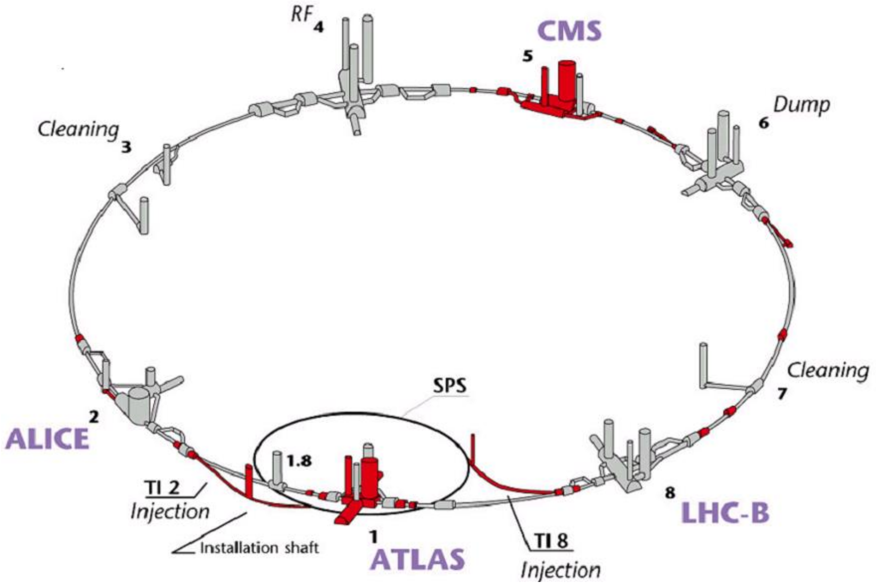
Higgs->γγ coupling study on ATLAS run 2

HUIJUN ZHANG（LAL）

Large Hadron Collider

- Worlds' largest accelerator
- ≈27 km circonference, 175 m under ground
- proton proton,$\sqrt{s}$=13 TeV(run 2)
- B=8,33 T (→≈4.16 T)
- ≈ 2800 bunches of protons (1 bunch ≈ 10^{11} p)→1380 bunches ; 1.5 10^{11} p
- collisions each 25 ns (→≈50 ns)



ATLAS	general purpose
CMS	general purpose
ALICE	quark–gluon plasma
LHCb	flavour physics, CP violation

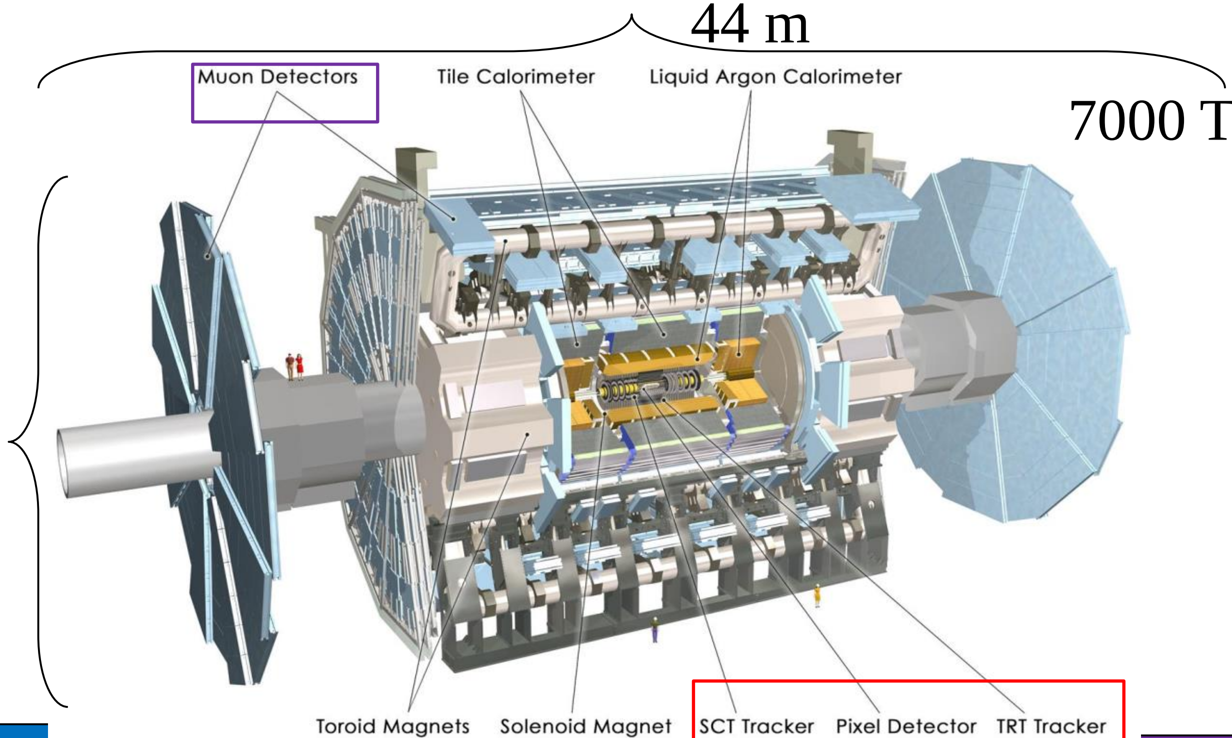
The experimental apparatus : ATLAS

1

Inner Detector ($|\eta|<2.5$, B=2 T)
Si pixels, strips, Transition Radiation Tracker
Tracking, vertexing, e/π separation
$\sigma(p_T)/p_T < 3.8.10^{-4}$ pT [GeV] $\oplus$ 0.015

2

EM Calorimeter ($|\eta|<3.2$)
Pb-LAr accordion, longitudinal segmentation
e/γ separation
$\sigma(E)/E \approx 10\ \%/\sqrt{E} \oplus 0.7\ \%$



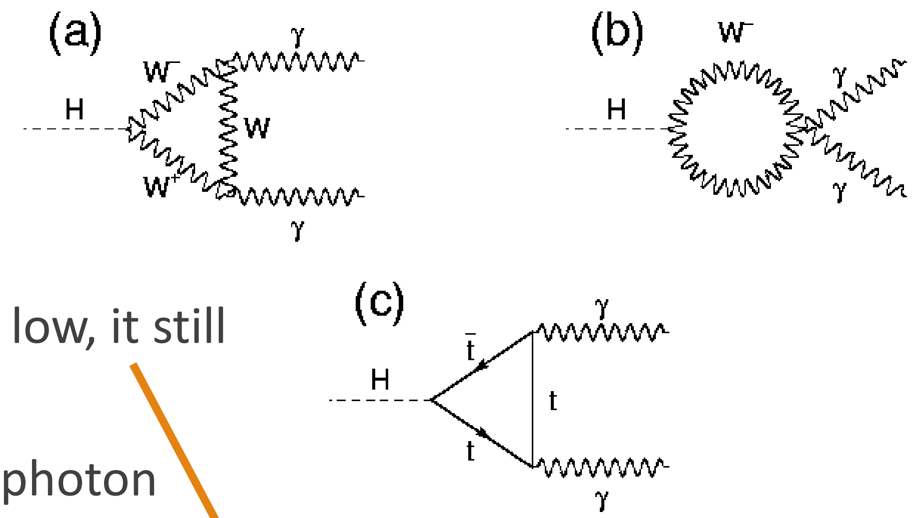
Hadronic Calorimeter
Fe-scint. ($|\eta|<1.7$) ; Cu-LAr $1.5<|\eta|<3.2$
Cu/W -LAr (fwd : $3.1<|\eta|<4.9$)
Trigger, jet, MET ; $\sigma(E)/E \approx 50\ \%/\sqrt{E} \oplus 3\ \%$

3

Muon Spectrometer ($|\eta|<2.7$)
Air core toroid magnets (0.5-1 T), gas chambers
μ trigger and momentum measurement
$\sigma(p_T)/p_T$=2% at 50 GeV ; 10 % at 1 TeV

