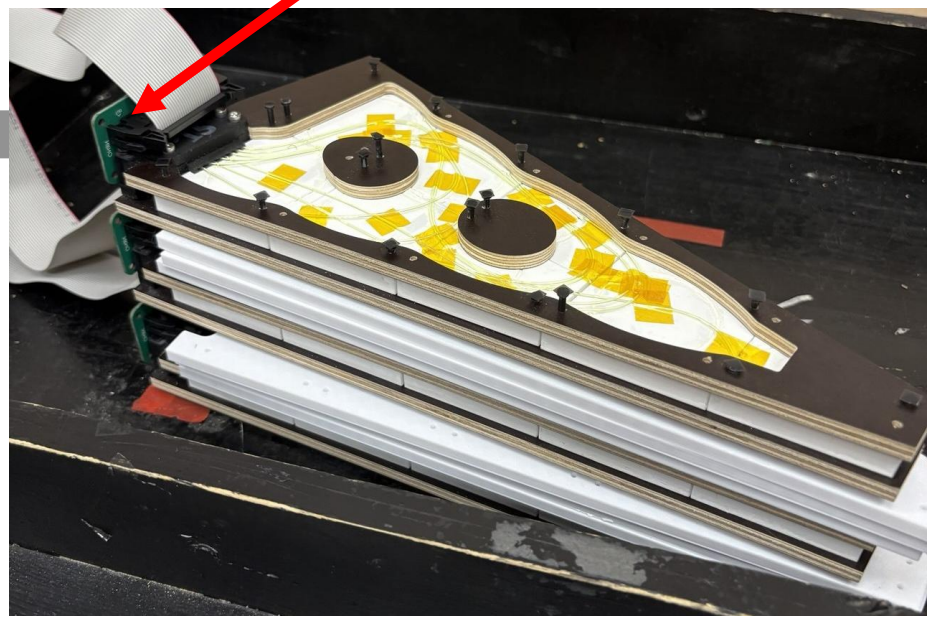
Both BBC wheels have been assembled and will be used in an upcoming test-beam campaign.

