Status of $h \to \mu^+\mu^-$ analysis

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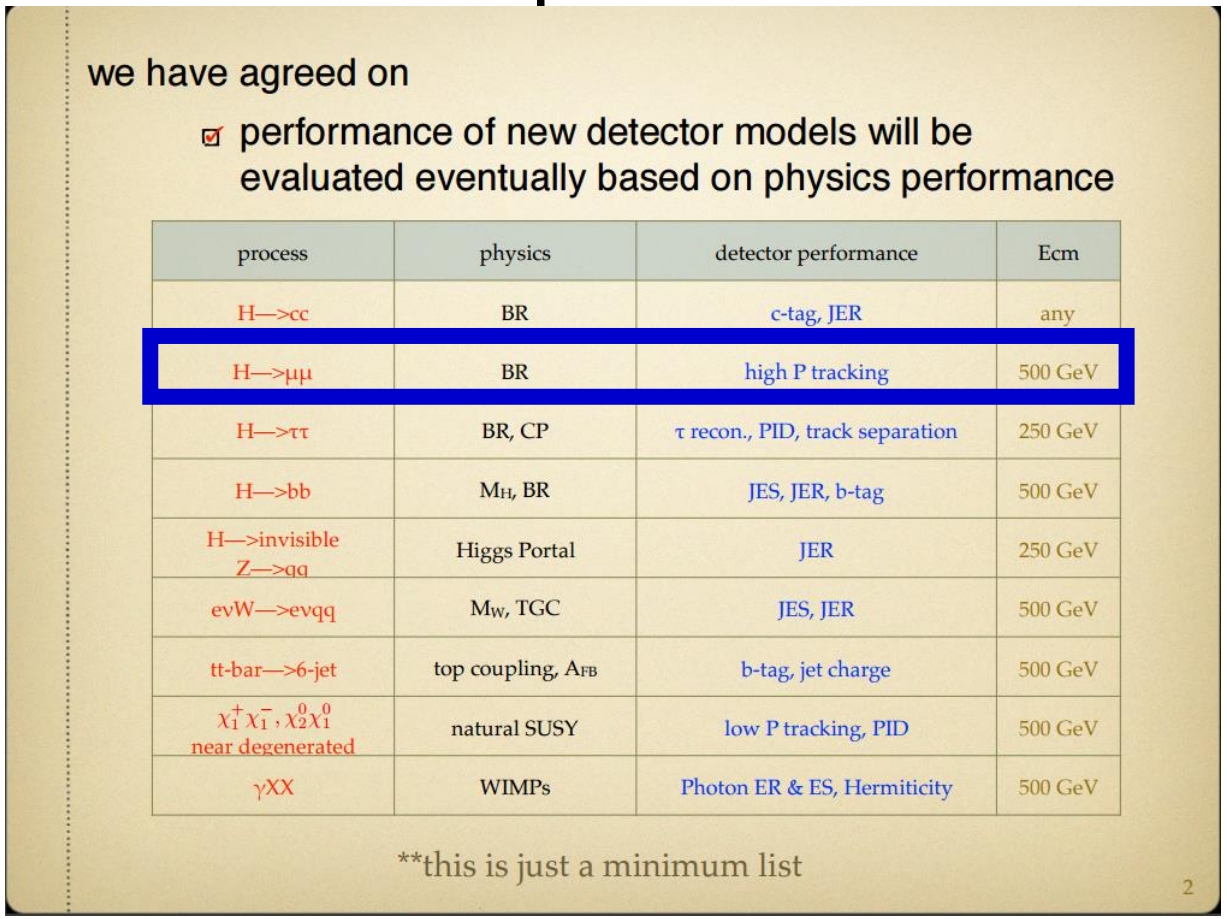
ILD Software/Analysis Meeting

I am sorry for interrupting Top/QCD 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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What I Talked in Lyon

- Result of nnh500-L (left-handed) analysis
- Some plots for impact of momentum resolution
- Slide is: https://agenda.linearcollider.org/event/7520/contributions/38901/attachments/31491/47426/SK_2017Apr25.pdf

