Detector Simulation Software

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Linear Collider Detector Environment

- Detectors designed to exploit the physics discovery potential of e^+e^- collisions at $\sqrt{s}$ ~ 1-3 TeV.
- Perform precision measurements of complex final states with well-defined initial state:
  - Tunable energy
  - Known quantum numbers & e^-, e^+, γ polarization
  - Possibilities for $\gamma\gamma$, γe^-, $e^- e^-$
  - Very small interaction region
  - Momentum constraints (modulo beam & bremsstrahlung)

LCD Simulation Mission Statement

- Provide full simulation capabilities for Linear Collider physics program:
  - Physics simulations
  - Detector designs
  - Reconstruction and analysis
- Need flexibility for:
  - New detector geometries/technologies
  - Different reconstruction algorithms
- 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.

Fast Detector Response Simulation

- Covariantly smear tracks with matrices derived from geometry, materials and point resolution using Billoir's formulation.

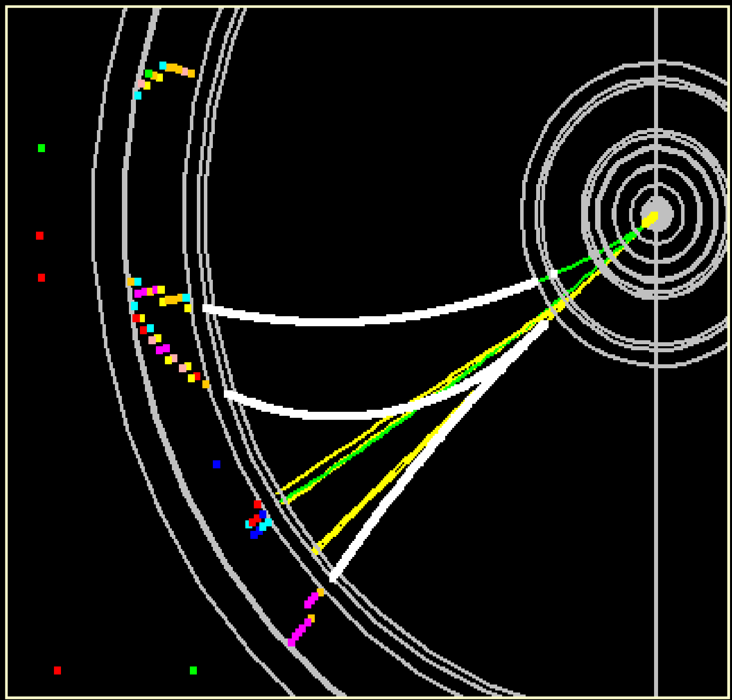
  http://www.slac.stanford.edu/~**schumm/lcdtrk**
- Provides smeared tracks with full covariance matrix, which can be used in analysis chain (e.g. vertexing).
- Calorimeter responses tuned to replicate PFA performance.

