Outline

- Background Sources
- Earlier Results
- New Wave
- Loads in IR and Detector
- R&D on Machine-Detector Interface
The high physics potential of a Muon Collider (MC) is reached only if a high luminosity of $\mu^+\mu^-$ collisions in the TeV range is achieved ($\sim 10^{34}$ cm$^{-2}$ s$^{-1}$). The overall detector performance in this domain is strongly dependent on the background particle rates in various sub-detectors. The deleterious effects of the background and radiation environment produced by muon decays is one of the fundamental issues in the feasibility study of MC ring, Interaction Region (IR) and detector.
Sources of Background at Muon Colliders

1. **IP $\mu^+\mu^-$ collisions**: Production x-section 1.34 pb at $\sqrt{S} = 1.5$ TeV (negligible compared to #3).

2. **IP incoherent $e^+e^-$ pair production**: x-section 10 mb which gives rise to background of $3 \times 10^4$ electron pairs per bunch crossing (manageable with the nozzle, TBC)

3. **Muon beam decays**: Unavoidable bilateral detector irradiation by particle fluxes from beamline components and accelerator tunnel - **major source at MC**: For 0.75-TeV muon beam of $2e12$, $4.3e5$ dec/m per bunch crossing, or $1.3e10$ dec/m/s for 2 beams.

4. **Beam halo**: Beam loss at limiting apertures; severe, but is taken care of by an appropriate collimation system far upstream of IP.
Suppressing Backgrounds: 1. Nozzle at IP

Very first calculations (~1995) have shown that expected particle fluxes and dose in MC detector components are well beyond known technological capabilities. First techniques: collimating nozzles at IP, detector magnetic field assisted.

Machine background reduction up to 500 times. Also can fully confine incoherent pairs if B > 3 T
~10 T dipoles in IR with tungsten masks in between: further substantial reduction in loads on central detectors; also help reduce Bethe-Heitler muon flux at large radii
Vertex Detector Hit Density (a layer of Silicon at a radius of 10 cm):

\[
\begin{array}{ccc}
750 \text{ photons/cm}^2 & \rightarrow & 2.3 \text{ hits/cm}^2 \\
110 \text{ neutrons/cm}^2 & \rightarrow & 0.1 \text{ hits/cm}^2 \\
1.3 \text{ charged tracks/cm}^2 & \rightarrow & 1.3 \text{ hits/cm}^2 \\
\text{TOTAL} & & 3.7 \text{ hits/cm}^2 \\
\end{array}
\]

\[\rightarrow 0.4\% \text{ occupancy in 300x300 } \mu\text{m}^2 \text{ pixels}\]

- **MARS** predictions for radiation dose at 10 cm for a 2x2 TeV Collider comparable to at LHC with \(L=10^{34} \text{ cm}^{-2}\text{s}^{-1}\)
  - Lifetime ~ several years

- At 5cm radius: 13.2 hits/cm\(^2\) → 1.3% occupancy

Need another factor of 6 for pattern recognition

OK
For TeV domain, extraction of muon beam halo with electrostatic deflector reduces loss rate in IR by three orders of magnitude.

Efficiency of an absorber-based system is much lower and can be used only if muon energy is < 50 GeV.
New Wave: 2009-2010

- Compact lattice: $C=2.5\ \text{km with } B=10\ \text{T}$
- Consistent IR design
- Realistic IR magnets
- Full MARS modeling of MDI
- Detector: fast and full simulators
### Muon Collider Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Value 1</th>
<th>Value 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E_{\text{cms}}$</td>
<td>TeV</td>
<td>1.5</td>
<td>4</td>
</tr>
<tr>
<td>$f_{\text{rep}}$</td>
<td>Hz</td>
<td>12</td>
<td>6</td>
</tr>
<tr>
<td>$n_b$</td>
<td></td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>$N$</td>
<td>$10^{12}$</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>$\varepsilon_{x,y}$</td>
<td>$\mu$m</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>$L$</td>
<td>$10^{34}$ cm$^{-2}$s$^{-1}$</td>
<td>1</td>
<td>4</td>
</tr>
</tbody>
</table>
8-T dipoles in IR to generate large D at sextupoles to compensate chromaticity and sweep decay products; momentum acceptance of 1.2%; momentum compaction factor of $-1.5 \times 10^{-5}$; dynamic aperture sufficient for transverse emittance of 50 $\mu$m; under engineering constraints.

