SiD Simulation Status Report

Norman Graf (SLAC)

SiD Workshop, Boulder

April 14,2008

LOI Simulation Requirements

- Characterize subdetector performance.
  - Single particle response can be used to demonstrate energy and position resolution, etc.
  - Very detailed geometric description and detector response can be modeled.
- Demonstrate physics capabilities of the combined detector.
  - Canonical Benchmark physics reactions defined.
  - Large statistics for both signal and background drive alternate, simplified detector response approach.
- Optimize detector design

Detector characterization

- For each detector, run neutral single particles to determine calorimeter sampling fractions:
  - n,n,K^0_L, gamma, 10k events per run
    - E = 1, 2, 5, 10, 20, 50, 100 GeV
    - θ = 90, 100, 110, 120, 130, 140, 150, 160, 170
- Single charged particles for tracking characterization and calorimeter shower/track association
  - $\mu^{+/-}$, $\pi^{+/-}$, p, $K^{+/-}$
- Composite single particles: π^0, τ, ρ, ψ, $K^0_{S,}$, etc.
- Single quarks (u,d,s) and Z^0($\rightarrow$uds) at fixed angles and energies
- Dijet (uds) events at 100, 200, 500, 1000 GeV cms
- ZZ($\rightarrow$qq$\ell\nu$ and $\rightarrow$qqqq), ZZ$\nu\nu$, WW$\nu\nu$, Zh(qqqq, qq$\tau\tau$, qq$\mu\mu$), ttbar, etc.
- Web accessible http://www.lcsim.org/datasets/ftp.html

Whizard SM Sample

- Generate an inclusive set of MC events with all SM processes
- WHIZARD Monte Carlo used to generate all 0,2,4,6-fermion and t quark dominated 8-fermion processes.
- 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.
- Events are weighted!

Standard Model Sample

- Full 2ab^{-1} SM sample available via ftp from SLAC.
- Each file corresponds to a particular initial e-/e+ polarization and final state

  ftp://ftp-lcd.slac.stanford.edu/ilc/whizdata/ILC500/

  cumbersome to work with for end user

  Have to mix polarizations by hand

  Each file contains only processes of one type, so need to run over complete data set (thousands of files) to get faithful subset.

- 500 fb^{-1} sample of these events generated with 80% e^{-}, 30% e^{+} polarizations, randomly mixed events from all processes
  - ftp://ftp-lcd.slac.stanford.edu/ilc/ILC500/StandardModel/
  - Roughly 400 million events

LOI SM Data Samples

- Removed 120 Higgs from n fermion final states at 500 GeV, and add explicit ffH, ffHH, etc. final states.
- Regenerated states with τ in final state using TAUOLA.
- Producing full SM data set at 250 GeV.

LOI Benchmarking Samples

- 500 fb^{-1} sample generated at 500GeV cms with 80% e^-, 30% e^+ polarizations, randomly mixed events from highly weighted processes,
  - ftp://ftp-lcd.slac.stanford.edu/ilc/ILC500/StandardModel/
  - Roughly 7 million events
    - 2453865 +80e- -30e+
    - 4737499 -80e- +30e+
- Six-fermion events appropriate for top analyses.
  - m_{top} = 173.5, 174.0 GeV
- 250 fb^{-1} sample to be generated at 250GeV cms with 80% e^-, 30% e^+ polarizations, randomly mixed events from highly weighted processes,
- Higgs-related samples available.
  - m_h = 120 GeV

Example Higgs File

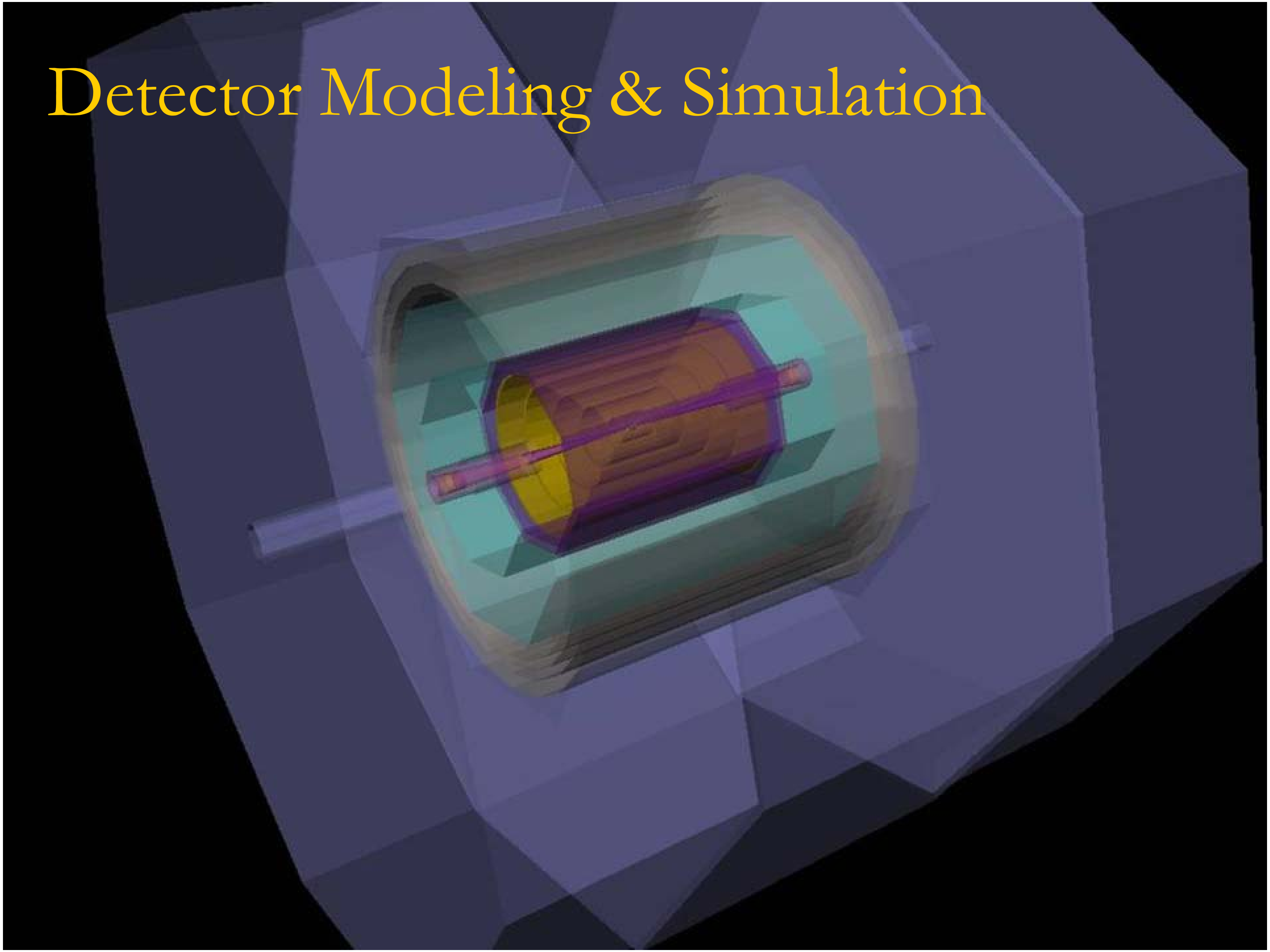
ILC250_125fb-1_-80e-_+30e+_higgs_run1.txt

