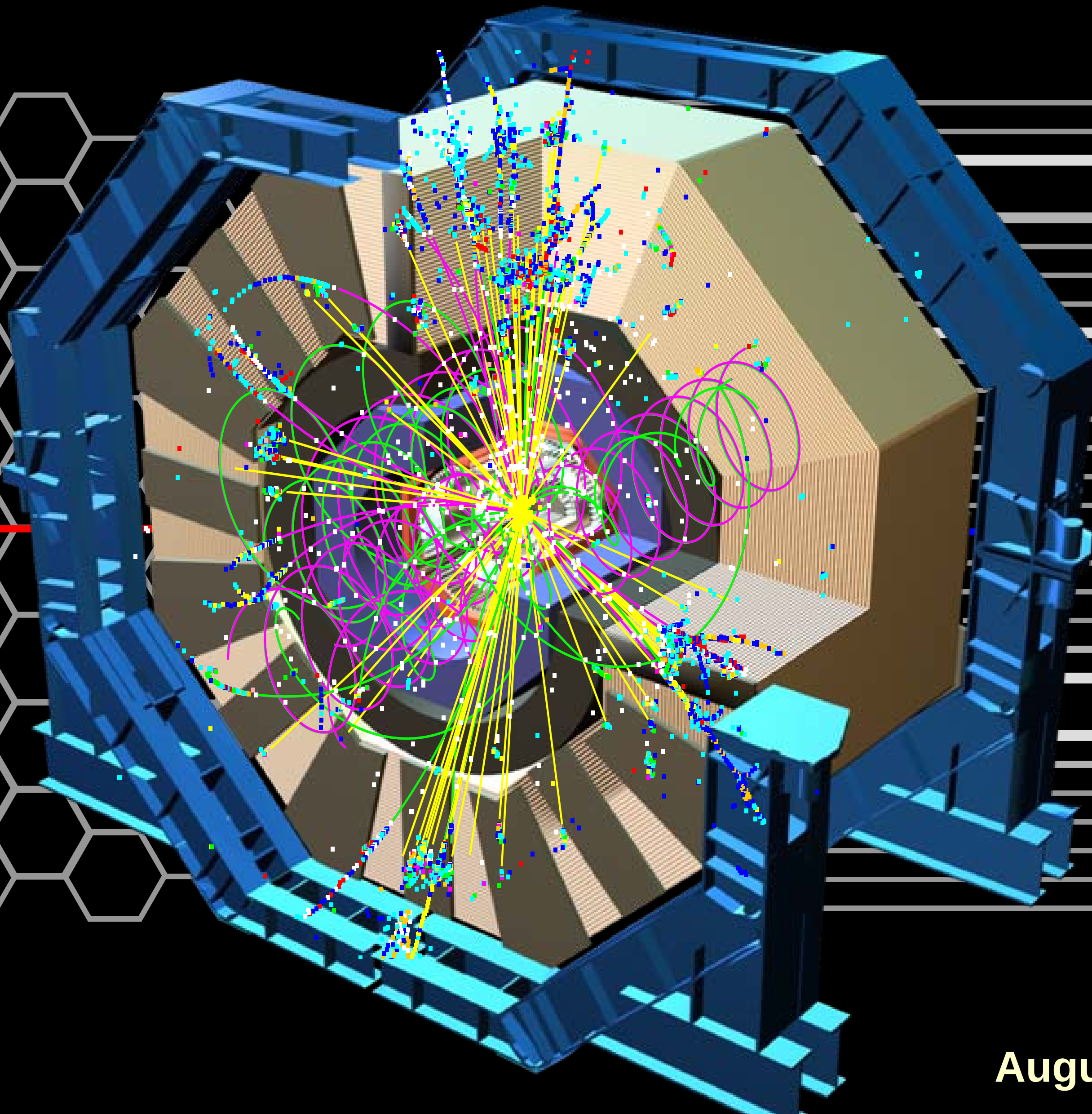
Simulating the Silicon Detector



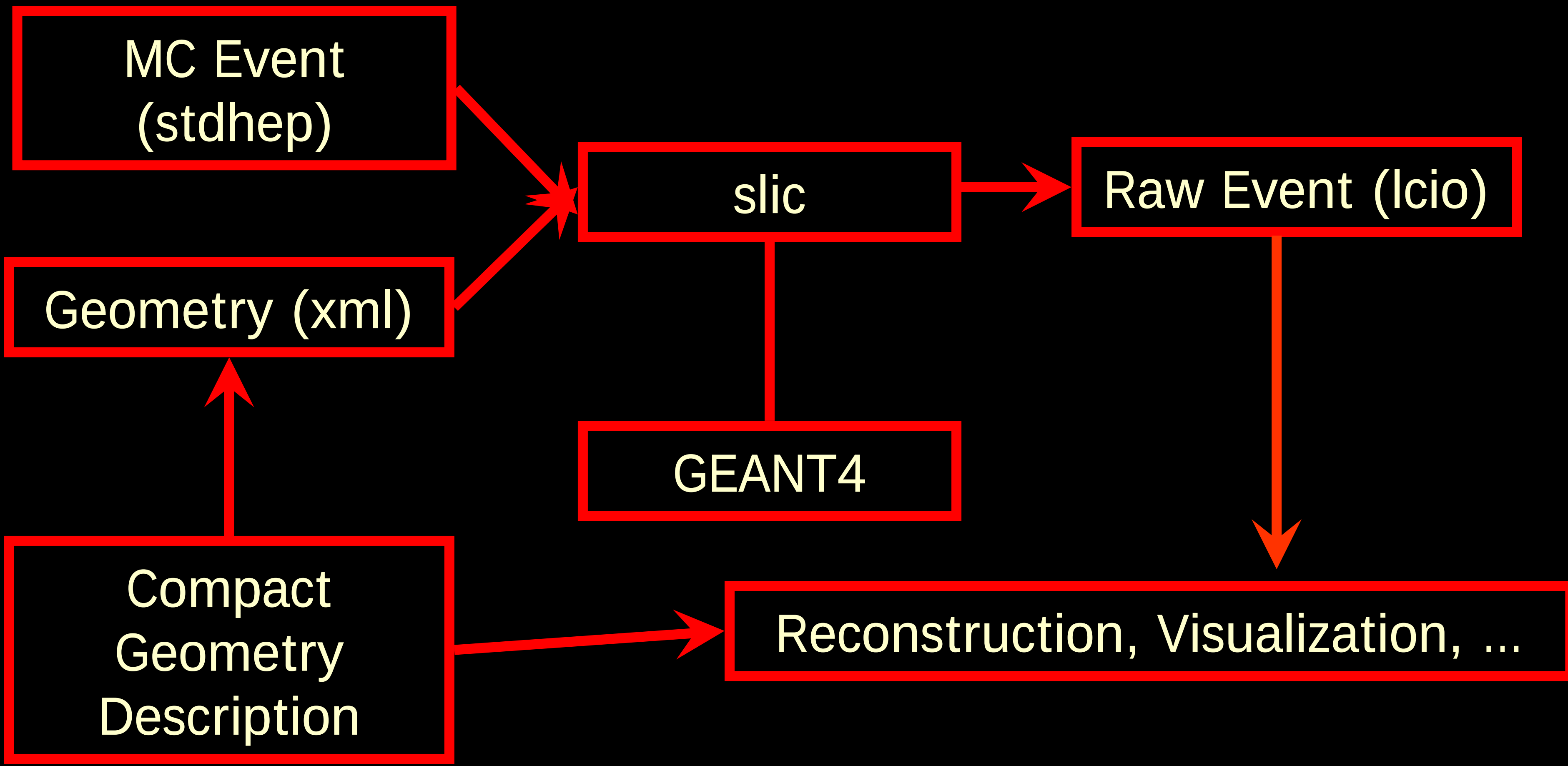
Norman Graf
SLAC

August 16, 2005

Detector Response Simulation

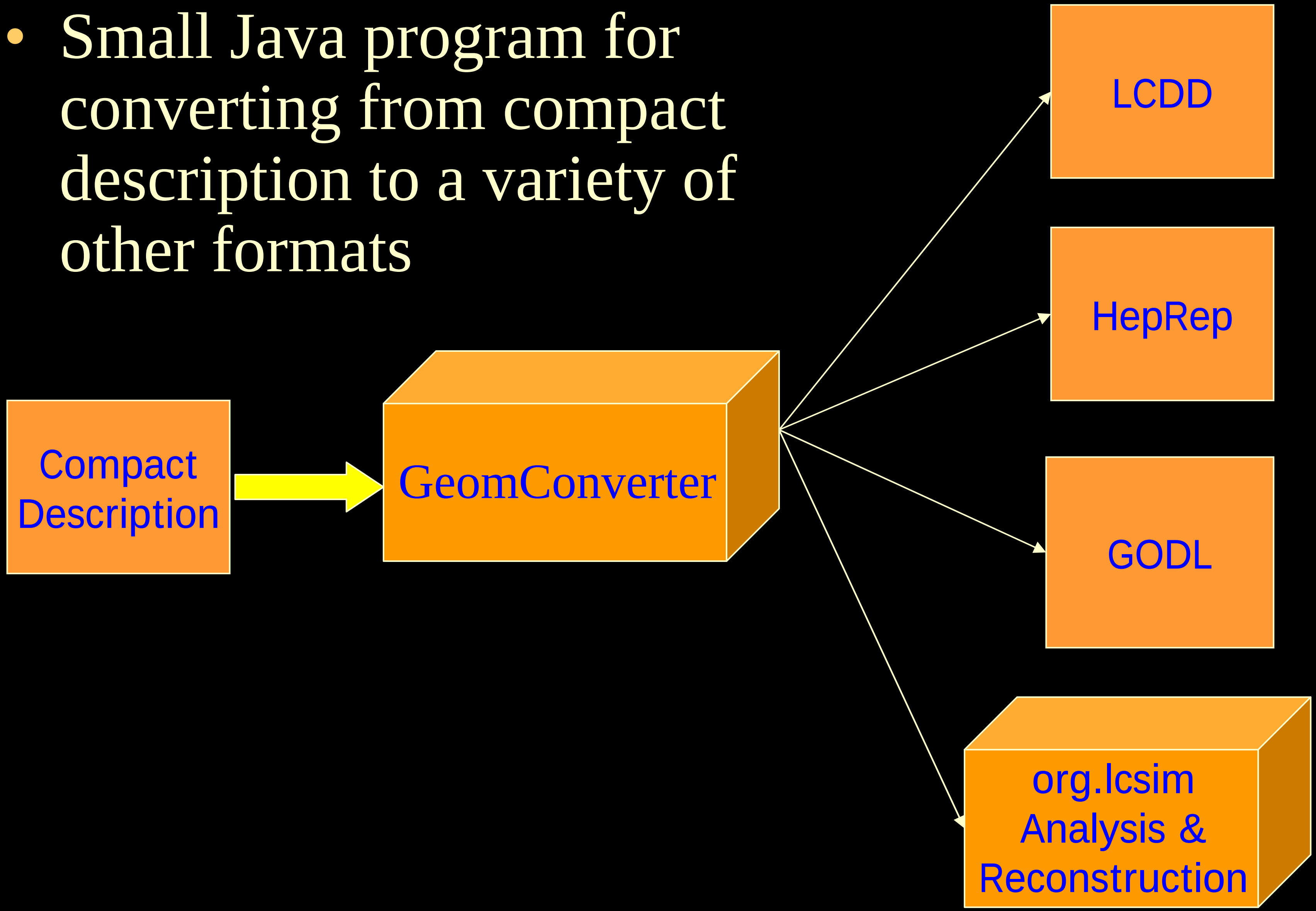
- Use Geant4 toolkit to describe interaction of particles with matter.
- Thin layer of LC-specific C++ provides access to:
  - Event Generator input (binary stdhep format)
  - Detector Geometry description (XML)
  - Detector Hits (LCIO)
- Geometries fully described at run-time!
  - In principle, as fully detailed as desired.
