# Measurement of the top Yukawa coupling at $\sqrt{s}$ = 1 TeV using the SiD detector
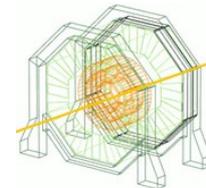
**Philipp Roloff** (CERN), **Jan Strube** (CERN)
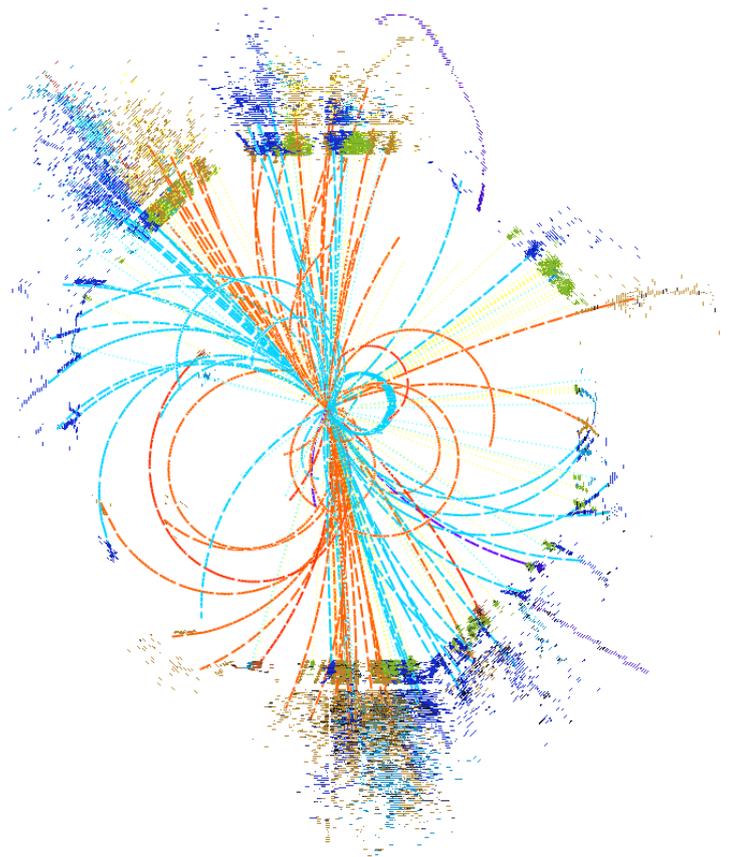
ECFA LC2013, 29/05/2013, DESY Hamburg
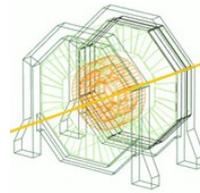
Introduction

- Detector benchmarking processes for the DBD

- **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 ttH production is directly sensitive to the top Yukawa coupling, y_t:

Extraction of the top Yukawa coupling
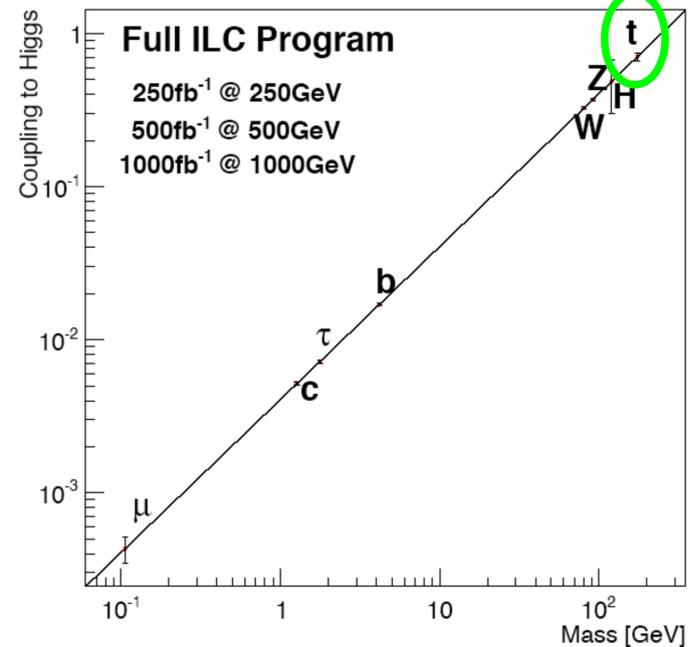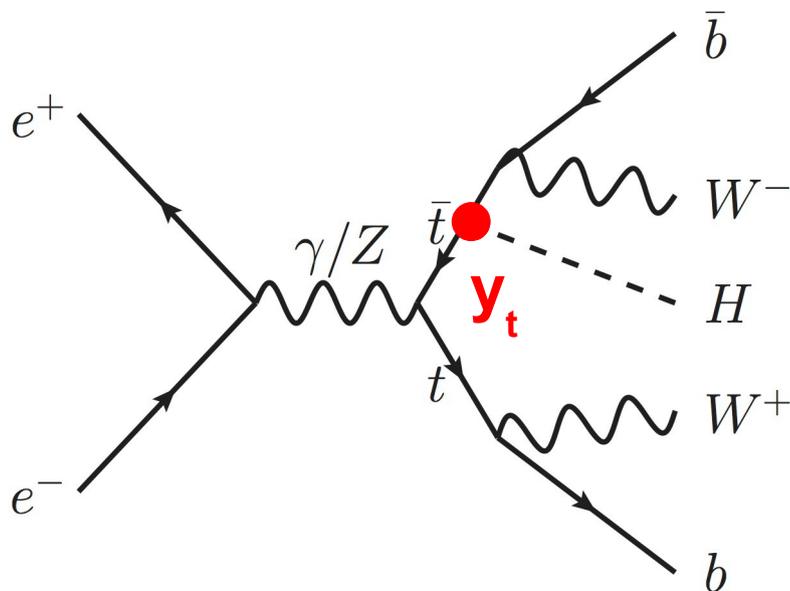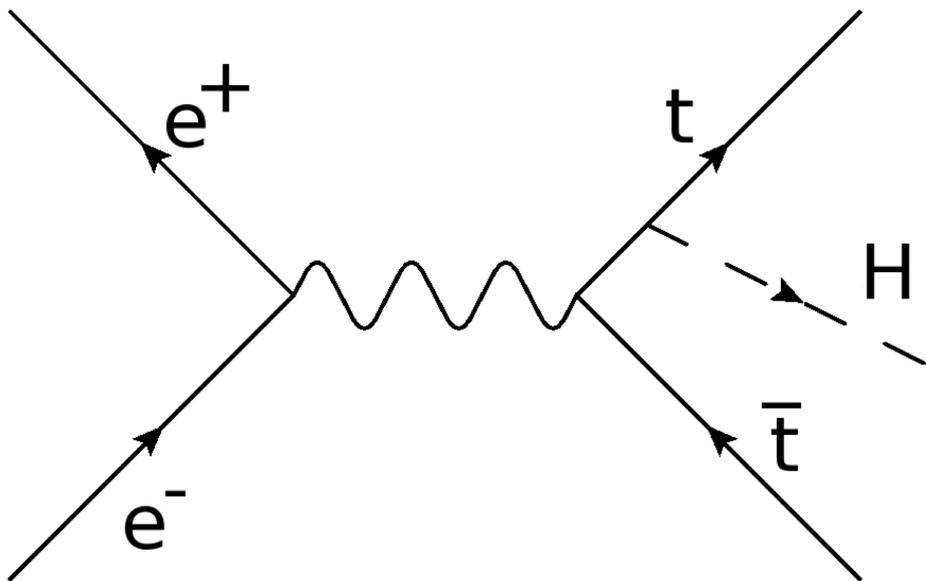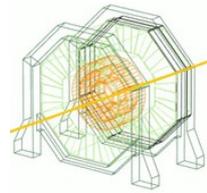
Without contribution from Higgsstrahlung:

$$\frac{\Delta y_t}{y_t} = 0.5 \frac{\Delta \sigma}{\sigma}$$
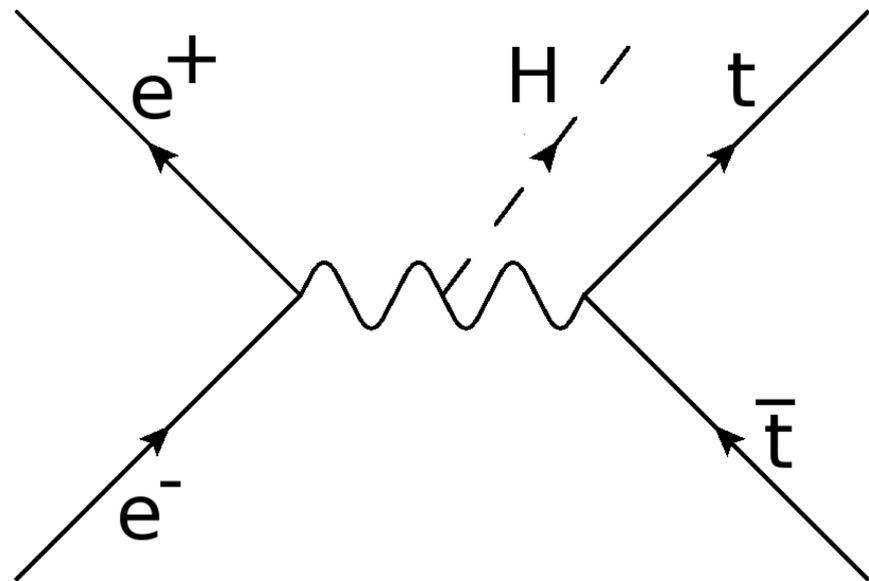
Including Higgsstrahlung:

$$\frac{\Delta y_t}{y_t} = 0.52 \frac{\Delta \sigma}{\sigma}$$

Signal and background processes
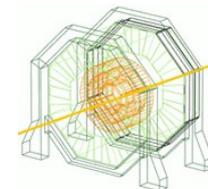
| Type	Final state	$P(e^-)$	$P(e^+)$	Cross section [$\times$ BR] (fb)
Signal	$t\bar{t}H$ (8 jets)	-80%	$+20\%$	0.87
Signal	$t\bar{t}H$ (8 jets)	$+80\%$	-20%	0.44
Signal	$t\bar{t}H$ (6 jets)	-80%	$+20\%$	0.84
Signal	$t\bar{t}H$ (6 jets)	$+80\%$	-20%	0.42
Background	other $t\bar{t}H$	-80%	$+20\%$	1.59
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	$t\bar{t}g^* \to t\bar{t}b\bar{b}$	-80%	$+20\%$	1.72
Background	$t\bar{t}g^* \to t\bar{t}b\bar{b}$	$+80\%$	-20%	0.86
Background	$t\bar{t}$	-80%	$+20\%$	449
Background	$t\bar{t}$	$+80\%$	-20%	170
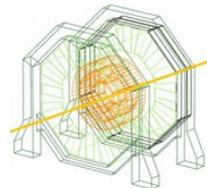
Event simulation

- **Full simulation** (Geant4) of the sidloi3 detector (used for DBD benchmark studies)

- The physics events were overlaid with beam-induced backgrounds corresponding to 1 BX (see next slide)

