Physics and Detector Simulations

A Summary of the
Simulation Tools Session

Norman Graf
(SLAC)

Representing the work of many

LCWS 2000

Common Goals

- **Provide full simulation of Linear Collider physics program:**
  - **Physics simulations**
  - **Detector simulations**
  - **Reconstruction and analysis**
- **Need flexibility for:**
  - **New detector geometries/technologies**
  - **Different reconstruction algorithms**
- **Limited resources demand efficient solution, focused effort.**

Presentations

Event Generators

- T. Ohl: O'Mega and WHIZARD
- T. Sjostrand: PYTHIA
- M. Peskin: pandora

Full Simulations and Reconstruction

- A. Miyamoto: JIM and JSF
- T. Behnke: BRAHMS
- R. Cassell: GISMO
- P. Mora de Freitas: GEANT4 Calorimetry
- G. Bower: LCD Reconstruction

Presentations

Fast Simulation and Analysis

H.J. Schreiber: SIMDET

M. Iwasaki: LCD ROOT

W. Walkowiak: LCD JAS

Event Visualization

H. Vogt: TESLA Event Display

Event Generators

- **LC Physics much more complicated than LEP**
  - **# of Feynman diagrams explodes combinatorially**
  - **algebraic expressions grow more complicated**
  - **phase space becomes more intricate**
- **Formalize calculations to eliminate repetition**
  - **CompHEP/LanHEP and Grace exist**
  - **O'Mega new fast and complete tree level calc.**
  - **WHIZARD adaptive phase space generation for many particles (using VAMP)**
- **Still need loops.**

pandora

An event generator for LC physics processes:

- **beam polarization**
- **beamstrahlung (using `consistent Yokoya-Chen’) and ISR (using Fadin-Kuraev structure fcns.)**
- **spin correlations and spin asymmetries**
- **inclusion of arbitrary hard processes**
- **hadronization via pandora_pythia**
- **OO C++, extensible, modular**

pandora

e beams have ISR and beamstrahlung for

NLC/JLC 500 1000 1500

TESLA 500 800

CLIC 500 1000 3000

or generic machine parameters N , β, σ

γ beams have γ, e spectra from Compton backscattering

ISR for scattered electrons

processes included in pandora 2.1

e^+e^- e^-e^- $\gamma\gamma$ beam classes

$e^+e^- \rightarrow l^+l^-$ $q\bar{q}$ $t\bar{t}$ W^+W^-
$Z^0\gamma$ Z^0Z^0 Z^0h^0

$e^+e^- \rightarrow t\bar{t}$ with general form factors

$\gamma\gamma \rightarrow l^+l^-$ $q\bar{q}$ $t\bar{t}$ h^0 W^+W^-

$e^-\gamma \rightarrow e^-\gamma$ e^-Z^0 νW^-

PYTHIA Status

- **"Complete" framework for $\gamma\gamma$, $\gamma\gamma^*$, $\gamma^*\gamma^*$ interactions at all Q^2.**
  - **New machinery for flux of brem. γ's**
  - **Dampening factors to remove double counting.**
- **QCD Final State Showers**
  - **Improved parton shower description**
  - **include mass effects ("dead cone")**
  - **match to process-specific ME's $O(\alpha_s)$**
- **On to C++, framework exists.**
- **Collaborative effort with HERWIG++ ?**

Beyond the Standard Model

SUSY: reasonably complete set of $2 \to 2$ MSSM R-conserving processes;

new:
- $\tilde{b}_1/\tilde{b}_2$ production, also b in PDF;
- $\tilde{G}$ as LSP (optionally)
- 3-body SUSY decays
- displaced vertices

Technicolor: new set of pair production of $\pi^{\pm}_{tc}/\pi^{0}_{tc}/\pi'^{0}_{tc}/W^{\pm}_{L}/Z^{0}_{L}/W^{\pm}/Z^{0}/\gamma$, with interference $\rho^{\pm}_{tc}/W^{\pm}$ and $\rho^{0}_{tc}/\omega^{0}_{tc}/Z^{0}/\gamma^*$

Z'^{0}: flavour-dependent couplings

Higgs: pair production, e.g. h^0A^0 or $h^0H^{\pm}$ (earlier partly as $\gamma^*/Z^0/Z'^0$ decays)

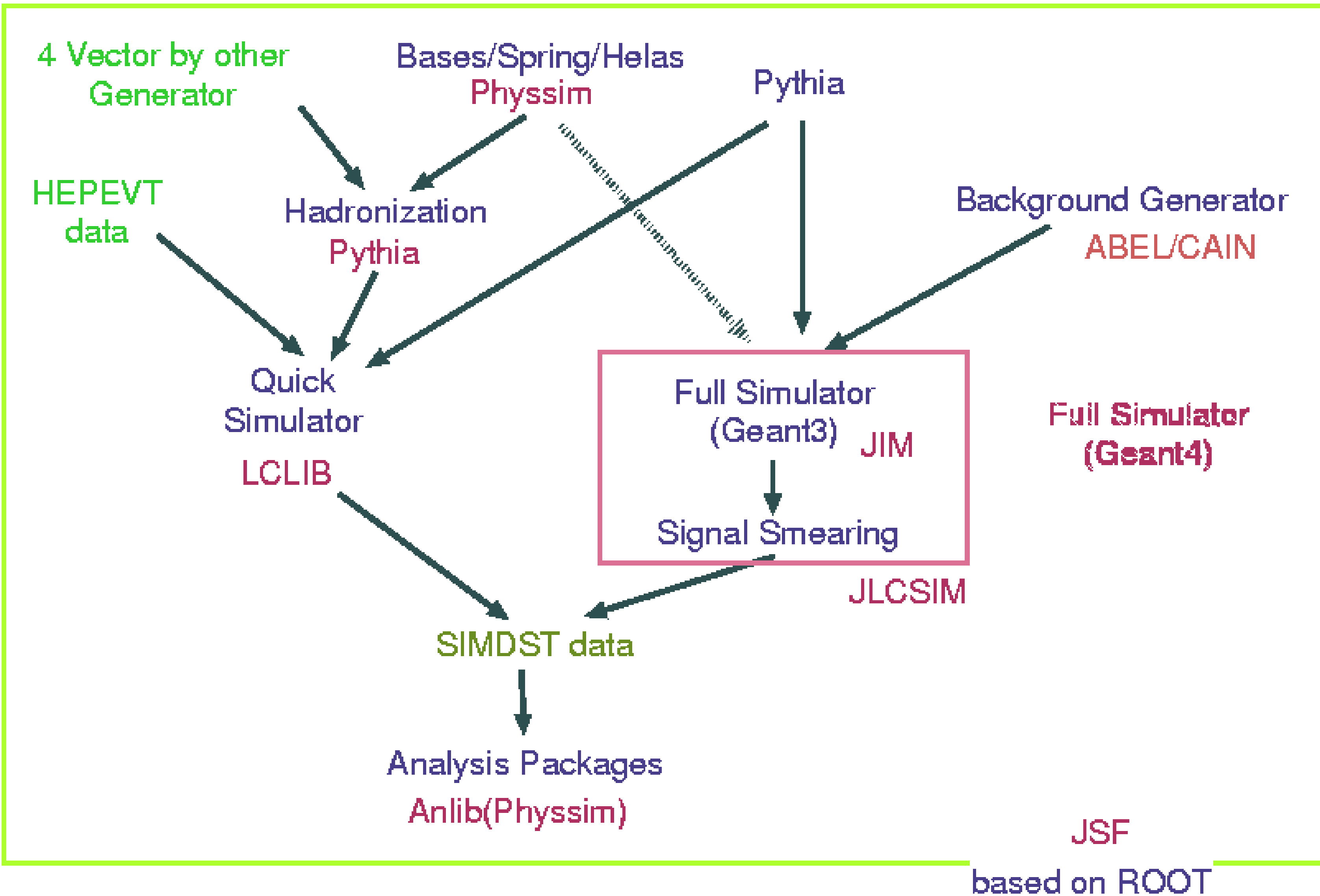
Left-right symmetry: $H^{\pm\pm}_{L,R}$ production

$H^{\pm\pm}_{L,R} \to \ell^{\pm}\ell^{\pm}/W^{\pm}_{L,R}W^{\pm}_{L,R}$ $\quad W^{+}_{R} \to q_i\overline{q}_j/\ell^{+}\nu_R$

Compositeness: a few further processes for e^*/q^*

Extra dimensions: only begun recently: narrow graviton excitation G^*

JLC Simulation Overview



LCWS2000 A.Miyamoto

Physsim Generator Package

Based on HELAS+BASES+SPRING

Processes:

- higgs: Zh
- SUSY: sfermion and chargino pairs
- top: eett, nntt, tth, tt, ttZ
- twoph: eeff (ff = e, μ, τ, q)
- wz: eeWW, eeZ, enW, nnWW, nnZ, WW, WWZ, ZZ

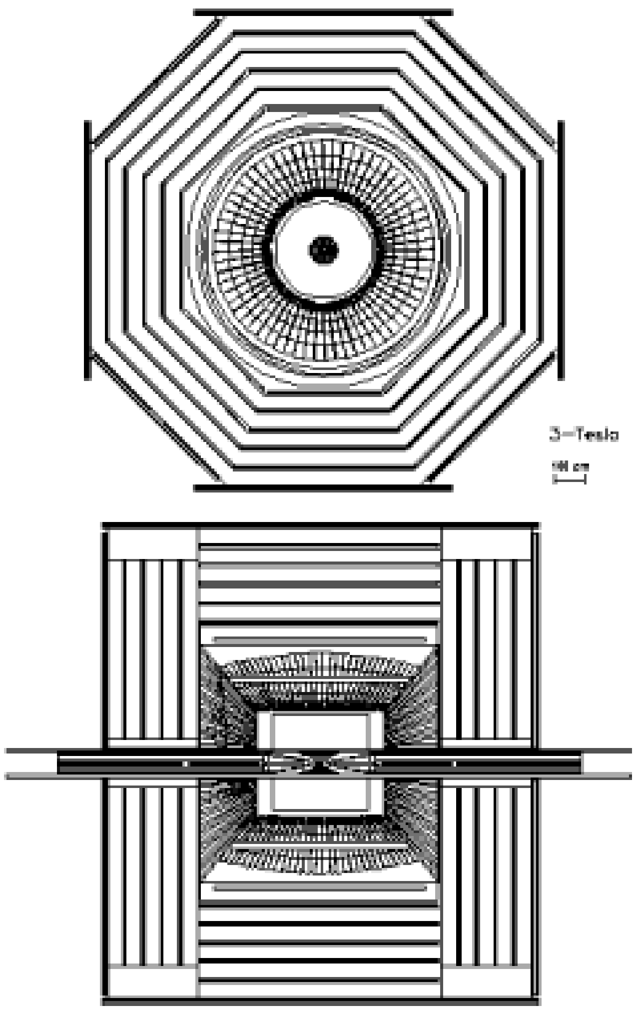
Included Effects

- Bremsstrahlung and Beamstrahlung
- W, τ polarization
- Virtual Higgs diagrams

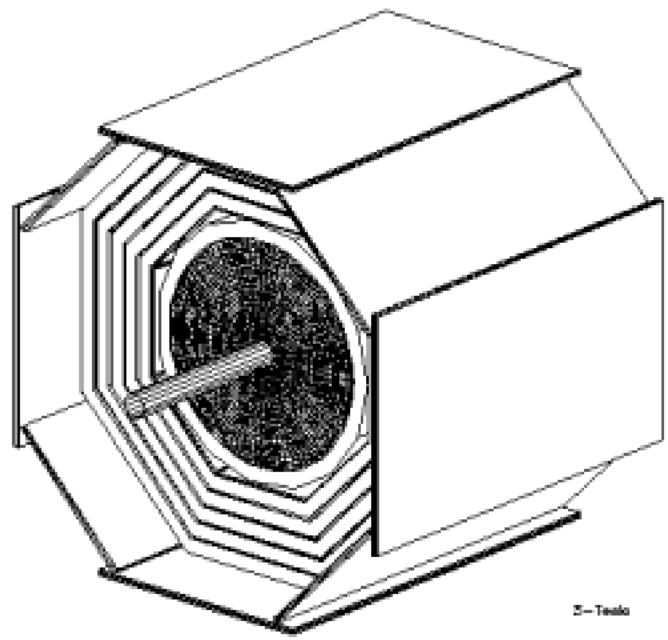
JIM Overview

- **GEANT3 based FORTRAN program**
- **Includes ZEBRA based data structure**
- **Realistic detector components**
- **Two versions of geometry models for 2 and 3-Tesla Fields**
- **Includes some analysis programs**
- **Generates ntuples with same structure as the quick simulation program for the JLC detector.**

