

Intelligent Detector Design

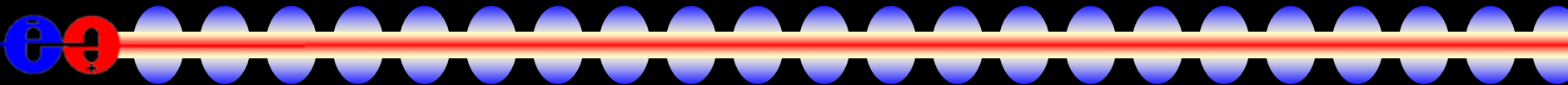
Norman Graf (SLAC)

(for the ALCPG Simulation & Reconstruction WG)

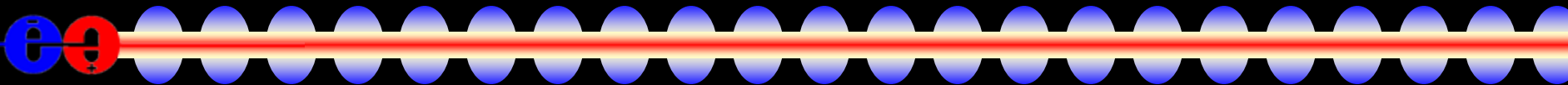
CHEP '07

September 3, 2007

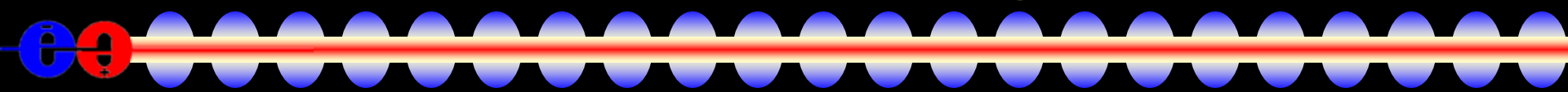
Linear Collider Detector Environment

- 
- Detectors designed to exploit the physics discovery potential of e^+e^- collisions at $\sqrt{s} \sim 1\text{TeV}$.
 - Perform precision measurements of complex final states with well-defined initial state:
 - Tunable energy
 - Known quantum numbers & e^- , e^+ , γ polarization
 - Possibilities for $\gamma\gamma$, γe^- , e^-e^-
 - Very small interaction region
 - Momentum constraints (modulo beam & bremsstrahlung)

Detector Requirements

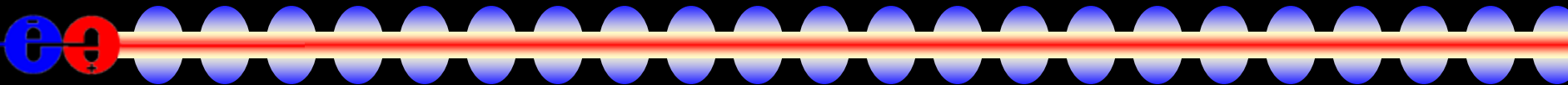
- 
- Desire to fully reconstruct hadronic final states
 - Ability to tag heavy (light) quarks
 - Excellent missing energy/mass sensitivity
 - Require:
 - Exceptional momentum resolution
 - Large volume TPC or low-mass Si μ -strip tracker
 - Excellent vertexing capabilities
 - Multi-layer pixel Vertex Detector (~GigaPixel)
 - Highly segmented (longitudinal & transverse) calorimetry
 - Imaging, (non-compensating) sampling calorimeter
 - Hermeticity
 - Minimal supports, on-detector readout.

Detector Design

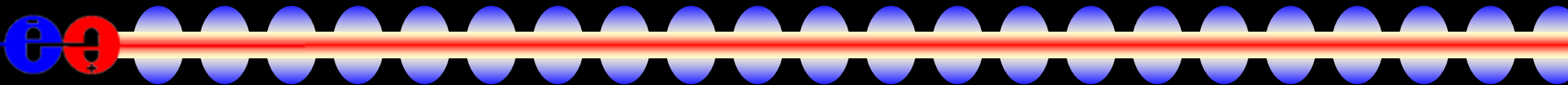


- Perception that LC detectors are trivial to build.
- Much R&D has been done for SSC/LHC, but optimizations are different.
- Hadron colliders have large cross sections and enormous backgrounds
- ILC has much smaller event rates, data sizes and small backgrounds.
- Precision vs. Robustness.

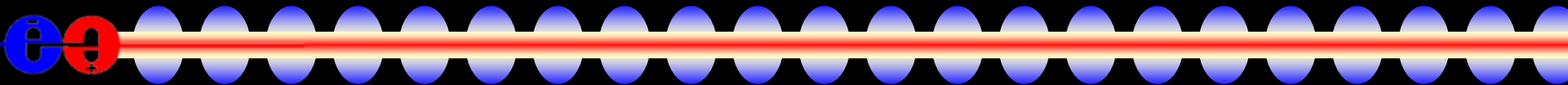
LCD Simulation Mission Statement

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

Overview: Goals

- 
- Facilitate contribution from physicists in different locations with various amounts of time available.
 - Use standard data formats, when possible.
 - Provide a general-purpose framework for physics software development.
 - Develop a suite of reconstruction and analysis algorithms and sample codes.
 - Simulate benchmark physics processes on different full detector designs.

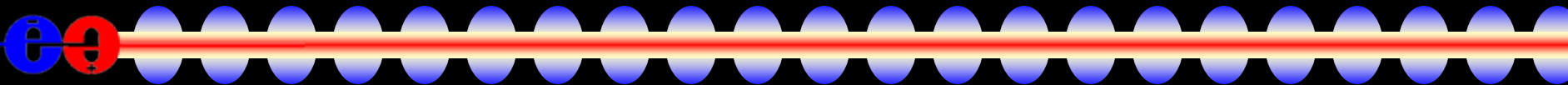
Fast Detector Response Simulation

- 
- Covariantly smear tracks with matrices derived from geometry, materials and point resolution using Billoir's formulation.

<http://www.slac.stanford.edu/~schumm/lcdtrk>

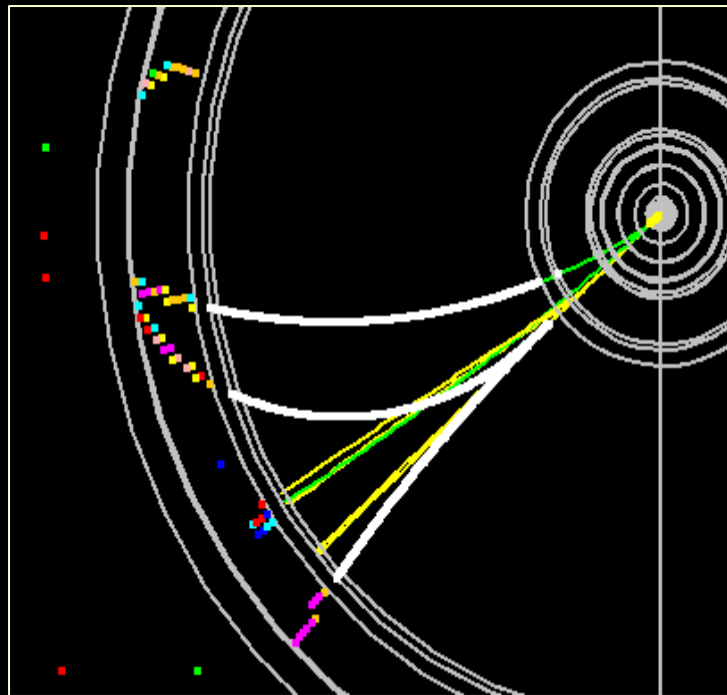
- Smear neutrals according to expected calorimeter resolution (EM for γ , HAD for neutral hadrons)
- Create reconstructed particles from tracks and clusters (γ , e , μ from MC, $\pi^{+/-}$, K^0_L for others)
- Can also dial in arbitrary effective jet energy resolution.

lelaps

- 
- Fast detector response package.
 - Handles decays in flight, multiple scattering and energy loss in trackers.
 - Parameterizes particle showers in calorimeters.
 - Produces lcio data at the hit level.
 - Uses runtime geometry (compact.xml → god1).
 - An excellent tool for designing tracking detectors!

