On extended Higgs sector of the Standard Model and gauge couplings unification

based on arXiv:**1509.07610**

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Gearing up for LHC13

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Running coupling "constants"

The Standard Model is based on the gauge group $SU(3)_C \times SU(2)_W \times U(1)_Y$ with the corresponding coupling constants

$$\mathbf{g_3 = g_s,\ \ g_2 = g = \frac{e}{\sin\theta_W}}\ \ \text{и}\ \ \mathbf{g_1 = \sqrt{\frac{5}{3}}g' = \sqrt{\frac{5}{3}}\frac{e}{\cos\theta_W}}$$

$$\alpha_i^{-1}(\mu) = \alpha_i^{-1}(M_Z) - \frac{b_i}{2\pi}\ln\frac{\mu}{M_Z},\ \text{were}\ \alpha_i = \frac{g_i^2}{4\pi};$$

$$b_1 = 4 + \frac{N}{10},\ \text{were}\ N\ \text{number of Higgs doublets}$$

$$b_2 = -2\frac{11}{3} + 4 + \frac{N}{6},$$

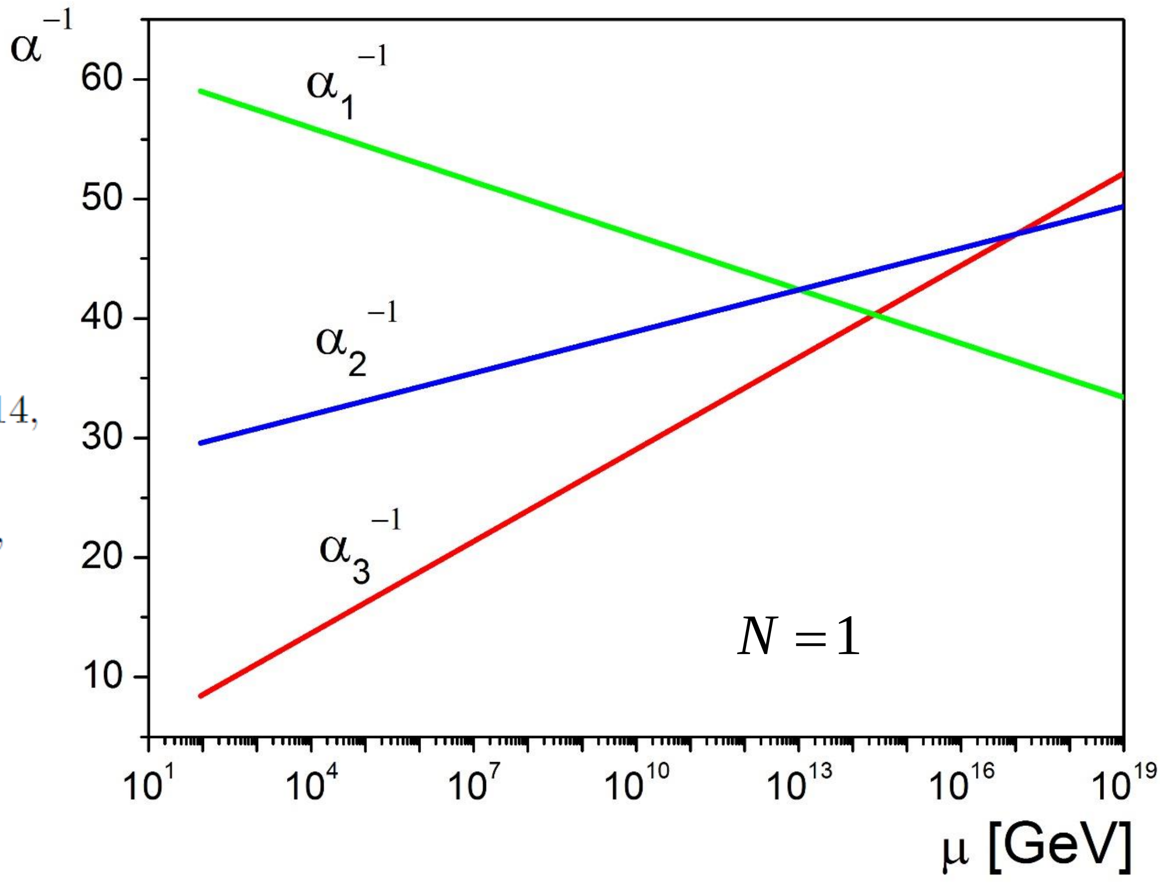
$$b_3 = -3\frac{11}{3} + 4.$$

All evaluations have been done in the one-loop approximation.

Gauge couplings evolution in the Standard Model

$$\hat{\alpha}(M_Z) = 1/127.940 \pm 0.014,$$
$$\sin^2\hat{\theta}(M_Z) = 0.23126 \pm 0.00005,$$
$$\alpha_s(M_Z) = 0.1185 \pm 0.0006.$$

$$\alpha_1^{-1}(M_Z) = \frac{3}{5}\frac{\cos^2\hat{\theta}(M_Z)}{\hat{\alpha}(M_Z)} = 59.012 \pm 0.014,$$
$$\alpha_2^{-1}(M_Z) = \frac{\sin^2\hat{\theta}(M_Z)}{\hat{\alpha}(M_Z)} = 29.587 \pm 0.007,$$
$$\alpha_3^{-1}(M_Z) = \alpha_s^{-1}(M_Z) = 8.439 \pm 0.043,$$

