Measuring the Beam Energy with Radiative Return Events

Master Thesis of Arnd Hinze

(presented by Klaus Moenig at LCWS05)

Introduction

- The beam energy is needed on the 10^{-4} level for mass determinations at the ILC (Higgs, top, SUSY...)

- The beam-energy measurement will mainly come from a magnetic spectrometer

- The absolute calibration of the spectrometer is difficult

- The sum of the beam energies is not necessarily equal to the luminosity weighted centre of mass energy $\sqrt{s}$ → next slide

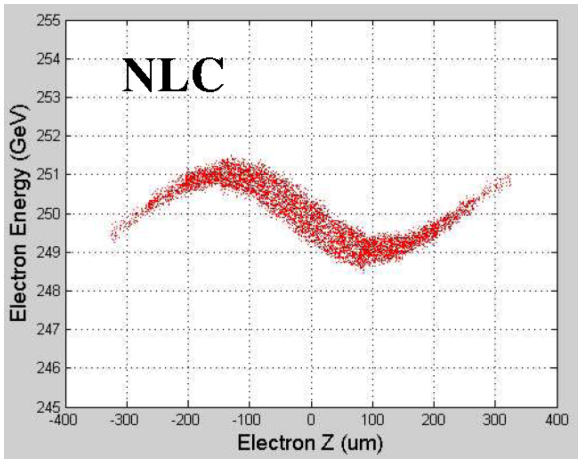
- It would thus be useful to have a method to determine the cms energy from real (annihilation) data

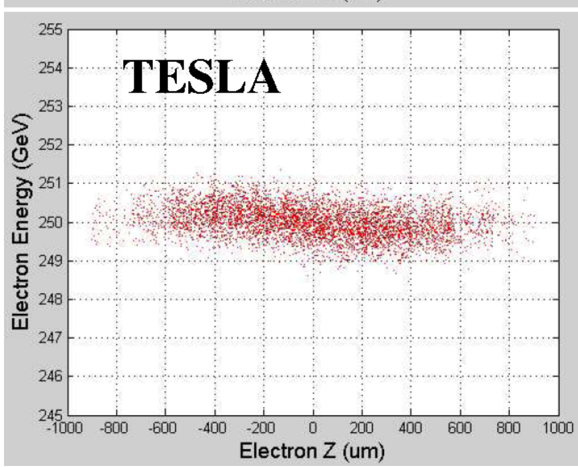
- Such a method exists: radiative return events $e^+e^- \rightarrow Z\gamma \rightarrow f\bar{f}\gamma$

- The validity of this method was already proven at LEP

Energy Bias from Kink-Instabilities

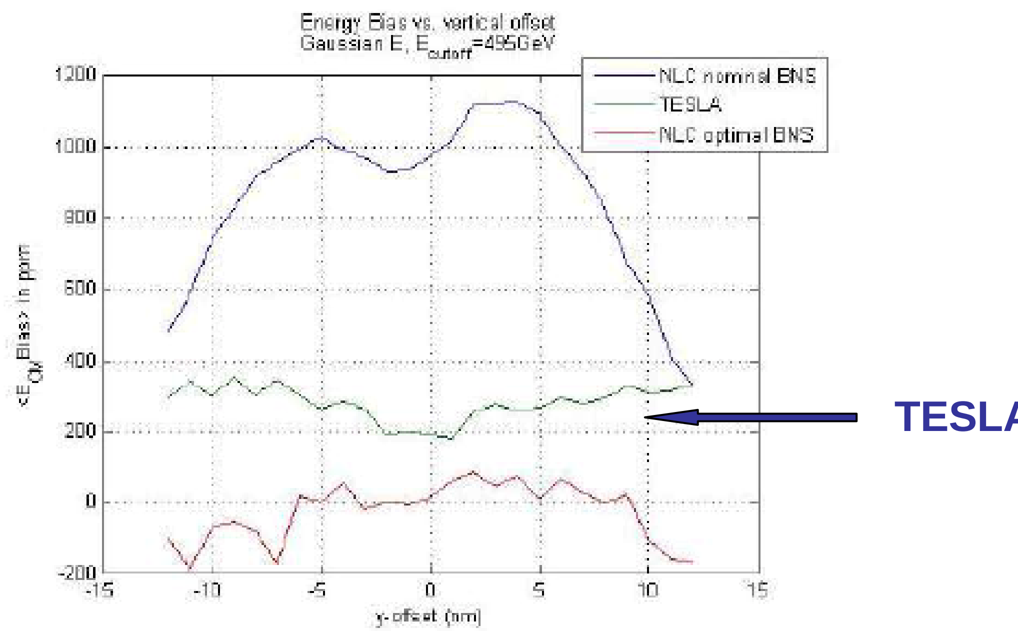
A. Florimonte, M. Woods, IPBI TN-2005-1





- Wakefields introduce a correlation z - E
- Disruption give a different weight to different parts of the bunch

