Searches for

BSM neutral Higgs

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IHEP, Beijing

Shift Apr-Jul 2014

Table includes what I have done this half year and what I will do up to the end of July

Newly joined RECO shift training and passed the exam becoming RECO shifter

A good starting for this year's shift :)

OTP

Personal Schedule Report - Summary

from 24-Apr-2014 to 28-Jul-2014 - XIAOHU SUN (4908)

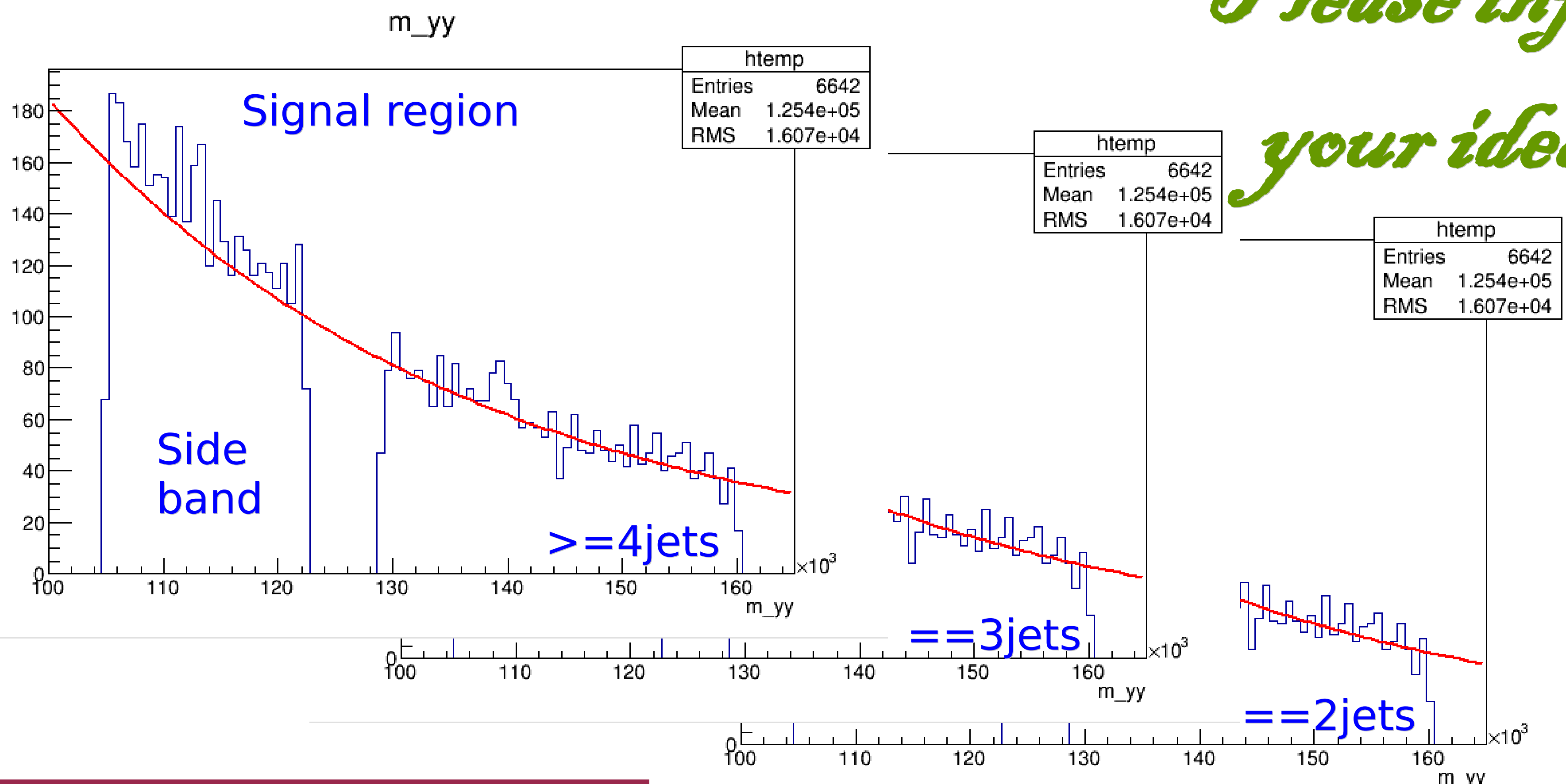
Activity	System	Task	Allocated Hours	Allocated Shifts	Allocated Fte
Computing/Softwar	General Tasks	529222- ADCoS Senior shifts	161.6	20.20	0.06
	General Tasks	529223- ADCoS Trainee shifts	0	0.00	0.00
	General Tasks	529614- Reconstruction Software Shifts	84	10.50	0.03
		Total in Computing/Software	245.6	30.70	0.08
		Total	245.6	30.70	0.08

More details were shown in this morning's talk
https://indico.cern.ch/event/323871/contribution/2/0/material/slides/0.pdf

WWyy basics – control regions

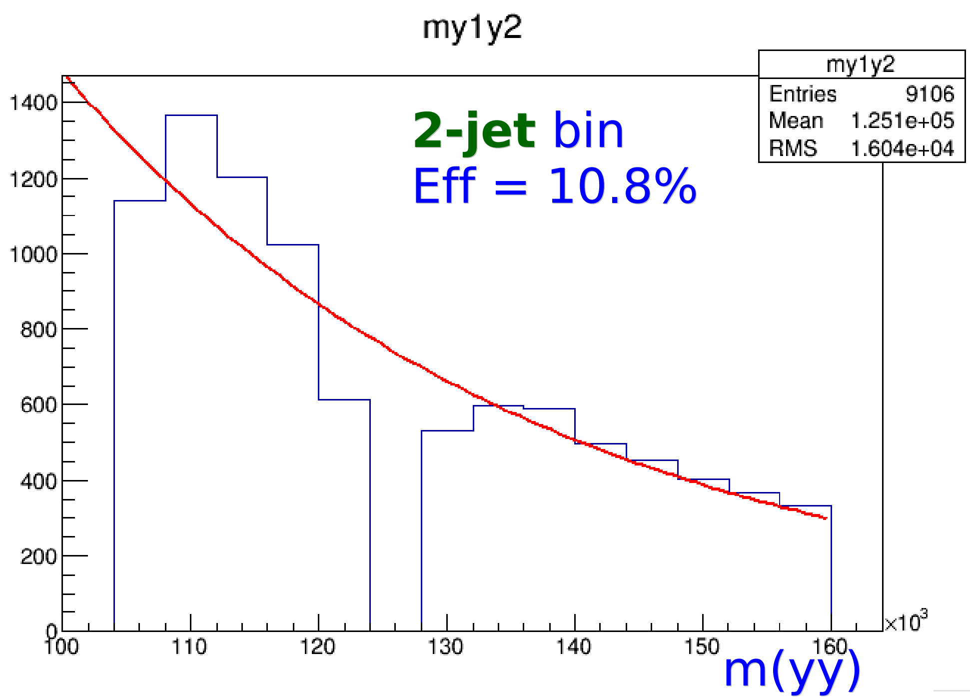
- To train MVA and to obtain the two efficiencies:
  - 2/3-jet bin is used for $\boldsymbol{\varepsilon_{\gamma\gamma}}$: window/sideband for bkg
  - 3-jet bin is used for MVA training: sideband for bkg
  - 3-jet bin is used for $\boldsymbol{\varepsilon_{MVA}}$: sideband bkg