Iterative studies on lattice and MDI with magnet experts:
High-gradient (field) large-aperture short Nb3Sn quads and dipoles.
Segment of the lattice $|S| < S_{\text{max}}$, where $S_{\text{max}} = 250$ m, implemented in MARS15 model with $\text{Nb}_3\text{Sn}$ quads and dipoles with masks in interconnect regions.

- Detailed magnet geometry, materials, magnetic fields maps, tunnel, soil outside and a simplified experimental hall plugged with a concrete wall.

- Detector model with $B_z = 3.5$ T and tungsten nozzle in a BCH$_2$ shell, starting at $\pm 6$ cm from IP with $R = 1$ cm at this $z$.

- 750-GeV bunches of $2 \times 10^{12}$ $\mu^-$ and $\mu^+$ approaching IP are forced to decay at $|S| < S_{\text{max}}$, where $S_{\text{max}} = 75$ to $250$ m at $4.28 \times 10^5$ per meter rate.

- Cutoff energies optimized for materials & particle types, varying from 2 GeV at $\geq 100$ m to 0.025 eV in the detector.
Detector Model and Source Term

Source term at black hole to feed detector simulation groups: INFN, CD, SiD

Sophisticated shielding: W, iron, concrete & BCH2
1. **Optimize and minimize it as much as possible** (20° to 10°) because of limitations on possible physics:
   - Top production in forward regions as CoM energy goes up
   - Asymmetries are more pronounced in forward regions
   - Z' => ttbar
   - Final states with many fermions (like ordinary SM tt events) are hardly ever contained in the central detector

2. **Instrument it:**
   - Forward calorimeter
   - Lumi-cal a'la ILC - 40-140 mrad for precise measurement of the integrated luminosity (ΔL/L ~ 10-3)
   - Beam-cal at smaller angles for beam diagnostics
Particle Tracks in IR
Number of particles per bunch crossing entering detector, starting from MARS source term for $S_{\text{max}} = 75m$

<table>
<thead>
<tr>
<th>Particle</th>
<th>Minimal “6-deg”</th>
<th>Optimal “10-deg”</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photon</td>
<td>1.5e11</td>
<td>1.8e8</td>
</tr>
<tr>
<td>Electron</td>
<td>1.4e9</td>
<td>1.2e6</td>
</tr>
<tr>
<td>Muon</td>
<td>1.2e4</td>
<td>3.0e3</td>
</tr>
<tr>
<td>Neutron</td>
<td>5.8e8</td>
<td>4.3e7</td>
</tr>
<tr>
<td>Charge hadr</td>
<td>1.1e6</td>
<td>2.4e4</td>
</tr>
</tbody>
</table>
Neutron and Photon Fluence

Fluence per bunch entering right-hand side of detector, starting from MARS source term for $S_{\text{max}} = 75$ m

Peak: $1/10 \times$ best 20-deg '96

Peak: $5 \times$ best 20-deg '96
Muon Fluence and Dose (vs LHC)

Fluence per bunch entering right-hand side of detector, starting from MARS source term for $S_{\text{max}} = 75$ m

Peak: $1/10 \times$ best 20-deg '96

Absorbed dose in Si for bilateral irradiation

Peak at $r=4$ cm:

**MC:** $0.1 \text{ MGy/yr}$

**CMS:** $0.2 \text{ MGy/yr} \times 10^{34}$
Energy Flux into Ecal and Hcal vs Rapidity

Total:

- $\gamma$ - 179 TeV
- n - 112 TeV
- $\mu$ - 31 TeV
- ch had - 3.4 TeV
- $e^+$ - 0.01 TeV
- sum - 326 TeV

