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SLD results from the study of polarized Z^0 produced at the **SLC***

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ABSTRACT

The results obtained during the 1992 run of the SLD detector at the SLC are reviewed together with the general performances of the machine. The first measurement of the left-right asymmetry, the determination of the Z^0 branching ratio to bottom quarks and the measurement of α_s are presented. Current plans and expectations for the 1993 run, when high polarization ($\geq 60\%$) GaAs strained cathodes sources will be used, are described.

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1. Introduction

The SLD (SLAC Large Detector) was moved to the SLC (SLAC Linear Collider) interaction point (I.P.) in January 1991: an engineering run was taken during that year to test and calibrate various components of the detector.[1] In 1992 a dedicated physics run was scheduled, following the commissioning of a GaAs polarized source for the SLC. The detector and the accelerator performed extremely well: a database of $\approx$ 10,000 polarized Z^0's was recorded in a period of about 4 months. In this paper I will review the performances of the machine and the polarized source, describe the measurements of $\mathrm{A_{LR}}$, $\mathrm{Br}(Z \rightarrow b\bar{b})$ and α_s and outline the plans and expectations for the 1993 run.

2. The 1992 SLC performances

The new features of the 1992 SLC running are[2] the 120 Hz operation of the Linac and the installation of a Polarized Electron Source (PES). The reliability of the accelerator complex was also increased, by improving the beam diagnostics with the addition of more beam position monitors connected to fast feedback loops. As a result, a dramatic improvement in peak luminosity ($\times 4$) and logged luminosity ($\times$ 10) with respect to the 1991 engineering run was obtained.

The PES[3] [4] is capable of delivering longitudinally polarized electrons from a Gallium Arsenide photocathode illuminated by a circularly polarized laser beam of 715 nm wavelength. The SLC requires two pulses of $\approx 6\times10^{10}$ electrons, 2 nsec. wide and $\approx$ 60 nsec apart. With the available laser power this requirement translates into a quantum efficiency of the photocathode above 3%. Such a value of the quantum efficiency was obtained using bulk GaAs as cathode material; cesiation of the cathode was performed roughly once a week, while activation of the source was performed once a month; the total down time due to the source, including extraordinary maintenance, was of about 6%.

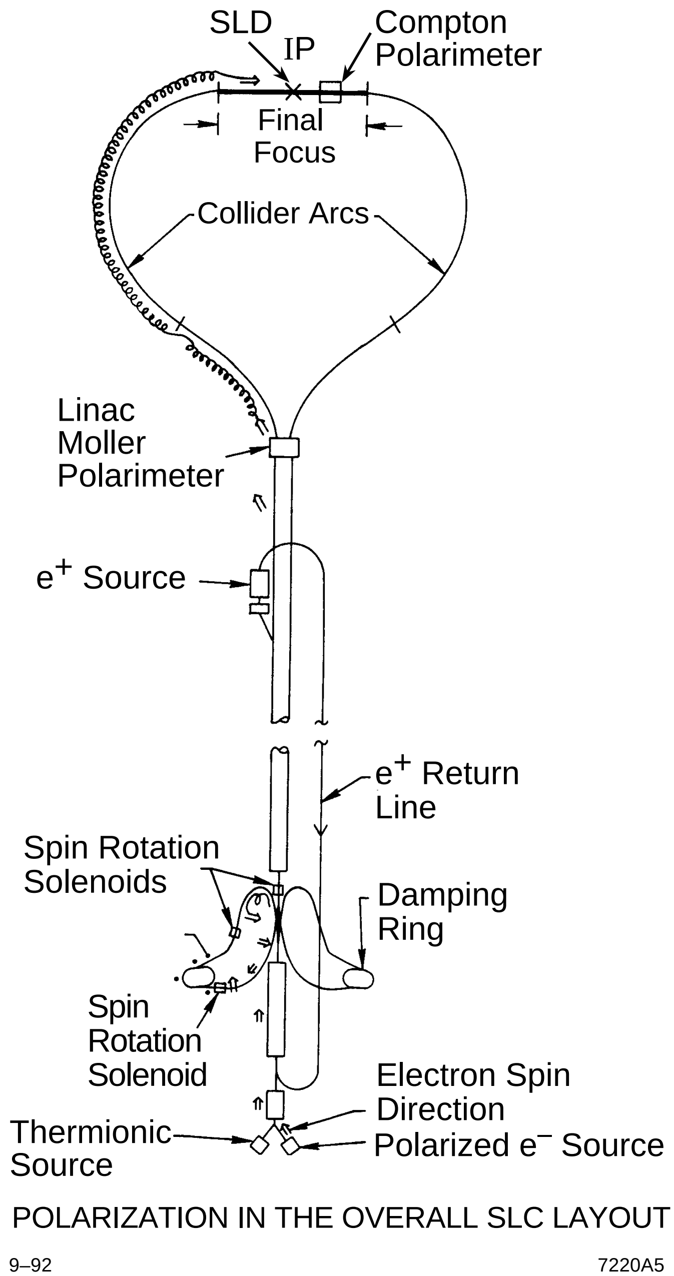

Figure 1. Schematic lay-out of the SLC.

