Measurement of the trilinear Higgs self-coupling at CLIC

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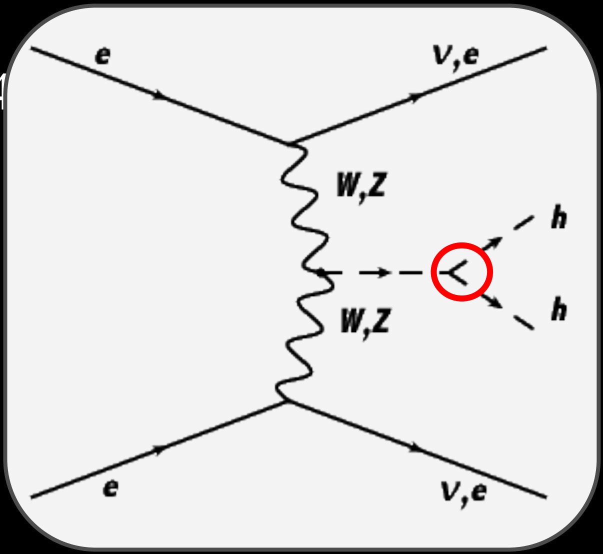
Introduction

$V(\eta_H) = \frac{1}{2} m_H^2 \eta_H^2 + \lambda v \eta_H^3 + \frac{1}{4} \lambda' \eta_H^4$

