30th International Scientific Conference of Young Scientists and Specialists

Light collection in scintillation plates of Beam-Beam Counter detector for the SPD experiment

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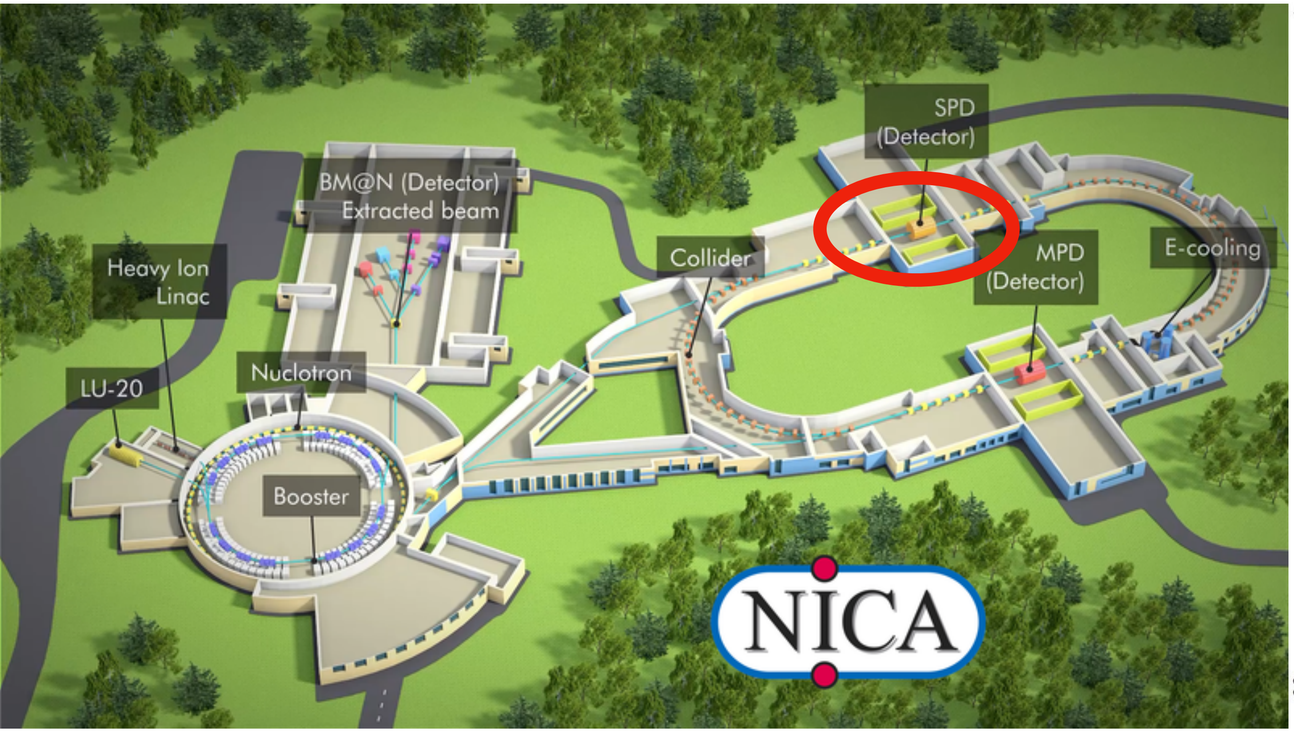
NICA collider and SPD experiment

The **Nuclotron-based Ion Collider fAcility (NICA)** is a new accelerator complex being developed at the Joint Institute for Nuclear Research (JINR) in Dubna, Russia, to study the properties of dense baryonic matter.

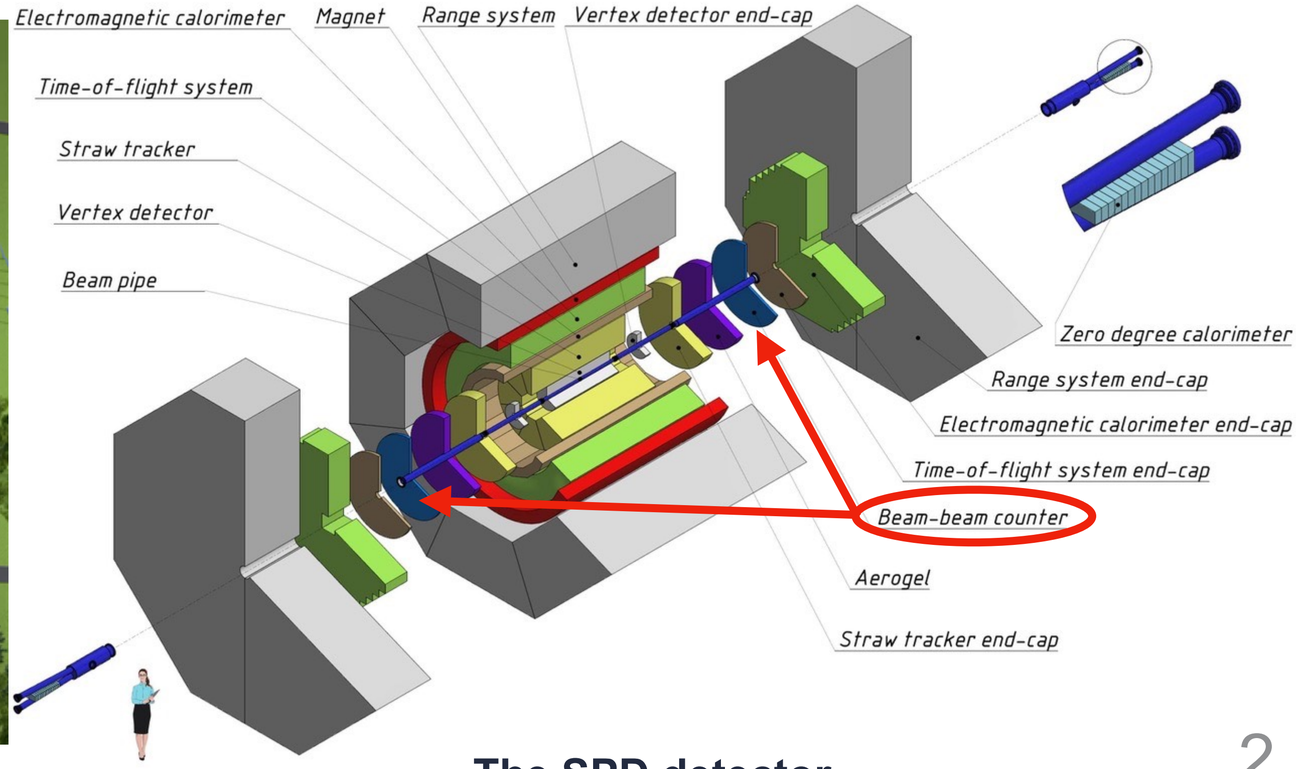
The facility is designed to operate with polarized beams at center of mass energies of up to 27 GeV and a collision rate of up to 4 MHz.

The **Spin Physics Detector (SPD)** is planned to be installed at one of these points.

SPD is a general-purpose detector designed to investigate the spin structure of nucleons and other spin-related phenomena.



