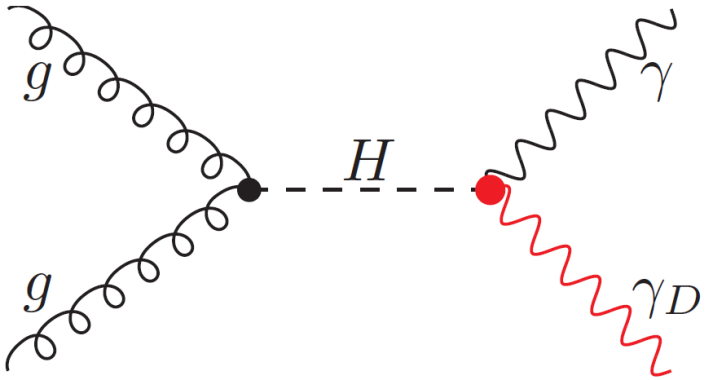
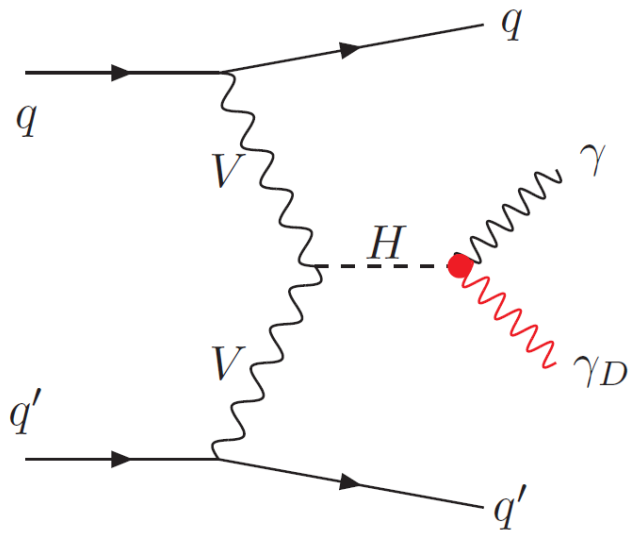
H->Photon+MET

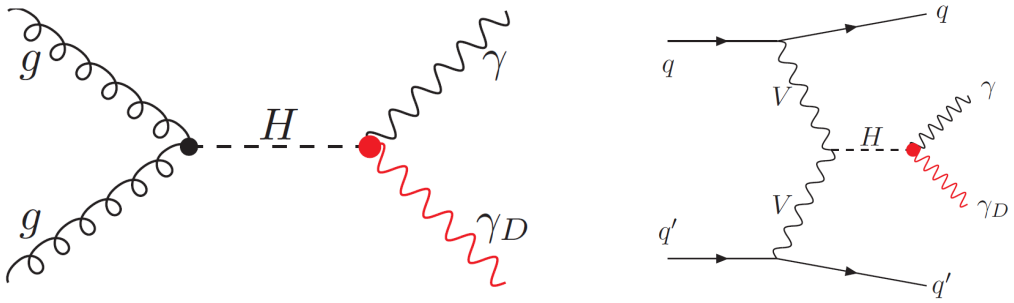


Longsheng Tan

2025.11.3



Motivations



- Higgs boson portal to dark sector

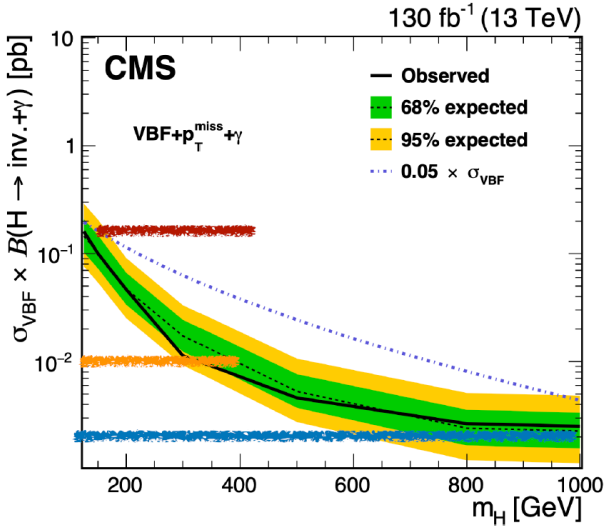
- Focus on exotic decay:
  - H-> gamma + met (Monochromatic photon + missing transverse energy(dark photon))

