Perspectives on BSM

Alfonso R. Zerwekh
Universidad Técnica Federico Santa María
Chile

ICHEP 2020

Content

- **Postmodern View of BSM**
- **Status of “Big Models”**
- **Hints of New Physics**
- **The rôle of the Higgs**
- **Conclusions**

Postmodern view of BSM

Rise and Fall of “Big Models”

Pre-LHC era was dominated by “Big Models”

- **SUSY**
- **Technicolor/Compositeness**
- **Extra Dimensions**

All these models were (partially) motivated by naturalness

All predicted big signals around the corner

BUT

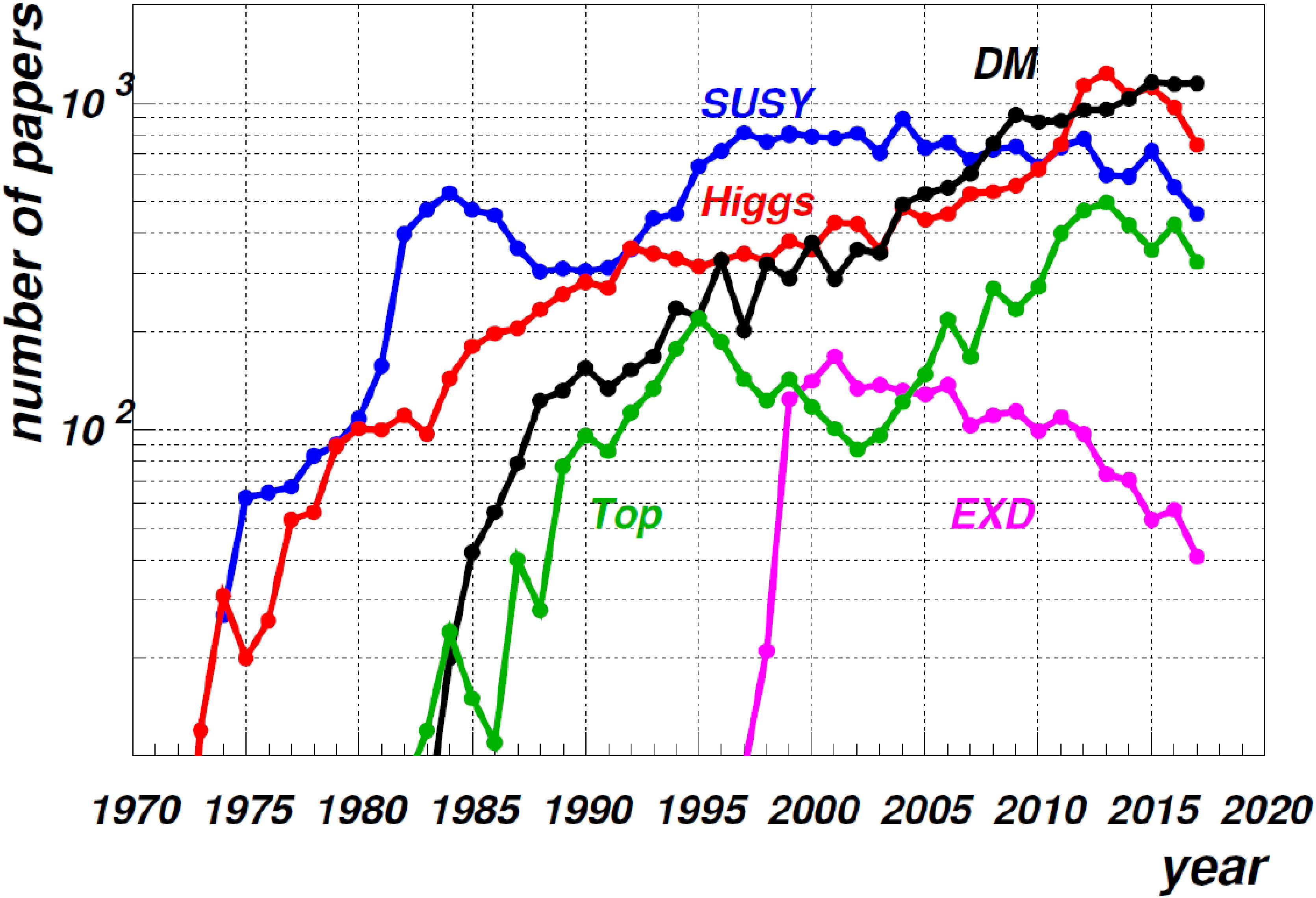
Warning

LEP $\Rightarrow \Lambda_{NP} > 5$ TeV

Rise and Fall of “Big Models”

The LHC discovered the Higgs but not BSM yet

- This is consistent with LEP warnings
- What about naturalness ?
- What about the “Big Models” ?

