Muon Collider simulations studies Advisors: Prof. Isobel Ojalvo, Pallabi Das Princeton University

Aditya Gandotra

June 17, 2021

Aditya Gandotra

Muon Collider simulations studies

June 17, 2021 1 / 14

Muon colliders have potential for very high energy collisions, in the multiple TeV range.

We aim to study feasibility of detecting four Higgs signals in a 3 TeV muon collider.

Signals:
$$\mu^+\mu^- \rightarrow \nu_\mu \bar{\nu_\mu} HH \qquad \mu^+\mu^- \rightarrow \mu^+\mu^- HH$$

 $\mu^+\mu^- \rightarrow ZHH \qquad \mu^+\mu^- \rightarrow H \rightarrow HH$

Backgrounds:

 $\mu^{+}\mu^{-} \rightarrow \nu_{\mu}\bar{\nu_{\mu}}bb\bar{b}\bar{b} \qquad \mu^{+}\mu^{-} \rightarrow \nu_{\mu}\bar{\nu_{\mu}}b\bar{b}H \qquad \mu^{+}\mu^{-} \rightarrow \nu_{\mu}\bar{\nu_{\mu}}b\bar{b}Z$

Generator level MC Samples

MADGRAPH5 was used to generate the MC level samples for the signals and backgrounds. Specific instructions on how to generate and store the output files is here:

https://github.com/agandotra611/MuC_Simulation_Workflow



Figure: For the $\mu^+\mu^- \rightarrow \nu_\mu \bar{\nu_\mu} HH$ signal, there were 8 possible Feynman diagrams that MADGRAPH generated.

Generator level validation plots

The Higgs pT, η,ϕ are plotted at the MC level for validation for $\approx 10^4$ events.



Figure: Generator level validation plots

Aditya Gandotra

Muon Collider simulations studies

Simulation workflow

- Generate MC samples using MADGRAPH5 (.hepmc format).
- 2 Use sim_steer.py with ddsim to simulate the MC samples and get simulation level plots (.slcio format).
- 3 Then we reconstruct these files using reco_steer.xml using Marlin to get reconstructed plots (.slcio format).
- Reconstructed files can be inputted into lctuple_steer.xml producing a root file with relevant variables.

The above files and how to run them are given in more detail in the git linked before.

Simulator level plots

The Higgs pT, η,ϕ are plotted at the simulator level for validation for $\approx 10^4$ events.



Figure: Simulator level validation plots

Details of steering files



Figure: The simulation and reconstruction steering files respectively

(日) (四) (日) (日) (日)

LCTuple Output

event	MC particles	Reco PF objects	reco jets	reco tracks	reco vtx	links to the MC truth	
%ktuple_example.cod	- b uucb	- 🔈 nec	- b 1	- De nitek	- Invt	(2mnrel	
B	- b mcori	hoon d	- max	- bot	- botv d	- 12mt	
- bevevt	- b mcpdg	- Ibicon	- moy	- btyp	- by vipri	- 12mt	
- b evrun	- b mogst		- jmoz	- bch2	- b vtpl	- 12mm	
evwpt	- b mosst	- ID ROOM	- imas	- bndf	- North All All All All All All All All All Al	- Izonrel	
- b evim	- b movtx		- jene	- bredx	- vtxxx	r2ct	
- b evsig	- b movty		- kha	- bede	- VINY	- 12ct	
- b evene	- movtz		- kov0	- buth	- vtzzz	- 12cw	
- b expoe	- mcepx		- jcov1	- bshn	- North	- A convert	
- b expop	- mcepy		- bov2	- tents	- Vorb		
- evnch	- mcepz		- bov3	- bits	- vicov		
- NORD	- momox		icov4	- trsip	- vtpar	b (21w	
	- momoy	- Тотох	- icov5	- bsth		- t2mrel	
	- memoz		- icov6	- bsh		- 121	
	- momas	- In Internet	b jcov7	- Insca		- 1211	
	- b moene	- In romas	- icov8	tertn 💰		- 12mm	
	- b mocha	- b roene	- jcov9	- tskoc			
	- b nctim	- b rocha	- b jevis	- b tsdze			
	- mospx	- In sontr	Prvis	- b tsphi			
	- mospy	- k rond	- Pyvis	- tsome			
	- mospz	- N KONP	Pzvis	- tszze			
	- moot0	- b rofer	- inom	- bitni			
	- moof1	- b rovts	- kost	- tscov			
	mcpa0	- b rovte		- topx			
	mcpa1	- b rocom	(Theta	- tspy			
	moda0	•	- Ph/s	- tspz			
	- moda1		- b jmis				
	- moda2		- b inmax		NP: The quicker	t way to doco	
	- mcda3		- Emiss		the variable names is to go		
	- b moda4		- Mmissq				
			Mmiss		directly to the	le source.	

