Beam backgrounds: Simulation & Effects on Reconstruction at ILD

- Introduction to beam induced backgrounds
- Simulation of beam background
  - Isotropic background
  - Overlaying real simulated background
- Background in TPC and VTX
- Physics analyses with beam background
Beam Induced Backgrounds

new problem faced by linear colliders – beam induced backgrounds

• machine induced backgrounds -> most important source of unwanted interactions
  
  - beamstrahlung (photons) & $e^+e^-$ pair production
  - photons strongly focused in forward direction, exit through beam tube
  - $e^+e^-$ pair production: direct and scattered particles in the detector
  - $10^5$ pairs per bunch crossing, total energy $\sim100\text{TeV}$, average few GeV per particle

• electron-positron pairs are unavoidable backgrounds

• other beam backgrounds (of small impact, not yet included in studies):
  
  - beam halo muons, beam gas interaction, synchrotron radiation from beam delivery, particle losses in extraction line, beam dumps
Beam Backgrounds in Detector

- Guinea Pig generation of $e^+e^-$ pairs
- full GEANT-4 simulation of pairs background
  - includes realistic description of forward region and magnetic fields
  - main gaseous tracker conversion of backscattering photons
  - tracks from the IP, rare, but mostly curlers
  - recoil tracks from neutron-proton
- mostly affected – VTX and forward detectors
  - VTX will integrate a large number of bunch crossings for every physics event
- necessary to find a way to simulate background
  - salt & pepper BG in VTX
  - overlayed background

Mokka hits in the TPC (100BX)
Salt & Pepper Background

• salt&pepper hits added to VTX (VTXNoiseHits Marlin Processor)
  • isotropically distributed hits added to SimTrackerHits collection after digitizing
  • hits added according to hit densities
  • layers 1-2: 83 BX/event, rest 333 BX/event (estimated from VXD readout times)

• fully reconstructed tracks after chain:
  • digitalization
  • silicon tracking
  • LEP tracking
  • full tracking

• hit densities calculated from number of hits in detector layers for 1 BX
  • average number of VTX hits calculated from Guinea Pig files simulated with Mokka (SimTrackerHit), ~100 BX used
Background: Hits & Tracks

- huge amount of additional background hits in VTX
- huge amount of additional tracks in VTX and whole detector
- problems in reconstruction
- ghost tracks from 'noise' hits
- hits might degrade the measurement of physics
- hits that are nearby (cluster extension)
- is tracking reliable?

<table>
<thead>
<tr>
<th></th>
<th>no background</th>
<th>background</th>
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</thead>
<tbody>
<tr>
<td>VTX hits</td>
<td>~400</td>
<td>~10^5</td>
</tr>
<tr>
<td>Si tracks</td>
<td>~60</td>
<td>~4000</td>
</tr>
<tr>
<td>Full tracks</td>
<td>~70</td>
<td>~1500</td>
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</table>
Background & Full Tracking

background (only in VTX)  no background

- tracking not really reliable
- can Pandora deal with that?
Background: PFOs

- Pandora does not crash!
- Number of PFOs higher
- Total energy slightly higher (more PFOs) but in reasonable range

**Pandora (sort of) works but reconstructs too many PFOs**

- Uses other variables & detectors
- Selection on tracks
Reducing Background after Reconstruction

- cuts to reduce background and keep physics events?
- best results with 2D cuts based on track D0, track pseudorapidity and number of hits used for track fit coming from TPC (background tracks rarely reach TPC)

Good agreement for track variables:
- background rejection \(\sim 97\%\), track efficiency \(\sim 1.5\%\) for \(p_T > 0.5\) GeV
More Realistic Background

- Isotropic background from Salt&Pepper processor realistic enough?
  - Not all distributions flat
  - Lack of real tracks
  - Background hits only in VTX

More realistic S&P:
  - Parametrize isotropic background according to real distributions
  - Add background in other detectors

Best approach - overlay simulated background on physics events

Physics processes overlayed with hits from simulated Guinea Pig $e^+e^-$ pairs
Overlay Processor

- **OverlayBX processor**, version v01-06-fw:
  - possibility to overlay n BX in TPC
  - 1 BX in other detectors with fast readout: SIT, FTD, SET, ECAL, HCAL, BCAL, LCAL, LHACAL
  - in VTX number of overlayed BX evaluated from readout times, 83 for 1-2 layers and 333 for the rest
  - uses ~2000 Ginea Pig BX
  - ILD_00fw model created to study background

- technically challenging
  - time consuming
  - different components - different readout times - different number of BX
  - need to account for time- and space-shifts for different BX
  - large pool of GP events necessary: 2000 BX (thanks to T. Hartin)
Beam Background in TPC

- background hits in TPC →

- $t\bar{t}bar$ events overlayed with hits from $e^+e^-$ pairs
  - 150 BX overlayed
  - improved digitalization

- specific pattern recognition software
  - micro-curlers removed:
    - 99% background hits removed
    - 3% signal hits removed, only 1% hits from tracks $p_T > 1$ GeV