JLC 3T Detector (JIM)



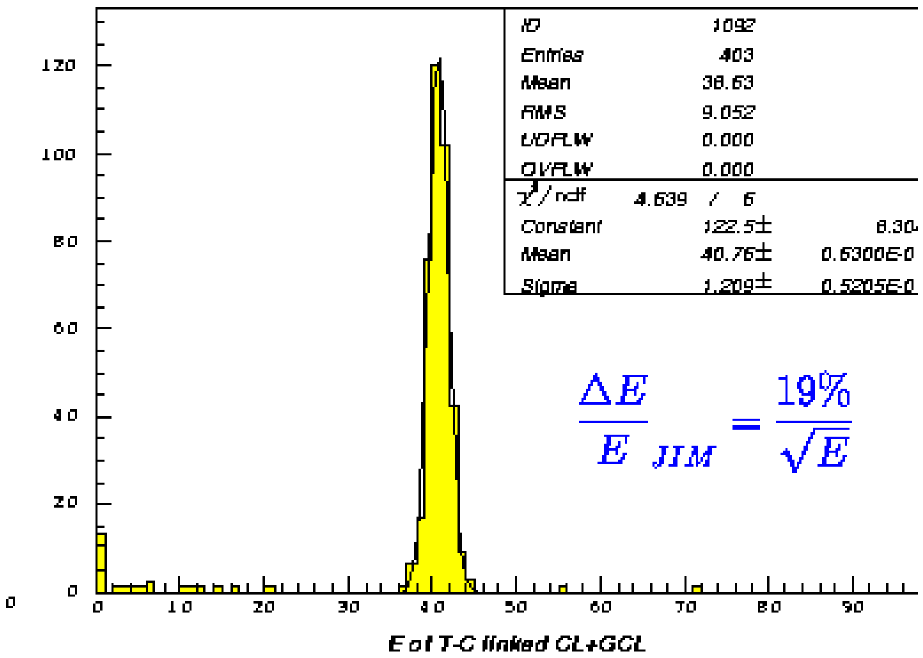
Junichi Kanzaki



LCWS2000 Akiya Miyamoto

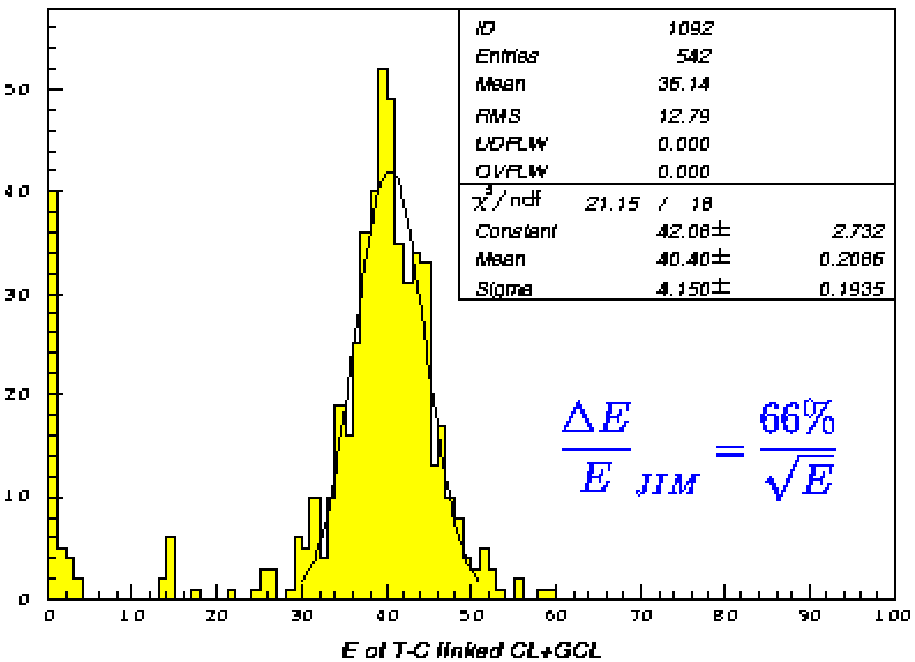
JIM Single Particle Response

Energy of EM cluster linked with e^- track



$$\frac{\Delta E}{E}_{JIM} = \frac{19\%}{\sqrt{E}}$$

Energy of EM cluster linked with π track



$$\frac{\Delta E}{E}_{JIM} = \frac{66\%}{\sqrt{E}}$$

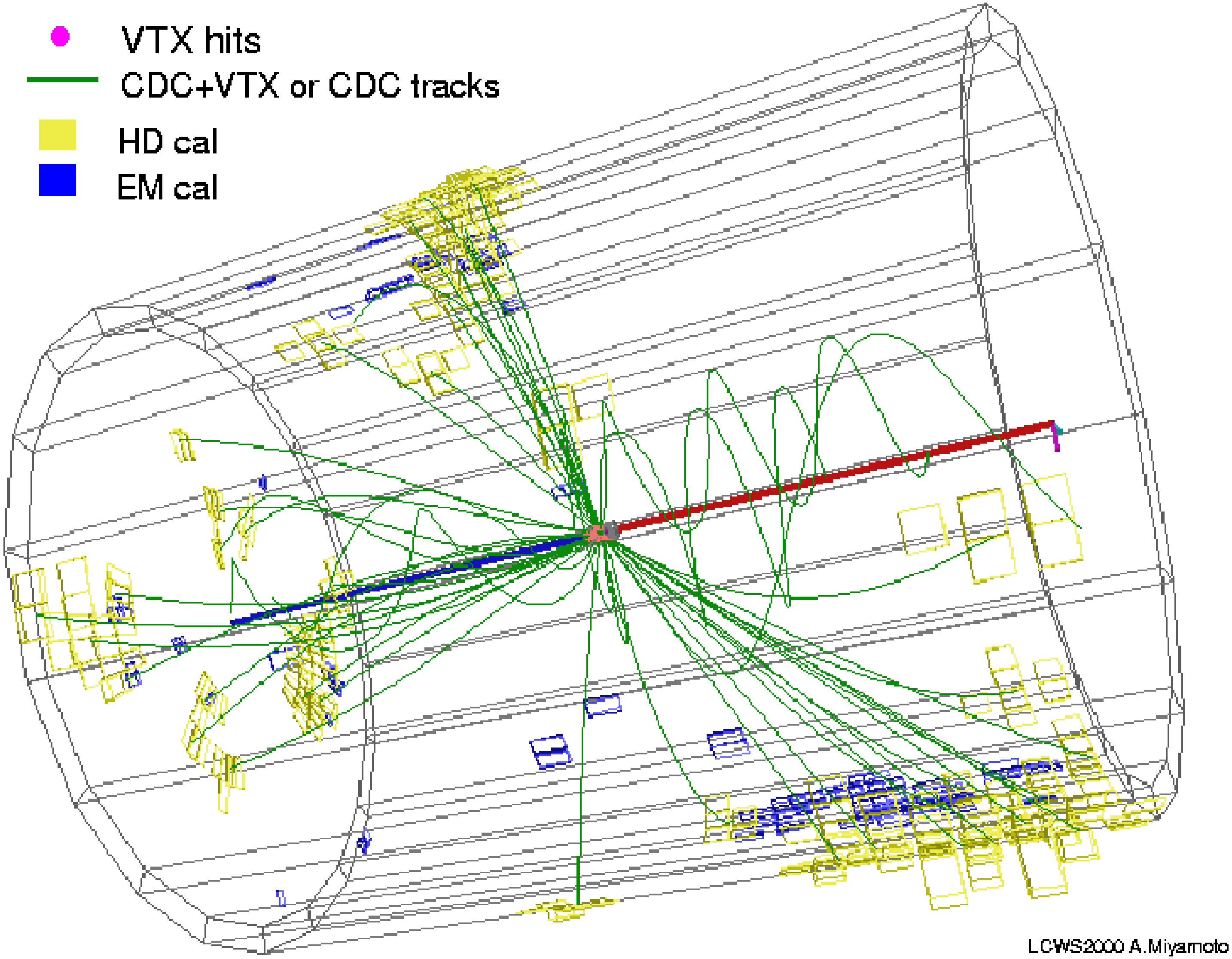
Tuning of simulation code still ongoing.

Aim to recreate test beam response.

