Intelligent Detector Design

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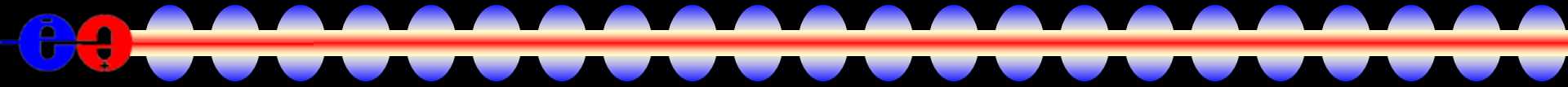
(for the ALCPG Simulation & Reconstruction WG)

CHEP ‘07

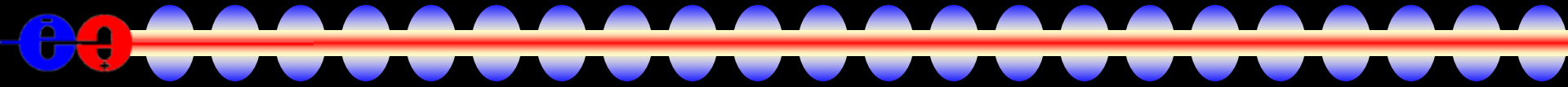
September 3, 2007

Linear Collider Detector Environment



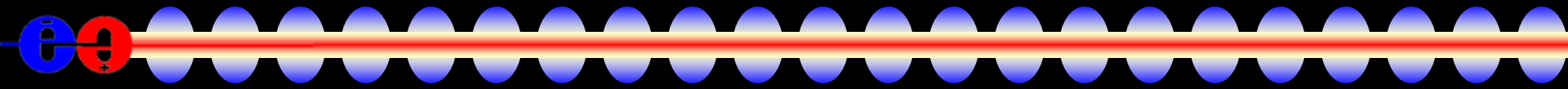
- Detectors designed to exploit the physics discovery potential of e^+e^- collisions at $\sqrt{s} \sim 1$TeV.
- Perform precision measurements of complex final states with well-defined initial state:
  - Tunable energy
  - Known quantum numbers & e^-, e^+, γ polarization
  - Possibilities for $\gamma\gamma$,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

Detector Requirements



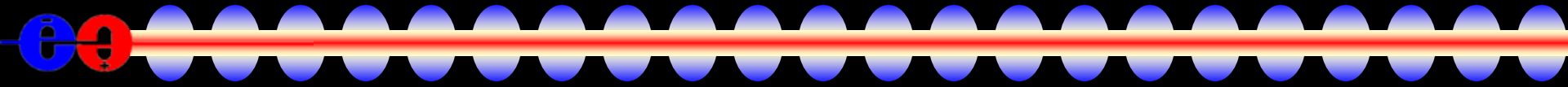
- Desire to fully reconstruct hadronic final states
- Ability to tag heavy (light) quarks
- Excellent missing energy/mass sensitivity
- Require:
  - Exceptional momentum resolution
    - Large volume TPC or low-mass Si μ-strip tracker
  - Excellent vertexing capabilities
    - Multi-layer pixel Vertex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

Detector Design



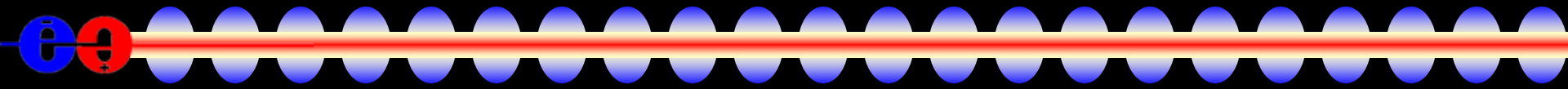
- Perception that LC detectors are trivial to build.
- Much R&D has been done for SSC/LHC, but optimizations are different.
- Hadron colliders have large cross sections and enormous backgrounds
- ILC has much smaller event rates, data sizes and small backgrounds.
- Precision vs. Robustness.

LCD Simulation Mission Statement



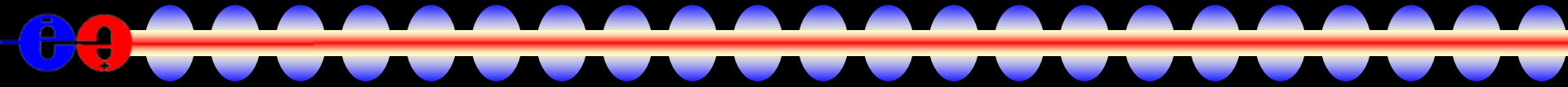
- Provide full simulation capabilities for Linear Collider physics program:
  - Physics simulations
  - Detector designs
  - Reconstruction and analysis
- Need flexibility for:
  - New detector geometries/technologies
  - Different reconstruction algorithms
- Limited resources demand efficient solutions,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

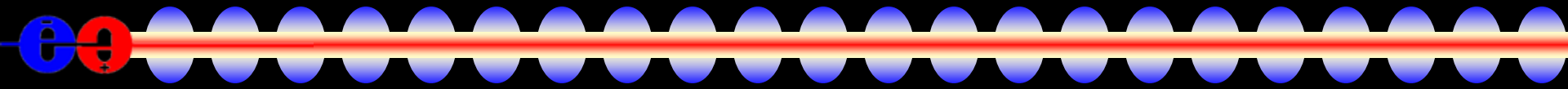


- Covariantly smear tracks with matrices derived from geometry, materials and point resolution using Billoir's formulation.

  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.

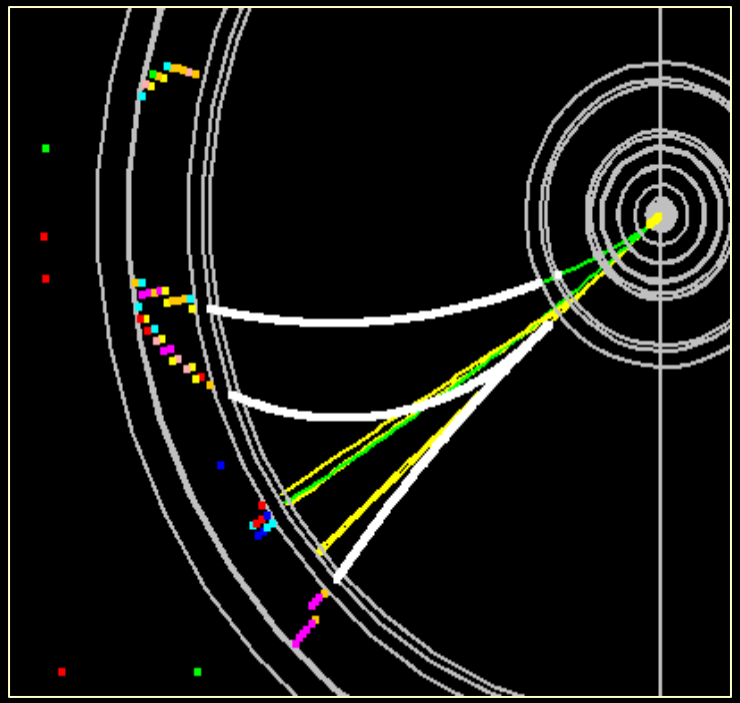
lelaps



- 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 → godl).
- An excellent tool for designing tracking detectors!

