Invisible Higgs

Using a Physics Analysis to Quantify Impact of Jet Energy Resolution

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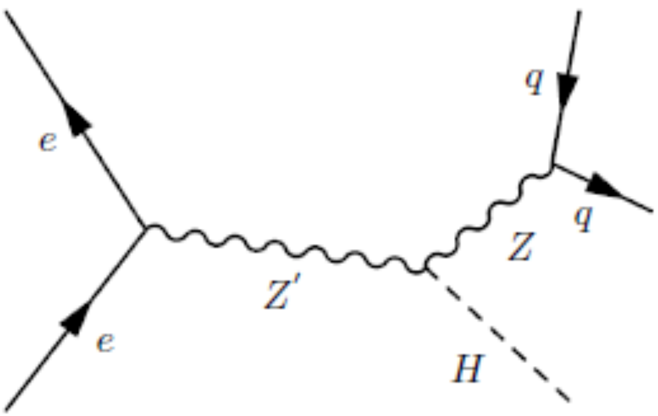
Outline

- Introduction to Invisible Higgs
- Preselection and TMVA Results
- Optimization Settings
- Results of Optimization
- Conclusion

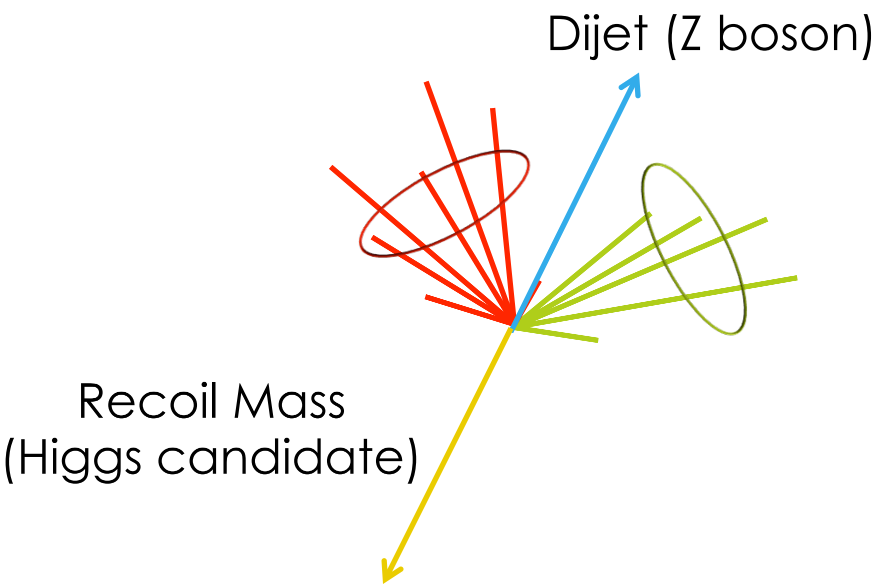
Introduction to Invisible Higgs

Invisible Higgs Events

- 350 GeV e^+e^- collisions
- Detector Model: ILD_o1_v05
- Signal: Higgsstrahlung events with final state of two jets + missing energy
- Background
  - Other HZ events (WW, ZZ, $\gamma\gamma, \tau\tau$)
  - 4 Jet and 2 Jet SM events



Event Analysis

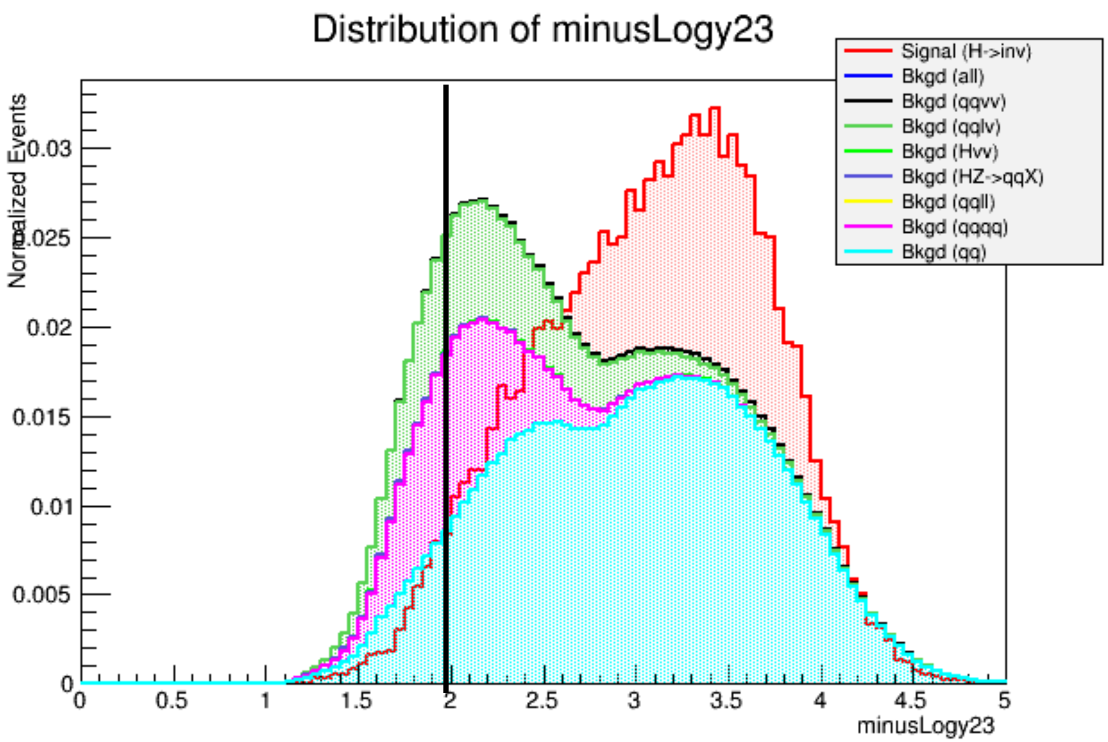


2 – Jet Event

- Used Pandora/FastJet to process event into 2, 3, 4, 5, and 6 jet topologies with R = 1.5
- Two jets most consistent with the Z mass is chosen as the dijet mass
- Invariant mass of the system recoiling against this dijet is measured (taking into account crossing beam angle)
- Theoretically, in Higgsstrahlung events, this recoil in the 2 jet topology is the Higgs candidate

ILC: Event Preselection

- If event looks like a 2 jet event:
  - Invisible Higgs analysis
- If event looks like a more than 2 jet event:
  - Visible Higgs analysis



