Simulation and data reconstruction framework
slic & lcsim

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SLAC
HPS Collaboration Meeting
May 27, 2011

Simulation Mission Statement

- Provide full simulation capabilities for physics program:
  - Physics signal & beam background simulations
  - Detector designs
  - Trigger simulations
  - Reconstruction and analysis
- Need flexibility for:
  - Optimizing detector geometries
  - Different reconstruction algorithms
  - Different machine environments
- Limited resources demand efficient solutions, focused effort.

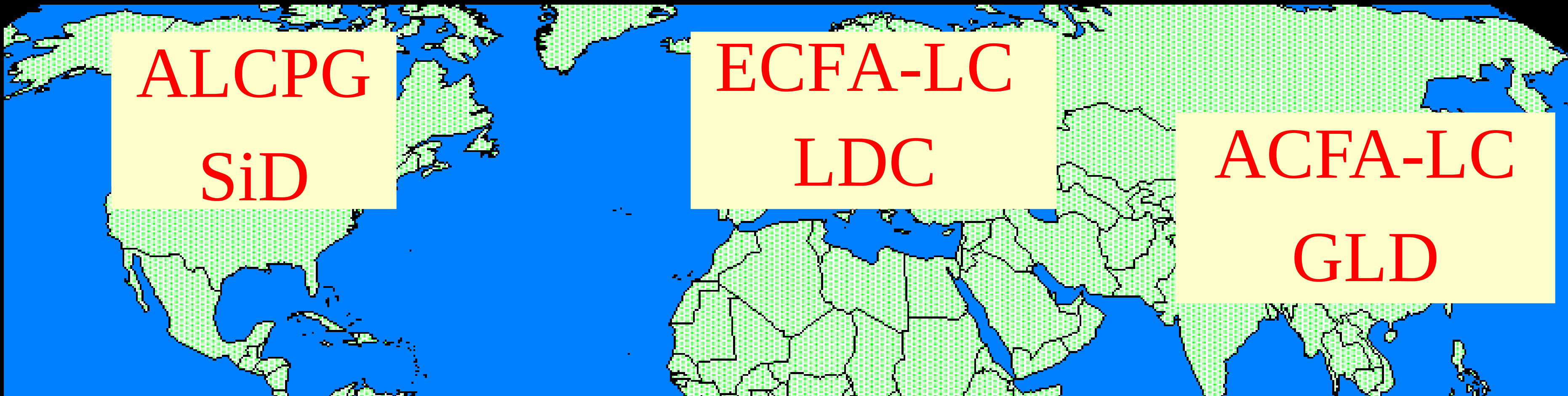
Overview: Goals

- 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 physics processes with full detector designs and full backgrounds.

Detector Performance Studies

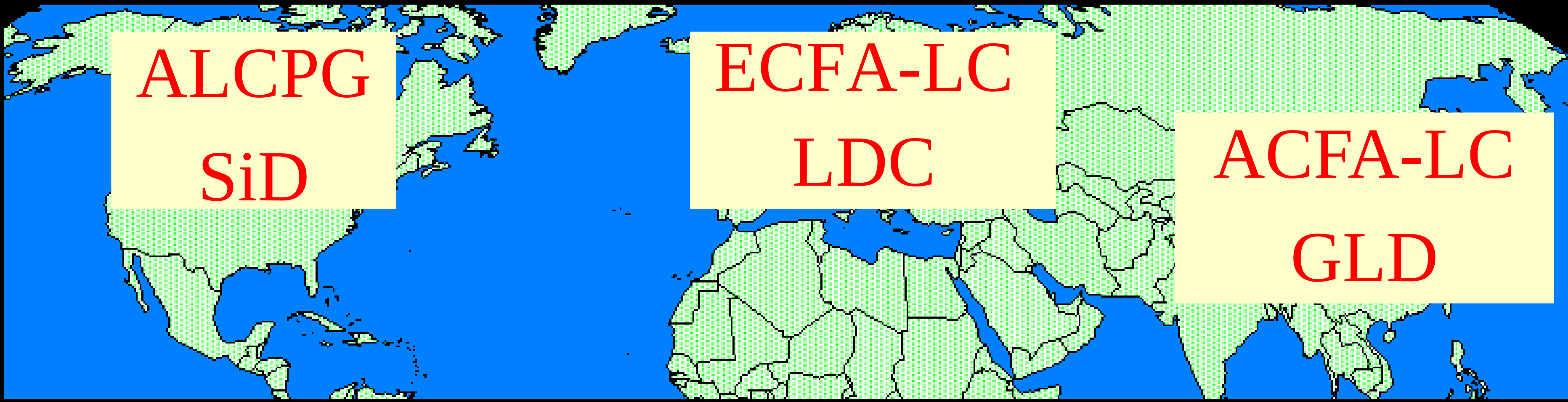
- The ILC community recently finished a very intensive round of detector performance and optimization studies, culminating in the submission of LOI's and is engaged in preparing more detailed updates for the DBD in 2012.
- The CLIC community is currently engaged in an aggressive effort to provide a CDR later this year.
- The Muon Collider community will be using these tools for physics and detector studies.
- HPS benefits from the very large investment in software and the lessons learned.

