Anomaly inspired new physics searches

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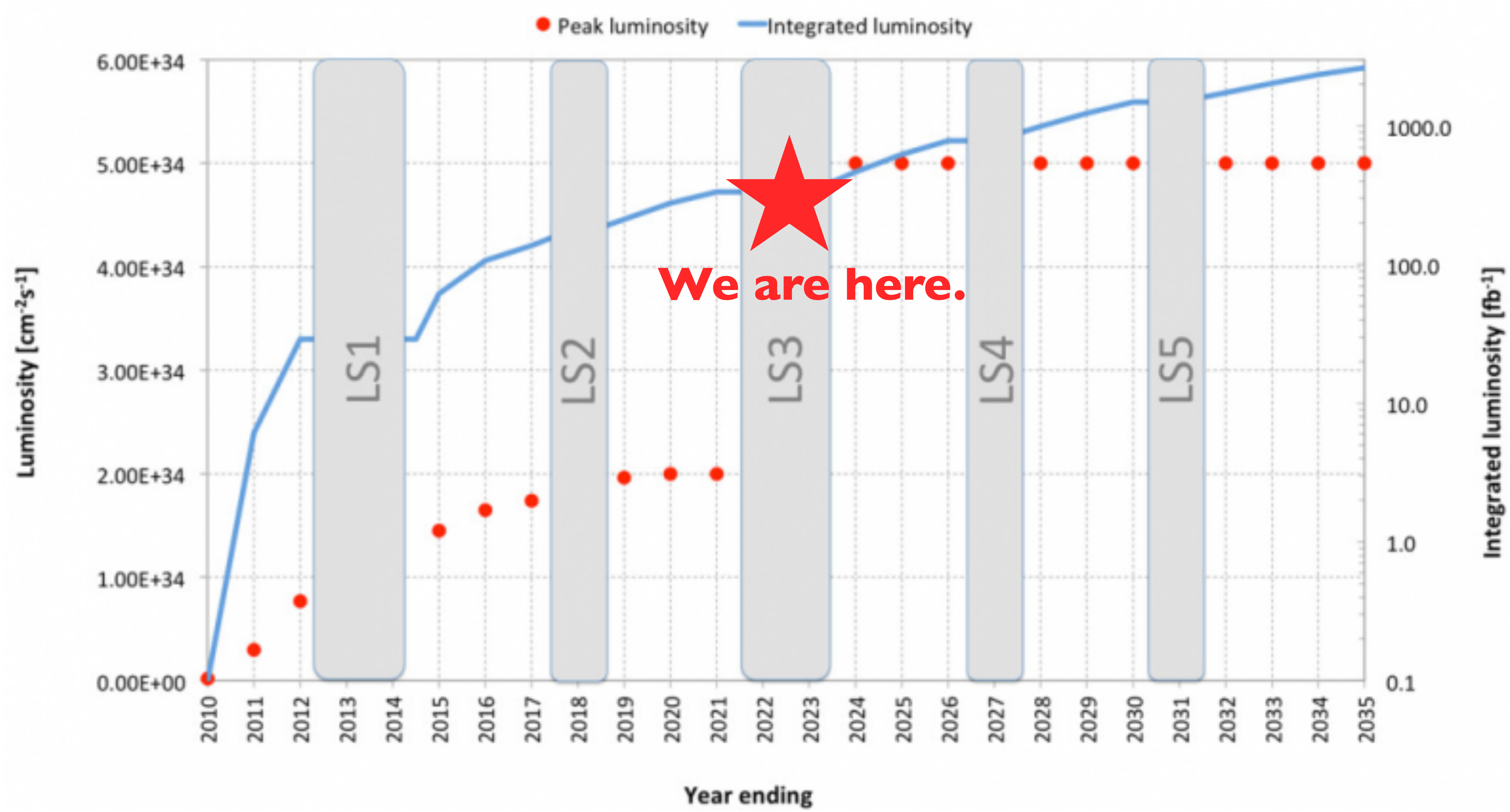
MEPA 2022. USTC. Dec 18.

The immediate future



Still about 10 times amount of data to come.

Most immediate question:
How to fully realize the potential of the LHC?

Bread and butter

For the coming couple of decades:

Filling gaps

Precision measurements: Higgs coupling etc.

Rare processes: exotic decays (h, W, Z, t), LLP

A lot of important physics to do!

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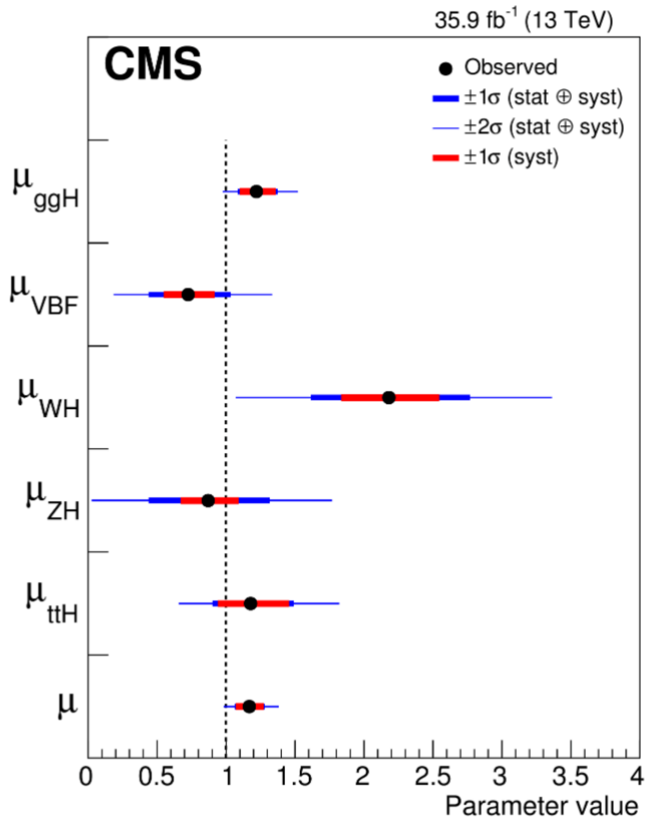
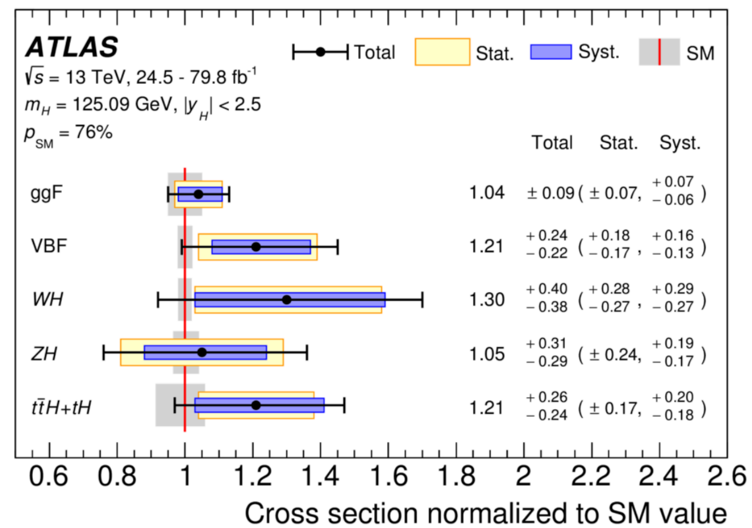
Precision: all eyes are on the Higgs

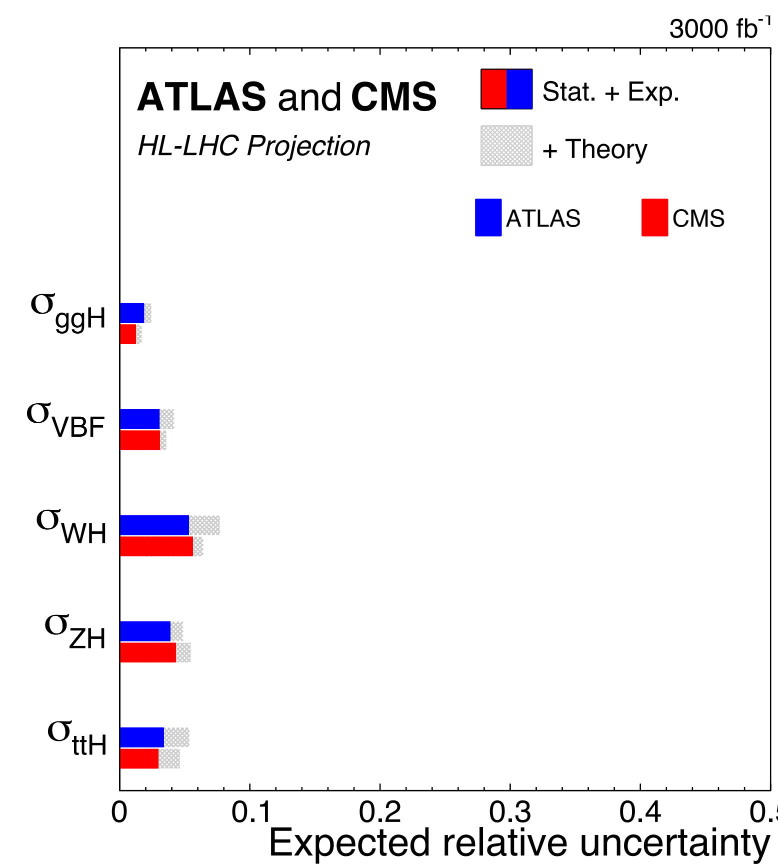
K. Köneke's talk at this conference





Current precision: 10(s)%

A few Percent by the end of the LHC



1902.00134

For the coming couple of decades:

Filling gaps

Precision measurements: Higgs coupling etc.

Rare processes: exotic decays (h, W, Z, t), LLP

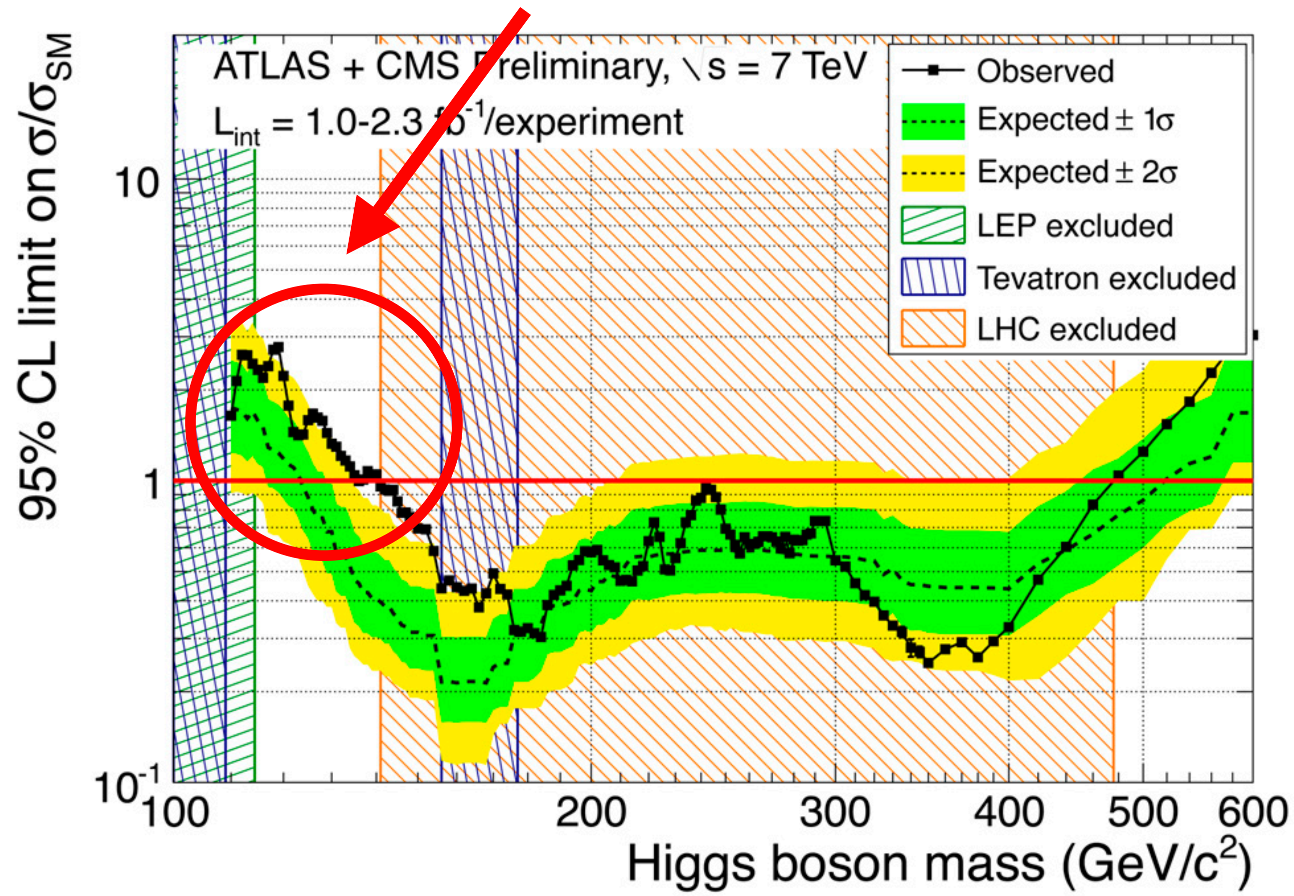
A lot of important physics to do!

The gaps

New physics could be exactly where our searches lose sensitivity.

Can Nature be this smart? Or we be this unlucky?

Remember this gap?

