Intelligent Detector Design

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LCD Simulation Mission Statement

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

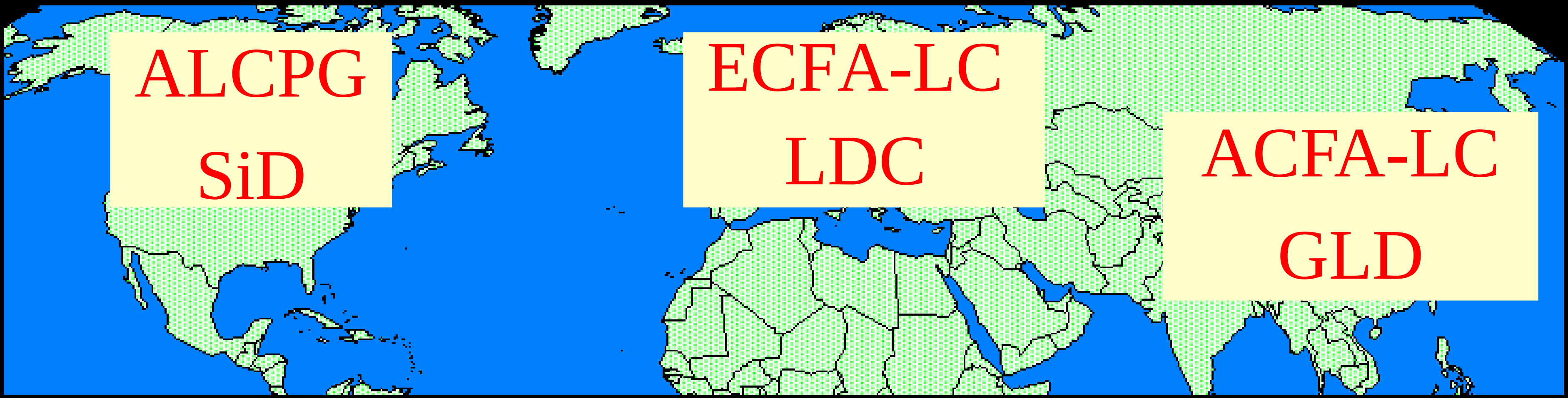
Overview: Goals

- 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.

Detector Performance Studies

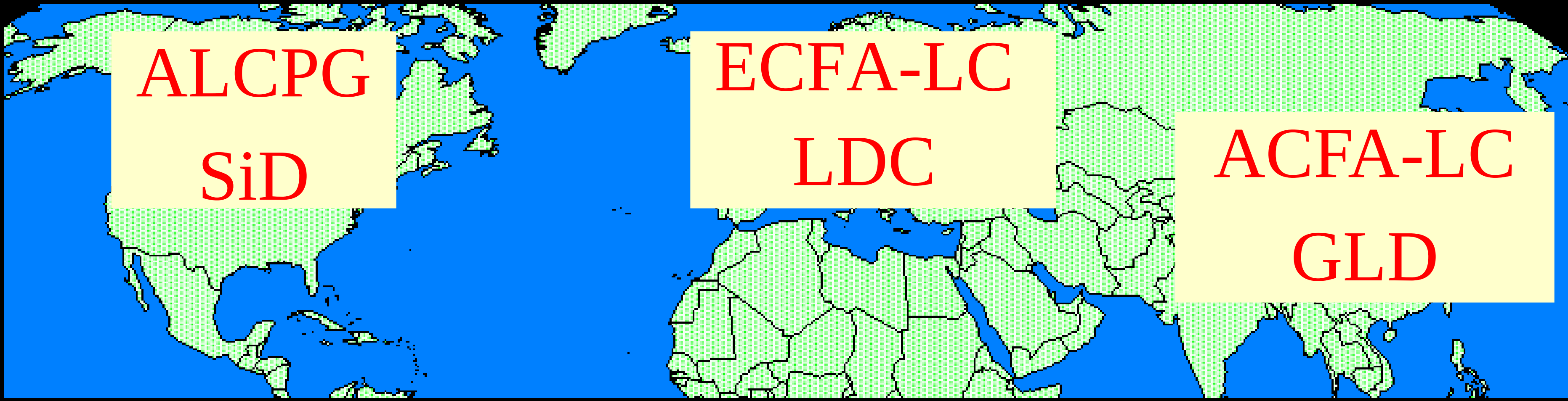
- The ILC community recently finished a very intensive round of detector performance and optimization studies, culminating in the submission of LOI's and is engaged in preparing more detailed updates for the DBD in 2012.
- The CLIC community is currently engaged in an aggressive effort to provide a CDR in 2011.
- Muon Collider physics and detector community beginning to study the experimental environment.
- Number of smaller experiments using various components of this toolkit.

