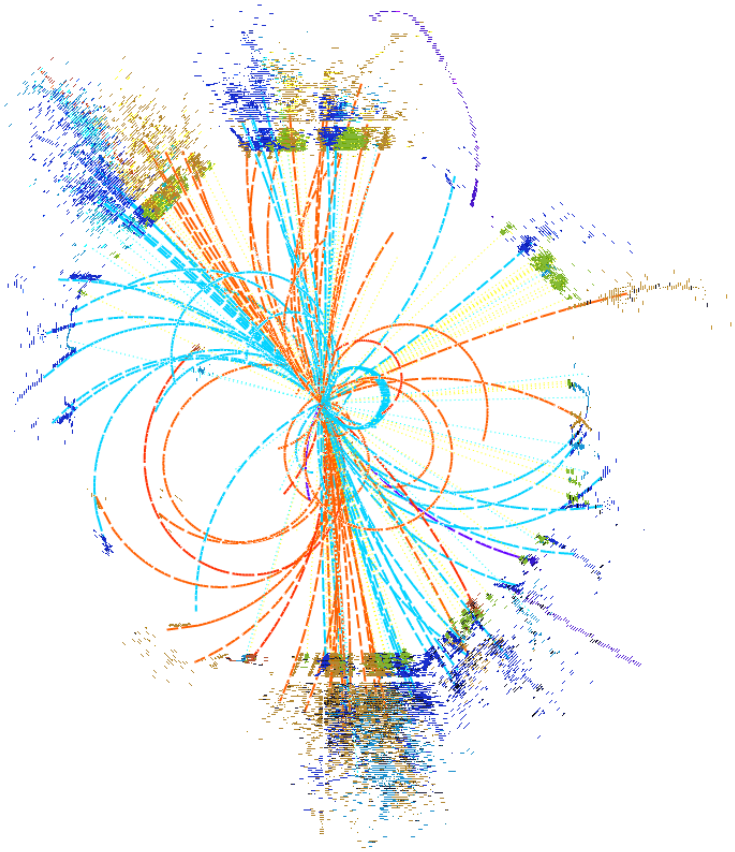
Measurement of the top Yukawa coupling at $\sqrt{s}$ = 1 TeV using the SiD detector

Philipp Roloff
(CERN)



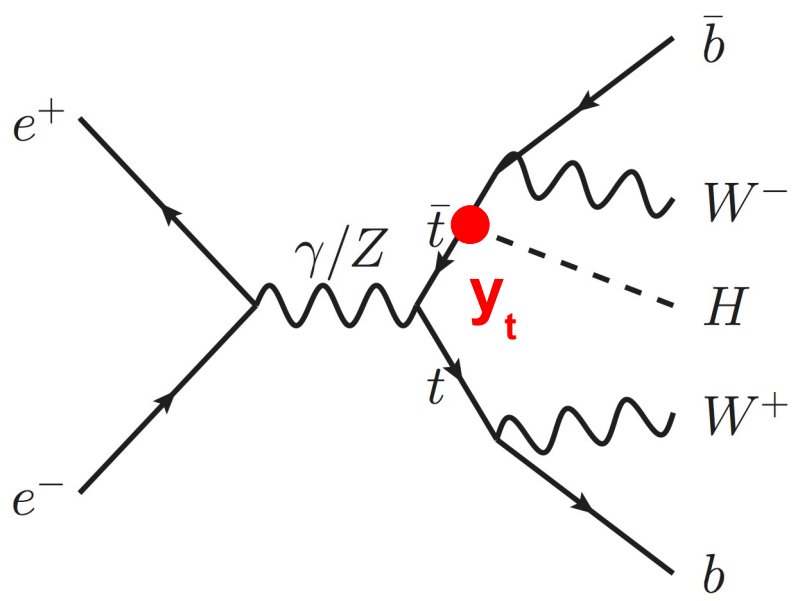
SiD Workshop, 17/01/2013

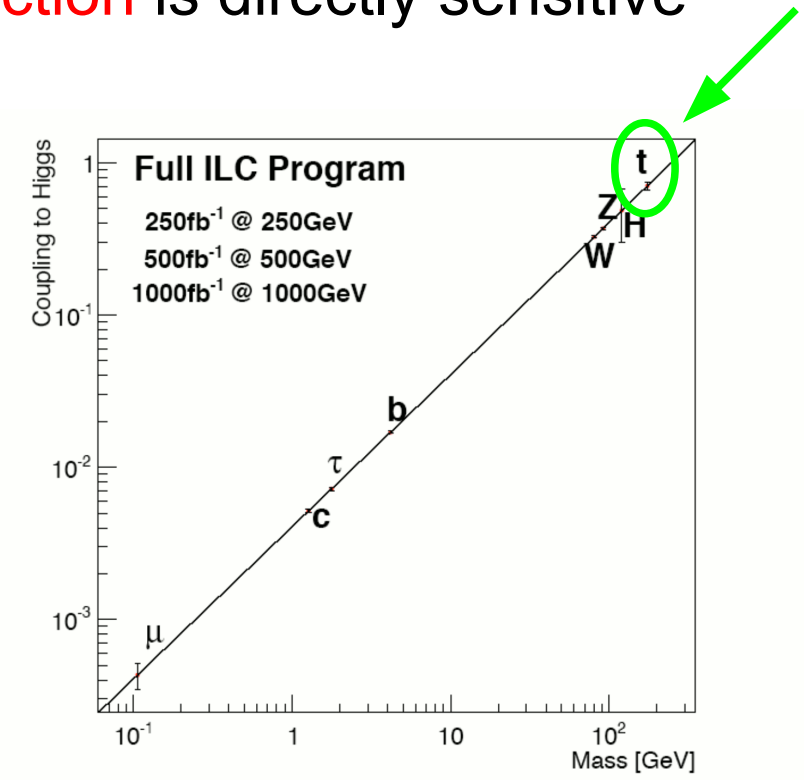
Introduction

- Detector benchmarking processes for the DBD

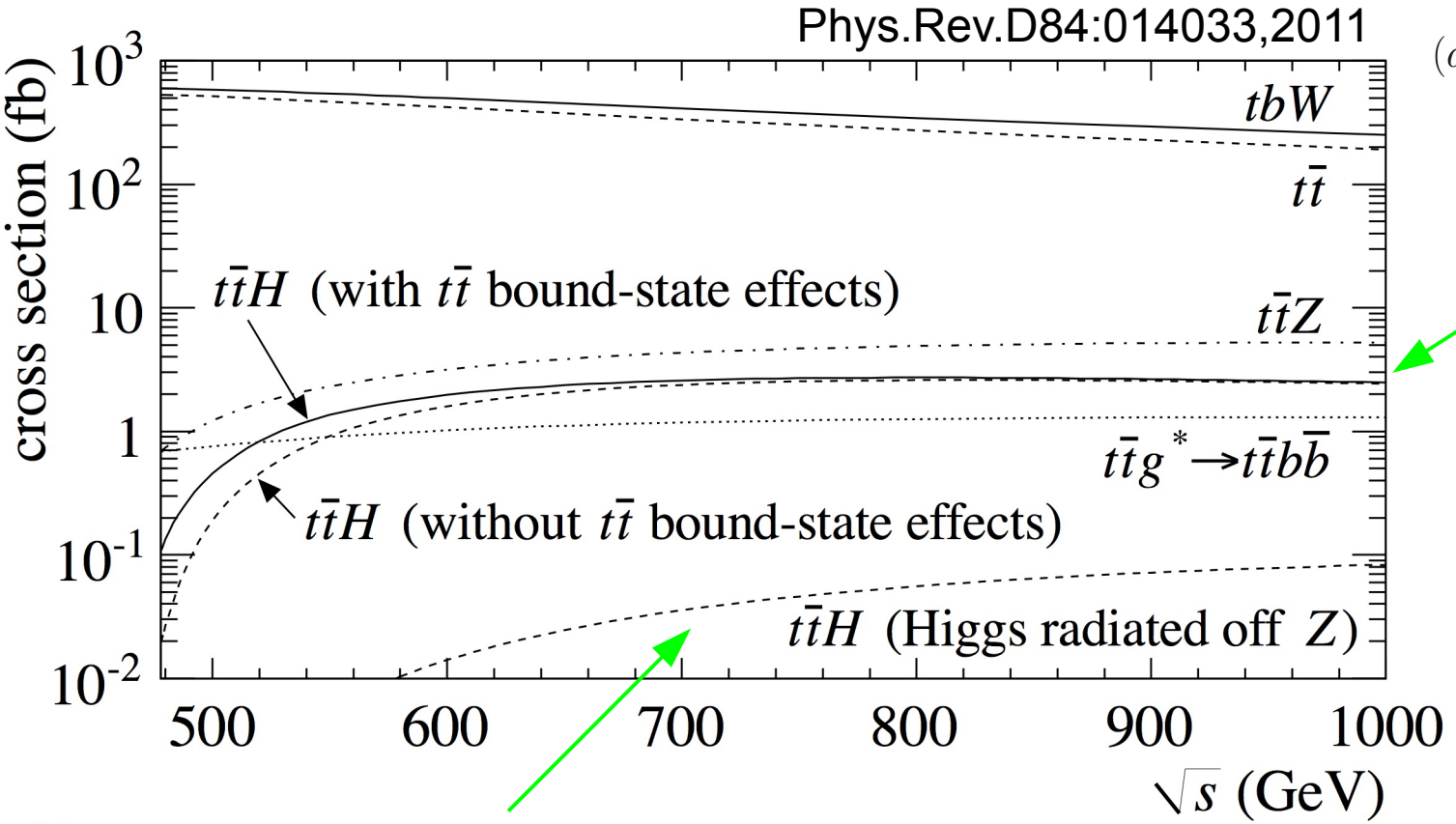
- **Final states:** - "6 jets": $t(\rightarrow qqb)\bar{t}(\rightarrow l\nu\bar{b})H(\rightarrow b\bar{b})$, m_H = 125 GeV
  - "8 jets": $t(\rightarrow qqb)\bar{t}(\rightarrow qq\bar{b})H(\rightarrow b\bar{b})$, m_H = 125 GeV

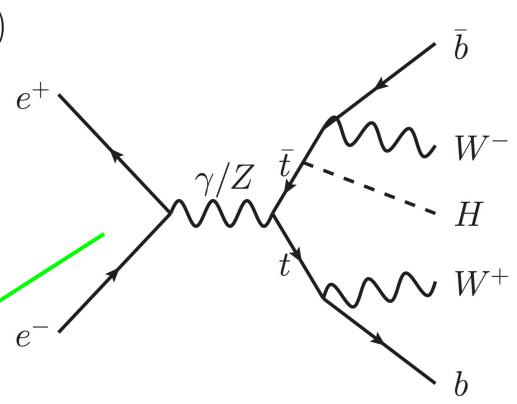
- **Motivation:** Cross section for $t\bar{t}H$ production is directly sensitive to the top Yukawa coupling, y_t:



