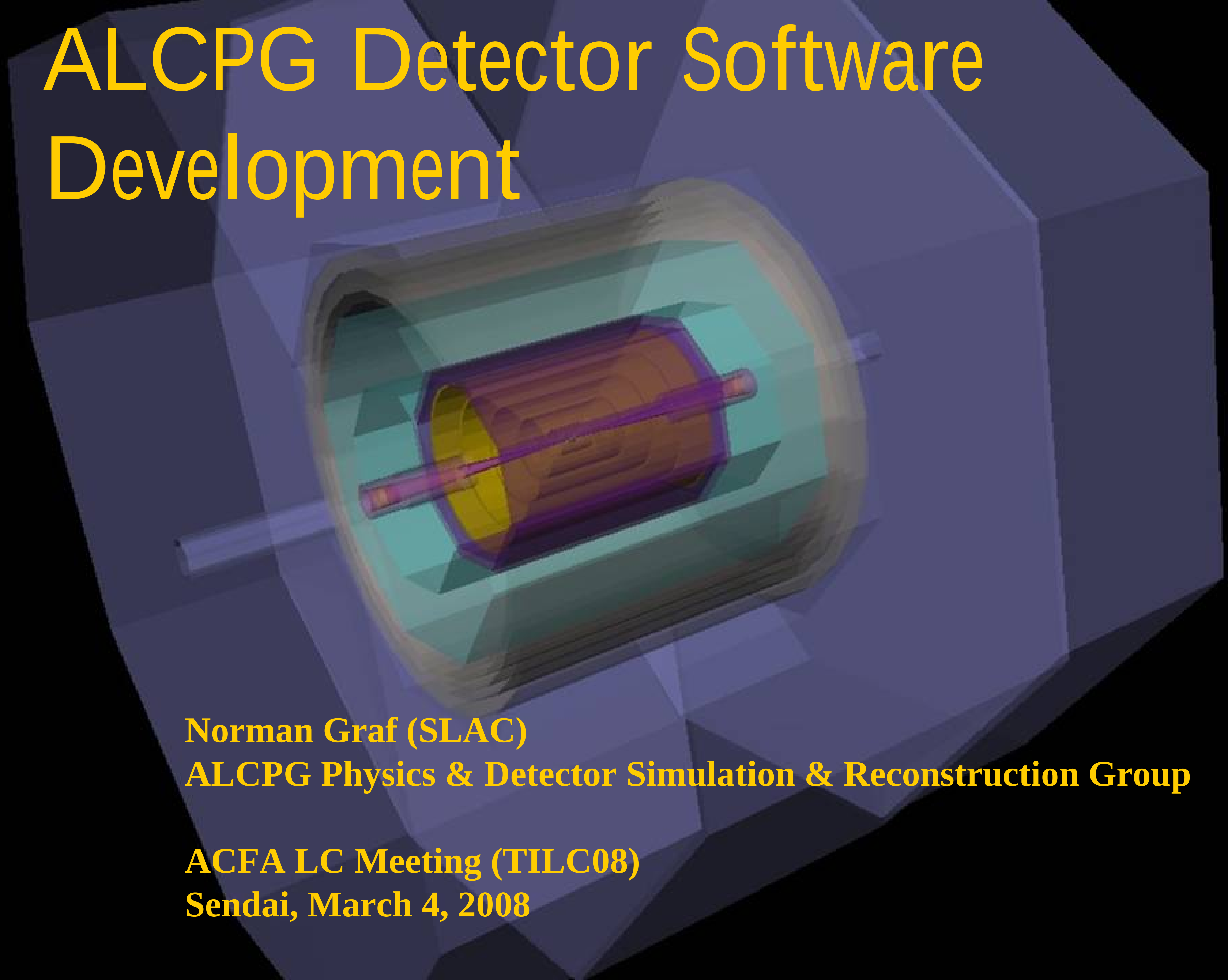
ALCPG Detector Software Development



Norman Graf (SLAC)
ALCPG Physics & Detector Simulation & Reconstruction Group

ACFA LC Meeting (TILC08)
Sendai, March 4, 2008

Software Development Overview

- Physics analyses.
  - Refine and strengthen the arguments for the ILC.
- Detector design.
  - Integrated system design for an optimal detector.
- Event reconstruction.
  - Demonstrate that proposed detector systems can conduct the physics program, and allows cost-benefit optimization to be done.
- Testbeam and prototype infrastructure.
  - Support subsystem design, readout and analysis.

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.
  - Strong connections between university groups, national labs, international colleagues.

Goals

- Facilitate contribution from physicists in different locations with various amounts of available time.
- Use standard data formats, collaborate & cooperate.
- 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.
- Software is easy to install, learn, use. “0 to analysis in 15 min.”
  - Goal is to allow software to be installed from CD or web with no external dependencies.
  - Support via web based forums, tutorials, meetings.

Fast Monte Carlo

- Despite the move towards more realistic, fully engineered detector designs, the need for fast Monte Carlo still exists.
  - Large statistics physics studies (see talk by T. Rizzo)
  - Understand full reconstruction needs and/or systematics
  - Perform first-pass filter on SM background sample & reduce number of events needed to be processed through GEANT
- FastMC
  - covariant track smearing, parameterized cluster smearing
- lelaps
  - fast track extrapolation with MCS & dE/dx, decays, tracker & cal. hit generation, param. shower shapes

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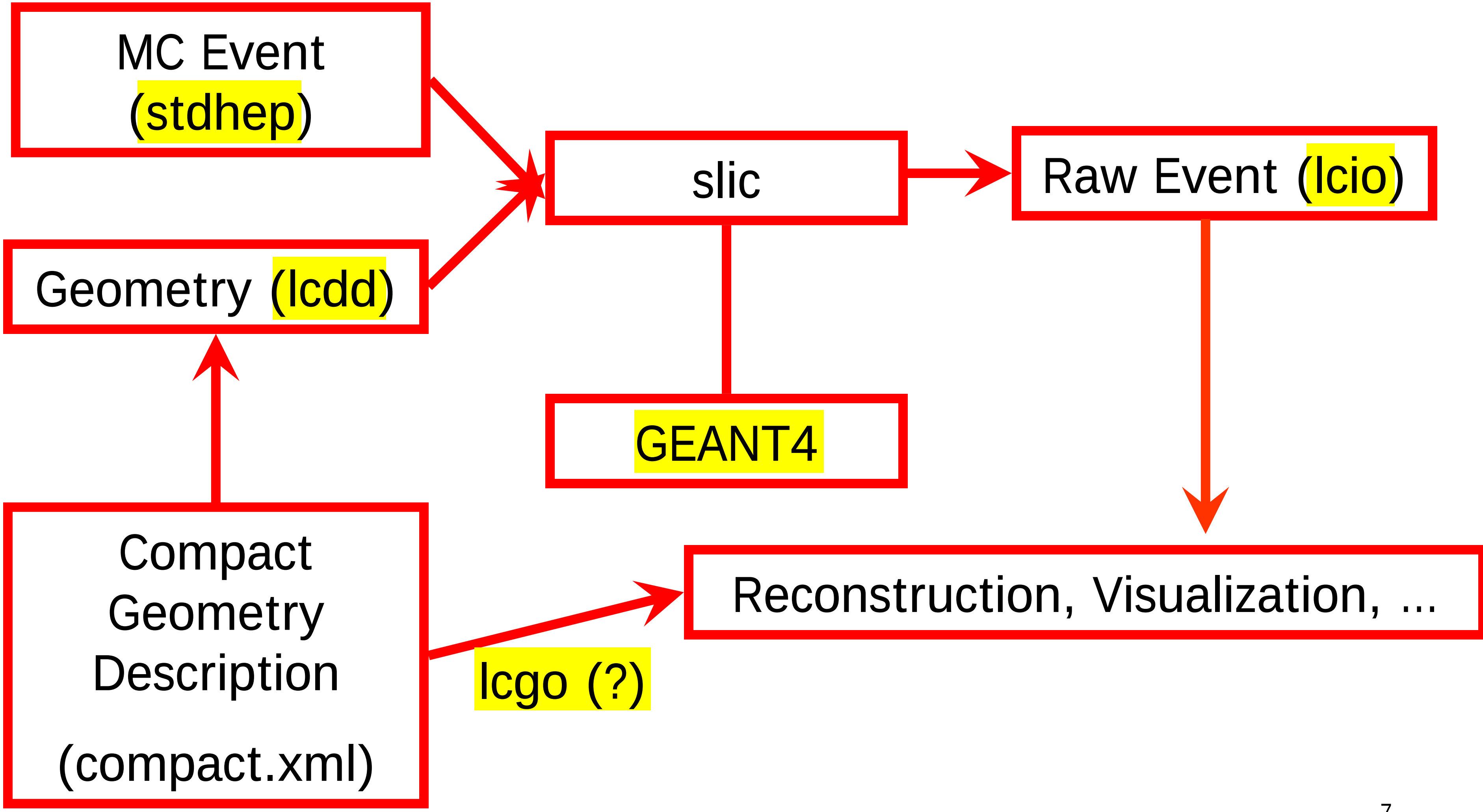
LC Detector Full Simulation

