On possible interpretation of the LHC Higgs-like state in the framework of the non-perturbative effective interaction of W-bosons.

Boris A. Arbuzov
D.V.Skobelltsyn Institute of Nuclear Physics
M.V.Lomonosov Moscow State University

1. Anomalous three-boson interaction – strong effective running coupling.
2. Scalar bound state of two W-s.
3. Experimental implications.
4. Comparison to experiments.
5. Conclusion.

Strong effective three-boson interaction

Recent LHC searches for Higgs (1, 2, 3, 4) result in the outstanding discovery of a state with mass around $125\,GeV$, which manifest itself in decays to $\gamma\,\gamma$ and $l^+ l^+ l^- l^-$. The results are interpreted not only in terms of SM Higgs, but also in different variants extensions of the SM. In any case data being presented in (1, 2, 3, 4) allow discussion of different options the more so, as agreement of the data with SM predictions is not very convincing yet.

The present talk is mostly based on works

B.A. A. and I.V. Zaitsev, Phys. Rev. D 85: 093001 (2012).(5)

B.A. A. and I.V. Zaitsev, Int. J. Mod. Phys. A 27: 1250012 (2012).(6)

B.A. A., arXiv: 1209.2831 (hep-ph) (2012).(7)

We would discuss an interpretation of the LHC $125\,GeV$ state in terms of non-perturbative effects of the electro-weak *interaction. For the purpose we rely on an approach induced by N.N. Bogoliubov compensation principle (8, 9). In works (10) - (16), this approach was applied to studies of a spontaneous generation of effective non-local interactions in renormalizable gauge theories. In particular, papers (15, 16) deal with an application of the approach to the electro-weak interaction and a possibility of spontaneous generation of effective anomalous three-boson interaction of the form*

$$
\begin{aligned}
& -\frac{G}{3!}\,F\,\epsilon_{abc}\,W^a_{\mu\nu}\,W^b_{\nu\rho}\,W^c_{\rho\mu}\,; \\
W^3_{\mu\nu} &= \cos\theta_W\,Z_{\mu\nu} + \sin\theta_W\,A_{\mu\nu}\,; \\
W^a_{\mu\nu} &= \partial_\mu W^a_\nu - \partial_\nu W^a_\mu + g\,\epsilon_{abc}W^b_\mu W^c_\nu\,.
\end{aligned}
\tag{1}
$$

with uniquely defined form-factor $F(p_i)$, which guarantees effective interaction (1) acting in a limited region of the momentum space. It was done of course in the framework of an *approximate scheme, which accuracy was estimated to be $\simeq 10\%$ (10).*

Would-be existence of effective interaction (1) leads to important non-perturbative effects in the electro-weak interaction. It is usually called anomalous three-boson interaction and it is considered for long time on phenomenological grounds (17, 18). Our interaction constant G is connected with conventional definitions in the following way

$$G = -\frac{g\,\lambda}{M_W^2}; \tag{2}$$

where $g \simeq 0.65$ is the electro-weak coupling. The current limitations for parameter λ read (20, 21, 22, 23) (95% C.L.)

$$-0.059 < \lambda < 0.026; \quad -0.036 < \lambda < 0.044;$$
$$-0.022 < \lambda_\gamma < 0.019; \quad -0.048 < \lambda_Z < 0.048. \tag{3}$$

Interaction (1) increases with increasing momenta p. For estimation of an effective dimensionless coupling we choose symmetric momenta (p ,q ,k) in vertex corresponding to the interaction

$$(2\pi)^4\, G\, \epsilon_{abc}\,\big(g_{\mu\nu}(q_\rho pk - p_\rho qk) + g_{\nu\rho}(k_\mu pq - q_\mu pk) + g_{\rho\mu}(p_\nu qk - k_\nu pq) + + q_\mu k_\nu p_\rho - k_\mu p_\nu q_\rho\big)\, F(p,q,k)\, \delta(p+q+k) + ...; \tag{4}$$

where $p, \mu, a;\ q, \nu, b;\ k, \rho, c$ are respectfully incoming momenta, Lorentz indices and weak isotopic indices of W-bosons. Explicit expression for the corresponding vertex is presented in work (15). Form-factor $F(p,q,k)$ is obtained in work (16) using the following approximate dependence on the three variables

$$F(p,q,k) \;=\; F\Big(\frac{p^2+q^2+k^2}{2}\Big). \tag{5}$$

Symmetric condition means

$$pq = pk = qk = \frac{p^2}{2} = \frac{q^2}{2} = \frac{k^2}{2} = \frac{x}{2}; \qquad (6)$$

Interaction (1) increases with increasing momenta p and corresponds to effective dimensionless coupling being of the following order of magnitude

$$g_{eff} = \frac{|g\,\lambda|\,p^2}{2M_W^2}\,F\Big(\frac{3\,p^2}{2}\Big). \qquad (7)$$

Behavior of $g_{eff}(t)$ is presented at Fig. 1.

