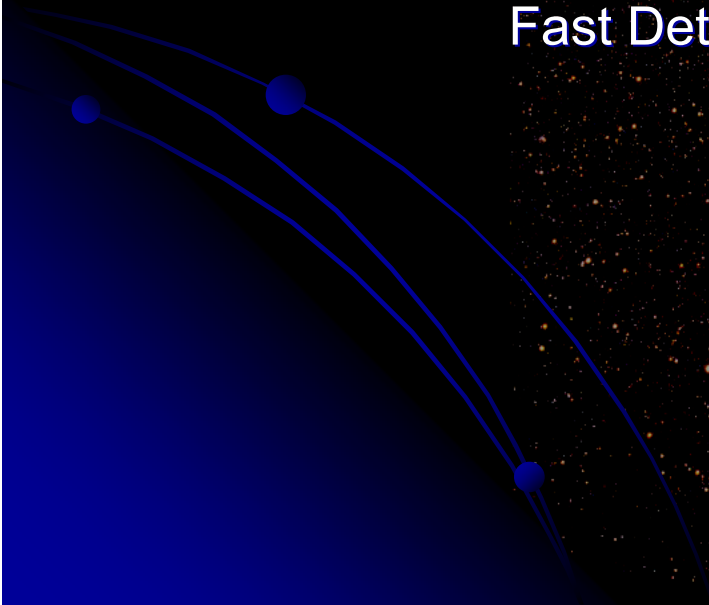


# Ληλαψ 3



Fast Detector Simulation Using Lelaps



# Overview

- Introduction
  - What does it do and what is it?
- The CEPack tool kit
  - Geometry and Materials
  - Tracking, Multiple Scattering and  $dE/dx$
  - Electromagnetic and Hadronic Shower Parameterization
  - Decays and Gamma Conversions
- Using CEPack inside Geant4
- Standalone CEPack: Lelaps
- Performance
- Future

## Introduction: What does it do?

- It swims particles through detectors, taking into account magnetic fields, multiple scattering and  $dE/dx$  energy loss.
- It produces parameterized showers in EM and hadronic calorimeters.
- It converts gammas.
- It supports decays of certain short-lived particles (“V” decays).
- It does all this very fast.

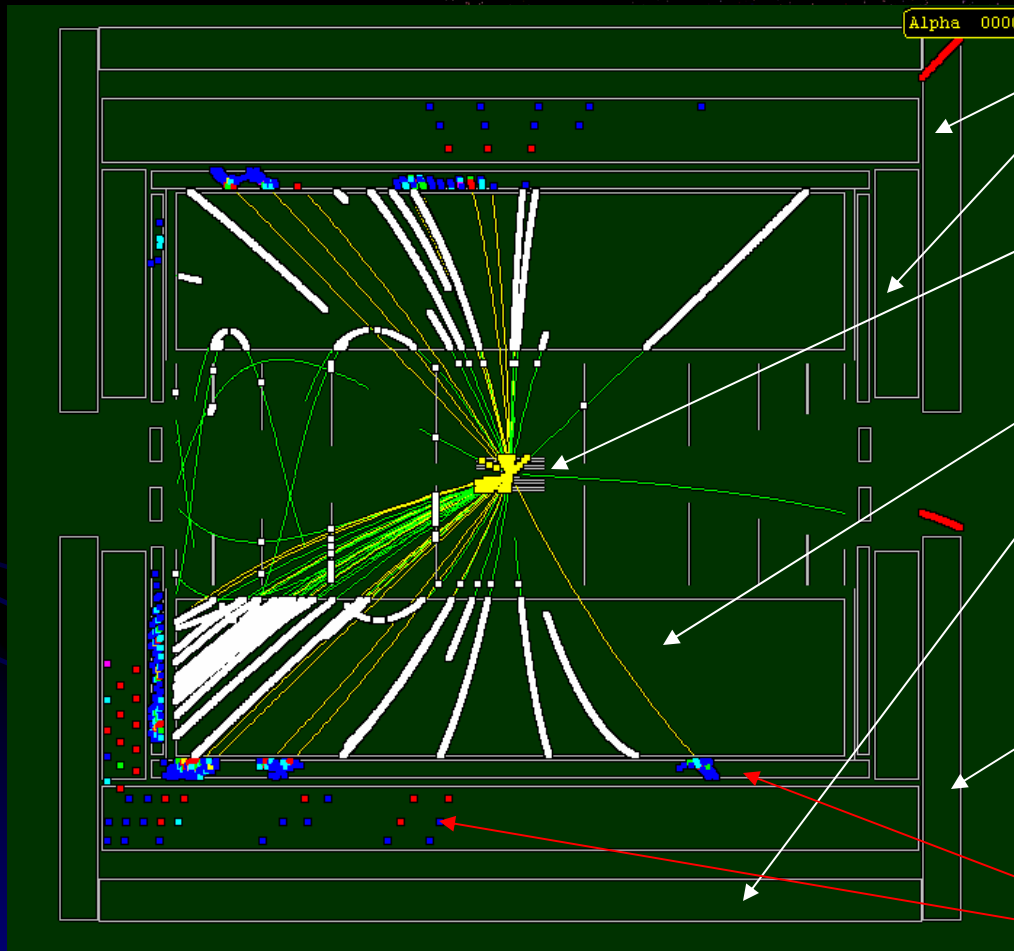
## Introduction: What is it?

