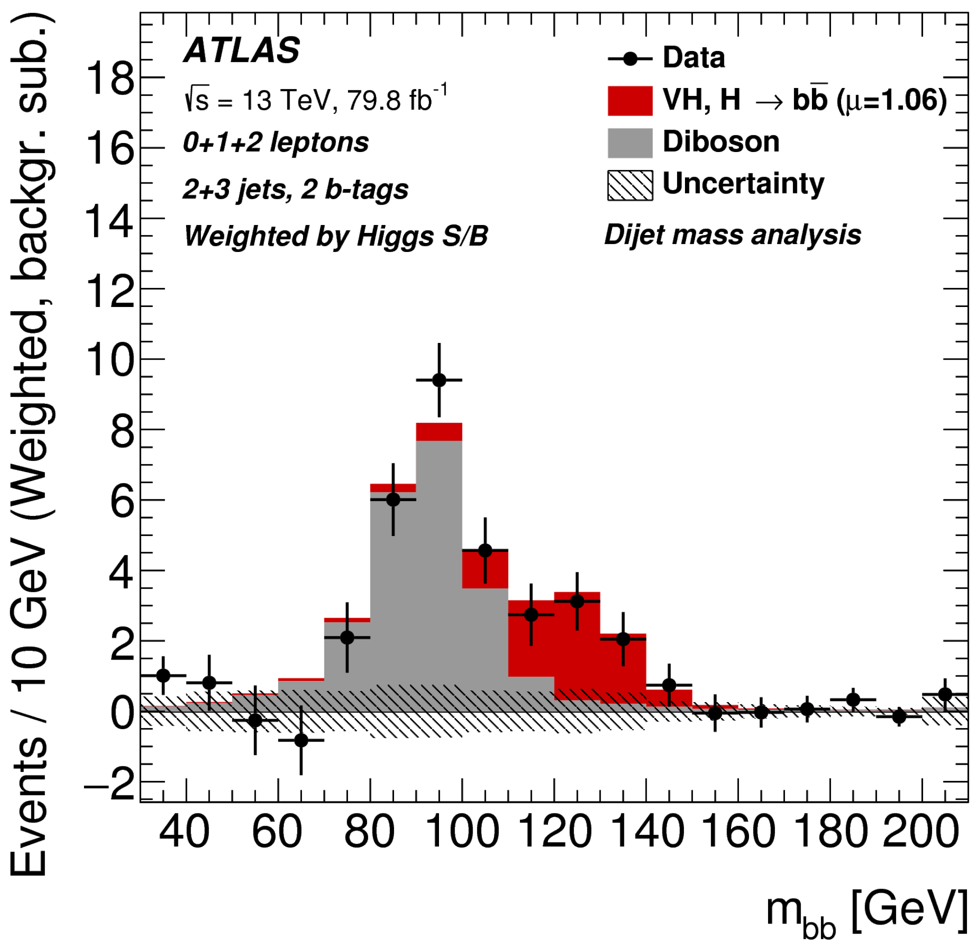
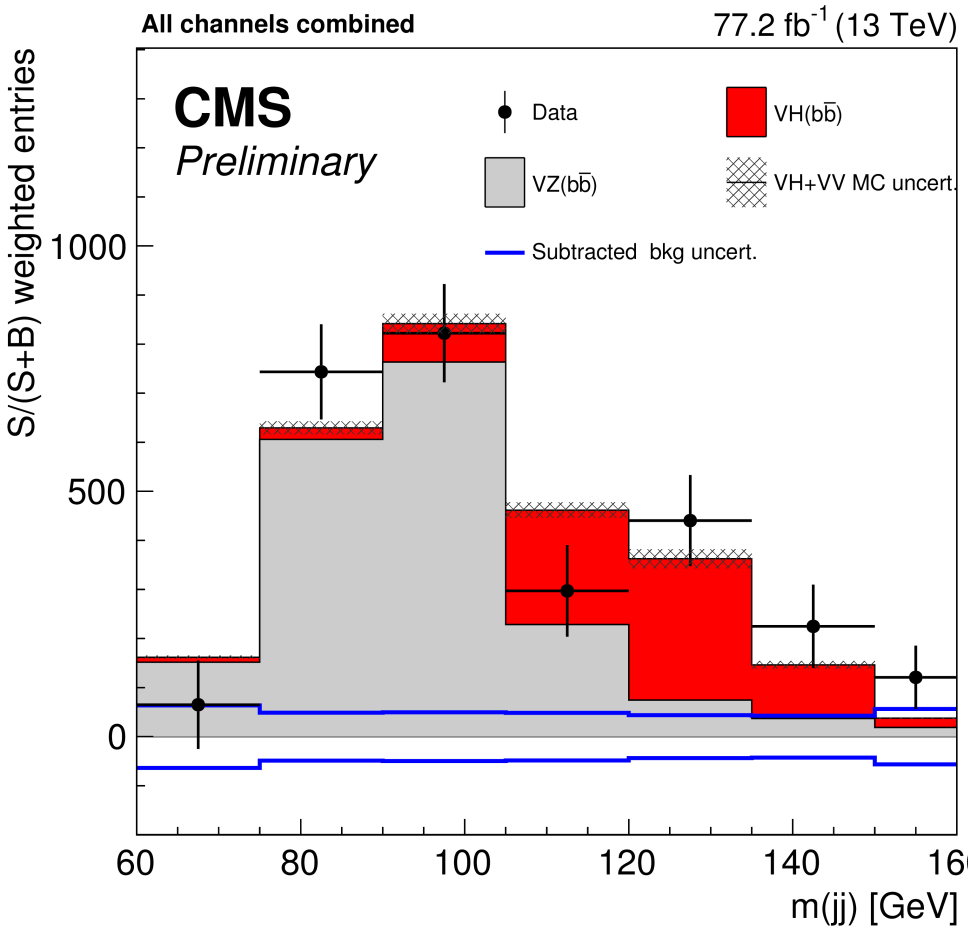
Discovering new Physics with the SM Higgs Field



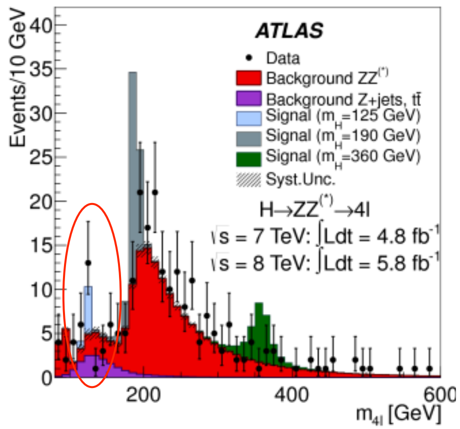


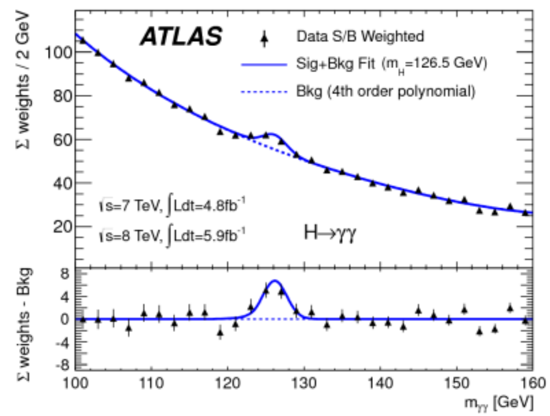
Stathes Paganis, Li You-Ying (NTU), Rosy Nicolaidou (Saclay)

Academia Sinica Seminar, 中研院, 30 Nov 2018

Outline

ATLAS/CMS: completed the H field!



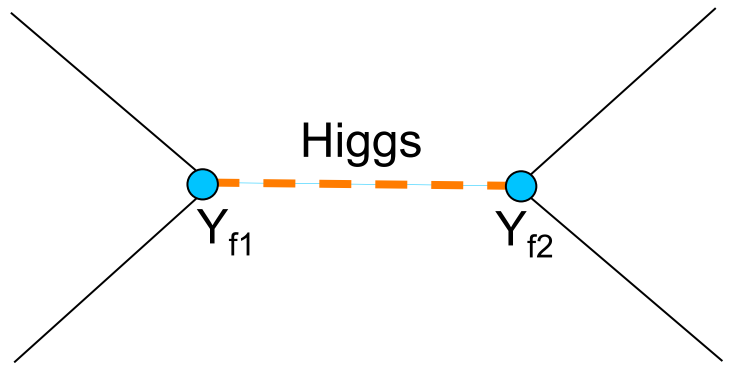


- Why VV scattering may be the key?
- VH with Higgs→bb: as a probe of new Physics.
- Heavy Resonances decaying to Higgs
  - Prospects for discovery vs Mass and Width
- Brief: Hardware "made in Taiwan" to do this Physics!

Motivation

- Higgs boson discovered in 2012: so far nothing else has been found.
- We now know: we definitely have a (single) Higgs doublet (4dof)
  - Why? (experimentalist answer: but I only need one!)
- Excitations of the 4th dof should be very heavy (decoupled).
  - Why it weighs only 125GeV?
  - Nuclear experimentalist answer: form factor?
  - 60's theorist answer: pseudo-Goldstone (example: pion)
- But NO evidence of compositeness yet
  - Issue: if Higgs composite we need to unitarize WW→WW

The Higgs "interaction"

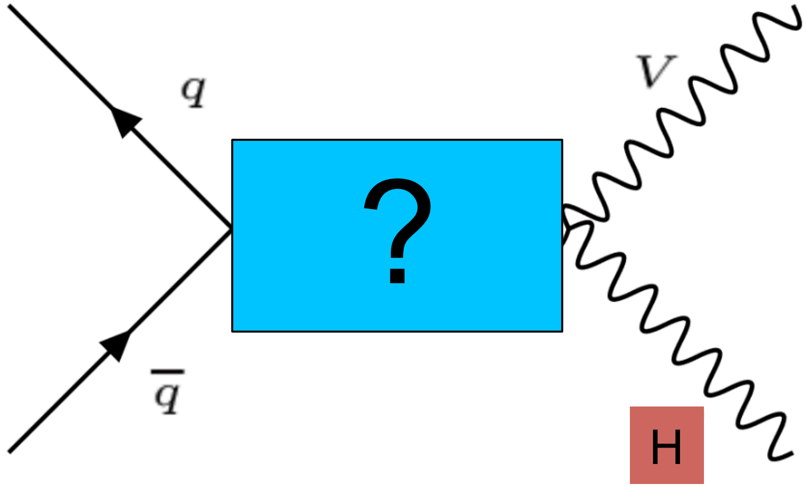


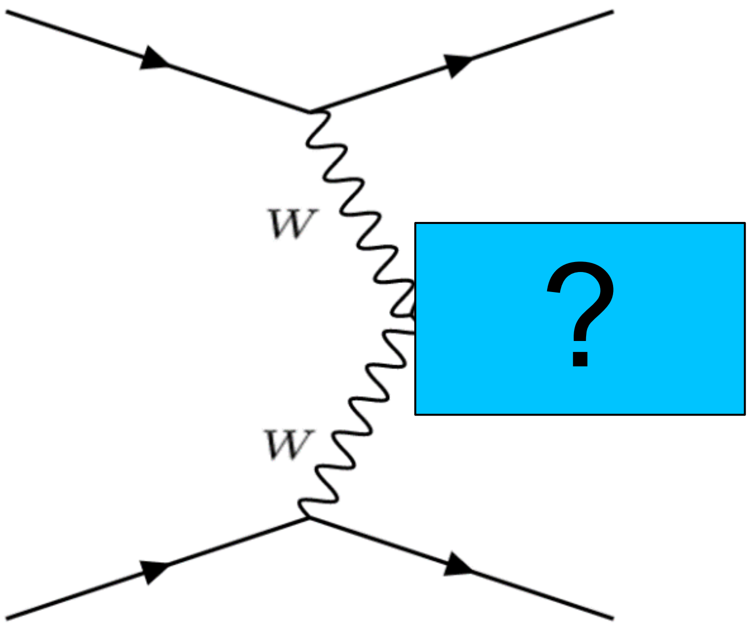
Q1: Dim(ffH)=4 is OK, but it does look like some sort of effective interaction!
<u>Strange</u>: look at the (p-scalar) pion of QCD, it mediates the nuclear force!

Q2: mass of Higgs at 125GeV but no sign of new Physics to protect its mass
<u>Strange</u>: the pion of QCD is also ~far from the QCD transition Λ=4*pi*100MeV

Experimentalist: What measurements can reveal any kind of form factor?

Measure VH and VV





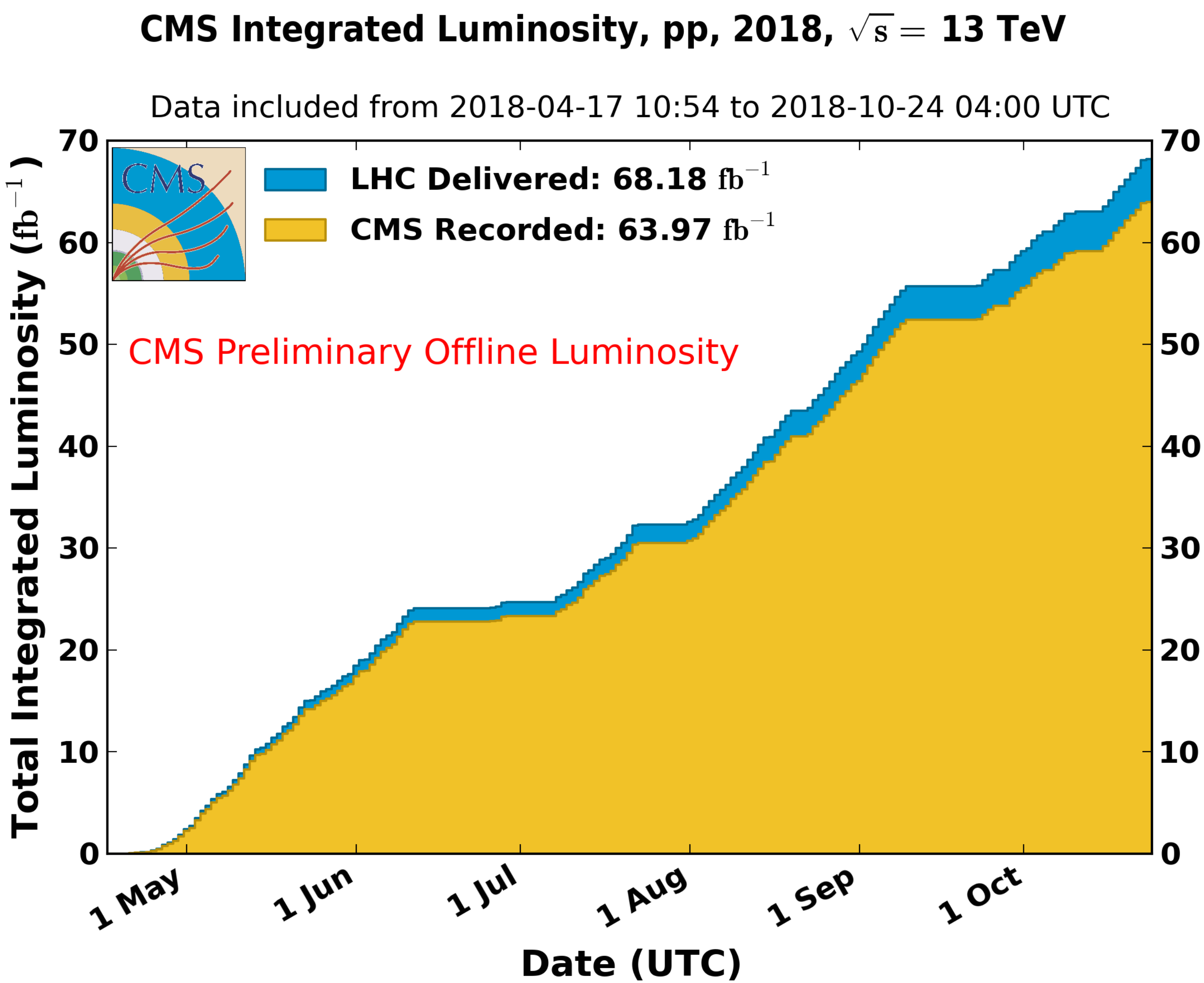
P5's Science Drivers

Five topics that should drive U.S. HEP program for next 10 years:

- Use the Higgs boson as a new tool for discovery.
- Pursue the physics associated with neutrino mass.
- Identify the new physics of dark matter.
- Understand cosmic acceleration: dark energy and inflation.
- Explore the unknown: new particles, interactions, and physical principles.

P5 identified the highest priority projects for a balanced program that addresses these science drivers in constrained budget scenarios.

How much data until today?



Ongoing Analyses in Run2?

