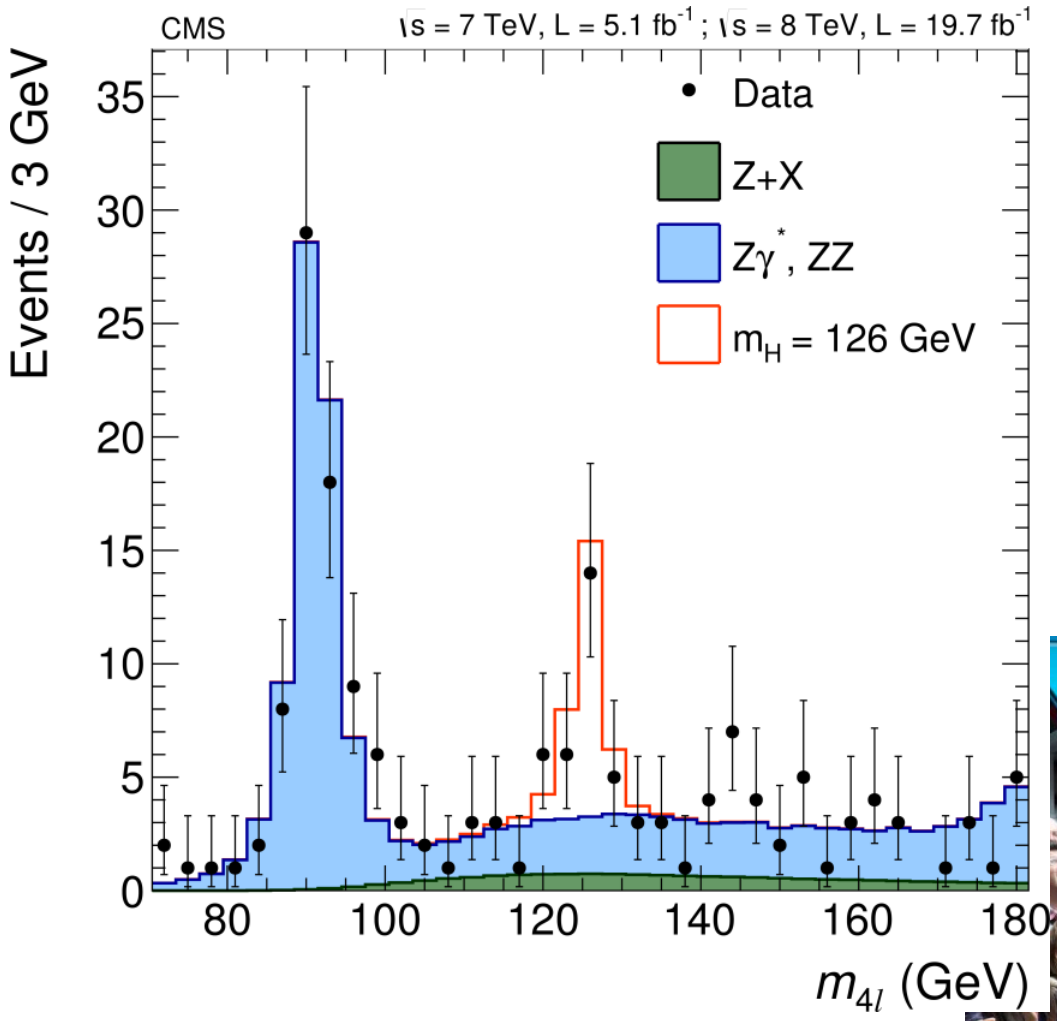
Probing New Physics with Higgs+2jets: VBF and VH

Stathes Paganis (NTU)
HEP2016, Thessaloniki, 12-May-2016

- Introduction: Higgs + jets as an early probe
- VH example: composite Higgs
- LHC: are we measuring the VBF component?
- Simultaneous extraction of VBF and ggF+jj (**new results**)

4th of July 2012: Higgs discovery



- 2013: Nobel prize to Englert-Higgs.
- 2015: Final results on Run1 show that what we discovered at CERN is consistent with SM Higgs to the extend that data (statistical) precision allows.

ATLAS Group NY Times

Motivation: new heavy particles

- BSM physics is around the corner. In most models there are new heavy states coupling to SM particles: Higgs,Z,W,top.
  - Focus in Higgs+jets, dominated by ggFjj.

- In Run1 analyses ggFjj **was not** directly measured but 'subtracted' using theory expectation with some systematic.

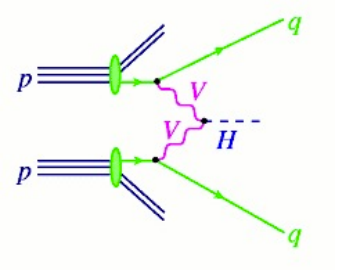
- This creates **questions** on the VBF signal extraction for which ggFjj is a background that must be subtracted.

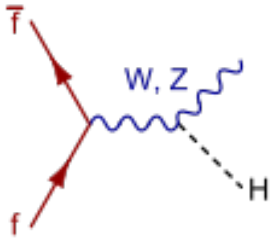
- My personal interest: (non-SM) Higgs produced from heavy exotic sources.

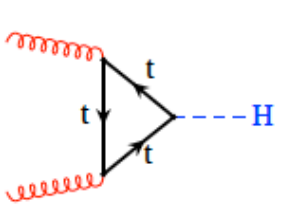
SM Higgs production modes

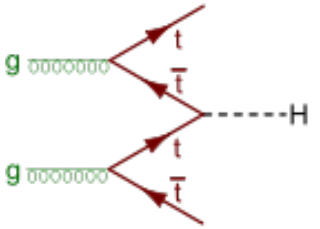
The main Higgs production mechanisms depend on V-H or top-H couplings