4

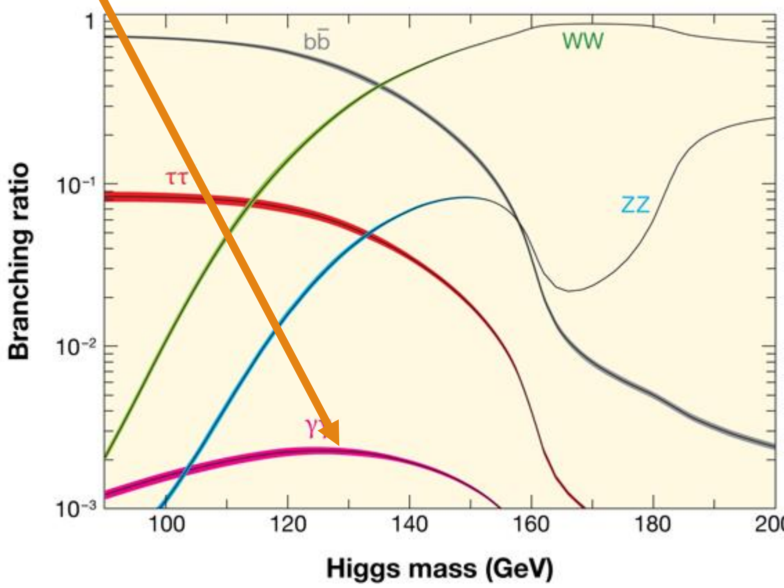
Higgs -> γγ



Although branching ratio for Higgs -> γγ is low, it still has many advantages:

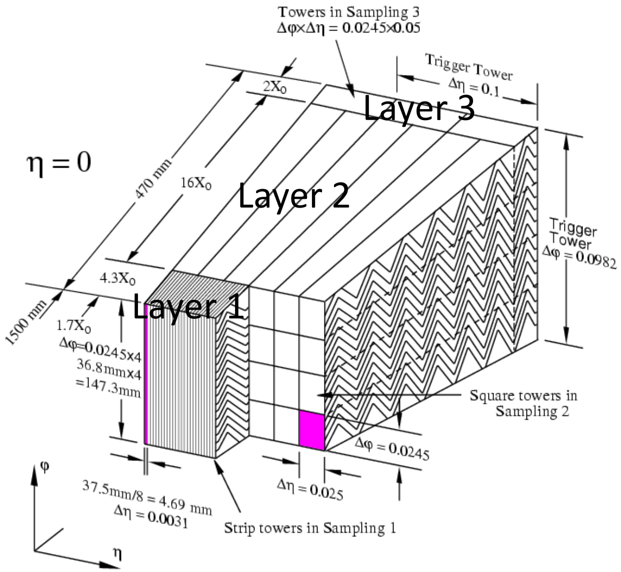
- Clear structure of final state: two high pT photon
- Relatively low background
- very nice resolution

➢ Together made γγ a important channel for the discovery and measurement of Higgs

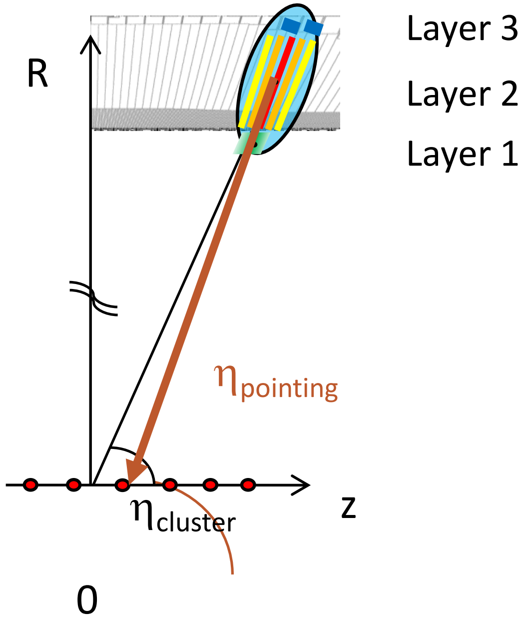


Photon selections

- exploits segmentation of electromagnetic calorimeter in order to :

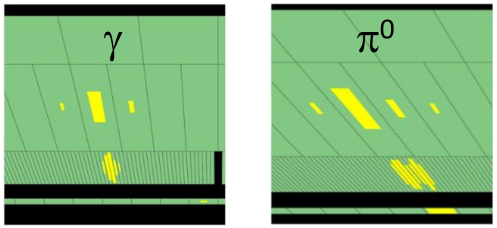


(1) measure direction : MVA :
{calorimeter pointing
+ some variables}

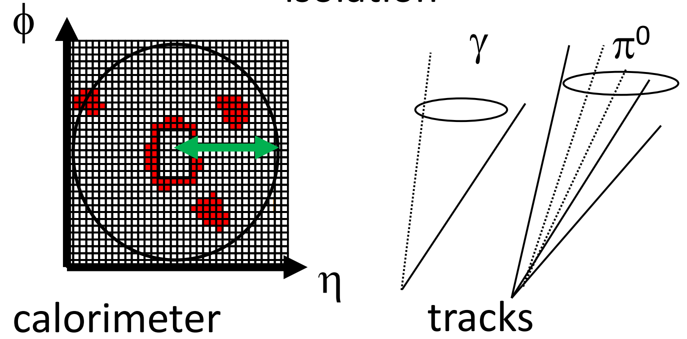


(2) identify photons
(suppress fake photons)

-shower shapes



-isolation



GOALs

Signal strengths, scale factor μ, κ framework

depends on reference to compare with (both model and precision)

Higgs Template Cross-Section (HTXS)

Compromise :
-Splitting by theoretical property (typically production mode)
-Merging of fiducial regions
Allow to test in a simplified way various BSM models
→exclusive kinematic fiducial regions

Fiducial / differential cross-sections

Region within detector acceptance
→no model dependence (when one extrapolates to higher acceptance)

Not included in this talk

measure strength of various Higgs production modes / couplings, with $H \rightarrow \gamma\gamma$ final state.

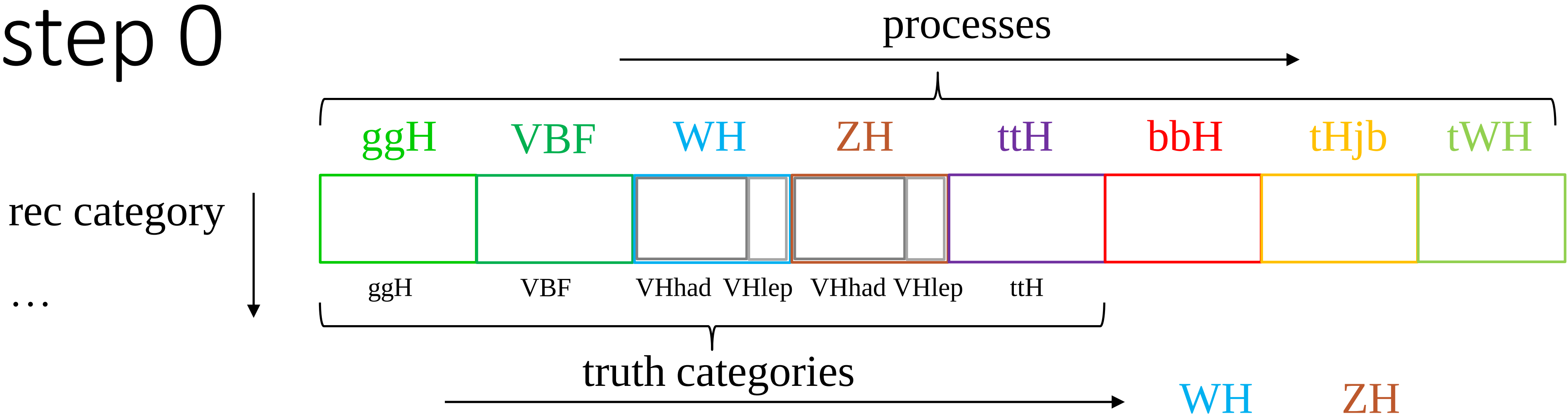
-signal strengths (μ_i)

