Measurement of the top Yukawa coupling at a1.4 TeV CLIC collider

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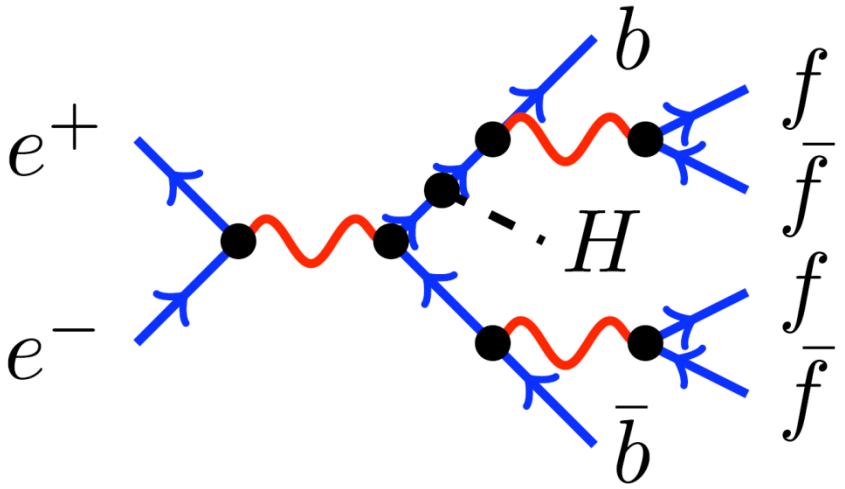
On behalf of the CLIC detector and physics study

Introduction

- We considered the benchmark production process $e^+e^- \rightarrow t\bar{t}H$ for CLIC SiD at 1.4 TeV with no beam polarization and a luminosity of 1.5 ab^{-1}
- Goal: analyze $t\bar{t}H$ decays to measure the **top Yukawa coupling**
- Two final states:
  - **6 jets semi leptonic mode** (Sophie Redford)
  - **8 jets fully hadronic mode** (Marcelo Vogel)



Motivation and signal

- There is a linear dependence between a Higgs-fermion coupling and the fermion mass
- The top quark, being the heaviest SM particle couples most strongly to the Higgs field
- New physics could induce sizable deviations from SM expectation

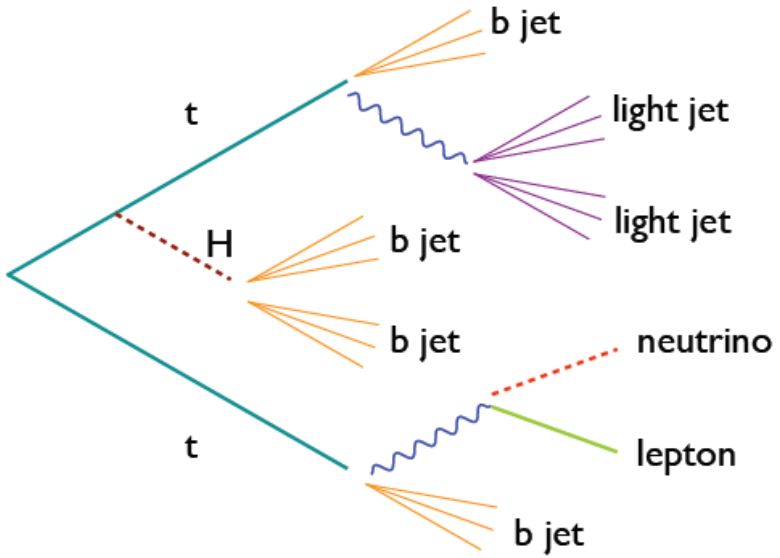
6 jets + lepton + nu

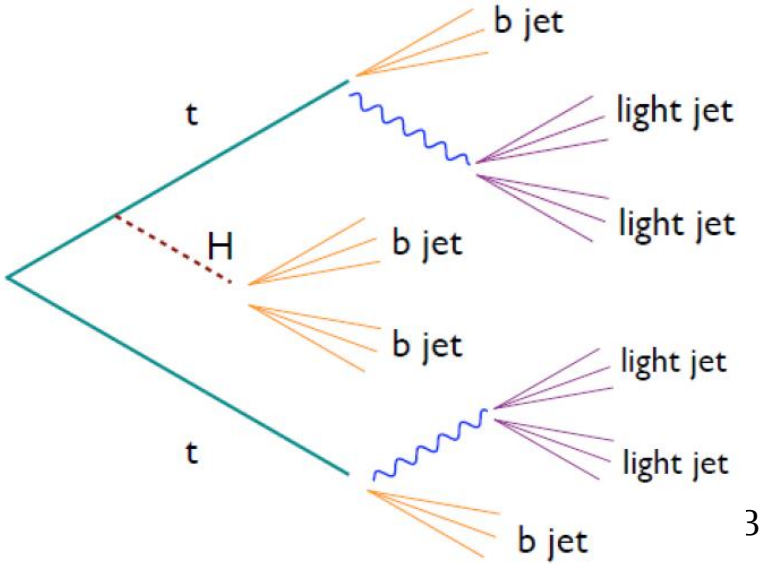
tt->bblvqq, H->bb

Exclusive samples

8 jets (lepton veto)

tt->bbqqqq, H->bb

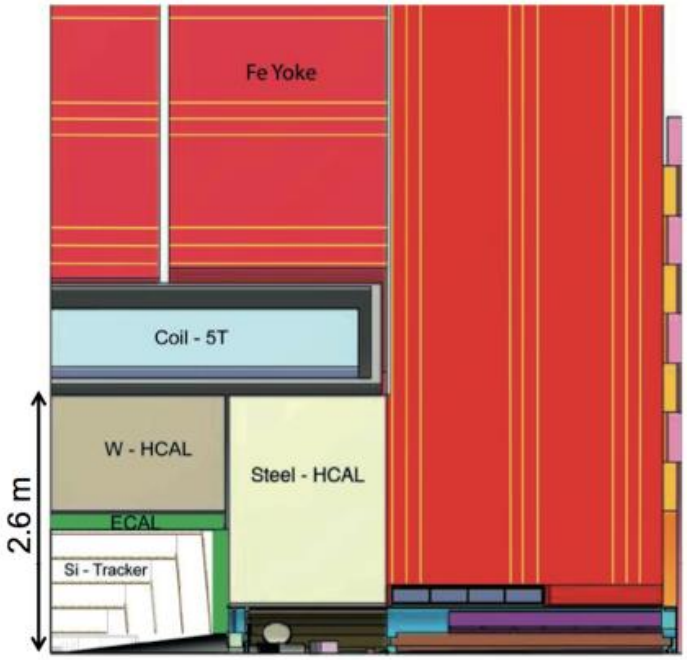




Overview

Simulation

- Physsim generates $t\bar{t}H$ events
- Pythia for hadronization
- Pile up from beam induced backgrounds (gamma gamma to hadrons) overlaid
- Full SiD detector simulation in GEANT4



