Precision top physics at the LC

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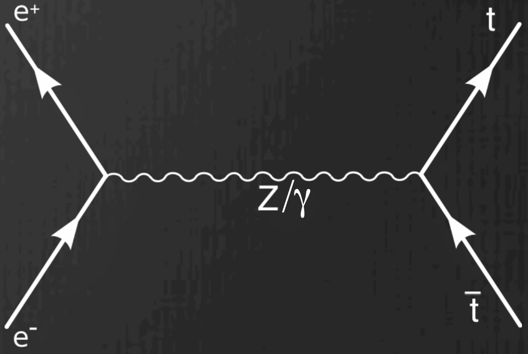
Theory

- The top quark is the heaviest elementary particle
- The top decays before hadronization: correlation between angular distribution of the decay products and the spin of the top → helicity angles
- The aim of this study is to measure the couplings of the top quark with γ and Z boson via the precision measurement of some observables

$$\Gamma^{\mu}_{t\bar{t}(\gamma,Z)} = ie\left[\gamma^{\mu}\left[F^{\gamma,Z}_{1V}+F^{\gamma,Z}_{1A}\gamma^{5}\right]+\frac{(p_t-p_{\bar{t}})^{\mu}}{2m_t}\left[F^{\gamma,Z}_{2V}+F^{\gamma,Z}_{2A}\gamma^{5}\right]\right]$$



Theory

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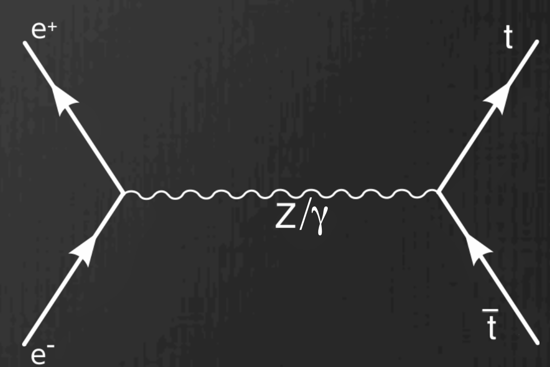
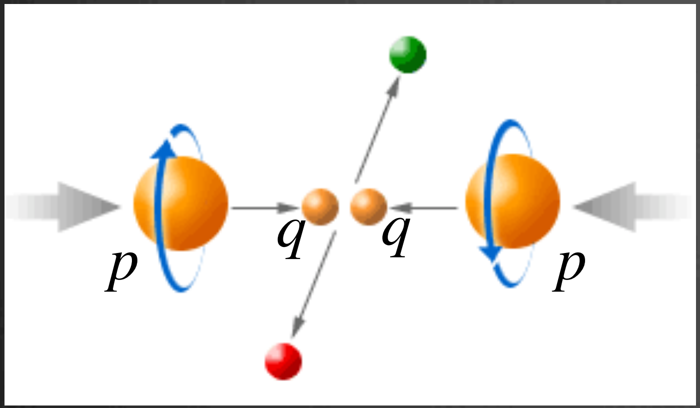
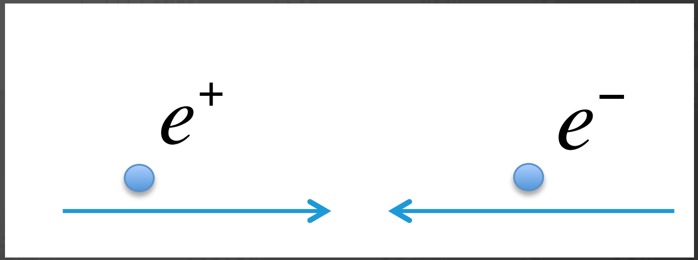


Top couplings with γ/Z

Hadron collider or Linear Collider e^+e^-?



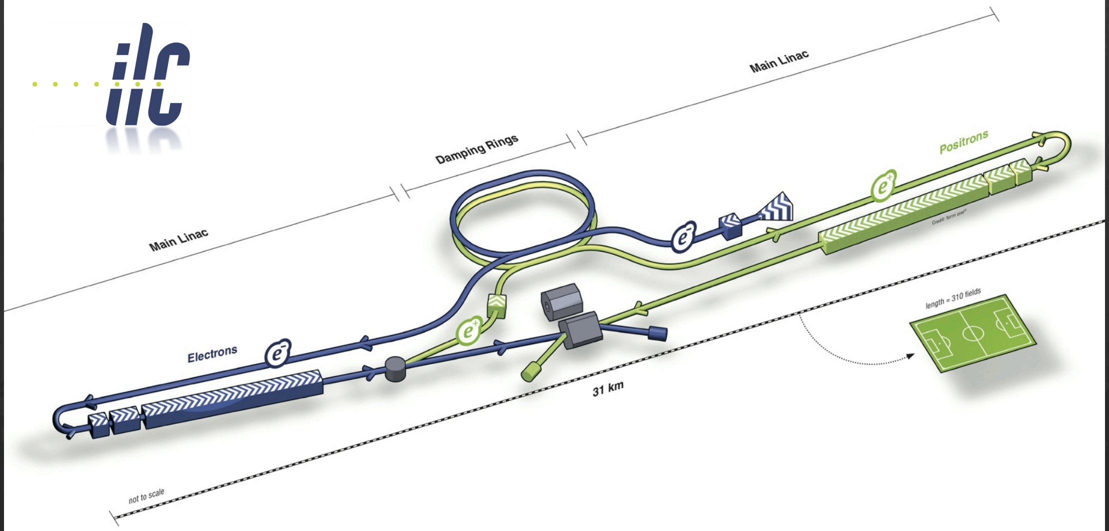


- Protons are **composite**
- **Unknown √s** for partons
- Partons are not polarised
- *Protons*: **Strong Interaction** → Lot of jets. Significant background
- **High energy collisions**

