Study of the sensitivity in measuring the Top electroweak couplings at the FCC-ee

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FCC-ee Workshop - February 2nd, 2016

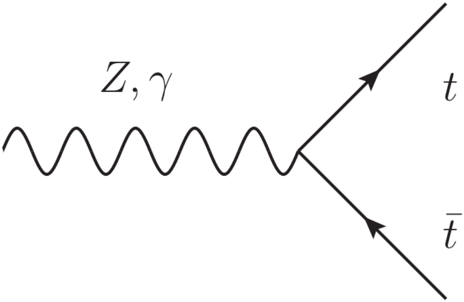
Top electroweak couplings (1)

Why should we study the Top EW couplings?

• Set constraints on new physics scale

• Very sensitive to BSM Physics

• Test of composite Higgs models



FCC-ee 4^{th} run is planned to study the Top physics
$\rightarrow$ a great opportunity to measure the Top EW couplings

Top electroweak couplings (2)

• The present LHC precision ($O(10\% \div 100\%)$) is not very constraining

$\rightarrow$ FCC-ee could reduce the statistical uncertainties by orders of magnitude

• The case has been already presented [1], the results [2] were obtained in a pure analytic way

• It was been shown that $\sqrt{s} = 365$GeV, just above the $t\bar{t}$ threshold, minimizes the statistical uncertainties

A full simulation study has been performed:
$\rightarrow$ we are confirming the analytic result

[1] P. Janot, FCC-ee physics meeting (indico.cern.ch/event/375193/)

[2] P. Janot, Arxiv 1503.01325, link.springer.com/article/10.1007%2FJHEP04%282015%29182

Software and simulation parameters

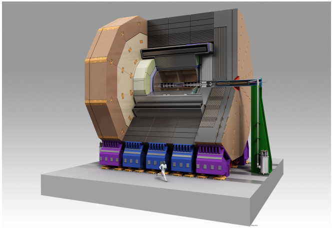
- Simulation characteristics
  - $\sqrt{s} = 365$ GeV assuming unpolarised beams
  - Integrated luminosity $\mathcal{L} = 2.5\text{ab}^{-1}$
  - Background inclusive generation

- Software
  - WHIZARD V57 samples generator [3]
  - Marlin particle flow reconstruction algorithm
  - CLIC/ILD detector

[3] Thanks to Philipp Roloff, and the CERN-CLIC group, who provided us with the simulated and reconstructed samples (twiki.cern.ch/twiki/bin/view/CLIC/MonteCarloSamplesForTopPhysics)

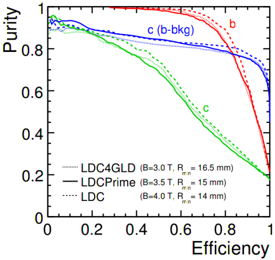
ILD Detector

- ILD is being developed for the LCC (ILC, CLIC)



ILD features [4]

- TPC and silicon tracker
  $\rightarrow \sigma(\frac{1}{p}) < 5 \cdot 10^{-5}\text{GeV}$
- ECAL SiW $\rightarrow \frac{\Delta E}{E} = 15\%/\sqrt{E[\text{GeV}]}$
- Great acceptance $\rightarrow$ up to $\theta = 85^\circ$
- High impact parameter resolution and vertex reconstruction:
  $\rightarrow \sigma(rz) = 5 \oplus 10/psin^{\frac{3}{2}}\theta\ \mu$ m
  $\rightarrow$ flavor jet tagging



The performance of the FCC-ee detector might be similar to those of the ILD.

[7]arXiv 1306.6329, arXiv 1006.3396v1

Couplings parametrization

- Top EW couplings can be described in this manner[5] (V=γ, Z):

$$\Gamma^{\mu}_{t\bar{t}V} = \frac{g}{2}\left[\gamma^{\mu}[(A_V + \delta A_V) - \gamma^5(B_V + \delta B_V)] + \frac{(p_t - p_{\bar{t}})^{\mu}}{2m_t}(\delta C_V - \delta D_V\gamma^5)\right]$$

- Anomalous couplings δX_V describe: (X=A,B,C,D and V=γ, Z)

  $\delta A_\gamma \rightarrow$ Electric charge $\neq \frac{2}{3}$

  $\delta B_\gamma \rightarrow$ Parity violation in the γ coupling

  δA_Z, $\delta B_Z \rightarrow$ Deviation from the SM in the Z coupling

  $\delta C_V \rightarrow$ Deviation from the SM in both the Z and γ coupling

  $\delta D_V \rightarrow$ CP violation in both the Z and γ coupling
- They influence the top polarization
  - Top polarization is maximally transferred to the decay products $t \rightarrow Wb$

