

# LATEST RESULTS FROM MRPC TIME RESOLUTION

■ CRISPIN WILLIAMS

INFN Bologna

## Abstract

The Multigap Resistive Plate Chamber (MRPC) is an important detector that was inspired with the R&D performed by the LAA project. The latest results from this detector will be presented. The NINO asic, used as the front-end amplifier/discriminator, will also be described.

## 1. Introduction

We have heard already about the LAA project set up at CERN in the 1980's by Professor Zichichi. In this paper, I will talk about one of the inventions that resulted from the LAA project, the 'Multigap Resistive Plate Chamber'. This device has revolutionised the time-of-flight (TOF) arrays used in particle physics throughout the world. As an example, the ALICE TOF array is an excellent candidate. This is a detector in form of a barrel of radius 3.7 m and 7 m long. It has 160,000 readout channels. Currently it is taking data and typically the system time resolution of the whole detector is  $\sim 80$  ps. To achieve such a resolution, one needs a detector with excellent and stable timing characteristics and that is easy to calibrate, and also very good front-end electronics. To this end, we developed, within the LAA project, a special front-end asic, known as the 'NINO': this asic will also be briefly described in this paper.

The precise measurement of the time it takes a particle to travel a certain distance is, in reality, a measurement of its velocity. This measurement, together with the momentum, measured from the curvature of tracks inside the magnetic field, allows the mass of the particle to be calculated. This is a very important aspect in particle physics as it classifies

the particle: all known stable particles have different mass. Thus with a TOF array one can search, for example, for strangeness enhancement, an important signature of the formation of quark-gluon plasma, a new state of matter expected to be observed with the ALICE detector with heavy-ion collisions.

## 2. The Multigap Resistive Plate Chamber (MRPC)

The Multigap Resistive Plate Chamber (MRPC) was invented in 1996 [1]. Since its conception, it has had particularly stable operating characteristics. The key difference between the MRPC and the more traditional single-gap resistive plate chamber (RPC), is that the multigap consists of a series of gas gaps all read out with a single set of readout pads. These gaps are created by inserting extra plates of resistive material in-between the two outer resistive plates. These extra resistive plates are allowed to electrically float, however there is a strong feedback mechanism that keeps all the plates at the correct voltage.

The detector built for the ALICE TOF [2] used glass plates for the resistive material and fishing line (250 micron diameter) as spacers between these plates. A schematic of the cross section of the detector is shown in figure 1.