Items highlighted in yellow represent common standards



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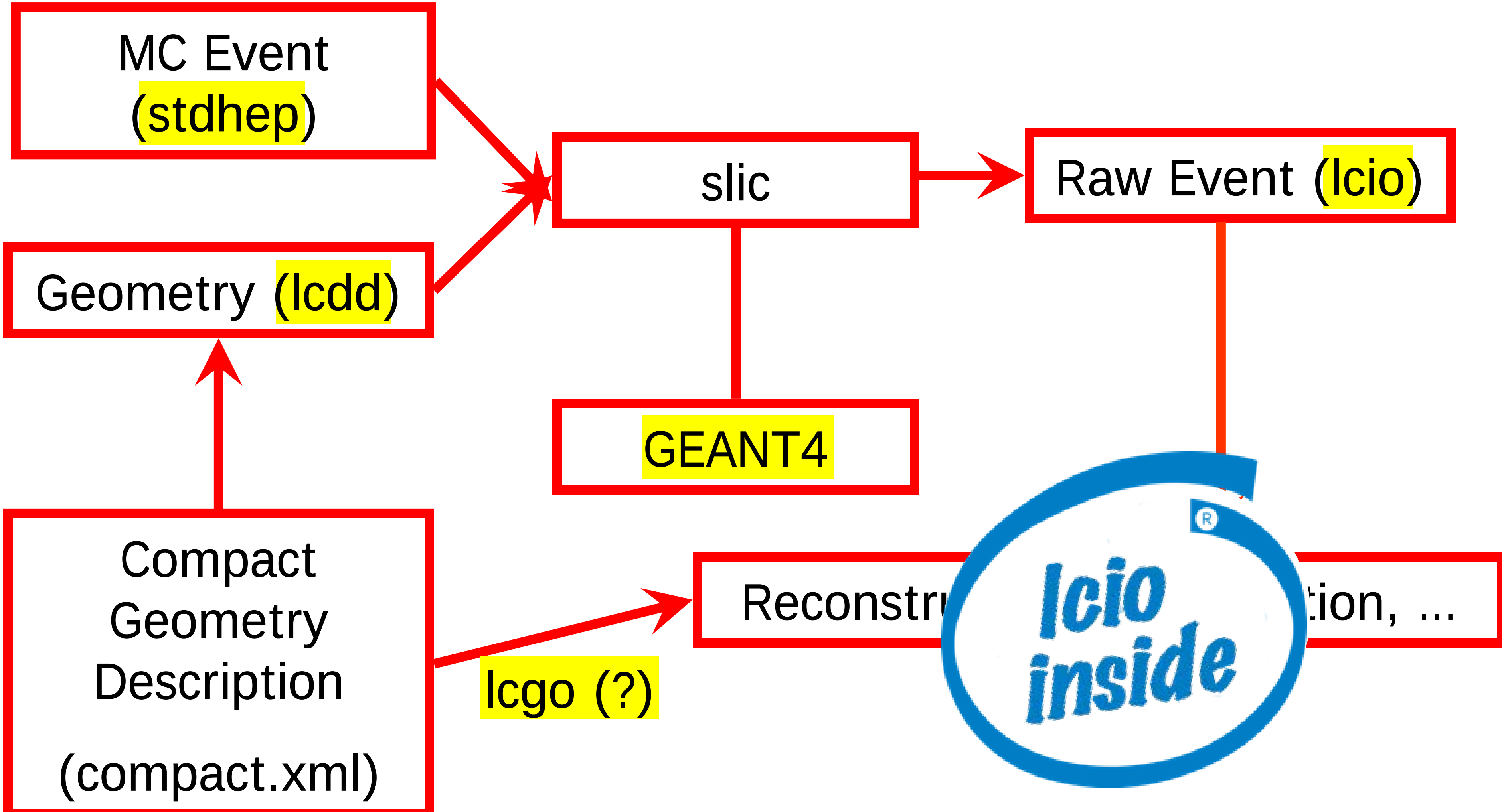


slic

- Number of internal optimizations and refactorings.
  - Should not be noticed by end users.
- Upgrades to recent version of Geant4 (9.1p1) has essentially eliminated problem of event aborts when particle tracking became stuck.
- Output file autonaming option provides provenance.

