Development of Hybrid Gaseous Detectors

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Gaseous Detectors

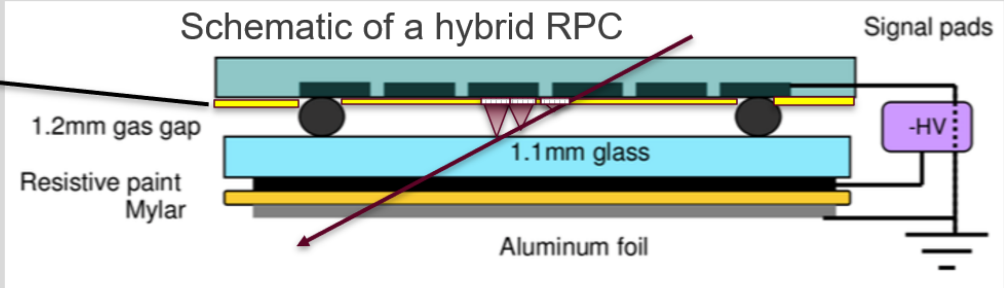
- Gaseous detectors are crucial components of the current and future collider experiments from tracker to muon chambers and even calorimeters. One of the major challenges for the future implementation of gaseous detectors is the limitations on the usage of some common detector gases.

- In order to address this issue, our team has developed the concept of “hybrid gaseous detectors”.

Introduction to Hybrid Gaseous Detectors

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

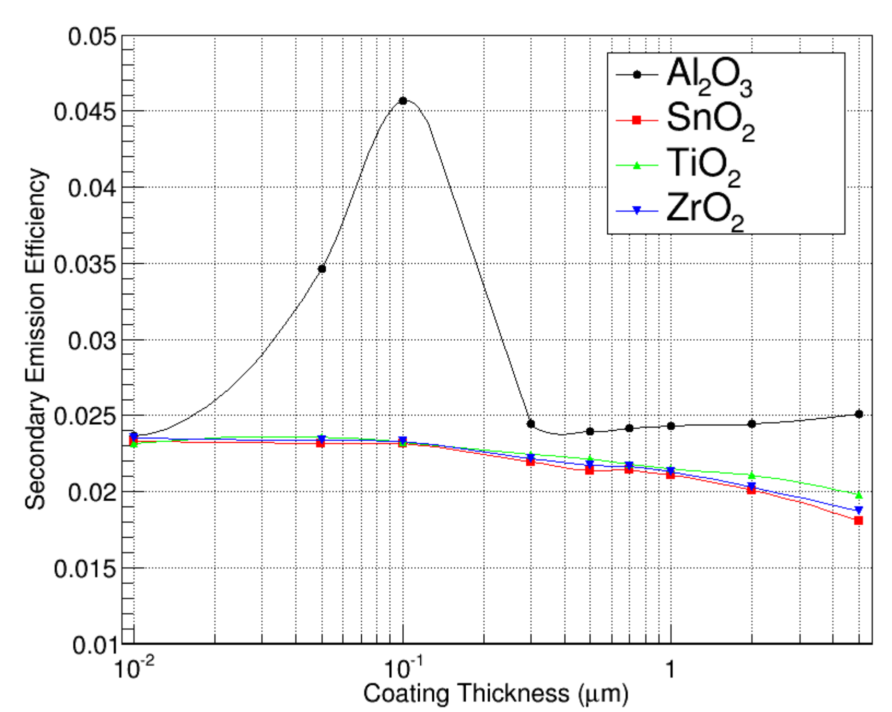
Secondary electron emission layer



- 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.

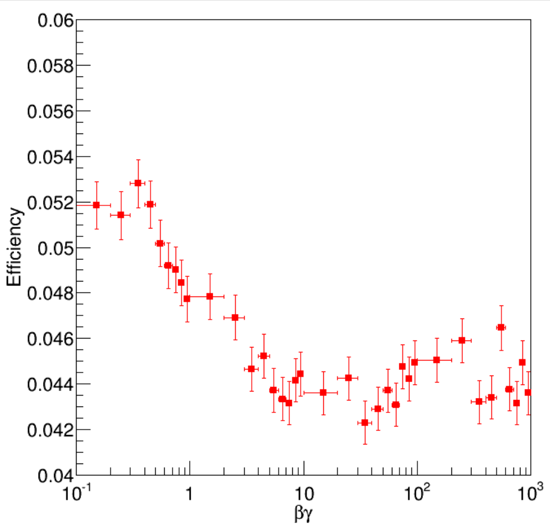
Potential Secondary Electron Emission Materials

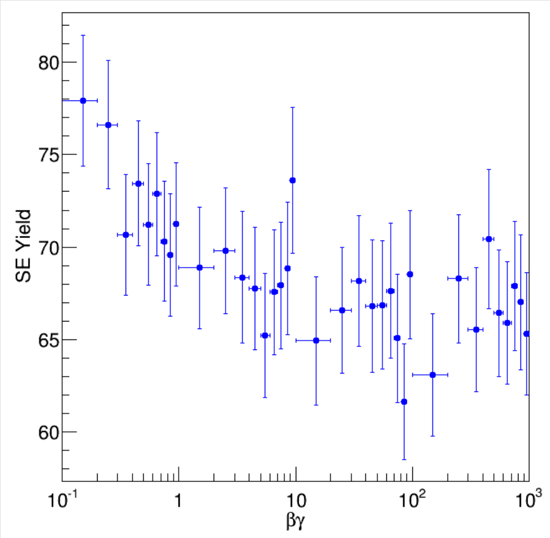
- Al_2O_3, SnO_2, TiO_2 and ZrO_2 secondary electron emission capabilities were simulated with Geant4 and average secondary electron emission efficiency was calculated for various thicknesses. The best performance was predicted to be with 100 nm thick Al_2O_3.



Potential Secondary Electron Emission Materials

- The secondary electron emission efficiency and the e⁻ yield of the 100-nm thick Al_2O_3 was simulated as a function of the βγ of the traversing particle. The minimum ionization occurs around βγ of 40 and the average secondary electron yield is around 68.