- PandoraPFA for particle flow reconstruction

Beam-induced backgrounds
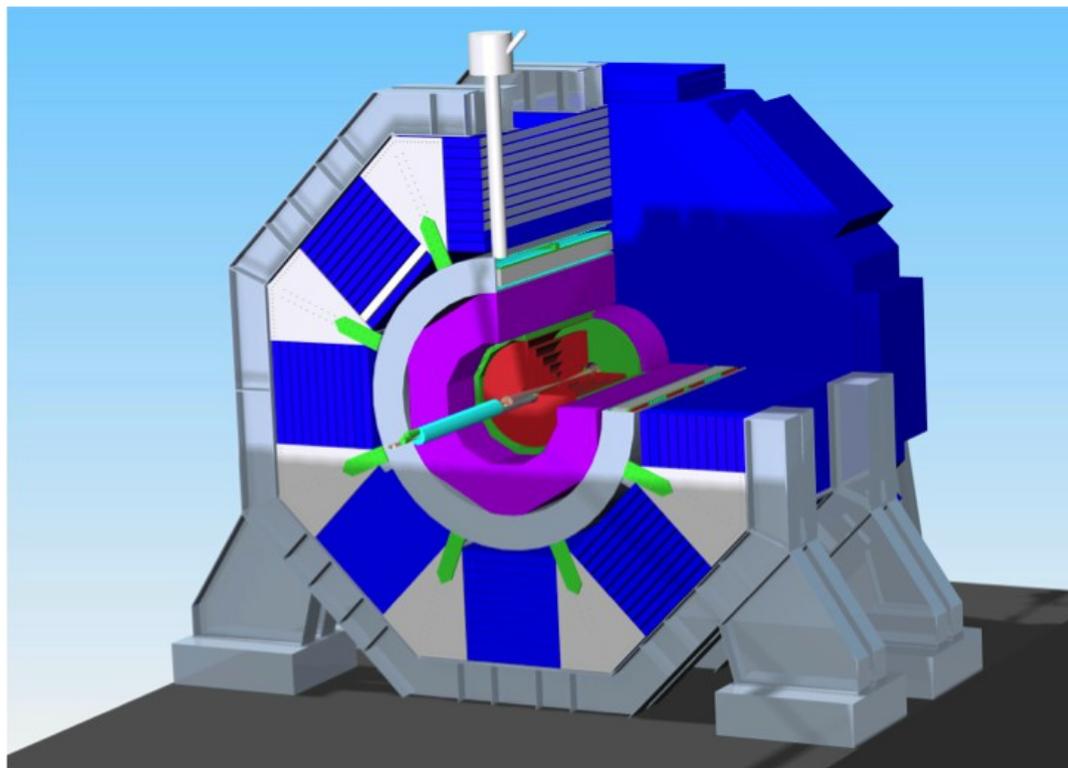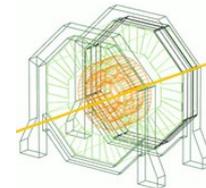
e⁺e⁻ pairs
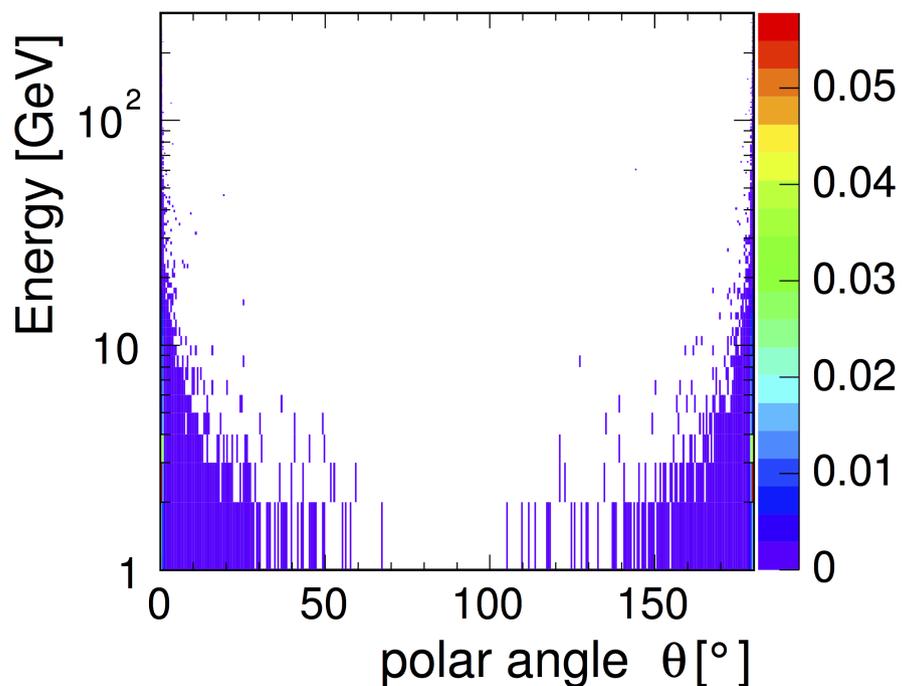
450000 particles per BX

γγ → hadrons
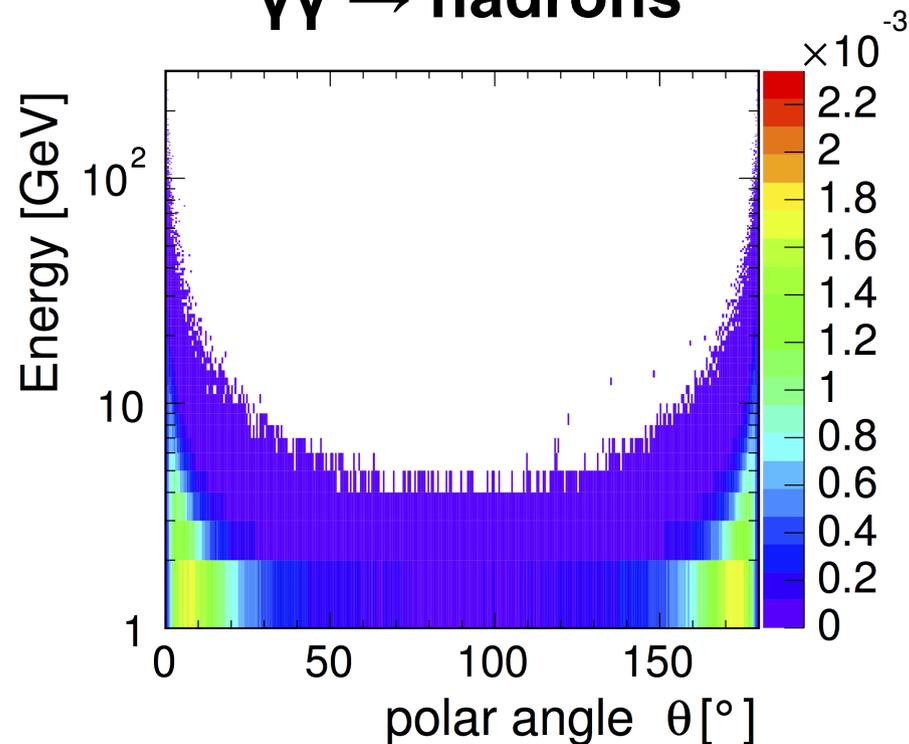

4.1 interactions per BX

- The particles from beam-induced backgrounds processes peak in the forward direction
- The ttH signal events are central (s-channel process)

Beauty-jet tagging
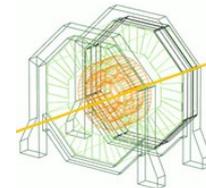
- Based on the LCFIPlus package
- Cuts adjusted for the SiD detector geometry
- Trained using bbbbbb, cccccc, qqqqqq at 1 TeV
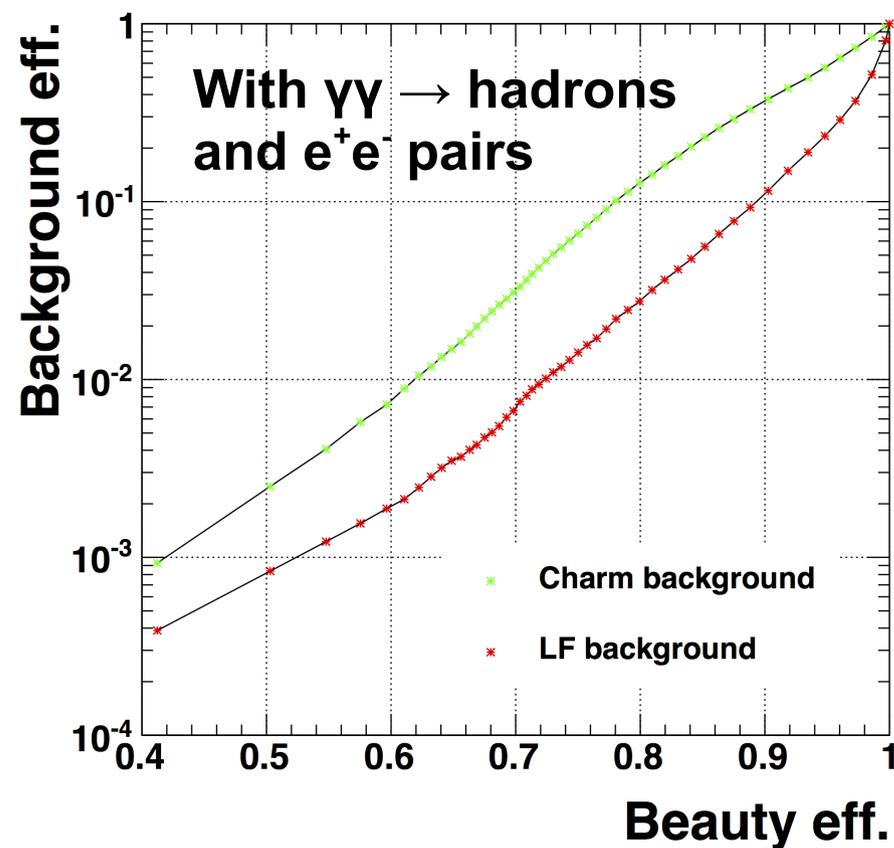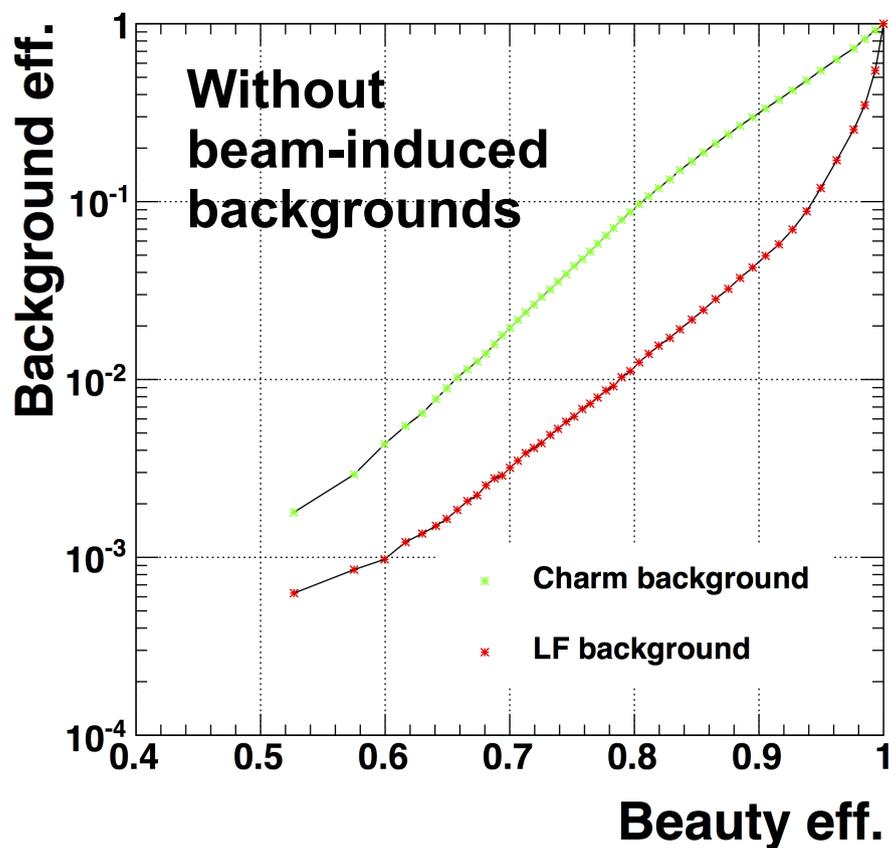
Test of the flavour tagging performance in $Z \to b\bar{b}$, $c\bar{c}$, $q\bar{q}$ events

