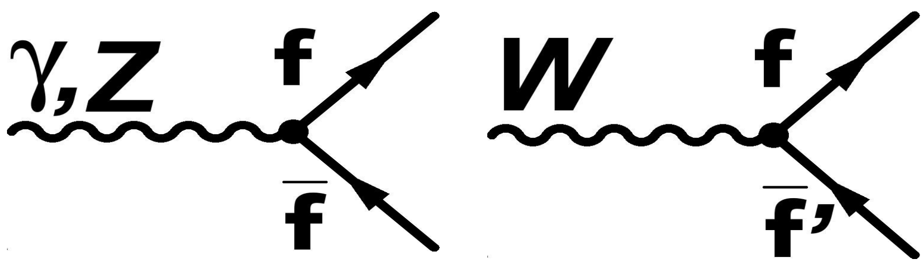
Triple Gauge Couplings and Polarization at the ILC

Ivan Marchesini, LC Forum Hamburg, 2012-02-08

Electro-Weak Sector

- Gauge group $SU(2)_L \otimes U(1)_Y$.
- Non-Abelian $SU(2)_L$ ⇒ gauge bosons **self-couplings**.
- In particular: Triple Gauge Couplings (TGCs) *WWV* ($V = \gamma$ or Z).
- "**Accidental**" in the theory. Want:



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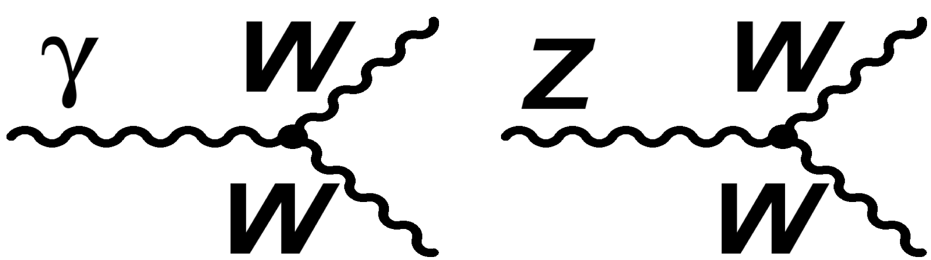

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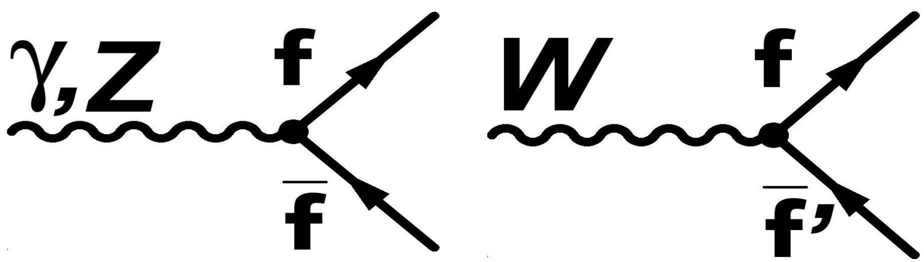

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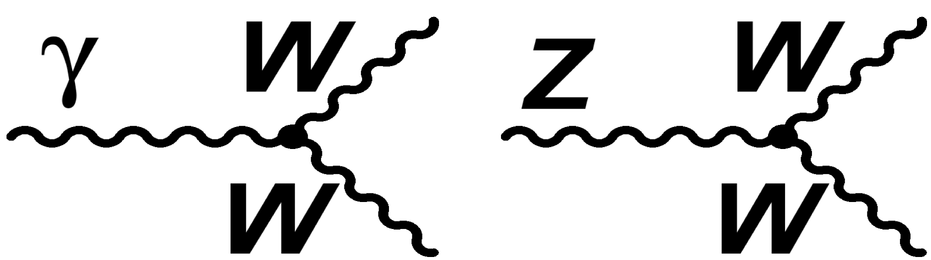
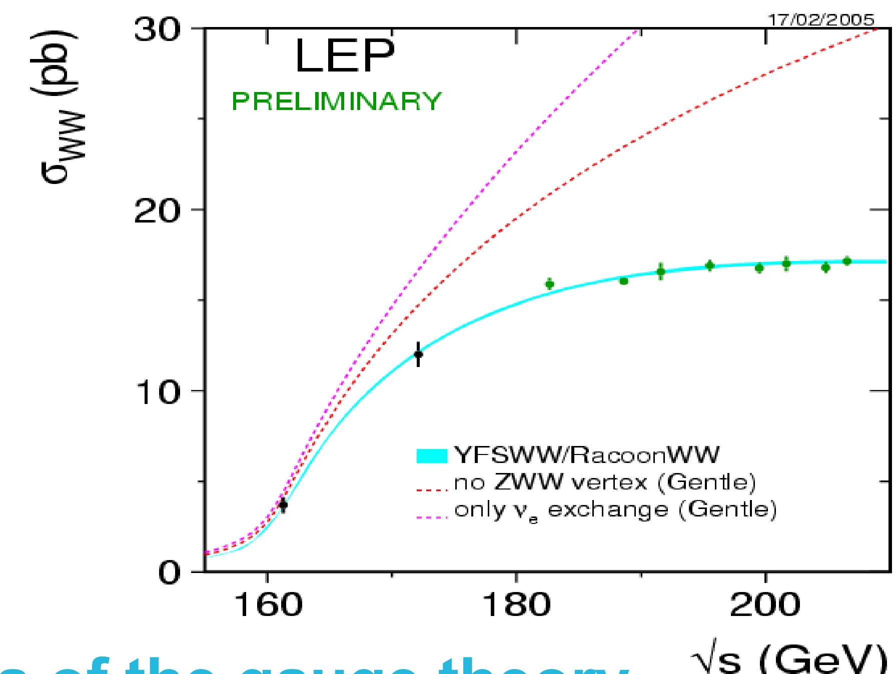




- Confirmed at LEP. Great **success of the gauge theory**.

Triple Gauge Couplings

- Deviations from SM loop-corrections and beyond-SM physics (need at least **10^{-3} precision**).
- TGCs parametrized by the effective Lagrangian (phenomenological, model independent, most general):

$$\begin{aligned}
\frac{\mathcal{L}^{WWV}}{ig_{WWV}} &= g_1^V V^\mu \left(W^-_{\mu\nu}W^{+\nu} - W^+_{\mu\nu}W^{-\nu}\right) - \kappa_V W^-_\mu W^+_\nu V^{\mu\nu} - \frac{\lambda_V}{m_W^2} V^{\mu\nu} W^{+\rho}_\mu W^-_{\rho\nu} \\
&+ ig_4^V W^-_\mu W^+_\nu (\partial^\mu V^\nu + \partial^\nu V^\mu) \\
&+ ig_5^V \varepsilon^{\mu\nu\rho\sigma} \left[(\partial_\rho W^-_\mu)W^+_\nu - W^-_\mu(\partial_\rho W^+_\nu)\right] V_\sigma \\
&- \frac{\tilde{\kappa}_V}{2} W^-_\mu W^+_\nu \varepsilon^{\mu\nu\rho\sigma} V_{\rho\sigma} - \frac{\tilde{\lambda}_V}{2m_W^2} W^-_{\rho\mu} W^{+\mu}{}_\nu \varepsilon^{\nu\rho\alpha\beta} V_{\alpha\beta}.
\end{aligned}$$

- 14 complex couplings: **28 free parameters**.
- SM predicts g_1^Z, g_1^γ, κ_γ and $\kappa_z = 1$ at tree level, others are 0.

LEP Combined Results

- **Assumptions** on the TGCs used at LEP and in this study:
  - Real, *C*- and *P*- conserving: g_1^Z, g_1^γ, κ_γ, κ_{Z}, λ_γ and λ_κ.
  - Electromagnetic gauge invariance $g_1^\gamma = 1$.
  - $SU(2)_L \otimes U(1)_Y$ local gauge invariance:

$$\begin{aligned} \Delta\kappa_Z &= -\Delta\kappa_\gamma \tan^2\theta_W + \Delta g_1^Z \\ \lambda_Z &= \lambda_\gamma. \end{aligned}$$

- 5 couplings, **3 independent**.
- LEP limits (one-parameter fits):

Parameter	68% C.L.
g_Z^1	$0.984^{+0.022}_{-0.019}$
κ_γ	$0.973^{+0.044}_{-0.045}$
λ_γ	$-0.028^{+0.020}_{-0.021}$

- No significant improvement at Tevatron or LHC: $O(10^{-2})$. **10^{-3} precision only at the ILC**.

