Assessing the Merits of Positron Polarization at a Linear Collider

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working group E3 – subgroup SO3

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A highly polarized e^- beam (at least 80%), with pulse-to-pulse helicity reversibility, will be available.

It may be possible to produce a moderately polarized e^+ beam (40%–60%), although the technologies are presently unproven.

- How compelling are the physics arguments for P_+ ?
- How encouraging are the technology/cost prospects ?
- Are there performance tradeoffs of any kind ?

Polarization basics and conventions

Conventions : RH (+ helicity) : $P > 0$
LH (– helicity) : $P < 0$, for both e^- and e^+

P_- = electron polarization, P_+ = positron polarization

For s-channel vector boson production, and for processes with similar helicity structure :

$$\sigma \sim (1 - P_-)(1 + P_+)\, g_L^{\,2} + (1 + P_-)(1 - P_+)\, g_R^{\,2} \ .$$

And if we define the asymmetry $(g_L^{\,2} - g_R^{\,2})/(g_L^{\,2} + g_R^{\,2}) \equiv A_{LR}$, then

$$\sigma = \sigma_0\,[1 - P_-\,P_+ - A_{LR}(P_- - P_+)\,] \ ,$$

Where $\sigma_0 \equiv$ the unpolarized cross section (for $P_- = P_+ = 0$).

A useful parameter is the effective polarization, P_{eff} , which is defined in terms of the P_- , P_+
spin-flip cross section asymmetry = $P_{eff}\,A_{LR}$, where

$$P_{eff} = (P_- - P_+)\,/\,(1 - P_-\,P_+\,) \ .$$

An example is the case $P_- = +0.80$ and $P_+ = -0.60$, for which $P_{eff} = 0.946$.

Experimental advantages of e^+ polarization

It is straightforward to see the how e^+ polarization can be helpful. The subtleties arise when more detailed experimental issues are examined.

First – we list the fundamental improvements possible when both beams are polarized.

$$P_{\text{eff}} > P_-$$

1. The larger effective polarization increases observed asymmetries.
2. The larger effective polarization can be used to further enhance desirable processes, and to further suppress backgrounds, compared to e^- polarization by itself.

$$d\,P_{\text{eff}} / P_{\text{eff}} < d\,P_- / P_-$$

1. With both beams polarized, and with a precision polarimeter for each of the beams, the measurement error for P_{eff} is smaller than the measurement error of either polarimeter. This is just a consequence of error propagation (as $P_{\text{eff}} \to 1$, $\delta P_{\text{eff}} \to 0$). For example, if both polarimeters have relative precisions of 0.25%, the measurement precision for P_{eff} is only 0.1% relative.

All four (LR,RL,LL,RR) helicity states are separately accessible.

1. The “*Blondel Scheme*” - By taking data in all four helicity configurations, one obviates the need for absolute polarimetry, all but eliminating associated systematic error. Two polarimeters are still required for relative (L versus R) polarization measurements.
2. One can directly study the four helicity contributions to any physics process.

Applications to specific physics analyses

Discussions of the physics studies that benefit from e^+ polarization appear in both the TESLA TDR and in the Linear Collider Resource Book (NLC). A more detailed phenomenological treatment appears in : Gudrid Moortgat-Pick and Herb Steiner, DESY 00-178 (2000).

Gudrid will be giving a talk on this topic on Tuesday.

I will make some general comments, and will mention some important experimental issues (see, for example R. Hawking and K. Mönig, DESY 99-157 (1999) and PCR and M. Woods, SLAC-PUB-8745 (2000).)

Klaus M., Eric Torrence and I, will introduce these exp. issues in the parallel session.

$P_{eff} > P_-$

The most effective application of signal enhancement/background suppression occurs when helicity dependence is maximal, ie. $A_{LR} = \pm 1$. This holds in WW or single W production production, due to the dominance of the amplitudes containing the $e^-_L \nu W$ vertex. For these processes :

For $P_- = +80\%$ and $P_+ = 0$, $\sigma = 0.20\ \sigma_0$
For $P_- = +80\%$ and $P_+ = -60\%$, $\sigma = 0.08\ \sigma_0$ - a factor of 2.5 improvement.
Desirable signals are increased by at most (for $P_+ = \pm 1$) a factor of 2, and generally less (1.6 for the case above).

Manipulation of the WW rates is useful for the W threshold scan (bkgrd control) where improvement of about a factor 2 are possible in the stat. error on M_W , and in any new physics search (eg. SS) where W's are a troublesome background → improve S/N.

In this maximal case, one can at most expect an improvement in S/ÖN of about 2.5.