panpyZmumuh120-0-500_SLIC-v2r3p10_geant4-v9r0p1_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
```

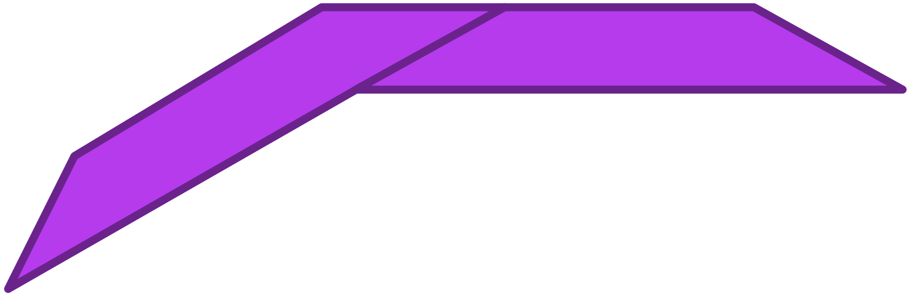
- Binaries also available for Windows, Mac, Linuxes

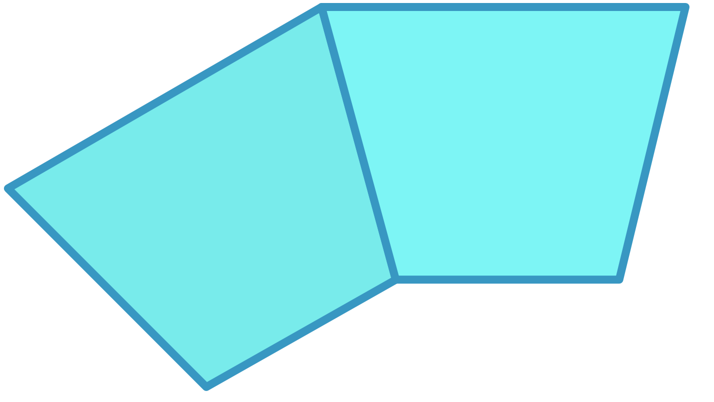
Detector Variants

- 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

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.

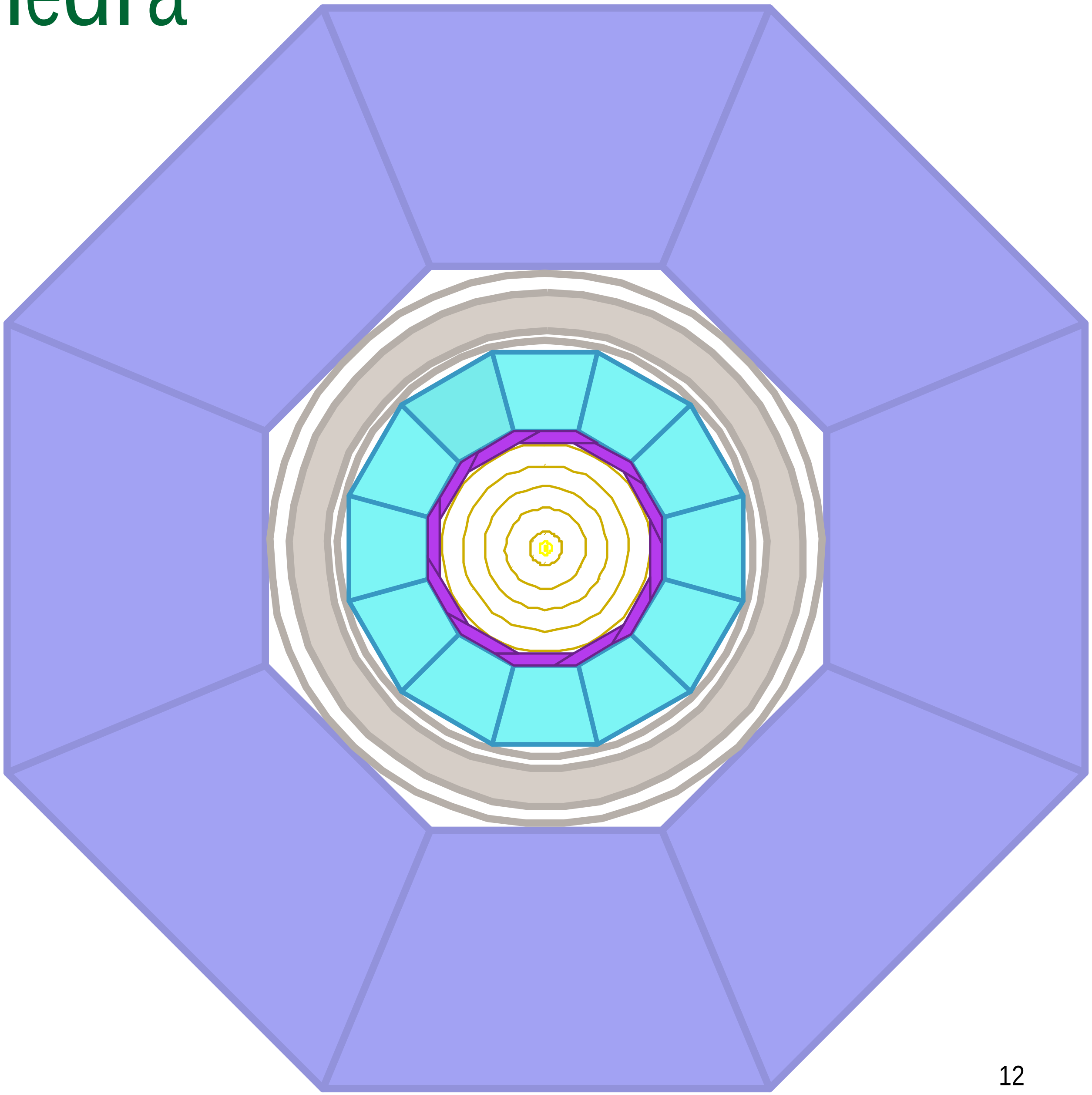
sid01_polyhedra

Dodecagonal, overlapping stave EMCal

Dodecagonal, wedge HCal

Cylindrical Solenoid with substructure

Octagonal, wedge Muon



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.

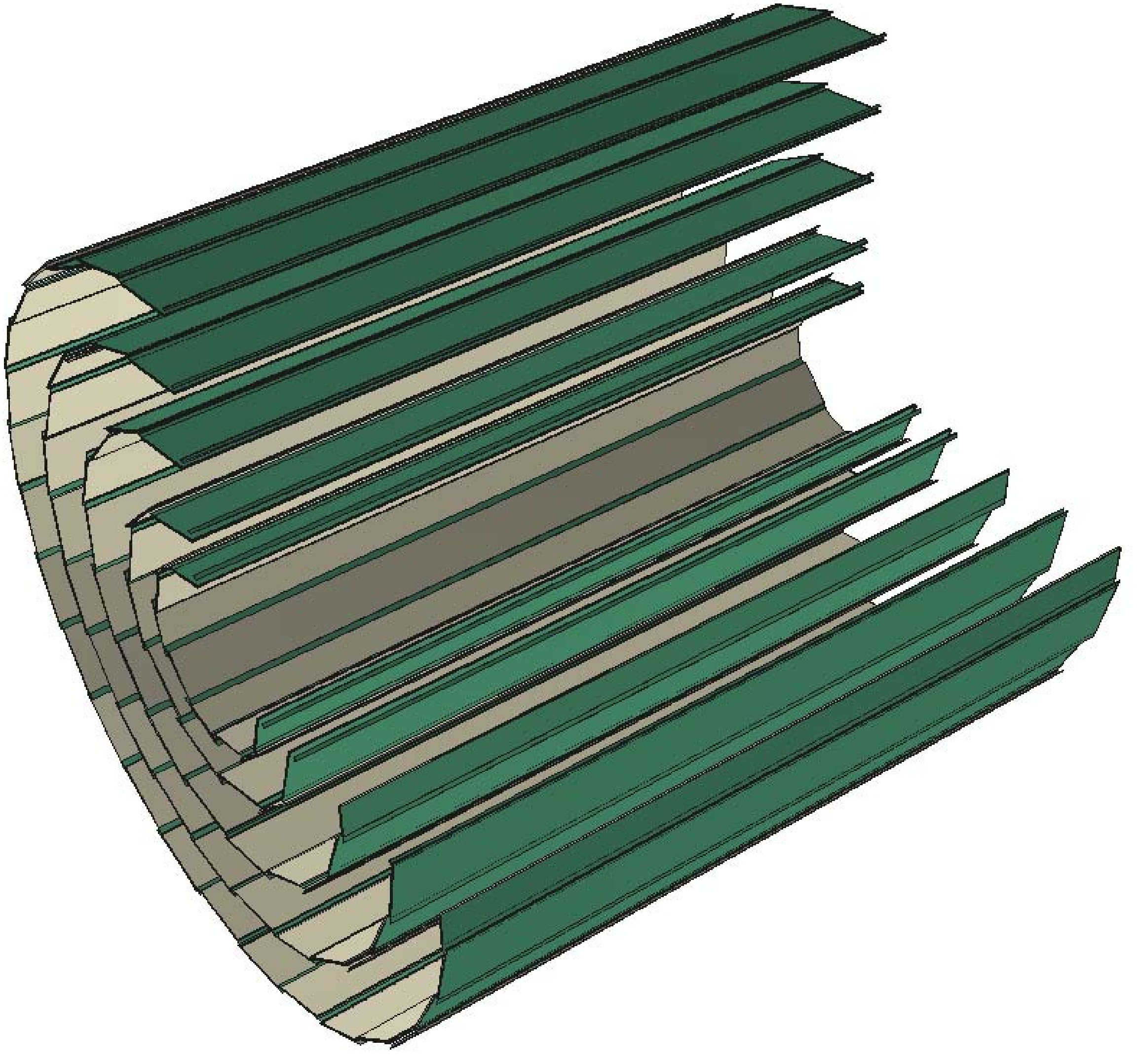
xml: Defining a Module