Progress After Lyon

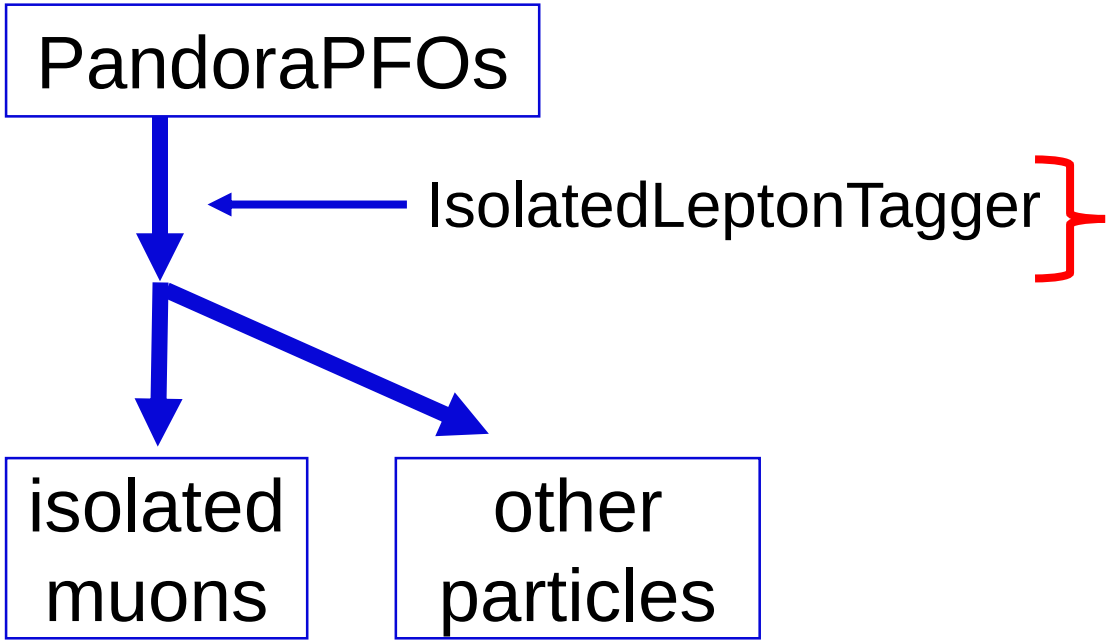
- Analysis of other channels
  - nnh500-L, nnh500-R (right-handed)
  - qqh500-L, qqh500-R: new study, first study with real analysis
  - MC samples increased a bit
  - I found a mistake in nnh500-L analysis ---> fixed and re-analyzed

- Personal analysis note is available: http://desy.de/~skawada/MyAnalysisNote/Analysis06_EN.pdf
  - Don’t ask the quality of English, this is not a peer-reviewed paper!
  - JP ver. is also available.

Analysis Settings

- Fully-simulated MC samples at 500 GeV
  - DBD configurations
  - signal: ffh_mumu (analyzed nnh-L/R and qqh-L/R)
  - background: 2f, 4f, 5f, aa_4f, higgs_ffh
  - ~~(As of 2016/Aug./2)~~ (As of end of the year 2016)
    - 4f_ZZ_leptonic, 4f_singleW_leptonic, aa_4f(eevv, llvv) are increased (ELOG ID up to No. 30)

nnh500-L/R Analysis Flow



※ isolated electrons are included in “other particles”

I accidentally set wrong value for MVA cut in electron in previous.

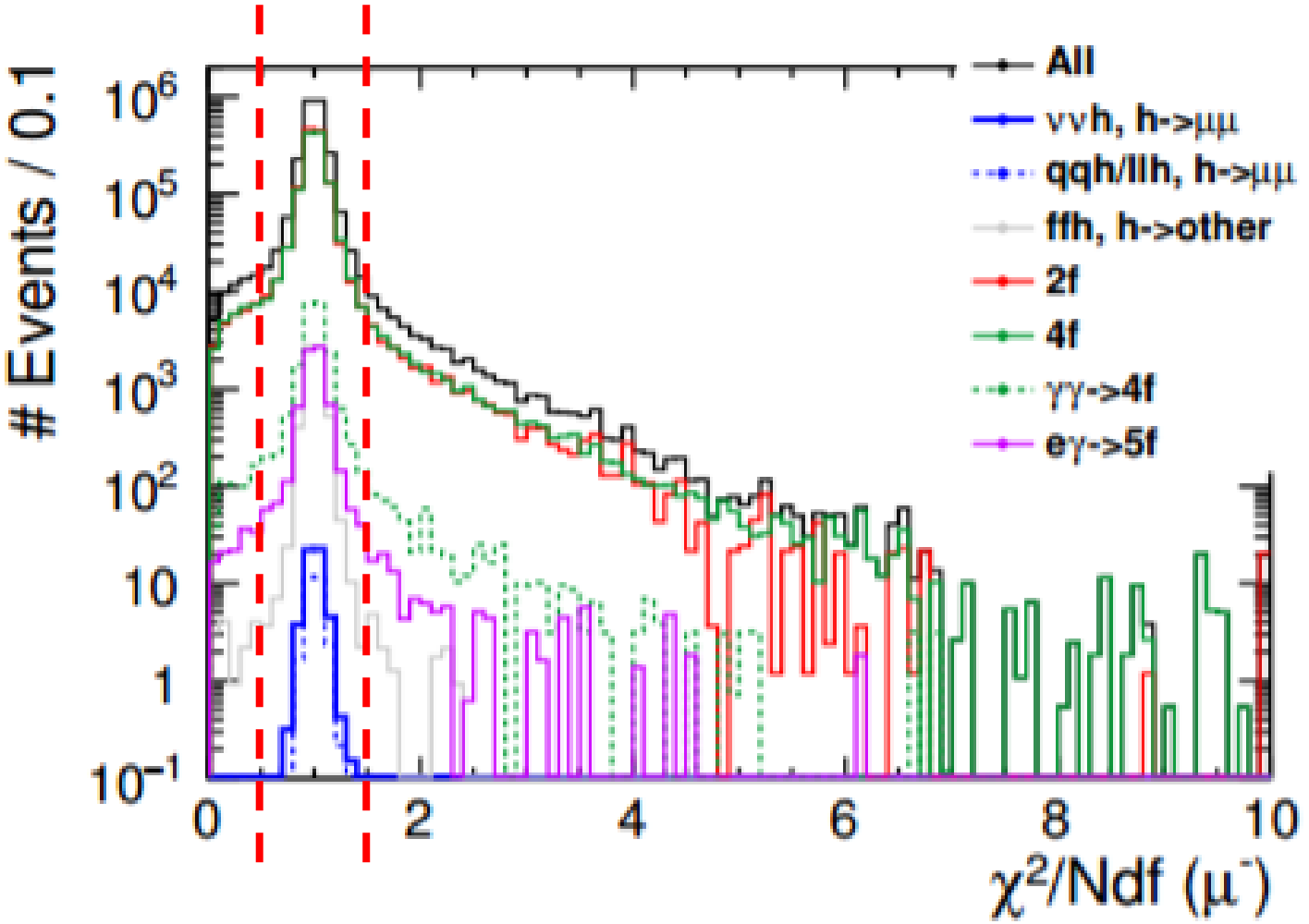
---> isolated electrons were included in “isolated muons” category.

