Construction and Testing of Resistive Plate Chambers with Optical Readout

B. Bilki[1], M. Tosun[1,2], S. Acikgoz[1,3]

[1] Turkish Accelerator and Radiation Laboratory, Ankara, Turkey
[2] Istinye University, Istanbul, Turkey
[3] Ankara University, Ankara, Turkey

TIPP 2026 International Conference on Technology & Instrumentation in Particle Physics
February 2 – 6, 2026
TIFR, India

This work is supported by Tubitak Grant No 123F304.

A Quick Summary of RPC R&D Progression

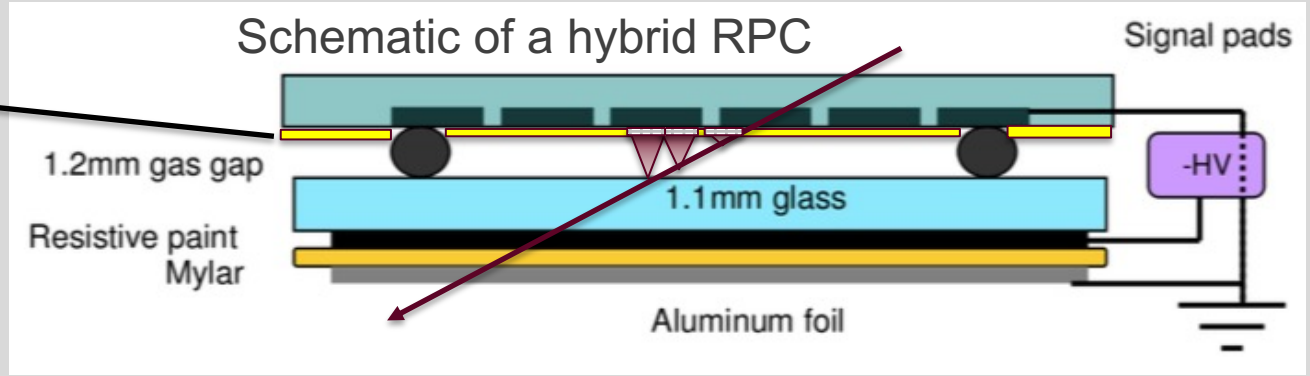
- The starting point of our team's R&D on RPCs is the development of the CALICE Digital Hadron Calorimeter (DHCAL)
  - 2-glass RPCs read out with 1 cm x 1 cm pads and digital readout
- The next step was the development of the 1-glass RPCs which are thinner, have higher rate capability and lower pad multiplicity compared to the DHCAL RPCs
- In parallel, we developed RPCs with low resistivity glasses for higher rate capability
- 1-glass RPC development provided the technological basis for implementing functional anodes in RPCs → hybrid RPCs
- Incorporating optical signal readout in RPCs enables a new class of RPC detectors with enhanced functionality and performance

Development of Hybrid Resistive Plate Chambers

- Part of the electron multiplication in the RPC is transferred to a thin film of high secondary emission yield material coated on the anode pad with the purpose of reducing/removing gas flow and enabling the utilization of alternative gases. → Functional anodes

- Many metal oxides such as Al_2O_3 and TiO_2 have high secondary electron emission yields and most of them can be coated as thin films with simple techniques such as magnetron sputtering.