Precision and Polarization

- ILC baseline includes e^- beam long.-polarized of at least **80%**.

- Possibility of e^+ long.-polarization: here **30%** and **60%** options considered.

- Polarized beams (both) are required to:

  - improve statistics: enhance signal, suppress backgrounds;

  - analyze the structure of new physics;

  - precision measurements of (deviations from) the SM.

- But: **polarization has to be known with high precision** (strong impact on the cross-sections).

Polarization Measurement at the ILC

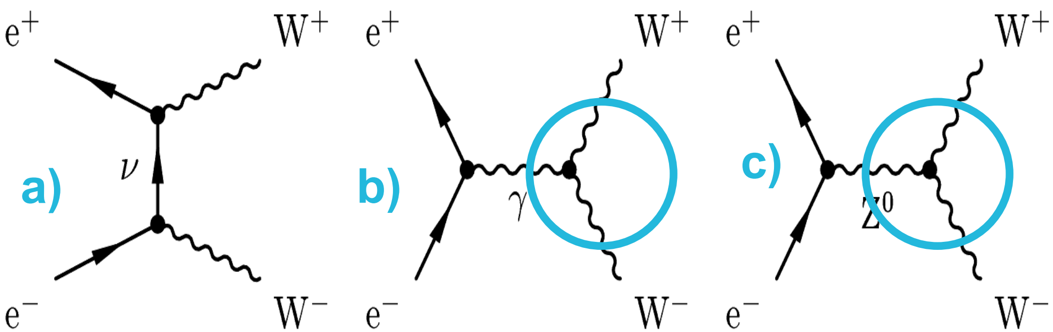
3-fold way: complementarity, cross-checks, redundancy.

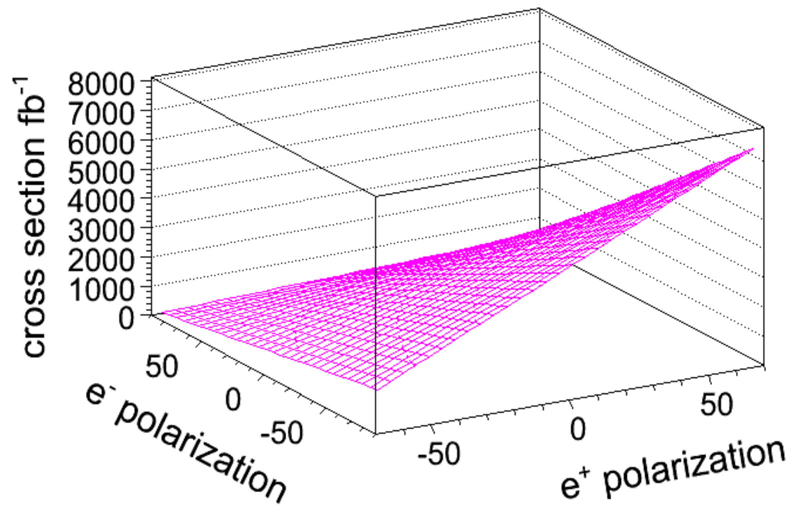
- **Upstream polarimeter:** high time-granularity, control over left-right polarization differences, correlations (**> 1 km from IP**).

- **Downstream polarimeter + spin tracking simulations**: measure depolarization effects.

- **Measurement from Data**:
  - access to luminosity-weighted polarization (**at the IP**) to complement the polarimeters (**check depolarization**);
  - average polarization (long time scale);
  - need polarimeters to correct for left-right differences;
  - need high cross-section, polarization-dependent process;
  - **W^+W^- production ideal**: process used for this study.

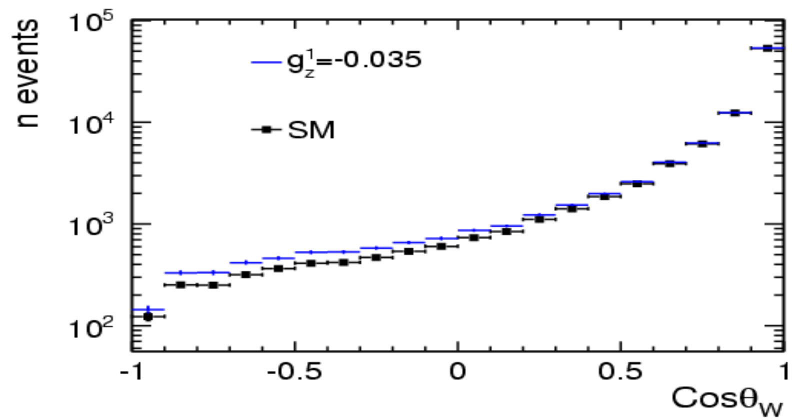
W^+W^- Production





a) **t-channel.** *W* can couple only to e^-_L and e^+_R: only the combination $e^-_L e^+_R$ is allowed.

b) c) **s-channel.** e^+ and e^- must have opposite polarizations, to give the SM vector boson. Sensitive to **TGCs**.



- Total cross-section: strong sensitivity to polarization.
- Golden channel to measure TGCs (LEP): angular distributions.
- Implement **simultaneous measurement**.

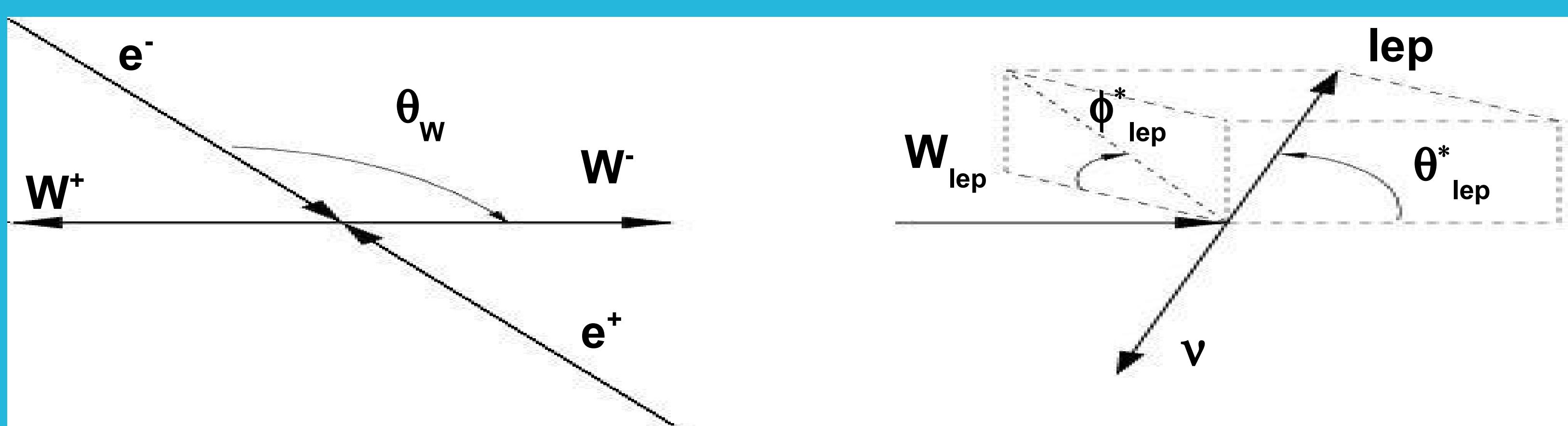
Selection

- Study performed in **full simulation** in ILD. Full SM background.
- Only **semi-leptonic W^+W^- decays towards electron or muon**,

$q\,q\,\mu\,\nu$ and $q\,q\,e\,\nu$:

  - cleanest reconstruction and lower background;
  - precise reconstruction of W decay angles: sensitive to TGCs.

- "tau-signal" $q\,q\,\mu\,\tau$ considered background.
- Leptonic decay **angles** ($\cos\theta^*_l$ and ϕ^*_l) and $\cos\theta_W$ are used.