LCIO



slic	MOKKA	JUPITER
org.lcsim	MarlinReco	Satellites
Java	C++	root

LCIO



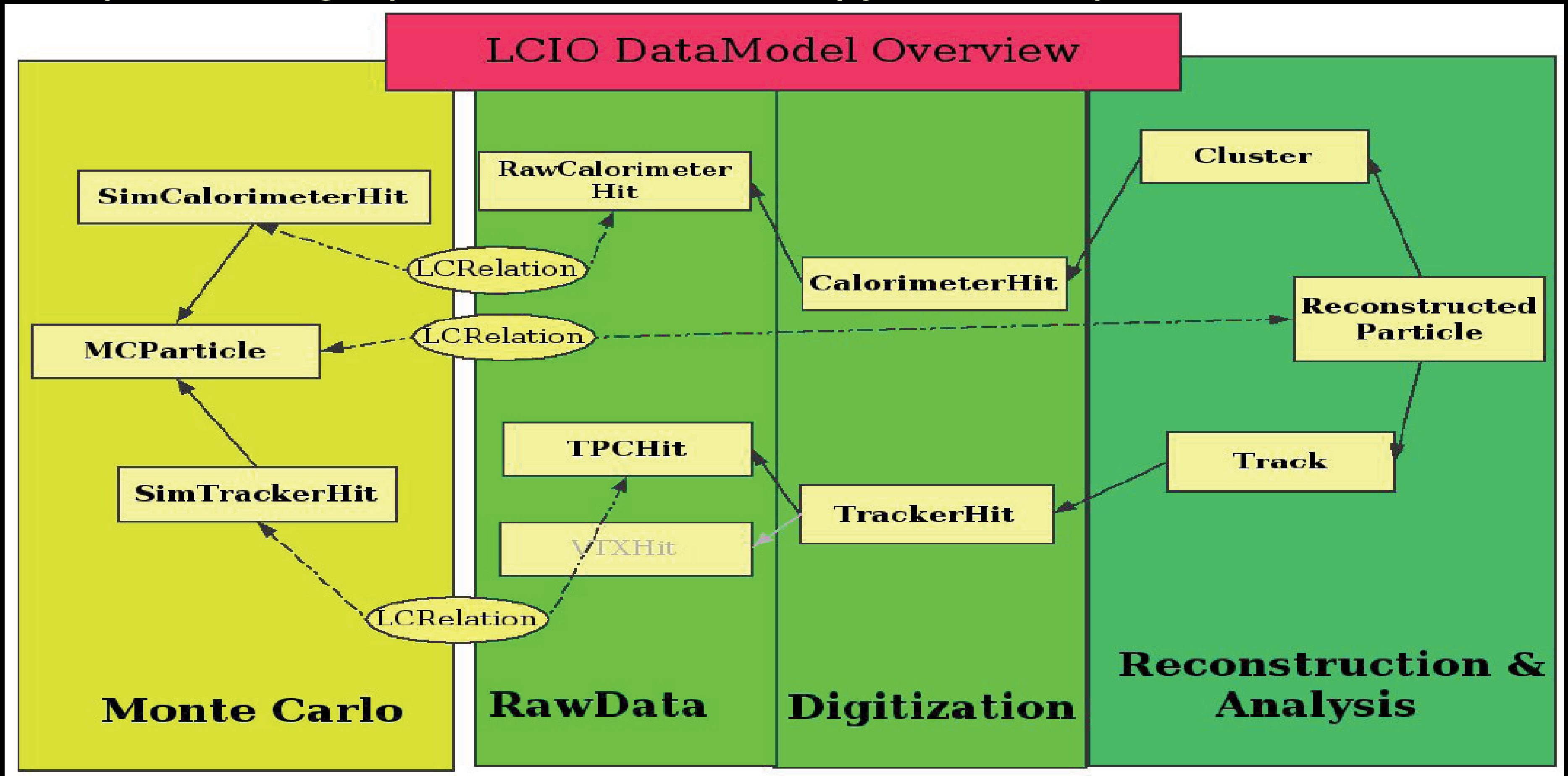
LCIO

Common Data Model

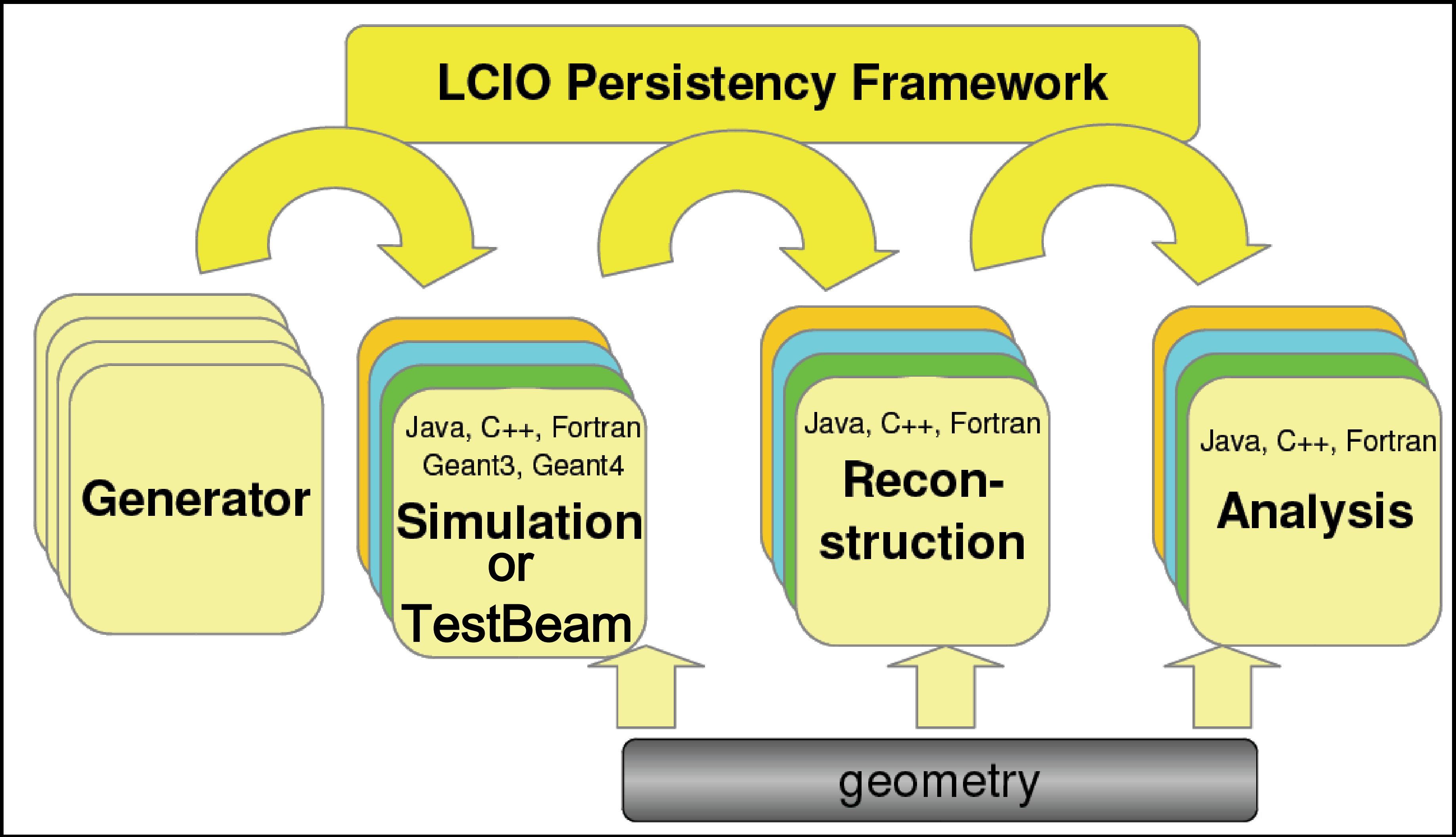
Common IO Format

LCIO Overview

- Object model and persistency format for HEP events
  - MC simulation
  - Test Beam data
  - Reconstructed Objects
- Multiple bindings (C++, Java, Fortran, python, root)



LCIO Overview



LCIO Interoperability

- All three regional LCD simulators write LCIO
  - Cross-checks between data from different simulators
  - Read/write LCIO from
    - Fast MC / Full Simulation / Test Beams
    - Different detectors
    - Different reconstruction tools
    - Different frameworks, languages, operating systems
- Reconstruction also targets LCIO
  - Can run simulation or reconstruction in one framework, analysis in another.
    - Generate events in Jupiter, analyze in MarlinReco.
    - org.lcsim to find tracks in Java, LCFI flavor-tagging to find vertices using MarlinReco (C++) package.

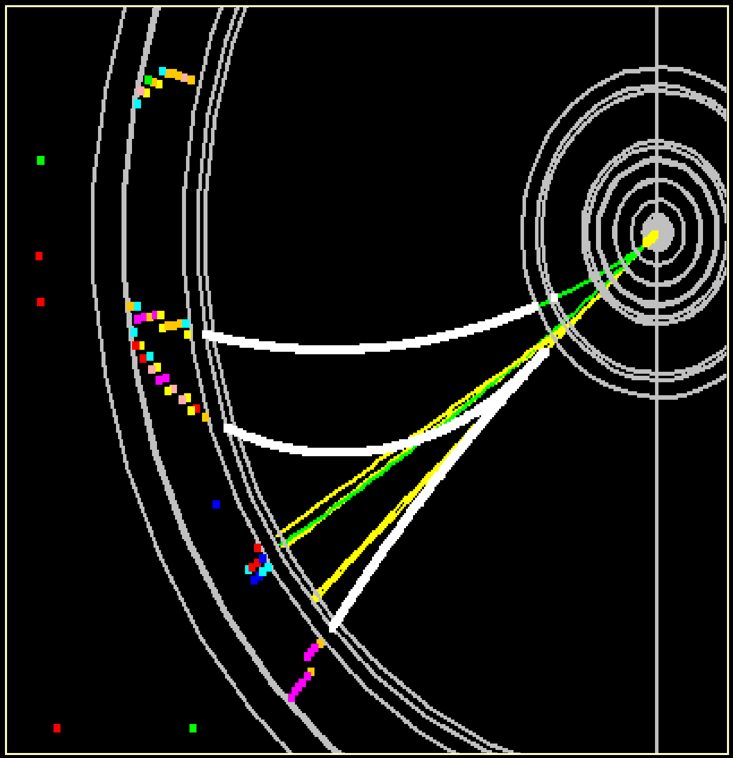
Fast Detector Response Simulation

- Covariantly smear tracks with matrices derived from geometry, materials and point resolution using Billoir's formulation.
  - Analytically from geometry description.
- Smear neutrals according to expected calorimeter resolution (EM for γ, HAD for neutral hadrons)
  - Derived from full Geant4 simulations
- 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.
  - Derived from full simulation, reconstruction & analysis.
- "Supersymmetry, the *ILC*, and the LHC *inverse problem*"

lelaps

- Fast detector response package.
- Handles decays in flight, multiple scattering and energy loss in trackers.
- Parameterizes particle showers in calorimeters.
- Produces detector data at the hit level.
  - Feeds directly into full reconstruction.
- Uses runtime geometry (compact.xml $\rightarrow$ godl).

Lelaps: Decays, dE/dx, MCS

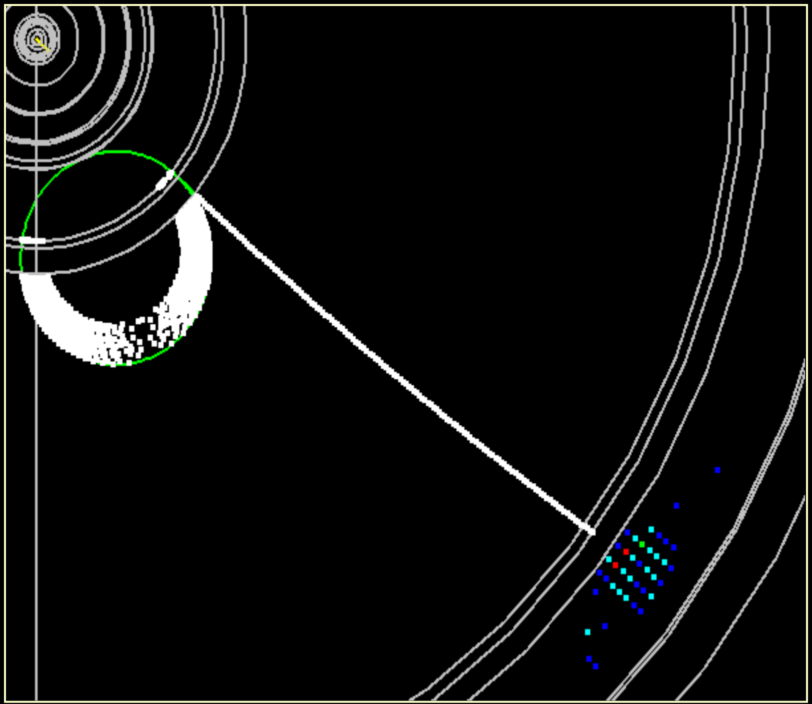


$\Omega^- \rightarrow \Xi^0 \pi^-$

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

$\Lambda \rightarrow p \pi^-$

$\pi^0 \rightarrow \gamma \gamma$ 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.
- The daunting machine backgrounds expected at the Muon Collider will require detailed full detector simulations.
- 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 and fields.
- Thin layer of C++ code 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.

Geometry Definition

- Goal was to free the end user from having to write any C++ code or be expert in Geant4 to define the detector.
- All of the detector properties should be definable at runtime with an easy-to-use format.
- Selected xml, and extended the existing GDML format for pure geometry description.

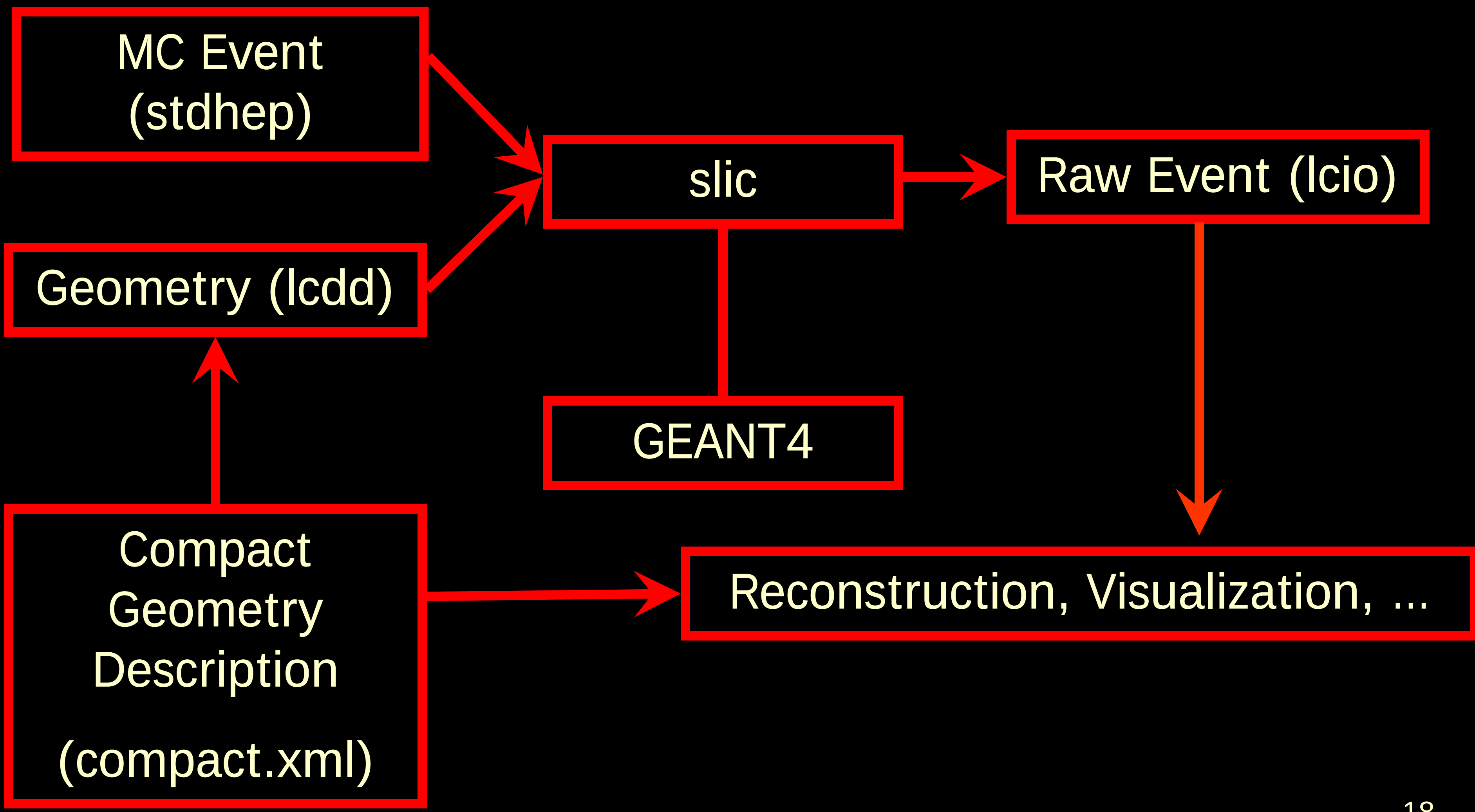
Full Simulation History

- Provide static binary to run full detector simulations using runtime xml detector descriptions.
  - in-house lcdparm xml format (1998)
  - collaboration with R. Chytracek on GDML (2000)
- GISMO (C++ GHEISHA + EGS, lcdparm) 1998
- LCDRoot (Geant4 + Root, lcdparm) 1999
- LCDG4 (Geant4 + sio, lcdparm) 2002
- LCS (Geant4 + lcio, lcdparm) 2004
- slic (Geant4 + lcio, GDML) 2005