Isolated lepton selection
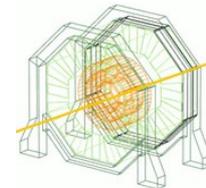
Kinematic Cuts:

- $\cos(\Theta_{cone}) > 0.99$

- $E_{Track} > 15$ GeV

- $E_{Cone} < (3.0 \cdot E_{Track})^{1/2}$

PID:

- Electrons:

$0.95 < E_{ECal}/E_{(HCal+ECal)} < 1$

and $0.85 < E_{ECal}/p_{track} < 1.15$

- Muons:

$0.03 < E_{ECal}/E_{HCal+ECal} < 0.2$ and $0.0 < E_{ECal} / p_{Track} < 0.4$

Lifetime information:

- $0 < d_0 < 0.02$ mm $0 < z_0 < 0.1$ mm $0 < d_0(3D) < 0.1$ mm

$$E_{Cone} = \sqrt{\frac{3.0}{GeV} E_{Track}} \; GeV$$

Event reconstruction I
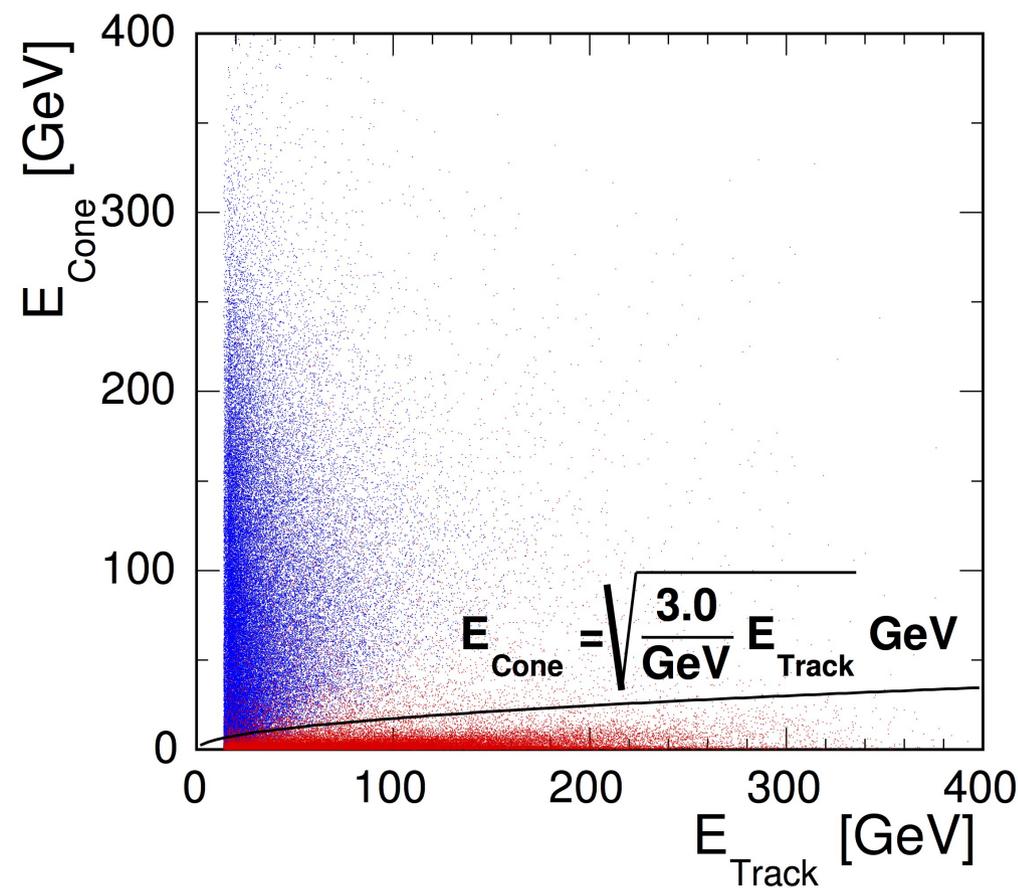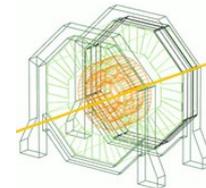
1.) Remove all PFOs with:

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

2.) Remove identified
isolated leptons
from PFO list

8jet signal event

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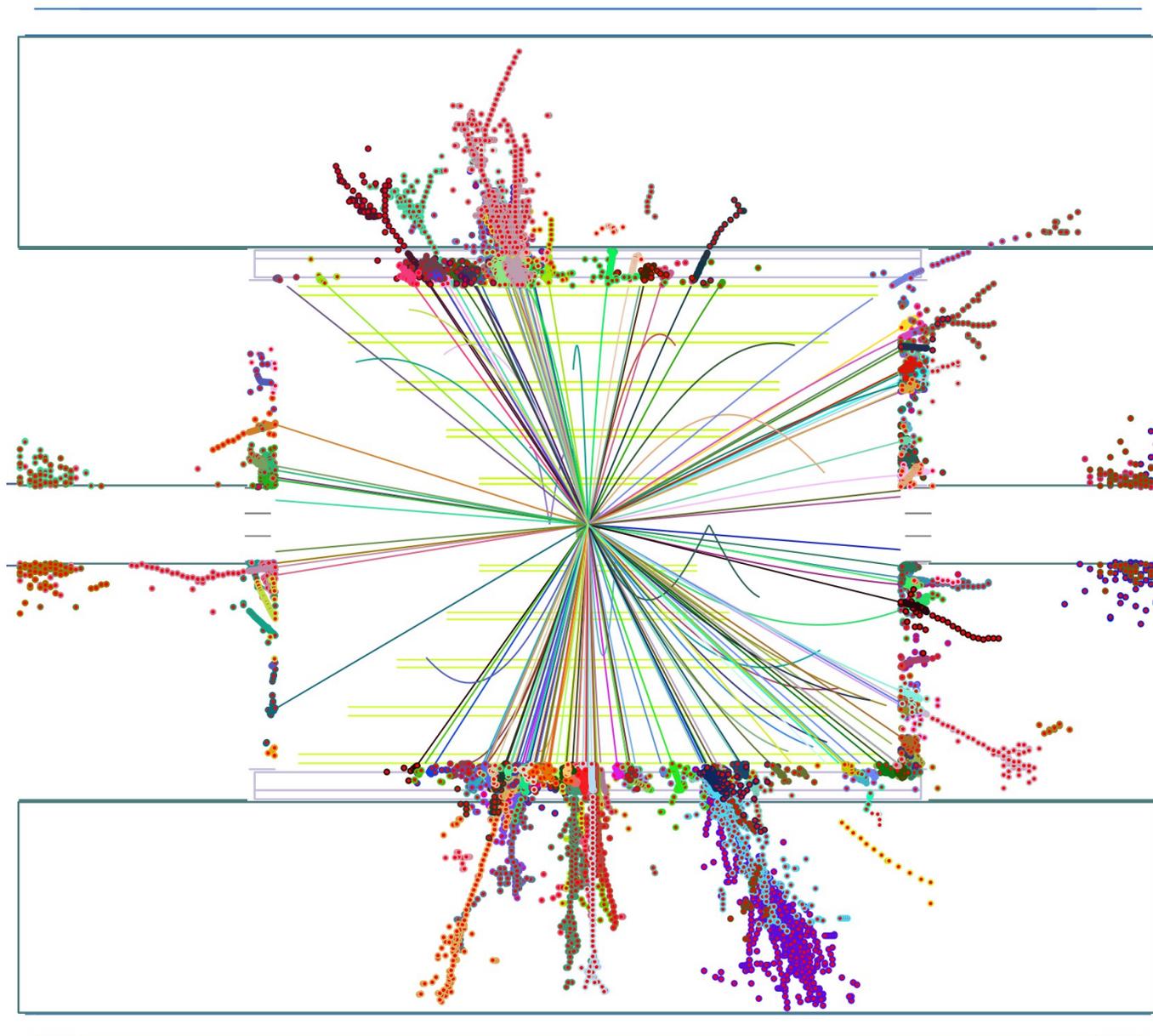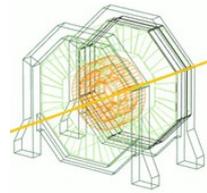
3.) Perform jet clustering using the Durham algorithm in the exclusive mode with 6 or 8 jets

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

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

6jets: $\dfrac{(M_{12} - M_{W\pm})^2}{\sigma^2_{W\pm}} + \dfrac{(M_{123} - M_t)^2}{\sigma^2_t} + \dfrac{(M_{45} - M_H)^2}{\sigma^2_H}$

8jets:

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

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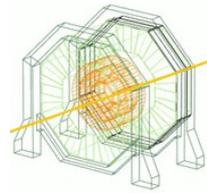
Signal events were selected using Boosted Decision Trees (BDTs) as implemented in TMVA.

