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Status Report of the NA59 experiment

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Abstract

We present a status report of the NA59 experiment, whose final goal is to study the use of a crystal as a 'quarter-wave plate' for photon with energy more than 100 GeV. We officially took data for three weeks at the beginning of the 1999 SPS fixed target run, and devoted the data taking to the measurement of the polarization of the generated linear polarization of photons produced by 180 GeV electrons transversing an aligned Si crystal, as requested by the SPSC. During this period we calibrated our experimental setup and took data to measure the polarization using two independent methods. First we will show part of the analysis of the 1999 data, from which we conclude that the degree of polarization should be as expected, and then we will describe the setup and the beam time required in the 2000 SPS fixed target run to finalize our study.

1 Introduction

The purpose of the NA59 experiment[1] is to study the use of a crystal as a 'quarter-wave plate' ($\lambda/4-$plate)[2] for polarized photon with energies of more than 100 GeV. That is, for photons with a wavelength of about 1.2×10^{-5} nanometers, compared to a wavelength of 550 nanometers were the 'conventional' quarter wave plates operate. If this works we will be able to produce high energy circularly polarized photons, starting from *unpolarized* electrons. This can be achieved with a two-crystal setup where electrons penetrating the first crystal generate linearly polarized radiation. The polarization of these photons is 'rotated' in a second crystal, which acts as a $\lambda/4-$plate. In addition, it will allow new polarimetry techniques for high energy polarized electron and photon beams.

The experiment was conducted in two stages. The first one, which took place in May-June 1999, was devoted to measuring the linear polarization of the photons produced in a 1.5 cm thick aligned Si crystal by unpolarized electrons with an energy of 180 GeV. Now we are ready for the second stage, where a 10 cm Si $\lambda/4-$plate will be added, and the subsequent production of circular polarization will be detected. As we will describe in detail, we have purshased and tested new equipment that will allow us to perform our measurement in a more efficient way than originally proposed. We are requesting four weeks of data taking during the fixed target run of the year 2000 for this purpose, with the same electron beam conditions provided to us in 1999 in the H2 beamline of the North Area.

2 1999: Data taking

In 1999, a total of three weeks of a 180 GeV electrons were provided. Data to measure the polarization with two independent methods were taken. Seven days were used to set up the system[1)], three days for the linear polarization measurement with the 'pair' method and eleven days with the 'rho' method. This disproportion of data taking time was needed to end with the same accuracy in the two polarization measurement. The pair method is model dependent but it takes short periods of time to accumulate sufficient amount of data, while the rho method is model independent but time consuming.

With the pair method, we take advantage of the fact that the pair production probability for linearly polarized photons penetrating into an aligned crystal is larger when the polarization is parallel to the crystallographic plane, than when the polarization is perpendicular to the crystallographic plane. Therefore, in this method we simply use another aligned crystal as an 'analyzer' and measure the asymmetry between the pair production probability of photons with 'parallel' and 'perpendicular' linear polarization.

In the rho method the polarization will be measured through the angular distributions of the $\pi^+ \pi^-$ pairs resulting from ρ^0 photo-production. For this purpose, data were taken for the resulting photon beam producing at least two tracks after impinging on a Be target.

2.1 Pair method in 1999: setup and analysis

The 1999 experimental setup for the pair polarization measurement method is shown in Fig. 1, with the exception that the $\lambda/4-$plate was not used in 1999. The setup is composed of two spectrometers. The upstream spectrometer (Bend-8) is used to determine

[1)] The beam arrived two days earlier than scheduled, and we were ready to take advantage of it and use it as part of our setup time. Therefore, the total setup time was nine days.

the energy lost by the electron in the crystal radiator (XTAL 1), while the downstream spectrometer (Trim-6) will be used to analyze the e^+e^- pairs produced by conversion of the photon beam in the crystal analyzer (XTAL 2). Details for each of its components of the setup are given below:

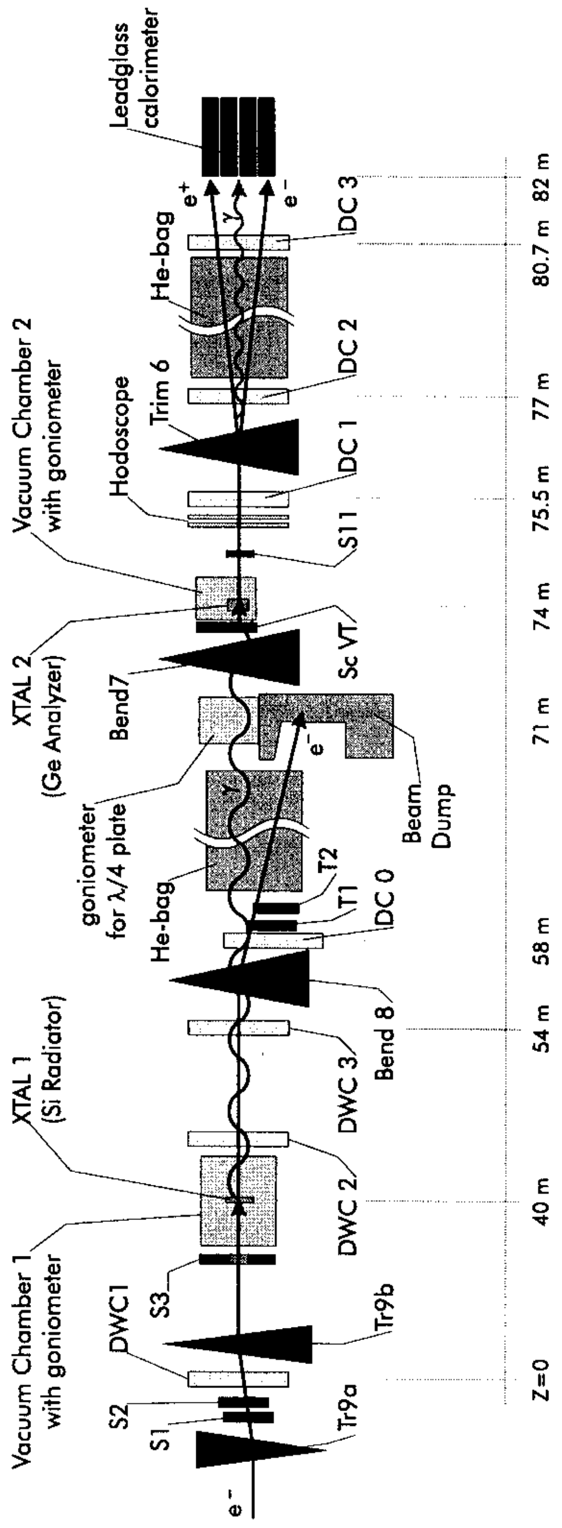

Figure 1: *Experimental setup used for the pair production asymmetry polarization method.*