Secondary electron emission layer

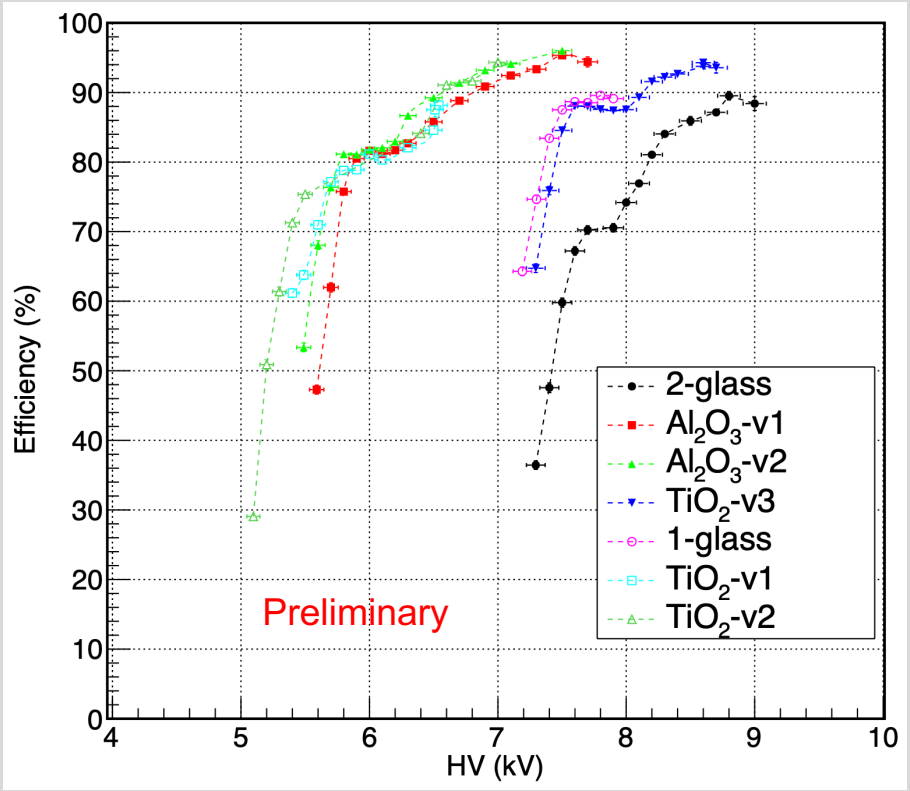


First-Generation Hybrid RPCs

We built several 10 cm x 10 cm hybrid RPCs as well as the standard 1-glass and 2-glass RPCs, and tested them in the laboratory and at Fermilab test beam. The gas gap was 1.3 mm and the gas mixture was the DHCAL RPC gas mixture R134A : Isobutane : SF_6 ; 94.5 : 5.0 : 0.5 at 2-3 cc/min flow rate (lower than the nominal 5 cc/min).

The chambers tested:

1. 2-glass RPC
2. 1-glass RPC
3. 500 nm Al_2O_3 (v1)
4. 350 nm Al_2O_3 (v2)
5. 1 mg/cm^2 TiO_2 (v1)
6. 0.5 mg/cm^2 TiO_2 (v2)
7. 0.15 mg/cm^2 TiO_2 (v3)



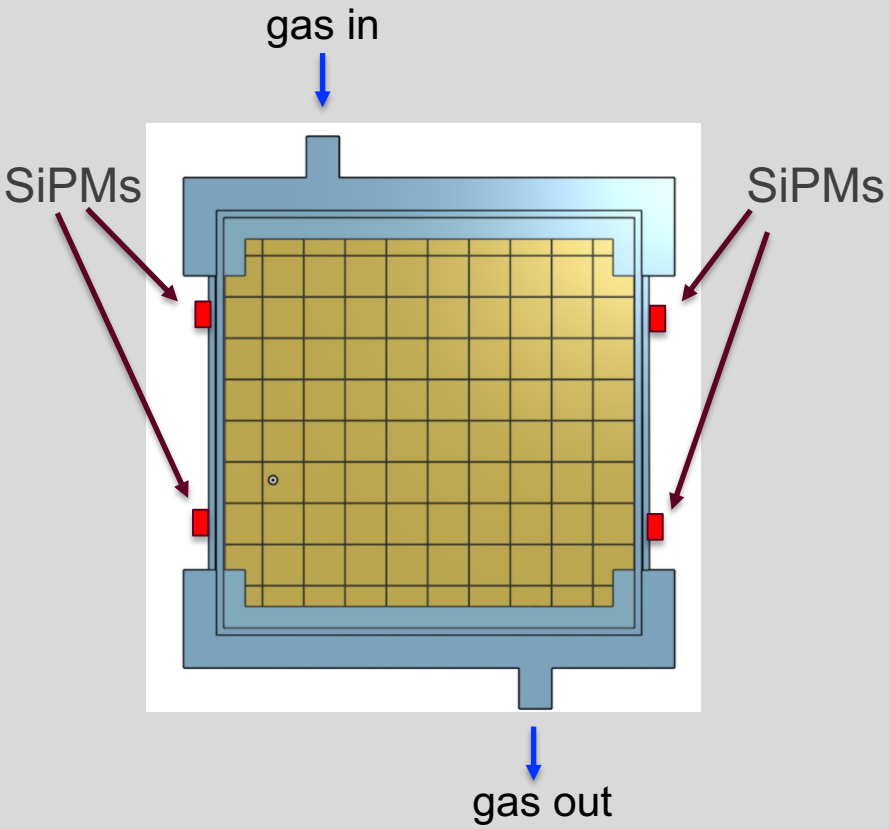
The charge multiplication in the secondary emission layer is qualitatively validated.

