Updates on $h \to \mu^+\mu^-$ @ 500 GeV

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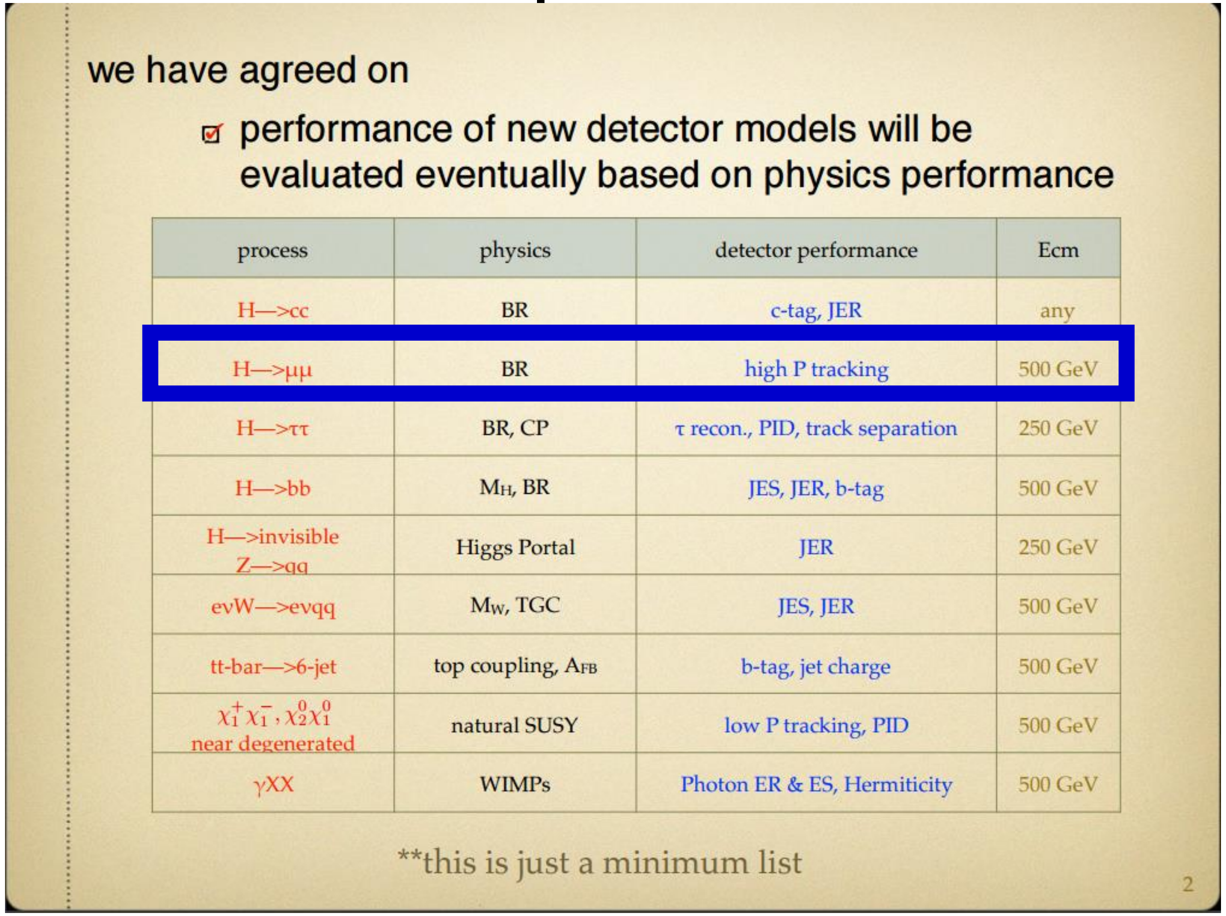
2017/January/11

ILD Analysis/Software Meeting

Quick Introduction

- $h \to \mu^+\mu^-$ @ 500 GeV is selected as the one of the physics benchmark process of ILD optimization.



we have agreed on

- performance of new detector models will be evaluated eventually based on physics performance

process	physics	detector performance	Ecm
H—>cc	BR	c-tag, JER	any
H—>μμ	BR	high P tracking	500 GeV
H—>ττ	BR, CP	τ recon., PID, track separation	250 GeV
H—>bb	M_H, BR	JES, JER, b-tag	500 GeV
H—>invisible Z—>qq	Higgs Portal	JER	250 GeV
evW—>evqq	M_W, TGC	JES, JER	500 GeV
tt-bar—>6-jet	top coupling, A_{FB}	b-tag, jet charge	500 GeV
$\chi_1^+\chi_1^-, \chi_2^0\chi_1^0$ near degenerated	natural SUSY	low P tracking, PID	500 GeV
γXX	WIMPs	Photon ER & ES, Hermiticity	500 GeV

**this is just a minimum list

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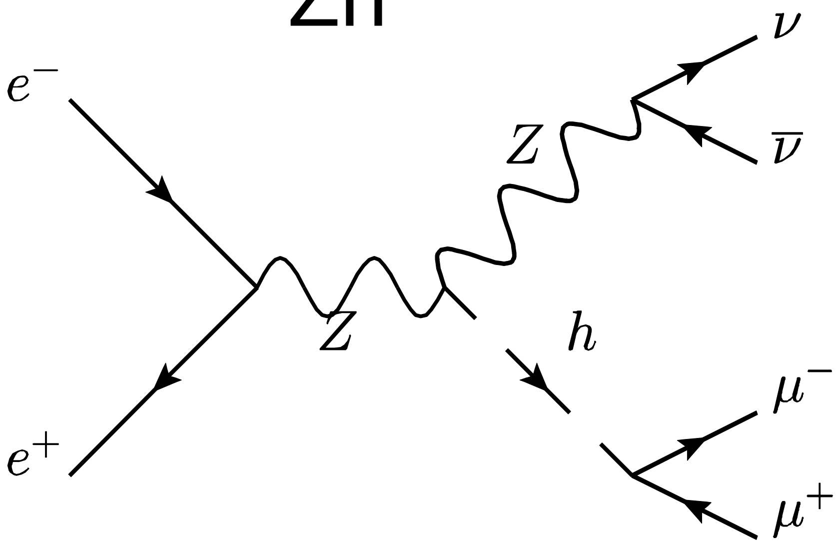
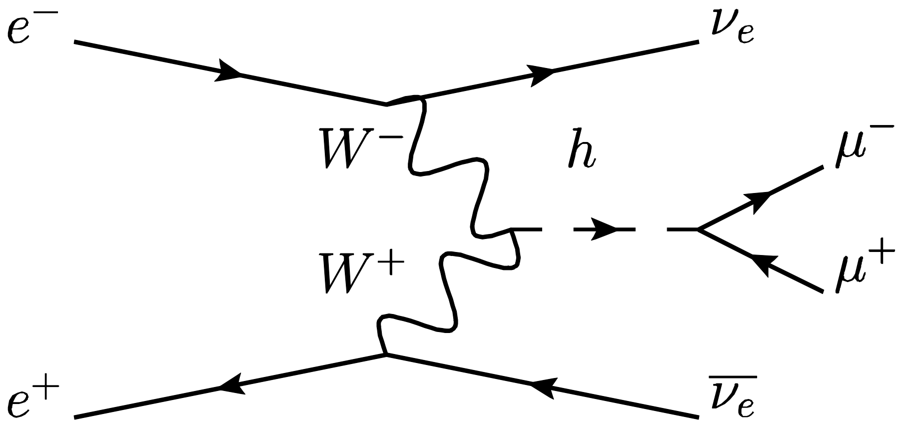
Signal

signal: $e^+e^- \to \nu\bar{\nu}h, h \to \mu^+\mu^-$

Zh



WW-fusion (WWF)