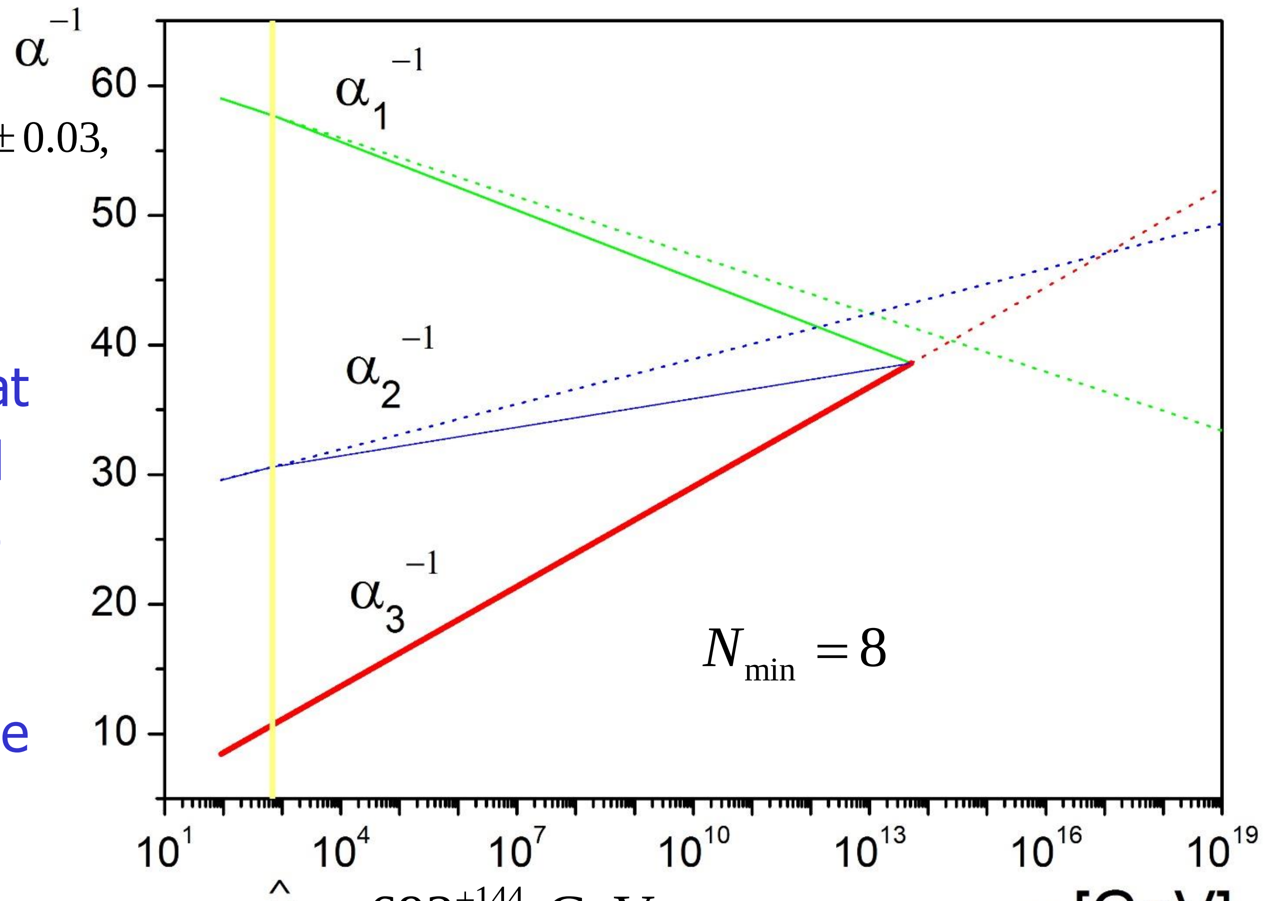


Gauge couplings unification with extended Higgs sector (N >1) and intermediate scale $\hat{\mu}$

$$\hat{\mu} = M_Z \exp\left[-\frac{2\pi\varepsilon_{ijk}(b_i - b_j)\alpha_k^{-1}(M_Z)}{\varepsilon_{ijk}(b_i - b_j)\Delta b_k}\right], \quad \bar{\mu} = M_Z \exp\left[-\frac{2\pi\varepsilon_{ijk}(\Delta b_i - \Delta b_j)\alpha_k^{-1}(M_Z)}{\varepsilon_{ijk}(b_i^0 - b_j^0)\Delta b_k}\right] = 5.09^{+0.09}_{-0.08}\times 10^{13}\ \text{GeV},$$

$$\alpha^{-1}(\bar{\mu}) = \frac{\varepsilon_{ijk}\Delta b_i b_j^0 \alpha_k^{-1}(M_Z)}{\sum_k \varepsilon_{ijk}\Delta b_i b_j^0} = 38.57 \pm 0.03,$$

where $\Delta b_i = b_i - b_i^0$ and $b_i^0 = b_i\big|_{N=1}$.



$\hat{\mu} = 692^{+144}_{-120}$ GeV

It is interesting to note that the unification scale $\bar{\mu}$ and coupling constant $\alpha(\bar{\mu})$ do not depend on doublets number, N. Furthermore, such a relatively small scale leads to "proper" neutrino mass ~ 0.6 eV.

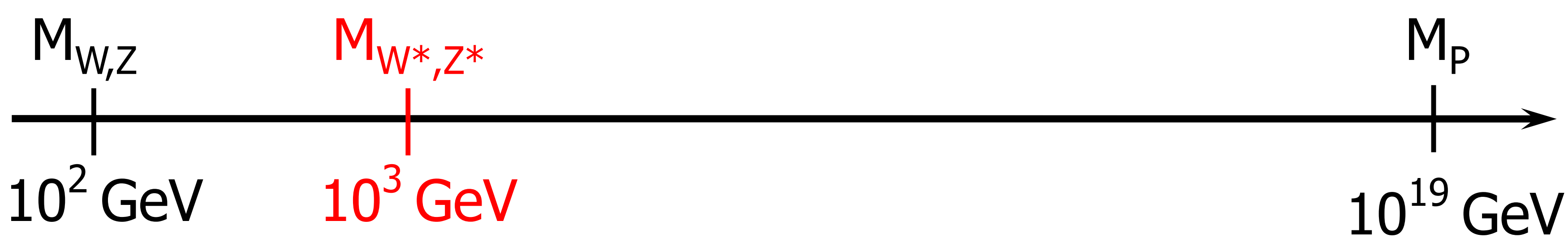
Seven additional Higgs doublets: it is a lot?!

Here we propose a different interpretation of the given result. The massive vector boson has three physical degrees of freedom and contributes to the gauge coupling evolution in the one-loop approximation three times more strongly than the scalar boson. Therefore, introduction of one pair of scalar and vector doublets is equivalent to the four Higgs doublets content.