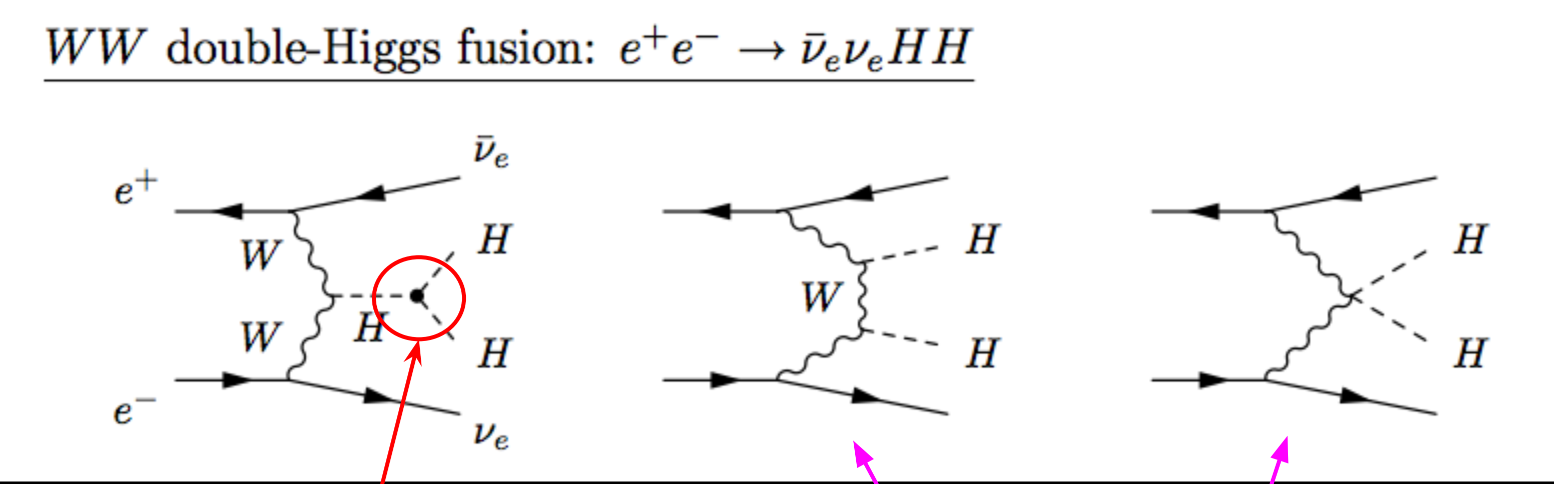


In the Standard Model:
$\lambda = \lambda' = \lambda_{SM} = m_H^2/2v^2$

Radiative corrections decrease this by ~10%
Can be increased by 100% in 2HDM

We want to measure the rate of double Higgs production and relate it to λ_{hhh}

Double Higgs Production channels



That's the one we are interested in

Signal modes that don't contribute to the measurement

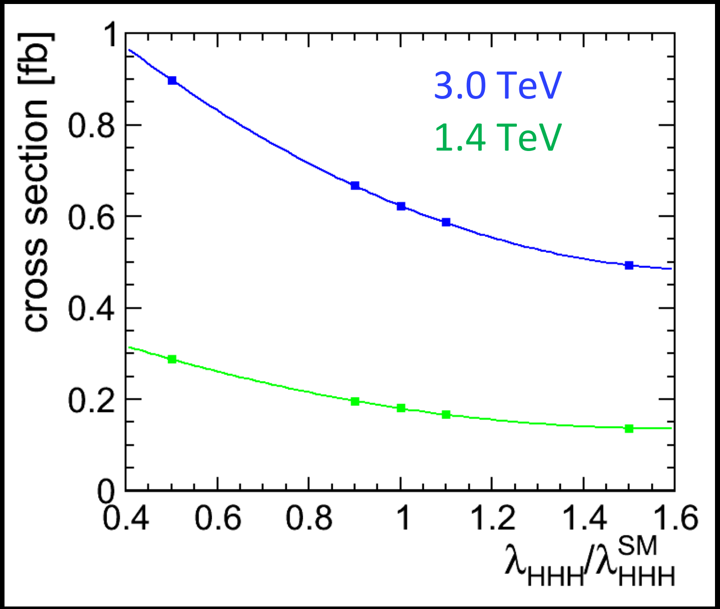
There is destructive interference between the diagrams.
The greater the value of λ_{hhh} the smaller the rate of producing two Higgs bosons.

Measuring the tri-linear self-coupling

Relating the measured uncertainty on the cross section to lambda

1. Change the value of λ in the event generator (whizard1)
2. Compute cross section taking into account the full CLIC beam spectrum and ISR
3. Fit with parabola. Derivative at $\lambda=\lambda_{SM}$ is the factor R in the relationship $\Delta\lambda = R\,\Delta\sigma$

⇒ The uncertainty on λ is larger by 20% - 54%

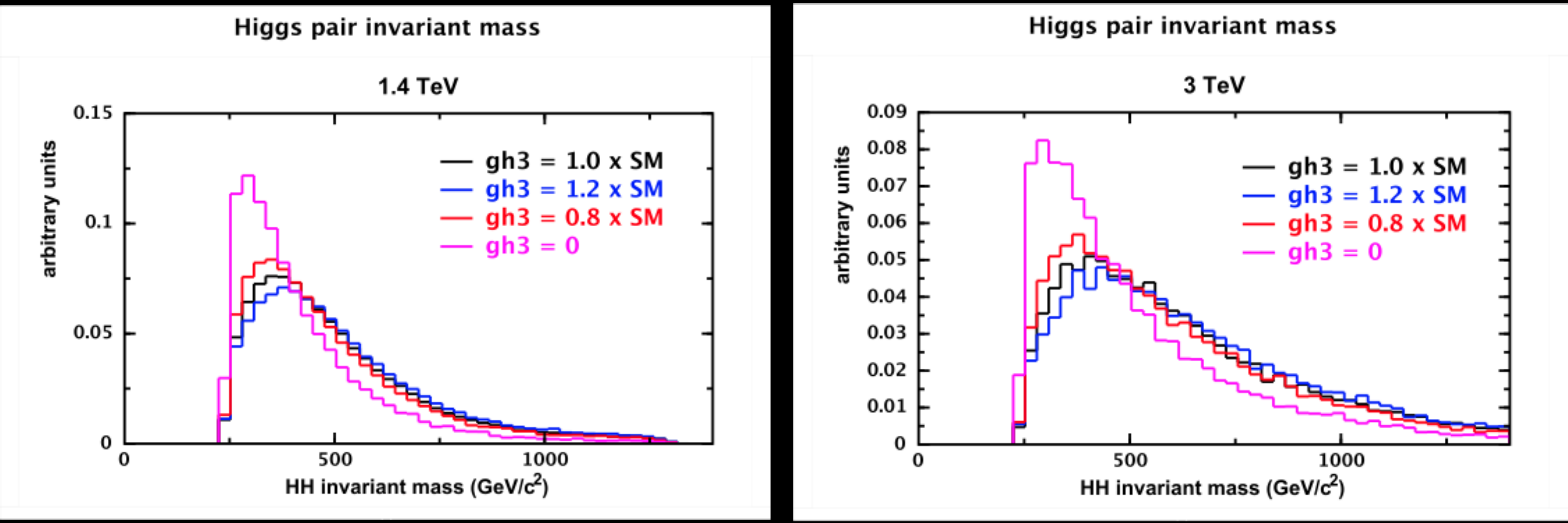


"Uncertainty factor"