For these techniques, some performance can be regained by increasing *P_-*.

(For $P_- = 92\%$, one gets the same bkgrd suppression, less signal enhancement.)

Applications to specific physics analyses, cont.

$d\ P_{eff}/\ P_{eff} < d\ P_{-}/\ P_{-}$

Improvements in polarimetery, either due to $P_{eff,}$, or to the Blondel scheme, are useful for reducing systematic effects in signal enhancement/bkgrd suppression analyses – For example, in the W threshold scan mentioned previously. Are these effects the limiting systematics ? Improvements over SLC performance are expected to be about a factor of 2 (see the table below), if an analogous Compton polarimeter can be built (see PCR/M.Woods, and MW, SLAC-PUB-8397 (2000).)

Energy calibration is likely to be a very challenging issue at the few MeV levels hoped for in δM_W.

	δP/P	δP/P (future)
Total error	0.50%	0.25%

The most dramatic improvements occurs for the A_{LR} measurement using a high-luminosity Z-pole run. With the improved e^- polarimetry above, 50 million events are sufficient to get an improvement of a factor of 5 over the SLD result. With e^+ polarization, and a polarimetry error of 0.1%, one can get an additional factor of 2.5, and 100 million events are sufficient. At and beyond this level, as for the W scan : Energy calibration is likely to be a difficult experimental problem (δ E < 5 MeV).

$A_{LR}(E_{cm})$ ® A^0_{LR} ($\equiv sin^2q_W^{eff}$)

Conversion to the Z-pole value requires accurate and precise knowledge of $E_{cm.}$

Important rule of thumb : 80 MeV error ® 1% A_{LR} error.

Finally – Interpretation of the A_{LR} measurement is limited by $\delta\alpha(M_Z^2)$.

Incl. possible improvements (factor of ≈4) this limit would be equivalent to the 100 MegaZ level.

Applications to specific physics analyses, cont.

All four (LR,RL,LL,RR) helicity states are separately accessible.

G. Moortgat-Pick and H. Steiner give an example of selectron pair production, where the s-channel (γ, Z) production amplitude can be turned off relative to the neutralino t-channel amplitude – by restricting the initial state to RR or LL. The slectron final state configuration of LR or RL is only accessible via the t-channel (the s-channel produces the LL and RR states). The L and R quantum numbers of the sleptons are untangled in a more straightforward manner. Information can be obtained with a polarized e^- beam by itself. The situation is most difficult when the L and R sleptons are close to degenerate in mass, as they are in many models.

Another example occurs in neutralino pair production, where different models give different cross section magnitudes for each of the four (LL,LR, RL and RR) helicity configurations.

This an example of an analysis that can *only* be done with e^+ polarization.
But can one use e^- polarization alone, along with some model assumptions,
to get at the same essential information ?

Some final comments on intrumental/accelerator issues

1. At the SLC, the control of small L/R polarization systematics exploited the ability of the source to **rapidly change beam helicity** (pulse-to-pulse). A plausible option for a polarized e^+ source, namely the helical undulator scheme, will not be able to do this. A fast kicker magnet in combination with two opposite sign spin rotators can be used to alleviate this problem (rotators must be used, in any LC, to force the bunches into transverse orientation prior to damping) – but it is not presently clear if this would be sufficient for the highest precision measurements.

Small correction terms are due to backgrounds (f_b),
LR asymmetries (A_x, with $x = b,L,P,E,e$) of
backgrounds,luminosity, polarization,
center-of-mass energy,detection efficiency
and possible undetected positron polarization (P_p)

$$\boldsymbol{A_{LR}} = \frac{\boldsymbol{A_m}}{\boldsymbol{P_e}} + \frac{1}{P_e}\left[f_b(A_m - A_b) - A_L + A_m^2 A_P - E_{cm}\frac{s'(E_{cm})}{s\,(E_{cm})}A_E - A_e \right] + P_p$$

2. Our studies concluded that the energy calibration precision (largely due to beam-beam energy loss effects) indicates that **lower-luminosity/lower beamstrahlung running is highly desirable for the precision weak-mixing angle determination.** This is also true for W-threshold scans, and for this case, statistical limitations are a more serious issue.

3. To what extent can higher e^- polarization compensate for the lack of two polarized beams ? If 90+% photocathodes become available in the decade or more prior to LC startup, it is certainly simpler to install these than it is to include a complex and expensive polarized e^+ source.

At the heart of the polarized e^+ discussion are the technical issues for polarized sources, polarimetry, energy spectrometry, and LC operation.