Top electroweak couplings study using di-leptonic state at $\sqrt{s} = 500$ GeV, ILC with the Matrix Element Method

AWLC2017, SLAC
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Outline

Motivation

Kinematical reconstruction of top quark
- Strategy of kinematical reconstruction
- Fraction of wrong assignment of b-jets
- Helicity angles computation

Matrix element method analysis
- Fit of CP-Conserving form factors
- Fit of CP-Violating form factors

Summary
Top EW Couplings Study

- Top quark is the heaviest particle in the SM. Its large mass implies that it is strongly coupled to the mechanism of electroweak symmetry breaking (EWSB)

→ Top EW couplings are good probes for New physics behind EWSB

\[ \mathcal{L}_{\text{int}} = \sum_{v=\gamma,Z} g^v \left[ V^V_t \bar{t} \gamma^l (F^V_{1V} + F^V_{1A} \gamma_5) t + \frac{i}{2m_t} \partial_\nu V^V_t \bar{t} \sigma^{l\nu} (F^V_{2V} + F^V_{2A} \gamma_5) t \right] \]

In new physics models, such as composite models, the predicted deviation of coupling constants, \( g_L^Z, g_R^Z \) (\( = F^Z_{1V} \mp F^Z_{1A} \)) from SM is typically 10%
Di-leptonic State of the top pair production

Top pair production has three different final states:

- **Fully-hadronic state** \((e^+e^- \rightarrow t\bar{t} \rightarrow b\bar{b}q\bar{q}q\bar{q})\) 46.2%
- **Semi-leptonic state** \((e^+e^- \rightarrow t\bar{t} \rightarrow b\bar{b}q\bar{q}l\nu)\) 43.5%
- **Di-leptonic state** \((e^+e^- \rightarrow t\bar{t} \rightarrow b\bar{b}l\nu l\nu)\) 10.3%

**Advantage**

- 9 helicity angles can be computed (details will be described later)
→ Higher sensitivity to the form factors

**Difficulty**

- Two missing neutrinos → Difficult to reconstruct top quark.

**Develop the reconstruction process in realistic situation**
## Set Up of Analysis

<table>
<thead>
<tr>
<th>Situation</th>
<th>On / Off</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full simulation of ILD</td>
<td>On</td>
</tr>
<tr>
<td>Hadronization</td>
<td>On</td>
</tr>
<tr>
<td>Gluon emission from top</td>
<td>On</td>
</tr>
<tr>
<td>ISR/BS</td>
<td>On</td>
</tr>
<tr>
<td>$\gamma\gamma \rightarrow$ hadrons</td>
<td>On</td>
</tr>
<tr>
<td>bkg. events</td>
<td>Off (ongoing)</td>
</tr>
</tbody>
</table>

### Sample (Only signal)

[Di-muonic state](#) 

$e^+e^- \rightarrow b\bar{b}\mu^+\nu\mu^-\bar{\nu}$

- $\sqrt{s}$: 500 GeV
- Polarization ($P_{e^-}, P_{e^+}$): (-0.8, +0.3) "Left" / (+0.8, -0.3) "Right"
- Integrated luminosity: 500 fb$^{-1}$ (50/50 between Left and Right)

### Generator

Whizard

### Detector

ILD_01_v05 (DBD ver.)
Reconstruction Process

- Isolated leptons tagging
  - Number of isolated leptons = 2 & Opposite charge each of two

- Suppression of $\gamma\gamma \rightarrow$ hadrons
  - $kt$ algorithm (cf. the Semi-leptonic analysis, $R = 1.5$)

- $b$-jet reconstruction
  - LCFI Plus (Durham algorithm)
  - The $b$-charge measurement is not used

- Kinematical reconstruction of top quark
**Kinematical Reconstruction of top quark**

\[ e^+ e^- \rightarrow \bar{t}t \rightarrow \bar{b}b \mu^+ \nu \mu^- \bar{\nu} \]

**Measurable**

- muon's: \( E_\mu^+, \theta_\mu^+, \phi_\mu^+ \), \( E_\mu^-, \theta_\mu^-, \phi_\mu^- \)
- b-jet's: \( E_{b1}, \theta_{b1}, \phi_{b1}, E_{b2}, \theta_{b2}, \phi_{b2} \)

**Missing**

- neutrino's: \( E_\nu, \theta_\nu, \phi_\nu, E_{\bar{\nu}}, \theta_{\bar{\nu}}, \phi_{\bar{\nu}} \)

\( \Rightarrow \) **6 unknowns**

To recover them, impose the kinematical constraints:

- **Initial state constraints**: \((\sqrt{s}, \vec{P}_\text{init.}) = (500, \vec{0})\)
- **Mass constraints**: \( m_t, m_{\bar{t}}, m_{W^+}, m_{W^-} \)

\( \Rightarrow \) **8 constraints (2 in excess)**

We don’t need \( E_{b1} \) and \( E_{b2} \) which are relatively difficult to reconstruct.