```
<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

```
<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

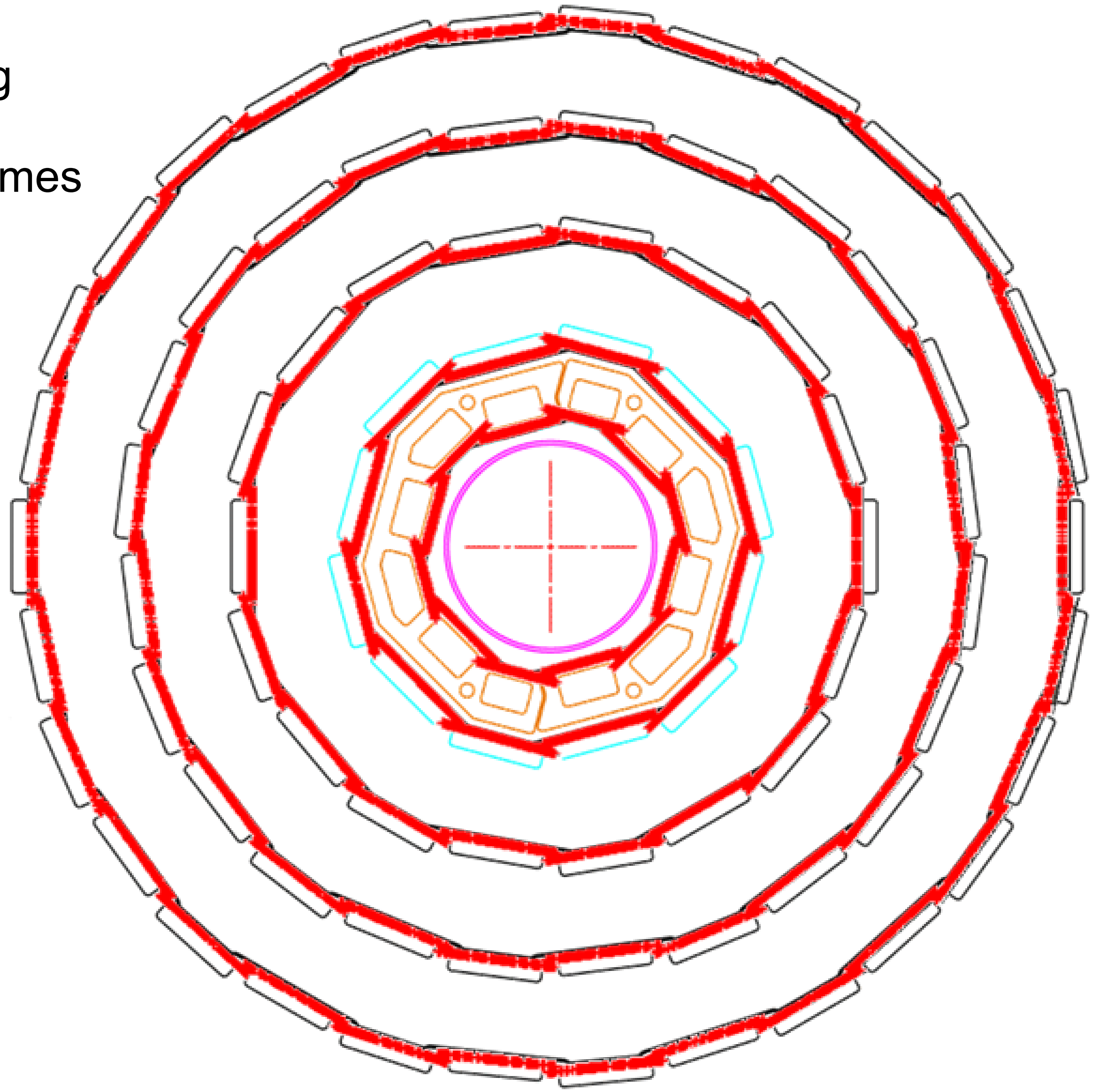


LCIO SimTracker Hits from Vertex

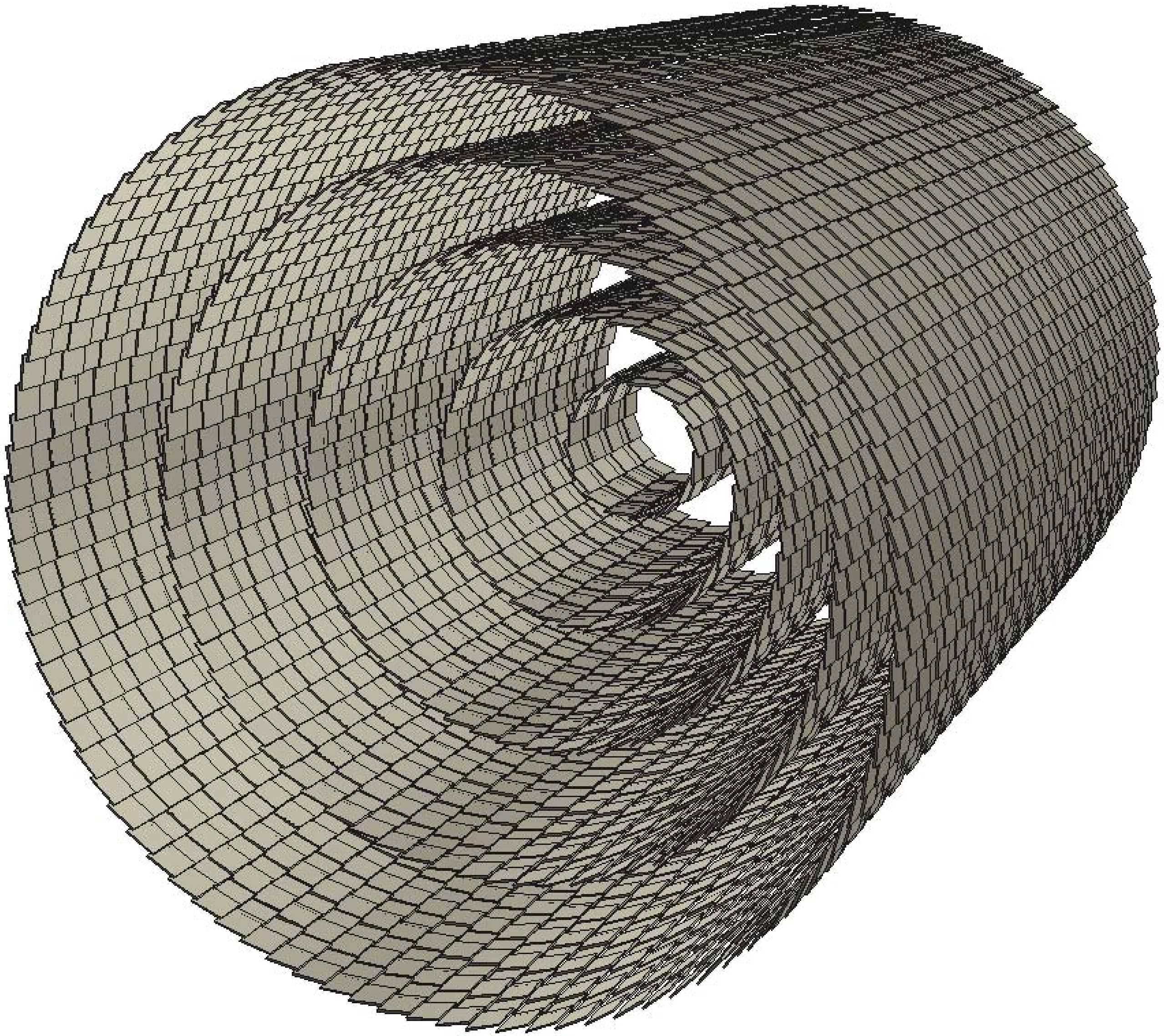
CAD Drawing

GEANT Volumes

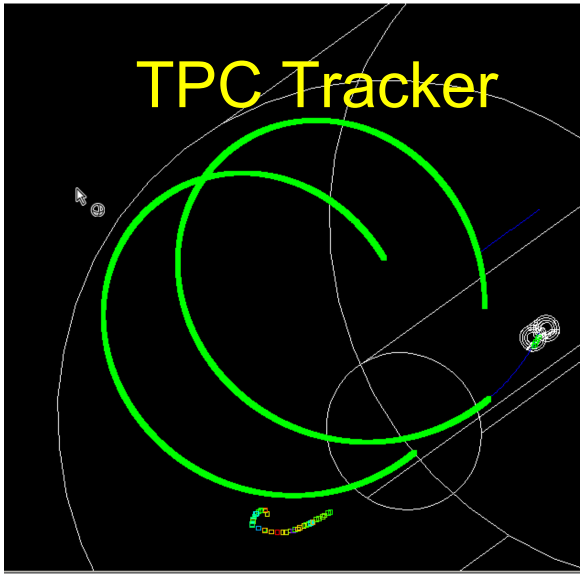
LCIO Hits

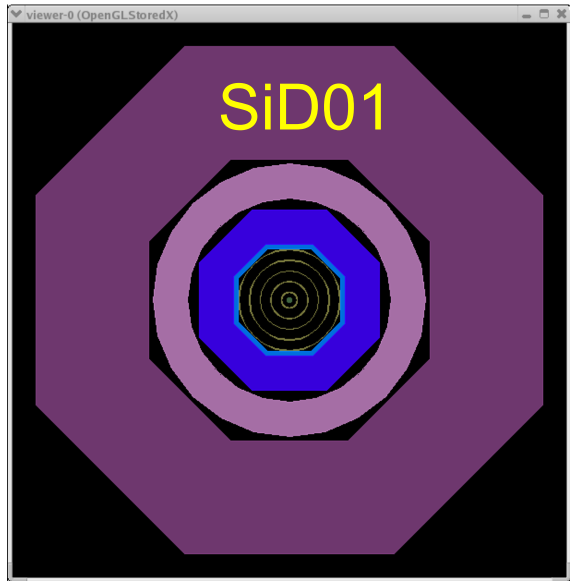


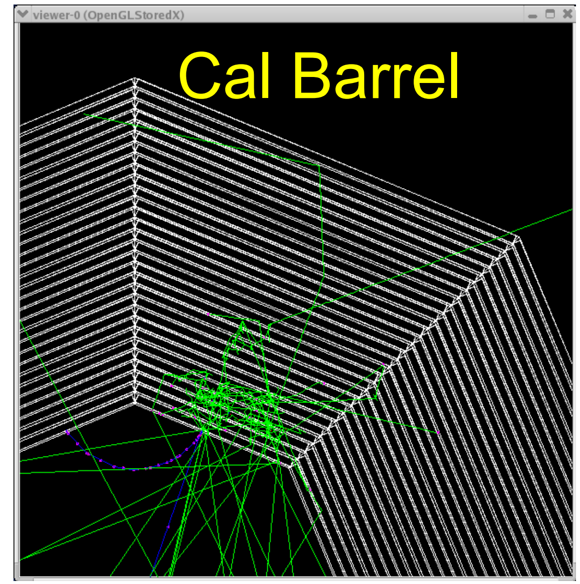
The Barrel Outer Tracker

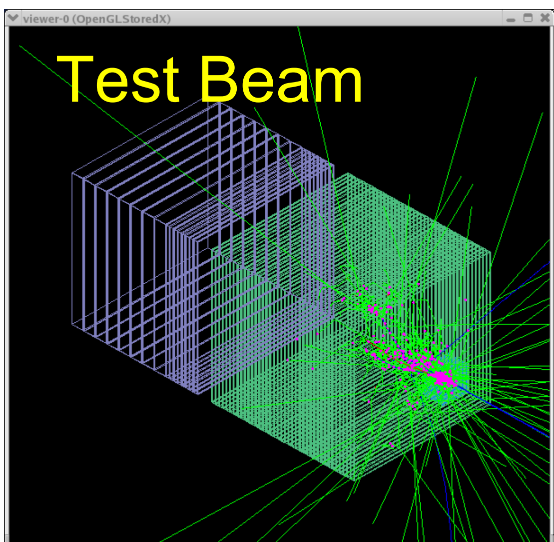


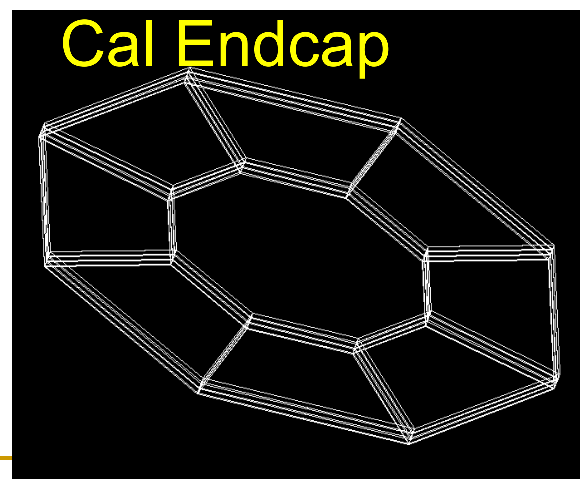
Example Geometries (same exe)



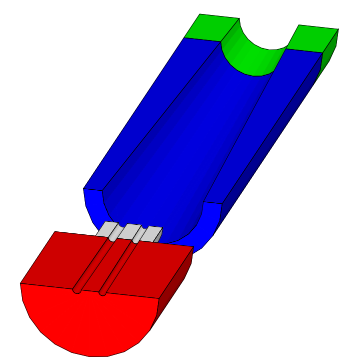








MDI-BDS

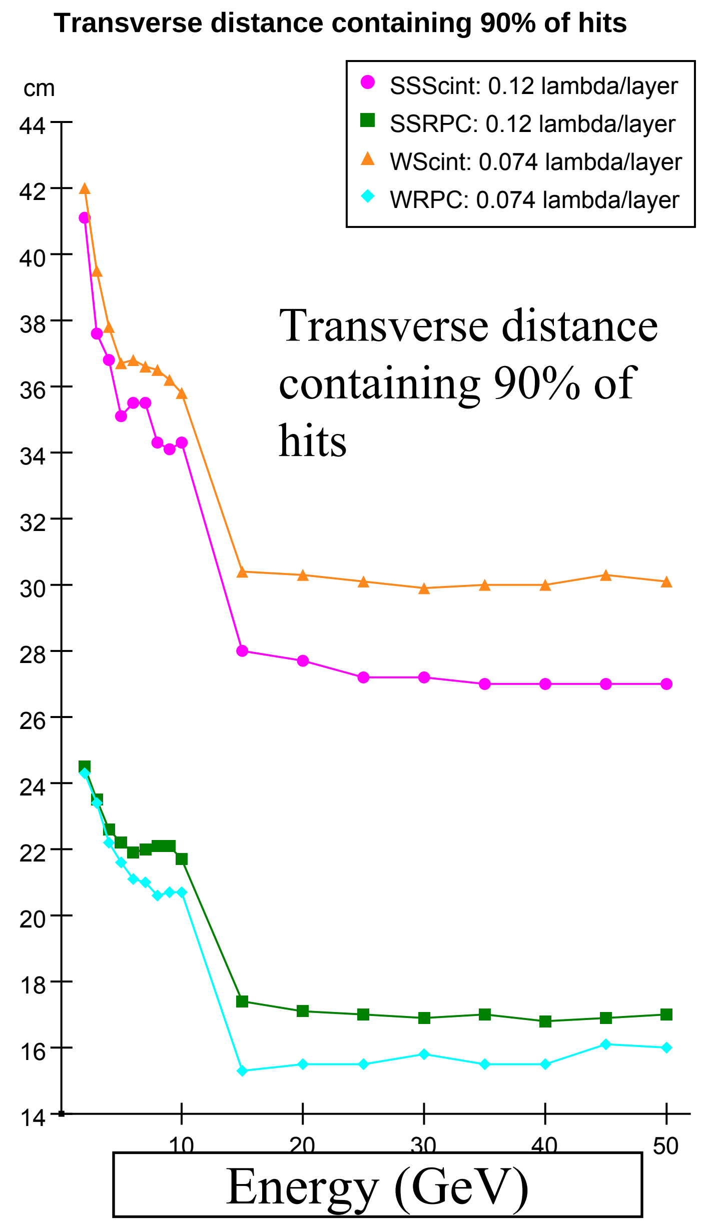


More complex geometries

- 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.

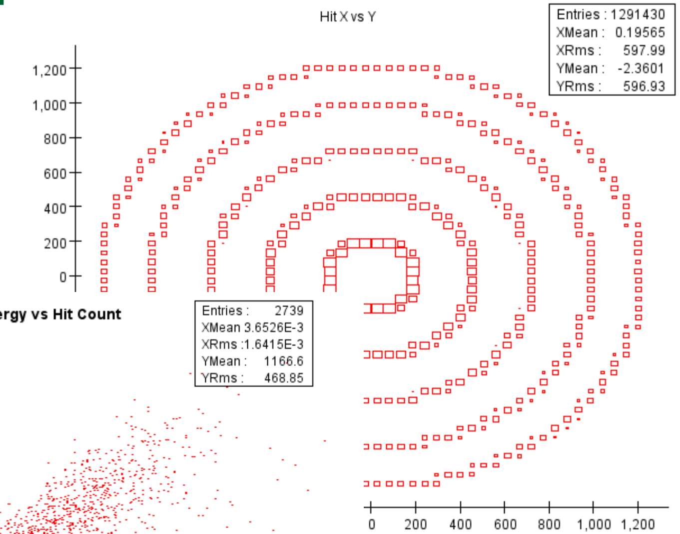
Physics Lists & Hadron Showers

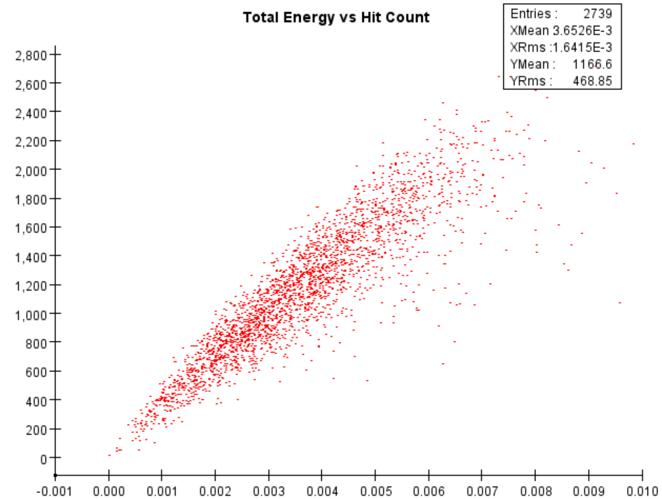
- Number of issues still unresolved with choice (or not) of showering models.
- For many neutral hadrons LHEP (Gheisha-inspired) is only choice.
- Transition regions still very worrisome.
- LCPhys is still default, but all lists available.
- FTFP_BERT looks good.

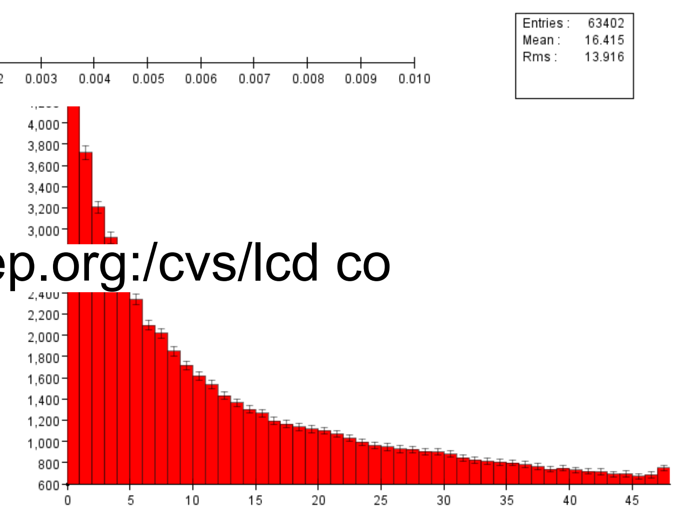


Diagnostic Histograms

- Diagnostic plots of event data
  - MCParticles, hits, clusters
- Runs on different detectors
  - must have compact description
  - also need sampling fractions
- Easy to use and setup
- on the web at
  - http://lcsim.org/SlicDiagWeb/
- SLAC CVS project
  - cvs –d :pserver:anonymous @cvs.freehep.org:/cvs/lcd co SlicDiagnostics
  - ./build.sh
  - ./bin/SlicDiagnostics [...]

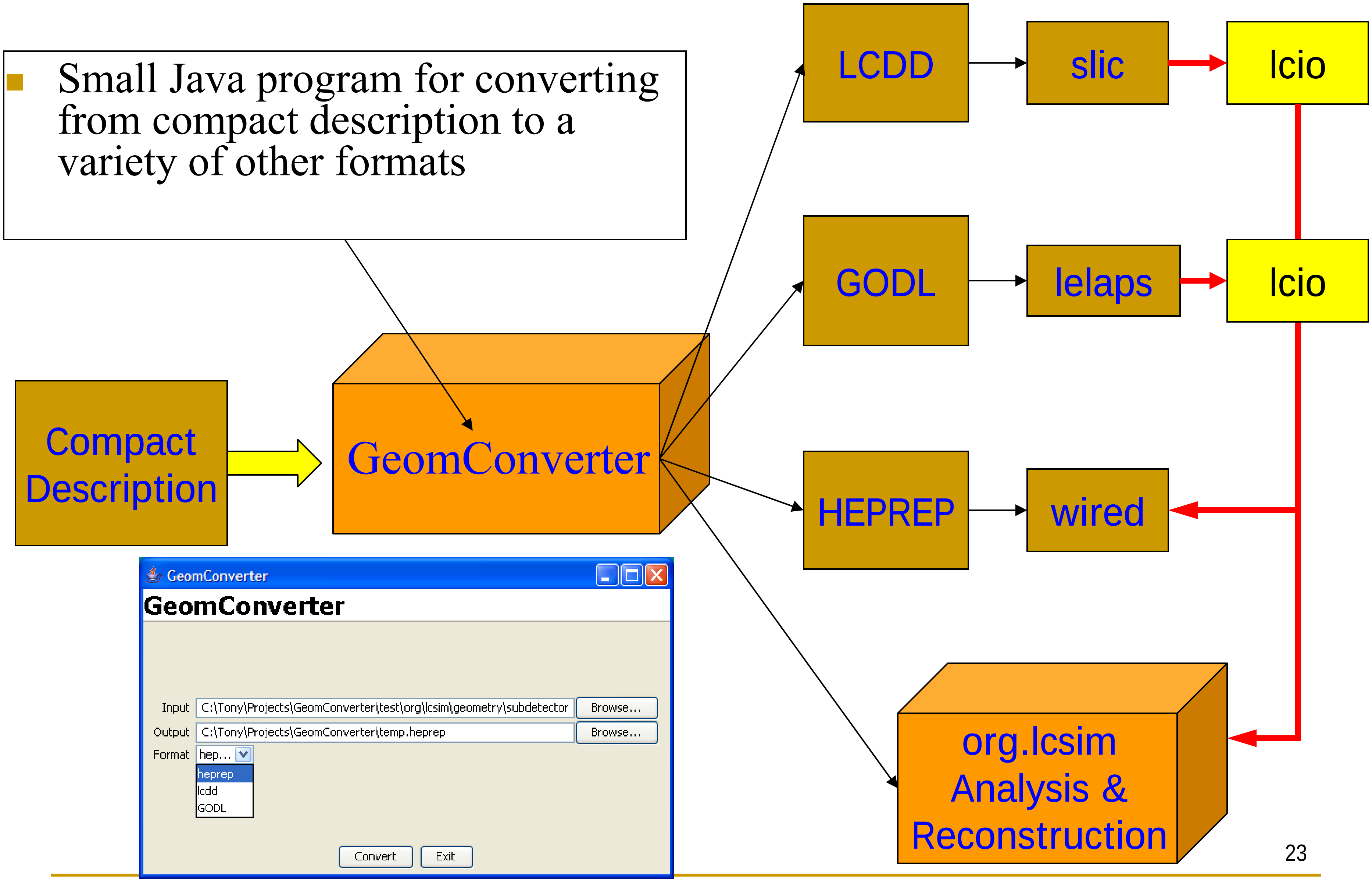






GeomConverter

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



Hit modules and strips in Wired

Event 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, …
- Z Pole events: comparison to SLD/LEP
- WW, ZZ, $t\bar{t}$, $q\bar{q}$, tau pairs, mu pairs, Zγ, Zh
