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W-BOSON RECONSTRUCTION IN FULL MONTE CARLO DETECTOR SIMULATIONS OF 500 GeV e^+e^- COLLISIONS [a]

M.T. RONAN
Lawrence Berkeley National Laboratory, 1 Cyclotron Road, Berkeley, CA 94720, USA
and
Stanford Linear Accelerator Center, Stanford University, Stanford, CA 94309, USA

In full Monte Carlo simulation models of future Linear Collider detectors, reconstructed charged tracks and calorimeter clusters are used to perform a complete reconstruction of exclusive W^+W^-production. The event reconstruction and analysis Java software is being developed for detailed physics studies that take realistic detector resolution and background modeling into account. Studies of track-cluster association and jet energy flow for two detector models are discussed. At this stage of the analysis, reference W-boson mass distributions for ideal detector conditions are presented.

1 Introduction

High performance detectors are being designed to carry out precision studies of e^+e^-annihilation events in the energy range of 500 GeV to 1.5 TeV. Physics processes under study include Higgs mass and branching ratio measurements, measurements of possible manifestations of Supersymmetry (SUSY), precision Electro-Weak (EW) studies and searches for new phenomena beyond our current expectations. The relatively-low background machine environment at future Linear Colliders will allow precise measurements if proper consideration is given to the effects of backgrounds on these studies. In current North American design studies, full Monte Carlo detector simulation and analysis is being used to allow detector optimization taking into account realistic models of machine backgrounds.

In this paper the design of overall event reconstruction and analysis Java software is discussed. In this study, charged tracks and neutral clusters are used in following standard energy-flow techniques in finding jets. Jet angle and energy measurement errors are compared for two reference detector models and preliminary results for W-boson mass reconstruction from hadronic jets is presented. The status of the software development effort is quantified by some reference performance measures, which will be modified by future work to include background effects.

2 Linear Collider Detector Simulations

The current Linear Collider Detector (LCD) simulation effort on detailed Monte Carlo tracking and event reconstruction studies is focused on two detector design

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Table 1: Large and Small detector specifications.

	Large Detector	Small Detector
Vertex Detector	CCD	CCD
inner, outer radii	1.5-2, 10 cm	1, 6 cm
Tracker: type	TPC	Silicon
inner, outer radii	25-50, 200 cm	14, 50-75 cm
half-length	290 cm	31, 89 cm
B Field	3 Tesla	6 Tesla
EM Calorimeter	Pb-Scin.	W-Si
inner, outer radii	200, 248 cm	75, 110 cm
endplanes	300, 348 cm	150, 185 cm
HAD Calorimeter	Pb-Scin.	Cu-Scin.
inner, outer radii	250, 375 cm	140, 250 cm
endplanes	350, 475 cm	186, 295 cm

options, known as Large and Small [1]. The Large detector is based on a central Time Projection Chamber (TPC) tracking system with a 3 Tesla superconducting coil mounted outside of Electromagnetic (EM) and Hadronic (HAD) calorimeters. The Small silicon tracking detector has a 6 Tesla field with the coil located inside of the Hadronic (HAD) calorimeter. Both detector models include an inner vertex detection system based on similar CCD designs, and an outer muon identification system.

Detector specifications for these Large and Small designs are summarized in Table 1.

2.1 Monte Carlo Generation and Analysis

A number of physics processes have been generated with four-vectors written to StdHEP format files. The GISMO C++ Monte Carlo tracking package is used to model the detectors described in ASCII parameter files [2]. The GISMO program reads the events, simulates hits in the various detectors without resolution smearing and writes out a portable ASCII format data file. A separate Java program reads these files and writes fully formated object data files for input into the JAS / hep.lcd reconstruction and analysis framework [3] written in Java.