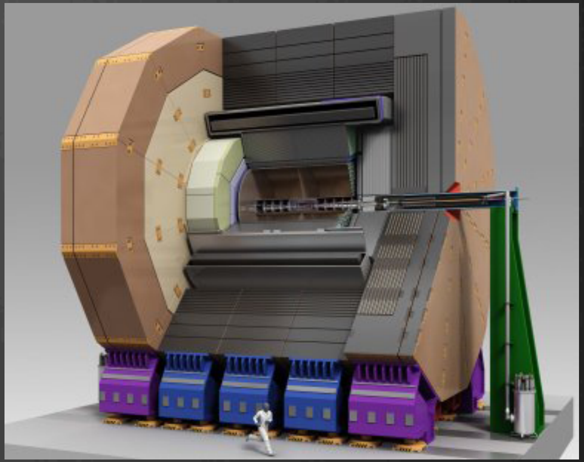
- Electrons and positrons are **pointlike particles**
- **Known √s** → 500 GeV in ILC
- Beams can be polarised
- *Electrons*: **EW Interaction** → Negligible bakcground
- **High precision results**

International Linear Collider (ILC)

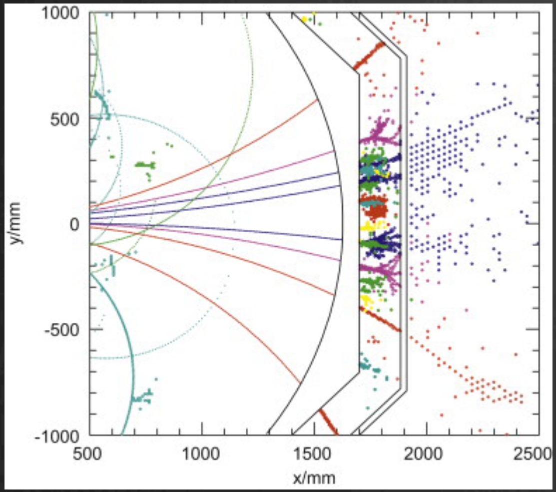
- This study is done in the case of the ILC → **e^+e^- collider**
- The center-of-mass energy: **$\sqrt{s}$ = 500 GeV**
- Luminosity: **$\mathcal{L}$ = 500 fb^{-1}** = 5 x10^8 pb^{-1} (estimated for 4 years of running)
- Beams are **polarised**: P(e^-) ≈ ± 80 % P(e^+) ≈ ± 30 %. This allows to double our observables using left-handed and right-handed polarisations



The International Large Detector (ILD)



- The ILD is one detector for the ILC
- The detectors are optimized for Particle Flow Algorithm



Detailed Geant4 model and sophisticated reconstruction software allow realistic estimates of performance

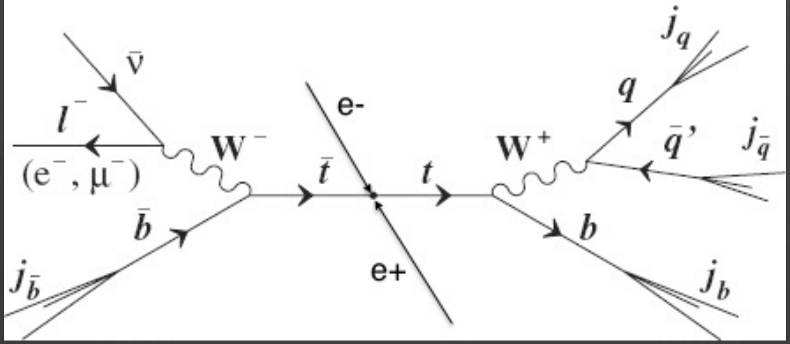
- Performance:
  - Vertex $\sigma(d_0) = \left[5 \oplus \frac{1}{p_T} \frac{10}{\sqrt{\sin\theta}} \right] \mu m$
  - Tracking $\sigma(p_T)/p_T \approx 2\cdot 10^{-5} p_T \oplus a$
    $a = 1\cdot 10^{-4}$ (multiple scattering)
  - Calorimetry $\sigma_E / E \approx \frac{30\%}{\sqrt{E}}$

E and p_T in GeV

Analysis

- The analysis is done on the events where one of the tops has a semi-leptonic decay:

$$t\bar{t} \longrightarrow (bW)(bW) \longrightarrow (bqq)(bl\nu)$$



- We use the charge of the lepton to know the charge of the top
- The full simulation is done with ILD detector (Mokka + Whizard software)
- The reconstruction is based on the Particle Flow Algorithm (Pandora) and has been done recently with Marlin on the data samples for the DBD!

Observables

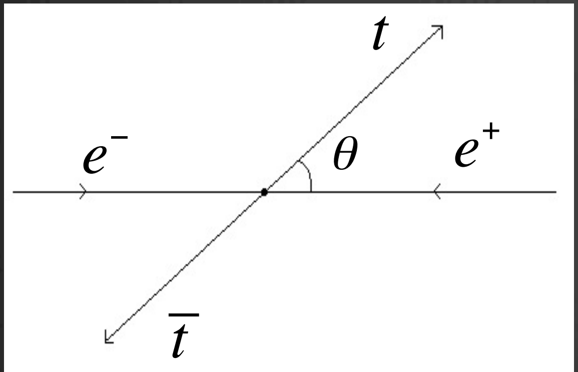
- Total cross section (σ)
- The Forward-Backward Asymmetry (A_{FB})
- Helicity angle (θ_{hel})