The NICA accelerator complex

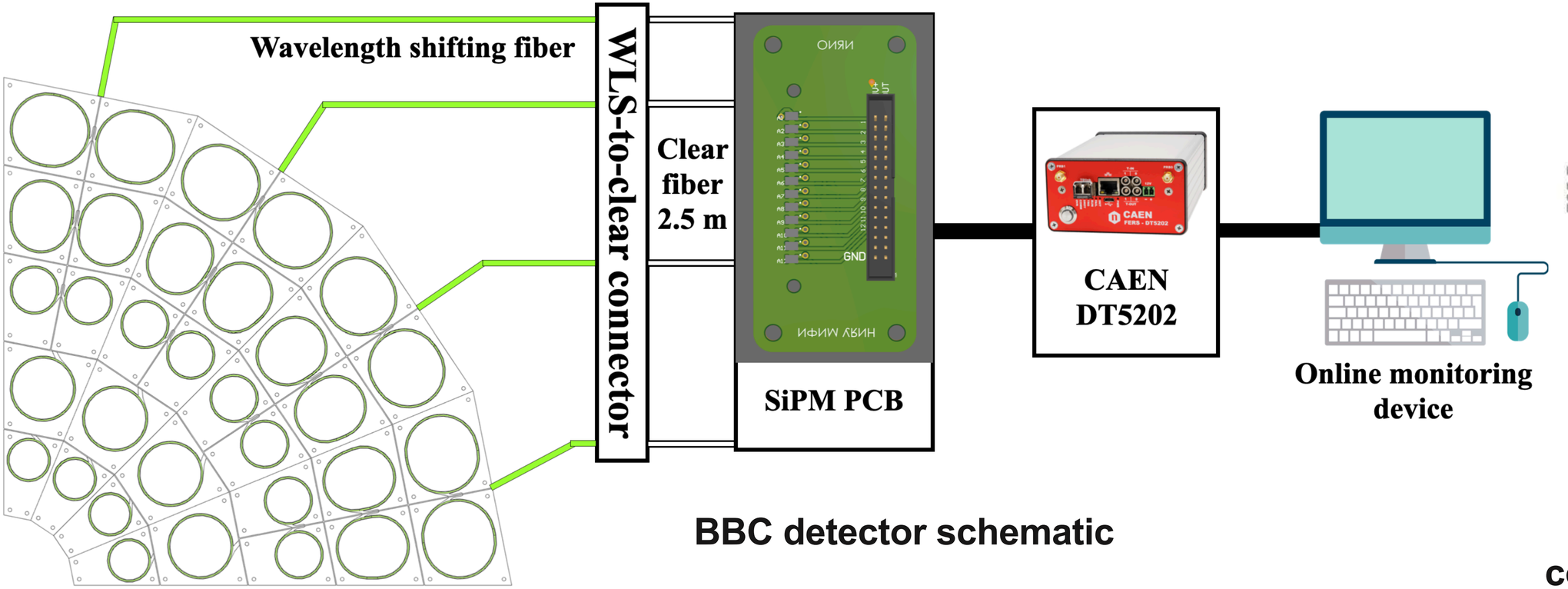


The SPD detector

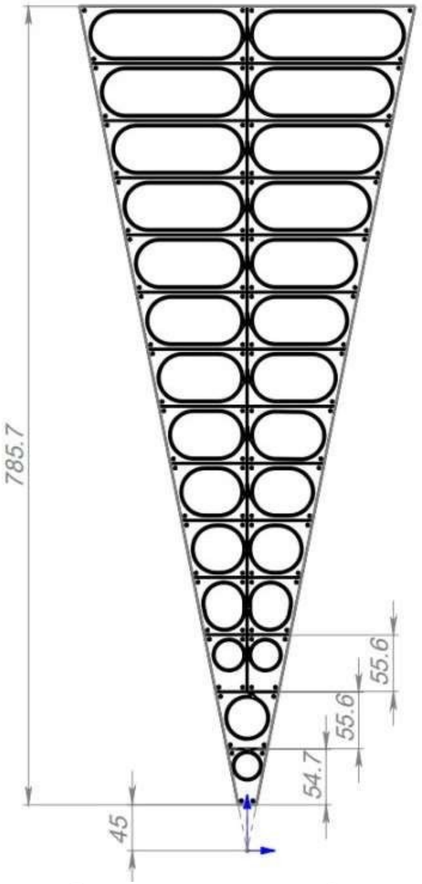
Beam-Beam Counter detector

The **Beam-Beam Counter (BBC)** is a segmented scintillation detector designed for beam-collision monitoring and local polarimetry.

- **BBC wheel:** 16 sectors; each sector contains 24 trapezoidal scintillator tiles.
- A wavelength-shifting (WLS) optical fiber is embedded in each tile in three loops and glued in place.
- **Optical path:** WLS fiber → clear optical fiber → silicon photomultiplier (SiPM).
- SiPM signals are read out by the CAEN DT5202 data acquisition system.



BBC detector schematic



Geometry of a complete BBC sector

Motivation and Objectives

The efficiency of signal detection depends on the entire optical chain, including photon collection in the scintillator, light transmission through the WLS and clear optical fibers, and photon count by the photodetector.

The number of detected photons defines the signal amplitude and affects the SNR. Studying the optical chain makes it possible to assess the contribution of its individual components to the BBC detector's signal detection efficiency.

Purpose:

To investigate the light collection performance of BBC detector prototypes.

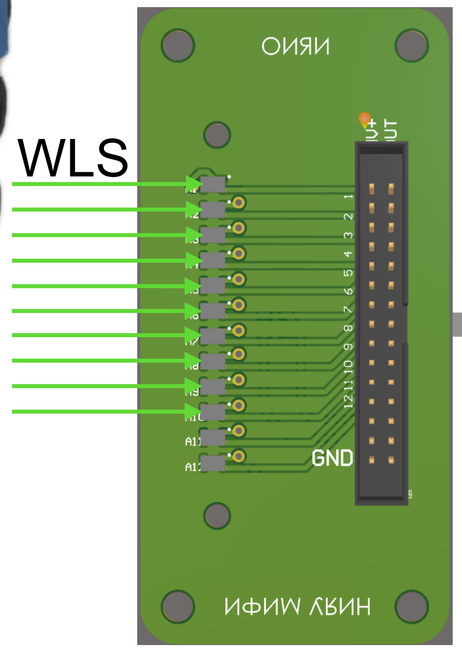
Objectives:

1. Compare light collection performance using different photodetectors.
2. Evaluate the effect of optical connections on light collection.
3. Investigate the truncated BBC sector performance with cosmic ray muons.

Test bench for comparative SiPM measurements



Cosmic-ray muon telescope



BBC photodetector board

Cabling



DT5202

- The telescope consists of 10 identical scintillator tiles.
- **WLS fiber:** Saint-Gobain BCF-92.
- The fiber is glued into the connector using the BBC assembly procedure.
- **SiPMs:** Onsemi MICROFC-10035 (1 × 1 мм²) and Hamamatsu S14160-1315PS (1.3 × 1.3 мм²);
- **SiPM bias and readout system:** CAEN DT5202;
- **Overvoltage:**
  - Onsemi: 5V
  - Hamamatsu: 8V
- **Trigger:** coincidence between signals from the two outermost tiles.

- **The WLS fiber in tile 10 was replaced with a Tver-developed wavelength-shifting fiber containing the OSL8 additive.**