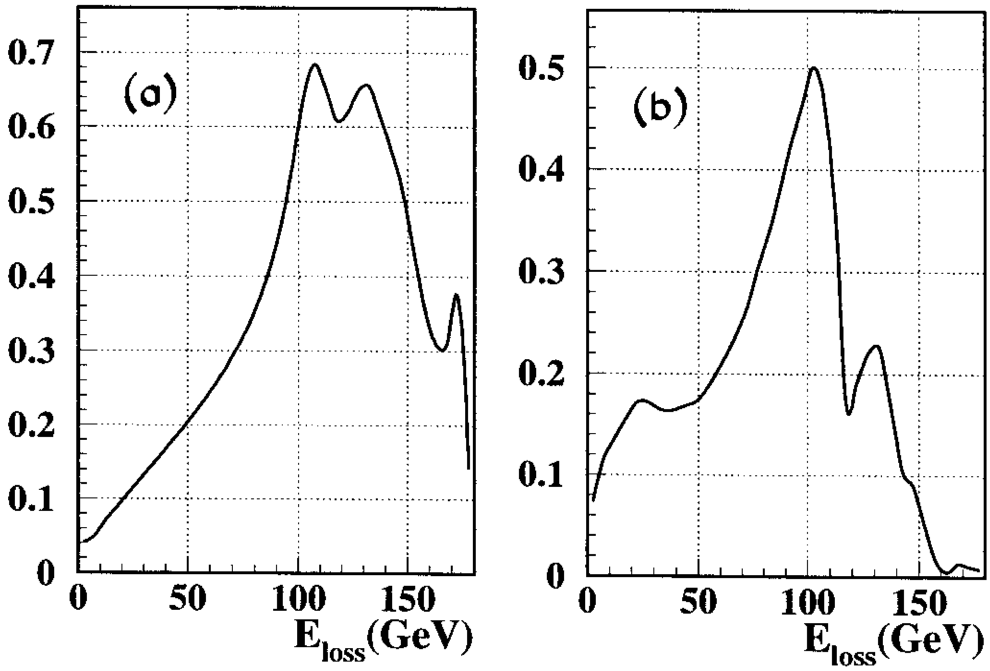

Figure 2: *(a) Predictions of the relative intensity of the energy loss by 180 GeV electrons penetrating a 15 mm thick Si-radiator. In this case the crystal is aligned with respect to the electron beam axis at an angle of 5 mrad from the $\langle 011 \rangle$ axis and 180 μrad from the (110) plane. (b) Expected polarization under the same conditions. The predictions were provided by [3].*

2.1.1 Beam:

An unpolarized electron beam with an energy of 180 GeV was provided for the final data taking, while additional beamline setups for 25, 50, and 100 GeV electrons were also available for calibration purposes. The available beam intensity was more than 2×10^5 particles/spill for 4.9×10^{12} proton on the T2 target at a 3 mrad production angle, and a beam spot with of diameter of 4 cm. This was better than expected. We ran at 8×10^4.

2.1.2 Crystals:

The material, thickness and angles of incidence of the electron (photon) beam with respect to the plane and the crystal axis are given in Table 1 for the aligned crystal used as a radiator (analyzer) and labeled as XTAL 1 (XTAL 2) in Fig. 1.

Radiator: In Fig. 2(a) we show the expected energy loss for 180 GeV electrons passing through the Si radiator under the described configuration and chosen alignment. The angles are large enough that only coherent effects across planes are relevant. A beam divergence of about 30 μrad was assumed in the calculations. The actual beam divergence is found to be around 50 μrad. As shown in Fig. 2(b), the maximum expected polarization is for photons with energy between 90 and 110 GeV.

Analyzer: In Fig. 3(a) we show the difference in pair production probability for the chosen Ge crystal for photons with a net polarization which is parallel (solid) or

Table 1: *Crystal thickness and beam angle of incidence. Crystal optimization for both radiator and analyzer were provided by [3].*

Usage	Crystal	Thickness (mm)	angle to axis (mrad)	angle to plane (μrad)
Radiator (Xtal-1, $e^- \to \gamma e^-$)	Si	15	5 mrad to $\langle 100 \rangle$	180 to (110)
Analyzer (Xtal-2, $\gamma \to e^+ e^-$)	Ge	1	3 mrad to $\langle 110 \rangle$	0 to $(1\bar{1}0)$

perpendicular (dashed) to the $(1\bar{1}0)$ crystallographic plane, respectively. Incoherent effects are taken into account and a beam divergence of about 60 μrad was assumed in the calculations.

Radiator+Analyzer: The expected asymmetry from the combined Si-radiator and Ge-analyzer dual crystal setup is shown in Fig. 3(b). A 5-6% asymmetry in the region of interest is expected.

