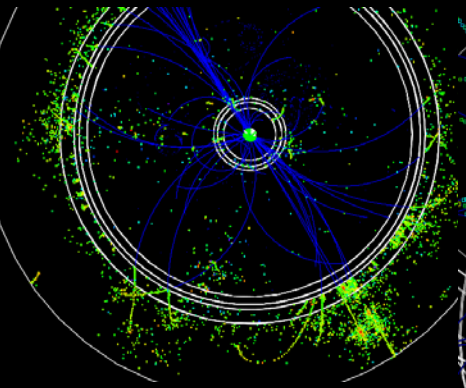
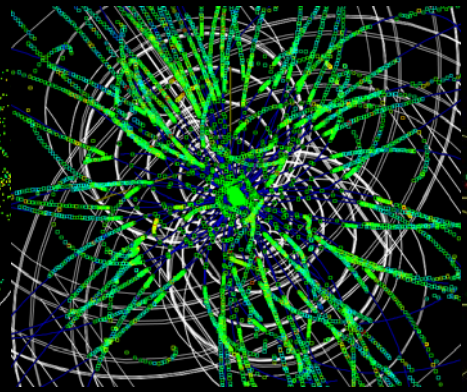
ILC Detector Simulations: Overview of the US Framework

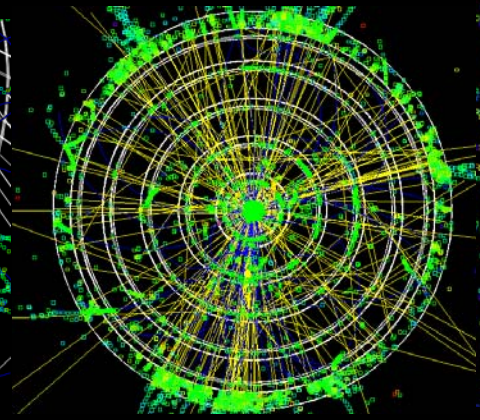
LDC: ttbar



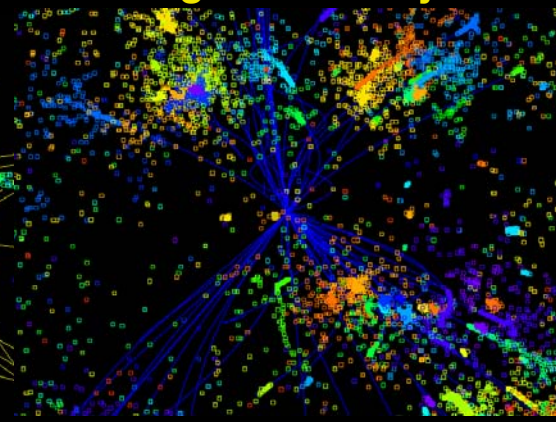
SiD May05: 100 muons



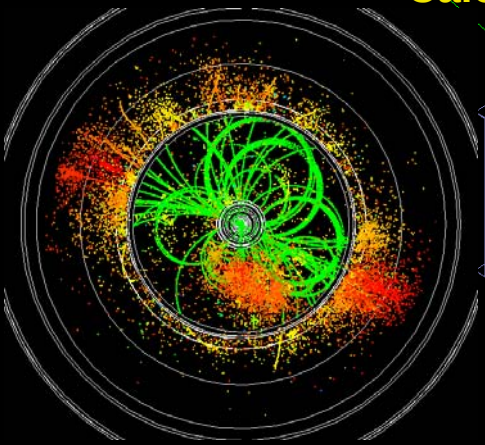
SiD Aug05: ttbar



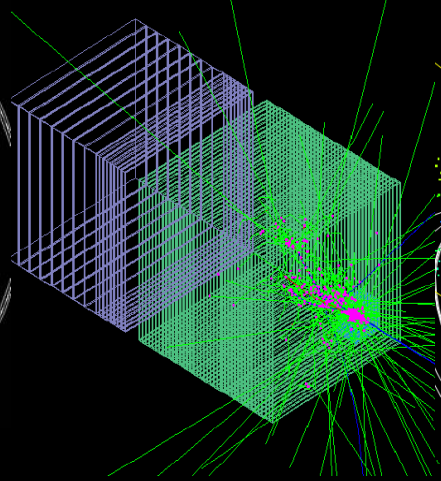
CDC Aug05: ttbar 6 jets



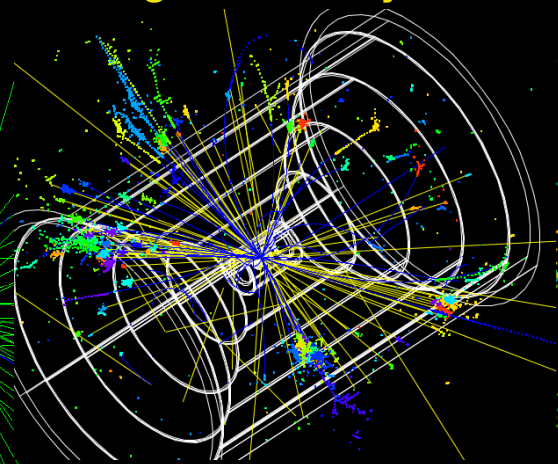
GLD: ttbar



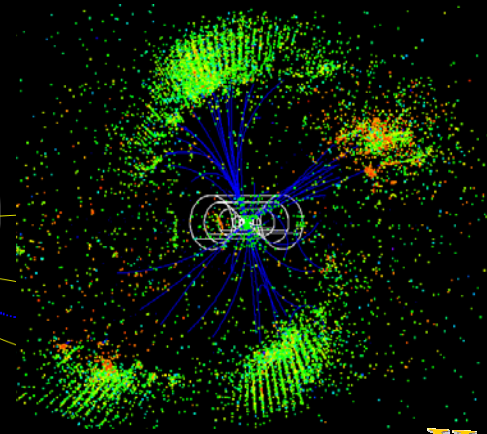
Calorimeter Testbeam



SiD Aug05: ttbar 6 jets



GLD: ZHiggs; M_H=120 GeV



Geant 4

World-Wide Studies of ILC Physics and Detectors

SLAC

Jeremy McCormick

SLAC LCD Simulations Group

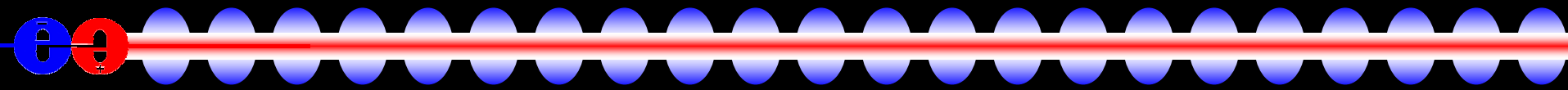
SiD

FREE HEP

ECFA Study

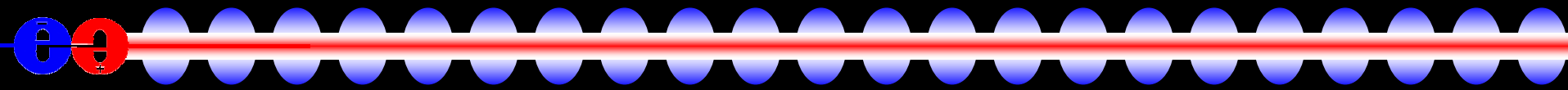
Physics and Detectors for a Linear Collider

Overview: Goals



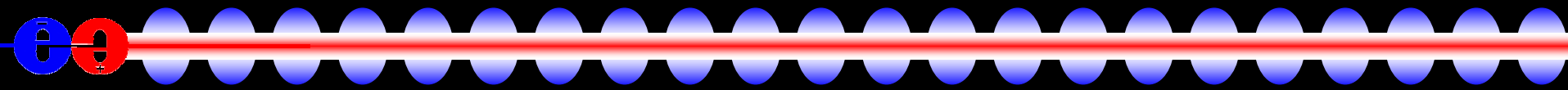
- Simulate benchmark physics processes on different full detector designs
- Develop a suite of reconstruction and analysis algorithms and sample codes
- Provide a general-purpose framework for physics software development
- Facilitate contribution from physicists in different locations with various amounts of time available
- Use standard data formats, when possible

Overview: Key Features



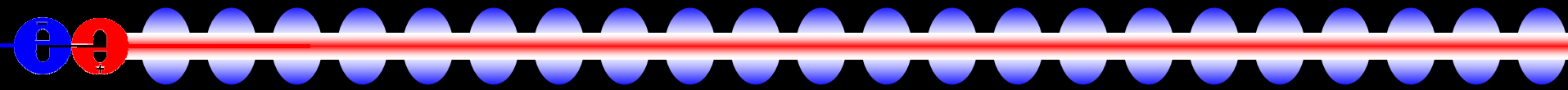
- Cross-platform compatibility
  - Java reconstruction software is write/run anywhere.
    - Maven for easy builds
  - The simulation software runs on OSX, Linux and Windows (with Cygwin).
    - GNU Autoconf/Make build system
- Supports ILC software standards
  - AIDA, LCIO, StdHep, HepRep
- Easy to model different detector designs
  - Geometry, materials, readout, and IDs easily customized.
  - Write hooks to Java classes for detector components
  - Convert to several different output geomery formats

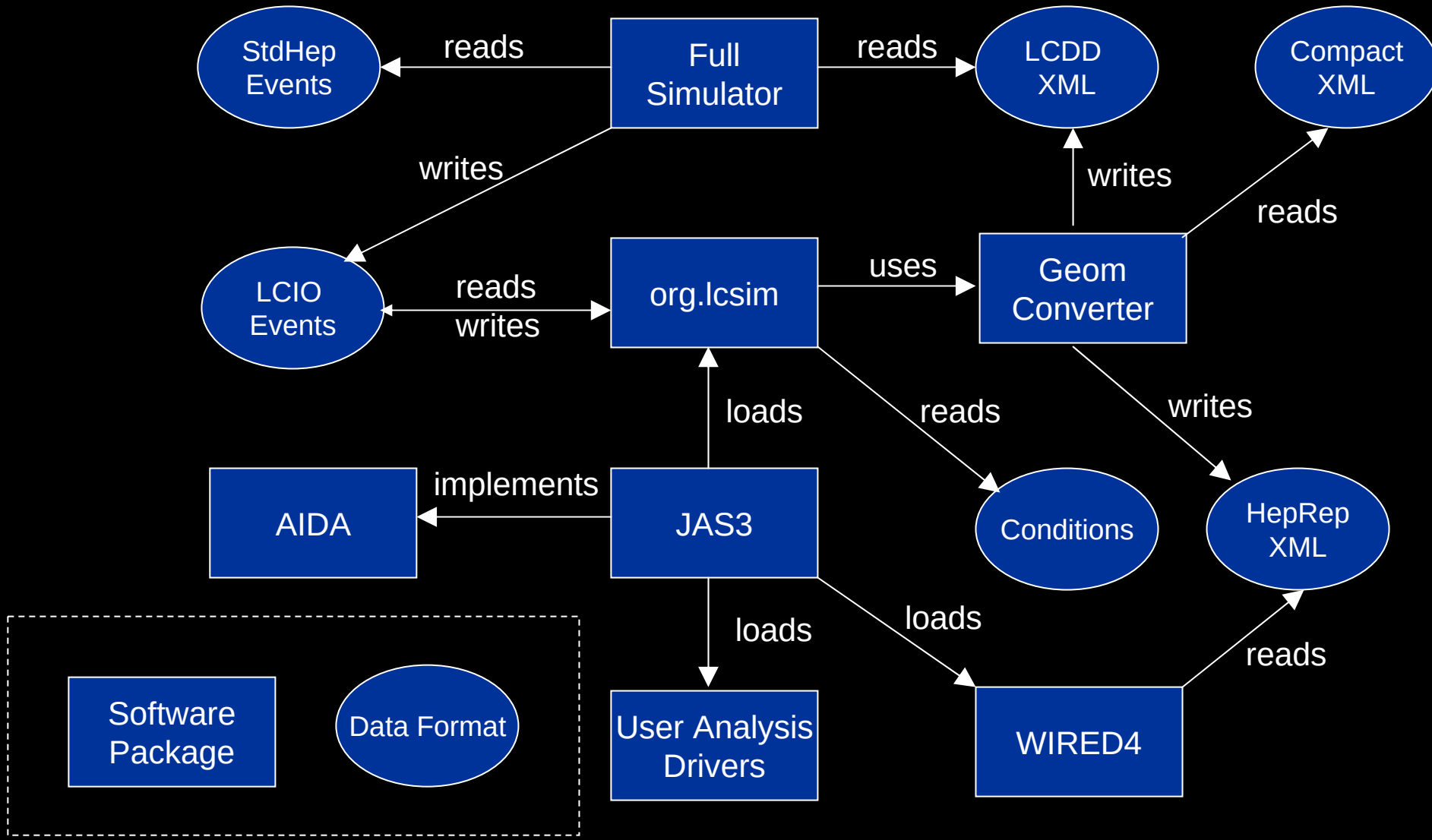
Overview: Key Features (cont'd)



