

*Simulation and data  
reconstruction framework  
slic & lcsim*

Norman Graf, Jeremy McCormick  
SLAC  
HPS Collaboration Meeting  
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# *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



ALCPG

SiD

ECFA-LC

LDC

ACFA-LC

GLD

slic

org.lcsim

Java

MOKKA

MarlinReco

C++

JUPITER

Satellites

root

# *LCIO*

A world map with a blue background and light green landmasses. Three yellow rectangular boxes are overlaid on the map, each containing red text. The first box is over North America, the second over Europe and Africa, and the third over Asia and Australia.

ALCPG

SiD

ECFA-LC

LDC

ACFA-LC

GLD

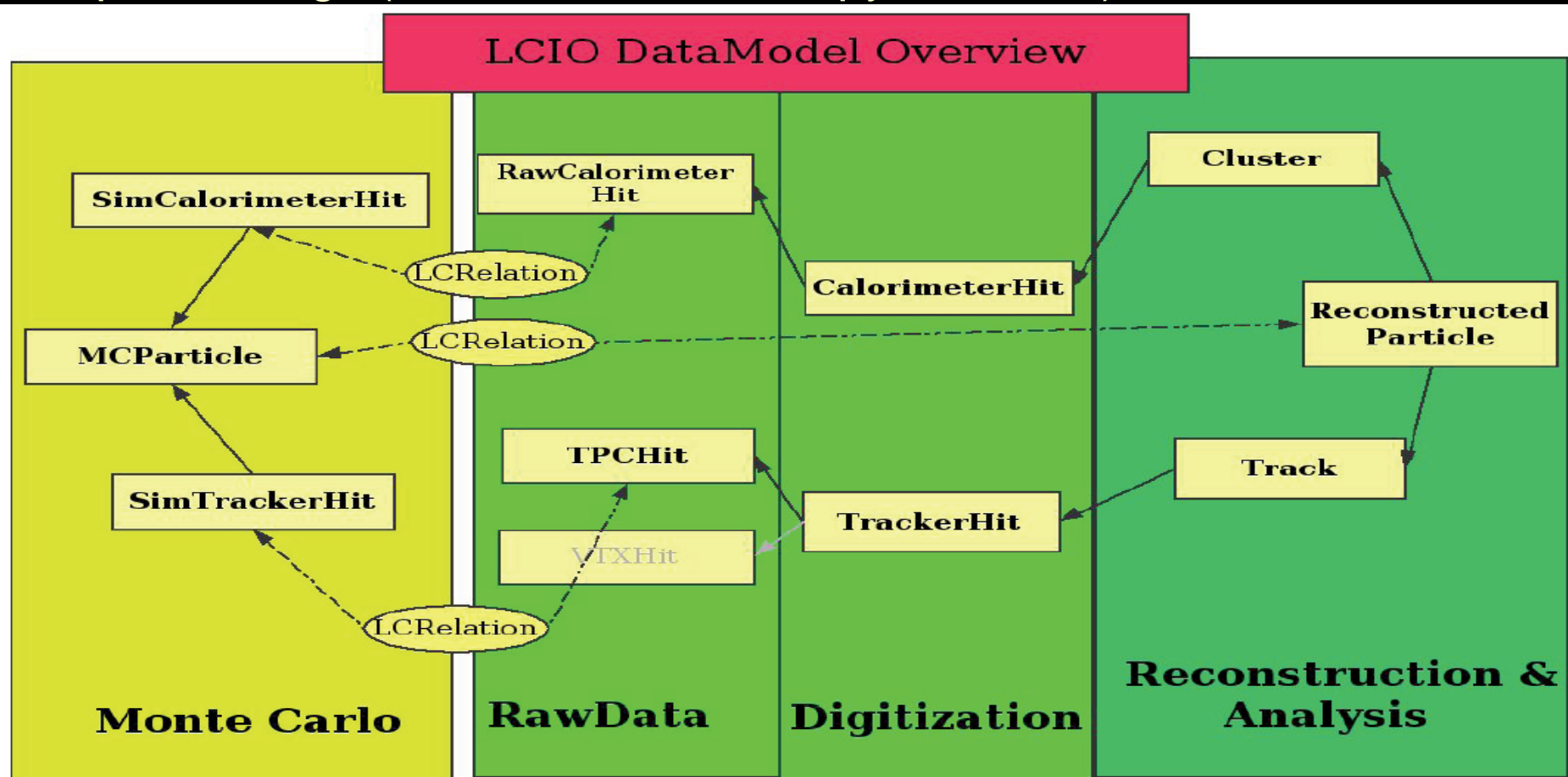
## **LCIO**

Common Data Model

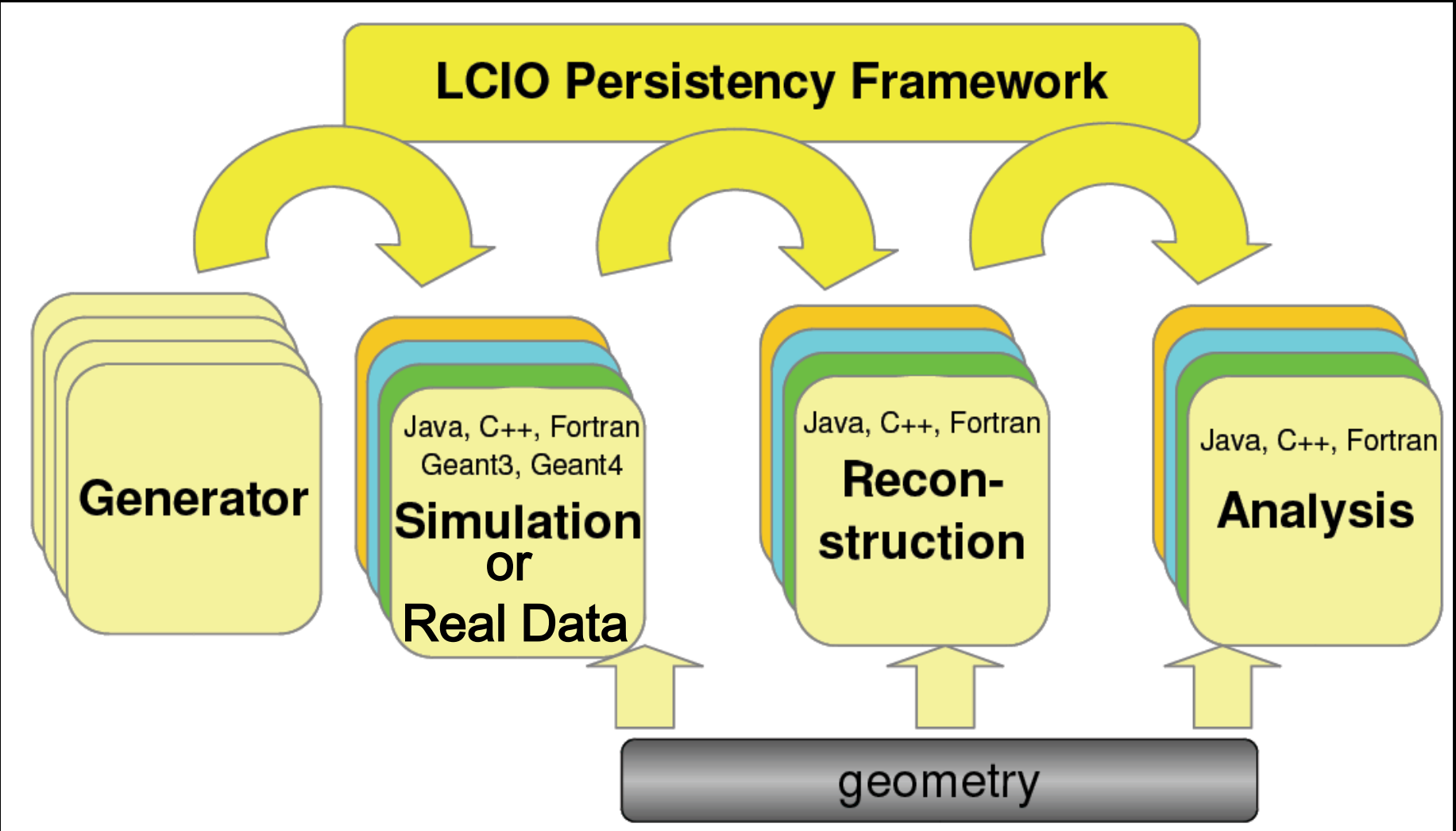
Common IO Format

# 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.

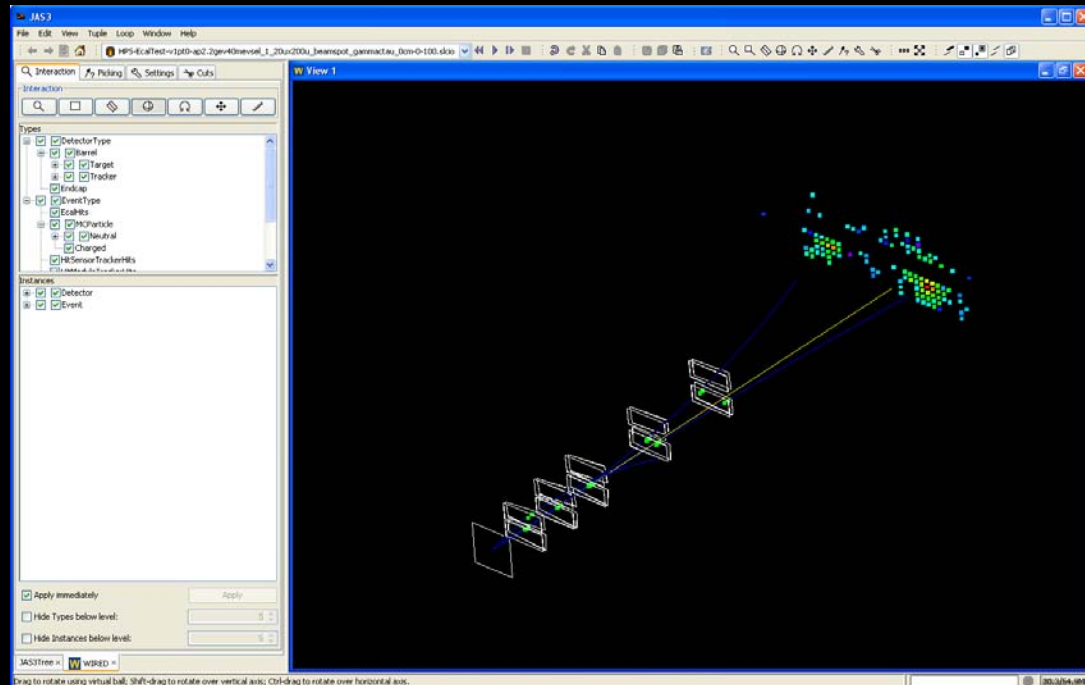
The screenshot shows the JAS interface with the following components:

- Left Panel (JAS Tree):** A hierarchical tree view showing the event structure. The selected event is Event 179, which is a Run0 event.