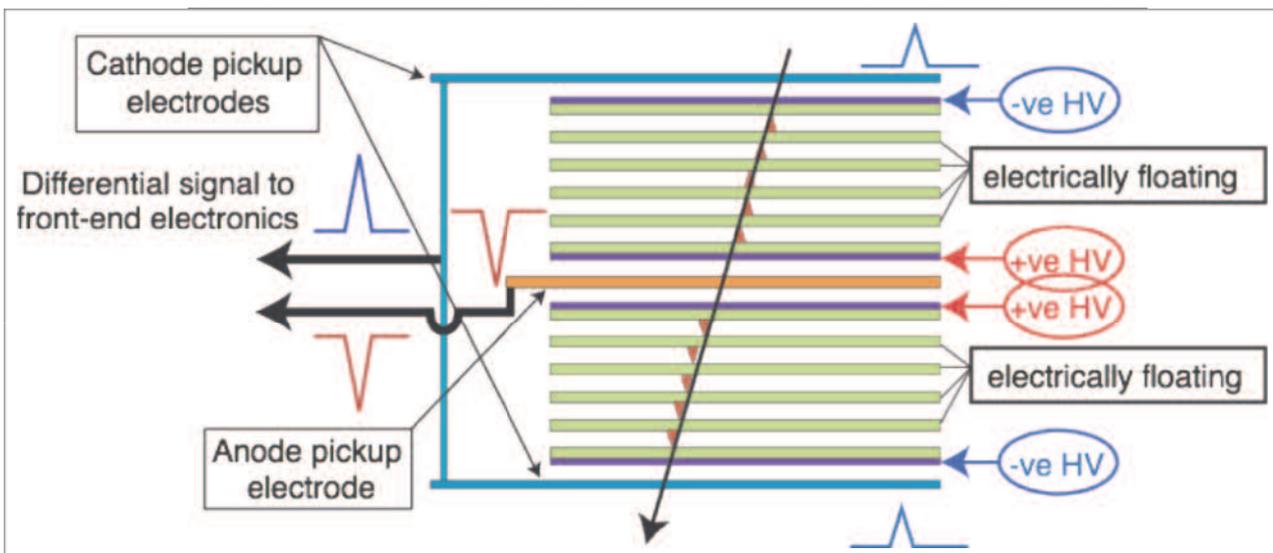


Figure 1: ALICE-TOF has 10 gas gaps (two stacks of 5 gas gaps). Each gap is 250 micron wide; it is built in the form of strips, each with an active area of  $120 \times 7.2 \text{ cm}^2$  and readout by 96 pads.

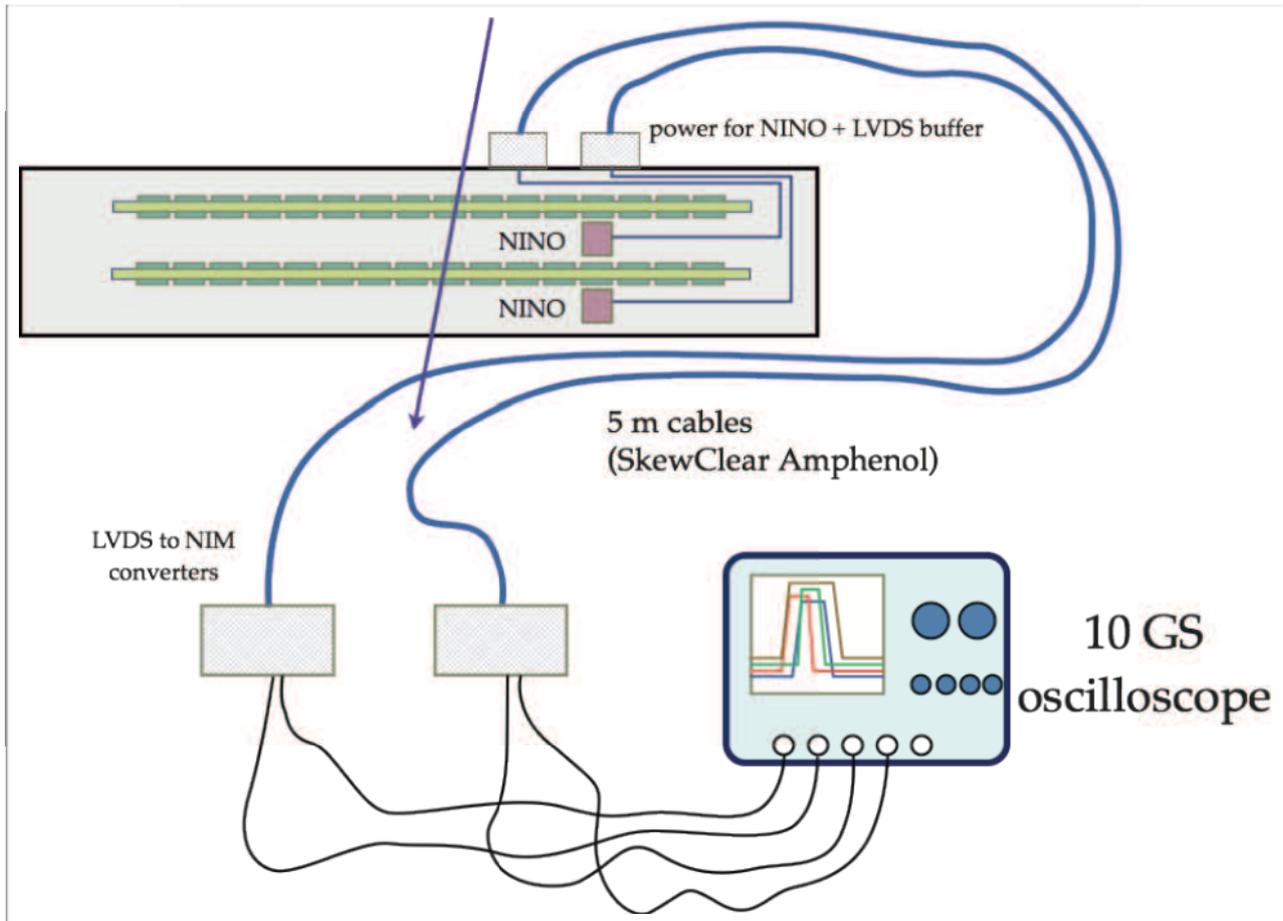
Since these internal plates are electrically floating, it makes the detector particularly easy to build. One simply stacks up the resistive plates and separates them with a spacer, fishing line is commonly used. However there are other important benefits of this type of detector that used very narrow gas gap, such as space charge effects that limit the growth of the avalanche. This effect limits the transition to streamers, and thus there is a long efficiency plateau versus voltage that is completely streamer-free. In addition, the positive and negative ions created in the gas gap recombine [3] rather than drift to the resistive plates. This allows the MRPC to operate at higher particle fluxes than expected.