- beam pairs, muons, $\gamma\gamma\rightarrow$ hadrons, etc. backgrounds
- inclusive 1 ab^{-1} Standard Model sample
- Web accessible http://www.lcsim.org/datasets/ftp.html
- Additive at the detector hit level, with time offsets.
  - Investigate effects of full backgrounds.

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

Reconstruction Toolkit

- Core reconstruction algorithms (track finding, fitting, calorimeter clustering, etc.) are in place.
- Interfaces defined for tasks, with many different plug-&-play implementations (e.g. calorimeter clustering).
- Standardized algorithm comparison tools.
- Analyses targeted to ReconstructedParticles
  - Decouples interdependencies of different tasks.
  - Allows comparisons between different algorithms or implementations.
  - Easily swap in MC "cheater" to study effects of particular analysis task, independent of other tasks.
  - Physics analyses can be developed and tested using fast Monte Carlo smearing, seamlessly transition to full reco.

Individual Particle Reconstruction

- Reconstruction is complex & you have to get many individual steps right:
  - track finding, fitting & extrapolation
  - track-cluster matching
  - MIP identification
  - photon identification
  - hadronic shower clustering (digital vs analog, scintillator vs gaseous readout)
  - handling of displaced secondaries
  - calibration of photons
  - calibration of neutral hadrons
  - E/p cut (including calibration)
- Algorithm development isn't about finding the "magic bullet" perfect algorithm. It's about iteratively
  - finding the worst problems that are limiting performance
  - fixing them
  - hopefully seeing things improve a little
  - finding the next worst problems

M. Charles

Individual Particle Reconstruction

- Algorithms being developed with minimal coupling to specific detector designs.
  - Will allow full phase space of detector designs to be studied in a common framework.
