Prospects for the Measurement of the Standard Model Higgs Production at the Muon Colliders

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The Muon Collider

To probe new physics, we need to go higher in energy and precision. Muon Collider offers:

- Higher energy potential than ee collider
- Cleaner final state than pp collider
- Precision measurements
- Improved understanding of Higgs potential via self-coupling

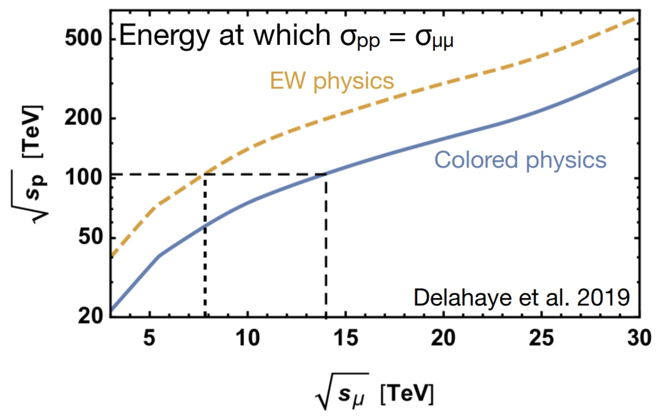
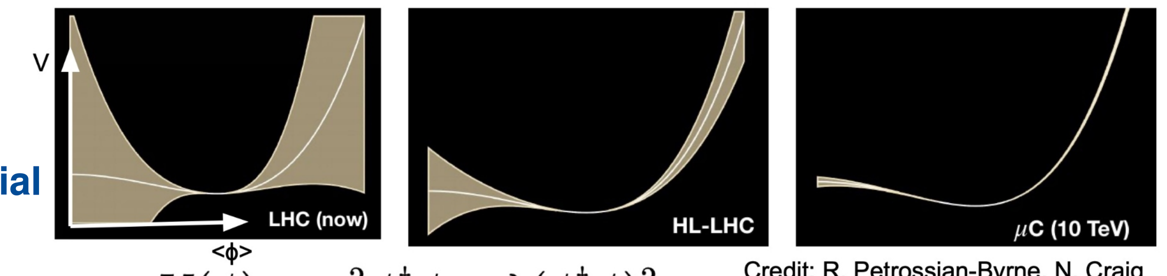


Figure 1: Physics reach of muon collider at 14TeV ~ pp collider at 100 TeV



$$V(\phi) = \mu^2 \phi^\dagger \phi + \lambda(\phi^\dagger \phi)^2$$

Credit: R. Petrossian-Byrne, N. Craig

Figure 2: Muon Collider can probe Higgs potential to higher precision

Beam Induced Background (BIB)