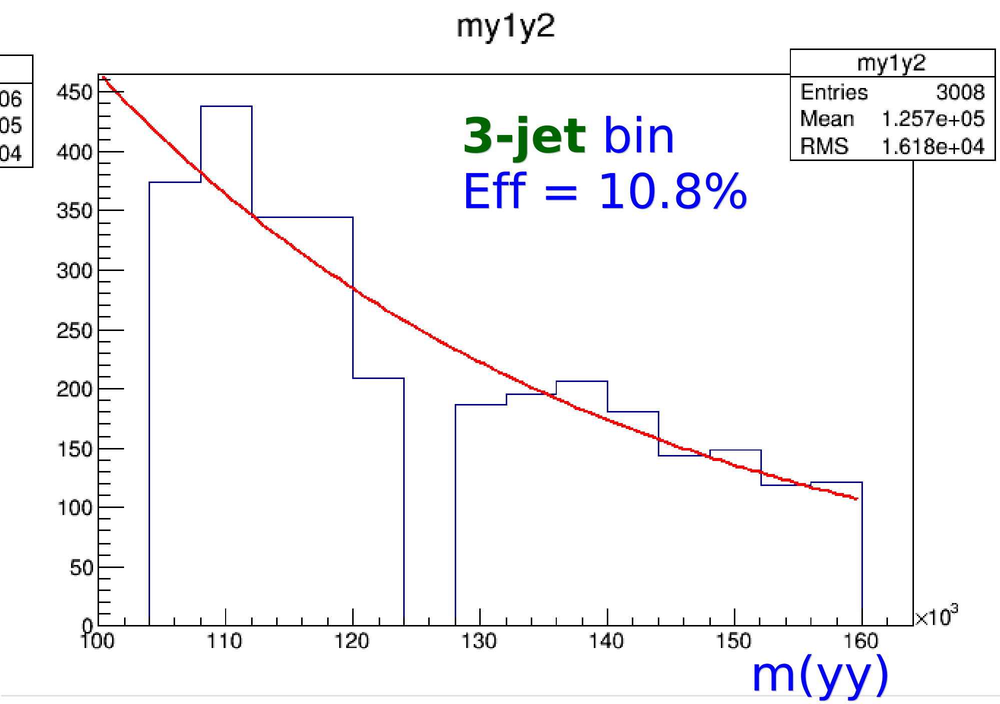
Please input your ideas



$\varepsilon_{\gamma\gamma}$ for backgrounds

- Fit the sidebands in 2/3-jet bin along the invariant mass of yy (binning is not good for the time-being)





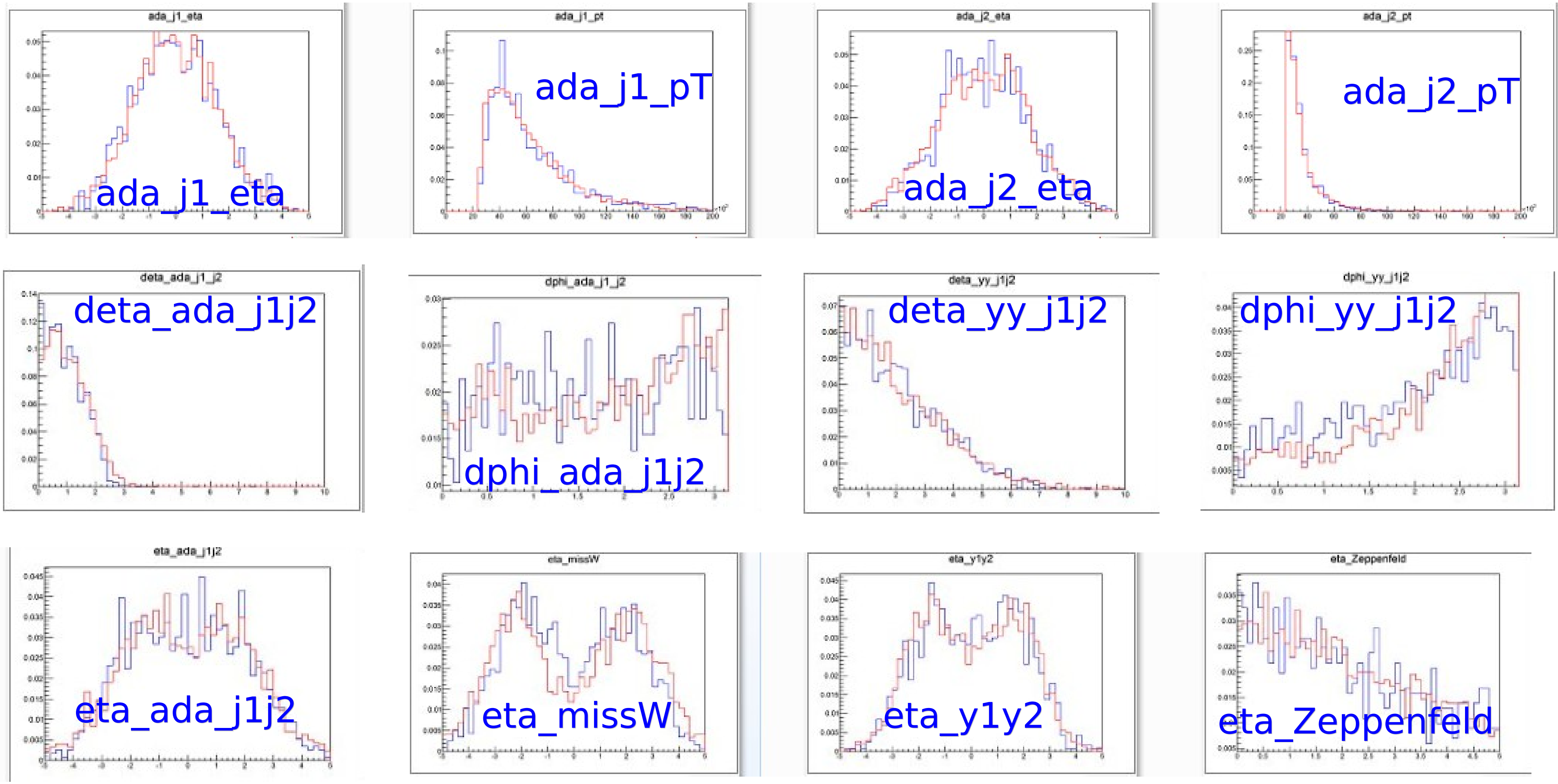
	2-jet bin	3-jet bin	4-jet bin (rev iso)
$\varepsilon_{\gamma\gamma}$	10.8%	10.8%	-

This efficiency is independent on jet multiplicity
Try to use it in 4-jet inclusive bin

Train/test MVA by using 3-jet bin

- MVA goal:
  - Effectively distinguish signal from backgrounds
  - Should be kept yy-mass independent
- MVA training sample:
  - Signal: ½ MC
  - Backgrounds: ½ sideband data in 3-jet
- The other halves are used for testing
- $\boldsymbol{\varepsilon_{MVA}}$ for both signal and backgrounds are measured in training sample and validated in testing sample
- One needs to verify that sideband data in 3-jet bin has similar modeling on the variable used in MVA to the sideband data in 4-jet

For MVA, compare 3/4inc-jet bin

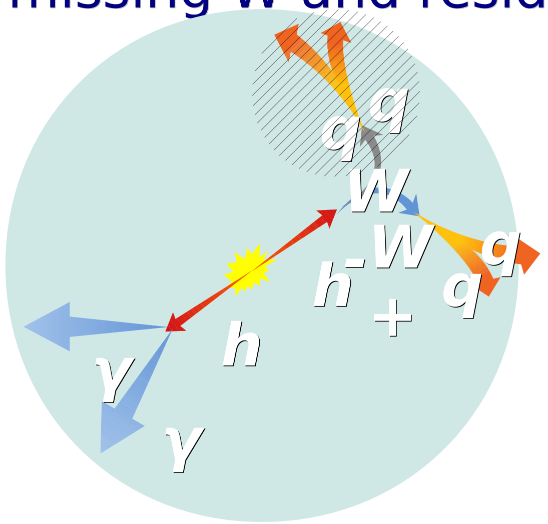


etc.