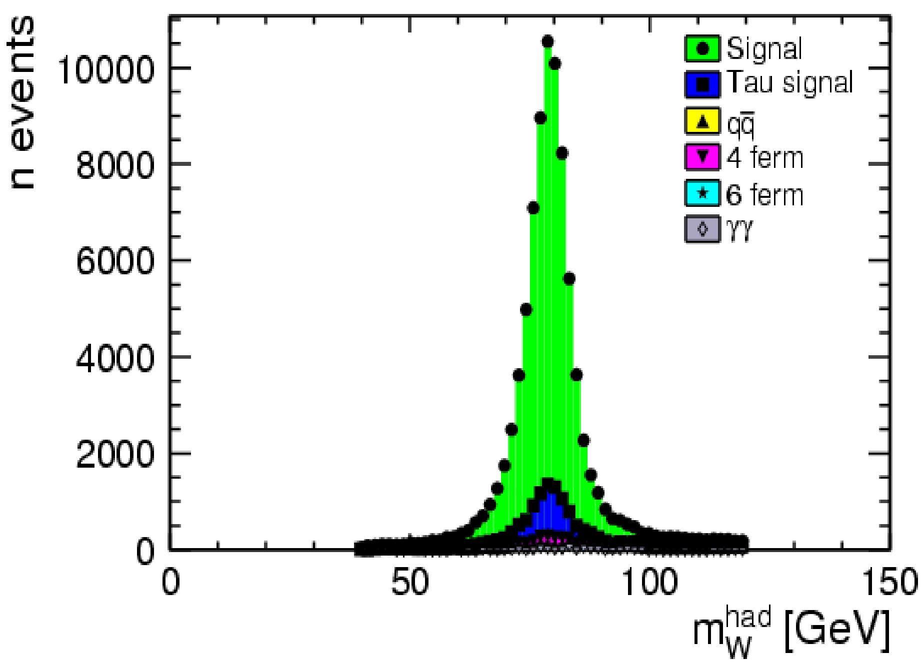
Selection

- Fully simulated Monte Carlo events in ILD. Full SM background.
- Pre-selection cuts (nº tracks, $\sqrt{s}$, P_T, total energy).
- Force 3 jets, the jet with lower particle multiplicity is associated to the lepton and has to have only one track with $p_T > 10$ GeV.
- "Tau-signal" $W^+W^- \rightarrow q\ q\ l\ \tau$ suppression via discriminating variable.
- Further cuts (Y cut, isolation, invariant mass, angular cuts).

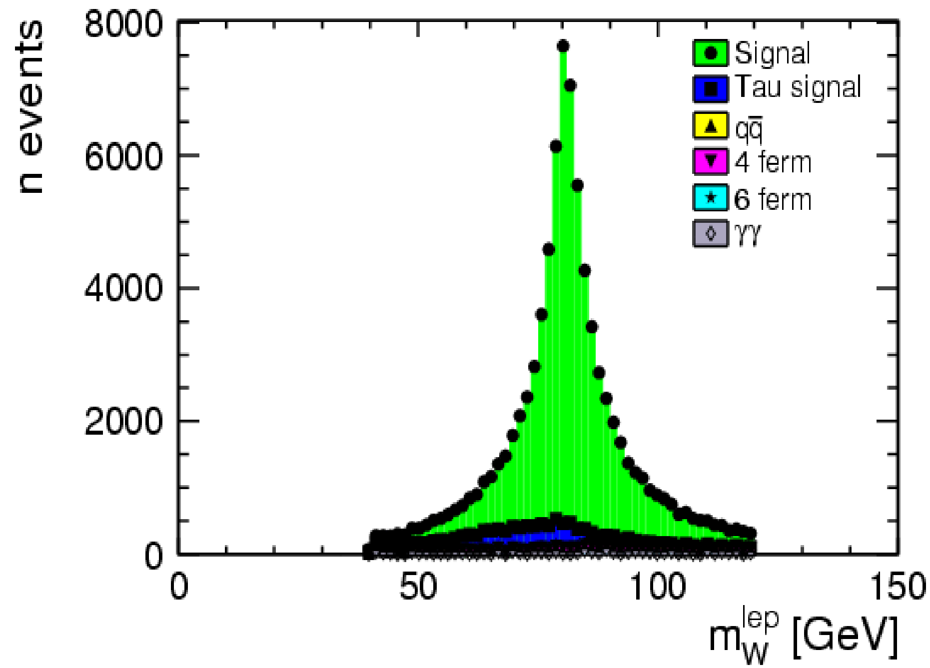
Final Selection

- Reconstructed *W* invariant mass from hadronic and leptonic decay.

hadronic



leptonic



- The final selection:
  - Signal efficiency ~ 67%.
  - non-"tau signal" background contamination ~ 6%.
  - "tau signal" ~ 10%.

Angular Fit

- 3D **Monte Carlo template** ($cos\theta^*_l$, ϕ^*_l , $cos\theta_W$).

- 4 “data” 3D ($cos\theta^*_l$, ϕ^*_l , $cos\theta_W$) distributions for the ++, +-, -+, -- helicity sets.

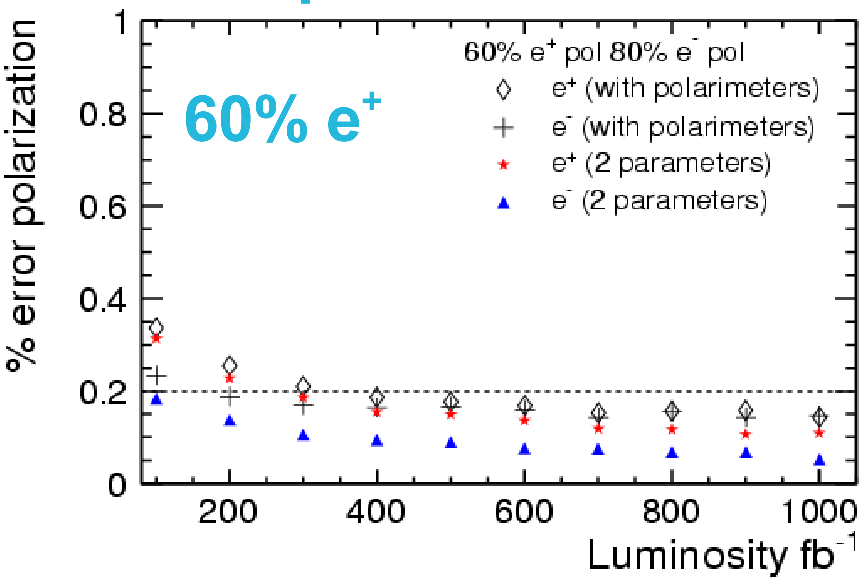
- **Likelihood** fit of data to template.

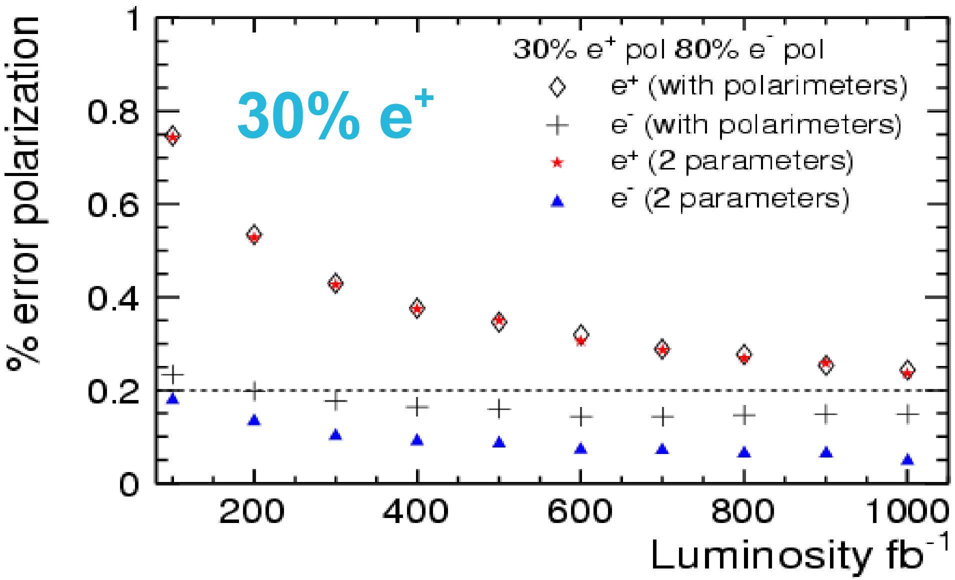
- **3** parameters for the TGCS **+ 2 parameters for the polarization**:
  - ideally: $|+P_{e-}| = |-P_{e-}|$ and $|+P_{e+}| = |-P_{e+}|$;
  - reality: $|+P_{e-}| \neq |-P_{e-}|$ and $|+P_{e+}| \neq |-P_{e+}|$:

    difference given by the polarimeters with **0.25%** uncertainty (major source of **systematics**).