The electron polarization at the gun was 28–29%; its sign was changed randomly switching the handedness of the (circularly polarized) laser light hitting the photocathode.

In order to preserve the electron beam polarization throughout the damping and acceleration cycle, some spin manipulation had to be performed. The spin rotation system included three superconducting solenoidal magnets to align the spin of the polarized beams parallel to the guide field at the entrance of the damping ring, and then to point it, upon exit, at an angle such that after precession in the arcs, it would be parallel (or antiparallel) to the momentum at the I.P.

The overall efficiency of the spin transport system was close to, but lower than, one; the two main depolarizing effects were due to: a) less then perfect match between the spin manipulation system at the entrance of the damping ring with the damping ring energy itself; b) the finite energy spread of the beams transported through the arcs. The spin rotators were in fact designed for the nominal damping ring energy (1.21 GeV) while the operational value was 1.16 GeV; this in turn caused a small but finite angle between the electron spin and the damping ring guide field, resulting in a net overall depolarization of $\approx 5\%$. The finite energy spread of the electron beam (0.3%) was responsible for a spread in the orientation of the spin vectors at the I.P.; different arc orbits as well would cause an effective depolarization, as the net spin rotation in the arc would vary. The overall spin transmission efficiency in the arc during the data taking period was about 85%.

In summary the main achievements of the machine during the 1992 run were an impressive increase in logged luminosity and the exploitation of longitudinally polarized beams.

3. The $\mathrm{A_{LR}}$ measurement

The left-right asymmetry is defined as the difference in Z^0 boson production cross sections for left-handed and right-handed electrons, normalized to the sum. In the framework of the Standard Model this is a quantity extremely sensitive to the electroweak mixing parameter $\sin^2\theta_W^{\mathrm{eff}}$ that in turn is a function of the vector v_e and axial vector a_e couplings of electrons to the Z^0.

$$A_{LR} = \frac{2 \times v_e \times a_e}{v_e^2 + a_e^2} = \frac{2 \times [1 - 4 \times \sin^2\theta_W^{\mathrm{eff}}]}{1 + [1 - 4 \times \sin^2\theta_W^{\mathrm{eff}}]^2} \tag{3.1}$$

since:

$$\sin^2\theta_W^{\mathrm{eff}} = \frac{1}{4} \times (1 - \frac{v_e}{a_e}) \tag{3.2}$$

Unlike the charge asymmetries that can be measured at the Z^0 pole, the left right asymmetry depends uniquely on the Z^0 coupling to the initial state; its expected value $\mathcal{O}(0.15)$ is rather large.

From the experimental point of view, the quantities to be measured are the polarization of the electron beam and the Z^0 production cross sections in the two helicity states of the electrons. The only quantity that has to be measured in absolute terms is the electron polarization; the cross sections can be measured on a relative scale.

3.1 Measuring the beam polarization

The absolute value of the electron beam polarization was measured with Compton scattering. The spent electron beam, before entering the transport line to the beam dump, scatters off a beam of circularly polarized photons produced by a frequency doubled Nd:YAG laser ($E_\gamma = 2.23$ eV). A system of dipole magnets is used to momentum analyze the scattered electron beam which exits the beam pipe through a thin window and is detected in an array of Cherenkov and proportional

