Searching for New Phenomena
(under susy abstinence)

Interpreting *null* results… and one hope!

Alex Pomarol, CERN & UAB/IFAE (Barcelona)

Impressive number of searches for new phenomena at LHC,

giving us **plenty of negative results!**

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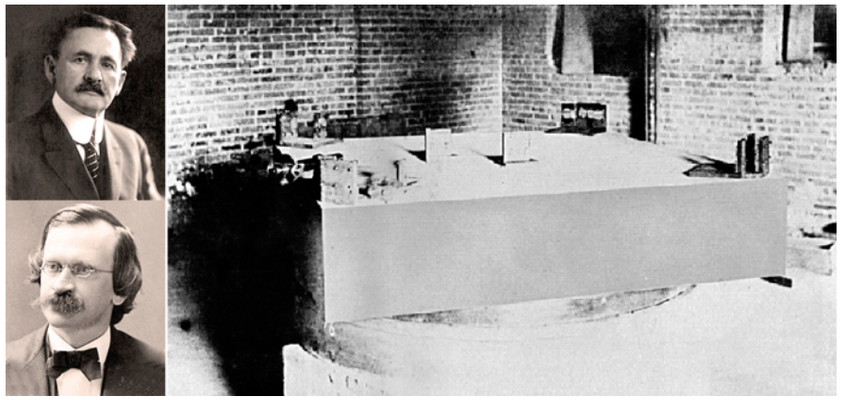
If experiments are well-motivated!



as Michelson-Morley experiment

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If we assume that **the only scale** is $\langle H \rangle \sim 246\ GeV$ **(as in the SM),**

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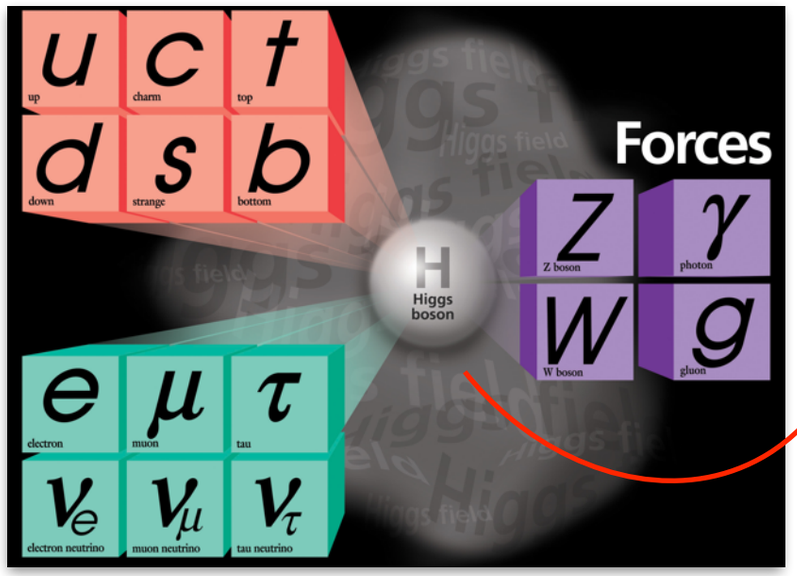

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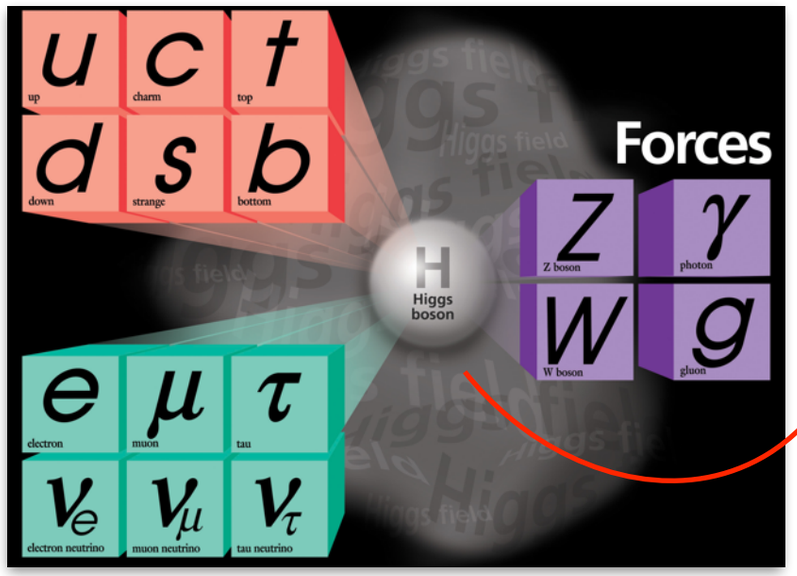

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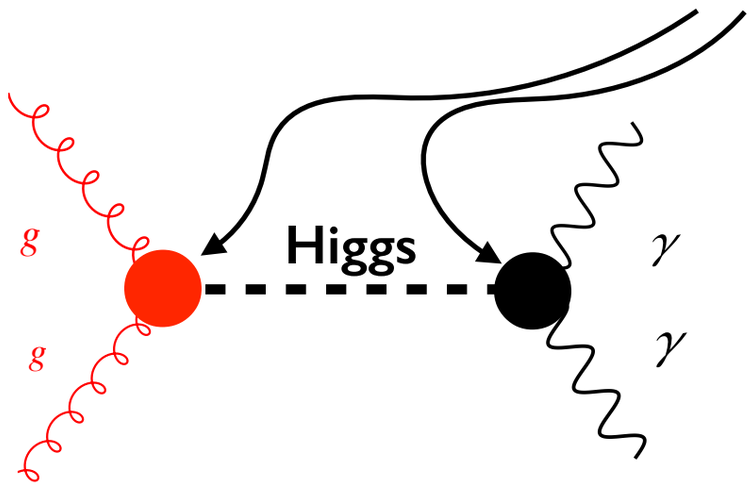
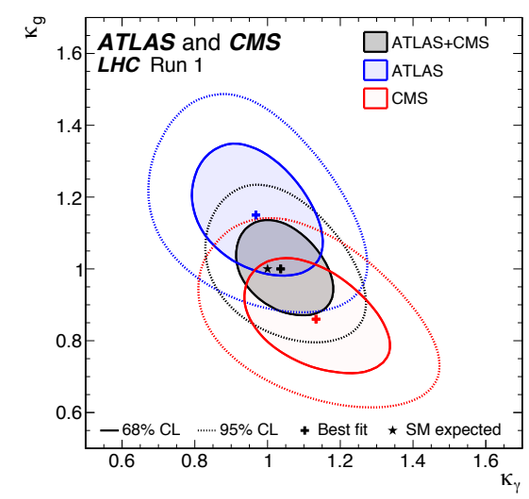
We know this thanks to the interplay between direct & indirect searches:

- **If light:** should have been seen in detectors
- **If heavy:** should have been seen indirectly

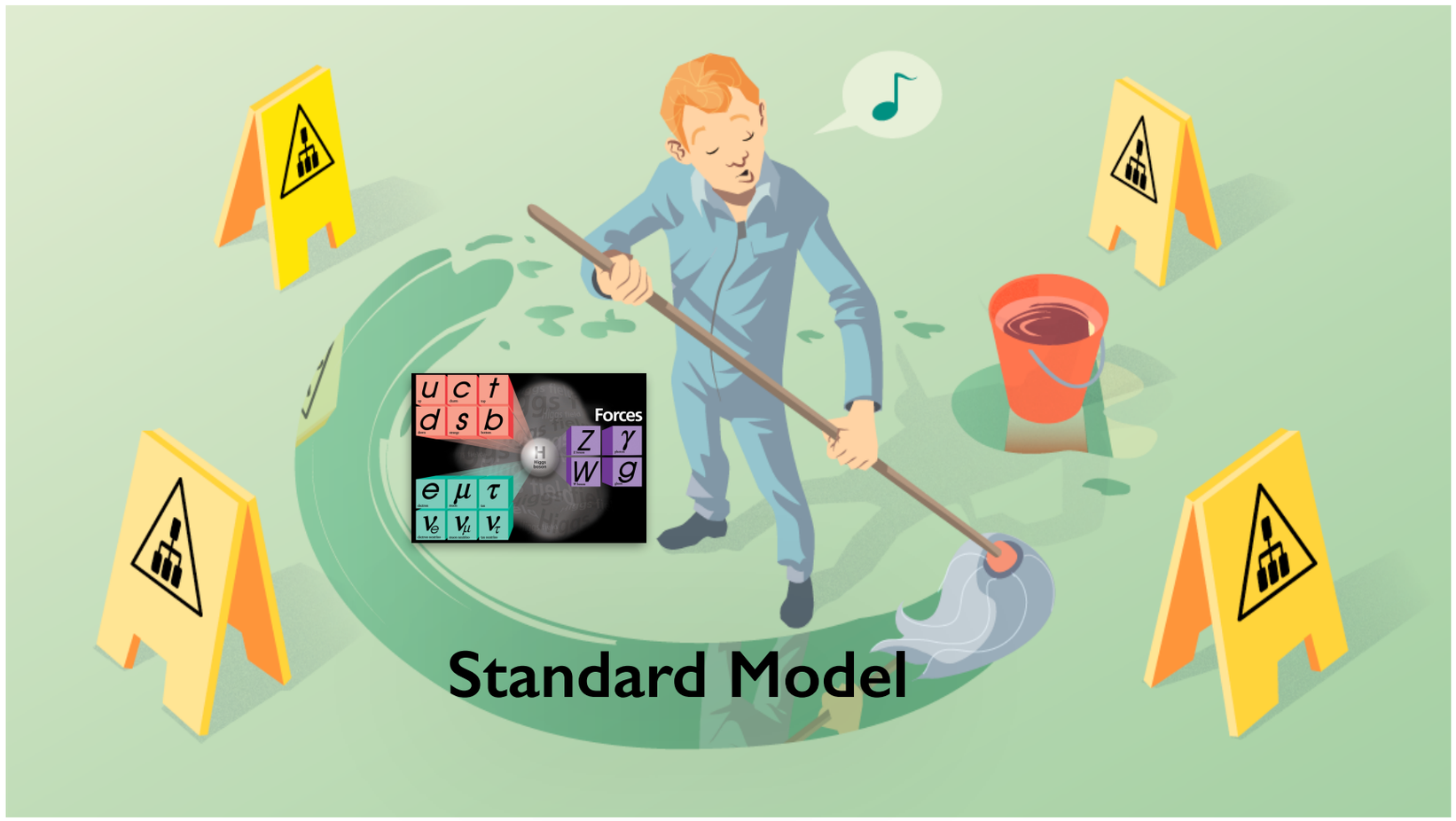




crucial piece of information!

Making progress from *null* results:

We have been able to **clean up** the electroweak sector, being now **confident in the SM**



No theory argument to have SU(3)xSU(2)xU(1) with 3 families (**the SM**), instead of something else

Consequences:

New states should bring their own mass-scale

e.g. $\mathrm{M}\bar{\Psi}\Psi$

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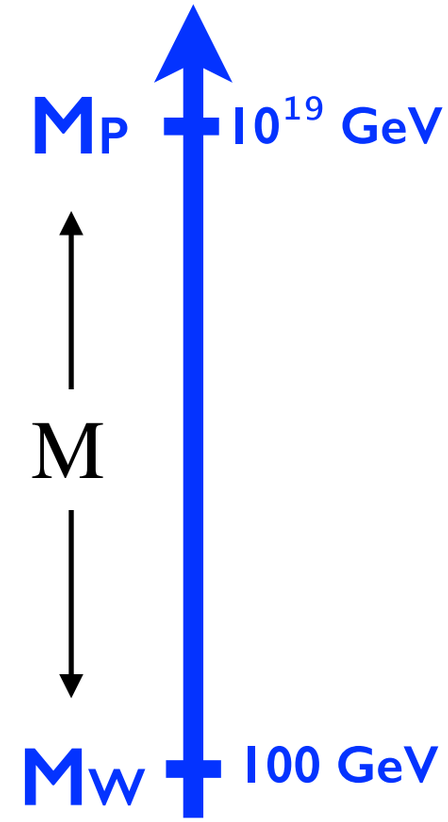

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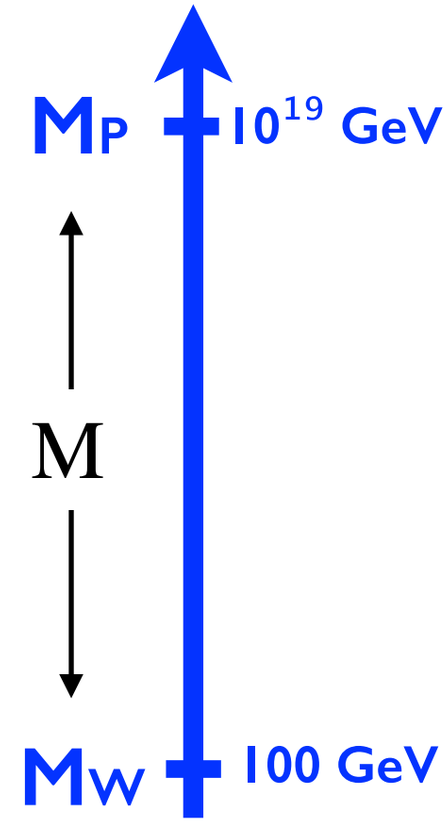

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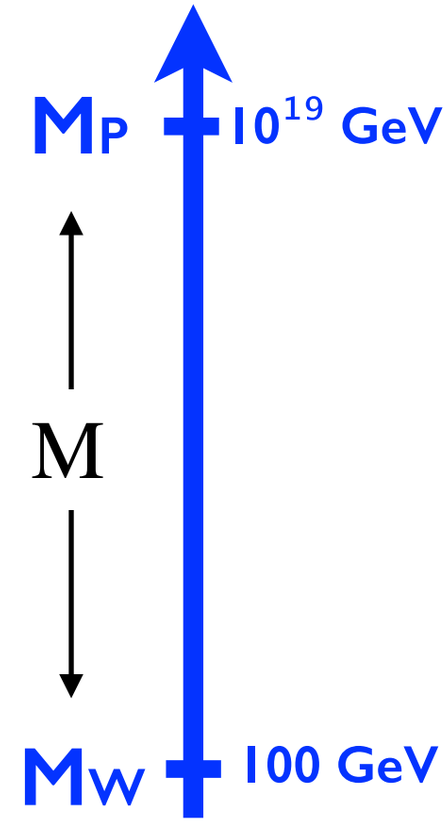

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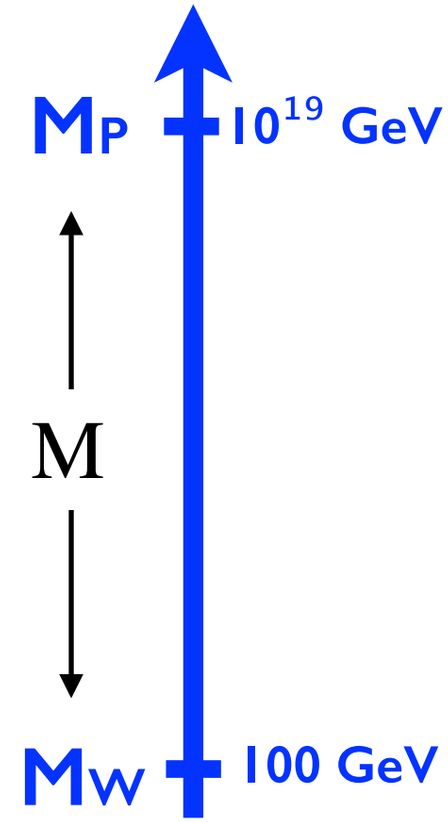

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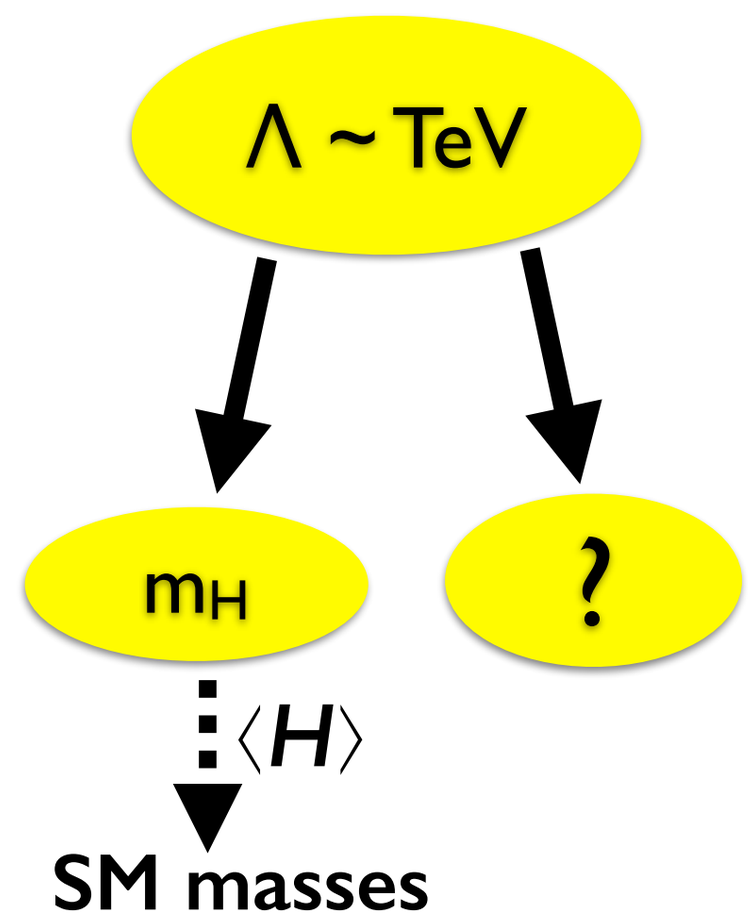
Assume $\langle H \rangle$ is not a fundamental parameter:

There is a more fundamental scale at ~TeV from which m_H (or $\langle H \rangle$) arises, together with something else



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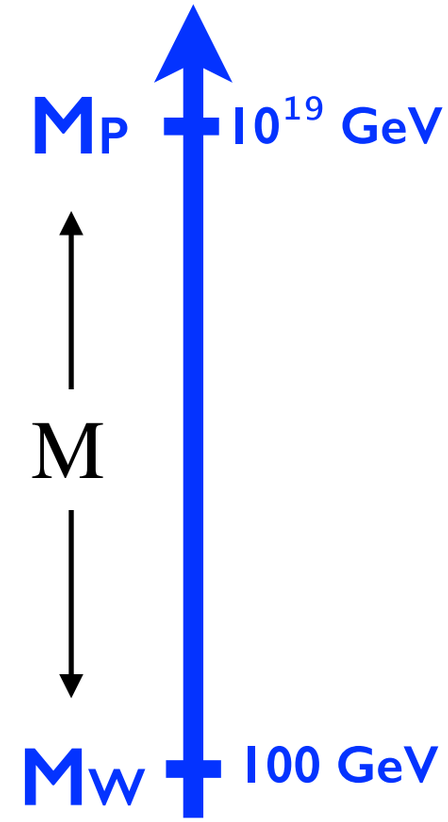

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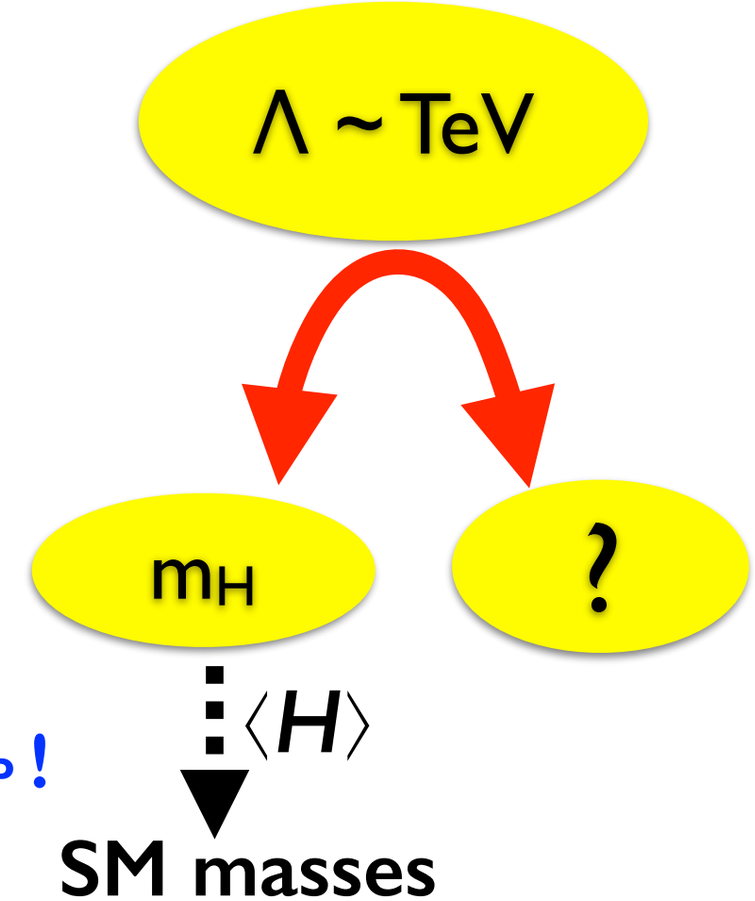


↳ **Also needed if we want to explain why $m_H \ll M_P$!**

What could be this $\Lambda \sim$TeV?

What could be this Λ~TeV?

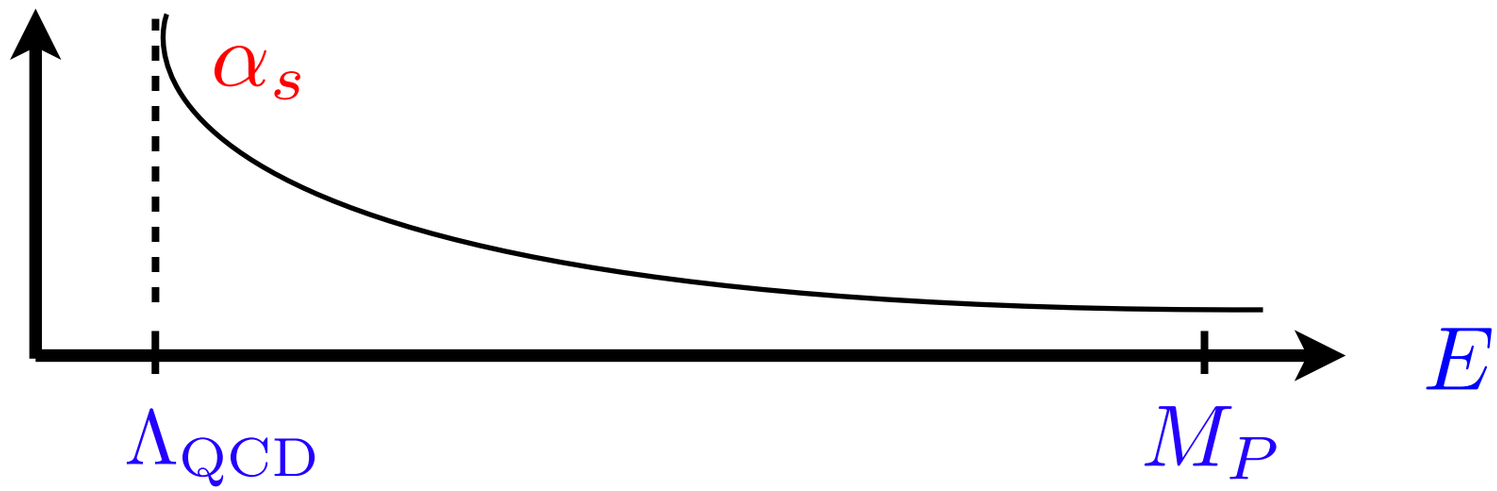
↳ In the Susy approach:

Λ ~ scale of Susy-breaking

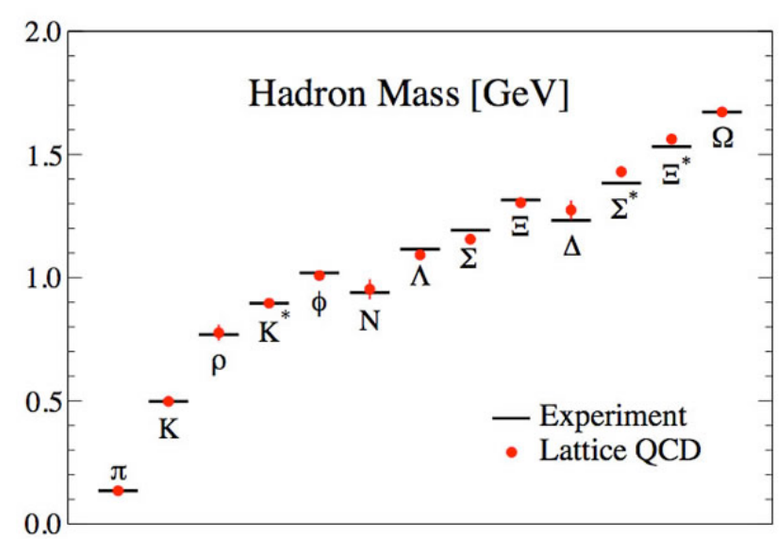
? = superpartners

What could be this Λ~TeV?

QCD as a guidance:



Explains why $\Lambda_{\rm QCD} << M_P$ and the origin of most hadron masses



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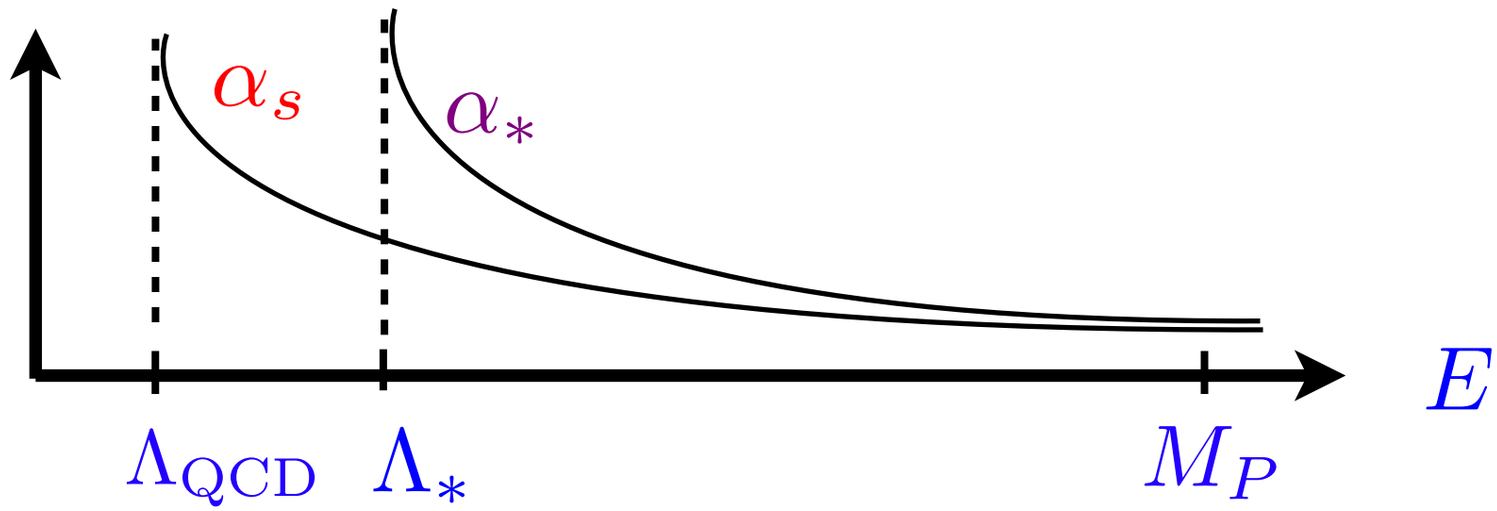
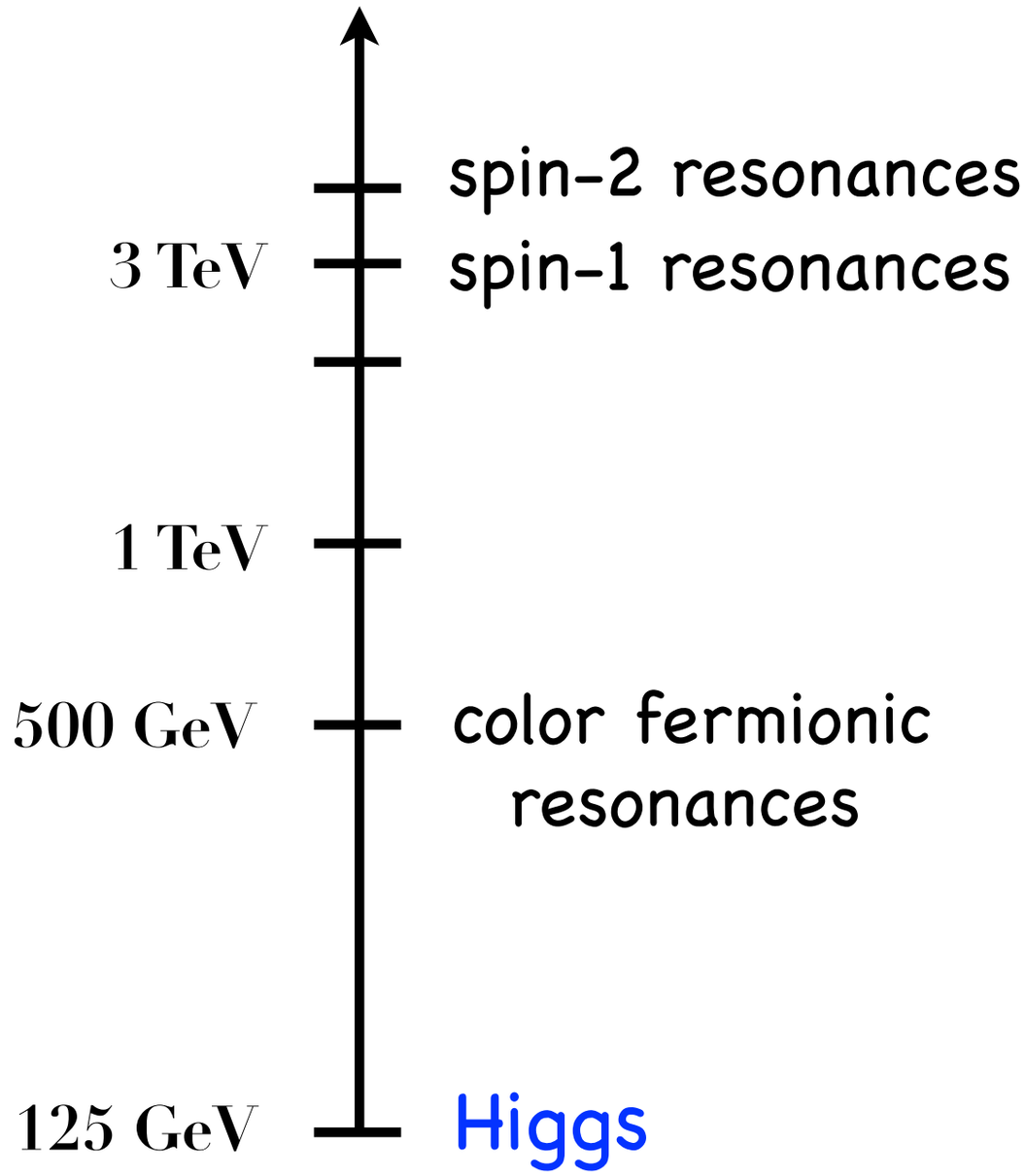


New strong dynamics at TeV

It could explain why $m_H \lesssim \Lambda_* \sim \mathrm{TeV} \ll M_P$

Composite Higgs

Expected spectrum of the TeV Composite Sector



Good BSM prototype for many searches

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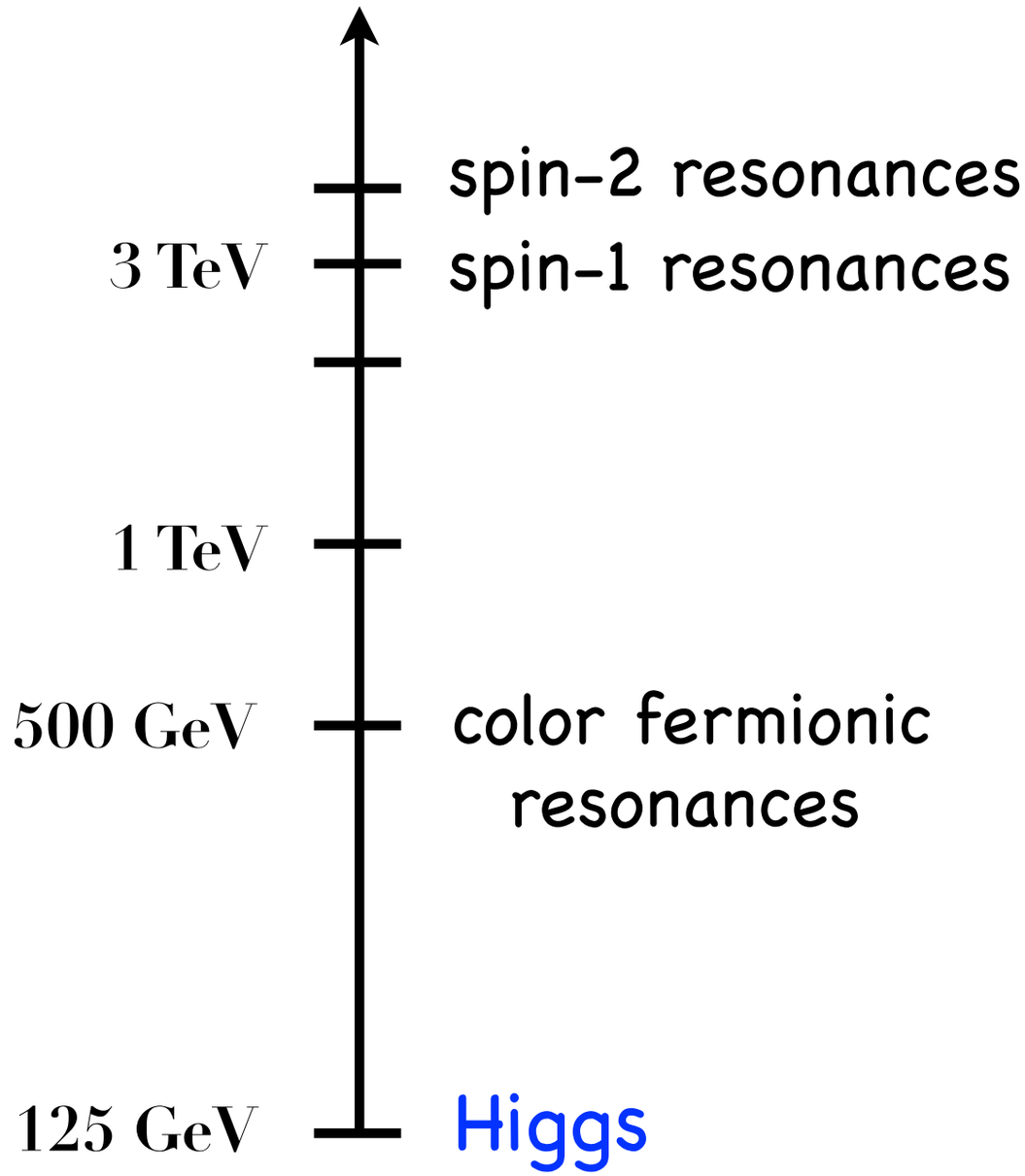