lelaps

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

http://lelaps.freehep.org/index.html

Lelaps: Decays, dE/dx, MCS

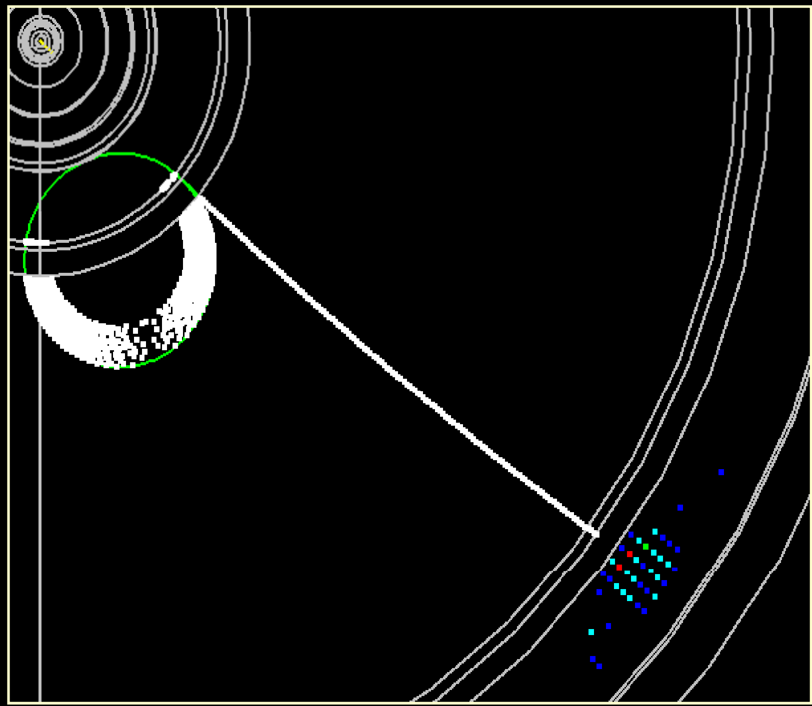


$\Omega^- \rightarrow \Xi^0 \pi^-$

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

$\Lambda \rightarrow p \pi^-$

$\pi^0 \rightarrow \gamma \gamma$ as simulated by Lelaps for the LDC model.



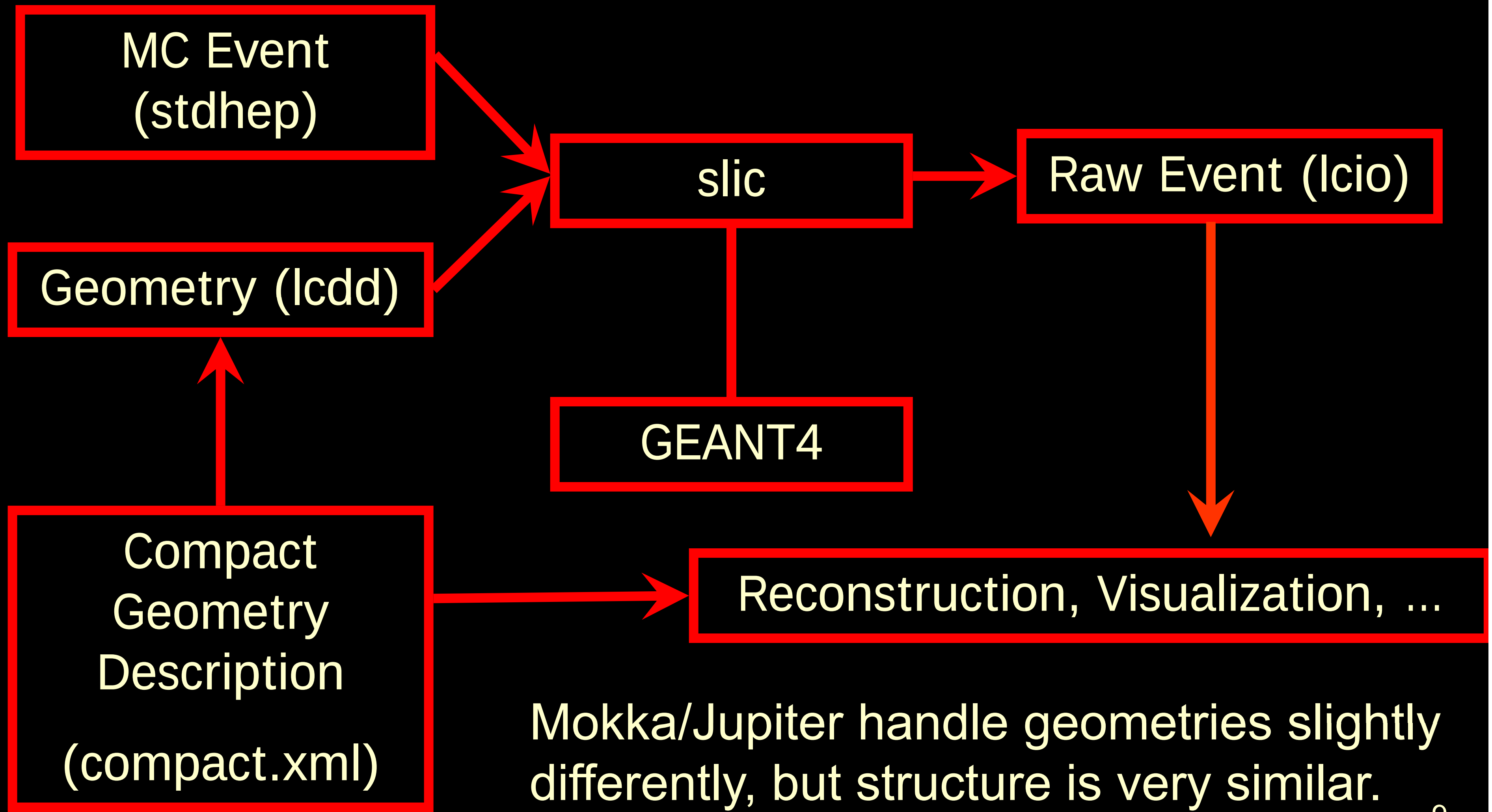
gamma conversion as simulated by Lelaps for the LDC model.

