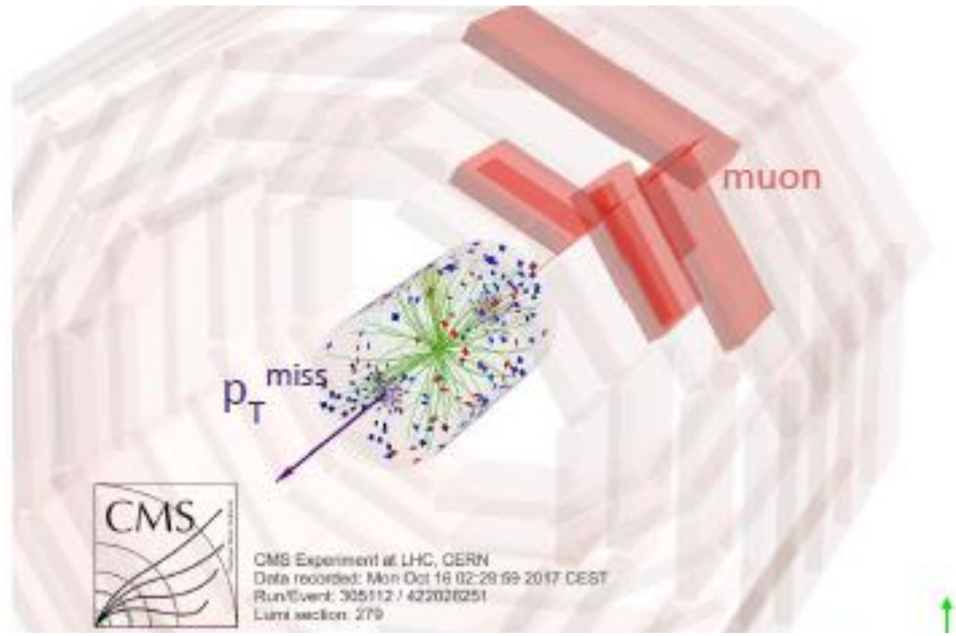
Direct & Indirect constraints on new physics from $l+p_t^{miss}$ (l^+l^-) final states in CMS

B. de la Cruz, I. Bachiller, J. Alcaraz

(CIEMAT)

+ CMS Collaboration



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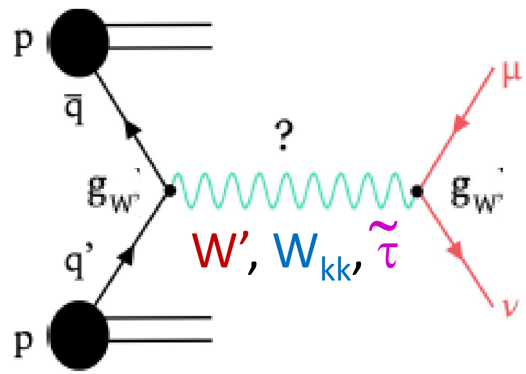
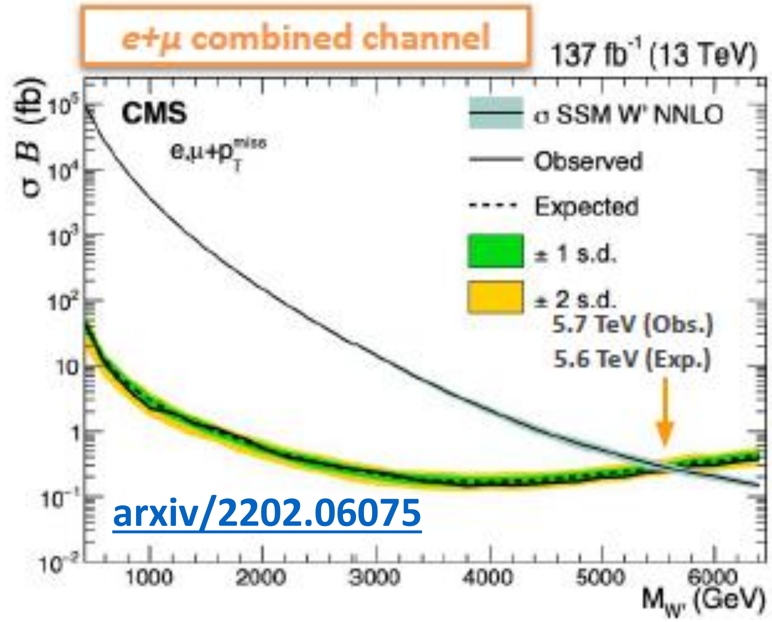
6th Red LHC (UAM-IFT 9-11 May 2022)

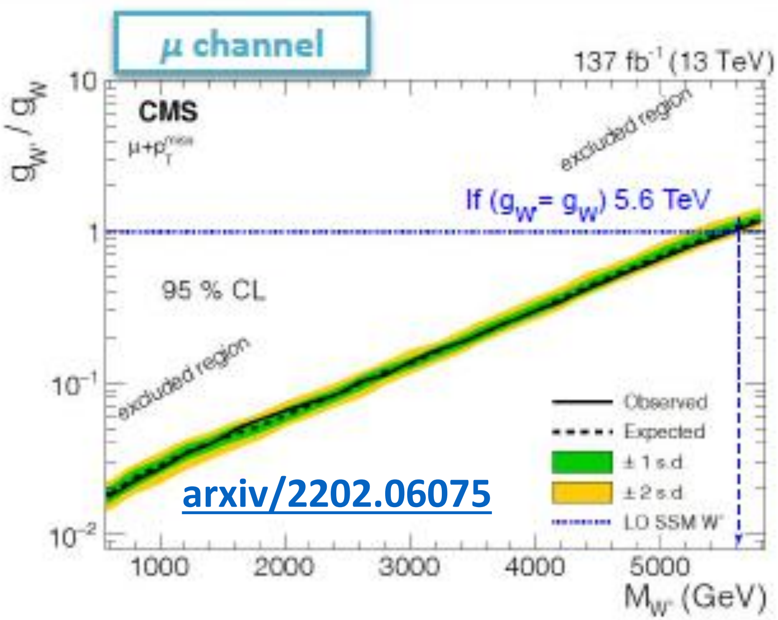
Motivation and context

137 fb^{-1} pp collision data from CMS during LHC Run2 used to search for new physics





$M_{W'}$ > 5.7 (5.6) TeV Obs. (Exp.)