- Lelaps consists of a set of C++ class libraries and a main program, which itself is called lelaps.
- The main library is called CEPack, which contains the actual simulation toolkit. It uses only one utility library, “vec”.
- Other utility libraries include: IStdHep, vlutil, plotpp, pl3.
- Main programs (“lelapses”) have been written for BaBar and for LCD (LDMar01, SDJan03 and SDMar04 are implemented).
- CEPack can also be used in conjunction with Geant4 parameterized volumes. In this way it is integrated in BaBar’s Geant4-based simulation.
- The standalone version for LCD reads StdHep generator files and produces SIO or LCIO output files that can be read by JAS and LCDWired.

# Geometry in CEPack

- Geometries are constructed using CENodes (which may contain a list of subnodes).
- A number of common CENodes are predefined
  - cylinders, cones, boxes, spheres
- Transformations may be applied to CENodes in order to position and orient them. Arbitrary transformations that preserve lengths are allowed.
- CENodes need to provide methods for tracks entering and exiting, and for determining whether points are inside them or not.
- CENodes may be assigned a numeric id and subid.
- CENodes may implement a method to compute a subid from a location.
  - May be used to compute calorimeter segmentation.
- CENodes do not have to be 3D objects.
  - Several predefined CENodes consist of one or more 2D surfaces.

# Geometry in CEPack: LD



- Most objects in the LD are cylinders.
- There are some conical masks (not drawn).
- TPC and barrel muon detector each contain a CENode with a set of concentric cylinder surfaces.
- Muon endcaps use a CENode with a set of cylindrical slices.
- Calorimeters use subid calculation for their segmentation.

# Materials in CEPack

- All elements built in with default pressure/temperature/density.
- Any compound can be specified by chemical formula and density or (for gasses) temperature and pressure.
- Mixtures can be created by mixing elements and compounds (by volume or by weight).
- All needed quantities are calculated automatically
  - Constants needed for multiple scattering and energy loss
  - Radiation lengths (Tsai, PDG)
  - Interaction lengths (from a fit to element data)
  - Other constants needed for shower parametrization

# Matprop

- Lelaps distribution comes with a little program called `matprop`:
  - `matprop U` # for elements (gasses at NTP)
  - `matprop SiO2/2.32` # for solids (and liquids) specify  
# density (g/cc)
  - `matprop CO2/1/298.15` # for gasses specify pressure (atm)  
# and temperature (K)
  - `matprop O2/STP` # for gasses at STP (0 C, 1 atm)
  - `matprop Ar/NTP` # for gasses at NTP (25 C, 1 atm)
  - `matprop H2//` # for gasses at NTP
- For a mixture (e.g. Air at 20 C) use (-g to indicate gas):
  - `matprop -g O2/1/293.15 20.946 N2/1/293.15 78.084`  
`Ar/1/293.15 0.934`
- Just type `matprop` to get a list of options
- Prints out lots of material properties
- Matprop is available online:  
<http://www.slac.stanford.edu/comp/physics/matprop.html>



## Tracking in CEPack

- Tracking is performed by taking steps along a linear trajectory with endpoints on a helix, such that the sagitta stays below a certain (settable) maximum.
- CENodes have bounding spheres (or bounding cylinders).
  - When computing distances to CENodes, only “relevant” CENodes are considered.
- After each step, the amount of material traversed is checked: if enough material was traversed, multiple scattering and energy loss is performed and track parameters and list of relevant CENodes are recalculated.
- When an intersection occurs within a step, the fractional step is executed, the CENode is entered, and the remaining fraction of the step follows.

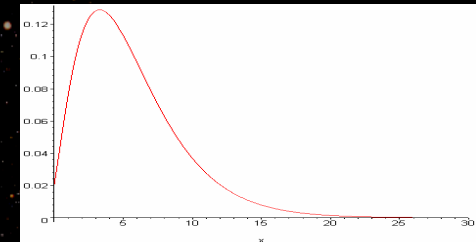
## Multiple Scattering and dE/dx

- Multiple scattering is performed using the algorithm of Lynch and Dahl.
  - Gerald R. Lynch and Orin I. Dahl, Nucl. Instr. And Meth. B58 (1991) 6.
- Material is “saved up” along the track until there is enough.
- 
- dE/dx is calculated using the methods by Sternheimer and Peierls.
  - R.M. Sternheimer and R.F. Peierls, Phys. Rev. B3 (1971) 3681.
- All constants precalculated by the material classes.

