WW scattering studies at a Future Linear Collider

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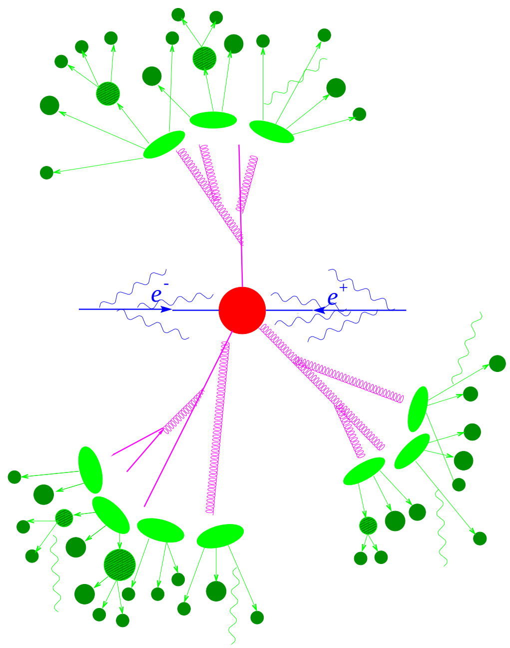


(From:F. Krauss)

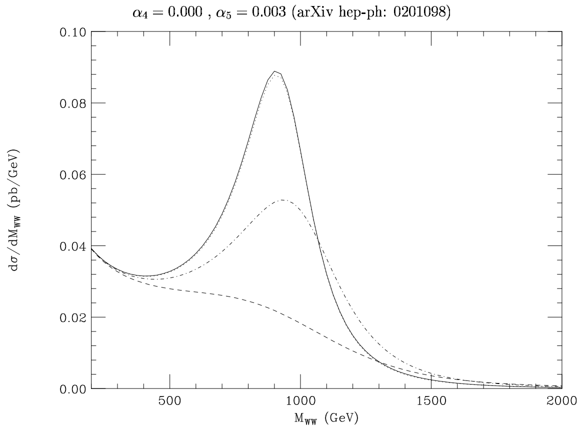
Motivations

- The symmetry of SU(2)⊗U(1) must be spontaneously broken to give mass to W and Z. But how?
- If there is no a Higgs, new physics is needed at the TeV scale to restore unitarity. It is in this context that the strong scattering of $W_L W_L$ bosons provides a window to look for information about the underlying symmetry.
- The EW interactions at low energies can be described by the EW Chiral Lagrangian.
- This is an effective theory which:
  - has operators of higher dimensions
  - introduces anomalous couplings
- There are two 4D operators:
  $L_4 = \frac{\alpha_4}{16\pi^2} tr(V_\mu V_\nu) tr(V^\mu V^\nu)$
  $L_5 = \frac{\alpha_5}{16\pi^2} tr(V_\mu V^\mu) tr(V_\nu V^\nu)$
- The coefficients α_4 and α_5 are related to the scale of the new physics (in the SM these parameters are 0)

Motivations

- From WW scattering studies at LHC (Butterworth,Cox,Forshaw):
  - EW Chiral Lagrangian
  - Unitarization protocols (Padé or N/D)

  ▷ Prediction of resonances depending on the values of the α_4 and α_5 parameters
- As an example:

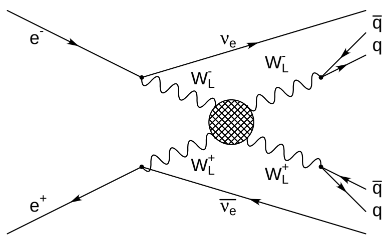


To sum up:

- What's the sensitivity to the α_4 and α_5 that can be reached at a Future Linear Collider?
- Given that these parameters can be measured, what can we learn about new physics at higher energies?
  (LHC - LC complementarity)

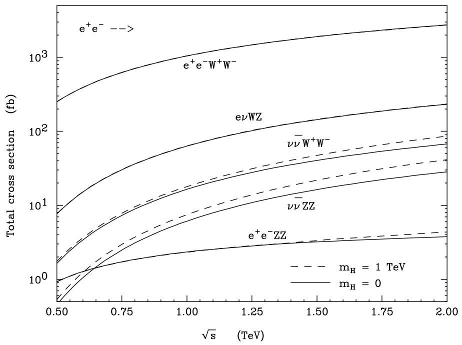
Analysis of process $W_L W_L \to W_L W_L$

