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Bundesministerium für Bildung und Forschung

PHYSICS AT THE TERA SCALE Helmholtz Alliance

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Combined measurement of Triple Gauge Boson couplings and polarization at the ILC

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Ivan Marchesini, IWLC2010, 2010-10-20

Overview

Precision and Polarization

- Polarized beams are required to:
  - Improve statistics: enhance signal, suppress backgrounds;
  - Analyze the structure of new physics;
  - Precision measurements of deviation from the SM;
  - Keep the systematics under control.
  - See ex. Gudi's talks.
- But: **polarization has to be known with high precision.**

Polarization measurement at the ILC

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

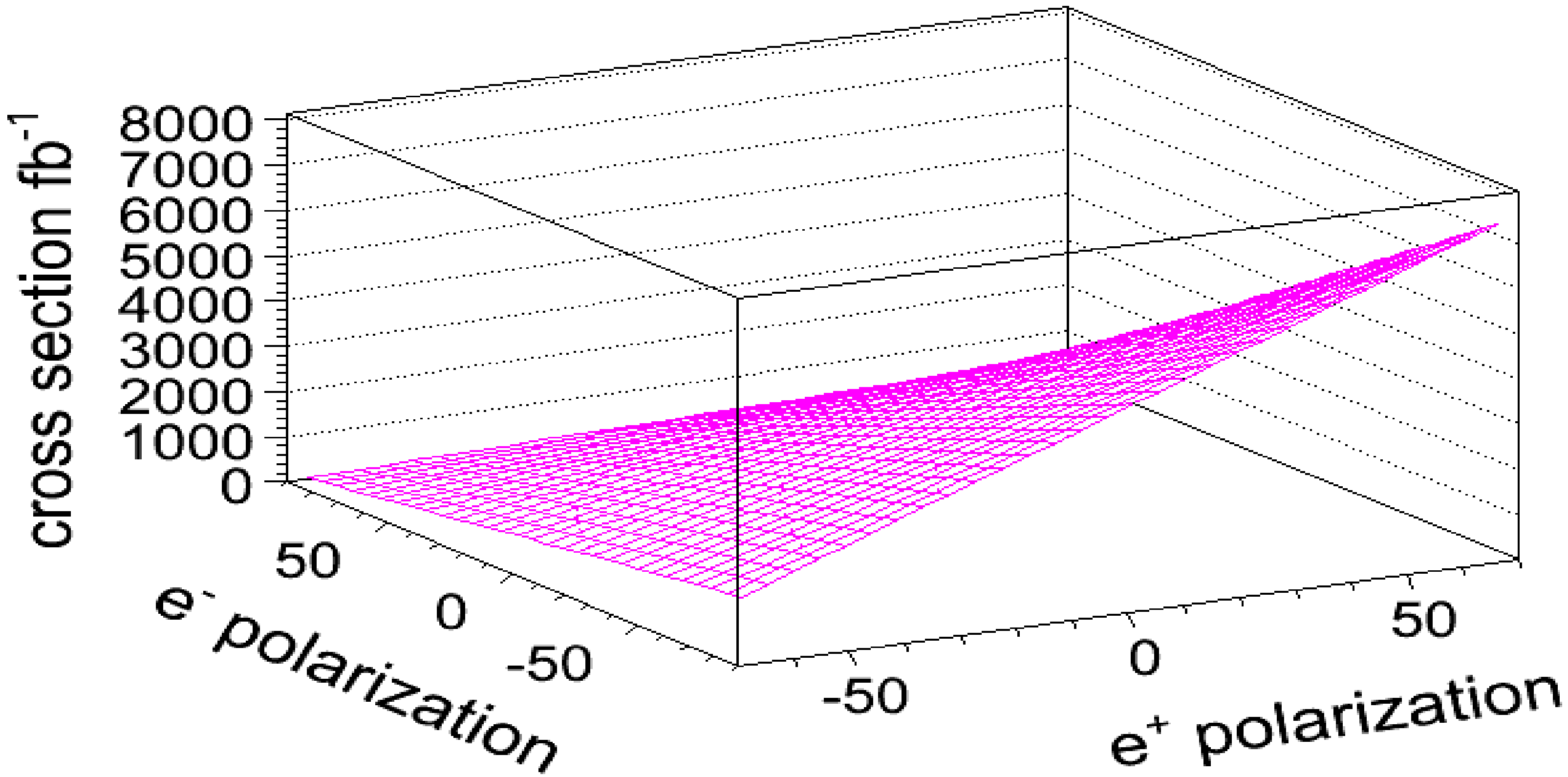
- **Upstream polarimeter:** high time granularity, control over left-right polarization differences, correlations (> 1 Km from IP!).

- **Downstream polarimeter**: measure depolarization effects.

- **Measurement from Data**:

  - Access to luminosity-weighted polarization (at the IP).
  - Average polarization (long time scale).
  - Needed: absolute calibration to the polarimeters (aimed **0.2% precision**).
  - Need polarimeters to correct for left-right differences.
  - Need high cross-section, polarization dependent process: **W^+W^- production ideal**.

W^+W^- total cross-section



- Total cross-section for W^+W^- semi-leptonic decays to muon or electron, at 500 GeV.

Triple Gauge Couplings

TGCs and W^+W^-

- SM gauge group is non-abelian, allowing TGCs vertexes *WWV* (*V* $=\gamma$ or *Z*).
- TGCs affect the s-channel of the W^+W^- production.
- The *WWV* vertex can be parametrized with 14 complex TGCs.
- SM predicts g_1^Z, g_1^γ, κ_γ and κ_z = 1 at tree level, and all the others are 0.
- Deviations from SM loop-corrections and beyond SM physics.

LEP Combined Results

- Assumptions on the couplings used at LEP, and in this study:
  - Real , C and P conserving: g_1^Z, g_1^γ, κ_γ , $\kappa_{Z;}$, λ_γ and λ_κ.
  - Electromagnetic gauge invariance $g_1^\gamma = 1$.
  - Gauge relations:

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

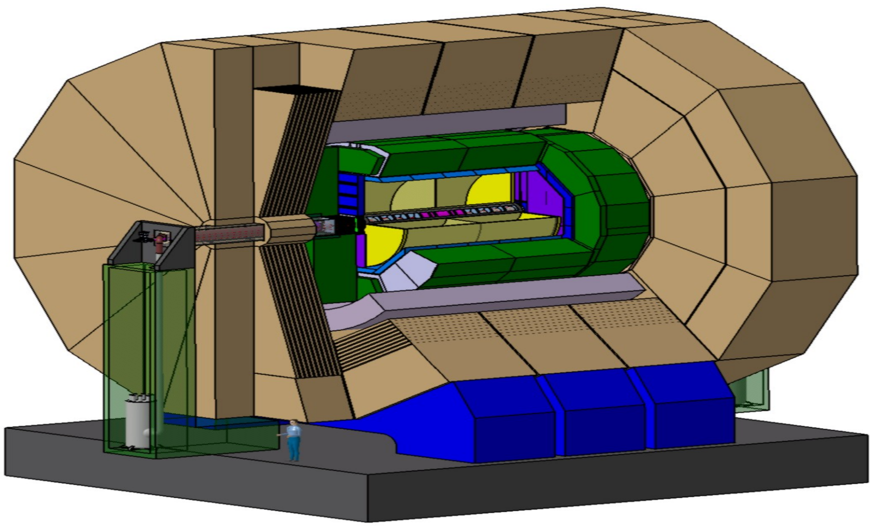
- 5 couplings, 3 independent.
- TGC measured one by one in fits, where the other two are set to the SM value.

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

- Deviations from the SM still allowed, **affecting the polarization measurement up to the % level: ideal simultaneous measurement**.

W^+W^- event selection

ILD



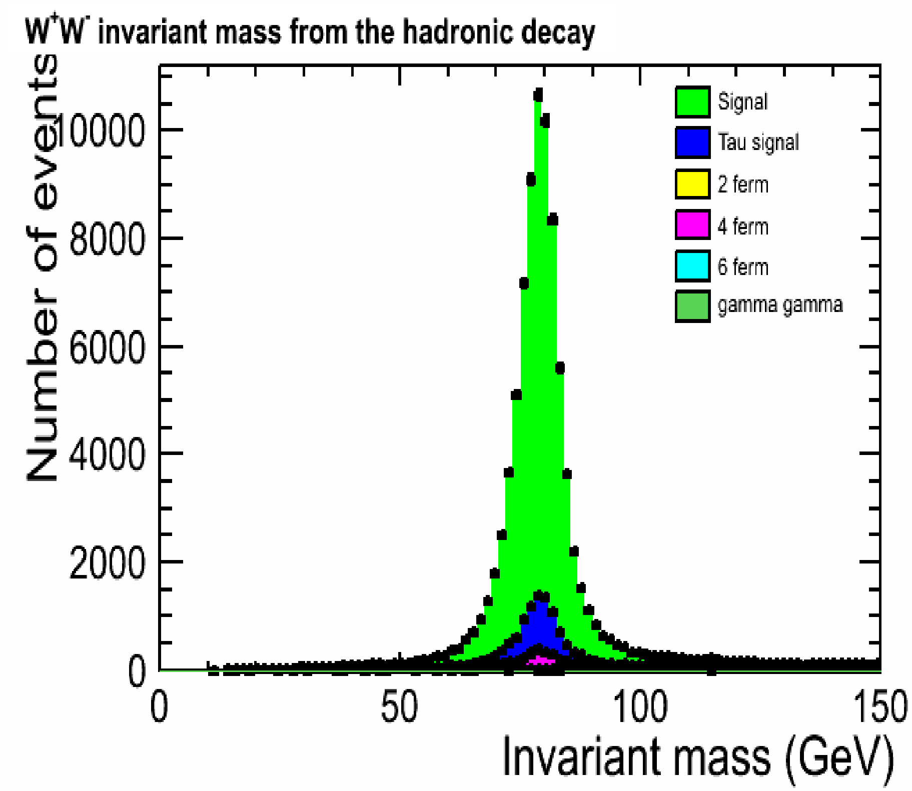
▶ This study took place in the context of the **ILD detector model optimization** studies:

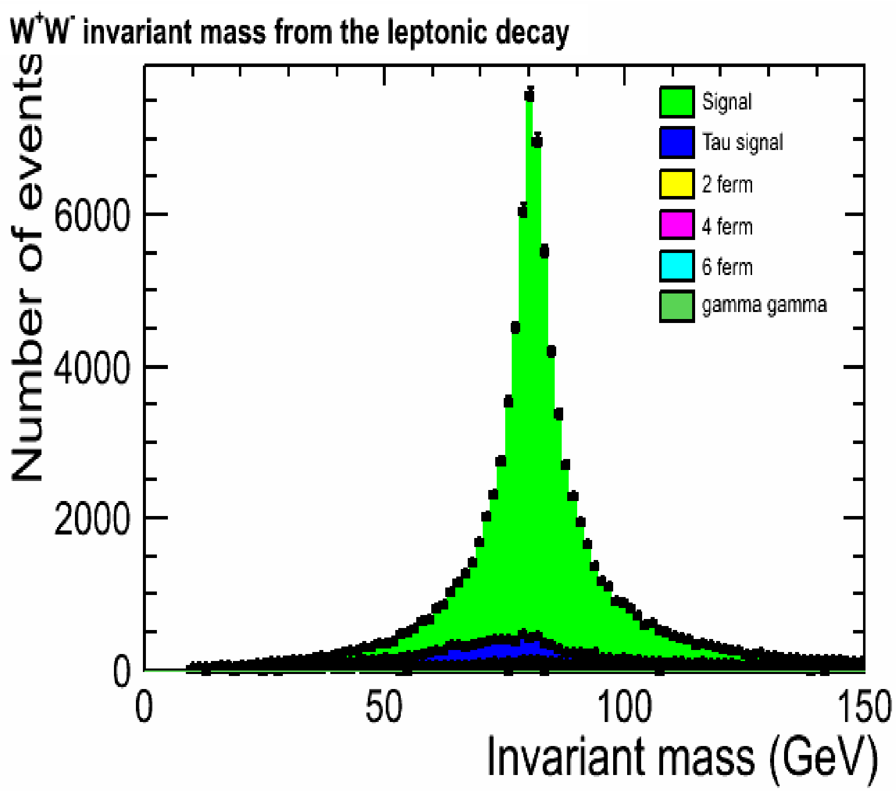
- use fully simulated Monte Carlo files;
- full SM background.

Selection

- Cleanest reconstruction: **semi-leptonic W^+W^- decays towards electron or muon**, $q\,q\,\mu\,\nu$ and $q\,q\,e\,\nu$.
- 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

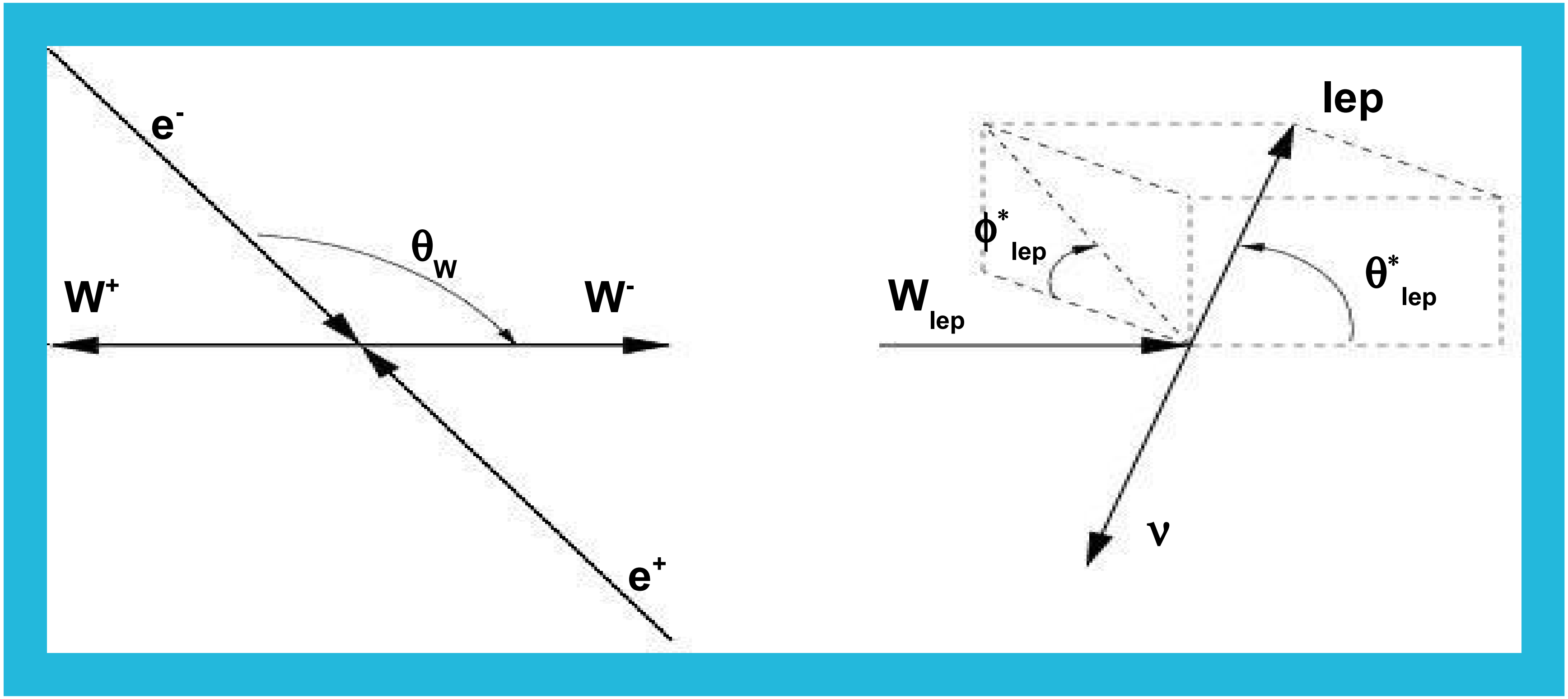




The final results for the selection are:
Signal efficiency ~ 70%.
Non-”tau signal” background contribution ~ 10%.

W Decay Angles

- Sensitive to the TGCs.
- Hadronic decay angles two-fold ambiguity.
- Leptonic decay angles $\boldsymbol{\cos\theta^*_l}$ and $\boldsymbol{\phi^*_l}$ used and to the $\boldsymbol{\cos\theta_W}$ observable.



Measurement

Simulation of the TGC

- O'Mega "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.
- Continuous dependence needed in a fit.
- 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 TGC

- 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:

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

Polarization + TGC Weight

- Also continuous dependence from the polarization needed.

- The weight is derived directly from the properties of the polarization:

$$P = P_R - P_L$$
$$P_R + P_L = 100.$$

- Each helicity combination ++, -+, +-, -- is like a different experiment. The weights can be factorized like:

$$weight = R(\Delta g_1^Z, \Delta\kappa_\gamma, \Delta\lambda_\gamma) * weight(P_{e^+}, P_{e^-}).$$

Angular fit

- 3D Monte Carlo distribution ($\boldsymbol{cos\theta^*_l}$, $\boldsymbol{\phi^*_l}$, $\boldsymbol{cos\theta_W}$).