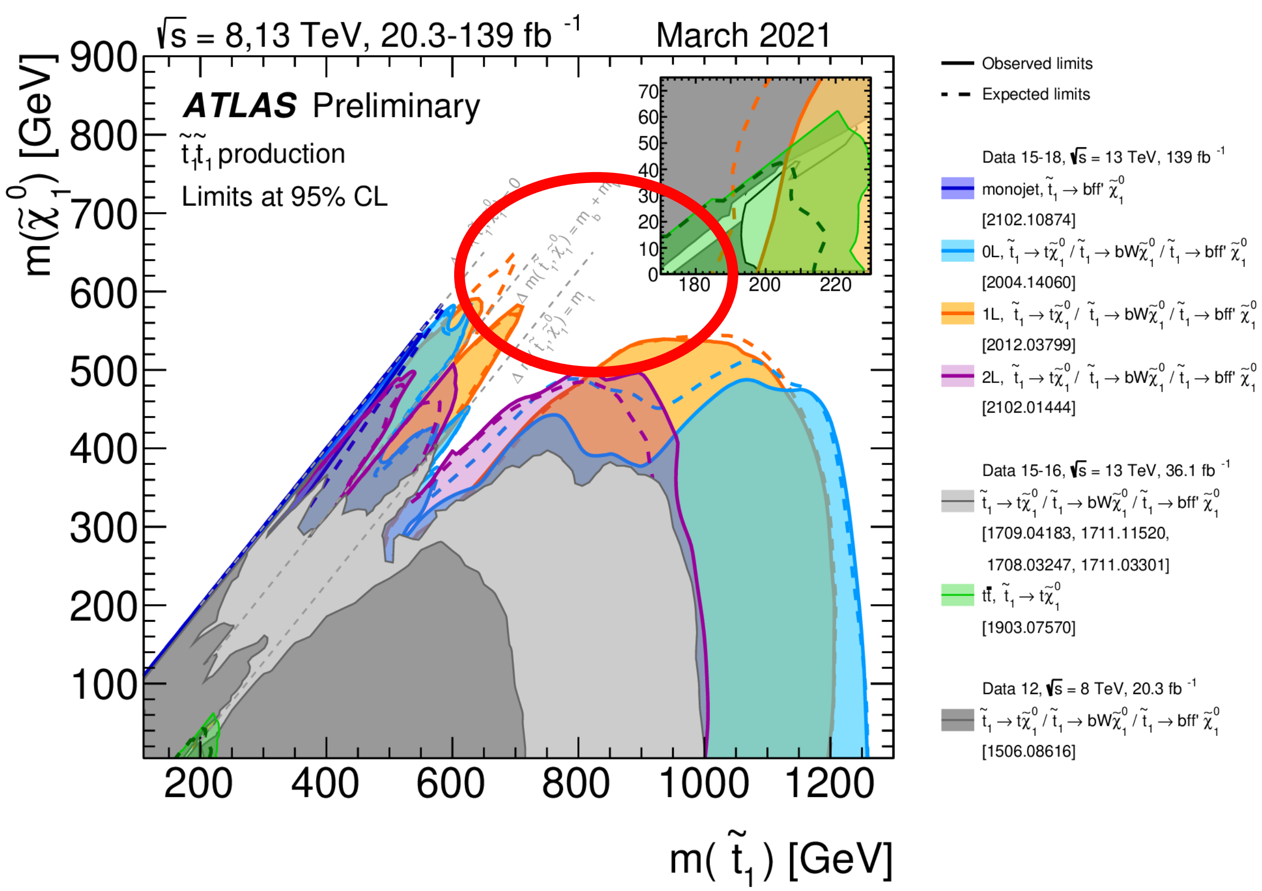


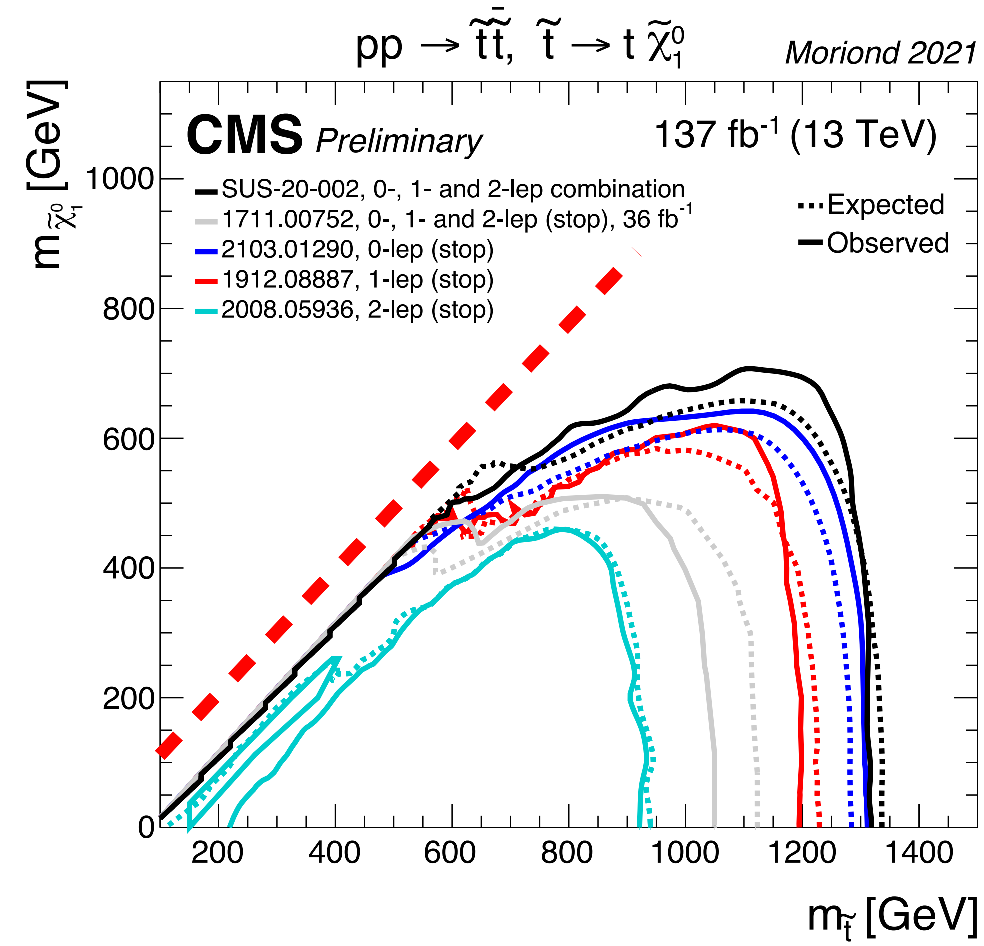
Higgs search,
on the eve of discovery

New physics could be exactly where our searches lose sensitivity.

Can Nature be this smart? Or we be this unlucky?

Stop gaps





Well known. Strong motivation.

A lot of effort went into it. Certainly worth covering as much as we can.

For the coming couple of decades:

Filling gaps

Precision measurements: Higgs coupling etc.

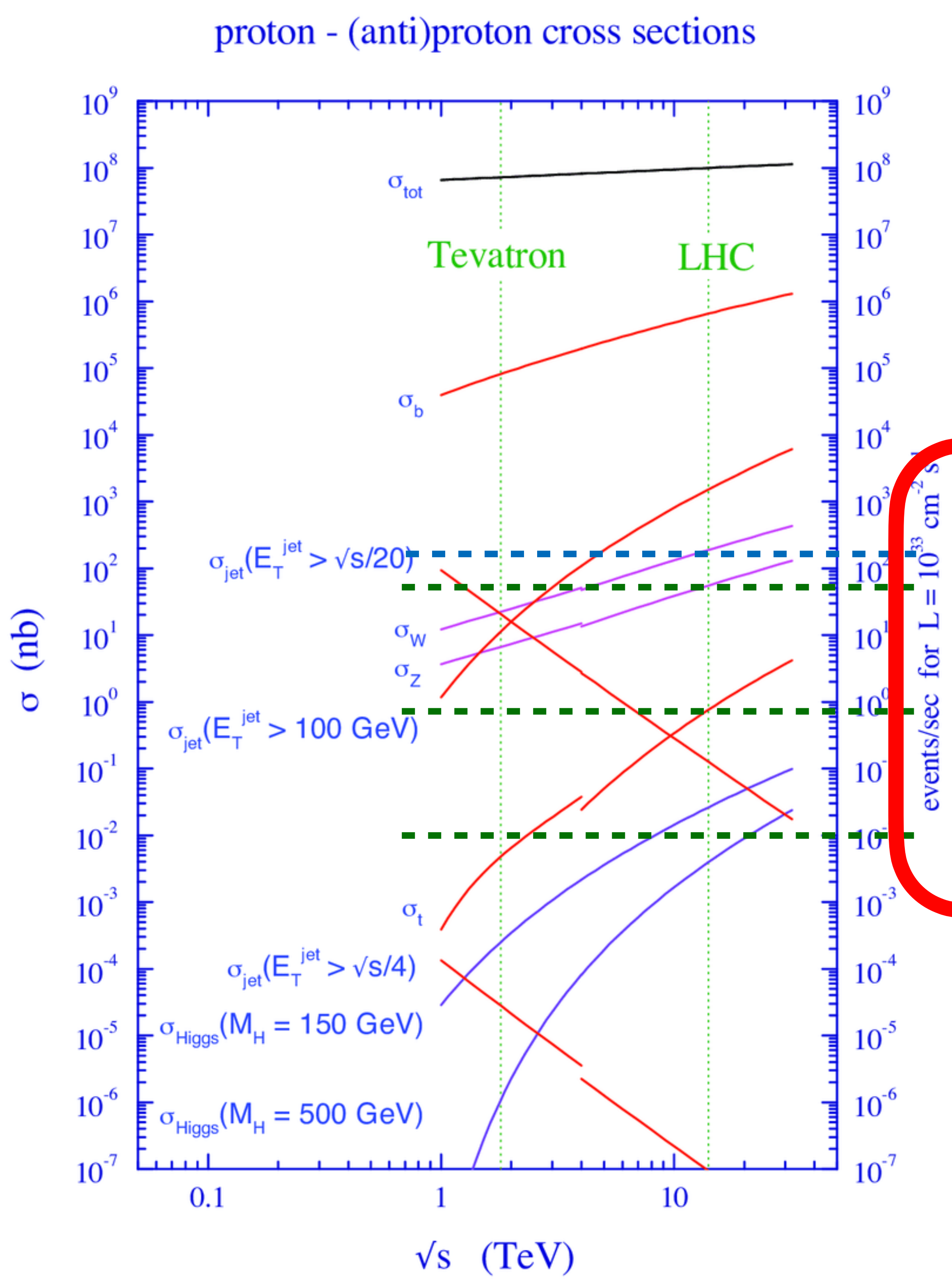
Rare processes: exotic decays (h, W, Z, t), LLP

A lot of important physics to do!

Rare processes

Unlikely, but seeing one can teach us a lot.

HL-LHC as particle factories



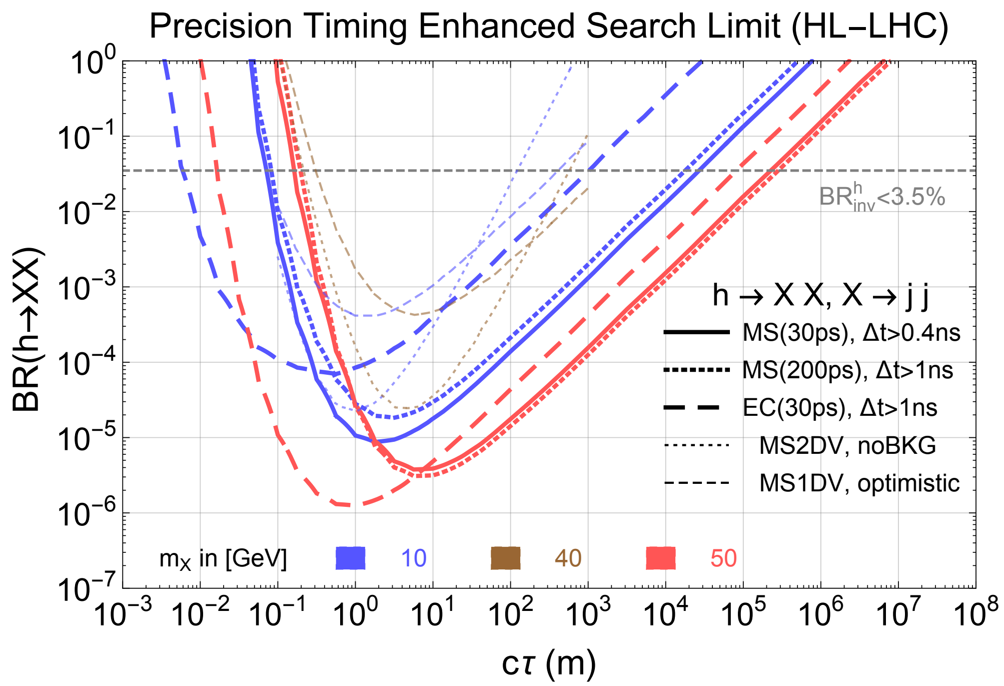
HL-LHC

- $> 10^{11}$ W and Zs
- $> 10^{9}$ tops
- $> 10^{8}$ Higgses

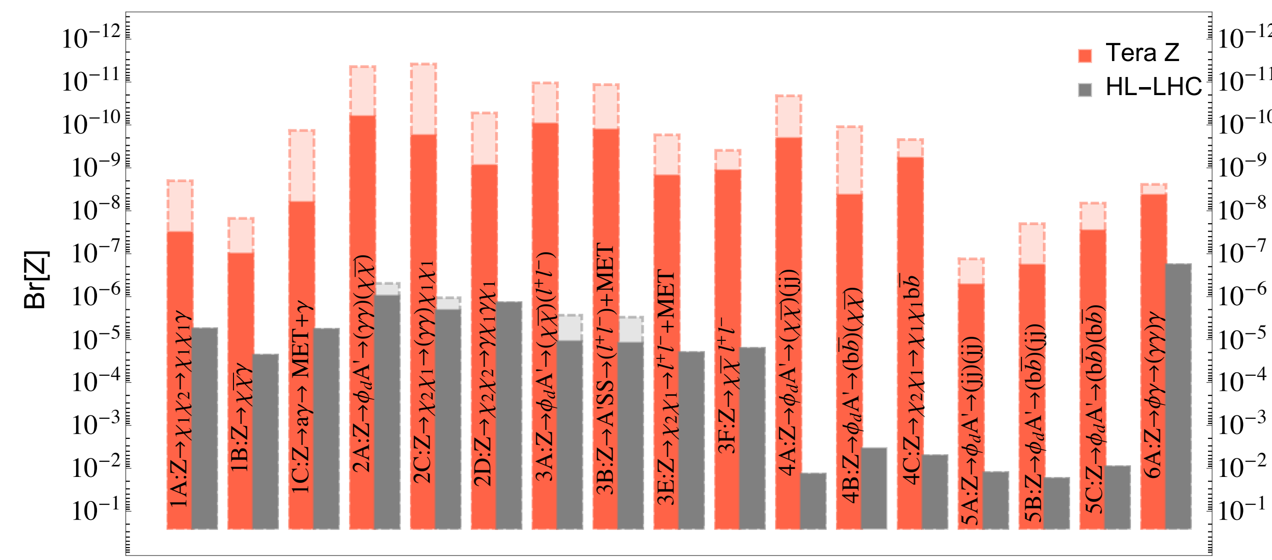
e^+e^-

- 10^{8} W, 10^{12} Z
- 10^{5} tops
- 10^{6} Higgses

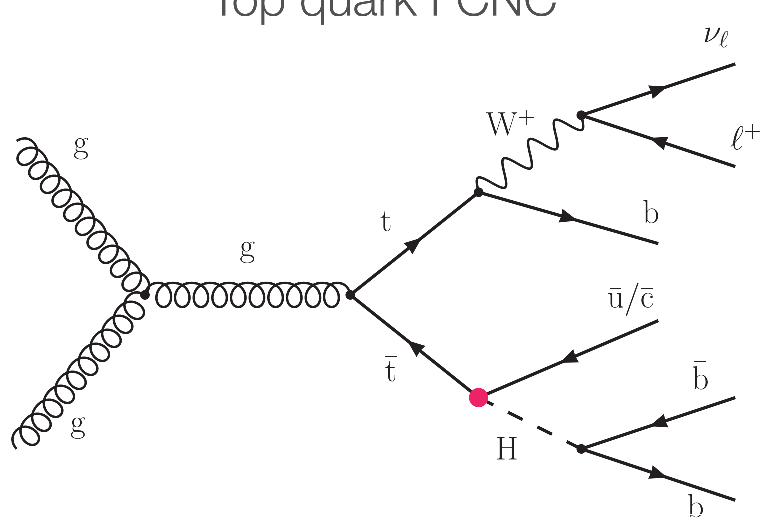
Higgs to LLP
J. Liu, Z.Liu, LTW, 1805.05957



