Detector Simulations at NICADD

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NICADD / NIU

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Outline

● Motivations

● Full detector: LCDG4
  - features
  - status

● Test beam simulation: TBMokka
  - features
  - status

● Summary
Digital Hadronic Calorimeter?

- High segmentation for better energy resolution: one bit (digital) or two bits (“semidigital” or multibit) per cell
- Questions to be addressed
  - Cost / performance optimization
  - Cell shapes (squares, rectangles, hexagons)
  - Cell dimensions
  - Absorber / active materials
  - Projective vs. non-projective calorimeters
  - Sampling fractions (number of layers, active to absorber ratios)
Detector Simulation Context

- **Event generation**
  (Pandora-)Pythia, Whizard, SingPartGen (java), or any other package with binary STDHEP output

- **LCDG4** for detector simulation
  Other options: Mokka, Gismo (old, not Geant4) and LCS (under development at SLAC)

- **Post-Geant processing** (to be developed)
  digitization, cell ganging, noise, inefficiencies, non-uniformities, pile-up, etc.

- **Analysis**
What is LCDG4

- A Geant4-based detector simulator to support detector R&D for the Linear Collider
- Goal: replace long-used, unsupported Gismo
  - Input format: binary STDHEP
  - Output format: SIO only for now, LCIO also soon
  - Several detector geometries are implemented via XML geometry files

  Simplistic geometry: cylinders, disks and cones only, no cracks, limited representation of support structure
Geometry info in XML

...<volume id="HAD_BARREL" rad_len_cm="1.133" inter_len_cm="0.1193">
  <tube>
    <barrel_dimensions inner_r = "144.0" outer_z = "286.0" />
    <layering n="34">
      <slice material = "Stainless_steel" width = "2.0" />
      <slice material = "Polystyrene" width = "1.0" sensitive = "yes" />
    </layering>
    <segmentation cos_theta = "600" phi = "1200" />
  </tube>
  <calorimeter type="had" />
</volume>
...

• Flexible, easy to change dimensions, materials, layering, segmentation, etc.
• Error-prone, not very user-friendly
Options under study: SD, LD, PD

Silicon Detector

Large Detector

Precise Detector

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LCDG4: General features

- Output contents: one particle collection and several hit collections (one collection per subdetector)
- Each hit points to the contributing particles (except tracker hits from calorimeter back-scatterings, as in Gismo)
- All secondaries above an energy threshold (now set at 1 MeV), except for shower secondaries, are saved in output with:
  - Particle id and status codes (generation and simulation)
  - Production momentum and ending position
  - Calorimeter entrance point: position and momentum
  - Pointers to secondary particles (decay or interaction)
$e^+e^- \text{ into ttbar event (SDJan03)}$
Zoom on the primary interaction

Preassigned decays are followed (not recommended)
LCDG4 processing times

(in a 2.4 GHz CPU)

• Single particles:
  - Physics events
    - Z to X @ 91 GeV: 0.65 min/evt
    - tt to X @ 350 GeV: 2.28 min/evt
    - ZH to Xbb @ 500 GeV: 2.89 min/evt
    - WW to qqb @ 500 GeV: 2.97 min/evt
Mokka and LCDMokka

- Mokka is another Geant4-based simulation framework for Linear Collider R&D
- Detector geometry is described using a MySQL database
- Based on Tesla model, many other models and prototypes have been added into the geometry database
- Input: ASCII StdHEP / Output: ASCII or LCIO
- For more info, please visit Mokka web site: http://polywww.in2p3.fr/geant4/tesla/www/mokka/mokka.html
- LCDMokka: XML capabilities into Mokka v01-05 (latest version is v02-03), while LCDG4 is not able to use MySQL geometry files (e.g. Tesla)
- Used LCDMokka for comparisons with LCDG4
Fair comparison

- Geant4 version 5.2
- SDJan03 geometry
  (cylindrical layers with virtual cells)
- Physics list from Mokka v01.05
- Range cut of 0.1mm
- Identical I/O formats (binary stdhep input, text output) implemented into both simulators
- Same events processed in both detector simulators
  - single particles: 50 GeV $e^\pm, \mu^\pm, \pi^\pm, \theta = 90^\circ$, flat in $\varphi$
- Same materials in sub-detectors (look at $X_0$, $\lambda_1$)
Ecal: energies per layer

Live energy per layer in ECal – Single particles, 50 GeV

MIP peaks

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Hcal: energies per cell

Slightly different slopes...

