$e^+e^- \rightarrow HA \rightarrow bbbb$ at 1 TeV ILC

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Motivation

- In addition of precision measurements of discovered 126 GeV Higgs boson, ILC also has potential for direct searches of additional states of extended Higgs sector.

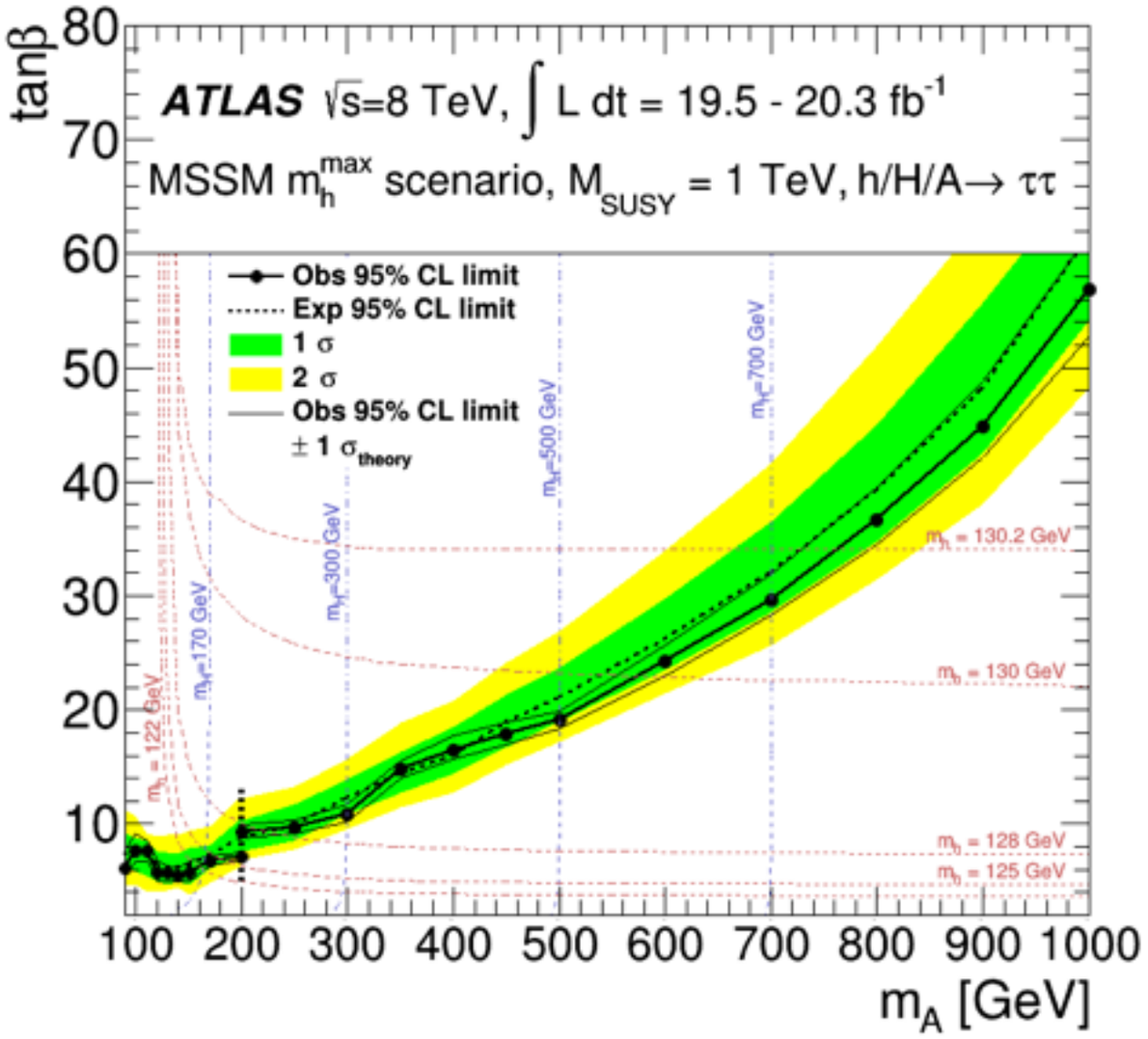
- Sensitivity of heavy Higgs pair production is expected to be close to kinematic limit of 1/2 $\sqrt{s}$.

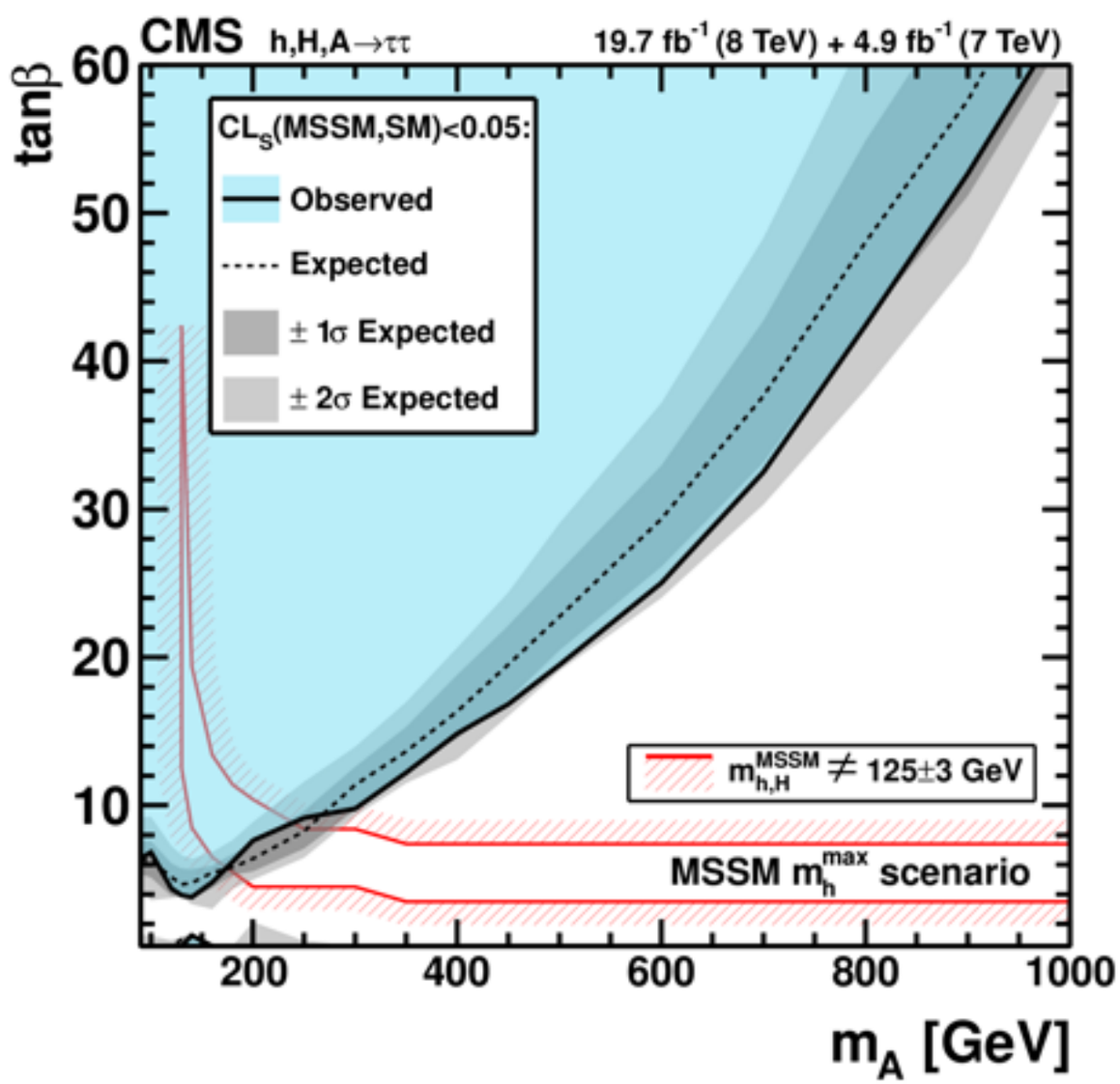
- The ILC with $\sqrt{s}$ = 1 TeV can directly study extra Higgs bosons with masses less than 500 GeV in relatively low tanβ regions, which can't be detected easily in LHC.

