Simulation/Reconstruction and Physics Benchmarking in the SiD DBD

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for the SiD Detector Concept

Dec 14, 2012

Outline

- Personnel
- Simulation/Reconstruction
- Physics Benchmarking
  - $t\bar{t}H$ Philipp Roloff and Jan Strube (CERN)
  - WW T.B.
  - $t\bar{t}$ Malachi Schram (PNNL)
  - $\nu\bar{\nu}H$ Homer Neal (SLAC)
- Summary

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DBD Benchmarking + SimReco Personnel

- CERN
  - Christian Grefe
  - Stephane Poss
  - Philipp Roloff
  - Jan Strube
- DESY
  - Alexander Grohsjen
  - Marcel Stanitzki
- PNNL
  - David Asner
  - David Cowley
  - Brock Erwin
  - Malachi Schram
- SLAC
  - Tim Barklow
  - Norman Graf
  - Jeremy McCormick
  - Homer Neal

Software Chain for the DBD

- Event Generation
  - Whizard, physsim, Guineapig
- Detector response simulation (slic)
- Event Reconstruction
  - Event overlay
  - lcsim tracking
  - slicPandora PFA
  - LCFI vertex finding
- Analysis
  - LCFI+ flavor tagging
  - Everything else

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Fully Simulated and Reconstructed Events

Process	$\sqrt{s}$ (GeV)	# Events (10^6)	$\mathscr{L}$ ab^{-1}
$t\bar{t}h$	1000	0.4	52
$ttZ, ttbb$	1000	0.4	15
tt	1000	1.0	2.0
$\nu\bar{\nu}h,\ h \to b\bar{b}, c\bar{c}, WW^*, gg$	1000	3.1	7.4
$\nu\bar{\nu}h,\ h \to \mu^+\mu^-$	1000	0.5	6400
$e\nu W, eeZ, \nu\nu Z \to e\nu qq, eeqq, \nu\nu qq$	1000	4.0	0.034
$eeZ, \nu\nu Z, WW \to ee\mu\mu, \nu\nu\mu\mu$	1000	1.0	0.004
WW	1000	6.0	2.0
all other SM processes	1000	6.0	$1 \cdot 10^5 - 1.0$
$t\bar{t}$	500	2.0	1.0 per m_{top}
$t\bar{t}$ background SM processes	500	2.0	varies
TOTAL		26	

Table 11.1.2: Contents of "all Other SM Processes" Mixed File.

Process	$\mathscr{L}$ ab^{-1} per pol.	# Events (10^5) P(e^-/e^+) -0.8/+0.2	# Events (10^5) P(e^-/e^+) +0.8/-0.2	Weight
$e\gamma \to e\gamma$	$4 \cdot 10^{-5}$	0.5	0.5	$2.5 \cdot 10^{+4}$
$e^+e^- \to 2f, 4f$	0.034	3.7	2.0	29
$e\gamma \to 3f$	0.003	3.5	3.1	330
$e\gamma \to 5f$	0.25	3.1	2.1	4
$e^+e^- \to 6f$	1.0	1.8	0.6	1
$\gamma\gamma \to 2f$	0.001	5.7	5.7	7700
$\gamma\gamma \to 4f$	0.083	2.5	2.5	12
$\gamma\gamma \to$ minijets:				
$4 < p_T < 40$ GeV	0.012	9.2	9.2	$80 - 9000$
$p_T > 40$ GeV	0.105	2.3	2.3	12

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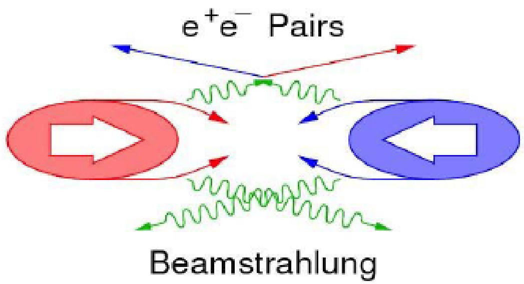
Beam-Induced Background

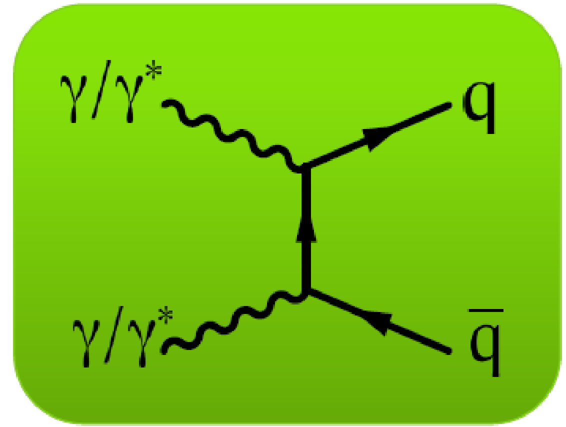


Pair background
1 event per BX
450k particles

Generated by GuineaPig
ascii → hepevt → stdhep

Merged with every "physics" event

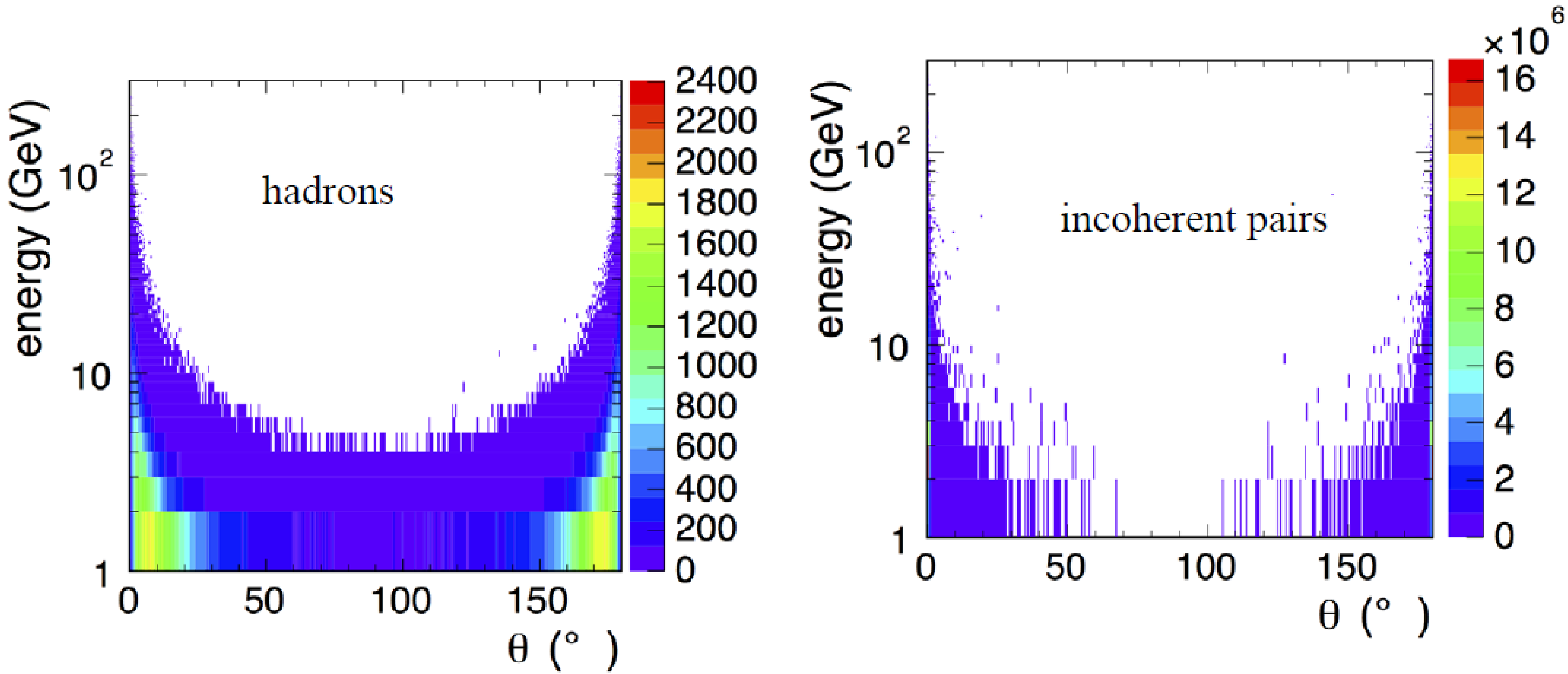
MCParticles that don't make hits will be dropped



<u>γγ interactions</u>
4.1 events per BX @ 1 TeV
1.7 events per BX at 500 GeV

Generated by Whizard

Angular distribution of background



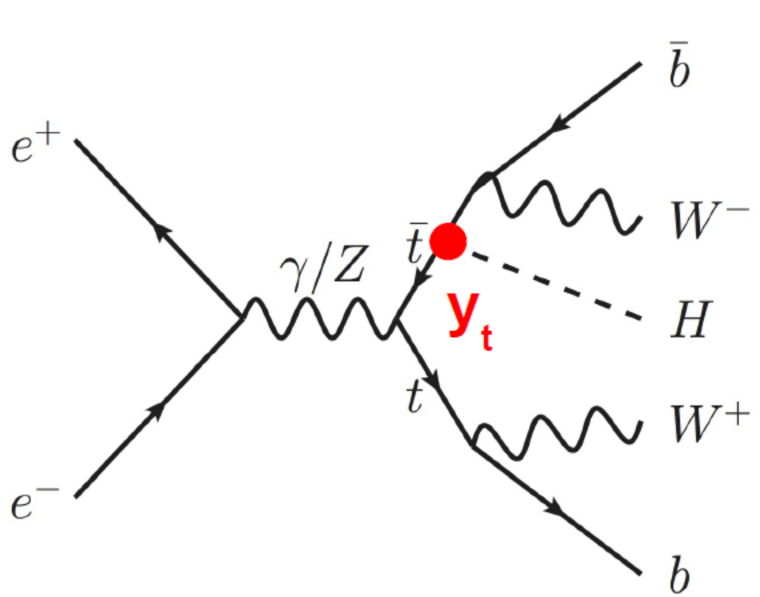
Incoherent pairs affect mostly occupancies and tracking efficiencies