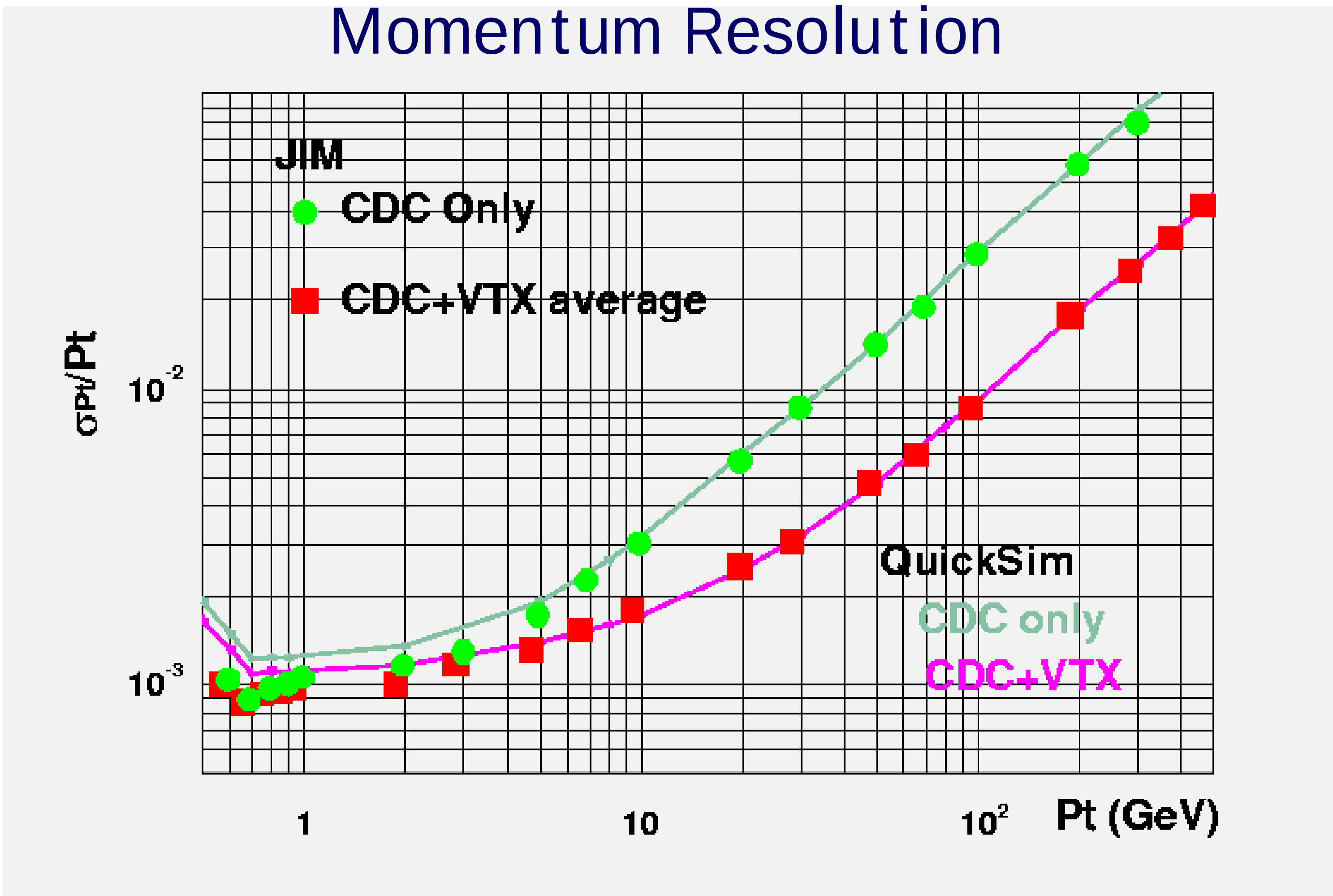
JLC QuickSim

- **Geometry, resolutions, etc., changeable via parameter file**
- **Particles are swum and smeared by MCS**
- **VTX & CDC**
  - **Sampling with $\sigma_{r\phi}$ and σ_z**
  - **Smear 5x5 combined track covariance matrix**
- **IMT Create smeared hit points**
- **CAL**
  - **Exponential lateral spread + E smearing**
  - **e,γ in EM, hadrons only in HAD Cal**

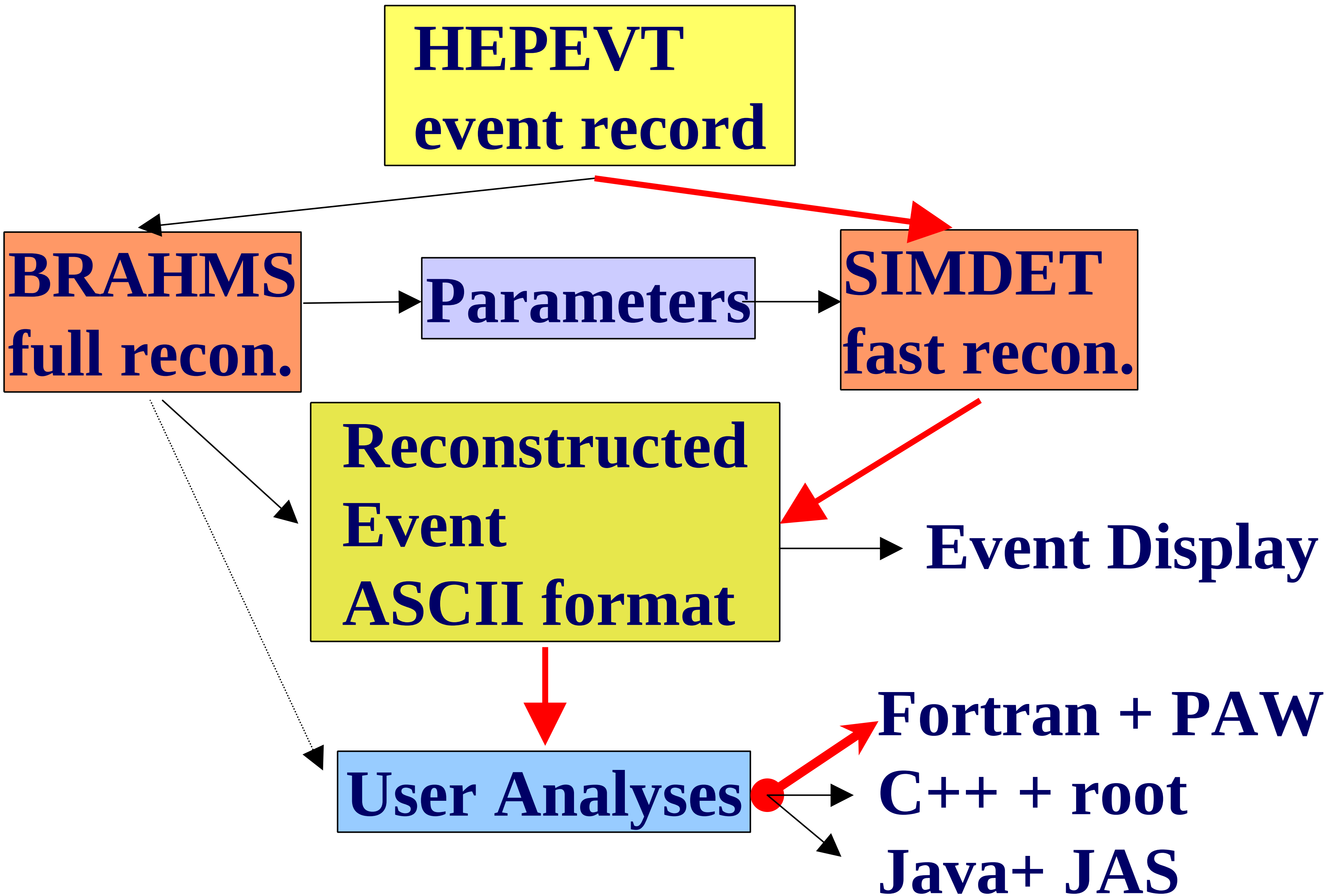
QuickSim Event



QuickSim vs J I M comparison



TESLA Event Flow



TESLA Full Simulation

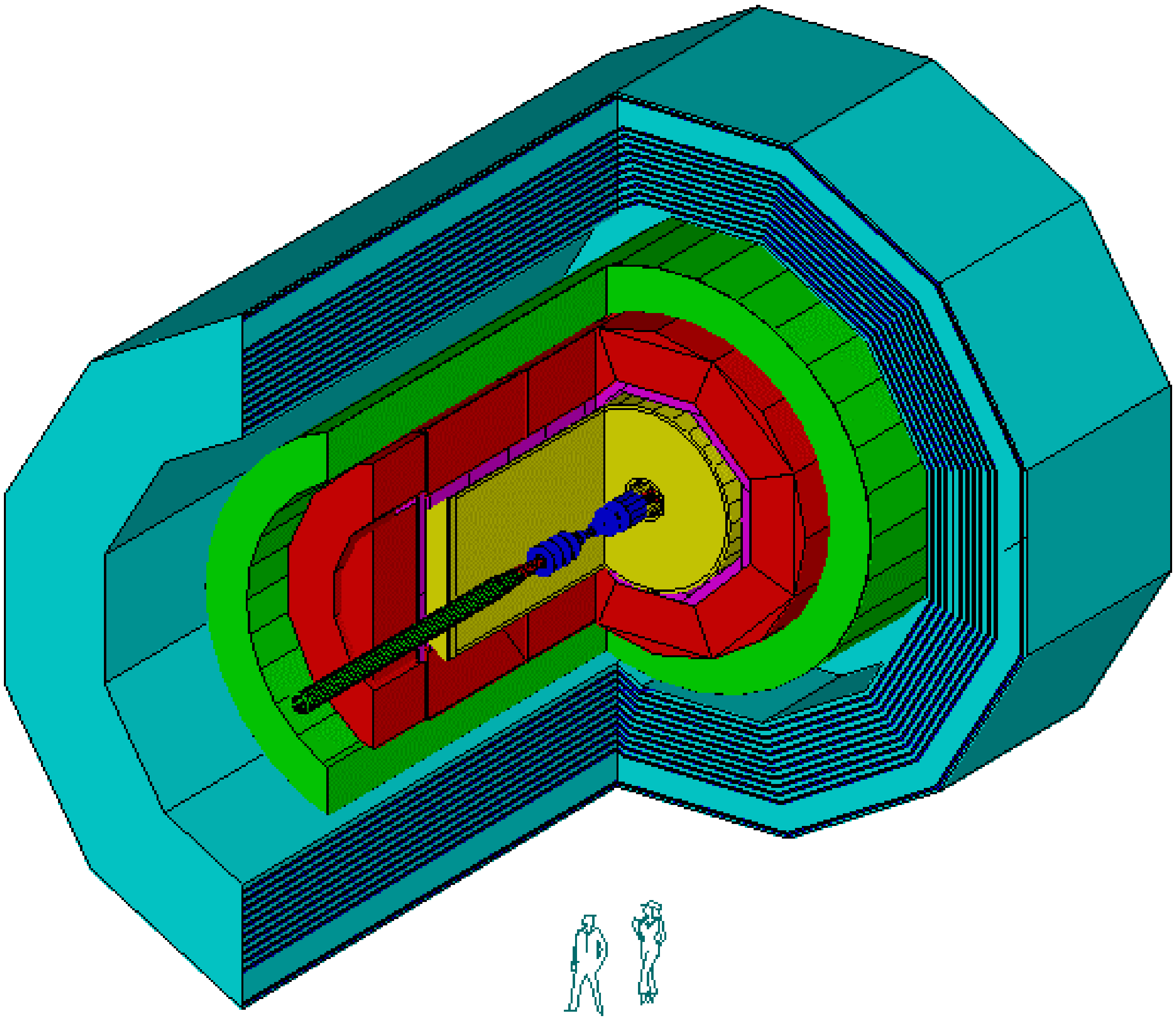
Narrowly focused to complete TDR with a well-defined detector

GEANT3 as main simulation frame

FORTRAN as programming language

ASCII as platform independent IO

TESLA Detector (Brahms)