Tile response vs SiPM model

SiPM Onsemi

Tile	MPV, p.e.
1	33
2	31
3	34
4	31
5	37
6	35
7	31
8	33
9	30
10 (OSL8)	49

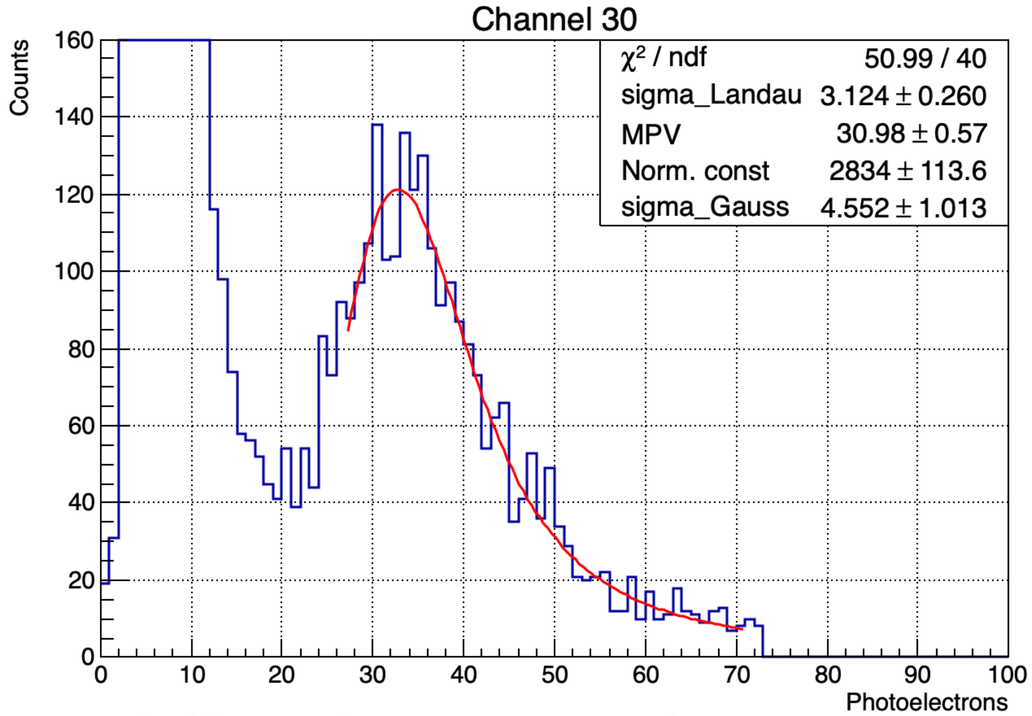
<MPV> (excluding tile 10): (33±3) p.e.

SiPM Hamamatsu

Tile	MPV, p.e.
1	39
2	40
3	44
4	42
5	49
6	46
7	43
8	49
9	40
10 (OSL8)	77

<MPV> (excluding tile 10): (43±4) p.e.

- Energy-loss spectra were obtained for two printed circuit board (PCB) configurations.
- The average most probable value (MPV) of the muon energy-loss distributions measured with Hamamatsu SiPMs is **23%** higher than that measured with Onsemi SiPMs.
- The tile with the Tver-developed WLS fiber has a **49%** (Onsemi) and **44%** (Hamamatsu) higher response than the average for tiles with SG BCF-92 fibers.

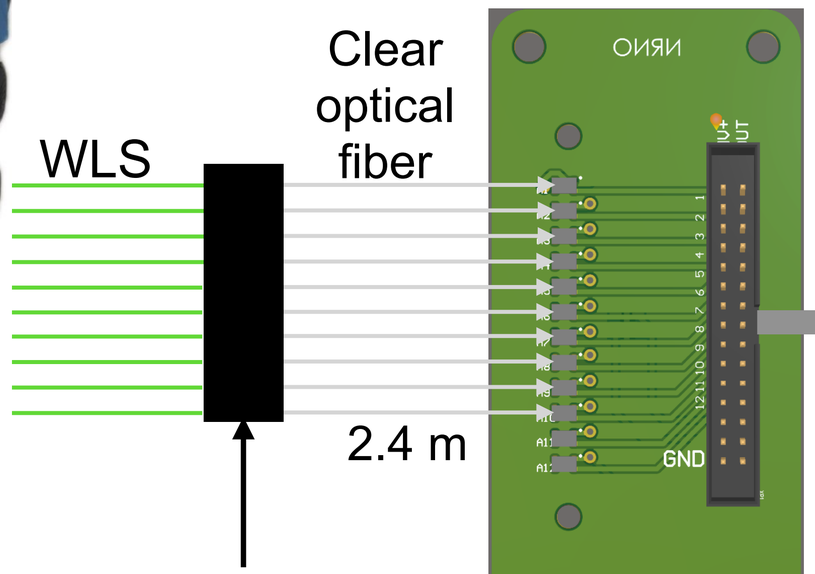


Calibrated muon energy-loss spectrum

Test bench with clear fiber cabling



Cosmic-ray muon telescope



BBC photodetector board

Cabling



DT5202

- Complete BBC design requires clear fiber optical cable.
- **Clear optical fiber:** SG BCF, 2.4 m long.
- The fiber ends were polished according to the BBC assembly procedure.
- The WLS-to-clear fiber interface was coated with Pate-7 optical grease.

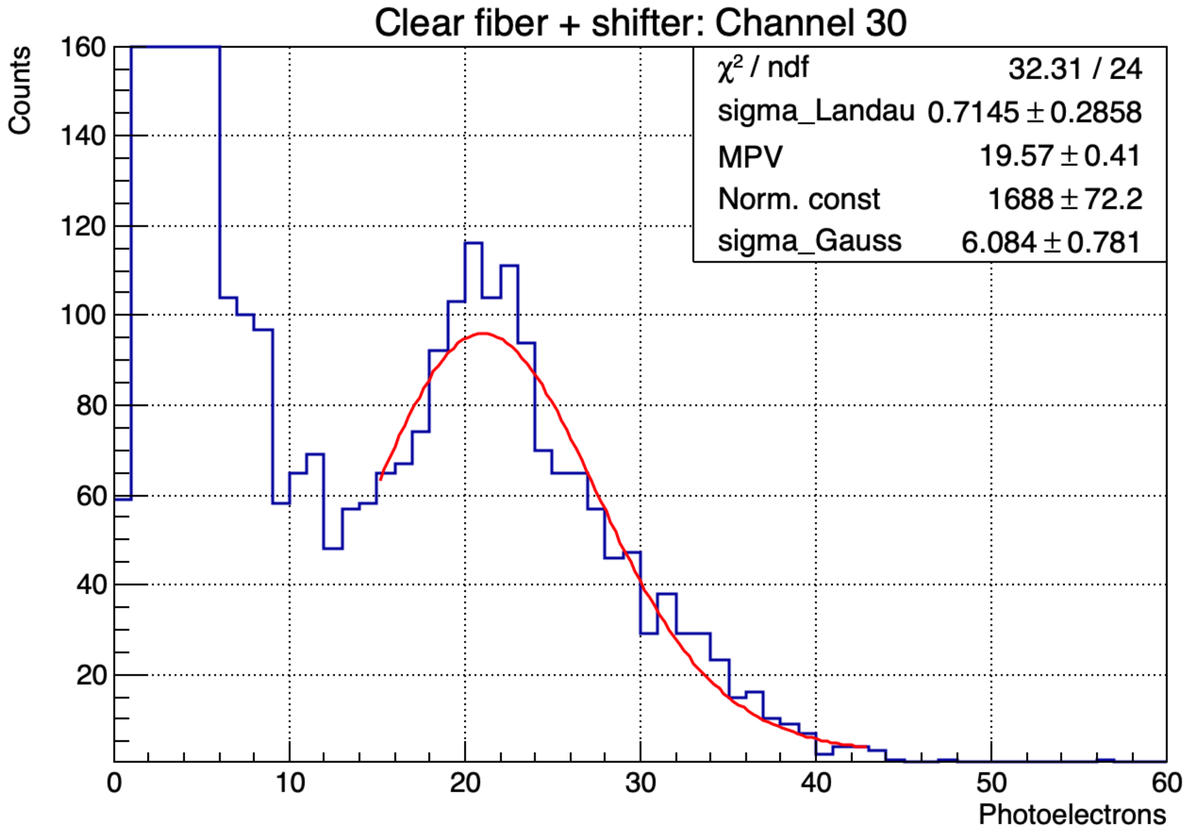
Effect of clear fibers on signal amplitude

SiPM Onsemi

Tile	MPV, p.e.
1	20
2	14
3	12
4	13
5	15
6	19
7	20
8	19
9	14
10 (OSL8)	34

<MPV> (excluding tile 10):

(16±3) p.e.