# Electromagnetic Shower Parameterization

- Electromagnetic showers are parameterized using the algorithms of Grindhammer and Peters.
  - G. Grindhammer and S. Peters, arXiv:hep-ex/0001020v1 (2000)  
(Paper is a 1993 conference contribution, submitted by request to the archive in 2000).
- Calorimeters are treated as homogeneous media, with longitudinal shower profile given by a gamma distribution (t in radiation lengths):

$$\frac{1}{E} \frac{dE(t)}{dt} = f(t) = \frac{(\beta t)^{\alpha-1} \beta e^{-\beta t}}{\Gamma(\alpha)}$$

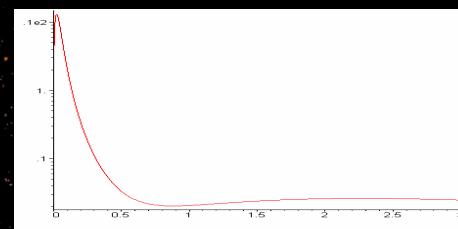


- Coefficients  $\alpha$  and  $\beta$  depend on the material (Z) and energy.
- The profiles are fluctuated, and correlations between  $\alpha$  and  $\beta$  are taken into account.

## EM Shower Parameterization: Radial Profile

- For each step of one radiation length, a radial profile is computed of the form:

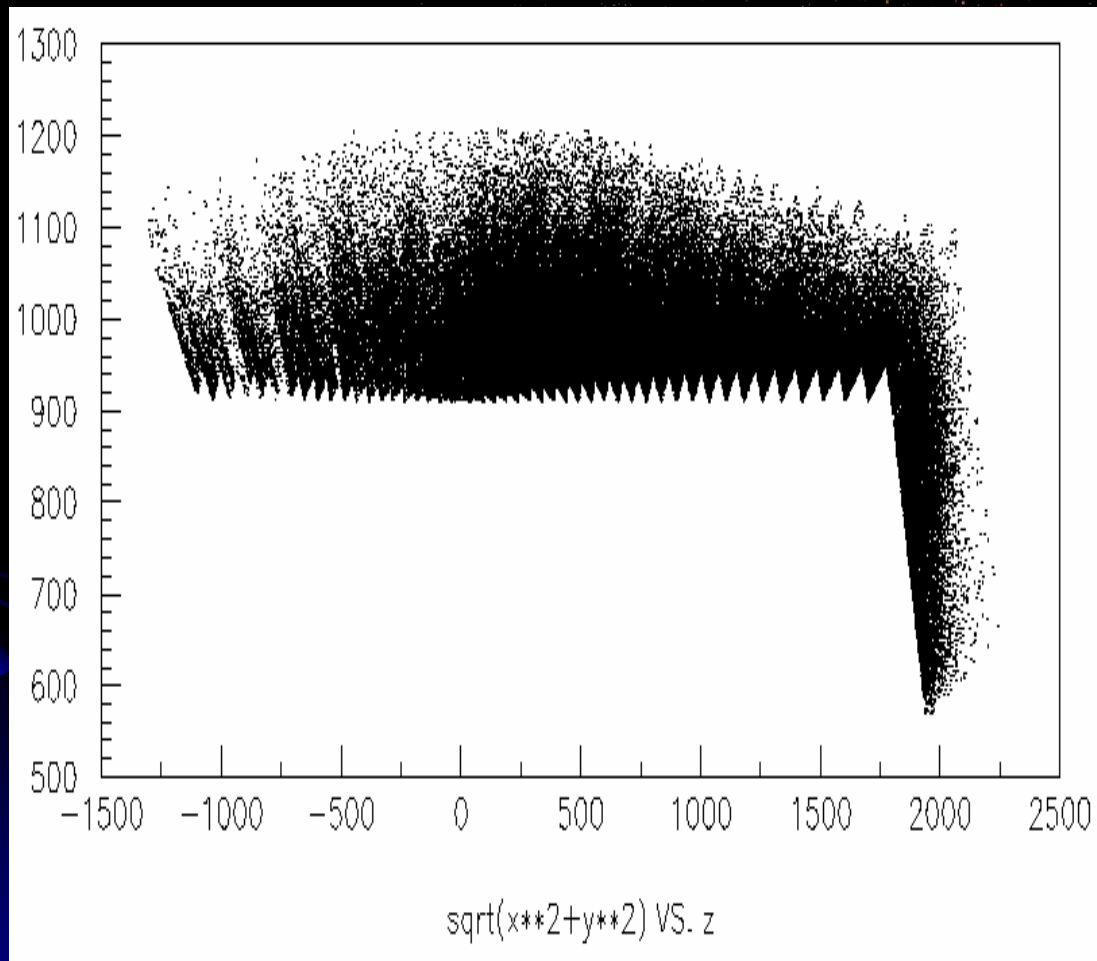
$$\frac{1}{dE(t)} \frac{dE(r,t)}{dr} = f(r) = p \frac{2rR_C}{(r^2 + R_C^2)^2} + (1-p) \frac{2rR_T}{(r^2 + R_T^2)^2}$$



with  $R_C$  the median radius (in units of Molière radius) of core component of the shower,  $R_T$  the median radius of tail component and  $p$  the fraction of “core” in the shower.

- $R_C$ ,  $R_T$  and  $p$  are functions of  $Z$ , shower depth  $t$  and  $E$ .
- Energy  $dE(t)$  is divided into spots (another gamma distribution with parameters depending on  $t$ ). Spots are thrown in  $r$  according to the profile above, uniformly in  $\phi$  and also uniformly between  $t$  and  $t+1$ .
- Roughly, about 400 spots are generated per GeV of shower energy.
- Spots are reported as “hits”.

