American Large Detector (LD) Design Studies

M. Ronan
LBNL (Berkeley)

Outline

Detector performance requirements
- Momentum resolution
- Jet energy resolution

Tracking
- Central TPC
- Intermediate / forward tracking

Calorimetry
- EM / HAD

Detector response simulations
- Fast Monte Carlo (FMC)
- GISMO

Hybrid Monte Carlo studies
- Using reconstructed tracks and clusters.

Detector Performance Requirements

- Momentum resolution $dp_T/p_T < 1 \times 10^{-4} * p_T$ [GeV]
- Tracking 2-hit separation < 2 mm
- Timing dT < 2 nsec
- Track-cluster matching < 1 mm
- Jet energy resolution $dE_{jet}/E_{jet} < 30\% / sqrt(E_{jet})$
- Good W/Z separation
- ...

W/Z separation

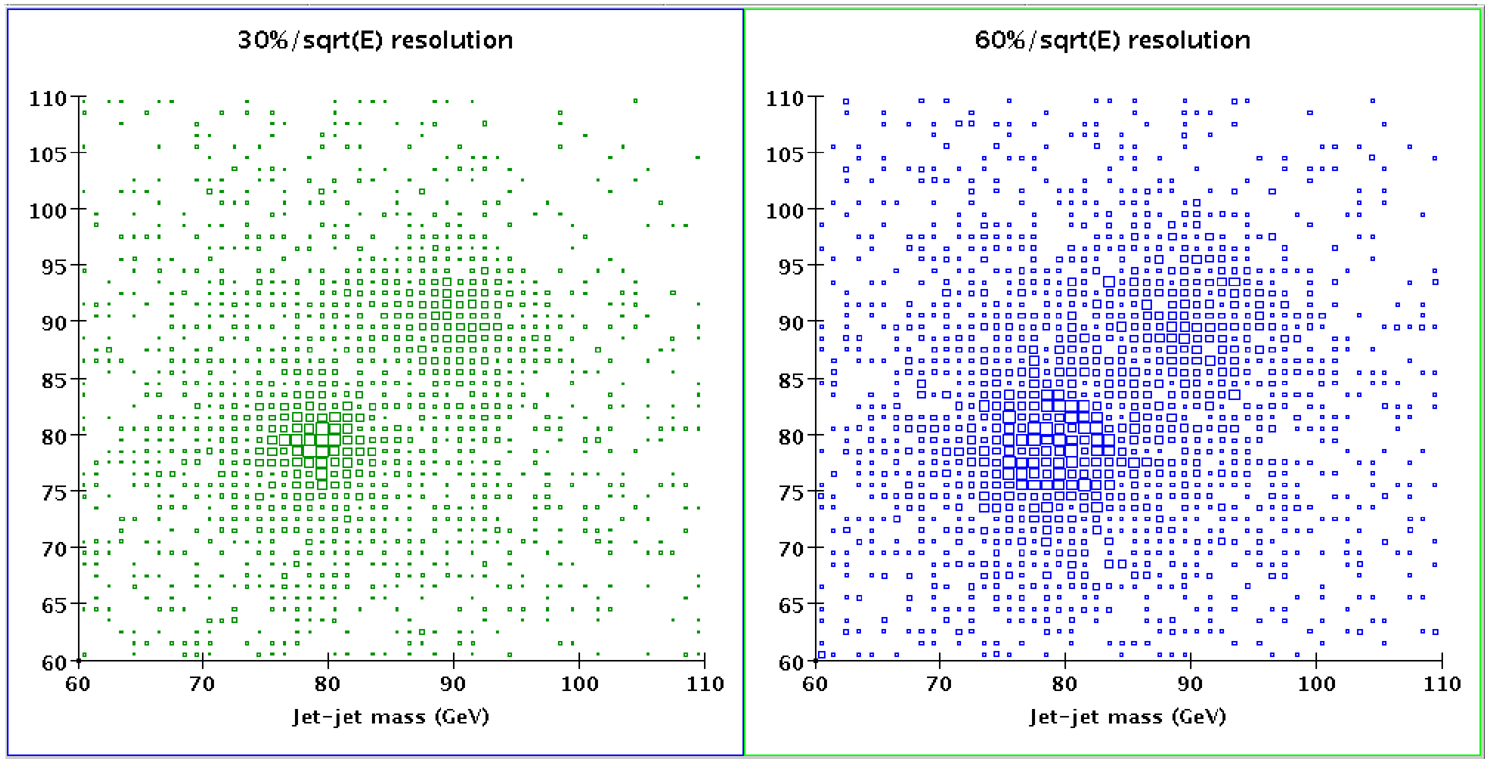
One should choose detector simulations carefully. Some detector models can be much more realistic than others, but are often less flexible.

Simple detector models: Smear MC Particle jets.

The required detector performance for reconstructing jets is often given as

dE/E(jet) = 30%/sqrt(E)

The resulting separation of WW and ZZ events is shown in comparison to what was achieved by the LEP detectors.



Ideal detector models: Fast Monte Carlo's (FMC's)

Realistic detector models: e.g. SimDet and QuickSim

Full detector simulation: LCD Framework packages and Hybrid Monte Carlo system.

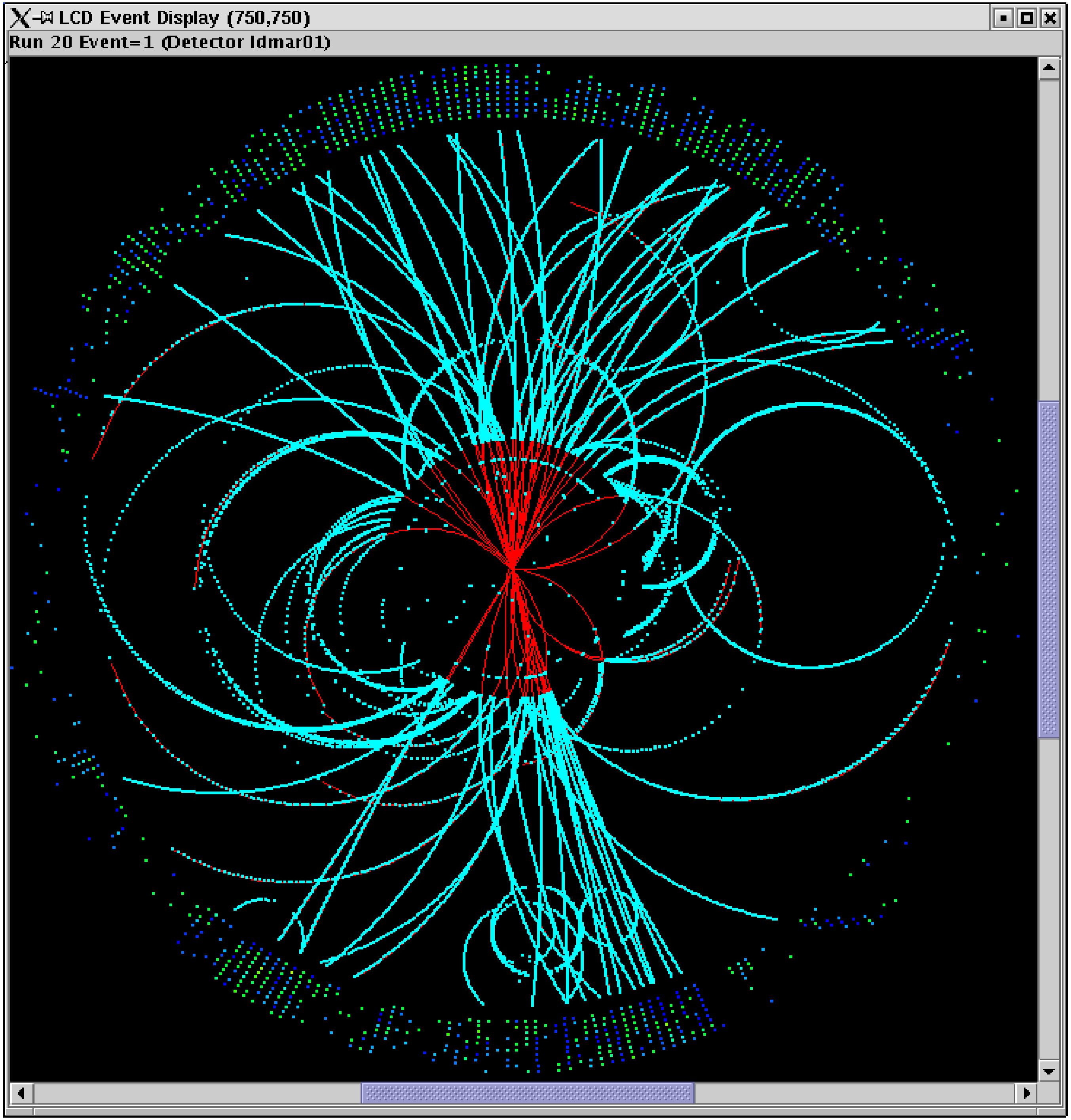
American Large TPC Detector Simulations

Geant4 Detector Simulation

Provides detector hits

LCD Analysis Modules:

- Hit smearing
- TPC Pattern recognition
- Calorimeter clustering
- Event display
- ...
- LCIO
- JAS histograms
- AIDA tuples



Detector: **ldmar01**

Hits: TPC (cyan),

Inner trackers (cyan)

EM Cal (blue)

Tracks (red)

Clusters (green)

American Large TPC Detector Design

4/12/04

Large (TPC) reference detector

Large TPC Chamber

dimensions	radius 2 m, half-length 2.5 m
pad layout	144-256 pad rows
readout options:	Wire or GEM or Micromegas

Electronics

Next generation	over 1M channels

Magnet

outside Cal.	3 T

Reconstruction **3D Pattern Recognition**

LCD Java Framework

modular design

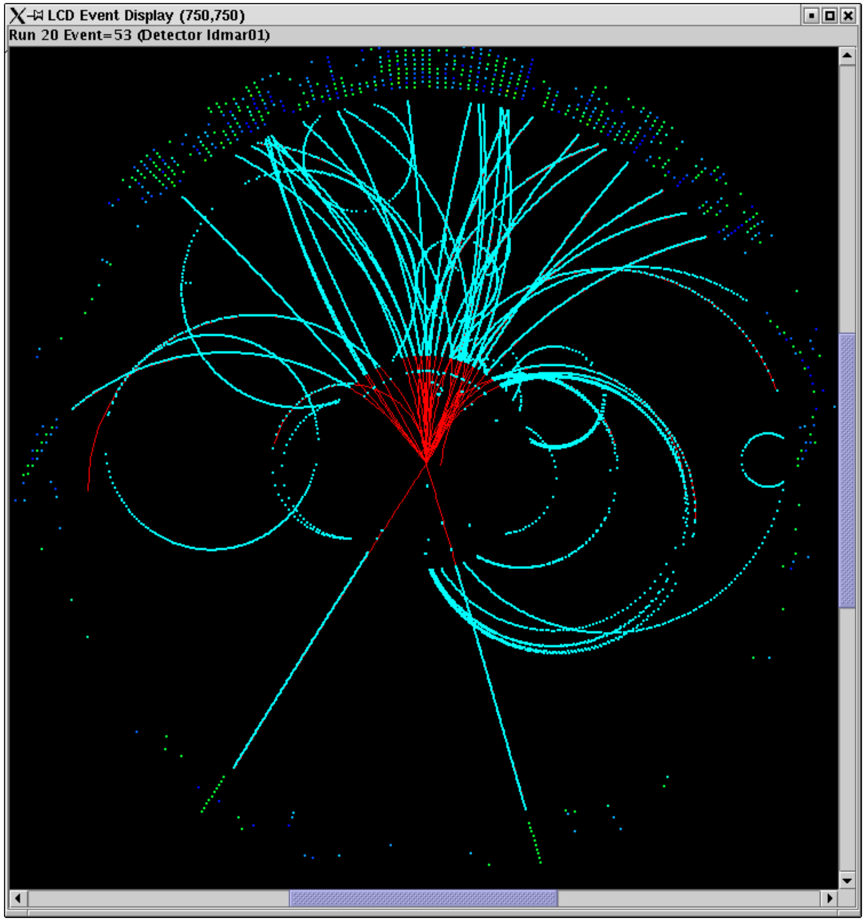
TPC Simulation

smear space points with 100-140 m resolution

no-detector effects

Tracking efficiency ~ 99%

Z(μμ) + H(jets) event



Hits: TPC (cyan), EM Cal (blue)
Tracks (red), Clusters (green)