LCIO



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

LCIO



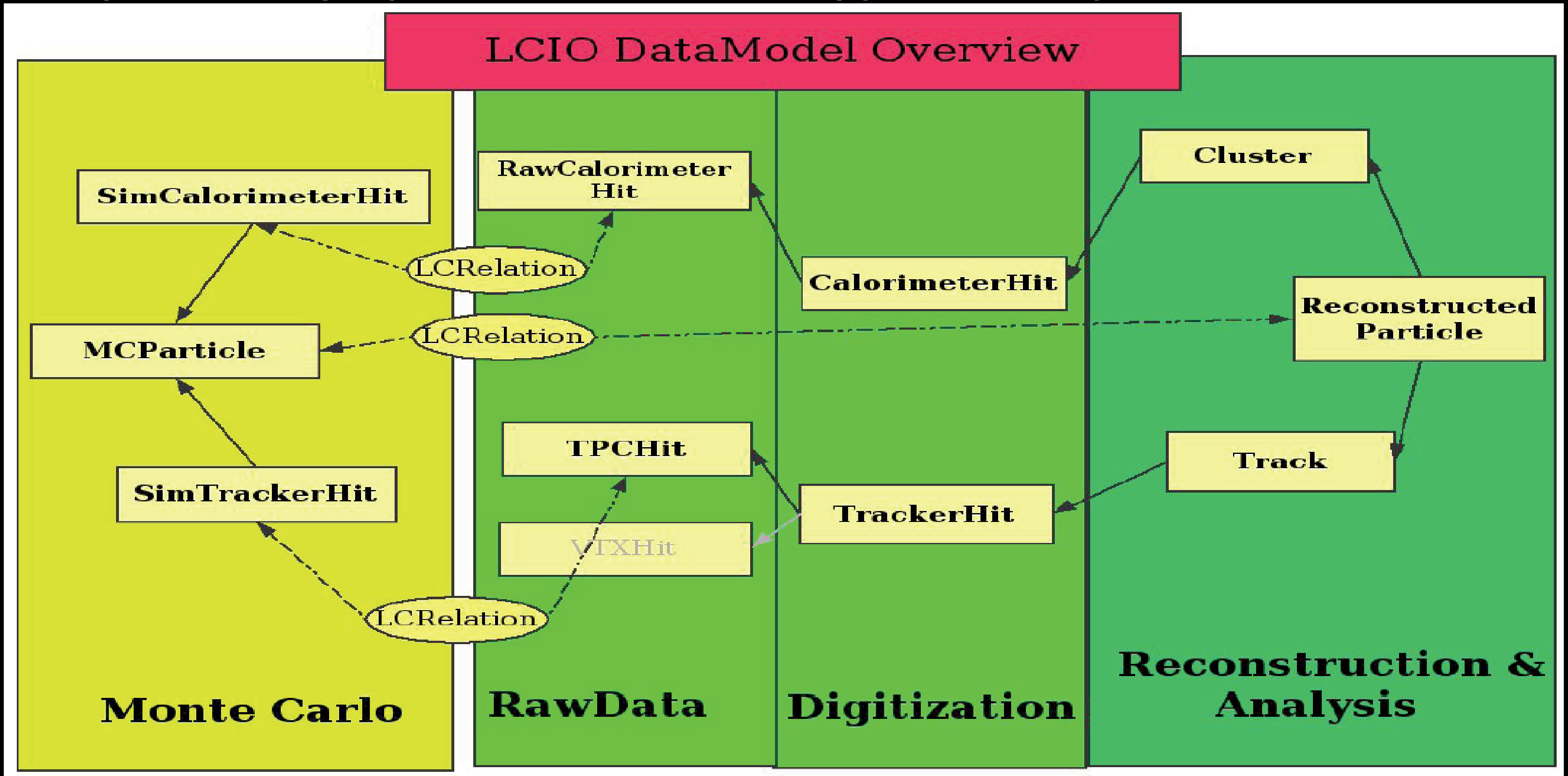
LCIO

Common Data Model

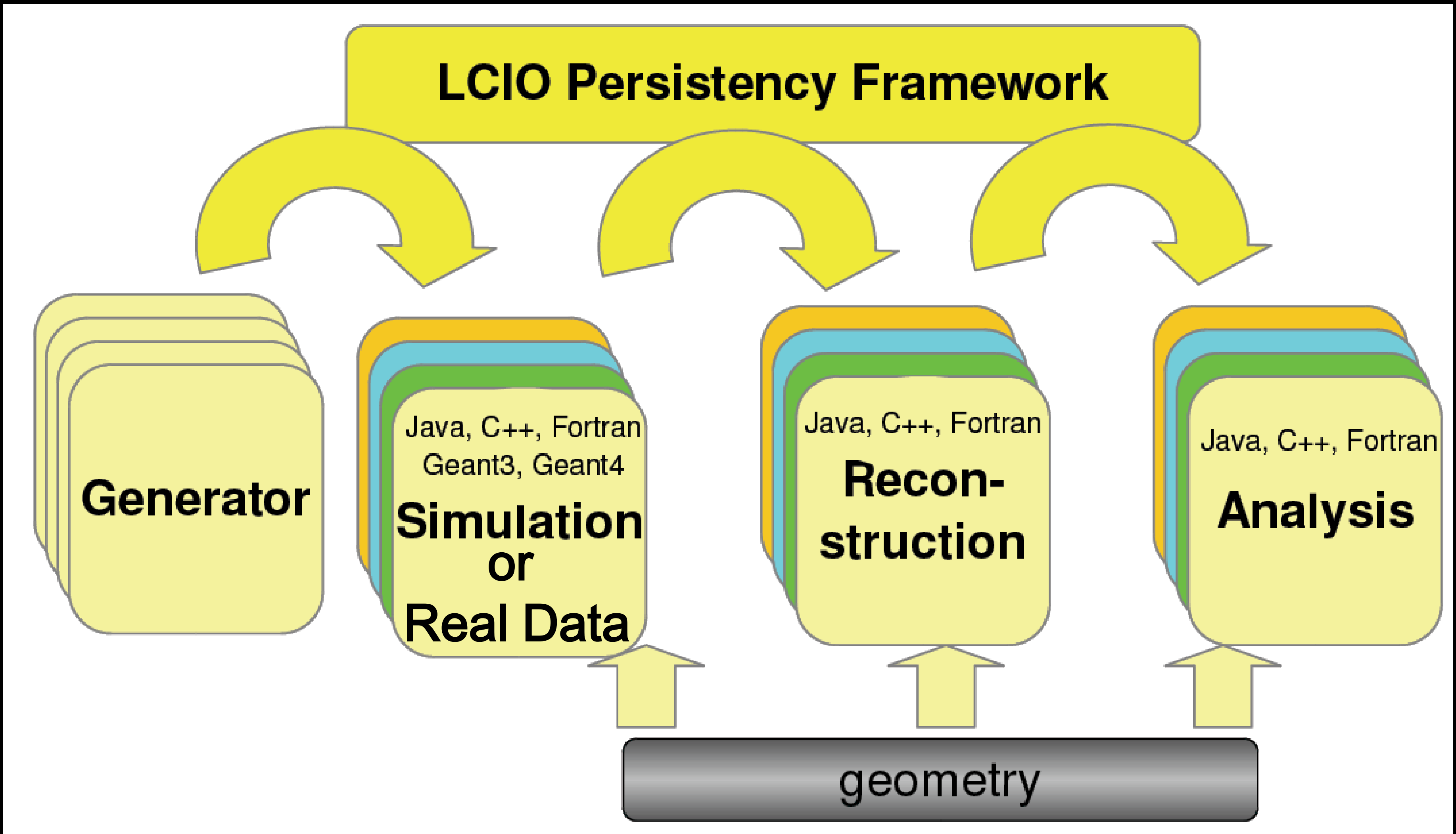
Common IO Format

LCIO Overview

- Object model and persistency format for HEP events
  - MC simulation
  - Data (experimental or testbeam)
  - Reconstructed Objects
- Multiple bindings (C++, Java, Fortran, python, root)



LCIO Overview

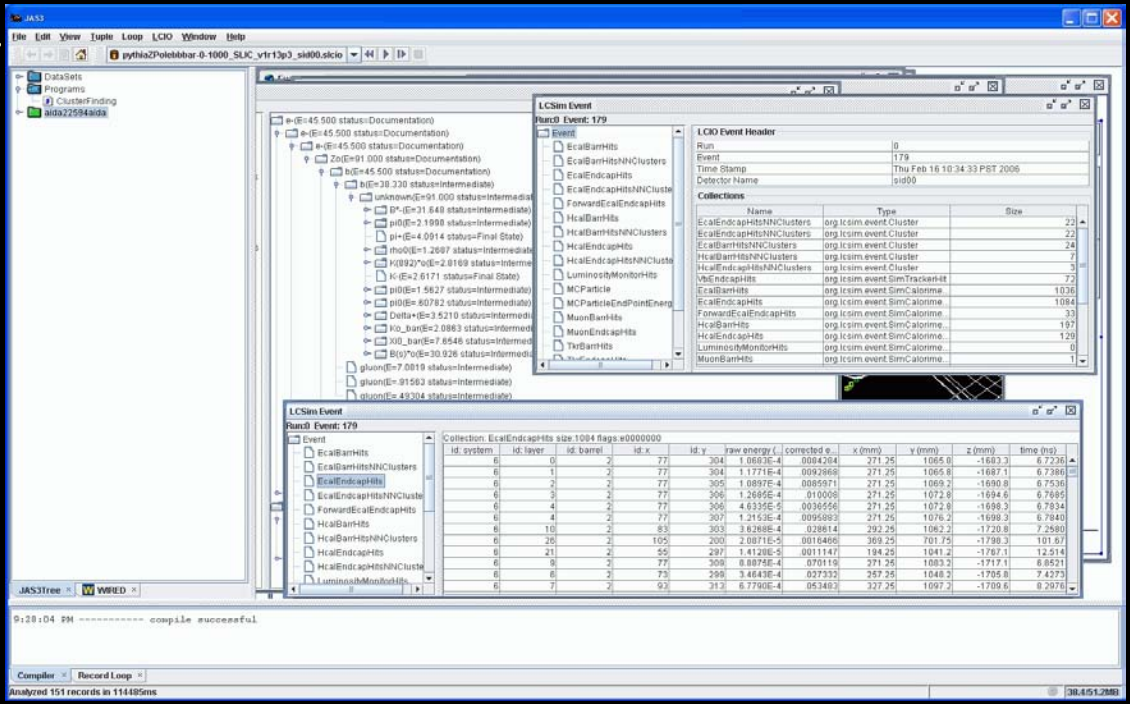


LCIO

- Direct access to events
  - Overlay of random background events
  - Physics analysis using preselection on metadata
- ROOT dictionary
  - use LCIO classes in root macros
  - write simple ROOT trees
  - write complete LCIO events in one ROOT branch
    - comes at a cost, of course, slower than native access
- LCIO 2.0 will add requested user functionality.

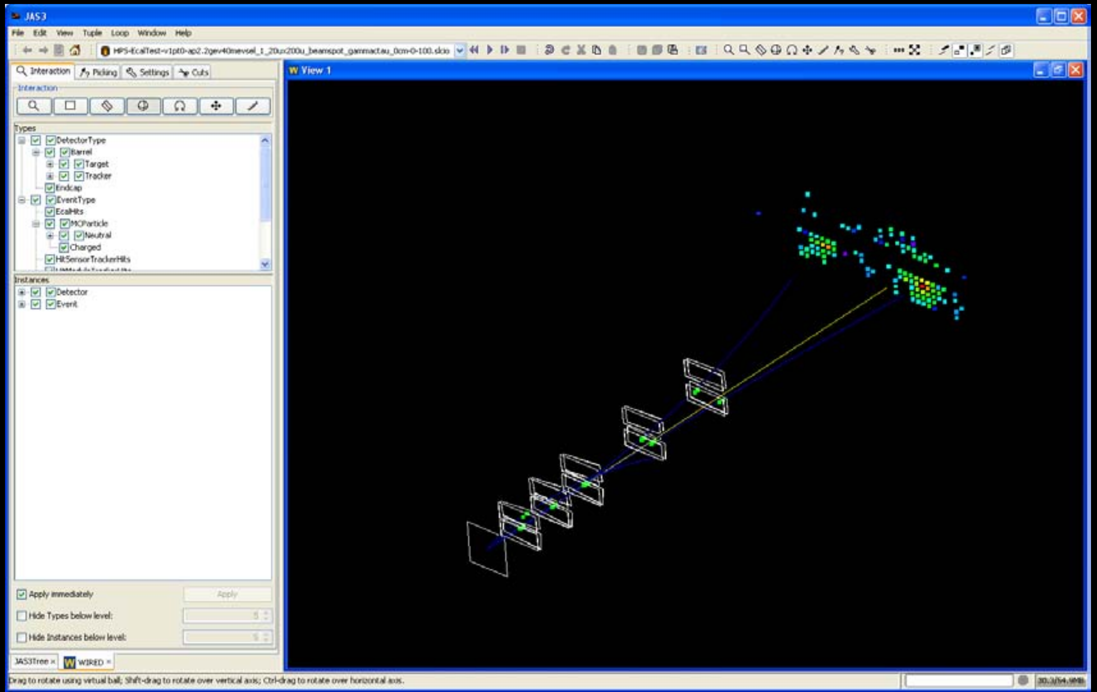
LCIO Event Browser

- Fully supported within JAS.
- Open any LCIO file, browse collections and objects.
- Traverse MC particle hierarchies
- Print, sort, analyze.



LCIO Event Display

- Fully integrated within JAS using Wired.
- Fully interactive event display
- Detector & Event objects selectable, pickable, queryable, can have cuts applied, etc.
  - Not just a static image.



Raw Data

- LCIO has been used for many years by various testbeam experiments, both tracking and calorimetry.
  - EDM supports raw data taking and analysis.
  - Simple, robust & fast
- Many tools exist for data monitoring, QA, analysis, etc.
- See talk by Ebrahim on LCIO / EVIO.

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.
- Beam backgrounds and time structure at HPS will require detailed full detector simulations involving correct handling of event overlays.