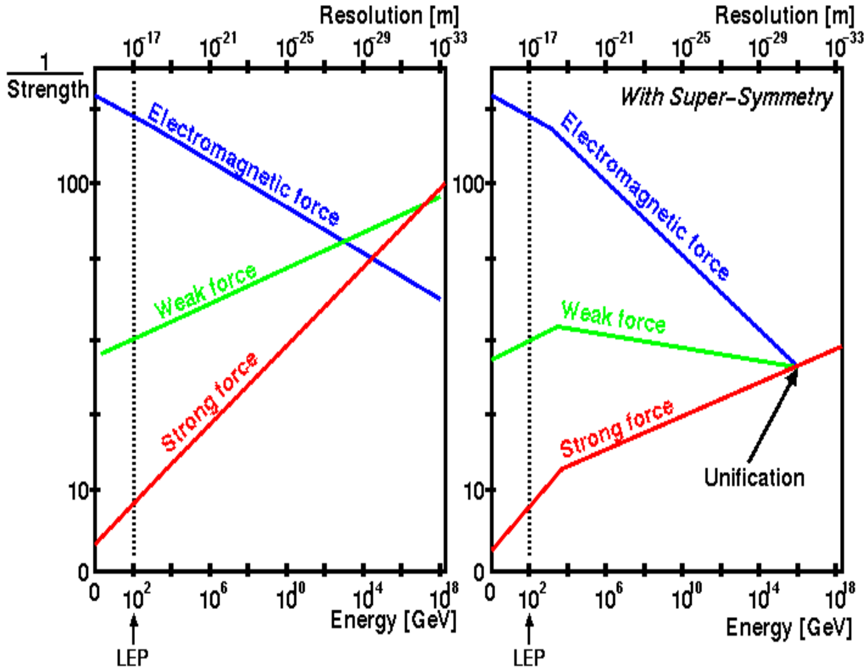


number of papers
10^3
10^2
SUSY
DM
Higgs
Top
EXD
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
year

Status of “Bigs Models”

SUSY

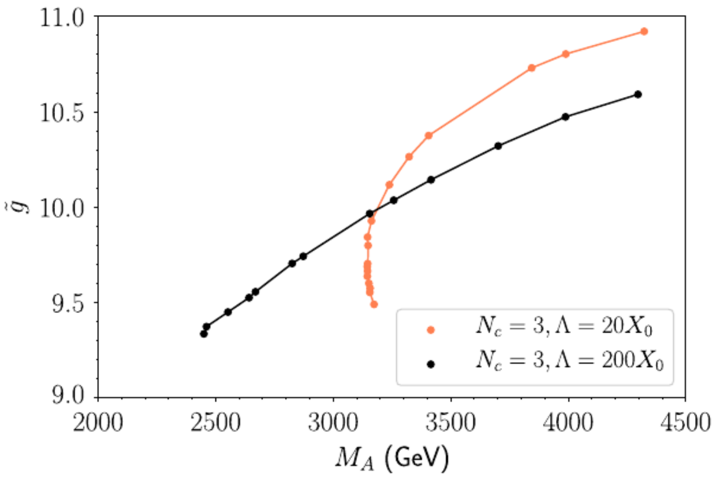
- **Still well motivated and atractive**
  - Unification
  - It paves the way to higher energies (TeV SUSY → GUT → SUGRA → Strings) using perturbative Physics
- **Could solve all the SM problems**
- **MSSM probably is not the answer**
  - Non minimal particle content needed

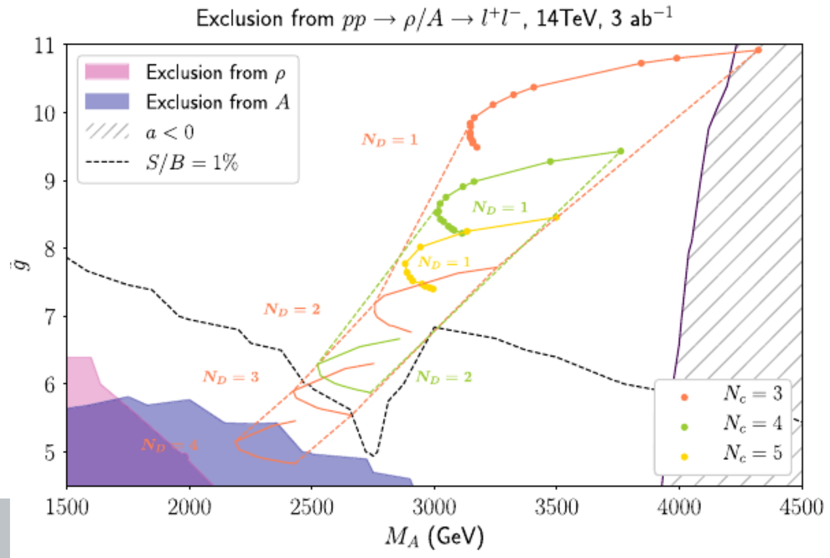


For current experimental status, see Cristina Botta’s talk

Technicolor and Compositeness

- **Technicolor is alive !**
- **Modern versions of Walking Technicolor produce a light Higgs-like scalar** **(D. D. Dietrich, F. Sannino and K. Tuominen, PRD 72,055001 (2005); A. Doff, A. Natale,P.S. Rodrigues da Silva, PRD 77 (2008) 075012)**
- **Holographic TC: Vector and Axial resonances with masses 3-4 TeV** **(Belyaev, Fadafans, Evans, and Gholamzadeh, PRD 101 (2020) 8, 086013)**
- **Interesting signal $\rho \rightarrow$ V h** **(A. Z. EPJ C 46 (2006) 791-795)**
- **PNGB in non-minimal models ?**



