Positron Polarization: Key Feature for ILC Physics

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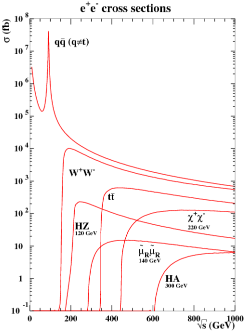
4 colliders in one



Outline

Introduction

Beam Polarization

- Long recognized that longitudinal beam polarization is an essential feature for probing electroweak interactions
- Single beam polarization (electron) is "straightforward" and an established aspect of linear collider concepts
- Positron polarization in addition has distinct advantages
- The ILC baseline positron source is compatible with positron polarization

Documents

1. Comprehensive 2008 paper. Polarized positrons and electrons at the linear collider. G. Moortgat-Pick et al, Phys. Rept. 460 (2008) 131-243. 83 authors. 338 references.
2. Recent white paper commissioned by LCC. K. Fujii et al, The role of positron polarization for the initial 250 GeV stage of the ILC, arXiv: 1801.02840.

Will not review these comprehensively. I will try to explain why many of us are convinced that positron polarization is close to essential for the ILC program.

An Experimentalist's Basic Picture

Three main benefits of positron beam polarization are:

Better Statistics Can obtain subsamples of data with higher rates for processes of interest, lower rates for backgrounds, and higher analyzing power. More physics per fb^{-1}. Less running time/operating costs for same physics.

More Observables Four distinct data-sets to experiment with. Most important reactions involve only the opposite-sign polarization collisions, but there are reactions where the two like-sign polarization collisions give additional or even unique information. This flexibility is a unique asset for ILC (also including unpolarized beam(s) or transversely polarized beam(s)).

Lower Systematics Positron polarization is key to reducing systematic uncertainties associated with the knowledge of the polarization and thus ensuring that the ILC facility can fully exploit the large integrated luminosities envisaged.

Polarization Measurements at ILC

A primary issue in using polarized beam(s) is measuring the amount of polarization. This can be a limiting systematic uncertainty for high statistics measurements.

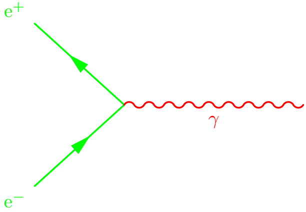
Several methods are envisaged with different strengths and weaknesses.

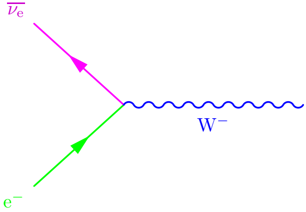
- **Polarimeters** Compton polarimeters upstream/downstream of IP with systematic uncertainties envisaged of $\Delta P/P$ of 0.25%. Essential for polarization monitoring. But need to correct to IP.
- **Cross-Section Based** In-situ measurement. Some physics assumptions. Often under assumption of perfect helicity reversal.
- **Differential Cross-Section Based** In-situ measurement. Some physics assumptions. Often under assumption of perfect helicity reversal.

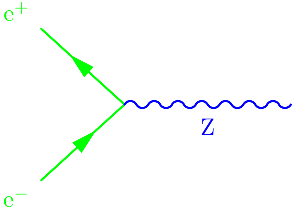
It turns out that adding positron polarization helps in two ways. One by providing additional measurements that help constrain the polarization measurement problem, and by increasing the effective polarization.

The in-situ methods are likely to provide the ultimate measurement, but require data-taking to be allocated to the normally less interesting same-sign configurations and potentially others.

SM Vertices



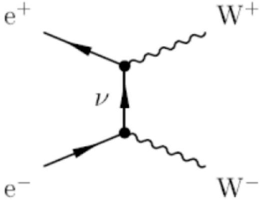




QED: γ Parity conserving, $A = 0$.

Charged Current: W Maximally parity violating, $A = 1$. Only left-handed electron couples to W^-.

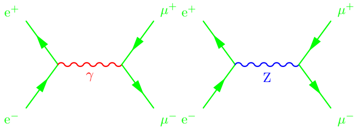
Neutral Current: Z Parity violating. ($A \approx 0.15$). Left-handed electron, right-handed positron favored.