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

Lelaps: Decays, dE/dx, MCS

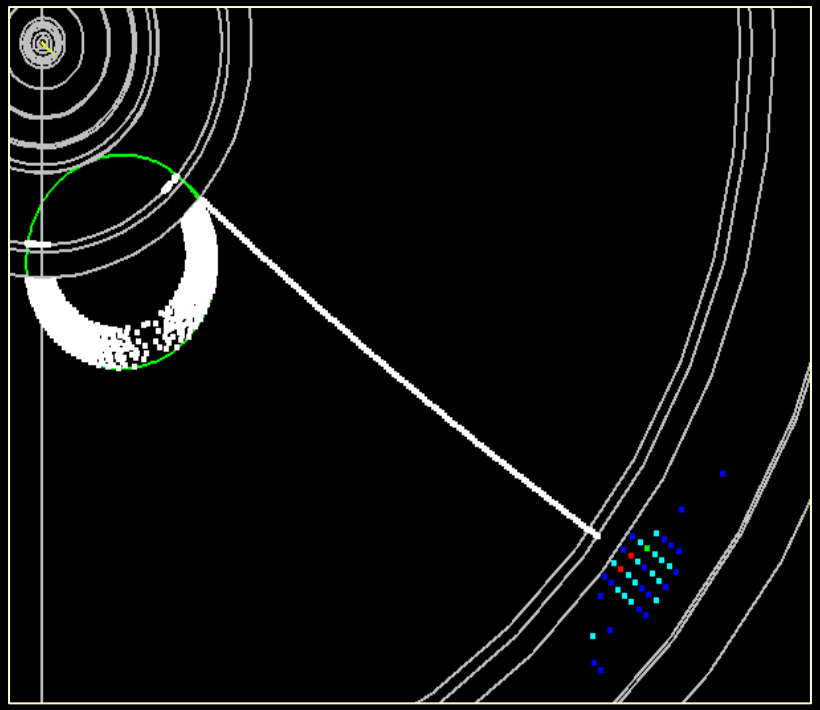


$\Omega^- \rightarrow \Xi^0 \pi^-$

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

$\Lambda \rightarrow p \pi^-$

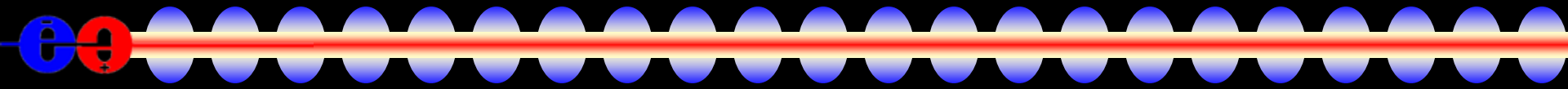
$\pi^0 \rightarrow \gamma \gamma$ as simulated by Lelaps for the LDC model.



gamma conversion as simulated by Lelaps for the LDC model.

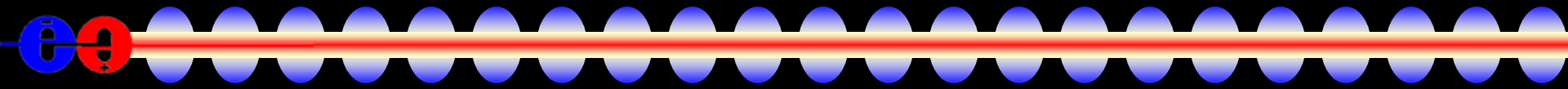
Note energy loss of electron.

Detector Design (GEANT 4)



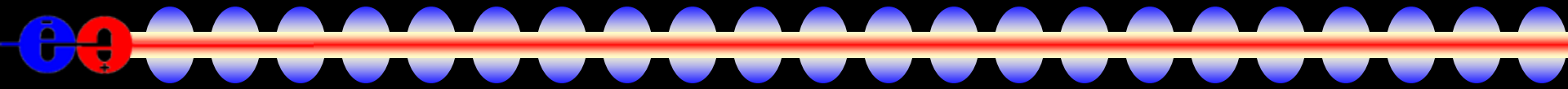
- Need to be able to flexibly, but believably simulate the detector response for various designs.
- GEANT is the de facto standard for HEP physics simulations.
- Use runtime configurable detector geometries
- Write out “generic” hits to digitize later.

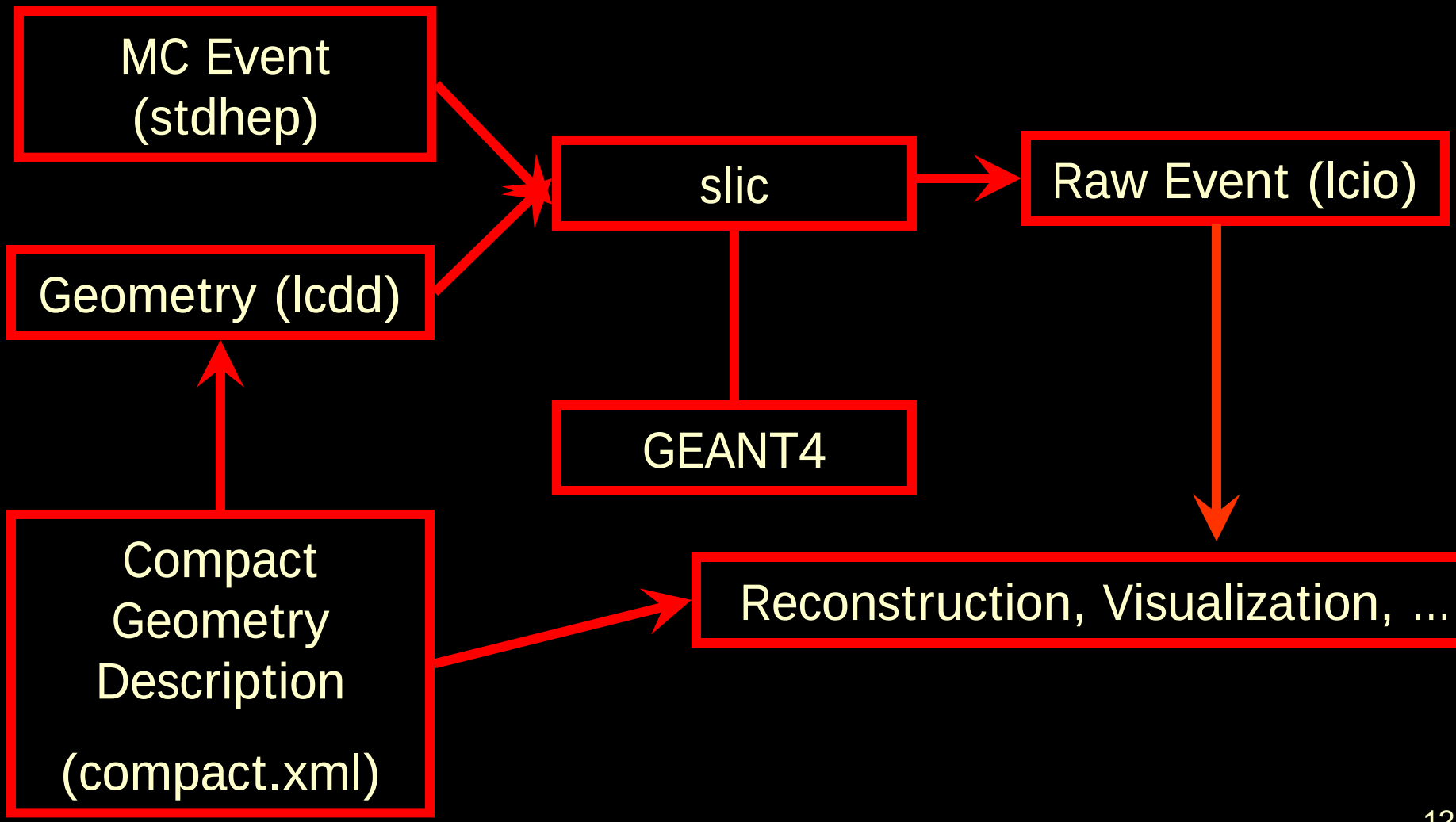
Full Detector Response Simulation



- 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.