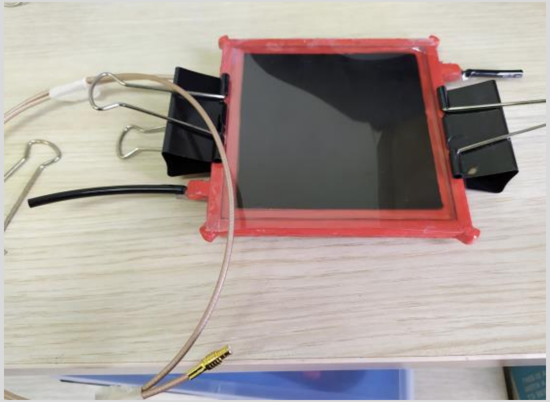


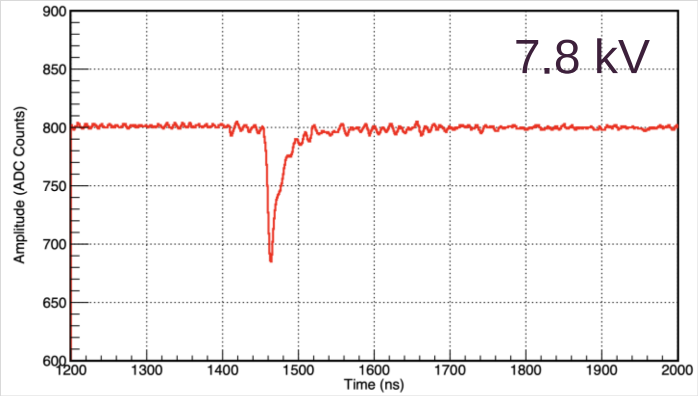


Development of Hybrid Resistive Plate Chambers

We built several 10 cm x 10 cm x 1.3 mm Resistive Plate Chambers (RPCs) with single pad readout and Al_2O_3 and TiO_2 coating on the anodes.

Coating of Al_2O_3 was made with magnetron sputtering at Gazi University Photonics Application and Research Center (https://fotonik.gazi.edu.tr/); and the coating of TiO_2 was made with airbrushing after dissolving TiO_2 in ethanol.



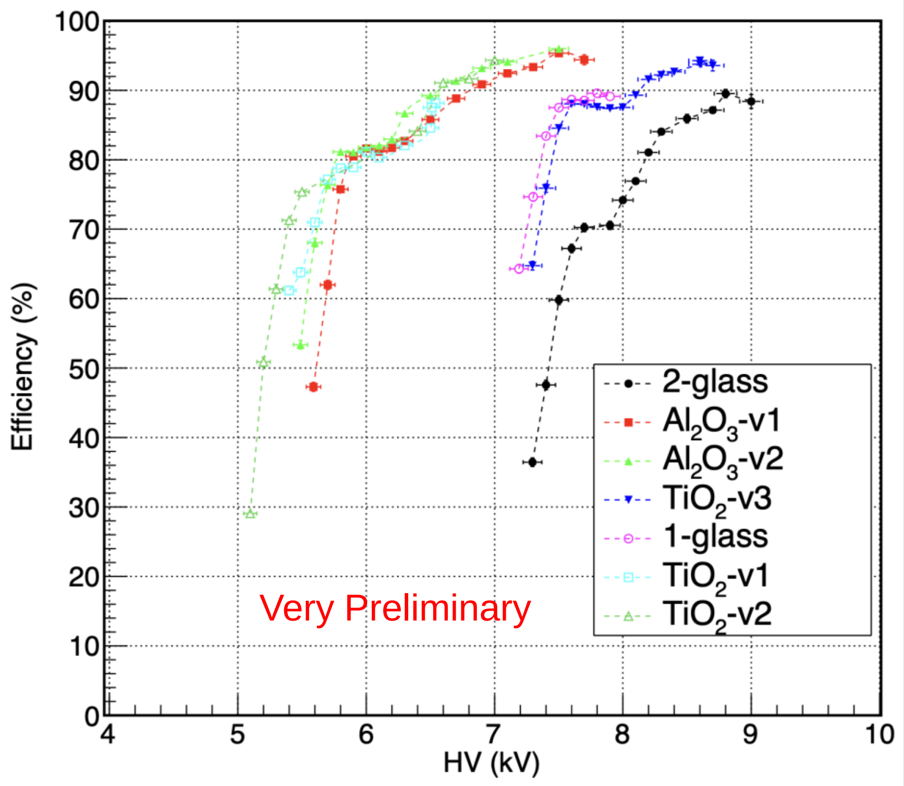


First-Generation Hybrid RPCs

We tested the first-generation hybrid RPCs as well as the standard 1-glass and 2-glass RPCs at Fermilab test beam. The lateral size of the chambers was 10 cm x 10 cm, 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)

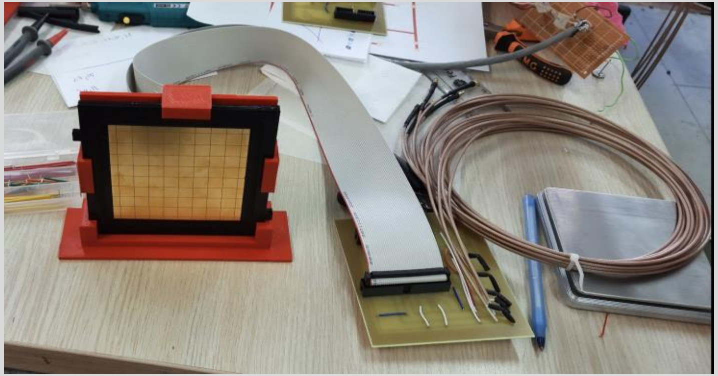


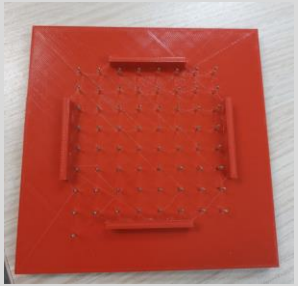
The charge multiplication in the secondary emission layer is qualitatively validated.