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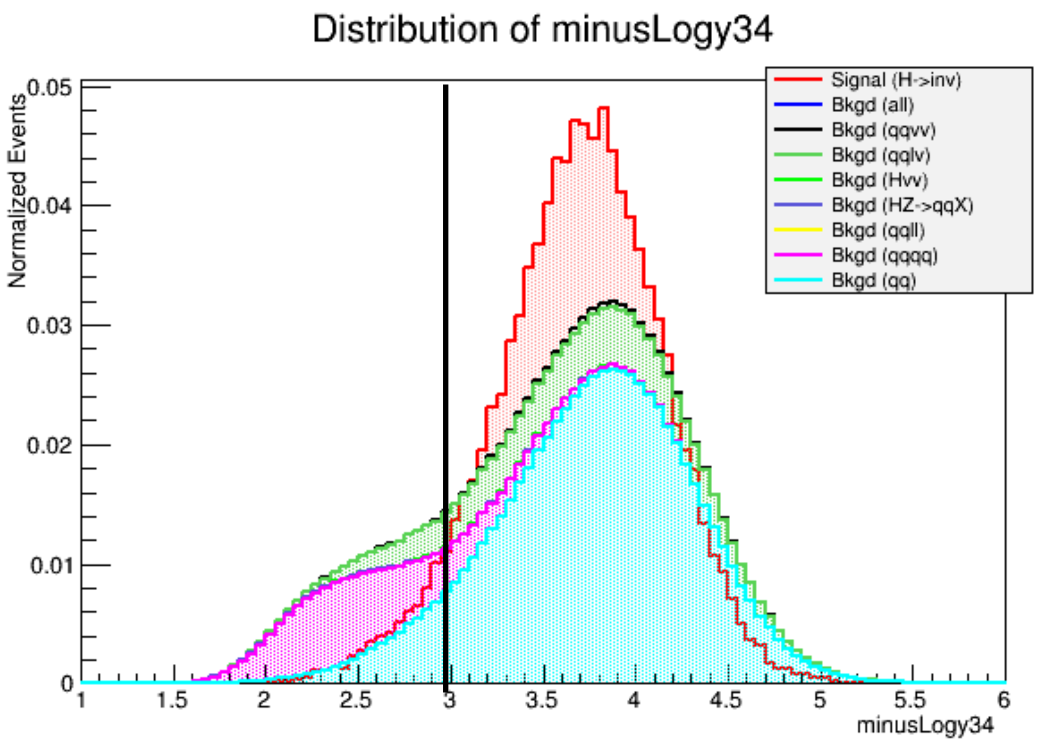
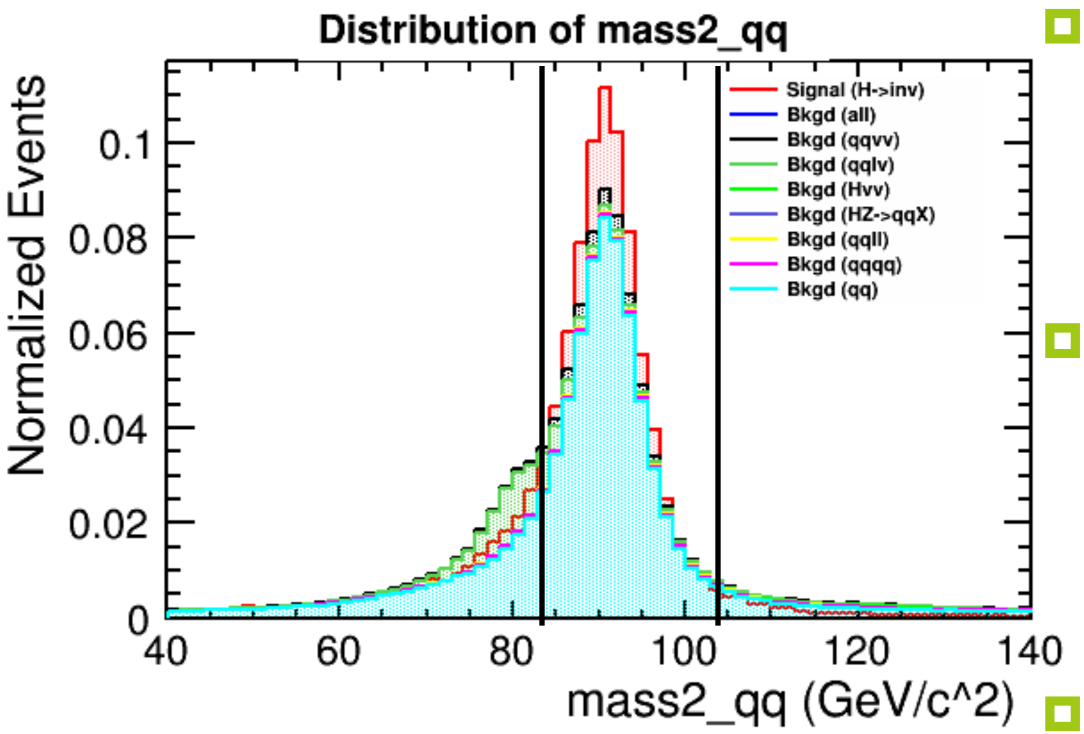


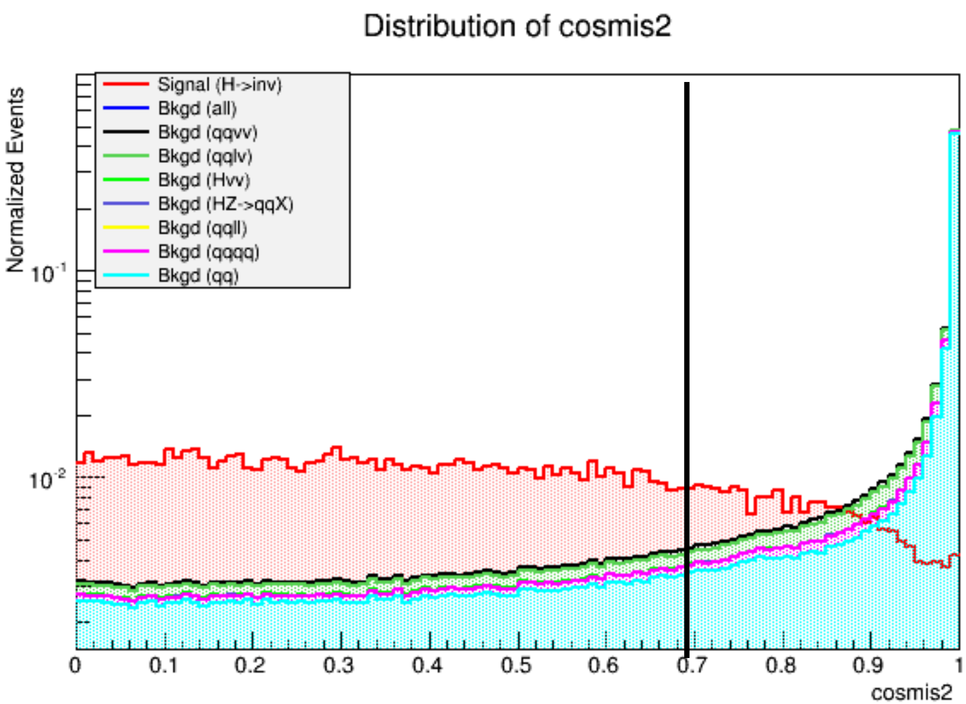
Preselection and TMVA Results

ILC: Rectangular Cuts



- Dijet mass cut was applied:
  - 84 GeV < m_{dijet} < 104 GeV
  - Select for Higgsstrahlung events
- Cut applied on forward region:
  - $|\cos(\theta_{dijet})| < .7$
  - Select for central region events
- Other event specific vetoes