A_{FB}

- The Forward-Backward Asymmetry

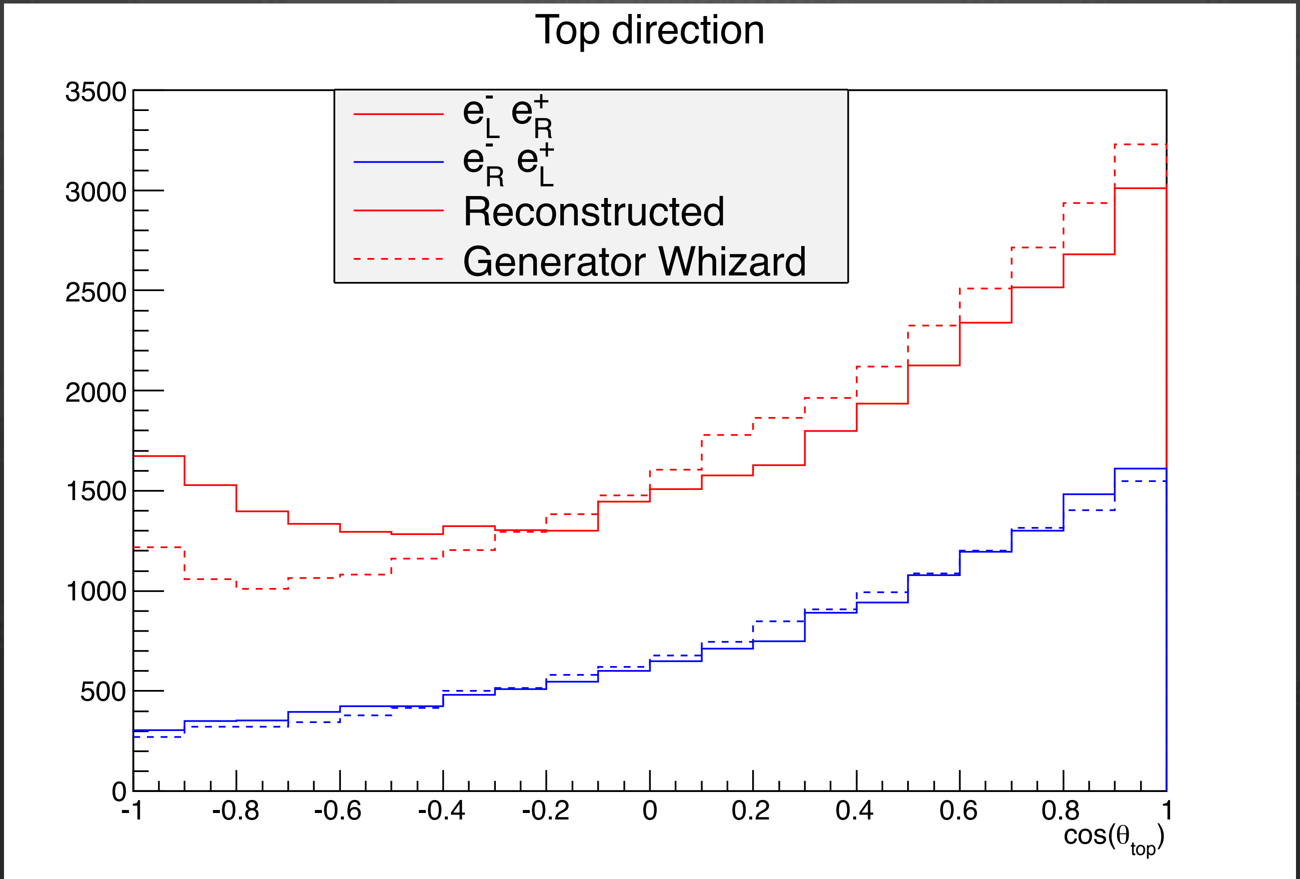
$$A_{FB} = \frac{N_{top}(\cos\theta > 0) - N_{top}(\cos\theta < 0)}{N_{top}(\cos\theta > 0) + N_{top}(\cos\theta < 0)}$$

$$\boxed{-1 < A_{FB} < 1}$$



- The sign of the top is the one of the lepton
- For $\bar{t}$ we change θ to $\theta + \pi$

Results for A_{FB}



We can see a clear migration effect for left-handed electrons

Where does this migration come from?

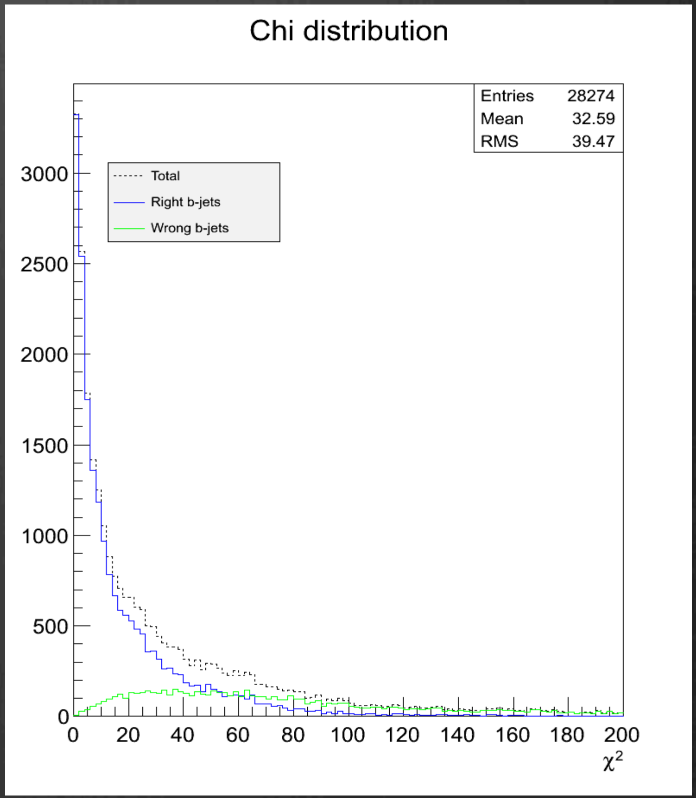
- There are two ways to reconstruct the top:
  - $t_1 = W + b_1$
  - $t_2 = W + b_2$
- As we don't know the sign of the reconstructed b-jet, about 30% of the times we combine the W with the wrong b-jet to create the top quark.
- This gives a wrong direction of the reconstructed top and produce the migration effect.

