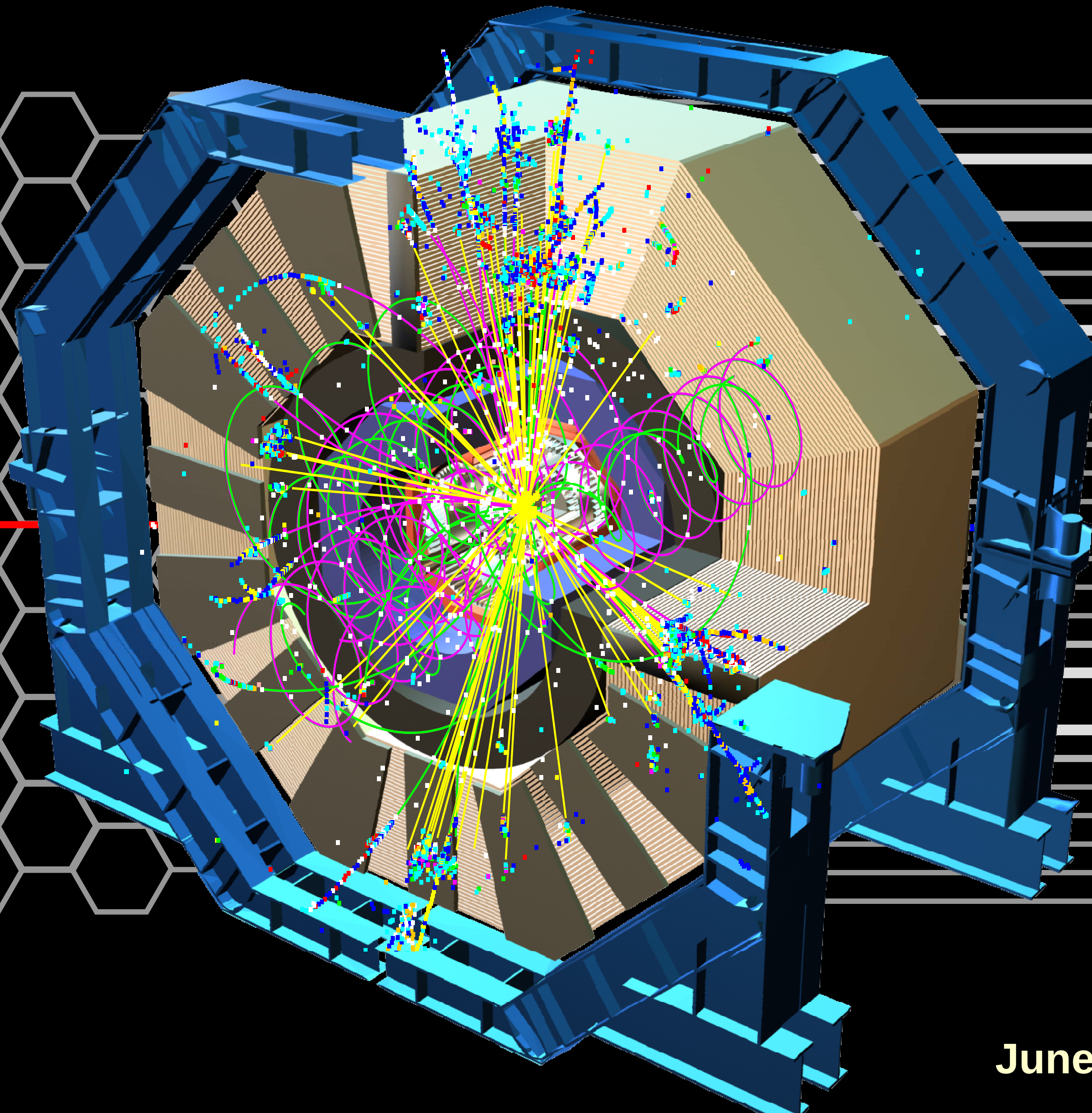
Simulating the Silicon Detector



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SLAC

June 15, 2005

Linear Collider Detector Environment

- Detectors designed to exploit the physics discovery potential of e^+e^- collisions at $\sqrt{s} \sim 1$TeV.
- Will perform precision measurements of complex final states.
- Require:
  - Exceptional momentum resolution
  - Excellent vertexing capabilities
  - "imaging" calorimetry
  - Hermeticity

Simulation Group's 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.

"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.
  – 350, 500, 1000, 1500 GeV center-of-mass energy
- Defining and generating "benchmark" physics processes which stress the detector capabilities.