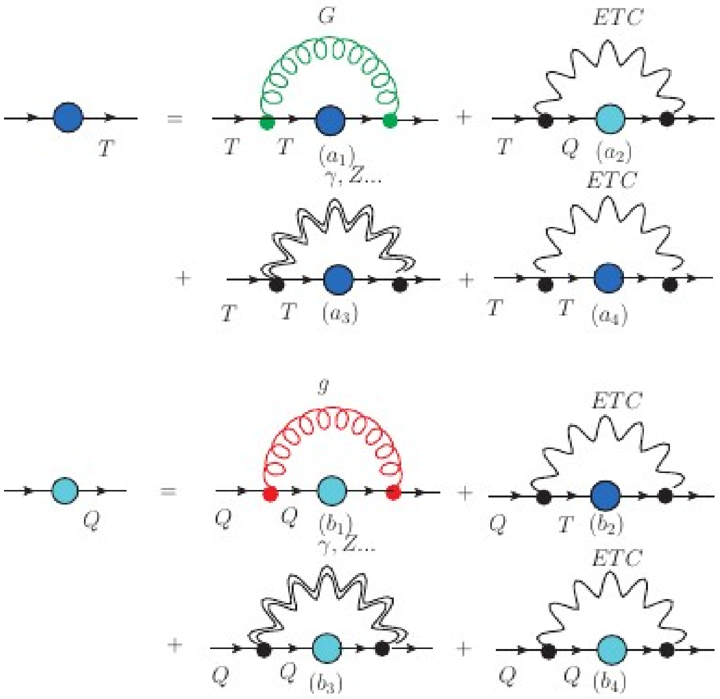


Technicolor and Compositeness

- **It is necessary to communicate EWSB to fermions ⇒ ETC**

- **Life is difficult: it may be necessary to solve ETC+TC+QCD together** (A.Doff and A. Natale PRD 99 (2019) 5, 055026)

- **Lattice can help** (Bennett et al. JHEP 12 (2019) 053)



Technicolor and Compositeness

- **For phenomenology: effective theories**
  - SM + Vector triplet (Pappadopulo et al, JHEP 09 (2014) 060; Cárcamo-Hernández et al. PRD 96 (2017) 11, 115027)
  - Low Energy TC Effective Lagrangian (Belyaev et al, PRD 79 (2009) 035006)
  - Linear BESS (Casalbuoni et al. PRD 56 (1997) 5731-5747; J.Urbina and A.Z. NPB 934 (2018) 653-664)

Guess the spectrum and construct the effective Lagrangian

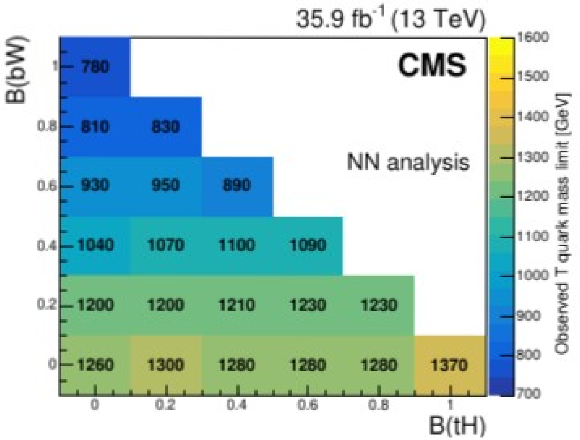
Higgs+Vector+Axial-Vector

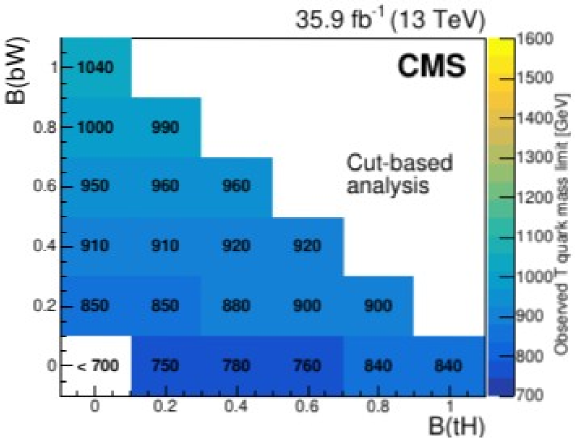
New neutral scalars: h, H_L, H_R

New Vectors: $V_L^{0,\pm}$, $V_R^{0,\pm}$

The Higgs Boson as a PNGB

- **This kind of models naturally predicts a "little desert" $\Lambda \sim 10$ TeV**
- **In general they predicts vector-like *top-partners* with masses $\geq$ 1 TeV**
- **Heavier top-partners, higher levels of fine-tuning**