The performance of the ALICE TOF is well documented [4]. It should be also noted that the same voltage is applied to all the MRPC modules and all the thresholds are set to the same value.

The performance of the MRPC in the ALICE TOF is exceptional and now there are many experiments that have followed the lead of ALICE, such as STAR at RHIC [5] and FOPI at GSI [6]. All these arrays are operating with a time resolution below 100 ps. However the question remains concerning what time resolution can be achieved with this detector.

The system time resolution of 80 ps for the ALICE TOF is made up of many contributions. The most important ones concern the track length. The trajectory of the particle is extrapolated from the TPC (that has an outer radius of 2.5 m) to the surface of the TOF detector at 3.7 m. In addition the pads of the ALICE TOF are read out only on one side so there is a correction that has to be made according to the impact point. There is also the time resolution of the TDC and the jitter introduced by the front-end electronics and cables. The actual intrinsic time resolution of the ALICE TOF MRPC is 15 ps. Given this, there are those who dream of an array that is capable of obtaining an overall resolution of 10 ps. Can the MRPC be used for such an array?

An important improvement can be made by reading out both sides of the readout pad and obtain two times,  $t_{\text{left}}$  and  $t_{\text{right}}$ . The time difference ( $t_{\text{left}} - t_{\text{right}}$ ) will give the position along the pad while the average time sum  $(t_{\text{left}} + t_{\text{right}})/2$  will give the time that the particle passed through the MRPC, and this time is independent of the hit position along the readout pad. The time resolution of the MRPC can also be improved by making the gas gaps smaller



*Figure 2: Two 24 gap MRPCs mounted one behind the other. The time of one MRPC was measured with respect to the other and the time resolution extracted.*

and by having more of them. In figure 2 we show a schematic of a particular test setup. Two 24 gap MRPCs were placed in a gas box, one behind the other. Each MRPC is arranged in 4 stacks of six gaps; the gap size is 160 micron. The front-end electronics (the NINO ASIC) was mounted on the chamber itself inside the gas volume. Since we do not have a TDC with suitable time resolution, a four channel digital oscilloscope was used to record the times. The complete setup is shown in figure 3.

The results of testing these chambers in a test beam at CERN (T10 of the East Hall) are shown in figure 4. A time resolution of 16 ps was obtained. We expect that the intrinsic time resolution of such an MRPC to be 8.5 ps and the contribution of the measuring system to be also 8.5 ps giving a total of 12 ps. Thus 16 ps, although excellent still has room for improvement. Details of these tests can be found in ref [7]

