**A large solid angle magnetic detector for precision studies
of e.m. processes in low-energy $\bar{p}$ interactions**

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Abstract

The detector presented is designed to measure the proton e.m. form-factors by measuring e^+e^- pairs produced in $\bar{p}p$ annihilations at low energy or at rest.

In this paper the apparatus is described in detail, with emphasis on how to achieve a suppression factor of about 10^{10} of the hadronic background.

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1. Introduction

The experiment PS170 at the CERN Low Energy Antiproton Ring (LEAR) has been designed to study with high statistics the proton electromagnetic form factors $|G_E|$ and $|G_M|$ in the time-like region via the reaction:

$$\bar{p}p \rightarrow e^+e^- \quad (1)$$

The low cross-section of reaction (1) (about 10^{-32} cm^2) requires an apparatus of large solid angle acceptance and good efficiency. In order to separate $|G_E|$ and $|G_M|$ the angular distribution has to be measured implying a large angular acceptance.

In $\bar{p}p$ annihilation the branching ratio for reaction (1) is smaller than 10^{-7} and hence the apparatus has to detect e^+e^- pairs in a high hadronic background from annihilations into pions and kaons. An adequate rejection factor is achieved by two different electron identifiers: a system of gas Cerenkov counters (filled with isobutane at atmospheric pressure) and a shower detector (lead plates interleaved with limited streamer tubes). The potential rejection factor against charged hadron pairs is 10^{-8} at the trigger level and 10^{-10} in the off-line analysis; however, in order to be conservative with respect to losses of signal events, the rejection at trigger level was in fact 10^{-6} .

We proposed to measure with the same apparatus the inelastic reaction:

$$\bar{p}p \rightarrow \begin{array}{c} V^0 + X \\ \downarrow \\ e^+e^- \end{array}$$

for $\bar{p}$ annihilations at rest. The reconstruction of the e^+e^- pair energy would allow the study of the mass spectrum of V^0 vector mesons in the range 1 to 2 GeV. This measurement requires a good energy resolution on the e^+ and e^- particles.

A 30 cm long, 6 cm in diameter, liquid hydrogen target located at the center of a C-magnet (1 m diameter and 0.4 m gap) ensures high luminosity.

The momentum measurement for the outgoing particles is performed by a central detector (CD) placed inside the magnetic field with geometrical acceptance in the horizontal plane of $.8 \times 2\pi$ and of $\pm 20^\circ$ in the vertical one. It is further improved by a double layer of drift tubes located at about 1.5 m from the center of the system. Scintillator hodoscopes for trigger purposes and beam defining counters complete the apparatus.

The complete layout is shown in fig. 1a and 1b.

2. Beam, target and beam hodoscopes

The $\bar{p}$ beam ejected from LEAR is transported, after a switchyard area, up to a first focal point where a scintillating counter for beam monitoring (B_0) is located. The B_0 counter consists of a $3 \times 3 \text{ cm}^2$ scintillator, 100 μm thick, enclosed in a box coated with white reflecting paper (Millipore) and is viewed by two high sensitivity photomultipliers. In order to reject halo particles, the counter is surrounded by an anticoincidence scintillator (AB_0).

Downstream a 37 metres long beam line, equipped with quadrupoles and bending magnets for beam tuning, transports the beam to the apparatus. The incoming $\bar{p}$ momenta range from 0.3 GeV/c up to about 2 GeV/c. A suitable entrance angle in the apparatus is achieved by a pair of bending magnets (wobblers) located upstream, the closer one sitting on a movable chariot while the whole apparatus can be rotated by $\sim 150^\circ$. At 0.3 GeV/c, e.g. the beam stops in the target and a high magnetic field (10 KG) can be kept in the SPECTRO magnet (fig. 1) by imposing a large angle to the beam (fig. 2a, "Low Energy Position"); for higher momenta where the non-interacting beam particles would hit the iron yoke the apparatus is turned (fig. 2b, "High Energy Position") and different settings for the wobblers are found allowing the use of the entire target length. A program based on the TRANSPORT package [1] has been used to calculate at each momentum the appropriate magnet setting.

Each incoming $\bar{p}$ is detected by the B_0 counter and by 2 additional counters located immediately upstream of the target: a Si μ -strips detector and a scintillator hodoscope (H_0).

