Restrictions on the mass of the KK excitation W' from the Higgs boson diphoton decay and the single top production

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Introduction

We consider a stabilized Randall-Sundrum brane-world model.

The lowest KK excitation of the W is called W'.

The distance between the branes is stabilized by a bulk scalar field.

If only SM gauge fields propagate in the RS bulk, the masses of the KK excitations of the SM gauge bosons have to be larger than 20 TeV in order not to contradict the EW precision data.

In the stabilized brane-world models, where the warp factor is different from the exponential of a linear function, lighter KK excitations of the SM fields may be allowed.

Motivation

The **excitations of the W boson** (W boson KK tower) contribute to the

single top quark production, as well as to the **diphoton decay of the Higgs**

boson via the triangle diagrams.

The correlation between these contributions and the growing precision of

experimental measurements may allow one to use these processes for

analyzing finer deviations from the SM predictions and gives new stronger

bounds on the W' boson mass.

Diphoton decay of the Higgs boson
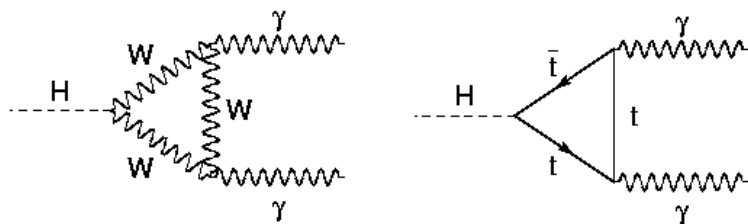
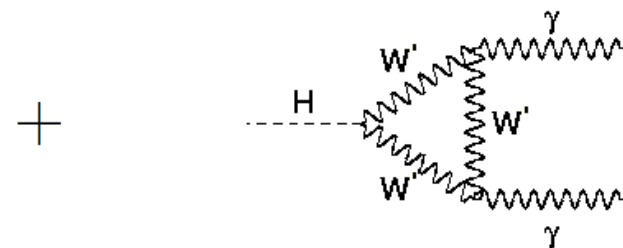The amplitude of the Higgs boson decay to two photons

$$M(h \to \gamma\gamma) = A\frac{\alpha}{4\pi v}(k_{1\mu}\epsilon_{1\nu} - k_{1\nu}\epsilon_{1\mu})(k_2^\mu \epsilon_2^\nu - k_2^\nu \epsilon_2^\mu)$$

The decay width in terms of the dimensionless amplitude A

$$\Gamma(h \to \gamma\gamma) = \left(\frac{\alpha}{4\pi}\right)^2 \frac{G_F m_h^3}{8\pi\sqrt{2}}|A|^2$$

The dominant contributions of the t-quark and W boson are taken into account

$$A_{SM} = \frac{4}{3}A_{\frac{1}{2}}(\tau_t) + A_1(\tau_W)$$

The contribution of the W boson KK tower to the Higgs decay to two photons

$$\Delta A = -7m_W^2 \sum_{n=1}^{\infty} \frac{\alpha_n^2}{m_{W_n}^2}$$

the first excitation should be identified with the W'

$$\sum_{n=1}^{\infty} \frac{\alpha_n^2}{m_{W_n}^2} = \frac{\alpha_1^2}{M_{W'}^2} + \sum_{n=2}^{\infty} \frac{\alpha_n^2}{m_{W_n}^2} = \frac{\alpha_1^2}{M_{W'}^2} + \frac{\alpha_1^2}{M_{eff}^2}$$
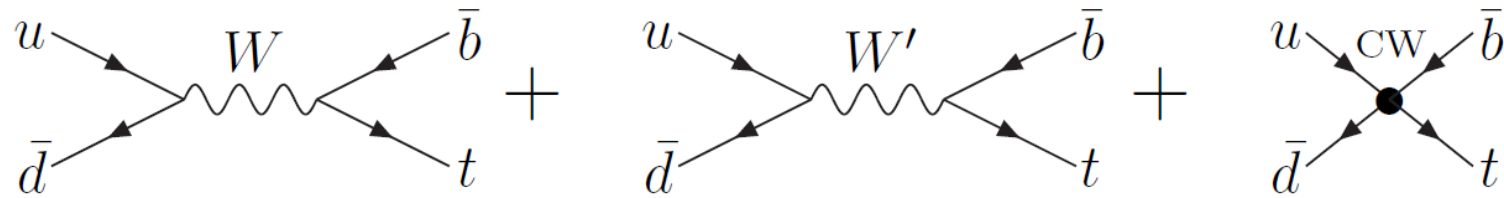
The parameterization for the rest KK tower is chosen as in *Theor. Math. Phys.170 (2012) 90*

$$M_{eff} = 1.4 M_{W'}$$

Finally, we present the Higgs decay width to two gamma as a function of the W' coupling and W' mass

$$\Gamma^{h \to \gamma\gamma}(\alpha_1, M_{W'}) = \left(\frac{\alpha}{4\pi}\right)^2 \frac{G_F m_h^3}{8\pi\sqrt{2}}|A_{SM} - 7m_W^2\left(\frac{\alpha_1^2}{M_{W'}^2} + \frac{\alpha_1^2}{(1.4M_{W'})^2}\right)|^2$$