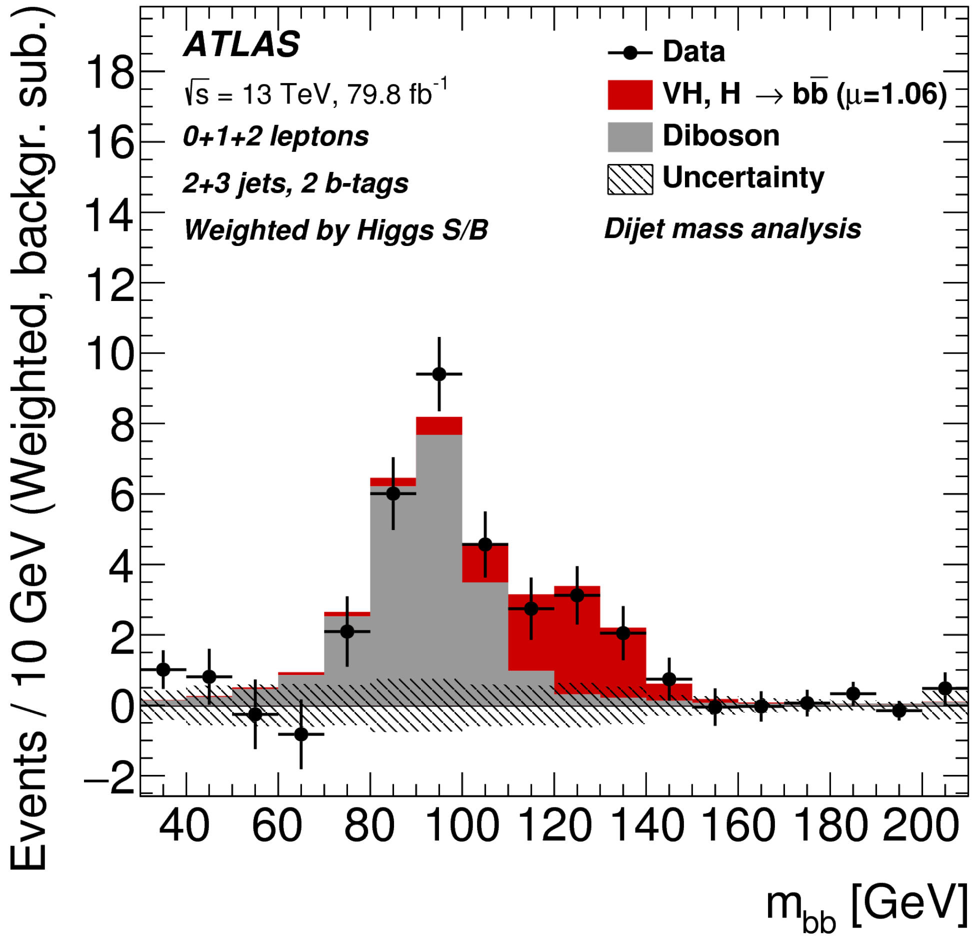
VBF Higgs→$\gamma\gamma$ (Andreas Psallidas, You-Ying, SP)

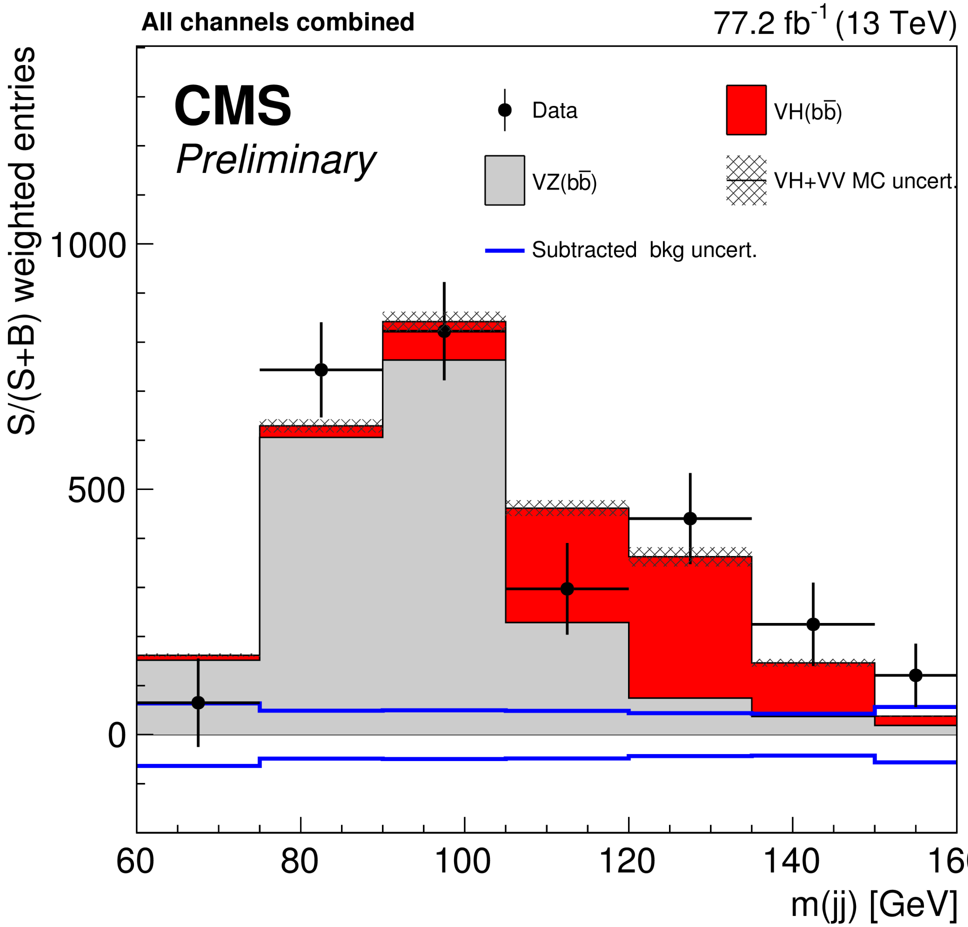
VH with Higgs→$\gamma\gamma$ (official analysis). We were invited to join. Only one other group involved

I would like: to be involved in VH→bb (relevant to this talk)

New results shown for the first time in this talk (Submitted to EPJC in October/10)

Example potential anomaly: H→bb





H→bb observed. Errors are still large, and the question is if these or future measurements can probe (or exclude) new Physics ➔

The goal of this work

Our Proposal: a smoking gun signature in Vbb searches.

A heavy (not necessarily narrow) resonance decay to Higgs + V/W:
- Gives an excess to 0 and 2 lepton final states (extra H+Z)
- Gives a bigger excess to the 1 lepton category (extra WZ and WH)
- BSM Higgs signal has higher Pt

Can we observe the decays of heavy >1TeV states, to VH?

ATLAS/CMS: tight limits on V’

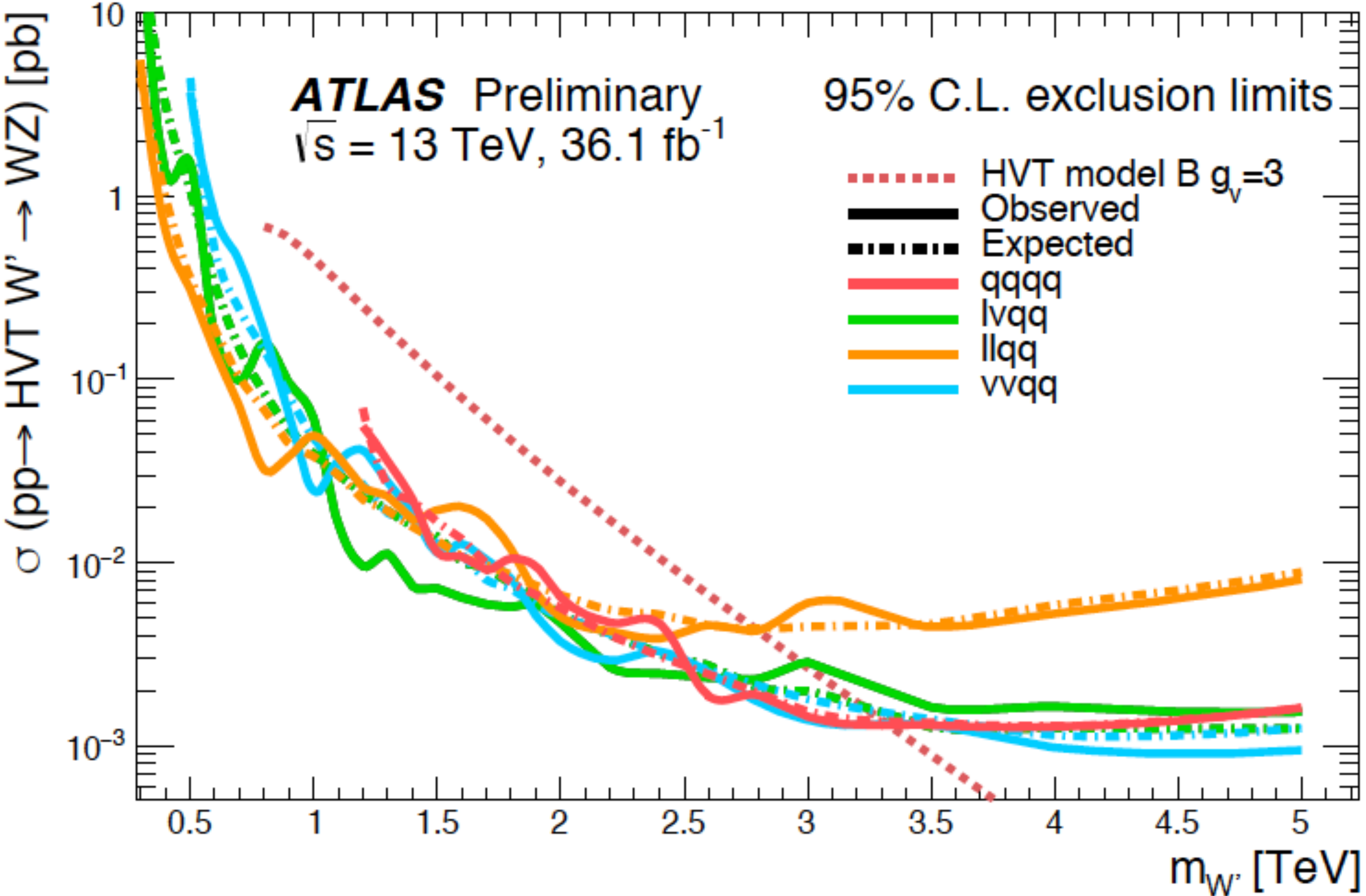
ATLAS and CMS exclude V’→VH and V’→VV, with dijets, H→bb, and di-leptons

	g	γ	W	Z	W/Z (hadronic)	H
g	arXiv:1703.09127 PAS-EXO-16-056	arXiv:1709.10440 arXiv:1711.04652			- arXiv:1708.05379	
γ		arXiv:1707.04147 arXiv:1606.04093	arXiv:1407.8150	arXiv:1708.00212 PAS-EXO-16-034	*Coming Soon* PAS-EXO-16-035	*Coming Soon*
W			arXiv:1710.01123 PAS-HIG-16-023	*Coming Soon*	arXiv:1710.07235 PAS-B2G-16-029	CONF-2017-055
Z				arXiv:1712.06386 PAS-HIG-17-012	arXiv:1708.09638 arXiv:1802.09407	CONF-2017-055
W/Z (hadronic)					arXiv:1708.04445 arXiv:1708.05379	arXiv:1707.06958 arXiv:1707.01303
H						CONF-2016-049 arXiv:1710.04960

ATLAS
CMS

New Result about to come out from CMS

Exclusions out to 3.4TeV



ATL-PHYS-SLIDE-2018-173

Dilepton searches: no peaks

https://arxiv.org/abs/1803.06292

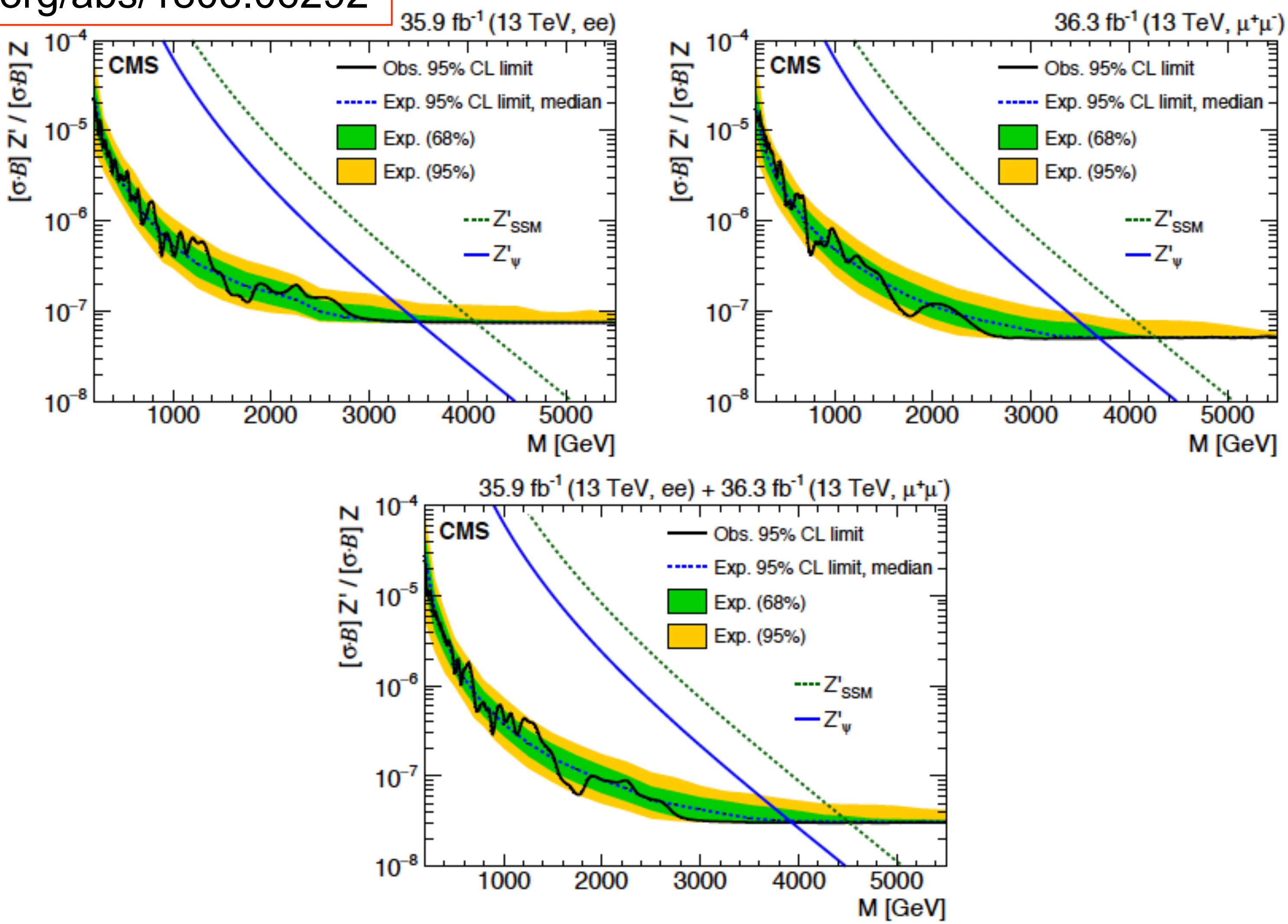
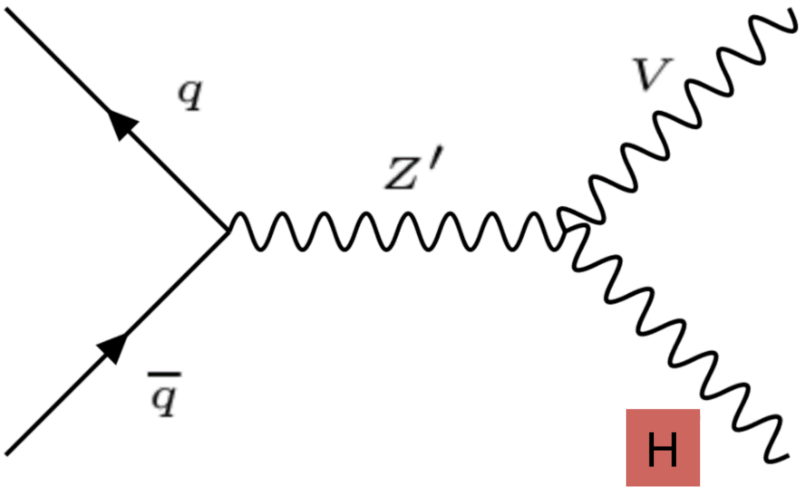


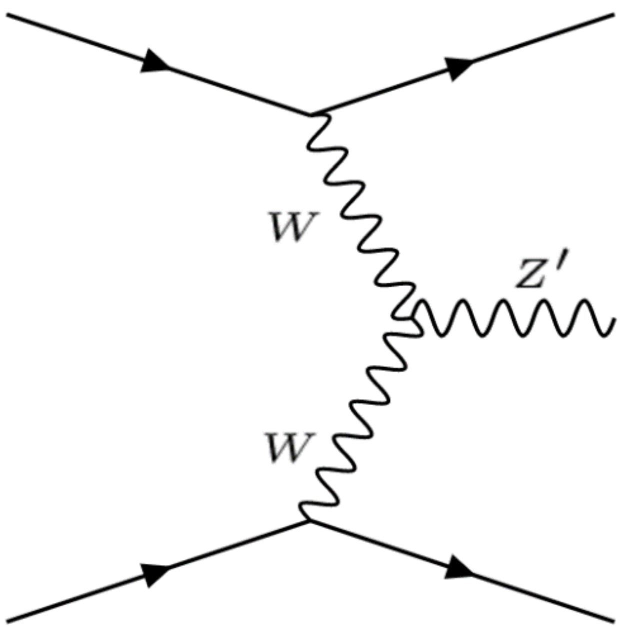
Figure 3: The upper limits at 95% CL on the product of production cross section and branching fraction for a spin-1 resonance with a width equal to 0.6% of the resonance mass, relative to the product of production cross section and branching fraction of a Z boson, for the dielectron channel (left), dimuon channel (right), and their combination (lower). The shaded bands correspond to the 68 and 95% quantiles for the expected limits. Theoretical predictions for the spin-1 Z'_{SSM} and Z'_{ψ} resonances are shown for comparison.

Can the VV/VH decay dominate?

22. M. Hoffmann, A. Kaminska, R. Nicolaidou, S. Paganis, Probing Compositeness with Higgs Boson Decays at the LHC, Eur. Phys. J. C74 (2014) no.11, 3181.