Input variables for the 6-jet final state:
M_{12}, M_{123}, M_{45}, four highest b-tags values, Thrust, Y_{56}, 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_{78}, number isolated leptons, number of PFOs, missing transverse momentum, visible energy
→ 15 variables
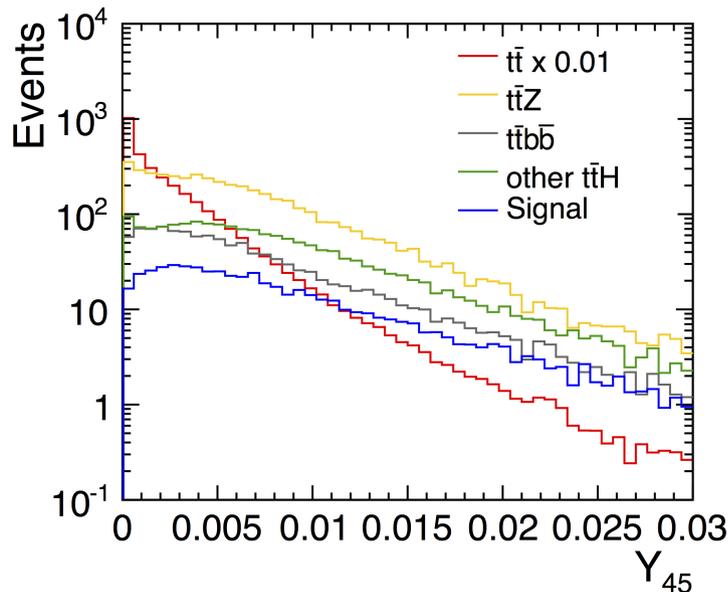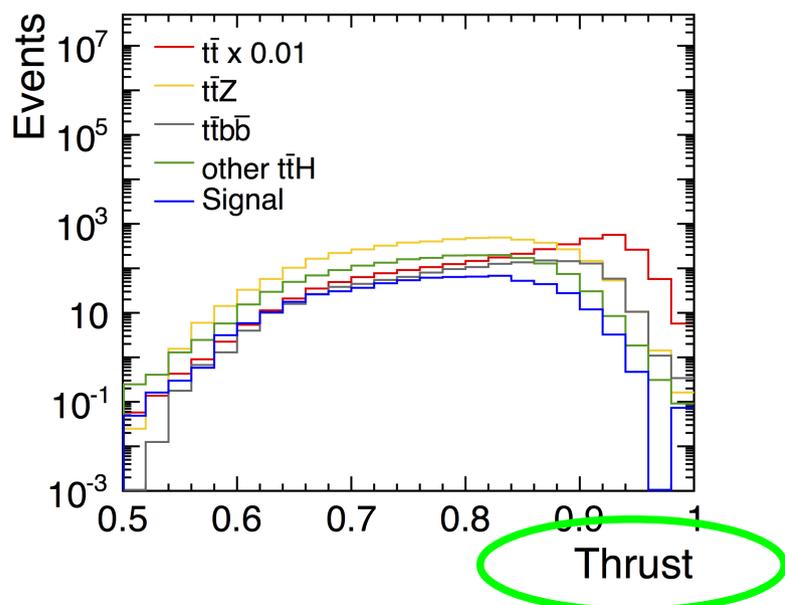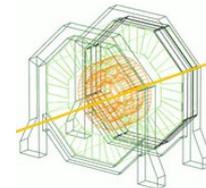
- t$\bar{\text{t}}$ background scaled by 0.01

- Y_{56} used instead of Y_{45} or Y_{67}
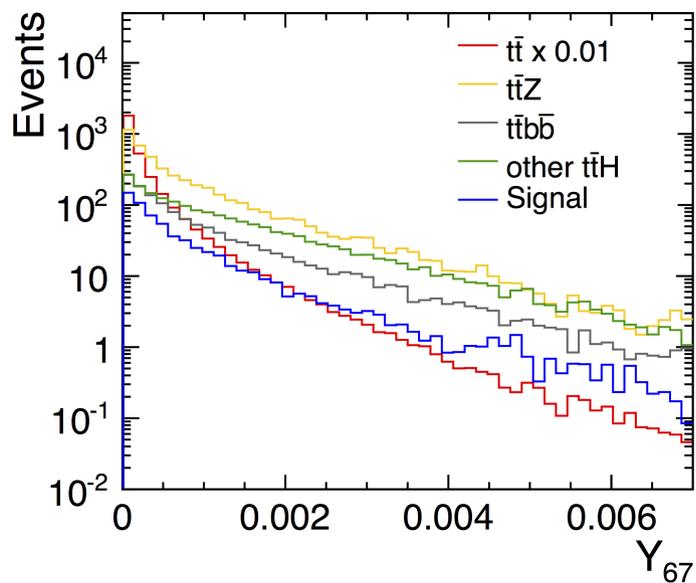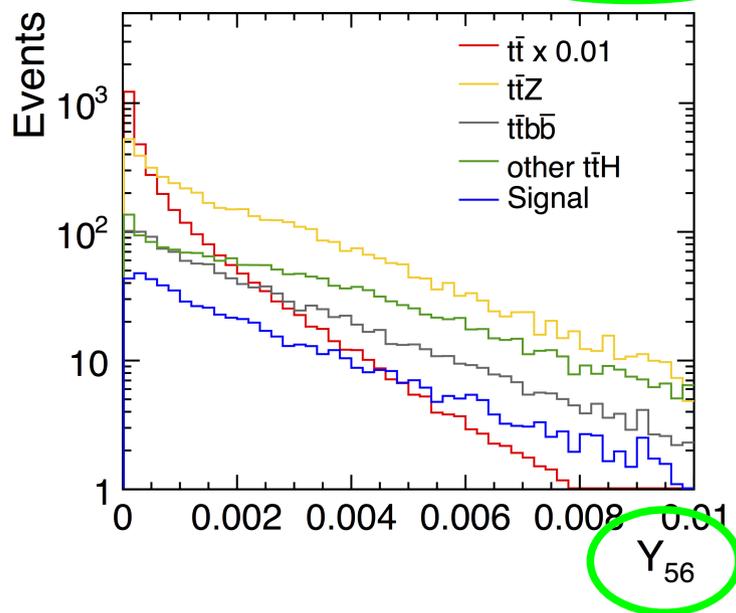
$L_{int} = 1 \text{ ab}^{-1}$
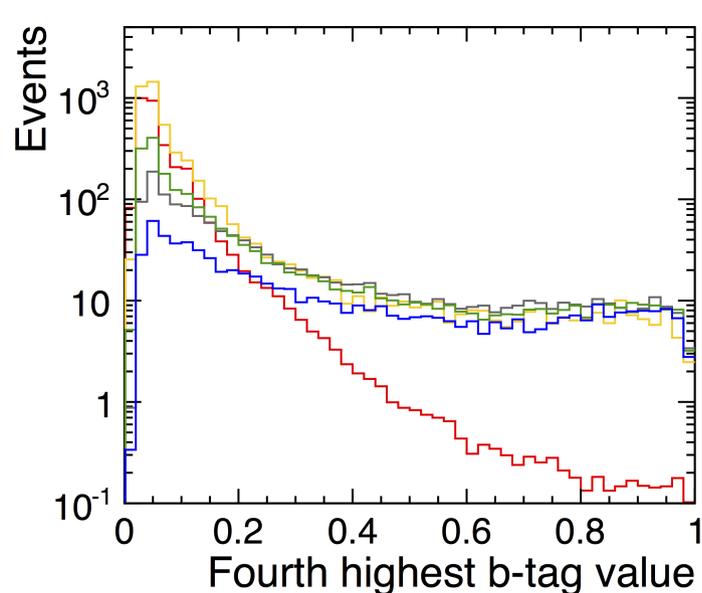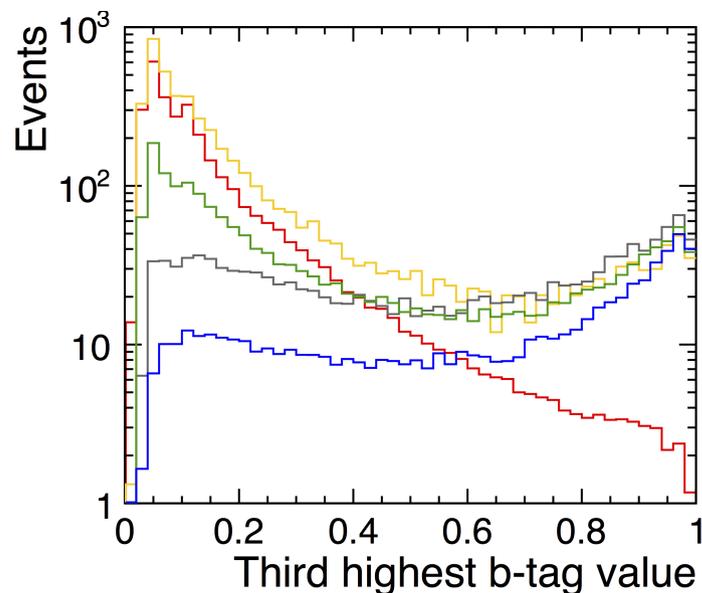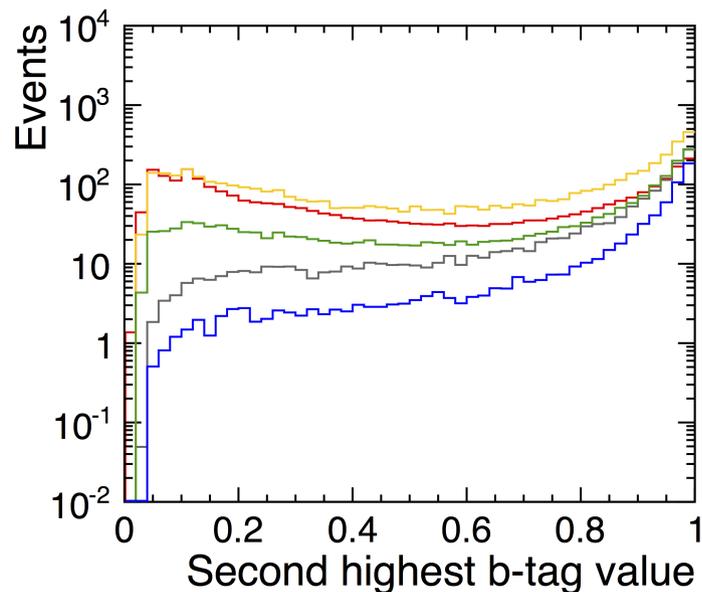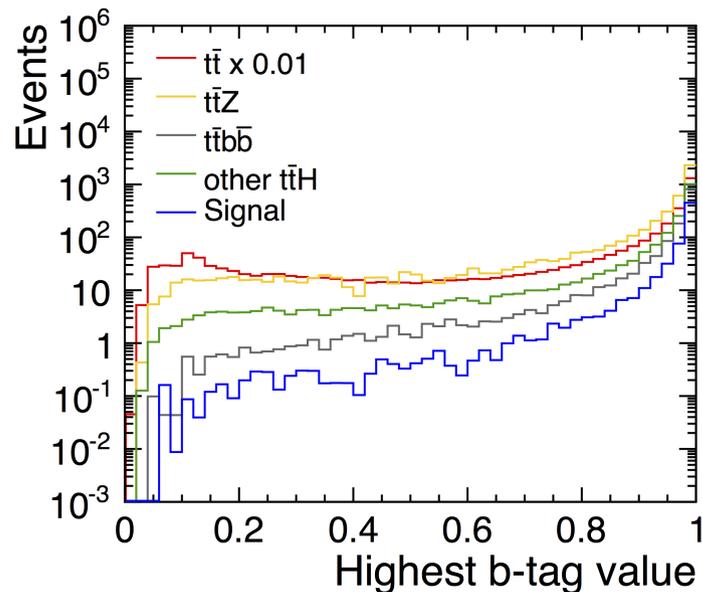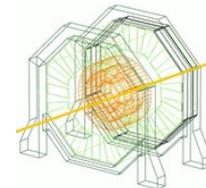
- $t\bar{t}$ background scaled by 0.01