BR($h \to \mu^+\mu^-$) ~ **2.2*10^-4^**

expected # events: **~60**

with 1600 fb^{-1}, $P(e^-, e^+)$ = (-0.8, +0.3) (“H20” scenario)

Reminder

- Last talk in ILD @ Higgs/EW Meeting (Aug./31)
  - Fully-simulated samples with DBD configuration (some of them are SGV)
  - Cut-based analysis
  - Precision $\frac{\Delta(\sigma\times\mathrm{BR})}{(\sigma\times\mathrm{BR})}$ ~60%
    - Relatively 50% worse than extrapolation

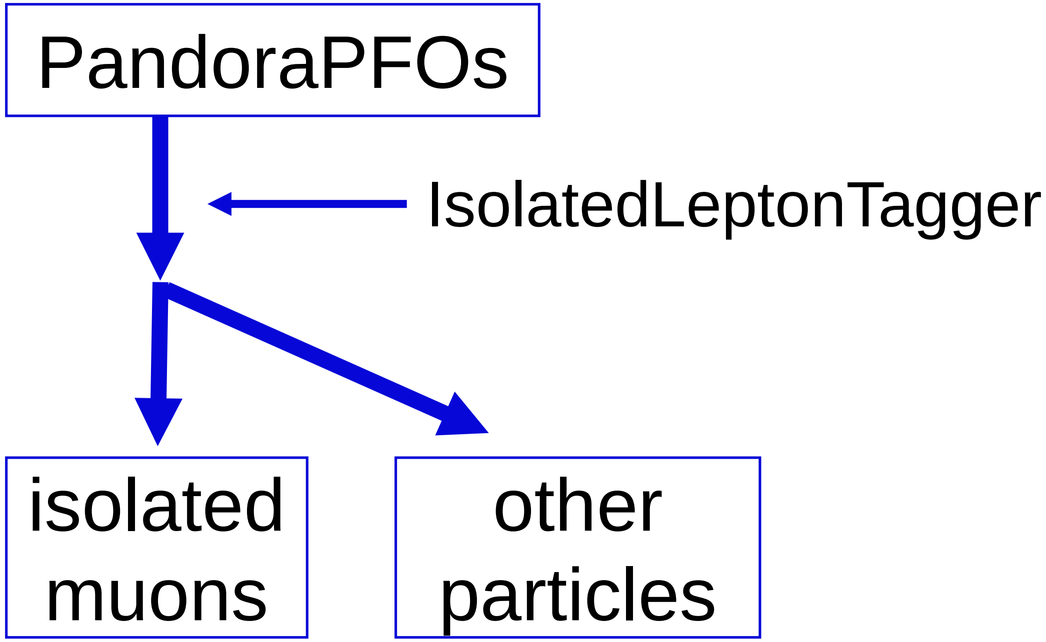
Progress

- IsolatedLeptonTagger
- More efficient cuts
- Separation between Zh and WWF
- Some try & error with TMVA(BDTG)

IsolatedLeptonTagger

- Originally developed under Higgs self-coupling study
- Use these values to tag leptons
  - $E_{ECAL}/(E_{ECAL}+E_{HCAL})$ (only for electrons)
  - $(E_{ECAL}+E_{HCAL})/|p|$
  - $|p|$
  - E_{yoke}
  - $|d_0/\sigma(d_0)|, |z_0/\sigma(z_0)|$
  - MVA cut for isolation
- Currently I did not include SGV samples due to E_{yoke}

Reconstruction Flow



※ isolated electrons are included in “other particles”

Reconstruction efficiency in signal

$$\equiv \frac{\#\ \text{events correctly reconstruct}\ 1\mu^{+}1\mu^{-}}{\#\ \text{events}}$$

= 94.9%

Purity in signal = 100%

Cuts

Exactly one μ^+ and one μ^-

(1) Select well-measured muon/muon pair

- χ^2/Ndf < 1.5
- Radius of innermost hit < 20 mm
- $\sigma(M_{\mu\mu})$ < 1 GeV

(2) Select signal-like events

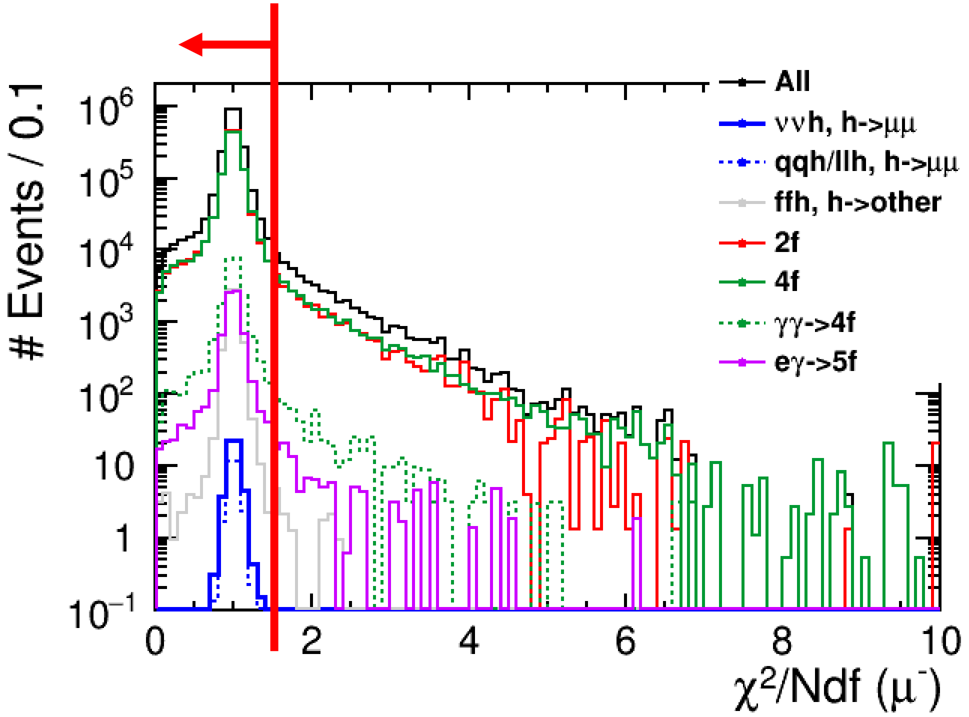
- $N_{P_t > 5\ \mathrm{GeV}} \leq 1$
- 125 < E_{vis} < 400 GeV
- 100 < $M_{\mu\mu}$ < 130 GeV