For $M_{W'}$ < 1 TeV, limit $g_{W'}/g_W$ > 0.03 excluded

Direct searches, limited by √s

Motivation and context

A. Wulzer et al
10.1016/j.physletb.2017.06.043

- SM constitutes an effective theory, applicable up to energies not exceeding a certain scale Λ.
- Extension of SM at higher energies imply including higher-dimensional operators which appear in the extended-SM Lagrangian as suppressed by powers of Λ.

$$\mathcal{L}_{\rm SMEFT} = \mathcal{L}_{\rm SM} + \sum_{i=1}^{2499} \frac{C_i}{\Lambda^2}\mathcal{O}_i\,, \quad \text{With } \Lambda > \sqrt{s}$$

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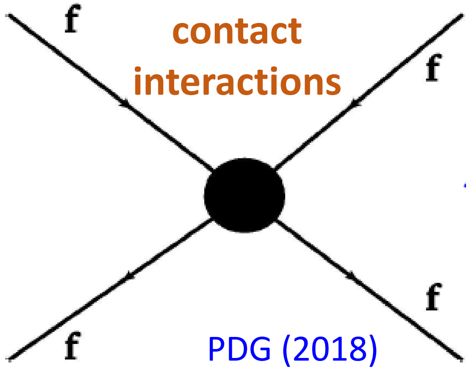
- Extension of SM at higher energies imply including higher-dimensional operators which appear in the extended-SM Lagrangian as suppressed by powers of Λ.
- Using the formalism of the SM effective field theories (SMEFT), truncating the effective expansion at dimension 6 operators, universal new physics effects in 4 fermion contact interactions type appear, which can be conveniently* described by the well-known "oblique parameters" S, T, W and Y.

$$\Delta\mathcal{L}_{\text{Universal}} = \frac{S}{16\pi v^2}\mathcal{O}_{WB} - \frac{2\alpha T}{v^2}\mathcal{O}_{HD} - \frac{Y}{2M_W^2}\mathcal{O}_{2B} - \frac{W}{2M_W^2}\mathcal{O}_{2W}$$

* Involving operators of W, Z, γ, Higgs

4 fermion contact interactions



PDG (2018)
DOI:10.1103

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/hep-ph/0405040
Phys.Rev. D46 (1992) 381

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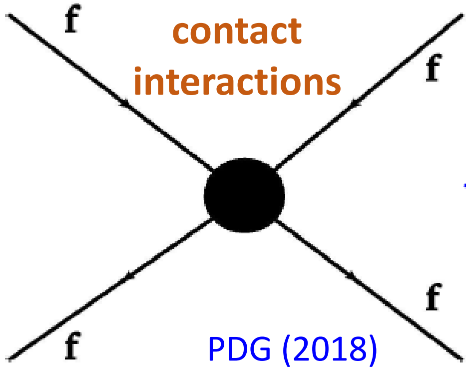

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S, T: induce effects constant with √s
current limits coming from fit to EW Precision Observables

W, Y: induce effects that grow with √s ➔ high-energy collider is ideal to test new physics ➔ Highest energies at LHC compensate worse experimental precision

DOI: 10.22323/1.314.0467
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W, Y parameters

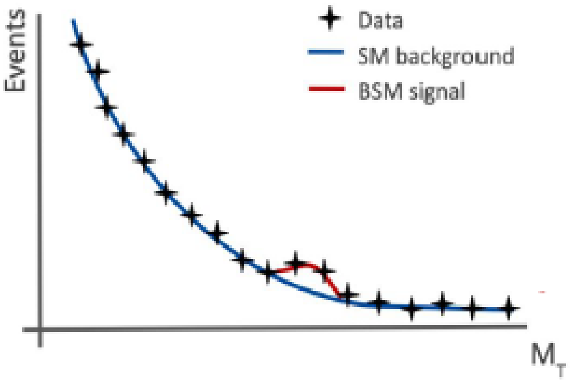
W, Y: leading constraints on W, Y from off-pole measurements at LEP2, but 8 TeV LHC results are more stringent ➔ expected to be improved with LHC @13 TeV and HL-LHC in the future

$$\begin{pmatrix} S \\ T \\ W \\ Y \end{pmatrix} = \begin{pmatrix} -0.10 \pm 0.13 \\ 0.02 \pm 0.08 \\ (-0.1 \pm 0.6) \times 10^{-3} \\ (-1.2 \pm 0.9) \times 10^{-3} \end{pmatrix}, \quad \rho = \begin{pmatrix} 1 & & & \\ 0.86 & 1 & & \\ -0.12 & -0.06 & 1 & \\ 0.70 & 0.39 & -0.49 & 1 \end{pmatrix}$$

https://arxiv.org/pdf/1706.03783.pdf

Useful Variables: Differential cross sections vs angle (η), invariant mass, M_T

Dilepton final states studied at LHC: $qq \to l^+l^-, l\nu$ ($l = e, \mu$)



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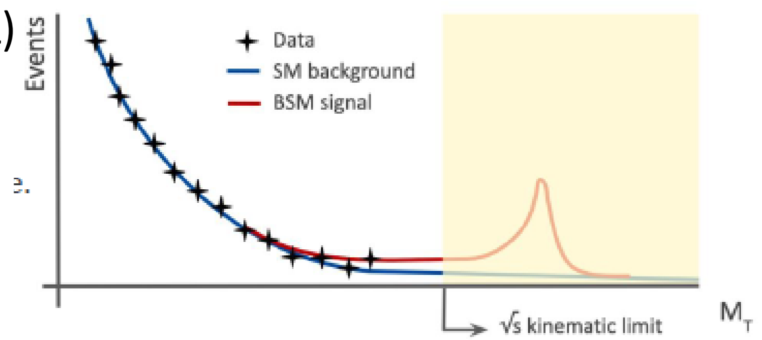


Effect of new terms in 4-fermion contact interactions is the modification of SM propagators of neutral (γ, Z) and charged (W) EWK gauge bosons, P(W, Y) .