<http://lelaps.freehep.org/index.html>

Lelaps: Decays, dE/dx , MCS

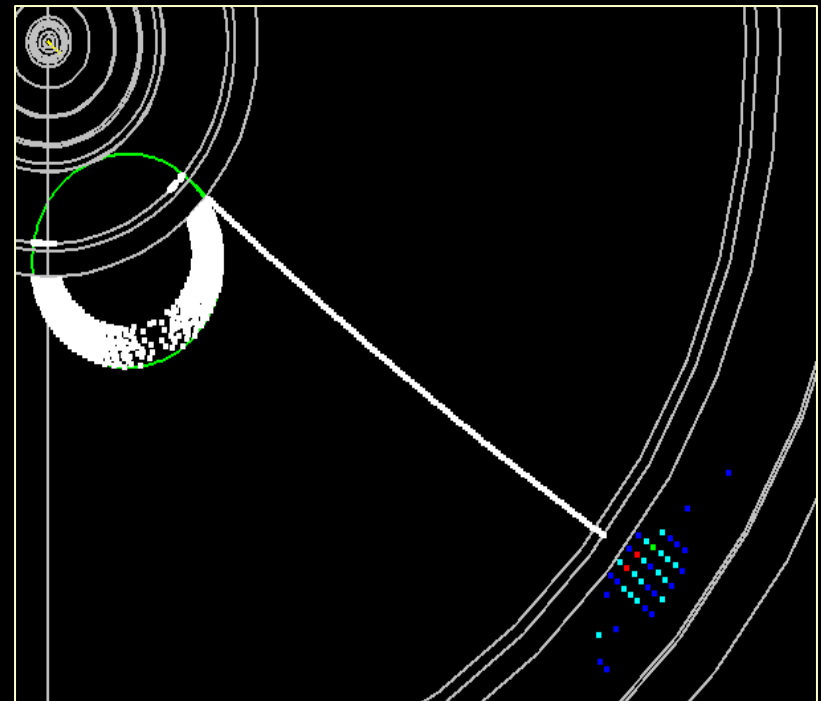


$$\Omega^- \rightarrow \Xi^0 \pi^-$$

$$\Xi^0 \rightarrow \Lambda \pi^0$$

$$\Lambda \rightarrow p \pi^-$$

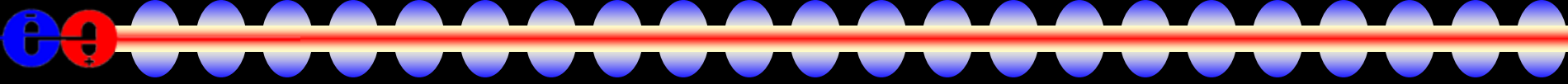
$\pi^0 \rightarrow \gamma \gamma$ as
simulated by Lelaps for the
LDC model.



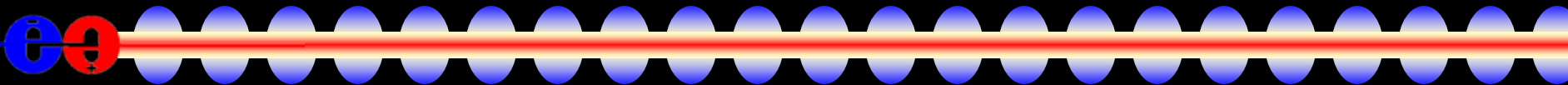
gamma conversion as
simulated by Lelaps for the
LDC model.

Note energy loss of electron.

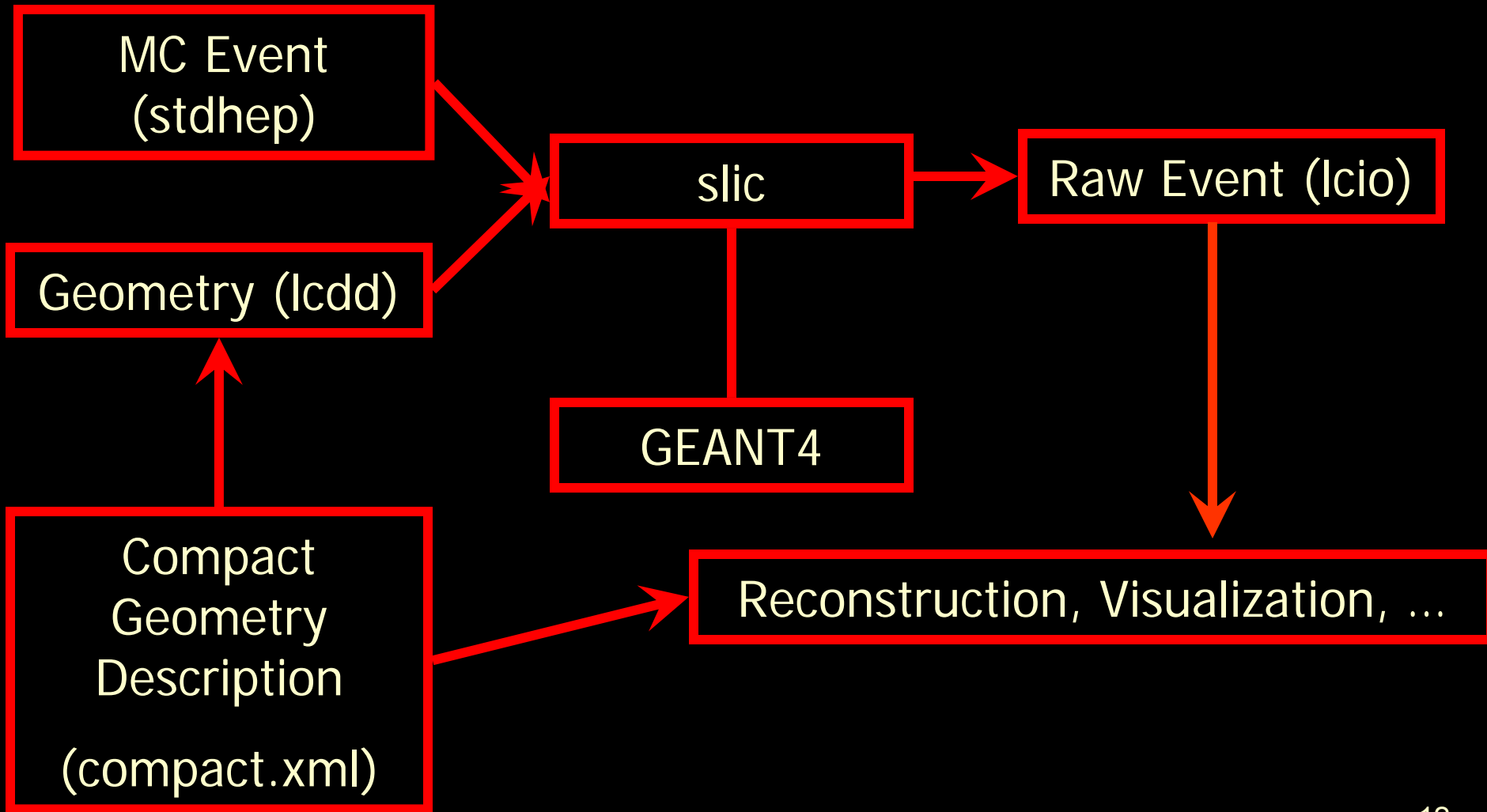
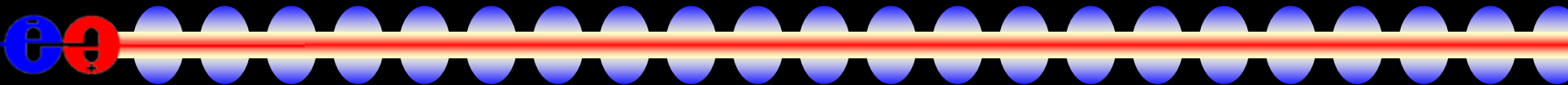
Detector Design (GEANT 4)

- 
- Need to be able to flexibly, but believably simulate the detector response for various designs.
 - GEANT is the de facto standard for HEP physics simulations.
 - Use runtime configurable detector geometries
 - Write out “generic” hits to digitize later.