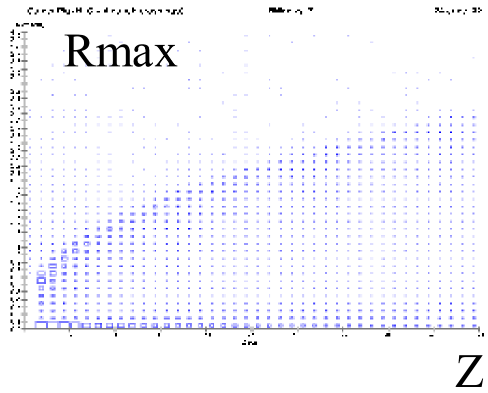
Background studies

Presented at LCWS, Jeju Is., Korea Aug. 26-30, 2002.

e+e- pair backgrounds

Produced in beam-beam collisions.

Strongly affected by detector magnetic field.



Rmax vs. Z position of electrons and positrons produced in beam-beam interactions.

Large detector simulation

TPC hits concentrated at small radius do not present a problem for 3D tracking.

TPC timing (2 nsec) provides good background e+/e- track rejection.

TPC hits

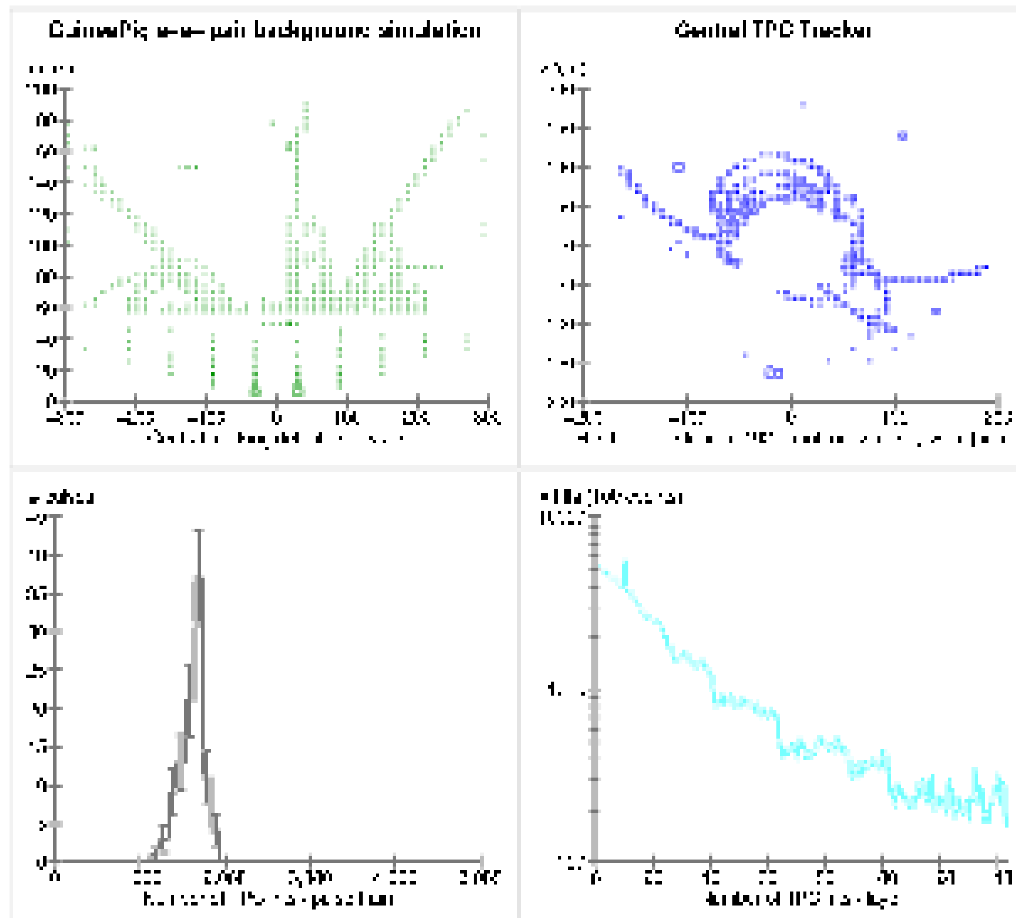


Figure (a.) R vs Z plot and (b.) X-Y plot of simulated TPC hits, (c.) Number of hits per bunch crossing, and (d.) Radial distribution of hits.

Multijet LC physics analysis

LC Note: ***LC-PHSM-2003-048***
Presented at LCWS, Jeju Is., Korea Aug. 26-30, 2002.

Higgsstrahlung signal and backgrounds

LC Physics generators
- **Pandora** M. Peskin
  - Developed spec. for LC simulations.
- **Pythia** T.Sjostrand
  - Standard HEP generator.
- **Whizard** W.Kilian
  - Automatically generates matrix elements for all processes.

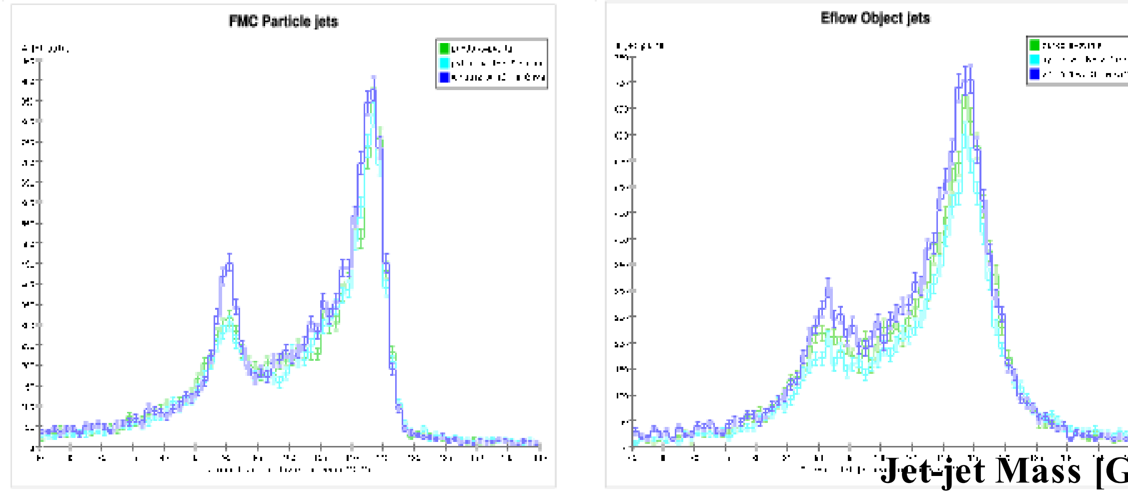


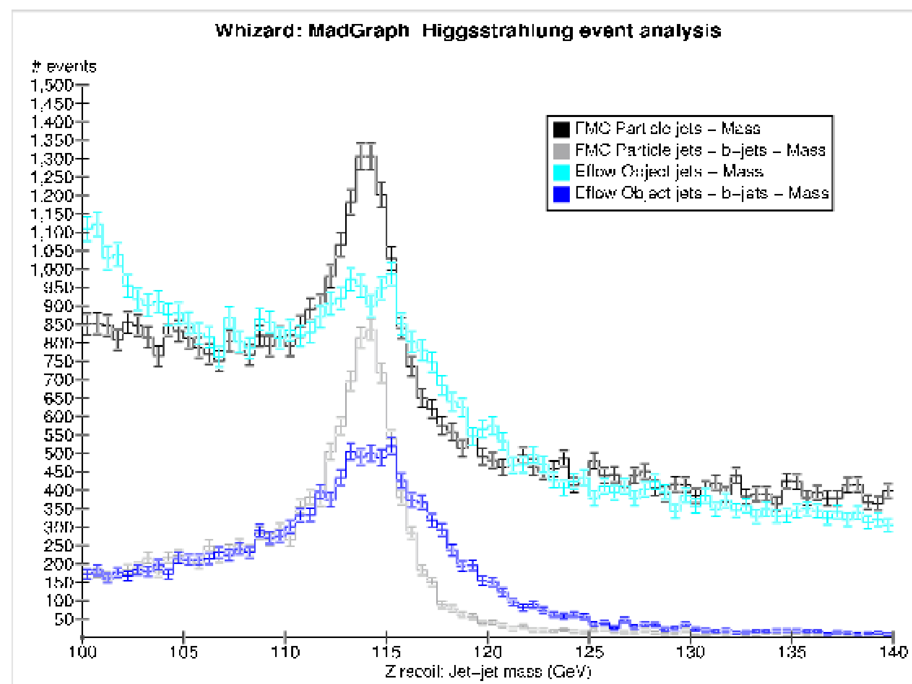
Figure 2: Jet-jet mass distributions: (a) for FMC Particle jets recoiling against a reconstructed Z candidate and (b) for SimDet "Energy-flow" Object jets.

Studied all LC backgrounds to Higgsstrahlung process.

Java-Native Interfaces (JNI)

Monte Carlo generators (e.g. Pandora, Pythia ...):
written in Fortran, C++ and Fortran 90/95

LC Detector simulations:
- U.S. Fast Monte Carlo (**LCD**)
- European detector simulation (**SimDet**)
- Asian detector simulation (**QuickSim**)



Jet-jet Mass [GeV]

LC Note: ***LC-Tool-2003-015***
Presented at CHEP 03, San Diego, CA Mar. 24-28, 2003

Hybrid Monte Carlo System

4/12/04

Using a Hybrid MC system to study detector effects.

FMC – Ideal detector simulation:

Perfect tracking and cluster efficiency

Perfect energy flow reconstruction

Smeared MC Particle Jets

Includes hadronization effects.