- Center Panel (LCIO Event Header):** A detailed view of the selected event (Event 179). It shows the event's name, time stamp, detector name, and a list of collections with their names, types, and sizes.
- Bottom Panel (Table):** A table displaying the event data. The table has columns for event ID, system, layer, barrel, x, y, raw energy, collected energy, and time. The data is sorted by event ID.

Event	System	Layer	Barrel	x	y	Raw Energy	Collected Energy	Time (ns)
0	EcalBarHits	0	2	77	304	1.0653E-4	0.004204	1065.0
1	EcalBarHits	0	2	77	304	1.1771E-4	0.002868	271.25
2	EcalBarHits	0	2	77	305	1.0897E-4	0.005871	271.25
3	EcalBarHits	0	2	77	306	1.2495E-4	0.01008	271.25
4	EcalBarHits	0	2	77	306	4.6335E-5	0.030550	271.25
5	EcalBarHits	0	2	77	307	1.3163E-4	0.005883	271.25
6	EcalBarHits	0	2	77	307	3.8268E-4	0.28614	292.25
7	EcalBarHits	0	2	77	308	2.0871E-5	0.011465	309.25
8	EcalBarHits	0	2	77	309	1.4120E-5	0.011147	194.25
9	EcalBarHits	0	2	77	309	8.8875E-4	0.70119	271.25
10	EcalBarHits	0	2	78	299	3.4449E-4	0.27332	287.25
11	EcalBarHits	0	2	83	313	5.7790E-4	0.53483	227.25