- Our signal consists of the following processes:
  $e^+e^- \to \nu\bar{\nu}W_L^+W_L^- \to \nu\bar{\nu}q\bar{q}q\bar{q}$
  $e^+e^- \to \nu\bar{\nu}Z_L Z_L \to \nu\bar{\nu}q\bar{q}q\bar{q}$



- Concentrate on M_{WW} and $\cos(\theta^*)$
- Backgrounds:
  $e^+e^- \to \nu\bar{\nu}q\bar{q}q\bar{q}$ (non-res.)
  $e^+e^- \to e^+e^-W^+W^-(ZZ)$
  $e^+e^- \to e^+\nu W^-Z$ + c.c.
  $e^+e^- \to W^+W^-(ZZ)$
  $e^+e^- \to q\bar{q}$

- Some of the main processes cross sections (without polarisation):



arXiv:hep-ph/9501379

- Summary of the cross sections obtained from our study:

type	Process	Xsec [fb]	Generator
6 fermions	Signal	12.92	Whizard
	$e^+e^- \to\to q\bar{q}q\bar{q}\nu\bar{\nu}$	5.5	Whizard
	$e^+e^- \to t\bar{t}$	136.9	Pythia *
	$\gamma\gamma \to t\bar{t}$	1.3	Pythia*
	$\gamma\gamma \to W^+W^-$	234.8	Pythia*
4 fermions	$e^+e^- \to W^+W^- \to q\bar{q}q\bar{q}$	1948.1	Pythia*
	$e^+e^- \to ZZ \to q\bar{q}q\bar{q}$	142.9	Pythia*
2 fermions	$e^+e^- \to q\bar{q}$	4464.6	Pythia*

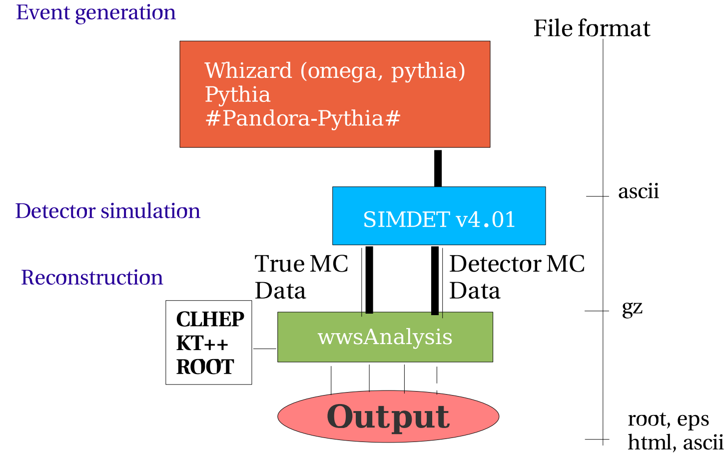
Setup of the Study

- For our study, we picked TESLA as our F.L.C:
  (TeV Energy Superconducting Linear Collider Accelerator)

  - Luminosity: $L = 100\ fb^{-1}$
  - C.M.E.: $\sqrt{s} = 800$ GeV
  - Polarised beams:
    0.80 e^{-}, 0.40 e^{+}

- Both ISR and FSR are turned On

- Framework:



- WHiZard (Kilian) is the main event generator:
  - 6 fermions final states
  - the a.c. quartic couplings are included
  - beam polarisation

Setup of the Study

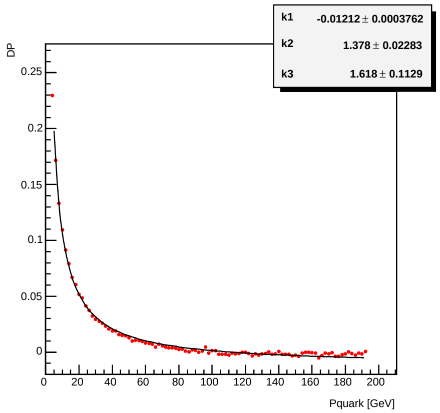
- We are using the fast Detector Simulation - SIMDET (Phol,Schreiber):
  - Tracking system: CCD vertex detector (1.5cm) + Forward Tracker
  - Magnetic field: 4 T
- Calorimetry:
  - ECal resolution: $\Delta E/E = 0.2/\sqrt{E}$
  - HCal resolution: $\Delta E/E = 0.4/\sqrt{E}$
- Jet energies are measured using the Energy Flow concept.

