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DESIGN AND REJECTION STUDIES FOR A CYLINDRICAL TRANSITION RADIATION DETECTOR FOR THE UA2 UPGRADE

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Abstract : A study of a compact and cylindrical transition radiation detector is described. A prototype has been built and tested with 40 GeV electrons and hadrons. The measurements have been done using 100 Mhz FADC. We have compared different radiators and chamber geometries using various algorithms. The cluster counting and the total integrated charge methods give comparable results. A comparison between radiators of lithium and polypropylene is made.

I. INTRODUCTION

The UA2 detector took its first data in 1981 and has been smoothly operated since then. The very successful performance of the Sp $\bar{p}$ S collider has given the opportunity to collect a large amount of very fruitful data.

After a long shut-down in 1986, the collider will resume operation with a substantially higher luminosity than presently available. In order to make the best use of the increased luminosity in terms of physics results the performance of the present UA2 detector has to be improved. The emphasis which was put on electron identification to observe the Intermediate vector bosons decaying into lepton pairs remains one of the main characteristics of the new detector. The total quark-antiquark cross-section at the Sp $\bar{p}$ S Collider energy is dominated by jet production in hard collisions and the probability of occurrence of events involving electrons is lower by about 5 orders of magnitude, one of

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the aims of the UA2 upgrade programme is to further decrease the background events which satisfy the charged lepton signature by at least an additional order of magnitude, with a good electron efficiency. The new design is expected to substantially reduce the two most significant sources of backgrounds faking electrons : converted photons from π^0 decays and narrow pairs formed of a π^0 and a charged hadron (overlaps). Detailed descriptions of the modifications of the UA2 detector have been given elsewhere ¹⁾; two major modifications are made. The insertion of a transition radiation detector to reduce the overlap background is a key feature of the new design. From a previous experiment we know that the pion rejections obtained in transition radiation detectors and electromagnetic shower detectors, are multiplicative ²⁾. A matrix of silicon counters ³⁾ is installed to identify ionisation loss from track pairs created by photon conversions in the inner part of the UA2 detector. The vertex detector inside the central calorimeter is redesigned and contains as inner tracking device a jet chamber vertex detector surrounding the beryllium vacuum pipe and a multilayer scintillating fibre detector ⁴⁾ as outer tracking and preshower device. The installation of a new end cap calorimeter and preshower detector will expand the acceptance of the present central calorimeter to a polar angle coverage between 10° and 170° , which implies instrumentation down to 5° and 175° over the full azimuthal range.

II. DESIGN PHILOSOPHY

The central calorimeter of the UA2 detector provides the main electron identification and the measurement of the jet momenta. It was designed with an inner free radius of 380mm ; this limited size greatly reduced its cost and construction time schedule. The insertion of a transition radiation detector requires a major fraction of the space available in the central region of UA2, about half of the radial range. The total active thickness of a transition radiation detector is a critical parameter limiting the expected rejection against hadrons ^{5) 6)}. The UA2 collaboration decided to modify the two extreme cells of the central electromagnetic calorimeter to increase the inner radius of the calorimeter to 420mm of which a radial thickness of 210mm was attributed to the transition radiation detector.

X-rays are emitted when a charged particle traverses the interface between two different medias. Such interfaces are obtained by stacking thin foils inside a gas container. The total radiated energy being proportional to the particle Lorentz factor $\gamma=E/M$, electrons radiate transition radiation Xrays along their path in the radiator whereas hadrons produce much less (see for example ⁷⁾). X-ray absorption in the gas of the detector is the signature of transition radiation emission in the radiator by the passage of

a charged particle. It gives rise to local charge clusters, which are superimposed with the ionisation loss along the charged track. Identification of X-ray absorption in the detector can be made either by measuring the total deposited charge along the track, or by the observation of local charge clusters as introduced by Fabjan et al⁸⁾. Charge integration has been used by earlier experimental set-ups, direct current from the anode wire was integrated either in a charge amplifier, or in a charge sensing ADC. Nowadays the use of Flash ADC's offers the opportunity to measure the direct current as a function of the arrival time on the anode wire or the cathode strip. The analysis can be done using several algorithms : total integrated charge, charge inside clusters, cluster counting, and likelihood methods ^{9) 10)}.

