Upgrade physics in VBF $H \rightarrow \gamma\gamma$ analysis

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Introduction

Investigate the upgrade performance and HGTD potential.

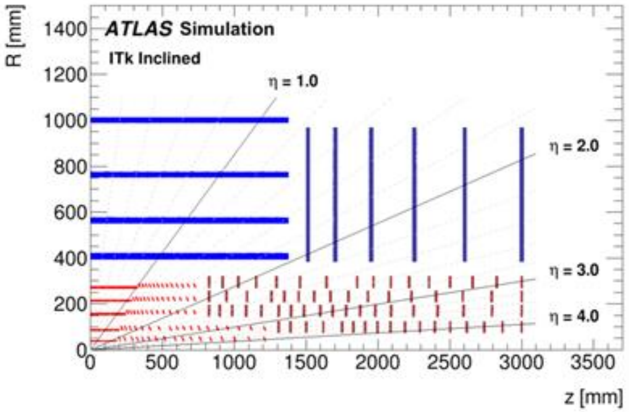
Upgrade detector

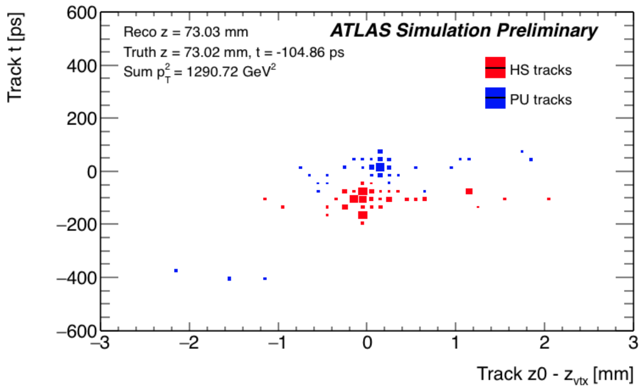
- **Inner Tracker(ITk)**: Replace the present Inner Detector with a full-silicon tracker. Cover a larger η range $|\eta| < 4.0$. Usage of tracks to mitigate PU jets up to $|\eta| < 4.0$.

  Run2: ID provides track measurement in $|\eta| < 2.5$. Usage of tracks to mitigate PU jets up to $|\eta| < 2.5$.

- **High Granularity Timing Detector**: A new timing detector in forward region $\eta \in [2.4,\ 4.0]$

  An additional timing information will be provided, to separate tracks from same position but different proton collision, for PU suppression.





Introduction

For physics performance: use VBF $H \rightarrow \gamma\gamma$ channel.

- MC sample for VBF $H \rightarrow \gamma\gamma$ analysis:

  Signal: VBF Higgs, 14TeV PowhegPythia8, CT10, Higgs mass 125GeV, di-photon decay channel, 0.7M

  Resonant background: ggF Higgs, 14TeV PowhegPythia8, CT10, Higgs mass 125GeV, di-photon decay channel, 1M

  Non-resonant background: 13TeV Sherpa NNPDFNNLO di-photon final state, $m_{\gamma\gamma} \in [90, 175]$GeV. Scale cross section from 13TeV to 14TeV(12%)

- HL-LHC simulation:

  Upgrade Performance Function package(UPF, tag 02-12-00, a smearing method on truth particle), with average pile-up value $\langle\mu\rangle = 200$, pile-up rejection factor 50(fix PU efficiency to 2%).

  Reconstructed photons with pT>25GeV, |eta|<2.37. Efficiency from UPF(~30% lower than Run2 due to PU)

  Jets with pT>30GeV, |eta|<3.8.(4.4 in Run2). HS jets efficiency from UPF(ITK simulation parameters).

  A simplified analysis to evaluate HGTD potential performance in HL-LHC.

Background component

Based on Run2, the non-resonant background has 2 parts:

- QCD $\gamma\gamma$ process, which can be simulated with MC.
- Fake events, with 1 or 2 photon is from fake jet (called γj and jj event). In Run2 this part is estimated from data-driven method(Purity 2x2DSB).

Background Estimate in HL-LHC

- No HL-LHC data for data driven, but we suppose fake rate for jet to photon is similar, so the relative fraction for these 2 part is also similar with Run2.
- Ignore the shape, only scale the QCD $\gamma\gamma$ events with its fraction, to the total event number.

	$\gamma\gamma$	γj	jj
VBF HjjLow loose	82.4%	16.3%	1.3%
VBF HjjLow tight	82.4%	16.2%	1.4%
VBF HjjHigh loose	80.9%	16.4%	2.7%
VBF HjjHigh tight	84.7%	13.5%	1.8%

Take average number and mix γj&jj part.
Used here:

- $\gamma\gamma$: 82.5%
- $\gamma j + jj$: 17.5%

(Ref: 36ifb Run2 supporting note)

Analysis strategy

VBF Pre-selection:

Number of photon ≥ 2

Number of jet ≥ 2

$\frac{pT_{leading\ photon}}{m_{\gamma\gamma}} \geq 0.35$

$\frac{pT_{sub-leading\ photon}}{m_{\gamma\gamma}} \geq 0.25$

$105GeV < m_{\gamma\gamma} < 160GeV$

$\Delta\eta_{jj} > 2$

$\left|\eta_{\gamma\gamma}^{Zepp}\right| < 5$

Scenarios:

- ITK: default one(Smearing & eff from UPF.)
- rmfwdPU: remove forward PU jets($\eta \in [2.5, 3.8]$), an ideal condition.
- PU50: remove 50% of forward PU jets, a naïve HGTD estimation.

Hope to see how much the PU influence analysis.

Cut flow

cut flow	ggH	VBF	background
2 photons	23.082%	26.877%	19.277%
Rel.pT	93.240%	89.157%	85.522%
Mass window	97.363%	95.403%	57.394%
2 jets	13.059%	41.212%	12.237%
$\Delta\eta_{jj} > 2$	40.177%	74.984%	37.631%
$\lvert\eta_{\gamma\gamma}^{Zepp}\rvert < 5$	99.572%	99.921%	98.246%
Total	1.095%	7.059%	0.428%
Scale to 3 ab-1	4075.59	2056.55	903483.7
$m_{\gamma\gamma}$ ∈[120, 130]	3833.98	1935.33	171160.76

ITK, $\sigma = 4.62 \pm 0.03$
(4.63 for s/$\sqrt{b}$)

cut flow	ggH	VBF	background
2 photons	23.082%	26.877%	19.272%
Rel.pT	93.240%	89.157%	85.539%
Mass window	97.363%	95.403%	57.392%
2 jets	12.748%	40.804%	11.726%
$\Delta\eta_{jj} > 2$	39.278%	75.139%	35.421%
$\lvert\eta_{\gamma\gamma}^{Zepp}\rvert < 5$	99.628%	99.929%	98.755%
Total	1.045%	7.004%	0.388%
Scale to 3 ab-1	3891.67	2040.57	819094
$m_{\gamma\gamma}$ ∈[120, 130]	3658.246	1920.014	163565.1

PU50, $\sigma = 4.69 \pm 0.03$
(4.70 for s/$\sqrt{b}$)

cut flow	ggH	VBF	background
2 photons	23.082%	26.877%	19.275%
Rel.pT	93.240%	89.157%	85.535%
Mass window	97.363%	95.403%	57.388%
2 jets	12.424%	40.413%	11.421%
$\Delta\eta_{jj} > 2$	38.418%	75.279%	34.506%
$\lvert\eta_{\gamma\gamma}^{Zepp}\rvert < 5$	99.750%	99.930%	98.874%
Total	0.998%	6.950%	0.369%
Scale to 3 ab-1	3714.08	2024.80	778098.6
$m_{\gamma\gamma}$ ∈[120, 130]	3489.97	1905.53	155338.8

rmfwdPU, $\sigma = 4.77 \pm 0.03$
(4.78 for s/$\sqrt{b}$)

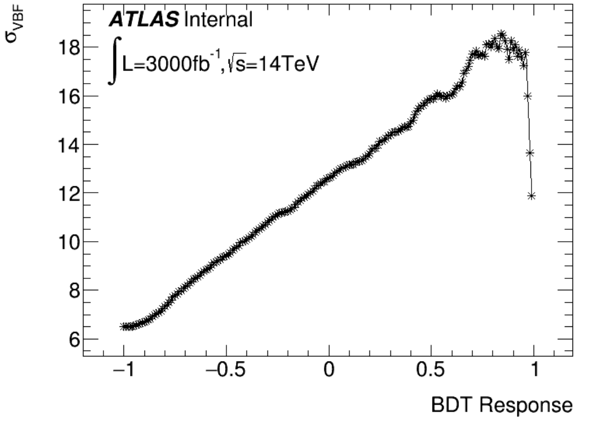
Cut flow and event number for signal and background in 3 scenarios.
Background event number is scaled to 14TeV cross section×($1/\gamma\gamma$ fraction).
The σ is calculated with VBF, ggH and background event number in mass window [120, 130]GeV by

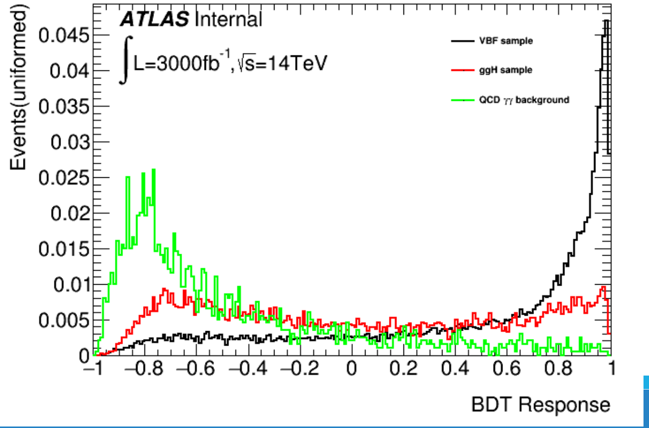
$\sigma_{VBF} = \sqrt{2 \times \left(\left(N_{VBF} + N_{ggF} + N_{bkg}\right) \times \ln\left(1 + \frac{N_{VBF}}{N_{ggF}+N_{bkg}}\right) - N_{VBF}\right)}$. Compared with ITK, remove forward PU and PU50

MVA optimization

A BDT categorization method to separate Higgs signal and QCD background. (Ref: 36ifb Run2 supporting note)

- Training sample: VBF Higgs as signal, and QCD $\gamma\gamma$+jets as background.
- Training variables: $m_{jj}, \Delta\eta_{jj}, \Delta\Phi_{\gamma\gamma,jj}, p_{Tt}, \Delta R^{min}_{\gamma,j}, \eta^{Zepp}$.
- Categorization: maximum $\sigma_{VBF} = \sqrt{2 \times \left(\left(N_{VBF} + N_{ggF} + N_{bkg}\right) \times \ln\left(1 + \frac{N_{VBF}}{N_{ggF}+N_{bkg}}\right) - N_{VBF}\right)}$ in mass window [120, 130]GeV to define a tight category, remove tight event and maximum σ_{VBF} again to have loose and rest categories. Specific BDT cut value is determined individually for 3 scenarios.
- Re-train the BDT in 3 scenarios to get the best performance.