\( \rightarrow \) Just use to decide the assignment of b-jets
Kinematical Reconstruction of top quark

To detect the solution, we solve the following equations.

\[ E_{\mu_{\pm}}^{W \pm \text{rest frame}}(\theta_t, \phi_t) = m_{W \pm}/2 \quad \text{(Red: } \mu^+, \text{ Green: } \mu^-) \]

**assignment A** (correct), \( b_1 = b, \ b_2 = \bar{b} \)

**assignment B** (wrong), \( b_1 = \bar{b}, \ b_2 = b \)

Typically, 4 candidates exist for each event.

We need to select the optimal solution from these candidates.
Kinematical Reconstruction of top quark

\[ \chi_b^2(\theta_t, \phi_t) \equiv \left( \frac{E_b(\theta_t, \phi_t) - E_b^{\text{meas.}}}{\sigma[E_b^{\text{meas.}}]} \right)^2 + \left( \frac{E_{\bar{b}}(\theta_t, \phi_t) - E_{\bar{b}}^{\text{meas.}}}{\sigma[E_{\bar{b}}^{\text{meas.}}]} \right)^2 = 2 \]  (Blue)

**assignment A** (correct), \( b_1 = b, \ b_2 = \bar{b} \)

**assignment B** (wrong), \( b_1 = \bar{b}, \ b_2 = b \)

The candidate A1 has the minimum \( \chi_b^2 \)

\[ \Rightarrow \] The assignment A is selected and the solution is \( (\theta_t, \phi_t) \approx (0.5, -0.35) \)
Kinematical Reconstruction of top quark

Technically, to obtain the solution, we minimize $\chi^2_{tot}$:

$$\chi^2_{tot}(\theta_t, \phi_t) = \chi^2_{\mu}(\theta_t, \phi_t) + \chi^2_{b}(\theta_t, \phi_t)$$

where $\chi^2_{\mu}(\theta_t, \phi_t) \equiv \left( \frac{E^{(W^+ \text{ rest frame})}(\theta_t,\phi_t)-m_{W^+}/2}{\sigma[E^{(W^+ \text{ rest frame})}]^2} \right) + \left( \frac{E^{(W^- \text{ rest frame})}(\theta_t,\phi_t)-m_{W^-}/2}{\sigma[E^{(W^- \text{ rest frame})}]^2} \right)$

$\chi^2_{\mu}$ is dominant to determine $(\theta_t, \phi_t)$ because $\sigma[E^{(W \text{ rest frame})}] \ll \sigma[E_b]$
$F_{\text{wrong}}$ : Fraction of the Wrong Assignment of b-jets

$F_{\text{wrong}}$ (the fraction of the wrong assignment of b-jets) = 22 %

When we use samples not including ISR, $F_{\text{wrong}} = 8 %$

$\rightarrow$ ISR significantly affects the assignment problem.

We use two quantities to reduce $F_{\text{wrong}}$

$\chi^2_{\text{tot}}$ (as mentioned)

$\Delta\chi^2_{\text{tot}} = |\chi^2_{\text{tot,assignment A}} - \chi^2_{\text{tot,assignment B}}|$
$F_{\text{wrong}}$ : Fraction of the Wrong Assignment of b-jets

We investigate $F_{\text{wrong}}$ and the efficiency varying the set of criteria for $(\chi^2_{\text{tot}}, \Delta \chi^2_{\text{tot}})$

The polar angle distribution of top is improved by the quality cut.