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Physics of Composite Sector ↔ Physics of Extra dimension

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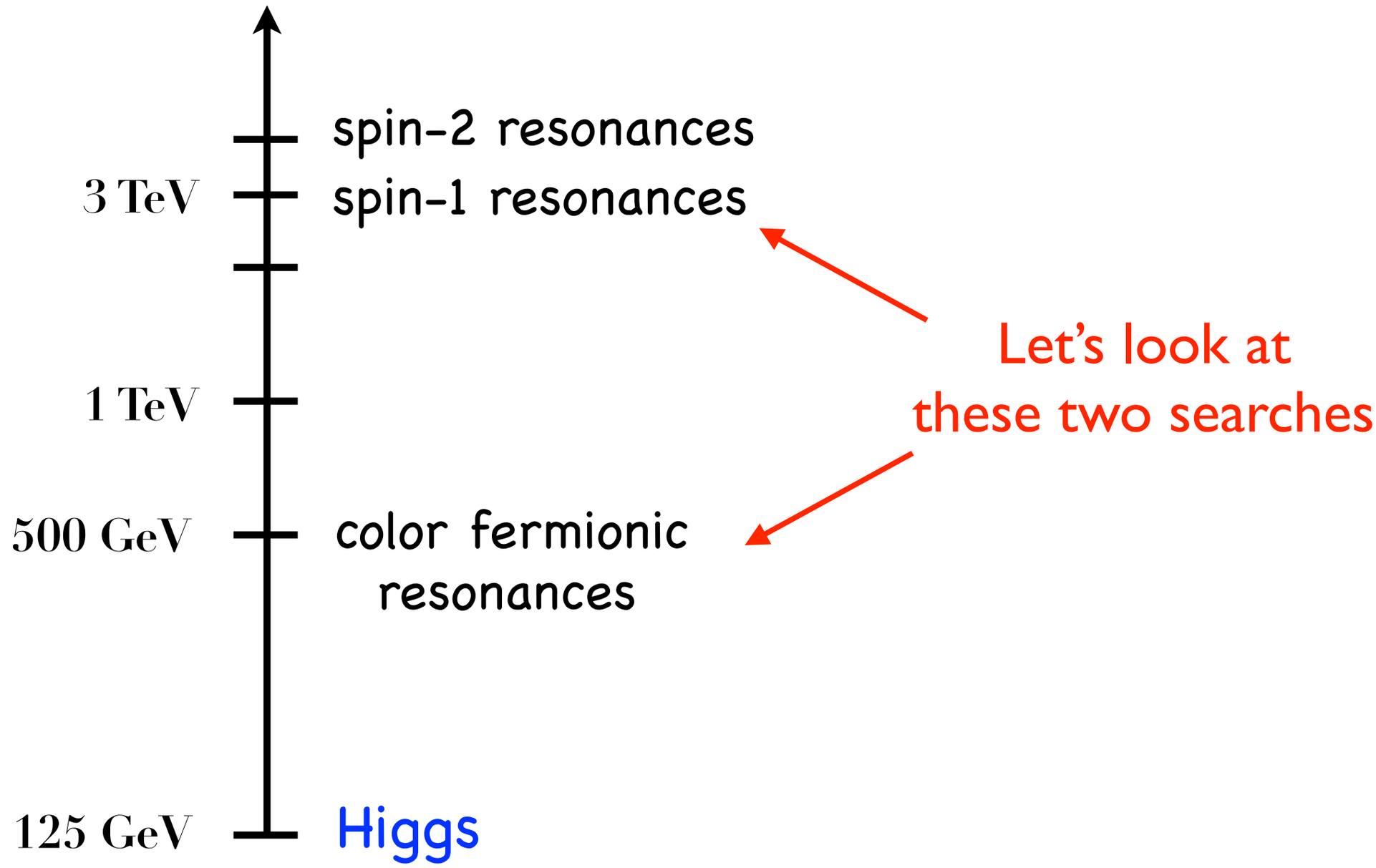

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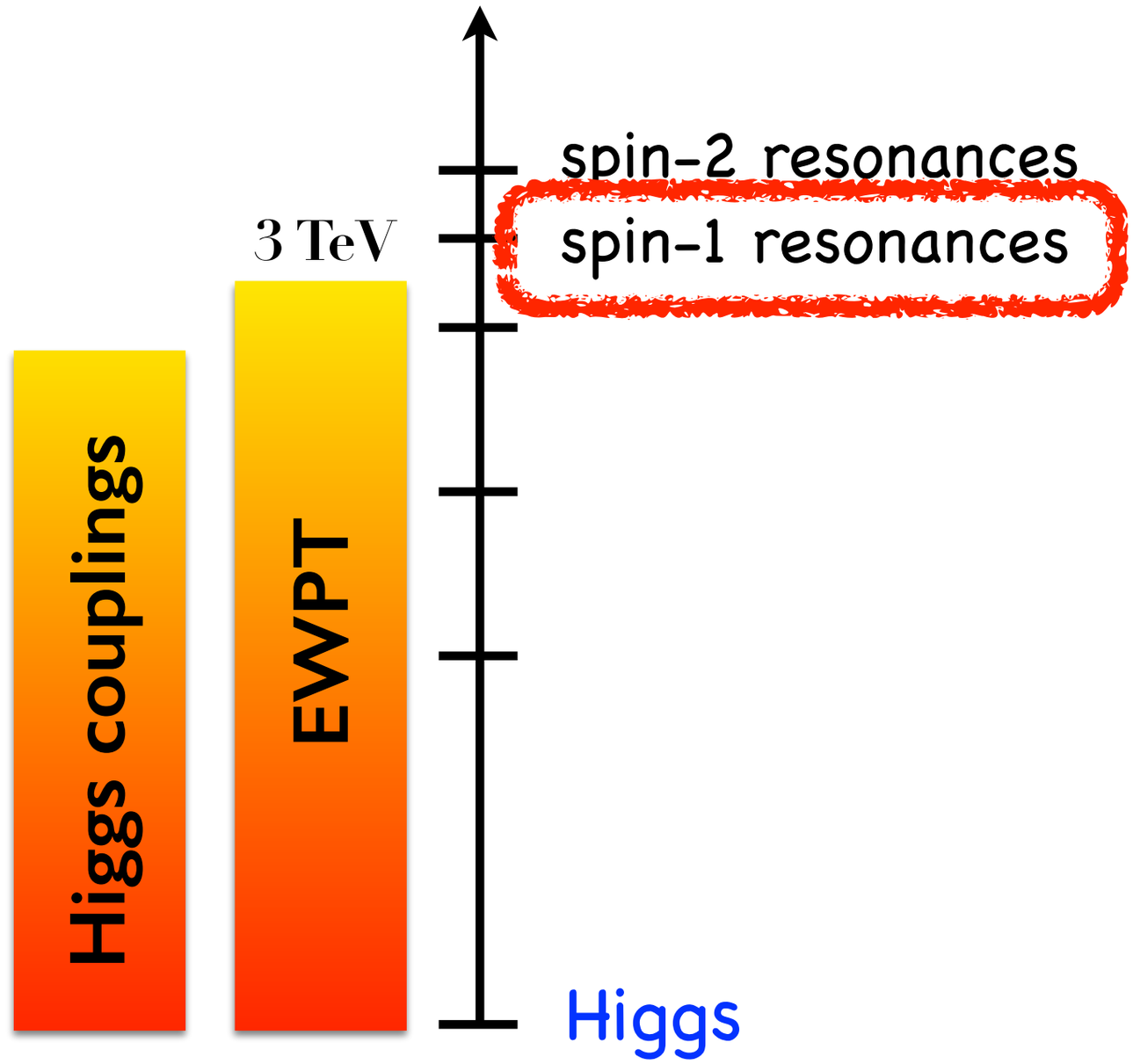

Before 13 TeV LHC bounds
dominated by indirect effects

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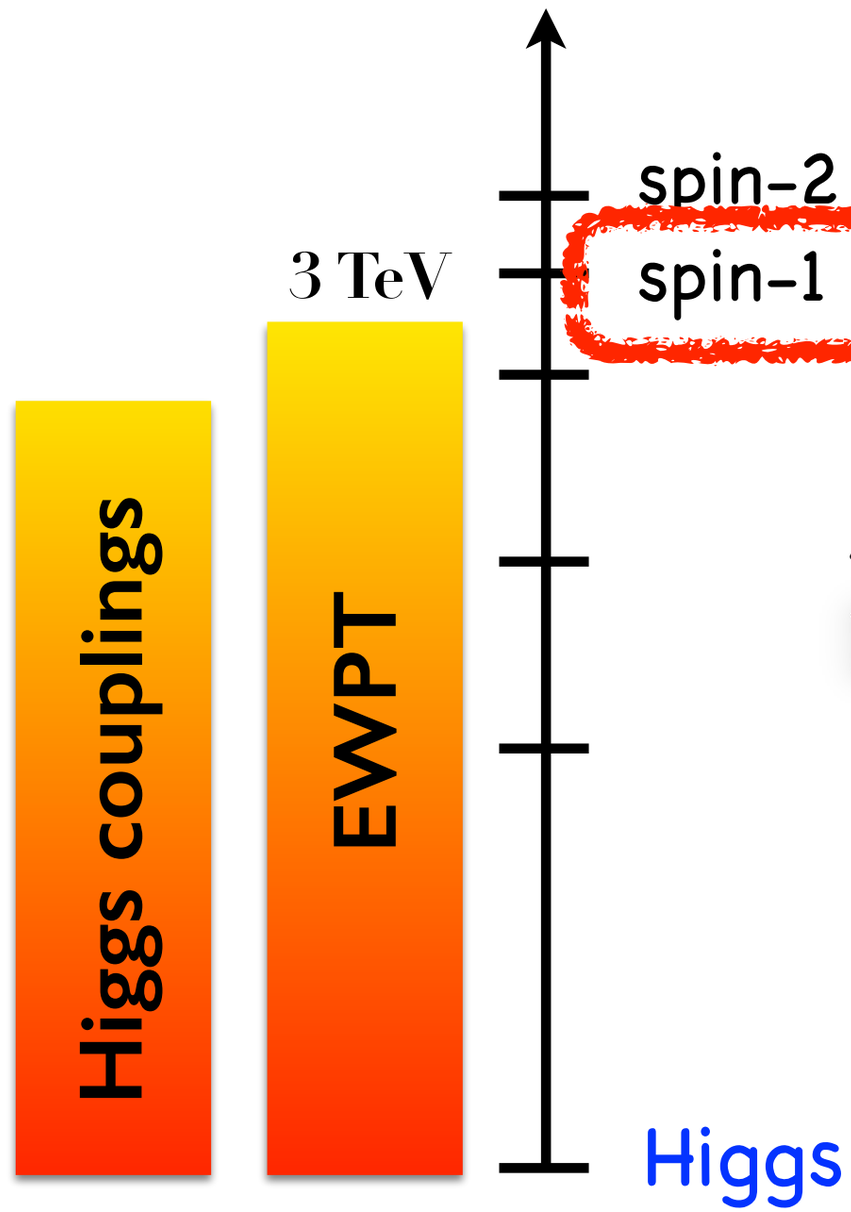
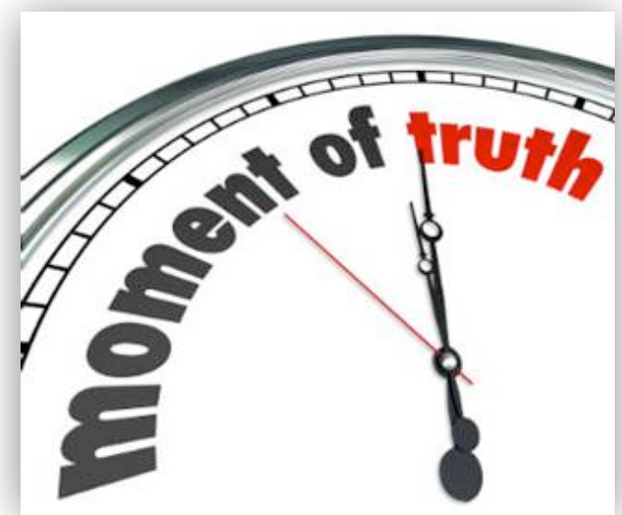


LHC 7/8 TeV → 13 TeV



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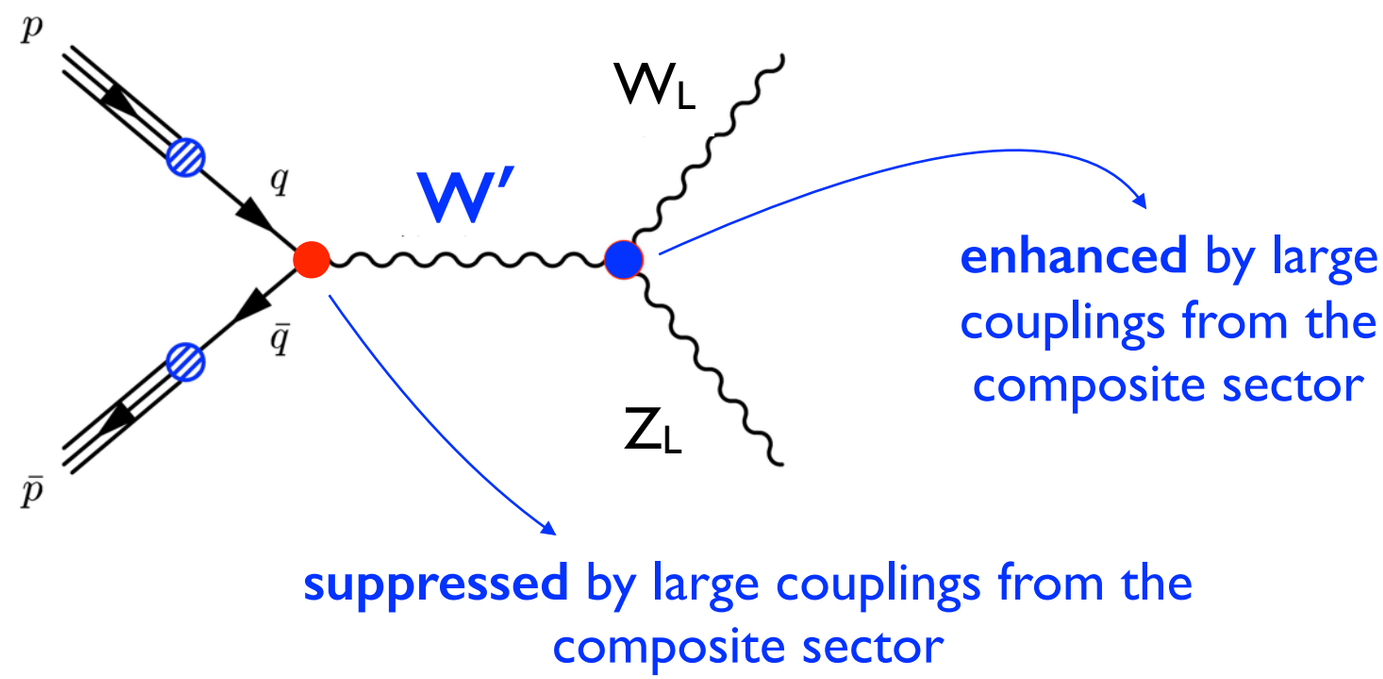
Spin-1 resonance searches:



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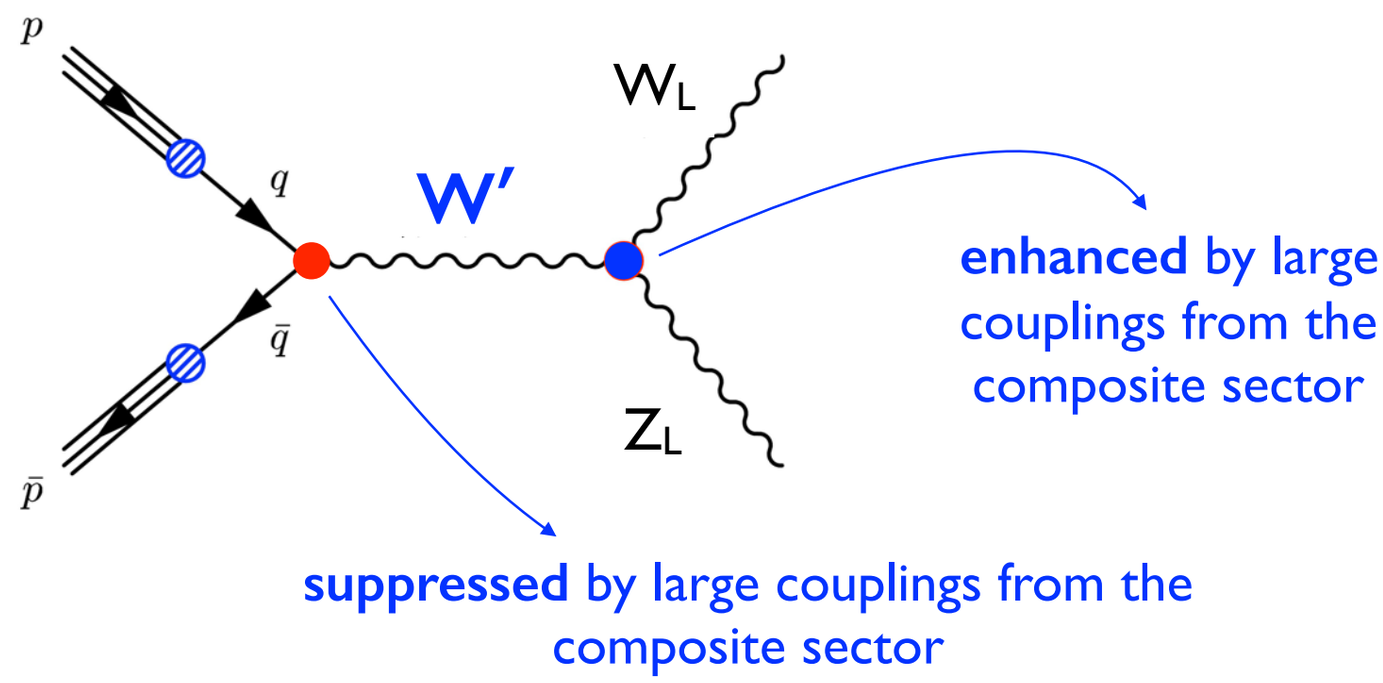
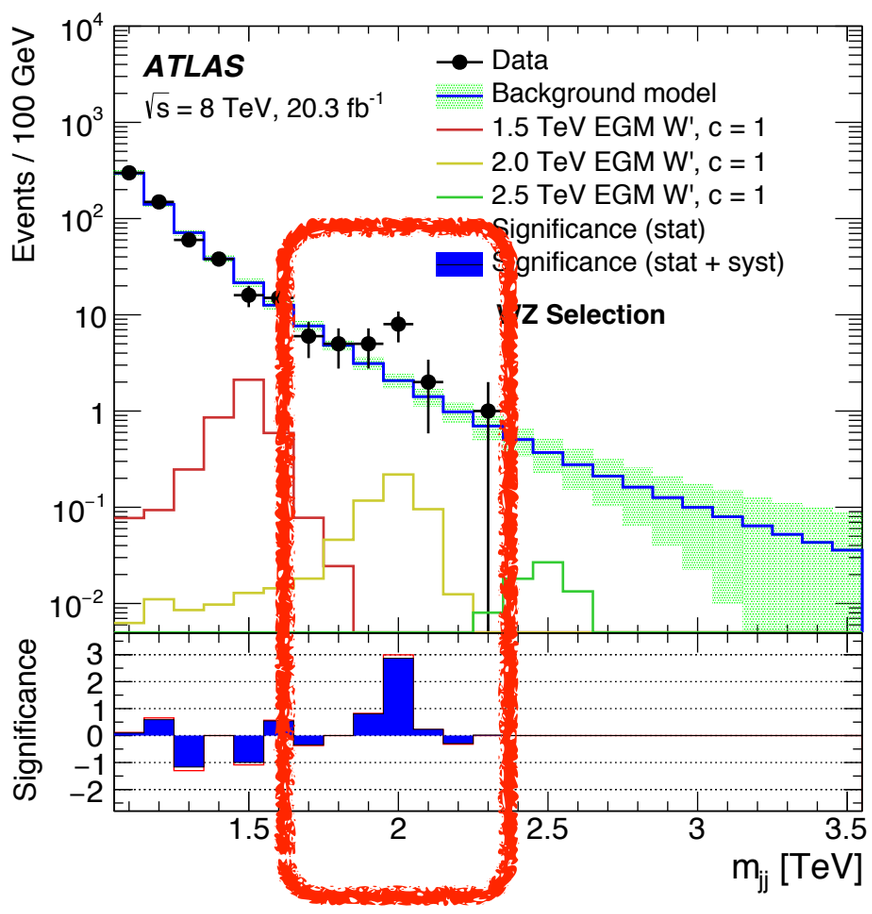
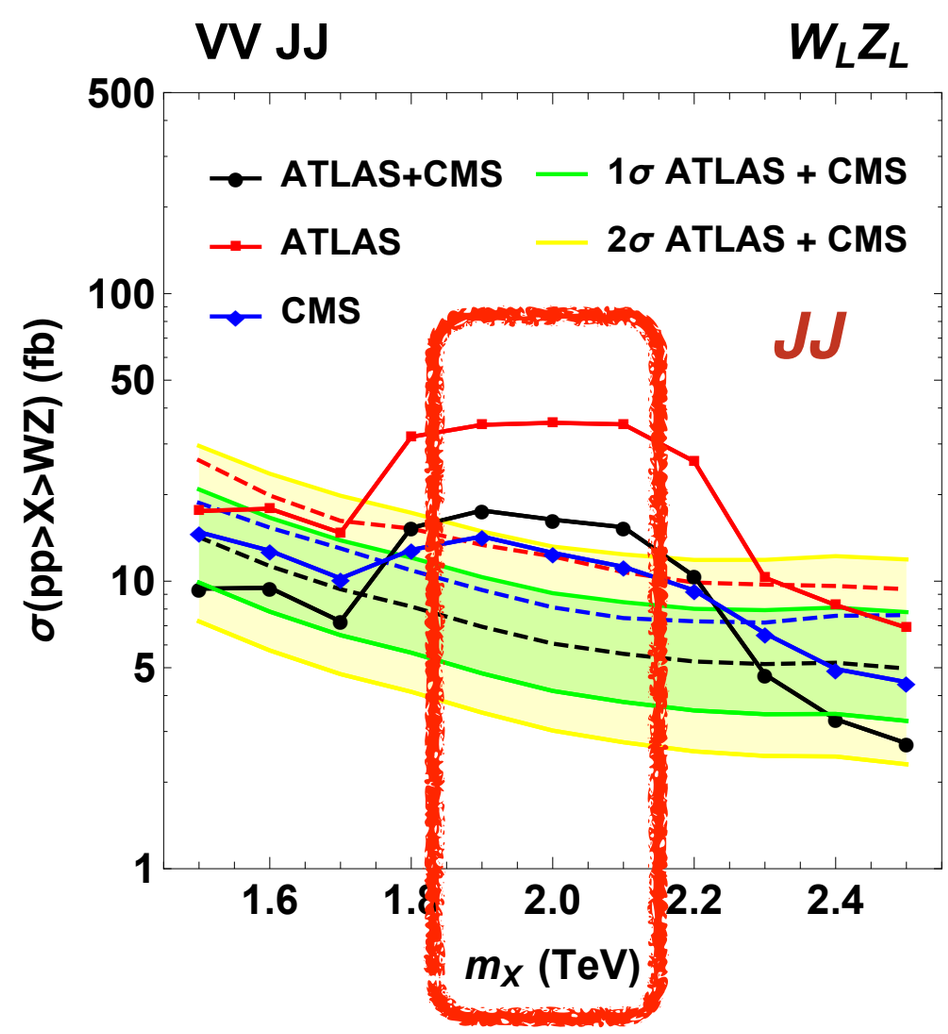


Glimpses at the LHC?

At 8 TeV, some <u>excess</u> in ZW decays (in jets) mostly in ATLAS:





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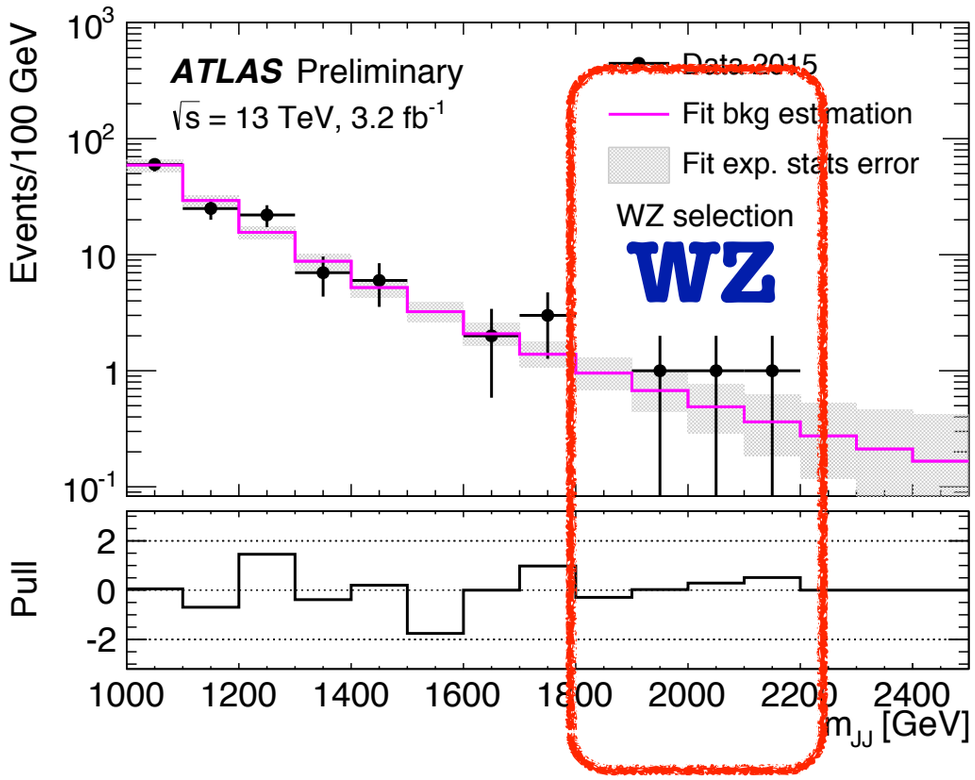
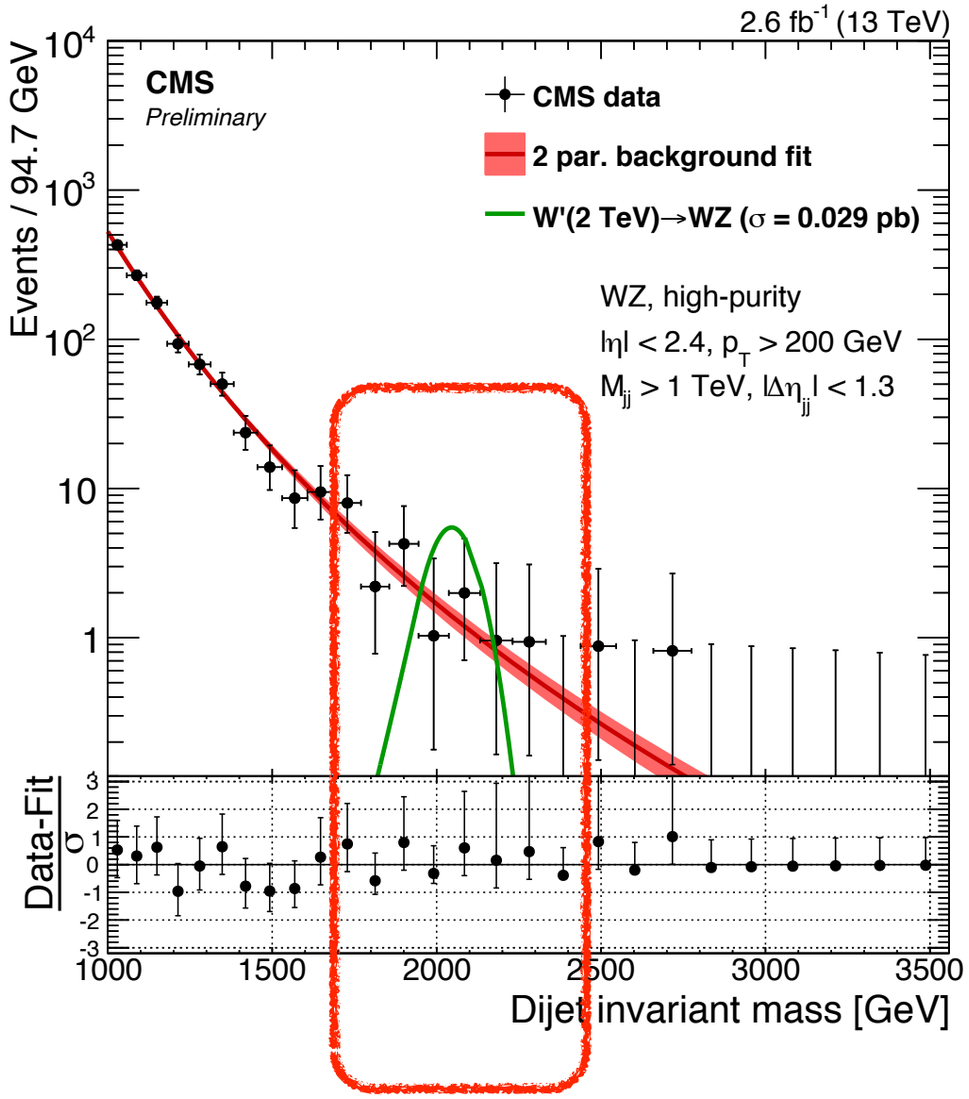
At the LHC 13 TeV…





Not much of a di-Boson excess…

but we are now at the interesting mass scale!