Note energy loss of electron.

Detector Design (GEANT 4)

- Need to be able to flexibly, but believably simulate the detector response for various designs.
- GEANT is the de facto standard for HEP physics simulations.
- Use runtime configurable detector geometries
- Write out “generic” hits to digitize later.

LC Detector Full Simulation



Mokka/Jupiter handle geometries slightly differently, but structure is very similar.

Full Simulations

slic MOKKA JUPITER

LCIO

Common Data Model

Common IO Format

LCIO Overview

- Object model and persistency for MC simulation & reconstruction
  - Events: Monte Carlo, Raw, Event and run metadata
  - Reconstruction: Parameters, relations, attributes, arrays, generic objects, …
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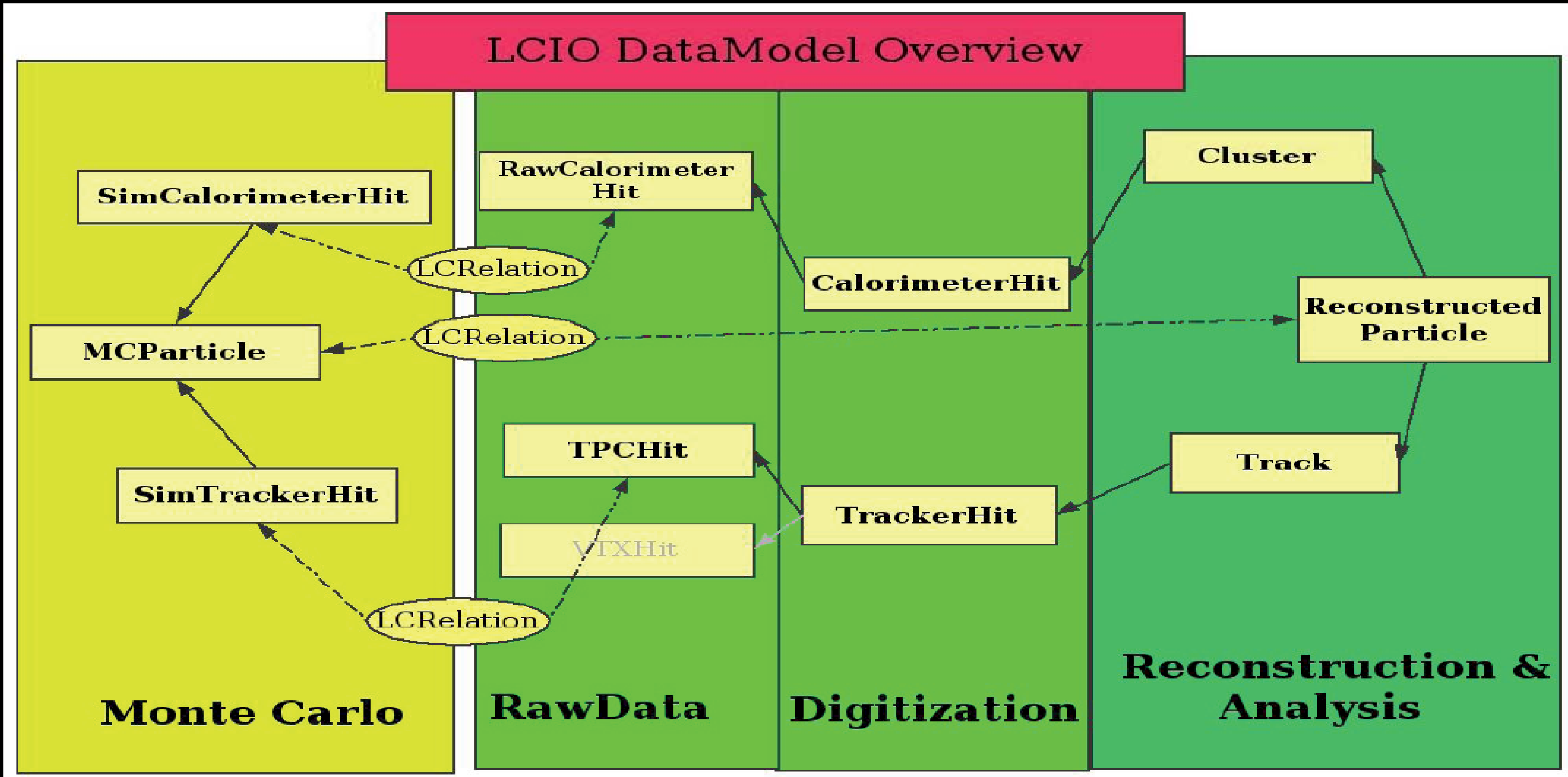