Efficient if charge > 300 fC

Second-Generation Hybrid RPCs

The hybrid RPCs with segmented readout of their anodes were constructed and tested at FTBF. The purpose was to study the spatial and timing properties of the various SE coatings in detail.

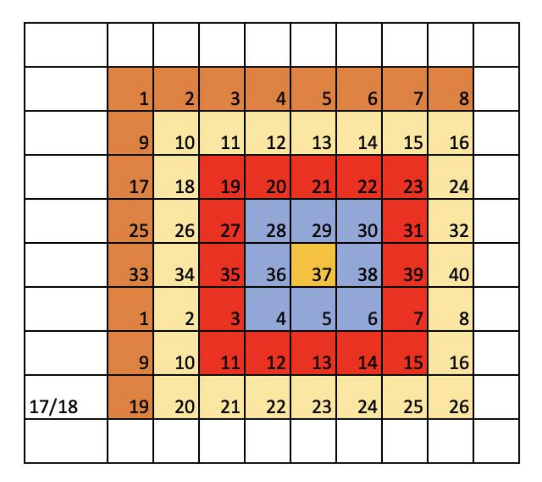


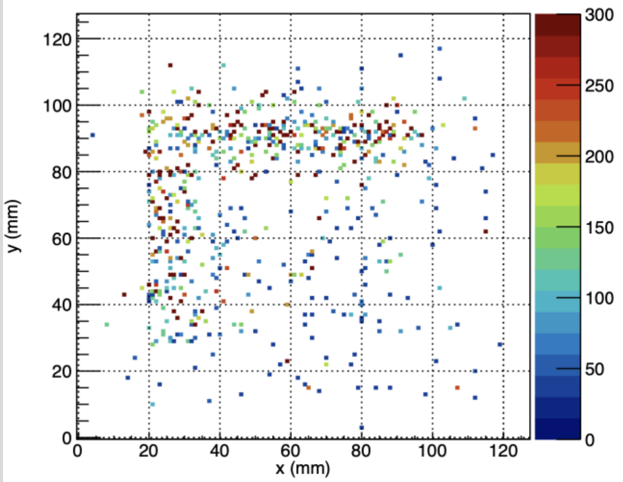


	1	2	3	4	5	6	7	8	
	9	10	11	12	13	14	15	16	
	17	18	19	20	21	22	23	24	
	25	26	27	28	29	30	31	32	
	33	34	35	36	37	38	39	40	
	1	2	3	4	5	6	7	8	
	9	10	11	12	13	14	15	16	
17/18	19	20	21	22	23	24	25	26	

Second-Generation Hybrid RPCs

The figure shows the average avalanche charge as a function of the wire chamber coordinates for the outermost L-shaped readout area. The boundary of the readout area is visible (very low statistics).

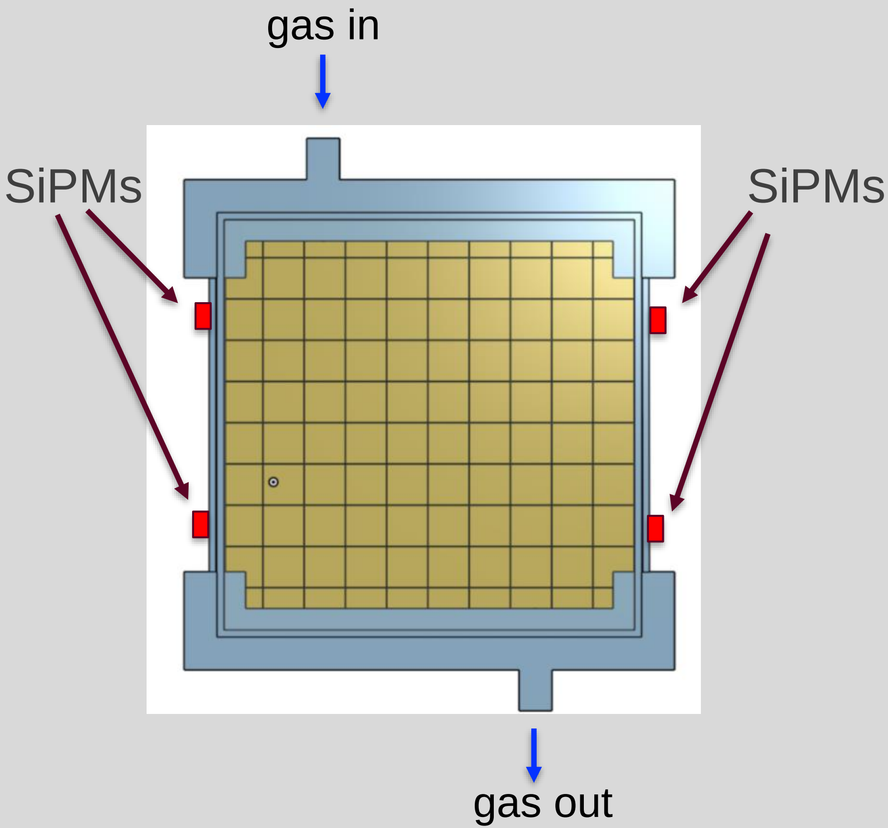




Hybrid RPCs with Optical Readout

- 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 RPCs with Optical Readout - I



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 artistic 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.

SiPM Options:

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

The Conceptual Design of RPCs with Optical Readout - II

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 artistic 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.