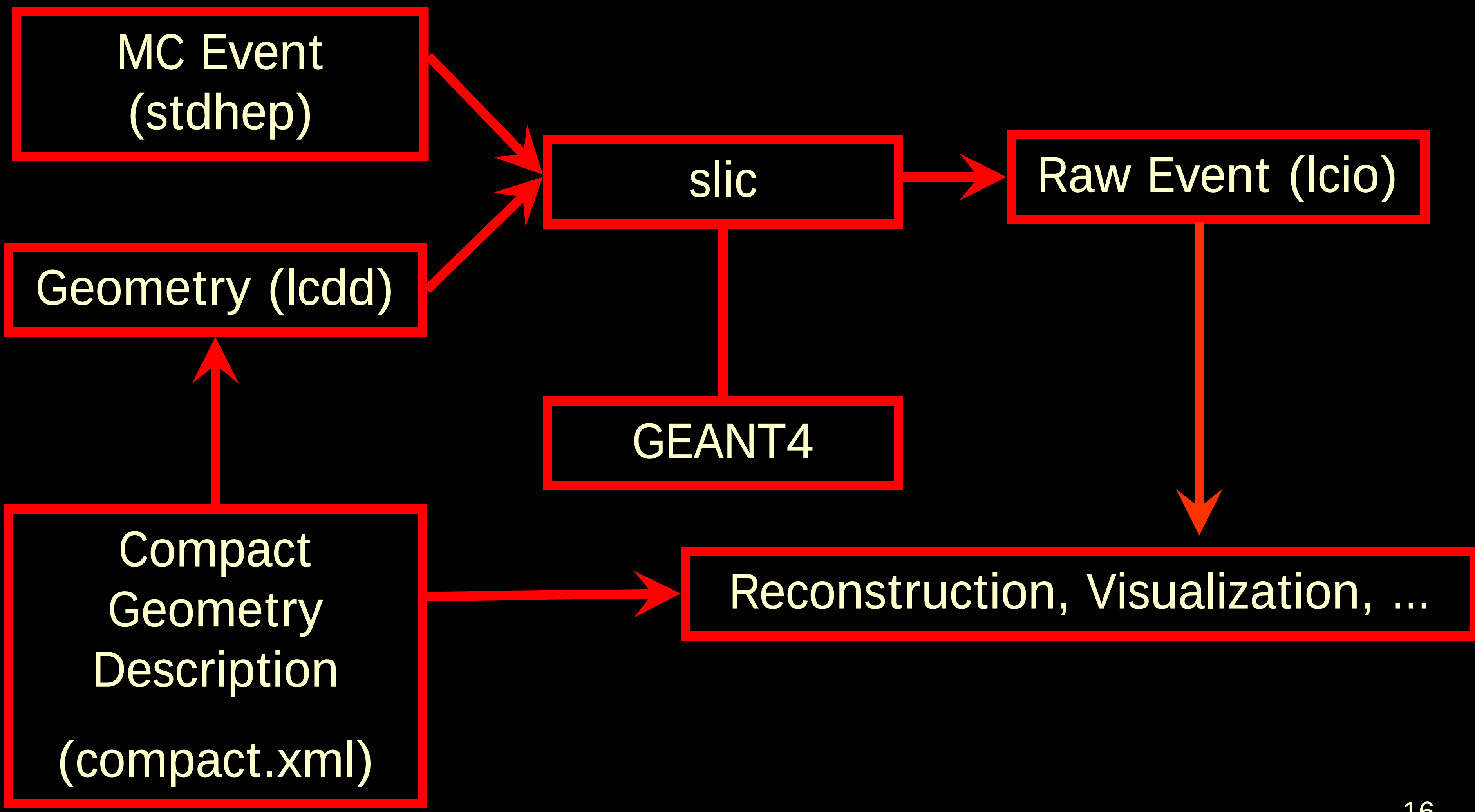
Full Detector Response Simulation

- 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.

LC Detector Full Simulation

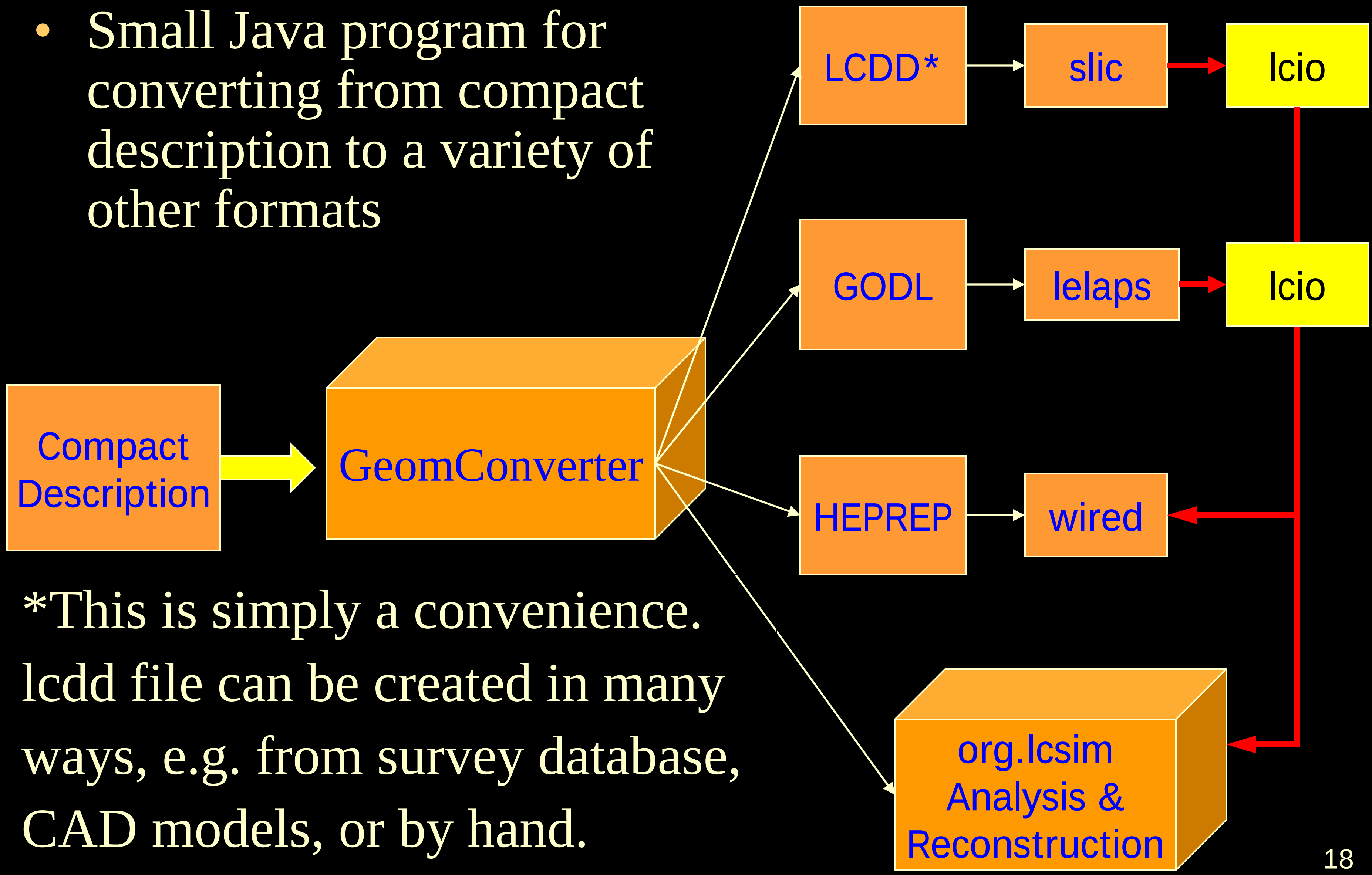


slic: The Executable

- Build static executables on Linux, Windows, Mac.
- Commandline or G4 macro control.
- Only dependence is local detector description file.
- Event input via stdhep, particle gun, …
- Detector input via GDML, lcdd
- Response output via LCIO using generic hits.

GeomConverter

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



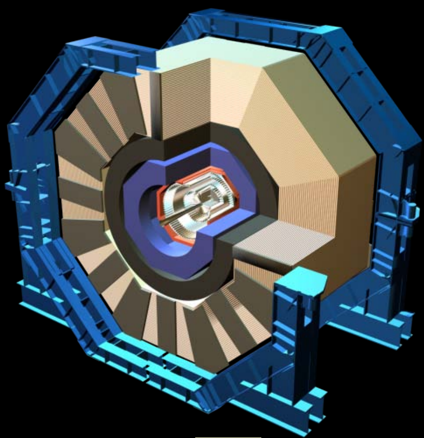
*This is simply a convenience. lcdd file can be created in many ways, e.g. from survey database, CAD models, or by hand.

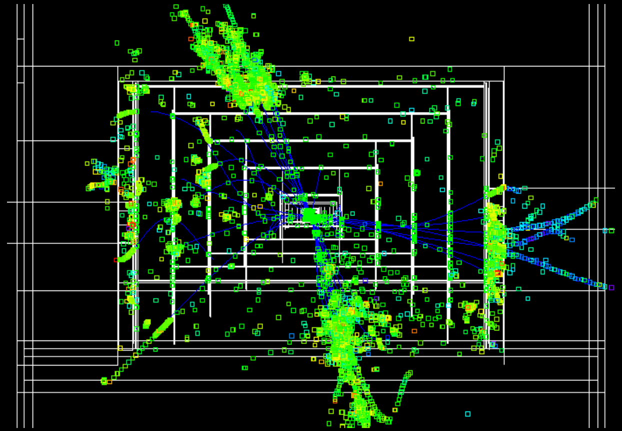
Detector Variants

- 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.