Efficient if charge > 300 fC

Hybrid RPCs with Optical Readout

- The gases used in gaseous detectors are also scintillators to some extent due to a certain recombination rate.
- The part of this light which is mostly in the ultraviolet range is considered problematic since it is heavily ionizing.
- On the other hand, the measurement of this light signal can provide additional high-time/spatial resolution data beyond conventional RPC measurements.
- Optical readout can also provide further insights into the avalanche/streamer development enabling the improvement of the simulations of gaseous detectors including the hybrid ones.

The Conceptual Design of Small-Size RPCs with Optical Readout



SiPMs integrated into the chamber

10 cm x 10 cm chambers with 1.3 mm gas gap (identical to 1st and 2nd generation hybrid RPCs)

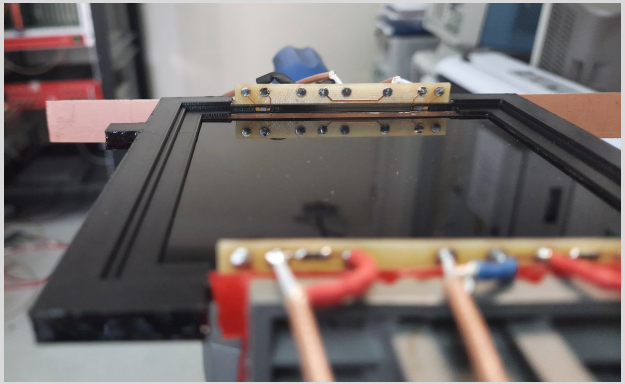
The resistive surface is provided by a mixture of artist paints to yield 1-5 MΩ/□. The paint is applied with air brush.

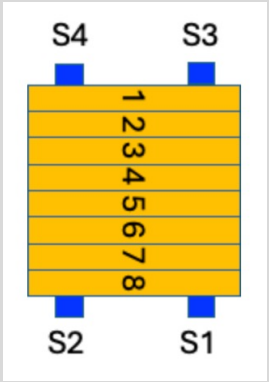
The 10 cm x 10 cm pad board with pad size of 1 cm x 1 cm is coated with TiO_2. TiO_2 is dissolved in ethanol and the solution is applied with air brush.

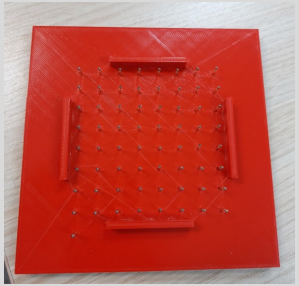
SiPMs Options:

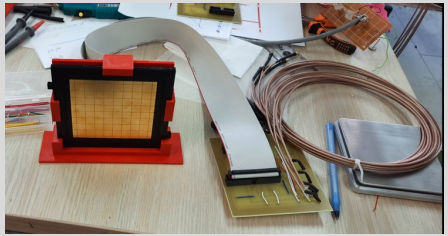
- KETEK PM1125-WB-C0 (1 mm x 1 mm)
- ONSEMI MicroFC-10035 (1 mm x 1 mm)

