PRAMANA
— journal of
physics

Vol. 63, No. 6
December 2004
pp. 1119–1134

Selected topics in Higgs physics at the LHC

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Abstract. In this talk I discuss a few selected topics in Higgs phenomenology at the LHC. After some brief remarks on the standard model Higgs I turn to more novel possibilities, discussing a heavy Higgs scenario, a light Higgs scenario and a no Higgs scenario. In the case of the light Higgs, I discuss briefly the physics opportunities afforded if it becomes possible to detect low angle scattered protons at the LHC.

Keywords. Spontaneous breaking of gauge symmetries; electroweak radiative corrections; extensions of electroweak Higgs sector; hadron-induced high- and super-high-energy interactions; standard-model Higgs bosons; non-standard-model Higgs bosons.

PACS Nos 11.15.Ex; 12.15.Lk; 12.60.Fr; 13.85.-t; 14.80.Bn; 14.80.Cp

1. Introduction and the standard model Higgs

Precision data, often at the per mil level, from the world's particle physics experiments imply a light Higgs boson when interpreted within the framework of the standard model, i.e. $m_{\mathrm{h}} = 96^{+60}_{-38}$ GeV [1,1a]. Similar conclusions are also reached in minimal supersymmetric extensions to the standard model, e.g. $m_{\mathrm{h}} < 135$ GeV in the unconstrained MSSM [4]. In this talk, I would like to focus on the alternative possibility that there is no light Higgs boson, a scenario which may well be realised in future experiments. This talk is certainly rather selective, covering just a few topics and neglecting many more.

Before commencing with alternative scenarios, let me recap the story in the standard model. In figure 1 the cross-sections for the principal production mechanisms for a standard model Higgs boson are shown as a function of Higgs mass, and in figure 2 the branching ratios for the various Higgs decay channels are shown. Over the whole range of Higgs mass gluon–gluon fusion provides the largest rate. However, rate is not the only consideration and the vector boson fusion (VBF) process illustrated in figure 3 (and marked qqH on figure 1) turns out to be extremely valuable over almost all of the interesting range of Higgs mass.

The power of VBF is illustrated in figure 4 where the statistical significance of the various channels is compared. Note the importance of the $qq\tau^+\tau^-$ channel (arising from VBF where the Higgs decays to a τ pair) for Higgs masses around 120 GeV

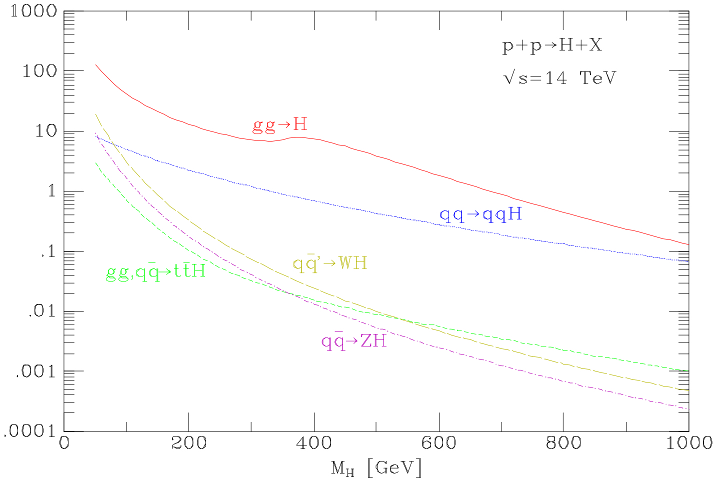


Figure 1. The cross-section for Higgs production at the LHC [5].

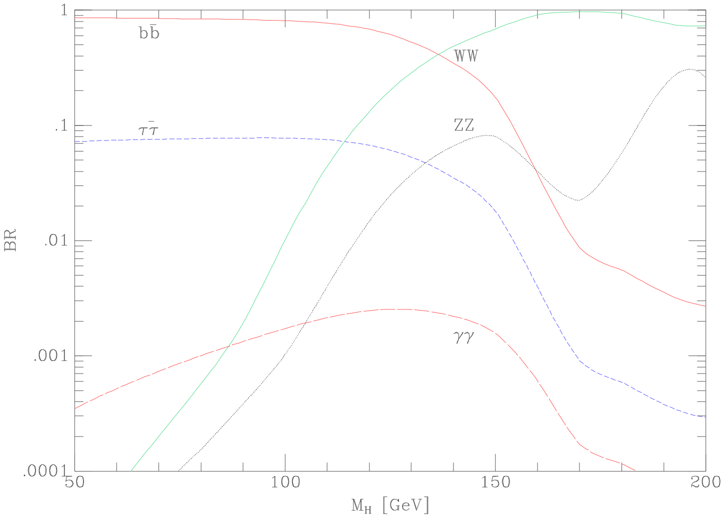


Figure 2. Higgs decay branching ratios [5].