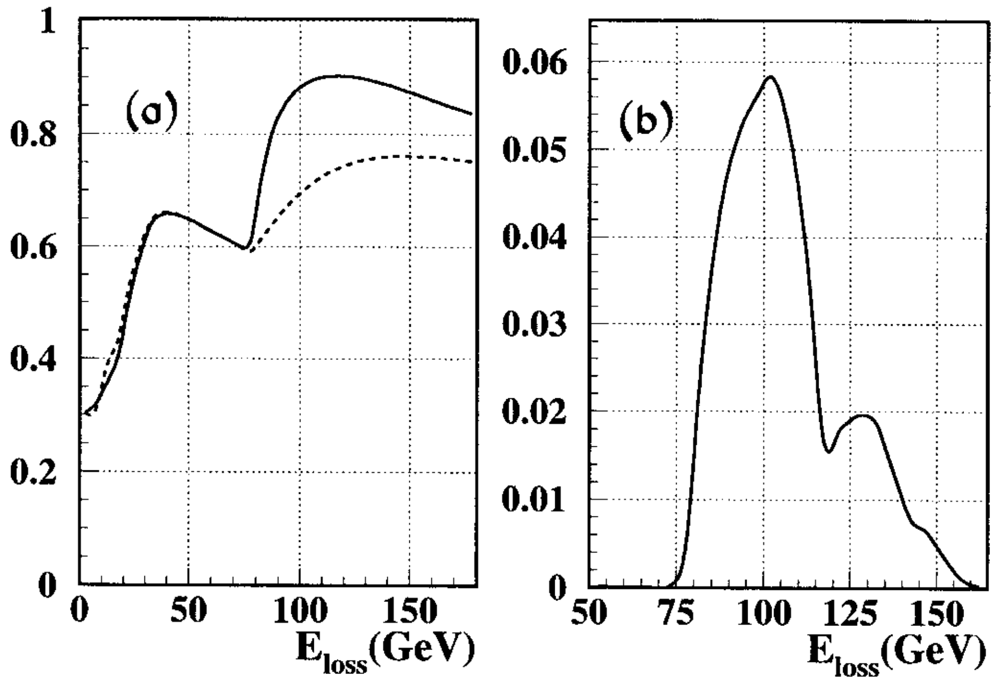

Figure 3: *(a) Pair conversion probability for photons with linear polarization that are parallel and perpendicular to the $(1\bar{1}0)$ crystollographic plane of the Ge-analyzer used. (b) Expected asymmetry for our experimental conditions (analyzed from the photon pair conversion probability induced by the Ge-analyzer) after taking into account the energy spectrum and the degree of linear polarization of the photon beam produced in the Si-radiator (Fig. 2(a)-(b)). Independent and consistent prediction were provided for the analyzing power of Ge [3], [4].*

Table 2: *Trigger definitions for the normalization (minimum bias), the electron radiation and the pair conversion trigger.*

Trigger	condition	downscaling
NORM	S1*S2*$\overline{S3}$	2^8
RAD	NORM*(T1 or T2)*(Lg≥threshold)	2^5
PAIR	RAD*(tracks≥1)	2^2

2.1.3 Triggers:

There were a total of three triggers defined from the S1, S2, $\overline{S3}$ counters and in some cases from the T1, T2 counters, the leadglass calorimeter, and the hodoscopes (see Fig. 1). They are:

- the minimum bias trigger (NORM) was used for normalization, and just requested that the electron went through the crystal-radiator.
- the electron radiation trigger (RAD) required extra condition on the energy loss by adding a lower energy cut in the leadglass calorimeter, and a minimum bending angle for the radiating electron in the upstream spectrometer.
- the photon convertion trigger for the Ge-analyzer (PAIR) is the same as the RAD trigger, but with the additional condition that there is at least one track recorded after the Ge-crystal, where photons are expected to convert and the original electrons do not arrive, since they are bent away by the upstream spectrometer magnet and stopped in the beam dump.

The hardware trigger conditions are summarized in Table 2. The RAD trigger is used to determined the acceptance effects of the energy requirements in the PAIR trigger, which is the our main physics trigger. This acceptance is shown in Fig. 4 and is dominated by the dimensions of the T1 counter shown in Fig. 1.

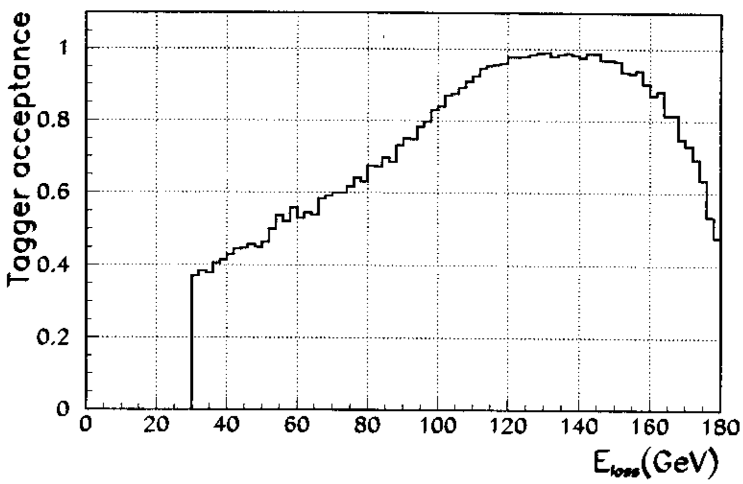

Figure 4: *Acceptance of the T1 and T2 counters used at the trigger level in the RAD and PAIR trigger.*

