Searches for

BSM neutral Higgs

Yaquan Fang, Xiaohu Sun
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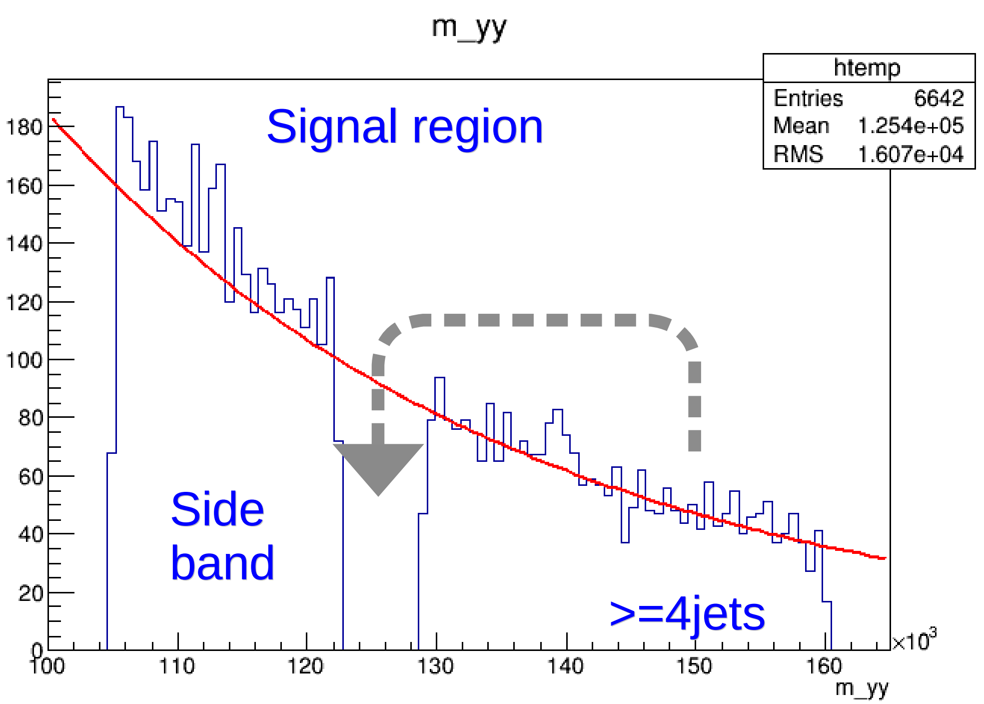
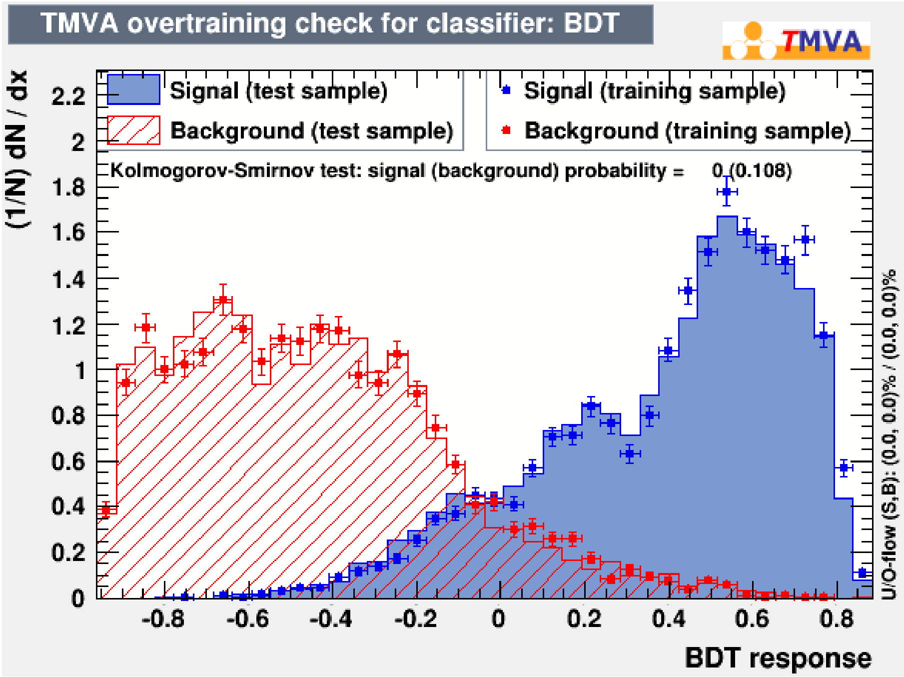
IHEP, Beijing

Huijun

WWyy basics

- Final states with 4 jets and 2 photons:
  - Searched by asking HSG1 yy trigger/cuts and njets>=4
  - Final cuts are on myy and MVA



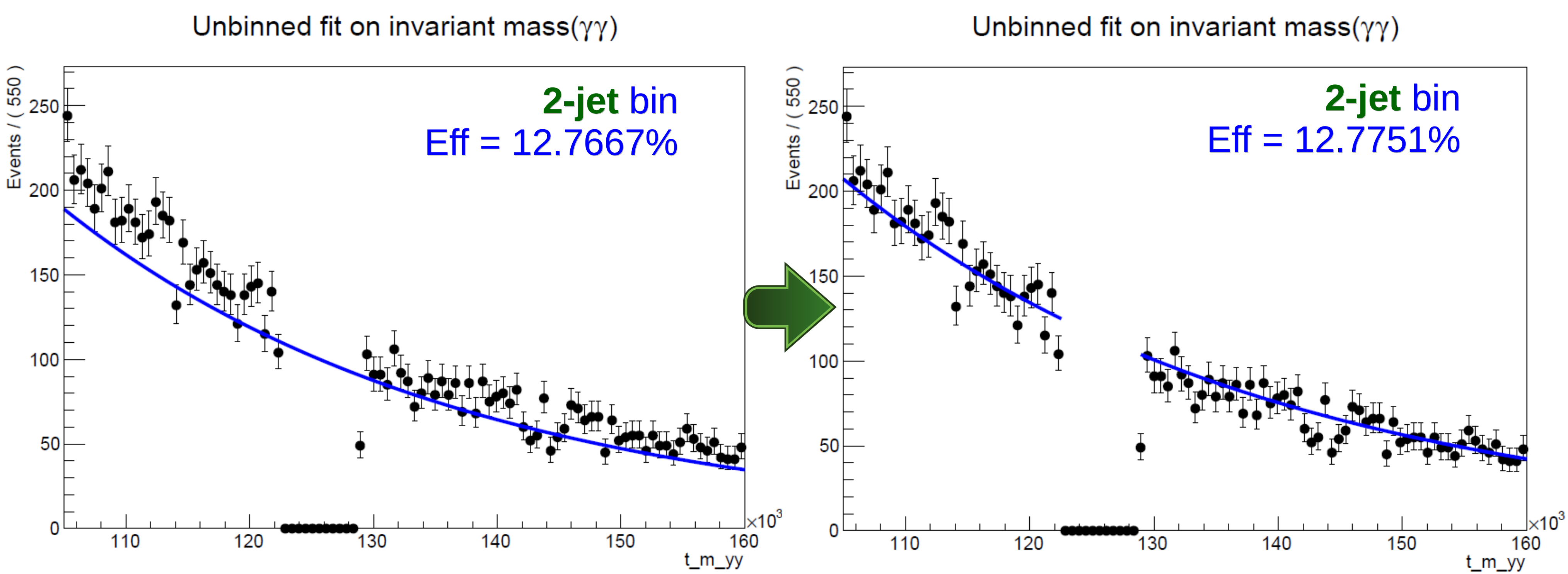


I For both signal and background efficiency on yy-mass window cut ε_{yy}

II In the mass window cut on MVA Efficiency MVA ε_{MVA}

ε_{yy} for backgrounds (2-jet bin)

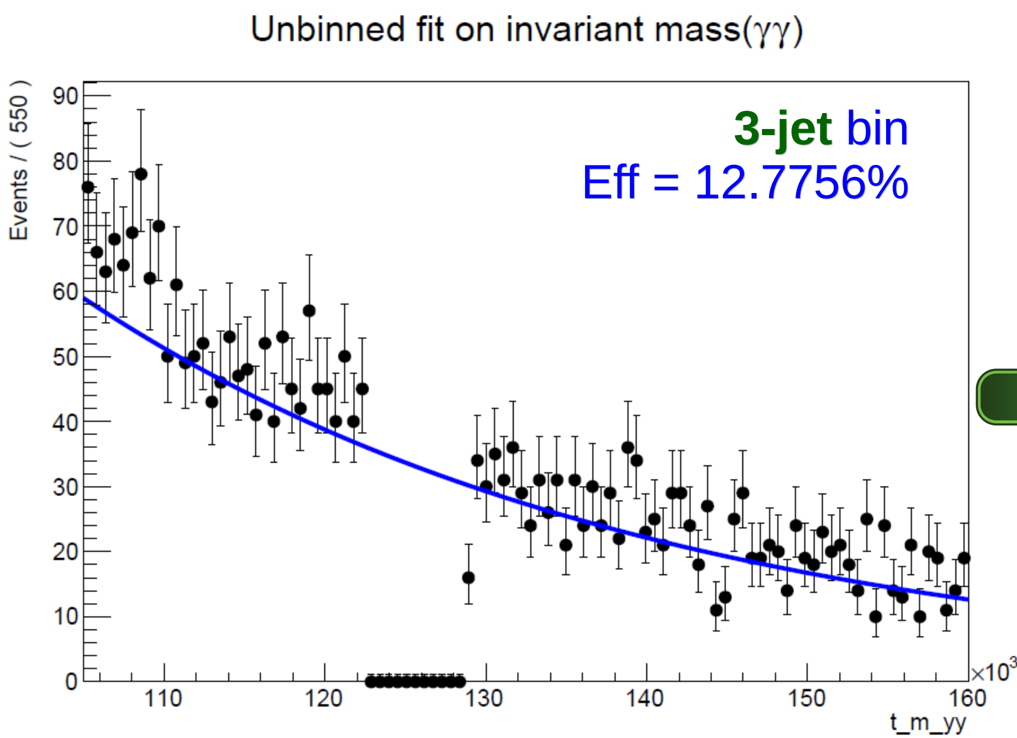
- Fit sideband data in 2/3-jet bin along the invariant mass of yy (**unbinned multi-ranged fit**: updated from previously), extrapolate these efficiencies into 4-jet inclusive bin
- This eff is shared by all mass points as well as non-resonant search