Muon energy-loss spectrum

The use of clear optical fibers reduced the most probable tile response by **51%!**

Testing innermost BBC sector

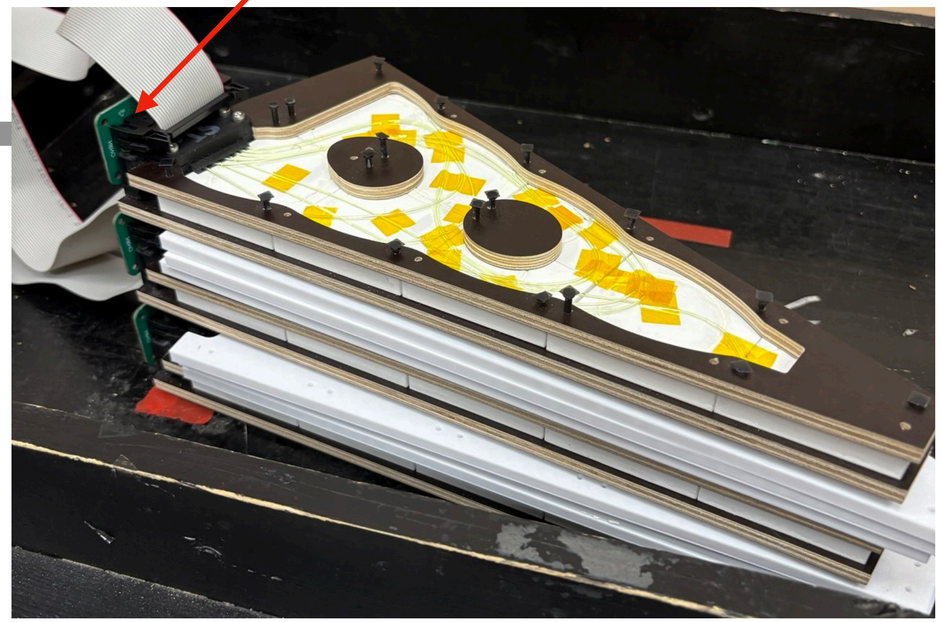
- The telescope consists of three innermost BBC sectors.
- The distance between sectors is 1.8 cm.
- The WLS fibers were polished according to the BBC assembly procedure.
- **Photodetector:** Hamamatsu SiPM.
- **Readout modes:** Amplitude and time-over-threshold (ToT) measurements.



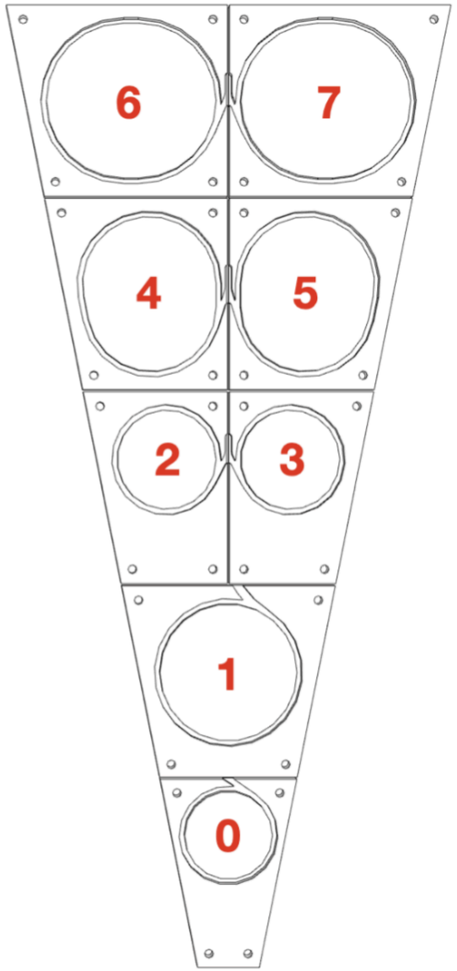
DT5202

Hamamatsu SiPM board

Cabling



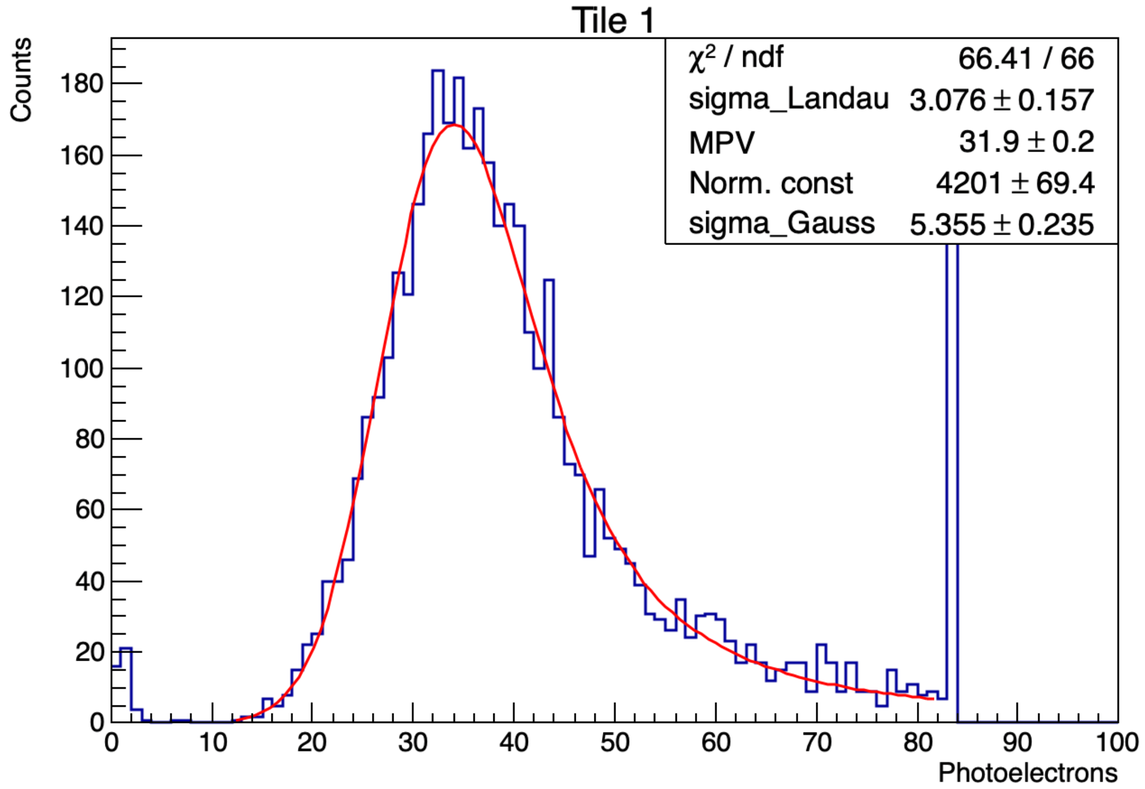
Truncated BBC sectors



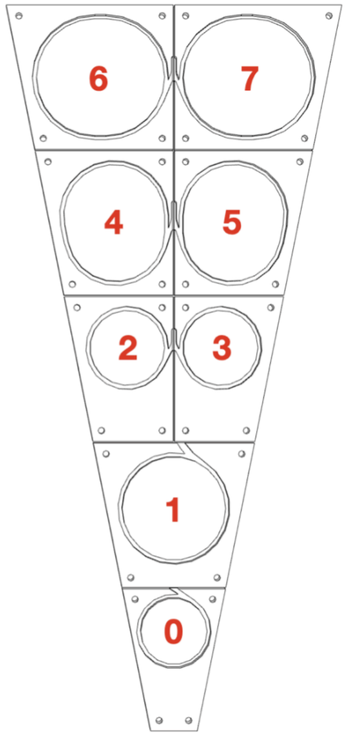
Model of a truncated sector with tile numbering