So, the solution with N = 8 can be interpreted as an extension of the SM Higgs sector with one additional Higgs doublet and two corresponding vector doublets. That is exactly the set of fields which was proposed in
M.V. Chizhov, Mod. Phys. Lett. A **8** (1993) 2753

Naturalness of the Higgs mass

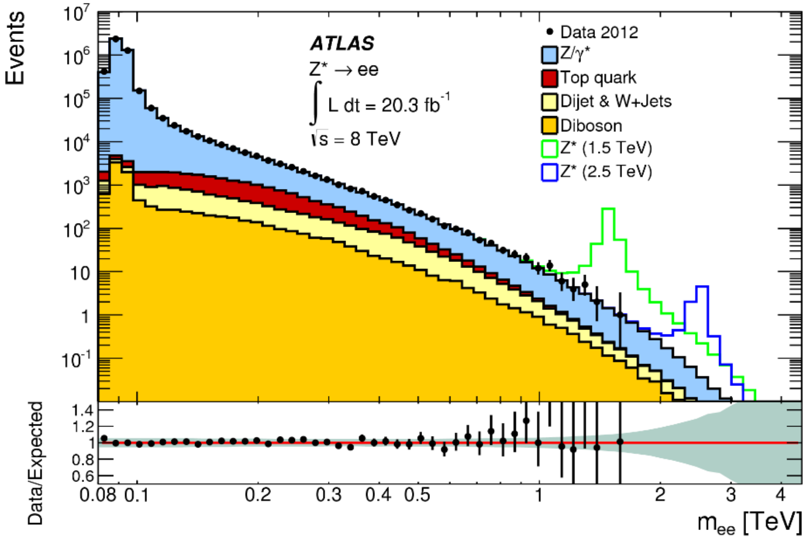
Introduction of new spin-1 bosons with the internal quantum numbers identical to the Standard Model Higgs doublet can help to solve by the Hierarchy Problem.

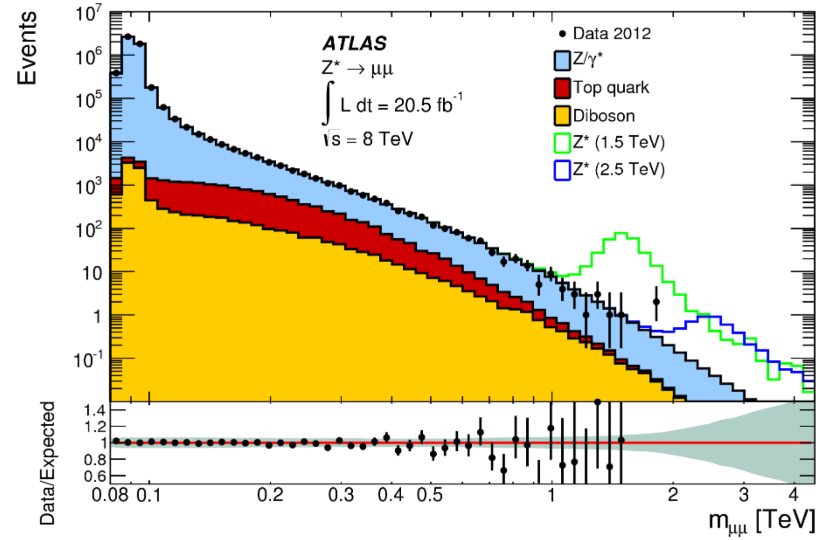


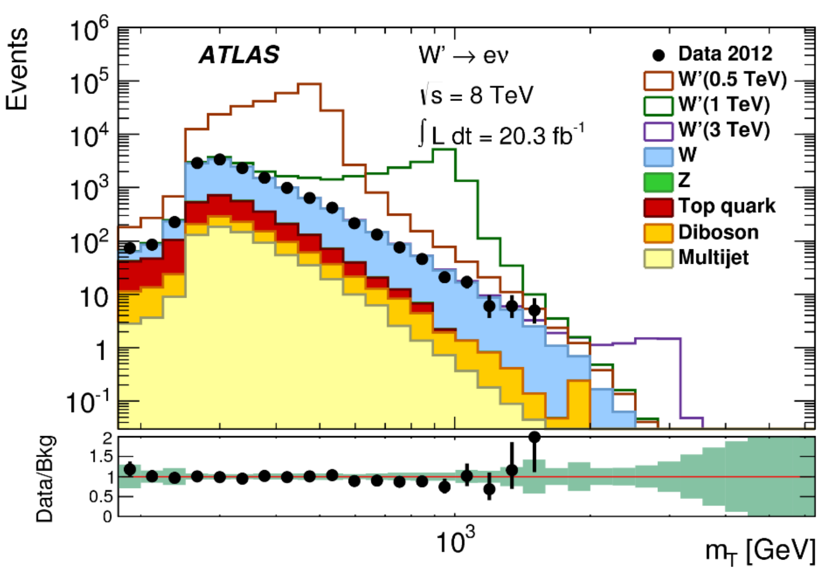
M. Chizhov and G. Dvali "Origin and Phenomenology of Weak-Doublet Spin-1 Bosons", Phys. Lett. B 703 (2011) 593, arXiv:0908.0924

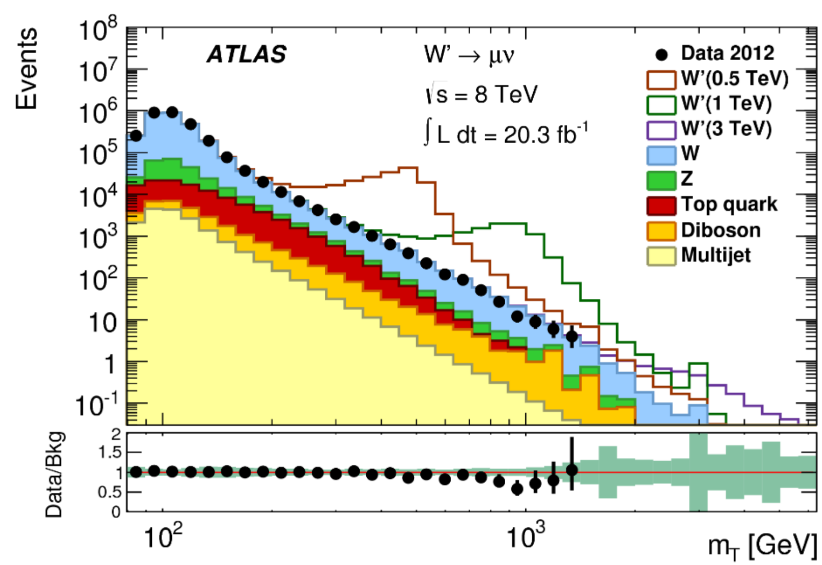
$$\begin{pmatrix} H^+ \\ H^0 \end{pmatrix} \leftrightarrow \begin{pmatrix} W_\mu^{*+} \\ Z_\mu^* \end{pmatrix}$$