- Finishing development of common infrastructure tools
  - Calibration method for detector models
  - Perfect PFA prescription
- Released reconstruction template
  - Enables e.g. Cluster algorithm substitution, CAL hit/cluster accounting
  - Migrating individual analyses into this framework
- Optimization & Standardization of reconstructors
  - Photon & muon finders fairly mature, close to release (meeting @ Clermont-Farrand in July)
- Use of LCIO allows (in principle) exchange of algorithms across language, OS and regional boundaries.
- Analysis emphasis on dijet invariant mass resolution in physics events
  - Currently $e^+e^- \rightarrow ZZ \rightarrow (\nu\bar{\nu})(q\bar{q})$ (No jet combinatorics, uds) (2)
  - Next in line $e^+e^- \rightarrow ZZ \rightarrow (q\bar{q})(q\bar{q})$ & $e^+e^- \rightarrow ZZ\nu\bar{\nu}$, $WW\nu\bar{\nu}$ (4)
  - $\rightarrow t\bar{t}$ (6)
  - $\rightarrow t\bar{t}h$ (8)

- Plan to release "canned" physics analyses to reduce systematic uncertainties in e.g. jet-finding, combinatorics, constrained fits, …

Performance Comparisons

- Reconstructing boson decays into dijets requires exceptional jet energy and direction resolution, is one of the driving forces in the current round of software development and will be used as a metric in the design of the detectors.
- Community benefits from close cooperation & collaboration.
  - Common input data samples (events in stdhep format)
  - Common simulation/reconstruction output formats
    - List of ReconstructedParticles in LCIO format
- Most important aspect of interoperability with other regional simulation and reconstruction efforts is a common data model!

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Root(?)

- ALCPG sim/reco group fully supported a Root-based environment starting in 1999.
- See, for instance, nice talk by M. Iwasaki at LCWS00