Polarization Measurement

Relative precision %

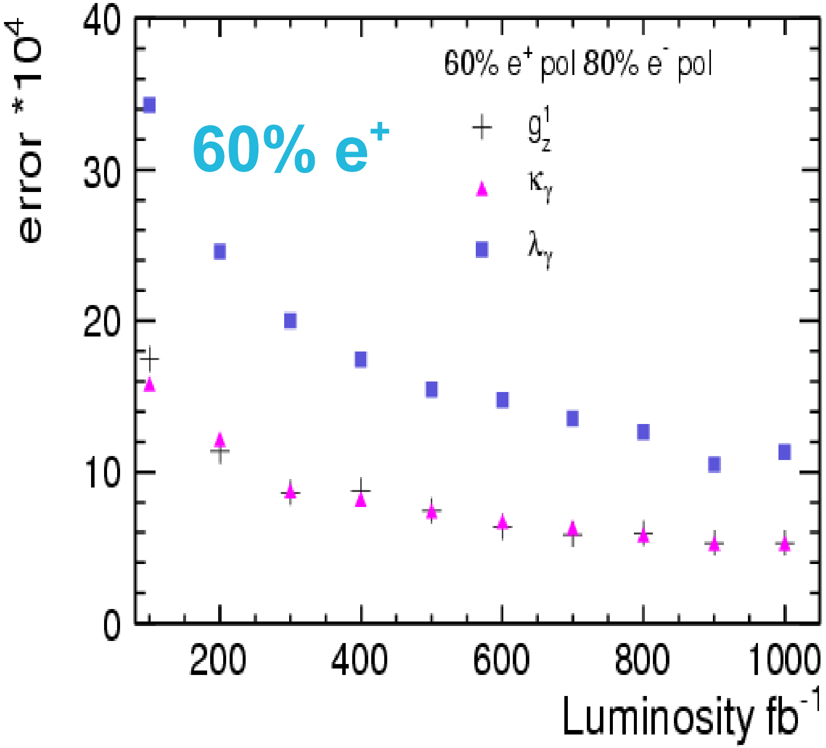


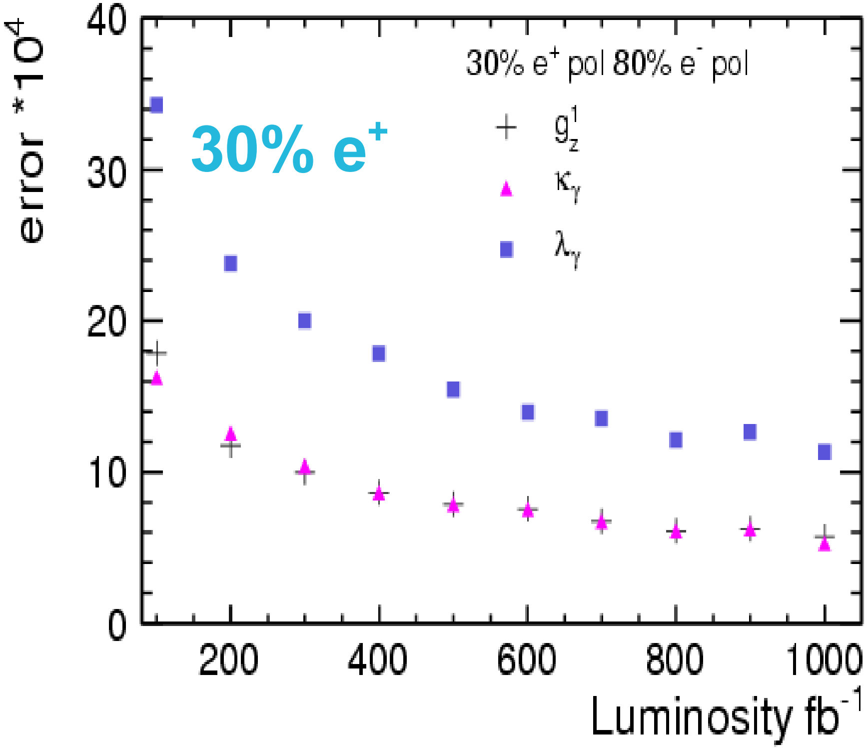


- Here shown sensitivity of fit TGCs+polarization, but same results when fitting polarization alone: highly uncorrelated.
- High positron polarization extremely more convenient.
- Systematics from $|+P_{e-}| \neq |-P_{e-}|$ and $|+P_{e+}| \neq |-P_{e+}|$ non-negligible, nevertheless excellent performance allowed.

Sensitivity to the TGCs

Absolute precision * 10^4





- Not influenced by the positron polarization choice.
- Systematics from $|+P_{e-}| \neq |-P_{e-}|$ and $|+P_{e+}| \neq |-P_{e+}|$ negligible.

Conclusions

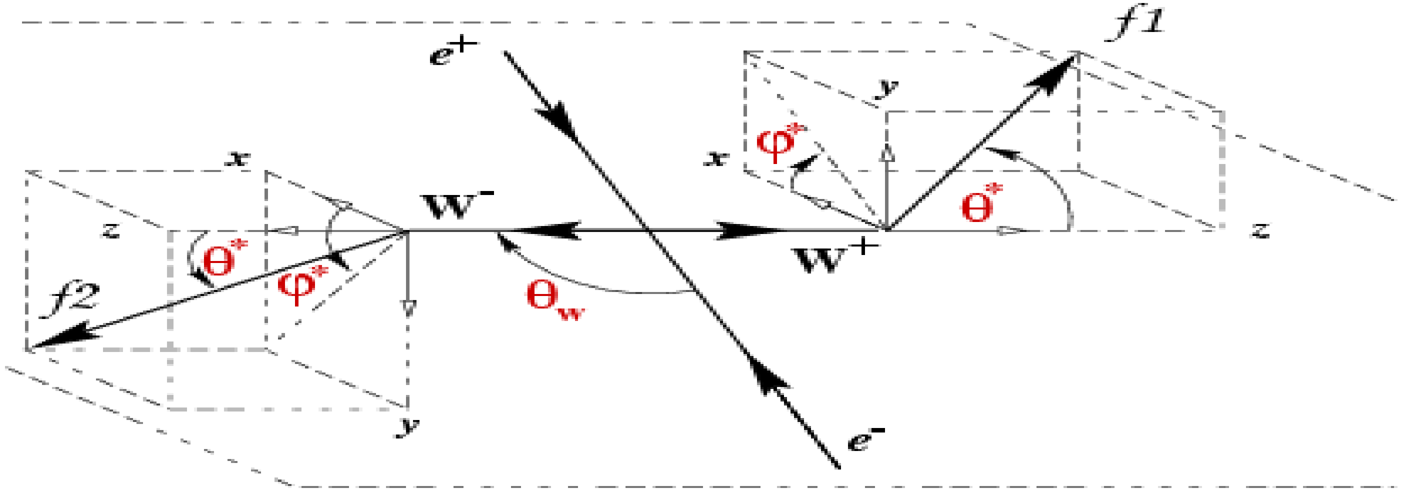
- **Higher positron polarization** strongly relevant from the polarization measurement point of view.

- Simultaneous fit of TGCs and polarization possible, without loosing sensitivity on the polarization measurement.

- Major systematic effect from $|+P_{e-}| \neq |-P_{e-}|$ and $|+P_{e+}| \neq |-P_{e+}|$: acceptable.

