Study of the charge induced by relativistic particles of different masses in MRPC detectors

INTRODUCTION

In this project the study of the growth of the electron avalanches produced by ionizing particles in the extremely high electrical field existing in RPC detectors is proposed. Although the process has previously been thoroughly studied using simulation methods [1] our aim is to measure the charge produced by the passage of relativistic particles of different masses using the CERN's MRPC detector around the ionization minimum at $\beta \cdot \gamma \sim 3$ [2, 3].
Unlike other detectors of the gas ionization family, the peculiarity of Multigap Resistive Plate Chambers [4] is that the primary ionizations occur within the same region where the electron amplification is produced. This unusual feature might have unforeseen space-charge effects worth analyzing. A possible evidence of one of these effects might have been already detected in the data of RPC TOF wall of the HADES spectrometer [5], at GSI (Darmstadt) where, as it is shown in Figure 1, a mass scaling or the median charge as a function of the velocity of the charged particles was observed.

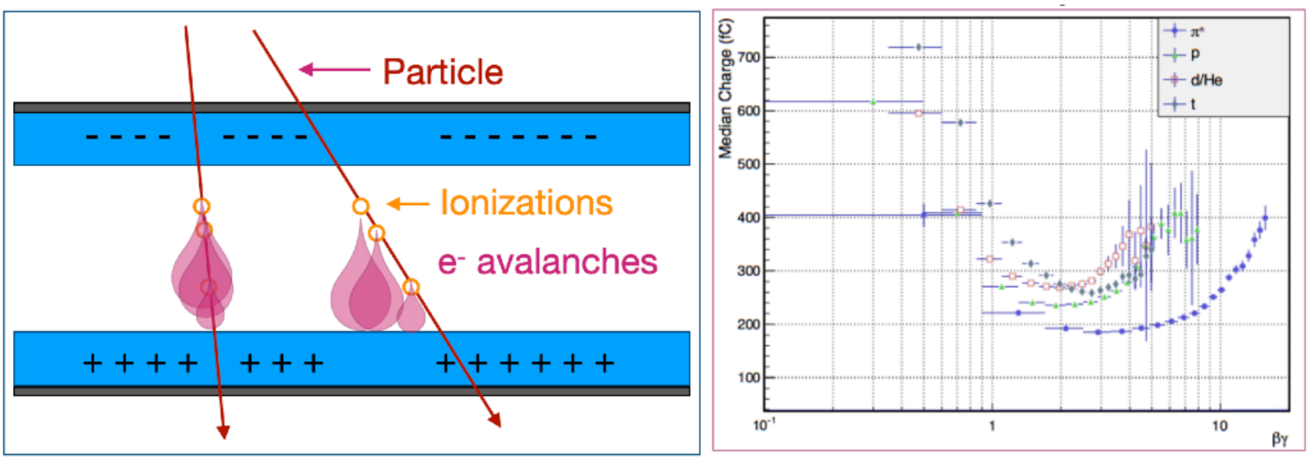

Figure 1. Left) Electron avalanches development in a Resistive Plate Chamber for an incident particle. At low angles the secondary avalanches growth inside a large distorted external electrical field. Right) Medians of the charges of particles of different masses measured by the HADES RPC ToF wall. An especially significant mass scaling effect is observed for $\beta \cdot \gamma > 3$.

Why we would like to go to CERN

The members of the Enrico Fermi Physics Club are students from different High Schools in the area of Vigo (Spain). The Club meets regularly to discuss issues and news related to modern aspects of the Physics.

Enrico Fermi was known to be an excellent theoretical and experimental physicist. Nowadays, physics is taught mostly from a theoretical perspective, lacking all the beauty and insight of experimental physics. For us, it is crucial to perform experiments and take actual measurements!

This aspect of physics is a driving force for us since the beginning of the BL4S program. Our team have already been shortlisted three times in BeamLine for Schools, and we are confident this time the dreams of the students might come true.

Description of the experiment

Our proposal is to study the charge induced by ionizing particles of different masses (pions, kaons and protons), at different velocities and at different incident angles effect in MRPCS detectors. The layout of the proposed experiment is shown in Figure 2.

Particles of different masses coming from the T9 beam will be selected through their time of flight (ToF) using two scintillators, S1 and S2, placed at a distance of 10 m. Complementarily, the times provided by the MRPCs will be used for a more accurate measurement of the velocity of the particles. Data will be acquired with the three available MRPCs, placed at the angles 0°, 5° and 37° between the incident particle and the avalanche direction.