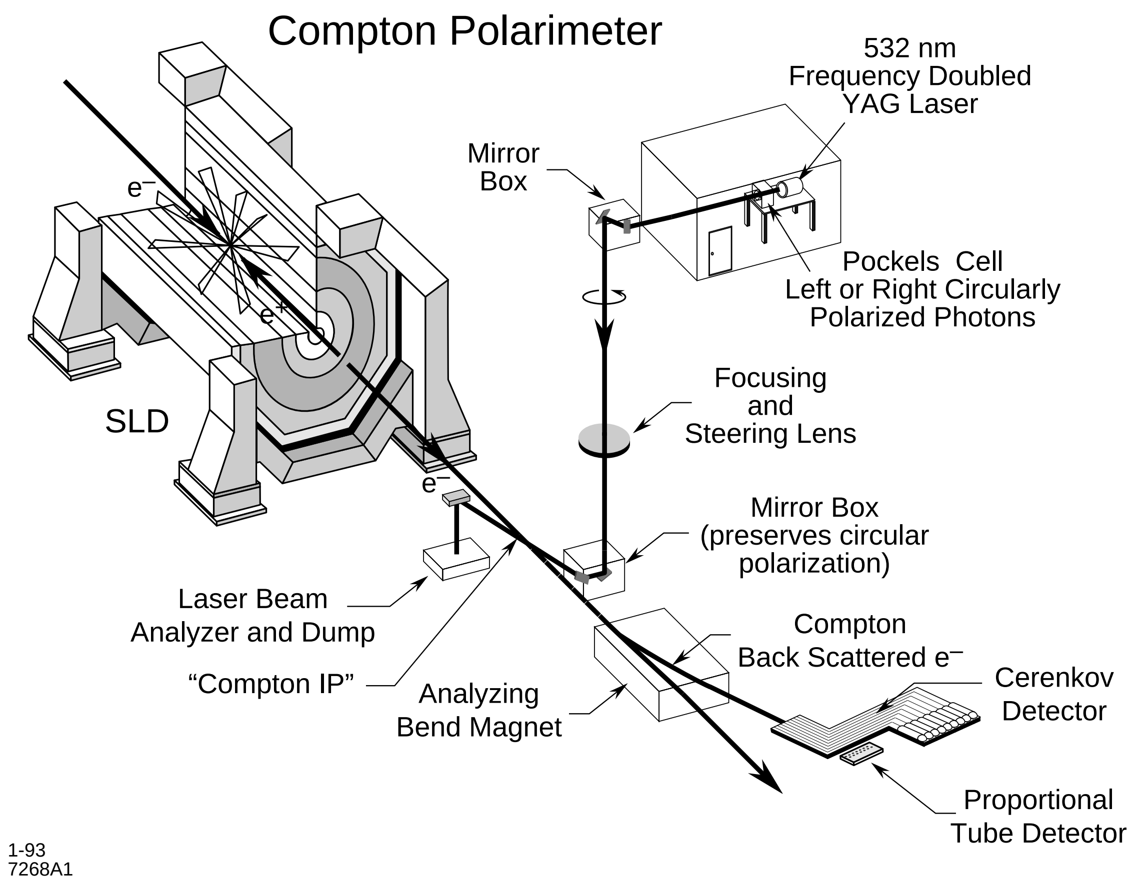

Figure 2. A view of the SLD detector and the Compton polarimeter.

tube counters. The momentum bite of the system (magnet and detectors) covers the interval 17-33 Gev/c. Figure 2 shows an artistic view of the detector and the Compton polarimeter.

The laser polarization, $\mathcal{P}_\gamma$, was measured to be $(93 \pm 2)\%$ at the $e\gamma$ interaction point and was randomly changed on a pulse by pulse basis. Measurements of the counting rate of different detectors were used to form an energy dependent experimental asymmetry, which is related to the theoretical asymmetry through the value of the electron and γ polarization.

The counting rates for the four different helicity combinations of the two beams yield the two experimental asymmetries corresponding to the two polarization