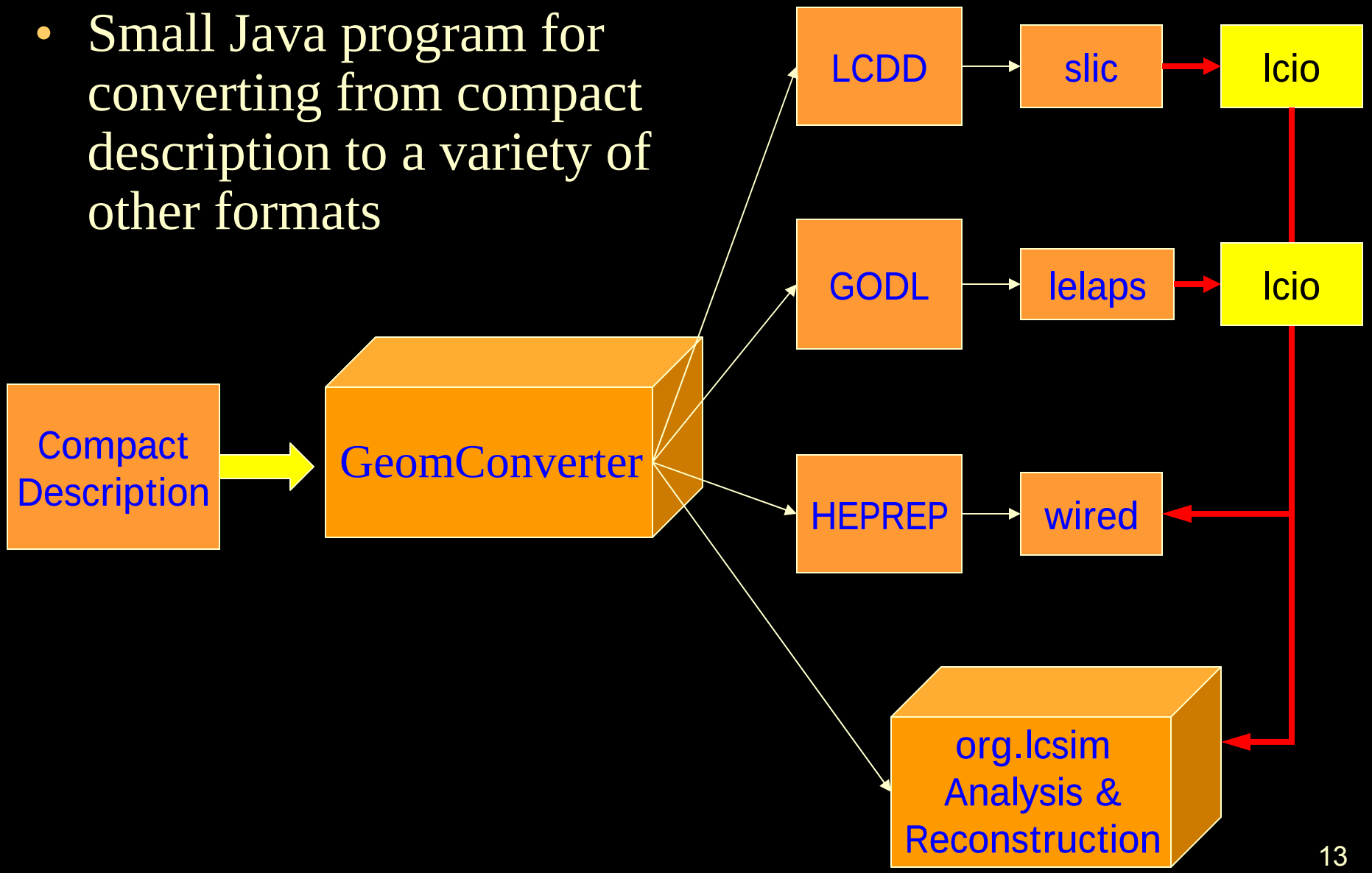
LC Detector Full Simulation



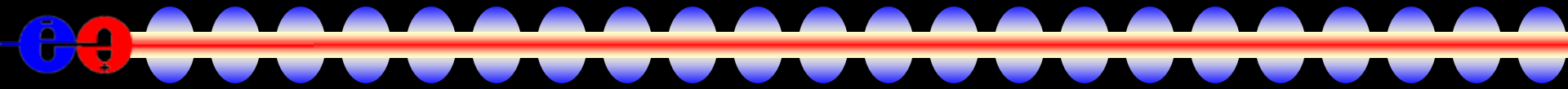


GeomConverter

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

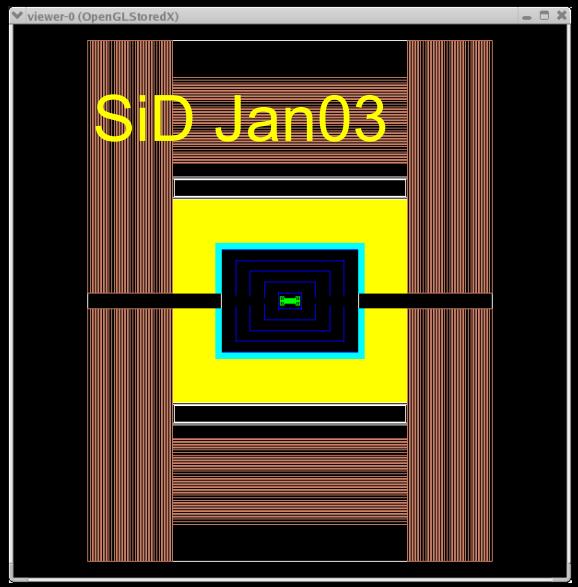


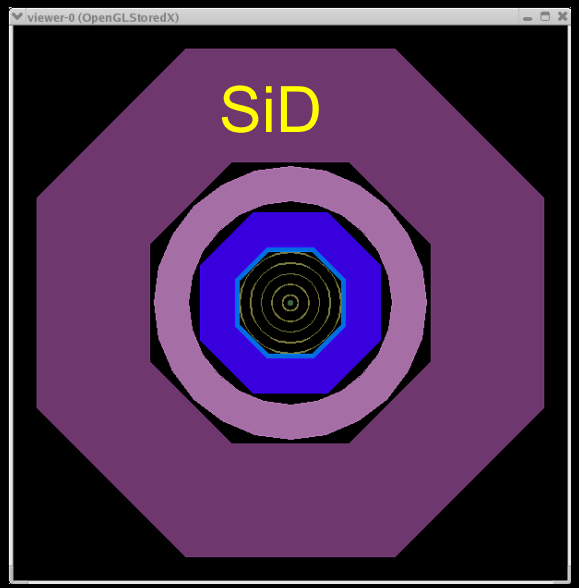
Detector Variants

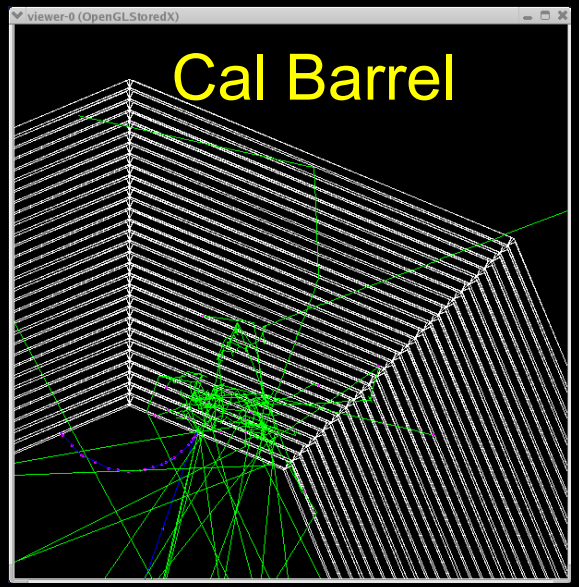


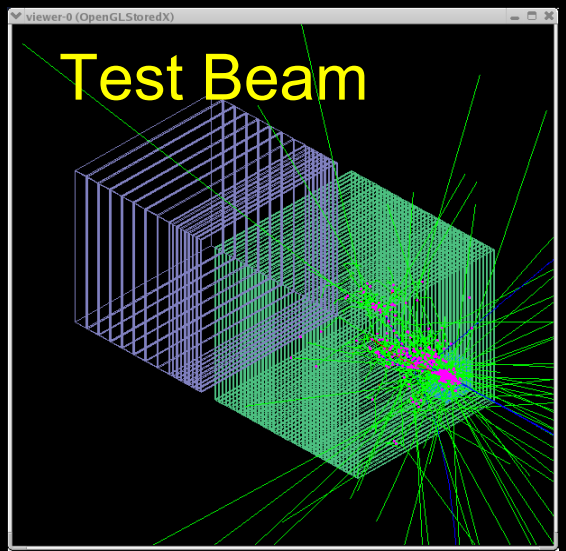
- Runtime XML format allows variations in detector geometries to be easily set up and studied:
  - Stainless Steel vs. Tungsten HCal sampling material
  - RPC vs. GEM vs. Scintillator readout
  - Layering (radii, number, composition)
  - Readout segmentation (size, projective vs. nonprojective)
  - Tracking 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