VBF		ZH		VBF+ZH	
Obs. (%)	Exp. (%)	Obs. (%)	Exp. (%)	Obs. (%)	Exp. (%)
3.5	$2.8^{+1.3}_{-0.8}$	4.6	$3.6^{+2.0}_{-1.2}$	2.9	$2.1^{+1.0}_{-0.7}$

  - Branching ratio up to 5%
    - observed (expected) limit ≈ 3.5% (2.8%) (Run2, VBF category, CMS)
    - observed (expected) limit ≈ 2.9% (2.1%) (Run2, VBF+ZH, CMS)

- Run3 provides higher energy, luminosity, improved triggers (low photon threshold) and ML tools → enhanced sensitivity

- Perform different categories for ggH + VBF to set stronger constraints on dark sector portals



Progresses

- Initially established a complete analysis framework based on pyRAT
  - Checked, More integrated
- Completed the preliminary object selection and event selection
  - Using 2024 data with 23MC
  - Based on Run2 VBF category
  - Introduce inclusive jets and jet-num category (In progress)
- Compared with Run2
  - Yields of SR CR
  - Preliminary results of the limit

Samples

Type	Name	Process	2024 ggF+VBF	Run2 VBF	Note	if reducible	if true	CR->SR
signal	ggF		✓	✓		*		
	VBF		✓	✓				
background QCD	Gjet	ϒ from q	✓	✓	with a mismeasured PT miss	✓		✓
	Wjet	q qbarprime	✓	✓	photon candidate is a misidentified electron.			✓
	Zjet	DYto2L-2Jets as CR	✓					
	Znunu	Zto2Nu-2Jets	✓	✓	which can contribute to the SR when a jet is misidentified as a photon			
	QCD multi jets		✓	✓				
background EWK	Gjet	VBFtoG	✓					
	Zjet	VBFto2L	✓					
	Wjet	VBFtoLNu	✓	✓	purely electroweak interactions, becomes more relevant at higher mjj			
	Znunu	VBFto2Nu	✓	✓				
	Zgamma			✓			✓	
	Wgamma			✓				
background V+gamma	Zgamma	ZGto2NuG-1Jets	✓	✓				✓
	Wgamma	WGtoLNuG-1Jets	✓	✓	irreducible background if the charged lepton falls outside of the detector acceptance			✓
background minor	TTbar	TTto2L2Nu,TTto4Q,TTtoLNu2Q	✓			✓		
	Diboson	WZ,WW,ZZ	✓			partial	partial	
Others	VV			✓	1. involving a photon and neutrinos or out-of-acceptance leptons 2. estimated directly from MC simulation			
	VVV			✓				
	TTbargamma			✓			✓	
	Tgamma			✓				

Preliminary Strategies

Data-taking year	2016	2017/2018		2024 SR	2024 gamma_jets_CR	2024 W_CR	comments
Trigger	VBF+γ	single photon	pt miss	single photon			
Number of photons	>=1			1			
pt γ	> 80GeV	> 230 GeV	> 80GeV	100GeV			
η γ	< 1.47			< 1.4442			
Number of leptons	0 (veto loose electron or muon)					0 (veto loose photon)	
pt j	> 30GeV						
pt j1,j2	>50GeV			j1>80GeV, j2>40GeV			
pt miss	> 100GeV	> 140GeV					
jet countinng	2 to 5			none			
mjj	> 500 GeV						
η j	< 4.7						
|Δηjj|	> 3.0						
ηj1ηj2	< 0						
jets and ptmiss dphi	> 1.0				<0.5	> 1.0	
Zeppendfeld	< 0.6						
total pt	< 150GeV						
dijet dphi	none			Δφ < 1.5			

- **g+jets CR**:the full SR selection is applied, but dphi(jets,met)< 0.5
- **W+jets CR**:an electron must be selected and no photons found electron is then used in place of the signal photon to build all kinematic variable

- Pt miss > 100(140) && azimuthal angle between all jets with pt >30 and met >1.0
  - For the purpose of rejecting the bulk of the g+jets background, as well as the signal process with small Lorentz boost of the Higgs boson
    - For g+jets background, the met is introduced by energy mismeasurement which value is around few
- veto is applied rejecting events with any loosely identified electron or muon
  - To reduce the background from leptonic events
- |Δηjj|>3 && mjj>500GeV &&Zeppenfeld<0.6

$$z_\gamma^* \equiv \left| \left(\eta_\gamma - (\eta_{j_1} + \eta_{j_2})/2 \right) / |\Delta\eta_{jj}| \right|$$

  - To select the VBF topology
- pt total < 150GeV
  - To reject events with jet pT mismeasurement or with additional hard jets.
- j1>80GeV, j2>40GeV
  - To loosen the subleading jet cut increases VBF signal acceptance while keeping backgrounds under control.
- Δφ(j1,j2) < 1.5
  - To suppress back-to-back QCD γ+jets backgrounds, with limited signal loss.