# 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.

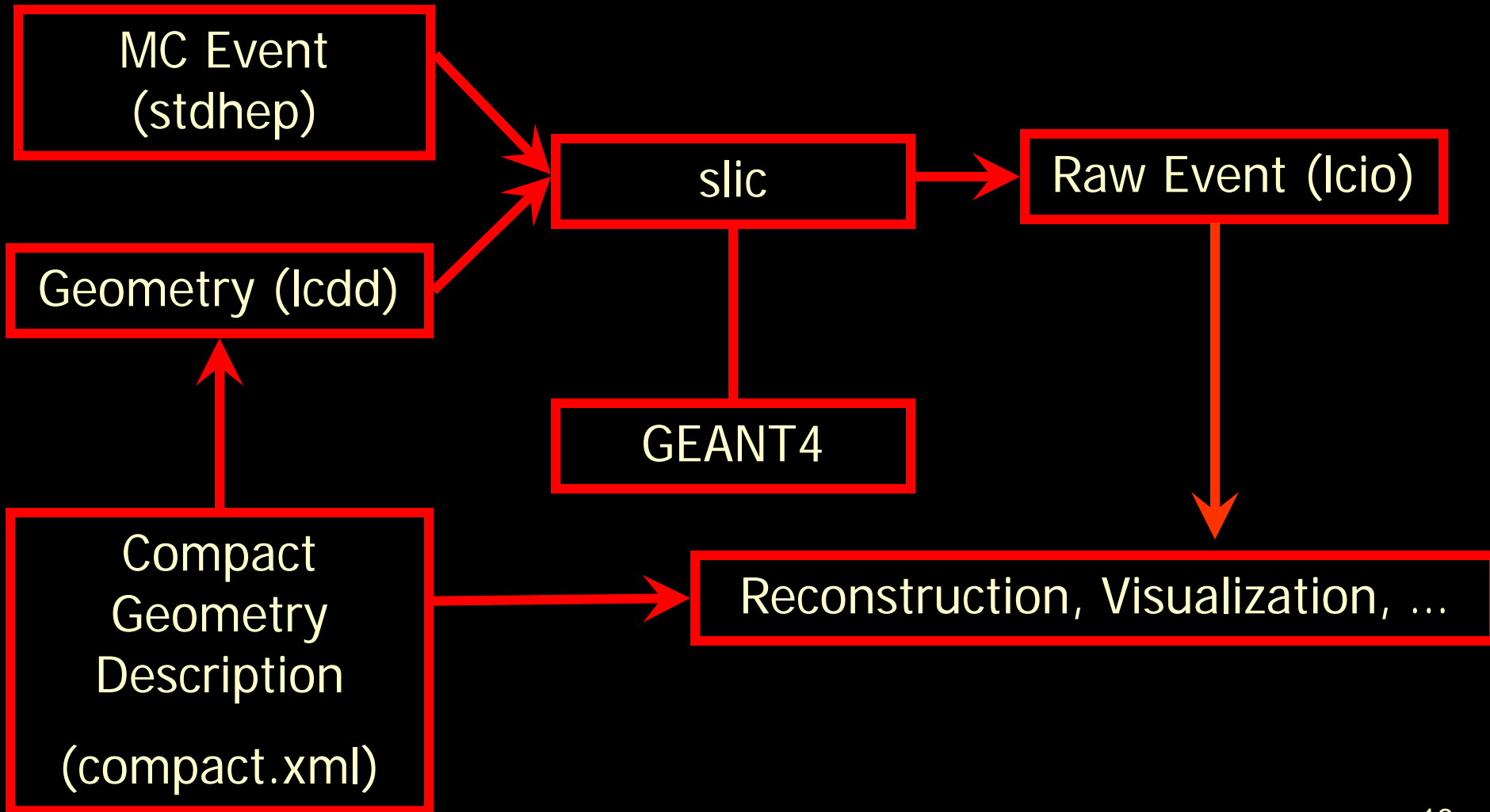
# *Full Detector Response Simulation*

- 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*



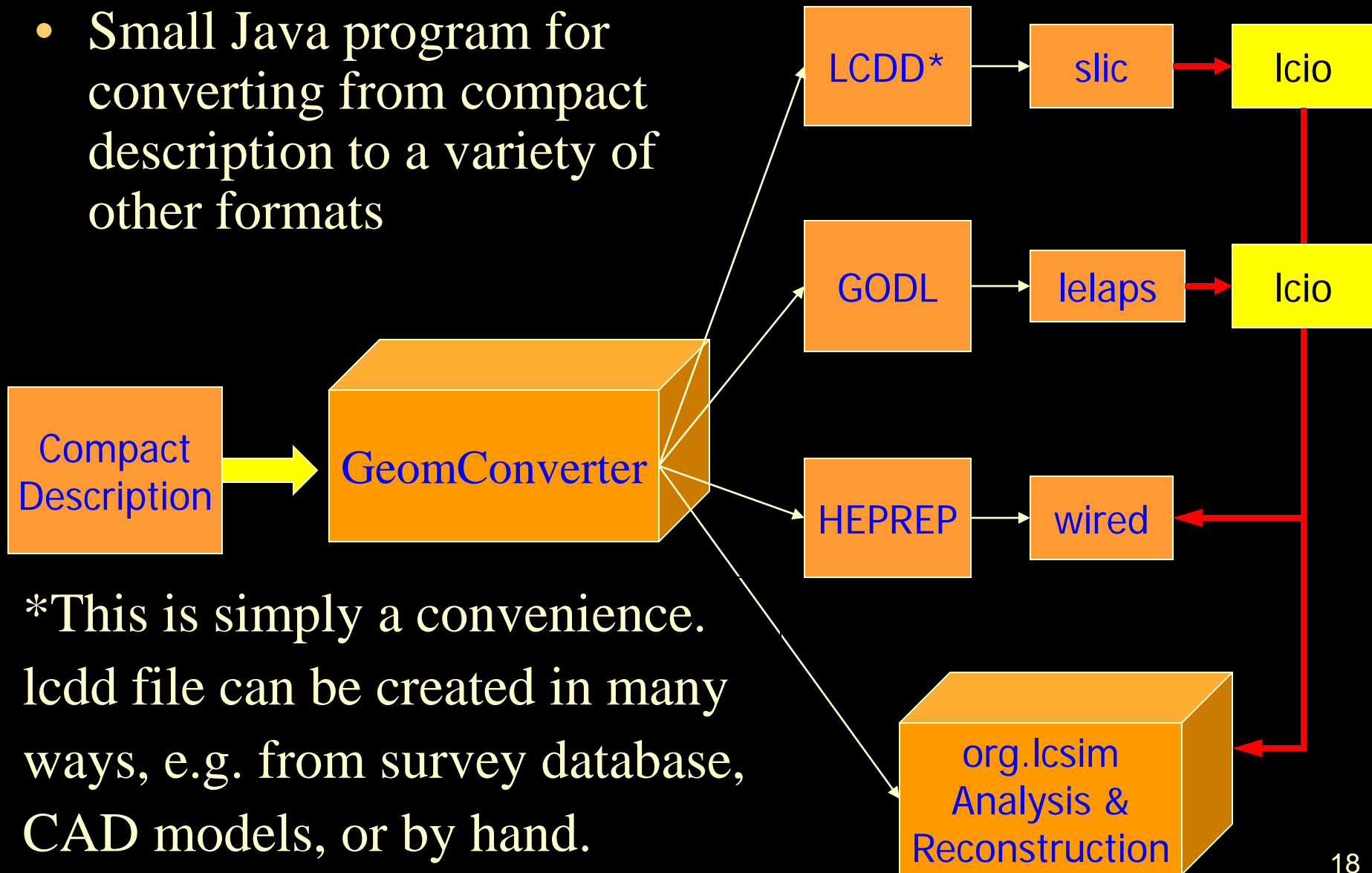


## *slic: The Executable*

- 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



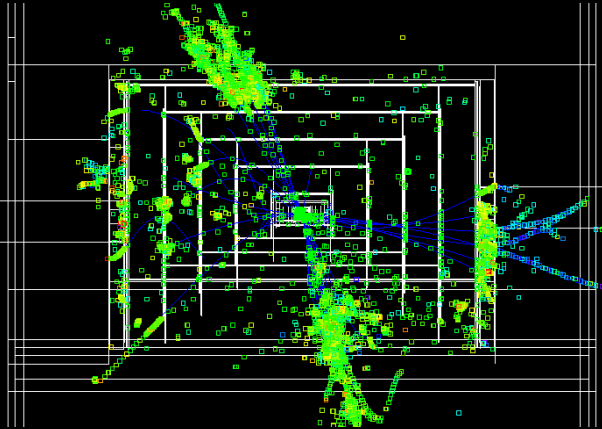
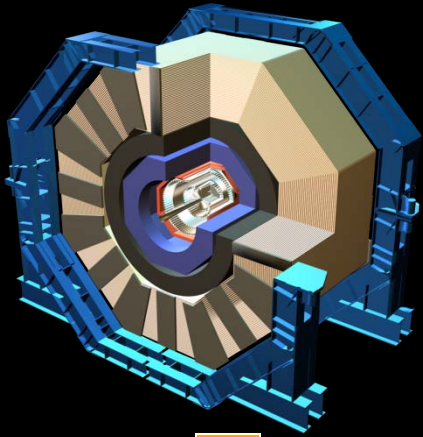
\*This is simply a convenience. Icdd file can be created in many ways, e.g. from survey database, CAD models, or by hand.