---> now fixed, did similar analysis for nnh500-L

---> first real analysis on nnh500-R

Precuts

- exactly one μ^+ and one μ^-
- $0.5 < \chi^2/\mathrm{Ndf}(\mu^\pm) < 1.5$
- $\sigma(M_{\mu\mu}) < 1$ GeV
- $100 < M_{\mu\mu} < 130$ GeV
- $\cos\theta_{\mu\mu} < 0.55$
- $N_{P_t>5\mathrm{GeV}} \leq 1$
- $125 < E_{\mathrm{vis}} < 320$ GeV
- $P_t > 5$ GeV
- $|\cos\theta_{\mathrm{miss}}| < 0.99$

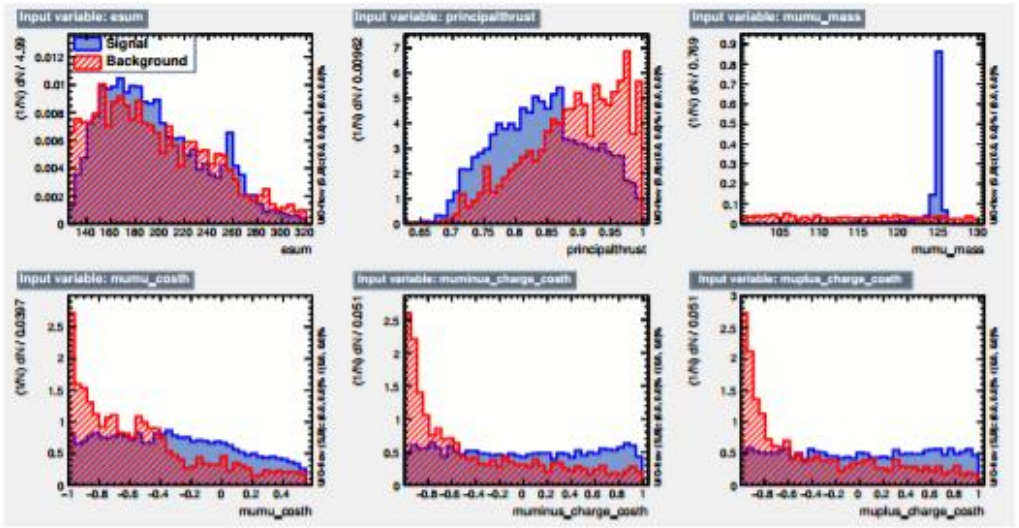


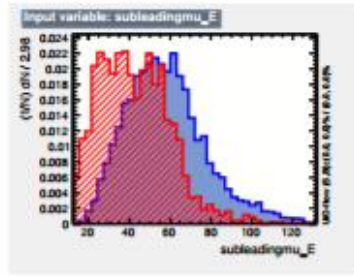
nnh500-L Precuts Cut Table

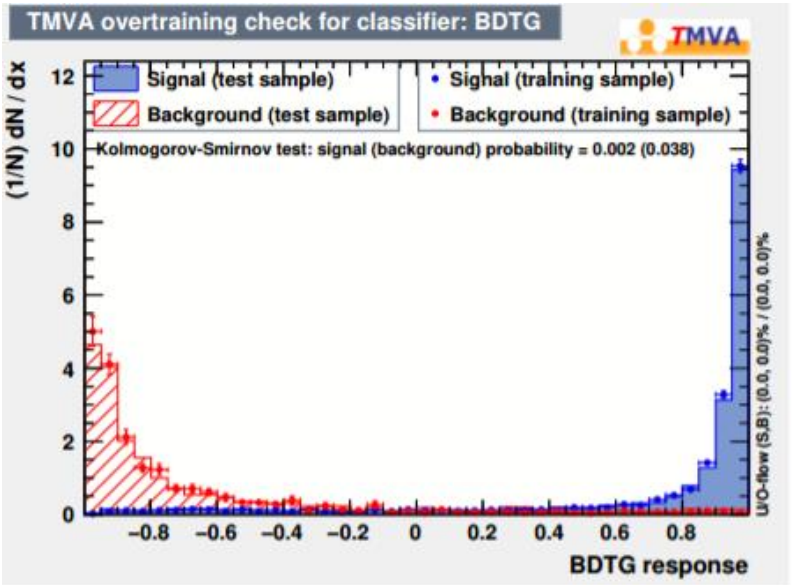
	$\nu\nu h$ $h \to \mu\mu$	$qqh+\ell\ell h$ $h \to \mu\mu$	ffh $h \to$ other	2f	4f	$\gamma\gamma \to$ 4f	5f
No cut	57.53	31.13	4.116×10^5	4.224×10^7	4.592×10^7	3.356×10^5	2.231×10^5