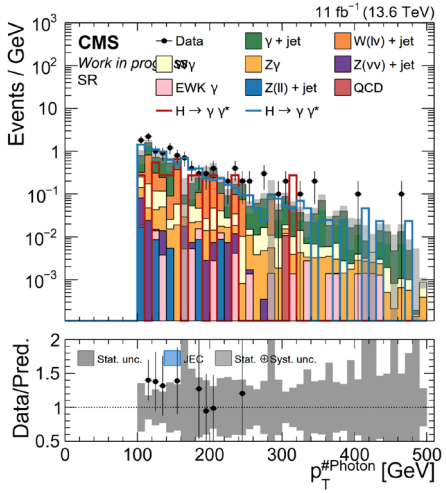
Yields of VBF category

	Type	Name	Run2(EW+QCD)	2024 11.42fb-1	2024 scaled to Run2	Ratio(Run2/2024 scaled)	Comments
SR	signal	ggF	30.6	33.91364	19.31025705	1.584650061	sig: factor = yield(12pb-1)*11.3879*0.05 bkg: factor = yield(12pb-1)*11.3879
		VBF	50.5	90.827787	51.71688778	0.976470205	
	background	Gjet	230	44.21629592	503.5307563	0.456774481	
		Wjet	250	19.812616	225.6240897	1.108037711	only QCD for 2024
		Znunu jet	41	1.331076	15.15816038	2.704813709	
		Zgamma	98	2.6761271	30.4754678	3.215701253	
		Wgamma	98	6.6987499	76.28469399	1.284661377	

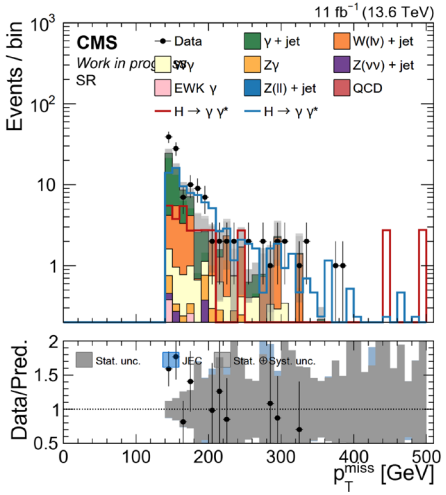
	Type	Name	Run2(EW+QCD)	2024 11.42fb-1	2024 scaled to Run2	Ratio(Run2/2024 scaled)	Comments
g+jets	signal	ggF	4.5	0	0	-	sig: factor = yield(12pb-1)*11.3879*0.05 bkg: factor = yield(12pb-1)*11.3879
		VBF	6.9	1.9606564	1.116387951	6.180647144	
	background	Gjet	1400	20.42021065	232.5433169	6.020383724	
		Wjet	180	-0.61514688	-7.005231155	-	only QCD for 2024
		Znunu jet	26	0.29030779	3.305996082	7.864498129	
		Zgamma	46	0.23849077	2.71590904	16.93723881	
		Wgamma	76	1.3064934	14.87821619	5.108139244	

	Type	Name	Run2(EW+QCD)	2024 11.42fb-1	2024 scaled to Run2	Ratio(Run2/2024 scaled)	Comments
W+jets	signal	ggF	1.2	2.7587919	1.570842314	-	sig: factor = yield(12pb-1)*11.3879*0.05 bkg: factor = yield(12pb-1)*11.3879
		VBF	1.7	4.2924684	2.444110045	0.695549697	
	background	Gjet	12	0.774578338	8.820820655	1.360417638	
		Wjet	10500	491.17354	5593.435156	1.87720063	only QCD for 2024
		Znunu jet	100	-0.22281022	-2.537340504	-	
		Zgamma	6.8	0.075261505	0.857070493	7.934003162	
		Wgamma	240	12.63157	143.847056	1.668438734	