V-H couplings



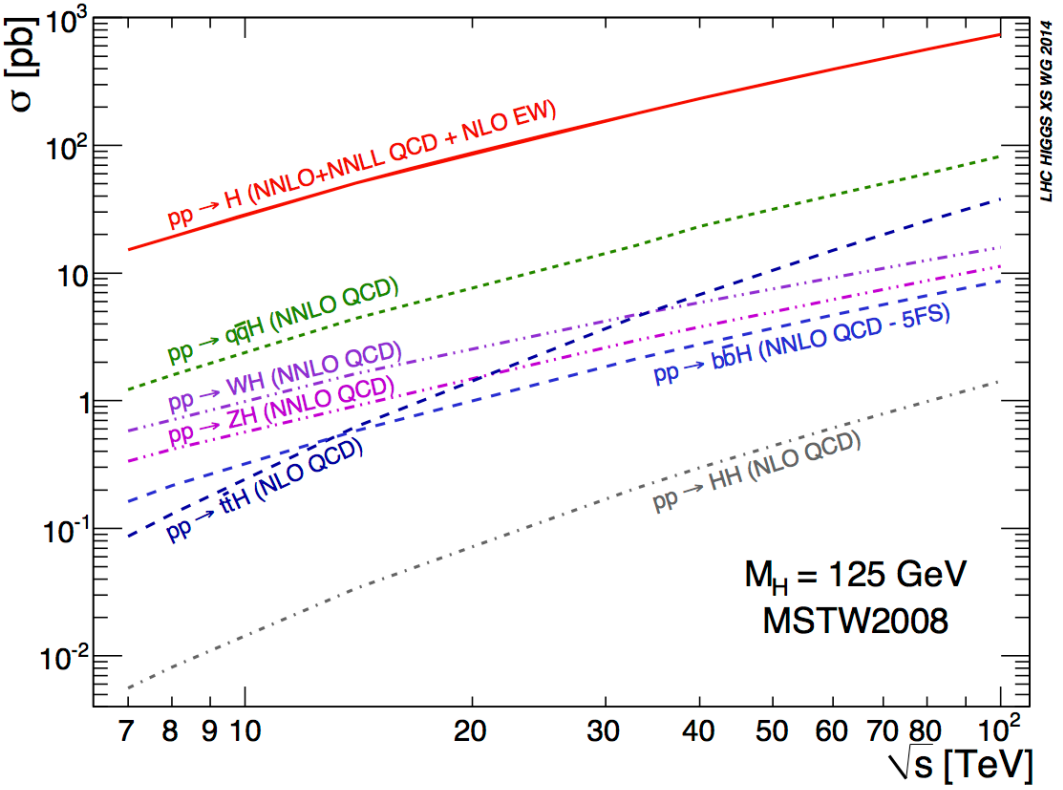






top-H couplings

VBF VH ggF ttH

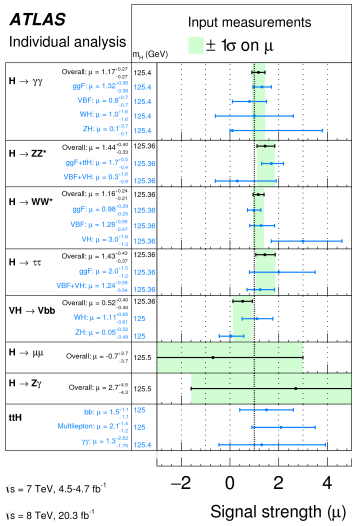


Run 1 final: Couplings

Sphicas: LHCP15

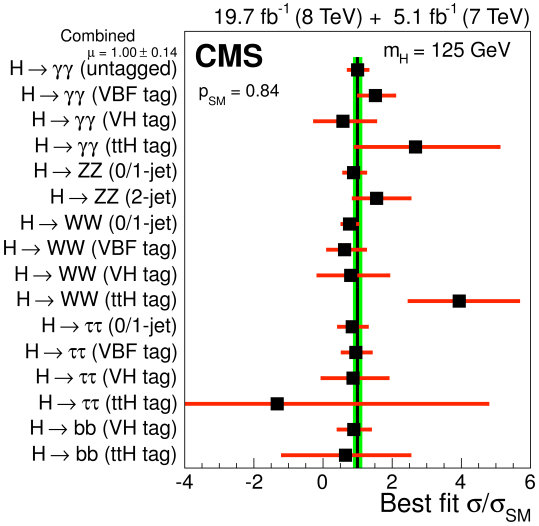
ATLAS

Mass: *Phys. Rev. Lett. 114, 191803*
Couplings: **arXiv:1507.04548**

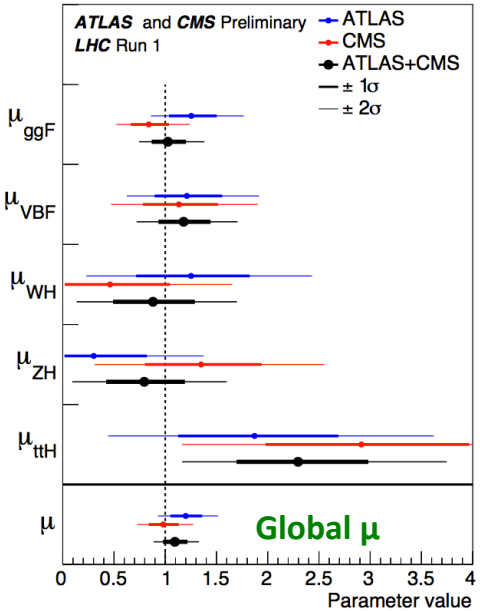


CMS

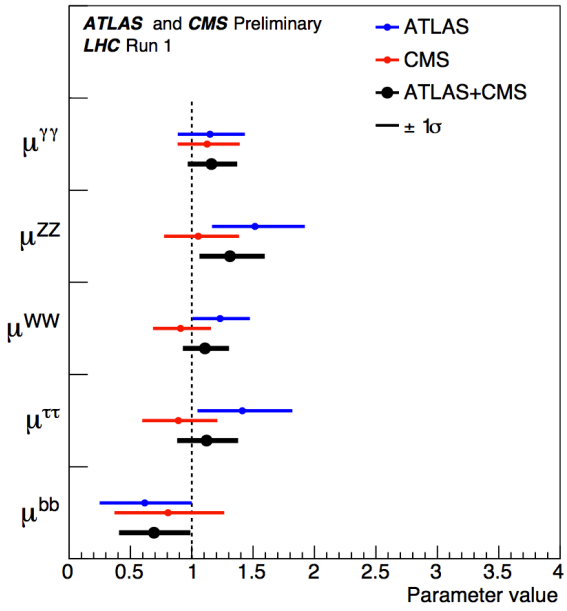
Mass and couplings:
Eur. Phys. J. C 75 (2015) 212



SM BRs assumed



SM production σ assumed



Production process	Observed Significance(σ)	Expected Significance (σ)
VBF	**5.4**	**4.7**
WH	2.4	2.7
ZH	2.3	2.9
VH	3.5	4.2
ttH	4.4	2.0
Decay channel		
H→ττ	**5.5**	**5.0**
H→bb	2.6	3.7

$\mu = 1.09\ ^{+0.11}_{-0.10}$

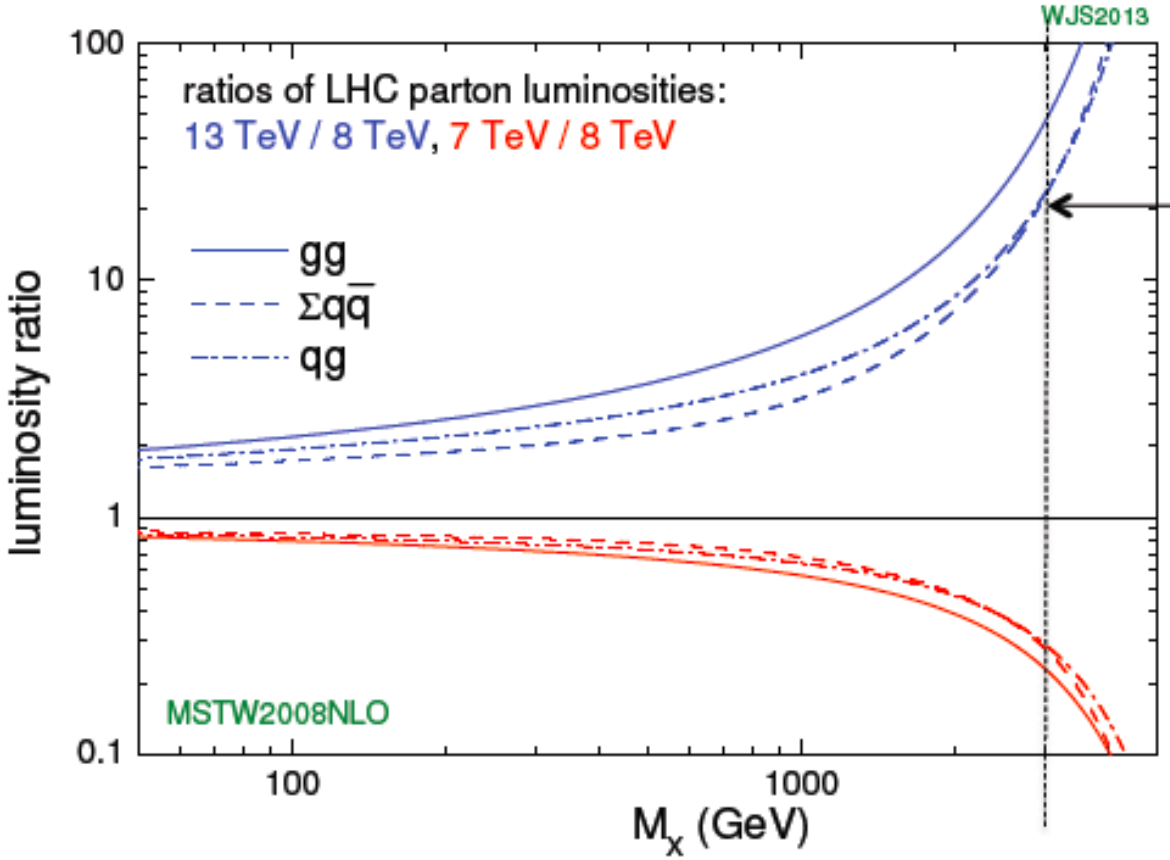
Consistent with the SM Higgs boson

SP: we surely observed non-zero VBF but is it SM-like?

Run2: sensitive to TeV heavy states

	Peak lumi E34 $cm^{-2}s^{-1}$	Days proton physics	Approx. int lumi [fb^{-1}]
2015	~0.5	65	3.6
2016	1.2	160	30
2017	1.5	160	36
2018	1.5	160	36

→ Acquired!
(~20fb^{-1} at 8TeV)

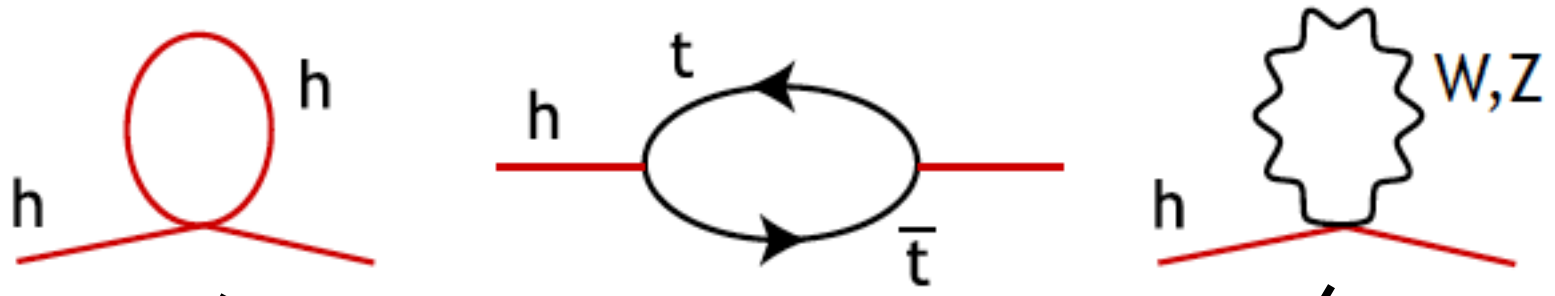


3TeV: x20
4TeV: x56
5TeV: x370
6TeV: x9000

Run 2 already sensitive to new heavy Particles

So, what's wrong with the SM Higgs?

If SM holds up to a (>> TeV) scale, Higgs mass receives (huge) higher order corrections.



$$\Delta m_h^2 = \frac{6}{8\pi^2}\left(-\lambda + y_t^2 - \frac{3g^2 + g'^2}{8}\right)\Lambda^2$$

Scale of new physics Λ should be at few TeV …

How to create a naturally light 125GeV scalar?

Relate the scalar to a fermion and use chiral symmetry to forbid mass $\delta h = \varepsilon \psi$	**SUSY**
Relate the scalar to a Boson and use gauge symmetry to forbid mass $\delta h = \varepsilon_\mu B^\mu$	**Extra Dimensions**
Mass forbidden due to a shift symmetry $\delta h = \varepsilon$	**Higgs as a pseudo-Goldstone**
Mass forbidden due to scale invariance $\delta h = \varepsilon h$	**Scalar is dilaton (not the Higgs)**

M.E.Peskin 2014

Pions in QCD transform by a shift (non-linearly) under an axial SU(2) rotation.

My interest is in BSM search using the SM Higgs itself.

What does Higgs+jets have to with the BSM physics?

Exotic Particles decaying to the 125GeV Higgs although a small contribution, in parts of phase space may be very large contributions (with respect to SM Higgs)!

