Simulation Tools For Machine Backgrounds

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- Overview of the problem.
- Brief overview of existing codes:
  - DECAY TURTLE & MUCARLO
  - MARS
  - Geant3
  - BDSIM: a Geant4 Beam Delivery System Simulation Program
- Conclusions + Final Remarks
Overview of the Problem

Obvious statements:

- At the end of the accelerator sits a detector.
- That detector needs to be able to turn on.
- One of the (many!) convincing arguments for an $e^+e^-$ linear collider is the cleanliness of the events. This assumes low machine-related backgrounds.
- The detector needs to see signal clearly.
- It needs to last at least about a decade.

There are of course machine/physics-related backgrounds – beam-beam interactions etc.; these are not the subject of this talk.

I will concentrate on issues relating to the Beam Delivery System (BDS).

- Particle loss in the BDS.
- Synchrotron radiation in the BDS and Final Focus sections.
- Muon production in spoilers and collimators.
- Neutron production in the BDS and beam dumps.
- Bremsstrahlung off beam-gas in BDS.
- ...
(from L. Keller, SLAC)

DECRYPT TURTLE, SLAC-246

- Modified by W. Kozanecki for SLC to include beam-gas bremsstrahlung and by D. Coufal and T. Fieguth for PEP-II.
- The program tracks the photon and degraded electron from bremsstrahlung off residual gas molecules and beam energy electrons from single coulomb scatters.
MUCARLO

- Program MUCARLO was originally written for SLC to estimate muon background in MARK-II and SLD.
- Muons are produced in collimators via the Bethe-Heitler process and direct annihilation of positrons on atomic electrons.
- Muons are stepped through the beamline and tunnel. The model includes tunnel walls, magnet support girders, and all bends and quadrupoles, including return flux in the iron and poletips.
- Various types of magnetized iron spoilers can be added to the tunnel at any location.
- A large variety of one- and two-dimensional histograms of the muon 4-vectors at any point in the tunnel can be generated.
- A particularly useful feature for understanding how muons manage to reach the detector is a printout of individual trajectories.
MARS
(from N. Mokhov, Fermilab)

- Program MARS is a Monte Carlo for inclusive and exclusive simulation of 3-D hadronic and EM showers, muon and low-energy neutron transport in shielding and in accelerator components in the energy range from a fraction of an eV to 100 TeV.

- Hadron and lepton interactions with nuclei and atoms from 0.1 MeV to 100 TeV. Includes a new nuclear cross-section library, a model for soft pion production and many others models.

- Detailed description of negative hadron and muon absorption and a unified treatment of muon and charged hadron EM interactions with matter.

- Particle tracking in magnetic fields, synchrotron radiation by electrons and muons...

In summary: A comprehensive and up to date package

The code is being used extensively for comparative studies of LC BDS and sets a benchmark for development of new code.

For more details see:

http://www-ap.fnal.gov/MARS/
GEANT3
(from T. Maruyama, SLAC)

Much work has been done in simulating BDS with GEANT3.

- Developing a tool based on Geant3 and TRANSPORT lattice.
- Builds geometry automatically.
- Interactions in spoilers and absorbers.
- Synchrotron radiation
- Collimator scattering.

See eg:

http://www-conf.slac.stanford.edu/1c02/wg3/
    WG3_maruyama_0207.pdf

Geant3 is a reliable and long-lived program and is an excellent basis
to perform BDS simulations and compare against other codes.

A similar approach is now being adopted in the Geant4 environment
The HEP world is now moving to Geant4.

- A vast library of physics processes from very low to very high energies.
- Object-oriented approach; well adaptable to accelerator objects.
- Code developed in this framework will probably last a very long time.

BDSIM has developed in this framework to provide:

- A flexible tool applicable rapidly to any BDS.
- Fast accelerator-style tracking for detailed tracking studies.
- Interface to a MAD-style optics file for easy build of beamlines.
- Full access to the Geant4 physics, geometry packages and visualisation packages.
Each component has its own geometry

- Outer Volume with magnetic field.
- Beampipe
- Inner beampipe with fast “Stepper” for machine-style tracking.

These objects can be repeated many times and placed along beamline by dedicated MAD-style interface.

Multipoles up to and including decapoles are included.

The detail of the G4 geometry can be easily increased, subject to memory capacity of the computer.
Fast Accelerator-style tracing has been developed:

- Known solution to equation of motion applied for Sector Bends and Quadrupoles
- Simple “kick” dynamics for higher multipoles.
- Avoids the use of Runge-Kutta techniques (time-consuming) for particles inside beampipe.
- Outside beampipe, default Geant4 tracking is used - slower, but allows more complicated outer fields etc. to be incorporated.
- Tracking is accurate - the nm spotsizes and distributions are obtained over many km (eg 6km CLIC BDS).
- Particle trajectories are in principle available, but not yet implemented directly.
- Step-length provided by Geant4; depends on processes present
BDSIM Processes

- Multiple Scattering - there “for free” in Geant4. Input via a “pressure” variable in BDS code for beam-gas studies.
- Muon production in spoilers etc. is included (H.Burkhardt et al. → next talk)
- Synchrotron radiation is included.
- Compton Scattering “Engine” included for scattering off thermal photons and also Laserwire (→ Laser-Wire Mini-Workshop on Wednesday).
- Entire G4 Physics Library easily accessible. Includes photo-nuclear and lepton-nucleon processes → neutron production etc.
Assuming a halo with uniform distribution of electrons leaving the linac with widths:

<table>
<thead>
<tr>
<th>Bunch parameter</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>( x )</td>
<td>( 10 \times 1.25 \times \sigma_x )</td>
</tr>
<tr>
<td>( y )</td>
<td>( 70 \times 1.25 \times \sigma_y )</td>
</tr>
<tr>
<td>( x' )</td>
<td>( 10 \times 1.25 \times \sigma_x )</td>
</tr>
<tr>
<td>( y' )</td>
<td>( 70 \times 1.25 \times \sigma_y )</td>
</tr>
<tr>
<td>( E )</td>
<td>( (0.98 - 1.02) \times E_0 )</td>
</tr>
</tbody>
</table>

The energy loss along the entire beam delivery system, including spoilers and absorbers gives, for 50k electrons:
50k CLIC halo electrons generated

Particle halo distributions (top) and energies (bottom) at the CLIC IP:
Photons

50k CLIC halo electrons generated
Muons

50k CLIC halo electrons generated

Distributions at final doublet:
Conclusions and Final Remarks

- Much progress has now been made through full simulation.
- A variety of tools is now emerging which will lead to independent cross-checks and development.
- I have not covered the usual accelerator tracking codes - but they are also very useful in determining backgrounds and collimator efficiencies etc.
- As the codes develop, it is increasingly important to apply consistent cross-checks.
- CPU is limited, but we need to address this to really pin down tails of distributions.

This is a field that needs lots of effort - feel encouraged to join in!