(Lepton) Collider Background Studies

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LCWS 2023 - SLAC
18 May 2023

Including information from: iLC, CLIC, C³
Overview

• Beam and machine induced backgrounds govern precision at lepton colliders
  - Less pristine detector environments result in low level and high-level mis-reconstructions
  - If background rate is too high, requires triggers, and may incur subtle biases

• There are three major types of these backgrounds
  - Incoherent pair production: e+ e- and mu+ mu-
  - Hadron photoproduction
  - Machine-beam interactions, e.g. collimation

• The importance of each backgrounds varies with beam configuration
  - Higher energies, larger or smaller emittance, bunch particle type all affect

• Most importantly, with new collider concepts we must repeat these studies!
  - C³ is a popular and new accelerator concept with a different configuration
  - Different generators for each background, preservation of techniques important

• This talk will focus on linear Higgs factories, but higher energies mentioned
ILC - C³ - CLIC

• There are extremely detailed performance calculations in the ILC TDR
  - However, C³ has a radically different bunch structure from ILC, reminiscent of CLIC

  \[\text{ILC timing structure}\]

  1 ms long bunch trains at 5 Hz
  2820 bunches per train
  308 ns spacing

  \[\text{C³ timing structure}\]

  Trains repeat at 120 Hz
  133 1 nC bunches spaced by 30 RF periods (5.25 ns)
  RF envelope 700 ns

• C³ Time structure and electronics needs at low level are different
  - But the overall concepts are similar, and technologies from LHC can deal with the 70x smaller bunch spacing (because of the 120 Hz repetition rate!)
  - Modern clocking and timing performance means that C3 background rates will be one-tenth of ILC due to the shorter bunch train and intrinsically better timing
Incoherent electron/positron pair production

This background comes from the generation of virtual or bremsstrahlung photons as bunches pass through each other.

To simulate the pair background we use the Guinea-Pig (GP) program:
- Use detailed input concerning expectations of beam focusing to predict bunch field and particle transport.
- There are additional handles for hadron photoproduction but GP’s implementation is known to be inaccurate.
- Refined error analysis of predictions lacking in recent studies, need to develop some prescription.

Source:
https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.44.2209&rep=rep1&type=pdf
https://bib-pubdb1.desy.de/record/405633/files/PhDThesis_ASchuetz_Publication.pdf
Results for previous ILC machine parameter update

- Most recent stable results are from 2017 machine parameter update
  - Simulation also with GuineaPIG
  - Detailed accounting of occupancy throughout detector
- Primary focus of this update was impact of muon backgrounds
  - Particular attention paid to investigating various shielding strategies
  - Muon background discussed later in this talk

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<th>ECOM [GeV]</th>
<th>aDID</th>
<th>nom. field [T]</th>
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Table 3: Estimated number of hits in the vertex detector induced by beamstrahlung pairs, split into early ($t < 15$ ns) and late ($t > 15$ ns) components. Hits induced by very low energy initial particles (less than 2 MeV) have a negligible contribution, and are ignored. Averaged over 100 BX.
Preliminary Results for $C^3$

- Checked many times to ensure fidelity of simulation and outcome of results
  - Concerns about magnetic field, exact versions of geometry, etc.
- Together with envelope confirmation indications that we could move the inner pixel layer closer
  - Closer hit: improved sagitta determination, HF tagging, triggering, electron reco.
- Confirms baseline expectation that $C^3 \sim ILC/10$
**Hadron Photoproduction**

- Diagrams have similar topology to electron-positron background but include the possibility that the virtual photons pair-produce quarks
- Given smaller coupling to quarks and requirement for internal conversion this background is smaller
  - Measurements indicate ~10% of pair background at calorimeters, more central than e+ e-!
- Given the c.o.m. range over which we’re producing events there are many details to consider

