

***LHC state at 125.5 GeV and FNAL data as an evidence for  
the existence of new class of particles – W-hadrons.***

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- 1. Anomalous tree-boson interaction – strong effective running coupling.***
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## **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**

$$\begin{aligned}
 & -\frac{G}{3!} F \epsilon_{abc} W_{\mu\nu}^a W_{\nu\rho}^b W_{\rho\mu}^c ; \\
 & W_{\mu\nu}^3 = \cos \theta_W Z_{\mu\nu} + \sin \theta_W A_{\mu\nu} ; \\
 & W_{\mu\nu}^a = \partial_\mu W_\nu^a - \partial_\nu W_\mu^a + g \epsilon_{abc} W_\mu^b W_\nu^c .
 \end{aligned} \tag{1}$$

**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***

$$G = - \frac{g \lambda}{M_W^2}; \quad (2)$$

***where  $g \simeq 0.65$  is the electro-weak coupling. The current limitations for parameter  $\lambda$  read (20, 21)***

$$-0.059 < \lambda < 0.026; \quad -0.036 < \lambda < 0.044; \quad (95\% \text{ C.L.}) . \quad (3)$$

**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**

$$\begin{aligned}
 & (2\pi)^4 G \epsilon_{abc} (g_{\mu\nu} (q_\rho p k - p_\rho q k) + \\
 & g_{\nu\rho} (k_\mu p q - q_\mu p k) + g_{\rho\mu} (p_\nu q k - k_\nu p q) + \\
 & + q_\mu k_\nu p_\rho - k_\mu p_\nu q_\rho) F(p, q, k) \delta(p + q + k) + \dots;
 \end{aligned} \tag{4}$$