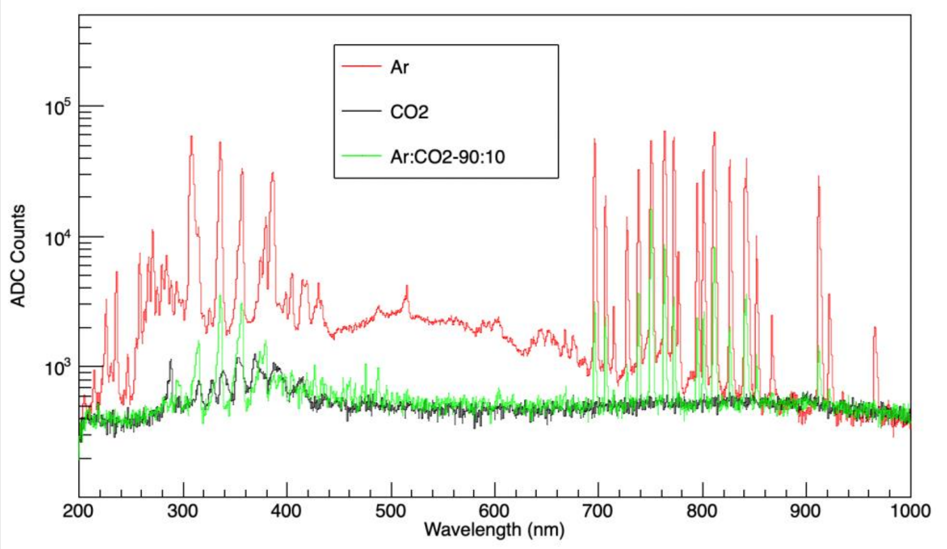
SiPM Options:

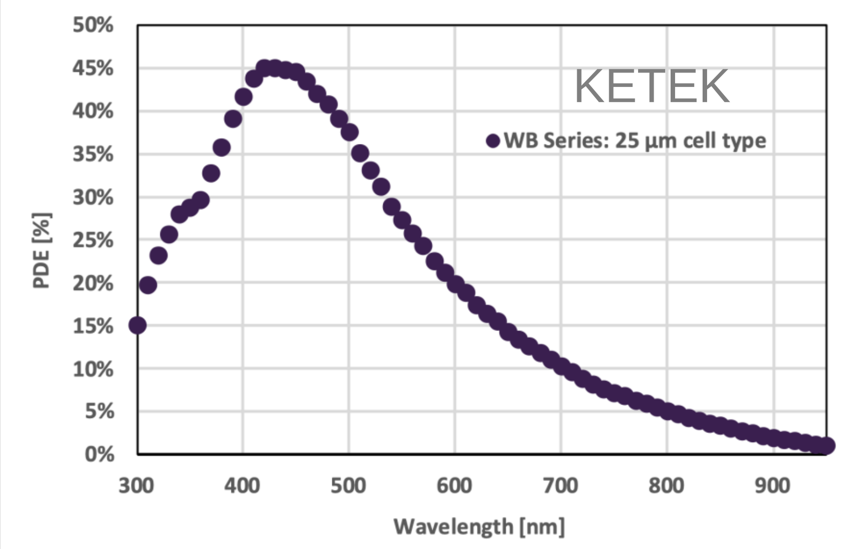
- KETEK PM3325-WB-C0 (3 mm x 3 mm)
- ONSEMI MicroFC-30035 (3 mm x 3 mm)
- BROADCOM AFBR-S4N22P014M (2 mm x 2 mm)

Expected Sensitivity for Hybrid RPCs with Ar-CO_2 Mixtures

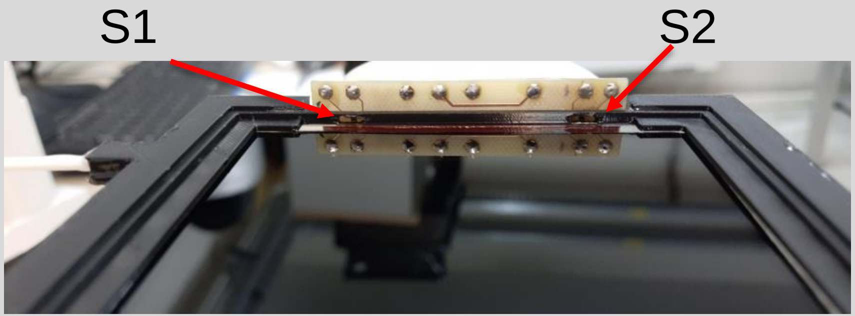
We have an in-house plasma light source and an Ocean Flame-S-XR1-ES spectrometer.

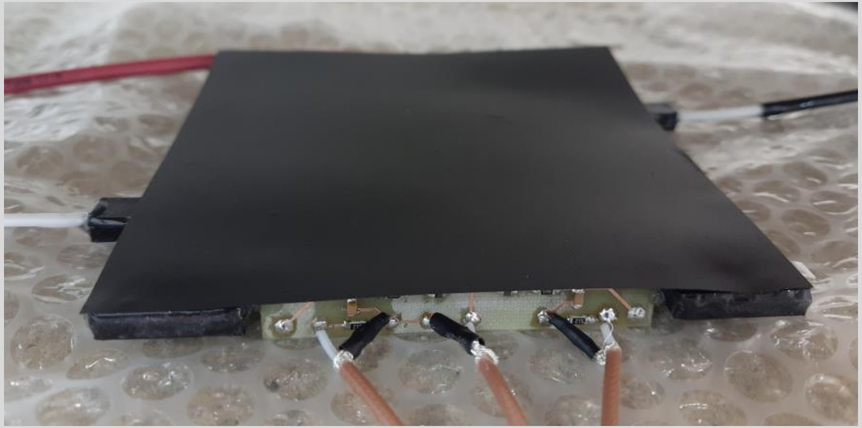
➔ Measurements of the emission spectra of gas mixtures of interest.





Construction and Testing of the First Hybrid RPC with Optical Readout





We made one 10 cm x 10 cm hybrid RPC with 1.3 mm gas gap.

For this version, we used SiPM readout from one side only.