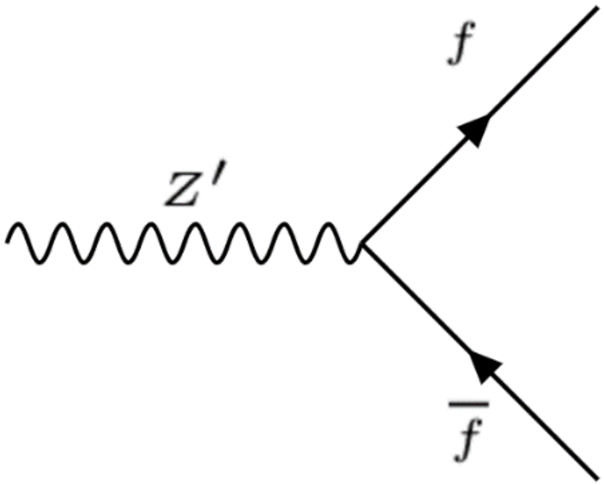
Drell-Yan production (dominant)



Vector Boson Fusion (VBF)

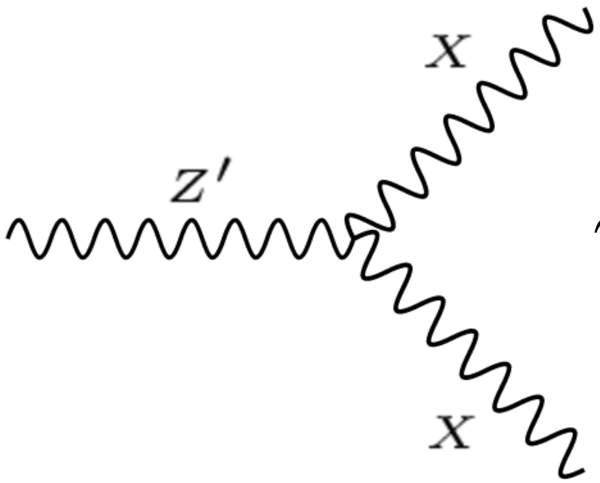
Need a model for BSM spin-1 resonances

Coupling of resonance to SM fermions through mixing with the Eweak bosons.



$$\sim \frac{g^2}{g_V}$$

Coupling of resonance to weak boson through effective coupling gV.

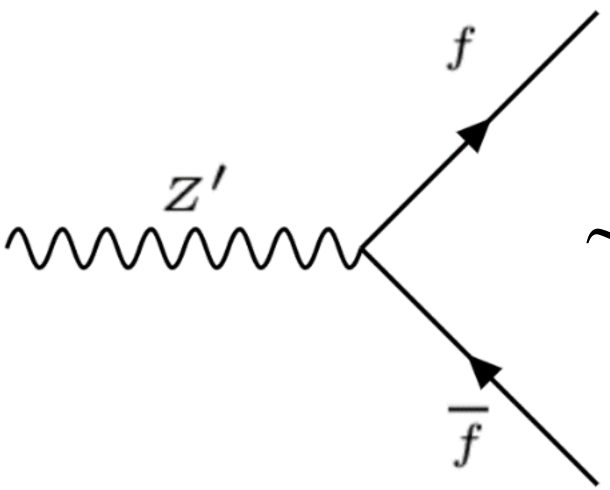


$$\sim g_V$$

Need a model for BSM spin-1 resonances

23. D. Pappadopoulo, A. Thamm, R. Torre and A. Wulzer, Heavy Vector Triplets: Bridging Theory and Data, JHEP 09 (2014) 060.

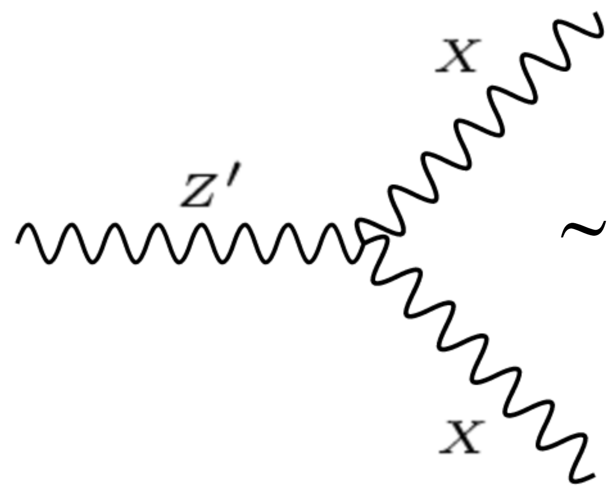
Coupling of resonance to SM fermions through mixing with the Eweak bosons.



$$\sim \frac{g^2}{g_V} c_F$$

Additional weight to the coupling to add flexibility

Coupling of resonance to weak boson through effective coupling gV.



$$\sim g_V c_H$$

Additional weight to the coupling to add flexibility

Heavy Vector Triplet simplified model

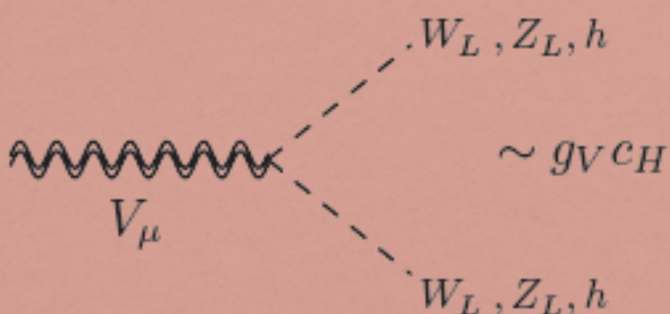
$$\mathcal{L}_V = -\frac{1}{4} D_{[\mu} V_{\nu]}^a D^{[\mu} V^{\nu]\,a} + \frac{m_V^2}{2} V_\mu^a V^{\mu\,a}$$

$$V = (V^+, V^-, V^0)$$

$$+\, i\, g_V c_H V_\mu^a H^\dagger \tau^a \overleftrightarrow{D}^\mu H + \frac{g^2}{g_V} c_F V_\mu^a J_F^{\mu\,a}$$

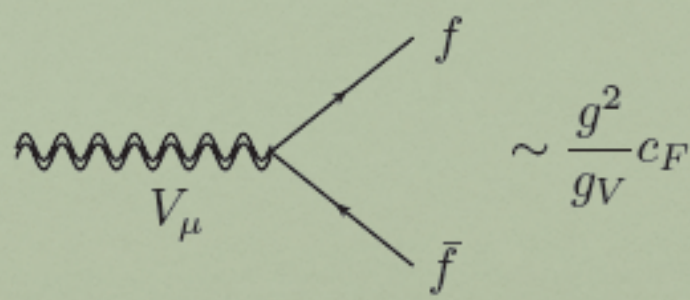
$$+ \frac{g_V}{2} c_{VVV}\, \epsilon_{abc} V_\mu^a V_\nu^b D^{[\mu} V^{\nu]\,c} + g_V^2 c_{VVHH} V_\mu^a V^{\mu\,a} H^\dagger H - \frac{g}{2} c_{VVW}\, \epsilon_{abc} W^{\mu\nu\,a} V_\mu^b V_\nu^c$$

Coupling to SM Vectors



Coupling to SM fermions

$$J_F^{\mu\,a} = \sum_f \bar{f}_L \gamma^\mu \tau^a f_L$$



$$c_F V \cdot J_F \;\rightarrow\; c_l V \cdot J_l + c_q V \cdot J_q + c_3 V \cdot J_3$$

Heavy Vector Triplet simplified model

$$\mathcal{L}_V = -\frac{1}{4} D_{[\mu} V_{\nu]}^a D^{[\mu} V^{\nu]\,a} + \frac{m_V^2}{2} V_\mu^a V^{\mu\,a} \qquad V = (V^+, V^-, V^0)$$

$$+ i\, g_V c_H V_\mu^a H^\dagger \tau^a \overleftrightarrow{D}^\mu H + \frac{g^2}{g_V} c_F V_\mu^a J_F^{\mu\,a}$$

$$+ \frac{g_V}{2} c_{VVV}\, \epsilon_{abc} V_\mu^a V_\nu^b D^{[\mu} V^{\nu]\,c} + g_V^2 c_{VVHH} V_\mu^a V^{\mu\,a} H^\dagger H - \frac{g}{2} c_{VVW}\, \epsilon_{abc} W^{\mu\nu\,a} V_\mu^b V_\nu^c$$

Couplings among Vectors

- do not contribute to V decays
- do not contribute to single production
- only effects through (usually small) VW mixing

⇒ irrelevant for phenomenology ⇒ only need (c_H, c_F)

Drell-Yan and VBF production modes

$$\sigma_{DY} = \sum_{i,j\in p} \frac{\Gamma_{V\to ij}}{M_V}\frac{4\pi^2}{3}\frac{dL_{ij}}{d\hat{s}}\bigg|_{\hat{s}=M_V^2} \qquad \sigma_{VBF} = \sum_{i,j\in p} \frac{\Gamma_{V\to W_{L\,i}W_{L\,j}}}{M_V} 48\pi^2 \frac{dL_{W_{L\,i}W_{L\,j}}}{d\hat{s}}\bigg|_{\hat{s}=M_V^2}$$

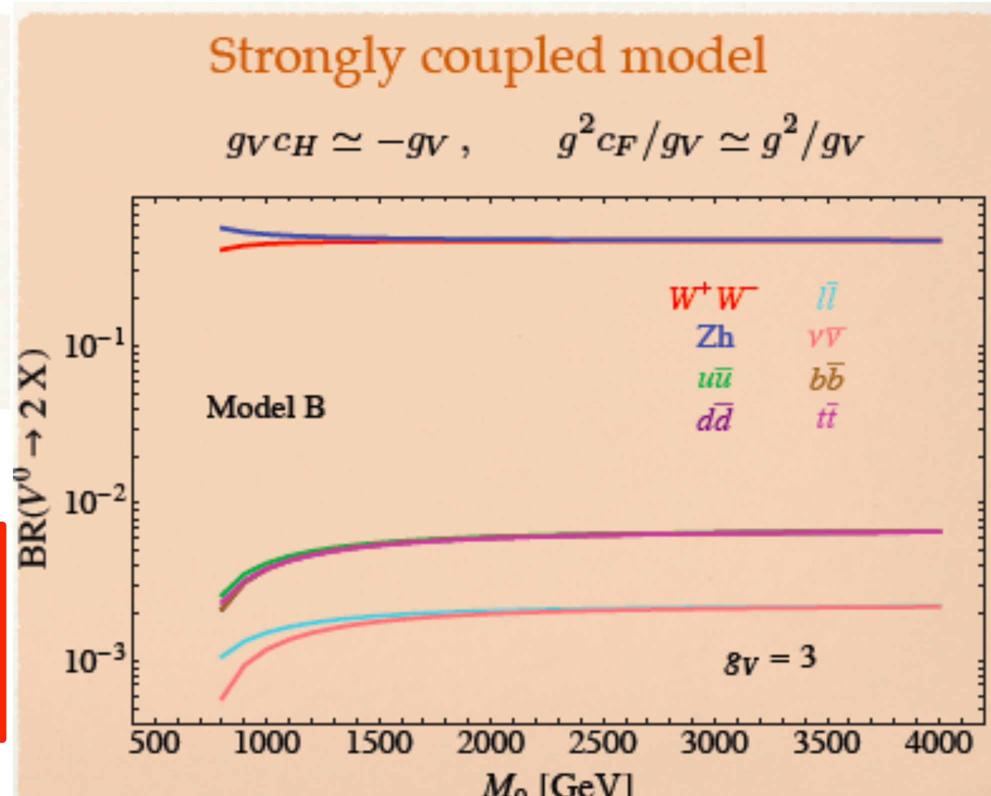
model dependent

model independent

$$\Gamma_{V_\pm\to f\bar{f}'} \simeq 2\,\Gamma_{V_0\to f\bar{f}} \simeq N_c[f]\left(\frac{g^2 c_F}{g_V}\right)^2 \frac{M_V}{96\pi}\,,$$

$$\Gamma_{V_0\to W_L^+W_L^-} \simeq \Gamma_{V_\pm\to W_L^\pm Z_L} \simeq \frac{g_V^2 c_H^2 M_V}{192\pi}\left[1+\mathcal{O}(\zeta^2)\right]$$

$$\Gamma_{V_0\to Z_L h} \simeq \Gamma_{V_\pm\to W_L^\pm h} \simeq \frac{g_V^2 c_H^2 M_V}{192\pi}\left[1+\mathcal{O}(\zeta^2)\right]$$



Note that the VBF partonic xsections are several orders of magnitute smaller (4 to 5) → sensitivity to DY production.

Benchmark Models (A, B)

General Model

Heavy Vector Triplet

4 free parameters
C_H, C_F, g_V, M_V

3 heavy bosons
Z', W'^{+}, W'^{-}

...

Benchmark Models

Model A

$(C_H = -\frac{g^2}{g_V^2}, C_F = -1)$

$g_V \leq 3$

extensions of the SM gauge group

Model B

$(C_H = -1, C_F = 1)$

$g_V \geq 3$

Composite Higgs models

Model A:

$C_F = -1$
DY or fermionic decay

$C_H = -\frac{g^2}{g_V^2}$
VBF or bosonic decay

Model B:

$C_F = 1$
DY or fermionic decay

$C_H = -1$
VBF or bosonic decay

Exclusions: fermion vs g_V plane

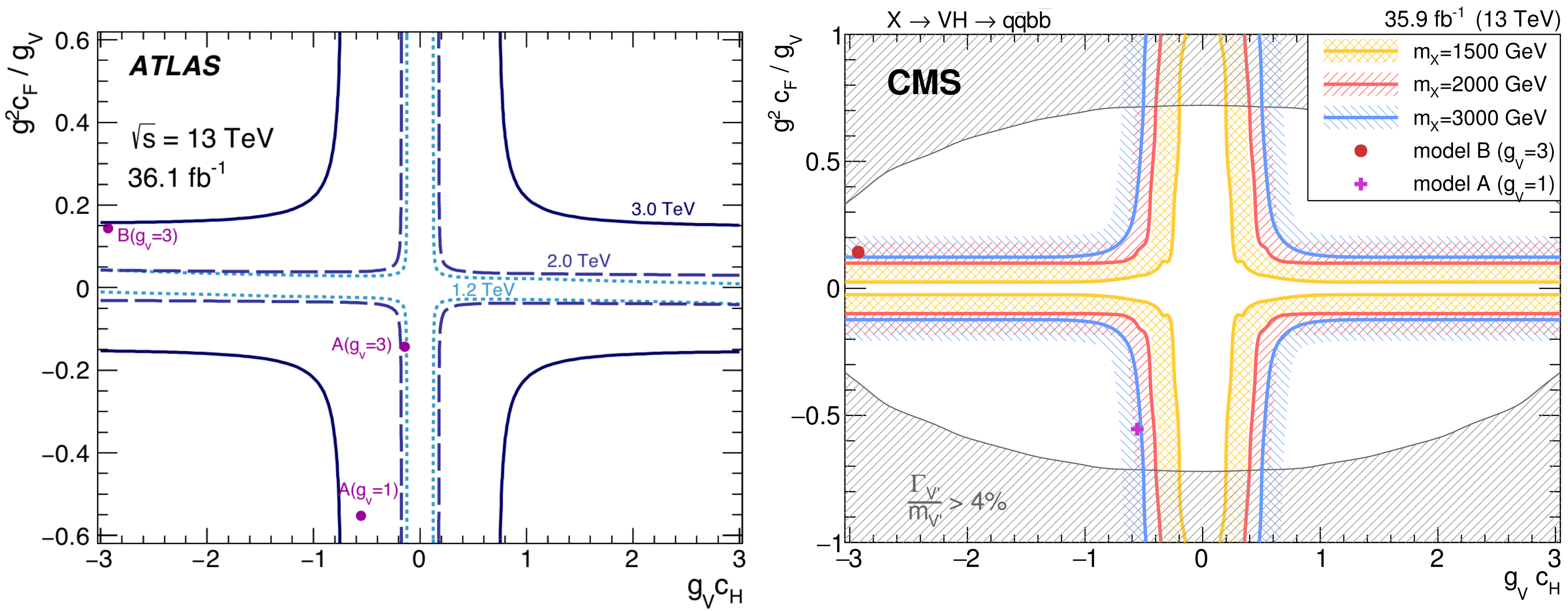
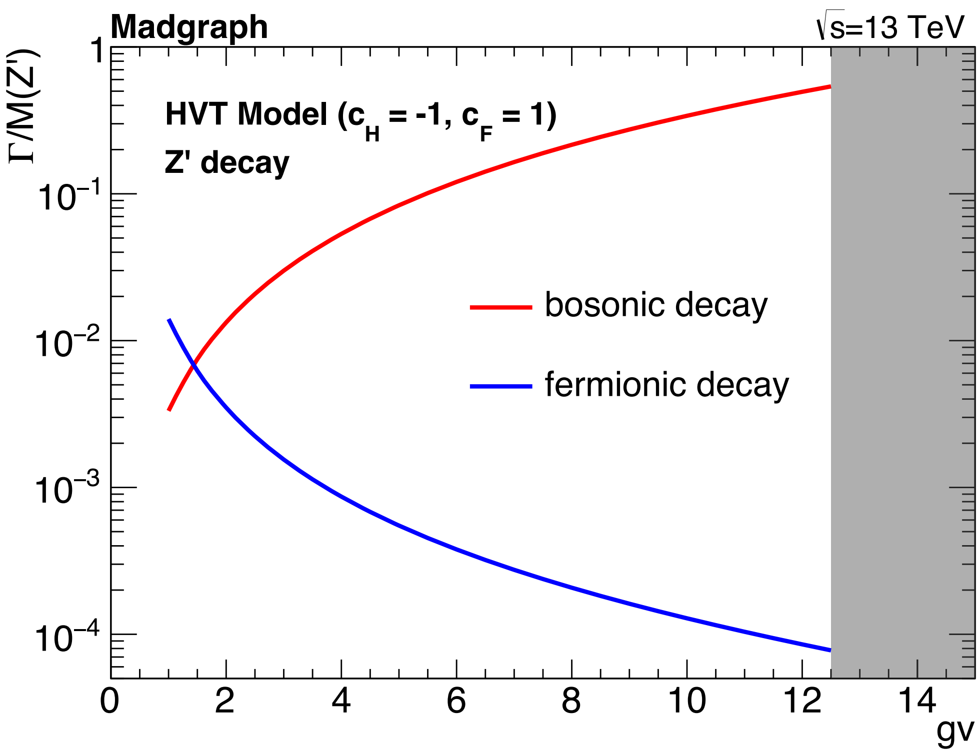
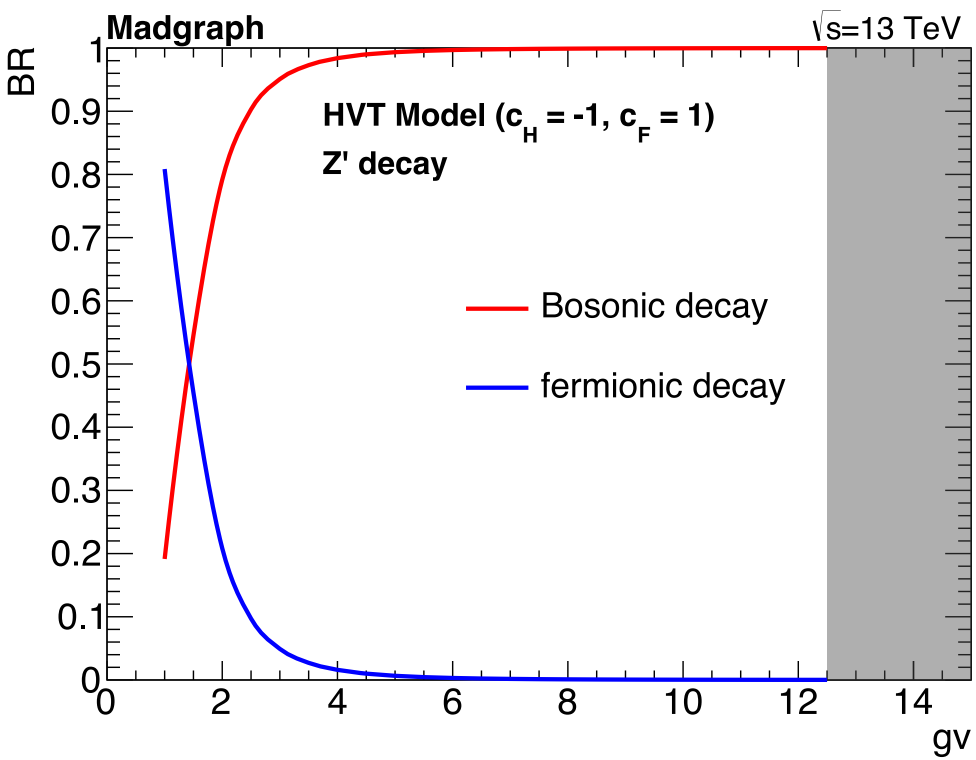


Fig. 1 ATLAS, [15], and CMS, [20], observed 95% CL exclusion contours in the HVT parameter space $g_V c_H, (g^2/g_V)c_F$ for narrow resonances of mass 1.2 TeV, 2.0 TeV and 3.0 TeV. Due to the narrow width approximation assumption, the exclusion validity is restricted to roughly $|g_V c_H| < 3.0$ (better shown in the left plot), thus leaving a large part of the available phase space unconstrained ($3 < |g_V c_H| < 4\pi$).