Full Detector Response Simulation

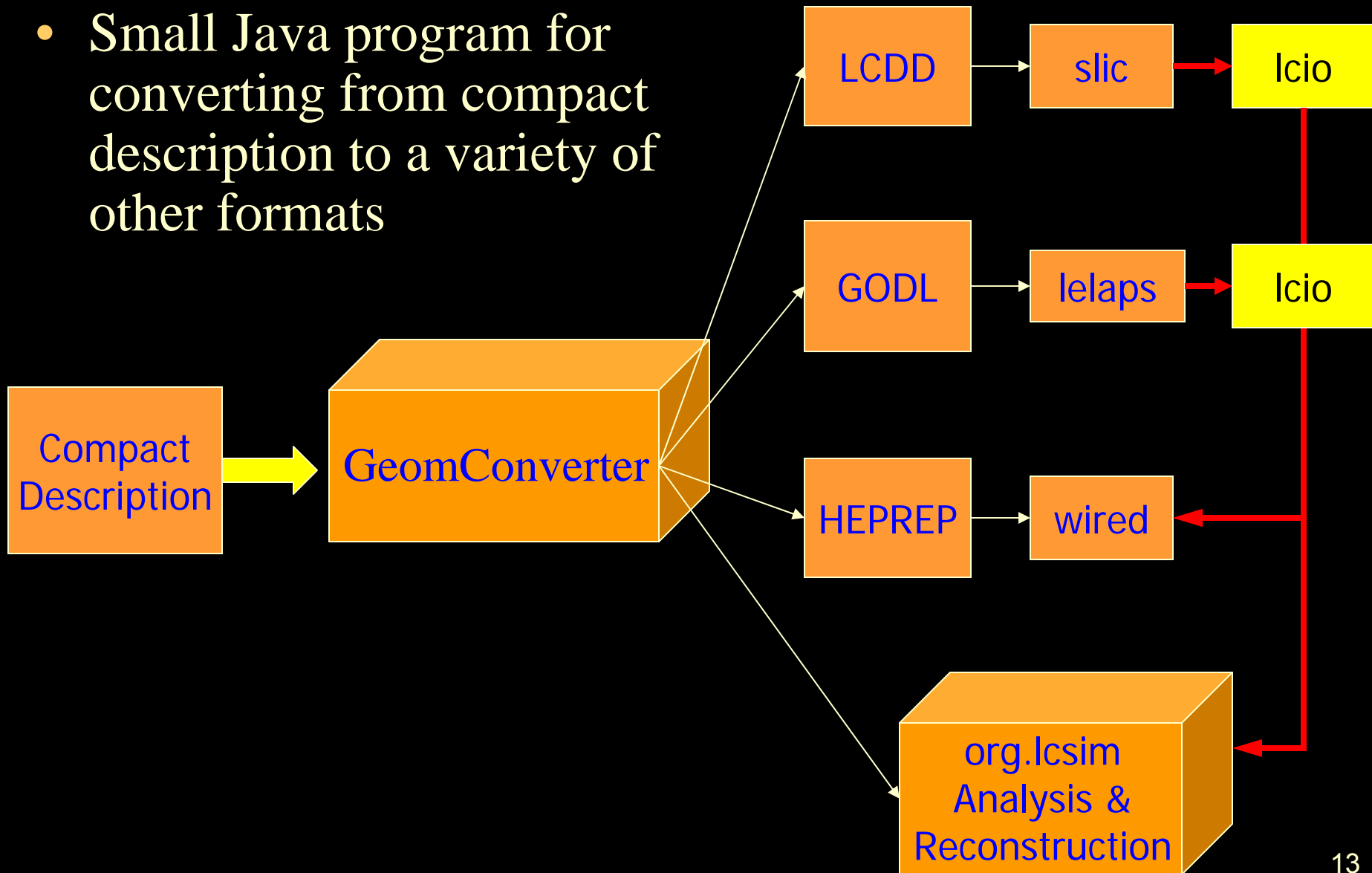
- 
- Use Geant4 toolkit to describe interaction of particles with matter.
 - Thin layer of LC-specific C++ provides access to:
 - Event Generator input (binary stdhep format)
 - Detector Geometry description (XML)
 - Detector Hits (LCIO)
 - Geometries fully described at run-time!
 - In principle, as fully detailed as desired.
 - In practice, will explore detector variations with simplified approximations.

LC Detector Full Simulation

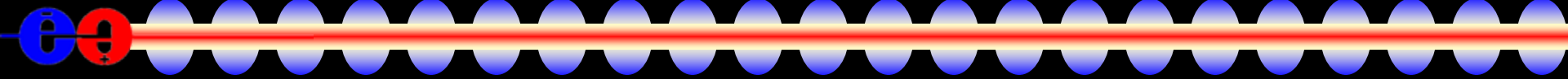


GeomConverter

- Small Java program for converting from compact description to a variety of other formats

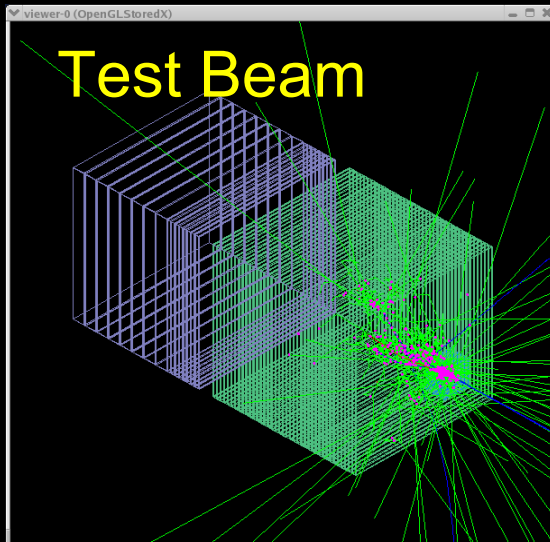
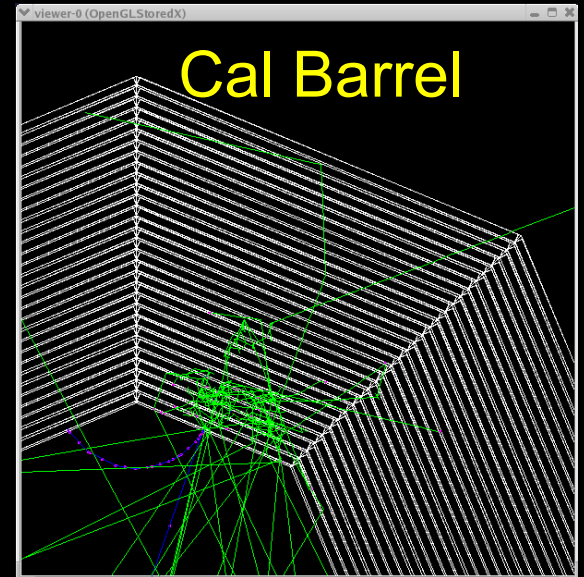
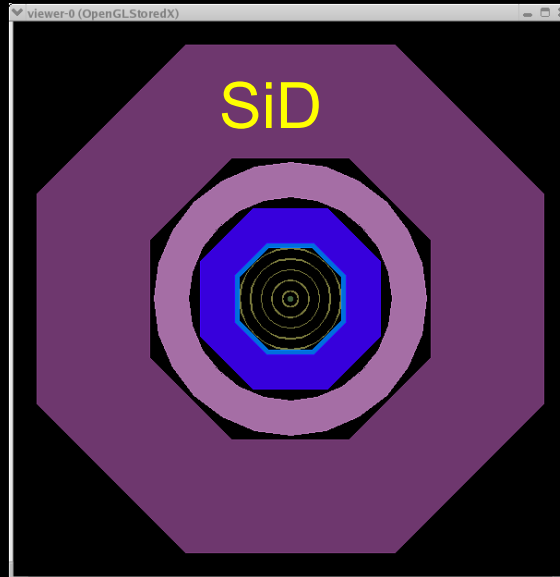
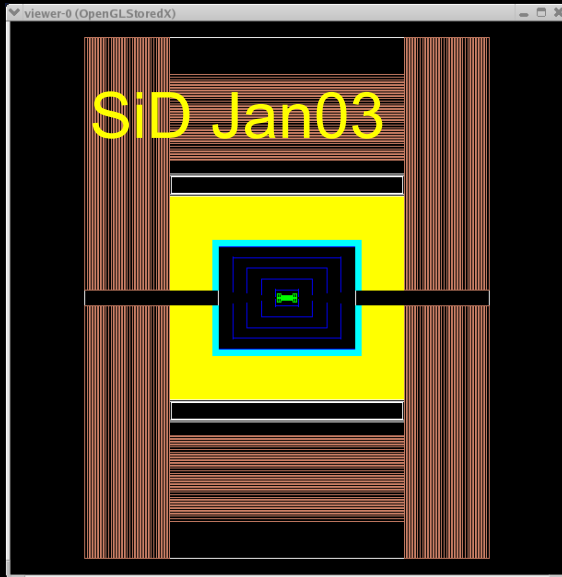