- Signal has 4 b-jets, part of the background samples contain only 2 b-jets
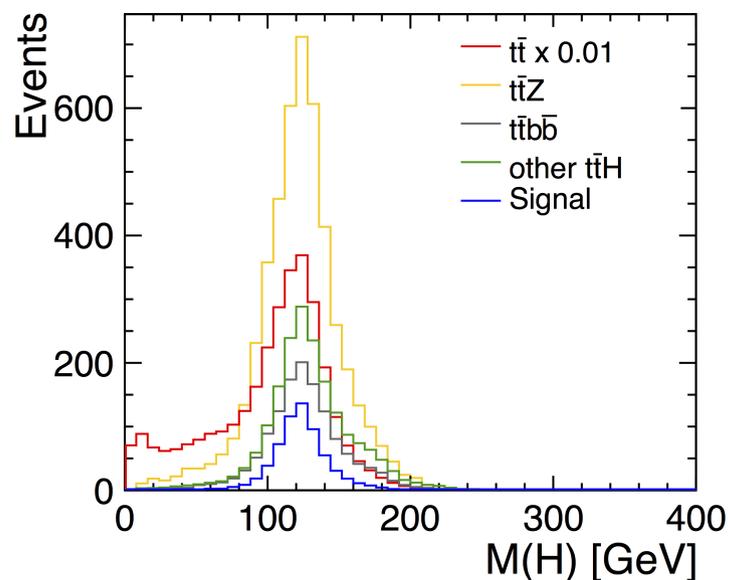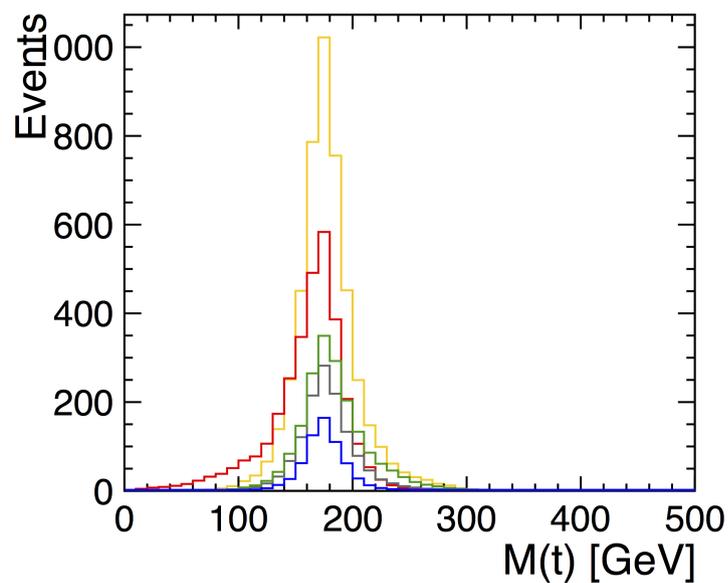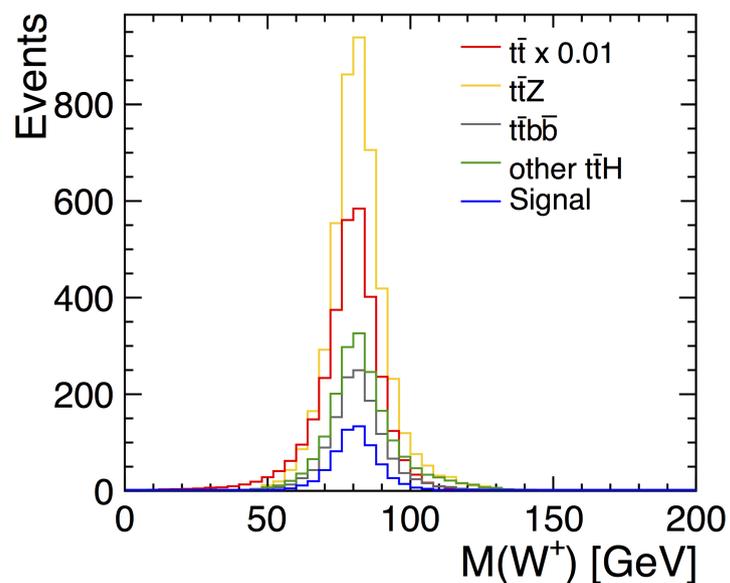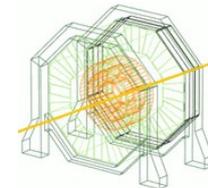
$L_{int} = 1\ ab^{-1}$