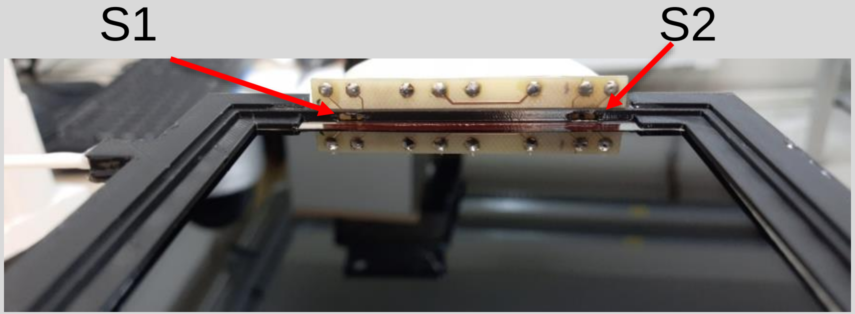
The SiPMs used were KETEK PM1125-WB-C0 (1 mm x 1 mm)

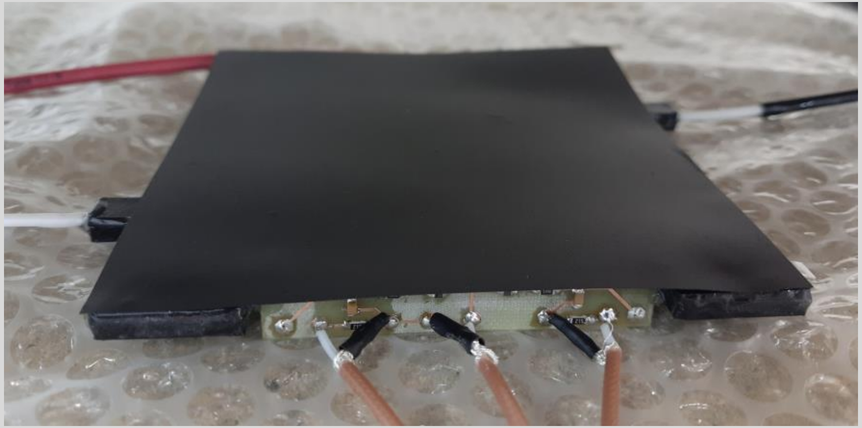
The SiPMs were mounted on a custom 2-sided PCB. On the in-chamber part, only the SiPMs and copper routes are placed. The through-holes and components were on the back side and the extended part.

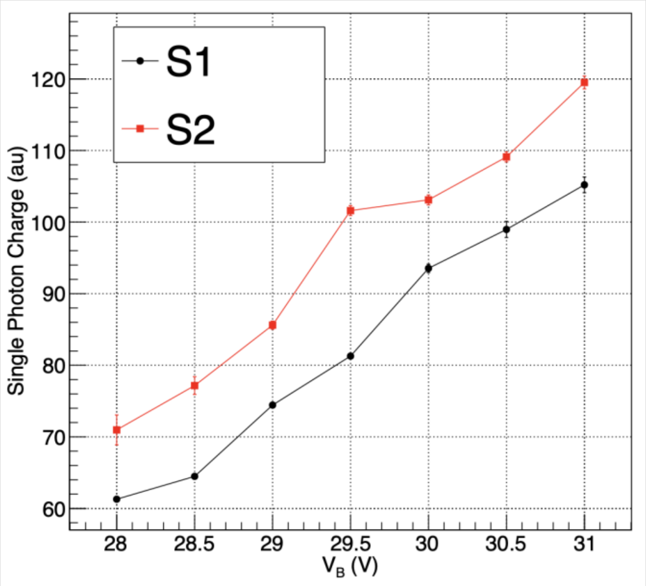
A single bias voltage is shared by the SiPMs and no pre-amplifiers were used.

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

Calibration of the SiPMs

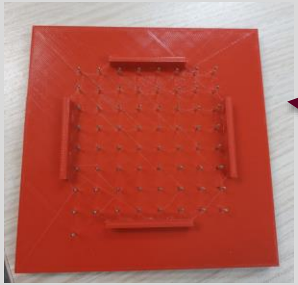






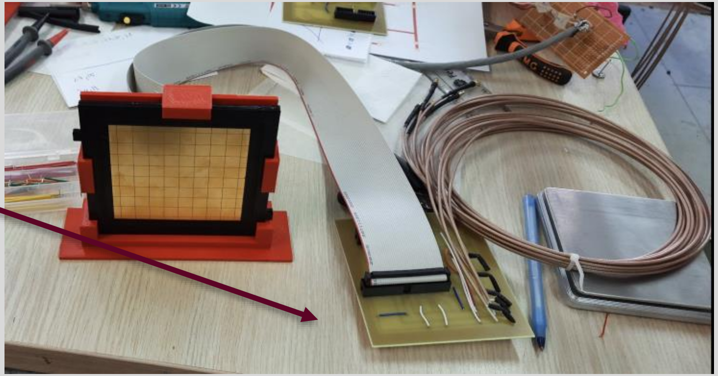
The calibration of the SiPMs <u>after</u> being mounted on the RPC: Following the initial tests, 29 V bias voltage (4 V above the breakdown voltage) was selected as the operating point.

The Readout of the Charge and Optical Signals



The pin board was coupled to the back of the pad board contacting 8 x 8 pads.

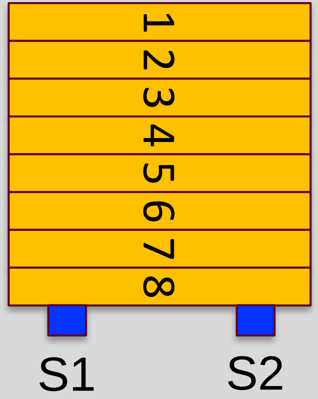
The adapter board combined the signals from pads along rows → 8 readout channels