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

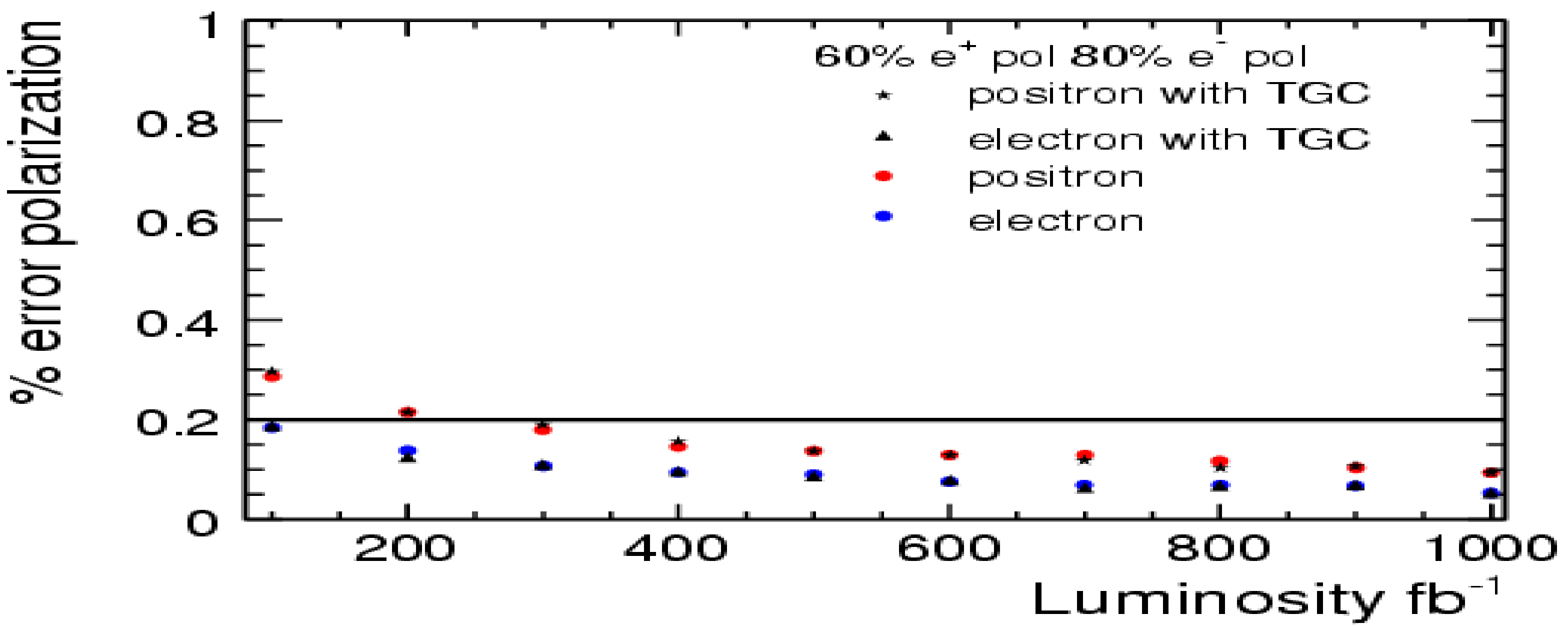
- Assumption: $|+P_{e-}| = |-P_{e-}|$ and $|+P_{e+}| = |-P_{e+}|$ (deviations from polarimeters).

- Data are varied randomly (poissonian).

- Each data sample fitted to the MC template of the ($\boldsymbol{cos\theta^*_l}$, $\boldsymbol{\phi^*_l}$, $\boldsymbol{cos\theta_W}$) distribution.

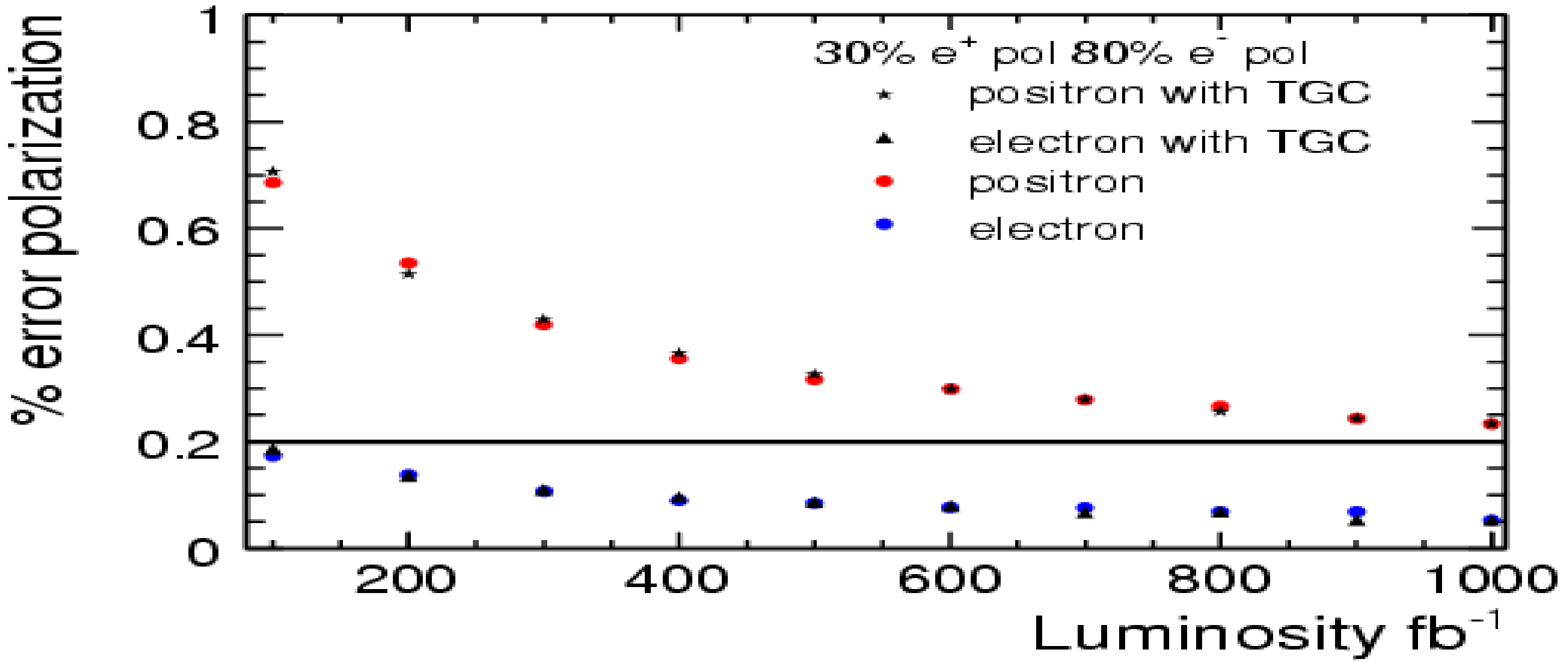
- Fit iterated for several independent data samples: statistical error is the dispersion of the measured fit parameters.

60% positron polarization



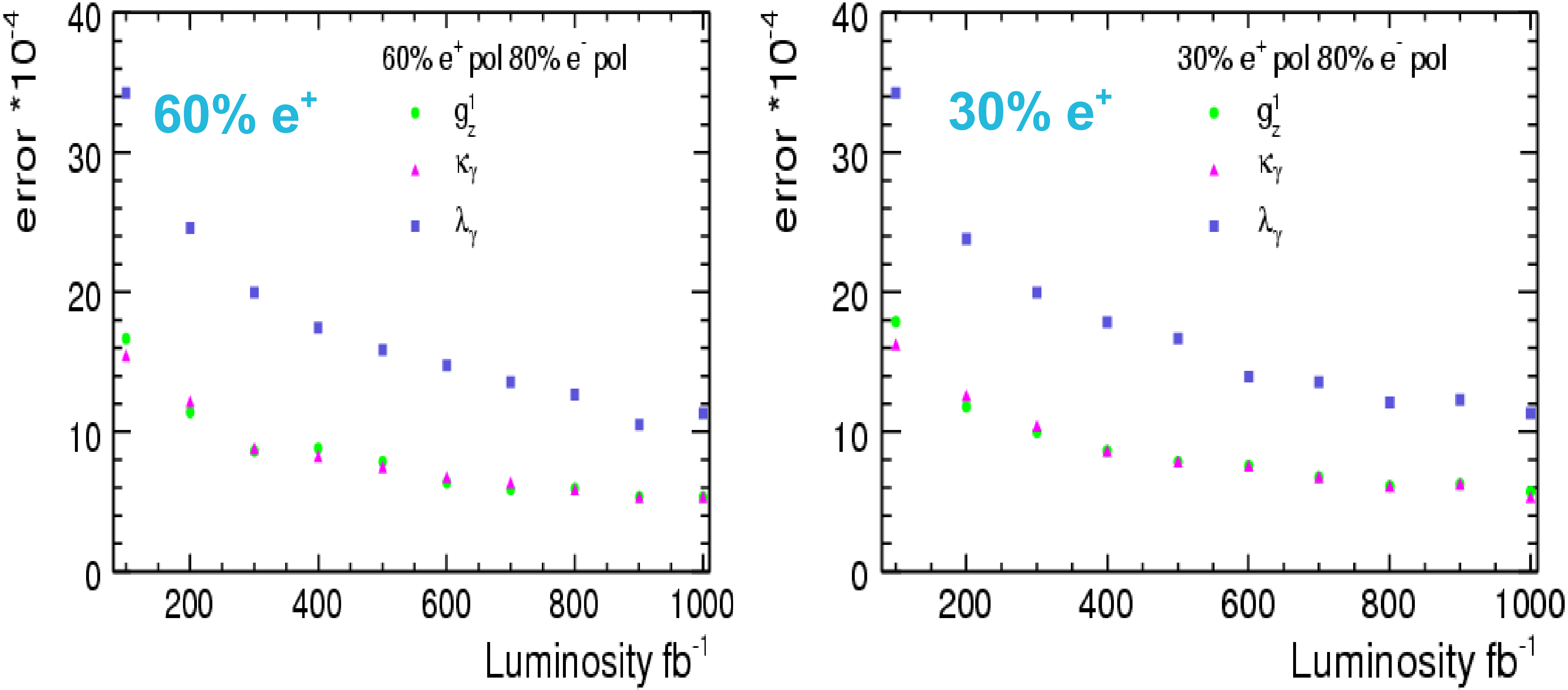
- 250 fb^{-1} of statistics give an error on the e^{-} polarization of ~0.1%, and ~0.2% on the e^{+} one.
- Luminosity equally shared between the four sign combinations of the polarization.
- e^{-} polarization always assumed 80%.
- No loss of sensitivity with the TGCs simultaneous fit.