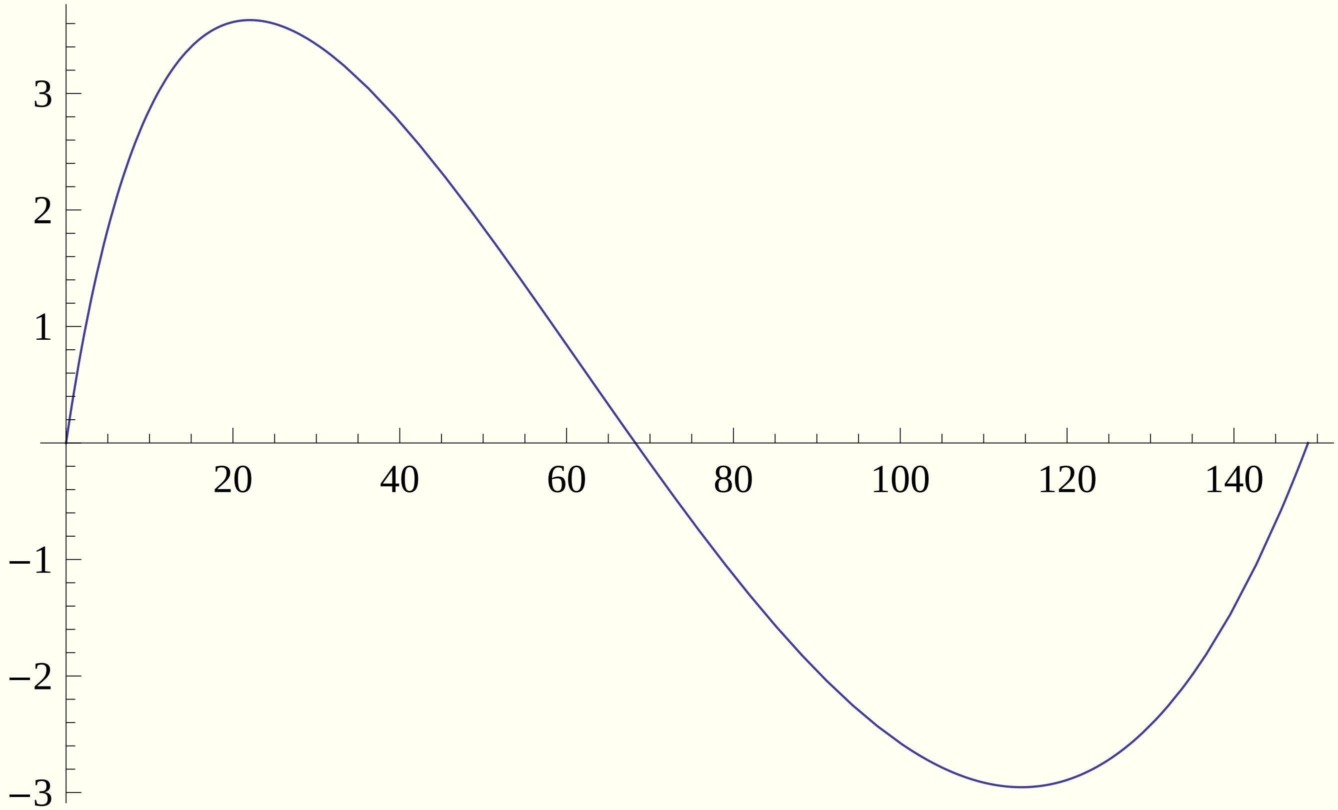


Fig. 1. Behavior of the effective coupling $g_{eff}(t)$, $t = G\,p^2$; $g_{eff}(t) = 0$ for $t > 148$.

We see that for $t \simeq 22$ the coupling reaches maximal value $g_{eff} = 3.63$ (e.g. $p(max) \simeq 5.4\,TeV$ with G from the forthcoming

solution), that is corresponding effective α is the following

$$\alpha_{eff} = \frac{g_{eff}^2}{4\,\pi} = 1.049\,. \tag{8}$$

Thus for sufficiently large momentum interaction (1) becomes strong and may lead to physical consequences analogous to that of the usual strong interaction (QCD). In particular bound states and resonances constituting of W-s (W-hadrons) may appear.