**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**

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

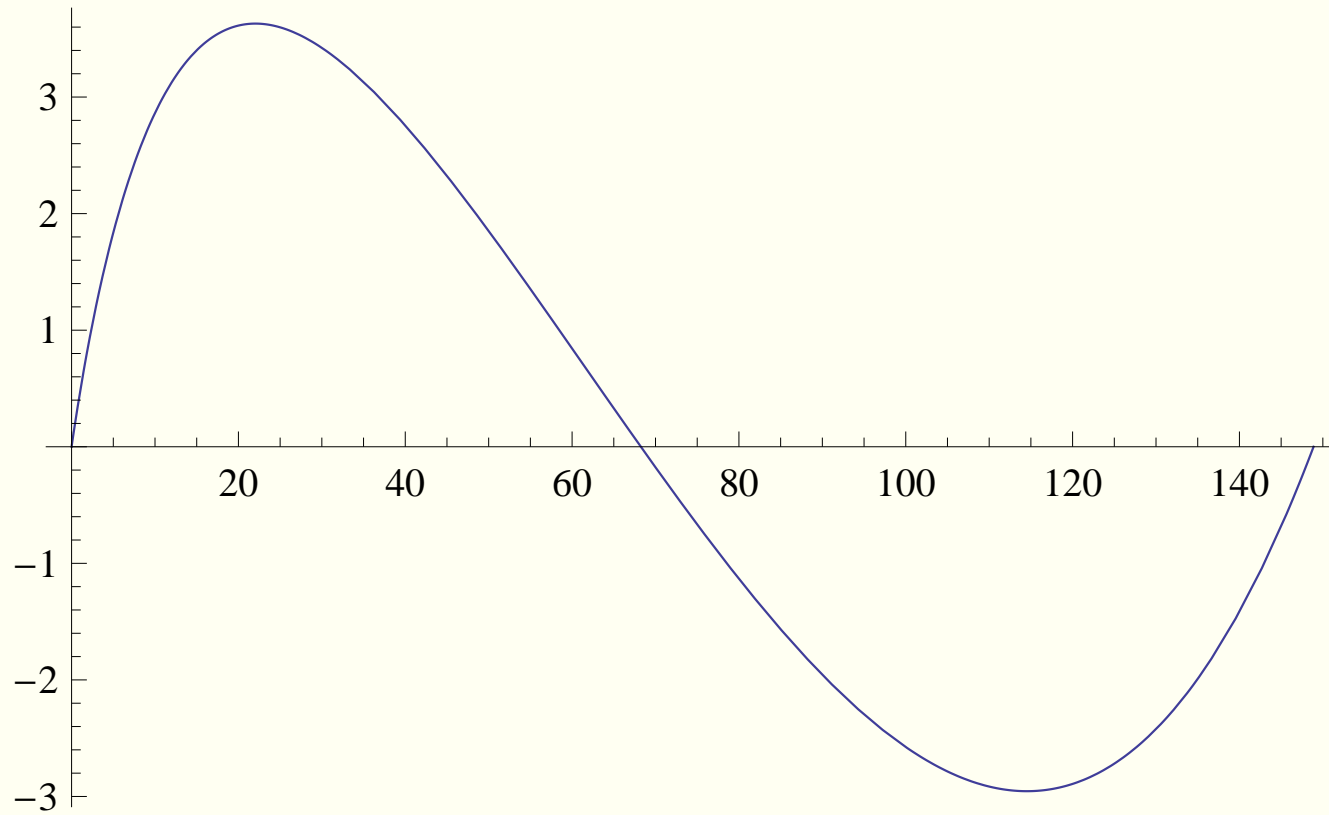
***Symmetric condition means***

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

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

$$g_{eff} = \frac{|g \lambda| p^2}{2M_W^2} F\left(\frac{3 p^2}{2}\right). \quad (7)$$

***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.  $p(max) \simeq 5.4 \text{ TeV}$  with  $G$  from the forthcoming**

***solution), that is corresponding effective  $\alpha$  is the following***

$$\alpha_{eff} = \frac{g_{eff}^2}{4\pi} = 1.049. \quad (8)$$

***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*

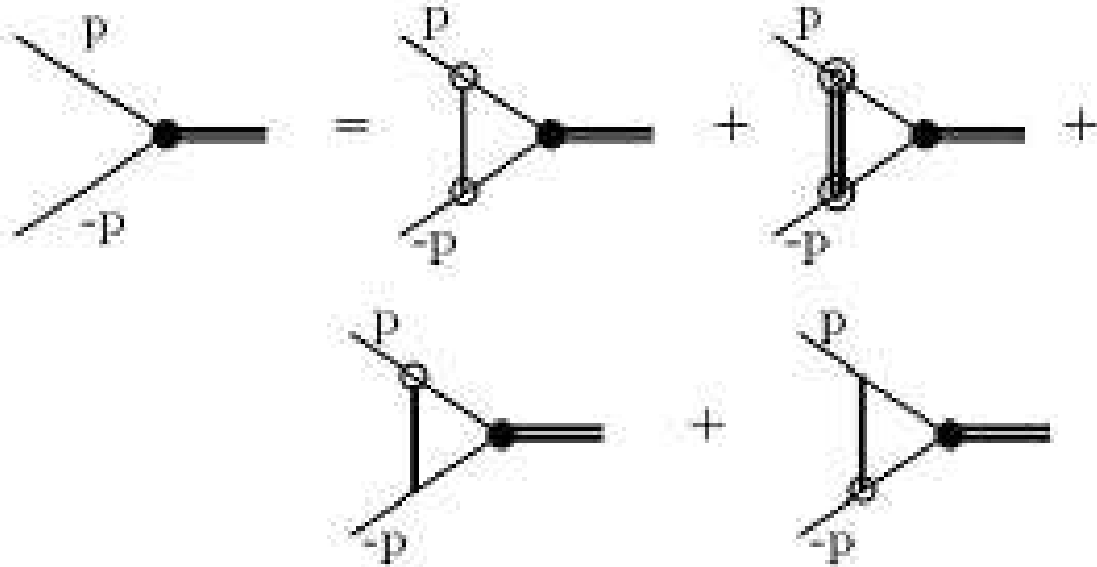
$$\frac{G_X}{2} W_{\mu\nu}^a W_{\mu\nu}^a X \Psi_0; \quad (9)$$

*where  $\Psi_0$  is a Bethe-Salpeter wave function of the bound state. Due to gauge invariance there is also three-boson term*

$$- g G_X \epsilon_{abc} W_{0\mu\nu}^a W_\mu^b W_\nu^c X; \quad (10)$$

*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  $M_s = 125 \text{ GeV}$  it leads to the unique solution of the set of equations and conditions with the following parameters**

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

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

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

**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 (25). We use parameter  $G_X$  (11) being obtained above and  $M_s = 125 \text{ GeV}$ . Cross-section of  $X$  production at LHC reads**

$$\begin{aligned}\sigma_X &= \sigma(p + p \rightarrow X + \dots) = 0.18 \text{ pb}; & \sqrt{s} &= 7 \text{ TeV}; \\ \sigma_X &= \sigma(p + p \rightarrow X + \dots) = 0.21 \text{ pb}; & \sqrt{s} &= 8 \text{ TeV}.\end{aligned}\quad (13)$$