LCIO Interoperability

- All three regional LCD simulators write LCIO
  - Cross-checks between data from different simulators
  - Read/write LCIO from
    - Fast MC / Full Simulation
    - Different detectors
    - Different reconstruction tools
- 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 MarlineReco (C++) package

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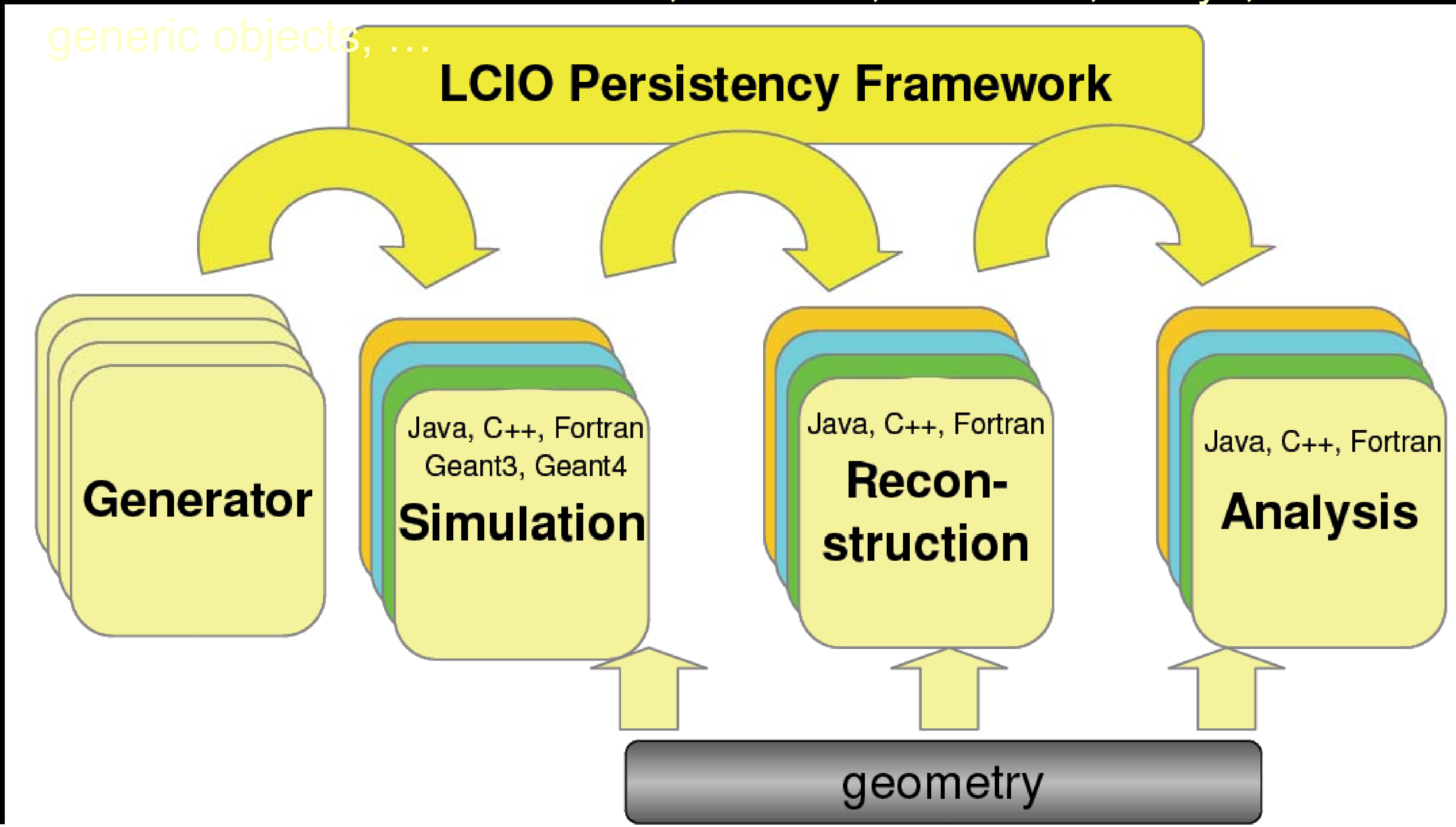