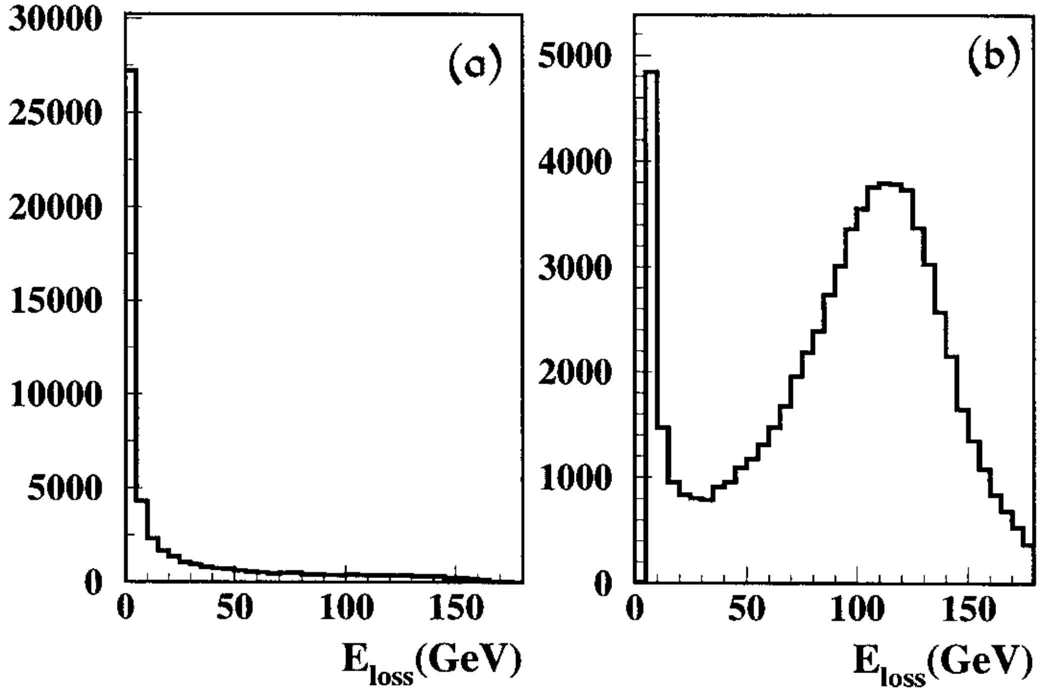

Figure 5: *Data showing the energy loss by the 180 GeV electron beam in the Si-radiator while the crystal is not aligned (a) and after alignment for the parallel polarization configuration (b). These results are based on a minimum bias trigger and the leadglass electromagnetic calorimeter information.*

2.1.4 Analysis:

We took two sets of data to analyze the polarization of the photon beam produced using the aligned Si-radiator from the 'pair' method. The alignment of the Ge-analyzer was kept constant during the two sets of data, but the radiator was 'rotated' by 90°. Therefore, the energy spectrum and the degree of polarization for the two data samples should be the same, but the orientation of the polarization will be perpendicular to each other.

The first checks on the data were made by looking at the energy loss by the electron beam with the aligned Si-radiator, and comparing them with an independent data sample taken with the Si-radiator at a 'random' position [2]. When the radiator is at random position there is no net polarization generated for the photon beam, and the energy loss follows the usual $1/E_{loss}$ energy spectrum. The results on energy loss are shown in Fig. 5 for the Si crystal at random and align with the configuration that produces a polarization that is parallel to the crystollagraphic plane of the Ge-analyzer located downstream. The energy loss in this case is estimated from the energy deposited in the leadglass electromagnetic calorimeter by the produced photon beam. For these checks only the minimum bias trigger was used to avoid the acceptance correction due to the tagger

[2] When the crystal is at a random orientation, away from crystalline planes, with respect to the incoming beam direction, then it behaves as an amorphous material and the energy loss by the electron follows the usual Bethe-Heitler behaviour.

(T1-T2 counters, see Fig. 4) used by the other triggers and to simplify the normalization of the data. Small deviations from the theory for the 'random' data at the higher energies are due to the fact that we are using a preliminary leadglass calibration, but we understand where the discrepancy is coming from, and it will be corrected in the near future.

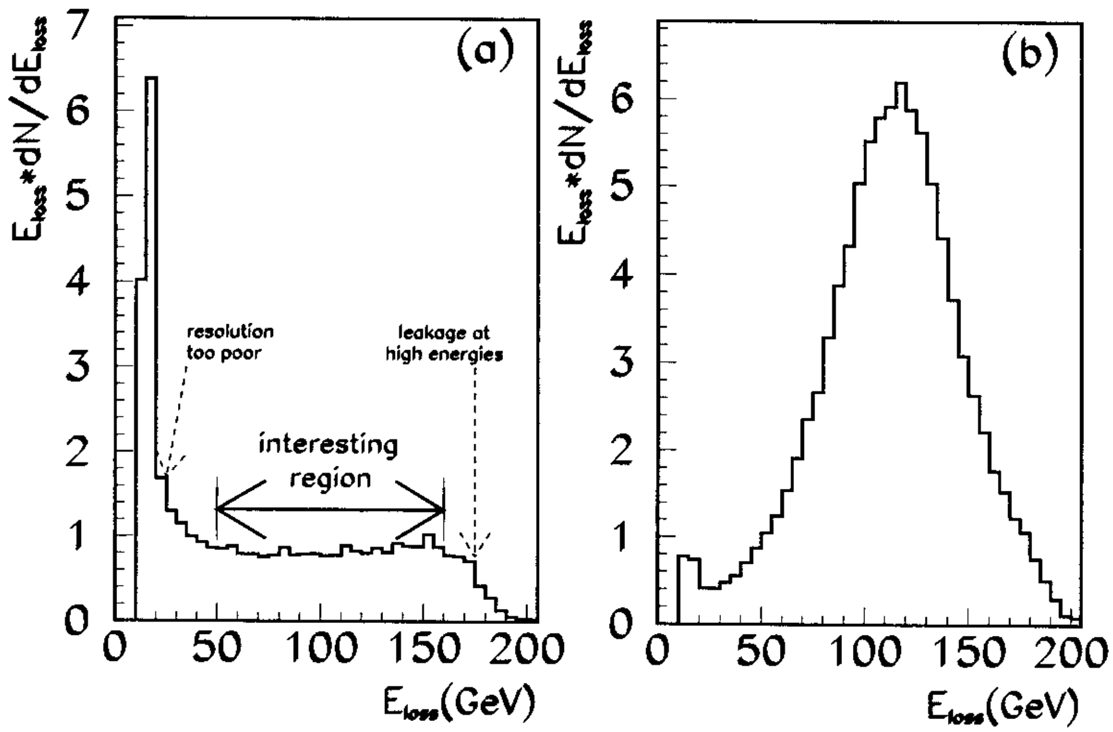

Figure 6: *Power spectrum for data shown in Fig. 2(a)-(b). As shown, there is a factor of six in enhancement for the chosen crystal alignment compared to the energy loss for unalign or random crystal Si-crystal setting.*

In Fig. 6 we show the power spectrum, $E_{loss} * (dN/dE_{loss})$ for the crystal at random and aligned orientations. The figure shows an enhacement of a factor of six of the radition due to the coherent effects that the electron experiences traversing the crystal. From the power spectrum for the Si at random orientation, which should be equal to one through the full range of E_{loss}, we can see that the most reliable region in the calibration and resolution of the leadglass calorimeter is between 50 to 160 GeV. For this reason we have limited the analysis to data in that region.