- Flexibility
  - Reconstruction and analysis
    - JAS3 analysis environment
      - Load/unload Java classes interactively
    - Java libraries automatically downloaded
    - FreeHep codebase
      - AIDA, Wired, HepRep, ROOT, StdHep, …
  - Simulation
    - XML detector input → No user C++ code required.
    - Drive from command-line or macros (1-to-1)
    - Geant4 MC toolkit
      - Multiple physis list selection

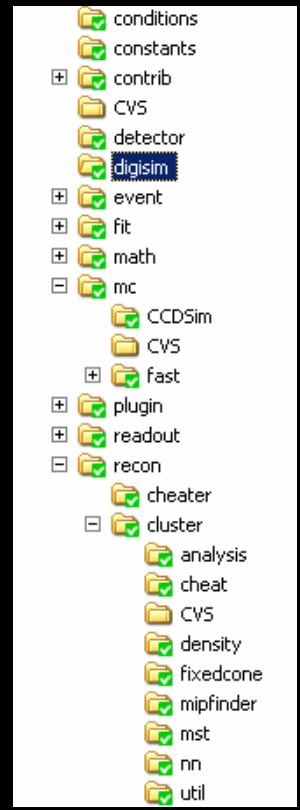
Overview: Framework Diagram





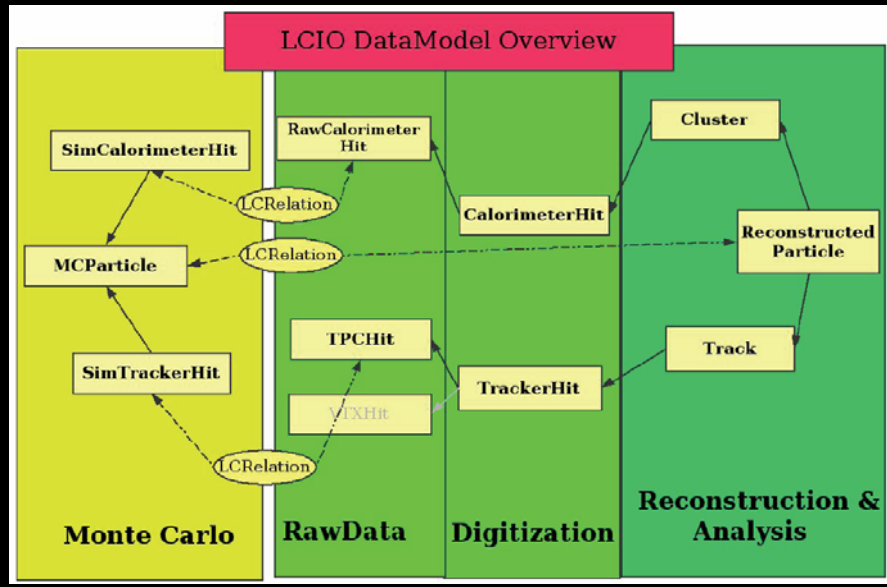
Reconstruction and Analysis Software

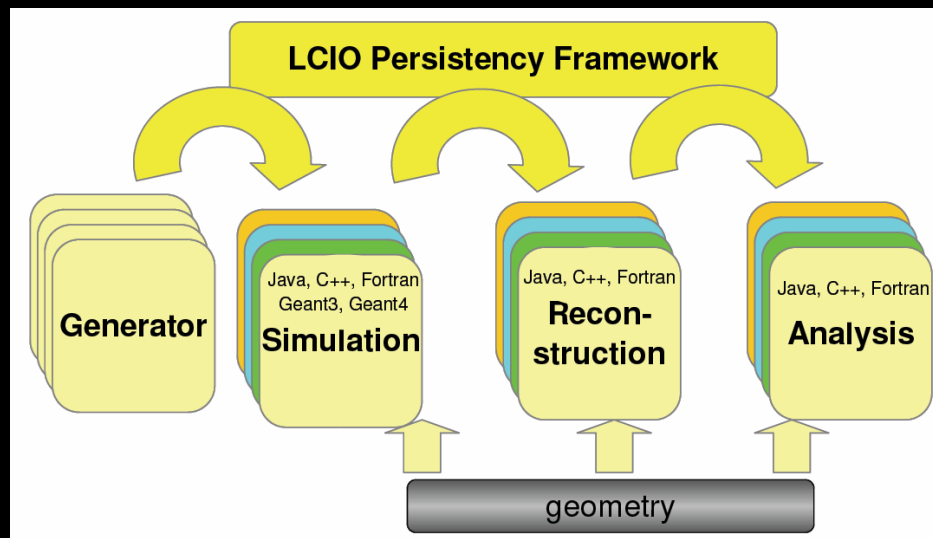
- org.lcsim
  - Reconstruction and analysis package
- GeomConverter
  - Geometry system
- FreeHep
  - Physics and graphics utilities
- JAS3
  - Studio application for analysis and development
- WIRED4
  - Event display
- LCIO
  - Object model and persistency
- AIDA
  - Plotting API and data format



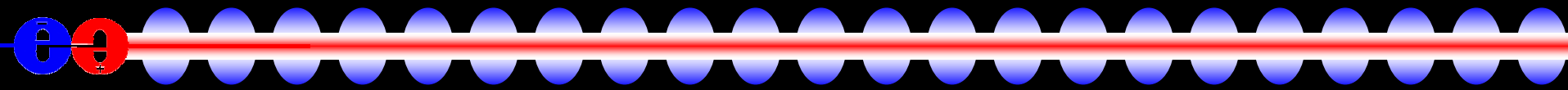
LCIO

- Object model and persistency
  - Events
    - Monte Carlo
    - Raw
    - Event and run metadata
  - Reconstruction
  - Parameters, relations, attributes, arrays, generic objects, …
- All the ILC simulators write LCIO
  - Enables cross-checks between data from different simulators
  - Read/write LCIO from
    - Fast MC / Full Simulation
    - Different detectors
    - Different reconstruction tools





LCIO: Data Samples

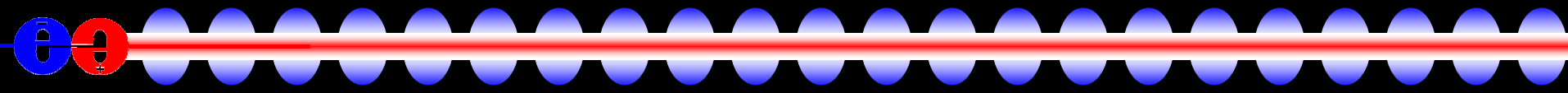


- LCIO data samples available via anonymous FTP
  - http://www.lcsim.org/datasets/ftp.html
- Data sets
  - ILC500
    - 500 GeV machine parameters
  - ILC1000
    - 1 TeV machine parameters
  - singleParticle
    - Single particle diagnostic events
  - Zpole
    - Zpole diagnostic events

Organization

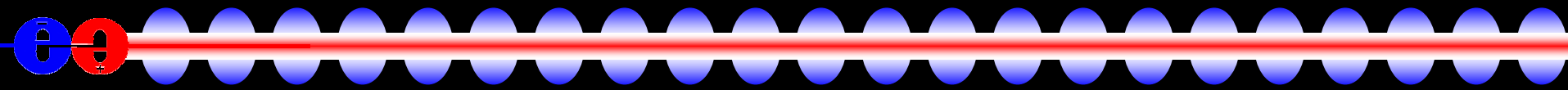
- **[event type]** - complex or single particle event type, e.g. ZZ, ZPole, muons, etc.
  - **stdhep** - input StdHep files used to generate the events
  - **[detector name]** - detector geometry tag, such as sidaug05
    - **[data file format]** - output datafile format, e.g. LCIO or SIO
      - **[simulator]** - simulator that generated the events, e.g. lcdg4, slic, lelaps, mokka, etc.
        - **logs** - simulator job logs

org.lcsim: Goals



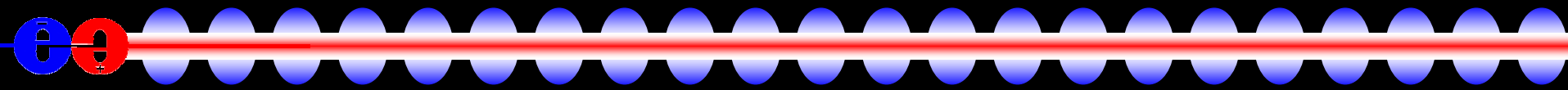
- Retain core functionality from hep.lcd package
  - Full suite of reconstruction and analysis tools
- Update to use latest LCIO for IO and as basis for simulation, raw data and reconstruction event formats
- Isolate users from raw LCIO structures
- Update and simplify framework using experience from hep.lcd
  - Provide good tutorial documentation
- Detector Independence
  - Make package independent of detector and geometry assumptions so can work with any detector
  - Read properties of detectors at runtime
- Update to Java 1.5
  - Simple, easy to learn, efficient, OO language
  - Many improvements since hep.lcd framework was created
- Ability to run standalone (command line or batch) or in JAS3

org.lcsim: History



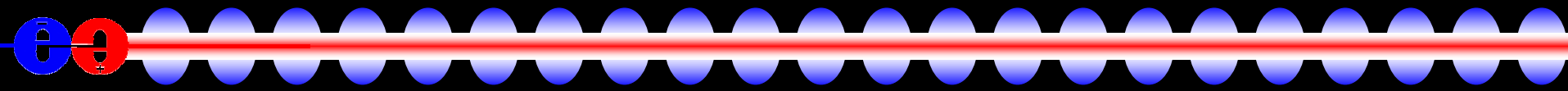
- org.lcsim evolved from
  - *hep.lcd* package, in use since last century
    - Full Reconstruction (tracking+calorimetry)
    - FastMC – track and cluster smearing
    - Physics Tools (Vertex Finding, Jet Finding)
    - Beam Background Overlays
    - Analysis tools including event display
  - LCIOPlugin
    - JAS3 plugin
    - Simple tool for viewing any LCIO file

org.lcsim: Drivers and Event data



- User reconstruction and analysis code written by extending Driver class
  - Usually only need to override single method
    - process(EventHeader)
- EventHeader
  - Access event data, conditions, and geometry
  - Add new collections
    - Clusters, reconstructed particles, hits, trackers, etc.
  - Collections and geometry displayed automatically in WIRED.
  - Write out objects added to event
    - Currently only LCIO objects supported
    - Use GenericObject for arbitrary data

org.lcsim: Plugin



LCSim Event

Run:0 Event: 0

- EcalBarrHitsCheatClusters
- EcalBarrHitsFixedConeClusters
- EcalBarrHitsNNClusters
- EcalEndcapHits
- EcalEndcapHitsCheatClusters
- EcalEndcapHitsNNClusters
- ForwardEcalEndcapHits
- ForwardEcalEndcapHitsCheatClusters
- ForwardEcalEndcapHitsNNClusters
- HcalBarrHits
- HcalBarrHitsCheatClusters
- HcalBarrHitsNNClusters
- HcalEndcapHits
- HcalEndcapHitsCheatClusters
- LuminosityMonitorHits
- LuminosityMonitorHitsCheatClusters
- LuminosityMonitorHitsNNClusters
- MCParticle
- MCParticleEndPointEnergy
- MuonBarrHits
- MuonBarrHitsCheatClusters
- MuonBarrHitsNNClusters
- MuonEndcapHits
- MuonEndcapHitsCheatClusters
- MuonEndcapHitsNNClusters
- RefinedCheatClusters
- TkrBarrHits
- TkrEndcapHits
- VtxBarrHits