SiPM Hamamatsu PCB

Cabling



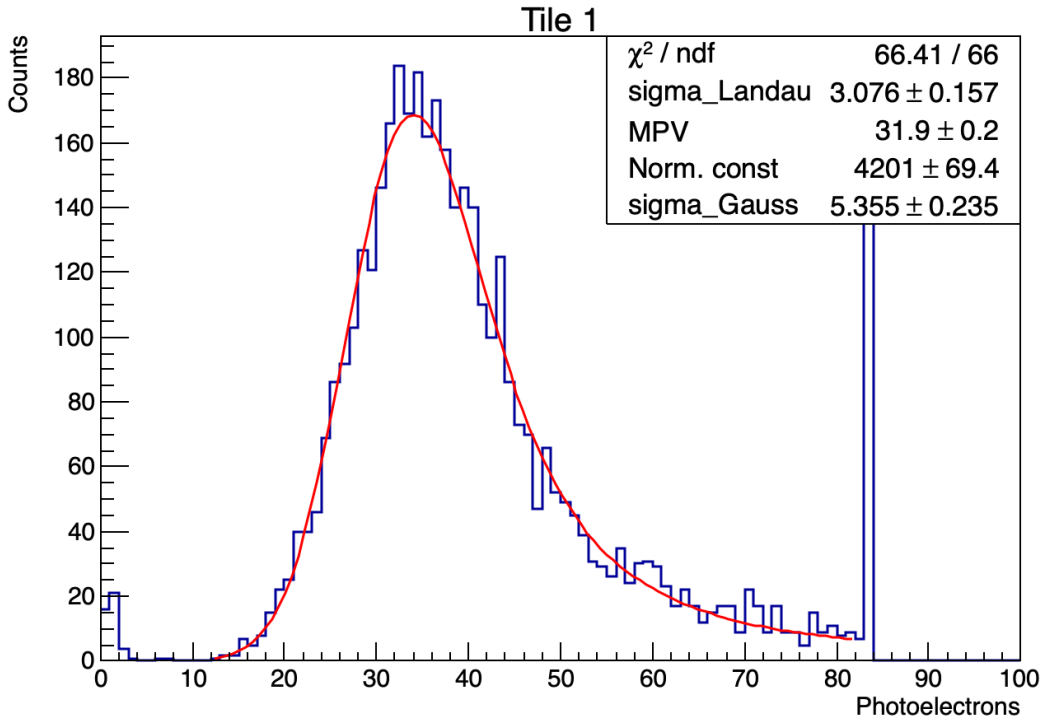
CAEN DT5202



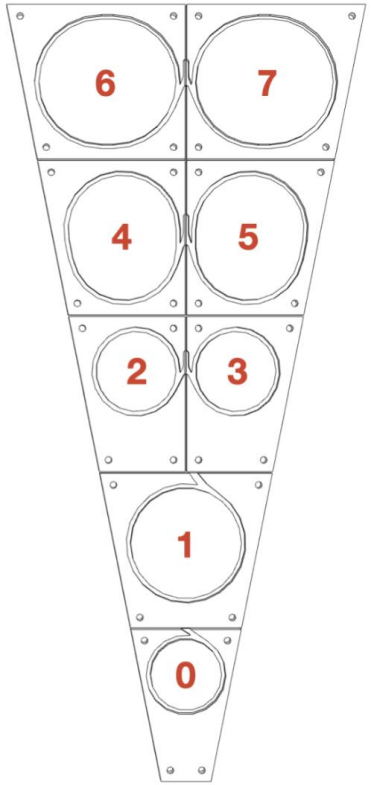
Reduced BBC sectors

Sector telescope responce

- Only events detected in corresponding tiles of all three sectors were included in the analysis.
- For all tiles, the most probable response exceeds the noise level and is at least 30 p.e.