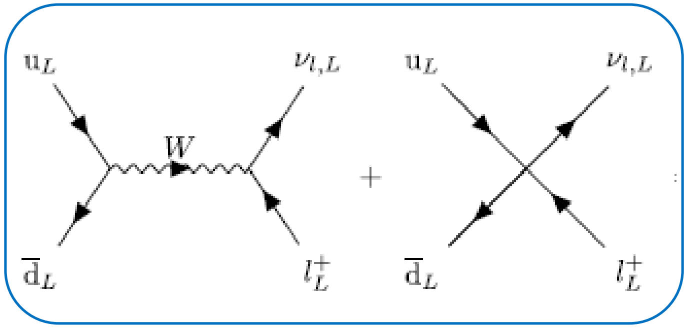
- relative deviations wrt SM given by the weight $|P(W, Y)/P(W=Y=0)|^2$
- a reweighting on evt-by-evt basis at generator level is possible
- $\frac{g^2 W}{m_W^2}, \frac{g'^2 Y}{m_W^2} \to \frac{c}{\text{Scale}^2}$ Terms in the interference between SM and New Physics, related to the ratio coupling/scale of NP

$qq \rightarrow l\nu$ (l= e, μ)

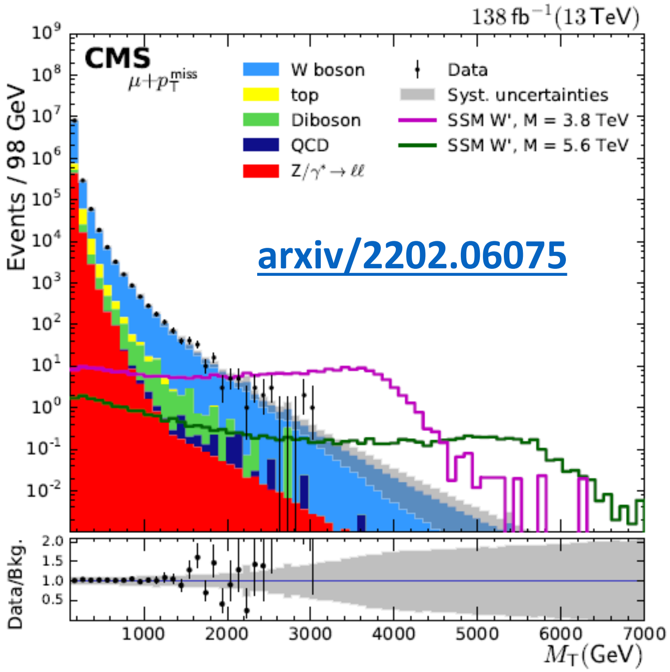
10.1016/j.physletb.2017.06.043

$$\left|\frac{P(W, Y)}{P(W=Y=0)}\right|^2 = \left(1 + \frac{(2t^2-1)W}{1-t^2} + \frac{t^2 Y}{1-t^2} - \frac{W\,(q^2 - m_W^2)}{m_W^2}\right)$$

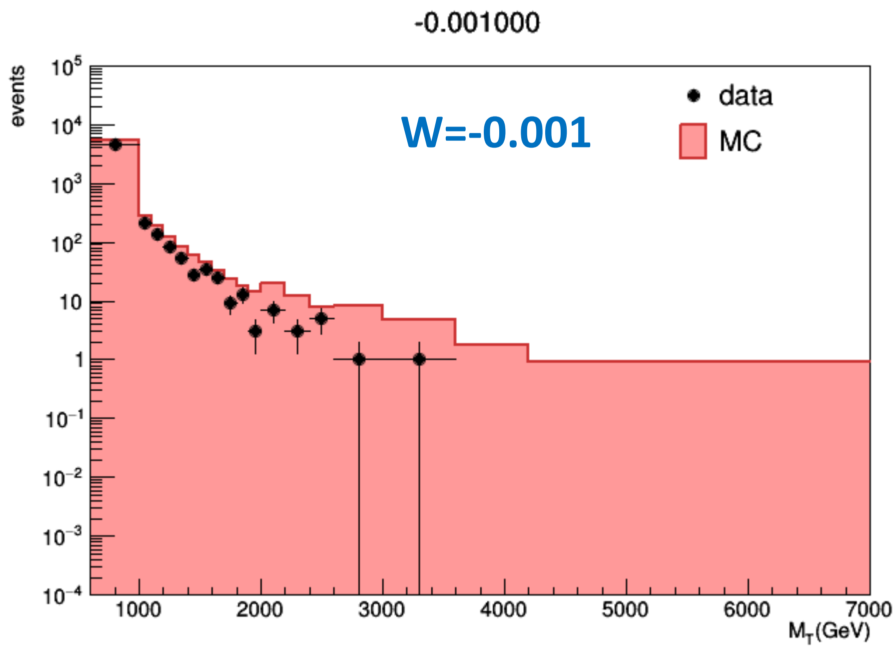
(t^2=tangent squared of SM weak mixing angle ~ 0.3)



- Relevant term at high energy is the last one, depending on q^2
- $l\nu$ final state is sensitive to W, independent of Y at high energy.
- Only info needed at generator level is q^2 , i.e. $l\nu$ invariant mass



arxiv/2202.06075



eν+μν, L=101 fb-1

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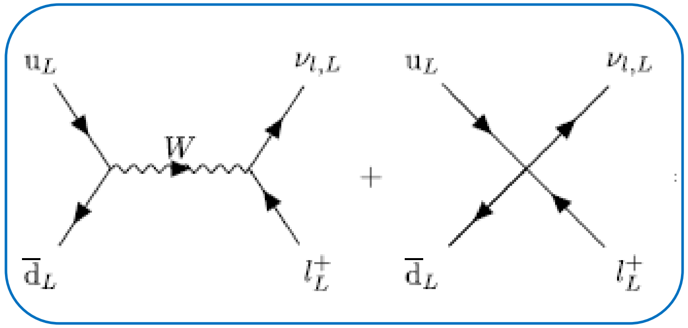