## EM Shower Parameterization: BaBar CsI



CEPack simulation of BaBar EM calorimeter in Moose (courtesy of Dominique Mangeol). See also the BaBar web site (computing – simulation – fast simulation).

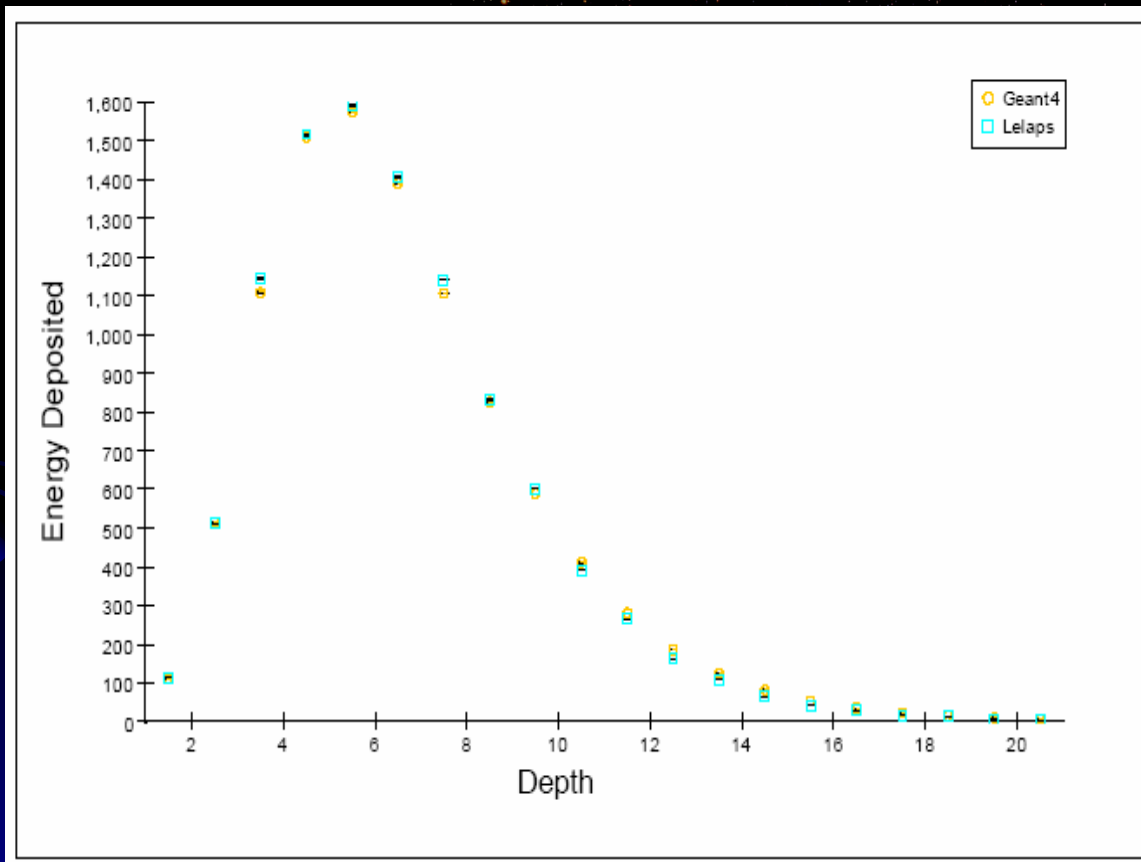
# Hadronic Shower Parameterization

- Hadronic showers are parameterized using code that is similar to the code for electromagnetic showers, with some modifications:
- The location where the shower starts is simulated using an exponential law with attenuation given by the interaction length.
- The longitudinal profile uses the Bock parameterization.
  - R.K. Bock, T. Hansl-Kozanecka and T.P. Shah, Nucl. Instr. And Meth. 186 (1981) 533.
- A combination of two gamma distributions, one using radiation lengths and the other interaction lengths, is used.
- Bock parameterization does not specify radial profiles. For the moment we use a radial profile similar to Grindhammer & Peters (for EM showers) but with radiation lengths replaced by interaction lengths and faster spread with depth. The parameters still need to be fine-tuned.

# Shower Parameterization Compared to Geant4

- Parameterized shower simulation was compared to Geant4.
  - “Parameterized Shower Simulation in Lelaps: A Comparison with GEANT4”, Daniel Birt, Amy Nicholson, Willy Langeveld, Dennis Wright, SLAC-TN-03-005, Aug 2003.
- In general pretty good agreement for EM showers. Hadronic showers agree pretty well longitudinally, but not as well radially.
- Hadronic shower parameterization has been tweaked since then.