Left: VBF significance vs. BDT cut value.

Right: BDT response in 3 templates

Event number and combined significance for each scenario

	tight	loose	Rest
VBF	482.88±6.34	555.79±6.80	896.66±8.64
ggF	214.82±8.94	561.06±14.45	3058.1±33.74
Background	1054±50	6509±125	163606±627
σ in category	12.85±0.28	6.53±0.10	2.19±0.02
S/B	0.383±0.016	0.079±0.0017	0.0054±0.00006
VBF purity	69.21%	49.76%	22.67%
Combined σ	14.58±0.25		
Combined S/B	0.391±0.016		

ITK

	tight	loose	Rest
VBF	444.67±6.08	652.94±7.37	822.41±12.64
ggF	219.66±9.04	723.76±16.42	2714.83±31.79
Background	938.6±54.0	7984±157	163565±713
σ in category	12.34±0.31	6.91±0.10	2.07±0.02
S/B	0.384±0.019	0.075±0.002	0.0052±0.00006
VBF purity	66.94%	47.43%	23.25%
Combined σ	14.30±0.27		
Combined S/B	0.391±0.019		

PU50

	tight	loose	Rest
VBF	432.35±6.00	640.45±7.30	832.73±8.33
ggF	174.98±8.07	627.70±15.29	2787.28±31.63
Background	772±53	7000±161	147567±740
σ in category	13.14±0.37	7.23±0.11	2.15±0.02
S/B	0.456±0.027	0.084±0.002	0.0055±0.00006
VBF purity	71.19%	50.50%	23.66%
Combined σ	15.15±0.33		
Combined S/B	0.464±0.026		

rmfwdPU

Event number and significance for ITK(left), PU50(middle) and rmfwdPU(right) scenario
S/B: signal-bkg ratio, $N_{VBF}/(N_{ggH}+N_{bkg})$
VBF purity: $N_{VBF}/(N_{VBF}+N_{ggH})$

Jet Component

tight+loose cat.

	ggH		VBF		bkg		ggH		VBF		bkg		ggH		VBF		bkg	
CH+CH	255.772	32.97%	205.103	19.74%	1830.28	24.21%	338.796	35.91%	234.071	21.30%	2557.88	28.67%	276.621	34.46%	212.512	19.79%	1857.5	23.90%
CH+CP	18.6151	2.40%	6.49272	0.62%	230.89	3.05%	29.7842	3.16%	9.1564	0.83%	369.852	4.14%	24.1997	3.01%	7.24188	0.67%	282.34	3.63%
CP+CP	0.372303	0.05%	0	0.00%	7.2153	0.10%	0	0.00%	0	0.00%	6.216	0.07%	0.372303	0.05%	0	0.00%	22.29	0.29%
CH+FH	378.26	48.75%	623.468	59.99%	3638.92	48.14%	451.604	47.87%	646.026	58.80%	4248.64	47.61%	411.767	51.30%	647.025	60.25%	4235.1	54.49%
CH+FP	31.6458	4.08%	6.07652	0.58%	557.983	7.38%	19.7321	2.09%	3.66256	0.33%	326.34	3.66%	0	0.00%	0	0.00%	0	0.00%
CP+FH	19.3598	2.50%	8.7402	0.84%	310.258	4.10%	24.1997	2.57%	11.5704	1.05%	369.852	4.14%	23.0828	2.88%	10.6547	0.99%	430.94	5.54%
CP+FP	1.11691	0.14%	0.08324	0.01%	26.4561	0.35%	1.48921	0.16%	0.08324	0.01%	52.836	0.59%	0	0.00%	0	0.00%	0	0.00%
FH-FH	56.9624	7.34%	184.293	17.73%	603.68	7.99%	65.153	6.91%	191.702	17.45%	736.596	8.25%	66.6422	8.30%	196.446	18.29%	943.61	12.14%
FH-FP	12.6583	1.63%	4.91116	0.47%	319.878	4.23%	12.286	1.30%	2.4972	0.23%	226.884	2.54%	0	0.00%	0	0.00%	0	0.00%
FP-FP	1.11691	0.14%	0.08324	0.01%	33.6714	0.45%	0.372303	0.04%	0	0.00%	27.972	0.31%	0	0.00%	0	0.00%	0	0.00%
total	775.8795	100.00%	1039.251	100.00%	7559.232	100.00%	943.4165	100.00%	1098.769	100.00%	8923.068	100.00%	802.685	100.00%	1073.88	100.00%	7771.78	100.00%

ITK scenario

PU50 scenario

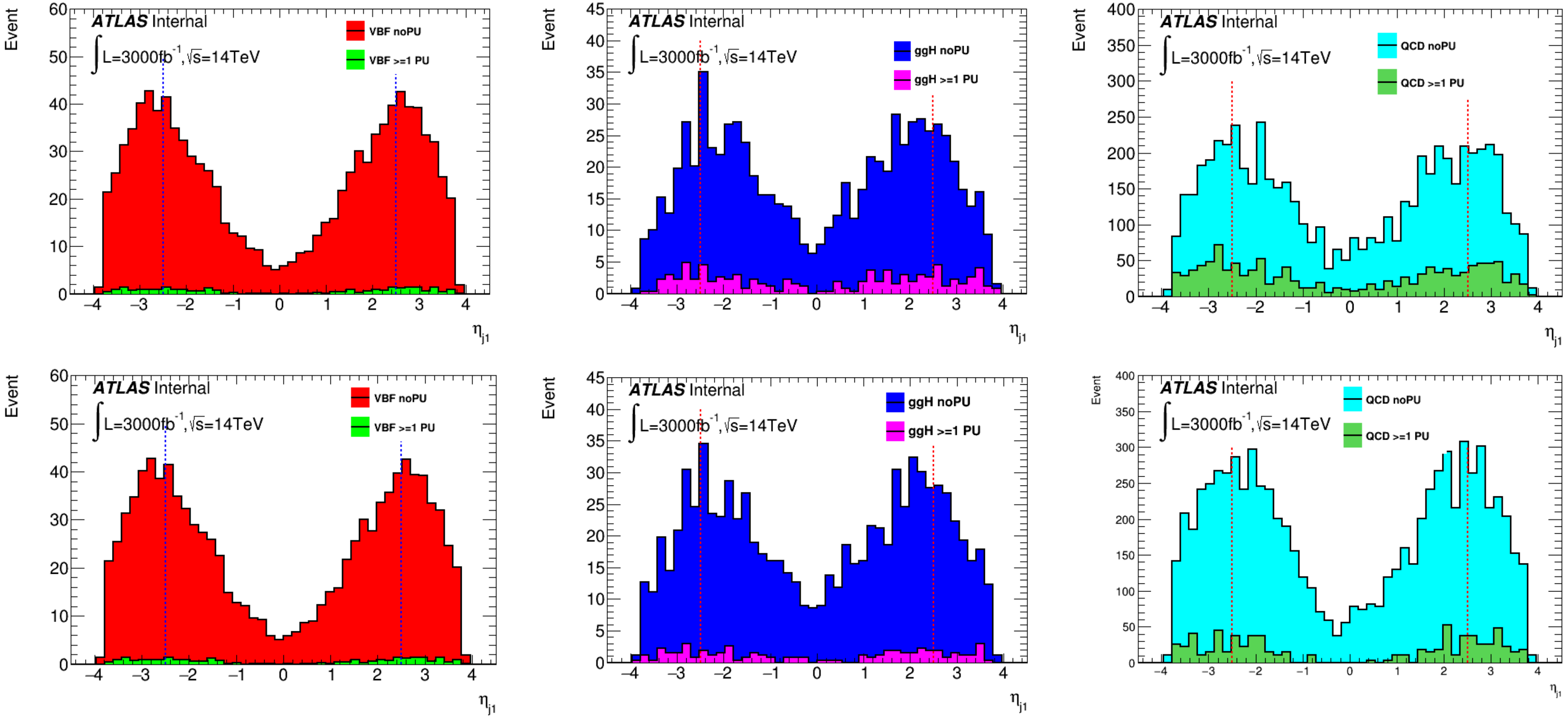
rmfwdPU scenario

Forward PU

Central PU

η_{j1} stack distribution

tight+loose cat.