Monte-Carlo simulations of transition radiation help to fix the detector geometry, by generating X-ray emission according to well established theoretical description⁷⁾. X-ray detection in a multiwire proportional chamber filled with Xenon is also simulated. By maximizing the X-ray yield at the exit of the radiator with respect to the foil spacing, and consequently the number of foils, the simulations allow to get an optimized geometry of the radiator. In the simulation possible fluctuations of the foil thickness are taken from commercially available materials. We also varied the number of detector sets along the particle track. Thus we established that given the space available in the UA2 detector we should use 2 sets of radiator and X-ray detector.

III. TEST SET UP

We have built a prototype test set-up to check the validity of the Monte Carlo simulation results, as well as the feasibility of the proposed detector. It is sketched on figure 1 and it includes the radiator under study and the X-ray detector.

III.1 Radiator

The prototype radiator is cylindrical with an inner radius of 170mm and an outer radius of 250mm, we have considered the possible use of lithium foils or polypropylene foils as radiator media. The lithium foils are commercially available with mean thickness of 40 μ , suitable to construct radiators ; the foil spacing is obtained by etching. We have built 3 radiators with the same technique, they only differ by the total amount of foils and have a total thickness of 80mm. All 3 radiators are installed in the same container, under permanent helium flow, the thickness of the exit window is critical as far as X-ray attenuation is concerned ; we have used two 25 μ thick mylar foils separated by a 3mm gap in which a permanent helium flow is maintained to reduce moisture transmission (see Fig. 1). We have also built a cylindrical radiator made of polypropylene foils, 20 μ

thickness and 200μ spacing, the total thickness of the radiator is 80mm. The foil separation is also obtained by etching and we checked regularly its stability : no variation was seen within 5 months. A simple method of using gas bubbles cushion commonly used for wrapping was abandoned, the separation given by gas bubbles decreases with time.

III.2 X-ray detector

As explained in the previous section, X-ray detection in the chamber gas is the signature of transition radiation emission in the radiator. A perfect identification of clusters gives the ultimate X-ray detection ability of the detector and so the ultimate rejection power. We have built a gas chamber with a geometry such as to enhance the X-ray signal with respect to ionisation loss. Drift chambers or proportional chambers have a symmetric geometry : the amplifying anode wires are located in the middle of the gap between the two cathodes and in this case the ionisation losses produced in the two half-gaps are merged on the anode wire. Instead we have used an asymmetric drift chamber (see Fig. 1) : the entrance window is the cathode of a drift space ; the amplification space is located between a voltage defining grid and the exit cathode of the chamber, the anode wires are centered inside this amplification space. X-ray absorption probability follows an exponential law, and X-rays are absorbed mostly near the entrance window of the chamber, in the drift space of the detector. The constant electric field in the drift space of the detector gives to the primary electrons a constant drift velocity towards the amplification space where gaseous amplification occurs. During the drift the longitudinal diffusion as well as the transverse diffusion will give rise to a finite spatial dimension of the clusters.

The prototype detector used is 2 meters long. It has a planar geometry : a 16mm drift space is defined by the entrance window and a grid ; the amplification space is 6mm thick between the grid and the exit cathode. The entrance window is a mylar foil 12μ thick with graphite on the interior side for cathode voltage setting ; the intermediate grid is made with 50μ tungsten wires, 2.5mm pitch ; the anode wires and the potential wires have a diameter of 20μ and 50μ respectively ; the distance between the anode and the potential wires is 2.5mm. The exit cathode is equipped with strips inclined at 35° with respect to the anode wires. The gas used is a Xenon (92%) methane (8%) mixture, the quencher concentration is permanently measured in a gas analyzer and corrected if necessary ; a permanent gas circulation across the chamber and purifiers allows to maintain the oxygen concentration down to less than 10 ppm.

III.3 Signal amplification and digitization

We have developed a low noise amplifier to detect the wire signal, the amplified signal is fed by a 65 meter long cable to a zero pole filter to correct for the signal distortions introduced by the wire chamber and the connection cable. The resulting pulse shape is gaussian with a FWHM of 40 ns, which is then digitized by a 100 Mhz Flash ADC ¹¹⁾. The typical amplifier noise measured at the input is about 2000 electrons for the amplifier with connection to a prototype chamber (20 picofarad load) through a 160 ohm resistor. This is to be compared to the signal from a particle traversing the chamber gas, typically $5 \cdot 10^5$ electrons after gas amplification.