In general, the modelings are consistent between 3- and 4inc-jet bins

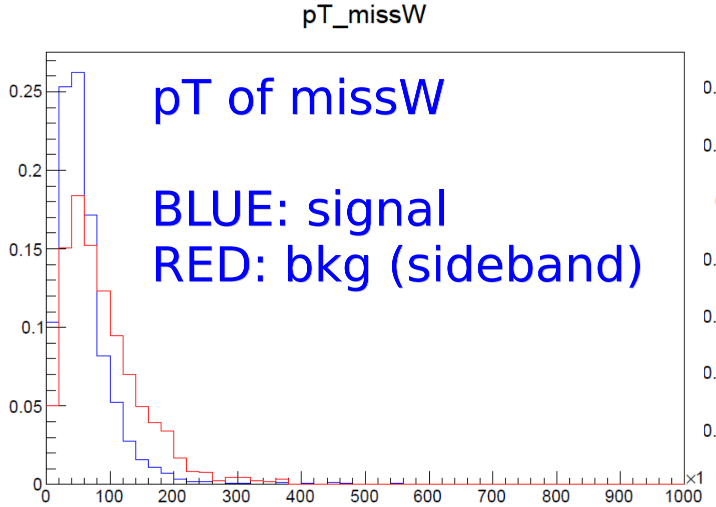
A new idea to try (from last pres)

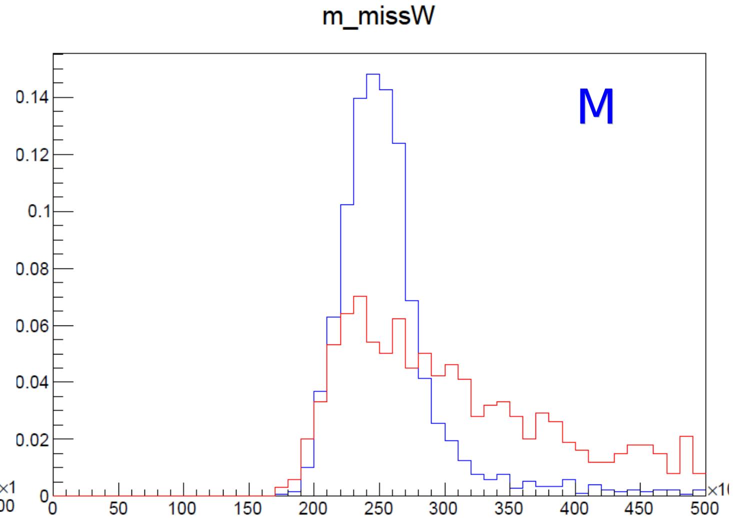
- Actually the missing W boson now I am constructing is a sum of missing W and residuals

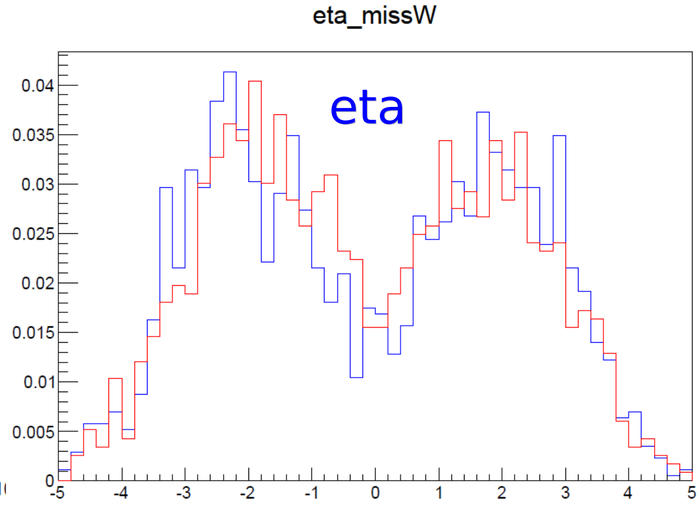


pT(yy) + pT(jxjy) + pT(missW) + pT(residual)= 0

To be calculated







promising

To-do list (in the order of priority)

- Instead of using j1 j2, find jx jy to be used to reconstruct only one W boson as precisely as possible (preliminarily explored)
- Using these new variables from adaptive method in MVA (trying)
- Validate the 3-jet bin can be used as training for 4-jet bin inclusive
- Introduce more variables into MVA training: y-jet variables, event shape variables (only yy side, only jets side) … going on …
- Explain the background components by using Du Chun's samples (jjjj,jjjy,jjyy): reading them now, mimicking the cuts from ATLAS
- Measure eff(m_yy) & uncertainties
- Freeze MVA cuts at some point, and measure eff(MVA) & uncertainties
- Learn and use Hfitter to build up the statistical model
- Start documentation
- Try deep learning if possible

News on 14TeV non-resonant

- Under center of mass energy 14 TeV, with 3000 fb-1 high luminosity assumed, people have started to search SM HH (**bbyy**) production before May 2014
- CDS link:
  - https://cds.cern.ch/record/1702033
-

Draft version x.y

Not reviewed, for internal circulation only

ATLAS NOTE

May 21, 2014

Higgs Pair Production in the channel $H(\to \gamma\gamma)H(\to b\bar{b})$ at the High-Luminosity LHC

Arnaez, O.[a], Bentvelsen, S.[b], van Eijk, B.[b], Escalier, M.[d], Oropeza Barrera, C.[c], Nisati, A.[e], Slawinska, M.[b], Styles, N.[h], Yao, W. M.[i], van den Wollenberg, W.[b]

News on 14TeV non-resonant

- Due to the limitation on computing, only truth level info is used with smearing in order to introduce the detector effects
- Cut-based analysis is implemented: an expected signal yield of 7.3 evts in 3000 fb-1 is obtained, expected bkg is 70 evts
- **S/sqrt(B)~0.87** (0.03 expected from 8TeV analysis)

Samples	Selected Events	Acc.(%)	Exp. (3000 fb^{-1})
$H(b\bar{b})H(\gamma\gamma)$	136	2.73	7.3±0.62
$jj\gamma\gamma$	39×0.231	1.8×01^{-5}	12±1.9
$c\bar{c}\gamma\gamma$	56×0.839	2.35×10^{-4}	11.1±1.5
$b\bar{b}\gamma\gamma$	94×1.0	2.1×10^{-3}	21.2±2.2
$t\bar{t}$	4	2.67×10^{-5}	2.3±1.1
$t\bar{t}\gamma$	7	1.1×10^{-4}	10.6±4.1
$t\bar{t}H(\gamma\gamma)$	208	0.18	7.4±0.52
$Z(b\bar{b})H(\gamma\gamma)$	8.48×10^{3}	0.424	3.9±0.04
$b\bar{b}H(\gamma\gamma)$	236	0.032	1.3±0.1
Total	-	-	70.0±5.4
$S/\sqrt{B}$	-	-	0.87

No chance to claim the observation alone with bbyy at 14 TeV

Has to be combined with other channels

Backup

Combination SM HH non-resonant

- With bbyy final state, expected upper limit 1.0 pb (HH) corresponding to **~114.5** times of SM HH production
  - Also, there is **2.4** standard deviation in observation
- With bbbb final state, expected upper limit corresponding to ***~40*** times of SM HH production by using m(lead) vs m(sub) corrected from 6th May, before including systematic uncertainties and before re-optimizing the cuts that are used for resonant search
- Regarding the limited differences on the sensitivities, it is still worthy to combine both results with Run I
  - To obtain a better upper limit on SM HH production
  - As well as, if possible, to extract a "significant" *significance*
  - To serve as a good reference for Run II
- The machinary for combination is in place, all we need to do is
  - Gather the workspaces from both analyses after optimization
  - Converge on the correlated uncertainties (lumi, JES, isr/fsr etc.)