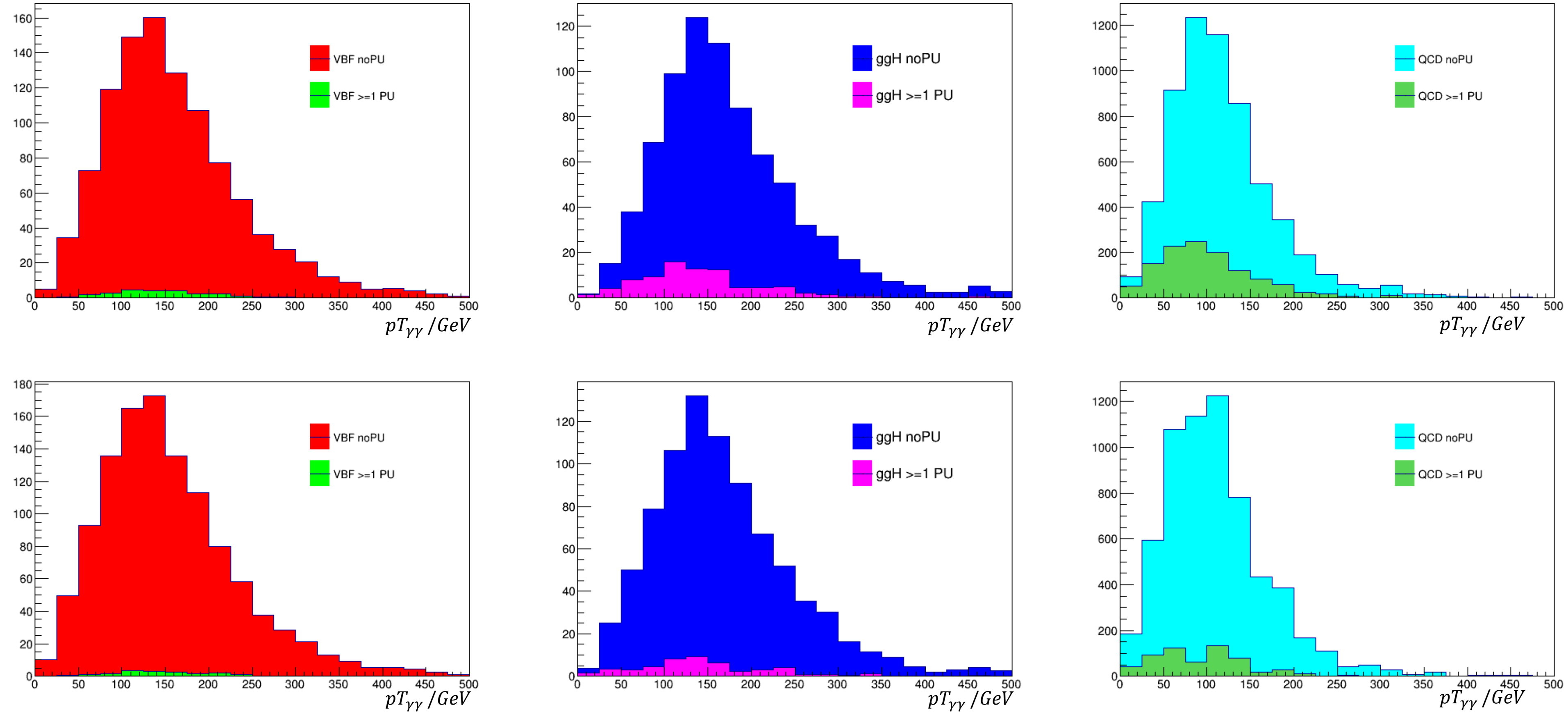
Up: ITK scenario

Down: rmfwdPU scenario

$\geq 1PU$: events with $\geq$ 1 PU jet

$pT_{\gamma\gamma}$ stack distribution

tight+loose cat.

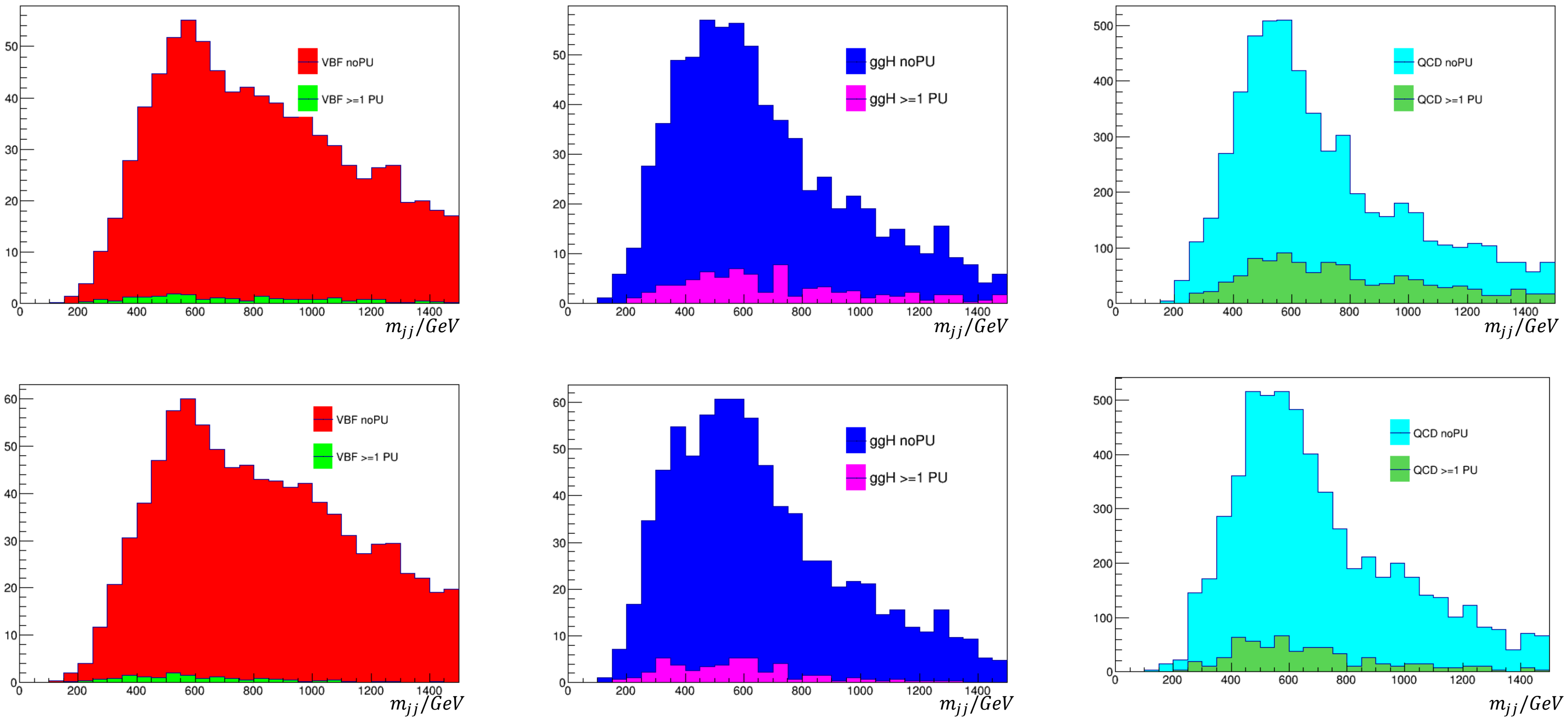


Up: ITK scenario

Down: rmfwdPU scenario

m_{jj} stack distribution

tight+loose cat.

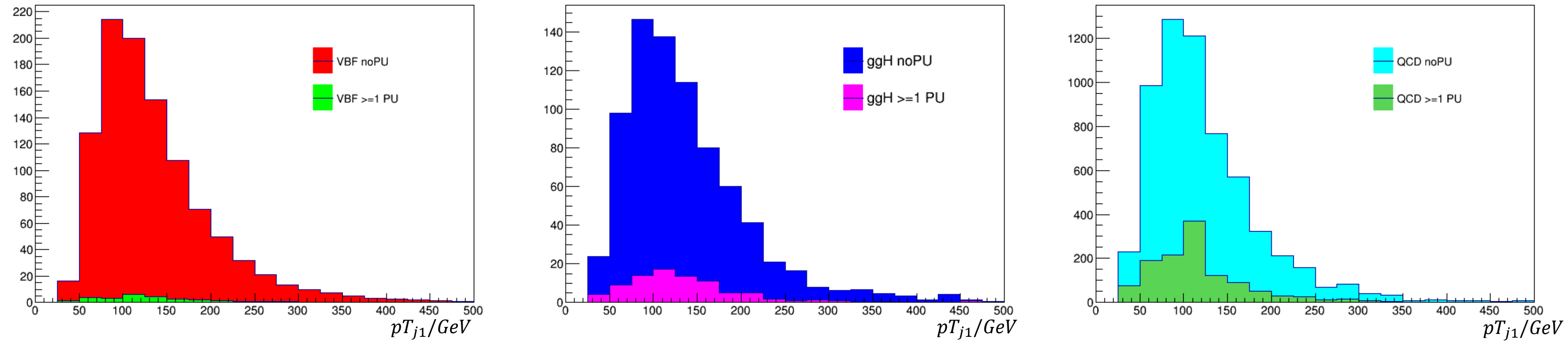


Up: ITK scenario

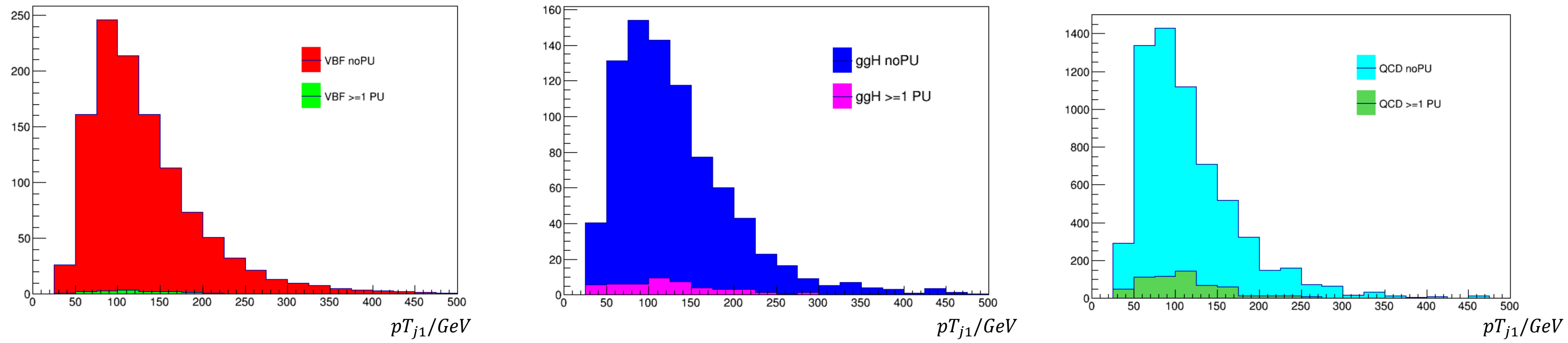
Down: rmfwdPU scenario

pT_{j1} stack distribution

tight+loose cat.



