Simulation of the tracker and vertex silicon detector hits response to machine backgrounds in a muon collider

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Outline

- **ILCRoot simulation for VXD and Tracker hits from 750+750 GeV Muon Collider MARS background**
  - Mass production (in different VXD and Tracker geometry sets)
  - Timing based background rejection results
- **LCSim (SLIC) simulation and hits analysis**
  - ILCRoot vs. LCSim (MARS background hit timing, first try)
- **Toward MDI for Higgs Factory Muon Collider**
- **Conclusion**
ILCRoot framework

• The ILCRoot - software Infrastructure for Large Colliders based on ROOT and Alice’s Aliroot with add-ons for Muon Collider studies (see backup slides for details)

• Available at Fermilab
  – ILCrootMuXDetV3 released by V. Di Benedetto with GEANT4 v9.5.1 (neutron timing patch was provided by GEANT4 team with help from V. Di Benedetto)
  – ILC SiD detector based geometry
  – implementation of double layer geometry in the Si Vertex and Tracker detectors with runtime controlled parameters
  – using QGSP_BERT_HP physics list for better neutron transport simulation

• ILCRoot new release(ILCrootMuXDetV3.1, by V. Di Benedetto)
  – based on previous VXD and Tracker dual layer version ILCrootMuXDetV3
  – has now runtime switch between single and dual layer geometry
  – tested for IP muons in dual layer (agrees with results of previous version) and single layer geometries
  – will use for MARS background simulation in single layer geometry similar to LCSim(SLIC) with goal to compare with LCSim(SLIC) hits
Working with MARS background simulation results for 750 + 750 GeV $\mu^+ \mu^-$ beams with $2 \times 10^{12} \mu$/BX each

- background yields/BX on $10^0$ shielding nozzle surface and MARS thresholds ($2.18e+08$ total yield/BX, weights included)

All MARS statistics (weights included) was used as input for ILCRoot simulation of the Si VXD and Tracker hits

- particles with weight N were smeared azimuthally to N particles (with preserved P and Pt)

<table>
<thead>
<tr>
<th>Yield</th>
<th>$\gamma$</th>
<th>$n$</th>
<th>$e^+$</th>
<th>$p$</th>
<th>$\pi^+$</th>
<th>$\mu^+$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1.77e+08$</td>
<td>$0.40e+08$</td>
<td>$1.03e+06$</td>
<td>$3.13e+04$</td>
<td>$1.54e+04$</td>
<td>$0.80e+04$</td>
<td></td>
</tr>
</tbody>
</table>

| $E_{thr}$, MeV | $0.2^*$ | $0.1^{**}$ | $0.2$ | $1.0$ | $1.0$ | $1.0$ |

*) Lowest limit available in current MARS code

**) Current MARS code has $E_{thr} = 1.0e-3$ eV for neutrons, 0.1 MeV threshold was chosen for muon collider background simulation
ILCRoot mass production simulation

- **ILCRoot mass production of simulated hits for MARS background, IP muons and protons - completed**
  - only VXD and Tracker hits, the rest of detector as material (includes calorimeters, beam pipe, 10° shielding cone etc. – full layout)
  - the hits were simulated in four geometries with VXD and Tracker double layers
    - 200 μ thick Si sub-layer, 1 mm and 2 mm space between sub-layers
    - 3.5 T and 7 T magnetic fields
    - IP smearing in Z_v (Gaussian σ = 1 cm) and X_v, Y_v (Gaussian σ = 6 μ) for IP muons and protons having flat P = 0.2 - 100 GeV/c distribution
  - the goal is to study criteria for MARS background hit rejection
    - using timing
    - double layer criteria vs. different geometries
• **Double layer criteria for muon collider background hit rejection**
  – suggested by J. Chapman and S. Geer for the muon collider
    ("The Pixel Microtelescope", J. Chapman, S. Geer, FERMILAB-Conf-96/375, see backup slide)
  – IP physics charged track makes hits in both sub-layers
  – readout takes AND of appropriate (IP oriented) pixel pairs in both sub-layers suppressing random neutral background hits
  – analysis of simulated hits in double layer geometry is in progress

• **The timing study was done for geometry set with two 200 μ thick Si sub-layers 1 mm apart and 3.5T magnetic field**
  – time resolution impact on background rejection
• **Timing for MARS background particles**
  - MARS background (on a surface of the shielding cone) is within ~500 ns with tail up to ~1000 ns of TOF (time of flight w.r.t. BX)

• **Timing of ILCRoot hits in VXD and Tracker (from MARS background)**
  - TOF for neutron hits has long tale up to a few msec (due to “neutron gas”)
• **Finishing hits timing study for 750+750 GeV Muon Collider**

  – simulation was done with hit time resolution of 0.2 ns, 0.5 ns and 1.0 ns for IP muons and MARS background