ILC: Rectangular Cuts



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TMVA

Variable Name	Description of Variable
m_{recoil}	mass of the recoil
m_{dijet}	mass of the dijet
$cos(\theta_Q)$	cosine of the decay angle of the jets in the rest frame
$p_T(dijet)$	transverse momentum of the Z boson
$cos(\theta_{mis})$	cosine of the polar angle of the missing momentum vector
$-log_{10}(y_{23})$	measure of how likely the event is a 2 or 3 jet event
$e_{visible}$	amount of visible energy measured in the event

- Multivariate Analysis (BDT) used to further separate signal and background
- Final list of variables obtained by starting with a larger sample size and then eliminating ones that did not affect significance

TMVA Efficiencies

Table 1: Signal and Background Efficiency for ILC

Channel	Cross Section	$\epsilon_{preselection}$	$\epsilon_{BDT>.13}$	Events Remaining
$e^+e^- \to q\bar{q}$	29658	$< 0.1\%$	$< 0.1\%$	0.3
$e^+e^- \to q\bar{q}q\bar{q}$	5514	$< 0.1\%$	$< 0.1\%$	0
$e^+e^- \to q\bar{q}\nu\nu$	324.2	16.6%	0.8%	1306.7
$e^+e^- \to q\bar{q}l\nu$	5738	0.3%	$< 0.1\%$	212.8
$e^+e^- \to q\bar{q}ll$	590.2	$< 0.1\%$	$< 0.1\%$	0.7
$e^+e^- \to H\nu\nu$	52.3	5.1%	0.1%	22.0
HZ (Standard Model)	93.8	$< 0.1\%$	$< 0.1\%$	4.4
$H \to inv$	100%	41.1%	19.5%	9162.6
$H \to q\bar{q}$		$< 0.1\%$	$< 0.1\%$	0
$H \to ZZ^*$		0.5%	$< 0.1\%$	0.2
$H \to \gamma\gamma$		$< 0.1\%$	$< 0.1\%$	0
$H \to \tau\tau$		0.7%	0.1%	2.5
$H \to Z\gamma$		1.0%	$< 0.1\%$	0
$H \to \mu^+\mu^-$		$< 0.1\%$	$< 0.1\%$	0
$H \to WW^*$		0.2%	$< 0.1\%$	1.7
$H \to WW^* \to l\nu l\nu$		0.5%	$< 0.1\%$	0.1
$H \to WW^* \to l\nu\tau\nu$		1.1%	0.1%	0.5
$H \to WW^* \to \tau\nu\tau\nu$		4.9%	1.0%	1.1
$H \to WW^* \to q\bar{q}l\nu$		$< 0.1\%$	$< 0.1\%$	0.0
$H \to WW^* \to q\bar{q}\tau\nu$		0.1%	$< 0.1\%$	0.0
$H \to WW^* \to q\bar{q}q\bar{q}$		$< 0.1\%$	$< 0.1\%$	0.0

$$\Delta\sigma = \frac{\sqrt{N_{back}}}{N_{sig,100\%}}$$

$$\Delta\sigma = .43\%$$

TMVA Efficiencies

Table 1: Signal and Background Efficiency for CLIC

Channel	Cross Section	$\epsilon_{preselection}$	$\epsilon_{BDT>.09}$	Events Remaining
$e^+e^- \to q\bar{q}$	25180	$< 0.1\%$	$< 0.1\%$	0
$e^+e^- \to q\bar{q}q\bar{q}$	5847	$< 0.1\%$	$< 0.1\%$	0
$e^+e^- \to q\bar{q}\nu\nu$	324.6	16.8%	1.9%	2980.3
$e^+e^- \to q\bar{q}l\nu$	5914	0.7%	$< 0.1\%$	613.67
$e^+e^- \to q\bar{q}ll$	1704	$< 0.1\%$	$< 0.1\%$	1.7
$e^+e^- \to H\nu\nu$	51.5	5.3%	0.2%	63.6
HZ (Standard Model)	93.5	0.2%	$< 0.1\%$	18.8
$H \to inv$	100%	41.1%	22.8%	10663.2
$H \to q\bar{q}$		$< 0.1\%$	$< 0.1\%$	0
$H \to ZZ^*$		2.4%	1.1%	13.9
$H \to \gamma\gamma$		$< 0.1\%$	$< 0.1\%$	0
$H \to \tau\tau$		0.7%	0.1%	2.2
$H \to Z\gamma$		1.0%	$< 0.1\%$	0
$H \to \mu^+\mu^-$		$< 0.1\%$	$< 0.1\%$	0
$H \to WW^*$		0.2%	$< 0.1\%$	2.7
$H \to WW^* \to l\nu l\nu$		0.6%	$< 0.1\%$	0.1
$H \to WW^* \to l\nu\tau\nu$		1.7%	0.3%	1.5
$H \to WW^* \to \tau\nu\tau\nu$		6.0%	0.8%	1.0
$H \to WW^* \to q\bar{q}l\nu$		$< 0.1\%$	$< 0.1\%$	0
$H \to WW^* \to q\bar{q}\tau\nu$		0.2%	$< 0.1\%$	0.1
$H \to WW^* \to q\bar{q}q\bar{q}$		$< 0.1\%$	$< 0.1\%$	0

$\Delta\sigma = .57\%$

Optimization Settings

Basic Settings

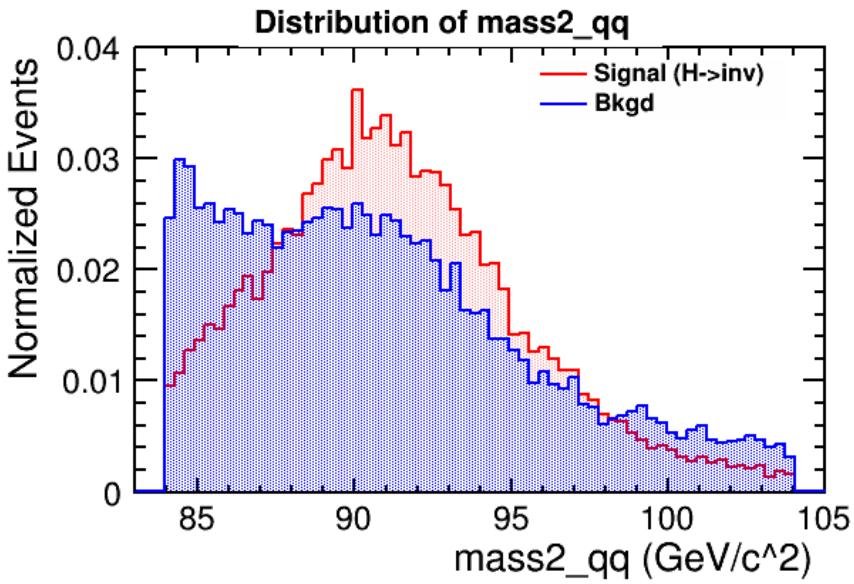
- ILCsoft Version: v01-16-p09_350 -> same as Akiya used for his generation
- STDHEP files used are located at:
  - /ilc/prod/ilc/mc-dbd/generated/350-TDR_ws/
- Marlin Reconstuction Steer File:
  - PandoraSettingsDefault.xml