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Single top quark s-channel production

The SM part of Lagrangian

The effective interaction Lagrangian of the W boson KK tower in the energy range close to the mass of the W' boson

$$L_{SM}$$

$$L_{eff\_W\_KK} = \frac{g\,\alpha_1}{\sqrt{2}}(J^{+\mu}W'^{-}_\mu + J^{-\mu}W'^{+}_\mu) - \frac{g^2\alpha_1^2}{2m^2_{W'\_sum}}J^{+\mu}J^-_\mu$$

Then the process amplitude is

Using the same parameterization:

$$\frac{1}{2}(\bar{d}\gamma_\mu(1-\gamma_5)u)(\bar{t}\gamma^\mu(1-\gamma_5)b)\left(\frac{g^2}{p^2-M^2_W}+\frac{g^2\alpha_1^2}{p^2-M^2_{W'}}-\frac{g^2\alpha_1^2}{M^2_{eff}}\right)$$

$$M_{eff} = 1.4 M_{W'}$$

This assumption allows one to present the single top quark production cross section as a function of the W' coupling and W' mass as well.

Numerical calculations have been done in a special version of the **CompHEP** package which includes functions for table calculations and also a routine for chi2-analysis of the signal strength.

Single top quark s-channel production modelling

We provide scan over W' mass and coupling and look for deviations in the region of W' mass

SM

W'

W' width changes with its mass and coupling dynamically

$$\sigma_{SM} = \sigma_{t\bar{b}} + \sigma_{tq\bar{b}}(p_{T_q} < 40 GeV)$$

$$\sigma_{SM}^{fid} = \sigma_{SM}(M_{W'} - 50 GeV \leq M_{t\bar{b}} \leq M_{W'} + 50 GeV)$$
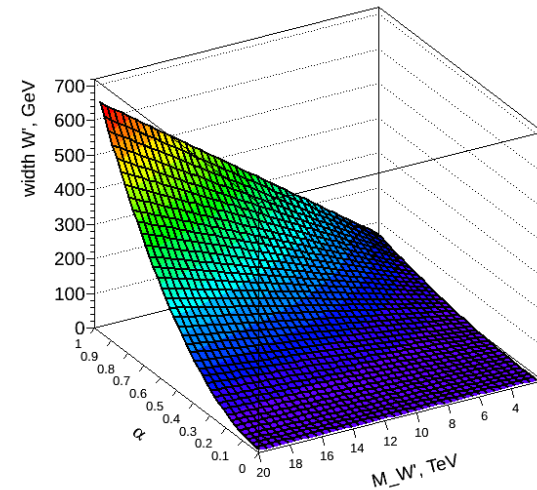
Cross section with W' and KK tower impact is calculated with similar cut on the invariant tB mass.

With W' mass growth it width comes more then 600GeV and its resonant impact becomes negligible.

Fiducial cross section for 14, 28 and 100 TeV collision energy

SM

W'