  - In practice, will explore detector variations with simplified approximations.

LC Detector Full Simulation



GeomConverter

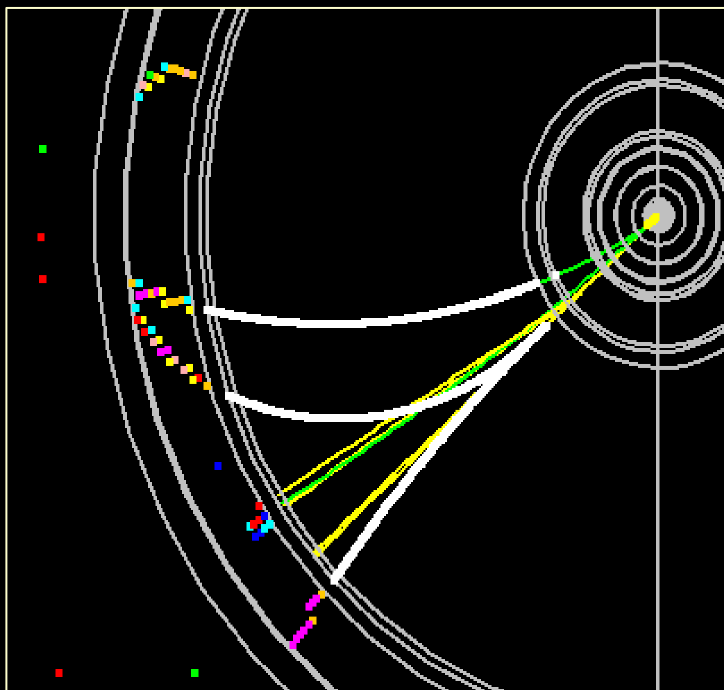
- Small Java program for converting from compact description to a variety of other formats



lelaps

- Fast detector response package (Willy Langeveld).
- Handles decays in flight, multiple scattering and energy loss in trackers.
- Parameterizes shower development in calorimeters.
- Targets both sio and lcio at the hit level.
- Detector description runtime definable (godl)
  - can be hand written
  - can be exported from the compact description.