Detector Variants

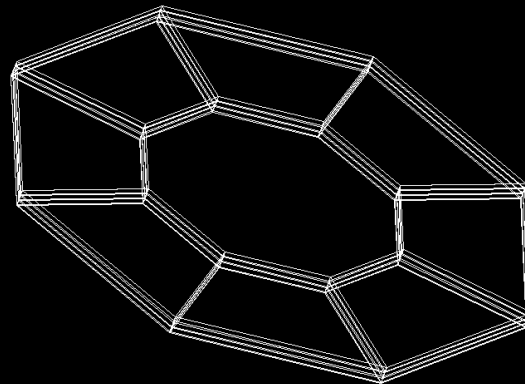


- Runtime XML format allows variations in detector geometries to be easily set up and studied:
 - Stainless Steel vs. Tungsten HCal sampling material
 - RPC vs. GEM vs. Scintillator readout
 - Layering (radii, number, composition)
 - Readout segmentation (size, projective vs. nonprojective)
 - Tracking detector technologies & topologies
 - TPC, Silicon microstrip, SIT, SET
 - “Wedding Cake” Nested Tracker vs. Barrel + Cap
 - Field strength
 - Far forward MDI variants (0, 2, 14, 20 mr)

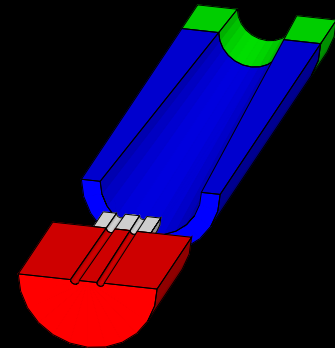
Example Geometries



Cal Endcap

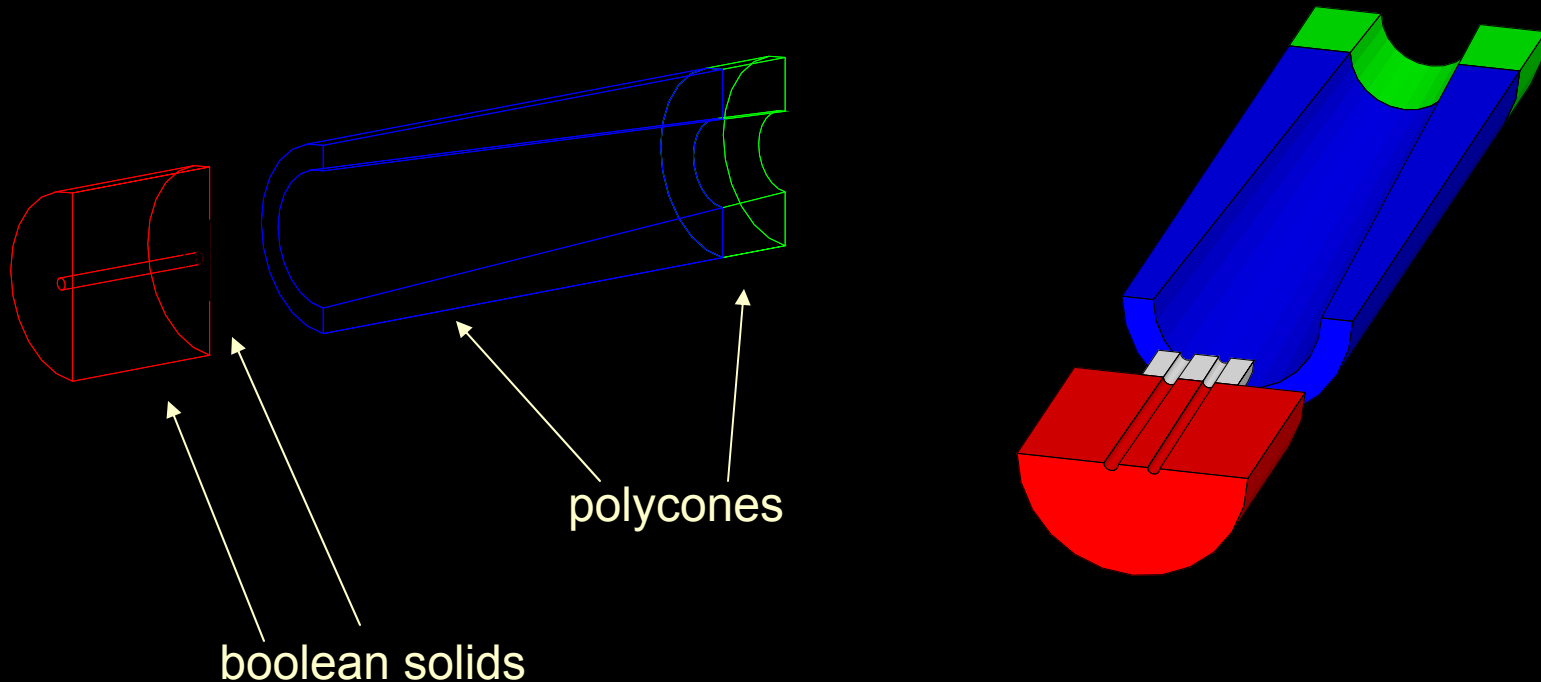


MDI-BDS



Far forward calorimetry

Machine Detector Interface and Beam Delivery System

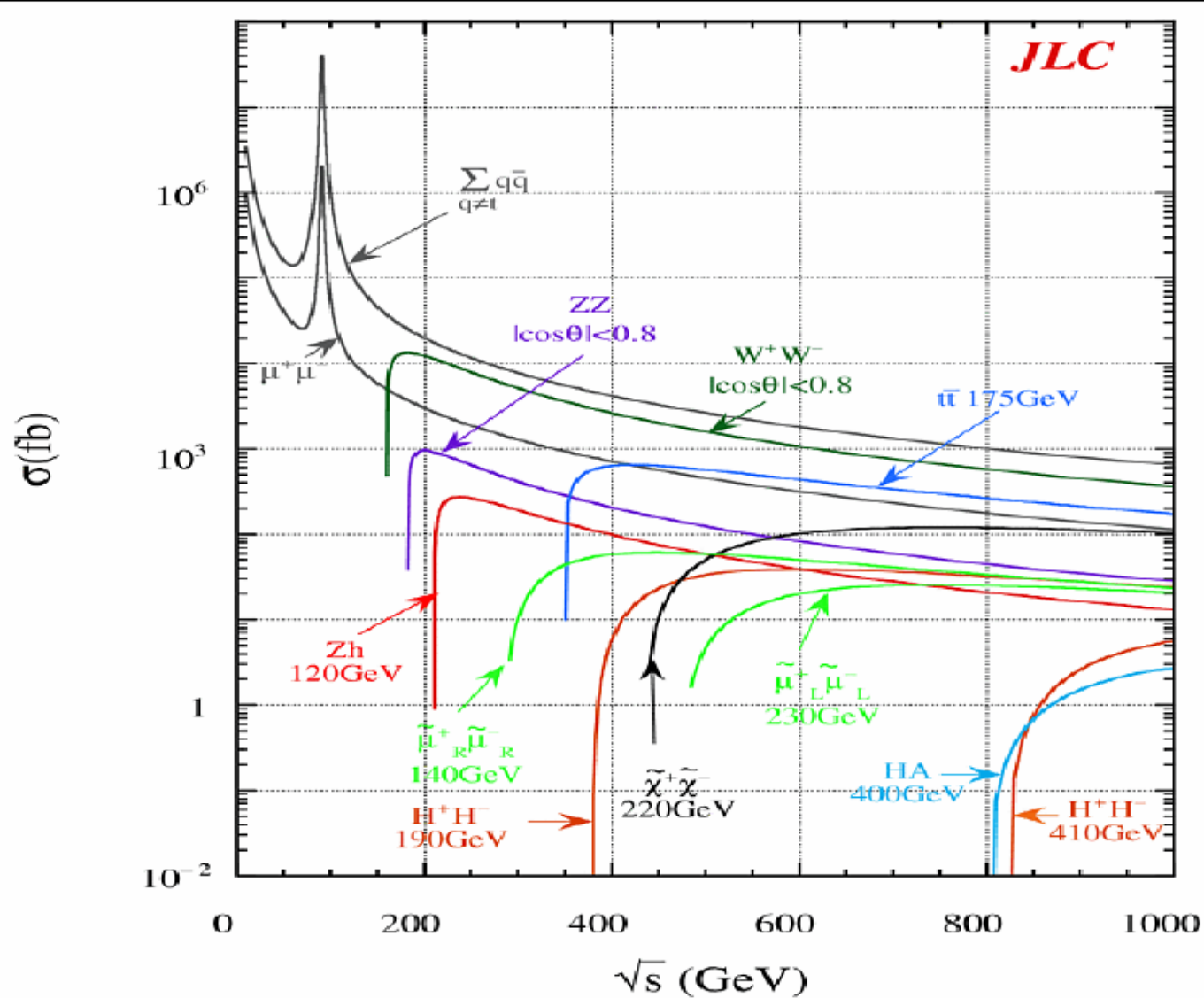


“Signal” and Diagnostic Samples

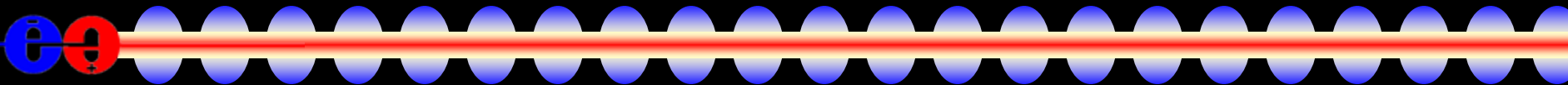
- Have generated canonical data samples and have processed them through full detector simulations.
- simple single particles: γ , μ , e , $\pi^{+/-}$, n , ...
- composite single particles: π^0 , ρ , K^0_S , τ , ψ
- Z Pole events: comparison to SLD/LEP
- WW, ZZ, $t\bar{t}$, $q\bar{q}$, tau pairs, mu pairs, $Z\gamma$, Zh:
- Web accessible:

<http://www.lcsim.org/datasets/ftp.html>

“Standard Model Processes”



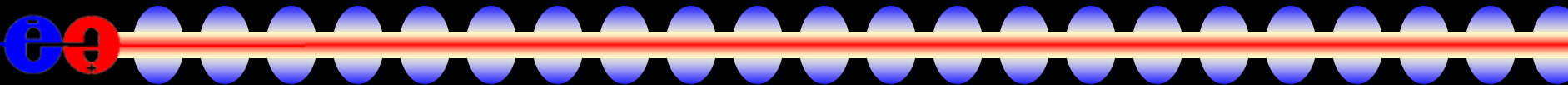
“Standard Model Sample”

- 
- Generate an inclusive set of MC events with all SM processes + backgrounds arising from beam- and brems-strahlung photons and machine-related particles. 500 fb^{-1} @ 0.5 TeV, 2 ab^{-1} @ 1.0 TeV
 - WHIZARD Monte Carlo used to generate all 0,2,4,6-fermion and t quark dominated 8-fermion processes.
 - Used for realistic analyses and represents a “standard” sample.
 - Canonical background for Beyond-SM searches.
 - 100% e^- and e^+ polarization used in generation. Arbitrary electron, positron polarization simulated by properly combining data sets.
 - Fully fragmented MC data sets are produced. PYTHIA is used for final state QED & QCD parton showering, fragmentation, particle decay.
