HIGH PRECISION ELECTRON BEAM POLARIZATION MEASUREMENT WITH COMPTON POLARIMETRY AT JEFFERSON LABORATORY

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Since 1999, a Compton polarimeter based on a Fabry-Perot cavity to amplify the laser light is operational in the hall A of the Jefferson Laboratory. In 2000, the beam polarization has been continuously measured during $N - \Delta$ and G_e^p experiment providing a relative total uncertainty of 1.4% in 40 mn at 4.5 GeV. These unprecedented results have been obtained thanks to a scattered electron detector which has allowed to determine the response function of the photon calorimeter.

1. Introduction

The new generation of parity violation or spin sensible experiments require an accurate knowledge of the target or beam polarization. In this spirit, a Compton polarimeter has been constructed at Jefferson Laboratory in 1998, to measure and to monitor the polarization of the electron beam in the Hall A. The Compton polarimeter has been operated for the first time during the HAPPEX experiment[1,2] and has provided an absolute monitoring of the electron beam polarization (100 μA, 3.3 GeV) during the entire run, with a total uncertainty of 3% in 1 hour[3]. In 2000, the Compton polarimeter has been running for $N - \Delta$[4] and G_e^{P}[5] experiments at $E_e = 4.5 \; GeV$ and $I = 40 \; \mu A$. The present contribution reports on the analysis method and the hardware improvements that have led to high precision Compton polarimetry measurements[6].

2. The Compton polarimeter

When longitudinally polarized electrons scatter off circularly polarized photon, the experimental asymmetry of the counting rates of the scattered events A_{exp} is proportional to the polarization of the electron beam:

$$A_{exp} = \frac{N^+ - N^-}{N^+ + N^-} = P_e \times P_\gamma \times < A_{th} >, \qquad (1)$$

where N^+ and N^- refer respectively to counting rates when the spin of the electron and the photon are parallel and anti-parallel, P_γ is the circular polarization of the photon beam and $< A_{th} >$ the analyzing power, entirely defined by QED and the experimental running conditions.

In Figures 1 and 2 are plotted the Compton cross section and the theoretical asymmetry for $E_e = 4.5\ GeV$ and $E_\gamma = 1.16\ eV$
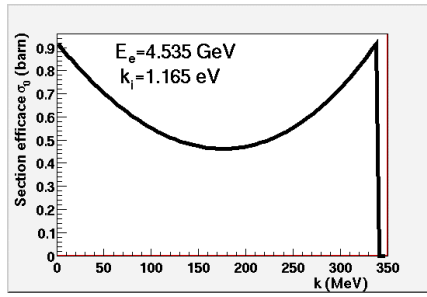

Figure 1. Compton cross section with respect to the energy of the scattered photon. The Compton edge is $K_{max} = 340\ MeV$.
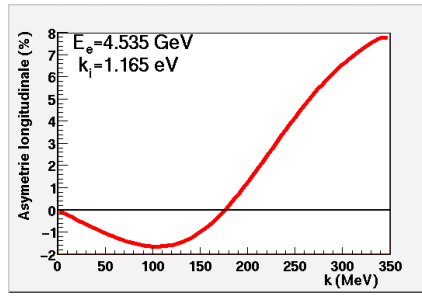
Figure 2. Theoretical asymmetry. The averaged asymmetry is 2%

The Compton polarimeter at Jlab hall A[8] consists in a magnetic chicane at the center of which the electron beam scatters off the photon beam. The main characteristic of this Compton polarimeter is a Fabry-Perot cavity[7] that amplifies the 250 mW IR laser light with a gain of 8000. The optical setup[8] provides a 1500 W laser light with a polarization of 99% at the Compton interaction point. The scattered photons are detected in the central crystal of a $25 \times 25\ PbWO_4$ scintillators $(2 \times 2 \times 20\ cm^3)$ matrix and the scattered electrons are detected in four planes made of 48 silicon strips (width=650 μm). The electron detector allows to determine the response function of the photon calorimeter and provides an complementary polarization measurement.

Scattered photons are detected in the central crystal and the deposited energy is measured with ADC's. Frequently, the laser light is turned off

in order to measure the background due to Bremsstrahlung coming from the interaction of the beam with the residual atoms in the vacuum pipe and with cavity mirror holders. The sign of the photon polarization is also reversed alternatively to correct for false asymmetries. One of the major sources of false asymmetry is the variation of the luminosity related to electron beam position variations correlated to the helicity. Therefore, to lower this effect, the beam in the magnetic chicane is locked to a nominal position corresponding to the maximum of the luminosity for the Compton interaction. Finally, the experimental asymmetry is determined from counting rates normalized to acquisition dead time and beam intensity. Runs are taken in both "coincidence" mode (to measure the response function) or in "only photon" mode (normal data acquisition).

3. Analyzing method

The analyzing method is called "*semi-integrated*" as the scattered photon counting rates are integrated from an energy threshold ($E_{th} = 200\ MeV$) to optimize the statistical precision and to minimize most of the systematics.