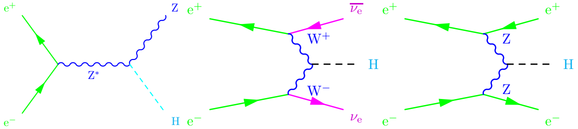
Here only $\mathrm{e_L}^-\mathrm{e_R}^+$ contributes (denote as LR).

Some Physics Processes

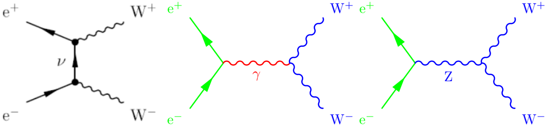
2f (LR and RL)



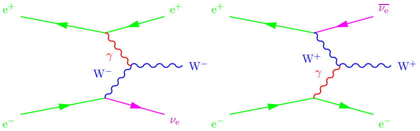
Higgs



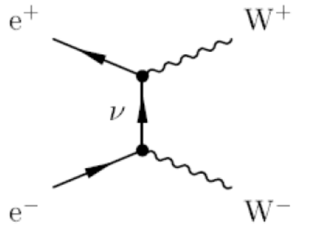
WW



single W^- (LR, LL). single W^+ (RL, RR)



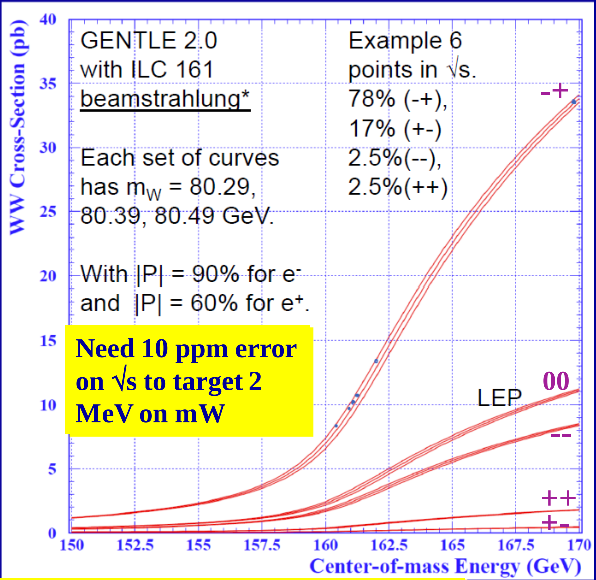
ILC Polarized Threshold Scan



Use (-+) helicity combination of e- and e+ to enhance WW.

Use (+-) helicity to suppress WW and measure background.

Use (--) and (++) to control polarization (also use 150 pb Z-like events)



Need 10 ppm error on √s to target 2 MeV on mW

Experimentally very robust. Measure pol., bkg. in situ

W mass from threshold (arXiv:1603.06016)

Fit parameter	Value	Error
m_W (GeV)	80.388	3.77×10^{-3}
f_l	1.0002	0.924×10^{-3}
ε (lvlv)	1.0004	0.969×10^{-3}
ε (qqlv)	0.99980	0.929×10^{-3}
ε (qqqq)	1.0000	0.942×10^{-3}
σ_B (lvlv) (fb)	10.28	0.92
σ_B (qqlv) (fb)	40.48	2.26
σ_B (qqqq) (fb)	196.37	3.62
A^B_{LR} (lvlv)	0.15637	0.0247
A^B_{LR} (qqlv)	0.29841	0.0119
A^B_{LR} (qqqq)	0.48012	4.72×10^{-3}
$\lvert P(e^-)\rvert$	0.89925	1.27×10^{-3}
$\lvert P(e^+)\rvert$	0.60077	9.41×10^{-4}
σ_{Z} (pb)	149.93	0.052
A^{Z}_{LR}	0.19062	2.89×10^{-4}

Table : Example ILC scan with 100 fb^{-1}

$\lvert P(e^-)\rvert$	$\lvert P(e^+)\rvert$	100 fb^{-1}	500 fb^{-1}
80 %	30 %	6.02	2.88
90 %	30 %	5.24	2.60
80 %	60 %	4.05	2.21
90 %	60 %	3.77	2.12

Table : Total m_W experimental uncertainty (MeV)

Fit essentially includes experimental systematics. Main one - background determination.

$$\Delta m_W(\mathrm{MeV}) = 2.4\ (\mathrm{stat}) \oplus 3.1\ (\mathrm{syst}) \oplus 0.8\ (\sqrt{\mathrm{s}}) \oplus \mathrm{theory}$$

Cross-section observables: conventional colliders

Hadron Collider

Tevatron, LHC

$$\sigma_{AB}(p,p') \sim \sum_{partons\ i,j} \int_0^1 \mathrm{d}x\,\mathrm{d}x'\ \hat{\sigma}_{ij}(xp, x'p')\,\phi_{i/A}(x)\,\phi_{j/B}(x')$$

One measurement. But complex sum over partonic processes and convolution with parton distribution functions.