V' exclusively decays to VV, VH

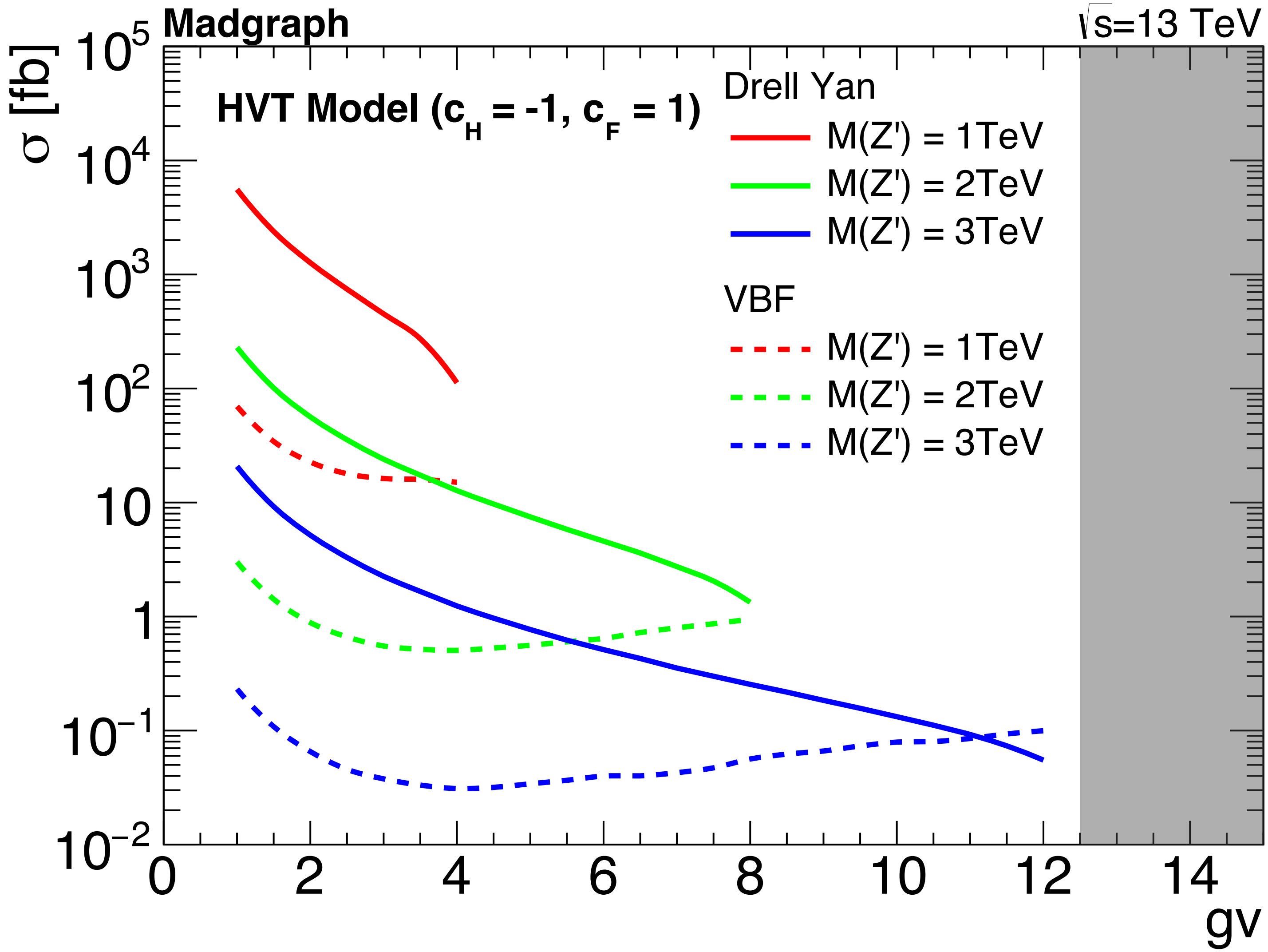




For large g_V the BR to fermions goes to 0. However the DY production still wins.

Large g_V also means larger width (>5%). Only close to NP regime width very large.

pp→Z' xsection at 13TeV



Event Selection: follow LHC analyses

arXiv:1708.03299

Selection	0-lepton	1-lepton		2-lepton
		e sub-channel	μ sub-channel	
Trigger	$E_{\mathrm{T}}^{\mathrm{miss}}$	Single lepton	$E_{\mathrm{T}}^{\mathrm{miss}}$	Single lepton
Leptons	0 loose leptons with $p_{\mathrm{T}} > 7$ GeV	1 tight electron $p_{\mathrm{T}} > 27$ GeV	1 medium muon $p_{\mathrm{T}} > 25$ GeV	2 loose leptons with $p_{\mathrm{T}} > 7$ GeV ≥ 1 lepton with $p_{\mathrm{T}} > 27$ GeV
$E_{\mathrm{T}}^{\mathrm{miss}}$	> 150 GeV	> 30 GeV	–	–
$m_{\ell\ell}$	–	–		81 GeV $< m_{\ell\ell} <$ 101 GeV
Jets	Exactly 2 or 3 jets			Exactly 2 or ≥ 3 jets
Jet p_{T}	> 20 GeV			
b-jets	Exactly 2 b-tagged jets			
Leading b-tagged jet p_{T}	> 45 GeV			
H_{T}	> 120 (2 jets), >150 GeV (3 jets)	–		–
$\min[\Delta\phi(\vec{E}_{\mathrm{T}}^{\mathrm{miss}}, \vec{\mathrm{jets}})]$	$> 20°$ (2 jets), $> 30°$ (3 jets)	–		–
$\Delta\phi(\vec{E}_{\mathrm{T}}^{\mathrm{miss}}, \vec{bb})$	$> 120°$	–		–
$\Delta\phi(\vec{b}_1, \vec{b}_2)$	$< 140°$	–		–
$\Delta\phi(\vec{E}_{\mathrm{T}}^{\mathrm{miss}}, \vec{E}_{\mathrm{T,trk}}^{\mathrm{miss}})$	$< 90°$	–		–
p_{T}^{V} regions	> 150 GeV			(75, 150] GeV, > 150 GeV
Signal regions	✓	$m_{bb} \geq 75$ GeV or $m_{\mathrm{top}} \leq 225$ GeV		Same-flavour leptons Opposite-sign charge ($\mu\mu$ sub-channel)
Control regions	–	$m_{bb} < 75$ GeV and $m_{\mathrm{top}} > 225$ GeV		Different-flavour leptons

- No $\Delta\varphi(ETmiss, ETtrkmiss)$ cut
- We allow ≥2 jets

Event yields after detector

Madgraph5+Delphes

The SM signal yield:

$$\text{Luminosity} \times \sigma_{pp\to H} \times \text{BR}(\text{H}\to\text{bb}) \times \text{Efficiency} = \text{N}_{\text{SM}}$$

The BSM signal yield:

$$\text{Lumi} \times \sigma_{pp\to V'} \times \text{BR}(\text{V}'\to\text{VH}) \times \text{BR}(\text{H}\to\text{bb}) \times \text{Eff} = \text{N}_{\text{BSM}}$$

~58%

$$\text{Lumi} \times \sigma_{pp\to V'} \times \text{BR}(\text{W}'\to\text{WZ}) \times \text{BR}(\text{Z}\to\text{bb}) \times \text{Eff} = \text{N}_{\text{BSM}}$$

~50% ~15%

Efficiencies in our simulations are normalized to the published data (ATLAS in our case)
This means our no-BSM analysis reproduces the ATLAS Mbb results.

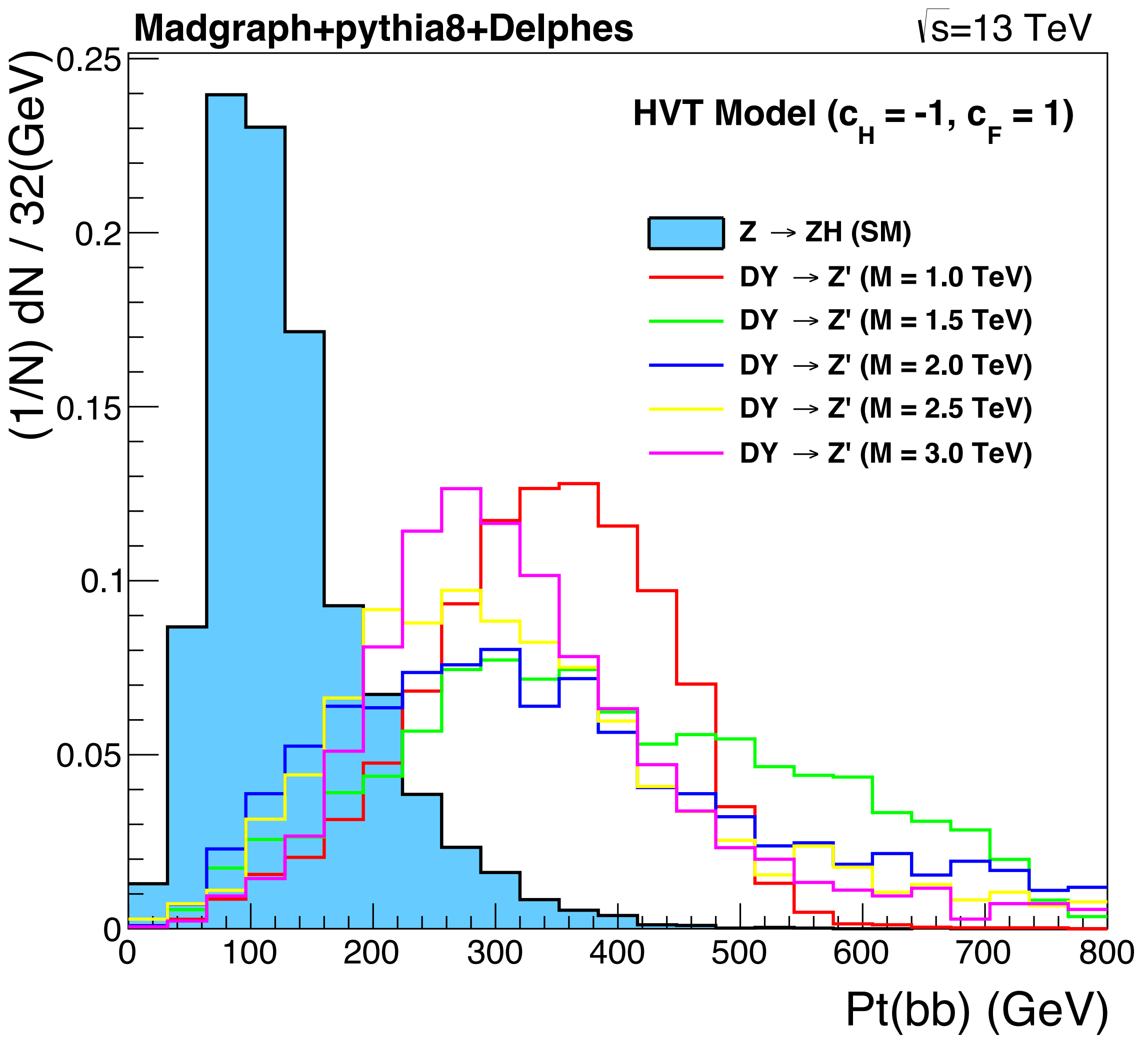
Event yields for V'

Process $qq \to X$	$\sigma \times BR$ [fb]	$A \times \epsilon$ [%]	Yield [100fb]	Yield $p_\perp >$ 200GeV
$Z' \to ZH \to \nu\nu b\bar{b}$	1.58	2.45	3.78	3.51
$Z \to ZH \to \nu\nu b\bar{b}$	97.2	5.01	486	224
$ZZ \to \nu\nu jj$	2580	0.27	697	248
$W' \to WH \to \ell\nu b\bar{b}$	3.87	5.5	21.3	19.4
$W' \to WZ \to \ell\nu jj$	3.79	0.23	0.81	0.59
$W \to WH \to \ell\nu b\bar{b}$	225	1.44	324	148
$WZ \to \ell\nu jj$	4148	0.13	529	173
$Z' \to ZH \to \ell\ell b\bar{b}$	0.553	4.76	2.6	2.2
$Z \to ZH \to \ell\ell b\bar{b}$	34.2	13.7	467	68.6
$ZZ \to \ell\ell jj$	910	0.96	875	72.6

Best Category

Table 1 Signal yield and resonant SM background yields for a 1.5 TeV resonance and $g_V = 5$, after baseline selection, and after an additional $p_\perp > 200$ GeV cut (last column).

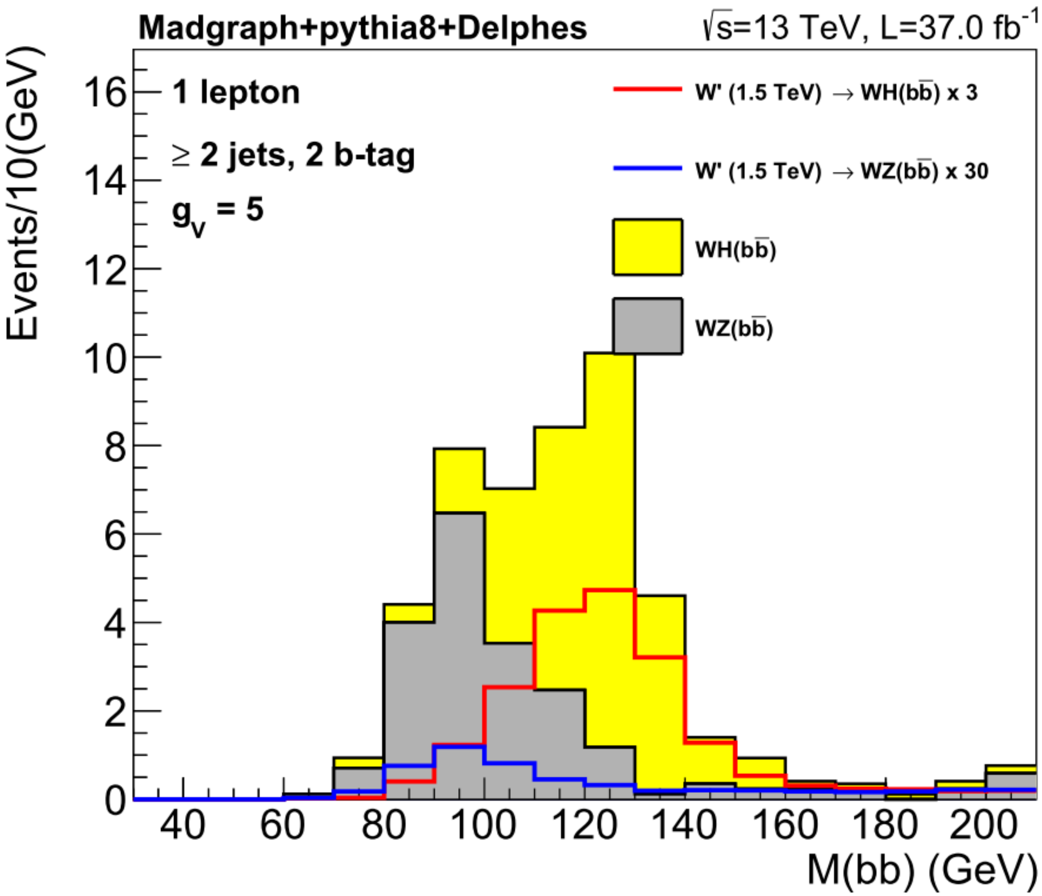
pp→Z' kinematics: bb is boosted



After ATLAS (or CMS) style selection.
The BSM signal is of higher Pt than the SM Higgs (blue dashed)
We decided to study the effect of the Pt cut.

