Use of Polarisation at the ILC.

- ♢ Introduction.

- ♢ Three points
  - i Use of beam polarisation :
    1. Longitudinal beam polarisation.
    2. Transverse beam polarisation.
  - ii Measurement of longitudinal polarisation of final state particles.

Take some examples: How to probe open issues in the SM as well as to probe physics Beyond the SM Physics.

1) TDR's: TESLA, JLC, NLC

2)G. Moortgat-Pick et al, Phys. Reports, 460 (2008) 131-243.

3) ILC : RDR, Physics at the ILC: A. Djouadi, J. lykken et al 0709.1893 [hep-ph].

The second reference specifically highlights that to get most advantage of an e^+e^- collider it is necessary to polarise **both** the beams.

transverse polarisation can play a crucial role in a model independent investigation of physics beyond the standard model, particularly for CP violation.

In this talk I would also like to add how measurement of (longitudinal) polarisation of ferrmions produced in the final state can help probe Physics of the SM and Beyond.

When talking specifically I have stolen plots from the following people:

1) $t\bar{t}H$: P.P.S. Bhupal Dev et al, Phys. Rev. Lett. 100, 051801 (2008)

2)Model independent analysis of Contact Interactions involving $t\bar{t}$, Z, γ :

S. D. Rindani , Phys. Lett. B 602, 97 (2004), S.D. Rindani et al, Phys. Lett. B 593, 95 (2004), Phys. Rev. D 70, 036005 (2004), Phys. Lett. B 606, 107 (2005),JHEP 0510, 077 (2005), Eur. Phys. J. C 46 705, (2006).

3)Model independent analyses of ZZH coupling, contact interactions involving $eeZH$:

S. D. Rindani et al, Phys. Lett. B642, 85 (2006), Phys. Rev. D 77, 015009 (2008), Phys. Rev. D 79, 075007 (2009); Biswal et al, Phys. Rev. D 73, 035001 (2006), Phys. Rev. D 79, 035012 (2009), Phys. Lett. B 680 (2009) 81.

4)Specific BSM physics: SUSY: MSSM, R-parity violating and CP violating SUSY, TeV Scale Gravity:

T. Rizzo JHEP 0302, 008 (2003), JHEP 0308, 051 (2003); S.D. Rindani et al, Phys. Lett. B 678 , 395, 2009; T. Gajdosik et al JHEP 0409, 051 (2004); L. Cabbibi et al, arXiv:0710.0726 [hep-ph]

Apologies to Oscar Wilde!

Beam Polarisation:

SM: Chiral theory. Clear that beam polarisation can play an important role.

Recall:

Polarised DIS gave a measurement of $\sin^2\theta_W$ which was competitive with higher energy ν experiments.

SLC got a competitive measurement of $\sin^2\theta_W$ with LEP, but with much lower luminosity.

Recall from LEP/SLC days:

$$A_{FB} = \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B} = \frac{3}{4} A_e A_f$$

$$A_{LR} = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R} \frac{1}{\langle |P_e| \rangle} = A_e$$

$$A_{LRFB} = \frac{(\sigma_F - \sigma_B)_L - (\sigma_F - \sigma_B)_R}{(\sigma_F - \sigma_B)_L + (\sigma_F - \sigma_B)_R} \frac{1}{\langle |P_e| \rangle} = \frac{3}{4} A_f$$

Here, $\langle |P_e| \rangle$ is the luminosity weighted electron beam polarisation.

In addition, one can also measure final state τ polarisation.

$$\langle P_\tau^0 \rangle = -A_\tau$$

SLC: 383500 Z's, $\sin^2\theta_W$ determined mainly from A_{LR}, A_{FB}^{LR}. Not affected by uncertainities in the Luminosities, efficiency etc, but affected by errors in knowledge of polarisation.

LEP: Millions of Z's. Much larger than SLC.

But SLC accuracy comparable to LEP for $\sin^2\theta_W$.

Thus one simple use of beam polarisation:

Increase the senstivity of a measurement with given luminosity OR decrease the luminosity required for a given level senstivity.

Questions:

What is the gain if the positron beam too is polarised?

Transverse polarisation of the electron/positron beams is available at no extra effort! Are there special advantages with transverse polarisation?

What extra does measurement of final state fermion (longitudinal) polarisation bring to the studies?

One can ask two sets of questions:

1)How does polarisation help in exploring issues in the SM that are not yet completely established?

2)Take a particular model beyond the SM and ask how much is the gain due to a single/double beam polarisation and polarisation measurement of final state fermions.

But both these questions can be addressed in a common framework by first looking at the queries in a model indpendent manner.

Anologous to the analysis of Ross,Dass Phys. Lett. B 57,173,1975; Nucl. Phys. B 118, 284 (1977), which was for probing the then undiscovered neutral currents.

Consider the process:

$$e^+ + e^- \to X$$

Helicity amplitude $F(\lambda_{e^-}, \lambda_{e^+}) \propto v(p_{e^+}, \lambda_{e^+})\Gamma_K u(p_{e^-}, \lambda_{e^-}) A_K$

Here $\Gamma_K = S, P, T, V$ and A_K is the transition amplitude which will depend on the particular final state X.

λ indicates the helicities. This describes all possible contributions (SM and beyond the SM).

In the high energy limit V,A couple opposite helicity states and S,T,P couple same helicity states.