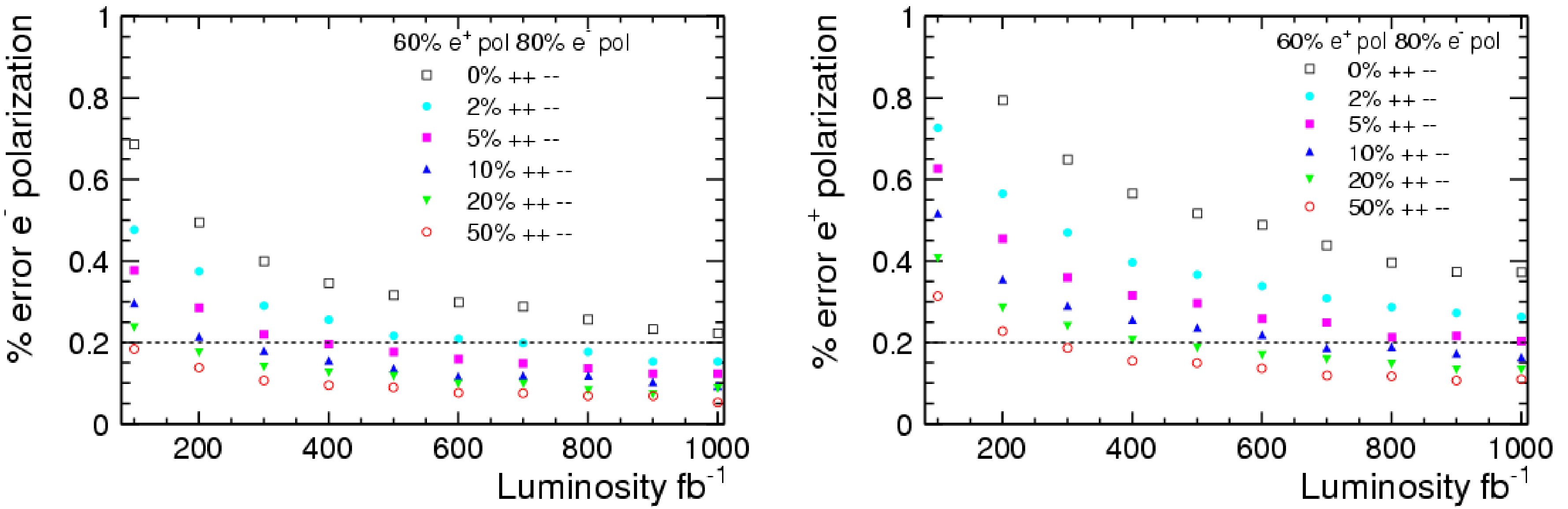
- With 60% positron polarization **error ≈0.2%** on both polarizations at ≈300 fb^{-1}.

