ALCPG Physics & Detector Simulation Toolkit

Norman Graf (SLAC)
(for the ALCPG Simulation & Reconstruction WG)

Muon Collider Physics & Detectors Study Group

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LCD Simulation Mission Statement

- Provide full simulation capabilities for Lepton 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.

Path Forward

- Defining characteristic of the μC detector environment is the large number of background particles.
- Two major consequences:
  - Shielding limits the acceptance and hermiticity of the detector.
  - Sensitive detectors required to be rad-hard and highly segmented to disambiguate signal from noise hits.

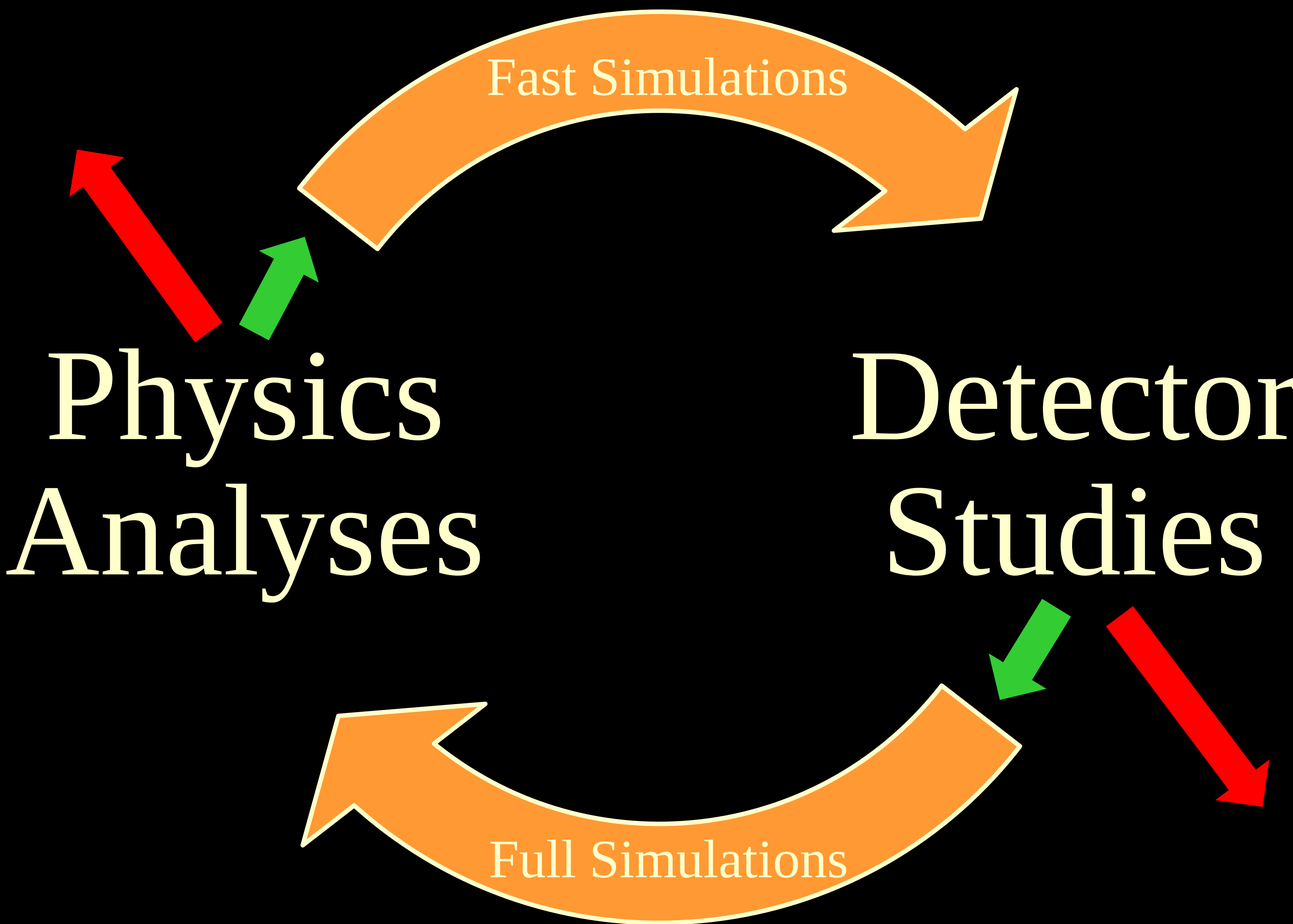
Can this Detector do the Physics?