    Affecting the decay product distribution (similar to $Z \rightarrow \tau^+\tau^-$ at LEP)

[5] B. Grzadkowski, Z. Hioki: arXiv:hep-ph/0004223v4

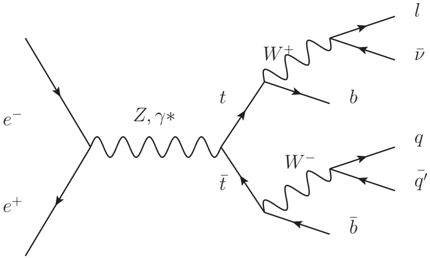
$t\bar{t}$ semileptonic final state

• We can measure the EW coupling by studying the energy-angle distribution of the lepton from the semileptonic decay:

$$e^+e^- \to \bar{t}t \to \bar{b}qq'bl\nu$$

• Studied only δA_z, δB_z, deviations in the Z couplings
• Related to the left and right handed top quark couplings

$$g_L = \frac{g}{2}(A_z + B_z)$$
$$g_R = \frac{g}{2}(A_z - B_z)$$

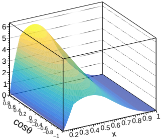


g_L and g_R are very sensitive to new physics (composite Higgs model particularly)

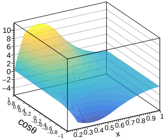
Parametrization of the differential cross section

- The differential cross section can be parametrized in this manner

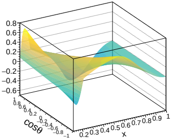
$\frac{d^2\sigma}{dE d\cos\theta}$ =

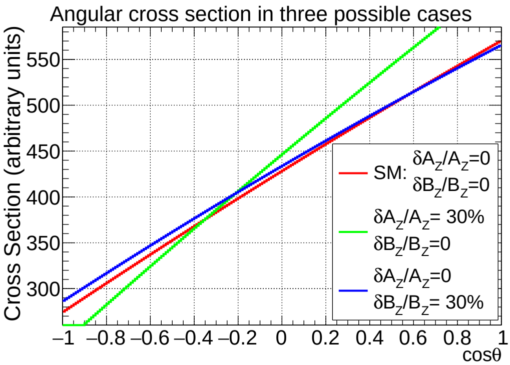


$+\delta A_Z \times$



$+\delta B_Z \times$





Kinematic variables

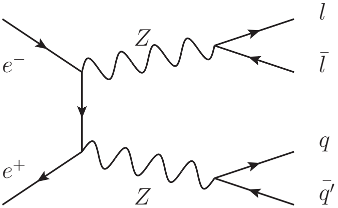
$$\beta = \sqrt{1 - 4m_t^2/s}$$

$$x = \frac{2E_f}{m_t}\sqrt{\frac{1-\beta}{1+\beta}}$$

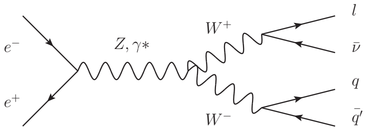
Background processes

Principal processes [6]

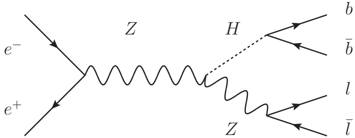
- $\bar{b}qq'bl\nu$ $\sigma = 290.5\text{fb}$
- $qq'l\nu_l$ $\sigma = 6400\text{fb}$
- $qq'l\bar{l}$ $\sigma = 1900\text{fb}$
- $qqqq$ $\sigma = 5900\text{fb}$
- $qq\nu\nu$ $\sigma = 365\text{fb}$
- HZ $\sigma = 110\text{fb}$



$e^+e^- \to ZZ$



$e^+e^- \to WW$



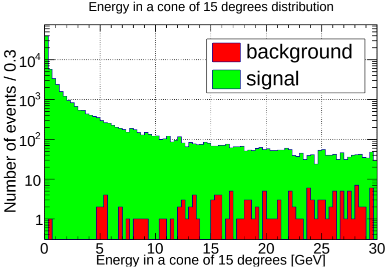
$e^+e^- \to HZ$

[5]The cross section are calculated using WHIZARD V57 (lowest order + ISR) + state of art QCD corrections.