Exotic Z decay
J. Liu, X.P. Wang, W. Xue, LTW, 1712.07237



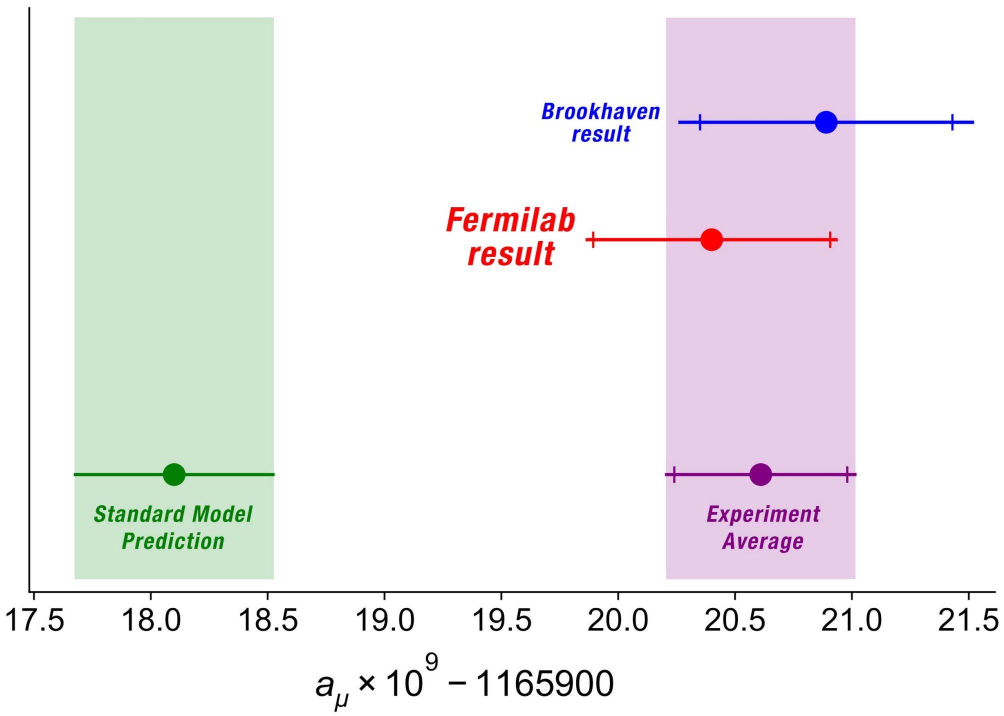
Top quark FCNC

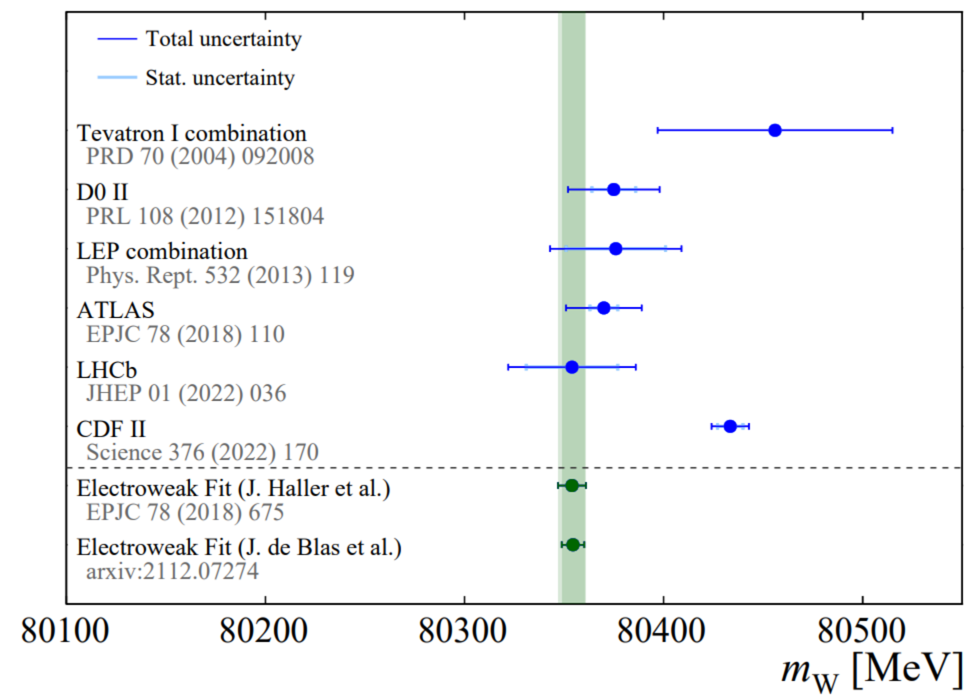


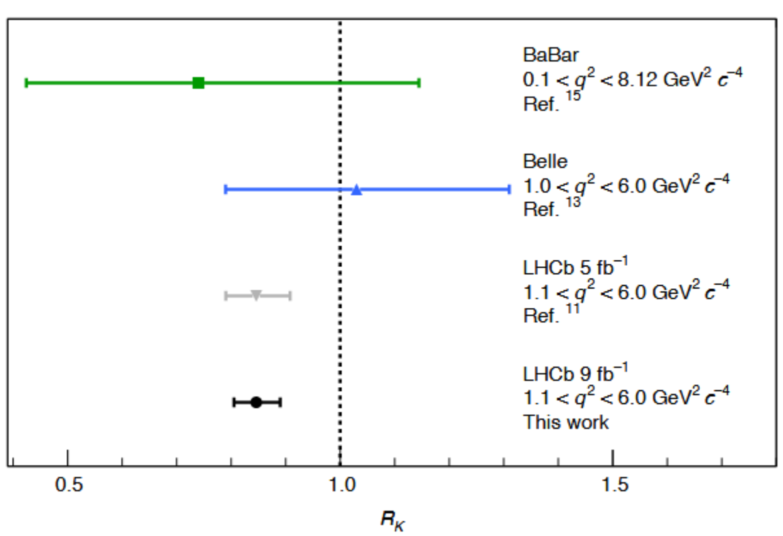
+ many more possibilities

This talk: “anomaly” inspired

Can these be it?







Before we begin:

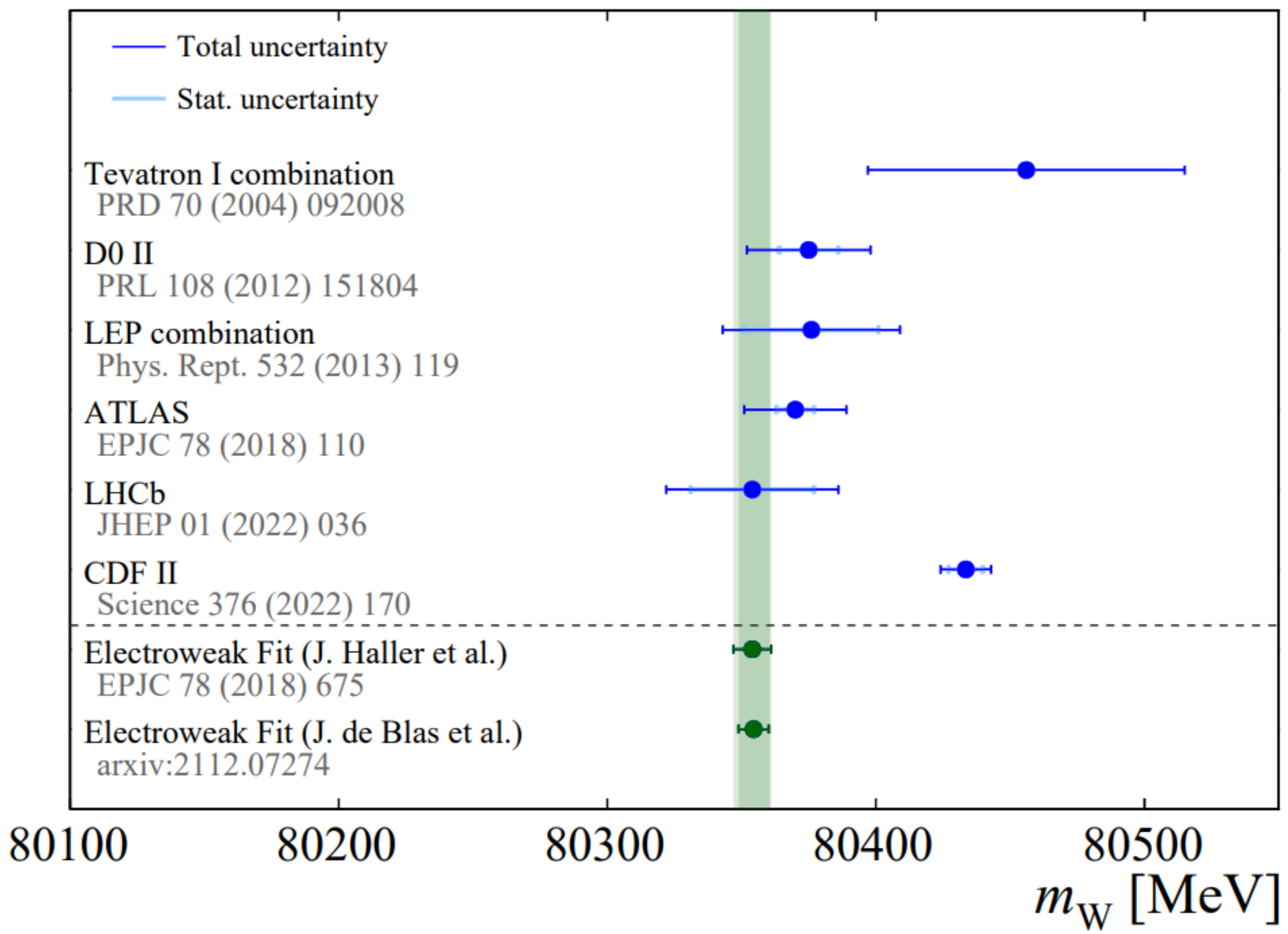
The chances of any of these turning out to be true is not high.

Some of them, such as W mass, will take a while to sort out.

These "anomalies" do motivate us to think about special kind of new physics, motivate new focus in searches.

Of course, there is always a chance for a discovery!
In this case, direct searches at the LHC will be a crucial step.

IF:



Next for LHC: confirm, or figure out the reason for difference

Here, I will focus on the new physics which could be responsible for this. Cover a couple of representative examples.

Scale of new physics

For example, custodial breaking operator

$$\frac{1}{\Lambda^2}|H^\dagger D_\mu H|^2$$

Also need a corresponding (and similar) contribution to

$$\frac{1}{\Lambda^2}(H^\dagger \tau^a H) W^a_{\mu\nu} B^{\mu\nu}$$

For 10^{-3} correction to the W mass

$$\Lambda \simeq 6 \text{ TeV}$$

Probing the new physics

$$\frac{1}{\Lambda^2}|H^\dagger D_\mu H|^2 \qquad \frac{1}{\Lambda^2}(H^\dagger \tau^a H)W^a_{\mu\nu}B^{\mu\nu} \qquad \Lambda \simeq 6 \text{ TeV}$$

Modification to SM tree level Higgs coupling (e.g. HZZ), at 10^{-3} , too small for even the Higgs factories.

SM 1-loop couplings (e.g. $h \to gg$, $h \to \gamma\gamma$): $\sim \frac{1}{(4\pi v)^2} H^\dagger H F^2 \sim \frac{1}{(\text{a few TeV})^2} H^\dagger H F^2$

The correction to these can be as large as 10(s)% (for $h \to gg$) and a few percent for $h \to \gamma\gamma$

Probing the new physics

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The correction to these can be as large as 10(s)% (for $h \to gg$) and a few percent for $h \to \gamma\gamma$

HL-LHC can be sensitive.
Current limit on $h \to gg$ rule out quite a few models already. Such as SUSY stop.

Probing the new physics

$$\frac{1}{\Lambda^2}|H^\dagger D_\mu H|^2 \qquad \frac{1}{\Lambda^2}(H^\dagger \tau^a H) W^a_{\mu\nu} B^{\mu\nu} \qquad \Lambda \simeq 6 \text{ TeV}$$

If NP contribution to W mass at tree level, M_{NP} ~ TeVs

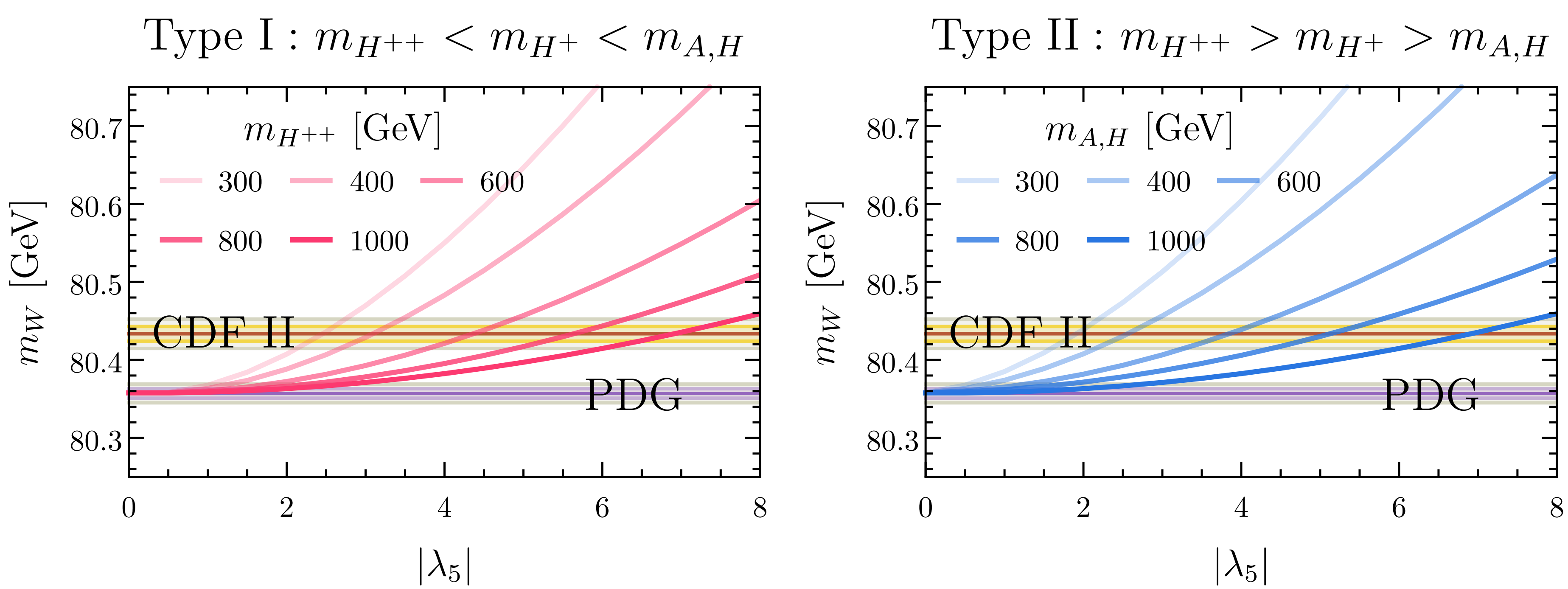
Example: Z', … Maybe borderline for LHC direct production.

Modification to Z coupling, 10^{-3}, Tera Z will confirm.

If NP contribution to W mass at 1-loop level, M_{NP} ~ a few hundred GeV

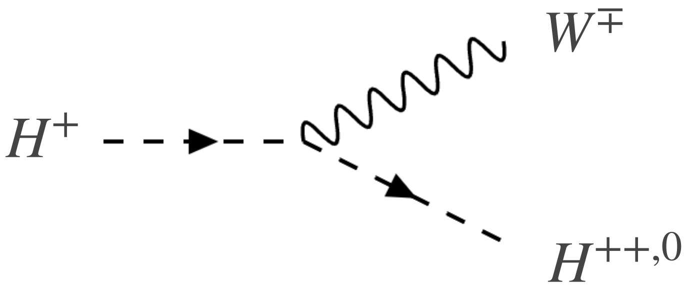
Ruled out already?

Has 100(s) GeV NP been ruled out?
Example: triplet

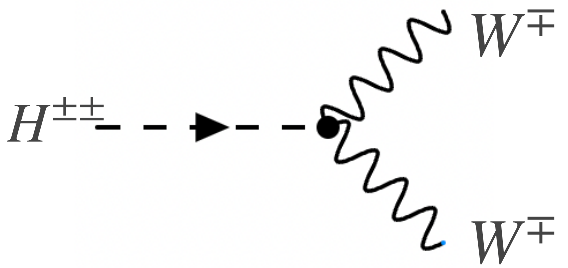


Mass about 100s GeV. Two possible hierarchies within triplet.

Mass splitting among multiplet: 50 GeV
Dominant decay within triplet:

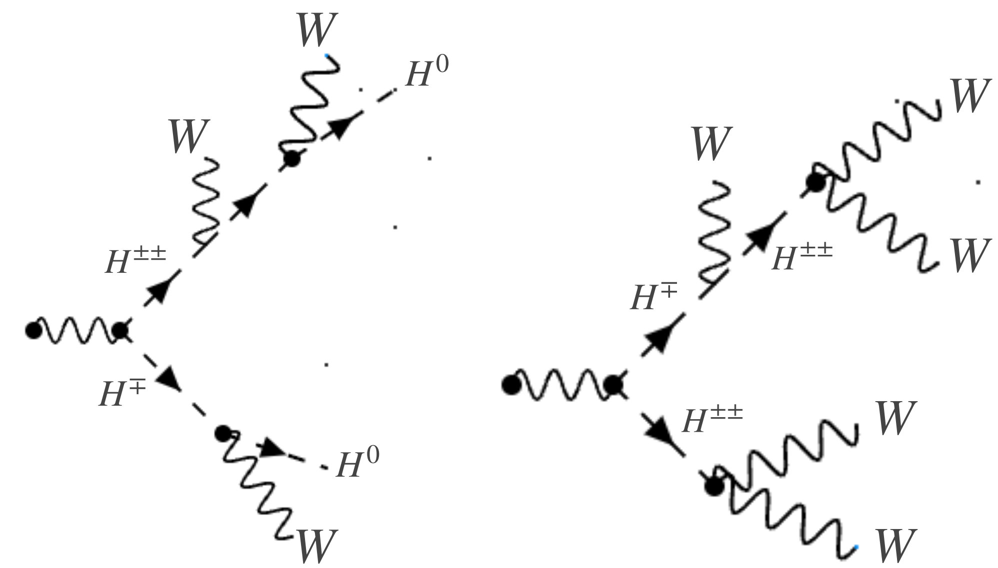


Lightest member: either stable (DM, MET), or



Has 100(s) GeV NP been ruled out?
Example: triplet

Main production mode: $pp \to H^{\pm}H^{\mp\mp}$



W-rich final state

Has 100(s) GeV NP been ruled out?

