SiD CDR:
Simulation and Reconstruction

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Silicon Detector Workshop
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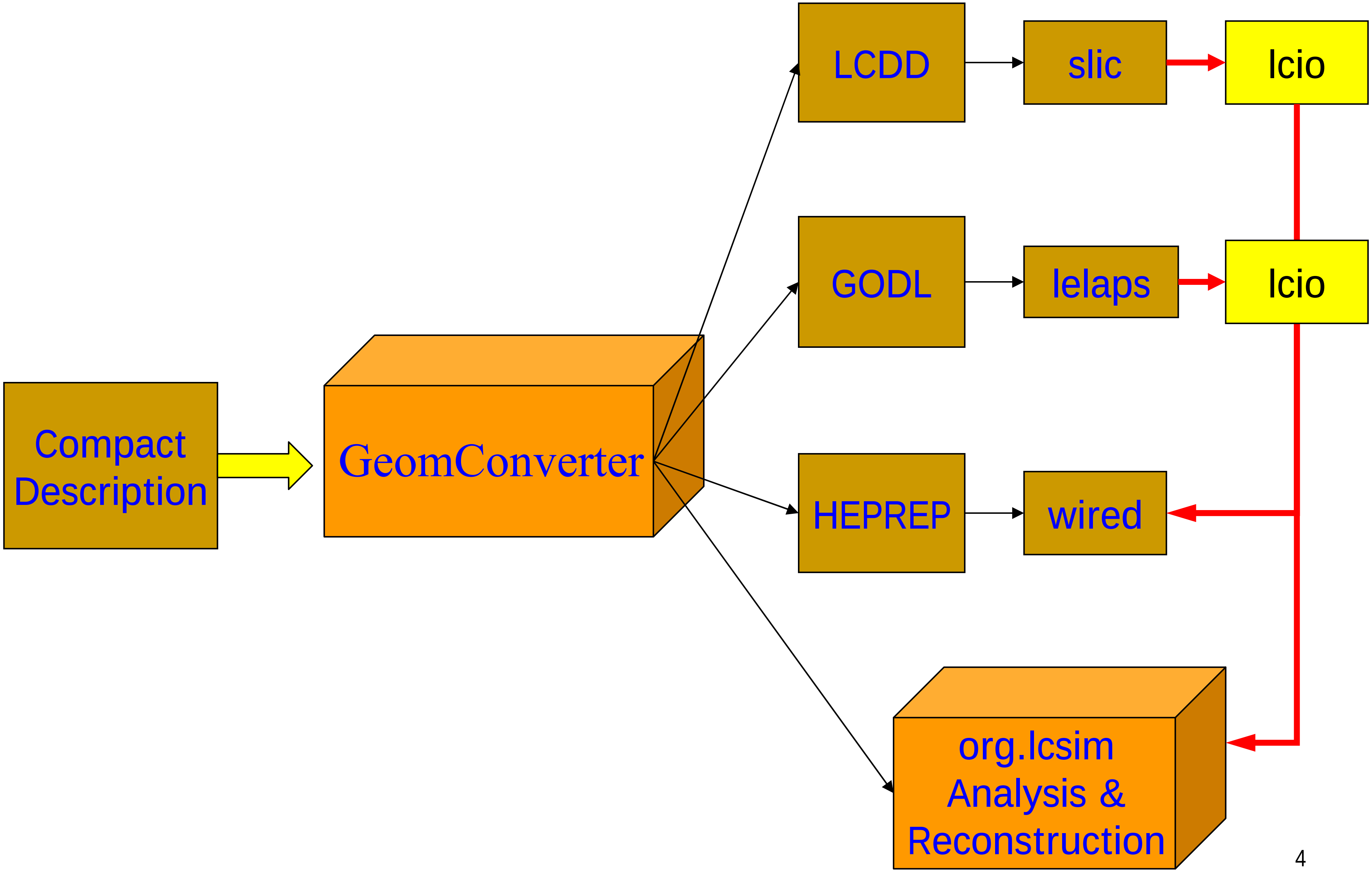
CDR Detector Simulations

- Need to clarify exactly what is required for the CDR and what is deferred to the TDR.
- However, generally agreed that the detector design should have some semblance to a detector which can be built.
  - e.g. no floating cylindrical calorimeters.
- Is the simulation infrastructure capable of modeling realistic detector geometries?
- Yes! The full simulation package slic reads in geometries in lcdd, which is a low-level format that targets Geant4 primitives.

CDR Detector Simulations

- However, it would be extremely tedious to generate these files.
- Would not provide a connection to the reconstruction, or to the event display.
- Prefer (but not required) to define geometries using a “compact” description.
- Small Java program for converting from compact description to a variety of other formats.
  - GeomConverter.

GeomConverter



Silicon Tracking Detectors

- For the purposes of quickly scanning the parameter space of number of tracking layers and their radial and z positioning, have been simulating the trackers as cylindrical shells or planar disks.
- Are now moving beyond this to be able to realistically simulate buildable subdetectors.
- Have always been able to simulate arbitrarily complex shapes in slic using lcdd, but this is a very verbose format.
- Have now introduced tilings of planar detectors (simulating silicon wafers) into the compact xml description.

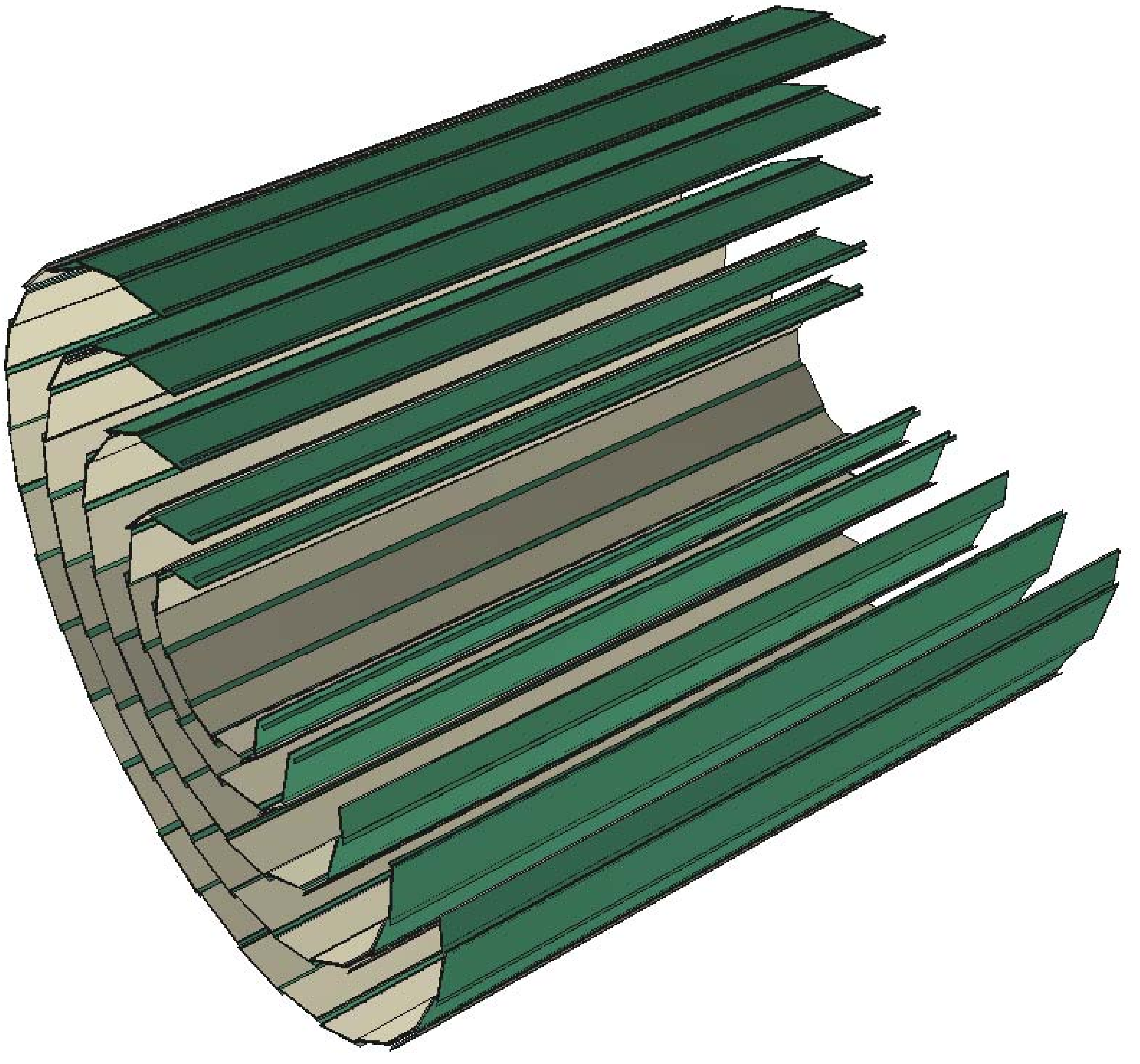
xml: Defining a Module

```
<module name="VtxBarrelModuleInner">
   <module_envelope width="9.8" length="63.0 * 2" thickness="0.6"/>
   <module_component width="7.6" length="125.0" thickness="0.26"
                              material="CarbonFiber" sensitive="false">
                           <position z="-0.08"/>
   </module_component>
   <module_component width="7.6" length="125.0" thickness="0.05"
                              material="Epoxy" sensitive="false">
                           <position z="0.075"/>
   </module_component>
   <module_component width="9.6" length="125.0" thickness="0.1"
                              material="Silicon" sensitive="true">
                           <position z="0.150"/>
   </module_component>
</module>
```