http://conferences.fnal.gov/lcws2000/web/Iwasaki_sessionD1/Iwasaki_sessionD1.pdf

- Documentation at:

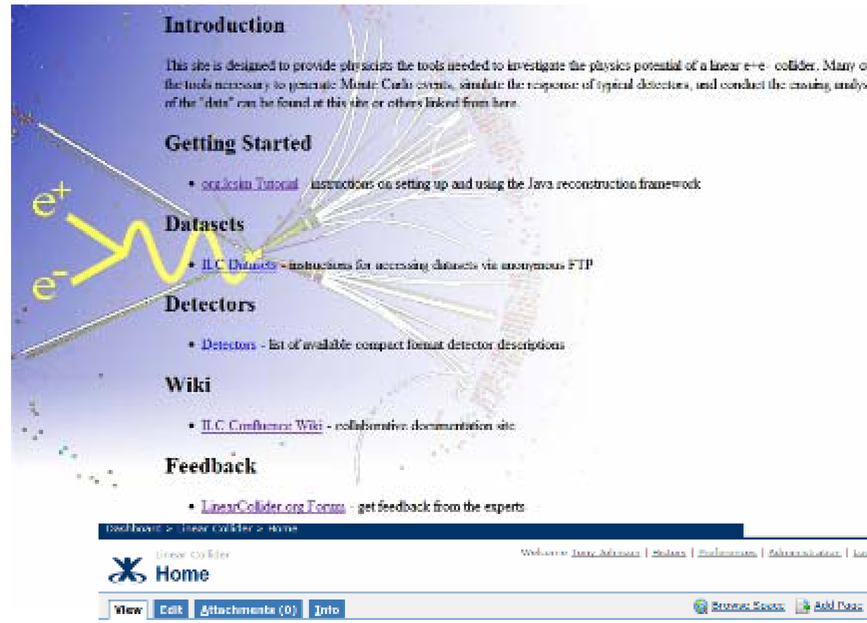
  http://www-sldnt.slac.stanford.edu/nld/New/Docs/LCD_Root/intro.htm

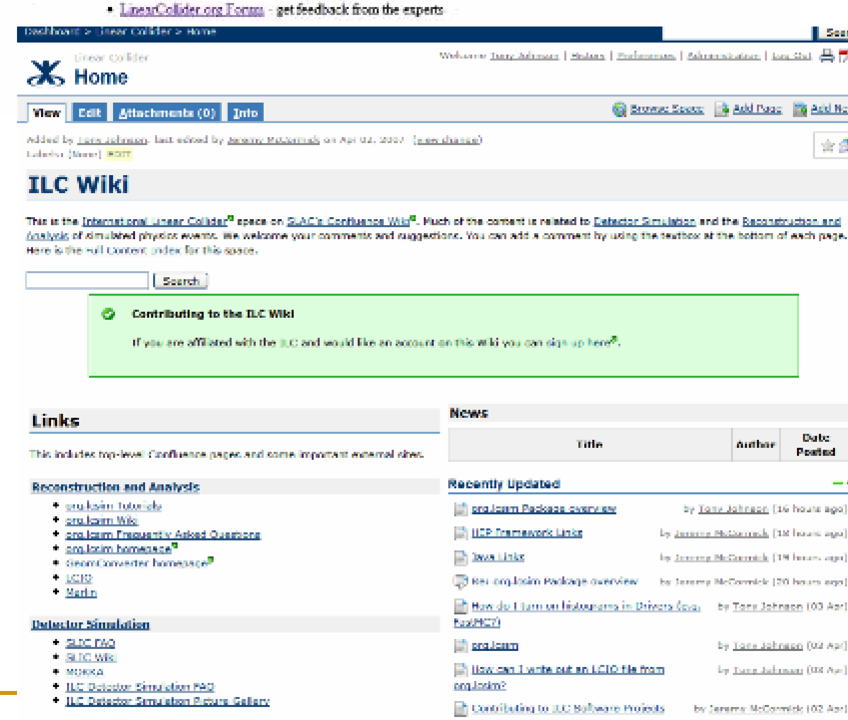
- Support lapsed due to developers (M. Iwasaki, T. Abe) moving on and lack of user base at the time.
- Jupiter & satellites written within a Root environment.
- Note that using Root does not provide interoperability
  - CDF/DØ @ TeVatron, CMS/ATLAS @ LHC all use Root, but have completely different event data models. No commonality!

Resources for getting started

- http://lcsim.org/ Web Site
  - Tutorials
    - Software installation
    - Using tools
    - Simple Analysis Examples
    - Developers Guide
  - Datasets
  - Documentation

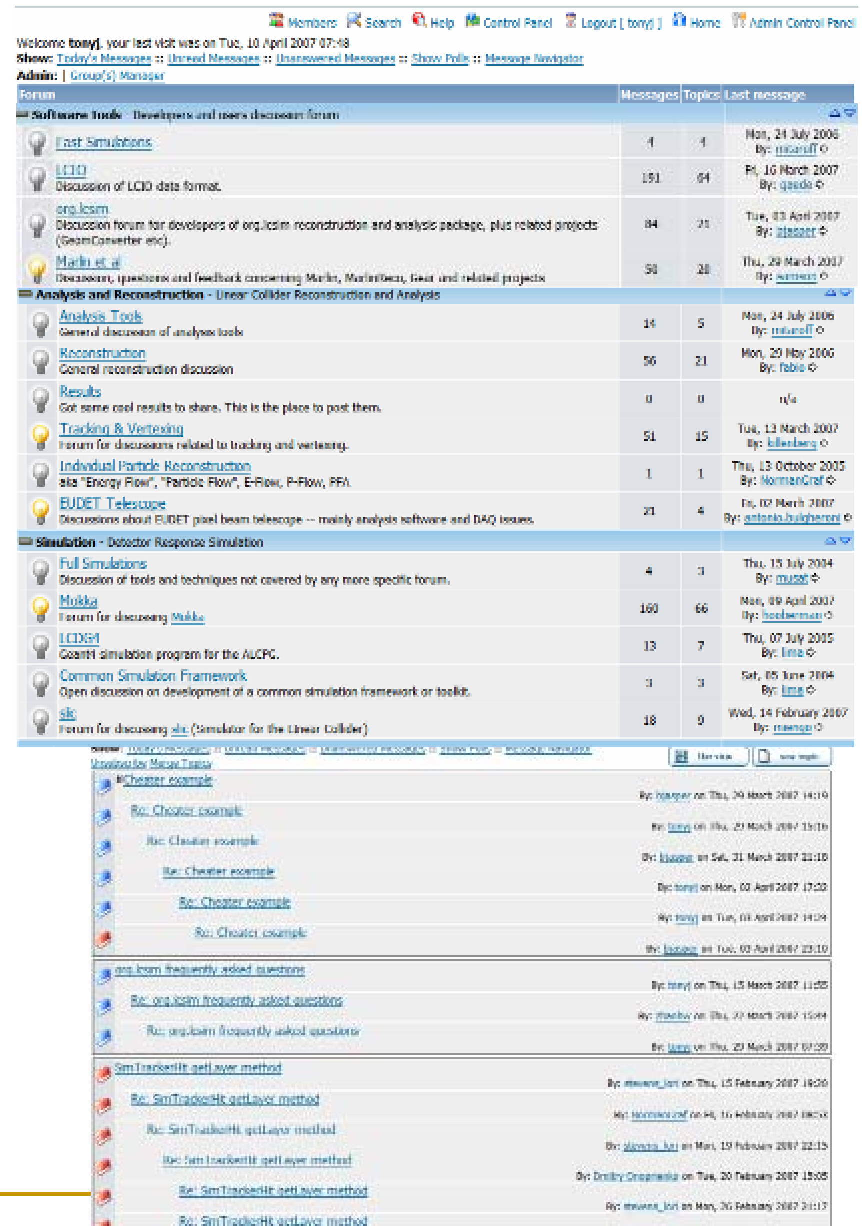
- Confluence Wiki
  - More tutorials
  - More documentation
  - Frequently asked Questions
  - Users are encouraged to comment on, add to, or correct existing documentation
    - https://jira.slac.stanford.edu/signup





Resources for getting started

- Discussion Forums
  - http://forum.linearcollider.org/
    - SLIC, org.lcsim
  - Not recommended
    - Spray E-mail to developers
      - Banging head against wall
      - Uninstall and reinstall software 3 times
  - Recommended
    - Post questions on the forum
      - You will get faster answers
      - You will get more accurate answers
      - Others will benefit from seeing answers to your questions
    - Discuss what you would like to do
      - get feedback on best practices



Summary

- ALCPG Sim/Reco team supports an ambitious physics and detector simulation, reconstruction & analysis effort.
- Goal is flexibility and interoperability, not technology or concept limited.
- Provides full data samples for ILC physics studies.
  - Stdhep and LCIO files available on the web.