- The impact of loss of angular acceptance and hermiticity can be studied fairly straightforwardly using fast detector response simulations.
- Establish a series of "fail fast" requirements on the analysis using:
  - Unsmeared MC particle 4-vectors
  - Individually smeared MC particle 4-vectors
  - Full detector simulation reconstruction w/o backgrounds
  - Full detector simulation reconstruction with backgrounds
- Analyses can be conducted by the theory community using fastMC tools.

Can this Detector take the Data?

- High backgrounds have two major detector impacts
  - require rad-hard technologies
  - require excellent segmentation to handle hit densities
- Establish a series of “fail fast” requirements on the detector using:
  - Reasonable detector design (e.g. CMS tracker, not SiD)
    - do conversions unacceptably exacerbate occupancy problem?
  - Include explicit backgrounds from machine calculations
- Analyses can be conducted by the detector community using flexible full simulation tools.

Synergies


Fast Simulations
Physics Analyses
Detector Studies
Full Simulations

Couplings

- To be efficient, one needs a tightly coupled community of physicists, as well as an integrated simulation toolkit, capable of ensuring commensurate performance of a specific detector design in both fast and full response simulations.
- ALCPG toolkit provides:
  - fastMC: covariant track smearing, shower smearing
  - lelaps: fast swimming, dE/dx, MCS, produces hits
  - slic: full and flexible Geant4-based response
  - org.lcsim full event reconstruction & analysis package