In Fig. 7 we show the comparison of both the parallel and the perpendicular configuration data with the prediction for the energy loss spectrum already shown in Fig. 2(a). As shown, both data samples are in good agreement with the theoretical estimations that predict about 50% polarization for E_{loss}=100 GeV.

The difference between the two configuration will appear when we make requirement on the conversion of their photons in the Ge-analyzer by first requiring two minimum ionizing signals in the S11 counter, which is located right after the Ge-analyzer, and later by an (e^+e^-)-pair detection with the pair spectrometer. This feature will give the asymmetry that we need to compare with the expectations shown in Fig. 3(b), hence

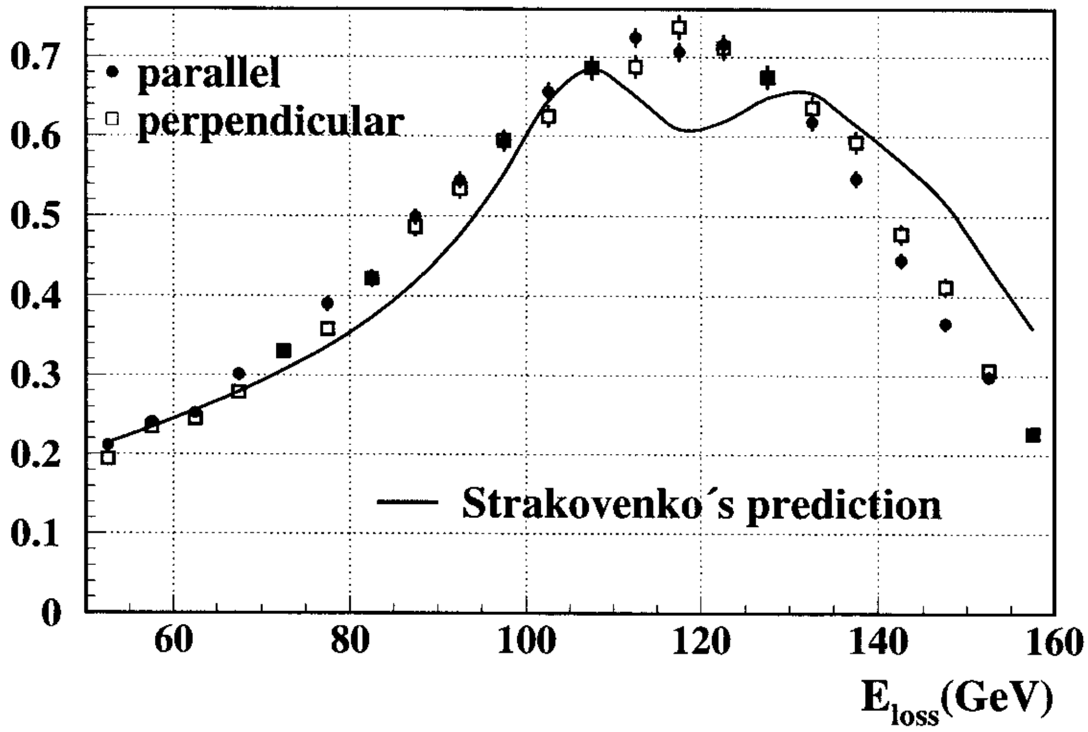

Figure 7: *Energy loss by 180 GeV electrons penetrating 15 mm of Si crystal aligned to an angle of 5 mrad from the* ⟨100⟩ *axis and 180 μrad from the (110) plane for the parallel and perpendicular polarization configurations compared to the theoretical prediction.*

inferring the degree of polarization.

The asymmetry that we will measure is $(\sigma_{\parallel} - \sigma_{\perp})/(\sigma_{\parallel} + \sigma_{\perp})$, where σ is the pair production probability ($\gamma \rightarrow e^+e^-$) measured with the Ge-analyzer. In order to determine $\sigma_{\parallel(\perp)}$ we will use the NORM trigger to determine the flux, while the $\gamma \rightarrow e^+e^-$ events are given by the PAIR trigger. Therefore, before making the asymmetry we are making sure that the deadtime of our system was democratic among all triggers, we are performing a cross check of our acceptance determination, and other data quality checks that are important for this analysis, like the angle of incidence of the electron beam into the crystal.

The asymmetry analysis is well advanced and the results will be available in the near future. We have more than 3 million events, after preliminary quality cuts, to determine the asymmetry.

2.2 Rho method in 1999: setup and analysis

The data analysis for the rho method is more time consuming and will begin as soon as we are done with the pair method analysis.

The setup was almost the same as the one shown in Fig. 1, except that the Ge-analyzer was replaced by a 6 cm long Berillium target where the ρ^0 are photo-produced, and we inserted a Silicon μstrip detector to improve our vertex resolution. As shown in Fig. 8, this silicon detector performed well and has a plane resolution of about 20 μm.

The amount of time devoted for this data taking was as long as originally requested, but we could have about 20-25% less events than expected due to a sudden increase in the deadtime time of our trigger. This was found to be caused by a change in the distribution of protons within the spill, which started to deliver most of the protons in the second half of the two second long spill (see Fig. 9). This problem, which also affected other experiments like NA48, was eventually fixed by the machine experts, but unfortunately not sooner than the end of our data taking. Nevertheless, we should have enough data to intercalibrate the pair and rho polarization measurement method.