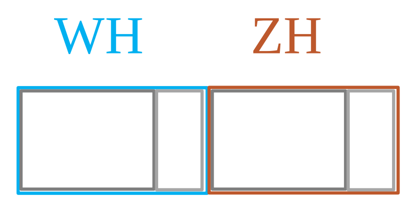
-simplified cross-sections ('HTXS') [**H**iggs **T**emplate Cross (**X**)-**S**ection]

-cross-sections (σ_ixBR) : total or fiducial

Ichep analysis : the three measurements done

Higgs template cross section (HTXS) step 0





Note the split/merge : truth category is **not** just a subset of one process

r : reconstructed category

t : truth category (split/merge of processes ⇔truth category)

A: Acceptance

$\mathrm{Pdf}=\Pi_r\,\{n_{sig}^r\,\mathrm{Pdf}_{sig}^r+n_{bkg}^r\mathrm{Pdf}_{bkg}^r\}$

POIs (here σ contains BR)

- $\mu=\sigma_t\,/\,\sigma_t^{SM}$ wo/ split/merge : full acceptance
- HTXS : σ_t

$$n_{sig}^r=\underbrace{\Sigma_t\,\underbrace{\overbrace{\sigma_t}^{\mu\,\sigma_t^{SM}}.A_{tr}^{SM}\,L}_{n_t}}_{n_{tr}}$$

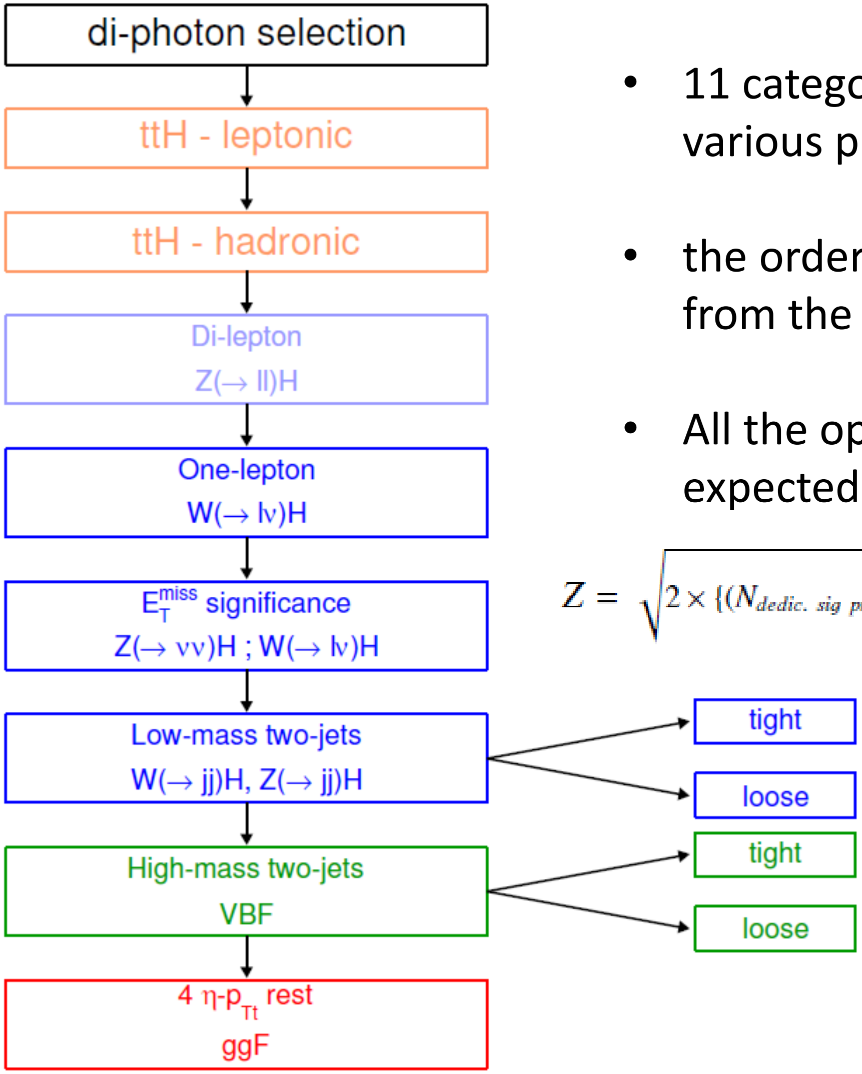
$$A_{tr}^{SM}=n_{tr}^{SM}/n_t^{SM}$$

$$n_t^{SM}=\sigma_t^{SM}.L$$

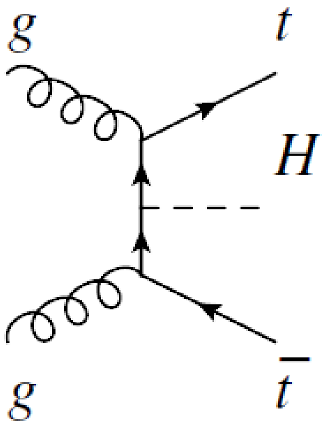
Categorization

- 11 categories are developed in order to probe the various production Higgs production modes
- the ordering is made in order to test the categories from the most rare to the most frequent
- All the optimizations of categories are based on Asimov expected significance

$$Z = \sqrt{2 \times \{(N_{dedic.\ sig\ proc} + N_{other\ sig\ proc} + N_{bkg}) \times ln\left(1 + \frac{N_{dedic\ sig\ proc.}}{N_{other\ sig\ proc.} + N_{bkg}}\right) - N_{dedic.\ sig\ proc.}\}}$$



Categorization

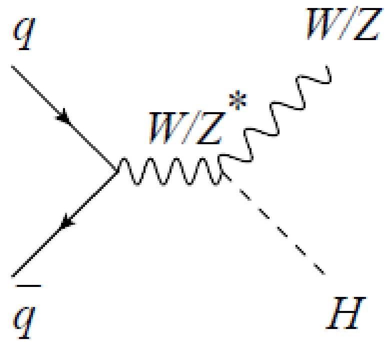


ttH categories:

ttH production is very rare but benefit from the raise of central energy, now the cross section is ~4 times @13TeV compare to LHC RUN1 @ 8TeV

The categorization is based on top W decay:

ttH lep	$N_{lep} \geq 1,\ N_{jets} \geq 2,\ N_{tags} \geq 1\ \ (\lvert\eta\rvert < 2.5,\ p_T > 25\ \mathrm{GeV})$ $\lvert m_{e\gamma} - 89\ \mathrm{GeV}\rvert > 5\ \mathrm{GeV},\ \lvert m_{\ell\ell} - 91\ \mathrm{GeV}\rvert > 10\ \mathrm{GeV},$ $E_{\mathrm{T}}^{\mathrm{miss}} > 20\ \mathrm{GeV}$ or $N_{tags} \geq 2$
ttH had	$N_{lep} = 0,\ \ N_{jets} \geq 5,\ N_{tags} \geq 1\ \ (\lvert\eta\rvert < 2.5, p_T > 30\ \mathrm{GeV})$



VH non had categories:

Both WH and ZH processes are considered

W/Z leptonic decay

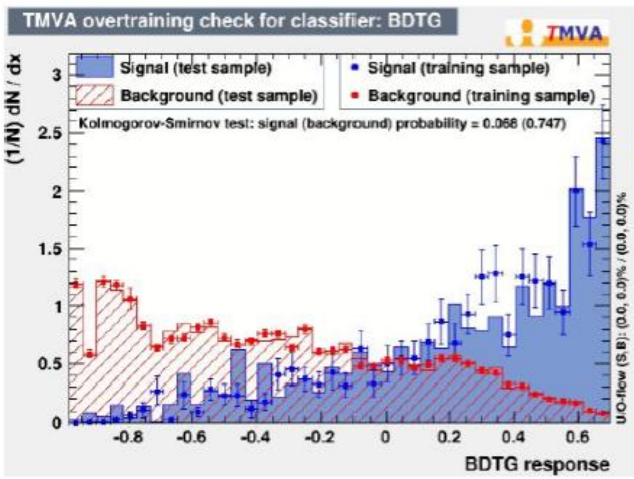
The selection is based on number of leptons and MET