- Also decoupling limit approaches relatively faster if Higgs masses are greater than 200 GeV, in which case additional Higgs bosons almost degenerates in mass and have similar decay properties.

From LHC

H → ττ decay.





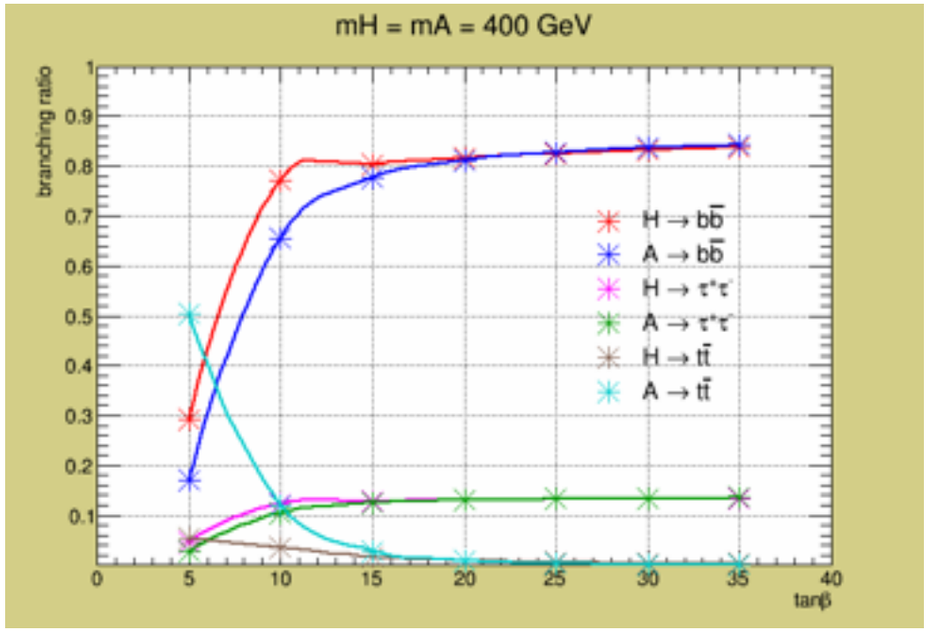
Most of the low mass and low *tanβ* region has been excluded in various MSSM scenarios.

Introduction

- Aim is cross-section and mass measurement for the process
  $e^+e^- \rightarrow HA \rightarrow bbbb$ at $\sqrt{s} = 1$ TeV.
- Integrated luminosity of 1000 fb^{-1} is assumed.

- Generated sample of HA→bbbb signal using Whizard, Pythia used for decay, with following specifications:

  same mass for both particles, 400 GeV
  $tan\beta = 10$
  x-section: $\sqrt{s} = 1$ TeV 2.38 fb
  prominent decay into bb(bar)
  Branching fraction for H → bb 77%
  A → bb 65%



- HA production is usually independent of tanβ but branching fraction depends on the tanβ.

Jet Selection

4 jet events are selected using mass reconstruction.

- Reconstruction using ChiSquare minimization

  -- same mass is assumed for both particles

$$\chi^2 = \sum \frac{(M_{ij} - M_{kl})^2}{\sigma_H^2}$$

  -- three set of jet pairs possible

  -- set of jet pairs with minimum ChiSquare are selected

  -- Sigma from truth matching reconstruction fit is used.

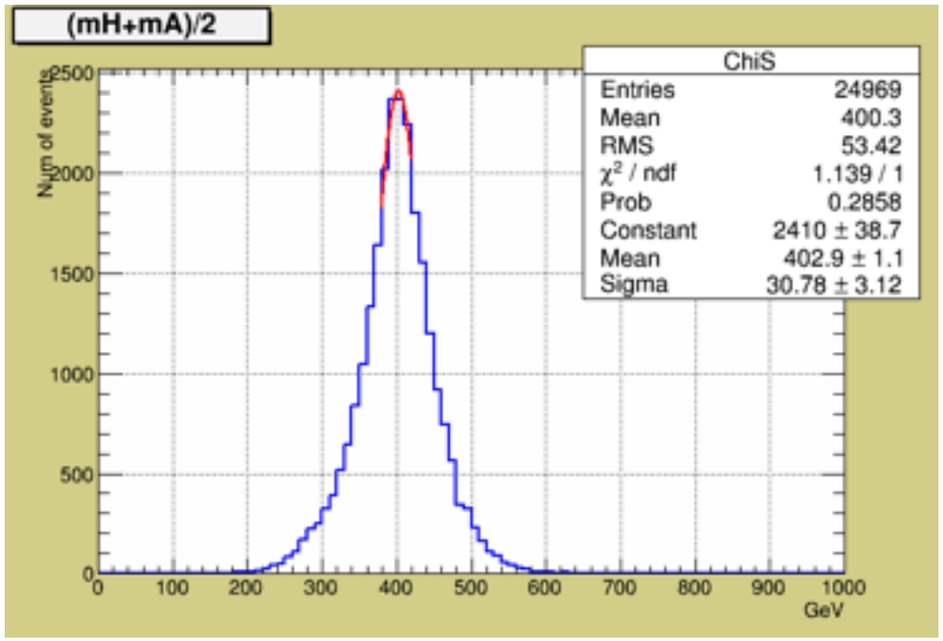
- Reconstruction using truth-matching

  -- associate the reconstructed jets to generated b-quarks from H/A decays using minimum ΔR between the jet and parton.

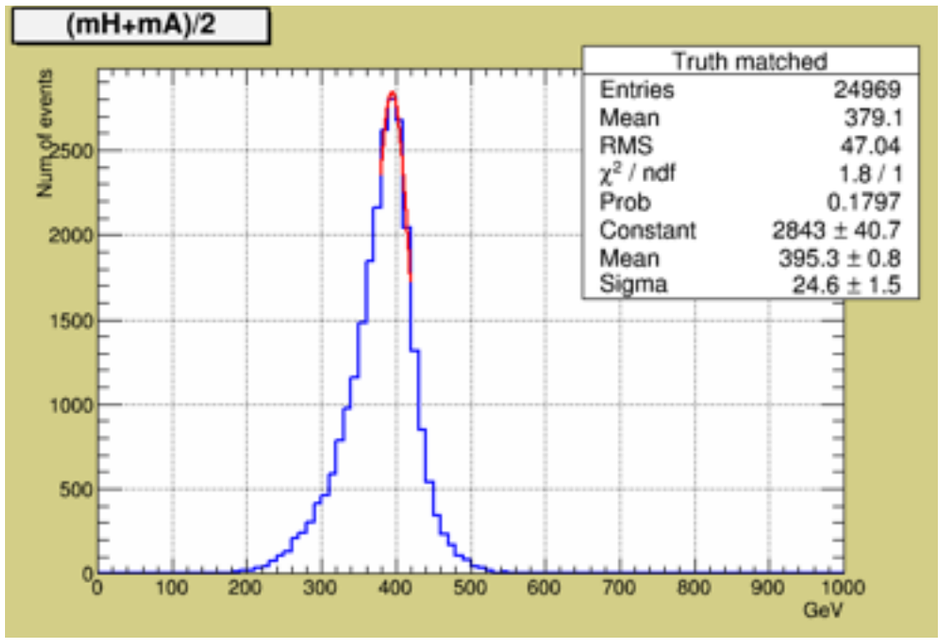
  -- in case of duplication, next minimum ΔR is selected.