Circular $\mathrm{e}^+\mathrm{e}^-$ Collider

PETRA, TRISTAN, LEP, CEPC, FCC-ee

$$\sigma = \sigma_U$$

One measurement. Very simple. Unpolarized - so averages over all initial spins.

$$\sigma_U = \frac{1}{4}\{\sigma_{LR} + \sigma_{RL} + \sigma_{LL} + \sigma_{RR}\}$$

But the 4 individual contributions can not be investigated.

Longitudinally polarized cross-sections

The cross-section measured for particular values of the longitudinal polarization of each beam, defined as

$$P \equiv \frac{N_R - N_L}{N_R + N_L}$$

is

$$\begin{aligned}\sigma(P_{\mathrm{e}^-}, P_{\mathrm{e}^+}) &= \frac{1}{4}\{(1 - P_{\mathrm{e}^-})(1 + P_{\mathrm{e}^+})\sigma_{LR} + (1 + P_{\mathrm{e}^-})(1 - P_{\mathrm{e}^+})\sigma_{RL} + \\ &\quad (1 - P_{\mathrm{e}^-})(1 - P_{\mathrm{e}^+})\sigma_{LL} + (1 + P_{\mathrm{e}^-})(1 + P_{\mathrm{e}^+})\sigma_{RR}\}\end{aligned}$$

where eg. σ_{LR} is the cross-section for the case where the e^- beam is completely left-handed polarized ($P_{\mathrm{e}^-} = -1$) and the e^+ beam is completely right-handed polarized ($P_{\mathrm{e}^+} = +1$). For realistic polarization values such as $(\pm 0.8, \pm 0.3)$, the observable cross-section will be this weighted sum of the pure chiral cross-sections, where each weight corresponds to the fraction of collisions associated with each of the four underlying spin configurations.

The four longitudinal spin configurations

	e^-	e^+		
σ_{RR}			$\frac{1+P_{e^-}}{2} \cdot \frac{1+P_{e^+}}{2}$	$J_z = 0$
σ_{LL}			$\frac{1-P_{e^-}}{2} \cdot \frac{1-P_{e^+}}{2}$	
σ_{RL}			$\frac{1+P_{e^-}}{2} \cdot \frac{1-P_{e^+}}{2}$	$J_z = 1$
σ_{LR}			$\frac{1-P_{e^-}}{2} \cdot \frac{1+P_{e^+}}{2}$	

Only the $J_z = 1$ configurations apply to s-channel photon and Z exchange.

Statistics

For processes with only LR and RL contributions, with unpolarized beams, only 50% of the collisions are useful. This has led to the concept of effective luminosity fraction,

$$L_{\mathrm{eff}}/L = \frac{1}{2}(1 - P_{\mathrm{e}^-} P_{\mathrm{e}^+})$$

Clearly only with both beams polarized is it possible to change this.

With $\mp$80%, $\pm$30%, the increase is 24% for $A = 0$

With $\mp$80%, $\pm$60%, the increase is 48% for $A = 0$

With $\mp$90%, $\pm$60%, the increase is 54% for $A = 0$.

For processes, like WW at threshold, where essentially only LR contributes ($A \approx 1$), only 25% of the collisions are useful with unpolarized beams.

$$L^{'}_{\mathrm{eff}}/L = \frac{1}{4}(1 - P_{\mathrm{e}^-})(1 + P_{\mathrm{e}^+})$$

With -80%, 0%, the increase is 80% (factor of 1.80)

With -80%, +30%, the increase is 134% (factor of 2.34)

With -80%, +60%, the increase is 188% (factor of 2.88)

With -90%, +60%, the increase is 204% (factor of 3.04)

These effects are quite substantial in terms of saved running time and consequent operation costs