 - 1 year’s worth of stdhep files fits on one external harddrive.

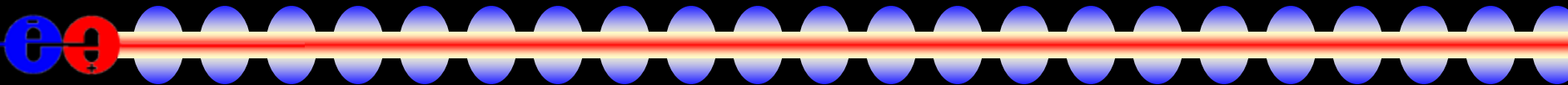
Reconstruction/Analysis Overview

- Java based reconstruction and analysis package
 - Runs standalone or inside Java Analysis Studio (JAS)
 - Fast MC → Smeared tracks and calorimetry clusters
 - Full Event Reconstruction
 - detector readout digitization (CCD pixels & Si μ -strips)
 - *ab initio* track finding and fitting for ~arbitrary geometries
 - multiple calorimeter clustering algorithms
 - Individual Particle reconstruction (cluster-track association)
 - Analysis Tools (including WIRED event display)
 - Physics Tools (Vertex Finding, Jet Finding, Flavor Tagging)
 - Beam background overlays at detector hit level

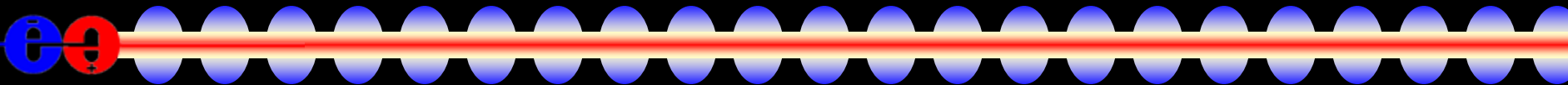
Tracking

- 
- Analytic covariance matrices available for fast MC smearing for each detector. Uses [lcdtrk](#).
 - Track “cheater” available for studies of full detector simulation events. Assigns hits on basis of MC parentage.
 - Ab initio track finding packages.
 - Fitting code incorporating multiple scattering and energy loss via weight matrix or Kalman Filter available.

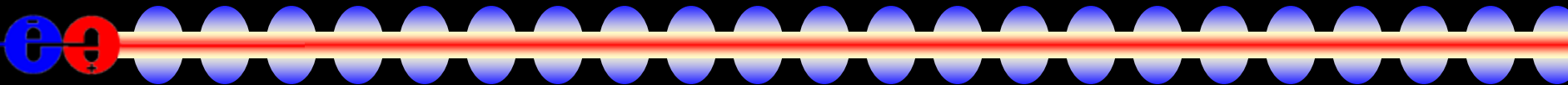
Tracking Detector Readout

- 
- Hits in Trackers record full MC information.
 - Module tiling and signal digitization is deferred to analysis stage.
 - Used to rapidly study many possible solutions.
 - Fully-featured package to convert MC hits in silicon to pixel hits. Fully configurable at runtime.
MC Hits → Pixel ID & ADC → Clusters → Hits ($x \pm \delta x$)
 - Can correctly study occupancies, overlaps, ghost hits, etc.

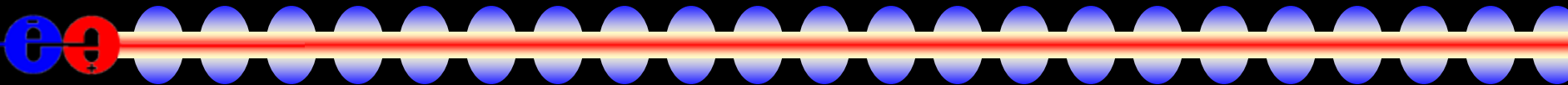
Track Finding

- 
- Standalone pattern recognition code for 1D (e.g. Si μ strip) and 2D (e.g. Si pixel) hits.
 - High efficiency, even in presence of backgrounds.
 - Efficient at low momentum.
 - Conformal-mapping pattern recognition also available, applicable also to TPC.
 - MIP stubs in highly segmented calorimeters also provide track candidates, propagate inwards to pick up tracker hits.