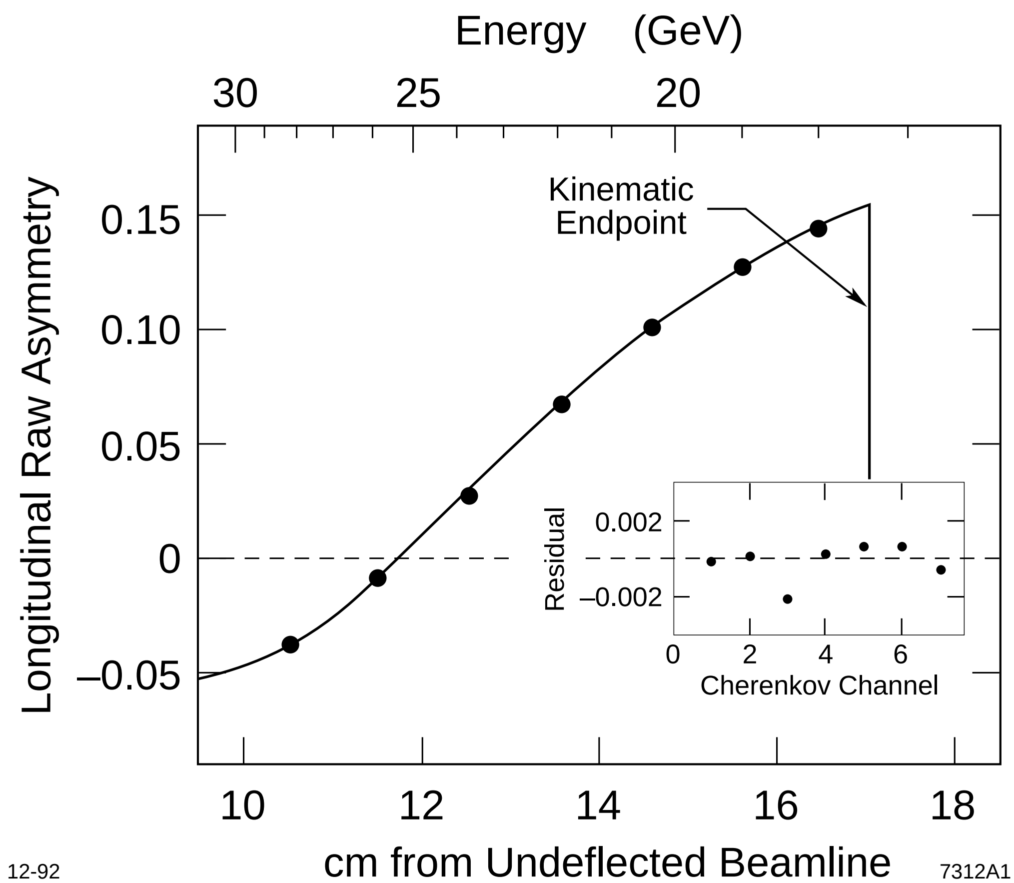

Figure 3. The counting rate asymmetry for the Compton polarimeter with $\mathcal{P}_e$=0.23 and $\mathcal{P}_\gamma$=0.93.

states of the electron beam and two pseudo-asymmetries, the values of which have to correspond to zero polarization and can be used to get a handle on systematics. Fig. 3 shows the expected asymmetry with the experimental points superimposed.

A typical polarization measurement with 22% electron polarization lasts about three minutes and has a statistical accuracy of $\approx 0.8\%$. The overall $\mathcal{P}_e$ measurement accuracy is limited by systematics, the breakdown of which is shown in Table 1.

We estimate that other effects related to beam dynamics depolarization give a negligible contribution to systematics. Fig. 4 shows the distribution of the beam polarization throughout the 1992 run.

Table 1. Systematic errors in the absolute $\mathcal{P}_e$ measurement.

Type of systematic error	Contribution to $\frac{\delta\mathcal{P}_e}{\mathcal{P}_e}$
Circular polarization of the laser	0.02
Calibration of the analyzing power	0.004
Linearity	0.015
Channel to channel intercalibration	0.009
Noise	0.004
Total	0.027