Muon energy-loss spectrum (in p.e.) for the first tile of the sector



Results for the second (central) sector

Tile number	MPV, p.e.
0	34
1	32
2	32
3	30
4	35
5	34
6	34
7	33

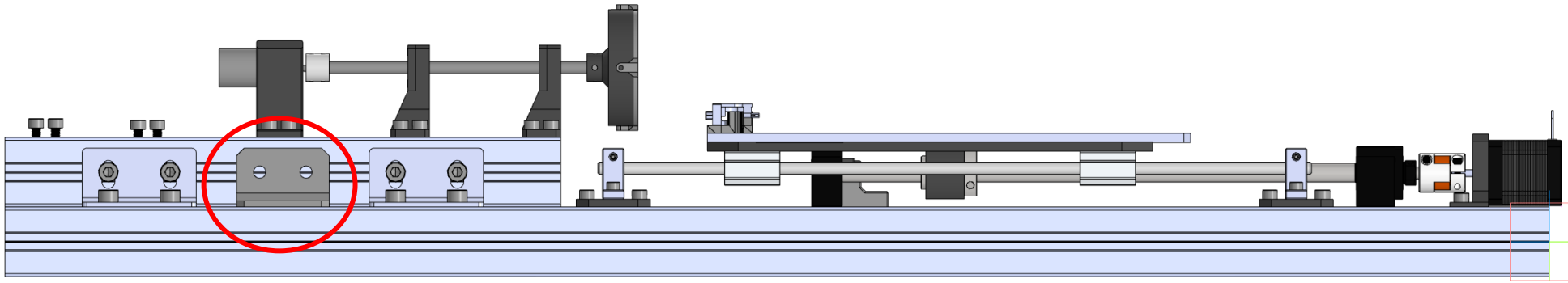
Conclusion

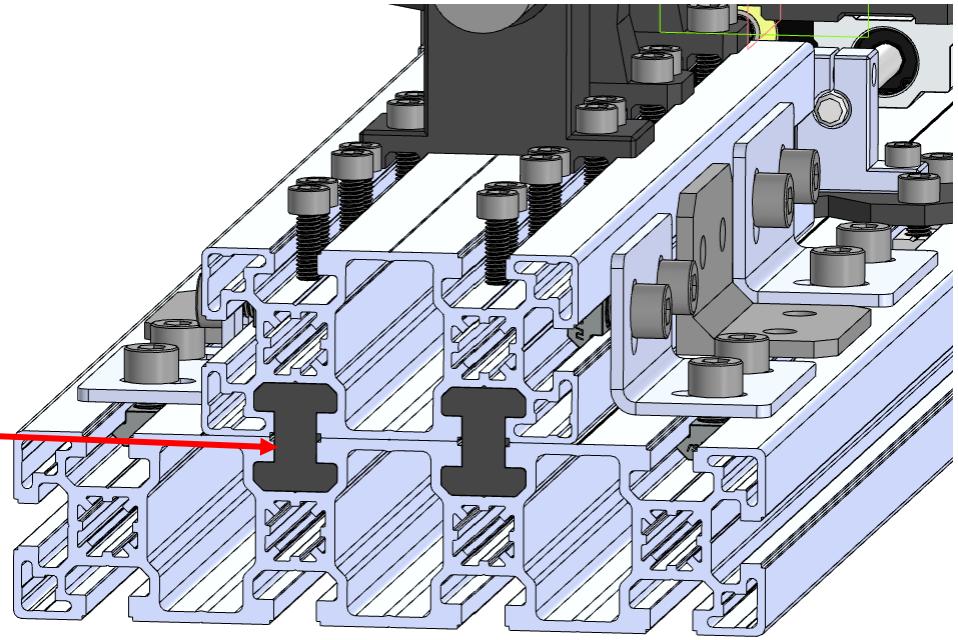
- A dedicated fiber polishing device and a 12-channel LED–SiPM test setup were developed for the SPD BBC.
- Improving the polishing quality increased the normalized SiPM response from **0.70 (P800) to 0.96 (P10000)**.
- At P1000, machine polishing provided an approximately **84% higher mean SiPM current** than manual polishing.
- The low channel-to-channel standard deviation of the normalized SiPM response (typically around 1–2% of the reference signal at finer polishing stages) indicates good optical response uniformity and suggests that the developed polishing procedure provides reproducible results.
- Cosmic-ray measurements with BBC sector prototypes demonstrated a most probable signal of **30–35 photoelectrons** across all eight tiles of the central sector.
- **Further work** will focus on improving the optical quality-control method and studying the SiPM response in pulse mode.

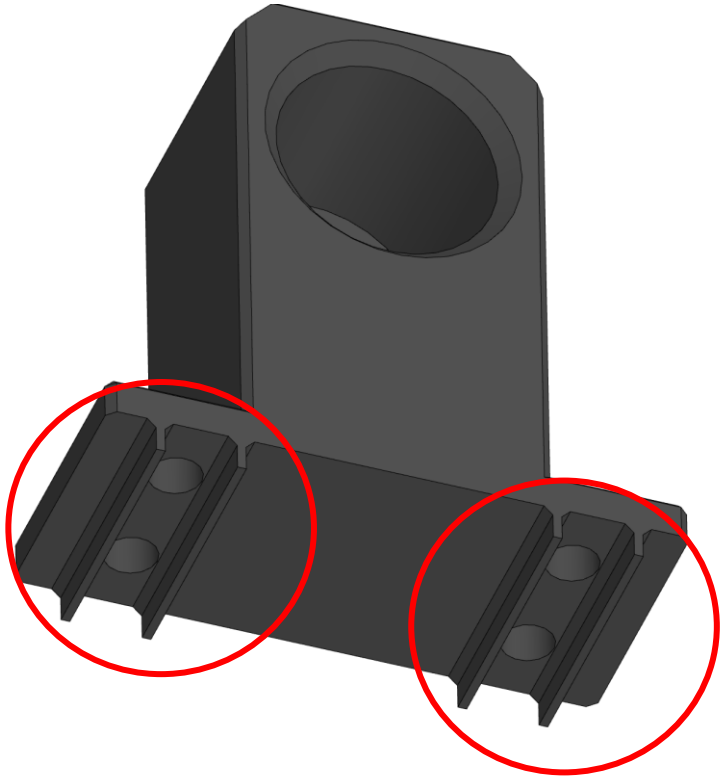
Thank you for your attention!