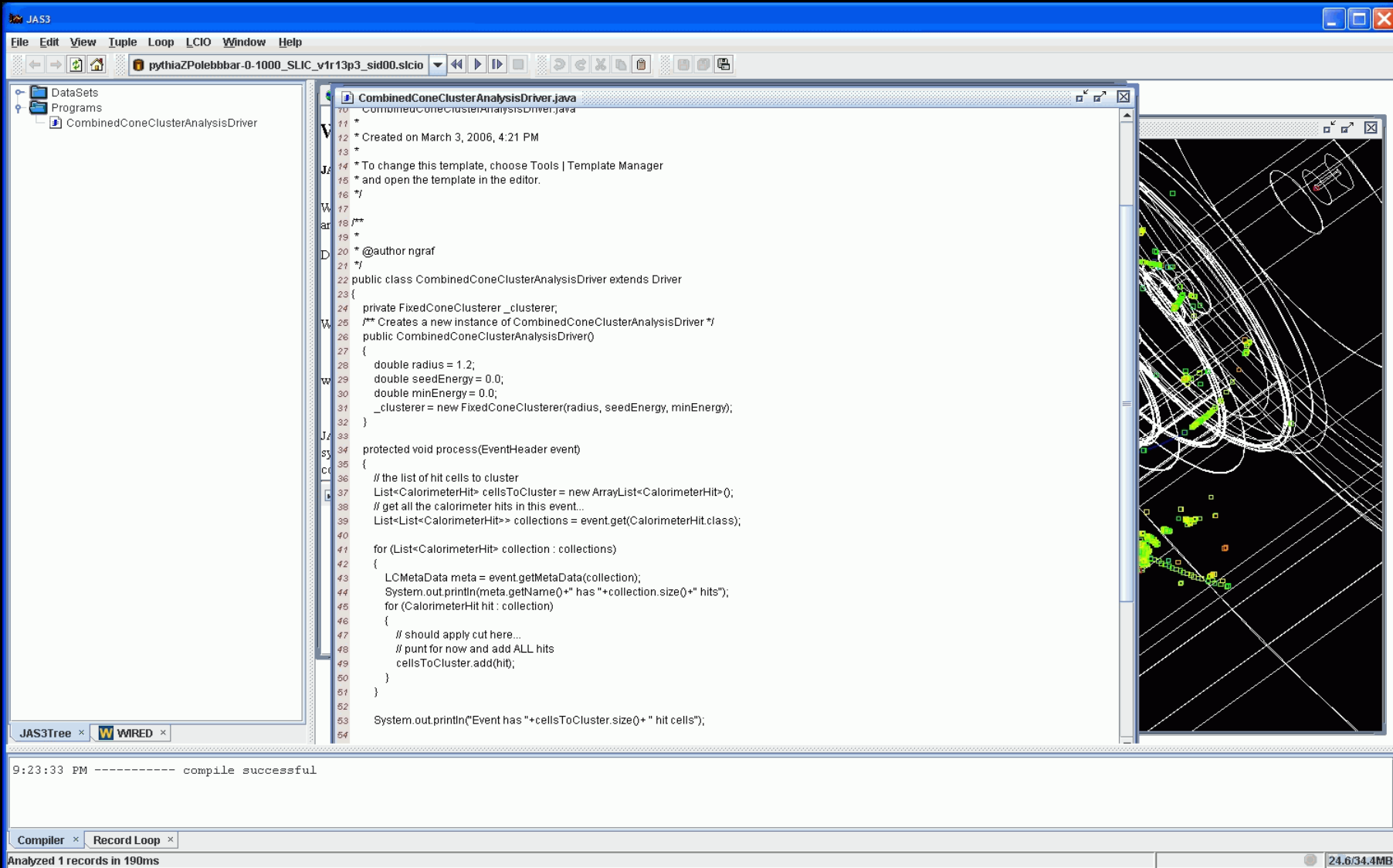
Particle Reconstruction

- 
- Several groups are following different approaches towards individual particle reconstruction
 - aka “energy flow” or “particle flow”
 - Template allows plug-and-play of different approaches.
 - Have first packages for identifying photons, electrons, charged & neutral hadrons and muons.
 - Being tuned and optimized for different detectors and different final states.
 - Main tool for detector optimization.

Java Analysis Studio (JAS)

- 
- Integrated Development Environment (editor, compiler)
 - Cross-platform physics analysis environment with iterative, event-based analysis model
 - quick development, debugging, ad hoc analysis
 - additional functionality with plugins
 - Dynamically load / unload Java analysis drivers
 - Supports distributed computing.
 - Plotting and fitting and analysis (cuts, scripting) engine
 - 1D, 2D histograms, clouds, profiles, dynamic scaling, cuts
 - high-quality output to vector or raster formats
 - Integrated event browser and event display

JAS editor/compiler



The screenshot displays the JAS3 editor/compiler interface. The main window is titled "JAS3" and contains a menu bar (File, Edit, View, Tuple, Loop, LCIO, Window, Help) and a toolbar. The left pane shows a file explorer with "DataSets" and "Programs" folders, and a sub-folder "CombinedConeClusterAnalysisDriver". The central pane shows the source code for "CombinedConeClusterAnalysisDriver.java". The code includes comments and a Java class definition for "CombinedConeClusterAnalysisDriver" that extends "Driver". The class has a constructor and a "process" method that iterates over "collections" of "CalorimeterHit" objects, printing out the number of hits for each collection. The right pane shows a visualization of the data, displaying a complex network of white lines and green/yellow points on a black background, representing a detector layout or event reconstruction. The status bar at the bottom indicates "9:23:33 PM ----- compile successful" and "Analyzed 1 records in 190ms".

```
70 CombinedConeClusterAnalysisDriver.java
71
72 *
73 * Created on March 3, 2006, 4:21 PM
74 *
75 * To change this template, choose Tools | Template Manager
76 * and open the template in the editor.
77 *
78 **
79 *
80 * @author ngraf
81 **
82
83 public class CombinedConeClusterAnalysisDriver extends Driver
84 {
85     private FixedConeClusterer _clusterer;
86     /** Creates a new instance of CombinedConeClusterAnalysisDriver */
87     public CombinedConeClusterAnalysisDriver()
88     {
89         double radius = 1.2;
90         double seedEnergy = 0.0;
91         double minEnergy = 0.0;
92         _clusterer = new FixedConeClusterer(radius, seedEnergy, minEnergy);
93     }
94
95     protected void process(EventHeader event)
96     {
97         // the list of hit cells to cluster
98         List<CalorimeterHit> cellsToCluster = new ArrayList<CalorimeterHit>();
99         // get all the calorimeter hits in this event...
100         List<List<CalorimeterHit>> collections = event.get(CalorimeterHit.class);
101
102         for (List<CalorimeterHit> collection : collections)
103         {
104             LCMetaData meta = event.getMetaData(collection);
105             System.out.println(meta.getName()+" has "+collection.size()+" hits");
106             for (CalorimeterHit hit : collection)
107             {
108                 // should apply cut here...
109                 // punt for now and add ALL hits
110                 cellsToCluster.add(hit);
111             }
112         }
113
114         System.out.println("Event has "+cellsToCluster.size()+" hit cells");
115     }
116 }
```

JAS3Tree x WIRED x

9:23:33 PM ----- compile successful

Compiler x Record Loop x

Analyzed 1 records in 190ms

24.6/34.4MB

JAS event browser

JAS3

File Edit View Tuple Loop LCIO Window Help

pythiaZPolebbar-0-1000_SLIC_v1r13p3_sid00.slcio

DataSets
Programs
ClusterFinding
aida22594aida

e-(E=45.500 status=Documentation)
 e-(E=45.500 status=Documentation)
 e-(E=45.500 status=Documentation)
 Zo(E=91.000 status=Documentation)
 b(E=45.500 status=Documentation)
 b(E=38.330 status=Intermediate)
 unknown(E=91.000 status=Intermediate)
 B*(E=31.648 status=Intermediate)
 pi0(E=2.1998 status=Intermediate)
 pi+(E=4.0914 status=Final State)
 rho0(E=1.2687 status=Intermediate)
 K(892)*o(E=2.8169 status=Intermediate)
 K-(E=2.6171 status=Final State)
 pi0(E=1.5627 status=Intermediate)
 pi0(E= 60782 status=Intermediate)
 Delta+(E=3.5210 status=Intermediate)
 Ko_bar(E=2.0863 status=Intermediate)
 Xi0_bar(E=7.6546 status=Intermediate)
 B(s)*o(E=30.926 status=Intermediate)
 gluon(E=7.0819 status=Intermediate)
 gluon(E= 91563 status=Intermediate)
 gluon(E= 49304 status=Intermediate)