# *Detector Variants*

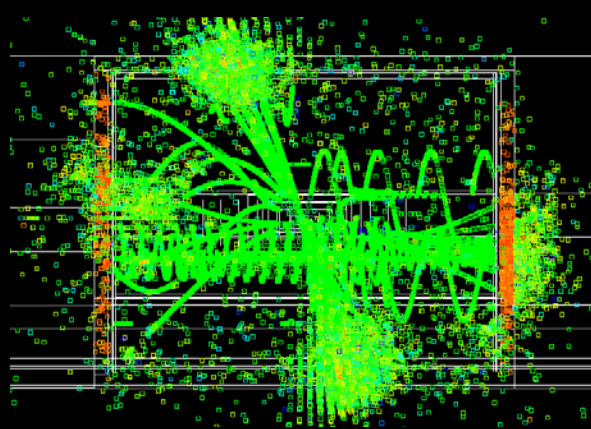
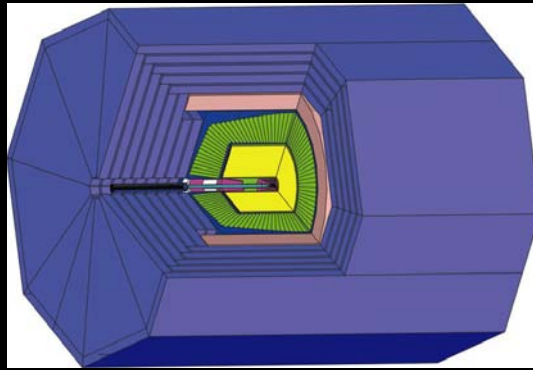
- Runtime XML format allows variations in detector geometries to be easily set up and studied:
  - Absorber materials and readout technologies for sampling calorimeters
    - e.g. Steel, W, Cu, Pb + RPC vs. GEM vs. Scintillator readout
  - Optical processes for dual-readout or crystal calorimeters
  - 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*

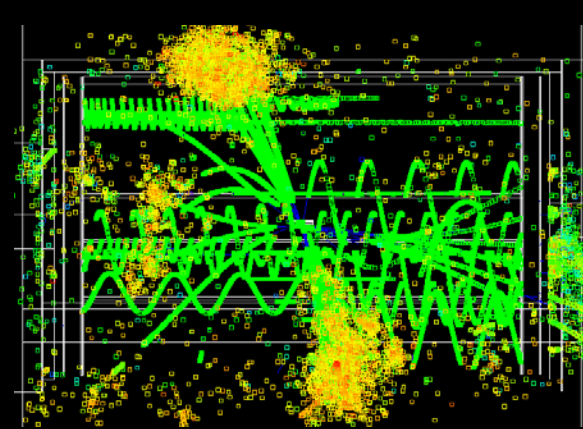
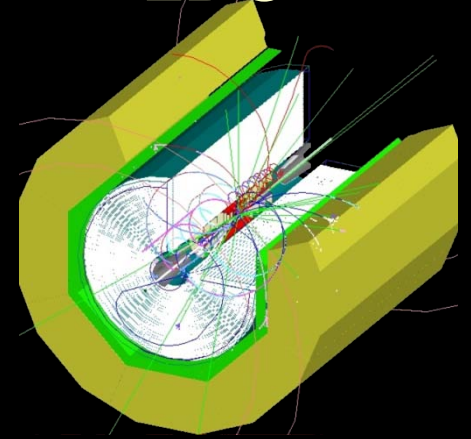
SiD



