HH Muon Collider Effort

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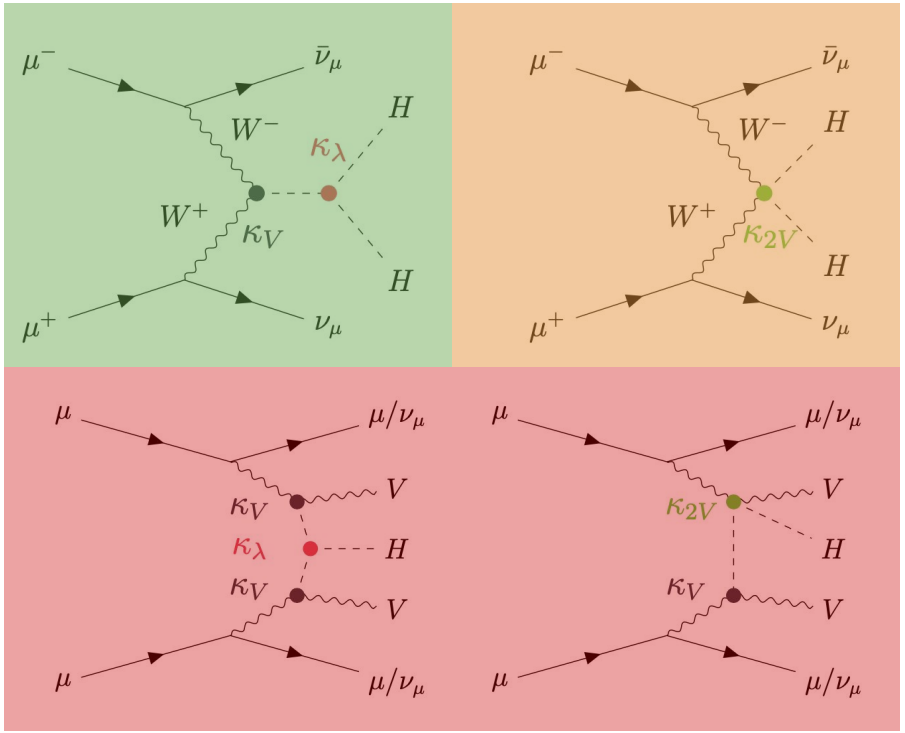
Our mission

- We want to produce **projections** for κ_λ and possibly, κ_{2V}
  - For 3 benchmarks 3 TeV, 10 TeV and 30 TeV
- To do this, we target **HH** processes for a **variety of final states**
- In order to improve our projections, we **may wish to combine** different final states
- To leave this option open, we should ensure the different final states have **common object definitions** and have orthogonal selections
- We are operating under a **tight timeline**, and so we must be **pragmatic** with what we can achieve

What are people's thoughts on HHarmonising?