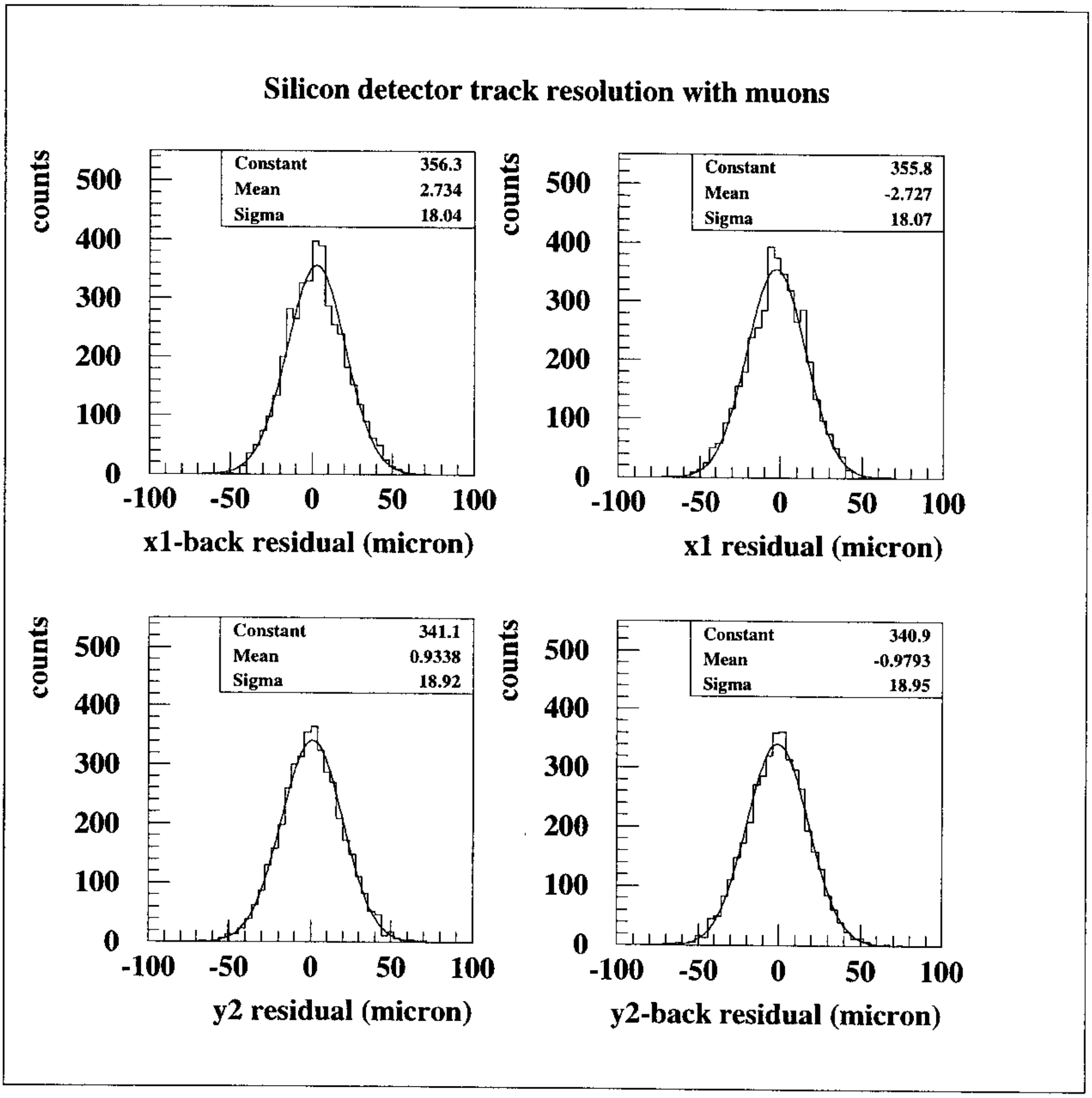

Figure 8: *Resolution of Si μstrip detector.*

3 2000: Preparation for data taking

The equipment needed in the year 2000 run is available and it is shown in Fig. 1. We plan to improve the readout system. Beside this, the main additions to the system will be described in the following subsections.

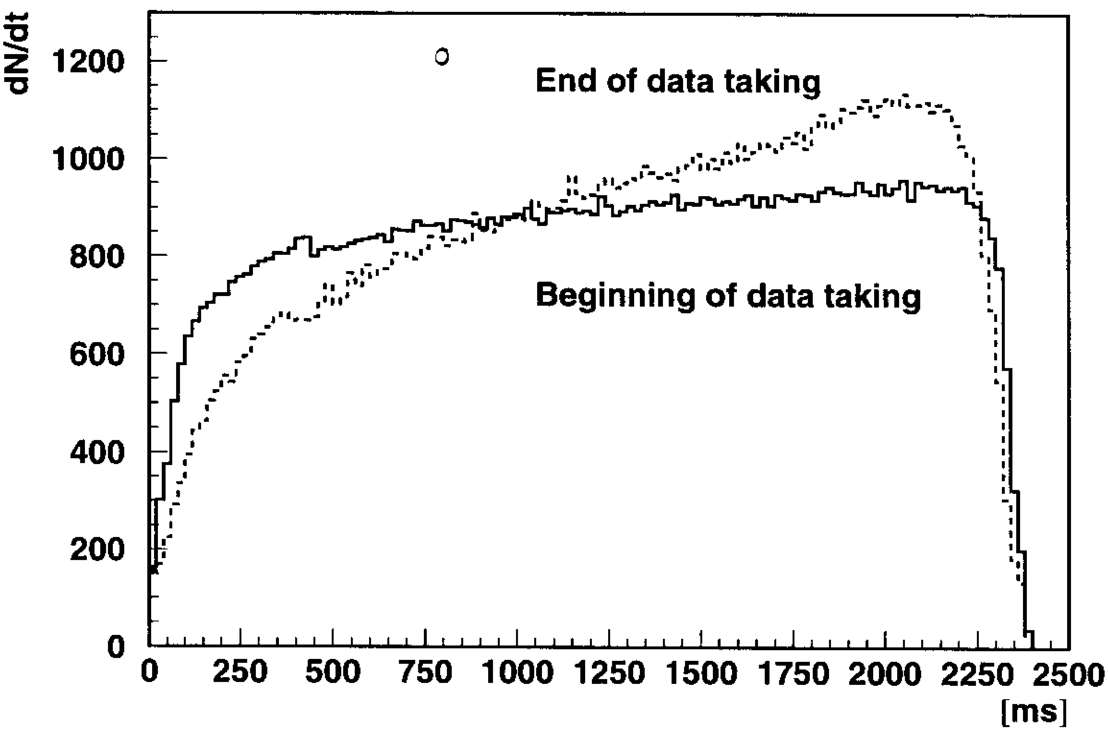

Figure 9: *Change in the distribution of protons within the 2.3 second long spill delivered to the experiment at the begining of the data taking and at the second half of the data taking.*

3.1 The $\lambda/4$-plate crystal

To test the $\lambda/4$-plate crystal we have chosen a 10 cm Si crystal, which will have a 70-80% 'rotation' efficiency for 100 GeV photons, and 20% of the photon beam will survive (more details are given in [1]). This is the best we can have in this energy range in the absence of large single diamond crystals.