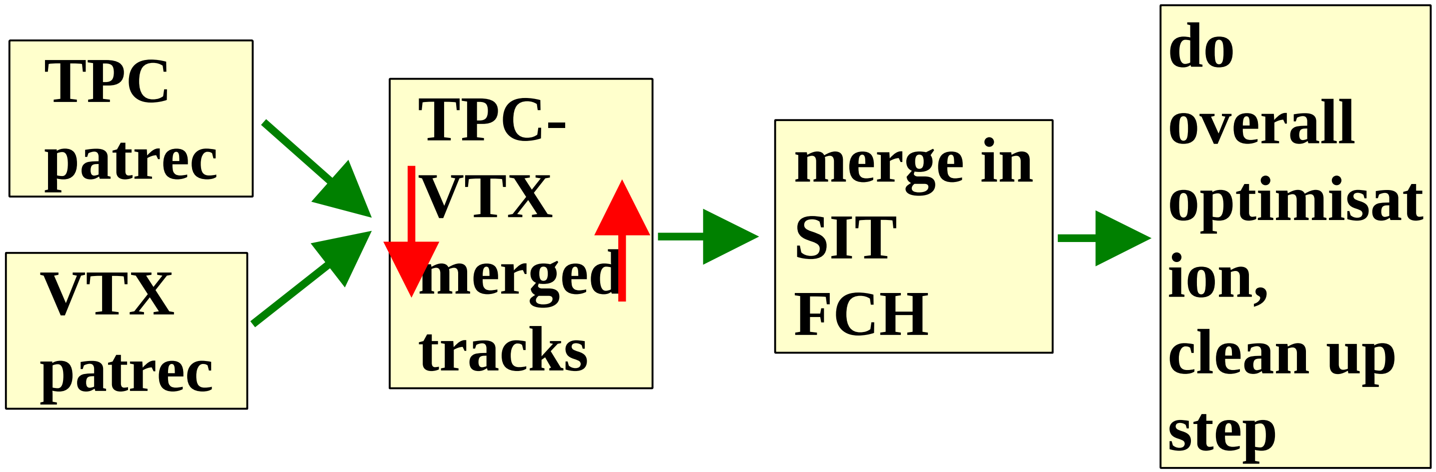
Track Reconstruction

TPC pattern recognition based on ALEPH software

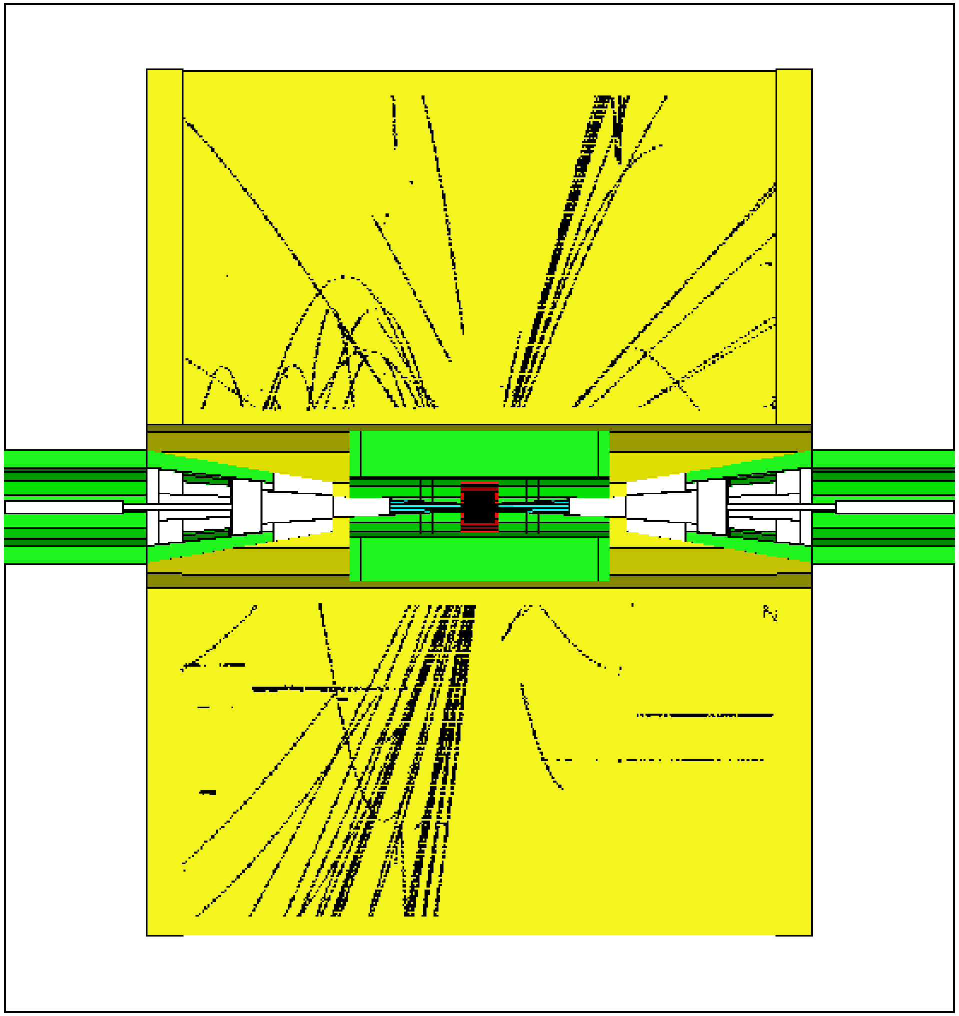
VTX pattern recognition based on OPAL software

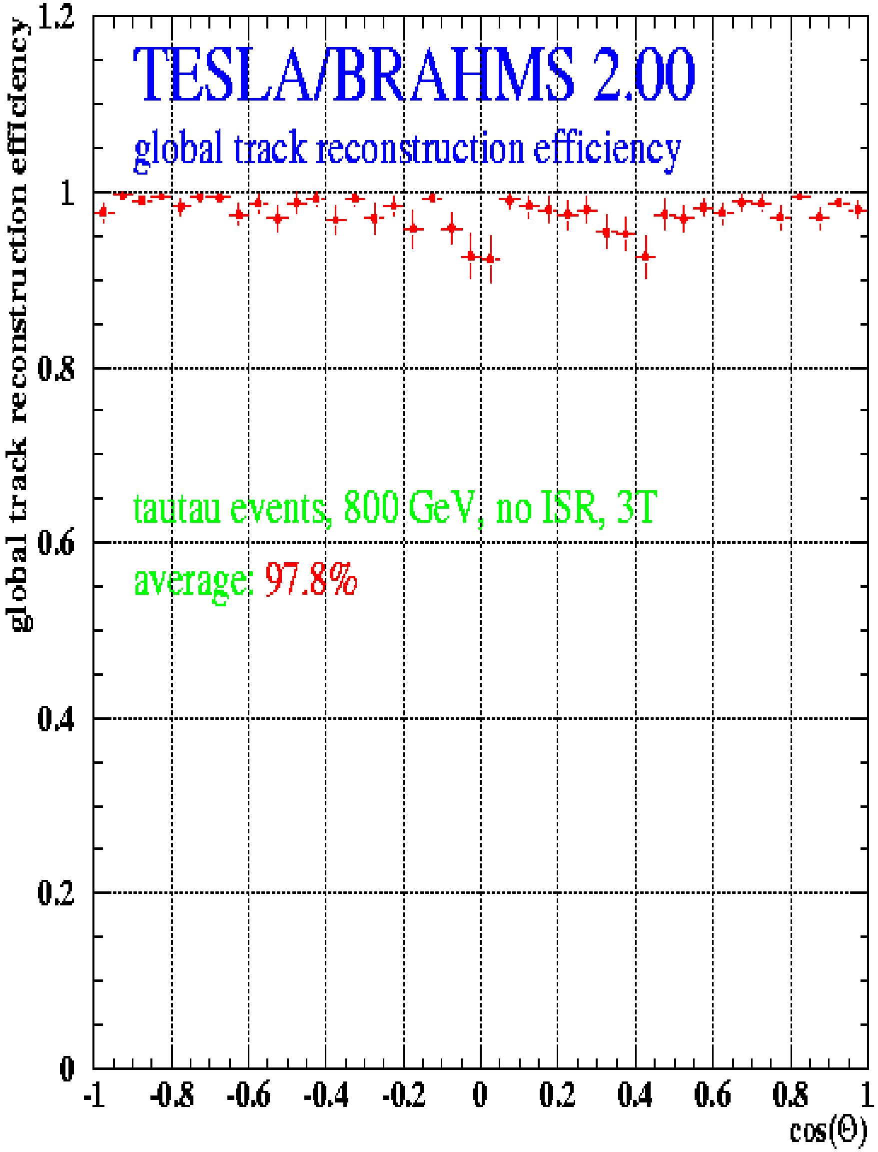
Merging processor based on DELPHI software

Global track fit based on DELPHI software



Tracking Results



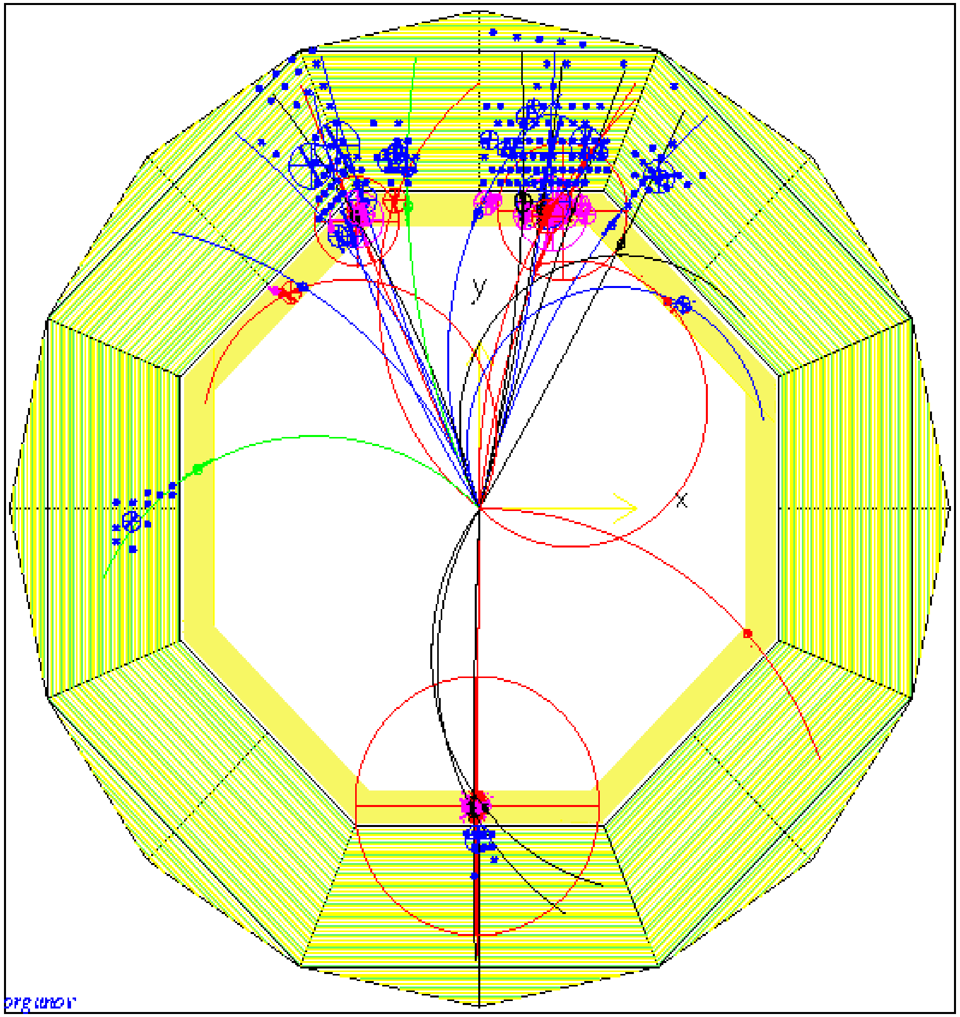


Calorimeter Reconstruction

First version of clustering and energy determination exists

GEANT4: France
GEANT3: DESY

Reconstruct Energy, direction, and Particle ID hypothesis from clusters in highly segmented calorimeter



SIMDET

- A parametric MC for a TESLA detector.
- Smears detector response to MC particles with functional forms determined from the full BRAHMS simulation.
- Incorporates reconstruction code to find and resolve calorimeter clusters.
- Links smeared tracks to clusters to give "Energy Flow" objects.
- Jet finding, particle ID, etc.