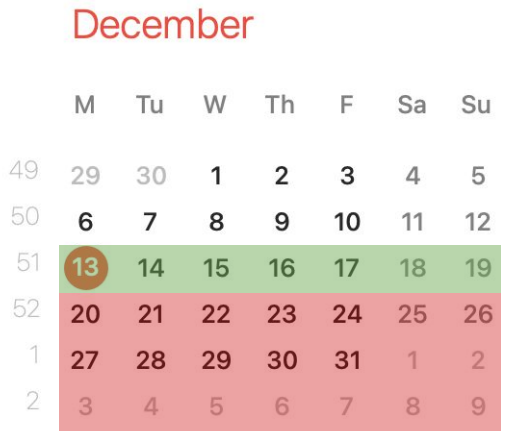


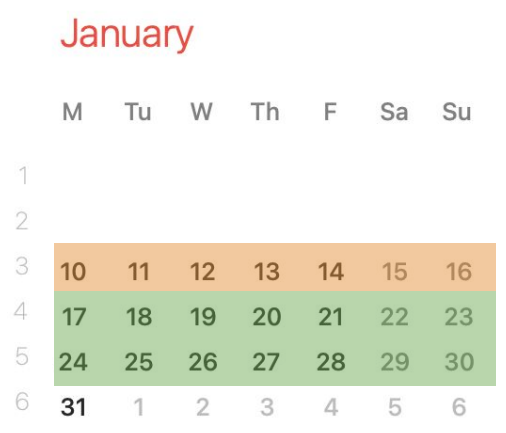
Higgs Self coupling diagrams

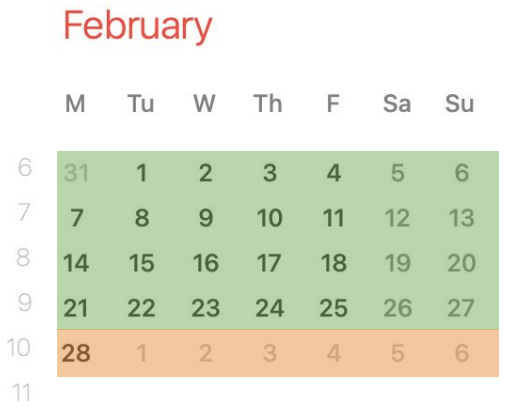
Our timeline

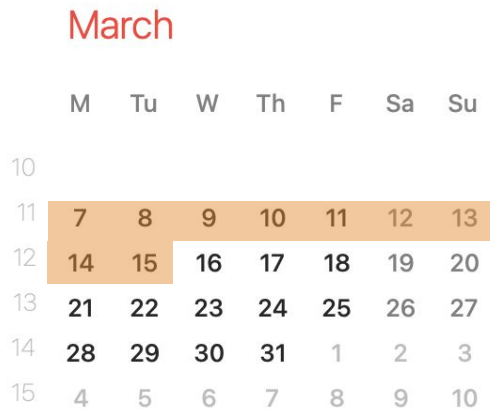
- The deadline for Snowmass whitepaper submission is “no later than 15th March”
  - **13 weeks from now**
- “Holiday period” starting from next week
- Working weeks: 9-10
- To reach deadline we will need analysis finished 2 weeks before hand : **Leaves 7 weeks or so**

Is there anything we are failing to consider?





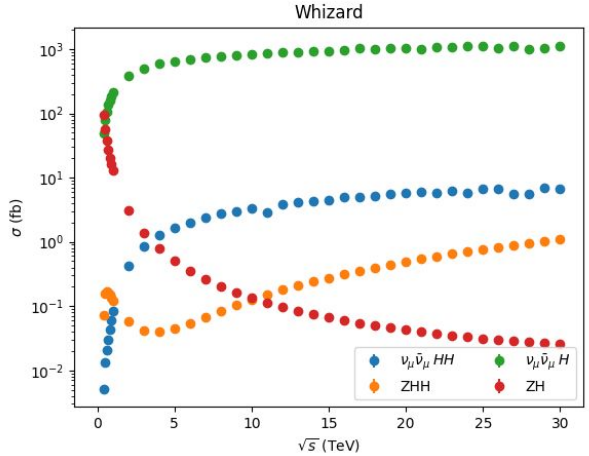


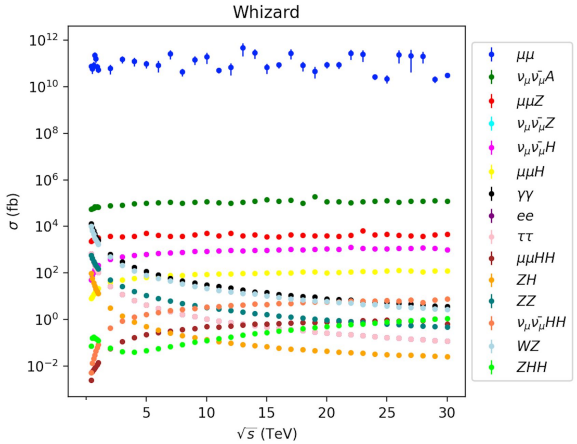


Our Samples

- Whizard and Madgraph are the standard MC generators for this work
- We have a complete Whizard workflow operational
  - Whizard->Pythia->Delphes
  - Can be found here
- Whizard uses a syntax very similar to madgraph in what are called “sindarin cards”
- Discussing with theorists on the ZHH curve
- Can offer assistance if desired

Do common MC samples exist?