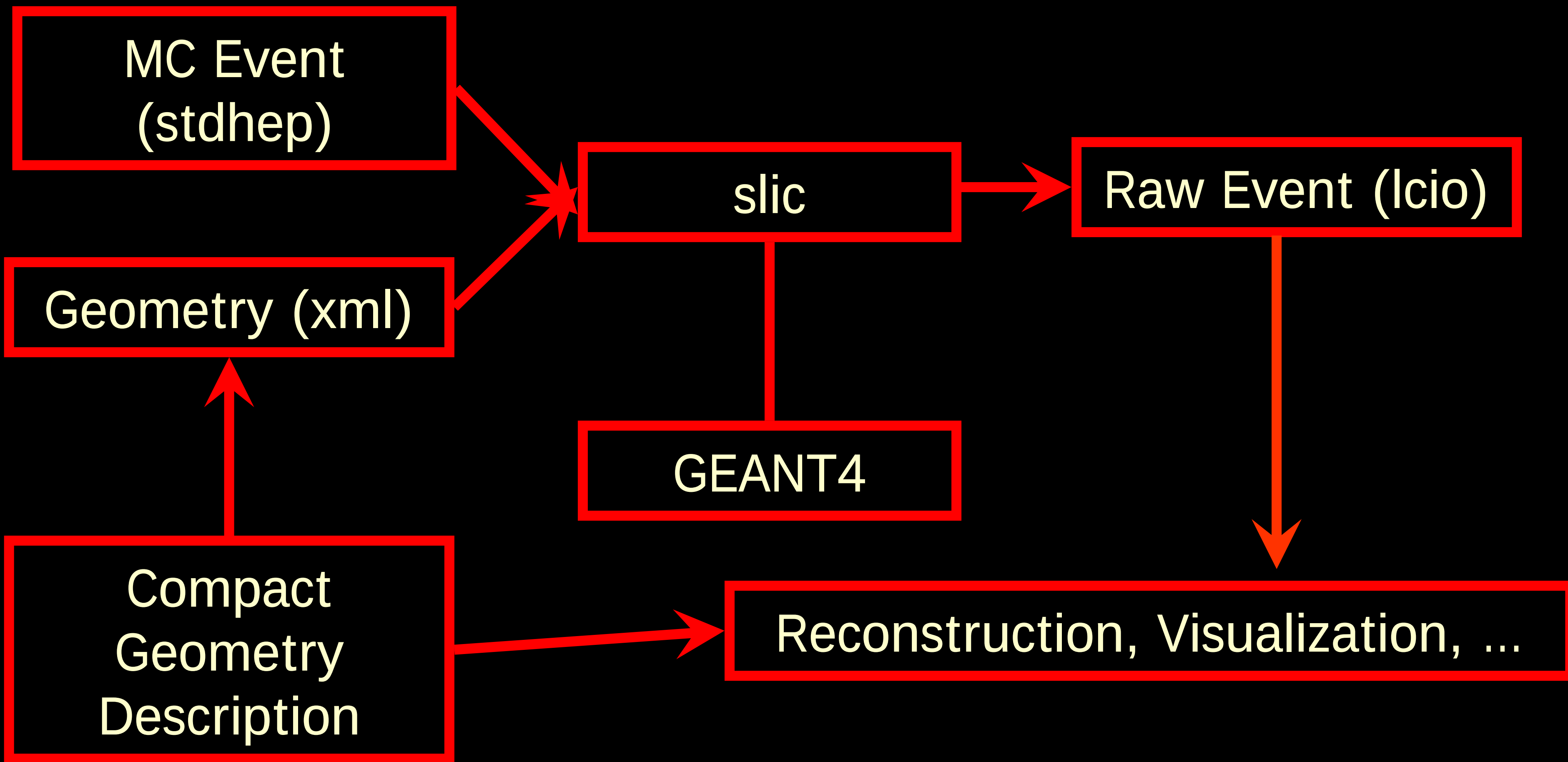
Silicon Detector (SiD) Requirements

- Superb dijet mass resolution to ~natural widths of W & Z for unambiguous identification of final states.
- Excellent flavor-tagging efficiency and purity (for both b- and c-quarks, hopefully also for s-quarks).
- Momentum resolution capable of reconstructing the recoil-mass to di-muons in Higgs-strahlung with resolution better than beam-energy spread .
- Hermeticity (both crack-less and coverage to very forward angles) to precisely determine the missing momentum.
- Timing resolution capable of separating bunch-crossings to suppress overlapping of events .

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.

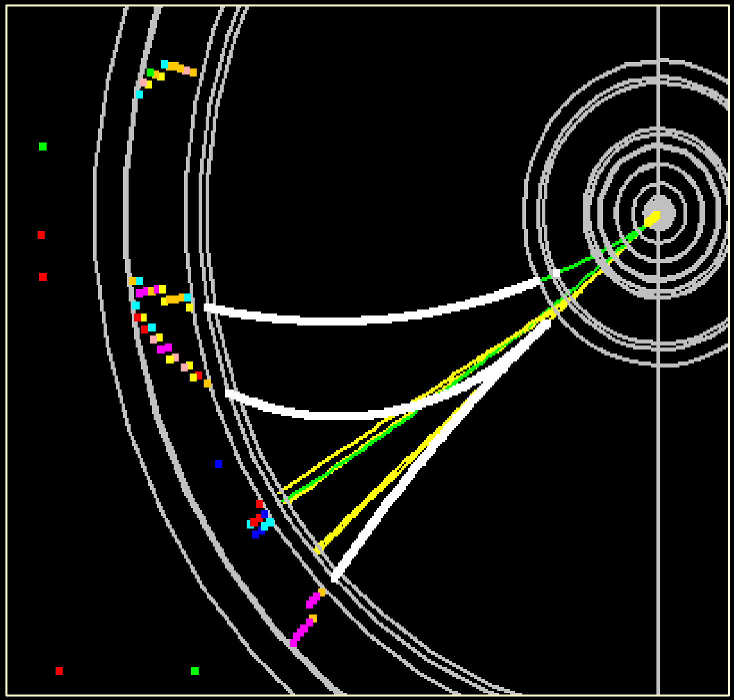
LC Detector Full Simulation



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.
- Recent overhaul of detector description.
  - Was hardcoded, now runtime definable
  - NOT XML, but its own format

Lelaps: Decays, dE/dx, MCS

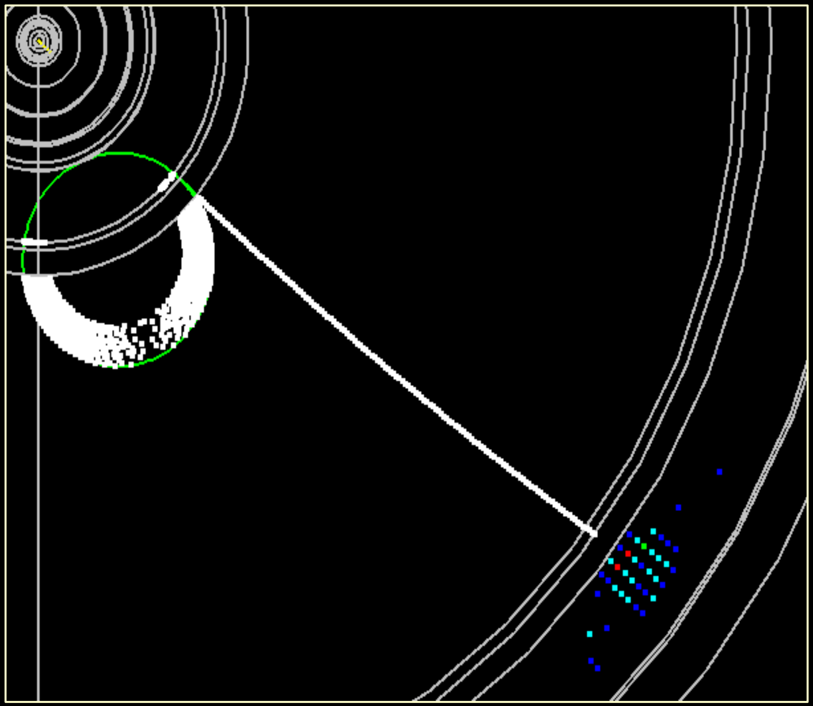


$\Omega^- \rightarrow \Xi^0 \pi^-$

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

$\Lambda \rightarrow p \pi^-$

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



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

Full Event Reconstruction Motivation

- Measure momenta of charged tracks in the tracker with superb resolution.
- Measure photons in highly segmented EM calorimeter with reasonable energy resolution.
- Remaining neutral hadrons measured in hadron calorimeter.