How to cure migration? **χ^2 strategy**

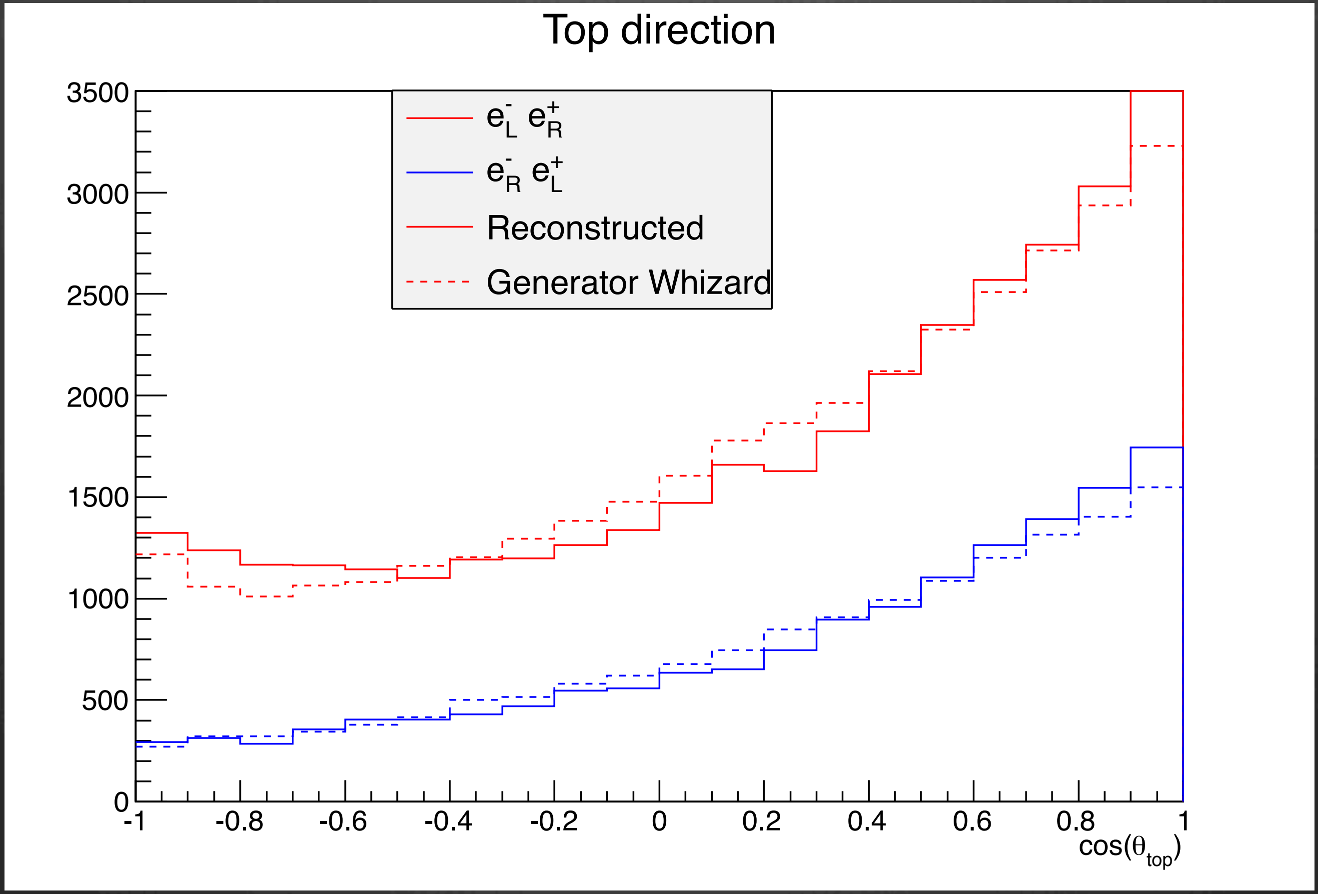
$$\chi^2 = \left(\frac{M_{top} - 174}{\sigma_{Mtop}}\right)^2 + \left(\frac{E_t - 250}{\sigma_{Etop}}\right)^2 + \left(\frac{E_b^* - 68}{\sigma_{E_b^*}}\right)^2 + \left(\frac{cos\theta_{bW} - 0.23}{\sigma_{cos\theta_{bW}}}\right)^2$$

- If we cut on χ^2 we reduce the number of wrong b-jets
- No χ^2 cut:
  - Efficiency: 70%
  - *A_{FB}(reco) = 21% / A_{FB}(true) = 31,7%
- $\chi^2 < 30$:
  - Efficiency: 38%
  - *A_{FB}(reco) = 30,7% / A_{FB}(true) = 31,7%

For left-handed electrons



Final results for A_{FB}

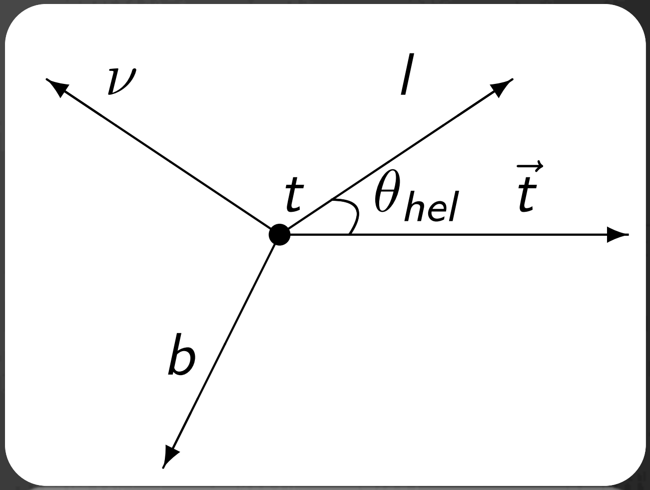


The χ^2 cut remove the migration effect for left-handed electrons

Helicity angle (θ_{hel})

- In the rest frame of the top, θ_{hel} is the angle between the initial direction of the top and the lepton.