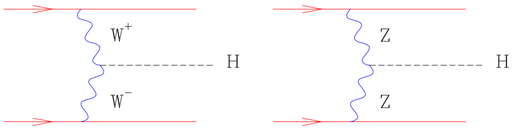


Figure 3. The vector boson fusion (VBF) process.

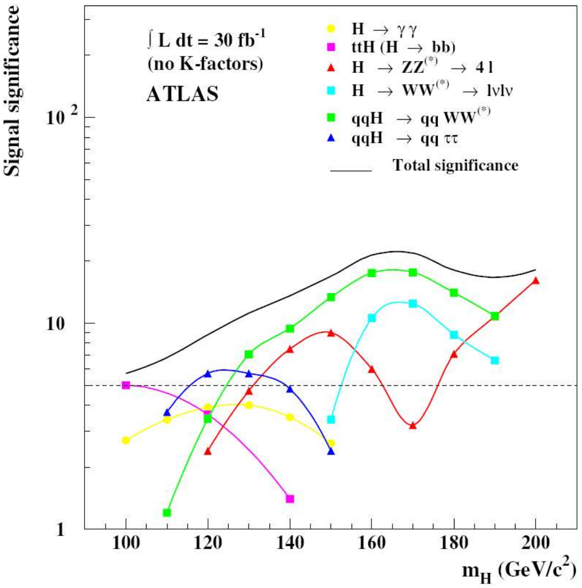


Figure 4. Standard model Higgs discovery potential at the LHC [6].

[6]. This is the difficult region in which $gg \to H \to \gamma\gamma$ was previously thought to be the best option.

VBF is so useful because it has a rather distinctive signature: the final state quark jets are typically far apart in rapidity and are not colour connected to the centrally produced Higgs. This lack of a colour connection implies a reduction in hadronic activity between the jets and the Higgs system which can help reduce QCD backgrounds. Indeed it has even been suggested that one might use VBF to improve even further in the region $m_{\mathrm{h}} < 140$ GeV by using the $b\bar{b}$ decay of the Higgs [7,8]. Naively this decay channel would be swamped by QCD background but if it could be possible to make a rather hard cut limiting hadronic activity between the forward and backward going quark jets (so-called 'tag jets') then it might prove useful. In the face of pile-up and an aggressive underlying event this might seem a forlorn task but the suggestion in [7] is that one might try to use tracking information to effectively exclude events with hadrons between the tag jets and the centrally produced b-jets. Clearly this is a challenging issue which merits further experimental study.

Apart from the VBF process, there are purely QCD processes which can lead to the distinctive qqH final state and these need to be considered. A full one-loop calculation of the pure QCD production has been performed [9]. However, if the experimental analysis utilizes cuts on the hadronic activity then it becomes necessary to consider the pattern of QCD radiation. For example, if one insists upon there being no extra jets (between the tags jets and the products of the Higgs decay) with $E_{\mathrm{T}} < Q_0$ then one will need to sum logarithms in Q_0. This resummation has been performed for the so-called 'gaps between jets' process in [10,11]. At the one-

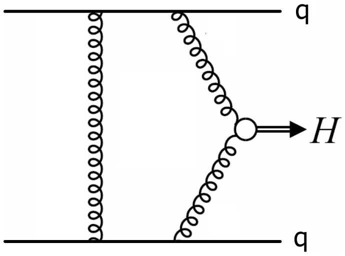


Figure 5. A formally two-loop contribution to QCD Higgs production.

loop level, all QCD processes involve either a colour connection between the tag jets (and therefore they will be Sudakov suppressed as the scale Q_0 is reduced) or a fermionic exchange in the t-channel (which will be suppressed exponentially in the rapidity interval between the tag jets). The lowest order diagram which survives (in a physical gauge) in the limit $Q_0 \to 0$ is the two-loop diagram illustrated in figure 5. The exchanged gluons form a colour singlet and as such allow the screening of QCD radiation in the central region. It would be interesting to extend the QCD calculations to include this diagram.

2. Heavy Higgs

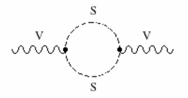
So much for the standard model, let me now turn to a specific extension of the standard model in which the lightest Higgs boson could be as heavy as 500 GeV. The model is very simple: a real $SU(2)_{\mathrm{L}}$ scalar triplet with hypercharge zero is added to the standard model Higgs doublet [12,13]. Such a real triplet has a singly charged scalar field, which can mix with those of the doublet to produce three would-be Goldstone bosons and a charged scalar, $H^{\pm}$, and a CP-even neutral scalar which mixes with the CP-even part of the doublet to produce two neutral scalars h^0 and H^0. Giving a vacuum expectation value (VEV) to the triplet will lead to a tree-level violation of the weak isospin relation:

$$\rho = \frac{M_W^2}{M_Z^2 \cos^2\theta_W} = \frac{1}{\cos^2\beta}, \tag{1}$$

where β is the ratio of the vacuum expectation value of the triplet to that of the doublet. Only when the triplet VEV is small will this model produce a viable phenomenology and in this case the h^0 field is predominantly doublet whilst H^0 is predominantly triplet.