Lelaps: Decays, dE/dx, MCS

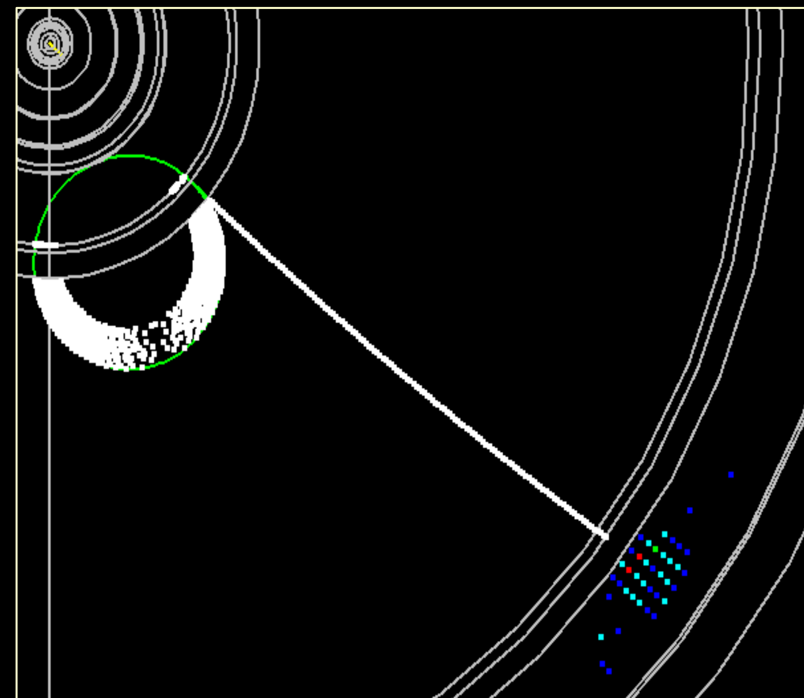


$\Omega^- \rightarrow \Xi^0 \pi^-$

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

$\Lambda \rightarrow p \pi^-$

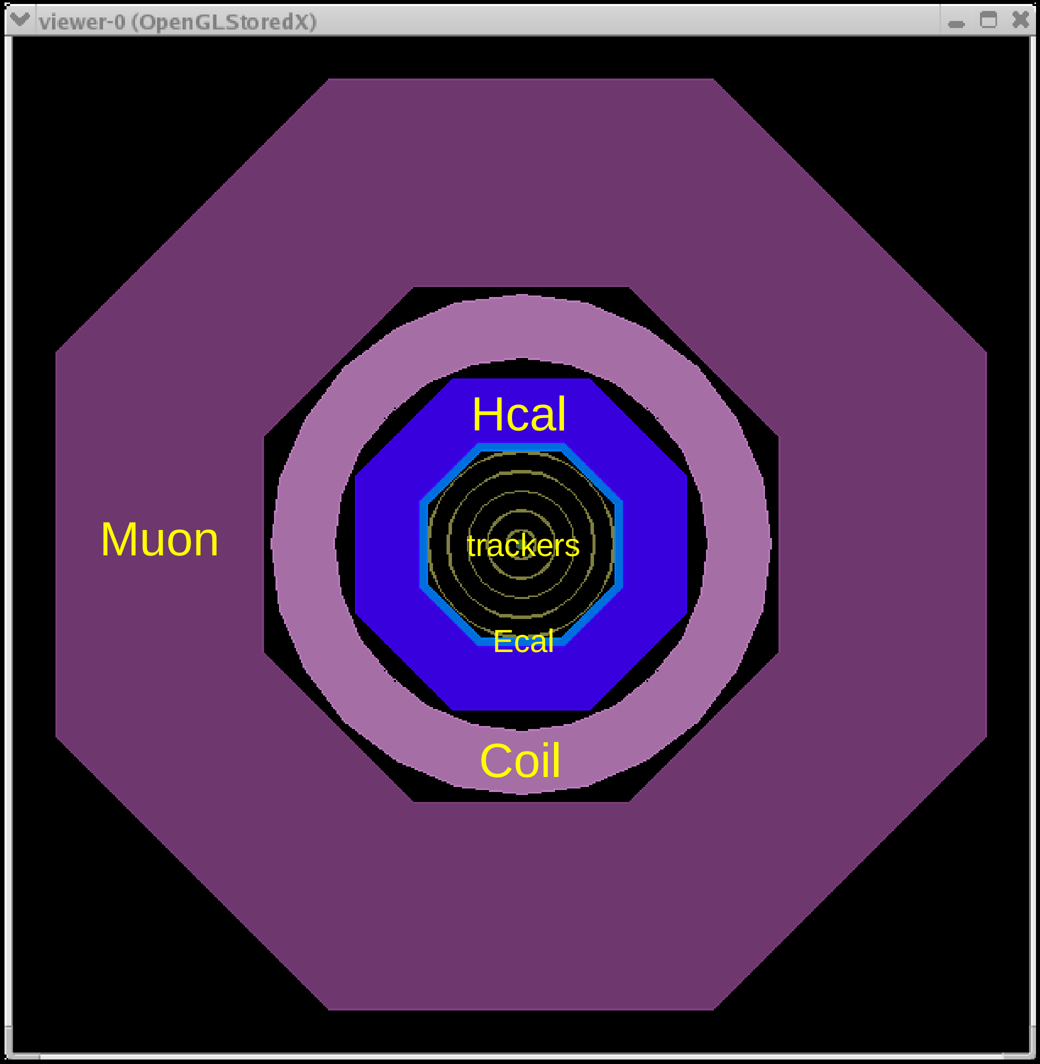
$\pi^0 \rightarrow \gamma \gamma$ as simulated by Lelaps for the LCD LD model.



gamma conversion as simulated by Lelaps for the LCD LD model.

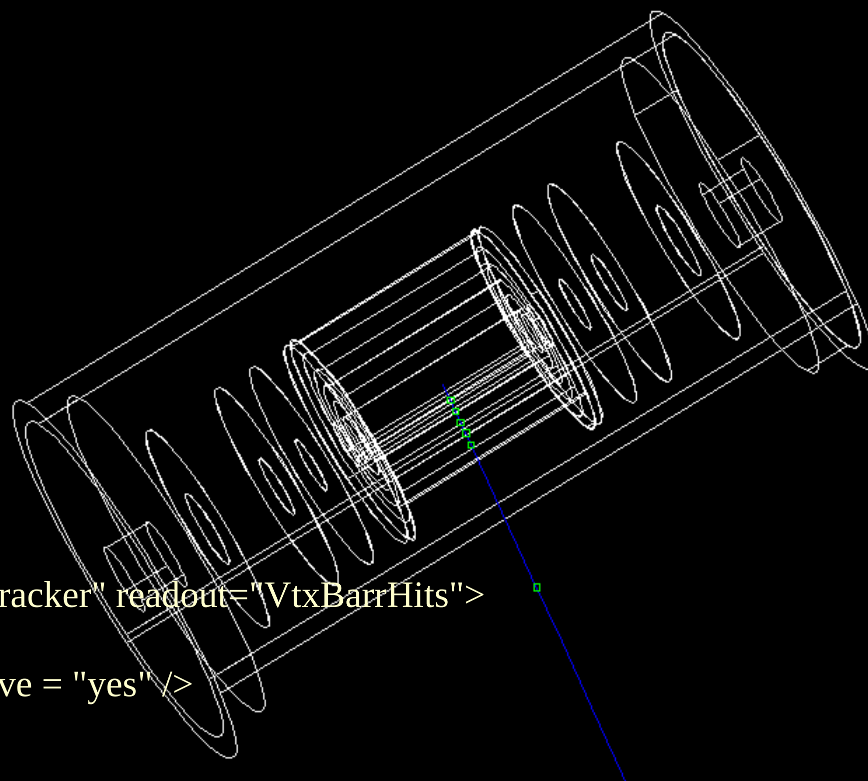
SiDFeb05 Detector Envelopes

- **./sid/SiDEnvelope.lcdd**
- *toy example* without real materials or layer structure
- polyhedra for calorimeter envelopes
- illustrates possibility of modeling realistic detector designs with “corners”
    - add trapezoid-shaped readout modules with box layers



Vertex Detector

- 5 Layer CCD Barrel
- 4 Layer CCD Disks
- Be supports
- Foam Cryostat



```
<detectors>
    <detector id="0" name="BarrelVertex" type="MultiLayerTracker" readout="VtxBarrHits">
        <layer id="1" inner_r = "1.5*cm" outer_z = "6.25*cm">
            <slice material = "Silicon" width = "0.01*cm" sensitive = "yes" />
        </layer>
        <layer id="2" inner_r = "2.6*cm" outer_z = "6.25*cm">
            <slice material = "Silicon" width = "0.01*cm" sensitive = "yes" />
        </layer>
        <layer id="3" inner_r = "3.7*cm" outer_z = "6.25*cm">
            <slice material = "Silicon" width = "0.01*cm" sensitive = "yes" />
        </layer>
        <layer id="4" inner_r = "4.8*cm" outer_z = "6.25*cm" >
            <slice material = "Silicon" width = "0.01*cm" sensitive = "yes" />
        </layer>
```