Analysis strategy

- Steps of the analysis
  - Samples generated with $\delta A_Z = \delta B_Z = 0$
  - Tagging of the semileptonic $t\bar{t}$ events
  - Background rejection using discriminating variables
  - Smearing of the theoretical distributions
  - Fit to obtain the statistical uncertainties $\sigma(\delta A_Z)$ and $\sigma(\delta B_Z)$
- Remarks
  - Muons and electrons coming from the tau decay are used as signal
  - Fully leptonic $t\bar{t}$ events are rejected as a first step
    $\rightarrow$ a specific analysis has already been planned
  - Use the MC flag to calculate efficiency and purity of the samples

Identification of the lepton in the semileptonic $t\bar{t}$ decay



Leptons selection:

- Kinematic cut:

$\rightarrow \quad 12GeV < E_l < 120\text{GeV}$

- Isolation:

$\rightarrow \quad E_{cone} \quad \theta_{cone} = 15^o$

- Cut optimization:

$\rightarrow E_{cone} < 12.8\text{GeV}$

- Results on $t\bar{t}$ signal events

	Electrons	Muons
Efficiency	0.78	0.9
Purity	0.998	0.9996

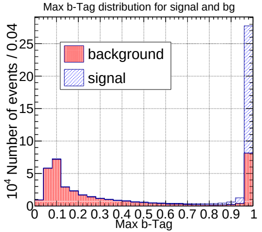
$$\text{efficiency} = \frac{\text{signal } \ell \text{ selected}}{\text{signal } \ell \text{ generated}}$$

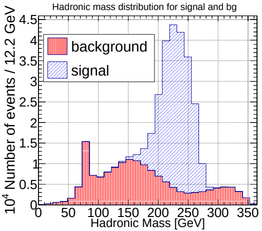
$$\text{purity} = \frac{\text{signal } \ell \text{ selected}}{\text{all the } \ell \text{ selected}}$$

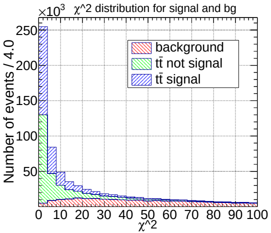
$\rightarrow$ Almost complete rejection of the leptons coming from b-decays

Background cuts

- max b-tag $> 0.85 \rightarrow$ rejecting events with a similar signature without b-jet, like $qql\nu$ final state
- Hadronic Mass in range 130 GeV $\div$ 300 GeV $\rightarrow$ rejecting events with ZZ and WW $\rightarrow$ four jets.
- Missing Energy in range 20 GeV $\div$ 140 GeV $\rightarrow$ rejecting events with Z $\rightarrow$ invisible in the final state
- Top and W mass constraint: $\chi^2 < 15 \rightarrow$ Rejecting the events with a similar signature to the signal, from ZZ, WW and HZ decays

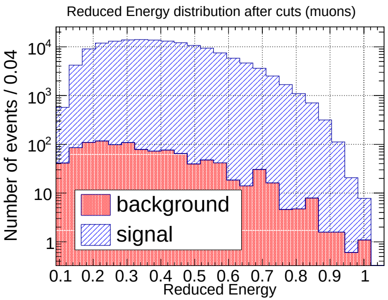


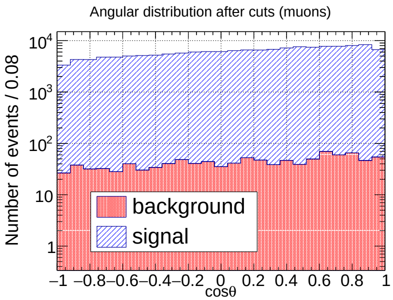




[8] All the plots are made with the muons sample. More plots in the backup.

Background cuts: results





$$\text{efficiency} = \frac{\text{signal} \quad \text{selected}}{\text{signal} \quad \text{generated}}$$

$$\text{purity} = \frac{\text{signal} \quad \text{selected}}{\text{selected} \quad \text{events}}$$

Results:

	Electrons	Muons
Efficiency	48%	56%
Purity	99%	99%

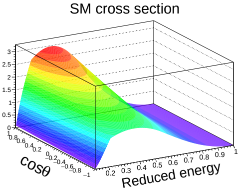
[9] All the plots are made with the muons sample. More plots in the backup.