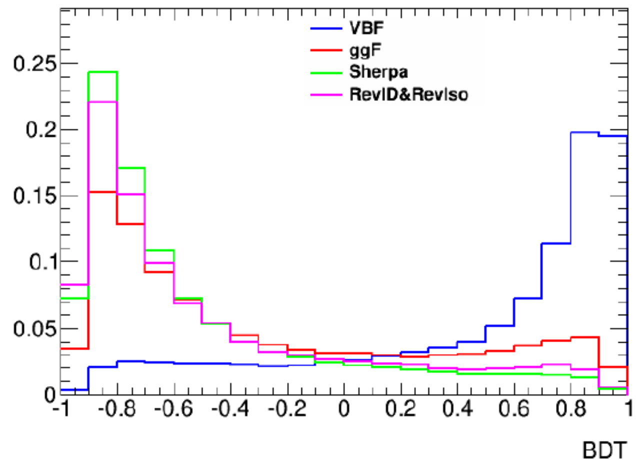
VH dilep	$N_{lep} \geq 2,\ 70\ \mathrm{GeV} \leq m_{\ell\ell} \leq 110\ \mathrm{GeV},$
VH lep	$N_{lep} = 1,\ \lvert me\gamma - 89\ \mathrm{GeV}\rvert > 5\ \mathrm{GeV},\ N_{tags} = 0,\ p_{\mathrm{T}\gamma\gamma} > 60\ \mathrm{GeV},$ $E_{\mathrm{T}}^{\mathrm{miss}}$ significance > 4.5
VH MET	$p_{\mathrm{T}\gamma\gamma} > 90\ \mathrm{GeV},\ E_{\mathrm{T}}^{\mathrm{miss}}$ significance > 7

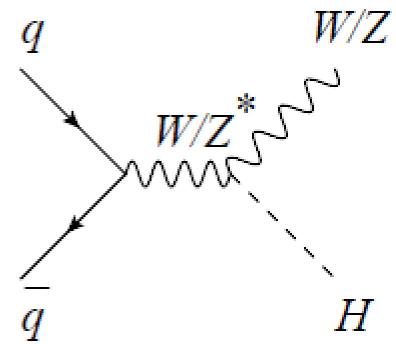
Categorization

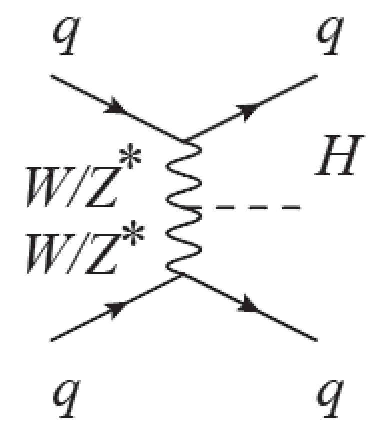
VH hadronic and VBF categories:

These categories have the same signature of 2 photon + 2 jets
BDT method is used for both analysis, each process is splitted to Tight loose 2 categories







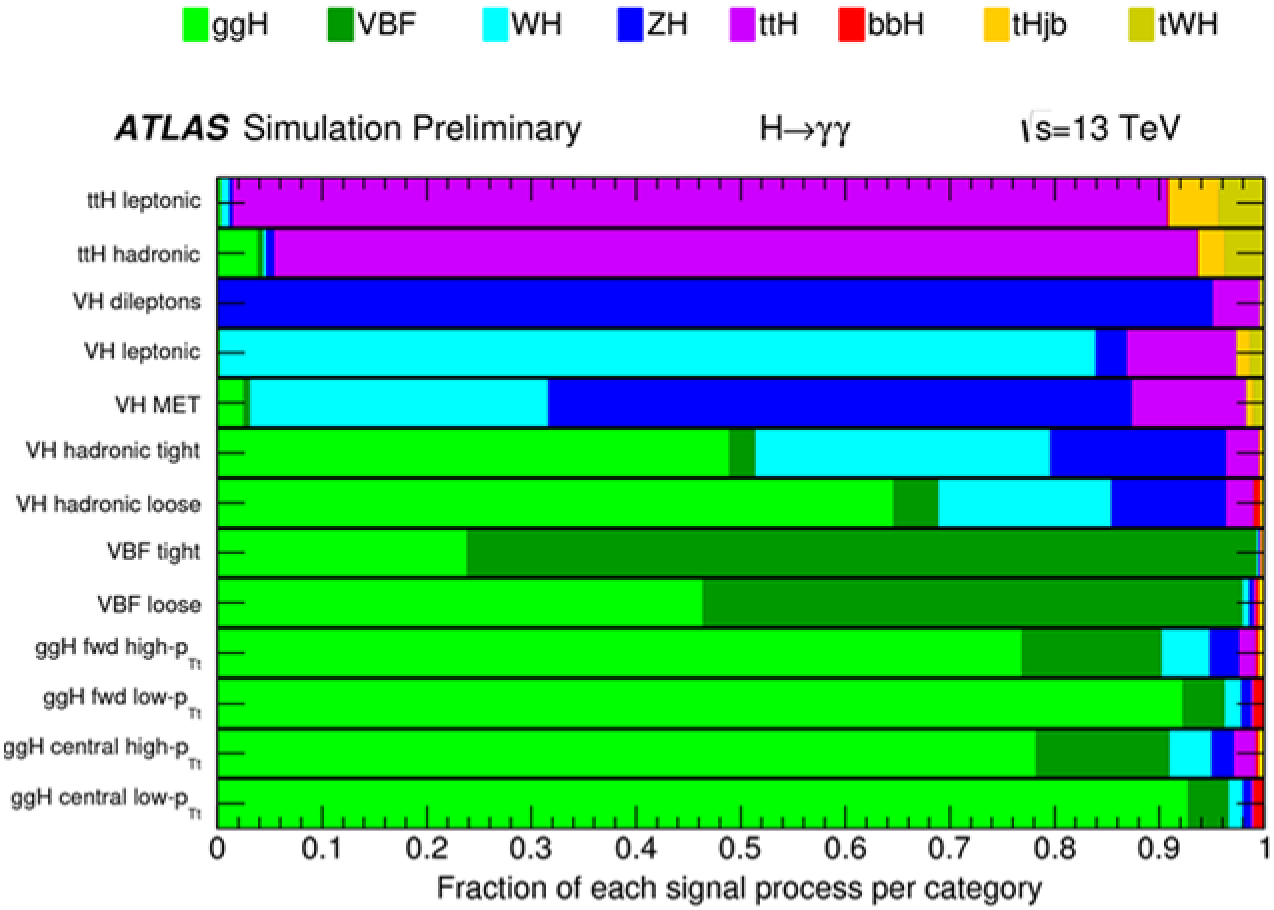


Rest categories:

The events passed inclusive photon selection but fail all above categories are considered to fall in ggH categories:
The ggH splitting is based on the photon Eta and pTt

ggH forward high p_{Tt}	remaining events, one photon w/ $\|\eta\| > 0.95$, $p_{Tt} > 70\ GeV$
ggH forward low p_{Tt}	remaining events, one photon w/ $\|\eta\| > 0.95$, $p_{Tt} \leq 70\ GeV$
ggH central high p_{Tt}	remaining events, two photons w/ $\|\eta\| \leq 0.95$, $p_{Tt} > 70\ GeV$
ggH central low p_{Tt}	remaining events, two photons w/ $\|\eta\| \leq 0.95$, $p_{Tt} \leq 70\ GeV$

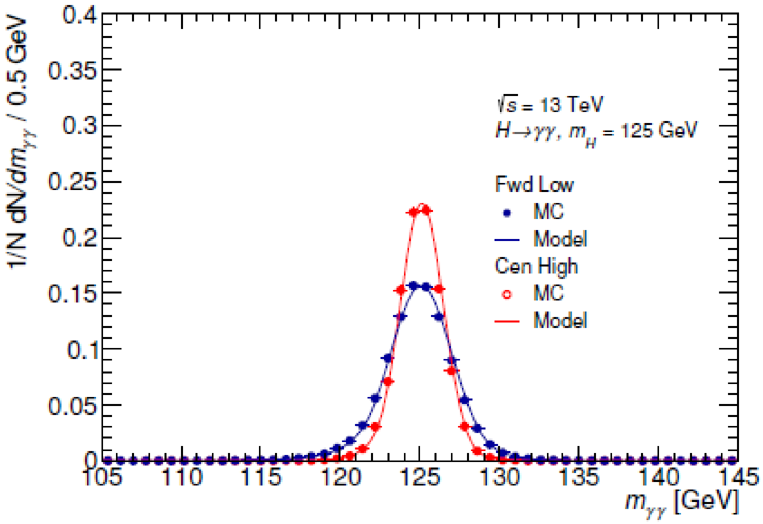
Categorization purity



Signal modelling

Crystal Ball function (CB)+Gauss (means)
function is used to describe the signal shape