End

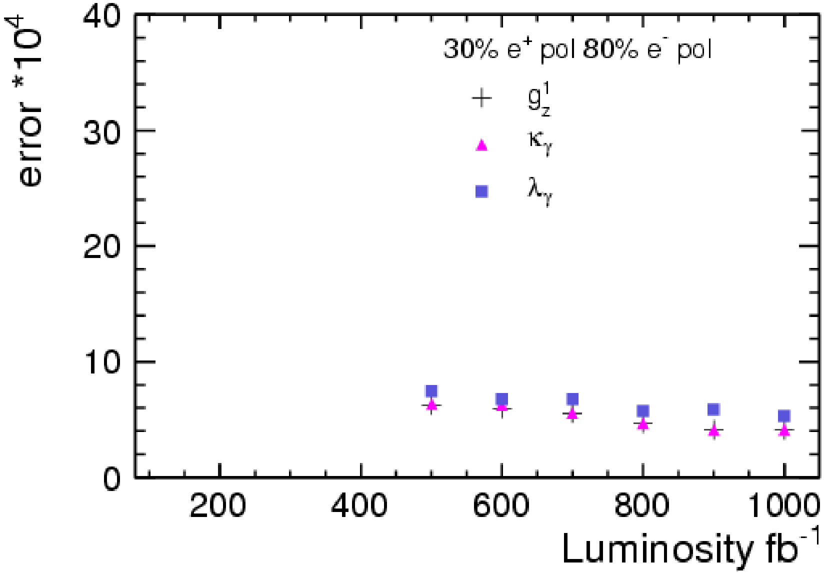


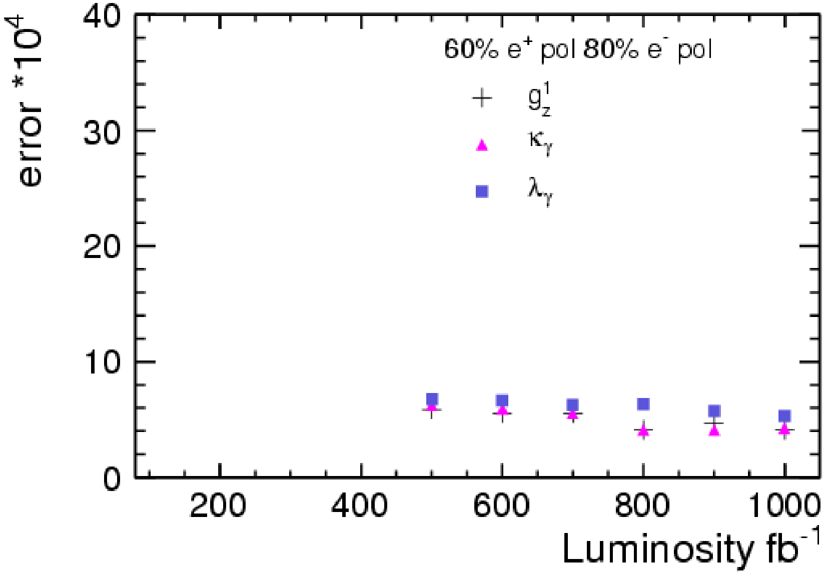
Additional Slides

Reducing ++ -- Combinations



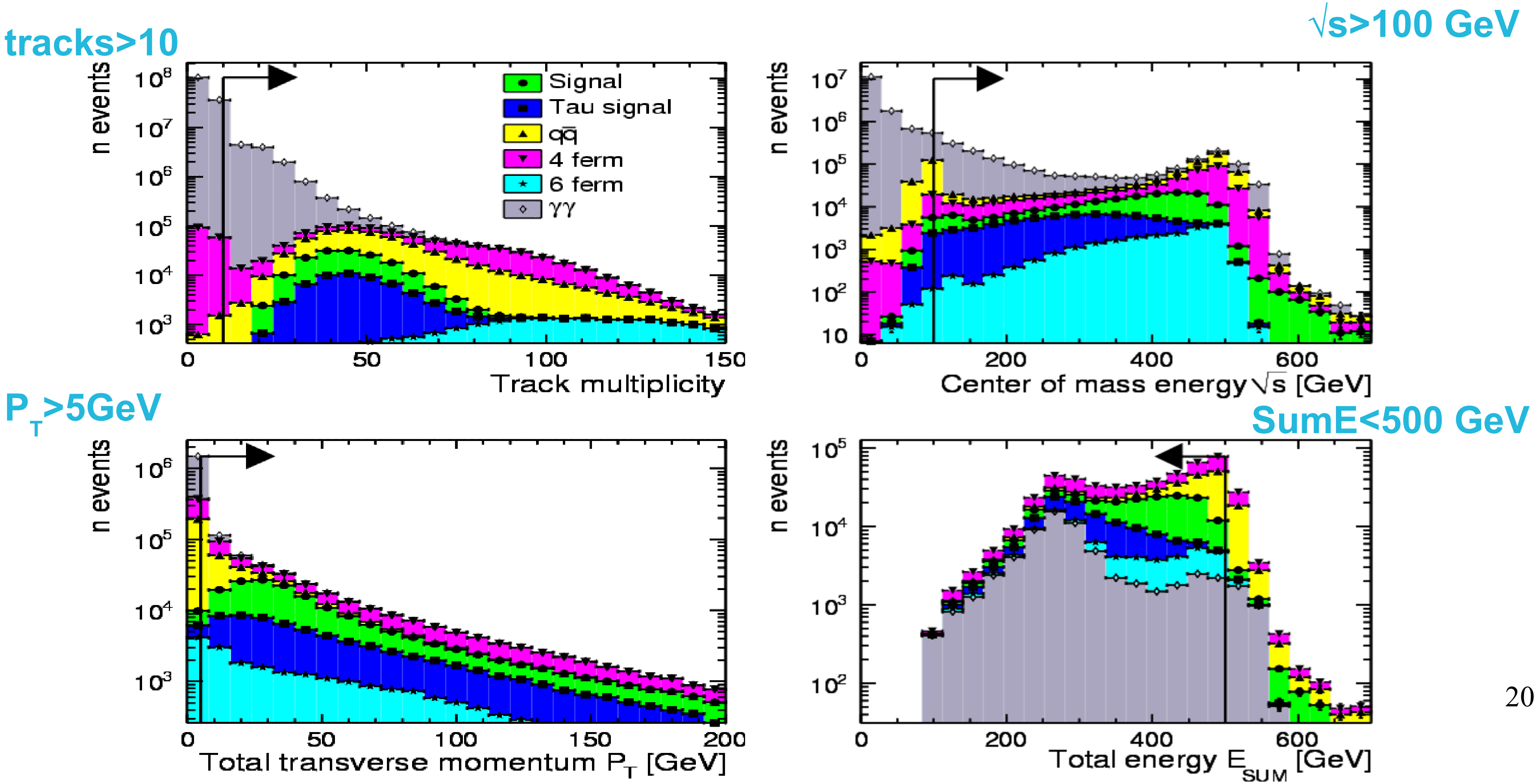
Finer Binning





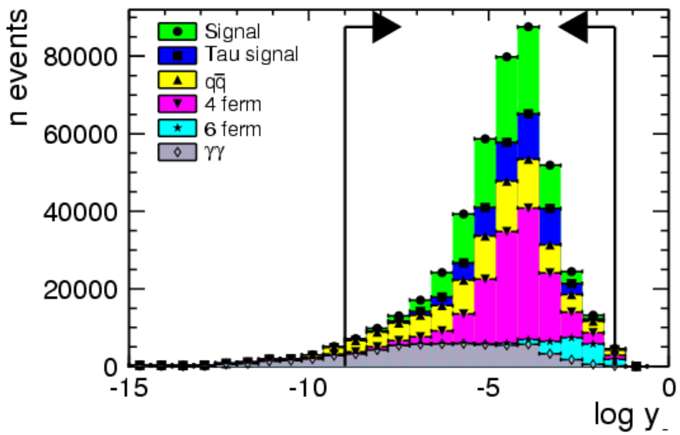
Preselection Cuts

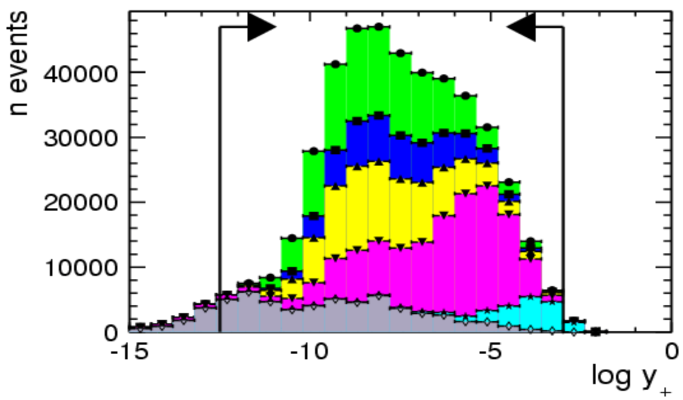
- Selection studied using fully simulated events in ILD.
- Full SM background included.
- Here e.g. 20 fb^{-1}, +30% e^{+}, -80% e^{-} polarization.

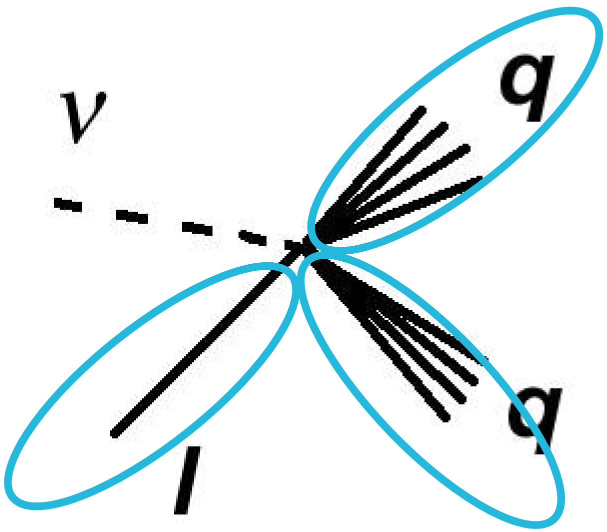


Jets Requirements

- Force **3 jets** (Durham). Two jets are for the hadronic decay. One jet associated to the lepton (jet with lower number of particles).
- Cut on the **y variable** of the jet finder (goodness of clustering).







Further Cuts

- Requirements on the jet associated to the lepton:
  - isolated (theta-phi isolation > 0.5);
  - one track with p_T > 10 GeV.
- $cos\theta_w$ > -0.95.

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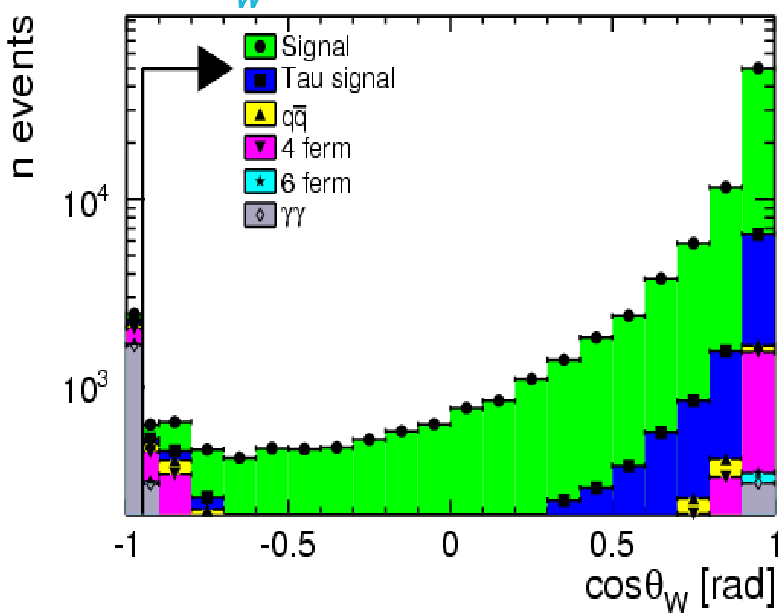
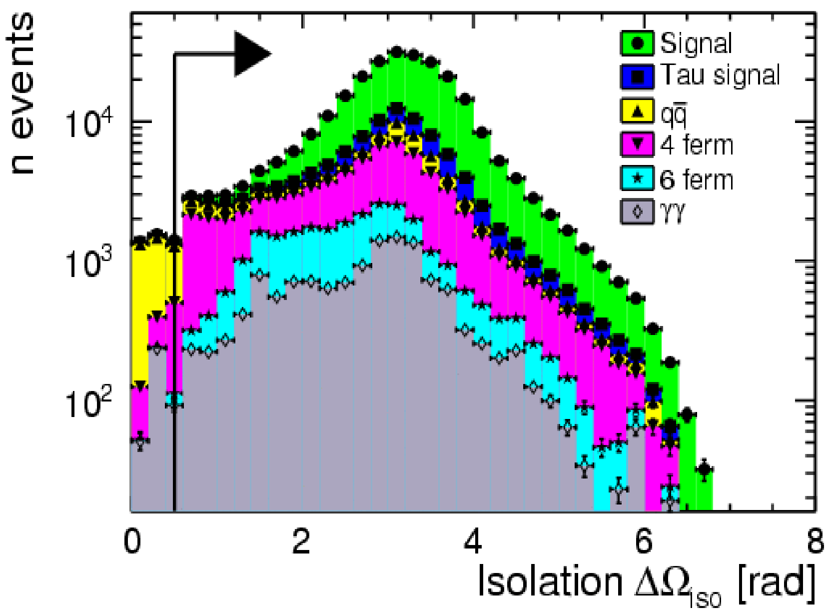
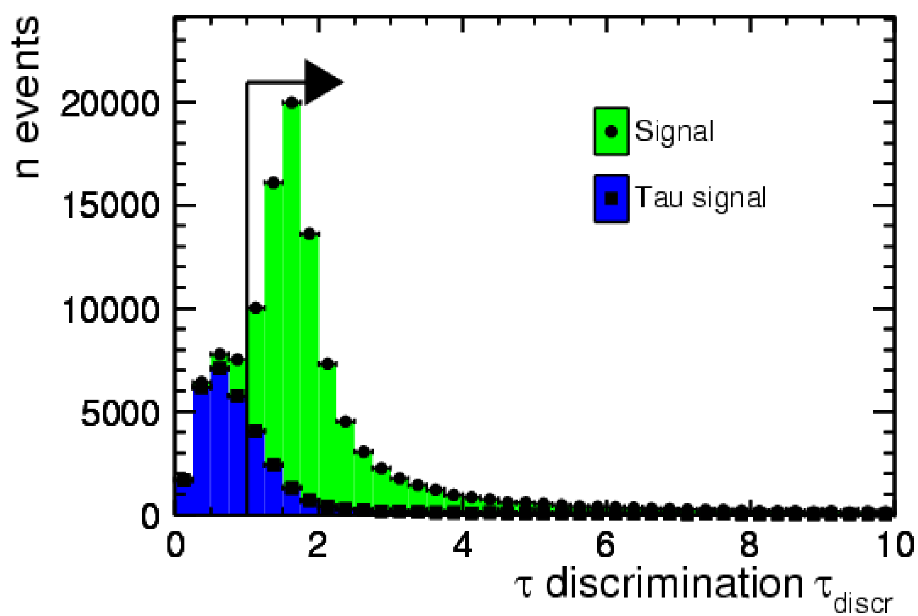