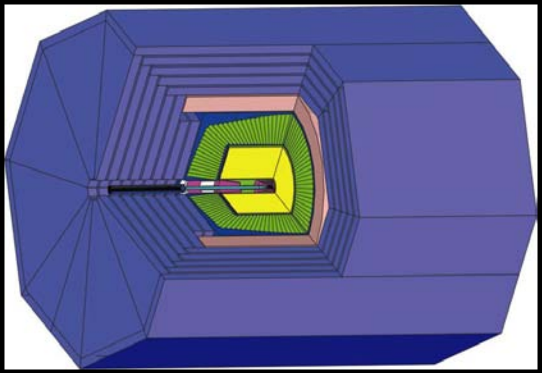
ILC Full Detector Concepts

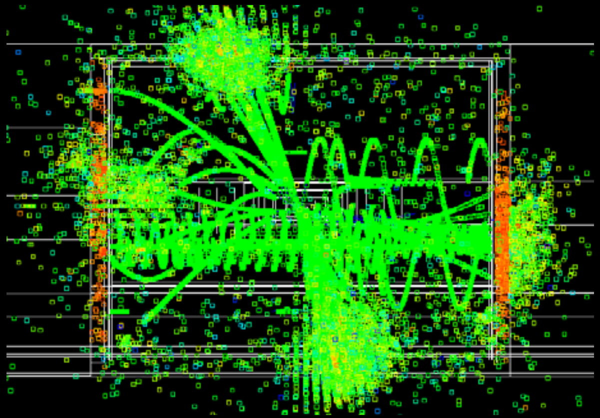
SiD



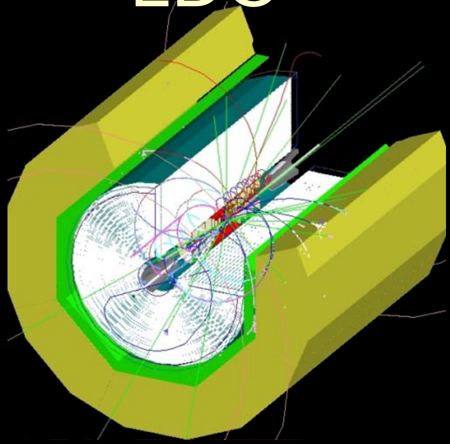


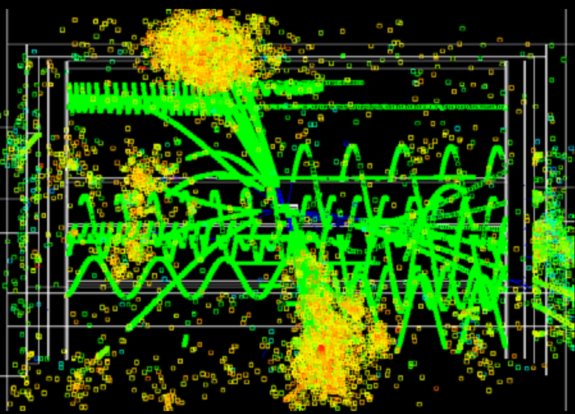
GLD



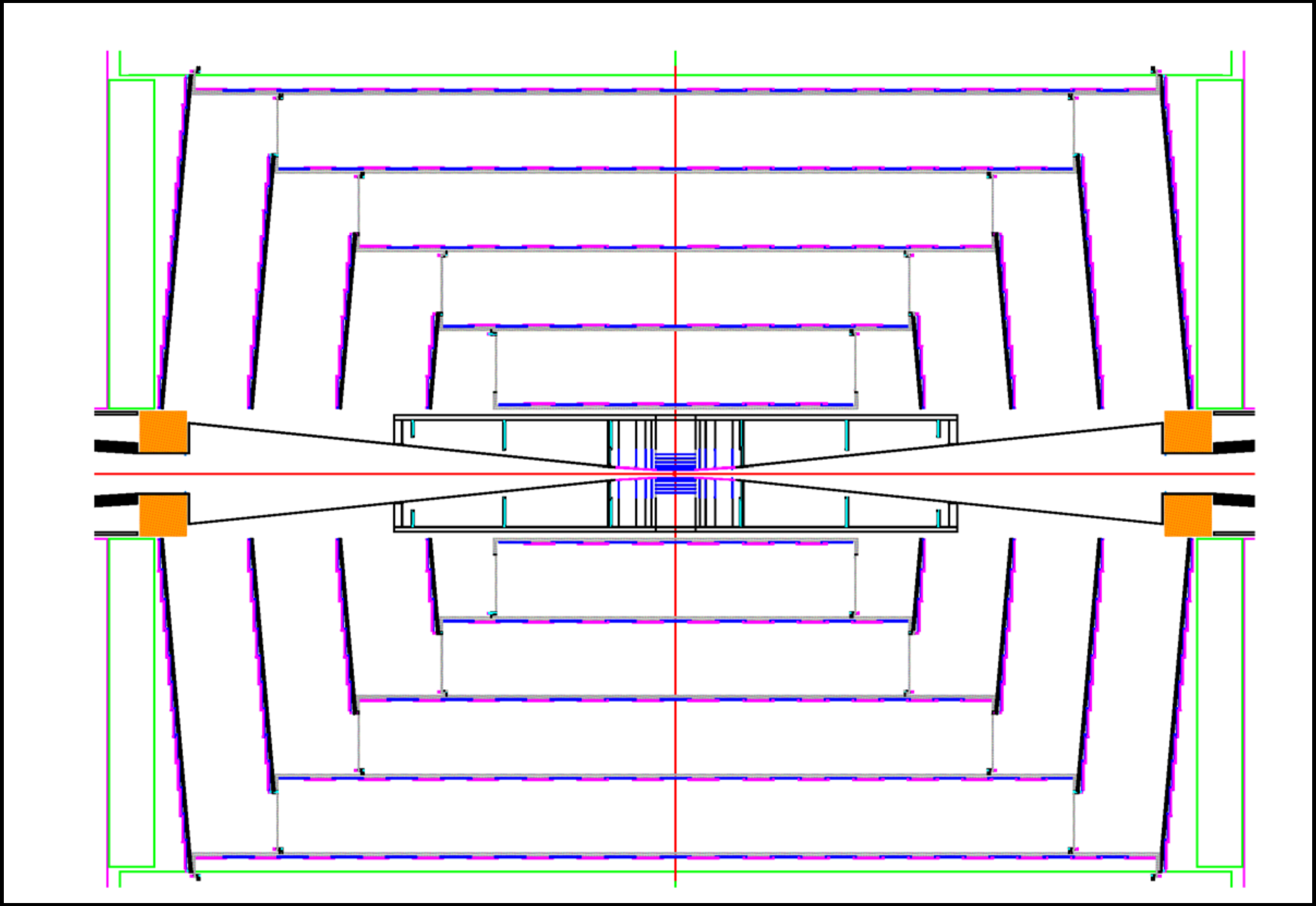


LDC



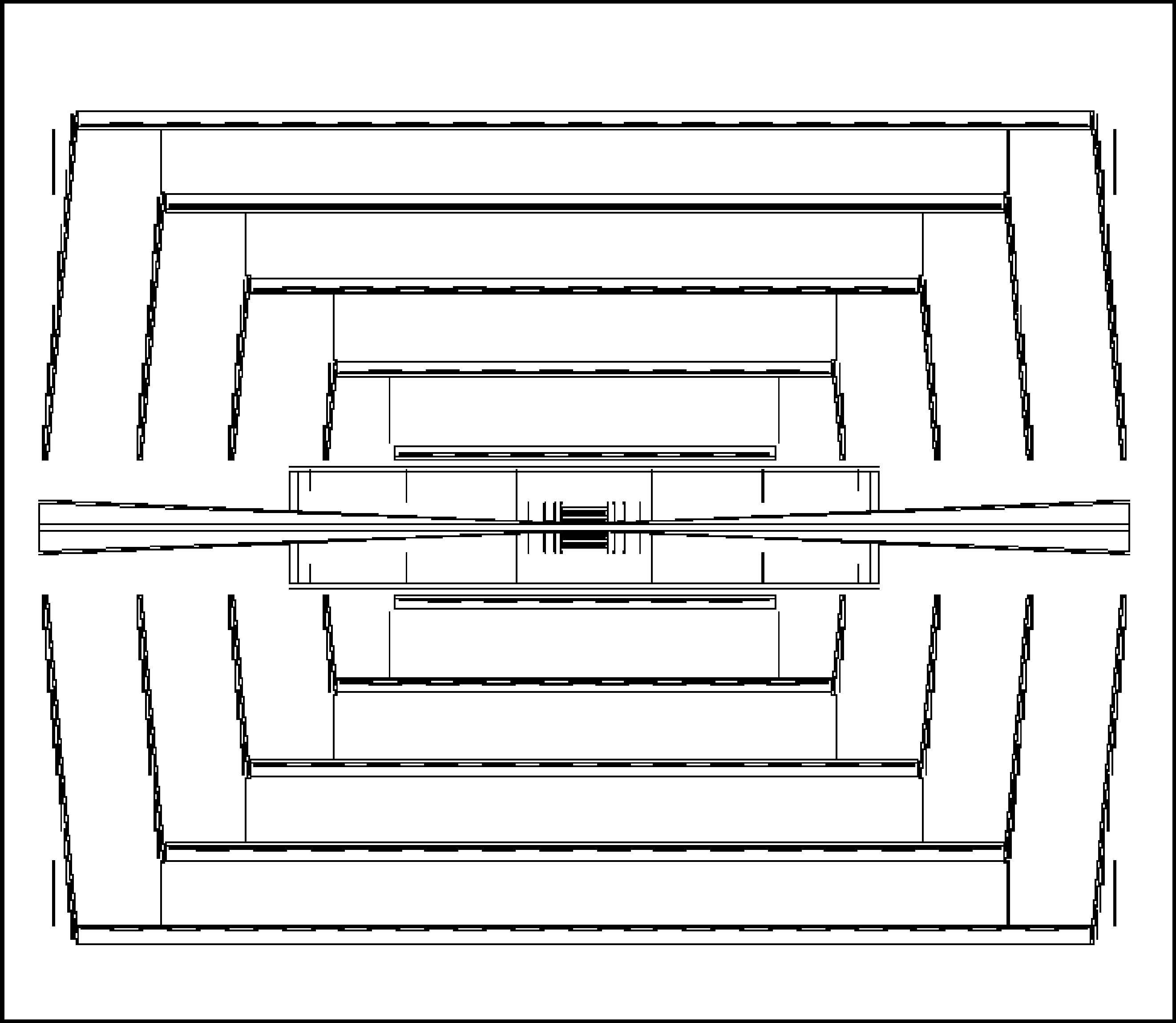


Silicon Detector Tracker



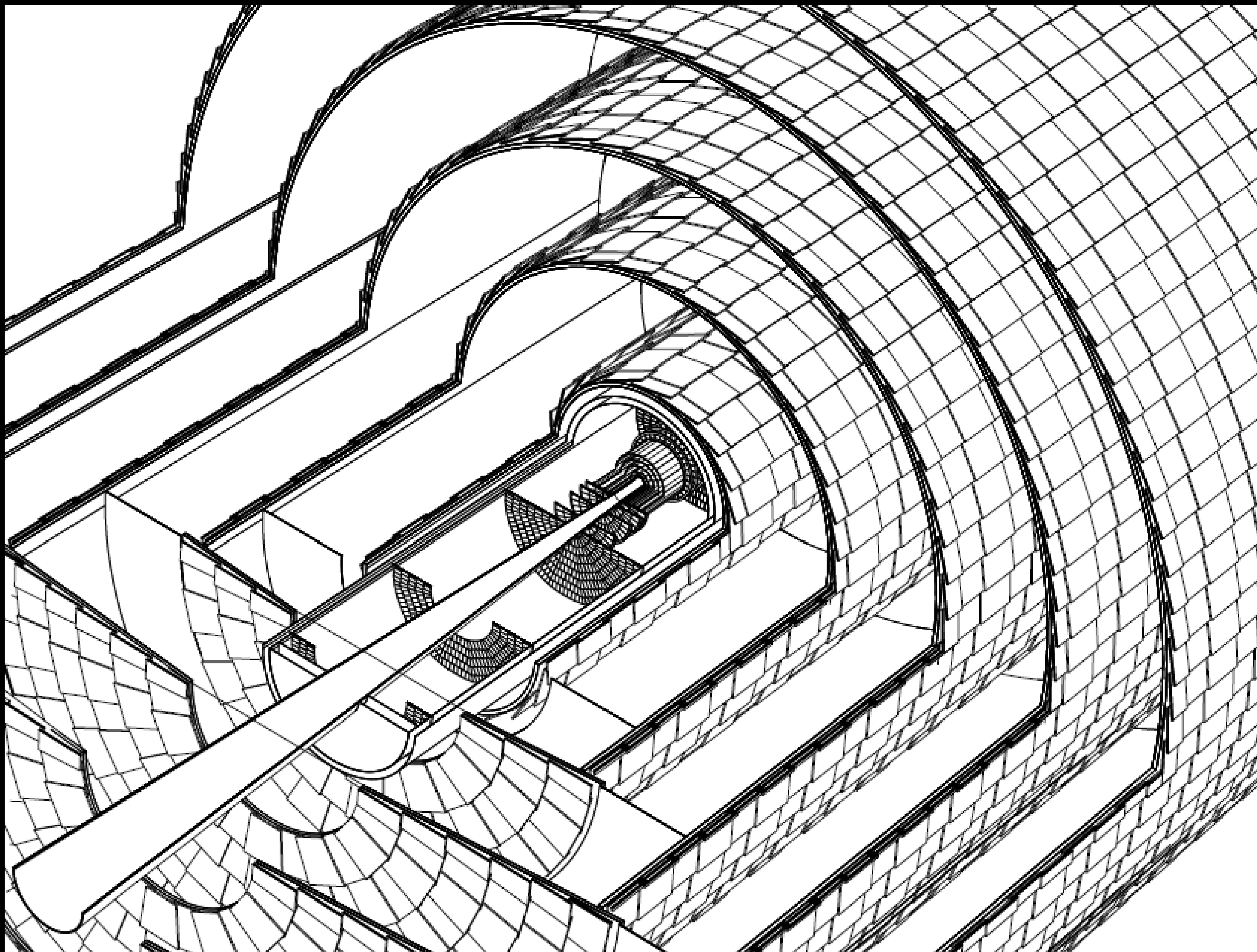
CAD Drawing

Silicon Detector Tracker



Geant Model

Silicon Detector Tracker



Simulating the HPS Tracker

- Complete control over definitions of tracker sensitive wafers and support structures.