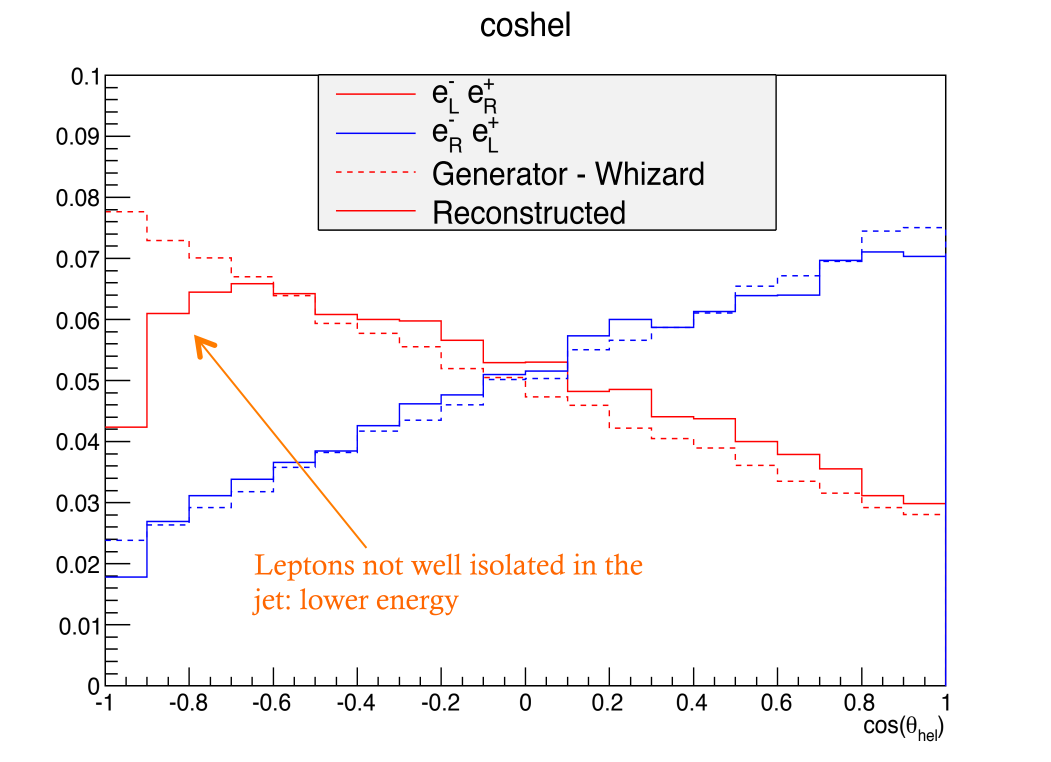
- We mesure the momentum of the top and then we make a Lorentz transform to the top rest frame to obtain $\cos\theta_{hel}$



$\cos\theta_{hel}$ distribution

- The slope (λ_t) of the distribution gives the fraction of t_L and t_R in the sample.

$$\frac{1}{\Gamma}\frac{d\Gamma}{dcos\theta_{hel}} = \frac{1+\lambda_t cos\theta_{hel}}{2}$$
$$\lambda_t = 1\ for\ t_R \quad \lambda_t = -1\ for\ t_L$$



- On a large part of the range the distribution is more robust to ambiguities, even without χ^2 cut

Extraction of the Physics

- We have 2 polarisations
  - 1) $P(e^-) = +80\% \quad P(e^+) = -30\%$
  - 2) $P(e^-) = -80\% \quad P(e^+) = +30\%$
- So, we have 6 observables

$$\begin{array}{llll} \sigma(+) & A_{FB}(+) & \lambda_{hel}(+) & (+ = e_R^-) \\ \sigma(-) & A_{FB}(-) & \lambda_{hel}(-) & (- = e_L^-) \end{array}$$

- With these 6 observables, we can obtain the following 5 couplings of the top quark

$$\left.\begin{array}{llll} \sigma(+) & A_{FB}(+) & \lambda_{hel}(+) & (+ = e_R^-) \\ \sigma(-) & A_{FB}(-) & \lambda_{hel}(-) & (- = e_L^-) \end{array}\right\} \Rightarrow \left\{ \begin{array}{ccc} F_{1V}^{\gamma} & * & F_{2V}^{\gamma} \\ F_{1V}^{Z} & F_{1A}^{Z} & F_{2V}^{Z} \end{array} \right\}$$

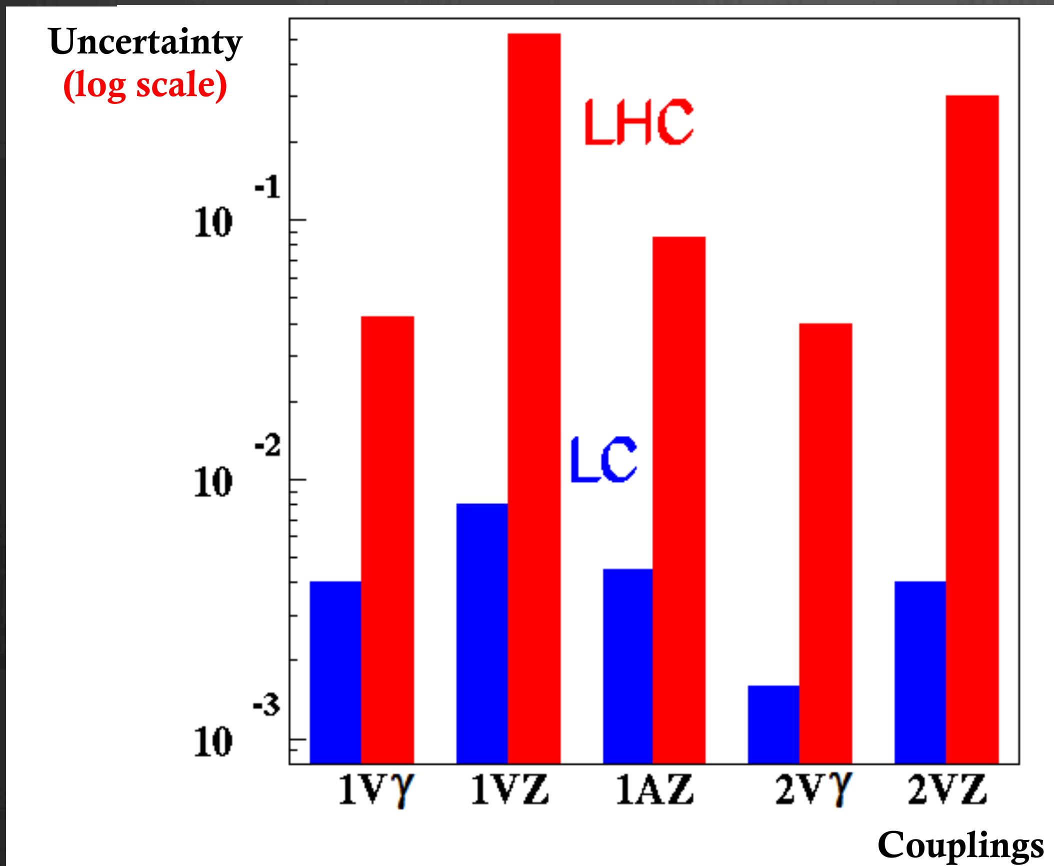
* $F_{1A}^{\gamma} = 0$ always because of the gauge invariance