Normalization : yields
-cross-sections : LHC Higgs WG
-effect of selection : from simulation (MC) samples



Category	$\sqrt{s}$=13 TeV	
	σ_{68} [GeV]	σ_{90} [GeV]
ggH CenLow	1.60	2.72
ggH CenHigh	1.39	2.36
ggH FwdLow	2.07	3.65
ggH FwdHigh	1.84	3.22
VBF low	1.68	2.96
VBF high	1.53	2.73
VH hadronic low	1.65	2.90
VH hadronic high	1.49	2.61
VH MET	1.65	2.86
VH leptonic	1.68	2.99
VH dileptons	1.73	2.99
ttH hadronic	1.60	2.87
ttH leptonic	1.65	2.85

Signal efficiency

- All the processes considered in the analysis are listed in the table
- These are the efficiency estimated from MC samples
- bbH, tHjb and tWH processes are not fitted in the final analysis due to their low cross section

	ggH		VBF		WH		ZH		ttH		bbH		tHjb		tWH		
Category	$\epsilon(\%)$	$f(\%)$	$\epsilon(\%)$	$f(\%)$	$\epsilon(\%)$	$f(\%)$	$\epsilon(\%)$	$f(\%)$	$\epsilon(\%)$	$f(\%)$	$\epsilon(\%)$	$f(\%)$	$\epsilon(\%)$	$f(\%)$	$\epsilon(\%)$	$f(\%)$	N_S
ggH CenLow	12.7	92.7	6.9	3.9	6.3	1.3	6.0	0.8	3.5	0.3	14.2	1.0	4.6	0.1	3.8	0.0	201.0
ggH CenHigh	1.2	78.2	2.4	12.8	2.1	4.0	1.8	2.2	2.9	2.0	0.4	0.3	3.7	0.4	5.1	0.2	21.5
ggH FwdLow	22.0	92.1	12.5	4.1	13.0	1.5	12.7	1.0	5.1	0.2	24.9	1.0	9.5	0.1	4.8	0.0	348.8
ggH FwdHigh	1.9	76.8	4.1	13.4	3.9	4.6	3.7	2.8	3.6	1.5	0.8	0.3	6.6	0.4	4.8	0.1	35.3
VBF low	0.5	46.3	7.3	51.6	0.2	0.6	0.2	0.4	0.3	0.3	0.4	0.3	3.4	0.5	0.6	0.0	16.2
VBF high	0.1	23.8	5.4	75.5	0.0	0.1	0.0	0.1	0.0	0.1	0.0	0.0	1.2	0.3	0.1	0.0	8.1
VH hadronic low	0.4	64.6	0.4	4.3	3.9	16.5	4.1	11.0	1.7	2.6	0.5	0.6	1.0	0.2	2.2	0.2	9.8
VH hadronic high	0.1	48.9	0.1	2.5	1.8	28.1	1.6	16.9	0.5	3.1	0.0	0.1	0.3	0.2	0.7	0.2	2.6
VH E_T^{miss}	0.0	2.4	0.0	0.6	0.6	28.5	1.9	55.8	0.6	10.9	0.0	0.0	0.3	0.7	1.2	1.0	0.9
VH one-lepton	0.0	0.2	0.0	0.0	1.3	83.7	0.1	3.0	0.4	10.4	0.0	0.0	0.4	1.3	1.1	1.3	0.6
VH dilepton	0.0	0.0	0.0	0.0	0.0	0.0	1.2	95.1	0.1	4.5	0.0	0.0	0.0	0.0	0.2	0.4	0.3
$t\bar{t}H$ hadronic	0.0	3.8	0.0	0.5	0.0	0.3	0.1	0.8	11.5	88.1	0.0	0.2	2.2	2.5	10.1	3.8	2.0
$t\bar{t}H$ leptonic	0.0	0.3	0.0	0.1	0.0	0.7	0.0	0.4	8.4	89.3	0.0	0.2	3.1	4.8	8.3	4.3	1.4
Total efficiency (%)	38.9	-	39.2	-	33.2	-	33.5	-	38.6	-	41.2	-	36.2	-	43.1	-	51.4
Events	568.8		44.6		13.7		8.9		5.9		5.6		0.8		0.3		648.6

Background modelling: composition

For categories only considering photon and jets, the dominant background is from SM γγ production(~80%),Following by γjet(18%), jetjet(2%)
For other categories, for ICEHP, we only considered γγ+jets and Vγγ processes

	Yield ± stat. ± syst.			Fraction ± stat. ± syst. [%]		
	$\gamma\gamma$	γ-jet	jet-jet	$\gamma\gamma$	γ-jet	jet-jet
Coupling Cat.						
Inclusive	$98012 \pm 432^{+2378}_{-5064}$	$23136 \pm 269^{+4394}_{-2057}$	$3151 \pm 61^{+609}_{-439}$	$78.9 \pm 0.2^{+1.9}_{-4.0}$	$18.6 \pm 0.2^{+3.5}_{-1.7}$	$2.5 \pm 0.1^{+0.5}_{-0.4}$
ggH CtrLow	$26422 \pm 210^{+699}_{-648}$	$4945 \pm 111^{+639}_{-572}$	$567 \pm 22^{+59}_{-175}$	$82.7 \pm 0.4^{+2.2}_{-2.0}$	$15.5 \pm 0.4^{+2.0}_{-1.8}$	$1.8 \pm 0.1^{+0.2}_{-0.5}$
ggH CtrHigh	$1163 \pm 41^{+75}_{-23}$	$157 \pm 18^{+20}_{-72}$	$5 \pm 1^{+4}_{-5}$	$87.8 \pm 1.5^{+5.8}_{-1.7}$	$11.8 \pm 1.5^{+1.5}_{-5.4}$	$0.4 \pm 0.1^{+0.3}_{-0.4}$
ggH FwdLow	$65744 \pm 364^{+1723}_{-4577}$	$16988 \pm 239^{+3918}_{-1447}$	$2545 \pm 58^{+578}_{-271}$	$77.1 \pm 0.3^{+2.0}_{-5.3}$	$19.9 \pm 0.3^{+4.6}_{-1.7}$	$3.0 \pm 0.1^{+0.7}_{-0.3}$
ggH FwdHigh	$3358 \pm 75^{+84}_{-125}$	$600 \pm 40^{+86}_{-76}$	$26 \pm 6^{+49}_{-8}$	$84.3 \pm 1.2^{+2.1}_{-3.1}$	$15.1 \pm 1.1^{+2.2}_{-1.9}$	$0.6 \pm 0.2^{+1.2}_{-0.2}$
VBF Low	$444 \pm 31^{+19}_{-11}$	$150 \pm 19^{+10}_{-23}$	$9 \pm 4^{+8}_{-5}$	$73.5 \pm 3.7^{+3.0}_{-1.9}$	$24.9 \pm 3.7^{+1.6}_{-3.9}$	$1.5 \pm 0.7^{+1.3}_{-0.8}$
VBF High	$52 \pm 11^{+1}_{-10}$	$21 \pm 7^{+11}_{-1}$	$2 \pm 1^{+3}_{-0}$	$69.7 \pm 11.1^{+1.5}_{-13.5}$	$27.8 \pm 10.9^{+13.9}_{-1.0}$	$2.5 \pm 1.8^{+4.0}_{-0.7}$
VH HadLow	$792 \pm 37^{+19}_{-30}$	$141 \pm 20^{+32}_{-17}$	$7 \pm 3^{+2}_{-5}$	$84.2 \pm 2.4^{+2.1}_{-3.2}$	$15.0 \pm 2.4^{+3.4}_{-1.8}$	$0.8 \pm 0.4^{+0.2}_{-0.5}$
VH HadHigh	$59 \pm 9^{+1}_{-3}$	$8 \pm 4^{+2}_{-1}$	$0 \pm 0^{+0}_{-0}$	$87.9 \pm 6.5^{+1.5}_{-3.2}$	$12.1 \pm 6.5^{+3.2}_{-1.4}$	$0.1 \pm 0.2^{+0.1}_{-0.1}$
VH MET	$4 \pm 12^{+8}_{-0}$	$15 \pm 9^{+0}_{-9}$	$1 \pm 2^{+1}_{-1}$	$19.5 \pm 56.3^{+41.0}_{-1.6}$	$76.6 \pm 56.0^{+0.6}_{-45.1}$	$3.9 \pm 11.0^{+4.3}_{-4.0}$
VH Lep	$6 \pm 6^{+1}_{-1}$	$2 \pm 2^{+1}_{-2}$	$0 \pm 5^{+1}_{-0}$	$74.8 \pm 67.8^{+13.0}_{-10.2}$	$24.2 \pm 45.1^{+9.7}_{-21.3}$	$1.0 \pm 58.9^{+8.3}_{-0.8}$
VH DiLep	$1 \pm 2^{+0}_{-1}$	$2 \pm 4^{+1}_{-1}$	$0 \pm 3^{+1}_{-0}$	$39.0 \pm 110.6^{+1.5}_{-32.6}$	$50.9 \pm 125.2^{+42.7}_{-19.5}$	$10.1 \pm 98.6^{+33.1}_{-10.3}$
ttH Had	$70 \pm 9^{+1}_{-12}$	$2 \pm 5^{+13}_{-1}$	$1 \pm 1^{+0}_{-1}$	$95.6 \pm 7.5^{+1.7}_{-17.2}$	$2.7 \pm 7.4^{+18.1}_{-1.4}$	$1.6 \pm 1.3^{+0.4}_{-1.0}$
ttH Lep	$20 \pm 15^{+1}_{-1}$	$1 \pm 2^{+1}_{-1}$	$0 \pm 0^{+0}_{-0}$	$94.4 \pm 10.7^{+5.7}_{-3.1}$	$5.4 \pm 10.6^{+3.0}_{-5.7}$	$0.2 \pm 0.6^{+1.8}_{-0.4}$