III.4 Data Collection

Data have been collected on the H2 beam in the North Area of the CERN SpS. This beam can be switched either to an electron or to an hadron enriched mode. During data taking the beam intensity was kept as low as a few 10^3 particles per burst of 8 seconds duration. A final electron or hadron selection is made using a pulse height cut on the signal from a scintillator located behind a lead radiator 1.5 radiation lengths thick, thus acting as a shower detector. The transition radiation test set-up is located between a set of beam chambers defining the incoming particle track. The electron contamination in the hadron sample must be kept as low as possible to have a correct estimate of the rejection factor of the detector. In our case, the electron content of the hadron enriched beam is 48% at 40 GeV/c momentum setting ; the pulse height cut on the shower scintillator brings a rejection factor of 100 thus reducing the electron contamination to less than 0.5%. In the case of an electron enriched beam the hadron contamination is about 1%, the pulse height cut brings a reduction factor of 70 to 100 thus reducing the hadron contamination to less than 0.01%.

IV. RESULTS

We present in these Proceedings the results from a preliminary analysis, more detailed results will appear in a subsequent paper.

As already pointed out, the Flash ADC samplings offer the maximum amount of information for a subsequent analysis. It is possible to compute the total charge ; it is also possible to find clusters associated to Xrays. Figure 2 is a typical current versus time plot given by the 100 Mhz Flash ADC from the signal associated to an incident electron track across one of the lithium radiators.

IV.1 Total integrated charge

Pedestal subtraction can be done accurately by the scan of the flash ADC bins before and after the signal for each event and before integration of the total charge. Typical distributions of the total charge are shown on figure 3. There is a clear difference between the hadron data which exhibit the well known Landau shape of ionisation loss, and the electron data which show the contribution of the X-rays detected in the chamber gas, added to the ionisation loss which is also higher in the ratio of the relativistic rise (a factor 1.11 at 40 GeV/c momentum).

The curve drawn on figure 3(a) was obtained by a fit to the data histogram. The fit procedure allows the convolution of a pure Landau distribution with a gaussian distribution. The curves drawn on figures 3(b), 3(c), 3(d) across the data histograms are the results of the Monte-Carlo simulation.

We show on figure 4 the variation of the hadron contamination versus the electron efficiency for a cut on the total integrated charge (curve Q). This is done with a single detector.

A maximum likelihood selection criterium was introduced in the following way. The measured total charge distribution was used to define the probability function that a charge q being detected in an event, it was generated by an incident electron (probability $P_e(q)$), or by an incident hadron (probability $P_h(q)$). P_e and P_h were obtained from the distributions shown in figure 3 after proper normalization. For the simulation of two detector sets the electron selection criterium corresponded to a cut on the probability ratio $P_e(q_1) \times P_e(q_2) / P_h(q_1) \times P_h(q_2)$, where q_1 and q_2 are charges recorded in two separate events. By varying the value of the cut we have obtained the correlated variation of the hadron contamination and the electron efficiency (curve L) shown on figure 4. At 90% electron efficiency the hadron rejection is 11, increasing to 26 at 80% electron efficiency.

IV.2 Cluster counting

A cluster algorithm has been developed to identify local bumps in the time distribution of the anode wire current as given by the sequential data from the flash ADC, they are interpreted as clusters. Over a large number of events we have obtained the distributions shown on figure 5 for the probability of observation of a cluster of energy E at the time t , where t is measured in nanoseconds after the event trigger, and E is measured in KeV : four plots are drawn for four intervals of E . There is a clear difference between hadron and electron data. Hadron clusters are mostly observed at low t value which corresponds to the amplification space of the detector. Electron clusters are spread over the full time interval ; the amplification space is still exhibited by an accumulation of

clusters at low t ; X-rays are also contributing to the amplification space but the exponential fall-off of the detection probability is clearly observed at the beginning of the drift space, with steeper slopes in the lower energy intervals. The distributions shown on figure 5 are used to define the probability that a cluster of charge E detected at an arrival time t was generated by an incident electron (probability $P_e(E,t)$) or by an incident hadron (probability $P_h(E,t)$).