Summary of the results

Observables	$e^-_L e^+_R$	$e^-_R e^+_L$
σ(fb)	964 ± 2	489.0 ± 1.5
A_{FB}	0.307 ± 0.003	0.447 ± 0.004
λ_{hel}	-0.45 ± 0.008	0.58 ± 0.0012

Couplings	SM Value	LHC 300 fb-1	e+e- this study
ΔF^{γ}_{1V}	-0.66	+0.043 -0.041	± 0.004
ΔF^{Z}_{1V}	0.23	+0.34 -0.72	±0.008
ΔF^{Z}_{1A}	0.59	+.079 -0.091	±0.0045
F^{γ}_{2V} F^{Z}_{2V}	0.015 0.018	±0.04 ±0.3	±0.0016 ±0.0040

LAL/IFIC preliminary results



Assumptions

LC (preliminary)
$\sqrt{s}$ = 500 GeV, L = 500/fb
P(e^-) = 80%, P(e^+)=30%

LHC (hep-ph/0601112)
14 TeV, 300/fb

Preliminary estimation of the precision we can reach

$$\Gamma^{\mu}_{t\bar{t}(\gamma,Z)} = ie\left[\gamma^{\mu}\left(F^{\gamma,Z}_{1V} + F^{\gamma,Z}_{1A}\gamma^{5}\right) + \frac{(p_t - p_{\bar{t}})^{\mu}}{2m_t}\left(F^{\gamma,Z}_{2V} + F^{\gamma,Z}_{2A}\gamma^{5}\right)\right]$$

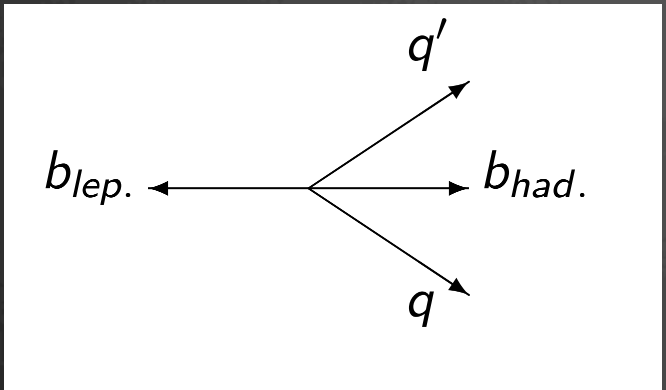
Conclusions

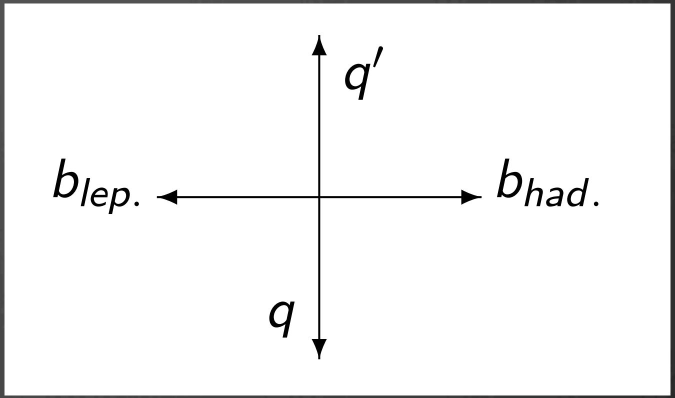
- Three observables are of particular interest: σ, A_{FB} and θ_{hel}
- For A_{FB} the migrations are understood and can be removed by a cut on χ^2
- The helicity distribution is studied and seems more robust to probe new physics
- Polarization allows to disentangle γ and Z couplings
- LC reaches accuracies one or two orders of magnitud better than LHC
- The final results will be included in the DBD of ILC (coordinated by M.Peskin)
  - DBD: Detailed Baseline Design (first draft will be presented in early 2013)

Thanks for your attention

BACKUP SLIDES

Where does this migration comes from?