Signal strength

$$h \rightarrow \gamma\gamma$$
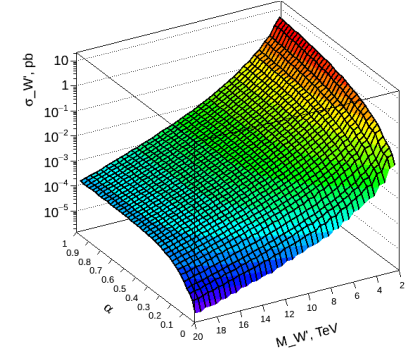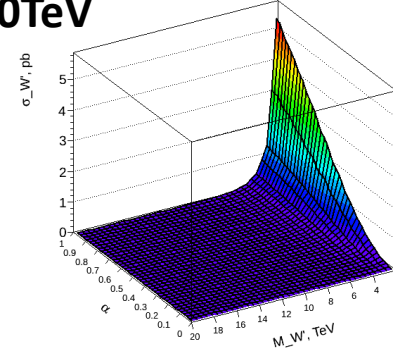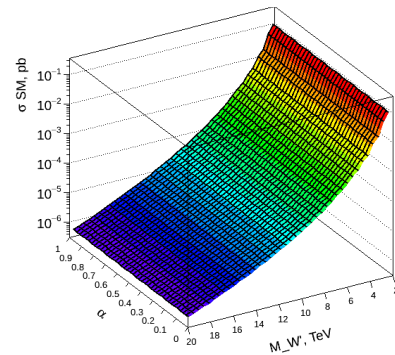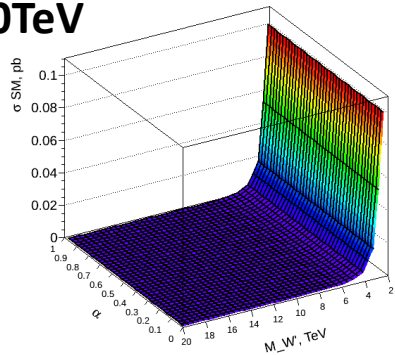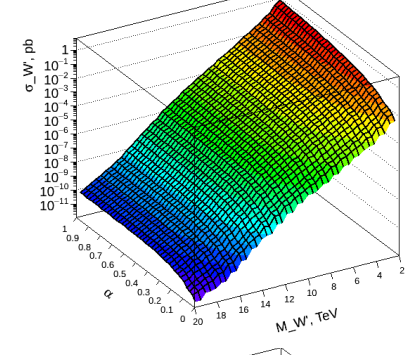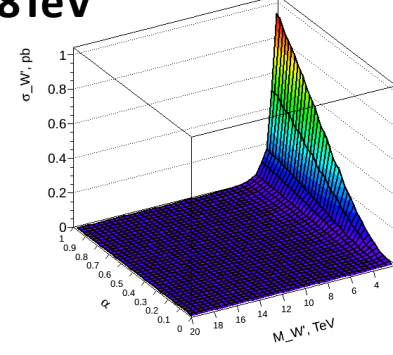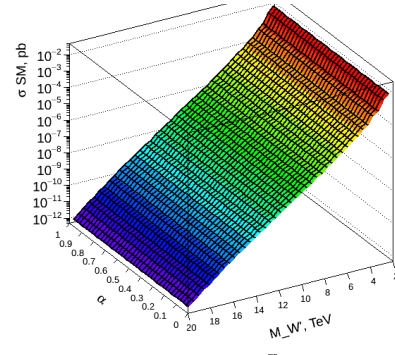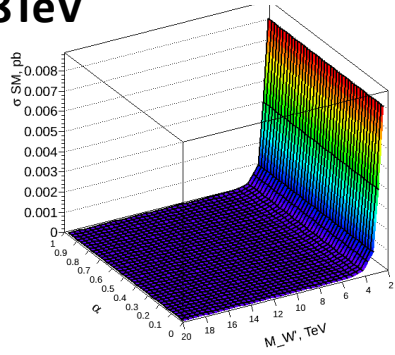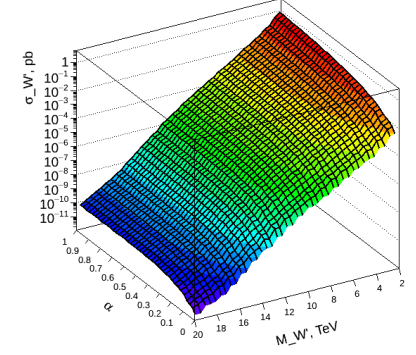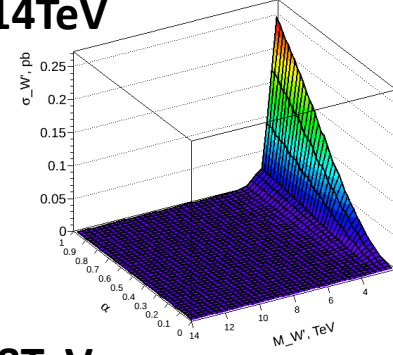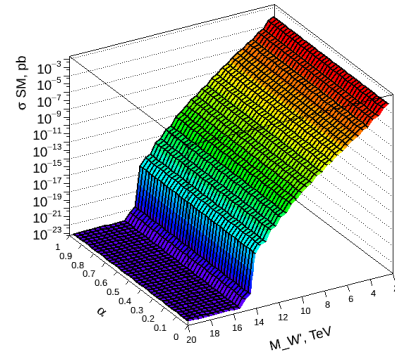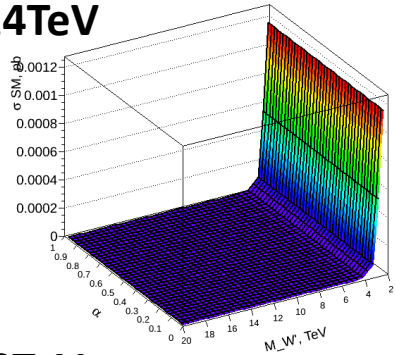
$$pp \rightarrow t\bar{b}$$