Scalar bound state of two W-s

In the present talk we apply these considerations along with some results of work (16) to data indicating the discovered excess in $\gamma\,\gamma$ and $l^+\,l^+\,l^-\,l^-$ production at LHC (1, 2) in region of invariant mass $\sim 125\,GeV$.

Let us assume that this excess is due to existence of bound state X of two W with mass M_s. This state X is assumed to have spin 0 and weak isotopic spin also 0. Then vertex of XWW interaction has the following form

$$\frac{G_X}{2}\,W^a_{\mu\nu}\,W^a_{\mu\nu}\,X\,\Psi_0\,; \tag{9}$$

where Ψ_0 is a Bethe-Salpeter wave function of the bound state. Due to gauge invariance there is also three-boson term

$$-\,g\,G_X\,\epsilon_{abc}\,W^a_{0\,\mu\nu}\,W^b_\mu\,W^c_\nu\,X\,; \tag{10}$$

and four-boson term also. In what follows we use expressions (9, 10). The main interactions forming the bound state are just non-perturbative interactions (1, 9). This means that we take into account exchange of vector

boson W as well as of scalar bound state X itself. In diagram form the corresponding Bethe-Salpeter equation is presented in Fig. 2.

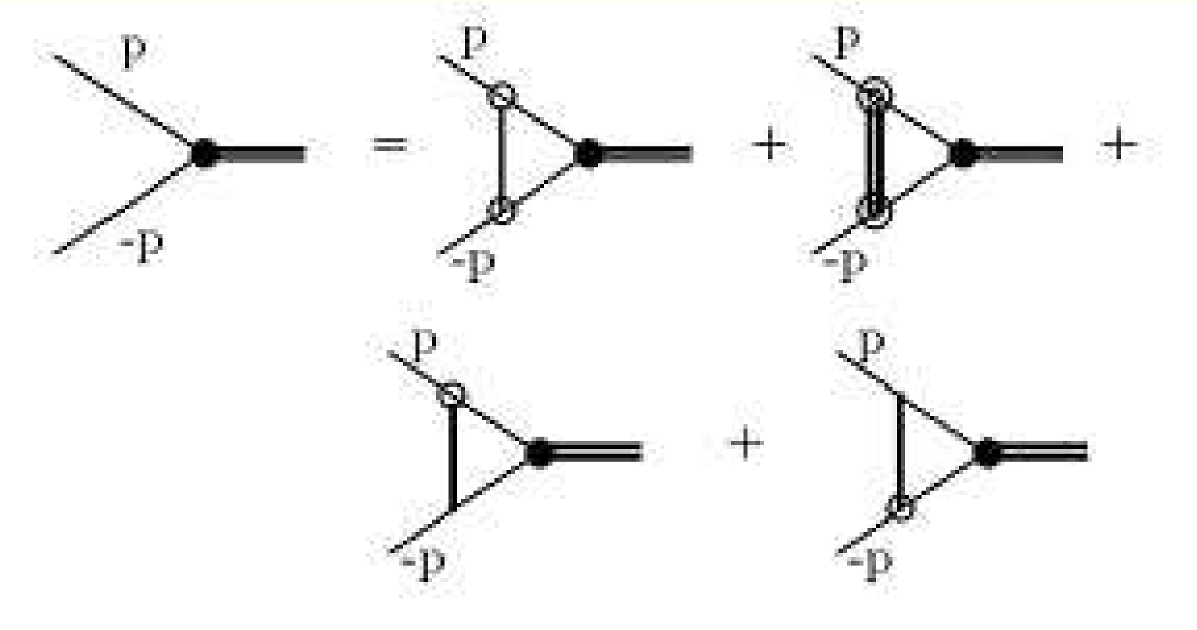


Fig. 2. Diagram representation of Bethe-Salpeter equation for W-W bound state. Black spot corresponds to XWW vertex (9) with BS wave function. Empty circles correspond to point-like anomalous three-boson vertex (1), double circle – point-like XWW vertex (9). Simple point – usual gauge triple W interaction. Double line – the bound state X, simple line – W.

We solve equation Fig. 2 by iterations and obtain a solution (details in (5)).

If we take experimental value $M_s = 125\,GeV$ it leads to the unique solution of the set of equations and conditions with the following parameters

$$G_X = 0.000666\,GeV^{-1};\; G = \frac{0.00484}{M_W^2}\,. \qquad (11)$$

Result (11) means parameter of anomalous triple interaction (1) with account of relation (2)

$$\lambda = -\frac{G\,M_W^2}{g} = -\,0.00744\,; \qquad (12)$$

which doubtless agrees limitations (3).