BACKUP

Polishing device: fixing angles



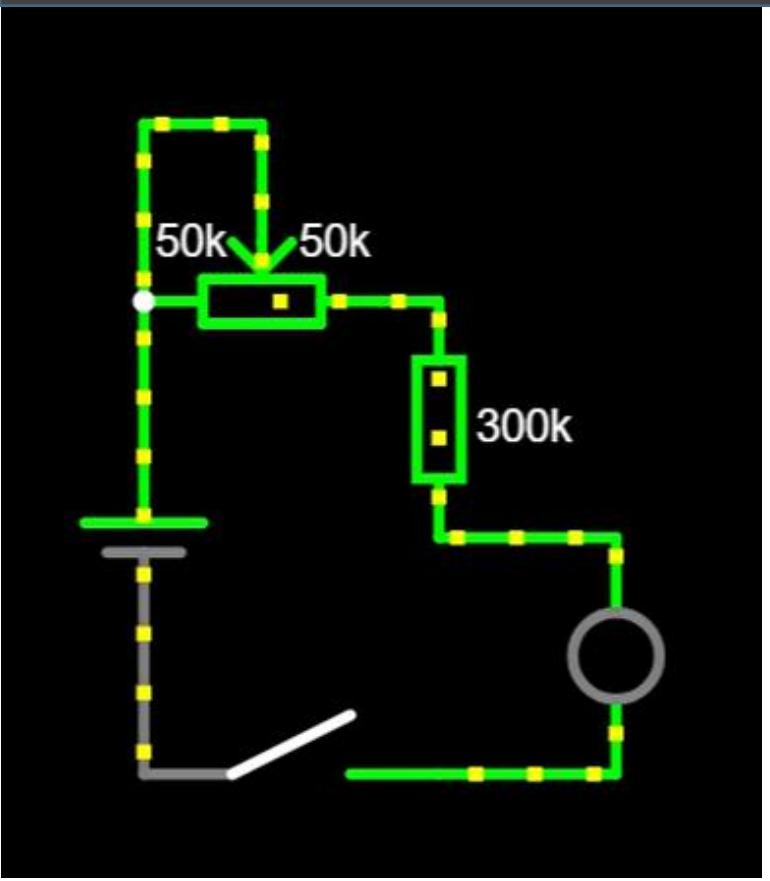




To ensure that the profiles remained parallel to one another, we used special inserts between them, as well as special side fixing brackets

Motor and bearing holders include special ski-like inserts, making holders to place perpendicular to profile

LED parameters





GNL-0603UBC

$\lambda_max = 470nm$

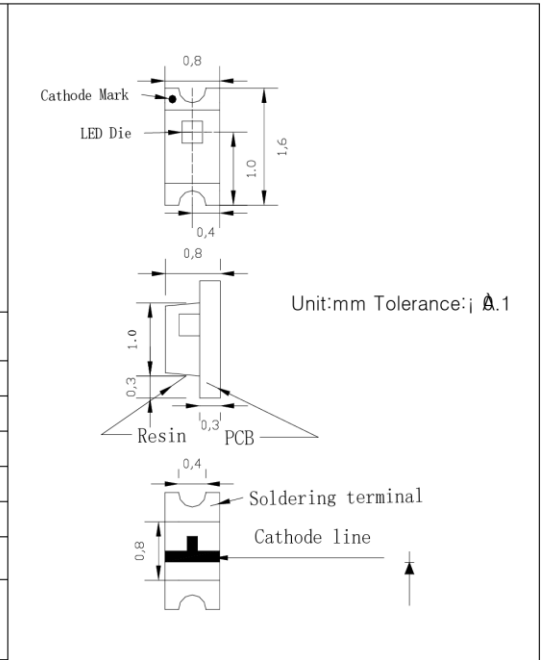
$S = 1,6 \times 0,8\ mm^2$

- Circuit designed to run LED at very beginning of open part of IV curve
- Potentiometer allows to adjust LED brightness to get SiPM response of 1 μA

GNL-0603xx
(0603 SMD TYPE)
Ultra Brightness

ABSOLUTE MAXIMUM RATING:(Ta=25℃)

Parameter			Unit
DC Forward Current	30		mA
Reverse Voltage	5		V
Reverse Current (Vr-5V)	10		μA
Peak Forward Current ,tw ,=1 msec Duty ,=1/20	150		mA
Operation Temperature	-40	+80	℃
Storage Temperature	-40	+100	℃
Solder Dip Temperature (5 seconds,1.6mm from body)	300	±5	℃



Material selection

Scintillator cover - **Matted** VS Tyvek:

- Matted collects more light (approximately);
- Matted is more convenient for mass production;
- Chemically matted tiles are more resistant to outer interactions and could be easily repaired;
- Tiles are matted by the scintillator manufacturer (Uniplast Vladimir), which is also cheap.