30%/sqrt(E) - LC design goal

60%/sqrt(E) - ALEPH reference

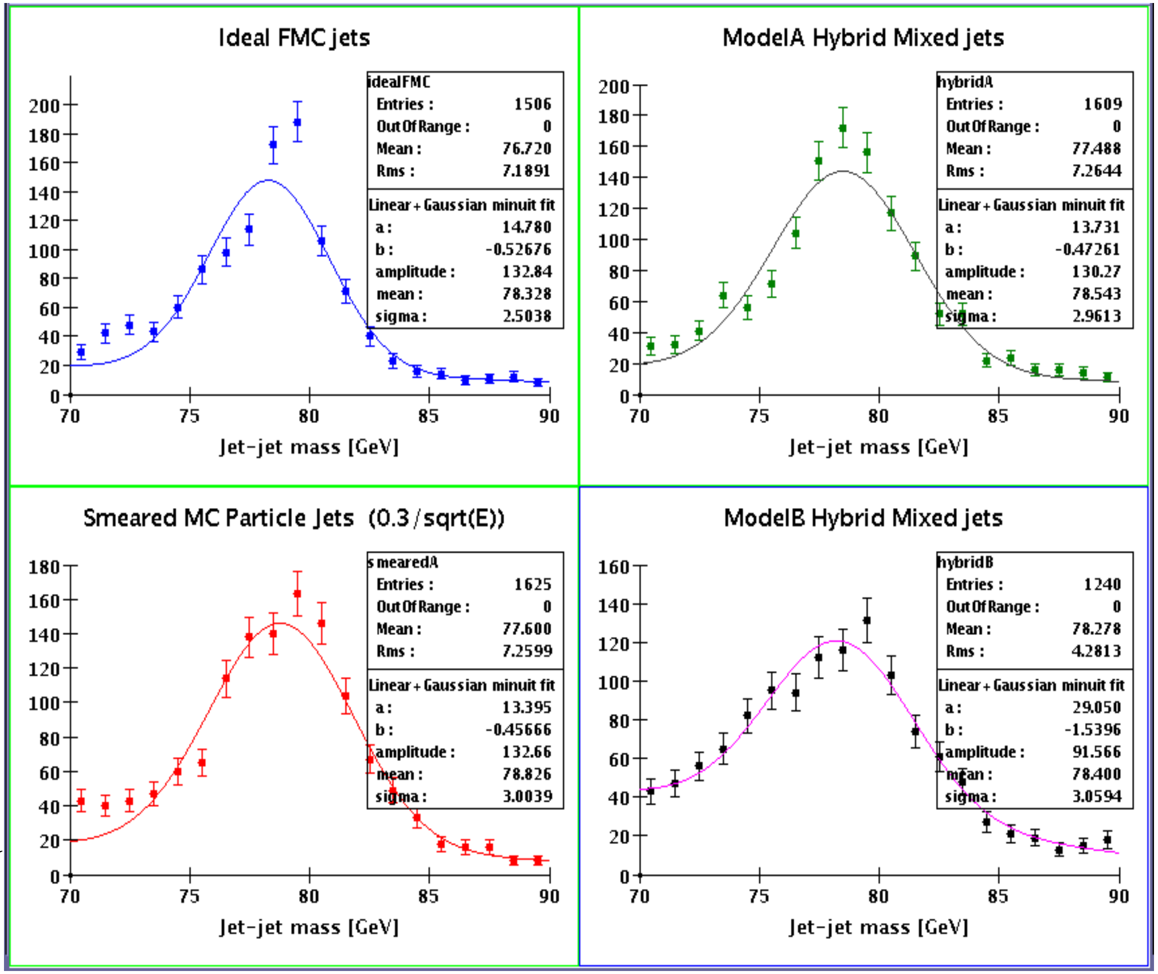
Hybrid MC "Reconstructed" Jets

- Use reconstructed charged tracks and clusters with an energy flow algoritm.
- Add missing tracks and clusters from FMC simulation or MC information.

Hybrid A - Use reconstructed tracks

Hybrid B - Use reconstructed tracks and clusters with perfect energy flow.

W mass fits



Ideal FMC W mass resolution of 2.5 GeV is somewhat better than the 3.0 GeV resolution obtained for the LC design goal of 30%/sqrt(E). Hybrid MC W mass resolutions of 2.9 and 3.0 GeV are obtained using reconstructed charged tracks and FMC neutrals, and reconstructed charged tracks and neutrals, respectively.

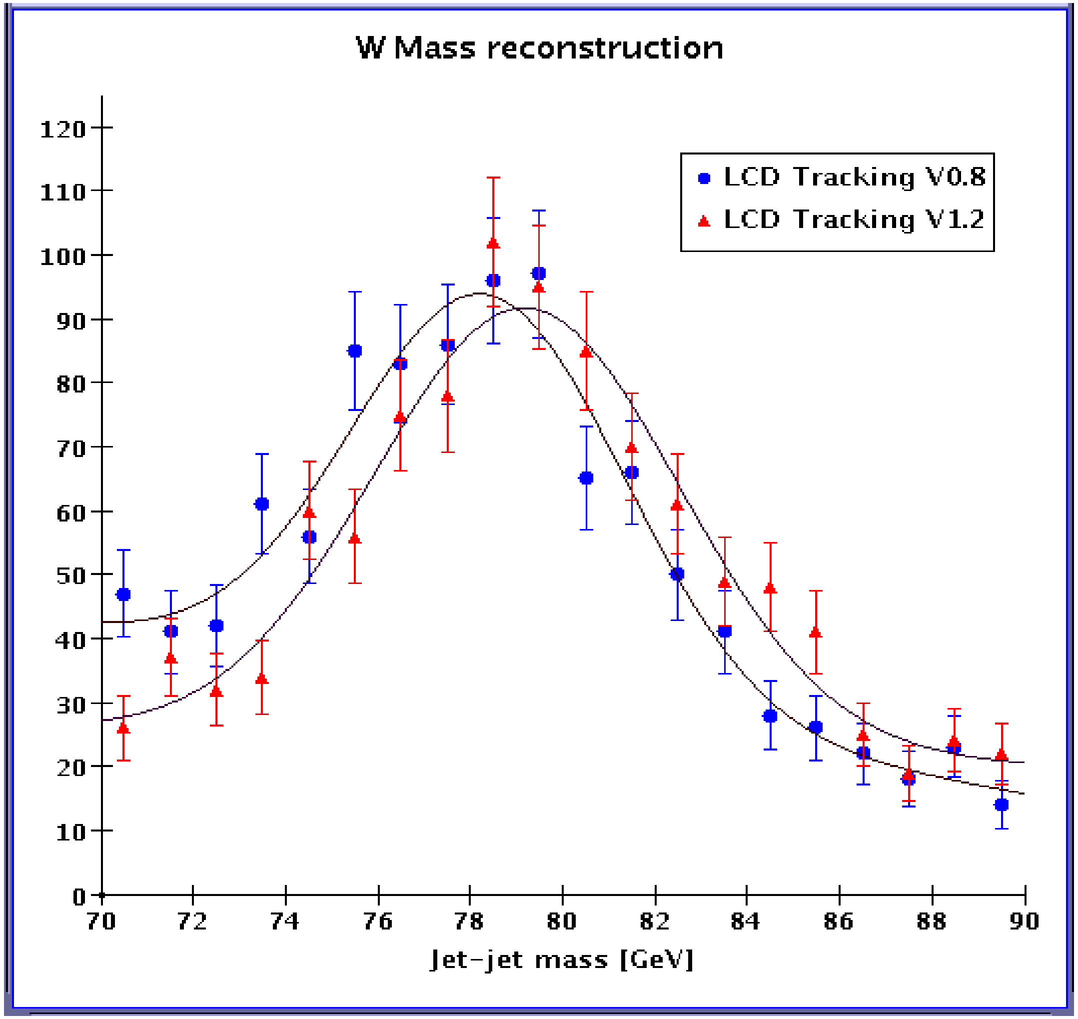
Tracking studies

We can use the Hybrid Monte Carlo to measure the significance of improvements in detector design or in reconstruction algorithms.

For example:
The original LCD TPC 3D tracking code was written in late 1998 in preparation for the Sitges LCWS. It was refered to as V0.8.
Various improvements in the tracking were made prior to Snowmass in 2001 and the Jeju LCWS meeting, resulting in V1.2.

Running the HMC with the two different versions of the code allows a quantitative measure of the improvement.

Note: In these comparisons, the charged tracking efficiency was improved in V1.2. The HMC allows investigation of resulting unassociated neutral calorimeter cluster.



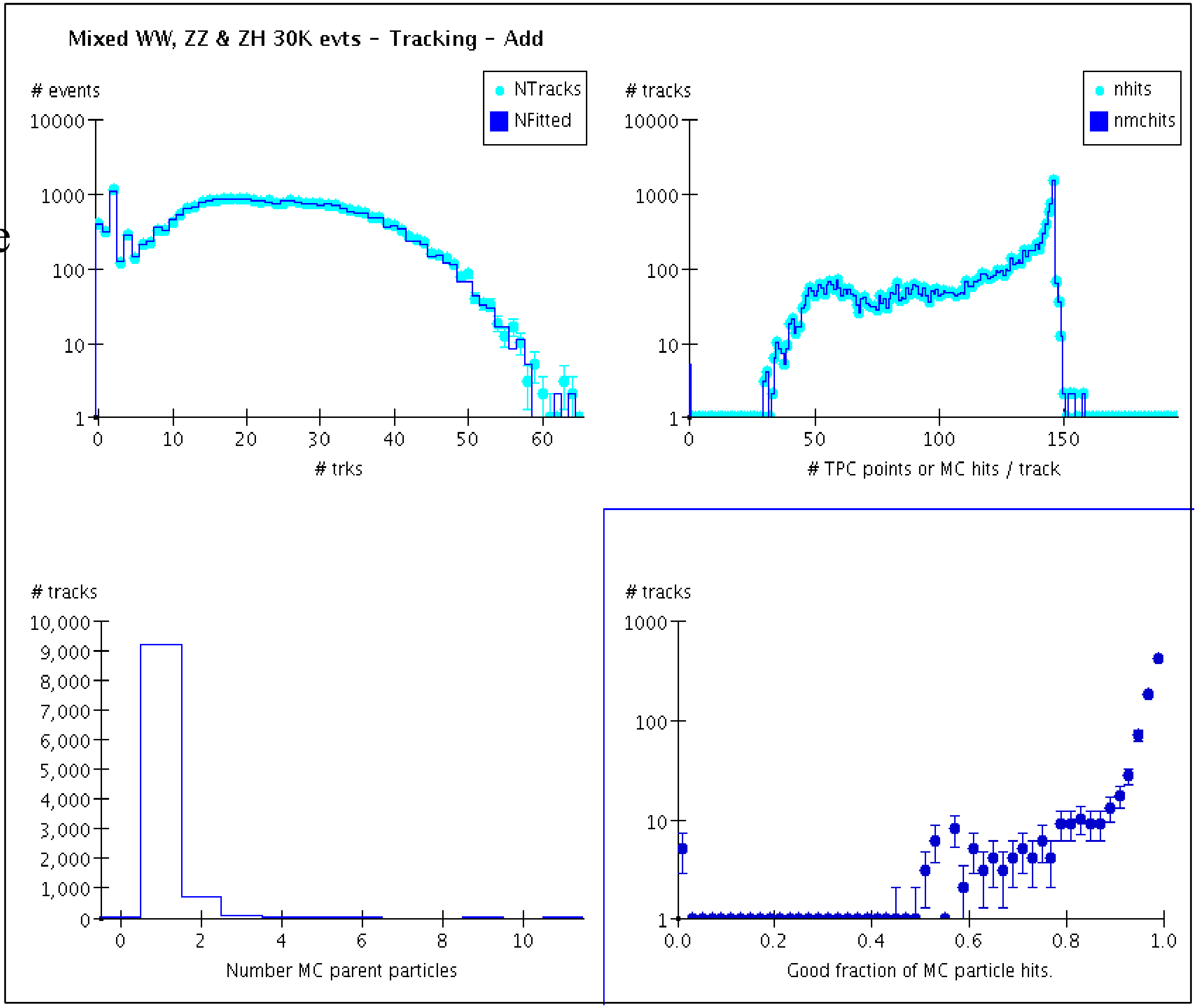
Reconstructed Jet-jet W mass using reconstructed charged tracks and FMC neutrals.