Fifth Generation

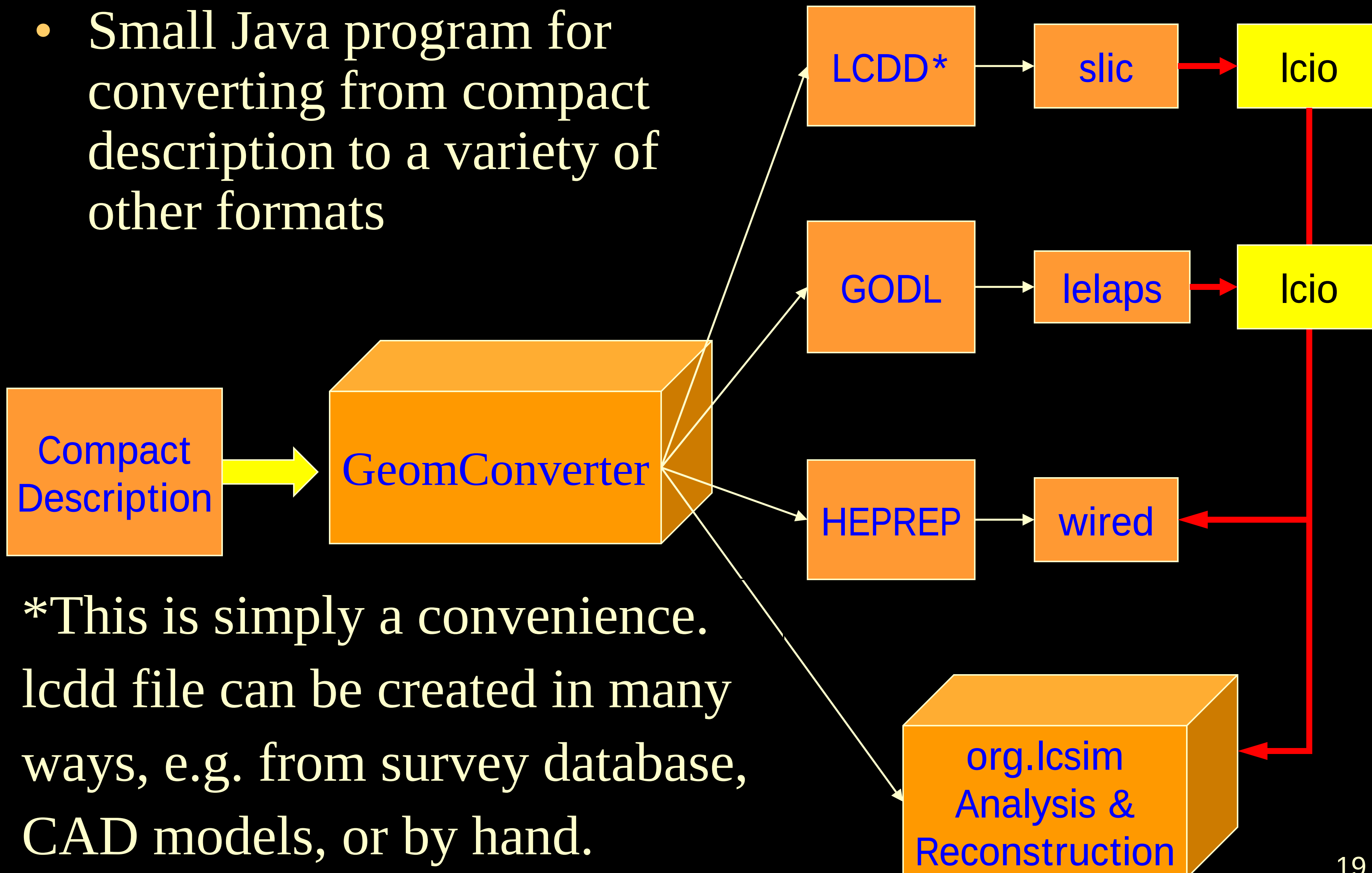
Lockheed-Martin F-22A Raptor
5th Generation Fighter

LC Detector Full Simulation



GeomConverter

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



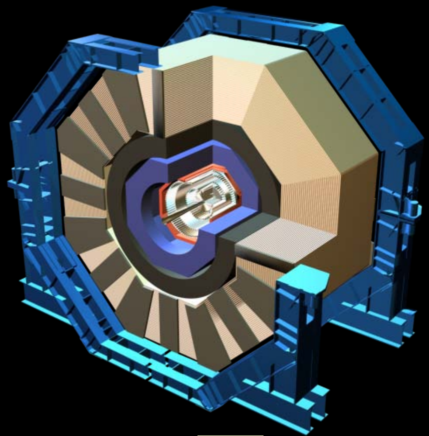
*This is simply a convenience. lcdd file can be created in many ways, e.g. from survey database, CAD models, or by hand.

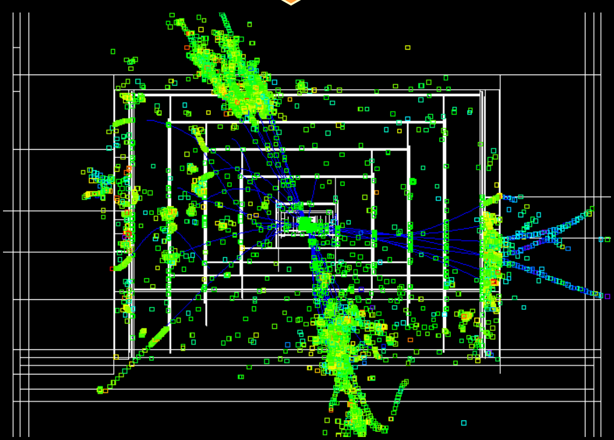
Detector Variants

- Runtime XML format allows variations in detector geometries to be easily set up and studied:
  - Absorber materials and readout technologies for sampling calorimeters
    - e.g. Steel, W, Cu, Pb + RPC vs. GEM vs. Scintillator readout
  - Optical processes for dual-readout or crystal calorimeters
  - Layering (radii, number, composition)
  - Readout segmentation (size, projective vs. nonprojective)
  - Tracking detector technologies & topologies
    - TPC, Silicon microstrip, pixels, …
    - “Wedding Cake” Nested Tracker vs. Barrel + Cap
  - Far forward MDI variants, shielding, field strength, etc.