Construction and Testing of the Small-Size Hybrid RPCs with Optical Readout









We made three 10 cm x 10 cm RPCs with 1.3 mm gas gap:

- Hybrid RPC with 2 uncoated SiPMs
- Plain 1-glass RPC with 2 uncoated SiPMs
- Hybrid RPC with 4 TPB-coated SiPMs: SiPM windows were coated with TPB (tetraphenyl butadiene) by dissolving the TPB in toluene and applying with airbrush

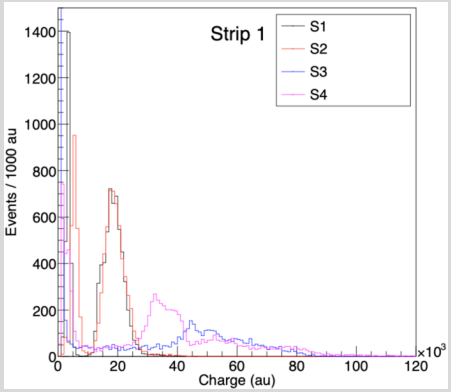
The SiPMs were mounted on a custom 2-sided PCB. On the in-chamber part, only the SiPMs and copper routes are placed. The through-holes and components were on the back side and the extended part.

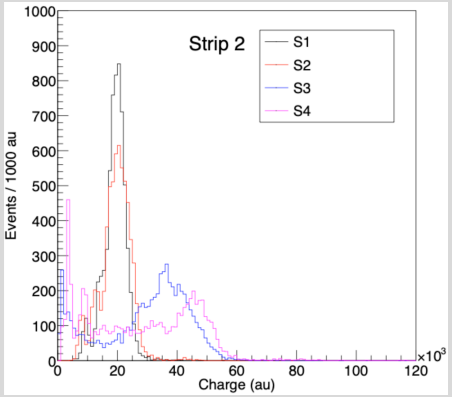
A single bias voltage is shared by the SiPMs and no pre-amplifiers were used.

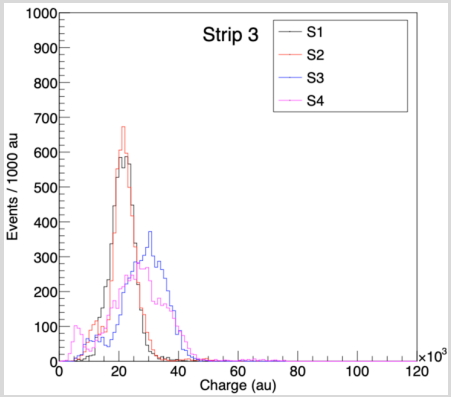
The RPC was flushed with Ar:CO_2 90:10 at 2 cc/min rate.

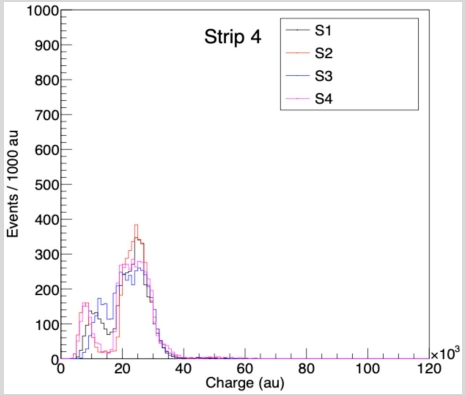
Pin and adapter boards were made to implement strip readout.