Jet Selection

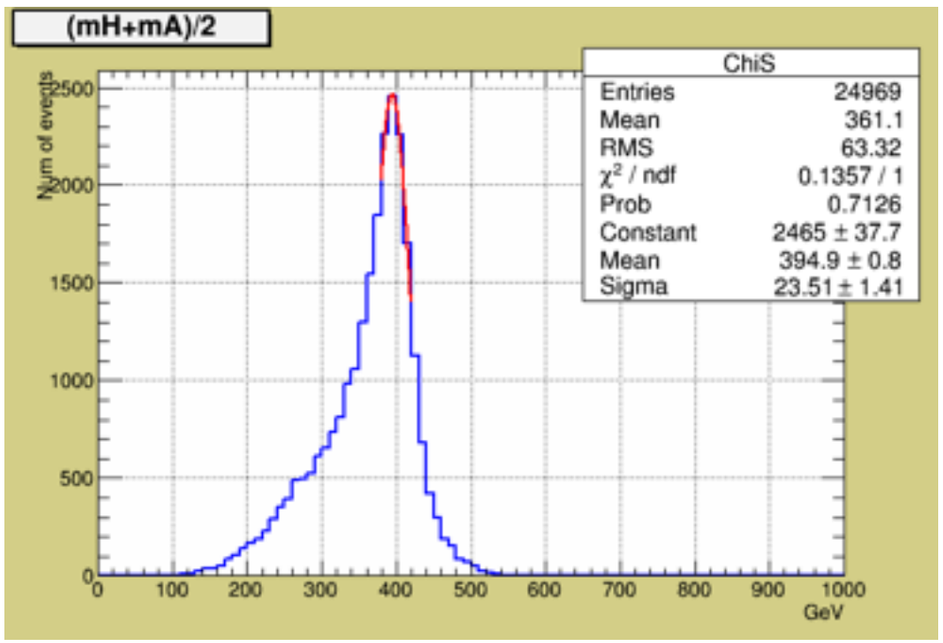
Truth match jets : Durham



kT algorithm with R=1.5



ChiSquare selected jets : kT



kT algorithm removes some of beam backgrounds resulting in Better resolution.

Chi square selected kT jets used for analysis.

SM Backgrounds

Main backgrounds giving same final states are bosons related:

- Z hadronic
- ZZ hadronic
- WW hadronic
- ZZWWMix hadronic

top pair related

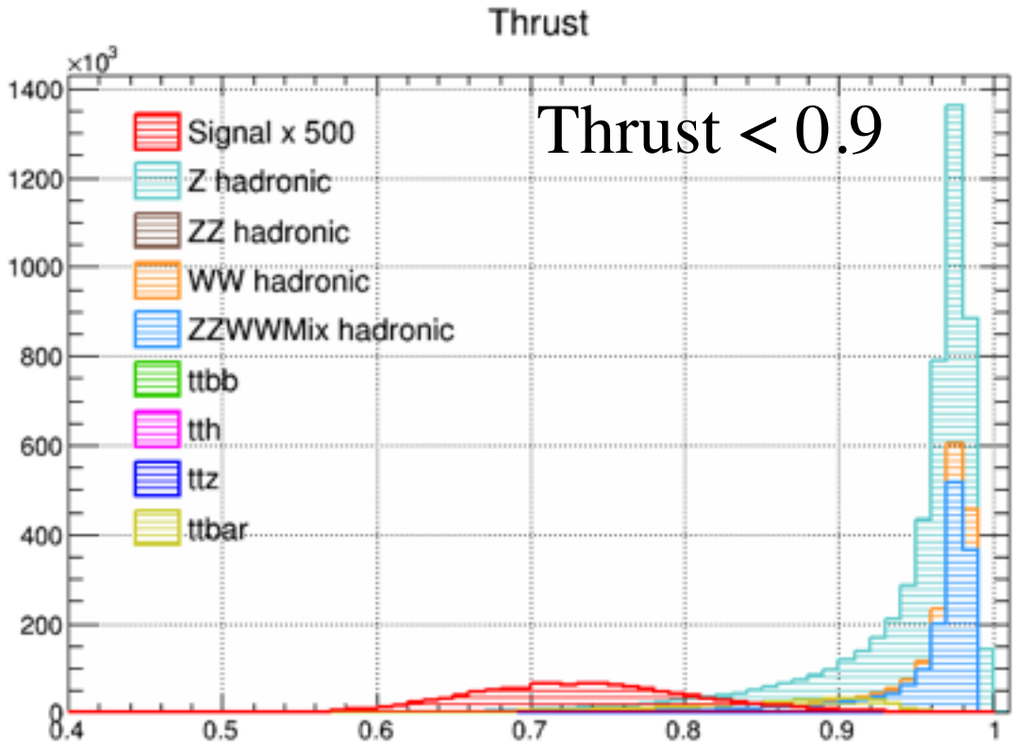
- ttbb : all decay states
- tth : consists of decay states
  - tth-2l2nbb-hbb, tth-2l2nbb-hnonbb
  - tth-ln4q-hbb, tth-ln4q-hnonbb
  - tth-6q-hbb, tth-ln4q-hnonbb
- ttz : all decay states.
- ttbar : ttbar decaying to 6 fermions.