→ These effects make the luminosity weighted cms energy different from twice the beam energy



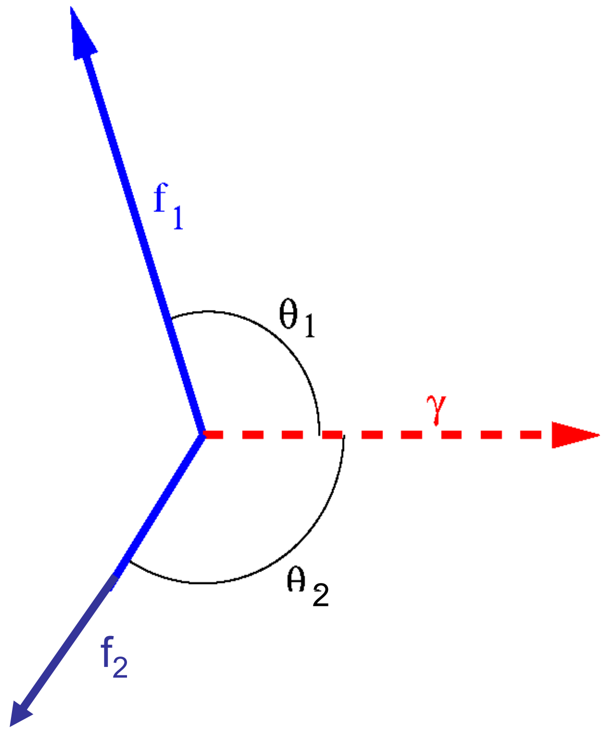
500 GeV TESLA: mean = 150 ppm
spread = 30 ppm
max = 350 ppm

Basic Idea of the Radiative Return Analysis

- The Z-mass is known with very high precision from LEP

- assume only one photon is radiated

  ⇒ √s' can be calculated from fermion angles only



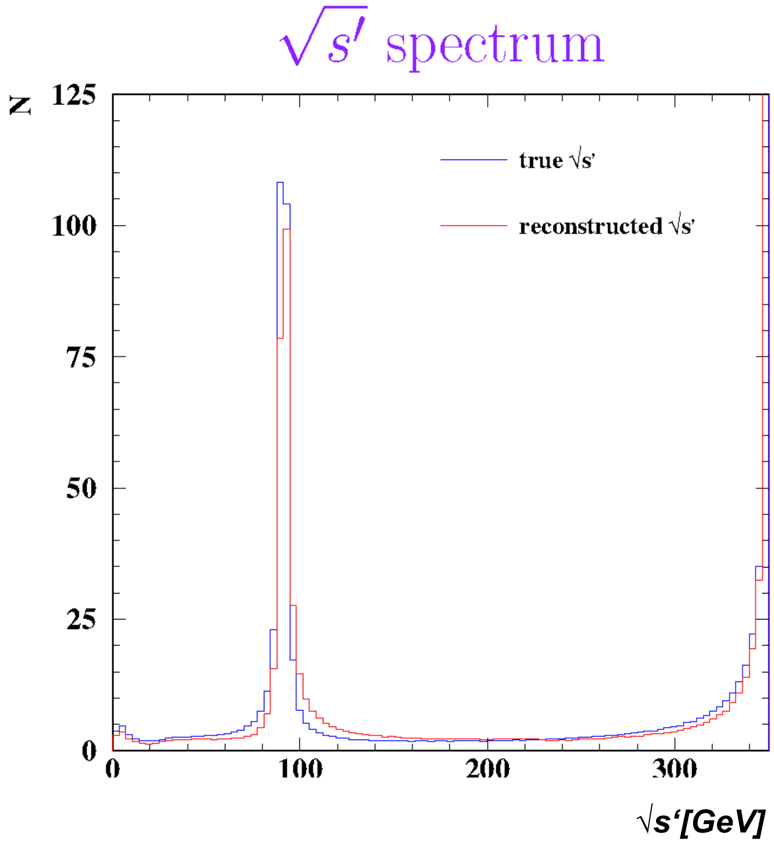
$$\frac{\sqrt{s^I}}{\sqrt{s}} = \sqrt{\frac{\sin\theta_1 + \sin\theta_2 + \sin(\theta_1+\theta_2)}{\sin\theta_1 + \sin\theta_2 - \sin(\theta_1+\theta_2)}}$$