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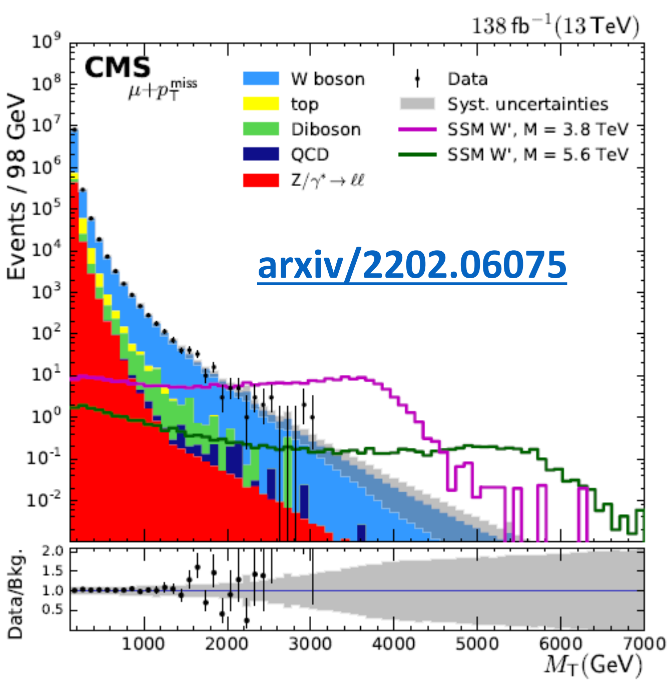

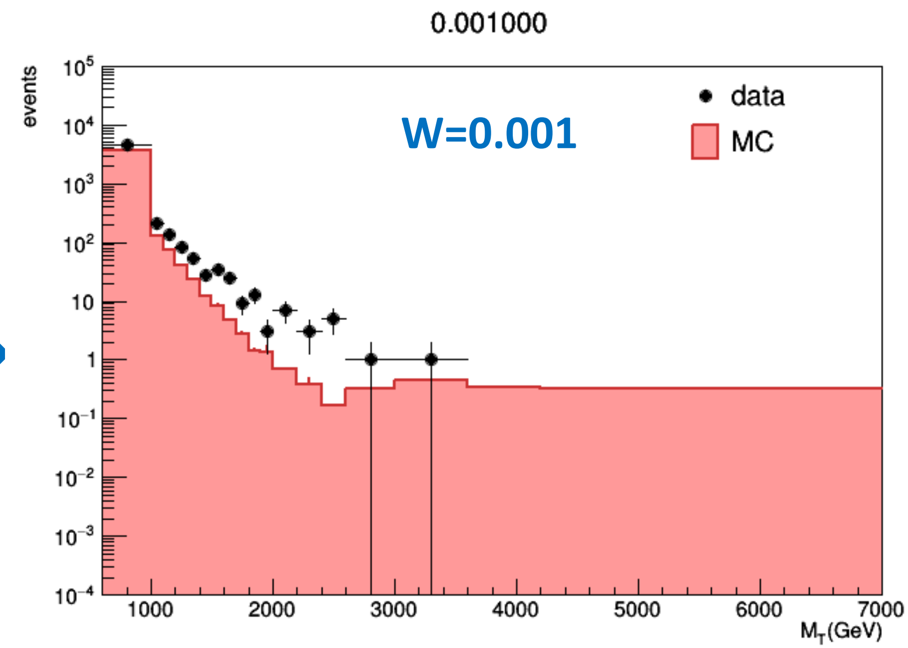

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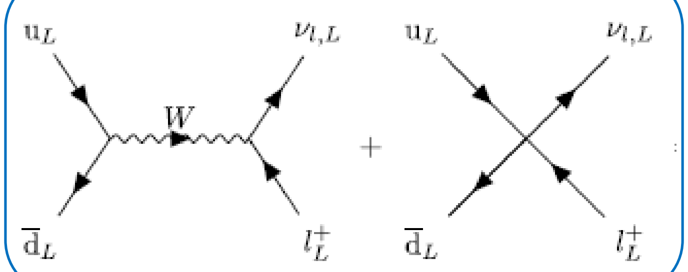

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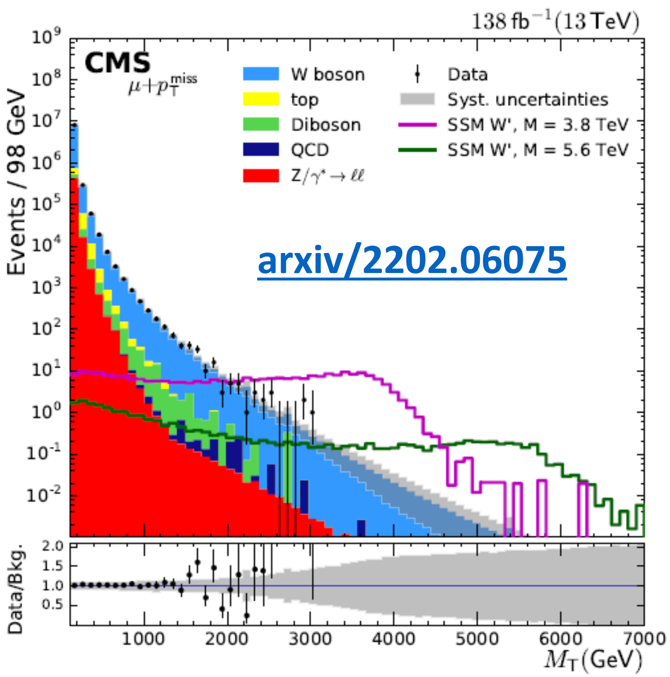
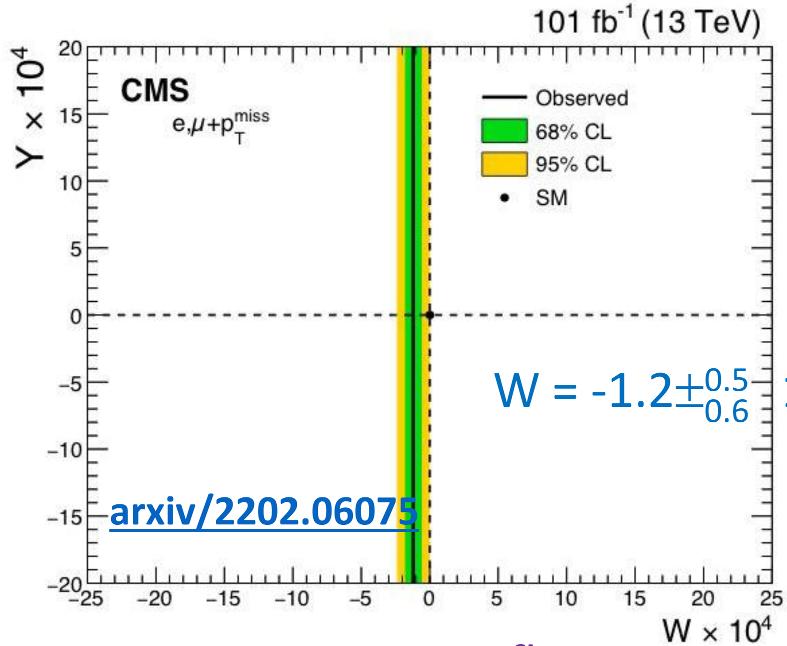