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**FIG. 2:** Comparison of cross sections for $\gamma\gamma \rightarrow$ hadron processes as a function of centre of mass energy obtained from Amaldi parameterization [3], Standard parameterization [8] in PDG, Pythia and data from LEP [1], PETRA [6] and VEPP [5]
Hadron photoproduction backgrounds particularly pernicious
- Larger c.o.m. produces more central particles, including photons from pi0
- Can affect jet reconstruction when rate is high enough

- As with pair production, hadron background scales with energy, emittance
  - Higher energy runs (WW, top) affected significantly more than Z-pole, Higgs-factory
  - cf. M. Swiatlowski Parallel on wakefield
Refinement of Simulation Strategy

- Previous hadron background studies combined multiple generators together
  - Various approximations for differential cross section
  - Hand-written generators in addition to Whizard and Pythia where their approximations hold
- Modern simulation significantly more streamlined
  - More direct integration of processes into Whizard and CIRCE programs
  - Best possible simulation of virtual photon flux throughout center-of-mass spectrum

FIG. 1: Energy spectrum of $\gamma\gamma \rightarrow$ low $p_T$ hadron events as a function of centre-of-mass energy. The figure shows the energy cutoff of 10 GeV below which the events are generated by the Barklow generator. Above 10 GeV the events are generated by Pythia.
Status of Results for C³

• While waiting for new generators, have completed Pythia 8 simulation
  - Find that hadron background in pixel detector (current focus) is 0.1% of pairs
  - Matches last ILC results for ratio to pair background, absolute yield is 10% of ILC
• Much more central occupancy distribution than electron pair production
  - As expected, backgrounds affect C³ detectors in the same way as ILC
  - Once we have T. Barklow generator in hand, proceed to overlay, physics studies!
Backgrounds from the Machine

- Incoherent muon production from beam interactions with collimator
- Mitigation strategies involve “spoiler” and “wall” magnets to deflect muons
  - Survivable rates achieved through a combination of both
- Simulation requires detailed transport treatment, material interactions in large volume
Results for ILC + ILD

- Muon simulations performed using MUCARLO (G. Feldman) simulation
  - Validated against older FLUKA implementations and measurements
  - Older results (ALCW2018) also show impact on TPC
- Variations of accelerator structure with and without magnetized wall
  - Wall reduces number of muons per bunch train by ~5x
  - Wall necessary for reasonable occupancy in ILD endcap detectors
  - Significant impact on detector design choices
Towards achieving results at C3

- C3 will have a different BDS compared to ILC, and is significantly shorter
  - Need to provide detailed geometry and specialize our own version of MUCARLO
  - However - little possibility to get this code running again from scratch
  - Very little documentation, abandoned dialects of fortran, …

- Starting software project to produce these results for C3 over this summer
  - Aim to validate against ILC results
  - Show differences, finer considerations for significantly more compact machine

See D. Ntounis Parallel
A Note on the Muon Collider

- Enormous background from muon decay products interacting with the accelerator structure
  - Also a small rate of incoherent pair and hadron photo production (comoving electrons!)
- Muon collider machine background simulations are assembled using FLUKA
  - Particles that reach the experiment hall can be recorded and entered into GEANT for overlay with event
  - FLUKA comes with a package for describing geometries / beam lines (we should use it!)
Remarks and Conclusions

- Beam and machine induced backgrounds at lepton machines pose challenges to detector design and physics reach
  - Machine and beam design: flavor, energy, charge, optics can alter primary backgrounds
  - Particularly at high energies and small emittance, these backgrounds can easily overwhelm modern detector concepts without optimizations

- Numerous promising future directions to open up design space

- C3 collider concept is making progress on its own background estimates
  - Major issue: 5ns bunch spacing requires accurate pileup overlay (CMS style)
    - This is a major software effort, but can/should be shared with MuC, FCC
  - However, assuming sufficient electronics: C3 = ILC / 10

- Updates to various collider concepts background studies at this workshop
  - Other plenaries, parallels - join in the discussion!
  - All lepton collider concepts use the same tools, we should work together
    - Not only to distribute expertise but to preserve knowledge about the tools we use to make these predictions