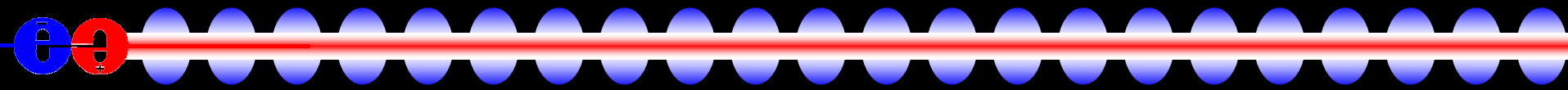
LCIO Event Header

Run	0
Event	0
Time Stamp	Wed Jan 04 22:17:10 PST 2006
Detector Name	sid00

Collections

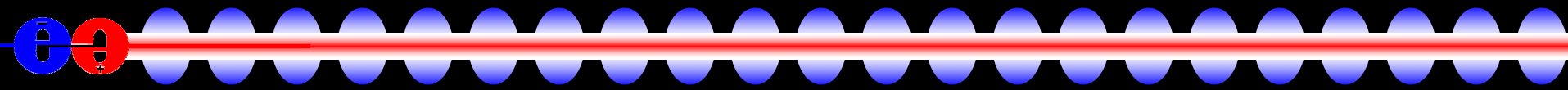
Name	Type	Size
ForwardEcalEndcapHitsCheatClusters	org.lcsim.recon.cluster.cheat.CheatCluster	6
EcalBarrHitsFixedConeClusters	org.lcsim.recon.cluster.util.BasicCluster	26
RefinedCheatClusters	org.lcsim.event.Cluster	77
ForwardEcalEndcapHitsCheatClusters	org.lcsim.event.Cluster	6
HcalBarrHitsCheatClusters	org.lcsim.event.Cluster	20
MuonEndcapHitsCheatClusters	org.lcsim.event.Cluster	2
MuonBarrHitsNNClusters	org.lcsim.event.Cluster	1
HcalEndcapHitsCheatClusters	org.lcsim.event.Cluster	1
EcalBarrHitsNNClusters	org.lcsim.event.Cluster	76
MuonBarrHitsCheatClusters	org.lcsim.event.Cluster	1
LuminosityMonitorHitsCheatClusters	org.lcsim.event.Cluster	2
MuonEndcapHitsNNClusters	org.lcsim.event.Cluster	1
LuminosityMonitorHitsNNClusters	org.lcsim.event.Cluster	2
HcalBarrHitsNNClusters	org.lcsim.event.Cluster	36
EcalEndcapHitsCheatClusters	org.lcsim.event.Cluster	26
ForwardEcalEndcapHitsNNClusters	org.lcsim.event.Cluster	1
EcalBarrHitsCheatClusters	org.lcsim.event.Cluster	58
EcalEndcapHitsNNClusters	org.lcsim.event.Cluster	14
EcalBarrHitsFixedConeClusters	org.lcsim.event.Cluster	26
MuonBarrHitsCheatClusters	org.lcsim.recon.cluster.cheat.CheatCluster	1
VtxEndcapHits	org.lcsim.event.SimTrackerHit	8
TkrBarrHits	org.lcsim.event.SimTrackerHit	273

org.lcsim: Conditions Database



- org.lcsim includes conditions framework
  - Detector geometry
  - Geometry-dependent algorithm (Driver) parameters
    - e.g. - calorimeter sampling fractions
  - Listeners can be updated when conditions change.
- File format
  - Parameters typically come from properties files.
    - .ini or .prop (similar to hep.lcd)
  - Flexible
    - Format independent
    - Register new data converters
- Web-based lookup + caching (~/.lcsim/cache)

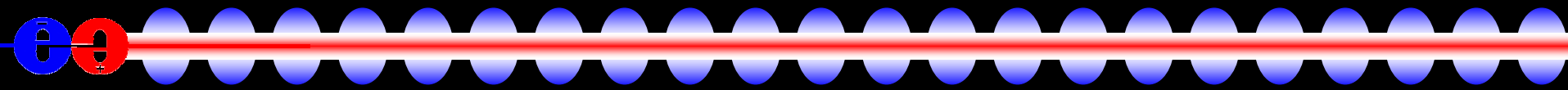
org.lcsim: Status



- **Physics Utilities** -done
  - stdhepreader
  - 3, 4-vector utilities
  - diagnostic generator
  - Jet finder, event shape utilities
- **Conditions framework** - done
  - Ability to read detector constants from zip file
  - To define new detector just create new zip file and place on web
  - File is read and cached locally
  - Ability to read compact geometry file
- **Driver framework** - done
- **Fast MC** - done
- **IO Framework** - done
- **Event Access** - done
- **Event Display interface** - done

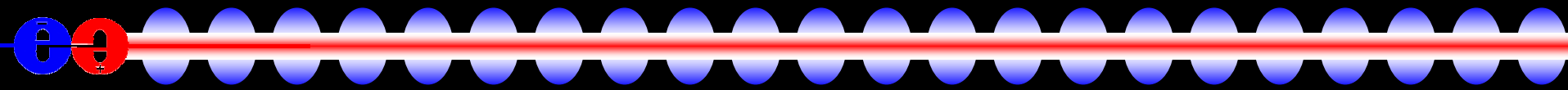
- **FastMC**
  - parameterized track and cluster smearing
  - Smearing constants read from conditions system
  - Now produces ReconstructedParticles
- **Digitization**
  - Digisim–Calorimeter digitization
  - *Tracker, Vertex digitization*
- **Clustering**
  - Cheater
  - Cone
  - Nearest Neighbor
  - *Minimal Spanning Tree*
- **Tracking**
  - SLDWeightMatrix, TRF, Garfield
- **Vertex Fitting**
  - ZVTop4
- **Analysis Examples**
  - Cluster Diagnostics
  - SLICDiagnostics
  - PFA
  - ClusterID
  - ParticleID

JAS3



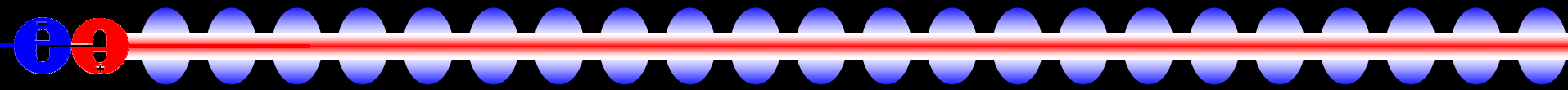
- Physics analysis environment
  - Additional functionality with plugins
- Iterative, event-based analysis model
  - quick development, debugging, ad hoc analysis
- Dynamically load / unload Java analysis drivers
  - From JAR files in the classpath
  - Written and compiled by user
- Plotting engine
  - 1D, 2D histograms, clouds, profiles
  - Output to PNG, JPG, WMF, PS, etc.
- Integrated event display

AIDA and Plotting



- JAS3
  - Interactive plotting
  - Supported plot types
    - Histograms, clouds, profiles (1D + 2D)
- AIDA API supports 3D plot creation
  - Open Scientist, PAIDA can plot these.
- N-tuples still not very functional, but doesn't seem to be too limiting to analysis. (?)
  - Need binary format → HDF5 ?
- Implementations
  - JAIDA/JAS3, Anaphe, OpenScientist, PAIDA (others?)