The silicon μ -strips detector is placed ~ 20 cm upstream of the H_0 counters and allows the reconstruction of the beam directions in the off-line analysis. It is an n-type wafer totally depleted at 70 V with useful surface of $50 \times 50 \text{ mm}^2$ and a thickness of 314 μm . The strips pitch is 600 μm , for a total of 84 channels; with an efficiency of $\geq 95\%$ the signal to noise ratio, for a minimum ionizing particle, is 1.8.

The H_0 hodoscope is made of 6 vertical scintillator counters, $1 \times 6 \text{ cm}^2$, 1 mm thick, coupled via a 2.5 m long quartz optical fiber bundle to a photomultiplier.

The liquid hydrogen target (LH2), placed in the center of the SPECTRO magnet, is 30 cm long and 6 cm in diameter. The target walls must be as light as possible because the huge amount of π^0 's produced can contaminate the electron sample via γ conversion. In order to satisfy these requirements the target walls are made of mylar 170 μm thick inside a "Rohacell" cylinder [2] 15 mm thick sandwiched between 2 layers of vetronite each 100 μm thick. In the transverse direction the total thickness corresponds to $3.7 \cdot 10^{-3}$ radiation lengths. The two target windows, in the forward and backward direction, are made of mylar 250 μm thick. The target length allows at low momenta (e.g. 0.3 GeV/c) to collect simultaneously data from annihilations at rest and in flight and, at higher momenta, to have the maximum possible luminosity in a region where $\bar{p}p \rightarrow e^+e^-$ cross section drops dramatically.

Finally, the magnet poles and the inner face of the iron yoke are covered with scintillators used in anticoincidence (Z_{Ch}) for charged secondaries outside the solid angle of the apparatus; this set of counters is completed, with the apparatus in the high energy position, by 5 scintillators A_j located on the beam path 1.5 m downstream from the target center to veto non-interacting beam particles.

3. The central detector

The electron momenta to be measured in the whole experimental program ranges from 0.3 to 2.6 GeV/c. In a 10 KG field and with a trajectory length of about 50 cm the corresponding sagitta is of the order of 1 to 9 mm. A system of multiwire proportional chambers with cathode analog read-out provides an intrinsic spatial resolution of a few hundred microns [3]. To reduce the Coulomb scattering and γ conversions, the amount of material had to be kept at a minimum.

A fast read-out electronics [4] has been designed to cope with the foreseen high interaction rate ($3 \cdot 10^{-5} \text{ s}^{-1}$) and possibly to use the CD information in the trigger logic.

3.1 Construction characteristics

The central tracking detector has an inner cylindrical MWPC (CYL) and 4 layers of planar wire chambers (CD), similar in the principle, but with different mechanical solutions. The magnetic field is vertical and the main magnetic deflection is in the horizontal plane. All sense wires are then horizontal and we measure with high resolution the coordinate along these wires by reading the induced signals on vertical cathode strips.

The 2 inner layers of CD (fig. 3) are continuous chambers: the same sense wire is stretched between the two ends A and B. The hexagonal shape is obtained by letting the wire turn around inox rods (6 mm diameter). The rods are covered with Kapton printed circuits where the wires are soldered. Mechanical rigidity is insured by vetronite frames which also hold the Mylar-Aclar sheet for gas containment (fig. 4a).

The 2 outer layers are segmented in 7 sectors (fig. 3). In each sector 4 inox rods (8 mm diameter) hold the sense wires and are kept in position by vetronite frames (fig. 4b). The dead angle due to the support rods is for all configurations less than 10% of the total angular acceptance. The gas envelope is the same for all sectors. Gold plated tungsten 20 μm wires are employed with a 2 mm pitch. The gap between sense wire plane and cathode planes is 4 mm.

The vetronite-inox rod structure described above is not able to support a set of horizontal wires and vertical strips: the tensile force would require much stronger frames with heavy vertical sides. We have therefore adopted a self-supporting structure: a typical cathode plane consists of a Rohacell sheet on which a Kapton printed circuit with parallel copper strips is glued (fig. 4c). The exact cathode structure for the 2 different sets of chambers is given in the table 3.1, with all relevant figures for CD, CYL and the target. The total thickness of the CD chambers is 4.5×10^{-2} radiation lengths.