$$E_{\text{jet}} = E_{\text{charged}} + E_{\text{photons}} + E_{\text{neut. had.}}$$

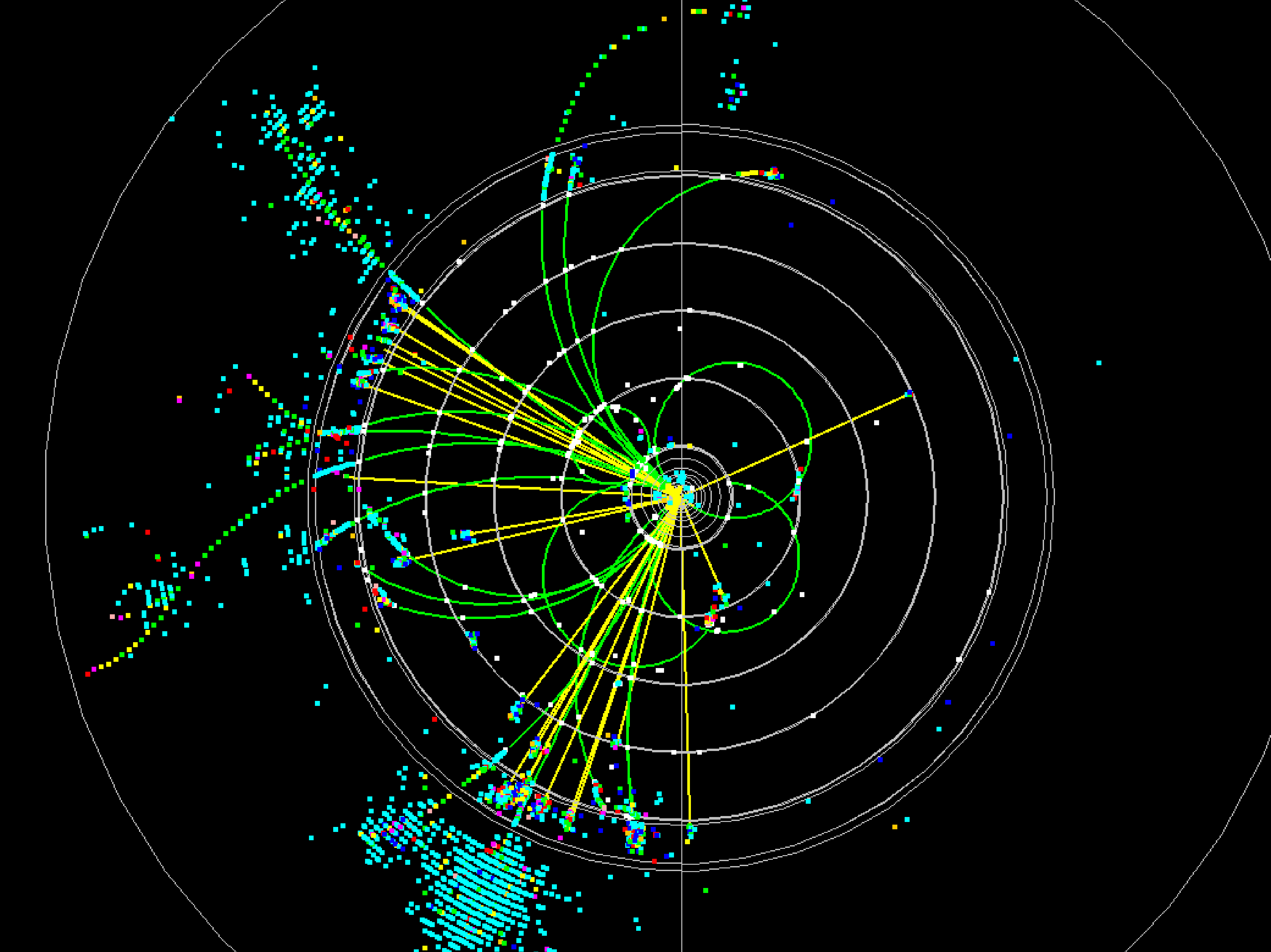
$$\sigma^2_{E\text{jet}} = \sigma^2_{E\text{charged}} + \sigma^2_{E\text{photons}} + \sigma^2_{E\text{neut.had.}} + \sigma^2_{\text{confusion}}$$

Calorimeter Design

- confusion is the largest term → “imaging” cal.
- EM Calorimeter: dense, small Moliere radius
  - fine transverse segmentation to accurately determine photon shower locations
  - fine longitudinal segmentation for efficient charged particle tracking through the EM Cal, and to separate charged and neutral particles.
- Hadron Calorimeter: Emphasize segmentation & granularity (transverse & longitudinal) over intrinsic energy resolution.

Silicon Detector Simulation

- Group provides simulation support for generic detector design: the software toolkit is capable of simulating any of the ILC detector concepts.
- Concentrate on the Silicon Detector (SiD) concept.
  - Characterize and optimize the design using simplified geometries for fast turnaround times.
  - Full reconstruction from digitized hits (+ backgrounds)
  - Complete physics analyses (jet-finding, flavor-tagging,…)
  - Release & document software, develop analysis tutorials
  - Provide “Snowmass CD” for CDR studies.