*Checks on the overlapped phase space in two analyses, should be negligible

Combination BSM H → hh

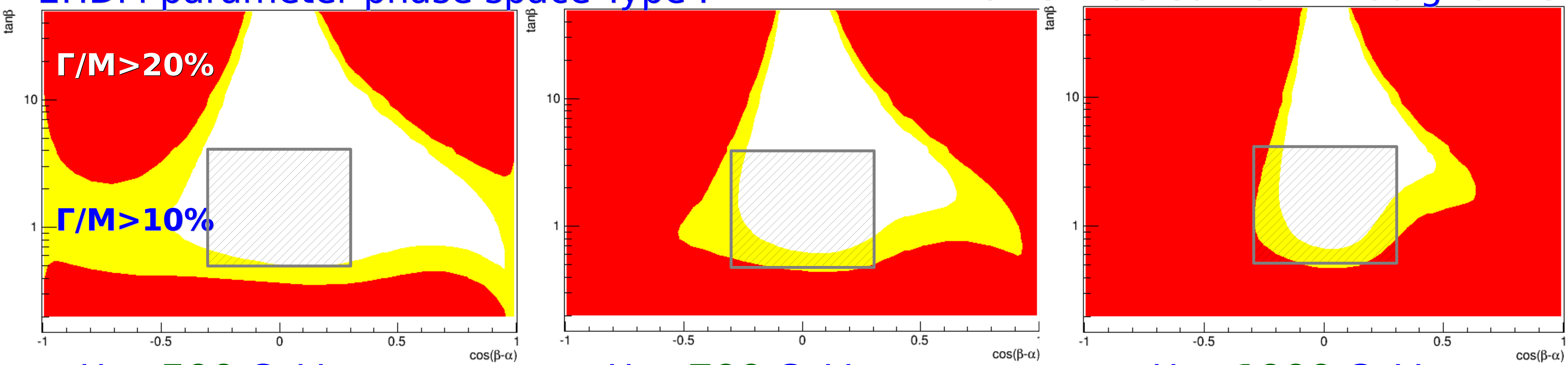
- The scanned mass points: bbyy final state covers from 260 GeV to 500 GeV, while with bbbb final state from 500 GeV 1000 GeV
  - bbbb signal acceptance drops significantly below 500 GeV
  - It seems that we can only combine in high mass region if bbyy final state can extend the search
- Well, if only looking at 500 GeV, by eye catching on the limit plots:
  - Expected upper limit on gg → H → hh (bbyy): **0.8** pb
  - Expected upper limit on gg → H → hh (bbbb): ***0.1*** pb from 6th May without systematic uncertainties
- At least at this joint mass point, both analyses are comparable with respect to the sensitivity
- Low mass (<500GeV), bbyy definitely has more sensitivities
- High mass (>500GeV), it is still hard to say now

Combination BSM H → hh (other issues)

- To interpret for 2HDM, in **high** mass region, one has to re-**check resonant width**, maybe has to redefine a smaller window

2HDM parameter phase space Type I

* all extracted from v160 grid file



mH = **500** GeV   mH = **700** GeV   mH = **1000** GeV

@ 500 GeV, consistent with what was checked by German
The windows is proposed by German to interpret bbyy result for 2HDM
cos(b-a) ~ [-0.3,0.3]; tanb ~ [0.5,4]

- The VBF, bbH production may also vary in high mass region, need to check when interpreting for 2HDM
- The signal templates are different: for bbyy final state, latest HeavyScalor in MG5; for bbbb final state, 2HDM in MG5
- As mentioned in SM HH comb, the overlapped phase space should be negligible

Combination BSM A → Zh and H → hh

- The basic idea is to combine the measurements from two different production: A → Zh, H → hh, by using one scale μ for both cross section
- Then by using this scale μ, one can provide the upper limits for each production as well as makes constraints in the tanb vs cos(b-a) plane
- If one assumes the cross section of H → hh is μ, then the cross section of A → Zh should be μ*(A/H)
  - Then the two measurements are correlated in the combination, leading to the possibility of obtaining from the fit the combined upper limits or "combined significance"
  - In the combined fit, the only POI is μ and (A/H) exists as a function of b and a
  - Due to the varying (A/H), one has to extract the upper limit for each point in the phase space to see if this certain point is rejected or not (quite computing-consuming)

Glance at H → hh → WWyy → jjjjyy

- In parallel, we started to look at gg → H → hh → WWyy with W hadronic decay leading to final state of jjjjyy
  - h→WW has the second largest branching ratio after h→bb
- Apply the same cuts from yy side, then ask njets>=4, estimate roughly the expected upper limit, and then additionally apply MVA cut to see the improvement on the expected upper limit

	Lumi (pb-1)	Branching ratio	Cut eff (yy&Njet>=4)	Upper limit	Cut eff (additionally MVA)	Upper limit
Non-resonant SM HH	20,000	4.48e-4	15%	**18 pb**	15%*93%	**7.2 pb**
Resonant 300GeV	20,000	4.48e-4	9%	**30 pb**	9%*63%	**14 pb**

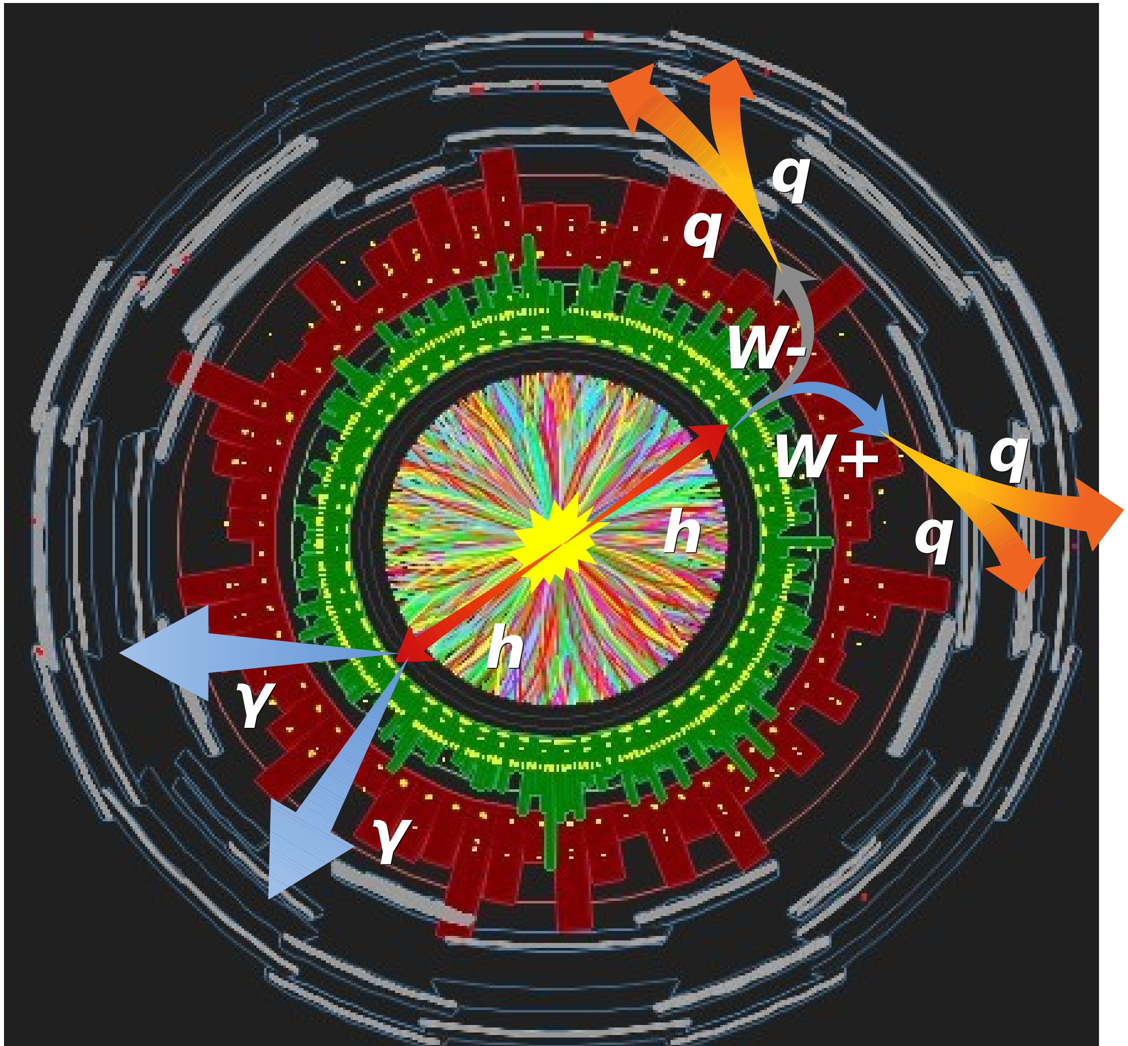
*The MVA is trained with signal MC sample and background from sideband
This leads to signal eff = 63%, bkg eff = 9% for resonant,
signal eff 93%, bkg eff = 13% for non-resonant

Compared to the expexted upper limits from bbyy analysis:
* Non-resonant: **1.0** pb
* Resonant @ 300GeV: **1.5** pb

10%

Introduction to jjjjγγ

- Final states jjjjγγ for searching
  - SM hh production
  - BSM gg → X → hh production