Changes Made

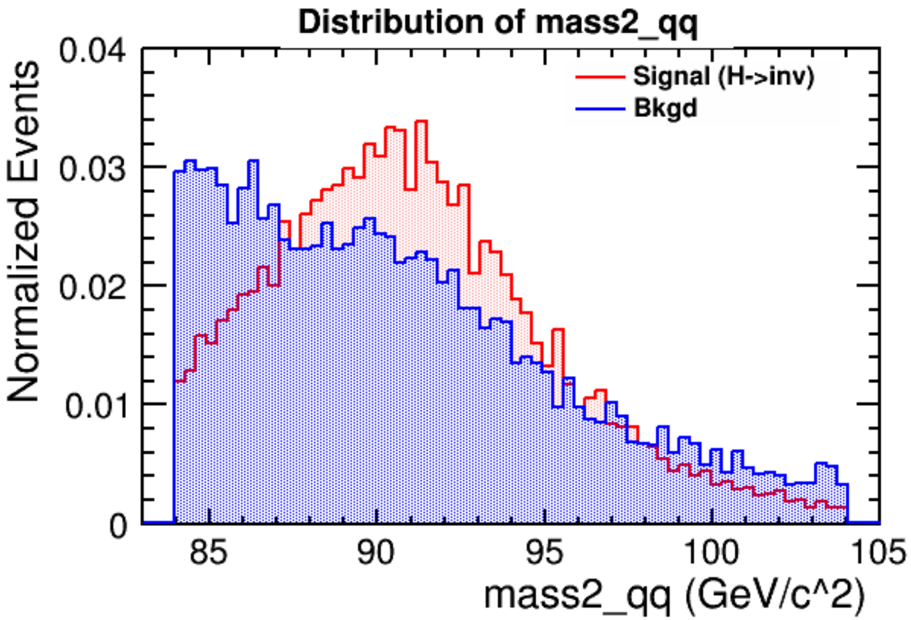
- Parameters changed:
  - Mokka Global Model Parameter:
    - Ecal_cells_size 15.0 (mm)
  - PandoraLikelhoodData9EBin.xml -> used svn copy
- Re-run with only the qqlν and qq$\nu\nu$ backgrounds -> dominant backgrounds in both original studies
- Distributions of variables are in the appendix

Variable Distributions: mass2_qq

SiW: 5X5

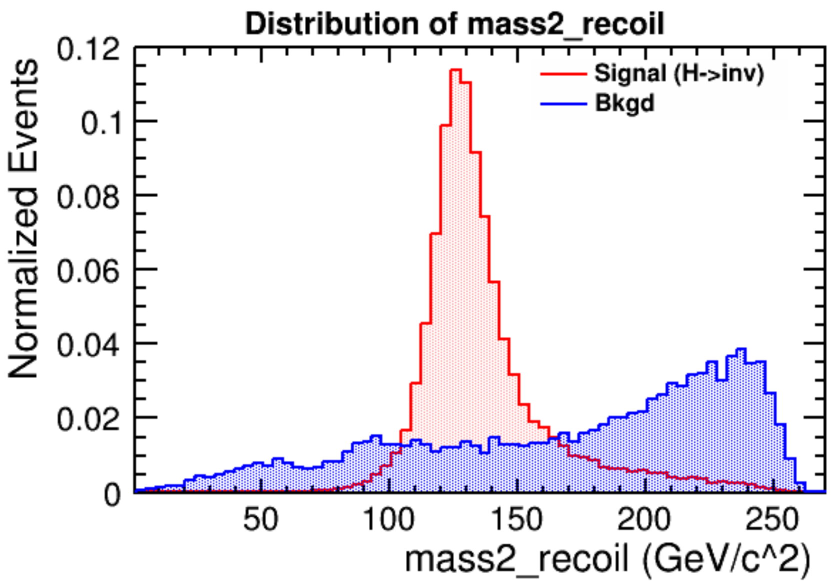


SiW: 15X15



Variable Distributions: mass2_recoil

SiW: 5X5



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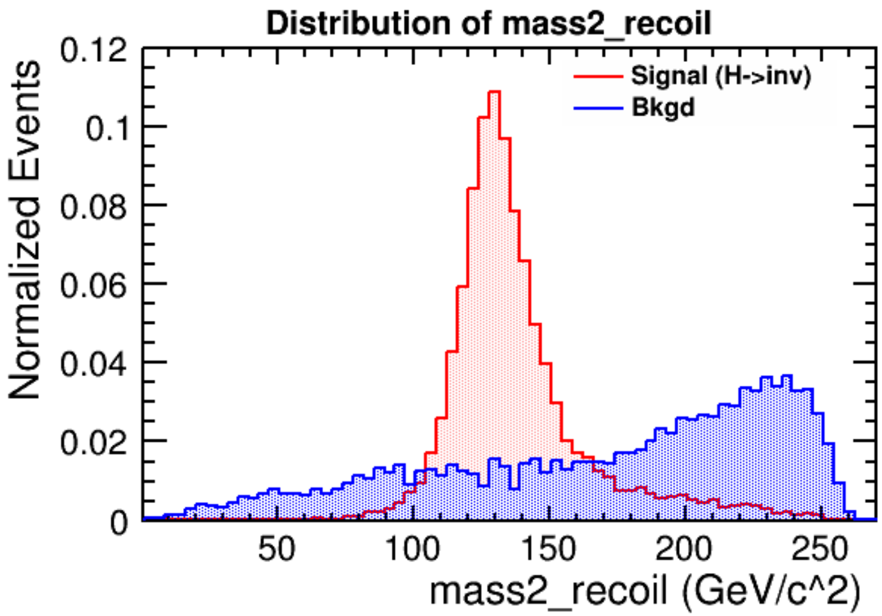


Results of Optimization

Pre-selection

ILC (ECal = 5 mm)

Event Type	N_start	N_after
Signal (HZ->inv)	46861.3	19284.1 (41.2%)
BKGD: qqvv	161127	26753 (16.6%)
BKGD: qqlv	2799670	9477.3 (0.3%)