/nfs/slac/g/lcd/ilc_data2/whizdata/ILC250//w20594_01.stdhep	1	95	1.000000	n1n1h_o	1	-1
/nfs/slac/g/lcd/ilc_data2/whizdata/ILC250//w20593_01.stdhep	1	4448	1.000000	n1n1h_o	-1	1
/nfs/slac/g/lcd/ilc_data2/whizdata/ILC250//w20598_01.stdhep	1	95	1.000000	n2n2h_o	1	-1
/nfs/slac/g/lcd/ilc_data2/whizdata/ILC250//w20597_01.stdhep	1	2474	1.000000	n2n2h_o	-1	1
/nfs/slac/g/lcd/ilc_data2/whizdata/ILC250//w20602_01.stdhep	1	95	1.000000	n3n3h_o	1	-1
/nfs/slac/g/lcd/ilc_data2/whizdata/ILC250//w20601_01.stdhep	1	2473	1.000000	n3n3h_o	-1	1
/nfs/slac/g/lcd/ilc_data2/whizdata/ILC250//w20606_01.stdhep	1	166	1.000000	uuh_o	1	-1
/nfs/slac/g/lcd/ilc_data2/whizdata/ILC250//w20605_01.stdhep	1	4327	1.000000	uuh_o	-1	1
/nfs/slac/g/lcd/ilc_data2/whizdata/ILC250//w20610_01.stdhep	1	166	1.000000	cch_o	1	-1
/nfs/slac/g/lcd/ilc_data2/whizdata/ILC250//w20609_01.stdhep	1	4331	1.000000	cch_o	-1	1
/nfs/slac/g/lcd/ilc_data2/whizdata/ILC250//w20615_01.stdhep	1	5	1.000000	e1e1h_o	1	1
/nfs/slac/g/lcd/ilc_data2/whizdata/ILC250//w20614_01.stdhep	1	49	1.000000	e1e1h_o	1	-1
/nfs/slac/g/lcd/ilc_data2/whizdata/ILC250//w20613_01.stdhep	1	1308	1.000000	e1e1h_o	-1	1
/nfs/slac/g/lcd/ilc_data2/whizdata/ILC250//w20612_01.stdhep	1	25	1.000000	e1e1h_o	-1	-1
/nfs/slac/g/lcd/ilc_data2/whizdata/ILC250//w20618_01.stdhep	1	48	1.000000	e2e2h_o	1	-1
/nfs/slac/g/lcd/ilc_data2/whizdata/ILC250//w20617_01.stdhep	1	1252	1.000000	e2e2h_o	-1	1
/nfs/slac/g/lcd/ilc_data2/whizdata/ILC250//w20622_01.stdhep	1	48	1.000000	e3e3h_o	1	-1
/nfs/slac/g/lcd/ilc_data2/whizdata/ILC250//w20621_01.stdhep	1	1250	1.000000	e3e3h_o	-1	1
/nfs/slac/g/lcd/ilc_data2/whizdata/ILC250//w20626_01.stdhep	1	212	1.000000	ddh_o	1	-1
/nfs/slac/g/lcd/ilc_data2/whizdata/ILC250//w20625_01.stdhep	1	5549	1.000000	ddh_o	-1	1
/nfs/slac/g/lcd/ilc_data2/whizdata/ILC250//w20630_01.stdhep	1	212	1.000000	ssh_o	1	-1
/nfs/slac/g/lcd/ilc_data2/whizdata/ILC250//w20629_01.stdhep	1	5549	1.000000	ssh_o	-1	1
/nfs/slac/g/lcd/ilc_data2/whizdata/ILC250//w20634_01.stdhep	1	212	1.000000	bbh_o	1	-1
/nfs/slac/g/lcd/ilc_data2/whizdata/ILC250//w20633_01.stdhep	1	5528	1.000000	bbh_o	-1	1

Additional Backgrounds

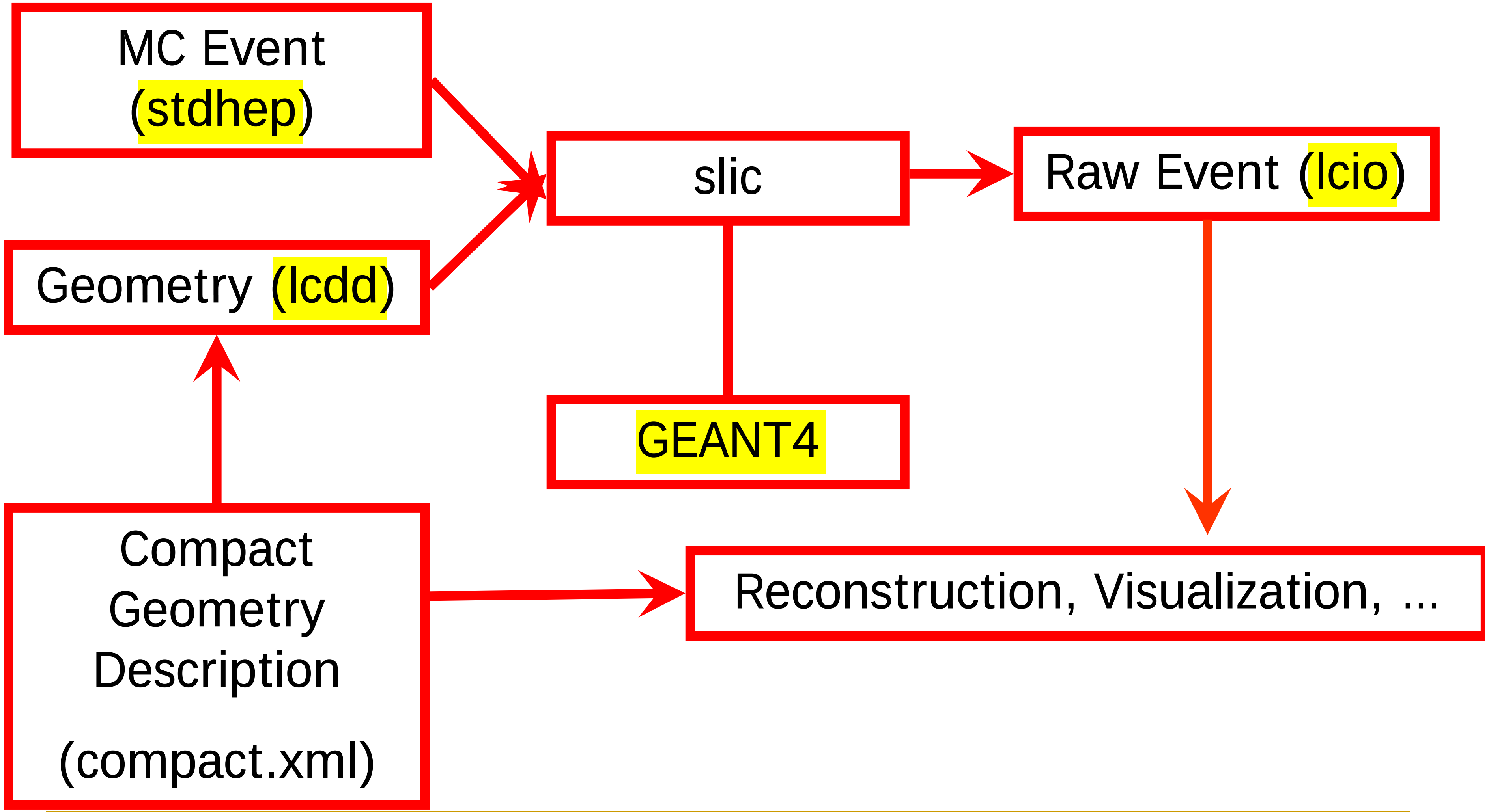
- GuineaPig pairs and photons (Cain too?)
  - Converted to stdhep, available here.
  - Full sets (~100k particles/event) and only prompt tracks entering detector available.
- Muons and other backgrounds from upstream collimators.
  - Need to validate and understand normalizations.
- $\gamma\gamma \rightarrow$ hadrons generated as part of the "2ab^{-1} SM sample."
- All events then capable of being processed through full detector simulation.
- Additive at the detector hit level, with time offsets, using LCIO utilities.
  - i.e. simulate response separately for signals and backgrounds, then add at digitization/reconstruction level.