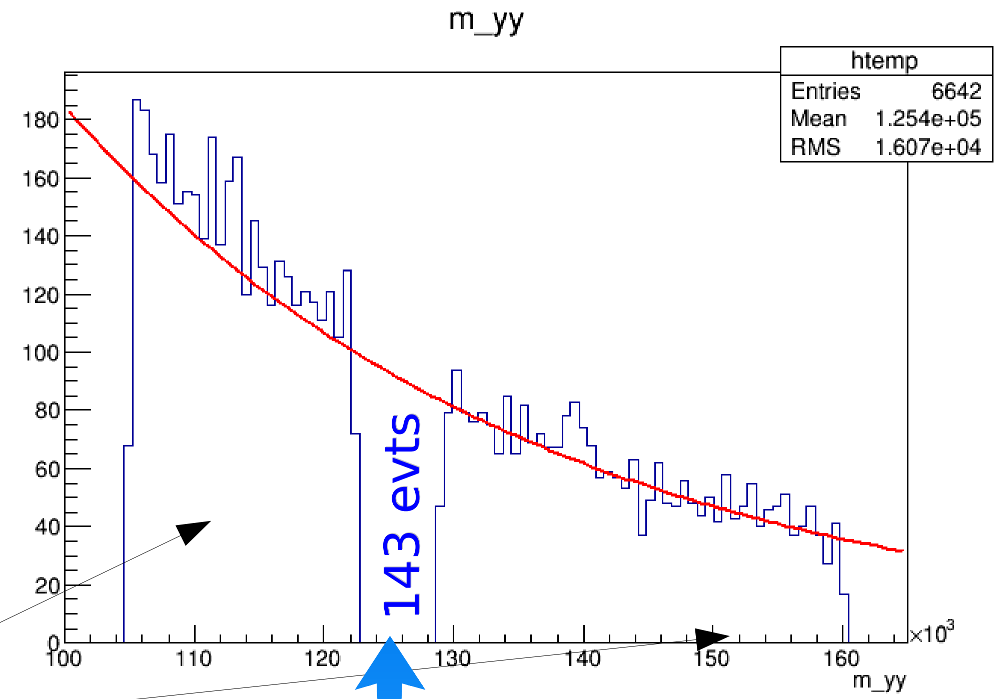


Signal region event yields [EXP]

- Signal region (ask yy cuts && njets>=4):
  - mass(yy) is required by $|m_h - \Delta m_h - m_{\gamma\gamma}| < 2\sigma_{\gamma\gamma}$
  - where mh=125.6, deltamh=0.15, sigma=1.6

SIGNAL REGION

bkg components	# of evt
SM H (ggH,VBF,VH,ttH)	~8
Continuum	~143
	~151



Sideband data

* bkg in signal region estimated by fitting to exponential with sideband data

JxJy not has to be j1j2

- Till now I only assume j1 j2 are from a real W boson and use them to reconstruct it for simplicity
- An adaptive method is used to improve the correctness of finding the two jets from a same W boson here
  - By asking the invariant mass of jx jy, and choose the pair with the mass closest to W boson mass from PDG

6%

Using j1j2

The correctness of finding jet pair from the same real W boson

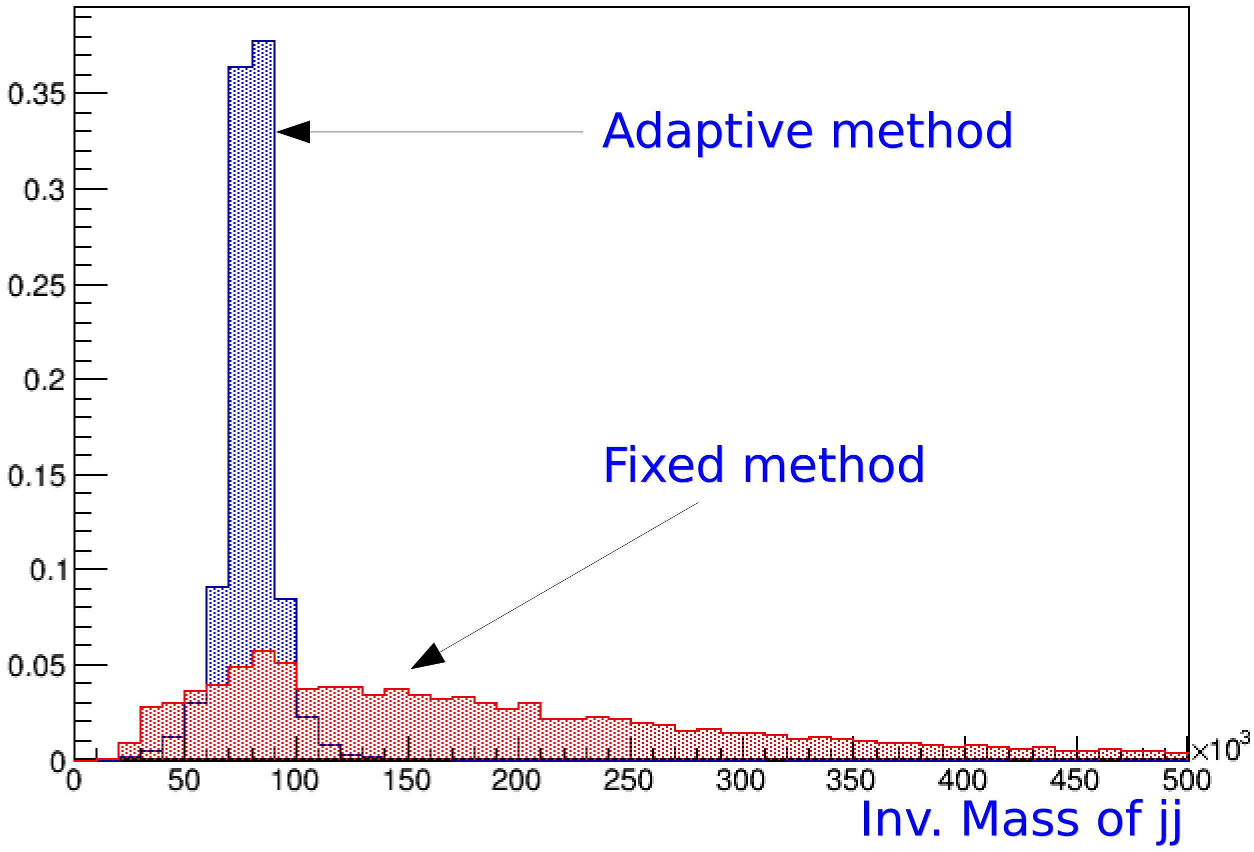
24%

Adaptive jxjy

*these correctness are calculated by using signal MC only @ mH=300GeV

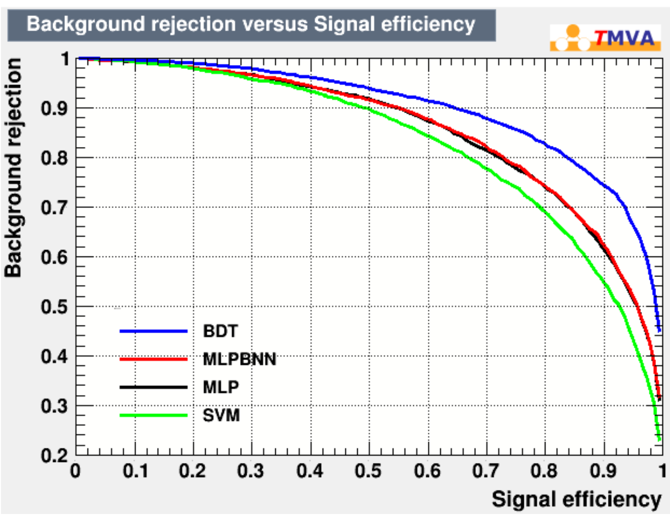
JxJy not has to be j1j2

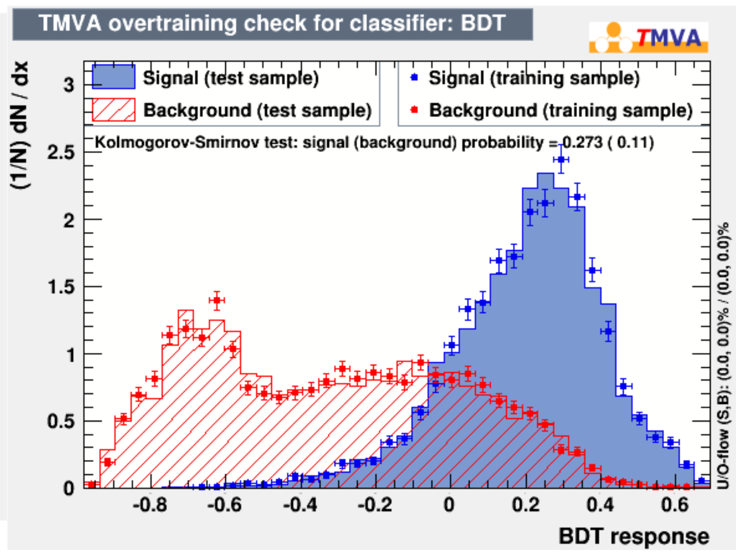
- Compare the invariant mass of jxjy in adaptive method and the one of j1j2 in the fixed method