Just an example … VH ➔

The (simplest) Minimal Composite Model

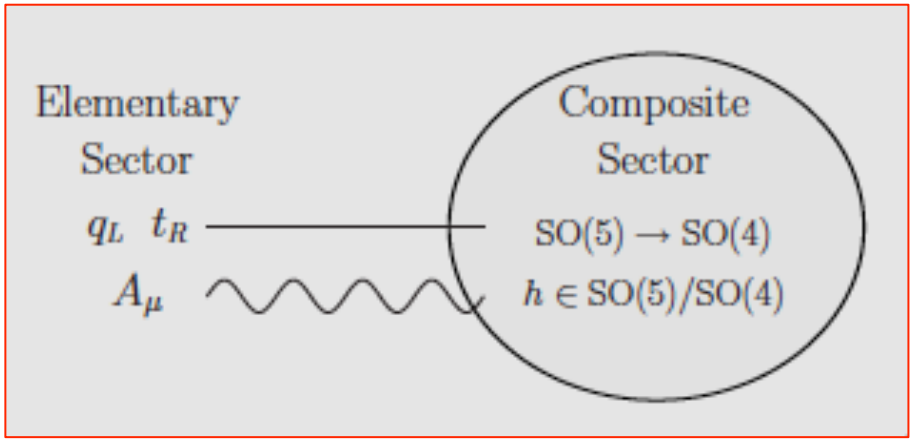
How to chose the simplest possible model giving just a Higgs doublet?

Agashe, Contino, Pomarol 2004
http://arxiv.org/abs/hep-ph/0412089

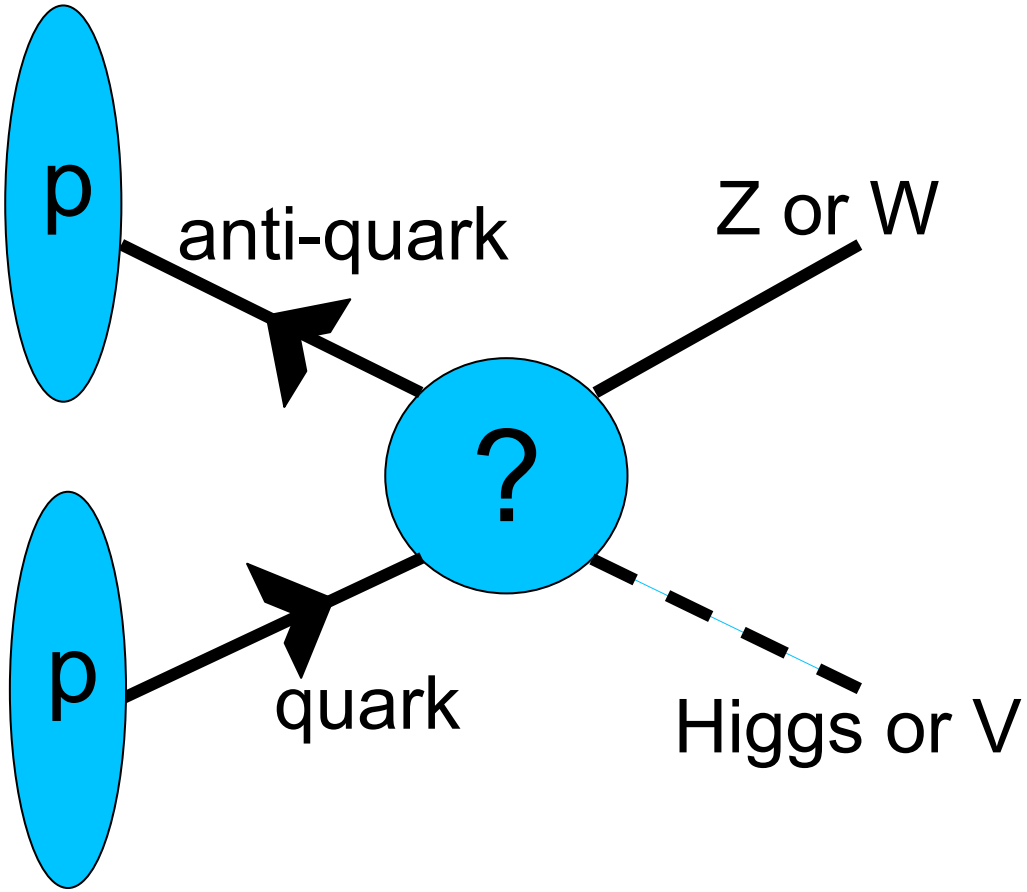
Requirements:

- The global group left unbroken by the strong dynamics must contain:
  - SU(2)xU(1)
  - Preserve SO(4) so we can end up with $SU(2)_V$ custodial symmetry.
- Need 4 Goldstones after global symmetry breaking.
- Simplest choice that works is SO(5) → SO(4)

$$\frac{SO(5)}{SO(4)} \qquad \frac{10 \text{ generators}}{6 \text{ generators}} + 4 \text{ broken (Goldstones)}$$



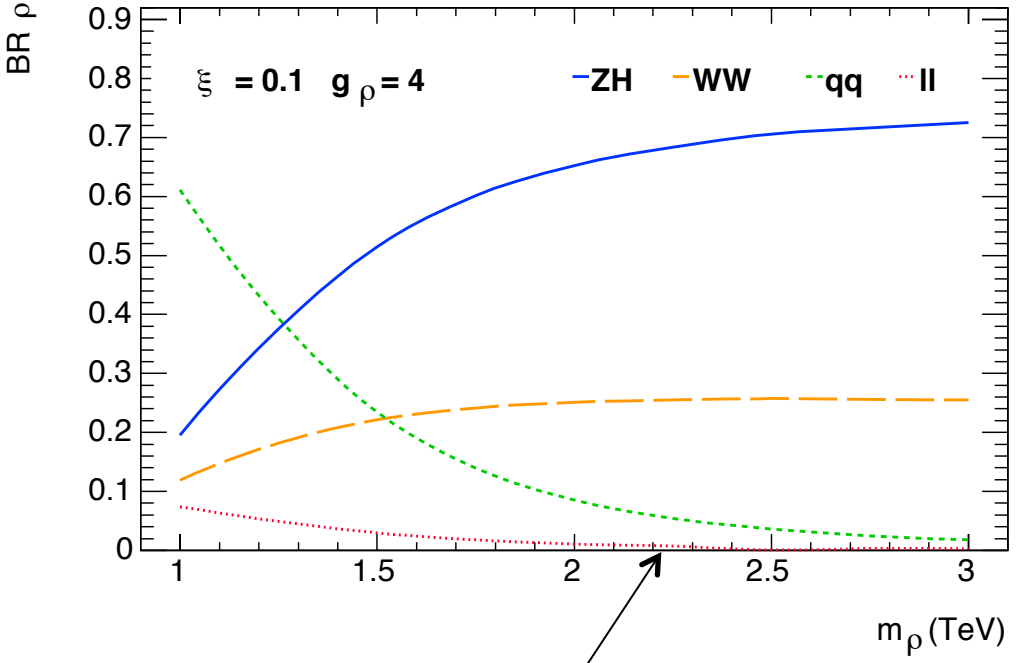
VH and VV vertex may hide new Physics

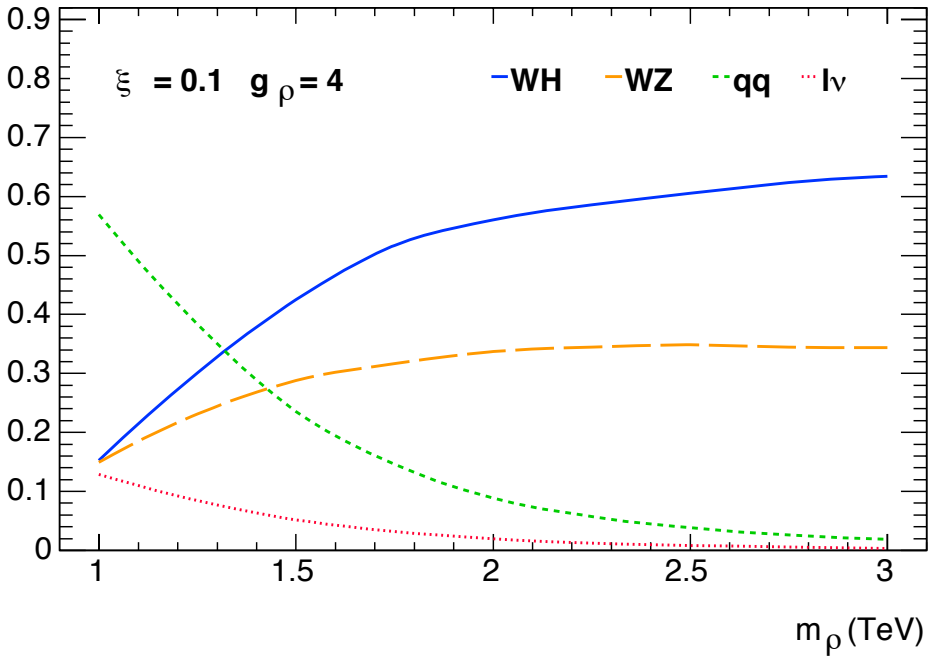


If observed, a heavy resonance triplet (TeV scale) must be responsible.
Example: spin 1 composite vectors ρ^+, ρ^-, ρ^0 ➔ Higgs is composite

ρ→VH production: 'composite Higgs smoking gun'

Hoffmann, Kaminska, Nikolaidou, SP, arXiv:1407.8000 EPJC 74 (2014)



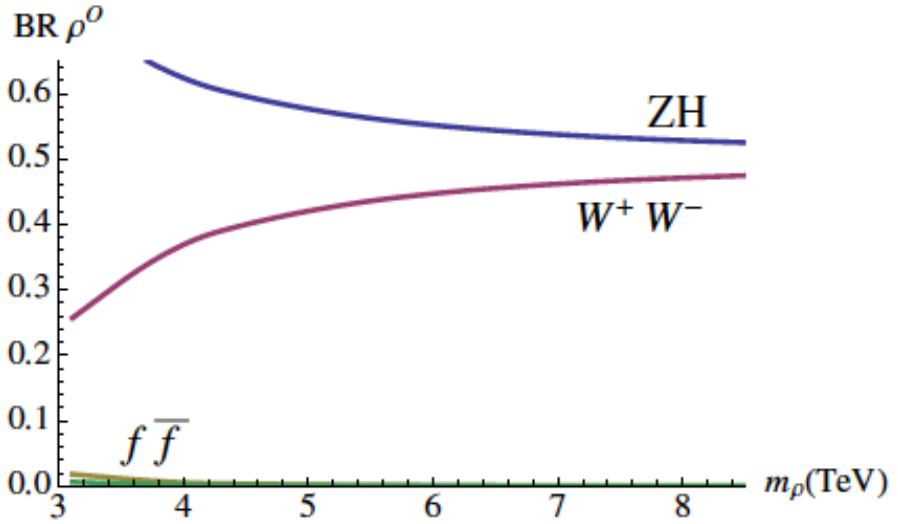


Branching ratio to Z/W+Higgs dominates for high ρ masses.