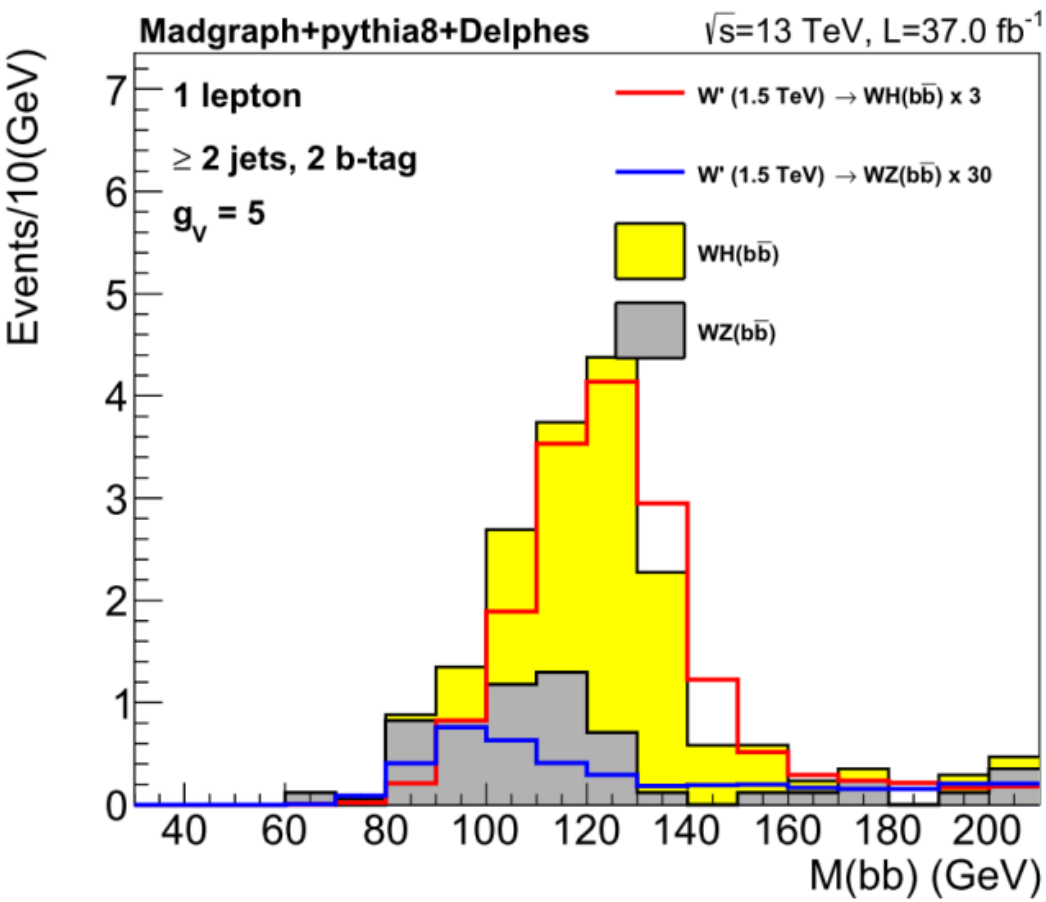
One-lepton category

Pt>250 GeV



SM VH, ZW yield : 47.92 events
95% CLs W'→WH : 15.5 events

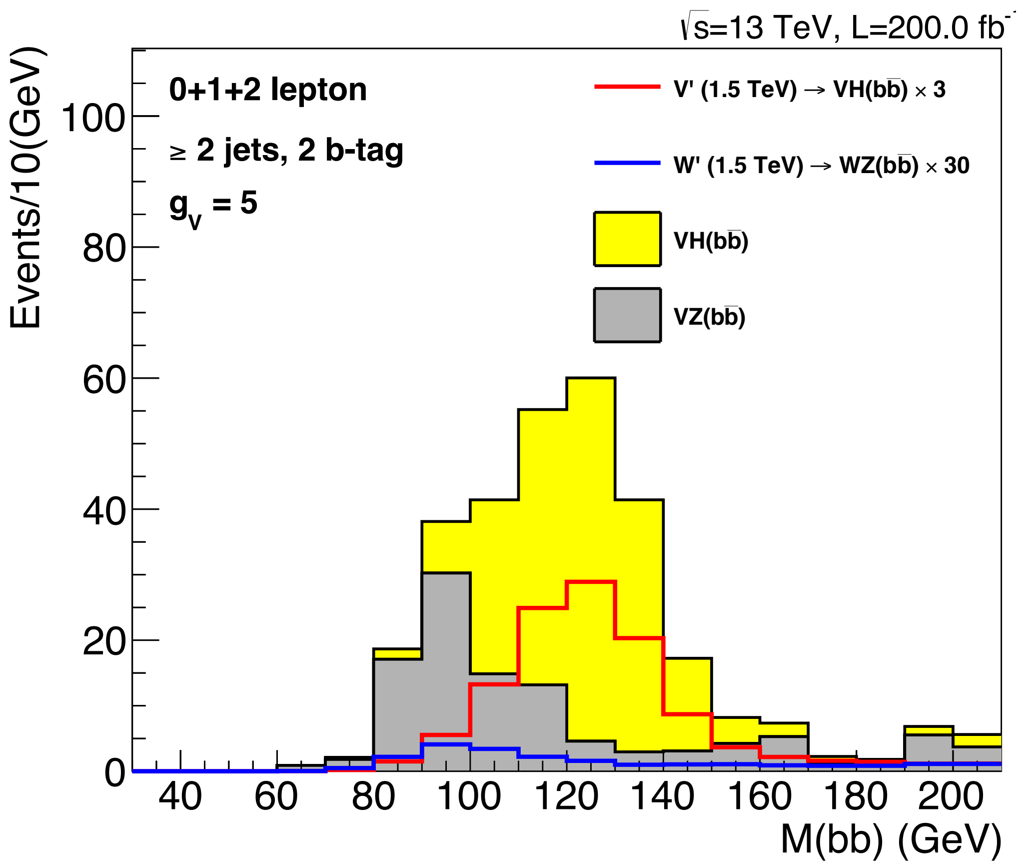
Pt>300 GeV

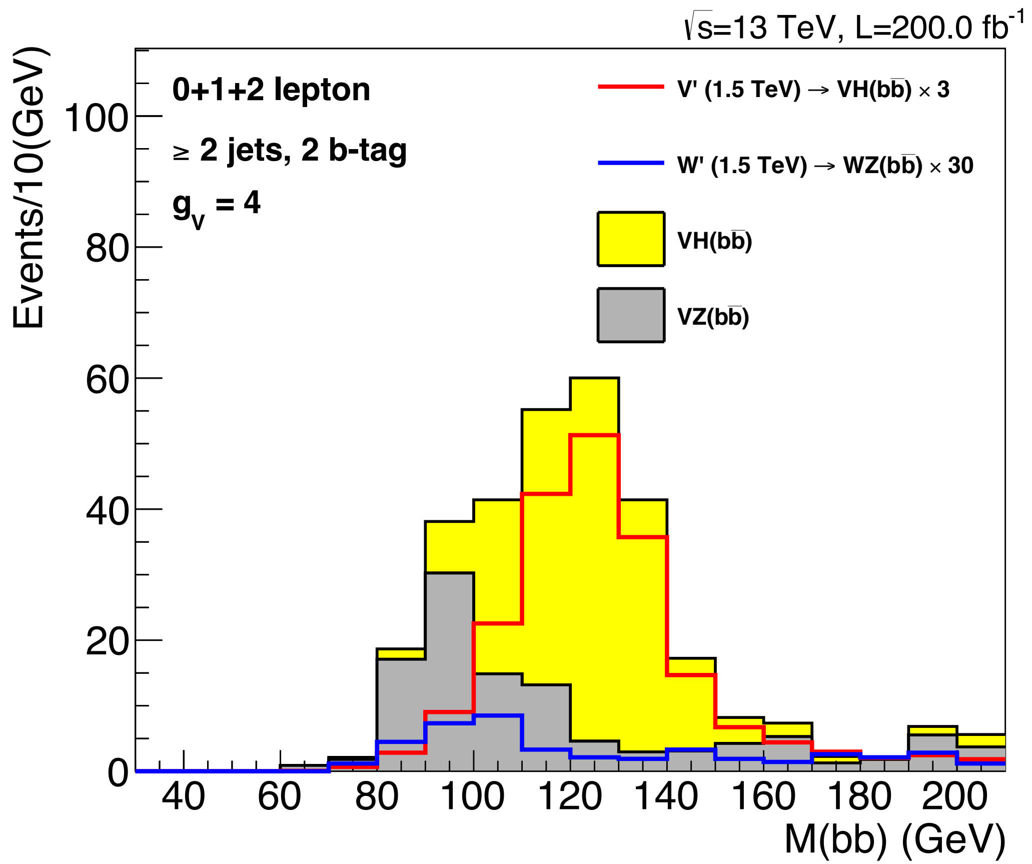


SM VH, ZW yield : 18 events
95% CLs W'→WH : 10.3 events

Projections (expected limits) for 200 fb^{-1}

All categories 200 fb^{-1}

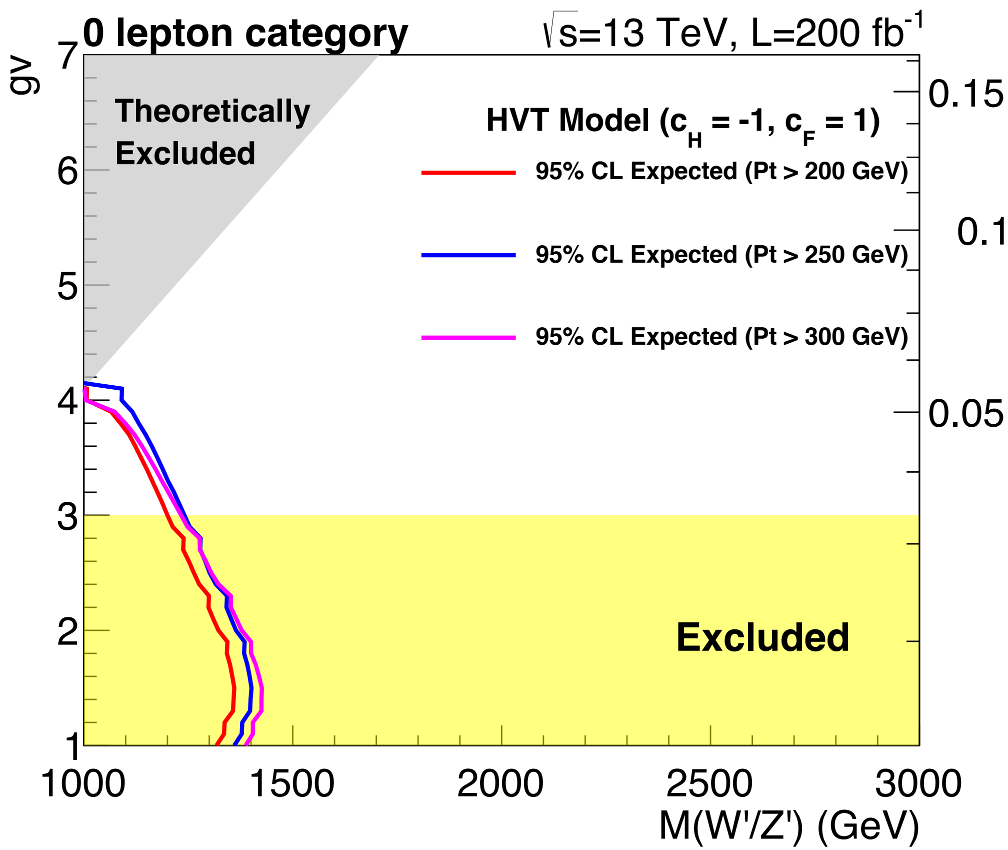


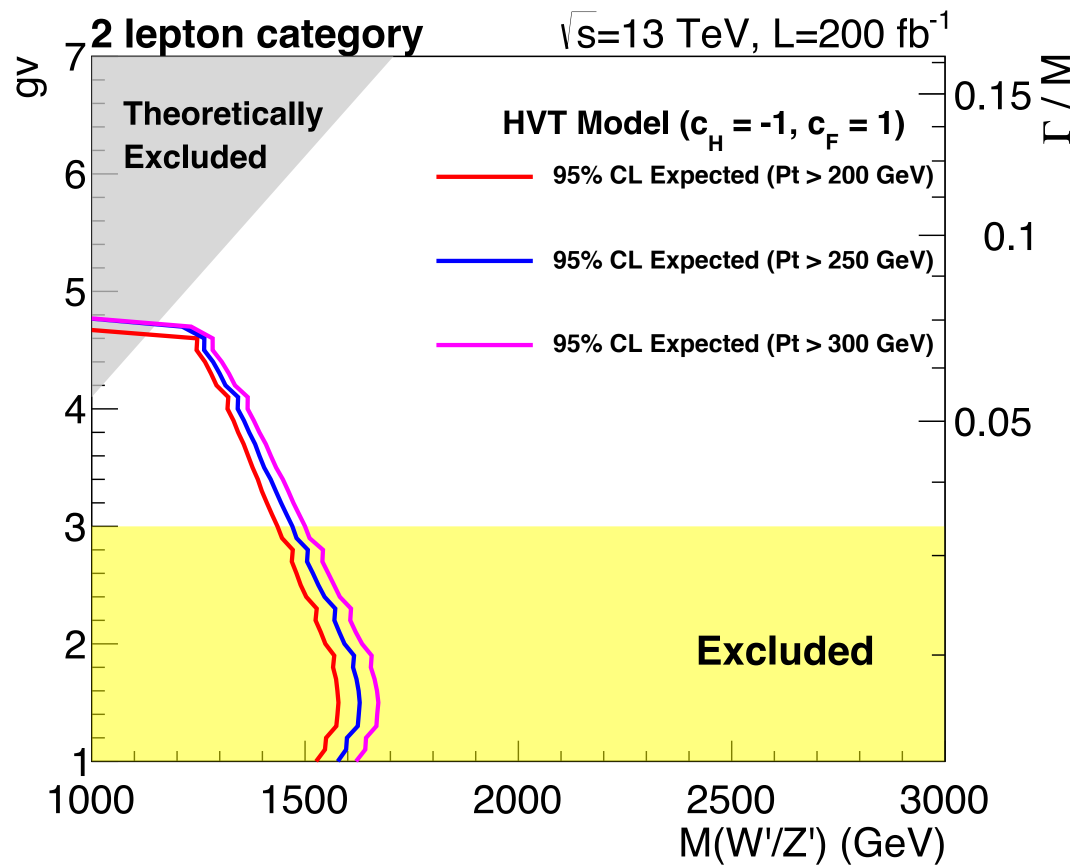


g_V reduction gives more exotic Higgs signal. The exotic WZ is still small

CLs Limits: 0-lep, 2-lep categories

$$\int L\,dt = 200\,fb^{-1}$$

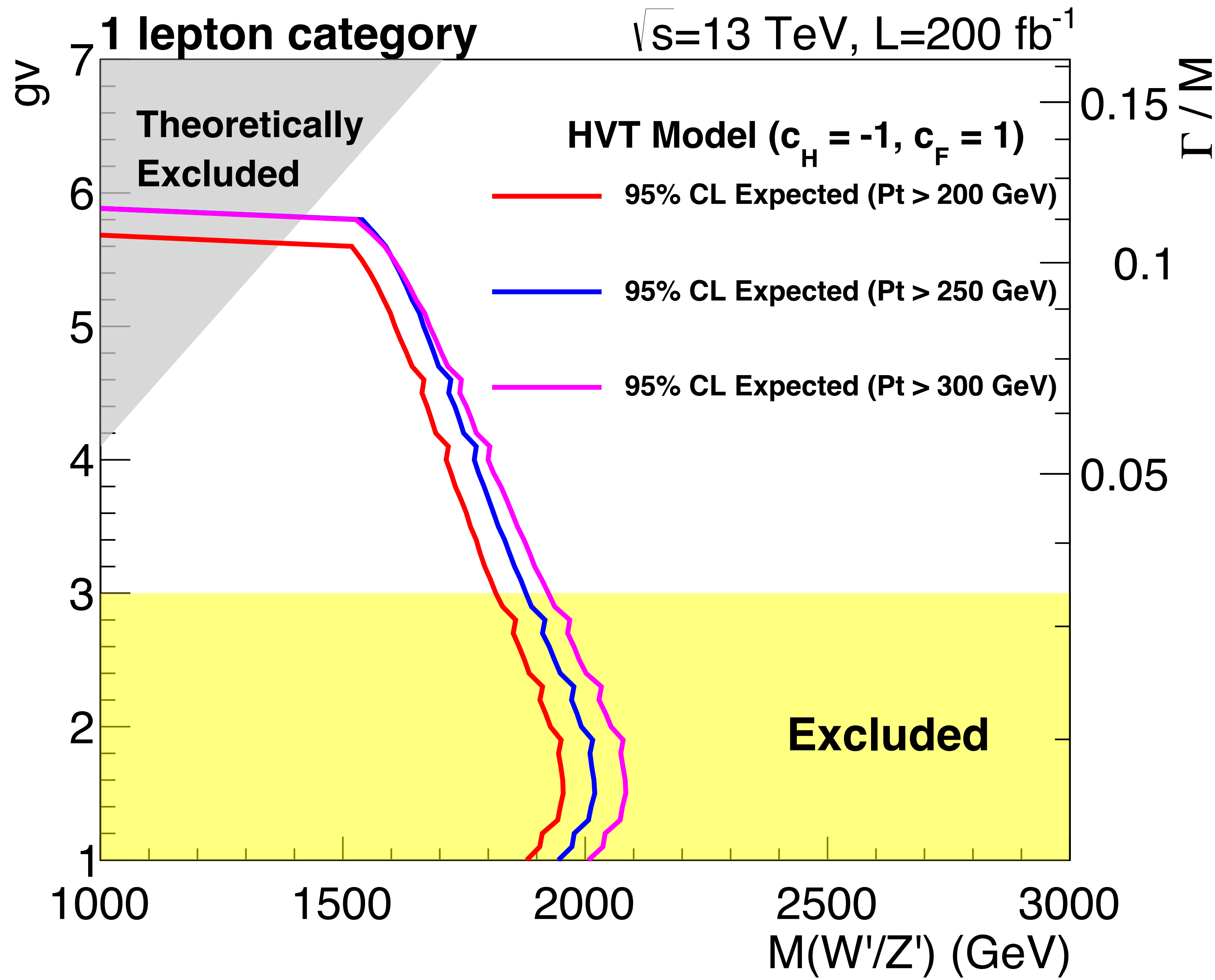




0-lepton category has lower sensitivity.