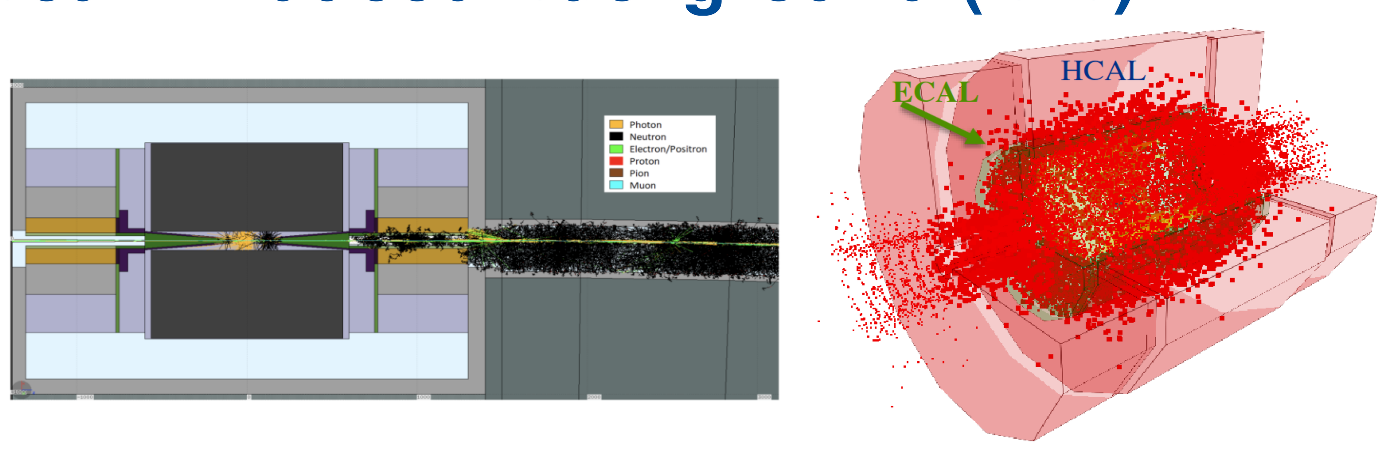


Figure 3: The left image shows tracks of secondary particles for a few μ− decays arriving from the right (IMCC:2203.07964). The right image shows decay products reaching calorimeter detector and leaving overwhelming number of hits.

One of the major challenges to the detector performance is the Beam-Incuded Background (BIB) originating from muon decays along the beam pipe. Secondary and tertiary decay products interact with the accelerator and machine detector interface and reach the detector components making the reconstruction of μ+μ- event extremely difficult. Large computing resources are needed to simulate and reconstruct these particles. Detailed simulations are studied in the next section taking into account the BIB effects in the Calorimeters.