Self GEN ILC (ECal = 15 mm)

Event Type	N_start	N_after
Signal (HZ->inv)	46821.1	18790.6 (40.1%)
BKGD: qqvv	161129	26302.2 (16.3%)
BKGD: qqlv	2807790	9977.3 (0.4%)

Post TMVA (BDT)

ILC (ECal = 5 mm)

Event Type	N_start	N_after
Signal (HZ->inv)	46861.3	10177.4 (21.7%)
BKGD: qqvv	161127	1644.47 (1.0%)
BKGD: qqlv	2799670	270.03 (0.01%)

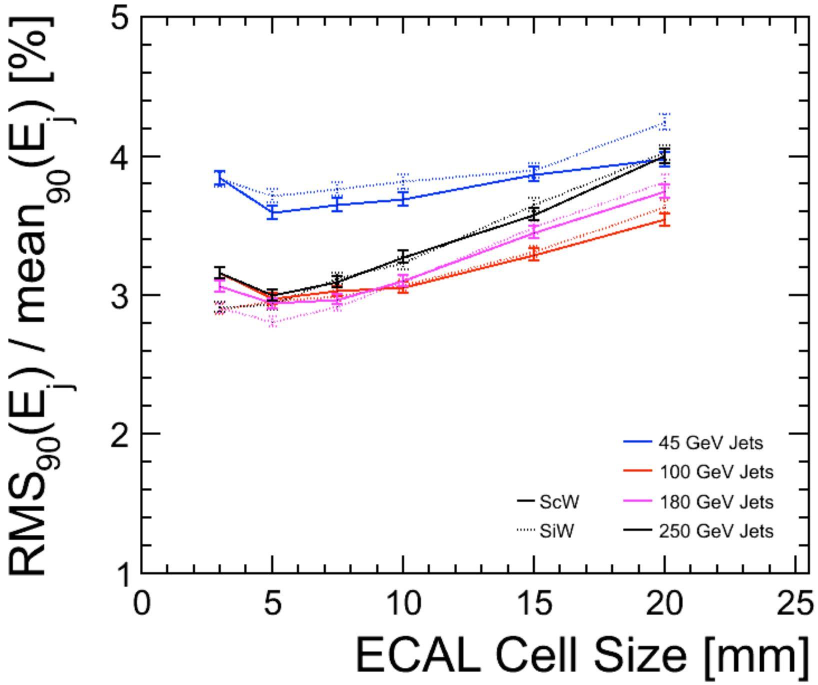
$$\Delta\sigma = .430 \pm .022\%$$

Self GEN ILC (ECal = 15 mm)

Event Type	N_start	N_after
Signal (HZ->inv)	46821.1	9792.1 (20.9%)
BKGD: qqvv	161129	1645.8 (1.0%)
BKGD: qqlv	2807790	282.7 (0.01%)

$$\Delta\sigma = .447 \pm .010\%$$

Connection to Jet Energy Resolution



Ecal Cell Size	5x5 mm SiW	15x15 mm SiW	Ratio
Δσ (H-> inv)	.430%	.447%	+3.9%
Jet Energy Resolution	2.96	3.31	+11.8%

Taken from John Marshall

Conclusions

Conclusions

- Based on the Invisible Higgs Analysis, changing the cell size for the electronic calorimeter, and hence degrading jet resolution measurements, has an adverse impact on the end result.
- Start of a study to potentially continue to link jet resolution with physics results.

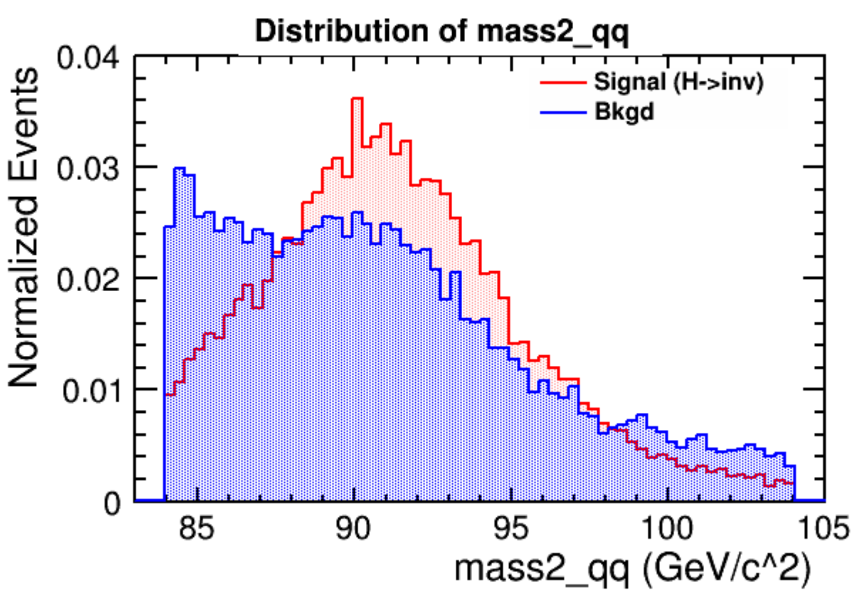
Appendix

ILC: Event Specific Vetoes

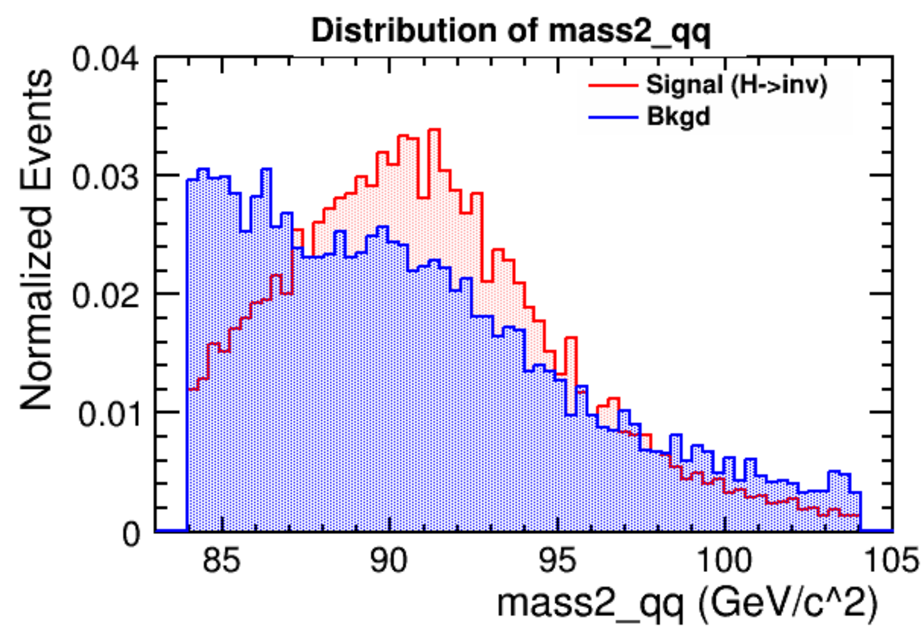
- Standard Model WW -> qqlv events:
  - Presence of a very energetic lepton in a jet that has few particles
  - Ntracks_3 < 4 && Elepton_3 > 25
- Standard Model ZZ events (low transverse momentum (pT < 25 GeV)):
  - If in the 4-jet topology, there are two Z candidates in the jets
    - mass4w_dijet > 80 && mass4w_dijet < 100
    - mass4w_other > 80 && mass4w_other < 100
- Standard Model qq events (low transverse momentum (pT < 25 GeV)):
  - The event looks significantly more like a 4-jet event than a 3-jet event
  - minusLogy34 > 3.0
- Standard Model WW events (low transverse momentum (pT < 25 GeV)):
  - If in the 4-jet topology, there are two W candidates in the jets
    - mass4w_dijet > 70 && mass4w_dijet < 90
    - mass4w_other > 70 && mass4w_other < 90
  - If in the 3-jet topology, there is one W candidate, and the recoil is within the W range (any pT)
    - mass3w_qq > 70 && mass3w_qq < 90
    - mass3w_recoil > 60 && mass3w_recoil < 140