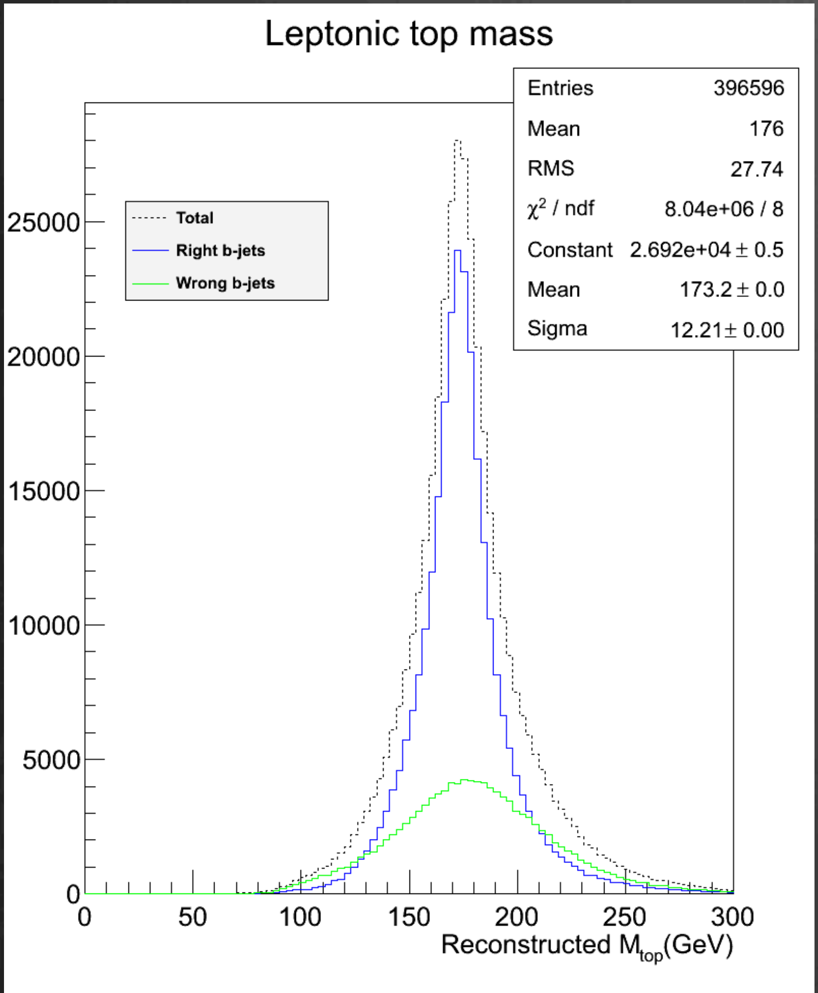


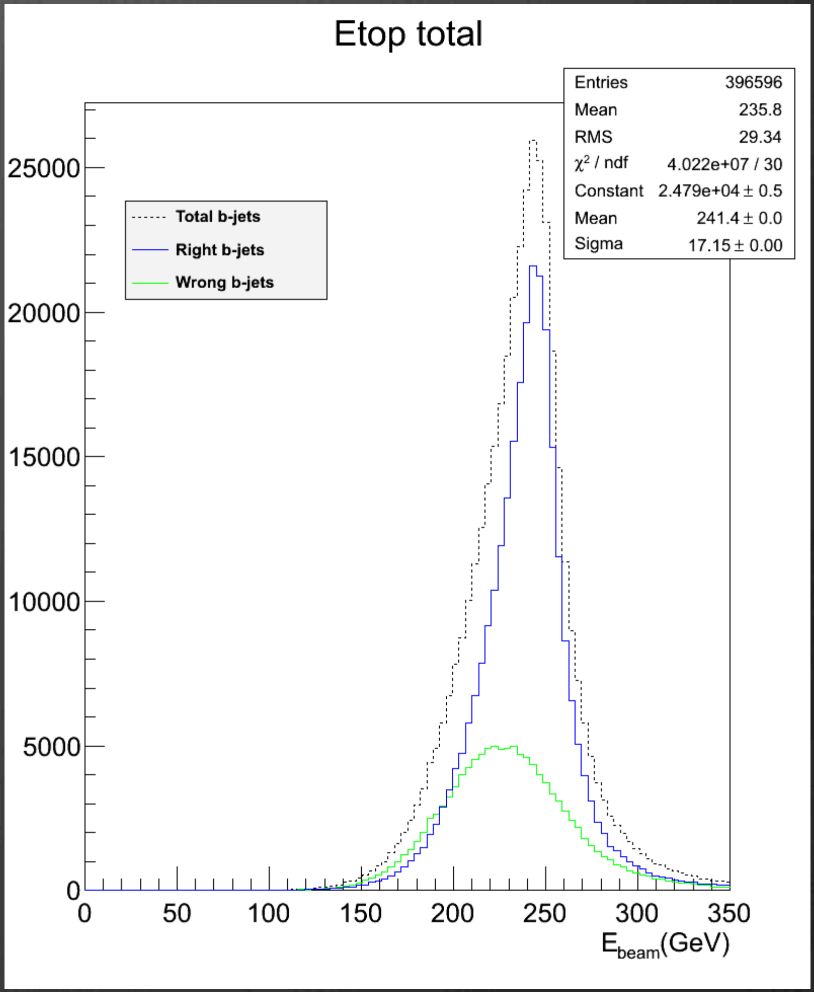


- Right-handed electron beam:
  - The W is emitted into the flight direction of the top togheter with a soft b
- In the case is the W is easily combine to good b to reconstruct the top

- Left-handed electron beam:
  - The W is emitted almost at rest togheter with a hard b
- In the case it is harder to combine the W and the good b to reconstruct the top

Distributions. σ(-) (e^-_L, e^+_R)