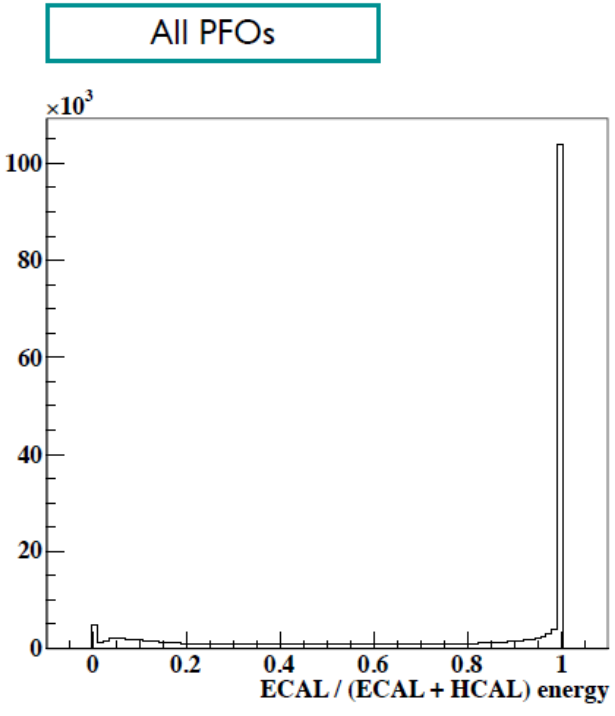
CLIC_SiD

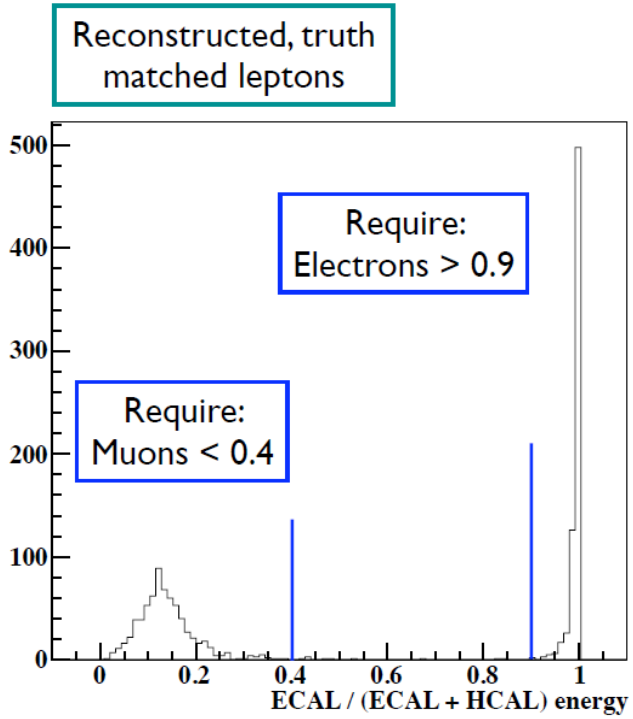
Reconstruction

- Particle Flow Objects (PFOs) reconstructed with Pandora
- Beam induced background suppressed by timing cuts:

Isolated lepton finding

- Isolated lepton finder (e/mu). Combination of tracking and calorimeter information
  - **Impact parameter IP < 0.2**
  - **Track energy > 15 GeV**
  - **Iso/p_T < 0.1, (p_T < 100 GeV)**
  - **ECAL/E_{Total} < 0.4 (muons), ECAL/E_{Total} > 0.9 (electrons)**
  - **87% of electrons or muons in signal events are found**



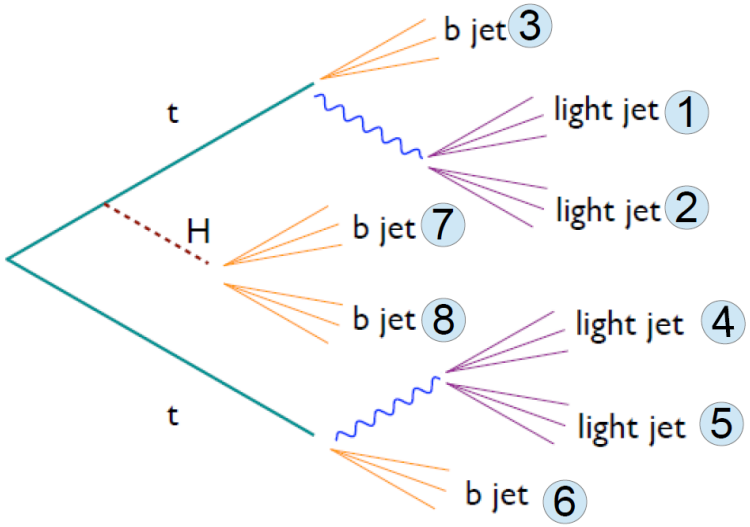


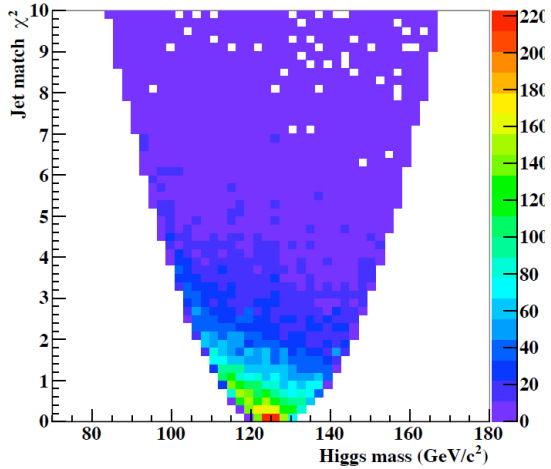
Event reconstruction

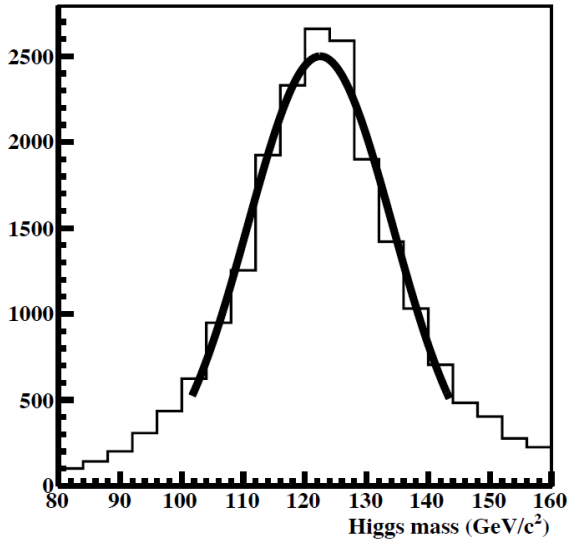
- Jet clustering in two steps:
  - kt algorithm with R = 1.0 to remove PFOs in beam jets
  - All PFOs in kt-jets (not beam jets) are input to a Durham jet clustering
- For each permutation of the 8 (6) jets, the chi2 is calculated.
- The configuration that minimizes the chi^2 is used to reconstruct the W, top and Higgs

$$\chi^2_{8\,\text{jets}} = \frac{(M_{12}-M_W)^2}{\sigma_W^2} + \frac{(M_{123}-M_t)^2}{\sigma_t^2} + \frac{(M_{45}-M_W)^2}{\sigma_W^2} + \frac{(M_{456}-M_t)^2}{\sigma_t^2} + \frac{(M_{78}-M_H)^2}{\sigma_H^2}$$

M_W, M_t, M_H, σ_W, σ_t and σ_H obtained by matching particles in jets to MC quarks

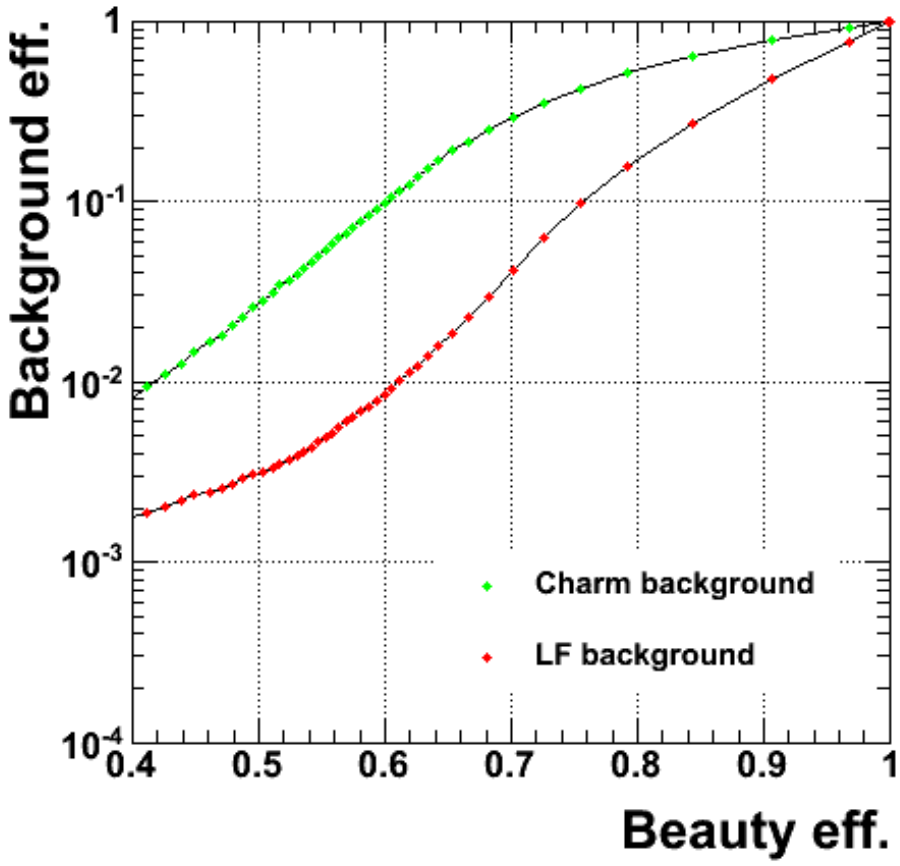






Flavor tagging

- First time that LCFIPlus has been used with the CLIC_SiD detector
- 6-jet events at 1.4 TeV used for training of flavor tagging
- 60Bx beam-induced backgrounds