3.0 TeV 1.54

1.4 TeV: 1.20

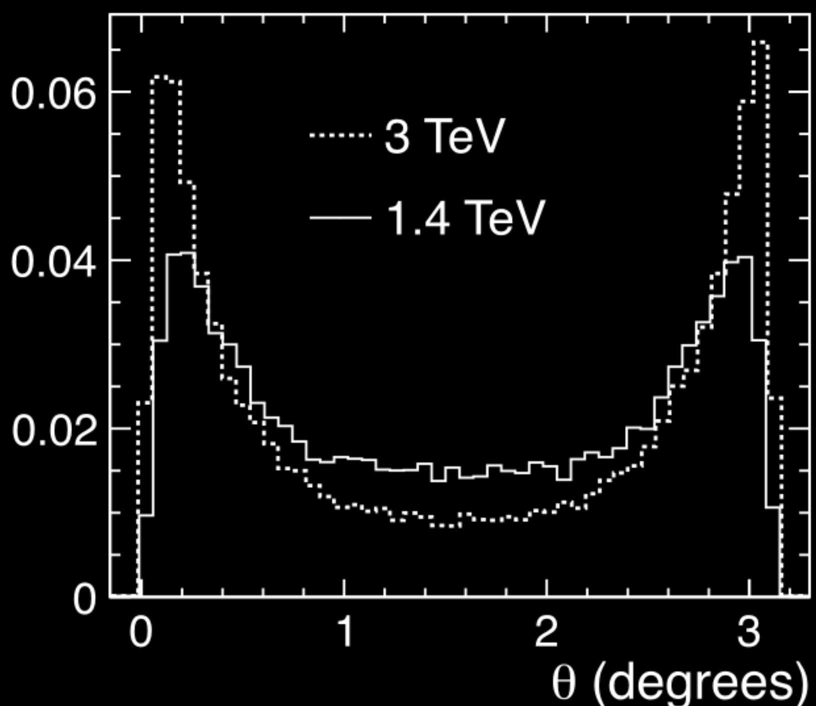
Measuring the tri-linear self coupling differently



The shape of the invariant mass of the Higgs pair changes with the value of the self-coupling. A neural network selection is sensitive to this change

Signal event properties

Higgs Boson polar angle



SM Higgs Boson Branching Ratios

Higgs Decay	m_H = 120 GeV	m_H = 126 GeV
$H \rightarrow bb$	65%	56%
$H \rightarrow WW$	14%	23%
$H \rightarrow \tau\,\tau$	7.0%	6.1%
$H \rightarrow cc$	3.3%	2.8%
$H \rightarrow ZZ$	1.6%	2.9%

Event Samples

Channel	$\sqrt{s}$ = 1.4 TeV cross section (fb) Target 1.5 ab^{-1}	$\sqrt{s}$ = 3.0 TeV cross section (fb) Target 2.0 ab^{-1}
2 Higgs + missing energy	0.16	0.63
4 jets + missing energy	24.7	74.1
4 jets + 2 leptons	71.7	182
4 jets + 1 lepton	115	
4 jets	1325	593
2 jets		3076
2 jets + missing energy	646	1305
2 jets + 2 leptons		3341
2 jets + 1 lepton		5255

The CLIC_SID detector

<u>Features:</u>

All-silicon tracker:

    5 layers VTX

    (inner layer 27 mm from IP)