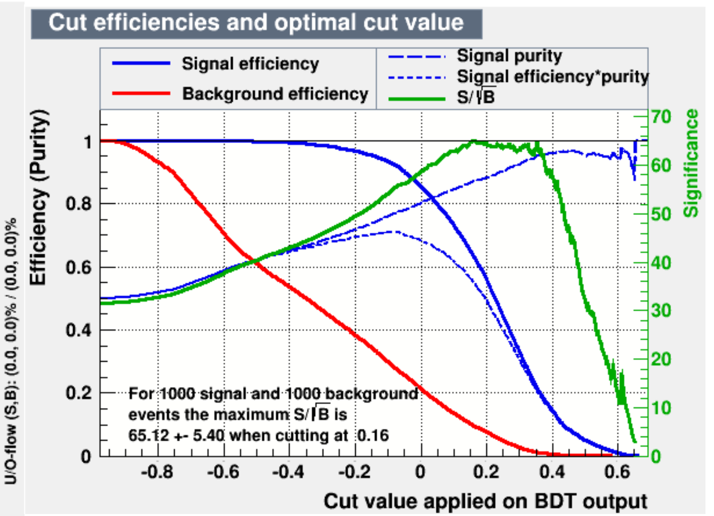


MVA with JxJy

- Train with the variables from JxJy instead of J1J2
- Much more better performance is obtained





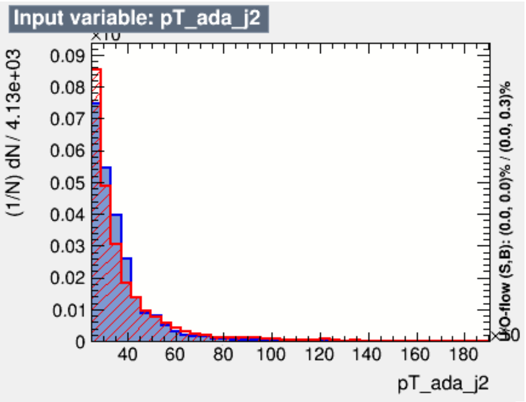


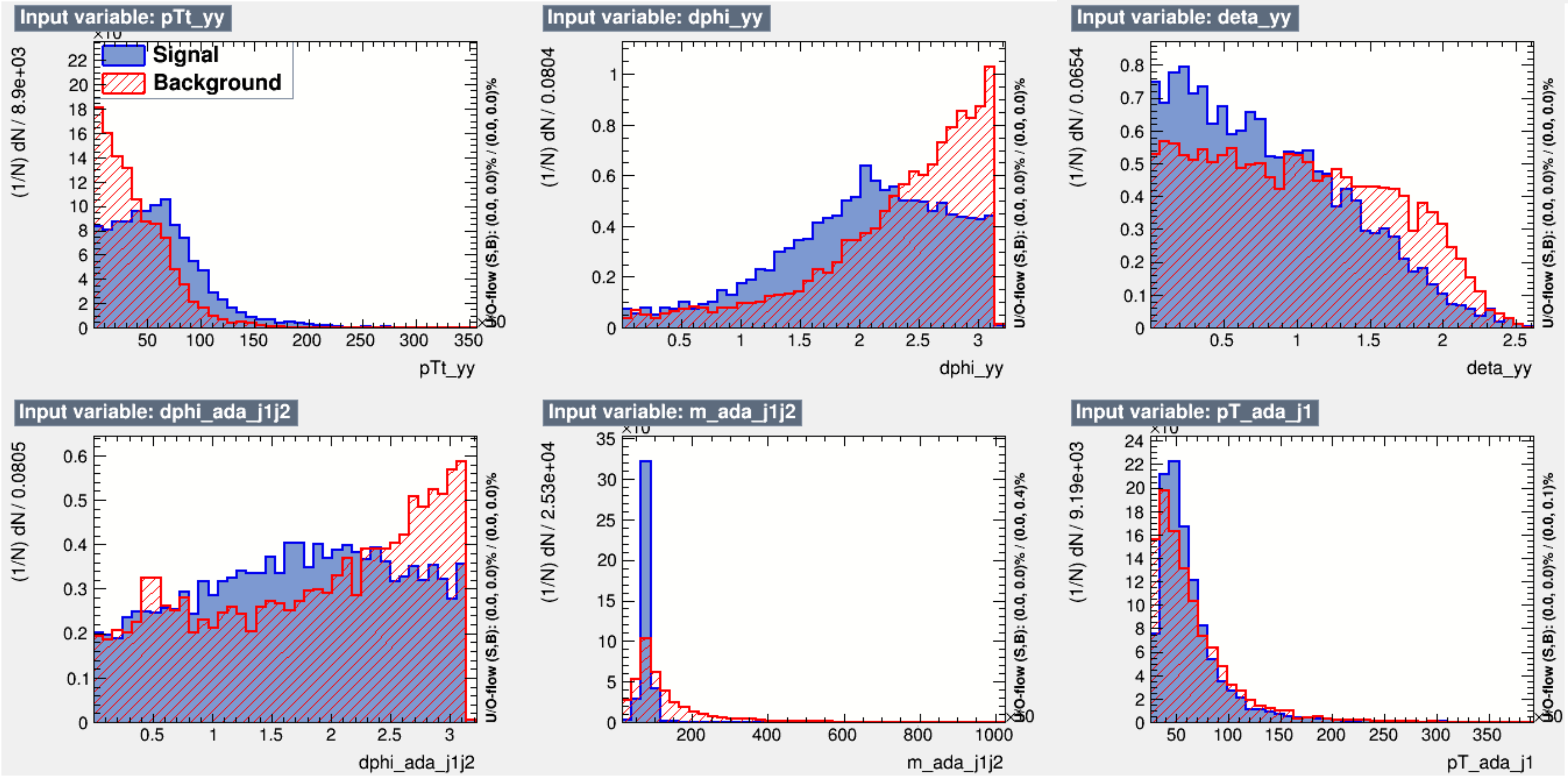
Classifier	(#signal, #backgr.)	Optimal-cut	S/sqrt(B)	NSig	NBkg	**EffSig**	**EffBkg**
MLP:	(1000,1000)	0.6192	(55 +- 4.8)	515.8762	87.92532	0.5159	0.08793
MLPBNN:	(1000,1000)	0.6068	(54.9 +- 4.8)	545.217	98.76543	0.5452	0.09877
BDT:	(1000,1000)	0.1597	(65.1 +- 5.4)	633.2395	94.54983	**0.6332**	**0.09455**