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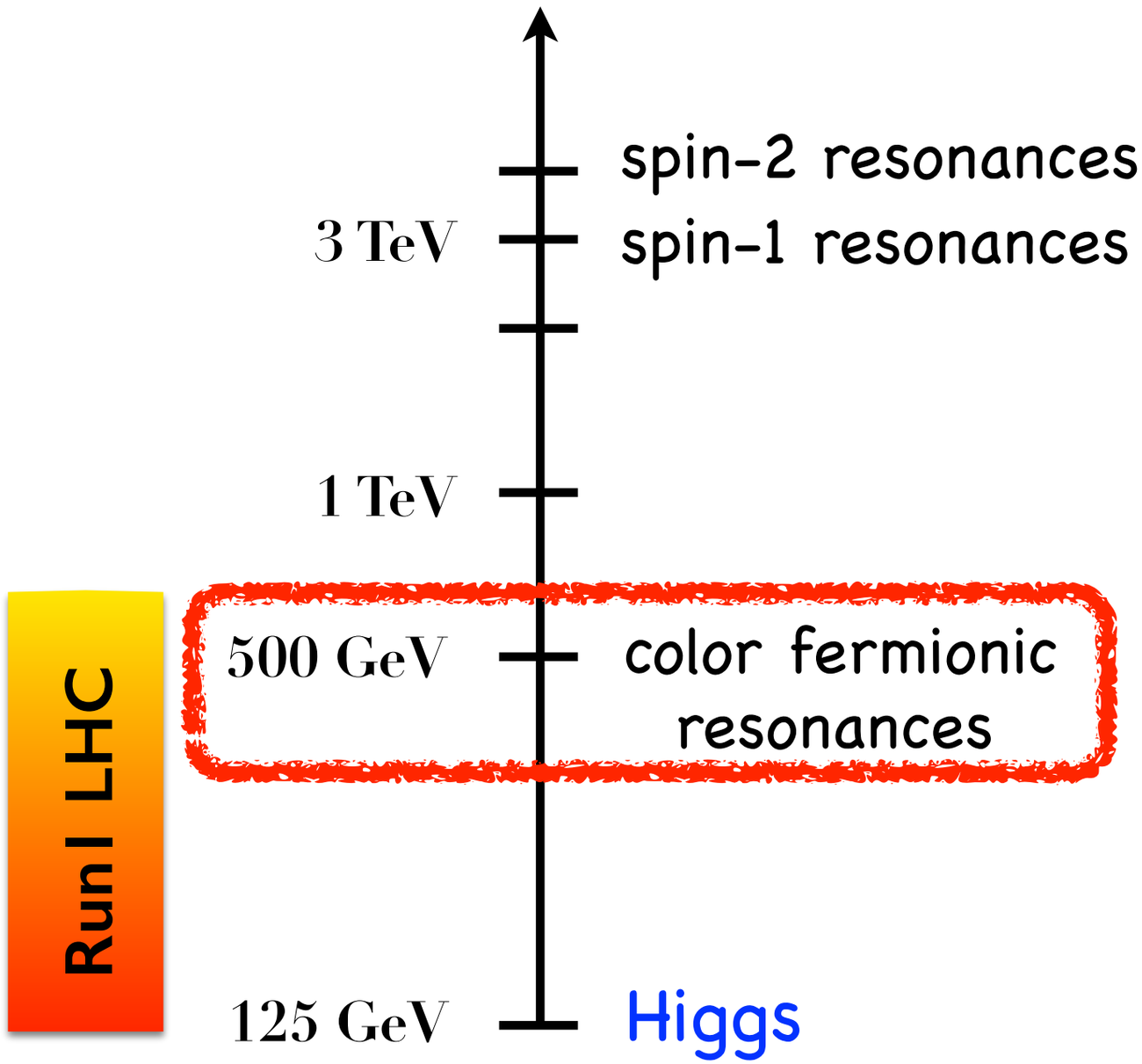
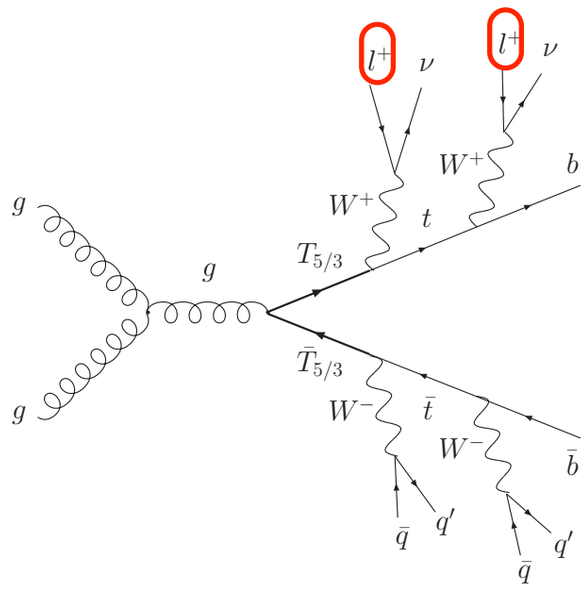
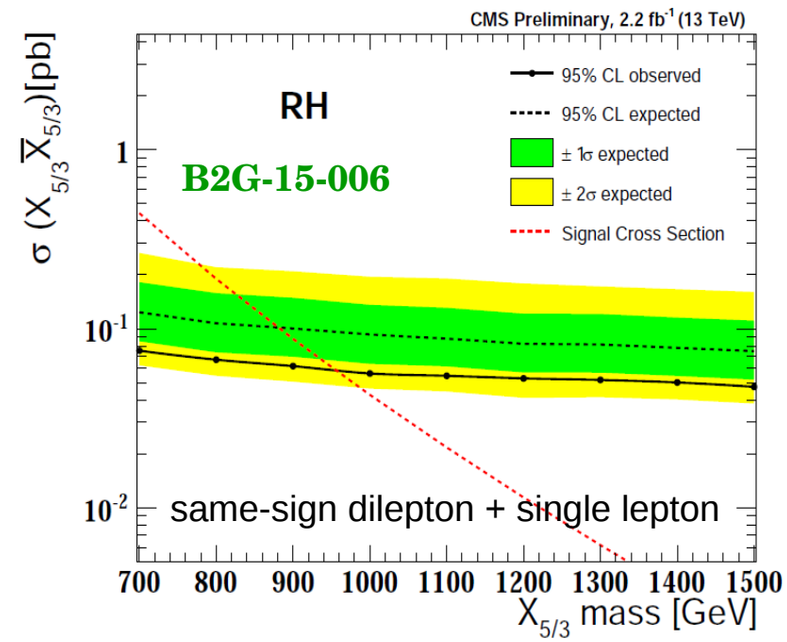


7/8 TeV LHC searches
"scratching the surface"

Colored fermion resonances at LHC 13 TeV





$$\mathbf{m(X_{5/3}) > 960\ GeV}$$

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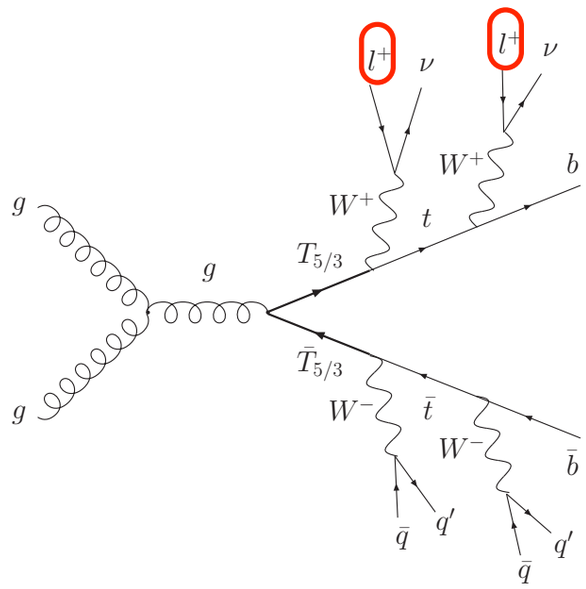

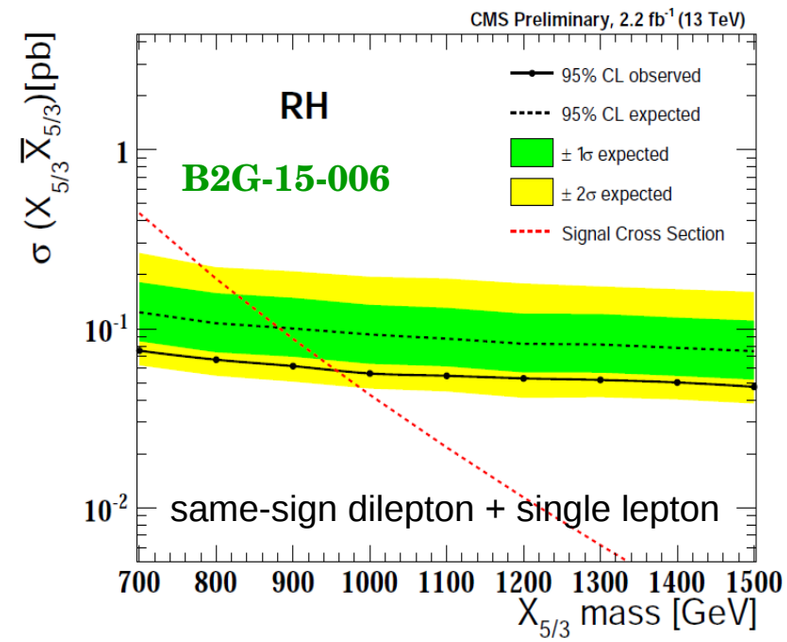

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The situation starts being worrisome..

but not yet desperate

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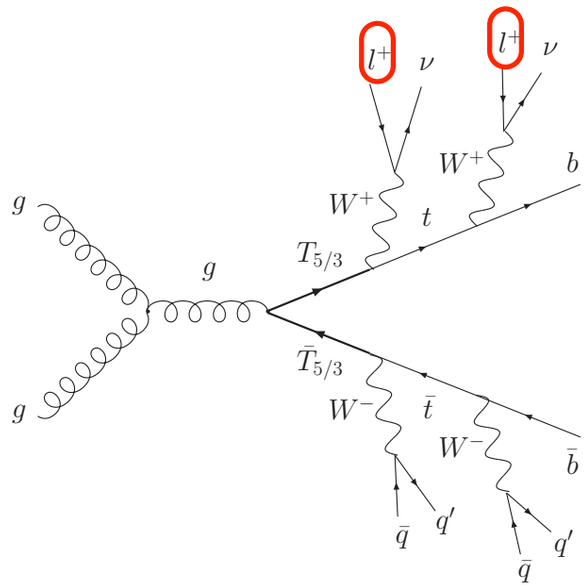

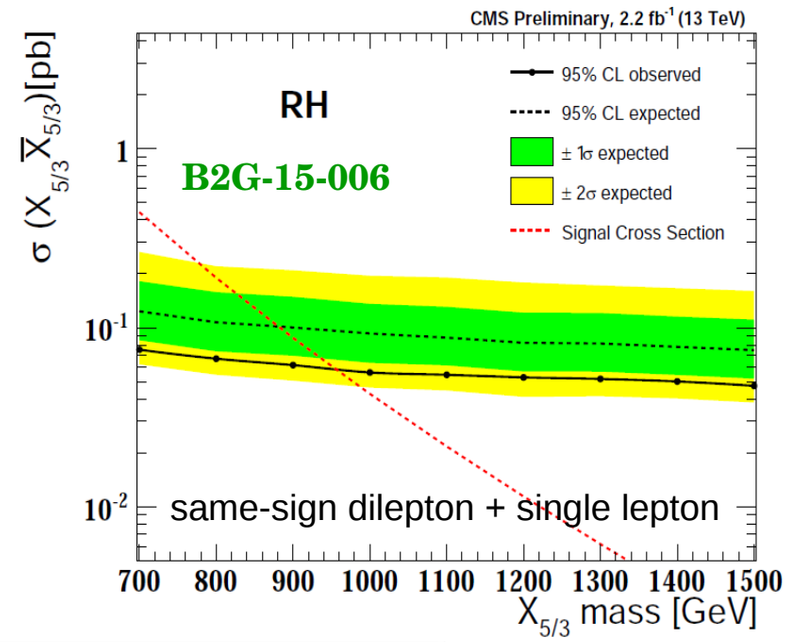

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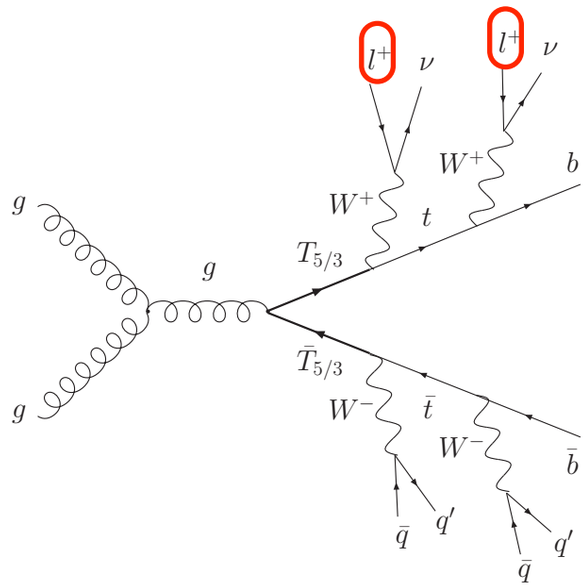

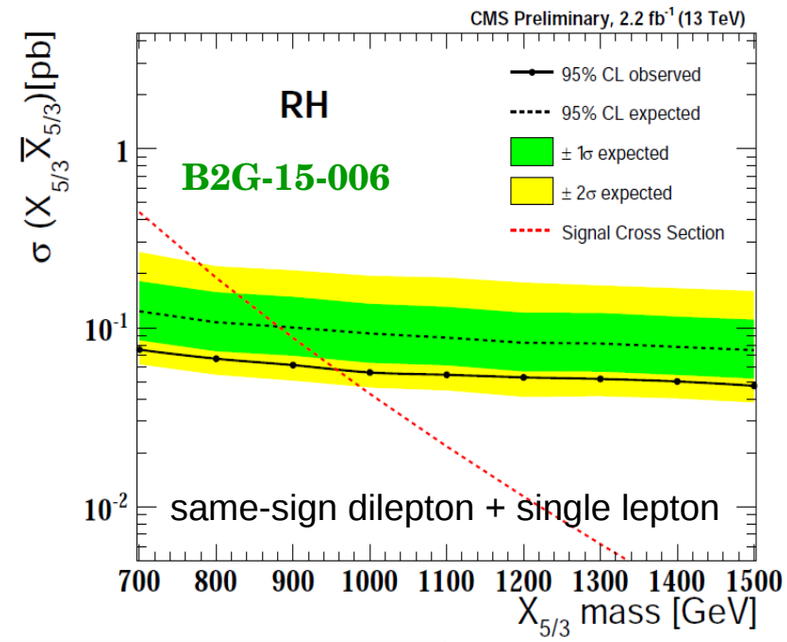

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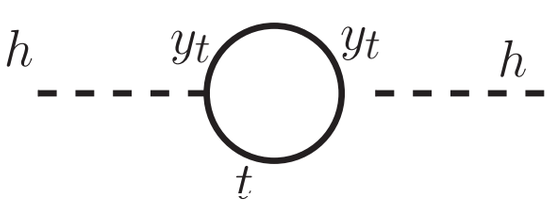
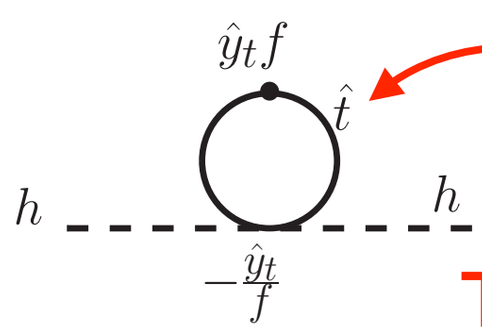
Who is keeping the Higgs light?

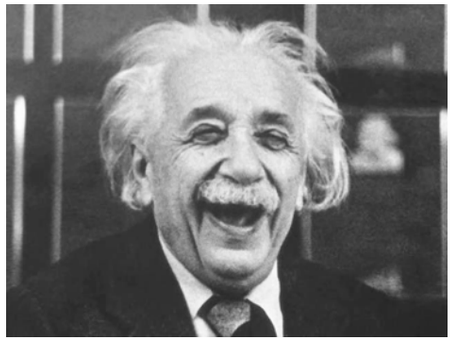




The missing top-partner problem!

“I have second thoughts. Maybe the Lord is malicious”

remark to Vladimir Bargmann, quoted in Einstein in America (1985)



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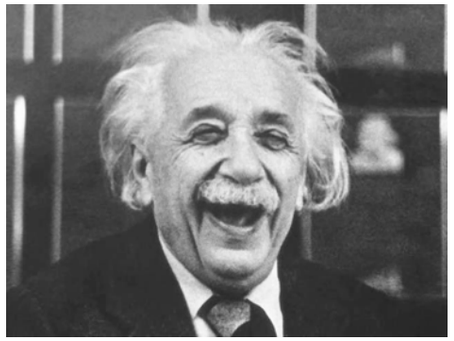
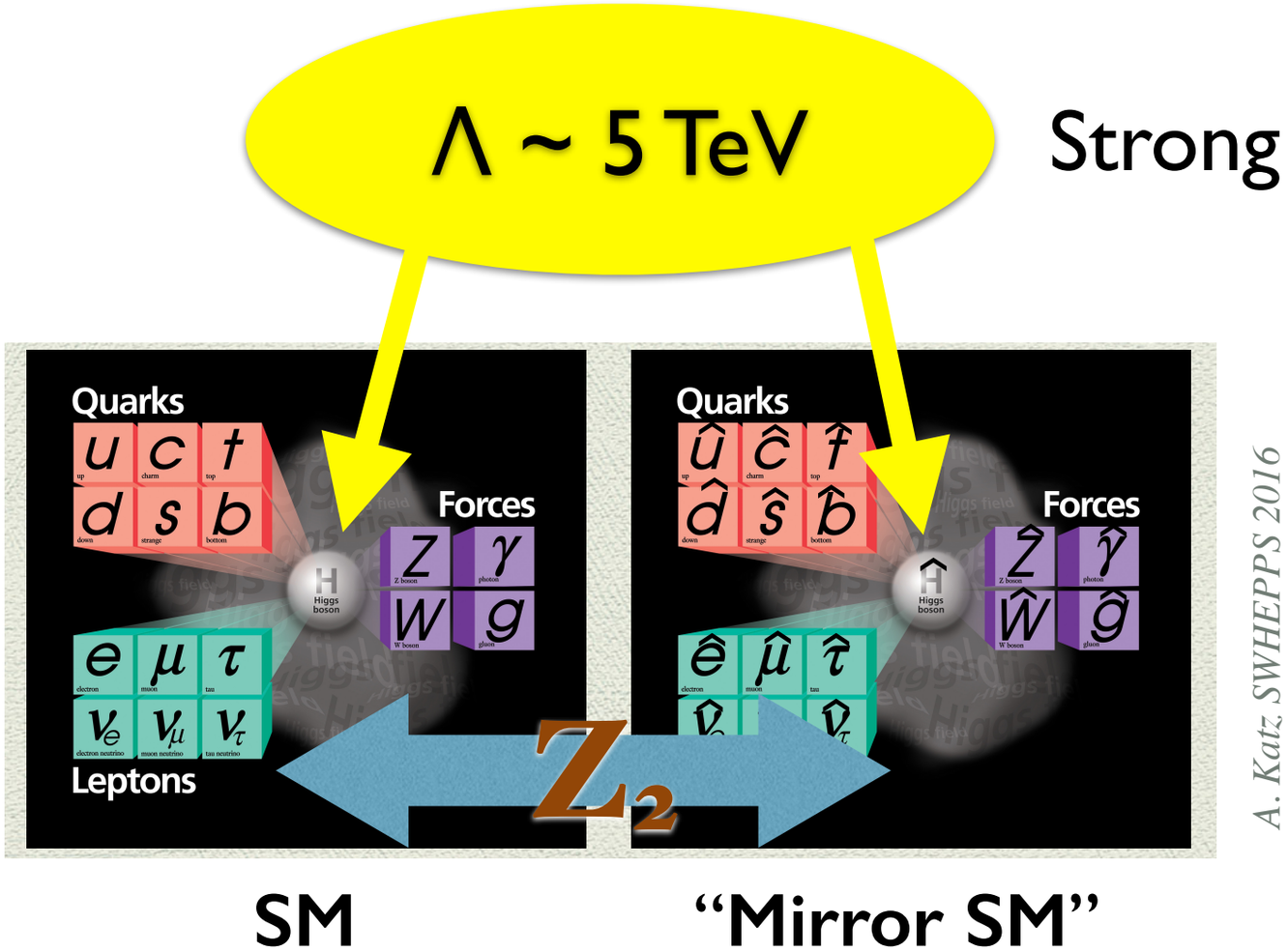