xml: Placing the modules

```
<layer module="VtxBarrelModuleInner" id="1">
        <barrel_envelope inner_r="13.0" outer_r="17.0" z_length="63 * 2"/>
        <rphi_layout phi_tilt="0.0" nphi="12" phi0="0.2618" rc="15.05" dr="-1.15"/>
        <z_layout dr="0.0" z0="0.0" nz="1"/>
</layer>
<layer module="VtxBarrelModuleOuter" id="2">
        <barrel_envelope inner_r="21.0" outer_r="25.0" z_length="63 * 2"/>
        <rphi_layout phi_tilt="0.0" nphi="12" phi0="0.2618" rc="23.03" dr="-1.13"/>
        <z_layout dr="0.0" z0="0.0" nz="1"/>
</layer>
<layer module="VtxBarrelModuleOuter" id="3">
        <barrel_envelope inner_r="34.0" outer_r="38.0" z_length="63 * 2"/>
        <rphi_layout phi_tilt="0.0" nphi="18" phi0="0.0" rc="35.79" dr="-0.89"/>
        <z_layout dr="0.0" z0="0.0" nz="1"/>
</layer>
<layer module="VtxBarrelModuleOuter" id="4">
        <barrel_envelope inner_r="46.6" outer_r="50.6" z_length="63 * 2"/>
        <rphi_layout phi_tilt="0.0" nphi="24" phi0="0.1309" rc="47.5" dr="0.81"/>
        <z_layout dr="0.0" z0="0.0" nz="1"/>
</layer>
<layer module="VtxBarrelModuleOuter" id="5">
        <barrel_envelope inner_r="59.0" outer_r="63.0" z_length="63 * 2"/>
        <rphi_layout phi_tilt="0.0" nphi="30" phi0="0.0" rc="59.9" dr="0.77"/>
        <z_layout dr="0.0" z0="0.0" nz="1"/>
</layer>
```