In order to quantify the impact of adding such a triplet to the standard model, we should determine its impact upon predictions of the precision electroweak measurements that have been made over the years (mainly from LEP, SLD and the Tevatron). The new scalar fields will couple to vector bosons and as such generate extra contributions to the gauge boson two-point functions (see figure 6) which have been accurately measured in experiment. The contribution of new physics to these two-point functions is typically represented by the gauge invariant S and T

$$\Pi_{\mu\nu}(q) \equiv g_{\mu\nu}\,\Pi(q^2) + \cdots \quad =$$



$$+ \quad \cdots$$

$$\Delta\Pi(m) \equiv \Pi(m^2) - \Pi(0)$$

Figure 6. Oblique radiative corrections.

parameters. The S parameter measures the mixing between the $U(1)_Y$ boson and the neutral member of the $SU(2)_{\mathrm{L}}$ gauge triplet, i.e.

$$S \sim \Delta\Pi_{BW_3},$$

whilst the T parameter is that linear combination of W and Z two-point functions which vanishes in the case that there is a global weak isospin symmetry, i.e.

$$T \sim \Pi_{WW}(0) - \Pi_{ZZ}(0)\cos^2\theta_W.$$

Since the triplet carries no hypercharge it make no contribution to S. The quantum corrections to T are also small for small mixing angles β since the model is then approximately weak isospin symmetric. This looks finely tuned: β must be kept small, otherwise there will be unacceptably large contributions to T. To a point this is true. However, it turns out that the data do allow β to be as large as 4° [13].

In order to quantify the above discussion one must compute T in the triplet model and compare the data collated in table 1. It turns out that the quantum corrections are typically negligible compared to the tree-level corrections to T arising directly from the relation (1). This correction is equivalent to a small shift in the W mass compared to the standard model value and as such it has a dramatic effect on almost all observables since it corresponds to an effective re-interpretation of the muon decay constant, which is a fundamental input to the fit, i.e.

$$G_F \approx G_F^{\mathrm{SM}}(1-\beta^2).$$

Trivially, this tree-level effect is equivalent to a positive contribution to the T parameter, i.e. $\Delta T_{\mathrm{tree}} \sim \beta^2$. This shift is quantified in figure 7. The interior of the ellipse is allowed by the data at 95% CL, and the set of parallel curves measure the impact of the triplet at different values of the mixing angle β and different h^0 masses. For reference, the curve at $\beta = 0$ is equivalent to that produced in the standard model. Clearly, by allowing a small positive contribution to T it becomes possible to fit the data with larger values of m_{h}.

A more detailed study of vacuum stability and perturbativity of the Higgs sector confirms that this triplet model is viable and perturbative with the lightest Higgs possibly as heavy as ~500 GeV [15].

Of course there are many other ways to accommodate a heavier Higgs boson [16]. As a parting remark it is clear that a future linear collider running at centre-of-mass energy equal to the Z^0 mass and capable of reducing the size of the $S-T$ ellipse by an order of magnitude would put very tight constraints on new physics such as that discussed here.

Table 1. Precision electroweak data [14].

		Measurement with total error	Systematic error	Standard model fit	Pull
$\Delta\alpha^{(5)}_{\rm had}(m_Z^2)$		0.02804 ± 0.00065	0.00064	0.02804	0.0
(a)	*LEP*				
	Line-shape and lepton asymmetries:				
	m_Z (GeV)	91.1875 ± 0.0021	0.0017	91.1874	0.0
	Γ_Z (GeV)	2.4952 ± 0.0023	0.0012	2.4962	−0.4
	σ^0_b (nb)	41.540 ± 0.037	0.028	41.480	1.6
	R_ℓ	20.767 ± 0.025	0.007	20.740	1.1
	$A^{0,\ell}_{\rm FB}$	0.0171 ± 0.0010	0.0003	0.0164	0.8
	+ Correlation matrix				
	τ polarisation				
	$\mathcal{A}_\tau$	0.1439 ± 0.0042	0.0026	0.1480	−1.0
	$\mathcal{A}_e$	0.1498 ± 0.0048	0.0009	0.1480	0.4
	$q\bar{q}$ charge asymmetry				
	$\sin^2\theta^{\rm lept}_{\rm eff}(\langle Q_{\rm FB}\rangle)$	0.2321 ± 0.0010	0.0008	0.23140	0.7
	m_W (GeV)	80.427 ± 0.046	0.035	80.402	0.5
(b)	*SLD*				
	$\sin^2\theta^{\rm lept}_{\rm eff}(A_\ell)$	0.23098 ± 0.00026	0.00018	0.23140	−1.6
(c)	*LEP and SLD heavy flavour*				
	R^0_b	0.21653 ± 0.00069	0.00053	0.21578	1.1
	R^0_c	0.1709 ± 0.0034	0.0022	0.1723	−0.4
	$A^{0,b}_{\rm FB}$	0.0990 ± 0.0020	0.0009	0.1038	−2.4
	$A^{0,c}_{\rm FB}$	0.0689 ± 0.0035	0.0017	0.0742	−1.5
	$\mathcal{A}_b$	0.922 ± 0.023	0.016	0.935	−0.6
	$\mathcal{A}_c$	0.631 ± 0.026	0.016	0.668	−1.4
	+ Correlation matrix				
(d)	*$p\bar{p}$ and νN*				
	m_W (GeV) ($p\bar{p}$)	80.452 ± 0.062	0.050	80.402	0.8
	$1 - m_W^2/m_Z^2$ (νN)	0.2255 ± 0.0021	0.0010	0.2226	1.2
	$m_{\rm t}$ (GeV) ($p\bar{p}$)	174.3 ± 5.1	4.0	174.3	0.0