BR to leptonic decays (dilepton, single-lepton) tends to zero.

Observation of Higgs events through the ρ→VH channel will be strong evidence of compositeness.

ρ BR to VH vs VV depends on g_ρ



Anna Kaminska 2014
(private comm)

Figure 1: Branching ratios of a neutral ρ resonance for $m_\rho = g_\rho f = g_\rho v_{EW}/\sqrt{\xi}$ and $\xi = 0.1$.

In large parts of the parameter phase space the BR to VH is much greater than to VV

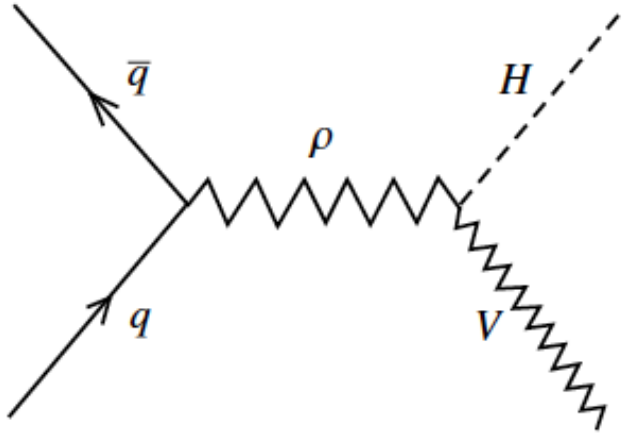
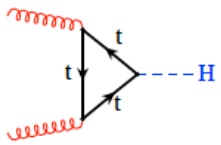
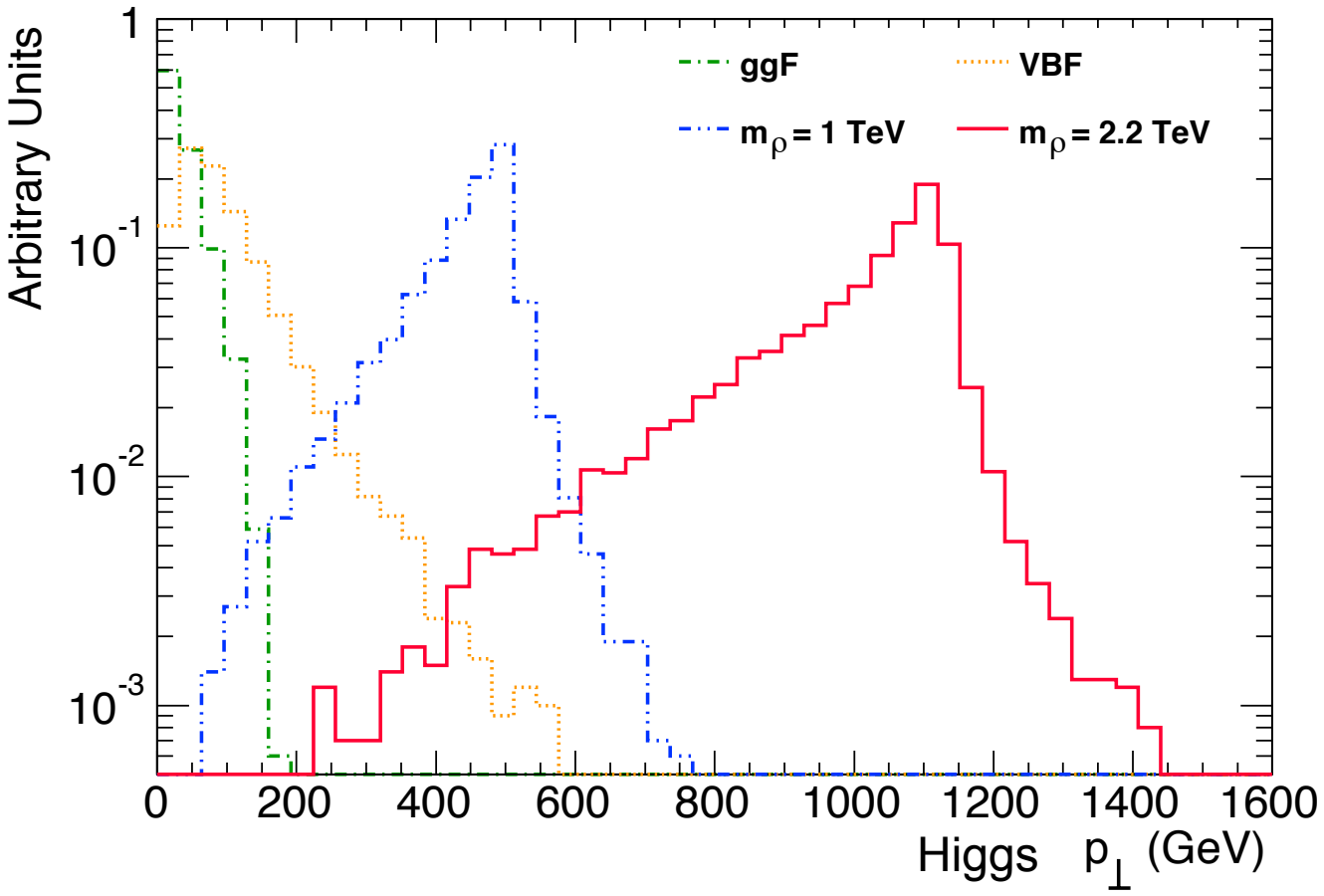
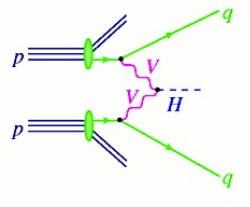