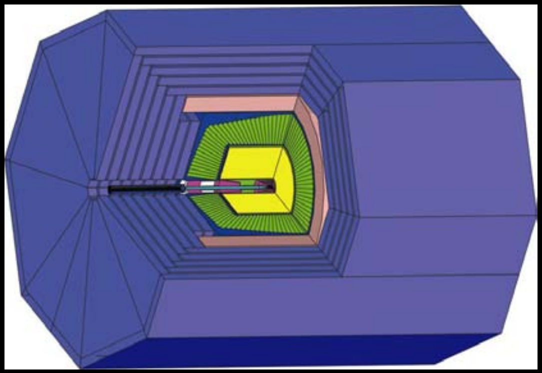
ILC Full Detector Concepts

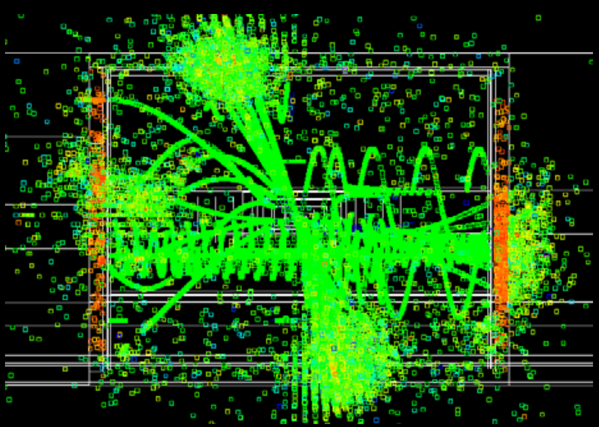
SiD



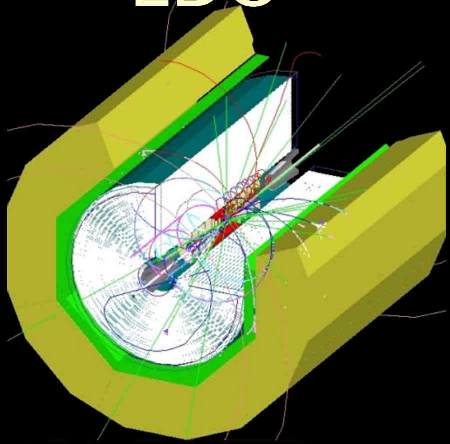


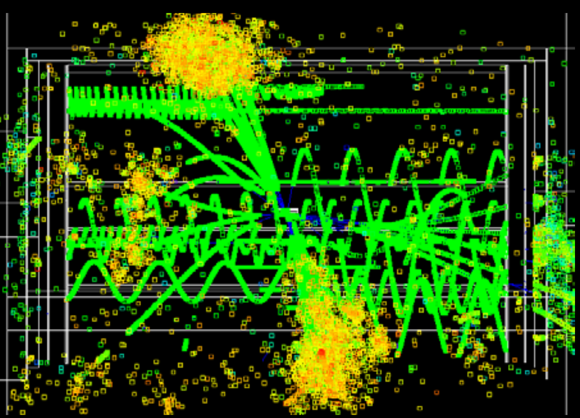
GLD



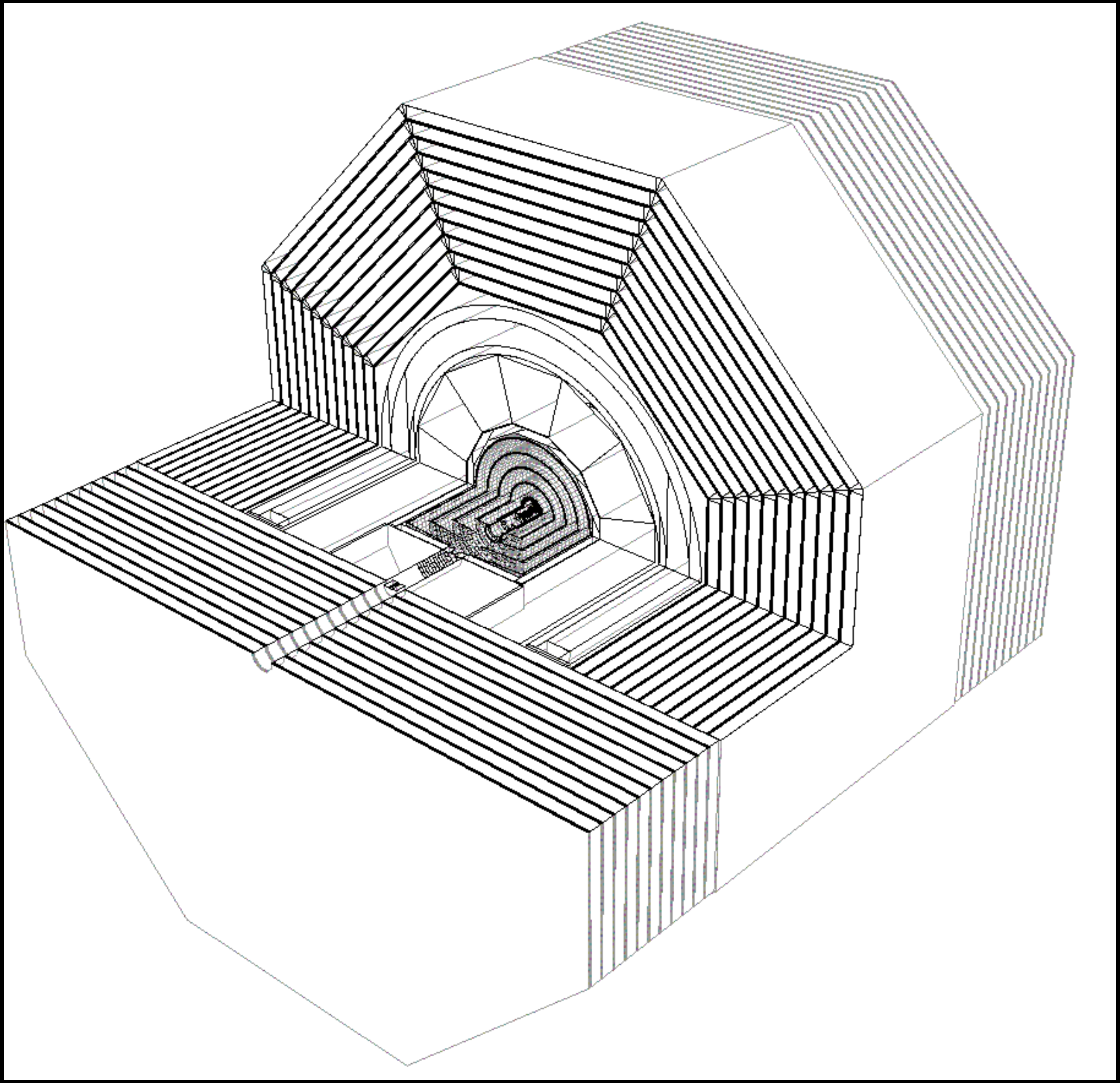


LDC

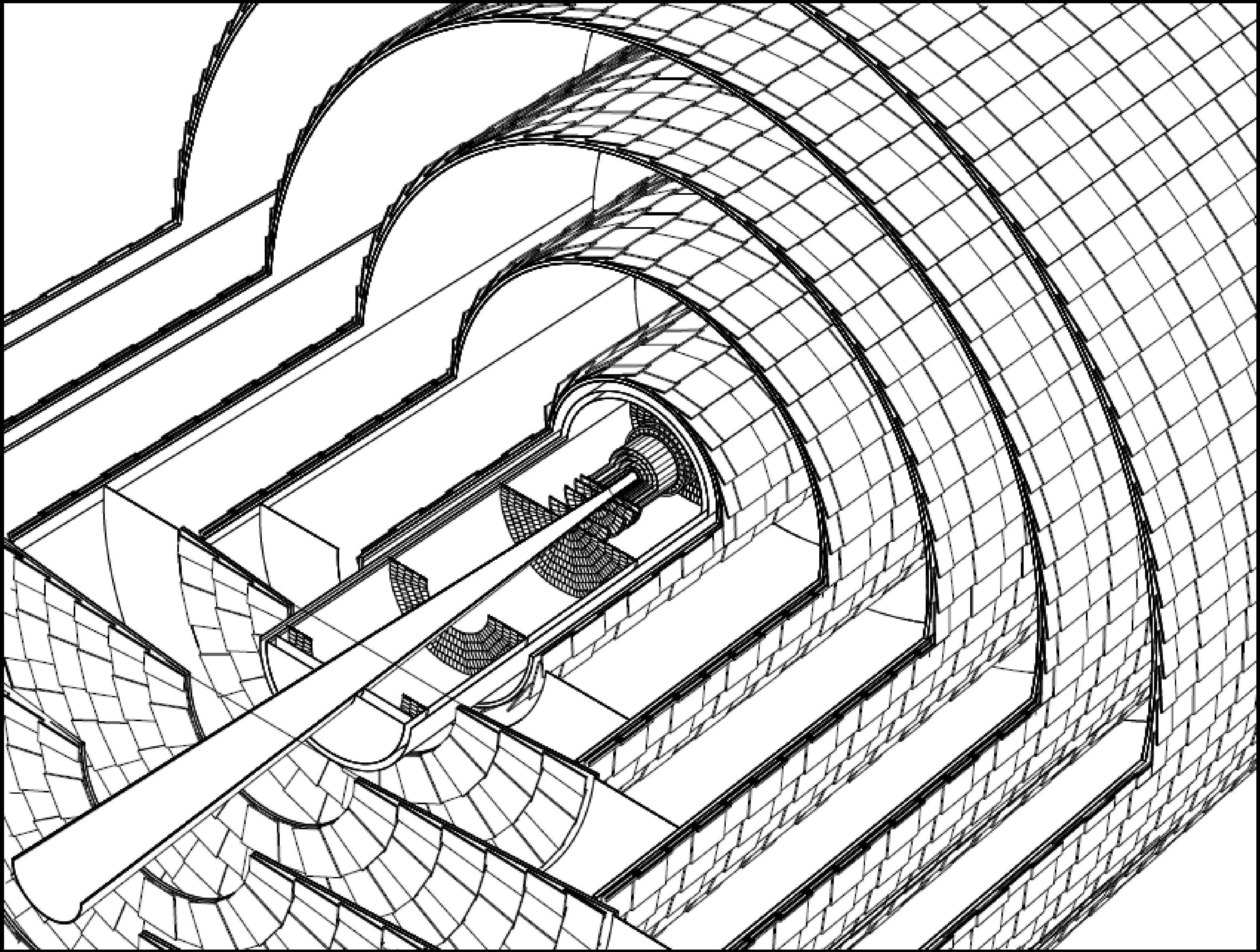




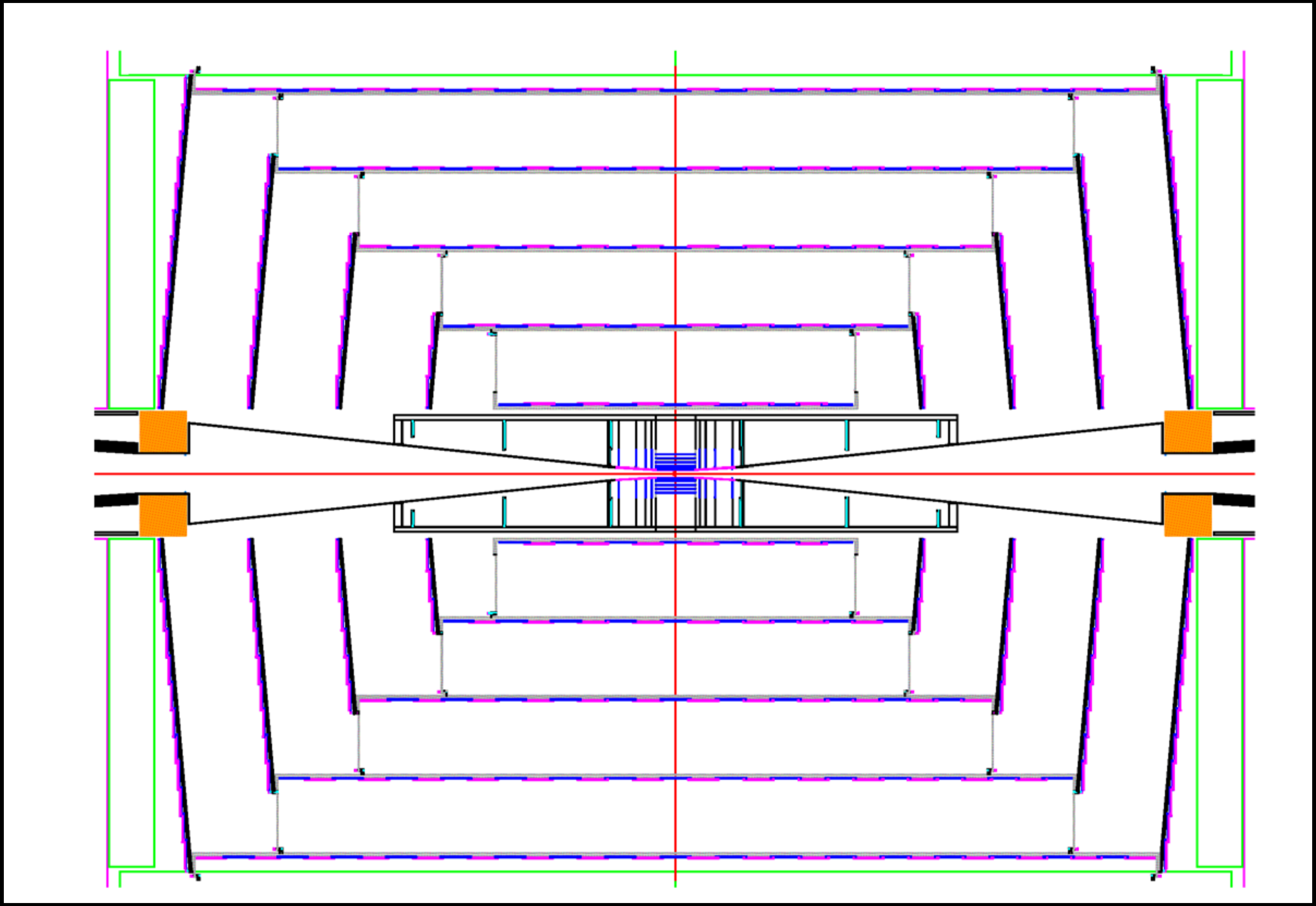
Silicon Detector Concept