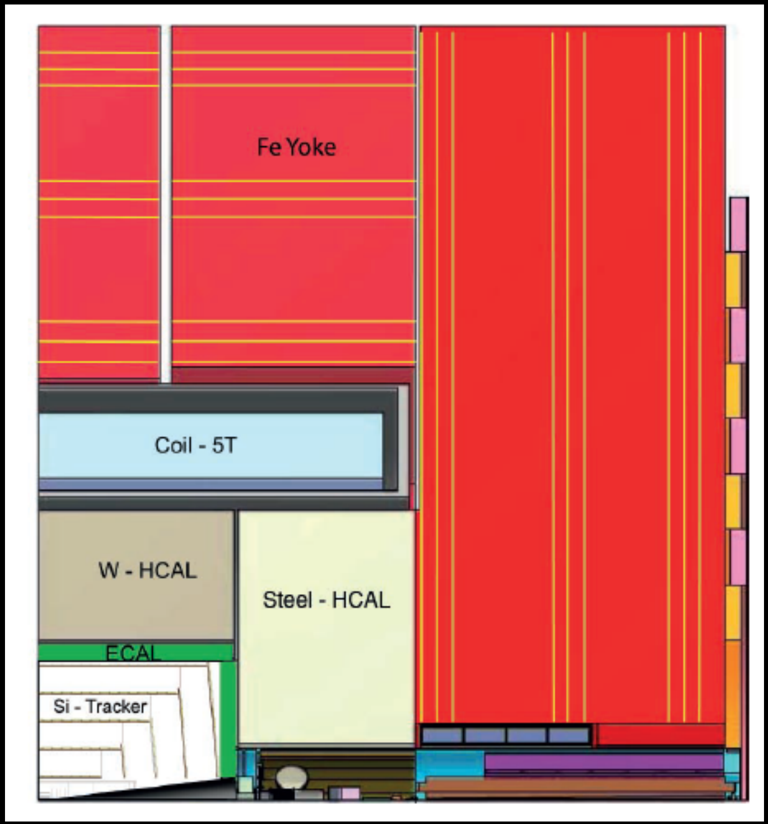
    5 layers strip tracker

(20+10) layers Si-W ECAL

7.5 λ W-HCAL barrel

5 T field

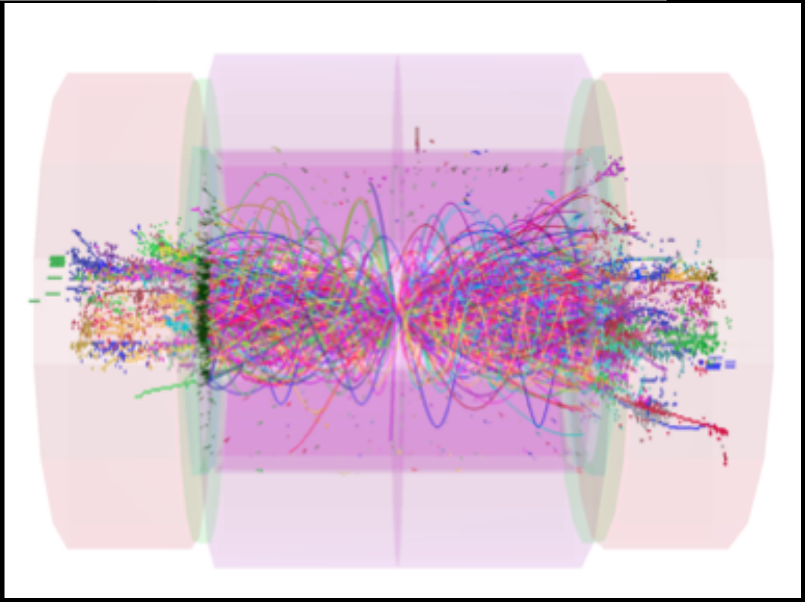
Tracking down to 10°



The CLIC environment

Collision energy	1.4 TeV	3.0 TeV
Bunch spacing	0.5 ns	0.5 ns
Bunches / Train	312	312
Bunch repetition rate	50 Hz	50 Hz
$\gamma\gamma \rightarrow$ hadrons per BX	1.3	3.2

Events pile up in the detectors
19 TeV / BX deposited in the calorimeters at $\sqrt{s}$ = 3.0 TeV



