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# Theoretical interpretation of non-resonant phenomena

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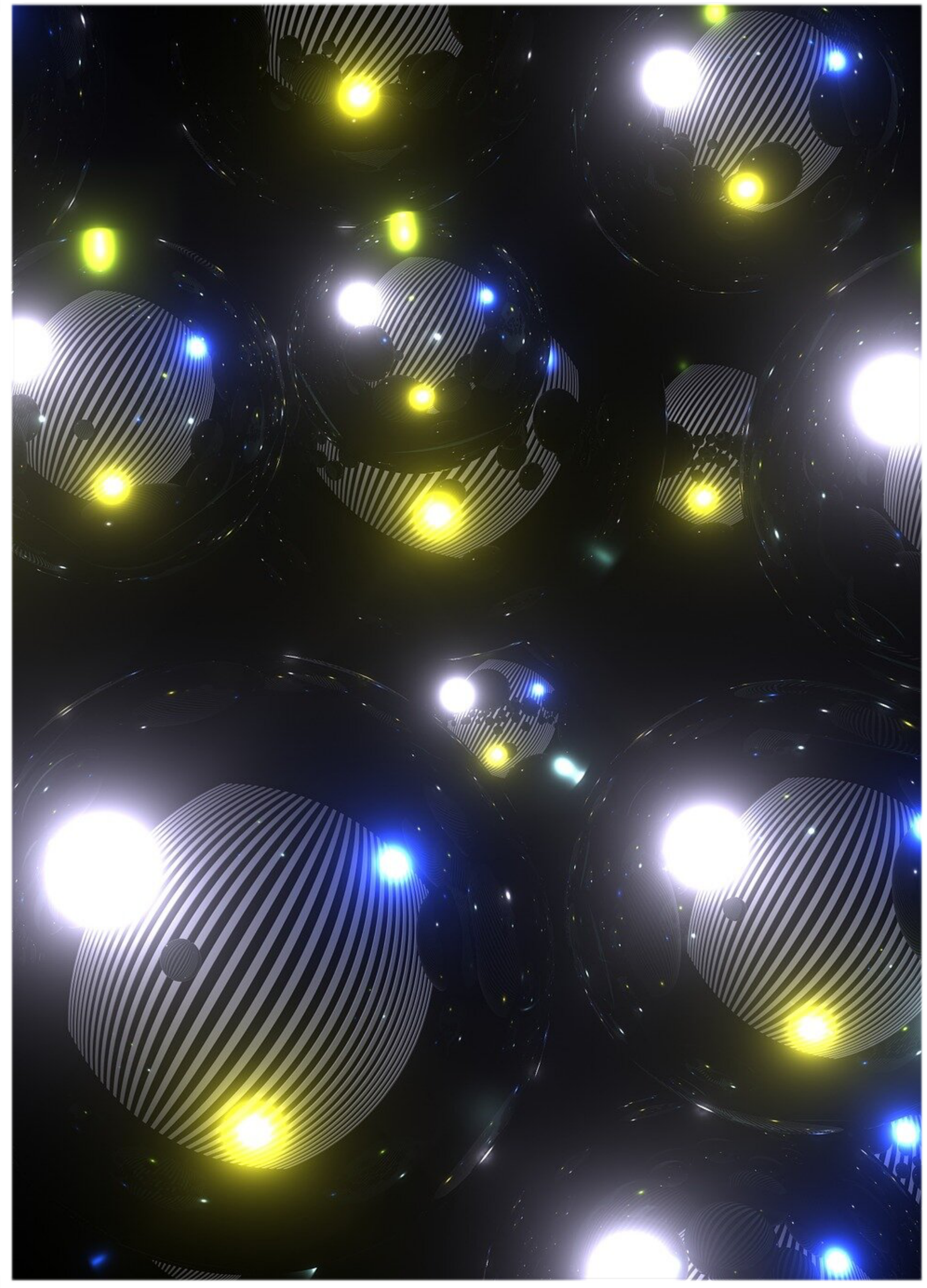
based on work with Miguel Folgado

arXiV: 2005.06492



# Why non-resonant?

The answer has to do with
why do we look for new physics

Best theoretical paradigms

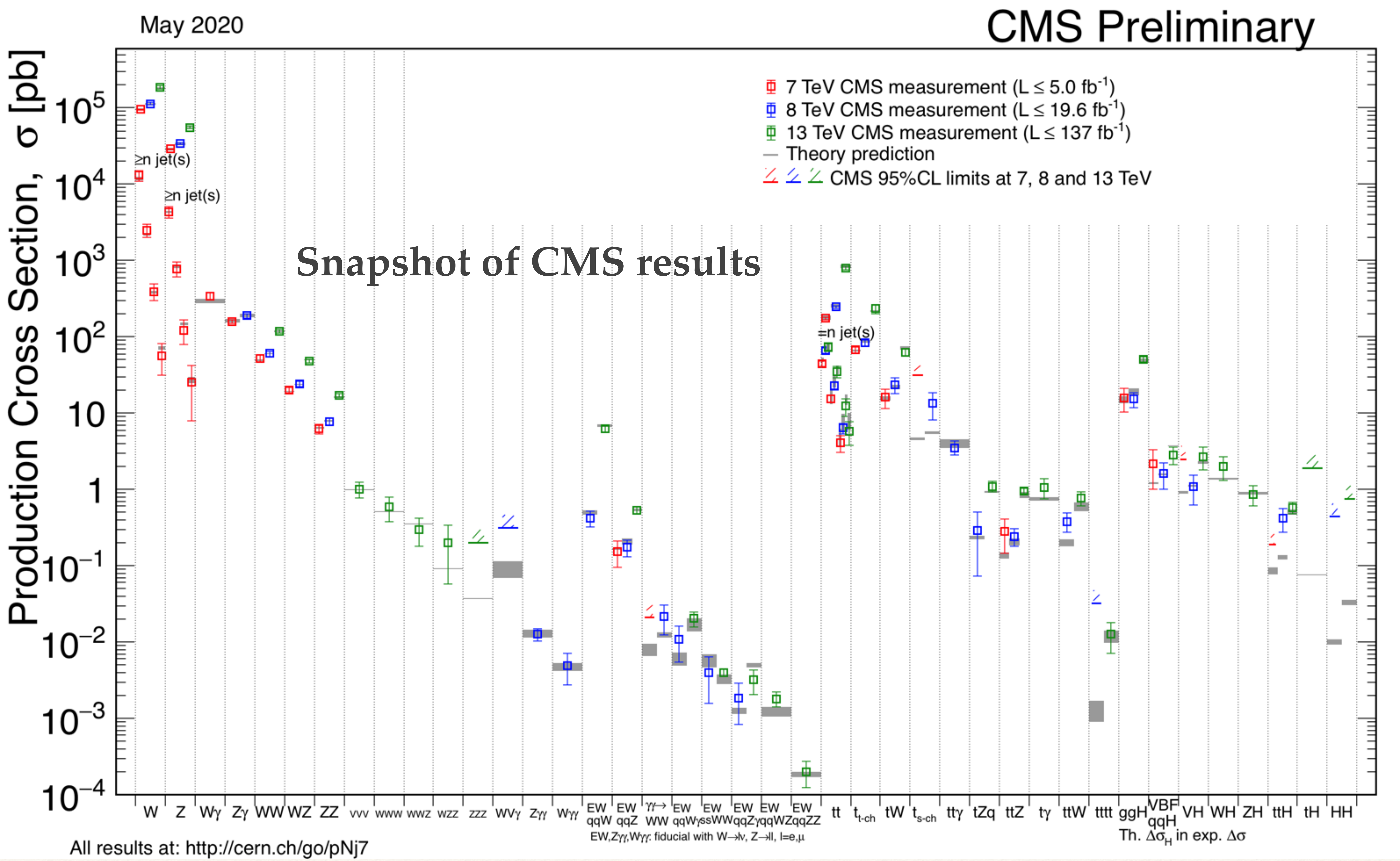
Standard Model
LambdaCDM

are based on a great deal of symmetries
and mostly minimal choices of matter content

How well do they work?

Let's focus on the SM and
on its best testing ground
the **LHC**

# Testing the Standard Model



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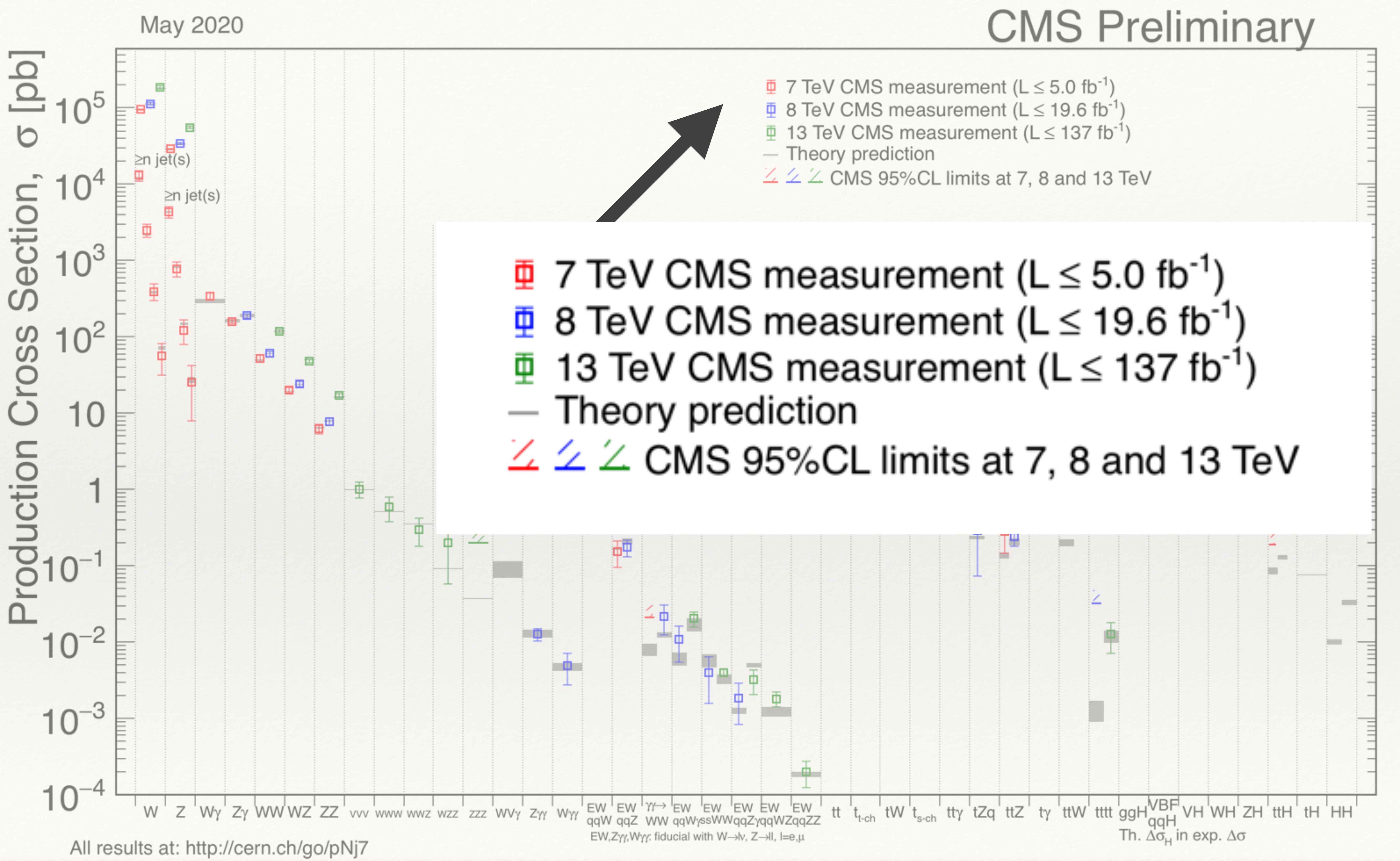