Silicon Detector Concept

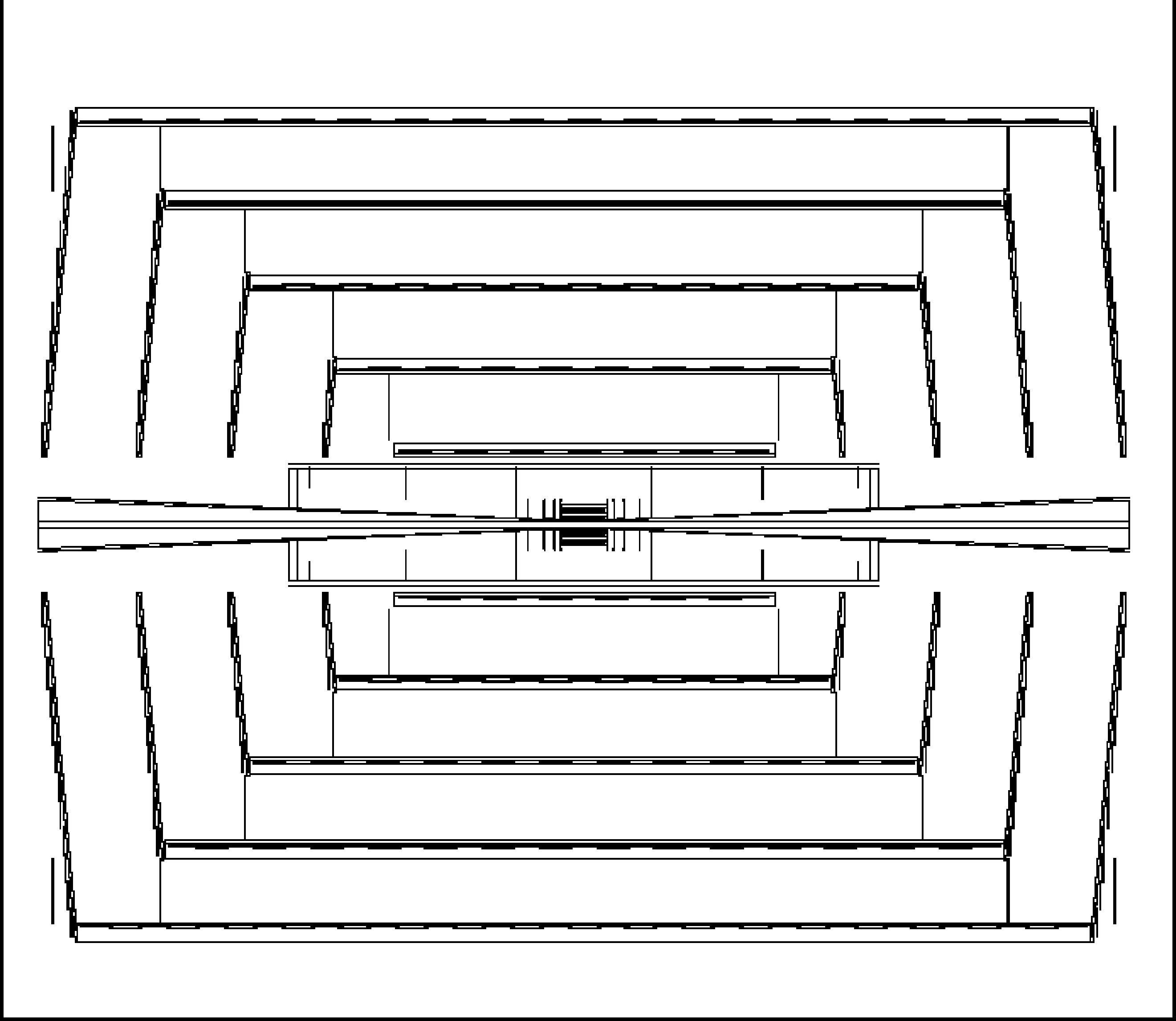


SiD Tracker



CAD Model

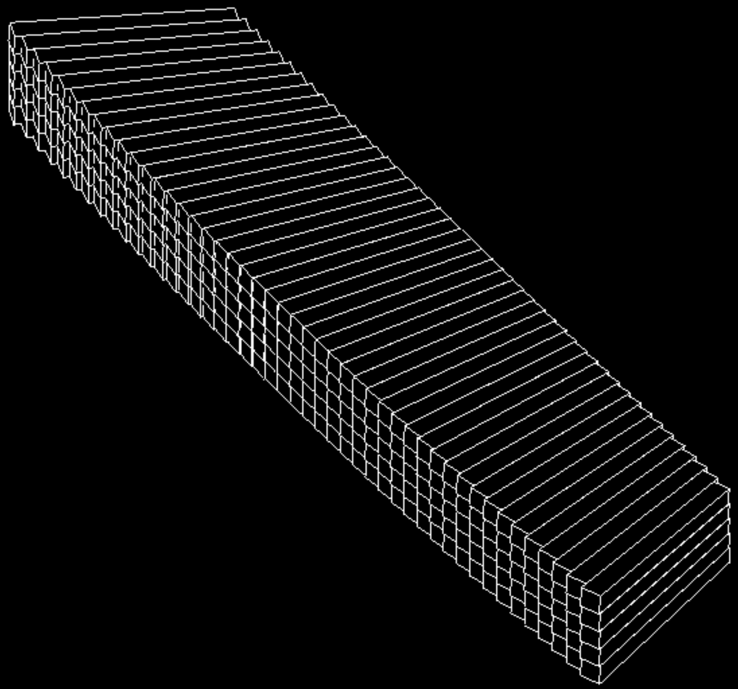
SiD Tracker

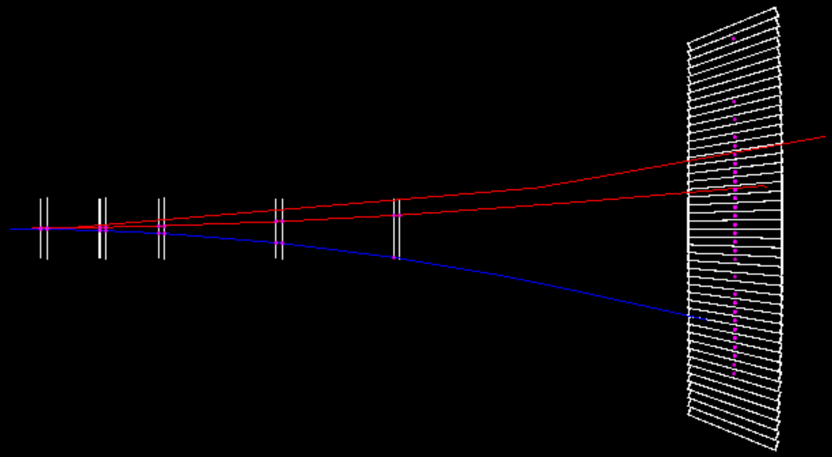


Geant4 Model

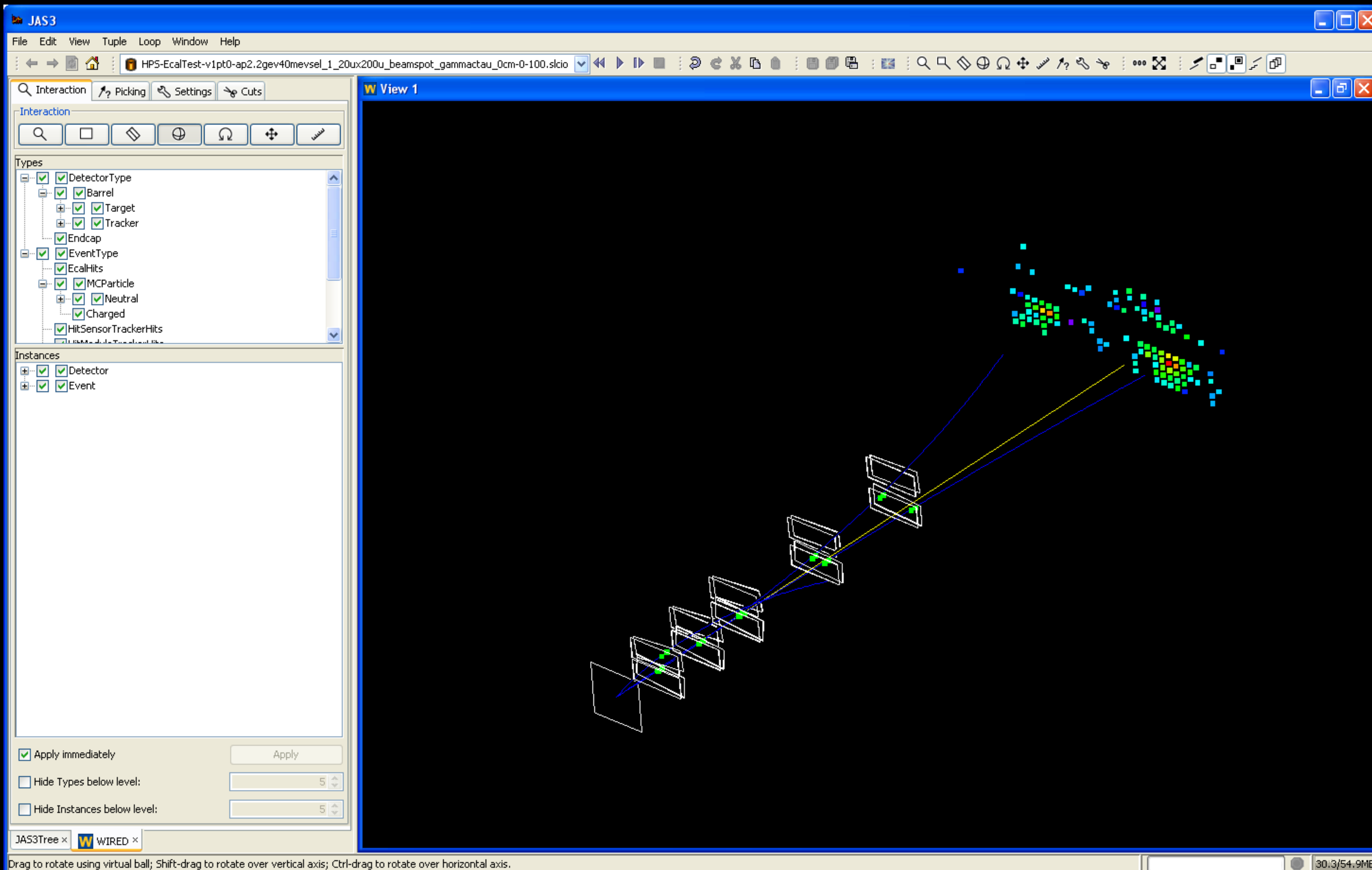
Simulating the HPS ECal

- Crystal array geometry and readout is supported in the compact format.