Experimental implications

Thus we have scalar state X with coupling (9, 11). In calculations of decay parameters and cross-sections we use CompHEP package (27). We use parameter G_X (11) being obtained above and $M_s = 125\,GeV$. Cross-section of X production at LHC reads

$$\sigma_X \;=\; \sigma(p+p \to X + ...) \;=\; 0.16\,pb; \quad \sqrt{s} \;=\; 7\,TeV\,; \tag{13}$$
$$\sigma_X \;=\; \sigma(p+p \to X + ...) \;=\; 0.19\,pb; \quad \sqrt{s} \;=\; 8\,TeV\,.$$

Parameters of X-decay are the following

$$\Gamma_t(X) = 0.000502\,GeV; \tag{14}$$
$$BR(X \to \gamma\gamma) \;=\; 0.430; \quad BR(X \to \gamma Z) \;=\; 0.305;$$
$$BR(X \to 4\,l(\mu,e)) \;=\; 0.00092; \quad BR(X \to b\,\bar{b}) \;=\; 0.000024\,.$$
$$BR(X \to \gamma e^+ e^-) \;=\; 0.0231; \quad BR(X \to \gamma\mu^+\mu^-) \;=\; 0.016;$$
$$BR(X \to \gamma\tau^+\tau^-) \;=\; 0.0125; \quad BR(X \to \gamma u\bar{u}) \;=\; 0.0478;$$
$$BR(X \to \gamma c\bar{c}) \;=\; 0.0368; \quad BR(X \to \gamma d\bar{d}) \;=\; 0.0446;$$
$$BR(X \to \gamma s\bar{s})) \;=\; 0.0430; \quad BR(X \to \gamma b\bar{b}) \;=\; 0.0416\,.$$

For decay $X \to b\bar{b}$ we calculate the evident triangle diagram and use $m_b(125\,GeV) \simeq 2.9\,GeV$. Branching ratios for decays to other fermion pairs are even smaller. We see that state X is quite narrow, so we would expect the observable width of the state to be defined by the corresponding experimental resolution.

Experimental data give in the region of the state the following results for $\sigma_{\gamma\gamma} = \sigma_X \, BR(X \to \gamma\gamma)$ *(3, 4)*

$$\mu_{\gamma\gamma} = \frac{\sigma \times BR(X \to \gamma\gamma)_{exp}}{\sigma \times BR(X \to \gamma\gamma)_{SM}} = 1.3 \pm 0.4\,; \tag{15}$$
$$\mu_{\gamma\gamma} = \frac{\sigma \times BR(X \to \gamma\gamma)_{exp}}{\sigma \times BR(X \to \gamma\gamma)_{SM}} = 1.6 \pm 0.4\,.$$

Here $\sigma \times BR(H \to \gamma\gamma)_{SM} \simeq 0.04\,pb$ *is the Standard Model value for the quantity under discussion, upper line corresponds to ATLAS data (3) and the lower line corresponds to CMS data (4). Firstly both limitations are quite consistent. Secondly our value for the same quantity from (13, 14) reads*

$$\mu_{\gamma\gamma} = \frac{\sigma \times BR(X \to \gamma\gamma)_{calc}}{\sigma \times BR(X \to \gamma\gamma)_{SM}} = 1.6\,; \tag{16}$$

that also agrees results (15), however it essentially exceeds the

SM value. At this point it is advisable to discuss accuracy of our approximations. The former experience concerning both applications to Nambu – Jona-Lasinio model in QCD (11, 12, 14) and to the electro-weak interaction (15, 16) shows that average accuracy of the method is around 10% in values of different parameters. So we may assume, that in the present estimations of coupling constant G_X we also have the same accuracy. For the cross-section this means possible deviation up to 15% of the calculated value. Thus we would change (16) to the following result

$$\mu_{\gamma\gamma} = (1.6 \pm 0.24)\,; \tag{17}$$

Branching ratios (14) do not depend on the value of G_X, so we assume their accuracy being considerably better than in (17). In any case result (17) agrees (15).