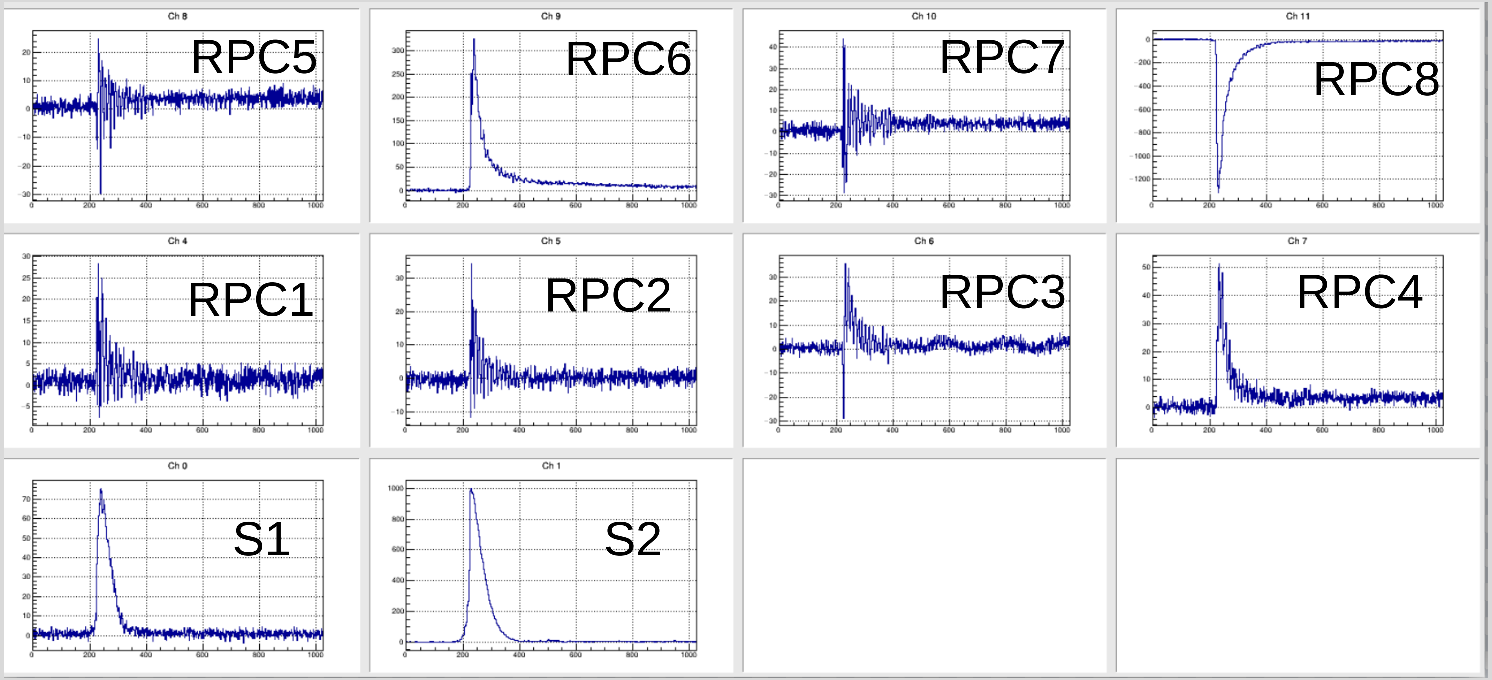


Together with the 2 SiPMs, a total of 10 signals were read out by CAEN v1743 digitizer.

The trigger was set as the OR of the 8 RPC signals below -100 mV.

Sample Event Display

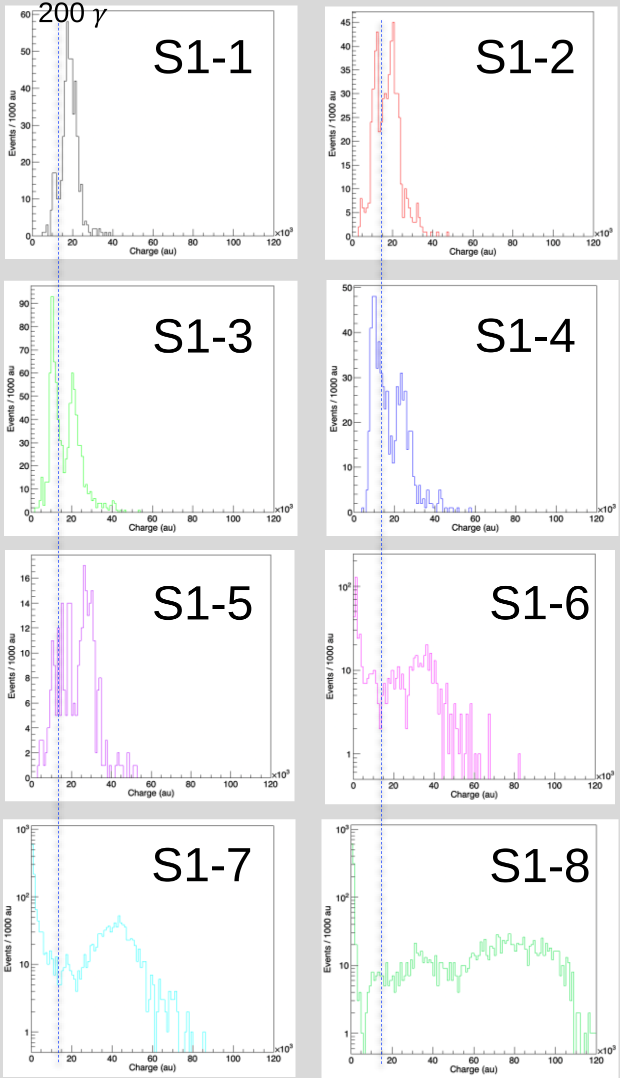




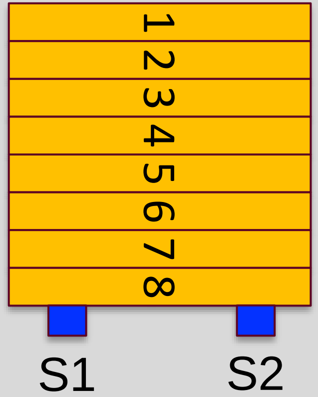
Ionization in RPC region 8, close to S2.

Significant cross-talk between the RPC channels.