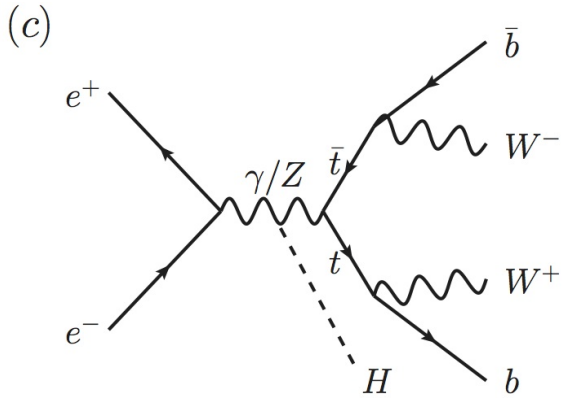


Cross sections





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



Higgs radiated off Z:
- σ ≈ 0.08 fb
- Not sensitive to y_t

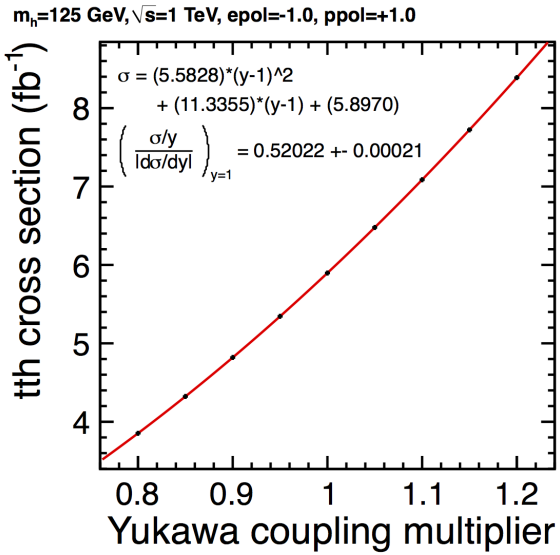
Extraction of the top Yukawa coupling

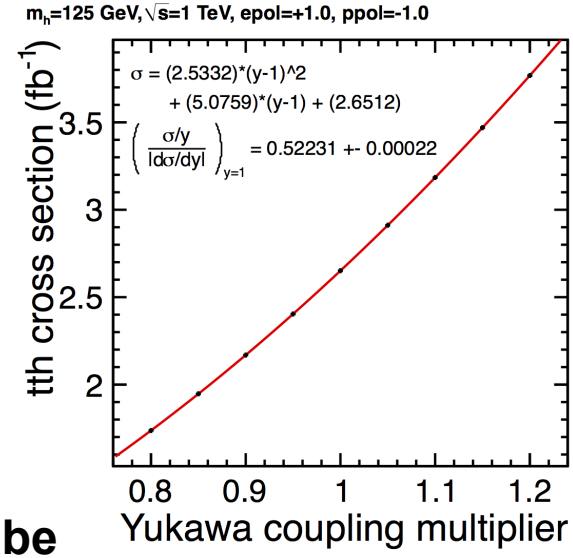
- Without Higgsstrahlung:

$$\frac{\Delta y_t}{y_t} = 0.5 \frac{\Delta \sigma}{\sigma}$$

- 4% correction for m_H = 125 GeV:

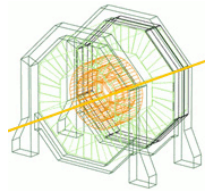
$$\frac{\Delta y_t}{y_t} = 0.52 \frac{\Delta \sigma}{\sigma}$$





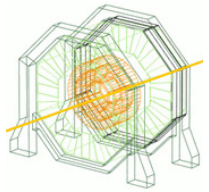
Tomohiko Tanabe

Monte Carlo samples

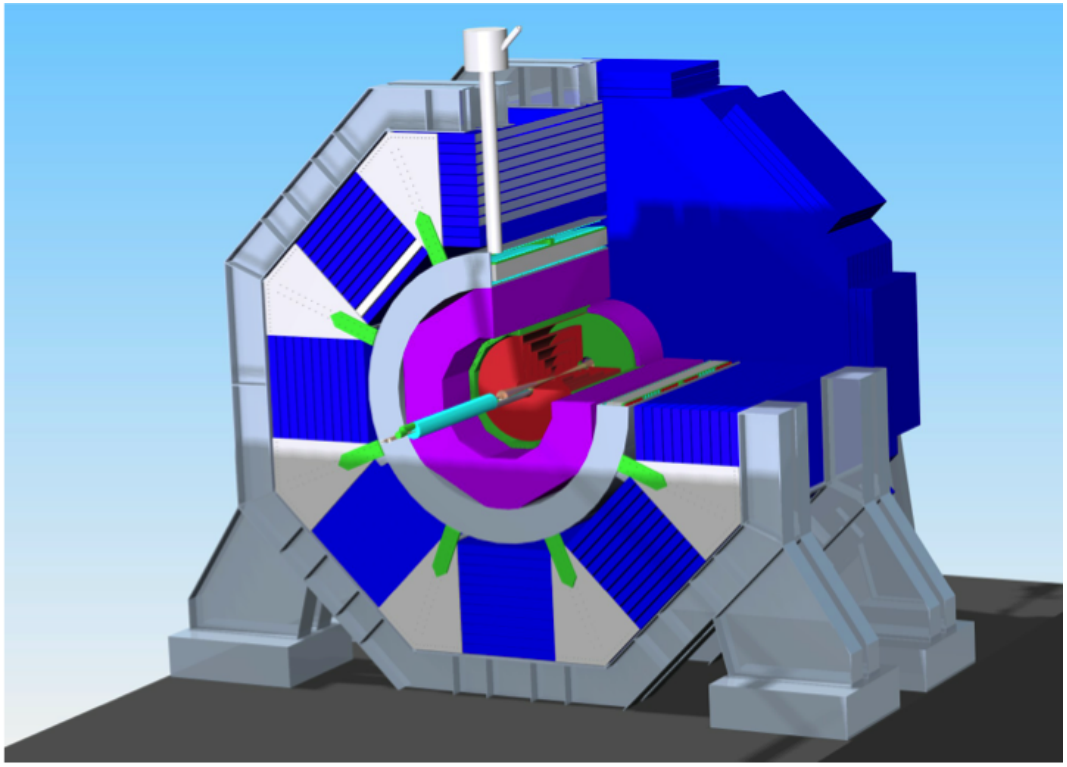


Final state	P(e) [%]	P(p) [%]	N(events)	N(L = 1 ab^{-1})
$t\bar{t}(\rightarrow lv4q)b\bar{b}$	+80	-20	20000	421
	-80	+20	20000	846
$t\bar{t}(\rightarrow 6q)Z$	+80	-20	20000	1328
	-80	+20	20000	3483
$t\bar{t}(\rightarrow 6q)b\bar{b}$	+80	-20	20000	436
	-80	+20	20000	874
$t\bar{t}(\rightarrow lv4q)Z$	+80	-20	20000	1277
	-80	+20	20000	3442
$t\bar{t}(\rightarrow 6q)H(\rightarrow b\bar{b})$	+80	-20	20000	439
	-80	+20	20000	866
$t\bar{t}(\rightarrow 6q)H(\text{not } b\bar{b})$	+80	-20	20000	321
	-80	+20	20000	634
$t\bar{t}(\rightarrow 2l2v2q)H(\rightarrow b\bar{b})$	+80	-20	20000	103
	-80	+20	20000	200
$t\bar{t}(\rightarrow 2l2v2q)H(\text{not } b\bar{b})$	+80	-20	20000	74
	-80	+20	20000	147
$t\bar{t}(\rightarrow lv4q)H(\rightarrow b\bar{b})$	+80	-20	20000	423
	-80	+20	20000	835
$t\bar{t}(\rightarrow lv4q)H(\text{not } b\bar{b})$	+80	-20	20000	307
	-80	+20	20000	608
$t\bar{t}$	+80	-20	566500	170198
	-80	+20	566500	449164

Event simulation



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



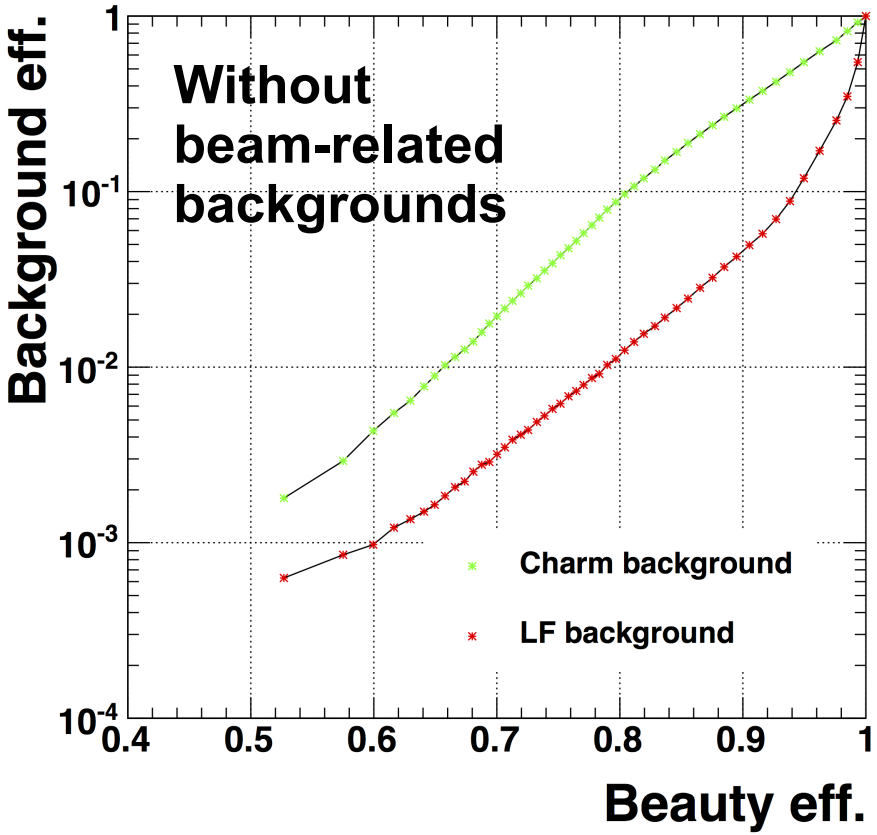
- **The physics events were overlaid with beam-related backgrounds corresponding to 1 BX:**

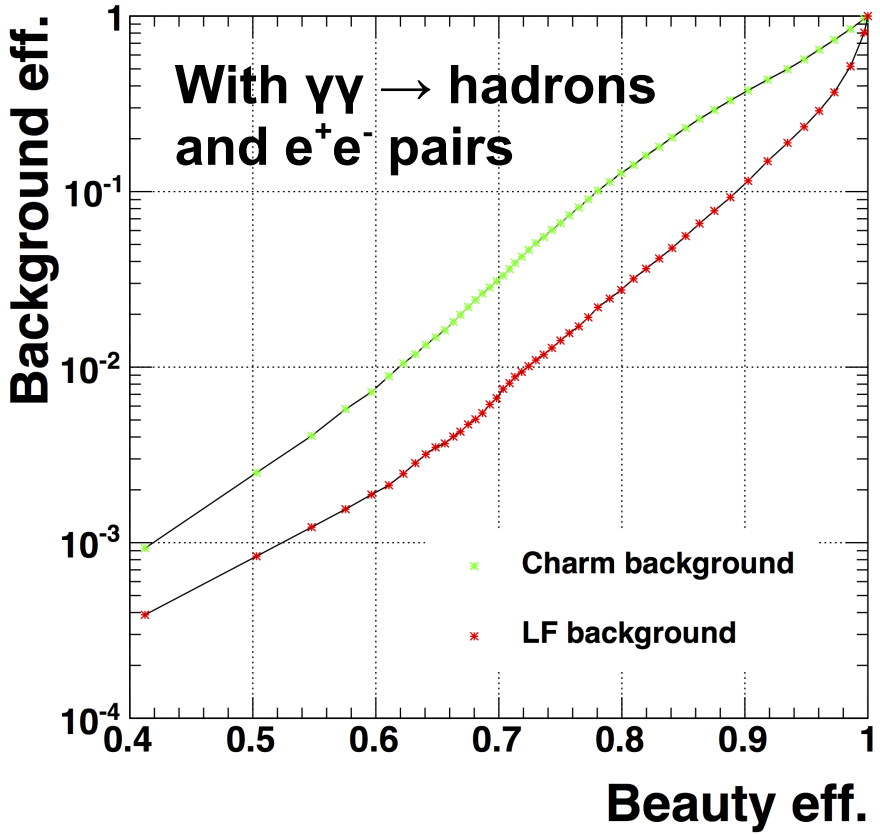
  - incoherent pairs (450.000 particles)
  - 4.1 $\gamma\gamma \rightarrow$ hadrons interactions

