Introduction to CMS Software

*Eric James*

*(Mostly Stolen from Hans Wenzel)*

- CMS Software Overview
- New versus Old Framework
- Tutorials/Getting Started
- Reconstruction Algorithms
The Analysis chain (current/old framework)

Production

MC generator → HEPEVT Ntuple

Oscar

SimReader

RecReader

Ntuple min bias

Dinner and a movie

Ntuple signal

Pool SimHits/minbias

Pool SimHits/signal

Pool Digis

ROOT Tree

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Software Projects

CMKIN: Interface to Generators

OSCAR: Geant-4 Simulation of Particle Interaction with Detector Material

ORCA: Simulation of Electronic Signals and Event Reconstruction

COBRA: Software Framework

FAMOS: Parameterized (Fast) Simulation

IGUANA: Visualization Framework (Event Display)

Geometry XML description
Welcome to the CMS Object-Oriented page

Object Oriented Projects

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Download Projects

- Software risk assessments
- Bug Reporting System (Savannah)
- Project dependency diagram

- CMS OO Software Architecture
- CMS Tier 3 Presentations
- CMS Documentation

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Event Generation: CMKIN

**GENERATORS**

- PYTHIA
- ISAJET
- HERWIG

**CMKIN INTERFACE**

- NTUPLE FILES
  - HEPEVT

**NTUPLE USAGE OPTIONS**

- OSCAR
- FAMOS
- NTUPLE ANALYSIS

- Geant-4
- Parameterized Simulation
GEANT4 Simulation : OSCAR

- Reads events from CMKIN produced Ntuple.
- Uses GEANT4 to simulate particle trajectories and their interactions with detector material.
- Creates collection of SimHits representing particle energy losses at fixed space points.
- Stores RawParticles, SimTracks, SimVertices and SimHits in POOL data files (in COBRA framework).
- Depending on the complexity of input events can take up to 100-200 s/event. Output is typically 1-2 MB/event.
Event Reconstruction : ORCA

- Object Oriented Reconstruction for CMS Analysis
- Also used to simulate the electronic signals from the detector (Digis).
- Raw Data is also converted to Digis (using separate software) for input to reconstruction.
- Can take 20-30 s/event (mostly tracking).
- ORCA is the program that provides input point to physics beyond analysis of ntuples.
ORCA

Simulation of Electronics

- 20 interactions/ crossing
- 25 ns crossing time: faster than detector response – read out (simulate) crossings -5; +3
- 200 pileup events per 1 signal event!

High-level Reconstruction and Analysis

HCAL

Tracks, Jets, Muons, Vertices, MET, Electrons, Photons, b-tags, etc…

Raw Data
Event Display : IGUANA
Old versus New Framework

Most Important Differences:

Events in the new framework are self-contained
Events are stored in a root compatible format
Events can be asked what information they contain
Jobs are based on a well-defined set of modules
Modules are run in a well-defined order
Events can be analyzed with subset of code libraries
New Framework (Example)

Time | Software Modules | Data in the Event
--- | --- | ---
 | Calo Digi Producers | Raw Data from FED |
 | Tower Producer | CaloDataFrames (digis) |
 | Jet Producer | CaloTowers (reco) |
 |  | CaloJets (reco) |
Framework Co-existence

Old/Current Framework is being used for algorithm development and TDR physics studies while new framework is under development.

CMS goal is to move to new framework for cosmic ray slice test in spring/summer of 2006.
LPC Tutorials

Old Framework:
Also serves as great intro for running on UAF.