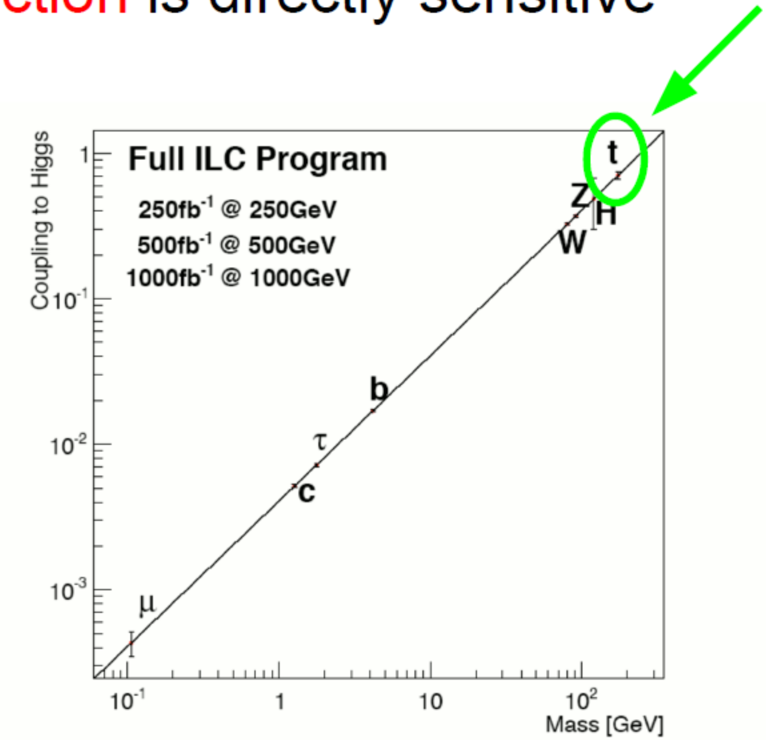
Hadrons have enough energy to reach the calorimeter

Measurement of the top Yukawa coupling

- **Final states:**
  - "6 jets": $t(\rightarrow qqb)\bar{t}(\rightarrow l\nu\bar{b})H(\rightarrow b\bar{b})$, m_H = 125 GeV
  - "8 jets": $t(\rightarrow qqb)\bar{t}(\rightarrow qq\bar{b})H(\rightarrow b\bar{b})$, m_H = 125 GeV

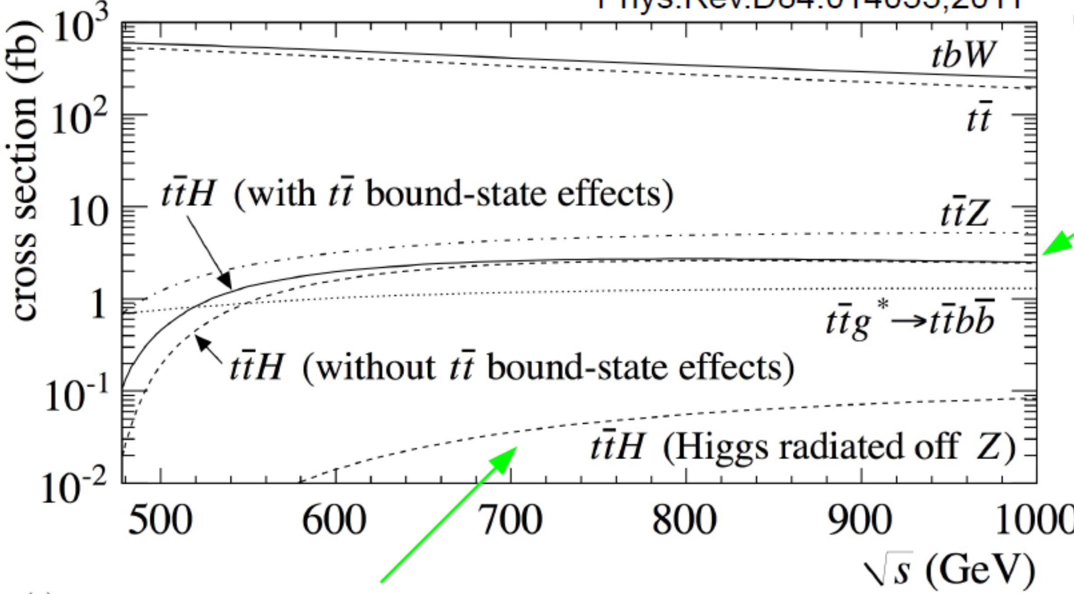
- **Motivation:** Cross section for $t\bar{t}H$ production is directly sensitive to the top Yukawa coupling, y_t:

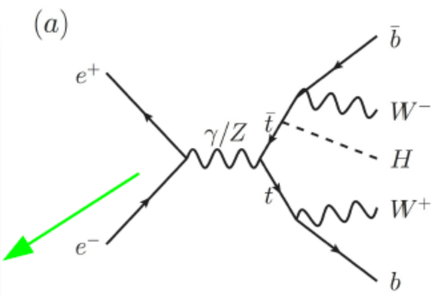




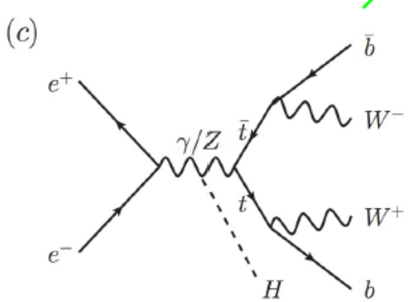
Cross sections

Phys.Rev.D84:014033,2011





At 1 TeV:
- $\sigma \approx 2.2$ fb
- $t\bar{t}$ bound-state effects can be neglected



Higgs radiated off Z:
- $\sigma \approx 0.08$ fb
- Not sensitive to y_t

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Monte Carlo samples

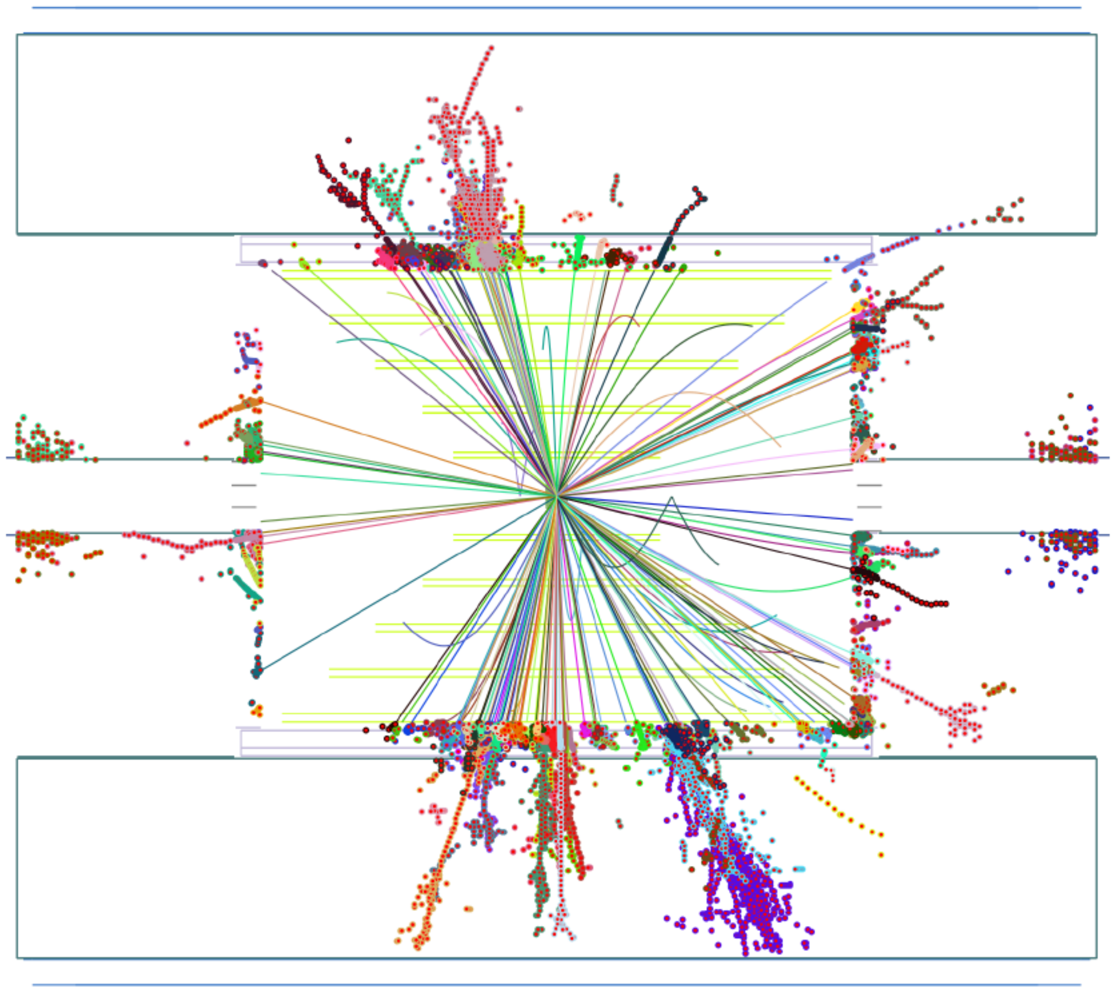
Type	Final state	$P(e^-)$	$P(e^+)$	Cross-section [× BR] (fb)
Signal	$t\bar{t}h$ (8 jets)	-80%	+20%	0.87
Signal	$t\bar{t}h$ (8 jets)	+80%	-20%	0.44
Signal	$t\bar{t}h$ (6 jets)	-80%	+20%	0.84
Signal	$t\bar{t}h$ (6 jets)	+80%	-20%	0.42
Background	other $t\bar{t}h$	-80%	+20%	1.59
Background	other $t\bar{t}h$	+80%	-20%	0.80
Background	$t\bar{t}Z$	-80%	+20%	6.92
Background	$t\bar{t}Z$	+80%	-20%	2.61
Background	$t\bar{t}g^* \rightarrow t\bar{t}b\bar{b}$	-80%	+20%	1.72
Background	$t\bar{t}g^* \rightarrow t\bar{t}b\bar{b}$	+80%	-20%	0.86
Background	$t\bar{t}$	-80%	+20%	449
Background	$t\bar{t}$	+80%	-20%	170

Event reconstruction I

1.) Remove all PFOs with:

- $p_T < 500$ MeV
- $\Theta < 20°$
- $\Theta > 160°$

2.) Remove identified isolated leptons from PFO list



8jet signal event

Event reconstruction II

3.) Perform jet clustering using the Durham algorithm in the exclusive mode with 6 or 8 jets

4.) Obtain b-tag value for each jet using LCFIPlus

5.) Group jets into $W^{\pm}$, H and top pairs by minimising:

6jets:

$$\frac{(M_{12} - M_{W^\pm})^2}{\sigma^2_{W^\pm}} + \frac{(M_{123} - M_t)^2}{\sigma^2_t} + \frac{(M_{45} - M_H)^2}{\sigma^2_H}$$

8jets:

$$\frac{(M_{12} - M_{W^\pm})^2}{\sigma^2_{W^\pm}} + \frac{(M_{123} - M_t)^2}{\sigma^2_t} + \frac{(M_{45} - M_{W^\pm})^2}{\sigma^2_{W^\pm}} + \frac{(M_{456} - M_t)^2}{\sigma^2_t} + \frac{(M_{78} - M_H)^2}{\sigma^2_H}$$

