Simulating Critical Processes

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Overview

- Provide full simulation capabilities for Linear Collider physics and detector program:
  - Physics simulations
  - Detector designs
  - Backgrounds
  - Reconstruction and analysis
- Whole world of accelerator simulations ignored!
Linear Collider 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.
- Need fairly mature reconstruction and analysis frameworks to study.
- Must be robust against both physics and machine backgrounds.
Current Activities

- Generate full suite of SM physics processes.
  - No longer sitting on the Z resonance!
- Concentrate on full detector simulation.
  - GEANT4
- Include backgrounds.
  - Irreducible physics, $\gamma\gamma \rightarrow $ hadrons.
  - Machine backgrounds
- Emphasize full reconstruction results.
- Iterate detector design based on above.
“Standard LC MC Sample”

- Generate an inclusive set of MC events with all SM processes represented.
- Used for realistic physics analyses and will represent a “standard” sample.
  - Canonical background for Beyond-SM searches.
- Samples will be generated at several points to systematically study the benefits of higher energy.
  - 0.5, 0.8, 1.0, 1.2, 1.5 TeV cms
WHIZARD, a generic MC generator for multi-particle processes at high-energy colliders, is being used to generate all of the following SM processes:

$$e^+e^- \rightarrow f_1 f_2, f_1 f_2 f_3 f_4, f_1 f_2 f_3 f_4 f_5 f_6$$

- PANDORA being used for 8 fermion $t\bar{t}$ processes.
- CIRCE is being used to model the beam- and bremsstrahlung spectra.
  - Parameterizations available for latest NLC/JLC configurations at 0.5, 0.8, 1.0, 1.2 and 1.5 TeV thanks to Torsten Ohl.
  - PANDORA now includes CIRCE beamstrahlung as an option.
- Events can be used for TESLA studies simply by reweighting.
Physics Sample Generation II

- Electron and positron polarizations of 100% are assumed in event generation.
  - Generate all four configurations
  - Simulate arbitrary polarizations by sampling from $e^-/e^{+}_{R}$, $e^-/e^{+}_{L}$, ...

- PYTHIA used for final state QED and QCD parton showering, fragmentation and decays.

- $\gamma\gamma \rightarrow e^+e^-$ and $\gamma\gamma \rightarrow$ hadrons will be overlaid.

- PYTHIA and HADES is being used to incorporate the $\gamma\gamma \rightarrow$ hadrons backgrounds.
Canonical SM sample

- A 1-2 ab\(^{-1}\) sample will be generated at each of the cms energies.
- Almost finished with first data point.
- Developing techniques to serve up correct mix of processes.
  - Weight >1 for some events (e.g. Bhabha’s)
- Appreciate strong SCS support
  - Batch queues for generation
  - Disk space for storage (~1.5 TB/point)
- Terrific work by Tim Barklow.
Detector Design

- Perception that LC detectors are trivial to build.
- Much R&D has been done for SSC/LHC, but optimizations are different.
- Hadron colliders have large cross sections, enormous backgrounds and QCD processes
  - Complex triggering and radiation damage crucial
  - Jet energy resolutions limited by QCD radiation
- LC much smaller event rates and data sizes and small backgrounds.
- Robustness vs precision
## Detector Design Comparison

<table>
<thead>
<tr>
<th></th>
<th>CMS</th>
<th>ATLAS</th>
<th>LC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tracker Thickness</td>
<td>0.3</td>
<td>0.28</td>
<td>0.05</td>
</tr>
<tr>
<td>VXD layer thickness</td>
<td>1.7%</td>
<td>1.7%</td>
<td>0.06%</td>
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<tr>
<td>VXD Granularity</td>
<td>39 MPixels</td>
<td>100MPixels</td>
<td>800 MPixels</td>
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<tr>
<td>ECAL granularity</td>
<td>76,000</td>
<td>120,000</td>
<td>32,000,000</td>
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</tbody>
</table>

Jim Brau
Detector Design (GEANT 4)

- De facto standard for HEP physics simulations.
- We have made the transition to GEANT4 as the full simulation engine (Toshi Abe).
  - Uses existing XML detector description as input.
  - Currently writes output in ROOT format.
  - Should have SIO output soon.
  - SIO2ROOT and SIO2LCD exist.
- Flexibility imposes some restrictions on complexity of detector descriptions.
Investigating alternate schemes for describing detector geometries.
- e.g. NICADD group installed MOKKA
- ATLAS and CMS have XML-based designs
  - Not commensurate with each other!
- CERN/IT working on common solution
  - GDML looks very promising
- Hoping GEANT4 adopts & supports a generic solution
Strawmen Detectors

- Currently have two example detectors implemented.
  - LD
  - SD

- Can “roll your own” simply by editing ASCII file.
  - Change Calorimeter composition, segmentation
  - Introduce different tracker designs.
  - ...

TPC Tracker, Si Disks, CCD VTX
All Si Tracker, CCD VTX
GEANT4 plans

- Next version due out imminently.
- Default hadronic showering code is a simple rewrite of GHEISHA into C++.
- Problems uncovered and discussed by Gary Bower and Ron Cassell in Chicago also present in GEANT4.
- Hope to expedite fixes locally.
- Make available to others in LC community.
Towards Internationalization

- Suggest that Tesla, NLC and JLC full simulation groups could run a single GEANT4 executable.
- Geometry determined at run-time (XML).
- Write out common "ideal" hits (~flat-file).
- Digitize as appropriate with plug-ins.
- Enormous savings in effort.
- Makes comparisons easy.
- "You don’t have to build it to use it."