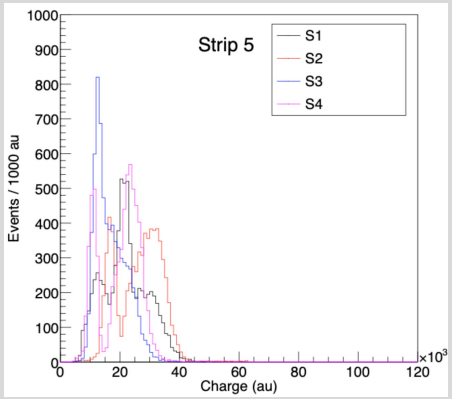
Tests of the RPC with TPB-Coated SiPMs

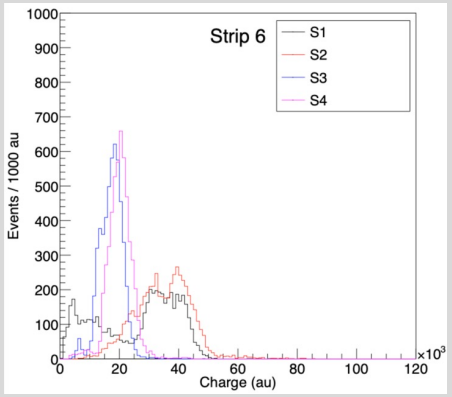


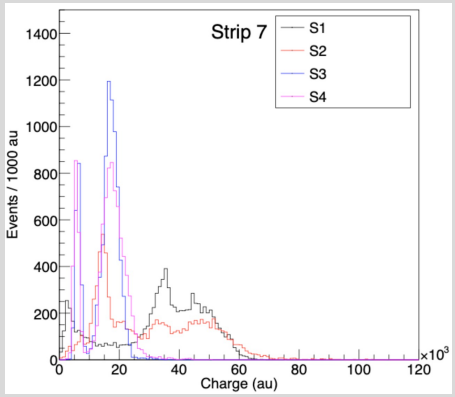


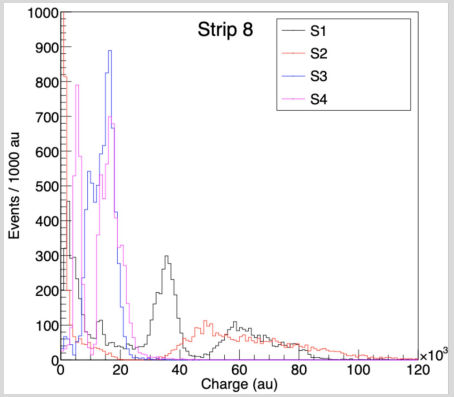


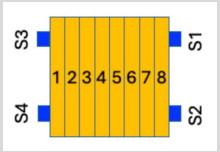








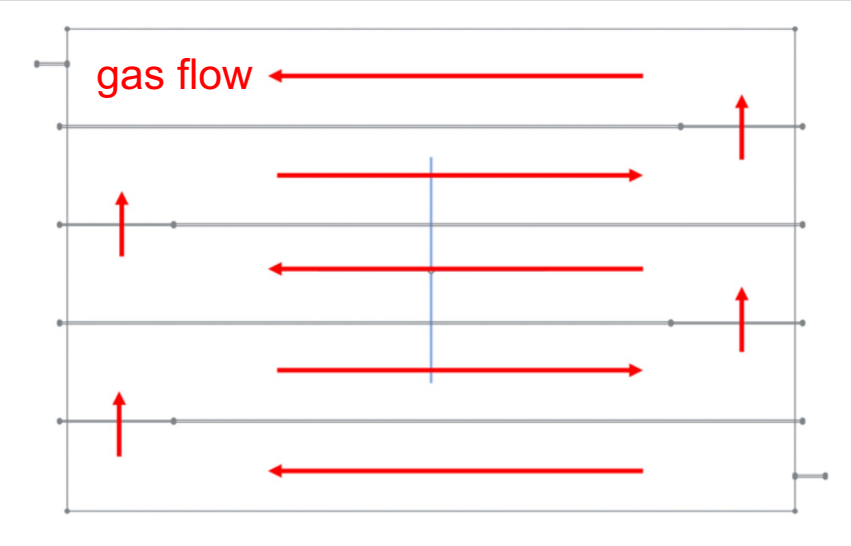




Single photon charge is ~100 integral units

Multi-peak structure is visible and is attributed to the high variation in the optical paths (multiple reflections and conversions are possible)

The Conceptual Design of Large-Size RPC with Optical Readout



Four quartz fibers are placed parallel to the long edge.