- Very detailed models for charge deposition, drift and diffusion available.
- Detailed model for the electronics response.

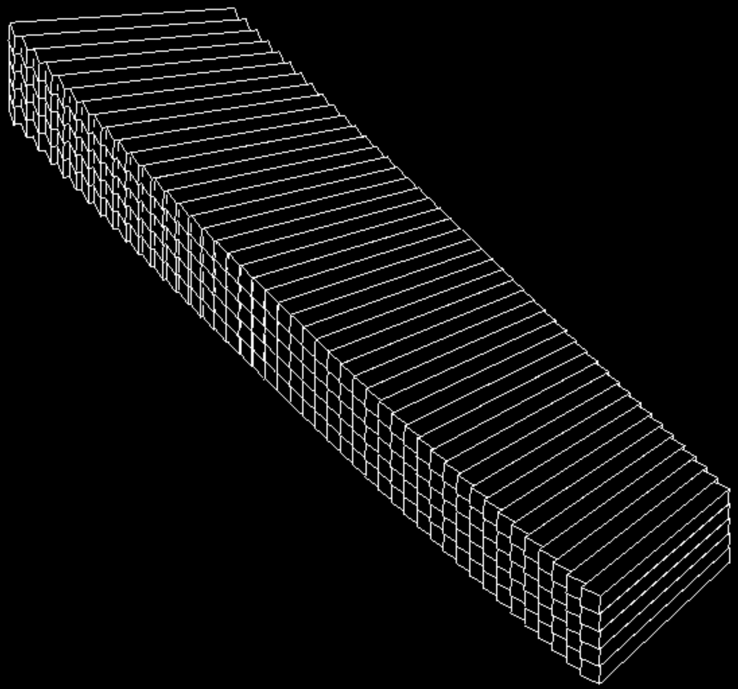
MC Hits$\rightarrow$ Channel ID & Pulse Height $\rightarrow$ Clusters $\rightarrow$ Hits (x +/- δx)

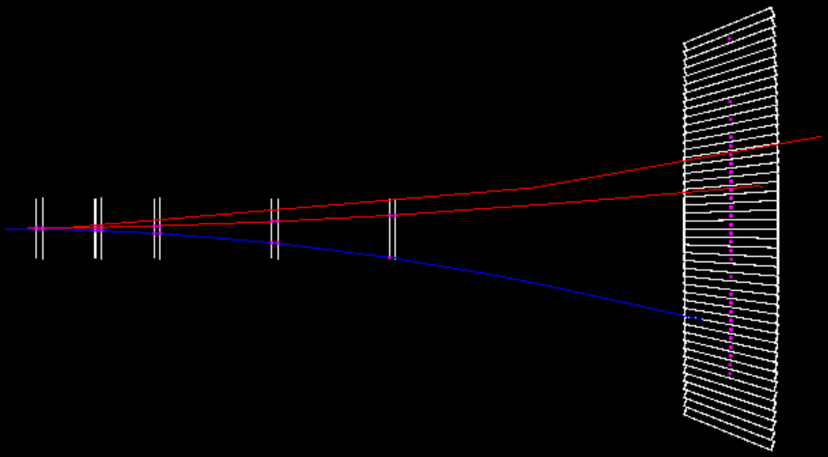
Response specific to the APV25 readout chip needs to be implemented.

- See talks by Matt for details.

Simulating the HPS ECal

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





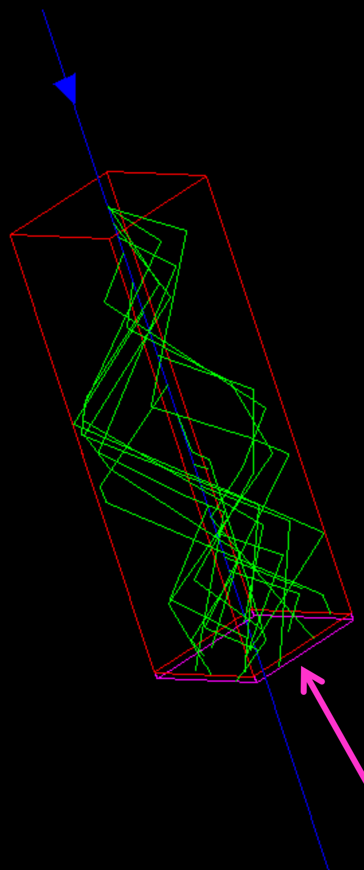
  – Some additional work needed to fully support shapes in reconstruction.