- PandoraPFA for particle flow reconstruction

Beauty-jet tagging

- Based on the LCFIPlus package
- Cuts adjusted for the SiD detector geometry
- Trained using bbbbbb, cccccc, qqqqqq at 1 TeV



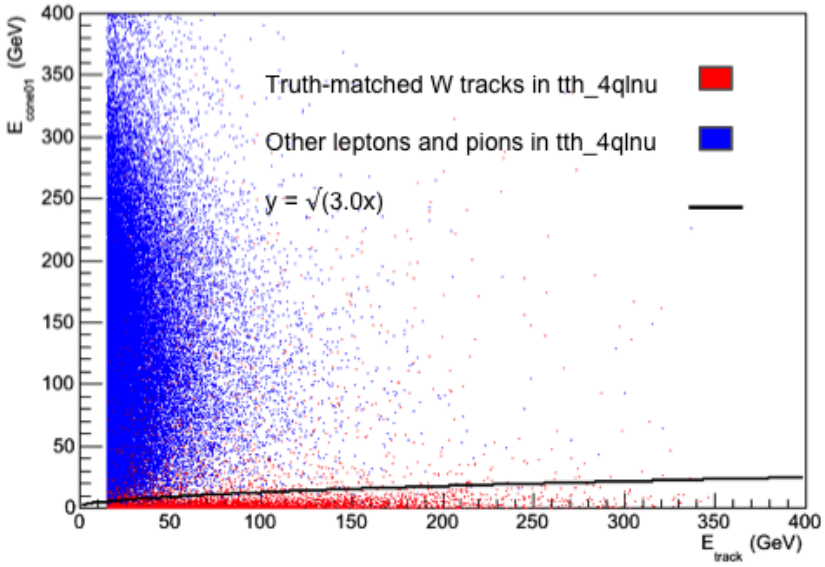


Test of the flavour tagging performance in $Z \rightarrow b\bar{b}$, $c\bar{c}$, $q\bar{q}$ events

Isolated lepton selection

Kinematic Cuts:

- $\cos(\Theta_{cone}) > 0.99$
- $E_{track} > 15$ GeV
- $E_{cone} < (3.0 \cdot E_{lepton})^{½}$



PID:

- Electrons:

$0.95 < E^{ECal} / E^{HCal} < 1$ $0.85 < E / p < 1.15$

- Muons:

$0.03 < E^{ECal} / E^{HCal} < 0.2$ $0.0 < E / p < 0.4$

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

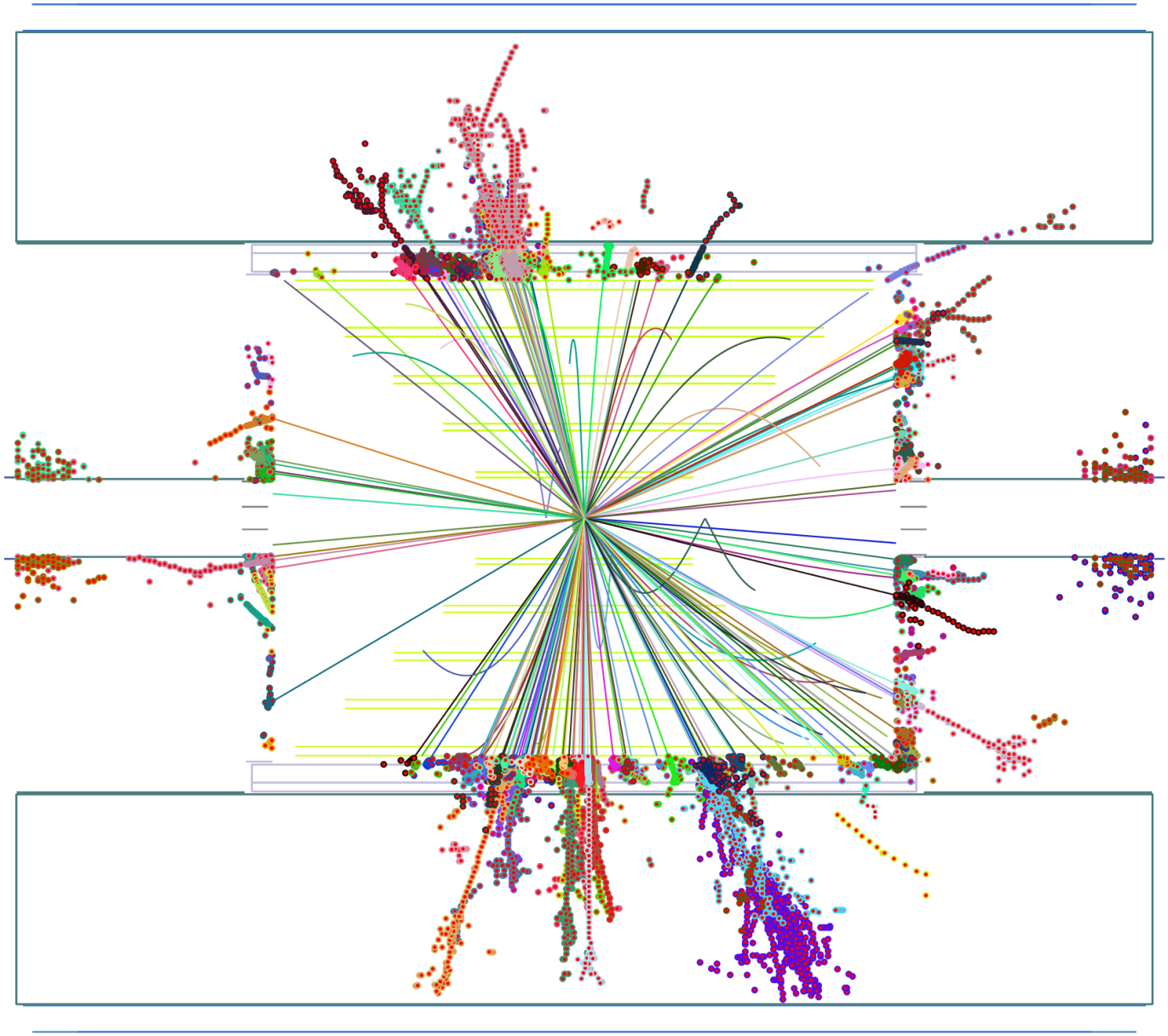
Jan Strube

Event reconstruction I

1.) Remove all PFOs with:

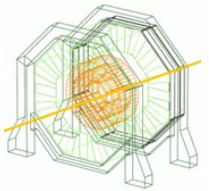
- p_T < 500 MeV
- Θ < 20°
- Θ > 160°

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

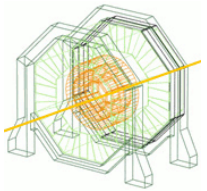
5.) Group jets into $W^{\pm}$, H and top pairs
by minimising:

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

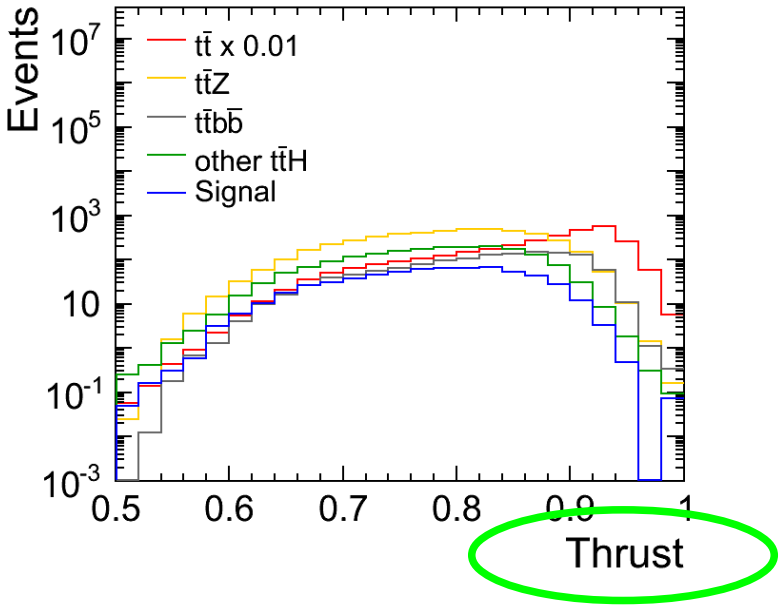


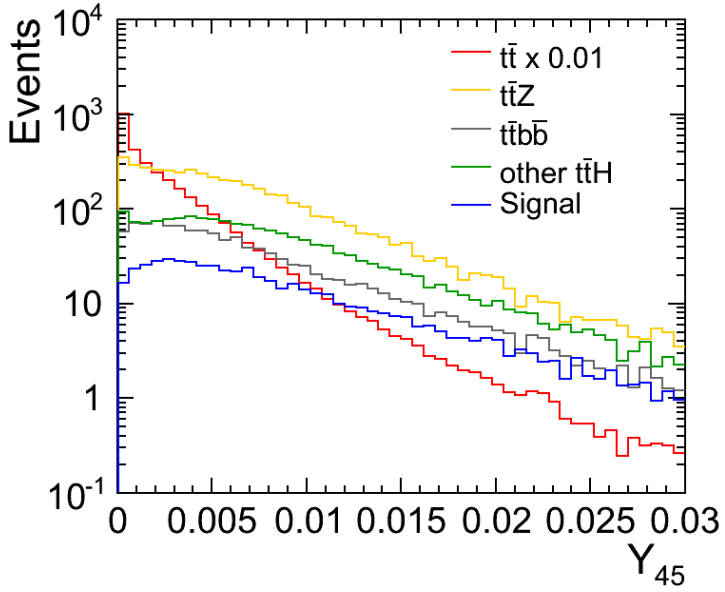
Signal events were selected using Boosted Decision Trees (BDTs) as implemented in TMVA.