30% positron polarization



- 500 fb^{-1} of statistics give an error on the e^- polarization of ~0.1%, and ~0.5% on the e^+ one.
- Higher e^+ polarization option more convenient from the polarization measurement point of view.

TGCs result



- Absolute precision on the TGCs.
- TGCs measurement not significantly influenced by the positron polarization choice.

Conclusions

Conclusions

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

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

- The Monte Carlo template fit appears to be promising and it allows to have a direct control over the TGCs.

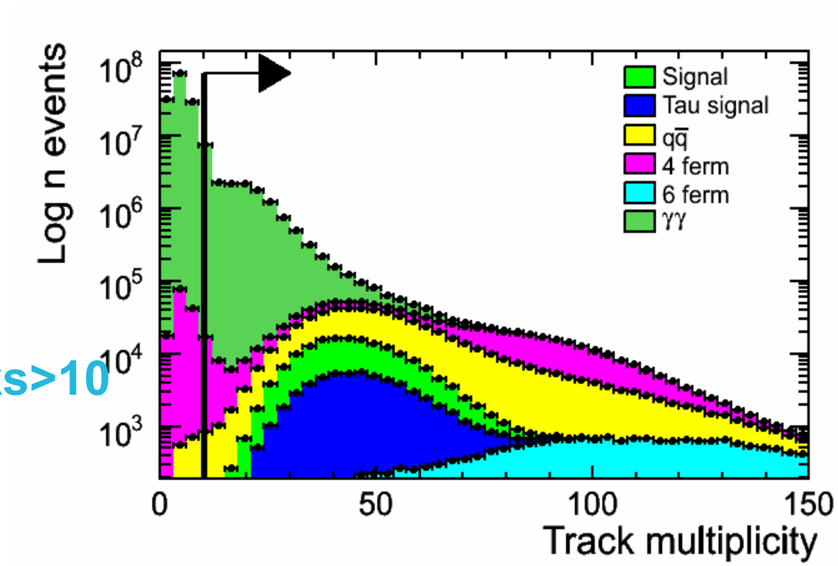
- **LC note** is under final review and covers further topics:
  - Comparison with the **Blondel** scheme;
  - Additional features of the fit technique investigated.
  - **Systematics** study.