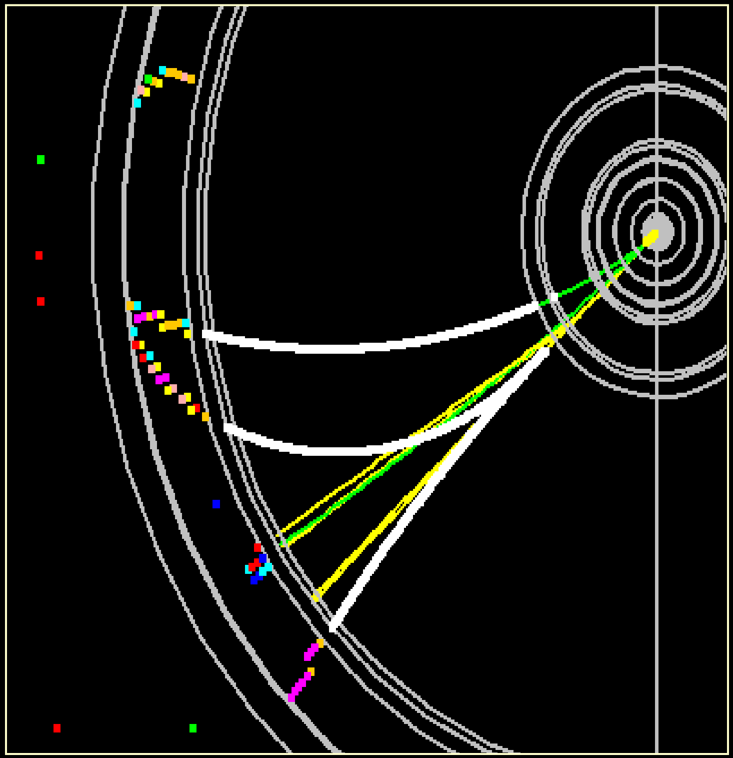
Fast Detector Response Simulation

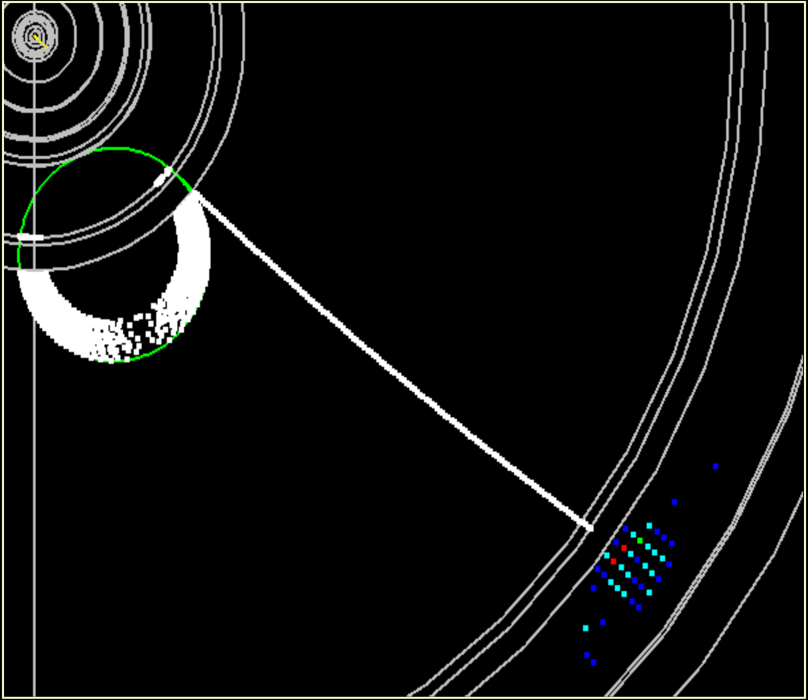
- Covariantly smear tracks with matrices derived from geometry, materials and point resolution using Billoir's formulation.
  - Analytically from geometry description.
- Smear neutrals according to expected calorimeter resolution (EM for γ, HAD for neutral hadrons)
  - Derived from full Geant4 simulations
- Create reconstructed particles from tracks and clusters (γ, e, μ from MC, $\pi^{+/-}$, K^0_L for others)
- Can also dial in arbitrary effective jet energy resolution.
  - Derived from full simulation, reconstruction & analysis.

lelaps

- Fast detector response package.
- Handles decays in flight, multiple scattering and energy loss in trackers.
- Parameterizes particle showers in calorimeters.
- Produces detector data at the hit level.
  – Feeds directly into full reconstruction.
- Uses runtime geometry (compact.xml → godl).

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.