Optical cement – **CKTN B**, E, OK-72:

- Viscosity of CKTN MED type B is reduced by 50 times in comparison with type E and relatively similar to the OK-72 – mass production convenience;
- CKTN B collects about the same number of photons as the E type, but significantly more than OK-72;
- According to data, CKTN series has a higher throughput to high-energy particles.

WLS fibers – SGC VS **Kuraray**:

- According to experimental data, Kuraray Y-11 collects more photons than Saint-Gobain Crystal BCF92;
- Experiment was performed with the same conditions – same run, positioning, cosmic rays as the source, e.t.c

Fit Param-s	Row 1 Matted	Row 1 Tyvek	Row 3 Matted	Row 3 Tyvek
Mean, Channels	372.9	346.7	406.9	348.3
Width, Channels	28.5	30.0	30.3	27.5

Fit Params	CKTN MED E	CKTN MED B	OK-72
Mean, Channels	354.5	387.6	307.2
Width, Channels	262.2	299.9	249.5

Fit Params	BCF92	Y-11
Mean, Channels	387.6	599.2
Width, Channels	299.9	370.2

Tables 1, 2, 3, correspondingly: fit parameters for covers, optical cements and WLS fibers comparisons

SiPM Temperature Dependence

onsemi C-Series • MicroFC-10035 (1 × 1 mm², 35 µm cells) — model on the PCB

Manufacturer specifications

Property	C-Series 10035
Active area / microcells	1 × 1 mm² / 504
Breakdown voltage at 21°C	24.7 V (typ.)
dVbr / dT	**+21.5 mV/°C**
dGain / dT	**–0.8%/°C**
Gain at OV = 2.5 V	3×10^6
Dark current at OV = 2.5 V	15 nA (typ.)
Recommended overvoltage	1–5 V

Illustrative response at fixed bias (21°C reference)

Temp., °C	ΔVbr, mV	ΔGain	I*, µA
18	**-64.5**	**+2.4%**	**51.2**
19	-43.0	+1.6%	50.8
20	-21.5	+0.8%	50.4
21	**0.0**	**0.0%**	**50.0**
22	+21.5	-0.8%	49.6
23	+43.0	-1.6%	49.2
24	+64.5	-2.4%	48.8

Cooling by 3°C: 50 µA → ~51.2 µA if only gain changes (+2.4%).

* NOT a measured photocurrent correction. Actual I(T) also depends on PDE(T), dark counts, correlated avalanches and illumination.

At fixed 29 V: ΔT = −3°C gives ΔVbr = −64.5 mV, so overvoltage increases by +64.5 mV.

Source: onsemi MICROC-SERIES/D, Rev. 9, Tables 1–2 (pp. 1–5). onsemi.com/pdf/datasheet/microc-series-d.pdf

Fiber Materials: WLS vs Clear

Saint-Gobain BCF-92 and Kuraray Clear-PS (Non-S type)

Property	BCF-92 (WLS)	Clear-PS (Non-S)
Function	Wavelength shifter	Low-loss light guide
Core material	**Polystyrene (PS) + WLS dyes**	**Polystyrene (PS), no WLS dye**
Core refractive index	~1.60	~1.59
Primary cladding	Acrylic / PMMA, n ≈ 1.49	PMMA, n ≈ 1.49
Optional outer cladding	Fluor-acrylic, n ≈ 1.42	Fluoropolymer, n ≈ 1.42
Wavelength conversion	**Yes: blue → green**	**No wavelength conversion**
Emission peak	**492 nm**	**Not applicable**
Reference attenuation	> 3.5 m	> 10 m*
Polymer orientation	Not specified here	Non-S: mostly unoriented PS core

Same PS base ≠ same optical behavior: WLS dyes add absorption / re-emission losses.

Changing clear fiber to BCF-92 changes spectrum, capture and attenuation; polishing trends may be similar, but currents need not match.

* Attenuation depends on wavelength, fiber design and test conditions. Outer cladding depends on the ordered variant.