Detector Modeling & Simulation



LC Detector Full Simulation

Items highlighted in yellow represent common standards



slic

- Number of internal optimizations and refactorings.
  - Should not be noticed by end users.
- Upgrades to recent version of Geant4 (9.1p2) has essentially eliminated problem of event aborts when particle tracking became stuck.
- Output file autonaming option provides provenance.

panpyZmumuh120-0-500_SLIC-v2r5p3_geant4-v9r2p1_LCPhys_sid01.slcio

input stdhep file name   generator & version   geant version   physics list   det name

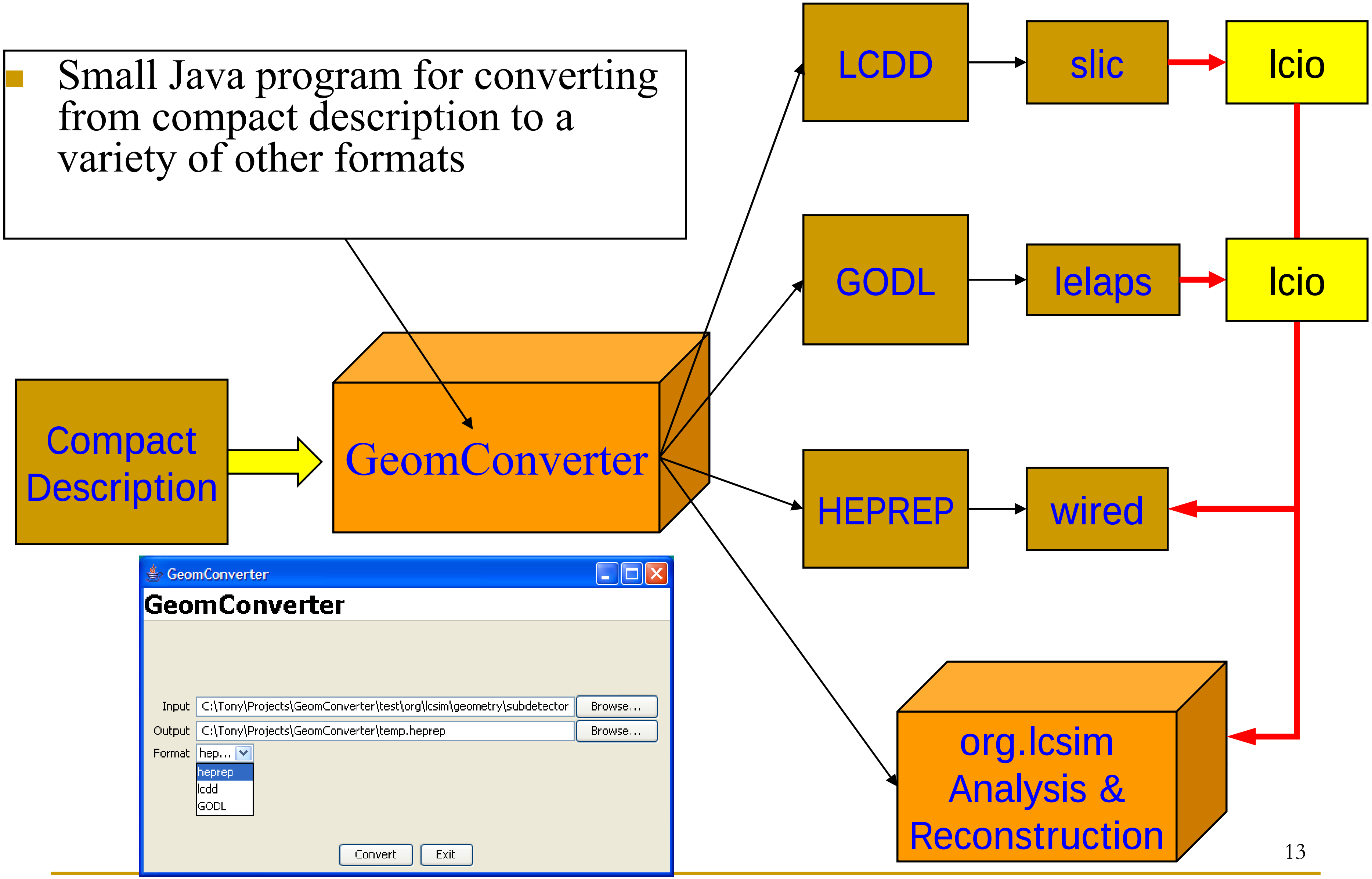
- slic from scratch:

```
cvs -d :pserver:anonymous@cvs.freehep.org:/cvs/lcd co SimDist
cd SimDist
./configure
make
```

- Binaries also available for Windows, Mac, Linuxes

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 vs. dual readout
  - Layering (radii, number, composition)
  - Readout segmentation (size, projective vs. nonprojective)
  - Tracking detector technologies & topologies
    - TPC, Pixels, Silicon microstrip, SIT, SET
    - "Wedding Cake" Nested Tracker vs. Barrel + Cap
  - Field strength
  - Far forward MDI variants