# EM Shower Parameterization and Geant4



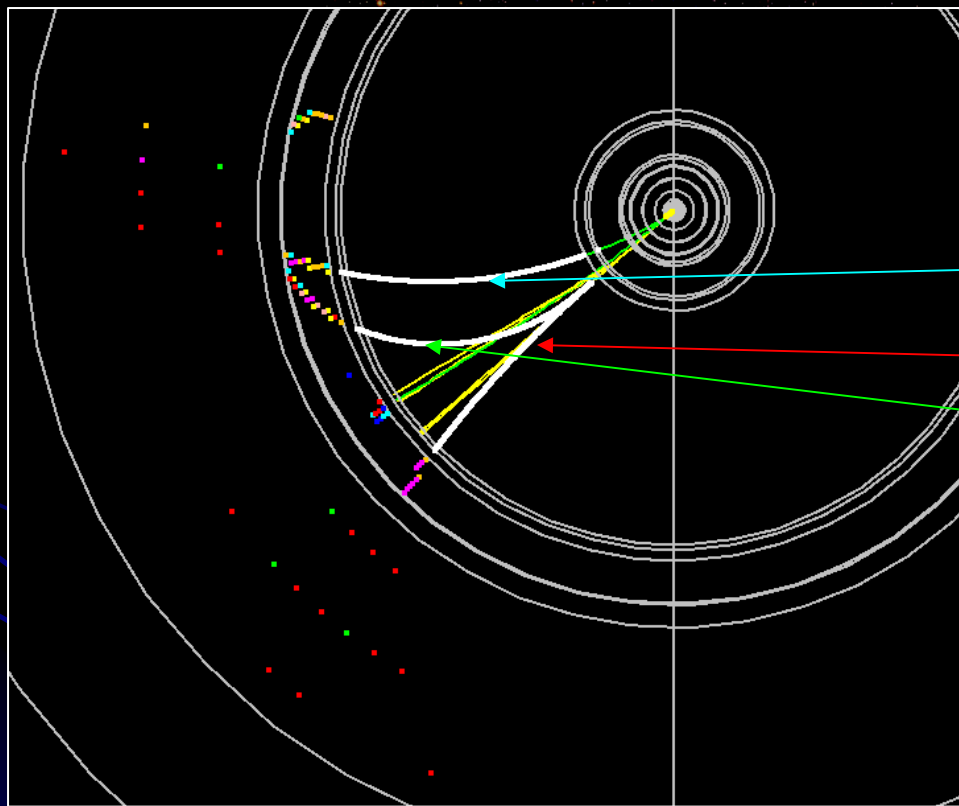
Comparison of CEPack longitudinal profile (green) of a 10 GeV electron in an EM calorimeter with Geant4 (orange).



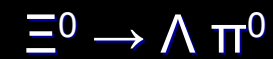
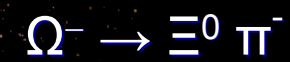
## Decays and Gamma Conversions

- Decays of unstable particles and gamma conversions are performed as follows:
- Lelaps loops over the particles in a list, turns them into CEMTracks and swims them through the geometry
- Tracks of decaying particles and converting gammas stop at the decay/conversion point
- For supported unstable particles, a CEPack utility function picks decay mode or conversion and adds products to the list
- Lelaps continues to loop over the particles in the list until there are none left
- Supported unstable particles are  $\pi^0$ ,  $K^0$ -short ( $K^0$ -long treated as stable),  $\Lambda$ ,  $\Sigma^{+/-/0}$ ,  $\Xi^{-,0}$  and  $\Omega^{-}$ . Only decay modes  $> 2\%$  supported (“V” decays)

## History: Lelaps and CEPack 3.x

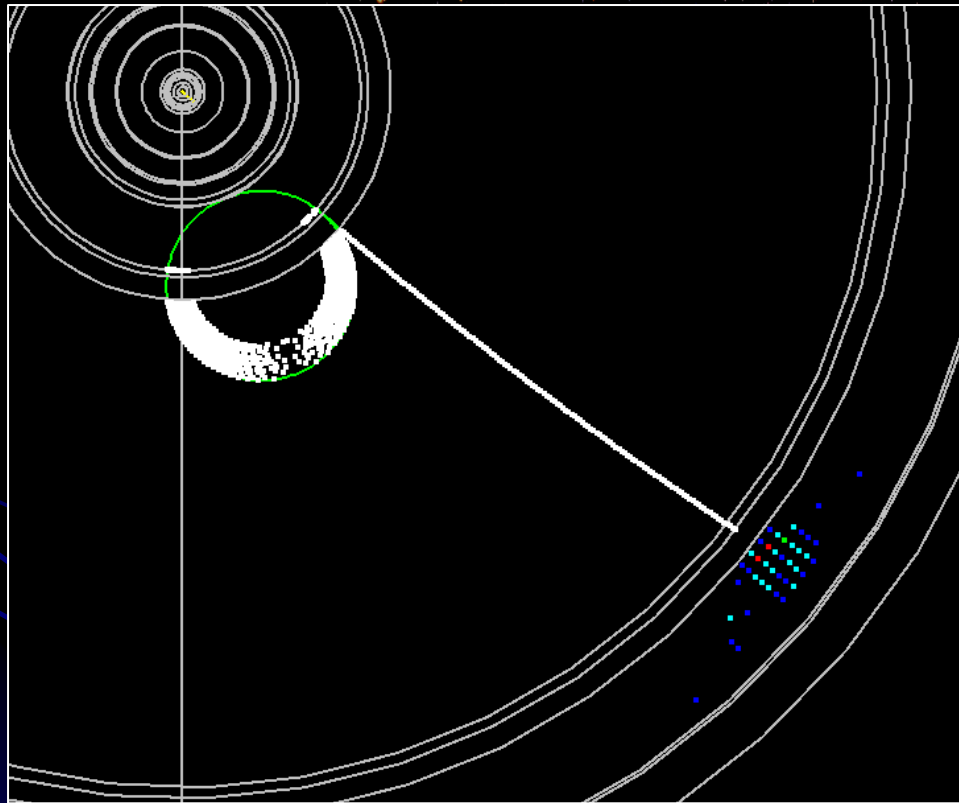


Wired picture of the  
decay chain:



as simulated by Lelaps  
for the LCD LD model.