TABLE 3.1

<i>Inner chamber cathode (CD)</i>	<i>Outer chamber cathode (CD)</i>
<div> <div> 17 μm Cu 90 μm Kapton 1000 μm Rohacell 125 μm Kapton 400 μm Araldite (4 layers) </div> <div> } 2 times </div> </div> <p>Each 4.7×10^{-3} rad. lengths</p>	<div> <div> 17 μm Cu 90 μm Kapton 1800 μm Rohacell 125 μm Kapton 600 μm Araldite (6 layers) </div> <div> } 2 times </div> </div> <p>Each 6.4×10^{-3} rad. lengths</p>
<i>Chamber cathode (CYL)</i>	<i>Target</i>
<div> 17 μm Cu 100 μm Kapton 2000 μm Rohacell 100 μm Araldite </div>	<div> 170 μm Mylar 200 μm Vetronite 1500 μm Rohacell 250 μm Mylar (windows) </div>

Since each layer of CD has two cathode planes one of them is equipped with vertical strips and the other with horizontal strips (2nd and 4th) or 45° inclined strips (1st and 3rd) with the same structure described in table 3.1. The horizontal strips are electrically connected to form only two sets of cathodes per layer, on the left and on the right side of the beam direction. The vertical strips are 4 mm wide and give the finest resolution [5]; the horizontal and 45° inclined strips are 8 mm wide as the vertical resolution is less critical.

The chambers are operated in an argon (76%) - isobutane (24%) gas mixture with 0.16 % of freon (in volume). The nominal voltage is 2800 V.

3.2 The cylindrical MWPC

The innermost part of the central detector is a cylindrical MWPC (CYL), surrounding the liquid hydrogen target. It covers about 70° azimuthal angle on each side of the target with 92 horizontal wires, 20 μm in diameter, 450 mm long, spaced by 2 mm. The 5 mm gap allows operation at 3 KV with the same gas mixture used in the other chambers of the central detector. Analog read-out by induction on cathode strips is provided on each side of sense wire layer. Vertical and 45° inclined strips amount to 240 channels. Owing to its position inside the apparatus, the uppermost care was devoted to have a light structure, rigid enough to support the whole compression strength exerted by the wires, which is about 5 Kg.

The cathodes of the chamber are two-layer cylinders of Rohacell 51, 1 mm thick, rolled up in a helical fashion, separated by 25 μm Kapton sheets. Stresses are well supported by this backbone, while deformation is prevented by the forward ring, on which wires are soldered. This ring is cut in a 0.5 mm fiber-glass sheet sandwiched between two 0.5 mm Rohacell layers, properly machined in order to keep cathodes in place. Printed circuits on flexible Kapton layers are provided on each end of the cylinder, to solder tungsten gold-plated wires.

The average thickness of the whole chamber in the forward direction is $6.2 \cdot 10^{-3}$ rad. lengths and in the radial one $3.7 \cdot 10^{-3}$ rad. lengths.

3.3 The read-out electronics

In the cathode read-out scheme the coordinate is reconstructed by looking off-line to the position of the centroid of signals coming from contiguous strips. Signals from each strip is linearly amplified, converted to a digital form and recorded only if the trigger conditions are satisfied.

The complete read-out circuitry is shown in fig. 5a. The first element is a 16-channel preamplifier (PRE) that houses 8 CIT-Alcatel 1757 hybrids (improved version of [6]). Each hybrid has two independent charge amplifier channels; the sensitivity is 160 mV/pC, a typical pulse shape at the output with 50 Ω load is shown in fig. 5b.

Since no space is available for the preamplifiers near the chambers the connection between the cathode strips and the preamplifier cards is done via twisted pair flat cables, 1.5 to 3.5 m long; a special grounding has been needed to avoid pick-up noise. The amplifier output signals are sent, via 50 m of 50 Ω coaxial cable, to the FADC modules (6 bits, logarithmic output, 25MHz conversion frequency). Sixteen channels are linked to one FADC module which is triggered by the summed output of its 16 channels, discriminated signal above a minimum value, in coincidence with the general trigger of the apparatus; this optimizes the recorded signals and minimizes the acquisition time.