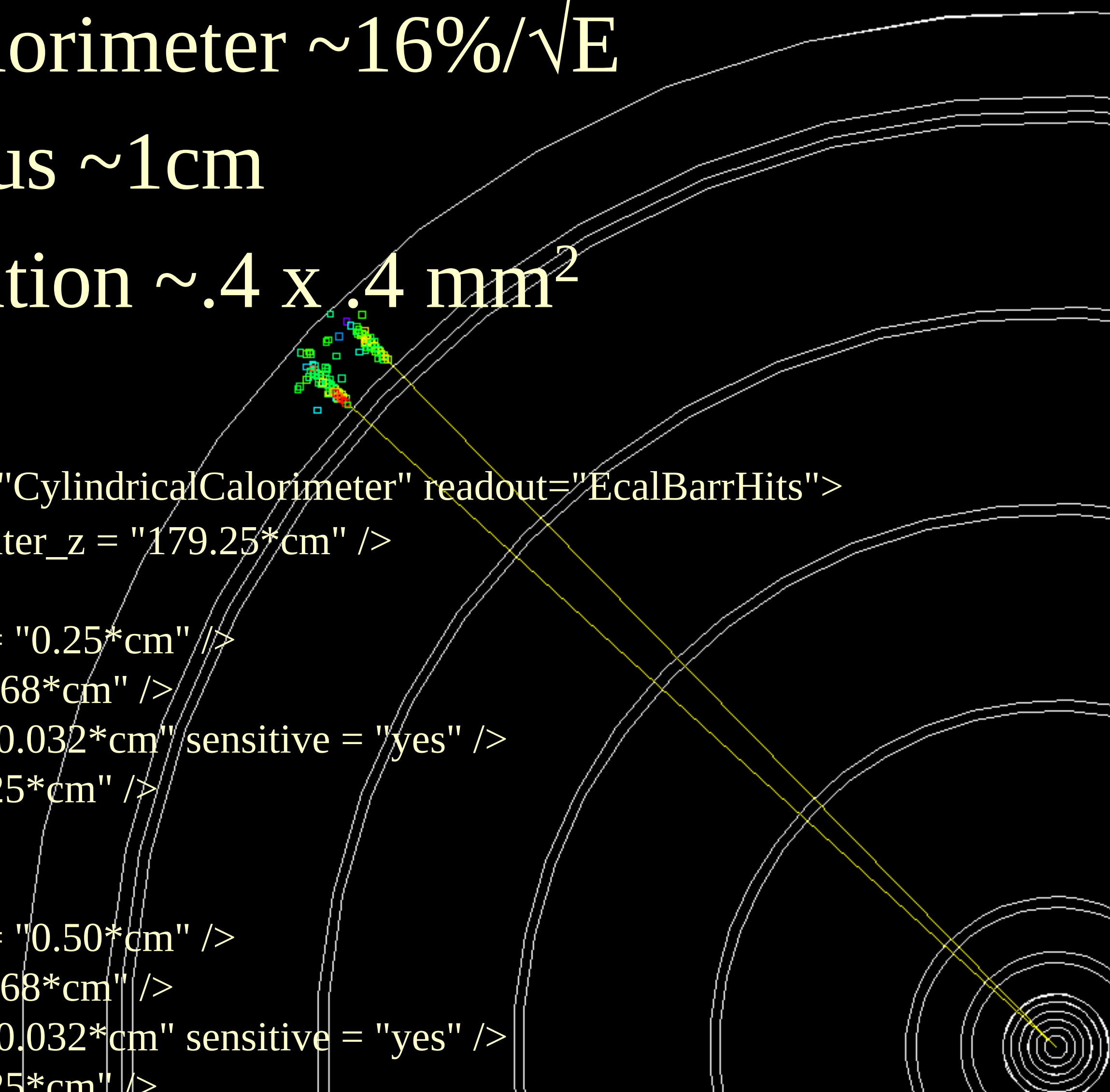


Detector Variants

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

EM Calorimeter

- Si-W Sampling Calorimeter ~16%/√E
- Small Moliere radius ~1cm
- Excellent segmentation ~.4 x .4 mm^2