SimpleMonteCarlo → MonteCarlo

In this analysis, a **SimpleMonteCarlo** LCD processor [3] was used to sort through the Monte Carlo generator information in extracting the primary **MCParticle** information and final state particles. **SimpleMonteCarlo** implements various methods specified in a general **MonteCarlo** interface, such as:

- getPartons() - returns a **MCParticle** array containing the primary partons
- getLeptons() - returns a **MCParticle** array containing final state leptons

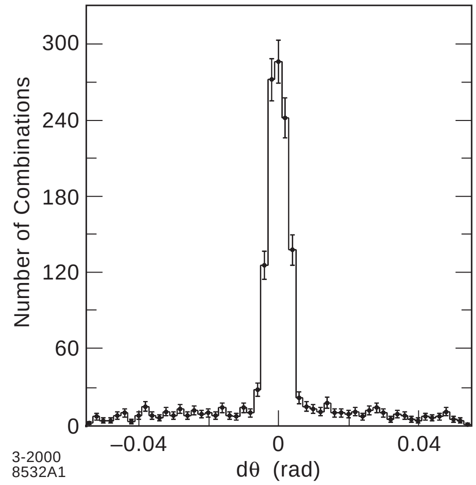

Figure 1: Angular separation between extrapolated reconstructed tracks and the innermost point of EM Calorimeter clusters in the non-bend (r-θ) plane.

3 Track and Cluster Reconstruction

3.1 Tracking and Cluster Finding

The overall Java reconstruction and analysis software design [3] emphasizes flexibility and extensibility in following object-oriented (OO) design rules, allowing for multiple algorithms for track and cluster finding. The analysis described here uses the (**TPCPat2**) track finder developed for full track reconstruction[4] and a **ClusterCheater** algorithm which uses Monte Carlo generator information to "cheat" in finding the clusters due to individual **MCParticles**.

3.2 Track-Cluster Association

The LCD processor **TrackClusterAssociator** associates tracks with calorimeter clusters. For each Electromagnetic (EM) and Hadronic Calorimeter (HAD) cluster, the **TrackClusterAssociator** uses a **HelicalSwimmer** to extrapolate each nearby reconstructed track to the calorimeter depth of the innermost point of the cluster. In track-cluster matching, the innermost cluster point best estimates the interaction or entry point of a track that might have given rise to the cluster. In associating EM Calorimeter clusters with charged tracks, the angular separation between the extrapolated track position and inner cluster point must be less than 10 mrad. in the non-bend (r-θ) plane, Fig. 1, and less than 25 mrad. in the bend (r-ϕ) plane. The corresponding maximum angular separations for HAD Calorimeter clusters were 100 mrad and 125 mrad, in non-bend and bend planes, respectively. Checks were made that there is no charge dependence in the track-cluster matching when the innermost point of the cluster is used.

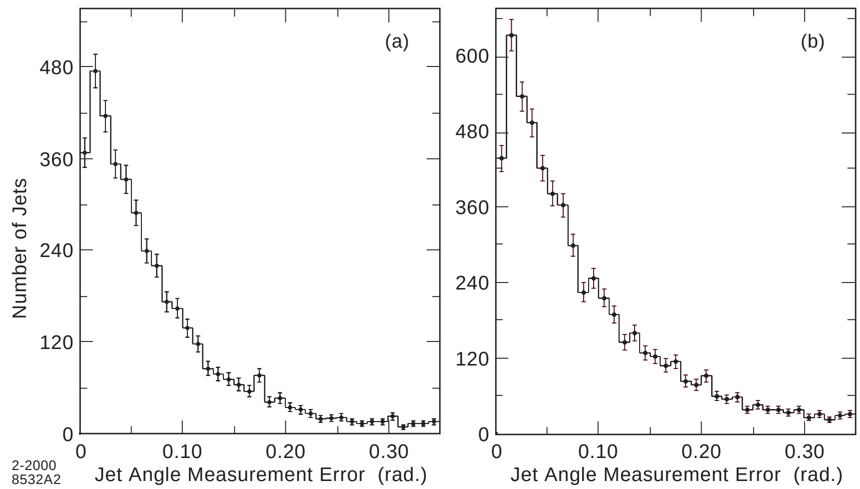

Figure 2: Angular correlation between reconstructed jets and the nearest Monte Carlo parton for the (a)Large TPC and (b)Small Silicon detector designs.

