On the determination of $\mathcal{CP}$-even and $\mathcal{CP}$-odd components of a mixed $\mathcal{CP}$ Higgs boson at e^+e^- linear colliders.

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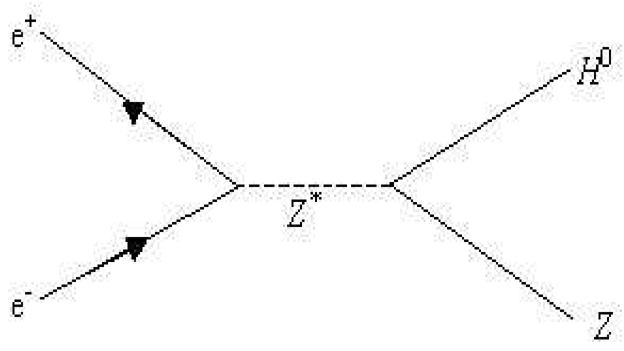
Physics Motivation

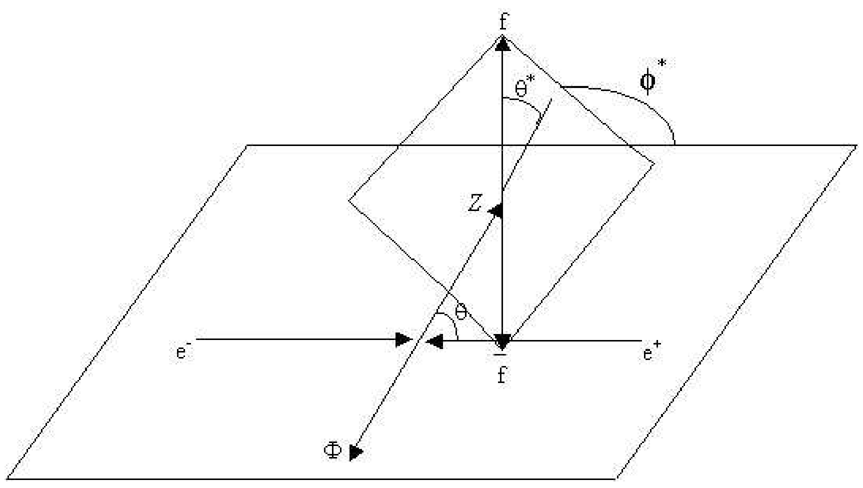
- Quantum numbers $\mathcal{J}^{\mathcal{PC}}$ of Higgs can be determined independently of the model.
- Higgstrahlung $e^+e^- \to Z\Phi$, Φ a generic Higgs boson, most important process to check deviations from SM.
- Φ could correspond to mixtures of $\mathcal{CP}$-even and $\mathcal{CP}$-odd states and exhibit $\mathcal{CP}$ violation.

We present a method to distinguish the SM-like Higgs boson from a $\mathcal{CP}$-odd state or a $\mathcal{CP}$ violating mixture Φ.

Higgs-strahlung



- *Angular distribution of production $\sigma_{e^+e^-\to Z\Phi}$ and decay $Z \to f\bar{f}$ allow determination of $\mathcal{J}$ and $\mathcal{P}$ of the Higgs.*



$\Rightarrow$ The angular distribution of the Higgs-strahlung process, can be written as a function of the angles θ, θ^*, ϕ^*, The corresponding distributions allow to distinguish if the Higgs Φ is $\mathcal{CP}$-even, $\mathcal{CP}$-odd or a mixture.

Method

Comparison of angular distribution of data with predictions from Monte Carlo.

- Simulation of a "data" sample with arbitrary value of η.
  $\rightarrow$ Obtained by weighting the distributions for $\eta = 0$:

$$W(\cos\theta, \cos\theta^*, \cos\phi^*) = \frac{|\mathcal{M}_{Z\Phi}(\eta)|^2}{|\mathcal{M}_{Z\Phi}(\eta = 0)|^2}$$

- 2,000 events; 2 years of TESLA ($\int Ldt$ = 500 fb^{-1}).

- Monte Carlo samples:
  1. Scalar Higgs events $e^+e^- \rightarrow ZH$ $[Z \rightarrow f\overline{f}]$ (MC_ZH).
  2. Pseudo-scalar Higgs events $e^+e^- \rightarrow ZA$ $[Z \rightarrow f\overline{f}]$ (MC_ZA).
  3. Interference term (MC_IN).

- Decay channel: $Z \rightarrow \mu^+\mu^-$ (cleanest).

- Use all kinematic variables: θ, θ^*, ϕ^*

- Generate 3-D distributions $\{\cos\,\theta, \cos\,\theta^*, \cos\,\phi^*\}$ of the"data" and Monte Carlo samples.