Detectors under investigation

acme0605
acme0605_1cmecal
acme0605_30layerecal
acme0605_40layerecal
acme0605_ecal150
acme0605_ecal150_4T
acme0605_ecal150_steel_rpc
acme0605_ecal150_steel_scint
acme0605_ecal150_w_rpc
acme0605_ecal175
acme0605_ecal175_3T
acme0605_ecal175_4T
acme0605_ecal175_steel_rpc
acme0605_ecal175_steel_scint
acme0605_ecal175_w_rpc
acme0605_steel_rpc
acme0605_steel_scint
acme0605_w_rpc
acme0703_cu_rpc
acme0703_cu_scint
acme0703_pb_rpc
acme0703_pb_scint

apex0705_r125_steel1.5_scint
apex0705_r125_steel2.5_scint
apex0705_r125_steel_scint
apex0705_r125_steel_scint_3x3hcal
apex0705_r125_w_scint
apex0705_r150_steel_scint
apex0705_r150_steel_scint_4T
apex0705_r175_steel_scint
apex0705_r175_steel_scint_3x3hcal
apex0705_r175_steel_scint_4T
apex0705_r175_steel_scint_4T_3x3hcal
apex0705_r200_steel_scint
apex0705_r200_steel_scint_4T
apex0705_r225_steel_scint
apex0705_r225_steel_scint_3x3hcal
apex0705_r225_steel_scint_3T
apex0705_r225_steel_scint_4T
sid01
sid01_scint
sid01_scint_3x3hcal
sid01_polyhedra
sid02
sid02_scint

The LOI Silicon Detector: sid02

- sid01 defined two years ago.
- A number of changes have occurred since then, so need to update the description of the silicon detector for the LOI.
- sid02 will be used for the LOI benchmarking exercise.
- We should continue in parallel to conduct overall detector optimization and improved subdetector response studies.

The sid02 Beampipe

- Beampipe has not changed from sid01.

The sid02 Vertex Detector

- Has not changed from sid0.

The sid02 Tracker

- Outer tracker has not changed from sid01.
- Far-forward tracking disks inside vertex support tube have been modified to reflect baseline change to pixel readout.

The sid02 EM Calorimeter

- Has not changed from sid01.

The sid02 Hadronic calorimeter

- Has had six layers added, for a total of 40 layers (2 cm steel absorber + .8cm RPC readout).
- RPC remains the baseline readout. Scintillator also an option (studying 1cm x 1cm vs 3cm x 3cm readout sizes).

The sid02 Solenoid

- Thicker HCal has moved solenoid out to 255 cm.

The sid02 Solenoid

```
<!-- Solenoid -->
    <detector id="0" name="SolenoidCoilBarrel" type="MultiLayerTracker" insideTrackingVolume="false">
      <layer id="1" inner_r="SolenoidBarrelInnerRadius" outer_z="SolenoidBarrelOuterZ">
        <slice material="Steel235" thickness="SolenoidBarrelInnerCryostatThickness" />
        <slice material="Air" thickness="SolenoidBarrelInnerAirgapThickness" />
      </layer>
      <layer id="2" inner_r="SolenoidBarrelConductorInnerRadius" outer_z="262.5*cm">
        <slice material="Aluminum" thickness="SolenoidBarrelAlConductorThickness" />
        <slice material="Steel235" thickness="SolenoidBarrelSteelThickness" />
      </layer>
      <layer id="3" inner_r="SolenoidBarrelOuterCryostatInnerRadius" outer_z="SolenoidBarrelOuterZ">
        <slice material="Air" thickness="SolenoidBarrelOuterAirgapThickness" />
        <slice material="Steel235" thickness="SolenoidBarrelOuterCryostatThickness" />
      </layer>
    </detector>

    <detector id="0" name="SolenoidCoilEnds" type="DiskTracker" reflect="true" insideTrackingVolume="false">
      <layer id="1" inner_r="SolenoidBarrelInnerRadius" inner_z="SolenoidBarrelOuterZ"
    outer_r="SolenoidBarrelOuterRadius">
        <slice material="Steel235" thickness="SolenoidEndcapCryostatThickness" />
      </layer>
    </detector>
```

The sid02 Muon System

- Thicker HCal has moved muon barrel system out to r = 338.8cm, z = 294.0 cm.
- Eleven layers of 20cm absorber plus double RPC readout.
- Endcaps start at z = 303 cm

The sid02 Far Forward region

- Baseline has all elements within 19.5cm support tube. Forward calorimeters begin at r=20cm.
- Changes made to LumiCal, BeamCal, mask and low Z shield in front of BeamCal.
- 14 mr crossing angle demands separate incoming (r=1cm) and outgoing (r-1.5cm) beampipes.

sid02 Current Status

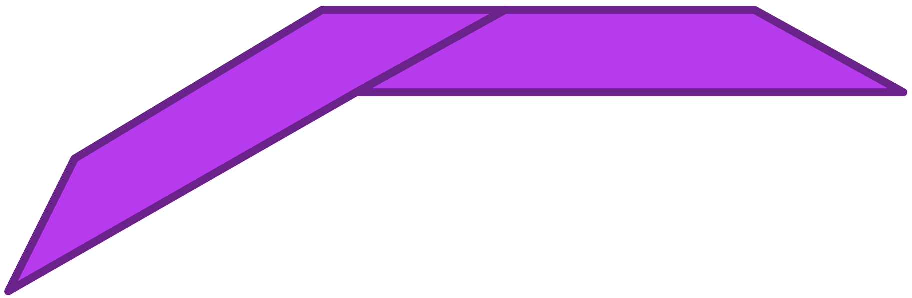
- All subsystems implemented.
- sid02 compact.xml committed to cvs.
- Single particle files generated for sampling fraction calculations.
- Subset of benchmarking physics samples put through simulation to gain timing numbers.
- LOI dataset production started.

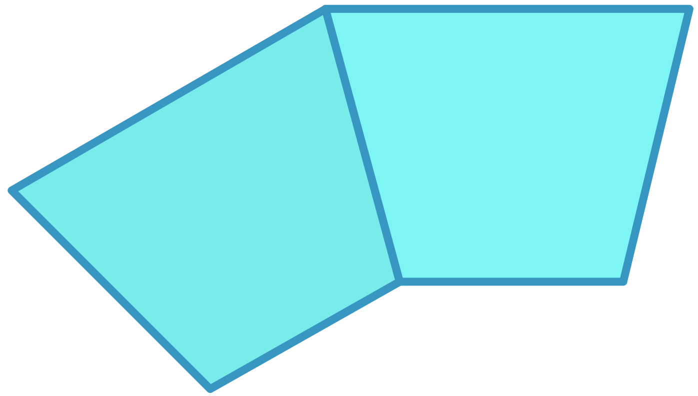
Calorimeter Improved Simulations

- 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 reconstructing and analyzing this, not simulating it.

Improved Calorimeter Simulations II

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





- Can define ~arbitrary layerings (and boundary stay-clears) within these envelopes to simulate sampling calorimeters.
- Additional geometries (e.g. tilted polyhedra) will be developed on an as-needed basis.
- Support for dual readout, e.g. optical processes, included.