Isolation cut



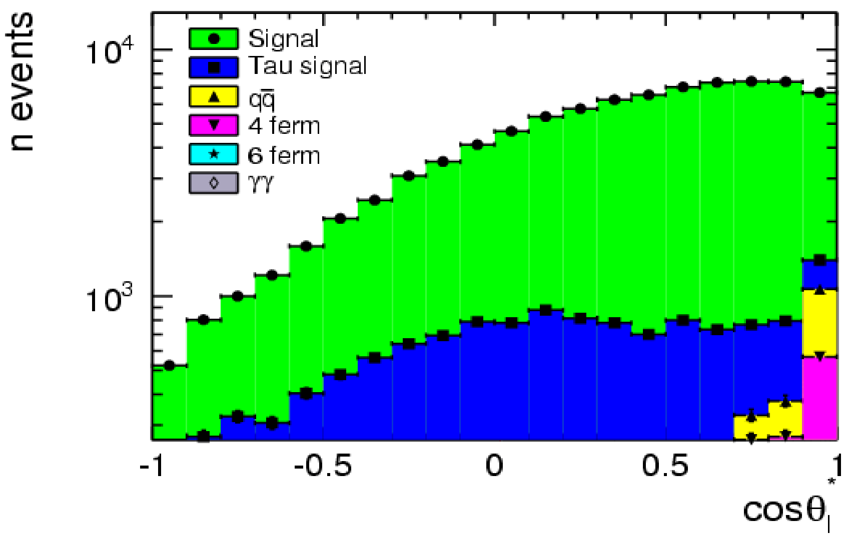
“Tau-signal” Suppression

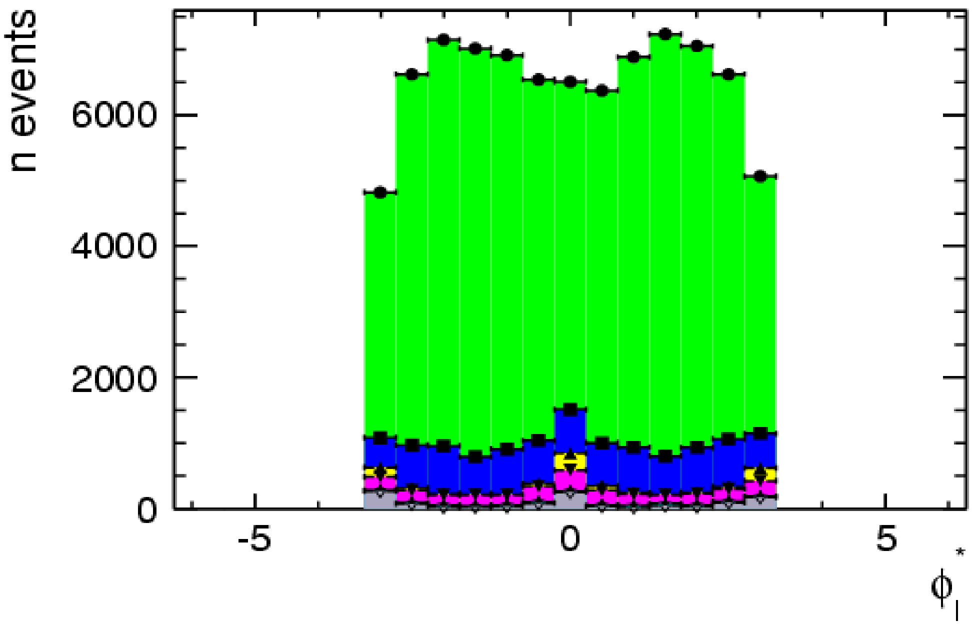
- Reconstruction semi-leptonic decays $q\,q\,\tau\,\nu$ less clean:
  - further neutrino in the final state from tau decay;
  - worse charge reconstruction of the lepton.
- Suppression by means of a discriminating variable:

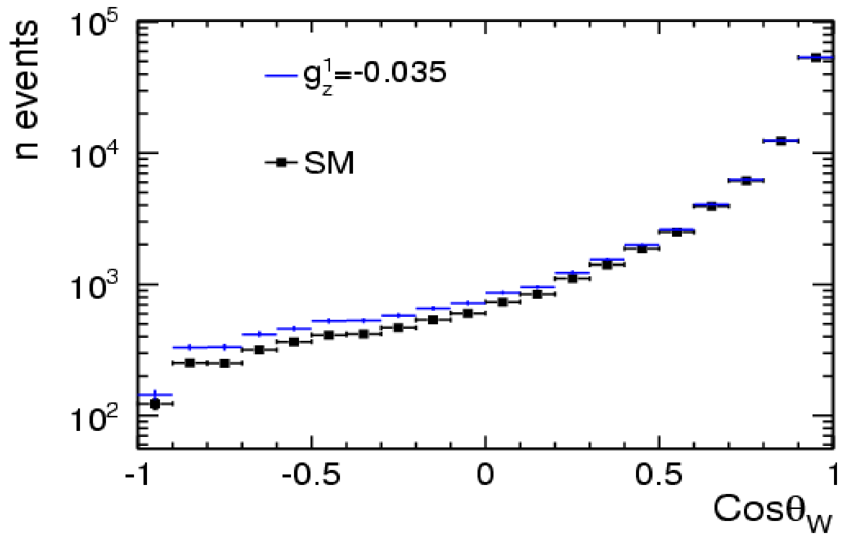


$$\left(\frac{2\,E_{lep}}{\sqrt{s}}\right)^2 + \left(\frac{m_W^{lep}}{m_W^{true}}\right)^2 > 1$$

Decay Angles







- Example of the impact of anomalous TGCs on the angular distributions.

Simulation of the TGCs

- "**Recalculate**" feature in Whizard:
  - change a parameter (TGC value);
  - rescan the sample;
  - weight given by the ratios of the new matrix element values to the old ones.
- Dependence of the differential cross-sections from the TGCs is quadratic. 3 independent TGCs → **9 parameters** for each event:

$$R(\Delta g_1^Z, \Delta\kappa_\gamma, \Delta\lambda_\gamma) = 1 + A\Delta g_1^Z + B\Delta\kappa_\gamma + C\Delta\lambda_\gamma + D\Delta {g_1^Z}^2 + E\Delta{\kappa_\gamma}^2 + F\Delta{\lambda_\gamma}^2 \\ + G\Delta g_1^Z\Delta\kappa_\gamma + H\Delta g_1^Z\Delta\lambda_\gamma + I\Delta\lambda_\gamma\Delta\kappa_\gamma.$$

Simulation of the TGCs

- Scan each event 9 times, for 9 different TGCs sets, getting the 9 weights R.