3. Light Higgs

The Higgs may be much lighter than predicted by the standard model. This possibility has emerged recently within the context of the CP-violating minimal supersymmetric standard model (MSSM) [17], and more generally it can be understood in two (or more) Higgs doublet models [18].

The general idea is simple: if the Higgs couples more weakly to the gauge bosons than in the standard model then it may have a mass below the direct search limit and have escaped detection at LEP and the Tevatron. One way to reduce the coupling to gauge bosons might be to mix in an admixture of a second scalar

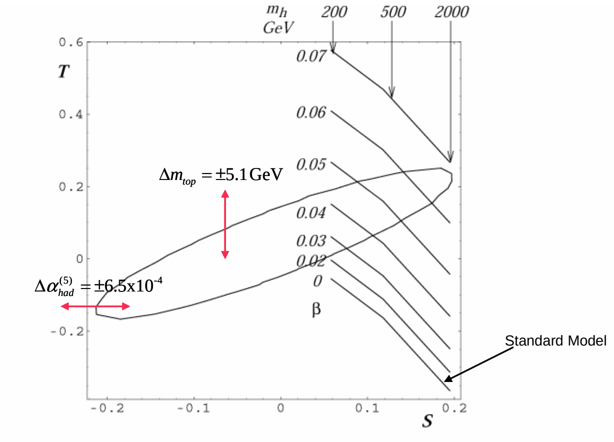


Figure 7. S and T in the triplet Higgs model [13].

field which has a weak coupling to the gauge bosons. This might be a radion in extra dimensions models, or it might (as in the CP-violating MSSM) be a mixing between scalar fields with different CP parity. The latter scenario becomes possible once one allows the soft SUSY breaking terms of the MSSM to become complex. In particular, complex values for the trilinear scalar couplings (which couple the Higgs fields to the squarks) and/or the gaugino masses give rise, through loop effects [17,19–21], to mass eigenstates that are no longer CP-eigenstates, i.e. there can be mixing between the neutral Higgs fields (h^0, H^0, A^0).

The so-called CPX scenario has been presented in [21,22] and in figure 8 we show the regions excluded (in the lightest Higgs mass m_{H1}–$\tan\beta$ plane) by existing data for different values of the phase of the third generation trilinear coupling and gluino mass (which are set equal to each other). The light grey regions, marked out by the red ellipses are not excluded by existing data. Moreover, it is unlikely that they can be excluded at future hadron colliders using conventional search channels since for such light scalars the backgrounds become unmanageable [22].

An intriguing possibility does however exist which might permit the discovery of such light scalar fields (i.e. with weak couplings to electroweak gauge bosons) provided that the fields have large enough effective couplings to gluons (as is the case in the CPX MSSM). Figure 9 illustrates the process whereby the light scalar is produced centrally in a process where the incoming protons remain intact and scatter at low angles, i.e. $pp \to pHp$. This exclusive process has been studied in some detail recently [23–28]. It has the marked advantage of being remarkably free from QCD backgrounds: as the scattering angle of the protons tends to zero, the centrally produced system tends to being purely 0^{++}. The chiral even nature of the quark coupling to gluons ensures that the direct production of fermion–antifermion pairs vanishes as the fermion mass tends to zero. One ought to caution that this otherwise powerful spin selection rule is less effective for light scalars, i.e. whose mass is not much heavier than the fermion–antifermion pair into which it decays. Detection of the scattered protons in very forward detectors is mandatory and this poses challenges to the machine physicists and experimenters. Studies to date