HCal threshold at 0.7 MeV
MC Samples for general use

• Samples currently available at NIU through sftp:
  scpuser@k2.nicadd.niu.edu (lcd_2004): /pub/lima/lcdg4/v02-23

  – 2K each of $e^\pm$, $\mu^\pm$, $\pi^\pm$, $\gamma$, $n$ at $\theta = 90^\circ$ and flat in $\varphi$
    energies = 2, 3, 5, 10, 15, 20, 30, 50 GeV
  – 10K Z into (hadrons) at 91 GeV
  – 5K ttbar inclusive at 350 GeV
  – 5K WW into (hadrons)(any) at 500 GeV
  – 2K ZH into (any)(bbbar) at 500 GeV and $M_H = 120$ GeV
  – 2K ZH into (any)(bbbar) at 500 GeV and $M_H = 160$ GeV

• Other samples can be requested to lima at fnal.gov. Please read http://nicadd.niu.edu/~jeremy/lcd/simreq/ for guidelines.
How to access the MC samples

Several single-particle and physics data samples available from NIU data server using secure ftp:

```
% sftp scpuser@k2.nicadd.niu.edu
password: lcd_2004
sftp> cd pub/lima/lcdg4/v02-23
sftp> ls  (to see a list of .sio files available)
sftp> mget muons-10gev*.sio  (for example)
sftp> quit
%
```

See http://nicadd.niu.edu/~jeremy/admin/scp/index.html for more detailed access instructions, including instructions for windows winscp utility.
LCDG4 status summary

- Detailed comparisons between LCDG4 v02-11 and LCDMokka 01-05 are in good agreement (discrepancies of ~20% to Gismo have been observed)
- LCDG4 faster than Mokka, but it cannot be used for Tesla geometry
- Only cylinders, disks, and cones supported by current LCDG4 version (like Gismo). More realistic geometries to be implemented in the medium term
- Several MC physics samples have been generated for algorithm development and studies (SIO format)
- Source code available from SLAC or NIU CVS repositories
- For more information please check: http://nicadd.niu.edu/~jeremy/lcd/lcdg4/index.html
Test beam prototype simulation

- TBMokka
- Based on Mokka/Geant4, MySQL, LCIO
- NICADD / DESY collaboration for CALICE test beam simulation development
### Single layer thicknesses (mm)

<table>
<thead>
<tr>
<th>Layer</th>
<th>Material</th>
<th>Thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ECal</strong></td>
<td>Tungsten</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>G10</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>Silicon</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td>Copper</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td>Air</td>
<td>0.6</td>
</tr>
<tr>
<td><strong>HCal</strong></td>
<td>Polystyrene</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Steel</td>
<td>25</td>
</tr>
<tr>
<td><strong>Tail Catcher</strong></td>
<td>Polystyrene</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Steel</td>
<td>100</td>
</tr>
</tbody>
</table>
TBMokka: cell geometry

**ECal**
- 1cm x 1cm cells
- 30 layers
- 1m x 1m total

**HCal**
- 3x3, 6x6, 12x12cm^2
- 39 layers
- 0.9m x 0.9m total

**Tail Catcher**
- 150cm x 10cm cells
- 16 layers (hor / vert)
- 1.5m x 1.5m total
TBMokka geometry persistency model

<table>
<thead>
<tr>
<th>table</th>
<th>field</th>
<th>value</th>
</tr>
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<tbody>
<tr>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>name</td>
<td>TB00</td>
</tr>
</tbody>
</table>

ingredients

sub_detector

<table>
<thead>
<tr>
<th>name</th>
<th>db</th>
<th>driver</th>
</tr>
</thead>
<tbody>
<tr>
<td>TBcatcher00</td>
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<tr>
<td>TBecal00</td>
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</tr>
<tr>
<td>TBhcal00</td>
<td>TBhcal00</td>
<td>TBhcal00</td>
</tr>
</tbody>
</table>

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TB Driver Databases

TBcatcher00
  catcher
  n_layers
  layer_start
  y_place
  layer
  cell_width
  n_cell
  layer_thickness
  poly_thickness
  steel_thickness

database
  table
  field

TBecal00
  ecal
  n_layers
  y_place
  layer
  cell_dim_x
  cell_dim_z
  n_cell_x
  n_cell_z
  layer_thickness
  w_thickness
  g10_thickness
  si_thickness
  cu_thickness
  air_thickness

TBhcal00
  hcal
  n_layers
  n_complex
  y_place
  layer_inner
  cell_dim_x
  cell_dim_z
  n_cell_x
  n_cell_z
  layer_outer
  cell_dim_x
  cell_dim_z
  n_cell_x
  n_cell_z
  layer_thickness
  poly_thickness
  steel_thickness
TB Mokka: other features

- Virtual 1cm x 1cm cells for better performance and reuse of simulated data for different cell configurations
- Implementation uses general concepts for any box-like detector
- A standalone version (no Mokka) also exists, with some additional features
- Well documented at http://nicadd.niu.edu/~jeremy/lcd/tbeam/index.html
Test beam event Displays

2 GeV Piplus

50 GeV Piplus, with a test geometry: 18x18cm Ecal and air gap before a fine+coarse tail catcher
Summary

• NICADD is actively involved with both full-detector and test beam simulations for the next Linear Collider

• Discussions are under way to unify/merge all existing full-detector simulation packages worldwide for a common simulations package (see document to be posted at the Full Simulations forum, http://forum.linearcollider.org/)