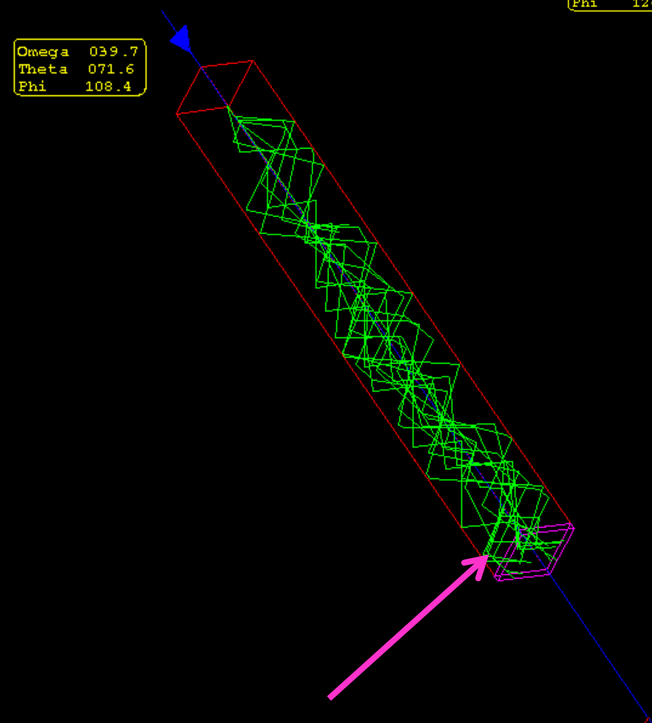
HPS ECal Response

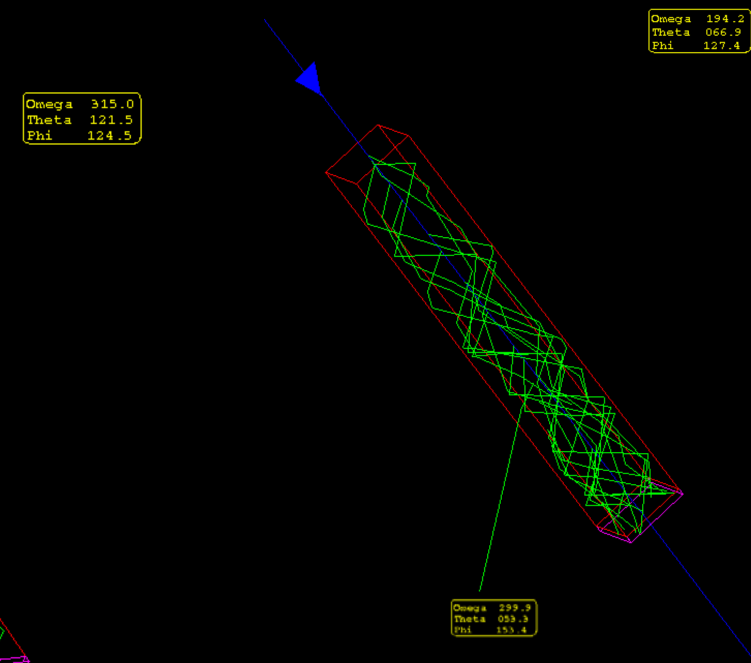
- Default Sensitive Detector response for calorimeters is to simply record energy deposition, time and MC particle information.
- Hans Wenzel has implemented scintillation and Cherenkov light deposition within slic/lcsim for studies of total absorption, dual-readout crystal calorimetry.
  - simple accumulation of energy deposit in crystal
- Currently implementing full optical photon ray tracing within crystal and propagation to sensitive detector.

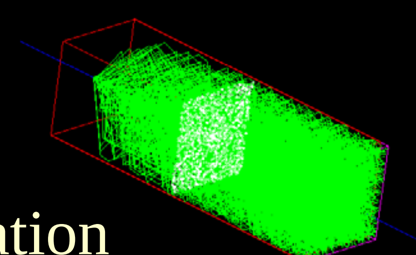
Optical Ray Tracing in Crystals

Configurable shape, material, and optical properties of crystals.









Configurable sensor records full MC information about each incident photon

Courtesy Hans Wenzel

Simulating the HPS ECal Response

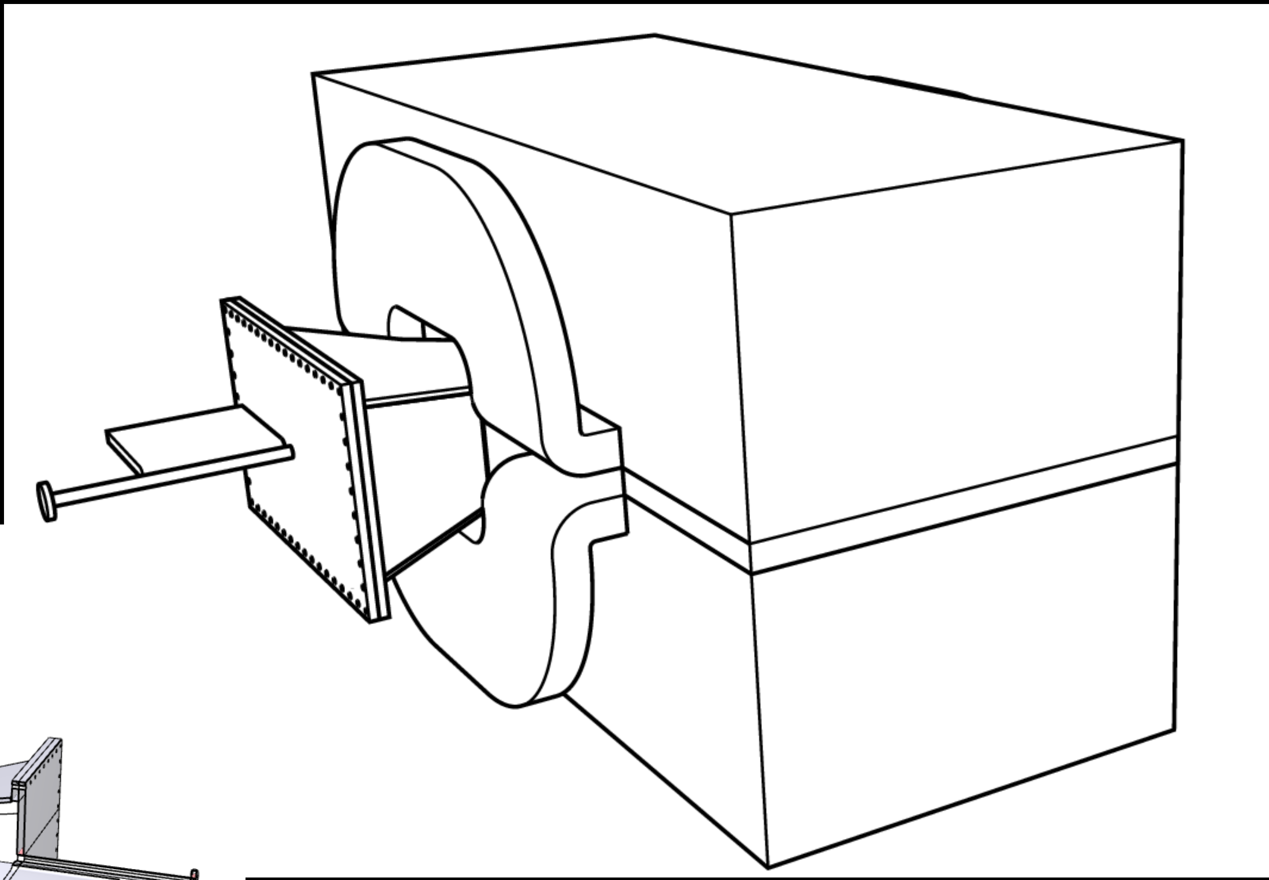
- LCIO / org.lcsim fully support event overlays with arbitrary time-offsets for signals.
- Work needed to transform delta-function MC energy depositions to signal waveform to FADC trace.
- Additional work will be needed to simulate FPGA processing of resulting signals.

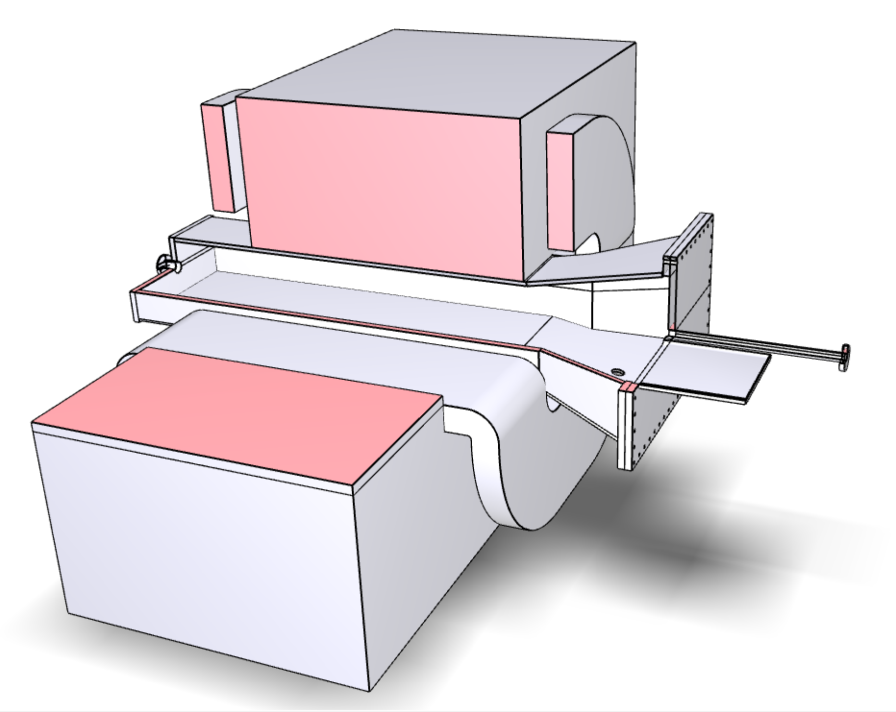
HPS Dipole and Vacuum Vessel

- CAD Model from Marco Oriunno
- Conversion to GDML by N. Graf
  - Resulting geometry is tesselated solid
    - performance not expected to be as good as using Geant4 primitives.
    - but most particles should never interact with these elements
  - included into compact.xml as gdml snippet