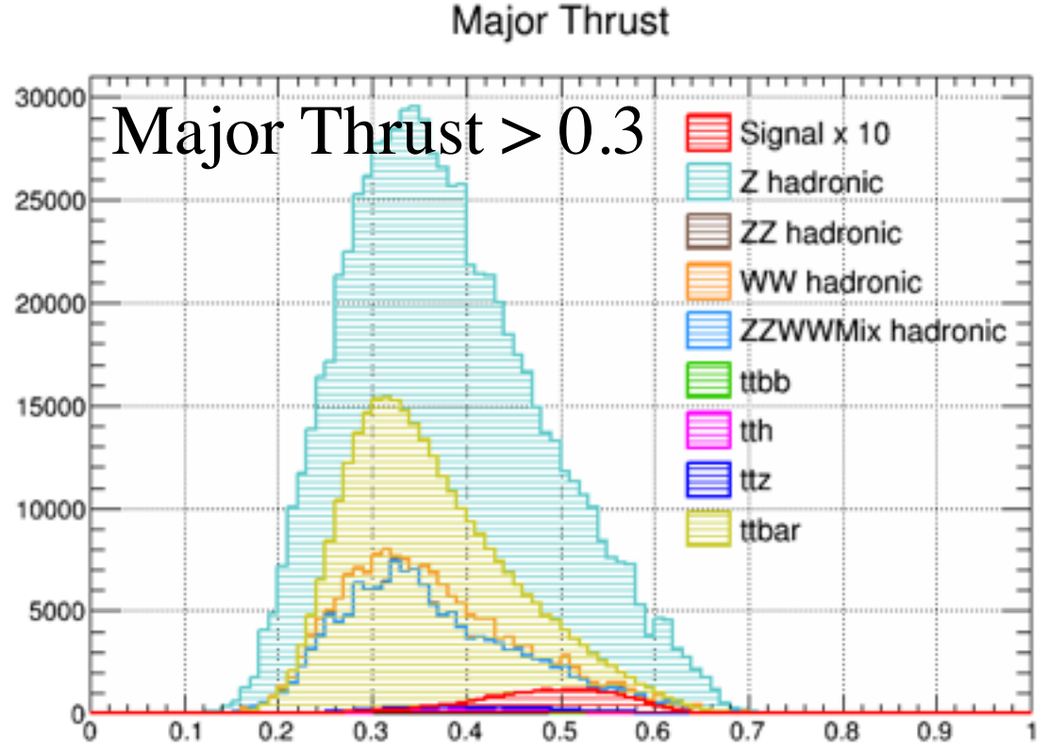
Cross-sections at (-0.8, +0.2) polarity

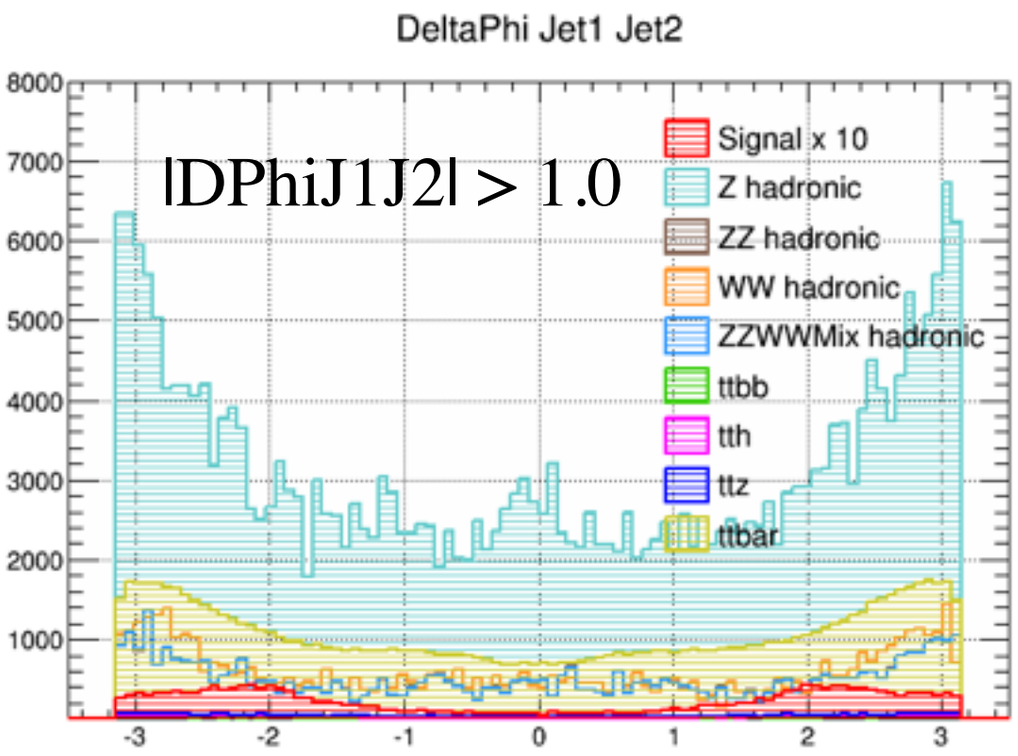
Cross-sections (fb)	eL.pR	eR.pL
Signal	2.27833	0.108
Z had	5062.662	208.134
ZZ had	162.806	4.61696
WW had	1811.6784	0.3517804
ZZWWMix had	1509.4836	1.1612
ttbb	3.184	0.106
tth	3.184	0.106
ttz	3.81691	0.174685
ttbar	436.489	1.17792

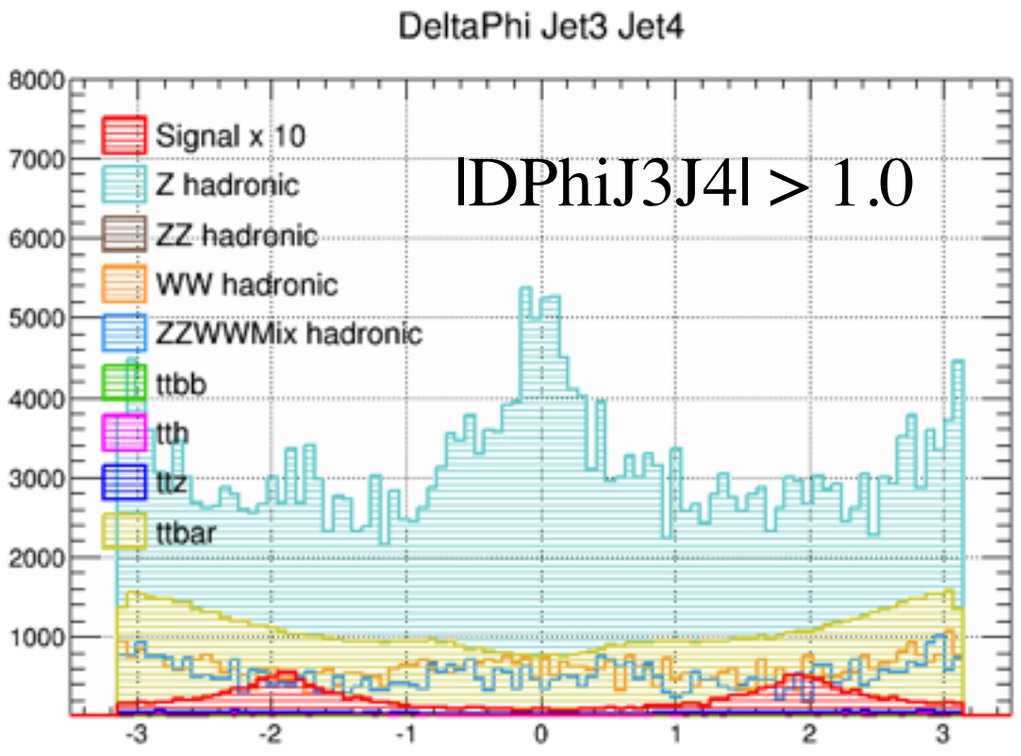
All samples generated using Whizard and Pythia.

Selection

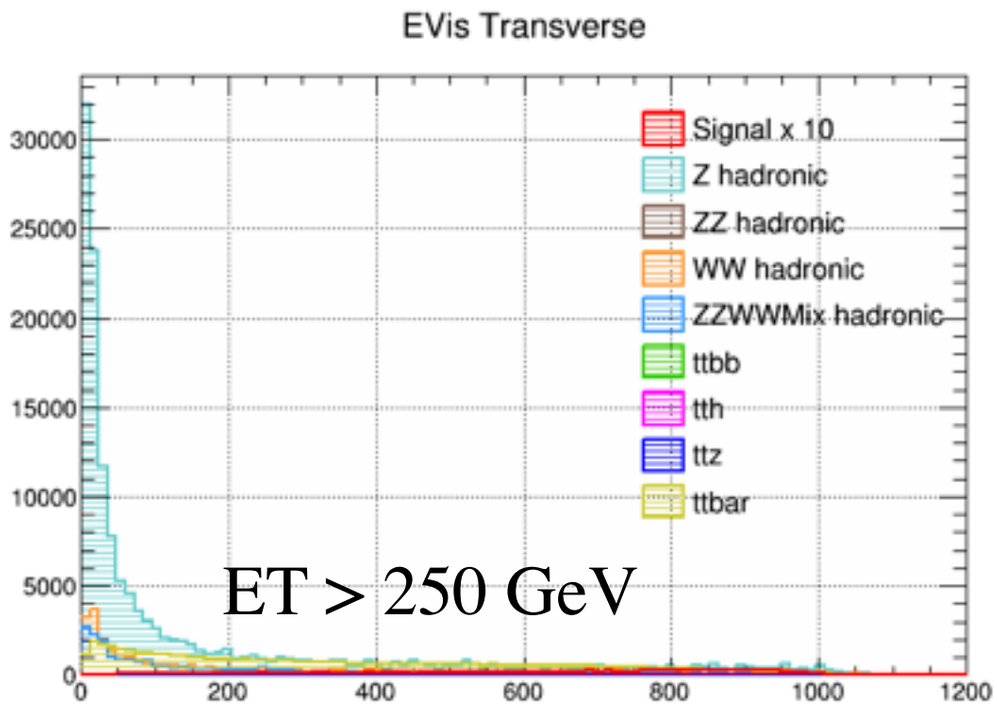

Thrust
×10^3
Thrust < 0.9
Signal x 500
Z hadronic
ZZ hadronic
WW hadronic
ZZWWMix hadronic
ttbb
tth
ttz
ttbar


Major Thrust
Major Thrust > 0.3
Signal x 10
Z hadronic
ZZ hadronic
WW hadronic
ZZWWMix hadronic
ttbb
tth
ttz
ttbar


DeltaPhi Jet1 Jet2
|DPhiJ1J2| > 1.0
Signal x 10
Z hadronic
ZZ hadronic
WW hadronic
ZZWWMix hadronic
ttbb
tth
ttz
ttbar


DeltaPhi Jet3 Jet4
|DPhiJ3J4| > 1.0
Signal x 10
Z hadronic
ZZ hadronic
WW hadronic
ZZWWMix hadronic
ttbb
tth
ttz
ttbar

Selection



Preliminary Cuts:

Cut 1 : Principal Thrust < 0.9

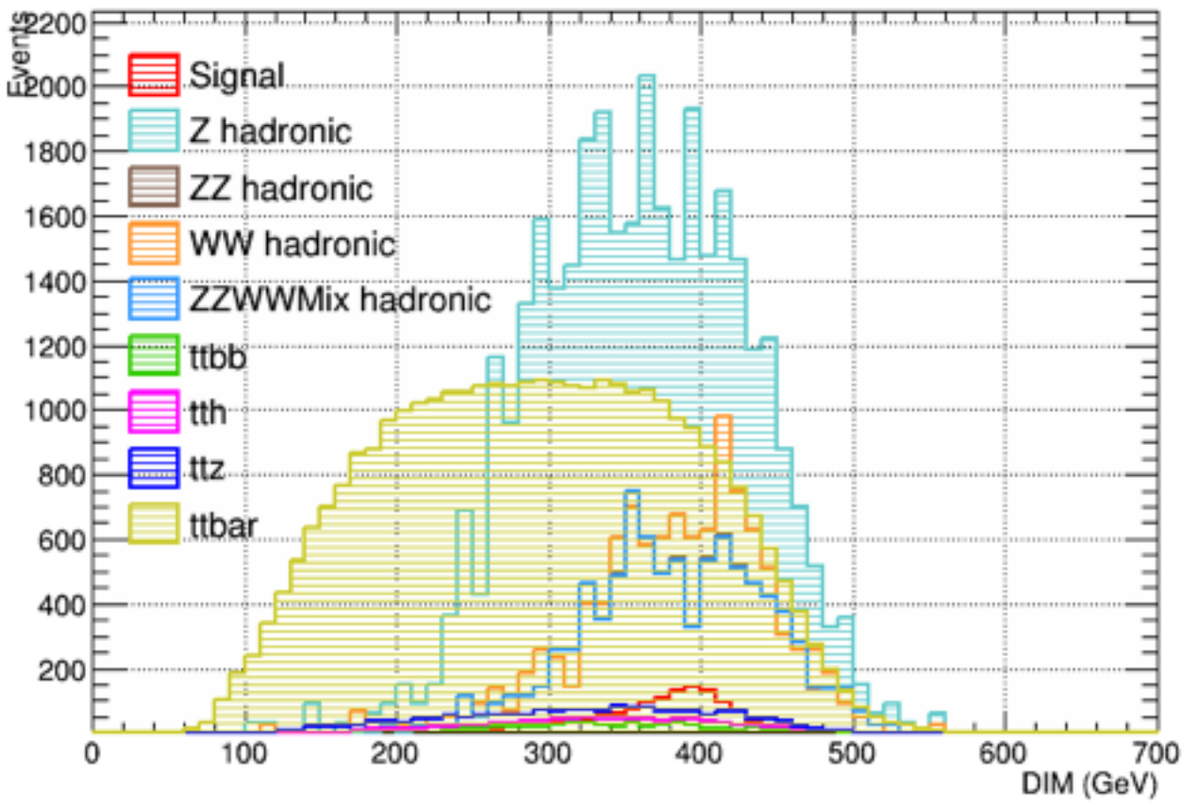
Cut 2 : Major Thrust > 0.3

Cut 3 : DPhi jet pairs > 1.0

Cut 4 : Transverse EVis > 250

After applying cuts still lots of background left.

So we will use TMVA analysis for further separation of signal from backgrounds.



Cut-flow table

Sample / Cuts	Signal	Z hadronic	ZZ hadronic	WW hadronic	ZZWW hadronic	ttbb	tth	ttz	ttbar	S/√S+B
Total	2386.33	5270800	167423	1812030	1510650	3290.41	3290.38	7745.81	437667	
Cut1	2350.28	745221	29138.9	171006	145472	3104.42	3273.35	7601.03	308032	
Eff %	98.49	14.14	17.40	9.44	9.63	94.35	99.48	98.13	70.38	1.98
Cut 2	1993.37	283567	10291.5	54032	46166.2	1260.97	1885.97	3902.8	96106.5	
Eff %	83.53	5.38	6.15	2.98	3.06	38.32	57.32	50.39	21.96	2.82
Cut 3	1528.52	145172	5739.32	29381.9	25159.9	802.79	1267.29	2526.36	57637.7	
Eff %	78.69	2.75	3.43	1.62	1.66	24.40	38.52	32.62	13.17	2.95
Cut 4	1308.1	34183.2	2116.57	10692.3	9051.87	592.79	928.84	1802.94	33083.1	
Eff %	54.82	0.65	1.26	0.59	0.60	18.02	28.23	23.28	7.56	4.27

After applying these cuts :

Signal events : 1308

Background events : 92452

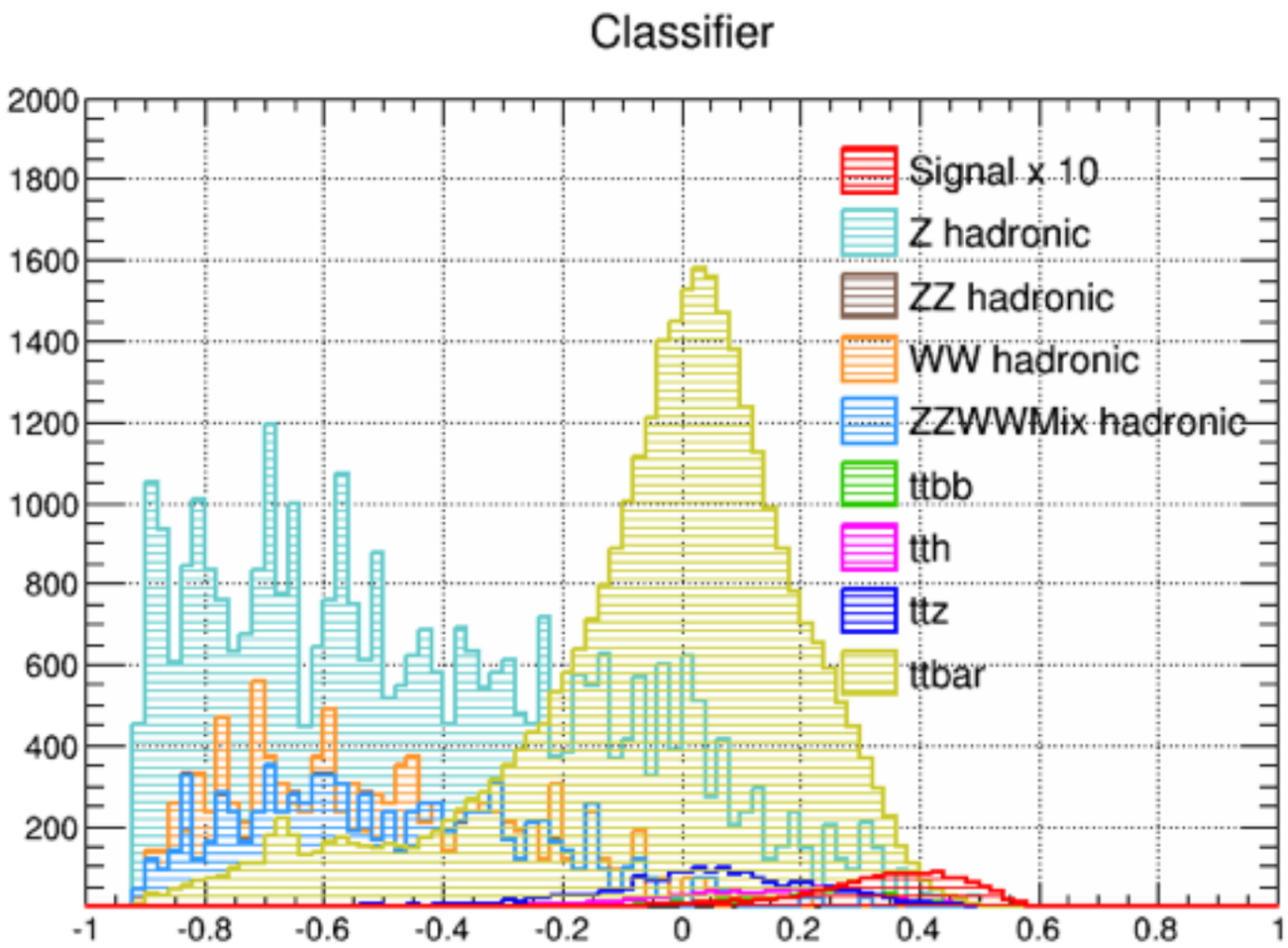
$S/\sqrt{S+B} = 4.30$

BDT analysis

Variables used for BDT training:

- BTag value for jets
- Y45, Y56, Y67, Y78 (distance for rejecting next jet cluster)

After applying all the cuts half of rest of events were used for training and other half for testing.



Classifier output is shown where we can see background events are peaking in -ve side and signal events are peaking in +ve side.