Cross-section observables: electron polarization only

SLC, CLIC

Take as standard example Z production. Define $A_{LR} \equiv \frac{\sigma_{LR}-\sigma_{RL}}{\sigma_{LR}+\sigma_{RL}}$
Now with $P_{\mathrm{e}^+} = 0$, we measure, assuming perfect helicity reversal,

$$\sigma_- = \sigma_U(1 + |P_{\mathrm{e}^-}|\, A_{LR}) \quad (1)$$

$$\sigma_+ = \sigma_U(1 - |P_{\mathrm{e}^-}|\, A_{LR}) \quad (2)$$

2 equations in 3 unknowns ..., leading to

$$\sigma_U = \frac{1}{2}(\sigma_- + \sigma_+) \quad (3)$$

$$A_{LR} = \frac{1}{|P_{\mathrm{e}^-}|}\,\frac{\sigma_- - \sigma_+}{\sigma_- + \sigma_+} \quad (4)$$

Assuming $L_- = L_+$,

$$\Delta A_{LR} = \frac{\Delta P}{P} A_{LR} \oplus \frac{\sqrt{1 - A_{LR}^2 P^2}}{P\sqrt{N}}$$

Systematic uncertainty on P, nominally 0.25%, limits A_{LR} precision

Cross-section observables: both beams polarized

ILC

Take as standard example Z production. Define $A_{LR} \equiv \frac{\sigma_{LR}-\sigma_{RL}}{\sigma_{LR}+\sigma_{RL}}$ Assume perfect helicity reversal for e^- and e^+, and defining $P^- = |P_{\mathrm{e}^-}|$ and $P^+ = |P_{\mathrm{e}^+}|$.

$$\sigma_{-+} = \sigma_U[1 + P^-P^+ + A(P^- + P^+)] \quad (5)$$

$$\sigma_{+-} = \sigma_U[1 + P^-P^+ - A(P^- + P^+)] \quad (6)$$

2 equations in 4 unknowns ..., leading to

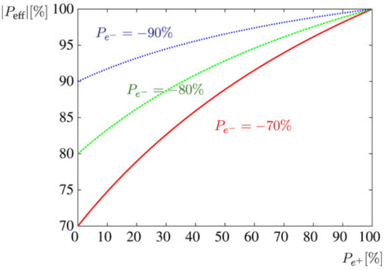
$$A_{LR} = \frac{1}{|P_{\mathrm{eff}}|}\frac{\sigma_{-+} - \sigma_{+-}}{\sigma_{-+} + \sigma_{+-}}$$

where

$$|P_{\mathrm{eff}}| = \frac{1 + P^-P^+}{P^- + P^+}$$

$$\Delta A_{LR} = \frac{\Delta P_{\mathrm{eff}}}{P_{\mathrm{eff}}} A_{LR} \oplus \frac{\sqrt{1 - A_{LR}^2 P_{\mathrm{eff}}^2}}{P_{\mathrm{eff}}\sqrt{N}}$$

Now systematic uncertainty on P_{eff} limits A_{LR} precision



Positron polarization increases $|P_{\rm eff}|$. Errors on A_{LR} decrease, partly because $|P_{\rm eff}|$ is larger, but mostly because $|P_{\rm eff}|$ is much less sensitive to uncertainties on the individual beam polarization values when positrons are polarized. Errors halved for $P^+ = 0.3$ - equivalent to quadrupling the statistics.

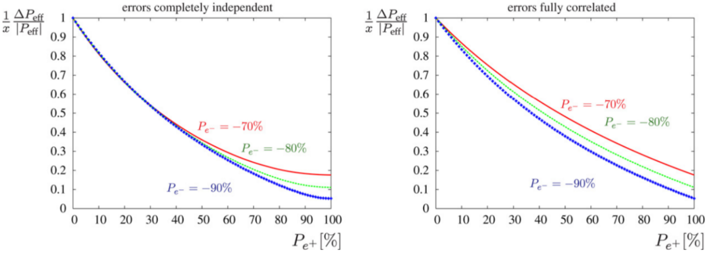


Fig. 1.7. Relative uncertainty on the effective polarization, $\Delta P_{\rm eff}/|P_{\rm eff}| \sim \Delta A_{\rm LR}/A_{\rm LR}$, normalized to the relative polarimeter precision $x = \Delta P_{e^-}/P_{e^-} = \Delta P_{e^+}/P_{e^+}$ for independent and correlated errors on P_{e^-} and P_{e^+}, see Eqs. (1.25) and (1.27).