4 Jet Analysis

4.1 Event Selection and Jet Finding

Simulated $e^+e^- \to W^+W^-$events with at least 2 minimum p_t reconstructed charged tracks are selected. To insure that events are full contained in the detector, a cut on the thrust axis determined by the **EventShape** utility ($|cos(\theta)| \leq 0.7$) is applied. In following standard Energy-Flow techniques, reconstructed charged tracks and unassociated neutral calorimeter clusters are used in finding jets. A hybrid Monte Carlo system [5] is used to add a parameterized simulation for particles that may have been missed.

In this analysis, the resulting mixed reconstructed and simulated particles are used by the JadeE **JetFinder** [6] to find the expected number of jets for the events being analyzed, e.g. 2,3 or 4 jets depending on whether the W's decayed leptonically or hadronically. As a check of the analysis, the angle between reconstructed jets and partons from the Monte Carlo generator information, Fig. 2, is typically within 100-150 mrad.

Uniquely identifying each jet with the closest Monte Carlo parton, the jet energy measurement errors for the Large and Small detector designs can be determined, Fig. 3. Under these ideal conditions, both detectors typically measure jet energies to within 5-6%.

4.2 ParticleID [Processor]

The LCD processor **ParticleID** is used to identify leptons as well as b and c-quark jets. After the "Mixed particle" jets have been found, a comparison of the jet directions with all primary leptons and partons from the Monte Carlo generator information, e.g. as shown in Fig. 2 for the parton-jet comparison, is used to

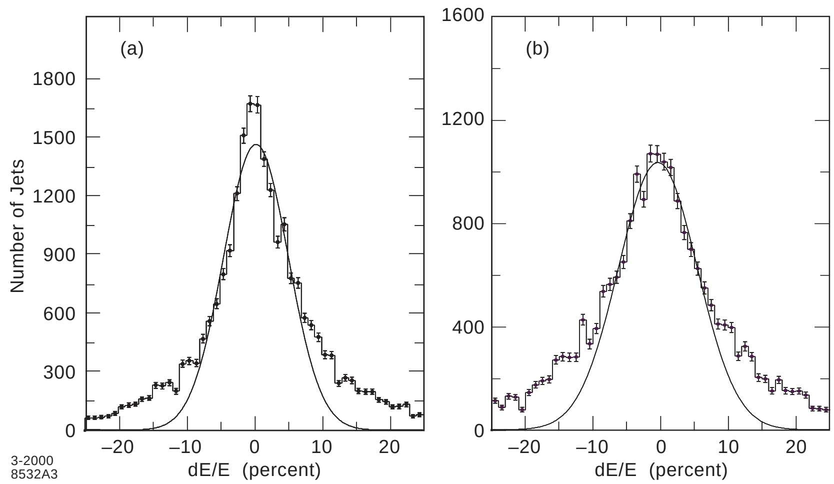

Figure 3: Ratio of reconstructed jet energy to associated parton energy for the (a)Large TPC and (b)Small Silicon detector designs.

associate each reconstructed jet with its parent **MCParticle**. Although the use here of the Monte Carlo information is idealistic, the performance of the reference detectors for lepton and b and c-quark vertex tagging is expected to be excellent. More realistic particle identification will be developed in future stages of the LCD simulation effort.

4.3 Event Analysis

AnlWWEnergyFlow [Driver] → AnlPID → TrackReco

The **AnlWWEnergyFlow** LCD driver [3] specifies the complete reconstruction and analysis chain. In extending the particle identification and jet finding **AnlPID**, and track reconstruction **TrackReco** packages, **AnlWWEnergyFlow** uses the full event reconstruction to analyze hadronic jets in $e^+e^- \to W^+W^-$events. It adds a **AnlJets** processor to classified events as being 2,3 or 4 jet events with an identified number of leptons. Subsequent 3 and 4-jet analysis processors, Sec. 5, analyze W-boson mass reconstruction for the different decay configurations.