# $\mu^{\pm}$	54.82	27.72	6553.83	1.314×10^6	1.262×10^6	2.227×10^4	7206.44
χ^2/Ndf	54.21	27.51	6494.56	1.210×10^6	1.157×10^6	2.023×10^4	6775.69
$\sigma(M_{\mu\mu})$	53.68	27.06	6424.05	8.132×10^5	1.116×10^6	1.999×10^4	6665.11
$M_{\mu\mu}$	52.08	26.32	164.85	3.863×10^4	3.152×10^4	364.55	468.14
$\cos\theta_{\mu\mu}$	52.07	26.29	117.99	2.462×10^4	3.007×10^4	364.55	468.14
N_{P_t}	52.03	1.73	8.44	2.428×10^4	2.480×10^4	324.86	351.40
E_{vis}	51.29	0.19	4.85	1.267×10^4	1.391×10^4	265.82	240.07
P_t	51.11	0.11	4.85	1172.44	1.298×10^4	234.55	234.35
$\cos\theta_{\text{miss}}$	50.07	0.08	4.85	208.25	1.126×10^4	210.81	190.87

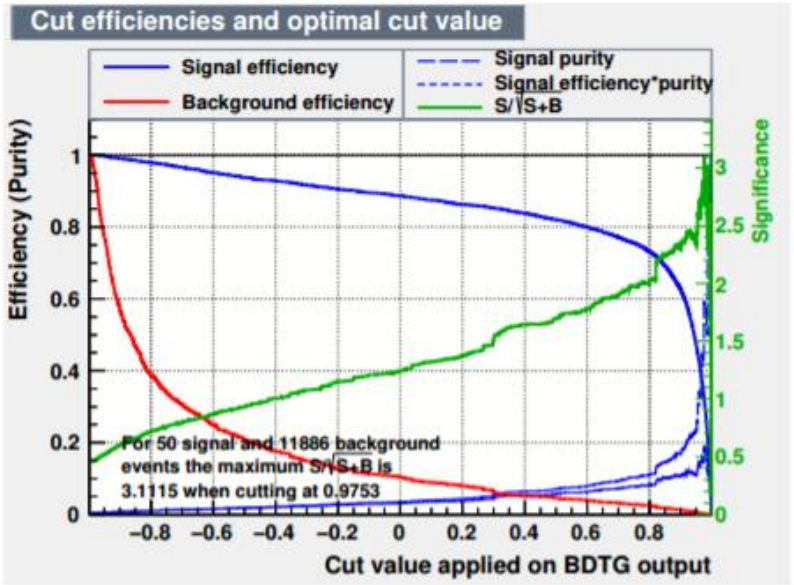
TMVA (BDTG) Analysis

- E_{vis}, thrust
- $M_{\mu\mu}$, $\cos\theta_{\mu\mu}$
- charge * $\cos\theta_{\mu^+}$, charge * $\cos\theta_{\mu^-}$, $E_{\mathrm{subleading}}$