Example: triplet

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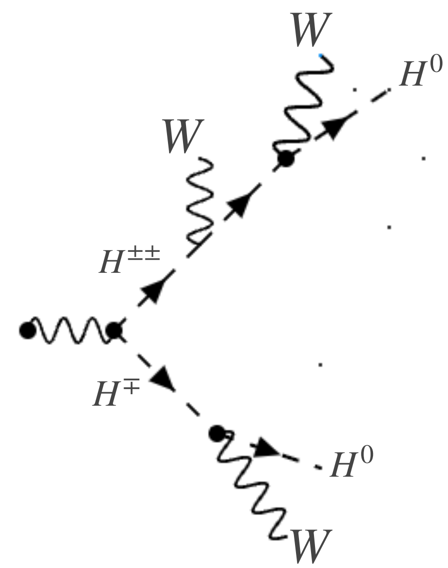
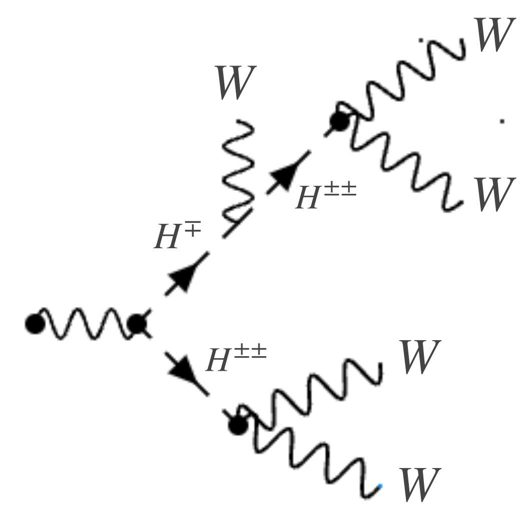
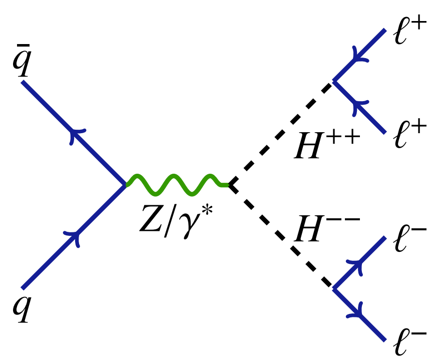
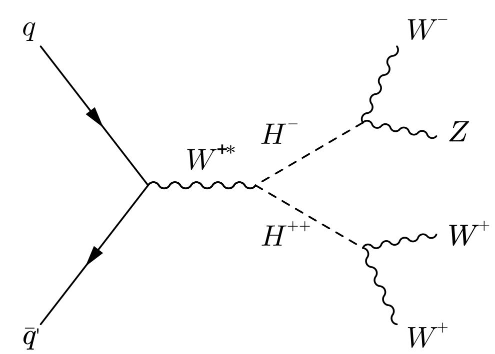


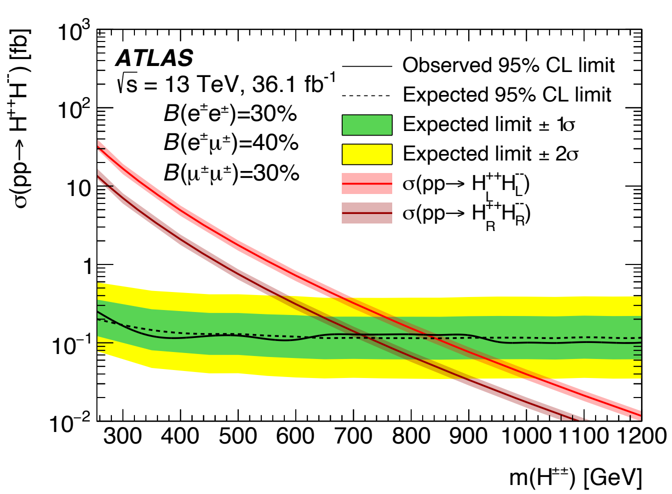


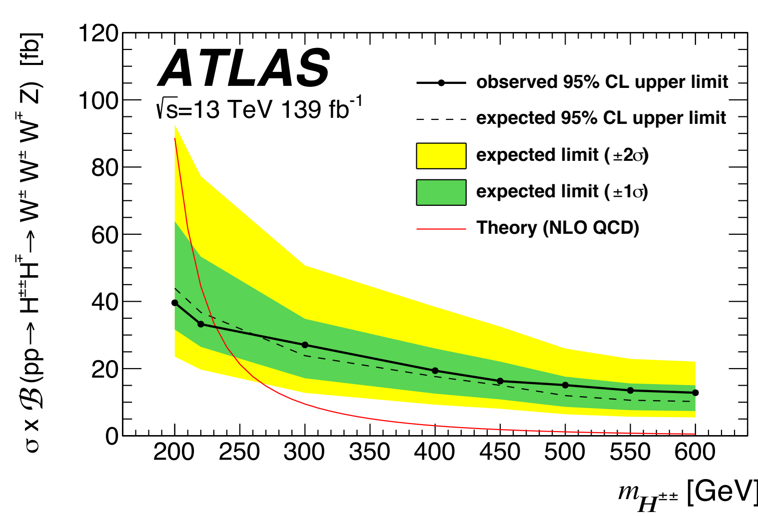
Some available searches





W-rich final state





New opportunities to make a discovery!

Different categories of NP

$$\frac{1}{\Lambda^2}|H^\dagger D_\mu H|^2 \qquad \frac{1}{\Lambda^2}(H^\dagger \tau^a H) W^a_{\mu\nu} B^{\mu\nu} \qquad \Lambda \simeq 6 \text{ TeV}$$

If NP contribution to W mass at tree level, M_{NP} ~ TeVs

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If NP contribution to W mass at 1-loop level, but to other observables at tree level?

Example: beautiful mirror model

D. Choudhury, T. Tait, C. Wagner, hep-ph/0109097

Introducing fermonic partners of bottom quark.

$$\Psi_{L,R} = \begin{pmatrix} B \\ X \end{pmatrix} \sim (3,2)_{-5/6}$$
$$\hat{B}_{L,R} \sim \ (3,1)_{-1/3} \,,$$

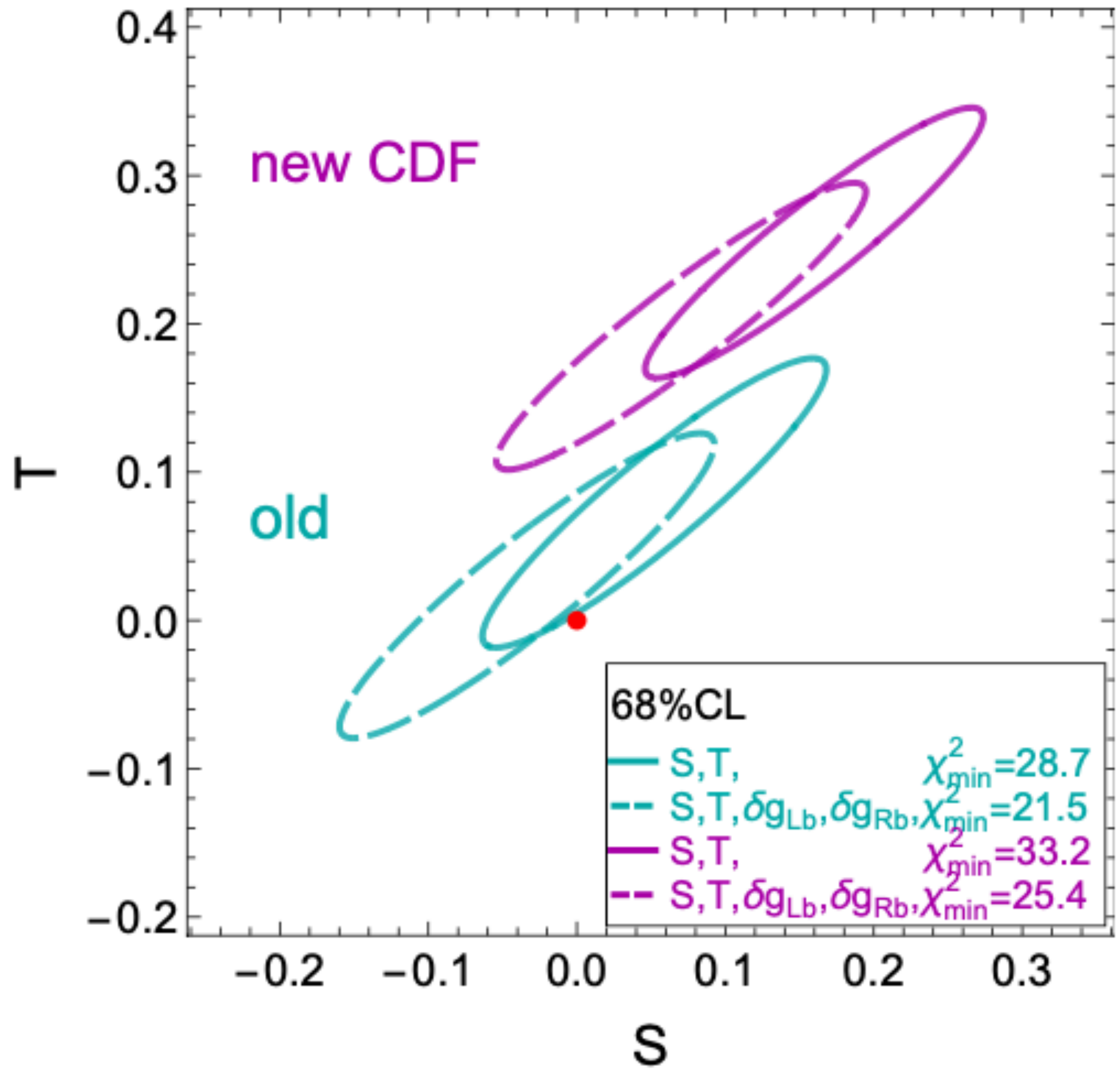
Contributes to the W mass at 1-loop

Corrects the Zbb coupling at tree level (∃ LEP anomaly)

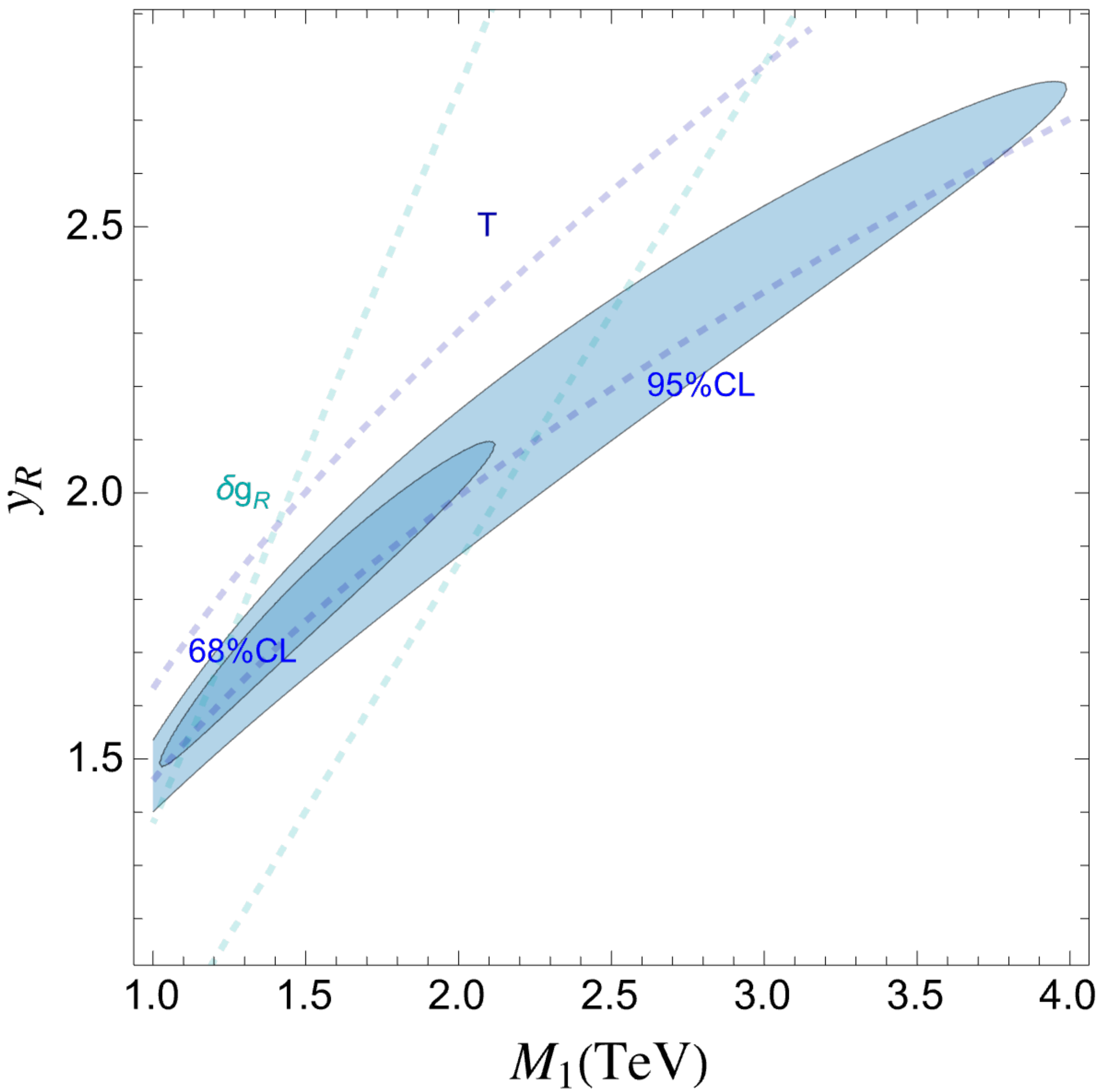
$$\delta g_{Lb} = \frac{y_L^2 v^2}{4M_2^2} \,, \qquad \delta g_{Rb} = \frac{y_R^2 v^2}{4M_1^2}$$

Gives a good fit (W mass + Z-pole)