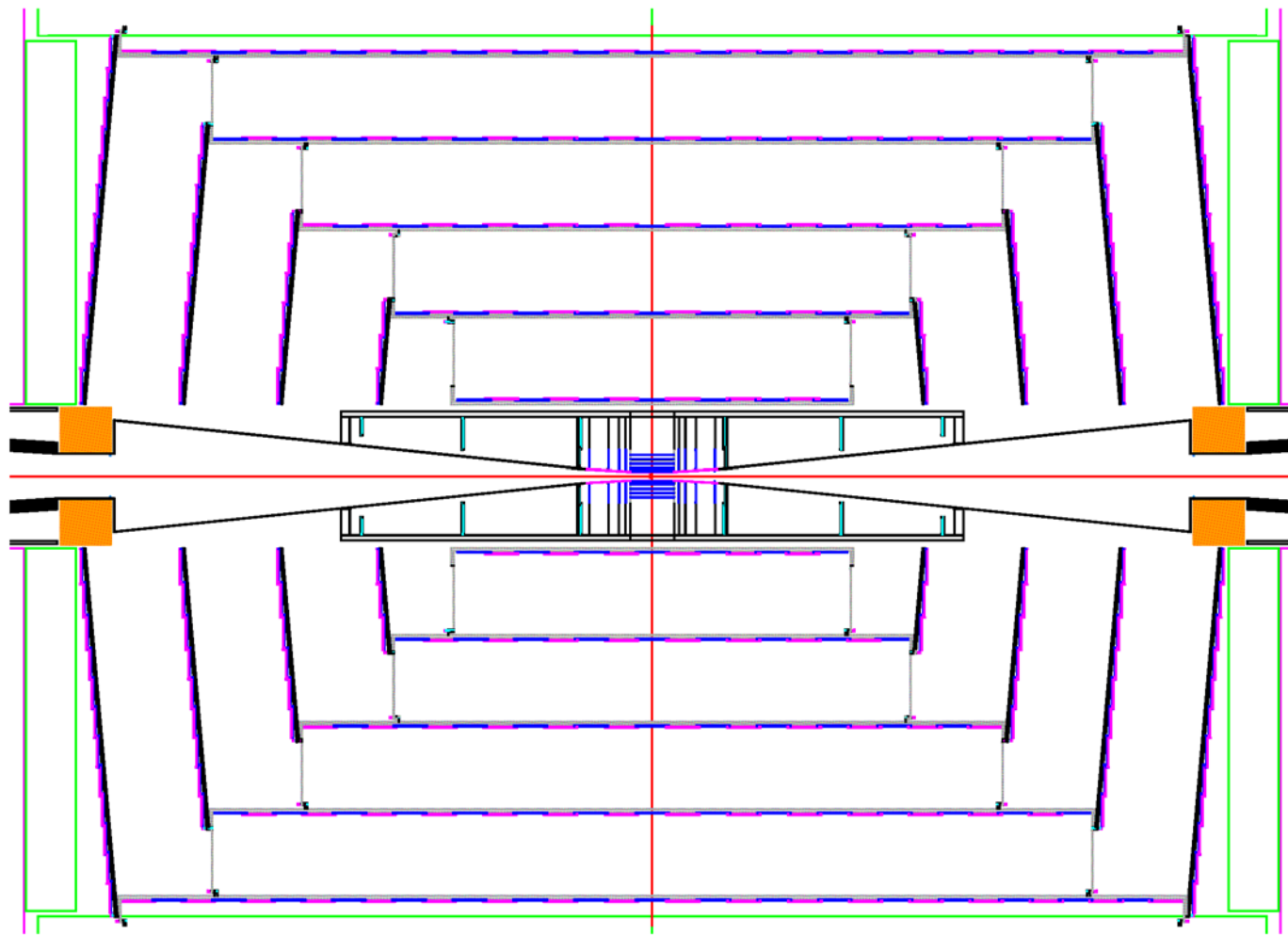
GLD



LDC

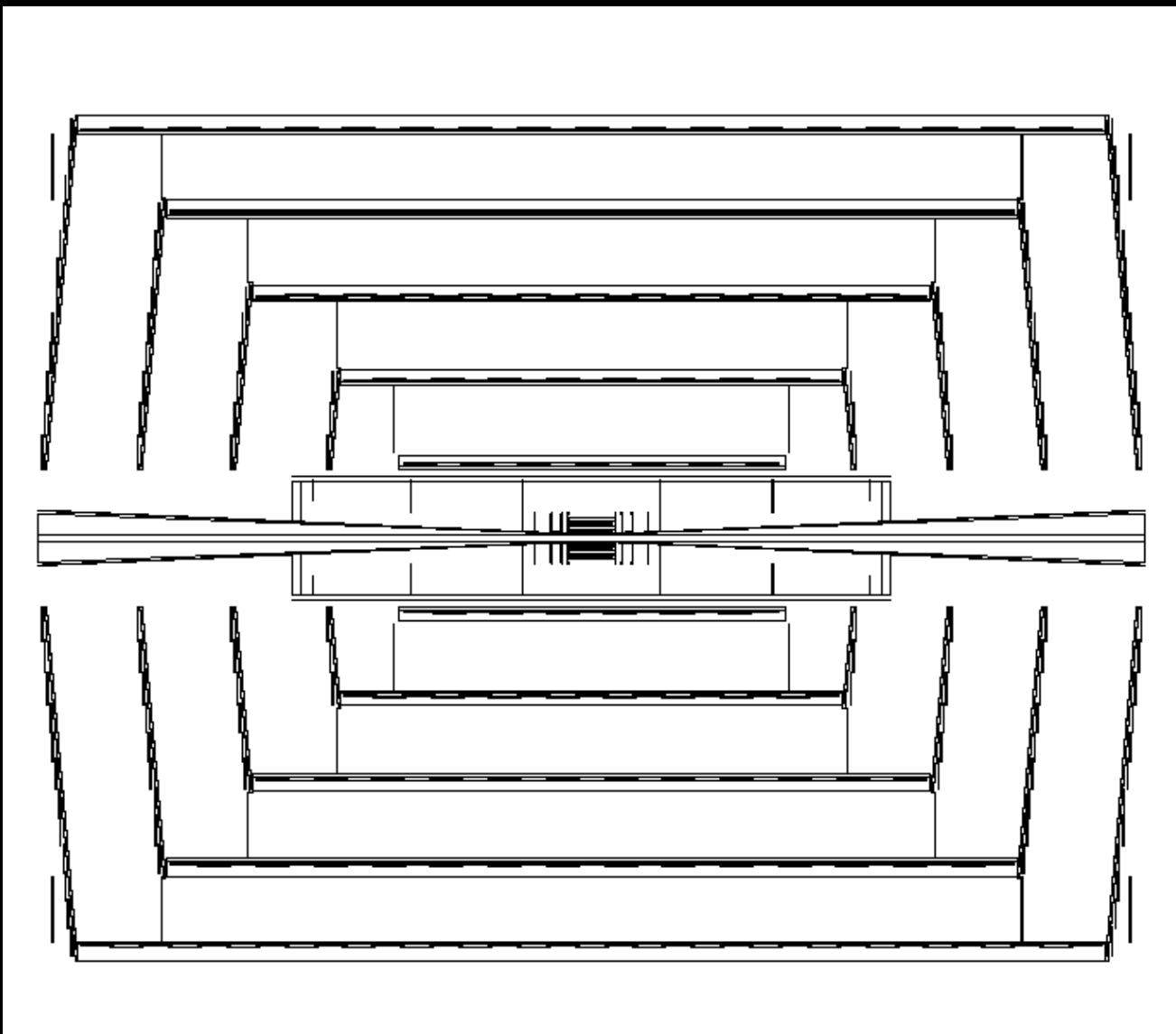


# *Silicon Detector Tracker*



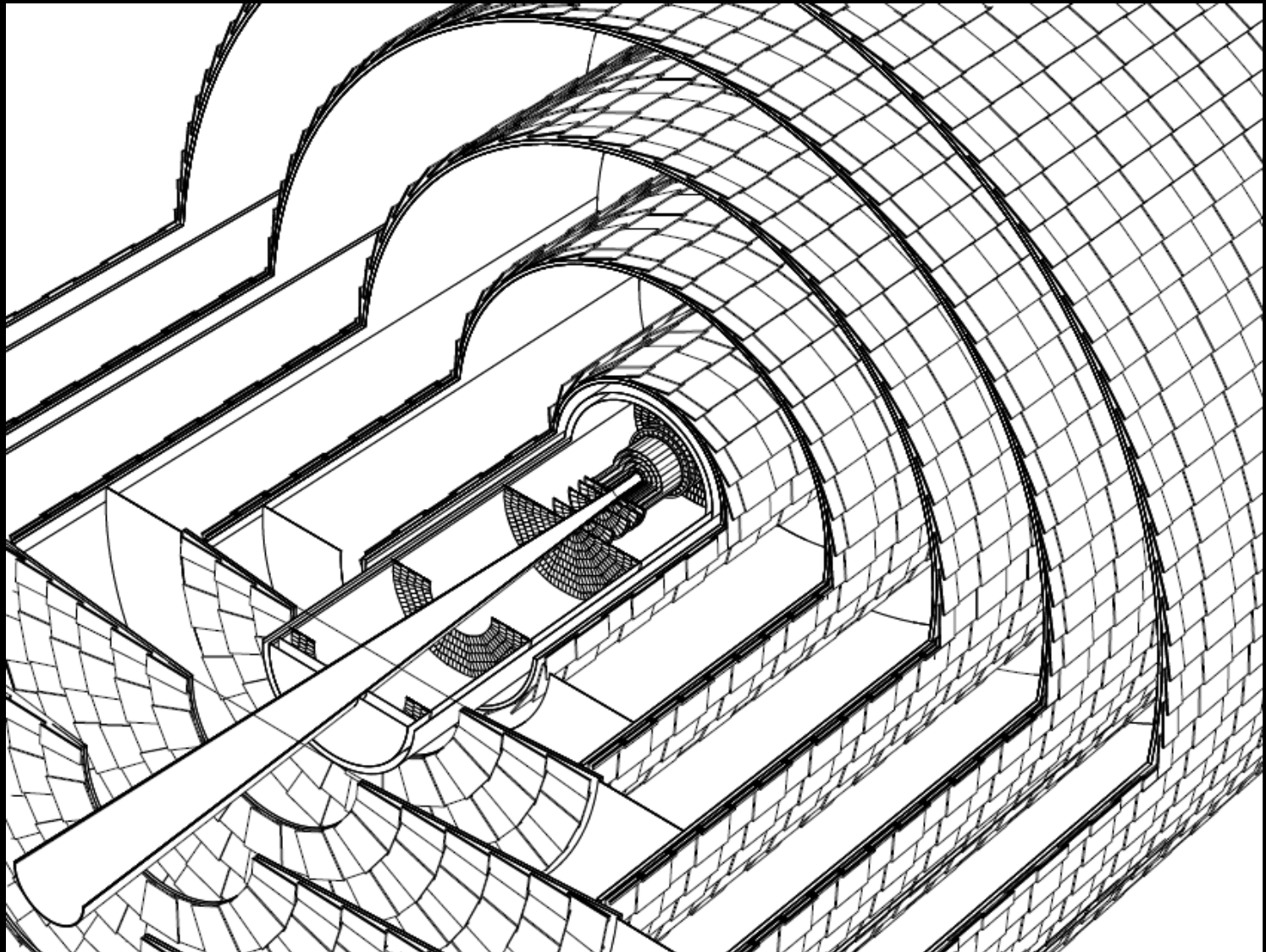
CAD Drawing

# *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.

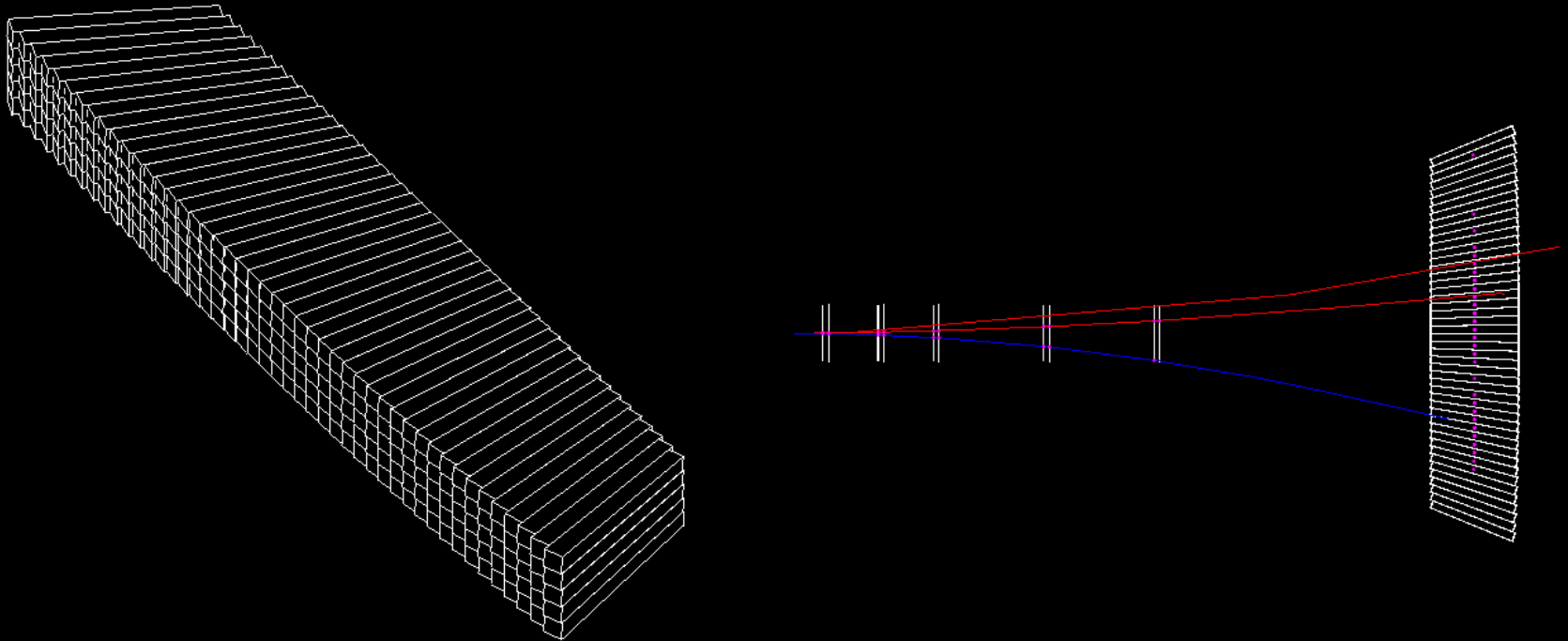
MC Hits → Channel ID & Pulse Height → Clusters → Hits ( $x \pm \delta x$ )  