LCSim Event
Run:0 Event: 179

Event
 EcalBarrHits
 EcalBarrHitsNNClusters
 EcalEndcapHits
 EcalEndcapHitsNNClusters
 ForwardEcalEndcapHits
 HcalBarrHits
 HcalBarrHitsNNClusters
 HcalEndcapHits
 HcalEndcapHitsNNClusters
 LuminosityMonitorHits
 MCParticle
 MCParticleEndPointEnergy
 MuonBarrHits
 MuonEndcapHits
 TrkBarrHits

LCIO Event Header

Run	0
Event	179
Time Stamp	Thu Feb 16 10:34:33 PST 2006
Detector Name	sid00

Collections

Name	Type	Size
EcalEndcapHitsNNClusters	org.lcsim.event.Cluster	22
EcalEndcapHitsNNClusters	org.lcsim.event.Cluster	22
EcalBarrHitsNNClusters	org.lcsim.event.Cluster	24
HcalBarrHitsNNClusters	org.lcsim.event.Cluster	7
HcalEndcapHitsNNClusters	org.lcsim.event.Cluster	3
VbEndcapHits	org.lcsim.event.SimTrackerHit	72
EcalBarrHits	org.lcsim.event.SimCalorime...	1036
EcalEndcapHits	org.lcsim.event.SimCalorime...	1084
ForwardEcalEndcapHits	org.lcsim.event.SimCalorime...	33
HcalBarrHits	org.lcsim.event.SimCalorime...	197
HcalEndcapHits	org.lcsim.event.SimCalorime...	129
LuminosityMonitorHits	org.lcsim.event.SimCalorime...	0
MuonBarrHits	org.lcsim.event.SimCalorime...	1

LCSim Event
Run:0 Event: 179

Collection: EcalEndcapHits size:1084 flags:e0000000

id: system	id: layer	id: barrel	id: x	id: y	raw energy (e...)	corrected e...	x (mm)	y (mm)	z (mm)	time (ns)
6	0	2	77	304	1.0683E-4	.0084284	271.25	1065.8	-1683.3	6.7236
6	1	2	77	304	1.1771E-4	.0092868	271.25	1065.8	-1687.1	6.7386
6	2	2	77	305	1.0897E-4	.0085971	271.25	1069.2	-1690.8	6.7536
6	3	2	77	306	1.2685E-4	.010008	271.25	1072.8	-1694.6	6.7685
6	4	2	77	306	4.6335E-5	.0036556	271.25	1072.8	-1698.3	6.7834
6	4	2	77	307	1.2153E-4	.0095883	271.25	1076.2	-1698.3	6.7840
6	10	2	83	303	3.6268E-4	.028614	292.25	1062.2	-1720.8	7.2580
6	26	2	105	200	2.0871E-5	.0016466	369.25	701.75	-1798.3	101.67
6	21	2	55	297	1.4128E-5	.0011147	194.25	1041.2	-1767.1	12.514
6	9	2	77	309	8.8875E-4	.070119	271.25	1083.2	-1717.1	6.8521
6	6	2	73	299	3.4643E-4	.027332	257.25	1048.2	-1705.8	7.4273
6	7	2	93	313	6.7790E-4	.053483	327.25	1097.2	-1709.6	8.2976

JAS3Tree x W WIRED x

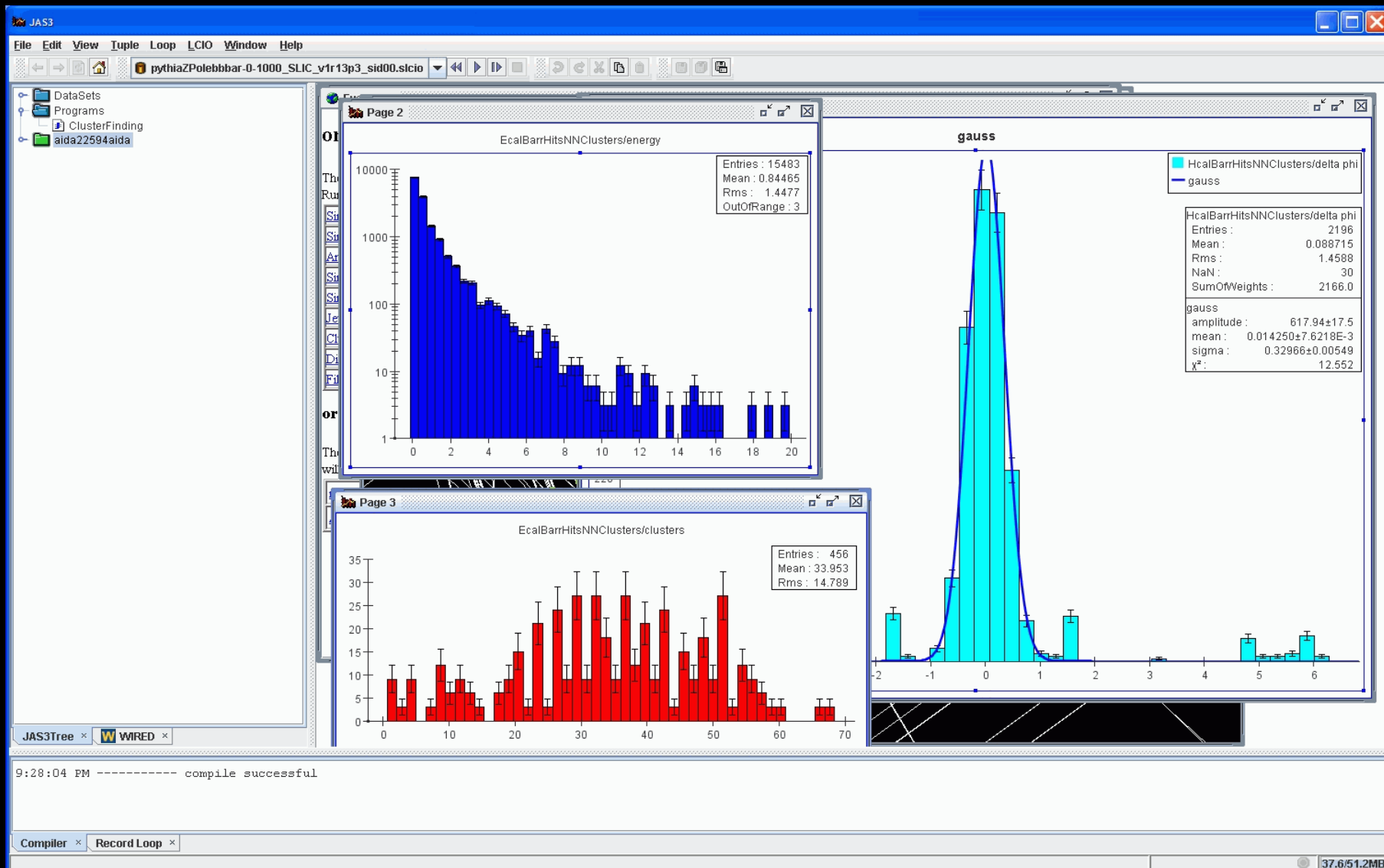
9:28:04 PM ----- compile successful

Compiler x Record Loop x

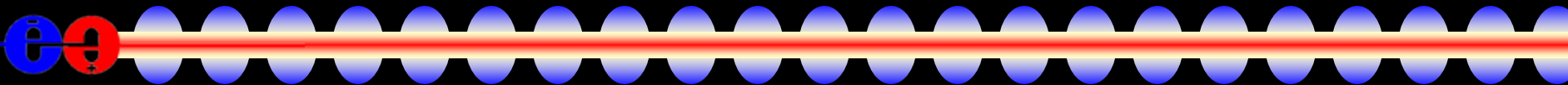
Analyzed 151 records in 114485ms

38.4/51.2MB

JAS histogramming/fitting



JAS LCD 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
 - Wired Event Display
 - Not just a data viewer.
 - 3D, interactive, pickable display provides access to the underlying data objects.
 - Particle Hierarchy Displays

Wired LCD Event Display

The screenshot displays the JAS3 software interface for event display. The main window, titled "View 1", shows a 3D visualization of particle tracks (white lines) and detector hits (colored squares) within a detector geometry. The tracks are complex and intertwined, indicating a high-energy event. The hits are concentrated in specific regions, likely corresponding to the calorimeters.