The Barrel Vertex Detector

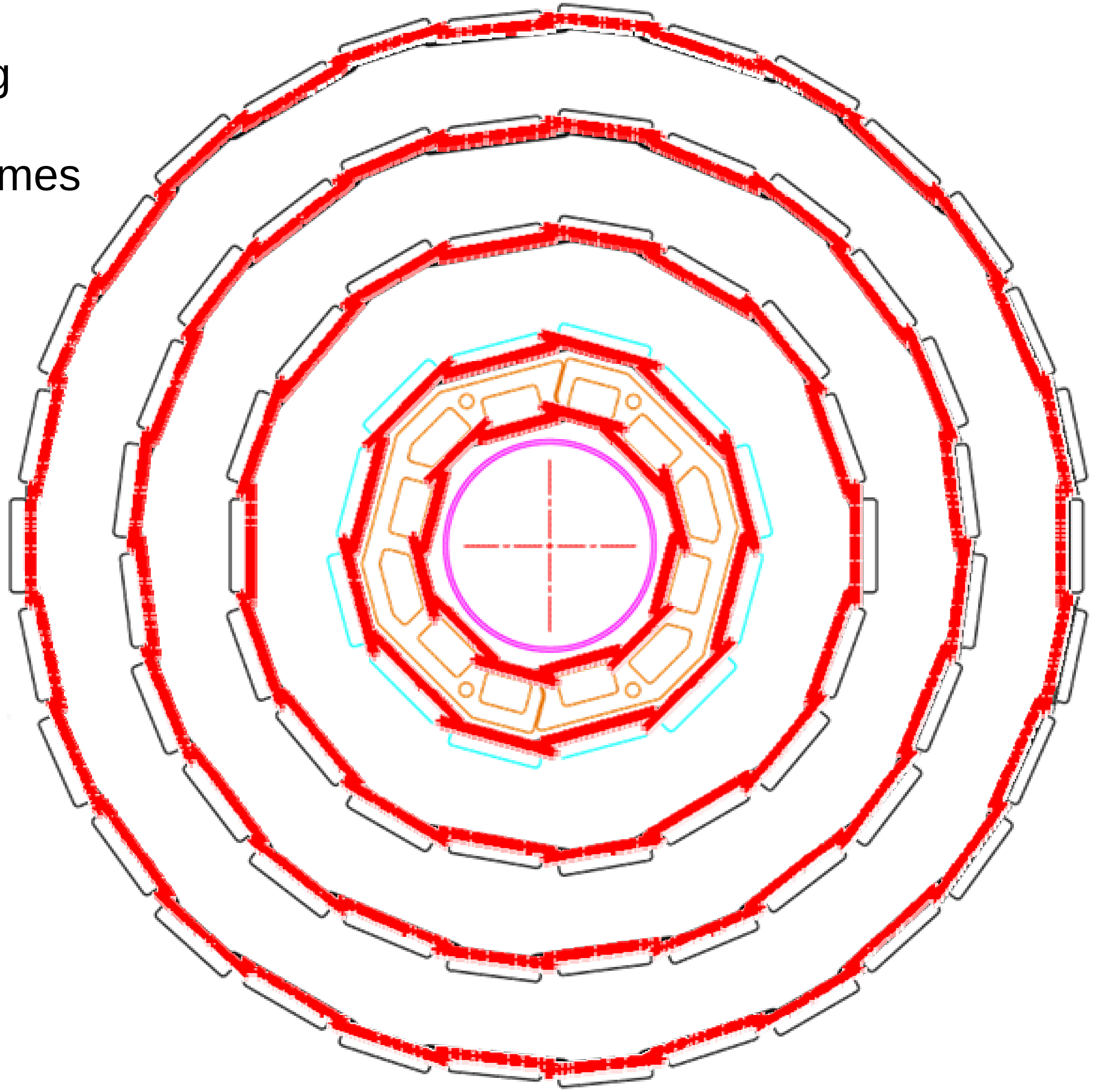


LCIO SimTracker Hits from Vertex

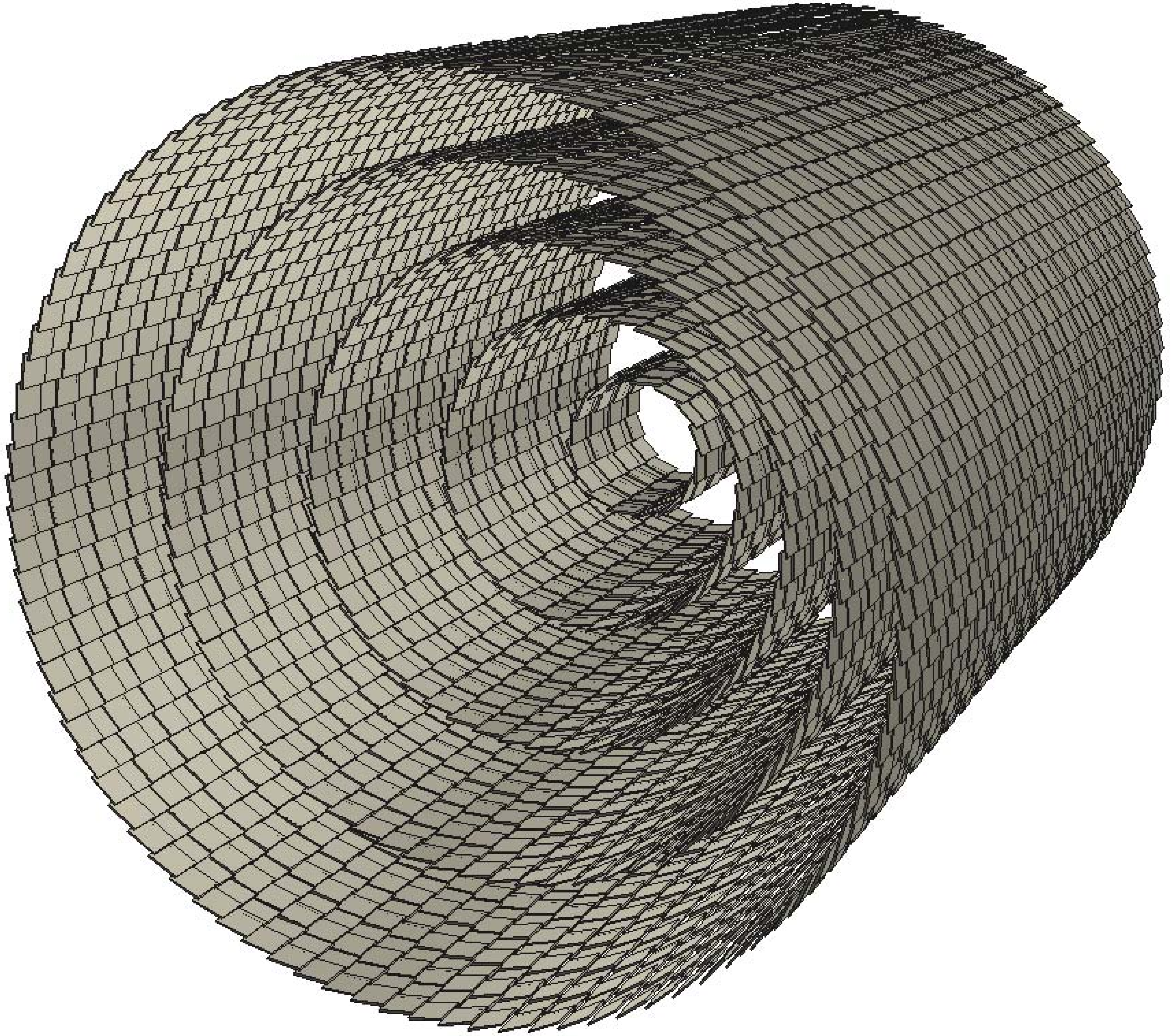
CAD Drawing

GEANT Volumes

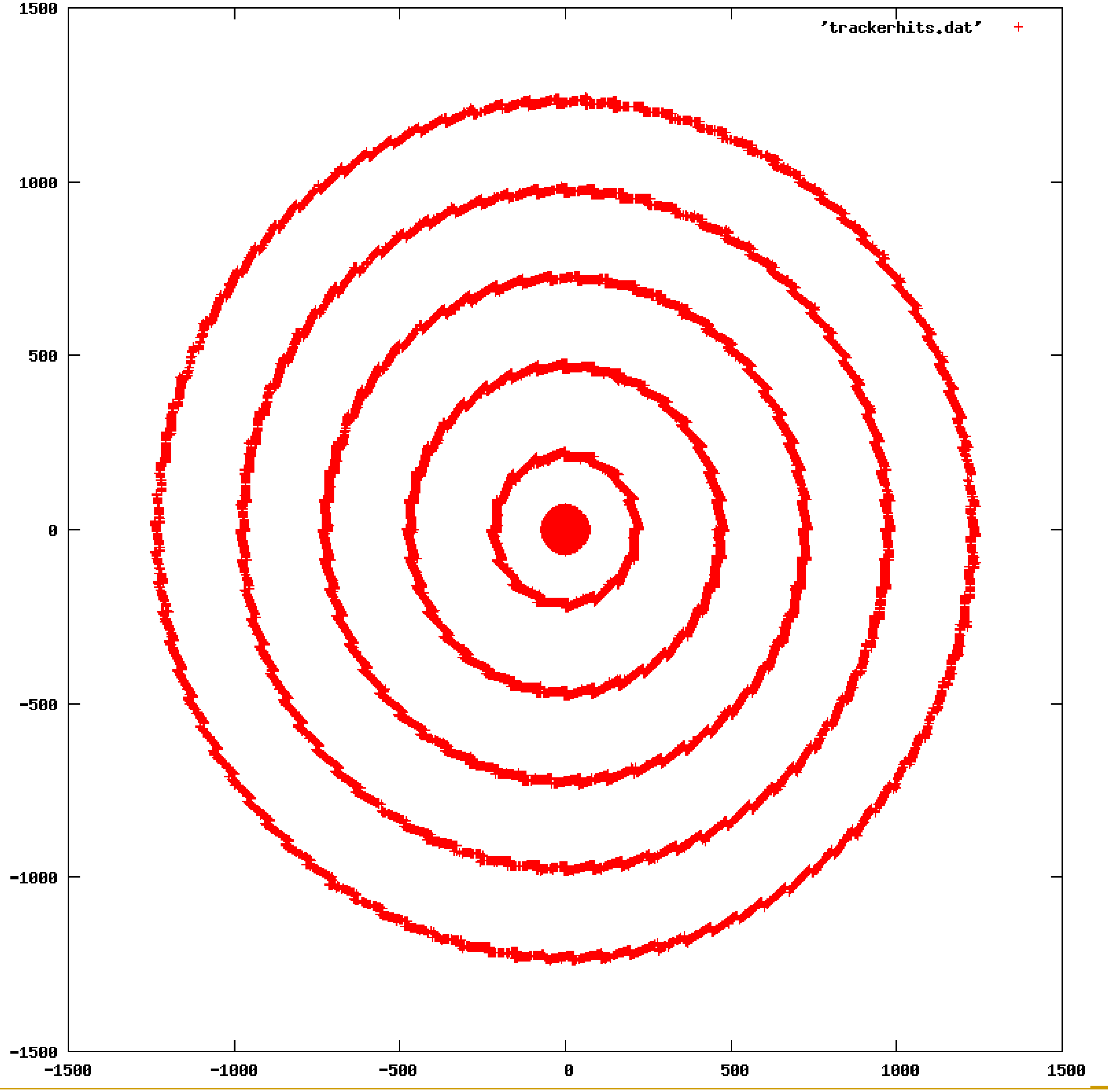
LCIO Hits



The Barrel Outer Tracker

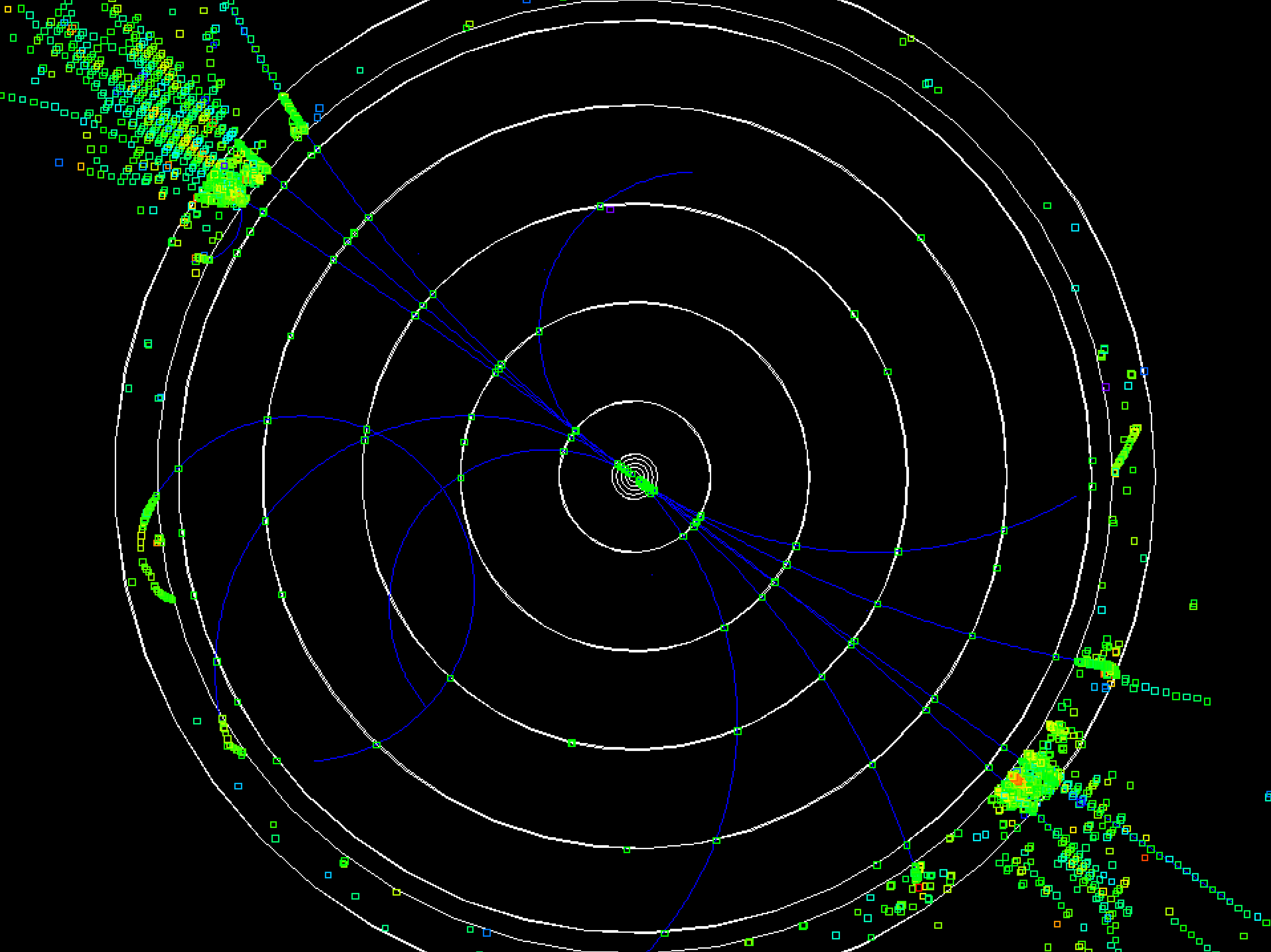


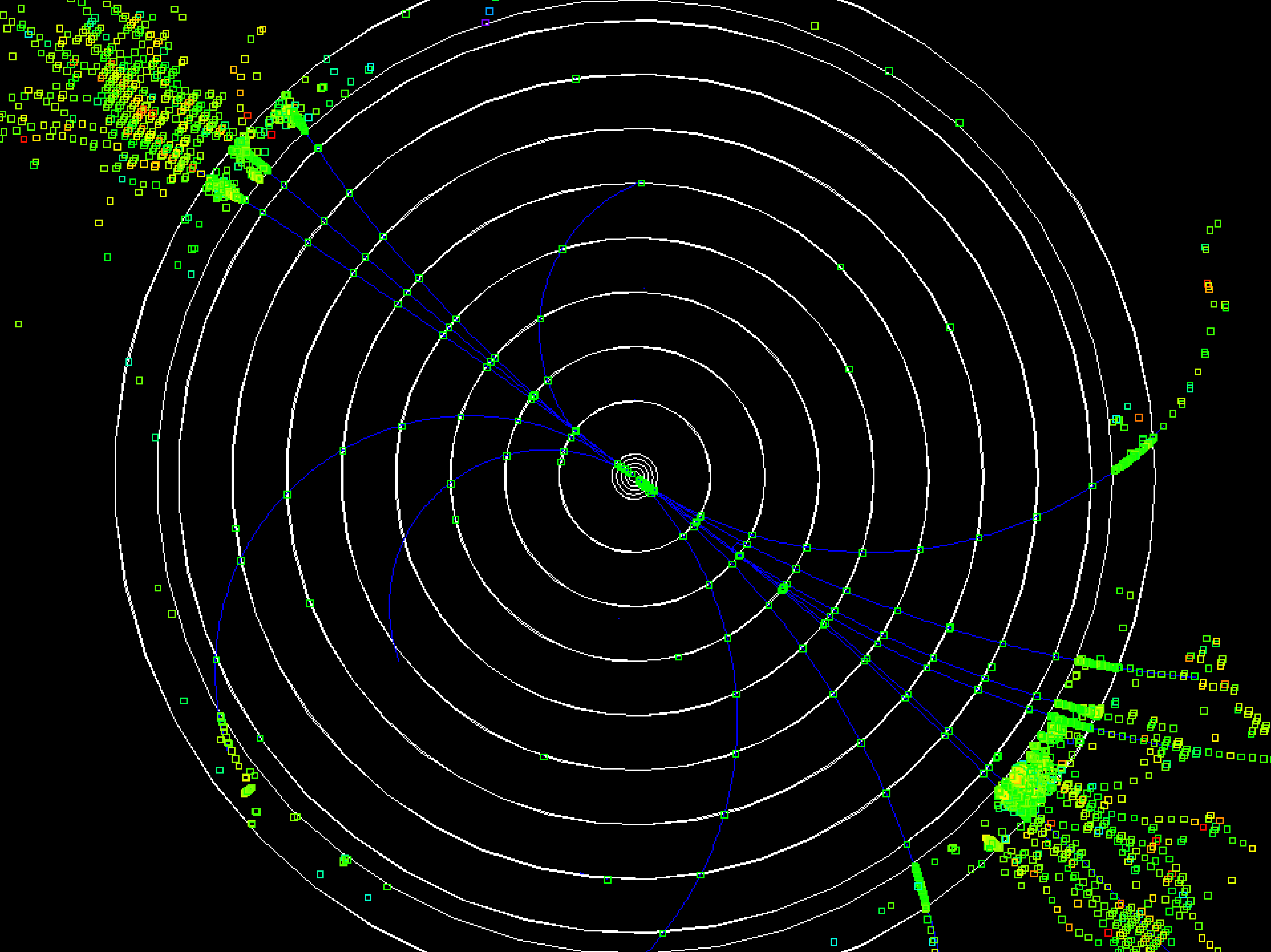
LCIO SimTracker Hits from Tracker



Big Picture Decisions

- There is still a need for people to investigate larger issues, such as the number and layout of tracker and vertex barrel and disk layers.
- This is most easily done with the simplified geometries.
- For example, changing from the 5-layer cylindrical barrel geometry to an 8-layer geometry took less than 15 minutes.
- The work lies in the analysis and comparisons.
- Looking forward to hearing back from Bruce & company at UCSC.