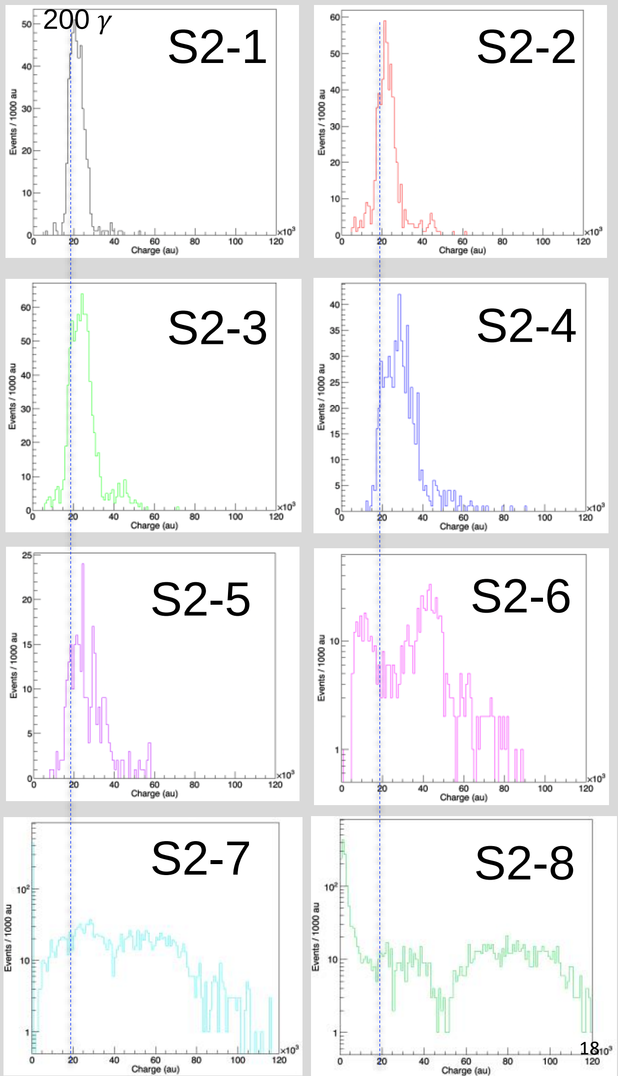
First Measurement of Light in Hybrid RPC-I



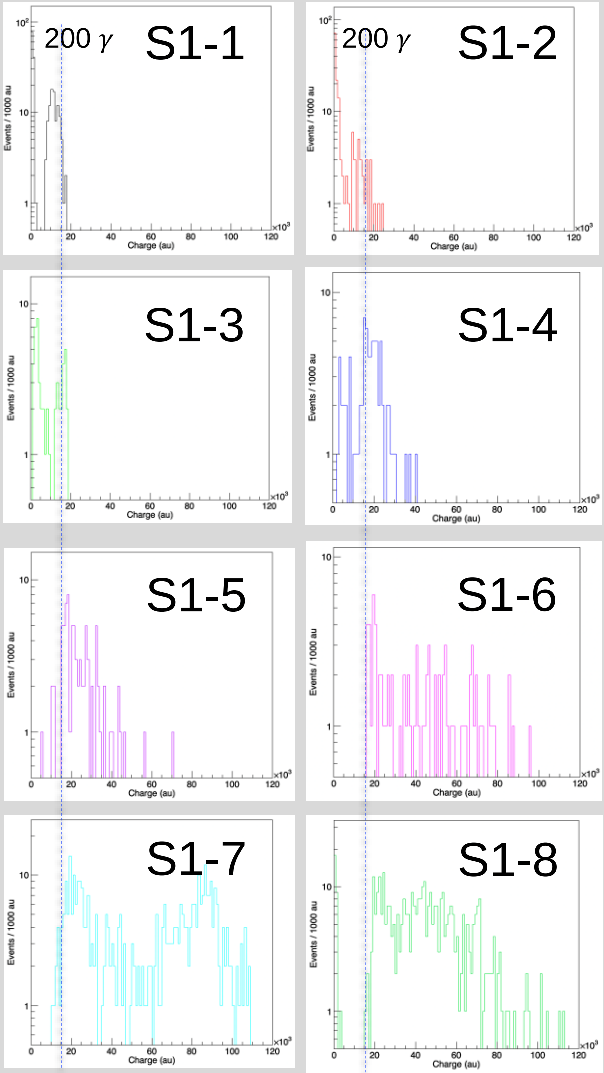
Very preliminary,
considered as qualitative



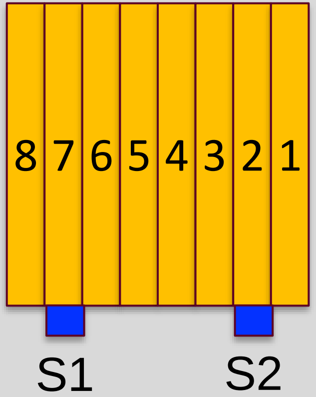
The effect of the field of view is visible; SiPM responses are not completely symmetric; double peak structure needs to be studied further.



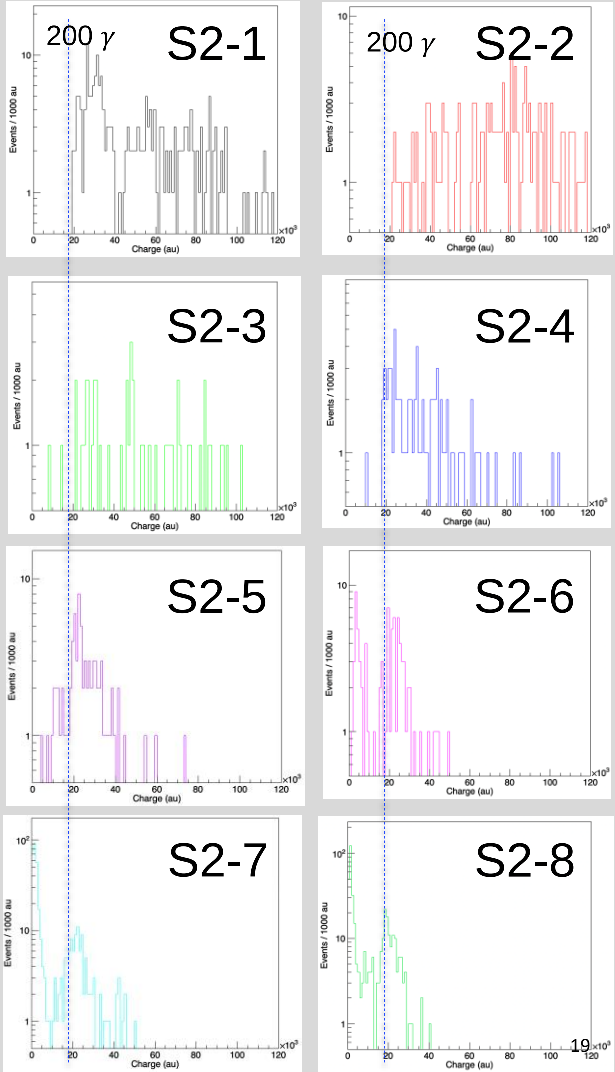
First Measurement of Light in Hybrid RPC-II