$\chi^2_{\text{tot}} < 5, \Delta \chi^2_{\text{tot}} > 6$

($F_{\text{wrong}} = 5.0 \%$

total efficiency = 28 \%)
All final state particles including two neutrinos can be calculated. The 9 helicity angles which are related to the $ttZ/\gamma$ vertex are computed.

$$\theta_t, \theta_{W^+}^{\text{frame}}, \phi_{W^+}^{\text{frame}}, \theta_{W^+}^{\mu+}, \phi_{\mu+}^{\text{frame}}, \theta_{W^-}^{\text{frame}}, \phi_{W^-}^{\text{frame}}, \theta_{\mu^-}^{\text{frame}}, \phi_{\mu^-}^{\text{frame}}$$


eg)

$$\cos \theta_{W^+}^{\text{frame}}$$

$$\cos \phi_{W^+}^{\text{frame}}$$

$$\chi^2_{tot} < 5, \Delta \chi^2_{tot} > 6$$
Matrix Element Method Analysis

Matrix element method is based on the maximum likelihood method.

\[-2 \log L(F) (= \chi^2 (F)) = -2 \left( \sum_{e=1}^{N_{\text{event}}} \log |M|^2 (\Phi_e, F) - N(F) \right)\]

$|M|^2$: the full matrix element, $\Phi_e$: the 9 helicity angles, $F$: the form factors, $N(F)$: the expected number of events.

The minimization of $\chi^2 (F)$ automatically introduces the derivatives;

\[\omega_i (\Phi_e) = \frac{1}{|M|^2 (\Phi_e)} \frac{\partial |M|^2 (\Phi_e)}{\partial F_i} \bigg|_{F \text{ at SM}}, \quad \Omega_i = \frac{1}{N} \frac{\partial N}{\partial F_i} \bigg|_{F \text{ at SM}}\]

The results of fit are related with $\omega_i (\Phi_e)$ and $\Omega_i$:

- $\delta F_i (= F_{\text{fit}} - F_{\text{SM}}) \approx \frac{<\omega_i - \Omega_i>}{<(\omega_i - \Omega_i)^2>}$

- covariance matrix, $V_{ij}$;

\[V_{ij}^{-1} = N_{\text{event}} < (\omega_i - \Omega_i)(\omega_j - \Omega_j) >\]
Fit of the CP-Conserving form factors

Result of $\delta \tilde{F}_{1V}^\gamma$ fit (the others are fixed at SM)

Before the quality cut (total efficiency 77%)

$$\delta \tilde{F}_{1V}^\gamma = 0.0223 \pm 0.0066, \ \chi^2_{\text{test}} = 11.4 \Leftrightarrow 0.07\% \text{ CL}$$

The $\omega - \Omega$ distribution of the wrong assignment (Green) is

- shifted to positive $\rightarrow$ bias
- blunter $\rightarrow$ over estimates the precision

* $\chi^2_{\text{test}} = \sum \delta F_i V_{ij}^{-1} \delta F_j$ : the chi-square test
Fit of the CP-Conserving form factors

Result of $\delta \tilde{F}^\gamma_{1V}$ fit (the others are fixed at SM)

Before the quality cut (total efficiency 77%)

$$\delta \tilde{F}^\gamma_{1V} = 0.0223 \pm 0.0066, \ \chi^2_{test} = 11.4 \Leftrightarrow 0.07\% \text{ CL}$$

After the quality cut ($\chi^2_{tot} < 5 \& \Delta \chi^2_{tot} > 6$, total efficiency 28%)

$$\delta \tilde{F}^\gamma_{1V} = 0.0075 \pm 0.0115, \ \chi^2_{test} = 0.43 \Leftrightarrow 51\% \text{ CL}$$

Good agreement between MC truth and Rec.

$\rightarrow$ The bias disappears.

$\rightarrow$ The error becomes larger ($\sim \sqrt{N}$)

The histogram of $\omega - \Omega$ for $\delta \tilde{F}^\gamma_{1V}$ (after quality cut)
The distributions of $\omega - \Omega$ (bef. the quality cut)

"Left" polarization

$\left( \delta \tilde{F}^\gamma_{1V} \right)$

$\left( \delta \tilde{F}^Z_{1V} \right)$

$\left( \delta \tilde{F}^\gamma_{1A} \right)$

$\left( \delta \tilde{F}^Z_{1A} \right)$

$\left( \delta \tilde{F}^\gamma_{2V} \right)$

$\left( \delta \tilde{F}^Z_{2V} \right)$

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The distributions of $\omega - \Omega$ (aft. the quality cut)