arxiv/2202.06075



$W = -1.2^{+0.5}_{-0.6}\ 10^{-4}$

arxiv/2202.06075

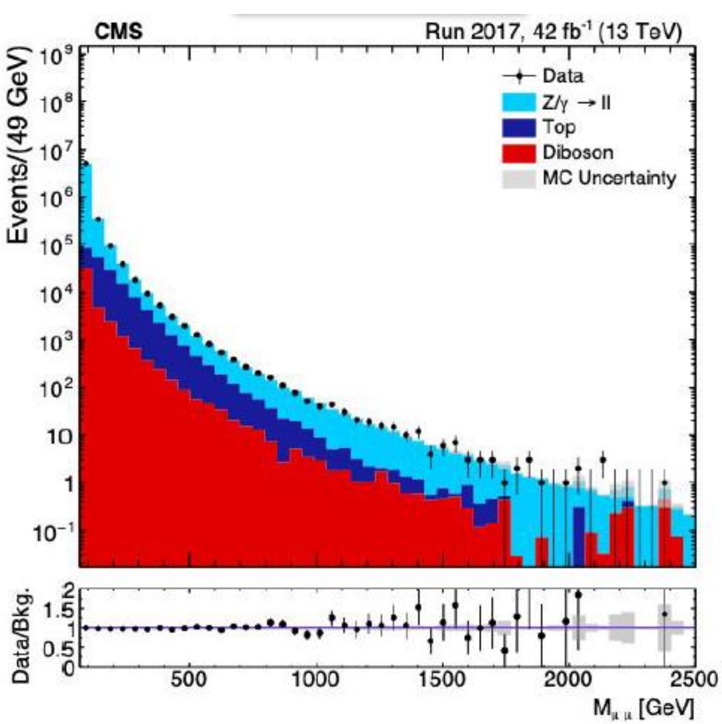
eν+μν, L=101 fb-1

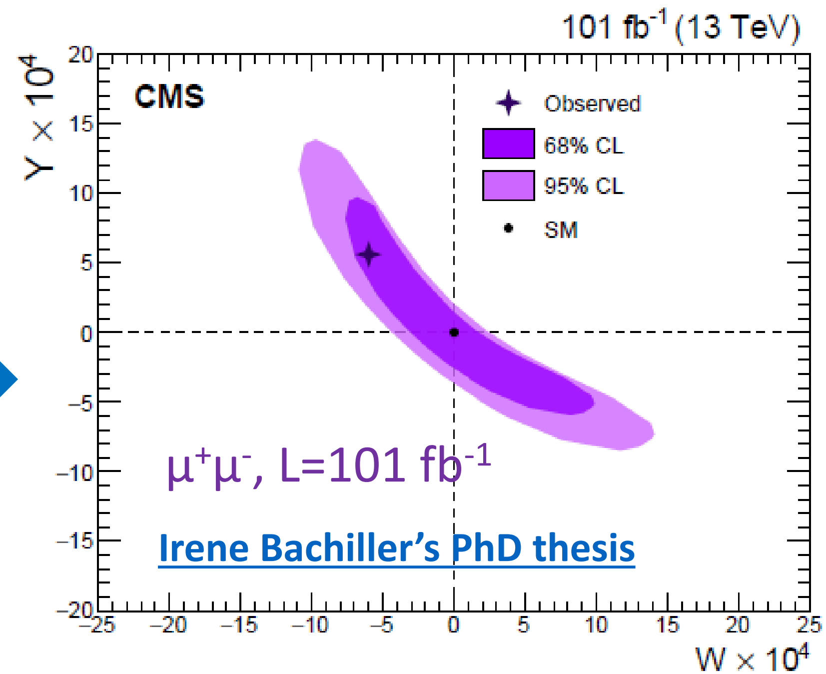
$q\bar{q} \rightarrow l^+l^-$ ($l = \mu$)

$$\text{Weight}(q^2, z, W, Y) = \frac{\left[\frac{d\sigma}{dz}(q^2, z, W, Y)\right]}{\left[\frac{d\sigma^0}{dz}(q^2, z)\right]}$$

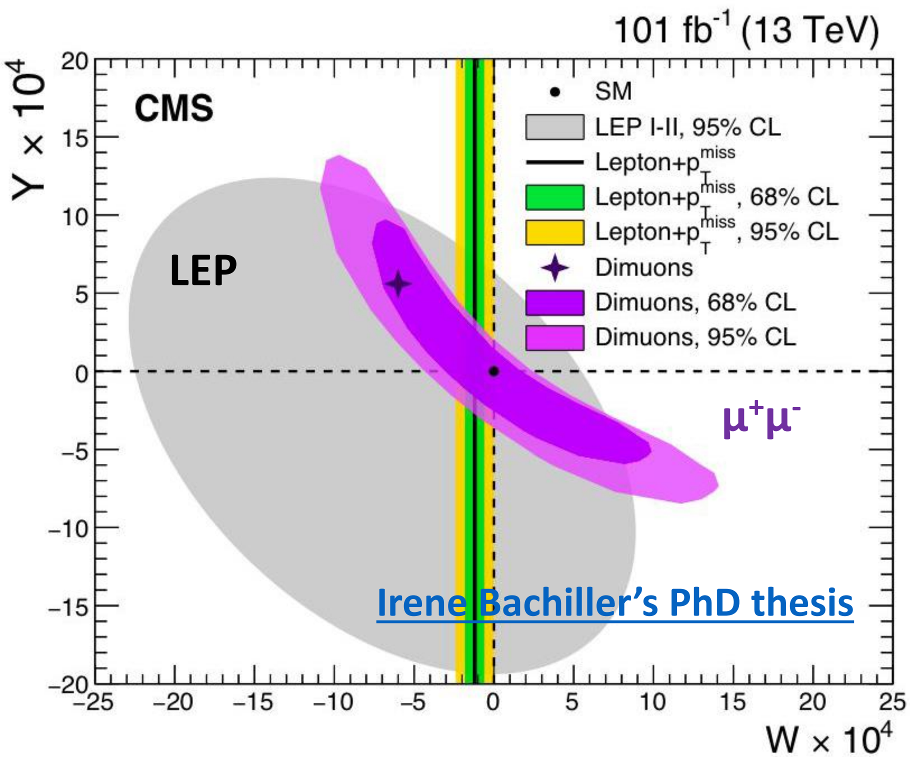
With z= cosθ, angle of final state l wrt incoming q in qqbar rest frame

- l+l- depends on both W, Y ➔ can constrain both parameters
- Info needed at generator level is q^2 (ll inv. mass), cosθ (could be replaced by CS angle), flavour of incoming q & qbar.