Analytic distributions smearing (1)

The bare theoretical energy and angular distributions cannot be used to fit the reconstructed distributions:

- Selection efficiency varies with the lepton energy and direction
- We do not observe the taus, but only the muons and electrons coming from their decay (with lower energy!)
- Presence of residual background

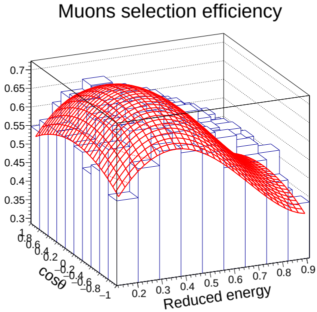
$\longrightarrow$ We used the MC information to compute the proper transfer functions



$\longrightarrow$ **?**

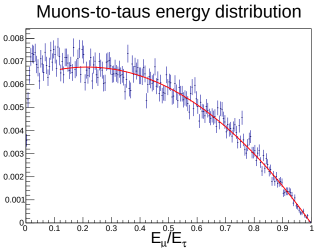
Analytic distributions smearing (2)

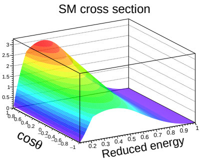
- Muons (electrons) detector efficiency



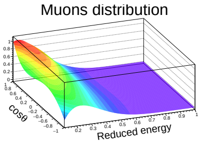
- $\epsilon_\ell = \dfrac{\ell \text{ detected and selected}}{\ell \text{ generated in } t\bar{t} \to b\bar{b}q\bar{q}'\ell\nu}$
- $\sigma_{RC,eff} = \sigma_{MC} \cdot \epsilon_\ell$

- Muons (electrons) from taus decay



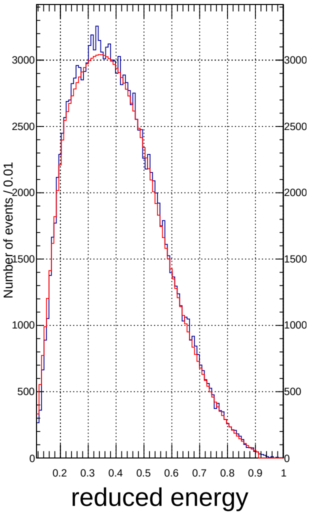


$\longrightarrow$

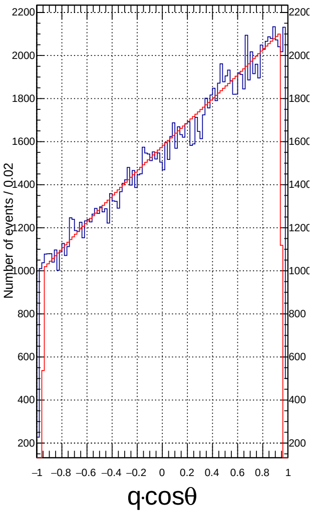


Muons (electrons) fit

Reduced energy projection



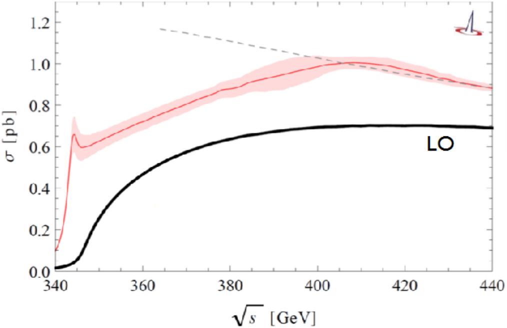
cosθ projection



- SM signal and background distributions are fixed
- BSM correction coefficients δA_Z, δB_Z are the free parameters of the fit
- $|\cos\theta| < 0.96$
- $x < 0.9$
- Analogous fit for the electrons (see the backup)

Systematic uncertainties: σ_{tot}

- Top pair cross section theoretical uncertainties might be too large
- At $\sqrt{s} = 365\text{GeV}$ the theoretical (just above the top threshold) must be known to a few %



- Now the theoretical uncertainties is $\simeq 4\%$

$\rightarrow$ could we reduce this value in $\simeq 25$ years? (before 2040)

[6] Taken from P. Janot, HEP-EPS Vienna, 25 July 2015; plot taken from the Talk by J.R. Reuter, Valencia, July '15 "Top Physics at Lepton Colliders"