Tere are also data for the 125 state production in the kinematical region of vector boson fusion (VBF). Here there is a remarkable deviation from the SM Higgs option. With our calculations we obtain significant difference:

$$\mu_{\gamma\gamma}(VBF) = 3.0 \pm 0.3 . \tag{18}$$

This could be compared with experimental values

$$\mu_{\gamma\gamma}(VBF) = 2.3 \pm 1.1 .(CMS) \tag{19}$$

There are also indications for some excess around $125\,GeV$ in four leptons states. With our numbers (13, 14) we have for decay $X \to l^+ l^+ l^- l^- (l = \mu, e)$: $\sigma \times BR = (0.00013 \pm 0.00003)\,pb$. This is approximately six times smaller the the SM result. Thus we have

$$\mu(4\,l)_{calc} \simeq 0.15; \tag{20}$$

The CMS data read

$$\mu(4\,l)_{CMS} = 0.8 \pm 0.4; \tag{21}$$
$$\mu(4\,l)_{ATLAS} = 1.2 \pm 0.7;$$

Our estimation (20) has no decisive contradiction with data. In the future more precise experiments at LHC the essential distinctions of our scheme and the SM Higgs boson variant could manifest themselves and decisively discriminate different variants. First of all, the distinctions refer to $\sigma_{\gamma\gamma}$ (18).

We would emphasize importance of channel $X \to \gamma\, l^+ l^-$. For this decay mode from (13, 14) we predict

$$\sigma_X\, BR(X \to \gamma l^+ l^-) = (0.0063 \pm 0.0011)\, pb; \tag{22}$$

that gives $N \sim 60$ events for already achieved luminosity (1, 2, 3, 4). This channel may serve for an accurate *test of our results because the SM value for quantity (22) gives around 5 events (28). By the way, authors of work(28) call this channel "overlooked" and I would incline to agree this definition, because the channel could be effectively studied.*

The main difference of our predictions with the SM results consists in decay channel $X \to b\bar{b}$. For SM Higgs which is usually considered for explanation of would-be $125\,GeV$ state this decay is dominant, whereas our result (14) gives extremely small $BR \simeq 3\,10^{-5}$. We would emphasize that SM Higgs interpretation could not be considered as proved unless $b\bar{b}$ channel with the proper intensity would be detected. Quite recent results from LHC read (30)

$$\mu_{bb} = -0.4 \pm 1.0\,(ATLAS)\,; \qquad (23)$$

$$\mu_{bb} = 1.3^{+0.7}_{-0.6}\,(CMS)\,.$$

The option under discussion gives significant probalities for proceeses in which the main $\gamma\gamma$ channel of X decay is accompanied by vector bosons. Namely this probabilities are the following for accompanying W, Z, γ

$$\begin{aligned} &W^{\pm}: \quad 0.49\,;\\ &Z\;: \qquad 0.19\,;\\ &A\;: \qquad 0.058\,. \end{aligned} \tag{24}$$

This means, for example, that a half of events in the 125 GeV peak contains also W. Maybe the most suitable process for study the effect is

$$p\,p\;\rightarrow\;\gamma\,+\,(X\;\rightarrow\gamma\,\gamma)\,. \tag{25}$$

According to (13, 14, 24) we have for the process

$$\sigma(p\,p\;\rightarrow\;\gamma\,+\,(X\;\rightarrow\gamma\,\gamma))\;=\;0.0036\,pb\,; \tag{26}$$

that is quite a significant effect.

Comparison to experiments

Thus we have scalar state X with coupling (9,11). In calculations of decay parameters and cross-sections we use CompHEP package (27).
Cross-section of X production at LHC with $\sqrt{s} = 7\,TeV$ is presented in (13). Branching ratios see (14). From (13, 14) we have for (quite unusual for the Higgs) decay $X \to \gamma l^+ l^-$ $(l = e, \mu)$ the following value

$$\sigma \times BR(X \to \gamma\, l^+\, l^-)_{calc} = \sigma_{\gamma\gamma\, SM} \mu_{\gamma\gamma\, calc} \times \frac{BR(X \to \gamma\, l^+ l^-)}{BR(X \to \gamma\,\gamma)} = 0.0063\, pb\,. \tag{27}$$

This prediction is decisive for checking of the option under discussion.

Remind that we have

$$\sigma_{\gamma\gamma}(SM) = \sigma_H\, BR(H \to \gamma\gamma) \simeq 0.04\, pb\,.$$

Our value for the same quantity from (13, 14) reads

$$\sigma_{\gamma\gamma} = 0.061\, pb\,; \tag{28}$$

that essentially exceeds the SM value $\sigma(SM)$.

The main results are presented in the following Table 1. Remind that signal-strenth

$$\mu$$

is a ratio of a quantity under consideration and of the same for the SM.