Polarisation of the beams:

The net matrix element square will be

$$|\mathcal{M}|^2 = \sum_{\lambda_{e^-}\lambda_{e^+}\lambda'_{e^-}\lambda'_{e^+}} \rho_{\lambda_{e^-}\lambda'_{e^-}} \rho_{\lambda_{e^+}\lambda'_{e^+}} F_{\lambda_{e^-}\lambda_{e^+}} F^*_{\lambda'_{e^-}\lambda'_{e^+}}$$

with

$$\rho_{\lambda_{e^\pm}\lambda'_{e^\pm}} = \frac{1}{2}(\delta_{\lambda_{e^\pm}\lambda'_{e^\pm}} + P^1_{e^\pm}\sigma^1_{\lambda_{e^\pm}\lambda'_{e^\pm}} + P^2_{e^\pm}\sigma^2_{\lambda_{e^\pm}\lambda'_{e^\pm}} + P^3_{e^\pm}\sigma^3_{\lambda_{e^\pm}\lambda'_{e^\pm}}).$$

Let p_{ref} be the reference momentum which along with p_{e^-} defines the scattering plane.

The $P^i_{e^\pm}$ are different components of the $e^\pm$ polarisation vectors. $P_{e^\pm} = P^3_{e^\pm}$ is the longitudinal degreee of polarisation, with positive (negative) values corresponding to right(left) handed polarisation;

$P_{e^\pm}^{1(2)}$ being transverse polarisation in and normal to the scattering plane. Here $S^{1(2)}$ components of the spin vector are chosen wrt the p_{e^-} and p_{ref}.

The general $\mathcal{M}^2$ can be written as a polynomial in $P_{e^\pm}$, the various coeffecients being combinations of different helicity amplitudes and cosine and sine of combinations of the azimuthal angle of the different polarisation vectors.

For example, terms containing ONLY longitudinal polarisations:

$$(1 - P_{e^-})(1 + P_{e^+})|F_{\mathrm{LR}}|^2 + (1 + P_{e^-})(1 - P_{e^+})|F_{\mathrm{RL}}|^2$$
$$+(1 - P_{e^-})(1 - P_{e^+})|F_{\mathrm{LL}}|^2 + (1 + P_{e^-})(1 + P_{e^+})|F_{\mathrm{RR}}|^2$$

Terms bilinear in $P_{e^\pm}^T$:

$$-2P_{e^-}^{\mathrm{T}} P_{e^+}^{\mathrm{T}}[\cos(\phi_- - \phi_+)\Re(F_{\mathrm{RR}}F_{\mathrm{LL}}^*) + \cos(\phi_- + \phi_+ - 2\phi)\Re(F_{\mathrm{LR}}F_{\mathrm{RL}}^*)]$$

etc.

Few facts:

The dynamics will decide F_{RL} etc. These contain dependence on scattering angles $\theta_i, \sqrt{s}$ etc.

The orientation of P_T for e^-/e^+ can be fixed independently using spin rotators.

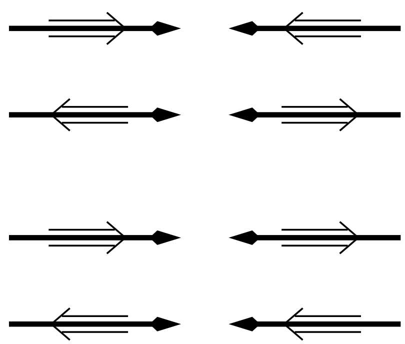
The contributions for different helicity configurations add up incoherently for longitudinally polarised beams.

Transversely polarised beams generate interference terms between left and right helicity amplitudes.

For longitudinally polarised beams alone:

$$\sigma_{P_{e^-}P_{e^+}} = \frac{1}{4}[(1+P_{e^-})(1+P_{e^+})\sigma_{\mathsf{RR}} + (1-P_{e^-})(1-P_{e^+})\sigma_{\mathsf{LL}} \\ +(1+P_{e^-})(1-P_{e^+})\sigma_{\mathsf{RL}} + (1-P_{e^-})(1+P_{e^+})\sigma_{\mathsf{LR}}],$$

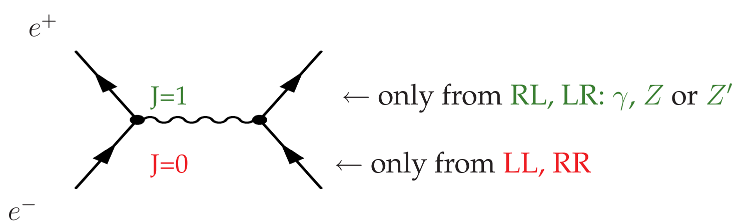
where σRR etc. correspond to the completely polarised cross-sections and correspond to different configurations:

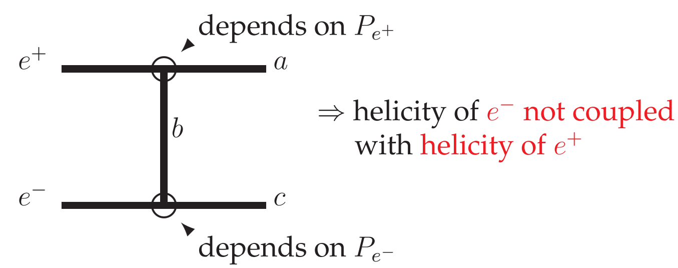


	e^-	e^+		
$\sigma_{\mathbf{RR}}$			$\frac{1+P_{e^-}}{2}\cdot\frac{1+P_{e^+}}{2}$	$J_z = 0$
$\sigma_{\mathbf{LL}}$			$\frac{1-P_{e^-}}{2}\cdot\frac{1-P_{e^+}}{2}$	
$\sigma_{\mathbf{RL}}$			$\frac{1+P_{e^-}}{2}\cdot\frac{1-P_{e^+}}{2}$	$J_z = 1$
$\sigma_{\mathbf{LR}}$			$\frac{1-P_{e^-}}{2}\cdot\frac{1+P_{e^+}}{2}$	

Whether polarisation of **both** beams will make any value addition will be decided by the dynamics we are trying to explore.