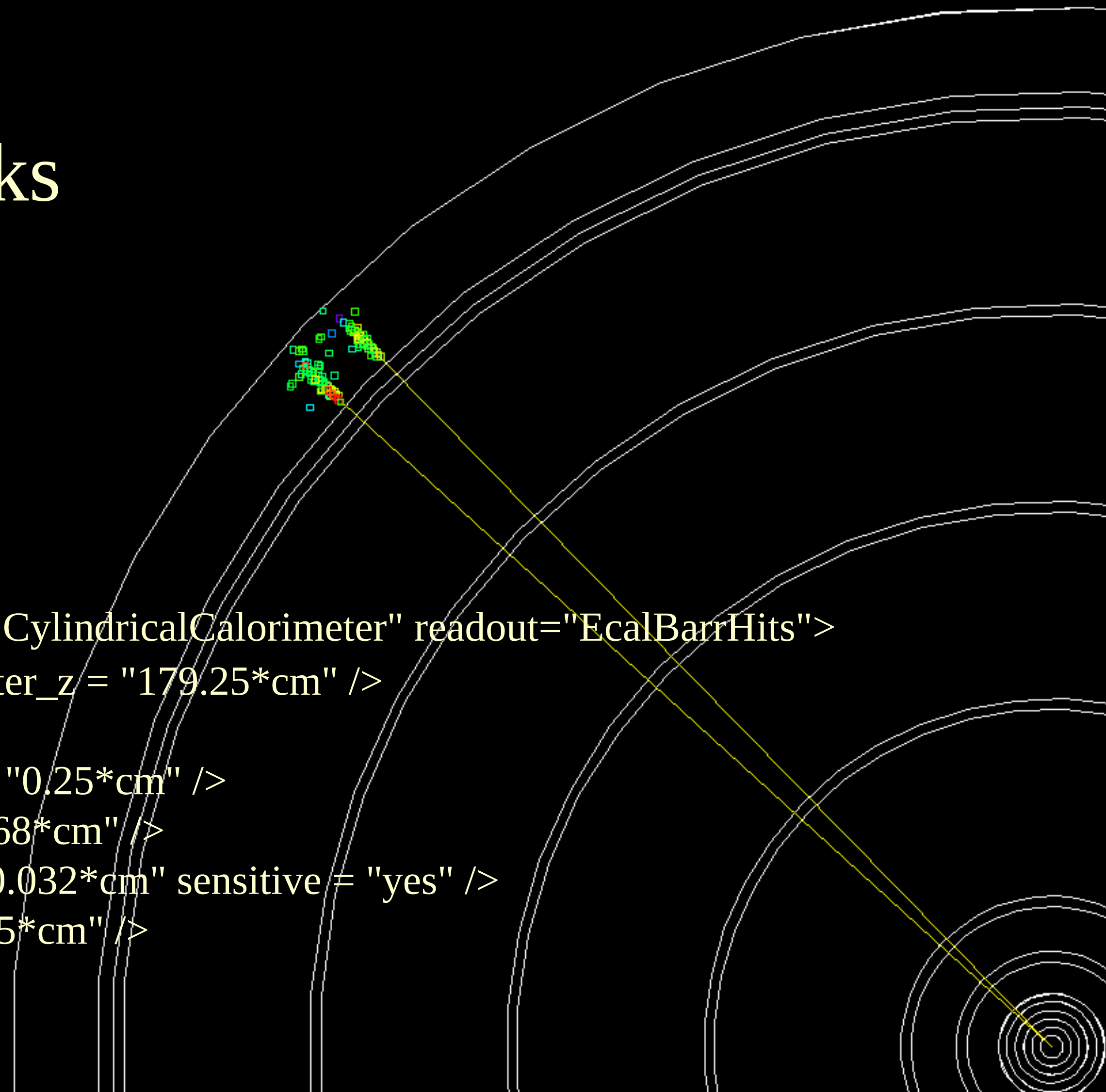
Central Tracking Detector

- 5 Layer Si μ-strips
- Barrel+Disk
- C-Rohacell-C supports

```
<detector id="2" name="BarrelTracker" type="MultiLayerTracker"  readout="TkrBarrHits">
        <layer id="1" inner_r = "18.635*cm" outer_z = "26.67*cm">
              <slice material = "CarbonFiber" width = "0.025*cm" />
              <slice material = "Rohacell31" width="1.3*cm" />
              <slice material = "CarbonFiber" width=".025*cm" />
              <slice material = "Silicon" width = "0.03*cm" sensitive = "yes" />
        </layer>
        <layer id="2" inner_r = "44.885*cm" outer_z = "61.67*cm">
              <slice material = "CarbonFiber" width = "0.025*cm" />
              <slice material = "Rohacell31" width="1.3*cm" />
              <slice material = "CarbonFiber" width=".025*cm" />
              <slice material = "Silicon" width = "0.03*cm" sensitive = "yes" />
        </layer>
```

EM Calorimeter

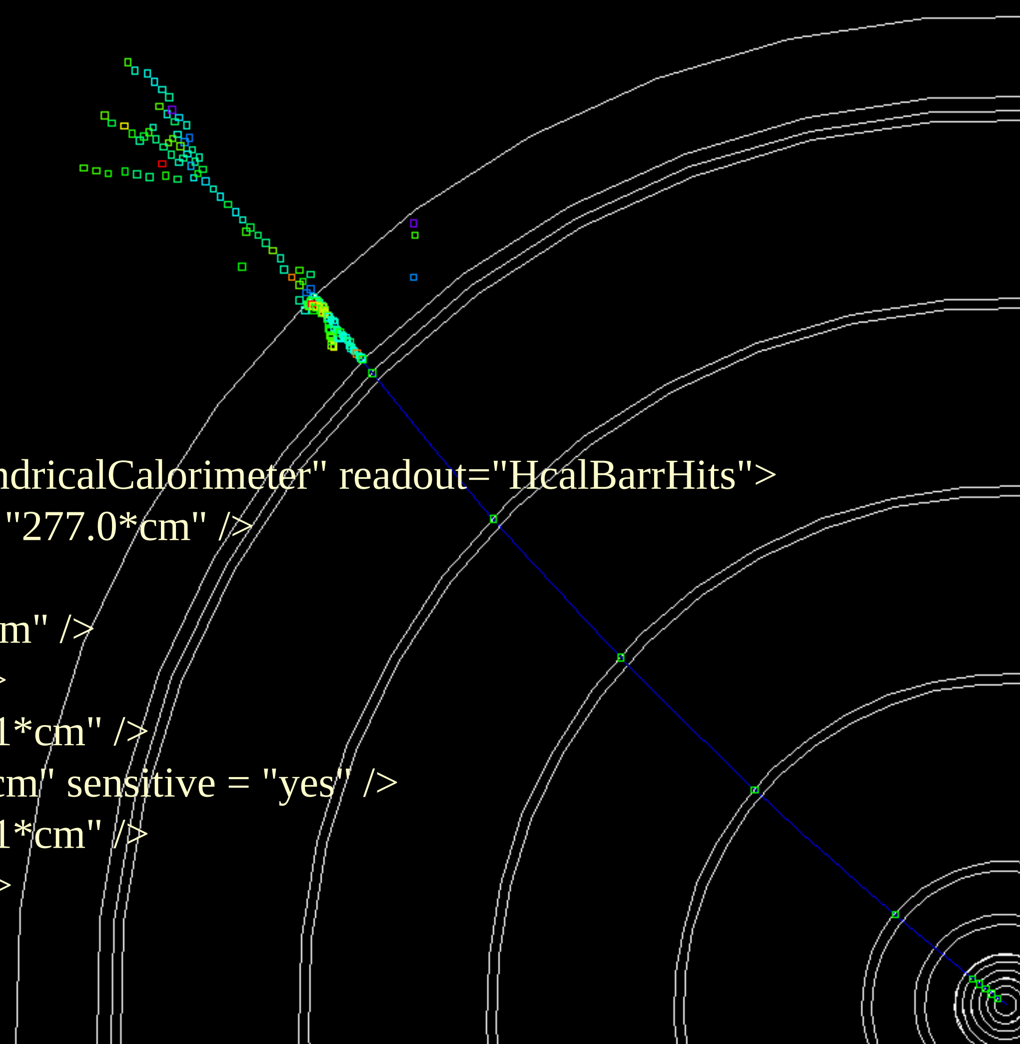
- W-Si Sampling
- Barrel+Endcap Disks



```
<detector id=“3" name="EMBarrel" type="CylindricalCalorimeter" readout="EcalBarrHits">
      <dimensions inner_r = "127.0*cm" outer_z = "179.25*cm" />
      <layer repeat=“30">
        <slice material = "Tungsten" width = "0.25*cm" />
        <slice material = "G10" width = "0.068*cm" />
        <slice material = "Silicon" width = "0.032*cm" sensitive = "yes" />
        <slice material = "Air" width = "0.025*cm" />
      </layer>
  </detector>
```