slic Overview

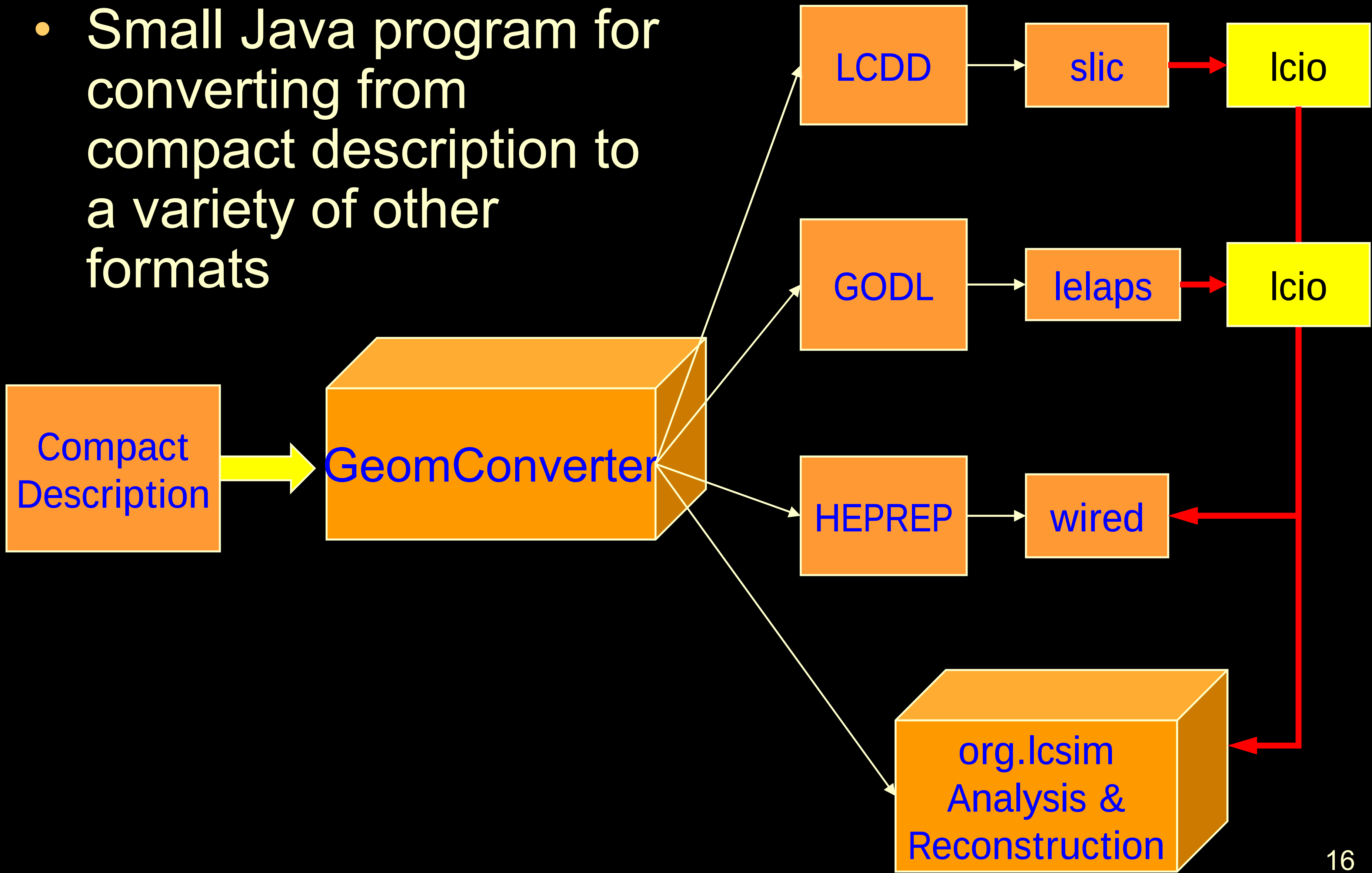
- Although fully featured, Mokka and Jupiter rely on a combination of hard-coded drivers and access to runtime databases to define subdetectors.
  - New detector type requires new code to be written.
- slic has adopted strategy for defining ALL the geometry at runtime. Maintain and distribute one single executable. Defining new detector only requires editing plain-text xml file.
  - may be more useful in the short term to cover