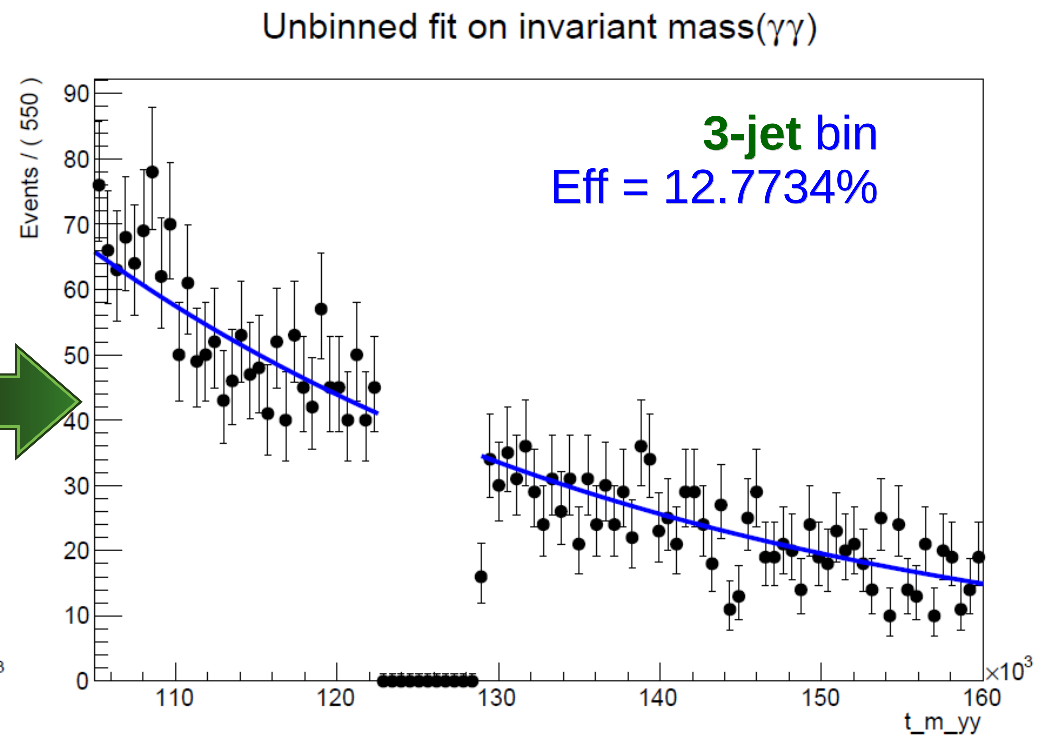


Consistent with 12.8% in bbyy analysis for the bkg efficiency on myy cut

ε_{yy} for backgrounds (3-jet bin)

- Fit sideband data in 2/3-jet bin along the invariant mass of yy (**unbinned multi-ranged fit**: updated from previously), extrapolate these efficiencies into 4-jet inclusive bin
- This eff is shared by all mass points as well as non-resonant search





Consistent with 12.8% in bbyy analysis for the bkg efficiency on myy cut

$\varepsilon_{\gamma\gamma}$ for signal

- Efficiencies for non-resonant and all resonant mass points are shown in the table
- Extracted directly from 4-jet inclusive bin with MC

	$\varepsilon_{\gamma\gamma}$ in 4-jet inclusive bin
SM HH	87.4%
resonants	
MH = 260 GeV	83.9%
MH = 300 GeV	84.2%
MH = 350 GeV	85.3%
MH = 400 GeV	86.8%
MH = 500 GeV	87.8%
MH = 800 GeV	90.5%
MH = 1000 GeV	91.3%

WWyy basics – train MVA (BKG)

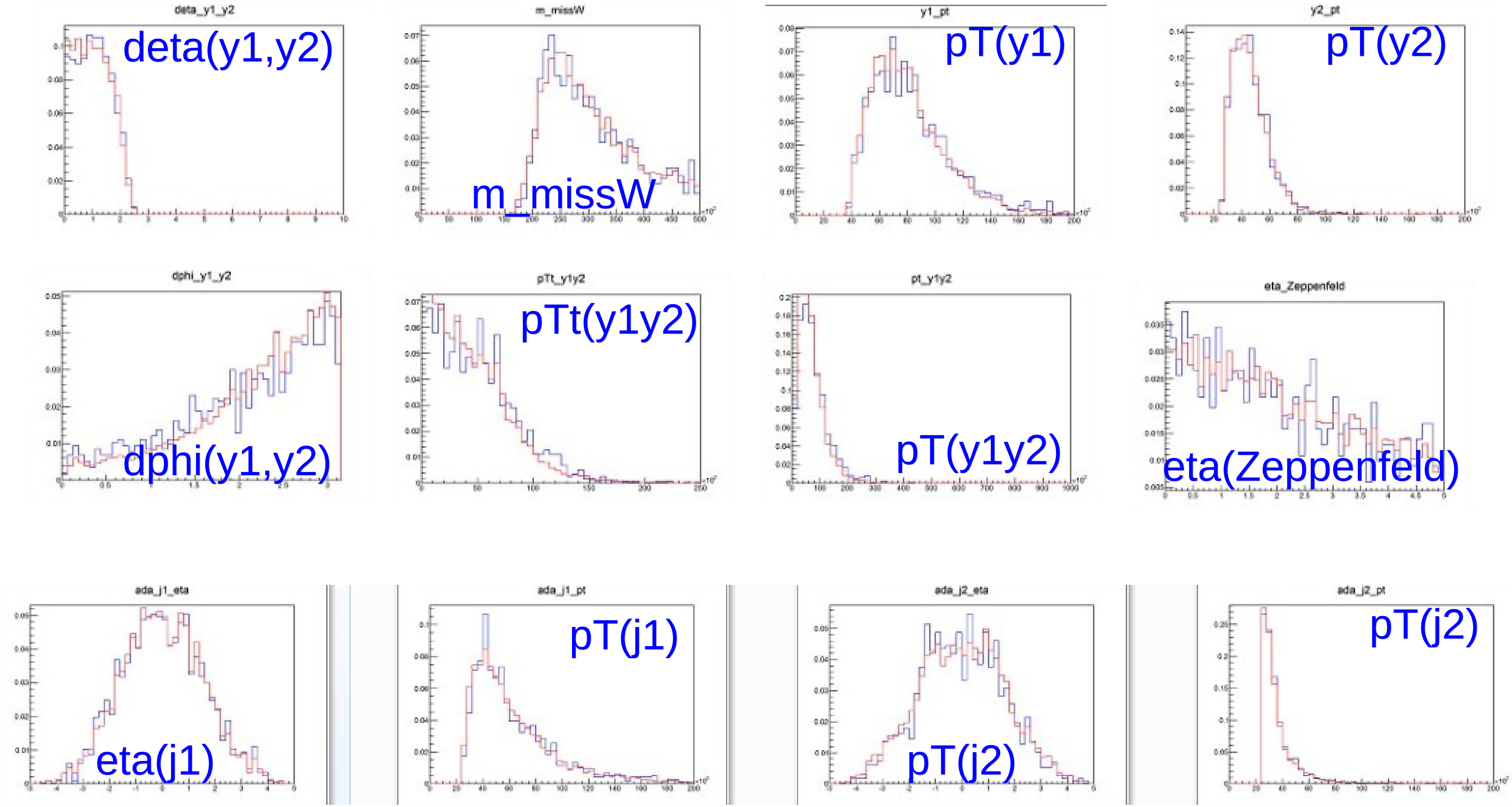
- To train MVA, one needs to find samples for signal and bkg with good modeling similar to the ones in signal region
  - 3-jet inclusive bin for training: sideband bkg
  - 3-jet inclusive bin for ε_{MVA}: sideband bkg