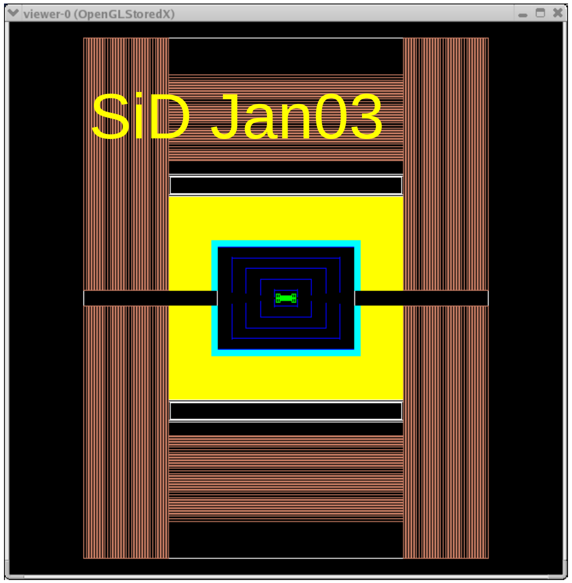


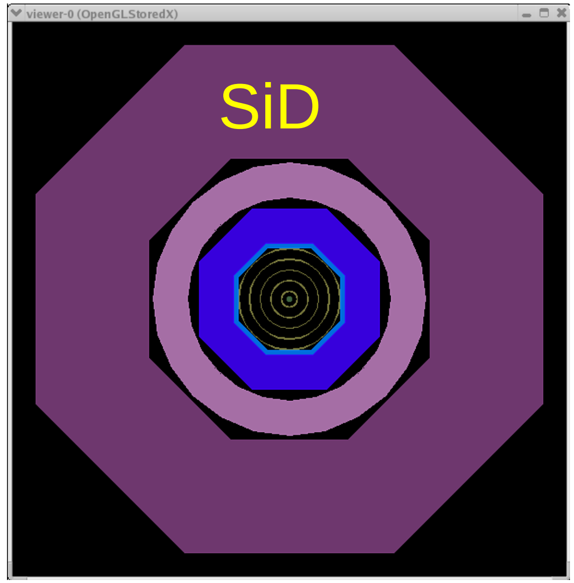


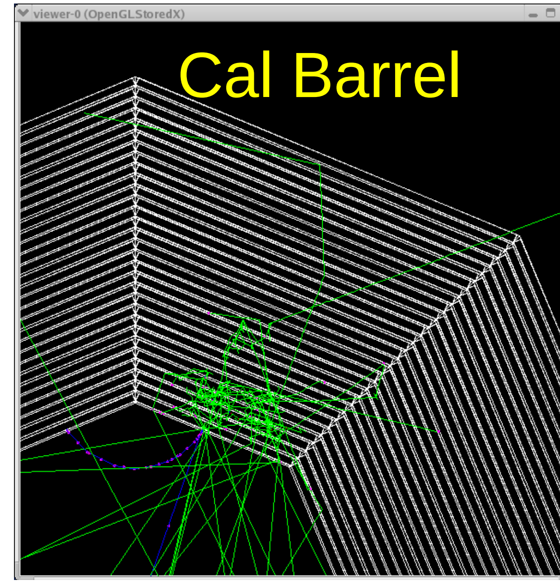
Detector Variants

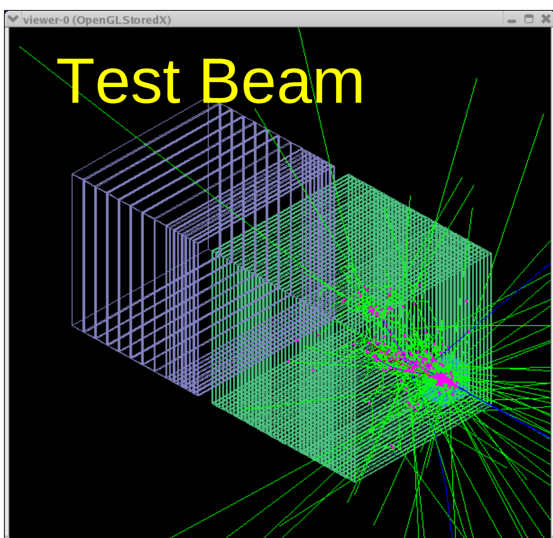
- Runtime XML format allows variations in detector geometries to be easily set up and studied:
  - Stainless Steel vs. Tungsten HCal sampling material
  - RPC vs. GEM vs. Scintillator readout
  - Layering (radii, number, composition)
  - Readout segmentation (size, projective vs. nonprojective)
  - Tracking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