For the existing published ATLAS/CMS analyses it will come out to have no sensitivity (HVT yields small in the full phase space)

W' Limits: 1-lepton category



10% width

4% width

Analysis sensitive even for present luminosity.

ATLAS/CMS VH→bb yields (0,1, 2lep)

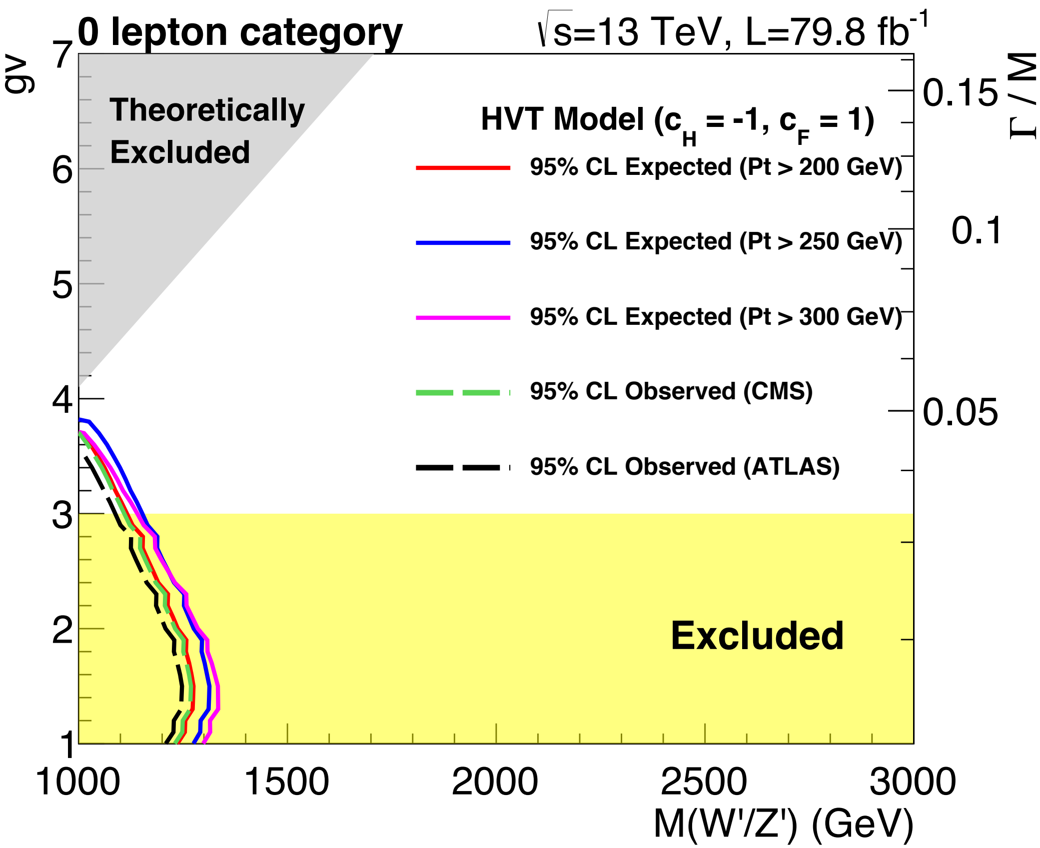
Signal strength	Signal strength	p_0		Significance	
		Exp.	Obs.	Exp.	Obs.
0-lepton	$1.04^{+0.34}_{-0.32}$	$9.5 \cdot 10^{-4}$	$5.1 \cdot 10^{-4}$	3.1	3.3
1-lepton	$1.09^{+0.46}_{-0.42}$	$8.7 \cdot 10^{-3}$	$4.9 \cdot 10^{-3}$	2.4	2.6
2-lepton	$1.38^{+0.46}_{-0.42}$	$4.0 \cdot 10^{-3}$	$3.3 \cdot 10^{-4}$	2.6	3.4
$VH, H \rightarrow b\bar{b}$ combination	$1.16^{+0.27}_{-0.25}$	$7.3 \cdot 10^{-6}$	$5.3 \cdot 10^{-7}$	4.3	4.9

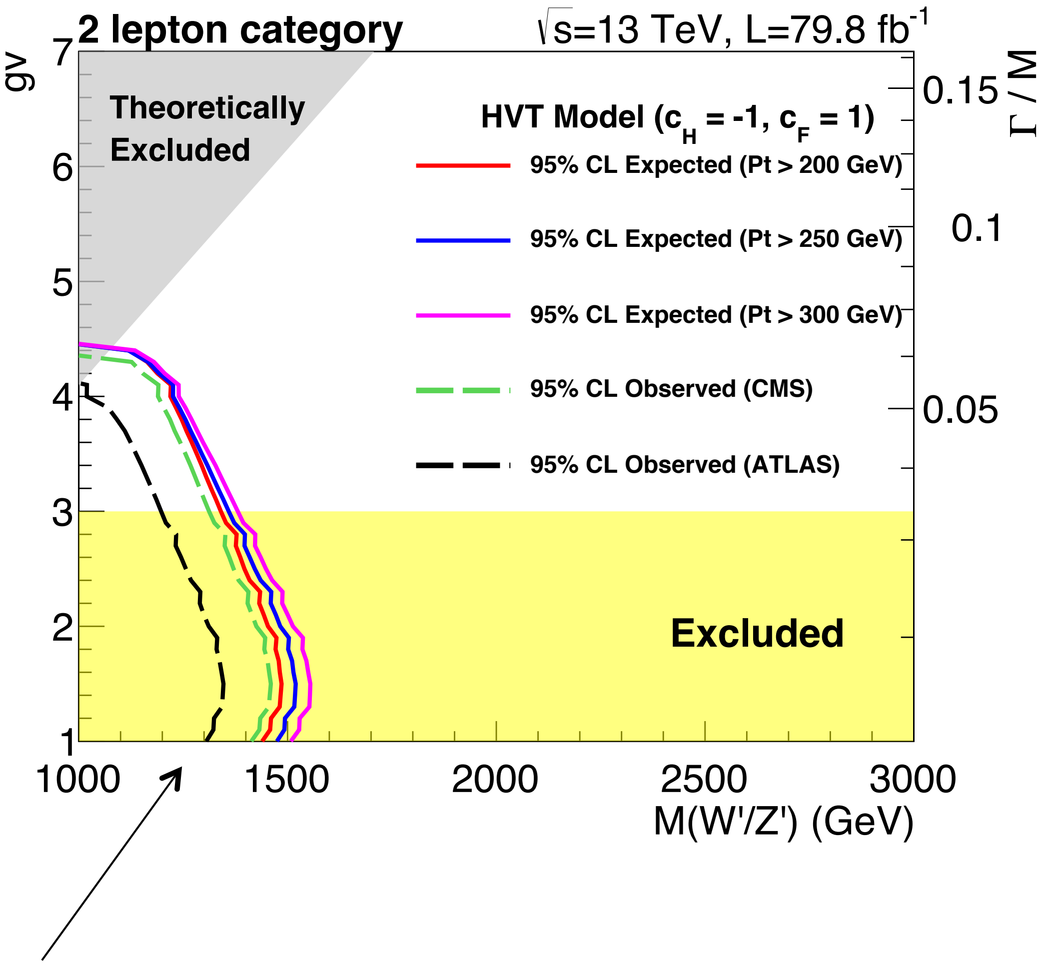
	Significance		
Channels	Expected	Observed	Signal strength
2017			
0-lepton	1.9	1.3	0.73 ± 0.65
1-lepton	1.8	2.6	1.32 ± 0.55
2-lepton	1.9	1.9	1.05 ± 0.59
Combined	3.1	3.3	1.08 ± 0.34
Run 2	4.2	4.4	1.06 ± 0.26
Run 1 + Run 2	4.9	4.8	1.01 ± 0.23

25. ATLAS Collaboration, Observation of $H \rightarrow bb$ decays and VH production with the ATLAS detector, arXiv:1808.08238 [hep-ex] (2018).

26. CMS Collaboration, Observation of Higgs boson decay to bottom quarks CMS-PAS-HIG-18-016 (2018).

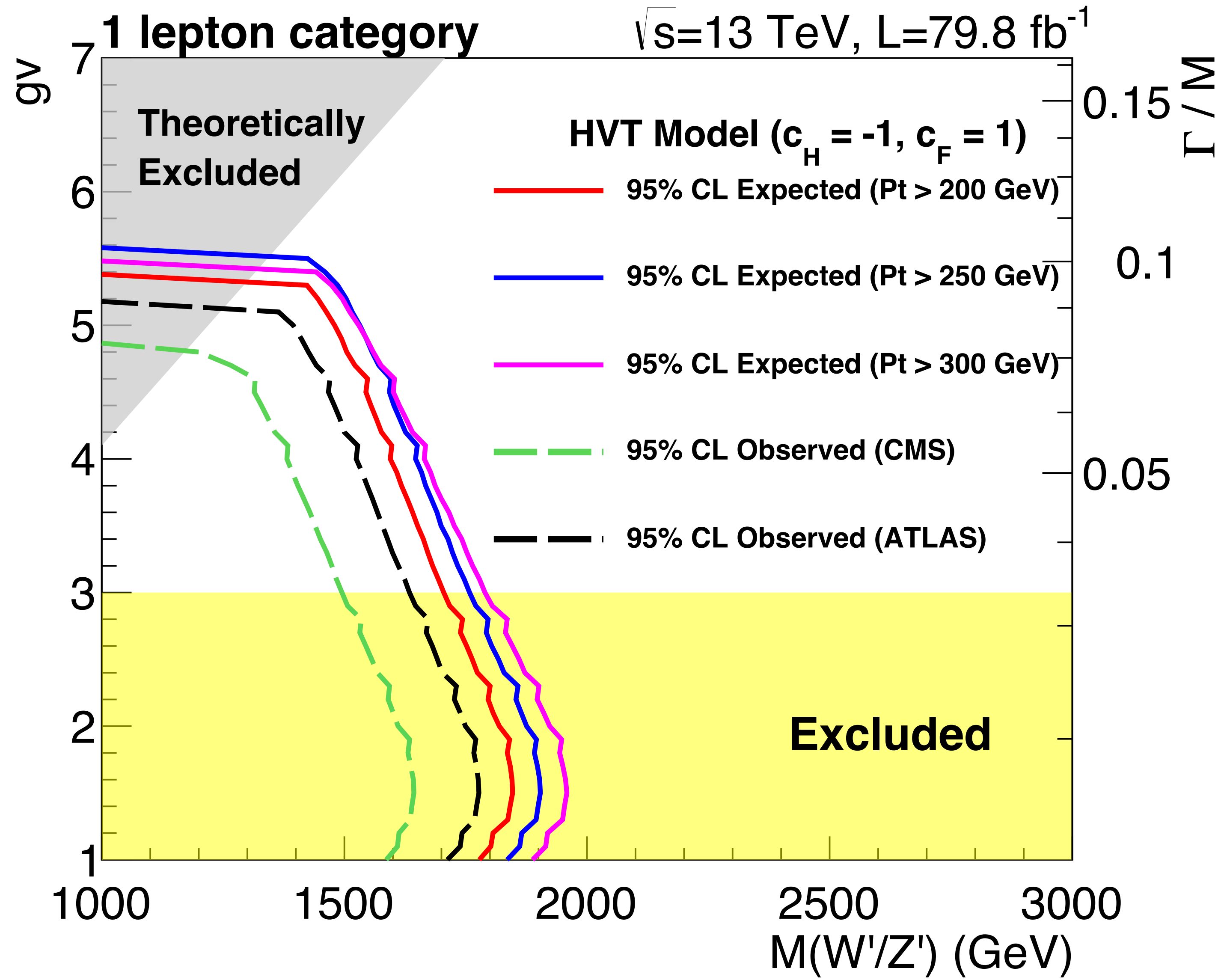
ATLAS/CMS exclusions: 0 lep , 2 lep





ATLAS exclusion lower than expectation due to an excess. (actually this would be the first sign of signal if both ATLAS/CMS showed “the same” observed limit weaker than expected).

W' Limits: 1-lepton category



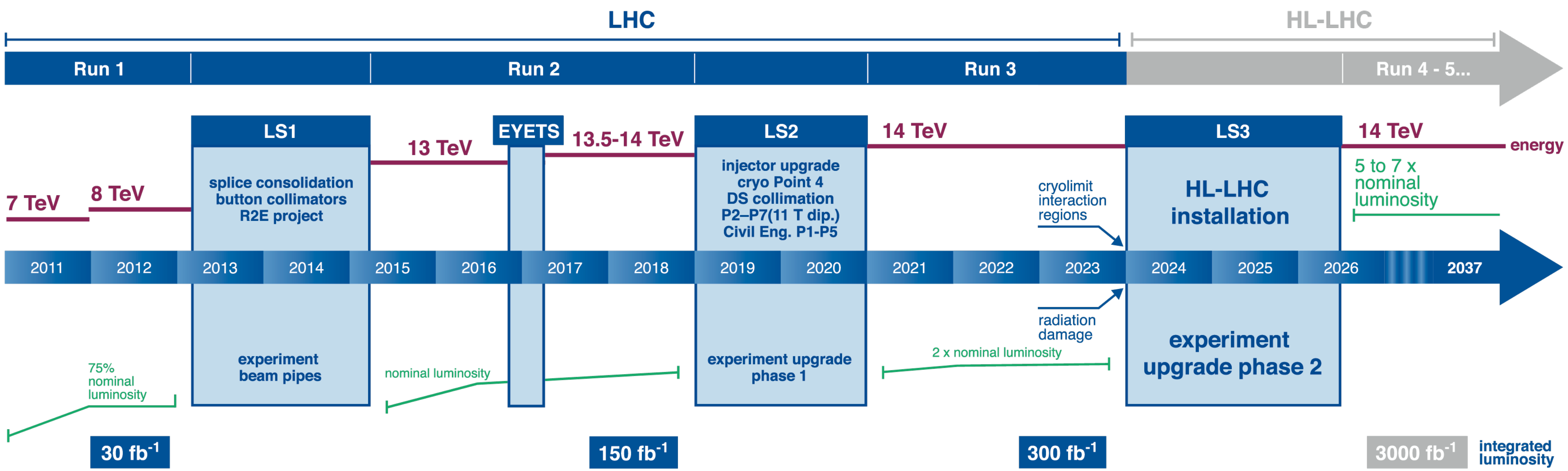
Reach out to 1.5 TeV to 2 TeV depending on the width
Note that part of the available param space is excluded.

Work in Taiwan

A few words about what we're doing

High Luminosity LHC

LHC / HL-LHC Plan



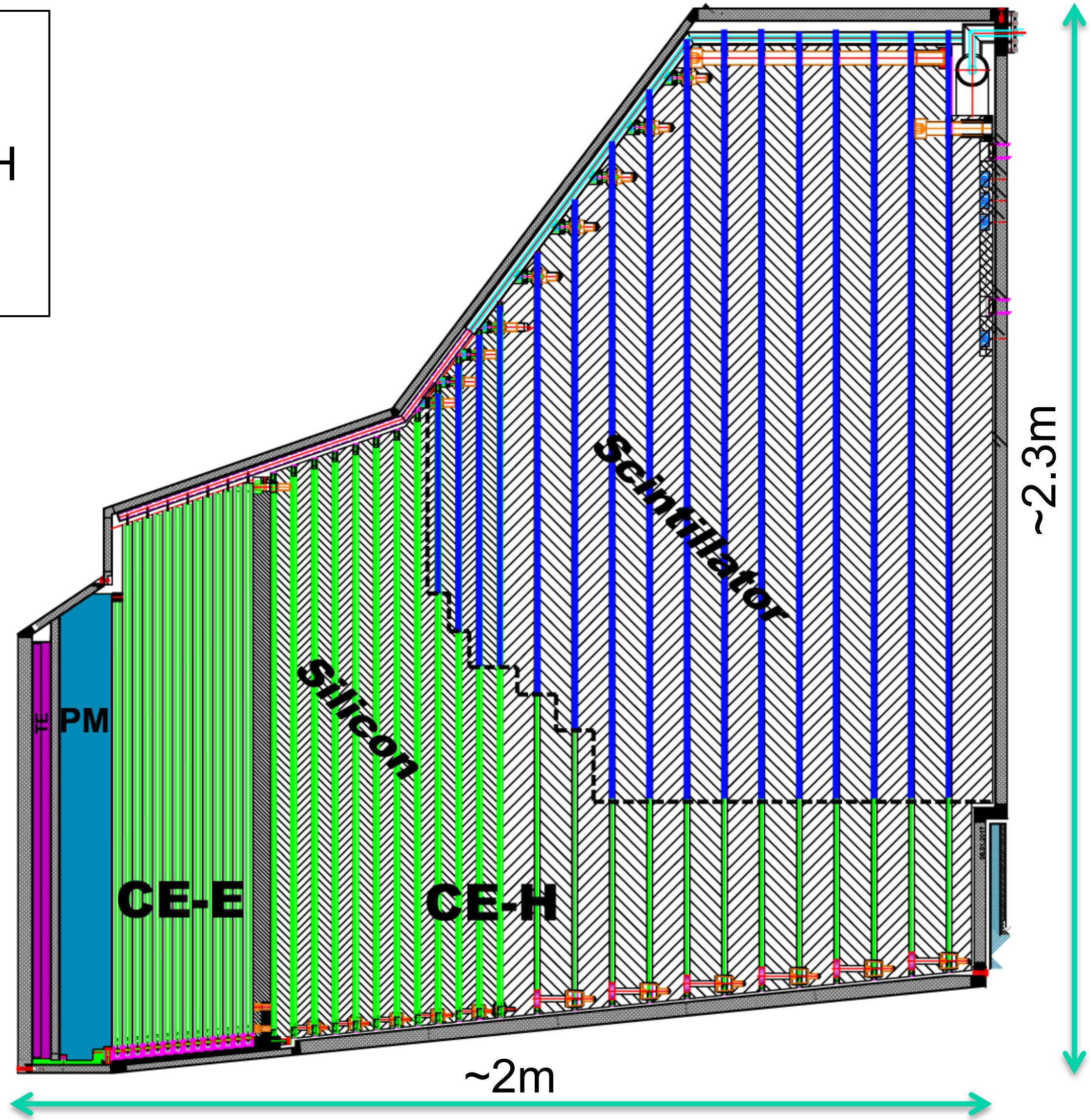
HL-LHC will enable precision measurements of H properties (couplings, self-couplings,…) and to probe the existence of very rare new physics processes.