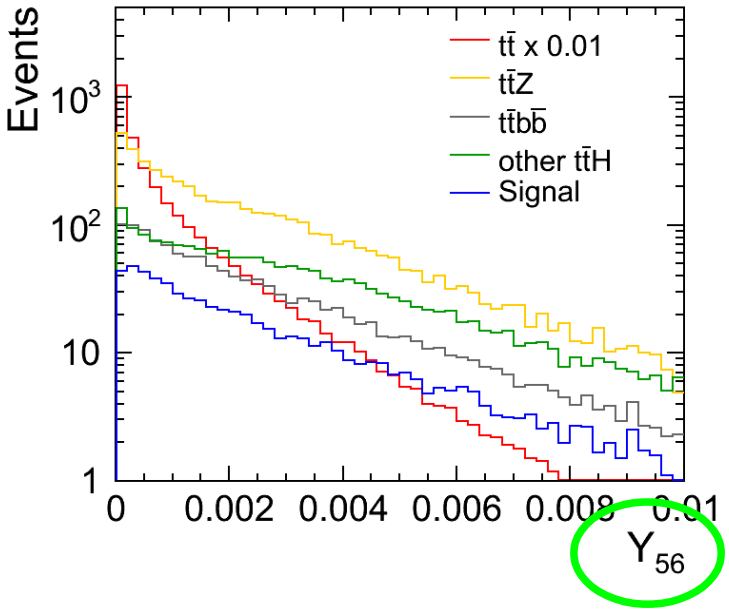
Input variables for the 6-jet final state:
M_{12}, M_{123}, M_{45}, four highest b-tags values, Thrust, $Y_{5\to6}$,
number isolated leptons, number of PFOs, missing transverse momentum, visible energy
→ 13 variables

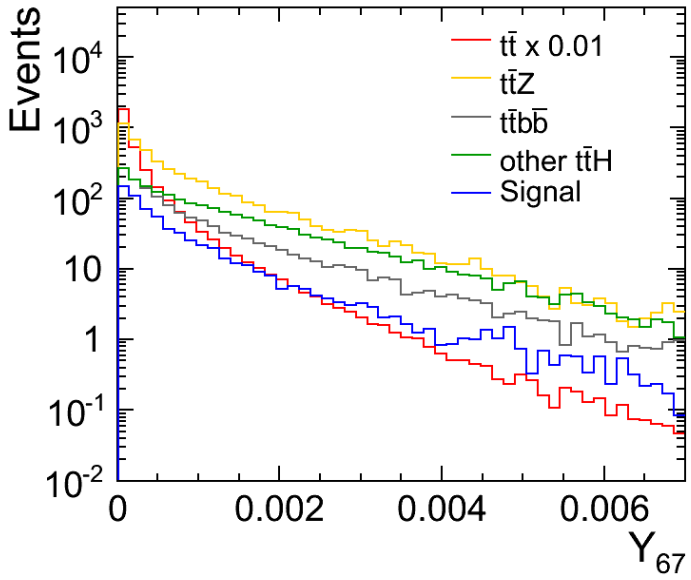
Input variables for the 8-jet final state:
M_{12}, M_{123}, M_{45}, M_{456}, M_{78}, four highest b-tags values, Thrust, $Y_{7\to8}$,
number isolated leptons, number of PFOs, missing transverse momentum, visible energy
→ 15 variables

6 jets: selection variables I





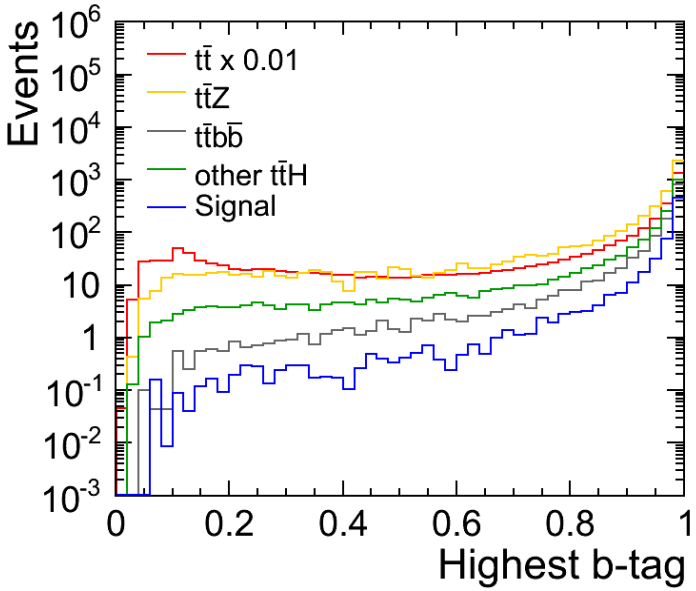


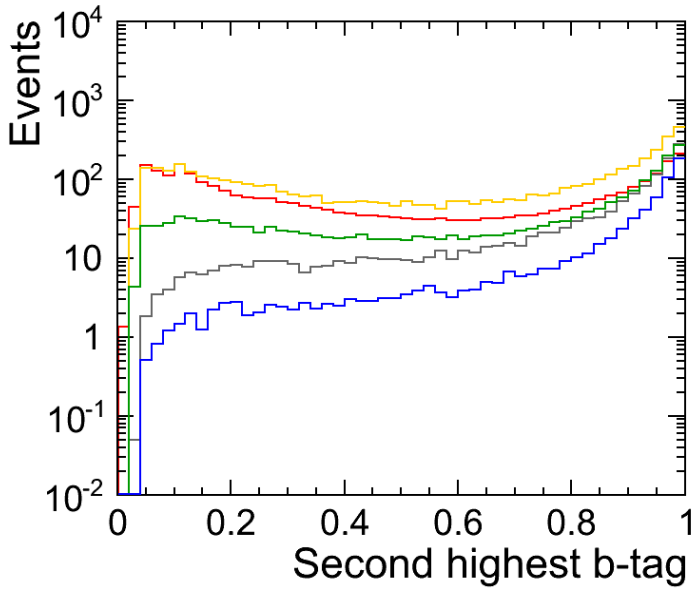


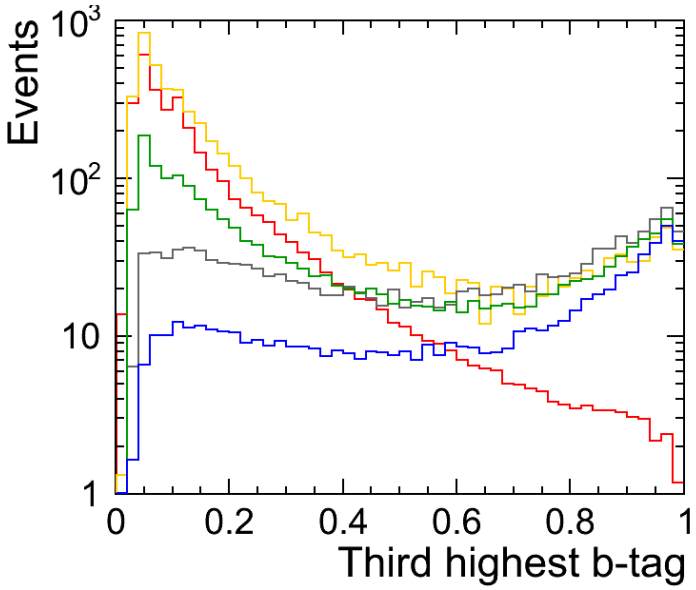
- $t\bar{t}$ background scaled by 0.01
- $Y_{5\to6}$ used instead of $Y_{4\to5}$ or $Y_{6\to7}$

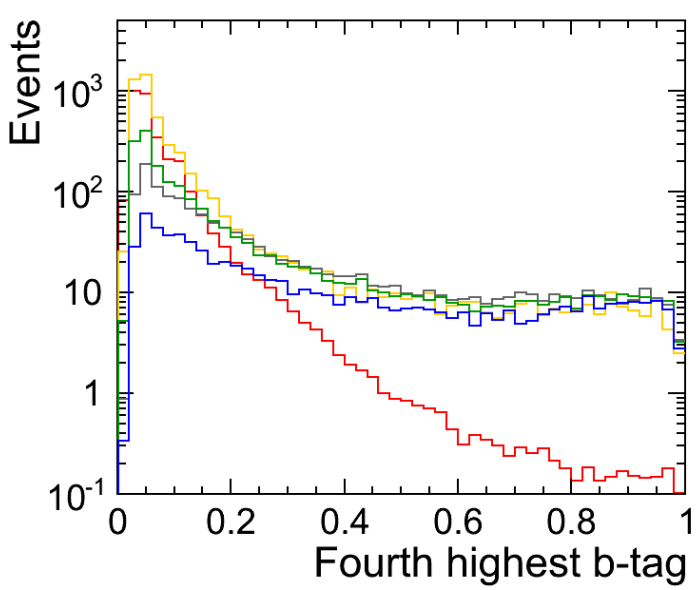
$L_{int} = 1\ ab^{-1}$

6 jets: b-tag values





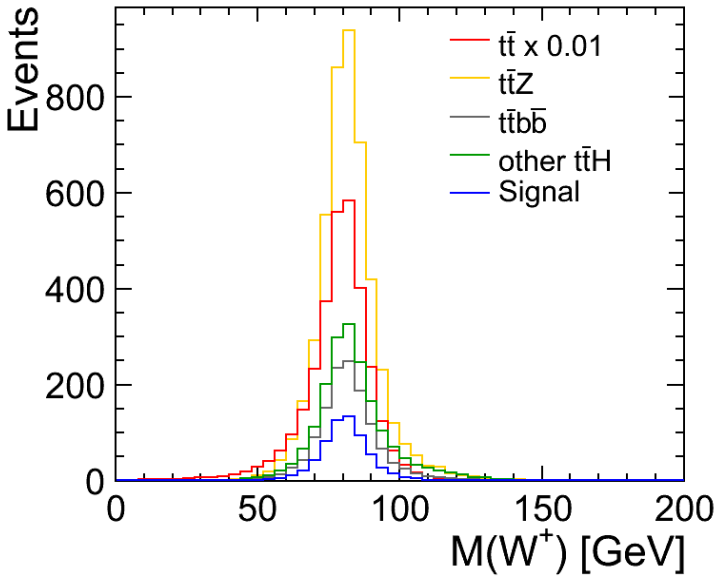


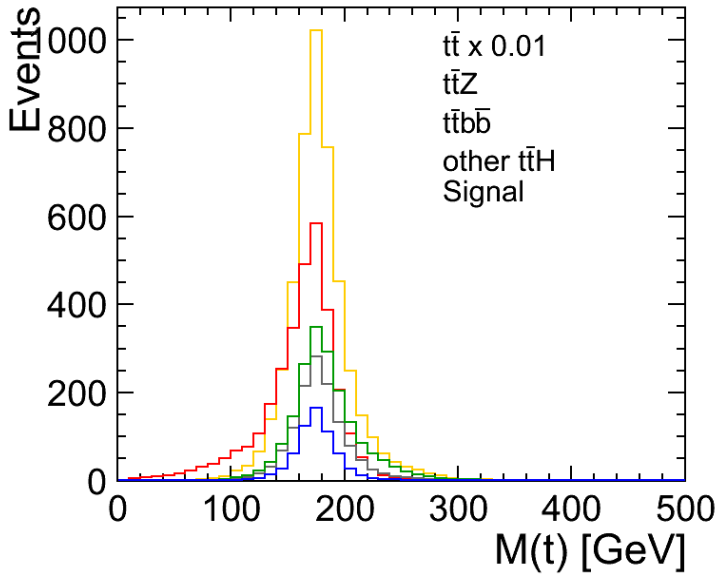


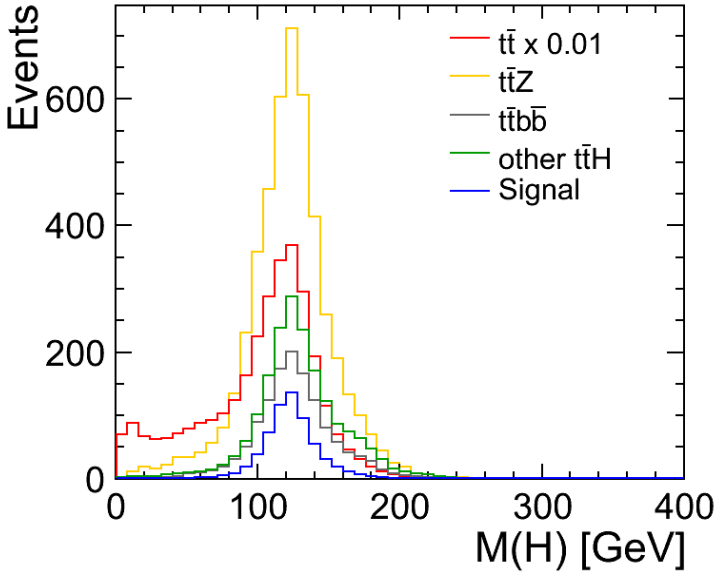
- $t\bar{t}$ background scaled by 0.01
- Signal has 4 b-jets, part of the background samples contain only 2 b-jets