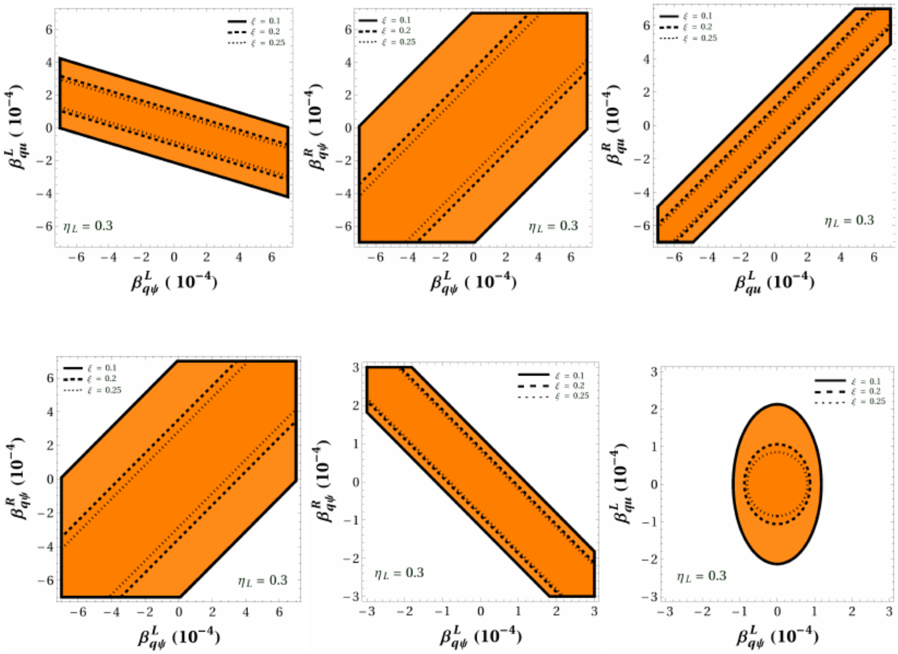




For better limits see Julie Hogan's talk

The Higgs Boson as a PNGB

- **Although resonance may be very massive they may induce EDM**
  (J. Yepes and A.Z Int.J.Mod.Phys.A 33 (2018) 11, 1841008)



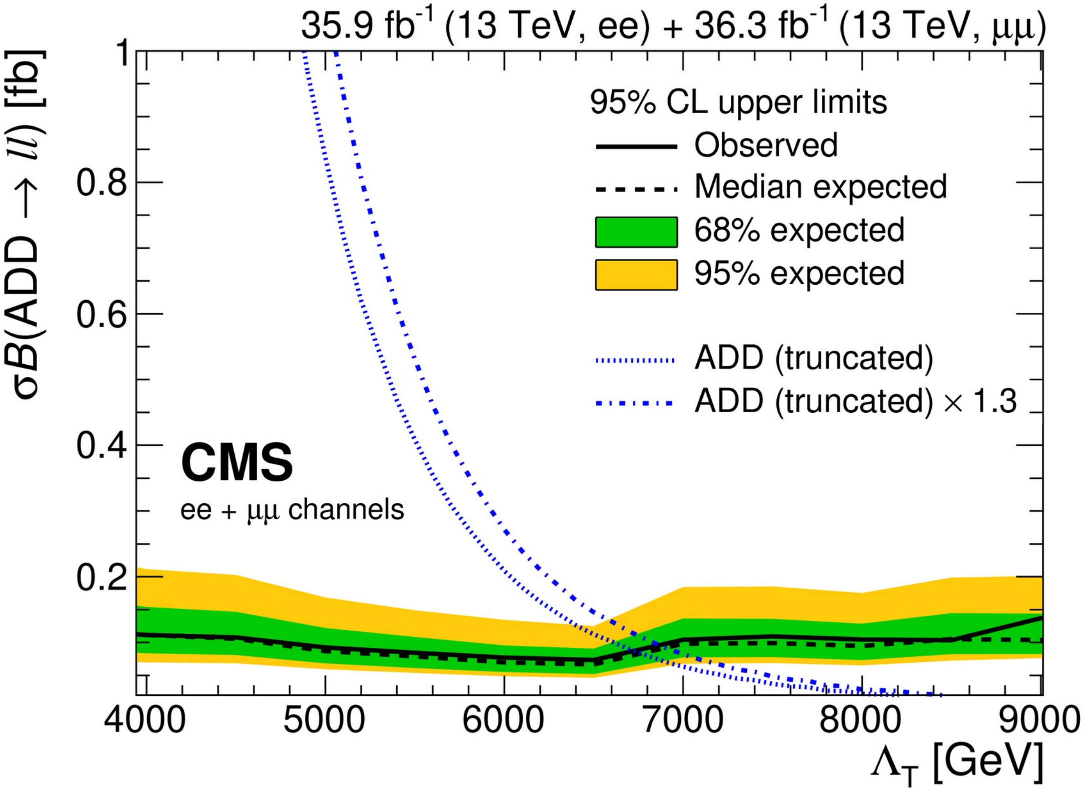
$$\mathscr{L}_{\mathrm{M}+\rho_\chi} = \frac{1}{\sqrt{2}}\,\alpha_i^\chi\,\mathcal{J}^\mu_{i\chi}\,(\rho_{\mu\chi} - e_{\mu\chi}) \;+\; \mathrm{h.c.}\,,$$

$$\mathscr{L}^{\mathrm{mag}}_{\mathrm{M}+\rho_\chi} = \frac{1}{f}\,\beta_i^\chi\,\mathcal{J}^{\mu\nu}_{i\chi}\,\rho_{\mu\nu\chi} \;+\; \mathrm{h.c.}\,,$$