## History: Lelaps and CEPack 3.x



Wired picture of a gamma conversion as simulated by Lelaps for the LCD LD model.

## Using CEPack inside Geant4

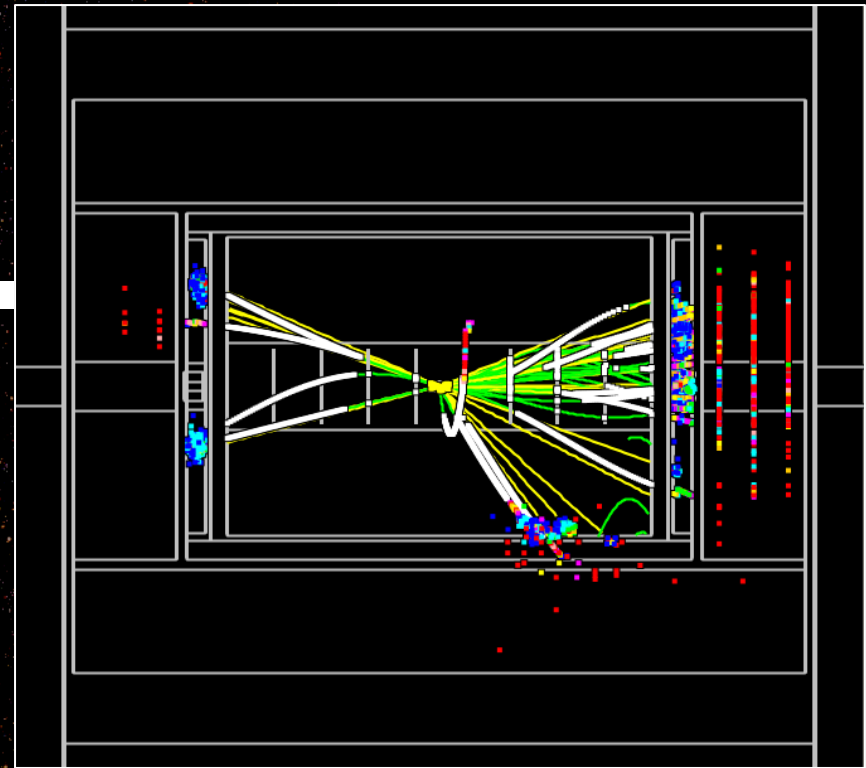
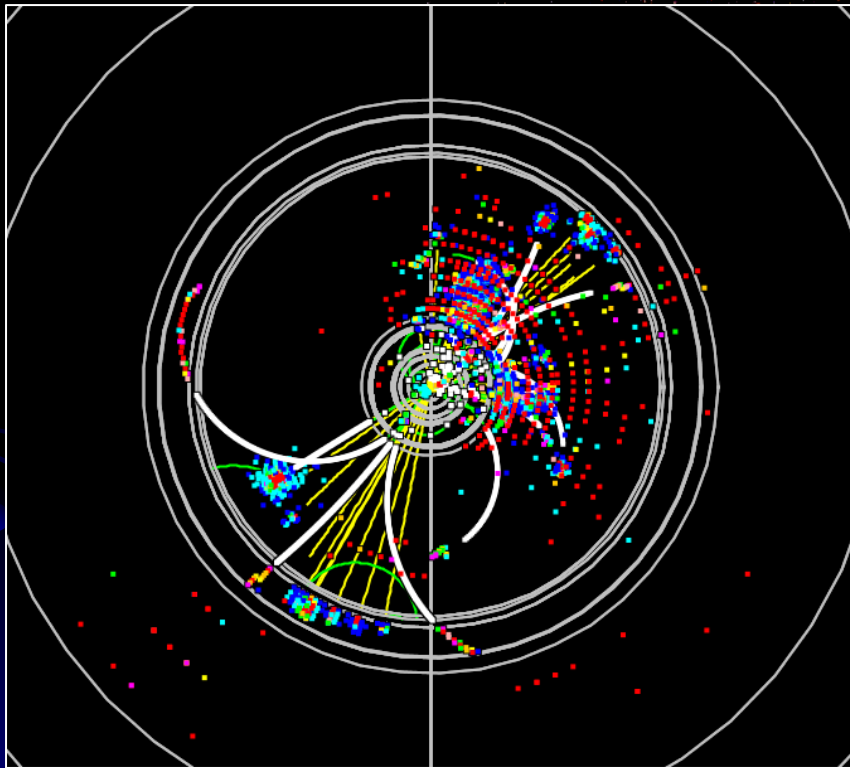
- To use CEPack inside Geant4, create a Geant4 parameterized model, e.g.:

```
class BgsSvtParamModel : public G4VFastSimulationModel
```
- In its `setup()`, create the CENode corresponding to the CEPack simulation with all its subnodes.
- In `Doit()`, convert from G4FastTrack track to CENode, and call `track.swim()`
- By subclassing CENode, all hits are reported using CENode `report_hit()` method. Convert hits to your favorite format.
- Update Geant4's notion of the track using G4FastStep (or call `KillPrimaryTrack()`)