Total:

- $\gamma$ - 2 TeV
- n - 36 TeV
- $\mu$ - 31 TeV
- ch had - 1.1 TeV
- $e^+$ - 0.02 TeV
- sum - 71 TeV

Energy flux on electromagnetic calorimeter

Energy flux on hadronic calorimeter
Energy Flux into Ecal and Hcal along Surface

**Energy flux on electromagnetic calorimeter**

- Total:
  - inner - 305 TeV
  - outer - 18 TeV
  - side - 3 TeV

**Energy flux on hadronic calorimeter**

- Total:
  - inner - 48 TeV
  - outer - 9 TeV
  - side - 14 TeV
Energy spectra in tracker (+-46x46x5cm)
Blue lines - from machine, red lines - Z0 events, green lines - Higgs events

Proton energy (GeV)

Neutron energy (GeV)

Pion energy (GeV)

Muon energy (GeV)

Gamma energy (GeV)

Electron energy (GeV)
Detector Simulation

- Using as a source term MARS files at MDI, fast parameterized Monte-Carlo to demonstrate that physics can be extracted in the presence of a fierce beam-related backgrounds, engaging the theoretical community.

- Calorimetry: use MARS energy flow, straightforward

- Tracker & vertex: occupancy & hit density, more challenging (statistical weight spread)

- Identify issues to optimize MDI and help set the focus for detector component research.

- 1 FTE of computing+scientist development effort for 3 years to built and use in MDI optimization a tool that incorporates an event generator and beam backgrounds to deliver parameterized detector response and analysis object.
Detector MC Development Flow Chart

- MARS Simulation
- Overlay Background Particles
- Truth Particles
- Resolution Geometry etc.
- Parameter File
- Detector Description
- Fast Detector Simulation
- Physics Objects
- ExRoot Analysis Tool
- Histograms Plots etc.

Parameter File
Physics Benchmark
Physics Event Generator
Detector Simulation Plan for 2011-2013

• Complete a fast Monte Carlo for physics simulations.

• Develop an initial physics and detector report by the end of 2011. Allows input to the design parameters of the MAP study:
  
  ➢ This study should set requirements on luminosity, energy, acceptable background event rates and suggest feasible methods of attaining these levels.

  ➢ Evaluate the impact of the polarized beams, energy spread, and detector fiducial volume.

  ➢ Compare physics opportunities to CLIC and take account of the substantial running of LHC after luminosity upgrade.

  ➢ Possible synergy with the ILC/CLIC and LHC detector R&D.

• Using existing framework (ILCRoot, SiD) do detailed simulations to identify further needs for detector development.
1. Thorough optimization of the nozzle and shielding at the machine-detector interface, for both 1.5 and 4 TeV, balancing advantages of a smaller nozzle angle vs effects of the greater background if it has a smaller angle, not sacrificing physics; consider its instrumentation (Lumical etc.). Optimization also includes the nozzle efficiency to confine incoherent pairs with the detector 3.5-T field.

2. Model detector response to physics signal in presence of IP and machine backgrounds. To first order, the backgrounds will drive critical parameters of the MC detector design, not the physics.

3. Design and optimization of the masks in the IR magnet interconnect regions and liners inside the magnets to mitigate effect of 0.5-1 kW/m loss rate on detector backgrounds and magnet performance (dynamic heat load, quench stability and lifetime).

4. Iterate with lattice and magnet designers to improve IR and MDI system performance.
MDI Design & Simulation Tasks to Complete Design & Feasibility Study

1. Design & optimization of detector shielding (50 pm)
2. Background simulations for 1.5 & 4 TeV com (45 pm)
3. Detector performance via fast Monte-Carlo (24 pm)
4. Radiation & heat load calculations (30 pm)
5. Beam halo collimation (12 pm)
6. Auxilary systems (12 pm)
7. Launch full detector simulations, ILCRoot & SiD (12 pm)

Related: IR lattice (20 pm) and IR Magnets (30 pm)

Efforts in person-months (pm)