The discriminator and the coincidence modules use ECL standard and a single width NIM module contains 32 channels especially designed for this experiment [7]. More details are given elsewhere [4].

The total number of channels is 2228.

3.4 Performances

Bench tests on the spatial resolution in the coordinate parallel to the sense wires (vertical strip read-out) give distributions with $\sigma(x) \sim 150 \mu\text{m}$ (without magnetic field and for tracks perpendicular to the chambers).

The spatial resolution of the horizontal strips is shown in fig. 6; the wire pattern is clearly visible and a correct assignment is possible.

At low energy notice that the beam crosses some chambers and as no beam-killer has been inserted, they have been working with typically $7 \cdot 10^5 \bar{p}/\text{s}$ (highly ionizing particles) in 1 cm^2 , without any appreciable loss in efficiency. Outside the beam region the typical working conditions are such that with the quoted beam intensity the entire inner chamber is crossed by about 500 particles/s cm^2 .

The average chamber efficiency, for perpendicular and inclined tracks, is 97% on most of the cathode surface excepted for about 8 mm side effects.

4. The Cerenkov counter

In order to properly measure reaction (1) a performant device to select e^+e^- pairs in a very large hadronic background is required. A gas Cerenkov counter is well suited to provide an e^+e^- trigger signal within about 200 ns.

A counter has been built using isobutane at atmospheric pressure. The isobutane gas has been chosen for its high index of refraction $(n-1) = 138 \cdot 10^{-5}$ and its low scintillation effect [8]. The threshold for Cerenkov light is 10 MeV for electrons and 2.8 GeV/c for pions. Below 1 GeV/c the pion rejection power is better than 10^4 [9]. Above 1 GeV/c the pions can eventually be detected via knock-on electrons and the rejection power is lower and depends on the threshold applied on the counter response.

4.1 Design of the counter

The Cerenkov detector is mounted around the magnet and occupies the smallest possible room in order to limit the size and the weight of the shower detector located behind. The thickness in radiation lengths of materials in front of the sensitive part of the counter must be small to minimize the electromagnetic effects mentioned above.

The counter consists of two aluminium tanks fitting the shape of the magnet. Each tank has a volume of about 2 m^3 and contains 7 up and 7 down cells each covering 22° in the horizontal plane and 20° in the vertical plane. The geometrical arrangement of the cells is shown in fig. 1. The entrance windows are made of 2 sheets of $30 \mu\text{m}$ thick mylar painted with black ink. The spherical mirrors consist of 1 mm thick plexiglass foils aluminized under vacuum. The reflecting surface is protected by a thin layer of magnesium fluoride. The mirror is strengthened by an aluminium honeycomb structure glued to its back. The total thickness is $4 \cdot 10^{-2}$ rad. lengths.

The Cerenkov light is emitted around the electron path at an angle of 2° ; the trajectories of electrons and Cerenkov photons are almost the same. With respect to the optics design the light source is the 30 cm long target, slightly widened ($\sim 5 \text{ cm}$) by 2 effects: the deflection of the particles by the magnetic field and the opening angle of the Cerenkov light. The optical system is shown in fig. 7.

In each cell the light is focused by a spherical mirror and deflected back to a 4 inches phototube by a plane mirror. The optical parameters of the various cells have been optimized by a Monte-Carlo program. The acceptance has been improved by mounting conical reflectors in front of the phototubes and by slightly incurvating the plane mirrors, around a vertical axis. The efficiency of the light collection is 100% for an electron emitted from the center of the target. For the cells around 90° w.r.t. the target direction this efficiency drops to 80% for the end of the target.

There is no optical separation between two adjacent cells and the Cerenkov photons from electrons travelling on the frontier between two cells can reach both the two adjacent phototubes. All the surfaces except mirrors are black painted to avoid the diffusion of light toward phototubes of nearby cells.

The phototubes (EMI 9870) are mounted as shown in fig. 8. An heavy shielding is needed against the 100 Gauss residual magnetic field. Three iron layers of 4 mm thickness reduce the magnetic field to a longitudinal component of only 1 Gauss near the photocathode. A coil around the phototube is used to compensate this longitudinal component of the field and finally, a μ -metal tube, 2 mm thick, absorbs the residual field.