Background modelling: shape

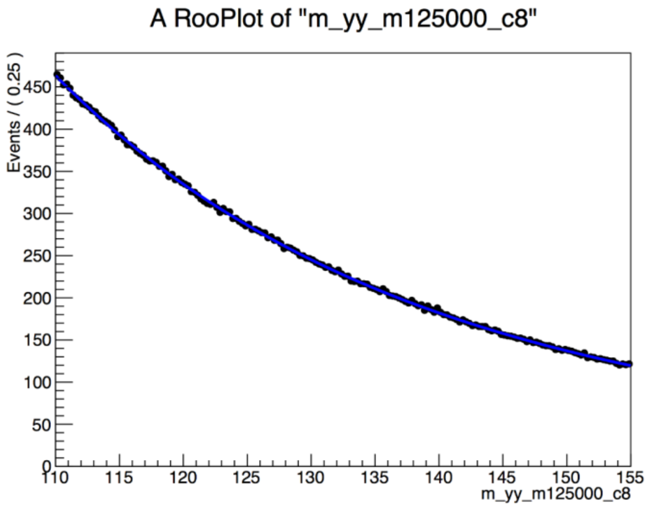
The function form of the background in each category is defined by spurious signal method

Spurious signal is the fake signal fitted from fluctuation of background only samples

Four different functions are tested and the one with least dimension of freedom satisfies at least one of the following two criteria:

- $N_{sp} < 10\% \, N_{Signal}$
- $N_{sp} < 20\%$ resolution$_{Signal}$

Will be chosen for the background shape, and the fitted spurious signal will be count as a source of systematic



Category	Model	$\sqrt{s}$ = 13 TeV N_{spur}	Z_{spur}	μ_{spur}
Inclusive	Exp2	-34.40	-26.5%	-7.0 %
ggH CenLow	Exp2	-4.22	-6.8 %	-2.8 %
ggH CenHigh	Exp2	1.12	10.1 %	5.9 %
ggH FwdLow	Exp2	-23.15	-19.5 %	-9.0 %
ggH FwdHigh	Exp2	-2.71	-11.9 %	-8.8 %
VBF loose	Exp1	0.76	10.1 %	6.1 %
VBF tight	Exp1	-0.15	-6.1 %	-2.5 %
VH hadronic loose	Exp1	0.69	7.1 %	8.9 %
VH hadronic tight	Exp1	0.26	10.6 %	13.3 %
VH MET	Exp1	-0.16	-10.6%	-23.1 %
VH leptonic	Exp1	0.07	7.6 %	13.8 %
VH dileptons	Exp1	-0.03	-6.9 %	-13.2 %

Systematics: components

Following systematics are considered in the analysis:

Theoretical uncertainties:

- The uncertainties due to theoretical miss modelling
- Divided into two parts
  - QCD & PDF on the yield
  - Pdf uncertainties on the acceptance
- Higgs -> γγ Branching ratio uncertainty

Experimental uncertainties:

- Uncertainties on the total signal yield:

  Luminosity, trigger, pile-up, photon id/isolation …
- Migration systematic uncertainties:
  - Uncertainties allow events move from one category to another
  - E.g. uncertainties from jets, leptons, missing ET

Systematics: Ranking

- Impact of NP :