Improved Silicon Tracking Detectors

- For the purposes of quickly scanning the parameter space of number of tracking layers and their radial and z positioning, etc. 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.
- Introduced Geometry and Detector Element trees to handle arbitrary hierarchies of detector elements.
- Have now introduced tilings of planar detectors (simulating silicon wafers) into the compact xml description.

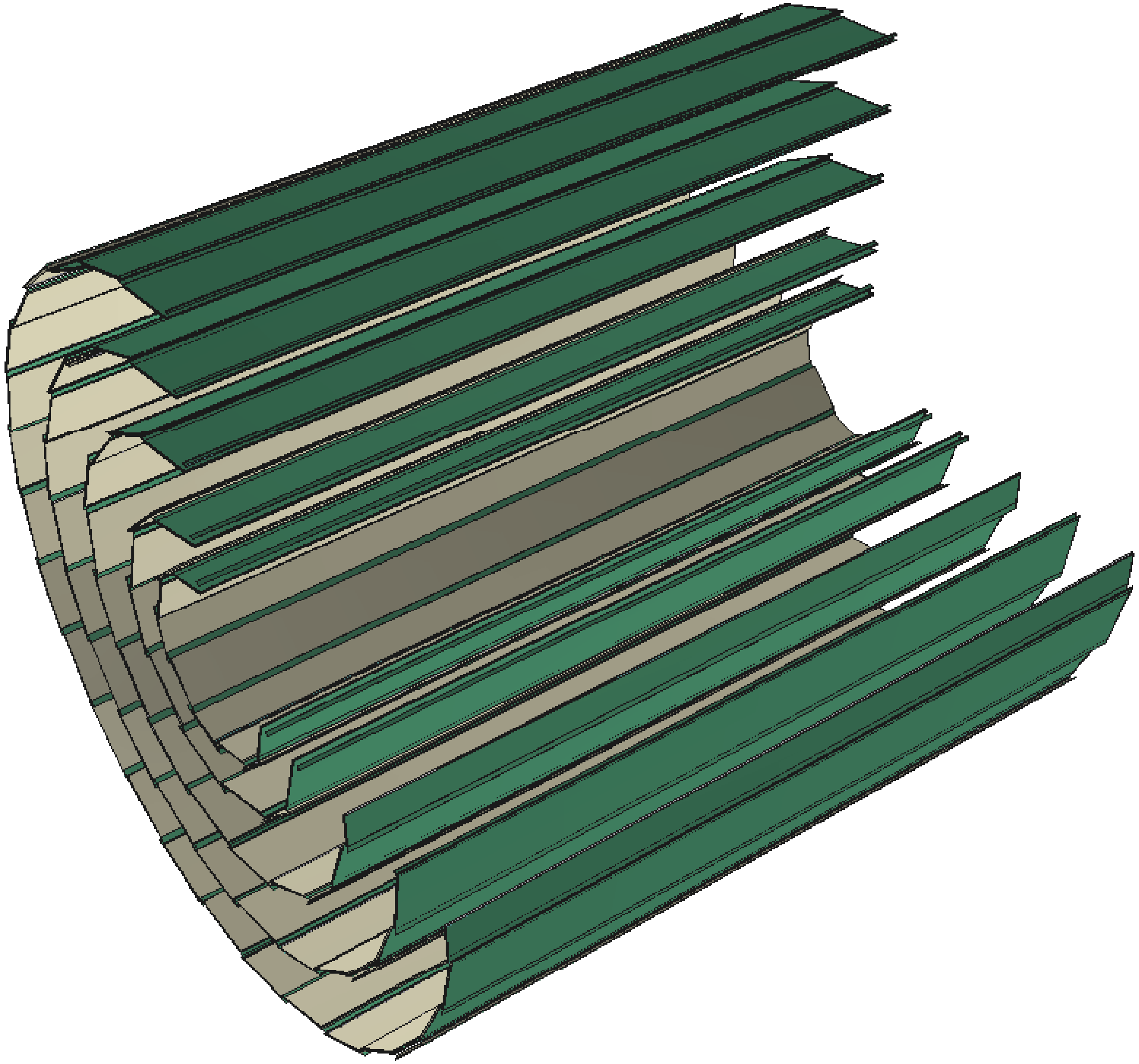
xml: Defining a Module

```
<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