	R_1	R_2	R_3	R_4	R_5	R_6	R_7	R_8	R_9
Δg_1^Z	+0.001	0	0	-0.001	0	0	+0.001	0	+0.001
$\Delta\kappa_\gamma$	0	+0.001	0	0	-0.001	0	+0.001	+0.001	0
$\Delta\lambda_\gamma$	0	0	+0.001	0	0	-0.001	0	+0.001	+0.001

- Solve the system in order to get the A,...,I coefficients:

$$R_1 = 1 + A \mid \Delta g_1^Z \mid + D \mid \Delta g_1^Z \mid^2,$$
$$R_2 = 1 + B \mid \Delta\kappa_\gamma \mid + E \mid \Delta\kappa_\gamma \mid^2,$$
$$R_3 = 1 + C \mid \Delta\lambda_\gamma \mid + F \mid \Delta\lambda_\gamma \mid^2,$$
$$R_4 = 1 - A \mid \Delta g_1^Z \mid + D \mid \Delta g_1^Z \mid^2,$$
$$R_5 = 1 - B \mid \Delta\kappa_\gamma \mid + E \mid \Delta\kappa_\gamma \mid^2,$$
$$R_6 = 1 - C \mid \Delta\lambda_\gamma \mid + F \mid \Delta\lambda_\gamma \mid^2,$$
$$R_7 = 1 + A \mid \Delta g_1^Z \mid + B \mid \Delta\kappa_\gamma \mid + D \mid \Delta g_1^Z \mid^2 + E \mid \Delta\kappa_\gamma \mid^2 + G \mid \Delta g_1^Z \mid\mid \Delta\kappa_\gamma \mid,$$
$$R_8 = 1 + B \mid \Delta\kappa_\gamma \mid + C \mid \Delta\lambda_\gamma \mid + E \mid \Delta\kappa_\gamma \mid^2 + F \mid \Delta\lambda_\gamma \mid^2 + I \mid \Delta\kappa_\gamma \mid\mid \Delta\lambda_\gamma \mid,$$
$$R_9 = 1 + A \mid \Delta g_1^Z \mid + C \mid \Delta\lambda_\gamma \mid + D \mid \Delta g_1^Z \mid^2 + F \mid \Delta\lambda_\gamma \mid^2 + H \mid \Delta g_1^Z \mid\mid \Delta\lambda_\gamma \mid .$$

Technique 1: Blondel Scheme

- Needs data to be collected for all the **four sign combinations** of polarization: ++, --, +- and -+.

- Assumption: $|+P_{e-}| = |-P_{e-}|$ and $|+P_{e+}| = |-P_{e+}|$ (**polarimeters** necessary to get deviations).

- From the cross sections for the different polarization signs, it is possible to get the polarization:

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

Technique 2: Angular Fit

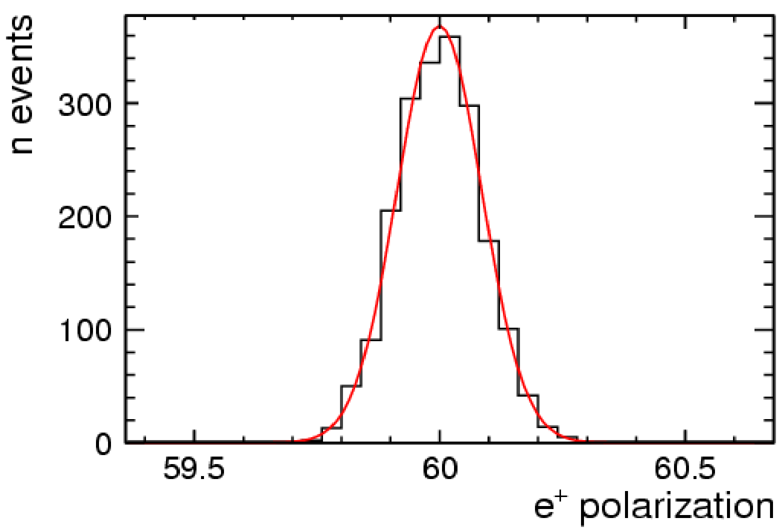
- 3D **Monte Carlo template** ($\cos\theta^*_l$, ϕ^*_l, $\cos\theta_W$).

- 4 "data" 3D ($\cos\theta^*_l$, ϕ^*_l, $\cos\theta_W$) distributions for the ++, +-, -+, -- helicity sets.

- Initially, assumption: $|+P_{e-}| = |-P_{e-}|$ and $|+P_{e+}| = |-P_{e+}|$.

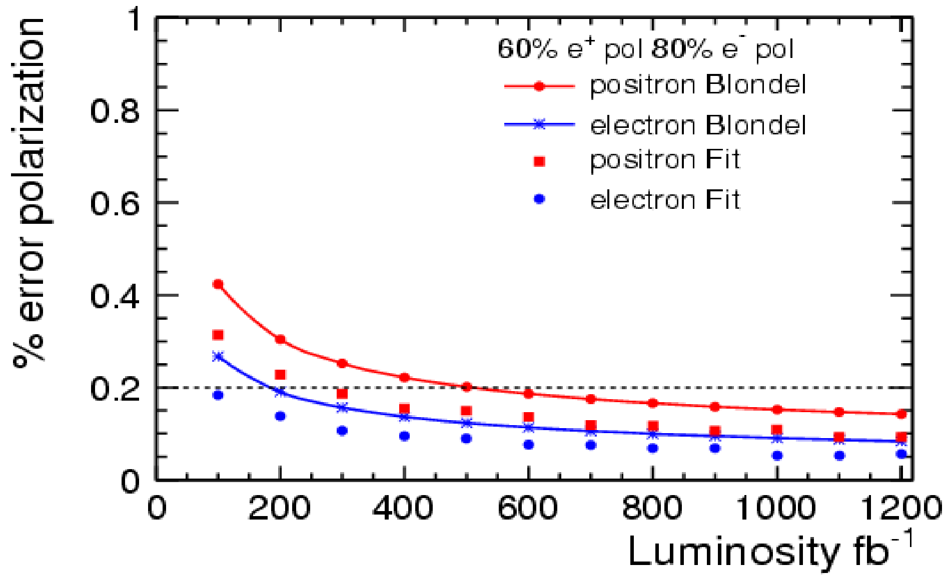
- Each data sample fitted to the 3D MC template.

- Fit iterated for several independent data samples (**poissonian random variation**): statistical error is the dispersion of the measured fit parameters.

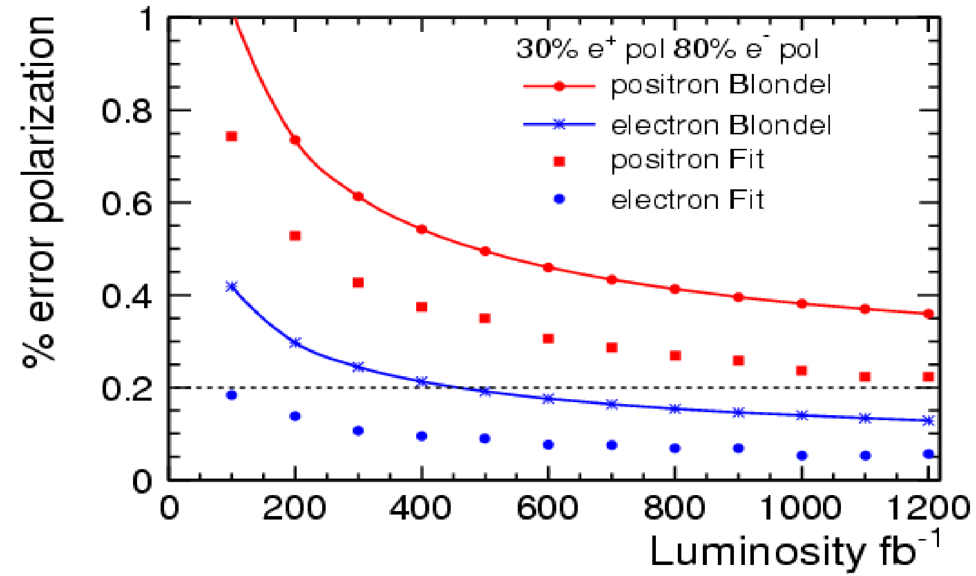


Results

60% e^+



30% e^+



- Luminosity equally shared between the four sign combinations of the polarization.
- Angular fit technique more sensitive.
- High positron polarization extremely more convenient.