S. Chai, J. Gu, LTW. To appear

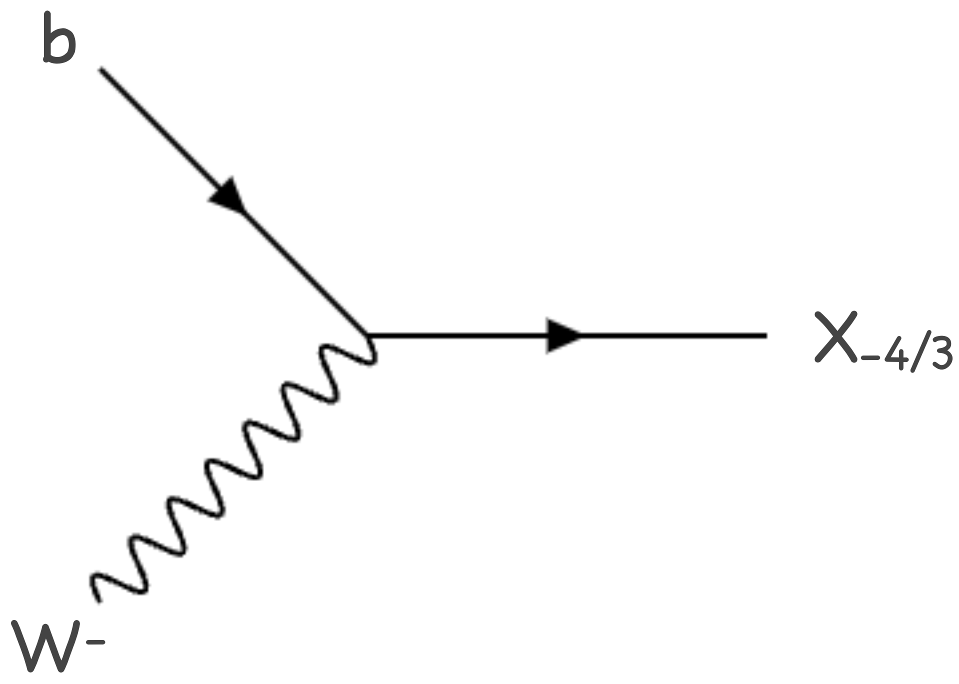


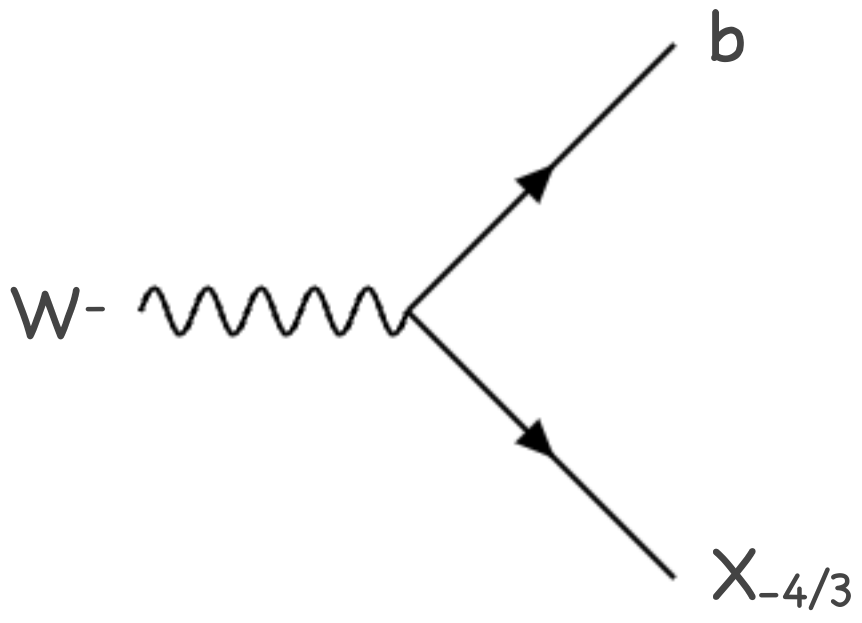
New particle $\Psi_{L,R} = \begin{pmatrix} B \\ X \end{pmatrix} \sim (3,2)_{-5/6}$



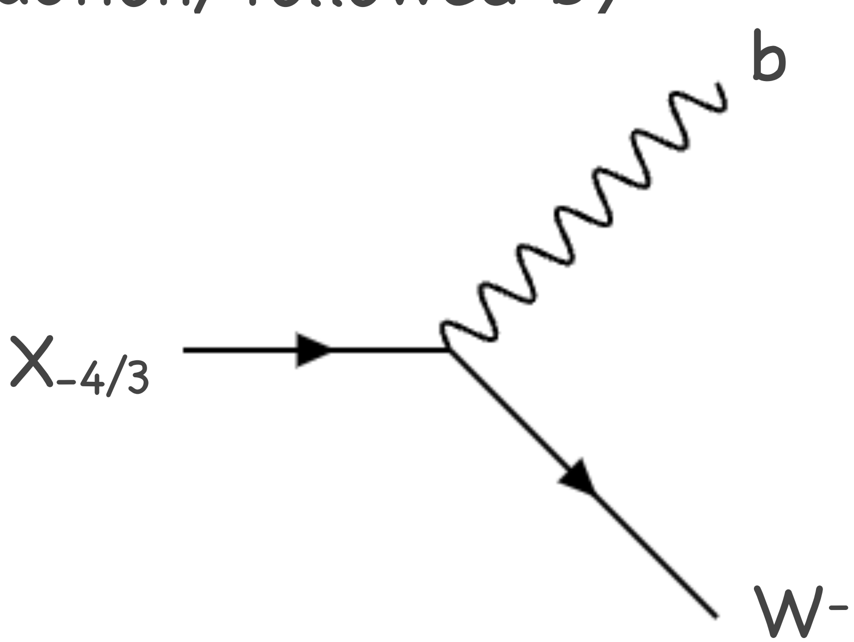
W mass preferred region

New particle search $\Psi_{L,R} = \begin{pmatrix} B \\ X \end{pmatrix} \sim (3,2)_{-5/6}$





Single production, followed by



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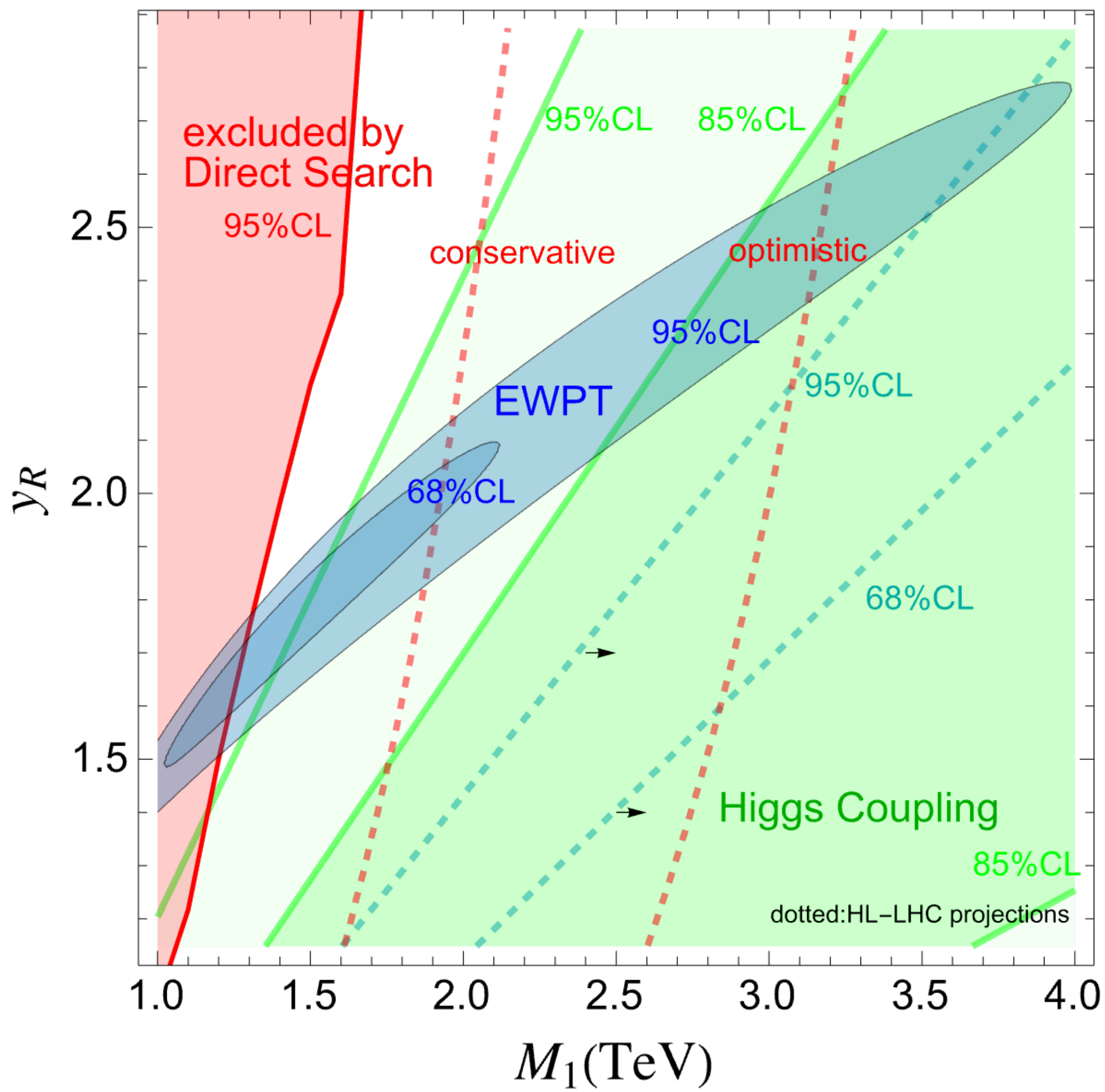


With direct searches and Higgs coupling measurements at the LHC

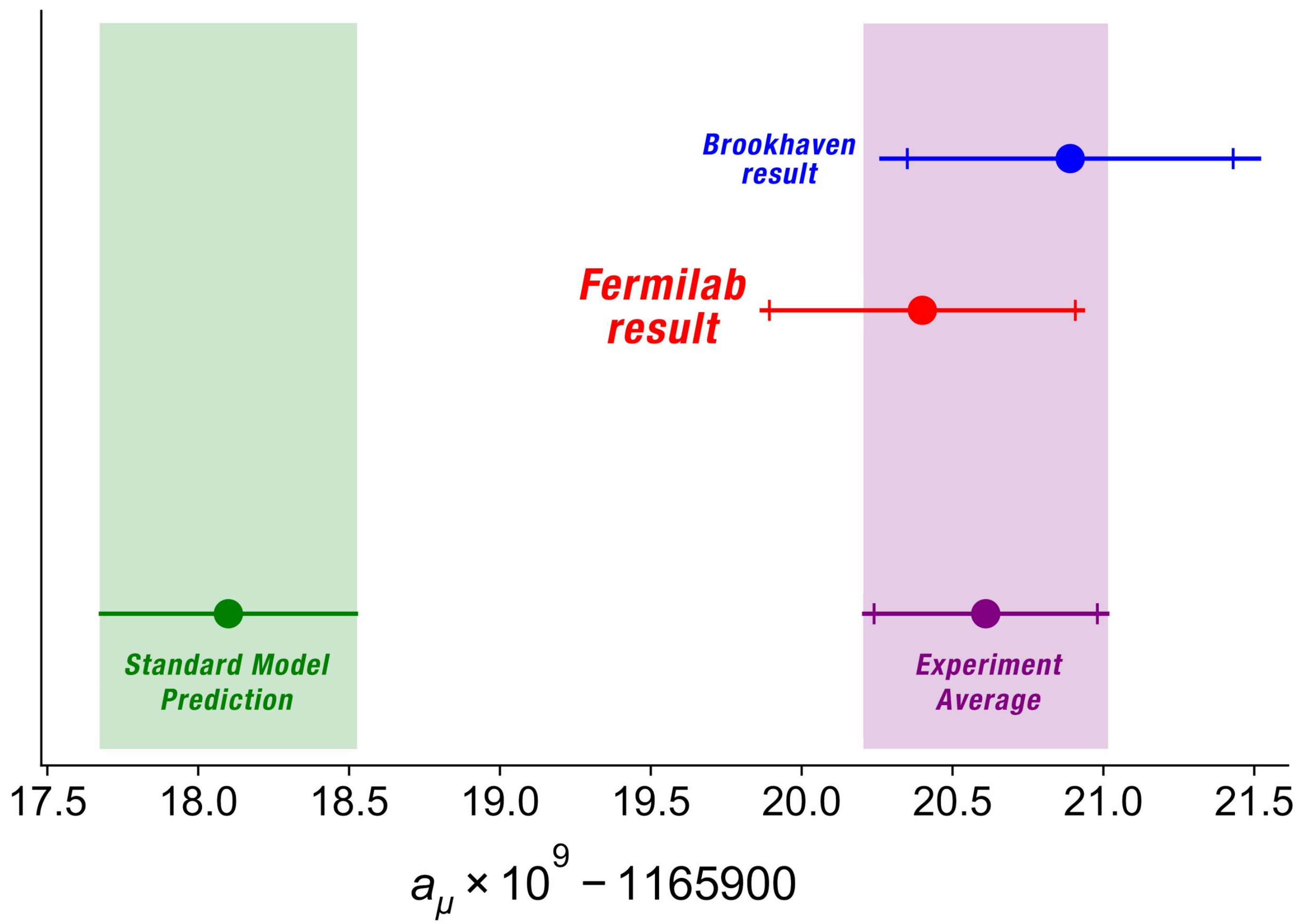
W mass inspired new physics summary

Likely to show up as deviations in the Higgs coupling measurements

100s GeV - TeV new physics should be within the reach of the direct Search at the LHC.

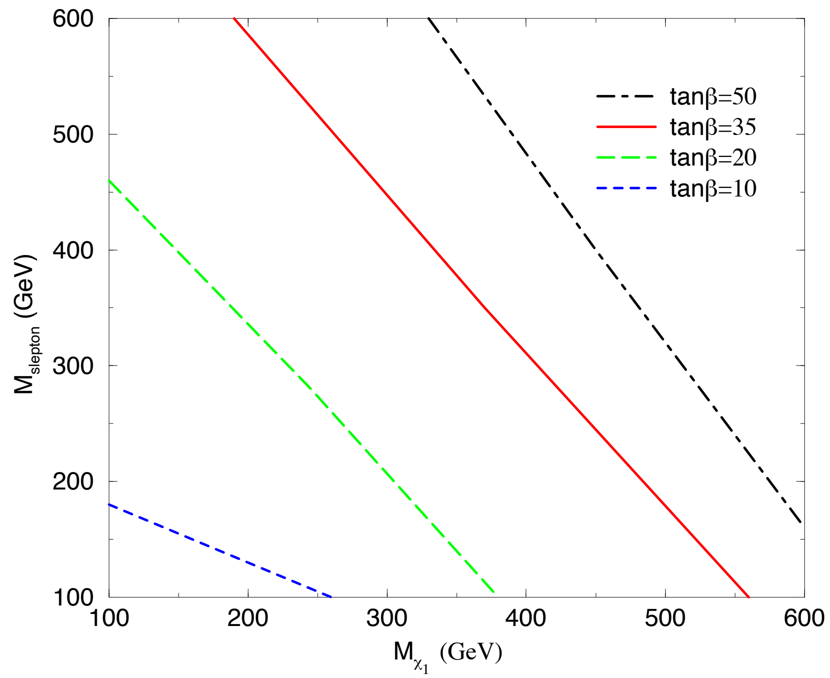
W rich final states, VLQ-like particles.

IF:



Lattice calculation seems to indicate otherwise (not settled yet).