We had proposed to use the rho method to measure the generation of circular polarization by the $\lambda/4$-plate. However, this would require more than 4 weeks of data taking due to the attenuation of the beam introduced by the $\lambda/4$-plate. At that time, we only had two goniometers which were both used when we took data for the pair method (one for the radiator, one for the analyzer). Now we have invested in a specially designed annular stage that is mounted in a goniometer borrowed from the SL-division. This will allow us to do our test in 2 weeks instead. We will do this by measuring the 'loss' of the linear polarization on the photon beam from the reduction in the asymmetry measured with the pair method. This is possible because the polarization of the photon beam is a conserved quantity, that is if we start with a 100% linearly polarized beam ($P^2_{linear} = 1$), then after going through the $\lambda/4$-plate we will have $P^2_{linear} + P^2_{circular} = 1$.

The $\lambda/4$-plate crystal mounted in the proper annular stage and goniometer are being tested. A photo of the $\lambda/4$-plate crystal and the annular stage are shown in Fig. 11. We have studied the alignment issues of this crystal and a prelimirary prealignment test with a γ-source facility in Grenoble was made. The results are shown in Fig. 10, from which we can see that the preliminary mounting of the crystal was ~ 0.30 mrad off from the rotation axis. This will be corrected to avoid the need for realigment of the $\lambda/4$-plate after performing a rotation.

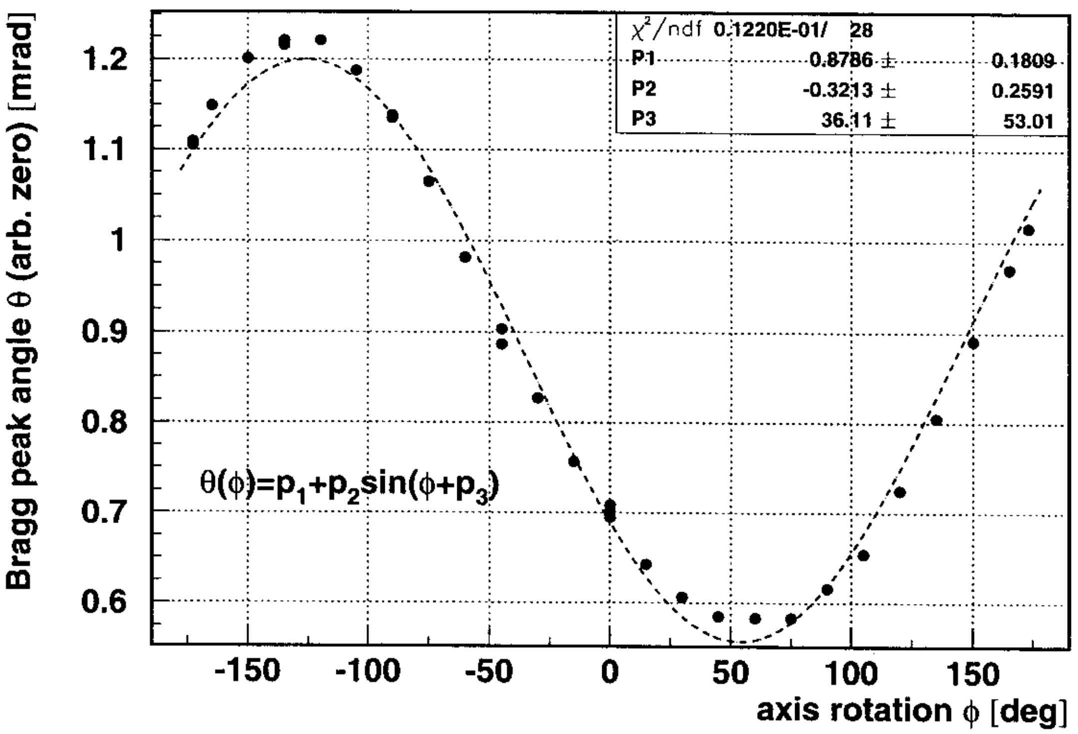

Figure 10: *Prealignment test of the $\lambda/4$-plate in the annular stage. It shows a shift of 0.32 mrad from the rotation axis, this will be corrected and retested.*

3.2 A new diamond radiator

For the 2000 run we are considering replacing our Si radiator by a 40×40×4 mm diamond radiator.

The advantages of using diamond as a radiative and/or as a converter target have been chronicled many times in the past. In a large number of physical paramaters diamond represents an extreme in the specific physical property, and this is typically, and fortunately, to our advantage. For example, in our case the new diamond radiator will provide an equivalent number of photons as the 100 mm Si radiator, but:

- the polarization will be 15% higher,
- the photon multiplicity will be a factor of two smaller.

While this assertion is probably universally accepted, the skill to grow diamond crystals of adequate quality and size – near-perfect crystals, with extremely low defect concentrations – is by no means an universally extant skill.

We have succeeded in persuading the de Beers Diamond Resarch Laboratory in Johannesburg, South Africa to engage seriously in a programme of research and development in the production of large high quality synthetic diamonds specifically for the purposes of (our) research at CERN and at the ESRF in Grenoble.