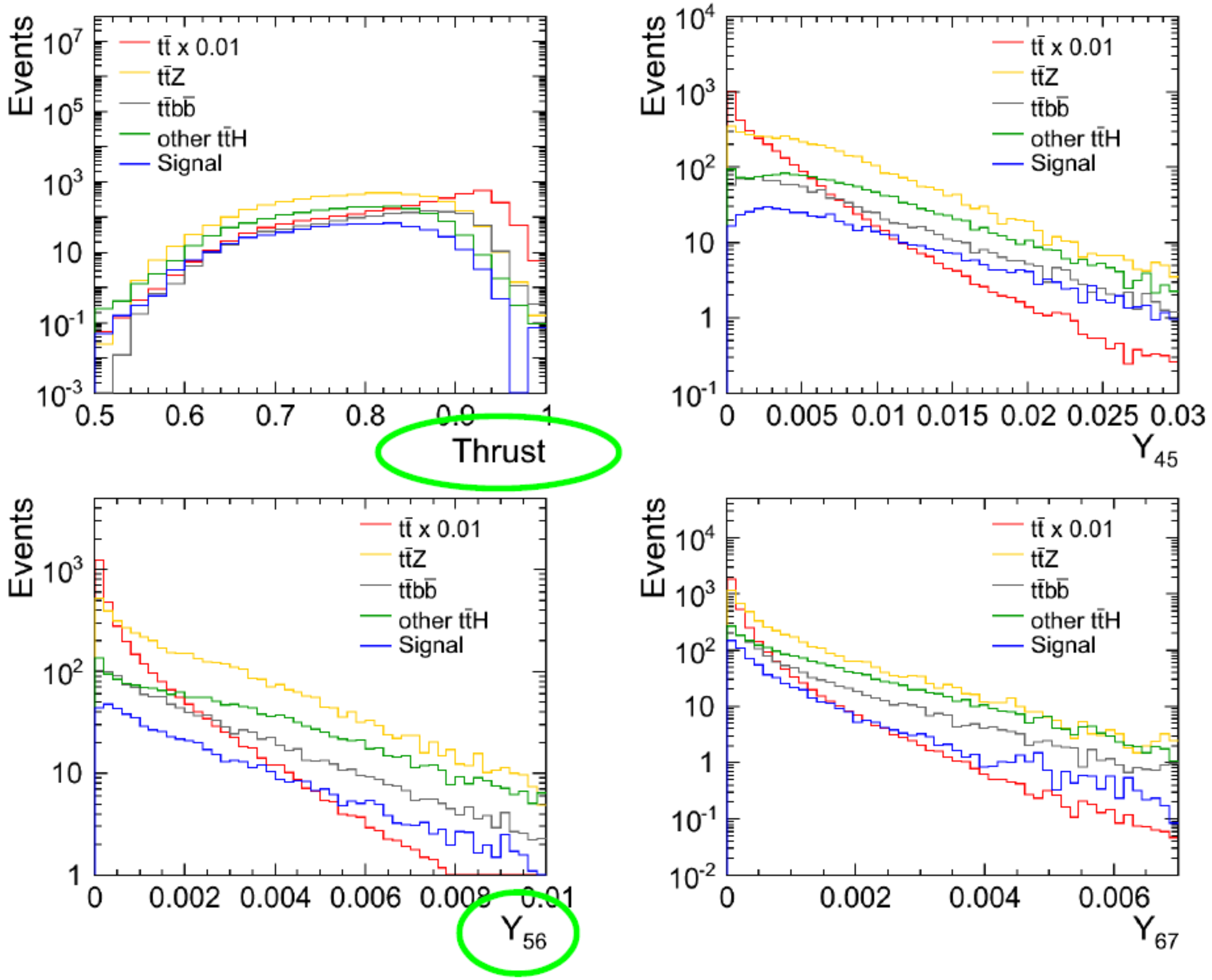
Event selection

Signal events were selected using Boosted Decision Trees (BDTs) as implemented in TMVA.

Input variables for the 6-jet final state:
M_{12}, M_{123}, M_{45}, four highest b-tags values, Thrust, $Y_{5\to6}$,
number isolated leptons, number of PFOs, missing transverse momentum, visible energy
→ 13 variables

Input variables for the 8-jet final state:
M_{12}, M_{123}, M_{45}, M_{456}, M_{78}, four highest b-tags values, Thrust, $Y_{7\to8}$,
number isolated leptons, number of PFOs, missing transverse momentum, visible energy
→ 15 variables

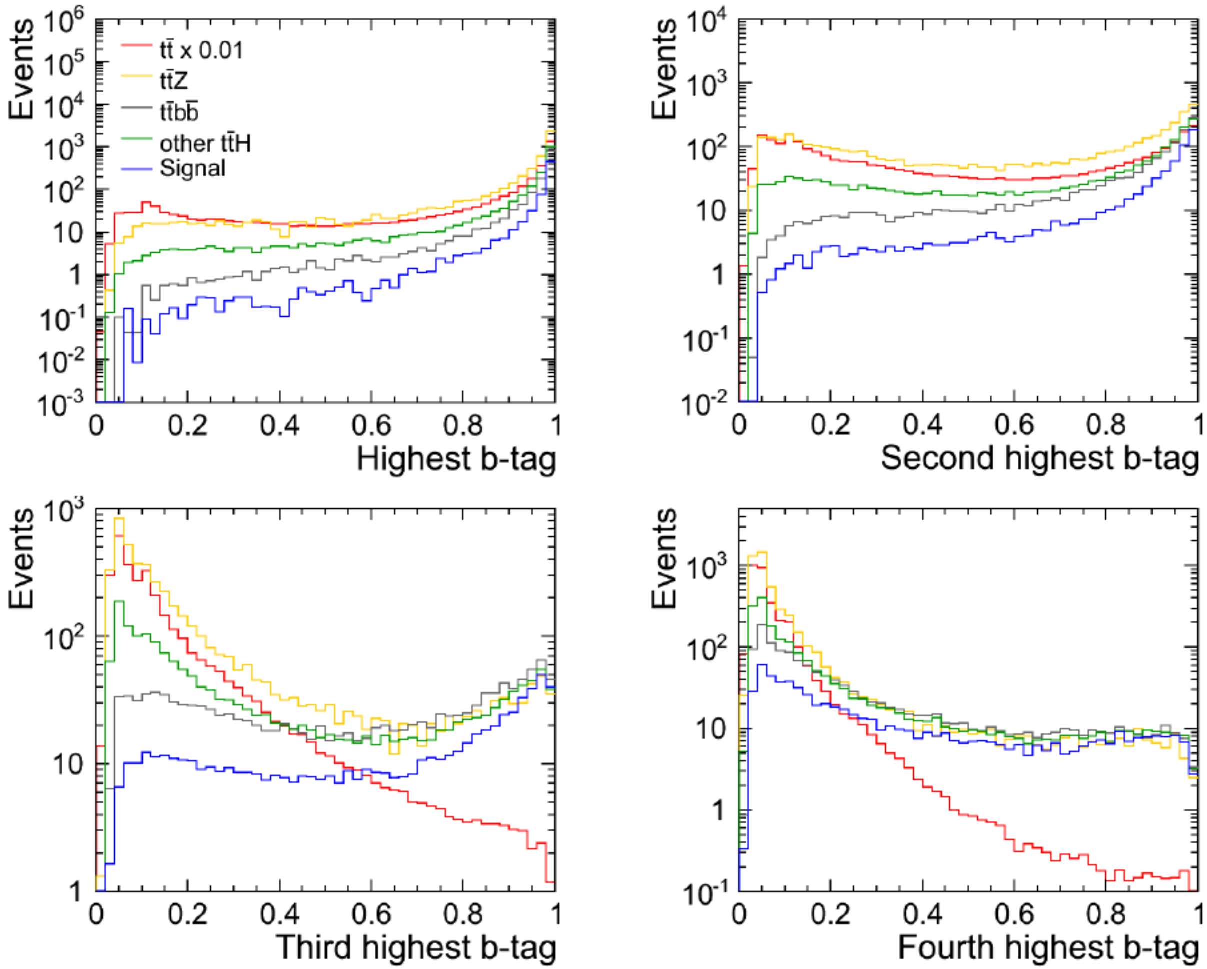
6 jets: selection variables I



- $t\bar{t}$ background scaled by 0.01
- $Y_{5\to6}$ used instead of $Y_{4\to5}$ or $Y_{6\to7}$

L_{int} = 1 ab^{-1}

6 jets: b-tag values



- $t\bar{t}$ background scaled by 0.01
- Signal has 4 b-jets, part of the background samples contain only 2 b-jets

L_{int} = 1 ab^{-1}

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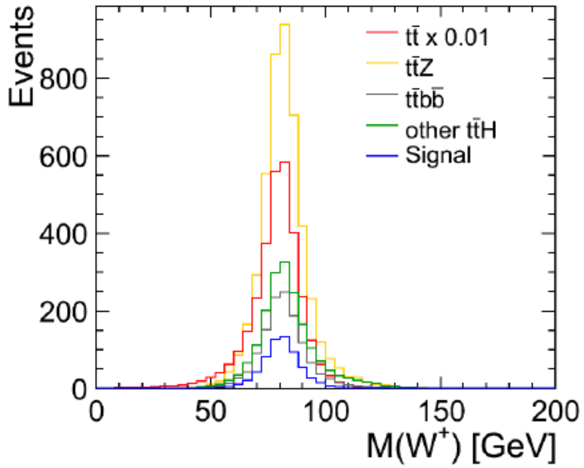
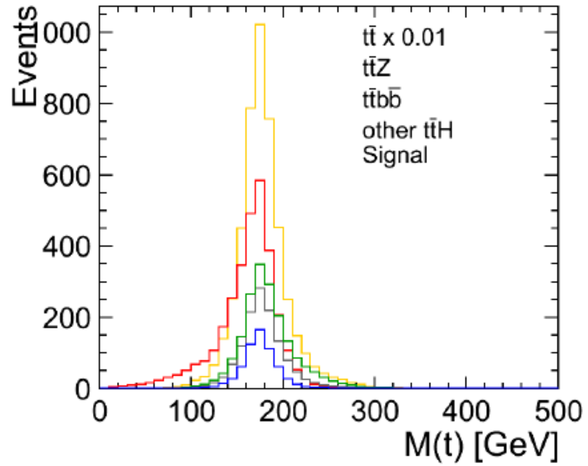
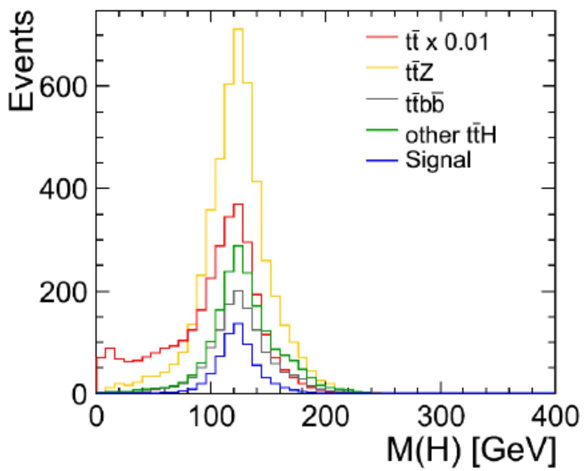
6 jets: W^+/top/Higgs masses