SiPMs are coupled to the fiber ends on both sides externally.

32 cm x 48 cm chambers with 1.3 mm gas gap

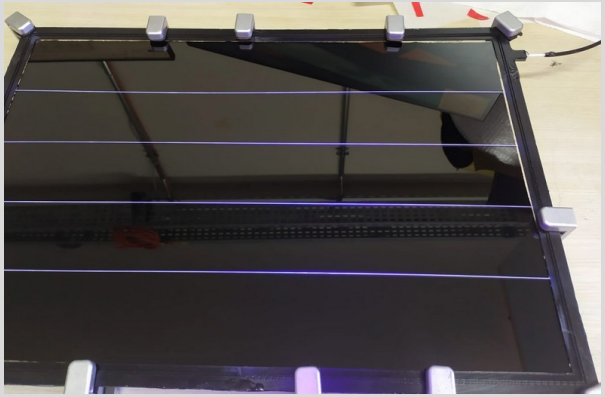
The resistive surface is provided by a mixture of artist paints to yield 1-5 MΩ/□. The paint is applied with air brush.

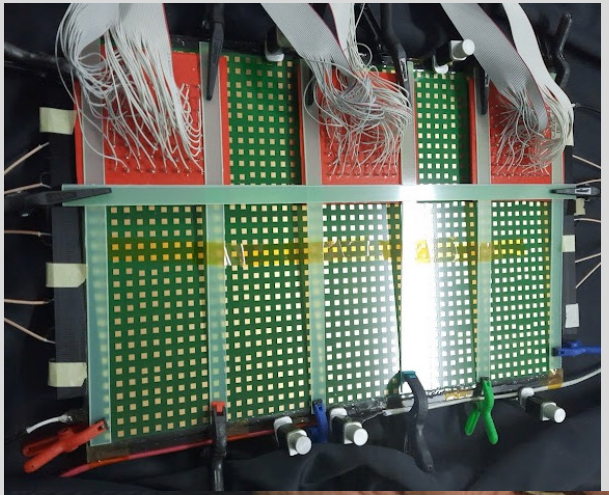
The 32 cm x 48 cm pad board with pad size of 1 cm x 1 cm is coated with TiO_2. TiO_2 is dissolved in ethanol and the solution is applied with air brush.

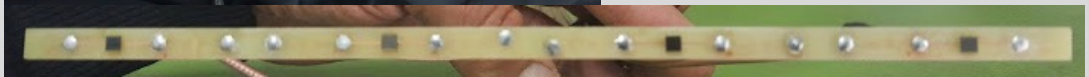
SiPM Options:

- KETEK PM3325-WB-C0 (3 mm x 3 mm)
- ONSEMI MicroFC-30035 (3 mm x 3 mm)
- BROADCOM AFBR-S4N22P014M (2 mm x 2 mm)