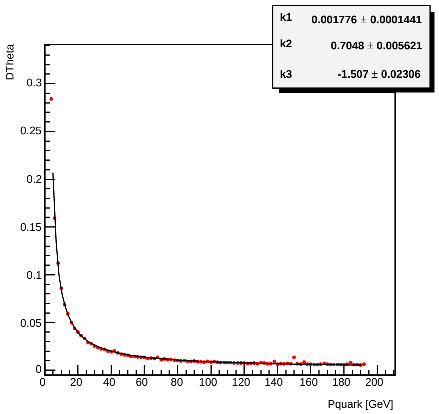
Z and W reconstruction

- Main problem is to reconstruct Z and W pairs
- Tracks from the detector simulation are forced into 4 jets using the K_T jet algorithm - If succeed, we then have 3 possible combinations
- First approach was to try a proximity selection method:
  $R^2 \leq (M_W - M_{12})^2 + (M_W - M_{34})^2$
  - given an appropriate value for R
- The results obtained were not really convincing:
  $\sim$50% correct pairing rate
- Therefore, we needed to improve the situation:
  ▷ Kinematic Fit + 1 Constraint
  $Q(\vec{x}, \vec{\lambda}) =$
  $(\vec{x} - \vec{x}_0)V^{-1}(\vec{x} - \vec{x}_0) + 2\vec{\lambda}\vec{f}(\vec{x})$
- Where: $\vec{f}(\vec{x})$: constraints
  $\vec{x}$: jet parameters (P_{tot},θ,ϕ)
  $\vec{\lambda}$: Lagrange multipliers
  $\vec{V}$: error matrix
  Error matrix: resolution functions
  $\sigma_{Ptot}(p_q)$, $\sigma_\theta(p_q)$, $\sigma_\phi(p_q, \theta_q)$
- 1c : $M_{12} = M_{34}$

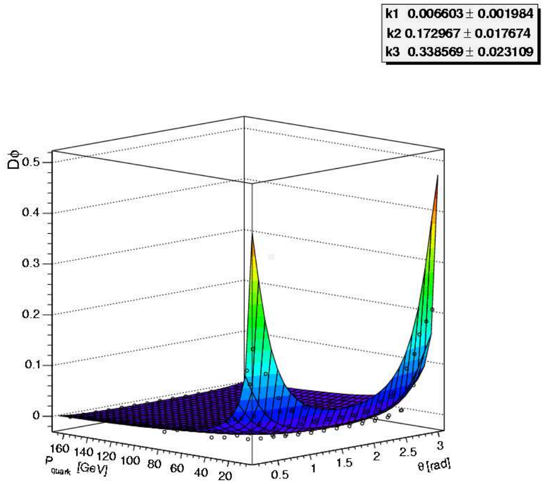
Z and W reconstruction

- Total momentum, and θ resolution:





- ϕ resolution:



$$\sigma_{Ptot} = -0.01212 + \frac{1.378}{P_q+1.618} \text{ for Ptot} < 100 \text{ GeV};$$

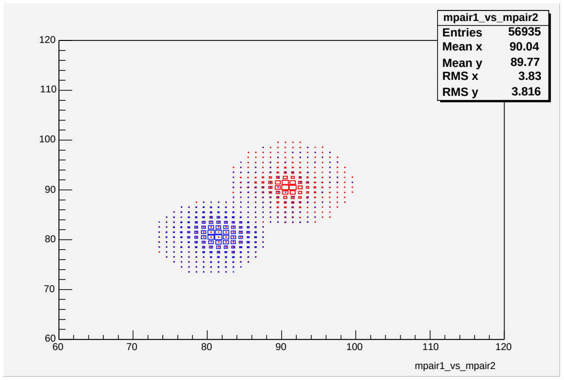
$$\sigma_{Ptot} = 0.0001 \text{ for Ptot} > 100 \text{ GeV}$$