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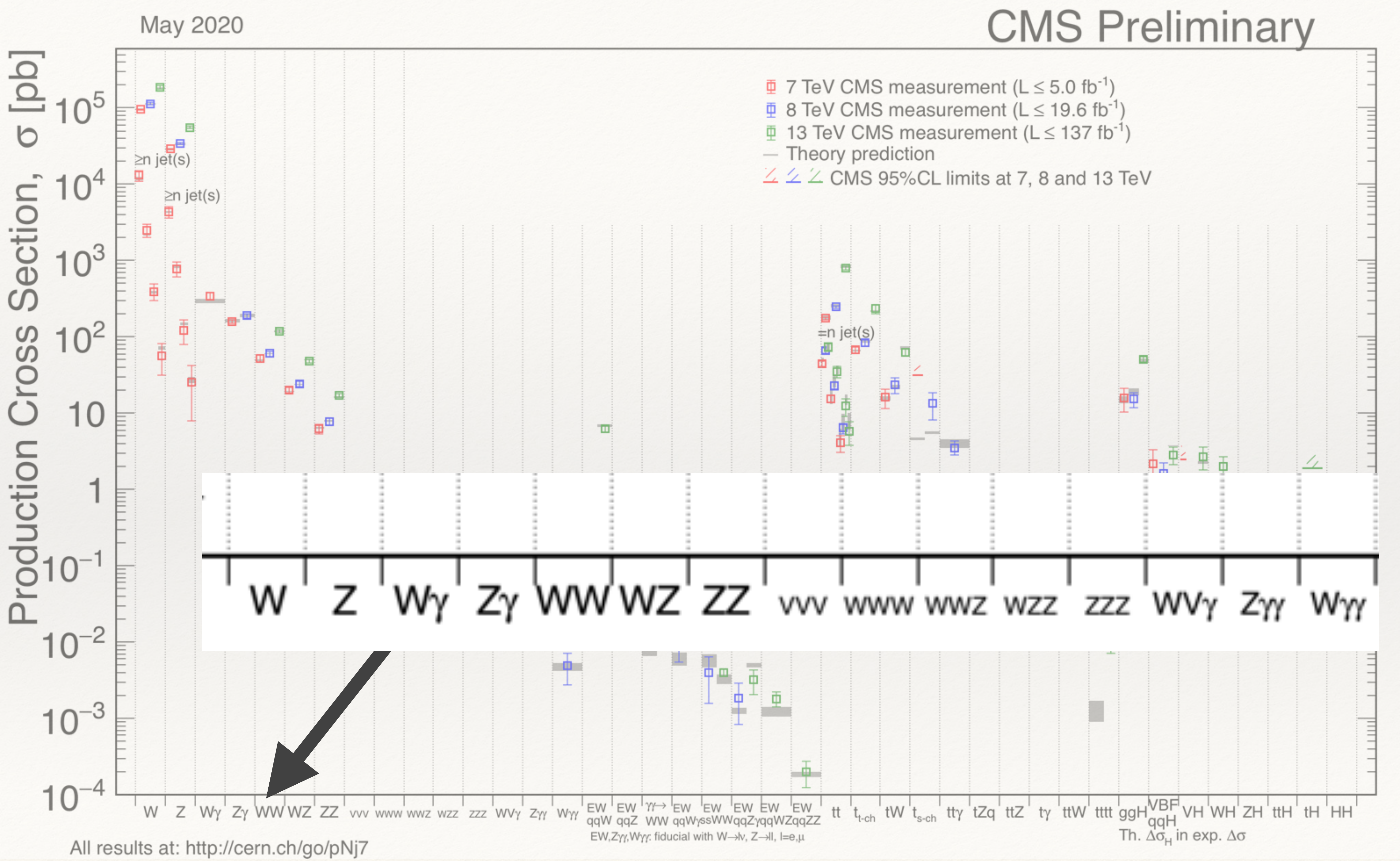

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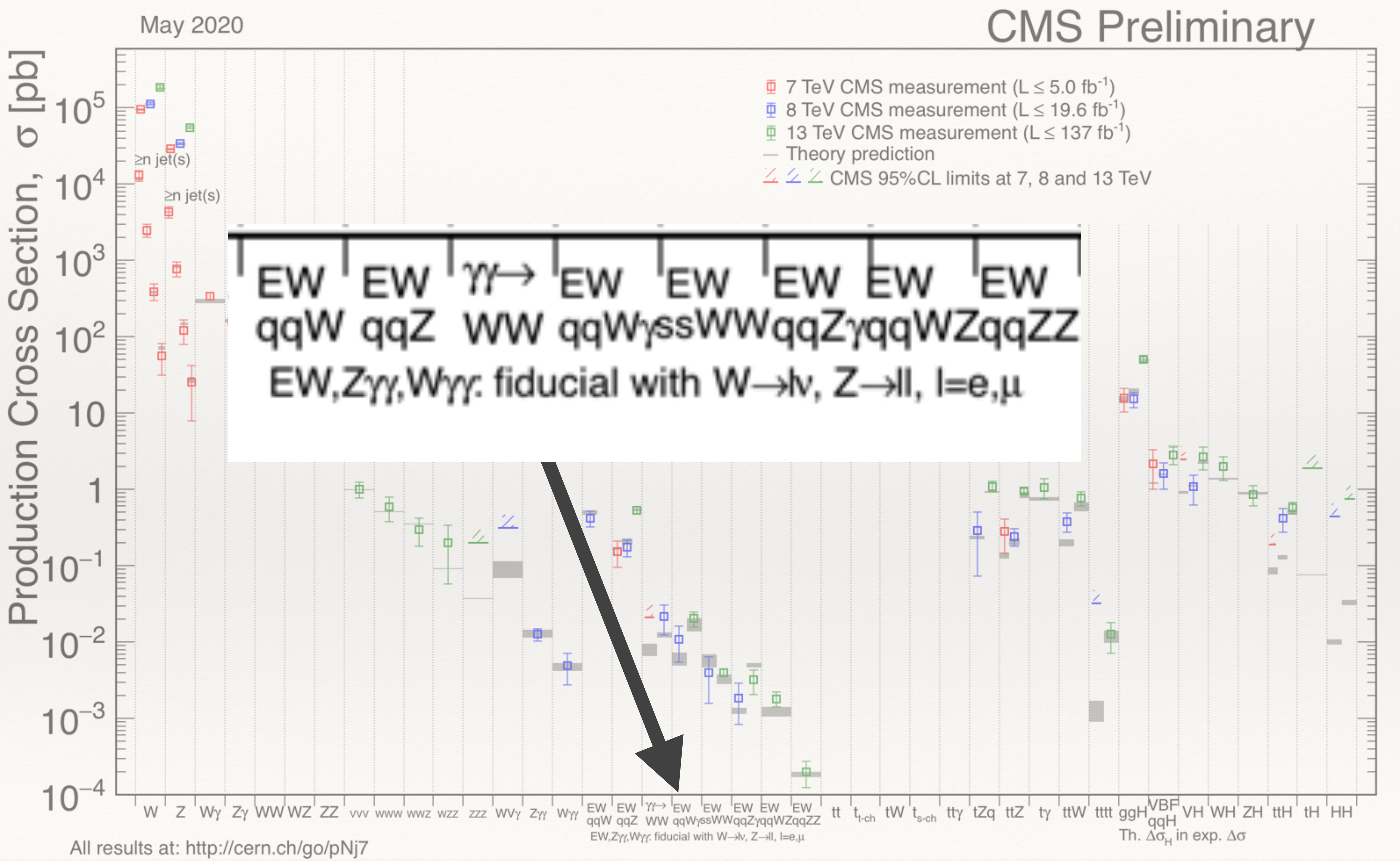

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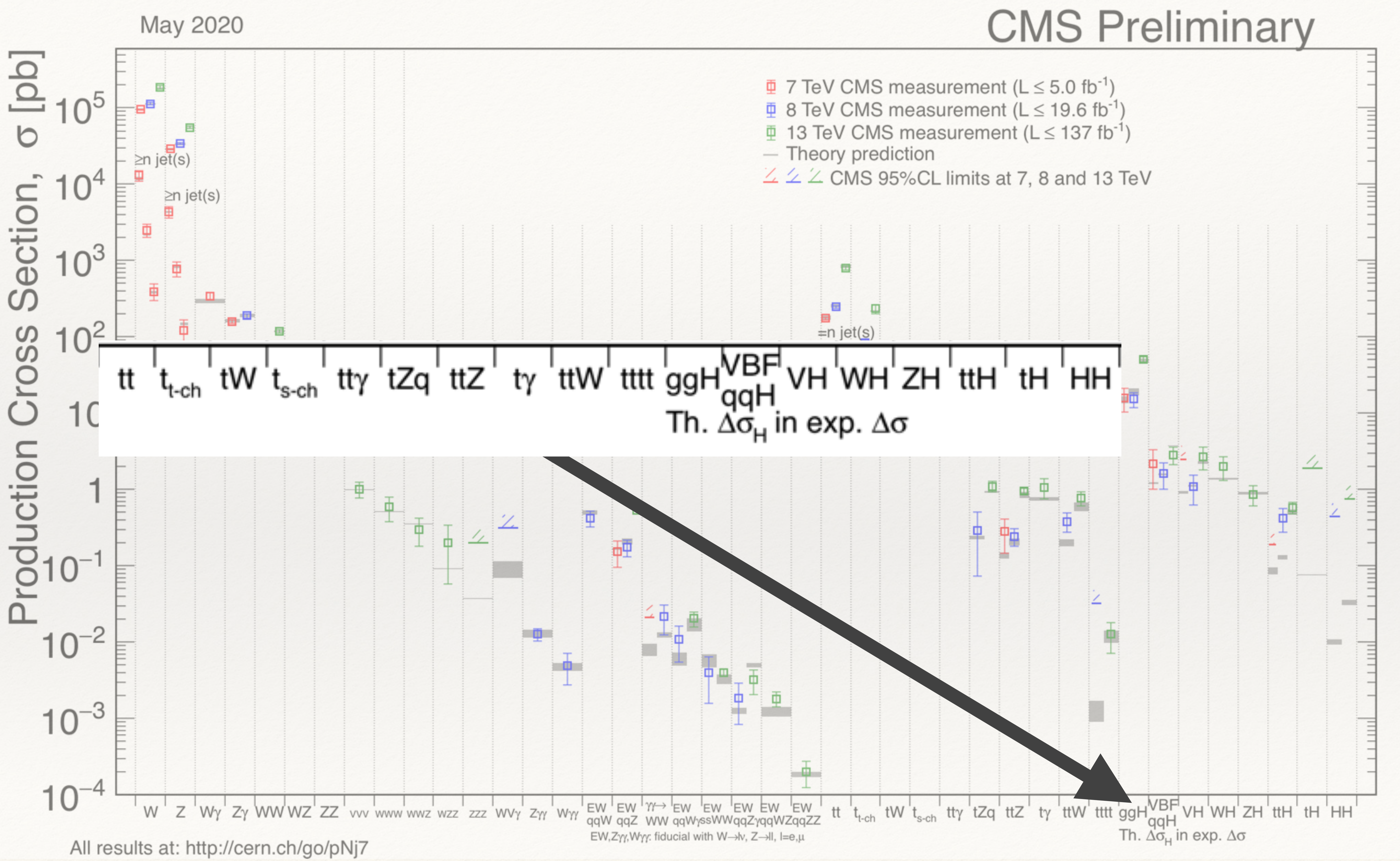

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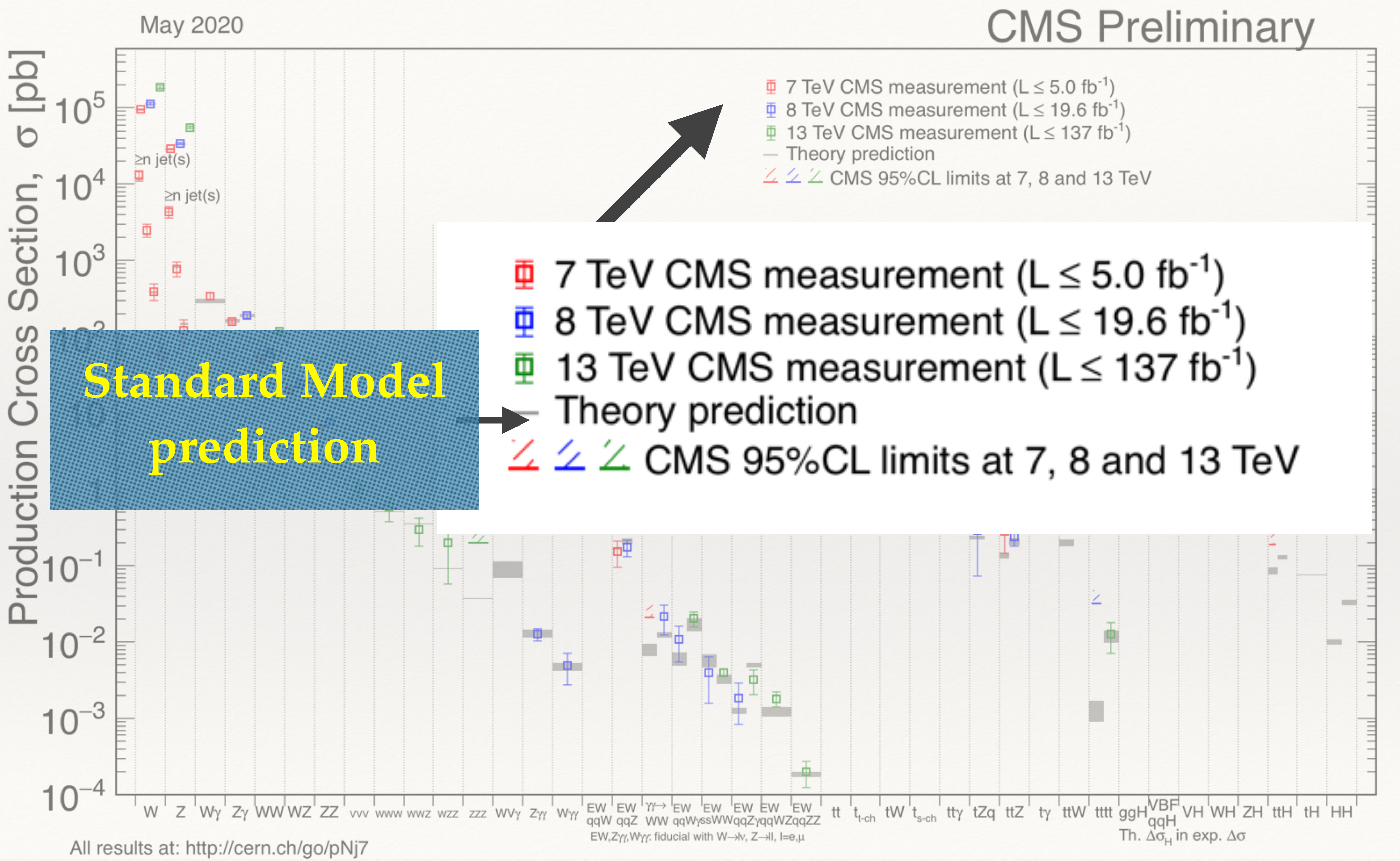