Results and comparison with analytical studies

Results: combination of $\mu^\pm$, $e^\pm$ information

$$\delta A_Z = (0.0 \pm 1.8)\cdot 10^{-3} \qquad \frac{\delta g_R}{g_R} = (0.0 \pm 2.2)\cdot 10^{-2}$$

$$\delta B_Z = (0.0 \pm 1.6)\cdot 10^{-2} \qquad \frac{\delta g_L}{g_L} = (0.0 \pm 3.9)\cdot 10^{-2}$$

Good agreement with the predictions in Arxiv 1503.01325[7]:

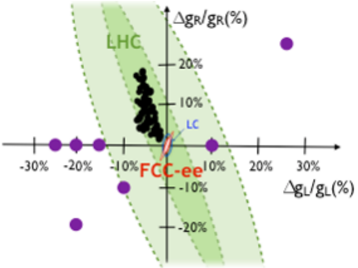
	Whizard full simulation	Arxiv 1503.01325
$\sigma(\delta A_Z)$	$1.8 \cdot 10^{-3}$	$1.5 \cdot 10^{-3}$
$\sigma(\delta B_Z)$	$1.6 \cdot 10^{-2}$	$1.6 \cdot 10^{-2}$

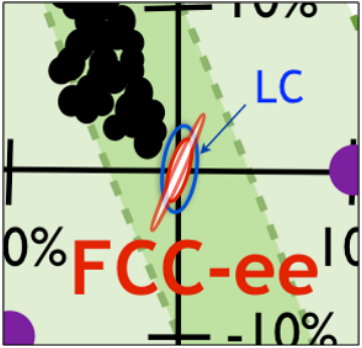
Arxiv 1503.01325:

- selection efficiency $\simeq 0.5$
- complete rejection of the background
- included also the fully leptonic final state analysis in its estimates

[7] P. Janot, Arxiv 1503.01325, link.springer.com/article/10.1007%2FJHEP04%282015%29182

- Purple dots: New Physics models tested at LHC
- Black dots: 4D Composite Higgs[8] models, $f < 2\text{TeV}$



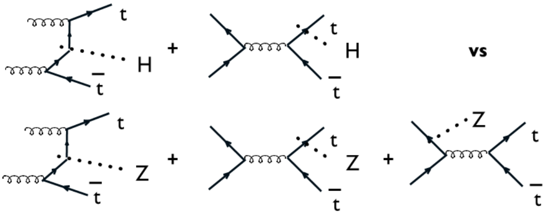


[8] S. De Curtis, presentation in this session.

[9] The plots are taken from P. Janot, HEP-EPS Vienna, 25 July 2015; Adapted from S. De Curtis et al. arXiv:1504.05407

Top Yukawa coupling

- Complementary between FCC-ee and FCC-hh



$$\frac{\sigma(ttH)}{\sigma(ttZ)} = \frac{\lambda_t^2}{(F_{1V}^Z)^2 + (F_{1A}^Z)^2}$$

- The ratio is quite independent from systematic uncertainties

$\rightarrow$ The ttH coupling could be measured with an uncertainty of $1 \div 2\%$

[10] Taken from P. Janot, HEP-EPS Vienna, 25 July 2015; P. Janot arXiv:1510.09056v1

Summary and future perspectives

Summary

- Studying the Top EW couplings is very important because of the sensitivity to new physics
- At FCC-ee 4^{th} run it is possible to perform this measure
- An analytical work has shown that at FCC-ee we could reach a satisfactory precision in this measure
- Now the analytical work is supported by a Montecarlo simulation