On the left side, there is a "Interaction" panel with a list of detector components and hit types, each with a checkbox. The "MCParticle" section is expanded, showing "Neutral" and "Charged" options. Below the list, there are checkboxes for "Apply immediately" and "Hide below level:" with a value of 2.

On the right side, there is a panel displaying statistical information for the event. The data is as follows:

sNNClusters/delta phi	2196
sNNClusters/delta phi	0.088715
	1.4588
ghts :	30
	2166.0
	617.94±17.5
	0.014250±7.6218E-3
	0.32966±0.00549
	12.552

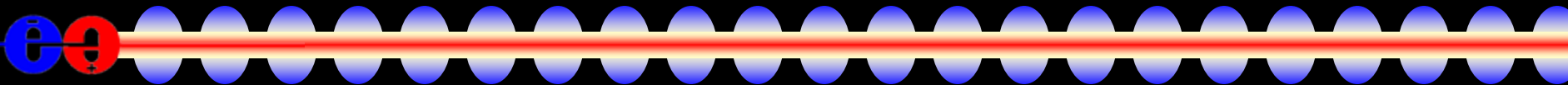
Below the statistics, there is a small histogram showing the distribution of hits, with a peak around 6.

At the bottom of the window, a status bar shows the time "9:28:04 PM" and the message "----- compile successful". There are also tabs for "Compiler" and "Record Loop". The system tray at the bottom right shows the memory usage "37.8/51.2MB".

Interoperability: LCIO / LCGO

- LCIO provides a common event data model and persistency mechanism for ILC physics and detector models.
 - Enables close collaboration and interplay between disparate groups working on different platforms, with different languages and frameworks.
- LCGO is intended to provide a similar functionality for the common description and interchange of detector geometries.
 - See the talks by F. Gaede.

JAS Remote Data Access



GUI

TCP/IP Network

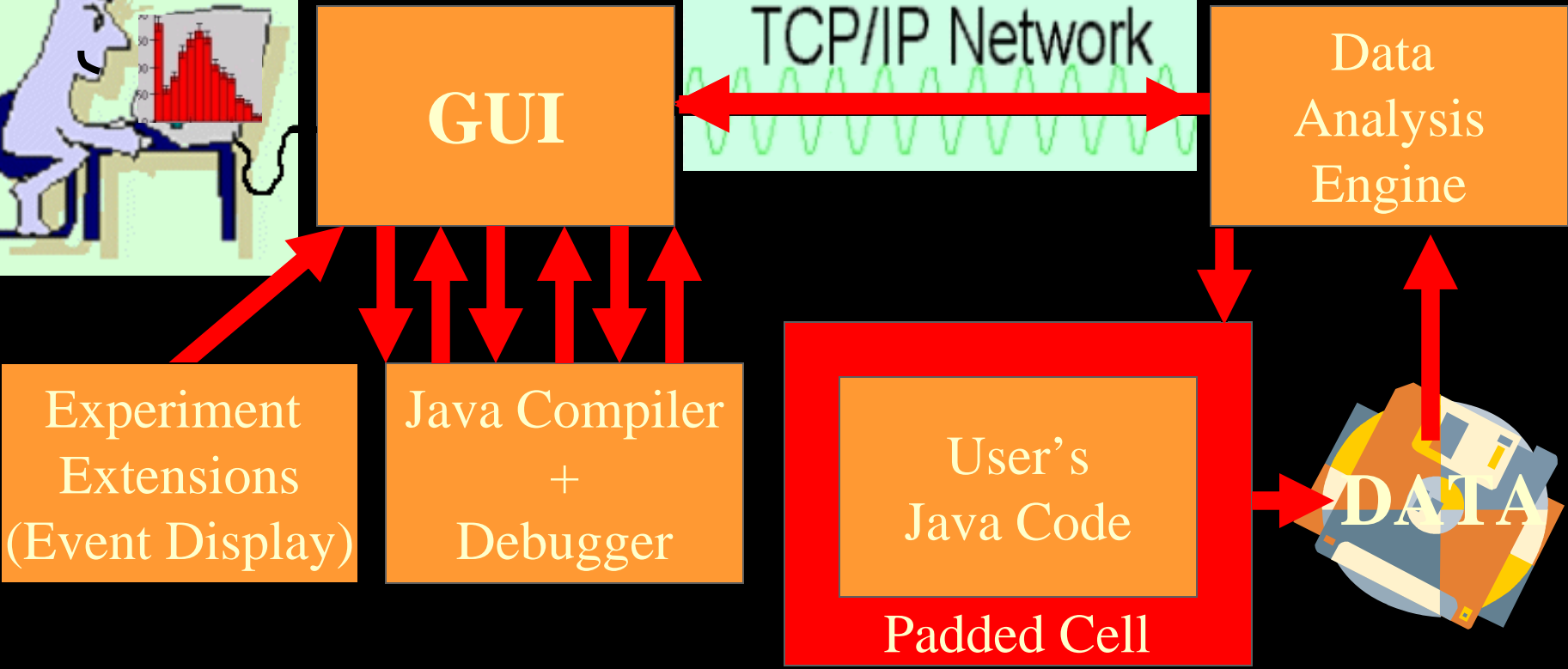
Data Analysis Engine

Experiment Extensions (Event Display)

Java Compiler + Debugger

User's Java Code
Padded Cell

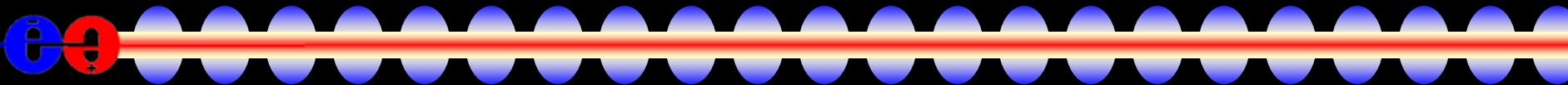
DATA



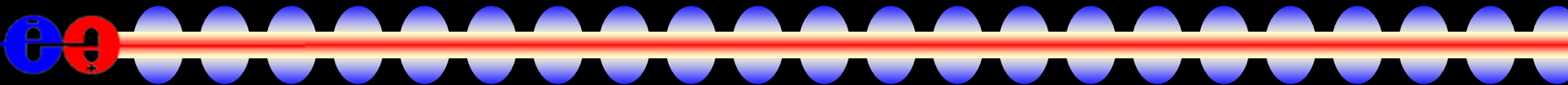
Detector Optimization (Costing)

- Goal is to fully simulate and validate baseline design.
- Then determine the dependence of performance on detector attributes.
- Iterate to achieve balance of cost, risk, & performance
- Excel Spreadsheet used for costing vs parameters.

Simulation Summary

- 
- ALCPG sim/reco supports an ambitious international detector simulation effort. Goal is flexibility and interoperability.
 - Provides full data samples for ILC physics studies.
 - Provides a complete and flexible detector simulation package capable of simulating arbitrarily complex detectors with runtime detector description.
 - Reconstruction & analysis framework exists, various algorithms implemented.
 - Need to iterate and apply to various detector designs₃₄.

Additional Information

- 
- Wiki - <http://confluence.slac.stanford.edu/display/ilc/Home>
 - lcsim.org - <http://www.lcsim.org>
 - org.lcsim - <http://www.lcsim.org/software/lcsim>
 - Software Index - <http://www.lcsim.org/software>
 - Detectors - <http://www.lcsim.org/detectors>
 - ILC Forum - <http://forum.linearcollider.org>
 - LCIO - <http://lcio.desy.de>
 - SLIC - <http://www.lcsim.org/software/slic>
 - LCDD - <http://www.lcsim.org/software/lcdd>
 - JAS3 - <http://jas.freehep.org/jas3>
 - AIDA - <http://aida.freehep.org>
 - WIRED - <http://wired.freehep.org>