"You don’t have to build it to use it."
Backgrounds

- Essential that detector design be robust against machine backgrounds.
- Crucial to undertake physics studies in the correct context of irreducible physics backgrounds.
  - Can no longer simply float $k_T$ to get 2 jets!
- Correctly simulate and overlay backgrounds on signal, event-by-event.
Machine Backgrounds

- Beam Delivery System group has sophisticated simulation of interaction region
- See plenary talk by Jeff Gronberg
- Run GuineaPig simulations of beam interactions.
- Follow all the particles.
- Record those which register hits in detector scoring planes.
BDS Simulation (GEANT3)
BDS in GEANT4 (G. Blaire)

Full simulation of em showers

Beamlines are built up out of modular accelerator components

All secondaries tracked

Synchrotron Radiation

Individual photons from individual parents
Machine backgrounds

- e+e- pairs from beam-beam interactions (T. Maruyama)
  - Generating large samples of events
  - Have added 192 bunches worth to some signal events, started tracking investigations

- Muons from collimator halo (L. Keller)
  - Event samples generated
  - Will be generated and available for overlay soon.

- See talks by Takashi Maruyama (|| Session II) and Mike Ronan (|| Session III)
Underlying Physics Processes

- Dominant background due to $\gamma\gamma \rightarrow$ hadrons resulting from beam- and bremsstrahlung photons.

- Extensively studied at LEPII, particularly by OPAL.

- Event generators usually considered:
  - PHOJET
  - PYTHIA
  - HERWIG
Generators

- Latest version of PYTHIA includes improved support for $\gamma\gamma$ processes.
  - Will use as default unless objections.
  - Does as well as PHOJET at LEPII.
  - PHOJET needs PYTHIA fragmentation.

- Use CIRCE to provide input $\gamma$ spectrum.

- PYTHIA allows event-by-event specification of cms energy.

- Generate inclusive $\gamma\gamma$ processes.
Overlaying Background Events

- Process background events through full simulation.
- Merge with fully simulated signal events.
  - Add appropriate number of beam bunches.
- SIOMerge combines MC particle hierarchy, tracker and calorimeter hits.
  - Renumbers MC particles, etc.
  - Does not yet account for time offsets in time-sensitive detectors (e.g. TPC).
Detector Issues

- Current simulations are good enough for many studies, but room for improvement.
- Need more detailed/realistic subdetector designs.
  - Current detectors are floating cylinders!
  - Luminosity monitors and masks neglected.
  - Calorimeters simple absorber/readout
  - Only projective tower geometry supported.
- Subdetector integration needs attention.
Tracking Detector Issues

- Forward tracking system very idealized
  - Simple disks providing 2D hits
  - Need wafer proposal and supports

TESLA TDR
Tracking Detector Issues

- Tracker MC hits all smeared with same resolutions (but see D. Karlen’s talk).
- Currently don’t merge tracker hits.
  - Need to digitize signals or simulate.
    - Axial Si $\mu$ strips
    - “ghosts” from forward stereo disks
  - Need to assign appropriate errors to merged hits.
- Don’t simulate detector inefficiencies.
- Don’t add detector noise.
Reconstruction Issues

- Most physics analyses based on fast MC.
  - Highly idealistic, assumes perfect pattern recognition and perfect resolutions.
  - Goal towards which to strive.
- Full reconstruction fundamentals available but not fully characterized or developed.
  - Track pattern recognition and fitting in central region (e.g. VXD+TPC)
  - Nearest Neighbor calorimeter clustering
Reconstruction Issues II

- Forward tracking and central region axial tracking still needed.
  - See talks in Tracking Session.

- Track-Cluster association and neutral hadron identification still needs a lot of work. “Energy Flow” being worked on.
  - See talks in combined Sim/Calor Session.

- Particle ID (see PID Session, R. Wilson)
  - Do we need it?
  - How good is TPC dE/dx?
Reconstruction Issues III

- In order to correctly judge the capability of detectors to accomplish the physics goals and the effect of backgrounds on the detector designs, we need capable, robust, believable event reconstruction.

- The only way to convince ourselves that this is true is to use it!

- Much is available, but there are many places where groups and individuals can plug in and contribute.
Summary

- Canonical SM Physics sample available soon.
  - Need to coordinate usage with physics groups.
- Background samples available.
  - Impact on detectors and physics only as good as the quality of the reconstruction.
- Detector descriptions need to become more Realistic & Detailed
  - R&D program?
Summary II

- Full reconstruction available, but underutilized.
  - What functionality do you need?
  - What functionality can you provide?

- Personal definition of “critical processes.”
  - What did I forget?
Informational Mailing Lists

- **lcd-sim**
  - This list is directed to those *using* the simulation, reconstruction and analysis software.

- **lcd-dev**
  - This list is directed to the simulation and analysis software *developers*. 
American Linear Collider Detector simulation efforts are documented at:

www-sldnt.slac.stanford.edu/nld

Binaries, full source, API, tutorials, etc.

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T. Abe, G. Bower, R. Cassell, M. Iwasaki,

Mail to: Norman.Graf@slac.stanford.edu