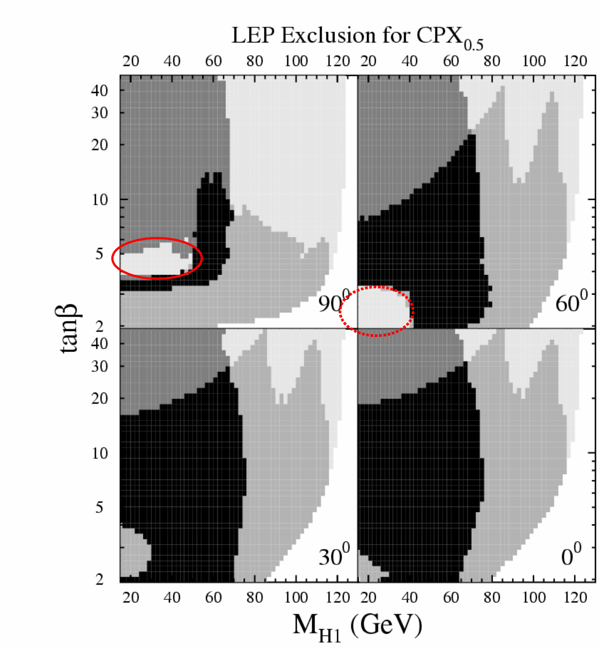


Figure 8. Regions of exclusion for the CPX scenario [22].

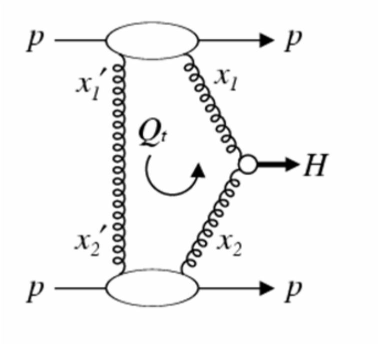


Figure 9. Central Higgs production with tagged protons [23].

indicate that such detectors could possibly be installed and that they might even be able to measure the invariant mass of the central system to within 1 GeV [24].

In figure 10 we show estimates for the production cross-section in the $b\bar{b}$ decay channel at the LHC and Tevatron as a function of lightest Higgs mass [25]. The CPX parameters are chosen so as to lie in the unexcluded regions of figure 8. Clearly the cross-section can become large at the LHC. However, the backgrounds also rise dramatically (due to the narrowing of the Higgs peak and the breakdown of the spin selection rule) and it may be that the cleaner decay of the Higgs to τ pairs is needed [26].

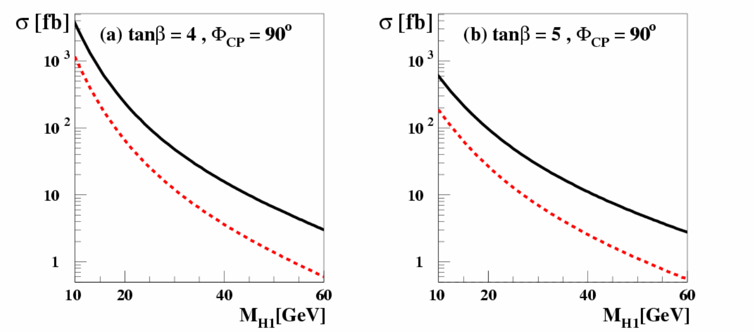


Figure 10. Production rate for centrally produced CPX Higgs (solid curve is for the LHC and the dotted curve is for the Tevatron) [25].

The exclusive channel for new particle production has been explored in other processes. For example, the intense coupling regime of the MSSM has been studied in [27] where it is concluded that central exclusive production could provide a very clean way of exploring this otherwise difficult region of parameter space.

4. Invisible Higgs

It is not hard to imagine scenarios where the Higgs decays invisibly, e.g. to a pair of neutralinos [29,30]. It has been proposed that such a Higgs could be discovered in VBF [31]. To discriminate what is essentially a two-jet final state from the potentially huge QCD background one ought to make a cut on the missing E_{T}: in contrast to the signal typical QCD backgrounds will not have a large missing E_{T}. Typically the tag jets arising from QCD processes will also be back-to-back in azimuth and this can be used to good effect to reduce background. An absence of hadronic activity in the region between the tag jets will help further reduce any QCD backgrounds [32].

It is worth noting that the effectiveness of the missing E_{T} and azimuthal cuts will be reduced when considering the NLO QCD backgrounds. Higher order QCD processes with final states containing more than two particles could well pass the missing E_{T} and azimuth cuts, and those configurations with colour singlet exchange between the tag jets will also pass any cuts related to reduced hadronic activity. Clearly such studies ought to be performed before any firm conclusions can be drawn on the usefulness of this channel as a means to discover an invisible Higgs and one may need to fall back on the associated production with a Z boson [33] or a $t\bar{t}$ pair [34].