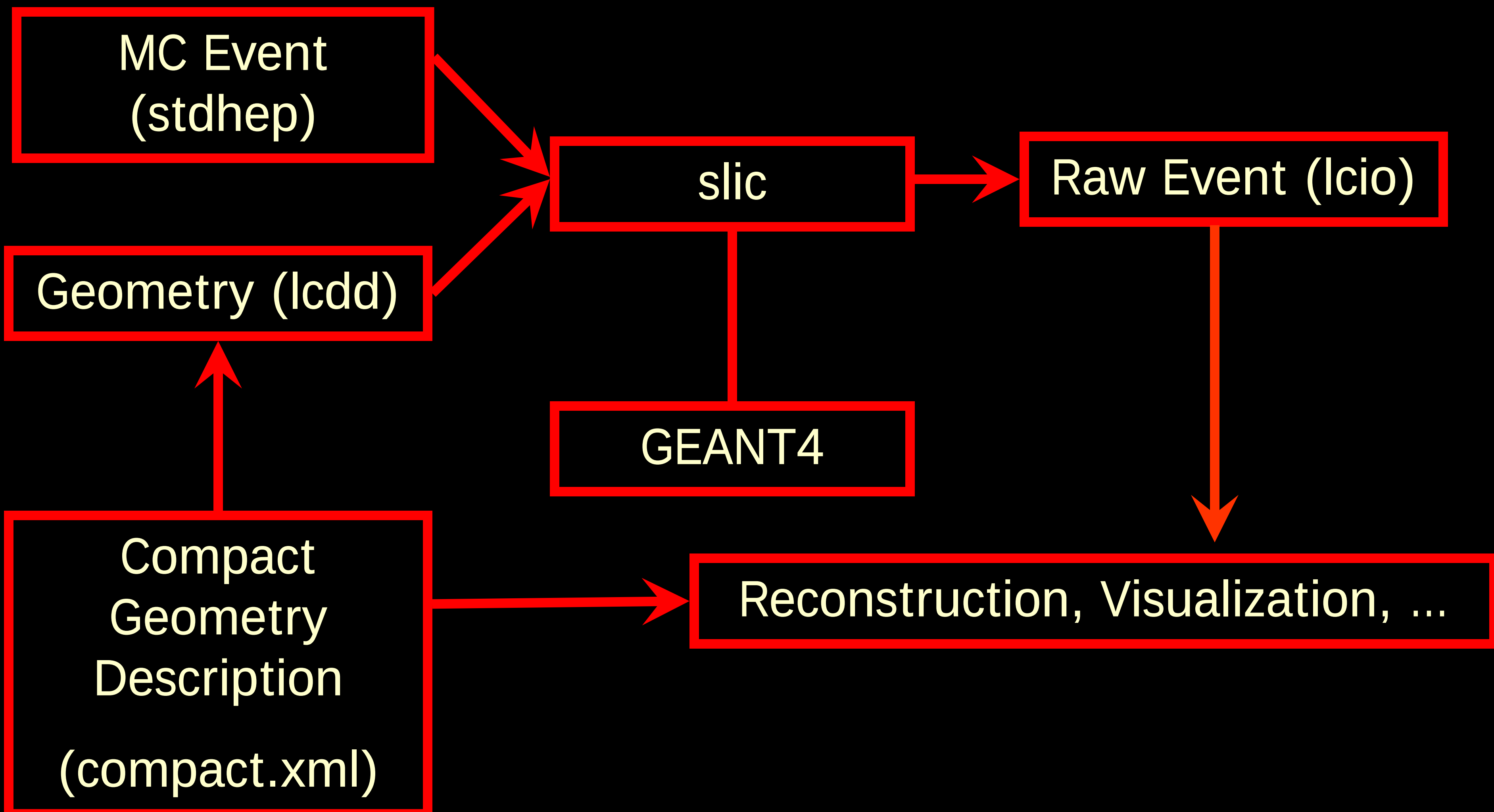
Detector Design (GEANT 4)

- 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.

Full Detector Response Simulation

- Use Geant4 toolkit to describe interaction of particles with matter.
- Thin layer of LC-specific C++ 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.