Backgrounds to $t\bar{t}h$

6 jet + l final state
Important backgrounds:
high jet multiplicity + one lepton

Process	Cross section (fb)	Events in 1.5 ab^{-1}	One lepton (6 jets)	No lepton (8 jets)
$t\bar{t}H$, 6 jets, $H \to b\bar{b}$	0.431	647	78	641
$t\bar{t}H$, 4 jets, $H \to b\bar{b}$	0.415	623	377	258
$t\bar{t}H$, 2 jets, $H \to b\bar{b}$	0.1	150	67	26
$t\bar{t}H$, 6 jets, H not $b\bar{b}$	0.315	473	127	386
$t\bar{t}H$, 4 jets, H not $b\bar{b}$	0.303	455	243	151
$t\bar{t}H$, 2 jets, H not $b\bar{b}$	0.073	110	41	15
$t\bar{t}b\bar{b}$, 6 jets	0.549	824	120	817
$t\bar{t}b\bar{b}$, 4 jets	0.529	794	481	342
$t\bar{t}b\bar{b}$, 2 jets	0.127	191	85	34
$t\bar{t}Z$, 6 jets	1.895	2843	442	2637
$t\bar{t}Z$, 4 jets	1.825	2738	1515	1087
$t\bar{t}Z$, 2 jets	0.439	659	274	110
$t\bar{t}$	135.8	203700	78269	139943

Backgrounds to $t\bar{t}h$

6 jet + l signal
Important backgrounds:
high jet multiplicity + one lepton

8 jet final state
Important backgrounds:
high jet multiplicity final states

Process	Cross section (fb)	Events in 1.5 ab^{-1}	One lepton (6 jets)	No lepton (8 jets)
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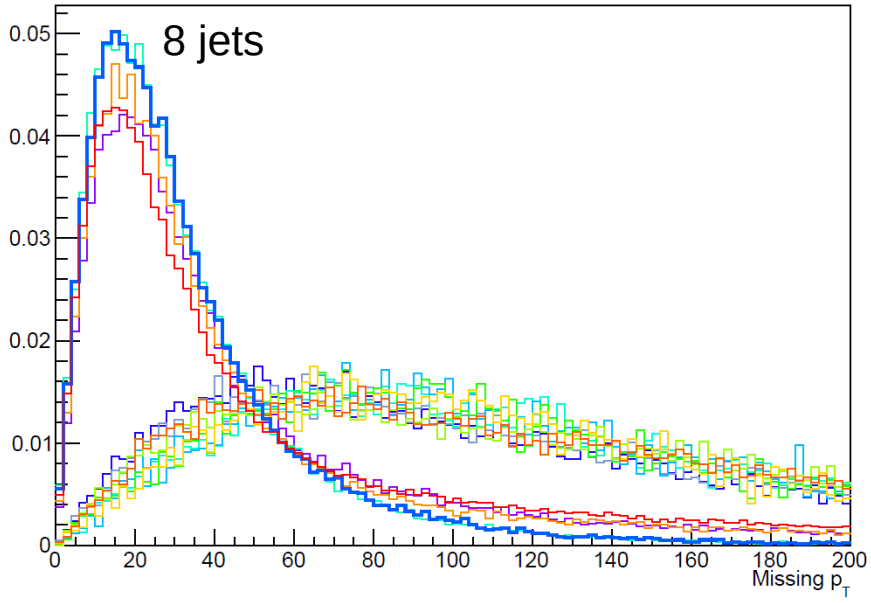
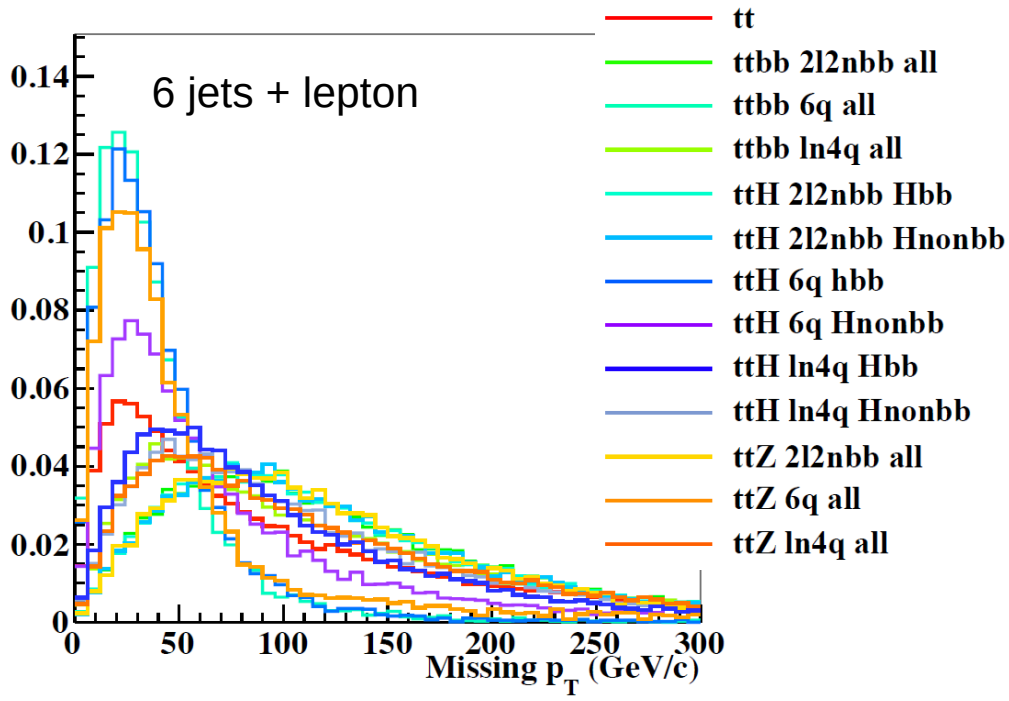
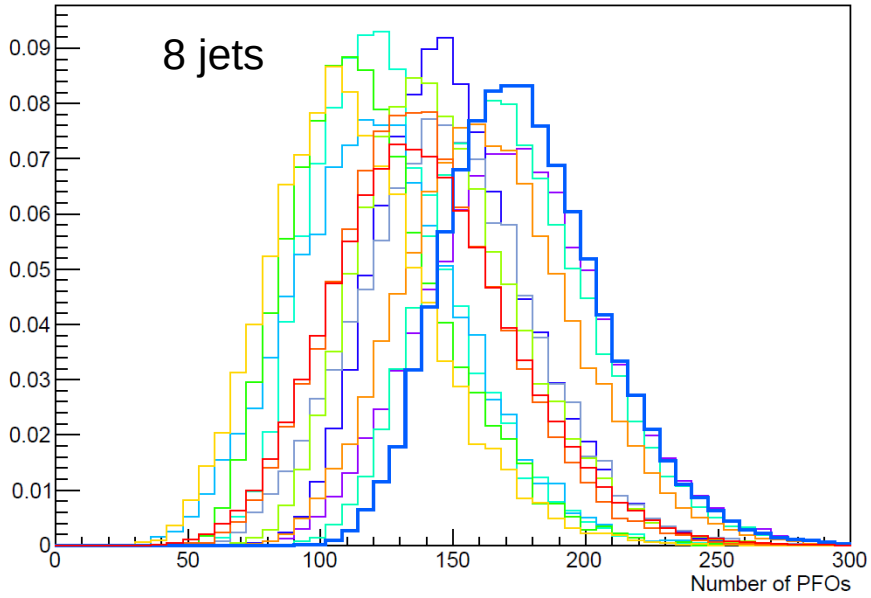
Discriminating variables for MVA