Event Display: Screenshot

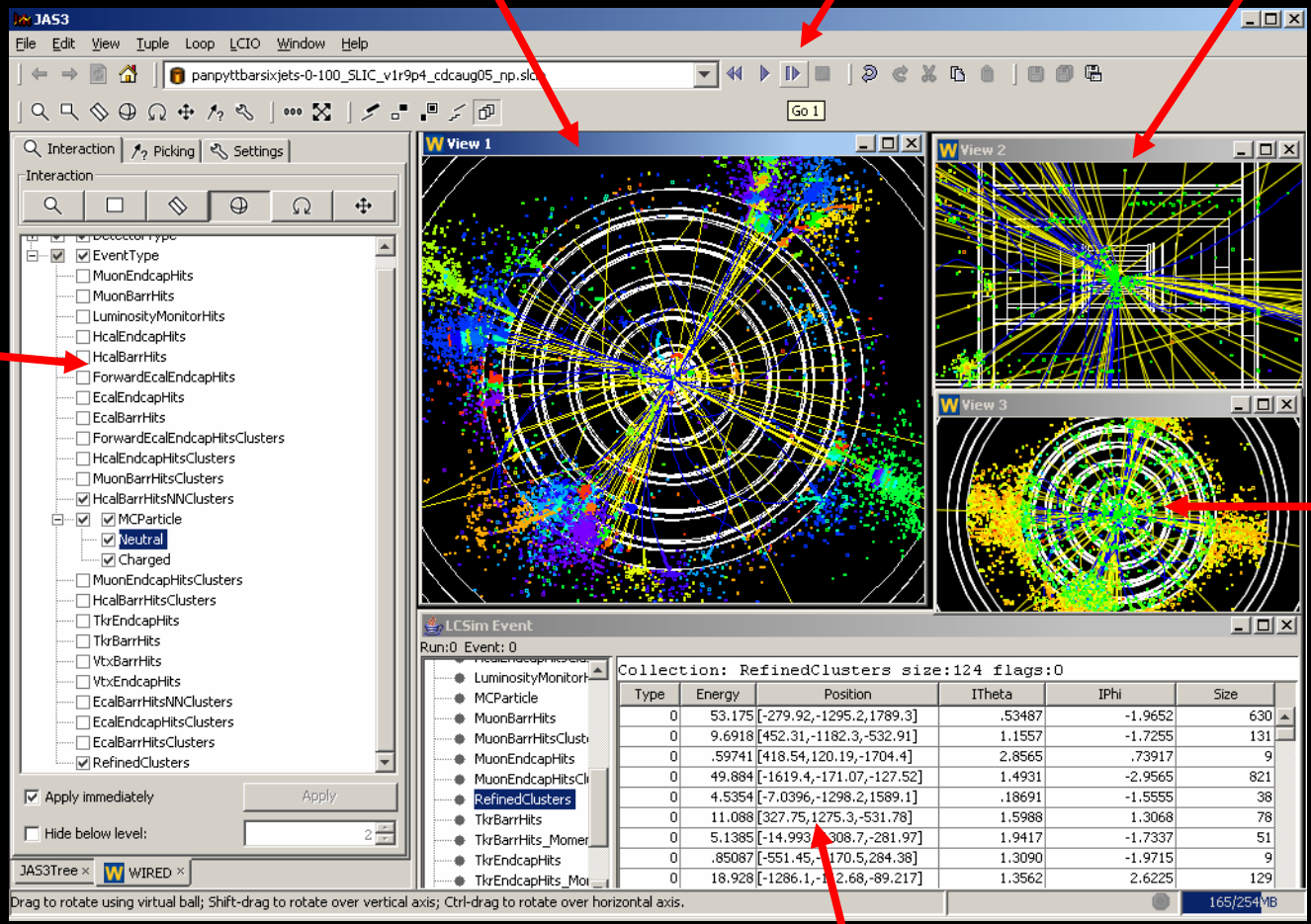


WIRED: Clusters

JAS3: Event Loop

WIRED: ZX View

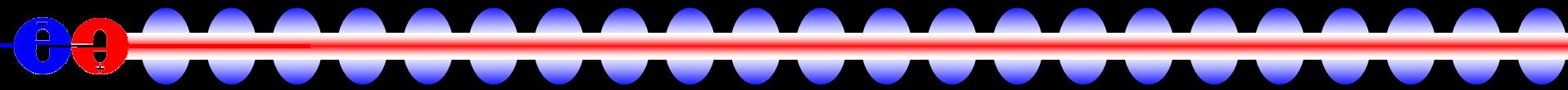
WIRED: LCIO Objects



WIRED: Beam View

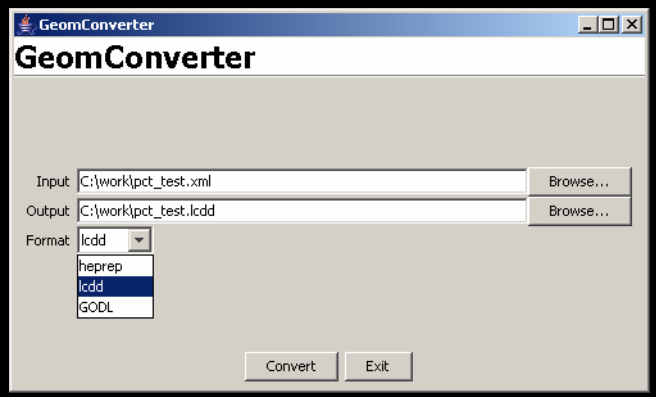
org.lcsim: LCSim Event Browser

Event Display: WIRED and HepRep



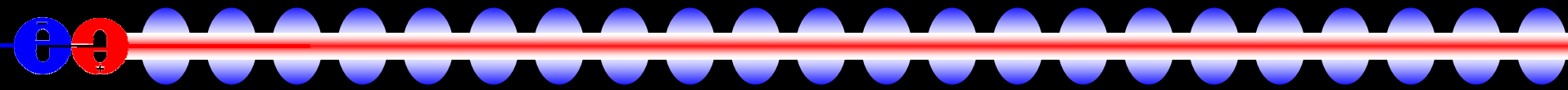
- HepRep file format
  - Generic format for event display
  - GeomConverter streams HepRep data to WIRED.
  - Also written out by Geant4
- WIRED4
  - Layers for detector, hits, MCParticles, etc.
  - Rotation, zoom, panning, picking
  - Interactive activation/deactivation of objects in display
  - Writes to PNG, JPG, WMF, HepRep, etc.

Detectors: Geometry Converter



- Convert from compact to
  - LCDD for simulator (SLIC)
  - HepRep for event display (WIRED4)
  - GODL for fast MC (Lelaps)
  - Java Objects for reconstruction (org.lcsim)

Detectors: Zip Files

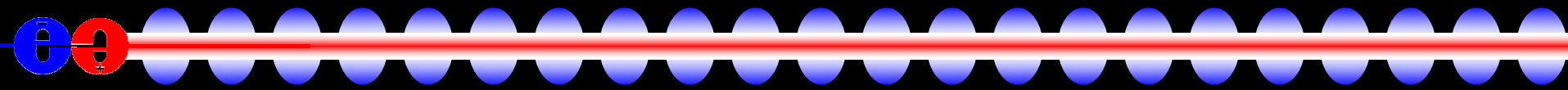


- Detector conditions bundled into downloadable Zip file
- Can also point org.lcsim to custom and development versions
- Canonical detectors location
  - http://www.lcsim.org/detectors
- sid00 examples
  - Zip file
    - http://www.lcsim.org/detectors/sid00.zip
  - LCDD
    - http://www.lcsim.org/detectors/sid00/sid00.lcdd
  - Compact
    - http://www.lcsim.org/detectors/sid00/compact.xml

sid00

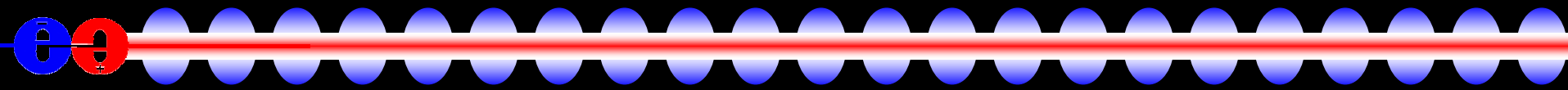
```
|-- ClusterParameters.properties
|-- IDEfficiency.properties
|-- IndividualParticleReconstruction.properties
|-- LongitudinalHMatrix.hmx
|-- SamplingFractions
|   |-- EMBarrel.properties
|   |-- EMEndcap.properties
|   |-- ForwardEMEndcap.properties
|   |-- ForwardLuminosityMonitor.properties
|   |-- HADBarrel.properties
|   |-- HADEndcap.properties
|   |-- LumEndcap.properties
|   |-- MuonBarrel.properties
|   `-- MuonEndcap.properties
|-- SimpleTrack.properties
|-- TrackParameters
|   |-- FullBarrelResolutionBc.ini
|   |-- FullBarrelResolutionNbc.ini
|   `-- sid00_lcdtrk.input
|-- TrackParameters.properties
|-- compact.xml
|-- detector.properties
|-- digisim
|   `-- digisim.steer
|-- sid00.lcdd
`-- sid00.zip
```

Detectors: Compact Detector Description



- Shorthand format for detector description
  - SiD 00 → 600 lines of XML
- Describes
  - Detector metadata
  - Materials
  - Readouts and identifiers
  - Detector components
    - Dimensions
    - Layering
  - Magnetic field

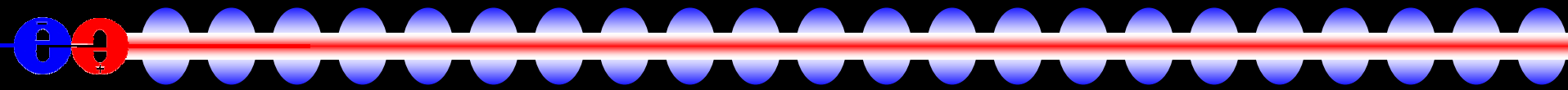
Detectors: Compact XML Example



Two layer stacks in an ECAL barrel

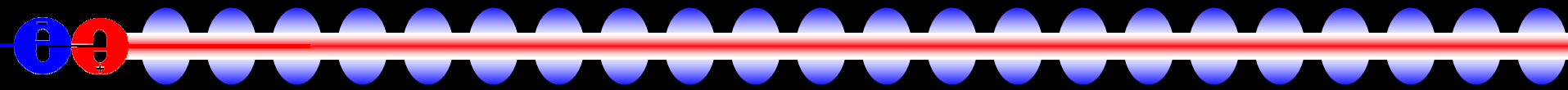
```
 <detector id="2" name="EMBarrel" type="CylindricalBarrelCalorimeter"
readout="EcalBarrHits">
      <dimensions inner_r = "150.1*cm" outer_z = "208.0*cm" />
      <layer repeat="20">
        <slice material = "Tungsten" thickness = "0.25*cm" />
        <slice material = "G10" thickness = "0.068*cm" />
        <slice material = "Silicon" thickness = "0.032*cm" sensitive = "yes" />
        <slice material = "Air" thickness = "0.025*cm" />
      </layer>
      <layer repeat="10">
        <slice material = "Tungsten" thickness = "0.50*cm" />
        <slice material = "G10" thickness = "0.068*cm" />
        <slice material = "Silicon" thickness = "0.032*cm" sensitive = "yes" />
        <slice material = "Air" thickness = "0.025*cm" />
      </layer>
  </detector>
```

Detectors: Repository



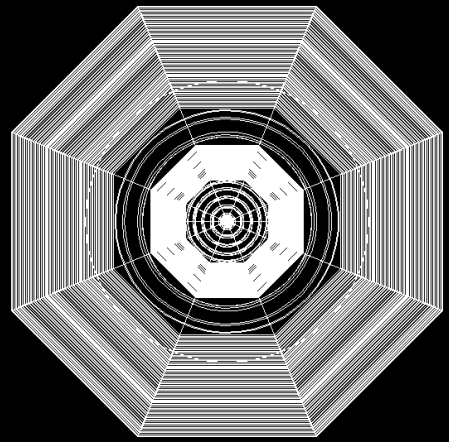
- Detector descriptions stored in CVS Project *LCDetectors*
- Easy to add new detectors based on existing ones
- All models in CVS periodically replicated to WWW locations
- Models
  - cdcaug05, cdcaug05_ecal150, cdcaug05_np, cdcaug05_rpchcal, gldaug05, hd3_1-oct05, ld3_1-oct05, ldcaug05, sdfeb05, sdjan03, sid00, sidaug05, sidaug05_20mr, sidaug05_4tesla, sidaug05_gemhcal, sidaug05_np, sidaug05_polyhedra, sidaug05_scinthcal, sidaug05_tcmt, sidmay05, sidmay05_20mr, sidmay05_2mr, sidmay05_np, sidmay05_scinthcal

Detectors: Geometry Displays

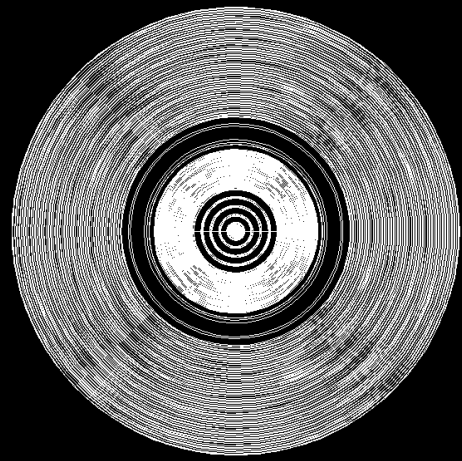


cdcaug05_ecal150

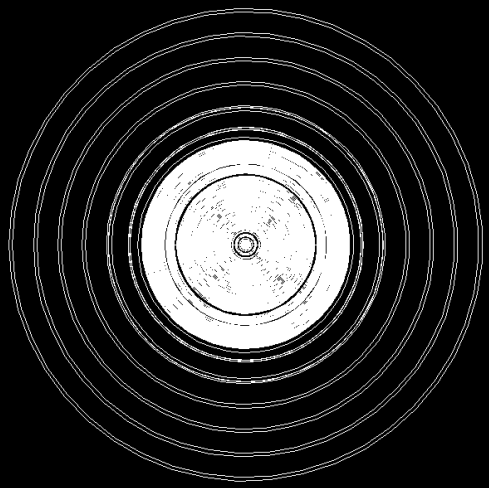
sidaug05_polyhedra



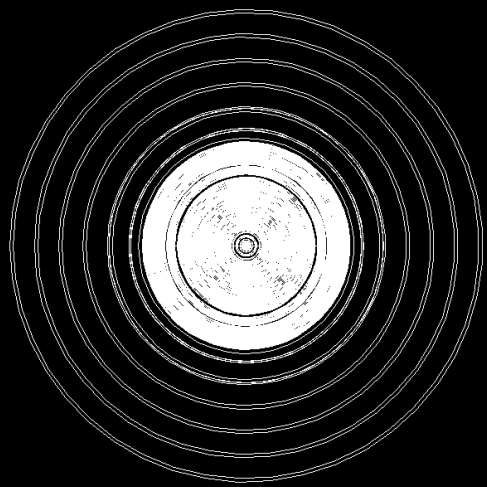
sid00



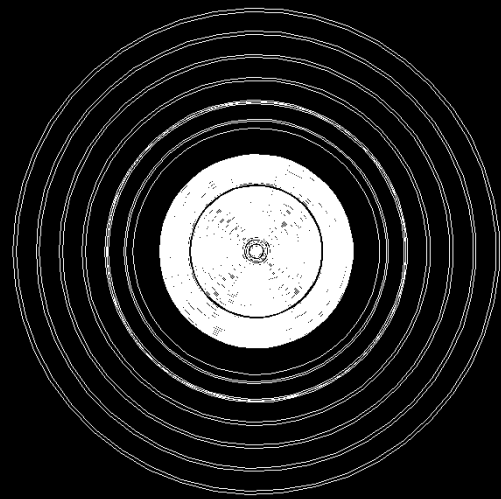
hd3_1-oct-05



ld3_1-oct-05

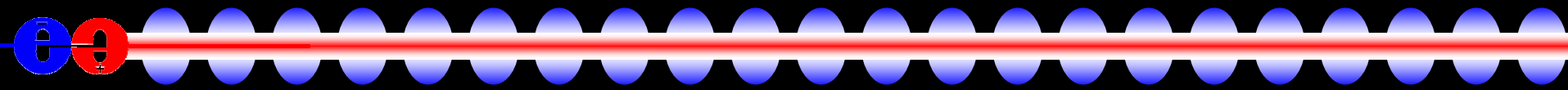


gldaug05



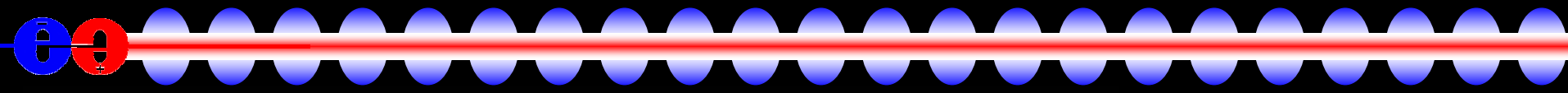
Geant4-generated HepReps drawn by WIRED4.