LC Detector Full Simulation

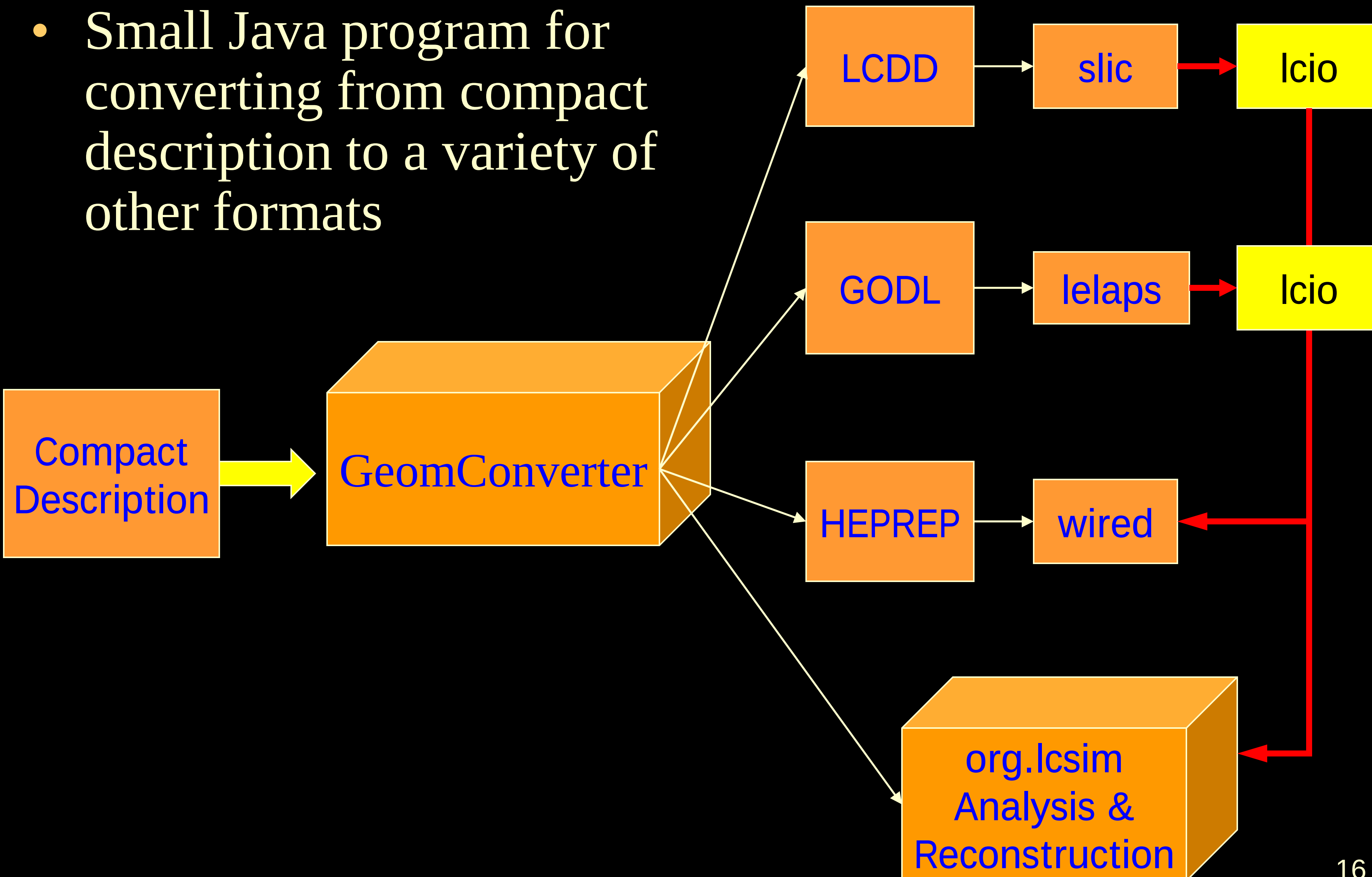


Detector Variants

- 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, field strength, etc.