	μ_{exp}	μ_{calc}
$H(X) \to \gamma\gamma$ **ATLAS**	1.4 ± 0.3	1.6
$H(X) \to \gamma\gamma$ **CMS**	1.6 ± 0.4	1.6
$H(X) \to \gamma\gamma_{VBF}$ **CMS**	2.3 ± 1.0	3.0
$H(X) \to 4\,l$ **ATLAS**	1.2 ± 0.6	$\simeq 0.15$
$H(X) \to 4\,l$ **CMS**	0.7 ± 0.4	$\simeq 0.15$
$H(X) \to b\bar{b}$ **ATLAS**	-0.4 ± 1.0	$\simeq 0$
$H(X) \to b\bar{b}$ **CMS**	$1.3^{+0.7}_{-0.6}$	$\simeq 0$
$H(X) \to \tau\bar{\tau}$ **ATLAS**	$0.16^{+1.72}_{-1.84}$	$\simeq 0$
$H(X) \to \tau\bar{\tau}$ **CMS**	$-\,0.14^{+0.76}_{-0.68}$	$\simeq 0$

Table 1. Comparison of experimental data to SM Higgs option and the W-hadrons option.

Let us draw attention to four leptons decays. We predict here one-two events for the achieved luminosity, while there are few events already observed. It is not a contradiction yet, however this problem might became a serious one, provided further studies would confirm the discrepancy with higher statistics.

Similar consideration may be expressed on $\bar{f} f$ decays.

Thus we have here admissible agreement for both variants: the SM Higgs and our WW state. We would hope that the forthcoming refinement of data should decide definitely for one definite variant [a]. For the decisive criterion for discrimination of the two variants under discussion we would emphasize importance of channel $X \to \gamma\, l^+ l^-$. For this decay mode from (13, 14) we predict

$$\sigma_X\, BR(X \to \gamma l^+ l^-) \;=\; (0.006 \pm 10)\; pb; \tag{29}$$

whereas for SM Higgs option such process is negligible. The decay (29) gives $N \simeq 60$ events for already achieved luminosity (1, 2, 3, 4). This channel might serve for accurate test of our results.

[a] Of course, one have to bear in mind also other options for interpretation of the effect.

There is also promising process $p + p \to \gamma + X + ...$, with cross-section strongly exceeding the cross-section of the process $p + p \to \gamma + H + ...$. This is due to $X\,Z\,\gamma$ vertex in interaction (9).

For illustration of effects we show in Table 2 the approximate number of events for processes under discussion. We present 3 values of the total energy: 7 TeV, 8 TeV and 14 TeV.

$\sqrt{s}\,;\,L$	$7\,TeV; 5\,fb^{-1}$	$8\,TeV; 15\,fb^{-1}$	$14\,TeV; 30\,fb^{-1}$
$N(X \to \gamma\gamma)$	380	1400	5900
$N^{SM}(H \to \gamma\gamma)$	200	780	3300
$N(\gamma + (X \to 2\gamma))$	17.5	66	285
$N^{SM}(\gamma + (H \to 2\gamma))$	0.015	0.056	0.0243
$N(X \to \gamma e^+ e^-)$	21	77	322
$N(X \to \gamma \mu^+ \mu^-)$	15	53	223
$N^{SM}(H \to \gamma l^+ l^-)$	1.2	4.5	19.3

Table 2. Number of events for processes (with 100% efficiency).

We also would draw attention to difference of our predictions with the SM results in decay channel $X \to b\bar{b}$. For SM Higgs which is usually considered for explanation of would-be $125\,GeV$ state this decay is dominant, whereas our result (14) gives extremely small $BR \simeq 3\,10^{-5}$ (see Table 1). We would emphasize that SM Higgs interpretation could not be considered as proved unless $b\bar{b}$ channel with the proper intensity would be detected. Let us remind recent result by CMS (30)

$$\mu(\bar{b}b) = 1.3^{+0.7}_{-0.6},$$

which nevertheless is not yet decisive.

We would also draw attention to quite promising process $p\,p \to \gamma + X + ...$ with $X \to \gamma\,\gamma$. Our option gives for the process cross-section $\sigma(\gamma, X \to 2\gamma + ...) \simeq 3.6\,fb$ at LHC, that for already reached luminosity $4.8\,fb^{-1}$ gives around 17 events, *whereas for the SM Higgs option the effect is negligible. This process could provide a decisive test of our proposal, the more so as the amount of data will increase in the near future.*

Conclusion

Thus we have an alternative interpretation of LHC $125\,GeV$ *phenomenon. The overall data do not contradict both the SM Higgs option and the scalar W-hadron* X *with account of the vector W-hadron* V *, which we discuss here. However our estimates of the effects seem to fit data rather better. The forthcoming increasing of the integral luminosity will undoubtedly discriminate this two options. Especially we would* *draw attention to processes*