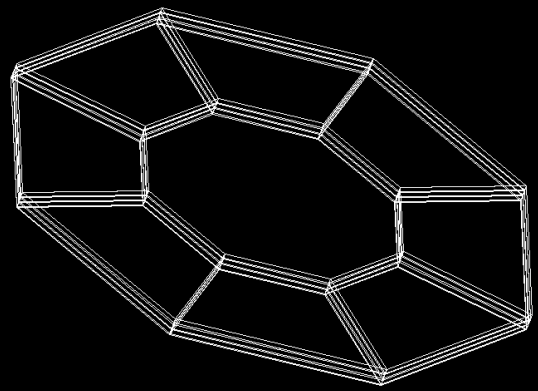




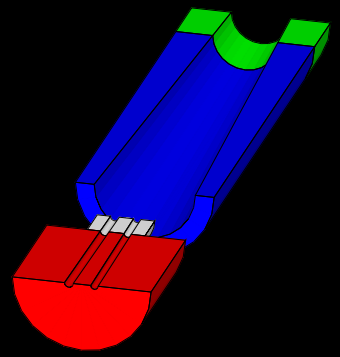




Cal Endcap

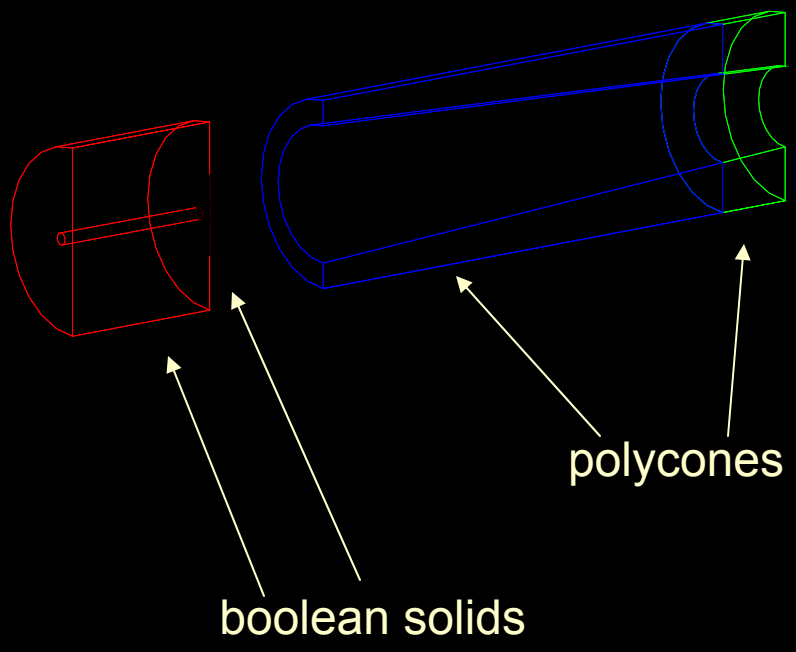


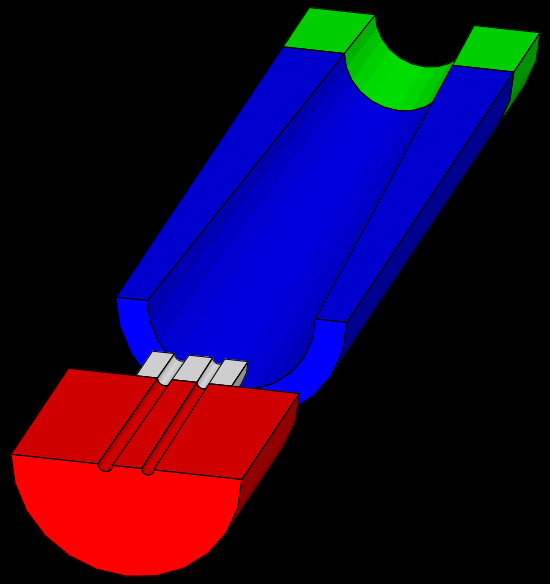
MDI-BDS



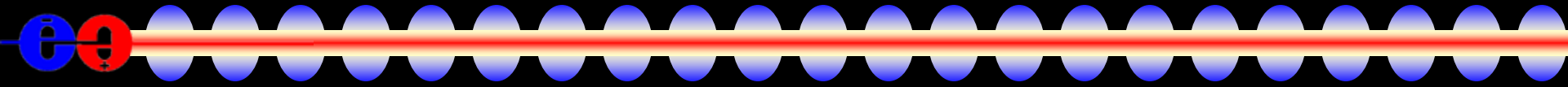
Far forward calorimetry

Machine Detector Interface and Beam Delivery System





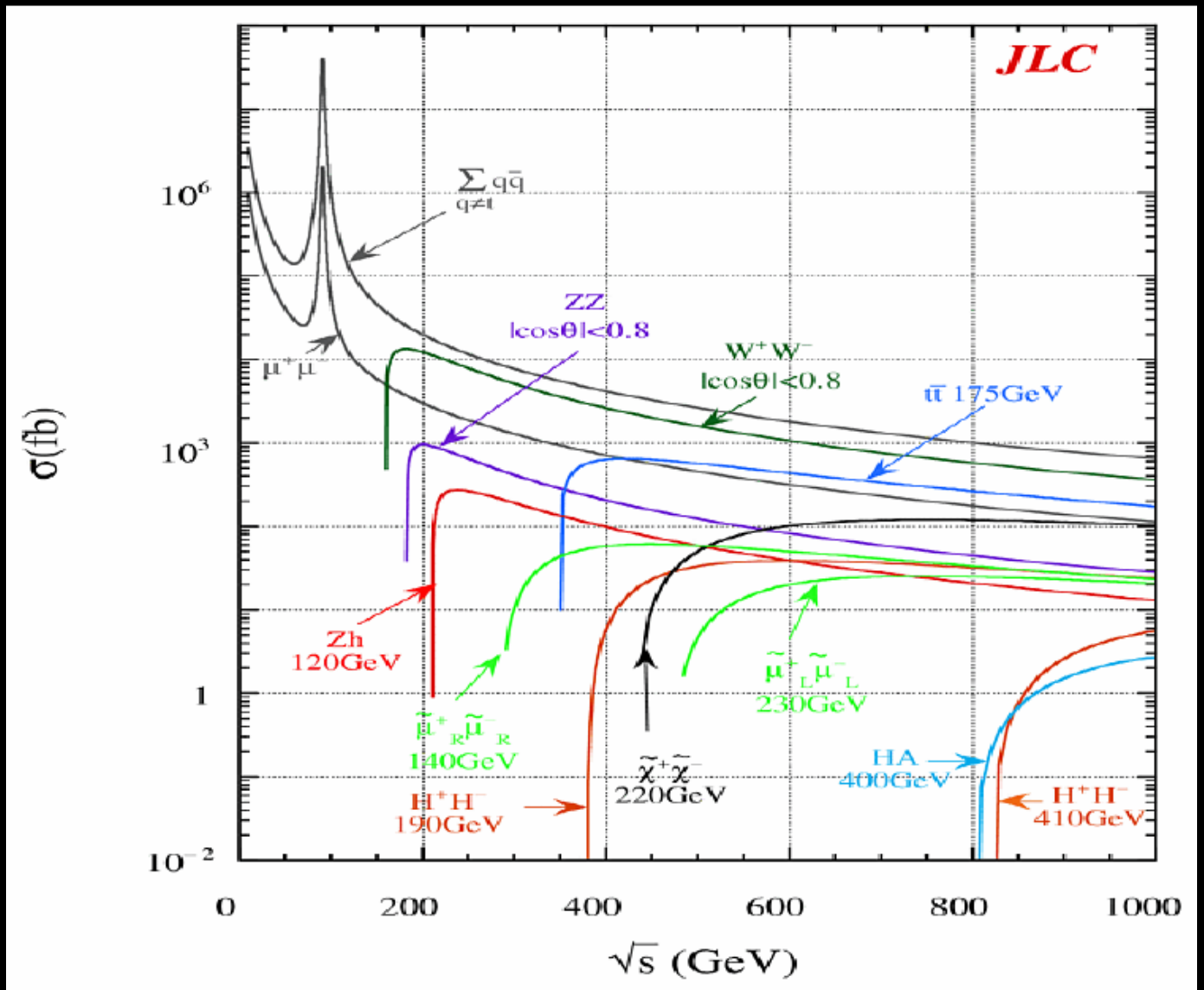
"Signal" and Diagnostic Samples



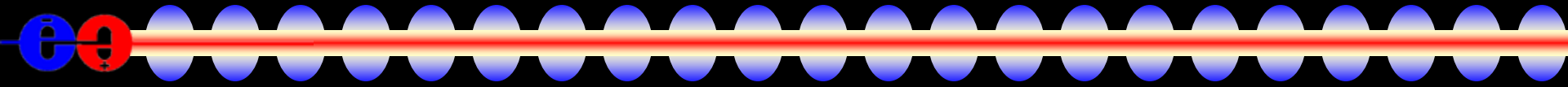
- Have generated canonical data samples and have processed them through full detector simulations.
- simple single particles: γ, μ, e, $\pi^{+/-}$, n, …
- composite single particles: π^0,ρ, K^0_S ,τ, ψ
- Z Pole events: comparison to SLD/LEP
- WW, ZZ, $t\bar{t}$, $q\bar{q}$, tau pairs, mu pairs, Zγ, Zh: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

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

"Standard Model Processes"