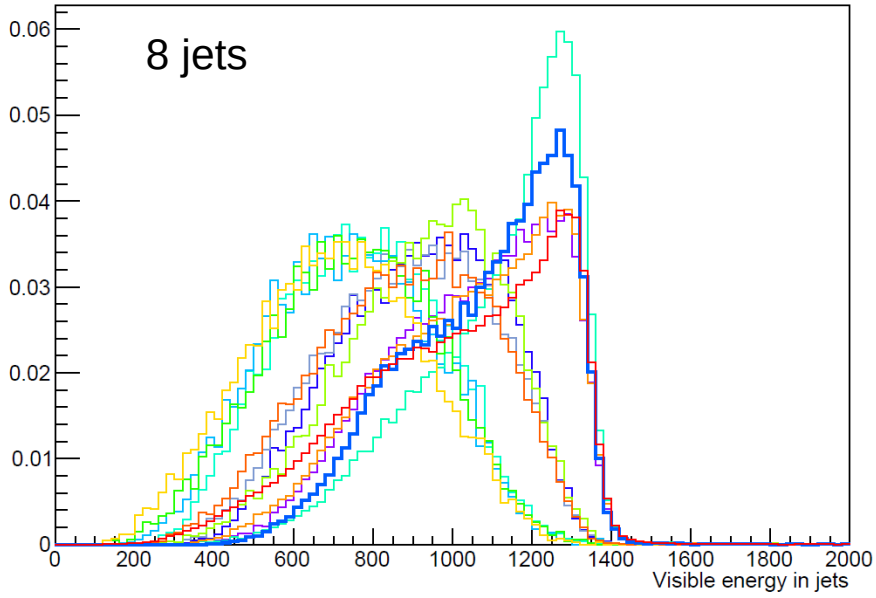
- **Kinematic**
  - Higgs mass, number of particles (PFOs), missing energy, visible energy in jets, Chi^2
- **Angular**
  - Top-Higgs angle, Higgs-bottom decay angle
- **Event shapes**
  - Sphericity, thrust
- **B-tags**

Kinematic variables

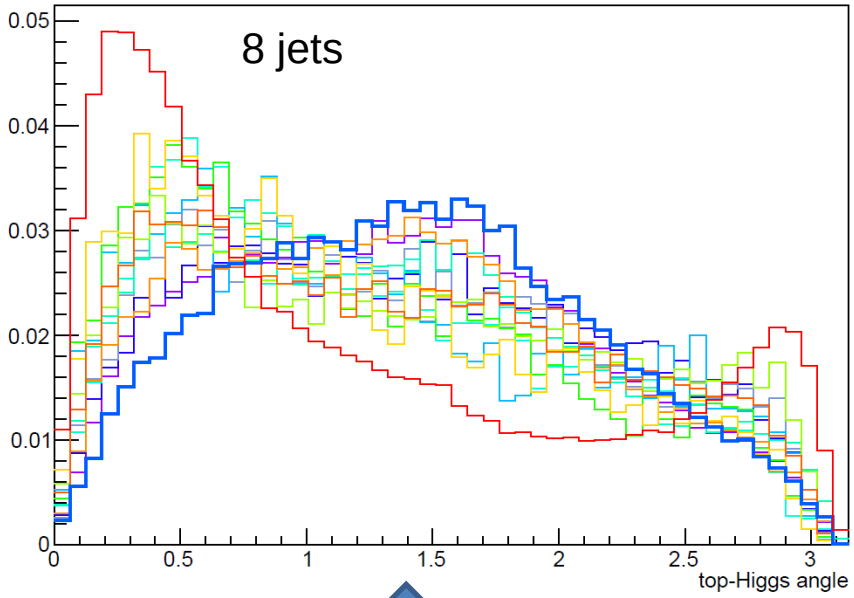




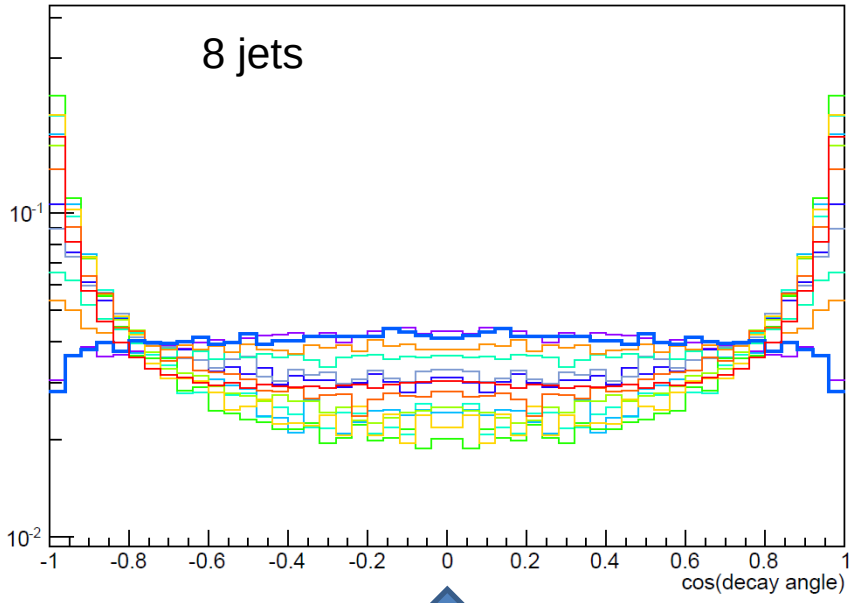




Angular Variables



Angle between top and radiated Higgs



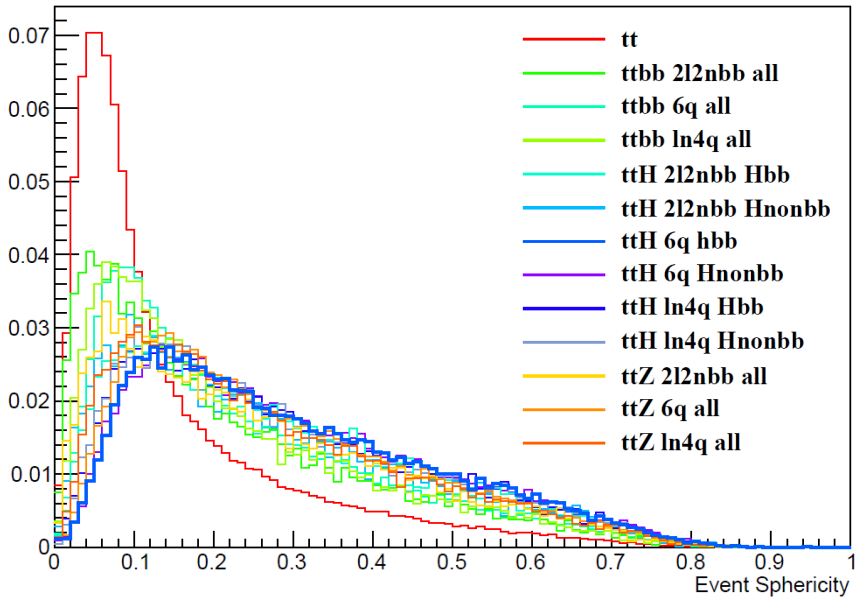
Angle between Higgs and b quark in the rest frame of Higgs

- tt
- ttbb 2l2nbb all
- ttbb 6q all
- ttbb ln4q all
- ttH 2l2nbb Hbb
- ttH 2l2nbb Hnonbb
- ttH 6q hbb
- ttH 6q Hnonbb
- ttH ln4q Hbb
- ttH ln4q Hnonbb
- ttZ 2l2nbb all
- ttZ 6q all
- ttZ ln4q all

Event shape variables (8 jets)