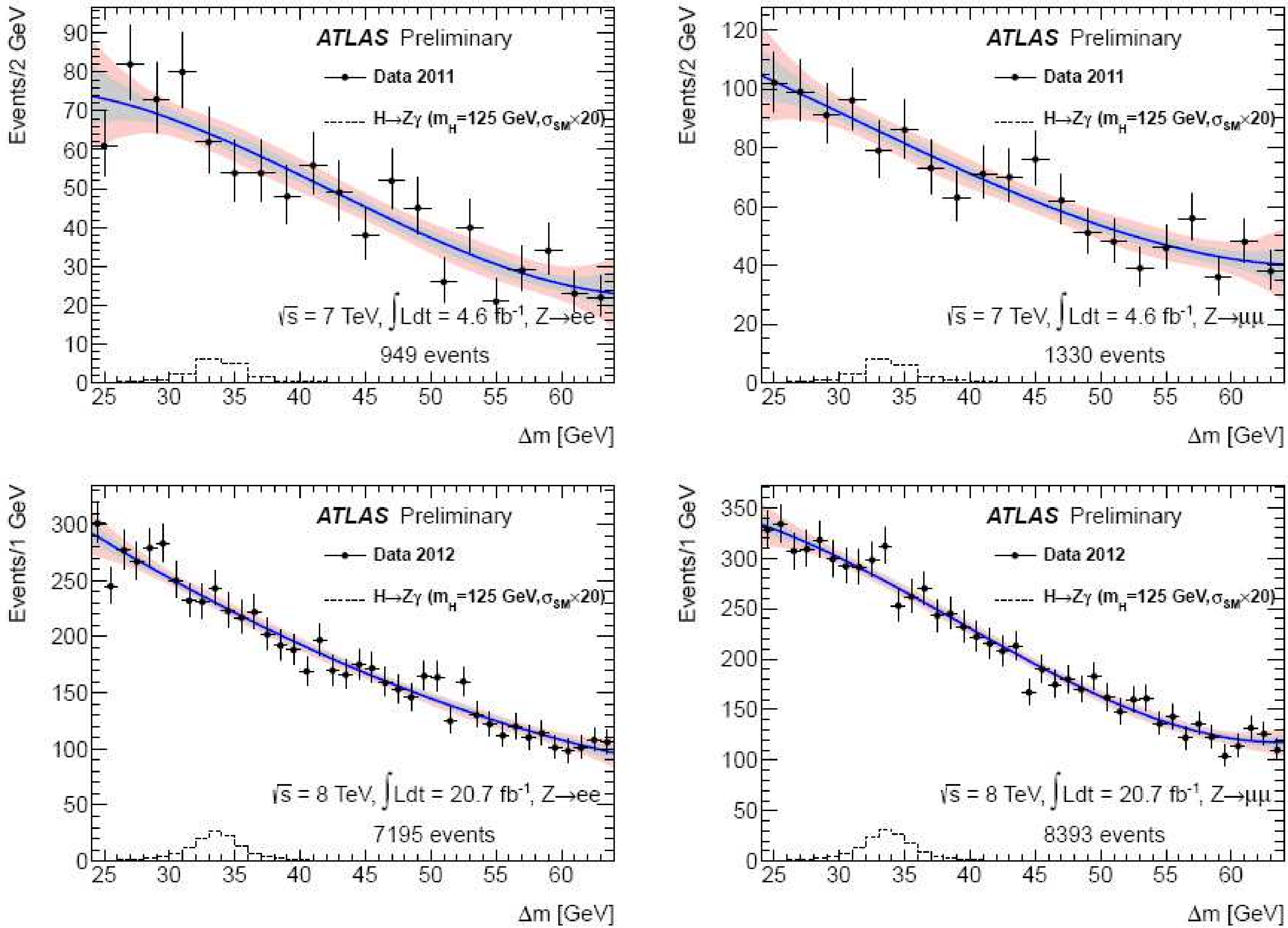
$$p\,p\;\rightarrow (X\rightarrow \gamma l^+ l^-) + ...;$$
$$p\,p\;\rightarrow \gamma + (X\rightarrow \gamma\gamma) + ...;$$

(30)

in which according to Table 2 the effect decisively exceeds the SM predictions.

We would draw attention to the non-perturbative effects, which are decisive for the presented option. Just W-hadrons in case of confirmation of their existence would follow from non-perturbative electro-weak physics almost in the same way as the usual hadrons follow from non-perturbative effects in QCD.