(3) Reject some backgrounds

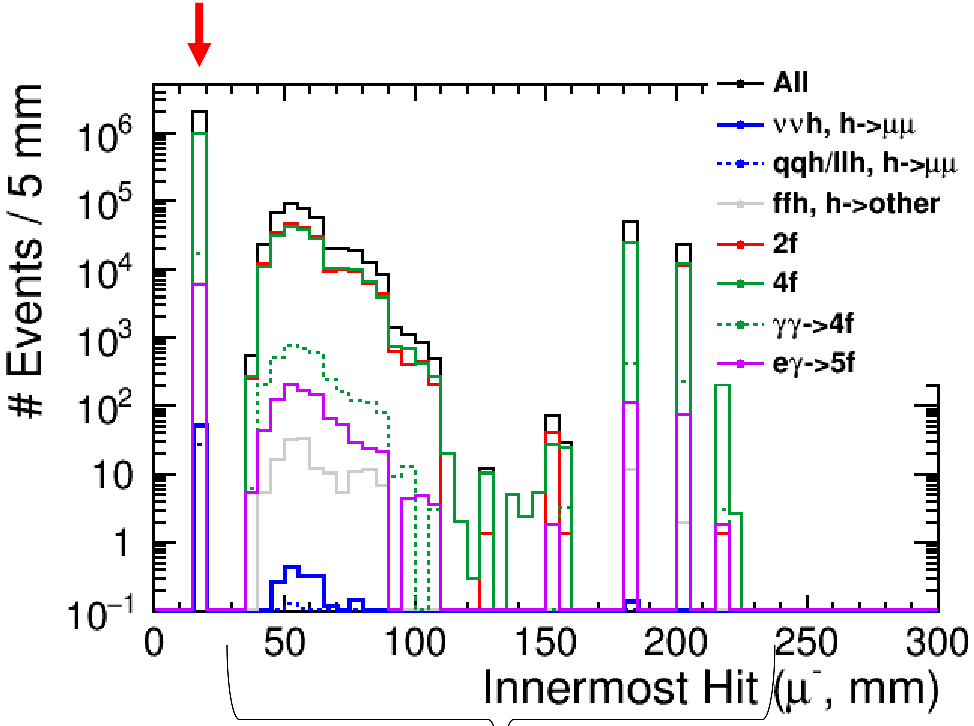
- $\cos\theta_{\mu\mu}$ < 0.55
- $|\cos\theta_{\mathrm{miss}}|$ < 0.999
- P_t > 5 GeV

Select Well-measured Muons

χ^2/Ndf
(track fitting parameter)

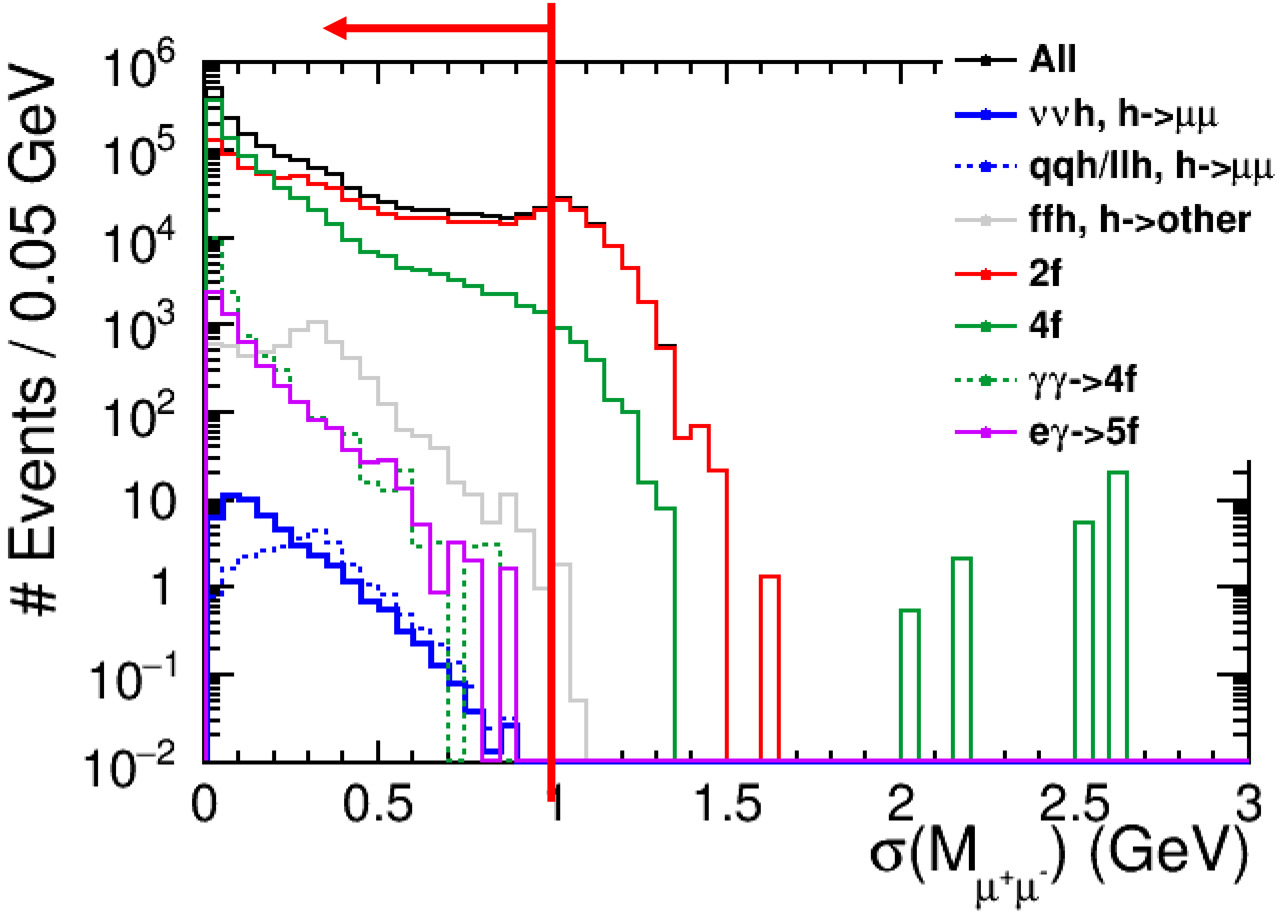


Radius of innermost hit
(first hit of track in detector)



flight forward region
sacrifice ~10% signal

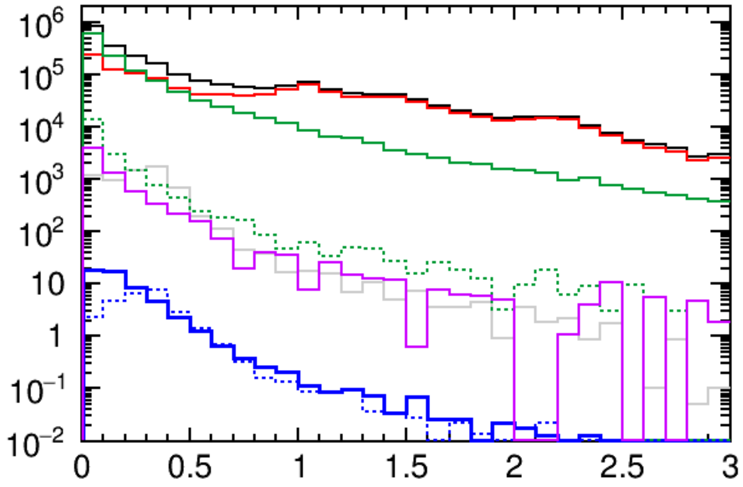
Select Well-measured Muons



$\sigma(M_{\mu\mu})$ (measured error of muon pair mass)