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          <slice material = "G10" width = "0.068*cm" />
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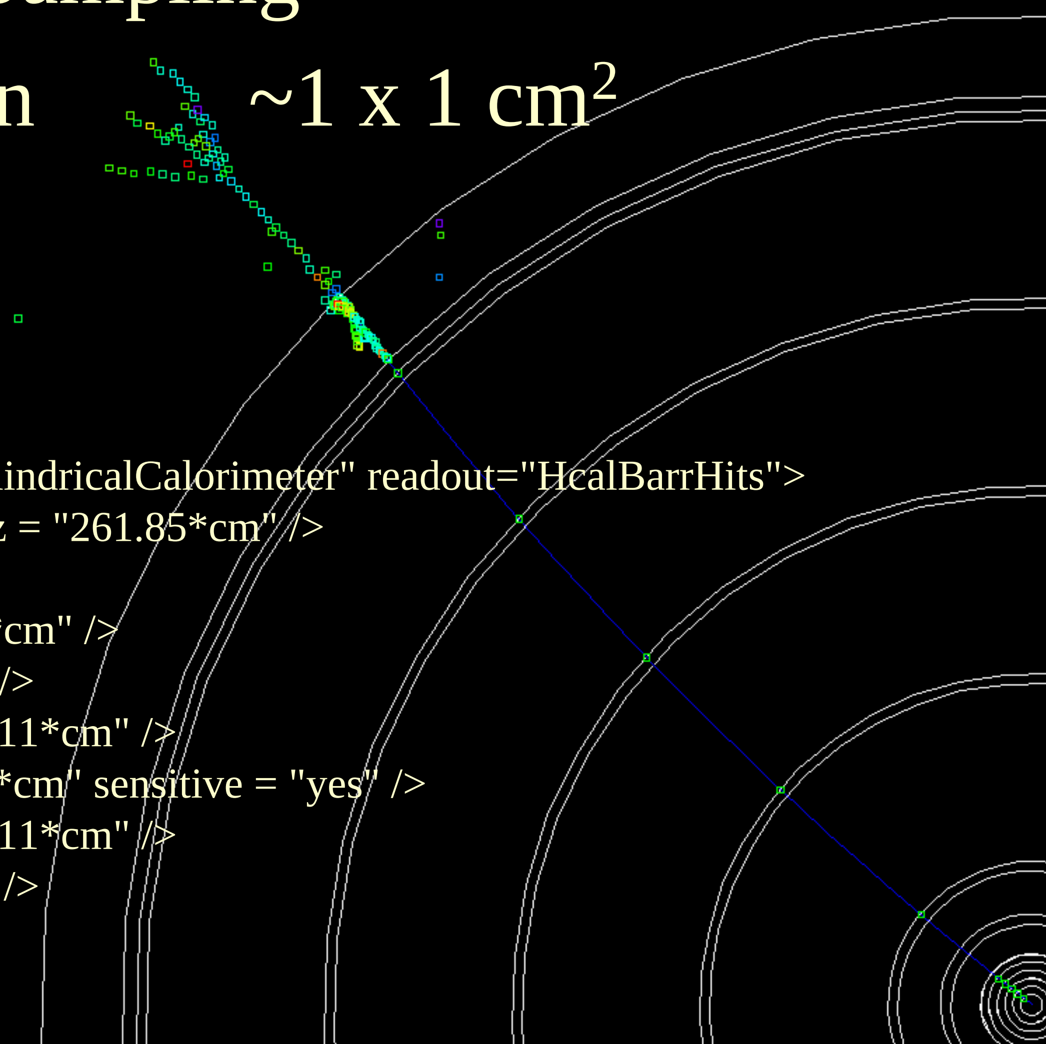
          <slice material = "Air" width = "0.025*cm" />
```

Hadronic Calorimeter

- W(SS)+RPC (Scint.) Sampling
- Excellent segmentation ~1 x 1 cm^2



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      </layer>
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```
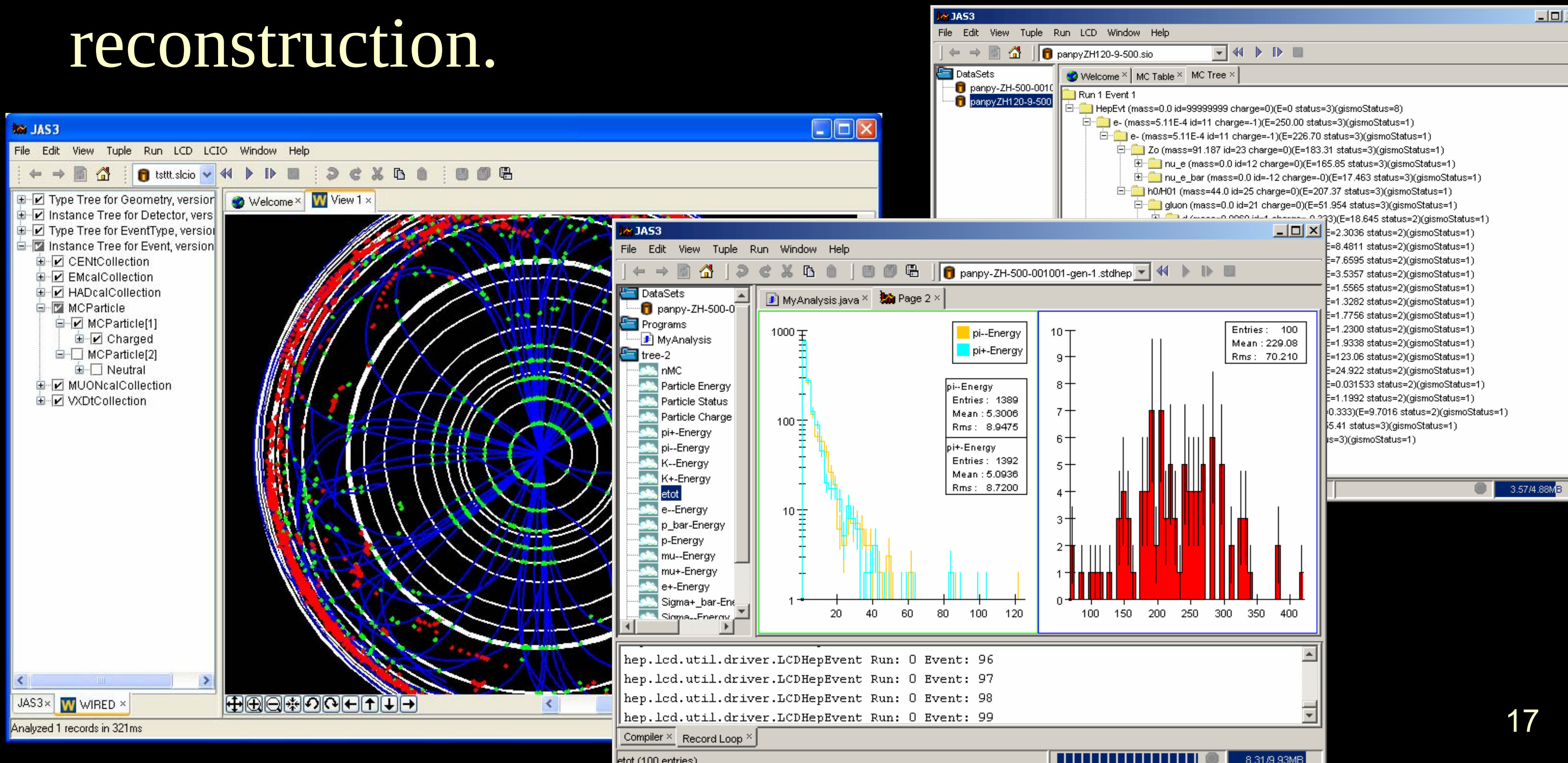

Reconstruction/Analysis

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



Reconstruction/Analysis Overview

- Java based reconstruction and analysis package
  - Runs standalone or inside Java Analysis Studio (JAS)
  - Fast MC → Smeared tracks and calorimetry 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."

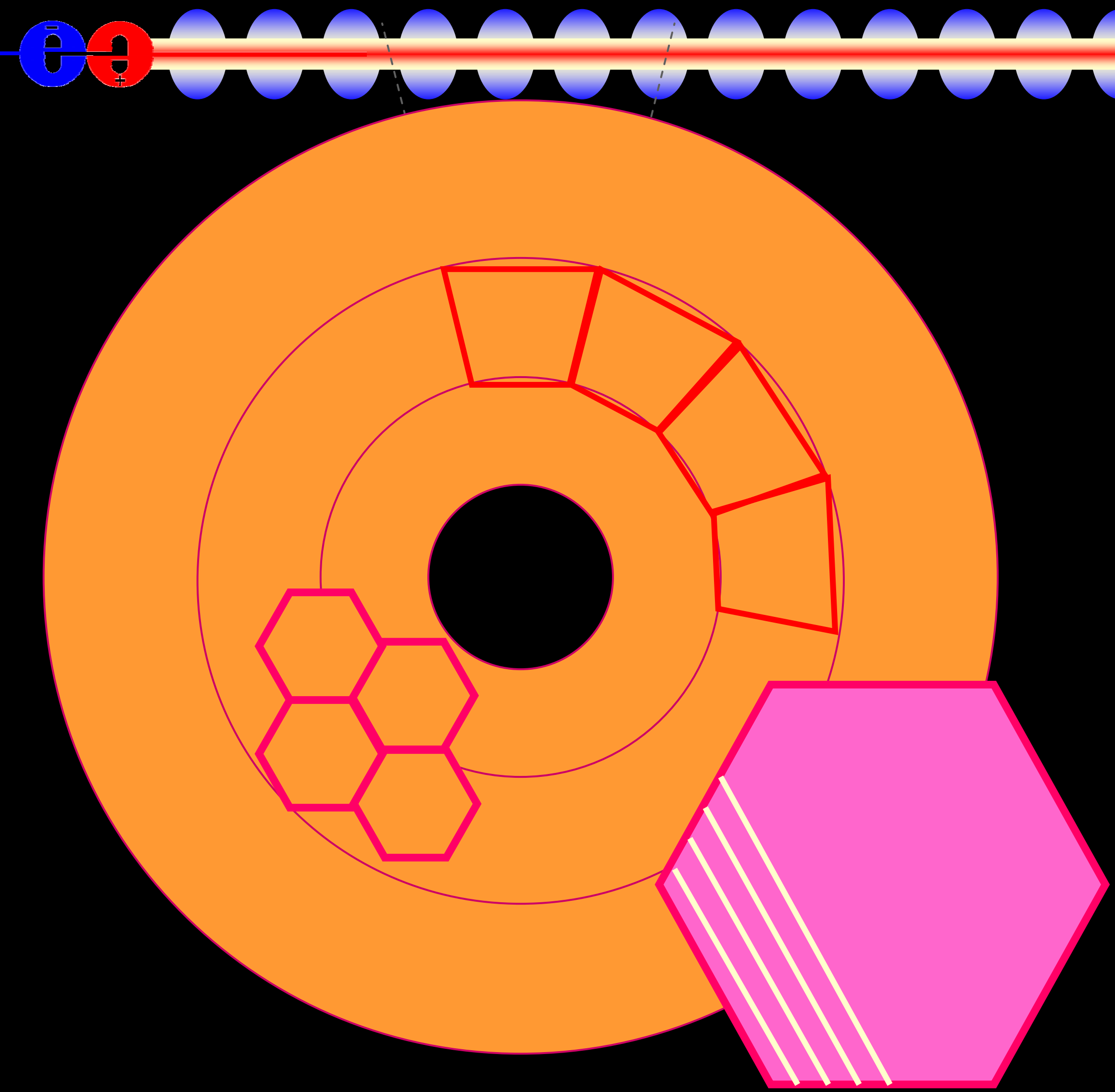