$$\mu = \frac{\Gamma_{theor}}{\Gamma_{SM}}$$

$$\mu = \frac{\sigma_{signal\,theor}}{\sigma_{signal\,SM}}$$

The experimental data provide the signal strength $\hat{\mu}$ and the corresponding error $\Delta\hat{\mu}$
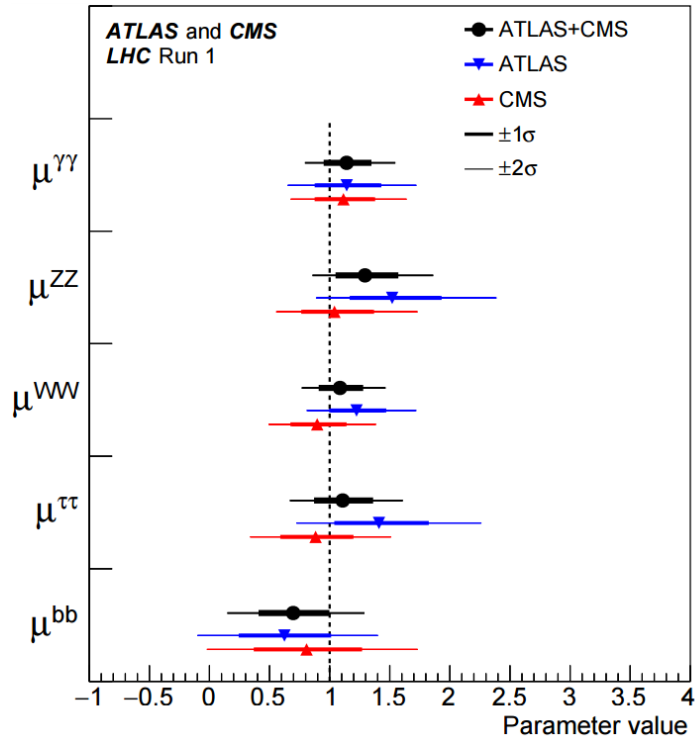
$$\hat{\mu} = \frac{N_{obs} - N_{bkgr}}{N_{signal\,SM}}$$

Global chi-squared

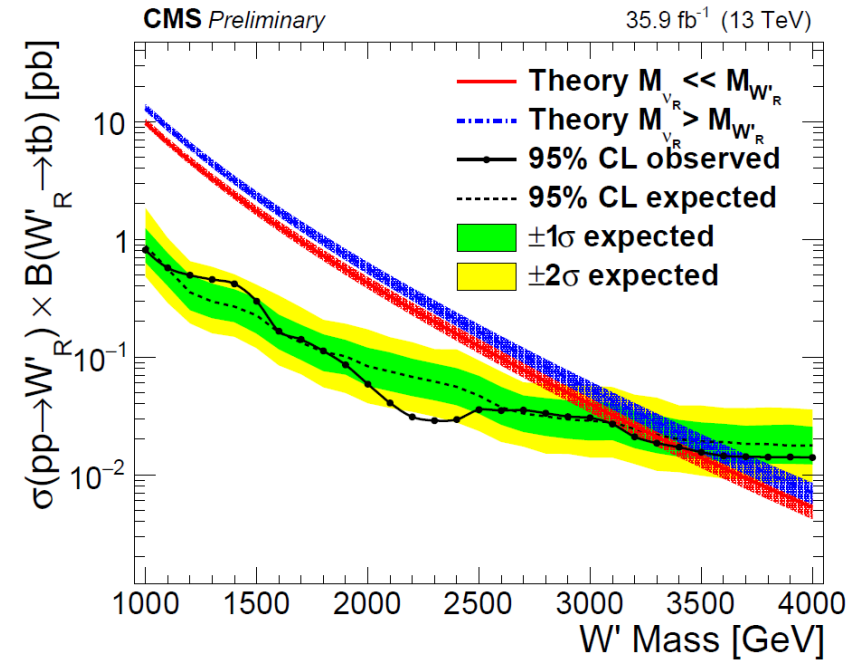$$\chi^2(\mu) = \left(\frac{\mu - \hat{\mu}}{\Delta\hat{\mu}}\right)^2$$

Experimental data

$$h \to \gamma\gamma$$

JHEP 08 (2016) 045, arXiv:1606.02266

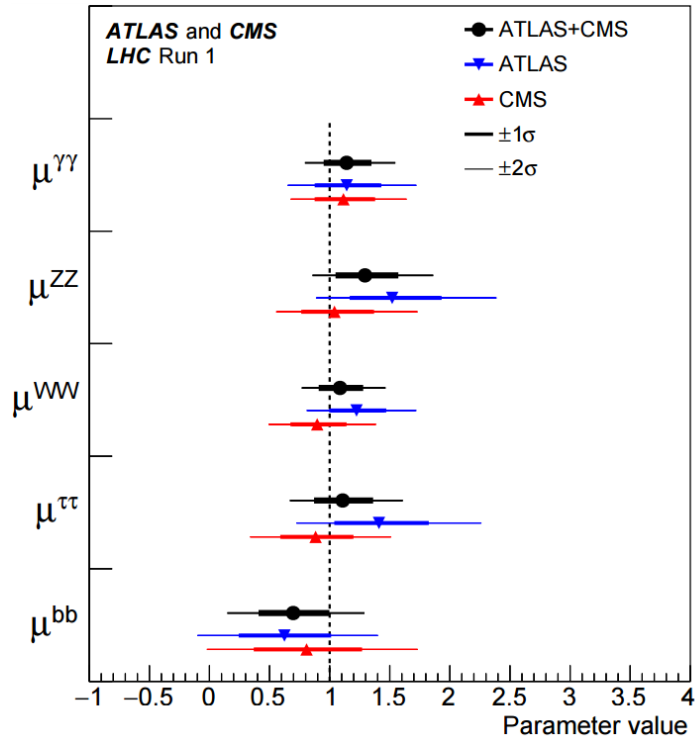| $\mu^{\gamma\gamma}$ | $1.14^{+0.18}_{-0.19}$ | ● ATLAS+CMS |
| | $1.14^{+0.27}_{-0.25}$ | ▼ ATLAS |
| | $1.11^{+0.25}_{-0.23}$ | ▲ CMS |