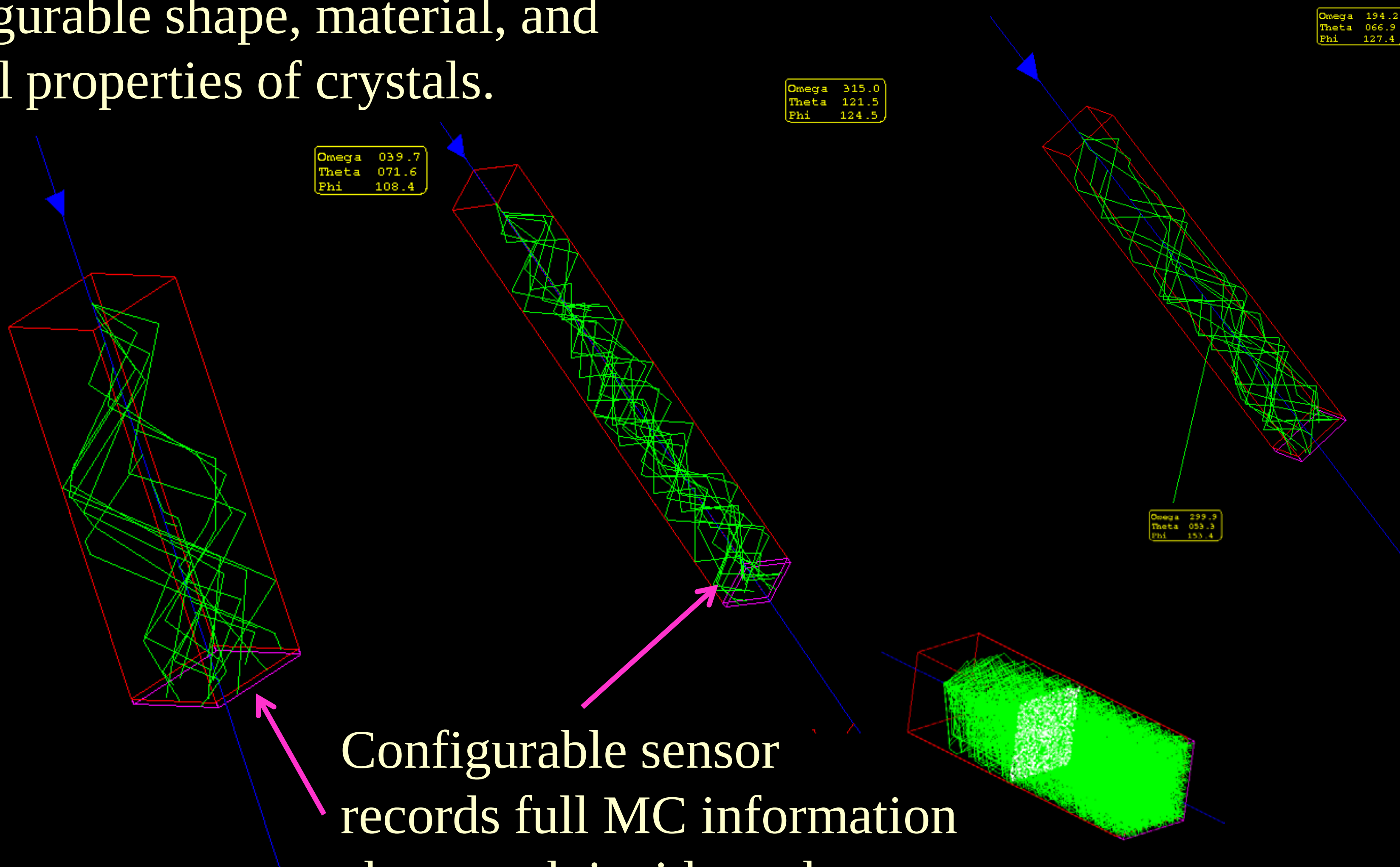


Wired Event Display



Optical Ray Tracing in Crystals

Configurable shape, material, and optical properties of crystals.



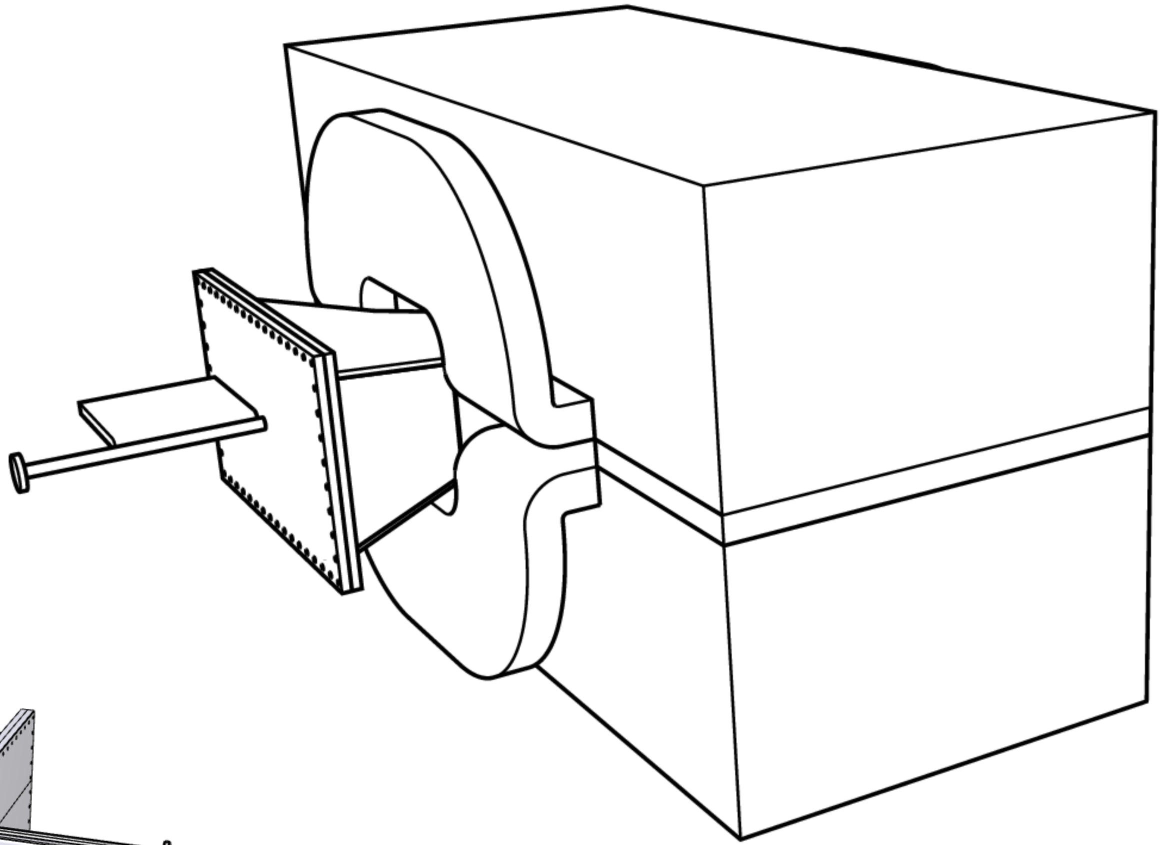
Configurable sensor records full MC information about each incident photon

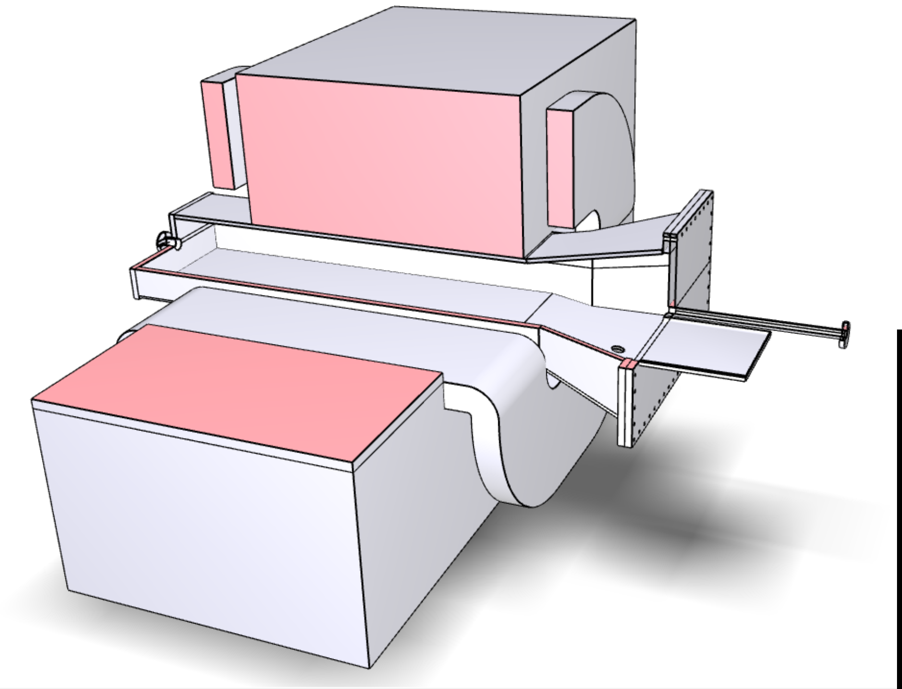
Courtesy Hans Wenzel

HPS Dipole and Vacuum Vessel

CAD to GDML.