requiring small innermost hit reduces the mass error

cf. no requirements in innermost hit

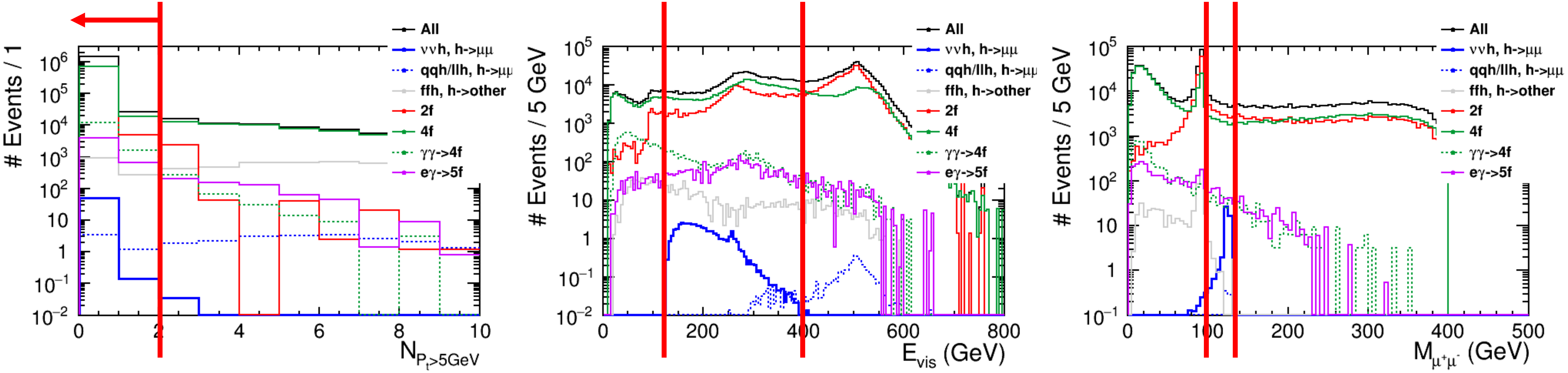


Select Signal-like Events

$N_{P_t > 5\ \mathrm{GeV}}$
(# charged particles with P_t > 5 GeV in "other particles")

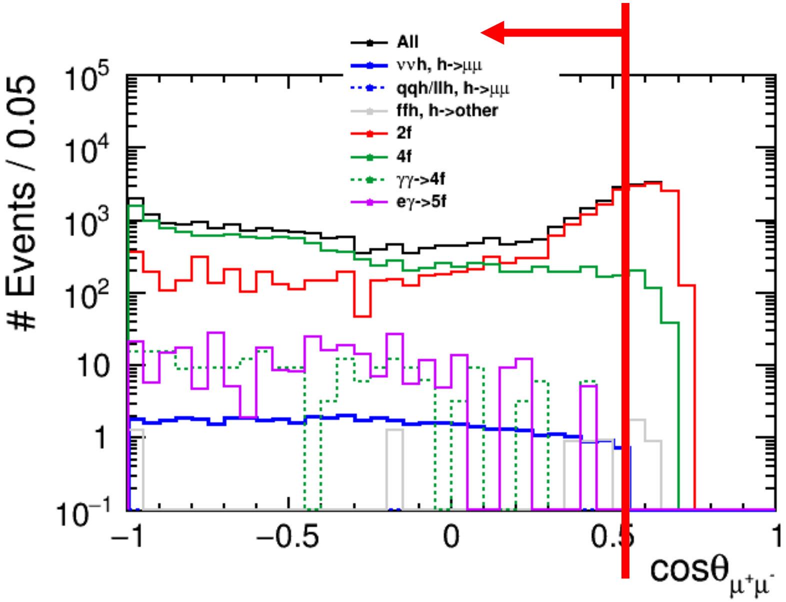
E_{vis}
(visible energy)

$M_{\mu\mu}$

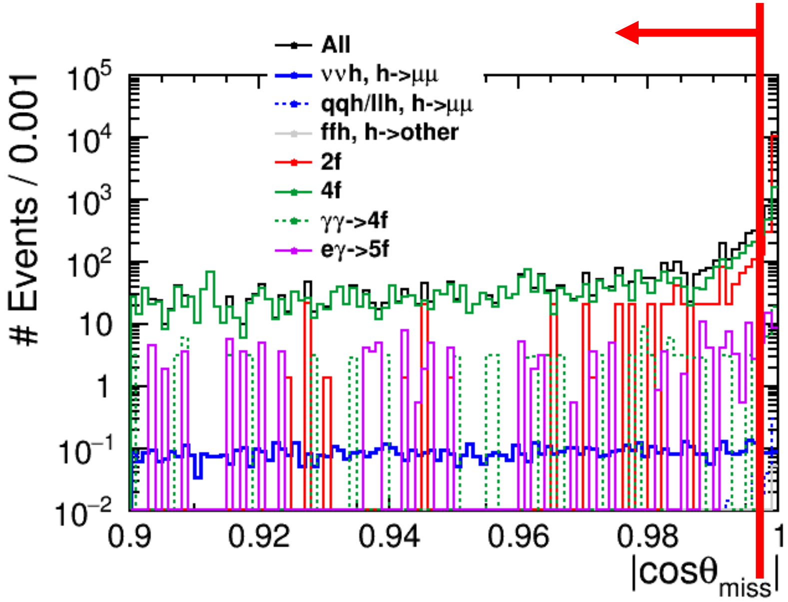


Reject Some Backgrounds

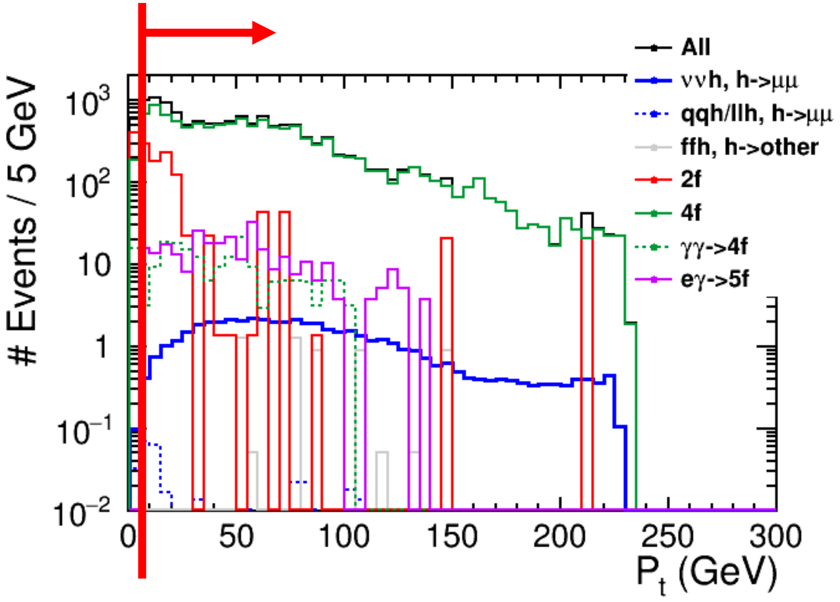
$\cos\theta_{\mu\mu}$



$|\cos\theta_{miss}|$
(missing angle)