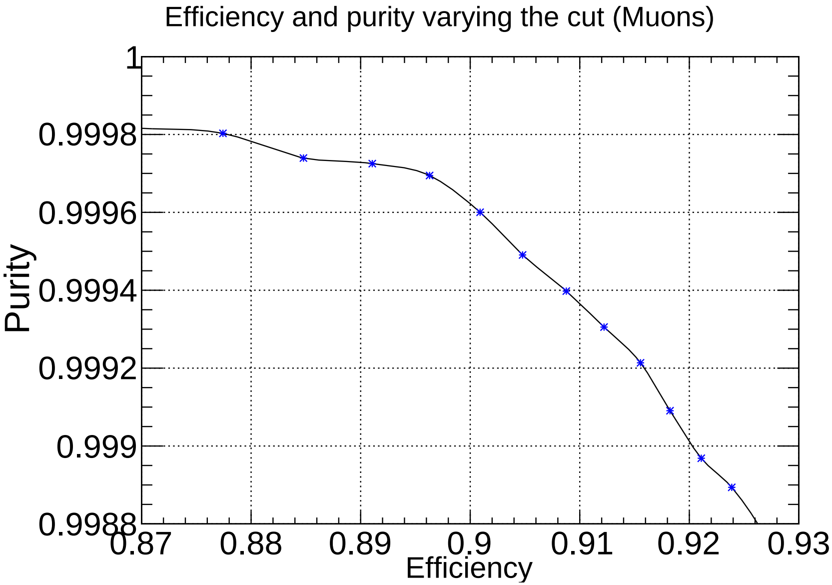
"To do" list

- Improve the analysis including fully leptonic final states and b quark energy-angle distribution
- Increase the efficiency of the cuts and repeat with toy data
- Repeat with a fast simulation

Thanks for your attention

Any questions/suggestions?

Cut optimization in tagging the events

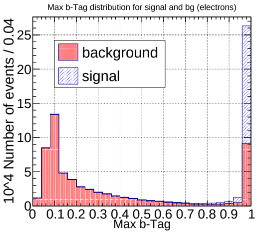


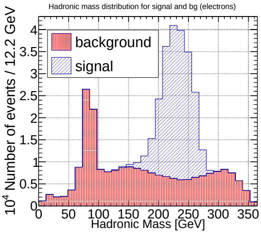
χ^2 definition

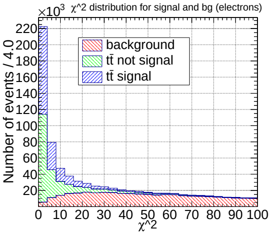
$$\chi^2 = \frac{(m^{rec}_{t-lep} - m_{t-lep})^2}{\sigma^2_{t-lep}} + \frac{(m^{rec}_{t-had} - m_{t-had})^2}{\sigma^2_{t-had}} +$$

$$+ \frac{(m^{rec}_{W-lep} - m_{W-lep})^2}{\sigma^2_{W-lep}} + \frac{(m^{rec}_{W-had} - m_{W-had})^2}{\sigma^2_{W-had}}$$