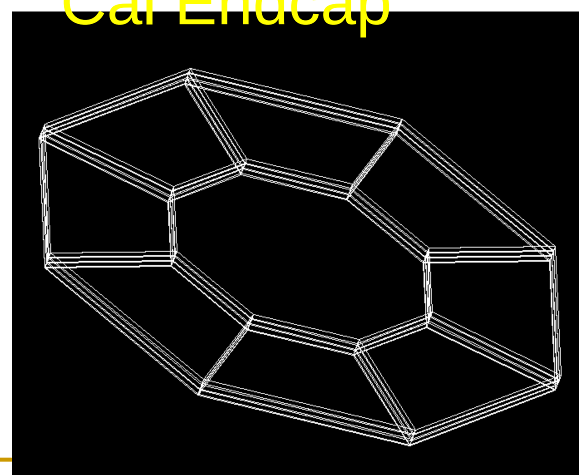




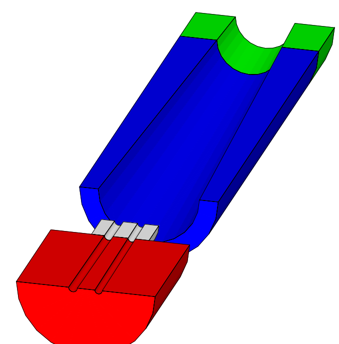




Cal Endcap



MDI-BDS



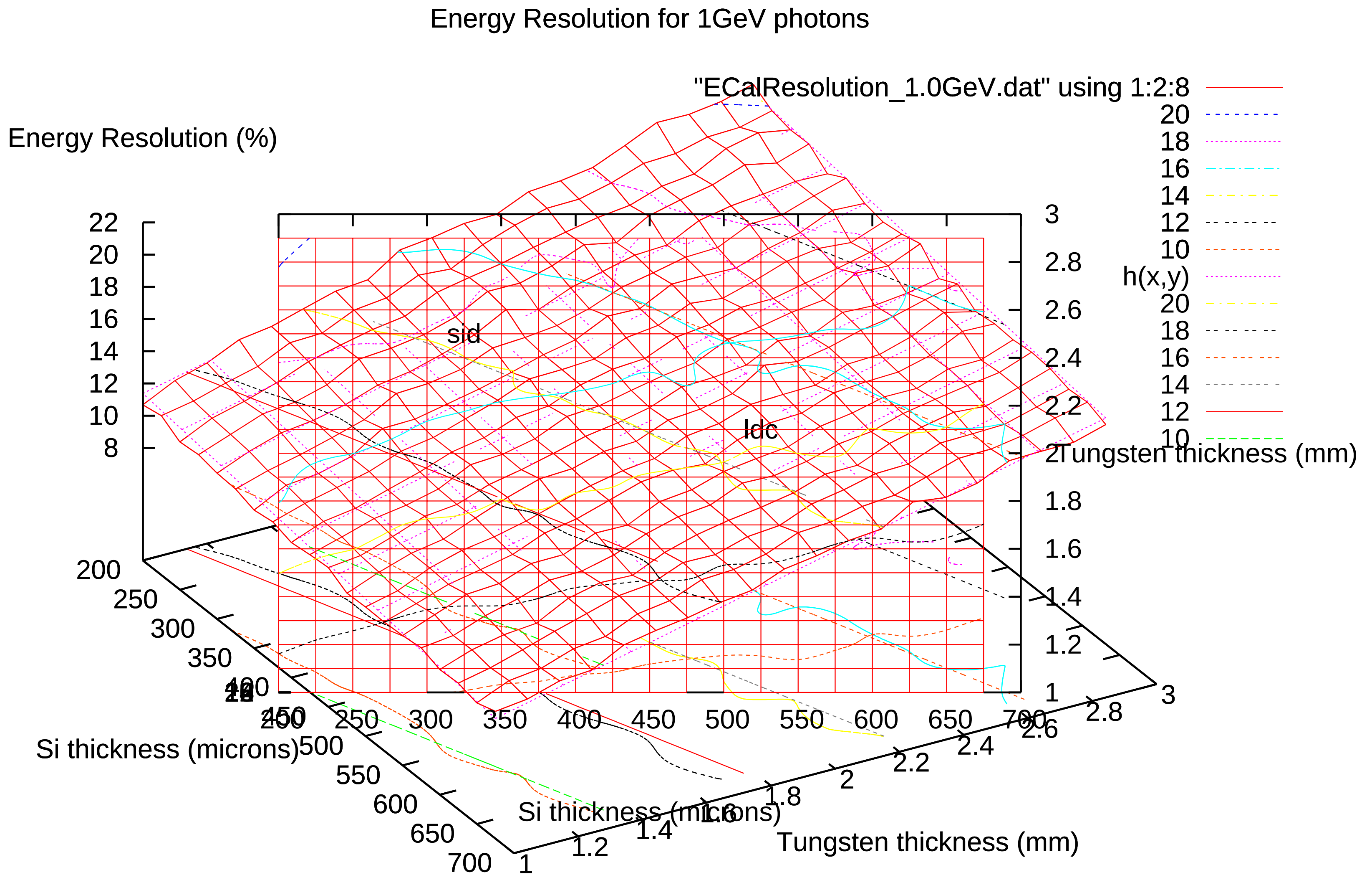
EM Calorimeter Analysis

- Can we use simulations to design a detector with good response to photons?
- Start by investigating the intrinsic detector characteristics:
  - Energy linearity
  - Energy resolution
- Analyze the response to single photons.

Simple Geant4 study

- Generate simple sampling calorimeters composed of tungsten-silicon sandwiches.
- Create stacks sufficiently large to contain the full particle showers.
- Vary thicknesses of tungsten and silicon to study the impact on the energy resolution.
- Simulate the response to single photons of varying energy.
- Plot resolution as a function of tungsten and silicon thickness.

Resolution as fn(d_W, d_{Si})



EM Calorimeter Resolution & Linearity

- Repeat study in full detectors, study resolution and linearity for mixed ECal & HCal designs.
- The tools are available to design a system of calorimeters with good energy resolution and linearity of response to photons.
- The baseline silicon detector calorimeters provide an energy resolution of:

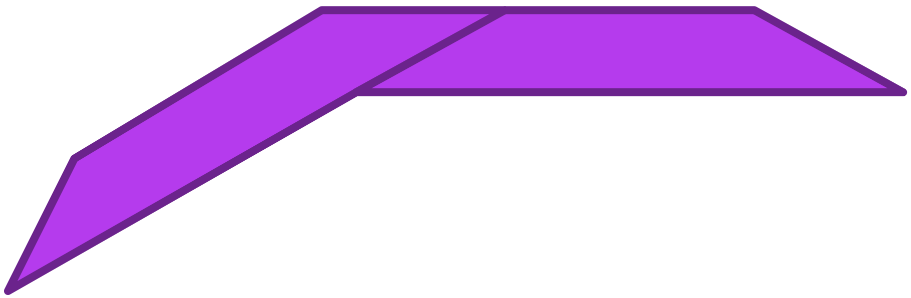
  $\sigma/E \sim 17\%/\sqrt{E}$ with ~ 0 constant term.
- However, if physics or benchmarking groups insist on better resolution, can straightforwardly come up with designs which provide that performance.

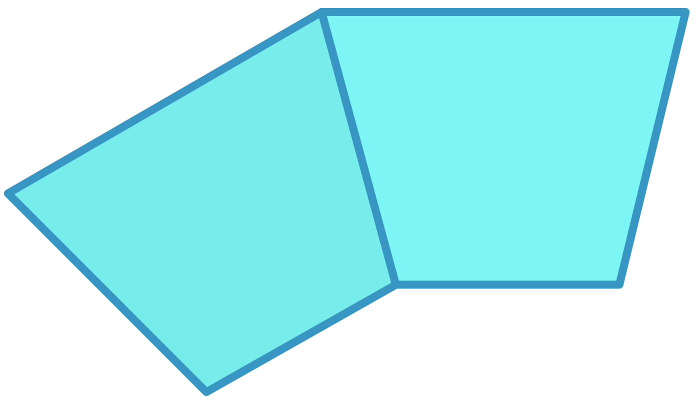
Calorimeter Improved Simulations

- Having settled on a concept with the requisite performance, will have to design a detector which can be built.
- Engineering will have to be done to come up with the plans, but the existing simulation package can already handle arbitrarily complex shapes.
- Can then study effects of support material, dead regions due to stay-clears, readout, power supplies, etc.
- However, hard work is in analyzing this, not simulating it.

Improved Calorimeter Simulations II

- Have two types of polygonal barrel geometries defined in the compact description:
- Overlapping staves: Wedge staves:

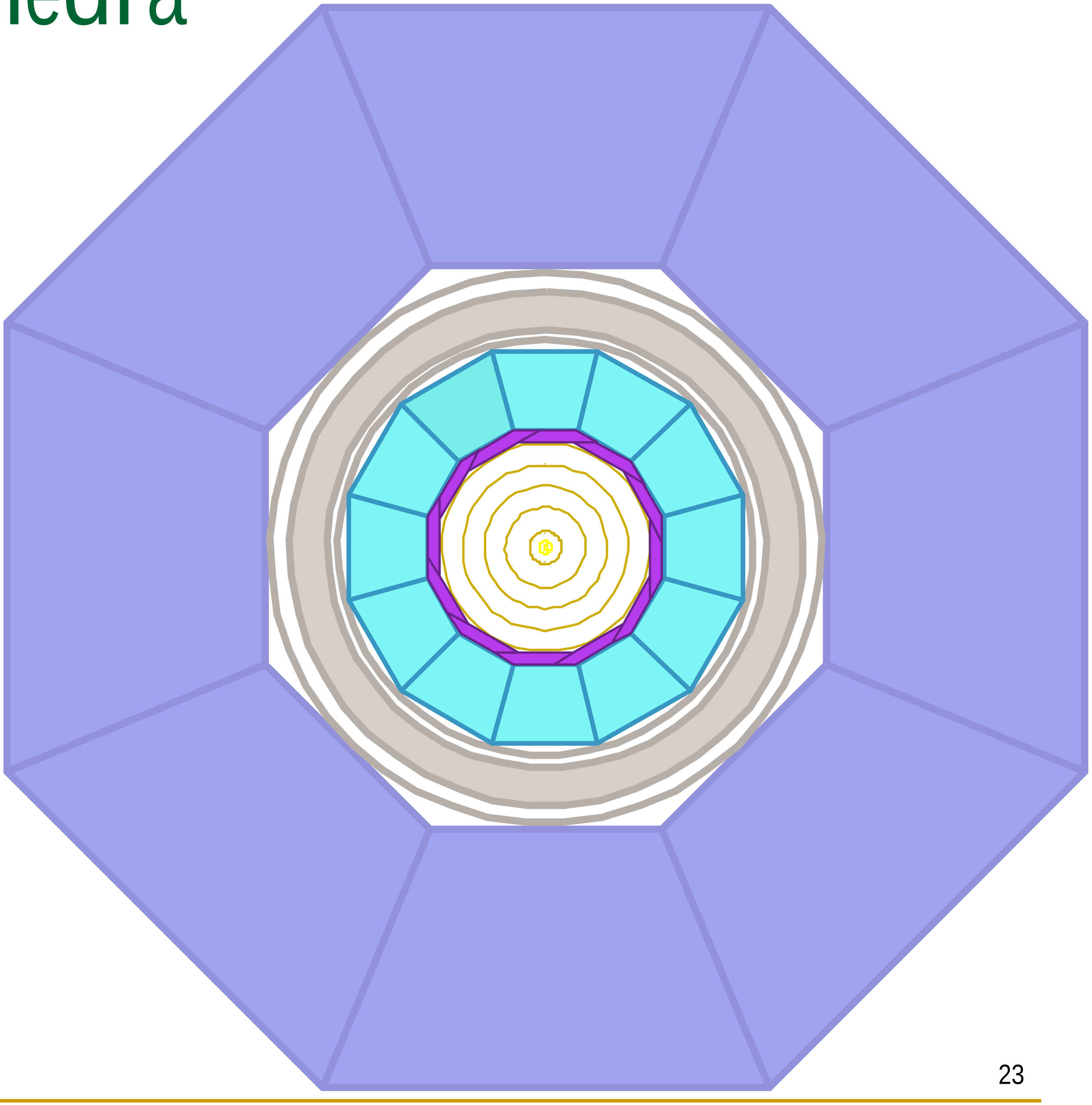




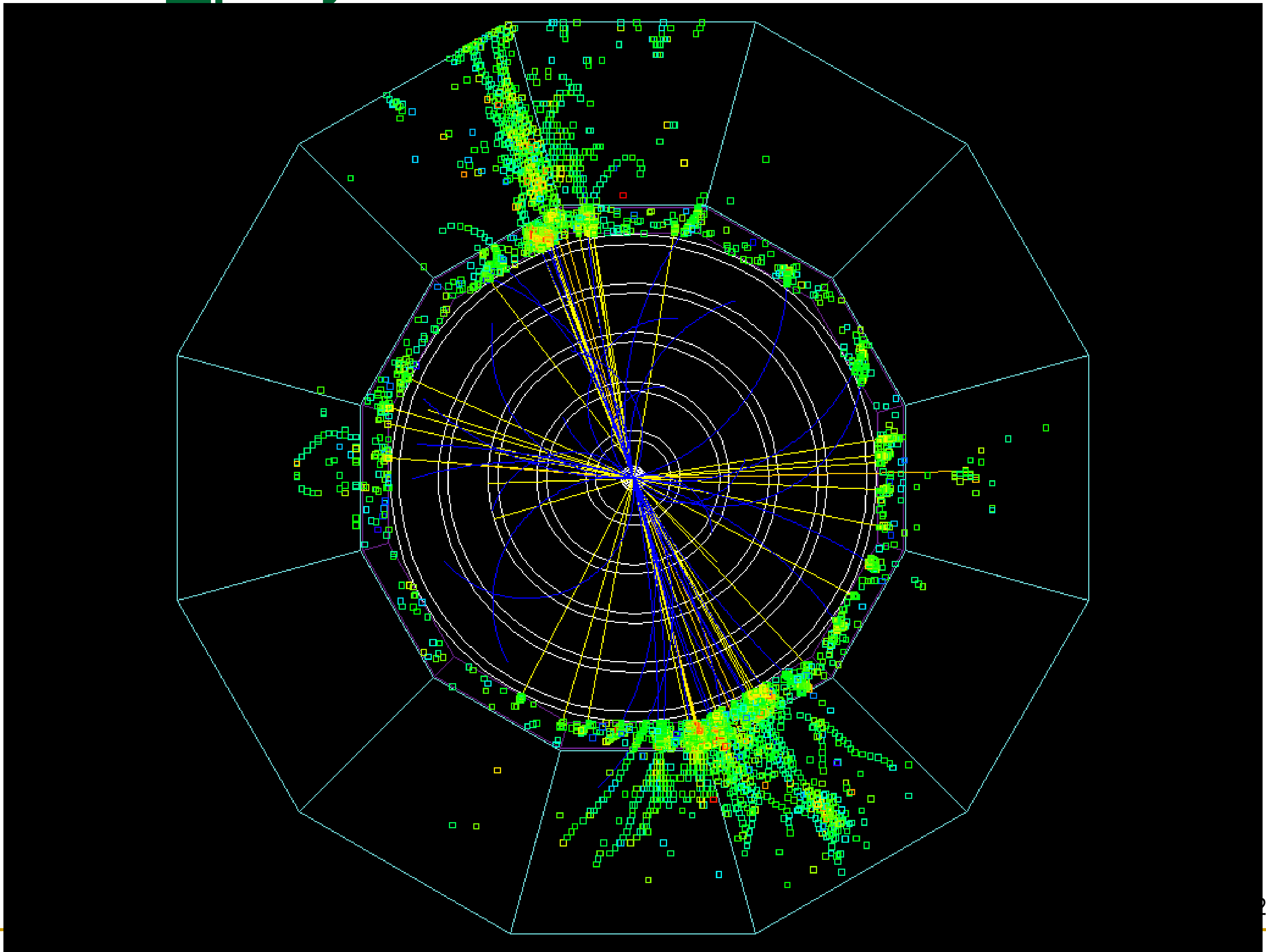
- Can define ~arbitrary layerings within these envelopes to simulate sampling calorimeters.