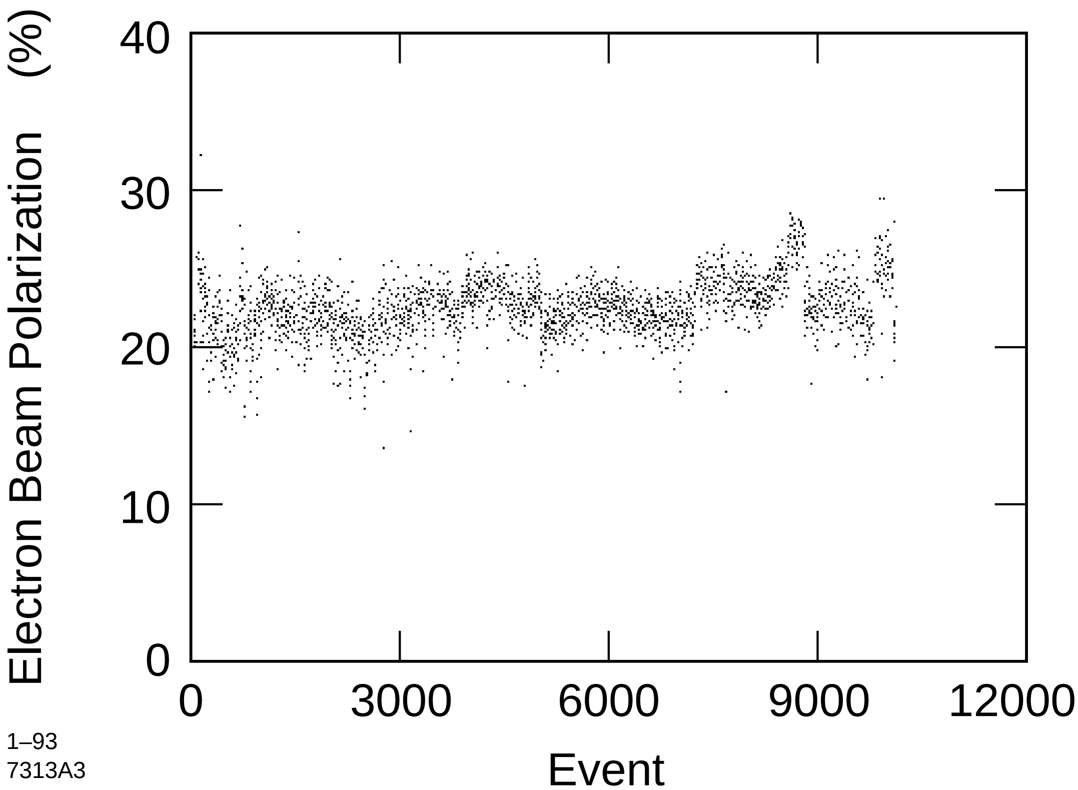

Figure 4. Distribution of beam polarization measurements, 1992 running cycle.

3.2 Data selection and analysis

The Z^0 hadronic decay selection is essentially based on the Liquid Argon Calorimeter (LAC)[5]; the coverage of this detector is $\gtrsim 98\%$ of the total solid angle. Its longitudinal segmentation is fourfold with two e.m. and two hadronic compartments; the transverse granularity (projective towers) is rather fine with $\sim\ 17,000$ towers in the e.m. section. The selection of the Z^0 decay events is made with a series of cuts both on energy deposition in the calorimeter towers and on energy clusters topology[6]. The overall trigger and selection event efficiency is evaluated to be (90±2)% for hadronic Z^0 decays and $\approx$ 30% for τ pairs. The background contamination of the data sample is estimated $\approx$ 1.4%, evenly split between Bhabha and beam related background. The actual value of the electron beam polarization is obtained from the sign of the (circular) polarization of the dye laser illuminating the photocathode, and is logged onto the data tape via two independent paths. The synchronization of the polarization information with the Z^0 triggers has often been verified. Possible instrumental effects on the measured asymmetry turn out to be small: the measurement of A_{LR} is independent on the final state acceptance and efficiency if $\epsilon \times \mathrm{Acc.}(\theta, fermion) = \epsilon \times \mathrm{Acc.}(\theta, antifermion)$. This condition is verified in the SLD detector because of the azimuthal symmetry of the magnetic field.

The total number of selected Z^0 decays is 10,224, broken down into 5,226 left-handed and 4,998 right-handed. The experimental A_{LR} is then

$$A^{meas}_{\mathrm{LR}} = \frac{N_L - N_R}{N_L + N_R} = (2.23 \pm 0.99) \times 10^{-2}$$

The value of A_{LR} is related to the measured quantity by:

$$A_{LR} = \frac{A^{meas}_{LR} \times (1 + \delta)}{\mathcal{P}_e} \tag{3.3}$$

where $\mathcal{P}_e$ is the luminosity weighted average beam polarization and δ is a correction factor in which many effects (residual background, luminosity asymmetry, energy asymmetry *etc.*) are folded in[6]; δ is evaluated to be small enough to be safely neglected. The measurement is then obtained just dividing the experimental value of the asymmetry by the average beam polarization :

$$A_{LR} = \frac{A_{LR}^{meas}}{\mathcal{P}_e} = 0.100 \pm 0.044 \text{ (stat)} \pm 0.004 \text{ syst.)} \tag{3.4}$$

from this value of A_{LR} one infers a value for $\sin^2\theta_W^{\text{eff}}$:

$$\sin^2\theta_W^{\text{eff}} = 0.2378 \pm 0.056 \text{ (stat)} \pm 0.004\text{(syst)} \tag{3.5}$$

This result, consistent with other determinations of $\sin^2\theta_W^{\text{eff}}$, in particular with LEP[7] measurement obtained with much larger samples of Z^0 events, shows the very high analyzing power of A_{LR} and its relative insensitivity to systematics.