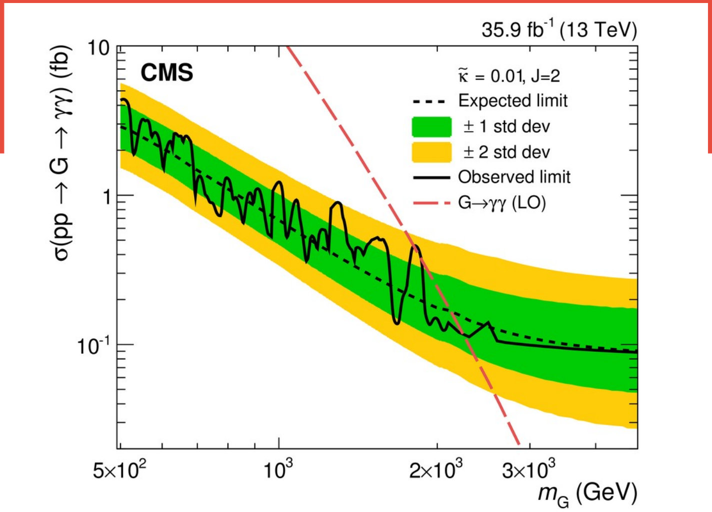
Large Extra Dimensions

Λ > 6 TeV

(CMS, JHEP 04 (2019) 114)



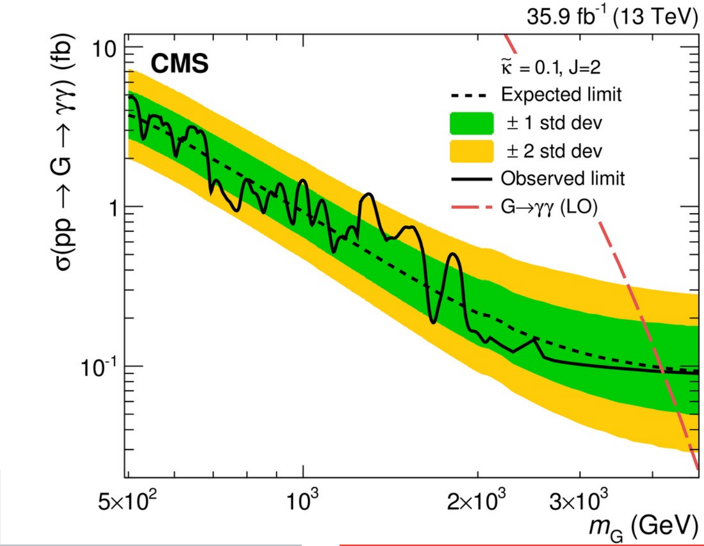
Randall-Sundrum



M > 2.3 TeV (κ=0.01)

M > 4.6 TeV (κ=0.2)

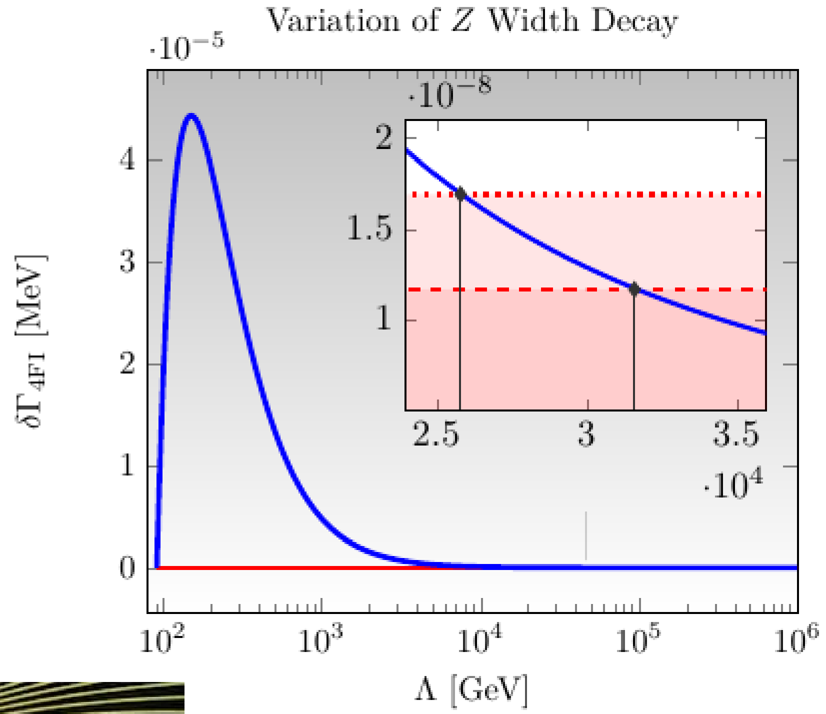
(CMS, Phys. Rev. D 98 (2018) 092001)