sid01_polyhedra

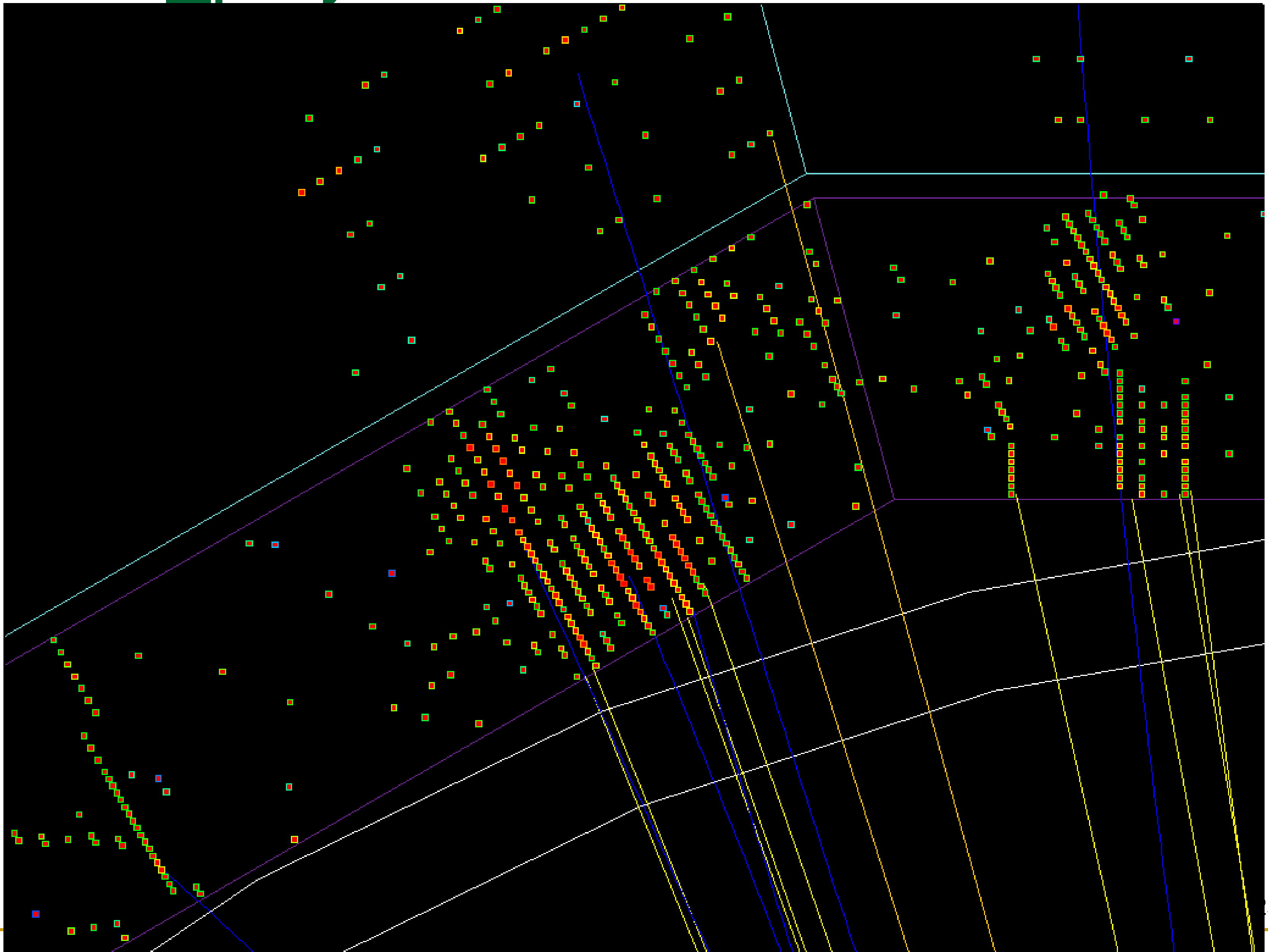
- Dodecagonal, overlapping stave EMCal
- Dodecagonal, wedge HCal
- Cylindrical Solenoid with substructure
- Octagonal, wedge Muon



sid01_polyhedra



sid01_polyhedra



Defining the Detector(s) for the CDR

- As the detectors become more realistic, and therefore more complex, more interaction is needed between subdetector experts and the simulation group.
- Takes much more time to incorporate these changes into the "official" design.
  - contrast how long it has taken to implement "sid01" design (>6 months and counting) to implementing other non-official designs (sometimes 15 minutes).
- Need to establish some sort of Change Control Board for the detector.

“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

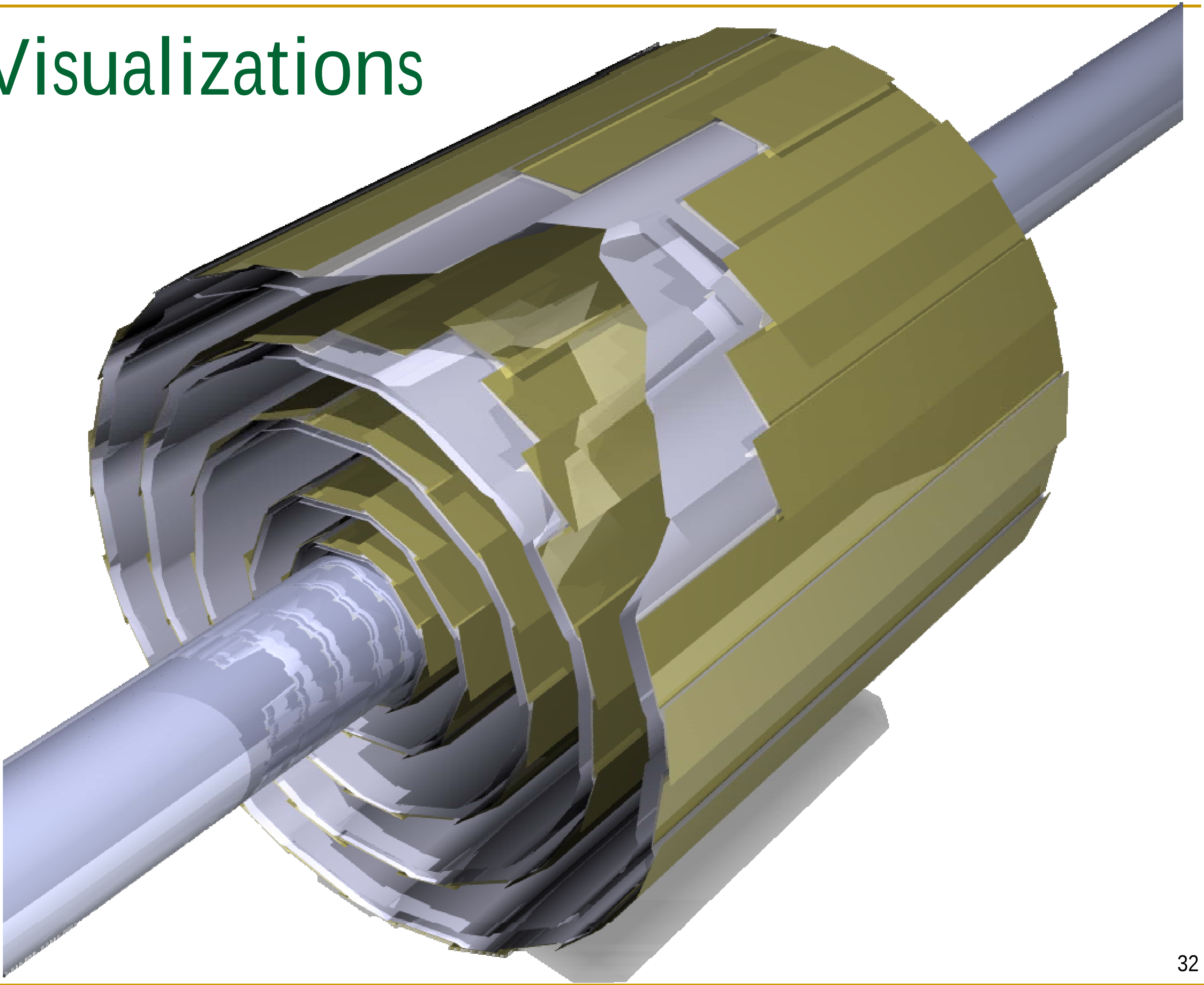
Backgrounds

- GuineaPig pairs and photons generated by T. Maruyama.
  - Add crossing angle (0, 2, 14, 20 mr), convert to stdhep
- Muons from upstream collimators generated by L. Keller. Also recent studies by Mokhov & Co. using MARS calculations, interfaced to slic.
- $\gamma\gamma \rightarrow$ hadrons generated by T. Barklow as part of the “2ab^{-1} SM sample.”
- All events capable of being processed through full detector simulation.
- Additive at the detector hit level, with time offsets.

Reconstruction

- This topic will be addressed by other speakers later today and tomorrow.
- Many of the reconstruction algorithms (track finding, fitting, calorimeter clustering, etc.) are in place.
- A number of weak links are identified and need work.
- Please do not reinvent the parts that have already been done!
- Use what we have!
- Adopt, adapt, improve.

Visualizations



Simulation Summary

- Sim/Reco team supports an ambitious 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.

- Special thanks to Tony Johnson, Jeremy McCormick & Ron Cassell here @ SLAC.

Additional Information

- lcsim.org - http://www.lcsim.org
- ILC Forum - http://forum.linearcollider.org

- Wiki - http://confluence.slac.stanford.edu/display/ilc/Home
- org.lcsim - http://www.lcsim.org/software/lcsim
- Software Index - http://www.lcsim.org/software
- Detectors - http://www.lcsim.org/detectors

- 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