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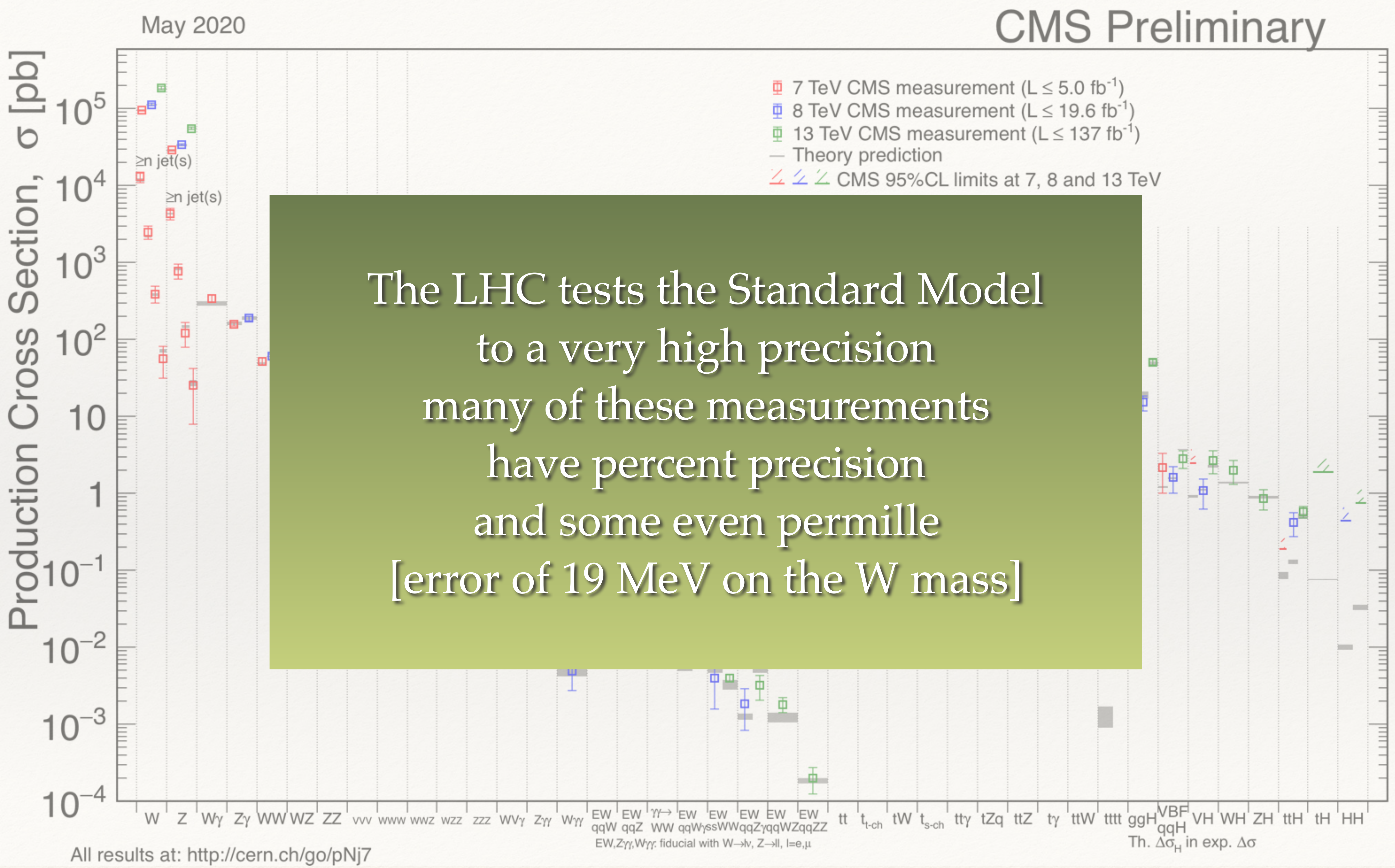



The LHC tests the Standard Model
to a very high precision
many of these measurements
have percent precision
and some even permille
[error of 19 MeV on the W mass]

# Celebrating the Standard Model

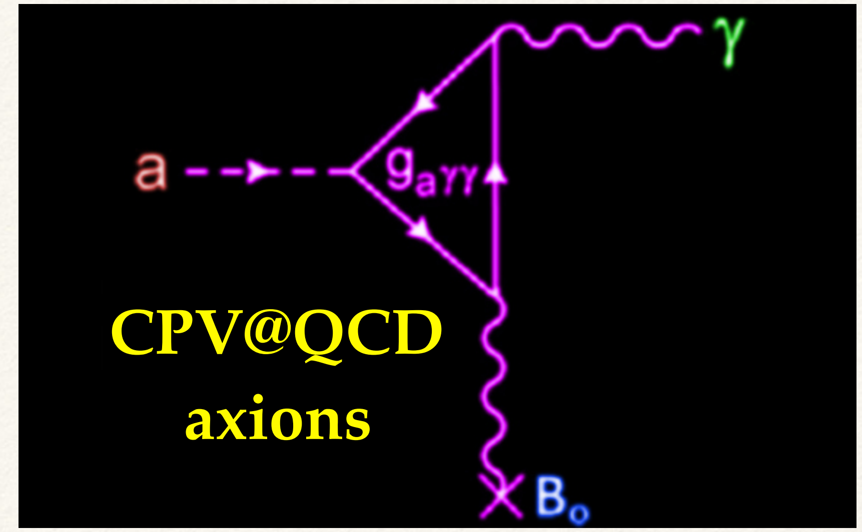
Those are impressive achievements

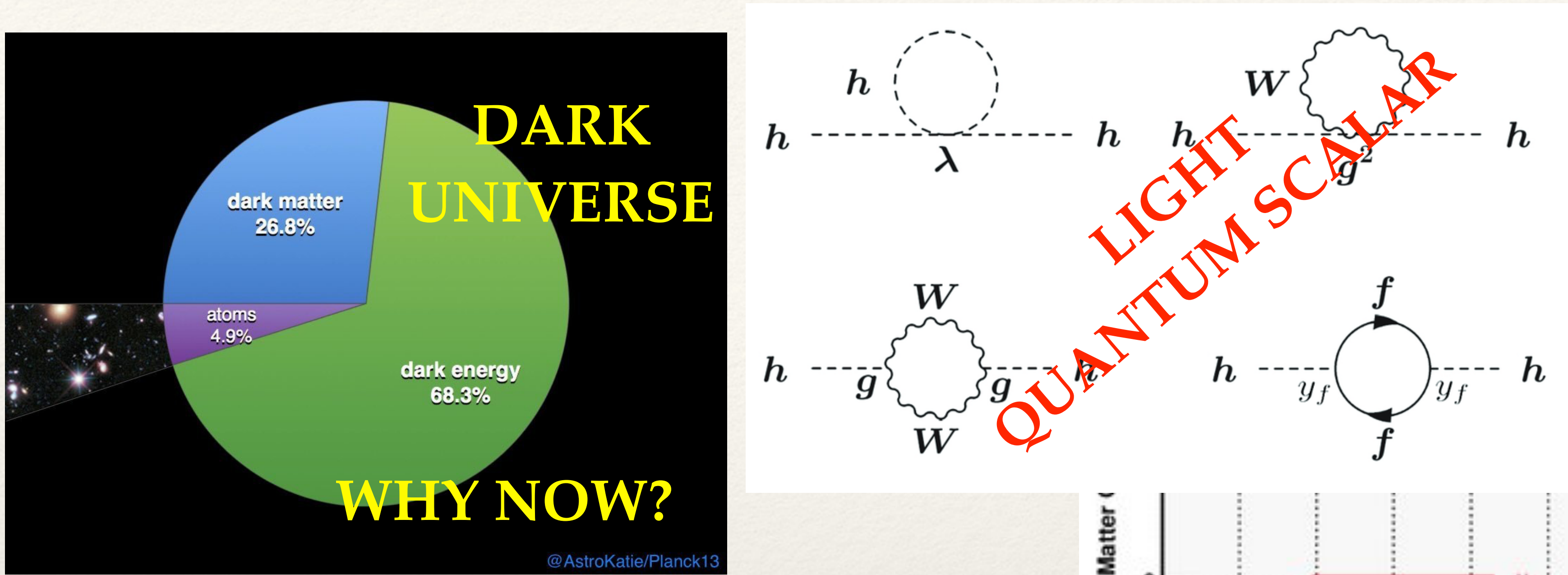
a single theory, developed long time ago
based on rather simple building blocks

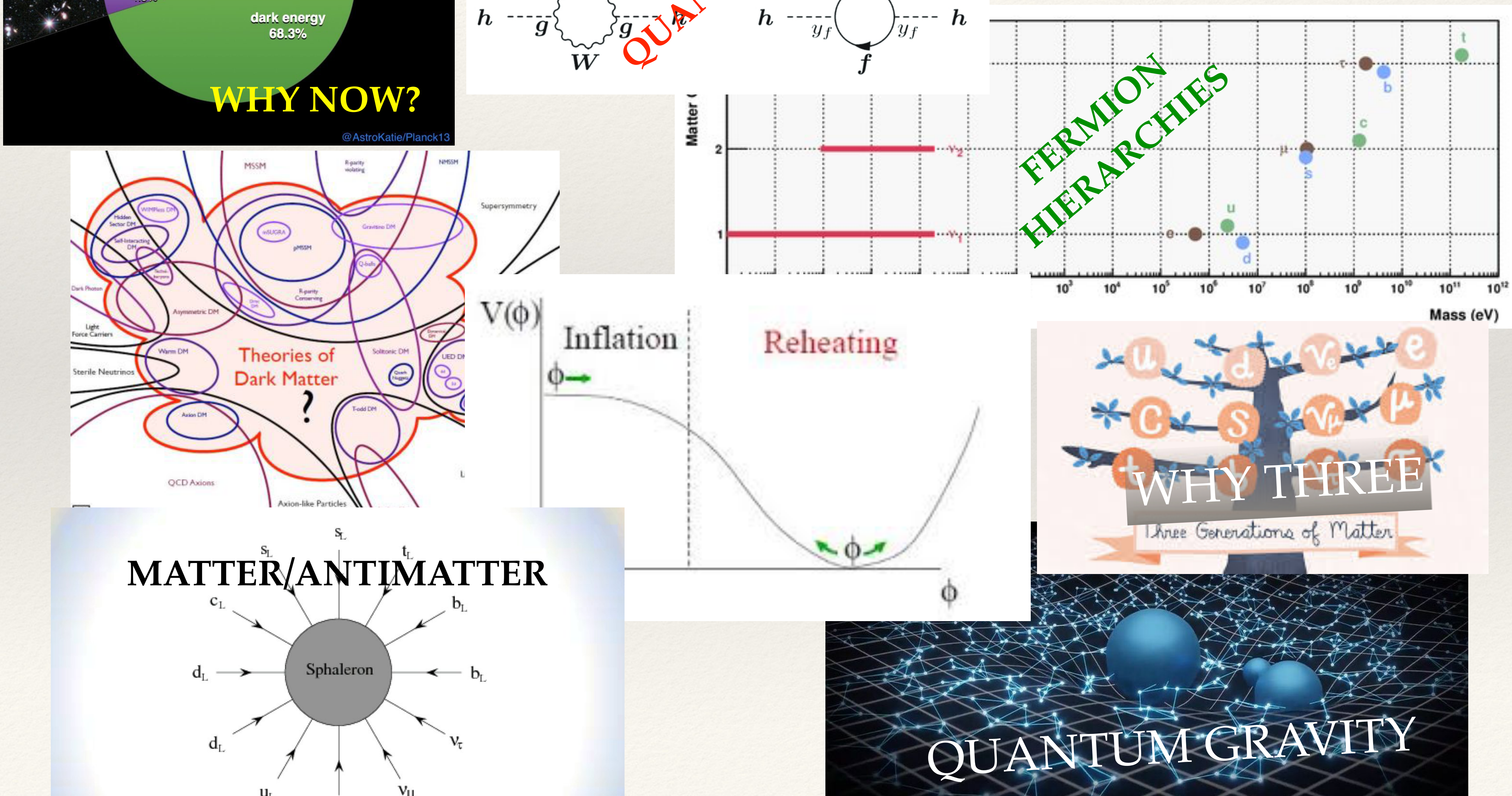
can predict Nature's behaviour at high energy
with unparalleled precision
in many kinematic situations
involving numerous different particles

So why aren't we just happy?