Sphericity = 0

2-Jet event

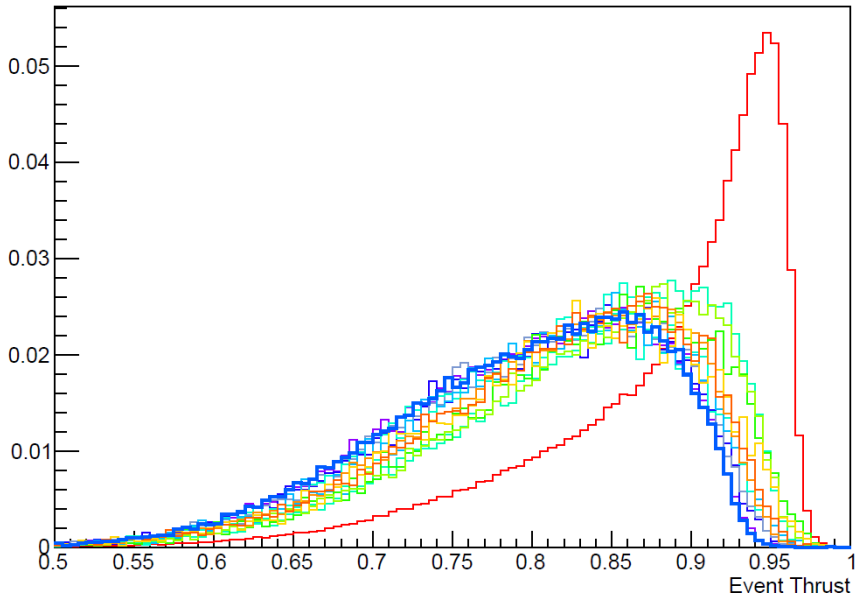


Sphericity = 1

Isotropic event

Thrust = ½

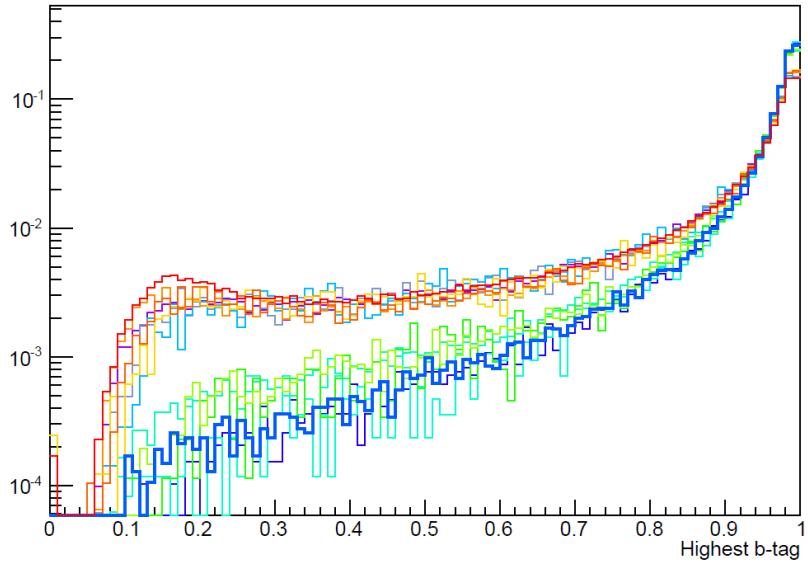
Isotropic event

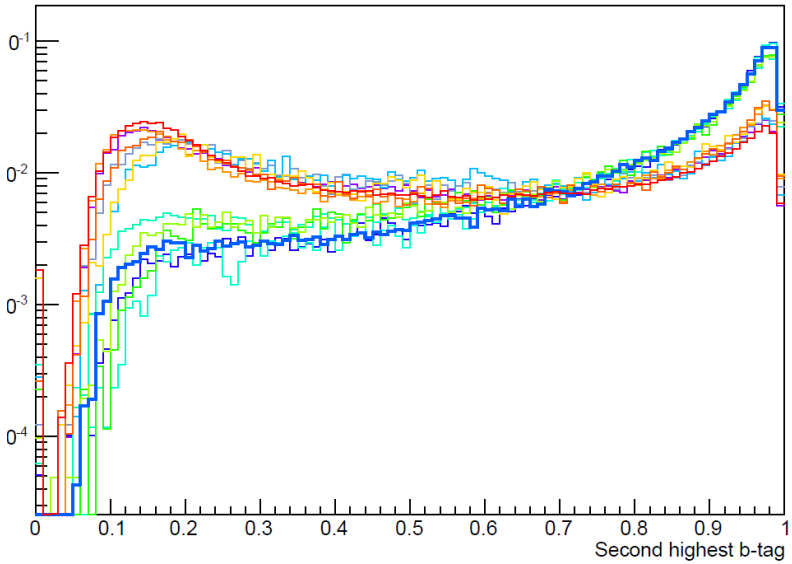


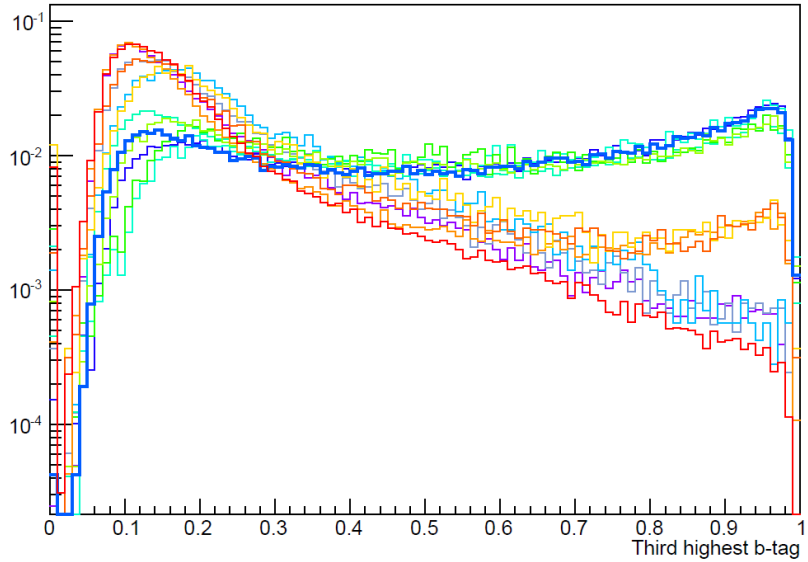
Thrust = 1

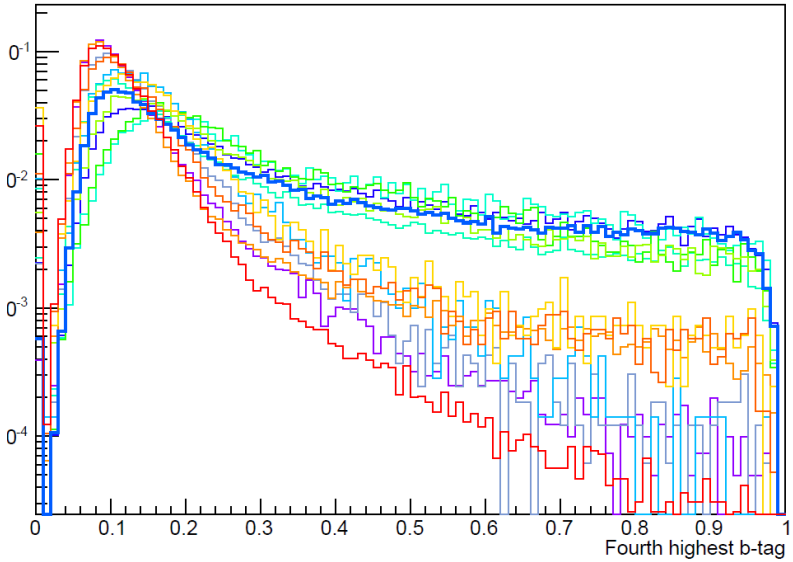
2-Jet event

B-tags (8 jets)