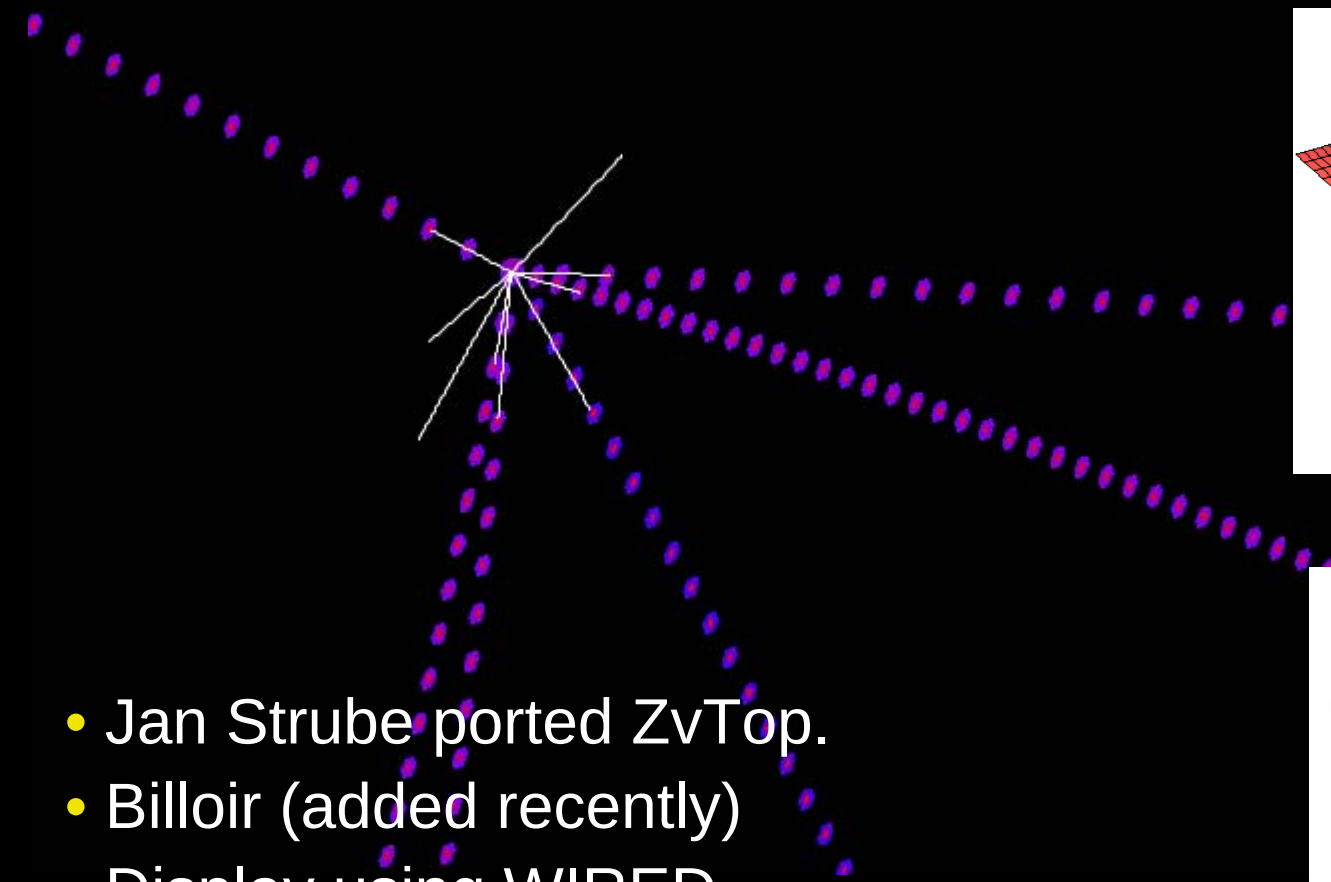
Reconstruction: Tracking

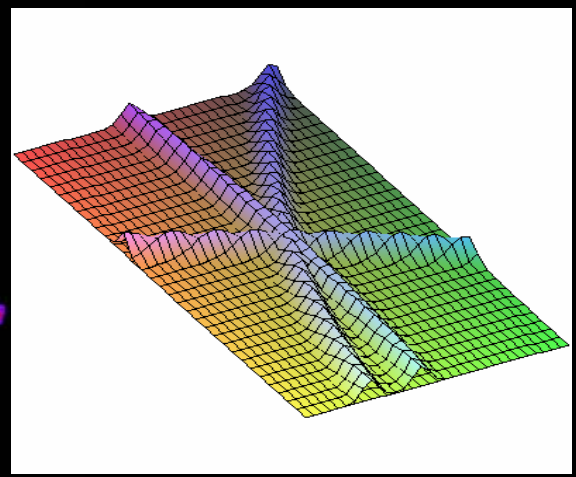


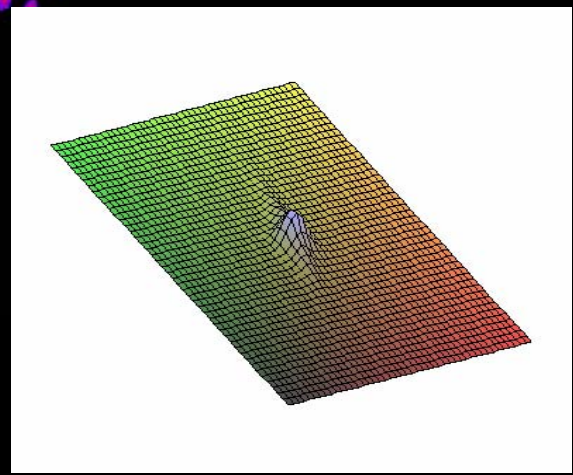
- Most US reconstruction algorithms still using cheater or MC based tracking
- Cheaters
  - MC Fast
  - Mike Ronan's cheater reco package
  - Or just use MCParticles
- Lots of good tools available in org.lcsim for real tracking algo
  - Norman Graf's track fitting and finding
  - Garfield for TPC
  - Nick Sinev's CCD reconstruction
  - Probably a lot of stuff not in org.lcsim CVS, yet (?)
  - Just need to put together into reconstruction algorithms

Reconstruction: Vertexing









- Jan Strube ported ZvTop.
- Billoir (added recently)
- Display using WIRED
- Still not integrated into reconstruction

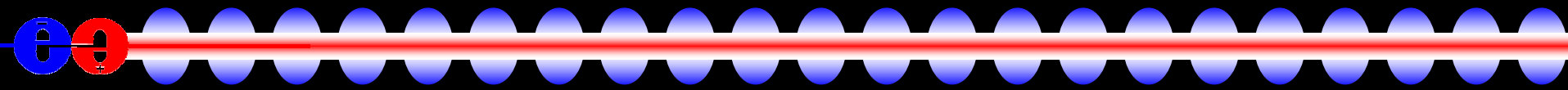
Reconstruction: Clustering Algorithms

- Clusterers
  - Nearest Neighbor
  - Fixed Cone
  - Directed Tree
  - Min Spanning Tree
  - MIP
  - Cheater
  - contrib/other

```
1  import org.lcsim.event.EventHeader;
2  import org.lcsim.recon.cluster.nn.NearestNeighborClusterDriver;
3  import org.lcsim.recon.cluster.cheat.CheatClusterDriver;
4  import org.lcsim.util.Driver;
5
6  public class ClusterFinding extends Driver
7  {
8          public ClusterFinding()
9          {
10                 int minCells = 5;
11                 add(new NearestNeighborClusterDriver(minCells));
12                 add(new CheatClusterDriver());
13         }
14
15         protected void process(EventHeader event)
16         {
17                 super.process(event);
18         }
19 }
```

- Pick the appropriate clusterer for your analysis
- Run in parallel to compare results
- Utilities and diagnostic plots, also
- Developed by N. Graf, R. Cassell, W. Mader, et al

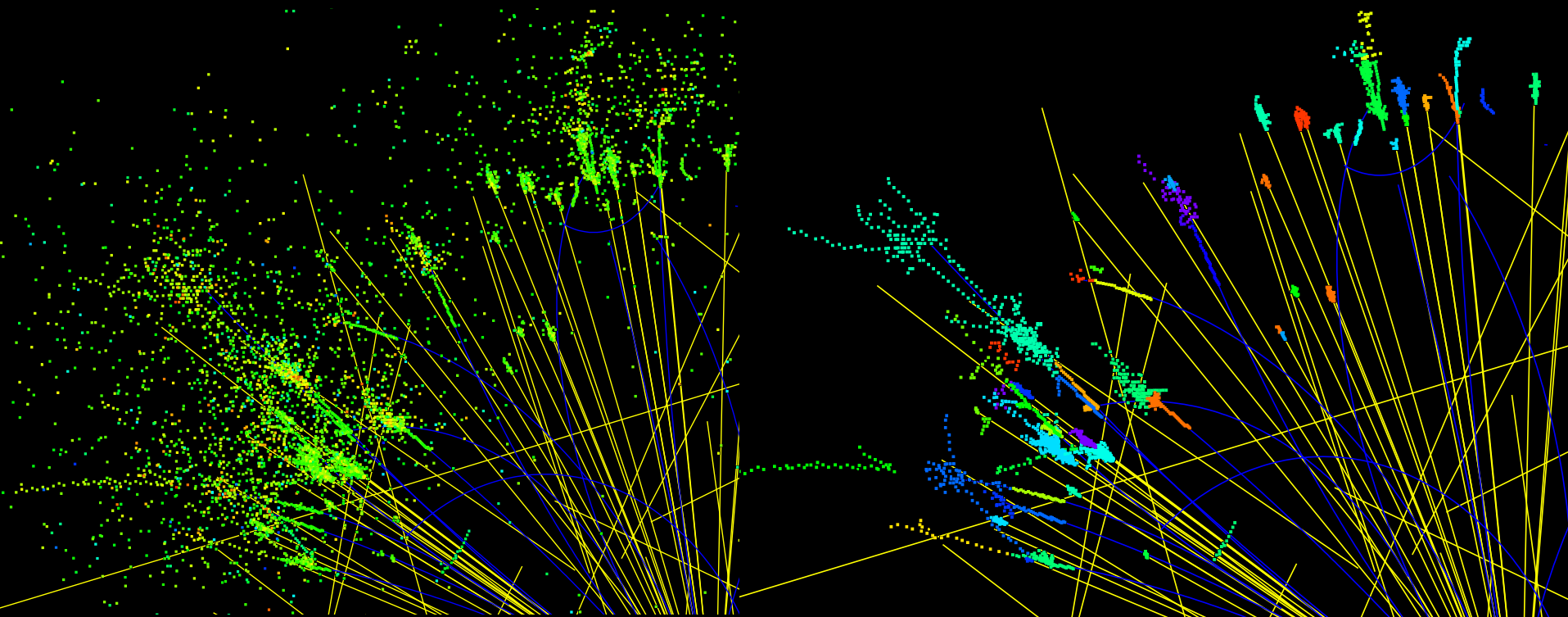
Reconstruction: Cluster Display



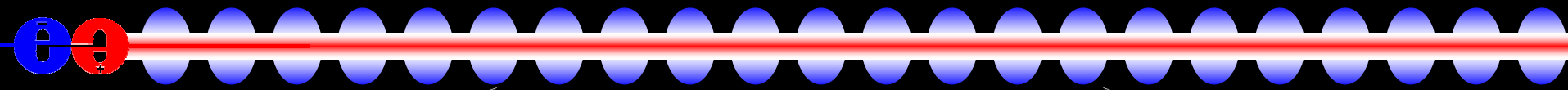
Clusters are displayed automatically by org.lcsim.