Different cases can be distinguished





For s-channel contribution the helcities of the two beams are coupled. In the t channel case the helicities of the incoming beams are linked to the helicities of the final state particles.

In the SM $F_{RR} = F_{LL} = 0$

Hence only $J = 0$ possible for the s-channel diagram.

These diagrams shows how by choosing the incling beam polarisations properly a particular background can be suppressed.

Also how final state particle polarisation can carry information on the dynamics

One can see from these expressions how (for example) the gain in sensitivity of probing a dynamics which will give rise to A_{LR}, with both beams polarised.

Will show details later

Hikasa: Phys. Lett. B 143 (1984) 266, PRD 33 (1986) 3203

For V/A couplings the amplitudes F_{RR} and F_{LL} are suppressed by m_e and thus zero.

Hence effect of transverse polarisation in this case vanishes after averaging over azimuthal angle.

Thus in this situation transverse polarisation can not give any extra information.

But if the new dynamics involves helicity changing amplitudes, then for arbitrary longitudinal polarisations there is no interference between the SM amplitudes (which conserve helicity) and the NP contribution which flip it.

In this case the new physics contributions are proportional to the square of the NP coupling.

With Transverse polarisation these interference terms are non zero and sensitivity to new couplings is then linear.

Clearly in such cases transverse polarisation can add to sensitivity of new physics, compared to the unpolarised and/or longitudinally polarised case.

Will give specific examples later

Why study τ $/(t)$ polarisation?

• Large mass of the top $\Rightarrow$ t decays before hadronisation. The decay l can retain the memory of the t polarisation and can be used as a polariometer.

I. Bigi and H. Krasemann, ZPC 7 (1981) 127 ; J. Kühn, Acta Phys. Austr. Suppl. XXIV (1982) 203; I. Bigi *et al.*, PLB 181 (1986) 157, for a recent review: S.D. Rindani, [hep-ph/0105318].

• The angular distribution of the decay l is unaffected by any non-standard contribution to the t decay vertex, to linear order in the anomalous coupling

B. Grzadkowski and Z. Hioki, PLB **476** (2000) 87; Z. Hioki, hep-ph/0104105,S.D. Rindani, Pramana **54** (2000) 791, K. Ohkuma, NP.Proc.Suppl. **111** (2002) 285, (hep-ph/0202126), R.G, S.D. Rindani and R. K. Singh, PRD **67** (2003) 095009

• τ has hadronic decay modes. The energy distribution of the π produced in the decay, $\tau \to \nu_\tau \pi$ as well as those in $\tau \to \rho\nu_\tau, \tau \to a_1\nu_\tau$ depends on the handedness of the τ. Thus τ polarisation can be determined using decay π energy distribution. K. Hagiwara, A.D. Martin and D. Zeppenfeld, PLB **235** 198 (1990), B.K.Bullock, K.Hagiwara and A.D.Martin, PRL **67**, 3055 (1991), NPB **395**, 499 (1993), D.P.Roy, PLB **277**, 183 (1992). D.P. Roy, RG, PLB **B 618** , 193, 2005.

Why is it important to measure this polarisation?

• Third generation sfermions expected to be among the lightest. $\tilde{\tau}$ is even the NLSP in many situations. Polarisation of the decay fermions can carry information on SUSY model parameters, sfermion or chargino/neutralino composition, since the polarisation of decay fermion decided by the L–R mixing amoing the sfermions as well as the higgsino/gaugino mixing in the $\tilde{\chi}^0/\tilde{\chi}^{\pm}$ sector. Third generation sfermions ⇒ third generation fermions among the decay products. t, τ among them.

♢ Thus t and τ polarisation can carry important information on different types of new physics AND can also be measured.

For an annihilation into a $J = 1$ particle only LR/RL will contribute

$$\sigma_{P_{e^-}P_{e^+}} = \left(1 - P_{e^+}P_{e^-}\right)\, \sigma_0\ [1\ -\ P_{\mathrm{eff}}\, A_{\mathrm{LR}}] \qquad (1)$$

with $\sigma_0 = \frac{\sigma_{\mathrm{RL}}+\sigma_{\mathrm{LR}}}{4}$,A_{LR} the asymmetry, with $P_{\mathrm{eff}} = \frac{P_{e^-}-P_{e^+}}{1-P_{e^+}P_{e^-}}$

Now one can see that if P_{e^-} and P_{e^+} are chosen with opposite signs one can in fact enhance the cross-section.