Cross-section observables: both beams polarized (P^+, P^-)

ILC: 4 polarization configurations

Z production. Also use some L on "wrong-sign" configurations. Assume perfect helicity reversal for e^- and e^+, and with $P^- = |P_{\mathrm{e}^-}|$ and $P^+ = |P_{\mathrm{e}^+}|$.

$$\begin{aligned}
\sigma_{-+} &= \sigma_U[1 + P^-P^+ + A(P^- + P^+)] &(7)\\
\sigma_{+-} &= \sigma_U[1 + P^-P^+ - A(P^- + P^+)] &(8)\\
\sigma_{--} &= \sigma_U[1 - P^-P^+ + A(P^- - P^+)] &(9)\\
\sigma_{++} &= \sigma_U[1 - P^-P^+ - A(P^- - P^+)] &(10)
\end{aligned}$$

4 equations in 4 unknowns (OK), leading to explicit expressions for the 4 unknowns (σ_U, A, P^+, P^-) in terms of the 4 measurements.

$$|A| = \sqrt{\frac{(\sigma_{-+} - \sigma_{+-} - \sigma_{--} + \sigma_{++})\,(\sigma_{-+} - \sigma_{+-} + \sigma_{--} - \sigma_{++})}{(\sigma_{-+} + \sigma_{+-} + \sigma_{--} + \sigma_{++})\,(\sigma_{-+} + \sigma_{+-} - \sigma_{--} - \sigma_{++})}}$$

$$|P_{e^\mp}| = \sqrt{\frac{(\sigma_{-+} + \sigma_{+-} - \sigma_{--} - \sigma_{++})\,(\pm\sigma_{-+} \mp \sigma_{+-} + \sigma_{--} - \sigma_{++})}{(\sigma_{-+} + \sigma_{+-} + \sigma_{--} + \sigma_{++})\,(\pm\sigma_{-+} \mp \sigma_{+-} - \sigma_{--} + \sigma_{++})}}$$

In this case, $|P_{\mathrm{e}^-}|$ and $|P_{\mathrm{e}^+}|$ are directly measured from the collision data.

Precision Measurement of A_{LR} at $\sqrt{s} = m_Z$

(Note I am using Z as an example, but basically the same principles can be applied to most processes at $\sqrt{s} = 250$ GeV.)
Studied by K. Mönig 1999
For $\mathrm{Z} \to \mathrm{f}\bar{\mathrm{f}}$, general cross-section formula simplifies to

$$\sigma = \sigma_u[1 - P^+P^- + A_{\mathrm{LR}}(P^+ - P^-)]$$

With four combinations of helicities, 4 equations in 4 unknowns. Can solve for A_{LR} in terms of the four measured cross-sections (assumes helicity reversal for each beam maintains identical absolute polarization). Needs positron polarization.
For $P^- = 0.8$, $P^+ = 0.6$, $f_{\mathrm{SS}} = 0.08$, $\sigma_U^{vis} = 33$ nb:

$$\Delta A_{LR}(\mathrm{stat}) = 1.7 \times 10^{-5}/\sqrt{\mathrm{L}(100\ \mathrm{fb}^{-1})}$$

Can easily handle 10^9 Z's in terms of systematics. Still worth doing with less.
SLD error: 0.0039 (with 0.64% relative error on P)

The Fine Print I

In practice, we want to be able to test and constrain the underlying assumptions. The primary one is the assumption of high quality helicity reversal, namely that the $\delta_{\pm}$ values defined below are small.

This is likely reasonable for the electron beam where the helicity sign is defined by the laser polarization. For the positron beam where the helicity is baked into the undulator winding sense (in that source scheme), it relies on the quality of the pre damping ring, parallel spin rotator sections with opposite solenoid fields (see L. Malysheva, LCWS15).