Calorimeter Hits

Nearest Neighbor Clusters
min cells = 5

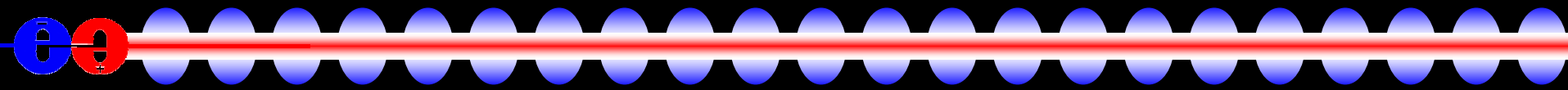


Reconstruction: Complete Algorithms



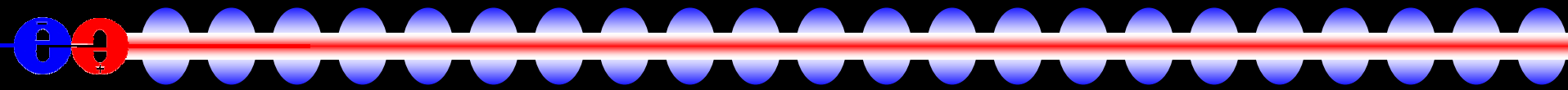
- Lots of people working on full PFA or portions
  - Steve Magill, Norman Graf, Guilherme Lima, Ron Cassell, Matt Charles, Steve Kuhlman, Lei Xia, …
  - See talk by Steve Magill
- Calorimetry part seems to have working PFA algorithms.
- Real tracking algorithms are not included (yet).
- Many utilities and tools exist.
  - Vertex and track fitting, clustering, jet finding
- Need to work on integration

Reconstruction: Software Development

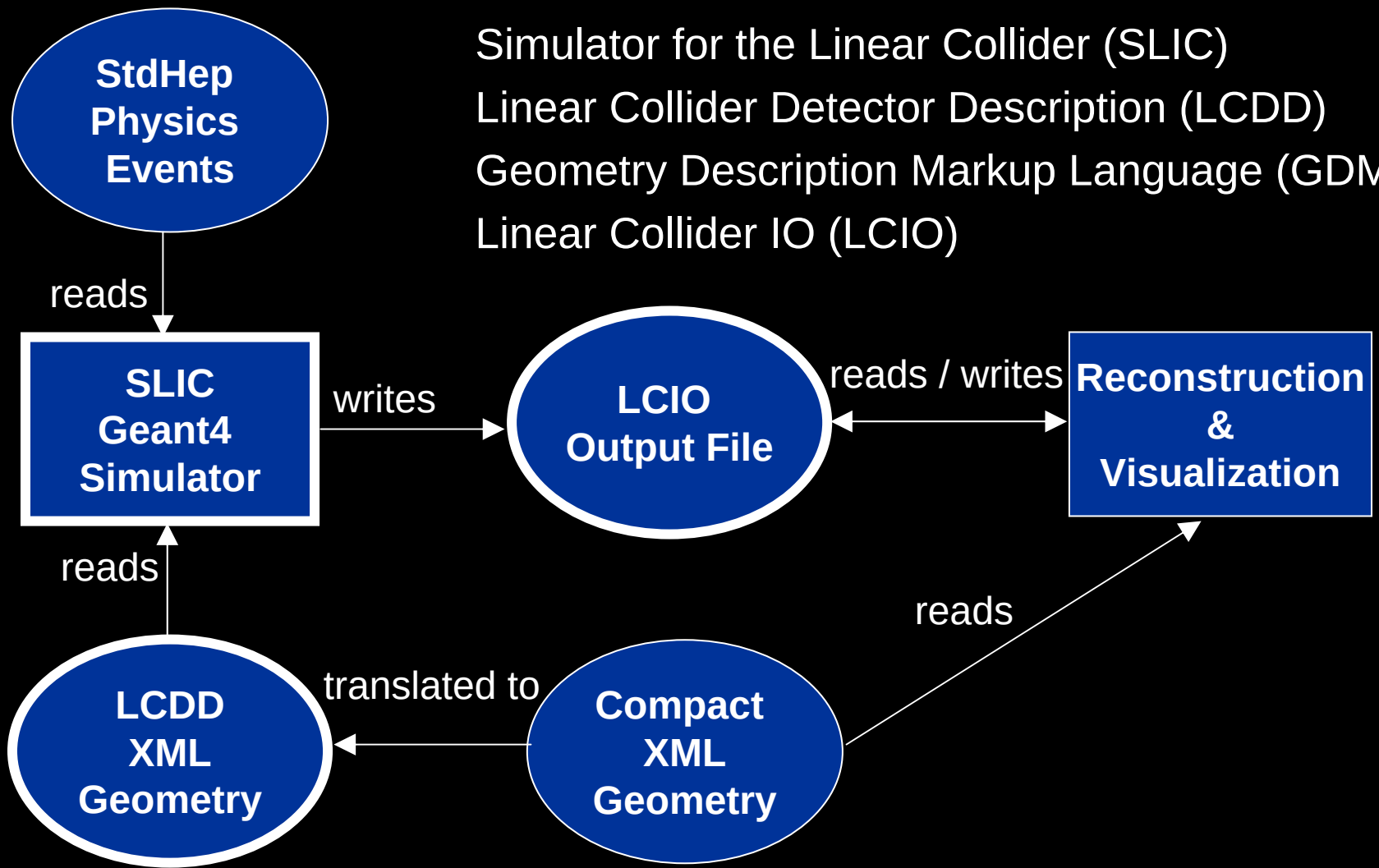


- Required tools
  - Java 1.5
  - Maven
- Recommended tools
  - Netbeans
  - Tortoise CVS (Windows)
- CVS account
  - Contact tony_johnson@slac.stanford.edu
- SLAC CVS projects
  - lcsim, GeomConverter, LCDetectors, SlicDiagnostics, freehep, etc.
- org.lcsim contrib area
  - WIP, personal, or non-compiling codes

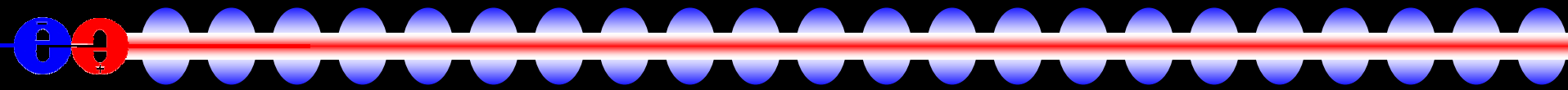
Simulation: SLIC



Simulator for the Linear Collider (SLIC)
Linear Collider Detector Description (LCDD)
Geometry Description Markup Language (GDML)
Linear Collider IO (LCIO)



Simulation: SLIC Commands



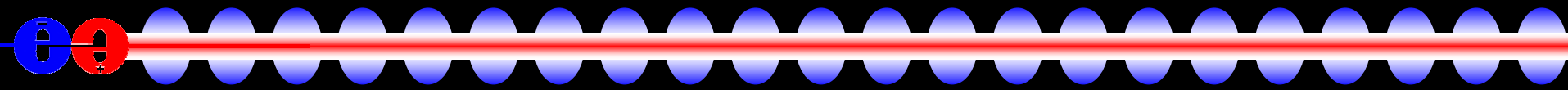
- All command-line options have equivalent Geant4 command
- Sample command

```
slic -g geometry.lcdd -i events.stdhep -x -O -l LCPhys -r 1000
```

- Equivalent macro

```
/lcdd/url geometry.lcdd
/run/initialize
/physics/select LCPhys
/generator/filename events.stdhep
/lcio/fileExists delete
/lcio/autoname
/run/beamOn 1000
```

Simulation: Detector Description



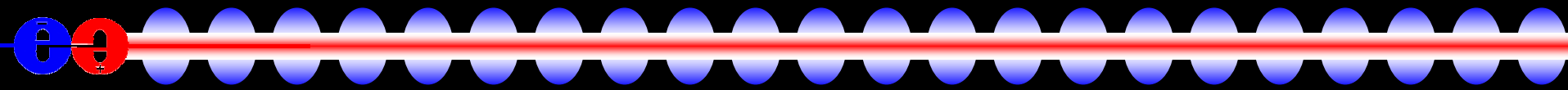
LCDD

- Identifiers
- Sensitive Detectors
- Regions
- Physics Limits
- Visualization
- Magnetic Fields

GDML

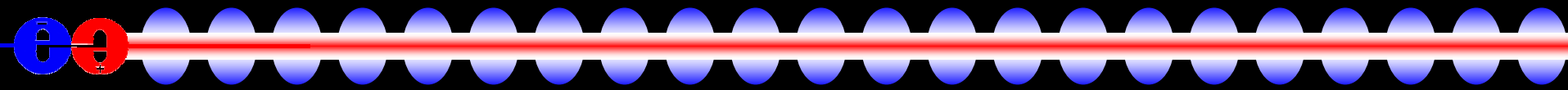
- Expressions (CLHEP)
- Materials
- Solids
- Volumes

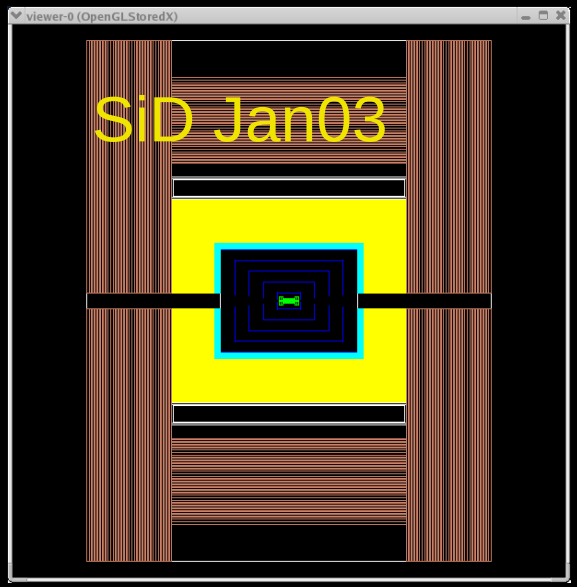
Simulation: LCDD Data Binding

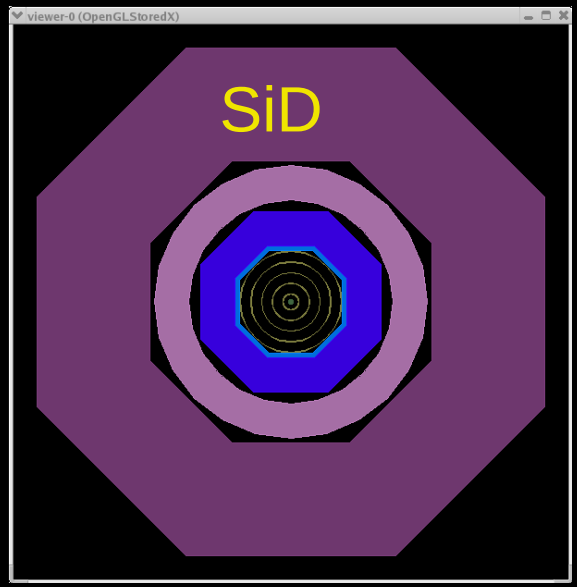


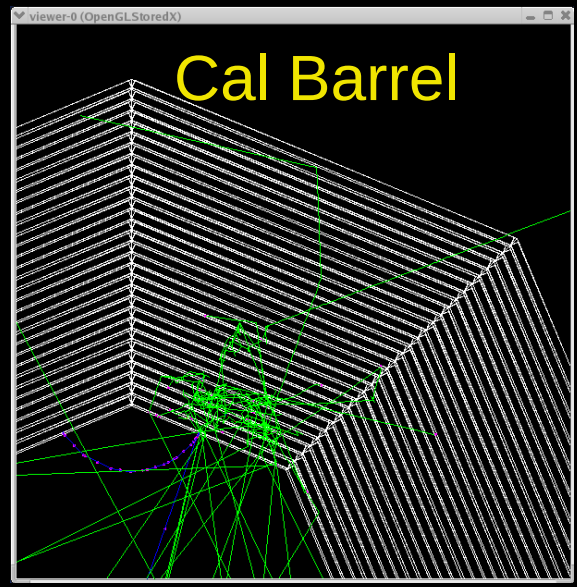
Area	Root Element	Geant4 Class(es)
Sensitive Detectors	<sensitive_detectors>	G4VSensitiveDetector
Identifiers	<iddict>	NA (custom classes)
Regions	<regions>	G4Region, G4VUserRegionInformation
Physics Limits	<limits>	G4UserLimits
Visualization	<display>	G4VisAttributes
Magnetic Fields	<fields>	G4MagneticField
Constants	<define>	NA (CLHEP expressions)
Materials	<materials>	G4Material, G4Element
Shapes	<solids>	G4VSolid
Volumes	<structure>	G4LogicalVolume, G4VPhysicalVolume