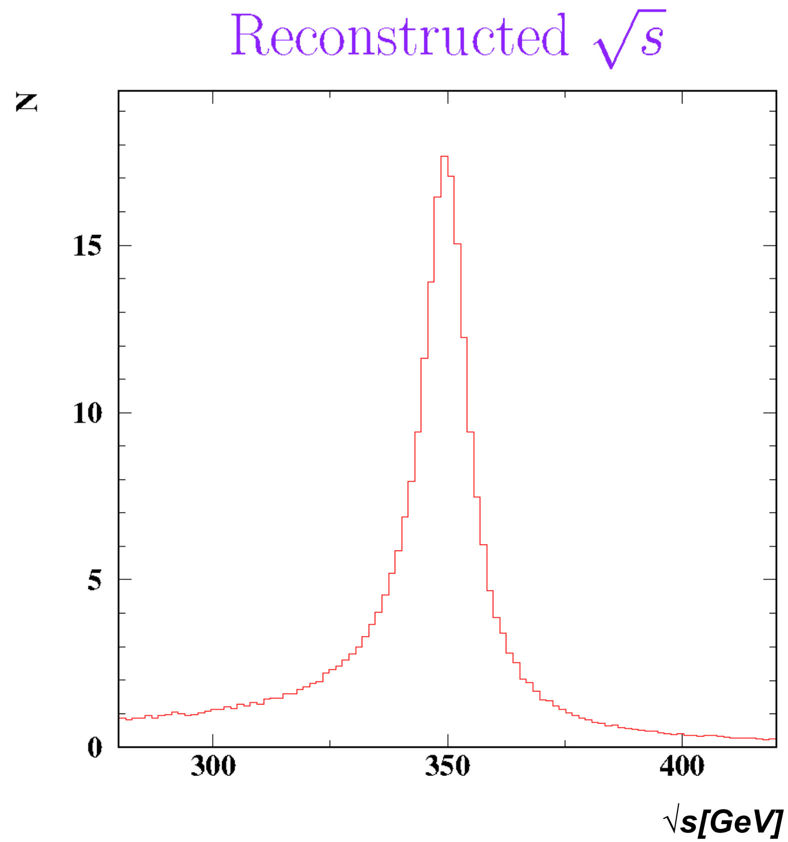
  - γ either along the beampipe or its angle is measured
  - this formula assumes that the fermion mass can be neglected

- Assume √s' = M_Z

$$\sqrt{s} = M_Z\sqrt{\frac{\sin\theta_1 + \sin\theta_2 + \sin(\theta_1+\theta_2)}{\sin\theta_1 + \sin\theta_2 - \sin(\theta_1+\theta_2)}}$$

First analysis with $e^+e^- \rightarrow \mu^+\mu^-\gamma$ at $\sqrt{s}$ = 350 GeV and int. lumi = 100 fb^{-1}





- σ(rad. ret.) ~ 0.5 pb, scales approx. with 1/s
- detector efficiency (7° cut) ≈ 90%
- ideal beam with beamstrahlung and 0.2% Gaussian energy spread

Method used: Fit Procedure

- χ^2 fit of 'data' to MC (reference) samples with free normalisation

  - 'data' sample at $\sqrt{s}_{dat}$ = 350 GeV, ***MC_{dat}***

  - and reference sample at $\sqrt{s}_{ref} = \sqrt{s}_{dat} + \Delta\sqrt{s}$ (= 1GeV), ***MC_{ref}***

$$N_{pred}(\sqrt{s}) = \frac{\sqrt{s_{ref}} - \sqrt{s_{dat}}}{\Delta\sqrt{s}}(MC_{ref} - MC_{dat})$$