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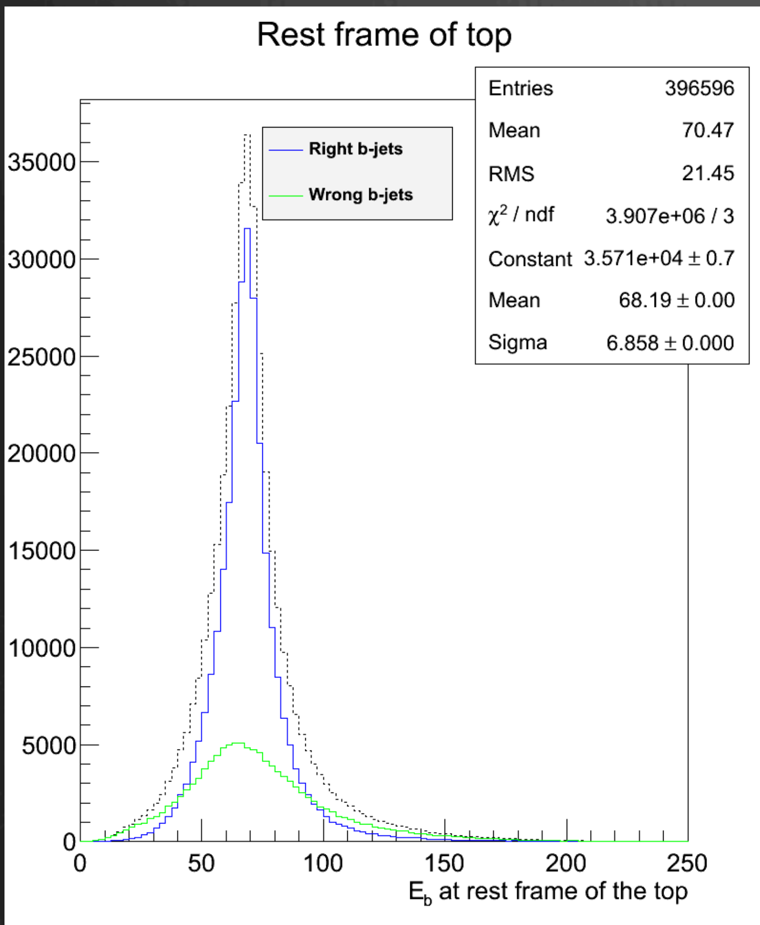
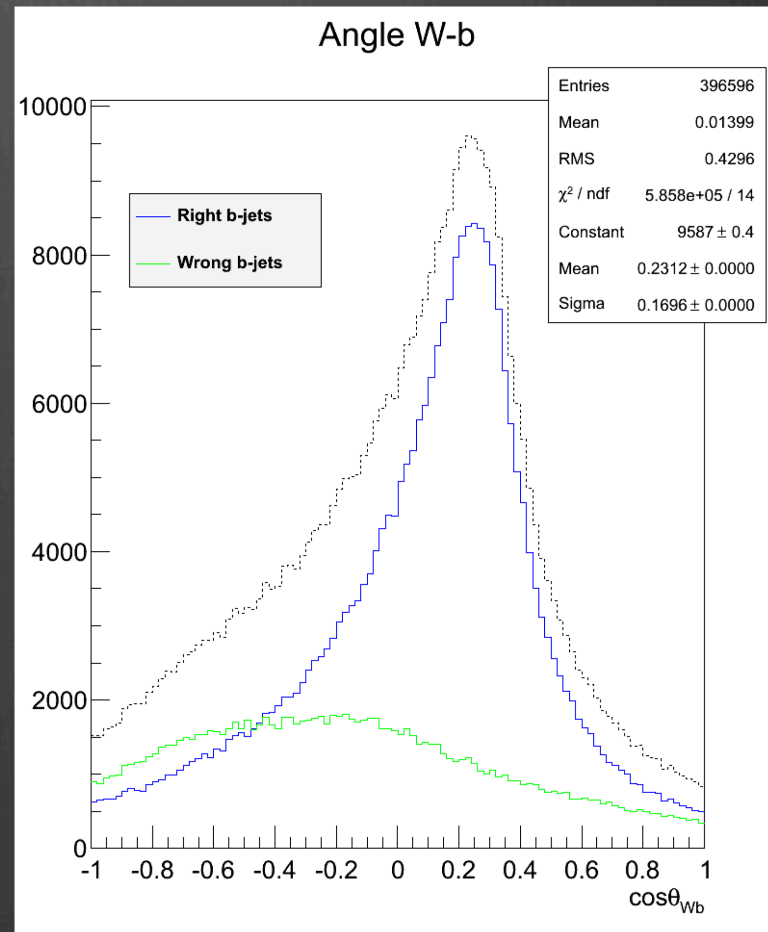




Particle Flow

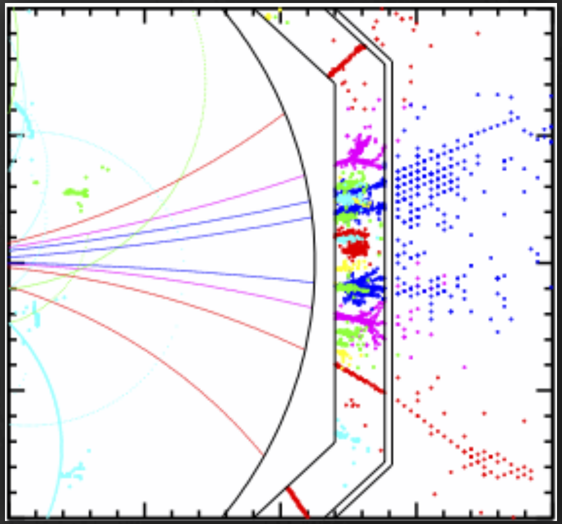
Particle Flow (a powerful tool to measure the energy of the jets)

- Measurement of the charged particle momentum in the tracker → <u>charged component of the jet</u>
- Measurement of the momentum of the neutral component of the jet = total energy measured in the calorimetry – energy of the charged particles in the calorimeter.
- Total energy of the jet = charged component + neutral component

$$\sigma_E / E \approx \frac{30\%}{\sqrt{E}} \quad (E\ en\ GeV)$$

Great granularity of the calorimeters

Calormeter (Silicon-Tungsten)



Comparison LHC vs ILC

	ATLAS	ILC	use
σ_E /E (jets)	60 % /√E	30 % /√E	Jet energy
Δp_T / p_T (charged track)	$4 \cdot 10^{-4}\, p_T \oplus a$	$2 \cdot 10^{-5}\, p_T \oplus a$	muon-momentum (electron at ILC)
$\sigma(d_0)$ (impact parameter)	$\left[11 \oplus \frac{1}{p_T}\frac{70}{\sqrt{\sin\theta}}\right] \mu m$	$\left[5 \oplus \frac{1}{p_T}\frac{10}{\sqrt{\sin\theta}}\right] \mu m$	b-tagging
Magnetic field	2 Tesla	3.5 Tesla	-

(p_T and E in GeV)