The signal eff is kept 63% while the bkg eff is lower 9%

MVA inputs with adaptive method

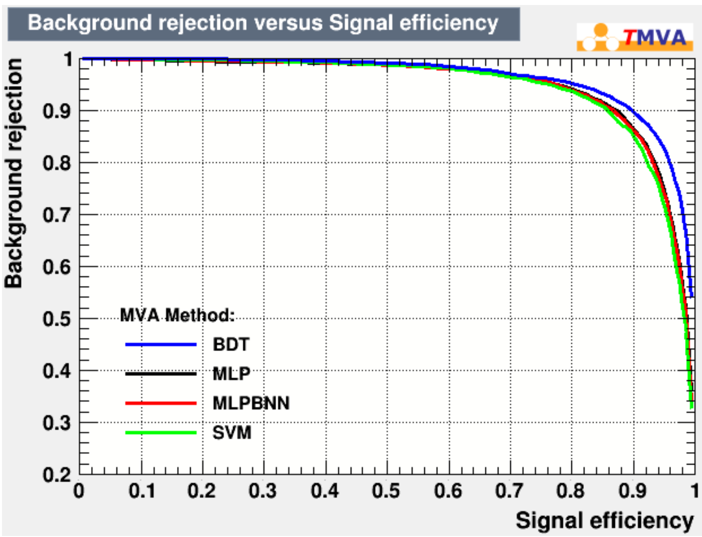
- J1J2 variables are replaced by the Jx Jy variables obtained by adaptive method

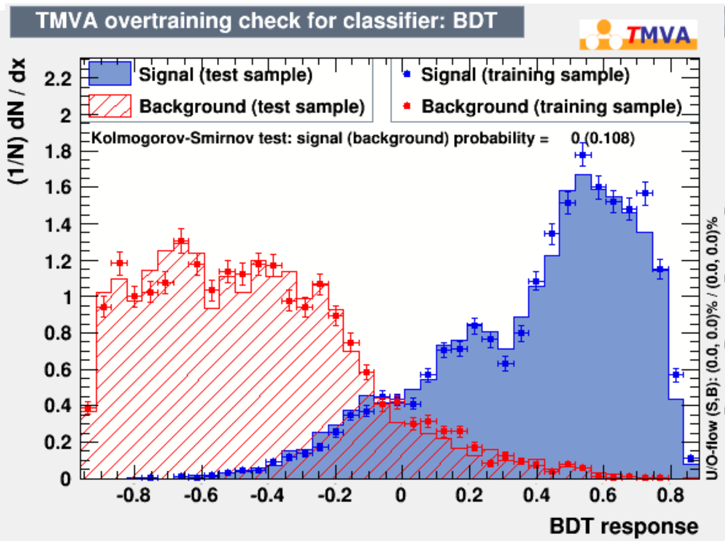


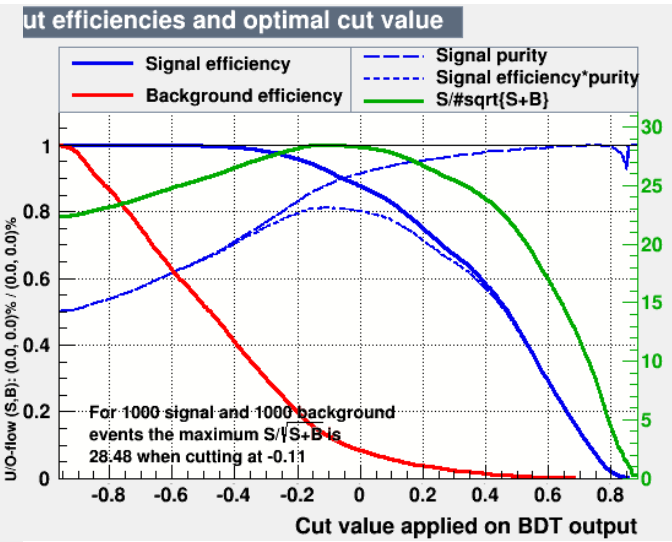


MVA with JxJy for **SM HH**

- Train with the variables from JxJy instead of J1J2







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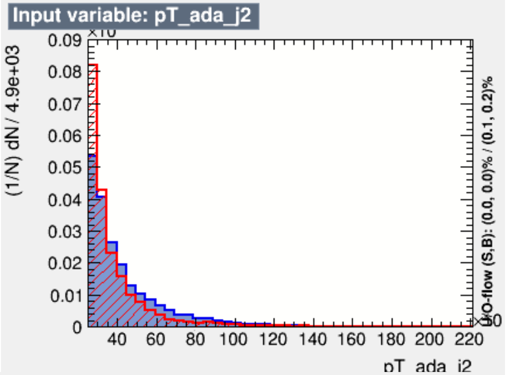
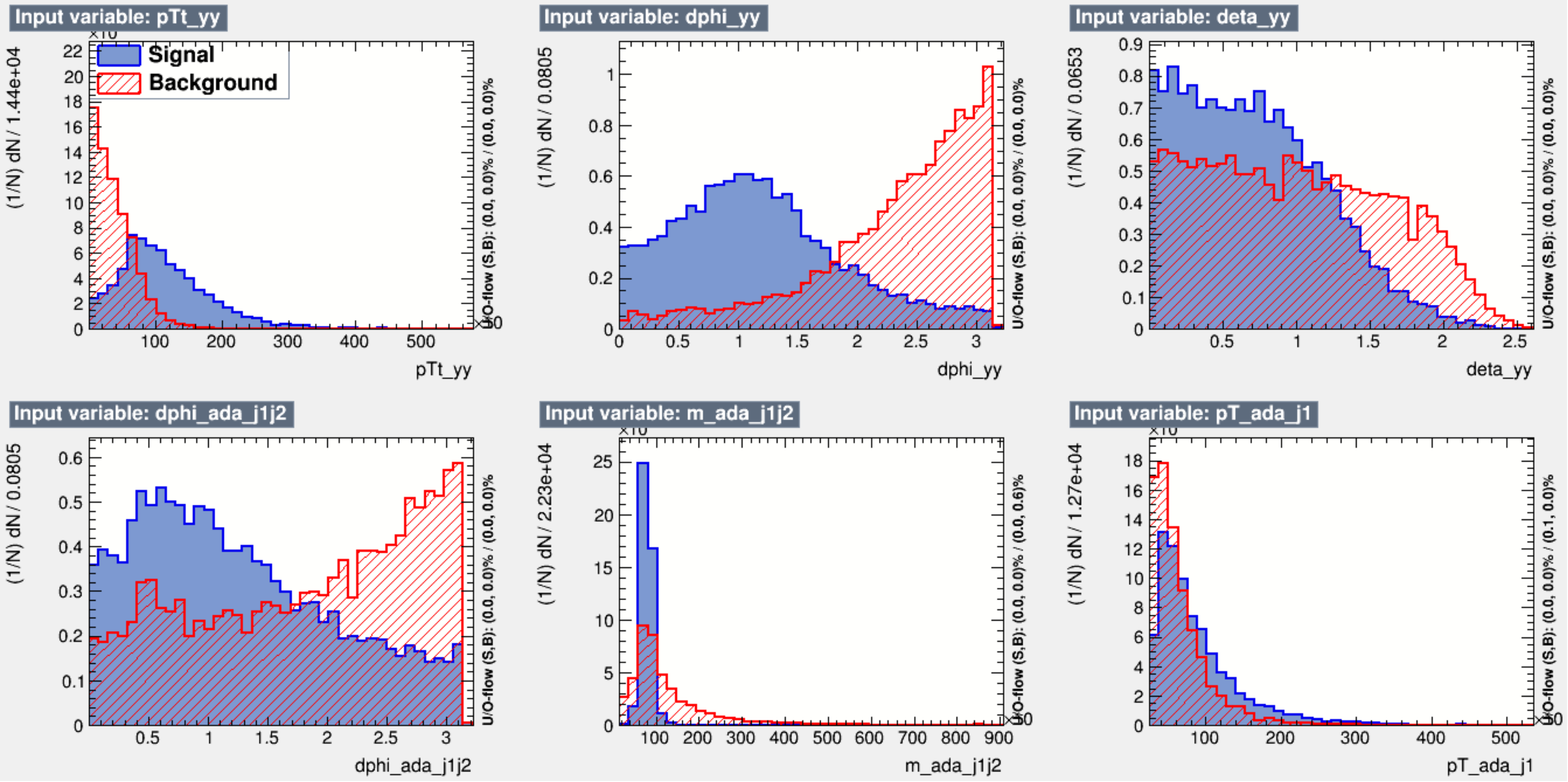
Classifier	(#signal,#backgr.)	Optimal-cut	S/sqrt(S+B)	NSig	NBkg	**EffSig**	**EffBkg**
MLP:	(1000, 1000)	0.4930	27.9795	895.2804	128.5757	0.8953	0.1286
MLPBNN:	(1000, 1000)	0.4863	27.9399	901.6102	139.717	0.9016	0.1397
SVM:	(1000, 1000)	0.4642	27.8195	893.3926	137.9103	0.8934	0.1379
BDT:	(1000, 1000)	-0.1115	28.4816	925.4858	130.3824	**0.9255**	**0.1304**