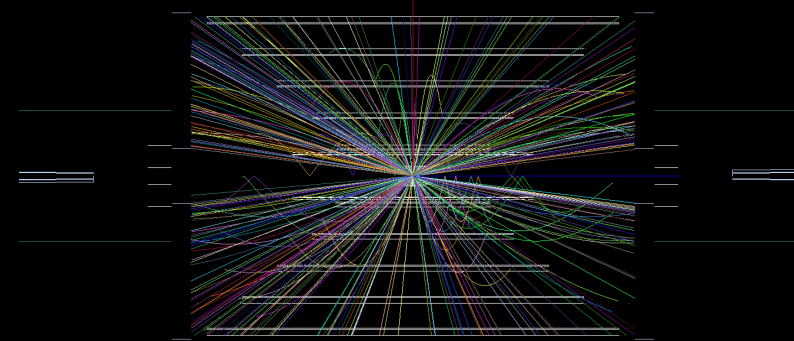
Treatment of Background

Gained experience with background during CDR analyses

Three ingredients:

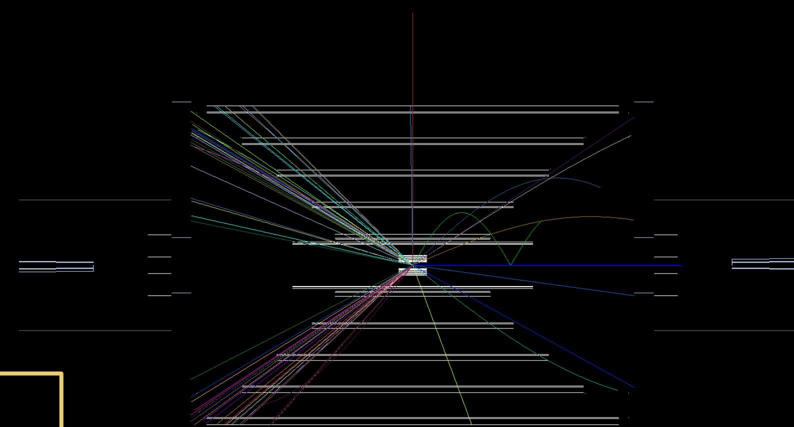
1. Identify physics event in the bunch train offline, discard hits outside of 10ns window (100 ns in the HCAL barrel)
2. Aggressive time stamping in the subdetectors (~ few ns) allows to match cluster- and track time
3. Jet reconstruction used in hadron colliders to collect remaining background in beam jets

HH$\nu\nu$ at 1.4 TeV



The second technique reduce this

to this



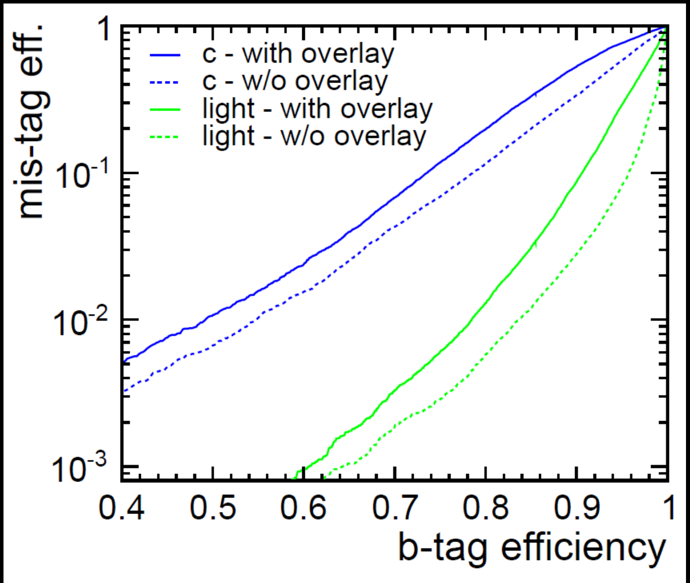
All studies done with full simulation of signal + 60BX of $\gamma\gamma \rightarrow$ hadrons