Constraints on W, Y using 101 fb^{-1} LHC data



W oblique parameter limits improve ~10-fold previous LEP constraints

Large potential of LHC data on Y oblique parameter from l+l- final state; less restrictive on W parameter than lν

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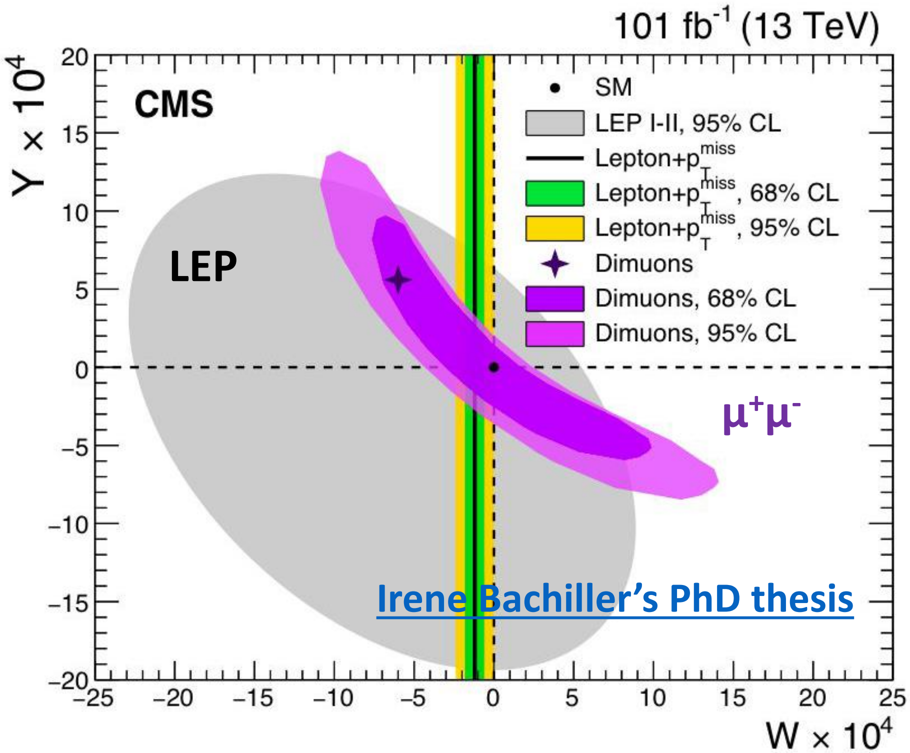

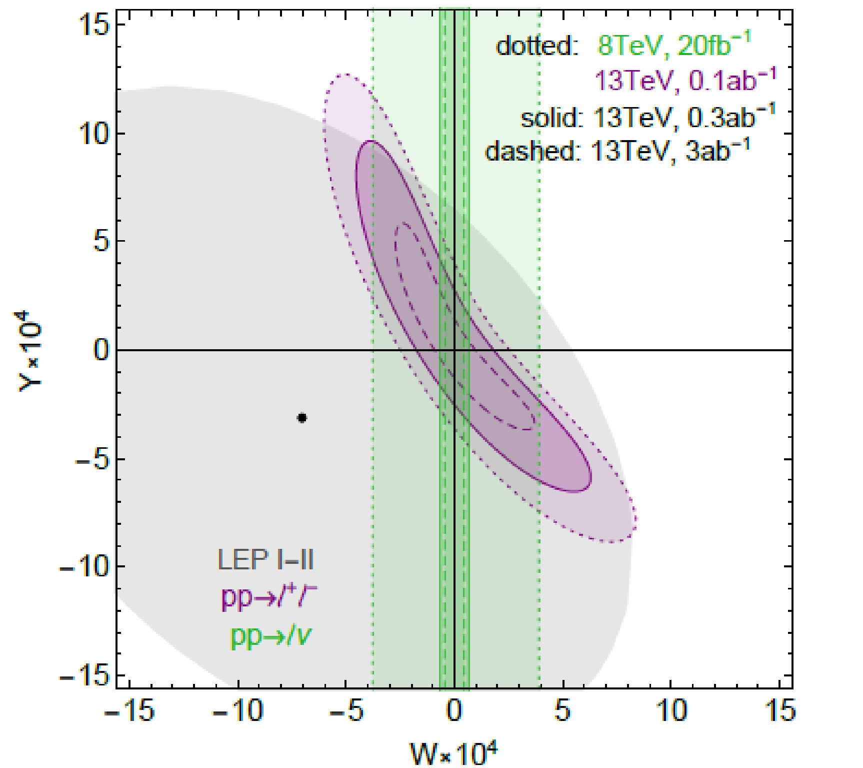

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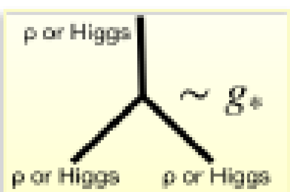
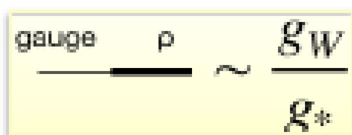
Projection by A. Wulzer et al using Run 1 &2 ATLAS and CMS data
https://arxiv.org/abs/1609.08157

Higgs Compositeness

Constraints on W & Y oblique parameters can be used to set bounds on several types of new models, among them Higgs Compositeness.