-- Track reconstruction

The standard TPC pattern recognition and track fitting software was improved prior to Snowmass in 2001.

The tracking efficiency was increased and tracking roads were narrowed to minimize the mis-assignments of hits to tracks.

However, these simulation have been done without a detailed TPC response simulation.

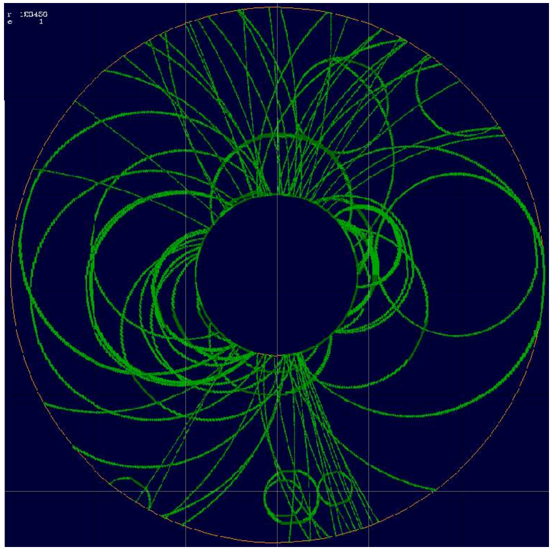


Reconstructed tracks in 30K WW, ZZ and ZH events. Figure (a.) displays number of tracks found, (b.) number of TPC hits per track, (c.) number of MC parents, and (d.) fraction of correctly assigned hits.

-- TPC Response Simulation and Pattern Recognition

4/12/04

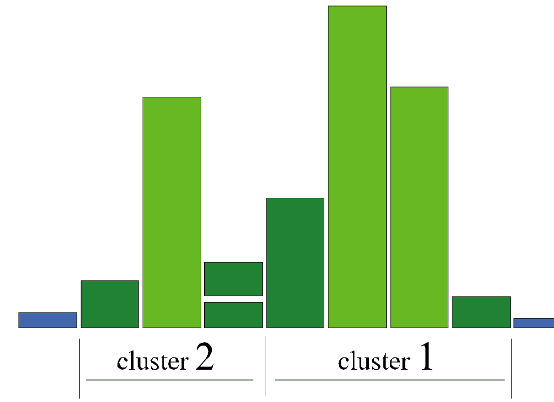
Cornell

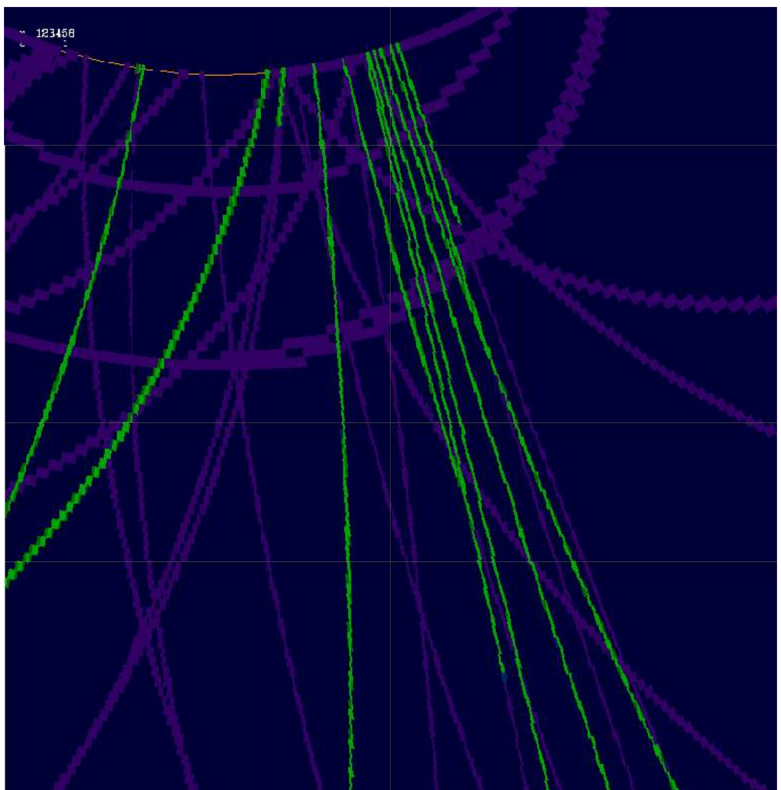


Response simulation
e.g.

<u>Clustering</u> in r-ϕ

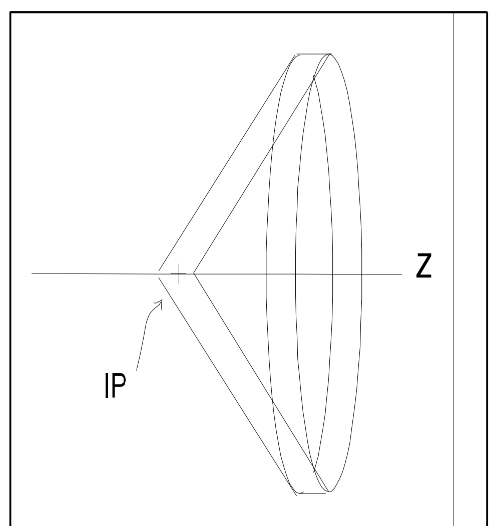
criteria for minimum **central pad** , added **adjacent** pads **splitting** at a local minimum, can lead to pulse height merging and incorrect clustering.

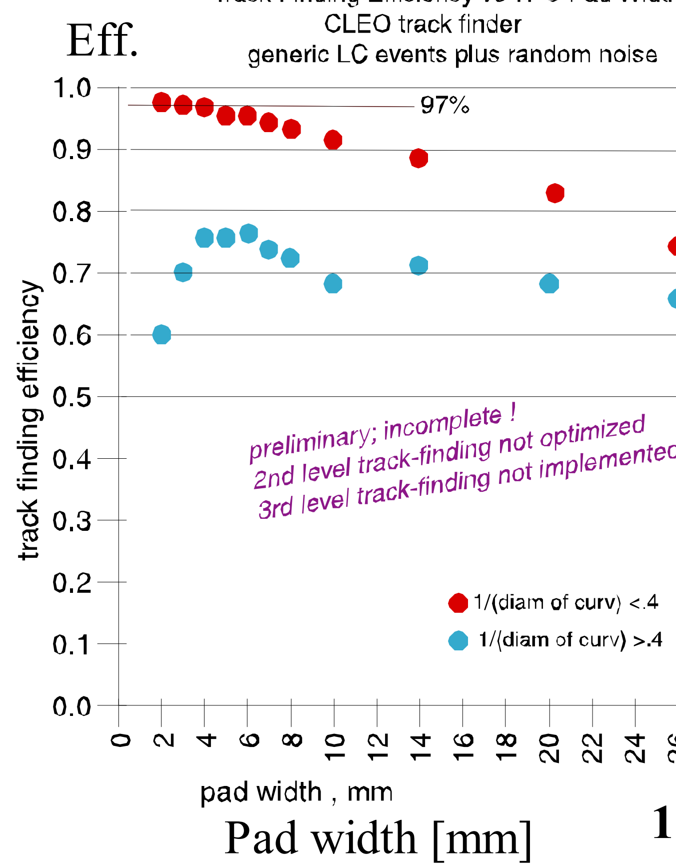




Pattern recognition

Segments found in pre-selected, I.P. pointing, cones are used as seeds for finding tracks.





American Large Detector (LD) Design Studies

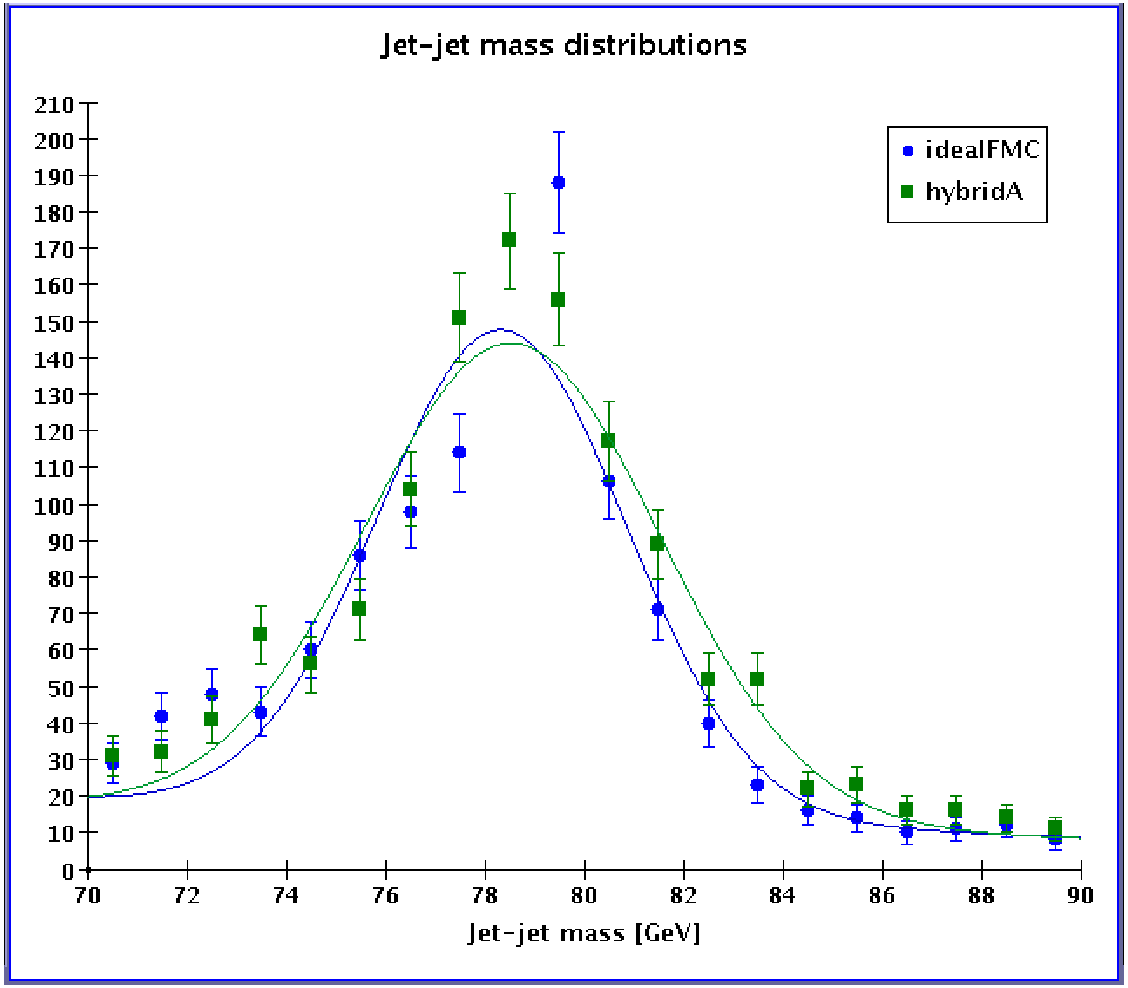
-- Studies of W mass resolution and W/Z separation

We can use the Hybrid Monte Carlo to quantify the performance of the tracking system by comparing it to FMC simulations.