***Parameters of  $X$ -decay are the following***

$$\Gamma_t(X) = 0.000502 \text{ GeV}; \quad (14)$$

$$BR(X \rightarrow \gamma\gamma) = 0.430; \quad BR(X \rightarrow \gamma Z) = 0.305;$$

$$BR(X \rightarrow 4l(\mu, e)) = 0.00092; \quad BR(X \rightarrow b\bar{b}) = 0.000024.$$

$$BR(X \rightarrow \gamma e^+e^-) = 0.0231; \quad BR(X \rightarrow \gamma\mu^+\mu^-) = 0.016;$$

$$BR(X \rightarrow \gamma\tau^+\tau^-) = 0.0125; \quad BR(X \rightarrow \gamma u\bar{u}) = 0.0478;$$

$$BR(X \rightarrow \gamma c\bar{c}) = 0.0368; \quad BR(X \rightarrow \gamma d\bar{d}) = 0.0446;$$

$$BR(X \rightarrow \gamma s\bar{s}) = 0.0430; \quad BR(X \rightarrow \gamma b\bar{b}) = 0.0416.$$

***For decay  $X \rightarrow b\bar{b}$  we calculate the evident triangle diagram and use  $m_b(125 \text{ GeV}) \simeq 2.9 \text{ GeV}$ . 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  $\sigma_{\gamma\gamma} = \sigma_X \text{BR}(X \rightarrow \gamma\gamma)$  (3, 4)**

$$\mu_{\gamma\gamma} = \frac{\sigma \times \text{BR}(X \rightarrow \gamma\gamma)_{\text{exp}}}{\sigma \times \text{BR}(X \rightarrow \gamma\gamma)_{\text{SM}}} = 1.8 \pm 0.5; \quad (15)$$

$$\mu_{\gamma\gamma} = \frac{\sigma \times \text{BR}(X \rightarrow \gamma\gamma)_{\text{exp}}}{\sigma \times \text{BR}(X \rightarrow \gamma\gamma)_{\text{SM}}} = 1.6 \pm 0.4.$$

**Here  $\sigma \times \text{BR}(H \rightarrow \gamma\gamma)_{\text{SM}} \simeq 0.04 \text{ pb}$  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**

$$\mu_{\gamma\gamma} = \frac{\sigma \times \text{BR}(X \rightarrow \gamma\gamma)_{\text{calc}}}{\sigma \times \text{BR}(X \rightarrow \gamma\gamma)_{\text{SM}}} = 1.9; \quad (16)$$

**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 20% of the calculated value. Thus we would change (28) to the following result**

$$\mu_{\gamma\gamma} = (1.9 \pm 0.38) \text{ pb}; \quad (17)$$

**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).**

***There are also indications for some excess around 125 GeV in four leptons states. With our numbers (13, 14) we have for decay  $X \rightarrow l^+ l^+ l^- l^-$  ( $l = \mu, e$ ):  $\sigma \times BR = (0.0002 \pm 0.00004) pb$ . Thus we have***

$$\mu(4l)_{calc} = 1.05; \tag{18}$$

***Our estimation (18) has no contradiction with data as well as the usual SM Higgs boson interpretation. 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  $\sigma_{\gamma\gamma}$  (17).***

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

$$\sigma_X BR(X \rightarrow \gamma l^+ l^-) = (0.0075 \pm 15) pb; \tag{19}$$



*that gives  $N \sim 70$  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 (30) gives around 5 events (26). By the way, authors of work (26) 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  $X \rightarrow b\bar{b}$ . 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  $BR \simeq 3 \cdot 10^{-5}$ . 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. However recently the results of TEVATRON were reported (27), in which there was an excess of  $b\bar{b}$  events registered in the region*

***120 GeV < M<sub>bb</sub> < 150. Provided this excess being prescribed to decay of Higgs the result reads (27)***

$$\mu_{bb} = 1.97^{+0.74}_{-0.73}; \quad (20)$$

***that the authors of (27) consider as a confirmation of SM Higgs interpretation of results (1, 2, 3, 4). We shall once more discuss this item after introduction of the vector W-state.***