Parametrize the four non-zero polarizations in terms of the respective beam's mean absolute polarization $|P|$ and (signed) polarization difference δ

$$P^{L}_{\mathrm{e}^-} = -|P_{\mathrm{e}^-}| + \tfrac{1}{2}\delta_- \quad P^{L}_{\mathrm{e}^+} = -|P_{\mathrm{e}^+}| + \tfrac{1}{2}\delta_+ \tag{11}$$

$$P^{R}_{\mathrm{e}^-} = \ \ |P_{\mathrm{e}^-}| + \tfrac{1}{2}\delta_- \quad P^{R}_{\mathrm{e}^+} = \ \ |P_{\mathrm{e}^+}| + \tfrac{1}{2}\delta_+ \tag{12}$$

These relative differences can be constrained by the polarimeters.

There are also collision based measurements feasible with other processes including WW and single W.

Current conclusions are that with positron polarization it should be feasible to constrain the polarizations to 0.1% with the full ILC program. With no positron polarization, the robustness decreases by large factors (5-10), and puts a big onus (too big ..) on the polarimeters. See studies by R. Karl and J. List.

The Fine Print II

We don't know for sure how robust the (4-configuration scheme, polarimeters, collision data) ensemble will be, and different measurements depend more or less on the polarization determination.
If necessary we could

1. Devote more integrated luminosity to the "wrong-sign" configurations improving statistical errors on the polarization measurement
2. Devote some integrated luminosity to only electron-beam polarized and to only positron-beam polarized, and even both unpolarized. Allows collision-based direct measurement of the δ's.

How to achieve unpolarized beam(s) is an interesting question. One option would be to keep the same polarization, but to rotate the polarization to the transverse plane, thus zeroing out the longitudinal polarization.
This could also allow exploration of transverse polarization effects in collision (which are generally sizeable for processes with small A), but mostly need both beams to be polarized!, and could provide complementary measurements of the absolute polarization.

General Cross-Section

For the completely general case of both beams potentially polarized and arbitrarily oriented polarization vectors, the cross-section is proportional to

$$
\begin{aligned}
|\mathcal{M}|^2 = \frac{1}{4}\Big\{ & (1 - P_{e^-})(1 + P_{e^+})|F_{\rm LR}|^2 + (1 + P_{e^-})(1 - P_{e^+})|F_{\rm RL}|^2 \\
& + (1 - P_{e^-})(1 - P_{e^+})|F_{\rm LL}|^2 + (1 + P_{e^-})(1 + P_{e^+})|F_{\rm RR}|^2 \\
& - 2P^{\rm T}_{e^-} P^{\rm T}_{e^+}\{[\cos(\phi_- - \phi_+)\,{\rm Re}\,(F_{\rm RR} F^*_{\rm LL}) + \cos(\phi_- + \phi_+ - 2\phi)\,{\rm Re}\,(F_{\rm LR} F^*_{\rm RL})] \\
& \quad + [\sin(\phi_- + \phi_+ - 2\phi)\,{\rm Im}\,(F_{\rm LR} F^*_{\rm RL}) + \sin(\phi_- - \phi_+)\,{\rm Im}\,(F^*_{\rm RR} F_{\rm LL})]\} \\
& \quad + 2P^{\rm T}_{e^-}\{\cos(\phi_- - \phi)[(1 - P_{e^+})\,{\rm Re}\,(F_{\rm RL} F^*_{\rm LL}) + (1 + P_{e^+})\,{\rm Re}\,(F_{\rm RR} F^*_{\rm LR})] \\
& \quad - \sin(\phi_- - \phi)[(1 - P_{e^+})\,{\rm Im}\,(F^*_{\rm RL} F_{\rm LL}) - (1 + P_{e^+})\,{\rm Im}\,(F^*_{\rm RR} F_{\rm LR})]\} \\
& \quad - 2P^{\rm T}_{e^+}\{\cos(\phi_+ - \phi)[(1 - P_{e^-})\,{\rm Re}\,(F_{\rm LR} F^*_{\rm LL}) + (1 + P_{e^-})\,{\rm Re}\,(F_{\rm RR} F^*_{\rm RL})] \\
& \quad + \sin(\phi_+ - \phi)[(1 - P_{e^-})\,{\rm Im}\,(F^*_{\rm LR} F_{\rm LL}) - (1 + P_{e^-})\,{\rm Im}\,(F^*_{\rm RR} F_{\rm RL})]\}\Big\},
\end{aligned}
$$

where P_e^-, P_e^+ are the (signed) longitudinal polarization components as usual, $P^{\rm T}_{e^-}$, $P^{\rm T}_{e^+}$ are the magnitudes of the transverse polarizations, and ϕ_- and ϕ_+ are the azimuthal orientations of the respective transverse polarizations, and the F_{ij} denote the helicity amplitudes. ϕ is the azimuthal angle of the reference momentum (eg of the μ^- in $\mathrm{e}^+\mathrm{e}^- \to \mu^+\mu^-$).