Training (½ total stat already in this table) For **bkgs** by using only sideband data in different jet bins to mimic kine in >=4 jet bin		
	>=2 jet evts	>=3 jet evts
stat	6k	**2k**
can be used as training sample?	**NO**, Kine is not the same as the ones in >=4 jet, especially in ==2jet evts, especially on kine of deta_j1j2, dphi_j1j2	**YES**, Except **missW pT,and eta**, **m_ada_j1j2**, well missW mass can be still used

>=3 jet bin increases stat by 0.5k from ==3 jet bin (1.5k)
>=4 jet bin has only ~0.5k evts (½ stat)

WWyy basics – train MVA (BKG)

- Plots for comparisons



WWyy basics – train MVA (SIG)

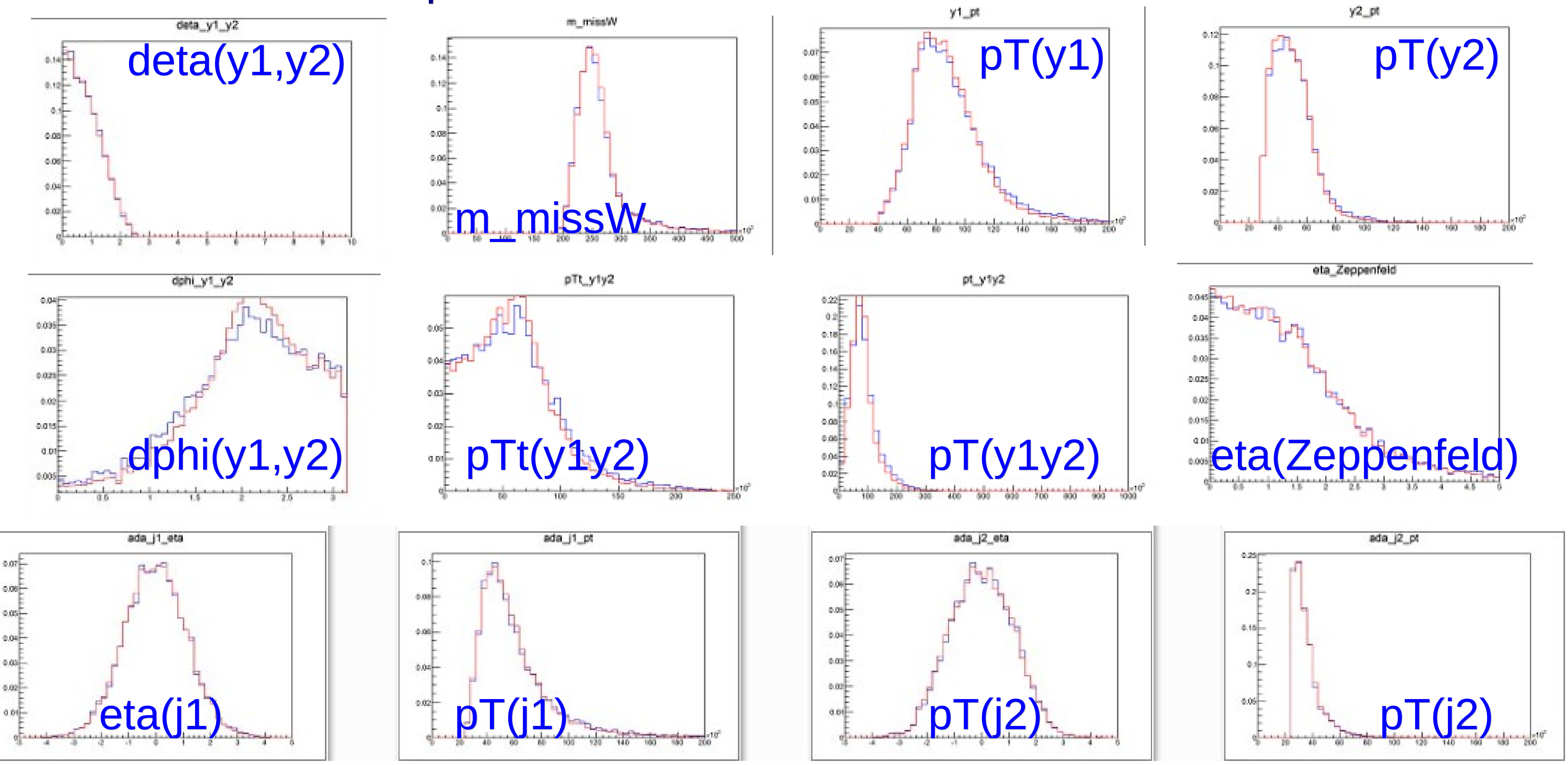
- To train MVA, one needs to find samples for signal and bkg with good modeling similar to the ones in signal region
  - 3-jet inclusive bin for training: MC signal
  - 3-jet inclusive bin for ε_{MVA}: MC signal

Training (½ total stat already in this table) For **signal** by using MC within m_yy mass window in different jet bins to mimic kine in >=4 jet bin		
	>=3 jet evts	>=4 jet evts
stat	10k	5k
can be used as training sample?	**YES**, especially dphi_yy_j1j2, m_ada_j1j2, eta/pT_missW	**YES**, but stat is low

This is for mh=300GeV, for other mass point stat is dropped by half

WWyy basics – train MVA (SIG)

- Plots for comparisons



Train MVA

- Train individual MVAs for all mass points
- Frequently used variables: pT_yy, deta_yy, dphi_yy, m_missW, E_missW etc.
- No plots are shown here, only showing the efficiencies

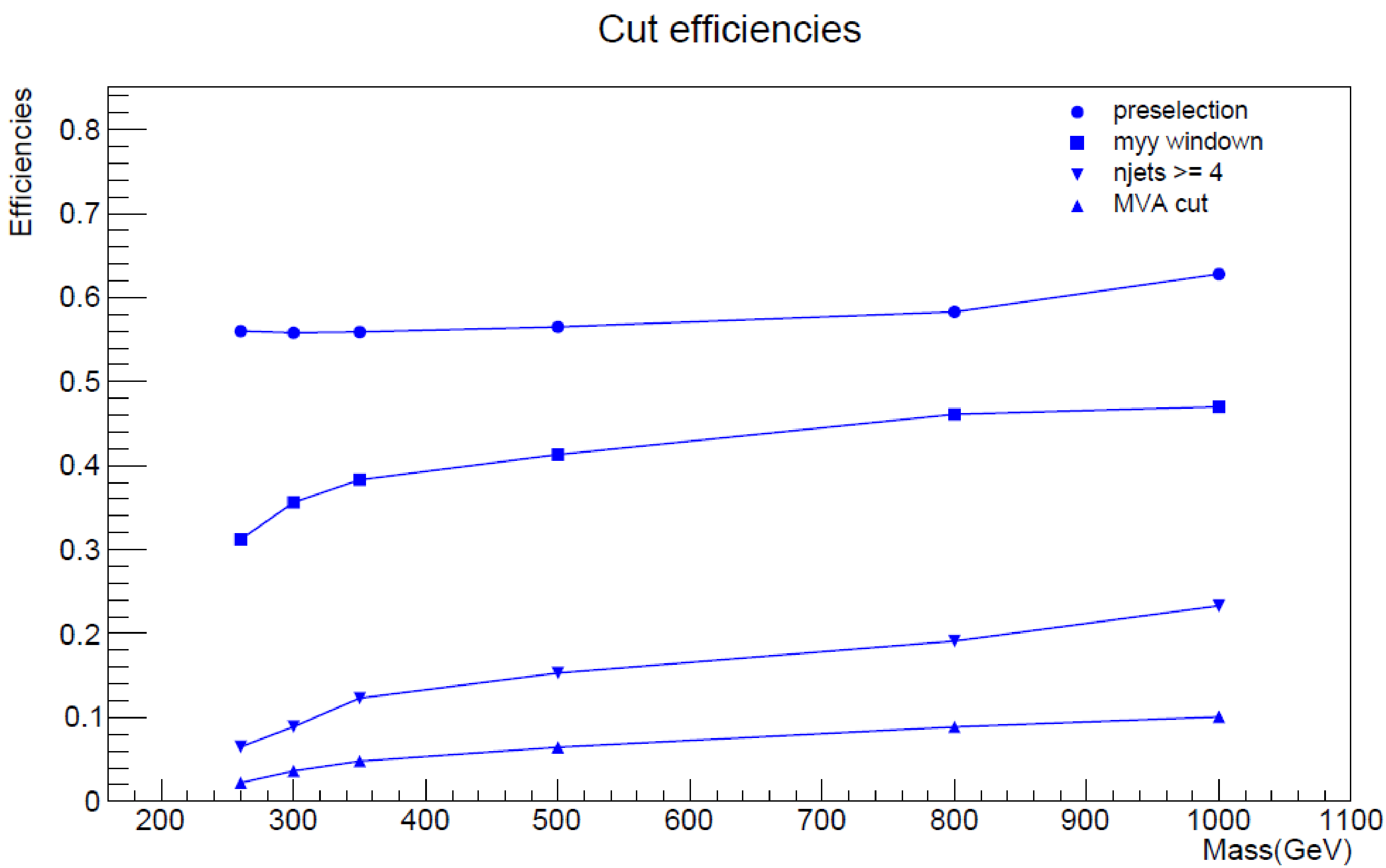
	Signal eff_mva	Bkg eff_mva
MH = 260 GeV	34.3%	1.5%
MH = 300 GeV	40.8%	2.6%
MH = 350 GeV	40.0%	1.7%
MH = 400 GeV	42.2%	0.7%
MH = 500 GeV	46.5%	0.5%
MH = 800 GeV	43.2%	0.04%
MH = 1000 GeV	76.5%	0.04%