- remaining hits - no problem for track-finding pattern recognition software

TPC hits for $t\bar{t}$bar events overlayed with 150 BX of pair-background hits

improved reconstruction “killing” micro-curlers

TPC tracks

courtesy of S. Aplin

for details check S. Aplin talk
Beam background in VTX

- GineaPig simulation of background analyzed (R. de Masi)
  - distribution of cluster sizes calculated
  - clusters: ellipses or rectangles on VTX ladder surfaces
    - two main cluster axes on the ladder
  - root-histograms provided
  - cluster sizes are strongly peaked at 3x3 pixels with long tails

- 2 Marlin processors adding ClusterParameters to VTX hits
- VTXNoiseClusters
  - distribution of cluster sizes from root-histograms

- VTXBgClusters
  - projected path length of MCParticle when going through sensitive part of VTX ladder
    - oriented along projection of particle's 3-momentum
  - needs 'dedicated' configuration parameter in Mokka simulation (not mass production)
Beam Background in VTX

- effect of measurement degradation from clusters studied
  - hit position of a physics hit (space point) falls within a background cluster hit:
    - physics hit removed (optionally background hit moved to the intermediate position)
    - resolution kept
  - effectively removes ~0.1-3.3% (occupancy) of the physics hits (different for different layers)

- Marlin processor to “simulate” lower occupancy
  - removes on statistical basis random hits from physics hits in VTX layers, according to numbers from degradation studies
  - quick - uses only physics sample
  - tests ran so far
  - another processor (not used yet)
    - uses simulated GP background to remove hits
    - time & resources consuming
Tagging Bunch Crossings

- Pattern recognition in presence of background challenging
  - Seeding for Si tracks changed
- Number of background ghost tracks dramatically decreased if BX tag used
  - At least 1 SiT hit OR
  - At least 10 TPC hits
- Much less tracks and higher $p_T$
- Leftover tracks
  - Relatively high $p_T e^+/e^-$
  - Combination of physics and BG hits
- Loss of efficiency due to requirements
  - 1% for $p_T < 1$ GeV, none for $p_T > 1$ GeV
Tracking Efficiency

- effect of overlayed background and VTX hit inefficiencies studied for $t\bar{t} \rightarrow 6$ jets events (for CME 500 GeV)

  - track efficiencies for $p_T < 300$ MeV reduced
  - for $p_T < 1$ GV inefficiency less than 0.1%
  - track efficiency 98.8%
  - for tracks that deposit energy in TPC and with $p_T < 1$ GV efficiency is > 99.9%

- track efficiencies not significantly degraded in by nominal level of BG
Impact on Physics Analyses

• IDAG requested studies for Higgs recoil mass with beam BG

• Track finding inefficiencies for high momentum muons from $ZH \rightarrow \mu^+ \mu^- X$ negligible

• Low $p_T$ tracks do not affect recoil mass distribution

• Effect from loss of hits in VTX due to occupancy negligible

• Full simulation of background time & CPU consuming
  • 150 BX in TPC
  • 1 BX in SiT
  • 83/333 BX in VTX overlayed for each physics event!
SUSY Sps1a': Stau Mass

\[ e^{+} e^{-} \rightarrow \tilde{\tau} \tilde{\tau} \rightarrow \tilde{\chi}_{1}^{0} \tau \tilde{\chi}_{1}^{0} \tau \]

- missing energy and 2 low multiplicity tau-jets
- \(\tau\) mass extracted from endpoint of tau-jet energy spectrum (assuming \(\tilde{\chi}_{1}^{0}\) mass)

\[
\begin{align*}
&\text{requirements:} \\
&\quad \text{• precision tracking} \\
&\quad \text{• good particle identification} \\
&\quad \text{• hermetic detector} \\
&\quad \text{• low machine background} \\
&\quad \text{• stat. error on end-point: 0.1 GeV} \\
&\quad \text{• accounting for } \tilde{\chi}_{1}^{0} \text{ mass uncertainty: } 0.1 \text{ GeV } \oplus 1.3\sigma_{LPS}
\end{align*}
\]

\(E_{\text{jet}} \text{ [GeV]}\)

courtesy of M. Berggren
SUSY Sps1a': Staus Revisited

\[ e^+ e^- \rightarrow \tilde{\tau} \tilde{\tau} \rightarrow \tilde{\chi}^0_1 \tau \tilde{\chi}^0_1 \tau \]

- studied with beam background present
  - each physics event overlayed with 1 BX of Guinea Pig pairs
  - set of cuts to remove background
    - particle energy \( E > 0.5 \) GeV
    - at least 1 hit in TPC (charged and neutral)
    - DELPHI jet algorithm used to find taus (more efficient than Durham)

for details check M. Berggren talk

charged particle \( \log_{10}(E) \)

no difference in \( \tau \) mass
extracted with beam background and without

courtesy of M. Berggren
Summary

- ILC faces novel problem of beam-related backgrounds
- we have to know its impact on reconstruction and physics analyses
  - we can simulate it
  - we are learning how to deal with it
  - we start to do analyses with real background simulation
Magnetic Field in Mokka

• B-Field problems found in the ILD_00fw model created to study background
  • strange radial components in the B-Field in the TPC

• new model created ILD_00fwp01
  • new non-uniform solenoid with anti-DID
  • GP files for background studies created with proper B-field