- Provides a complete and flexible detector simulation package capable of simulating arbitrarily complex detectors with runtime detector description.
- Reconstruction & analysis framework exists, core functionality available, individual particle reconstruction template developed, various analysis algorithms implemented.
- Effort sorely lacking in manpower. Any additional support provides immediate detector performance results.

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

Backup Slides

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**

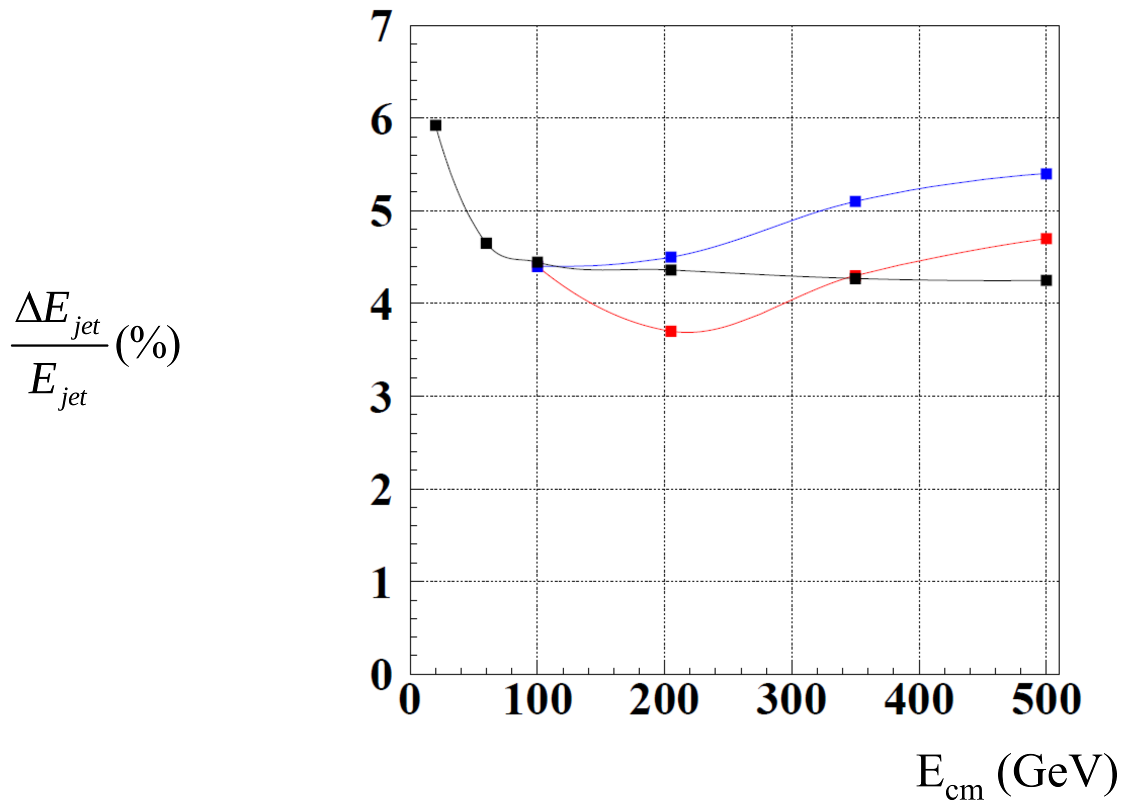
- Derivative of TRKERR.
- Provides smeared tracks with full covariance matrix.
- Electromagnetic showers smeared in energy and position according to parameterized EM cal response.
- Hadron showers smeared in energy and position according to parameterized HCal response.
  - can mimic some aspects of confusion.
- "Jet Energy Resolution" can be input, will tweak the ratio of neutral to charged response to deliver "correct" $a/\sqrt{E}$.

FastMC simulation of Calorimeter/PFA output

ccount for confusion term by blowing up single particle resolution for neutral hadrons

GLD PFA (blue) — LDC PFA (red) — org.lcsim FASTMC with (black)

$$\frac{\Delta E_{\gamma}}{E_{\gamma}} = \frac{0.18}{\sqrt{E_{\gamma}}} \qquad \frac{\Delta E_{n,K_L^0}}{E_{n,K_L^0}} = 0.28$$



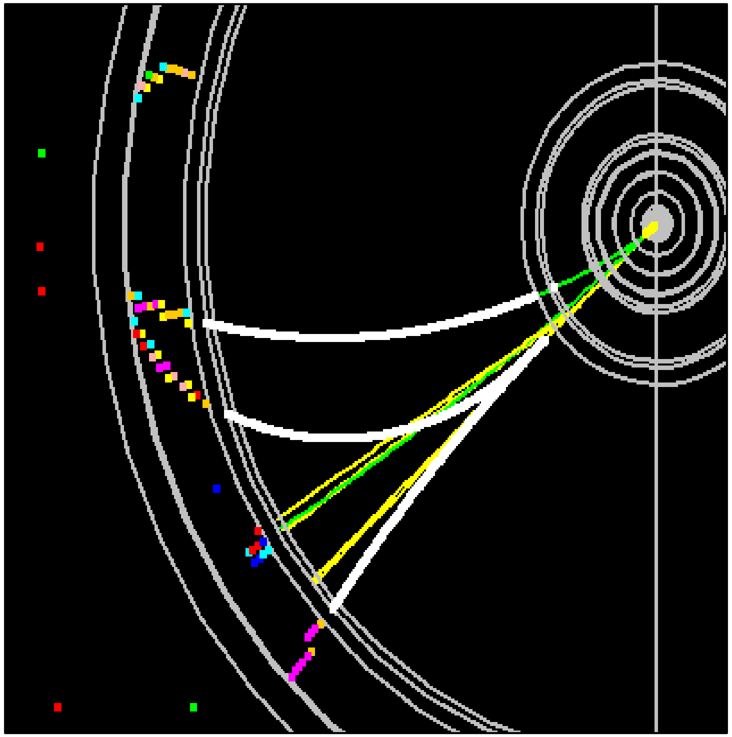
Light quark jets ee→qq

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 → godl).
- An excellent tool for designing tracking detectors!

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

Lelaps: Decays, dE/dx, MCS

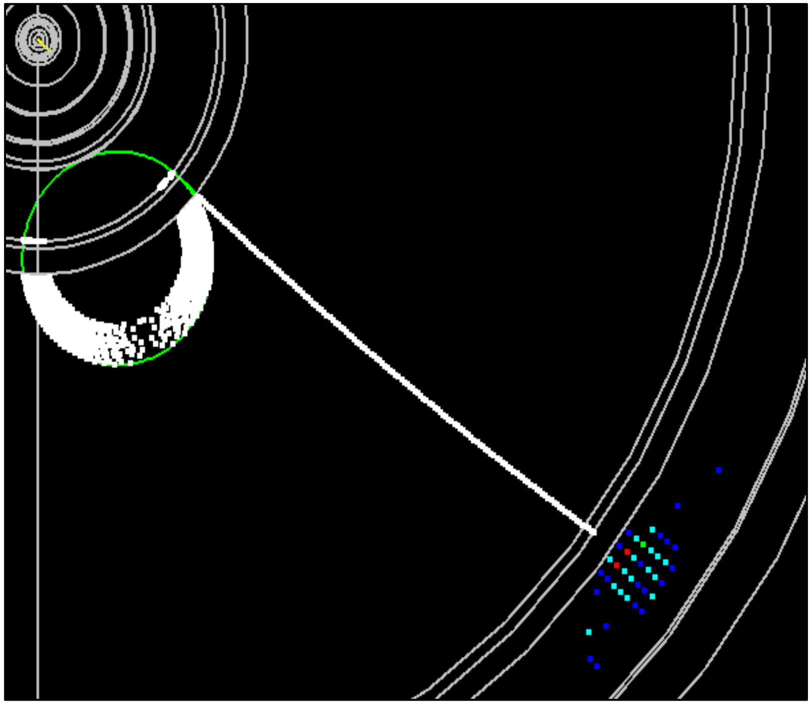


$\Omega^- \rightarrow \Xi^0 \pi^-$

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

$\Lambda \rightarrow p \pi^-$

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



gamma conversion as simulated by Lelaps for the LDC model.

Note energy loss of electron.