Software Distribution

- SLIC requires
  - Geant4, CLHEP, GDML, LCDD, Xerces, LCPhys, LCIO
  - Automated build system provided
- Binary downloads
  - http://www.lcsim.org/dist/slic
  - Linux, Windows (Cygwin), OSX
  - All packages (dist) or just runtime dependencies (bin)
- Or checkout and build from scratch
  - cvs –d :pserver:anonyous@cvs.freehep.org:/cvs/lcd co SimDist
  - cd SimDist
  - ./configure
  - make
- Installed at SLAC, NICADD, FNAL, IN2P3, RAL, ...

GeomConverter

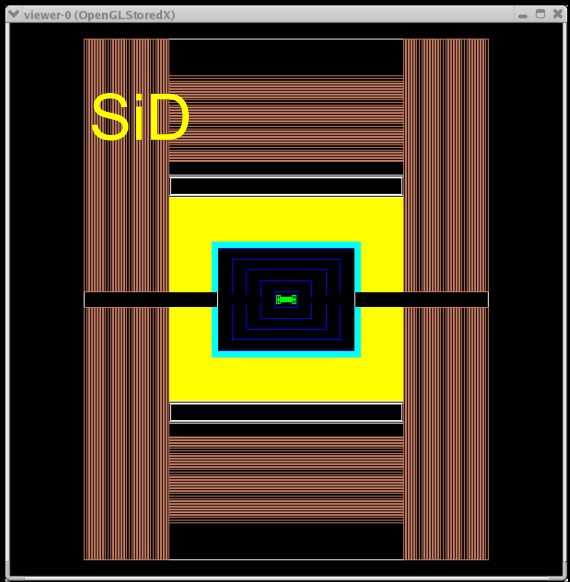
- Small Java program for converting from compact description to a variety of other formats

