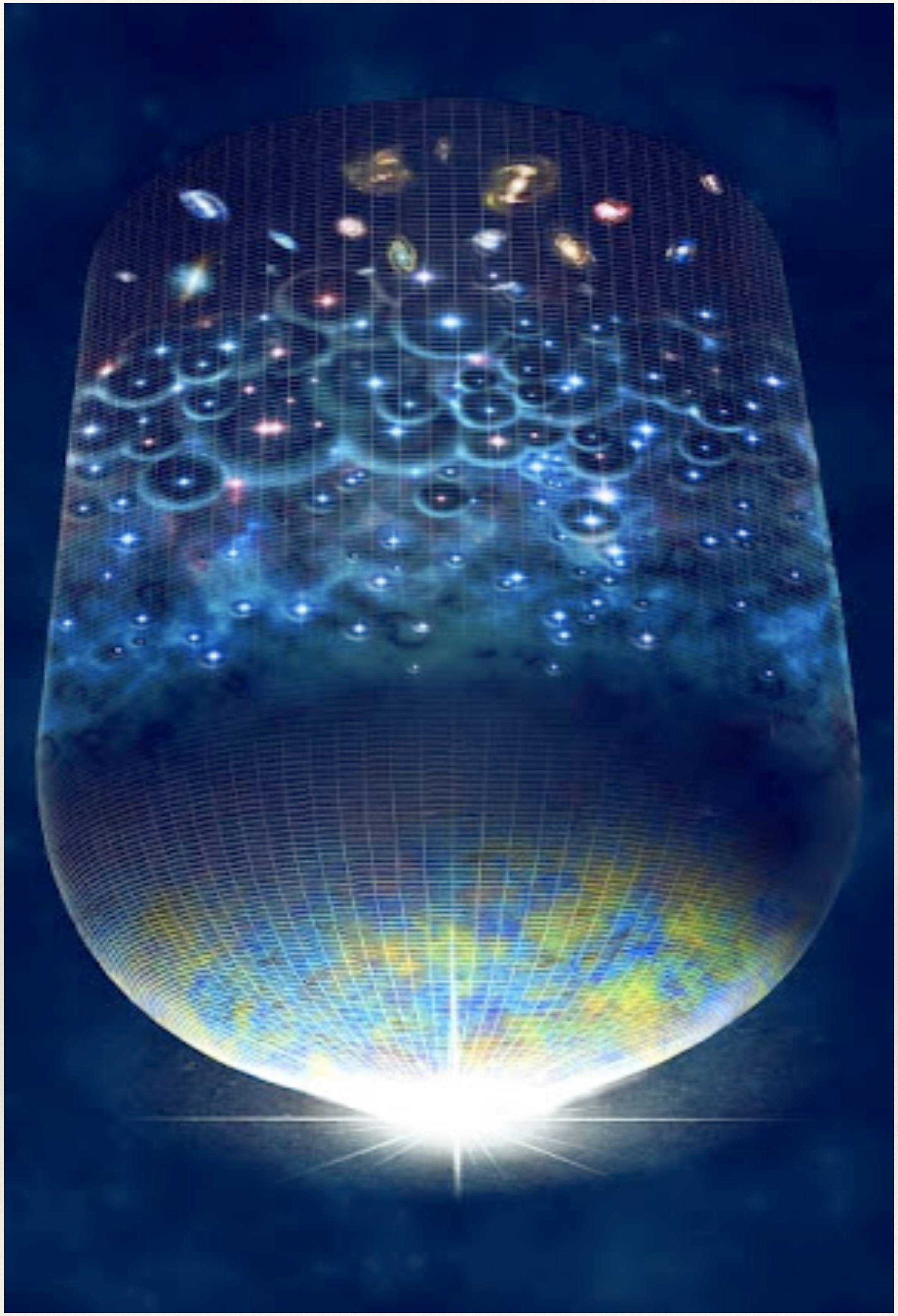
LCHP 2021

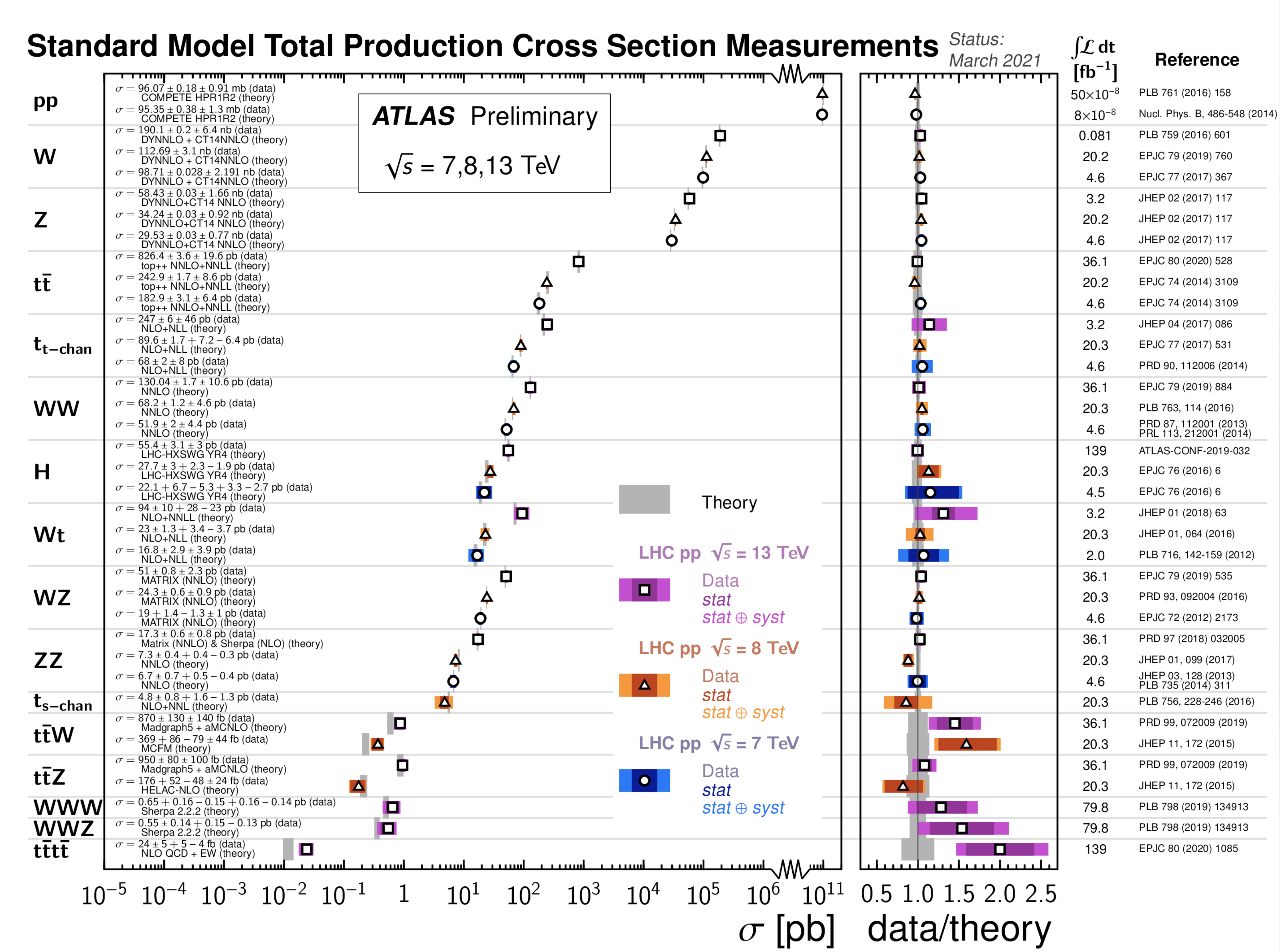
New ideas for TeV-scale model building

Veronica Sanz (IFIC-UV and Sussex)