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

6 jets: W^+/top/Higgs masses



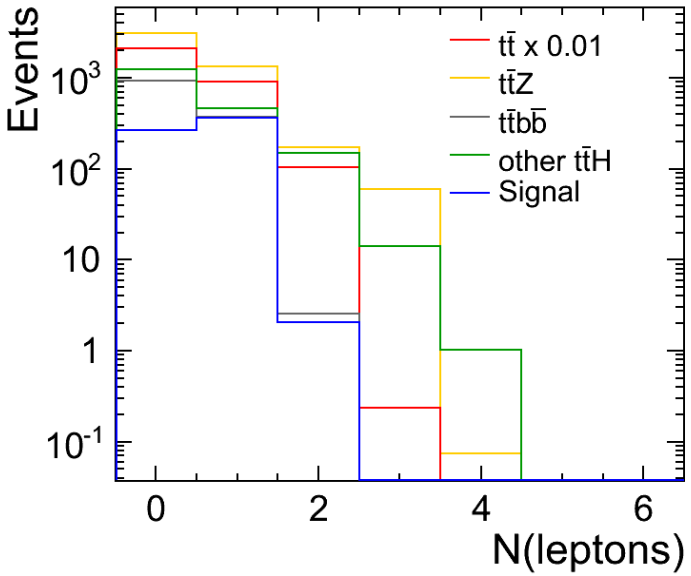


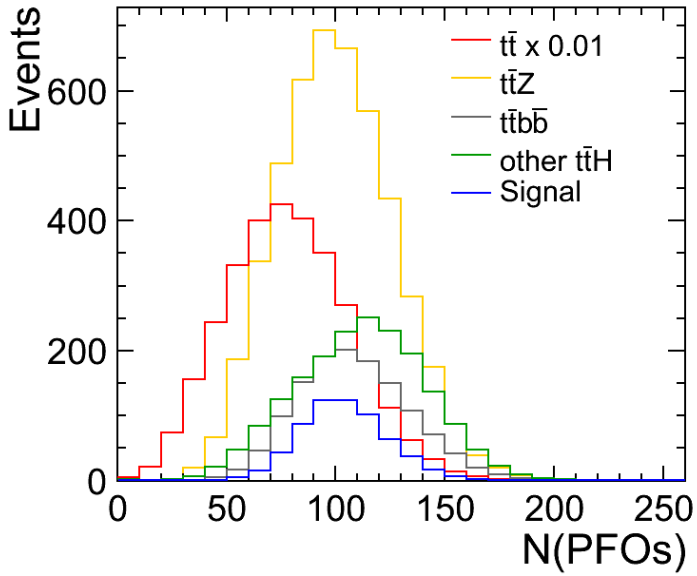


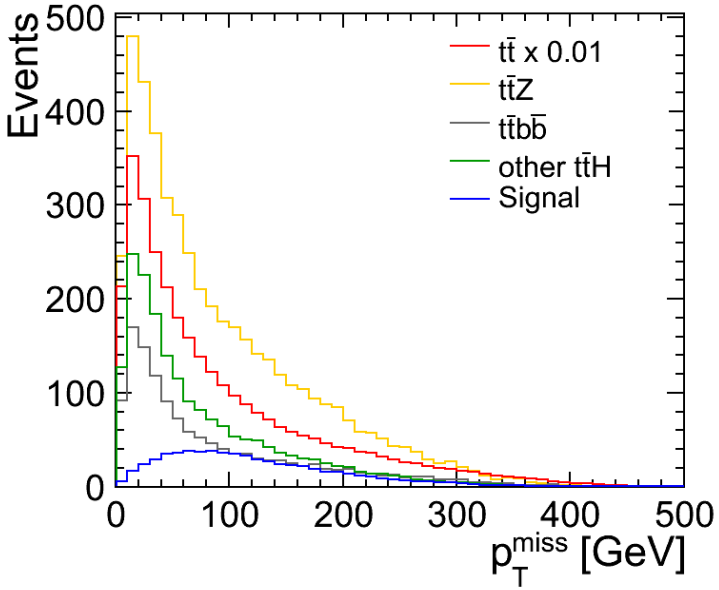
- $t\bar{t}$ background scaled by 0.01
- The background distributions are broader than the signal peaks

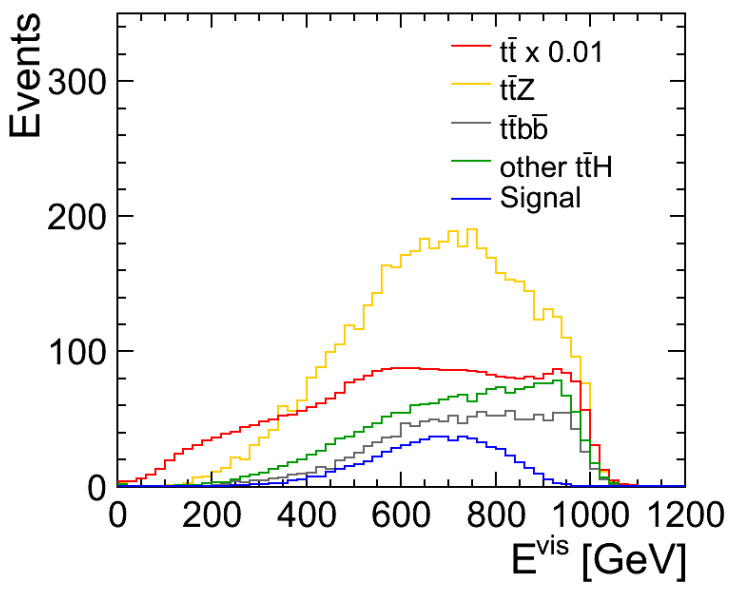
$L_{int} = 1\ ab^{-1}$

6 jets: new variables









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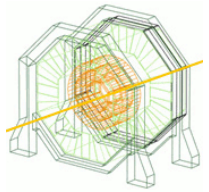
$L_{int} = 1\ ab^{-1}$

8 jets: selection variables I



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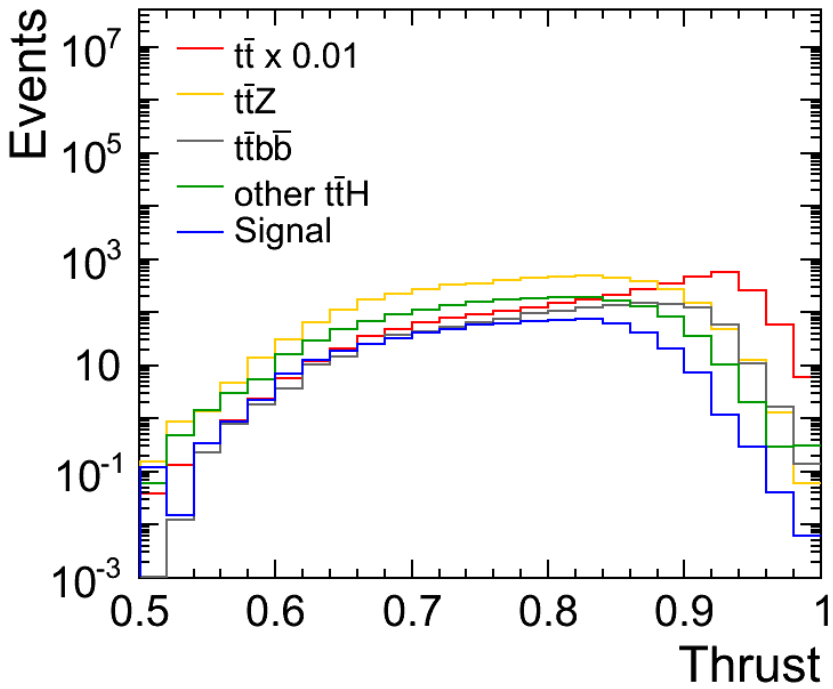
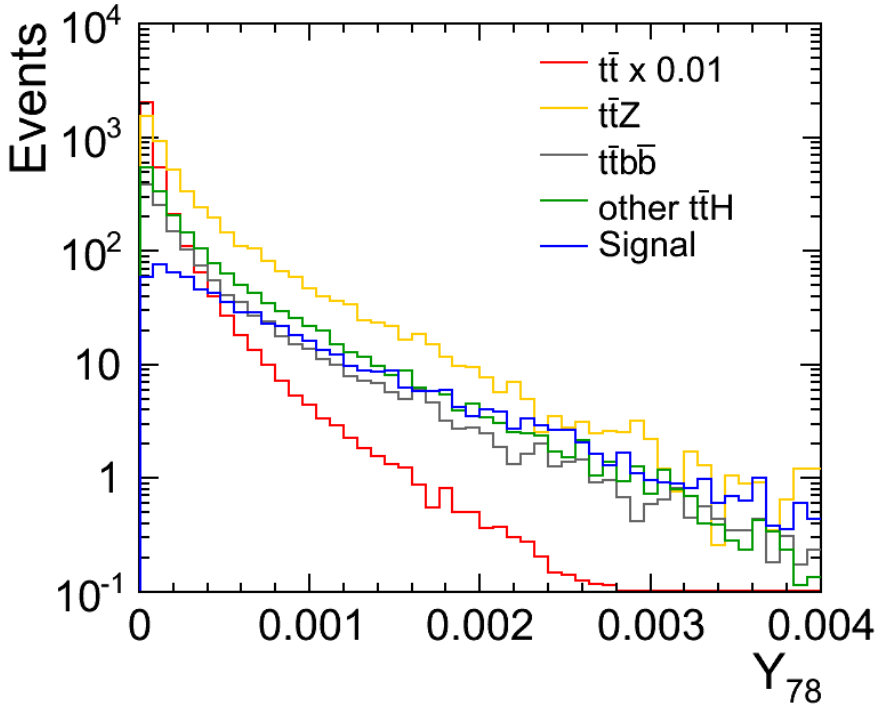
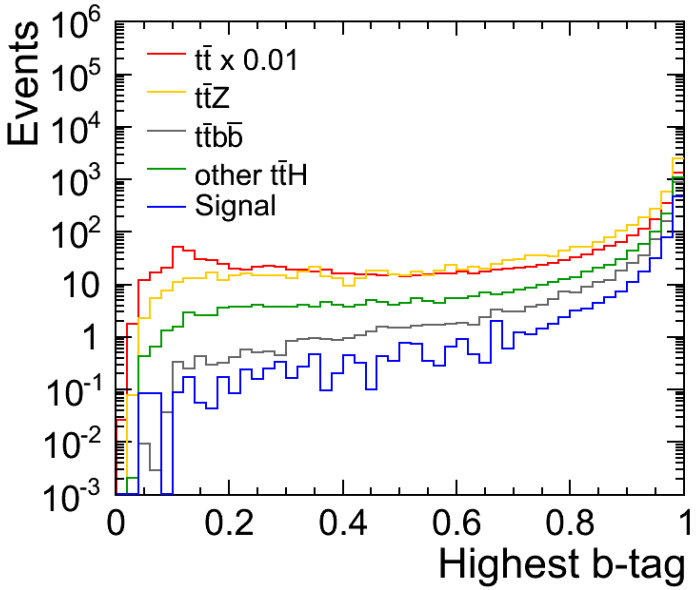
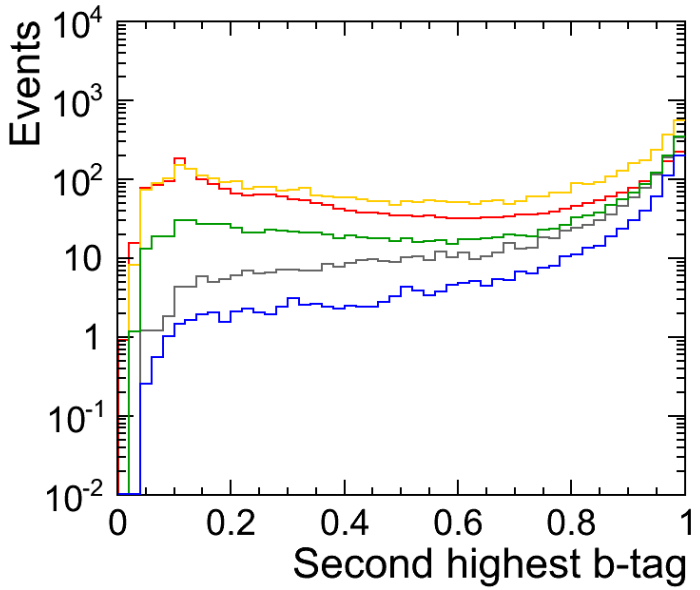