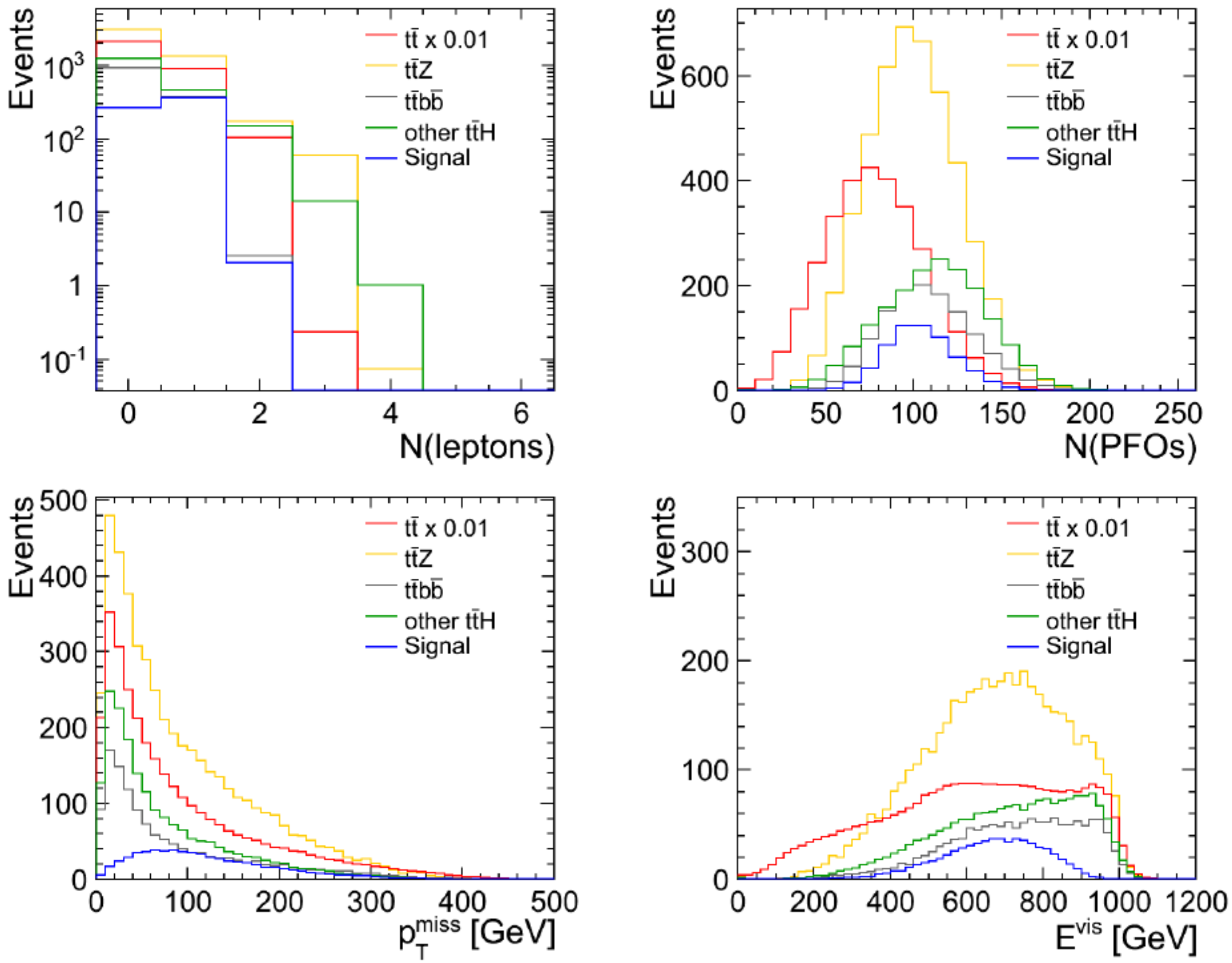




- $t\bar{t}$ background scaled by 0.01
- The background distributions are broader than the signal peaks

$L_{int} = 1\ ab^{-1}$

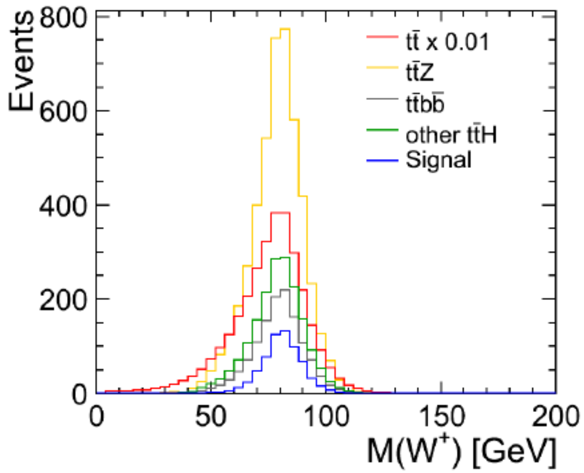
6 jets: selection variables II

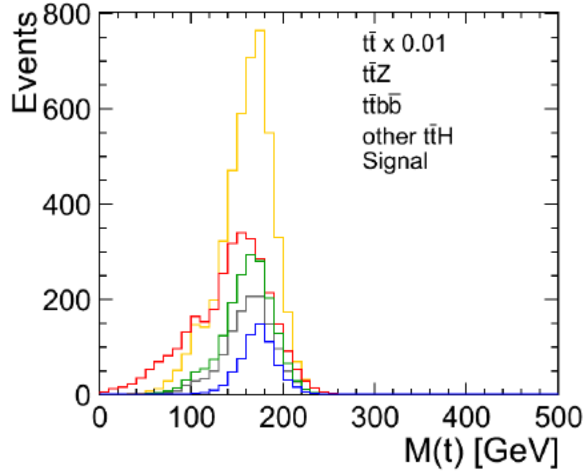


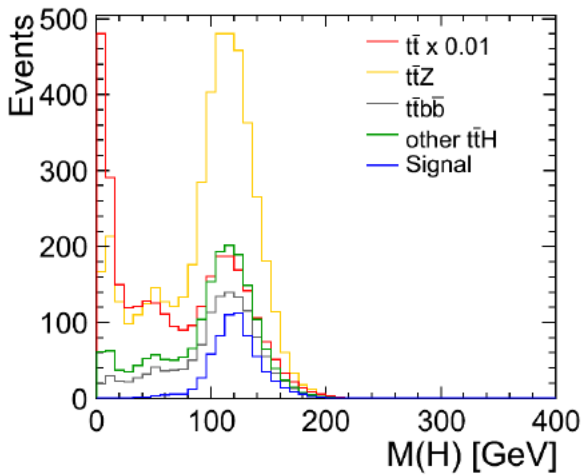
- $t\bar{t}$ background scaled by 0.01

L_{int} = 1 ab^{-1}

8 jets: W^+/top/Higgs masses





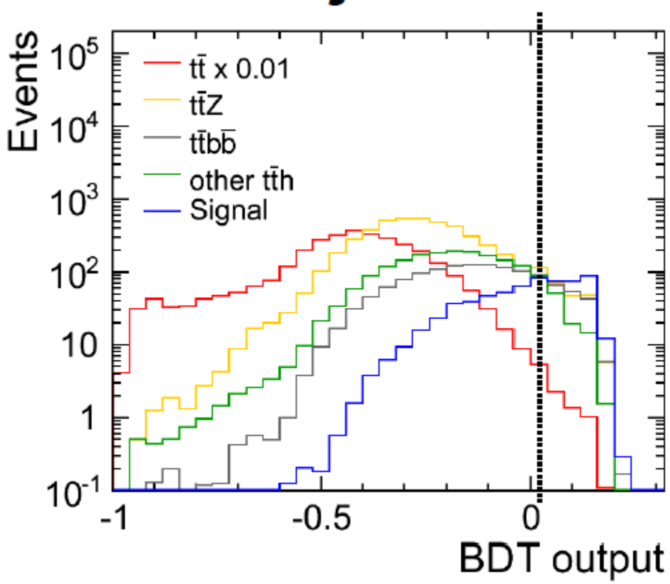


- $t\bar{t}$ background scaled by 0.01
- The background distributions are broader than the signal peaks

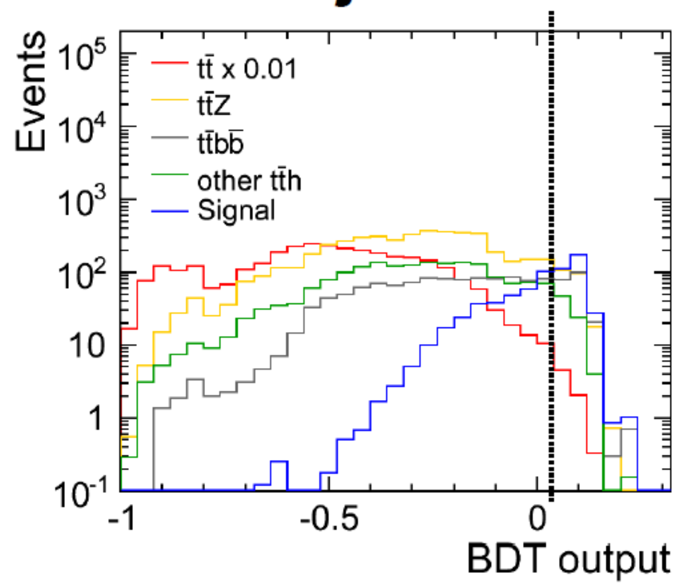
$L_{int} = 1\ ab^{-1}$

BDT outputs and results

6 jets: BDT > 0.0266



8 jets: BDT > 0.0363



Using cut on BDT output with best $S / (S + B)^{½}$

$\Delta\sigma / \sigma = 13.6\% \rightarrow \Delta y_t / y \approx 6.8\%$	$\Delta\sigma / \sigma = 12.3\% \rightarrow \Delta y_t / y \approx 6.2\%$

Combined: $\Delta y_t / y \approx 4.6\%$ 500 **fb^{-1} each pol.** **L_{int} = 1 ab^{-1}**

$\Delta y_t / y \approx 4.1\%$ **all 1 ab^{-1} at P(**e^- / e^+) = −.8 / +.2

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$e^+e^- \rightarrow W^+W^- \quad \sqrt{s} =$ **1 TeV**

Four Jet Topology **($0.8<\cos\Theta<1$ only)**

Two Jets Plus Lepton Topology **($0.8<\cos\Theta<1$ and $-1<\cos\Theta<1$)**

Beam Polarization Measurement Only

Use 50%/50% lumi at $Pol(e^- / e^+) = (-0.8 / +0.2) / (+0.8 / -0.2)$

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$e^+e^- \rightarrow W^+W^- \quad \sqrt{s} =$ **1 TeV**