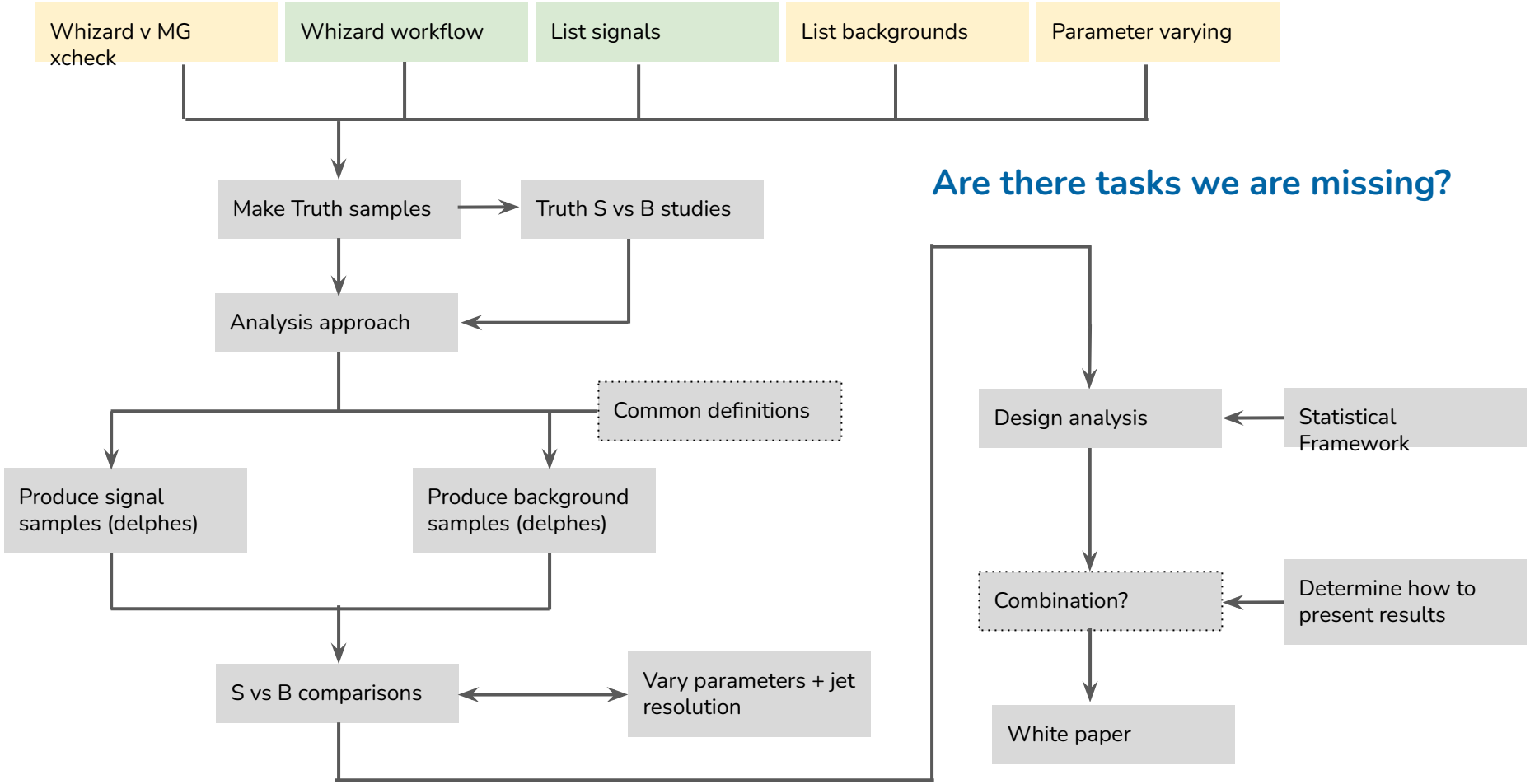




Signals and many production processes

Our Tasks

Legend	Complete	In progress	To be done



Concluding Remarks

Open questions:

- What are people's thoughts on HHarmonising definitions
  - Possible 4b and 2b+XX combination
- Analysis designs?
  - Cut and count (maybe a bit vanilla / not powerful)
  - Orthogonal BDTs - design for combination, then optimal signal separation
  - Neural Network approach
  - How do we present the results (statistical significance, upper limits on kappa_lambda)?
- Are there things we are not considering?
- How should we go about producing samples?
  - If a simple setup is provided, could this task be split?
- Any useful resources people want to recommend or general comments, please let us know