Also if we define

$$\mathcal{L}_{\text{eff}} = \frac{1}{2}(1 - P_{e^-}P_{e^+})\mathcal{L}$$

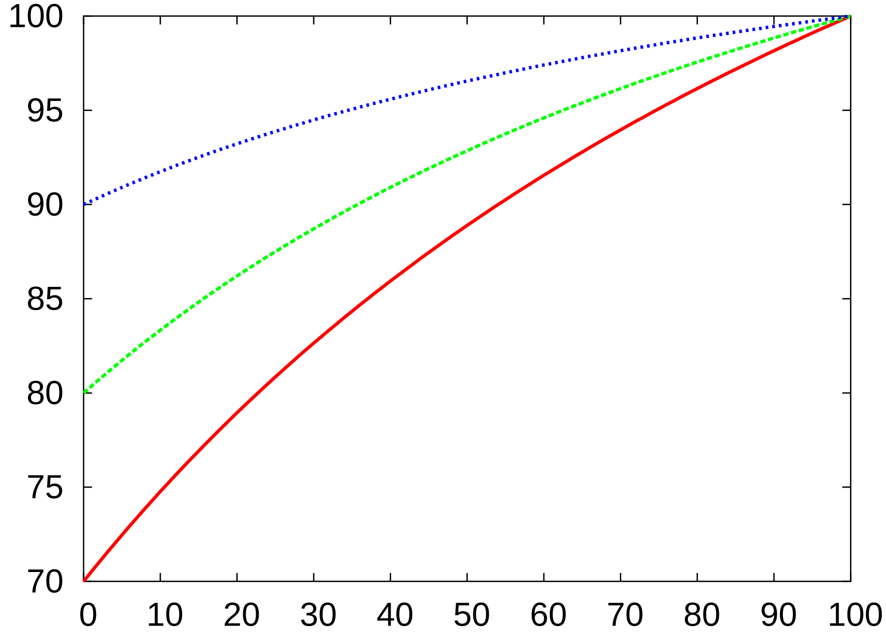
we have

$P_{e^-} = \quad 0\%$, $P_{e^+} = 0$ $P_{eff} = 0\%$ and $\mathcal{L}_{eff}/\mathcal{L} = 0.5$.

$P_{e^-} = -100\%$, $P_{e^+} = 0$ $P_{eff} = -100\%$ and $\mathcal{L}_{eff}/\mathcal{L} = 0.5$.

$P_{e^-} = -80\%$, $P_{e^+} = +60\%$ $P_{eff} = -95\%$ and $\mathcal{L}_{eff}/\mathcal{L} = 0.74$

$\sigma_{P_{e^-}P_{e^+}} = 2\sigma_0(\mathcal{L}_{eff}/\mathcal{L})[1 - P_{eff}A_{LR}]$



Y-axis: P_{eff}, X-axi: Positron poalrisation. Red: 70% electron polarisation, blue: 90% electron polarisation.

The *Effective* polarisation can be close to 100% if both beams are polarised even if each of the beam is less than 100% polarised.

Thus clear advantage of having *both* beams polarised.

- The chiral structures of interactions in various processes can be identified independently and unambiguously. This provides the possibility of determining the quantum numbers of the interacting particles and testing stringently model assumptions. Several of these tests are not possible with polarized electrons alone.

- The larger number of available observables is crucial for disentangling the new physics parameters in a largely model independent

- The enhanced rates with suitable polarizations of the two beams would allow for better accuracy in determining cross sections and asymmetries. This increase of the signal event rate may even be indispensable, in some cases, for the observation of marginal signals of new physics.

- A more efficient control of background processes can be obtained. The higher signal-to-background ratio may be crucial for finding manifestations of particles related to new physics and determining their properties. Important examples are the searches for signatures of massive gravitons, whose existence is foreseen by models with extra dimensions, and of supersymmetric particles.

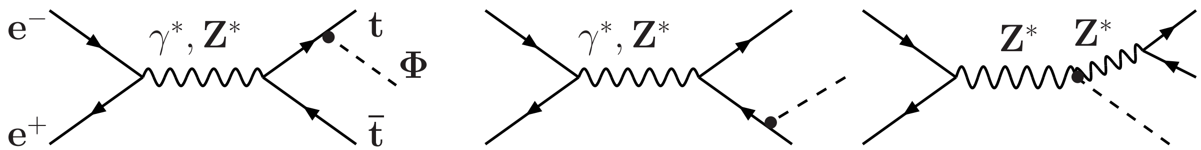
- In indirect searches the statstical significance of the measurment is imporved and the range to which one can probe beyond the beam energy increases

- Increased sensitivity to the spin of the s- and t- channel exchange particle (Rizzo)

- Improves discrimination between different type of new physics

- Transverse polarisation offers possibility of consturcting new asymmetries , allows the same measurement w/out measuring the polarisation of final state particles.

$t\bar{t}H$: P.P.S. Bhupal Dev et al, Phys. Rev. Lett. 100, 051801 (2008)