A simple analysis module, called **SimpleAnlParticleID**, analyzes energy measurements in high energy e^+e^-events. It's found that roughly two-thirds of the energy appears as charged particles in the events. The central tracking system measures this energy to better than 1%. The neutral component mainly consists of photons from π^0 decays, K_L^0's and neutrons. The photons are well measured by the EM Calorimeter while the K_L^0ś and neutrons are rather poorly measured in the HAD Calorimeter. The energy response for individual particle types are used to calibrate the full calorimeter energy reconstruction. The measured centroid of the jet energy error distribution, Fig. 3, is off by less than 1% for both detector models.

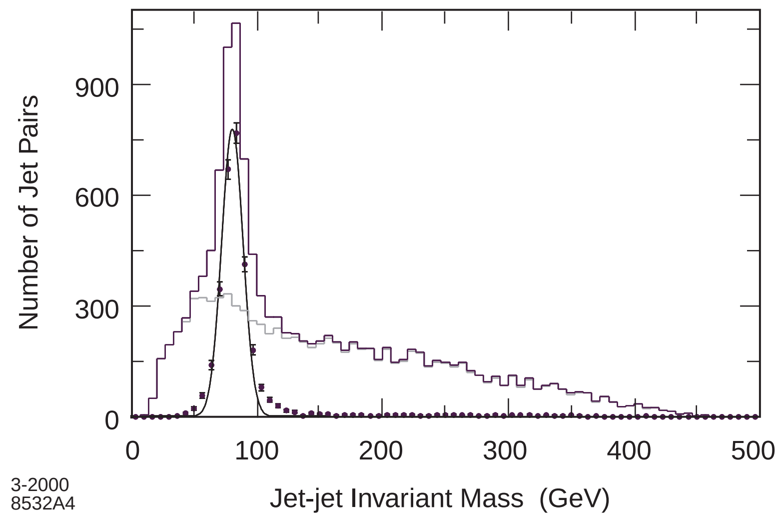

Figure 4: Jet-jet invariant mass distribtion in events with both W's decaying hadronically for the Small Silicon detector design. The solid histogram represents all jet pair combinations. The data points and light histogram are constructed for jets from the same or different W-boson parents, respectively. The curve is from a Gaussian fit to the central W-boson mass region.

5 W-boson Mass Reconstruction

The following analysis processors are included in the WW Energy-Flow analysis package, Sec. 4.3.

5.1 AnlWWJets [Processor] → AnlJets

The **AnlWWJets** LCD processor uses the Monte Carlo generator information to separate events with W-bosons decaying into leptons and quarks, Sec. 4.2. Events with both W's decaying hadronically into 4 jets and those with one W decay leptonically are analyzed separately.

5.2 AnlWW4Jets [Processor]

The LCD processor **AnlWW4Jets** analyzes 4-jet events by separating the events with 4 hadronic jets from those with a lepton and 3 hadronic jets. Reconstructed jet-jet mass combinations for these $e^+e^- \rightarrow W^+W^- \rightarrow 4$ hadronic jet events is shown in Fig. 4 for the Small Silicon detector design. Monte Carlo generator information is used to plot the reconstructed W mass for jets from the same W parent and those from different parents separately. The true W-boson jet pair mass combinations follow a central Gaussian distribution with resolution tails. Gaussian fits in a $\pm$ 5GeV region around the true W mass yield a reconstruction W mass of 80.4 Gev with a measurement resolution of 6-7 GeV for both detector designs. Further developments of the reconstruction and analysis technique will allow a more definitive comparison of the different detector models.