Pre-fit : using nominal NP

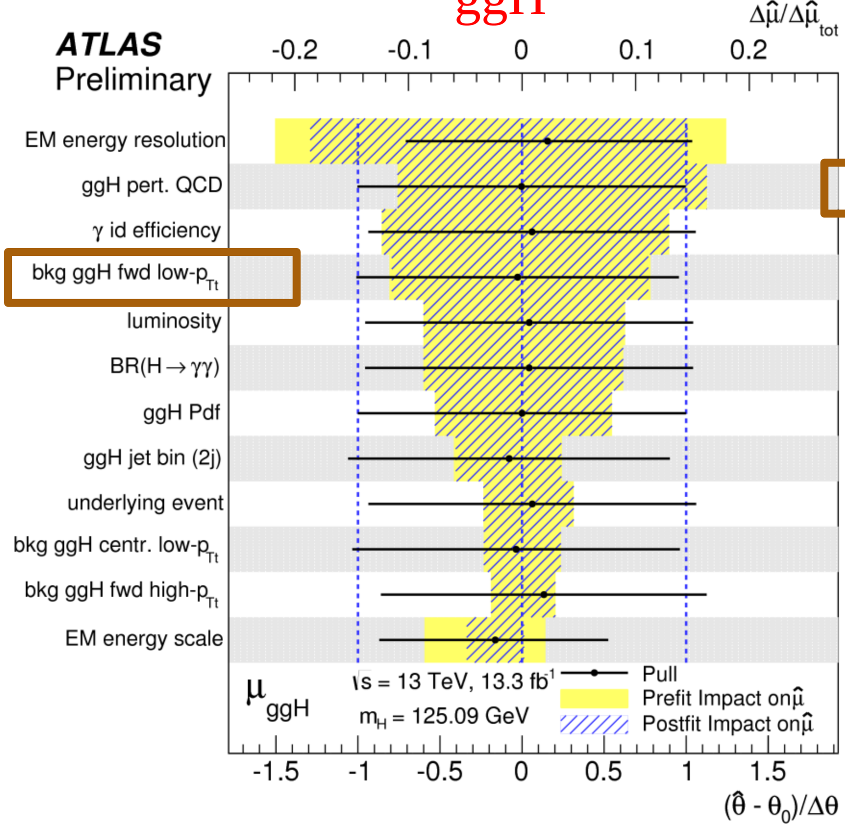
Post-fit : using NP obtained from fit

- Pull

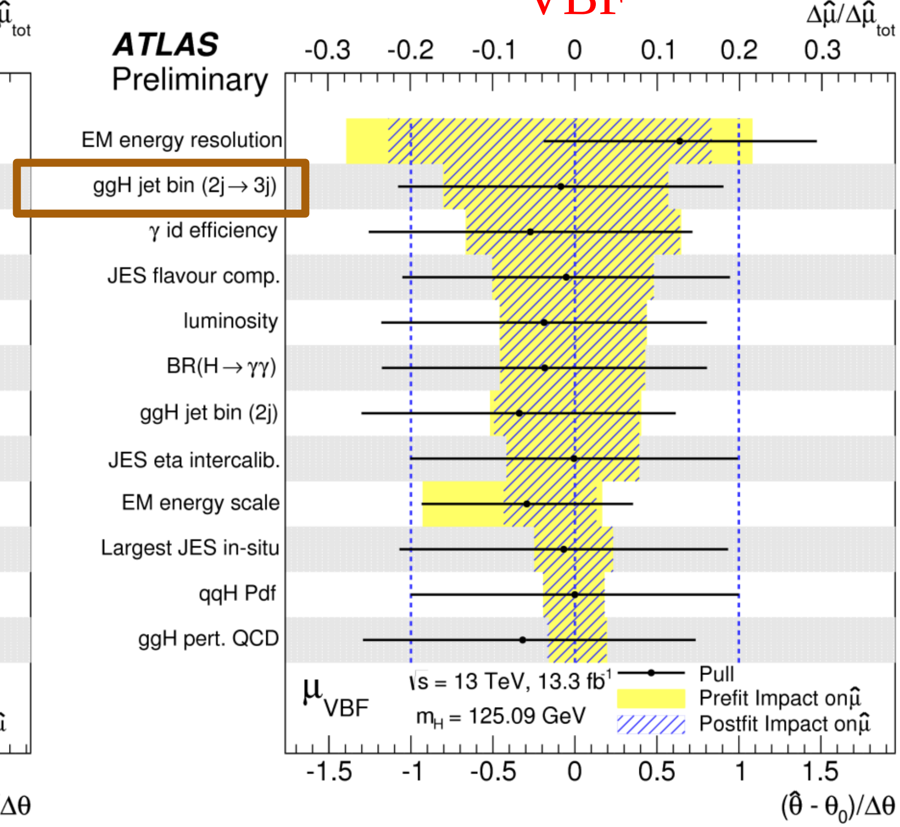
Would hint a problem of modelization

→looks fine for the available statistics

ggH



VBF



- Calibration : dominant sources of systematics

Results ICHEP ATLAS couplings H→γγ

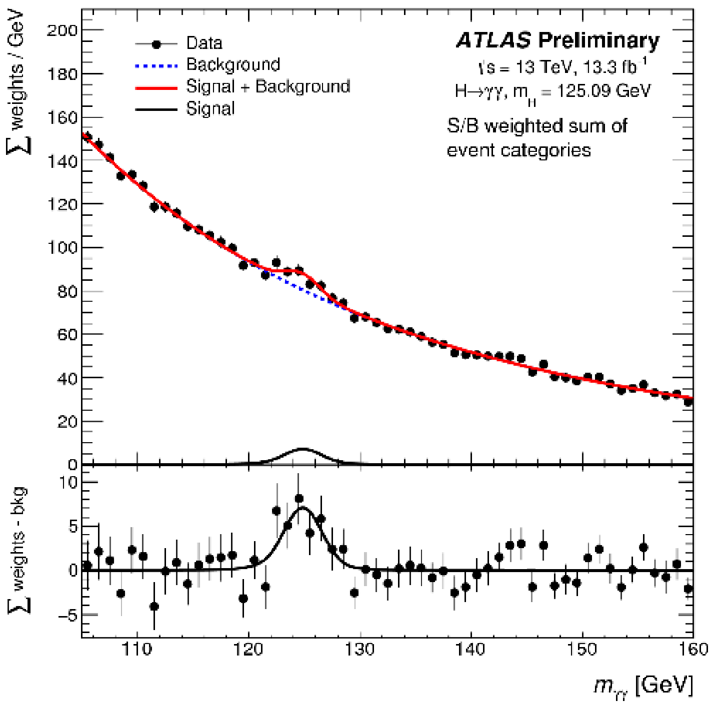
L=13.3 fb^{-1} (2015 : 3.2 fb^{-1}, 2016 : 10.1 fb^{-1}) <μ>=13.7

- Fixing $\mathbf{m_H}$=125.09 GeV $\mathbf{Z}_{obs}$=4.7 σ (Z_{exp}=5.4 σ) **μ**=$0.85^{+0.22}_{-0.20}$
- HTXS, step 0

$$\sigma_{ggH} \times \mathcal{B}(H \to \gamma\gamma) = 63 ^{+30}_{-29} \text{ fb}$$
$$\sigma_{\mathrm{VBF}} \times \mathcal{B}(H \to \gamma\gamma) = 17.8 ^{+6.3}_{-5.7} \text{ fb}$$
$$\sigma_{\mathrm{VHlep}} \times \mathcal{B}(H \to \gamma\gamma) = 1.0 ^{+2.5}_{-1.9} \text{ fb}$$
$$\sigma_{\mathrm{VHhad}} \times \mathcal{B}(H \to \gamma\gamma) = -2.3 ^{+6.8}_{-5.8} \text{ fb}$$
$$\sigma_{t\bar{t}H} \times \mathcal{B}(H \to \gamma\gamma) = -0.3 ^{+1.4}_{-1.1} \text{ fb}$$

- Total production cross-section

$$\sigma_{ggH} \times \mathcal{B}(H \to \gamma\gamma) = 65 ^{+32}_{-31} \text{ fb}$$
$$\sigma_{\mathrm{VBF}} \times \mathcal{B}(H \to \gamma\gamma) = 19.2 ^{+6.8}_{-6.1} \text{ fb}$$
$$\sigma_{VH} \times \mathcal{B}(H \to \gamma\gamma) = 1.2 ^{+6.5}_{-5.4} \text{ fb}$$
$$\sigma_{t\bar{t}H} \times \mathcal{B}(H \to \gamma\gamma) = -0.3 ^{+1.4}_{-1.1} \text{ fb}$$