Very preliminary,
considered as qualitative



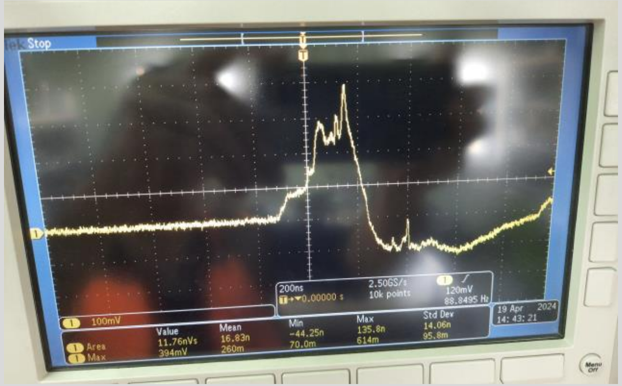
The effect of the field of view is visible (which are different for the two SiPMs); double peak structure needs to be studied further.



Development of Hybrid Drift Tubes

This is a recent development to be used as the beam loss monitoring system at the Turkish Accelerator and Radiation Laboratory.

127 μm diameter nichrome wire coated with TiO_2/Al_2O_3 is used as the central electrode at the center of a 10 mm inner-diameter stainless steel tube. TiO_2 coating is done by dipping the wire in the TiO_2-ethanol bath and letting ethanol evaporate; >90% coating coverage with relatively good uniformity (observed with optical microscope). Al_2O_3 coating is done with magnetron sputtering, ~40% coating coverage with the current wire rotation system.



First Hybrid Drift Tubes

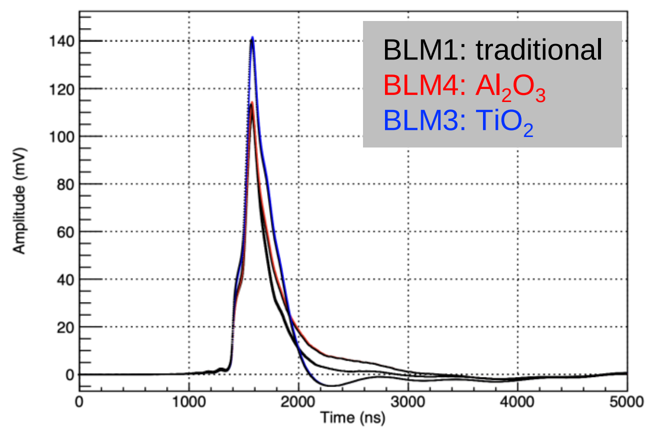
We made 6 drift tubes: 5 hybrid drift tubes and 1 traditional drift tube

BLM1: traditional drift tube

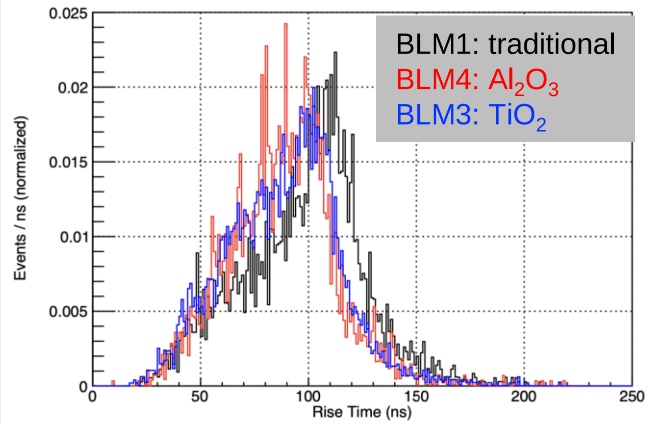
BLM2, BLM3, BLM5, BLM6: TiO_2 coated anode wire

BLM4: Al_2O_3 coated anode wire

Custom readout boards with separate high voltage and signal layers are used.



Average waveforms: Hybrid drift tube pulses are wider than the traditional drift tube pulses. Larger maximum amplitude and increased overshoot for TiO_2-hybrid drift tubes are observed.



Distribution of the Rise Times (5 mV to 50 mV): Hybrid drift tube pulses have faster rising pulses (minimal difference but important for operations). Peaks in the Al_2O_3-hybrid drift tube rise times is due to inhomogeneity of the coating.

Summary

- The development of the hybrid gaseous detectors opens the chapter of functional anodes in gaseous detectors.

- The hybrid gaseous detectors are expected to relax/remove the requirements on gases by shifting part of the electron multiplication in the gas layer to materials with high secondary electron multiplication capability coated on the in-gas anode surfaces.

- Laboratory and beam tests of the developed first-generation hybrid gaseous detectors are underway; their preliminary design, production and working principles are validated.

- The readout of the optical signal generated in the gaseous detectors can provide high-precision information about the spatial and temporal properties of the ionizations.

Future Directions

- 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
- Construct large-size hybrid RPCs to test scalability
- Perform simulation studies to test the feasibility of large-scale implementations