Variable Distributions: mass2_qq

SiW: 5X5

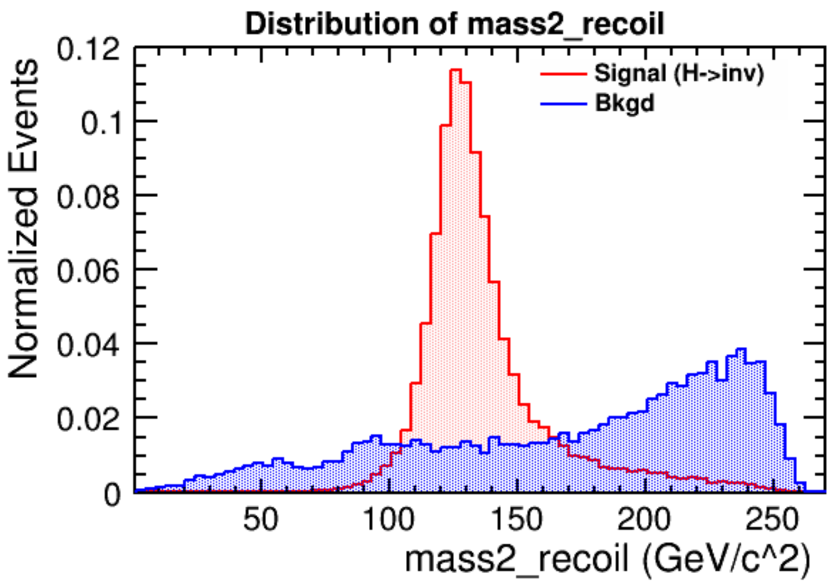


SiW: 15X15

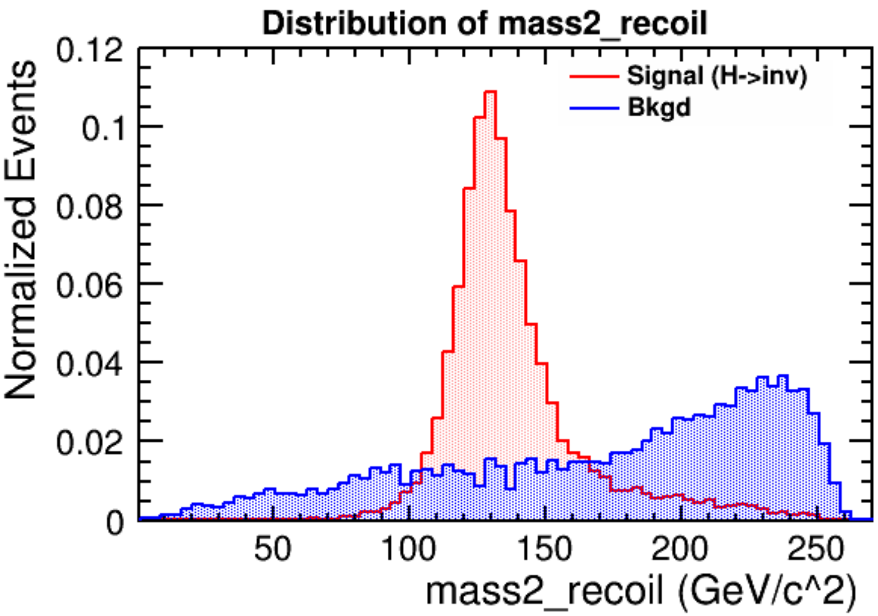


Variable Distributions: mass2_recoil

SiW: 5X5

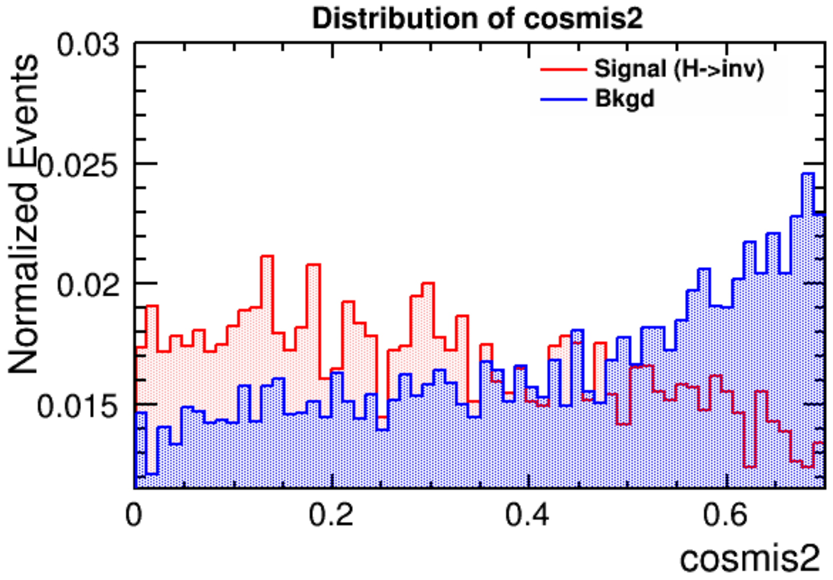


SiW: 15X15

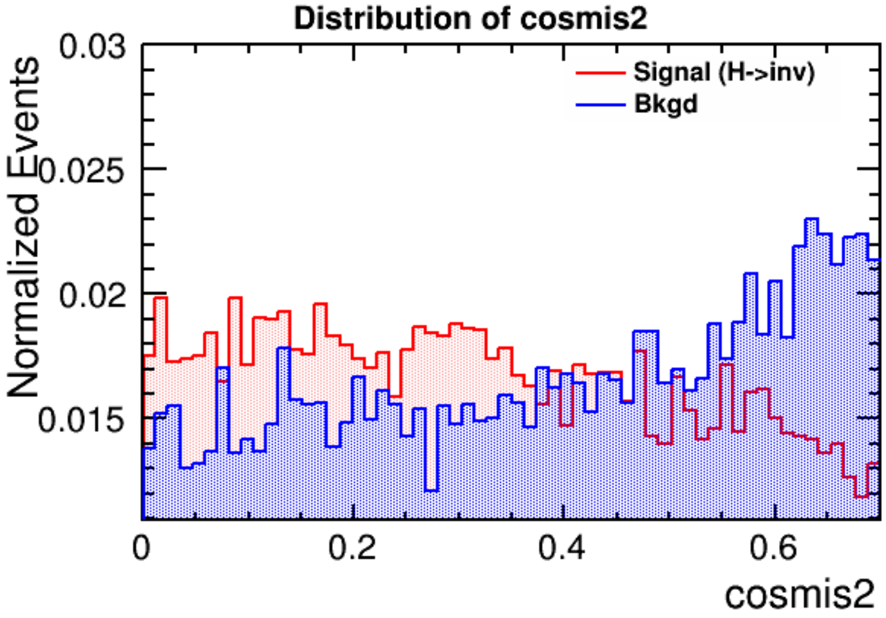