Tracking Detector Readout

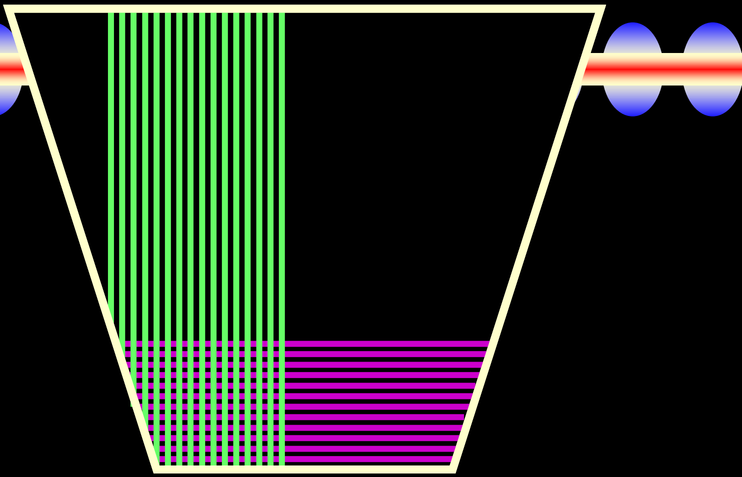
- Hits in Trackers record full MC information.
- Digitization is deferred to analysis stage.
- Nick Sinev has released a package to convert hits in silicon to CCD pixel hits.

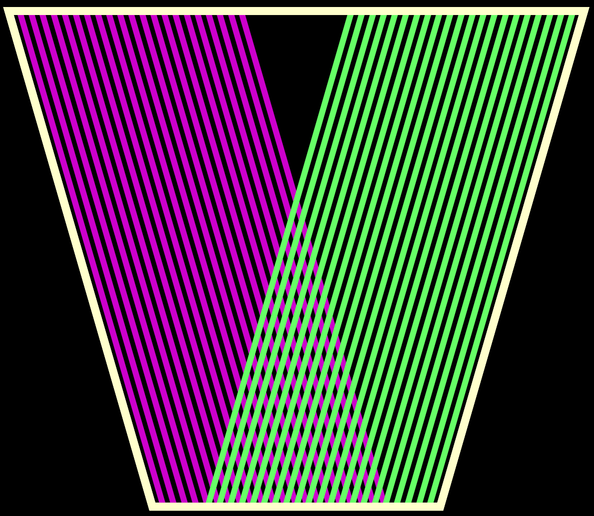
  MC Hits$\rightarrow$ Pixels & PH$\rightarrow$ Clusters$\rightarrow$ Hits ($x \pm \delta x$)
- UCSC developed long-shaping-time μ-strip sim.

  MC Hits$\rightarrow$ Strips & PH$\rightarrow$ Clusters$\rightarrow$ Hits ($\varphi \pm \delta\varphi$)
- SLAC developing short-strip simulation.
- Correctly study occupancies, overlaps, ghost hits.

Tiling Forward Disks



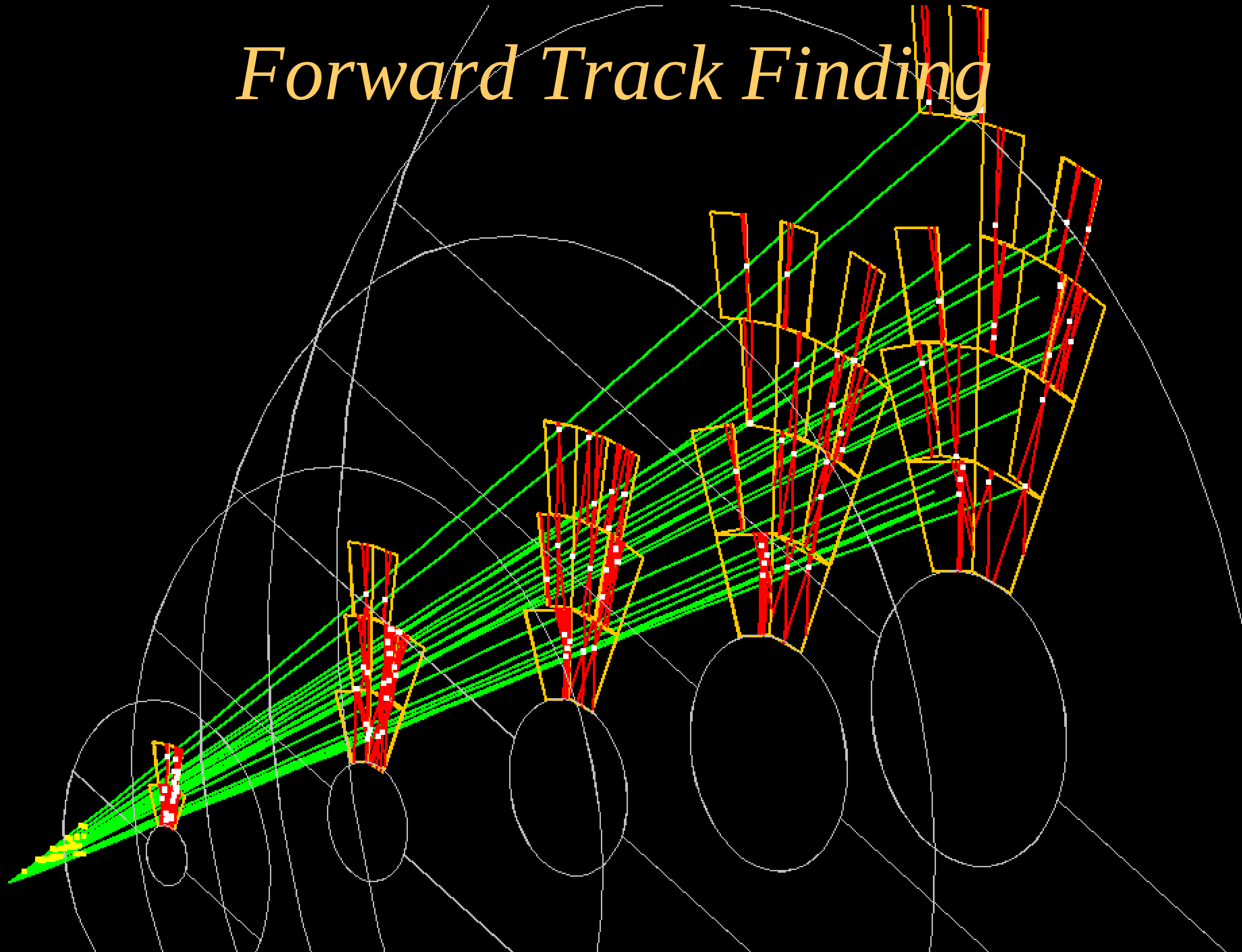




Track Finding

- Nick Sinev has released standalone pattern recognition code for the 2D Barrel VXD hits.
  - High efficiency, even in presence of backgrounds.