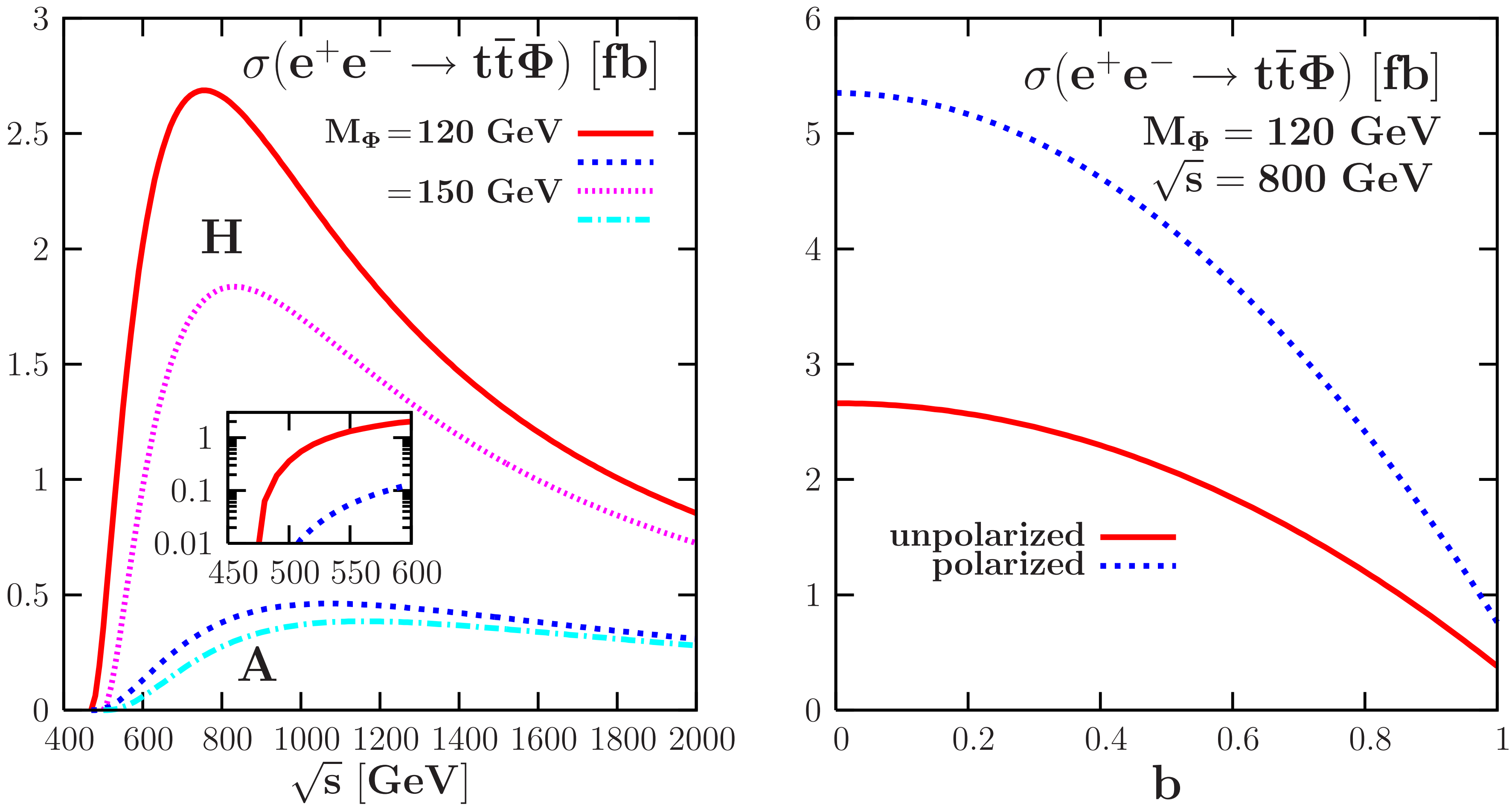
The parity violating nature of the Z coupling means $t/\bar{t}$ can have nonzero polarisation and it will be different from H/A.

The cross-sections may also be enhanced by choosing e^+/e^- polarisation judiciously.

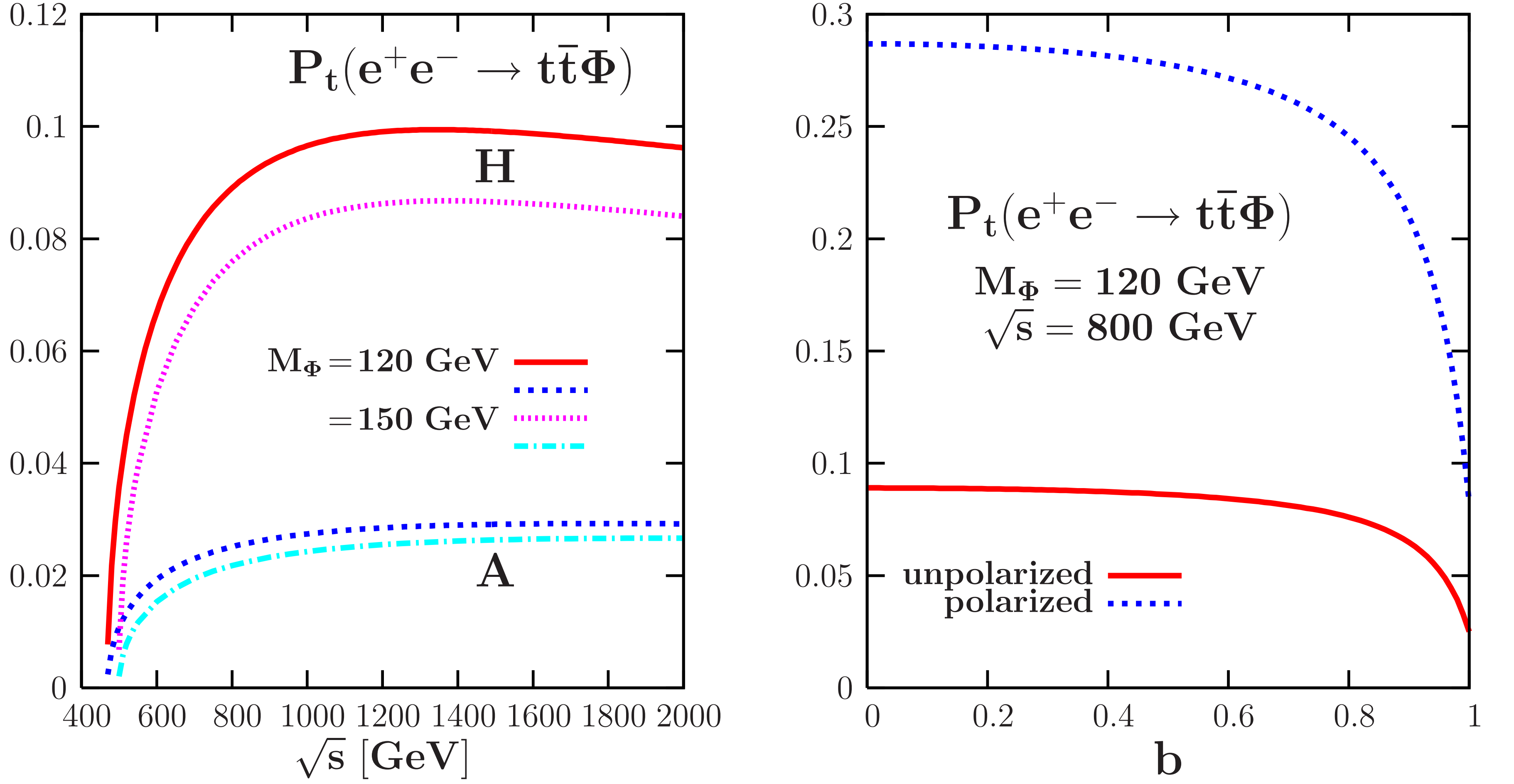
$\phi_i t\bar{t} : -\bar{t}(a + ib\gamma_5) f \frac{gm_f}{2m_W}$

In the SM, $a = 1 = c$ and $b = 0$.