General Cross-Section Remarks

As before,

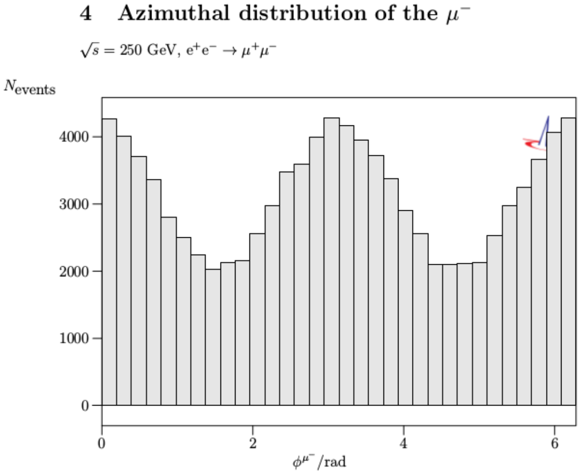
$$
\begin{aligned}
|\mathcal{M}|^2 = \frac{1}{4}\Big\{ & (1-P_{e^-})(1+P_{e^+})|F_{\rm LR}|^2 + (1+P_{e^-})(1-P_{e^+})|F_{\rm RL}|^2 \\
& + (1-P_{e^-})(1-P_{e^+})|F_{\rm LL}|^2 + (1+P_{e^-})(1+P_{e^+})|F_{\rm RR}|^2 \\
& - 2P^{\rm T}_{e^-}P^{\rm T}_{e^+}\{[\cos(\phi_- - \phi_+)\,{\rm Re}\,(F_{\rm RR}F^*_{\rm LL}) + \cos(\phi_- + \phi_+ - 2\phi)\,{\rm Re}\,(F_{\rm LR}F^*_{\rm RL})] \\
& \quad + [\sin(\phi_- + \phi_+ - 2\phi)\,{\rm Im}\,(F_{\rm LR}F^*_{\rm RL}) + \sin(\phi_- - \phi_+)\,{\rm Im}\,(F^*_{\rm RR}F_{\rm LL})]\} \\
& \quad + 2P^{\rm T}_{e^-}\{\cos(\phi_- - \phi)[(1-P_{e^+})\,{\rm Re}\,(F_{\rm RL}F^*_{\rm LL}) + (1+P_{e^+})\,{\rm Re}\,(F_{\rm RR}F^*_{\rm LR})] \\
& \quad - \sin(\phi_- - \phi)[(1-P_{e^+})\,{\rm Im}\,(F^*_{\rm RL}F_{\rm LL}) - (1+P_{e^+})\,{\rm Im}\,(F^*_{\rm RR}F_{\rm LR})]\} \\
& \quad - 2P^{\rm T}_{e^+}\{\cos(\phi_+ - \phi)[(1-P_{e^-})\,{\rm Re}\,(F_{\rm LR}F^*_{\rm LL}) + (1+P_{e^-})\,{\rm Re}\,(F_{\rm RR}F^*_{\rm RL})] \\
& \quad + \sin(\phi_+ - \phi)[(1-P_{e^-})\,{\rm Im}\,(F^*_{\rm LR}F_{\rm LL}) - (1+P_{e^-})\,{\rm Im}\,(F^*_{\rm RR}F_{\rm RL})]\}\Big\},
\end{aligned}
$$

The first two lines are the standard contributions from longitudinal polarization. The next two are the contributions that only exist when BOTH beams have transverse polarization. The following four are the contributions from the transverse polarization of each beam.

In practice for most known processes of interest, and in the $m_{\rm e} \to 0$ limit, $F_{LL} = F_{RR} = 0$, implying that transverse polarization only has observable effects if BOTH beams are polarized and have a transverse polarization component. The transverse polarization effect is then a ϕ modulation of the differential cross-section with the ϕ averaged total cross-section unchanged.

Azimuthal distribution with transverse polarization

Differential distribution in ϕ for $\phi_- = 0, \phi_+ = \pi$. For illustration with $P^{\mathrm{T}}_{e^-} = 1$ and $P^{\mathrm{T}}_{e^+} = 1$.