The signal eff is 93% while the bkg eff is 13%

MVA inputs with ada method (**SM HH**)

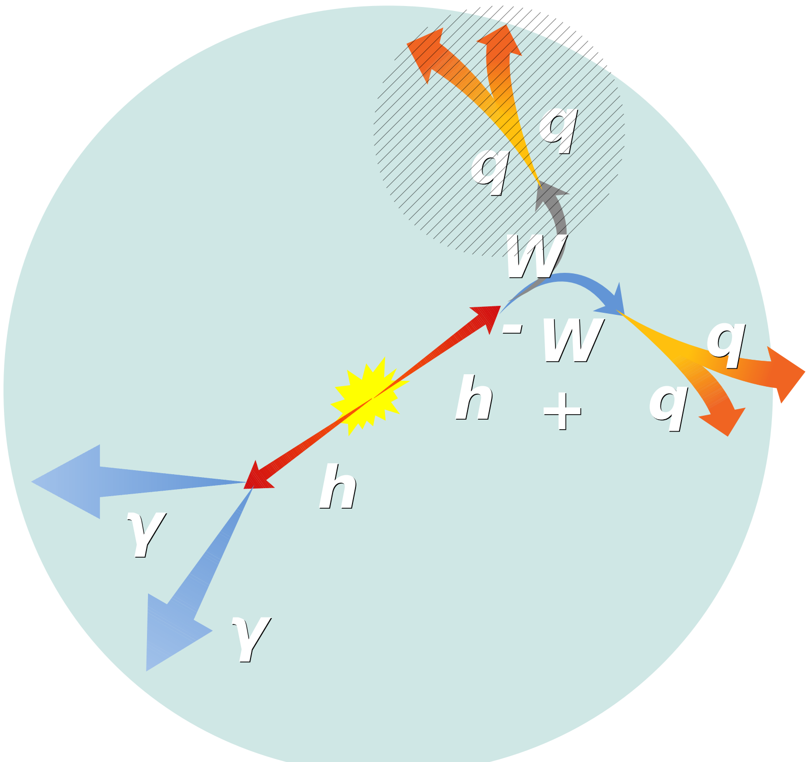
- J1J2 variables are replaced by the Jx Jy variables obtained by adaptive method





A new idea to try

- We all know missingET, which is due to the undetectable neutrino
- In our case, we don't have missingET, instead, we have a missing W since our pT requirements on jet almost remove all the 3^{rd} and 4^{th} jets
- We can try to reconstruct the other W boson by the momentum conservation law in transverse plan!

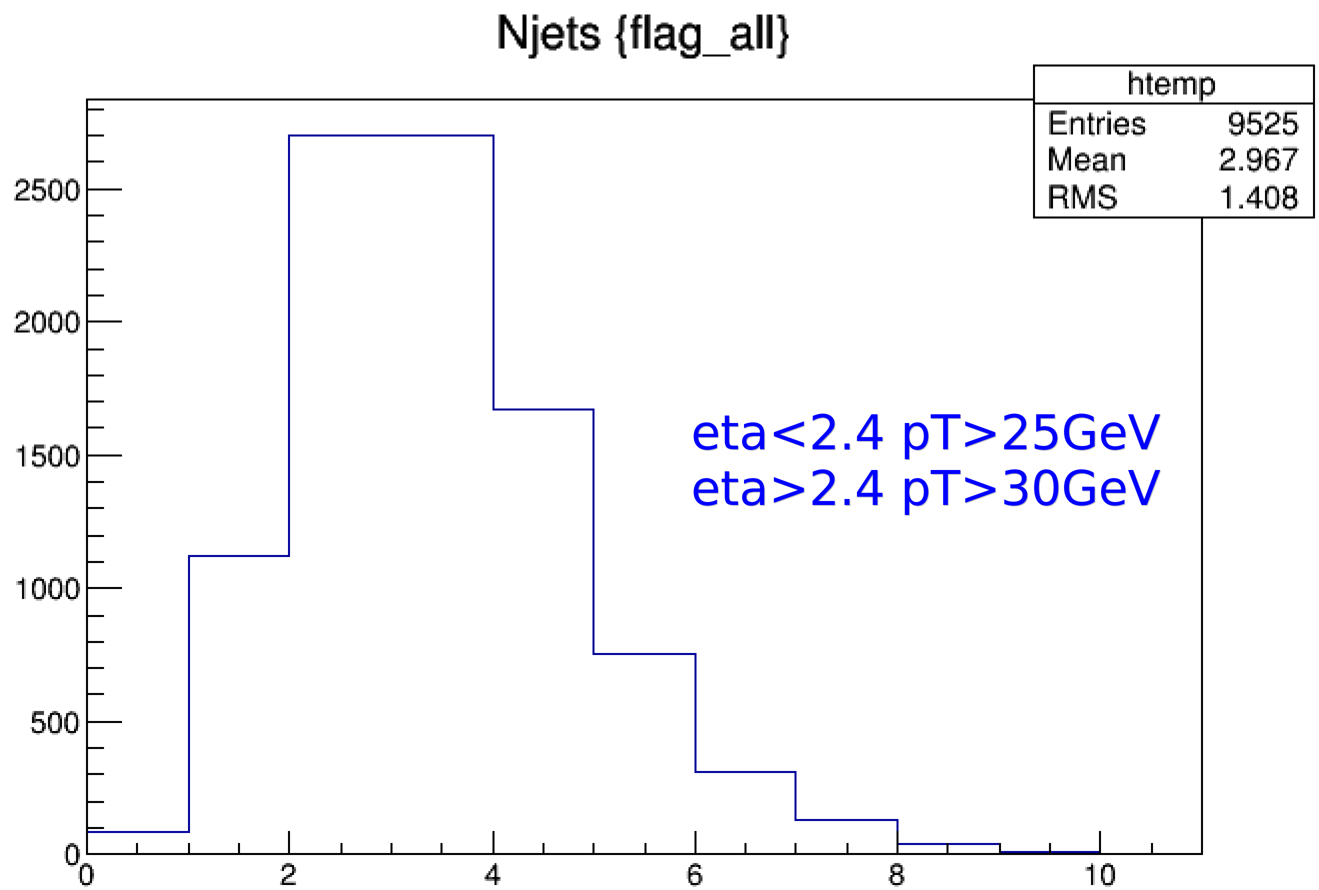


pT(yy) + pT(jxjy) + pT(missW) + pT(residual)= 0

To be calculated

Additional cuts

- Additionally, we will cut on kinematics of the children from the other Higgs boson
  - To do some studies on cuts: deltaPhi(j,j) deltaEta(j,j)
  - To find the more correct combinations of jets originating from the same W boson



Jet multiplicity after all cuts from yy side

A first look at sideband region

Njets>=4

- Sideband region:
  - mass(yy) within [100,160] GeV
  - mass(yy) is excluded from $|m_h - \Delta m_h - m_{\gamma\gamma}| < 2\sigma_{\gamma\gamma}$
  - where mh=125.6, deltamh=0.15, sigma=1.6

sideband	# of evt
ggH	0.467175
VBF	0.123474
WH	0.0638113
ZH	0.0405459
ttH	0.138622
Continuum	?
In data	1170

Continuum?

There are large components in backgrounds not yet clear
Need to at least introduce pp→jjjjyy and pp→jjyy

Bkg samples, use bbyy continuum samples?

A first look at signal region

Njets>=4

- Signal region:
  - mass(yy) is required by $|m_h - \Delta m_h - m_{\gamma\gamma}| < 2\sigma_{\gamma\gamma}$
  - where mh=125.6, deltamh=0.15, sigma=1.6

sideband	# of evt
ggH	4.91724
VBF	1.0963
WH	0.570564
ZH	0.374228
ttH	1.34295
Continuum	?
est bkg*	143

* bkg in signal region estimated by fitting to exponential with sideband data