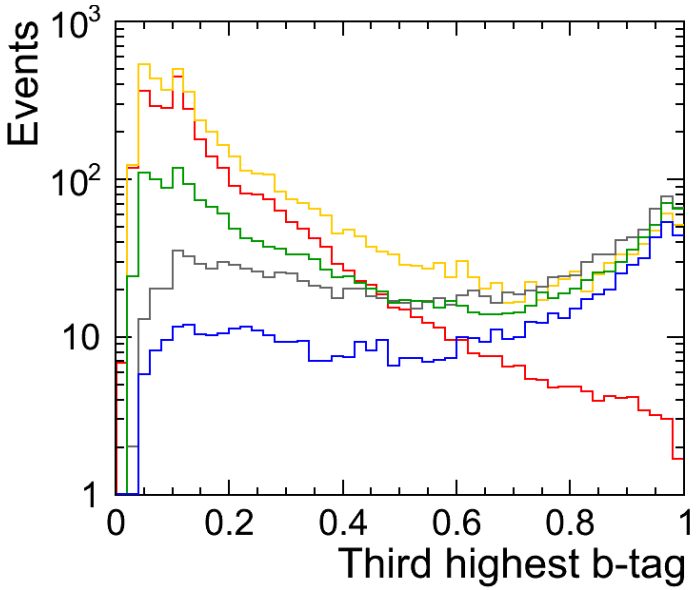


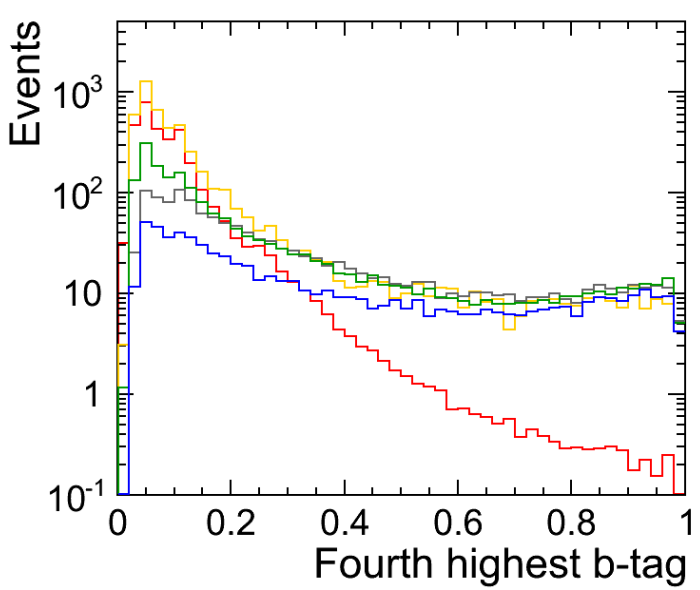
$L_{int} = 1\ ab^{-1}$

8 jets: b-tag values









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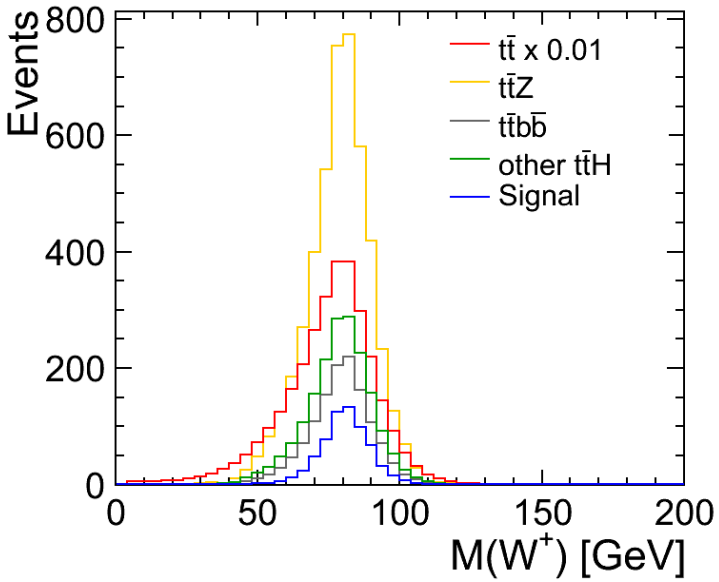
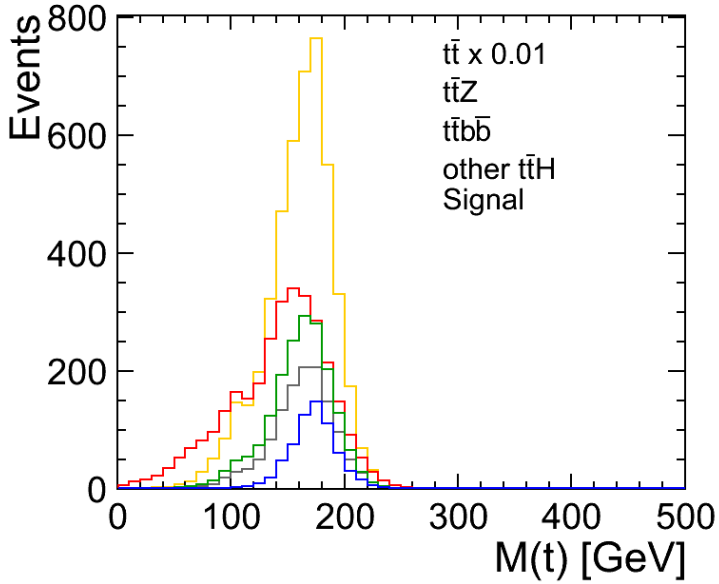
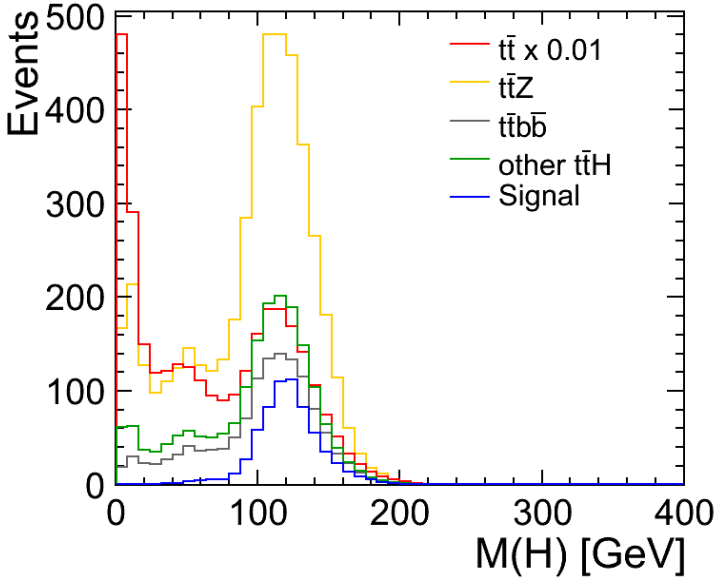
- Signal has 4 b-jets, part of the background samples contain only 2 b-jets