"Left" polarization

$(\delta \delta^\gamma_{1V})$  
$(\delta \delta^Z_{1V})$  
$(\delta \delta^\gamma_{1A})$

$(\delta \delta^Z_{1A})$  
$(\delta \delta^\gamma_{2V})$  
$(\delta \delta^Z_{2V})$
Fit of the CP-Conserving form factors

Results of 6 CPC form factors fit

**Before quality cut (total efficiency 77%)**

\[
\begin{align*}
\mathcal{R}e \, \delta \tilde{F}_{1V}^\gamma &= +0.0188 \pm 0.0089 \\
\mathcal{R}e \, \delta \tilde{F}_{1V}^Z &= +0.0293 \pm 0.0161 \\
\mathcal{R}e \, \delta \tilde{F}_{1A}^\gamma &= +0.0280 \pm 0.0133 \\
\mathcal{R}e \, \delta \tilde{F}_{1A}^Z &= +0.2250 \pm 0.0202 \\
\mathcal{R}e \, \delta \tilde{F}_{2V}^\gamma &= -0.0246 \pm 0.0260 \\
\mathcal{R}e \, \delta \tilde{F}_{2V}^Z &= +0.1448 \pm 0.0435
\end{align*}
\]

\[\chi^2_{\text{test}} = 166 \Leftrightarrow \sim 0\% \, \text{CL}\]

**After quality cut (\(\chi^2_{\text{tot}} < 5 \& \Delta \chi^2_{\text{tot}} > 6\), total efficiency 28%)**

\[
\begin{align*}
\mathcal{R}e \, \delta \tilde{F}_{1V}^\gamma &= +0.0088 \pm 0.0154 \\
\mathcal{R}e \, \delta \tilde{F}_{1V}^Z &= +0.0339 \pm 0.0270 \\
\mathcal{R}e \, \delta \tilde{F}_{1A}^\gamma &= +0.0233 \pm 0.0221 \\
\mathcal{R}e \, \delta \tilde{F}_{1A}^Z &= +0.0704 \pm 0.0340 \\
\mathcal{R}e \, \delta \tilde{F}_{2V}^\gamma &= +0.0788 \pm 0.0461 \\
\mathcal{R}e \, \delta \tilde{F}_{2V}^Z &= +0.1244 \pm 0.0762
\end{align*}
\]

\[\chi^2_{\text{test}} = 10.0 \Leftrightarrow 12.5\% \, \text{CL}\]
Fit of the CP-Violating form factors

Result of $Re\delta F_{2A}^{Y}$ fit (the others are fixed at SM)

Before the quality cut (total efficiency 77%)

$$Re\delta F_{2A}^{Y} = -0.0172 \pm 0.0185, \chi^2_{test} = 0.87 \Leftrightarrow 35\% \text{ CL}$$

The $\omega - \Omega$ distribution of the wrong assignment (Green) is

- centered at 0
  - no apparent effect on the bias
  - $\chi^2_{test}$ is misleading
- if we use a CP-Violating sample, the wrong assignment will dilute the effect of CPV
  - blunter $\rightarrow$ over estimates the precision

* $\chi^2_{test} = \sum \delta F_i V_{ij}^{-1} \delta F_j$ : the chi-square test
Fit of the CP-Violating form factors

Result of $Re\delta F_{2A}^\gamma$ fit (the others are fixed at SM)

Before the quality cut (total efficiency 77%)

$$Re\delta F_{2A}^\gamma = -0.0172 \pm 0.0185, \quad \chi^2_{\text{test}} = 0.87 \Leftrightarrow 35\% \text{ CL}$$

After the quality cut ($\chi^2_{\text{tot}} < 5 \& \Delta \chi^2_{\text{tot}} > 6$, total efficiency 28%)

$$Re\delta F_{2A}^\gamma = -0.0052 \pm 0.0287, \quad \chi^2_{\text{test}} = 0.034 \Leftrightarrow 85\% \text{ CL}$$

Good agreement between MC truth and Rec.  
$\Rightarrow$ The error is estimated correctly.