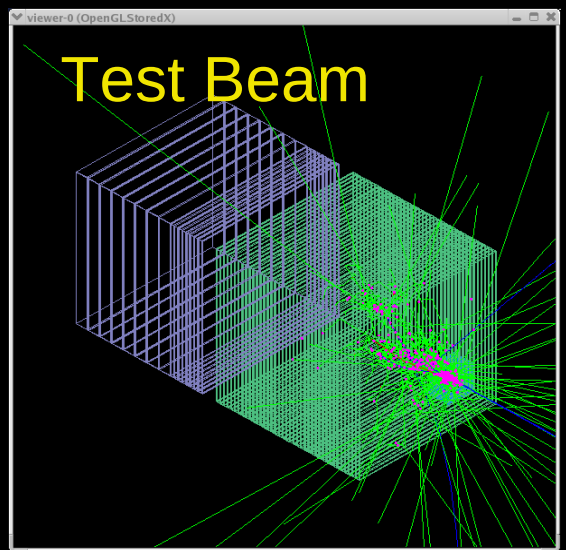
Simulation: Example Geometries



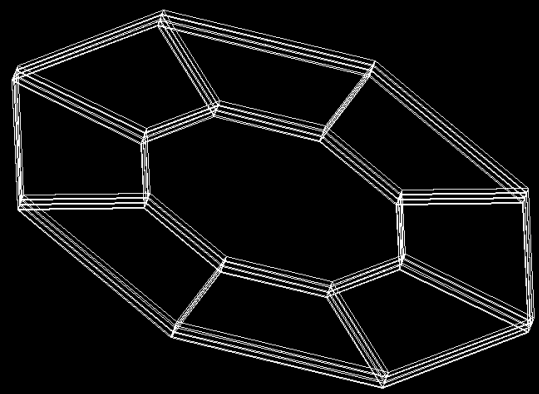




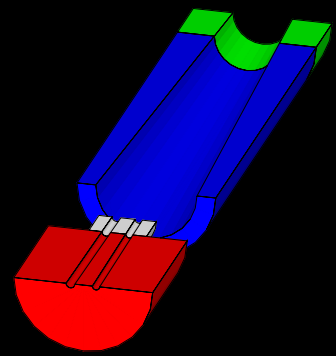




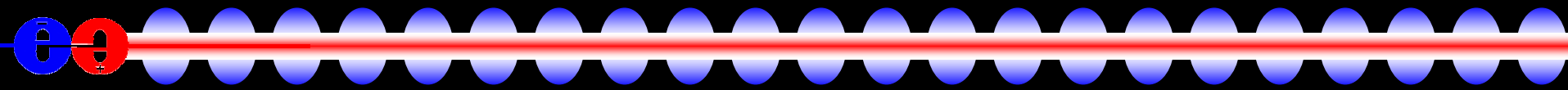
Cal Endcap



MDI-BDS

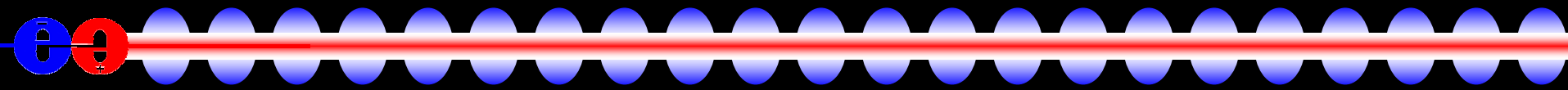


Event Generation

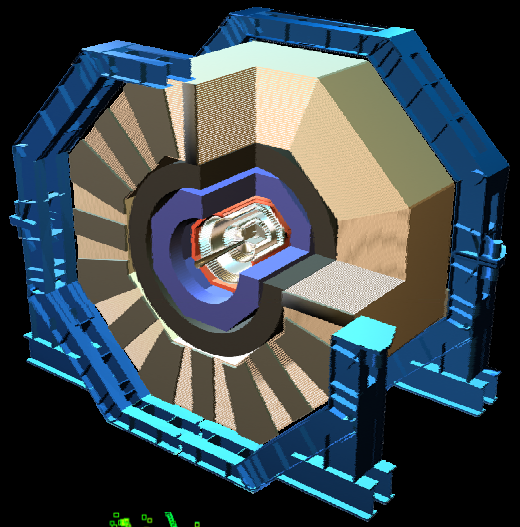


- Still a messy area → not much integration
  - Generation usually based on custom compiled code using a particular FORTRAN or C++ library
  - Different HEPEVT interpretation depending on generators
  - Some generators more “friendly” than others
- Physics generators
  - Pythia, Pandora-Pythia
  - ISAJET
  - WHIZARD
- Single Particles
  - Geant4 GPS
  - Java Diagnostic Event Generator
- Thoughts
  - Would be very useful to have a wrapper similar to ATLAS EvtGen
    - Python probably most promosing for this (or Java)
  - Usually best to rely on existing (debugged/checked) StdHep files