Variable Distributions: cosmis2

SiW: 5X5

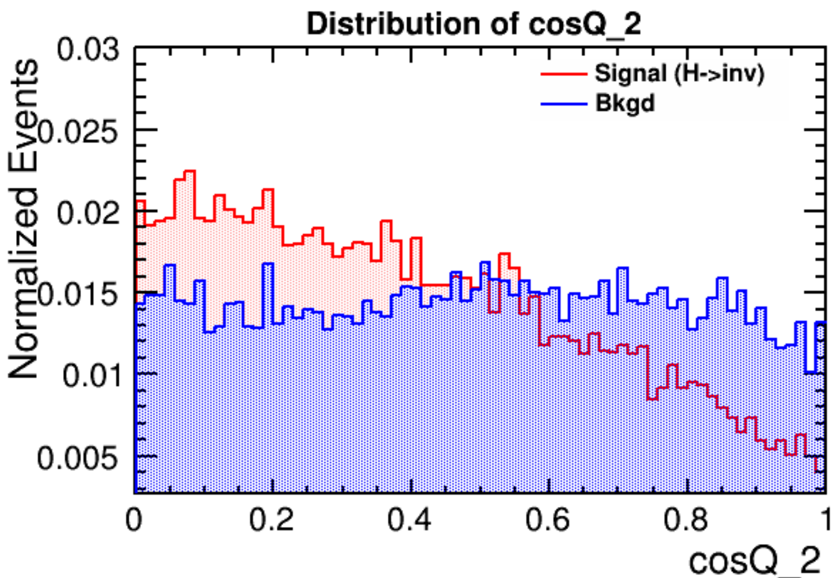


SiW: 15X15



Variable Distributions: cosQ_2

SiW: 5X5



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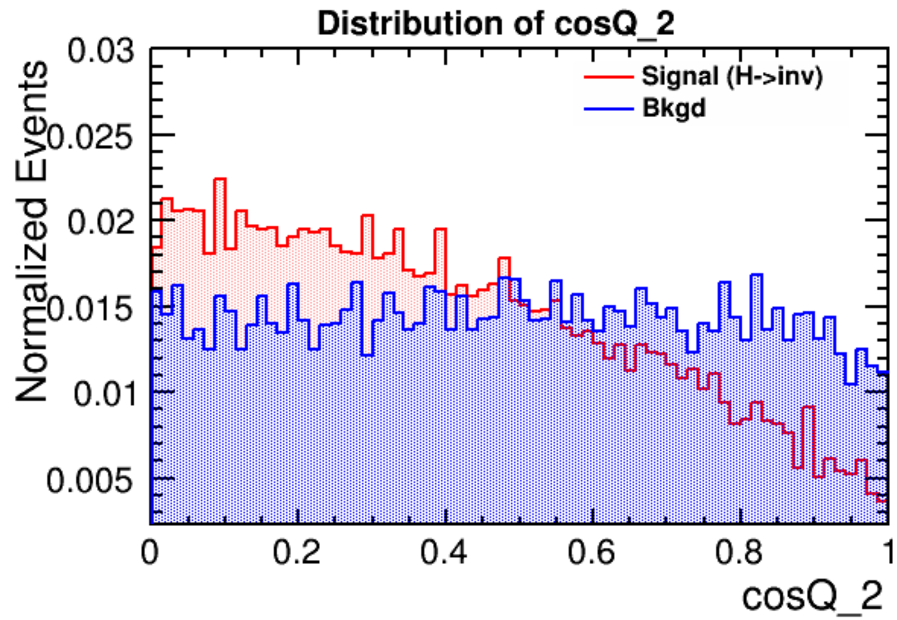
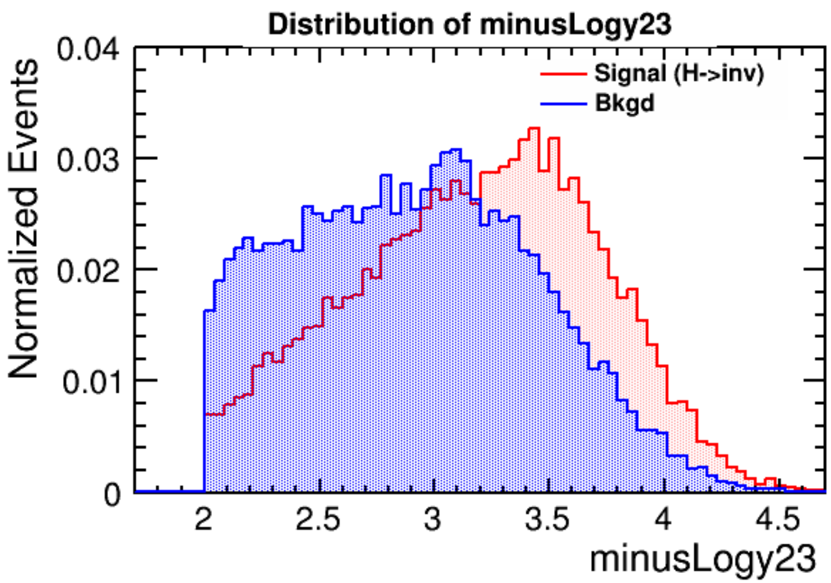


Variable Distributions: -log(y23)