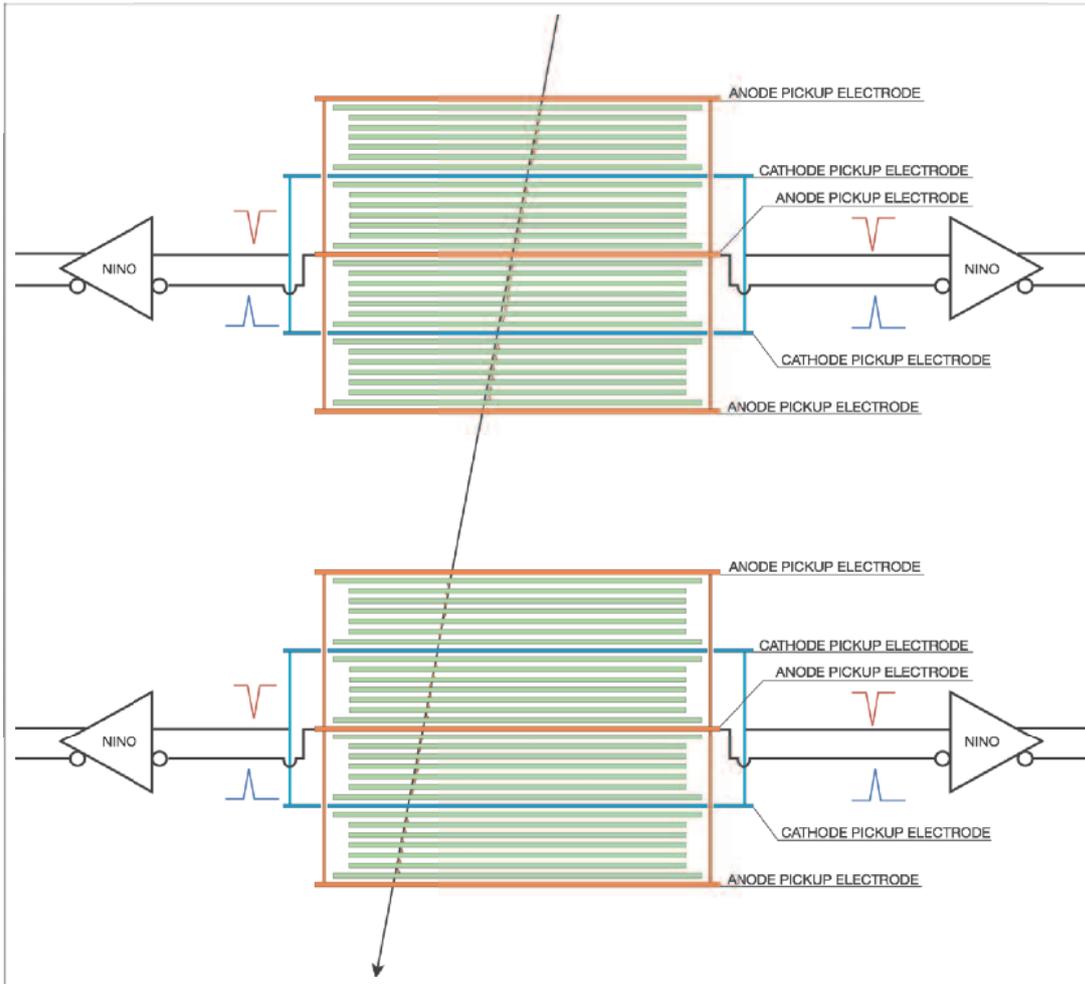


Figure 3: The two 24 gap MRPCs mounted one behind the other in a gas tight box. The front-end amplifier/discriminator (NINO ASIC) was mounted on the MRPC strip as close to the pickup pad as possible. To obtain the necessary time resolution, a digital oscilloscope was used to record the times of the signals.

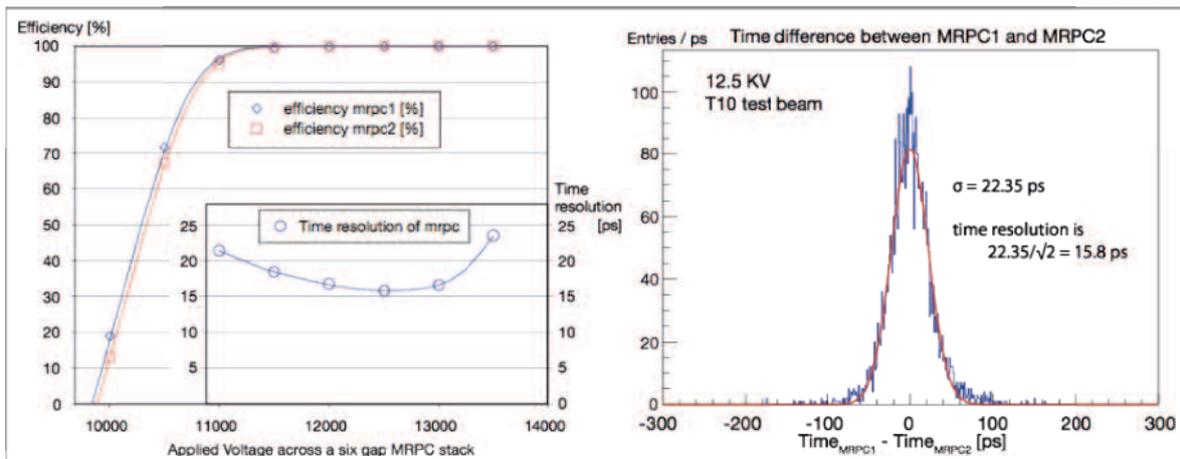


Figure 4: The time difference between MRPC1 and MRPC2 is shown by the histogram on the right hand side. The plot on the left hand side shows the efficiency and the time resolution as a function of applied voltage.