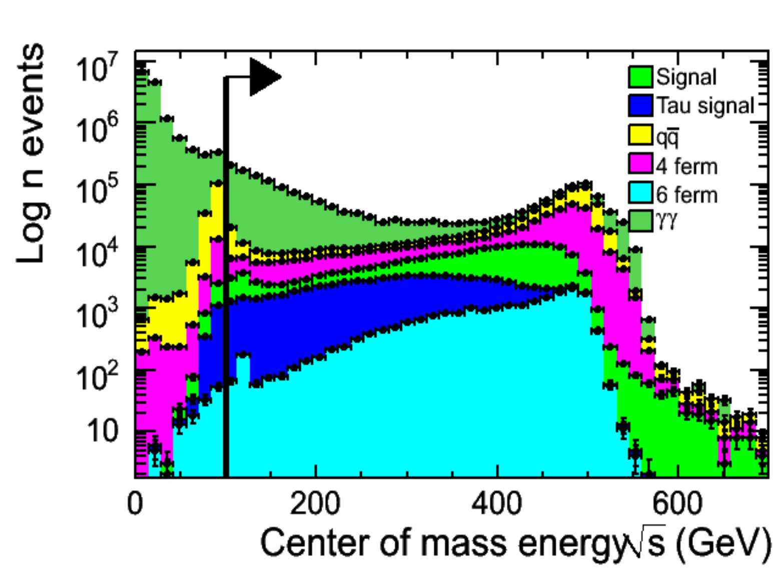
End

Additional slides

Preselection cuts

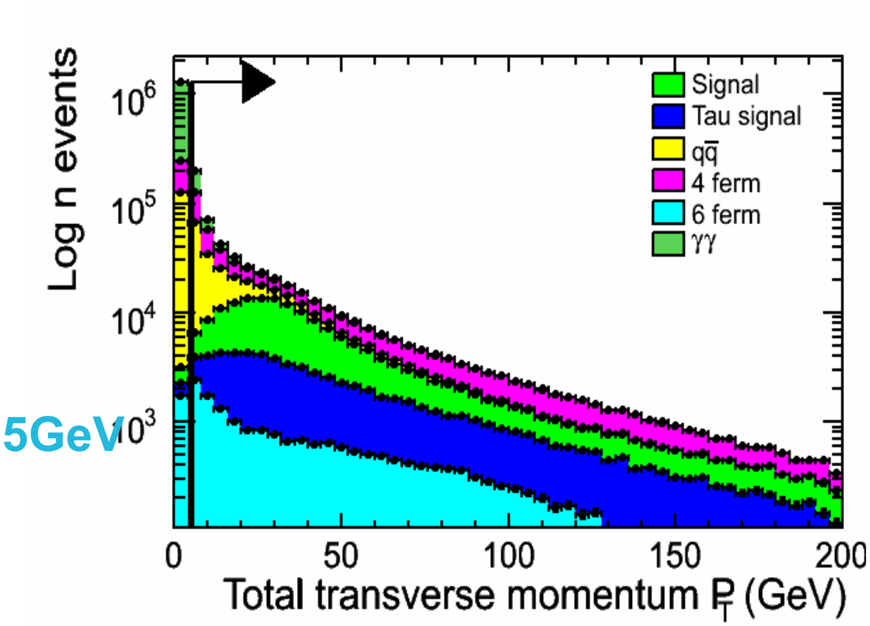
tracks>10

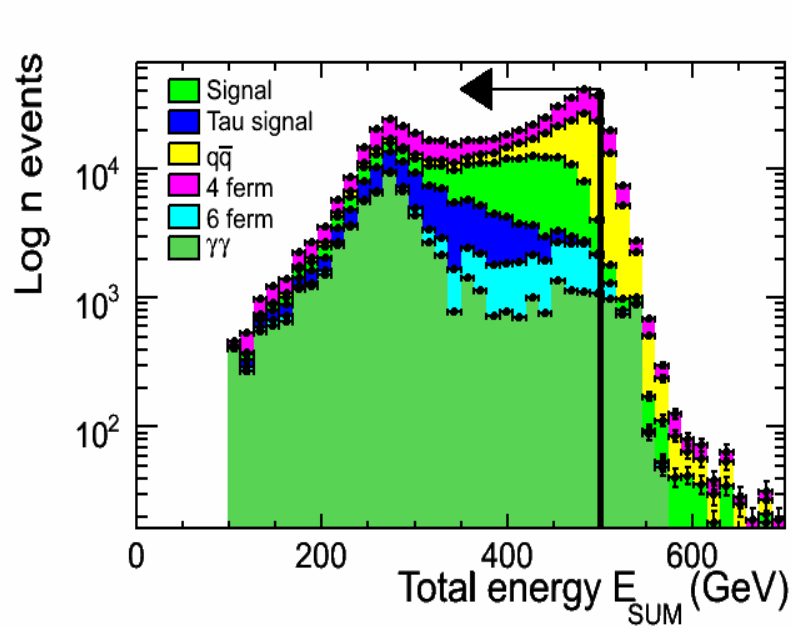




$\sqrt{s}$>100 GeV

P_T>5GeV





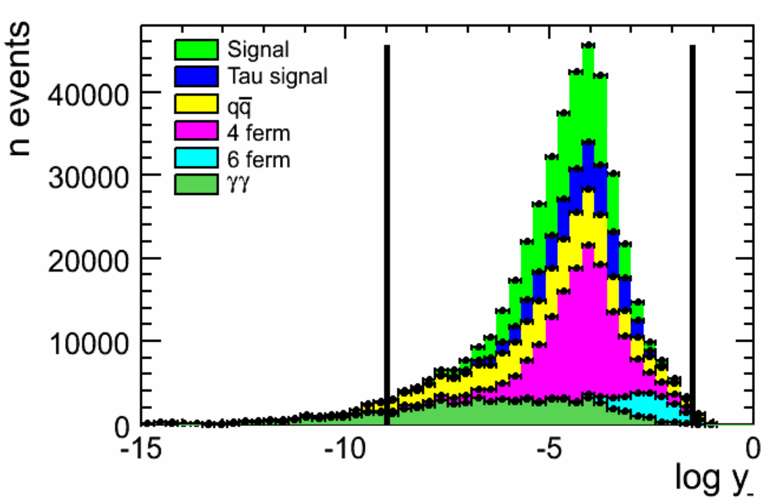
SumE<500 GeV

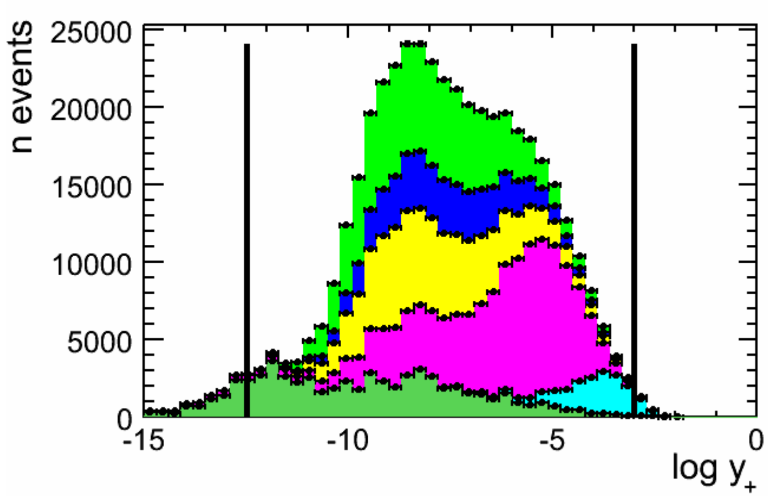
Jet requirements

- We force 3 jets (Durham). Two jets are for the hadronic decay. One jet is the lepton. The jet with lower number of particles is taken as the leptonic jet.

Yminus
-9<<-1.5

Yplus
-12<<-3





First technique: Blondel scheme

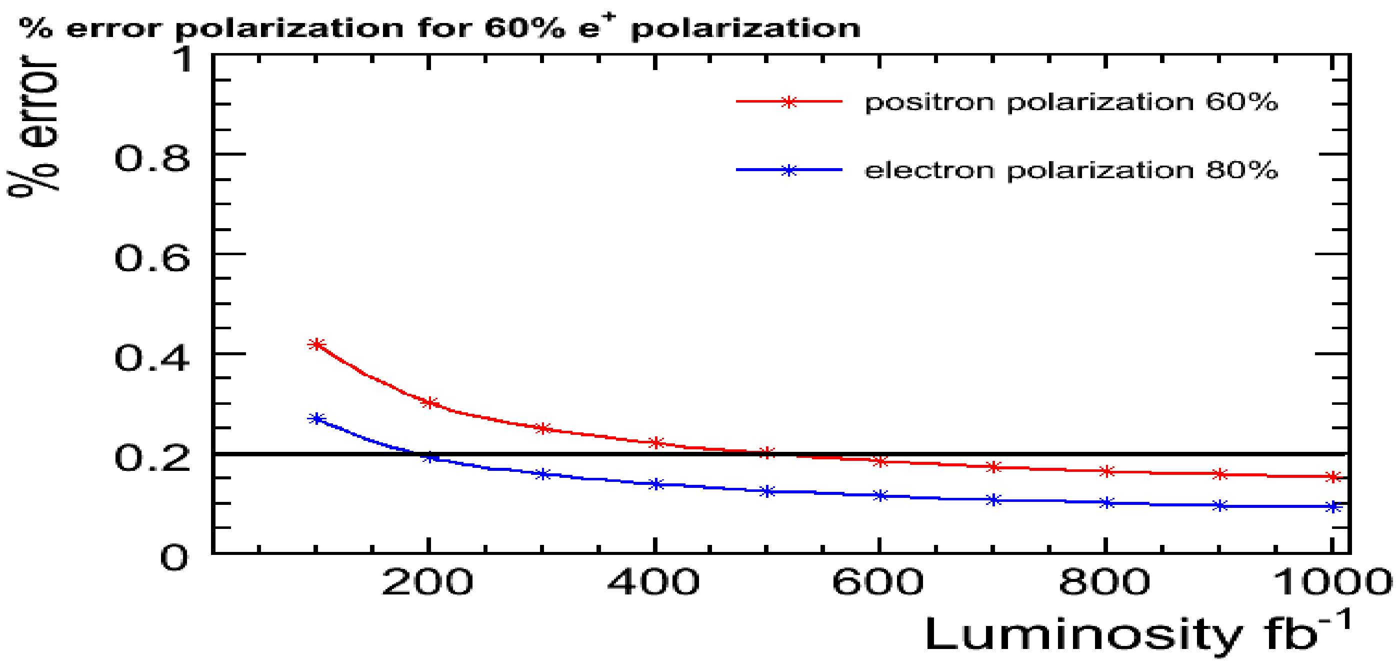
- Needs data to be collected for all the four sign combinations of polarization: ++, --, +- and -+.

- 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:

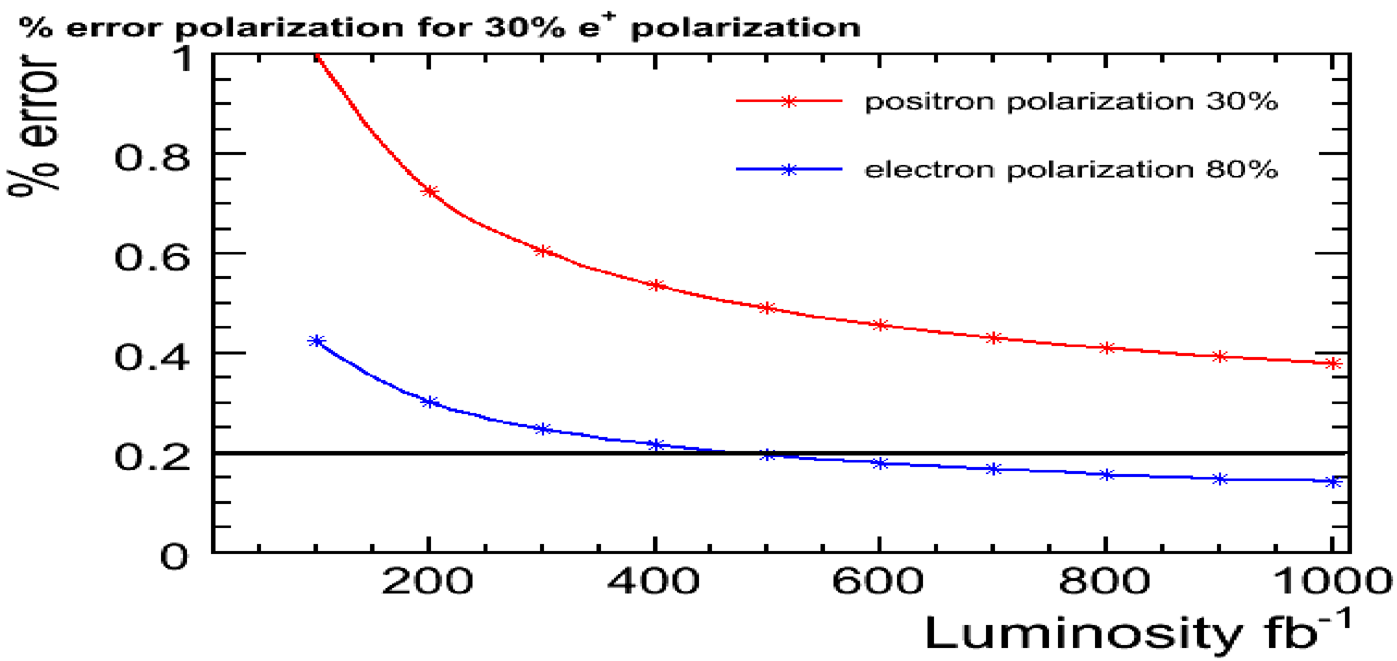
$$|P_{e^\pm}| = \sqrt{\frac{(\sigma_{-+} + \sigma_{+-} - \sigma_{--} - \sigma_{++})(\pm\sigma_{-+} \mp \sigma_{+-} + \sigma_{--} - \sigma_{++})}{(\sigma_{-+} + \sigma_{+-} + \sigma_{--} + \sigma_{++})(\pm\sigma_{-+} \mp \sigma_{+-} - \sigma_{--} + \sigma_{++})}}$$