$$pp \to t\bar{b}$$

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$$\mu^{s-channel} = 2 \pm 0.9$$

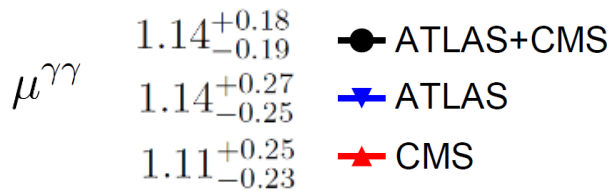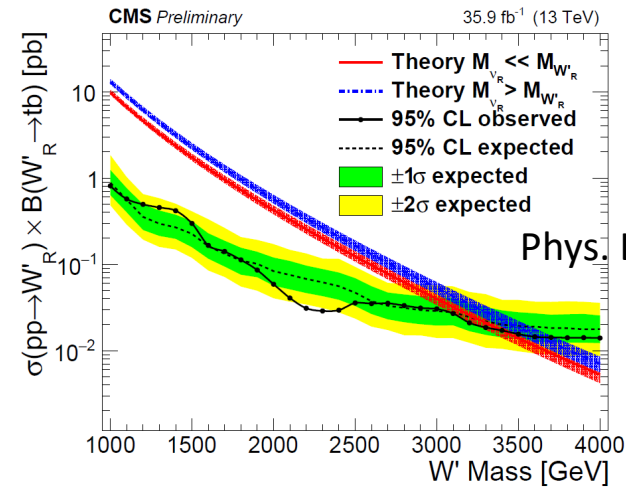*J. High Energy Phys. 09 (2016) 027 arXiv:1603.02555*

Experimental data

$$h \to \gamma\gamma$$

JHEP 08 (2016) 045, arXiv:1606.02266

$\mu^{\gamma\gamma}$
- $1.14^{+0.18}_{-0.19}$ — ● ATLAS+CMS
- $1.14^{+0.27}_{-0.25}$ — ▼ ATLAS
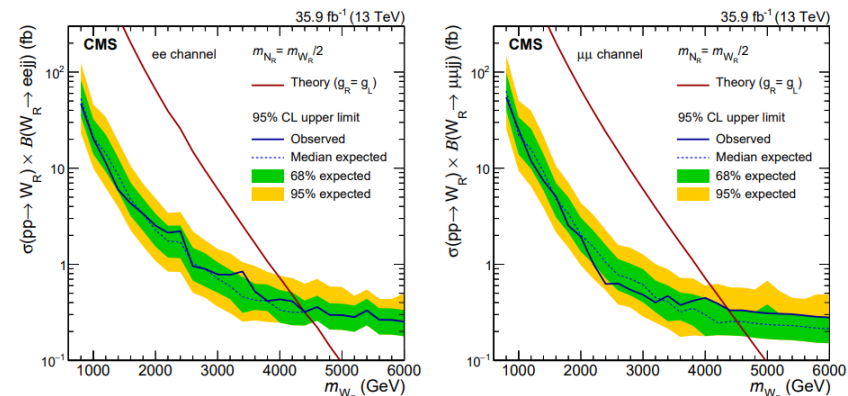- $1.11^{+0.25}_{-0.23}$ — ▲ CMS

$$pp \to t\bar{b}$$

Phys. Lett. B 777 (2018) 39

$$\mu^{s-channel} = 2 \pm 0.9$$
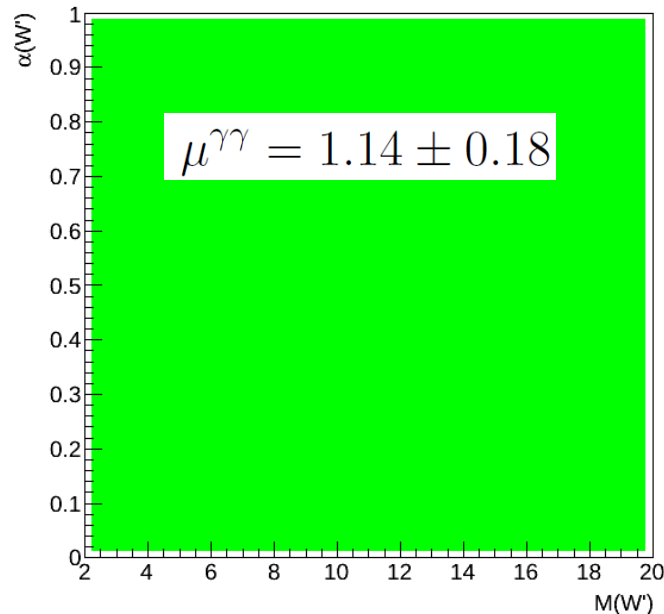
J. High Energy Phys. 09 (2016) 027 arXiv:1603.02555