Full Simulation and Jets Performance

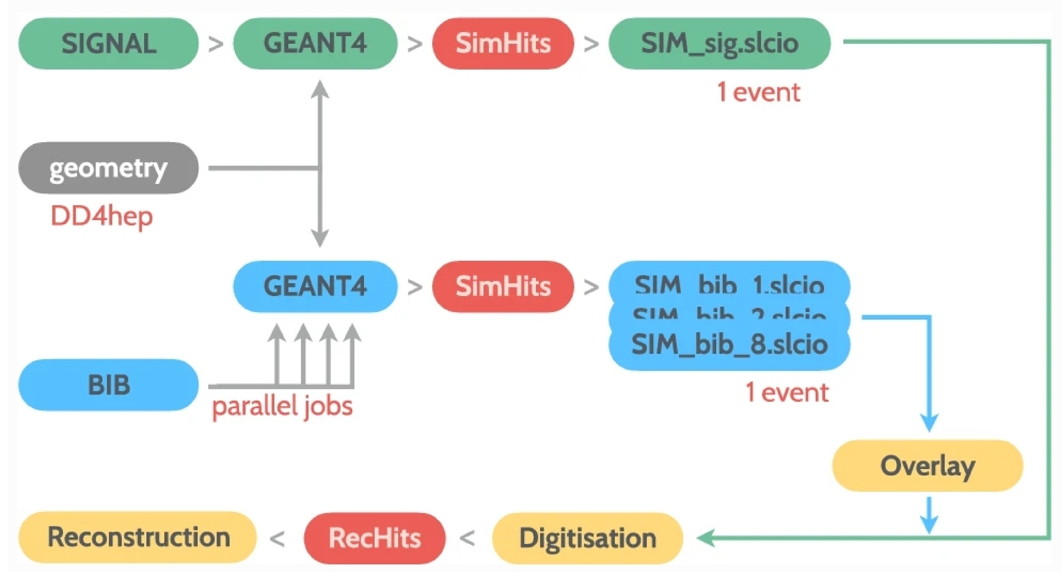


Figure 4: Event Simulation Process in Software Framework

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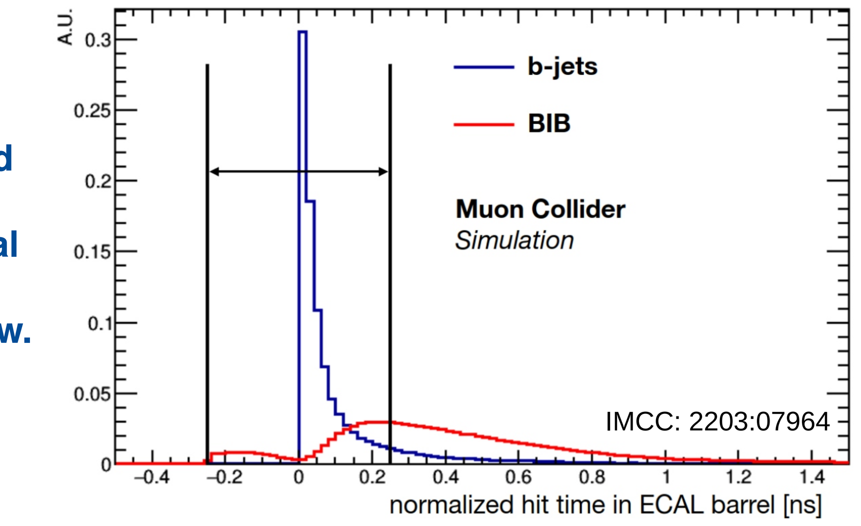

Figure 5: Key discriminating feature of BIB hits is the delayed arrival time with respect to the bunch crossing making it crucial for BIB suppression. We select hits within ± 0.25 ns time window.

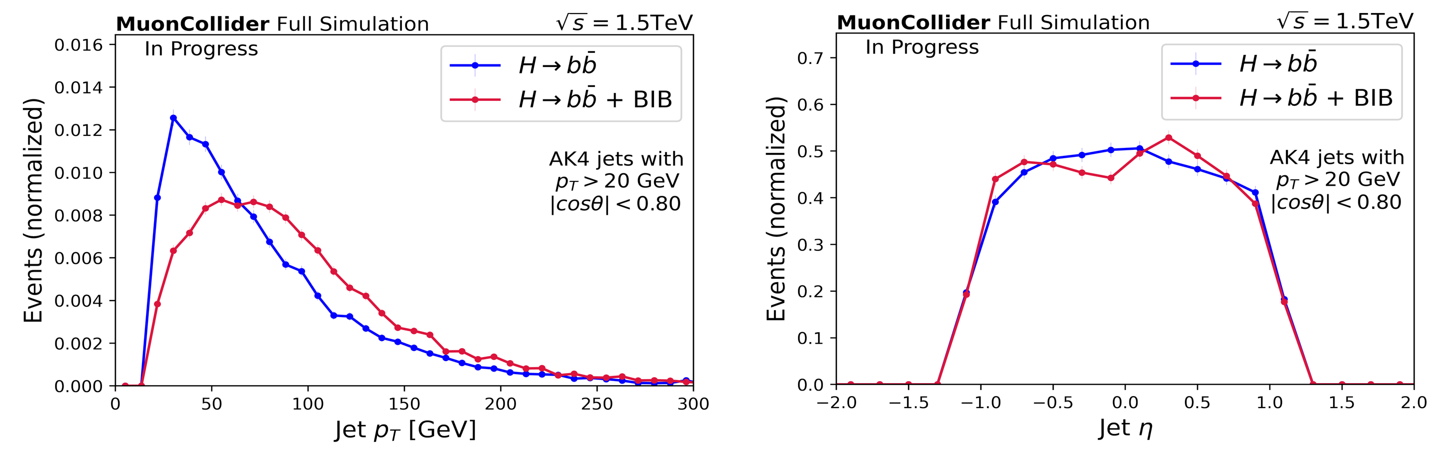

Figure 6: Jet p_T (left) and η (right) with (red) and without (blue) BIB presence. The overlay of BIB hits result in reconstructed jets with higher p_T and forward η.

With further jet cleaning and BIB mitigation strategy using jet substructure, the reconstruction performance can be improved.

Di-Higgs Signal Significance Study

Assuming a perfect mitigation strategy for the BIB effect at the Muon Colliders, this study also estimates the expected significance of measuring the SM di-Higgs production in three final states of di-Higgs decay: $HH \to bbbb$, $HH \to bb\gamma\gamma$, and $HH \to bb\tau+\tau-$.

Reference:

[1] arXiv: 2203.07964 [hep-ex]

[2] doi: 10.1007/jhep07(2014)079.