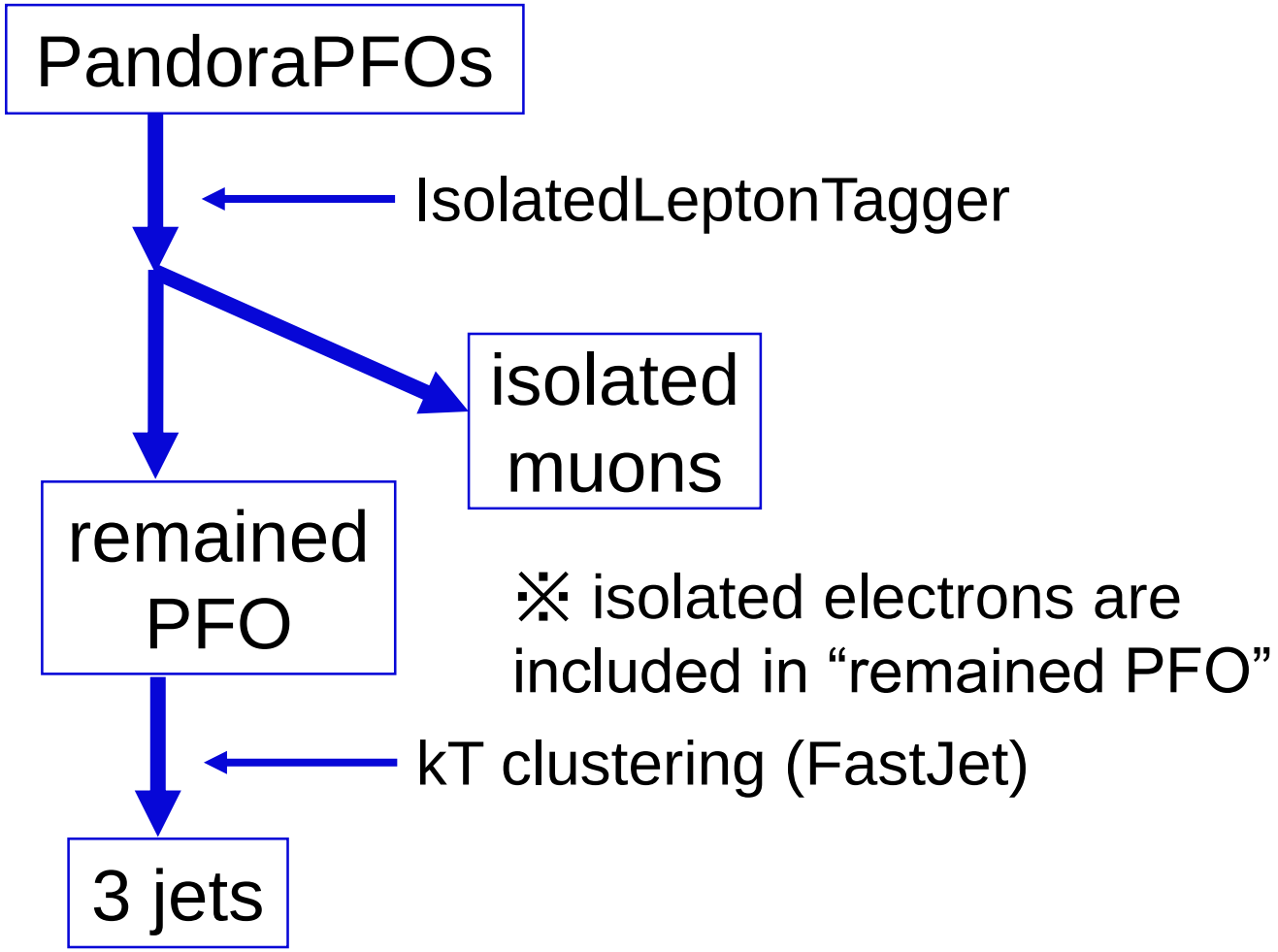






N_{sig} = 16.25, N_{bkg} = 11.63
signi. = 3.1
precision = 32%

qqh500-L/R Analysis Flow

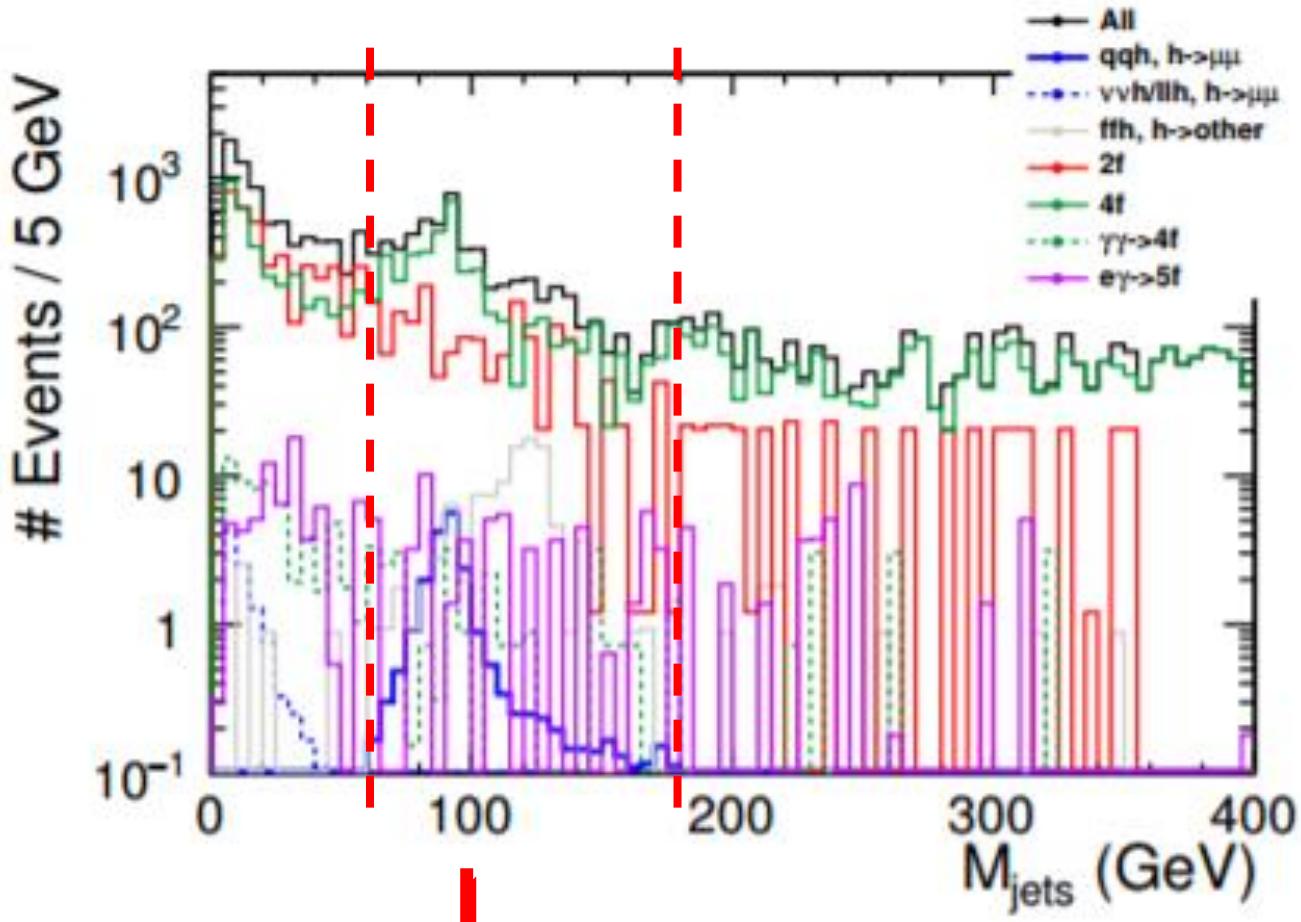


First real analysis
(> 1 TeV: WWF dominant)

Probably more techniques can be applied in future.

Precuts

- exactly one μ^+ and one μ^-
- $0.5 < \chi^2/\mathrm{Ndf}(\mu^\pm) < 1.5$
- $\sigma(M_{\mu\mu}) < 1$ GeV
- $100 < M_{\mu\mu} < 130$ GeV
- $\cos\theta_{\mu\mu} < 0.55$
- number of jets is non-zero
- number of tracks should be grater or equal to 8
- $60 < M_{\mathrm{jets}} < 180$ GeV
- thrust < 0.95