Hadronic Calorimeter

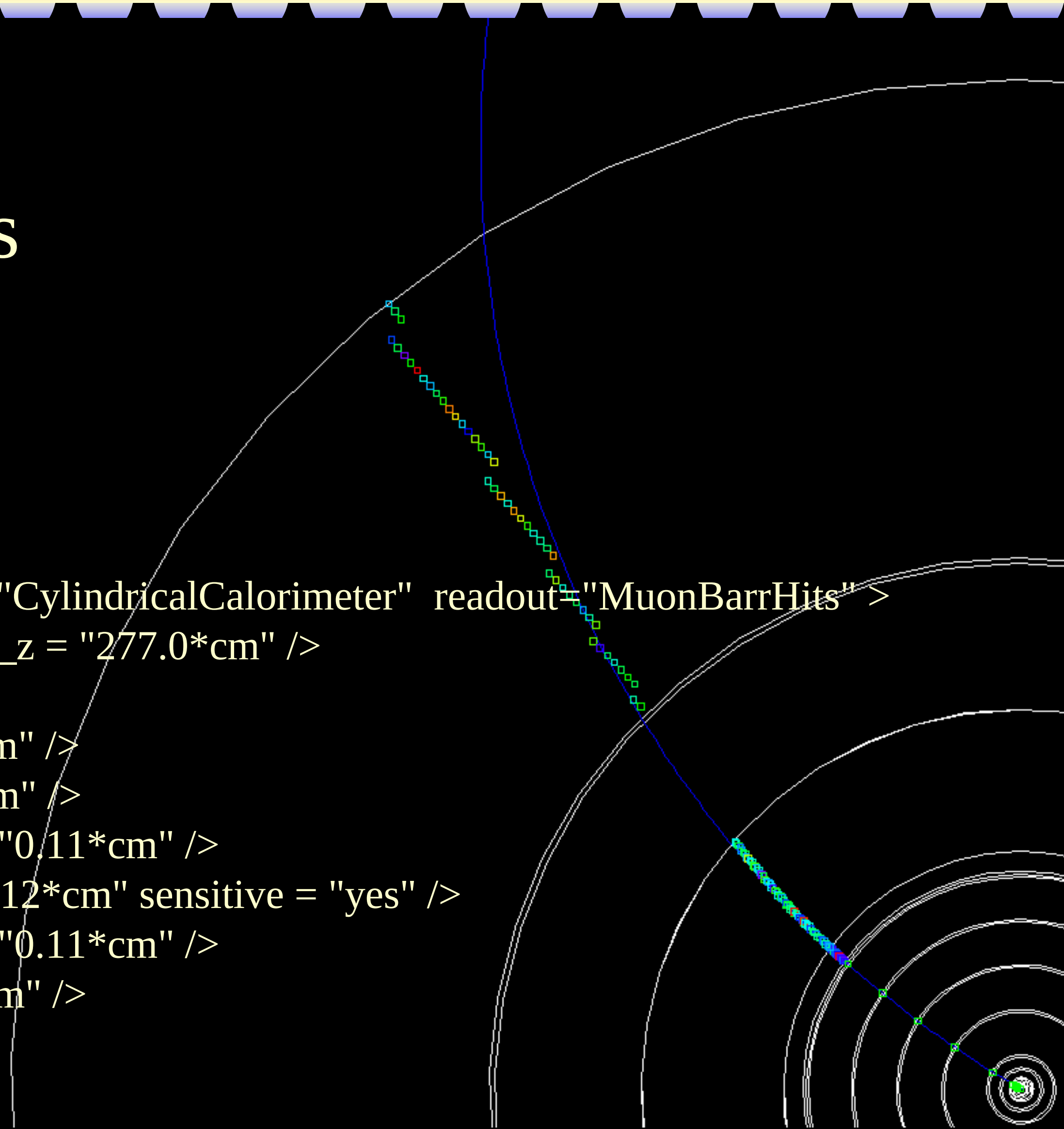
- SS+RPC Sampling
- Barrel+Endcap Disks



```
<detector id="3" name="HADBarrel" type="CylindricalCalorimeter" readout="HcalBarrHits">
      <dimensions inner_r = "138.5*cm" outer_z = "277.0*cm" />
      <layer repeat=“34">
        <slice material = “Stee1235" width = “2.0*cm" />
        <slice material = "G10" width = "0.3*cm" />
        <slice material = "PyrexGlass" width = "0.11*cm" />
        <slice material = "RPCGas" width = "0.12*cm" sensitive = "yes" />
        <slice material = "PyrexGlass" width = "0.11*cm" />
        <slice material = "Air" width = "0.16*cm" />
      </layer>
  </detector>
```

Muon System

- Fe + RPC (Scint.)
- Barrel+Endcap Disks



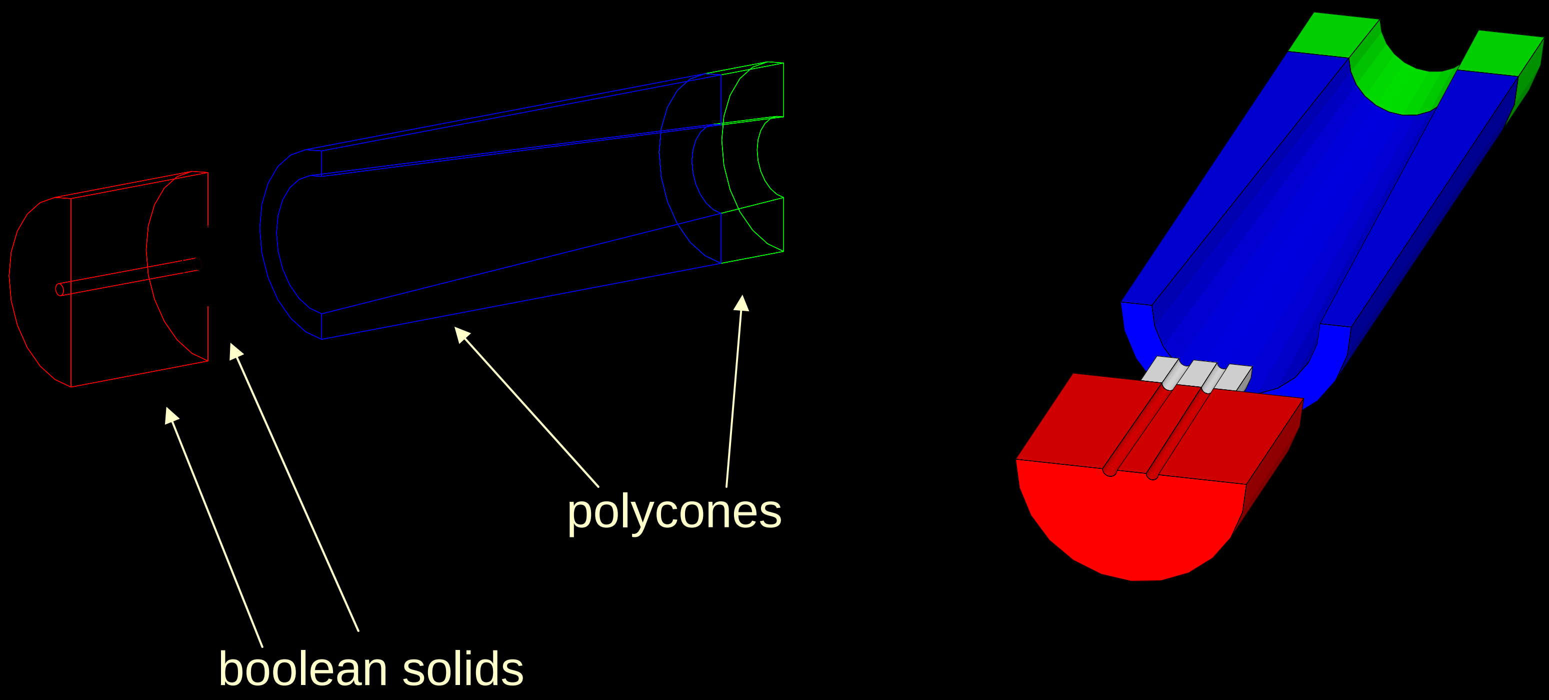
```
<detector id="4" name="MuonBarrel" type="CylindricalCalorimeter"  readout="MuonBarrHits" >
      <dimensions inner_r = "333.0*cm" outer_z = "277.0*cm" />
      <layer repeat="48">
        <slice material = "Iron" width = "5.0*cm" />
        <slice material = "G10" width = "0.3*cm" />
        <slice material = "PyrexGlass" width = "0.11*cm" />
        <slice material = "RPCGas" width = "0.12*cm" sensitive = "yes" />
        <slice material = "PyrexGlass" width = "0.11*cm" />
        <slice material = "Air" width = "0.16*cm" />
      </layer>
 </detector>
```

Far Forward Calorimetry

- W+Si Sampling, follows the layout of EM endcap.
- Needs to be refined, currently only a placeholder.