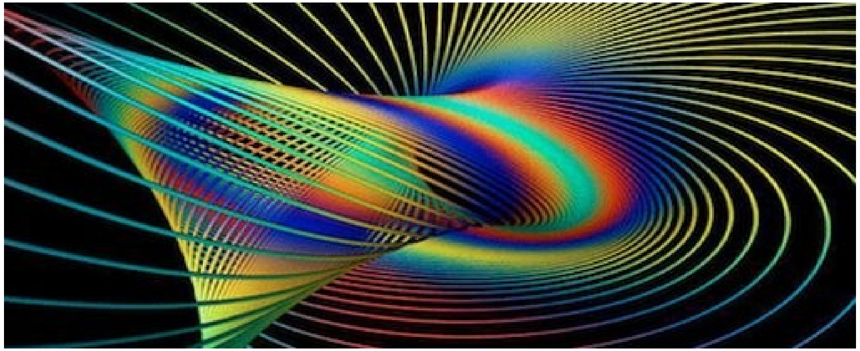


Beyond GR in the Bulk

Torsion in 5D **(O. Castillo-Felisola, C. Corral, S. Kovalenko, I. Schmidt PRD 90 (2014) 2, 024005)**

- Torsion induce 4-fermion interactions
- Produces corrections to Z's decay width
- Λ > 30 TeV





Hints of New Physics

(g-2)

Devoudiasl and Marciano PRD 98 (2018) 7, 075011

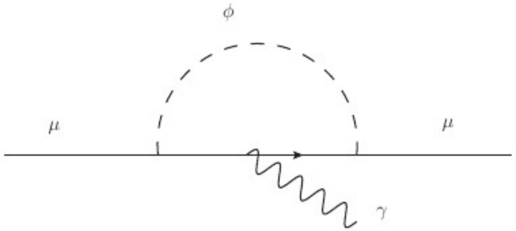
$$a_\mu \equiv (g_\mu - 2)/2$$

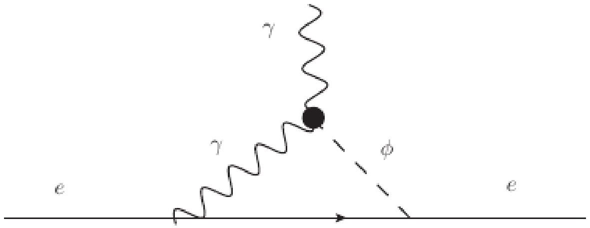
$$\mathcal{L}_\phi = -\frac{1}{2} m_\phi^2 \phi^2 - \sum_f \lambda_f \phi \bar{f} f - \frac{\kappa_\gamma}{4} \phi F_{\mu\nu} F^{\mu\nu},$$

$$\Delta a_\mu \equiv a_\mu^{\rm exp} - a_\mu^{\rm th} = (274 \pm 73) \times 10^{-11}$$

$$m_\phi = 250 \text{ MeV} \quad \text{and} \quad \lambda_\mu = 10^{-3}$$

$$\Delta a_e = (-87 \pm 36) \times 10^{-14}$$





Many other possibilities

Lepton Universality

Huang, Morais and Santos 2007.05082

$$R(K^{(*)}) = \mathcal{B}(B \to K^{(*)}\mu^+\mu^-)/\mathcal{B}(B \to K^{(*)}e^+e^-)$$

Exp

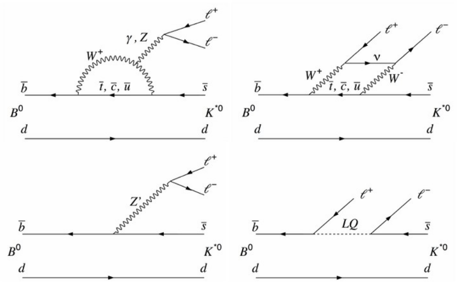
$$R(K) = 0.846^{+0.060+0.016}_{-0.054-0.014}\,, \qquad q^2 \in [1.1, 6]\mathrm{GeV}^2\,,$$

$$R(K^*) = \begin{cases} 0.660^{+0.110}_{-0.070} \pm 0.024\,, & q^2 \in [0.045, 1.1]\mathrm{GeV}^2\,, \\ 0.685^{+0.113}_{-0.069} \pm 0.047\,, & q^2 \in [1.1, 6]\mathrm{GeV}^2\,. \end{cases}$$

SM

$$R(K) = 1.0004(8)\,, \qquad q^2 \in [1.1, 6]\mathrm{GeV}^2\,,$$

$$R(K^*) = \begin{cases} 0.920 \pm 0.007\,, & q^2 \in [0.045, 1.1]\mathrm{GeV}^2\,, \\ 0.996 \pm 0.002\,, & q^2 \in [1.1, 6]\mathrm{GeV}^2\,. \end{cases}$$



Leptoquark ?