- easy to include all effects into fit

- fit tested to be bias free in region $\sqrt{s}_{dat} \pm \Delta\sqrt{s}$

Cuts:
- 7° < $\theta_{1,2}$ < 183° (detector acceptance of muons)
- M_Z − 5 GeV < $m(\mu^+\mu^-)$ < M_Z + 5 GeV

Backgrounds

γγ background ($e^+e^- \rightarrow e^+e^-\mu^+\mu^-$):

- very large cross section without cuts
- less than 10% background in fit range after $m(\mu^+\mu^-)$ cut

Zee:

- cross section similar to signal
- after cut on visible electrons ~25% background remains
- however kinematics similar to signal, so no problem

WW, ZZ:

- ZZ already small, WW reduced by $m(\mu^+\mu^-)$ cut
- in the end ~1% background

Results

Fit to 100 fb^{-1} including beam effects and background:

stat. error

$$\Delta\sqrt{s} = 47\ \mathrm{MeV} \qquad \left(\frac{\Delta\sqrt{s}}{\sqrt{s}} = 1.3\ 10^{-4} \right)$$

$\sqrt{s}$ = 350 GeV

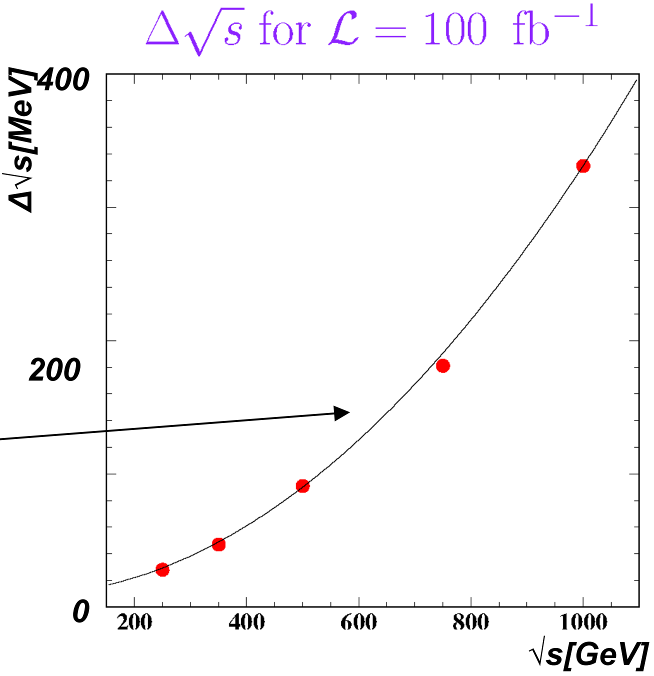
- without beamstrahlung and energy spread ~10% better
- little effect from background
- slight improvement possible if 2D fit ($\sqrt{s}$, θ)

Result strongly energy dependent:

- cross section proportional 1/s
- resolution deteriorates with larger s
- background rises with s
- acceptance worse at larger s

Parameterisation:

$\Delta\sqrt{s} = (8.8 + 0.0026\sqrt{s}/\mathrm{GeV} + 0.0032 s/\mathrm{GeV}^2)$ MeV



Systematics

Background: no effect for 20-30% background uncertainty

Energy spread: $\Delta\sqrt{s}$ = 10 MeV if Gaussian energy spread is replaced by rectangular, no effect if 0.1% instead of 0.2%

Beamstrahlung: method largely cancels errors from beamstrahlung determination

Aspect ratio of tracker: LEP error $\Delta(\delta R/\delta L) = \delta\tan\theta = 5 \cdot 10^{-4}$

→ ***$\Delta\sqrt{s}$ = 160 MeV, which has to be about an order of magnitude better !***

Conclusions

The centre of mass energy can be measured on the 10^{-4} level from radiative return events.

Inclusion of Bhabha scattering $e^+e^- \rightarrow e^+e^-\gamma$, $e^+e^- \rightarrow \tau^+\tau^-\gamma$ or $e^+e^- \rightarrow q$ q-bar γ might improve the result.
But each of this channel contains additional complications, which dilute possible improvements.

This is a high luminosity analysis, so relative measurements e.g. in a scan are needed from spectrometers.

The length to radius ratio of the tracking detector needs to be known to better than 10^{-4} not to be limited by this effect.

A global analysis of Bhabha acolinearity for beamstrahlung and radiative return events for the beam energy is needed to understand effects from beam-beam correlations.