HPS Dipole and Vacuum Vessel

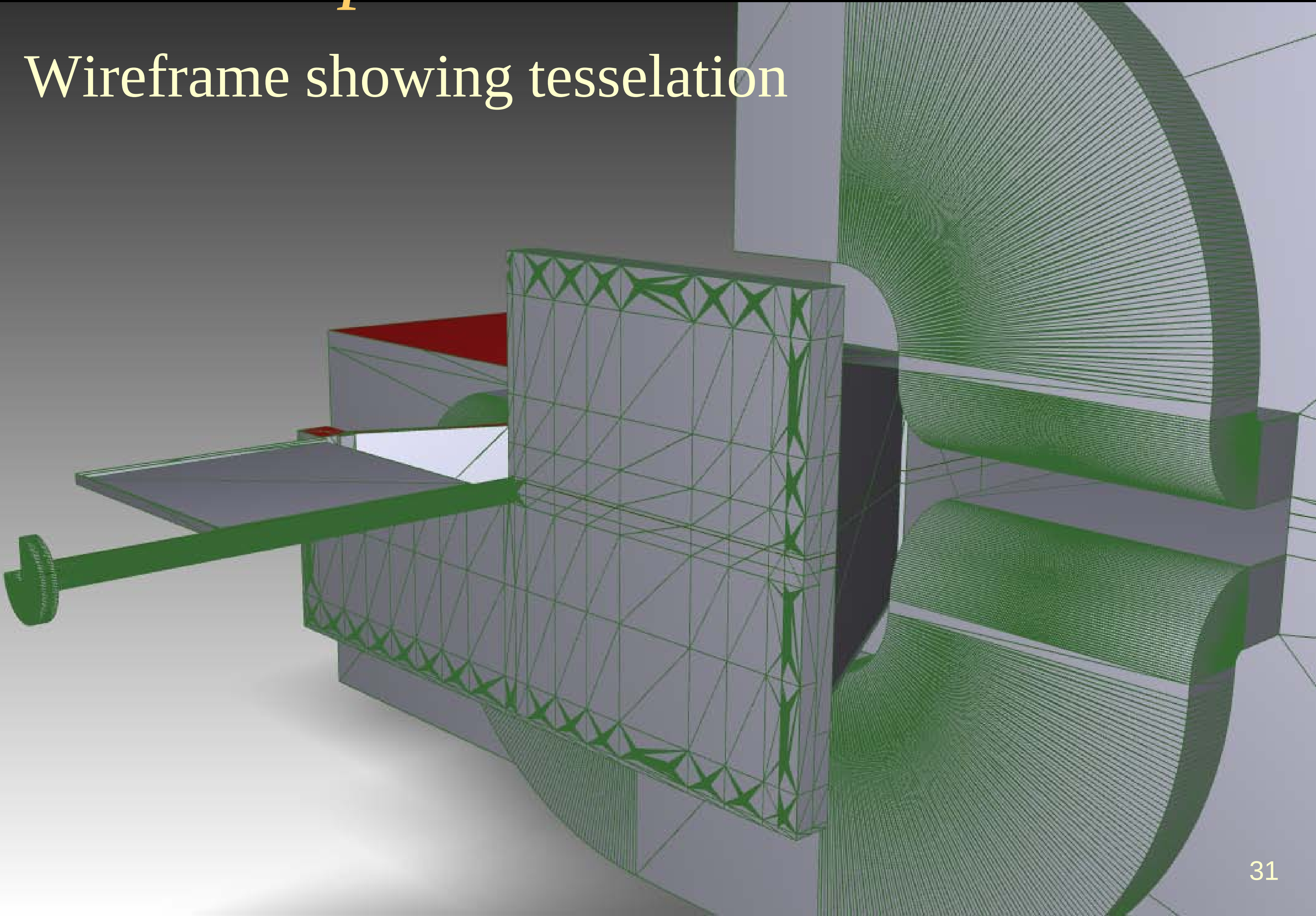
- Images from geometry output from slic.





HPS Dipole and Vacuum Vessel

- Wireframe showing tesselation



Beamline, Magnets and Supports

- Is CAD to Geant solution usable?
  - Memory and time requirements on slic.
  - but should ~never be hit: balance speed against realism
- If not, what level of simplification can be achieved automatically? What level requires manual intervention?
- Magnetic field map is supported in slic
  - Will need to characterize impact on simulation times
- Work needed to incorporate magnetic field map in org.lcsim reconstruction
  - Runge-Kutta stepper will slow down the reconstruction

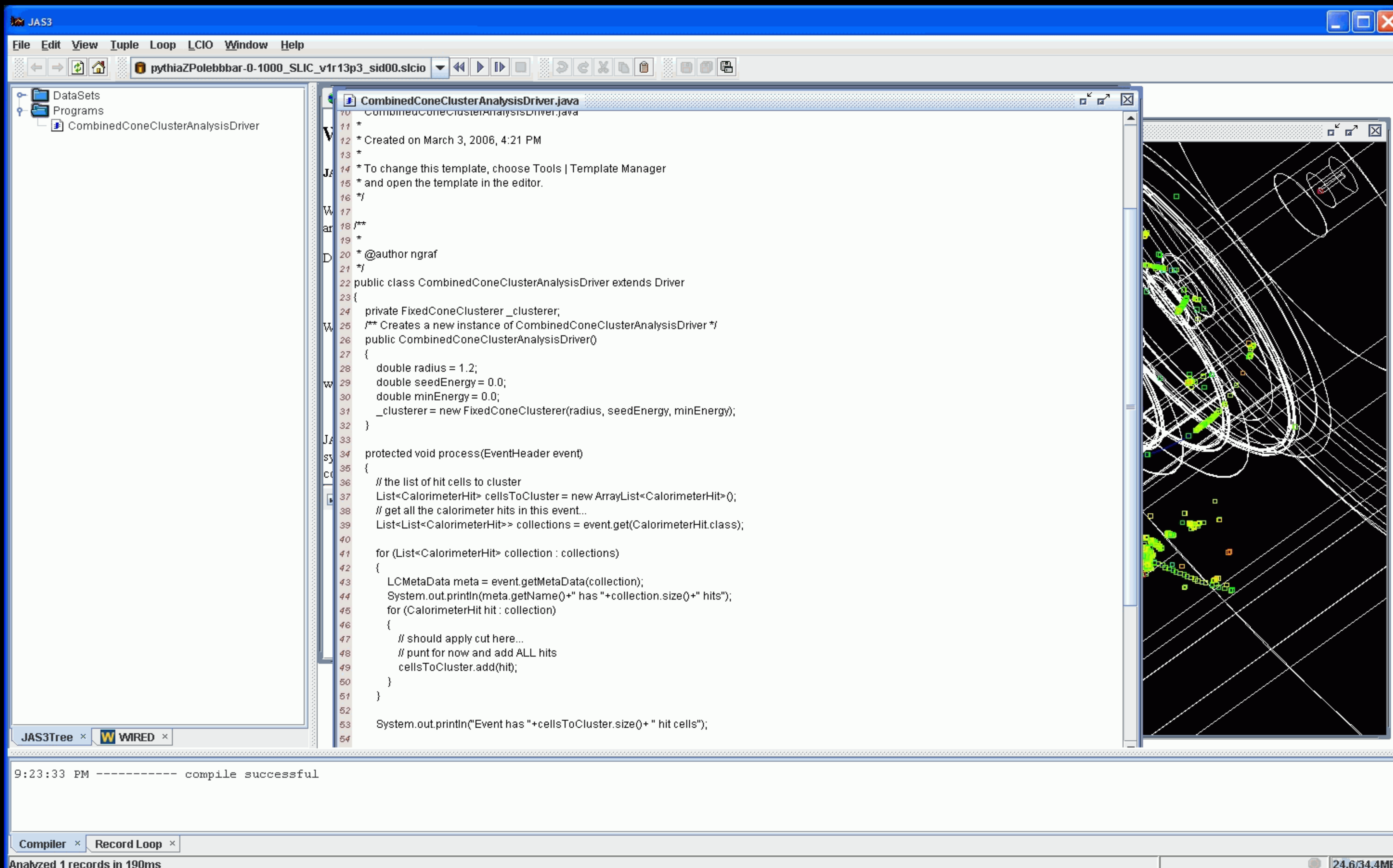
Reconstruction/Analysis Overview

- Java based reconstruction and analysis package
  - Runs standalone or inside Java Analysis Studio (JAS)
  - Full Event Reconstruction
    - Beam background overlays at detector hit level, including time offsets.
    - detector readout digitization (drift, diffusion & electronics simulation)
    - *ab initio* track finding and fitting
    - trigger calorimeter clustering algorithm implemented, others soon.
  - Analysis Tools (including WIRED event display)
- Write once run, run anywhere
  - Exact same libraries run on all platforms (Windows, Mac, Linux(es)) using the Java Virtual Machine.

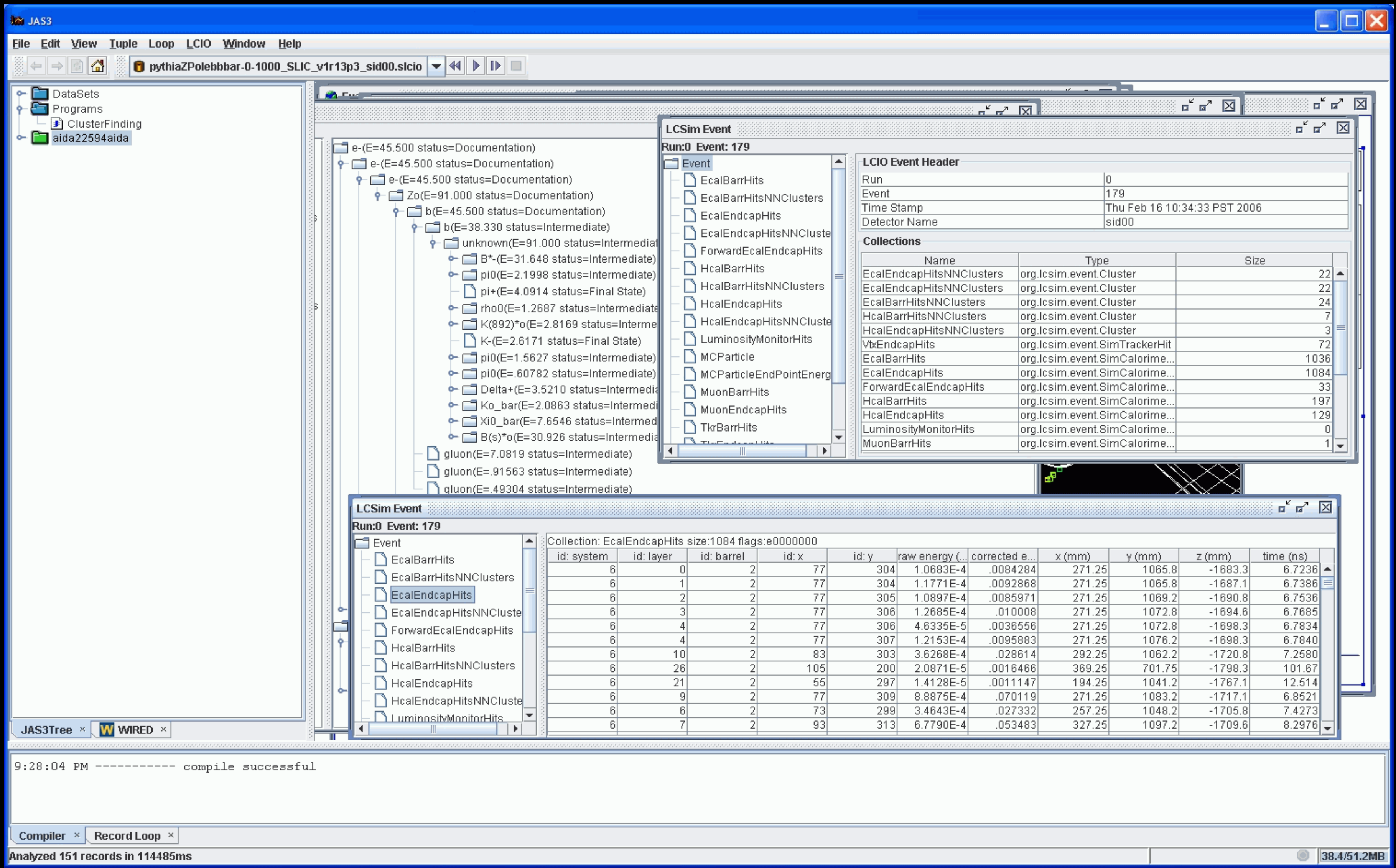
Java Analysis Studio (JAS)