- tt̄ background scaled by 0.01

- The background distributions are broader than the signal peaks

L_{int} = 1 ab⁻¹

6 jets: other variables
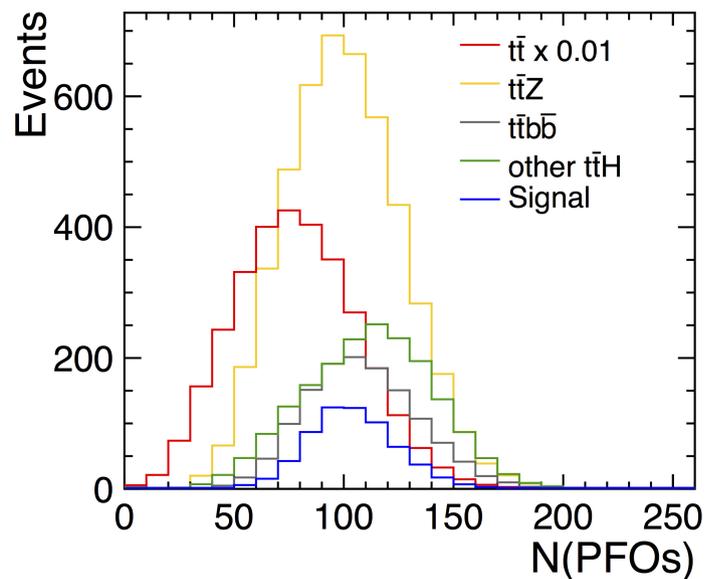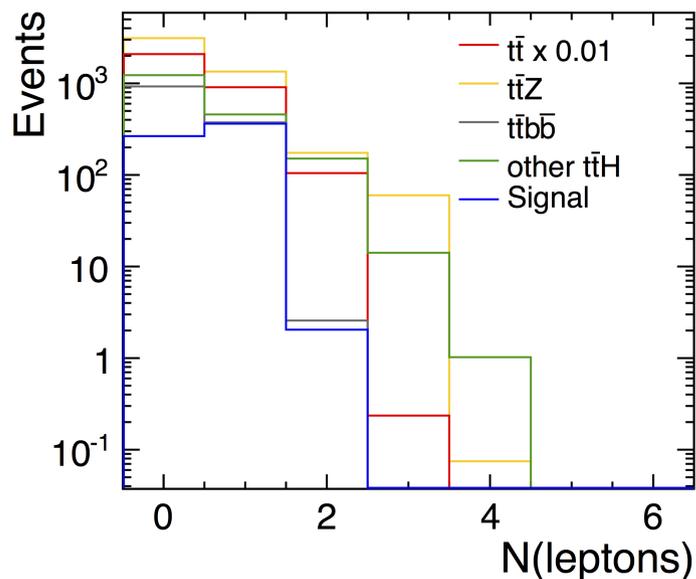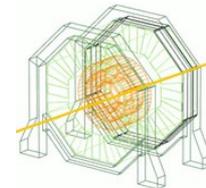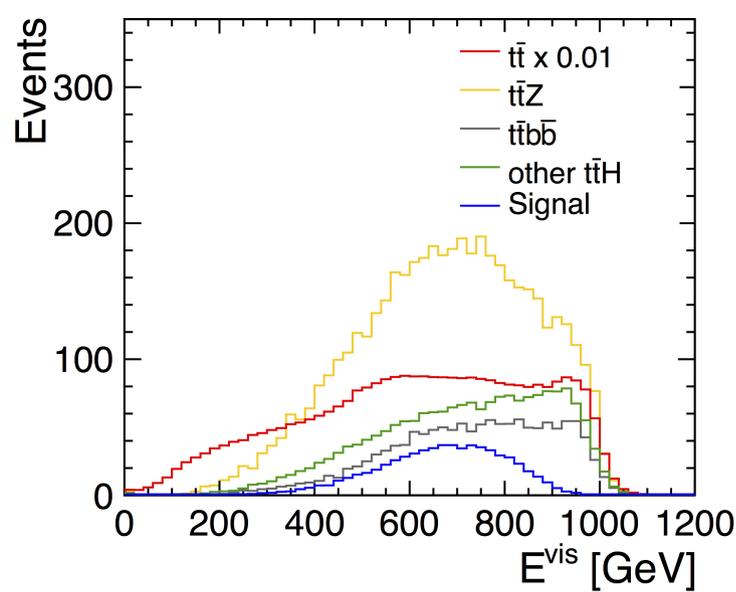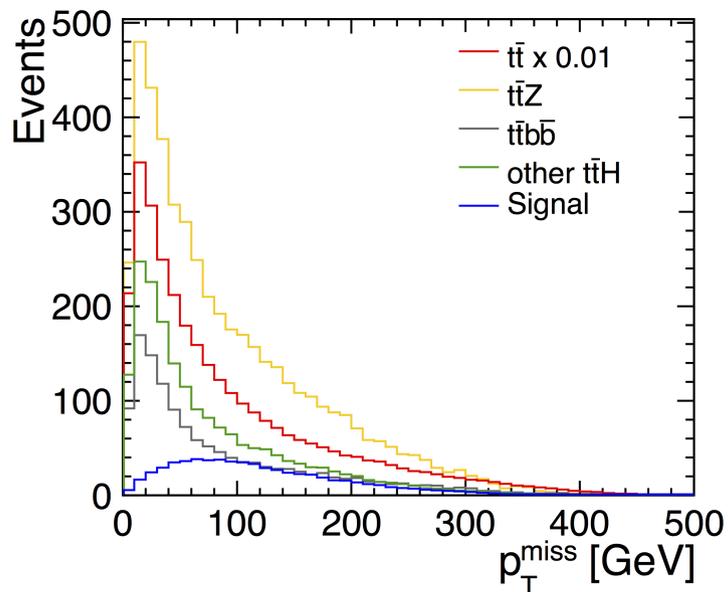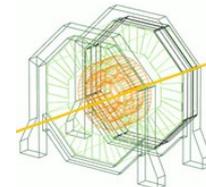
- t̄t background scaled by 0.01
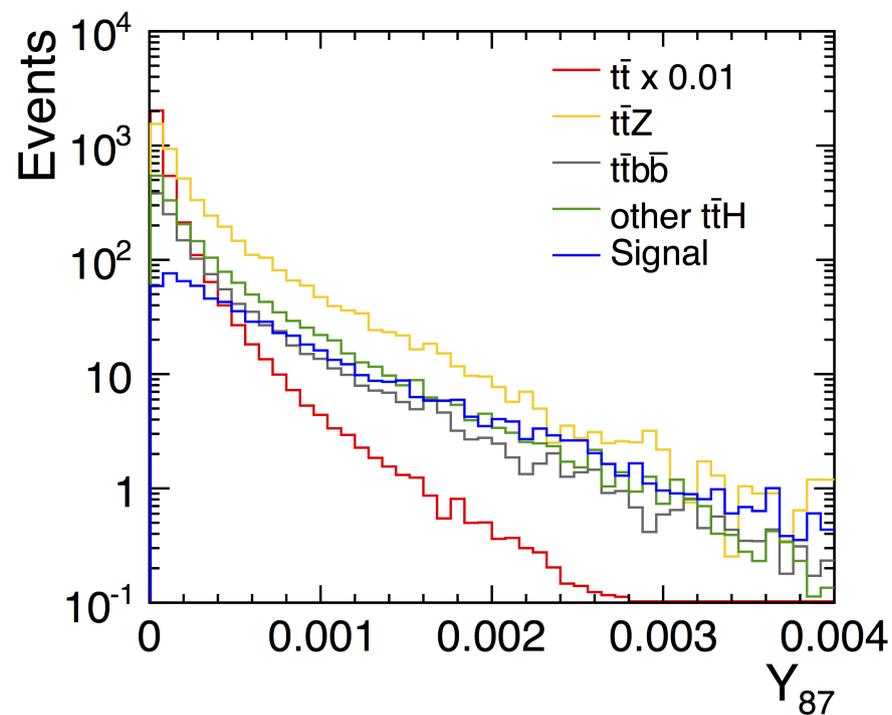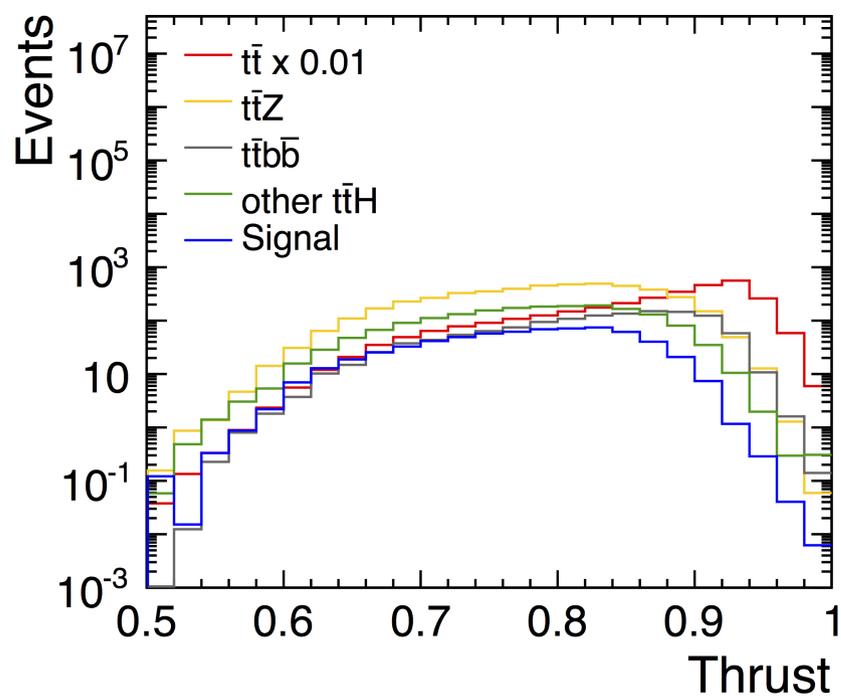
$L_{int} = 1\ ab^{-1}$
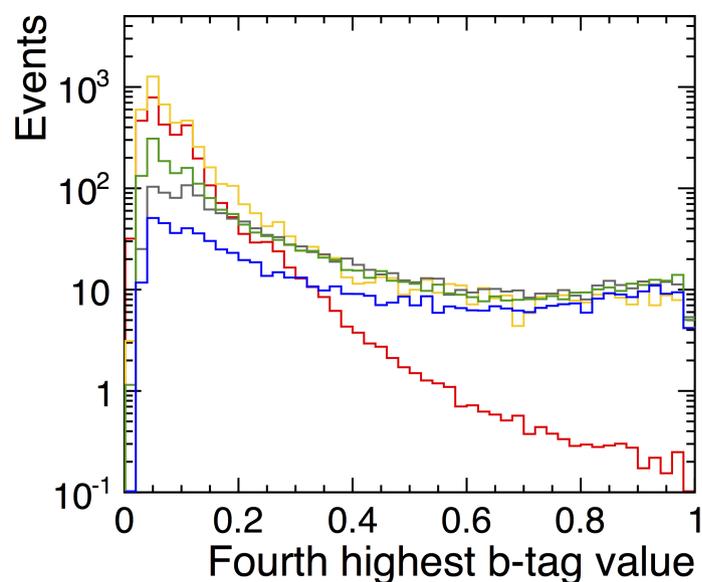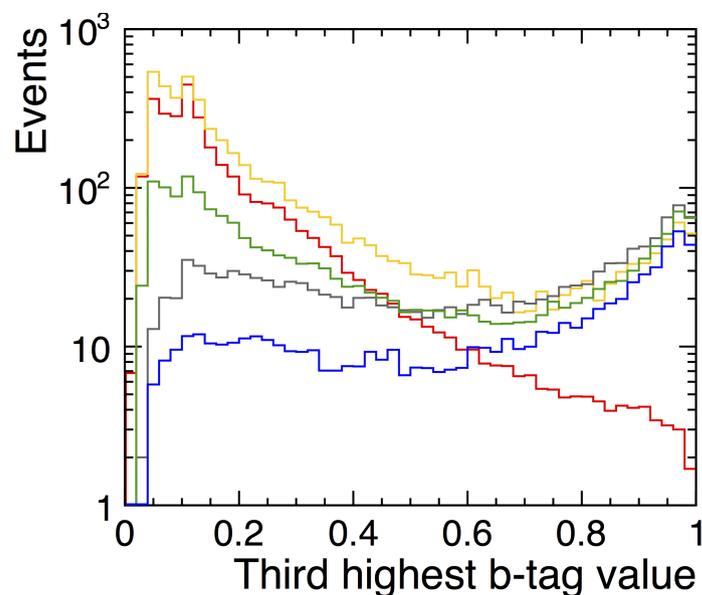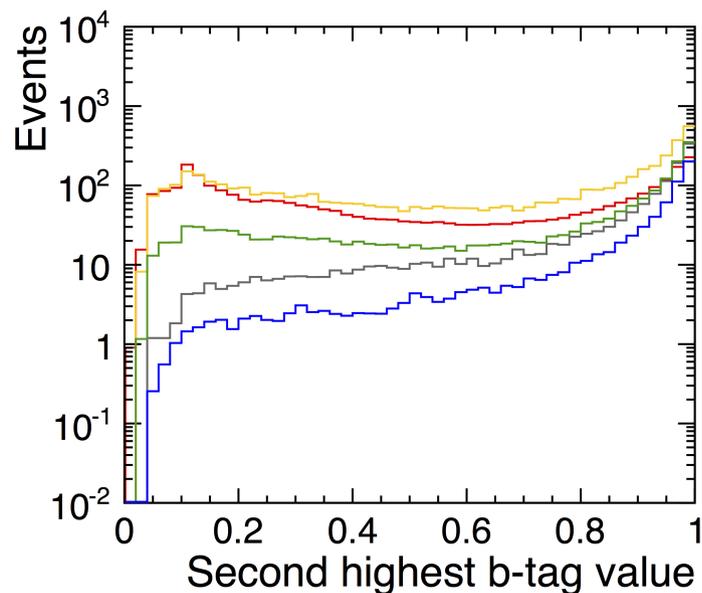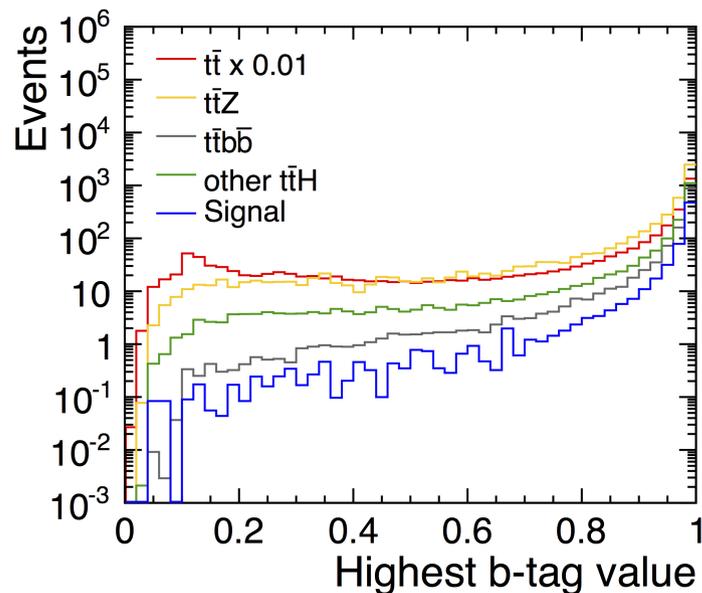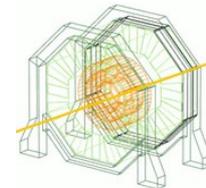
- $t\bar{t}$ background scaled by 0.01

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

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- Signal has 4 b-jets, part of the background samples contain only 2 b-jets
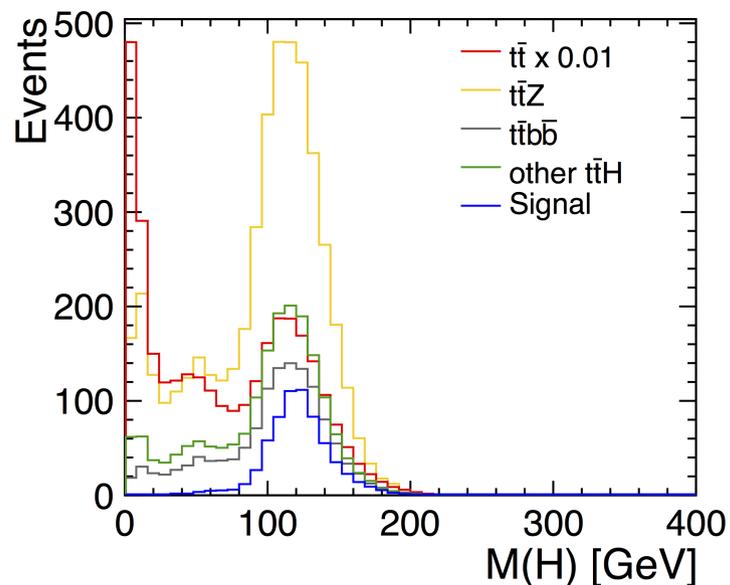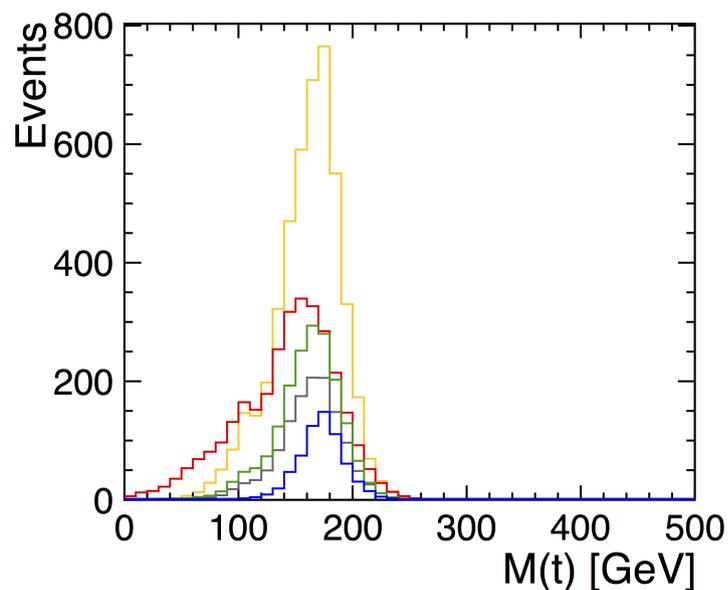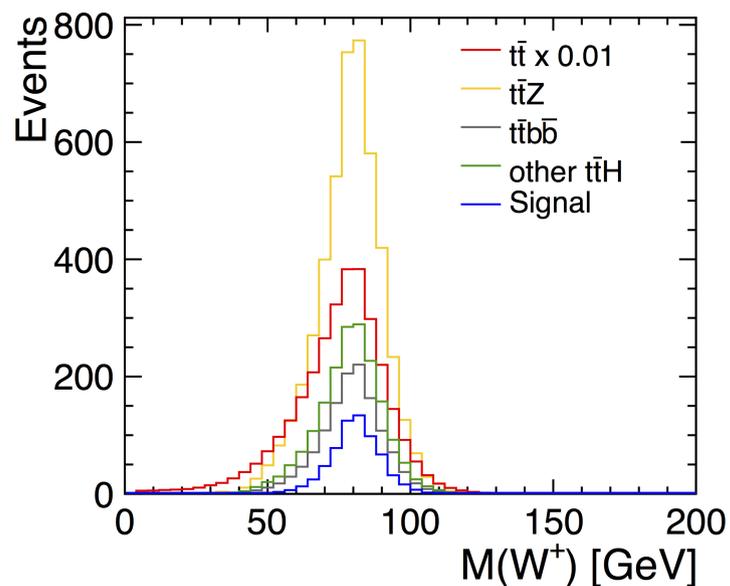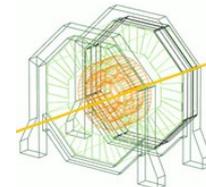
$L_{int} = 1\ ab^{-1}$