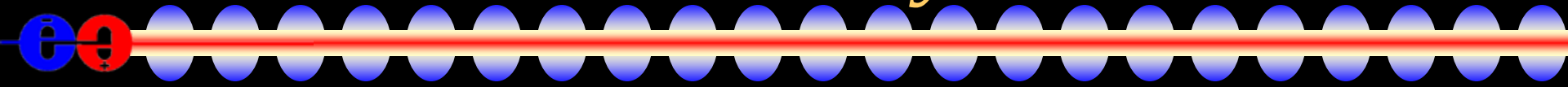


"Standard Model Sample"



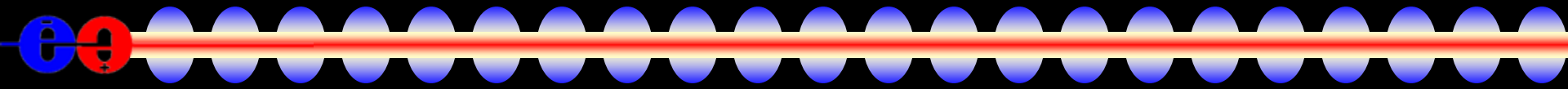
- Generate an inclusive set of MC events with all SM processes + backgrounds arising from beam- and brems-strahlung photons and machine-related particles. 500 fb^{-1} @ 0.5 TeV, 2 ab^{-1} @ 1.0 TeV
  - WHIZARD Monte Carlo used to generate all 0,2,4,6-fermion and t quark dominated 8-fermion processes.
- 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



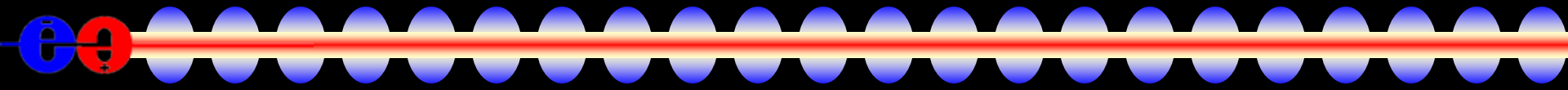
- Java based reconstruction and analysis package
  - Runs standalone or inside Java Analysis Studio (JAS)
  - Fast MC $\rightarrow$ Smeared tracks and calorimetry clusters
  - Full Event Reconstruction
    - detector readout digitization (CCD pixels & Si μ-strips)
    - *ab initio* track finding and 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.