SIMDET Tracking

Smear $1/p_T$, θ, ϕ, dca_{xy} & dca_z independently as function of MC particle angle, θ, and momentum.

Some overall tracking efficiencies, charge mismeasurements and misidentifications.

SIMDET Calorimetry

- **Swim MC particles to calorimeter face.**
- **Distribute energy in central tower and laterally into three rings of towers**
  - **Truncated Gaussian for EM**
  - **Exponential tails added for hadron showers**
- **Correlations included binomially**
- **Clustering then done in towers, which approximates cluster merging**
- **Rather good agreement using such simple parameterizations.**

SIMDET Output

Particle ID as follows:

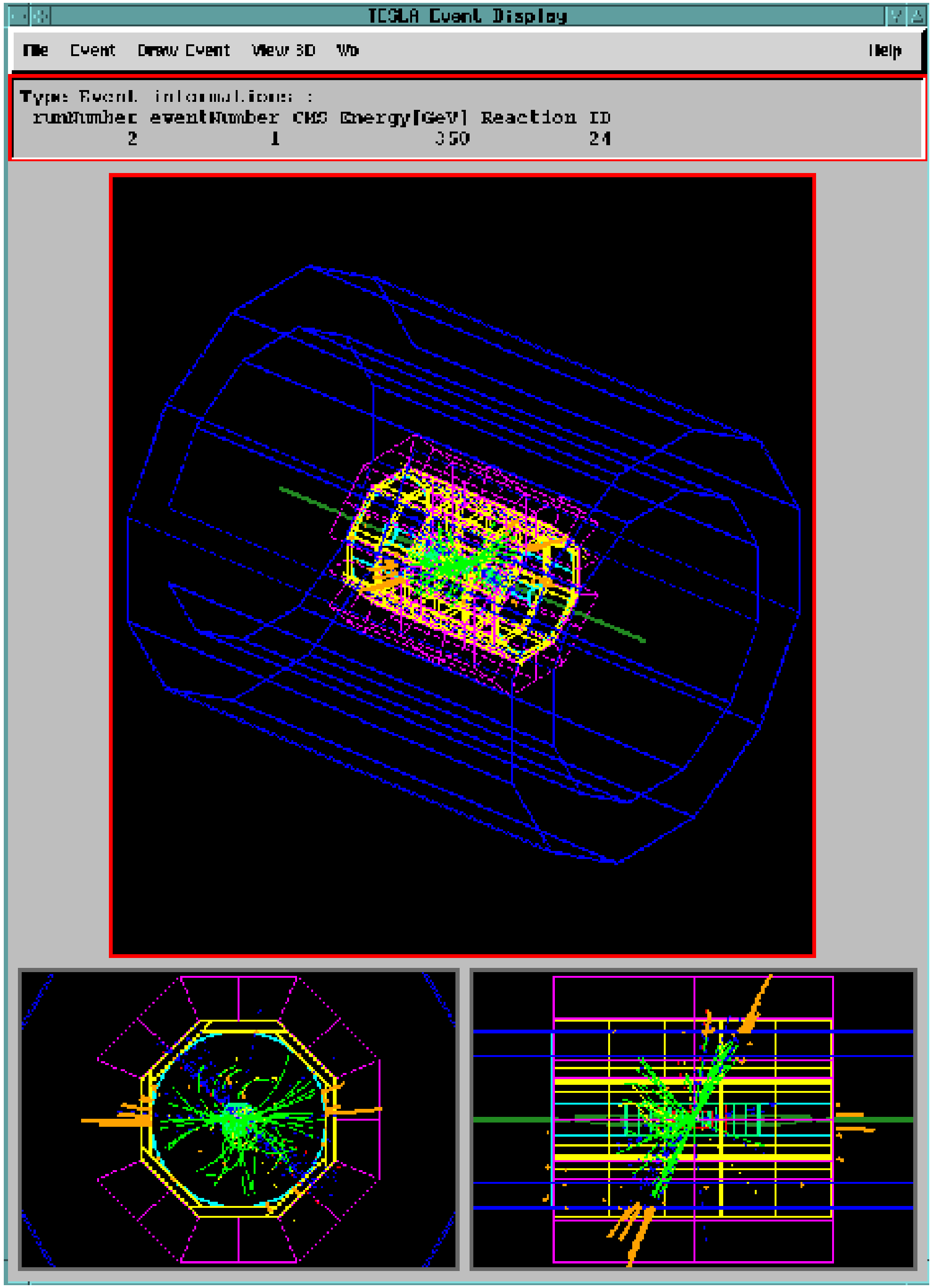
$\mu^{+/-}$	track + MIP	
$e^{+/-}$	track + EM shower	
γ	EM shower	
$h^{+/-}$	track + HAD shower	
h^0	HAD shower	

ASCII IO:

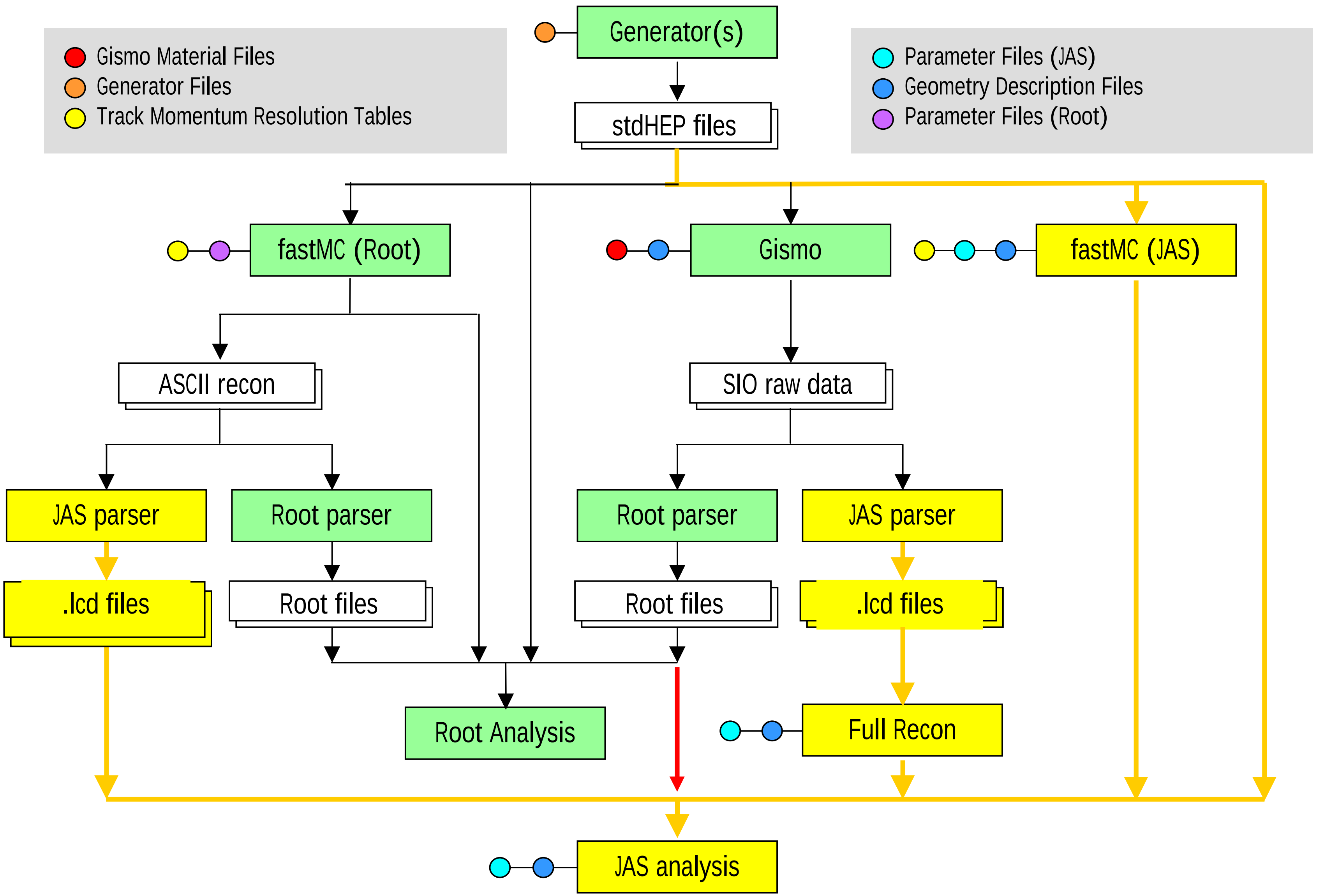
- Track parameters + covariance matrix
- Cal clusters, energy and directions.

OPACS

- A TESLA event display for visualizing MC and reconstructed objects.
- Detector geometry is drawn in wireframe.
- Can draw MC Particles, charged tracks, and neutral calorimeter clusters.
- Customizable widget hierarchies.
- Part of GEANT4 visualization.
- Solid rendering possible via OpenGL/Mesa.
- Java GUI is also possible.


TESLA Event Display
File Event Draw Event View 3D Wo Help
Type Event informations :
runNumber eventNumber CMS Energy[GeV] Reaction ID
2 1 350 24

LCD Software Roadmap



Gismo: Full Simulation

Reasonably full-featured full simulation package - C++

- complex geometries
- EGS & GHEISHA
  - cutoffs set at 1 MeV
- multiple scattering, dE/dx, etc

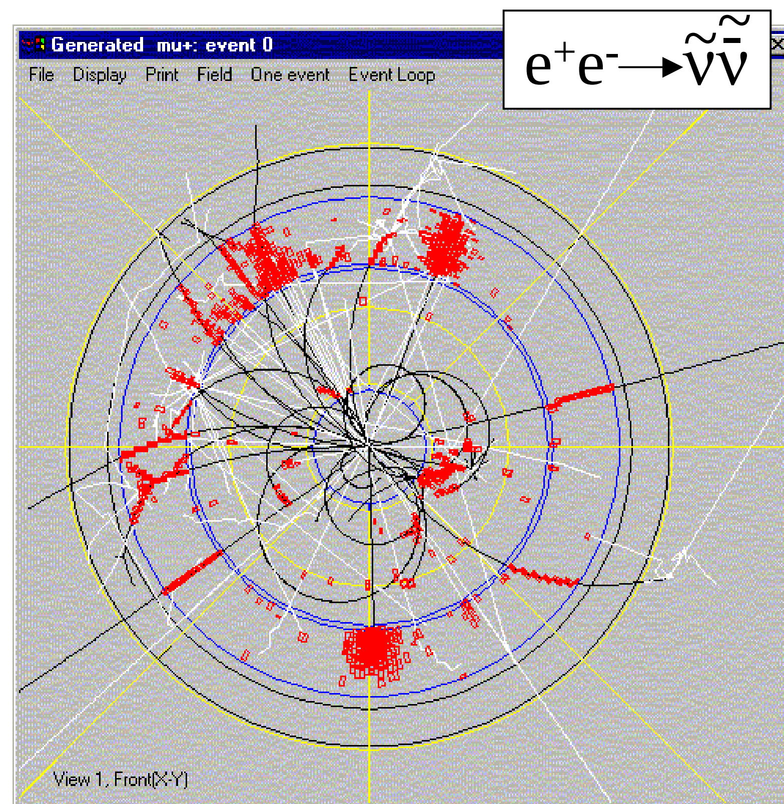
Generator input from /HEPEVT/ via FNAL STDHEP I/O package