e^+ polarization 60%



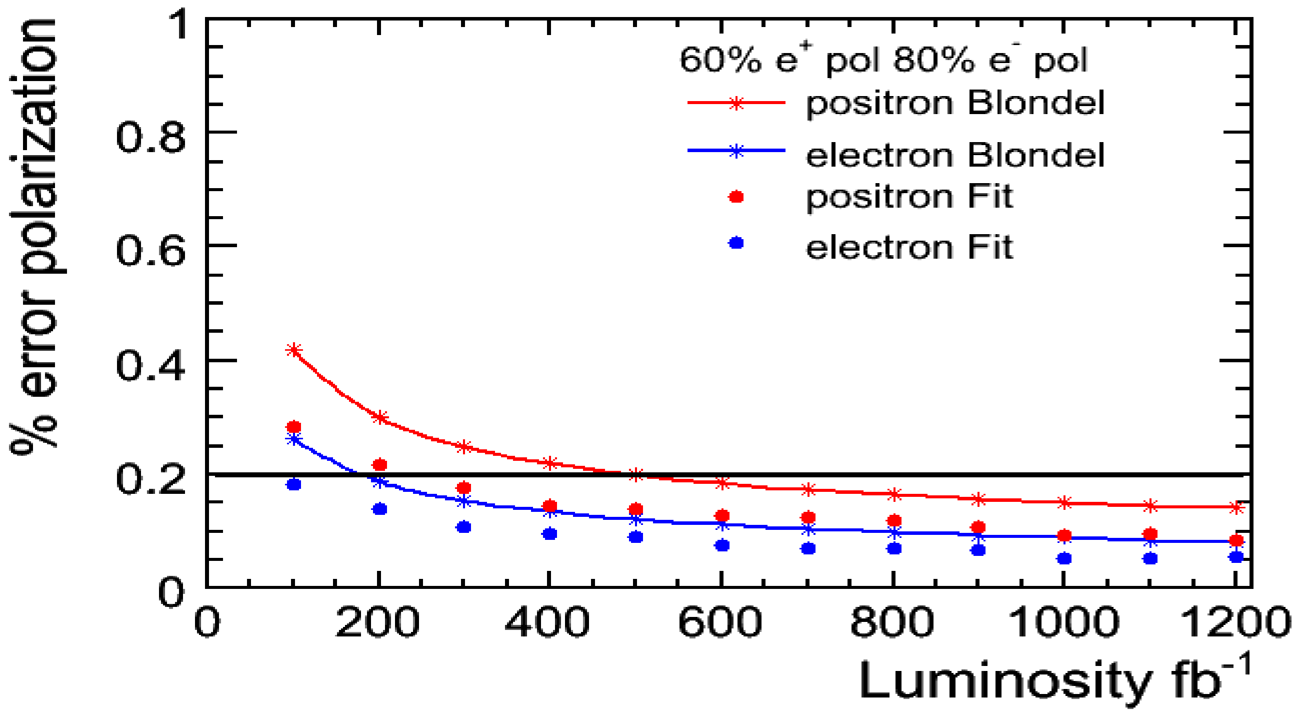
- 500 fb^{-1} of statistics give an error on the e^- polarization of ~0.1%, and ~0.2% on the e^+ one.
- Luminosity equally shared between the four sign combinations of the polarization.
- e^- polarization always assumed 80%.

e^+ polarization 30%



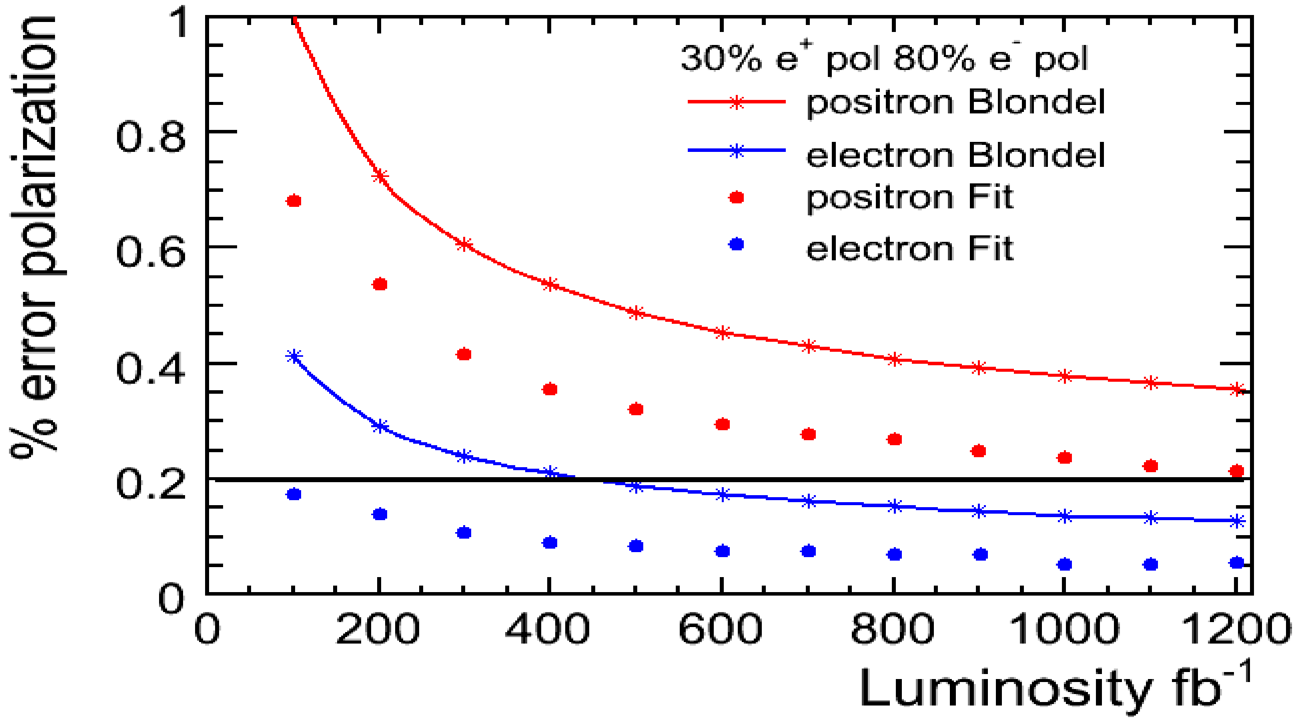
- Up to reasonable luminosities the aimed precision on the e^+ polarization not reached.
- 500 fb^{-1} of statistics give an error on the e^- polarization of ~0.2%, and ~0.5% on the e^+ one.

Case 60% e^+ polarization



The luminosity demand is ~250fb^{-1} (Blondel: 500 fb^{-1}).
Total luminosity is assumed to be equally share between ++, +-, -+ and --.

Case 30% e^+ polarization



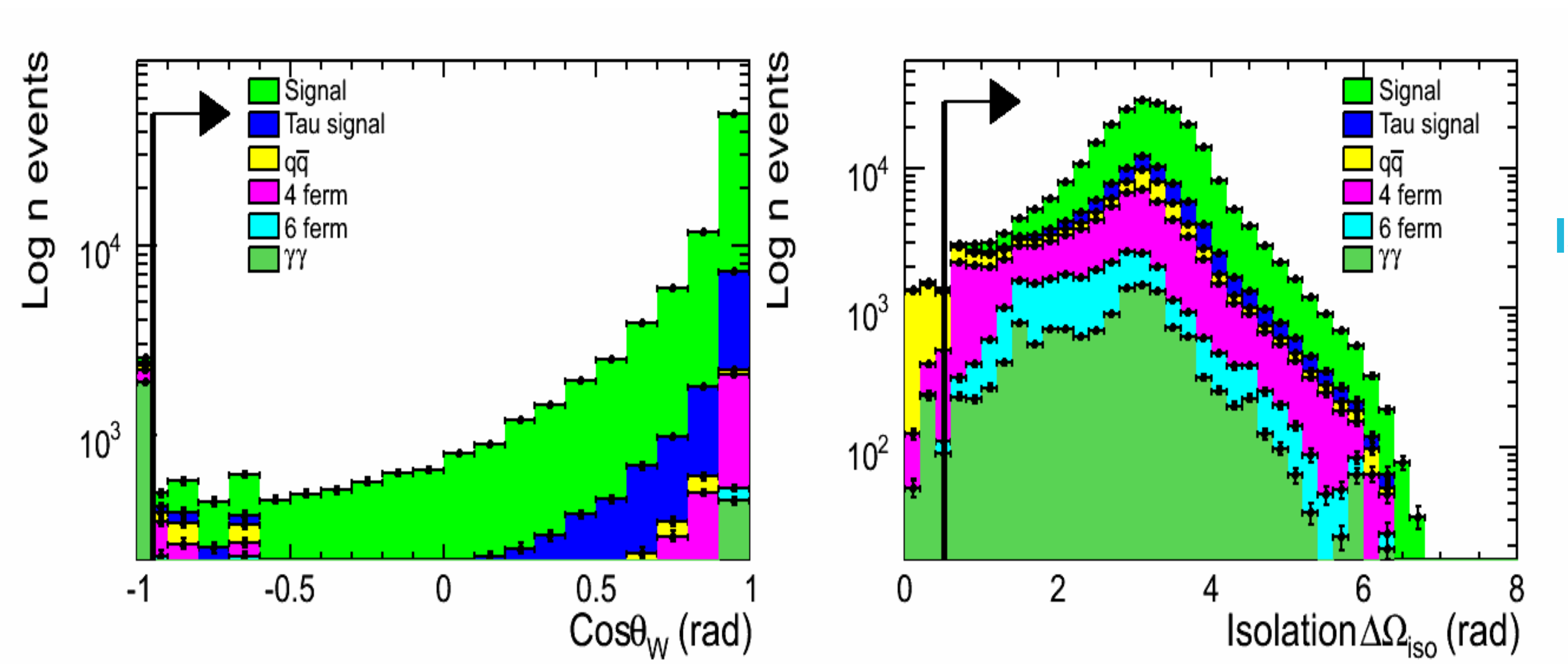
Still non convenient with respect to the 60% case, though large improvement with respect to the Blondel scheme.