## **Vector isovector state and $b\bar{b}$ bump at TEVATRON**

*In work (6) the interpretation of CDF jet – jet enhancement around 140 GeV was interpreted as a manifestation of isovector W-hadron with spin 1. We assume that this excess is due to existence of bound state V of two W. This state V is assumed to have spin 1 and weak isotopic spin also 1. Then vertex of VWW interaction has the following form*

$$\frac{G_V}{2} \epsilon_{abc} W_{\mu\nu}^a W_{\nu\rho}^b V_{\rho\mu}^c \Psi_V; \quad (21)$$

*where  $\Psi_V$  is a Bethe-Salpeter wave function of the bound state.*

*Solving this equation we obtain  $G_V$*

$$G_V = \frac{0.1425}{M_W^2}. \quad (22)$$

**Behaviour of the wave function defines form-factor  $F(p)$  for calculation of cross-sections with the aid of CompHEP package (25). With value (22) we have for the cross-section at TEVATRON for production of  $jet\ jet\ (W, Z)$  (22)**

$$\begin{aligned}\sigma_{jjW,Z} &\simeq 1.1\ pb \quad (M_V = 140\ GeV); \\ \sigma_{jjW,Z} &\simeq 1.2\ pb \quad (M_V = 130\ GeV).\end{aligned}\tag{23}$$

**These values do not contradict both CDF (22) ( $\sigma = 4.0 \pm 1.2\ pb$ ) and D0 (23) ( $\sigma < 1.9\ pb$ ) data.**

**Let us denote these vector states as  $V, V^\pm$ . Then neutral state  $V$  has significant BR for decay  $V \rightarrow b\bar{b}$ ,  $BR(b\bar{b}) = 0.143$  (6). The cross-section of  $V$  production with accompanying  $W^\pm$  at TEVATRON also is easily extracted from (6) results with account of value (22):  $\sigma(W^\pm V) = 1.3\ pb$ . Thus we have**

$$\sigma(W^\pm V) \times BR(b\bar{b}) \simeq 0.17\ pb;\tag{24}$$

**that is to be compared with experimental number (27), which was obtained in the course of the SM Higgs search:**

$$\sigma(W^\pm H) \times BR(b\bar{b}) = 0.23^{+0.09}_{-0.08} pb; \quad (25)$$

$$\sigma(W^\pm H) \times BR(b\bar{b})_{SM} = 0.12 \pm 0.01 pb;$$

**where we also show the SM value for this quantity calculated on assumption of the data being due to the would-be 125 GeV Higgs. As a matter of fact experiment does not contradict both options but agrees the W-vector bound state option (24) rather better.**

**For comparison with LHC data we calculate also the effect of jet jet decay of 135 GeV V state. For  $p p$ ,  $\sqrt{s} = 7 TeV$  we have**

$$\sigma_{jjW,Z} = 4.6 pb; \quad (26)$$

**that agrees recent data (24)  $\sigma_{jjW,Z} < 5 pb$ .**

## Comparison to experiments

Thus we have scalar state  $X$  with coupling (9,11) and vector state  $V^a$  with coupling (21,22). In calculations of decay parameters and cross-sections we use CompHEP package (25). Cross-section of  $X$  production at LHC with  $\sqrt{s} = 7 \text{ TeV}$  is presented in (13). Branching ratios see (14). From (13, 14) we have for (quite unusual for the Higgs) decay  $X \rightarrow \gamma l^+ l^-$  ( $l = e, \mu$ ) the following value

$$\sigma \times BR(X \rightarrow \gamma l^+ l^-)_{calc} = \sigma_{\gamma\gamma SM} \mu_{\gamma\gamma calc} \times \frac{BR(X \rightarrow \gamma l^+ l^-)}{BR(X \rightarrow \gamma\gamma)} = 0.0075 \text{ pb} . \quad (27)$$

