Study of physics performances at Muon Collider

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1. Why Muon Collider?
No conclusive signs of New Physics at LHC so far: new accelerator needed after 2040

Conceptually different approaches: directly (produce BSM particles) vs. indirectly (observe deviations from SM)

- **direct** produce BSM particles: high collision energy → hadron collider (pp)
- **indirect** observe deviations from SM: high precision → lepton collider (e+e-)

- High collision energy + high precision in a single machine: Muon Collider (μμ-)
- μμ- at \( s = 14 \) TeV equivalent to pp at \( \sqrt{s} = 100 \) TeV

2. Challenges at a Muon Collider
Muon lifetime very short: \( 2 \times 10^{-6} \) s → acceleration must be fast

At \( \sqrt{s} = 1.5 \) TeV with \( 2 \times 10^{32} \) μb/s bunch expecting 4.1 \( \times 10^9 \) decays/m

- Additional heat load and radiation damage to magnets (need protection)
- Environmental radiation hazard from the high flux of neutrons
- Secondary particles arriving to the detector (needs very detailed studies)
- Impact depends on the accelerator layout and detector technologies

All kinds of secondary particles produced due to the muon decays:

\[ \mu \rightarrow \gamma \rightarrow e/\mu/\gamma \]

3. Beam-induced background

Machine-detector interface (MDI) plays a crucial role in reducing the rate of secondary particles reaching the detector

Studied using a dedicated simulation tool developed within the Muon Accelerator Program (MAP)

- Interaction of muon decay products with the accelerator lattice in the region of \( \pm 200 \) m from the interaction point simulated with MARS15
- Further interaction with the detector and MDI simulated with GEANT4

MDI implemented as two cone-shaped tungsten nozzles cladded with borated polyethylene (5 cm) (shape optimised for a specific collision energy)

Flux of secondary particles reduced by up to 3 orders of magnitude

Surviving particles have low momenta \( p_T > 17 \text{ GeV} \)

4. Detector simulation

Detector model inherited from MAP for detailed performance studies in the presence of the beam-induced background

Featuring precise geometry, magnetic field map, digitization, resolution + noise effects implemented in the ILRoot software package

5. Detector performance [at \( \sqrt{s} = 1.5 \) TeV]

Particles from the beam decays have different timing wrt muons from the interaction point (IP)

Precise timing information crucial for track reconstruction

Strong reduction of tracker occupancy with precise timing in the tracking detectors

Timing information at ns level needed in calorimeter

6. Jet reconstruction [at \( \sqrt{s} = 1.5 \) TeV]

Reconstructing jets from calorimeter clusters with a simple cone algorithm \( R = 0.5 \)

Beam induced background + \( \mu^+\mu^- \rightarrow H \rightarrow bb^n \)

7. Summary

- **Muon Collider** is a very attractive candidate for a future machine after the LHC
  - Combines advantages of \( hh \) and \( e^+e^- \) colliders in a single machine
- Beam induced background poses a serious challenge
  - Needs careful consideration in both the accelerator and detector design
- First performance estimation at \( \sqrt{s} = 1.5 \) TeV done using the MAP framework and precise background simulations with MARS15
- Precision measurements at a Muon Collider are possible: arXiv:1905.03725
- Timing information crucial in a future detector: tracker and calorimeter
- Several key improvements needed for further studies:
  - Improved software framework for detector simulation
  - Better detector design with modern technologies: position/energy/time resolution
  - Dedicated reconstruction algorithms and analysis techniques