The American Fast Monte Carlo uses parameterizations of the expected track momenum resolution, and neutral energy measurement. It assumes perfect tracking and cluster finding efficiency, and perfect energy flow.

Here the HMC ModelA uses reconstructed tracks and FMC neutrals. In this comparison, any missing charged tracks are added in to achieve an overall tracking efficiency of 100%.

This comparison thus demonstrates that there are no large tracking errors being made in the reconstruction.



Reconstructed Jet-jet W mass using reconstructed charged tracks and FMC neutrals compared to the idealistic FMC simulation.

Other comparisons can be made to determine the full effects of tracking inefficiencies using the Calorimeter to find energy from missed tracks.

-- Intermediate and small angle tracking

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<u>Intermediate tracker options</u>:

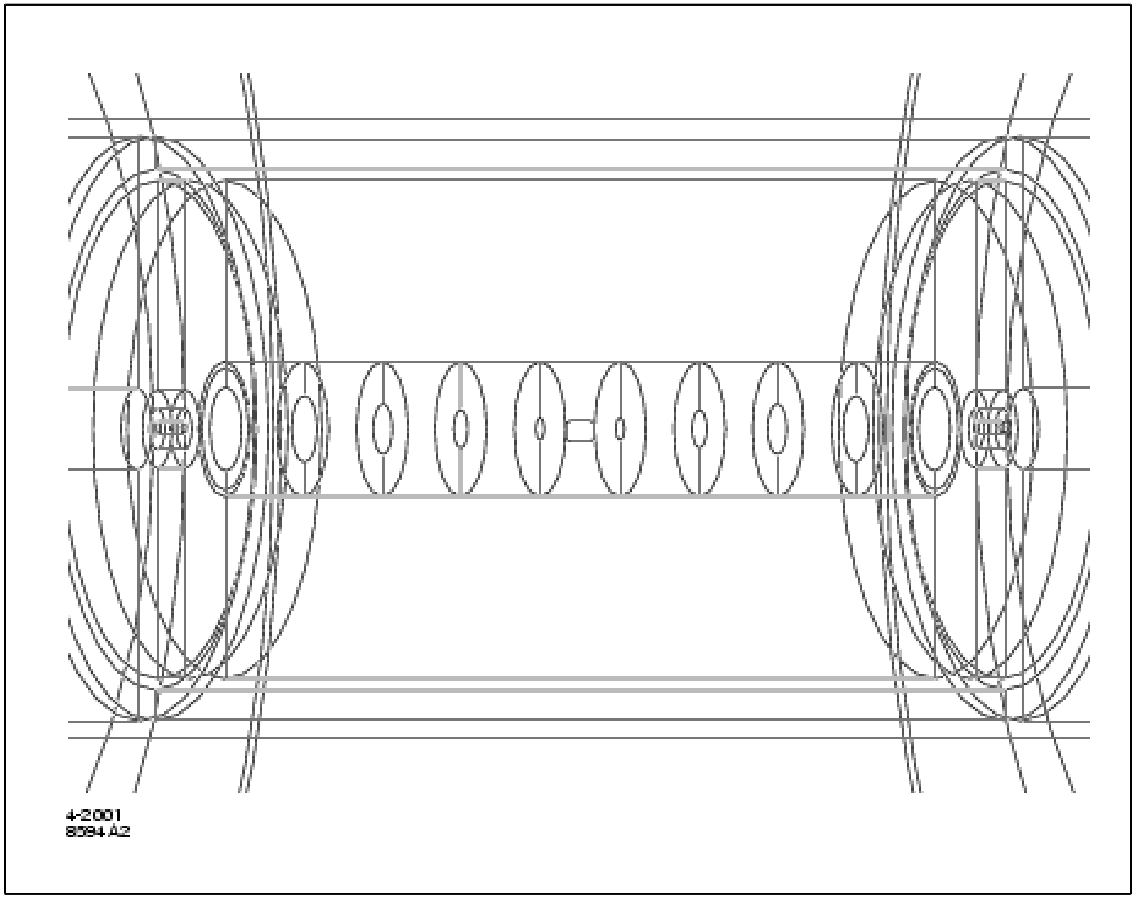
Scintillating fiber

Silicon strips

<u>Small angle tracking</u>:

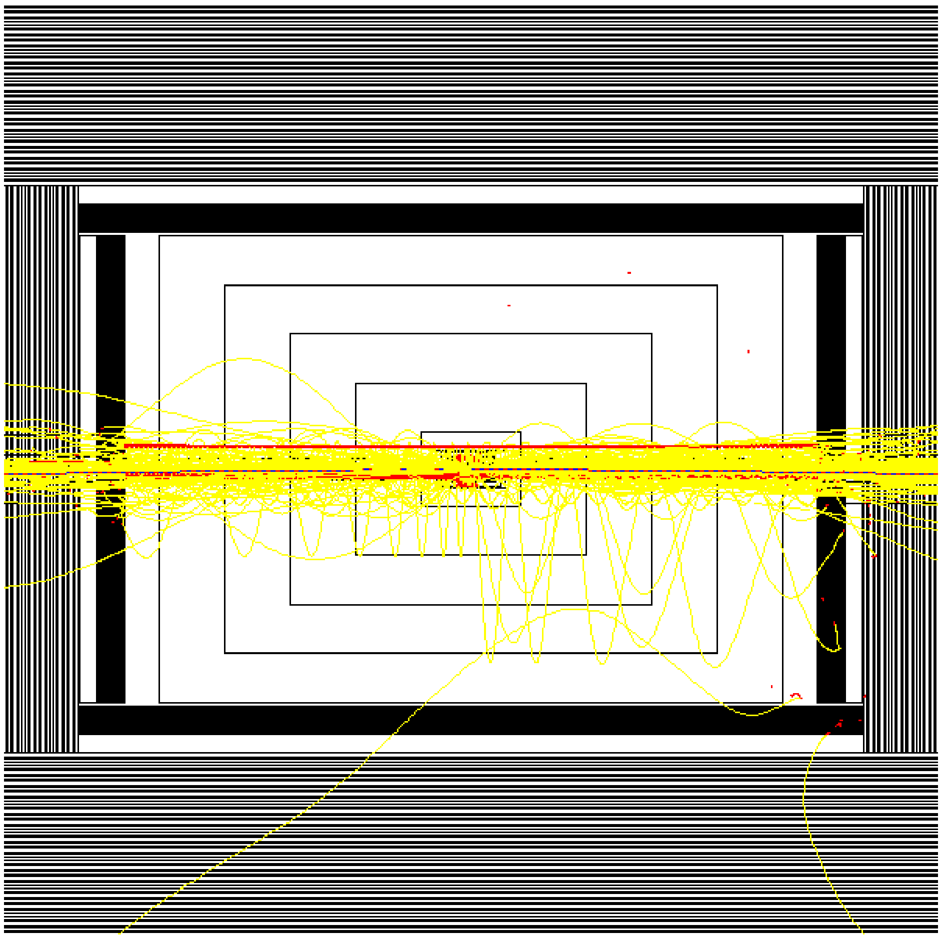
GEM or Micromegas planes

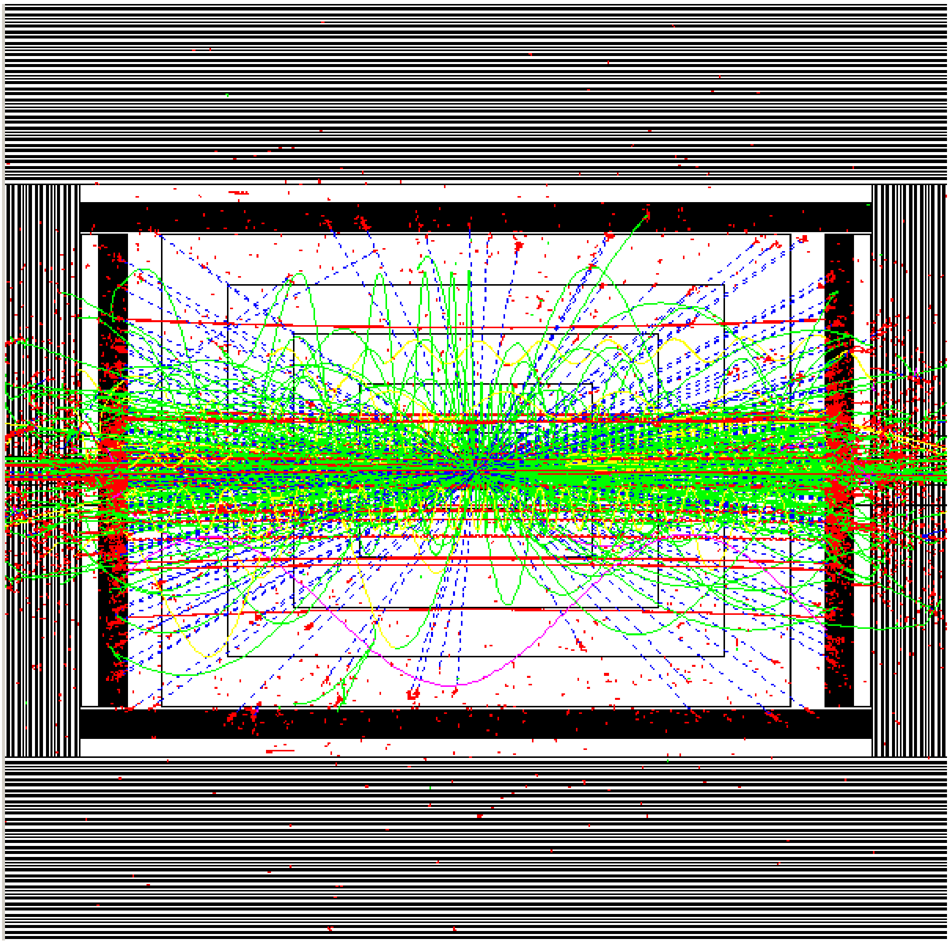
Silicon disks



WIRED 3D display of central tracking elements.