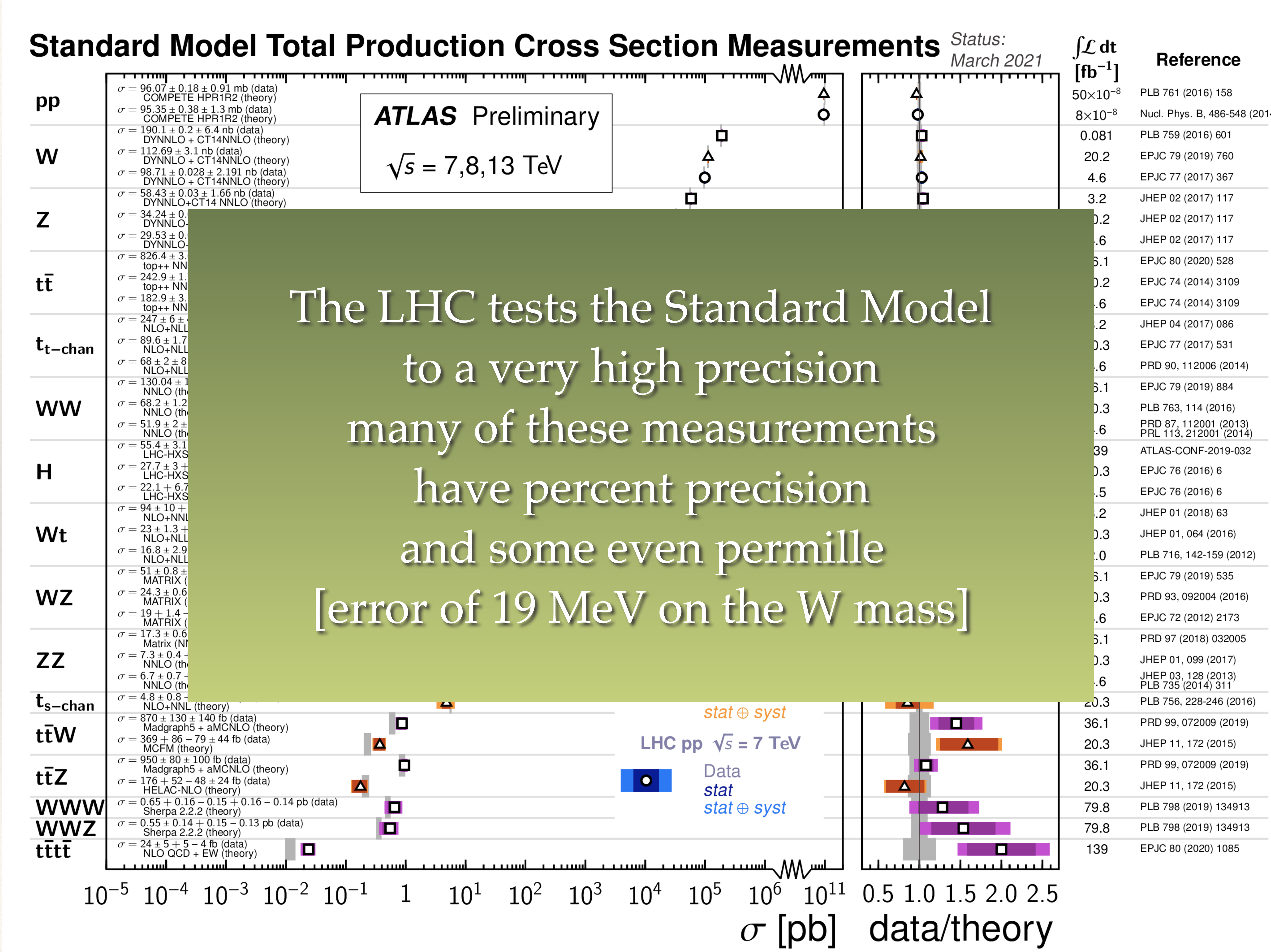


University of Sussex
Vniversitat de València
IFIC Institut de Física Corpuscular
CSIC Consejo Superior de Investigaciones Científicas