- 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

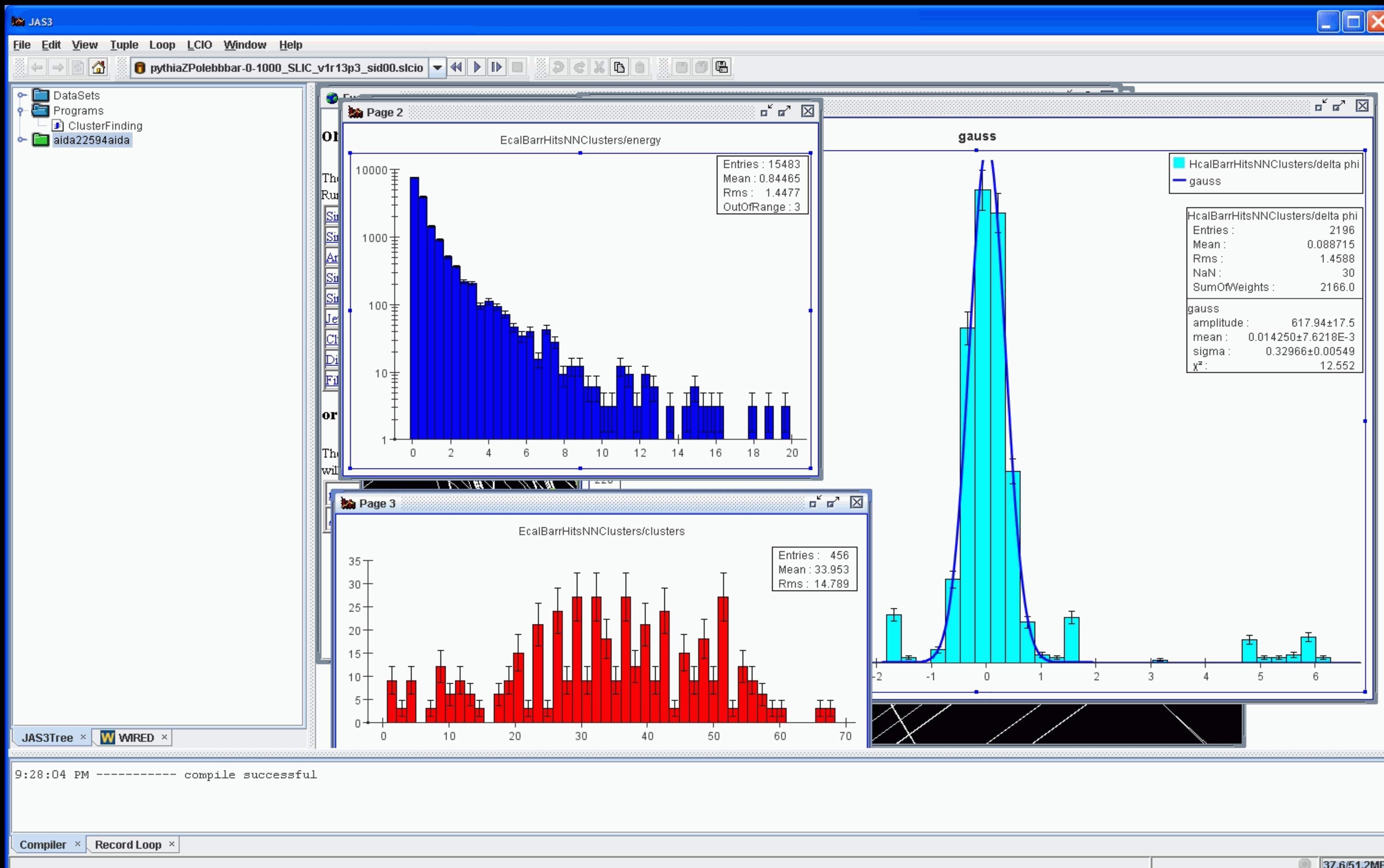
JAS editor/compiler



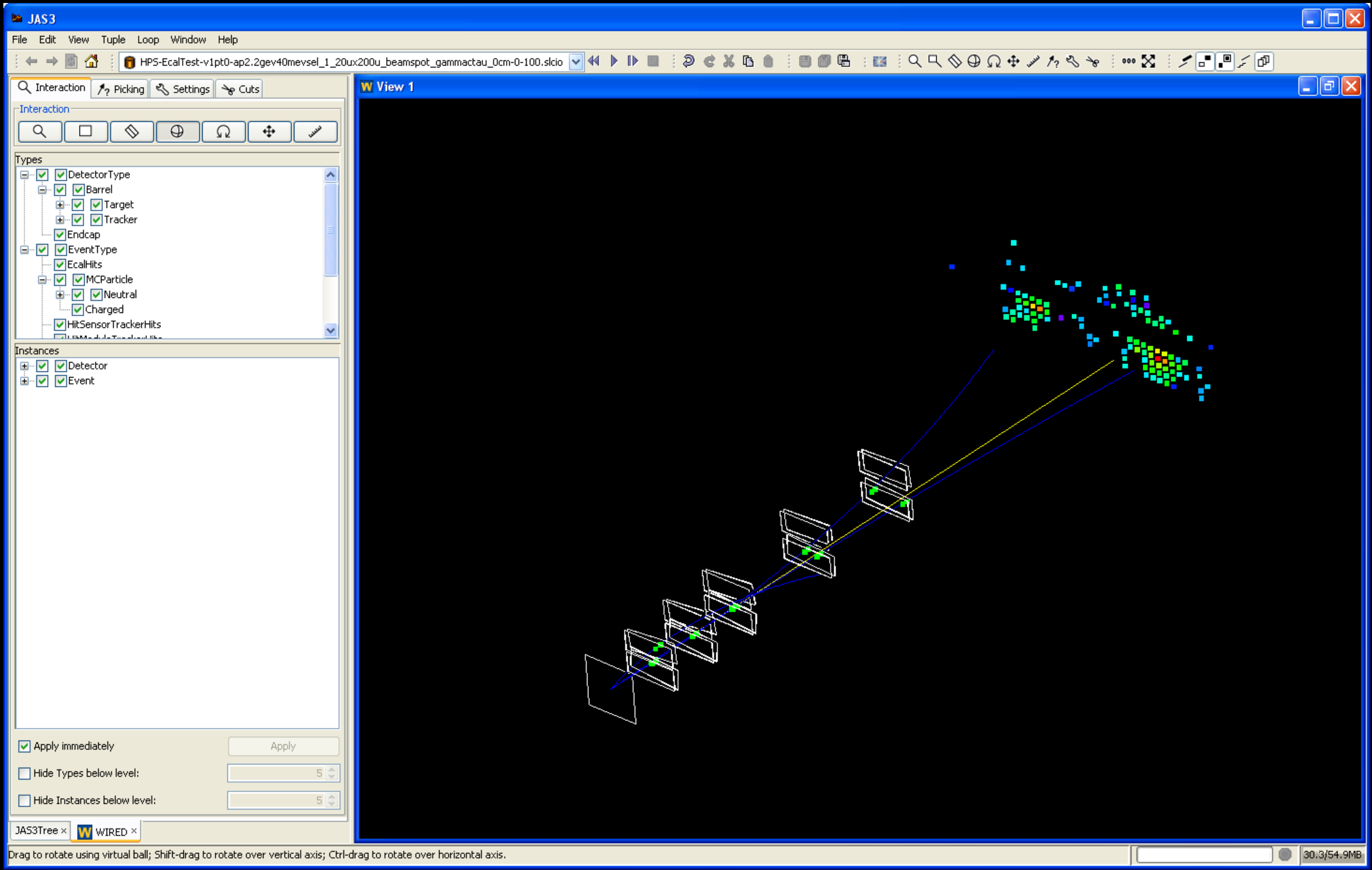
JAS event browser



JAS histogramming/ fitting



Wired Event Display



Using root

- Can analyze output AIDA files using RAIDA.
  - non-official root binding to AIDA
- Can analyze output LCIO files two ways:
  - Using root LCIO Dictionary
  - Using rlcio files, LCIO event data model written as root files
    - output files are larger
    - read times are longer
- Roll your own
  - write out native root files yourself.

User base

- ILC physics and detector community
  - primarily Silicon Detector Concept
- CLIC physics and detector community
  - CERN-based SiD’ studies
- MuC physics and detector community
  - FNAL-based
- FNAL dual-readout crystal calorimetry R&D group

Summary

- Only touched on slic and org.lcsim.
- Other tools are also available
  - GEMC, for instance, has impressive capabilities
  - see talks by Maurizio, Maurik, et al.
- Very useful Software Intensive Meeting held earlier this week.
  - Tutorial presented
  - Useful discussions
  - Preliminary task lists emerging
- Still a lot of work to do, but off to a good start.
  - See remaining talks this afternoon

Additional Information

- Wiki - https://confluence.slac.stanford.edu/display/hpsg/Heavy+Photon+Search+Experiment
- lcsim.org - http://www.lcsim.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