Very preliminary

Beyond 500GeV, quite boosted regime, kine change a lot

Signal acceptances

- All efficiency curves after four levels of cuts for all mass points in signal are shown



All extracted from MC signal samples

To-do list (in the order of priority)

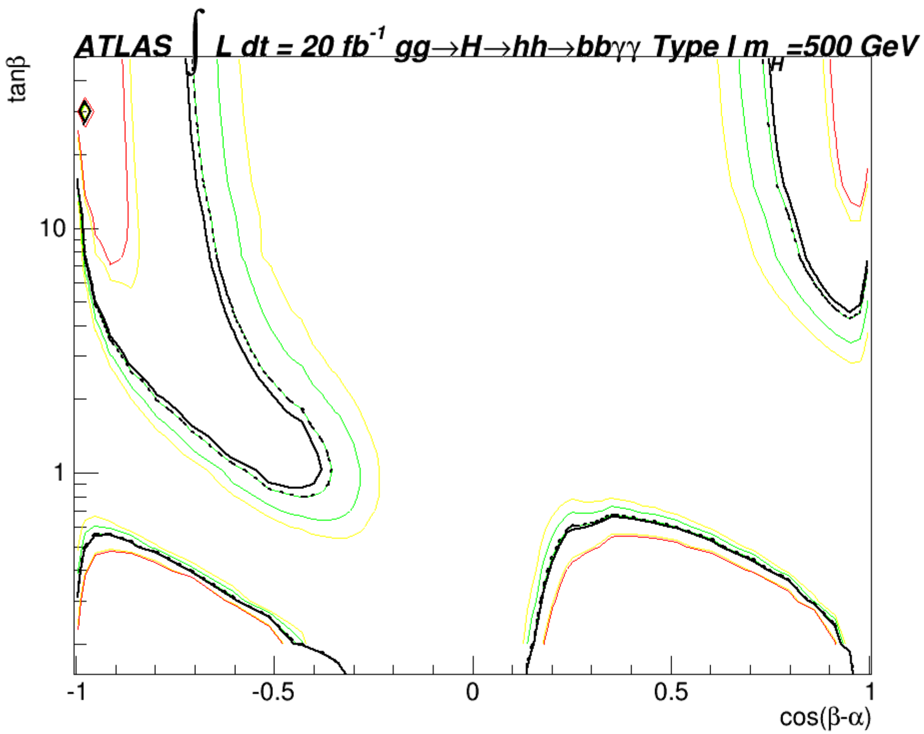
- Instead of using j1 j2, find jx jy to be used to reconstruct only one W boson as precisely as possible (preliminarily explored)
- Using these new variables from adaptive method in MVA (trying)
- Validate the 3-jet bin can be used as training for 4-jet bin inclusive
- Introduce more variables into MVA 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

The task on HiggsBSM2HDMPlotting

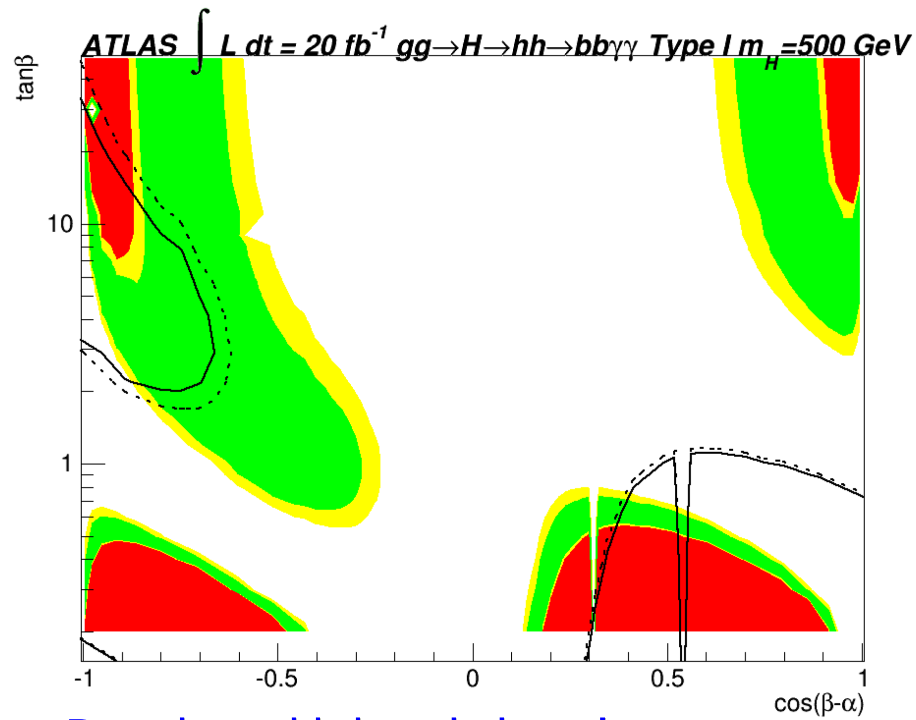
- Called by Nikos and German, a plotting tool needs to be unified in HSG6 for 2HDM parameter limit plotting
- I develop the limit plotting tool based on ROOT-built-in interpolation realization
- Build up documentation on twiki
  - https://twiki.cern.ch/twiki/bin/viewauth/AtlasProtected/HiggsBSM2HDMPlotting
- Build up the compilable code on svn
  - svn co svn+ssh://YOUR-USER-NAME@svn.cern.ch/reps/atlasphys/Physics/Higgs/HSG6/workspaces/Summer2014/HiggsToHiggs/LimitPlotting2HDM
- Circulated in the group and being fed back with questions and comments

The task on HiggsBSM2HDMPlotting

- In general, this tool supports various constraints on 2-D planes of 2HDM parameters by using only upper limits from cross sections in the experiments



Contours with bands in line style are working well now



Drawing with bands in color
Still debugging, the misalignement is caused by coordinate system problem in ROOT

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 $H \rightarrow hh$

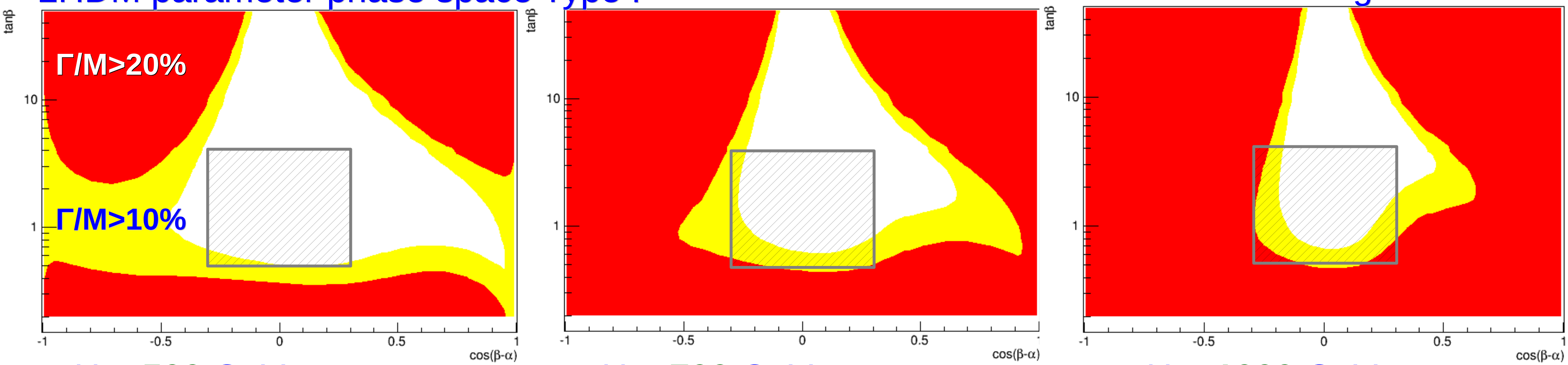
- The scanned mass points: bbyy final state covers from 260 GeV to 500 GeV, while with bbbb final state from 500 GeV 1000 GeV
  - bbbb signal acceptance drops significantly below 500 GeV
  - It seems that we can only combine in high mass region if bbyy final state can extend the search
- Well, if only looking at 500 GeV, by eye catching on the limit plots:
  - Expected upper limit on $gg \rightarrow H \rightarrow hh$ (bbyy): **0.8** pb
  - Expected upper limit on $gg \rightarrow H \rightarrow hh$ (bbbb): ***0.1*** pb from 6^{th} 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**

