Geant4 Simulations of Machine-Induced Background in a TPC

Primary Charges and Occupancies

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Background Sources at the ILC

e⁺e⁻ pairs are a main source of background

- beams have to be focused very strongly ($\sigma_y = 5 \text{ nm}$)
- beam-beam interaction creates beamstrahlung
- beamstrahlung photons scatter to e⁺e⁻ (10⁵/BX)
- e⁺e⁻ smash into forward calorimeters (BeamCal) and magnets of the beam delivery / extraction line
- Iots of photons, neutrons, and charged particles

Other sources are supposed to be negligible (beam dump, synchrotron radiation, ...) or have to be studied in further detail (beam halo, extraction line losses)

Problems with Background

Inner silicon trackers (VXD, SIT, FTD)

- hits from charged particles (direct/indirect)
- silicon bulk damage from neutron fluence

Main gaseous tracker (TPC)

- Compton scattering, photon conversion
- neutron-proton collisions (recoil) with hydrogen
- additional primary ionisation, field distortions

Calorimeters (ECAL, HCAL)

- more photons from nuclear reactions, neutron capture
- random low-energy hits, radiation damage (?)

Simulation Tools – Guinea Pig

Input

set of beam parameters (*E*, $\vec{\sigma}$, $\vec{\beta}$, *Q*,...)

Output

- particles in the disrupted beams
- beamstrahlung photons
- e⁺e⁻ pair particles
- hadronic scattering products ("minijets")

Existing simulation data

- TESLA beam parameters (500 GeV, 800 GeV)
- various ILC parameter sets (500 GeV, 1 TeV)

ILC Beam Parameters

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Simulation Tools – Mokka

Mokka is a full detector simulation

- based on the Geant 4 framework (currently 8.1.p01)
- written in C++, contains various detector geometries
- main development at LLR, France
- now: contributions from many different users
- successor of Brahms (GEANT3, Fortran)

Mokka uses LCIO as a persistency framework

- predefined storage classes (particle, track, hit, ...)
- lightweight and robust, cross-platform design
- supported by large parts of the ILC community

"Small" LDC Detector Design

- Coil and TPC have been shortened
- ECAL and LumiCal have been pulled towards the IP
- FF at L* = 4.05 m remains unchanged
- BeamCal stays where it was
- New layout of the forward region



LDC Detector Geometry



14 mrad crossing angle with anti-DID field (1:10)



Forward region design (compressed view 1:2)

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Computing

Simulations need a lot of computing time

- $\mathcal{O}(10^5)$ particles per BX, many create EM showers
- full simulation is required: looking for "rare" incidences
- run time is 12 h to 48 h per BX (depending on settings)

Jobs are run on the Grid

- more than 20 computing centres support the VO "ilc"
- over 8000 CPUs are available (shared with other VOs)
- data for this talk was produced in HH, Zeuthen, Lyon
- 100 BX can easily be processed in a single day

The Grid also provides mass storage for simulated data

TPC Hits – "Salt and Pepper"

Mokka hits in the TPC (overlay of 100 BX)



Front view

Side view

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Occupancy – Analysis

Transformation of "Mokka hits" to a realistic occupancy

- set up a map of discrete voxels
- fill in each energy deposit (with charge sharing)
- calculate the fraction of occupied voxels (for 100 BX)

Some simplified assumptions (for the beginning)

- perfect charge sharing, no diffusion effects yet
- no gain fluctuations, no electronics effects
- drift with endless "time loop" (modulus operation)
- scalable dependency on the voxel size

This method will account for the background "structure"

Occupancy – Scaling



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Occupancy – Radial Dependency



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Primary Space Charge



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Energy Deposition per Voxel

- Consider only voxels $(5 \times 1 \times 10 \text{ mm}^3)$ which are non-empty
- Huge fluctuations of the charge per voxel
- Voxels can contain hundreds of electrons
- Landau-like distribution of dE/dx only valid for continuous tracks, but not applicable for "salt-and-pepper" hits



Neutrons might be an important aspect of the background

- created in showers, can easily reach the TPC
- collisions with protons produce (short) recoil tracks
- can we use a quencher containing hydrogen?
- test: use 20% of CH₄ (instead of the usual 5%)

Neutron modelling is a difficult issue

- Geant4 provides several "high precision" physics lists
- test: compare QGSP_BERT_HP with LHEP_BIC_HP
- what happens to neutrons capture? decay? escape?
- will delayed neutrons become important?

Particles entering the TPC (per BX)

	BERT	20% CH ₄	BIC
Neutrons	142 ± 20	146 ± 25	138 ± 22
Photons	947 ± 57	955 ± 44	952 ± 49
Electrons	$6\pm~13$	6 ± 12	8 ± 13

Particles created in the TPC (per BX)

Influence of neutrons is visible, but negligible

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Summary

The occupancy looks easily manageable

- no fully-fledged digitisation yet, but:
- occupancy is well below the magic limit of 1 %
- that number does not even take the special structure into account (microcurlers which blind a few pads)
- pattern recognition should remove most of this
- but what about space charge and field distortions?

Neutrons (and hydrogen) seem to be no problem

- recoil protons do appear, but very rarely
- choice of the physics list is not crucial
- some photons might have neutrons as ancestors

Outlook

Further possible simulation runs

- get more statistics (a whole bunch train?)
- try different cuts (neutron behaviour, delta electrons)
- what about minijets from Guinea-Pig?

Reconstruction and analysis

- provide a "background library" with ready-to-use events
- integrate background into the TPC software package
- long-term goal: comparison of a physics analysis
 (e.g. ZH $\rightarrow \mu\mu$ X) with and without background
- will the background signals have an impact on pattern recognition, efficiencies, resolutions?