Fig. 1. Diagram depicting the process $pp \to \rho \to VH$

ρ decays produce highly boosted Higgs events

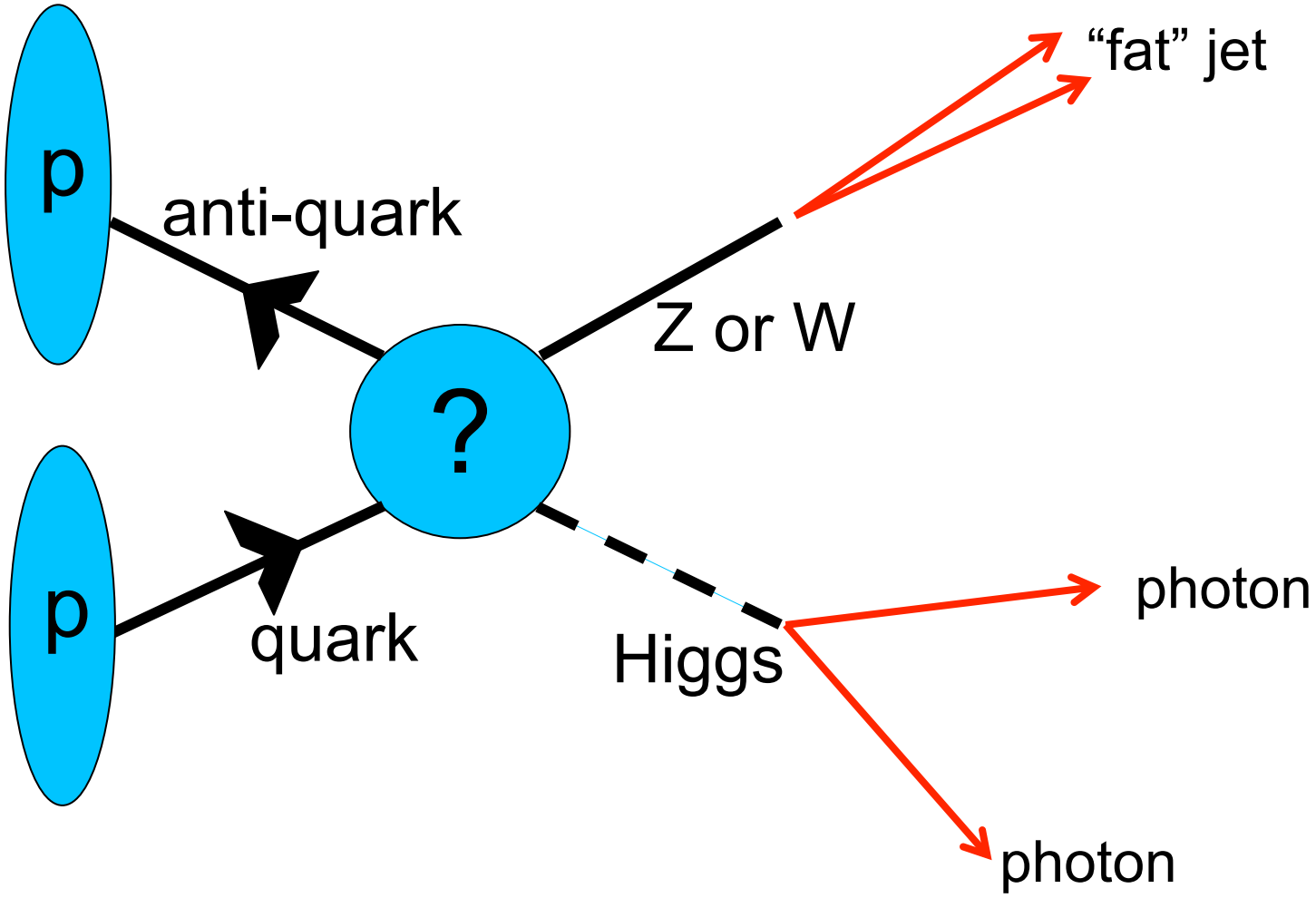






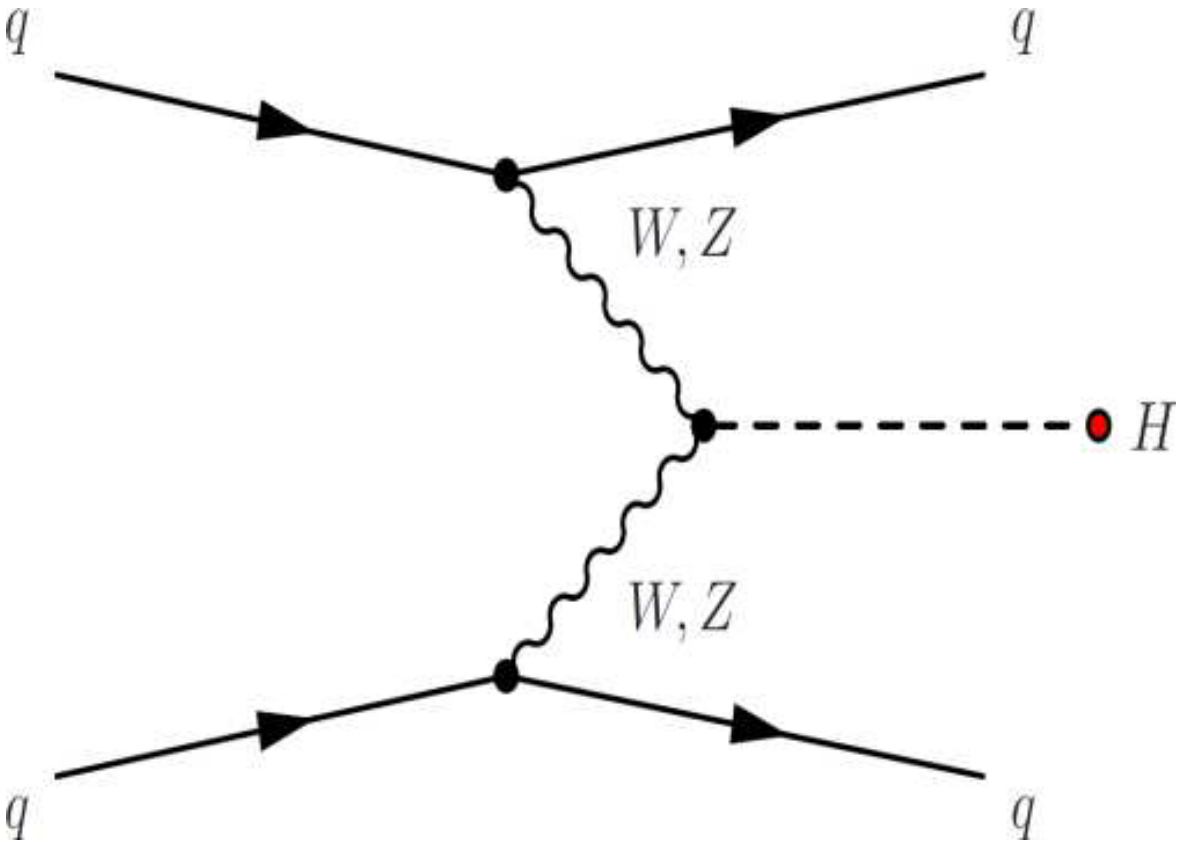
For heavier > 1.5 TeV ρ masses the Higgs kinematics is fully distinguishable from the SM Higgs kinematics.

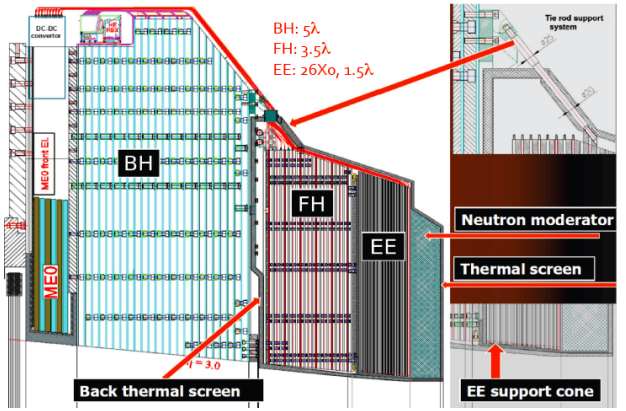
VH and VV vertex hides new Physics



Simple calculation based on "ATLAS Anomaly": expect one such event every 3fb^{-1}.

How about VBF?





CMS HGCal to tag these jets
Strong Greek Involvement:

Andreas Psallidas,
Niki Saoulidou,
Arnaud Steen + SP

SP leads hardware activities in Taiwan (build modules of such devices).

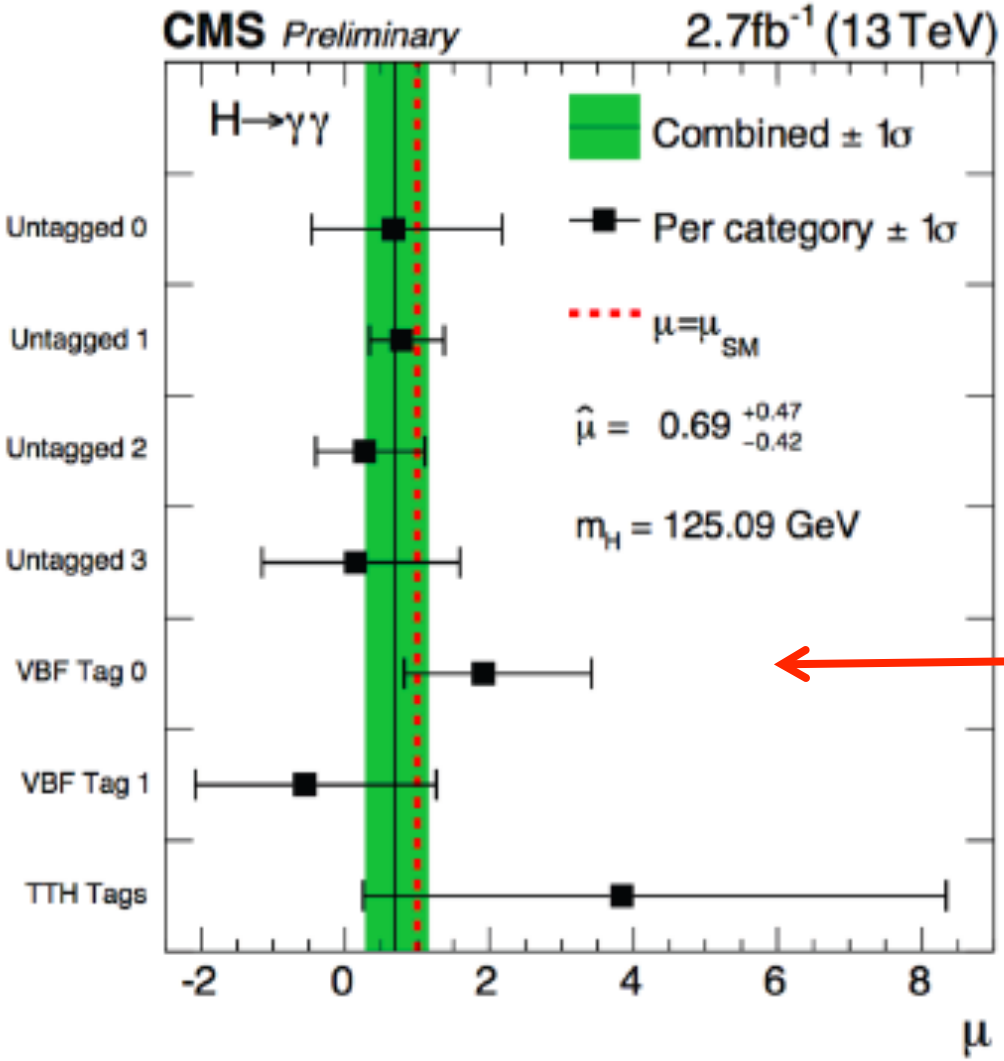
What if an excess (or deficit) is observed in the data?

Interest in models in which heavy new states are VBF produced and decay to final states including the 125GeV Higgs

LHC H→γγ: do we really measure VBF?

Fresh results from CMS:

Reported by Seth Zenz in Moriond 2016 (March 16).