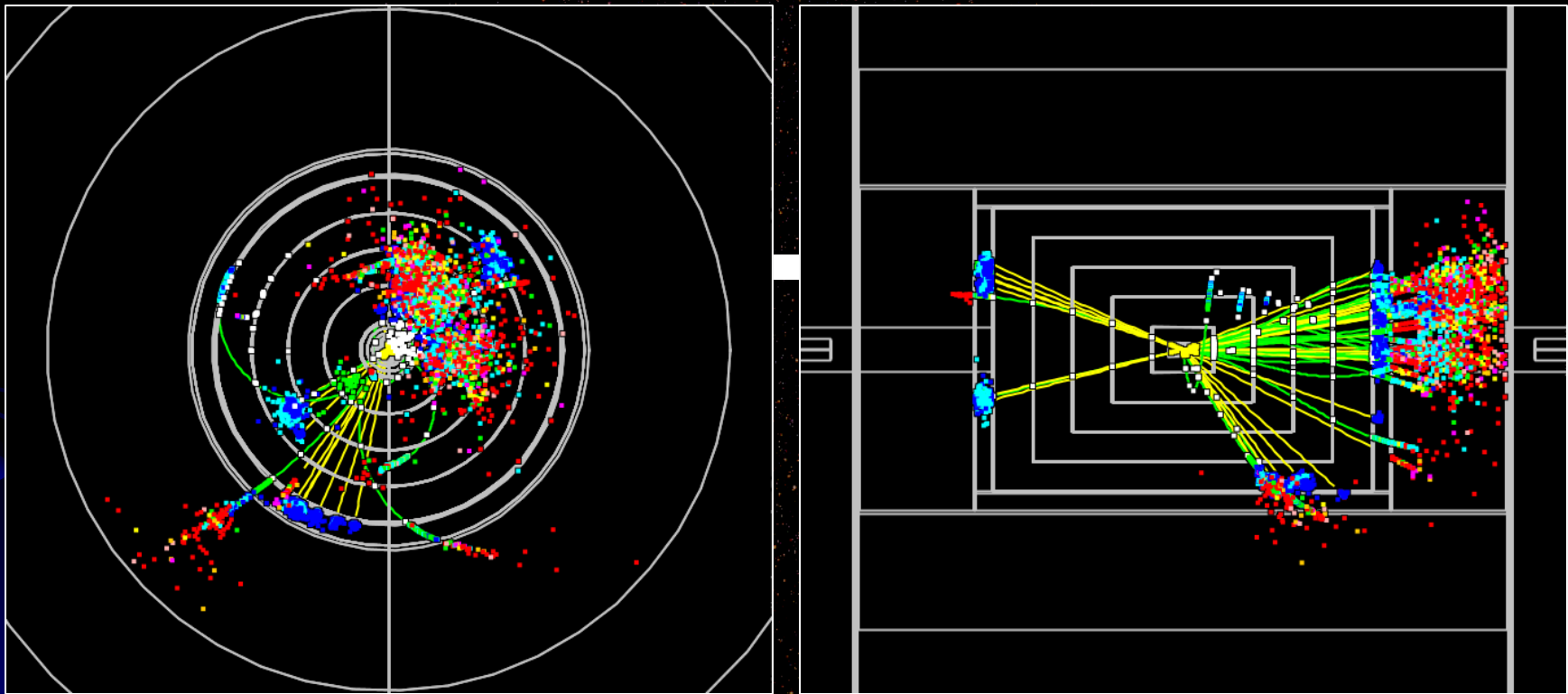
## CEPack and Lelaps

- Lelaps for LCD is a standalone program which uses CEPack.
- It sets up the CEPack geometry (supports LDMar01, SDJan03 and SDMar04).
- It uses IStdHep (“StdHep light” – included in the distribution): a class library to read generator event files in StdHep format. StdHep particles are converted to SIO or LCIO particles.
- Loops over events, creating Cetracks. When hits are reported, they are added to SIO/LCIO hit lists. For calorimeter hits, the “spots” are first accumulated and turned into energy depositions in individual calorimeter cells and then added.
- Finally, the SIO or LCIO event structure is written out.