4. The measurement of $\text{Br}(Z^0 \rightarrow b\bar{b})$

The Z^0 branching fraction to $b\bar{b}$:

$$R_b = \frac{\Gamma_{Z^0 \rightarrow b\bar{b}}}{\Gamma_{Z^0 \rightarrow hadr}} \tag{4.1}$$

is a quantity very sensitive to physics *beyond* the Standard Model: this is essentially because the oblique corrections cancel in the ratio[8] and vertex correction at the $Z^0 - b\bar{b}$ side stand up. The dependence of R_b on α_s is very weak: the relative variation of R_b for a 10% variation of α_s is 0.1%. A measurement of R_b to $\approx 1\%$ accuracy would allow, once the top mass is known, to discriminate between the various extensions of the Standard Model *e.g.* Minimal Supersymmetric Standard Model, Double Higgs *etc.*. The superior quality of the SLD vertex detector and the micron size beam spot at the SLC, allow to tag $b\bar{b}$ events just using vertex topologies, with improved statistical sensitivity and reduced systematic uncertainties. In this type of analysis the calorimeter system of the SLD is used just to select hadronic decays of the Z^0: the subsystems used in the data reduction are the Central Drift Chamber (CDC)[9] covering $\approx 85\%$ of the total solid angle and the Vertex Detector (VXD)[10], with a coverage of 75% of 4π. The reconstruction of charged tracks is done with the CDC; they are then extrapolated back to the vertex detector, and linked with different pixel clusters. The overall fit takes into account both measurement errors and Coulomb scattering contribution: the impact parameter resolution of the SLD tracking system can be parameterized as:

$$\delta d_{r\phi} = \sqrt{13^2 + \frac{70}{p \times sin^3(\theta)}}\ \mu m$$

$$\delta d_{rz} = \sqrt{52^2 + \frac{70}{p \times sin^3(\theta)}}\ \mu m$$

in the $r\phi$ plane and in the rz plane respectively.

The stability of the beam position has been investigated in great detail as this is a very important ingredient to exploit the detached vertices tagging. The luminous region, typically $2 \times 2 \times 650\ \mu m^3$ in volume, can be monitored using Z^0 events. About 50 tracks with small impact parameter are used to fit a common I.P over a time span of the order of 1-2 hours. During the 1992 running we obtained about 500 different determinations each of them with a precision of $\approx 10\mu$m. The distribution of the impact parameter for ee and $\mu\mu$ events is depicted in Fig. 5: after unfolding the contribution of the single track resolution (measured from the miss distance for the same events), the $\sigma_{I.P.}$ turns out to be 11 μm.

The selection of the $b\bar{b}$ events is made in two steps: we start selecting events with good tracks (at least seven) and good links (at least three) in a fiducial solid angle ($|cos\theta| \leq 0.71$). This selection is quite insensitive to the final state flavour: the Monte Carlo estimate yields for the relative efficiency of b events to hadronic events the value of 1.0 ± 0.07. Two kind of analyses are then performed on the selected events[11]: the first one chooses events with at least three tracks with a normalized *positive* impact parameter with respect to the nearest jet (that