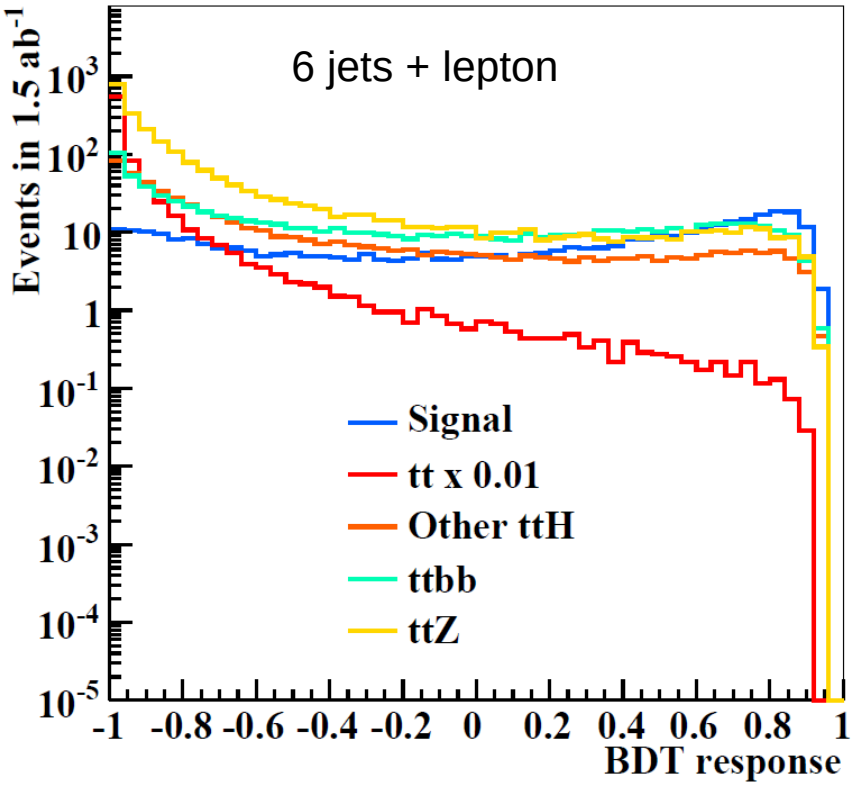


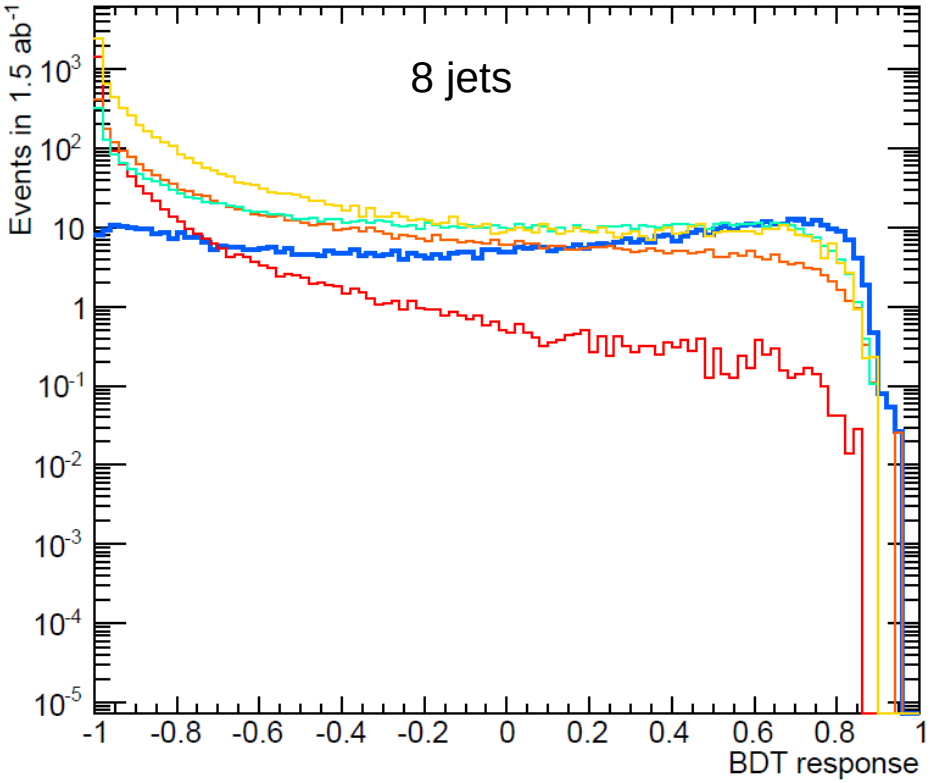


tt
ttbb 2l2nbb all
ttbb 6q all
ttbb ln4q all
ttH 2l2nbb Hbb
ttH 2l2nbb Hnonbb
ttH 6q hbb
ttH 6q Hnonbb
ttH ln4q Hbb
ttH ln4q Hnonbb
ttZ 2l2nbb all
ttZ 6q all
ttZ ln4q all

TMVA (Toolkit MVA)

- BDT with gradient boost
- Trained on 20 variables
- ‘Default’ options
- We cut on the the BDT response that maximize the signal significance





Yields after BDT selection

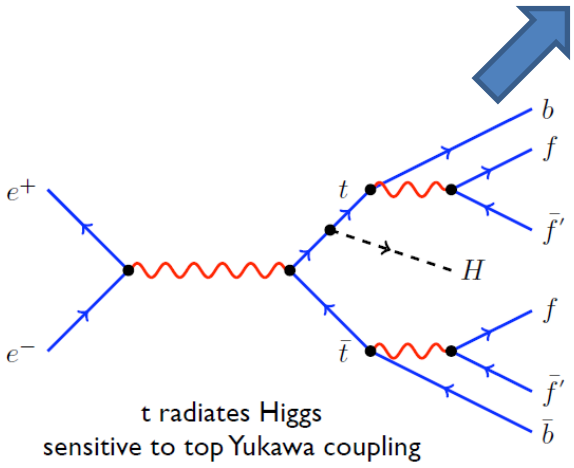
6 jet + l signal
Important backgrounds:
high jet multiplicity + one lepton

8 jet signal
Important backgrounds:
highest jet multiplicity
final states

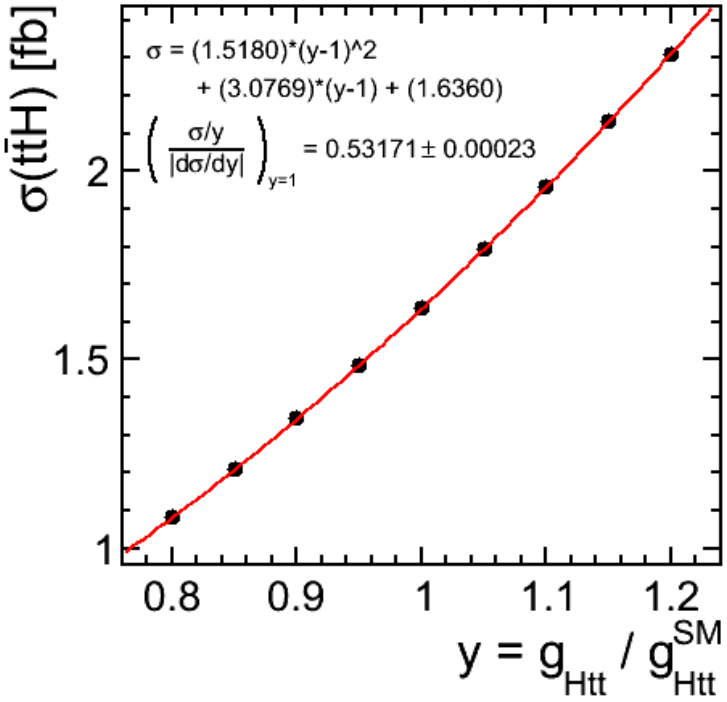
Process	Cross section (fb)	Events in 1.5 ab^{-1}	Pass BDT (6 jets)	Efficiency (%)	Pass BDT (8 jets)	Efficiency (%)
$t\bar{t}H$, 6 jets, $H \to b\bar{b}$	0.431	647	10	1.54	318	49.1
$t\bar{t}H$, 4 jets, $H \to b\bar{b}$	0.415	623	171	27.4	62	9.93
$t\bar{t}H$, 2 jets, $H \to b\bar{b}$	0.1	150	22	14.7	2	1.27
$t\bar{t}H$, 6 jets, H not $b\bar{b}$	0.315	473	2	0.423	17	3.63
$t\bar{t}H$, 4 jets, H not $b\bar{b}$	0.303	455	7	1.54	3	0.621
$t\bar{t}H$, 2 jets, H not $b\bar{b}$	0.073	110	1	0.909	1	0.101
$t\bar{t}b\bar{b}$, 6 jets	0.549	824	7	0.850	244	29.6
$t\bar{t}b\bar{b}$, 4 jets	0.529	794	124	15.6	42	5.31
$t\bar{t}b\bar{b}$, 2 jets	0.127	191	17	8.90	2	0.783
$t\bar{t}Z$, 6 jets	1.895	2843	6	0.211	217	7.64
$t\bar{t}Z$, 4 jets	1.825	2738	104	3.80	36	1.33
$t\bar{t}Z$, 2 jets	0.439	659	14	2.12	1	0.201
$t\bar{t}$	135.8	203700	274	0.134	802	0.394

tt̄h Combination

- The signal cross section (all tt̄h samples) can be measured with a precision of:
  - Δσ/σ = 12.9% in the 6 jet final state
  - Δσ/σ = 10.4% in the 8 jet final state
  - Δσ/σ (combined) = 8.1%. Independent samples
- $\Delta g_{ttH}/g_{ttH} = 0.50$ Δσ/σ = 4.3%