Count events in bins of ($\cos\Theta, \cos\theta$)

where Θ **is polar angle of** W^- **in lab frame and**

θ **is either the polar angle of the lepton in** W^- **rest frame or an average of all four quark angles in their parent** W **rest frame in the case of the fully hadronic topology.**

To account for detector efficiency and resolution do template fit of parameters a **&** b **where for each bin** i

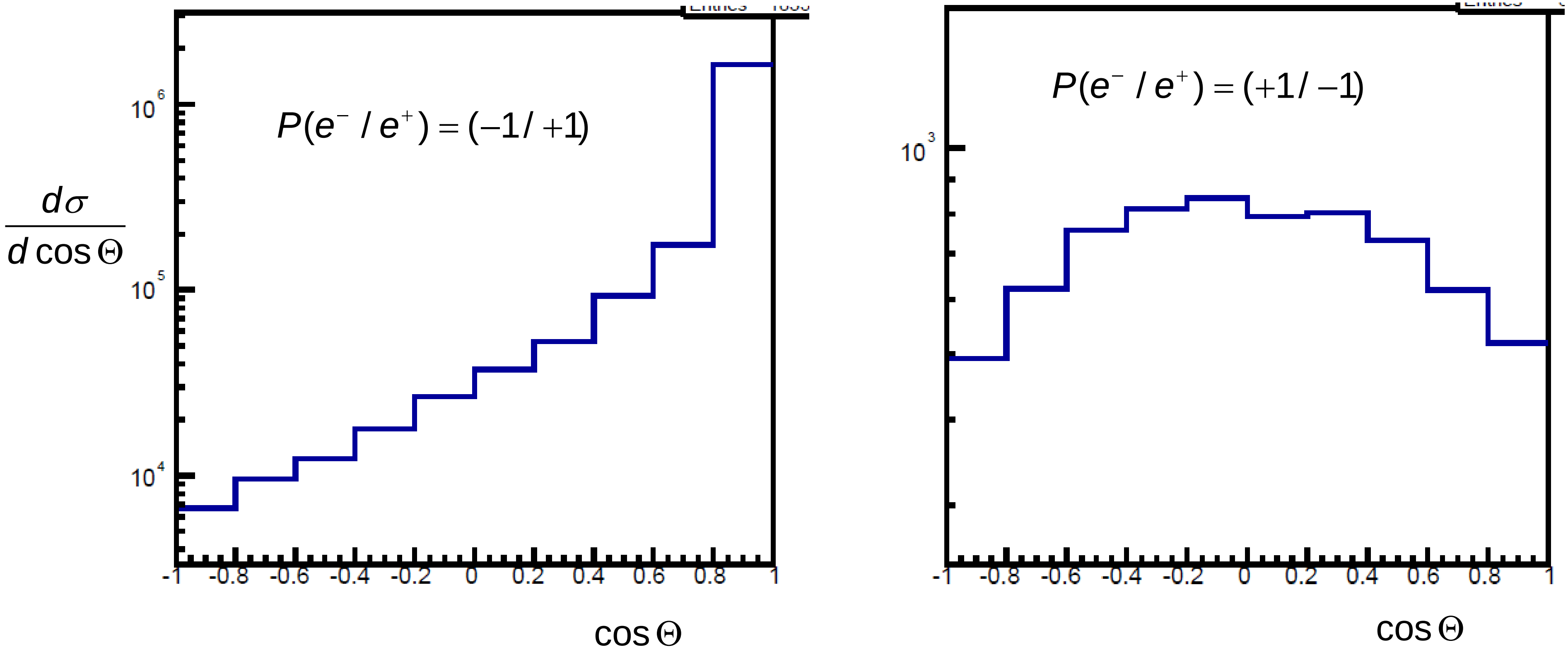
$$N_i = a\int d\vec{x}_i d\vec{x}'\,\eta(\vec{x}')\Omega(\vec{x},\vec{x}')\frac{d\sigma_{LR}}{d\vec{x}'} + b\int d\vec{x}_i d\vec{x}'\,\eta(\vec{x}')\Omega(\vec{x},\vec{x}')\frac{d\sigma_{RL}}{d\vec{x}'}$$

$$a = \frac{(1-P(e^-))(1+P(e^+))}{4}$$

$$b = \frac{(1+P(e^-))(1-P(e^+))}{4}$$

(then convert a **&** b **meas. to** $P(e^-)$ **&** $P(e^+)$ **)**

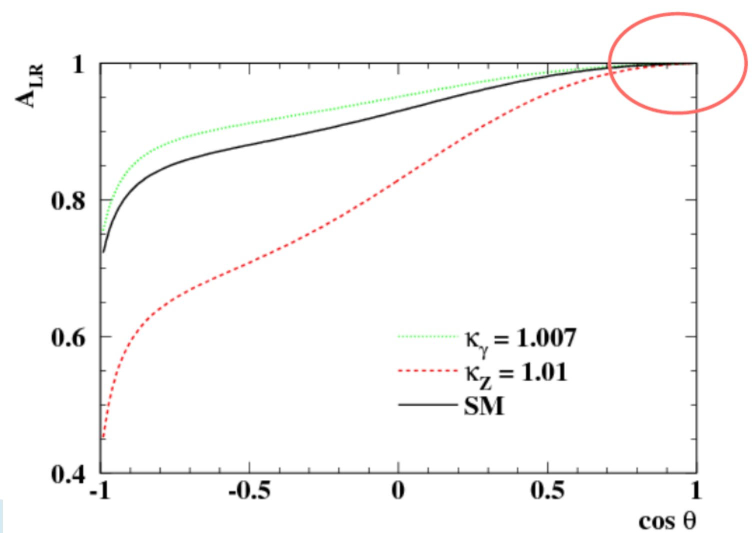
$$e^+e^- \to W^+W^- \quad \sqrt{s} = \textbf{1 TeV}$$



Either fit over entire $\cos\Theta$ **range and assume SM**

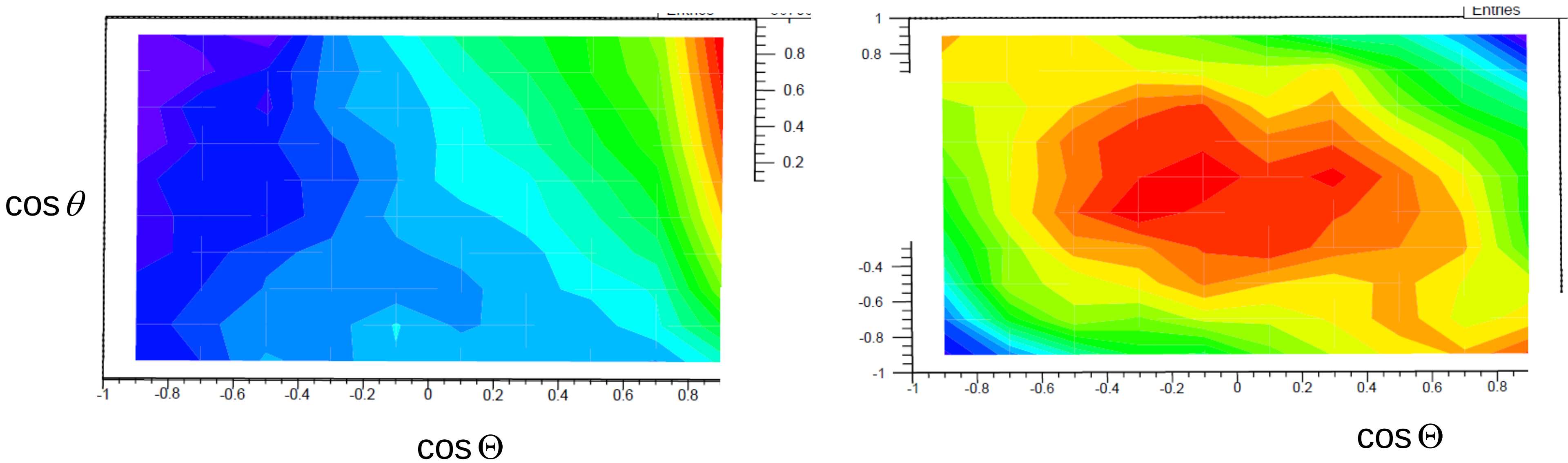
or

restrict fit to $1-\varepsilon < \cos\Theta < 1$



$e^+e^- \to W^+W^- \quad \sqrt{s} = \mathbf{1\ TeV}$

$P(e^- / e^+) = (-1/+1)$ $\qquad$ $P(e^- / e^+) = (+1/-1)$



Four Jet Topology (0.8<cosΘ<1 only)

Two Jets Plus Lepton Topology (0.8<cosΘ<1 and -1<cosΘ<1)

Analysis for $e^{+}e^{-} \rightarrow WW \rightarrow \nu\mu qq$

Require 1 **isolated muon, 0 isolated electron & 0 isolated photon**

Set isolated muon aside and perform jet analysis on remaining PFO's using the kt-algorithm in exclusive mode with 2 jets with ∆R=0.7. This algorithm will identify beams jets and group everything else into 2 jets.

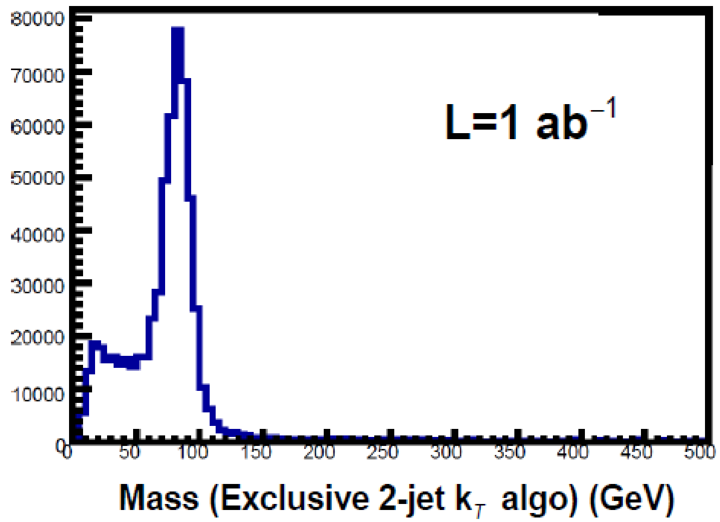
The 2 jets that remain after discarding the beam jets represent the jets from the hadronically decaying W.