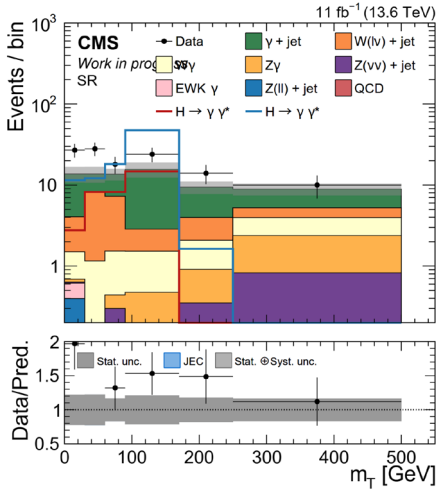
SR Distributions of VBF category



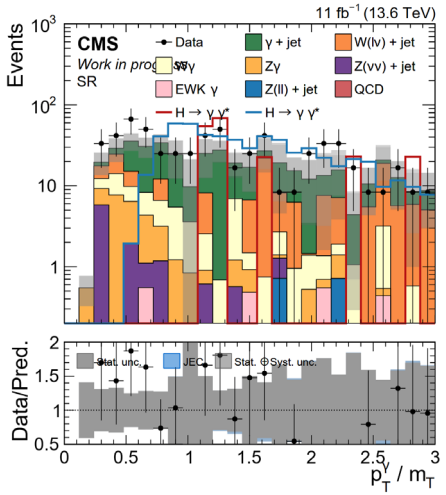
Gamma pt



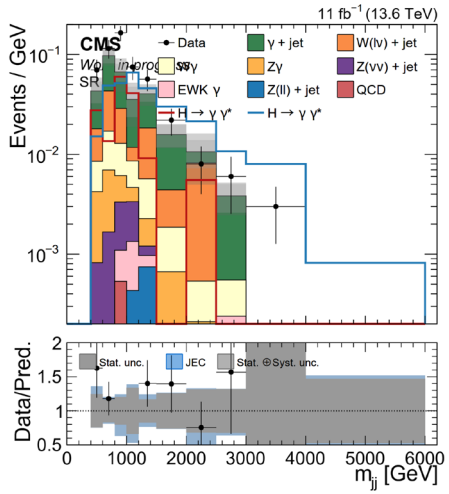
MET



MT



pt_gamma_over_MT

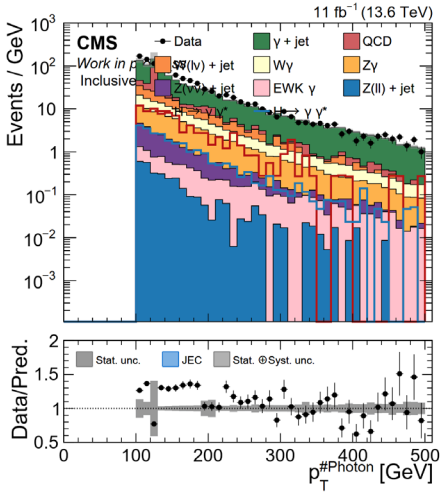


Mjj

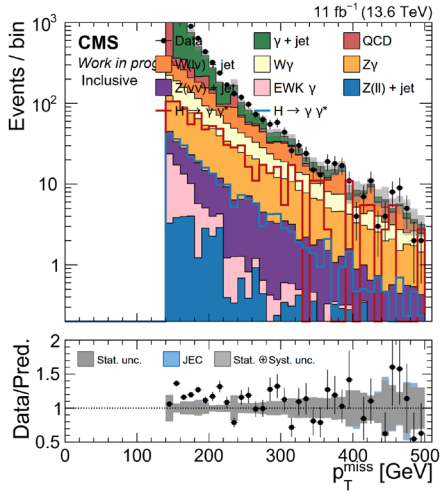
/eos/home-i00/l/lotan/www/pyRATOUTPUT/darkphoton_11_3/SR_VBF

- Data matches well with the MC for gamma pt and pt_gamma_over_MT
- No major issues with the MET modeling
- Minor deviation in the mid–high MT region
- VBF topology well captured

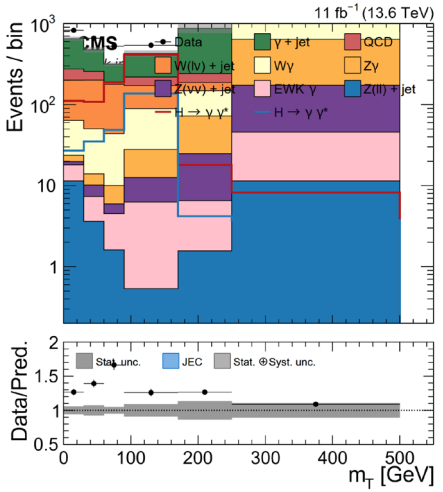
SR Distributions of Inclusive jets category