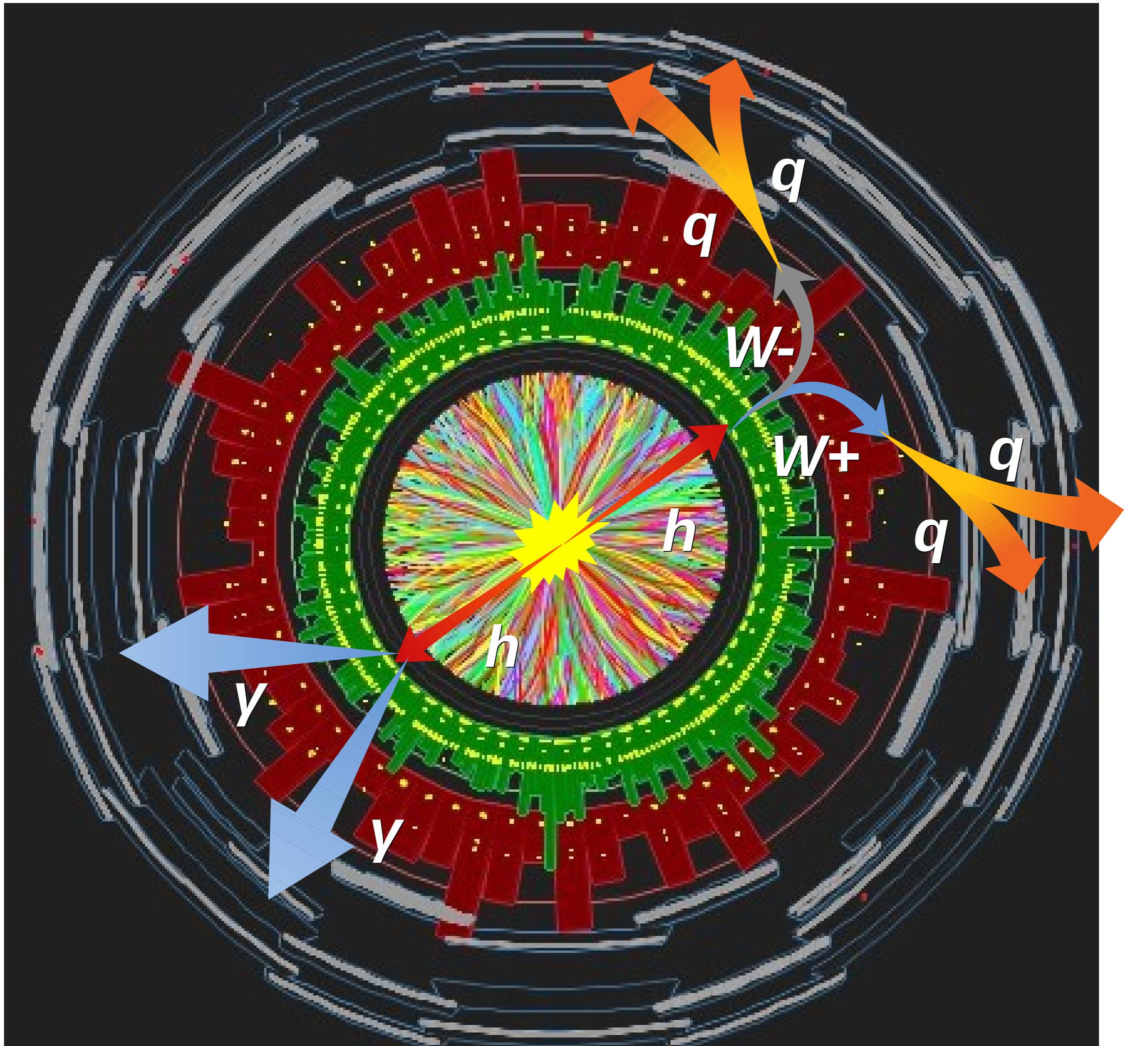
*The MVA is trained with signal MC sample and background from sideband
This leads to signal eff = 63%, bkg eff = 9% for resonant,
signal eff 93%, bkg eff = 13% for non-resonant

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

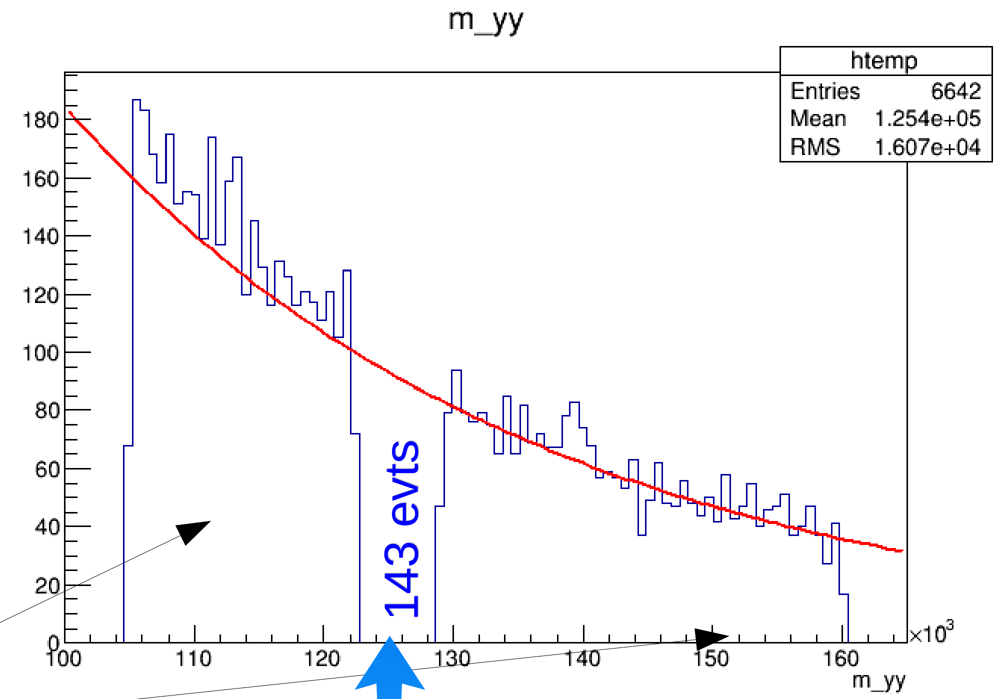


Signal region event yields [EXP]