Response of innermost BBC sector in PHA mode

- 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 greater than **30 p.e.**



Muon energy-loss spectrum for the first tile of the sector

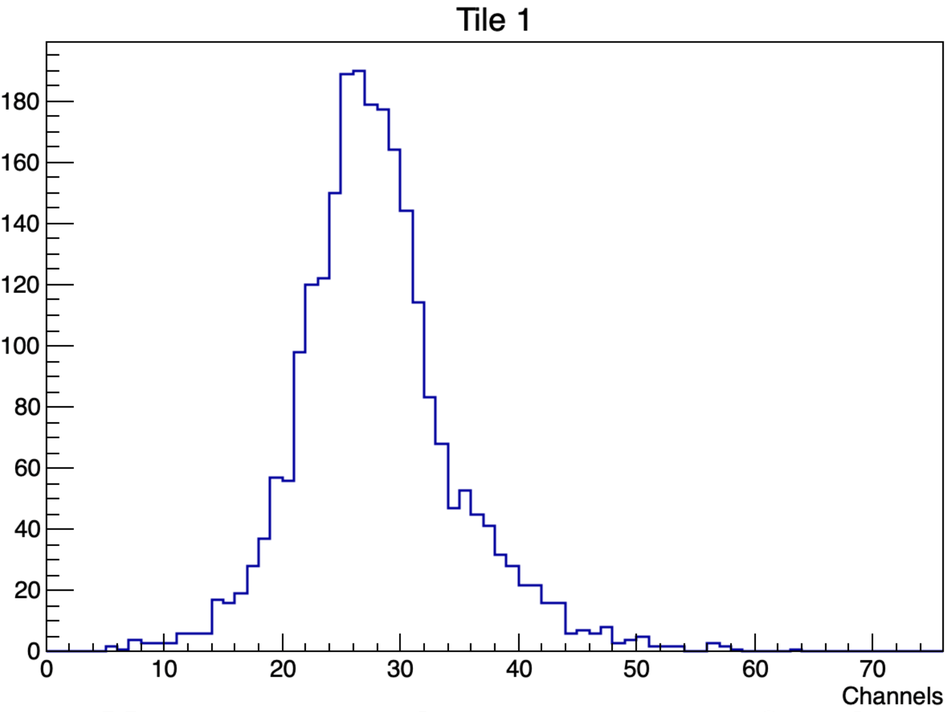


Results for the second (central) sector

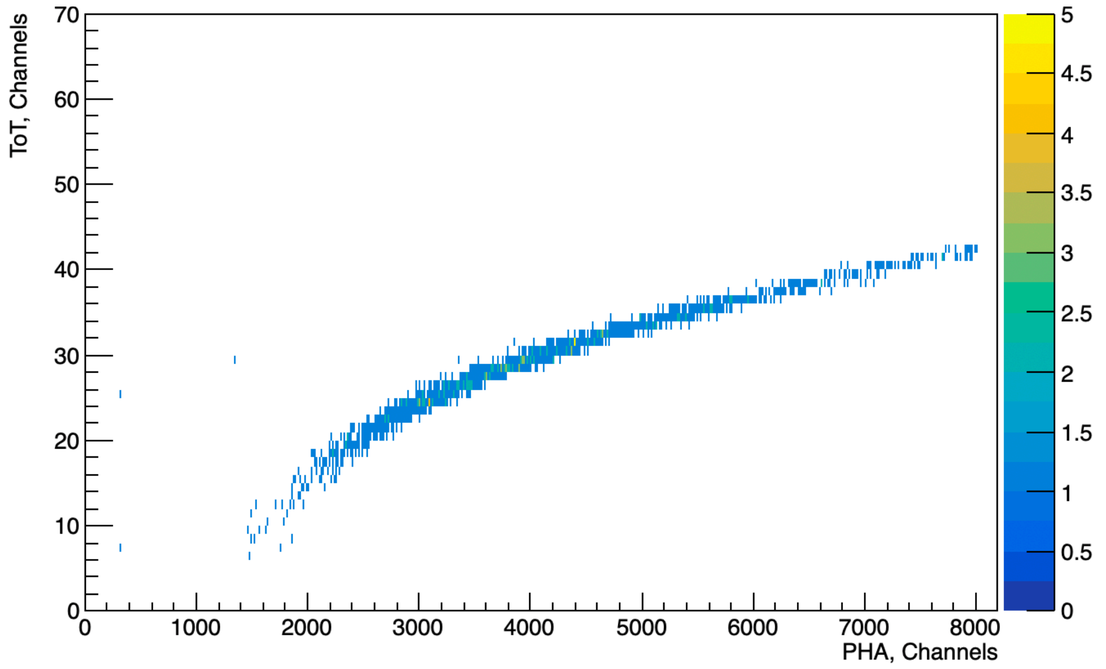
Tile	MPV, p.e.
0	34
1	32
2	32
3	30
4	35
5	34
6	34
7	33

Response of innermost BBC sector in ToT mode

- The ToT mode is nonlinear.
- Tile responses were measured in both amplitude and timing modes.
- A calibration curve for the ToT mode was obtained.
- VCP channel time resolution: 0.5 ns



Muon energy-loss spectrum for the first tile of the sector in ToT mode



ToT scaling curve

Peak position

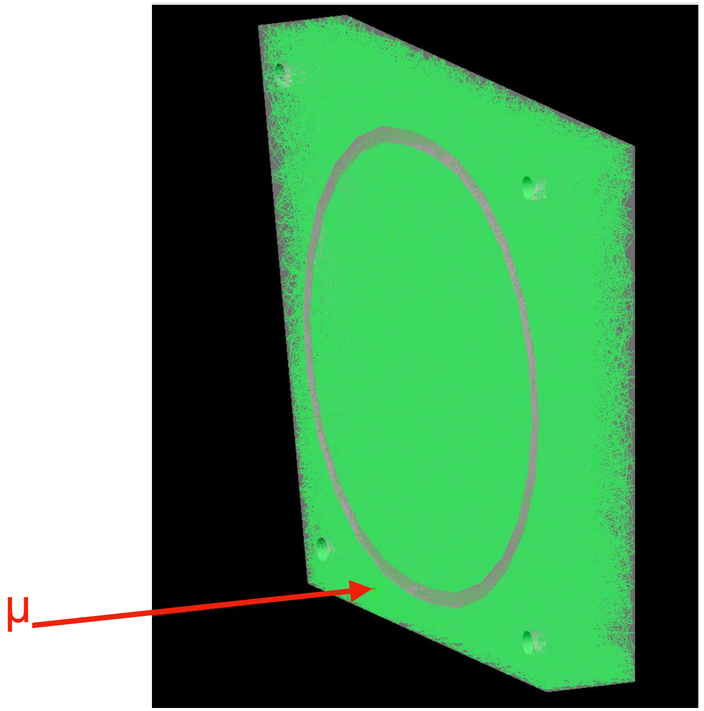
Tile	Channels
0	25
1	27
2	29
3	21
4	28
5	28
6	29
7	26