For aligned spins, there will be a phase shift of $\pi/2$.

Unique Physics Examples I

Can measure things like double polarization asymmetries, (eg. Moortgat-Pick, Osland, Pankov, Tsytrinov, PRD87 (2013) 095017) that can be sensitive to new physics.

$$A_{\mathrm{double}} = \frac{(\sigma_{LR} + \sigma_{RL}) - (\sigma_{LL} + \sigma_{RR})}{(\sigma_{LR} + \sigma_{RL}) + (\sigma_{LL} + \sigma_{RR})}$$

$$A^{\mathrm{meas}}_{\mathrm{double}} = \frac{(\sigma_{-+} + \sigma_{+-}) - (\sigma_{--} + \sigma_{++})}{(\sigma_{-+} + \sigma_{+-}) + (\sigma_{--} + \sigma_{++})}$$

and

$$A_{\mathrm{double}} = \frac{1}{|P^{-}||P^{+}|} A^{\mathrm{meas}}_{\mathrm{double}}$$

For WW production this should equal 1 in the SM. But if there is new physics like exotic heavy leptons it can be affected.

Unique Physics Examples II

The most general parametrization of WW production involves 7 complex coupings for $\mathrm{WW}\gamma$ and 7 complex couplings for WWZ. Eight of them are CP conserving and the other six are CP violating.
Fully exploring all 28 parameters is greatly facilitated with both beams polarized.
The measurement of all possible couplings needs some time spent on collisions with both beams transversely polarized for one of the CP violating couplings.
See Diehl, Nachtmann, Nagel, EPJC 32 (2003) 17.

Main Conclusions of Recent Paper

1. Statistical advantage with positron polarization
2. Positron polarization plays an important role in controlling systematic uncertainties enabling full exploitation of the ILC
3. Without positron polarization many important measurements will be systematics limited
4. Positron polarization often opens the door to more model-independent interpretations of the data
5. Positron polarization plays a large role in identifying the new physics model underlying potential discoveries
6. In conclusion, positron polarization has distinct advantages and has an important role to play in the ILC program

My Conclusions

1. Positron polarization is mandatory for a high precision measurement of A_{LR} at m_Z
2. Positron polarization is also mandatory for a viable high precision m_W measurement at threshold
3. High statistics processes such as di-fermion production and WW production need significant attention to systematics, and will benefit greatly from the more robust determination of the beam polarization(s) afforded by positron polarization
4. Positron polarization offers new ways to search for new physics and understand in detail what we uncover
5. The positron source obviously needs to work as a positron source for luminosity.

References I

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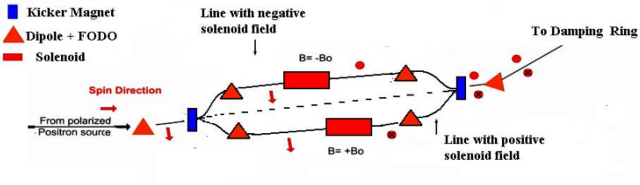
Backup Slides

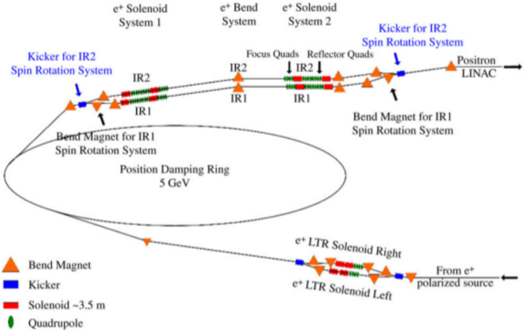
Acknowledgements

Thanks to Robert Karl for sharing some of his thesis on polarization measurements and TGCs.

Spin Management

Helicities can be flipped prior to DR for both e^- and e^+ train-by-train. RTML spin rotator system allows arbitrary orientation of P vector for both beams





Higgs Physics

Details particularly in the context of the EFT were discussed in Michael Peskin's talk this morning, where "polarization is the reason" for ILC doing so well compared to unpolarized concepts.
However I have not emphasized this here because the Higgs statistics are typically two orders of magnitude less than the higher statistics channels (WW, ff) where systematics are the primary concern and positron polarization plays the key role.