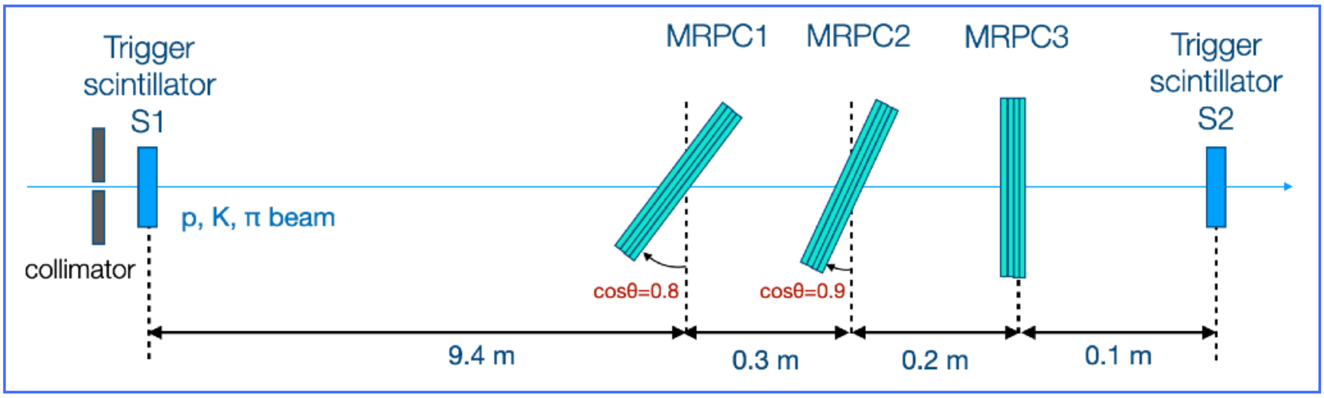

Figure 2. Proposed setup of the experiment. The trigger scintillators are placed at 10 m downstream maximizing the time of flight of the particles and the capability of the system for separating particles of different masses. The three MRPCs are placed at different angles in order to analyze the angular dependence of the induced charges.

Table 1 shows the expected ToF of pions, kaons and protons at given values of the beam momentum and the capability of the arrangement to separate particles of different masses measured in standard deviations. Following the BL4S [6] document, approximate time resolutions of 250 ps for a single scintillator, 150 ps for a single MRPC and 350 ps for a scintillator-MRPC pair were assumed. The joint use of the time provided by all the detectors will increase significantly the mass separation performance.

10	Beta·Gamma			ToF/ns			dToF/ns			nSig (2 Scintillators)			nSig (1 Scint+1MRPC)		
P/(GeV/c)	Pi	K	Proton	Pi	K	Proton	Pi-K	Pi-P	K-P	Pi-K	Pi-P	K-P	Pi-K	Pi-P	K-P
0.3	2.1	0.6	0.3	36.8	63.8	109.6	27.1	72.9	45.8	76.5	206.1	129.5	92.8	249.9	157.1
0.4	2.9	0.8	0.4	35.3	52.7	85.1	17.4	49.8	32.4	49.2	140.9	91.7	59.7	170.9	111.2
0.6	4.3	1.2	0.6	34.2	43.0	62.0	8.8	27.7	18.9	24.9	78.4	53.5	30.2	95.1	64.9
1.2	8.6	2.4	1.3	33.6	36.0	42.3	2.4	8.8	6.3	6.9	24.8	17.9	8.4	30.1	21.7
1.5	10.7	3.1	1.6	33.5	35.1	39.3	1.6	5.9	4.3	4.5	16.6	12.1	5.4	20.1	14.6
2	14.3	4.1	2.1	33.4	34.3	36.8	0.9	3.4	2.5	2.6	9.7	7.1	3.1	11.7	8.6
2.5	17.9	5.1	2.7	33.4	34.0	35.6	0.6	2.2	1.6	1.6	6.3	4.7	2.0	7.6	5.6
3	21.4	6.1	3.2	33.4	33.8	34.9	0.4	1.6	1.2	1.1	4.4	3.3	1.4	5.4	4.0
3.5	25.0	7.1	3.7	33.4	33.7	34.5	0.3	1.2	0.9	0.8	3.3	2.4	1.0	4.0	2.9
4	28.6	8.2	4.3	33.4	33.6	34.2	0.2	0.9	0.7	0.6	2.5	1.9	0.8	3.0	2.3

Table 1. Summary of the expected capability of the proposed layout to analyze particles in different energy ranges. The first cell of values shows the beta-gamma factors for each particle and each beam momentum. The second cell shows the differences in the time of flight between each pair of particles for a total distance of 10m. The last two cells show the expected number of standard deviations for identifying particles using a pair of scintillators and a scintillator and a MRPC. Orange and green small cells show the values we have chosen for the proposed experiment.