- 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

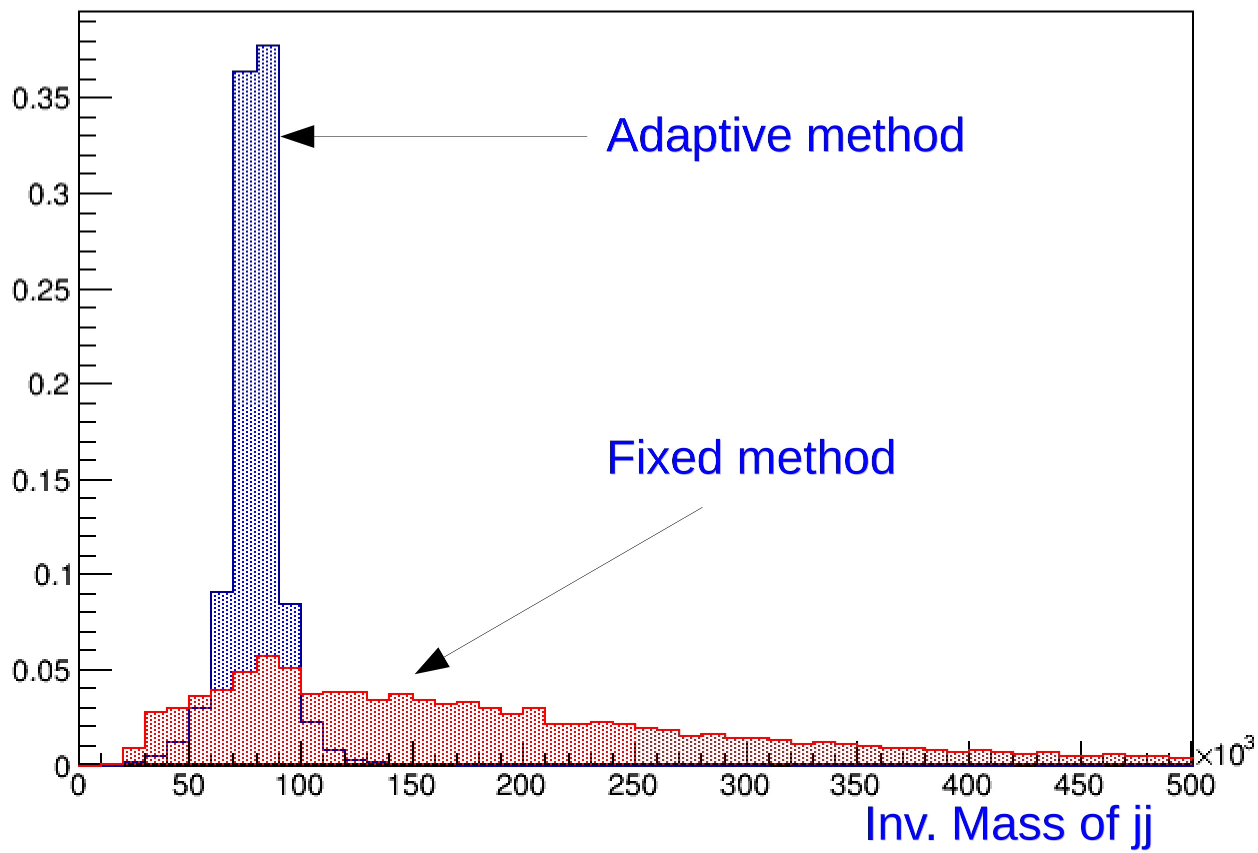
24%

Adaptive jxjy

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

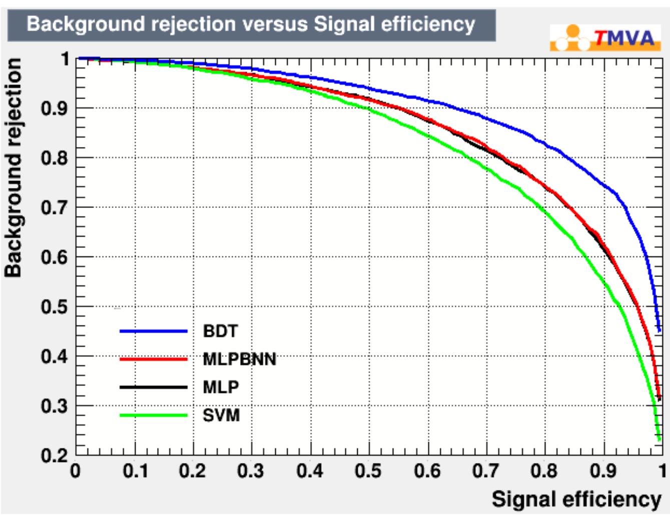
JxJy not has to be j1j2

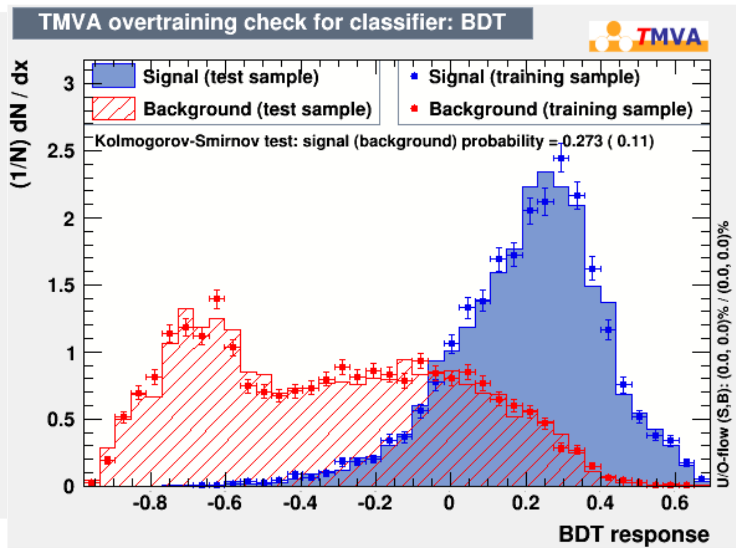
- Compare the invariant mass of jxjy in adaptive method and the one of j1j2 in the fixed method

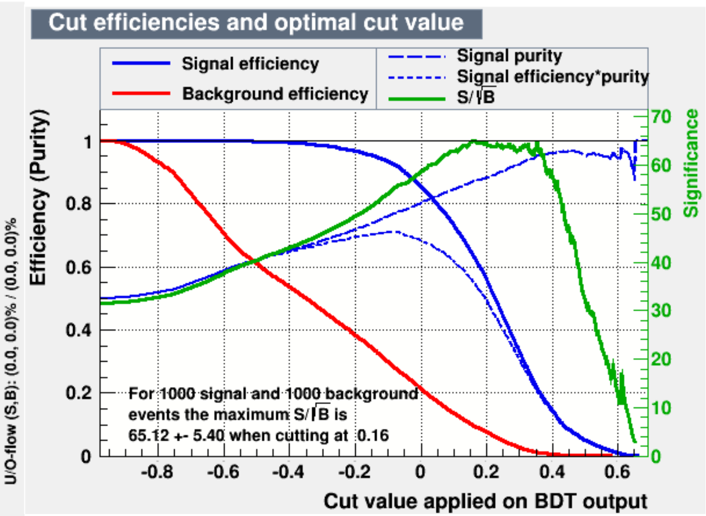


MVA with JxJy

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







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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

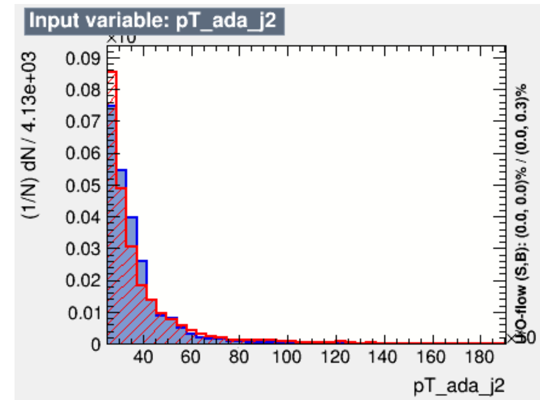
MLPBNN: (1000,1000) 0.6068 (54.9 +- 4.8) 545.217 98.76543 0.5452 0.09877

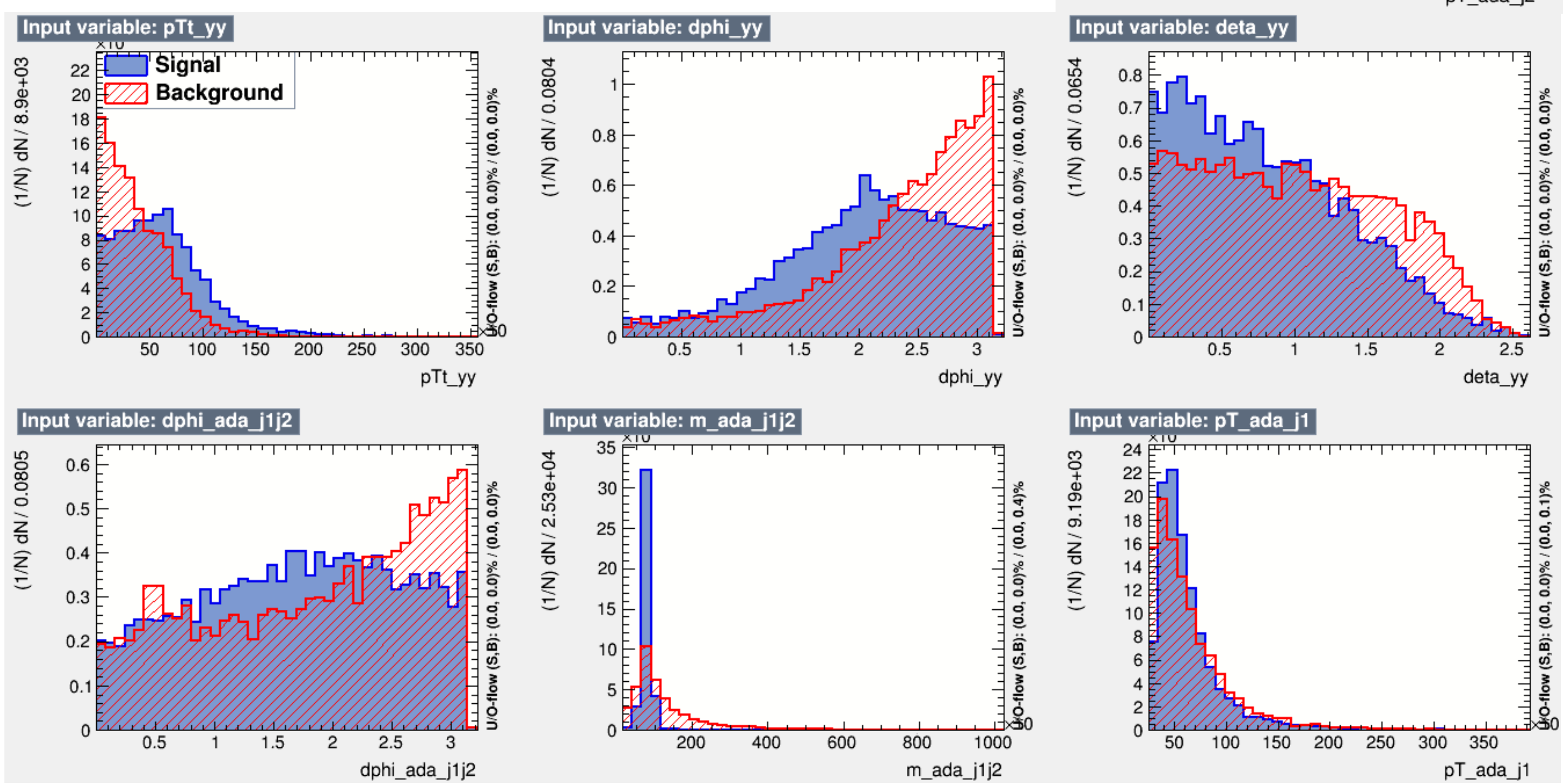
BDT: (1000,1000) 0.1597 (65.1 +- 5.4) 633.2395 94.54983 **0.6332** **0.09455**