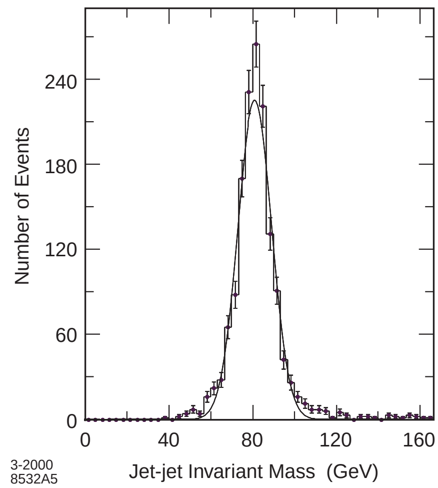

Figure 5: Jet-jet invariant mass distribtion in events with one W decaying hadronically and the other leptonically for the Large TPC detector design. The curve is from a simple Gaussian fit to the simulated data over the full mass range with a fitted mass 80.6±0.2 GeV. Here, the fitted W mass resolution of 7.5±0.16 Gev is larger because of the extended range of the fit, see also Fig. 6.

AnlWW3Jets [Processor]

Events with a lepton and 2 hadronic jets are analyzed by the **AnlWW3Jets** LCD processor. The jet-jet W mass reconstruction in these $e^+e^- \rightarrow W^+W^-$events with one W decay leptonically is straight forward, Fig. 5.

5.3 Analysis of W/Z jet-jet mass separation

An expanded reconstructed jet-jet mass distribution for the Large TPC detector design is shown in Fig. 6. A Gaussian fit in the central W mass region suggests that the inclusive reconstruction of W and Z-bosons from hadronic jets might allow a 2 sigma separation.

6 Plans

Basically, the plan is to continue to optimize the event reconstruction software for this stage of the analysis. That is, high-level optimization of the full reconstruction system may well be beyond the scope of design level studies. Techniques for mixing reconstructed tracks and clusters with parameterized simulations of missing Monte Carlo particles are being developed[5] to allow precision physics studies to be made. As the physics and detector issues are better defined, detailed studies of the variation in performance of the detectors for different effects will be determined by understanding the sensitivity to deficiencies in the reconstruction, e.g. the effect of missing low p_t or small angle tracks, unresolved calorimeter clusters or unassociated charged clusters.

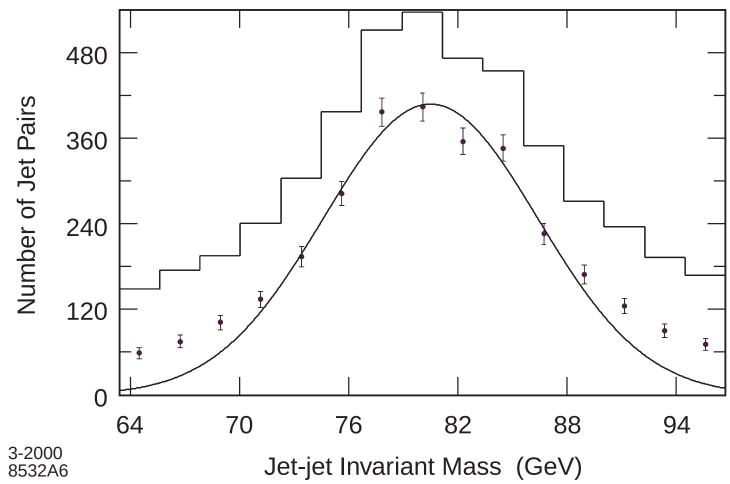

Figure 6: Jet-jet invariant mass in events with both W's decaying hadronically for the Large TPC detector design. The solid histogram represents all jet pair mass combinations. The data points are constructed for jets from the same W-boson parent. The curve is from a Gaussian fit to the central W mass region with a fitted mass and resolution of 80.5 ± 0.3 GeV and 5.9 ± 0.6 Gev.

6.1 Background simulations

Detailed machine background simulations have been made for the most significant sources of backgrounds. These backgrounds will be superimposed on simulated events before reconstruction in the next phase of these studies.

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