Construction of The Large-Size RPC with Optical Readout







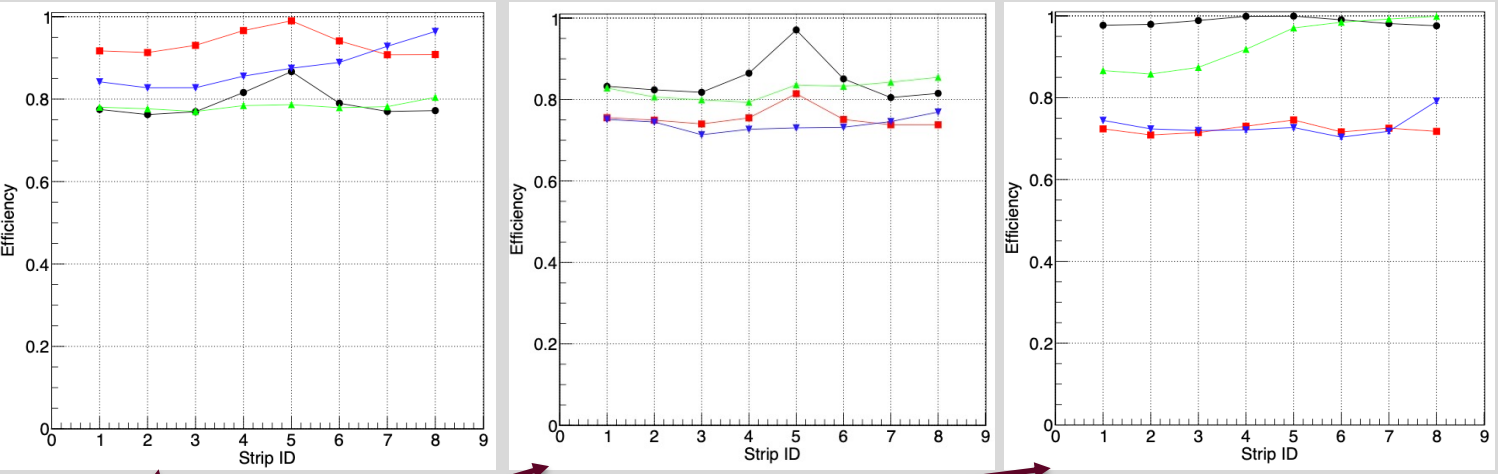
- The quartz fibers were stripped of their claddings and subsequently coated with **TPB (tetraphenyl butadiene)** by dissolving TPB in toluene and applying the solution uniformly using an airbrush technique.

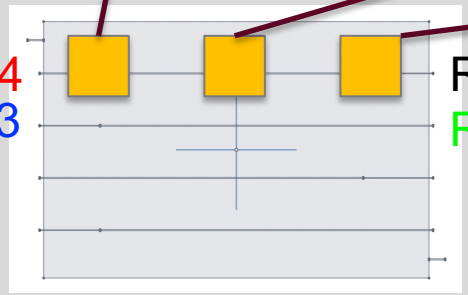
- The RPC frame was fabricated using **3D printing** as multiple modular components, which were assembled and bonded using a two-component epoxy adhesive.

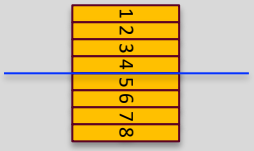
- Assembly proceeded by sequentially bonding the **cathode electrode glass**, the **TPB-coated quartz fibers**, and the TiO_2-coated **pad readout board** to the frame.

- A dedicated **PCB hosting four SiPMs** was designed and manufactured, together with custom **3D-printed optical coupling frames** to ensure stable alignment and efficient light collection.