Optical cement and WLS parameters

Таблица 2.1 — Оптические наполнители и их характеристики

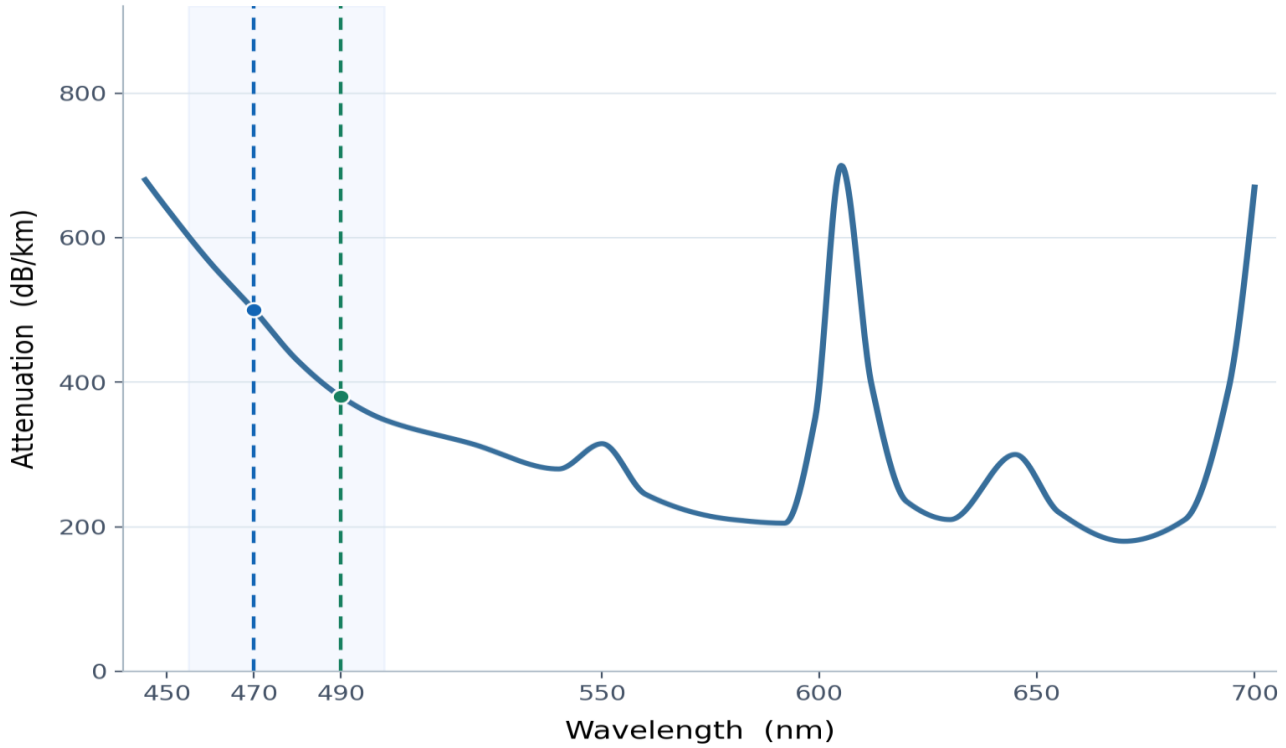
Марка	Вязкость	Диапазон рабочих температур	Спектральные характеристики	Показатель преломления
EJ-500	800 cPs	От -65 до +105 °C	60-95% 300-350 нм, 95-100% 350-600 нм	1.574
СКТН МЕД Марки Б	16 - 90 на ВЗ-1, с	—	92-96% 500 нм	1.606
СКТН МЕД Марки Е	601 - 1200 на ВЗ-1, с	—	92-96% 500 нм	1.606
ОК-72	15 - 18 на ВЗ-1, с	От -60 до +60 °C	99% 400-2700 нм	1.587

Таблица 2.2 — Оптические волокна и их параметры

Волокно	Цвет эмиссии	Пик высвечивания, нм	Время высвечивания, нс	Длина затухания, м
Kuraray Y-11	зеленый	476	7.4 [8]	>3.5
SG Crystals BCF91AS	зеленый	494	12	>3.5
SG Crystals BCF92S	зеленый	492	2.7	>3.5

Spectral attenuation of Kuraray Clear-PS

Short blue-wavelength transport is slightly more attenuated than green light



Approximate spectral losses

BLUE LED

470 nm ≈ 500 dB/km

10 cm: 1.14% propagation loss

BCF-92 WLS EMISSION

490 nm ≈ 380 dB/km

10 cm: 0.87% propagation loss

For L = 0.10 m: $T = 10^{-}(\alpha L / 10)$
(α in dB/km, L in km)

Curve redrawn approximately from Kuraray, “Plastic Scintillating Fibers”, p. 10. Losses exclude end-face, connector and coupling losses.