Response specific to the APV25 readout chip needs to be implemented.

- See talks by Matt for details.



# *Simulating the HPS ECal*

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



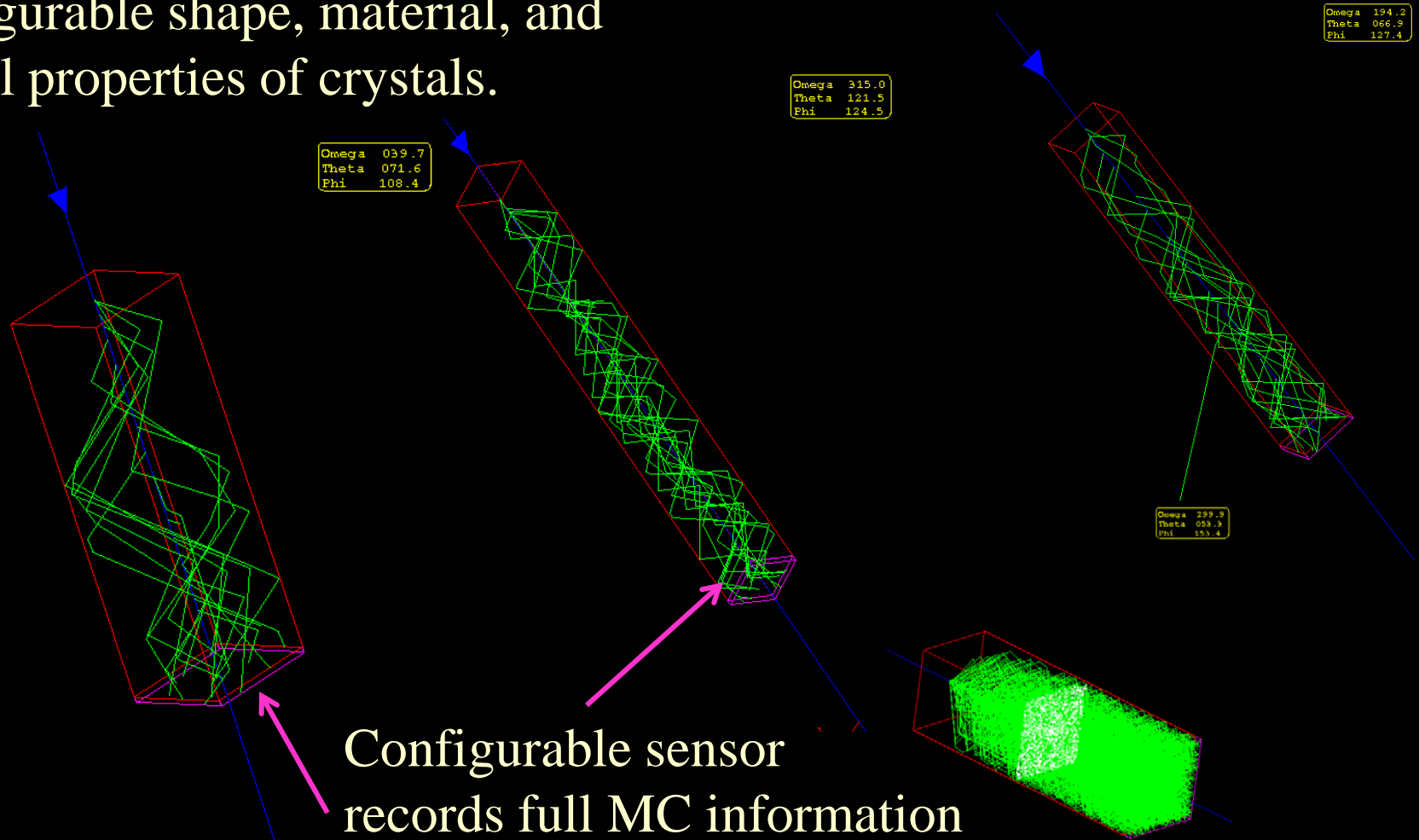
- Some additional work needed to fully support shapes in reconstruction.