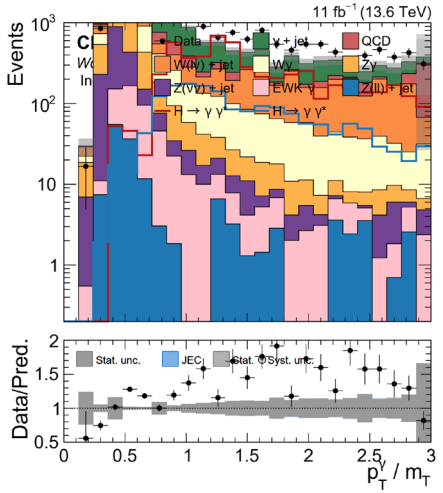
Gamma pt



MET



MT



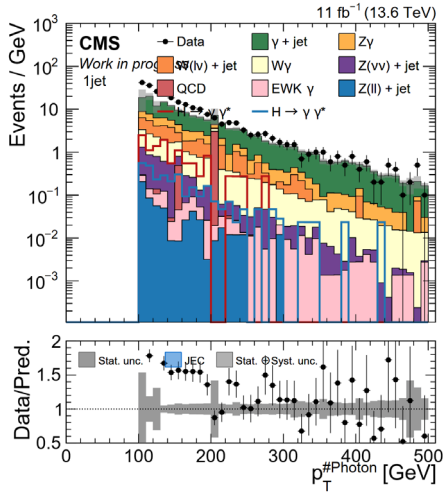
pt_gamma_over_MT

/eos/home-i00/l/lotan/www/pyRATOUTPUT/darkphoton_11_3/SR_Inclusive

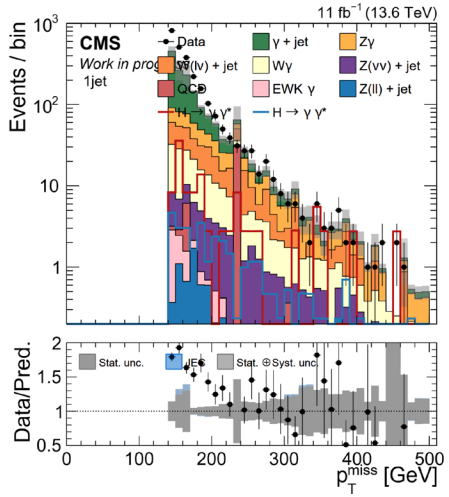
- More statistics
- Data matches well with the MC for MET
- Deviation in the mid–high MT region
- Further improvements are needed for the selection