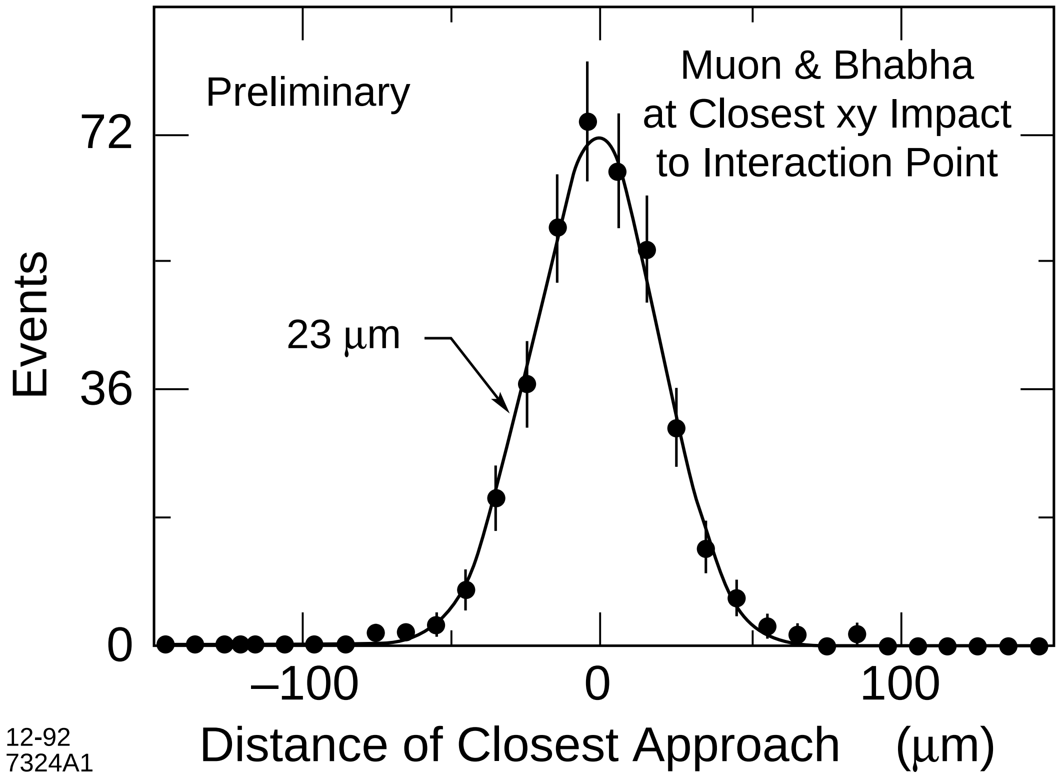

Figure 5. The impact parameter distribution in the plane perpendicular to the e^+e^- line of flight (XY) for $\mu\mu$ and e^+e^- events.

is impact parameter divided by its overall error including I.P. position) bigger than 3. The second one selects events in which at least 4 two prong vertices have a normalized flight distance (flight distance divided by its error) greater than 6. The two methods yield an efficiency of 71% and 58% respectively; the purity of the two samples are 71% and 77%. A consistent overlap ($\approx$ 75%) is observed for the two samples. The values obtained for R_b are: 0.214 ± 0.01 and 0.204 ± 0.011. A detailed study of the systematic effects, can be found in Ref 11; the systematic error are 0.025 and 0.03 respectively and reflect the less than perfect knowledge of out detector simulation. They do no present any insurmountable obstacle or limit for these analysis methods.

5. The measurement of α_s

The value of the strong coupling constant α_s was measured with several methods. All analyses concerning this quantity were performed using charged tracks reconstructed in the CDC. I will mention three different techniques to evaluate the strong coupling constant: measurement of jet rates, energy energy correlations and the asymmetry in energy energy correlations. All these analyses are well established: to measure three jets rate SLD[12] uses a modified Jade[13] jet finding algorithm, the value of α_s turns out to be:

$$\alpha_s = 0.119 \pm 0.002 \text{ (stat)} \pm 0.003\text{(syst)} \pm 0.014\text{(theory)}$$

The other two methods,[14] again use standard analysis techniques to extract from the momentum weighted angular distribution of the reconstructed tracks:

$$\alpha_s = 0.121 \pm 0.002\text{(stat)} \pm 0.004\text{(syst)}^{+0.016}_{-0.009}\text{(theory) en. en. correlation}$$

$$\alpha_s = 0.108 \pm 0.002\text{(stat)} \pm 0.005\text{(syst)}^{+0.008}_{-0.003}\text{(theory) en. en. correlation asymmetry}$$

5.1 Measurement of α_s for b quarks

Using the techniques described in the two previous paragraphs it is possible to measure α_s for events with enhanced b quark content unfolding the contribution of the light quarks to obtain a measurement of the strong coupling constant for b quarks. The three jet analysis is carried out on events tagged as $b\bar{b}$[15] by vertex topology; the purity of the sample is again evaluated by Monte Carlo. Effects due to the high mass of the b quarks increase to some extent the rate for three jets events (as the average $\mathrm{p_t}$ of the tracks is higher); by the same token b quarks would have a reduced probability of gluon emission because of the reduced phase space.

Monte Carlo corrections are applied to the data correspondingly. After unfolding the background, the SLD preliminary result is:

$$\frac{\alpha_s(b)}{\alpha_s(udsc)} = 1.18 \pm 0.11(\text{stat}) \pm 0.05(\text{syst})$$

6. Future outlook

The 1993 SLD run is presently under way at SLC; it is even more successful than anticipated after the 1992 campaign. High polarization guns, based on the strained lattice technique[16] have shown enough current capability and reliability to be installed on the machine at the very beginning of the 1993 cycle. These cathodes allow running with a polarization value ≥ 60 % at the I.P.; polarization as high as 85-90% has been observed in the test laboratory. Furthermore the use of flat beams has increased the peak luminosity of the machine by an extra factor of 3 (as of now the peak luminosity observed at the SLC correspond to a rate of ≈ 1 Z^0/min), without increasing beam related backgrounds. At the moment of this writing the SLD has on tape a database of $\approx$ 30,000 Z^0, with an average polarization of 62%, and we expect to at least double our statistics by the end of this cycle. In Fig. 6 is depicted the expected precision in the measurement of $\sin^2\theta_W^{\text{eff}}$ as a function of the number of detected decays: at the actual rate SLD would reach a precision of 0.0009 by the end of the 1993 run.