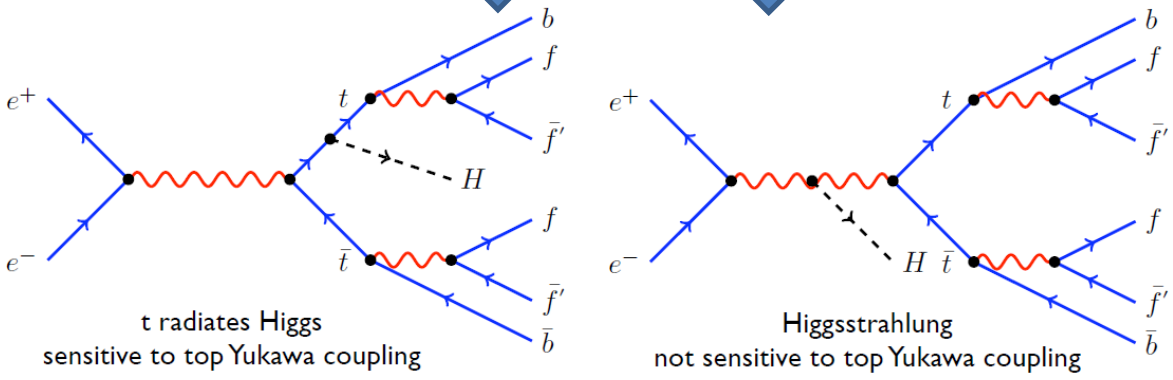


t radiates Higgs
sensitive to top Yukawa coupling



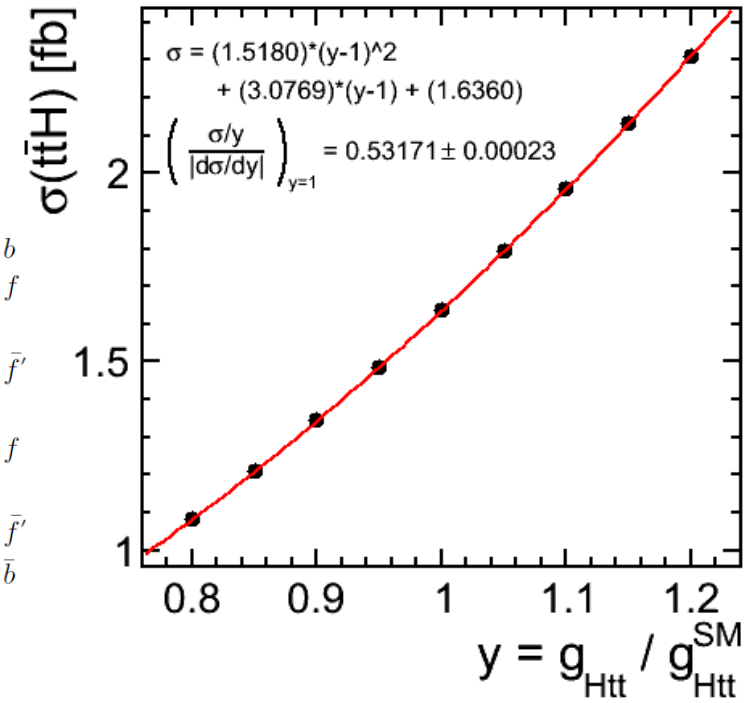
$t\bar{t}h$ Combination

- The signal cross section (all $t\bar{t}h$ samples) can be measured with a precision of:
  - $\Delta\sigma/\sigma$ = 12.9% in the 6 jet final state
  - $\Delta\sigma/\sigma$ = 10.4% in the 8 jet final state
  - $\Delta\sigma/\sigma$ (combined) = 8.1%. Independent samples
- $\Delta g_{ttH}/g_{ttH} = 0.53\,\Delta\sigma/\sigma = 4.3\%$



t radiates Higgs
sensitive to top Yukawa coupling

Higgsstrahlung
not sensitive to top Yukawa coupling



Summary

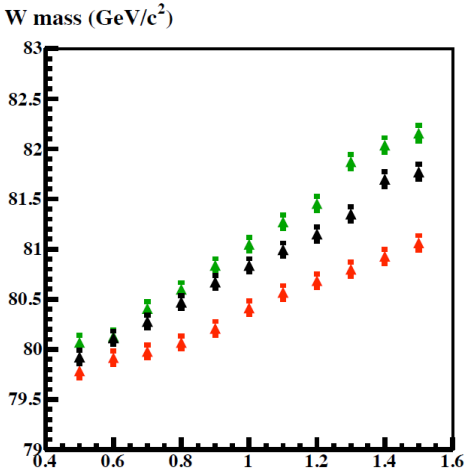
- Summary
  - We analized the production process $e^+e^- \rightarrow t\bar{t}H$ in its semileptonic (6 jets + lepton) and fully hadronic final states (8 jets)
  - We obtained a combined uncertainty on the top Yukawa coupling of $\Delta g_{ttH}/g_{ttH} = 4.3\%$
  - The measured uncertainty can be compared to those measured in two previous ILC analyses at 1 TeV for an ILD detector with $\Delta g_{ttH}/g_{ttH} = 4.3\%$ (LC-REP-2013-004), and for an SiD detector with $\Delta g_{ttH}/g_{ttH} = 4.5\%$ (arXiv:1307.7644)

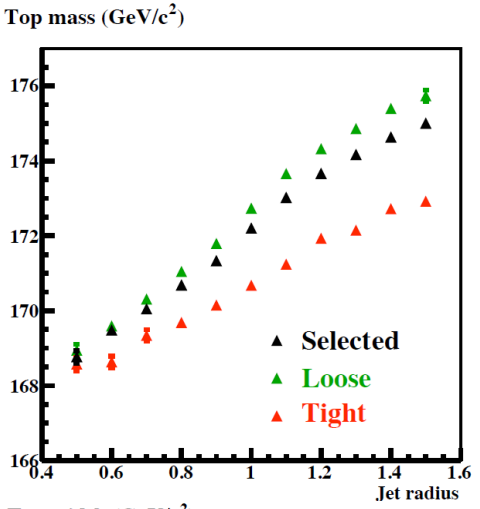
- Future steps
  - Improved lepton finder, including a dedicated tau finder
  - More realistic jet matching chi^2 function
  - Shows improvement of ~5% in semi-leptonic channel, hadronic channel to be checked

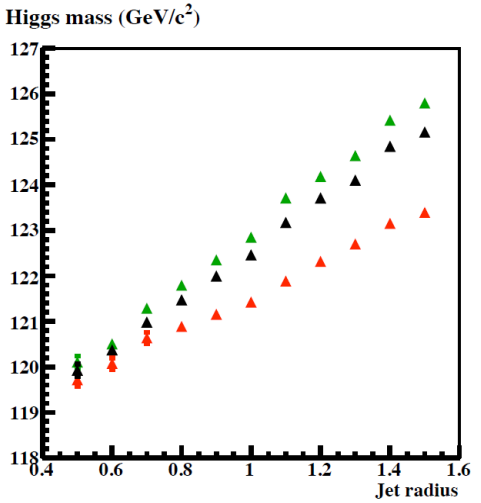
Backup

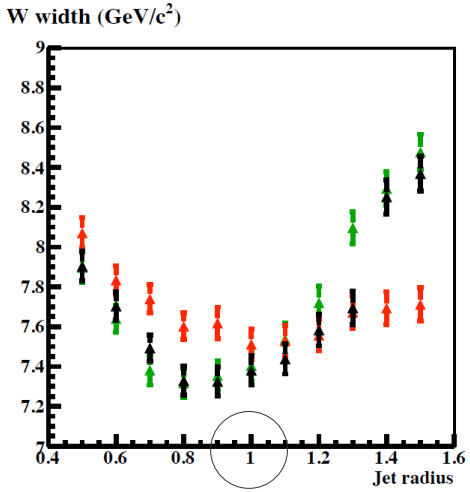
- Selection of PFO collection and jet radius
  - Beam induced backgrounds suppressed with timing cuts. 3 collections available: selected, loose selected and tight selected
  - For each collection:
    - Run FastJet (exclusive Kt algorithm) for different jet radii between 0.5 and 1.5. Merging stops when number of jet = 6 (8)
    - Match jets to W, t and Higgs using chi^2 method
  - Plot reconstructed masses and widths as functions of collection and jet radii
  - Choose Pandora PFO collection and jet radius with the best resolution

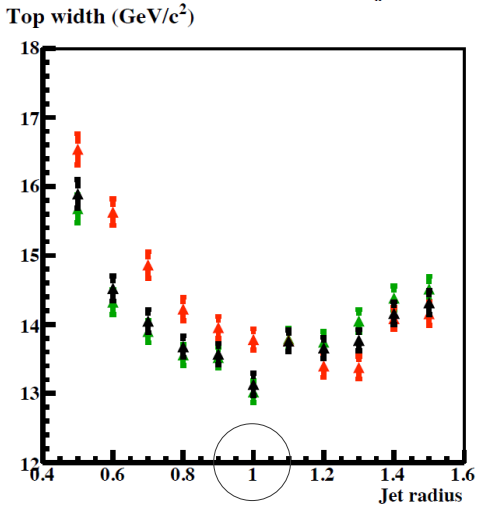
- Resolution as a function of PFO collection and jet radius
  - Measure width of W, top and Higgs obtained from the minimization of chi^2
  - Repeat for each PFO collection and for different jet radii between 0.5 and 1.5