# *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

# *Simulating the HPS ECal Response*

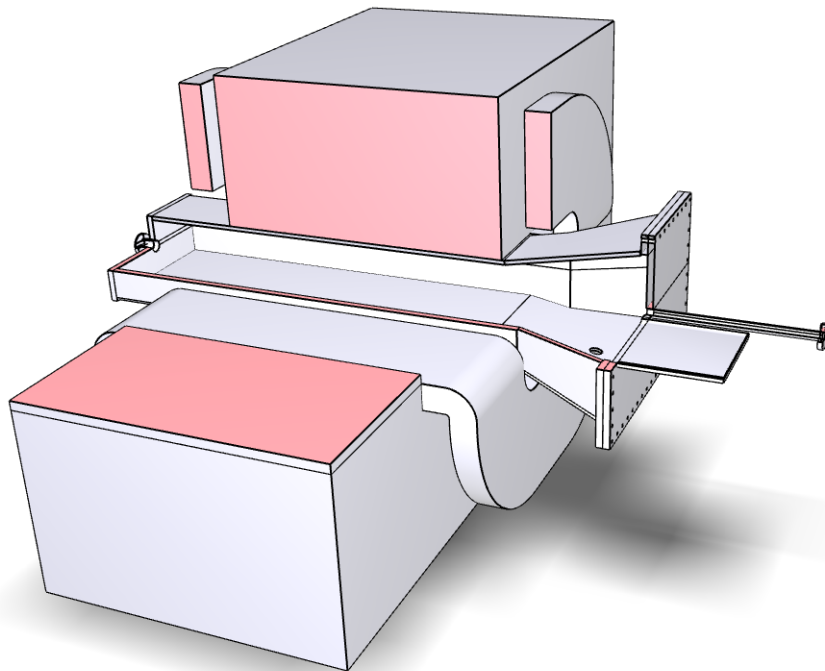
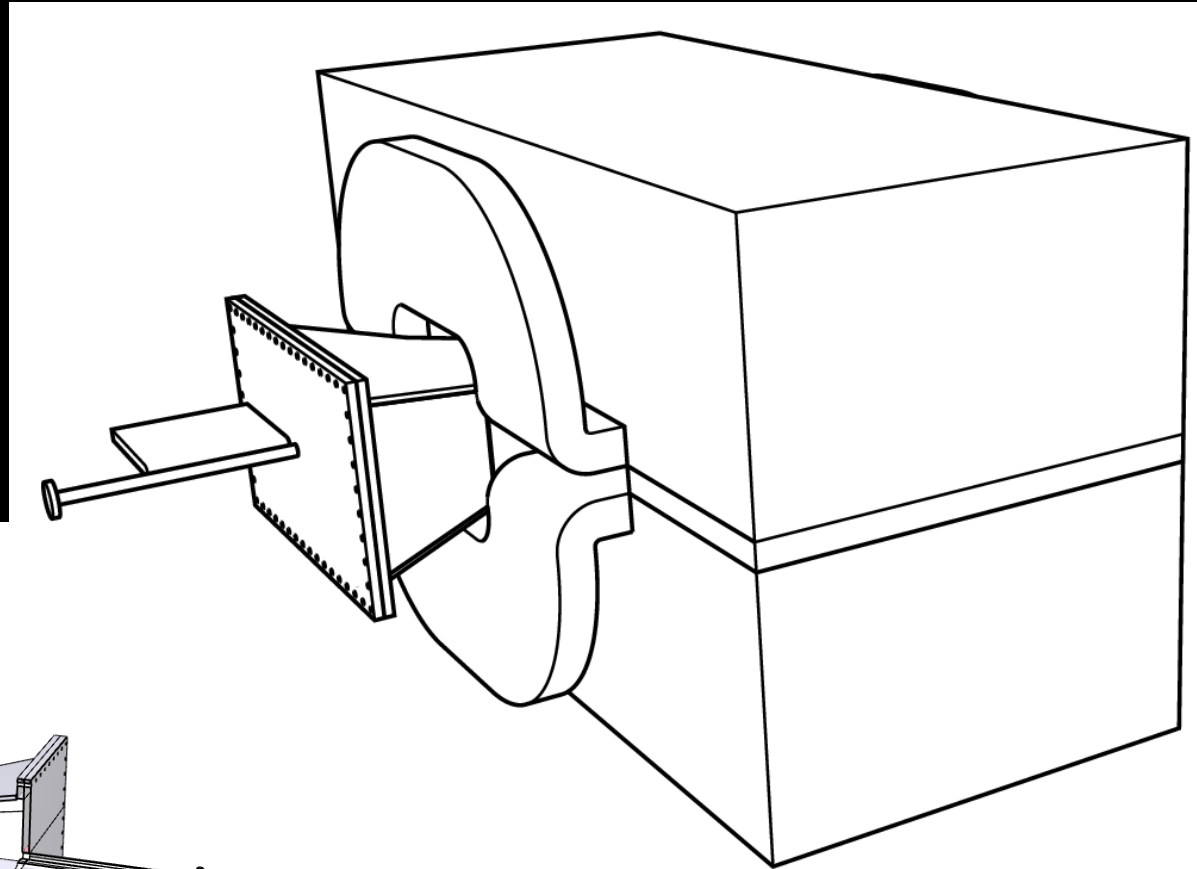
- LCIO / org.lcsim fully support event overlays with arbitrary time-offsets for signals.
- Work needed to transform delta-function MC energy depositions to signal waveform to FADC trace.
- Additional work will be needed to simulate FPGA processing of resulting signals.

# *HPS Dipole and Vacuum Vessel*

- CAD Model from Marco Oriunno
- Conversion to GDML by N. Graf
  - Resulting geometry is tessellated 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