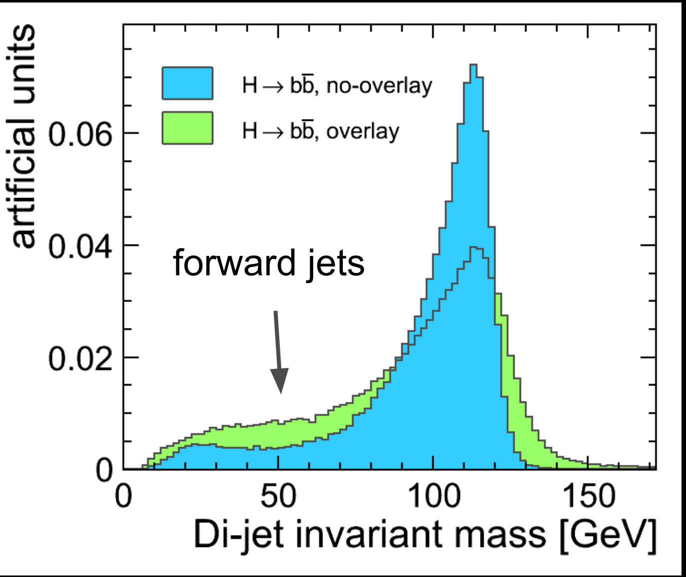
b-jet reconstruction

LCFIVertex package:

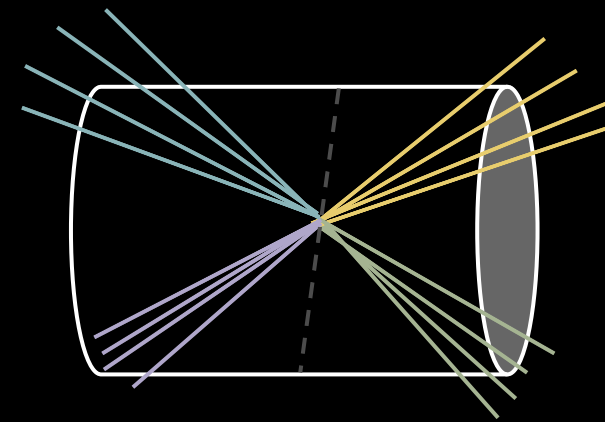
- ZVTop vertex reconstruction
- Flavor tagging using FANN

Background impact on both invariant mass and b-tagging performance is fairly well understood

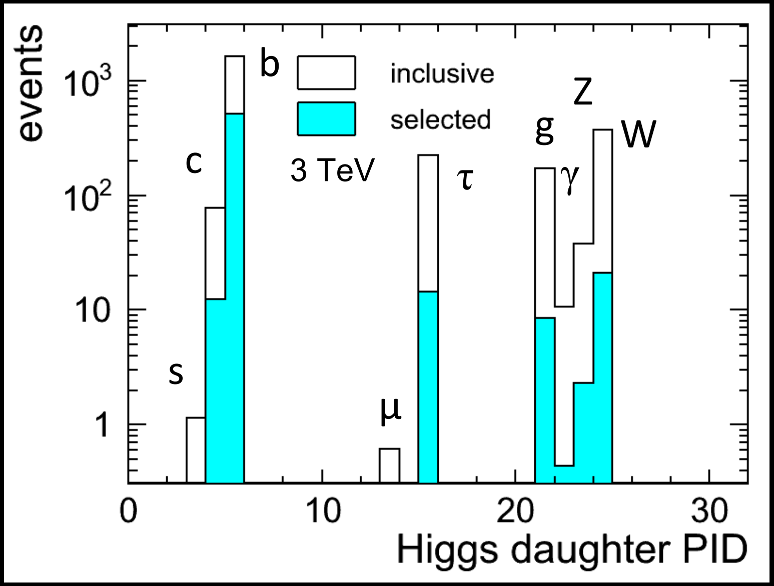




Analysis Strategy



- Isolated Lepton Finding
  - Reduces 4 jets + 1-2 leptons background
- Force events into four jets (FastJet kt R=1.0)
- Divide event into hemispheres based on thrust
  - Pair jets by hemisphere, if possible
  - Using kinematic criteria otherwise
- Neural Network (FANN) to distinguish between signal / background
  - Train 50 networks independently to improve stability
  - Using inclusive Higgs sample as signal
  - Works reasonably well for 120 GeV Higgs
  - Somewhat different BR for 126 GeV Higgs call for more differentiated approach
- Cut-and-count as cross-check.
  Neural network template fit for improved performance