5. No Higgs

As a final possibility, it may be that electroweak symmetry breaking (EWSB) does not arise in conjunction with a fundamental scalar field. In this section I would like to consider Higgsless scenarios in general within an effective field theory approach. If we assume that there is no physics other than that which we have already seen in experiments up to a scale Q then for energies $E \ll Q$ we can systematically compute observables as a power expansion in E/Q. The new physics associated with the scale Q shows up in that it fixes the coefficients in the E/Q expansion. We know that Q cannot be much beyond 1 TeV in order that it tame the very rapid rise of the $W_{\mathrm{L}}W_{\mathrm{L}}$ scattering cross-section which occurs in the absence of new physics. Moreover, new physics is expected in the TeV scale on the grounds of naturalness, since we already know the scale of EWSB, i.e. $v = 246$ GeV.

The elastic scattering of longitudinally polarized W and Z bosons is the ideal place to look for evidence of any new, heavy, physics and so we shall focus our attention entirely on this VBF process. In particular, we shall focus on VBF production of W bosons, with one W decaying hadronically and the other leptonically. This is the process which is expected to have the largest rate. Figure 11 illustrates the process at the LHC and shows also the two principal backgrounds; from $t\bar{t}$ production and from W+jets production.

To build our effective theory we must write down the Lagrangian, using only those fields corresponding to already discovered particles, which contains all possible gauge invariant terms consistent with any additional symmetries which we may wish to impose [35]. To simplify the treatment, we will impose a global weak isospin symmetry (which ensures that $\rho = 1$ at tree level) [35a]. Of course there is an infinity of such terms. To organize our expansion, it suffices to keep terms up to some energy dimension since higher dimensional terms must be suppressed by

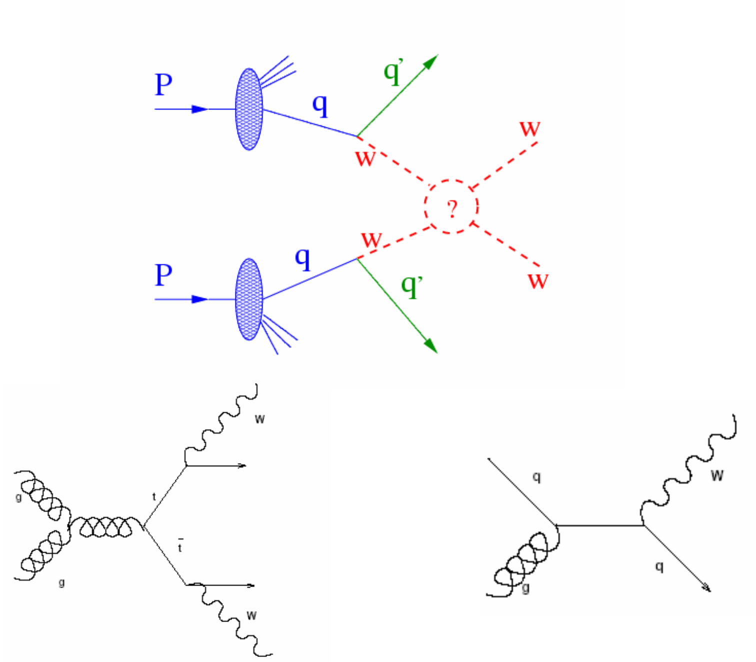


Figure 11. VBF production and main backgrounds.

inverse powers of the new physics scale Q. It turns out that, given these constraints, there are only two terms which we need to consider when exploring the VBF process. They are the two dimension four terms which can give rise to interactions involving four gauge bosons, i.e.

$$L_{\text{quartic}} = a_4 \text{Tr}\left[D_\mu U (D_\nu U)^\dagger\right]^2 + a_5 \text{Tr}\left[D_\mu U (D^\mu U)^\dagger\right]^2, \tag{2}$$

where $U = \exp(i\pi \cdot \tau / v)$ and π^a are the would-be Goldstone bosons arising from EWSB. For centre-of-mass energies $s \ll Q^2$, we can compute the amplitude for elastic electroweak vector boson scattering as an expansion in s/v^2, i.e.

$$A(s,t,u) = \frac{s}{v^2} + \frac{s^2}{v^4} g(s,t,u) + \cdots. \tag{3}$$

The dependence upon a_4 and a_5 is to be found in the function $g(s,t,u)$.

At the LHC we expect to be pushing into the energy range $E \sim Q$, in which case, the usefulness of the effective theory breaks down. In order to anticipate some of the physics which might show itself in the VBF process let us boldly attempt to take the amplitude written in (3) and try to make some ansatz for its completion in the high energy range. Clearly without knowledge of the new physics we cannot do this but by making a particular ansatz we shall be faced with a rich variety of possible new physics signals. It is appropriate to ask how the LHC might cope in the face of such physics.