```xml
<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

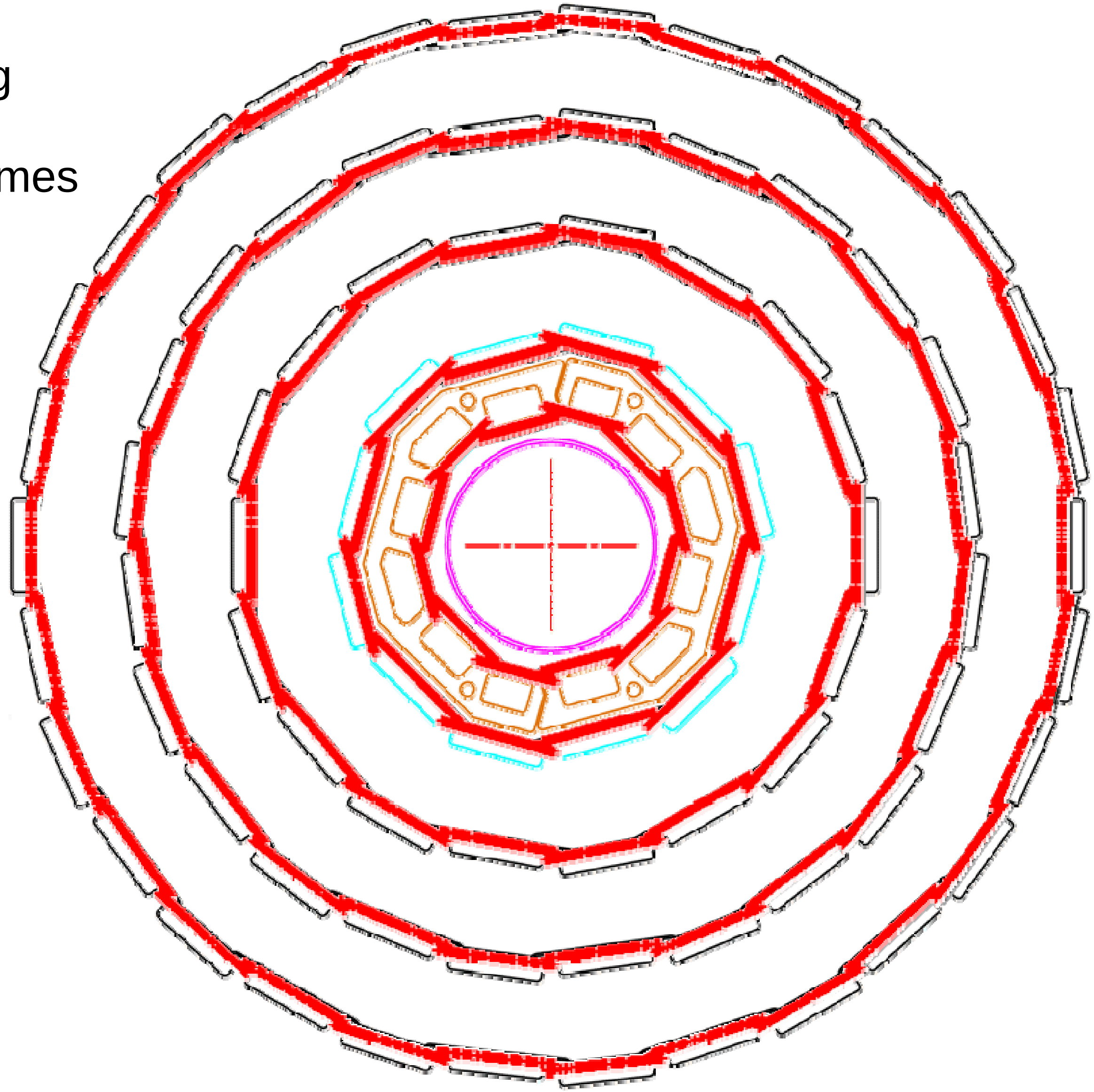


LCIO SimTracker Hits from Vertex

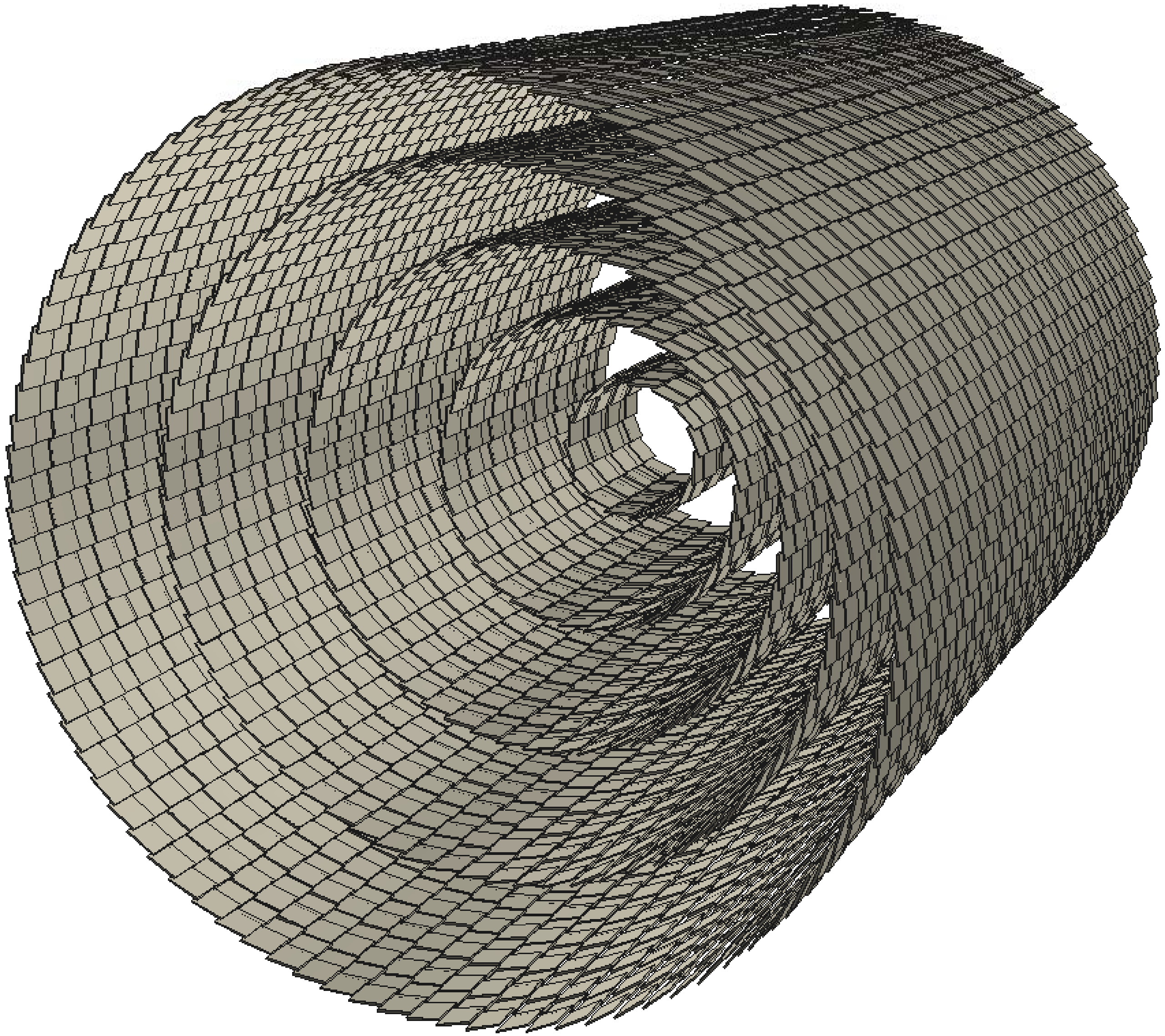
CAD Drawing

GEANT Volumes

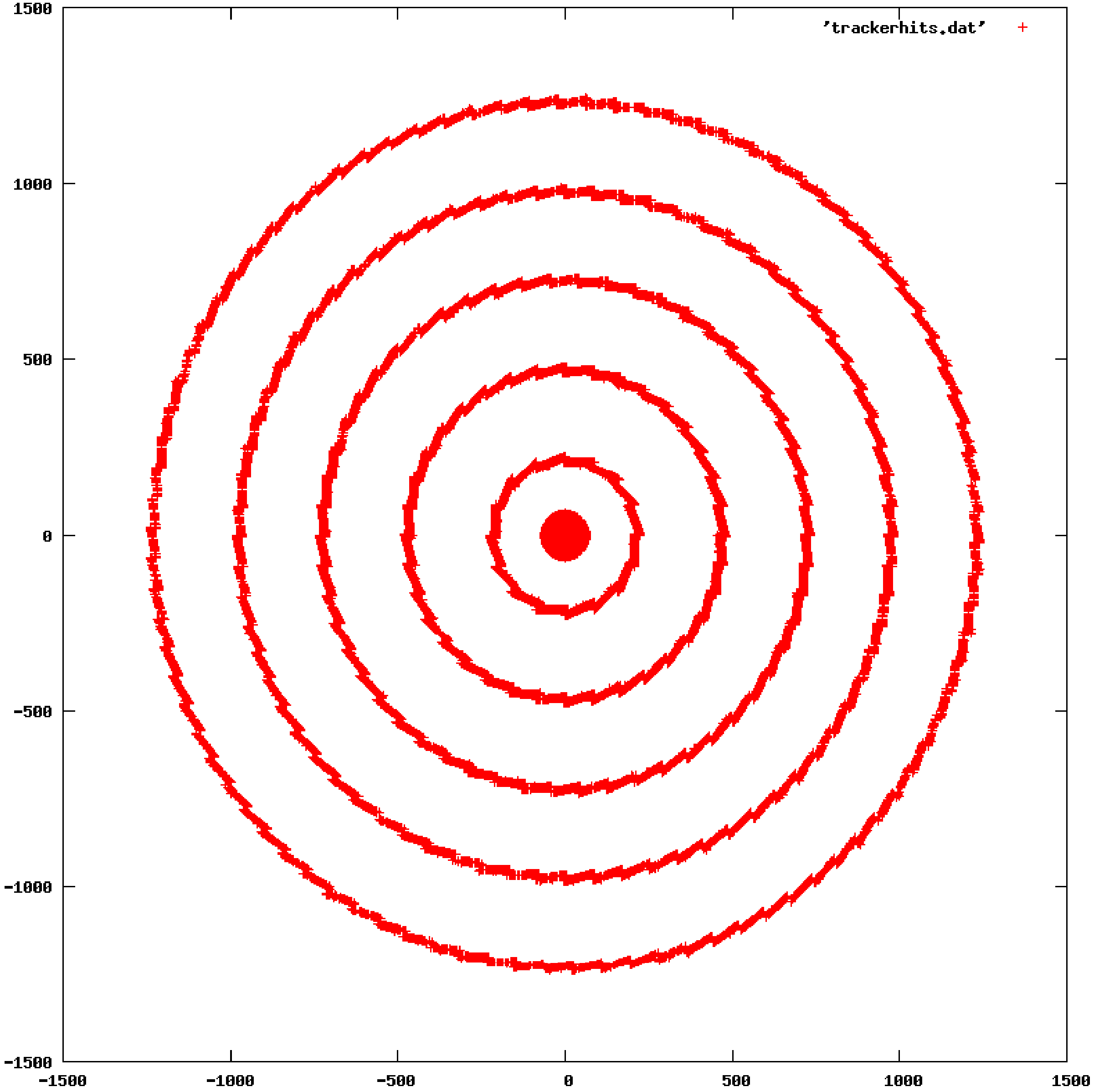
LCIO Hits