One of the major improvements of the Compton polarimeter data analysis since HAPPEX measurements[3] is the determination of the response function of the central crystal. For "coincidence" runs, this response function is determined using the electron detector where each strip defines a narrow energy band ($\sim 5\ MeV$). For a given scattered electron energy (i.e.d. scattered photon energy k) the central crystal ADC spectrum is fitted (see Figure 3) with an empirical function $g(ADC, k)$, of which the particularity is to reproduce the asymmetrical behavior of the deposited energy distribution and the low energy tail. For all the runs taken in "only
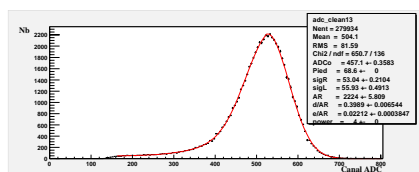

Figure 3. Fit of the response function of the central crystal for a 200 MeV incident photon.
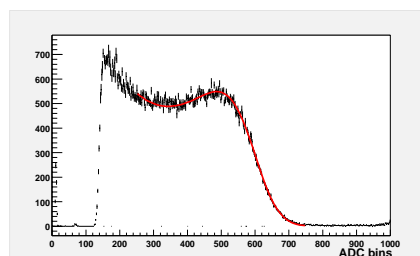
Figure 4. Fit of the ADC spectrum with the theoretical Compton cross section convoluted with the response function of the calorimeter.

photon" acquisition mode, the ADC spectrum is fitted (see Figure 4) with the theoretical Compton cross section convoluted with the response function:

$$\frac{d\sigma(ADC)}{dADC} = \int_0^{k_{max}} \frac{d\sigma_0(k)}{dk} g(ADC, k) dk \qquad (2)$$

Possible run by run gain fluctuations λ can be thus taken into account. The response function allows thus to determine, the probability $p(k)$ for a photon with a given energy k to be detected in the calorimeter with an amplitude above ADC_{th} (corresponding to $E_{th} = 200\ MeV$):

$$p(k) = \frac{\int_{ADC_{th}/\lambda}^{\infty} g(ADC, k) dADC}{\int_0^{\infty} g(ADC, k) dADC} \qquad (3)$$

and the analyzing power can be thus deduced from $p(k)$:

$$< A_{th} >= \frac{\int p(k) \frac{d\sigma_0(k)}{dk} A_{th}(k) dk}{\int p(k) \frac{d\sigma_0(k)}{dk} dk} \qquad (4)$$

4. Beam polarization results

330 polarization measurements have been performed during $N - \Delta$ experiment and 110 during G_e^P. The results are plotted in Figures 5 and 6. A 1% relative error, corresponding to common systematic uncertainty, must be added to all this points.

The typical relative uncertainty for a run of 40 mn is 0.8% statistics and 1.1% systematics, which gives a total uncertainty of 1.4%. The contribution of the different sources of errors are presented in table 1
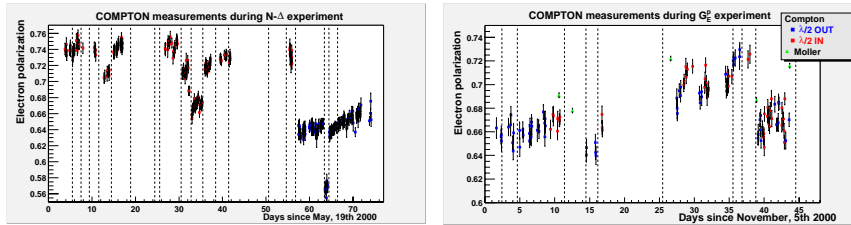

Figure 5. Errors are statistics plus run by run uncorrelated uncertainties. Dashed lines represent spot moves at the electron source .

Figure 6. Errors are statistics plus run by run uncorrelated uncertainties. Dashed lines represent spot moves at the electron source. Preliminary Moller points (statistic only) have been added for comparison.

Table 1. Error budget of Compton polarimeter measurements during $N - \Delta$ and G_e^P experiments

Error source	typical relative uncertainty (%)
Experimental asymmetry	
Statistical (40 mn)	0.80
Positions and angles	0.45
Events selection	0.10
Background asymmetry	0.05
Dead time	0.10
Laser beam	
Polarization P_γ	0.45
Analyzing power	
Modelization	0.45
Energy Calibration	0.60
Pile-up	0.45
Radiative corrections	0.25
total systematics	1.10
TOTAL	1.40

5. Conclusions

A Compton polarimeter operating a Fabry-Perot cavity is operational at JLAB since 1999. In 2000, during $N - \Delta$ and G_e^p experiments, a careful study of all sources of uncertainties and a new analysis approach[6] have allowed to measure continuously the beam polarization with a typical total relative uncertainty of 1.4% in 40 mn data taking, which are unprecedented results at these kinematical conditions (E=4.5 GeV, I=40 μA). For the first time, the electron detector has been used to determine the response function of the calorimeter. It will offer a complementary method to measure the beam polarization for the next generation of parity violation experiments above 3 GeV with a relative uncertainty better than 2%.

References

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