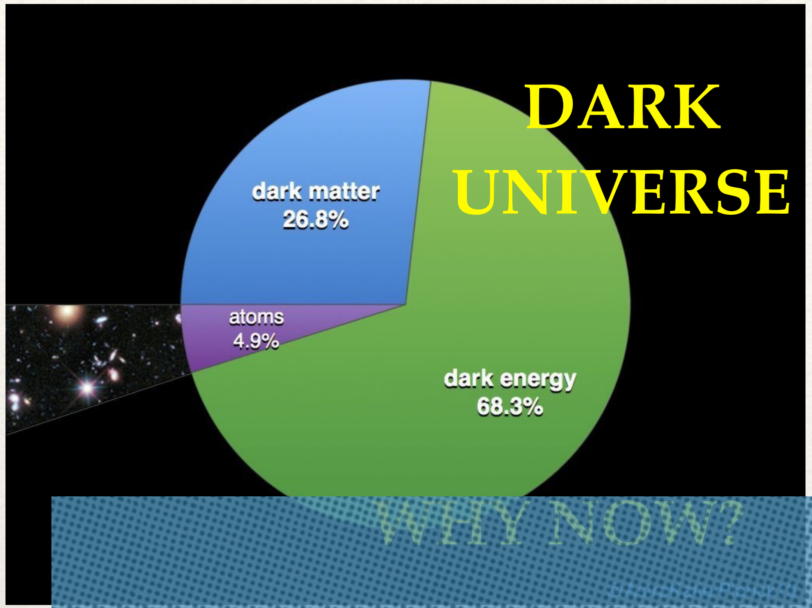
# Because that can’t be it

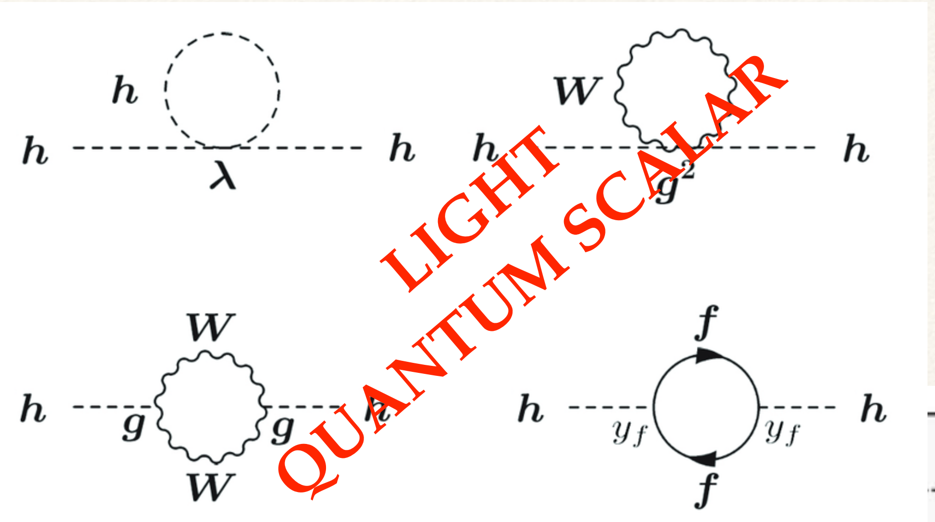


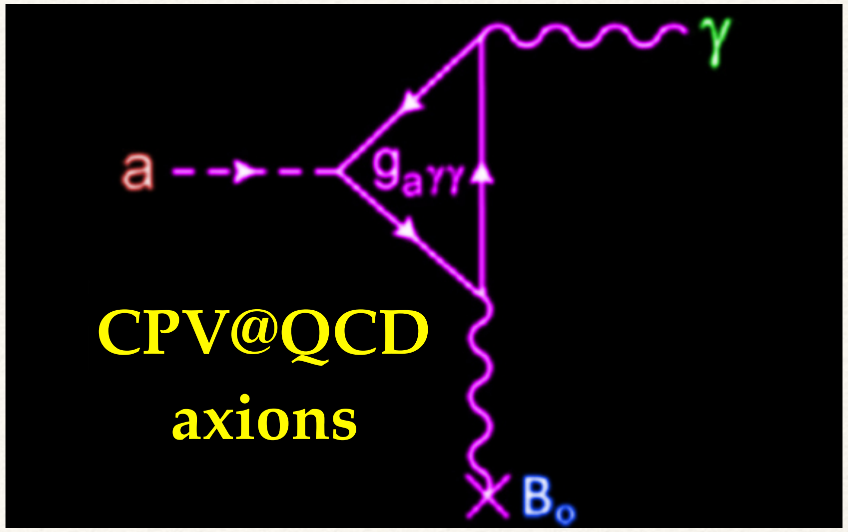



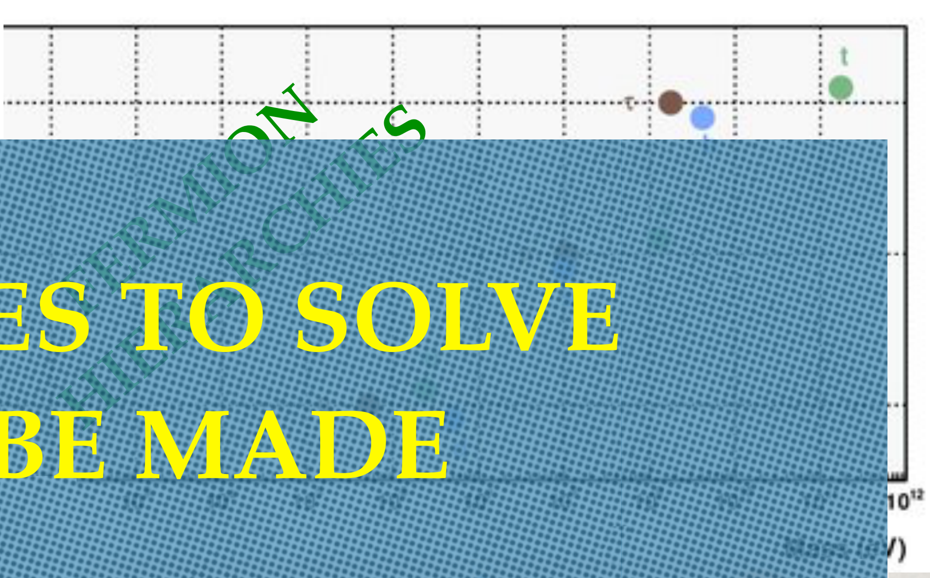



# Because that can't be it

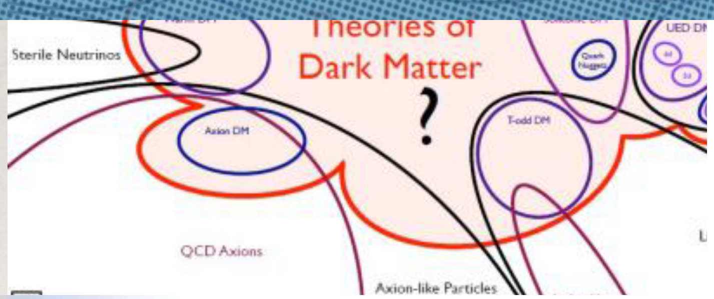


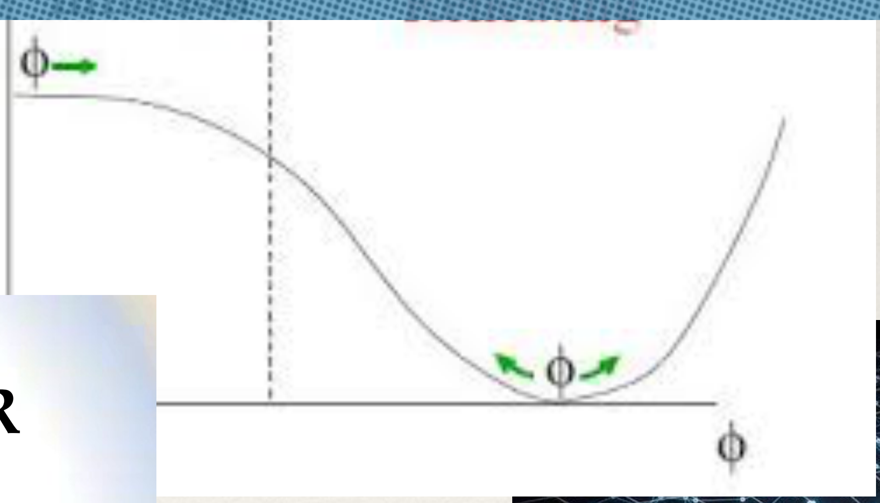



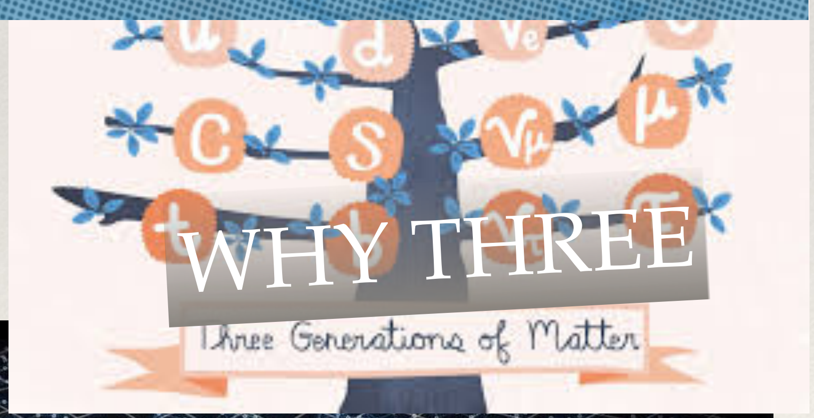



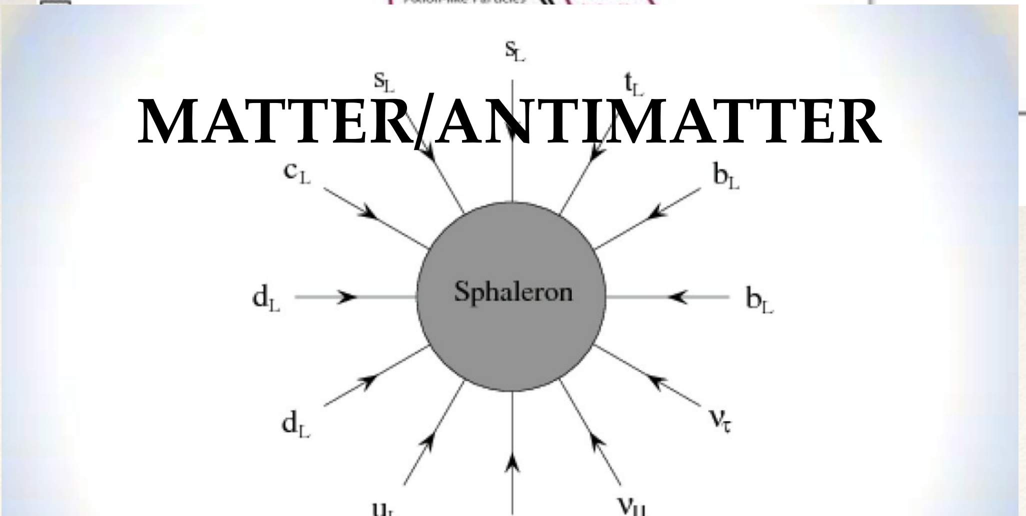



**THERE ARE MANY MYSTERIES TO SOLVE**
**MANY DISCOVERIES TO BE MADE**

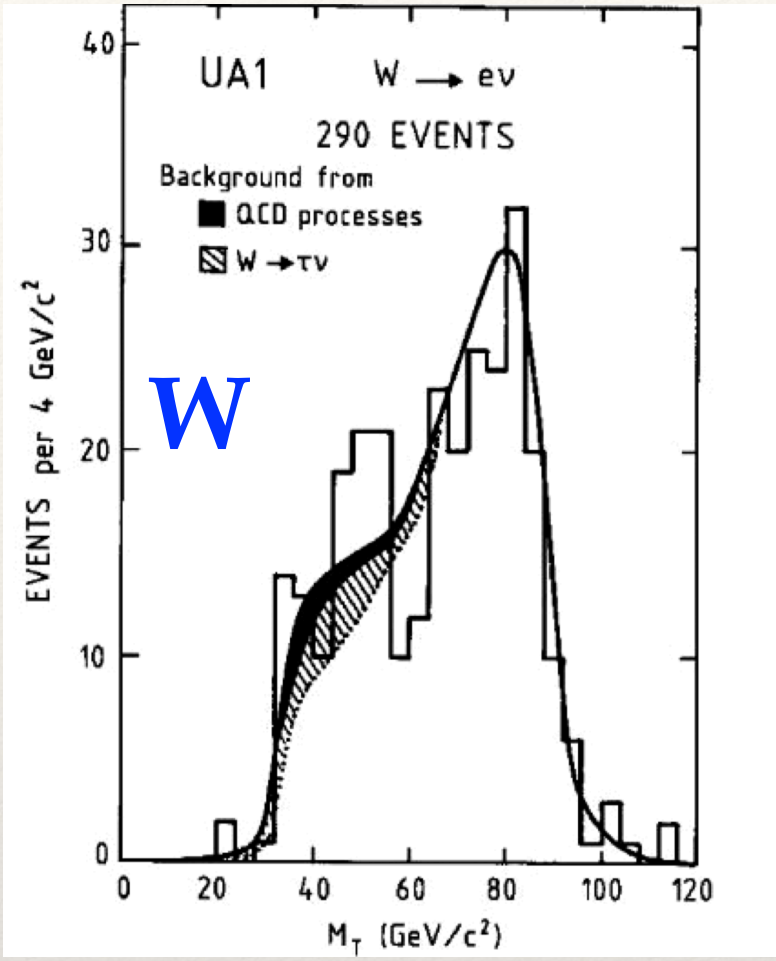


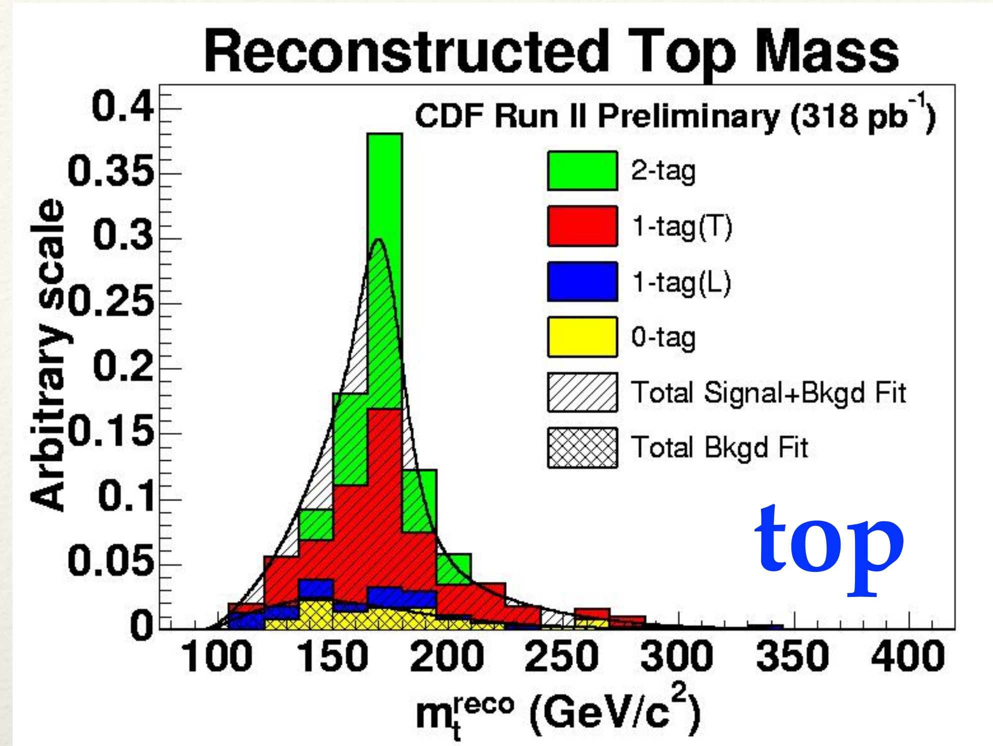



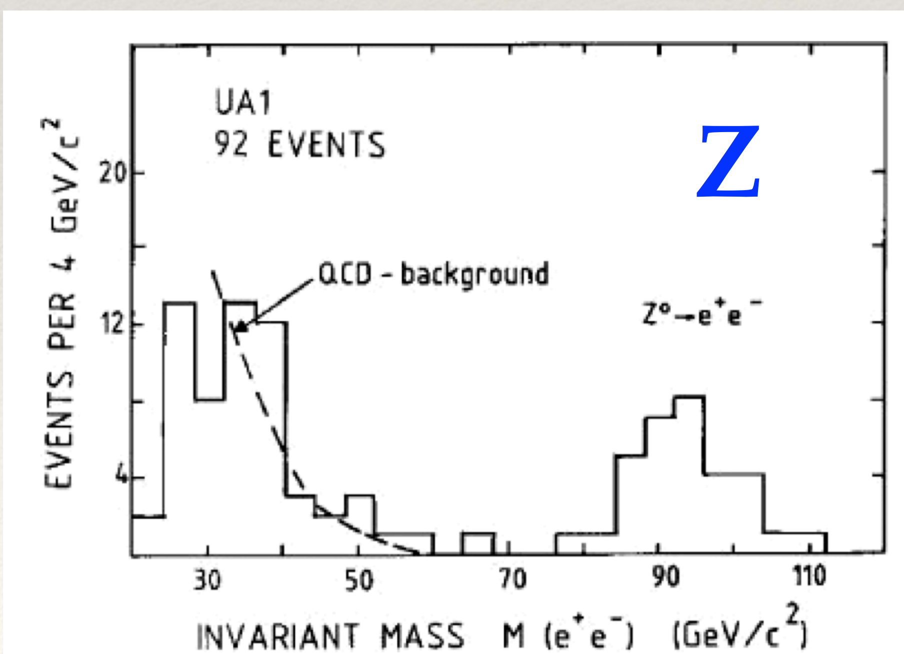


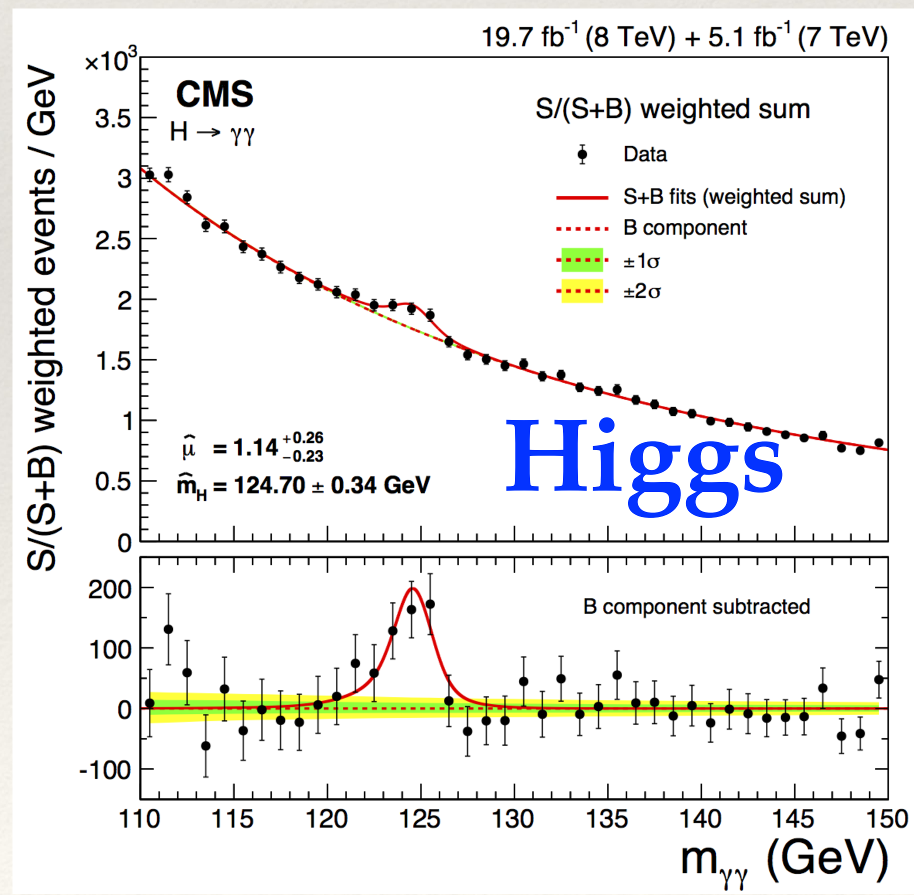




# Discoveries = Resonances?

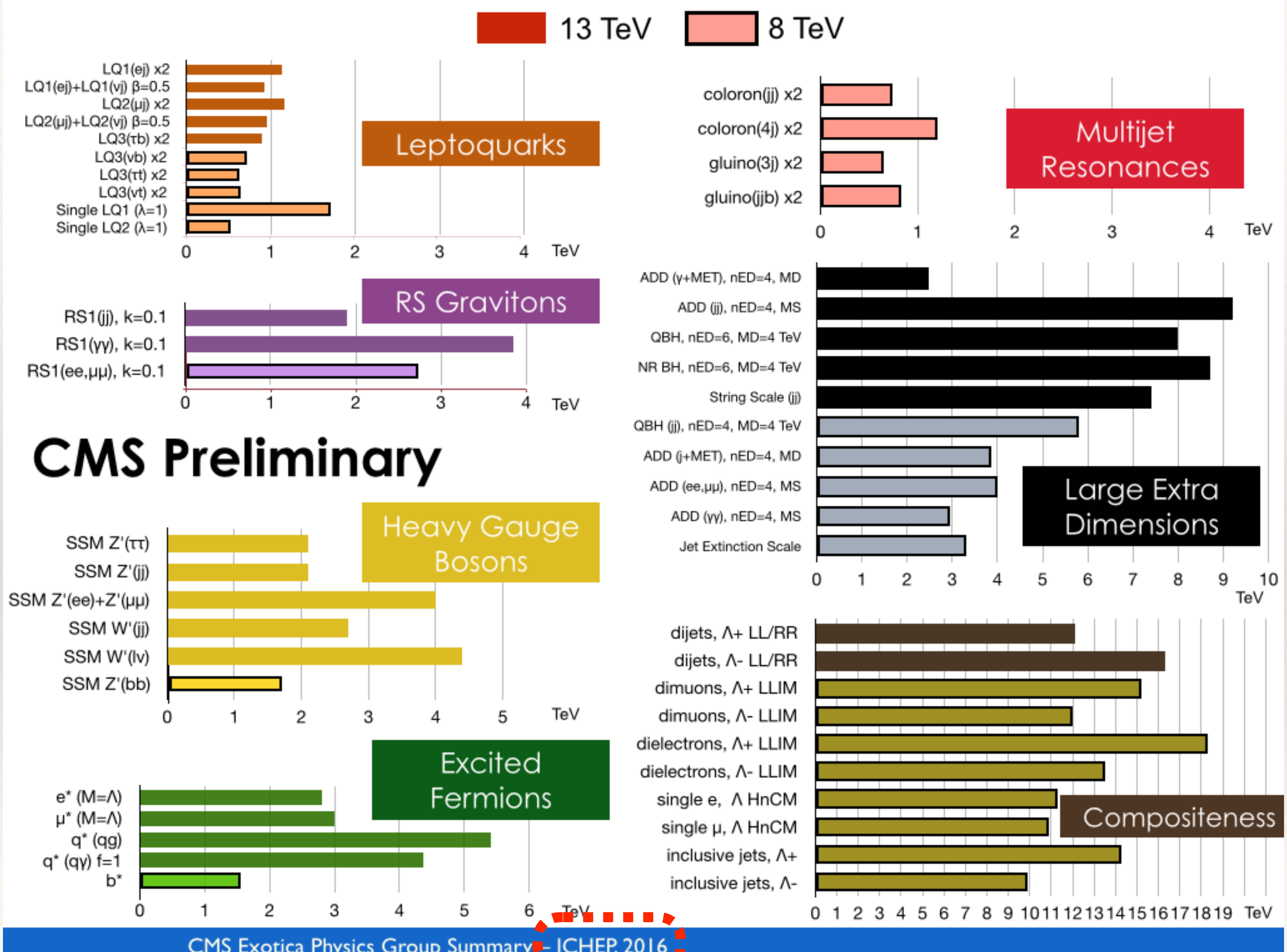


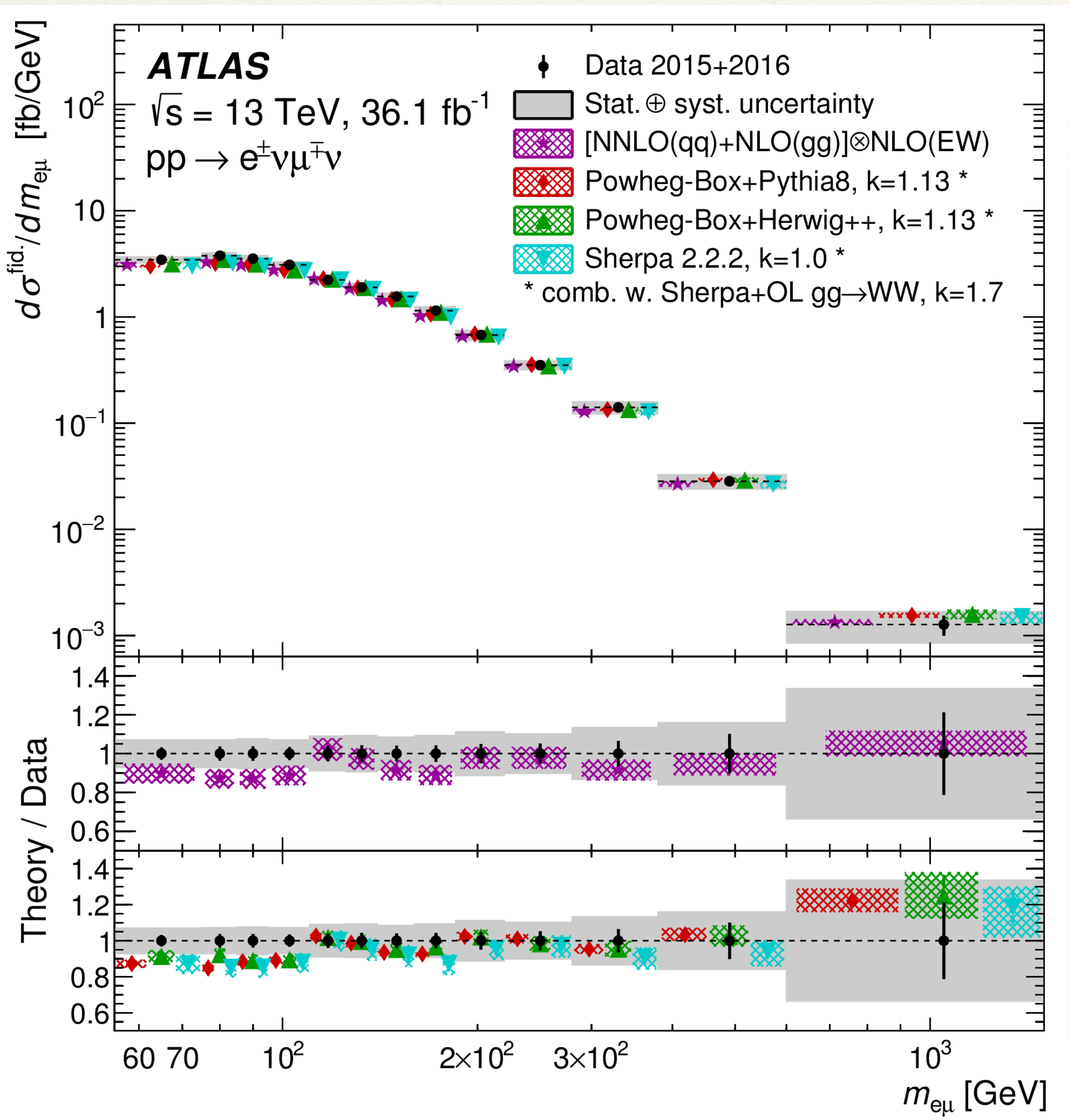