Digitization

- tracking
  - hit points at tracking/VXD layers
- calorimeters
  - total energy per channel
- muon strips
- all digi's have full MC record

Output to SIO file

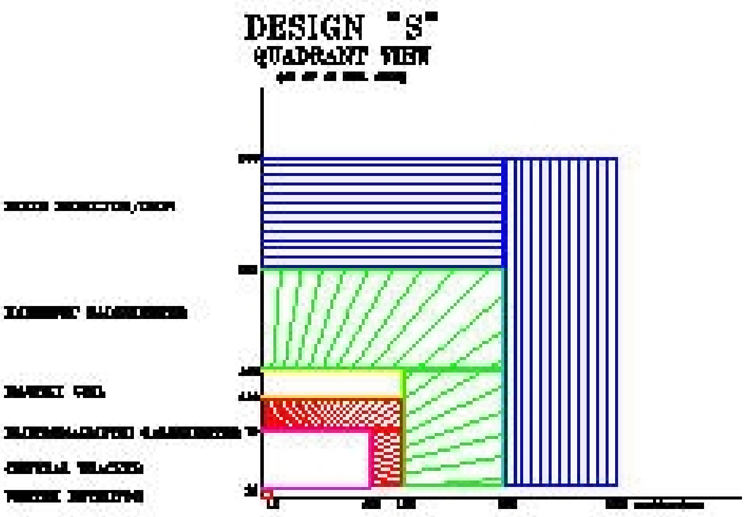
- allows parsers to translate to JAS & Root for further analysis/processing



Full Sim: Geometry Elements

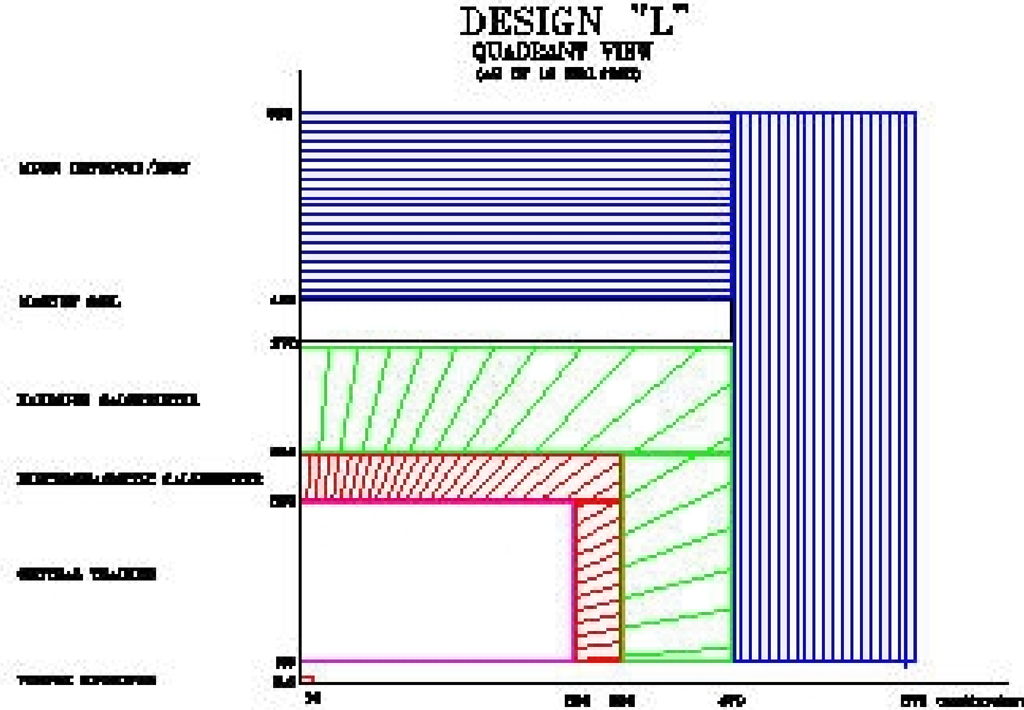
- Input by detector file in XML format
- trackers and calorimeters can have inner/outer skins and endplates
- tracker/VXD layers can be individually positioned and sized
- user sets longitudinal cell composition (multi-materials allowed) and ‘sensitivity’
- configurable conical masks

S



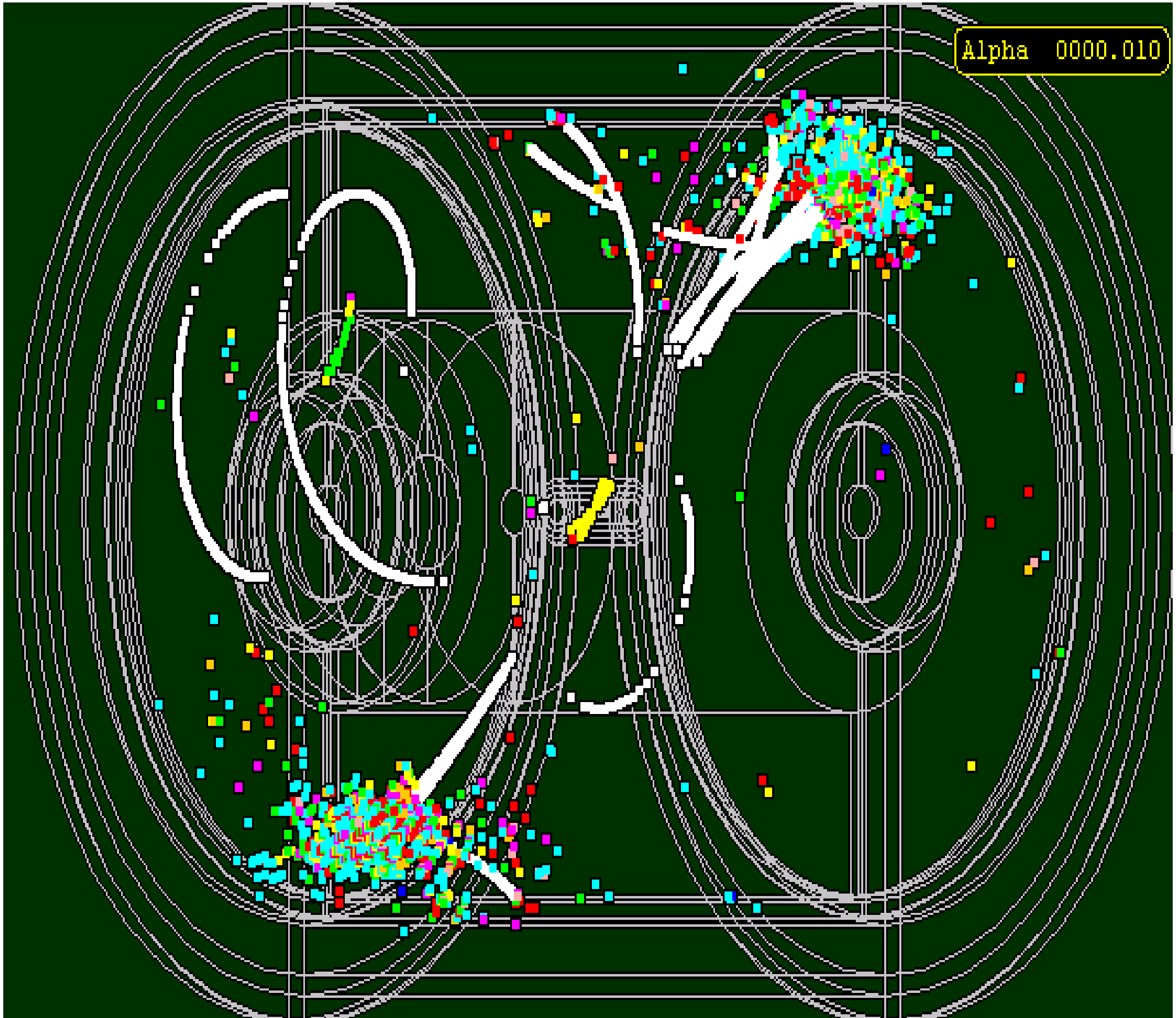
B=6T

L



B=3T

GISMO Event



Beam Background Overlays

- **Take output from full beam simulation (from IR/backgrounds group)**
- **Feed into full Gismo simulation**
- **Build library of simulated background bunches**
- **Overlay backgrounds on signal events at start of reconstruction**
  - **Adjust timing of hits (for TPC e.g.)**
  - **Add energy in calorimeter cells**

Allows to change #bunches/train, bunch timing

LCD Tracking Reconstruction

Hit Smearing/Efficiency (since Gismo gives "perfect" hits)

Random Background overlay

Track Finding:

- Full pattern recognition in the Central Barrel region
  - Tuned for Large + Small detector

Track Fitters:

- SLD Weight Matrix Fitter
- Can do Single Detector or Combined fit (e.g. VTX+TPC)

What's still needed:

- More Track Finding Algorithms (Pure Projective Geometry)
- End Cap tracking
- Hit Merging
- Kalman Filter (incorporating multiple scattering) coming soon

Calorimeter Reconstruction

Cluster Finding

- **Three Clustering Algorithms Currently Implemented**
  - **Cluster Cheater (uses MC truth to "cheat")**
  - **Simple Cluster Builder (Touching Cells)**
  - **Radial Cluster Builder**
    - All algorithms tend to produce many very low energy clusters - important to set sensible thresholds

Still Needed - Cluster Refinement Stage

- **Combine HAD + EM clusters**
- **Endcap + Barrel overlap region**

In Progress - Track Cluster Association

- **Need to Extend Definition of Clusters**
  - **Directionality, Entry point to calorimeter**

LCD Fast MC Simulations

Fast, parametric simulations supported in two Object Oriented environments:

ROOT/C++

- **Large HEP user community**
- **Library of HEP utilities**
- **Access to growing C++ software packages**

JAS/Java

- **Growing user community**
- **Library of HEP utilities**
- **“Gentler” environment for physicists**
- **Platform independence**

LCD Fast MC Simulations

ChargedTracks Smear track parameters using the full 5x5 covariance matrix, extrapolate to calorimeter face.