- t̄t background scaled by 0.01

- The background distributions are broader than the signal peaks

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

8 jets: other variables



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

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

BDT outputs and results
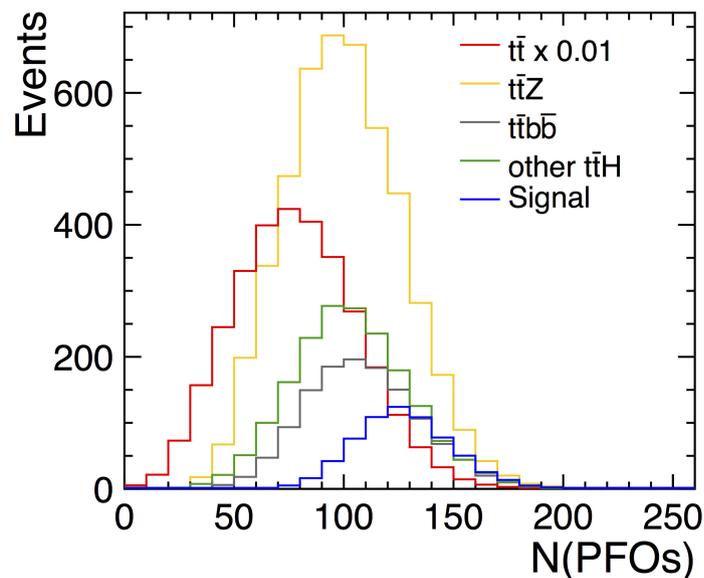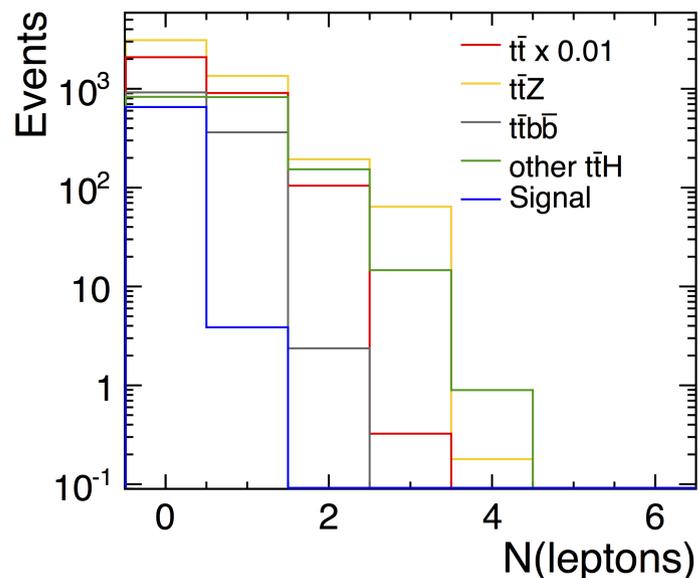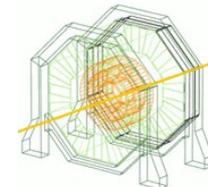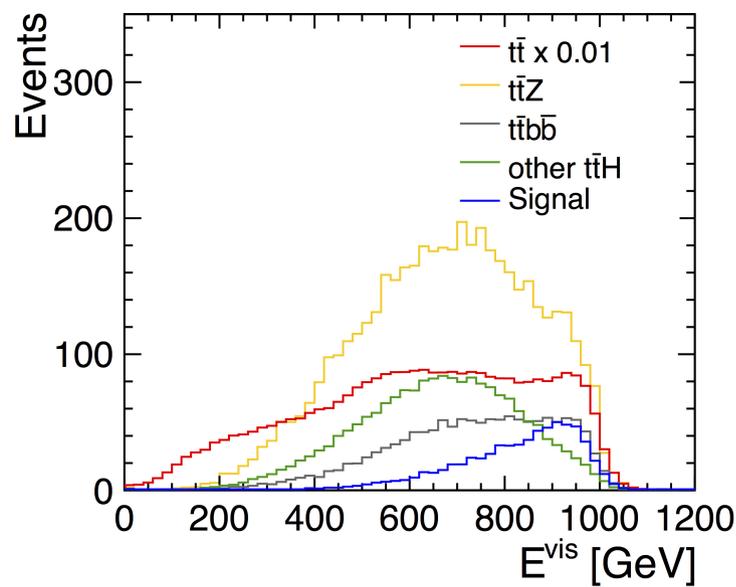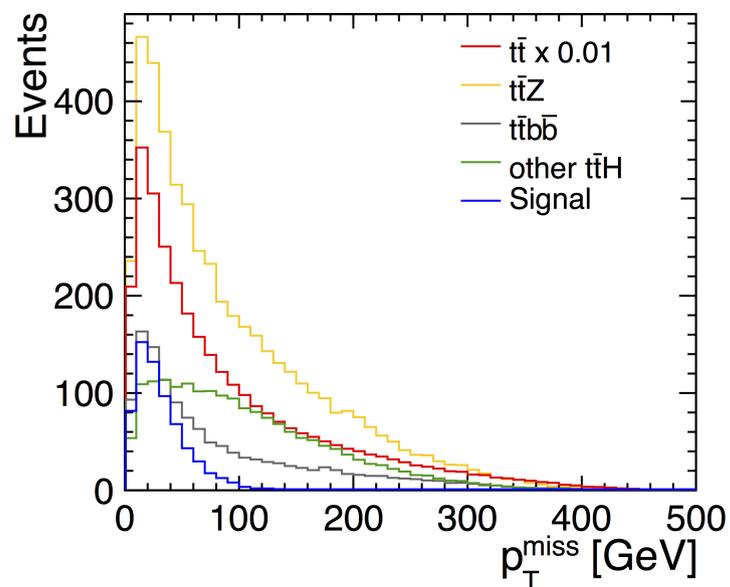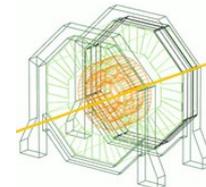
6 jets:

8 jets:

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

BDT outputs and results
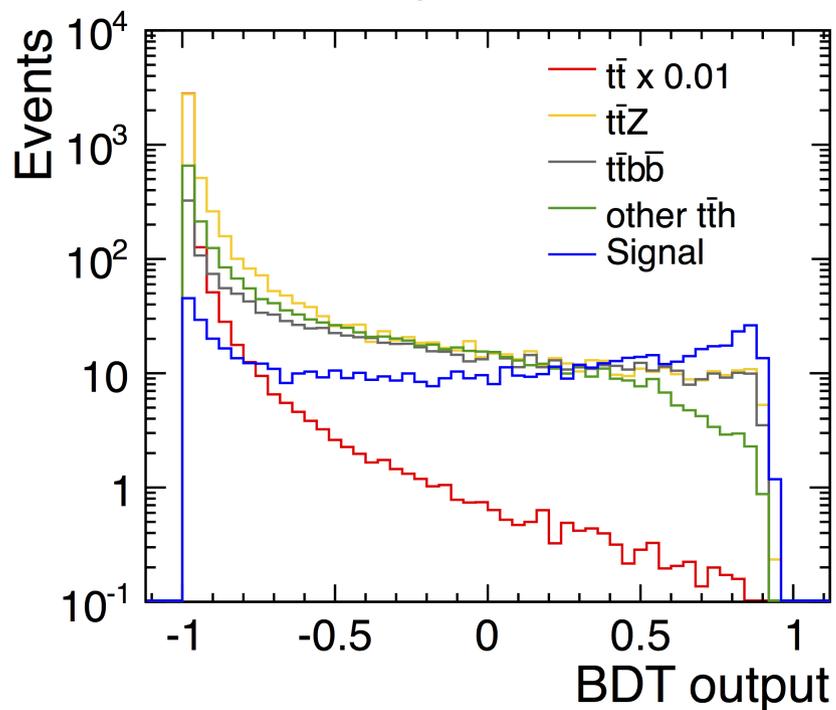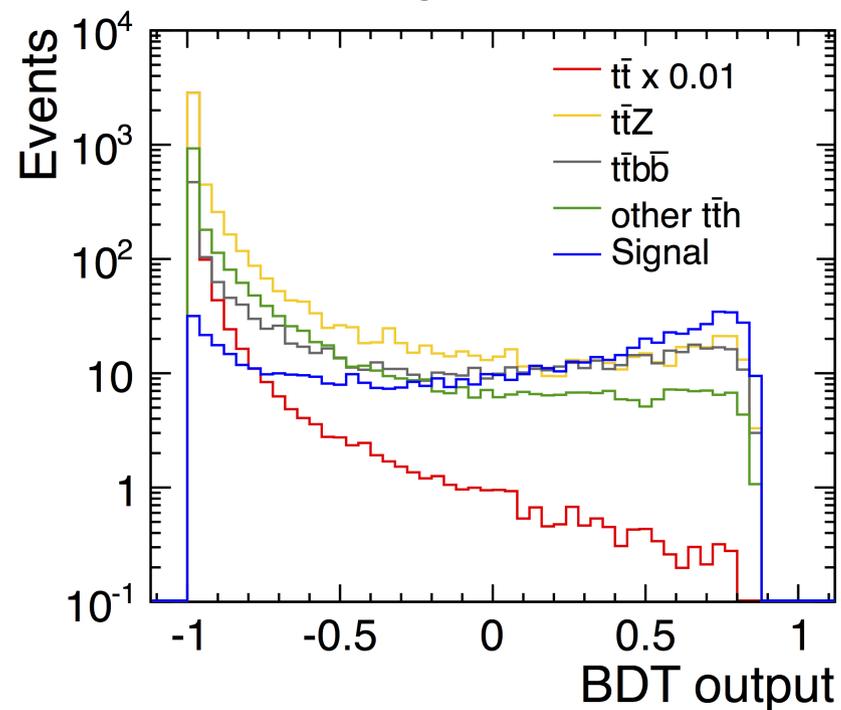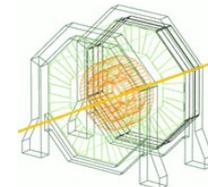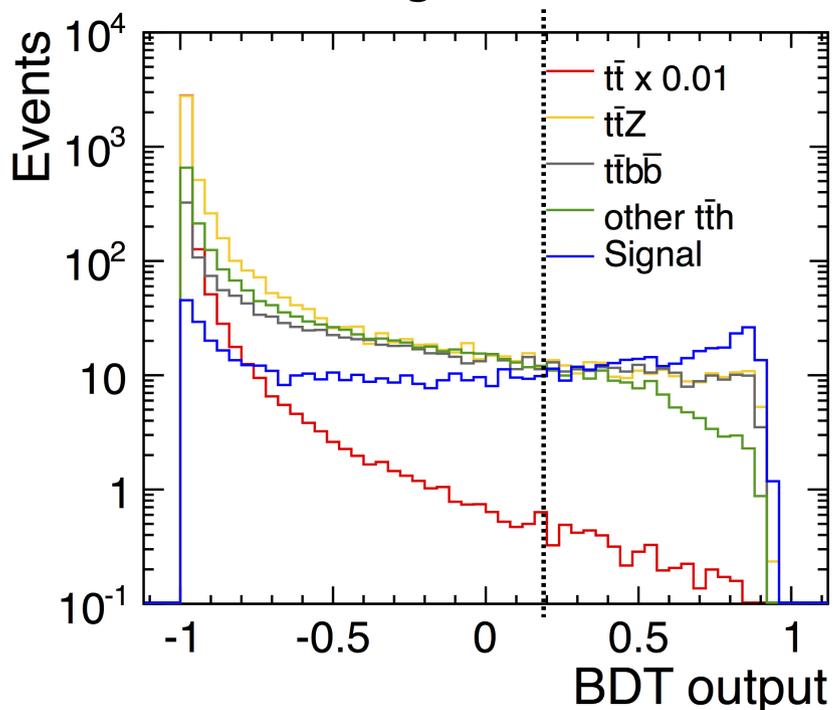
6 jets: BDT > 0.1978