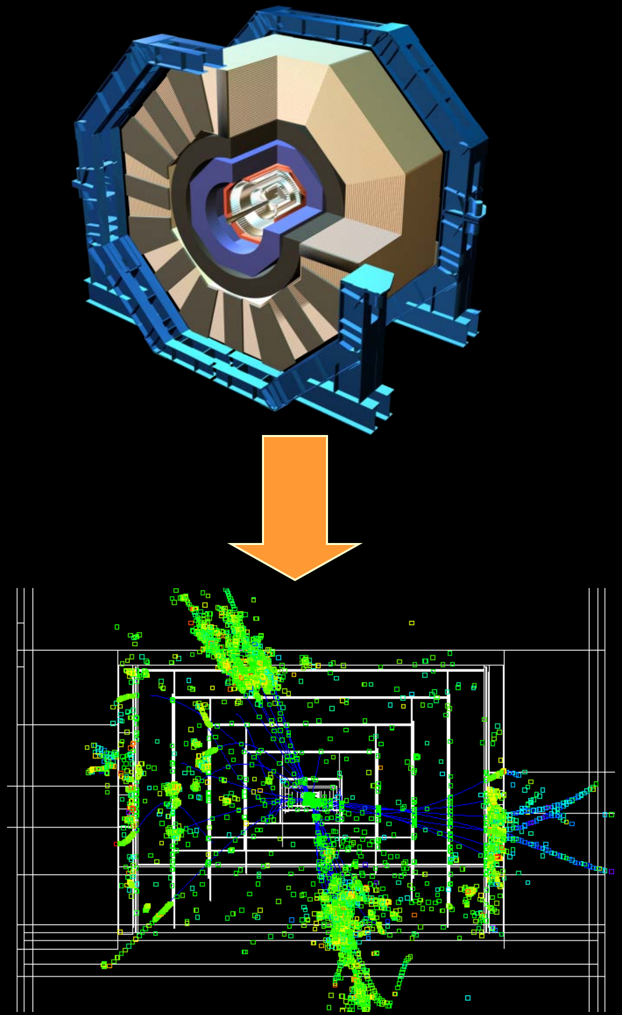
GeomConverter

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

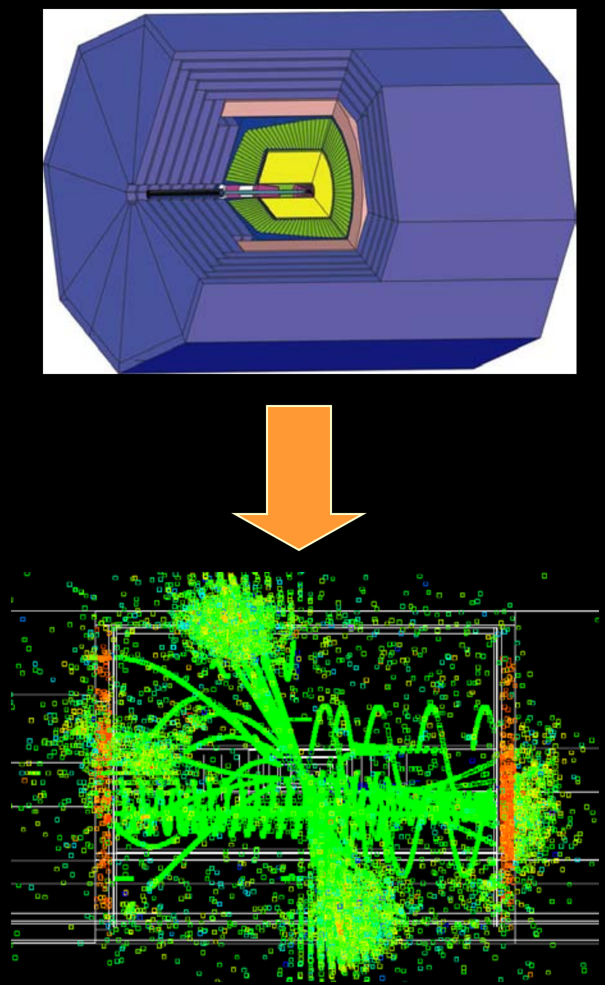


ILC Full Detector Concepts

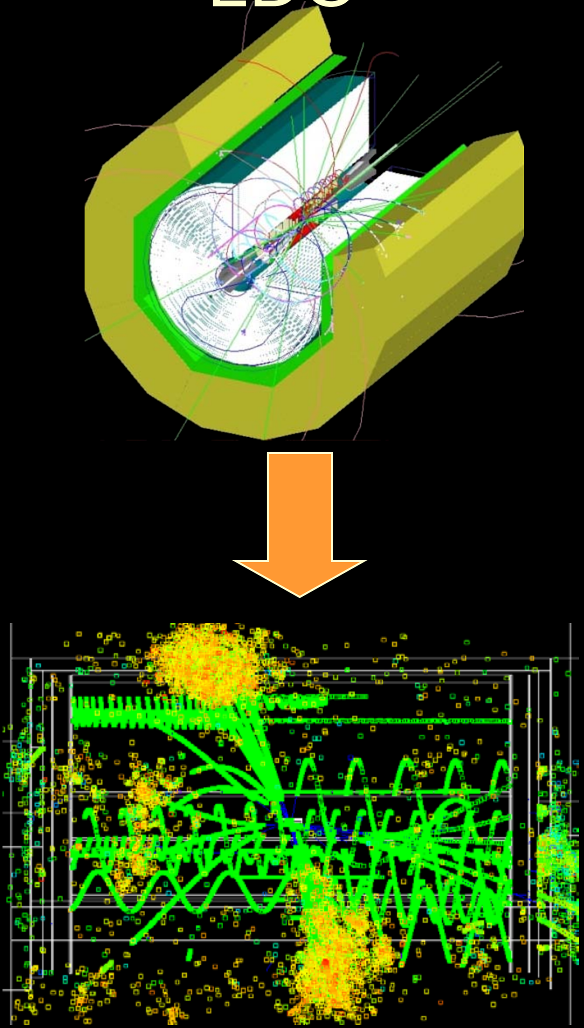
SiD



GLD



LDC



slic: The Executable

- Build static executables on Linux, Windows, Mac.
- Commandline or G4 macro control.
- Only dependence is local detector description file.
  – Trivial Grid usage (no database call-backs, etc.)
  – Grid ready, Condor and lsf scripts available.
- Event input via stdhep, particle gun, …
- Detector input via GDML, lcdd
- Response output via LCIO using generic hits.
- Fast and flexible (cuts, regions, physics lists)
- No license requirement

Reconstruction/Analysis Overview

- Java based reconstruction and analysis package
  - Runs standalone or inside Java Analysis Studio (JAS)
  - Fast MC $\rightarrow$ Smeared tracks and calorimetry clusters
  - Full Event Reconstruction
    - Beam background overlays at detector hit level, including time offsets.
    - detector readout digitization (CCD pixels, Si μ-strips, TPC pad hits)
    - *ab initio* track finding and fitting for ~arbitrary geometries
    - multiple calorimeter clustering algorithms
    - Individual Particle reconstruction (cluster-track association)
  - Analysis Tools (including WIRED event display)
  - Physics Tools (Jet Finding, Vertex Finding, Flavor Tagging)
- Write once run, run anywhere
  - Exact same libraries run on all platforms (Windows, Mac, Linux(es), Grid) using the Java Virtual Machine.

Tracking

- Analytic covariance matrices available for fast MC smearing for each detector.
- Track “cheater” available for studies of full detector simulation events. Assigns hits on basis of MC parentage.
- Ab initio track finding packages.
- Fitting code incorporating multiple scattering and energy loss via weight matrix or Kalman Filter available.

Tracking Detector Readout

- Hits in Trackers record full MC information.
- Module tiling and signal digitization is deferred to analysis stage.