New Framework:
See http://agenda.cern.ch/askArchive.php?base=Agenda&categ=a055467&id=a055467s12t2/actionlist
Other CMS Tutorials

http://cmsdoc.cern.ch/cms/software/tutorials/

Special Tutorials


- Introduction to CMS software - The Basics: slides
- Simulation and Reconstruction - The Full Chain: slides
- Reconstruction and DST Analysis: slides
- Analysing Data with PAX: slides
- Muon and MuonReco software: slides
- Tracker and TrackerReco software: slides
- ECAL and ElectronPhoton software: slides
- HCAL and JetMET software: slides
- Visualisation software: slides
- Vertex software: slides
- b-tagging software: slides
- Visualisation software (2): slides
- Analysis Job Submission (CRAB) and the PHYSH tool: slides
- Analysis Tool Root Tree Maker: slides


- New User Tutorial (basic introduction): slides, video
- The Full Simulation/Reconstruction Chain Tutorial: slides, video
ExRootAnalysis

Making a root ntuple : See
http://lynx.fnal.gov/runjob/MCPS_20ExRootAnalysis

List of available files : See

Definitions of ntuple variables : See
Getting Help

Take advantage of experts at LPC

In particular, Patrick Gartung runs LPC help desk

Send email to helpdesk at fnal.gov or call x3832

Subscribe to lpc-howto mailing list:

Send email to listserv at fnal.gov with “subscribe lpc-howto” in message body (subject line blank)

USCMS Software and Computing Webpage

CMS Tracker

Outer Barrel (TOB): 6 layers
- Thick sensors (500 mm)
- Long strips

Endcap (TEC): 9 Disk pairs
- r < 60 cm thin sensors
- r > 60 cm thick sensors

Inner Barrel (TIB): 4 layers
- Thin sensors (320 mm)
- Short strips

Inner Disks (TID): 3 Disk pairs
- Thin sensors

Black: total number of hits
Green: double-sided hits
Red: ds hits - thin detectors
Blue: ds hits - thick detectors

Radius ~ 110cm, Length ~ 270cm
h~1.7

Radius ~ 110cm, Length ~ 270cm
h~2.4

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Tracking

Very few measurements per track
very precise
very low occupancy: $10^{-4}$ in pixels, <5% in strips

A lot of material in the tracker
0.5-1.5 $\chi_0$: electrons brem, photons convert
0.1-0.4 $\lambda$: pions interact

Track inside out: start in pixels and extrapolate to strips
Can use external seeds (i.e. a pixel hit and an EM cluster)

![Graphs showing efficiency vs. rapidity for single $\mu$ and $\pi$](image-url)
Electrons and Photons

Lead Tungstate crystals $\Delta \phi \times \Delta \eta \sim 0.02 \times 0.02$

Biggest challenge is the amount of material in front of the ECAL

Cluster Reconstruction:
- find bumps in calorimeter
- cluster the bumps
- approximate window size $\Delta \phi \times \Delta \eta \sim 0.8 \times 0.06$

Corrections:
- containment, cracks, energy loss in the tracker material

Electrons and photons propagate differently
- electron continuously loses energy via Bremsstrahlung
- photons propagate intact until the first conversion
- Energy scales are different and depend on detector region (both rapidity and azimuth) – measuring amount of material *in situ* is needed
Jets & Missing $E_T$

- **Biggest challenges:**
  - calorimeter non-compensation and pile-up

- **High Level Trigger:** EcalPlusHcalTowers
  - Correspond to HCAL $\eta-\phi$ towers
  - One HCAL tower matches 5x5 ECAL crystals (approximately in EC)

- **Offline**
  - Use both longitudinal and transverse segmentation (RecHits)
  - Refine jets and MET with tracks and muons

- **Jet Algorithms available:**
  - **Cluster based:**
    - Inclusive $kT$
    - Exclusive $kT(d_{cut})$
  - **Cone based:**
    - Simple Cone
    - Iterative Cone
    - MidPoint Cone

\[ \Delta \eta \times \Delta \phi = 0.1 \times 0.1 \]
Muon Reconstruction
Global Muon Reconstruction

- Start with a local muon (~10% resolution @ 100 GeV)
- Extrapolate to the interaction point and find track seeds
  - can have many track seeds per muon
  - build a track propagating out, including hits in muon system
  - resolve ambiguities and do a final fit