$$W_R \to \ell\ell jj$$

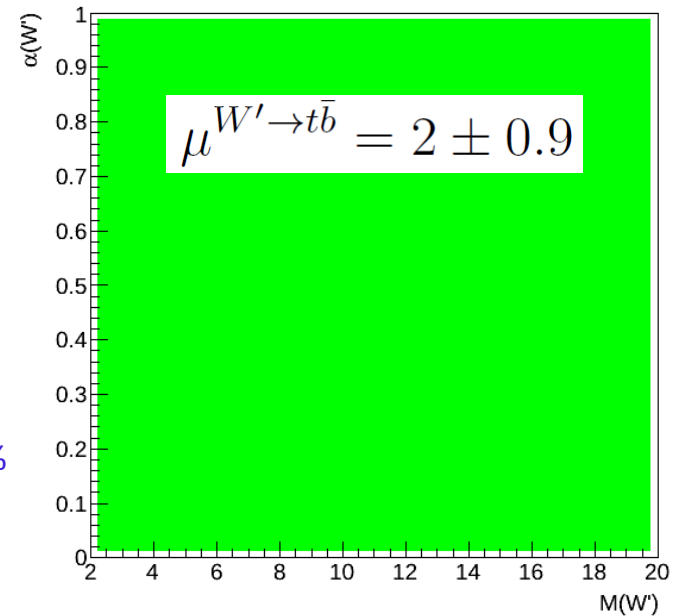JHEP 05 (2018) 148

Experimental data fit

$$h \to \gamma\gamma$$

$$pp \to t\bar{b} \qquad 14\,TeV$$

$$\mu^{\gamma\gamma} = 1.14 \pm 0.18$$

$$\mu^{W' \to t\bar{b}} = 2 \pm 0.9$$

CL of the fit 68%, 95%

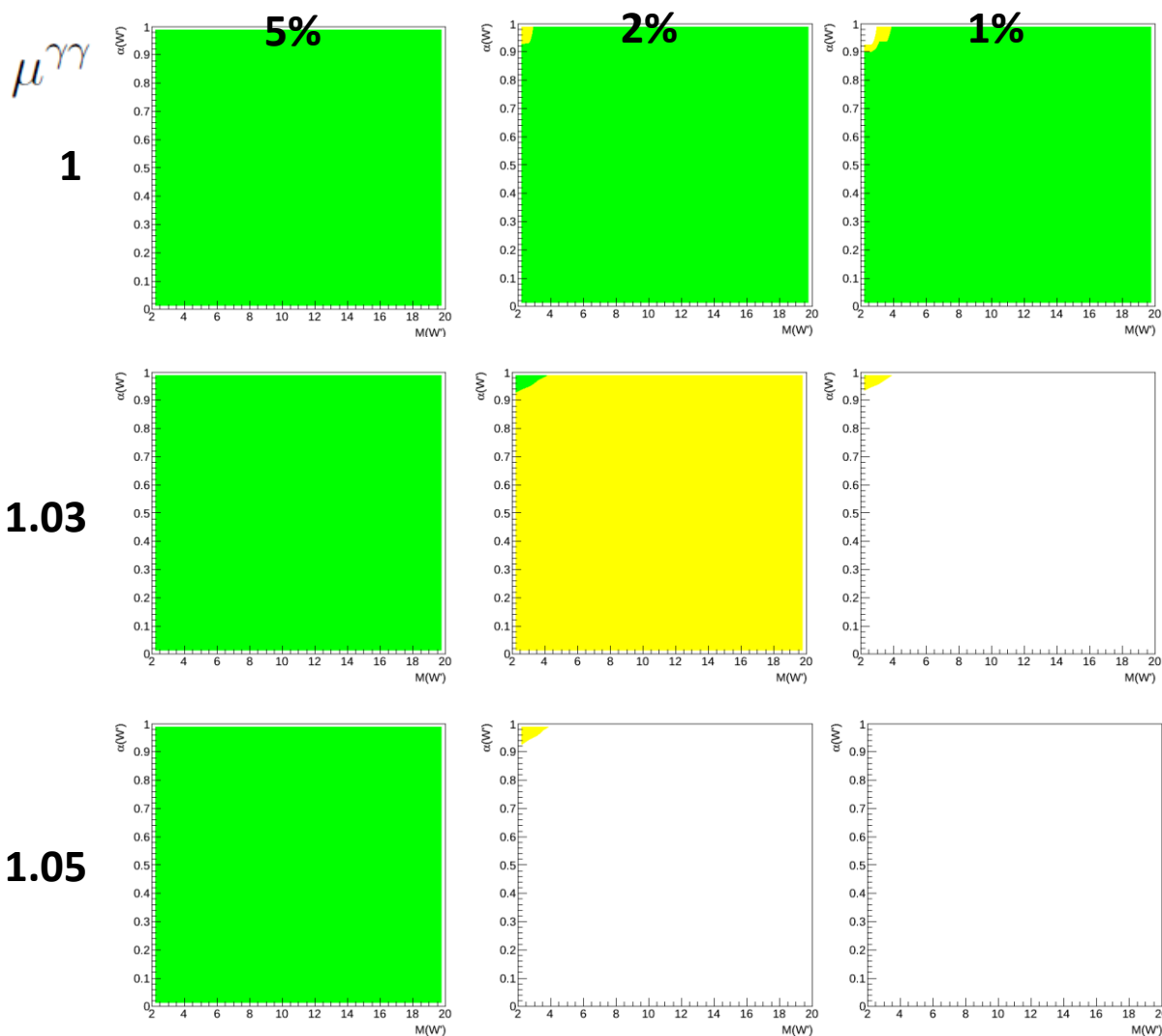The available experimental data on signal strength do not allow one to obtain restrictions on the W' mass.