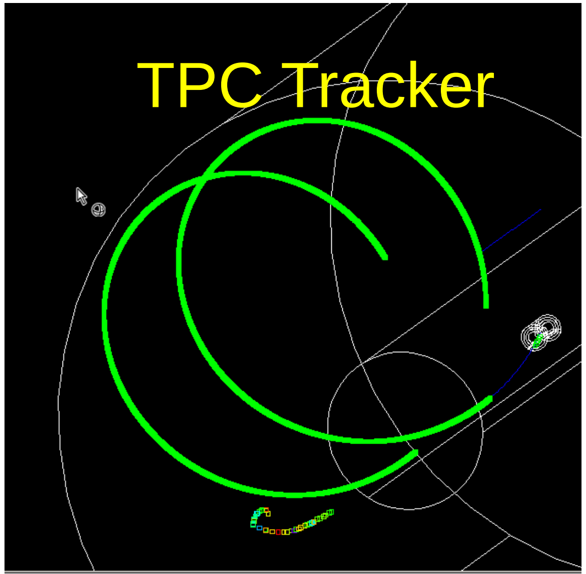
The Barrel Outer Tracker

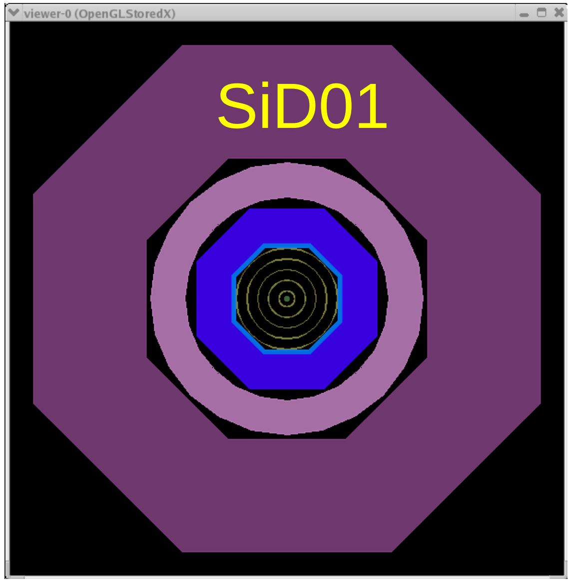


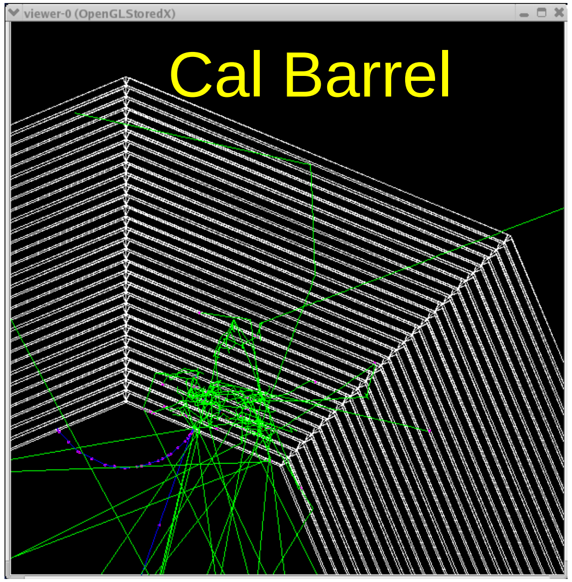
LCIO SimTracker Hits from Tracker

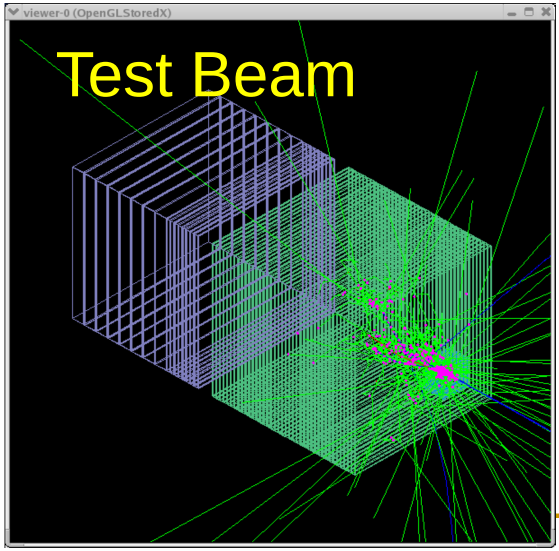


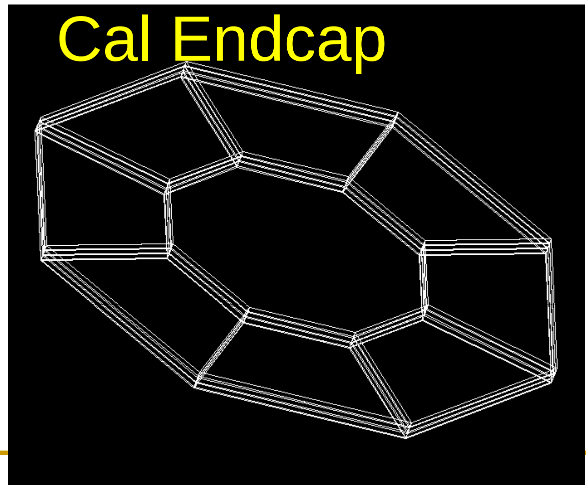
Example Geometries (same exe)