An upgrading program is also foreseen for the SLC: after the 1993 run the damping ring vacuum pipes will be replaced with new ones designed with smoother transitions: this will allow the handling of higher currents. A complete rearrangement of the final focus will allow to correct aberrations up to the third order and achieve even smaller beam spots. An extra factor four in luminosity is foreseen for the 1994 cycle. The SLD collaboration is proposing to run until a data base of about 1,000,000 Z^0 with a ≥ 65% polarization will be collected, the goal being to reach precision of 0.00025 on $\sin^2\theta_W^{\text{eff}}$ and possibly to measure the oscillation parameter for B_s mesons. This goal should be achieved by the end of 1997.

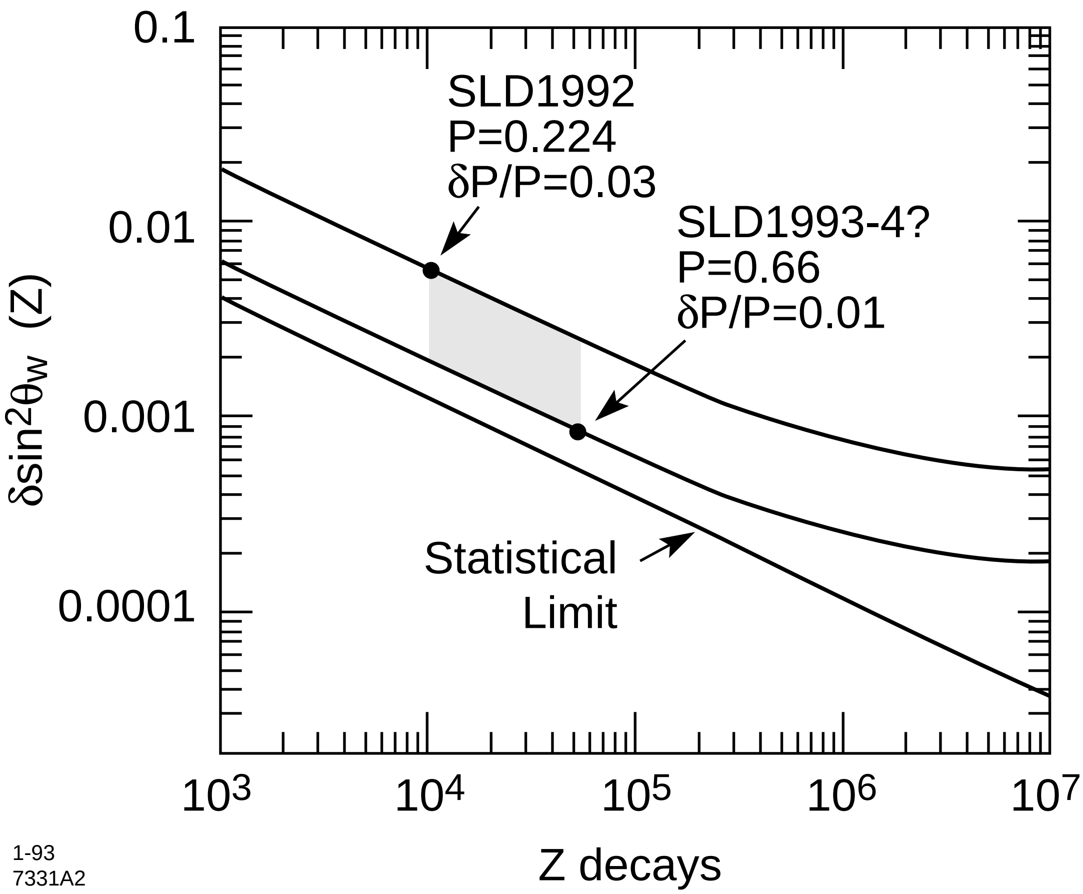

Figure 6. The expected precision in the measurement of $\sin^2\theta_W^{\rm eff}$ as a function of the number of detected Z^0 decays.

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