LHCb,PRL 22 (2019) 191801

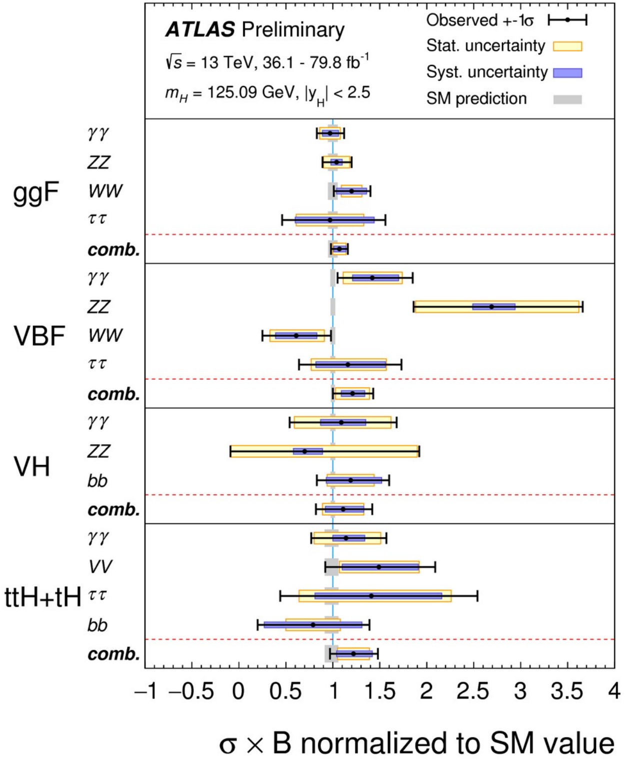
LHCb,JHEP 08 (2017) 055

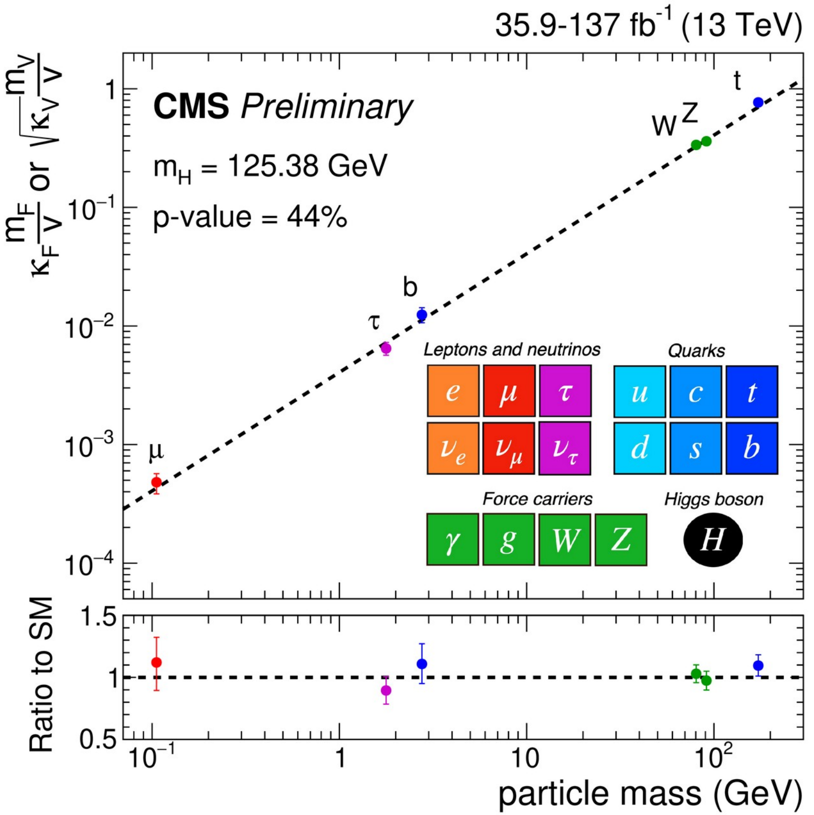
Precision Tests

Quantity	Value	Standard Model	Pull
M_Z [GeV]	91.1876 ± 0.0021	91.1882 ± 0.0020	-0.3
Γ_Z [GeV]	2.4955 ± 0.0023	2.4942 ± 0.0009	0.6
σ_{had} [nb]	41.481 ± 0.033	41.482 ± 0.008	0.0
R_e	20.804 ± 0.050	20.736 ± 0.010	1.4
R_μ	20.784 ± 0.034	20.735 ± 0.010	1.4
R_τ	20.764 ± 0.045	20.781 ± 0.010	-0.4
R_b	0.21629 ± 0.00066	0.21581 ± 0.00002	0.7
R_c	0.1721 ± 0.0030	0.17221 ± 0.00003	0.0
$A_{FB}^{(0,e)}$	0.0145 ± 0.0025	0.01619 ± 0.00007	-0.7
$A_{FB}^{(0,\mu)}$	0.0169 ± 0.0013		0.5
$A_{FB}^{(0,\tau)}$	0.0188 ± 0.0017		1.5
$A_{FB}^{(0,b)}$	0.0996 ± 0.0016	0.1030 ± 0.0002	-2.1
$A_{FB}^{(0,c)}$	0.0707 ± 0.0035	0.0736 ± 0.0002	-0.8
$A_{FB}^{(0,s)}$	0.0976 ± 0.0114	0.1031 ± 0.0002	-0.5
$\bar{s}_\ell^2$	0.2324 ± 0.0012	0.23153 ± 0.00004	0.7
	0.23148 ± 0.00033		-0.2
	0.23129 ± 0.00033		-0.7
A_e	0.15138 ± 0.00216	0.1469 ± 0.0003	2.1
	0.1544 ± 0.0060		1.2
	0.1498 ± 0.0049		0.6
A_μ	0.142 ± 0.015		-0.3
A_τ	0.136 ± 0.015		-0.7
	0.1439 ± 0.0043		-0.7
A_b	0.923 ± 0.020	0.9347	-0.6
A_c	0.670 ± 0.027	0.6677 ± 0.0001	0.1
A_s	0.895 ± 0.091	0.9356	-0.4

The rôle of the Higgs

Is it the SM Higgs ?