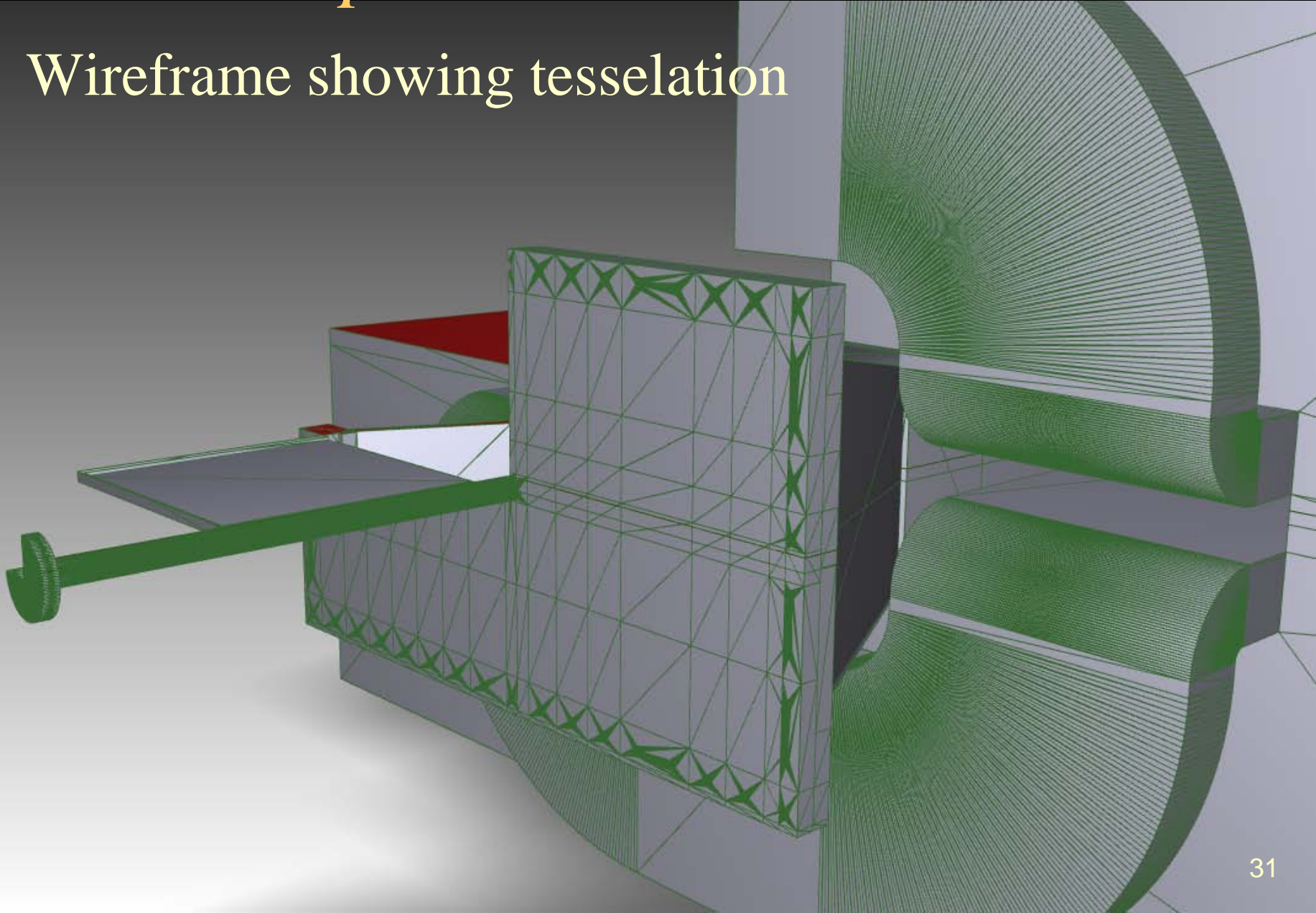
# *HPS Dipole and Vacuum Vessel*

- Images from geometry output from slic.



# *HPS Dipole and Vacuum Vessel*

- Wireframe showing tessellation



# *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

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 tree with "DataSets" and "Programs" folders, and a sub-folder "CombinedConeClusterAnalysisDriver". The central pane shows the source code for "CombinedConeClusterAnalysisDriver.java". The code includes a class definition and a process method that iterates over calorimeter hits and clusters them. The right pane shows a plot of calorimeter hits, with green and yellow squares representing hits and white lines representing clusters. The status bar at the bottom shows "9:23:33 PM ----- compile successful" and "Analyzed 1 records in 190ms".

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

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

pythia2Polebbar-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

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 (...)	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	-1690.9	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

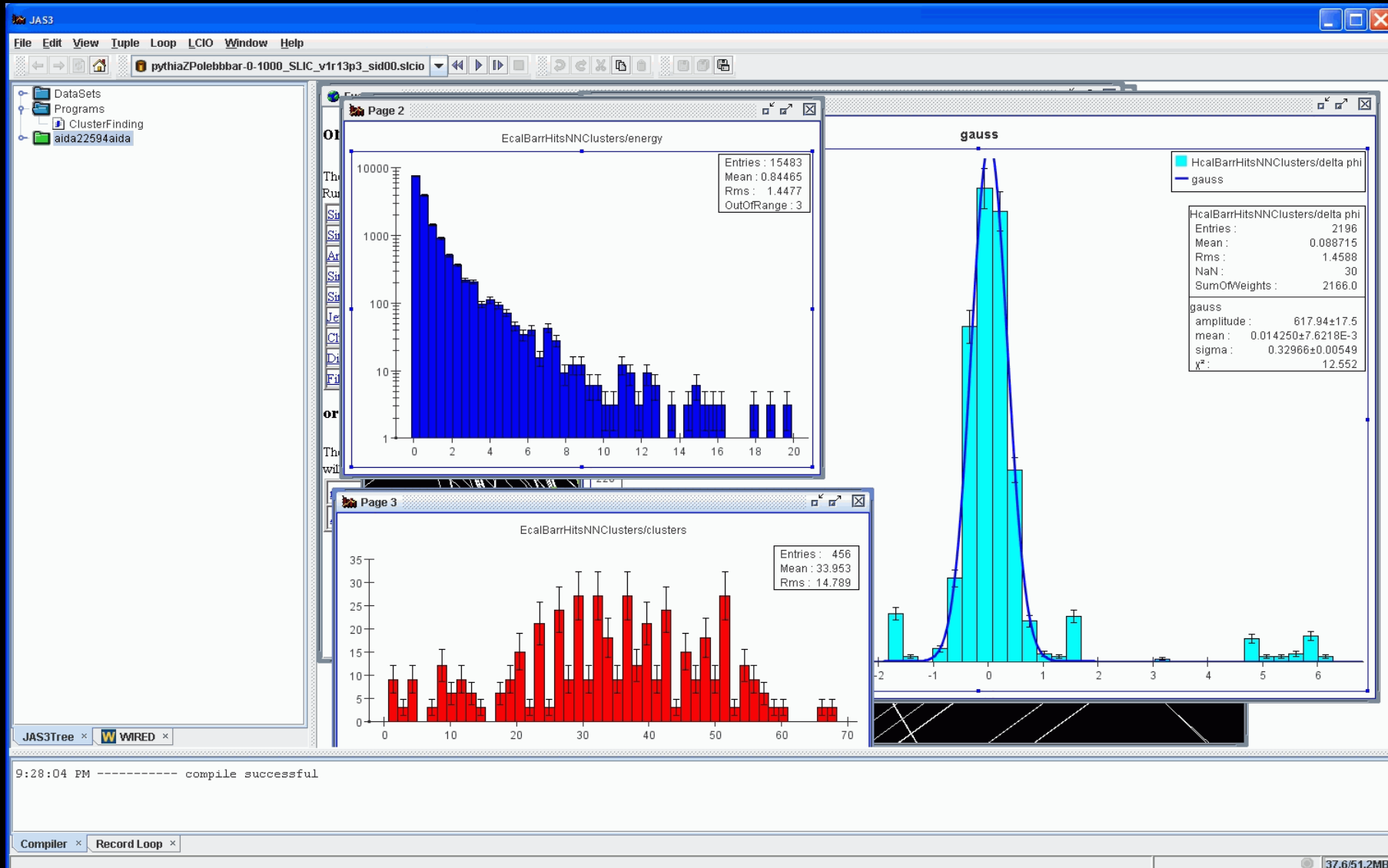
9:28:04 PM ----- compile successful

Compiler x Record Loop x

Analyzed 151 records in 114485ms

38.4/51.2MB

# JAS histogramming/fitting



# Wired Event Display

The screenshot displays the JAS3 software interface. The main window is titled "JAS3" and contains a menu bar (File, Edit, View, Tuple, Loop, Window, Help) and a toolbar. The left-hand panel is divided into several sections:

- Interaction:** Contains search and navigation icons.
- Types:** A tree view showing detector components and event types. Checked items include: DetectorType, Barrel, Target, Tracker, Endcap, EventType, EcalHits, MCParticle, Neutral, Charged, HitSensorTrackerHits, and HitSensorTrackerHits.
- Instances:** A list of loaded instances, currently showing Detector and Event.
- Settings:** Includes an "Apply immediately" checkbox, an "Apply" button, and "Hide Types below level:" and "Hide Instances below level:" options with numeric input fields set to 5.

The main 3D view, titled "View 1", shows a perspective view of a particle detector. It features a series of detector layers (represented as rectangular planes) connected by lines, forming a structure that resembles a calorimeter or tracker. A cluster of colorful points (representing an event) is visible on the right side of the detector. The bottom status bar shows "JAS3Tree x W WIRED x" and "30.3/54.9MB".

Drag to rotate using virtual ball; Shift-drag to rotate over vertical axis; Ctrl-drag to rotate over horizontal axis.

# *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>