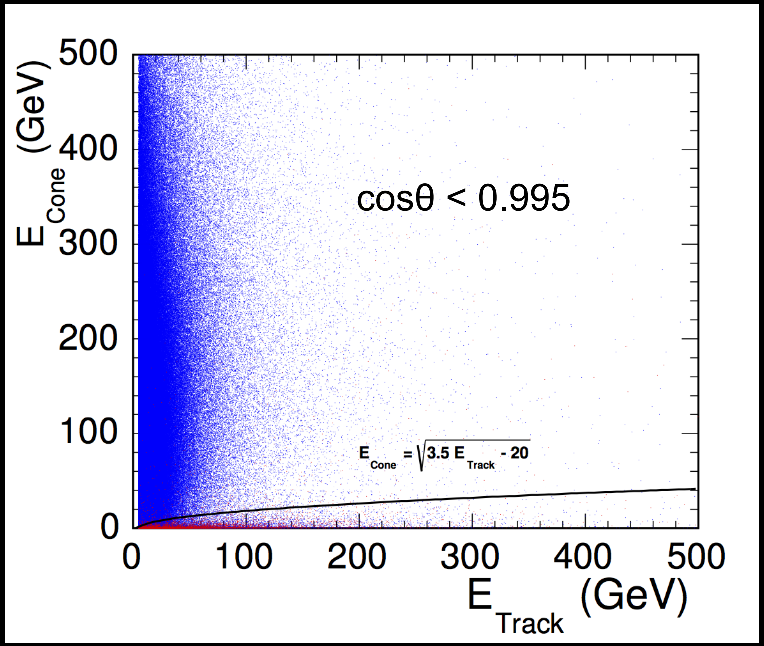


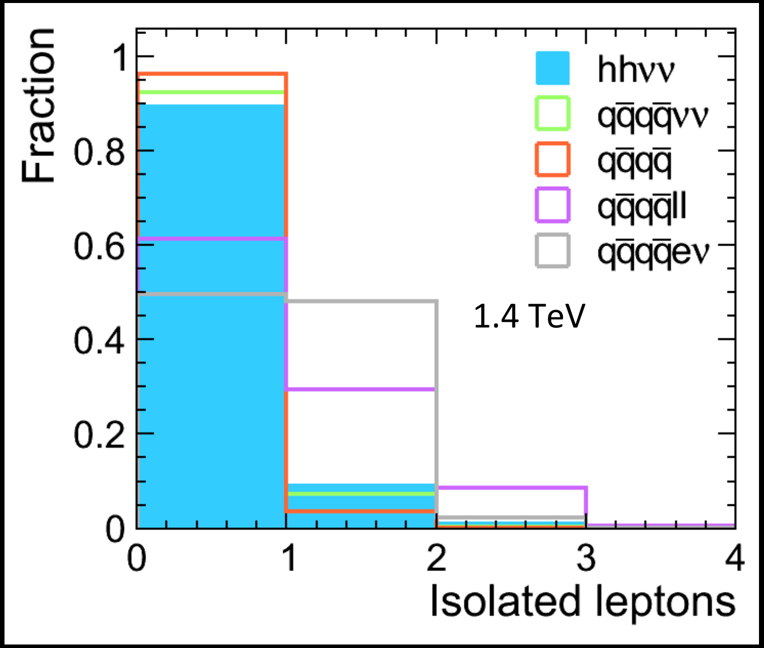
Isolated Leptons

IsolatedLeptonFinder in MarlinReco allows to use parabolic relationship between cone energy and track energy

Performance has been studied in a sample containing one leptonic W decay

Optimization studies ongoing





Neural net event selection

Inputs (22 in total):

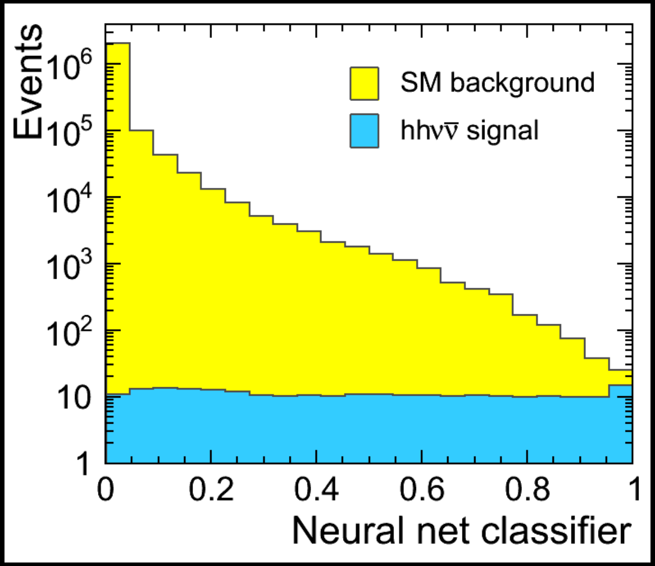
- Invariant masses of jet pairs
- Sum of jet flavour tags for each pair separately
- Angle between jet pairs
- Event invariant mass and total energy
- number of leptons and photons
- max(|eta_i|) of jets
- p_T^{max} and p_T^{min} of jets
- y_{min} from FastJet