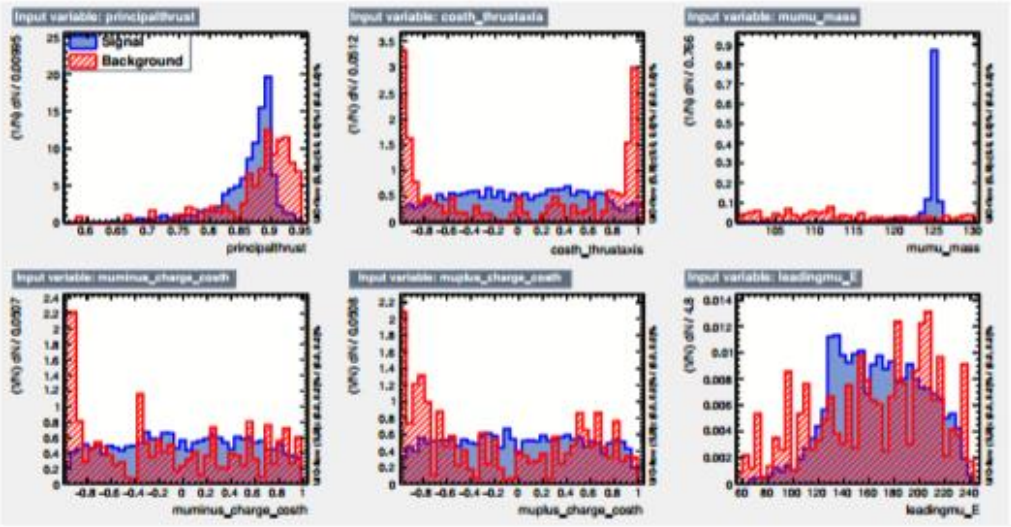


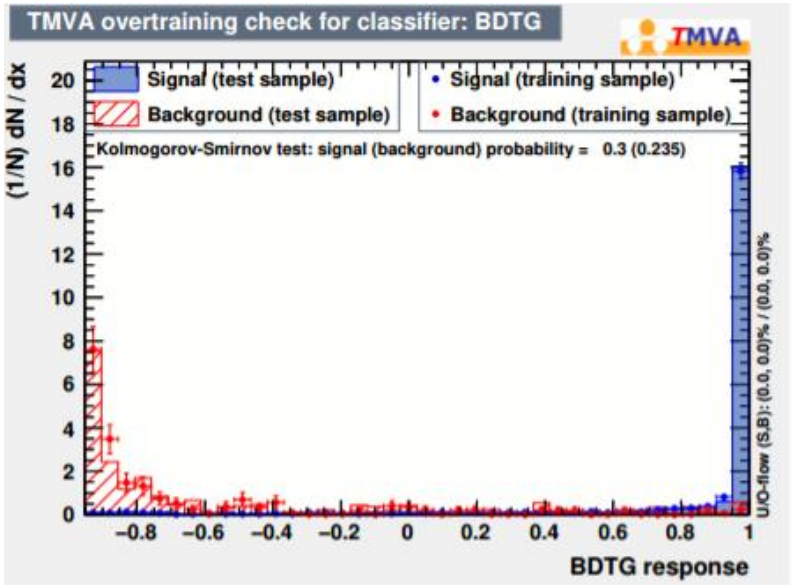
qqh500-L Precuts Cut Table

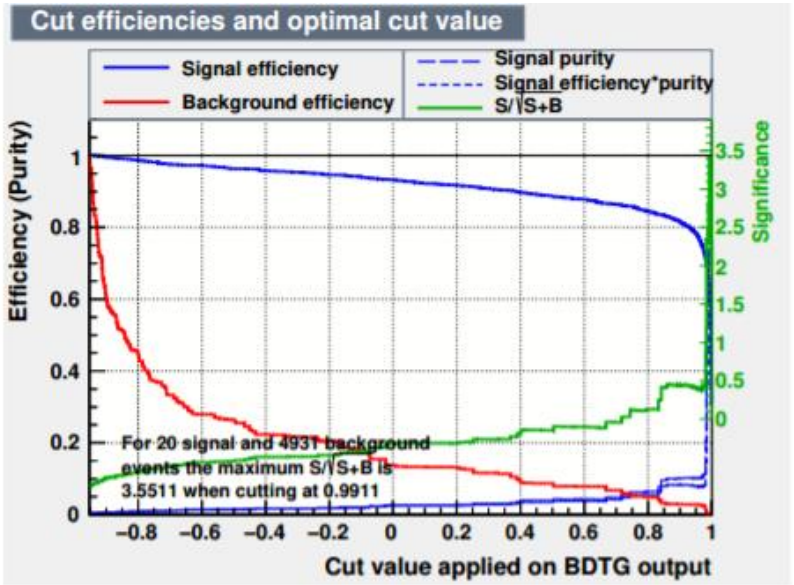
	qqh $h \to \mu\mu$	$\nu\nu h + \ell\ell h$ $h \to \mu\mu$	ffh $h \to$ other	2f	4f	$\gamma\gamma \to$ 4f	5f
No cut	24.56	64.10	4.116×10^5	4.224×10^7	4.592×10^7	3.356×10^5	2.231×10^5
# $\mu^{\pm}$	22.76	59.72	6450.41	1.309×10^6	1.015×10^6	1.472×10^4	5922.55
χ^2/Ndf	22.59	59.07	6392.52	1.206×10^6	9.251×10^5	1.301×10^4	5526.02
$\sigma(M_{\mu\mu})$	22.19	58.50	6322.01	8.092×10^5	8.845×10^5	1.275×10^4	5415.43
$M_{\mu\mu}$	21.58	56.83	164.95	3.863×10^4	3.153×10^4	377.11	468.14
$\cos\theta_{\mu\mu}$	21.54	56.81	117.99	2.462×10^4	3.008×10^4	377.11	468.14
# jet	21.54	43.45	116.67	2.099×10^4	2.677×10^4	312.92	430.86
# tracks	21.54	13.05	112.87	5953.80	1.025×10^4	98.81	160.22
M_{jets}	19.99	0.83	101.17	1592.94	4049.17	25.42	56.36
thrust	19.90	0.83	101.17	1281.58	3492.73	21.39	56.36

TMVA (BDTG) Analysis

- thrust, $\cos\theta_{\text{thrust}}$
- $M_{\mu\mu}$
- charge * $\cos\theta_{\mu+}$, charge * $\cos\theta_{\mu-}$, E_{leading}







N_{sig} = 12.99, N_{bkg} = 0.39
signi. = 3.6
precision = 28%

Results

E_{CM} = 500 GeV	qqh	nnh
Left (L) 1600 fb^{-1}	28%	32%
Right (R) 1600 fb^{-1}	35%	63%

Combining these 4 results: **17%**

※ ~7sigma with 3000 fb^{-1} at HL-LHC ---> ~14%

(ref.: DESY seminar on 2017/Mar./14)

Comparison with Extrapolation (qqh500)

arXiv:1506.07830 [hep-ex] (ILC operating scenario)