SiW: 5X5



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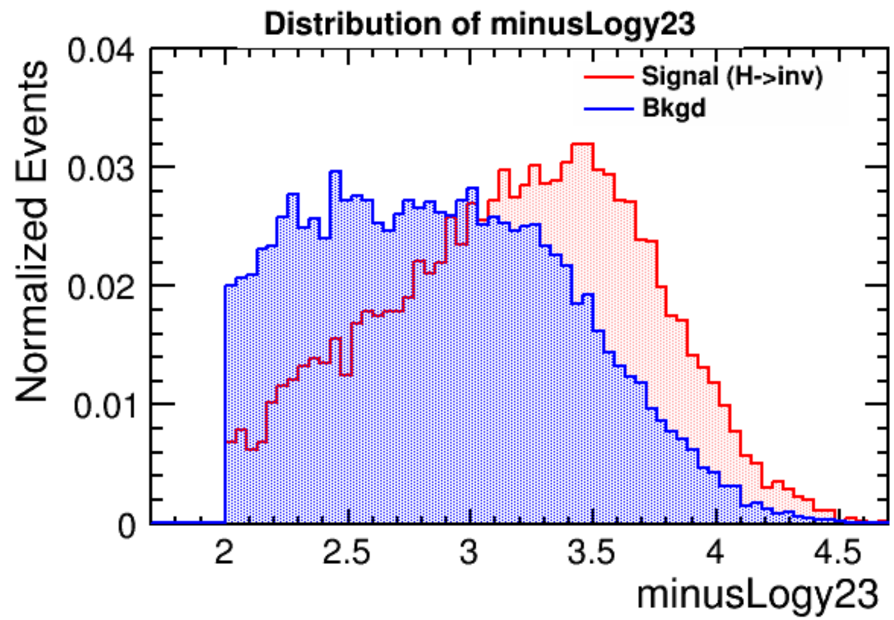
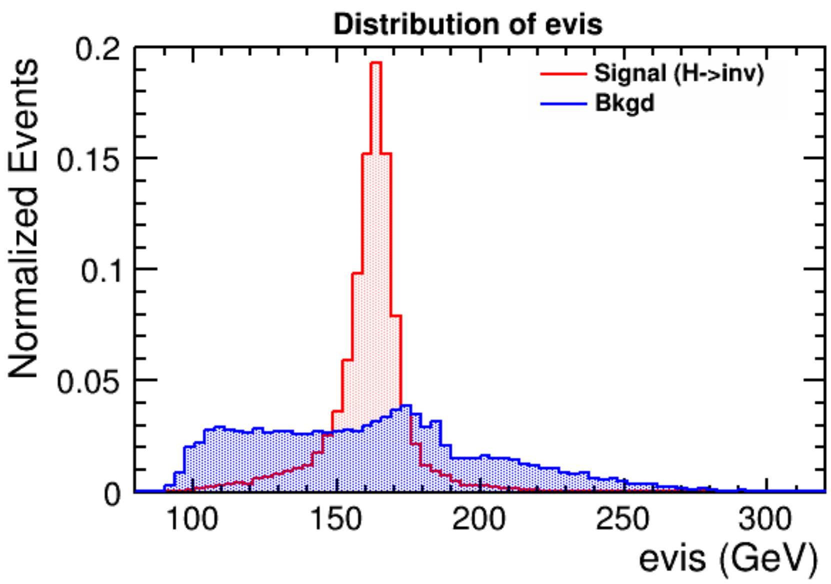


Variable Distributions: evis

SiW: 5X5



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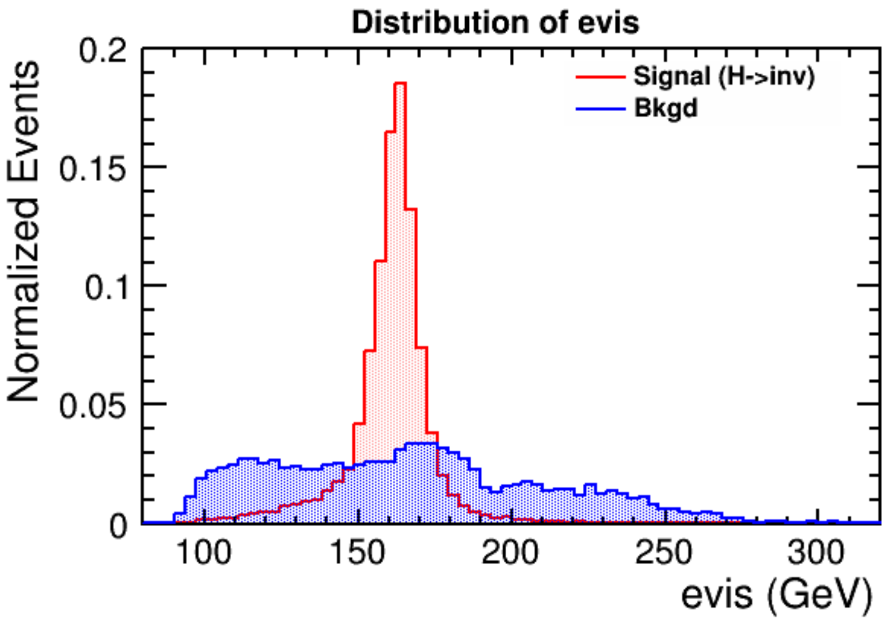
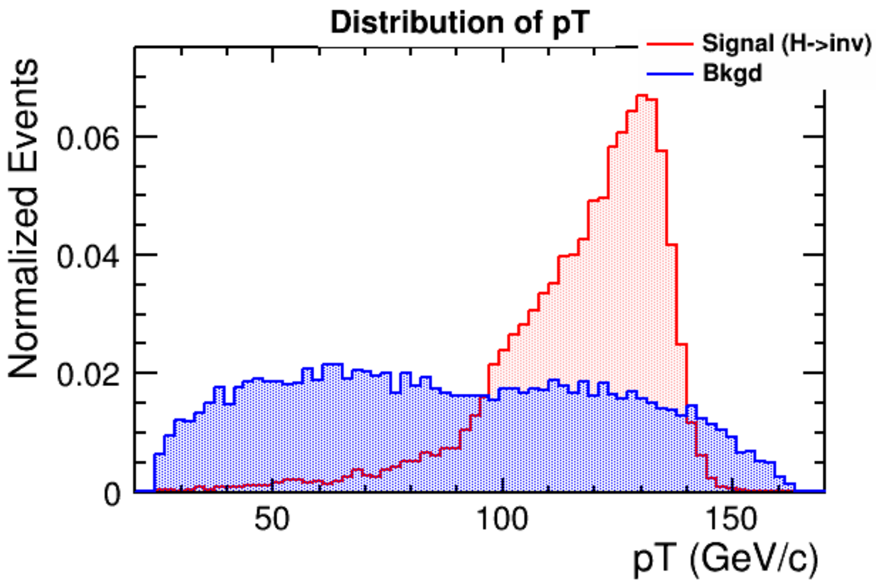


Variable Distributions: pT

SiW: 5X5



SiW: 15X15