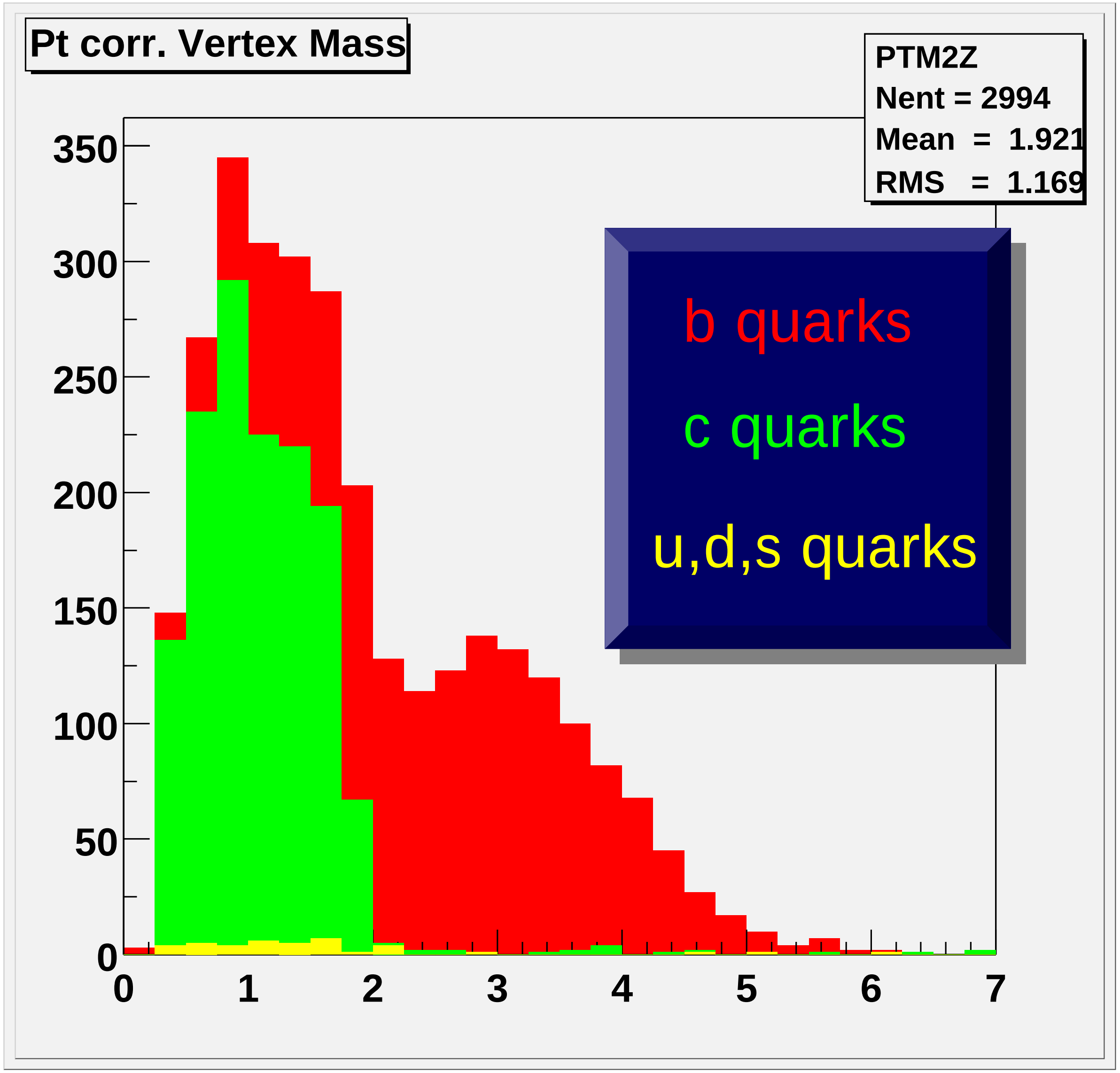
Clusters Smear particle position & energy according to detector and particle type. Naïve merging.

Have access to the full suite of reconstruction tools.

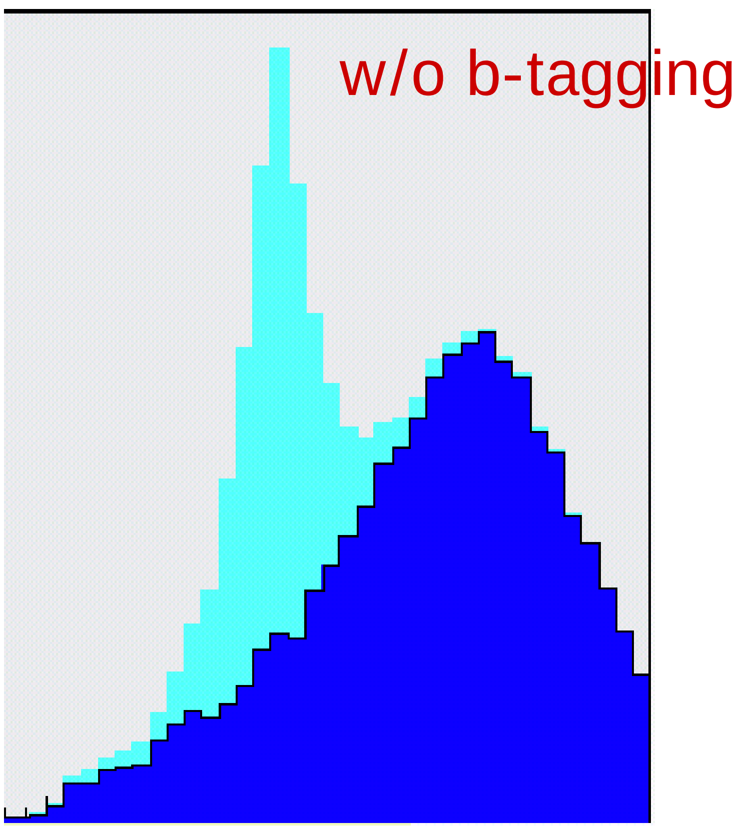
LCD FastMC Analysis

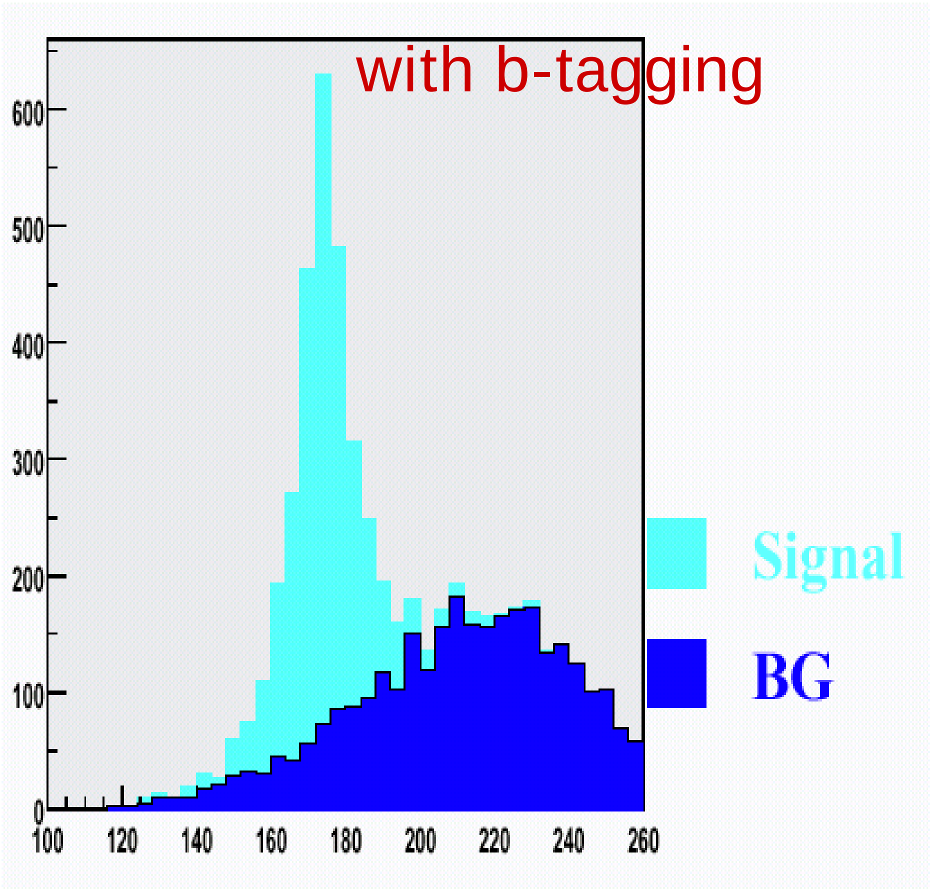
- With correctly smeared tracks, can start undertaking sophisticated analyses with realistic flavor-tagging
- Implementations of topological vertex finding algorithm ZVTOP in both C++ and Java
- ROOT analysis implemented pT-corrected vertex mass
  - b efficiency 60% purity 98%
  - c efficiency 30% purity 80%