Yellow = muons Red = electrons Green = charged pions
Dashed Blue = photons with E > 100 MeV





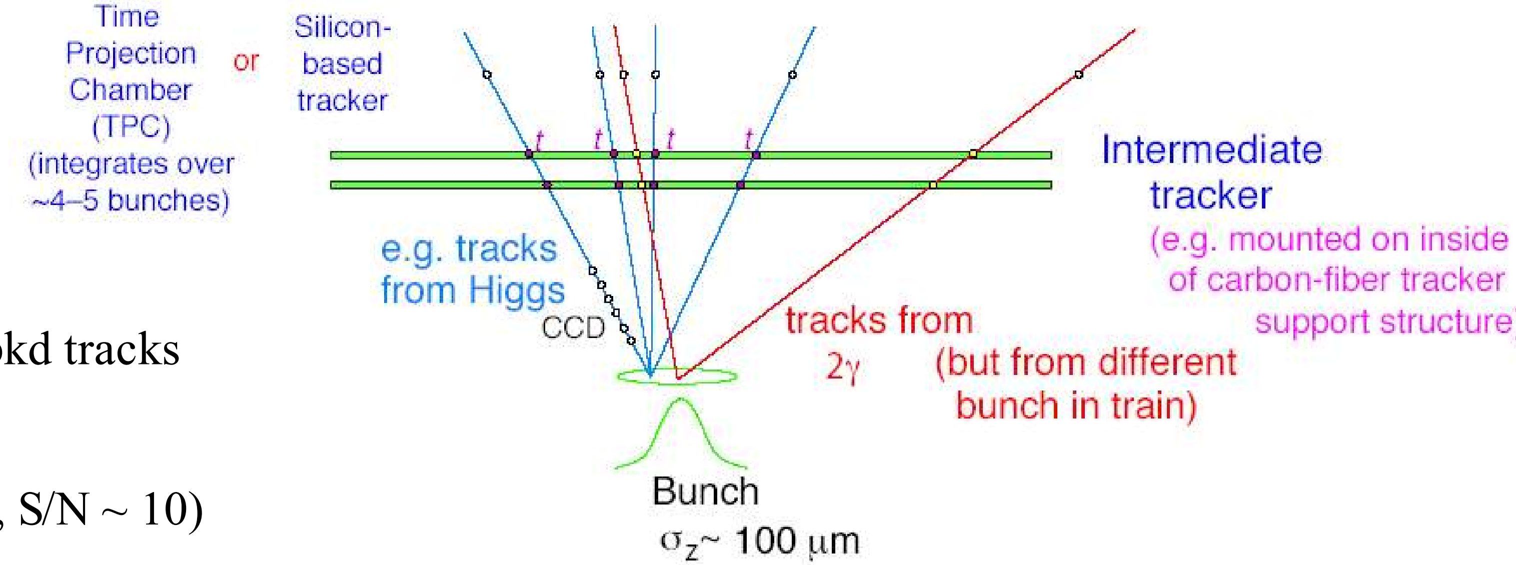
154 □□ pairs / train
56 GeV / train detected energy
24 detected charged tracks / train

56 hadronic events / train
no pt cut; Ecm down to □□threshold
454 GeV / train detected energy
100 detected charged tracks / train

-- Bunch Timing with Scintillating Fibers

Indiana & Notre Dame

Warm machine
bunch structure
192 1.4 nsec
pulse rate 120 Hz

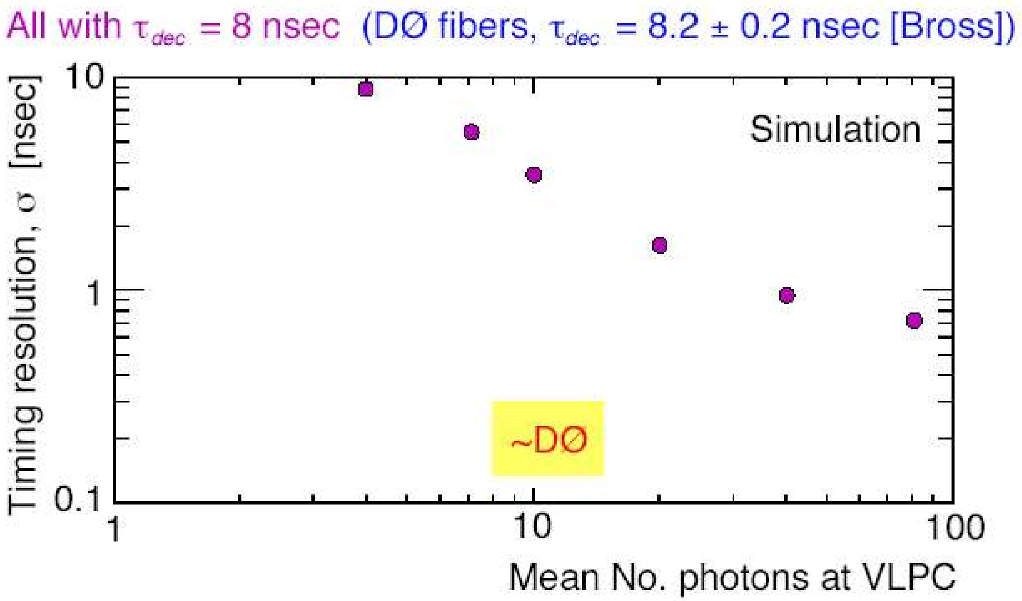


γγ background tracks
54 tracks / train
need timing to eliminate bkd tracks

TPC 2.4 nsec
SiD 150 nsec (3 μsec, S/N ~ 10)

Track bunch timing
Use scintillating fiber int. tracker

Readout with
VLPC - Visible Light Photon Counter
APD - Avalanche Photodiode (Geiger mode)
SiPM - Silicon Photon Multiplier



-- Overall momentum resolution

One can use **LCDTRK** to calculate the expected momentum resolution for different detector designs including intermediate and forward tracking.

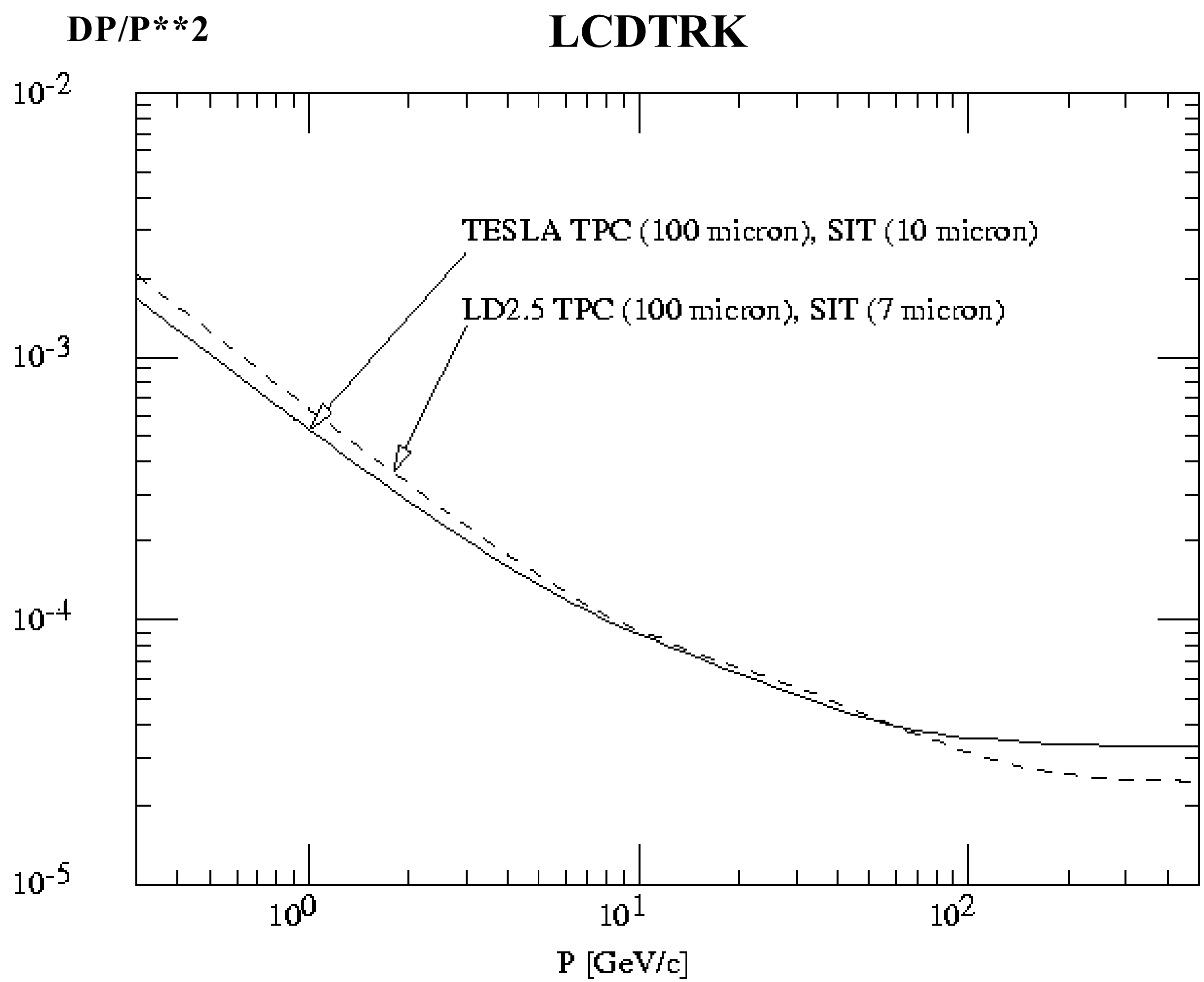
Here is a comparison of a modified version of the American LD detector to the TESLA TPC performance.

Both TPC's are taken to have the same pad size and point resolution.

The TESLA TPC has better low momentum resolution since its inner radius is smaller.

The assumed intermediate tracker resolutions are taken from the corresponding studies resulting in a difference at high momenta.

There should be no difference in the assumed SIT resolution. The comparison indicates how the SIT could improve overall momentum resolution.



Comparison of TESLA TPC and updated American Large Detector (LD2.5) momentum resolution.

-- Forward Tracking Detectors

Initial studies and concepts for forward tracking detector were presented at the recent ALCPG meeting at SLAC.

GEM Detectors

L.Sawyer, LA Tech

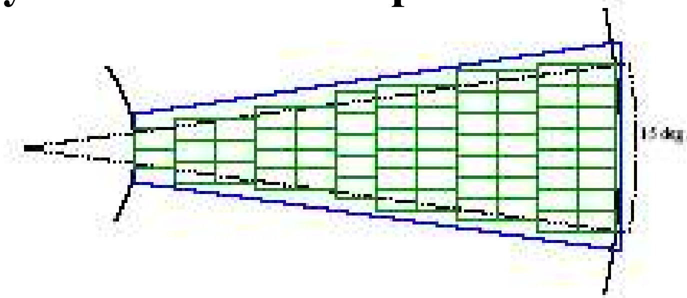
Detailed GEM simulations in progress.

Thin silicon detectors:

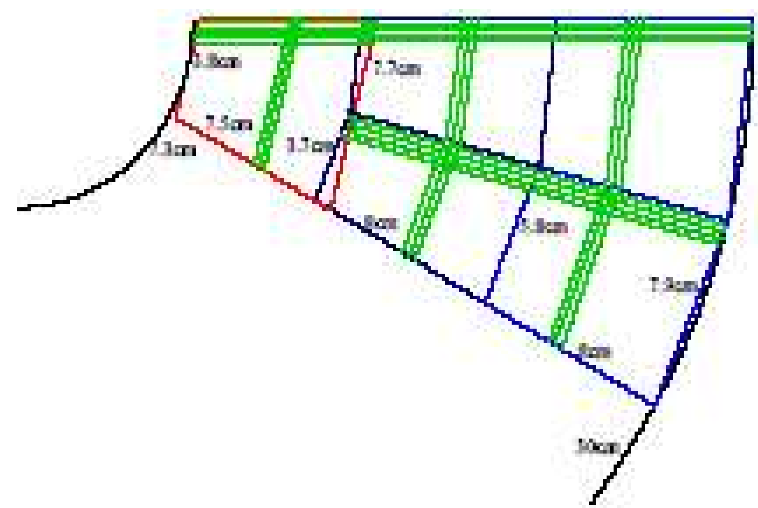
D.Bortoletto, Purdue

- Technical problems:
  - Manufacturing of thin devices is difficult
  - Thinning after processing is difficult
  - Industry has expressed interest in thin silicon devices
  - Collaboration with vendors is critical
- How thin:
  - The m.i.p. signal from such a thin, 50μm, silicon sensor layer is only ~3500 e-h pairs.
- R&D at Purdue has started last year. We got quotes from two vendors: Sintef and Micron
- Sintef: min. thickness 140 μm on 4 inch wafers
- Micron: 4" Thickness range from 20μm - 2mm, 6" Thickness range from 100μm - 1mm

Layout for a forward pixel detector



Layout for a forward strip detector



...