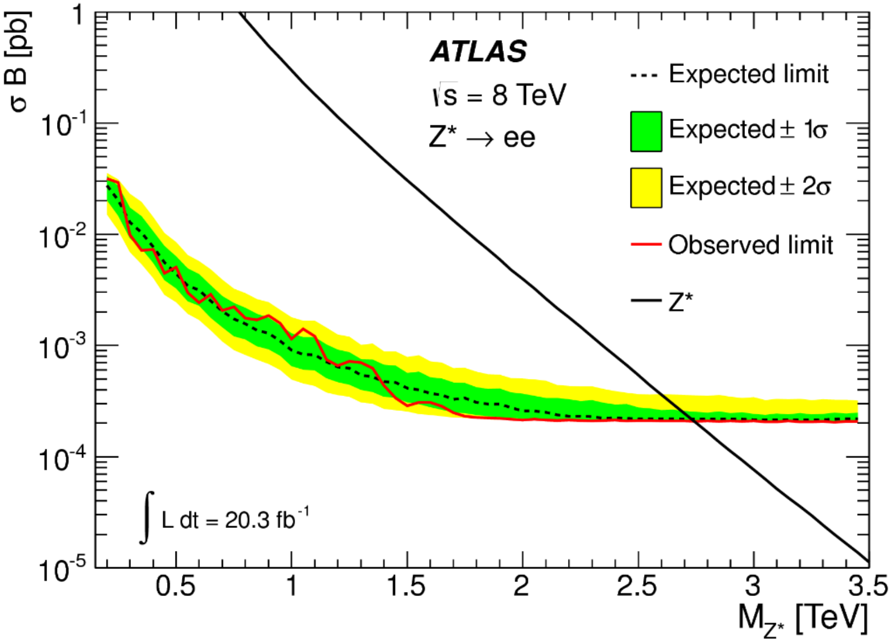
Search of new Z^*/W^* bosons at LHC

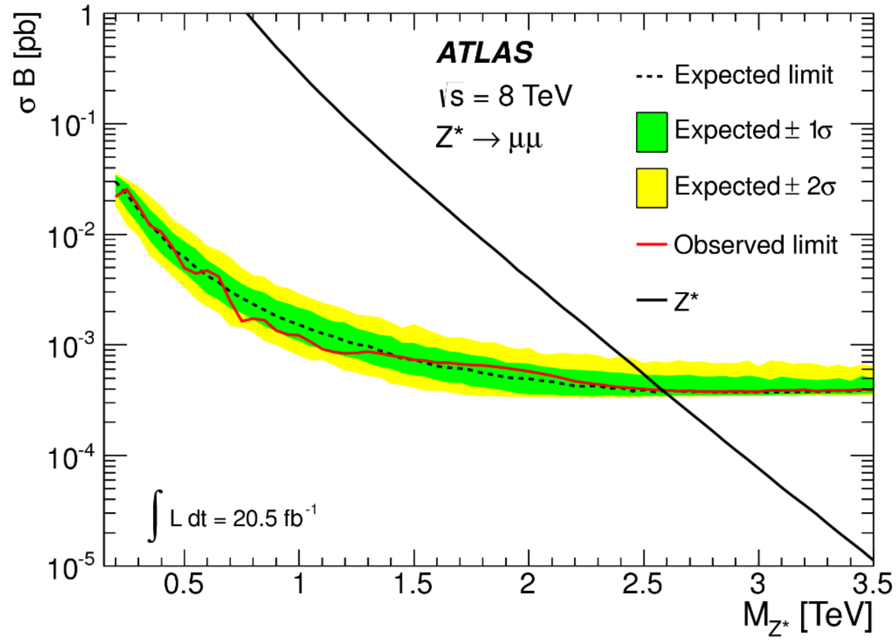


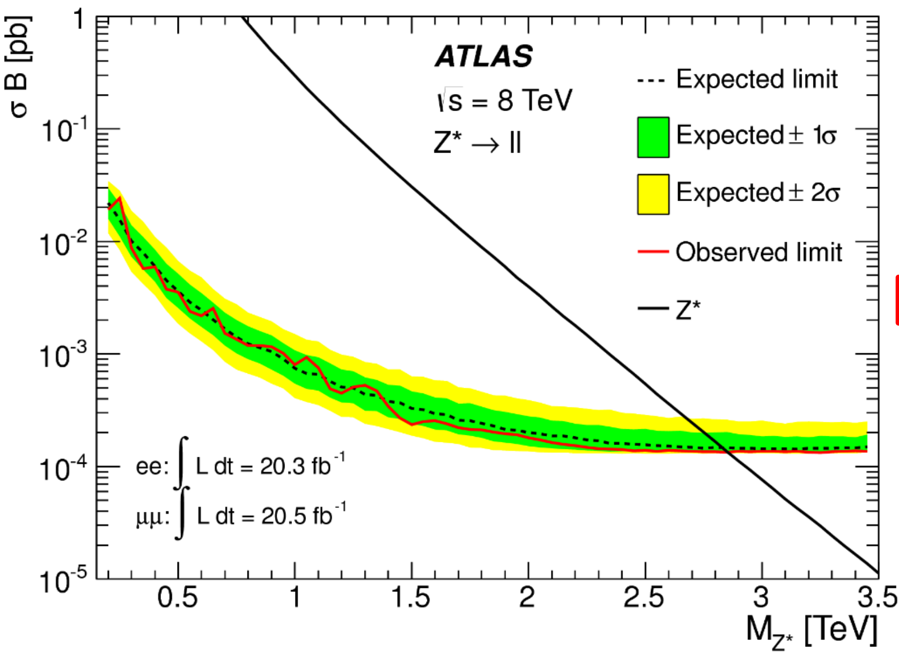






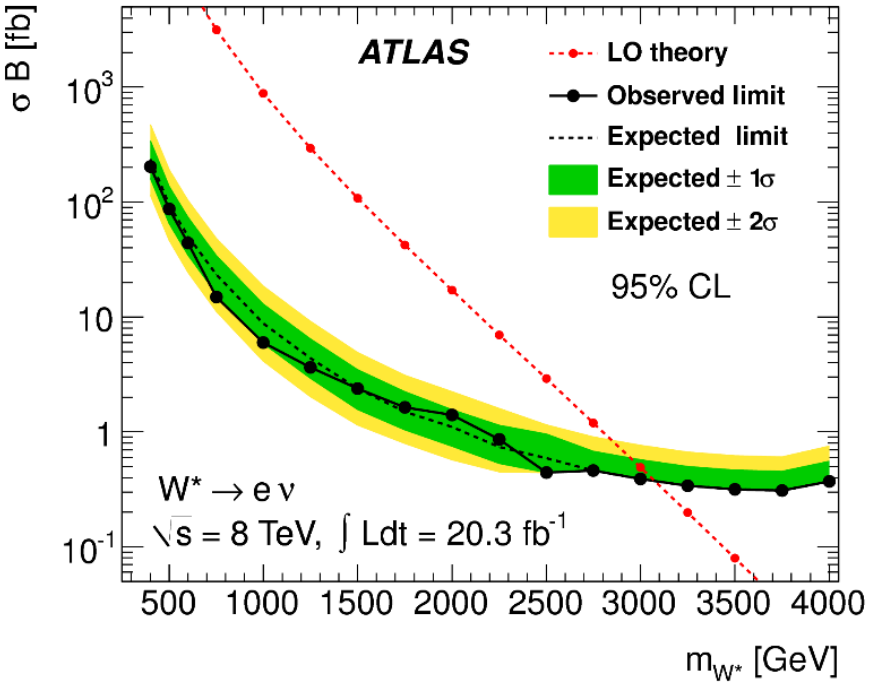