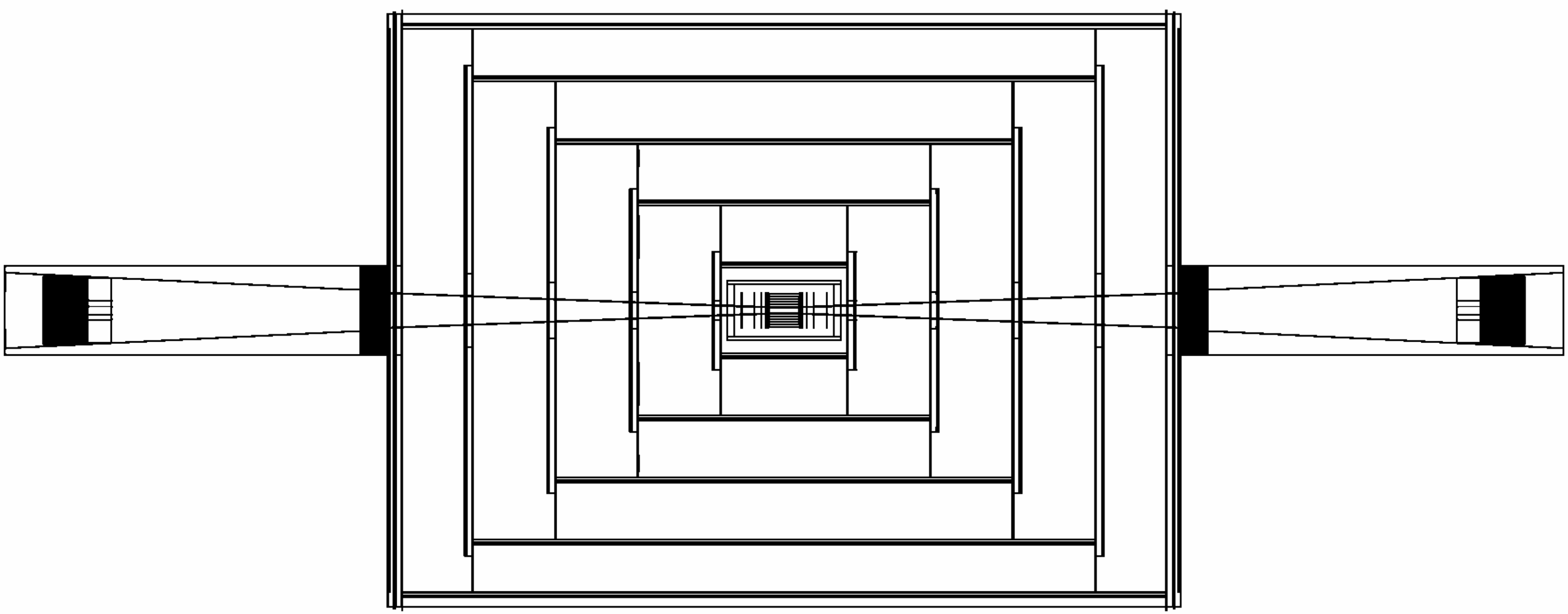
MDI - BDS

Machine Detector Interface and Beam Delivery System



Both 2 and 20 milliradian solutions implemented.

2 and 20 milliradian



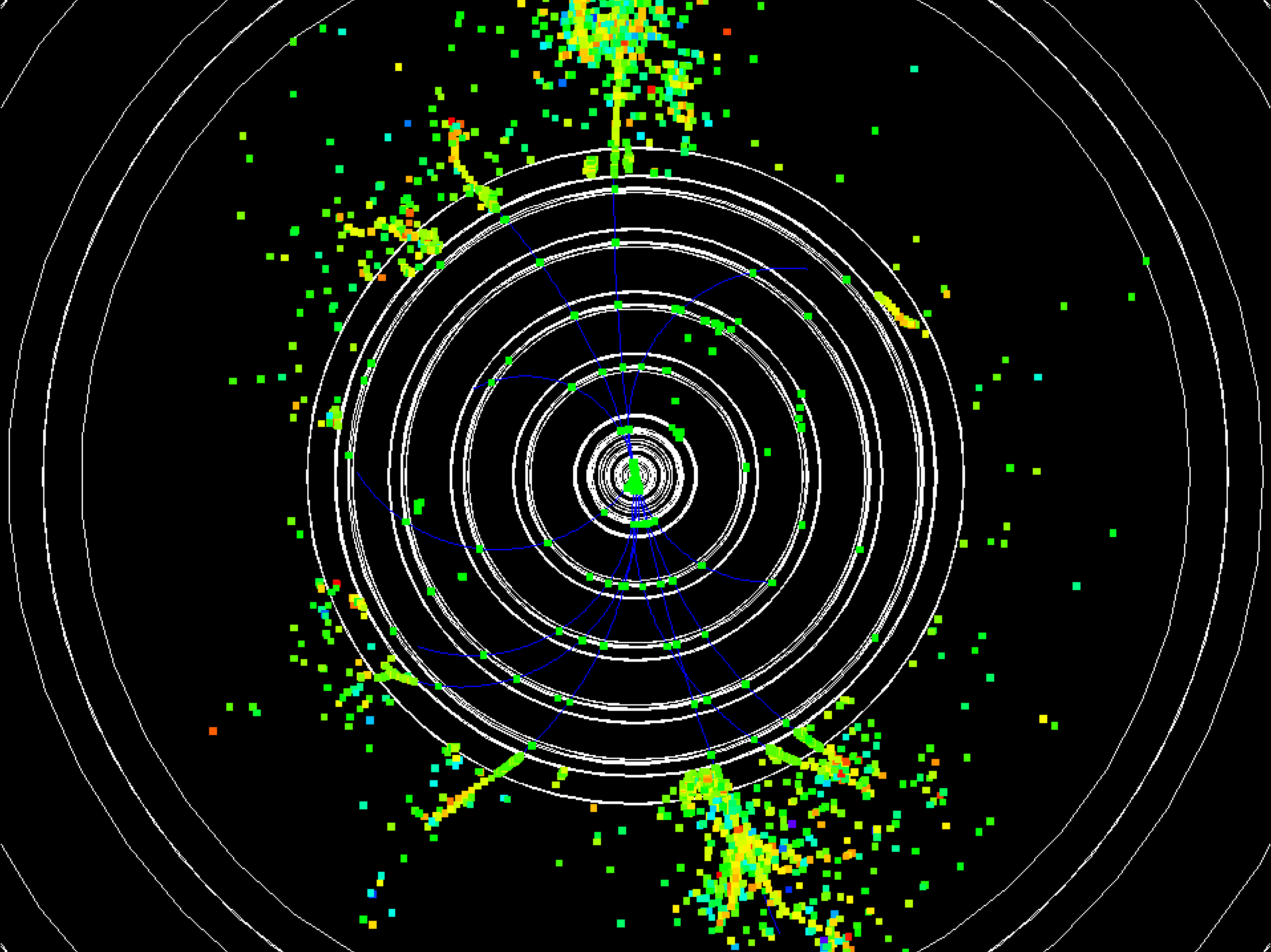
Detector Variants

- XML format allows variations in detector geometries to be easily set up and studied:
  - Stainless Steel vs. Tungsten HCal sampling material
  - RPC vs. Scintillator readout
  - Layering (radii, number, composition)
  - Readout segmentation
  - Tracking detector topologies
    - “Wedding Cake” Nested Tracker vs. Barrel + Cap
  - Field strength