"Left" polarization

The histogram of $\omega - \Omega$ for $Re\delta F_{2A}^\gamma$  
(after quality cut)
The distributions of $\omega - \Omega$ (bef. the quality cut)

“Left” polarization

$\langle Re\delta\tilde{F}^V_{2A} \rangle$

$\langle Im\delta\tilde{F}^V_{2A} \rangle$

$\langle Re\delta\tilde{F}^Z_{2A} \rangle$

$\langle Im\delta\tilde{F}^Z_{2A} \rangle$
The distributions of $\omega - \Omega$ (aft. the quality cut)

"Left" polarization

$\text{(Re}\delta \tilde{F}^{\gamma}_{2A})$

$\text{(Im}\delta \tilde{F}^{\gamma}_{2A})$

$\text{(Re}\delta \tilde{F}^{Z}_{2A})$

$\text{(Im}\delta \tilde{F}^{Z}_{2A})$
Fit of the CP-Violating form factors

Results of 4 CPV form factors fit

Before quality cut (total efficiency 77%)

\[
\begin{bmatrix}
\mathcal{R}e \delta F_{2A}^\gamma \\
\mathcal{R}e \delta F_{2A}^{Z} \\
\mathcal{I}m \delta F_{2A}^\gamma \\
\mathcal{I}m \delta F_{2A}^{Z}
\end{bmatrix}
= 
\begin{bmatrix}
-0.0196 \pm 0.0185 \\
+0.0307 \pm 0.0357 \\
-0.0324 \pm 0.0177 \\
+0.0111 \pm 0.0239
\end{bmatrix}
\]

\[\chi^2_{\text{test}} = 5.0 \Leftrightarrow 29\% \text{ CL}\]

After quality cut (\(\chi^2_{\text{tot}} < 5 \& \Delta \chi^2_{\text{tot}} > 6, \text{ total efficiency 28\%}\))

\[
\begin{bmatrix}
\mathcal{R}e \delta F_{2A}^\gamma \\
\mathcal{R}e \delta F_{2A}^{Z} \\
\mathcal{I}m \delta F_{2A}^\gamma \\
\mathcal{I}m \delta F_{2A}^{Z}
\end{bmatrix}
= 
\begin{bmatrix}
-0.0022 \pm 0.0287 \\
+0.0423 \pm 0.0567 \\
-0.0026 \pm 0.0300 \\
+0.0148 \pm 0.0419
\end{bmatrix}
\]

\[\chi^2_{\text{test}} = 0.64 \Leftrightarrow 96\% \text{ CL}\]
Relation of the helicity angles of $\mu^\pm$ and $\omega - \Omega$

When we don't use the $\phi_{\mu^\pm}$ or $(\phi_{\mu^\pm}, \theta_{\mu^\pm})$, the $\omega - \Omega$ distribution becomes sharper, hence the sensitivity becomes lower.

$\rightarrow (\phi_{\mu^\pm}, \theta_{\mu^\pm})$ has a sensitivity to the $ttZ/\gamma$. 

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Summary

- Di-leptonic state analysis produces the 9 helicity angles which are sensitive to the form factors.

- Reconstruct top quark imposing the kinematical constraints
  - ISR significantly affects the assignment problem of b-jets
  - The quality cut improves the fraction of wrong assignment of b-jets, hence the angular distributions.

- Fit the form factors with the Matrix element method
  - CPC: After quality cut, results are consistent with SM.
  - CPV: The wrong fraction has no effects on the bias, but it will dilute the CPV effects if we use a CPV sample.
Suppression of $\gamma\gamma \rightarrow$ hadrons & b-jet reconstruction

Particles from $\gamma\gamma \rightarrow$ hadrons are mostly emitted along the beam direction. The direction of the b-jet is affected by these particles.

Suppress these particles using the $kt$ algorithm ($R=1.5$).

$\implies$ The direction of the b-jet is improved.

The polar angle distribution b-jets. A: without the suppression of $\gamma\gamma \rightarrow$ hadrons, B: with the suppression of $\gamma\gamma \rightarrow$ hadrons
Scalar product, $\hat{\eta}_{t,MC} \cdot \hat{\eta}_{t,Rec.}$
Kinematical reconstruction of top

To select the optimal solution, we compare $E_b$ and $E_{\bar{b}}$ between calculated by $(\theta_t, \phi_t)$ and measured by the b-jet reconstruction.

$$\chi_b^2(\theta_t, \phi_t) = \left( \frac{E_b(\theta_t, \phi_t) - E_{b}^{\text{meas.}}}{\sigma[E_b^{\text{meas.}}]} \right)^2 + \left( \frac{E_{\bar{b}}(\theta_t, \phi_t) - E_{\bar{b}}^{\text{meas.}}}{\sigma[E_{\bar{b}}^{\text{meas.}}]} \right)^2$$

Compute $\chi_b^2$ for each candidate → **Pick one which has the smallest $\chi_b^2$**
Luminosity spectrum

Because we impose the initial state constraints, the events which have low $\sqrt{s}$ are badly reconstructed.