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

MVA inputs with adaptive method

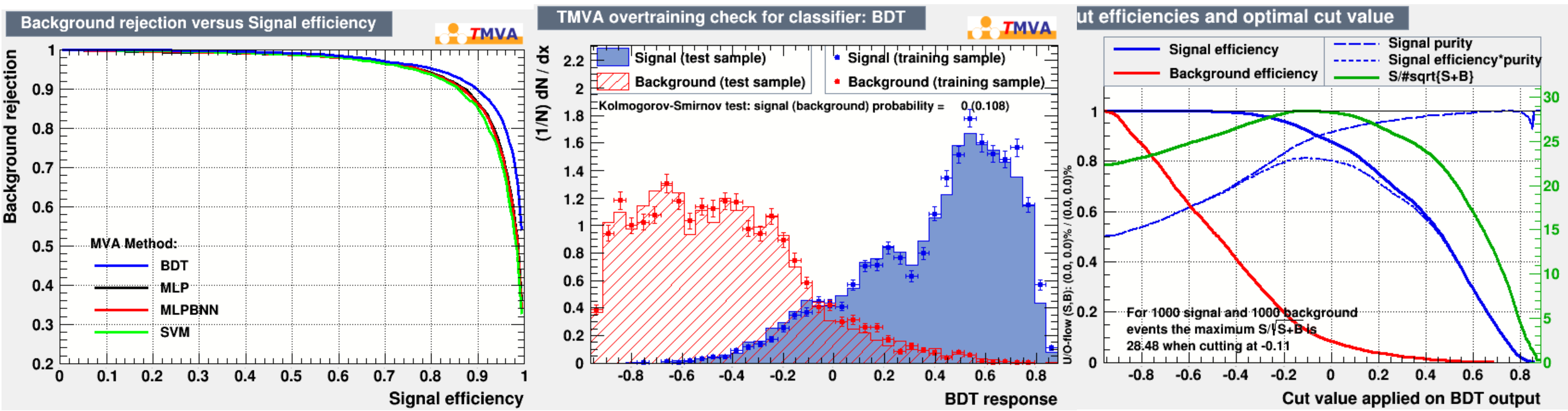
- J1J2 variables are replaced by the Jx Jy variables obtained by adaptive method





MVA with JxJy for **SM HH**

- Train with the variables from JxJy instead of J1J2

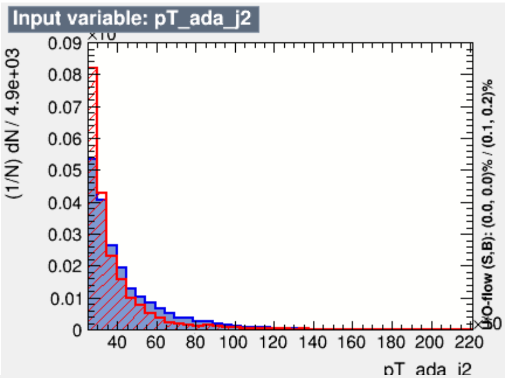


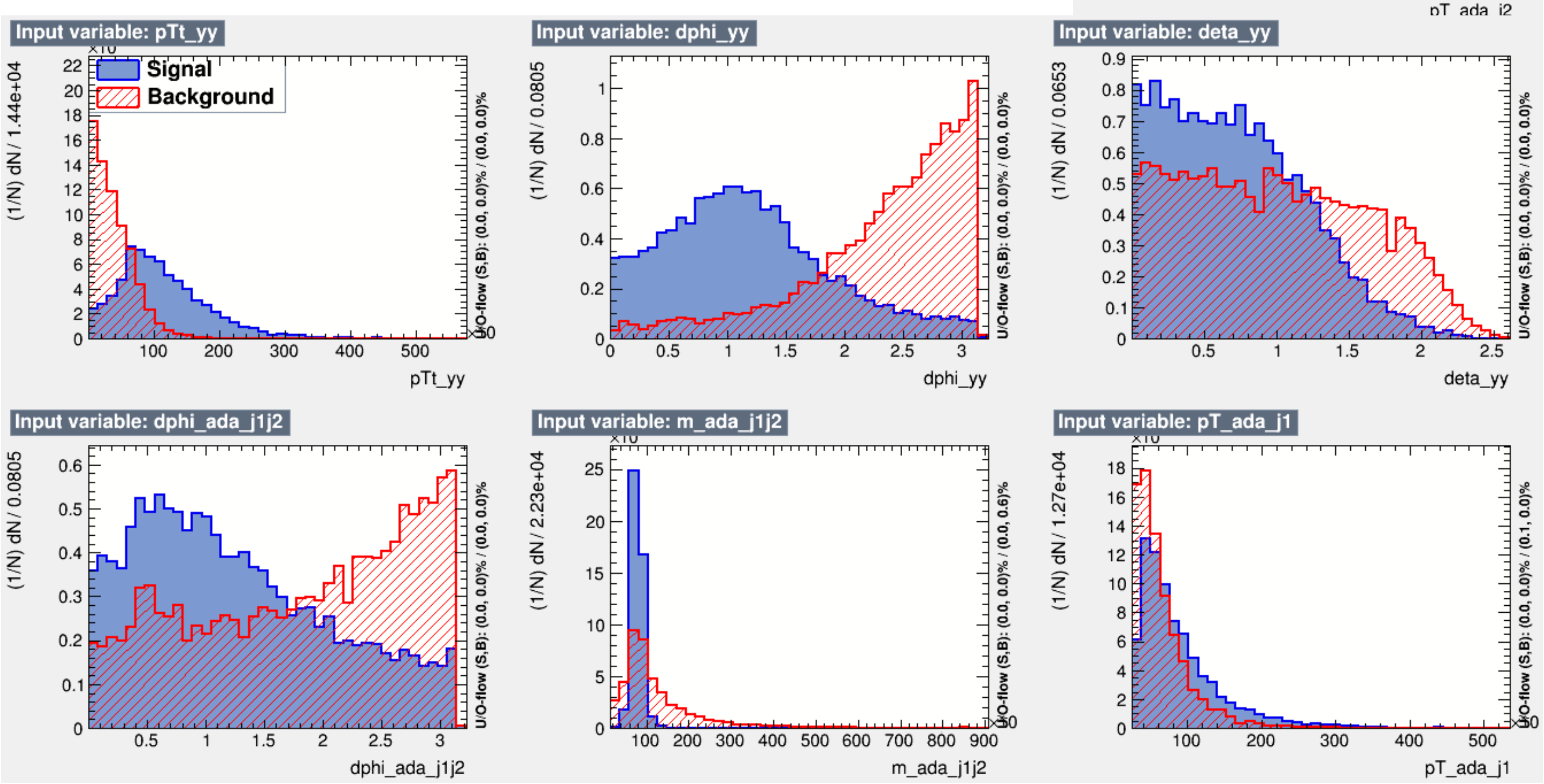
Classifier	(#signal,#backgr.)	Optimal-cut	S/sqrt(S+B)	NSig	NBkg	**EffSig**	**EffBkg**
MLP:	(1000, 1000)	0.4930	27.9795	895.2804	128.5757	0.8953	0.1286
MLPBNN:	(1000, 1000)	0.4863	27.9399	901.6102	139.717	0.9016	0.1397
SVM:	(1000, 1000)	0.4642	27.8195	893.3926	137.9103	0.8934	0.1379
BDT:	(1000, 1000)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