8 jets: BDT > 0.1248
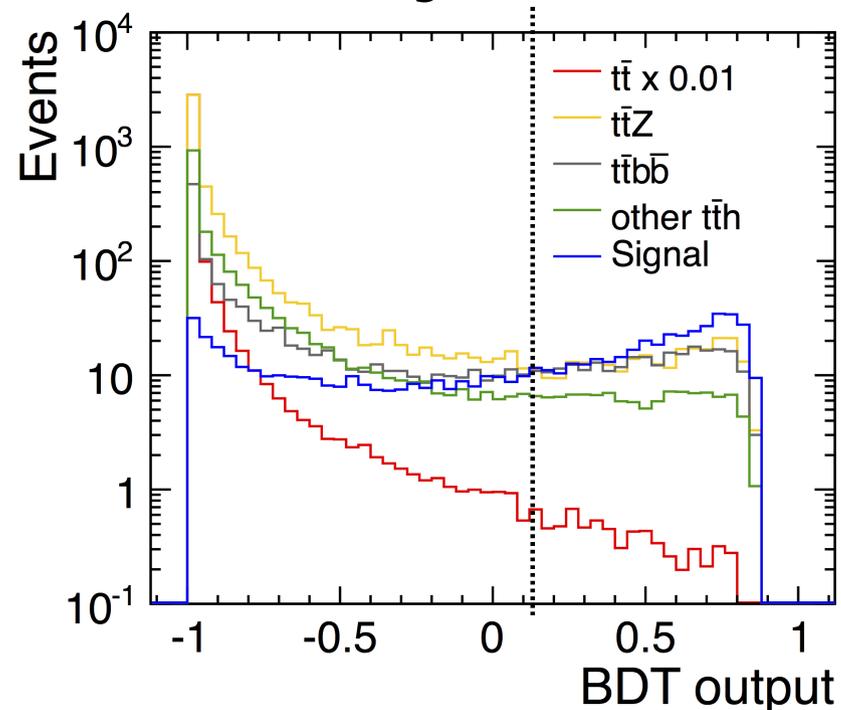
Using cut on BDT output with best significance:

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

$\Delta\sigma / \sigma$ = 13.2% → $\Delta y_t / y$ ≈ 6.9%

$\Delta\sigma / \sigma$ = 11.5% → $\Delta y_t / y$ ≈ 6.0%

Combined: $\Delta y_t / y$ ≈ 4.5% (4.0% for only P(e$^-$) = -0.8 and P(e$^+$) = +0.2)

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

Preselection on isolated leptons
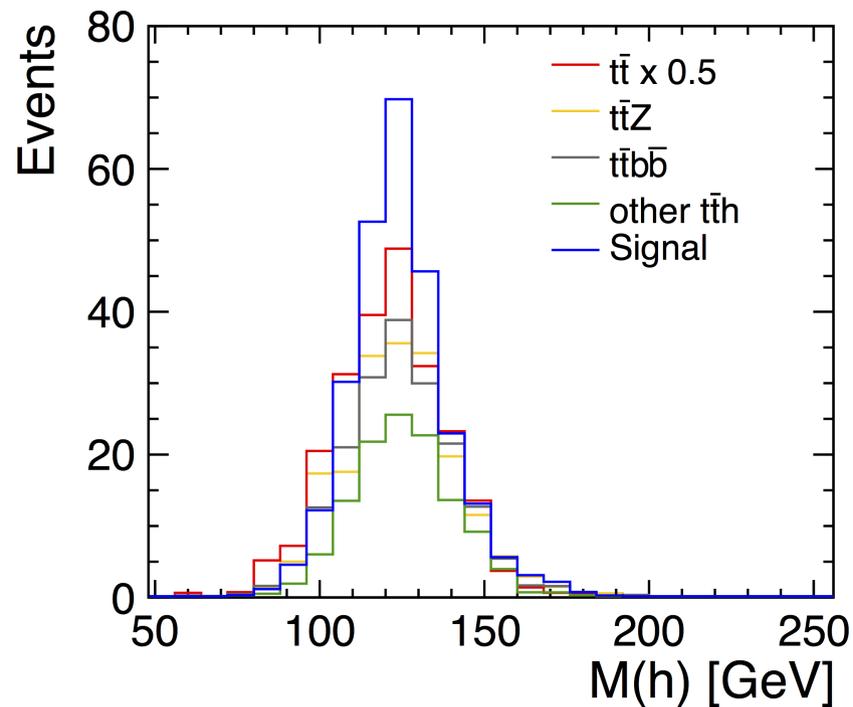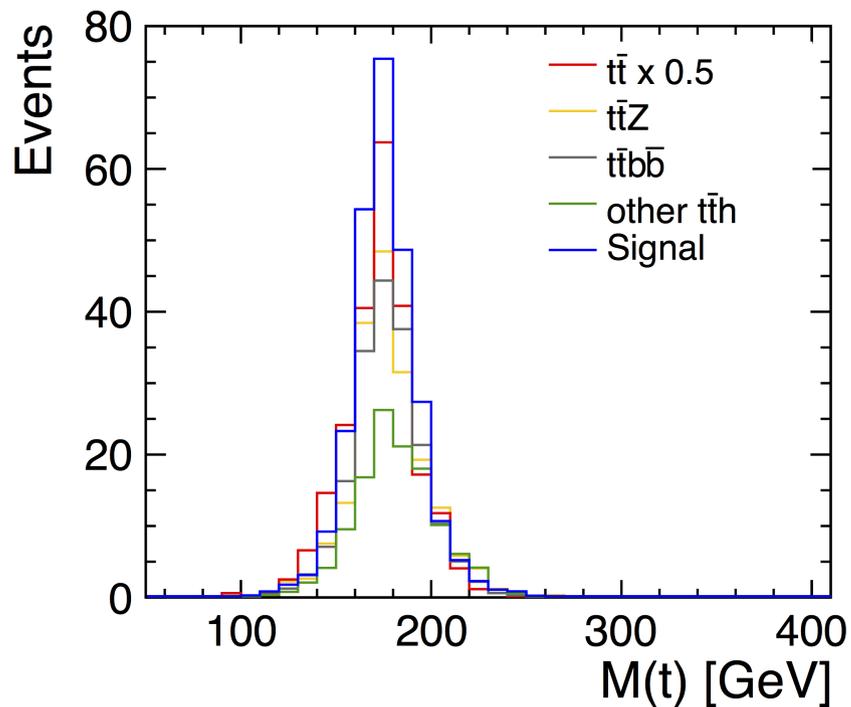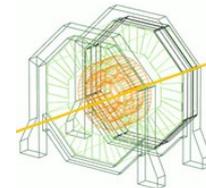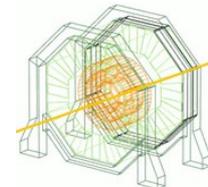
• **Preselection:** For 6 jets only accept events with one isolated lepton, for 8 jets only accept events without isolated lepton (like ILD analyses).

• Boosted decision trees retrained using the preselected signal and background samples.

6 jets: $\Delta y_t / y \approx 7.0\%$ (6.9% for default analysis)
8 jets: $\Delta y_t / y \approx 5.8\%$ (6.0% for default analysis)

Combined: $\Delta y_t / y \approx 4.5\%$ (as for default analysis)

→ **Results (almost) unchanged**

Summary and conclusions
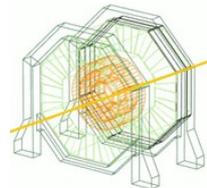
- The cross section for the t̄tH final state was extracted using two signal channels

- For a combination of both channels a precision of about 4.5% on the top Yukawa coupling can be achieved for 0.5 ab^{-1} with P(e$^-$) = -0.8, P(e$^+$) = +0.2 and 0.5 ab^{-1} with P(e$^-$) = +0.8, P(e$^+$) = -0.2

- Good agreement with the ILD analysis (see previous talk by Tomohiko Tanabe)

- The results are unchanged if events are preselected using the number of isolated leptons

Numbers of selected events
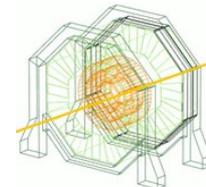
Final state	BDT trained to select 6 jets	BDT trained to select 8 jets
$t\bar{t}H$, $H \to b\bar{b}$ (6 jets)	264.9	87.2
$t\bar{t}H$, $H \to b\bar{b}$ (8 jets)	72.6	356.2
$t\bar{t}H$, H not $b\bar{b}$ (6 jets)	11.7	5.1
$t\bar{t}H$, H not $b\bar{b}$ (8 jets)	4.3	21.6
$t\bar{t}H$ (4 jets)	32.8	2.1
$t\bar{t}Z$	188.4	253.6
$t\bar{t}g^* \to t\bar{t}b\bar{b}$	185.0	243.6
$t\bar{t}$	459.3	687.0

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

Numbers of selected events for analysis with preselection
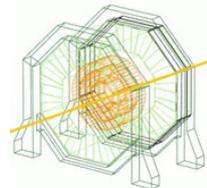
Final state	BDT trained to select 6 jets	BDT trained to select 8 jets
$t\bar{t}H$, $H \rightarrow b\bar{b}$ (6 jets)	191.6	57.4
$t\bar{t}H$, $H \rightarrow b\bar{b}$ (8 jets)	1.6	299.4
$t\bar{t}H$, H not $b\bar{b}$ (6 jets)	9.6	2.8
$t\bar{t}H$, H not $b\bar{b}$ (8 jets)	2.5	12.4
$t\bar{t}H$ (4 jets)	20.9	1.4
$t\bar{t}Z$	105.6	187.1
$t\bar{t}g^* \rightarrow t\bar{t}b\bar{b}$	100.1	180.7
$t\bar{t}$	232.0	381.6

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