# And resonances have been searched for, indeed!



# Run3 and beyond

The LHC is a hadron machine, a **discovery** machine
yet it had to re-invent itself to become a **precision** machine



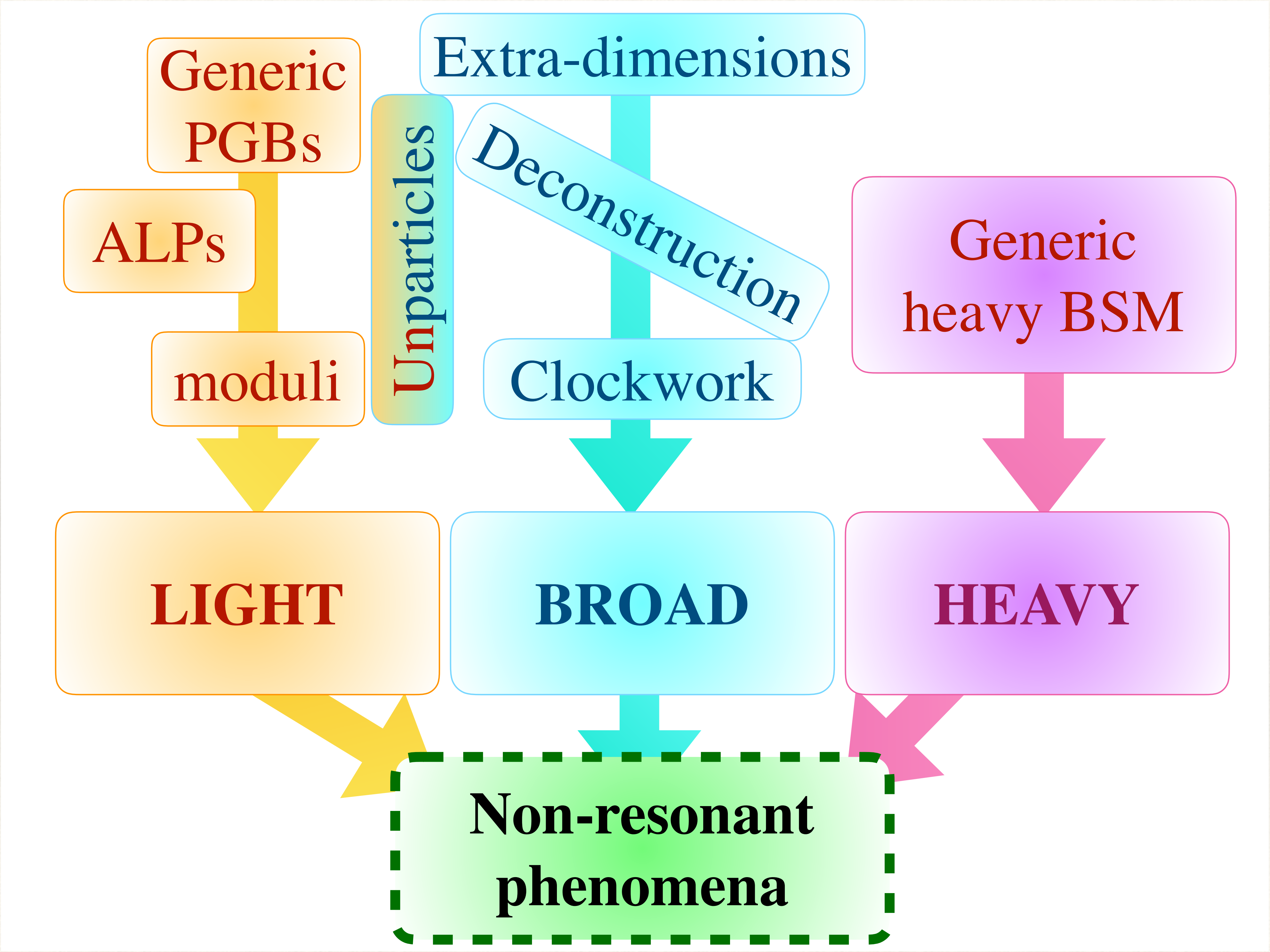

Traditional resonant searches have been so far unfruitful

On the other hand, more statistics and better understanding of the experiment allows diving into extreme kinematic regions

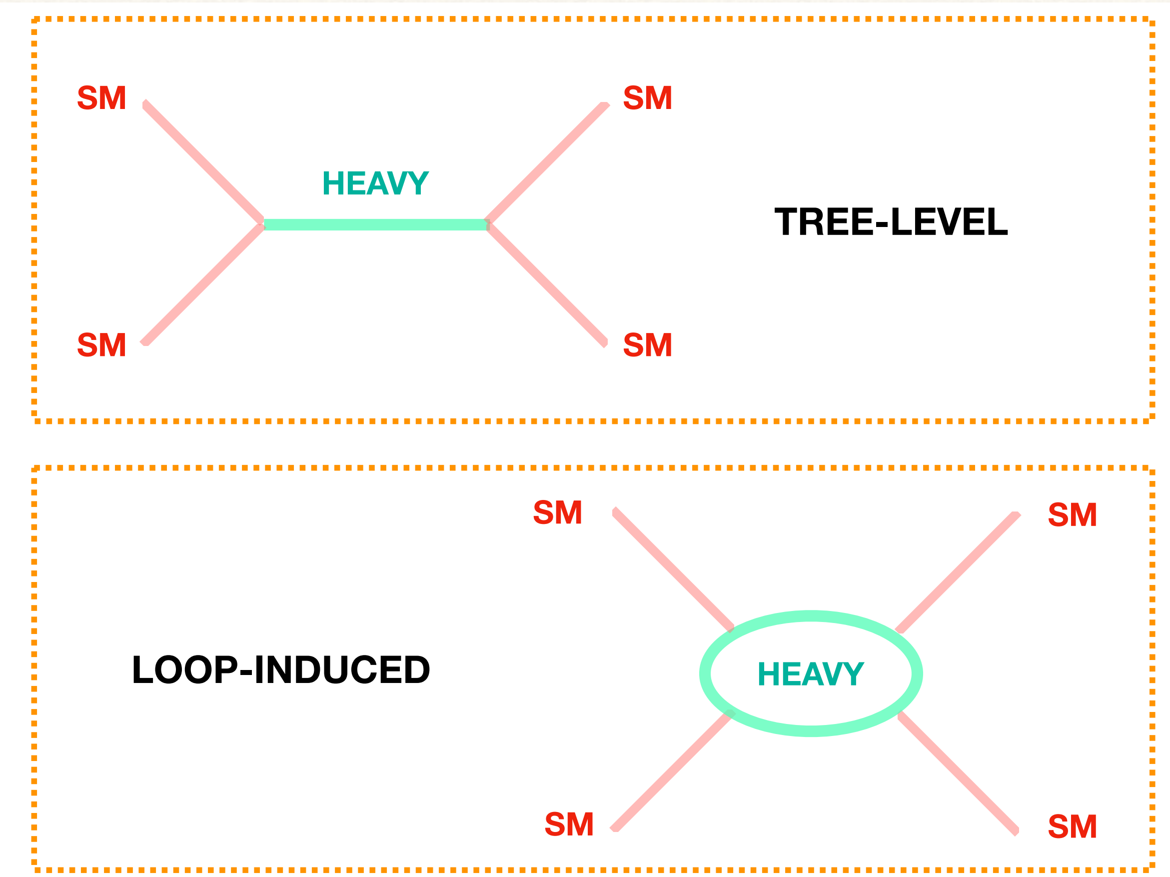
Let's embrace this state-of-affairs to perform different searches for new phenomena, beyond resonances

# Many scenarios

Many scenarios for new physics do not predict resonances@LHC
but could be discovered in this machine using its non-resonant behaviour



# The EFT: heavy new physics




$$\bar{c}_{HW} \frac{2\,g}{m_W^2} \left(D^\mu H^\dagger (T_2)_k D^\nu H\right) W^k_{\mu\nu}$$

$$[h(p_1),\, W^\mu(p_2),\, W^\nu(p_3)] = i\, g\, m_W [\eta^{\mu\nu} + \frac{\bar{c}_{HW}}{m_W^2} (2p_2.p_3 + (p_2^2+p_3^2) - 2p_2^\nu\, p_3^\mu - (p_2^\mu p_2^\nu + p_3^\mu p_3^\nu)]$$

High-pT behaviour used in
Global EFT fits
e.g. 1404.3667, 1410.7703
State-of-the-art in EFTs

Model interpretation:
dictionary between models
and EFT
e.g. 1502.07352
same limit on coefficients,
different interpretation

$$\begin{aligned}
\bar{c}_{HW} &\simeq \lambda_{hS}^2 \frac{v_s^2 v^2}{m_S^4} && (SU(2)_L\ \textbf{Singlet}) \\
&\simeq -\frac{2\lambda_{hH}}{192\,\pi^2} \frac{m_W^2}{m_{H_2}^2} && (SU(2)_L\ \textbf{Doublet}) \\
&\simeq -\frac{c_{CFT}}{4} \frac{m_h^2\, v^2}{f^2\, m_r^2} && \textbf{(Radion/Dilaton)}
\end{aligned}$$