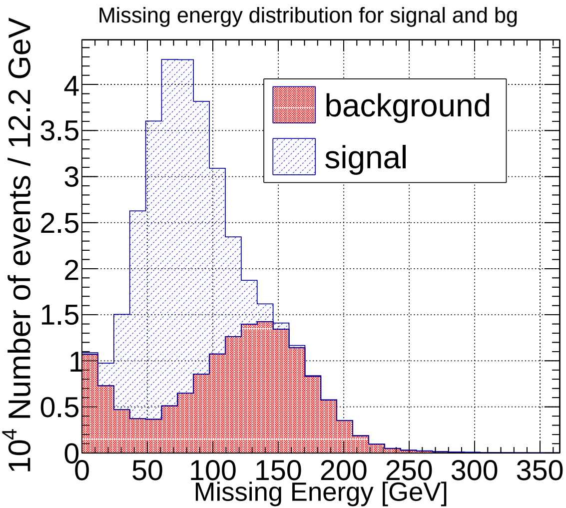
Electrons cuts plot



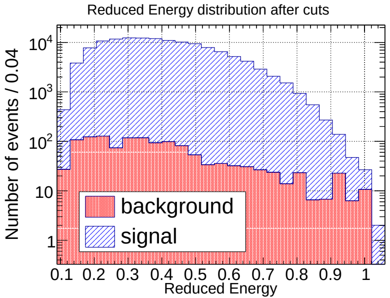


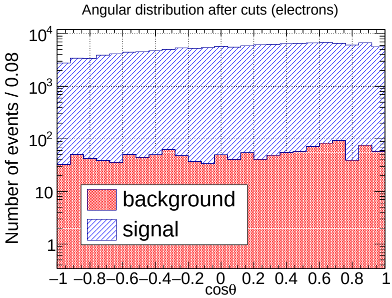


Missing Energy Muons plot

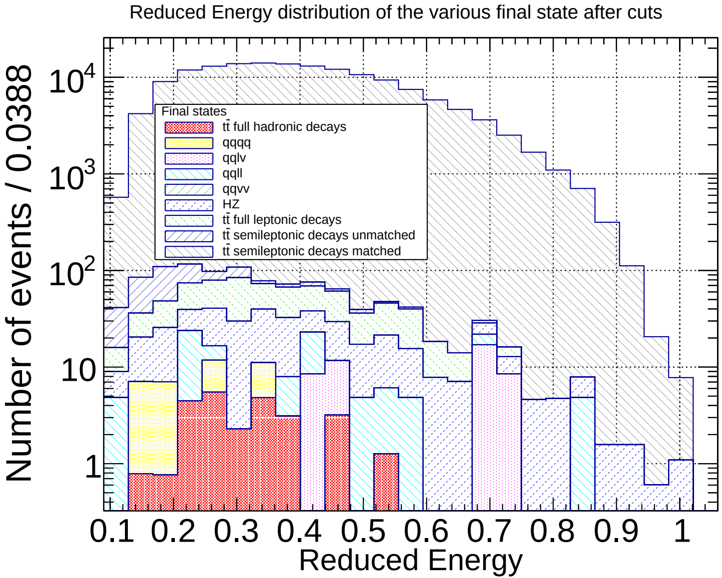


Electrons results after cuts

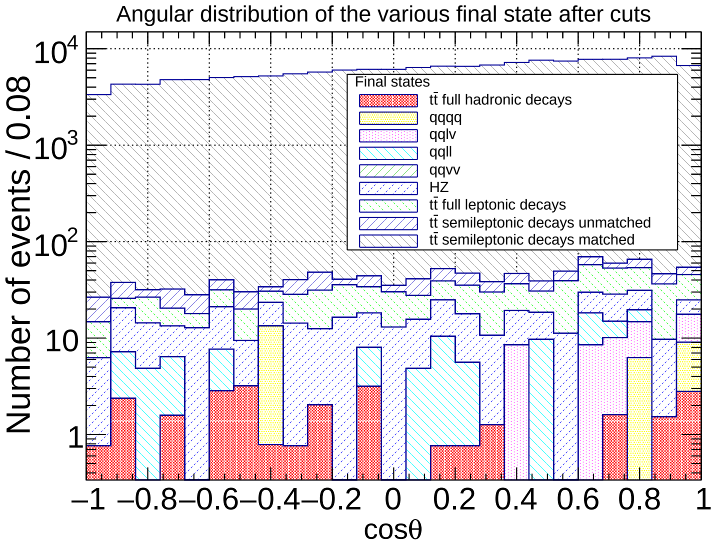




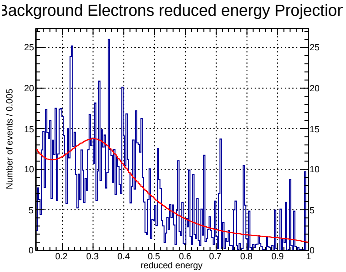
Reduced energy distribution after cuts, all BG, muons

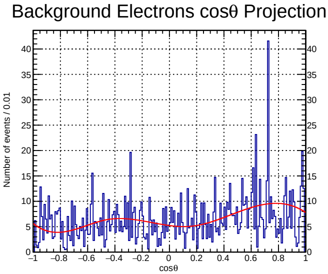


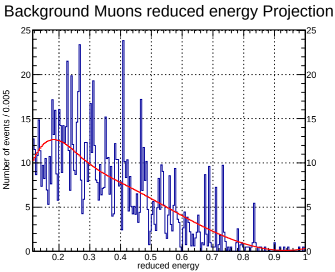
CosTheta distribution after cuts, all BG, muons