  - Used to rapidly study many possible solutions.
- Fully-featured package to convert MC hits in silicon to pixel hits. Fully configurable at runtime.

  MC Hits→ Pixel ID & ADC→ Clusters→ Hits (x   δx)
- Can correctly study occupancies, overlaps, ghost hits, etc.

Track Finding

- Standalone pattern recognition code for 1D (e.g. Si μstrip) and 2D (e.g. Si pixel) hits.
  - High efficiency, even in presence of backgrounds.
  - Efficient at low momentum.
- Conformal-mapping pattern recognition also available, applicable also to TPC.
- MIP stubs in highly segmented calorimeters also provide track candidates, propagate inwards to pick up tracker hits.

Validated

- This suite of software tools provides:
  - Physics event generation & bindings to most legacy generators through the stdhep format.
  - Full detector response simulation using precompiled binaries & runtime geometry definition (no coding!).
  - Full detector digitization (x-talk, noise, diffusion, etc.)
  - Hit-level overlay of arbitrary background events.
  - Access to other LCIO-compliant software frameworks.
  - Full ab-initio event reconstruction and analysis suites.
  - Tested on hundreds of millions of events.
- "From zero to analysis in 15 minutes."

Simulation Summary

- ALCPG sim/reco supports an ambitious international detector simulation effort. Goal is flexibility and interoperability.
- Provides a complete and flexible detector simulation package capable of simulating arbitrarily complex detectors with runtime detector description.
- Reconstruction & analysis framework was used to characterize the Silicon Detector and was essential to that concept's successful validation in the LOI process.
- Currently being used for CLIC studies.
- Being used to design Linear Collider Detectors, but has also been applied to other application domains.

Additional Information

- Wiki - http://confluence.slac.stanford.edu/display/ilc/Home
- lcsim.org - http://www.lcsim.org
- ILC Forum - http://forum.linearcollider.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