Tests with Readout Strips Parallel to the Optical Fiber

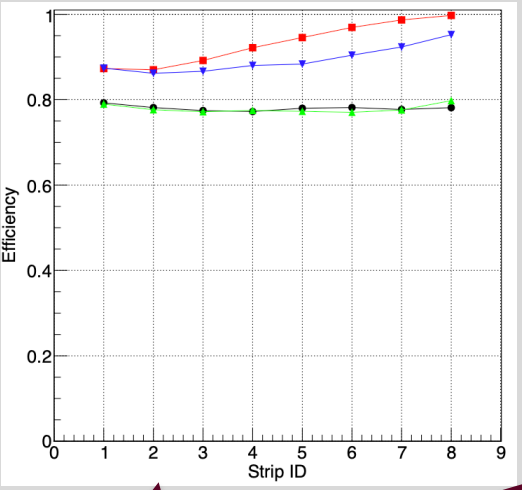


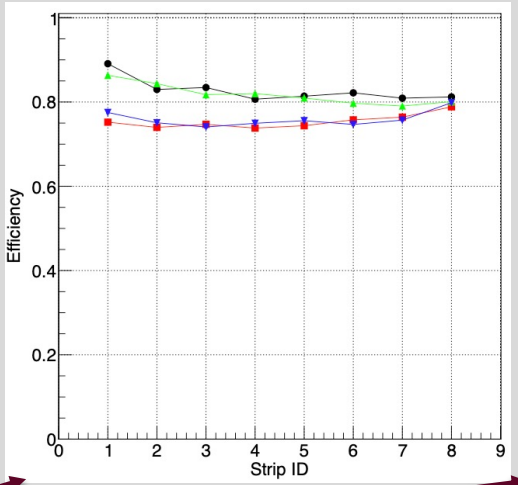


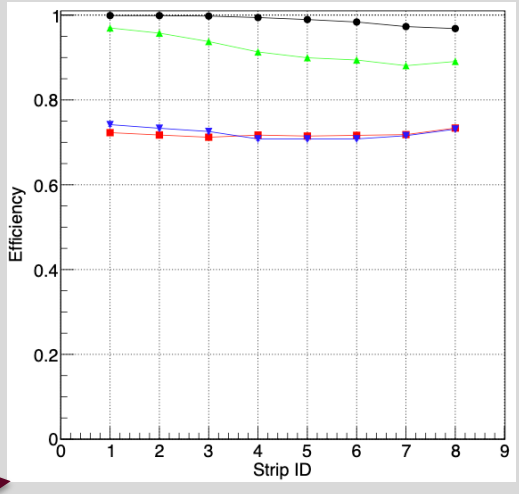


- SiPM readout is considered efficient if the signal is above 1.4 x single photon level
- Within 10 cm of the SiPM locations, the optical readout is more than 90% efficient within 4 cm of the optical fiber
- At 24 cm distance from the SiPM locations, the optical readout efficiency is above 70%
- The optical readout is not completely symmetric mostly due to inhomogeneity in the fiber coating, fiber end cutting differences and the fiber-SiPM optical matching differences.

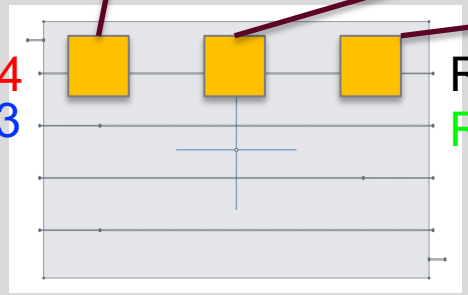
Tests with Readout Strips Perpendicular to the Optical Fiber







R4
L4
R3
L3



- SiPM readout is considered efficient if the signal is above 1.4 x single photon level
- Along the 48 cm length of the optical fibers, the efficiency stays above 70 %, being above 90 % within 5-10 cm of the SiPM locations
- The efficiency drop is 1-2.5%/cm
- The asymmetry of the response is visible

Summary

- The development of hybrid RPCs with optical readout enables the simultaneous measurement of scintillation light and avalanche charge generated in the RPC gas gap, providing unprecedented insight into the dynamics of avalanche development.

- In these hybrid RPC designs, the requirements on gas composition are expected to be significantly relaxed or partially eliminated by shifting a fraction of the electron multiplication from the gas volume to materials with high secondary electron emission capability, deposited on the in-gas anode surfaces.

- Optical readout of the signals produced in RPCs offers high-precision information on the spatial and temporal characteristics of primary ionization and avalanche formation, complementing the conventional charge-based readout and enhancing detector performance.

- Laboratory and beam tests of the developed RPC prototypes are currently underway, and their preliminary design, fabrication, and operating principles have been successfully validated.

Outlook

- ❑ Fully characterize the secondary emission materials, also with detailed simulations.
- ❑ Perform high segmentation readout of the hybrid RPCs
- ❑ Study the optical measurements in detail
- ❑ Study the long-term behavior
- ❑ Perform simulation studies to test the feasibility of large-scale implementations