The same data sample was used to measure the variation of the hadron contamination versus the electron efficiency for a cut on the observed number of clusters, weighted by their probability of observation. For each event we measure the total number of observed clusters, and each cluster has a weight $P_e(E_i,t_i)$ and a weight $P_h(E_i,t_i)$. So the probability for an event to be given by an incident electron is $\prod P_e(E_i,t_i)$, and to be given by an incident hadron is $\prod P_h(E_i,t_i)$ the products run over all the observed clusters. We have thus measured the correlated variation of the hadron contamination versus the electron efficiency shown on figure 4 (curve W) . The curve labelled W refers to an analysis done with a single radiator, which improves over the total integrated charge algorithm, mostly at low electron efficiency. The curve labelled L refers to the simulation of two detector sets, in this case the product $\prod P_e(E_i,t_i)$ and $\prod P_h(E_i,t_i)$ run over all the observed clusters in two separate events.

IV.3 Comparison between a polypropylene radiator and a lithium radiator

We have made a comparison between the results obtained with various radiators in order to make a decision on the radiator material. Installation of two radiator sets on the UA2 experiment implies the selection of the radiator giving the best achievable rejection ability. Such a decision is also based on our knowledge of the technical feasibility of a radiator, the long term stability of the radiator which is a worry for the polypropylene foils, and even more for the lithium foils. For a realistic comparison we have selected the best results obtained with a lithium radiator and the best results obtained with a polypropylene radiator. For the comparison we have selected the 500 lithium foil radiator ($40\mu/160\mu$) and the 367 polypropylene foil radiator ($20\mu/200\mu$), both having a total thickness of 80mm. The rejection of the lithium radiator is better by 10% to 20% depending on the electron efficiency as shown on figure 6 for the total integrated charge selection criteria.

V. CONCLUSION

The aim of this work was to prepare the construction of a transition radiation detector for the UA2 upgrade programme, with the goal to gain an order of magnitude better rejection at a good electron efficiency. We have shown that we can achieve this goal with several algorithms on the same data sample. If we apply the cluster counting algorithm, we do observe an improvement with a single radiator and detector set, this improvement is sizeable at low electron efficiency. Nevertheless, a difference is not seen if we use two sets and compare the cluster counting algorithm to a likelihood on the total integrated charge.

The two detector sets have to be built in a very compact configuration, the choice of the radiator media is critical. We have decided to use polypropylene foils.

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FIGURE CAPTIONS

Figure 1 : Test set-up ; the radiator is inside a container with permanent helium flow ; the exit window is in front of the detector, an asymmetric drift chamber filled with a Xenon methane mixture (92%, 8%), the lead scintillator is used as electron tagger.

Figure 2 : Example of a signal digitized by the 100 Mhz Flash ADC, the event is identified as an incident electron across the 400 lithium foil radiator.

Figure 3 : The total integrated charge distributions :

- (a) incident 40 GeV/c pion, the solid line is the result of the fit of the convolution of a Landau function with a gaussian distribution with variance 40%
- (b) incident 40 GeV/c electron, 367 polypropylene foil radiator, the solid line is the result of the Monte-Carlo simulation
- (c) incident 40 GeV/c electron, 400 lithium foil radiator with the result of the Monte-Carlo simulation
- (d) incident 40 GeV/c electron, 500 lithium foil radiator with the result of the Monte-Carlo simulation.

Figure 4 : The variation of the pion contamination versus the electron efficiency for the following methods of analysis :

- (a) curve Q : total integrated charge with one detector set,
- (b) curve W : weighted number of clusters with one detector set,
- (c) curve L : likelihood selection with a simulation of two detector sets, the likelihood on the total integrated charge and the likelihood on the weighted number of clusters give similar results.

Figure 5 : The cluster probability of observation versus their arrival time for electrons (lower part of the plot) and pions (upper part of the plot), for four intervals on the cluster energy E : $5\text{KeV} < E < 8\text{KeV}$, $8\text{KeV} < E < 12\text{KeV}$, $12\text{KeV} < E < 16\text{KeV}$, $E > 16\text{KeV}$, low values of the arrival time are correlated to the amplification zone, high values correspond to the entrance cathode.

Figure 6 : Pion contamination versus electron efficiency for the total integrated charge cut, one detector set, upper points : 367 polypropylene foils radiator ($20\mu/200\mu$), lower points : 500 lithium foils radiator ($40\mu/120\mu$).

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig.5

Fig.6