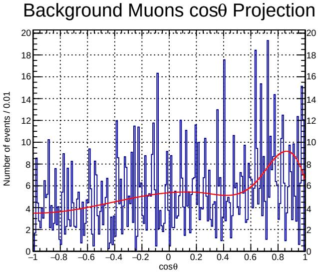


Background analytic distributions: expected values vs data

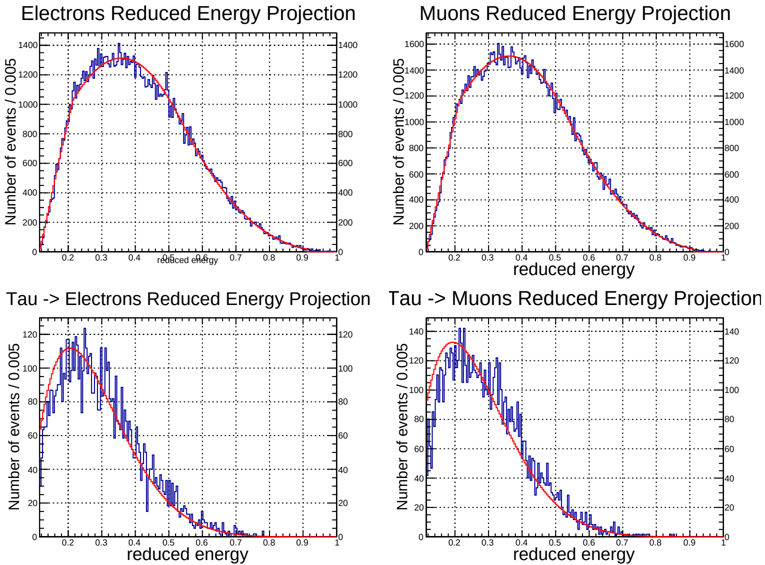




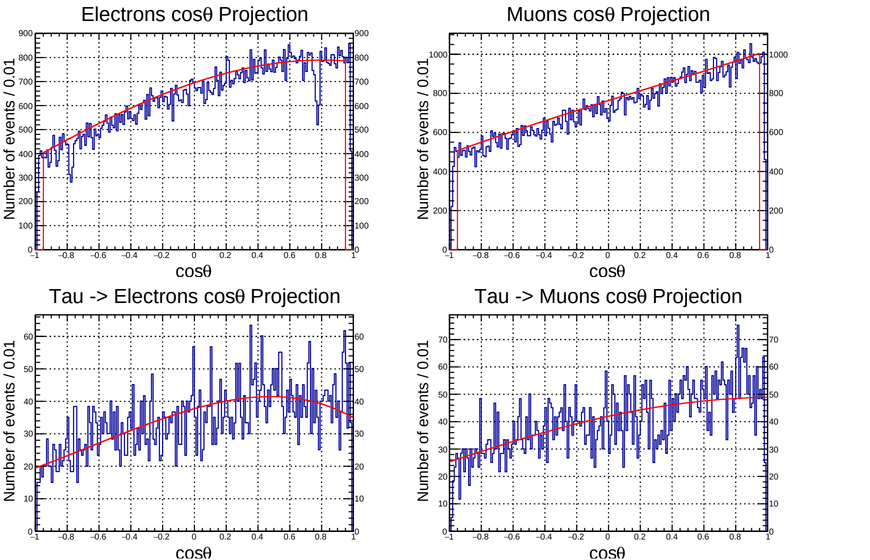




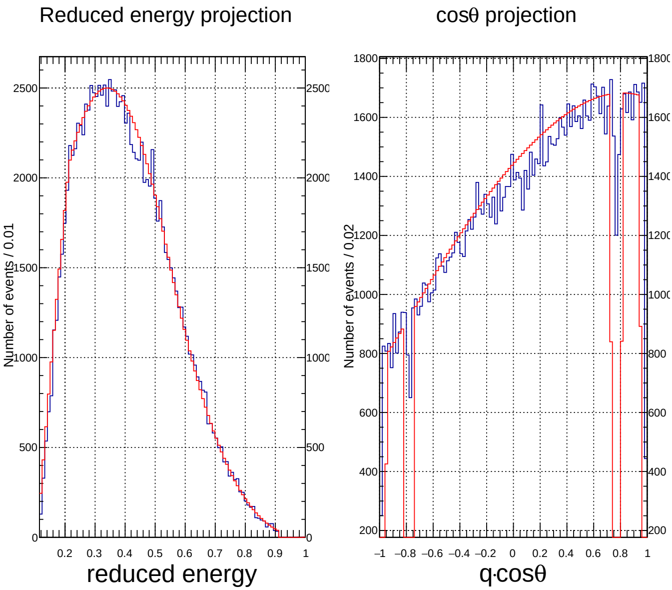
Signal analytic energy distributions: expected values vs data



Analytic distributions muons: expected values vs data



Electrons and positrons fit



Results

- Analytic distributions are calculated with a renormalization scheme which is different from the one used by Whizard $\longrightarrow \delta A_Z^{fit}, \delta B_Z^{fit} \neq 0$
- We subtracted the values of $\delta A_Z, \delta B_Z$ obtained from the theoretical distribution from the results of the fit, to avoid any bias introduced by the difference of renormalization scheme used for the theoretical distributions (MSBar) and WHIZARD (GF).

Separate fits

	δA_Z	δB_Z
muons	$(0.2 \pm 2.5) \cdot 10^{-3}$	$(2.3 \pm 2.2) \cdot 10^{-2}$
electrons/positrons	$(3.1 \pm 2.8) \cdot 10^{-3}$	$(-4.8 \pm 2.4) \cdot 10^{-2}$