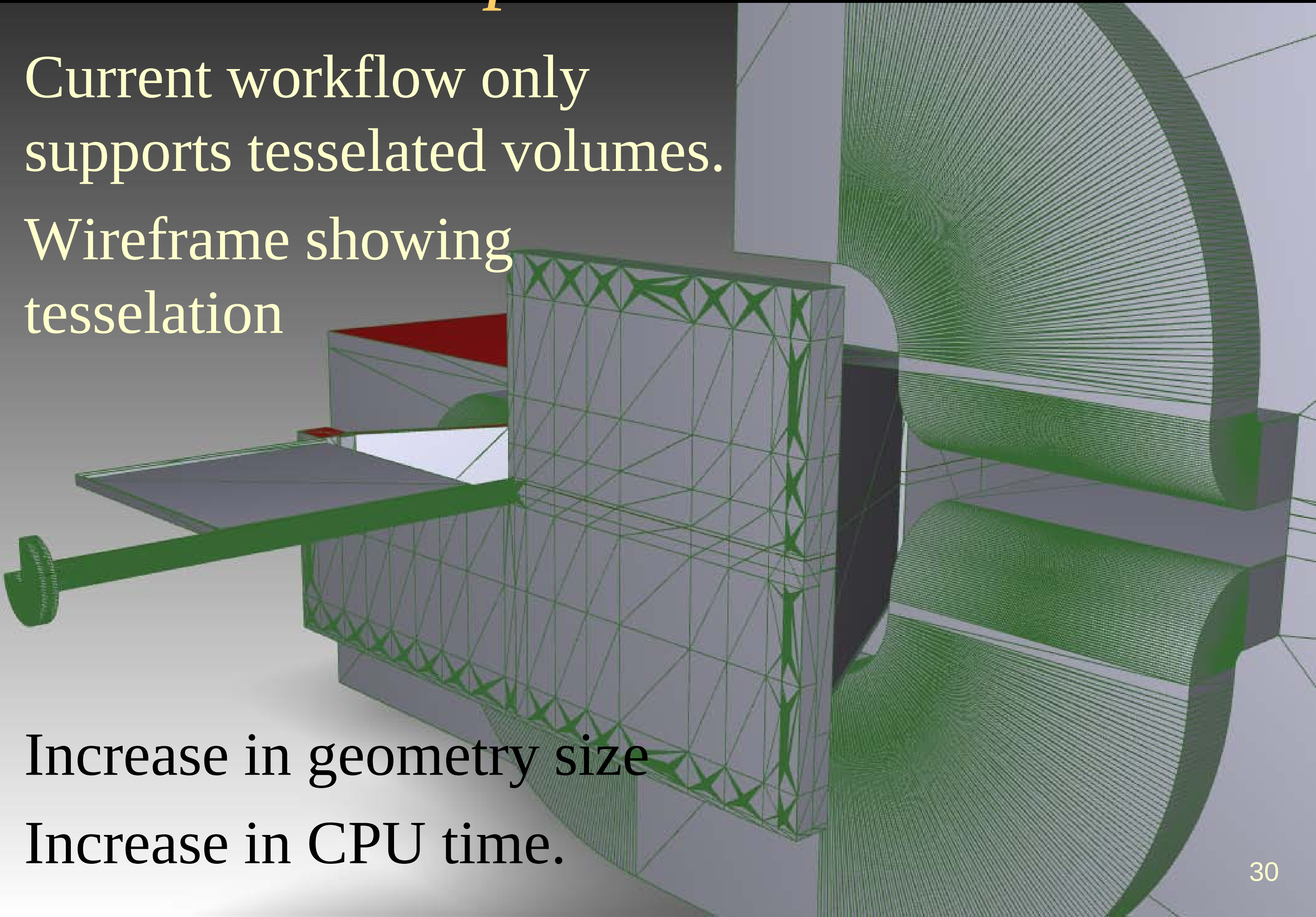
Can be used for non-sensitive elements





CAD-imported elements.

- Current workflow only supports tesselated volumes.
- Wireframe showing tesselation



- Increase in geometry size
- Increase in CPU time.

slic: The Executable

- Build static executables on Linux, Windows, Mac.
- Commandline or G4 macro control.
- Only dependence is local detector description file.
  - Trivial Grid usage (no database call-backs, etc.)
  - Grid ready, Condor and lsf scripts available.
- Event input via stdhep, particle gun, …
- Detector input via GDML, lcdd
- Response output via LCIO using generic hits.

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
    - Beam background overlays at detector hit level, including time offsets.
    - detector readout digitization (CCD pixels, Si μ-strips, TPC pad hits)
    - *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 (Jet Finding, Vertex Finding, Flavor Tagging)
- Write once run, run anywhere
  - Exact same libraries run on all platforms (Windows, Mac, Linux(es), Grid) using the Java Virtual Machine.

Tracking

- Analytic covariance matrices available for fast MC smearing for each detector.
- 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.

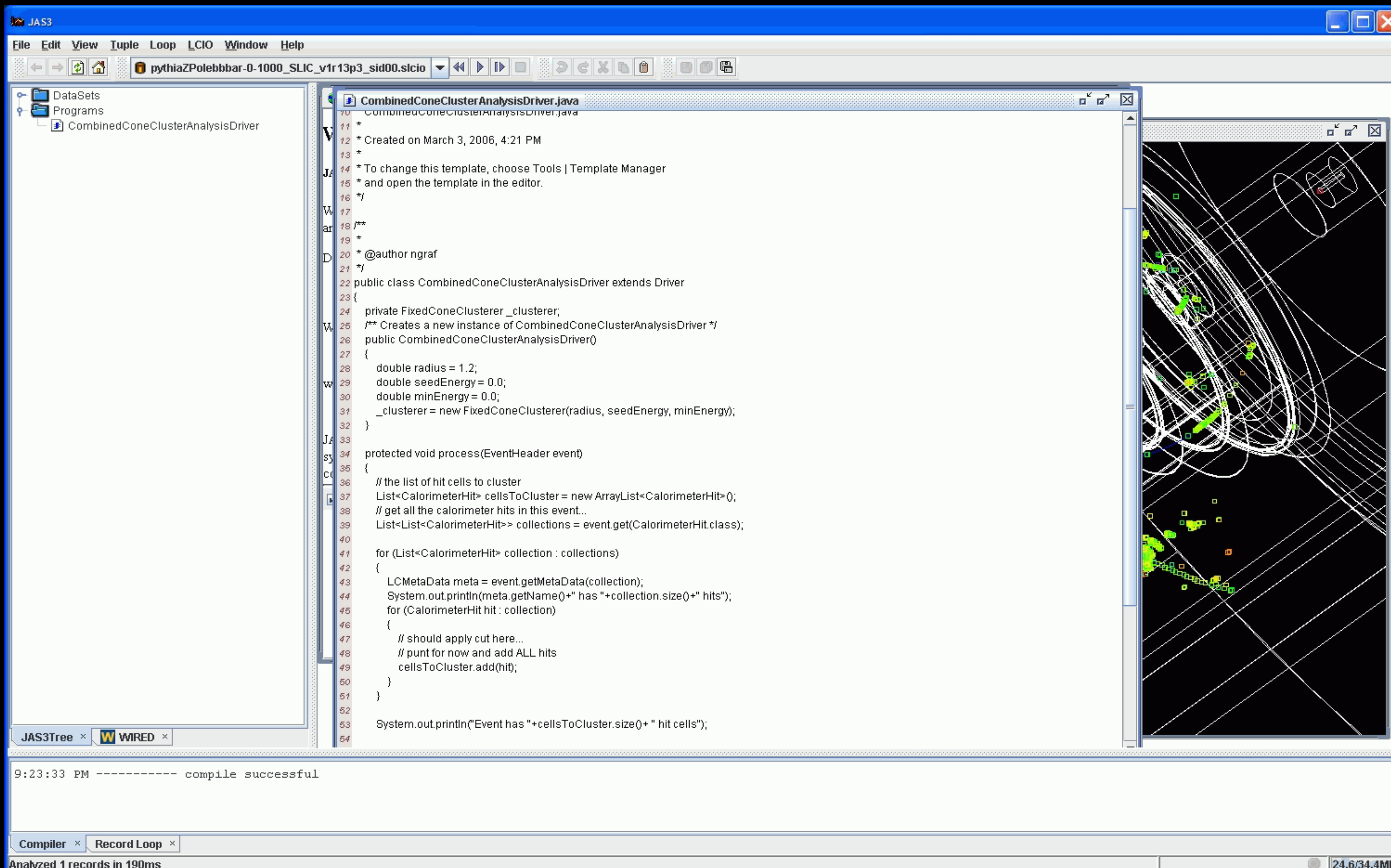
Track Finding

- Standalone pattern recognition code for 1D (e.g. Si 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.

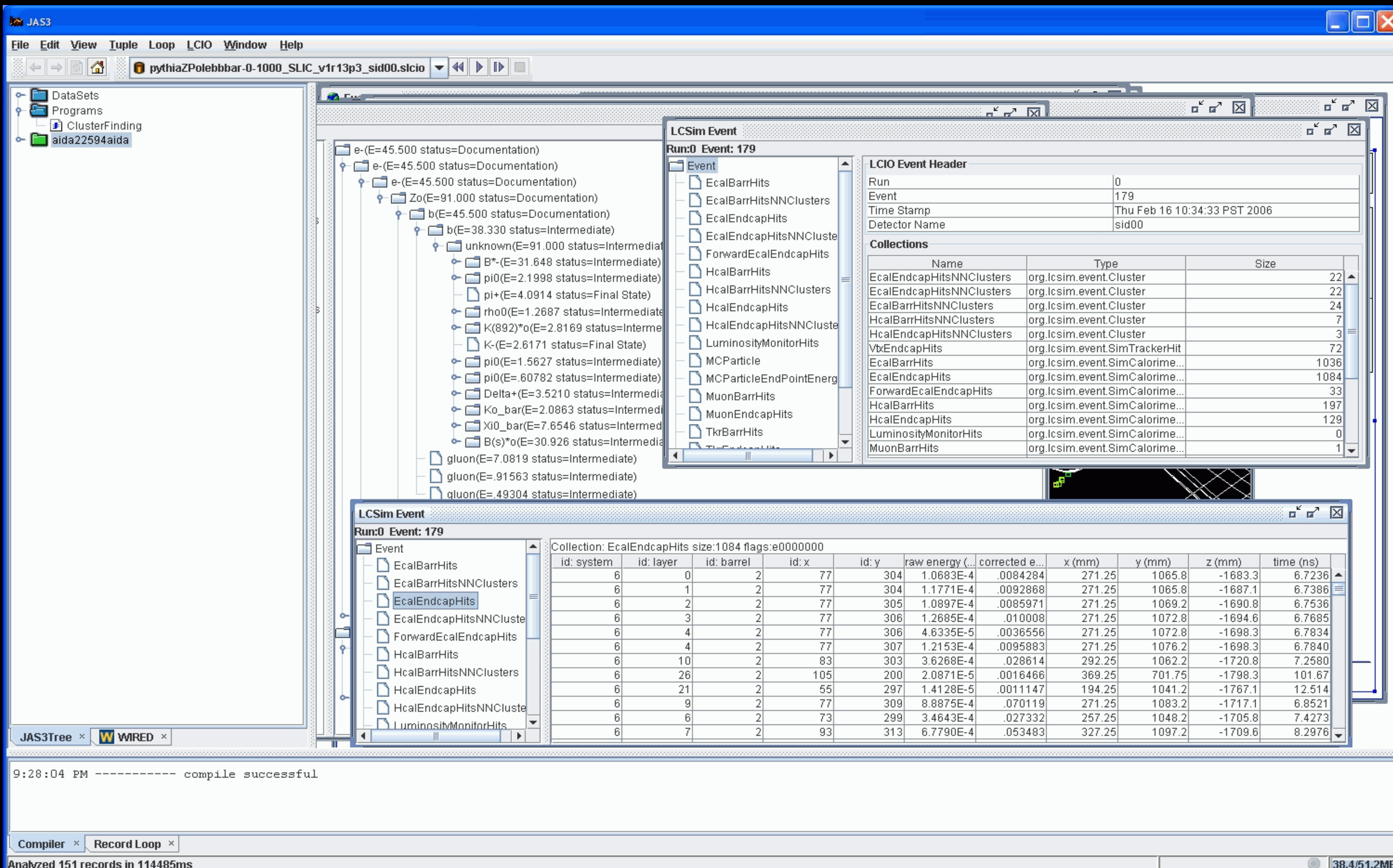
Java Analysis Studio (JAS)