Further cuts

- Requirement on the leptonic jet:

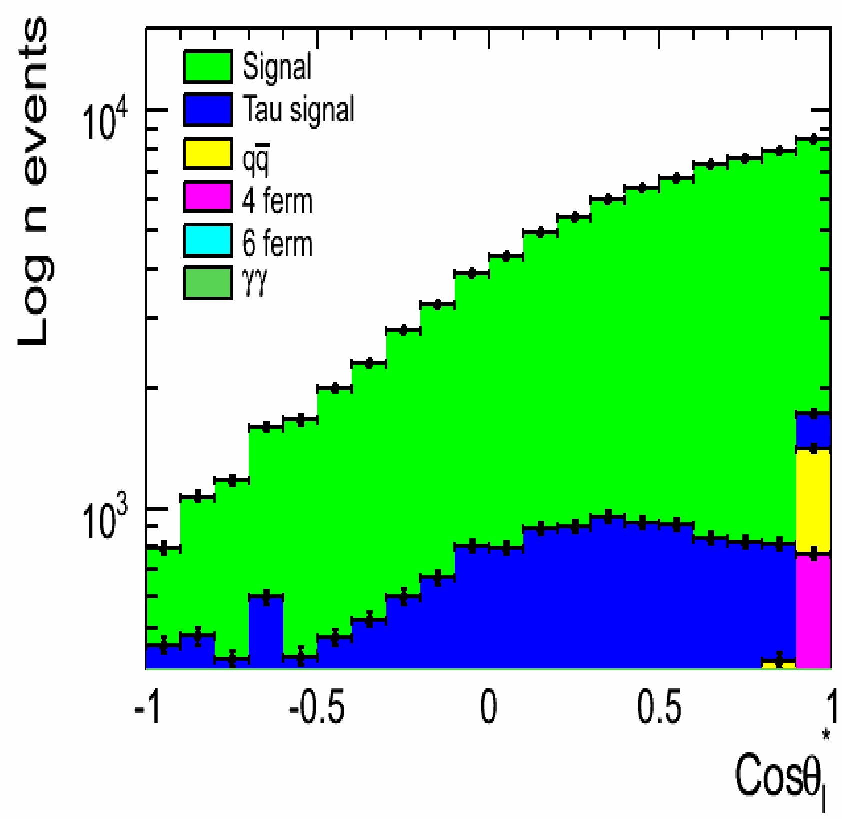
- Isolated (theta-phi isolation > 0.5).
- One track (charged) p_T > 10 GeV.
- Semi-leptonic tau decays suppressed using a discriminating variable.

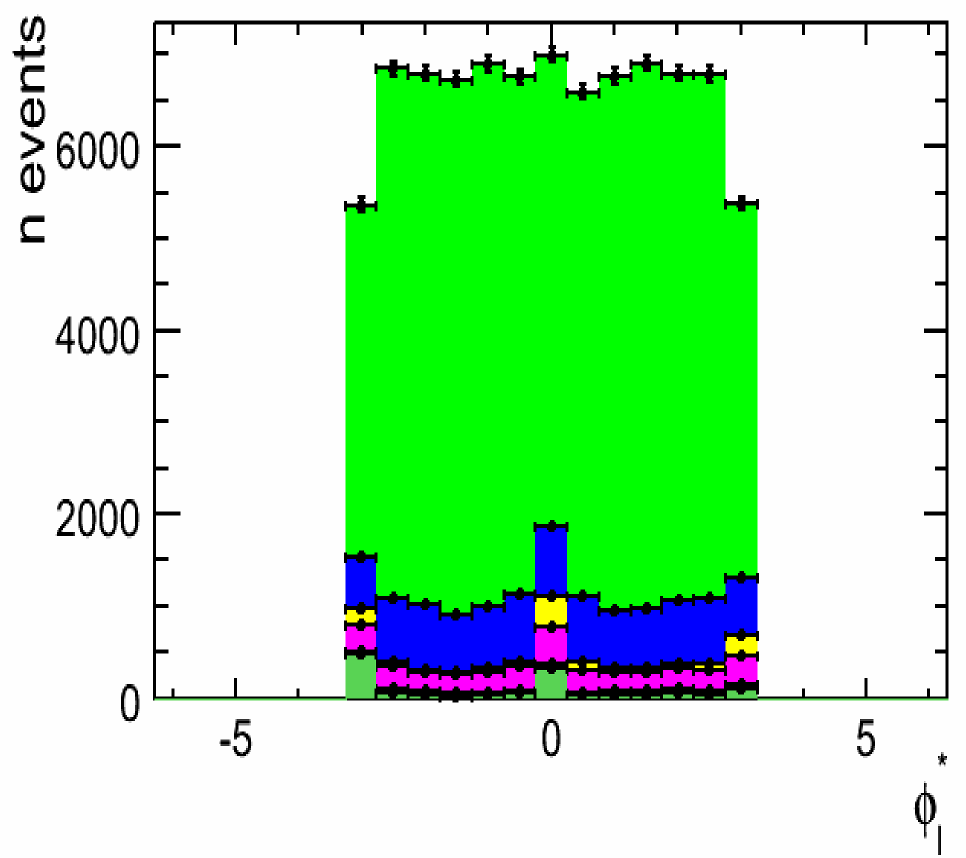
$\cos\theta_W > -0.95$



Isolation cut

Leptonic Decay Angles





W Decay Angles

- Sensitive to the TGCs.
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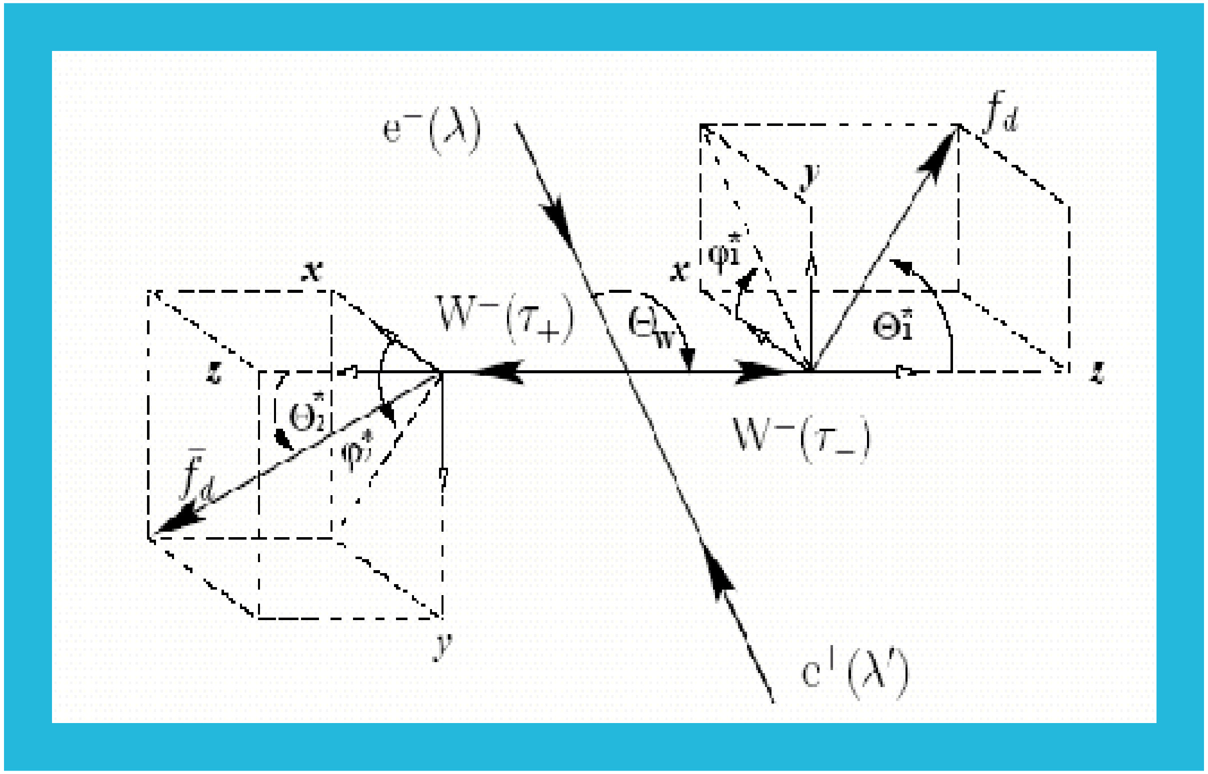
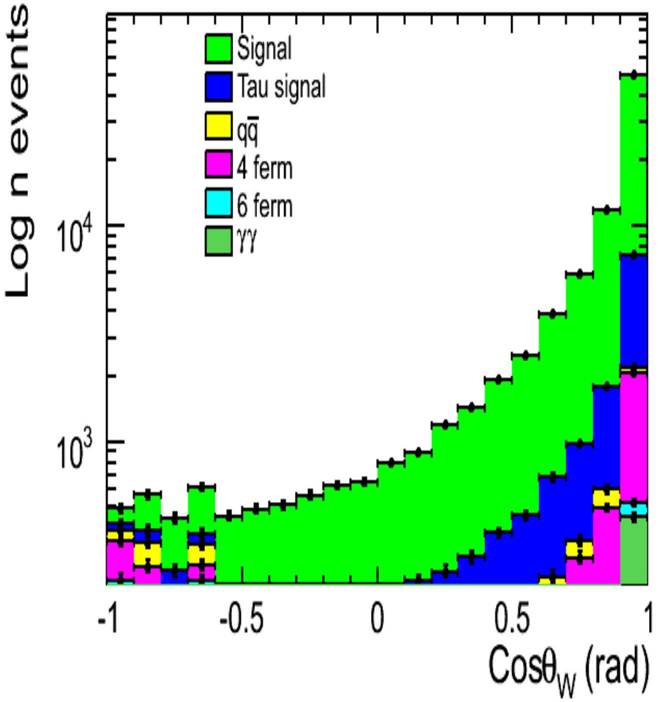
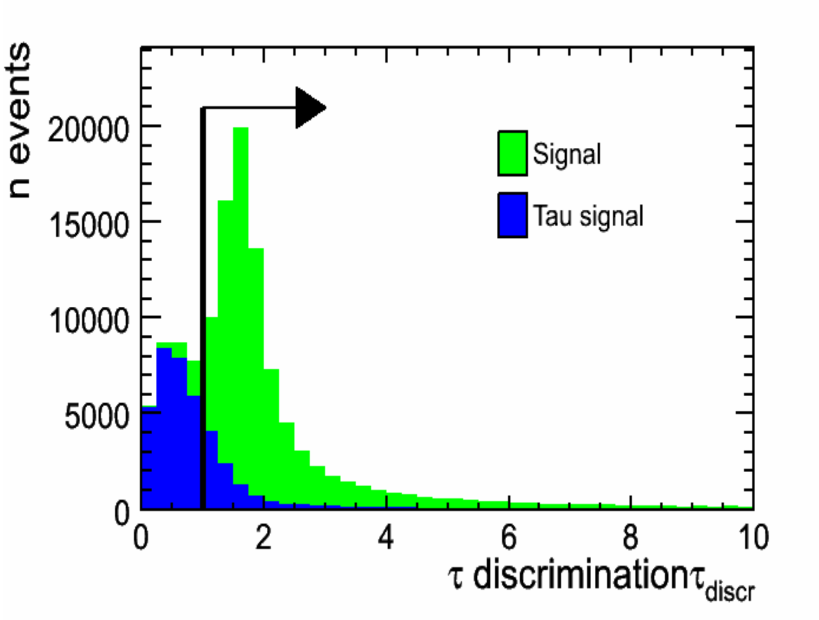