Our ansatz is to transform $A(s,t,u)$ into a form which guarantees that elastic unitarity is satisfied in the partial waves. If t_J is the partial wave corresponding to angular momentum J, then we make the Padé approximation that

$$t_J = \frac{t_J^{(1)}}{1 - \frac{t_J^{(2)}}{t_J^{(1)}}}, \tag{4}$$

where $t_J^{(n)}$ is the coefficient of the $(s/v^2)^n$ term in the effective theory expansion. In this way each partial wave now satisfies the requirement of elastic unitarity whilst at the same time it matches the NLO calculation within the effective theory. This Padé procedure typically results in the emergence of resonances in VBF process [37]. In figure 12 we show a map of the quartic coupling parameter space; there is a region of only scalar resonances, one of only vector resonances, one of both scalar and vector resonances, and there is even a region where unitarization occurs in the absence of any resonances.

Within this scenario, we now ask the question: How well could the LHC do within 1 year of running in identifying each of the scenarios marked A to E in figure 12? This question has been explored in detail in [38]. Here we shall focus on one or two salient points. The challenge is to beat down what is a formidable background. In table 2 we summarize the analysis of [38]. Before any cuts, one is starting from a signal of around 100 events set against a background of order 10^5 events. The most important cuts are surrounded by boxes. Here we discuss only the subjet cut which is very effective in reducing the W+jets background.

The subjet method allows one to identify whether a jet of hadrons with an invariant mass close to the mass of the W has actually originated from the decay of

Table 2. The effect of various cuts on S/B for the VBF process.

Cuts	Efficiency	Signal σ (fb)	$t\bar{t}$ σ (fb)	$W+$ jets σ (fb)	Sig/B
Generated	A:100%	72	Pythia		8.7×10^{-4}
	B:100%	104	18,000	65,000	1.3×10^{-3}
	C:100%	44	Herwig		5.3×10^{-4}
	D:100%	113	14,000	53,000	1.4×10^{-3}
	E:100%	47			5.0×10^{-4}
p_{T} (Lep. W) > 320 GeV	A:11%	8.2	Pythia		1.5×10^{-3}
and	B:11%	11	910	4400	2.1×10^{-3}
p_{T} (Had. W) > 320 GeV	C:10%	4.4	Herwig		8.3×10^{-4}
	D:10%	11	750	3600	2.1×10^{-3}
	E:10%	4.7			8.8×10^{-4}
70 GeV $< M$ (Had. W)	A:6.7%	4.8	Pythia		6.3×10^{-3}
< 90 GeV	B:6.2%	6.4	56	700	8.4×10^{-3}
	C:5.8%	2.6	Herwig		3.4×10^{-3}
	D:5.6%	6.3	52	480	8.3×10^{-3}
	E:5.8%	2.7			3.6×10^{-3}
$1.6 < \log(p_{\mathrm{T}} \times \sqrt{y}) < 2.0$	A:4.7%	3.4	Pythia		3.2×10^{-2}
	B:4.4%	4.5	28	78	4.3×10^{-2}
	C:4.1%	1.8	Herwig		1.7×10^{-2}
	D:4.0%	4.5	27	66	4.3×10^{-2}
	E:4.1%	1.9			1.8×10^{-2}
Top quark veto	A:4.3%	3.1	Pythia		5.6×10^{-2}
(see text)	B:4.0%	4.2	3.2	52	7.5×10^{-2}
	C:3.8%	1.7	Herwig		3.0×10^{-2}
	D:3.6%	4.1	3.4	43	7.3×10^{-2}
	E:3.8%	1.8			3.2×10^{-2}
Tag jets	A:1.6%	1.1	Pythia		2.7
$p_{\mathrm{T}} > 20$ GeV, $E > 300$ GeV	B:1.5%	1.6	0.030	0.38	3.8
(see text)	C:1.4%	0.63	Herwig		1.5
	D:1.3%	1.5	0.082	0.42	3.6
	E:1.4%	0.67			1.6
Hard $p_{\mathrm{T}} < 50$ GeV	A:1.5%	1.1	Pythia		3.2
	B:1.5%	1.5	0.020	0.32	4.5
	C:1.4%	0.61	Herwig		1.8
	D:1.3%	1.4	0.048	0.37	4.3
	E:1.4%	0.65			1.9
Minijet veto	A:1.5%	1.1	Pythia		4.3
$p_{\mathrm{T}} > 15$ GeV (see text)	B:1.5%	1.5	0.013	0.24	6.0
	C:1.4%	0.61	Herwig		2.4
	D:1.3%	1.4	0.048	0.36	5.6
	E:1.4%	0.65			2.6

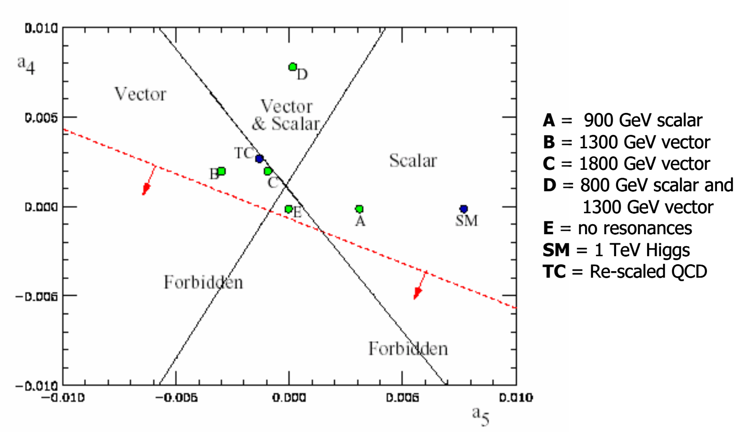


Figure 12. Map of resonances using Padé unitarization [37,38].