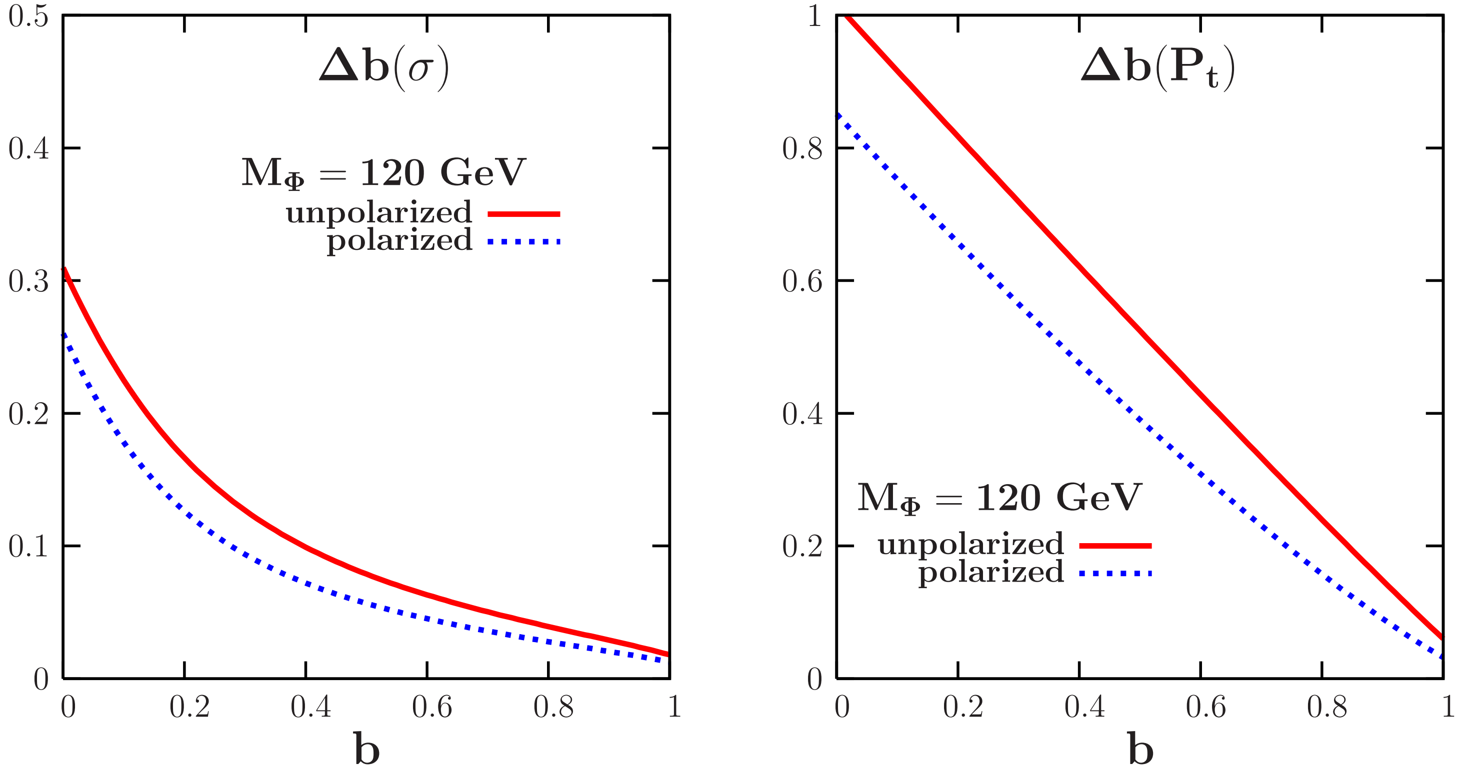
A model-independent way of parametrization can be $|a|^2 + |b|^2 = 1$.



$\sigma(e^+e^- \to t\bar{t}\Phi)$ [fb]
$M_\Phi = 120$ GeV
$= 150$ GeV
H
A
$\sqrt{s}$ [GeV]
$M_\Phi = 120$ GeV
$\sqrt{s} = 800$ GeV
unpolarized
polarized
b



0.12
0.1
0.08
0.06
0.04
0.02
0
400 600 800 1000 1200 1400 1600 1800 2000
$\sqrt{s}$ [GeV]
$P_t(e^+e^- \to t\bar{t}\Phi)$
H
A
$M_\Phi = 120$ GeV
$= 150$ GeV
0.3
0.25
0.2
0.15
0.1
0.05
0
0 0.2 0.4 0.6 0.8 1
b
$P_t(e^+e^- \to t\bar{t}\Phi)$
$M_\Phi = 120$ GeV
$\sqrt{s} = 800$ GeV
unpolarized
polarized



Polarisation of top not very sensitive to b except for b very close to 1. But the only unambigious one for the pseudoscalar state.

Nevertheless, both good observables to distinguish a purely CP-even state from a purely CP-odd one.

$$\text{scaling factor} = \sigma^{(P_{e^-},P_{e^+})_{b)}} / \sigma^{(P_{e^-},P_{e^+})_{a)}}. \tag{2}$$

Using both beams polarized in configuration b) instead of just the electron beam polarized in configuration a) can lead to a scaling factor between 0 and at most 2.