BDT analysis

Sample / Cuts	Signal	Z hadronic	ZZ hadronic	WW hadronic	ZZWW hadronic	ttbb	tth	ttz	ttbar	S/√S+B
Total	2386.33	5270800	167423	1812030	1510650	3290.41	3290.38	7745.81	437667	
All Cuts	2350.28	745221	29138.9	171006	145472	3104.42	3273.35	7601.03	308032	
Eff %	54.82	0.65	1.26	0.59	0.60	18.02	28.23	23.28	7.56	4.30
BDT	697.21	183.19	48.28	0	23.28	87.17	87.24	71.63	529.56	
Eff %	29.16	0.003	0.03	0	0.001	2.64	2.65	0.92	0.12	21.68

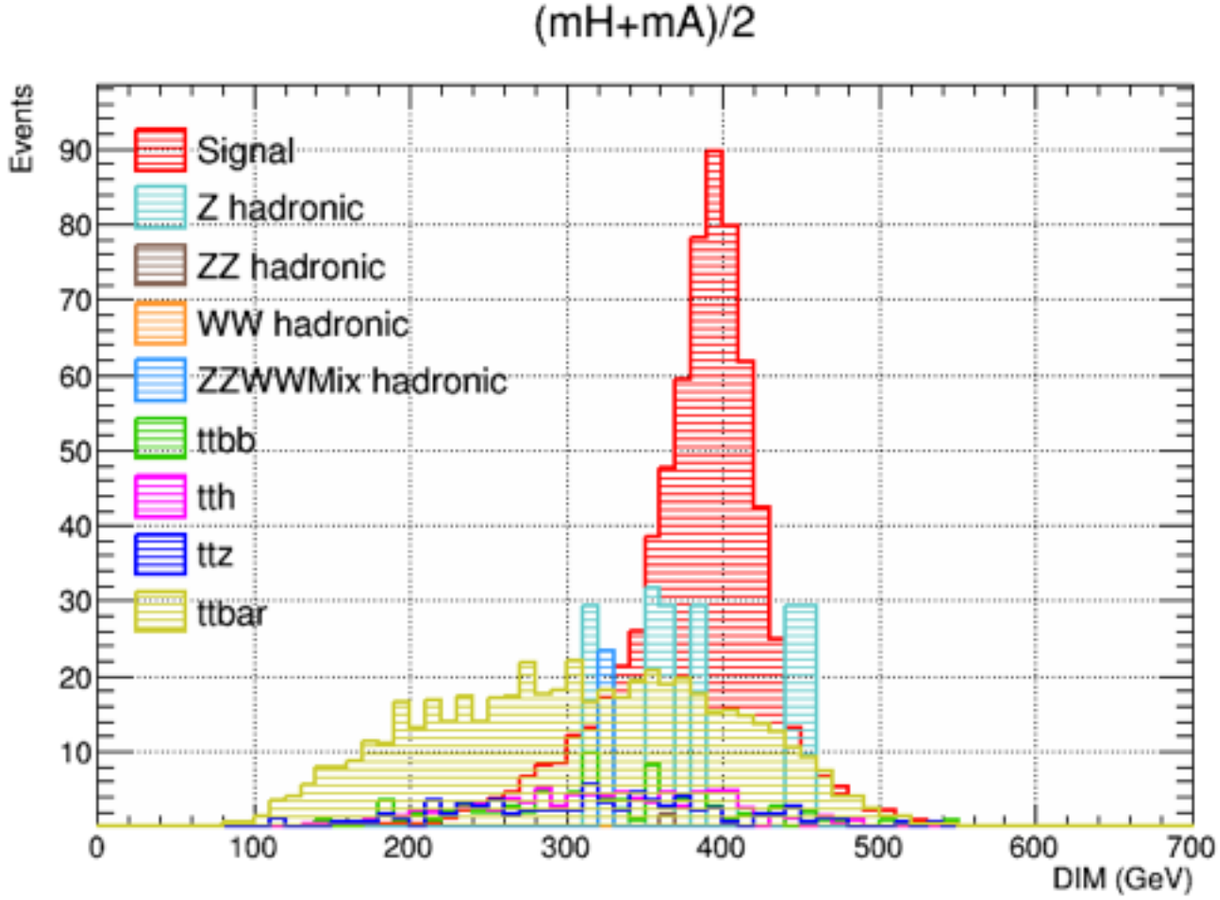
Applying a cut of 0.35 on BDT :

Signal events : 697

Background events : 1030

$S/\sqrt{S+B} = 16.77$

Clear separation of Signal.