Resources

- Working Google doc
- Whizard code: https://github.com/MarcoValente/whizard-pythia-delphes/tree/master
- Delphes card location: https://muoncollider.web.cern.ch/node/14
- CLIC paper:
  - https://arxiv.org/pdf/1901.05897.pdf
- Vector Boson Fusion at multi-TeV muon colliders:
  - https://arxiv.org/pdf/2005.10289.pdf
- Electroweak Couplings of the Higgs Boson at a Multi-TeV Muon Collider:
  - https://arxiv.org/pdf/2008.12204.pdf

That’s all for today

Additional Material

Muon Collider Forum talk:

DiHiggs with Hadronic Final States

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Measuring the Higgs Self-coupling

We understand very well what is required to measure the Self-coupling of the Higgs

1. **Low signal rate**
   - Require High Branching Ratio - good reco and good b-tagging
2. **Dominant production mode is VBF w/ neutrinos**
   - Good MET reconstruction
3. **Cross sections are low, but scale with E - especially WWHH couplings**
   - High COM energies

For the most part 3) is fixed with benchmarks, and 2) is a feature muon colliders.

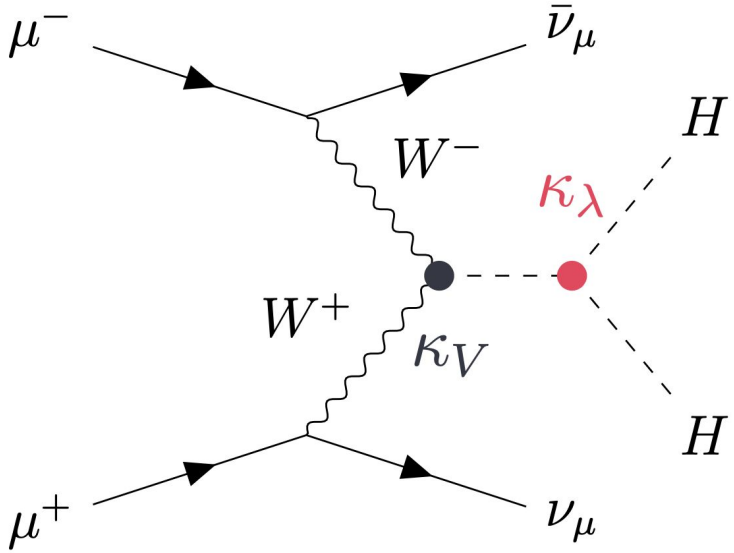

Fig. The dominant production pathway

Branching Ratios

The order of most dominant decay processes are:

- $HH \to bbbb$ at about 33%
- $HH \to bbWW$ at about **25%**,
  - Hadronically **50%**
  - Semi-leptonically **40%**
  - Leptonically **10%**
- $HH \to bbgg$ at about 9.8%
- $HH \to bb\tau\tau$ at about 7.2%
  - Hadronically 65%
  - Other 35%
- Given the low signal rates, this very clearly lays out the processes we should be targeting
- This doesn't highlight the differences in backgrounds, but at a lepton collider these may be manageable

$HH \to$	bb	WW	gg	$\tau\tau$
bb	33%	25%	9.8%	7.2%
WW		4.7%	3.7%	2.7%
gg			0.7%	1.1%
$\tau\tau$				0.4%

Fig. Branching Ratios for Dihiggs decay processes

DiHiggs with Hadronic Final States

- Naturally, all final states are of interest, but given short timescales it makes sense to focus on high BR final states: acceptance drives sensitivity
- If ***bbbb*** requires extra personpower, we can contribute there; that withstanding;
- Both hadronic ***bbWW*** and ***bbgg*** can offer significant contributions to the self-coupling sensitivity studies
- We propose we provide projections for self-coupling sensitivities using these hadronic final states
  - Primarily focusing on bbWW
  - Secondarily, the ***bbgg*** final state
- Naturally, there will be overlap between all channels, so effective communication will save everyone time

HH→	**BR(HH->X)**
bbbb	33
Hadronic ***bbWW***	12.5
Semileptonic ***bbWW***	10
bbgg	9.8
Hadronic ***bbττ***	4.9
other ***bbττ***	2.6
Leptonic ***bbWW***	2.5

Useful reading