Suppression of WW backgrounds can always be done very effectively by choosing beam polarisation. $e^+e^- \to W^+W^- = 6.2pb$ (unpolarised)

$e^+e^- \to W^+W^- = 1.2pb$ (With only electron poalrised 80%)

$e^+e^- \to W^+W^- = 0.6pb$ (With both e^- and e^+ polarised.)

Scale factor 0.5. S/B increases.

Even if both the signal and background increase similarly with polarisation and S/B does not change, $S/\sqrt{B}$ can change. I.e. the statistical significance can improve.

S. Kraml et al

L Cabbibi et al

Earlier analyis : Optimal observable analysis:

Our new analysis Biswal, et al. Phys. Rev. D **73**, 035001 (2006); PRD **79**, 035012 (2009).

Most general VVH coupling structure:

$$\Gamma_{\mu\nu} = g_V \left[a_V \ g_{\mu\nu} + \frac{b_V}{M_V^2} \ (k_\nu^1 k_\mu^2 - g_{\mu\nu} k^1.k^2) + \frac{\tilde{b}_V}{M_V^2} \ \epsilon_{\mu\nu\alpha\beta} k^{1\alpha} k^{2\beta} \ \right]$$

- $\tilde{T}$: Naive time reversal operation.

- Cross-sections integrated over $CP\tilde{T}$ symmetric phase space will probe only the $CP-even$, $\tilde{T}$–even couplings. in the approximation that the anomalous couplings are small.

- Partially integrated cross-sections will be able to probe these. for example to probe a P-odd cpupling we construct Forward-Backward asymmetry.

- Constructed different observables out of the available momenta such that they have specific CP and $\tilde{T}$ transformation properties.

- Look at expectaion value of 'sign' of these observables.These asymmetries, are proportional to the part of the anomalous coupling which has the **same** CP and $\tilde{T}$ transformation properties as the observable, to leading order in the anomalous coupling.

Biswal et al:

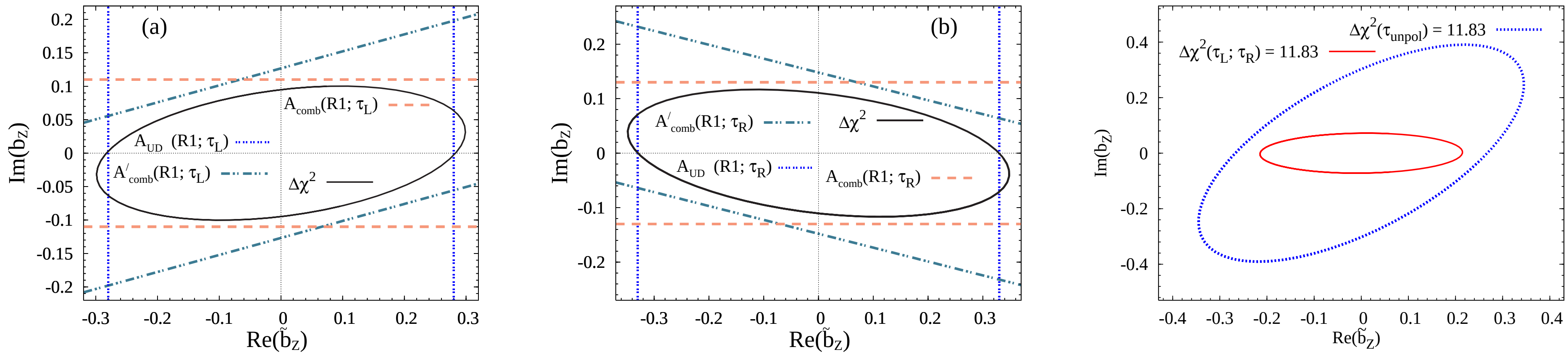
Studied $e^{+}e^{-} \rightarrow f\bar{f}H$

We construct various asymmetries, using the mometa of particles. For some of the couplings these asymmetries are propotional to $(l_f^2 - r_f^2)$. For the Zee coupling this makes them small.

Hence by choosing either polarised beams and/or measuring the polarisation of the final state particles one can improve the sensitivity.

Using Polarized Beams			Unpolarized States	
Coupling	Limits	Observable used	Limits	Observable used
$\|\Re(\tilde{b}_Z\| \quad \leq$	0.067	$\mathcal{O}_{UD}(R2;e)$	0.067	$A_{UD}(R2;e)$
$\|\Re(\tilde{b}_Z)\| \quad \leq$	0.17	$\mathcal{O}_{UD}(R1;\mu)$	0.91	$A_{UD}(R1;\mu)$
$\|\Im(\tilde{b}_Z)\| \quad \leq$	0.011	$\mathcal{O}_{FB}(R1;\mu,q)$	0.064	$A_{FB}(R1;\mu,q)$

Han et al. have also observed the improvement for $\Im(\tilde{b}_z)$; T. Han and J. Jiang, Phys. Rev. D **63**, 096007 (2001).



$$\Im(b_z) \quad : \quad A_{comb}; \qquad \Re(\tilde{b}_z) \quad : \quad A_{UD}; \qquad \Im(b_z),\ \Re(\tilde{b}_z) \quad : \ A'_{comb}.$$

- Sensitivity limit on both the $\tilde{T}$-odd couplings ($\Im(b_z)$ and $\Re(\tilde{b}_Z)$) can be improved by a factor up to 3–4 assuming the efficiency of isolating events with τ's of -ve helicity state to be 40%.

Hagiwara and Stong: If one has real anomalous couplings no gain by transverse poalrisation.

Rindani et al: Noticed this is not true when some couplings are complex, i.e CP violation. But used only $e^+e^- \to ZH$ and not the l^+l^- coming from Z decay. Some of the couplings then not accessible.