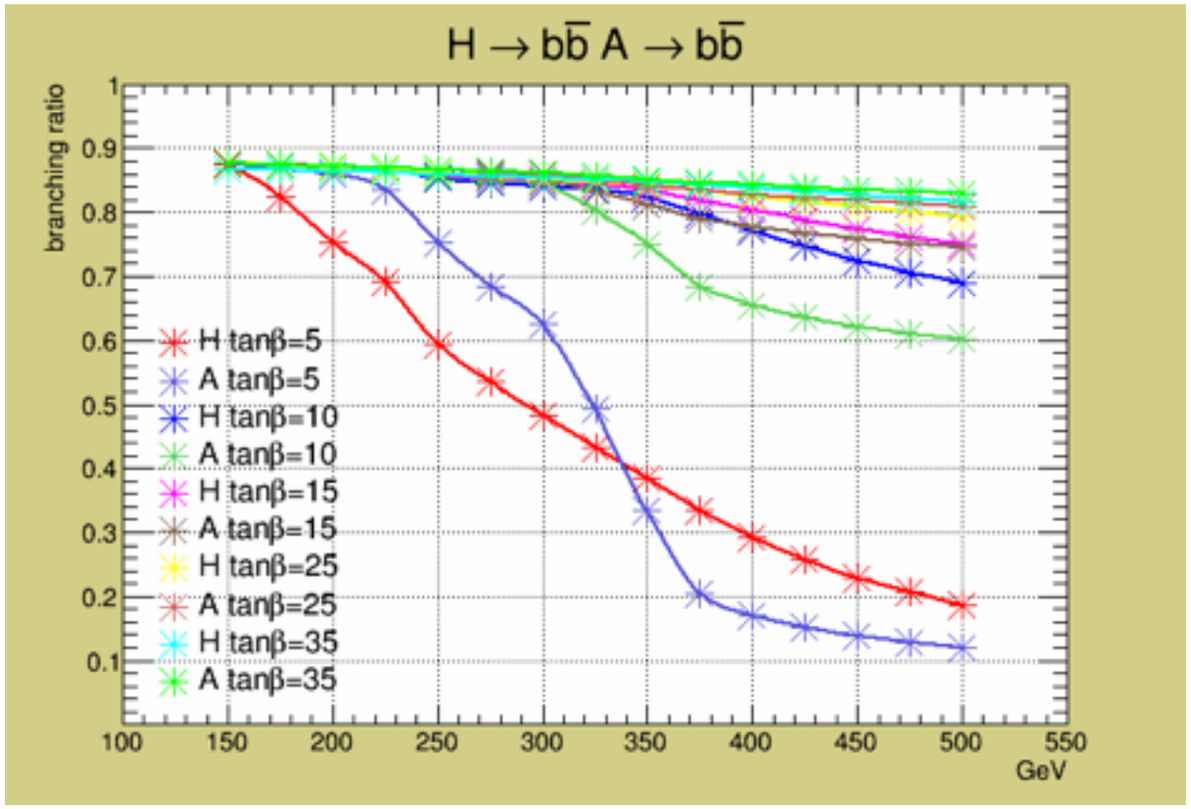


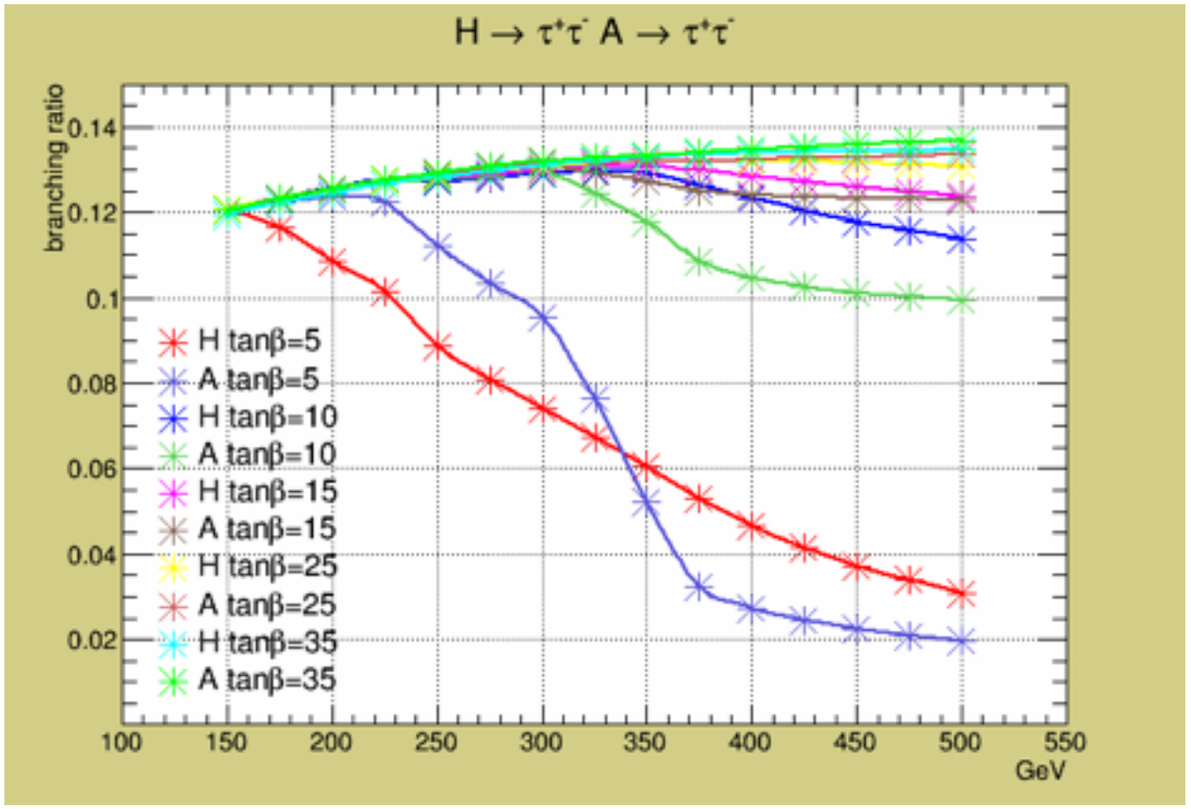
Conclusions and Plans

- Presented status of the heavy Higgs search at 1 TeV ILC.
- Clear separation of signal from background was achieved.
- Have to completely understand beam background, so that proper b-jet energy corrections can be applied.
- Will complete mass and cross-section measurements at tanβ and also evaluate systematics.
- Next plan is to set a limit independent of mass and tanβ.