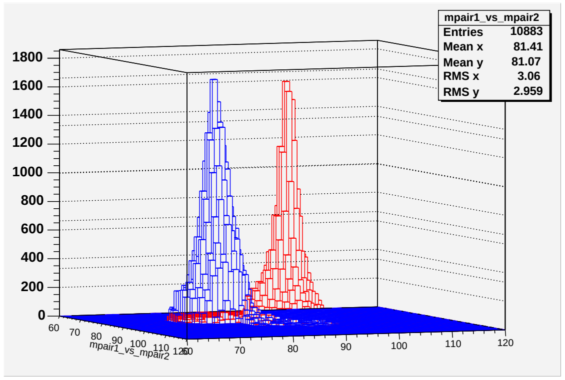
$$\sigma_\theta = 0.001776 + \frac{0.7048}{P_q-1.507}$$

$$\sigma_\phi = 0.006603 + \frac{0.172967}{P_q(\sin^2\theta+0.338569^2)}$$

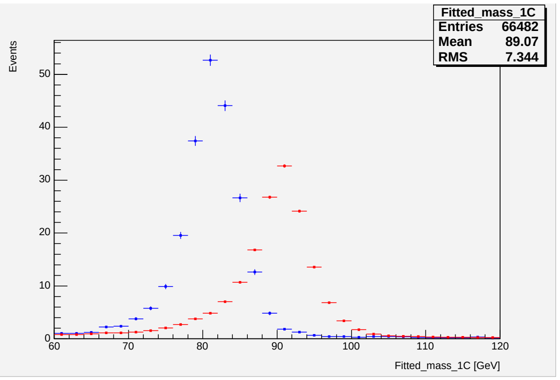
Kinematic fit

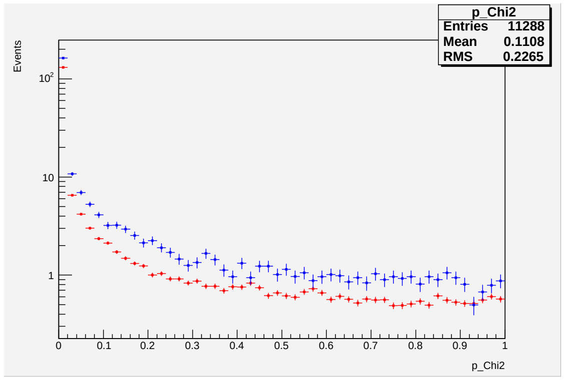
- ZZ/WW selection (using 1st method)





- Now with the 1C Kinematic Fit:





- Correct pairing has raised up to $\sim$ 75 %

Selection cuts

- ZZ selection
  - Missing mass: $200 < E_{miss}$
  - $|\cos\theta_{P_{miss}}| < 0.99$
  - $|\cos\theta_{P_{Emax}}| < 0.99$
  - $nTracks > 2$
  - Prob(χ^2) > 0.70
  - $85 < M_{1C} < 100$ GeV
- WW selection
  - $150 < E_{trans} < 600GeV$
  - $M_{recoil} > 200GeV$
  - $P_T > 20GeV$
  - $5.0 < y^*_{cut} < 7.5$
  - Prob(χ^2) > 0.70
  - $75 < M_{1C} < 85$ GeV

Summary

- Our initial approach to reconstruct Z and W wasn't perfect
  ▷ Needed a better method for our selection
- 1C Kinematic fit for the mass of Z and W: very is promising
  ▷ Improvement in correct pairing selection $\sim$ 75 %
- We performed a detailed study on the resolution functions for the measured variables
- Cut analysis for the following processes is made for TESLA:

$$e^+e^- \rightarrow \nu\bar{\nu}W_L^+W_L^- \rightarrow \nu\bar{\nu}q\bar{q}q\bar{q}$$
$$e^+e^- \rightarrow \nu\bar{\nu}Z_LZ_L \rightarrow \nu\bar{\nu}q\bar{q}q\bar{q}$$

- However, this is not yet optimised

Outlook

Ongoing progress on:

- Refining the selection cuts
  ▷ study sensitivity of the two a. c. α_4 and α_5
- Take above 90 % the correct pair selection
- LHC-LC comparison