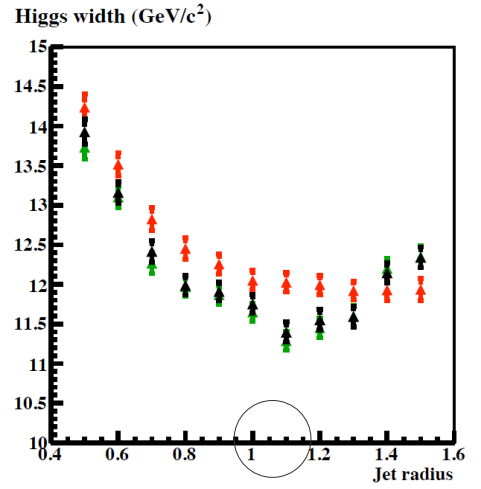










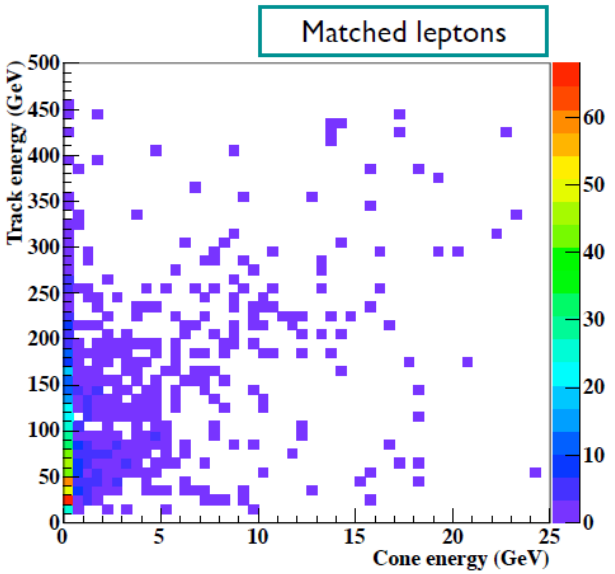


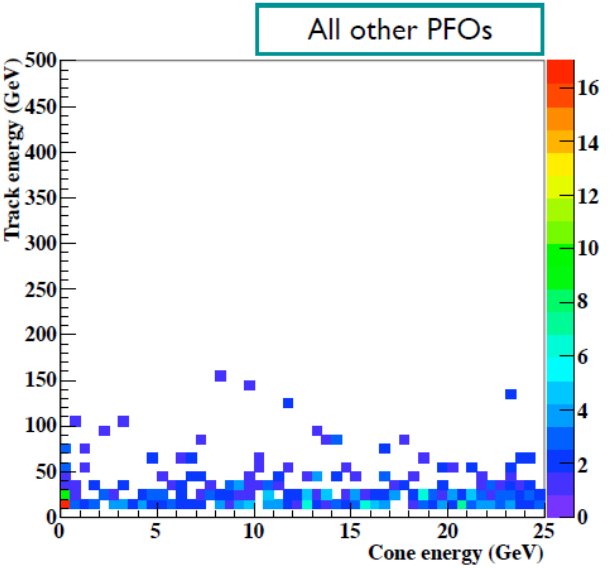
Analysis Overview

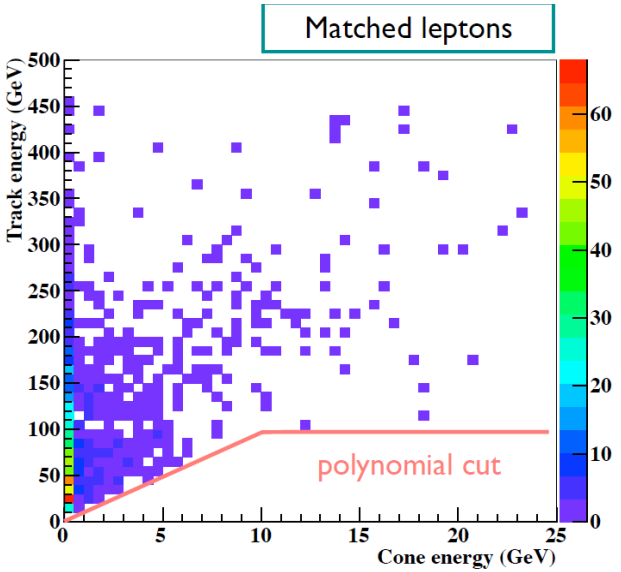
- Selection of Particle Flow Object (PFO) collection and jet radius
  - Jet clustering to 6 or 8 jets. FastJet hadron collider kT algorithm
  - Jet matching to W, t and Higgs. Choose collection and jet radius that minimizes the resolution
- Analysis of chosen PFO collection
  - Marlin processors: isolated lepton finder, vertex finder, jet clustering and flavor tagging processor (Lcfiplus).
  - Creation of root trees to study kinematics of signal and background
  - MVA selection and maximization of significance

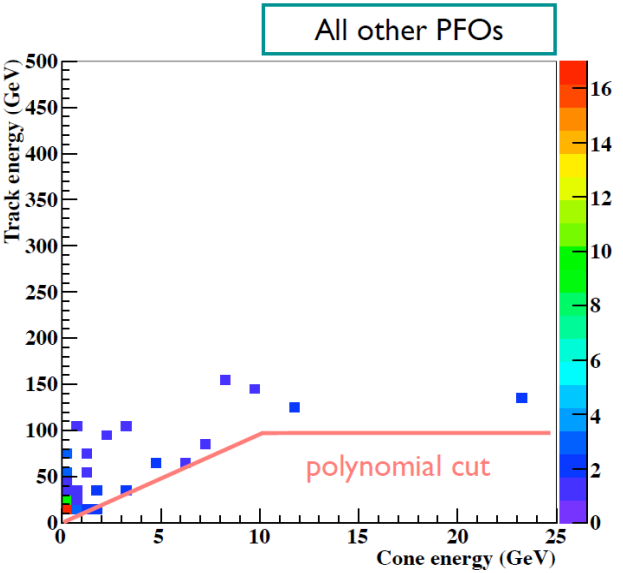
Lepton identification

- Isolated lepton finder (e/mu): **Isolation**
- After IP and track energy cut





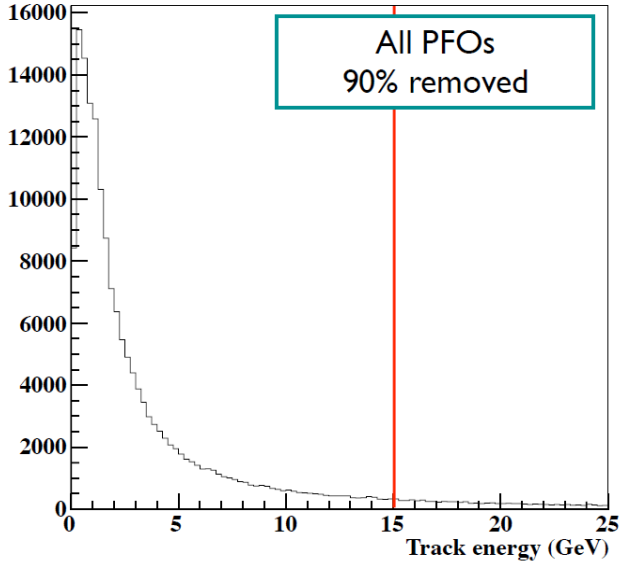


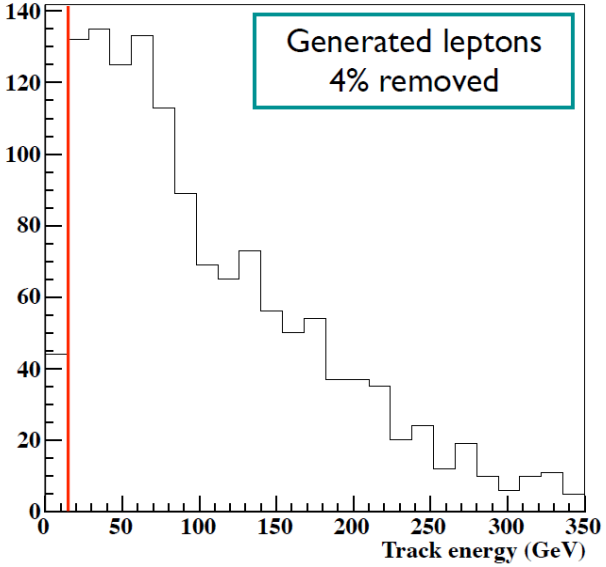


Lepton identification

- Isolated lepton finder (e/mu)

Track energy





Impact parameter