Table 2 shows the expected rates of the three particles at the beam momenta proposed and the corresponding times needed for acquiring a sample of 100 K events per run. As, usually, RPCs cannot be operated in high rate environments and assuming a rate limit of 1 kHz/cm^2, the corresponding reduction factor of the beam at different energies has been estimated. If such reduction was not possible, data are to be collected placing the detectors in the beam halo.

	Estimated # Particles/Spill/1000				Estimated # Partícles/cm2·s/1000				Reduction
P/(GeV/c)	Pi	K	P	Total	Pi	K	P	Total	Factor
0.3	10	1	7	18	8	1	5	14	14
0.4	12	1	7	20	10	1	6	16	16
0.6	18	2	10	30	14	1	8	24	24
1.2	60	5	4	69	48	4	3	55	55
1.5	90	8	40	138	72	6	32	109	109
2	110	10	50	170	88	8	40	135	135
2.5	150	13	70	233	119	10	56	185	185
3	200	18	85	303	159	14	68	241	241
3.5	210	20	100	330	167	16	80	263	263
4	220	22	130	372	175	18	103	296	296
Wanted Sample/1000		100							
	Expected # Partícles/cm2·s/ spill			Red. # Partícles/cm2·hour/100			Time /Hours for Wanted Sample		
P/(GeV/c)	Pi	K	P	Pi	K	P	Pi	K	P
0.3	571	57	371	69	7	45	1	15	2
0.4	591	64	345	71	8	41	1	13	2
0.6	604	60	336	72	7	40	1	14	2
1.2	870	72	58	104	9	7	1	12	14
1.5	655	55	291	79	7	35	1	15	3
2	647	59	294	78	7	35	1	14	3
2.5	644	56	300	77	7	36	1	15	3
3	660	59	281	79	7	34	1	14	3
3.5	636	61	303	76	7	36	1	14	3
4	591	59	349	71	7	42	1	14	2
				Total time required/hour			6.5	71.2	10.9

Table 2. Up. Estimated rate expected for different particles at different momenta for the nominal beam intensity. The reduction factor is calculated to limit the rate in the MRPCs to 1KHz particles/cm^2. Down. Corrected rate of particles per spill and integrated number of particles per hour. The last box shows the time needed for the different particles and momenta to reach a data sample of 10^5 events.

The experimental setup:

The scheme of our experiment is shown in Figure 2. The devices needed are the following:

1. Beam collimator, to limit the rate to a maximum of 1kHz/cm^2.
2. 2 scintillators, to trigger the data acquisition system, separating particles of different masses using a Time of Flight method, and to trigger the QDC.
3. Three MRPC detectors.
4. Read out electronics. The tentative block diagram is shown in Fig. 3. The definitive one will be defined together with the CERN experts depending on the characteristics of the available devices.