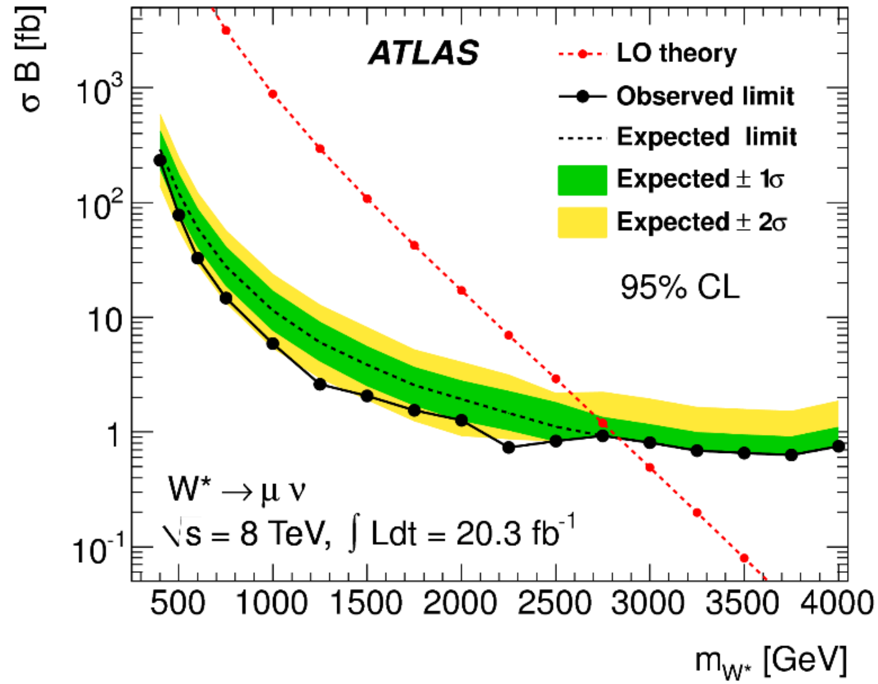


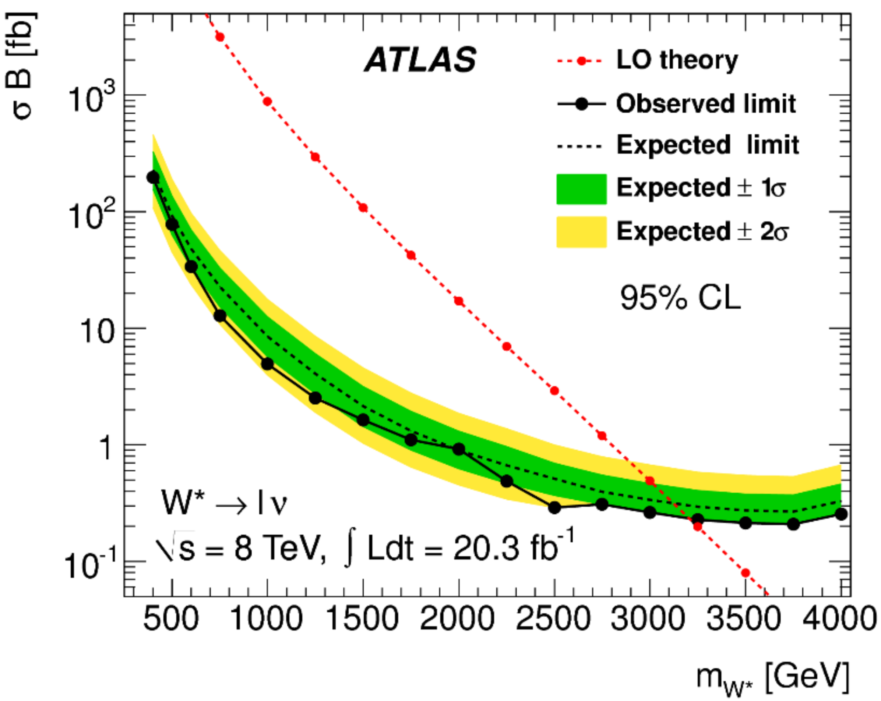


Model	Width [%]	Observed limit [TeV]	Expected limit [TeV]
Z'_{SSM}	3.0	2.90	2.87
Z'_{χ}	1.2	2.62	2.60
Z'_{ψ}	0.5	2.51	2.46
Z^*	3.4	2.85	2.82