Major detector upgrades foreseen to maximise the physics outcome from high integrated luminosity and limit the degradation from radiation and high pileup rate.

CMS HGCAL: a 52-layer sampling calorimeter with unprecedented number of readout channels

Active Elements:
- Hexagonal modules based on Si sensors in CE-E and high-radiation regions of CE-H
- Scintillating tiles with SiPM readout in low-radiation regions of CE-H

Key Parameters:
- HGCAL covers 1.5 < η < 3.0
- **Full system maintained at -30°C**
- **~600m²** of silicon sensors
- **~500m²** of scintillators
- 6M Si channels, 0.5 or 1.1 cm² cell size
  - Data readout from all layers
  - Trigger readout from alternate layers in CE-E and all layers in CE-H
- ~27000 Si modules

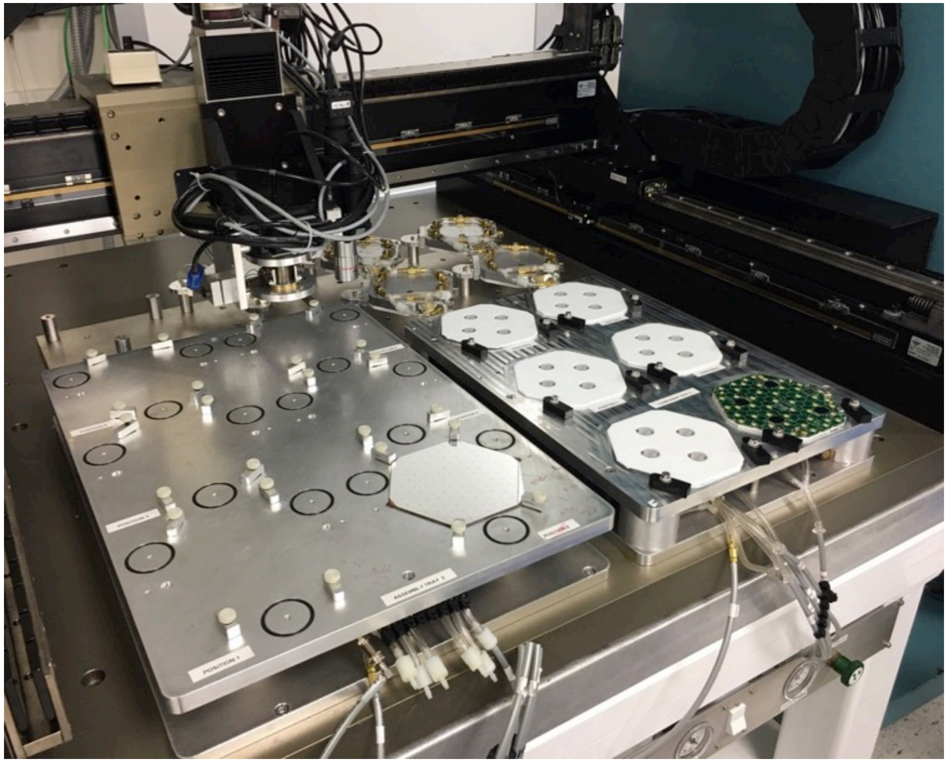


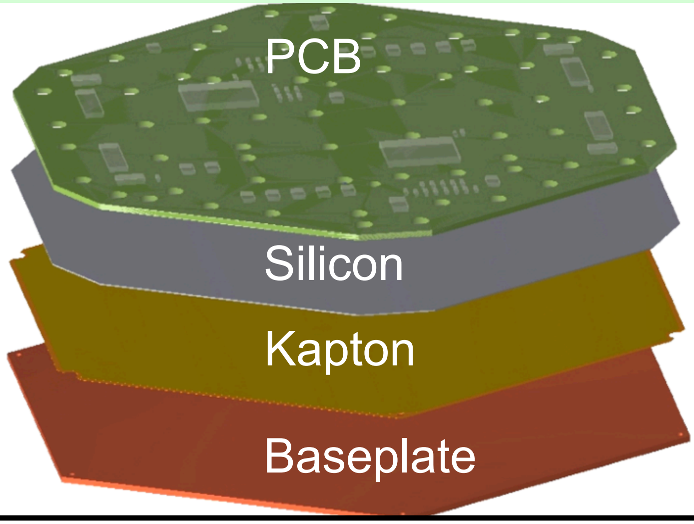
EM calorimeter (**CE-E**): **Si**, Cu/CuW/Pb absorbers, 28 layers, 26 X_0 & ~1.7λ

Hadronic calo (**CE-H**): **Si** & **scintillator**, steel absorbers, 24 layers, ~9.0λ

Si modules are glued assemblies

Automated gantry @ UCSB
used previously for CMS tracker assembly

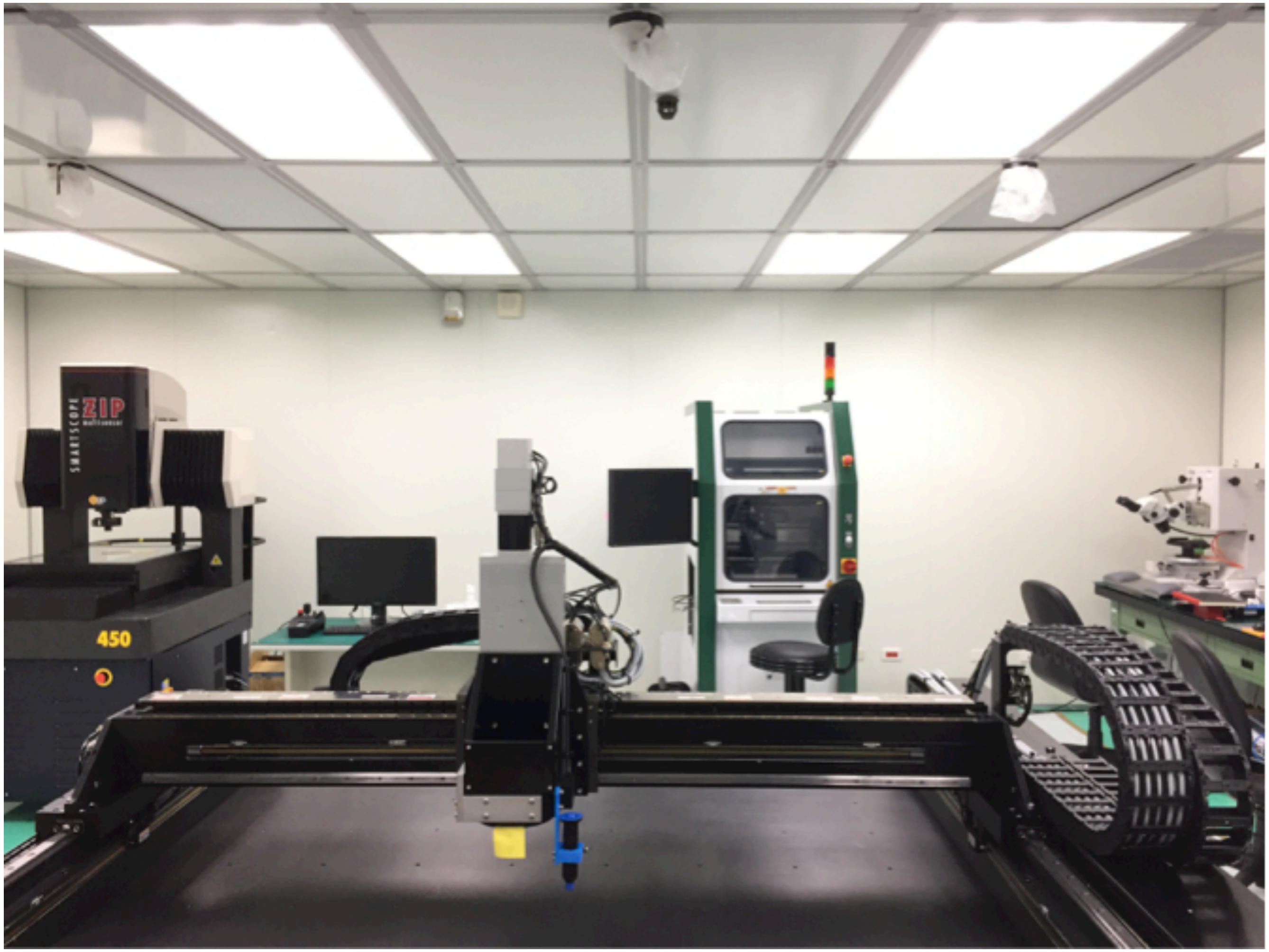


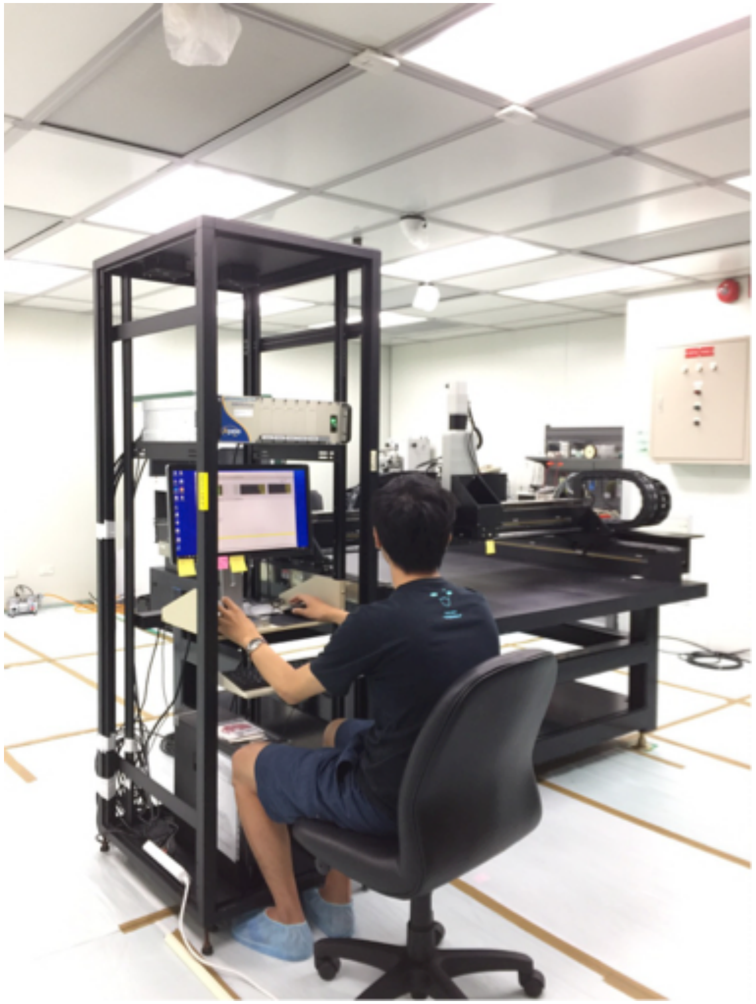


In CE-E, baseplate = 1.2mm CuW, to keep overall density high

Three centers are being setup in Asia: India, China (IHEP), **Taiwan**

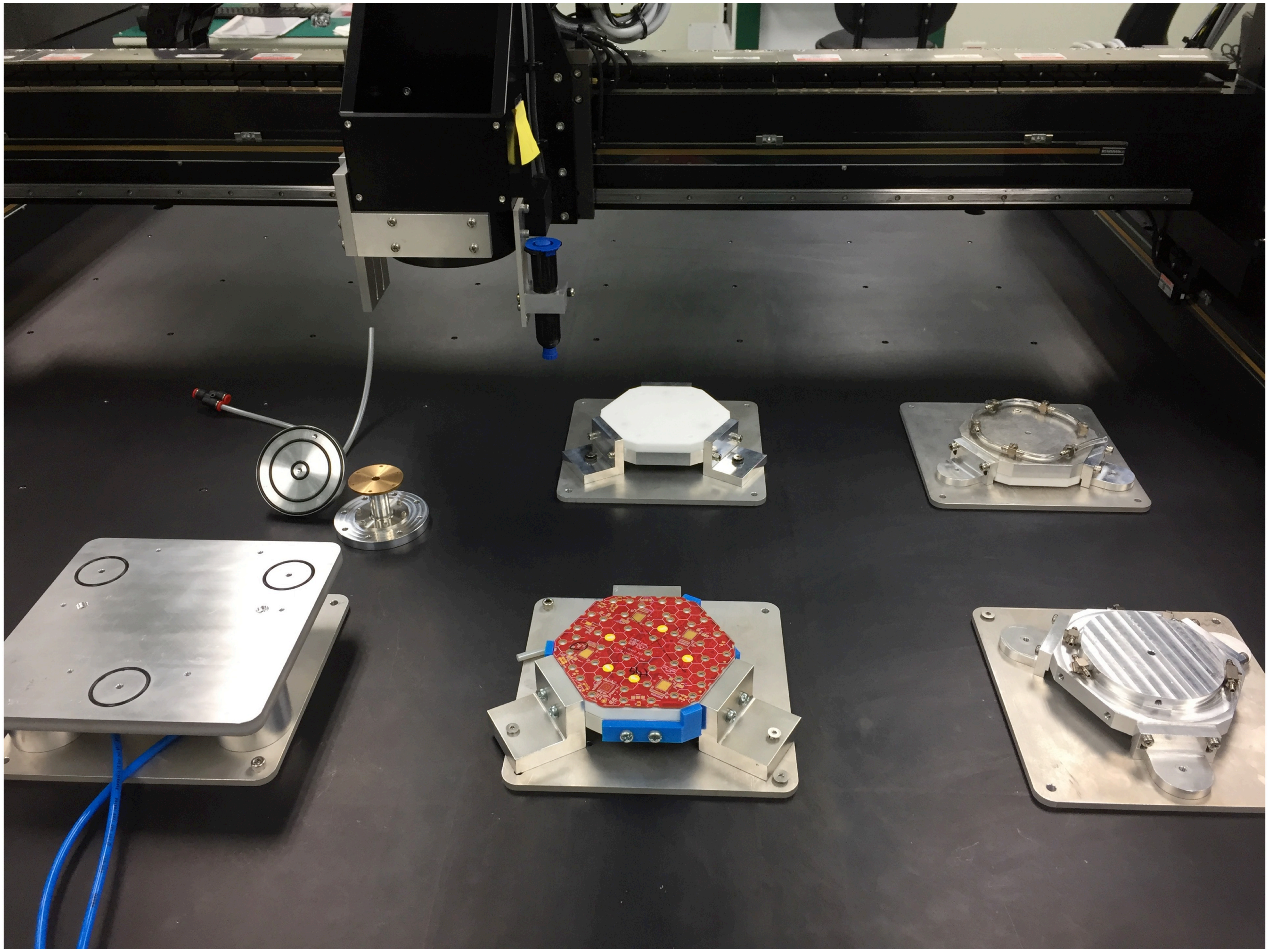
Cleanroom ready (OGP is in)

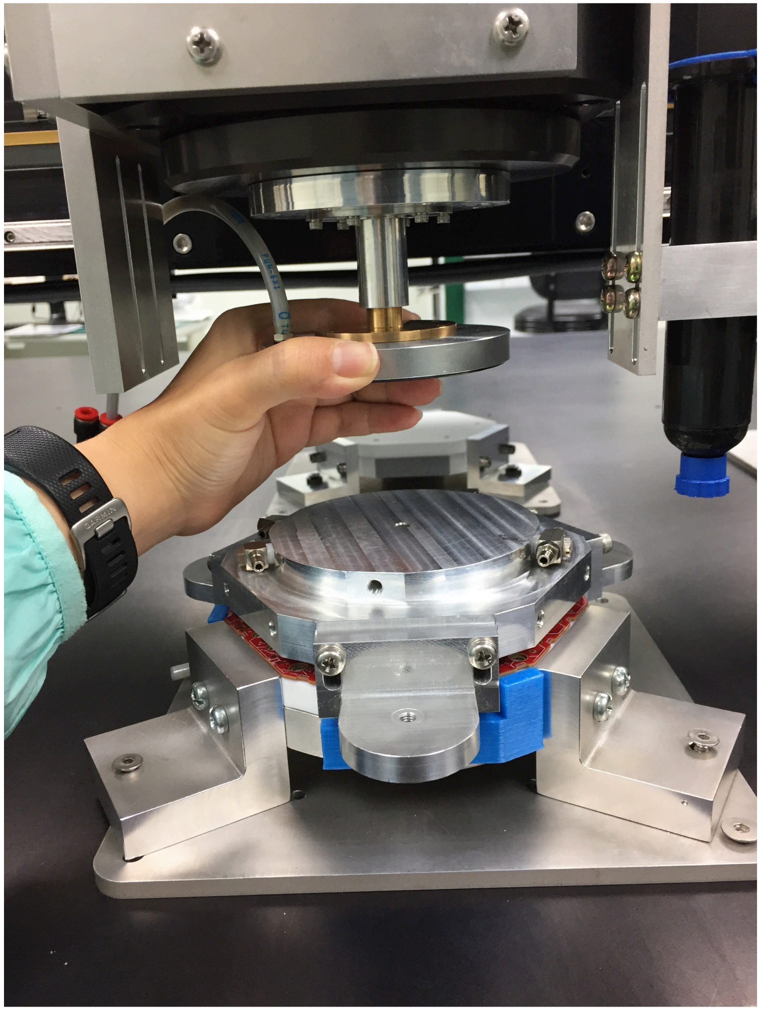




We are now moving to the R&D phase.
Next milestone to build a module.

Tooling work





This is ongoing work to use our std tools for pickup. The first batch of these have shown some leaks, but we can set vacuum and pick up mock sensors.