Tag0 means BDT>0.0 (VBF-richer region)

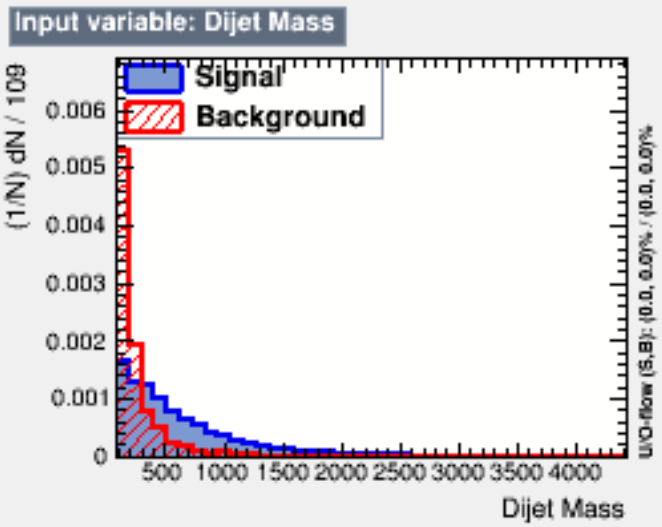
BDT included dijet and diphoton kinematics

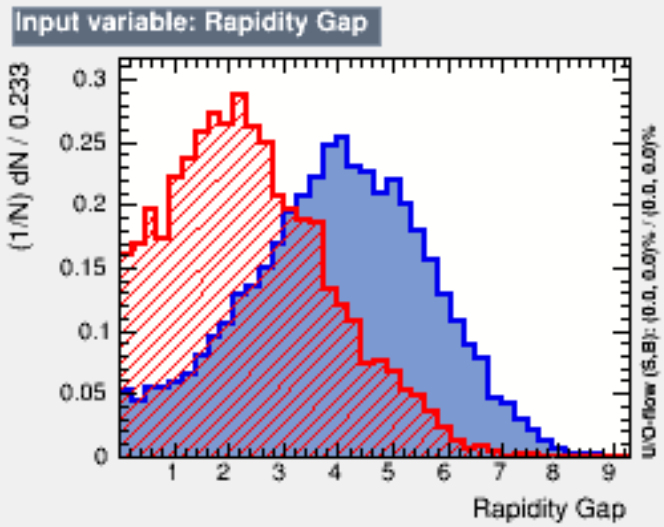
Simultaneous measurement of VBF, ggFjj

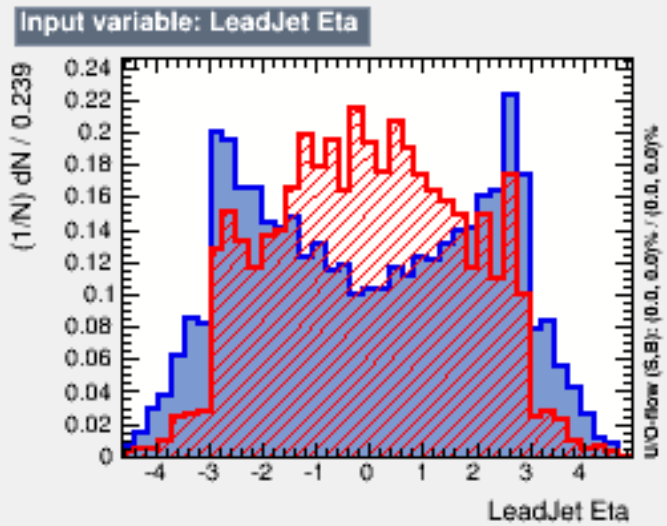
- Select H→γγ + 2jets events (ATLAS/CMS-like selection)
  - Selected events are both rich in VBF and ggF+jj
- Use dijet kinematics (eg. BDT) to and Mγγ discriminate between VBF and ggF/continuum.
  - The continuum is normalized by the Mγγ sideband
- Perform a 2D fit on the BDT vs Mγγ plane
  - Proposal: reduce to 1Dx1D. Can this work?
- Extract components: VBF and ggF+jj

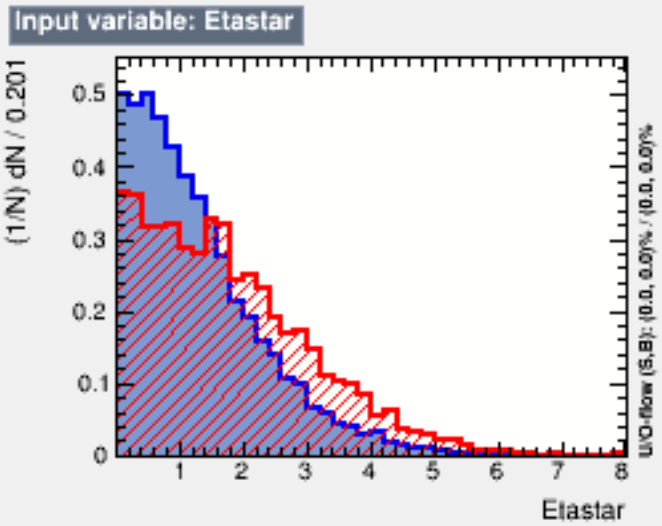
Work with:
Kai-Feng Chen
George Hou
You-Ying Li
A. Psallidas et al.

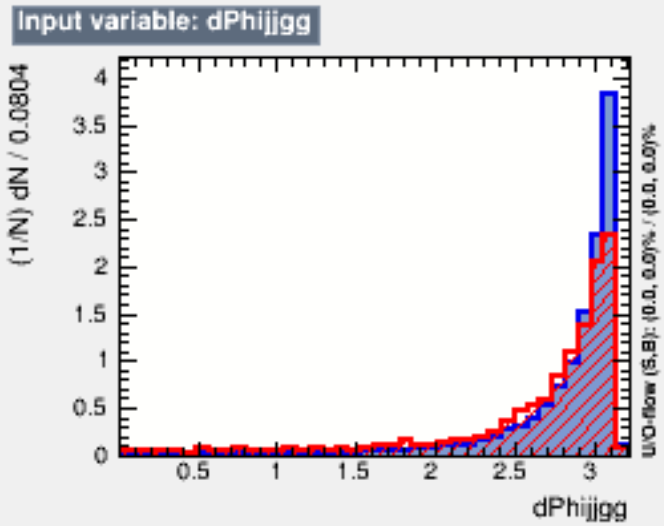
Build a BDT with 5 variables











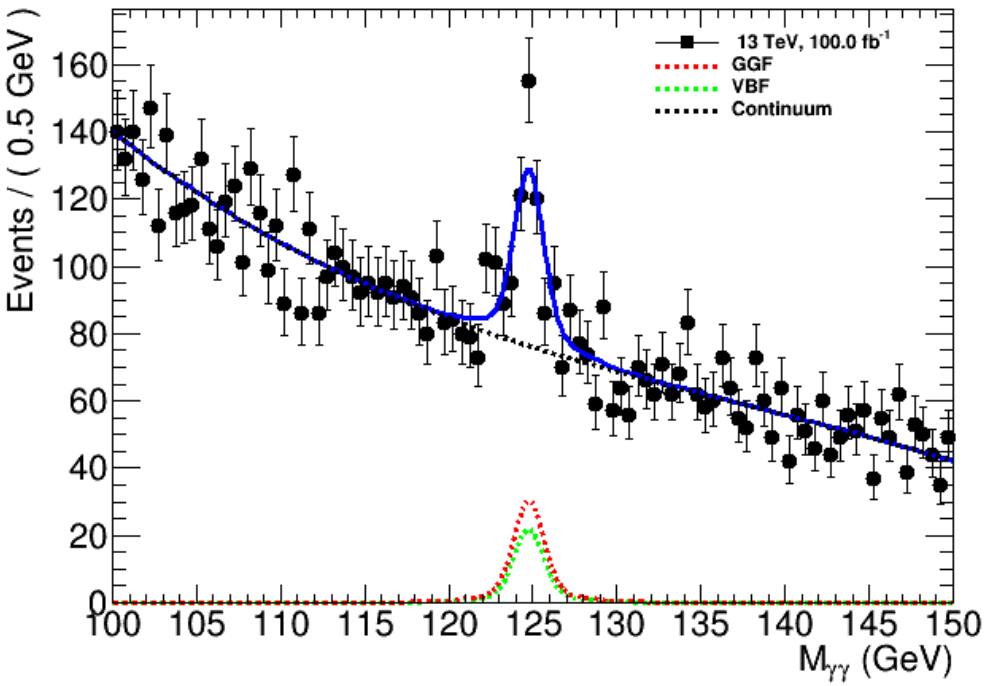
"Signal": VBF
"Bkg": ggFusion (only)

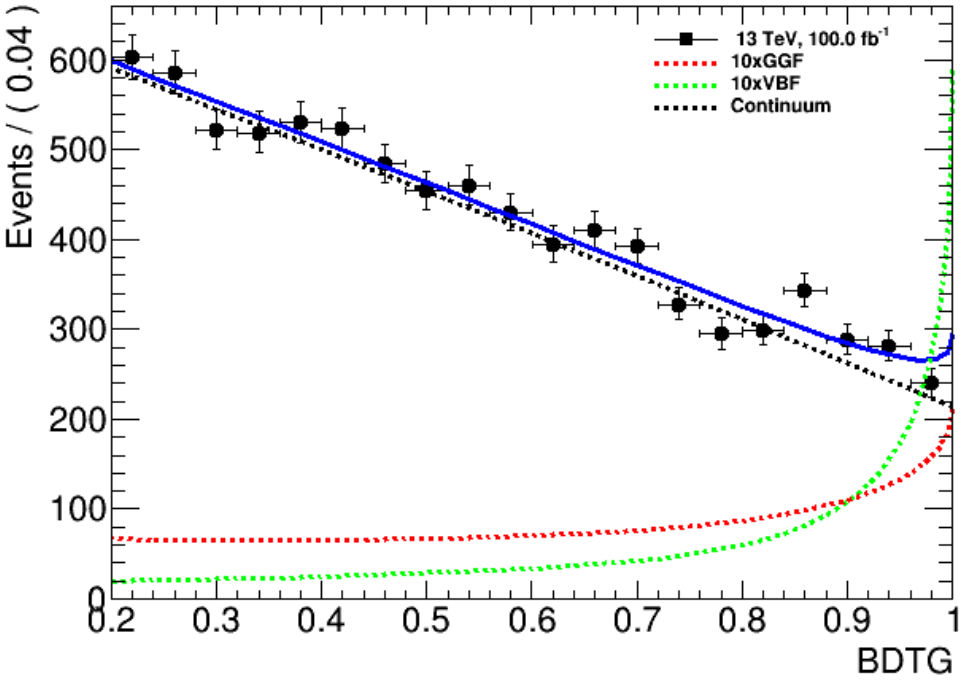
LHC-like selection plus:
2Jets with pt>25GeV
Pick 5 variables to build a BDT

$$\eta^* \equiv \eta_{\gamma\gamma} - (\eta_{j1} + \eta_{j2})/2$$

Note that further cuts on these variables are applied to reduce the continuum. Example: detajj>2.0