ZVTOP Vertex Mass



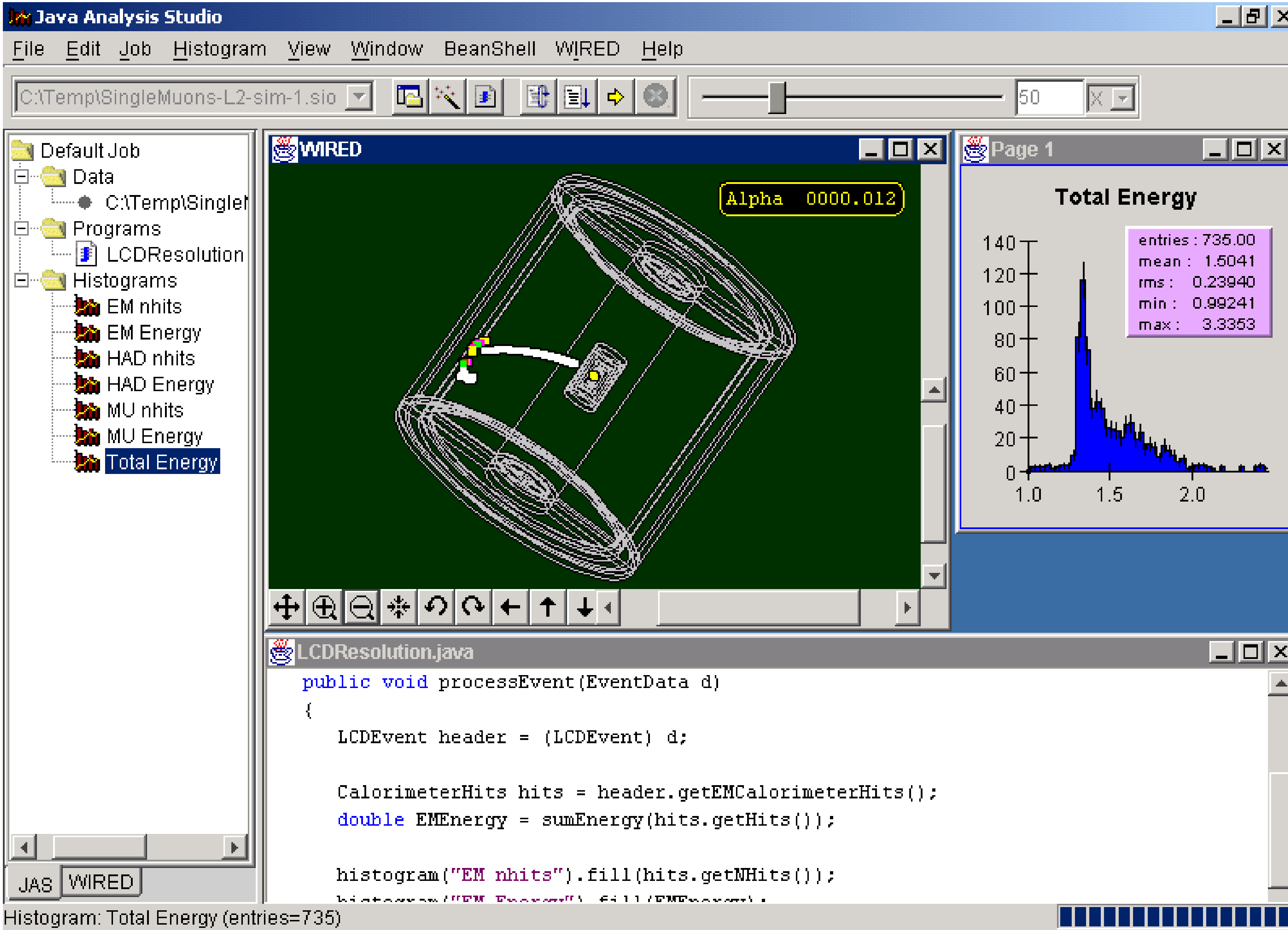
Top quark Mass Measurement





ROOT FASTMC

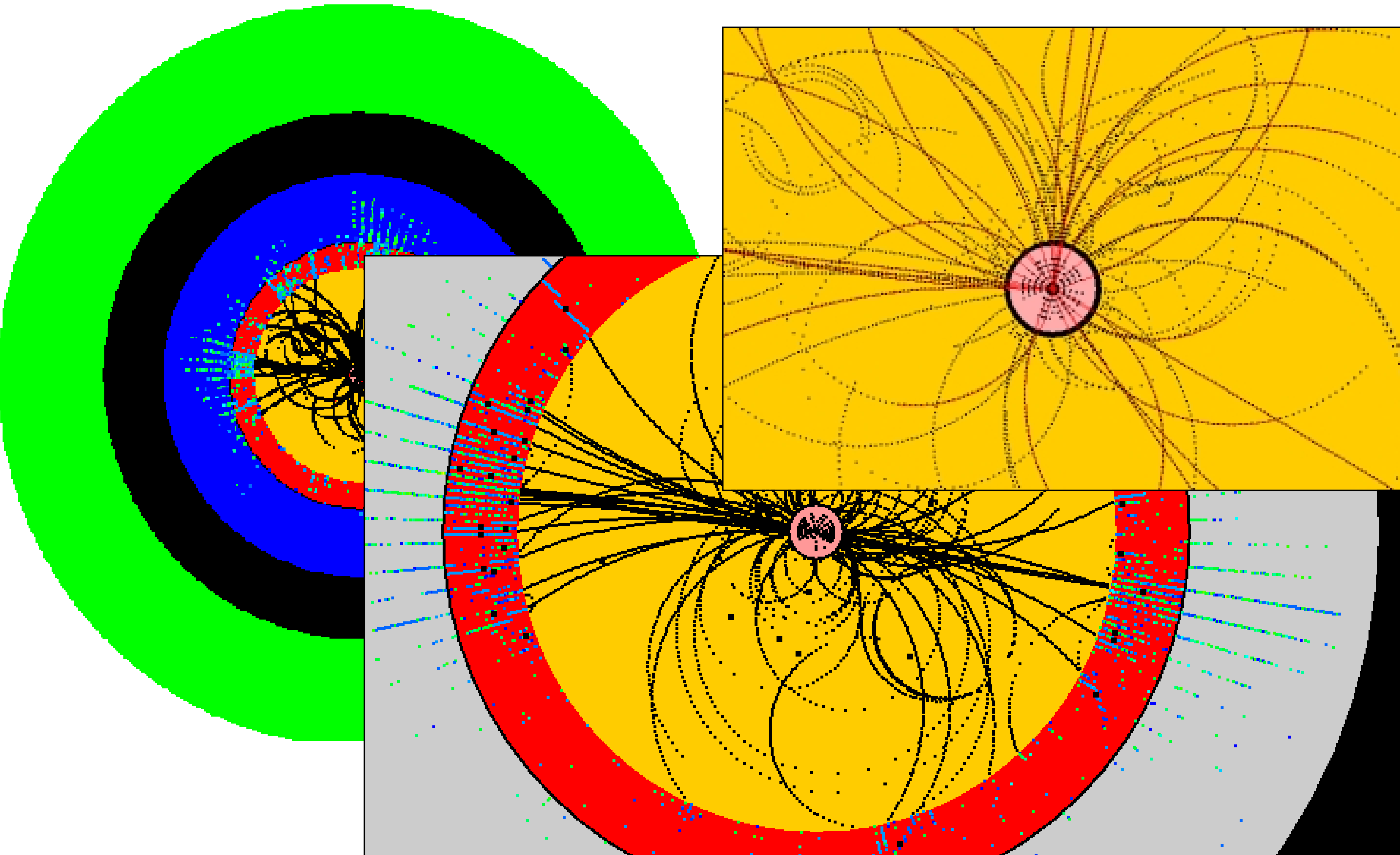
Java Analysis Studio



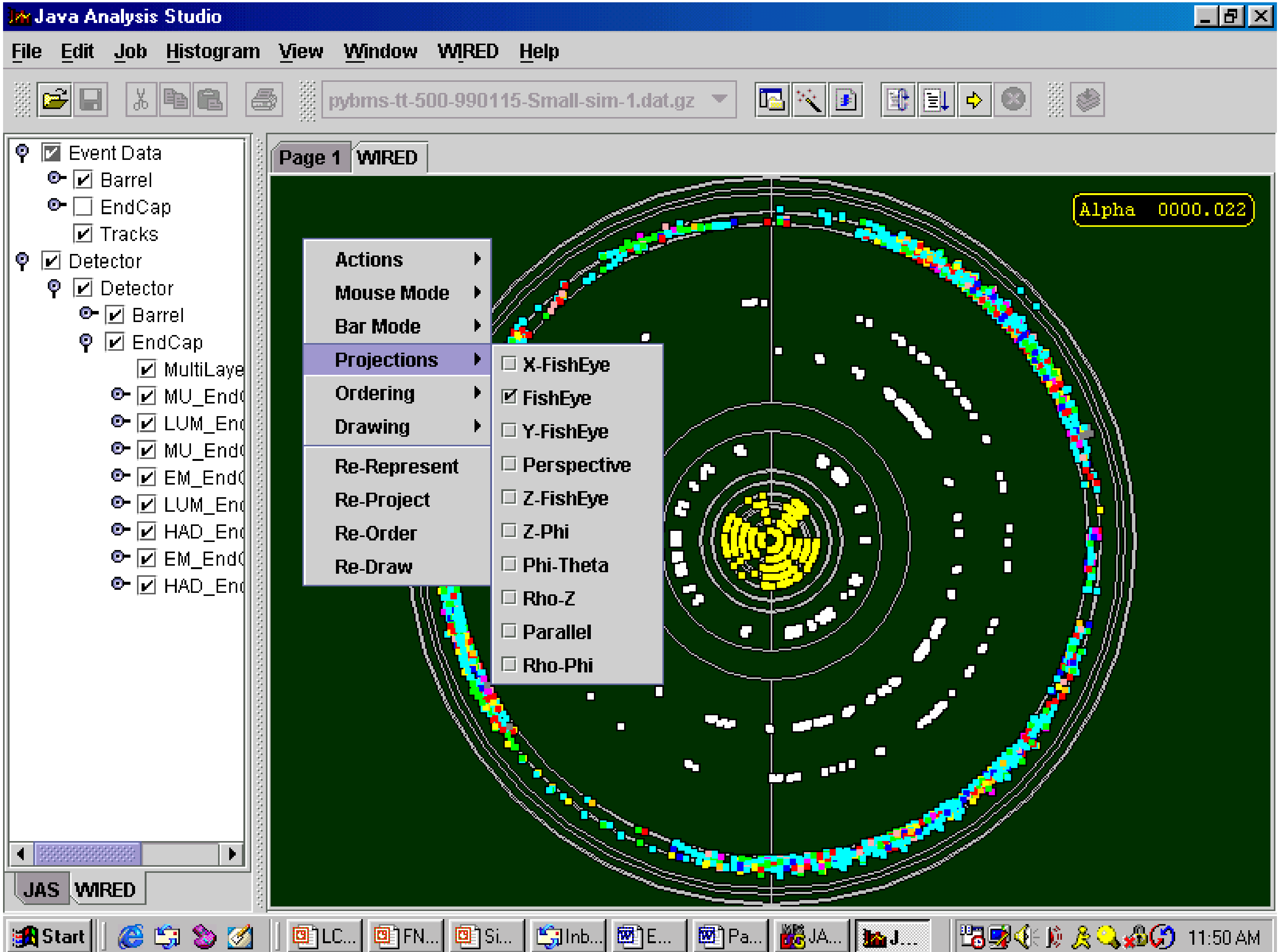
JAS Physics Utilities

- Physics Utilities
  - 4-vector, 3-vector classes
  - Event shape/Thrust finder
  - Jet Finders
    - Many kT algorithms implemented (e.g. Jade and Durham)
    - Extensible to allow implementation of other algorithms
- Contributed Area
  - Analysis Utilities and sample analyses provided by users
- 2 Event Displays
  - 2D - Suitable for debugging reconstruction and analysis
  - Wired for full 3D support
- Particle Hierarchy Display

2D Event Display



Wired Event Display



Where do we go from here?

- **We believe that the physics case for the LC has been made.**
- **We need now to optimize the detector design using more realistic physics studies based on full simulations and event reconstruction.**
- **Object-Oriented methodology provides the necessary flexibility to efficiently study multiple designs.**

Full Simulations

- **Detailed, realistic descriptions of the detector elements.**
  - **Including support material, cracks, etc.**
- **Complete accounting of physics processes, track swimming, particle showering, etc.**
- **Essential for detector development and derivation of fast simulation parameterizations.**

Full Simulations

LCD Full Sim

GISMO

C++

BRAHMS

GEANT3

FORTRAN

JIM

GEANT3

FORTRAN

Common GEANT4

Object-Oriented

Approach

Geant4 current state

History:

- **CERN RD44 started in 1994 brings the first public Geant4 release in December 1998**
- **Geant4 collaboration for the development and the maintenance since January 1999**
- **Geant4 has more than**
  - **700,000 lines of ANSI C++**
  - **1,200 classes**

Geant4's last public release : 2.0 in July 2000

NLC studies with Geant4

Software developments for the NLC calorimeter simulation:

- Lineaire: **First approach with Geant4 and the NLC project geometry, started at January 1999**
- Mokka: **Production release for the Tesla TDR exploiting Geant4, started at December 1999**
- **Automatic backward Geant3 code generation for** Brahms**, to insure geometry coherence**

Current status

- Lineaire **frozen but still in use**
- Mokka **is “de facto” the reference for the Tesla TDR calorimetry energy flow study**
- **Brahms backward compatibility fully implemented and running at DESY**
- Mokka **should still be in use after the Tesla TDR, mainly for the calorimeter optimization studies**

Future

- Lets try to join efforts to develop together a linear collider detector simulation tool.
- Could Mokka be a good starting point?
  - We'll need a good database and management design
  - Probably it'll be a Geant4 application
- In any case, lets start trying to define the user requirements before coding.

Fast Simulations

Simulations based on parameterized, or simplified detector responses

Fast, can be flexible, but have limitations.

QuickSim

C++/ROOT

FastMC

ROOT

C++

JAS

Java

Common (Object-Oriented) Approach

SIMDET

FORTRAN

Summary

- **The talk this morning has only scratched the surface on a large body of work conducted by a remarkably small community of dedicated individuals.**
- **Very similar approaches are being followed by the various groups, although implementation is not cohesive.**
- **Much work remains to be done and we could all benefit from collaborative effort.**
- **Perhaps now is the time to create the Linear Collider Tools Working Group.**