BACKUP

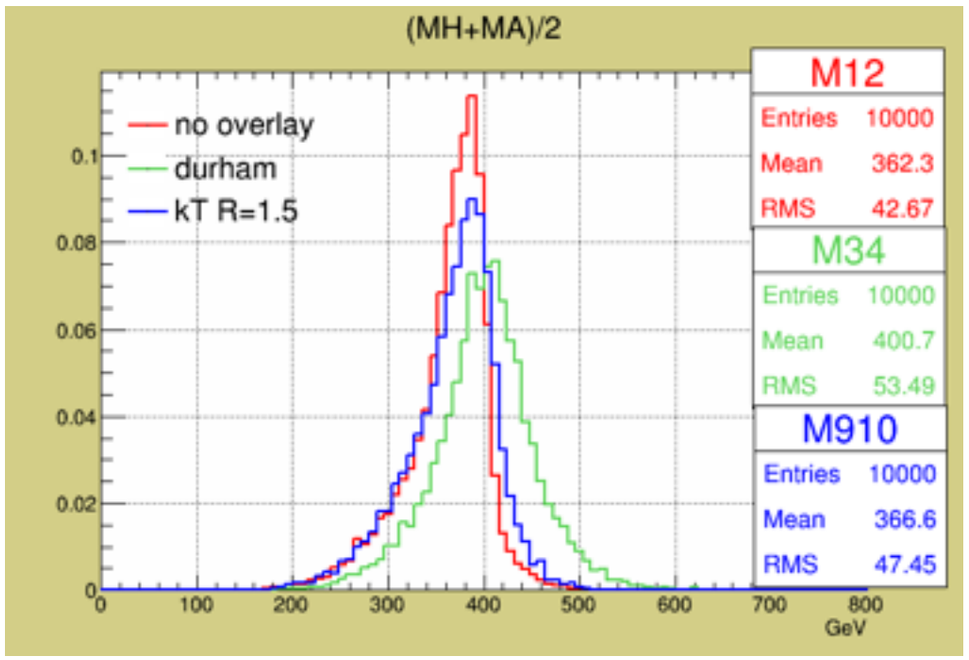
branching fractions



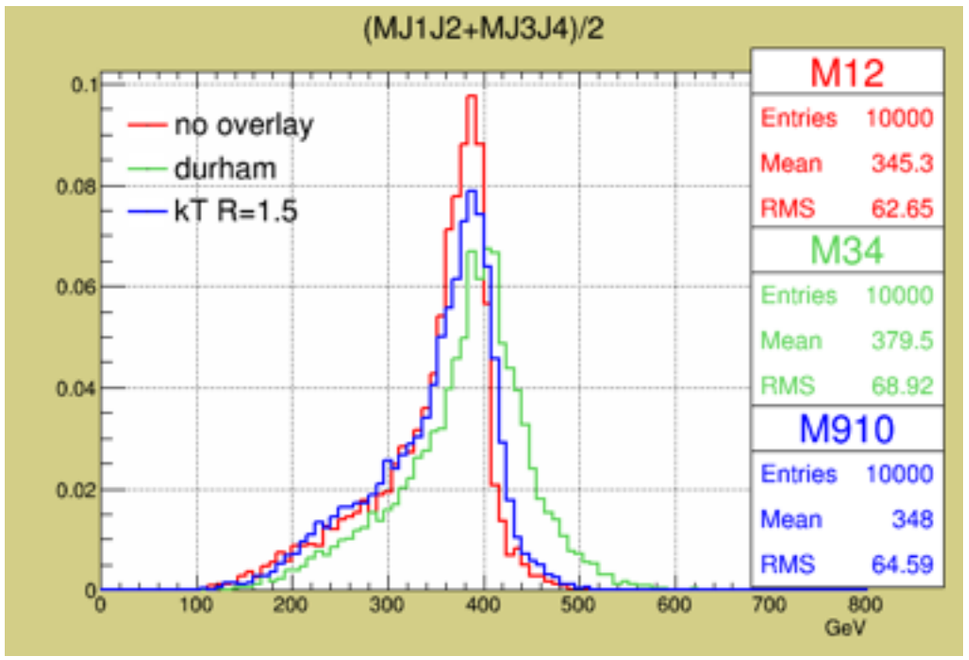


Durham and kT comparison

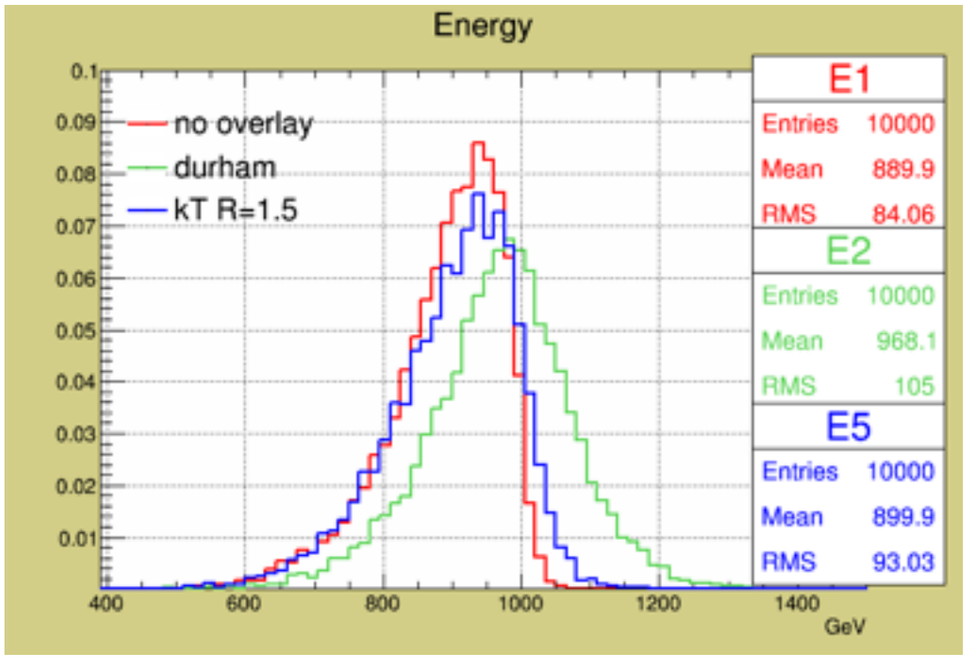
Mass : Truth matched jets



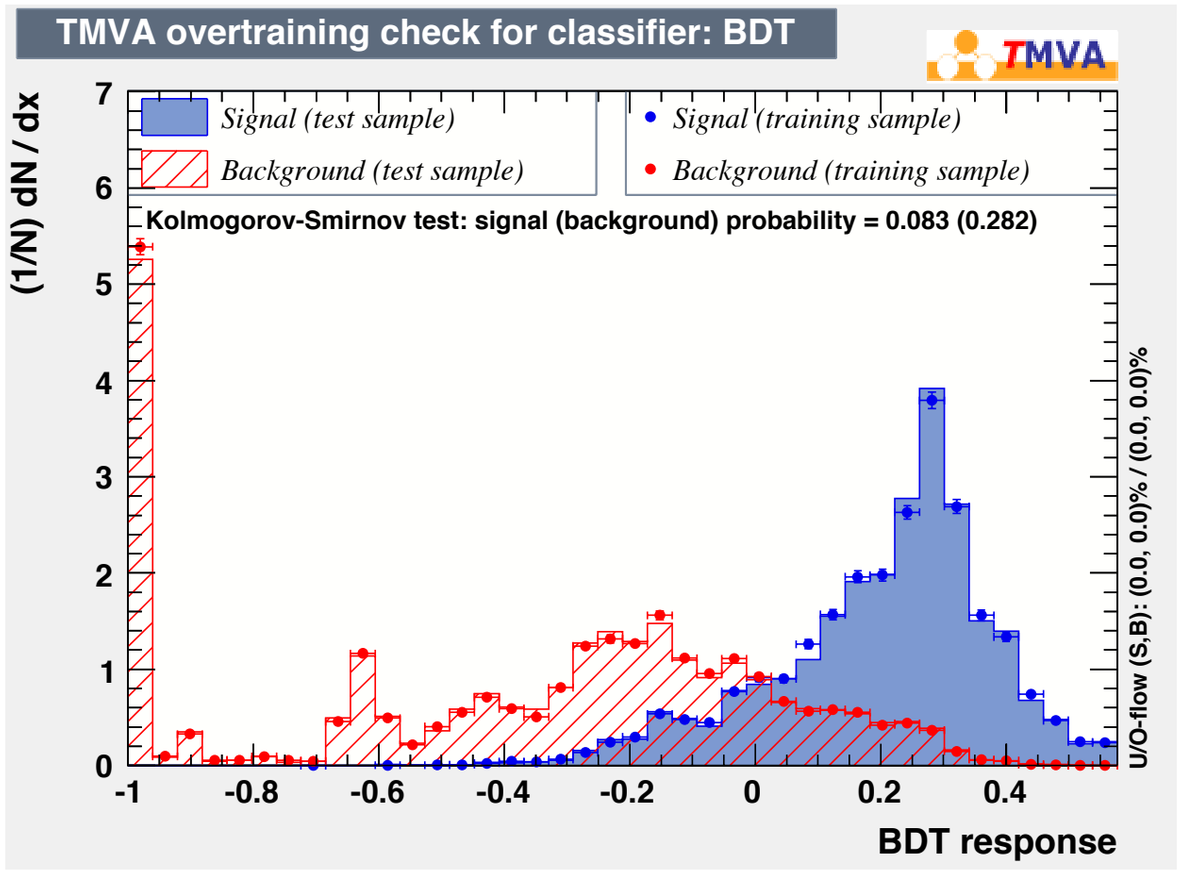
Mass : Chi square jets

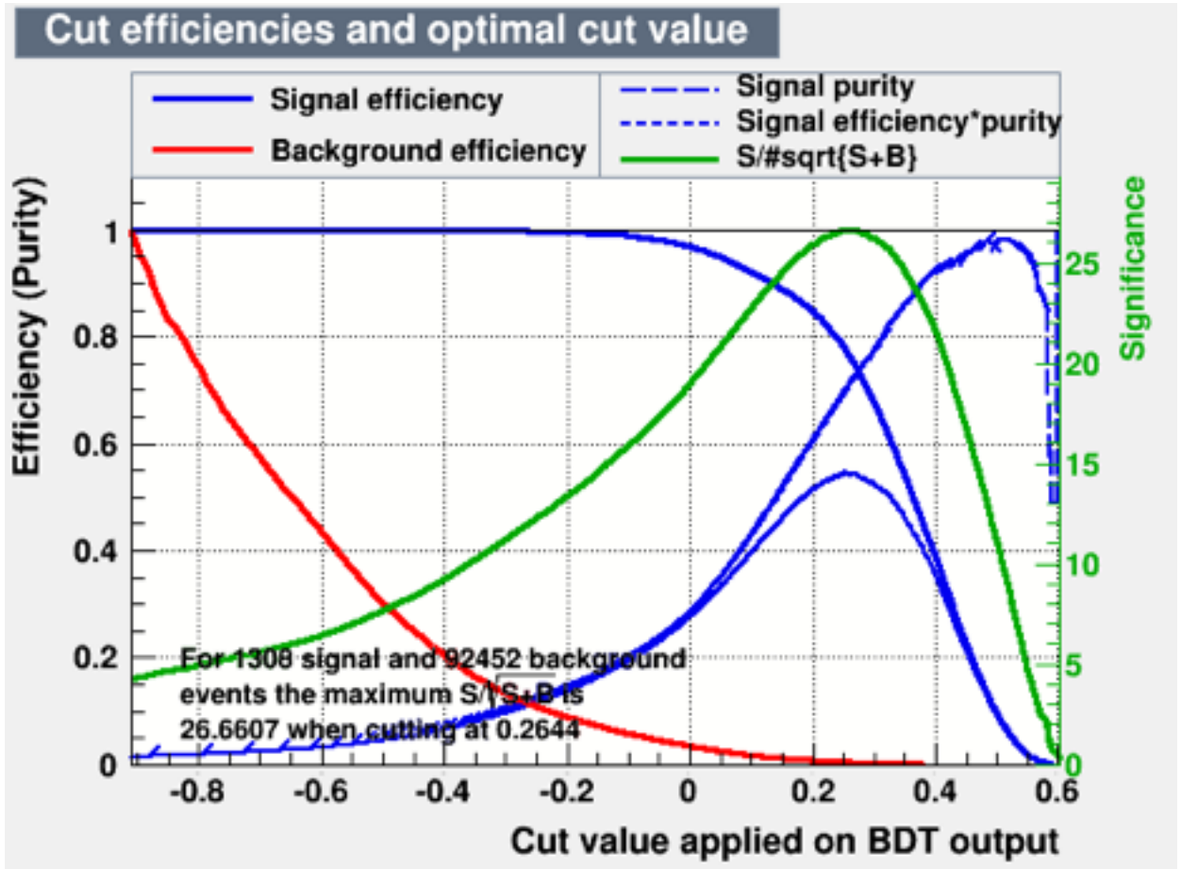


Total visible energy



TMVA


TMVA overtraining check for classifier: BDT
TMVA
Signal (test sample)
Background (test sample)
Signal (training sample)
Background (training sample)
Kolmogorov-Smirnov test: signal (background) probability = 0.083 (0.282)
(1/N) dN / dx
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.0)%
BDT response


Cut efficiencies and optimal cut value
Signal efficiency
Background efficiency
Signal purity
Signal efficiency*purity
S/#sqrt{S+B}
Efficiency (Purity)
Significance
For 1308 signal and 92452 background events the maximum S/#sqrt{S+B} is 26.6607 when cutting at 0.2644
Cut value applied on BDT output