Mγγ/BDT fit: 100 fb^{-1}





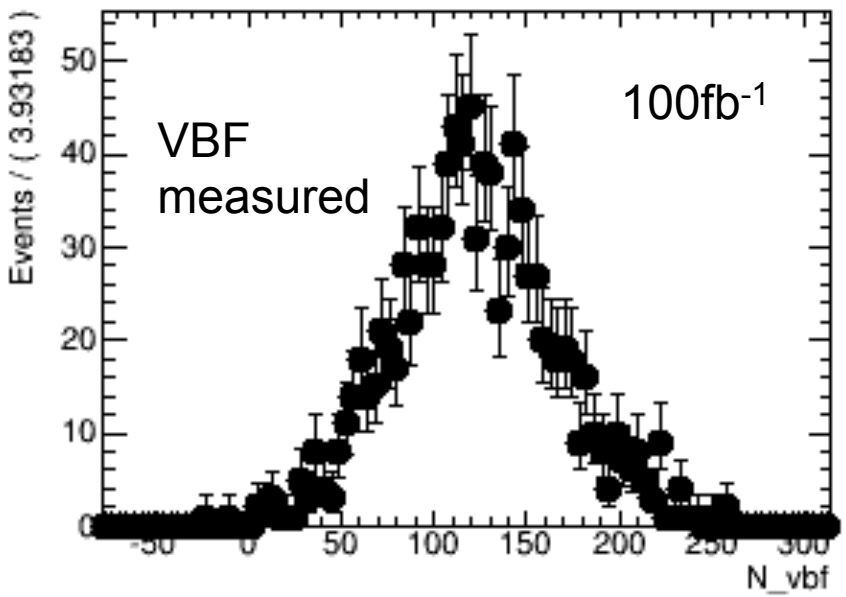
This is a realistic expectation based on SM prediction.

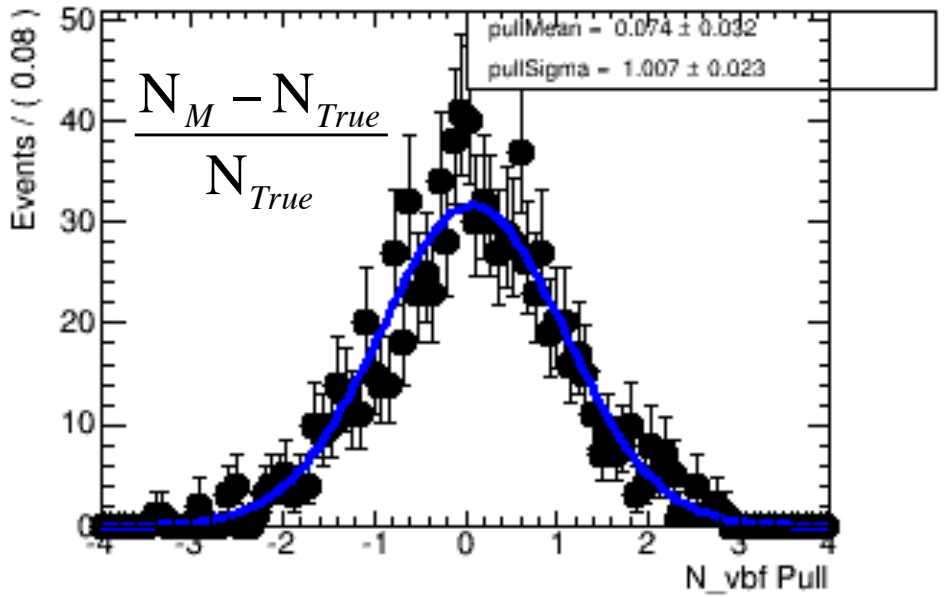
Background normalization can be checked at the Run2 L=2.7 fb point.

Predicted S/B inside 124.5-125.5 GeV is about 1/1

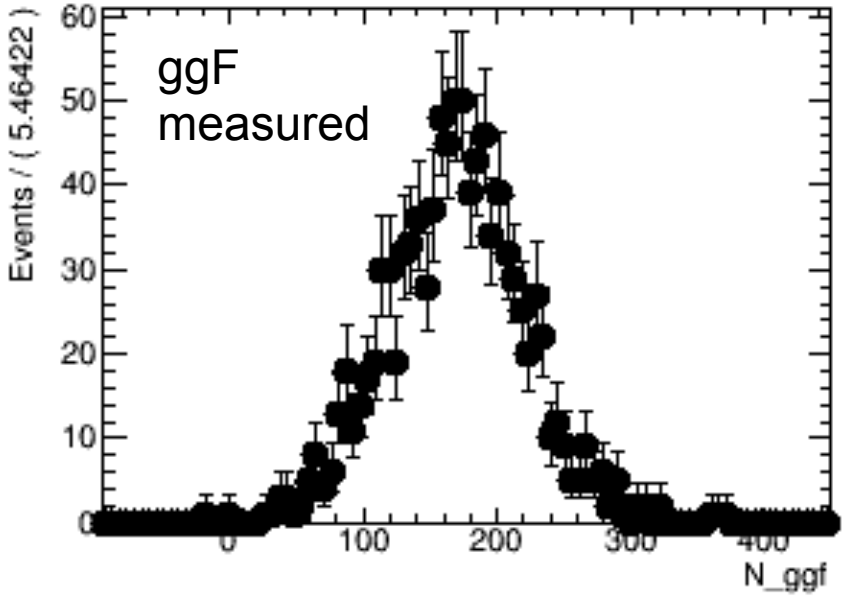
Problem: performing a 2D fit can bring systematics compromising the measurement!
Can we do this? ➔ **Simplest thing to try 1Dx1D fit on 2D input.**

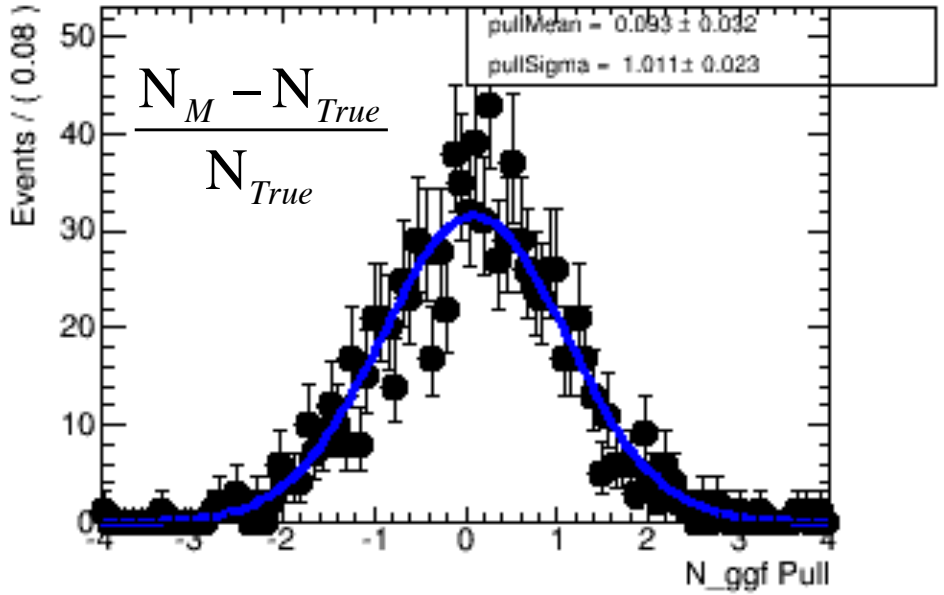
1Dx1D fit works: 100fb^{-1} example





New result: 1Dx1D fit works. Will allow measurement without complications.