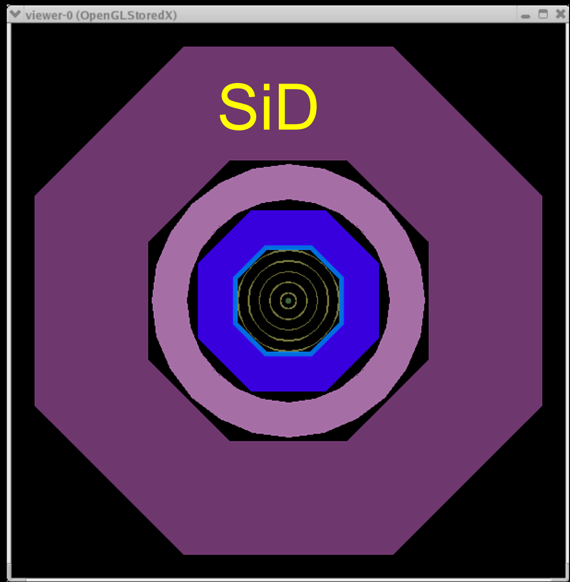


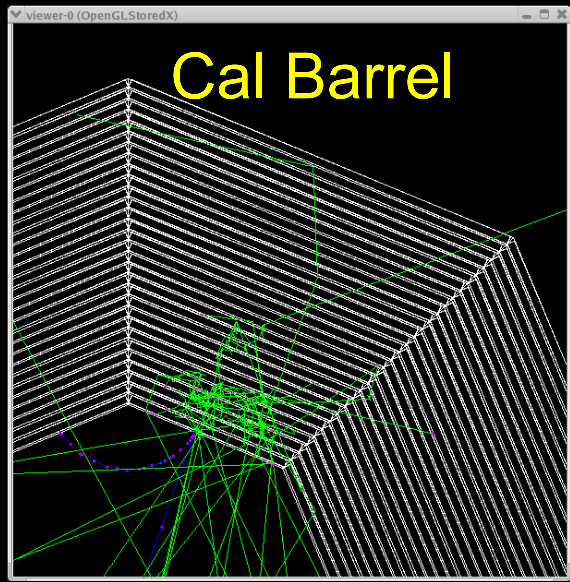
Detector Variants

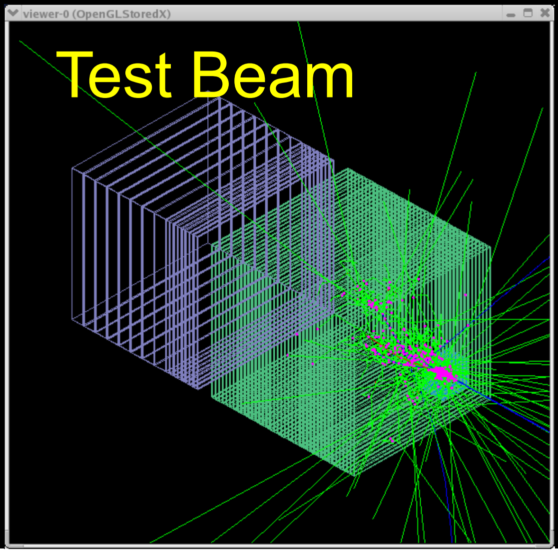
- Runtime XML format allows variations in detector geometries to be easily set up and studied:
  - Absorber materials and readout technologies for sampling calorimeters
    - e.g. Steel, W, Cu, Pb + RPC vs. GEM vs. Scintillator readout
  - Optical processes for dual-readout or crystal calorimeters
  - Layering (radii, number, composition)
  - Readout segmentation (size, projective vs. nonprojective)
  - Tracking detector technologies & topologies