To control the magnetic field effect, two photodiodes are mounted on each phototube. The first one lights the whole surface of the photocathode and the second one the side only. The current in the coil is adjusted to maximize the pulse height produced by the side photodiode. The central one is used to control the average response of the phototube.

4.2 Test measurement

Above 1 GeV/c the probability for pions to produce Cerenkov photons via knock-on electrons is no more negligible, but very few photoelectrons are produced in this way and the pion rejection depends on the threshold which can be applied without cutting too much the electron signal.

Measurement have been done in a beam of electrons and pions with momenta ranging from 0.5 to 1.75 GeV/c. The results show that for a threshold on the phototube signal, corresponding to 3 photoelectrons, the pion efficiency at 1.75 GeV/c is lower than 10^{-3} , while the electron efficiency is still better than 98% (fig. 9). The response of the counter to electrons has a gaussian shape. Assuming the width of the distribution to be due only to the statistical fluctuations, the electron peak corresponds to about 10 photoelectrons.

5. Drift tubes

In this experiment, the momentum resolution is critical and is significantly improved by adding a point on the charged particle trajectory outside the magnetic field (see general layout fig. 1). A solution based on drift tubes which allows precise measurement in the horizontal plane was adopted instead of a system of multiwire proportional chambers which would have been much more expensive.

Each drift tube is made in an extruded aluminium profile 140 cm high, 15 cm wide and 4.5 cm thick. This kind of tubes has been used elsewhere and their mechanical and electrical characteristics can be found in [10]. A first layer of 50 tubes is placed after the Cerenkov counters and covers a vertical angle of about $\pm 25^\circ$ with respect to the center of the target. To take into account the acceptance loss between two contiguous tubes and to solve the well-known ambiguity problem of drift chambers, a second layer of 50 tubes, shifted by 5 cm, is installed close to the first layer.

The electric field is obtained with three shaping cathodes on each side of the tube set at -5KV and -7KV (the sensitive wire being at +2.65 KV) which allow to achieve a linear time-space relation up to a maximum drift distance of 7 cm (fig. 10a,b). Under these electrical conditions and with a gas mixture of argon-ethane (50%-50%) a well-saturated electron drift velocity of about 50 $\mu\text{m/ns}$ is reached and the maximum drift time is about 1.4 μs .

The amplifier* is located in each individual tube inside a closed box, acting as an electrical shield. The DTR system [11] is used for the acquisition of the data. The start is given by each tube wire and the general stop is provided by the trigger of the experiment, properly delayed.

A spatial resolution of about 300 μm has been reached in a test beam for tracks perpendicular to the front face of the tubes.

6. The shower detector

All around the detectors, an electromagnetic shower detector provides a further rejection factor of 10^{-3} against a single pion. It consists of a 9 layer lead-streamer tubes system and of a scintillator hodoscope. The first lead layer is 5 mm thick while the remaining 8 are of 3 mm; in total the shower detector corresponds to 5.5 radiation lengths. Charged particles in the showers are detected by cathode readout streamer tubes [12] with horizontal and vertical pick-up strips, for a total of 11088 digital channels. The limited streamer tubes are 1.64 m long; the strips length ranges from 1.6 m to 6.2 m. The tubes are operated with an Argon/Isobutane gas mixture (34% - 66%). In the off-line analysis where the momentum and the direction of the particle is known from the central detector and the drift tubes, a shower shape multiplicity analysis leaves $\leq 10^{-3}$ pion contamination (fig. 11).

7. Trigger and hodoscopes

The trigger hodoscopes, denoted by H_1 and H_2 , are located behind the drift tubes layer. The H_1 hodoscope consists of 28 vertical scintillators each 1.4 m high, 1 cm thick and width ranging from 28.5 cm to 35 cm in order to have 11° angular coverage for each scintillator; moreover each H_1 element is split in up and down parts. The H_2 hodoscope is located after 2 radiation lengths of the shower detector and is made of 30 vertical scintillators 1.4 m long, 30 cm wide and 2.5 cm thick.

The interaction signal is made using B_0 , H_0 and the anticoincidence A_j during the high energy runs.