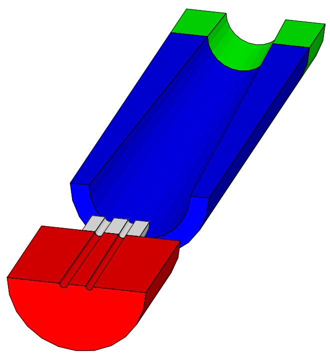








MDI-BDS

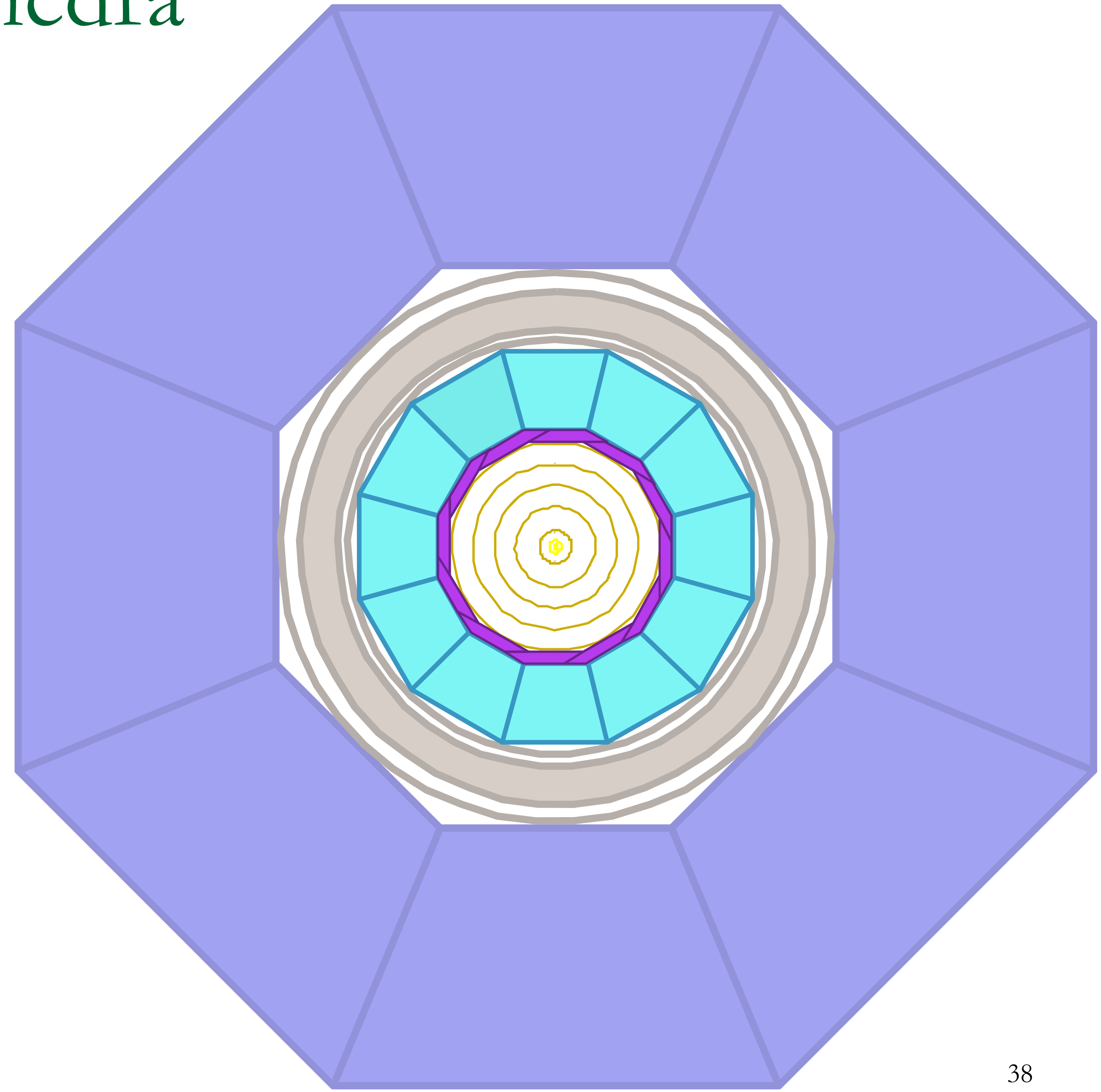


More complex geometries

- Arbitrarily complex geometries can be accommodated in the lcdd detector description, but these will not be propagated to the reconstruction system.
  - May be appropriate for supports, readouts, and far-forward BDS/MDI elements.
- CAD to GEANT functionality implemented, and tested for simple elements, so engineering drawings for some elements can be adopted ~as-is.
- Will, of course, have an impact on performance due to use of BREPS in Geant.

sid01_polyhedra

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



Beam Background Overlays

- Take output from full beam simulation (from IR/backgrounds group)
- Feed into full detector simulation
- Build library of simulated background bunches
- Overlay backgrounds on signal events at start of reconstruction
    - Adjust timing of hits (for TPC e.g.)
    - Add energy in calorimeter cells
  - Allows to change #bunches/train, bunch timing
- Will most likely not be done for full benchmarking studies, but needed for subdetector characterization.

Summary

- The ALCPG sim/reco group provides SiD a mature, full-featured, detector simulation package, capable of modeling very detailed geometries.
    - How detailed should the simulations be for the LOI?
- LCIO event data model and file format allows exchange of simulated (& reconstructed) data between regional software packages.
    - Number of analyses presented at TILC08 exploited this functionality, e.g.
        - Jupiter GLD simulation input to MarlinReco PandoraPFA
        - slic SiD simulation fed to LCFI flavor-tagging package

Advice for the SiD LOI

- "Don't get it right, get it written"

  James Thurber

- Waiting for all of the elements to be designed in excruciating detail is a recipe for failure.
- It would be much better to proceed with what we have all the way through to the end, even if this means simplified detector designs and partial reconstruction, than to wait until the very end.
- Get a draft out soon, then refine it.

Additional Information

- SiD – http://silicondetector.org

- 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
- Detectors - http://www.lcsim.org/detectors

- LCIO - http://lcio.desy.de
- SLIC - http://www.lcsim.org/software/slic
- JAS3 - http://jas.freehep.org/jas3
- AIDA - http://aida.freehep.org
- WIRED - http://wired.freehep.org