P_t



mostly for rejecting 2f processes which is reducible

Cut Table at Precuts

	$\nu\nu h$ $h \to \mu\mu$	$qqh{+}\ell\ell h$ $h \to \mu\mu$	ffh $h \to$ other	2f	4f	$\gamma\gamma \to$ 4f	5f
No cut	57.53	31.13	4.116×10^5	4.224×10^7	4.592×10^7	3.356×10^5	2.209×10^5
$\# \mu^\pm$	54.82	27.72	6553.83	1.314×10^6	1.262×10^6	2.216×10^4	7206.44
χ^2/Ndf	54.51	27.59	6525.51	1.261×10^6	1.208×10^6	2.107×10^4	6978.30
Innermost	50.26	26.18	6194.38	8.042×10^5	8.045×10^5	1.393×10^4	5185.97
$\sigma(M_{\mu\mu})$	50.25	26.18	6192.51	7.287×10^5	8.022×10^5	1.393×10^4	5185.97
$N_{P_t > 5\mathrm{GeV}}$	50.22	4.64	1208.32	7.262×10^5	7.432×10^5	1.354×10^4	4567.99
E_{vis}	50.16	0.72	551.95	2.549×10^5	4.244×10^5	5379.29	3343.95
$M_{\mu\mu}$	48.65	0.72	8.06	2.076×10^4	1.361×10^4	217.37	304.69
$\cos\theta_{\mu\mu}$	48.64	0.72	5.40	1.198×10^4	1.325×10^4	217.37	304.69
$\cos\theta_{\mathrm{miss}}$	48.55	0.42	5.35	1418.20	1.167×10^4	198.64	295.95
P_t	48.45	0.39	5.35	1010.82	1.149×10^4	183.07	295.95
# MC	14491	1187	8	79	4910	59	93

signal efficiency = 84.2%
backgrounds suppressed ~3 order of magnitude

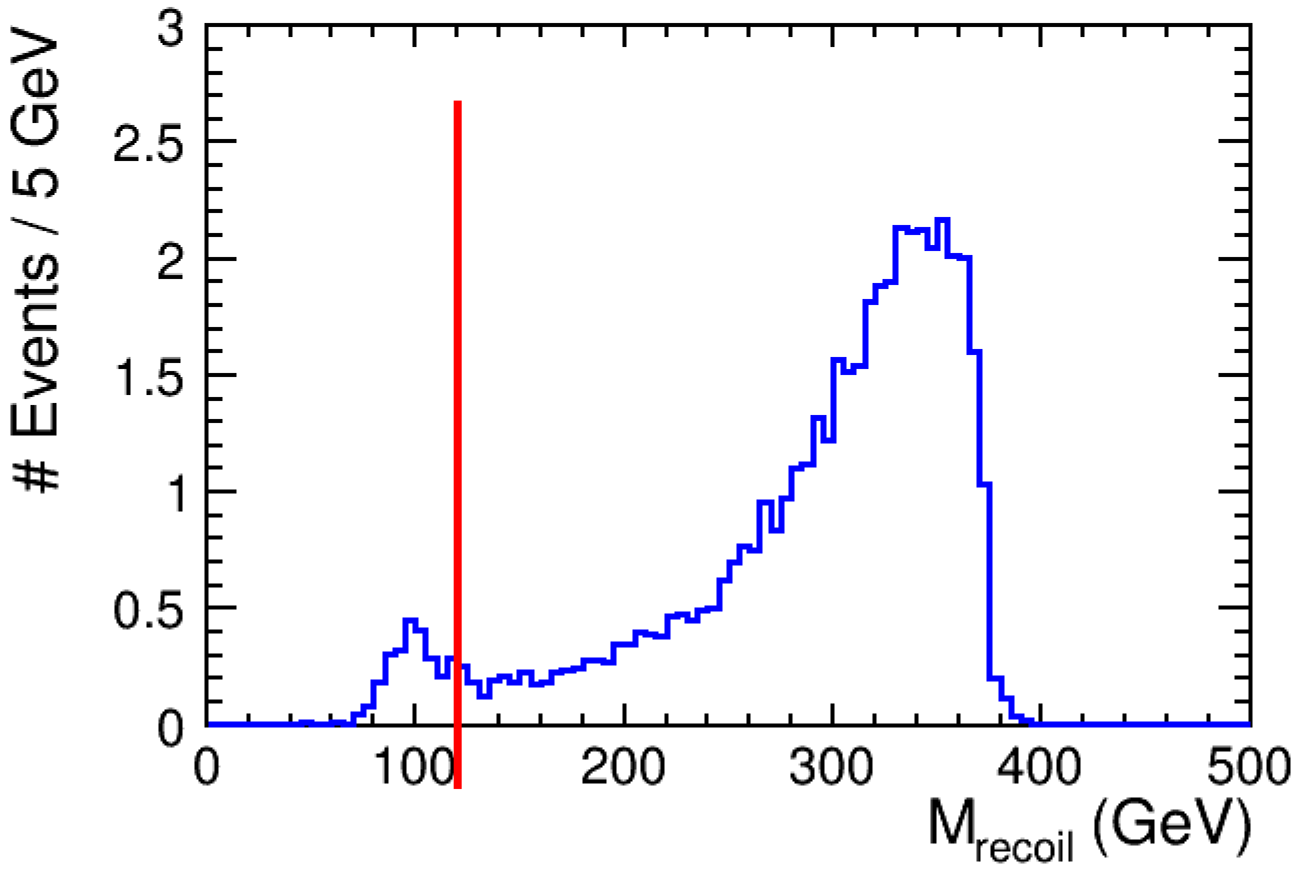
Remained Backgrounds

2f		
$\mu\mu$	875.21	86.6%
$\tau\tau$	135.61	13.4%

$\gamma\gamma \rightarrow$ 4f		
4μ	3.17	1.7%
$2\nu2\mu$	173.60	94.8%
$2\nu1\mu1\tau$	6.30	3.4%

4f		
$2q2\mu$	41.45	0.36%
$2e2\mu$	1553.93	13.5%
$2\mu2\tau$	40.13	0.35%
$2q1\nu1\mu$	40.25	0.35%
$2q1\nu1\tau$	20.13	0.18%
$2\nu2\mu$	8235.94	71.7%
$2\nu2\tau$	44.16	0.38%
$2\nu1\mu1\tau$	1510.71	13.2%