A selective trigger is based upon around the 2-body kinematics making use of the H_1 and H_2 hodoscopes. A 2 charged particle event is defined by asking a multiplicity of 2 on the $H_1 * H_2$ coincidences ($H_1 = H_{1\text{up}} + H_{1\text{down}}$). A 2-body event is specified by an angular correlation between 2 charged particles. A matrix of fast ECL coincidence circuits is programmed according to the distribution of the 2-body kinematics in the apparatus obtained by selecting the coplanar up-down events from the vertical H_1 partition but the up-up and down-down events are also recorded to study the multibody events.

Most of the 2-body triggers are hadronic annihilations and contain the reactions:

$\bar{p}p \rightarrow \pi^+\pi^-$ or $\bar{p}p \rightarrow K^+K^-$. A fraction of them (1/100 to 1/1000) are registered for monitoring purposes.

* developed by J.C. Santiard, CERN EF.

An electron trigger is obtained by requiring a Cerenkov response in addition to the 2-body hadronic signal. For that any H1 signal has to be validated by the 4 surrounding Cerenkov cells. The trigger layout is reported in fig. 12. The time needed to achieve the logic of the trigger is 250 ns after the interaction. A cut on the H_2 pulse height provides a rejection factor of 10 at the trigger level. This particular cut was considered as a reserve to decrease the trigger rate but was not used in the experiment because the trigger rate was acceptable. The full trigger circuitry is based on ECL standards with remote control facilities.

At various $\bar{p}$ momenta the typical rates are given in table 7.1.

TABLE 7.1

Typical rates for 10^9 incident $\bar{p}$				
$\bar{p}$ momentum	hadr. trigger	$h^+ h^-$ evts	elect. trigger	$e^+ e^-$ evts
0.3 GeV/c	60000	600	60000	50
0.6 GeV/c	10000	30	10000	1

The reduction factor of the hadronic triggers was adjusted to get about the same number of hadronic and electronic triggers.

Most of the triggers, particularly in the electron channel, are due to γ -rays from π^0 converted in the materials before the Cerenkov counter that give no signal in the central detector. A logic combination of the chamber signals based on the 2-body kinematics can be used to validate the previous trigger just before the data recording, improving by a factor 3 to 5 the trigger efficiency and allowing data taking at higher $\bar{p}$ beam intensities.

8. Data acquisition system

The online data acquisition system (fig. 13) is based on a 128K memory NORD-100 computer, equipped with two 10 megabytes disks and two 1600 bpi tape units. The computer is interfaced to the CAMAC electronics through the GEC-ELLIOT system crate. Part of the electronics modules are read using the REMUS/ROMULUS system and part are read via an ordinary CAMAC branch.

The Direct Memory Access readout for an average event of 600 words takes about 7 ms, the data acquisition software being based on the Cern system DAS [13]. The dead time of the data taking (<8%) tolerates about 20 triggers/s. The maximum rate of incident $\bar{p}$ is then $10^6/s$ at 0.6 GeV/c and $3 \cdot 10^5/s$ at 0.3 GeV/c. Monitoring tasks allow to store data in buffers or use data to record on magnetic tape, display events and control the quality of the various devices. For example, the ECL trigger logic status used to select the two-body events is followed with particular care during the data taking. Automatic calibration runs

to get the PDC pedestals are made in between the LEAR spills, as well as systematic high voltages controls and ECL matrix configuration check.

9. Detector performances

In the experimental set-up the spatial resolution for the central detector (§ 3.4) is affected by possible mis-alignment of different planes and the combined effect of inclined tracks and $\vec{E} \times \vec{B}$. The residuals obtained by fitting straight tracks in a calibration run with cosmic rays and the SPECTRO magnet off are shown in fig. 14; the width of the distribution is $\sigma(x) = 400 \mu\text{m}$ and includes the multiple scattering and inclined tracks effects.

The momentum resolution achieved with the combined system CD + drift tubes is demonstrated by the momentum distribution of $\pi^+\pi^-$ and K^+K^- pairs (from $\bar{p}$ annihilations at rest) shown in fig. 15a. The two classes of events are clearly well separated and from the pion peak one obtains $\sigma(p)/p = 2.1\%$.