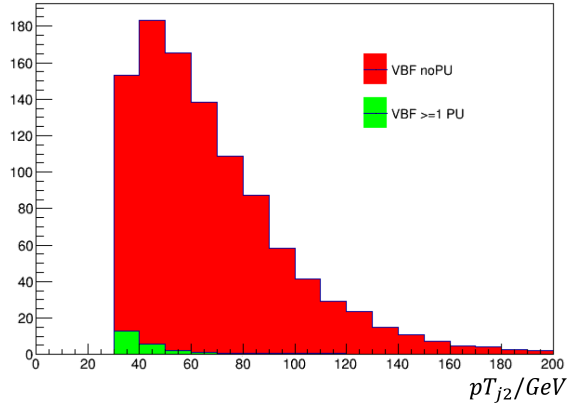
Up: ITK scenario

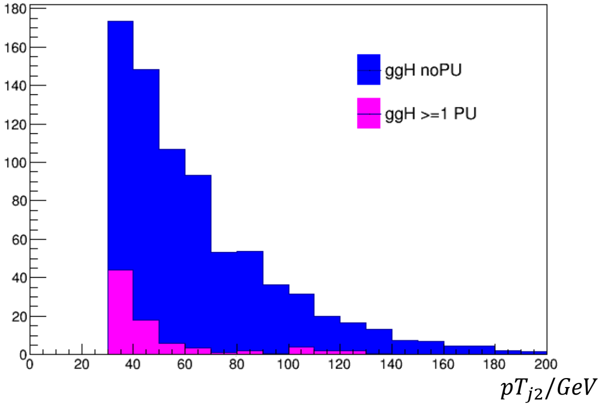


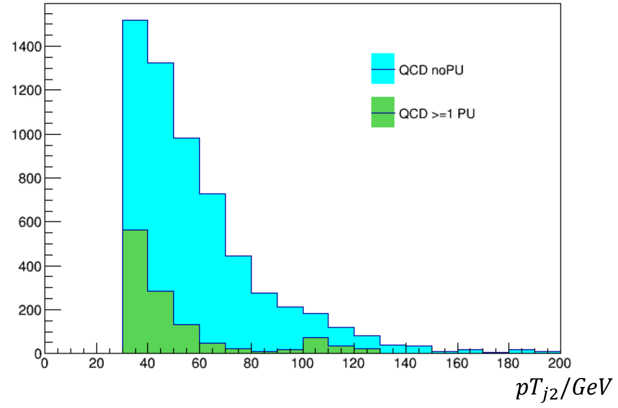
Down: rmfwdPU scenario

pT_{j2} stack distribution

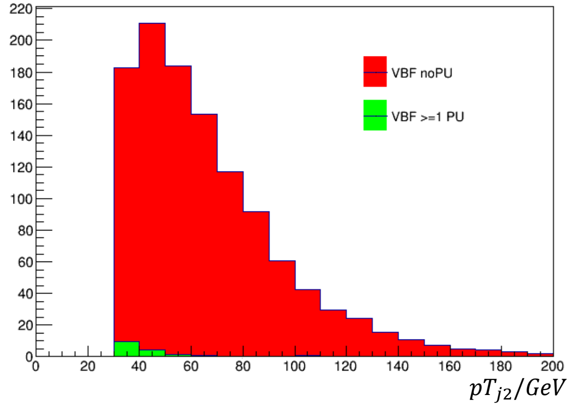
tight+loose cat.

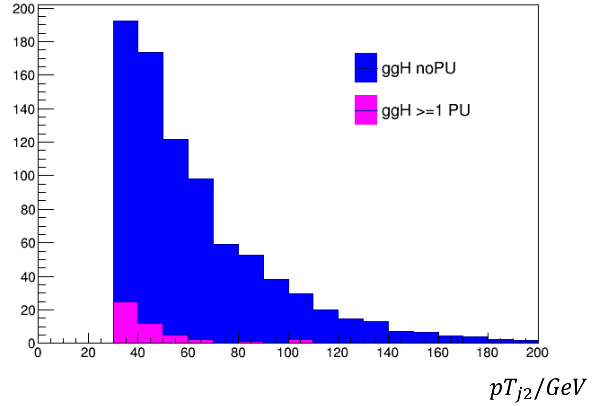


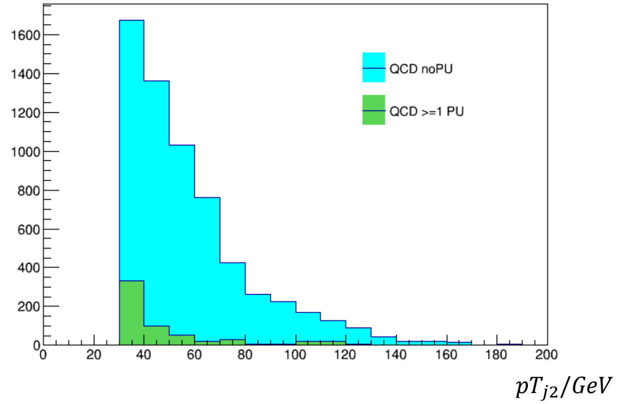




Up: ITK scenario







Down: rmfwdPU scenario

MVA optimization

VBF significance

Scenario	$\boldsymbol{\sigma_{VBF}}$	**Improvement**
ITK	14.58±0.25	0
PU50	14.30±0.27	-1.92%
rmfwdPU	15.15±0.33	3.91%

VBF S/B ratio

Scenario	$\boldsymbol{S/(B_1+B_2)}$	**Improvement**
ITK	0.391±0.016	0
PU50	0.391±0.019	0
rmfwdPU	0.464±0.026	18.67%

Conclusion

All results are based on statistics uncertainty only.

The improvement depends on the benchmark to show it:

- In VBF significance, rmfwdPU can only provide ~4% improvement, within 1 sigma uncertainty.
- In S/B ratio, rmfwdPU shows ~19% improvement.

Gain of rmfwdPU mainly comes from the η distribution in VBF and background sample.

AI from Last Higgs meeting

- Clearly state in conclusion that you compare only stat errors.

  >>Yes, I have noticed
- Implement cut Ptj1 > 45GeV.

  >>We think it’s not necessary. A brief slide in backup shows the s/sqrt(b) value corresponding to different jet pT cut.
- Explain why you do not do Run 2 cuts : mjj and zeppenfeld cut.

  >>These two variables are used in BDT training
- The gain is from QCD part, so be strong on the understanding of this background.

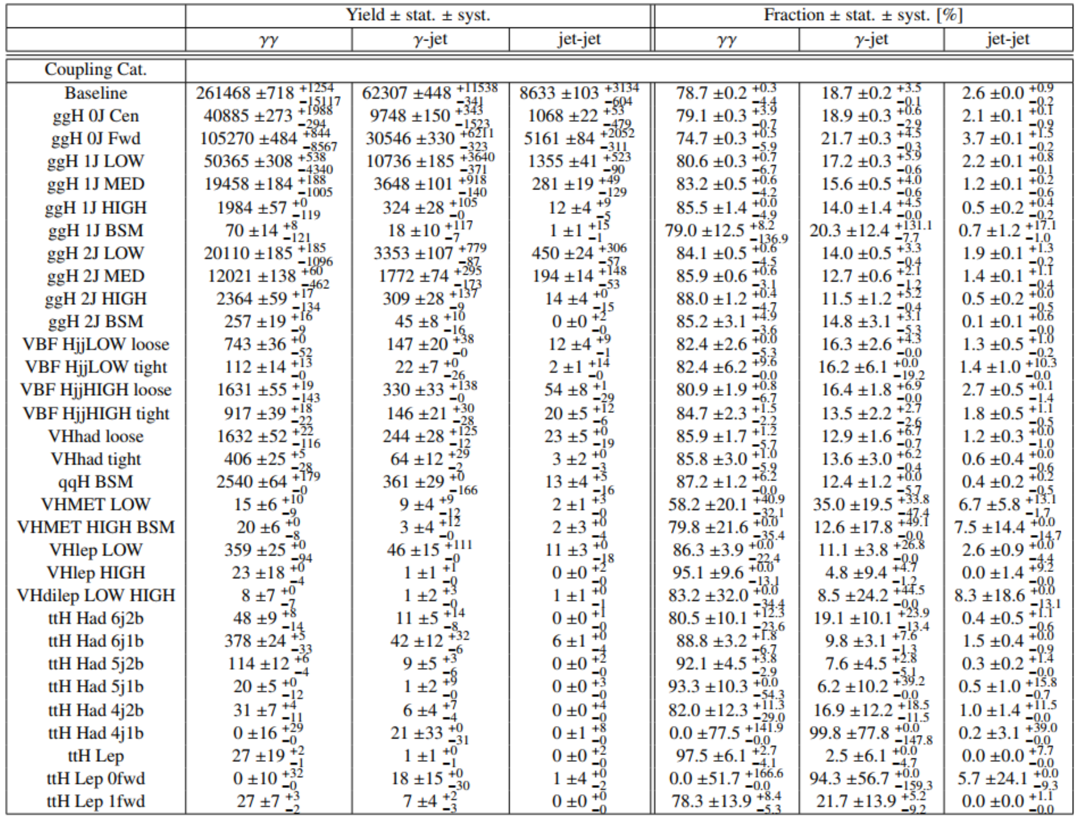
  >>QCD process has its special performance, I have a Discussion chapter in the note.
- Estimate background with fake photon from QCD jets+1y + jet->y smearing function.