"Twin Higgs" Models:



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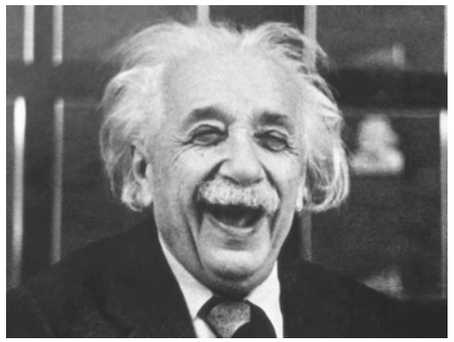
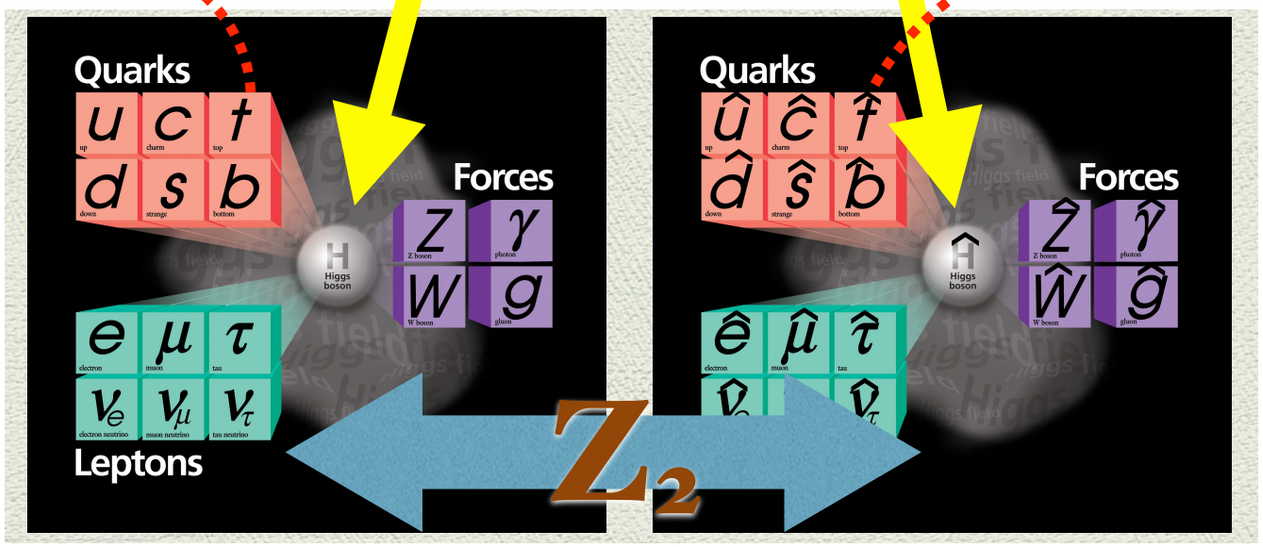


"Twin Higgs" Models:

$\Lambda \sim 5$ TeV

Strong sector



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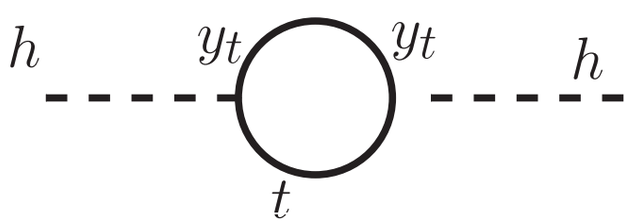
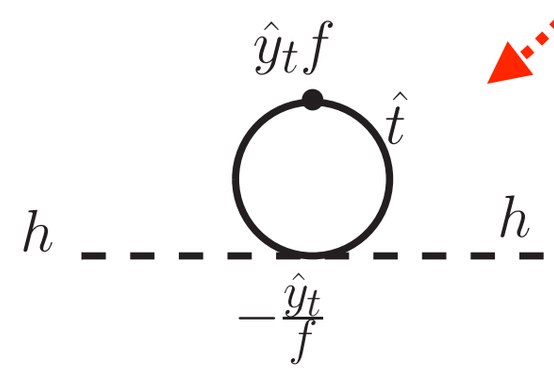
SM

"Mirror SM"

a neutral sector keeps the Higgs light!

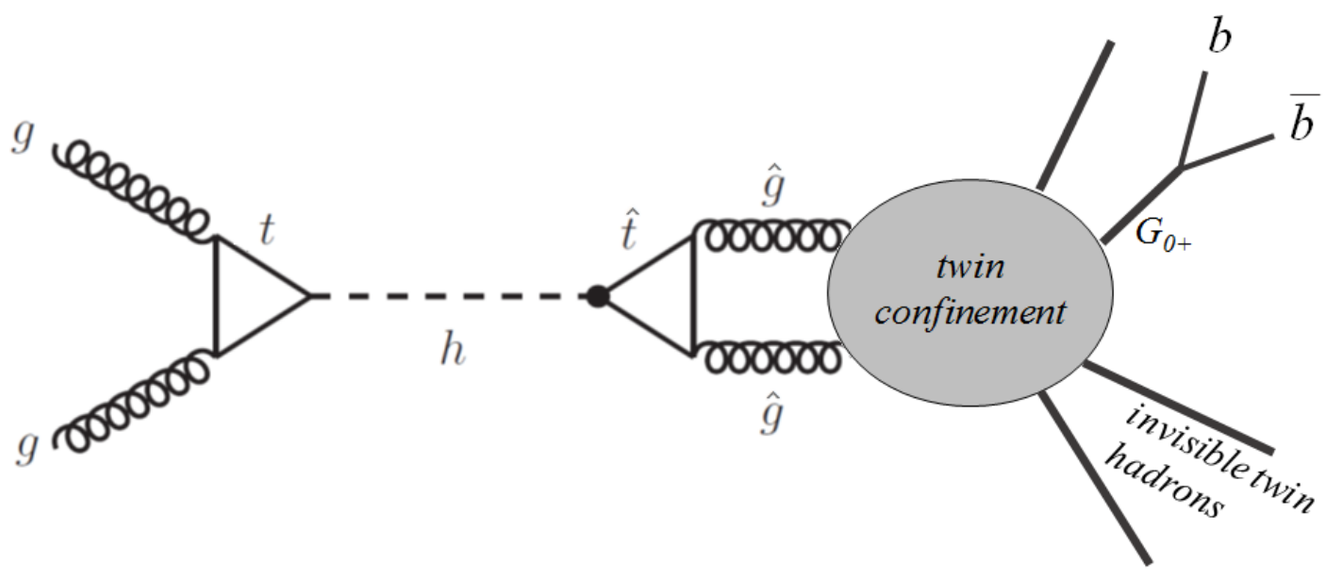




Not possible to see these top-partners at the LHC
as they are **not charged under the SM**

Main LHC signature:
Higgs decays invisibly (to the "mirror" world)
that **could** decay back to us (giving displaced vertices)

arXiv:1501.05310



Higgs portal to the "Mirror SM"

In spite of so much negative results…

”We are allowed to be slightly excited”

CERN Director-General

In spite of so much negative results…

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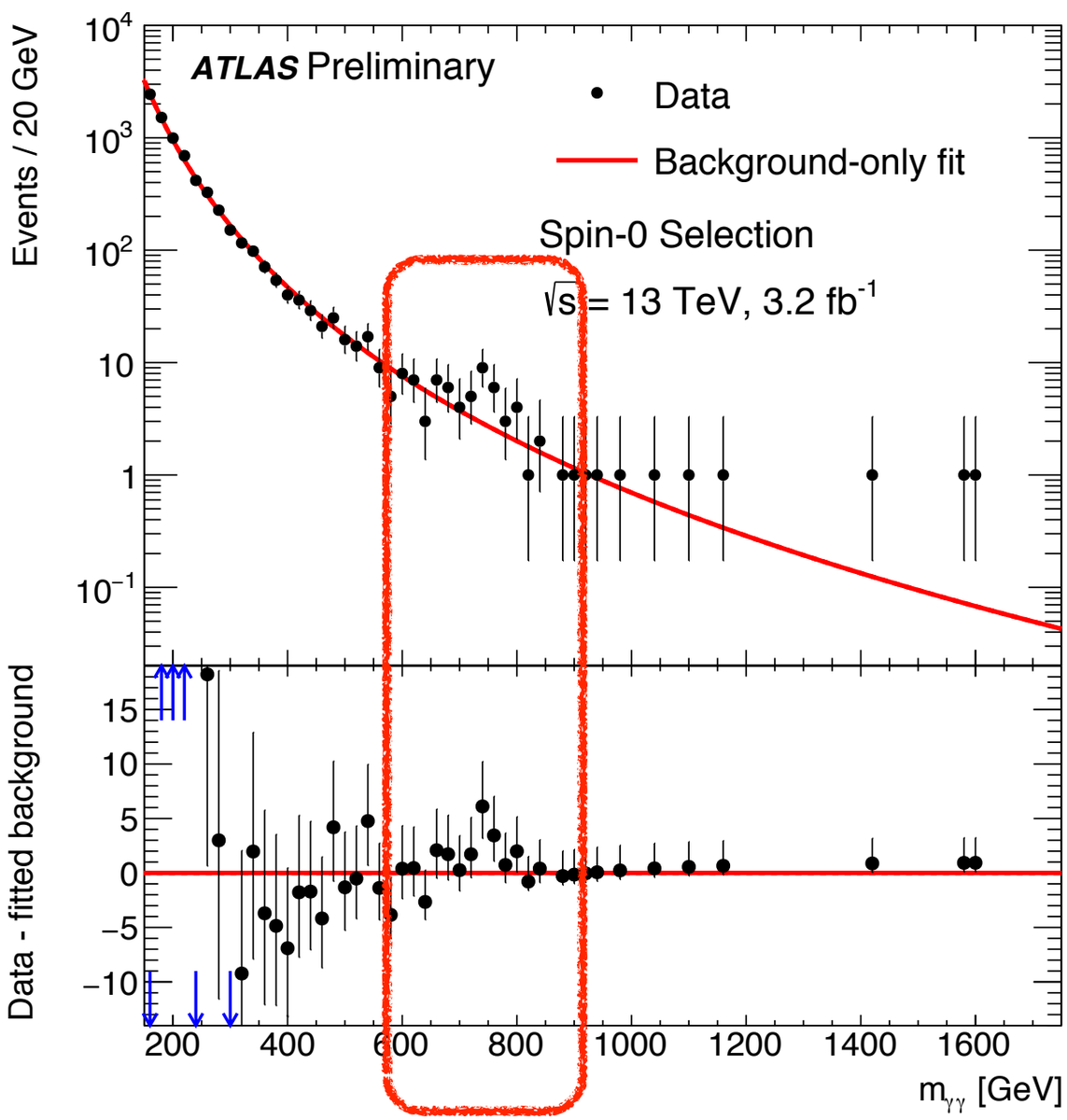
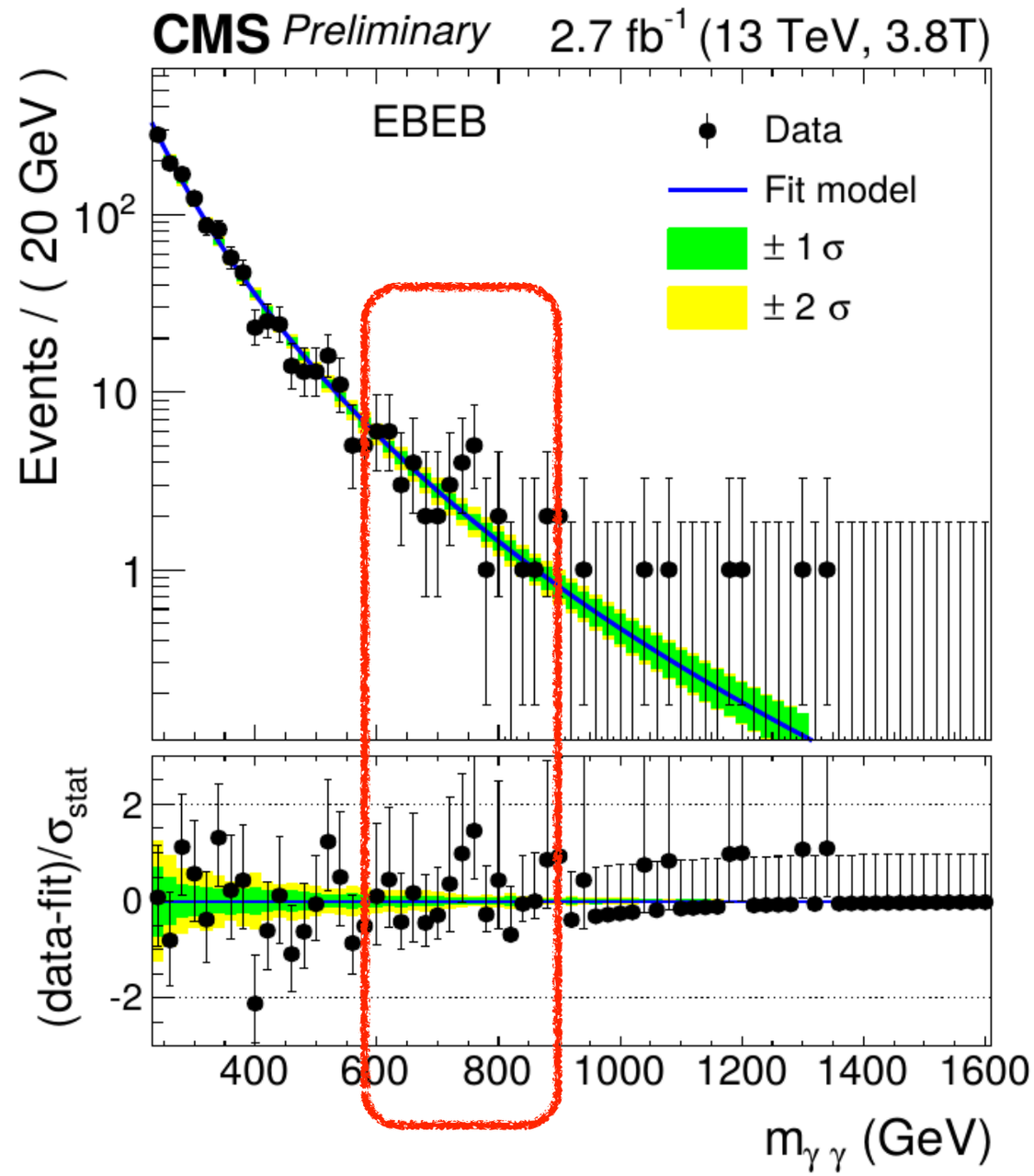
The word *"slightly"* not fully understood by theorists !