For example: g-2 and smuon gap

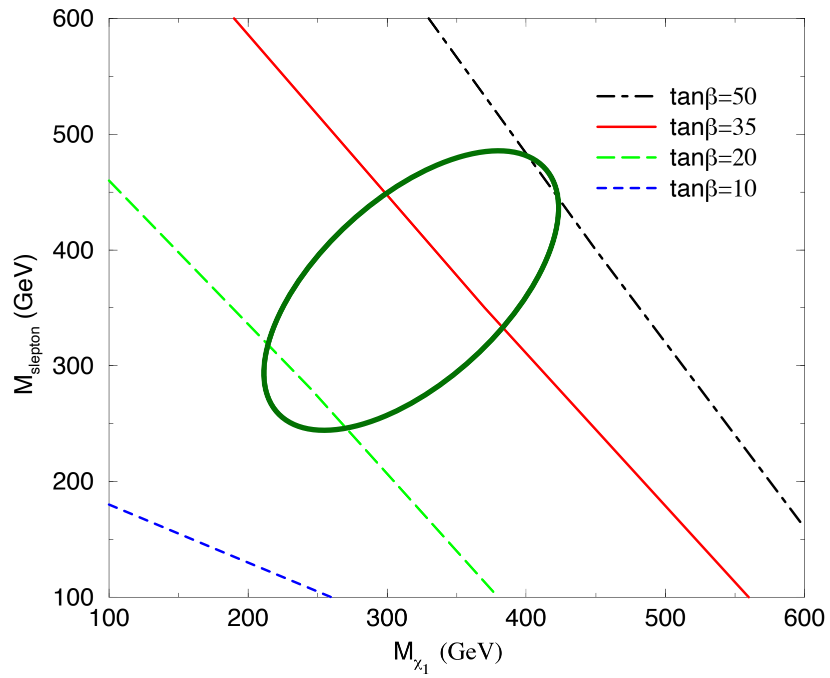


Everett, Kane, Rigolin, LTW hep-ph/0102145

Personal note: topic of my first ambulance chasing paper, 2001

My first reaction to the g-2 news last year:
Can't be SUSY, such light smuon must be ruled out by LHC already

For example: g-2 and smuon gap



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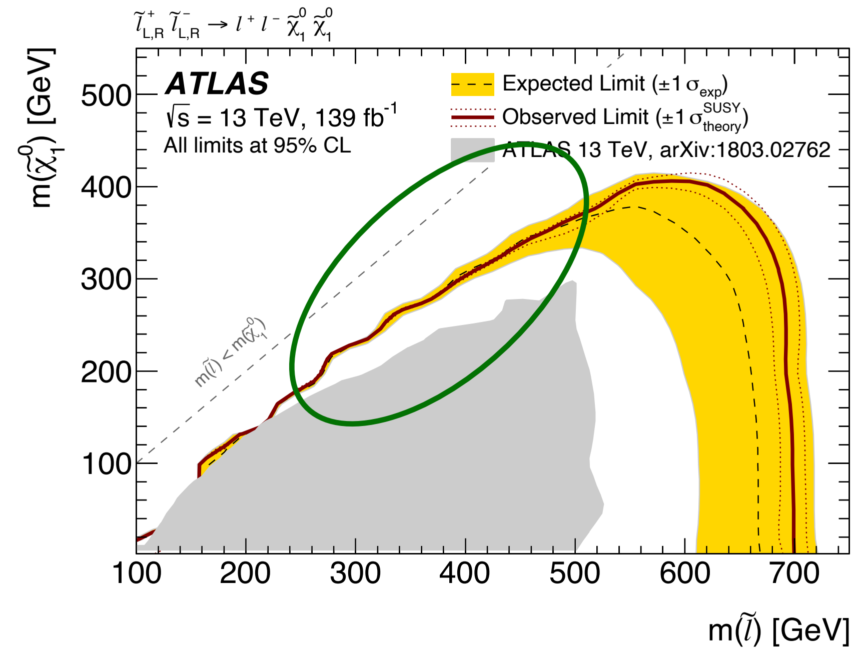

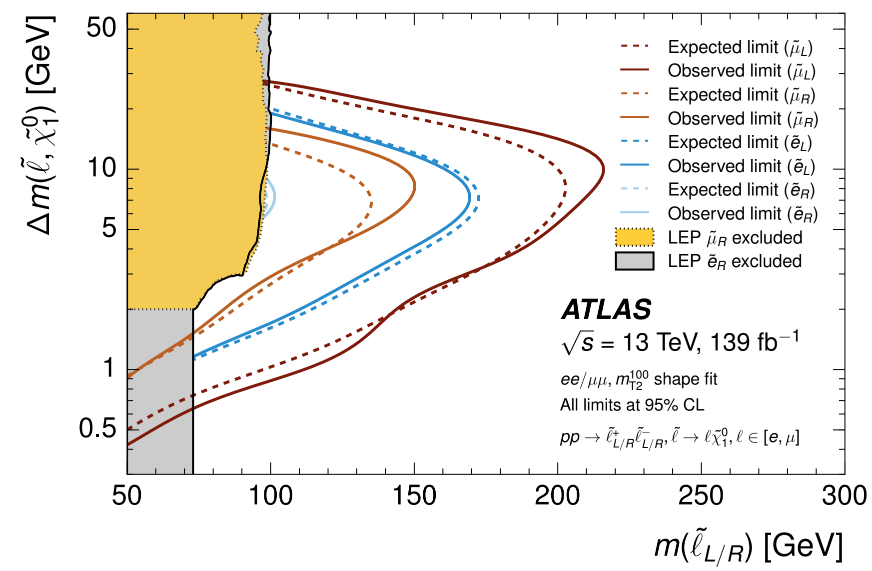

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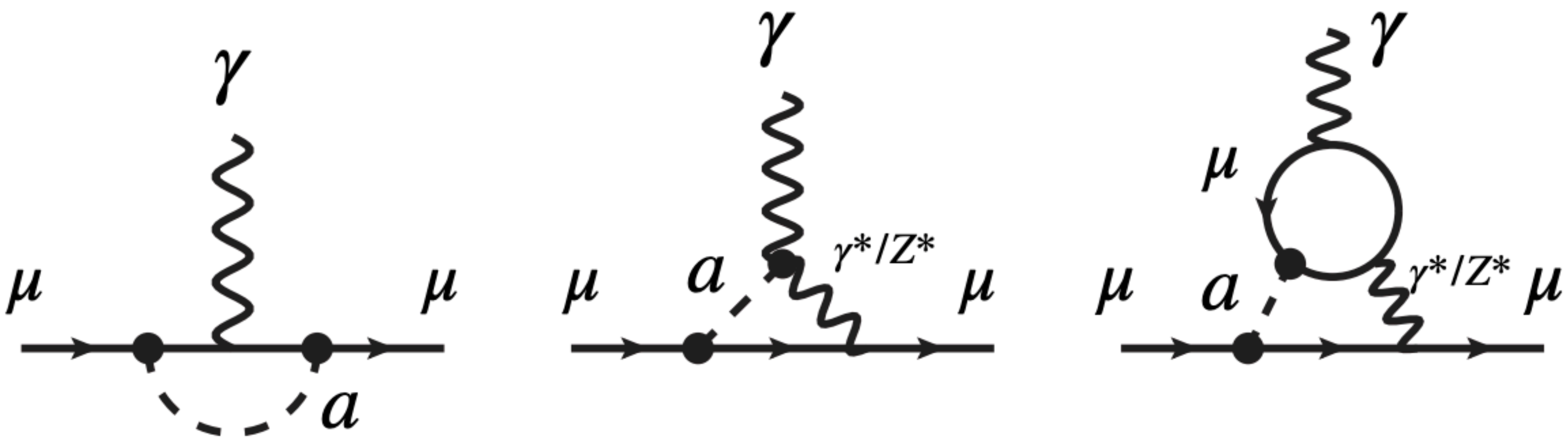
Can't be SUSY, such light smuon must be ruled out by LHC already

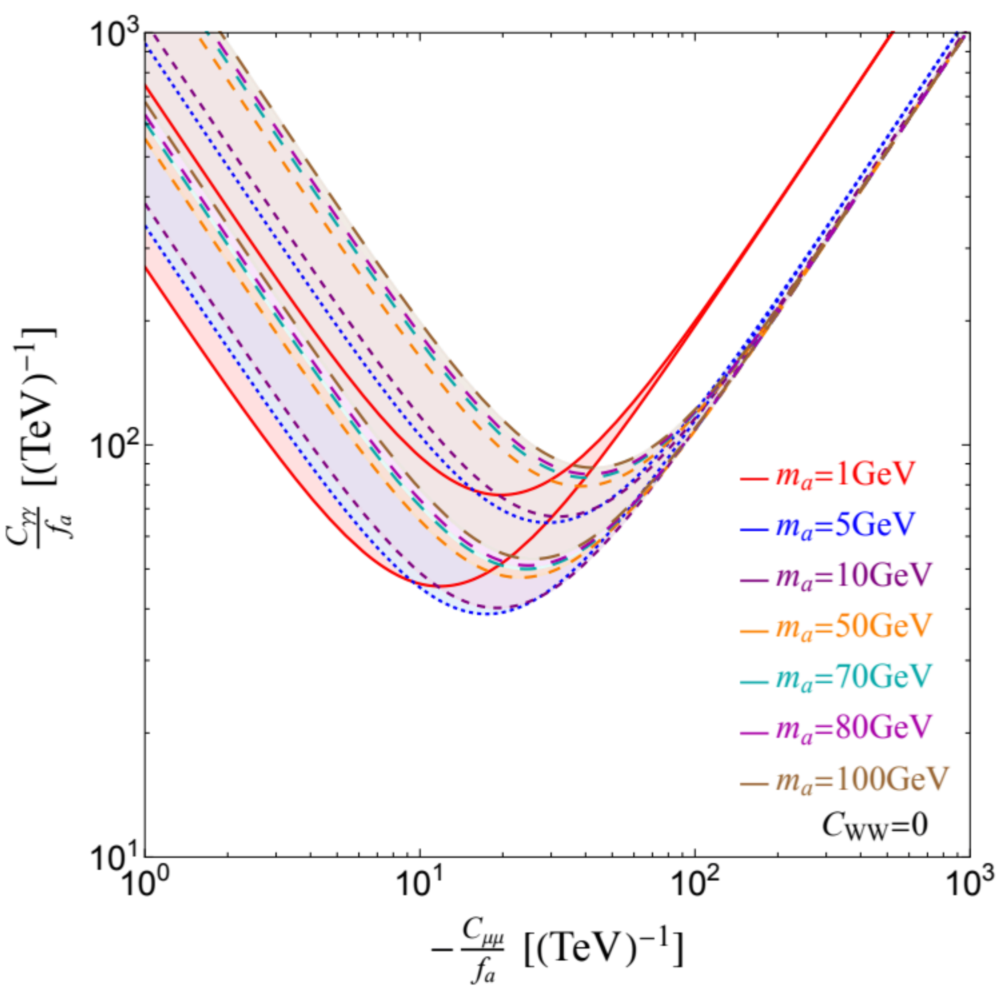
Maybe a discovery at the LHC is waiting here?

The ALP explanation (2-loop)

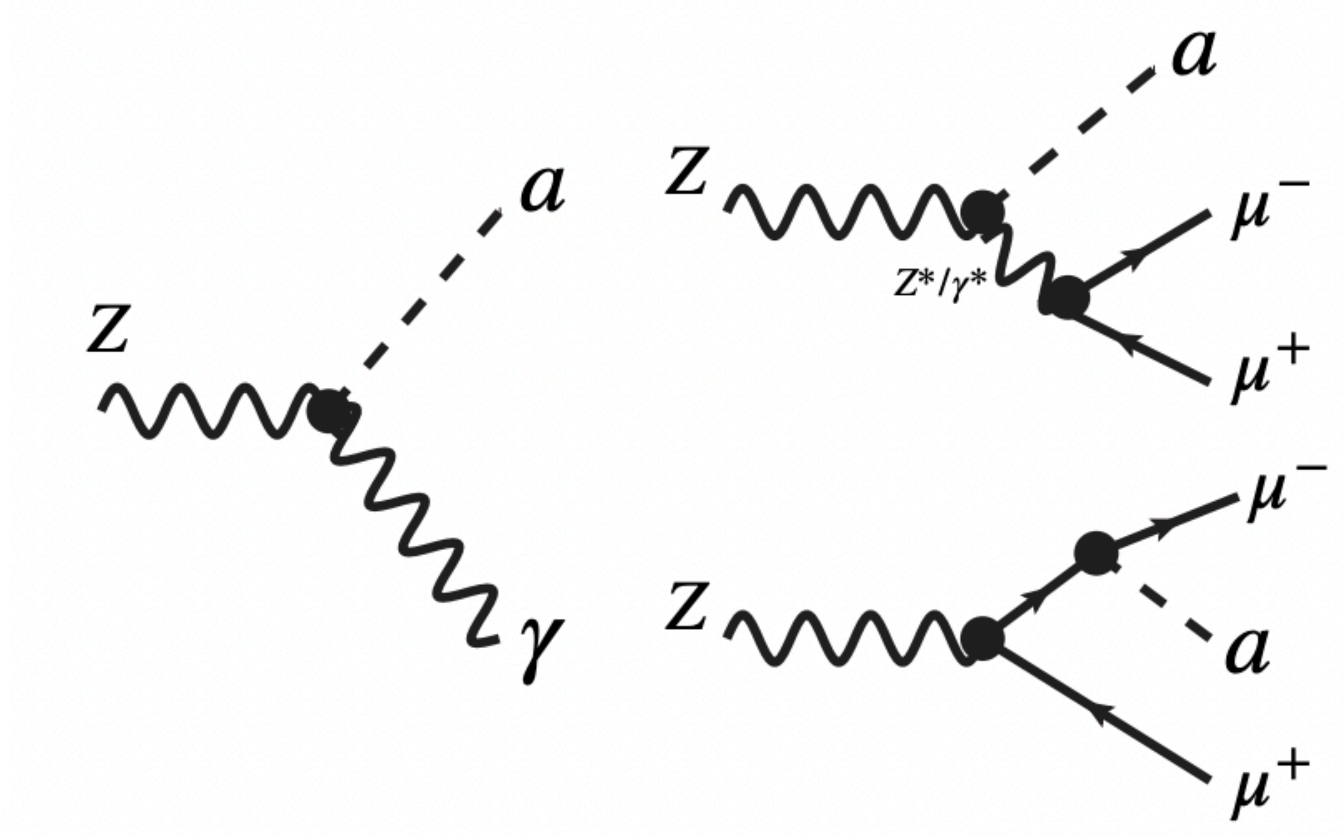
J. Liu, X. Ma, X.-P. Wang, LTW 2210.09335

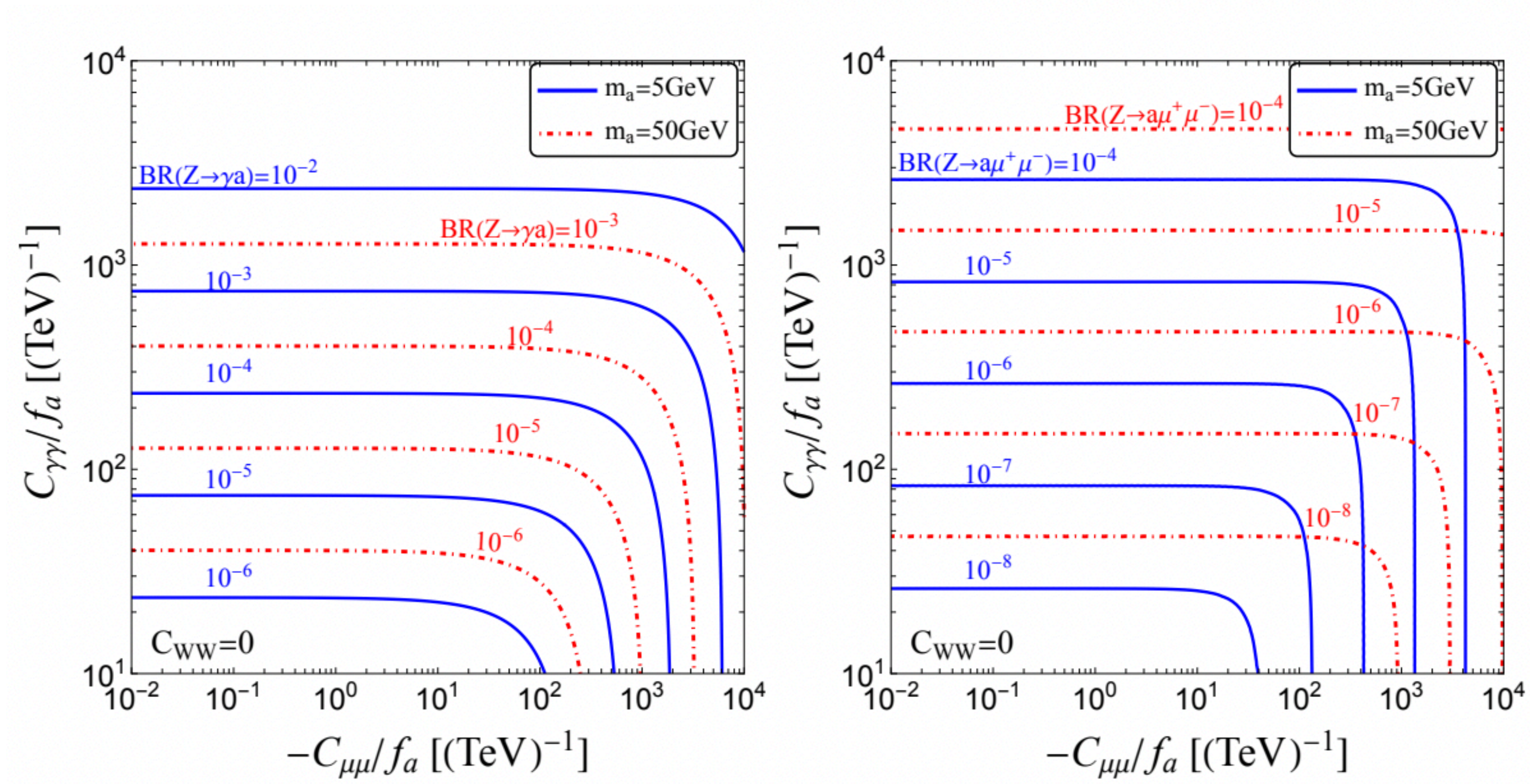


g-2 preferred parameter region:



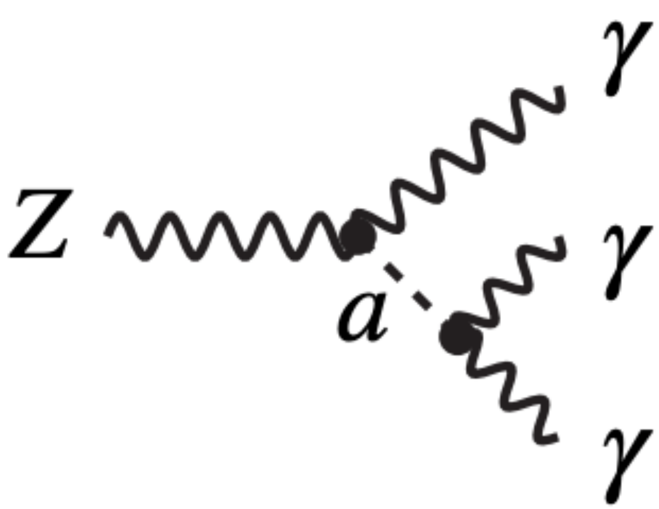
Rare Z decay



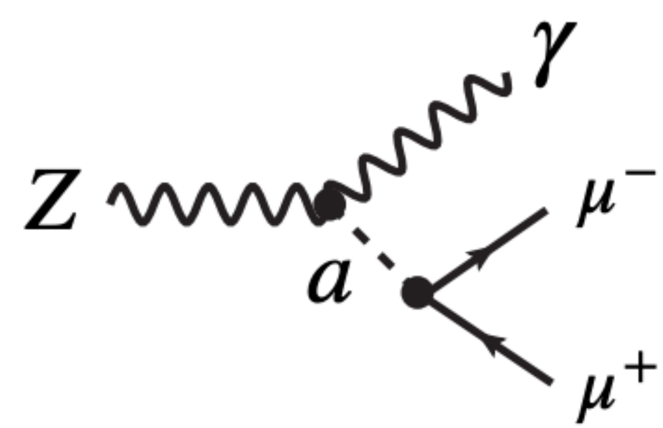


c.f. 10^{11} Zs at the LHC, great potential.

Signal from Z-> a γ

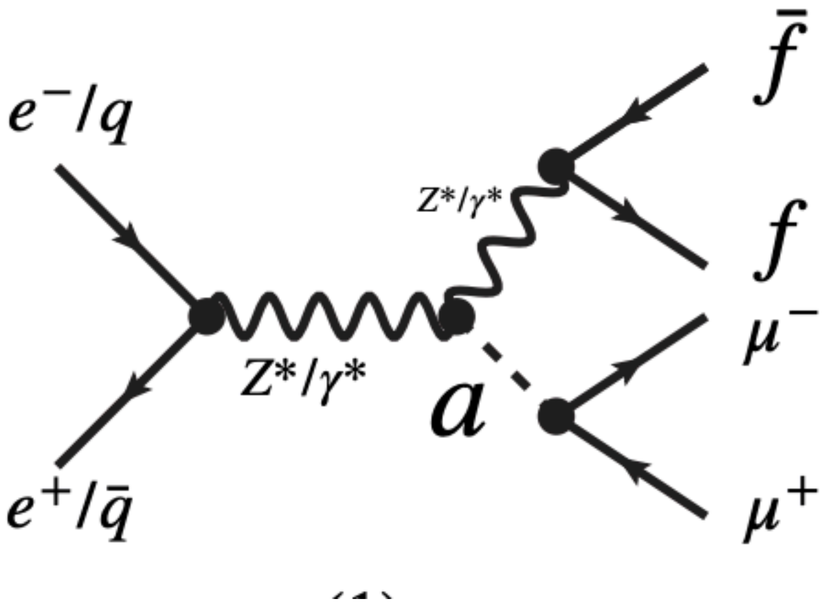


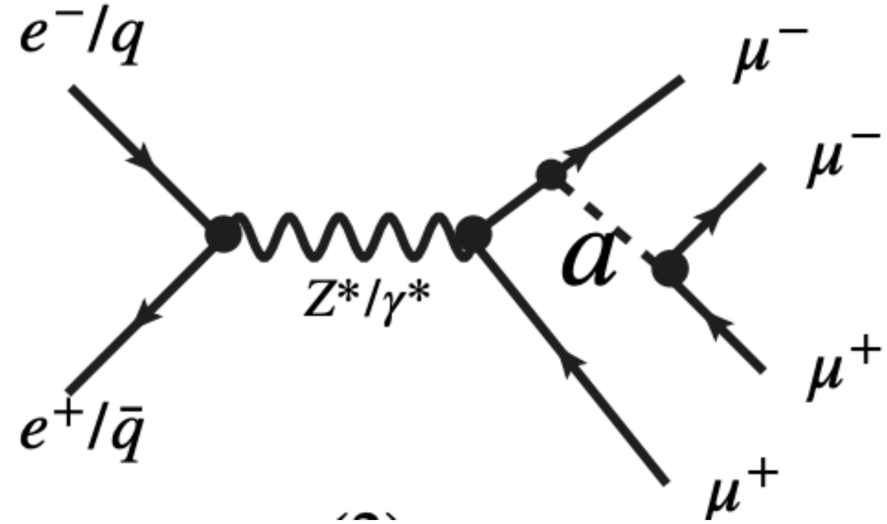
ATLAS 8 TeV data,
1509.05151 BR<2.2x10^{-6}



OPAL (1991), BR<5.6x10^{-4},

4 fermion final state

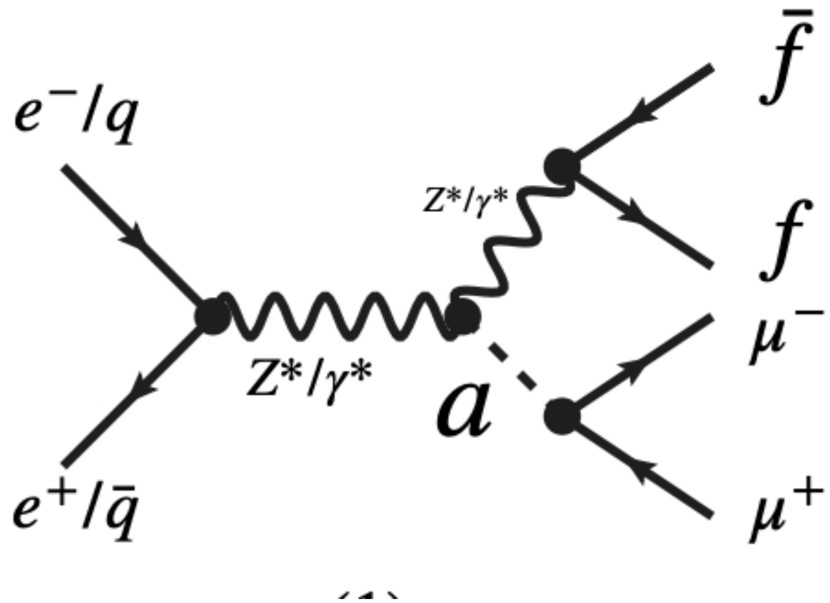


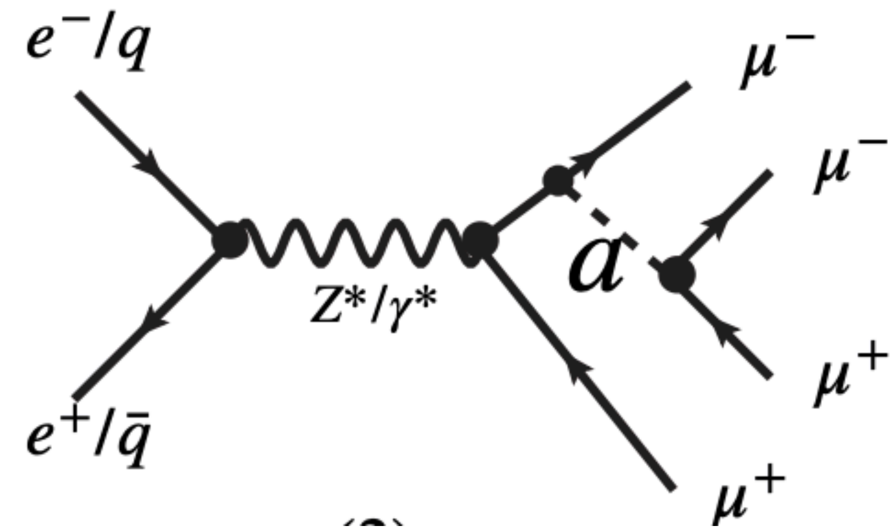


CMS. ttμμ, 1911.04968

Babar. 1606.03501
CMS. 1808.03684

4 fermion final state

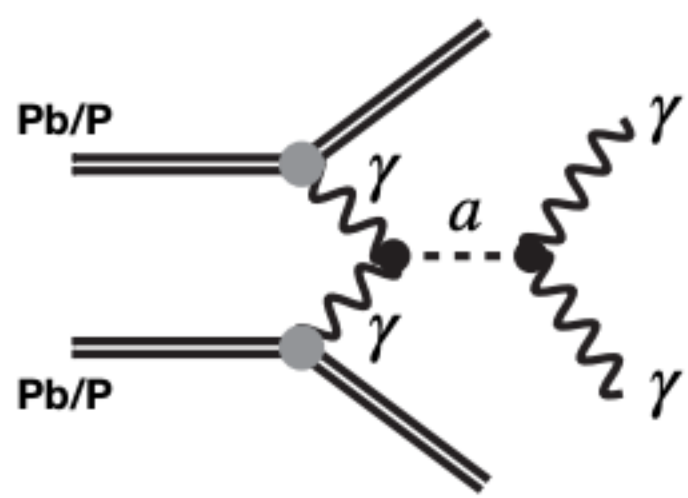




CMS. ttμμ, 1911.04968

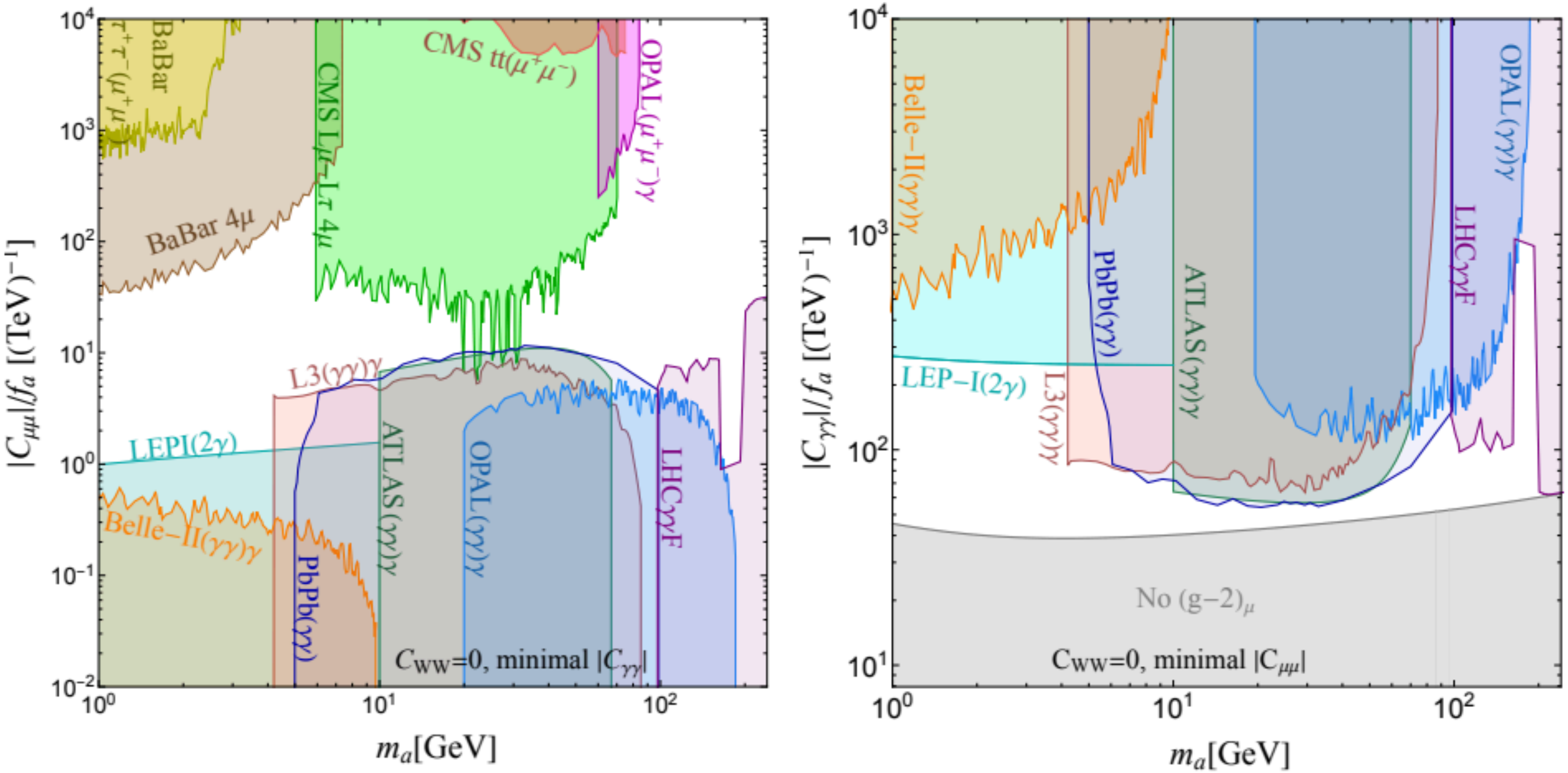
Babar. 1606.03501
CMS. 1808.03684

γγ fusion



ATLAS. 2008.05355. CMS. 1810.04602, 2110.05916, 1209.1666

Searches

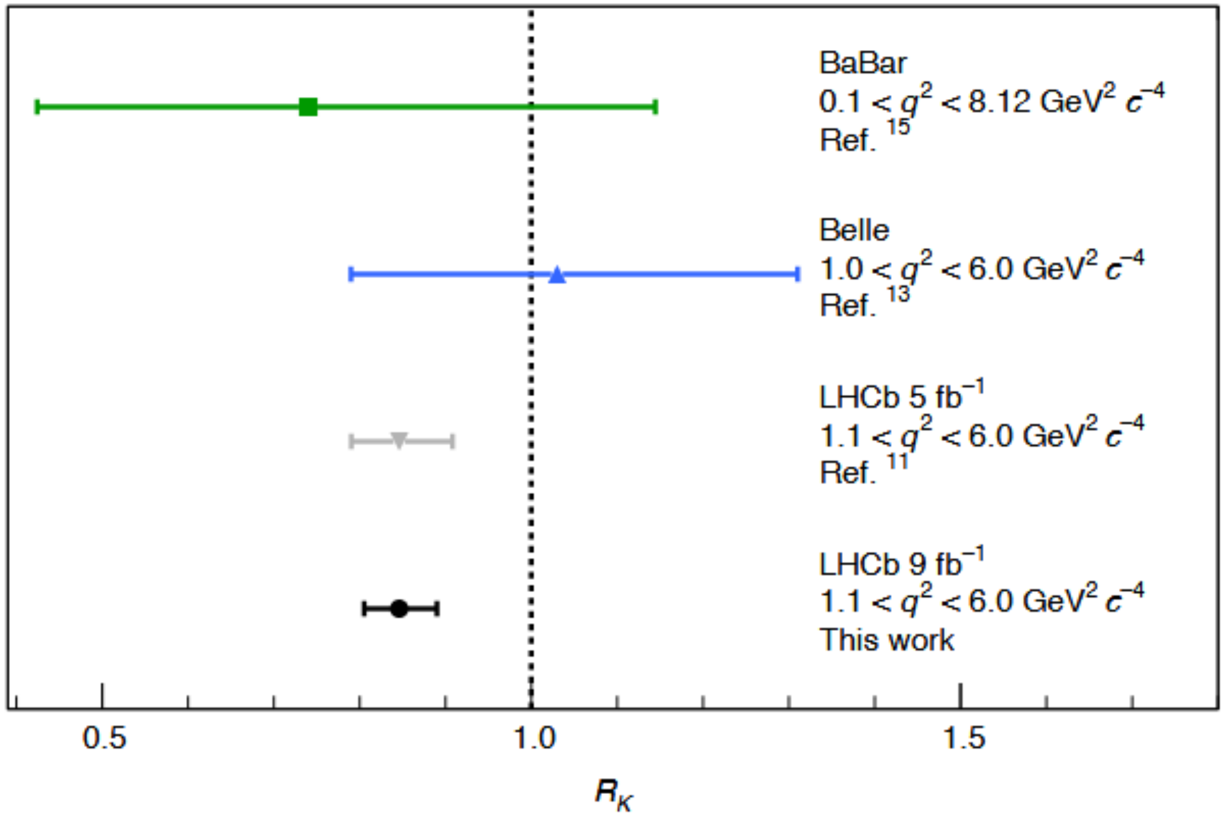


Current limits still leave room for new physics.