LD Calorimeter Model

EM Calorimeter

Lead / Scintillator
40 layers of 4+0.5 mm Pb, 1+0.5 mm Polystyrene

Expected resolution **15 % / sqrt(E)**

Barrel
Inner, outer radii 196, 220 cm Outer z
Endcap
Inner, outer planes 297.5, 321.5 cm

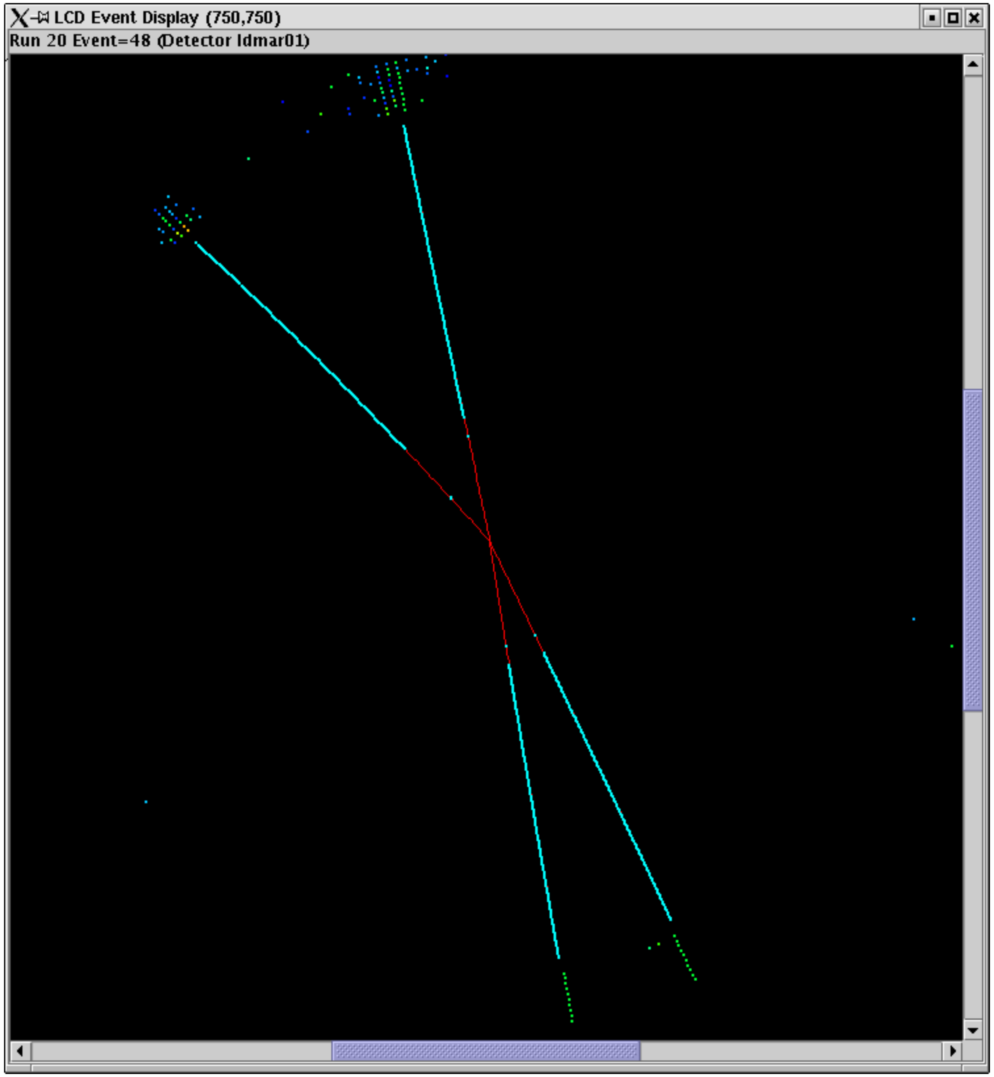
HAD Calorimeter

Lead / Scintillator
Stacks of 8+0.5 mm Pb, 3+0.5 mm Polystyrene
Only 3 samples in depth !!!

Expected resolution **40 % / sqrt(E)**

Barrel
Inner, outer radii 233.4, 365.4 cm Outer z 466 cm
Endcap
Inner, outer planes 334, 466 cm

Higgsstrahlung event



Hits: TPC (cyan), EM Cal (blue)
Tracks (red), Clusters (green)

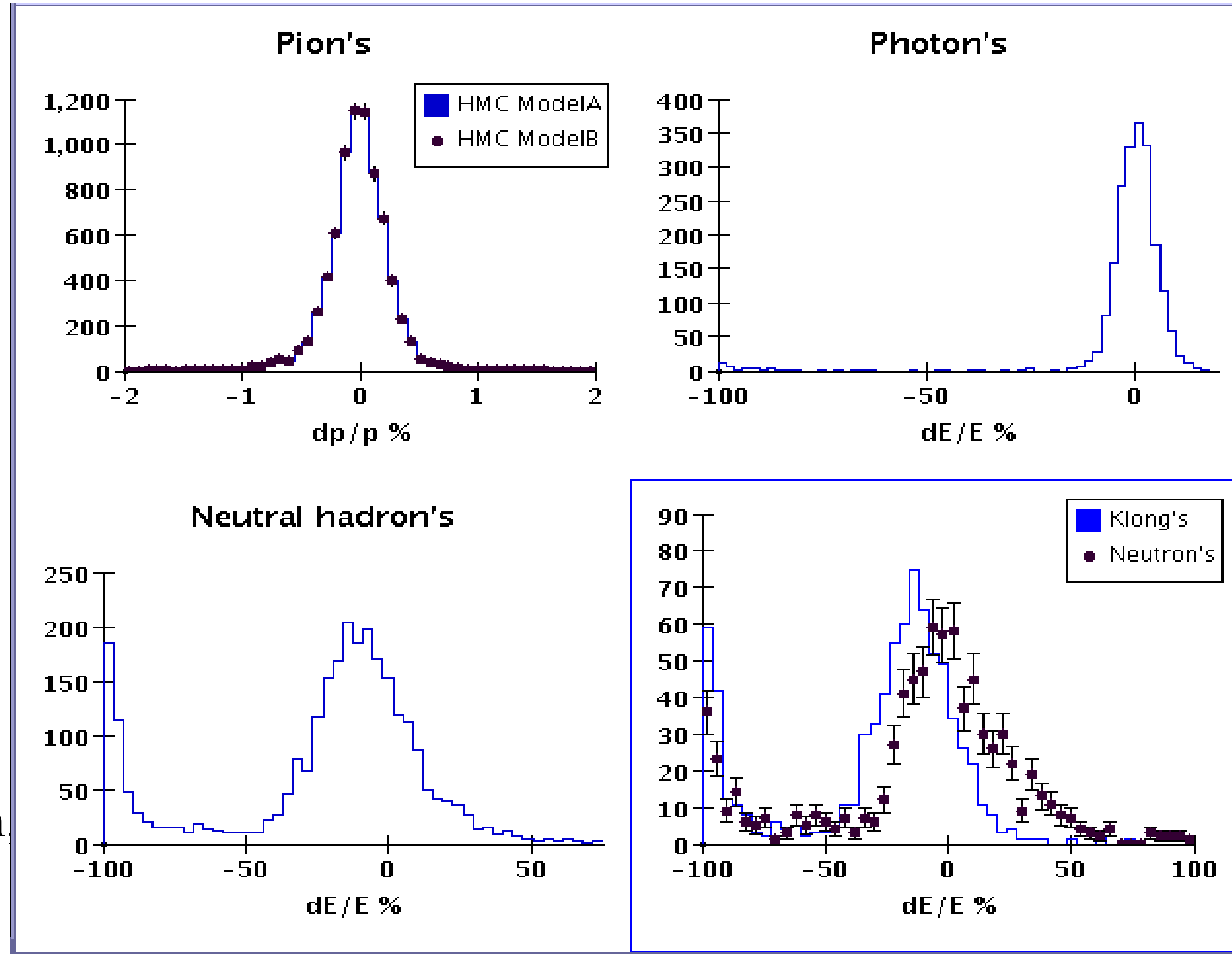
-- Measurement errors

The Hybrid Monte Carlo can also be used to study detector response to different types of particles.

As the HMC processor reads the lists of reconstructed tracks and clusters, comparisons can be made with the original MC Particle.

The HMC Selector is invoked for each particle as the list of reconstructed objects is being filled.

Similarly, if the option is chosen, the Selector will be invoked for all non-reconstructed FMC tracks and clusters, and any other remaining MC Particles before being added to a final "Mixed Particle" list.



Reconstructed total energy measurement errors: (a.) pion momentum measurement error, (b.) photon EM calorimeter measurement error, (c.) neutral hadron EM+HAD total energy measurement error, (d.) same plotted separately for neutrons and Klong's..