A useful thing to do is to switch off MC Particles in the reco_steer.xml file, so you can save space by keeping only the reconstructed events

This is an example from <u>JetBranches.cc</u>

To understand what these variables represent, one should look at the .cc and header files in

https://github.com/iLCSoft/ LCTuple/blob/master/src/

// Write default jet parameters
_jmox[i] = jet->getMomentum()[0];
_jmoy[i] = jet->getMomentum()[1];
_jmoz[i] = jet->getMomentum()[2];
_jmas[i] = jet->getMass();
_jene[i] = jet->getEnergy();
_jcha[i] = jet->getCharge();
_jcov0[i] = jet->getCovMatrix()[0];
_jcov1[i] = jet->getCovMatrix()[1];
_jcov2[i] = jet->getCovMatrix()[2];
_jcov3[i] = jet->getCovMatrix()[3];
_jcov4[i] = jet->getCovMatrix()[4];
_jcov5[i] = jet->getCovMatrix()[5];
_jcov6[i] = jet->getCovMatrix()[6];
_jcov7[i] = jet->getCovMatrix()[7];
_jcov8[i] = jet->getCovMatrix()[8];
icov9[i] = iet_pagetCovMatrix()[9]

Aditya Gandotra

June 17, 2021 8 / 14

Reconstructed invariant mass distributions

After reconstruction, we get the jet momenta and energies, which can be used to calculate the invariant mass $m = \sqrt{E^2 - p^2}$. We define m1 and m2 are the invariant masses of the highest and lowest jet pT pairs. We stack the signals on the background normalised by cross section.



Figure: Invariant mass distributions

Optimising $S/\sqrt{S+B}$ ratio

We aim to improve the signal-background ratio by making some cuts on the jet pT and m1. The most effective ones we found were m1 > 100 and pT > 20. After the cuts we get the plots below.



Figure: Invariant mass plots with m1 > 100 and pT > 20

Aditya Gandotra

Kinematic fitter

The kinematic fit uses the reconstructed variables and imposes a mass constraint on the jets, i.e. that we need two diHiggs jets. It minimizes the χ^2 and calculates the probability of goodness of fit per event, $P_{gof} = e^{-\chi^2/2}$.

Considered three permutations for jet combinations and picked events with lowest χ^2 value.

-> Number of measured Particles :	
-> Number of unmeasured particles:	: 0
-> Number of constraints :	
-> Number of degrees of freedom :	
-> Number of parameters A :	: 0
-> Number of parameters B :	: 12
-> Maximum number of iterations :	: 30
-> Maximum deltaS :	0.01
-> Maximum F :	0.1
************************************	**********
-> Status :	: 0
-> Number of iterations :	
-> S ::	35.7374
-> F ::	0.00126087

Figure: Output of the kinematic fit on an event

$|P_{gof}|$ and χ^2

From the plots, it seems ideal cuts would be $P_{gof} > 0$ and S < 20.



Figure: P_{gof} and χ^2 plots

m1, m2 after kinematic fit cuts

Performing the kinematic fit while calculating the invariant mass to pick the jet combination with lowest χ^2 , yields corrected m1, m2 plots.



Figure: m1, m2 plotted using kinematic fit to pick best combinations



Source of peaks needs to be diagnosed from the ntuples.



Figure: m1, m2 plotted using kinematic fit to pick best combinations with $\chi^2 < 20 \ {\rm cut}$