The di-photon ANOMALY

An unexpected newcomer?

see also Michele Redi's talk



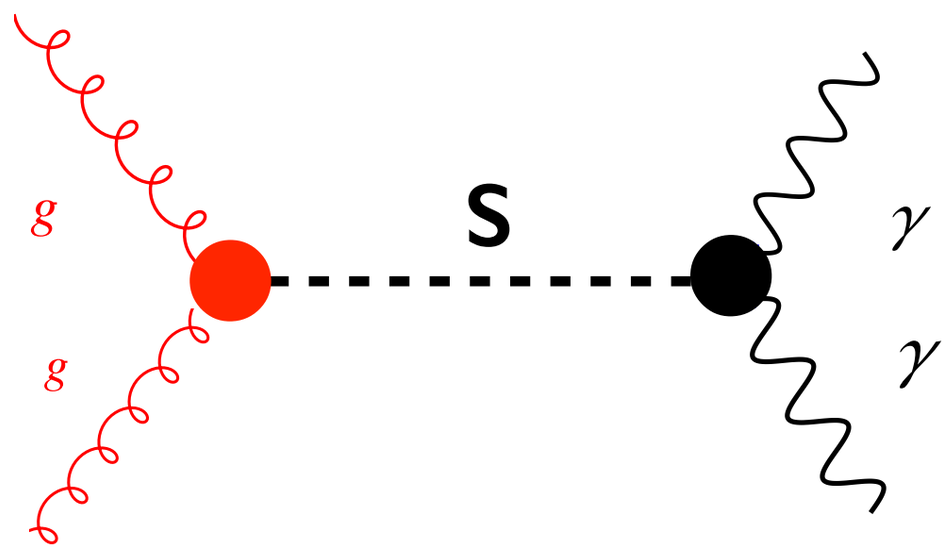


- ✓ $m_X \sim 750$ GeV, $\Gamma_X \sim 45$ GeV (6%)
- ✓ Local Z = **3.9 σ**
- ✓ Global Z = **2.0 σ**

Pointing towards…

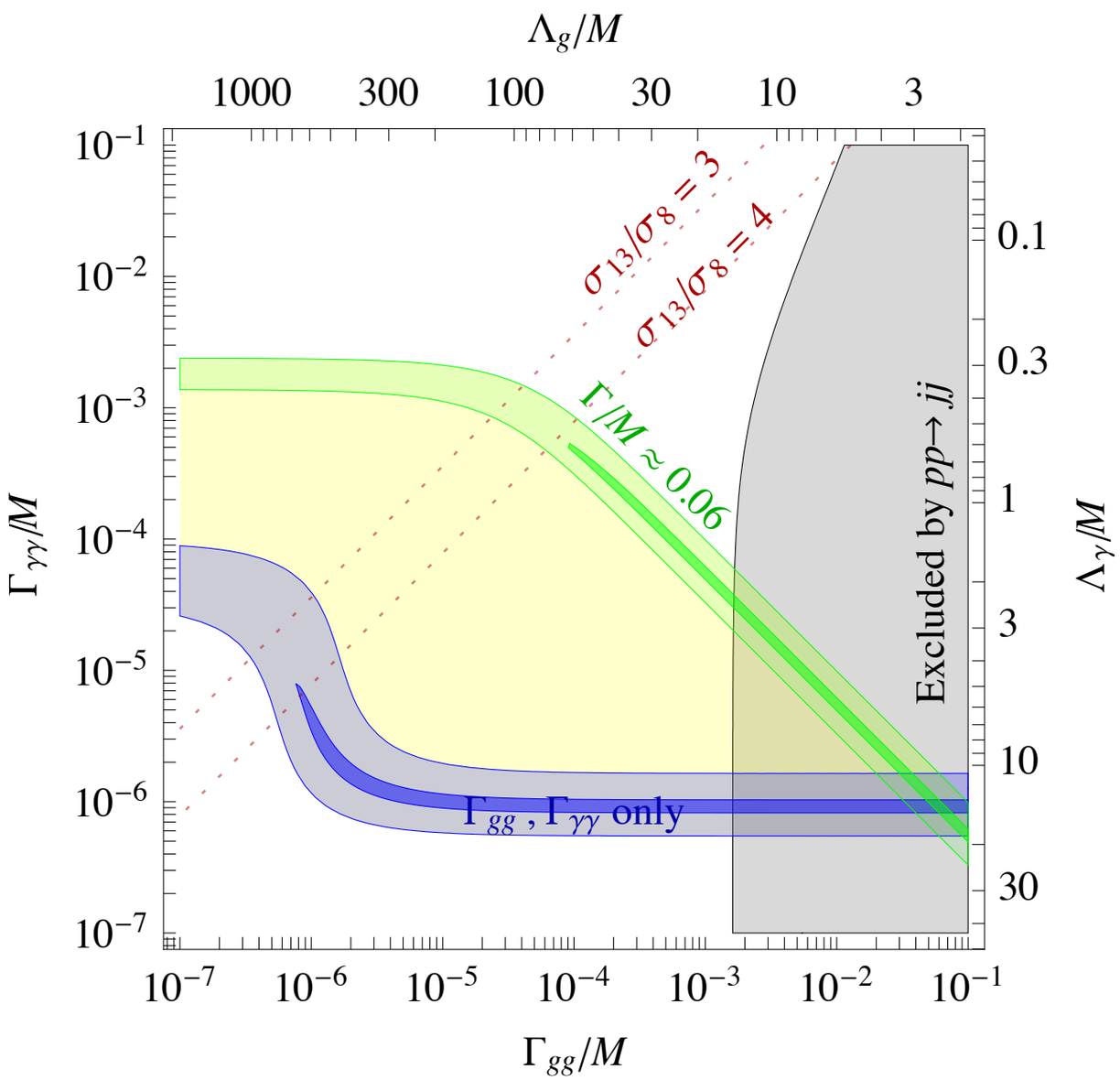
a (pseudo)-scalar of mass 750 GeV

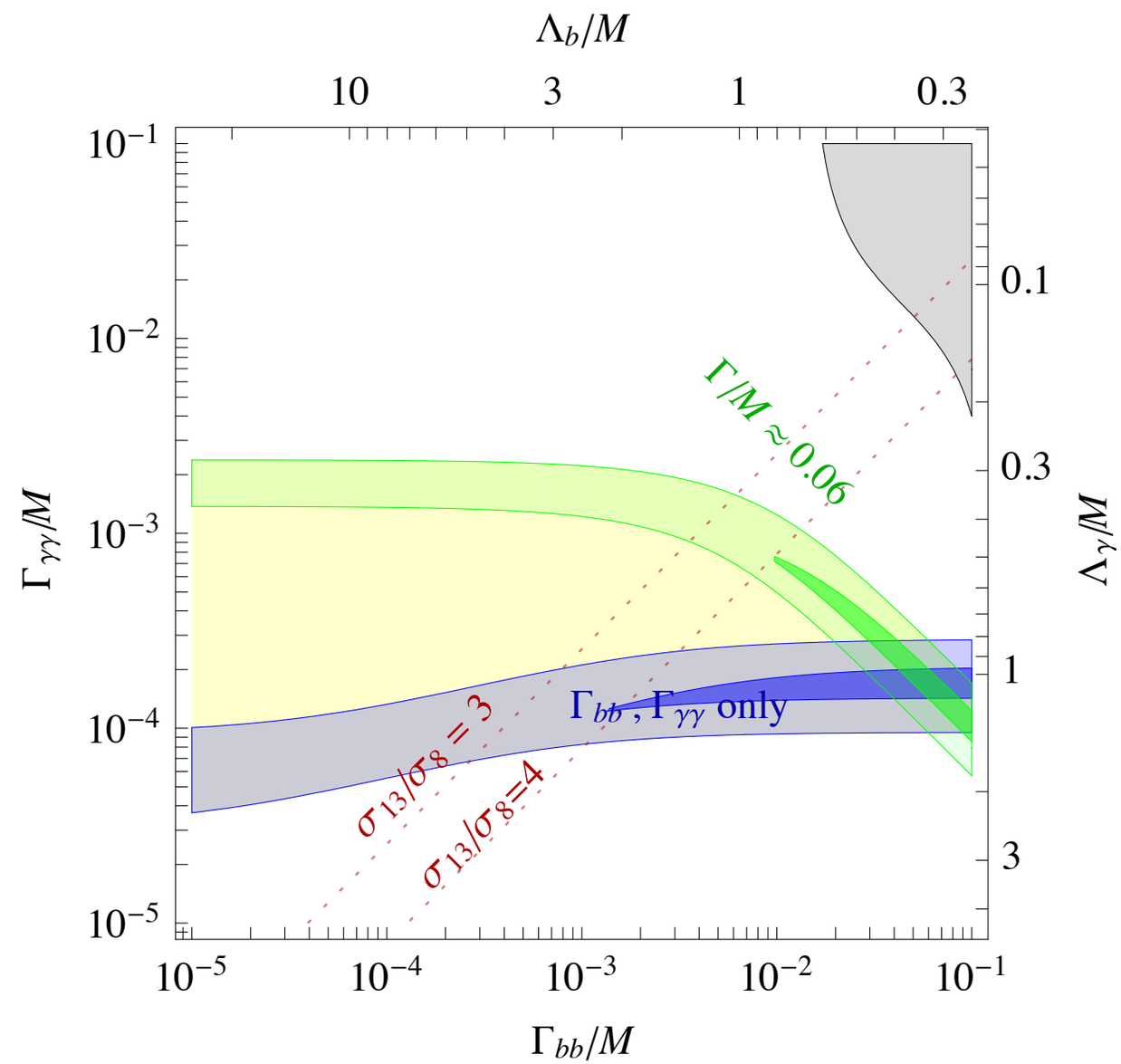
with sizable couplings to photons & gluons (or bottoms)



a width Γ/M of 6% slightly favored!

Required size for partial widths





arXiv:1512.04933

If large width (Γ/M~6%), we must have $\Gamma_{\gamma\gamma}/M \gtrsim 10^{-4}$

What is this S(750) telling us?

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Theorist recent entertainment:

The pleasure (and risk) of extrapolation!

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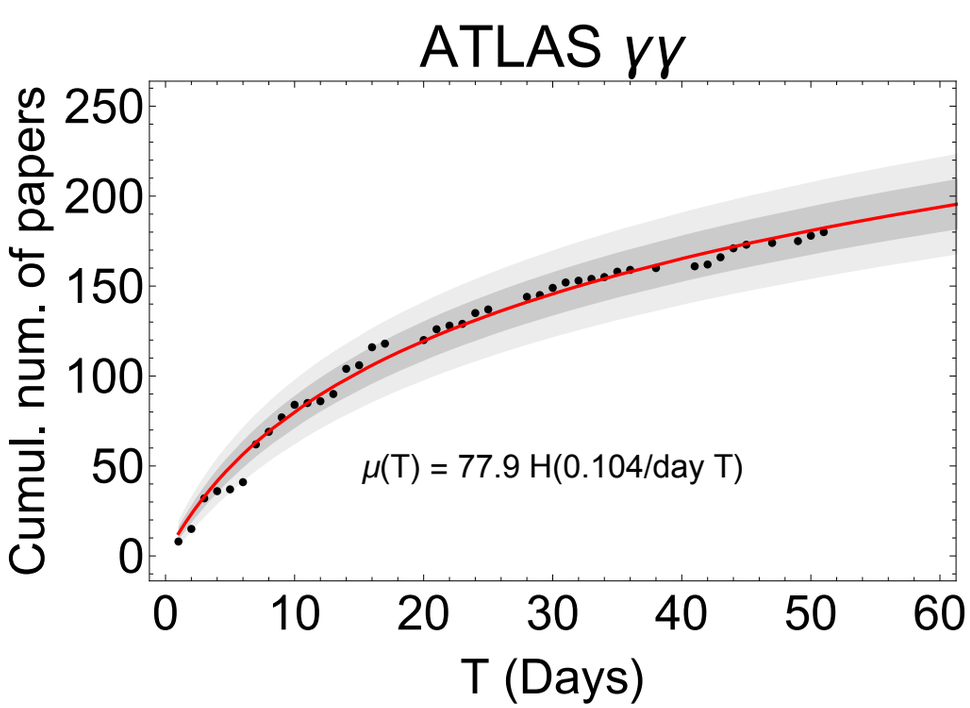

arXiv:1603.01204 [physics.soc-ph]

Above expectations: ~390 in 5 months!

Couplings needed for S(750):

$$\mathbf{S}\,\mathbf{F}^{\mu\nu}\mathbf{F}_{\mu\nu}$$

$$\mathbf{S}\,\mathbf{G}^{\mu\nu}\mathbf{G}_{\mu\nu}$$

(or the CP-odd counterparts)

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- Higgs: $\mathbf{\Gamma_{\gamma\gamma}/m_H \sim 10^{-7}}$ much smaller! ✗
- Axion: but $m_a \ll 750$ GeV! ✗
- SGoldstino in GMSB: but expected heavier ✗
- Goldstone (as pions in QCD)? ✓
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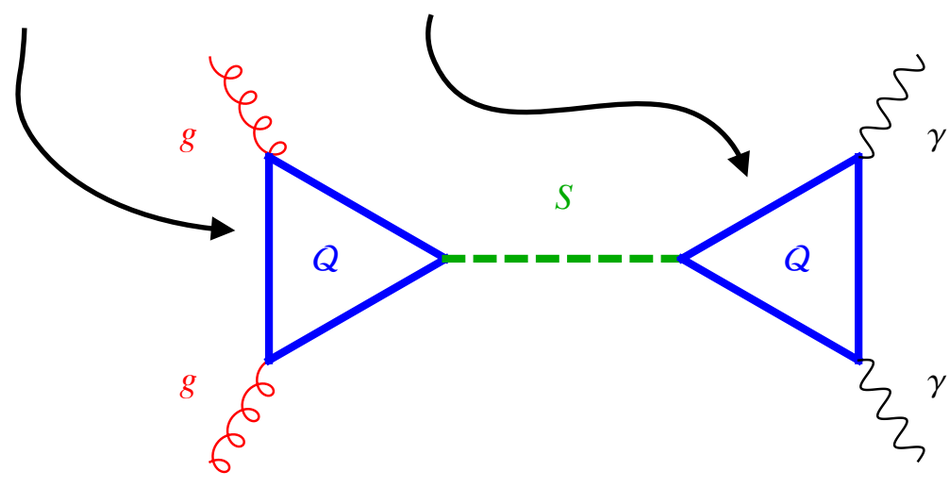
S(750) as an extra Higgs

☛ many Higgs in supersymmetric models:

MSSM + Singlet = NMSSM

↳ can be accommodated to be the 750

BUT, extra **colored & charged states** needed !



Smallest width: $N_{\text{fermions}} \sim 6$

Large width (6%): $N_{\text{fermions}} \sim 60$

$$\times \left(\frac{1}{Q_f}\right)^2 \left(\frac{1}{y_f}\right) \left(\frac{M_f}{750\ \text{GeV}}\right)$$

↳ **Sick theory: Couplings blow-up below M_P**

☛ more must be added at higher energies

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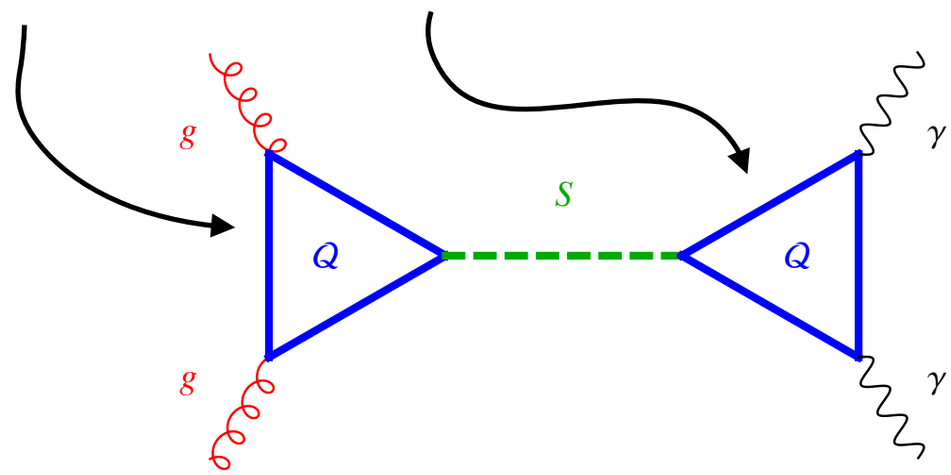

Why so much extra matter there?
Possible, but not expected!