Recent data (31) – The ATLAS Collaboration, ATLAS-CONF-2013-009.:


ATLAS Preliminary
Data 2011
H→Zγ (m_H=125 GeV,σ_SM×20)
√s = 7 TeV, ∫Ldt = 4.6 fb⁻¹, Z→ee
949 events
Events/2 GeV
Δm [GeV]
ATLAS Preliminary
Data 2011
H→Zγ (m_H=125 GeV,σ_SM×20)
√s = 7 TeV, ∫Ldt = 4.6 fb⁻¹, Z→μμ
1330 events
Events/2 GeV
Δm [GeV]
ATLAS Preliminary
Data 2012
H→Zγ (m_H=125 GeV,σ_SM×20)
√s = 8 TeV, ∫Ldt = 20.7 fb⁻¹, Z→ee
7195 events
Events/1 GeV
Δm [GeV]
ATLAS Preliminary
Data 2012
H→Zγ (m_H=125 GeV,σ_SM×20)
√s = 8 TeV, ∫Ldt = 20.7 fb⁻¹, Z→μμ
8393 events
Events/1 GeV
Δm [GeV]

We predict in both down pictures 33 events in the peak.

NO CONTRADICTION (EVEN HINTS in the right one)

Thanks to everybody

References

(1) G. Aad *et al.* (ATLAS Collaboration), Phys. Lett. B 710, 49 (2012).

(2) S. Chatrchyan *et al.* (CMS Collaboration),Phys. Lett. B 710, 26 (2012).

(3) G. Aad *et al.* (ATLAS Collaboration), Phys. Lett. B 716, 1 (2012).

(4) S. Chatrchyan *et al.* (CMS Collaboration),Phys. Lett. B 716, 30 (2012).

(5) B.A. Arbuzov and I.V. Zaitsev, Phys. Rev. D 85: 093001 (2012).

(6) B.A. Arbuzov and I.V. Zaitsev, Int. J. Mod. Phys. A, 27: 1250012 (2012).

(7) B.A. Arbuzov, arXiv: 1209.2831 (hep-ph) (2012).

(8) N.N. Bogoliubov. Soviet Phys.-Uspekhi, 67, 236 (1959).

(9) N.N. Bogoliubov. Physica Suppl., 26, 1 (1960).

(10) B.A. Arbuzov, Theor. Math. Phys., 140, 1205 (2004);

(11) B.A. Arbuzov, Phys. Atom. Nucl., 69, 1588 (2006).

(12) B.A. Arbuzov, M.K. Volkov and I.V. Zaitsev, Int. J. Mod. Phys. A, 21, 5721 (2006).

(13) B.A. Arbuzov, Phys. Lett. B, 656, 67 (2007).

(14) B.A. Arbuzov, M.K. Volkov and I.V. Zaitsev, Int. J. Mod. Phys. A, 24, 2415 (2009).

(15) B.A. Arbuzov, Eur. Phys. J. C, 61, 51 (2009).

(16) B.A. Arbuzov and I.V. Zaitsev, Int. J. Mod. Phys. A, 26, 4945 (2011).

(17) K. Hagiwara, R.D. Peccei, D. Zeppenfeld and K. Hikasa, Nucl. Phys. B, 282, 253 (1987).

(18) K. Hagiwara, S. Ishihara, K. Szalapski and D. Zeppenfeld, Phys. Rev. D, 48, 2182 (1993).

(19) B.A. Arbuzov, Phys. Lett. B, 288, 179 (1992).

(20) LEP Electro-weak Working Group, arXiv: hep-ex/0612034v2 (2006).

(21) The D0 Collaboration, arXiv: 1208.5458 (hep-ex) (2012).

(22) LEP Electro-weak Working Group, arXiv: 1302.3415 (hep-ex) (2013).

(23) The CMS Collaboration, arXiv: 1306.1126 (hep-ex) (2013).

(24) T. Aaltonen *et al.* (CDF Collaboration), Phys. Rev. Lett., 106: 171801 (2011).

(25) V.M. Abazov *et al.* (D0 Collaboration), Phys. Rev. Lett., 107: 011804 (2011).

(26) The CDF Collaboration, arXiv: 1208.3477 (hep-ex).

(27) E. Boos *et al.* (CompHEP Collaboration), Nucl. Instrum. Meth. Phys. Res. A, 534, 250 (2004).

(28) J.S. Gainer *et al*, Phys. Rev. D 86: 033010 (2012).

(29) T. Altonen, V. M. Abazov *et al.*, arXiv: 1207.6436 (hep-ex) (2012).

(30) Y. Nagai, arXiv: 1306.1784 (hep-ex).

(31) The ATLAS Collaboration, ATLAS-CONF-2013-009.