More dedicated searches at LHC can cover more ground.

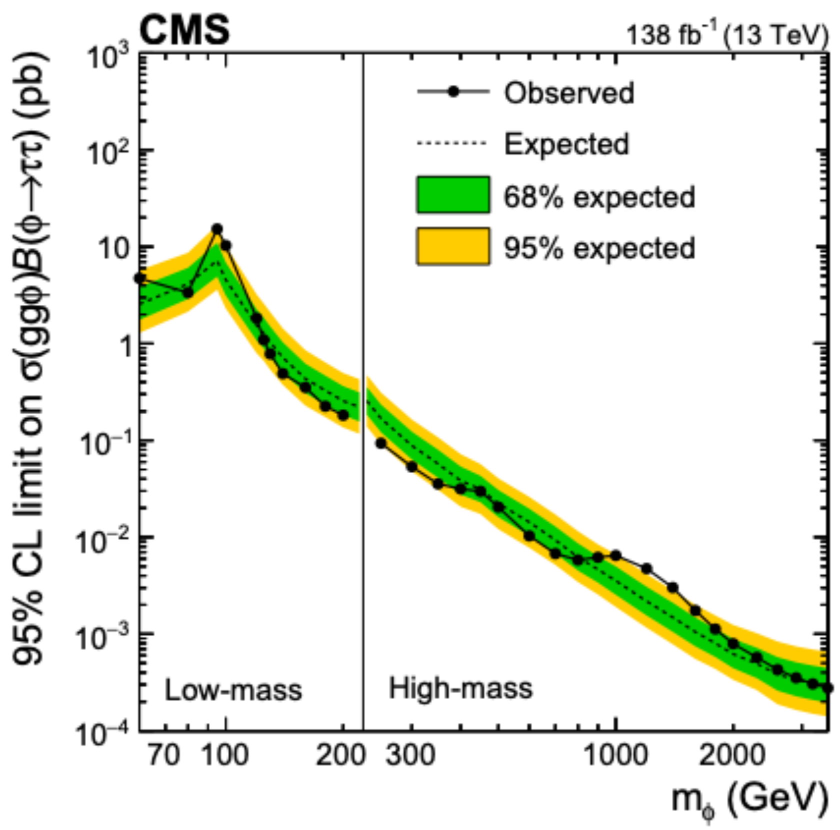
IF:

Lepton universality in B decay

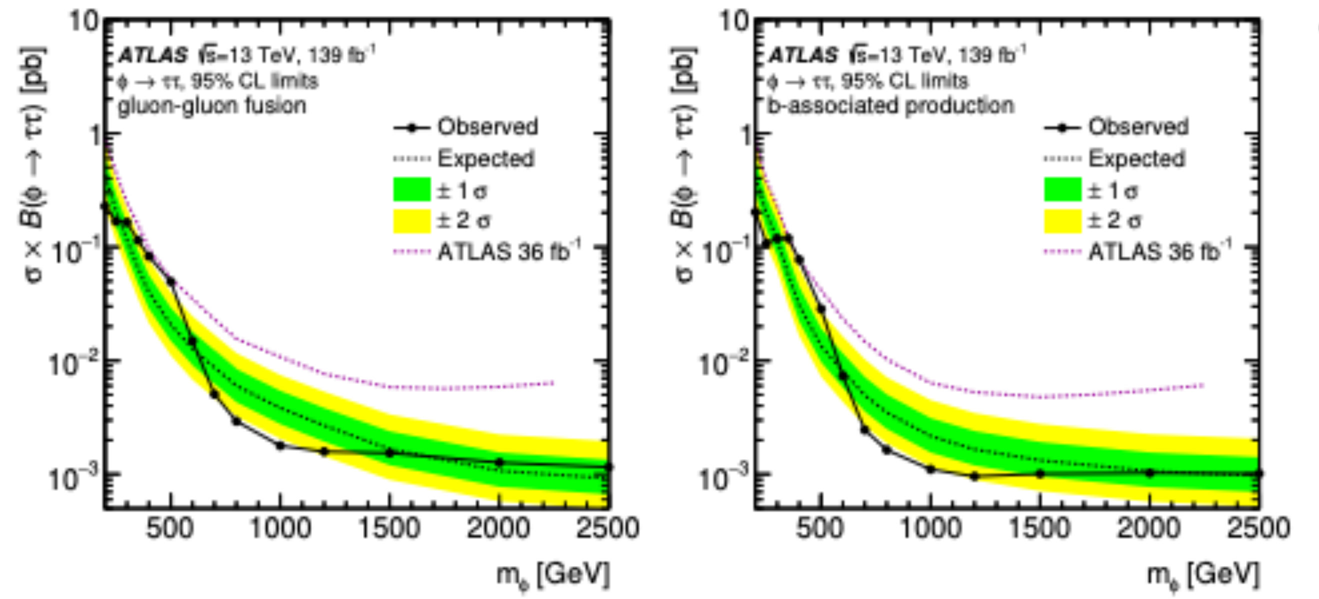


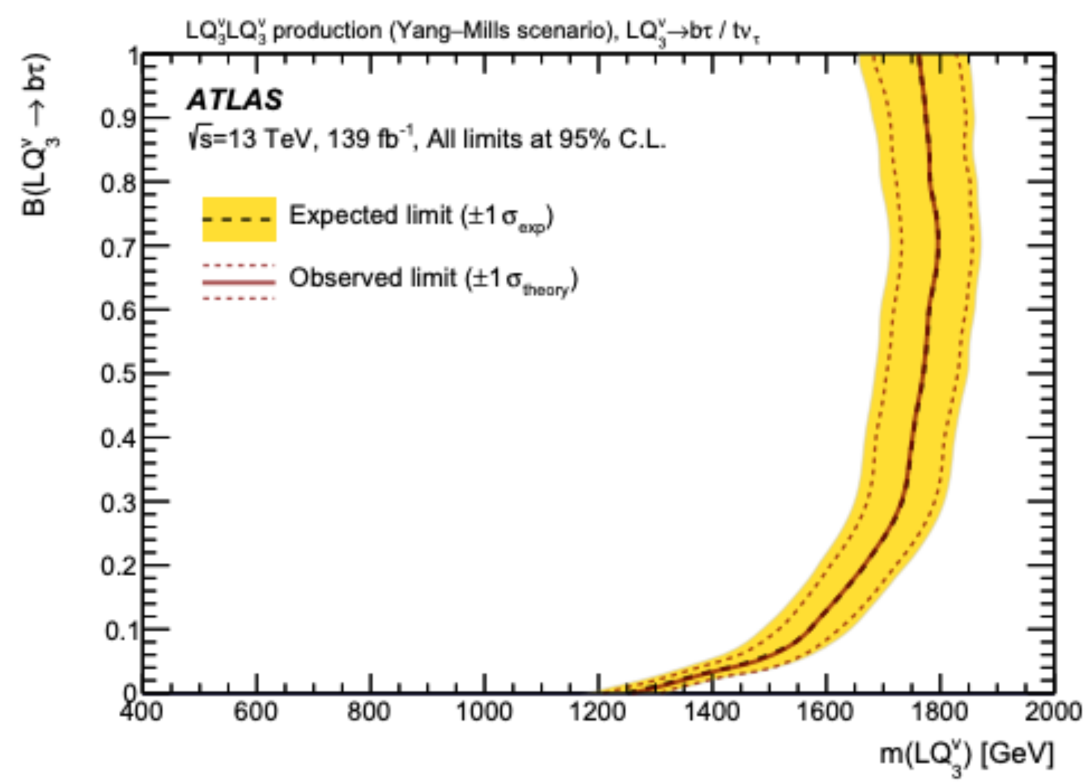
Maybe clarified very soon. (Upcoming LHCb announcement)

Leptoquark back in the spotlight



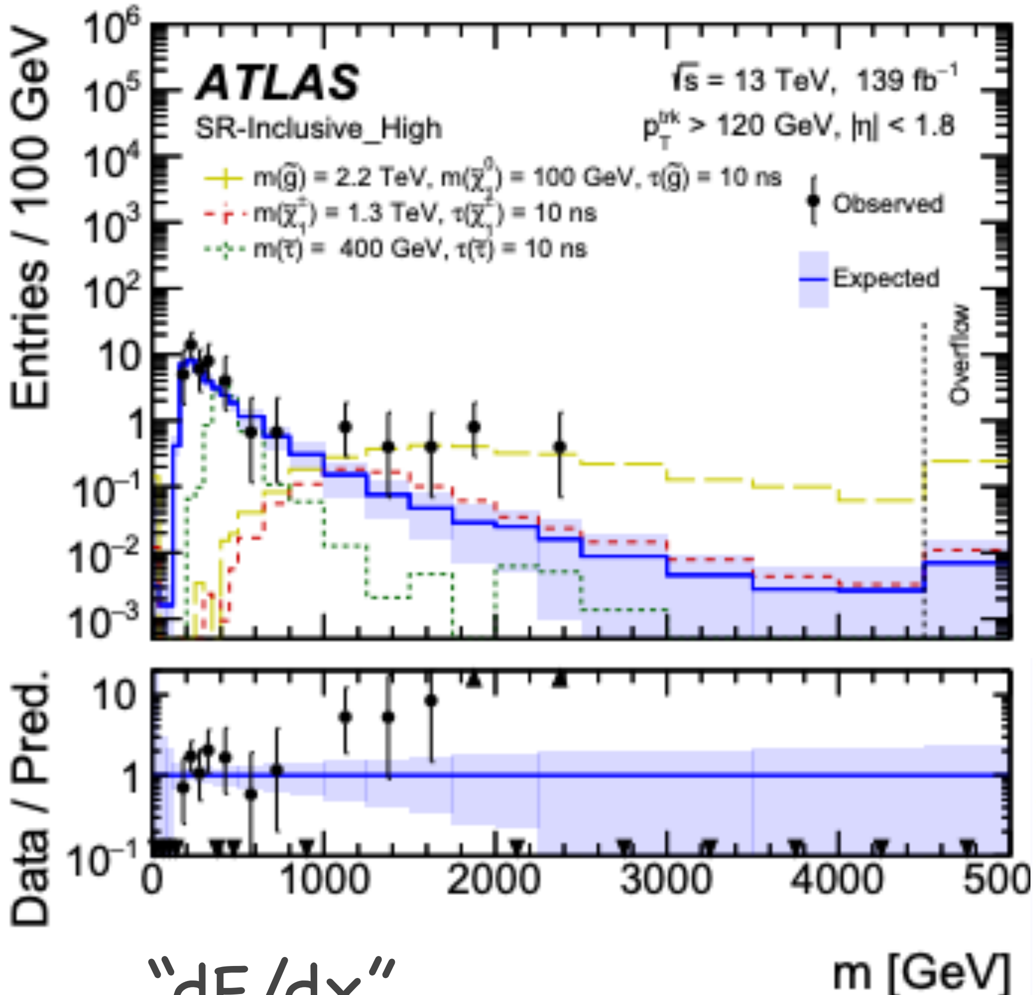
Is there an excess?



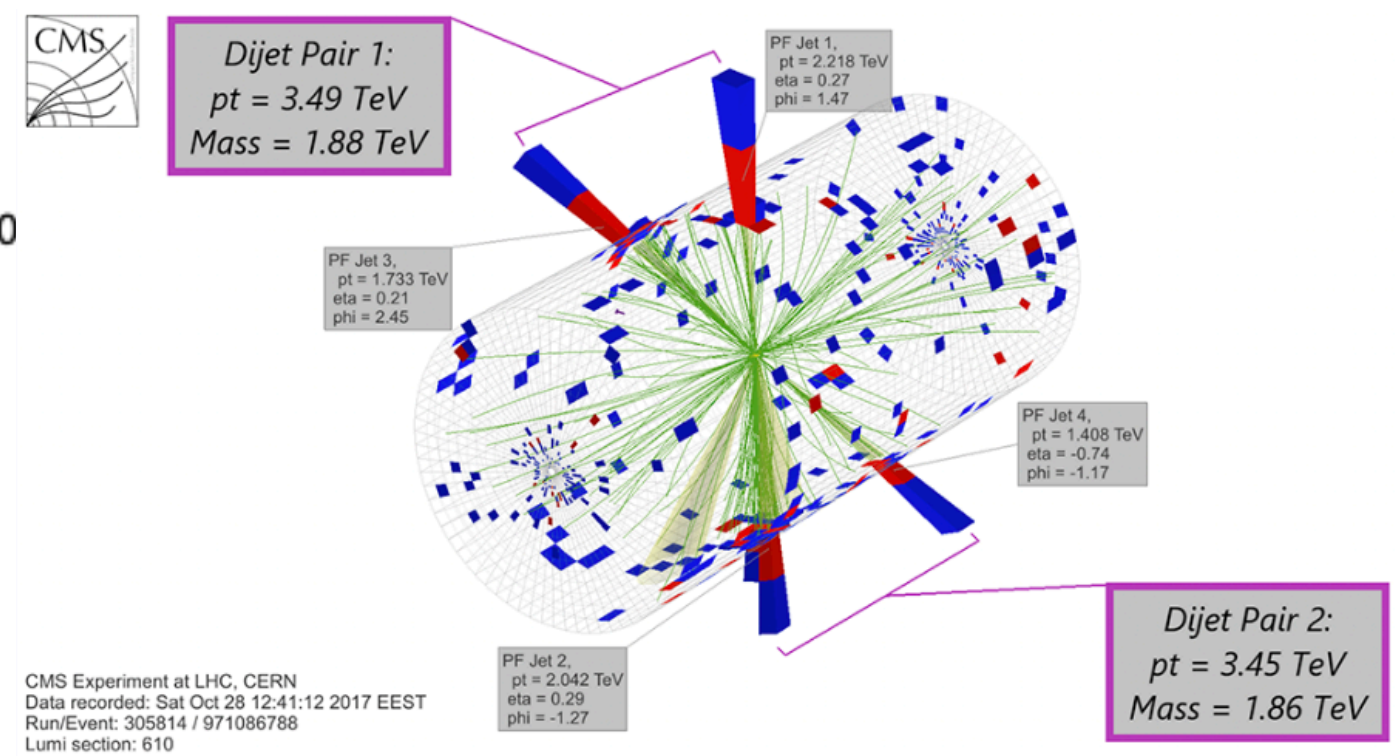


Not there in ATLAS data (yet)

Things to keep an on



"dE/dx"



A bit early to think about models. But, could become very interesting soon.

Conclusions

- We expect more excitement in the upcoming runs of the LHC.
- Bread and butter: precision, exotic decays
- At the same time, “anomalies” can also point us to interesting directions.