Separation of Zh and WWF



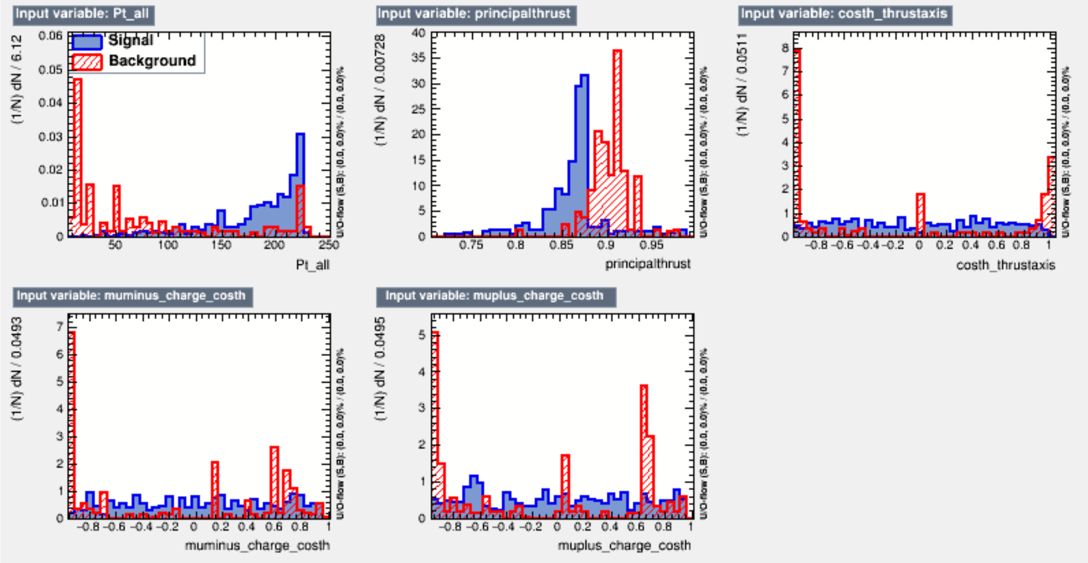
I used recoil mass (corresponds to Z mass) peak around Z mass shifted higher due to FSR

I defined cut at 120 GeV
Zh: < 120 GeV (2.65)
WWF: > 120 GeV (45.80)

Try & Error with TMVA(BDTG)

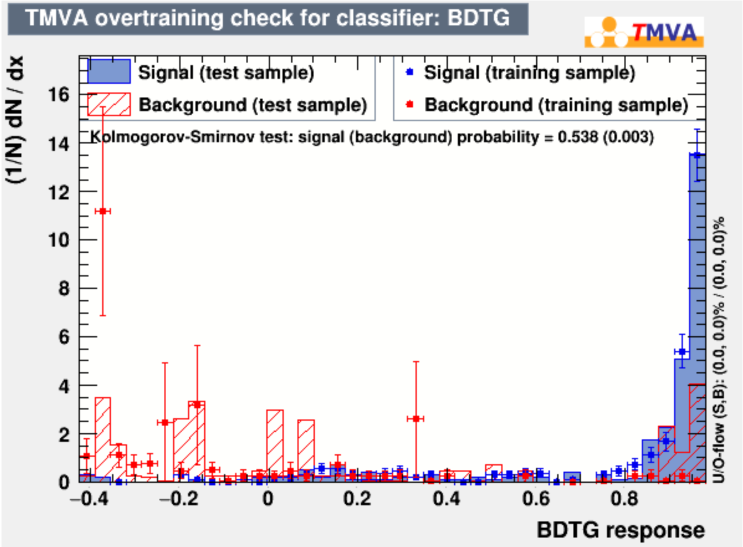
- Usually gives better results than cut-based
  - Half of MC are used for training and other for testing
  - Low MC stat...
- Mostly determined only by $M_{\mu\mu}$, I tried without and with $M_{\mu\mu}$
- Zh and WWF separately