### 3. The NINO ASIC

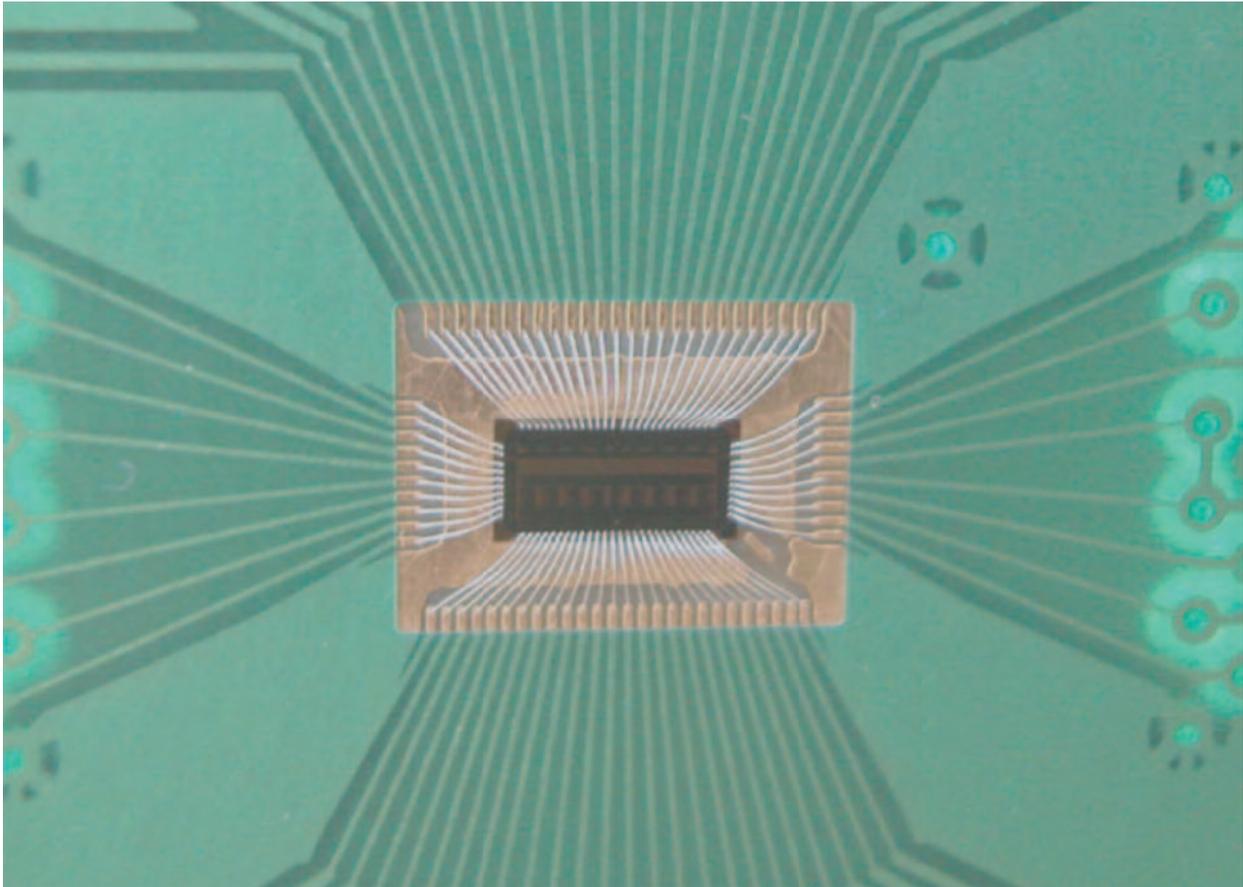
A critical device for precise timing is the front-end electronics. The lowest noise front-end electronics is a single-ended amplifier followed by a discriminator. A differential front-end multiplies the electronic noise by  $\sqrt{2}$ . However, and especially for large devices, the intrinsic noise of the electronics is not the dominating contribution. Instead, the biggest contribution comes from the detector itself. Single-ended electronics measures everything with respect to ground; however all the other channels inject fast current pulses into the ground and this becomes dominant source of noise for large systems. Early on during the ALICE TOF R&D phase, we found that we could not get better time resolution than 150 ps when testing an MRPC built as single-ended device (anode readout pads and a common cathode plane). However this time resolution improves dramatically when a differential signal is derived from the MRPC; this can be easily seen with the result from the previous section. Thus a key ingredient for precise timing is a detector that produces a differential signal and front-end electronics designed to fully exploit it. The NINO asic [8], developed within the LAA project, is just such electronics.