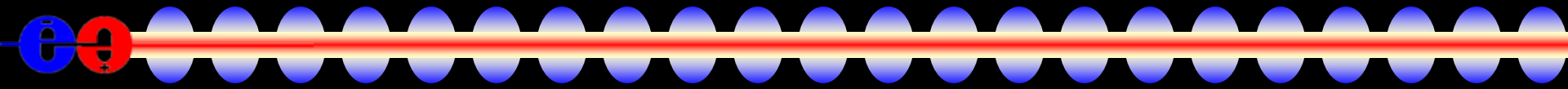
Tracking Detector Readout



- 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.

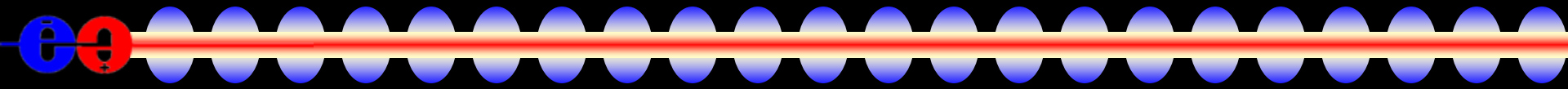
  MC Hits$\rightarrow$ Pixel ID & ADC$\rightarrow$ Clusters$\rightarrow$ Hits ($x \pm \delta x$)
- Can correctly study occupancies, overlaps, ghost hits, etc.

Track Finding



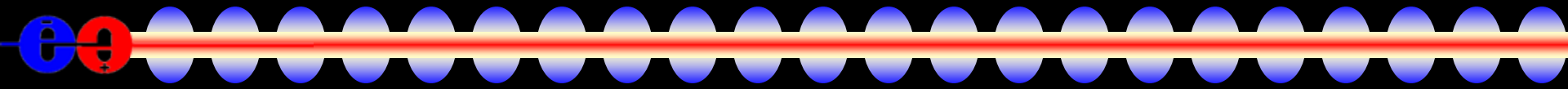
- Standalone pattern recognition code for 1D (e.g. Si μstrip) and 2D (e.g. Si pixel) hits.
  - High efficiency, even in presence of backgrounds.
  - Efficient at low momentum.
- Conformal-mapping pattern recognition also available, applicable also to TPC.
- MIP stubs in highly segmented calorimeters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

Particle Reconstruction



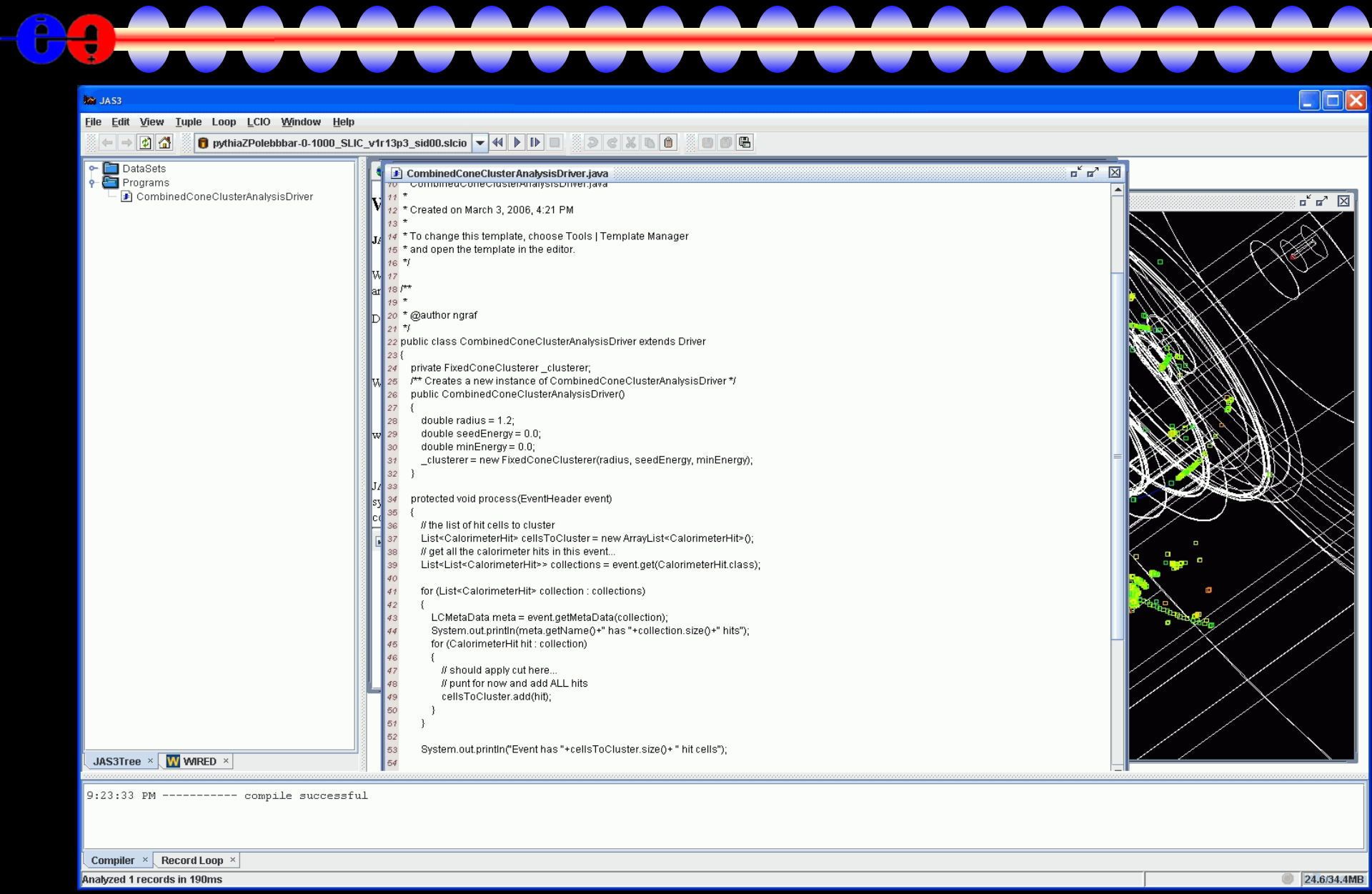
- Several groups are following different approaches towards individual particle reconstruction
  - aka “energy flow” or “particle flow”
- Template allows plug-and-play of different approaches.
- Have first packages for identifying photons, electrons, charged & neutral hadrons and muons.
- Being tuned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

Java Analysis Studio (JAS)