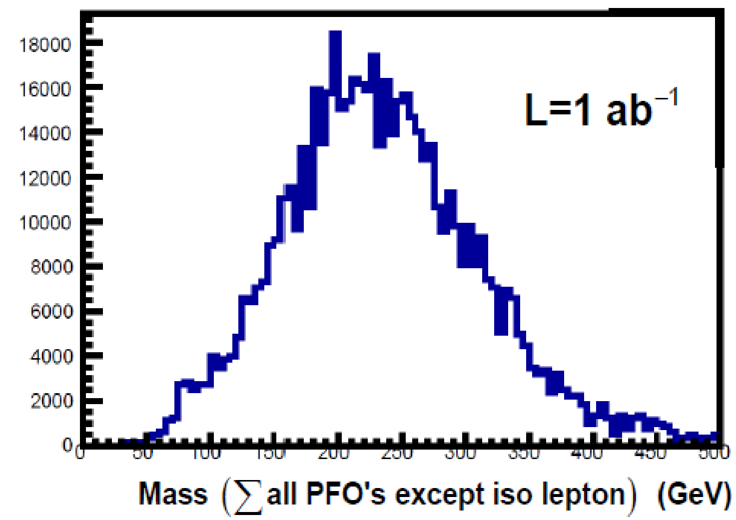
Require

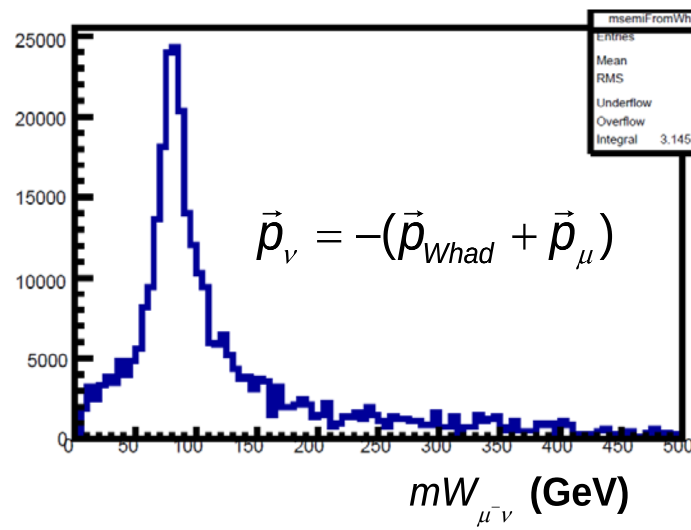
$N_{PFO}(remaining)$ **> 12**

$60 < M_{2j} < 100$ **GeV** $E_{2j} > 300$ **GeV**

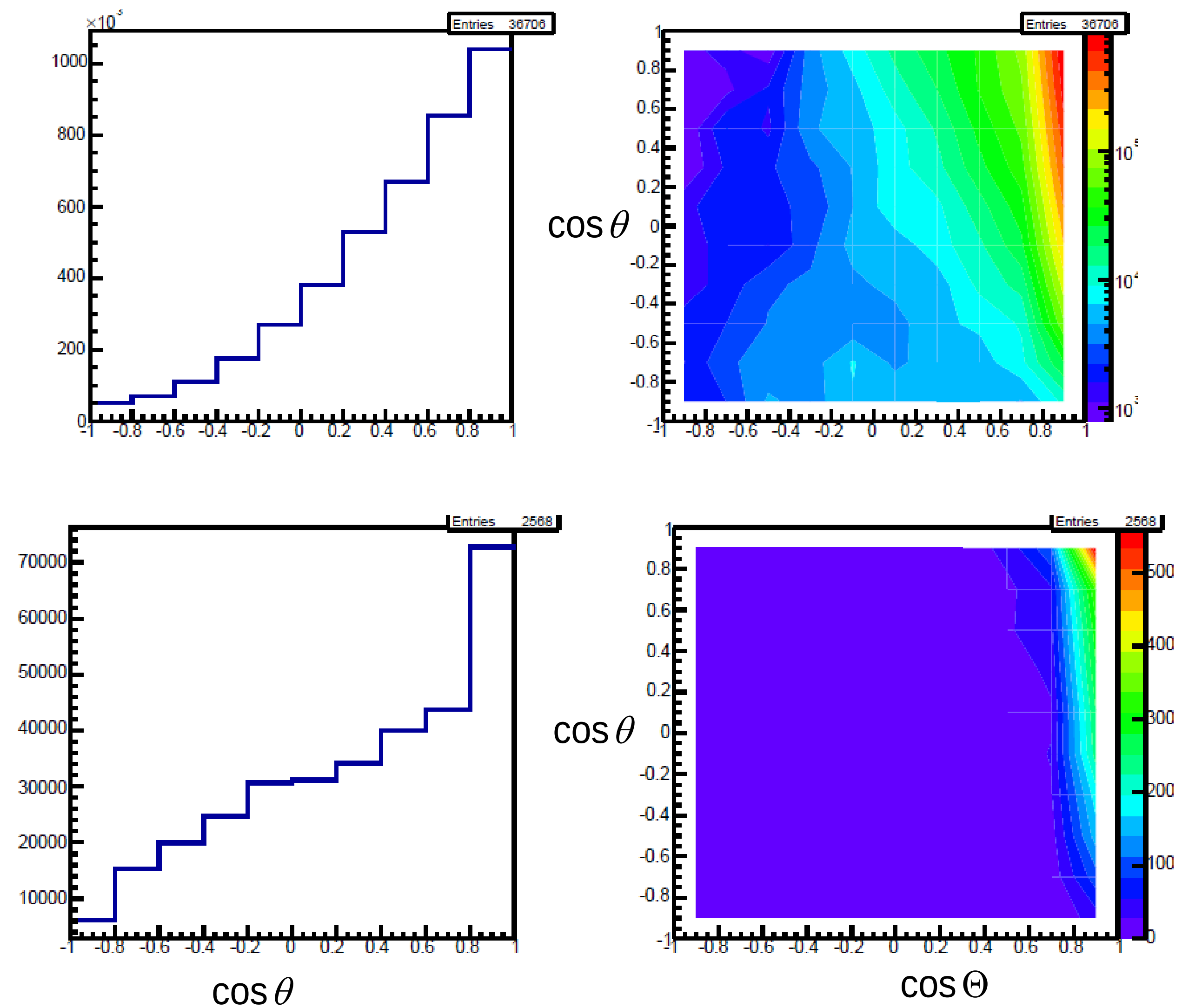
$$e^+e^- \to WW \to \nu\mu qq$$







$$e^+e^- \to WW \to \nu\mu qq$$

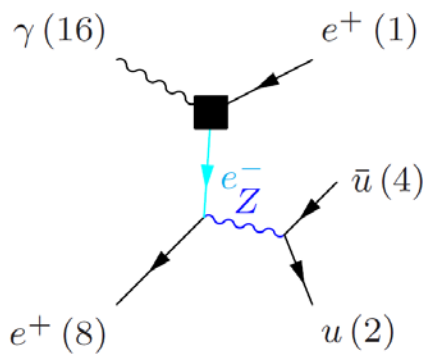


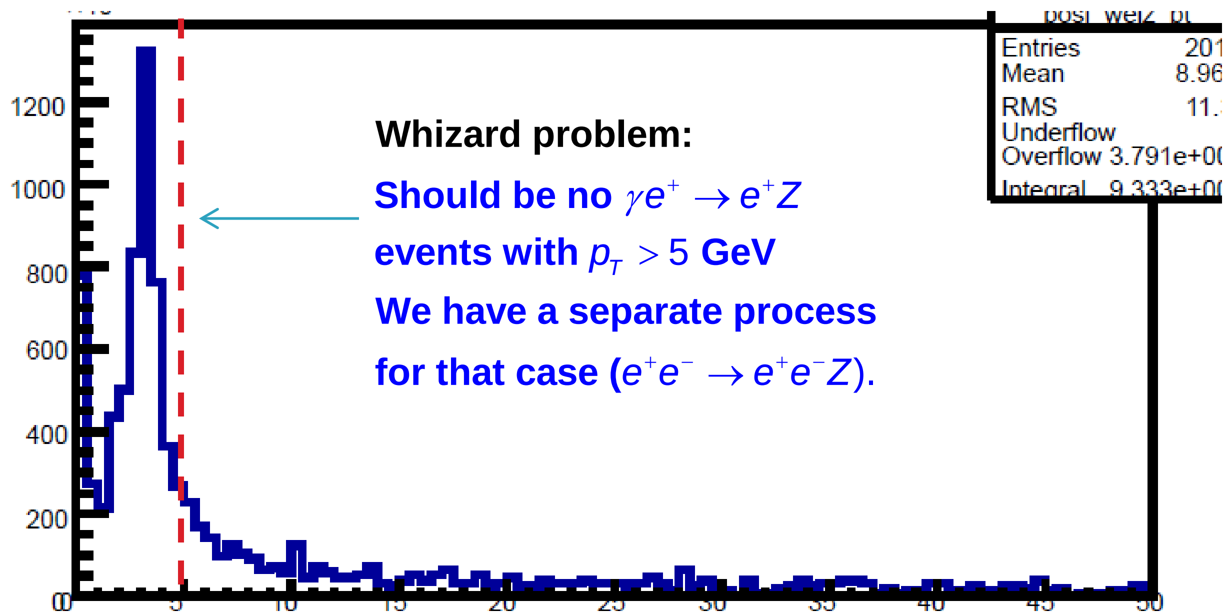
True angles

Reco angles

$$e^+e^- \to WW \to \nu e q q$$

Electron background very different from muon





Whizard problem:

Should be no $\gamma e^+ \to e^+ Z$

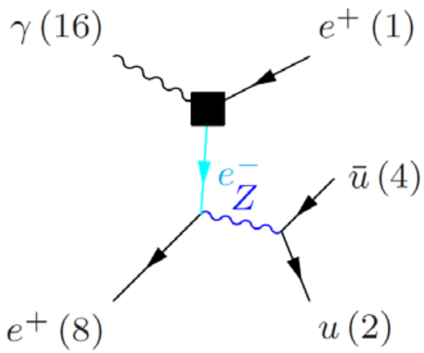
events with $p_T > 5$ GeV

We have a separate process

for that case ($e^+e^- \to e^+e^- Z$).

p_T **(e^- that radiated Weiz-Will γ) (GeV)**

$$e^+e^- \to WW \to \nu eqq$$



Compton scattering problem:

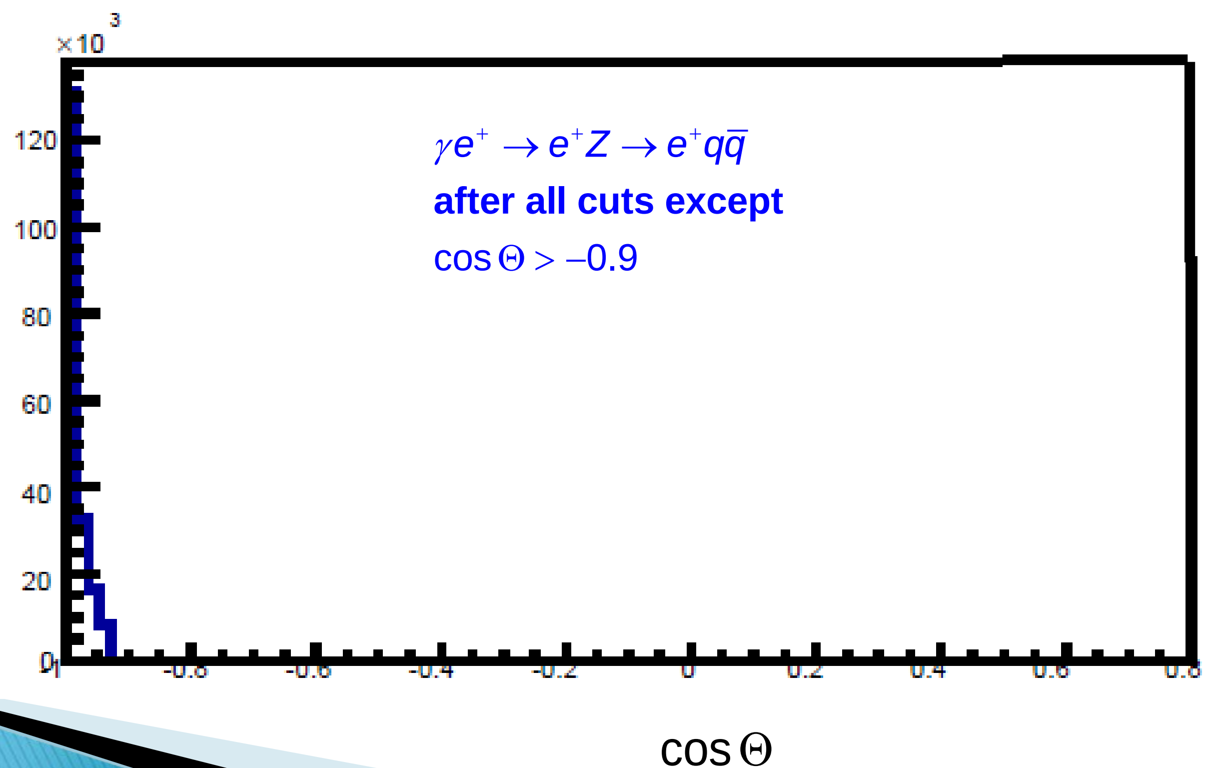
$\gamma e^+ \to e^+ Z$

leads to events with e^+ / e^-

in backwards direction.

For e^+ / e^- only require

cos$\Theta > -0.9$



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$$e^+e^- \to WW \to \nu lqq$$

Table 11.4.3: Number of events passing semileptonic W^+W^- cuts for 500 fb^{-1} luminosity.

Type	Solid Angle	$P(e^-)$	$P(e^+)$	Number of events
Signal	$0.8 < \cos\Theta < 1.0$	-80%	+20%	122300
Signal	$-1 < \cos\Theta < 0.8$	-80%	+20%	37040
Signal	$0.8 < \cos\Theta < 1.0$	+80%	-20%	8490
Signal	$-1 < \cos\Theta < 0.8$	+80%	-20%	3216
Background	$0.8 < \cos\Theta < 1.0$	-80%	+20%	3547
Background	$-1 < \cos\Theta < 0.8$	-80%	+20%	5050
Background	$0.8 < \cos\Theta < 1.0$	+80%	-20%	3985
Background	$-1 < \cos\Theta < 0.8$	+80%	-20%	3699

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Analysis for $e^+e^- \to WW \to qqqq$

Require 0 isolated muons, electrons, & photons

Perform jet analysis using the kt-algorithm in exclusive mode with 4 jets with ΔR=0.7. This algorithm will identify beams jets and group everything else into 4 jets.

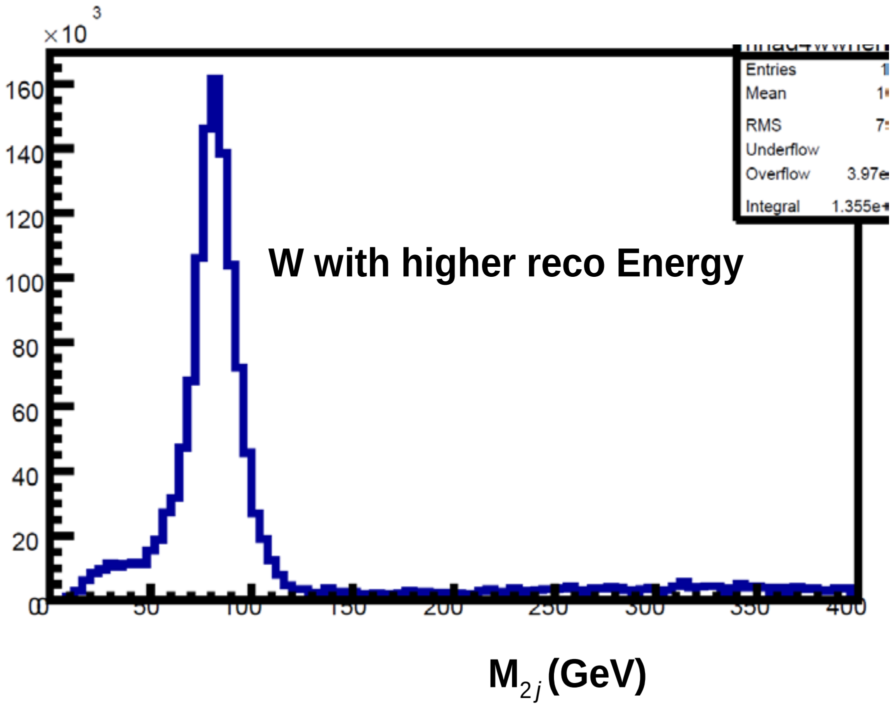
The 4 jets are divided into two 2-jets systems using a chisquare minimization similar to that used in $t\bar{t}h$ analysis

Require

N_{PFO} **> 28**

55 $< M_{2j} < 105$ **GeV** $E_{4j} > 600$ **GeV**

$$e^+e^- \rightarrow WW \rightarrow qqqq$$



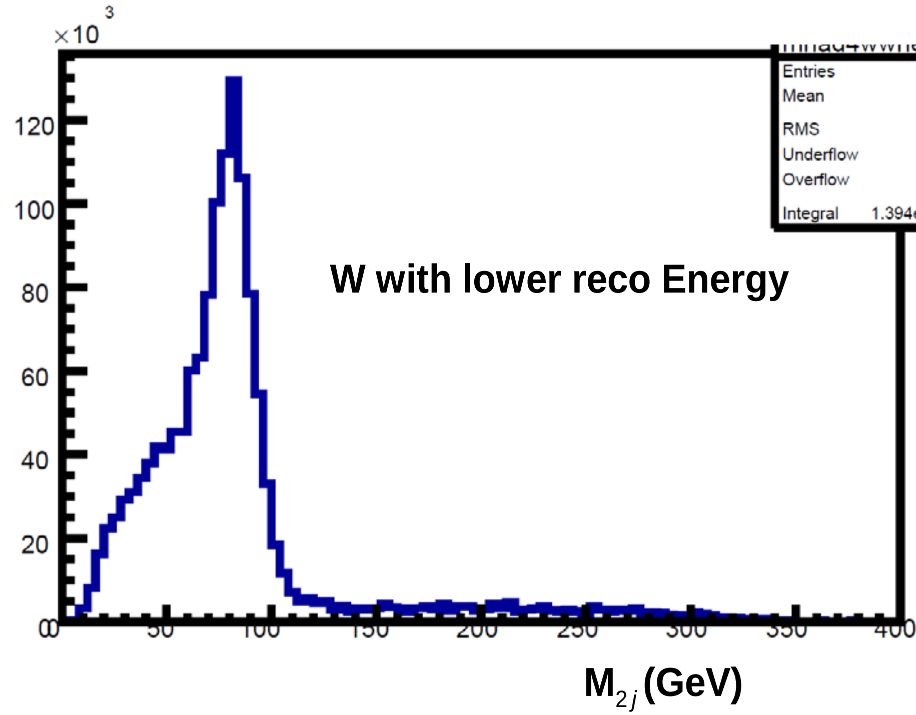


Table 11.4.4: Number of events passing fully hadronic W^+W^- cuts for 500 fb^{-1} luminosity.

Type	Solid Angle	$P(e^-)$	$P(e^+)$	Number of events
Signal	$0.8 < \lvert\cos\Theta\rvert < 1.0$	-80%	+20%	293250
Signal	$0.8 < \lvert\cos\Theta\rvert < 1.0$	+80%	-20%	23720
Background	$0.8 < \lvert\cos\Theta\rvert < 1.0$	-80%	+20%	32971
Background	$0.8 < \lvert\cos\Theta\rvert < 1.0$	+80%	-20%	7851

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$e^+e^- \to W^+W^- \quad \sqrt{s} =$ **1 TeV**

Beam Polarisation Measurements

The effective polarisation parameters a and b are extracted by counting events in bins of $(\cos\Theta, \cos\theta)$ and fitting for a and b with a linear least squares fit:

$$\chi^2 = \sum_i \frac{(N_i - (a\mu_i + b\nu_i)L)^2}{N_i}$$

where N_i is the number of events in bin i, L is the integrated luminosity

$$\mu_i = \int d\vec{x}_i d\vec{x}' \eta(\vec{x}')\Omega(\vec{x}_i, \vec{x}') \frac{d\sigma_{LR}}{d\vec{x}'}$$

$$\nu_i = \int d\vec{x}_i d\vec{x}' \eta(\vec{x}')\Omega(\vec{x}_i, \vec{x}') \frac{d\sigma_{RL}}{d\vec{x}'}$$

Let M_{ki} be the number of events in bin i from a Monte Carlo sample produced with effective beam polarisations a_k and b_k and luminosity L_k.

$$\mu_i = \frac{1}{a_1 b_2 - a_2 b_2}\left[b_2 \frac{M_{1i}}{L_1} - b_1 \frac{M_{2i}}{L_2}\right], \qquad \nu_i = \frac{1}{a_1 b_2 - a_2 b_2}\left[-a_2 \frac{M_{1i}}{L_1} + a_1 \frac{M_{2i}}{L_2}\right].$$

$e^+e^- \to W^+W^- \quad \sqrt{s} =$ **1 TeV**

Table 11.4.5: Polarisation errors assuming 500 fb^{-1} luminosity for each initial state polarisation configuration.