depends on the jet pairing, depends only on the jet reconstruction

does not depend on the jet pairing nor on the jet reconstruction (except the beam jet)

Neural Network results

1.4 TeV (1.5 ab^{-1})

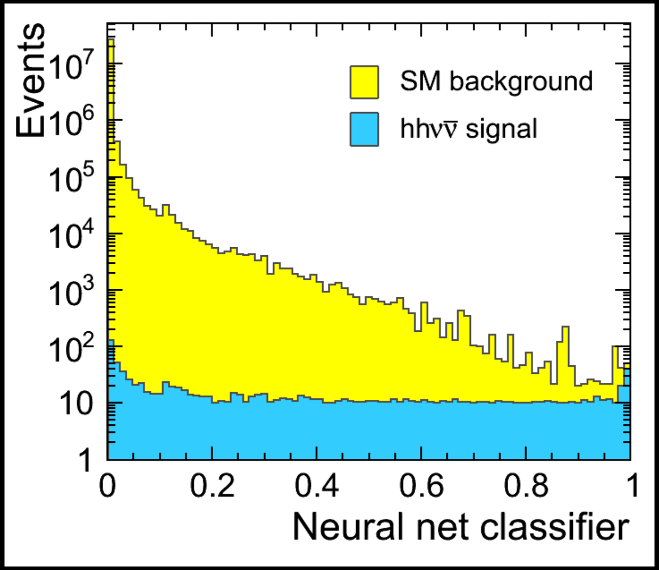


$\sigma_{HH\nu\nu}$ uncertainty: 25%

λ_{HHH} uncertainty: 31%

background dominated by generic 4-jet background (+ lν or νν)

3.0 TeV (2 ab^{-1})



$\sigma_{HH\nu\nu}$ uncertainty: 10%

λ_{HHH} uncertainty: 16%

complete set of backgrounds, except 4 jets + 1 lepton (in progress)

Ways to increase the number of signal events

collision energy Polarization e^- /e^+	$\sqrt{s}$ = 1.4 TeV unpolarized	$\sqrt{s}$ = 3.0 TeV unpolarized	$\sqrt{s}$ = 3.0 TeV -80% / 0	$\sqrt{s}$ = 3.0 TeV -80% / +30%
$\sigma(HH\nu\nu)$	0.16 fb	0.63 fb	1.05 fb	1.37 fb

Other Channels contributing
at 1.4 TeV: ZHH cross section ~50% of $HH\nu\nu$
at 3.0 TeV: ZHH cross section < 10% of $HH\nu\nu$

Z boson fusion diagrams (electrons in final state)
< 15% of W boson fusion cross section

m_H = 126 GeV results in slightly smaller signal cross sections
$\sigma(HH\nu\nu)$ = 0.15 fb at 1.4 TeV
$\sigma(HH\nu\nu)$ = 0.59 fb at 3.0 TeV

Further development

Limiting factors are

- Forward Jet reconstruction
- Flavor tagging
- Forward lepton tagging

Each can be addressed by optimizing detector performance

Needs careful study -- a lot of work

Further opportunities for improvement in analysis strategy and reconstruction software. They hopefully add up.

Summary and Conclusions

- The measurement of the Higgs tri-linear self-coupling requires large luminosity (and probably a high-energy linear collider)
- The measurement at 1.4 TeV with unpolarized beams is marginal
- The higher cross section at 3.0 TeV makes this measurement feasible
    - Polarization of electron and positron beam help
- The study is currently being updated with m_H = 126 GeV
- A few improvements to the analysis remain
- More importantly, possibility of further improvement to the detectors

Backup