The ATLAS Collaboration "Search for high-mass dilepton resonances in *pp* collisions at √s=8 TeV with the ATLAS detector", Physical Review D **90** (2014) 052005







	$m_{W'}$ [TeV]		m_{W^*} [TeV]	
Decay	Exp.	Obs.	Exp.	Obs.
$e\nu$	3.13	3.13	3.08	3.08
$\mu\nu$	2.97	2.97	2.83	2.83
Both	3.17	3.24	3.12	3.21

The ATLAS Collaboration "Search new particles in events with one lepton and missing transverse momentum in *pp* collisions at √s=8 TeV with the ATLAS detector", JHEP **09** (2014) 037

Alternative of universality

At first glance, these results exclude the possibility of existence of the lightest states with masses M ~ 700 GeV. However, their production and decays were searched only in the clearest channels at LHC: Drell-Yan processes. In other words, the quark-lepton and family universality was assumed.
This assumption is natural for the vector fields like Z′/W′ from the adjoint representations of the gauge group in order to avoid tree-level flavor-changing neutral currents, whereas the scalar Higgs doublet from the fundamental representation interacts mainly with the fermions from the third family, which is the source of the flavor violation in Nature. Since the vector doublets come along with the scalar doublets, it is more natural to suggest a similar pattern of couplings for the vector doublets too.

Example with extra dimensions

Let us consider a doublet of the gauge fields in N-dimension Minkowski space. Then its the fifth and the subsequent components can play a role of the Higgs fields (so-called Gauge-Higgs unification)

$$\begin{pmatrix} W_M^{*+} \\ Z_M^{*} \end{pmatrix} = \begin{pmatrix} W_\mu^{*+}, H^+, \ldots \\ Z_\mu^{*} \quad , H^0, \ldots \end{pmatrix}$$

N.S. Manton, Nucl. Phys. B 158 (1979) 141;
D.B. Fairlie, J. Phys. G 5 (1979) L55; Phys. Lett. B 82 (1979) 97.

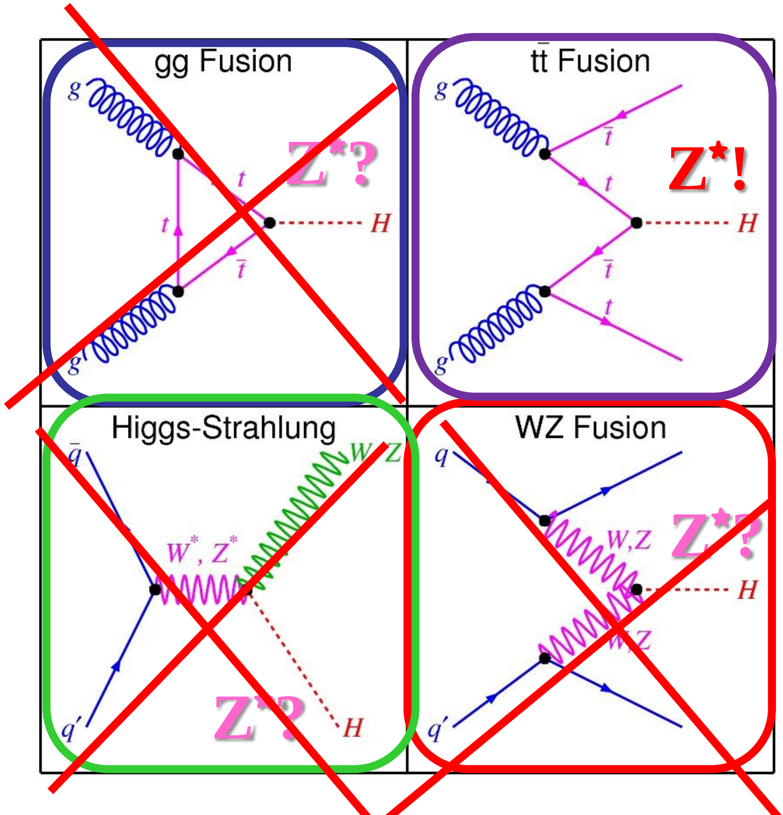
The lightness of the Higgs doublets is guaranteed by the gauge symmetry. This symmetry is spontaneously broken by compactification. In this way the mass of the Higgs doublet is controlled by the compactification scale, as opposed to the high-dimensional cutoff of the theory.