Detector Variants for Snowmass

- sidaug05
- sidaug05_np
- sidaug05_4tesla
- sidaug05_scinthcal

- cdcaug05
- cdcaug05_np
- cdcaug05_rpchcal
- cdcaug05_ecal150



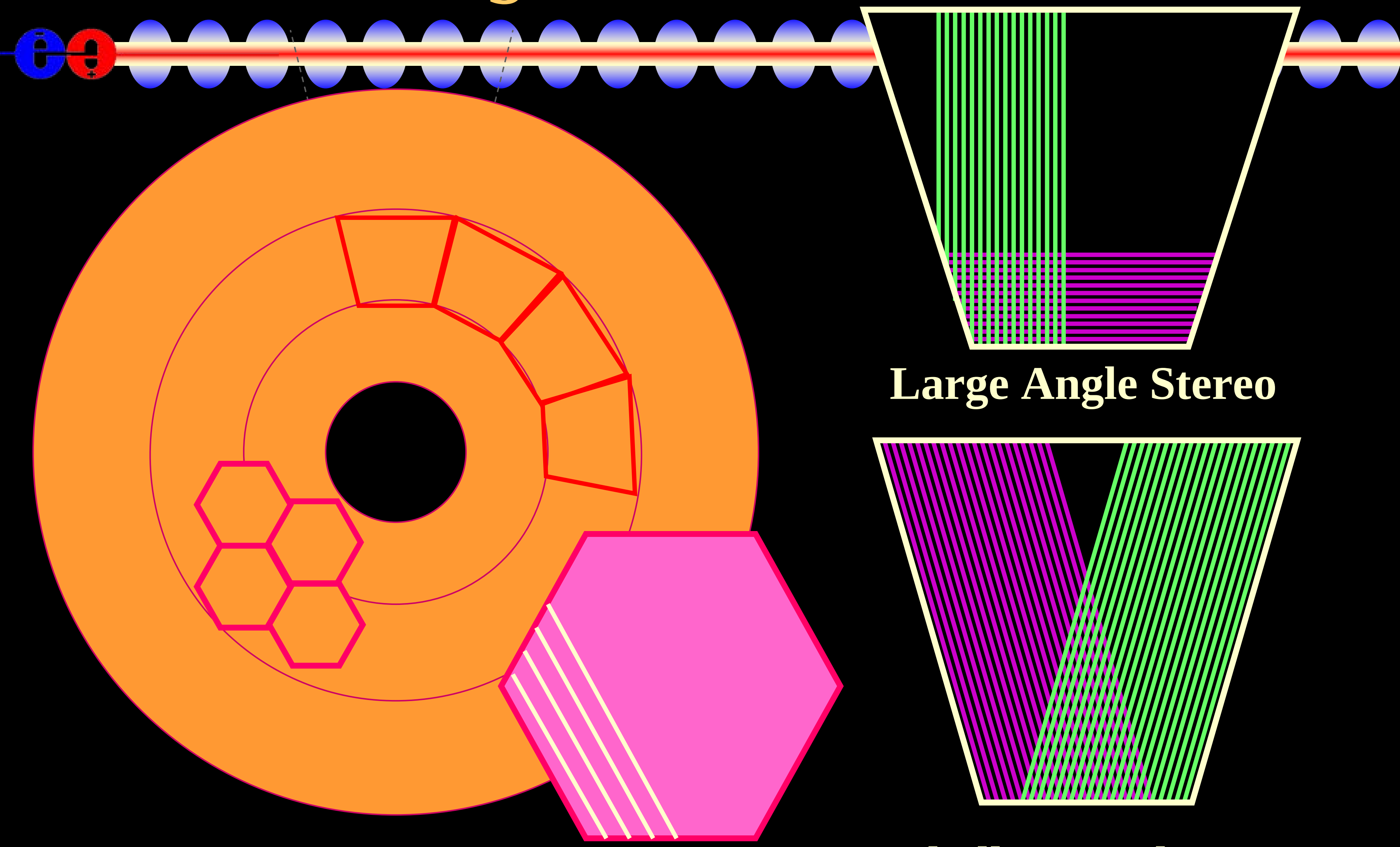
Tracking Detector Readout

- Hits in Trackers record full MC information.
- Digitization is deferred to analysis stage.
- Nick Sinev has released a package to convert hits in silicon to CCD pixel hits.*

  MC Hits$\rightarrow$ Pixels & PH$\rightarrow$ Clusters$\rightarrow$ Hits ($x \pm \delta x$)
- UCSC developed long-shaping-time μ-strip sim.*

  MC Hits$\rightarrow$ Strips & PH$\rightarrow$ Clusters$\rightarrow$ Hits ($\varphi \pm \delta\varphi$)
- Need short-strip simulation.
- Need tiling design for strip detectors.

Tiling Forward Disks



Shallow Angle Stereo

Tracking

- Analytic covariance matrices available for fast MC smearing for each detector. Uses lcdtrk.
- Track “cheater” available for studies of full detector simulation events. Assigns hits on basis of MC parentage.
- Ab initio track finding and fitting code from hep.lcd being ported to org.lcsim.

Calorimeter Reconstruction

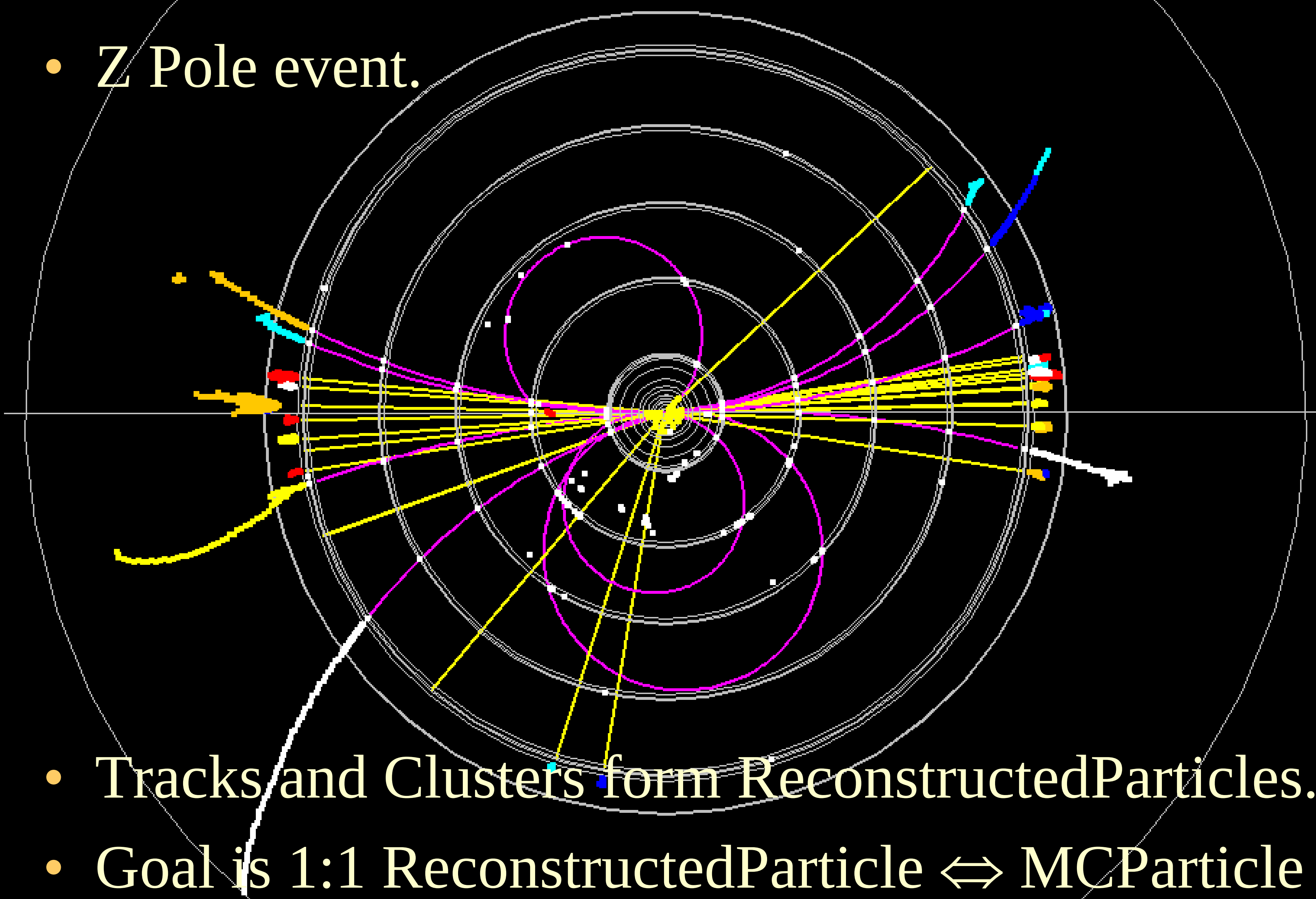
- Sampling Fractions determined for each calorimeter and available at reconstruction time.
  - derived from single particle response.
  - remaining issues wrt digital/analog readout.
- Nearest-Neighbor and fixed-cone algorithms available in code distribution.
- Basic Cluster interface defined, can be extended.
  - provides E, position centroid, direction, etc.
- EM shower shape χ^2 parameters defined, available at reconstruction time.

Individual Particle Reconstruction

- Several groups are following different approaches towards individual particle reconstruction
- Identifying photons, electrons, charged & neutral hadron showers and muons.
- FastMC currently writes out LCIO files containing ReconstructedParticle objects.
- Aim to have the same for full reconstruction at the end of this workshop.
- Having physics analyses which use this data would be a great help in characterizing the detectors.

Individual Particle Reconstruction

- Z Pole event.