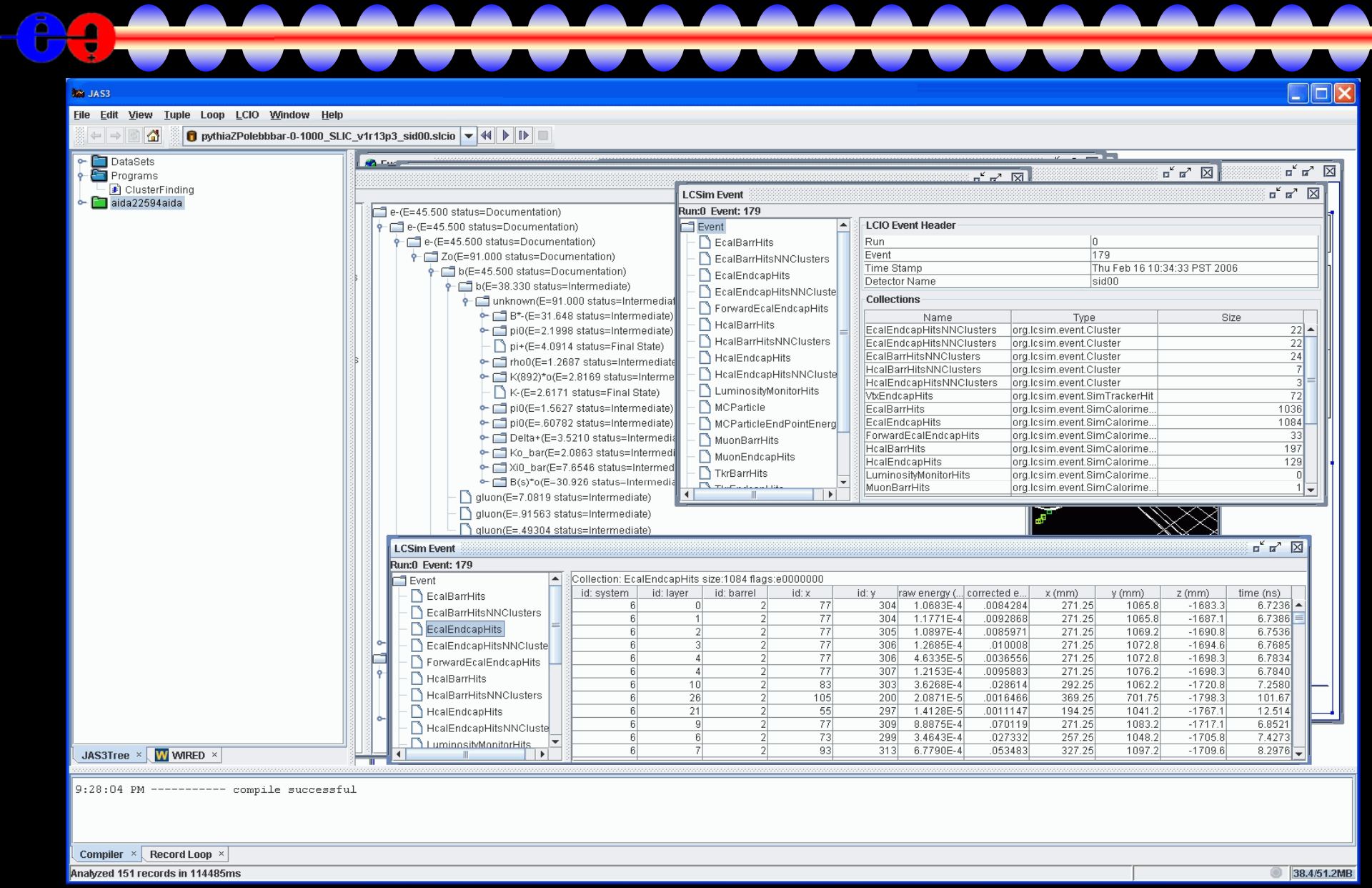


- Integrated Development Environment (editor, compiler)
- Cross-platform physics analysis environment with iterative, event-based analysis model
  - quick development, debugging, ad hoc analysis
  - additional functionality with plugins
- Dynamically load / unload Java analysis drivers
  - Supports distributed 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