[3] doi: 10.1007/JHEP02(2014)057

Event Generation and Detector Simulation

- Use energy/luminosity benchmarks proposed by the Snowmass Muon Collider Forum.
- Generate 100k events for each channel at each detector setting using MadGraph, shower with Pythia. Using Delphes for the detector response with Muon Collider card, with b-tagging and τ-tagging for anti-k_T jets.

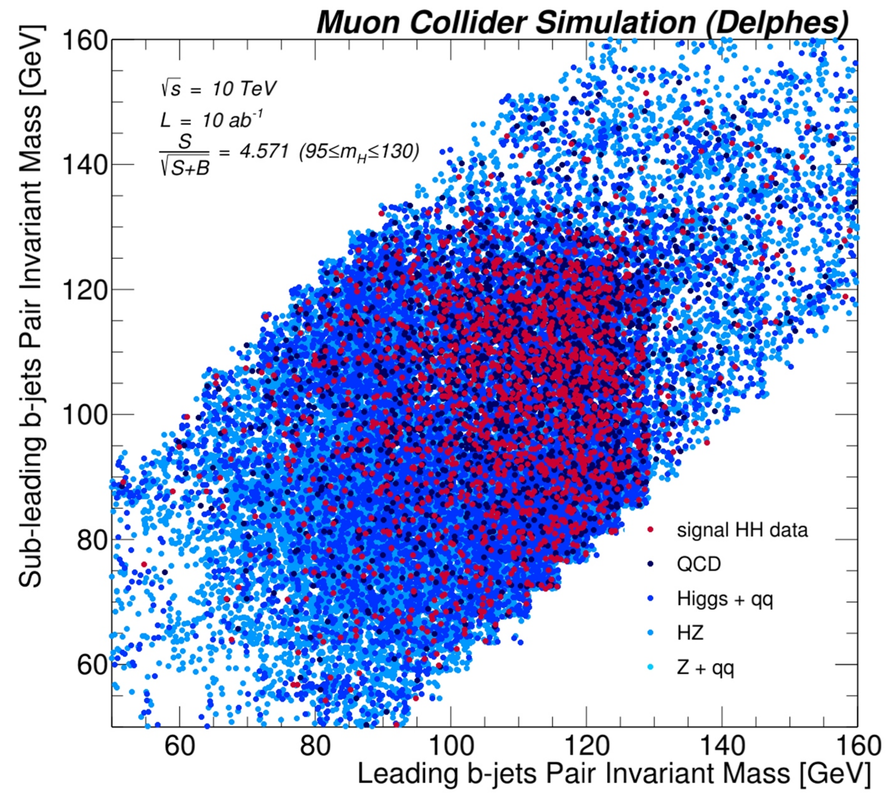

Figure 7: 4 channel event distribution of both signal and backgrounds channels in Leading and Sub-leading b-Jet Pairs Invariant Mass Plane for $\sqrt{s}$ = 10 TeV data.

Final states / $\sqrt{s}$ ($\int d\mathcal{L}$)	3 TeV (1 ab^{-1})	6 TeV (4 ab^{-1})	10 TeV (10 ab^{-1})	30 TeV (10 ab^{-1})
$b\bar{b}b\bar{b}$	1.176	2.812	4.571	5.690
$b\bar{b}\gamma\gamma$	0.389	0.922	1.392	1.823
$b\bar{b}\tau_{had}\tau_{had}$	0.902	2.604	4.029	4.803
$b\bar{b}\tau_{lep}\tau_{had}$	0.989	2.856	4.340	5.040
Combined	1.728	4.597	7.166	8.678

Table 1: Significance for the extraction of di-Higgs events combining all studied channels using various analysis techniques for muon colliders operating at various centers of mass and integrated luminosity.

The aggregated estimated signal significance values are presented for all four collider configurations in table above. The benchmark is projected to be attainable at a Muon Collider with a 10 TeV center-of-mass energy.

Conclusion

Improvements in BIB mitigation are necessary to provide the desired jet reconstruction performance to begin physics performance studies. This study estimates the expected significance of measuring the SM di-Higgs production at various benchmarks of collider center-of-mass energy and integrated luminosity in three final states of di-Higgs decay at the Muon Colliders.