SR Distributions of jet-num category

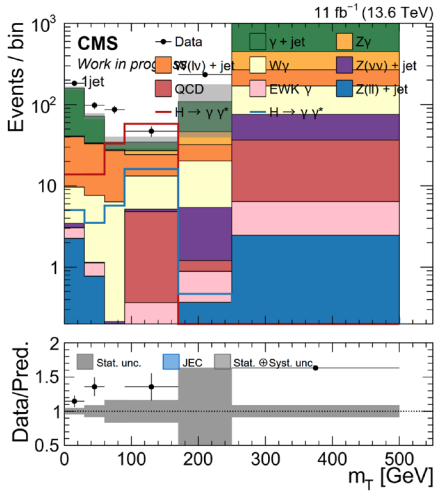
1-jet



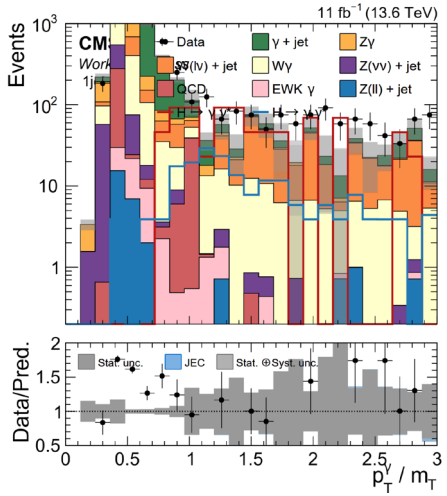
Gamma pt



MET



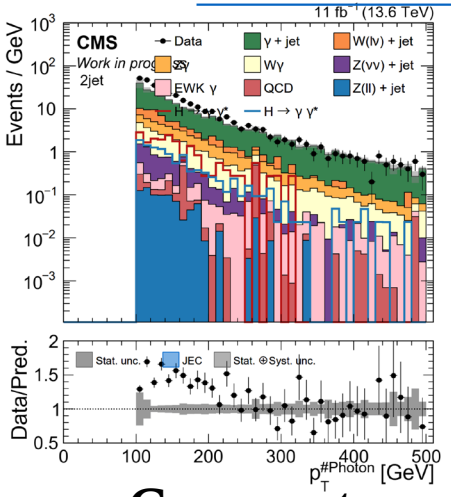
MT



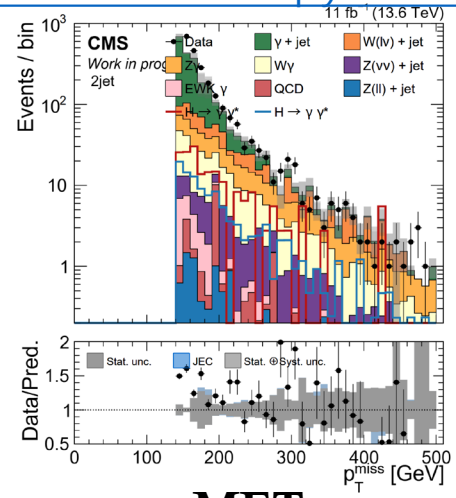
pt_gamma_over_MT

/eos/home-i00/l/lotan/www/pyRATOUTPUT/darkphoton_11_3/SR_1jet

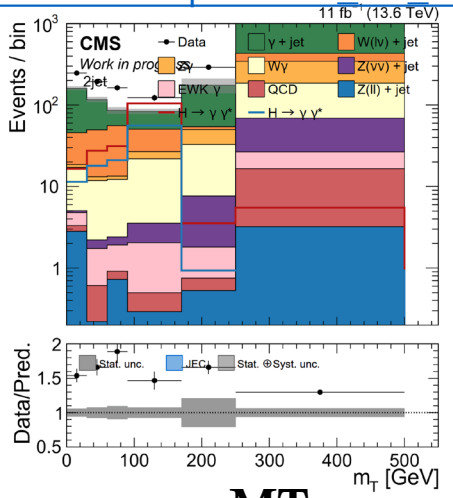
2-jets



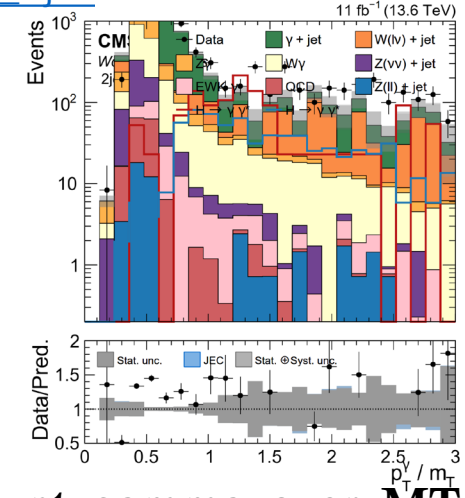
Gamma pt



MET



MT



pt_gamma_over_MT

/eos/home-i00/l/lotan/www/pyRATOUTPUT/darkphoton_11_3/SR_2jet

Preliminary Limit

- **Processes used: ggF, VBF, QCD Gjet, QCD_Wjet, EWK Gjet, Zgamma, Wgamma**

		2024				Run2		
		VBF category	Inclusive jets category	1-jet category	2-jet category	VBF category	VH category	VBF+ZH category
11.42pb-1	SR_VBF(mjj whole region)	11.91%	6.49%	14.16%	11.08%	-		
	SR_VBF(mjj 500 1500)	42.38%	-					
	SR_VBF(mjj 1500 6000)	17.24%						
	SR_VBF(mjj combine)	15.72%						
Scaled to Run2 luminosity								
130pb-1	SR_VBF(mjj whole region)	3.53%	1.92%	4.20%	3.28%			
	SR_VBF(mjj 500 1500)	12.56%	-					
	SR_VBF(mjj 1500 6000)	5.11%						
	SR_VBF(mjj combine)	4.66%				2.80%	3.60%	2.10%

Next

- Improve VBF category
  - Lower photon threshold
  - Refine selections
  - Introduce CR control
- Introduce more uncertainties
- Develop inclusive jets and jet-num category