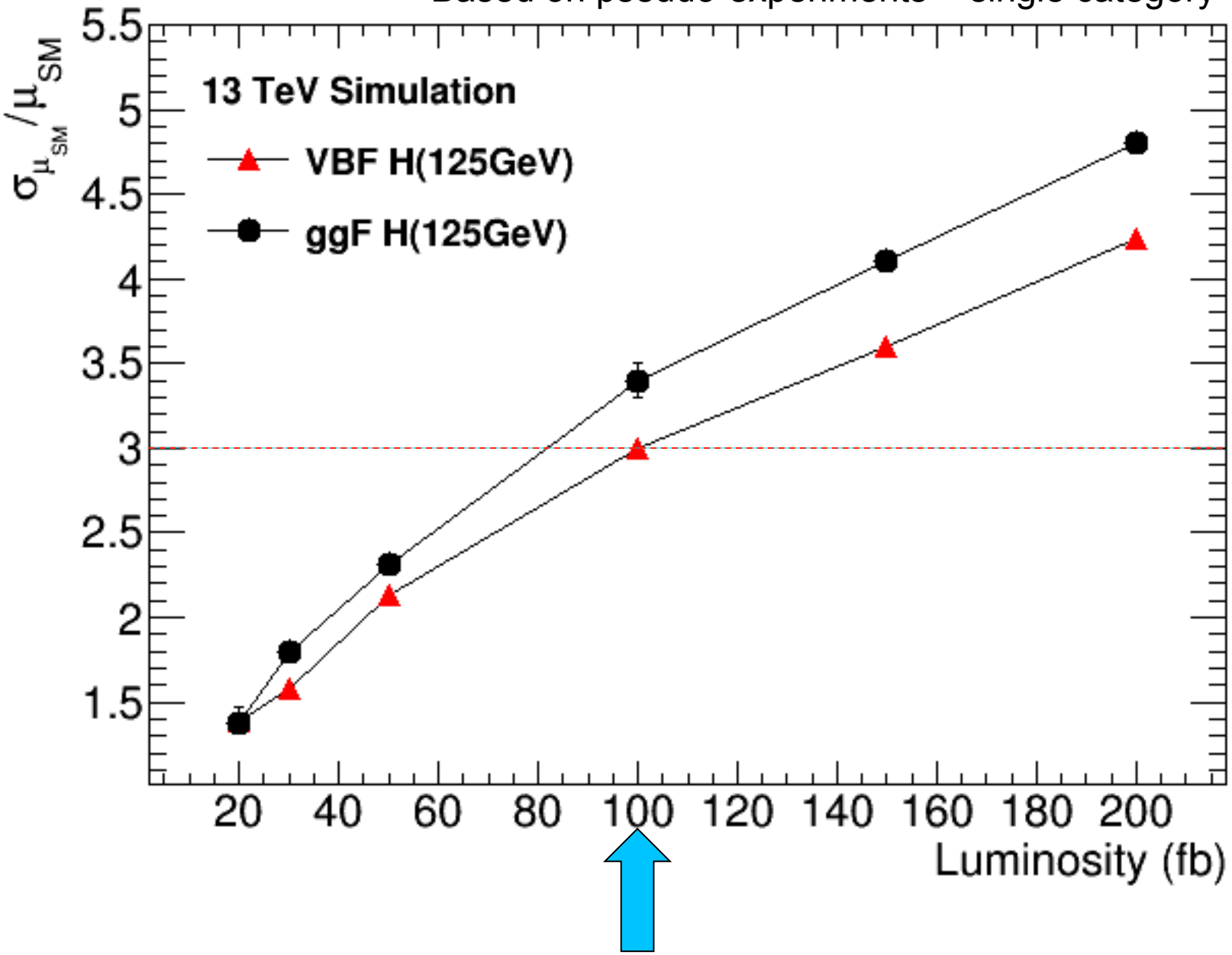




 INPUT: 1000 experiments from full 2D model, fitted with 1Dx1D likelihood

Projection of ggF/VBF measurement

Based on pseudo-experiments + single category



3σ line

Rough estimate: ±0.2-0.3μ

Summary

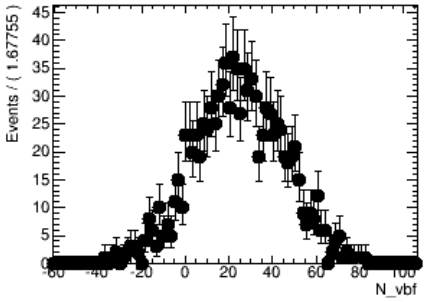
- H+jets production at LHC can provide the first hints for new physics BSM.

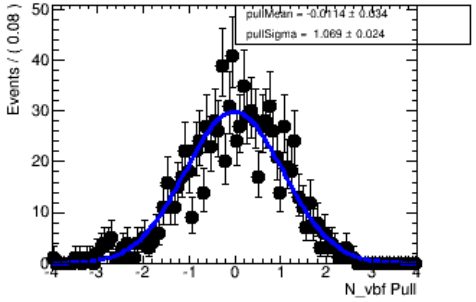
- Must relax our dependence on theory (SM) and actually measure the ggFjj, VBF, VH components, even allowing for exotic contributions.
  - High pt Higgs candidates
  - Higgs candidates associated with high MET.

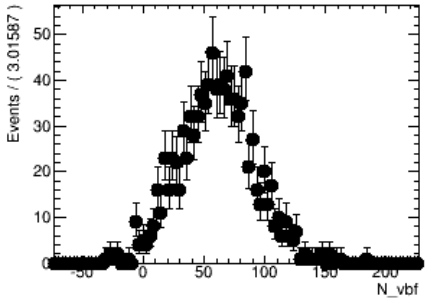
- Let’s look in the Run2 data for the first BSM hints.

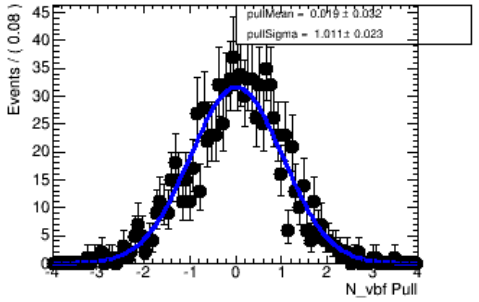
Backup

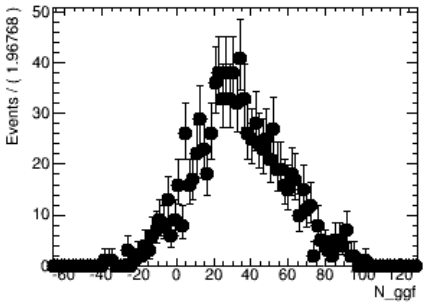
1Dx1D fit closes: 20-200fb^{-1}

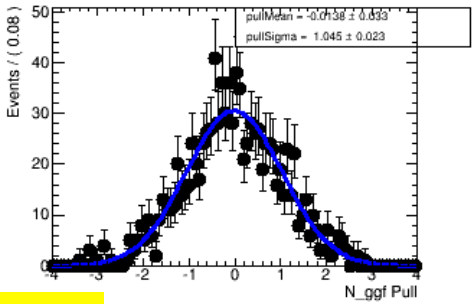




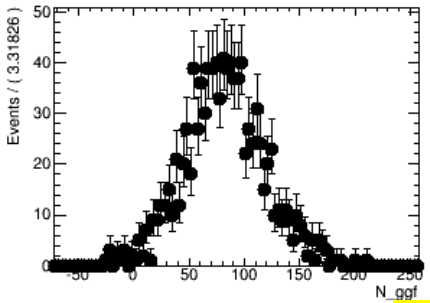


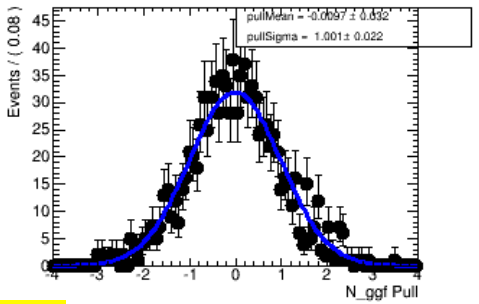






20 fb^{-1}





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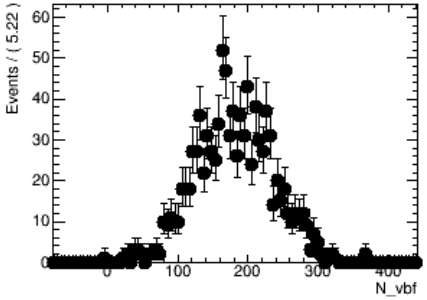

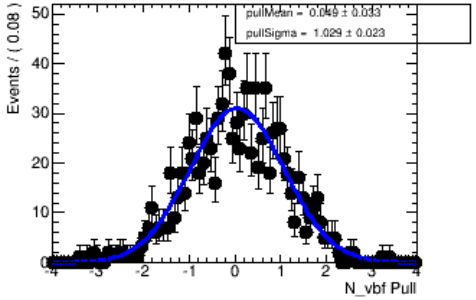

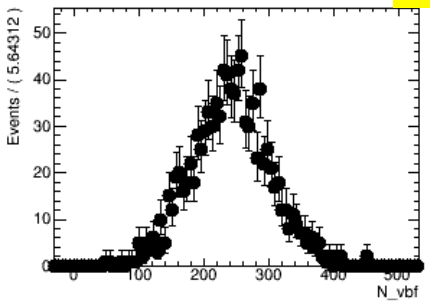

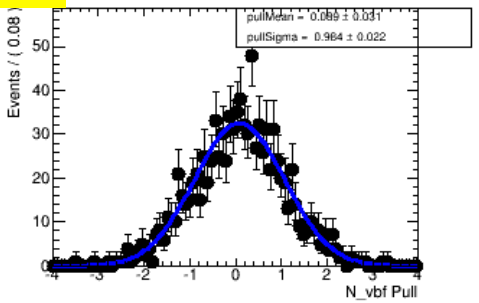

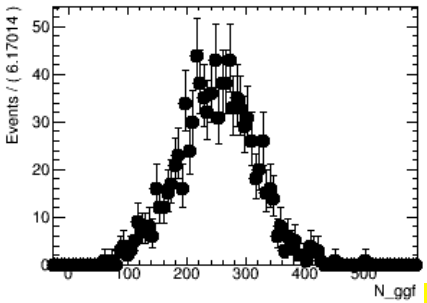

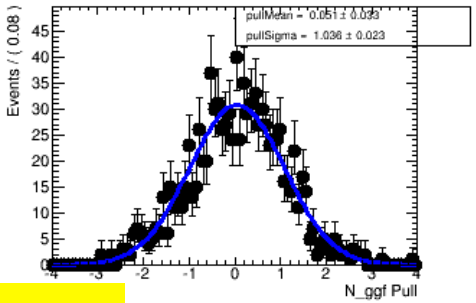

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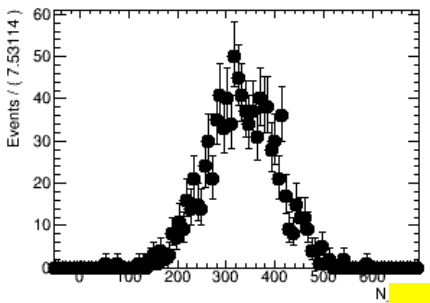

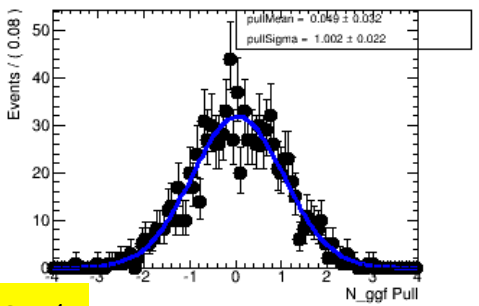

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