This programme of research is currently flourishing with ever-better control of the growth parameters. The phase diagramme of carbon is of course well-known, but what is assuredly less well-known is how to maintain conditions in the diamond-stable region of this diagramme (extremes of pressure and temperature, with critical gradients and control of growth orientation) ... and how to emerge out of this region of extremes back to normal temperature and pressure without total or even significant partial dissolution of the diamond which was so tortuously grown. These imperatives are fortunately yielding to current research and development.

Consequently our South Africa colleages feel able, with a significant measure of confidence, to respond to the opportunity of providing a diamond target of high crystal quality of dimensions (approximate) of 40 x 40 x 4.0 mm. It will be composed of 16 diamond tiles, each mutually oriented to a polar angle of within 0.002 degrees.

4 Summary and beamtime request

Good estimates to obtain the linear polarization from the time efficient pair method are now available. Given the good agreement of the data with the predicted energy loss for the chosen radiator, we believe that the predictions are reliable enough to say the linear polarization of the beam is 50% at a 100 GeV. This should be confirmed in the near future from the asymmetry measurement, and subsequently by the rho analysis.

For the year 2000 data we can increase the linear polarization by 15% if we us the new 4 mm diamond radiator. To test the $\lambda/4$-plate under the proposed conditions we will measure the drop in linear polarization of the photon beam (before the $\lambda/4$-plate $P_{linear} = 0.5 - 0.6$, after the $\lambda/4$-plate $P_{linear} = 0.35 - 0.42$.

From the experience gained in the 1999 data taking we conclude that we will need a total of four weeks of data taking to be used as follows: (1) 1.5 weeks for setup, calibration, alignment of the radiator, analyzer, and $\lambda/4$-plate crystals; (2) 0.5 week for the linear polarization measurement of the beam using the pair method; (3) 2 weeks for the data with the $\lambda/4$-plate and measurement of loss of linear polarization using also the pair method.

The beam requirements are the same as in 1999. We would like to use the 180 GeV electron beam available in the H2 beamline in the North Area. In order to get 8×10^4 electrons/burst we need 5×10^{12} protons/pulse on T2 and a production angle of $\simeq 3.0$ mrad [5].

We request the 4 weeks preferably at the beginning of the 2000 fixed target SPS run. In addition to the installation and removal of the experiment apparatus, at least one full day each is needed to change the layout of beam elements forth and back as required.

References

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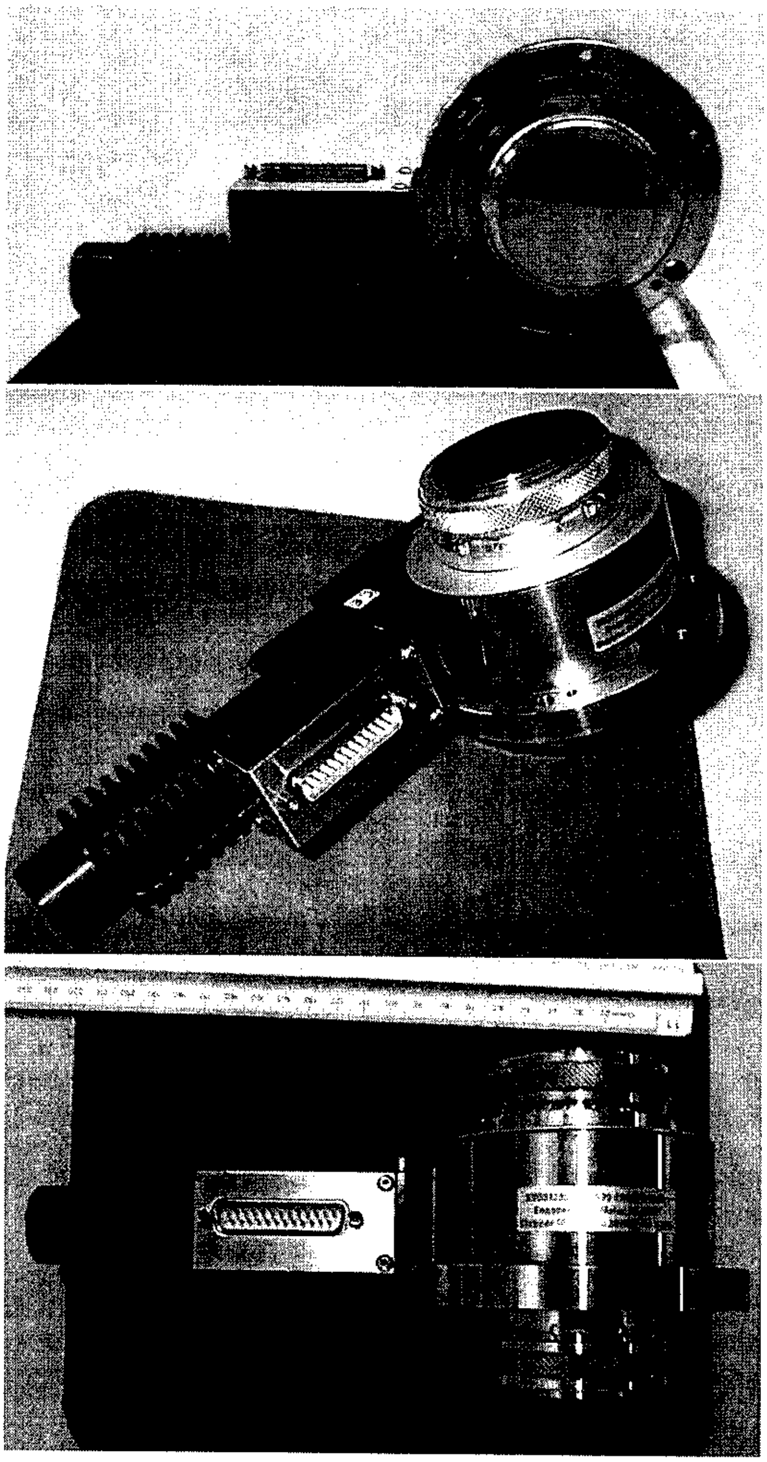

Figure 11: *The Si $\lambda/4$-plate crystal mounted in the annular stage. The crystal has a diameter of 5 cm and a length of 10 cm.*