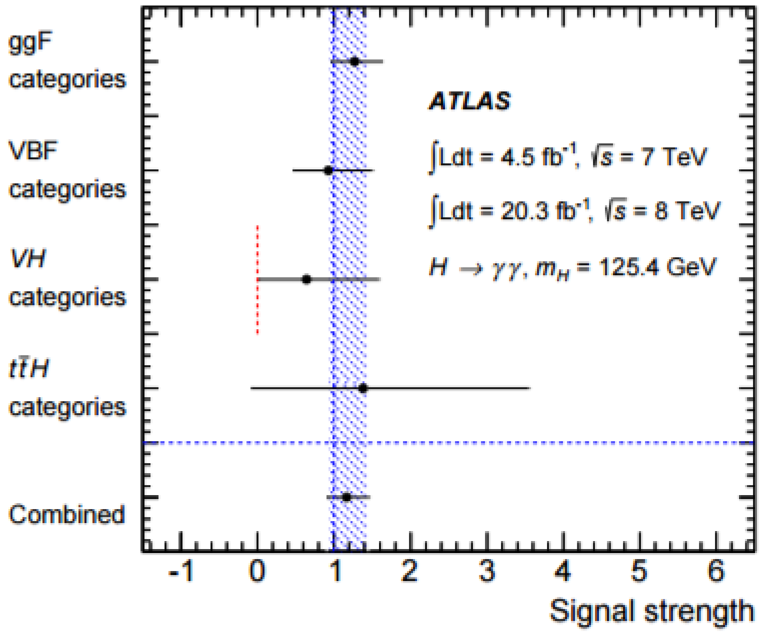


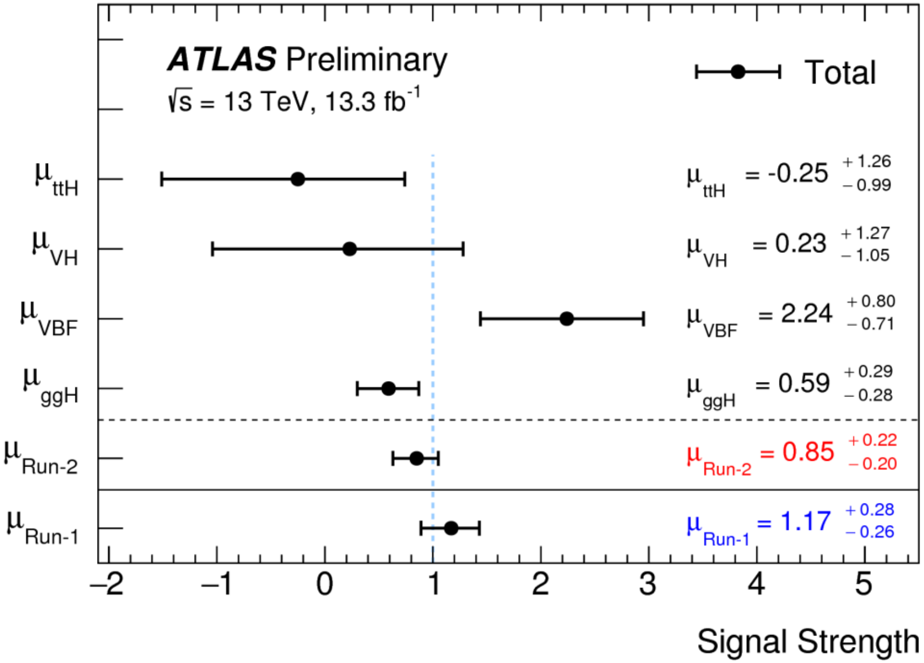
Results ICHEP ATLAS couplings $H \rightarrow \gamma\gamma$

L=13.3 fb^{-1} (2015 : 3.2 fb^{-1}, 2016 : 10.1 fb^{-1}) <μ>=13.7

- Fixing $\mathbf{m_H}$=125.09 GeV $\mathbf{Z_{obs}}$=4.7 σ (Z_{exp}=5.4 σ) $\boldsymbol{\mu}=0.85^{+0.22}_{-0.20}$

Signal strength

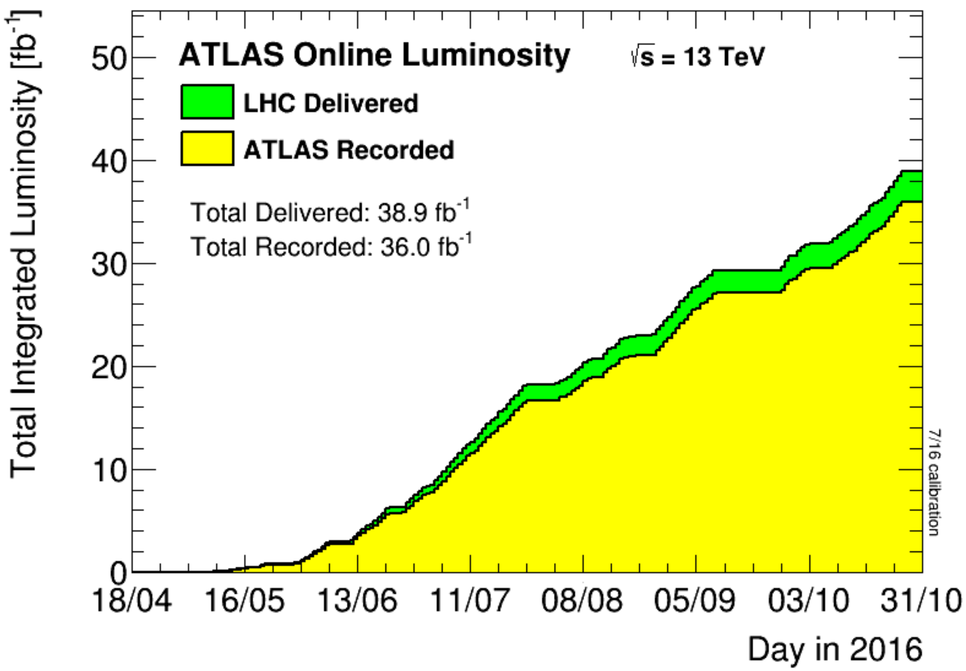




Beyond ICHEP: data

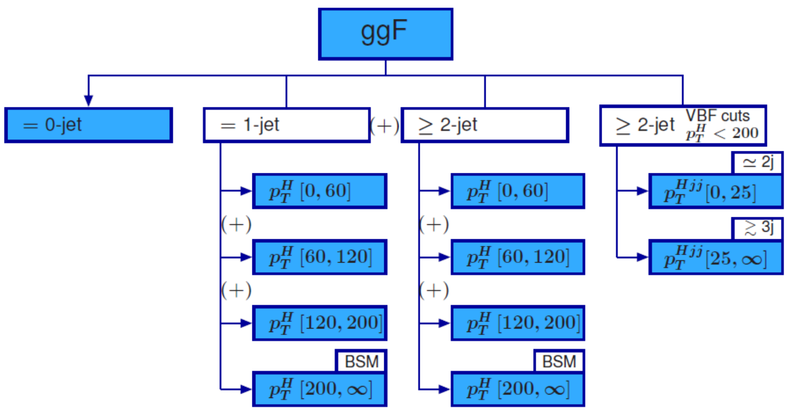
Thank to the excellent performance of LHC, we get more data then our expectation

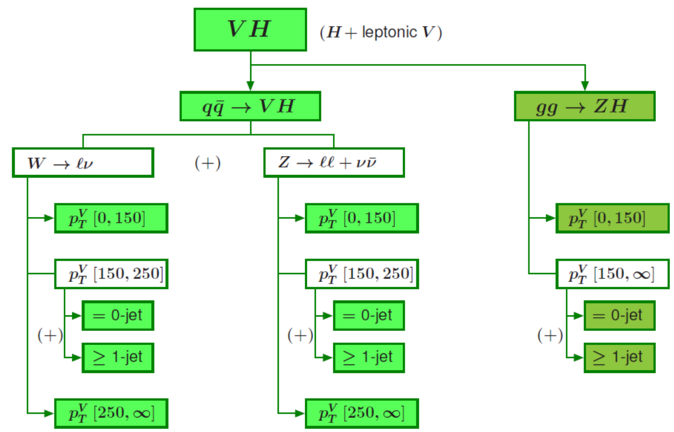
For the whore 2016, we will have 40 fb^{-1}
Stat uncertainty is improving with $\sqrt{s}$
so factor 2 luminosity means factor 1.4 improvement on stat uncertainty

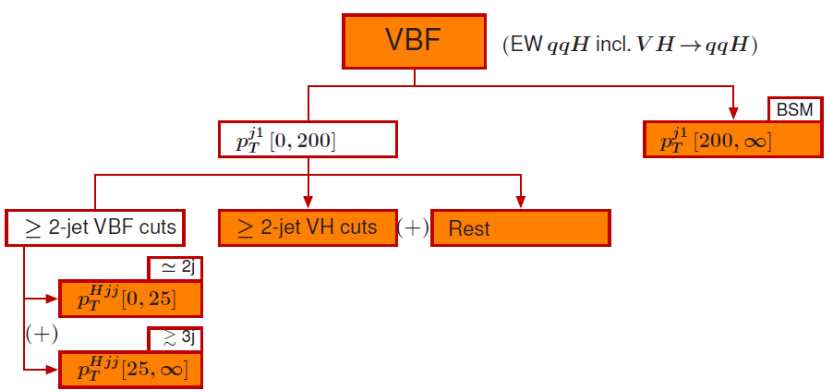


Beyond ICHEP: HTXS step 1

After ICHEP's step 0, step 1 for HTXS will be the baseline for publication, we are optimizing the analyses to match the requirement







Compare to step-0, step-1 split the truth categories also with the pT of Higgs, which allows to do more accurate measurement and isolate the BSM physics

Conclusion

Thank to all our colleges, we achieved very impressive results for moriond

Now the data taking of ATLAS for 2016 is done, with higher statistic of data, we hope we can do better measuring the higgs