The **high luminosity** programme is scheduled to start in 2024   Phys. Lett. B 777 (2018) 39

luminosity $5\,(7.5) \times 10^{34}\,\mathrm{cm^{-2}s^{-1}}$

Integrated luminosity $3\,\mathrm{ab^{-1}}$

Significant decrease of experimental uncertainties is expected!

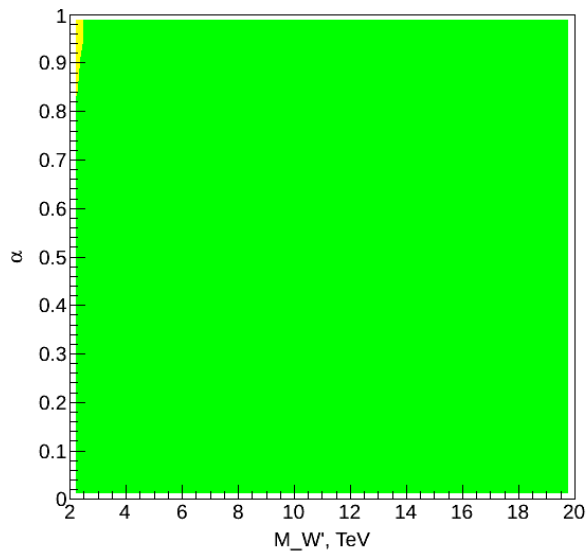# Diphoton decay of the Higgs boson study

1% precision don't allow valuable deviations from the SM model in this channel
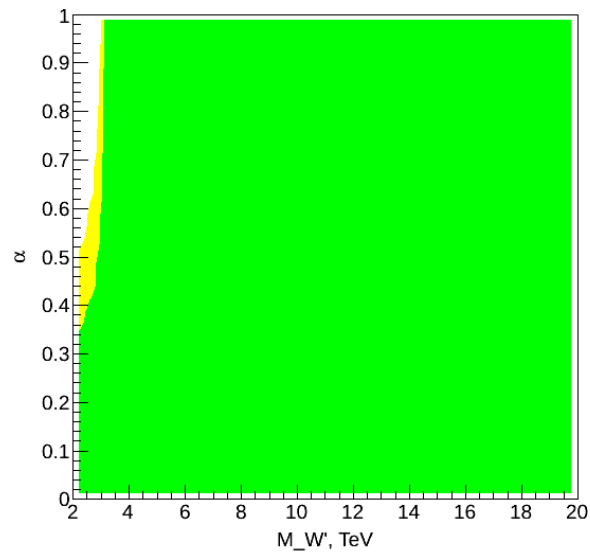
CL of the fit 68%, 95%