The NINO asic was designed with the following criteria: (a) differential architecture throughout; (b) fast peaking time, (1 ns) to minimise jitter; (c) input charge encoded into the width of the output pulse (so that a charge measurement can be made with a TDC measuring the leading and trailing edges of the output pulse); (d) low power (45 mW/channel). This asic was realised in 0.25 micron CMOS. In figure 5 the first NINO prototype is shown bonded to a PCB.

The jitter of the NINO amplifier/discriminator is very low - we measured 2 ps on the test bench, but much of this measured jitter was contributed by the test set up. This asic has quickly becoming the 'asic of choice' in all experiments that require precise timing.

### 4. Conclusions

The LAA project was dedicated to advance R&D in detectors used for particle physics, and the Multigap RPC and the NINO asic are two examples where the frontiers have been pushed back.



*Figure 5: A photograph of the NINO prototype binded to PCB. Subsequently it was packaged in a plastic TAPP package and soldered onto the PCB used for the ALICE front end.*

The MRPC has now generated a new interest in ‘time of flight’ arrays. It is now possible to build a highly segmented TOF that has exceptional timing. This is extremely relevant to heavy ion physics and has generated a wave of new TOF arrays in Europe and the United States.

## References

1. E. Cerron Zeballos, I. Crotty, D. Hatzifotiadou, J. Lamas-Valverde, S. Neupane, M. C. S. Williams, A. Zichichi, “A new type of resistive plate chamber: the multigap RPC”, Nucl. Instr. Meth., vol. A374, pp. 132-135, 1996.
2. A.N. Akindinov et al., “Latest results on the performance of the multigap resistive plate chamber used for the ALICE TOF”, Nucl. Instr. Meth., vol. A533, pp 74-78, 2004.

3. K. Doroud, H. Afarideh, D. Hatzifotiadou, J. Rahighii, M.C.S. Williams, A. Zichichi, “Recombination: An important effect in multigap resistive plate chambers”, *Nucl. Instr. Meth.*, vol. A610, pp 649–653, 2009.
4. A. Akindinov et al., “The MRPC-based ALICE Time-Of-Flight detector: Commissioning and first performance”, *Nucl. Instr. Meth.*, vol. A661, pp S98-S101, 2012.
5. W.J. Llope for the STAR Collaboration, “Multigap RPCs in the STAR experiment at RHIC”, *Nucl. Instr. Meth.*, vol. A661, pp S110-S113, 2012.
6. M. Kiš et al. “A Multi-strip Multi-gap RPC Barrel for Time-of-Flight Measurements”, *Nucl. Instr. Meth.*, vol. A646, pp 27–34, 2011.
7. S. An, Y.K. Jo, J.S. Kim, M.M. Kim, D. Hatzifotiadou, M.C.S. Williams, A. Zichichi, R. Zuyeuski, “A 20 ps timing device—A Multigap Resistive Plate Chamber with 24 gas gaps”, *Nucl. Instr. Meth.*, vol. A594, pp 39–43, 2008.
8. F. Anghinolfi, P. Jarron, A.N. Martemiyarov, E. Usenko, H. Wenninger, M.C.S. Williams, A. Zichichi, “NINO: an ultra-fast and low-power front-end amplifier/discriminator ASIC designed for the multigap resistive plate chamber”, *Nucl. Instr. Meth.*, vol. A533, pp 183–187, 2004.