  >>As an estimation, we think the fake rate in Run2 and HL-LHC(UPF) is similar, so the fake condition should also be similar. If we do that we need a very large amount of QCD jets MC.
- Why VBF amplitude is not the same for ITK and rmfwdPU. There is no contamination from PU

  >>In the slide I showed the event in BDT tight+loose category. ITK and rmfwdPU have different definition here.

backup

Background component



	Yield ± stat. ± syst.			Fraction ± stat. ± syst. [%]		
	$\gamma\gamma$	γ-jet	jet-jet	$\gamma\gamma$	γ-jet	jet-jet
Coupling Cat.						
Baseline	$261468 \pm 718\,{}^{+1254}_{-15117}$	$62307 \pm 448\,{}^{+11538}_{-341}$	$8633 \pm 103\,{}^{+3134}_{-604}$	$78.7 \pm 0.2\,{}^{+0.3}_{-4.4}$	$18.7 \pm 0.2\,{}^{+3.5}_{-0.1}$	$2.6 \pm 0.0\,{}^{+0.9}_{-0.2}$
ggH 0J Cen	$40885 \pm 273\,{}^{+1988}_{-294}$	$9748 \pm 150\,{}^{+343}_{-1523}$	$1068 \pm 22\,{}^{+53}_{-479}$	$79.1 \pm 0.3\,{}^{+3.9}_{-0.7}$	$18.9 \pm 0.3\,{}^{+0.6}_{-2.9}$	$2.1 \pm 0.1\,{}^{+0.1}_{-0.9}$
ggH 0J Fwd	$105270 \pm 484\,{}^{+844}_{-8567}$	$30546 \pm 330\,{}^{+6211}_{-323}$	$5161 \pm 84\,{}^{+2052}_{-311}$	$74.7 \pm 0.3\,{}^{+0.5}_{-5.9}$	$21.7 \pm 0.3\,{}^{+4.5}_{-0.3}$	$3.7 \pm 0.1\,{}^{+1.5}_{-0.2}$
ggH 1J LOW	$50365 \pm 308\,{}^{+538}_{-4340}$	$10736 \pm 185\,{}^{+3640}_{-371}$	$1355 \pm 41\,{}^{+523}_{-90}$	$80.6 \pm 0.3\,{}^{+0.7}_{-6.7}$	$17.2 \pm 0.3\,{}^{+5.9}_{-0.6}$	$2.2 \pm 0.1\,{}^{+0.8}_{-0.1}$
ggH 1J MED	$19458 \pm 184\,{}^{+188}_{-1005}$	$3648 \pm 101\,{}^{+918}_{-140}$	$281 \pm 19\,{}^{+49}_{-129}$	$83.2 \pm 0.5\,{}^{+0.6}_{-4.2}$	$15.6 \pm 0.5\,{}^{+4.0}_{-0.6}$	$1.2 \pm 0.1\,{}^{+0.2}_{-0.6}$
ggH 1J HIGH	$1984 \pm 57\,{}^{+0}_{-119}$	$324 \pm 28\,{}^{+105}_{-0}$	$12 \pm 4\,{}^{+9}_{-5}$	$85.5 \pm 1.4\,{}^{+0.0}_{-4.9}$	$14.0 \pm 1.4\,{}^{+4.5}_{-0.0}$	$0.5 \pm 0.2\,{}^{+0.4}_{-0.2}$
ggH 1J BSM	$70 \pm 14\,{}^{+8}_{-121}$	$18 \pm 10\,{}^{+117}_{-7}$	$1 \pm 1\,{}^{+15}_{-1}$	$79.0 \pm 12.5\,{}^{+8.2}_{-136.9}$	$20.3 \pm 12.4\,{}^{+131.1}_{-7.7}$	$0.7 \pm 1.2\,{}^{+17.1}_{-1.0}$
ggH 2J LOW	$20110 \pm 185\,{}^{+185}_{-1096}$	$3353 \pm 107\,{}^{+779}_{-87}$	$450 \pm 24\,{}^{+306}_{-57}$	$84.1 \pm 0.5\,{}^{+0.6}_{-4.5}$	$14.0 \pm 0.5\,{}^{+3.3}_{-0.4}$	$1.9 \pm 0.1\,{}^{+1.3}_{-0.2}$
ggH 2J MED	$12021 \pm 138\,{}^{+60}_{-462}$	$1772 \pm 74\,{}^{+295}_{-173}$	$194 \pm 14\,{}^{+148}_{-53}$	$85.9 \pm 0.6\,{}^{+0.6}_{-3.1}$	$12.7 \pm 0.6\,{}^{+2.1}_{-1.2}$	$1.4 \pm 0.1\,{}^{+1.1}_{-0.4}$
ggH 2J HIGH	$2364 \pm 59\,{}^{+17}_{-134}$	$309 \pm 28\,{}^{+137}_{-9}$	$14 \pm 4\,{}^{+0}_{-15}$	$88.0 \pm 1.2\,{}^{+0.4}_{-4.7}$	$11.5 \pm 1.2\,{}^{+5.2}_{-0.4}$	$0.5 \pm 0.2\,{}^{+0.0}_{-0.5}$
ggH 2J BSM	$257 \pm 19\,{}^{+16}_{-9}$	$45 \pm 8\,{}^{+10}_{-16}$	$0 \pm 0\,{}^{+2}_{-0}$	$85.2 \pm 3.1\,{}^{+4.9}_{-3.6}$	$14.8 \pm 3.1\,{}^{+3.1}_{-5.3}$	$0.1 \pm 0.1\,{}^{+0.6}_{-0.0}$
VBF HjjLOW loose	$743 \pm 36\,{}^{+0}_{-52}$	$147 \pm 20\,{}^{+38}_{-0}$	$12 \pm 4\,{}^{+9}_{-1}$	$82.4 \pm 2.6\,{}^{+0.0}_{-5.3}$	$16.3 \pm 2.6\,{}^{+4.3}_{-0.0}$	$1.3 \pm 0.5\,{}^{+1.0}_{-0.2}$
VBF HjjLOW tight	$112 \pm 14\,{}^{+13}_{-0}$	$22 \pm 7\,{}^{+0}_{-26}$	$2 \pm 1\,{}^{+14}_{-0}$	$82.4 \pm 6.2\,{}^{+9.6}_{-0.0}$	$16.2 \pm 6.1\,{}^{+0.0}_{-19.2}$	$1.4 \pm 1.0\,{}^{+10.3}_{-0.0}$
VBF HjjHIGH loose	$1631 \pm 55\,{}^{+19}_{-143}$	$330 \pm 33\,{}^{+138}_{-0}$	$54 \pm 8\,{}^{+1}_{-29}$	$80.9 \pm 1.9\,{}^{+0.8}_{-6.7}$	$16.4 \pm 1.8\,{}^{+6.9}_{-0.0}$	$2.7 \pm 0.5\,{}^{+0.1}_{-1.4}$
VBF HjjHIGH tight	$917 \pm 39\,{}^{+18}_{-22}$	$146 \pm 21\,{}^{+30}_{-28}$	$20 \pm 5\,{}^{+12}_{-6}$	$84.7 \pm 2.3\,{}^{+1.5}_{-2.2}$	$13.5 \pm 2.2\,{}^{+2.7}_{-2.6}$	$1.8 \pm 0.5\,{}^{+1.1}_{-0.5}$
VHhad loose	$1632 \pm 52\,{}^{+22}_{-116}$	$244 \pm 28\,{}^{+125}_{-12}$	$23 \pm 5\,{}^{+0}_{-19}$	$85.9 \pm 1.7\,{}^{+1.2}_{-5.7}$	$12.9 \pm 1.6\,{}^{+6.7}_{-0.7}$	$1.2 \pm 0.3\,{}^{+0.0}_{-1.0}$
VHhad tight	$406 \pm 25\,{}^{+5}_{-28}$	$64 \pm 12\,{}^{+29}_{-2}$	$3 \pm 2\,{}^{+0}_{-3}$	$85.8 \pm 3.0\,{}^{+1.0}_{-5.9}$	$13.6 \pm 3.0\,{}^{+6.2}_{-0.4}$	$0.6 \pm 0.4\,{}^{+0.0}_{-0.6}$
qqH BSM	$2540 \pm 64\,{}^{+179}_{-0}$	$361 \pm 29\,{}^{+0}_{-166}$	$13 \pm 4\,{}^{+5}_{-16}$	$87.2 \pm 1.2\,{}^{+6.2}_{-0.0}$	$12.4 \pm 1.2\,{}^{+0.0}_{-5.7}$	$0.4 \pm 0.2\,{}^{+0.2}_{-0.5}$
VHMET LOW	$15 \pm 6\,{}^{+10}_{-9}$	$9 \pm 4\,{}^{+9}_{-12}$	$2 \pm 1\,{}^{+3}_{-0}$	$58.2 \pm 20.1\,{}^{+40.9}_{-32.1}$	$35.0 \pm 19.5\,{}^{+33.8}_{-47.4}$	$6.7 \pm 5.8\,{}^{+13.1}_{-1.7}$
VHMET HIGH BSM	$20 \pm 6\,{}^{+0}_{-8}$	$3 \pm 4\,{}^{+12}_{-0}$	$2 \pm 3\,{}^{+0}_{-4}$	$79.8 \pm 21.6\,{}^{+0.0}_{-35.4}$	$12.6 \pm 17.8\,{}^{+49.1}_{-0.0}$	$7.5 \pm 14.4\,{}^{+0.0}_{-14.7}$
VHlep LOW	$359 \pm 25\,{}^{+0}_{-94}$	$46 \pm 15\,{}^{+111}_{-0}$	$11 \pm 3\,{}^{+0}_{-18}$	$86.3 \pm 3.9\,{}^{+0.0}_{-22.4}$	$11.1 \pm 3.8\,{}^{+26.8}_{-0.0}$	$2.6 \pm 0.9\,{}^{+0.0}_{-4.4}$
VHlep HIGH	$23 \pm 18\,{}^{+0}_{-4}$	$1 \pm 1\,{}^{+1}_{-0}$	$0 \pm 0\,{}^{+2}_{-0}$	$95.1 \pm 9.6\,{}^{+0.0}_{-13.1}$	$4.8 \pm 9.4\,{}^{+4.7}_{-1.2}$	$0.0 \pm 1.4\,{}^{+9.2}_{-0.0}$
VHdilep LOW HIGH	$8 \pm 7\,{}^{+0}_{-7}$	$1 \pm 2\,{}^{+3}_{-0}$	$1 \pm 1\,{}^{+0}_{-1}$	$83.2 \pm 32.0\,{}^{+0.0}_{-34.4}$	$8.5 \pm 24.2\,{}^{+44.5}_{-0.0}$	$8.3 \pm 18.6\,{}^{+0.0}_{-13.1}$
ttH Had 6j2b	$48 \pm 9\,{}^{+8}_{-14}$	$11 \pm 5\,{}^{+14}_{-8}$	$0 \pm 0\,{}^{+1}_{-0}$	$80.5 \pm 10.1\,{}^{+12.3}_{-23.6}$	$19.1 \pm 10.1\,{}^{+23.9}_{-13.4}$	$0.4 \pm 0.5\,{}^{+1.1}_{-0.6}$
ttH Had 6j1b	$378 \pm 24\,{}^{+5}_{-33}$	$42 \pm 12\,{}^{+32}_{-6}$	$6 \pm 1\,{}^{+0}_{-4}$	$88.8 \pm 3.2\,{}^{+1.8}_{-6.7}$	$9.8 \pm 3.1\,{}^{+7.6}_{-1.3}$	$1.5 \pm 0.4\,{}^{+0.0}_{-0.9}$
ttH Had 5j2b	$114 \pm 12\,{}^{+6}_{-4}$	$9 \pm 5\,{}^{+3}_{-6}$	$0 \pm 0\,{}^{+2}_{-0}$	$92.1 \pm 4.5\,{}^{+3.8}_{-2.9}$	$7.6 \pm 4.5\,{}^{+2.8}_{-5.1}$	$0.3 \pm 0.2\,{}^{+1.4}_{-0.0}$
ttH Had 5j1b	$20 \pm 5\,{}^{+0}_{-12}$	$1 \pm 2\,{}^{+9}_{-0}$	$0 \pm 0\,{}^{+3}_{-0}$	$93.3 \pm 10.3\,{}^{+0.0}_{-54.3}$	$6.2 \pm 10.2\,{}^{+39.2}_{-0.0}$	$0.5 \pm 1.0\,{}^{+15.8}_{-0.7}$
ttH Had 4j2b	$31 \pm 7\,{}^{+4}_{-11}$	$6 \pm 4\,{}^{+7}_{-4}$	$0 \pm 0\,{}^{+4}_{-0}$	$82.0 \pm 12.3\,{}^{+11.3}_{-29.0}$	$16.9 \pm 12.2\,{}^{+18.5}_{-11.5}$	$1.0 \pm 1.4\,{}^{+11.5}_{-0.0}$
ttH Had 4j1b	$0 \pm 16\,{}^{+29}_{-0}$	$21 \pm 33\,{}^{+0}_{-31}$	$0 \pm 1\,{}^{+8}_{-0}$	$0.0 \pm 77.5\,{}^{+141.9}_{-0.0}$	$99.8 \pm 77.8\,{}^{+0.0}_{-147.8}$	$0.2 \pm 3.1\,{}^{+39.0}_{-0.0}$
ttH Lep	$27 \pm 19\,{}^{+2}_{-1}$	$1 \pm 1\,{}^{+0}_{-1}$	$0 \pm 0\,{}^{+2}_{-0}$	$97.5 \pm 6.1\,{}^{+2.7}_{-4.1}$	$2.5 \pm 6.1\,{}^{+0.0}_{-4.7}$	$0.0 \pm 0.0\,{}^{+7.7}_{-0.0}$
ttH Lep 0fwd	$0 \pm 10\,{}^{+32}_{-0}$	$18 \pm 15\,{}^{+0}_{-30}$	$1 \pm 4\,{}^{+0}_{-2}$	$0.0 \pm 51.7\,{}^{+166.6}_{-0.0}$	$94.3 \pm 56.7\,{}^{+0.0}_{-159.3}$	$5.7 \pm 24.1\,{}^{+0.0}_{-9.3}$
ttH Lep 1fwd	$27 \pm 7\,{}^{+3}_{-2}$	$7 \pm 4\,{}^{+2}_{-3}$	$0 \pm 0\,{}^{+0}_{-0}$	$78.3 \pm 13.9\,{}^{+8.4}_{-5.3}$	$21.7 \pm 13.9\,{}^{+5.2}_{-9.2}$	$0.0 \pm 0.0\,{}^{+1.1}_{-0.0}$