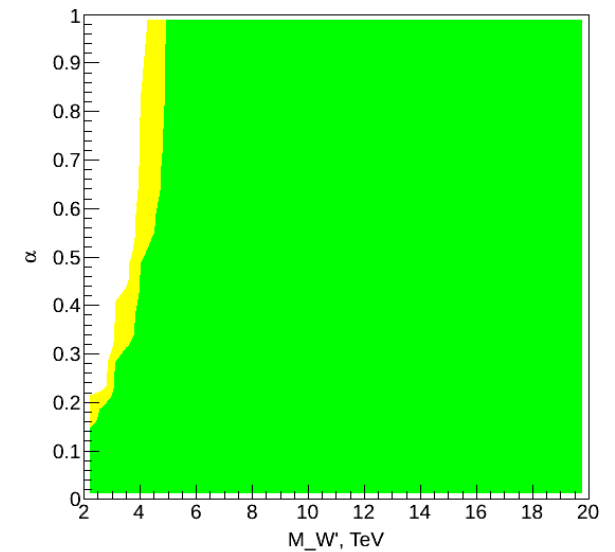# Single top quark s-channel production fit

$$pp \to t\bar{b}$$

$$\mu^{W' \to t\bar{b}} = 1.0 \pm 0.2$$

$$14\,TeV \qquad 28\,TeV \qquad 100\,TeV$$

CL of the fit 68%, 95%

Combined fit

$$h \to \gamma\gamma \qquad\qquad + \qquad\qquad pp \to t\bar{b}$$

$$\mu^{\gamma\gamma} = 1.03 \pm 0.01 \qquad\qquad\qquad \mu^{W' \to t\bar{b}} = 1.0 \pm 0.2$$
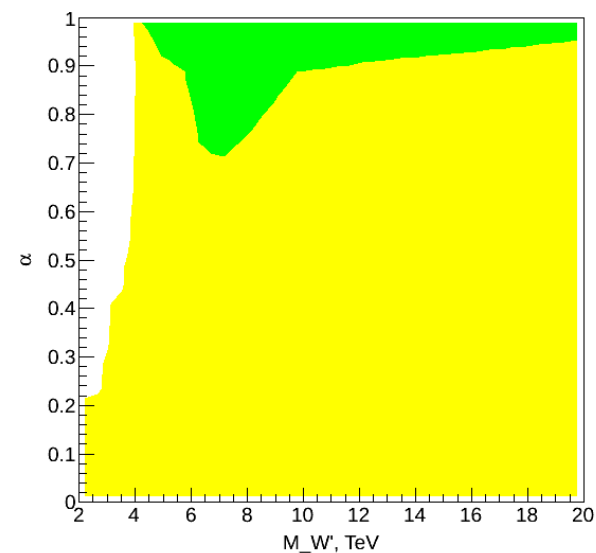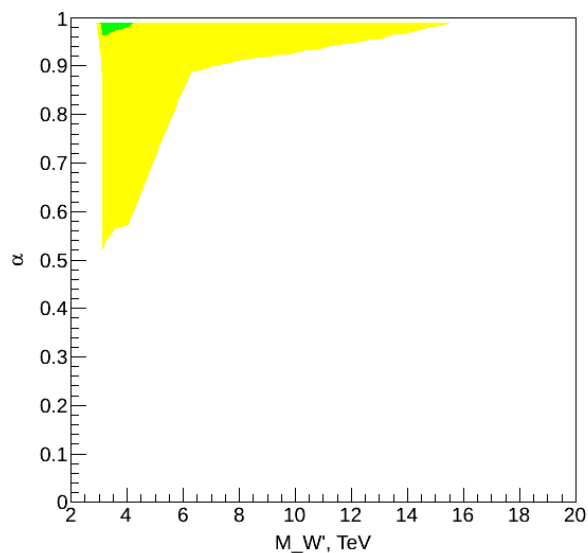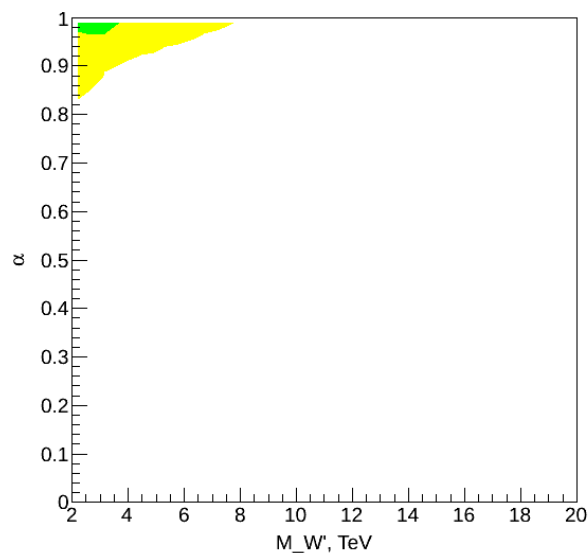
CL of the fit 68%, 95%

Combination with $h \to \gamma\gamma$ provides additional restrictions on model parameters

Conclusions

- Simultaneous calculations of the signal strengths of the single top quark production and Higgs boson decay to two photons processes for the W' boson masses in the range from 2 TeV to 20 TeV and the coupling from 0 to 1 have been done.

- It is shown that the available experimental data do not allow one to obtain restrictions on the W' mass from the diphoton Higgs decay channel or the single top quark production.

- The restrictions on the W' boson mass have been estimated for future colliders.

Acknowledgments
to the Russian Science Foundation

Thank you!