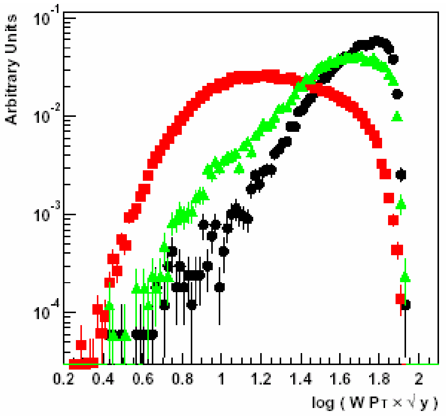


Figure 13. Subjet method for identifying boosted W bosons: black circles are the signal, red squares are the W+jets background and green triangles are the $t\bar{t}$ background [38].

an energetic W, rather than being a high mass jet. The idea is very simple: one should perform a subjet analysis on the candidate jet and look to see at what scale the jet resolves into two subjects. If the jet arises from a primary W then this resolution scale should be $\sim M_W$. Shown in figure 13 is the distribution of hadronically decaying W candidates in the variable $p_{TW}\sqrt{y_{\mathrm{cut}}}$ which is approximately equal to the relative p_{T} of the two subjets. The true W candidates in the signal clearly peak around $p_{TW}\sqrt{y_{\mathrm{cut}}} \approx M_W$, far above the peak in the W+jets background. The cut is not so useful in eliminating the top background since it contains genuine W bosons.

After all cuts, figure 14 shows the anticipated number of events with 100 fb^{-1} of data for the various possible signal scenarios and the backgrounds. Not only is it possible to identify resonances out to almost 2 TeV, it may well also be possible

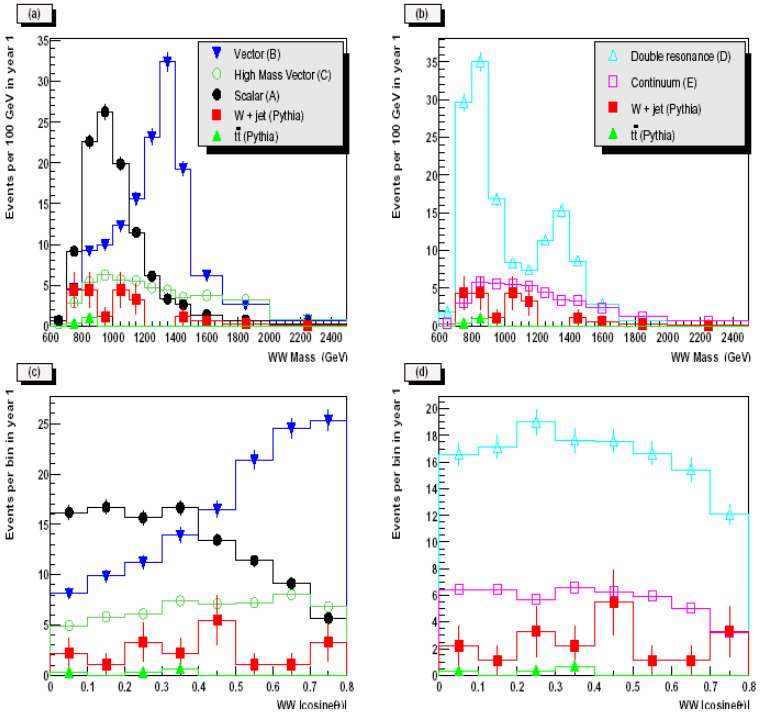


Figure 14. Expected number of events for VBF process.

to determine their spin by studying the angular distribution of the W-pair in the WW centre-of-mass.

6. Concluding remarks

Although it is true that the existing data support the hypothesis of a standard model Higgs boson, it remains the case that the breaking of electroweak symmetry could give rise to some other new physics. In this talk, I have explored a tiny part of this alternate landscape with the hope of highlighting some of the possibilities which may lie in store. I have in particular emphasized the role that vector boson fusion might play in examining the new physics and also the possibility that one might try to detect low angle scattered protons at the LHC in order to open up the possibility to explore exclusive particle production such as $pp \to p + H + p$.

Acknowledgements

The author would like to thank all his collaborators.

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