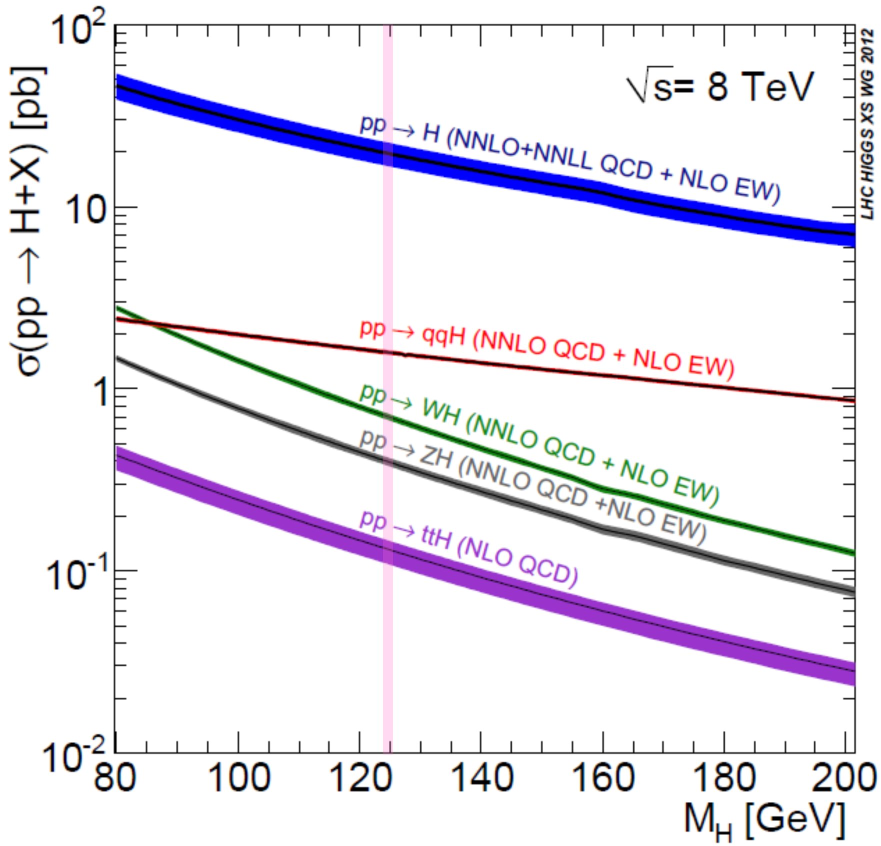
$$\mathcal{L}^{\star} = \frac{g^{\star}}{M_{W^{\star}}}(\partial_\mu W_\nu^{\star -}\, \overline{b}_L \sigma^{\mu\nu} t_R + \partial_\mu W_\nu^{\star +}\, \overline{t}_R \sigma^{\mu\nu} b_L)$$

$$+ \frac{g^{\star}}{\sqrt{2} M_{Z^{\star}}}(\partial_\mu \mathrm{Re}\, Z_\nu^{\star}\, \overline{t}\, \sigma^{\mu\nu} t + i\partial_\mu \mathrm{Im}\, Z_\nu^{\star}\, \overline{t}\, \sigma^{\mu\nu} \gamma^5 t)$$

Higgs vs. new bosons production at LHC

https://twiki.cern.ch/twiki/bin/view/LHCPhysics/CrossSections





σ[pb]

19.27

1.578

0.7046

0.4153

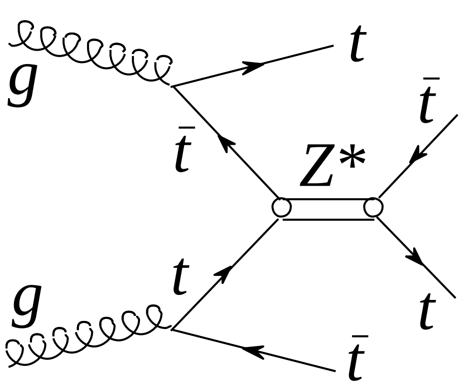
0.1293

125 GeV

Signature of neutral Z* bosons

The neutral Z* bosons are interacting mainly with top quarks. Therefore, they will produce in top quarks annihilation and decay to them. However, at LHC energy the protons do not contain practically top quarks and the only mechanism of their occurrence is gluon splitting: $gg \to t\bar{t}\,Z^{\star} \to t\bar{t}\,t\bar{t}$

$$(\sigma_{t\bar{t}t\bar{t}}^{\mathrm{SM}} \approx 1\ \mathrm{fb}\ @\ \sqrt{s} = 8\ \mathrm{TeV})$$



$$t \to bW,\ W \to \ell\nu\ (3\times 10\%),\ \tau \to \ell\nu\nu\ (2\times 20\%)$$
$$\to q\bar{q}\ (70\%)$$

1 lepton (e,μ) + jets: $\approx 41\%$

0 leptons: $\approx 30\%$

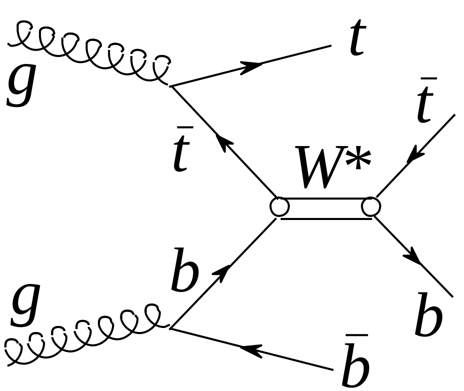
2 leptons: $\approx 22\%$

3-4 leptons: $\approx 6\%$

Signature of charged W* bosons (1)

The charged W* boson is interacting mainly with top and bottom quarks. Therefore, it will produce in top-bottom quarks annihilation and decay to them.

This process is analogous to previous neutral Z* boson production: $gg \to t\bar{b}W^{\star -} \to t\bar{t}\,b\bar{b}$



The final state coincides with the associated production of the Higgs boson with a top quark pair and its decay into bottom quarks, although with absolutely different kinematics.

Collider Cross Talk

https://indico.cern.ch/event/386258/

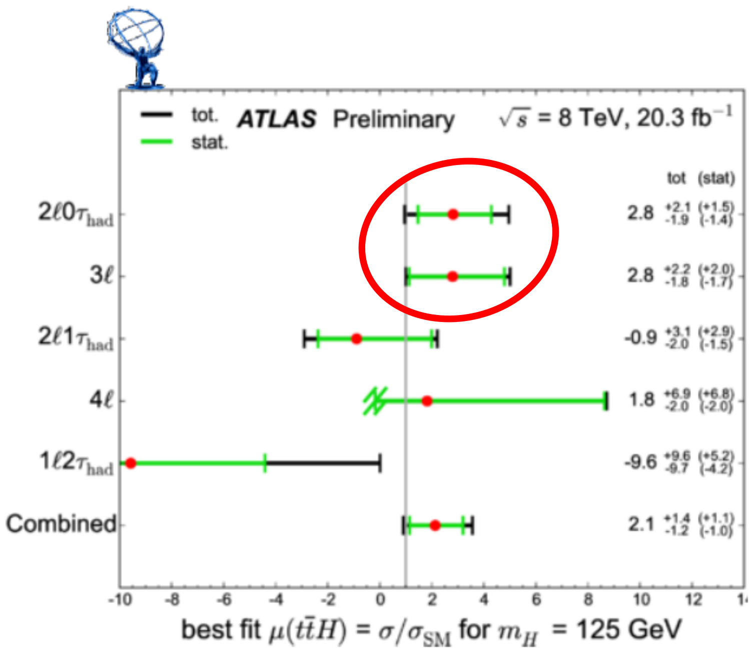
ttH Results in Leptonic Channels from ATLAS and CMS