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

8 jets: W^+/top/Higgs masses



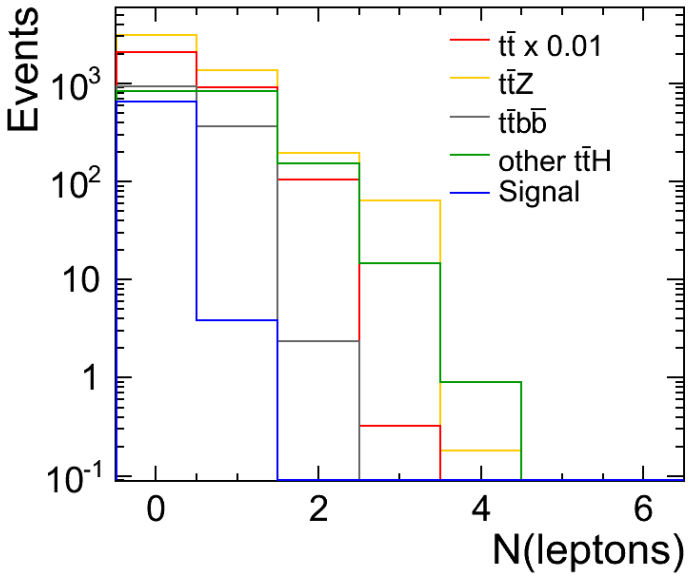


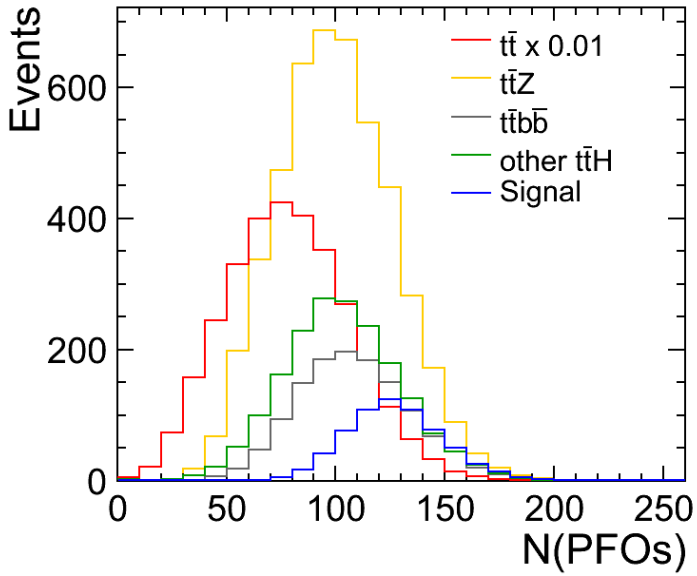


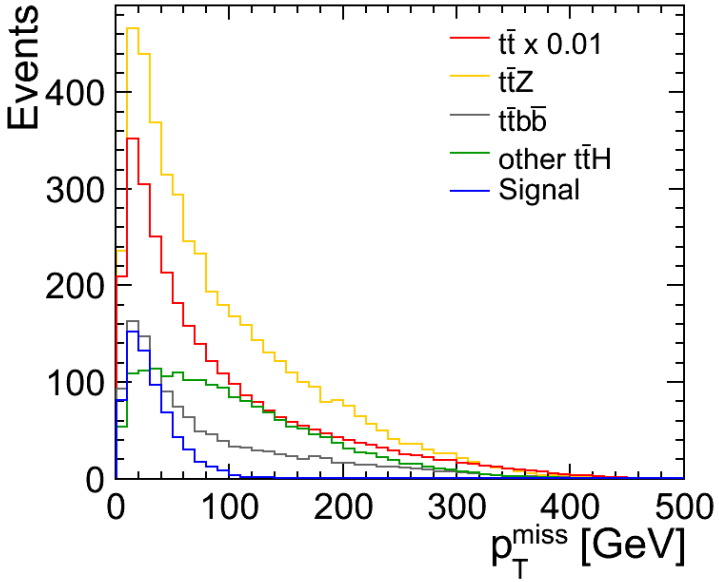
- $t\bar{t}$ background scaled by 0.01
- The background distributions are broader than the signal peaks

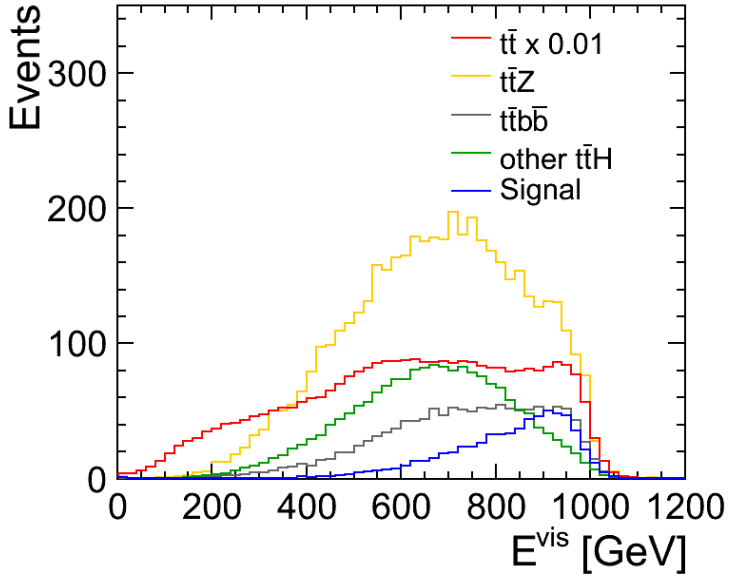
$L_{int} = 1\ ab^{-1}$

8 jets: new variables







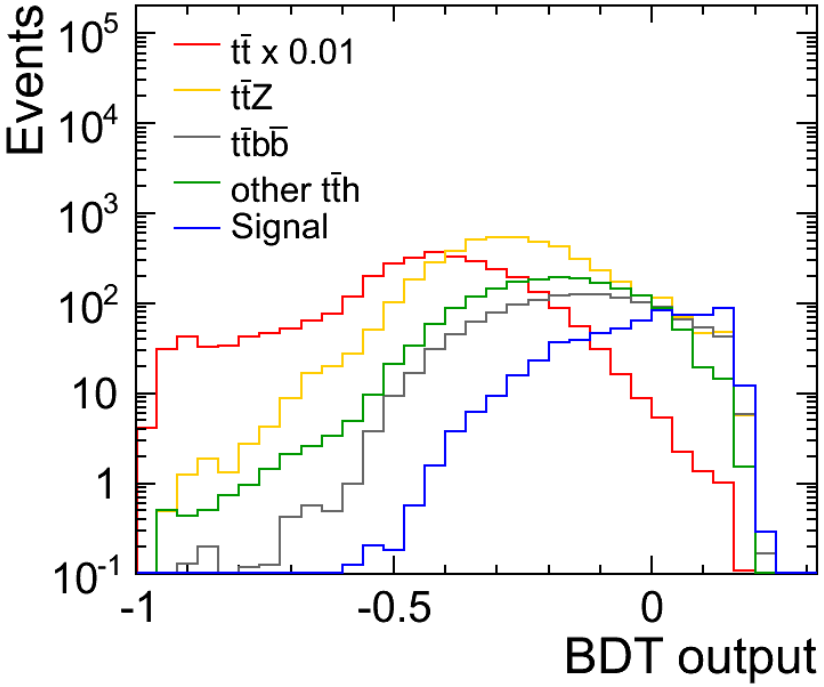


- $t\bar{t}$ background scaled by 0.01

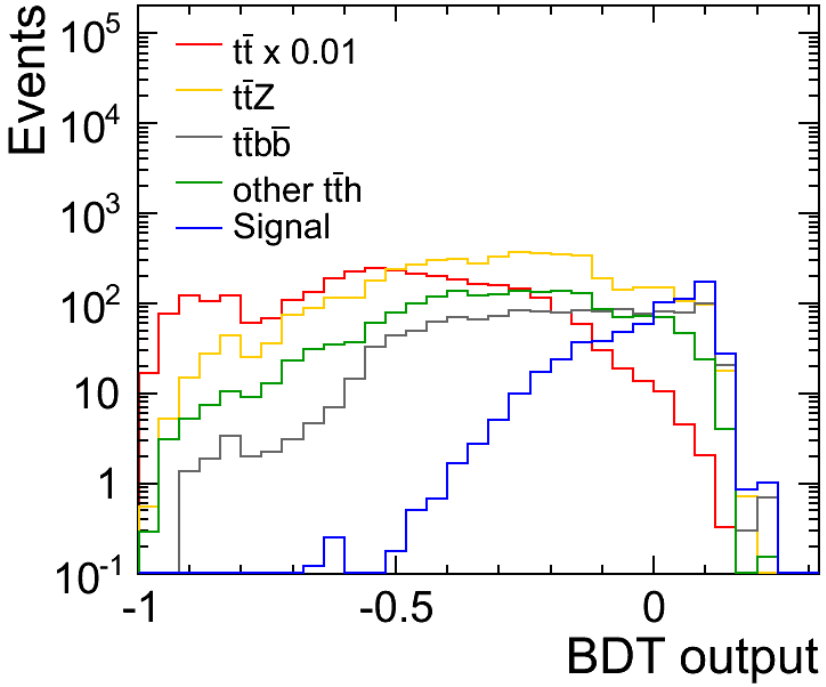
$L_{int} = 1\ ab^{-1}$

BDT outputs and results

6 jets:



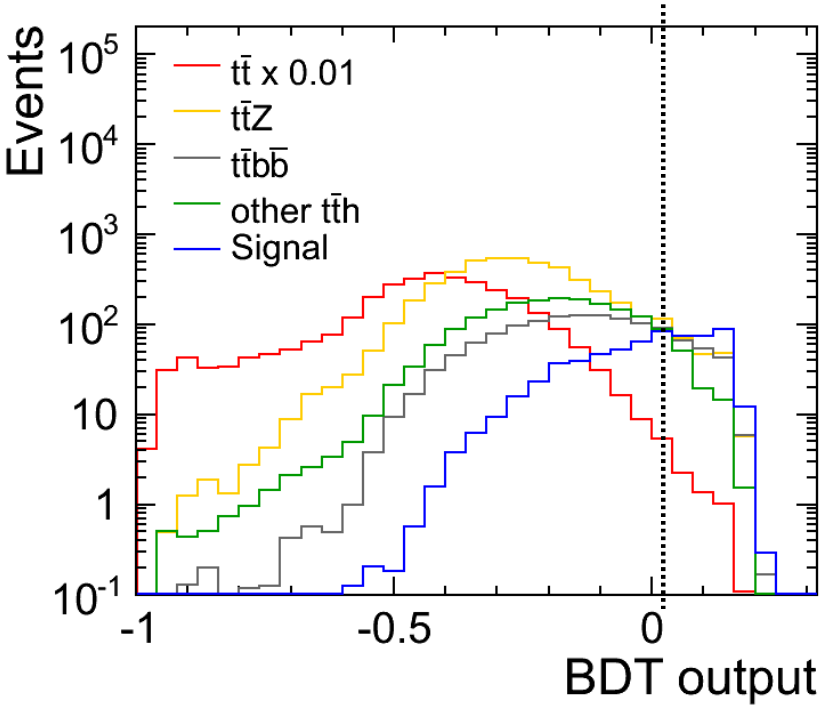
8 jets:



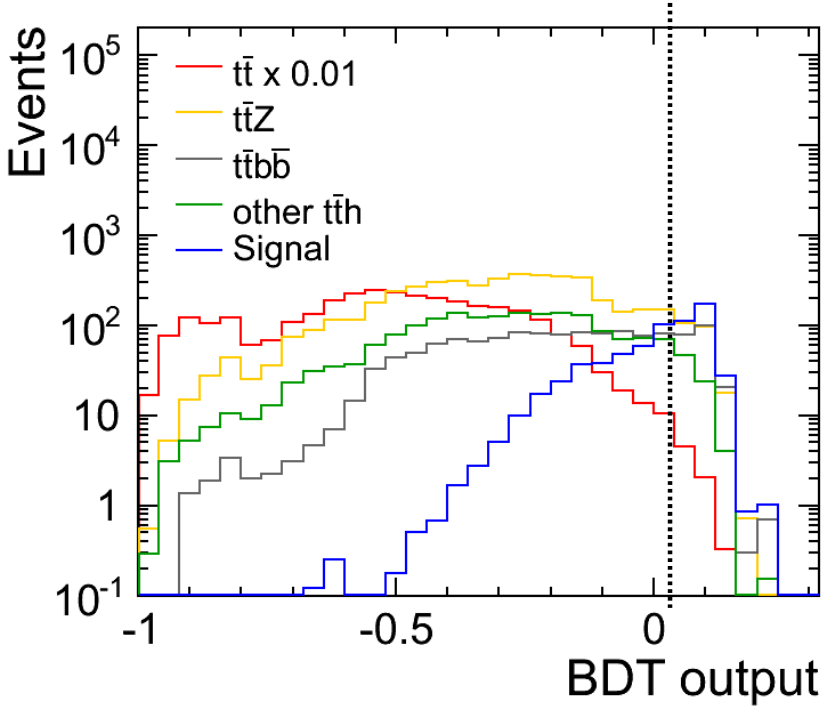
$L_{int} = 1\ ab^{-1}$

BDT outputs and results

6 jets: BDT > 0.0266



8 jets: BDT > 0.0363



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

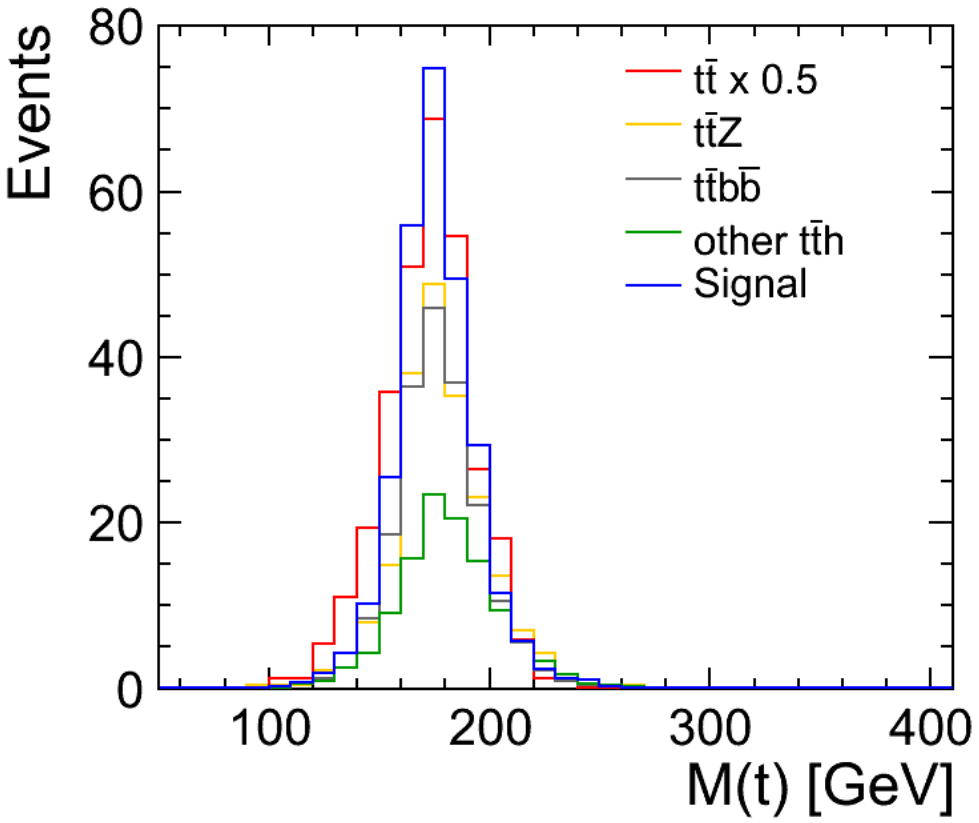
$\Delta\sigma / \sigma = 13.6\% \rightarrow \Delta y_t / y \approx 7.1\%$

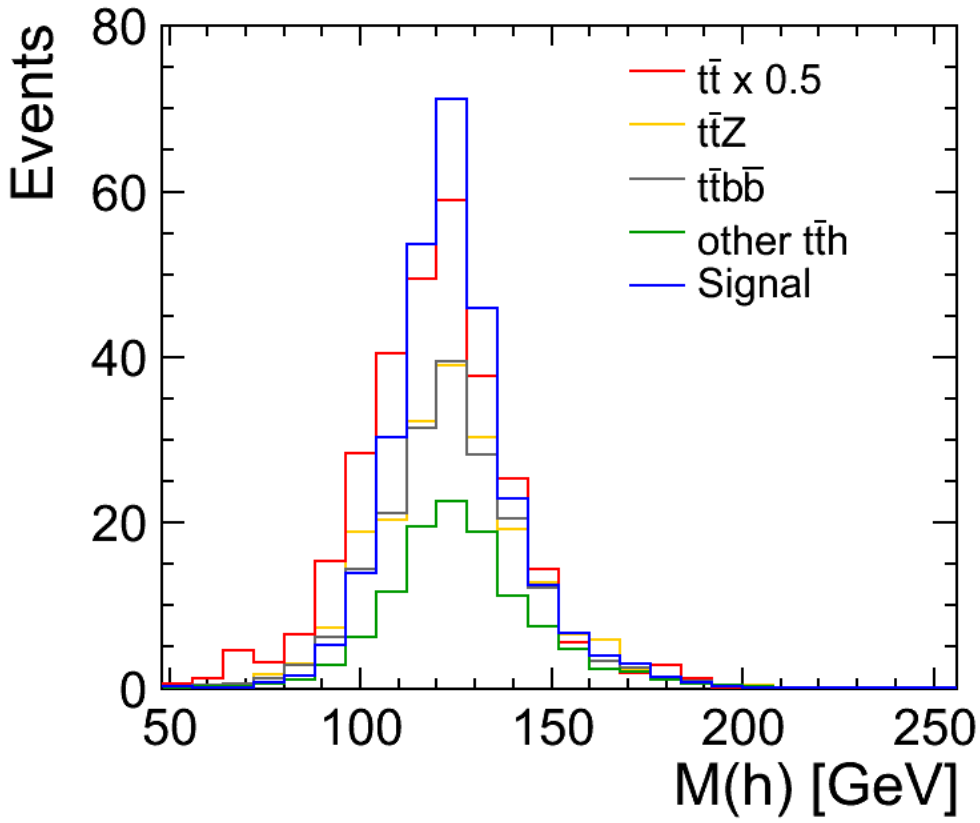
$\Delta\sigma / \sigma = 12.3\% \rightarrow \Delta y_t / y \approx 6.4\%$

Combined: $\Delta y_t / y \approx 4.8\%$

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

M(t) and M(h) for selected events with 6 jets

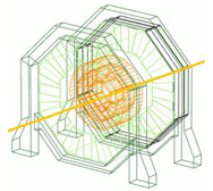




These figures are shown in the DBD

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

Results with 1 ab^{-1} with P(e) = -0.8 and P(p) = +0.2

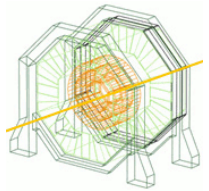


6 jets: $\Delta y_t / y \approx 6.3\%$ (7.1% for default polarisations)

8 jets: $\Delta y_t / y \approx 5.8\%$ (6.4% for default polarisations)

Combined: $\Delta y_t / y \approx 4.3\%$ (4.8% for default polarisations)

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.

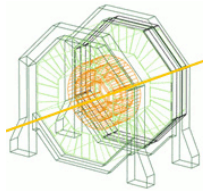
6 jets: $\Delta y_t / y \approx 7.4\%$ (7.1% for default analysis)

8 jets: $\Delta y_t / y \approx 6.4\%$ (6.4% for default analysis)

Combined: $\Delta y_t / y \approx 4.8\%$ (as for default analysis)

→ **Results (almost) unchanged**

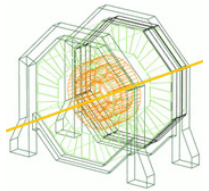
Summary and conclusions



- The cross section for the $t\bar{t}H$ final state was extracted using two signal channels

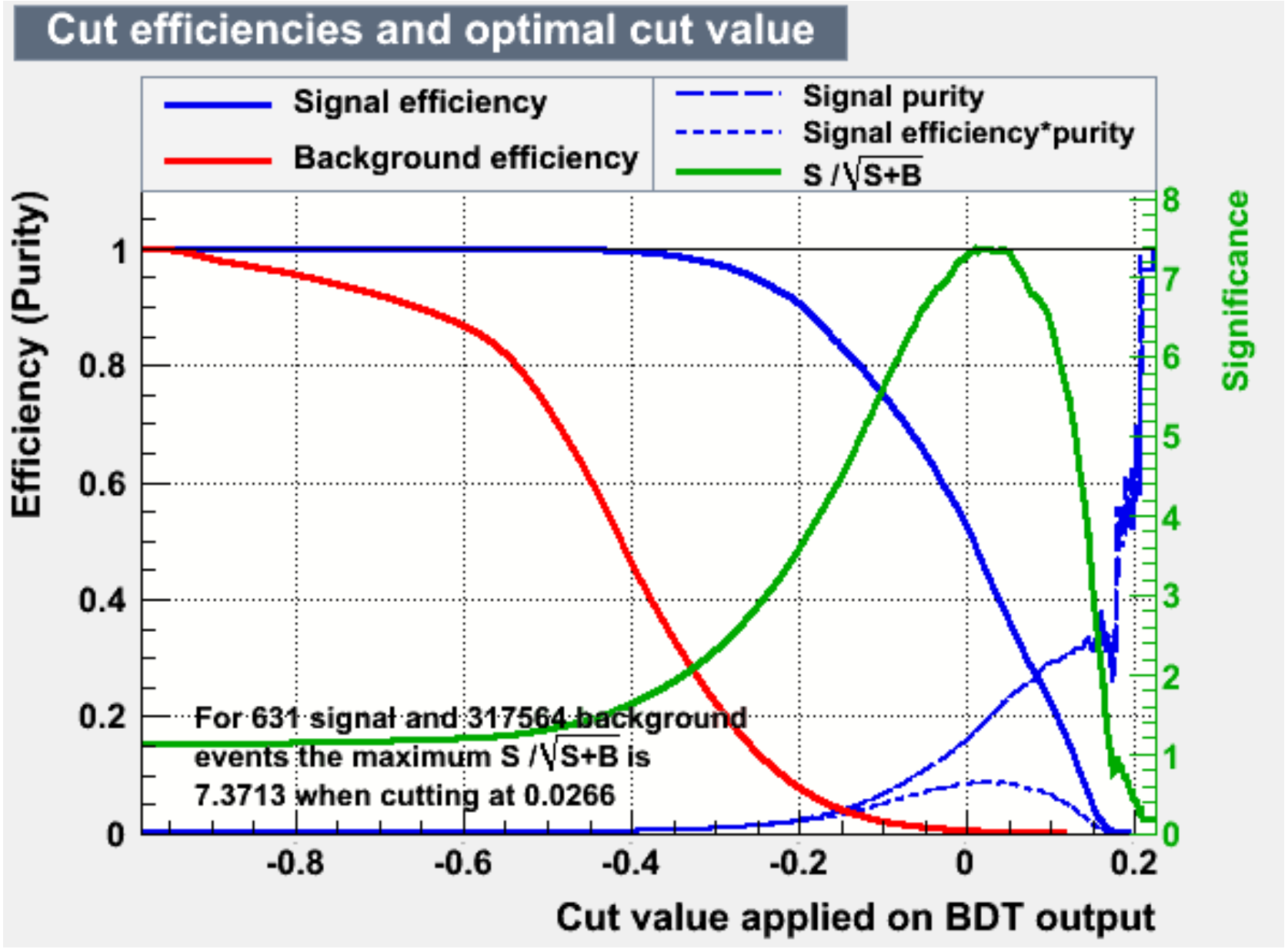
- For a combination of both channels a precision of about 4.8% on the top Yukawa coupling can be achieved for 0.5 ab^{-1} with P(e) = -0.8, P(p) = +0.2 and 0.5 ab^{-1} with P(e) = +0.8, P(p) = -0.2

- **Ideas for further improvement (for publication):**
  - Try kinematic fitting
  - Include tau-leptons for final state with 6 jets?



Backup

Significance: 6 jets



Significance: 8 jets