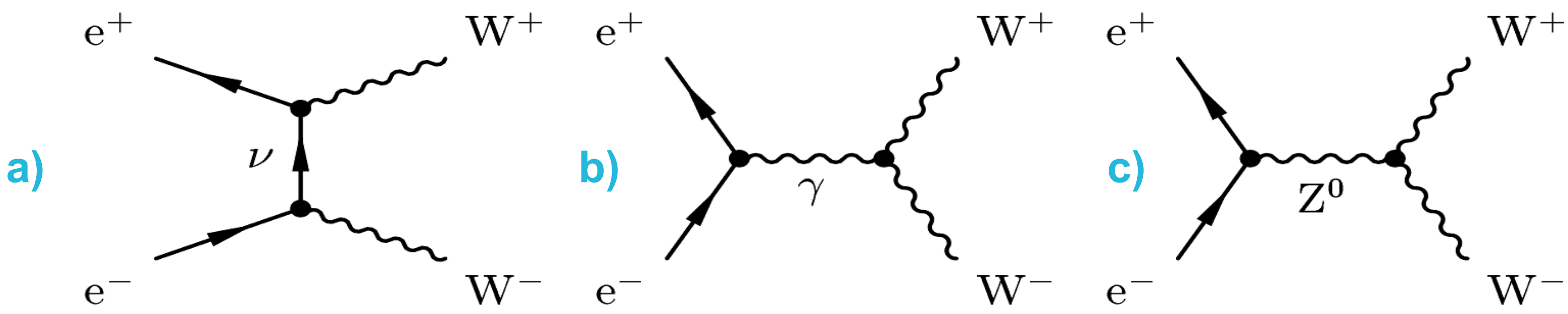
"Tau-signal" suppression

- Semi-leptonic decays towards tau less clean:
  - Further neutrino in the final state from tau decay;
  - Worse charge reconstruction of the lepton;
  - Higher backgrounds.
- Suppression by means of a discriminating variable:



$$\tau_{discr} = \left(\frac{2E_{lep}}{\sqrt{s}}\right)^2 + \left(\frac{m_W^{lep}}{m_W^{true}}\right)^2 < 1.$$

W^+W^- production and polarization

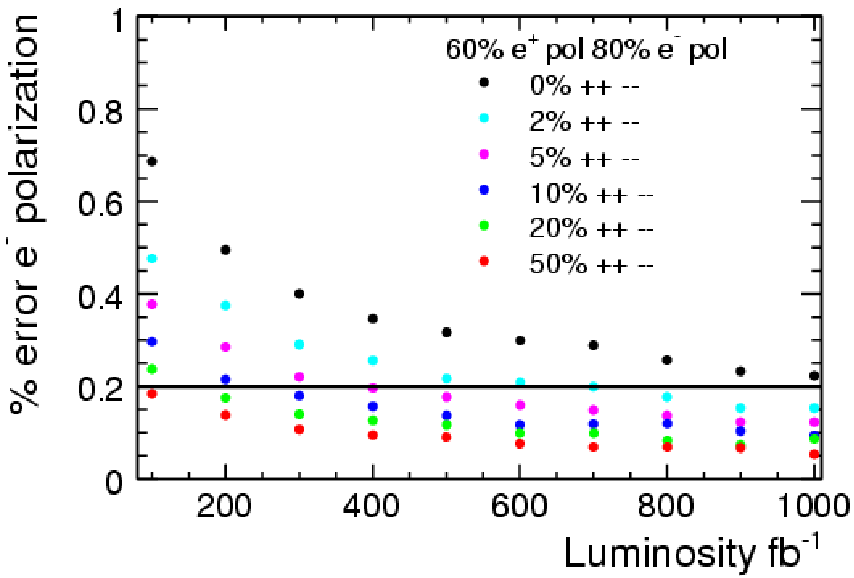


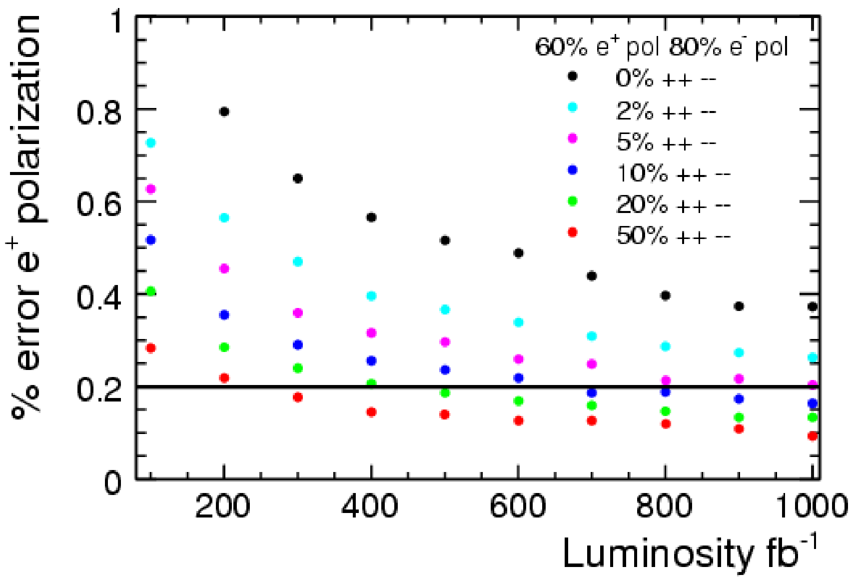
b) c) s-channel: e^+ and e^- must have opposite polarizations, to give the vector boson.

J_z=1 allows vector mediator

a) t-channel: same polarizations for e^+ and e^- are generally allowed. But the W can couple only to e^-_L and e^+_R: so for the W^+W^- production only the combination $e^-_L e^+_R$ is allowed.

Reducing ++ -- combinations





- In the 60% e^+ polarization option room for reducing the time spent on the "less-interesting" physics combinations (++ --).

- 50% → 20% of the luminosity to the ++ -- combinations: ~250fb^{-1} → ~400fb^{-1}.

Correlations

- Fit correlations:

60% e^+ polarization		30% e^+ polarization	
e^-/e^+	-3.54	e^-/e^+	1.92
e^-/tgc1	3.63	e^-/tgc1	9.97
e^-/tgc2	-9.94	e^-/tgc2	0.33
e^-/tgc3	-7.24	e^-/tgc3	-0.76
e^+/tgc1	-5.71	e^+/tgc1	5.23
e^+/tgc2	-3.59	e^+/tgc2	0.40
e^+/tgc3	-2.75	e^+/tgc3	2.63
tgc1/tgc2	67.70	tgc1/tgc2	73.34
tgc1/tgc3	23.71	tgc1/tgc3	19.77
tgc3/tgc2	16.36	tgc3/tgc2	19.57

tgc1=g^1_Z tgc2=κ_γ tgc3=λ_γ

- The correlations between polarizations and TGCs are negligible. Higher correlations between the TGCs, but still in an acceptable range.