- 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

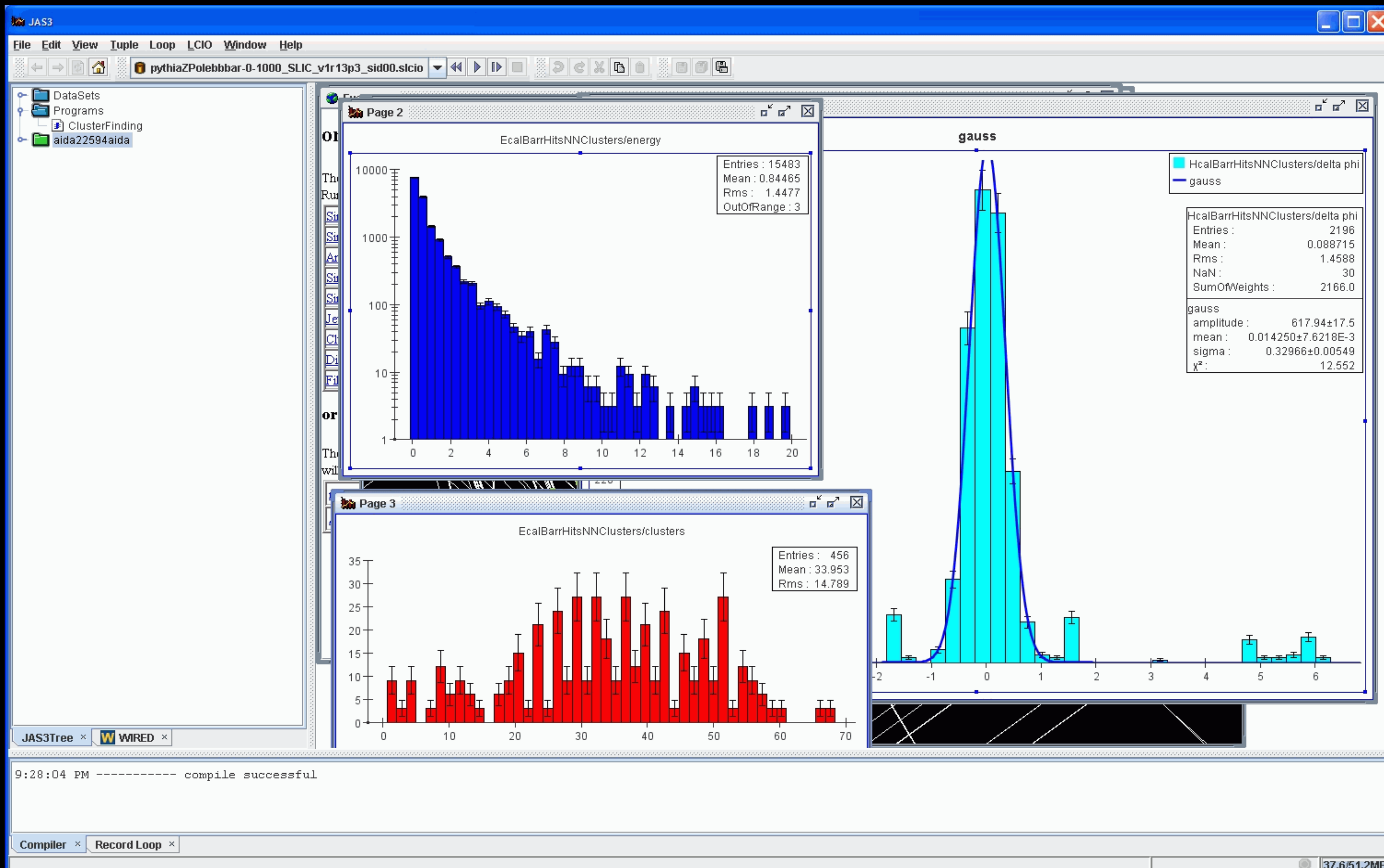
JAS editor/compiler



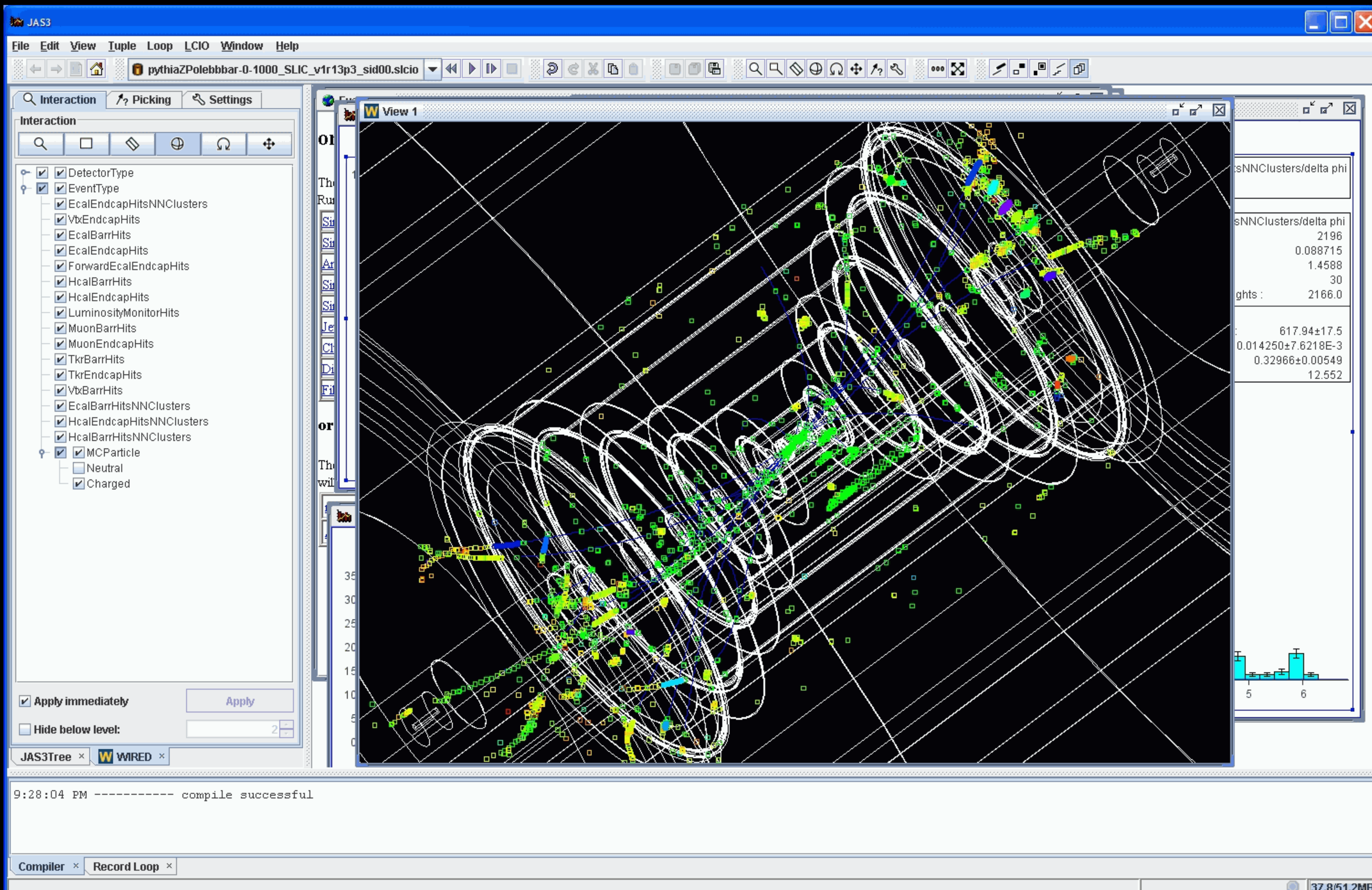
JAS event browser



JAS histogramming/ fitting



Wired LCD Event Display



Validated

- This suite of software tools provides:
  - Physics event generation & bindings to most legacy generators through the stdhep format.
  - Full detector response simulation using precompiled binaries & runtime geometry definition (no coding!).
  - Full detector digitization (x-talk, noise, diffusion, etc.)
  - Hit-level overlay of arbitrary background events.
  - Access to other LCIO-compliant software frameworks.
  - Full ab-initio event reconstruction and analysis suites.
  - Tested on hundreds of millions of events.
- "From zero to analysis in 15 minutes."

User base

- ILC physics and detector community
  - primarily US and UK members of SiD
- CLIC physics and detector community
  - CERN-based SiD’ studies
- Muon collider physics and detector community
- JLAB heavy-photon search proposals
  - HPS: SLAC-based, fixed target, forward detector
  - DarkLight: MIT-based, gas-jet, asymmetric detector.
- FNAL dual-readout crystal calorimetry

Simulation Summary

- ALCPG sim/reco supports an ambitious international detector simulation effort. Goal is flexibility and interoperability.
- Provides a complete and flexible detector simulation package capable of simulating arbitrarily complex detectors with runtime detector description.
- Reconstruction & analysis framework was used to characterize the Silicon Detector and was essential to that concept's successful validation in the LOI process.
- LCIO provides interoperability with tools developed in other regions (e.g. jet flavor tagging (LCFI), particle flow (Pandora)), other languages (FORTRAN, java, C++, python) and other analysis frameworks (e.g. Marlin, root).

Additional Information

- Wiki - http://confluence.slac.stanford.edu/display/ilc/Home
- lcsim.org - http://www.lcsim.org
- 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