Fit technique

Binned maximum likelihood fit of the 3-D distributions.

$$\mathcal{L} = \prod_{(\cos\theta)_i,(\cos\theta^*)_j,(\cos\phi^*)_k} \frac{\mu_{ijk}{}^{N_{sample}(i,j,k)} e^{-\mu_{ijk}}}{N_{sample(i,j,k)}!}$$

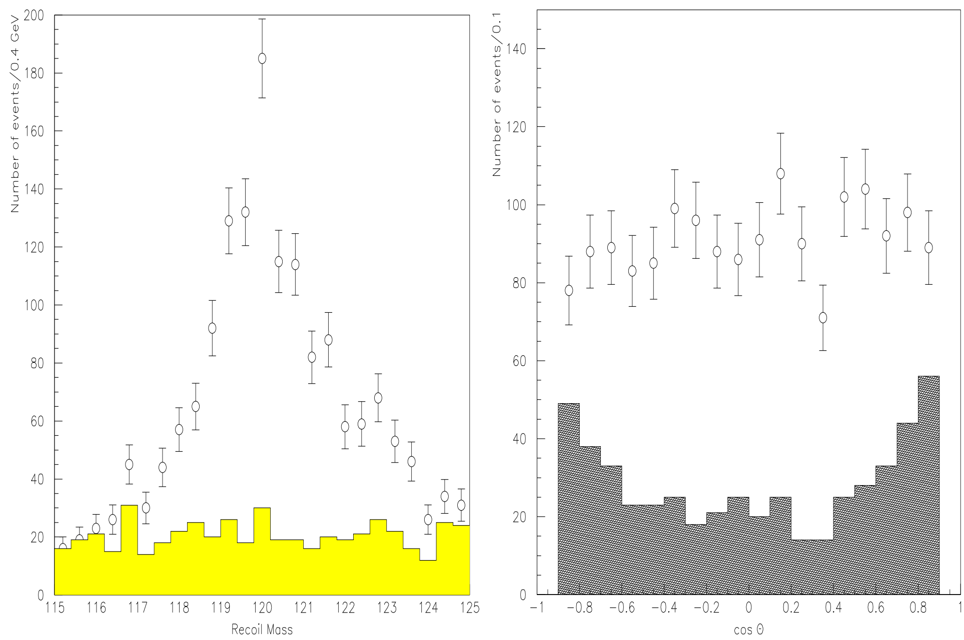
$$\mu_{ijk} = \mathcal{N}(\alpha MC\_ZH + \beta MC\_IN + \gamma MC\_ZA)$$

$\mathcal{N}$ is the normalization factor between number of data and Monte Carlo events (≈ 0.1 in our case).
Parameters α, β and γ give the contributions of scalar, interference and pseudoscalar events, needed to build the data sample.

- Estimation of the parameters is done minimizing the function $-2\ln\mathcal{L}$.

Kinematical cuts: some distributions

1. A pair muon and anti-muon are identified with E $\geq$ 15 GeV each.
2. Invariant mass of the system consistent with Z boson hypothesis within 5 GeV.
3. Recoil mass of the di-muon system consistent with H boson hypothesis within 5 GeV.
4. The absolute z-component of the di-muon system should be smaller than 120 GeV. This removes a significant part of the remaining background.



Left: Recoil mass spectra of the Z in $e^+e^- \rightarrow ZH \rightarrow \mu^+\mu^- X$.

Right: Angular distribution, cos θ, of the selected events.

Results

η	α	β	γ
-0.4	0.002 ± 0.03	-0.05 ± 0.02	0.98 ± 0.04
-0.25	0.08 ± 0.04	-0.06 ± 0.02	0.92 ± 0.04
-0.1	0.43 ± 0.04	-0.09 ± 0.02	0.57 ± 0.04
-0.05	0.69 ± 0.04	-0.06 ± 0.02	0.31 ± 0.04
0	0.97 ± 0.05	0.003 ± 0.02	0.03 ± 0.04
0.05	0.70 ± 0.05	0.05 ± 0.02	0.29 ± 0.04
0.1	0.40 ± 0.04	0.04 ± 0.02	0.59 ± 0.04
0.25	0.08 ± 0.04	0.04 ± 0.02	0.92 ± 0.04
0.4	0.002 ± 0.03	0.01 ± 0.02	0.98 ± 0.04

- α gives the contribution of CP-even Higgs in the sample.
- γ gives the contribution of CP-odd Higgs in the sample.
- β gives the interference term which constitutes a distinctive signal of $\mathcal{CP}$ violation.

High sensitivity:

- To distinguish pure $\mathcal{CP}$-even state ($\eta = 0$) from pseudoscalar $\mathcal{CP}$-odd.
- To determine whether the Higgs is a $\mathcal{CP}$ mixture and measure the odd and even components.

Summary

- Novel method for the measurement of the parity of the Higgs.

- For $\int \mathcal{L}dt \sim 500\ fb^{-1}$ at 350 GeV center of mass energy TESLA will unambiguously determine whether a Higgs is:

- 0^{++} ($\mathcal{CP}$-even, scalar), or
- has also a contribution 0^{-+} ($\mathcal{CP}$-odd, pseudoscalar)

- Statistical uncertainties for the measurement of the $\mathcal{CP}$ violating interference terms are presented.