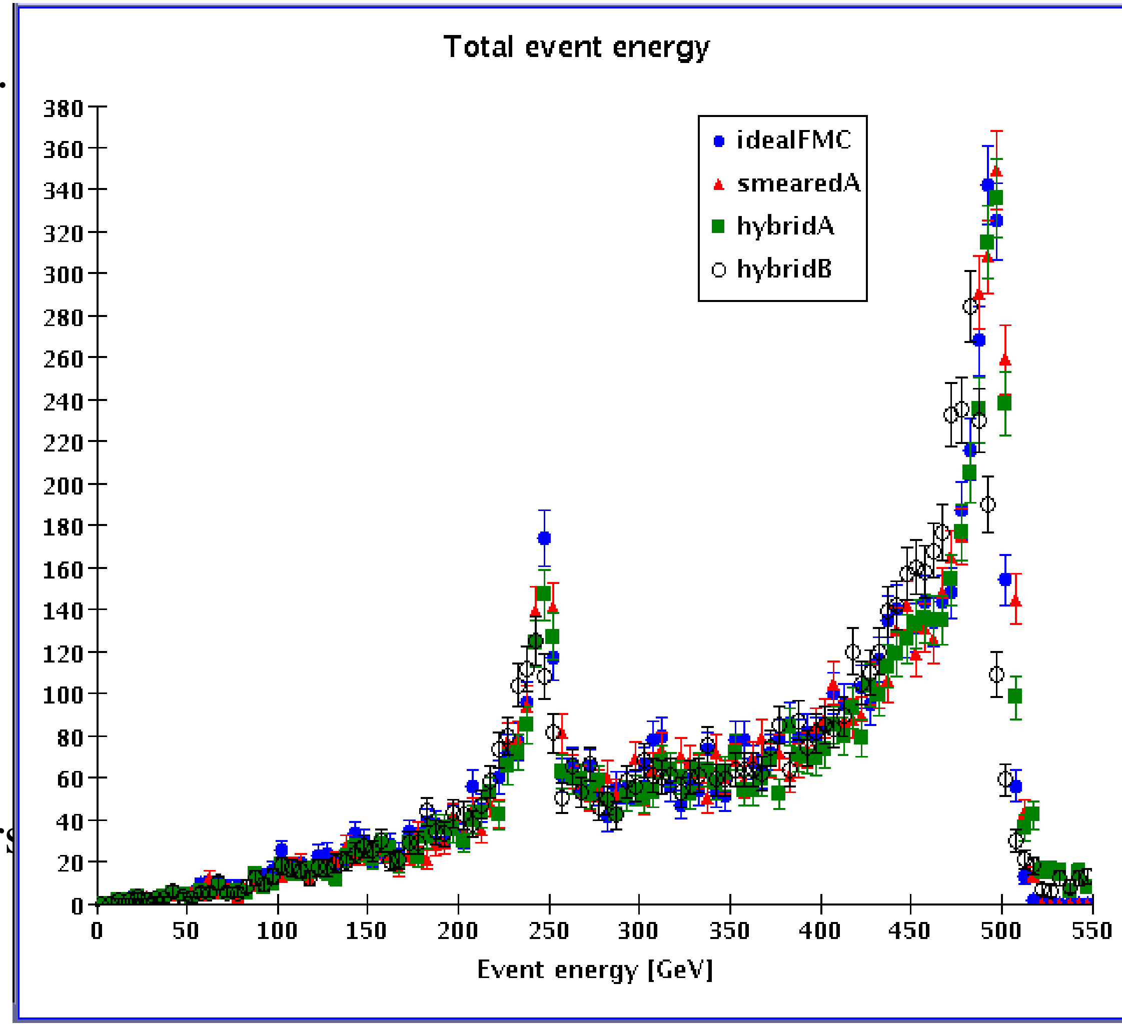
-- Total event energy measurement

In comparing results of ideal and realistic detector simulations with fully reconstructed simulated events or with the output of Hybrid Monte Carlo simulations, it is quite informative to study the total event energy measurement.

Here the total energy for WW and ZZ events is displayed. One sees the main peak at the CM energy and a secondary peak from events where one of the Z's has decayed into neutrinos. The long lower-energy tail is due to lost neutrinos, to energy leakage from the calorimetry and from acceptance effects.

The resolution of the high energy edge is sensitive to the overall event reconstruction whereby tracks and clusters can be missed, or double counted.

In these GISMO simulations, an additional small flat tail arises from confusion in parsing the MC tracking information.



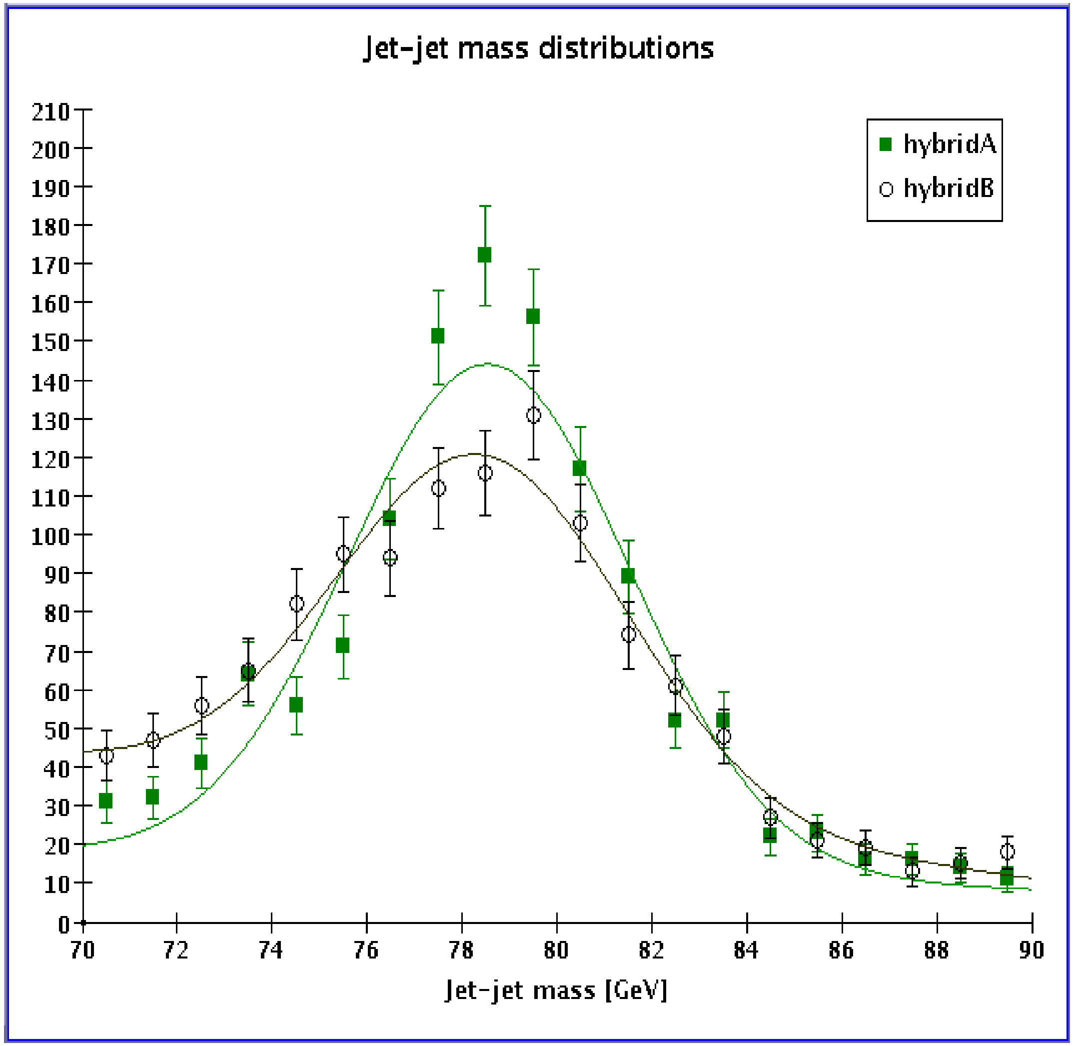
Reconstructed total event energy in WW and ZZ events.

-- Reconstructed W mass

In studying W/Z separation, one can measure the low and high mass tails in W reconstruction.

Here, W jet-jet mass reconstruction is shown for two Hybrid models: One (A) using reconstructed charged tracks and FMC neutrals, and the other (B) using all reconstructed particles. At this stage in the development of reconstruction algorithms, tracks and clusters that were missed are added from FMC simulations, and perfect energy flow is used. In addition, the study uses a **ClusterCheater** to find calorimeter clusters.

One sees that the W mass resolution is significantly degraded by the poor sampling of the present Large detector (LD) calorimetry.



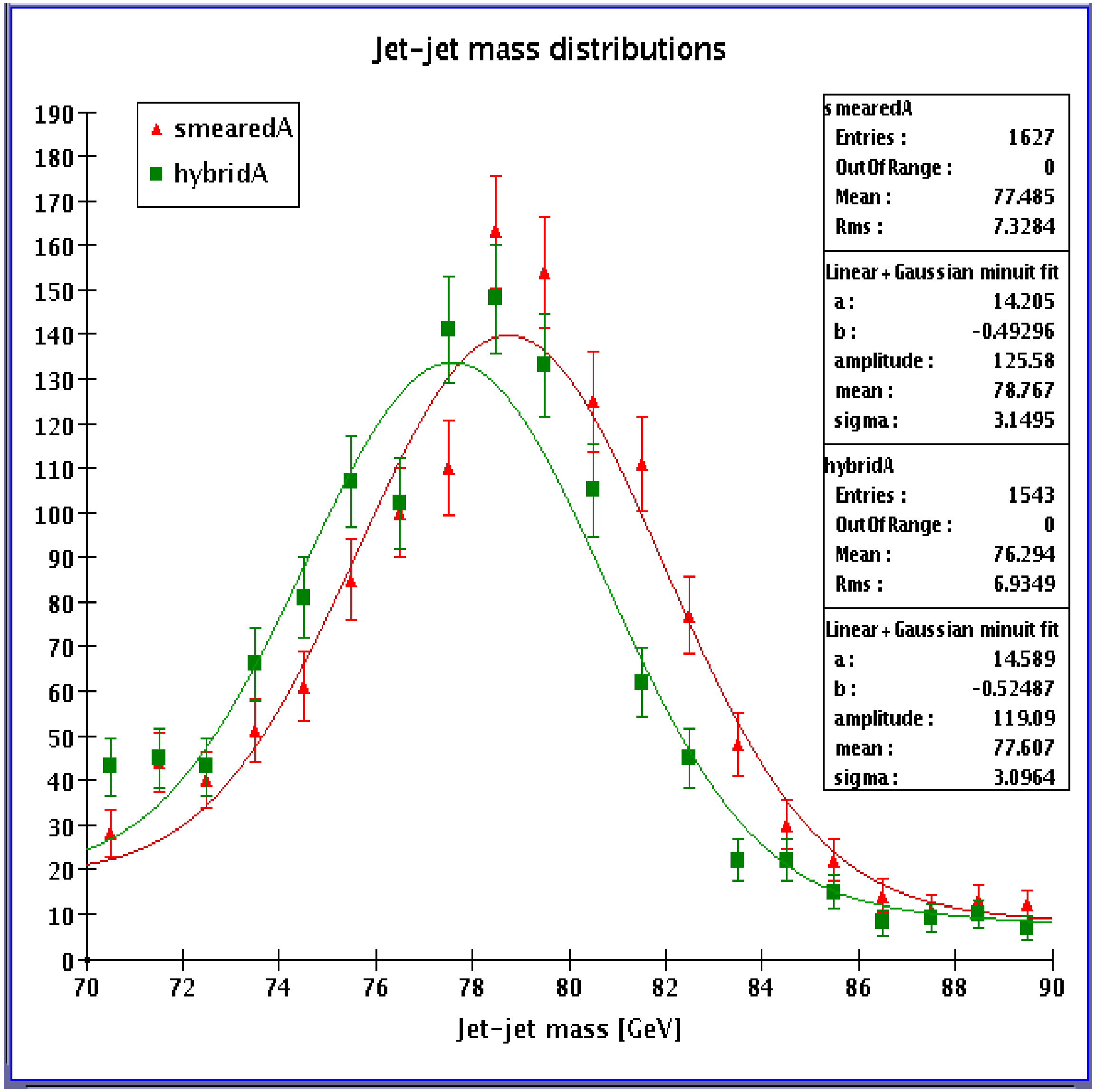
Reconstructed W mass using reconstructed charged tracks and “ClusterCheater” neutrals.

Low mass tails would effect the W and Z reconstruction efficiency.

One can measure the impact of track reconstruction losses by not adding FMC tracks that were missed.

Here we compare the Hybrid Monte Carlo model A with the smeared jet simulation. In this result only reconstructed tracks are used. FMC neutrals are used in place of reconstructed clusters.

While the reconstructed W mass shifts, the mass resolution would meet the LC design goals.



Reconstructed W mass distributions for smeared jets and reconstructed charged tracks and FMC neutrals.

Summary

- Ideal detector simulations are useful for initial physics studies.
- TPC response simulation and track reconstruction in hand.
- Calorimeter cluster finding and energy flow algorithms need to be developed.
- Realistic detector simulations and detector design studies are possible within the Hybrid Monte Carlo framework. See HMC talk in simulation session.
- New Large detector calorimetry options to be studied in the coming year.