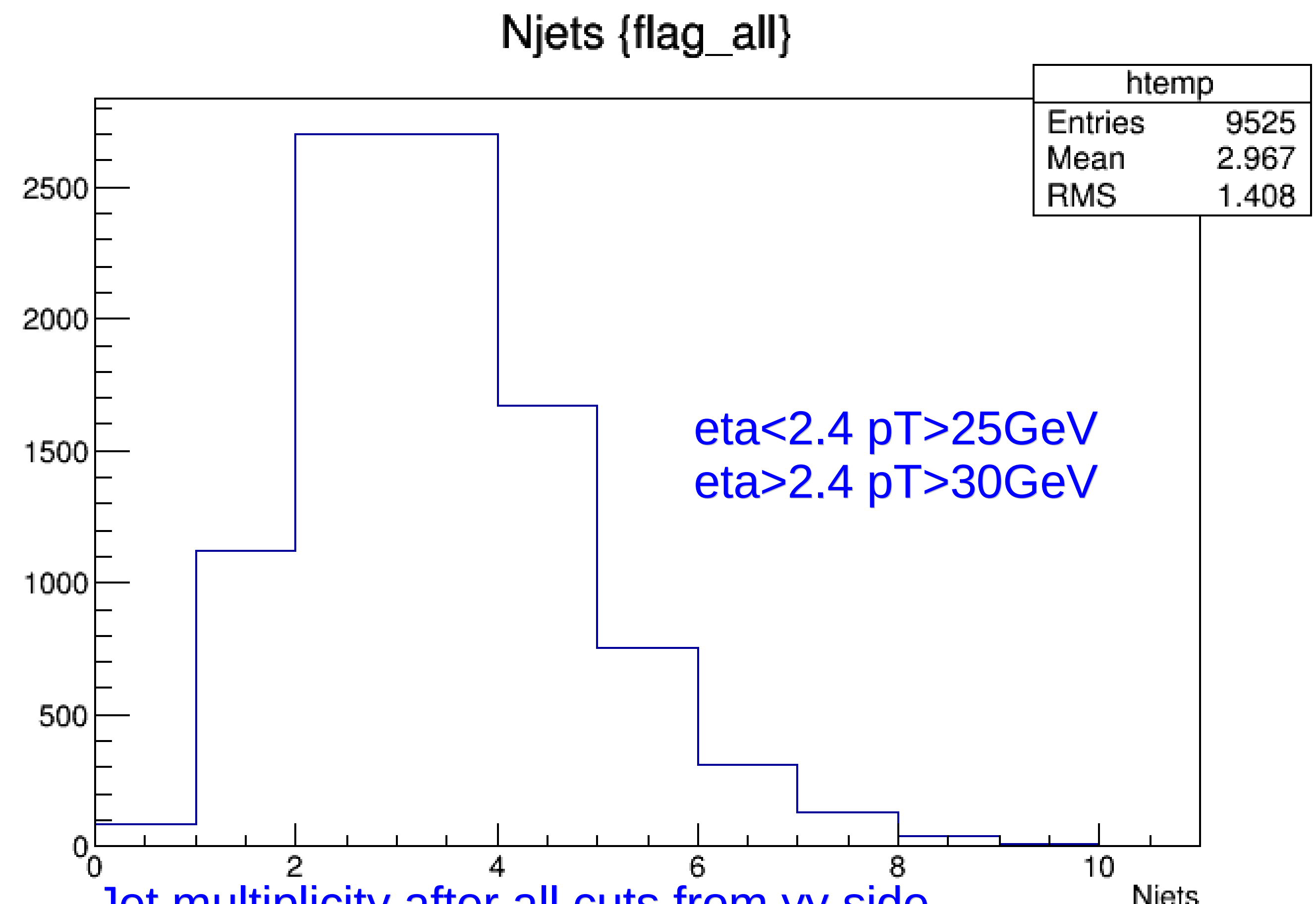
- J1J2 variables are replaced by the Jx Jy variables obtained by adaptive method





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

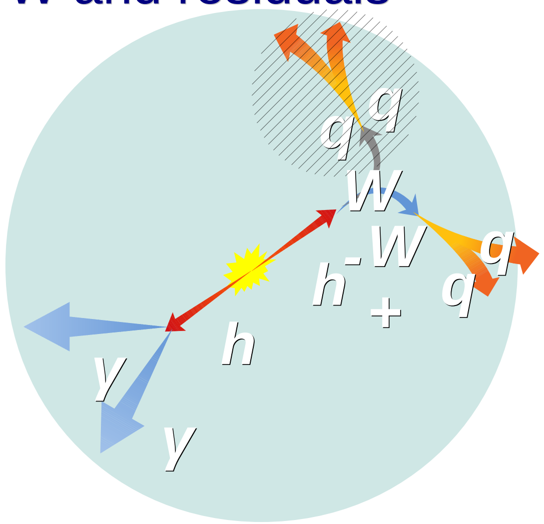
- Signal region:
  - mass(yy) is required by $|m_h - \Delta m_h - m_{\gamma\gamma}| < 2\sigma_{\gamma\gamma}$
  - where mh=125.6, deltamh=0.15, sigma=1.6

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

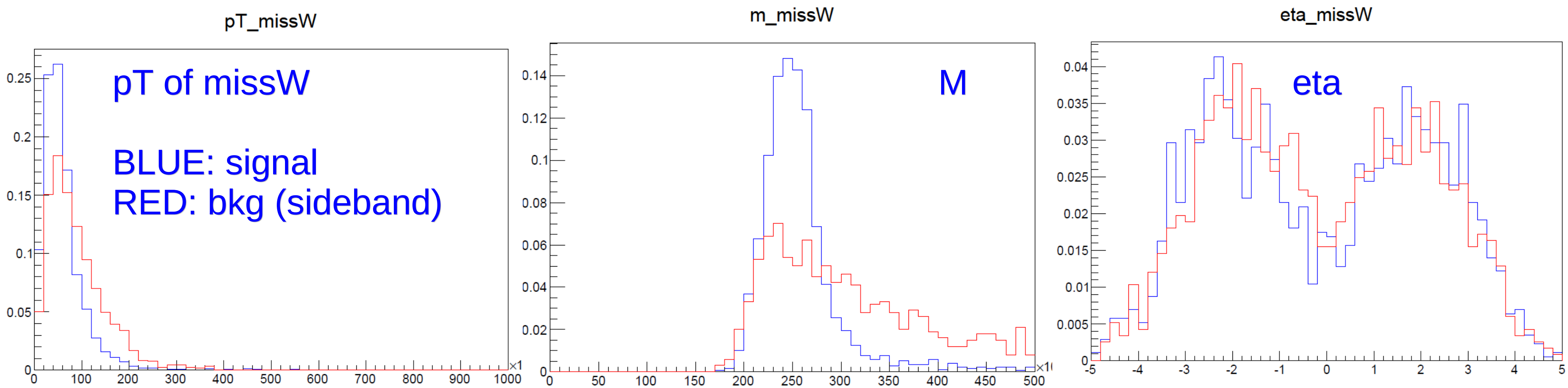
A new idea to try (from last pres)

- 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

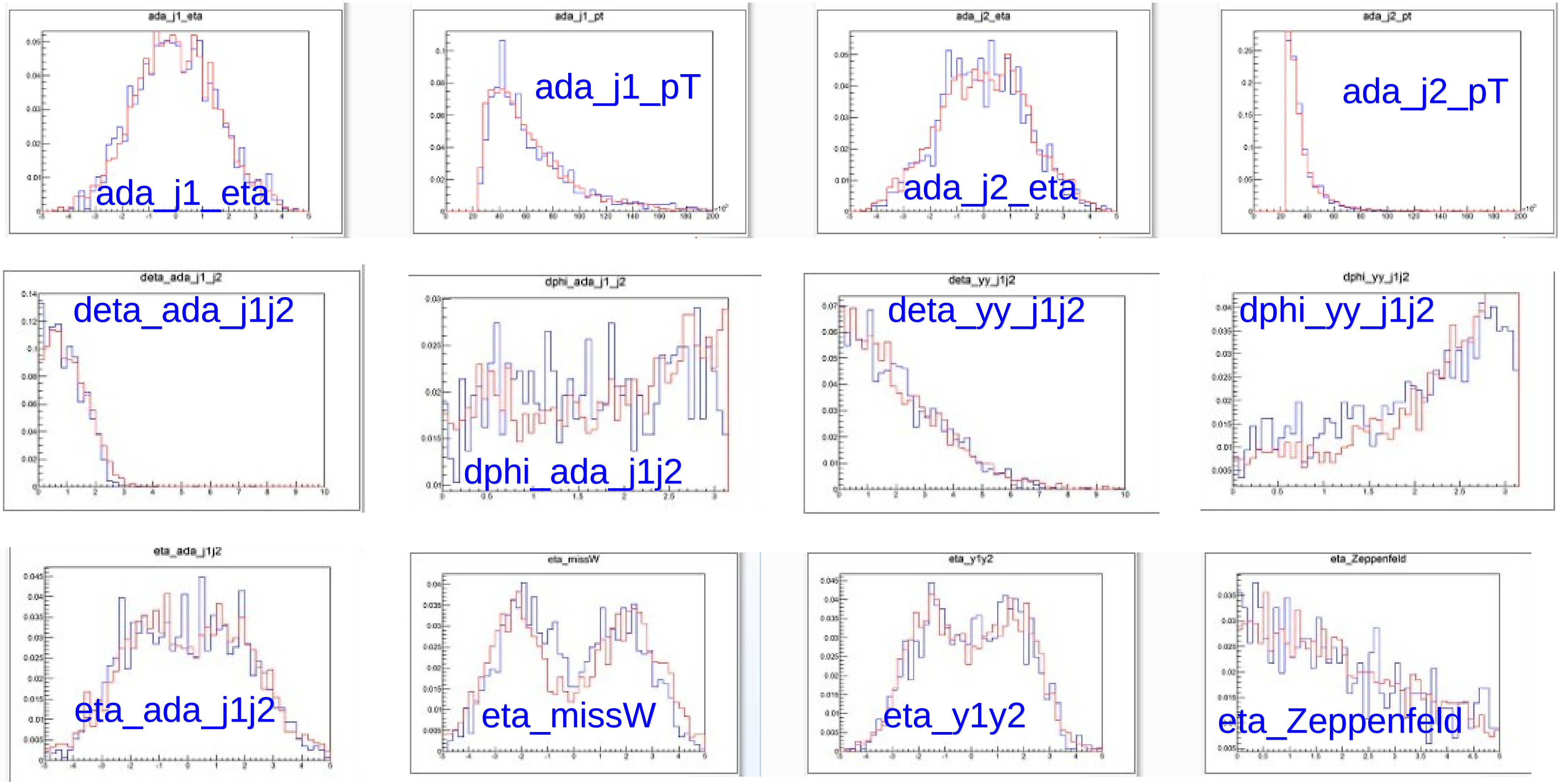


promising

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
- ε_{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

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 $H(\rightarrow \gamma\gamma)H(\rightarrow b\bar{b})$ 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