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

***Remind that we have***

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

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

$$\sigma_{\gamma\gamma} = 0.079 \text{ pb}; \tag{28}$$

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

***The main results are presented in the following Table 1.***

	$\mu_{exp}$	$\mu_{calc}$	$\mu_{eff}(V\ 140\ GeV)$
$H(X) \rightarrow \gamma\gamma$ <b>ATLAS</b>	$1.8 \pm 0.5$	1.9	–
$H(X) \rightarrow \gamma\gamma$ <b>CMS</b>	$1.6 \pm 0.4$	1.9	–
$H(X) \rightarrow 4l$ <b>ATLAS</b>	$1.2 \pm 0.6$	1.05	–
$H(X) \rightarrow 4l$ <b>CMS</b>	$0.7 \pm 0.4$	1.05	–
$H(X) \rightarrow b\bar{b}$ <b>ATLAS</b>	$0.48^{+2.17}_{-2.12}$	0	1.01
$H(X) \rightarrow b\bar{b}$ <b>CMS</b>	$0.15^{+0.73}_{-0.66}$	0	1.01
$H(X) \rightarrow \tau\bar{\tau}$ <b>ATLAS</b>	$0.16^{+1.72}_{-1.84}$	0	2.5
$H(X) \rightarrow \tau\bar{\tau}$ <b>CMS</b>	$-0.14^{+0.76}_{-0.68}$	0	2.5
$H(X) \rightarrow b\bar{b}$ <b>TEVATRON</b>	$1.97^{+0.74}_{-0.73}$	0	1.42

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



**The last line of Table 1 describes recent joint results of CDF and D0 on detection of  $b\bar{b}$  pair production in region of effective masses  $120 \text{ GeV} < M < 150 \text{ GeV}$  (27). This result may be considered as a confirmation of data (1, 2, 3, 4). In the framework of the present interpretation we prescribe this effect to production of the resonance  $V(140)$ .**

**Resonance  $V(140)$  also give contribution to process  $p + p \rightarrow (W, Z) + \text{jet jet} + \dots$ . CMS result (24) gives limitation for possible contribution  $\sigma < 5 \text{ pb}$  of a resonance with mass  $120 \text{ GeV} < M_R < 150 \text{ GeV}$ . The contribution for this process of the resonance  $V(140)$  is calculated to be the following**

$$\sigma_{(W,Z)jj} = 4.6 \text{ pb} . \quad (29)$$

**Thus we have here also absence of a contradiction. We would hope that the forthcoming refinement of data should decide**

**definitely for one definite variant<sup>a</sup>. For the decisive criterion for discrimination of the two variants under discussion we would emphasize importance of channel  $X \rightarrow \gamma l^+ l^-$ . For this decay mode from (13, 14) we predict**

$$\sigma_X BR(X \rightarrow \gamma l^+ l^-) = (0.0075 \pm 15) pb; \quad (30)$$

**whereas for SM Higgs option such process is negligible. The decay (30) gives  $N \simeq 70$  events for already achieved luminosity (1, 2, 3, 4). This channel might serve for accurate test of our results.**

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

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<sup>a</sup>Of course, one have to bear in mind also other options for interpretation of the effect.

***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 <sup>-1</sup>	8 TeV; 15 fb <sup>-1</sup>	14 TeV; 30 fb <sup>-1</sup>
$N(X \rightarrow \gamma\gamma)$	<b>380</b>	<b>1400</b>	<b>5900</b>
$N^{SM}(H \rightarrow \gamma\gamma)$	<b>200</b>	<b>780</b>	<b>3300</b>
$N(\gamma + (X \rightarrow 2\gamma))$	<b>17.5</b>	<b>66</b>	<b>285</b>
$N^{SM}(\gamma + (H \rightarrow 2\gamma))$	<b>0.015</b>	<b>0.056</b>	<b>0.0243</b>
$N(X \rightarrow \gamma e^+ e^-)$	<b>21</b>	<b>77</b>	<b>322</b>
$N(X \rightarrow \gamma \mu^+ \mu^-)$	<b>15</b>	<b>53</b>	<b>223</b>
$N^{SM}(H \rightarrow \gamma l^+ l^-)$	<b>1.2</b>	<b>4.5</b>	<b>19.3</b>

***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  $X \rightarrow b\bar{b}$ . 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  $BR \simeq 3 \cdot 10^{-5}$  (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.***

***We would also draw attention to quite promising process  $p p \rightarrow \gamma + X + \dots$  with  $X \rightarrow \gamma\gamma$ . Our option gives for the process cross-section  $\sigma(\gamma, X \rightarrow 2\gamma + \dots) \simeq 3.6 \text{ fb}$  at LHC, that for already reached luminosity  $4.8 \text{ fb}^{-1}$  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***

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

$$p p \rightarrow \gamma + (X \rightarrow \gamma\gamma) + \dots;$$

(31)

***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.***

***Thanks to everybody***

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