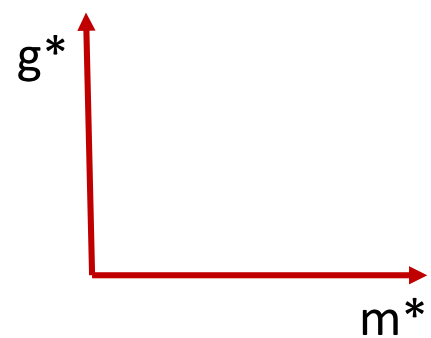
Higgs boson as bound state (eg new strong interaction) ➔ new set of composite resonances (W’, Z’,…)
- new layer of complexity, m*
- coupling to SM particles (g*) or resultant of integrating out the new states (g/g*)





4f, W'/Z' $\quad \dfrac{c_{2W}}{\Lambda^2} = \dfrac{1}{g_*^2 m_*^2}$

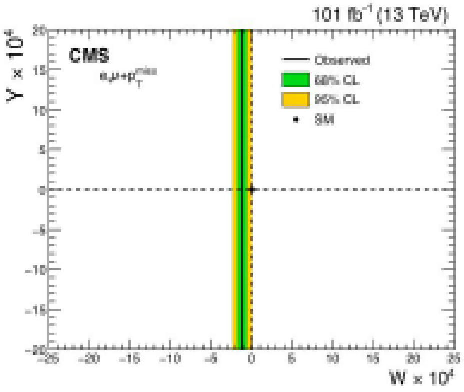
H $\quad \dfrac{c_\phi}{\Lambda^2} = \dfrac{g_*^2}{m_*^2}$



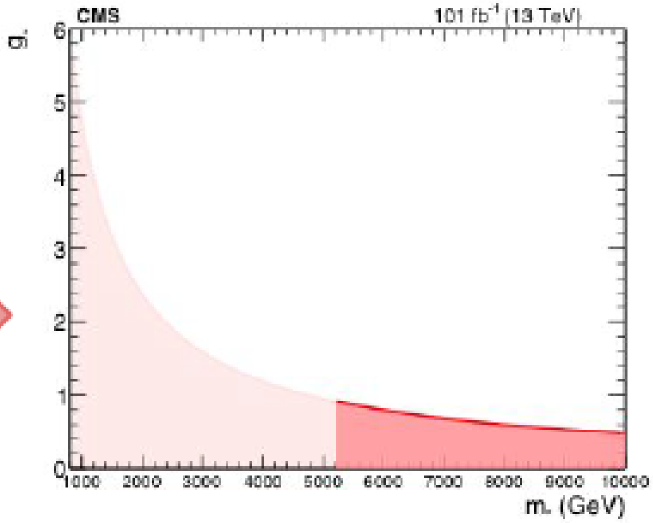
Indirect bound from W oblique parameter

$$g_*{}^2 = \frac{g_W^2 M_W^2}{W m_*^2}$$

W = [-1.2 ± 1.2] × 10^{-4} 95 % CL

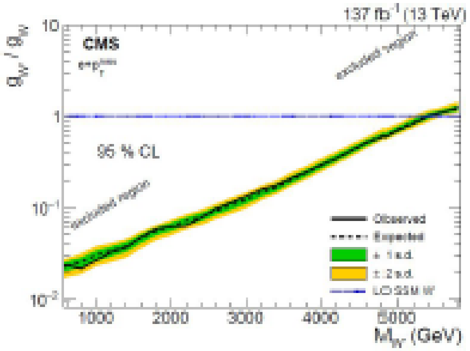


$$g_* < (4770\ \mathrm{GeV}) / m_*$$



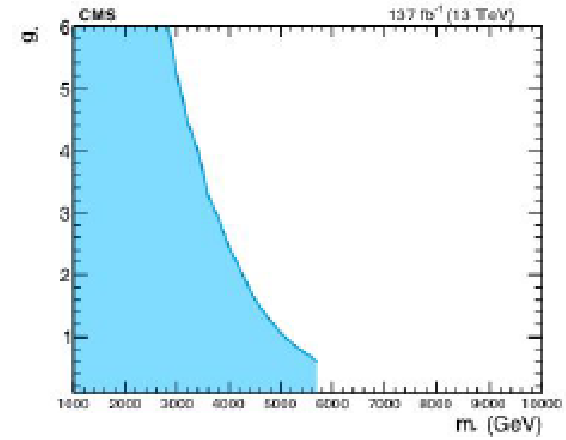
Direct bound from search for W'

SSM: W' decay only to fermions

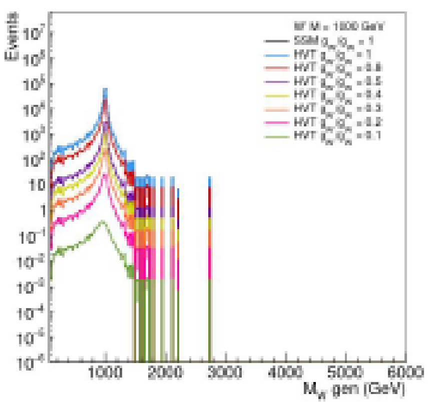


Limit set by the **W' coupling strength limit** with Γ (W')/m(W') < 5% narrow resonance assumption.

$$g_{W'} = \frac{g_W^2}{g_*} \qquad g_*^2 < \frac{m_W^2 \; g^2}{m_*^2 \; W}$$

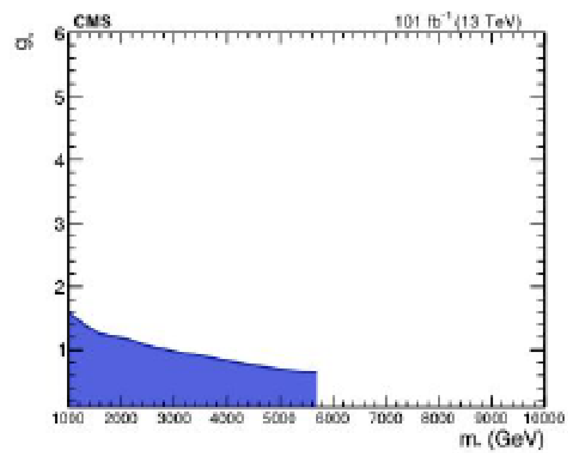


HVT: W' decay to fermions+bosons



Limit set by the W' coupling strength from HVT model where widths and cross sections are consistent with **bosonic and fermionic** couplings.