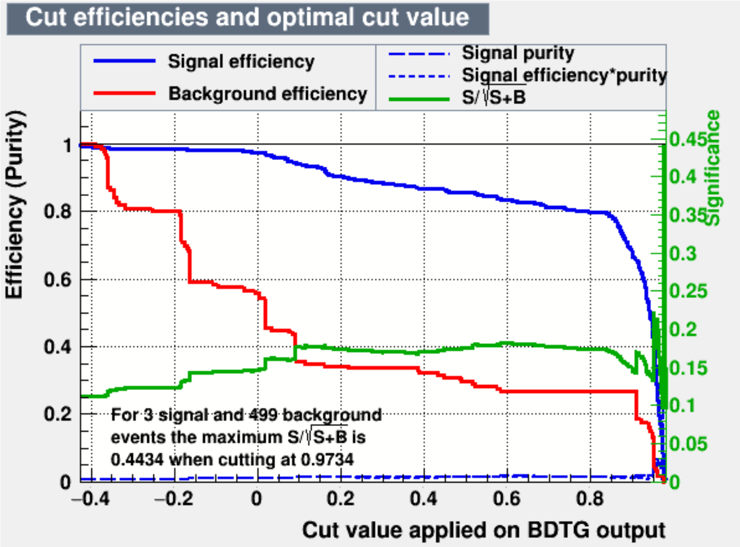
Zh without $M_{\mu\mu}$



5 Inputs:

E_{vis}, thrust, $\cos\theta_{thrust}$, charge * $\cos\theta_{\mu^\pm}$





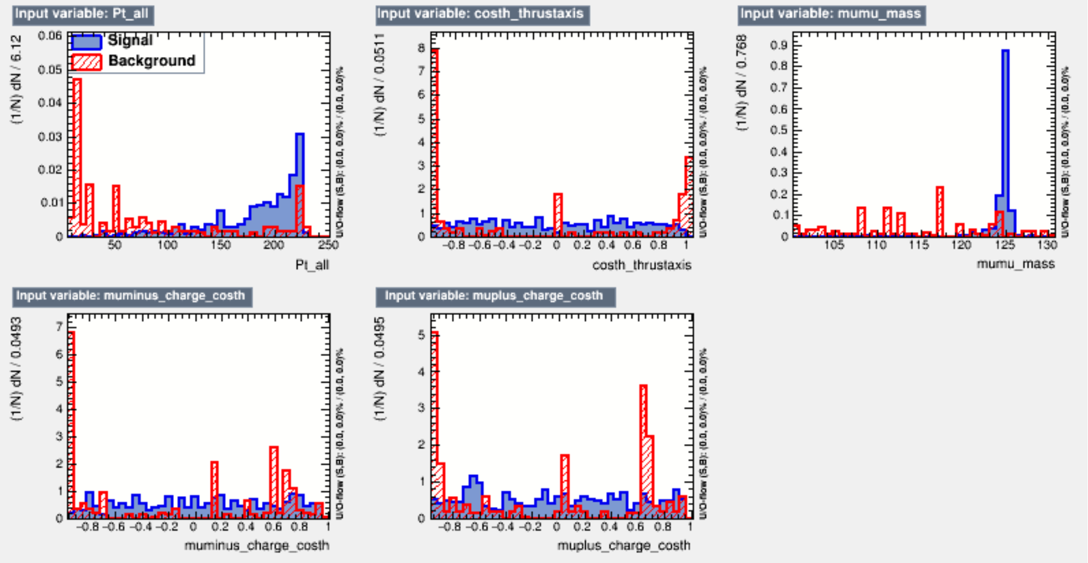
$N_{sig} = 0.20$

$N_{bkg} = 0$

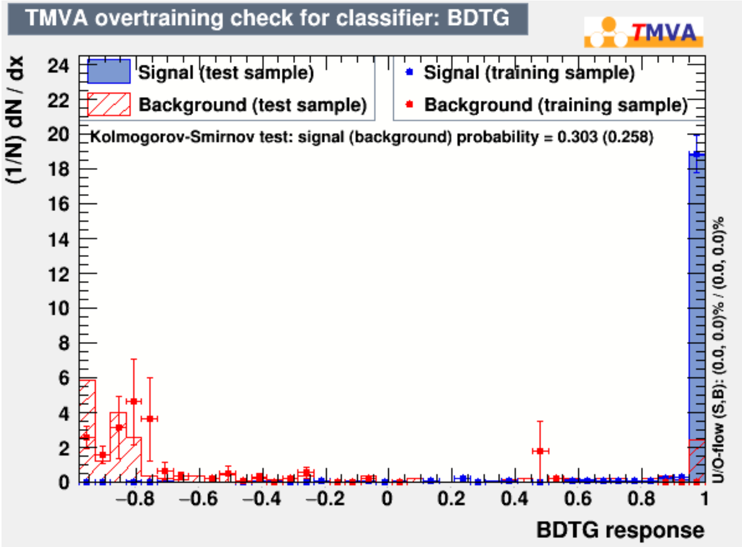
$\frac{S}{\sqrt{S+B}} = 0.4$

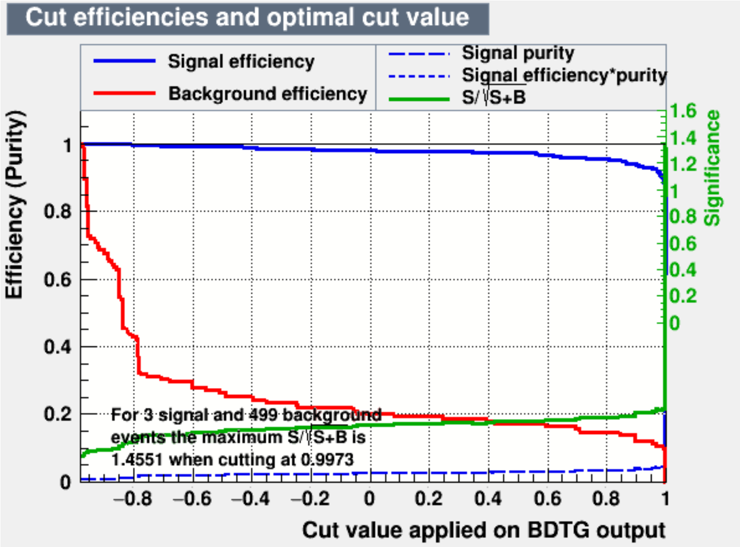
precision > 200%

Zh with $M_{\mu\mu}$



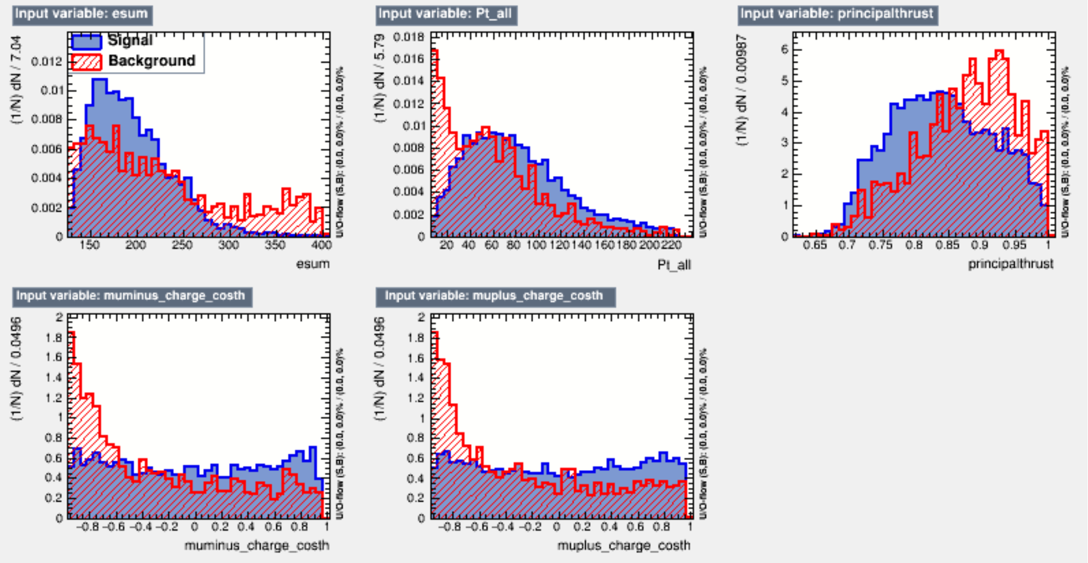
5 Inputs:
P_t, $\cos\theta_{\mathrm{thrust}}$,
$M_{\mu\mu}$, charge * $\cos\theta_{\mu^\pm}$