# The light case: pseudo-Goldstone

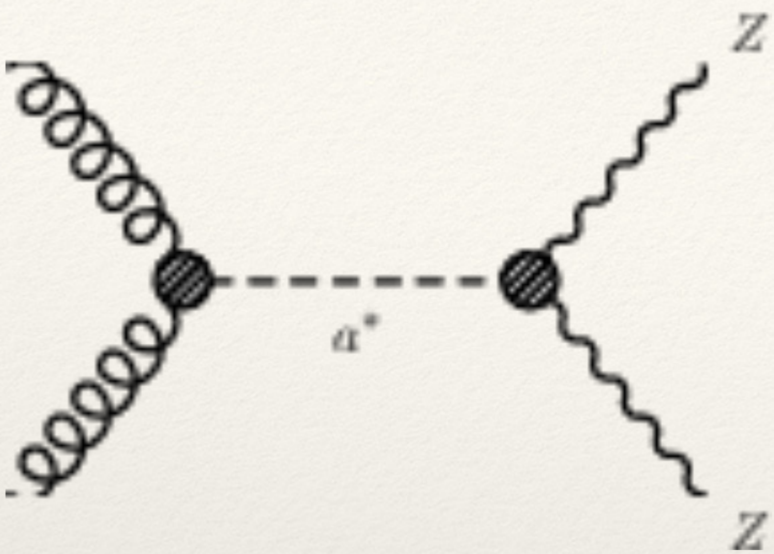
What if your new sector was very light?
imagine, for example, you are looking for a particle
which decays into photons with mass $<<$ GeV

Resonant searches would be impossible
Triggers remove very soft stuff
indistinguishable from QCD backgrounds

This particle can't be searched for a high-energy collider like the LHC

BUT
what if your new particle was a pseudo-Goldstone boson?
its couplings to SM particle would grow with energy
we may not see the particle as a resonance but feel its effect
in high-energy tails

# The light case: pseudo-Goldstone

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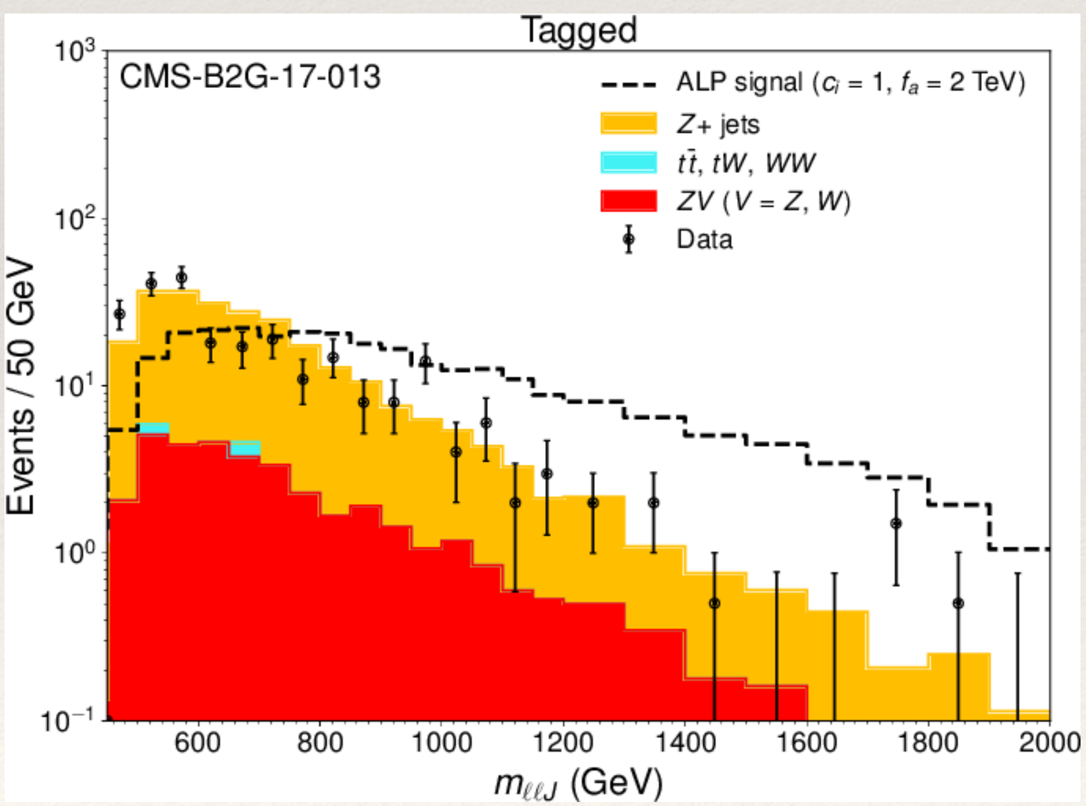
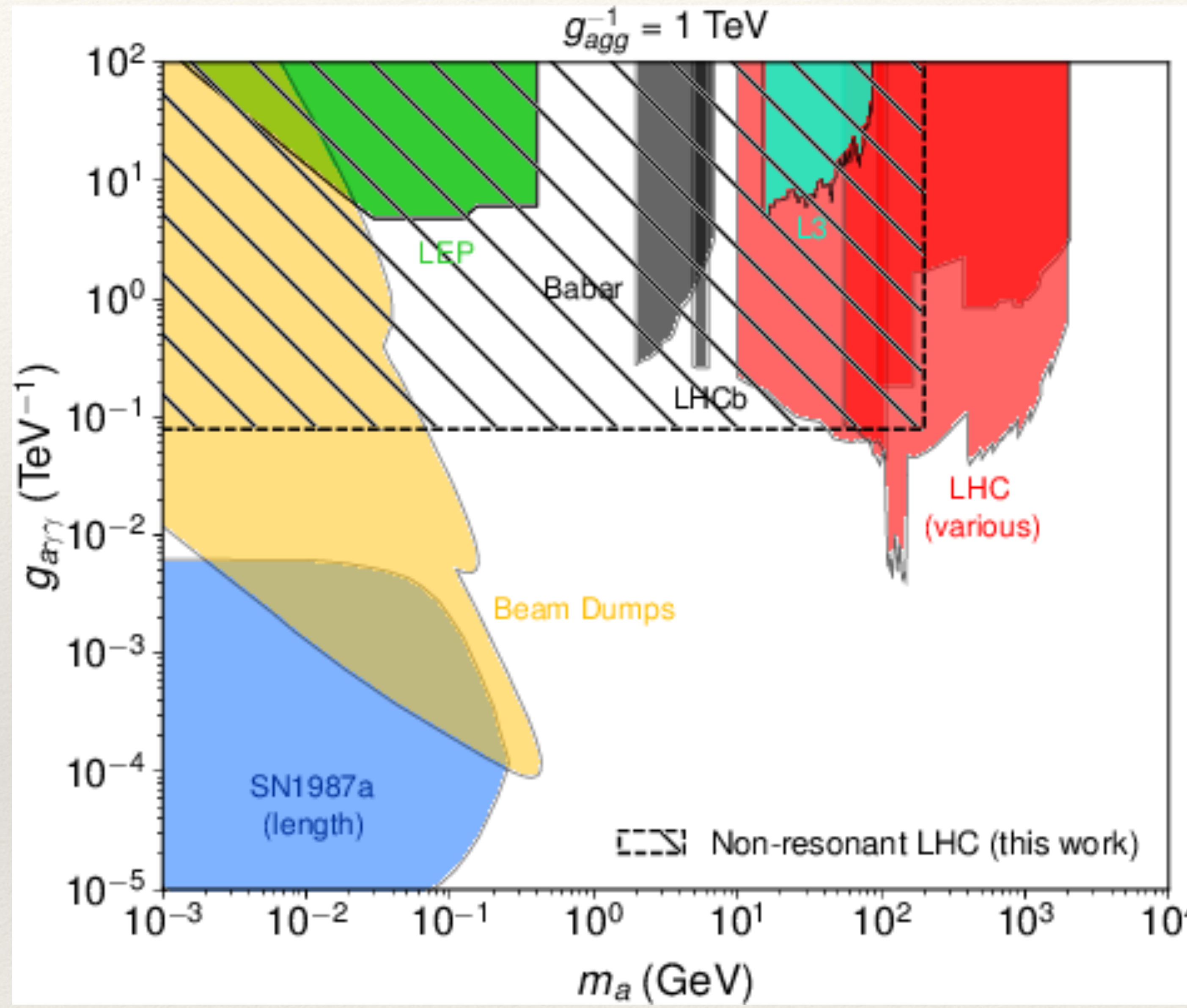


# The broad case

Non-resonant phenomena: close-by resonances
overlap and form a quasi-continuum
How weird is this? what is the theoretical interpretation?

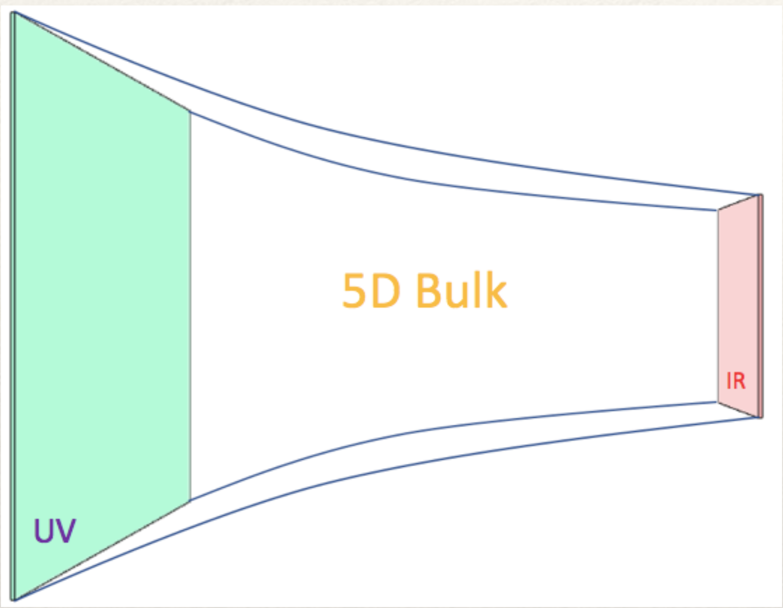
Remember that in QCD at large-Nc *expect* a tower of resonances
example: s=1 rho, rho'… and a whole tower until LambdaQCD
width ~ 1/Nc^2
but Nc=3 not a large number, so rho and rho' are relatively narrow
but after that we got a continuum of the "rho-tower"
mesonic QCD in the intermediate region is non-resonant

In many scenarios for BSM physics there is a well-motivated region
of non-resonant behaviour which has been largely unexplored
(focus on low-hanging fruit)

# The broad case

There are plenty of examples of BSM models which predict towers or resonances with the same quantum numbers

**EXTRA-DIMENSIONS**




Example: **Warped Extra-Dimensions**

$$ds^2 = e^{-2kr_c|y|}\eta_{\mu\nu}dx^\mu dx^\nu - r_c^2 dy^2$$

Fields propagating in the xdim behave as a tower of 4D fields with the same quantum numbers but increasing mass
Kaluza-Klein tower

**Unavoidable**: KK-gravitons coupled to SM particles via the stress-tensor
mass and 1/coupling ~ TeV

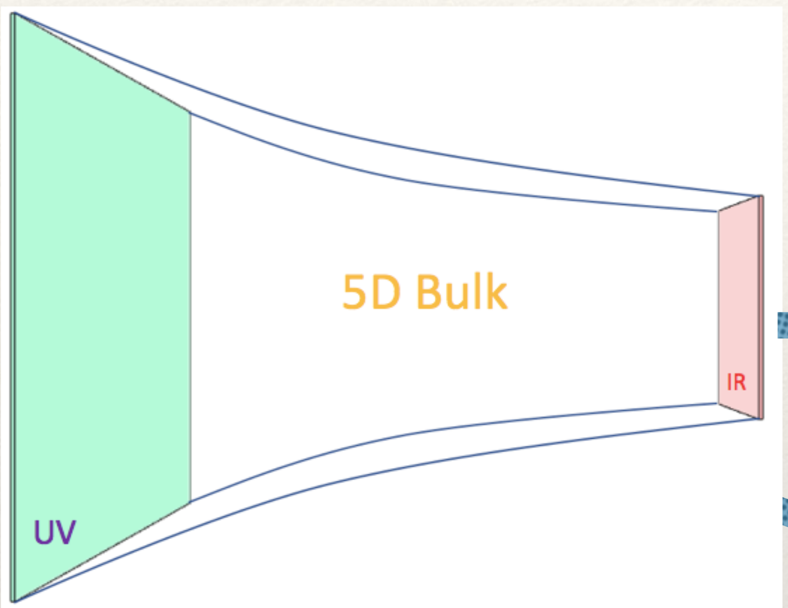
$$\mathcal{L} = -\frac{1}{\Lambda}\sum_{n=1}^{\infty} h^n_{\mu\nu}(x)T^{\mu\nu}(x),$$

This tower's resonances could be close-by and produce a continuum would **evade resonant searches**
KK-gravitons could be much lighter than typical limits ( >~ TeV) and only discovered by analysis of tails