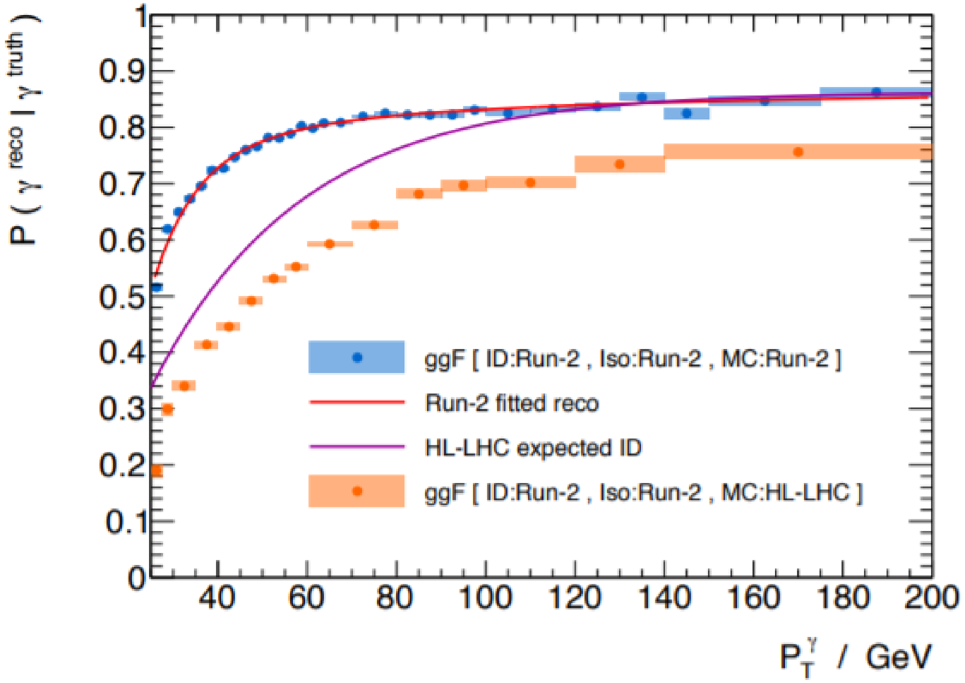
Table 27: Yields and fraction decomposition of $\gamma\gamma$, γ-jet and jet-jet events entering each category after the final selection, obtained from the 2×2D Sideband Method using 36.1 fb^{-1} of 13 TeV data. Note: the small Drell-Yan contribution is included in the $\gamma\gamma$ yields and fractions. (This takes into account h016b)

Yields and fraction decomposition of background component in Run2 36.1 fb^{-1} supporting note. Page 89.

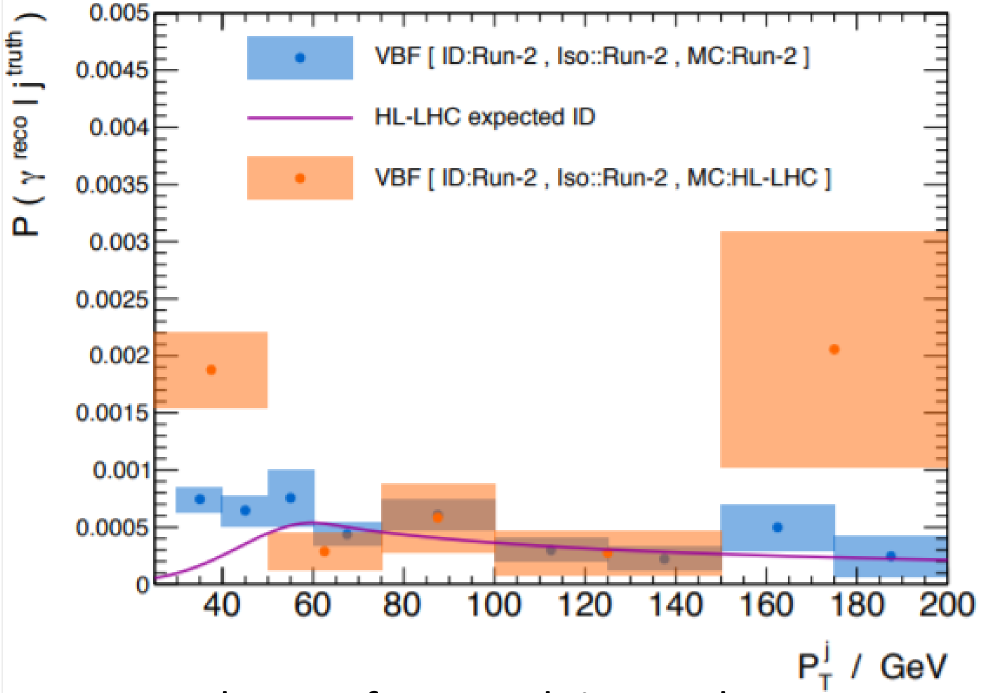
4 VBF categories (VBF HjjLOW loose, VBF HjjLOW tight, VBF HjjHIGH loose, VBF HjjHIGH tight) are considered in this work.

Background component

Photon efficiency and fake rate in HL-LHC and Run2



Photon reconstruction efficiency with photon pT



Fake rate from truth jet to photon.