  – the previous results were obtained with TOF (time of flight) global timing gate (e.g. one and the same TOF gate in all VXD and Tracker layers)
    • for gate width of ~9.3 ns, IP efficiency 99.7% and time resolution 0.5 ns
    MARS background hits fraction ~4%

  – no front-end time delay (charge collection time + rise time of preamplifier + discriminator response time) --> start at -2.3 ns

  – not important now (delays are similar for IP particles and MARS background signal)

  – too early to simulate front-end today
Layer dependent time tuning

- instead of global timing, tune start and width of TOF gate for IP particles in each layer keeping IP hits efficiency 99.7% per layer (pictures for 0.5 ns time resolution)

VXD Barrel innermost layer (R ~3cm)  Tracker Barrel outmost layer (R ~120 cm)
- **Layer dependent time tuning**
  - several times gain in MARS background rejection if compare with global TOF timing gate
  - tuning within the layer will provide further improvement in rejection
    - will be effective for outmost tracker layers
    - alternative to TOF-T0 timing (T0 – photon TOF from IP to the point of hit)
ILCRoot VXD and Tracker hits timing study

- **MARS background hits per layer fraction, time gate width and density** (for 0.5 ns time resolution, see backup for 0.2 ns and 1.0 ns)
• LCSim framework installed at Fermilab since 2011 (H. Wenzel, Fermilab)
  - GEANT4, v9.5.p01
  - detector response to MARS background for \(750+750\text{ GeV}\) Muon Collider and 10\(^{\circ}\) shielding cone was simulated by H. Wenzel
  - SLIC
    (Simulation for the Linear Collider), part of LCSim framework, simulation of detector geometries and readout technologies
  - mcdrcal00 detector
    (5T solenoidal field, BGO calorimeters, SLAC VXD, Tracker, Si 20\(\mu\),300\(\mu\))
  - no MARS particle statistics weight was taken into account, therefore actually \(~5\%\) of background was simulated
  - no shielding cone material included
  - 9+9 (for MARS background from \(\mu^{+}\) and \(\mu^{-}\) beams) output *.slcio files
LCSim VXD and Tracker hits for MARS background

- 100° nozzle geometry, VXD and Tracker layout in LCSim (SLIC)

General (1/2 RZ) view

Zoom in beam pipe

W – tungsten
Be – beryllium
BCH2 – borated polyethylene
(current SLIC does not include material of the nozzle)
LCSim VXD and Tracker hits for MARS background

- Code to access VXD and Tracker hits in SLIC output *.slcio files and convert output *.aida files to simple ROOT ntuples
  - a good starting point was “LCSIM Tutorial for Muon Collider Studies” by Jeremy McCormick, Norman Graf (SLAC) and Hans Wenzel (Fermilab), 19 December 2012, indico.fnal.gov/conferenceDisplay.py?confId=6191
  - then used official example TrackerHitAccessDriver provided by Norman A. Graf and Jeremy McCormick, see "A simple example of how to access the SimTrackerHits in an event“ in confluence.slac.stanford.edu/display/ilc/Accessing+SimTrackerHit+information
  - modified it to store VXD and Tracker hits parameters in simple Ituple *.aida file for each *.slcio file
  - converted each *.aida file to ROOT ntuple (following confluence.slac.stanford.edu/display/ilc/AIDA+xml+to+ROOT+Ttree+convertor and installing PAIDA)
  - joined 18 ROOT ntuples into one for analysis
- **Hit R vs. Z for MARS background**

LCSim VXD and Tracker hits for MARS background

**VXD + Tracker**

**VXD**
• **Hit timing for MARS background**
  - hit TOF is time of the hit relatively to BX (bunch crossing)
  - LCSim user’s cut at TOF = $10^4$ ns ? (no such cut in ILCRoot)
LCSim VXD and Tracker hits for MARS background

• **Hit timing for MARS background in ILCRoot and LCSim**
  
  – LCSim (SLIC) seems to produce smaller hits fraction than ILCRoot at TOF < 50 ns, (e.g. larger tail at TOF>50 ns), however:

  - small difference in geometries for VXD and Tracker
  - SLIC simulation – ignores the stat. weight of MARS particles, no material in shielding cone, 5T magnetic field (3.5T in ILCRoot), **different physics list (neutrons)**
  - for adequate comparison have to provide similar conditions?
Hit timing for MARS background in ILCRoot and LCSim (cont’d)