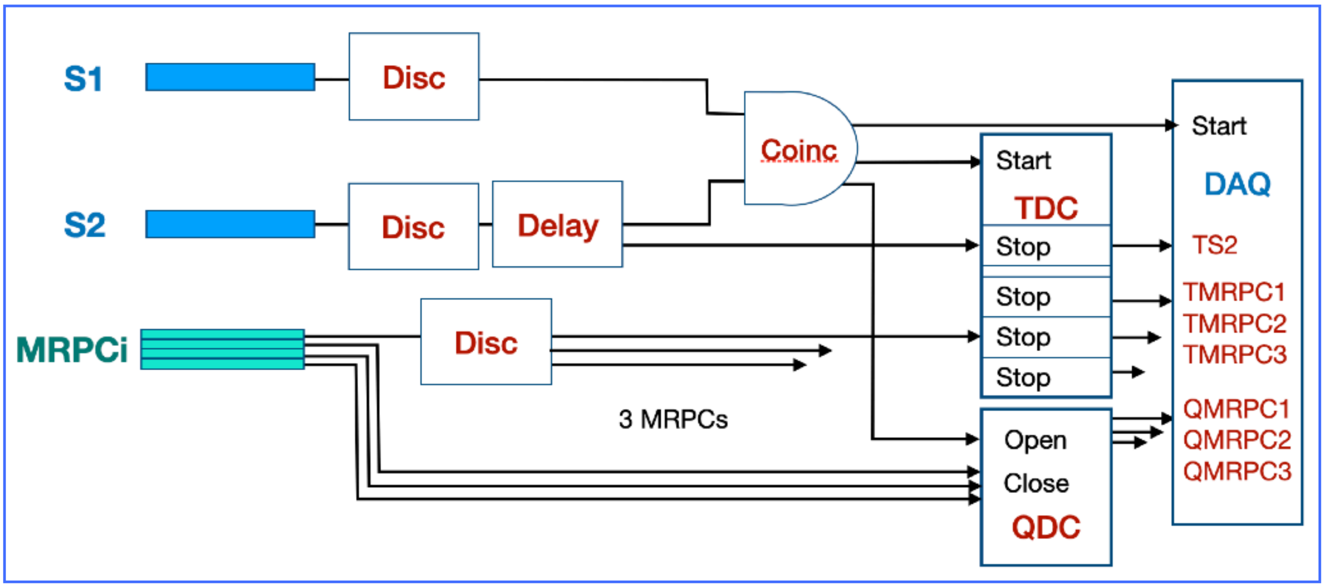

Figure 3. Tentative block diagram of the DAQ system.

Experimental method:

Our proposal is to measure the charge induced by pions, kaons and protons of different velocities in the MRPCs. For each particle, data will be collected at 4 points around the Bethe-Bloch minimum, at $\beta \cdot \gamma \sim 3$. Our interest lies solely in the central strips of the MRCP detectors, that are fired by the beam. For each particle, the acquisition will be triggered by a coincidence between S1 and S2, with a given delay that depends on the chosen particle.

The main variables to be analyzed are the time of flight of each particle measured by the TDC and the corresponding charge measured by the QDC. For each beam energy, the main statistical variables of the charge distribution (mean, median and standard deviation) will be analyzed at three different angles, looking for the effect shown in Figure 1, right.

Schedule:

Our experiment is scheduled to run in around 8 days. Additional days will be reserved for extra runs if necessary and the analysis of the data. The tasks to be performed each day are the following:

Days 1-4: Experiment and layout commissioning

Day 5. Pion run at 4 energies.

Day 6. Proton run at 4 energies

Days 7-8 and previous nights: Kaon run at 4 energies

What we hope to gain from this experience

Making a particle physics experiment at CERN will be an amazing experience for the chance of living an outstanding scientific experience in many areas: the commissioning of an experiment, becoming familiar with Particle Physics instrumentation and concepts (radiation-matter interactions, special relativity…), collecting data with particles detectors, learn about data acquisition systems and performing data analysis looking for statistically significant conclusions. It is also worth to make a special mention to the opportunity of working in teams, collaborating with CERN experts.

Acknowledgements

We acknowledge all the help provided by Margherita Boselli y Markus Joos, from CERN, in the ZOOM meetings and e-mails. We also express our gratitude to Alberto Blanco (LIP, Coimbra), Pablo García Abia (CIEMAT, Spain), Juan A. Garzón (Univ. of Santiago de Compostela, Spain) and Georgy Kornakov (Warsaw Tech. University, Poland) for all their ideas and corrections to this proposal.

References

[1] C. Lippmann, W. Riegler and B. Schnizer. “Space charge effects and induced signals in resistive plate chambers”. Nucl. Instr. Meth., vol. A508 (2003), pp. 19-22.

[2] G. Knoll. “Radiation detection and measurement”. J. Wiley & Sons, 2010.

[3] P. Ladrón de Guevara. Principios de detectores de partículas. CIEMAT 2008. Madrid

[4] P. Fonte, A. Smirnitski and M. C. S. Williams, "A new high-resolution TOF technology", Nucl. Instr. Meth., vol. A443 (2000), pp. 201-204.

[5] G. Kornakov. “New advances and developments on the RPC TOF Wall of the HADES Experiment at GSI”. Phd. Thesis. Univ. Santiago de Compostela, 2012.

[6] CERN BL4S. Beamline for schools. cern.ch/bl4s.

Extension Proposal

The Enrico Fermi Physics Club (https://fermiclub.blogspot.com) appeared several decades ago to introduce High Energy Physics to High School students in the Vigo area. This topic was not included in the Physics programs, and the director of the Enrico Fermi Physics Club, who participated in the HST 2000 at CERN, decided to involve students into studying this, because of the attraction of the topic.

Every year, the Club announces the beginning of its activities through the press and the High Schools of the city. More than 20 generations of students have already participated in the Club. It should be mentioned that we have achieved that among the participants the number of girls is equal to or even higher than that of boys. Many of our participants have decided to study Physics at the Universities and we have involved many smart and intelligent students into Physics, and with this we have contributed to science.

The BL4S contest fits perfectly with our goals. We have always presented ourselves and winning in the BL4S would be great, we would level-up from being known not only in our city but in the whole country.