Ref: Hgam xs in HL-LHC

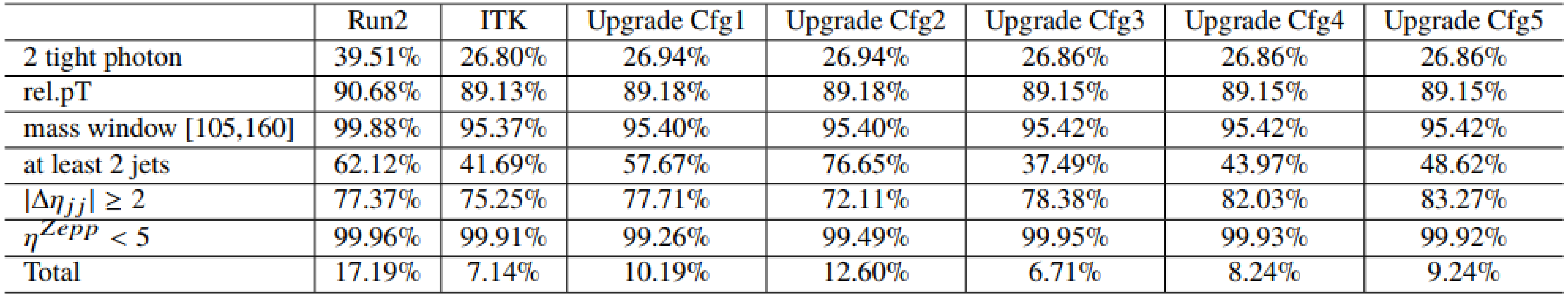
Comparison with Run2

Internal note: CDS link

Extra configurations in Upgrade

- Upgrade Cfg1: $|\eta_j|$<4.4, Tracking Confirmation(TC) up to 3.8
  in region $3.8 < |\eta| < 4.4$, $\varepsilon_{jet} = 1$
- Upgrade Cfg2: $|\eta_j|$<4.4, Tracking Confirmation(TC) up to 2.5
  in region $2.5 < |\eta| < 4.4$, $\varepsilon_{jet} = 1$
- Upgrade Cfg3: $|\eta_j|$<3.8, Tracking Confirmation(TC) up to 3.8
  remove all the pile-up jets with truth information
- Upgrade Cfg4: $|\eta_j|$<4.4, Tracking Confirmation(TC) up to 3.8
  in region $3.8 < |\eta| < 4.4$, $\varepsilon_{jet} = 1$, remove all the pile-up jets with truth information
- Upgrade Cfg5: $|\eta_j|$<4.4, Tracking Confirmation(TC) up to 2.5
  in region $2.5 < |\eta| < 4.4$, $\varepsilon_{jet} = 1$, remove all the pile-up jets with truth information

Discussion——jet region



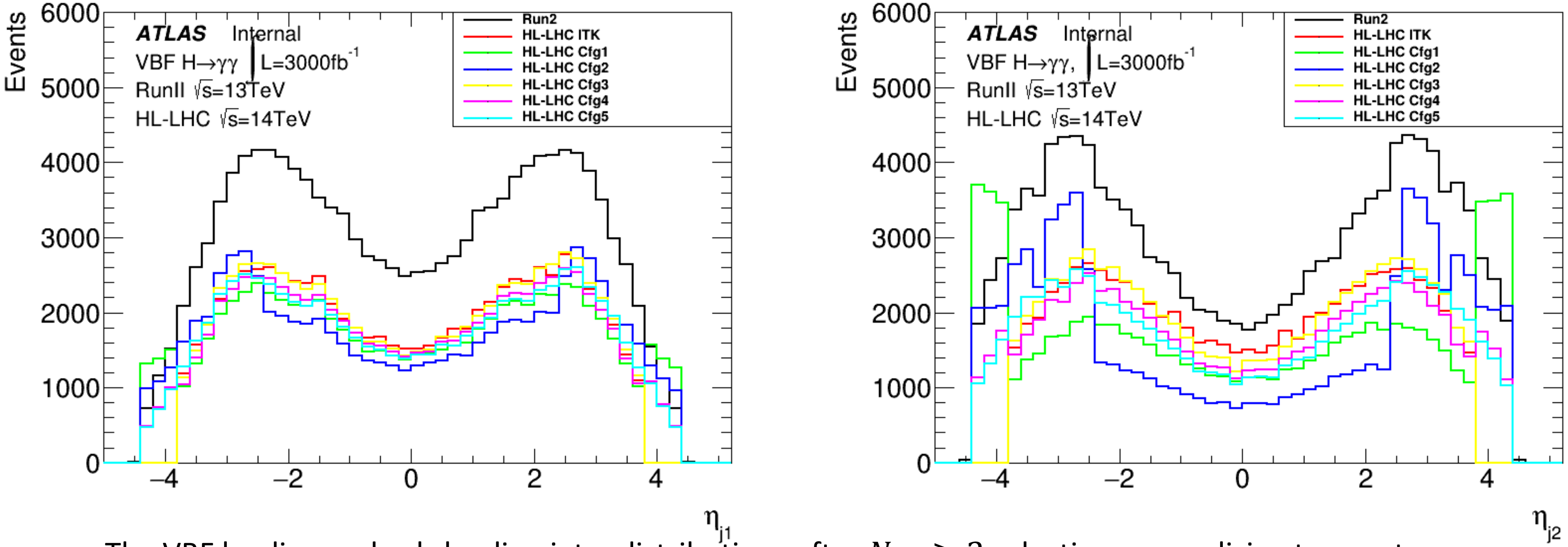
	Run2	ITK	Upgrade Cfg1	Upgrade Cfg2	Upgrade Cfg3	Upgrade Cfg4	Upgrade Cfg5
2 tight photon	39.51%	26.80%	26.94%	26.94%	26.86%	26.86%	26.86%
rel.pT	90.68%	89.13%	89.18%	89.18%	89.15%	89.15%	89.15%
mass window [105,160]	99.88%	95.37%	95.40%	95.40%	95.42%	95.42%	95.42%
at least 2 jets	62.12%	41.69%	57.67%	76.65%	37.49%	43.97%	48.62%
$\|\Delta\eta_{jj}\| \geq 2$	77.37%	75.25%	77.71%	72.11%	78.38%	82.03%	83.27%
$\eta^{Zepp} < 5$	99.96%	99.91%	99.26%	99.49%	99.95%	99.93%	99.92%
Total	17.19%	7.14%	10.19%	12.60%	6.71%	8.24%	9.24%

The VBF sample selection efficiency in each step.

The differences in photon-relative cut may come from the fake photon from the jets (fake rate is $\sim 10^{-3}$)

Expanding the jet η region helps to recover the efficiency(ITK vs. Cfg1, Cfg3 vs. Cfg4), but the ggH and $\gamma\gamma$ background events also increase(in next slides)

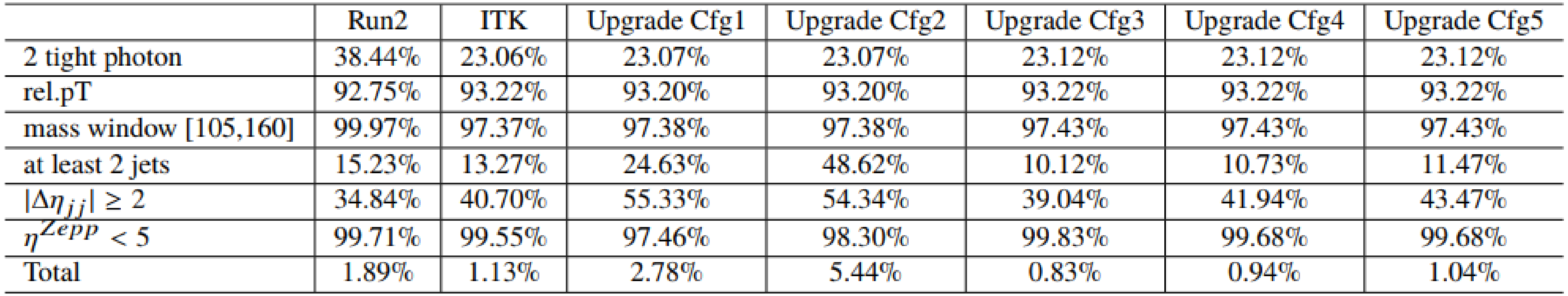
Discussion——jet region



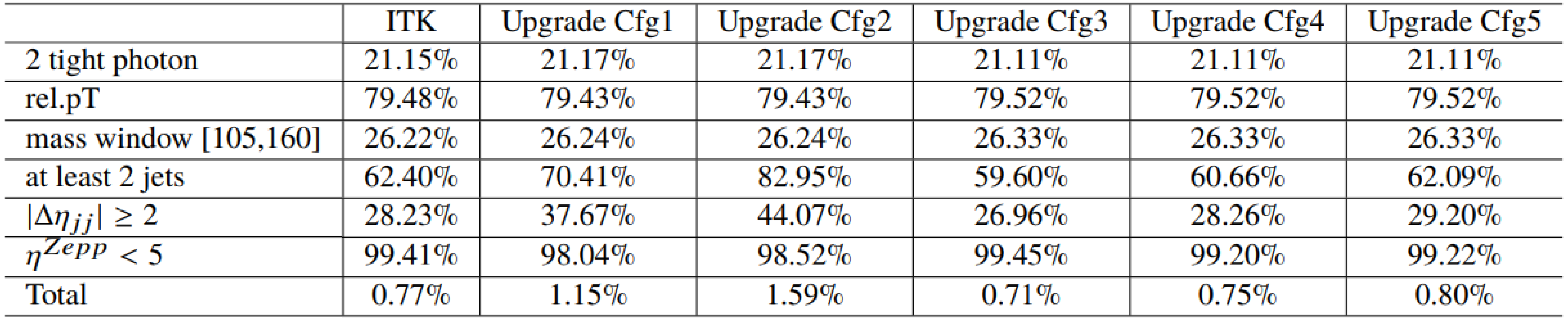
The VBF leading and sub-leading jet η distributions after $N_{jet} \geq 2$ selection, normalizing to event number after the mass window cut.

- The forward jets have contribution to the selection, a precise jet reconstruction efficiency would be very helpful.
- Whether the jet reconstruction efficiency is the same in the Upgrade and ATLAS data need further check.