- Tracks and Clusters form ReconstructedParticles.
- Goal is 1:1 ReconstructedParticle ⇔ MCParticle

"Standard LC MC Sample"

- Generate an inclusive set of MC events with all SM processes + backgrounds arising from beam- and brems-strahlung photons and machine-related particles.
- Used for realistic physics analyses and used by the ILC physics community to represent a "standard" sample.
  - Canonical background for Beyond-SM searches.
- Samples will be generated at several energy points to systematically study different ILC configurations.
  - 500 GeV done.
  - 350 GeV & 1 TeV in progress.
- 1 year's worth of stdhep files fits on one external harddrive.

Benchmark Data Samples

- Have generated canonical data samples and have processed them through full detector simulation.
- Single particles of various species: ~million events
- Z Pole events: 30k/detector, 240,000 events
- WW, ZZ, tt, qq, tau pairs, mu pairs, Zγ, Zh:
  – 10-30k/detector, 960,000 events

http://www.lcsim.org/datasets/ftp.html

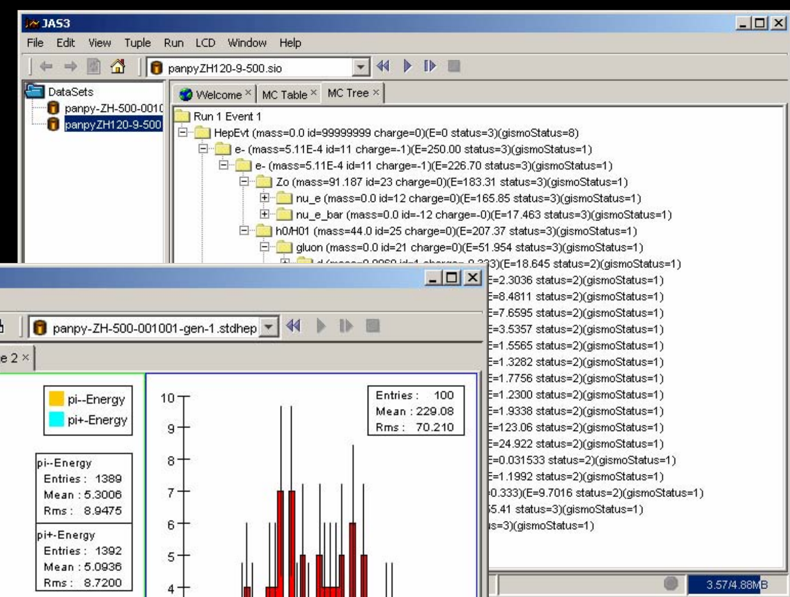
- Also available here at Snowmass on USB/Firewire external drives.

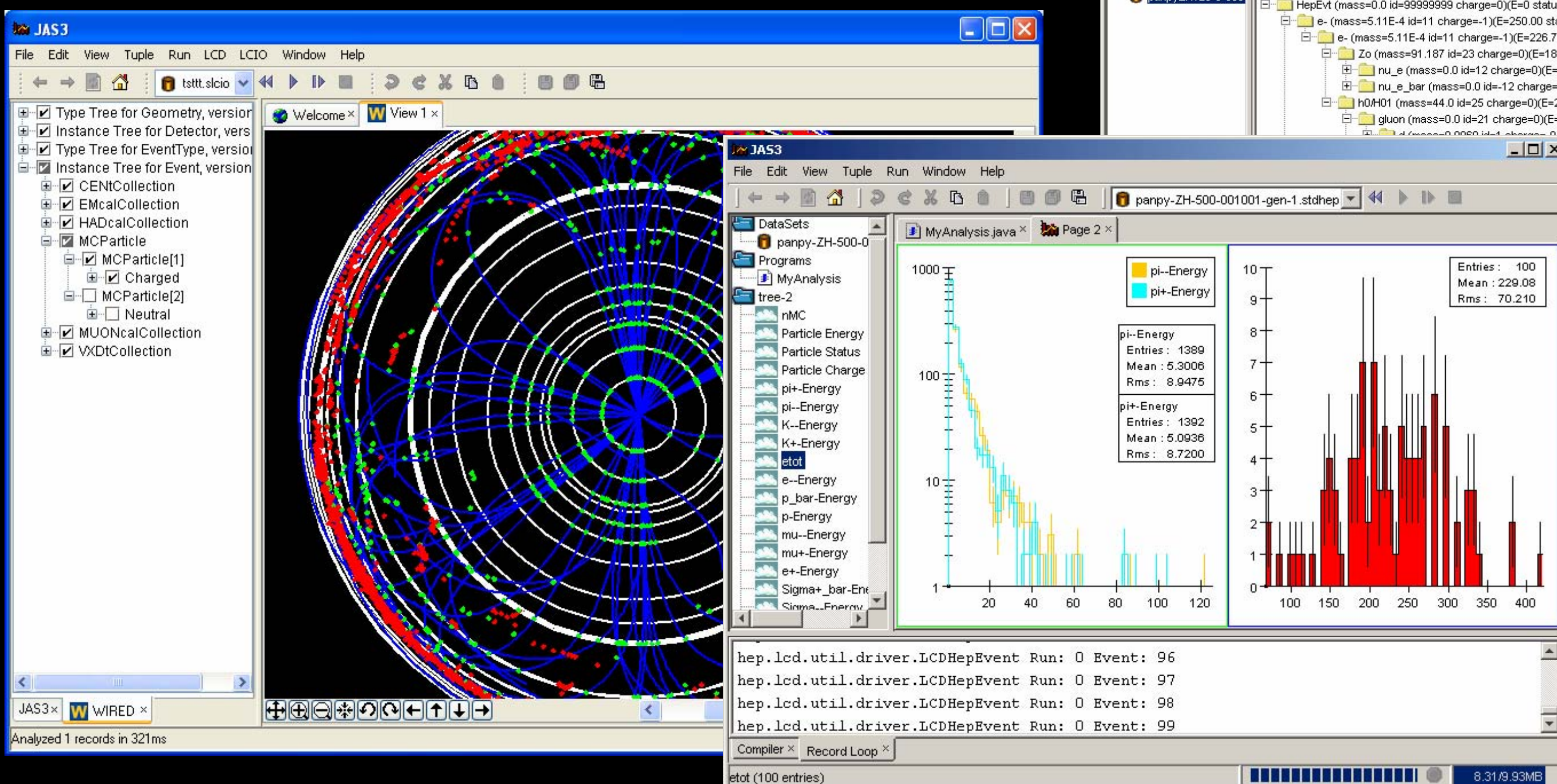
Reconstruction/Analysis Overview

- Java based reconstruction and analysis package
  - Runs standalone or inside Java Analysis Studio (JAS)
  - Fast MC $\rightarrow$ Smeared tracks and calorimeter clusters
  - Full Event Reconstruction
    - detector readout digitization (CCD pixels & Si μ-strips)*
    - *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 (Vertex Finding*, Jet Finding, Flavor Tagging*)
  - Beam Background Overlays at detector hit level*
- Very aggressive program, strong desire to “do it right.”

Reconstruction/Analysis

- Java Analysis Studio (JAS) provides a framework for event visualization (with WIRED) and reconstruction.





Software CD

- We have developed a CD containing simulation and reconstruction software as well as documentation and tutorials. In addition, a small amount of data is available on this CD. (More on the Snowmass Data DVD.)
- Full Detector simulation is available through slic (GUI available for Windows).
- Fast Detector simulation is available through lelaps (Windows executable on CD).
- Reconstruction/analysis via org.lcsim & JAS.

Computing Resources

- Your laptop!
  - slic and lelaps executables available on the CD
  - run your own events.
- SLAC Computing Services
  - 300 batch slots available in dedicated queue
    - thanks to BaBar.
  - 4 TB disk space available for a short time
    - thanks to GLAST.
- NICADD
  - 50 processors with batch availability.

Summary

- Framework exists for straightforwardly defining detector geometries.
- Digitization of tracker hits at analysis stage provides more degrees of freedom (pixel size, strip pitch, length, orientation, …)
- Reconstruction & analysis framework is available, tuning and improvements welcomed.
- Data samples for several configurations available.
- This is your detector, help define it!

Additional Information

- Linear Collider Simulations
  - http://www.lcsim.org
- Silicon Detector Design Study
  - http://www-sid.slac.stanford.edu/
- Discussion Forums
  - http://forum.linearcollider.org