- difference comes mainly from Tracker outmost barrel layers

VXD barrel layer, $R \approx 5$ cm

Tracker barrel layer, $R \approx 122$ cm
• Questions from detector side for 62.5 + 62.5 GeV Muon Collider beams decays induced background
  – total yield of the background particles (from the shielding cone surface) per BX and its components (photons and neutrons)
  – the peak position in their time distribution (closer to TOF = 0 means decreased background rejection, picture for 750+750 GeV Muon Collider)
  – what front-end time resolution will be needed for timing based background rejection to provide the VXD and Tracker layers background hit occupancies acceptable for tracking of IP particles
  – neutrons hits contribution from the previous BXs (time between BXs?)
  – Z smearing of IP?
• **The first shielding cone for 62.5 + 62.5 GeV Muon Collider**
  (see talk by N. Mokhov)
  – 7.6° angle (was 10° angle for 750 + 750 GeV Muon Collider)
  – shorter in Z and narrower in R, shielding cone tips are farther from IP due to large Z smearing of IP (σ ~ 5.6 cm !)
  – comprises only one material (tungsten, beryllium is for the beam pipe)
  – preserves the current LCSim (SLIC) mcdrcal00 detector layout
Conclusion

- **ILCRoot VXD and Tracker hits timing study for 750+750 GeV Muon Collider MARS background** was done, the results illustrate that:
  - with layer by layer tuned timing the remaining background hit fraction can be as low as ~0.4% at 0.5 ns hit time resolution and 99.7% IP hit efficiency
  - corresponding hit maximum density is ~ 4 hits/cm² in the innermost layer of VXD barrel

- **Hit timings in ILCRoot and LCSim (SLIC) were compared first time for 750+750 GeV Muon Collider MARS background**
  - SLIC seems to produce more hits at large TOF
  - detailed study is needed to understand the reason

- **Toward Higgs Factory Muon Collider MDI** – suggestions are:
  - include new 7.60° nozzle into existing mcdrcal00 detector geometry and simulate in SLIC the hits from coming MARS background from 62.5+62.5 GeV Muon Collider
  - do the same (with new nozzle) in ILCRoot with existing SiD detector?
• The **ILCRoot** - software Infrastructure for Large Colliders based on **ROOT** and Alice’s **Aliroot** with add-ons for Muon Collider studies
  
  – “Recent developments on ILCroot”, V. Di Benedetto, May 18, 2011, Fermilab (indico.fnal.gov/getFile.py/access?contribId=1&resId=0&materialId=slides&confId=4455)
  
  
ILCroot: root Infrastructure for Large Colliders

- Software architecture based on root, VMC & Aliroot
  - All ROOT tools are available (I/O, graphics, PROOF, data structure, etc)
  - Extremely large community of users/developers
- Re-alignment with latest Aliroot version every 1-2
- It is a simulation framework and an Offline Systems:
  - Single framework, from generation to reconstruction and analysis!!
  - It naturally evolves into the offline systems of your experiment
  - Six MDC have proven robustness, reliability and portability
- It is Publicly available at FNAL on ILCSIM since 2006

The Virtual Montecarlo (VMC) Concept

- Virtual MC provides a virtual interface to Monte Carlo
- It allows to run the same user application with all supported Montecarlo’s
- The real Monte Carlo (Geant3, Geant4, Fluka) is selected and loaded at run time
MARS + ILCroot (Oct. 2009)
Dedicated ILCroot framework for MUX Physics and background studies
(in collaboration with N. Mokhov group)

- **The ingredients:**
  - Final Focus described in MARS & ILCroot
  - Detector description in ILCroot
  - MARS-to-ILCroot interface (Vito Di Benedetto)

- **How it works**
  - The interface (*ILCGenReaderMARS*) is a *TGenerator* in ILCroot
  - MARS output is used as a config file
  - *ILCGenReaderMARS* creates a STDHEP file with a list of particles entering the detector area at \( z = 7.5 \text{m} \)
  - MARS weights are used to generate the particle multiplicity for G4
  - Threshold cuts are specified in Config.C to limit the particle list fed to G4
  - Geant4 takes over at 7.5m
  - Events are finally passed through the usual simulation (G4)-> digitization-> reconstruction
• MARS background particle tracks near the detector, 750+750 GeV Muon Collider
A stacked layer design to reduce random neutral background occupancy based on inter-layer correlations

- Suggested by S. Geer for the muon collider in 1996
- A single layer replaced with two layers being 1-2 mm apart
- Soft MeV tracks from background hit in one layer do not reach the second layer (B=4T)
- IP physics charged track makes hits in both layers
- Readout takes AND of appropriate pixel pairs in both layers suppressing background hits
ILCRoot VXD and Tracker hits timing study

- **MARS background hits rejection per layer vs. hit time resolution**
ILCRoot VXD and Tracker hits timing study

- IP muons defined time gate widths per layer vs. hit time resolution

![Graphs showing time gate widths for different time resolutions (σ = 0.2 ns, 0.5 ns, 1 ns) for VXD and Tracker hits across different layers.](image-url)
ILCRoot VXD and Tracker hits timing study

- **MARS background hits occupancy density per layer vs. hit time resolution**