$$g_{W'} = \frac{g_W^2}{g_*} \qquad \Gamma_{HVT} = \Gamma_{SSM} + \frac{M_{W'} g_*^2}{48\pi}$$



Limited by √s

Bounds on Higgs Compositeness

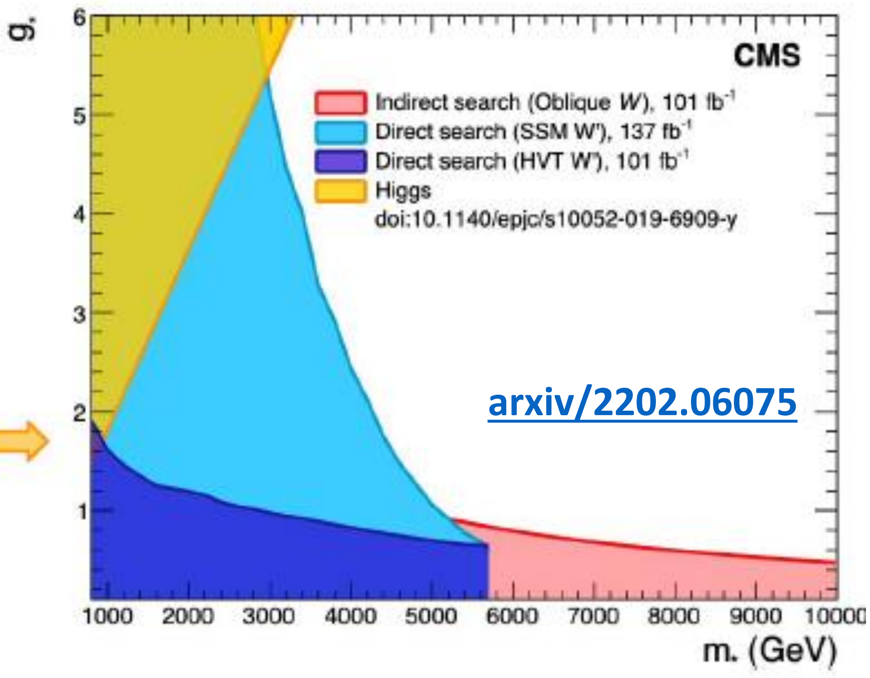
Using Higgs cross section strength, μ, measurement at CMS

$$\Delta\mu = \frac{{g_*}^2 v^2}{m_*^2}$$

μ = CMS measured Higgs boson σ / SM expectation σ
= 1.17 ± 0.10

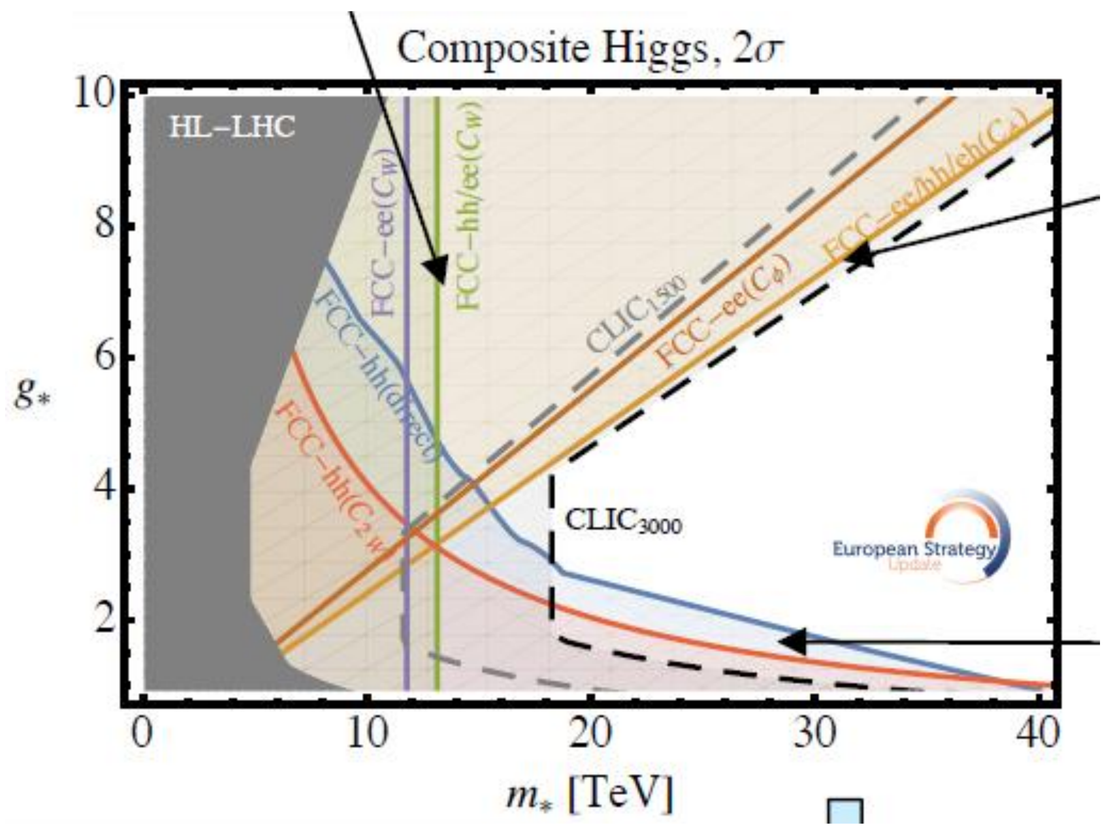
doi: 10.1140/epjc/s10052-019-6909-y

$\Delta\mu < 0.20$ at 95 % CL ⇨ $g_* < (1.82\ 10^{-3}\ \mathrm{GeV}^{-1})\ m_*$ ⇨



Higgs Compositeness excluded below 1 TeV (HVT) or 3 TeV (SSM)

Thank you


Composite Higgs, 2σ
HL-LHC
FCC-ee(C_W)
FCC-hh/ee(C_W)
FCC-hh(direct)
FCC-hh(C_2W)
CLIC_1500
FCC-ee(C_φ)
FCC-ee/hh/eh(C_φ)
CLIC_3000
European Strategy Update
g_*
m_* [TeV]
0
10
20
30
40
2
4
6
8
10