# Lelaps (LDMar01)



# Lelaps (SDJan03)



# Lelaps: Usage

- Most common usage:
  - `lelaps -o foo.sio -E bar1.stdhep bar2.stdhep ...`  
reads one or more StdHep files and produces SIO output file.
  - Defaults to SDJan03. Use `-L LDMar04` for LD, etc.
- Also has built-in simple particle “gun”:
  - `lelaps -o foo.slcio -i 11 -m 10 -n 4 -N 1000`  
generates 1000 events with 4 electrons/event with 10 GeV each random in  $4\pi$  and produces LCIO output file.
- Options for generation in x,y plane ( $2\pi$ ) or along x, y, z directions
- Options for turning off energy loss, multiple scattering and/or showering in calorimeters
- Options for turning off decays and/or conversions and tracking their secondaries



## Performance (LDMar01)

- 100  $ee \rightarrow ZZ$  events\* at 500 GeV c.m. energy in the LD on a 1.4 GHz Pentium 4 running Linux (Noric03) gives the following performance (all numbers converted to 1 GHz processor speed):

	Overall time (at 1 GHz)	Time/event (msec at 1 GHz)	Time/track (msec at 1 GHz)
Tracking only (with dE/dx & MS)	27.9 s	279 ms	4.6 ms
+ EM showers	31.2 s	312 ms	5.2 ms
+ had. showers	36.7 s	367 ms	6.1 ms
+ decays/conversions	43.0 s	430 ms	5.0 ms
+ LCIO output file	62.9 s	629 ms	7.3 ms

\* panpy-ZZ-500-001001-gen-1.stdhep (5973 tracks)

## Performance (SDMar03)

- 100  $ee \rightarrow ZZ$  events\* at 500 GeV c.m. energy in the SD on a 1.4 GHz Pentium 4 running Linux (Noric03) gives the following performance (all numbers converted to 1 GHz processor speed):

	Overall time (at 1 GHz)	Time/event (msec at 1 GHz)	Time/track (msec at 1 GHz)
Tracking only (with dE/dx & MS)	47.7 s	477 ms	8.4 ms
+ EM showers	56.1 s	561 ms	9.4 ms
+ had. showers	56.3 s	563 ms	9.5 ms
+ decays/conversions	69.2 s	692 ms	9.7 ms
+ LCIO output file	90.6 s	906 ms	12.7 ms

\* panpy-ZZ-500-001001-gen-1.stdhep (5973 tracks)

## Performance: Analysis

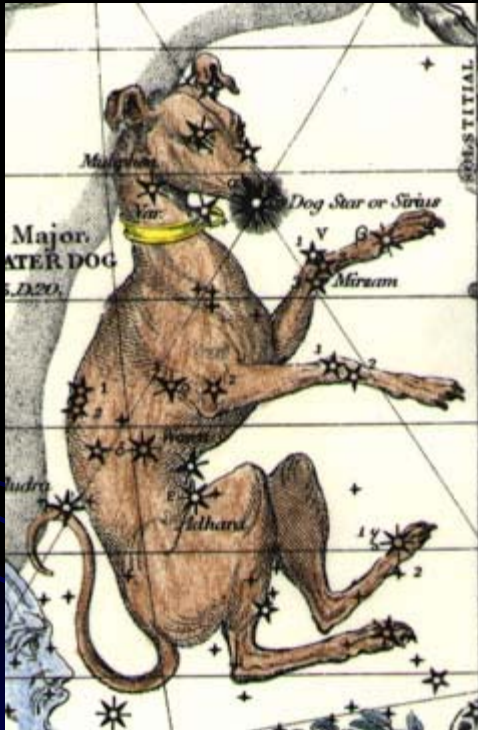
- Tracking alone: 3 - 4 events/s (at 1 GHz) for LD, 2 events/s for SD.
- Adding parameterized showering costs 15% (SD) to 30% (LD).
- Adding decays and conversions adds 20%.
- LCIO output file (14 MB, compressed) adds another 40%.
  - SIO output takes much longer (factor 2 to 4 depending heavily on calorimeter segmentation). Could be optimized.
- Platform/machine dependent. Tracking only, time per event:

● Noric03 (1.4 GHz, gcc 2.95.3)	0.281 sec at 1 GHz
● Tersk09 (0.44 GHz, Solaris with WS 7)	0.154 sec at 1 GHz
● Windows (2 GHz, cygwin with gcc 3.2)	0.384 sec at 1 GHz

# Future

- Lelaps and CEPack interfaces are not yet frozen!
- New features planned for CEPack
  - Combinatorial geometry
  - Shower continuation into next volume
- New features planned for Lelaps:
  - Read in geometry from some “standard” file format
- Old features need to be tested more thoroughly
  - More tuning of hadronic showers
- Review of code, improvements in consistency
- Revisit optimization

## About the name Lelaps



Lelaps (“storm wind”) was a dog with such speed that, once set upon a chase, he could not fail to catch his prey. Having forged him from bronze, Hephaestus gave him to Zeus, who in turn gave him to Athena, the goddess of the hunt. Athena gave Lelaps as a wedding present to Procris, daughter of Thespius, and the new bride of famous hunter Cephalus.

A time came when a fox created havoc for the shepherds in Thebes. The fox had the divine property that its speed was so great that it could not be caught. Procris sent Lelaps to catch the fox. But because both were divine creatures, a stalemate ensued, upon which Zeus turned both into stone. Feeling remorse, Zeus elevated Lelaps to the skies, where he now shines as the constellation Canis Major, with Sirius as the main star.

# Introduction: Lelaps

...but clearly, Lelaps (the program) is not a dog!





The End