Plans for a Taiwan-HEP collaboration

Develop sensors for:

- Build 5000 HGCAL modules (2021-2023)

- CEPC (Circular 100km collider in China)
  - Luminosity Monitor (PI: Suen Hou)
  - ILD-like calorimeter (similar to HGCAL)

- Sensors for Particle Astrophysics and Medical Apps
  - Gaseous VUV and Xray sensors (SP)
  - Others? (MPPCs, Scnanowires, etc)

- Generic R&D
  - Silicon sensors from Taiwan + PCB from Taiwan

Extra Slides

Fraction of fat jets vs Mass

Normal jet : Eta < 2.5, pass btagging, 80< dijet_mass < 160
Fat jet : exactly 1 jet with eta < 2.5 , 80 < this single jet mass < 160

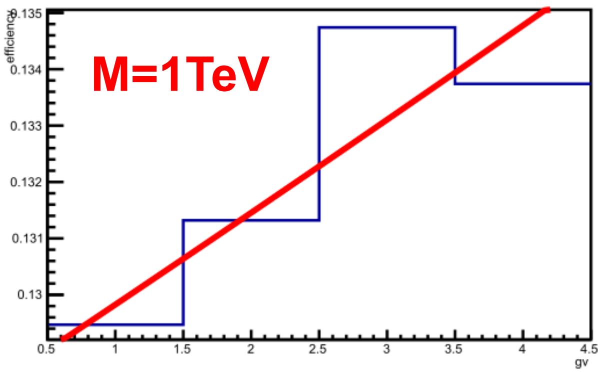
Fat jet rate

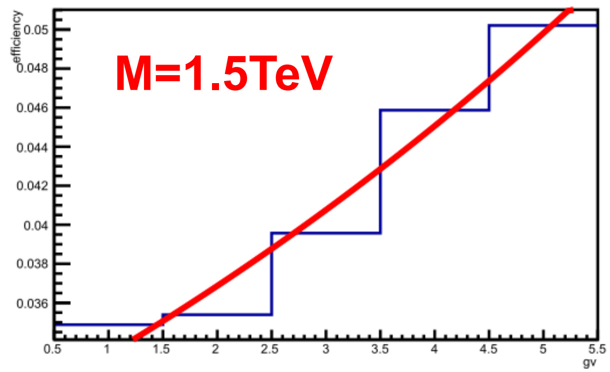
1.0 TeV 47.4 %
1.5 TeV 85.6 %
2.0 TeV 94.8 %
2.5 TeV 98.0 %
3.0 TeV 98.9 %

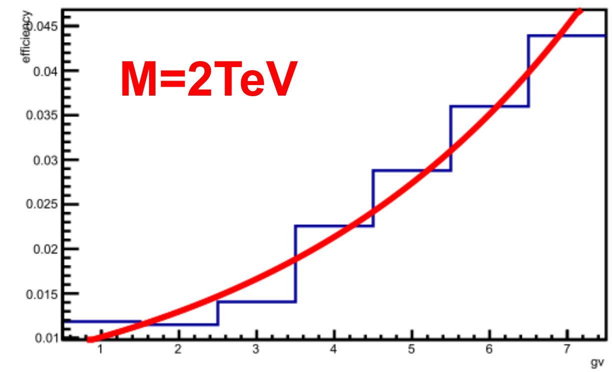
Efficiencies for V'

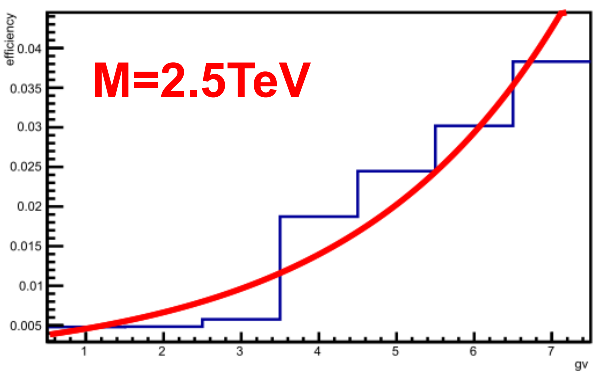
Significant amount of work to find the efficiencies vs $M_{V'}$ and g_V.

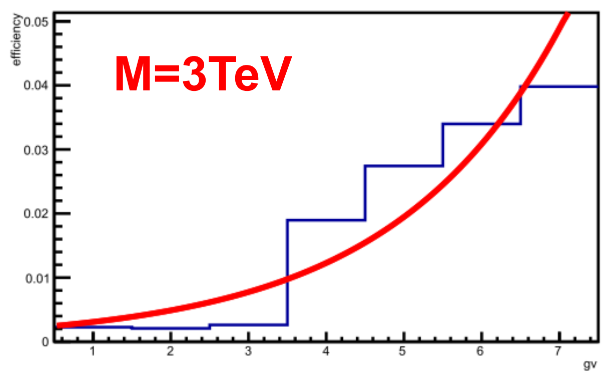
Example: efficiencies for bb Pt>200 GeV.







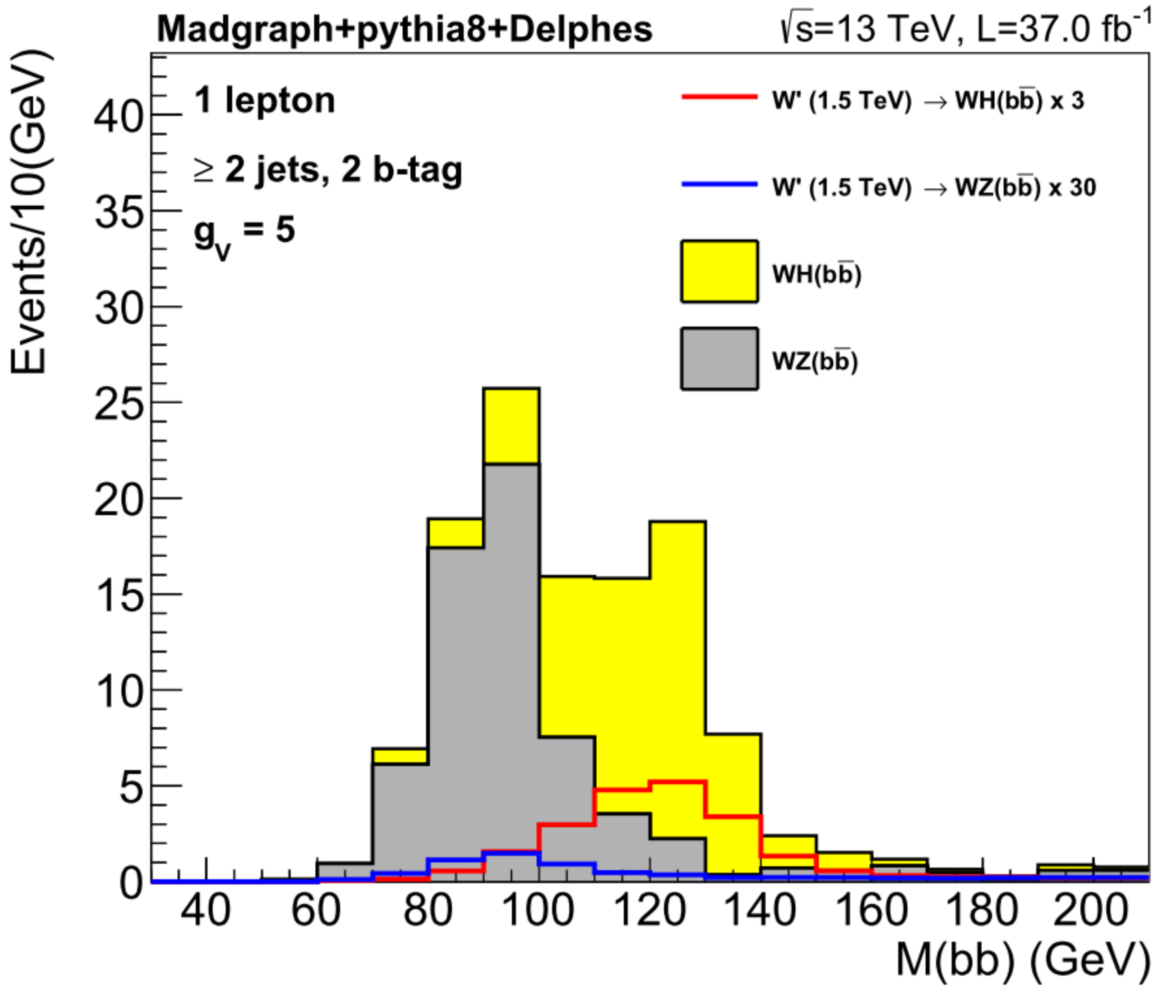




$$\varepsilon = \varepsilon\left(\mathrm{M}_{V'}, g_V\right)$$

One-lepton category 37fb^{-1}

ATLAS-like analysis with the addition of Higgs Pt>200GeV cut

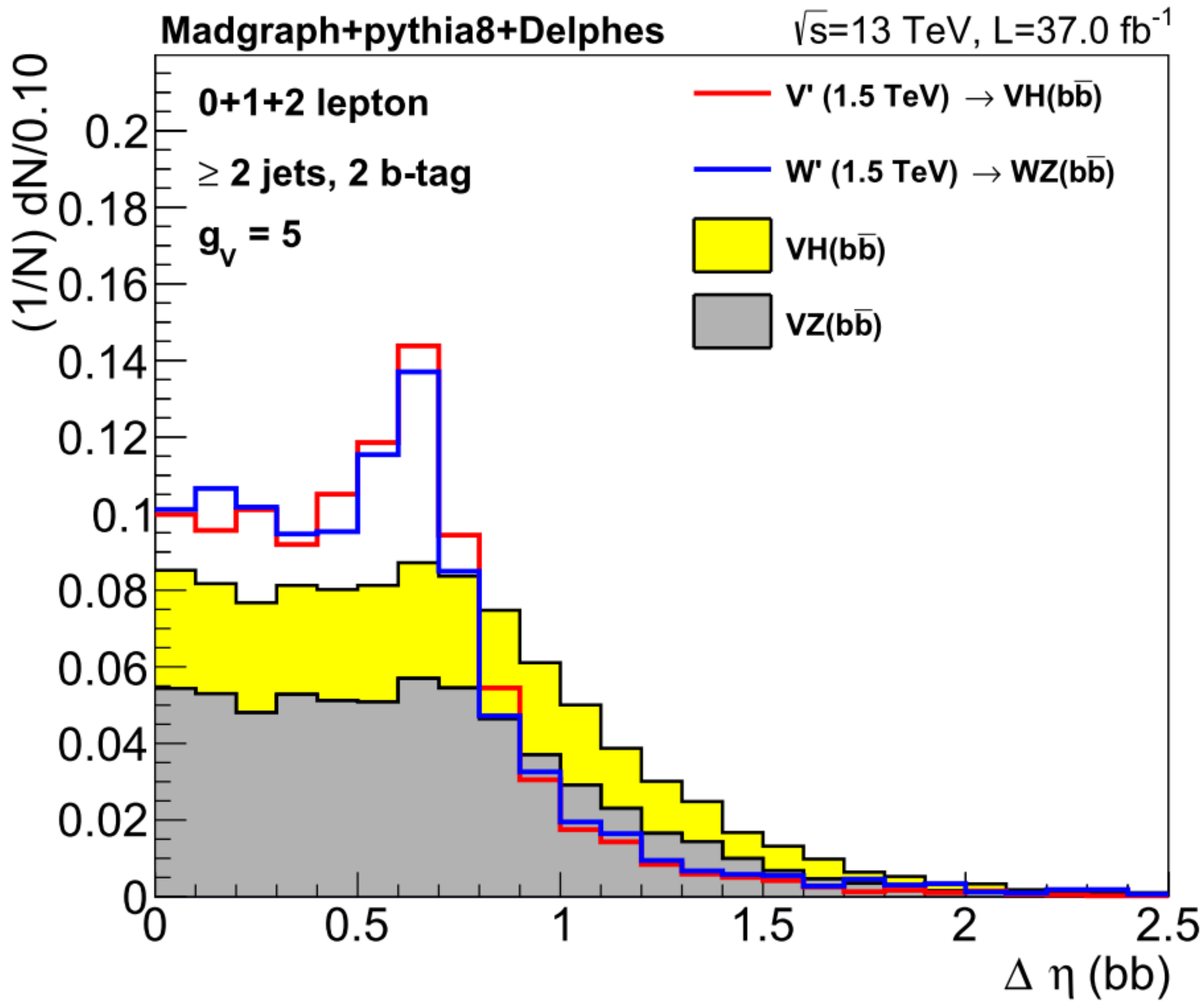


BR(Z→bb)=15%
BR(H→bb)=58%

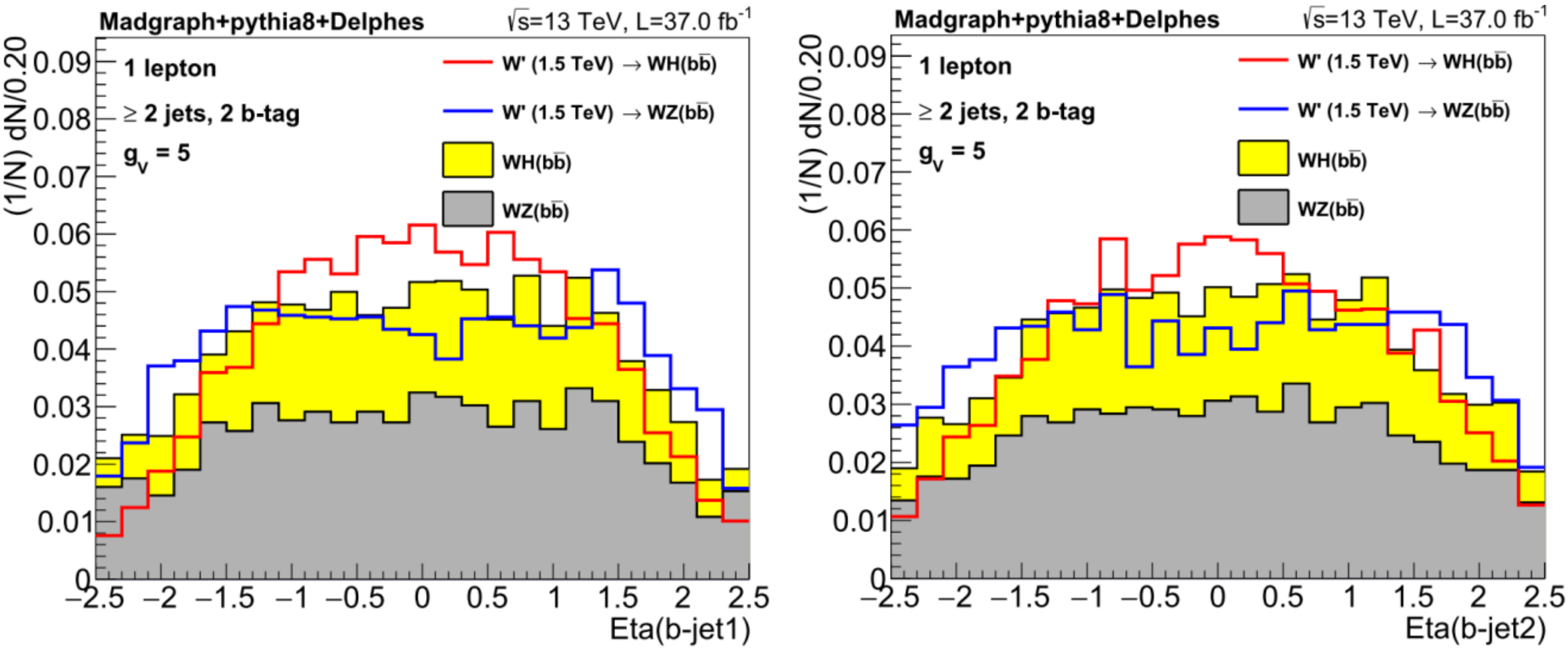
So, the WZ BSM signal is 4x lower than the WH (SHOWN in **blue**)

SM VH, ZW yield : 118.55 events
95% CLs W'→WH : 22.8 events

Δη(bb) distribution after detector



$\Delta\eta$(bj) distributions after detector



Comment on the V self-interactions

Our parametrization of the operators is useful at the theoretical level but obviously redundant as g_V could be reabsorbed in the c's and is not a genuine new parameter of the model. For instance, one could resolve the redundancy by setting $c_{VVV} = 1$ and thus define g_V as the V self-interaction strength. However for practical purposes, and in particular for presenting the experimental limits of the model, it could be easier to treat $g_V c_H$ and $g^2/g_V c_F$, the combinations that enter in the vertices, as fundamental parameters.

Comment on “Theory Excluded”

Strongly coupled heavy vector

This case is depicted in the middle and lower plots of Figure 3.1 for an intermediate, $g_V = 3$, and rather stronger, $g_V = 6$, coupling. A strongly coupled vector resonance like a new composite vector boson, analogous to the ρ in QCD, arising for example in Composite Higgs models is excluded up to $\sim 1.5 - 2$ TeV for intermediate coupling of the strong sector and almost unconstrained for large enough coupling ($g_V \gtrsim 5$). The most constraining searches are those into di-boson final states because, as described above, the BRs into vector bosons are much larger than those into fermions. $t\bar{t}$ and tb searches are not particularly sensitive. Notice, however, that we are working under the assumption of a universal coupling to fermions. In potentially realistic strongly coupled scenarios the parameter c_3 is actually expected to be enhanced, improving the sensitivity of third family searches. A careful assessment of this interesting effect is left to future work. Notice that a large portion of the mass range is theoretically excluded, as shown in the plots. This corresponds to regions where it is not possible to reproduce the SM input parameters $\alpha_{\rm EW}$, G_F and M_Z for such a small physical mass and large g_V coupling.

Setting Limits procedure

1 lepton category ($qq \rightarrow W' \rightarrow WH(\rightarrow l\nu bb)$) (Pt > 200 GeV)

Expected bkg (VH +VV) events for $37\mathrm{fb}^{-1}$: 119 (based on ATLAS paper and additional selection)

b-only (Poisson counting + CLs) →

22.8 new physics events (95% CL expected limit)

BR(H→ $b\bar{b}$), BR(W→ $l\nu$), selection efficiency ↓