$\cos\Theta$ range	P_{e^-}, P_{e^+}	Δa	Δb	ΔP_{e^-}	ΔP_{e^+}
$0.8 < \cos\Theta < 1$	-0.8,+0.2	0.0011	0.62	3.77	2.51
$0.8 < \cos\Theta < 1$	+0.8,-0.2	0.00030	0.20	0.13	0.27
$-1 < \cos\Theta < 1$	-0.8,+0.2	0.0010	0.084	0.51	0.32
$-1 < \cos\Theta < 1$	+0.8,-0.2	0.00027	0.032	0.020	0.08
$\cos\Theta$ range	P_{e^-}, P_{e^+}	$\Delta\alpha$	$\Delta\beta$	$\Delta\lvert P_{e^-}\rvert$	$\Delta\lvert P_{e^+}\rvert$
$-1 < \cos\Theta < 1$	sum	0.00097	0.00027	0.0017	0.0027

Notes on these errors:

- **Results obtained before Weis-Williams Whizard problem identified. Electron eff. will be higher when final result is calculated leading to improved results.**

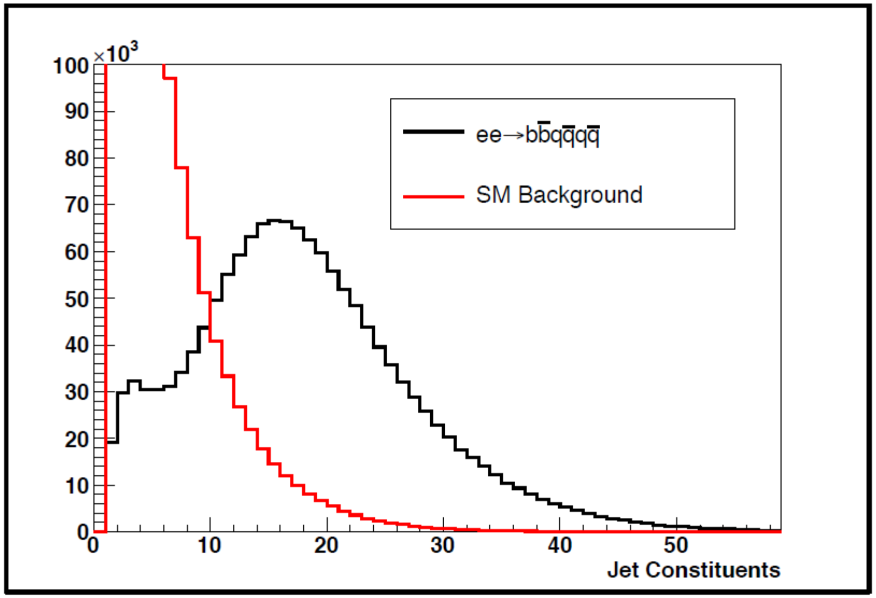
- **Background events do not have a polarization dependence in these results. When background polarization dependence is included Δb improves a lot for $-1 < \cos\Theta < 1$ because of small WW cross sec. for Pol($e^- / e^+) = +1/-1$.**

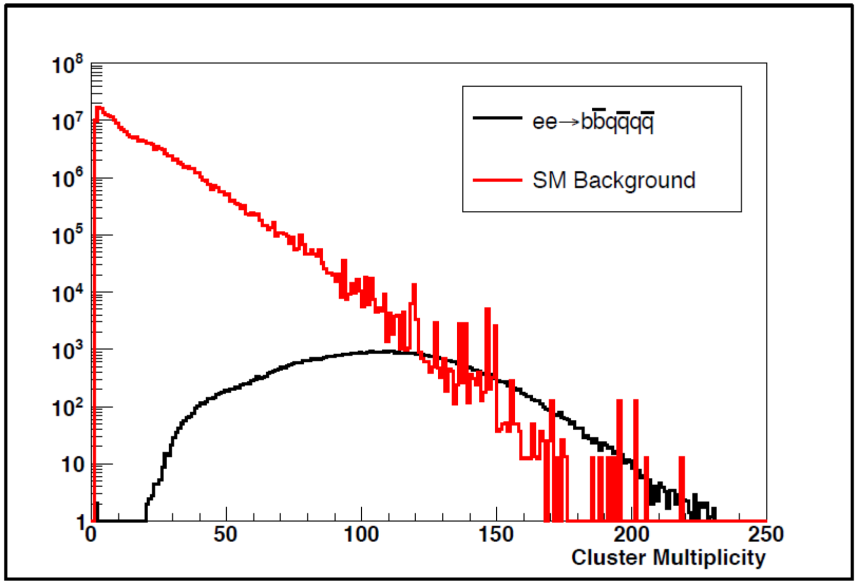
$t\bar{t}$ at $\sqrt{s} = 500$ GeV

preselection

- Reject events with isolated lepton
- Requires 6 jets
- Sum of the jet energy > 400 GeV
- Track multiplicity > 30
- Jet particle constituents > 5
- Sum of the jet particle constituents > 80

$e^+e^- \rightarrow t\bar{t}$





Further Event Selection $e^+e^- \to t\bar{t}$

Using LCFI to identify b-jets require one jet with a b-tag>0.9 and one other jet with b-tag>0.4

Associate other jets with W bosons and perform kinematic fit using these constraints. Use a χ^2 minimization to resolve combinatorics.

Table 11.4.1: Top mass kinematic constraints.

$m(\text{top}_1)$	=	$m(\text{top}_2)$
$m(W_1)$	=	80.4 GeV
$m(W_2)$	=	80.4 GeV
$m(b_1)$	=	5.8 GeV
$m(b_2)$	=	5.8 GeV
E_{tot}	=	$\sqrt{s}$
$\vec{p}_{tot}$	=	0

$$e^+e^- \to t\bar{t}$$

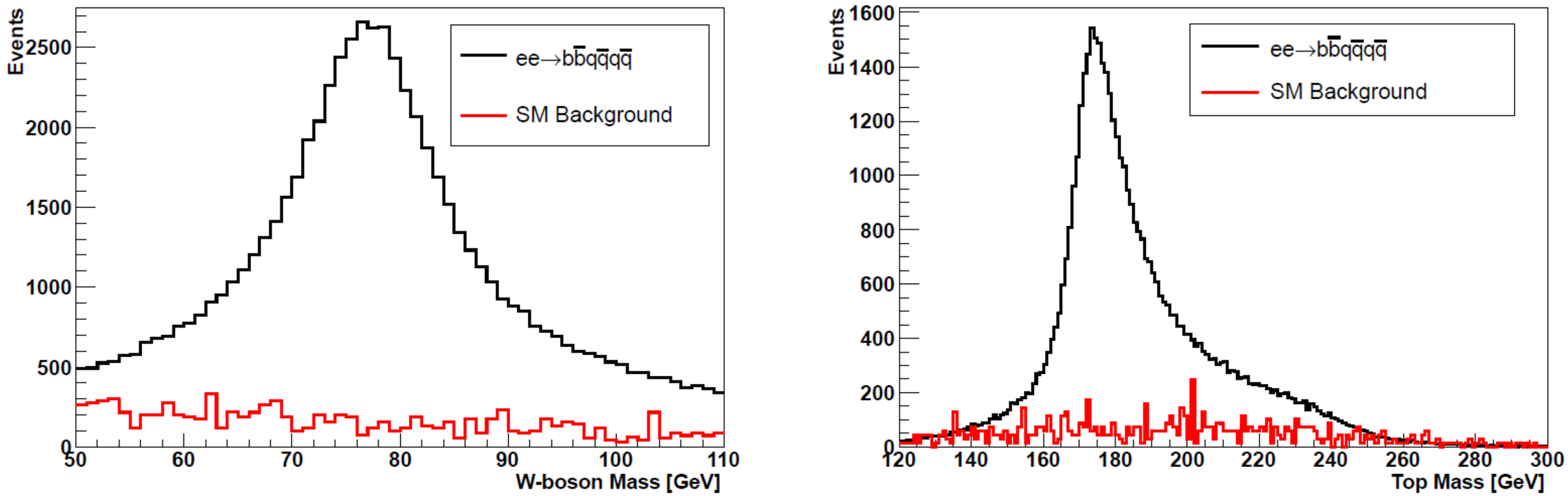


Figure 11.4.9: Mass distribution of the W boson candidates (left) and top quark candidates (right).

For a top mass cut of 145 GeV $< M_t <$ **195 GeV we obtain an efficiency of** $27.2 \pm 0.1\%$, **and a cross section error of** $\mathbf{354.3 \pm 1.4}$ **fb for the polarization** $P(e^- / e^+) = +0.8 / -0.2$

$$e^+e^- \to t\bar{t}$$

$$A_{FB} = \frac{\sigma(\theta < 90^o) - \sigma(\theta > 90^o)}{\sigma(\theta < 90^o) + \sigma(\theta > 90^o)}$$

Define vertex charge & jet charge by $Q = \frac{\sum_j p_j^k Q_j}{\sum_j p_j^k}$

Use single discriminant $C = \frac{1-r}{1+r}; \quad r = \prod_i \frac{f_i^{\bar{b}}(x_i)}{f_i^b(x_i)}$

Results on A_{FB} available soon.

Higgs $\sigma \times$ BR , $H \to bb, cc, WW^*, gg, \mu^+\mu^-$ using $e^+e^- \to \nu\bar{\nu}H$ at $\sqrt{s} = 1$ TeV

Analysis for $e^+e^- \to \nu\bar{\nu}H$

Require

$100 < E(visible) < 400$ **GeV** $\quad$ $20 < p_T(visible) < 250$ **GeV**

Perform jet analysis using the kt-algorithm in exclusive mode with 2 jets with ΔR=1.5.

Fisher discriminants as implemented in TMVA are used to to distinguish a Higgs decay mode from non-Higgs background and other Higgs decay modes. Inputs to the Fisher discriminants include

- **Number of good tracks**
- **Number of isolated leptons**
- *b* **and** *c* **flavor tagging outputs**
- **mass of the 2-jet system and individual jet masses**
- **polar angles of jets**

$e^+e^- \rightarrow \nu\bar{\nu}H$

Table 11.4.1: Simulated data samples used for the $\nu_e\bar{\nu}_e h$ analysis.

Process	Polarization	#events
higgs_ffh_nomu	-80/+20	1,544,398
evW_eeZ_vvZ_semileptonic	-80/+20	6,570,292
all_other_SM_background	-80/+20	3,232,672

The $\Delta\sigma \times BR$ numbers in the Nov 30 draft were way off because event weights were not used (typically 0.3 for signal and 1 - 1000 for background). The table below will be filled in soon. Our apologies for the confusion.

Table 11.4.2: Relative uncertainties on the Higgs $\sigma \times BR$ expected for an integrated luminosity of 1 ab^{-1} at $\sqrt{s}$ =1 TeV using the SiD detector.

h→	#events	$\Delta(\sigma \times BR)$
$b\bar{b}$	xxx	xxx
$c\bar{c}$	xxx	xxx
W^+W^-	xxx	xxx
gg	xxx	xxx

Summary

- Analyses for the tth, WW, $t\bar{t}$, and $\nu\bar{\nu}H$ DBD benchmarks using full simulation and reconstruction for the SiD detector have been presented.
- The top Yukawa coupling results are essentially final
- WW beam polarization results will receive an update with improved electron channel efficiency and the inclusion of background polarization dependence
- Additional results for tt and the Higgs σXBR numbers will be available soon.