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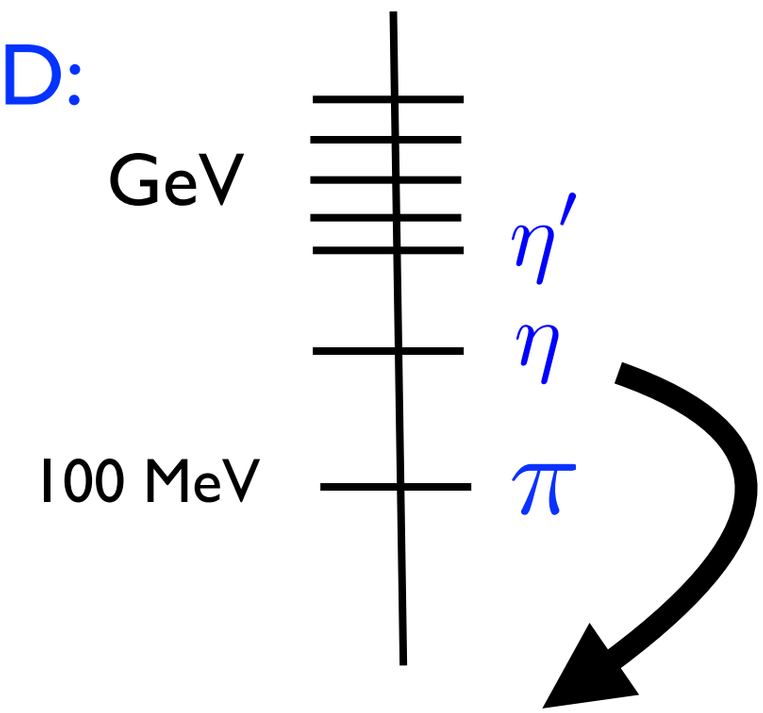
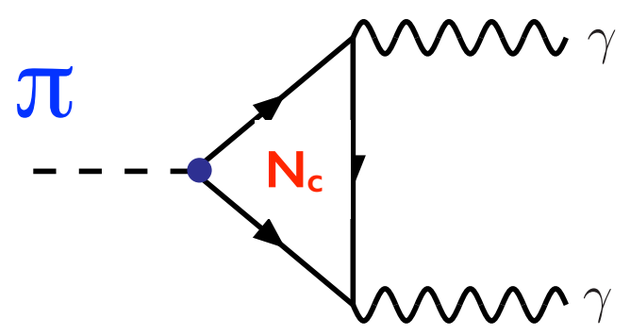
S(750) as a Pseudo-Goldstone

Lessons from QCD:



Lighter as they are Pseudo-Goldstone bosons (PGB)

☛ pseudo-scalars have sizable couplings to photons:



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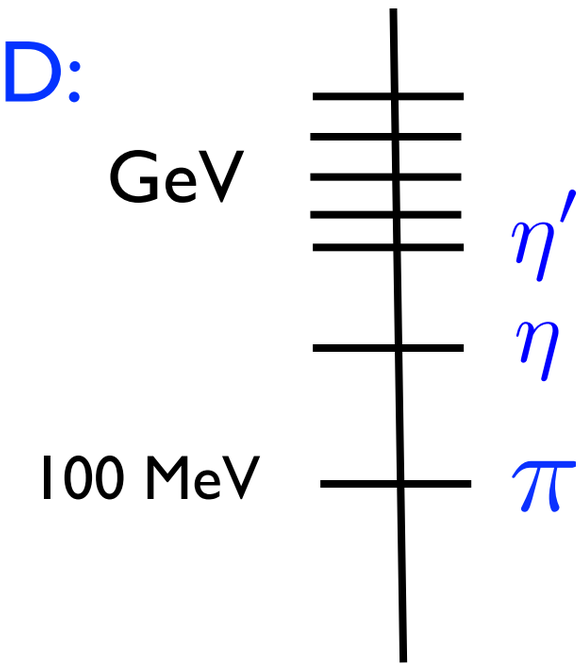
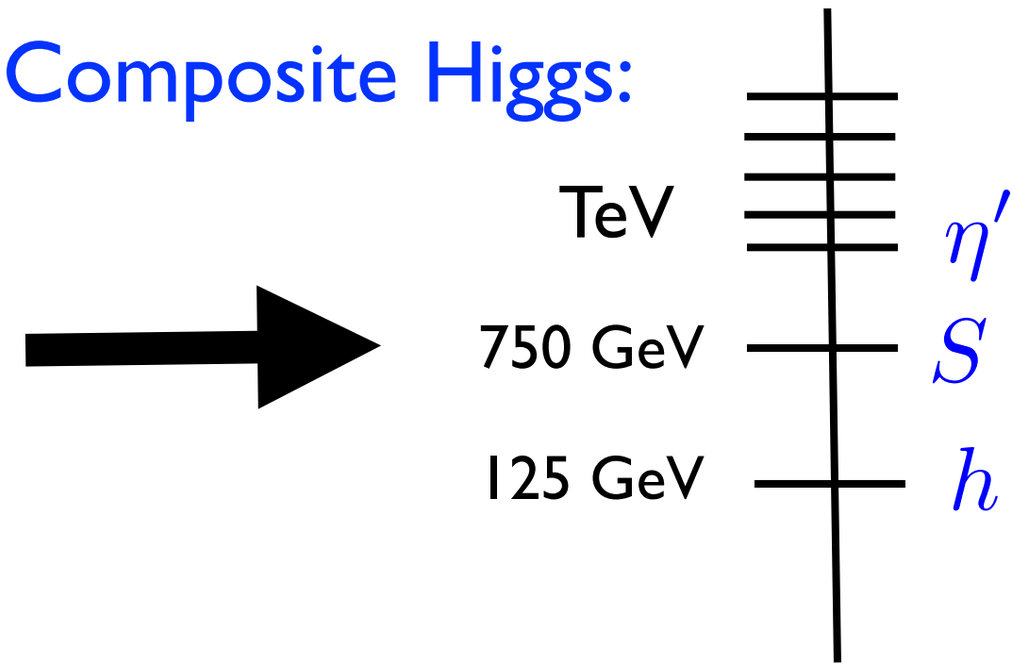


Composite Higgs:



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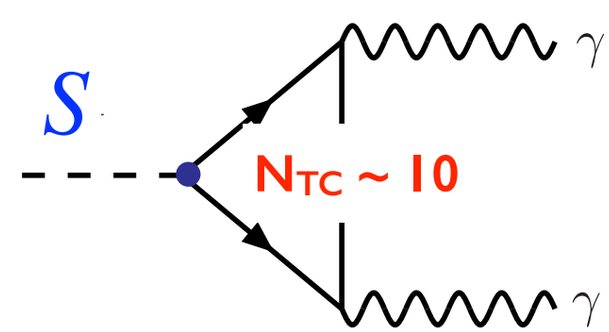
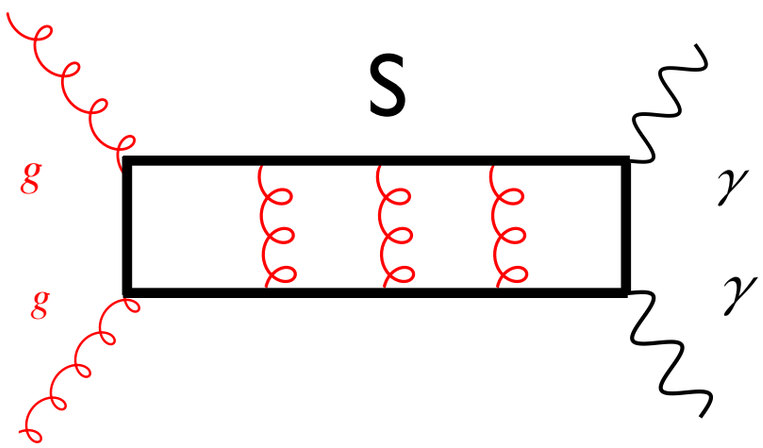


S(750) as a Quarkonium

= 

QCD
bound state

arXiv:1602.08819

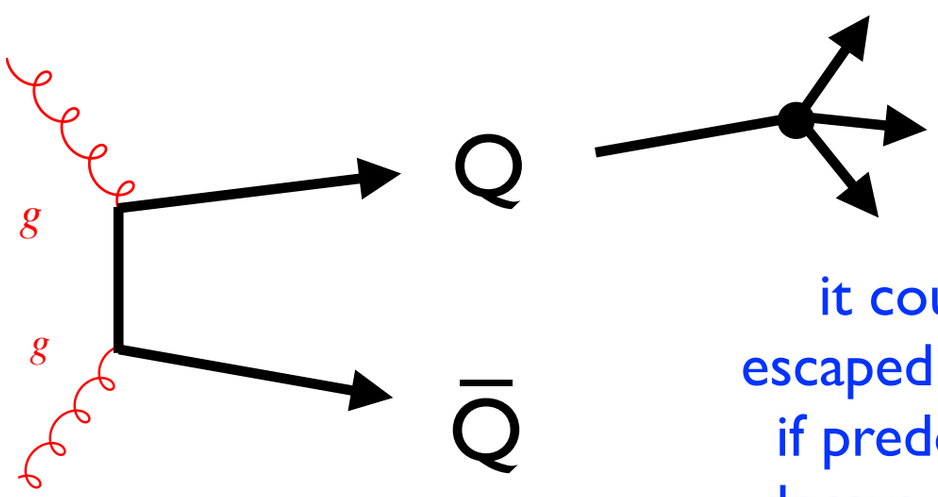


Q: new vector-like quark

m_Q = 750/2 GeV =375 GeV

|EM-charge| ≥ 4/3

But also possible double-production of **Q**:



it could have
escaped detections
if predominately
decays to 3 quark

Signal: pp→jjj+jjj

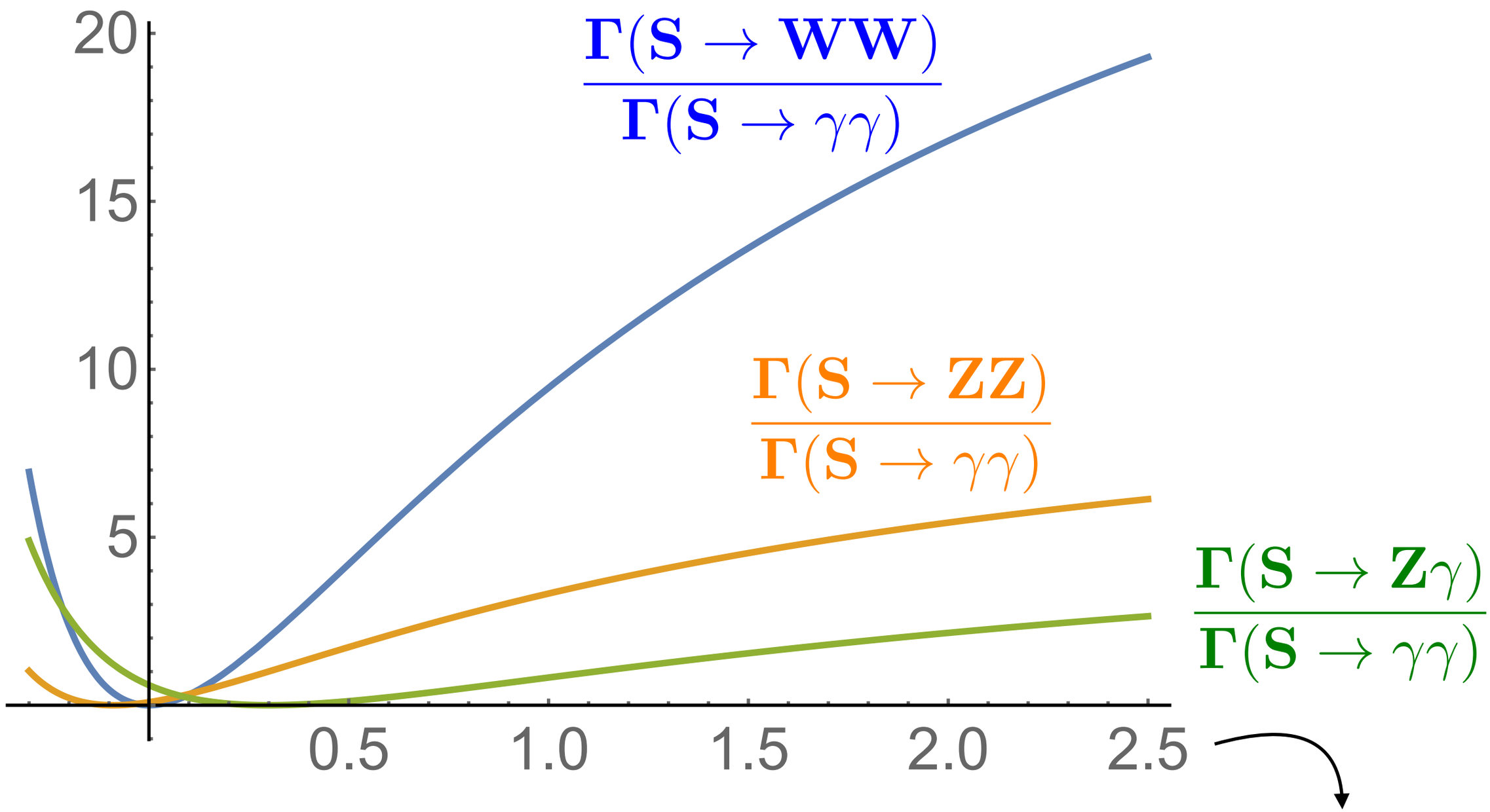
Still the question, why is m_Q around the EW scale?

For the future…

"Consistency checks" for the future

SU(2)$_L$ invariance implies:

(lower-bounds for CP-even S)



ratio of coefficients of the SU(2)$_L$ invariant operators

"Consistency checks" for the f

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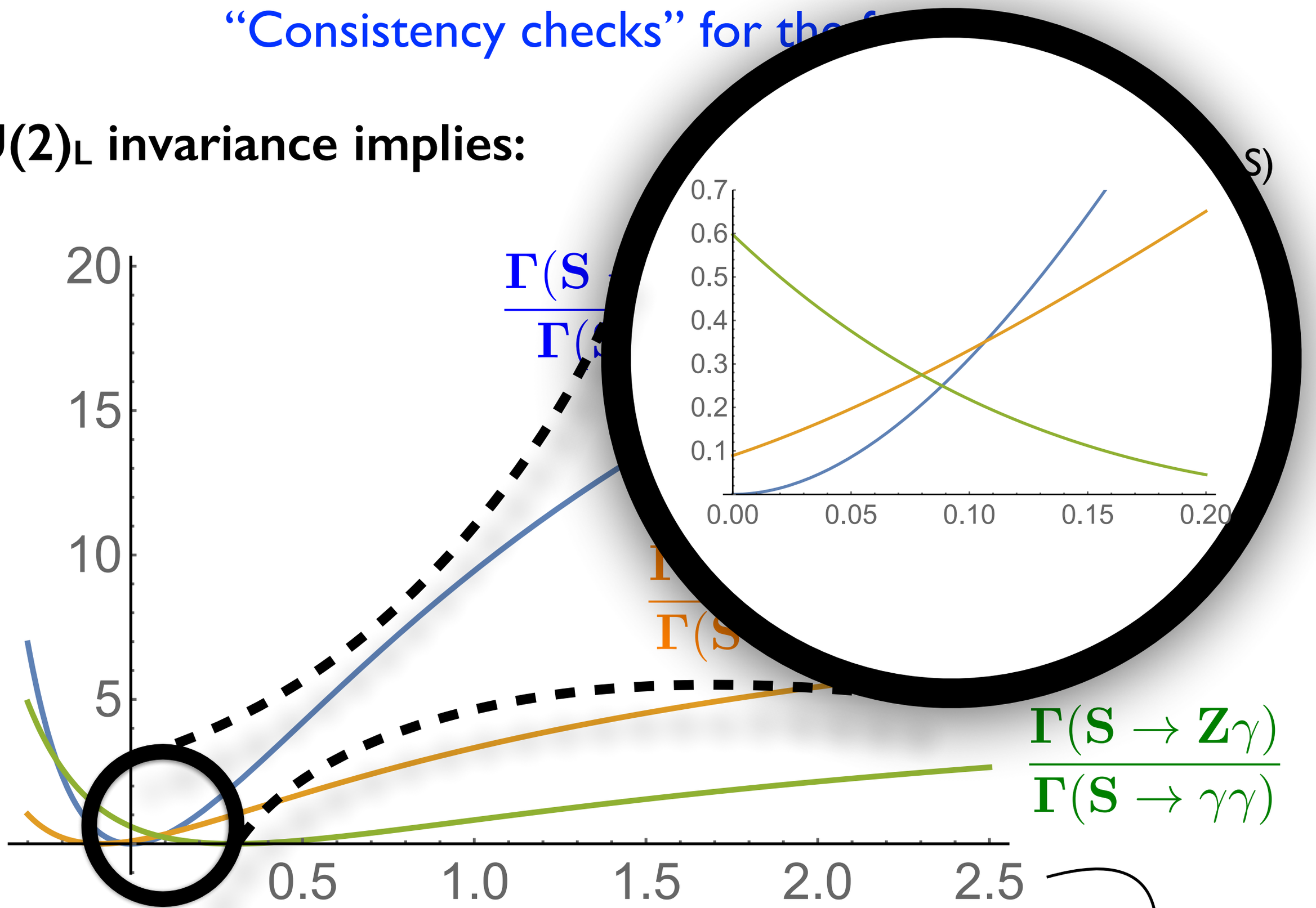

ratio of coefficients of the SU(2)$_L$ invariant operators

Important things we want to know:

(similar as the Higgs scrutinization, but here different priority list)

- **Is it real?**
- Assure that it's a scalar & whether has narrow or broad width

  ☛ possibly with more $\gamma\gamma$

- CP-odd or CP-even?

  ☛ look at distributions in **$pp \to Sjj$** and/or in **$S \to ZZ$** if found

- Surrounded by other scalars?

  (complex field? $\to$2 states, weak-doublet? $\to$4 states, …)

  ☛ look around as EWSB-effects are small: **$m_W \ll M_S$!**

- Its couplings: search for new decays & production mechanisms

Conclusions

- The long-awaited **13 TeV collider** is finally here!

  Main aim: learn on the origin of the SM electroweak scale

  First rounds: **Mostly Negative Results!**
- **Missing top-partner problem** becoming more severe

  but we must *dig* more to see how serious it is!
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If true, a lot more waiting to be discovered!

Thank you!