Example Geometries

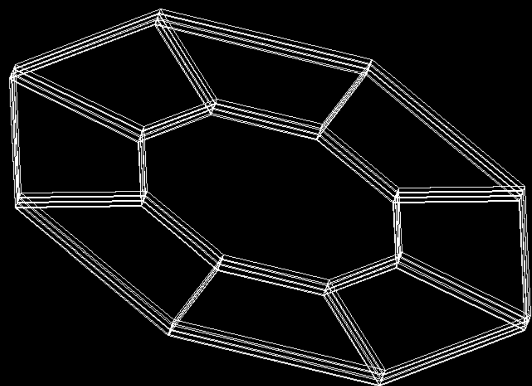




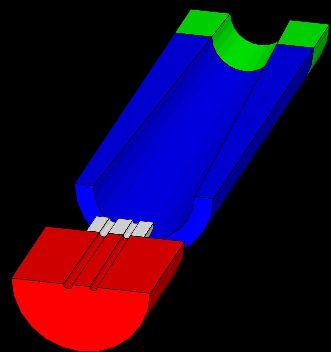




Cal Endcap

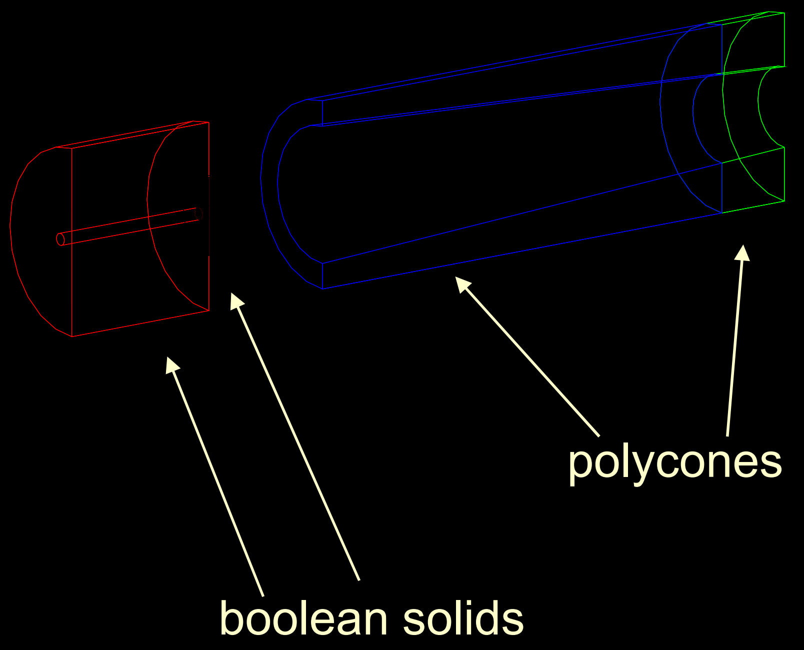


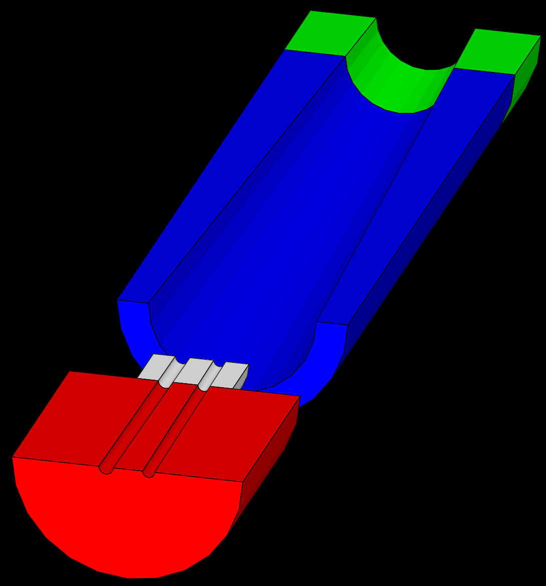
MDI-BDS



Far forward calorimetry

Machine Detector Interface and Beam Delivery System





Simulation Output

- Uses LCIO, a lightweight persistency framework for LC simulations.
  - FORTRAN, C++ & Java bindings
- Simulation produces collections of:
  - MCParticles
    - both generator-level and secondaries produced in Geant
  - SimTrackerHits
    - Full information about position-sensitive detectors
  - SimCalorimeterHits
    - Full information from showering detectors.

Tracker Hit

- **MC Track producing hit**
- Encoded **detector ID** (detector dependent)
- Global **hit position at entrance** to sensitive volume
- Global **hit position at exit** of sensitive volume
- **Track momentum** at entrance to sensitive volume
- **Energy deposited** by track in sensitive volume
- **Time** of track's crossing

- Hit number
- Local hit position at entrance to sensitive volume
- Local hit position at exit of sensitive volume
- Step size used by simulator in sensitive volume

Tracker Digitization

- The simulation of the electronic response to the energy deposied by tracks is done as part of the reconstruction.
- Necessary if one adds events together post-Geant.
- Allows flexibility in studying layout of e.g. TPC endplate readout pads, or silicon module size, silicon readout technology (strip or pixel), or readout pitch.

Tracker Digitization

- Flexible “virtual segmentation” package developed by D. Onoprienko enables study of silicon sensor layout/readout to be studied.
  – define simplified geometry (cylindrical or large disk)
- Once design is settled, define the realistic “planar” geometry in Geant and use detailed silicon response packages to digitized
  – Very complete, multi-technology pixel response package by N. Sinev
  – Silicon strip response package by T. Nelson.

Calorimeter Hit

- Encoded detector ID (detector dependent)
- MC ID, time and energy deposited by each contributing particle

- Hit Number
- Cell position
  - Radius, Phi, Z of cell
  - X, Y, Z of cell
- Total energy deposited in cell

Calorimeter Digitization

- Can define small readout cells in Geant, then gang together to study effects of cell size.
- Very flexible package (digisim, G. Lima) to handle effects of:
  - cross-talk
  - efficiency
  - noise
  - pedestals
  - nonlinear-response
  - timing,
  - etc.

Reconstruction

- Ab initio track finding and fitting available in all of the LC packages (emphasis on TPC in Asian and European packages, all-silicon in ALCPG).
- Calorimeter clustering and track association with PFA in mind done for SiD, ILD Concepts.
  - produces a list of ReconstructedParticle objects.
  - Goal is 1:1 correspondence to MCParticle.
- Dual-readout approach taken by 4th Concept.

Summary

- The regional Linear Collider detector simulation groups have developed a suite of tools being used to design detectors for the ILC.
  - slic / org.lcsim
  - Jupiter / satellites
  - Mokka / Marlin

  } **LCIO**
- Flexible, fully-featured Geant4-based detector response packages stress different aspects of the design cycle, but use of common output data model and persistency format allows intercommunication.
  - Can benefit from the strengths of each package.

Additional Information

- ILC Forum - http://forum.linearcollider.org
- Wiki - http://confluence.slac.stanford.edu/display/ilc
- lcsim.org - http://www.lcsim.org
- ilcsoft - http://ilcsoft.desy.de
- acfahep - http://acfahep.kek.jp/subg/sim
- LCIO - http://lcio.desy.de