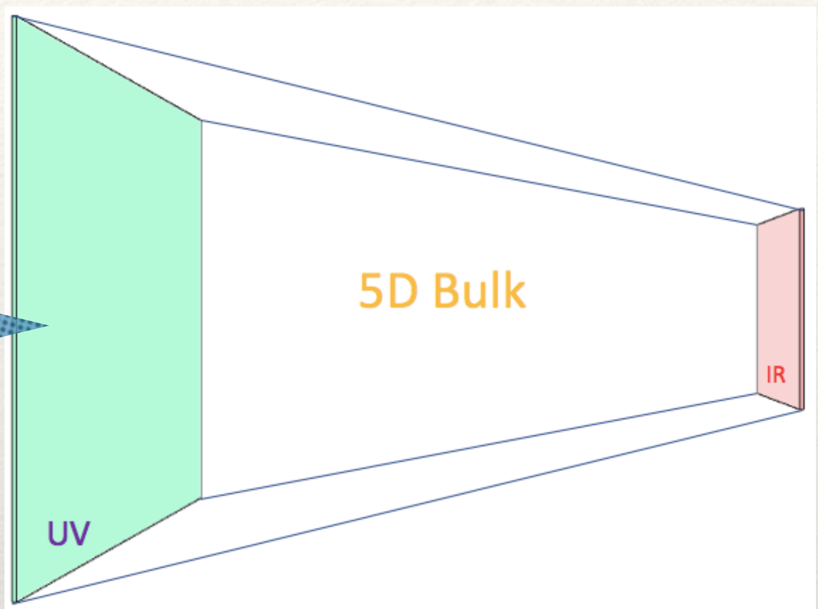
# The broad case

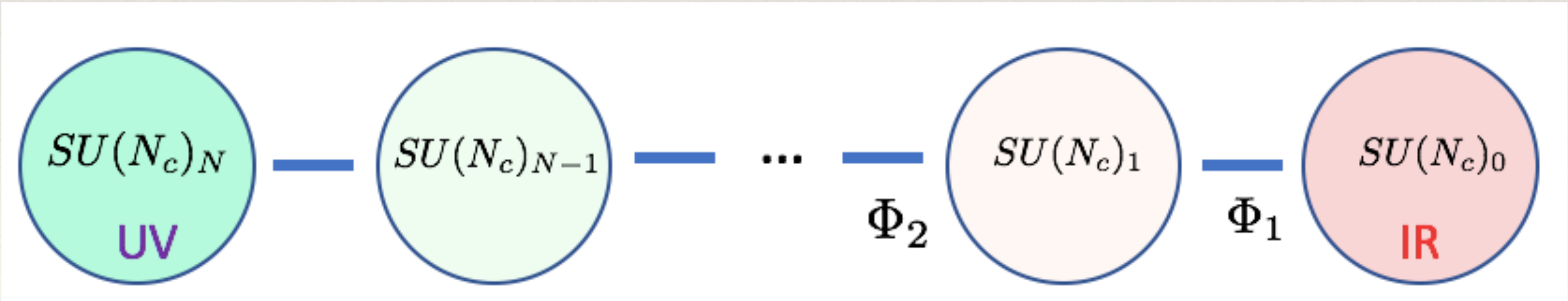
AND there are plenty of other scenarios with the same rough characteristics related to Extra-Dimensions via **dualities**

**EXTRA-DIMENSIONS**




**CLOCKWORK**




**MOOSE/DECONSTRUCTION**

**Unparticles**
**Black-Holes w/hair**
**quantum critical Higgs**
***a* new quasi-conformal sector**

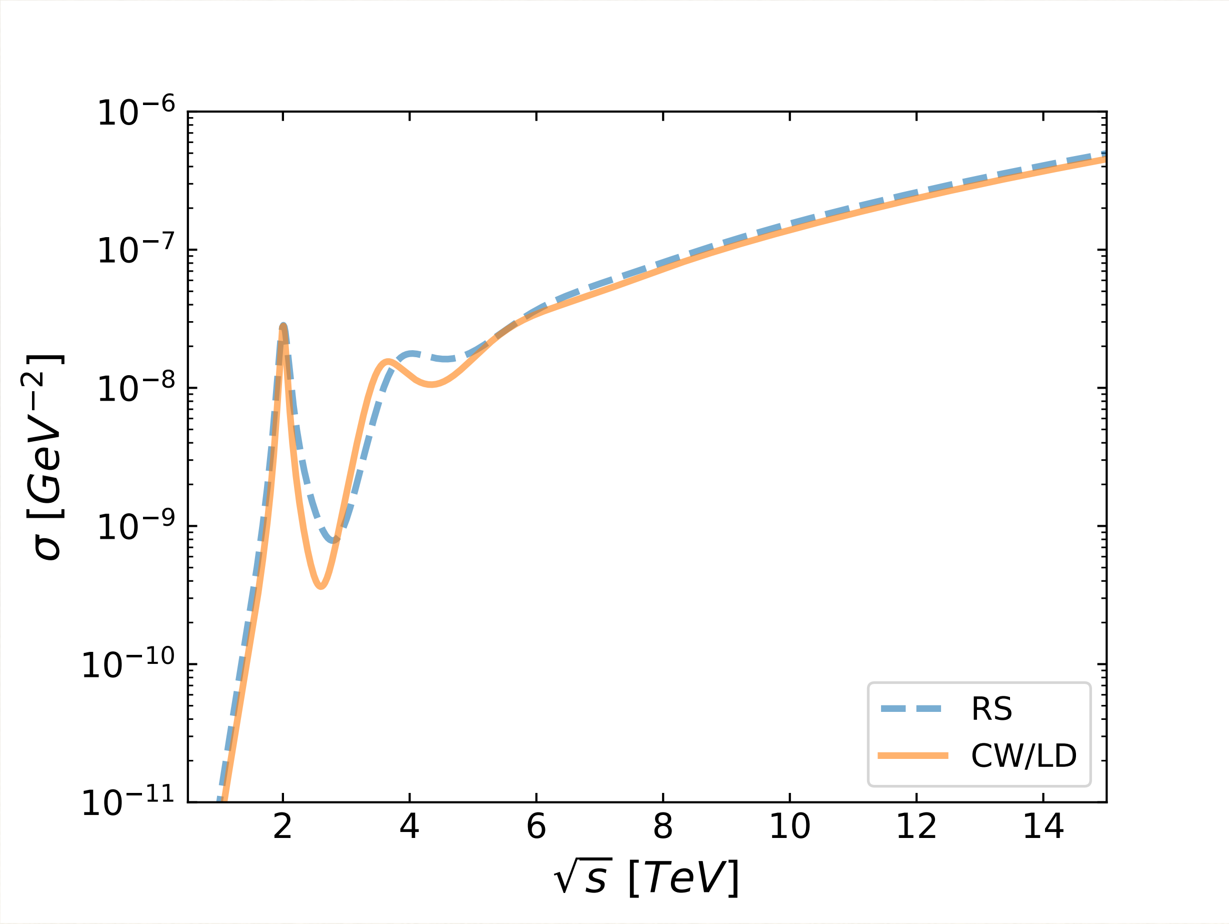
# The broad case: matching

All these models are roughly characterised by the threshold and slope of the tail

| | RS | CW/LD | Decon. |
|---|---|---|---|
| Fundamental parameters | $k_{RS}$<br>$R_{RS}$ | $k_{CW}$<br>$R_{RS}$ | $N$<br>$gv$ |
| Useful parameters | $m_1$<br>$\Lambda_{RS}$ | $k_{CW}$<br>$M_{5CW}$ | $M_1$<br>$gv$ |

An interpretation in terms of Extra-Dimensions can be matched to other scenarios

Typically the first resonance may be *narrow* but soon reaches the continuum



# Putting it all together

Although all these scenarios lead to non-resonant behaviour there are differences

**At parton level**

### EFT

$$\frac{\hat{\sigma}-\hat{\sigma}_{SM}}{\hat{\sigma}_{SM}} \propto \bar{c}\,\frac{\hat{s}}{M^2}$$

*leading interf.*

### ALP

$$\frac{\hat{\sigma}-\hat{\sigma}_{SM}}{\hat{\sigma}_{SM}} \propto \frac{\hat{s}^2}{M^4}\,,$$

$$f_a \simeq M/\sqrt{\tilde{c}} \quad (\textbf{ALP} \leftrightarrow \textbf{EFT})$$

### EFT'

$$\frac{\hat{\sigma}-\hat{\sigma}_{SM}}{\hat{\sigma}_{SM}} \propto \tilde{c}^2\,\frac{\hat{s}^2}{M^4}\,,$$

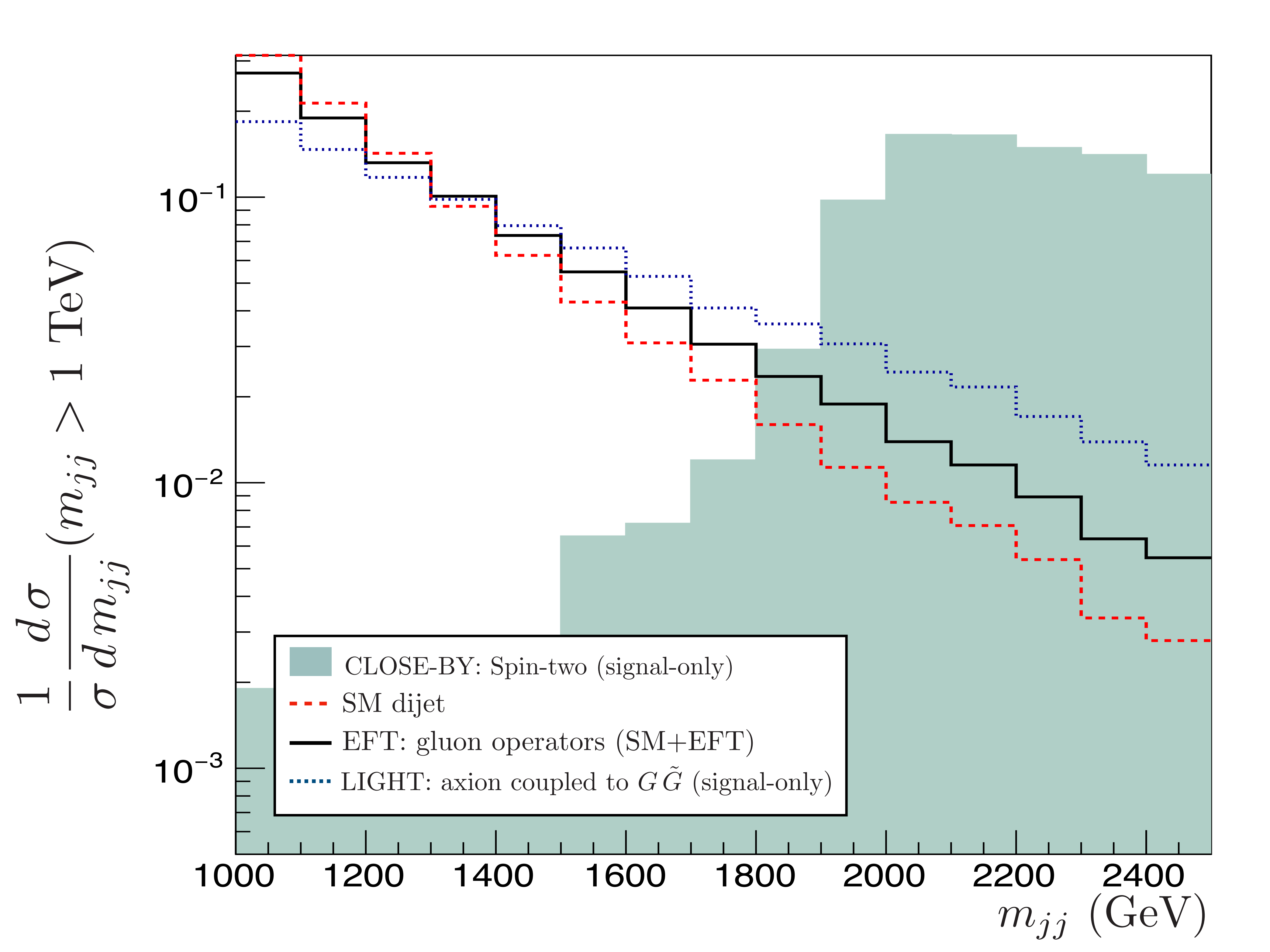
*quadratic*

**Tower:** SUM of

$$\hat{\sigma} \propto \frac{\hat{s}}{\Lambda_{RS}^2}\,.$$

# Putting it all together

Including PDFs, in the dijet channel



# Summary

Same non-resonant analysis can be interpreted in a number of ways

*narrow* light or heavy resonances

*broad* close-by resonances at intermediate energies

This covers a tremendous amount of scenarios

Generic heavy BSM, generic pseudo-Goldstone bosons, new strong interactions in the confining phase, new extra-dimensions, cascades of global symmetries, TeV black holes…

**Slope** and **threshold** may allow us to disentangle some of these, but many related by field-theoretical dualities