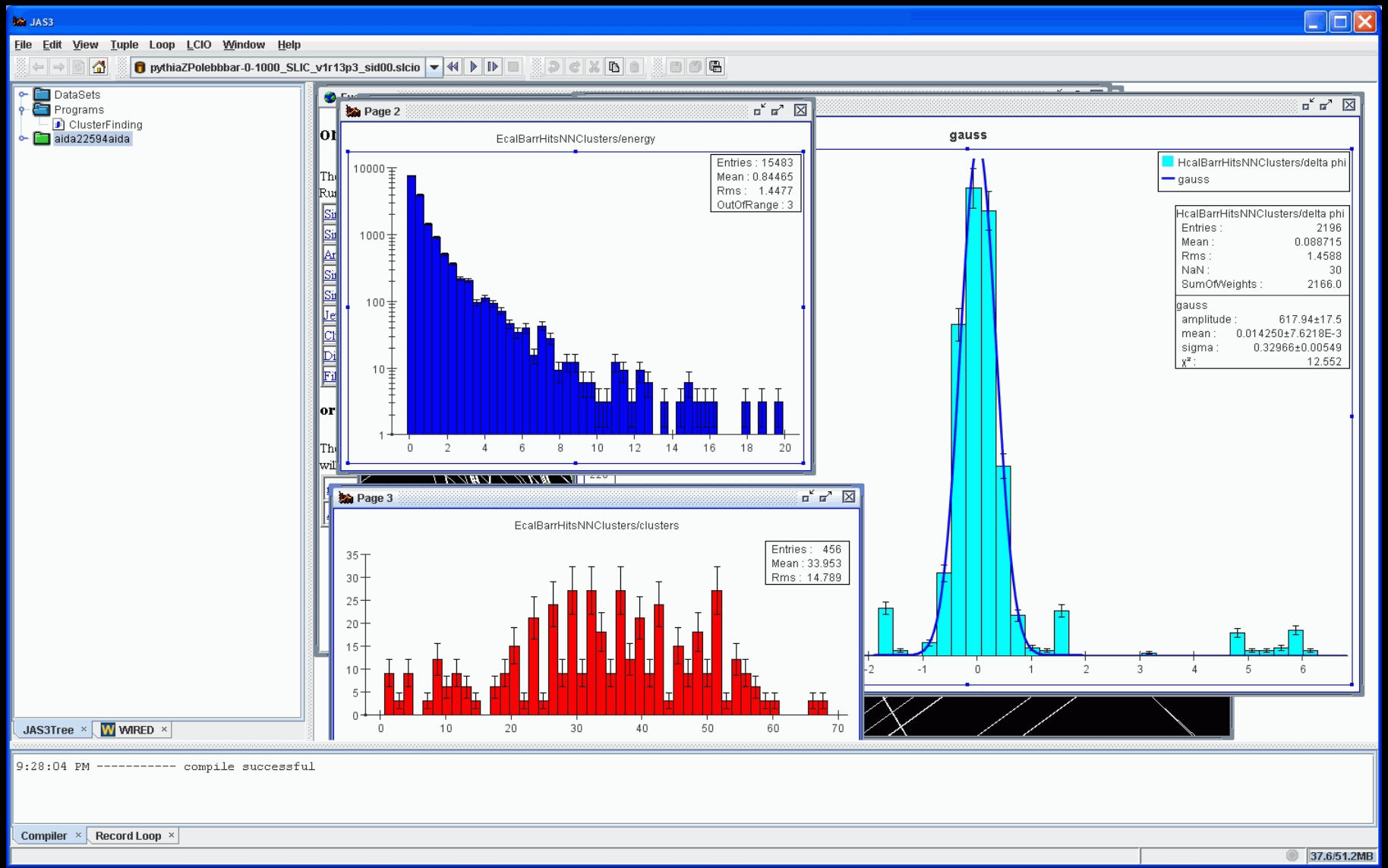
JAS editor/compiler



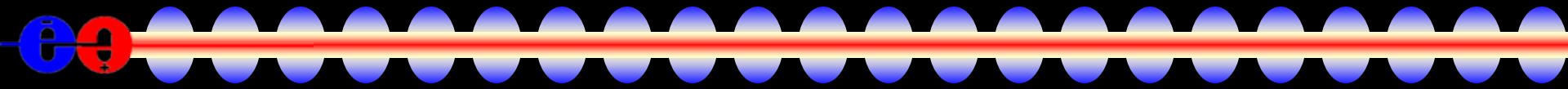
JAS event browser



JAS histogramming/ fitting

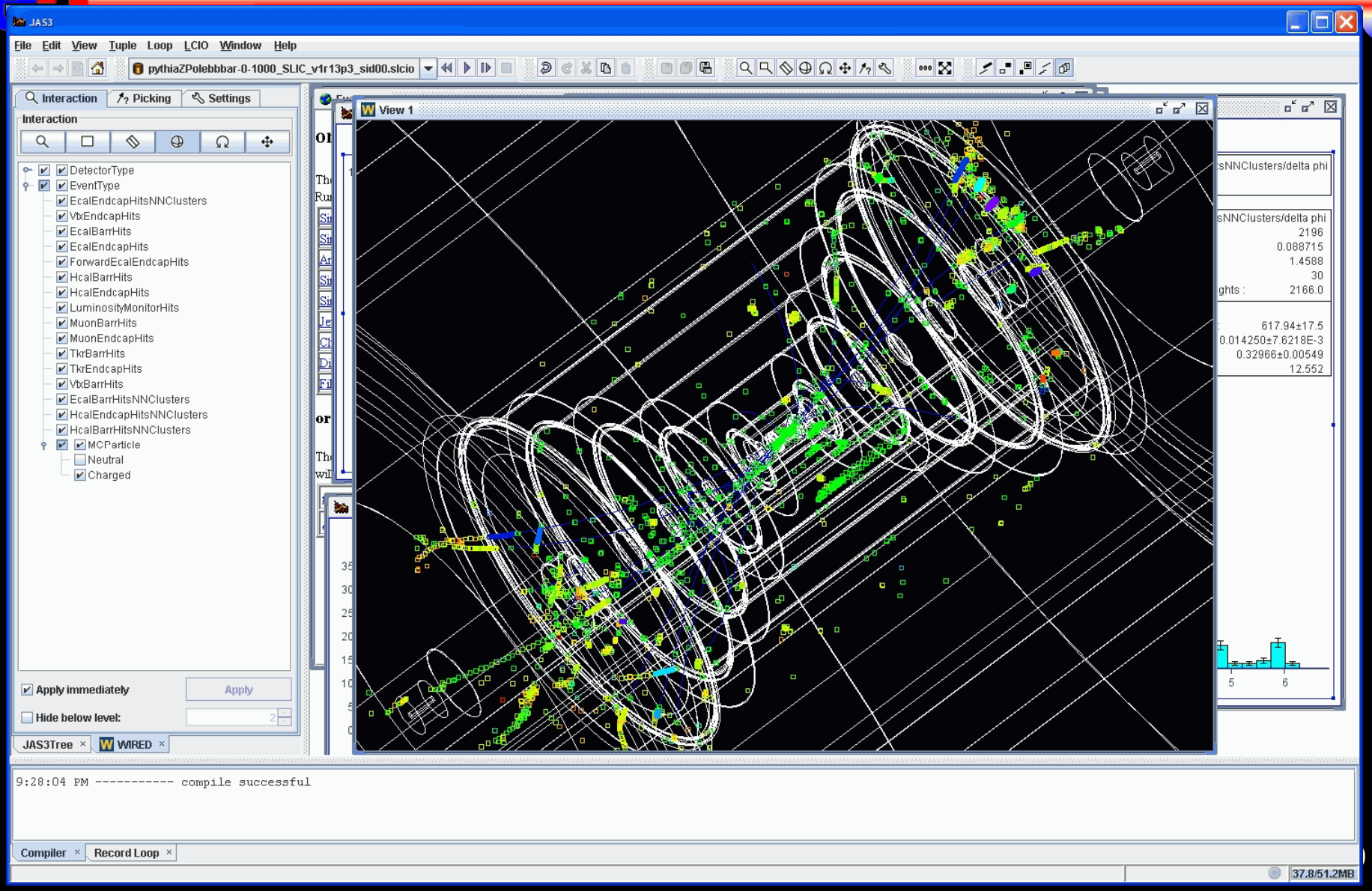


JAS LCD Physics Utilities



- 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

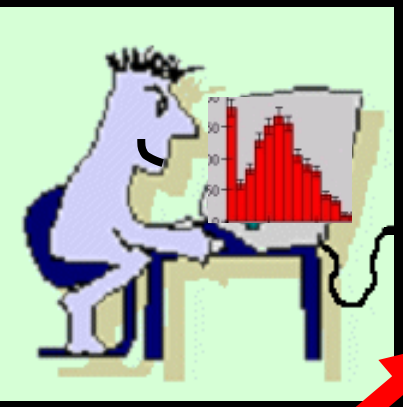
Wired LCD Event Display



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)

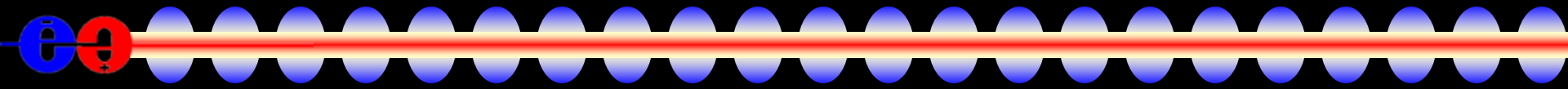
Java Compiler + Debugger

User's Java Code

Padded Cell

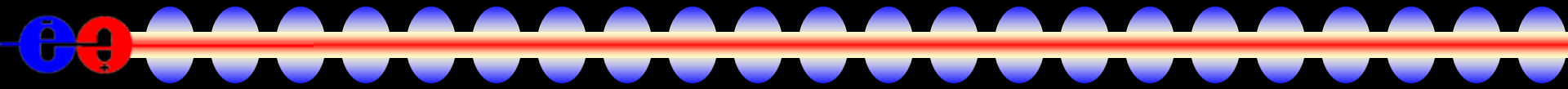
DATA

Detector Optimization (Costing)



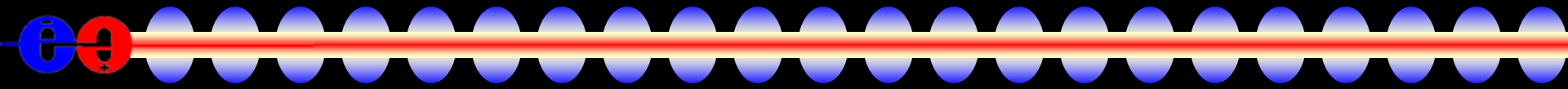
- Goal is to fully simulate and validate baseline design.
- Then determine the dependence of performance on detector attributes.
- Iterate to achieve balance of cost, risk, & performance
- Excel Spreadsheet used for costing vs parameters.

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 designs.

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