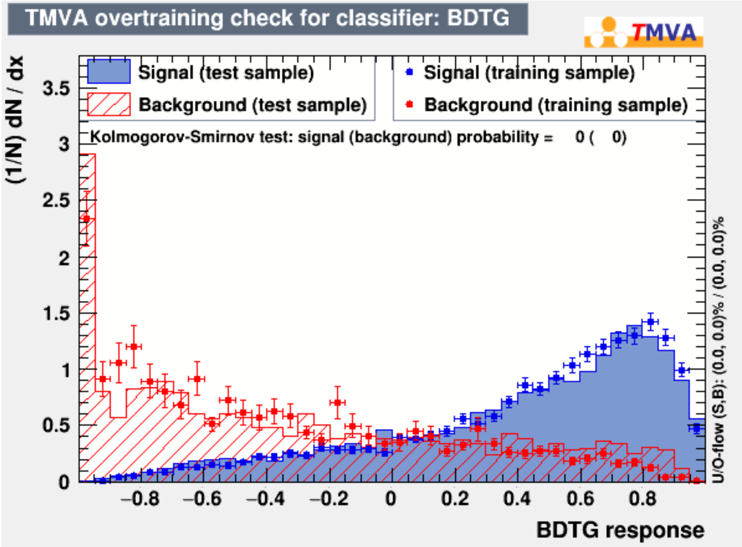


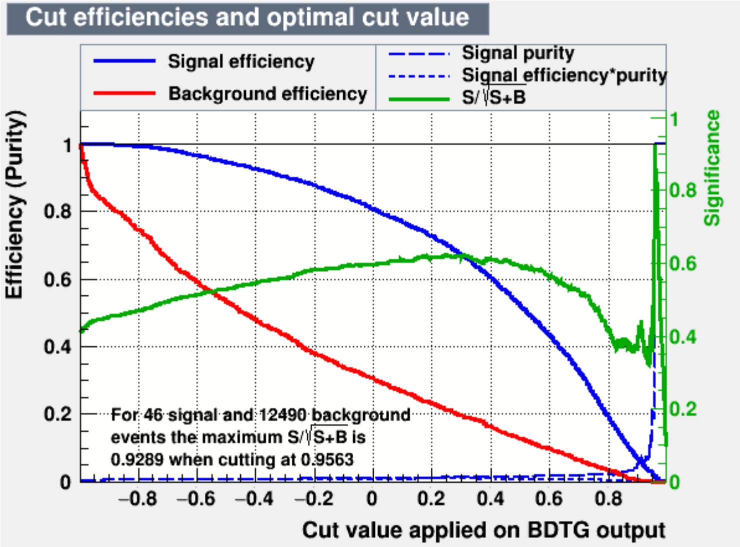
$N_{sig} = 2.19$
$N_{bkg} = 0.07$
$\frac{S}{\sqrt{S+B}} = 1.5$
precision = 69%

WWF without $M_{\mu\mu}$



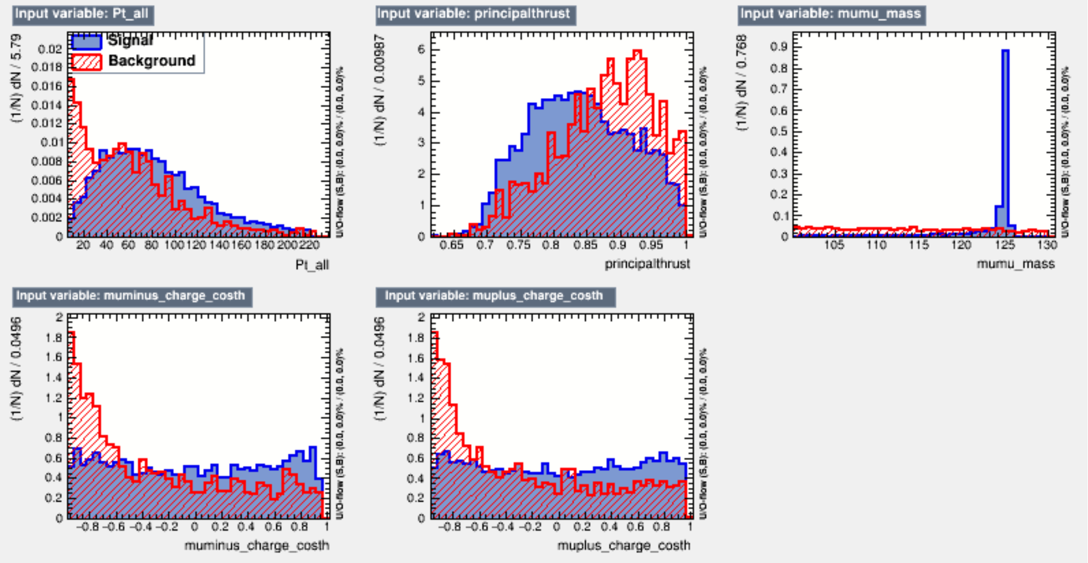
5 Inputs:
E_{vis}, P_t, thrust,
charge * $\cos\theta_{\mu^\pm}$





$N_{sig} = 0.86$
$N_{bkg} = 0$
$\frac{S}{\sqrt{S+B}} = 0.9$
precision = 108%

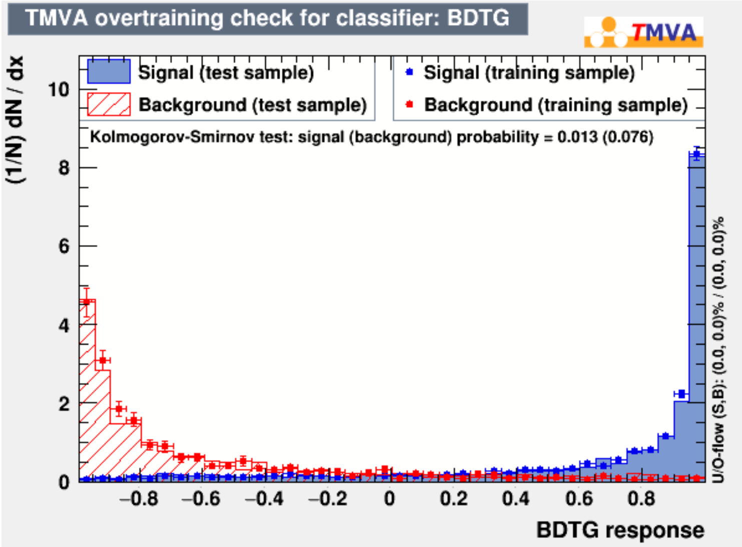
WWF with $M_{\mu\mu}$

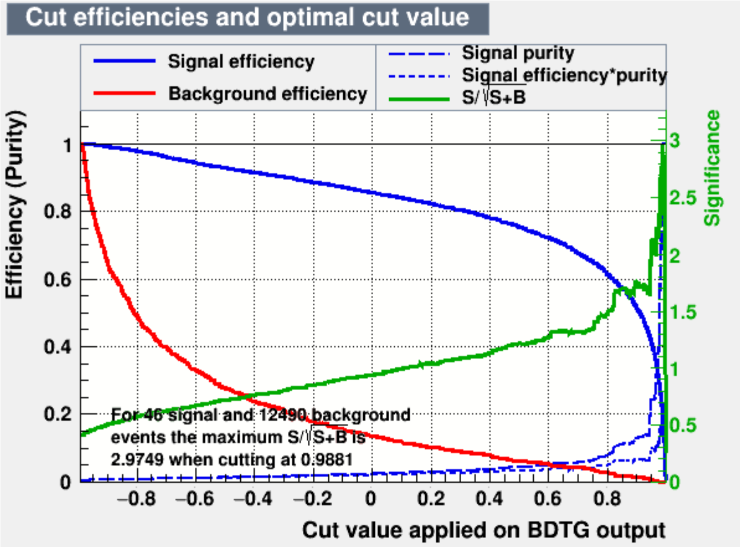


5 Inputs:

P_t, thrust,

$M_{\mu\mu}$, charge * $\cos\theta_{\mu^\pm}$





$N_{sig} = 8.86$

$N_{bkg} = 0.01$

$$\frac{S}{\sqrt{S+B}} = 3.0$$

precision = 34%

Summary

Significant progress in this analysis using new tools

	Zh	WWF
without $M_{\mu\mu}$	> 200%	108%
with $M_{\mu\mu}$	69%	34%

- better than extrapolation
- MC stat., overtraining...
- separation doesn't help for improvement???

Plans:

Study without separation

FSR study, re-weighting, search better way/variables...