  - Efficient at low momentum.
  - Propagates tracks into Central Tracker to pick up φ hits
- Conformal-mapping pattern recognition also available. Fast, but not yet tuned (97% vs 99+%).
- Work also ongoing to find MIP stubs in Cal and propagate inwards to tracker (Kansas State).

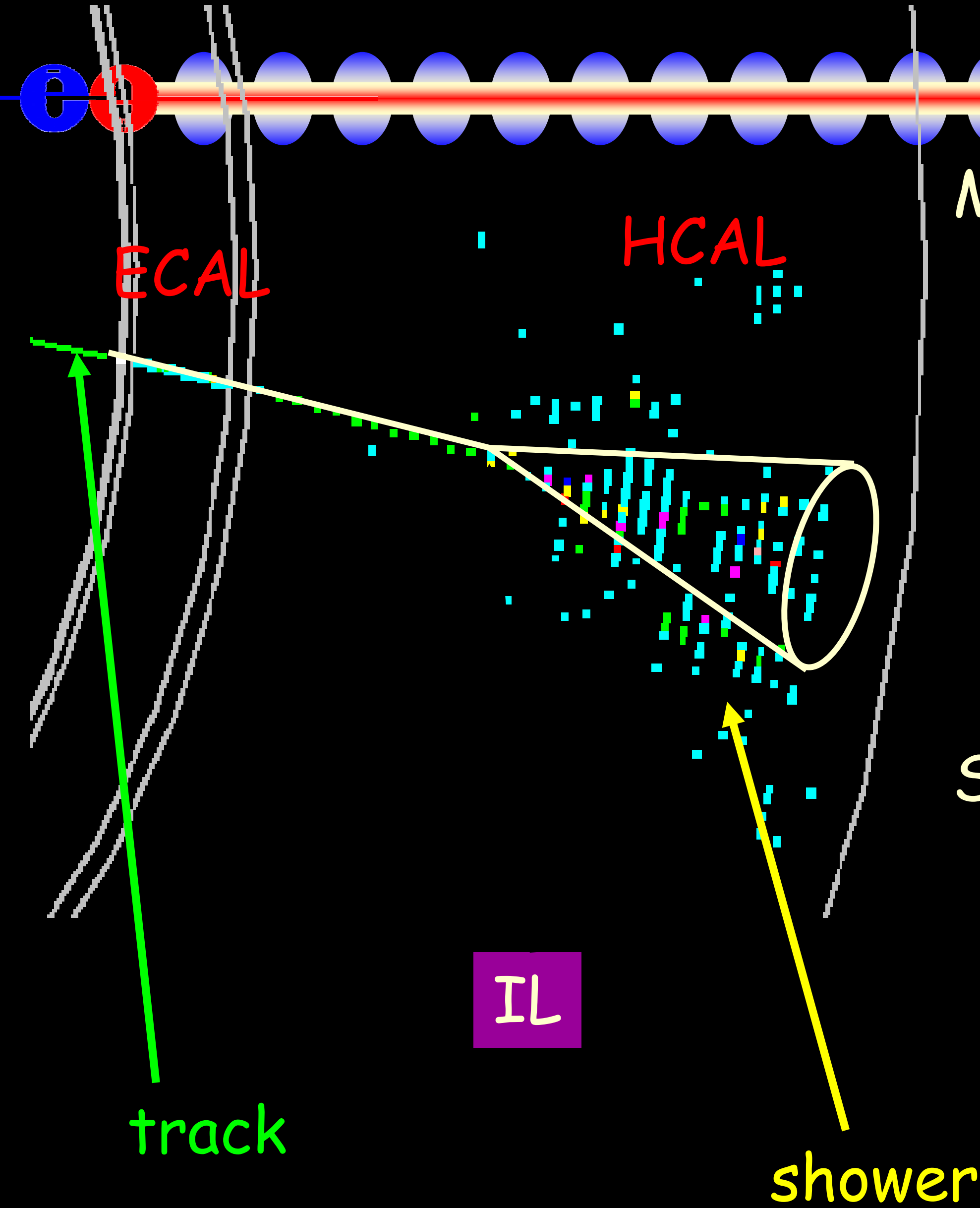
Forward Track Finding



Calorimeter Reconstruction

- A number of groups are following different approaches towards individual particle reconstruction ("particle flow")
  - SLAC, Argonne, NICADD, Kansas State, Iowa, …
- Identifying photon, electron, charged & neutral hadron showers and muons in the calorimeter.
- Tracking in the calorimeter can assist pattern recognition in the trackers!

Shower reconstruction by track extrapolation



Mip reconstruction :

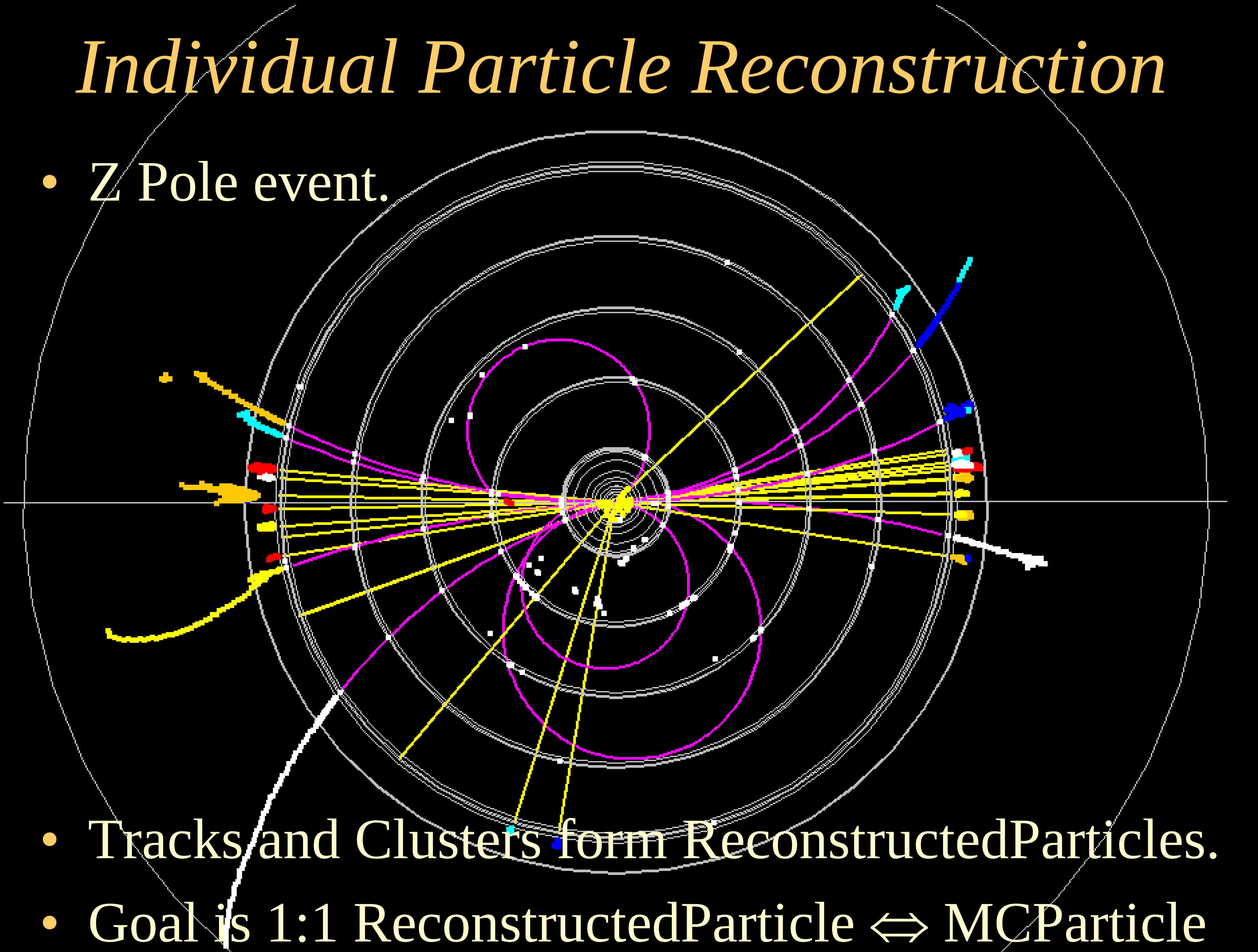
Extrapolate track through CAL layer-by-layer
Search for "Interaction Layer"
-> Clean region for photons (ECAL)

Shower reconstruction :

Define tubes for shower in ECAL, HCAL after IL
Optimize, iterating tubes in E,HCAL separately (E/p test)

Individual Particle Reconstruction

- Z Pole event.



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

Simulation Summary

- SLAC supports an ambitious international simulation effort with a very small group of people.
- Provides full data samples for ILC physics studies.
- Provides a complete and flexible detector simulation package capable of simulating arbitrarily complex detectors with runtime detector description.
- Reconstruction & analysis framework maturing, additional manpower maps directly to physics and detector results.
- Will characterize/optimize performance of the Silicon Detector (SiD) for CDR starting at Snowmass.

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