Biswal et : We used $e^+e^- \to f\bar{f}H$. Already showed examples of improvement with Long. polarisation.

Next : What about trans. polarisation?

Biswal and Godbole, Phys. Lett. B **680**, 81 (2009) [arXiv:0906.5471 [hep-ph]].

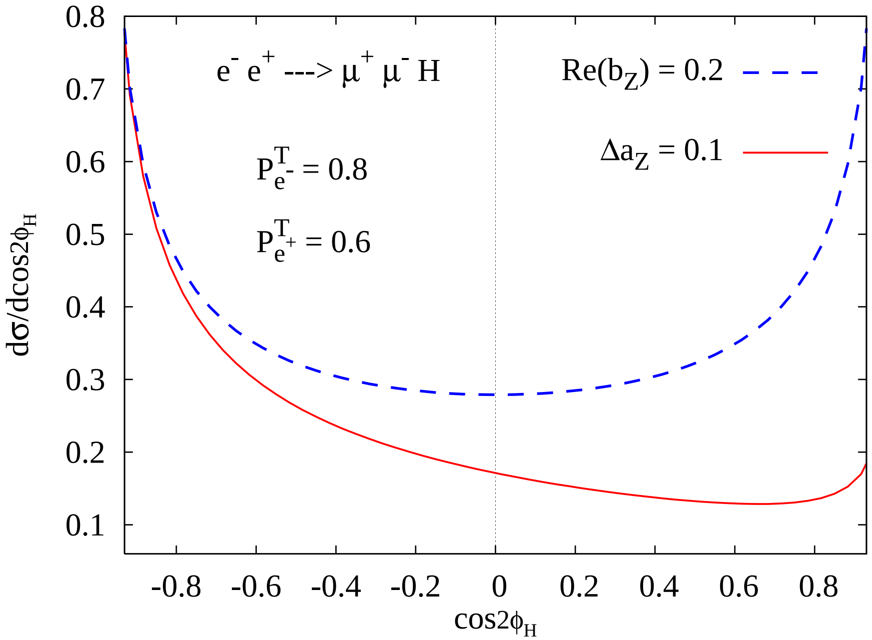
$$\vec{P}_f \equiv \vec{p}_f - \vec{p}_{\bar{f}}$$

ID	$\mathcal{C}_i^{\mathsf{T}}$	C	P	CP	$\tilde{T}$	$CP\tilde{T}$	Observable (O_i^{T})	Coupling
1	$(\vec{p}_{_H})_x^2 \;-\; (\vec{p}_{_H})_y^2$	$+$	$+$	$+$	$+$	$+$	O_1^{T}	$a_V,\ \Re(b_V)$
2	$(\vec{P}_f)_x * (\vec{P}_f)_y * (\vec{p}_{_H})_z$	$+$	$-$	$-$	$-$	$+$	O_2^{T}	$\Re(\tilde{b}_Z)$
3	$(\vec{p}_{_H})_x * (\vec{p}_{_H})_y * (\vec{P}_f)_z$	$-$	$-$	$+$	$-$	$-$	O_3^{T}	$\Im(b_Z)$

- For each combination, observable can be constructed as:

$$O_i^{\mathsf{T}} = \frac{1}{\sigma_{\mathsf{SM}}} \int [\mathsf{sign}(\mathcal{C}_i^{\mathsf{T}})] \frac{d\sigma}{d^3p_H d^3p_f} d^3p_H d^3p_f$$
$$= \frac{\sigma(\mathcal{C}_i^{\mathsf{T}} > 0) - \sigma(\mathcal{C}_i^{\mathsf{T}} < 0)}{\sigma_{\mathsf{SM}}}$$

Independent probes of CP- and $\tilde{T}$-even ZZH couplings. Biswal and Godbole, Phys. Lett. B **680**, 81 (2009) [arXiv:0906.5471 [hep-ph]].



$$O_1^{\mathsf{T}} \equiv O_1^{\mathsf{T}}(\Delta a_Z) \propto [\sigma(\cos 2\phi_H > 0) - \sigma(\cos 2\phi_H < 0)]$$

Probe of Δa_Z

Very interesting: the two CP even $\tilde{T}$ even contribution can be separated from each other using transverse polarisation.

Same thing observed by Rindani et al for on shell Z's

Related to the fact the contribution proportional to $\Re(b_Z)$ had a coeff. $\vec{S} \cdot \vec{P}$.

Using $\mathcal{C}_1^{\mathsf{T}}$ we construct an azimuthal asymmetry:

$$\mathcal{A}_1^{\mathsf{T}} = \frac{\sigma(\cos 2\phi_H > 0) - \sigma(\cos 2\phi_H < 0)}{\sigma(\cos 2\phi_H > 0) + \sigma(\cos 2\phi_H < 0)}$$
$$\equiv \mathcal{A}_1^{\mathsf{T}}(\Re(b_Z)) : \text{Probe of } \Re(\mathrm{b_Z})$$

Both the CP- and $\tilde{T}$-even couplings, $\Re(b_Z)$ and Δa_Z, can be probed independently using $\mathcal{A}_1^{\mathsf{T}}$ and O_1^{T} respectively, which was not possible with unpolarized and/or linearly polarized beams.

S.D. Rindani et al, Phys. Lett. B 678 , 395, 2009

Considered $e^+e^- \to \mu^+\mu^-$

The modification of contact interactions by R-parity violating $S-$ channel or t-channel exchange

Due to transverse poalrisation indeed we can construct azimuthal asymmetries which were proportional linearly to the RPV couplings.

Current constraints obtained from rates.

With longitudinal polarisation (Rizzo) ILC sensitivity using angular distribution obtained

In our study the use of transverse polarisation increased the sensitivity.