$\int \mathscr{L} dt$ at $\sqrt{s}$	250 fb^{-1} at 250 GeV		330 fb^{-1} at 350 GeV		500 fb^{-1} at 500 GeV		
$P(e^-, e^+)$	(-80%,+30%)						
production	Zh	$\nu\bar{\nu}h$	Zh	$\nu\bar{\nu}h$	Zh	$\nu\bar{\nu}h$	$t\bar{t}h$
decay	$\Delta(\sigma \cdot BR)/(\sigma \cdot BR)$						
$h \to \mu^+\mu^-$ [45]	72%	-	76%	140%	88%	72%	-

[45] C. Calancha, private communication.

scale to 1600 fb^{-1}: ~50%

My result: 28% for qqh500-L

factor ~2 better

only qqh channel

Summary

- Analyzed 4 channels in total, bug fixed
- nnh500-L: not changed drastically
- qqh500: first real analysis, **SIGNIFICANTLY BETTER** than extrapolation!
  - qqh250 will provide better precision than qqh500, because we have more qqh signals at 250 GeV
- Combined precision: 17% <---> ~14% HL-LHC
  - Reached similar precision!

BACKUP

nnh500-R Precuts Cut Table

	$\nu\nu h$ $h \to \mu\mu$	$qqh+\ell\ell h$ $h \to \mu\mu$	ffh $h \to$ other	2f	4f	$\gamma\gamma \to$ 4f	5f
No cut	7.93	20.71	1.274×10^5	2.820×10^7	1.744×10^7	3.356×10^5	1.472×10^5
# $\mu^{\pm}$	7.48	18.38	3870.91	9.847×10^5	8.587×10^5	2.227×10^4	5773.28
χ^2/Ndf	7.41	18.26	3840.66	9.083×10^5	7.822×10^5	2.023×10^4	5411.67
$\sigma(M_{\mu\mu})$	7.31	17.97	3790.67	6.265×10^5	7.561×10^5	1.999×10^4	5326.57
$M_{\mu\mu}$	7.10	17.42	107.34	2.655×10^4	1.556×10^4	364.55	279.94
$\cos\theta_{\mu\mu}$	7.09	17.40	76.56	1.773×10^4	1.486×10^4	364.55	279.94
N_{P_t}	7.08	1.07	3.89	1.755×10^4	1.189×10^4	324.86	229.64
E_{vis}	6.77	0.14	2.83	9359.68	3625.09	265.82	160.85
P_t	6.76	0.09	2.83	1072.68	2937.32	234.55	154.87
$\cos\theta_{\text{miss}}$	6.68	0.05	2.83	393.42	1587.83	210.81	134.19

qqh500-R Precuts Cut Table

	qqh $h \to \mu\mu$	$\nu\nu h + \ell\ell h$ $h \to \mu\mu$	ffh $h \to$ other	2f	4f	$\gamma\gamma \to$ 4f	5f
No cut	16.45	12.19	1.274×10^5	2.820×10^7	1.744×10^7	3.356×10^5	1.472×10^5
# $\mu^{\pm}$	15.29	10.56	3843.84	9.802×10^5	6.168×10^5	1.472×10^4	4532.72
χ^2/Ndf	15.19	10.46	3815.54	9.043×10^5	5.552×10^5	1.301×10^4	4226.24
$\sigma(M_{\mu\mu})$	14.94	10.33	3765.55	6.226×10^5	5.294×10^5	1.275×10^4	4141.14
$M_{\mu\mu}$	14.51	10.01	109.04	2.655×10^4	1.556×10^4	377.11	279.94
$\cos\theta_{\mu\mu}$	14.49	10.01	76.56	1.773×10^4	1.486×10^4	377.11	279.94
# jet	14.49	8.29	75.64	1.529×10^4	1.417×10^4	312.92	257.74
# tracks	14.49	2.58	71.17	3464.06	4941.36	98.81	86.77
M_{jets}	13.38	0.49	67.08	898.60	1803.33	25.42	19.00
thrust	13.31	0.49	67.08	838.60	1646.66	21.39	19.00

Remaining Events at Precuts (qqh500-L)

- 2f_z_l
  - mumu(1281.58)
- 4f_sznu_l, 4f_zz_sl, 4f_ww_sl, 4f_zz_l, 4f_zzorww_l, 4f_sze_l
  - 2tau: 2q2tau(1.20), 2mu2tau(46.52)
  - 0tau: 2q2mu(2513.03), 2q1mu1nu(140.89), 4mu(5.77), 2mu2nu(136.68), 2e2nu(648.65)
- aa_llvv, aa_llxx
  - 0tau: 2mu2nu(11.98), 2q2mu(9.41)

MC Samples

- ffh_mumu @ 250 GeV: job submitted
- 500 GeV
  - 5f, aa_4f: looks like already finished (ELOG ID 53 & 54, need to confirm)
  - 4f: TODO
  - e2e2h & e3e3h: job submitted
  - processes need more stdhep:
    - small number: asked Mikael (7 processes)
    - large number: generator-level cut is needed, study ongoing