Geant 4

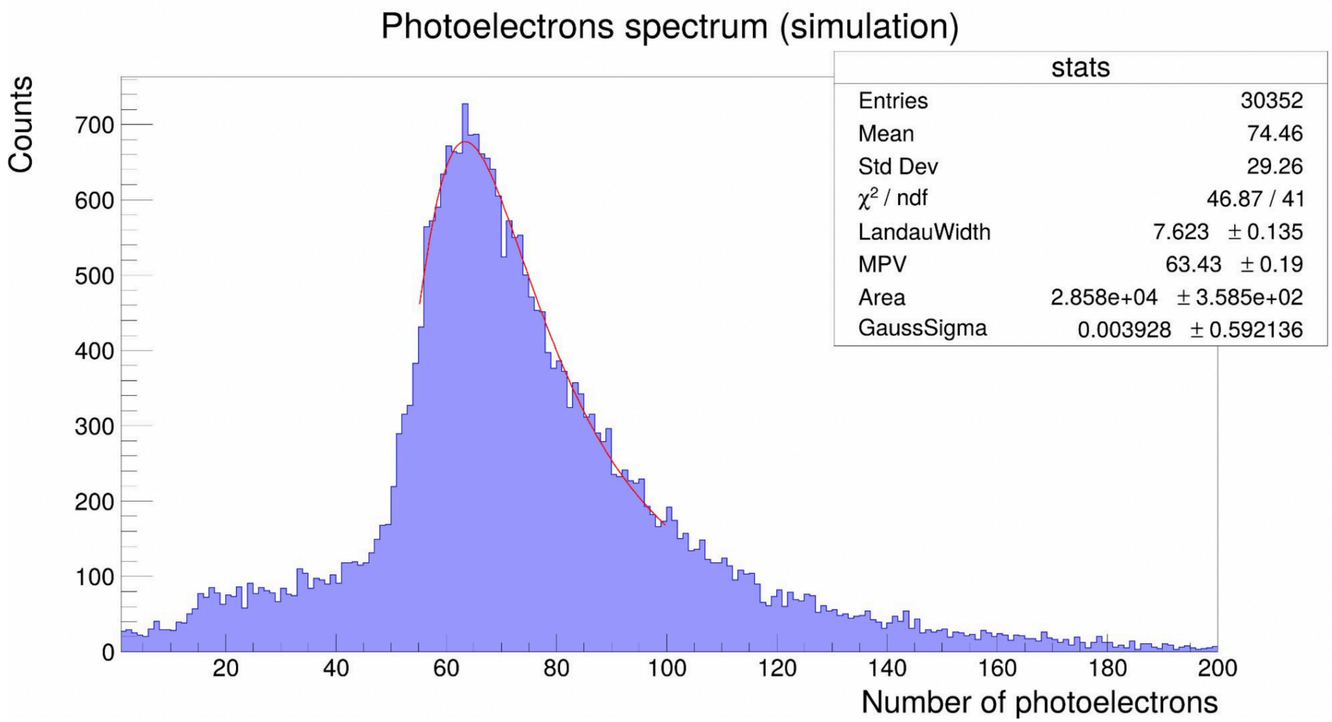
Main goal: develop a Geant4 model for integration into the SPDROOT simulation framework.

- To realistically simulate the production, collection, and transport of scintillation photons in scintillator tiles and wavelength-shifting (WLS) fibers.
- To reproduce the measured response of BBC tiles to cosmic-ray muons.
- To describe the muon response distribution using a Landau–Gaussian convolution (Langauss)

Work in progress



Geant4 Model of the Scintillator Tile



The spectrum was obtained by simulating muons traversing the tile, accounting for their energy and zenith-angle distributions.

Conclusion

1. A setup was developed to measure the light collection efficiency of the detector elements of the BBC. The ToT measurement method was tested and validated.

2. The mean number of photoelectrons detected with Hamamatsu SiPMs is **23%** higher than that detected with Onsemi SiPMs.

3. Adding clear optical fibers to the light transmission path reduces the response by **51%**.

4. The response of innermost BBC sector tiles was studied with cosmic-ray muons. The MPV for each tile exceeds **30 p.e.**

5. A detailed Geant4 model of the scintillator tiles was developed, accounting for photon propagation.

6. The full production, assembly, and commissioning cycle was successfully completed for the detector sectors.

Thank you for attention



Back up

OSL8 fiber specifications

- Fiber diameter: 1 mm
- Fluorophore: OSL8
- Emission peak: 501 nm
- Absorption peak: 401 nm
- Emission color: green (blue-to-green wavelength shifting)
- Attenuation length: at least 2.0 m
- Minimum bend diameter: 30 mm for a 1 mm-thick fiber
- Reflective cladding: PMMA or fluoropolymer

Scintillator Specifications

НИЯУ МИФИ

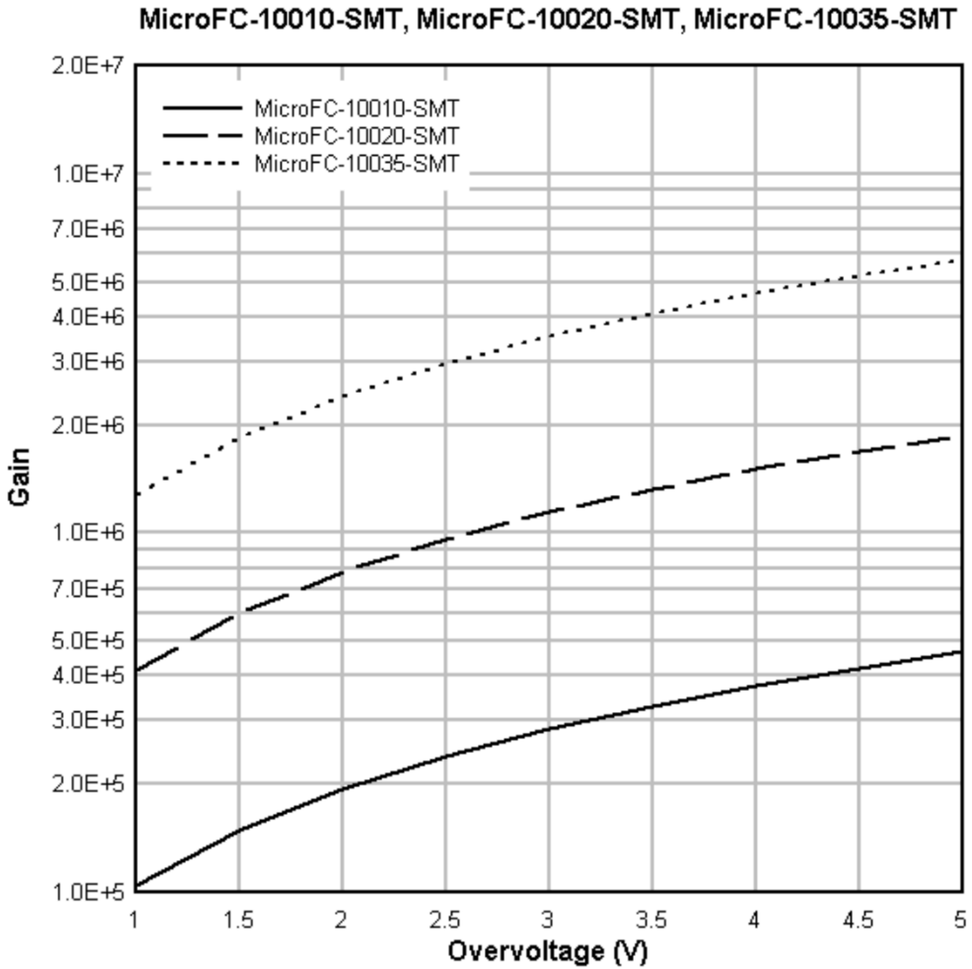
Scintillator composition:

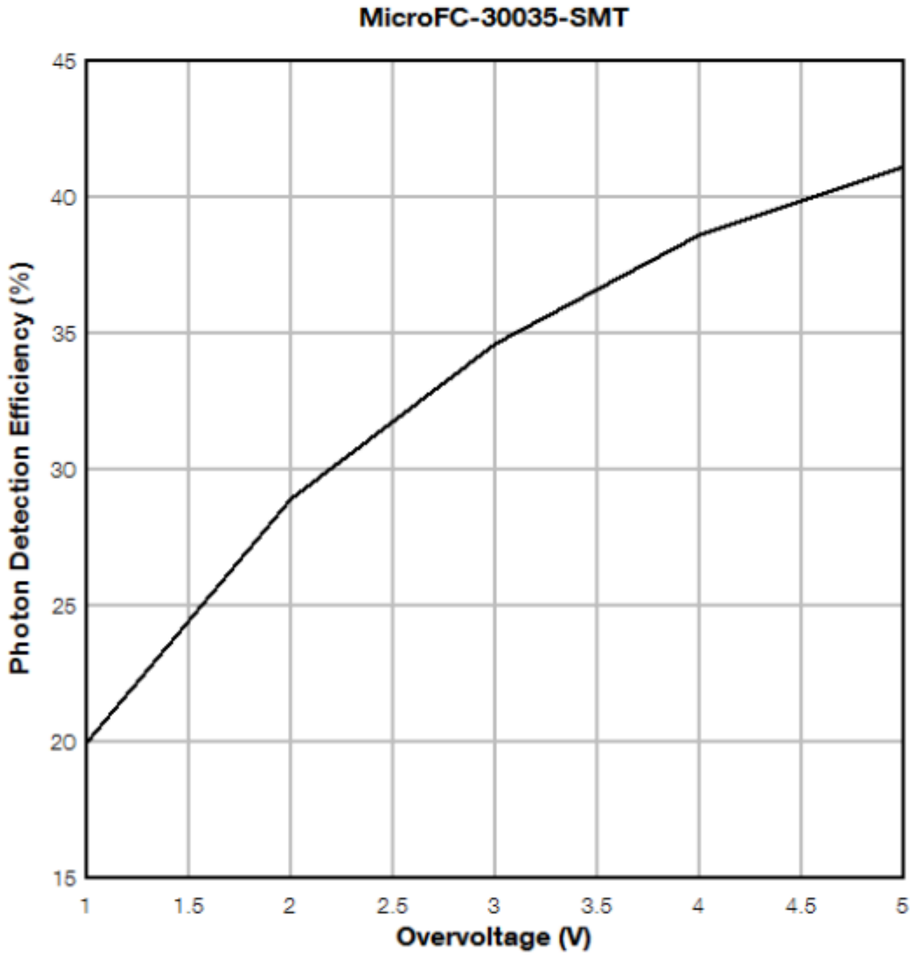
- polystyrene Styrolution 124N — 98.0 - 98.5%;
- p-Terphenyl (CAS 92-94-4) — 1.5 - 2.0%;
- POPOP (CAS 1806-34-4) — 0.01-0.04%.

Light output, % anthracene	Decay time, ns	Wavelength of max. emission, nm	Light attenuation length, sm	Main applications
60 - 70	2.5	430	>200	$\alpha, \beta, \gamma,$ fast n

SiPM Onsemi MICROFC 10035

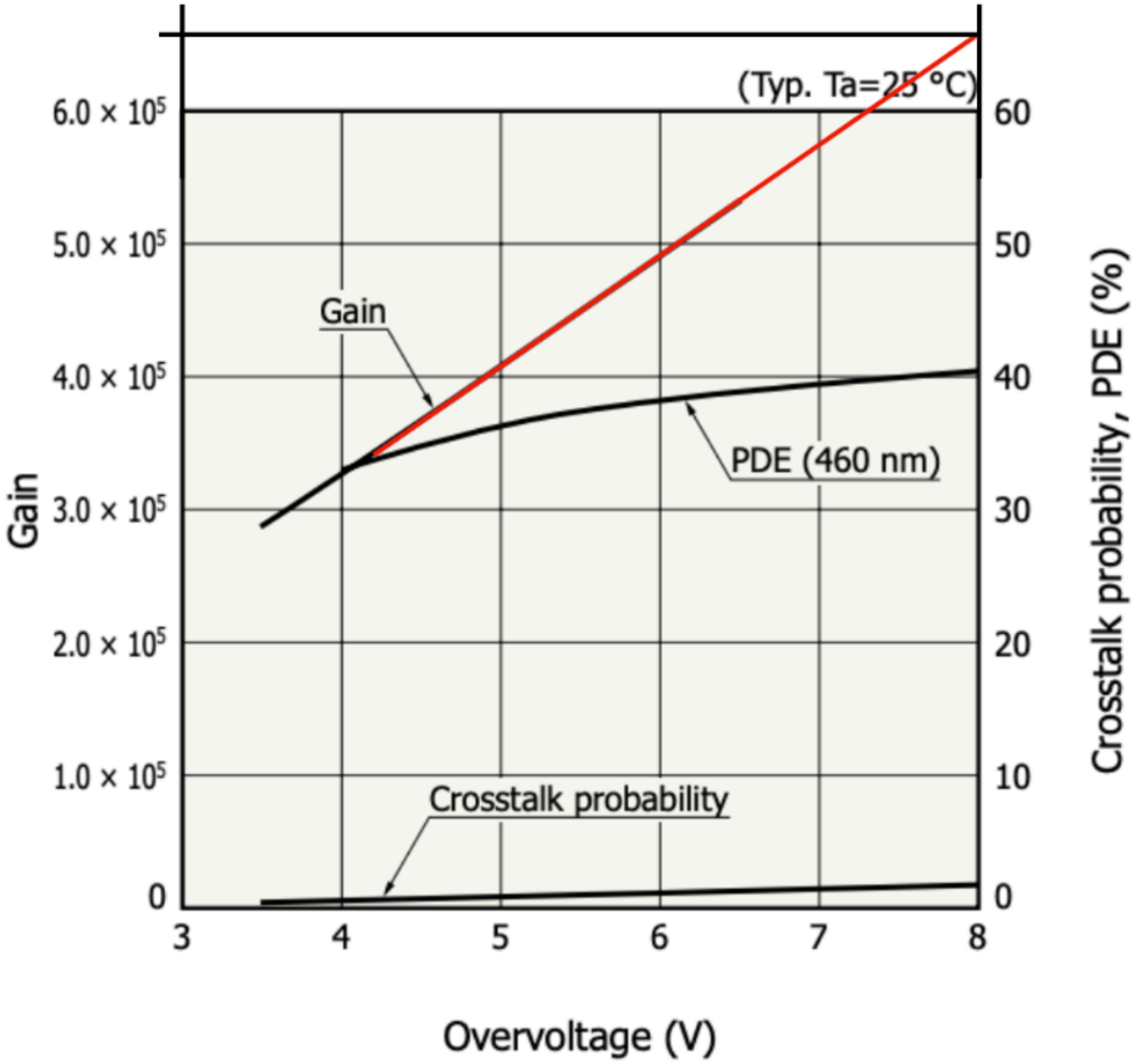
SiPM Onsemi microfc 10035 parameters:

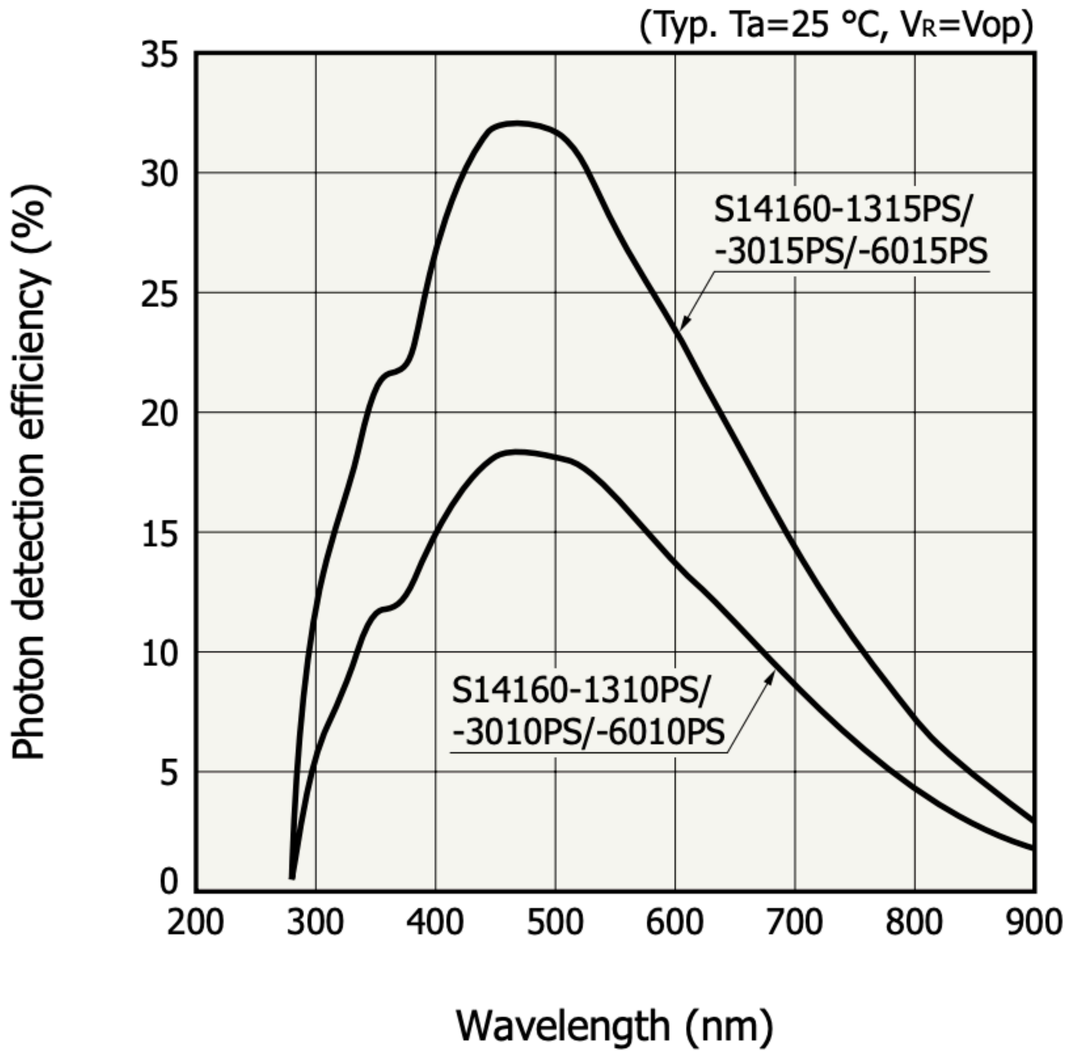




For microfc 10035 the peak is at 31%

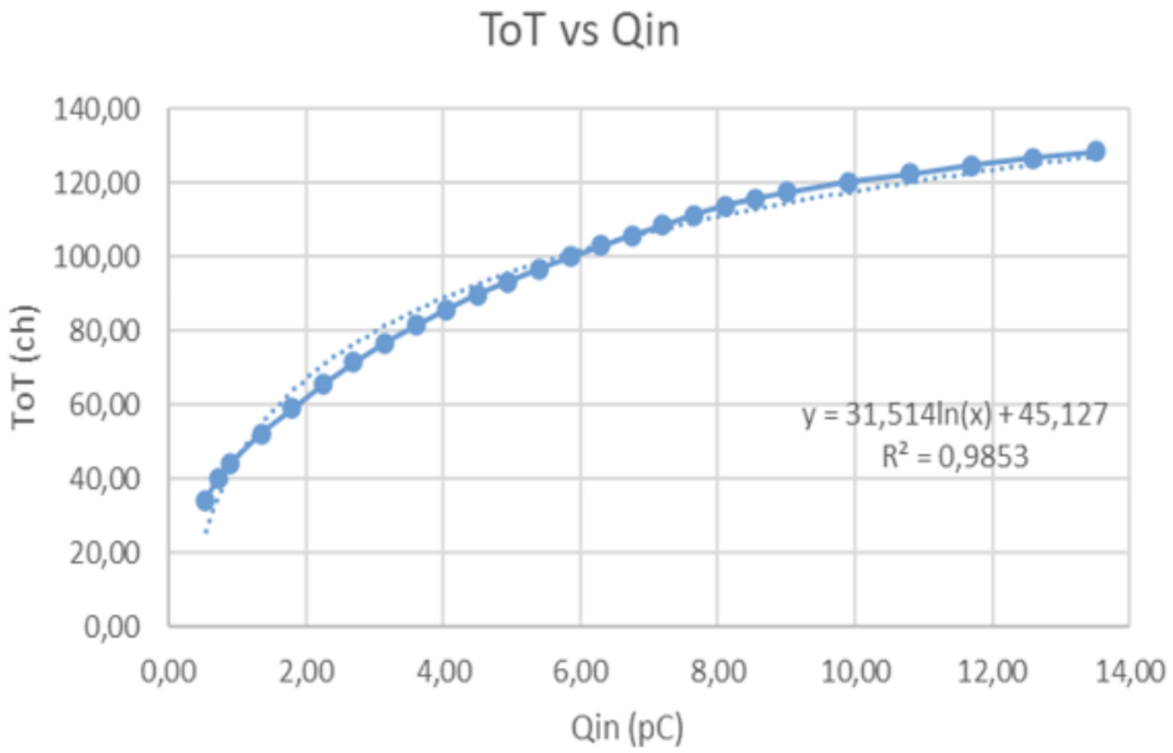
SiPM Hamamatsu S14160-1315PS





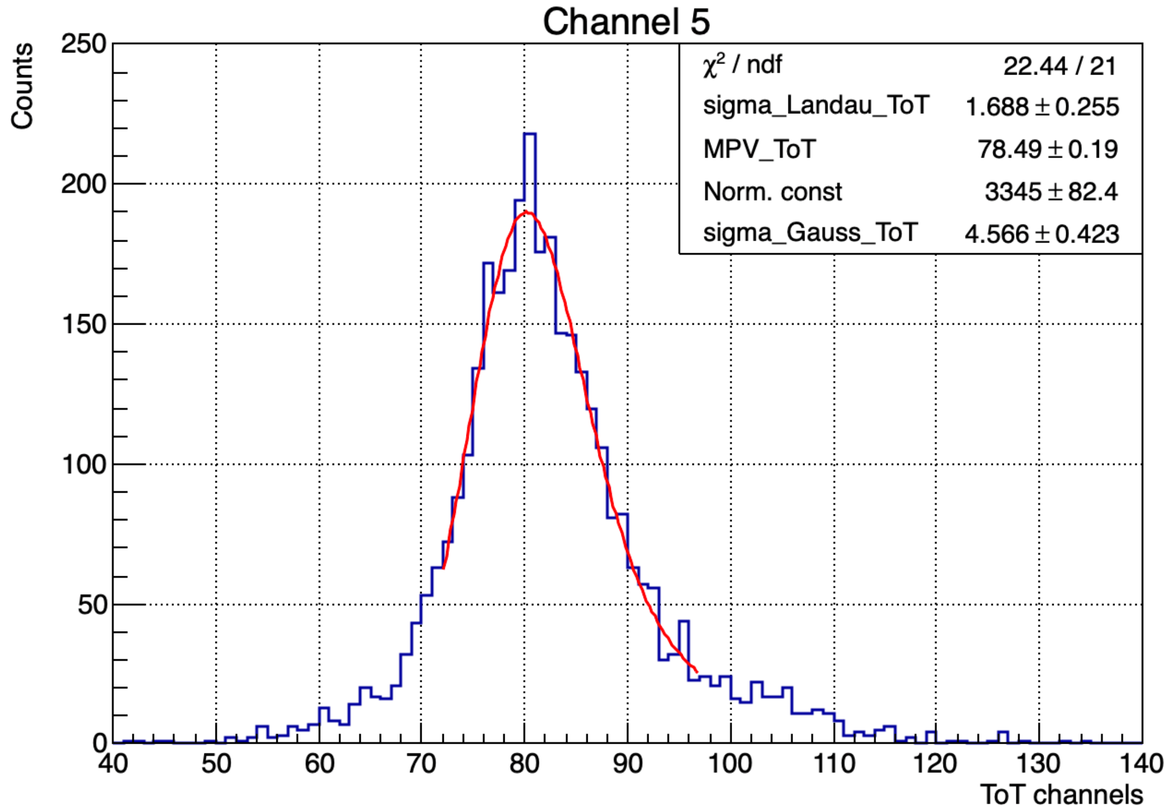
ToT response

From the DT5202 manual:



$$\mathrm{ToT} = 0{,}0409\,Q_{\mathrm{in}}^{3} + 19{,}749\,Q_{\mathrm{in}}^{2} - 1{,}4547\,Q_{\mathrm{in}} + 26{,}873$$

- VCP channel time resolution: 0.5 ns



Muon energy-loss spectrum in ToT mode

- The Landau–Gaussian fit was modified to account for ToT nonlinearity.