Superimposed on the data is an absolute prediction of a Monte Carlo calculation that includes all the details of the apparatus; the intrinsic resolution of the CD chambers used was measured in a bench test and parametrized as follows:

$$\sigma(x) = (120 + \frac{200}{30} \Theta) \mu\text{m}$$

with Θ in degrees and $\Theta = 0^\circ$ is normal incidence.

The same distribution is shown in fig. 15b for e^+e^- events. The absence of a peak at the kaon momentum shows the goodness of the rejection of the hadronic events. The tail at lower momenta is due to radiative effects and is well reproduced by a Monte Carlo calculation.

The π^- angular acceptance for the 2 body events at rest is shown in fig. 16. The limitations due to the yoke is denoted by Y and the effects of the rods by R_1 and R_2 . The MC calculation reproduces the data. The peculiar structure in R_2 is due to the combined effects of rods R_1 acting on π^+ and rods R_2 acting on π^- for collinear events produced in the center of the magnet; this effect disappears for in flight events that are produced over the whole length of the target.

Fig. 17 finally shows the opening angle of h^+h^- ($\pi^+\pi^-$ or K^+K^-) pairs produced at rest; on fig. 17a is shown the distribution for all the accepted events and in fig. 17b the same distribution after applying a cut on the coplanarity and the momentum of the 2 particles. The background is almost totally suppressed. On the left side of the peak appears an enhancement of the background representing the "in flight" events produced during the slowing down process.

10. Conclusions

The performances of the apparatus can be summarized as follow:

- the 2-body events (e^+e^- , $\pi^+\pi^-$, K^+K^-) are selected without any ambiguity from the other annihilation processes;
- the hadron rejection in the e^+e^- events is better than 10^{10} ;
- the energy resolution (2.1%) allows a clear separation between the K^+K^- and the $\pi^+\pi^-$ events;
- the total acceptance (solid angle x efficiency) is about 10%.

Fig. 2 - a) Apparatus in "Low Energy Position".
b) Apparatus in "High Energy Position"

- Fig. 3 - Top view of the central detector.
- Fig. 4 - a) Inner chambers: schematic sketch of wiring;
b) outer chambers: schematic sketch of wiring;
c) cathodic structure.
- Fig. 5 - a) Read-out scheme;
b) pulse shape (preamplifier output).
- Fig. 6 - Reconstructed wire pattern (horizontal strips); 200 μm bins.
- Fig. 7 - Vertical cut of the Cerenkov counter and its position w.r.t. the magnet. Trajectories of the Cerenkov light in the vertical and horizontal plane are shown.
- Fig. 8 - Mounting of the phototubes with the magnetic field shielding and the conical reflectors.
- Fig. 9 - Response of an isobutane (atm. pressure, 70 cm long) Cerenkov counter to electrons and pions.
- Fig. 10 - a,b) Drift tubes.
- Fig. 11 - Shower multiplicity in the shower detector;
shown for 2 body events $\left(\frac{N_{\text{hits}}}{N_{\text{planes}}} \right)_{\text{track 1}} * \left(\frac{N_{\text{hits}}}{N_{\text{planes}}} \right)_{\text{track 2}}$
- Fig. 12 - Sketch of the trigger system.
- Fig. 13 - Data acquisition system.
- Fig. 14 - Residual on CD tracks; $\sigma = 400 \mu\text{m}$
- Fig. 15 - Momentum spectrum of: a) hadron pairs ($\pi^+\pi^-$ or K^+K^-);
full line: data
broken line: Monte Carlo (see text)
b) e^+e^- pairs; full line: data
broken line: Monte Carlo
- Fig. 16 - π^- acceptance for events at rest;
dots: data
broken line: Monte Carlo
- Fig. 17 - Angular correlation for hadron pairs:
a) all events;
b) after cuts on coplanarity and momentum.

(a)

(b)

Fig. 1

(a)

(b)

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6

Fig. 7

Fig. 8

Fig. 9

a)

b)

FIG. 10

SHOWER MULTIPLICITY

Fig. 11

Fig. 12 - SKETCH OF THE TRIGGER SYSTEM

Fig. 13

Fig. 14

Fig. 15

Fig. 16

Fig. 17