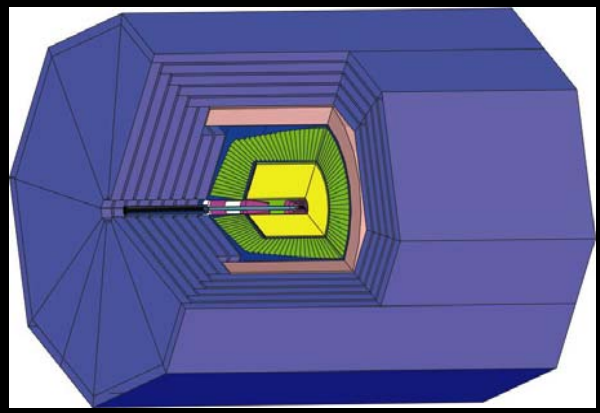
Interoperability: Event Display



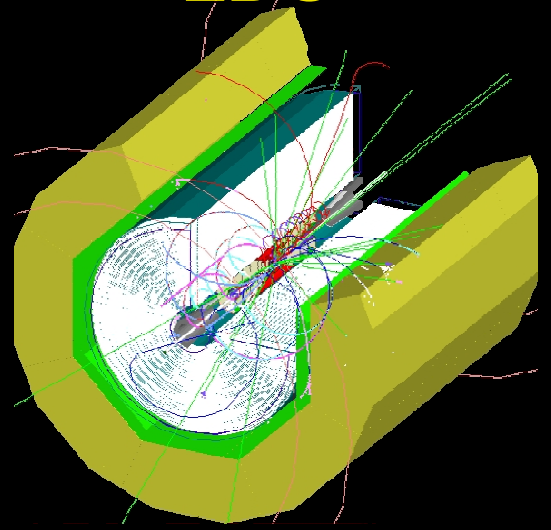
SiD

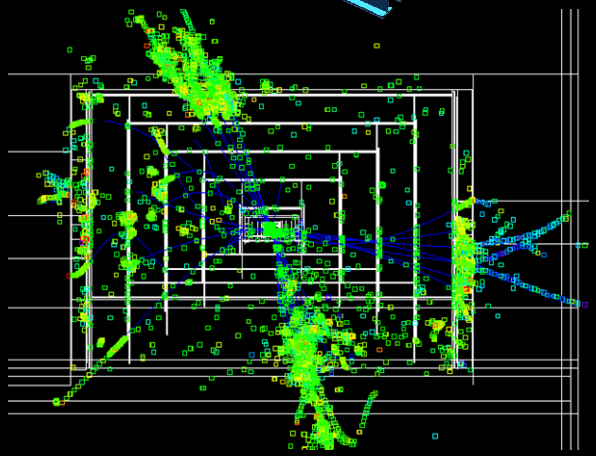


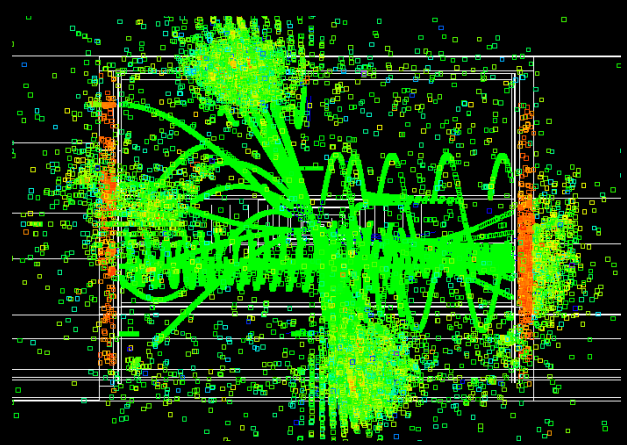
GLD

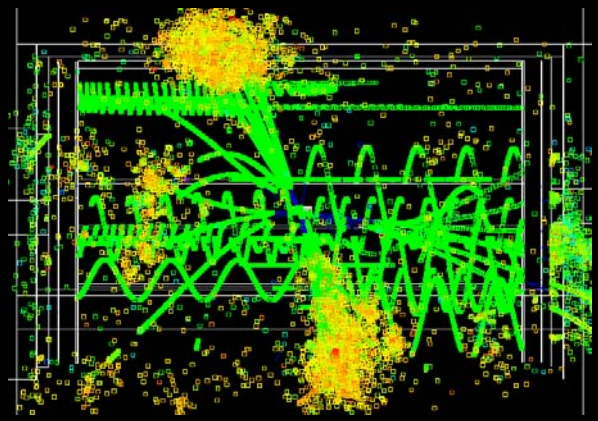


LDC



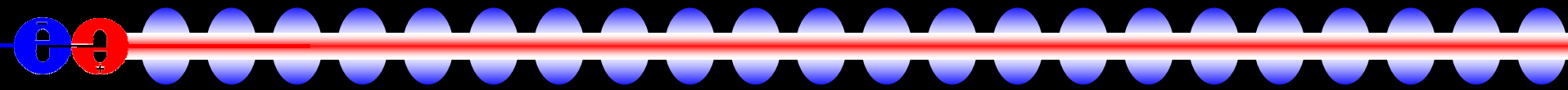






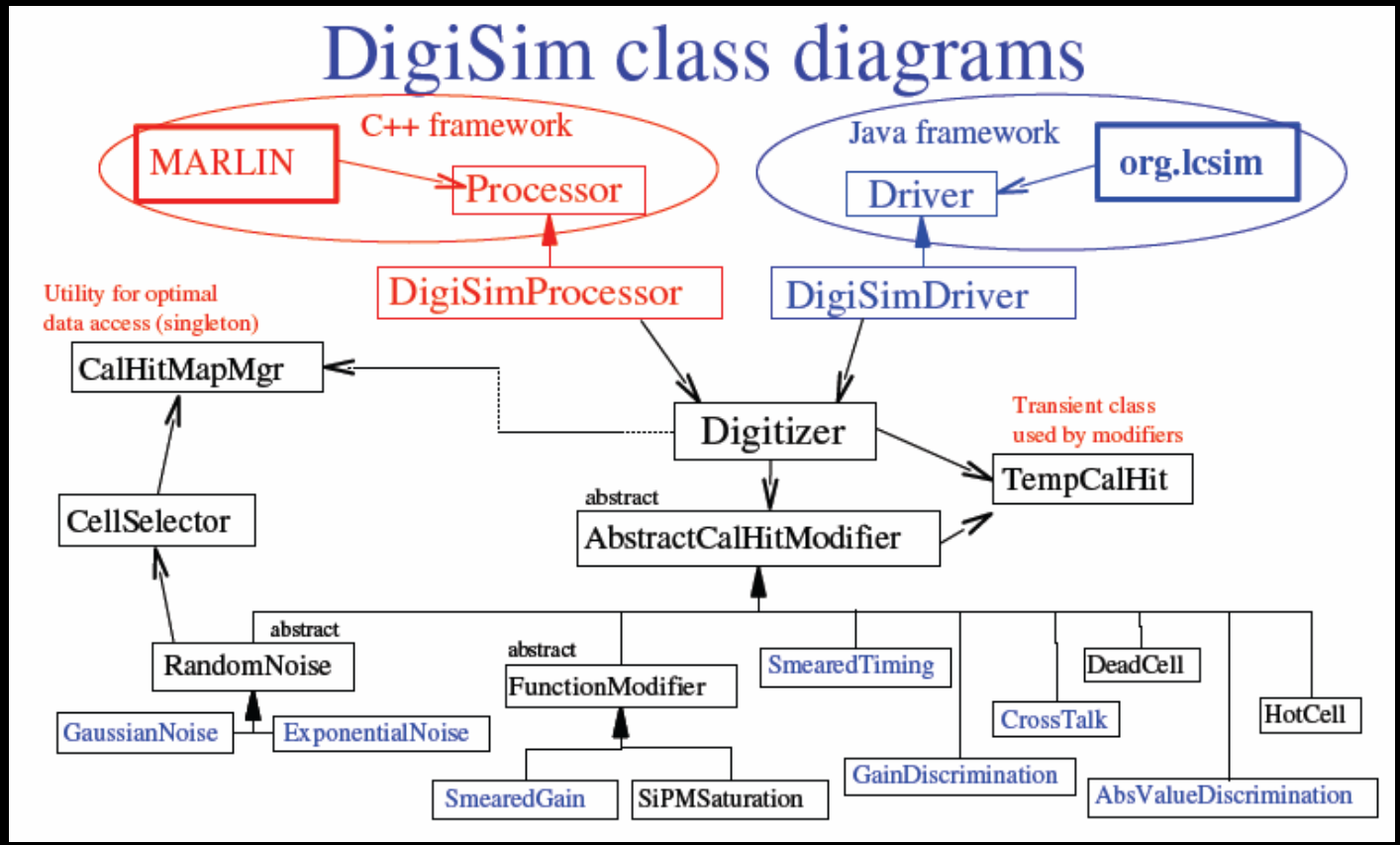
Z Higgs (M_H=120 GeV) → same simulator, three different full detector geometries

Interoperability: Analysis



- Same analysis can be run on LCIO files from different simulators
  - Compare performance of detectors
    - e.g. - plot overlays
  - Cross checks
    - Physics
    - Geometries
    - LCIO output
  - Generate LCIO reconstruction objects from different simulator data
- Plot data interchange using .aida files
- JAS3 can also read/write ROOT and PAW files using Freehep libs.
- Some problems with decoding IDs from non-lcsim detectors
  - Working on this!
  - Probably should add more Id'ing metadata to LCIO format

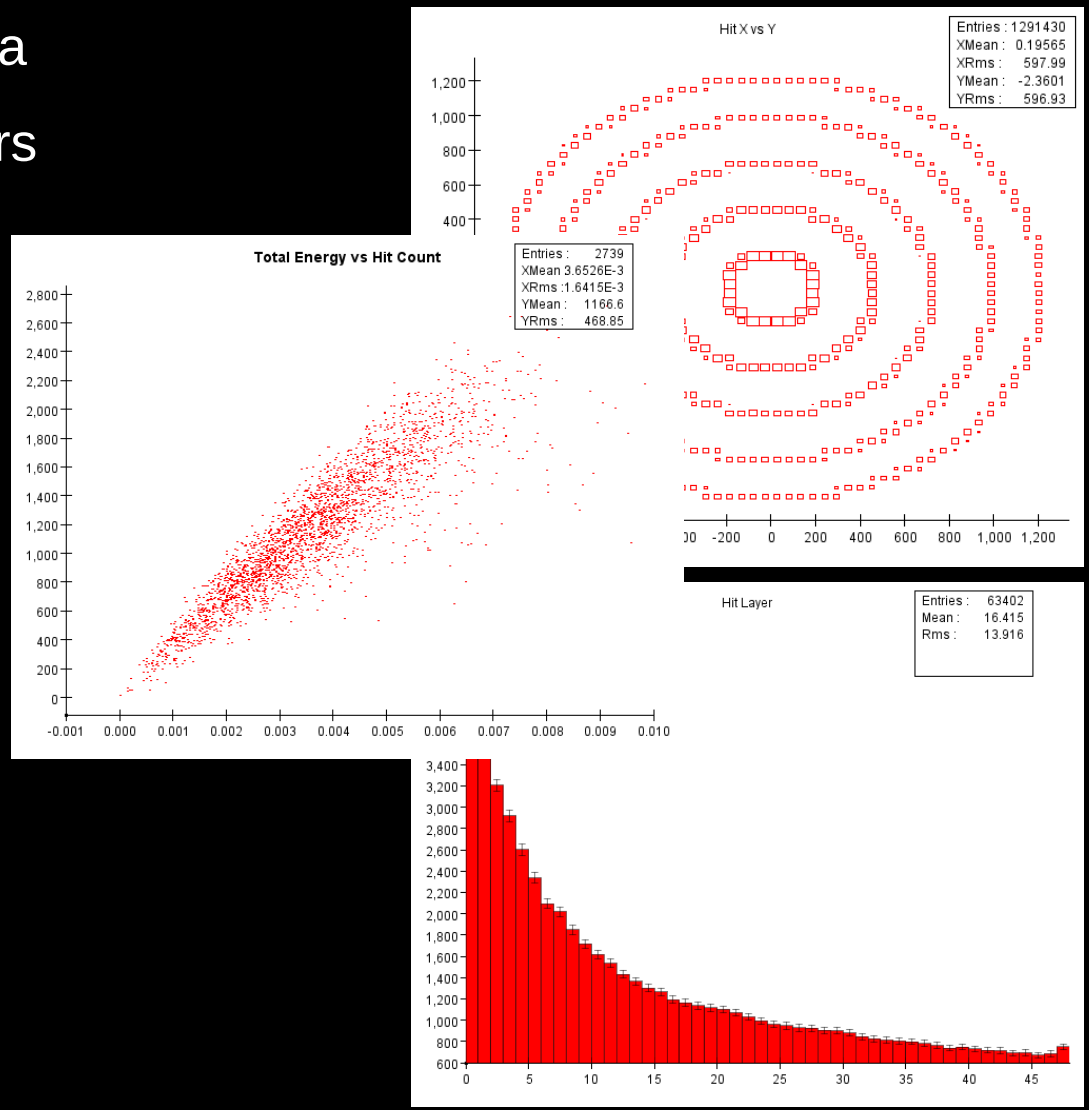
Example Project: DigiSim



- Goal: a program to parametrically simulate the signal propagation and digitization processes for the ILC detector simulation
- Author: Guilherme Lima

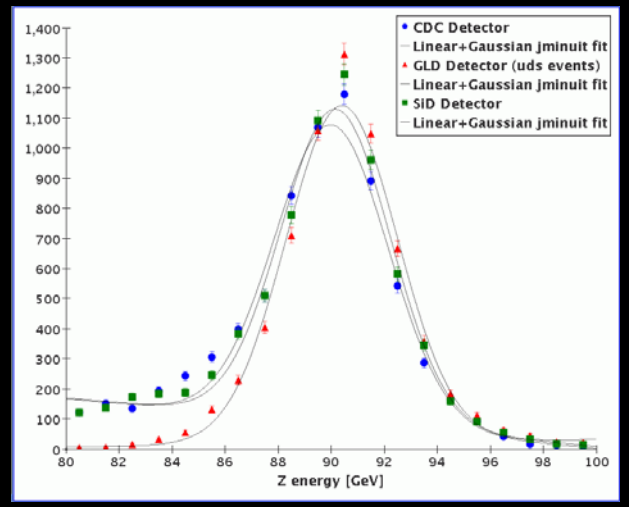
Example Project: SlicDiagnostics

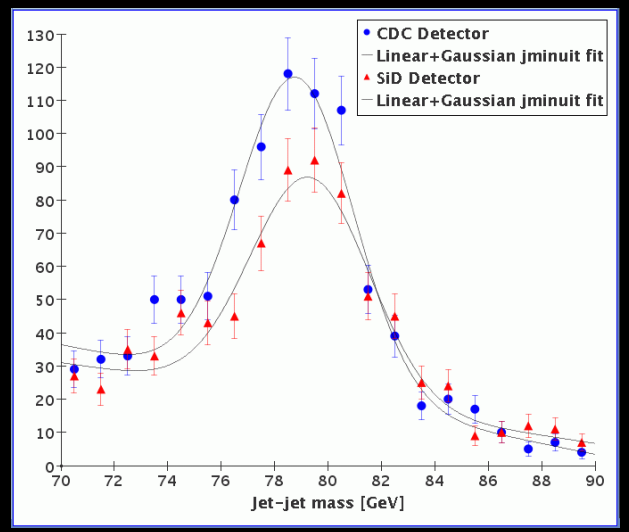
- Diagnostic plots of event data
  - MCParticles, hits, clusters
- Run on different detectors
- Easy to use and setup
  - Maven project
- SLAC CVS project
  - SlicDiagnostics
- Author: Jeremy McCormick



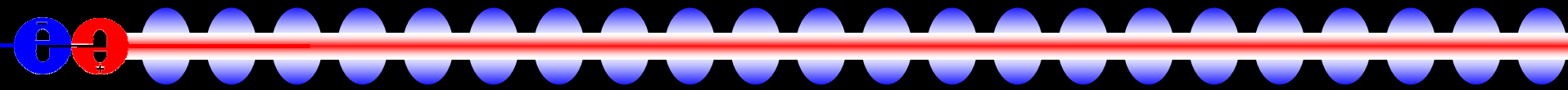
Example Project: Recon Cheater

- Makes reconstruction objects from event data
  - Tracks
  - Clusters, refined clusters
  - Reconstructed particles
- Benchmark
  - Detector designs
  - Compare reconstruction algorithms
- Drivers
  - ClusterCheater
  - TrackingCheater
- Customizable using CheatingTable conditions
- Author: Mike Ronan



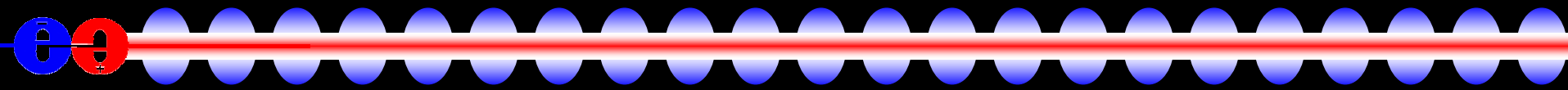


Documentation



- IIC Wiki used for supplementary docs
  - HTML-like syntax
  - Export to PDF
  - Need account to contribute (email Tony Johnson)
- Doxygen for C++ documentation
  - SLIC, LCDD
- JavaDoc for Java documentation
  - org.lcsim, GeomConverter
  - Generated automatically along with website by Maven

Links



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