The quality cut reduces low $\sqrt{s}$ events, but there are still a tail.
Luminosity spectrum

Tried to fit the energy of ISR photon along beam direction;

\[ e^+ e^- \rightarrow b\bar{b}\mu^+ \nu\mu^- \bar{\nu} + \gamma_{ISR} \]

→ Another parameter, K

- \(|K| = E_\gamma/250\), hence \(\sqrt{s} = 500 \times \sqrt{1 - |K|}\)
- If \(\gamma\) is emitted in the \(e^-(e^+)\) direction, \(K\) is positive (negative).

Then one minimizes \(\chi^2_{tot}'(\theta_t, \phi_t, K)\);

\[ \chi^2_{tot}'(\theta_t, \phi_t, K) = \chi^2_{tot}(\theta_t, \phi_t, K) - 2 \log \text{PDF}_K(K) \]

→ Reconstructed \(\sqrt{s}\) don’t correlate MC truth.

→ The constraints are not enough.

Now we fix \(K = 0\) (i.e. use \(\chi^2_{tot}(\theta_t, \phi_t)\))
$\tilde{F}_{2V}^Z$ fit (The simplest case)

Other ways to reduce the bias

• Convolve the $|M|^2$ with the resolution function of the helicity angles

\[ |M|^2 \ast = |M|_{\text{cov.}}^2 \]

The deviation of each helicity angles

• Use other quantities for the quality cut.

eg) $|\chi^2_{\text{tot,caseA1(B1)}} - \chi^2_{\text{tot,caseA2(B2)}}|$
$\tilde{F}_{2V}^Z$ Fit (The simplest case)

(Fix the other form factors at the SM)

**Before quality cut**

\[ \delta \tilde{F}_{2V}^Z = 0.117 \pm 0.033, \quad \chi^2_{\text{test}} = 12.6 \text{ (confidence level = 0.03\%)} \]

**After quality cut** (\(\chi^2_{\text{tot}} < 5 \& \Delta \chi^2_{\text{tot}} > 6\), efficiency 36%)

\[ \delta \tilde{F}_{2V}^Z = 0.096 \pm 0.055, \quad \chi^2_{\text{test}} = 3.0 \text{ (confidence level = 8.3\%)} \]
6 CPC form factors fit

Fit 6 form factors \((\tilde{F}_{1V}^{\gamma}, \tilde{F}_{1V}^{Z}, \tilde{F}_{1A}^{\gamma}, \tilde{F}_{1A}^{Z}, \tilde{F}_{2V}^{\gamma}, \tilde{F}_{2V}^{Z})\)

Before quality cut

\[
< \sigma_F > = 0.021, \chi^2 = 141 \text{ (confidence level ~ 0 %)}
\]

After quality cut \((\chi^2_{tot} < 5 \& \Delta \chi^2_{tot} > 6, \text{ efficiency 36%})\)

\[
< \sigma_F > = 0.035, \chi^2 = 10.5 \text{ (confidence level = 11 %)}
\]
4 CP Violating Form Factors Fit

Fit 4 form factors \( (Re\tilde{F}_{2A}^\gamma, Re\tilde{F}_{2A}^Z, Im\tilde{F}_{2A}^\gamma, Im\tilde{F}_{2A}^Z) \)

**Before quality cut**

\(< \sigma_F > = 0.026, \chi^2 = 8.6 \) (confidence level = 7.2 %)

**After quality cut** \( (\chi^2_{tot} < 5 \& \Delta\chi^2_{tot} > 6, \text{efficiency 35\%}) \)

\(< \sigma_F > = 0.038, \chi^2 = 3.7 \) (confidence level = 45 %)
The distributions of $\omega - \Omega$ (bef. the quality cut)

"Left" polarization

"Right" polarization
The distributions of $\omega - \Omega$ (bef. the quality cut)

“Left” polarization

“Right” polarization