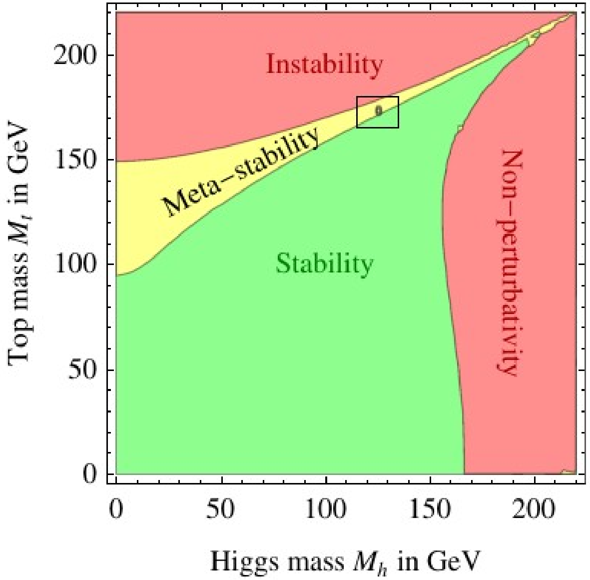


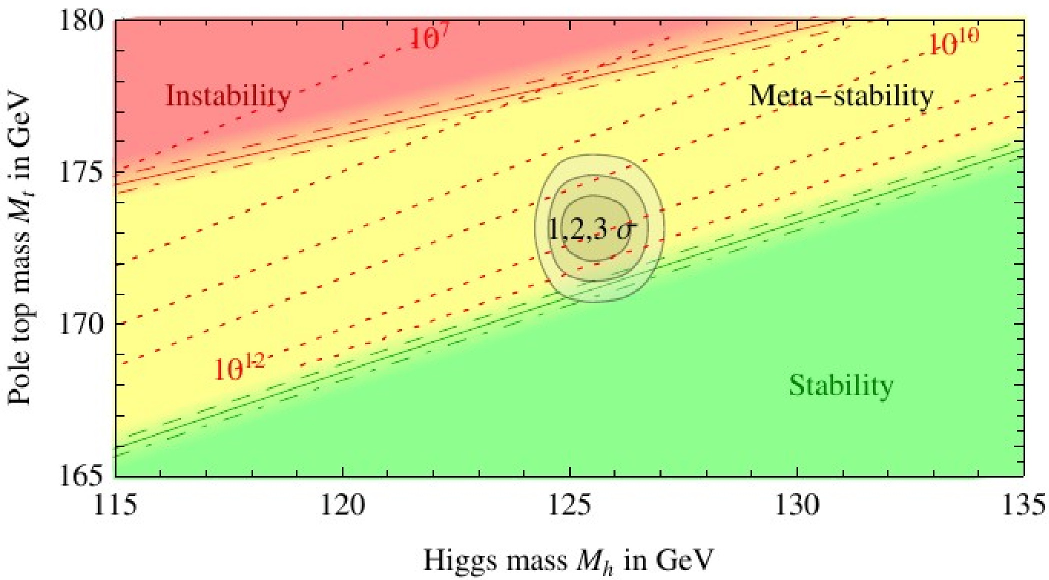
Why do we expect New Physics in the EWSB sector ?

- **We would like to understand why the Higgs is light**
- **The Standard Model doesn’t explain what triggers the EWSB (why $\mu^2<0$?)**
  - **What’s the origin of Higgs Potential ?**
  - **What’s the origin of Yukawa couplings ?**
  - **Most (all?) of the SM problems are related to the fact that the potential and the Yukawas don’t come from a (gauge) symmetry principle,**
- **It is very easy to couple the Higgs doublet to new scalars and vectors**
- **Vacuum stability**

Vacuum Stability

Degrassi et al. JHEP 08 (2012) 098





Further Thoughts and Conclusions

Other sources of BSM physics

- CP violation and Baryon Asymmetry
- Dark Matter
- Neutrino Physics
- Lorentz Violation
- Etc…

We have not discovered New Physics yet, but...

- It should have been expected if we had listened to LEP

- There good reasons to expect NP in sectors other than neutrinos and DM

- Probably the NP will not be related to the Naturalness problem

- There is a lot of ideas that can explain current “anomalies” and are not related to the big narratives of the “Big Models” and are worth to be explored

A little story of caution

- **Before the era of geografical explorations, educated Europeans expected to find antipodean monsters beyond the Equator line**

- **They found exotic fauna but not monsters**

- **There was a lack of understanding of how gravity works**

A little story of caution

- Maybe the TeV scale is our Equator line and we will not find monster.
- For sure we will find new things and phenomena, but not monster

- It is even possible that again a better understanding of gravity can explain the stability of the TeV scale

Caminante, no hay camino. Se hace camino al andar

Walker, there is no way. You make your way by walking

Antonio Machado

We are making the ways

Thank You