Discussion——background efficiency



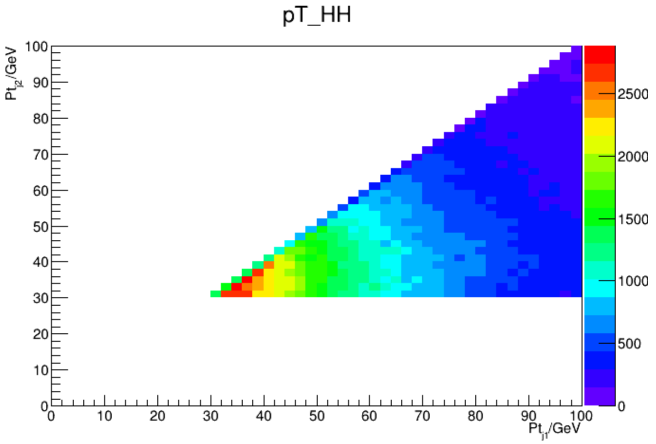
	Run2	ITK	Upgrade Cfg1	Upgrade Cfg2	Upgrade Cfg3	Upgrade Cfg4	Upgrade Cfg5
2 tight photon	38.44%	23.06%	23.07%	23.07%	23.12%	23.12%	23.12%
rel.pT	92.75%	93.22%	93.20%	93.20%	93.22%	93.22%	93.22%
mass window [105,160]	99.97%	97.37%	97.38%	97.38%	97.43%	97.43%	97.43%
at least 2 jets	15.23%	13.27%	24.63%	48.62%	10.12%	10.73%	11.47%
$\|\Delta\eta_{jj}\| \geq 2$	34.84%	40.70%	55.33%	54.34%	39.04%	41.94%	43.47%
$\eta^{Zepp} < 5$	99.71%	99.55%	97.46%	98.30%	99.83%	99.68%	99.68%
Total	1.89%	1.13%	2.78%	5.44%	0.83%	0.94%	1.04%

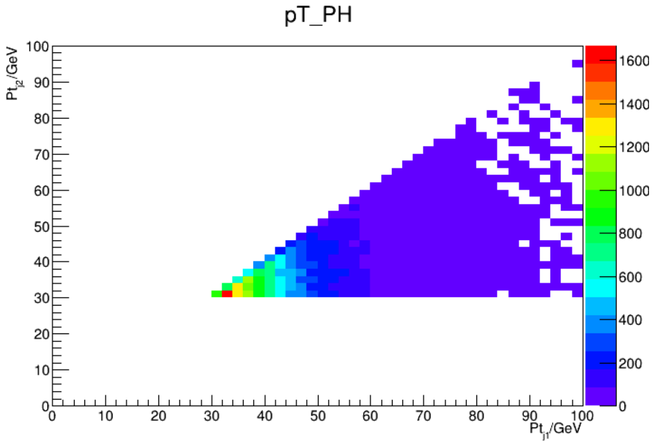


	ITK	Upgrade Cfg1	Upgrade Cfg2	Upgrade Cfg3	Upgrade Cfg4	Upgrade Cfg5
2 tight photon	21.15%	21.17%	21.17%	21.11%	21.11%	21.11%
rel.pT	79.48%	79.43%	79.43%	79.52%	79.52%	79.52%
mass window [105,160]	26.22%	26.24%	26.24%	26.33%	26.33%	26.33%
at least 2 jets	62.40%	70.41%	82.95%	59.60%	60.66%	62.09%
$\|\Delta\eta_{jj}\| \geq 2$	28.23%	37.67%	44.07%	26.96%	28.26%	29.20%
$\eta^{Zepp} < 5$	99.41%	98.04%	98.52%	99.45%	99.20%	99.22%
Total	0.77%	1.15%	1.59%	0.71%	0.75%	0.80%

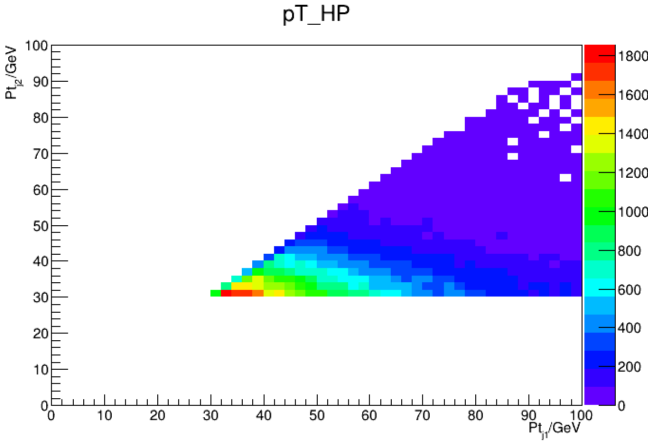
- Expending the jet η region increases the efficiency by 85% in ggH and 17% in $\gamma\gamma$ background(ITK vs. Cfg1)
- Removing pile-up can help to reject more background sample. (ITK, Cfg1~2 vs. Cfg3~5)

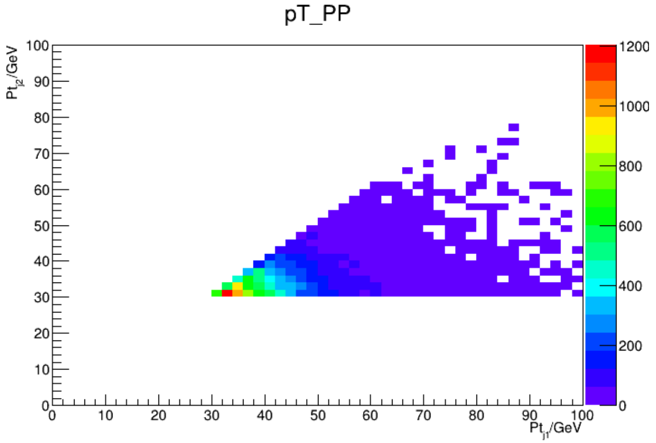
Jet Pt distribution


pT_HH


pT_PH

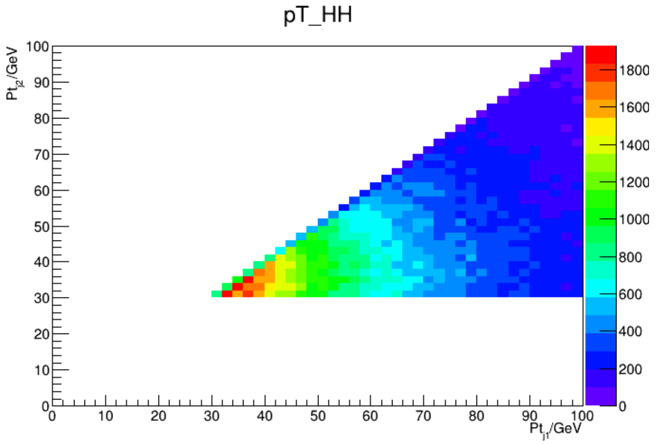
	#Event (scaled)
HSj1+HSj2	619493
PUj1+HSj2	60422
HSj1+PUj2	136153
PUj1+PUj2	39364
total	855433

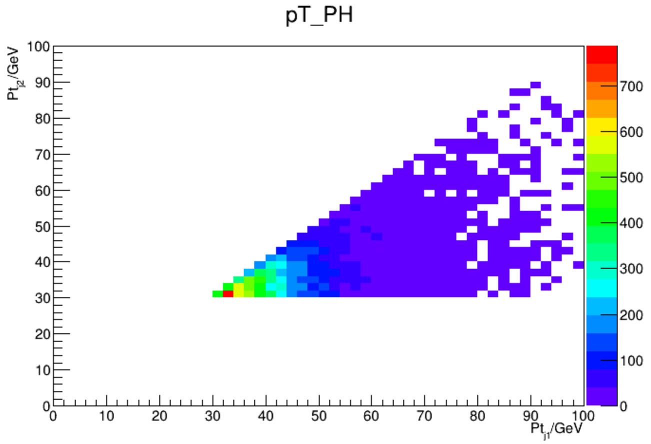

pT_HP


pT_PP

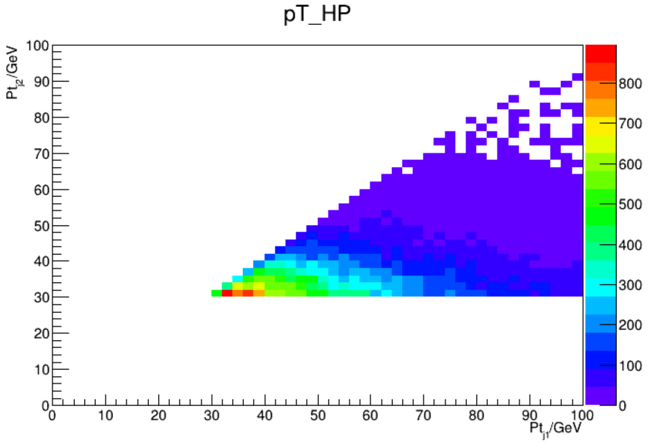
ITK scenario
leading jet pT vs. sub-leading jet pT for:
Leading HS+subleading HS(left top),
leading PU+subleading HS(right top),
leading PU+subleading HS(left bottom),
Leading PU+subleading PU(right bottom).

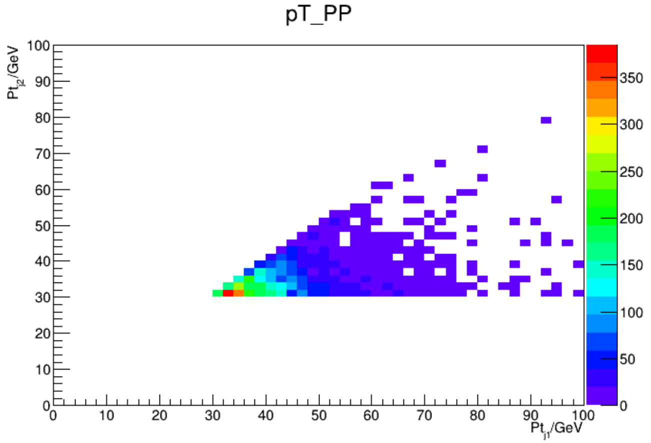
Jet Pt distribution





	#Event
HSj1+HSj2	624406
PUj1+HSj2	42595
HSj1+PUj2	92792
PUj1+PUj2	18306
total	778099





rmfwdPU scenario
leading jet pT vs. sub-leading jet pT for:
Leading HS+subleading HS(left top),
leading PU+subleading HS(right top),
leading PU+subleading HS(left bottom),
Leading PU+subleading PU(right bottom).

Significance with different jet pT cut

	30GeV	45GeV	60GeV	75GeV
30GeV	4.69			
45GeV	4.91	4.65		
60GeV	5.08	4.67	3.95	
75GeV	4.91	4.53	3.85	3.11

ITK scenario

	30GeV	45GeV	60GeV	75GeV
30GeV	4.73			
45GeV	4.84	4.47		
60GeV	4.99	4.51	3.91	
75GeV	4.94	4.55	3.92	3.22

rmfwdPU scenario

	30GeV	45GeV	60GeV	75GeV
30GeV	0.853%			
45GeV	-1.426%	-3.871%		
60GeV	-1.772%	-3.426%	-1.013%	
75GeV	0.611%	0.442%	1.818%	3.537%

improvement in significance $\sigma = s/\sqrt{b}$

calculated VBF significance in different jet pT cut.
Column: pT cut in leading jet j1.
row: pT cut in sub-leading jet j2.
top left: ITK scenario. top right: rmfwdPU scenario.
bottom: improvement from rmfwdPU.