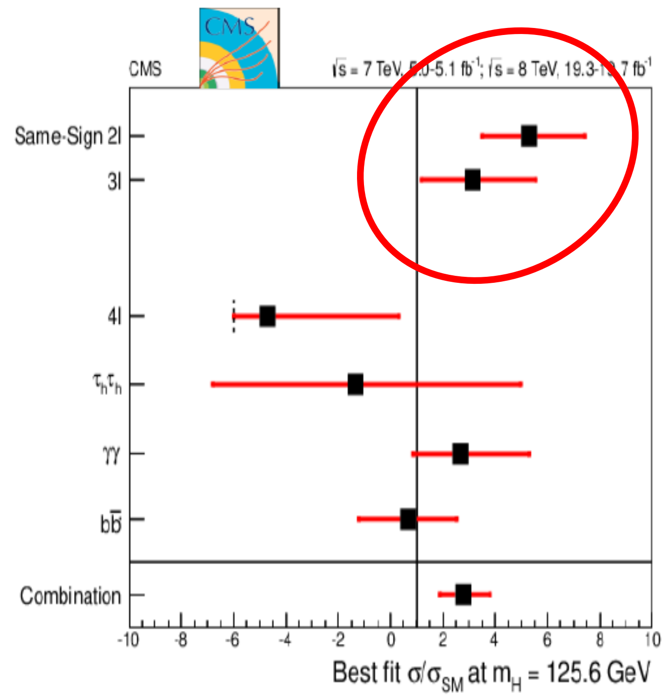
by Dr. Djamel Eddine Boumediene (Univ. Blaise Pascal Clermont-Fe. II (FR)), Giovanni Petrucciani (CERN)

Thursday, 30 April 2015 from **11:00** to **12:00** (Europe/Zurich)
at CERN (4-2-011 - TH common room)

Description The new ATLAS search for ttH asdociated production with multi-lepton final states will be presented. The search targets Higgs boson decays to WW, ZZ and $\tau\tau$, and relies on final states with two same-sign, three or four leptons, and includes final states with hadronically decaying taus. The earlier CMS analysis targetting the same final state will also be discussed and similarities and differences between the two analyses will be highlighted.

ATLAS Result | CMS Result | Slides





$5.3^{+2.1}_{-1.8}$

$3.1^{+2.4}_{-2.0}$

$-4.7^{+5.0}_{-1.3}$

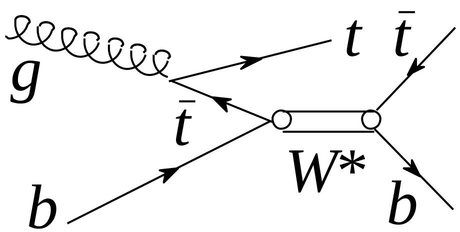
$-1.3^{+6.3}_{-5.5}$

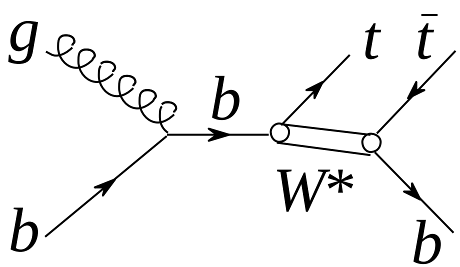
$\mu(2\ell+3\ell+4\ell) = 3.9\ ^{+1.7}/_{-1.4}$

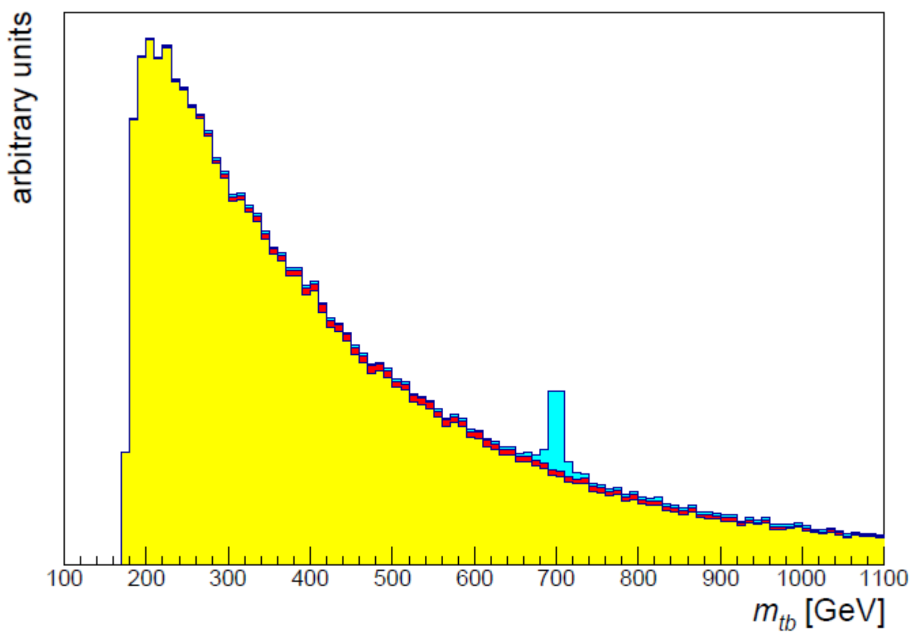
Signature of charged W* bosons (2)

The second signature of the charged W* boson production, with the bottom quark from the proton contamination, is much simpler than the previous ones and can be used even for direct reconstruction of the $\bar{b}t$ - invariant mass.

$$gb \to tW^{\star -} \to tb\bar{t}$$







Conclusion

The increasing gluon luminosity due to higher centre-of-mass energies in the second LHC run will lead to an order of magnitude higher cross sections for the considered processes than in the first LHC run.