Testing the Standard Model



Testing the Standard Model



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

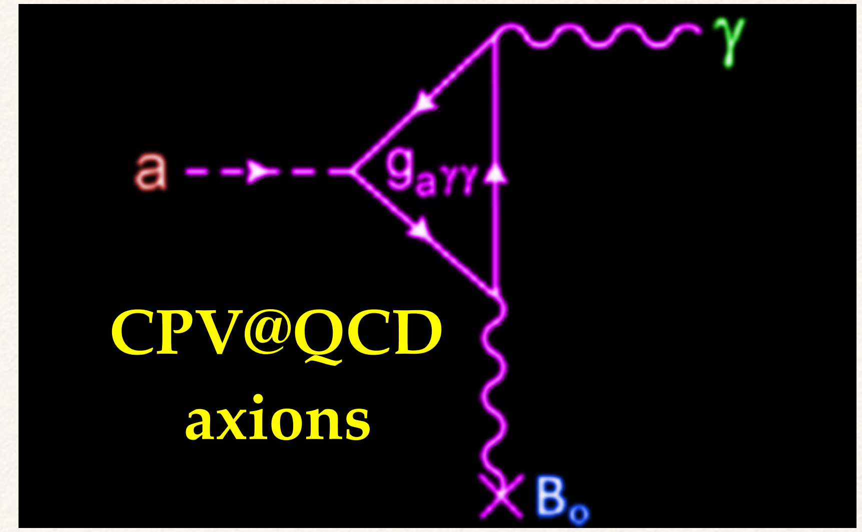
Those are impressive achievements

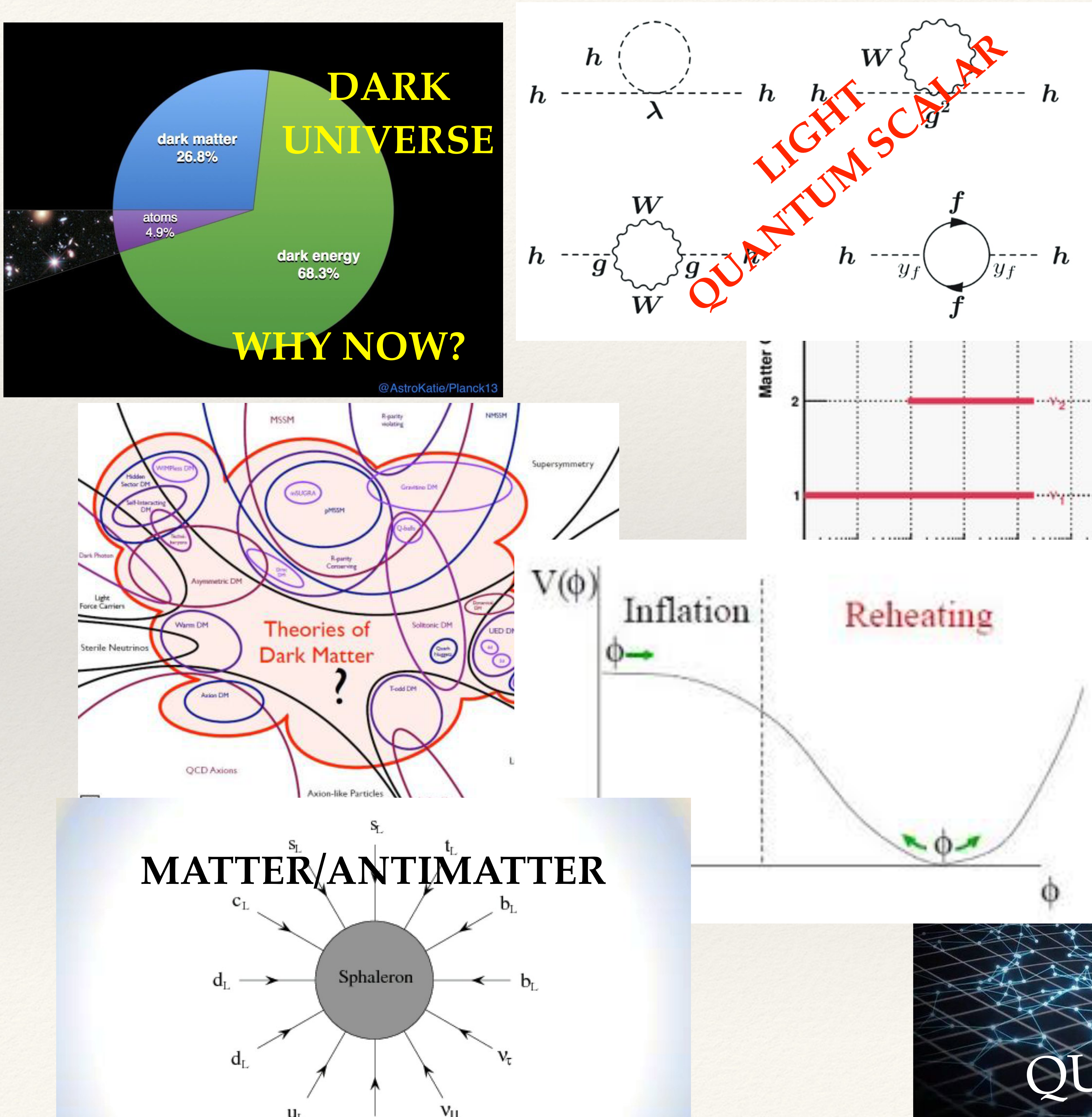
a single theory, developed long time ago
based on rather simple building blocks

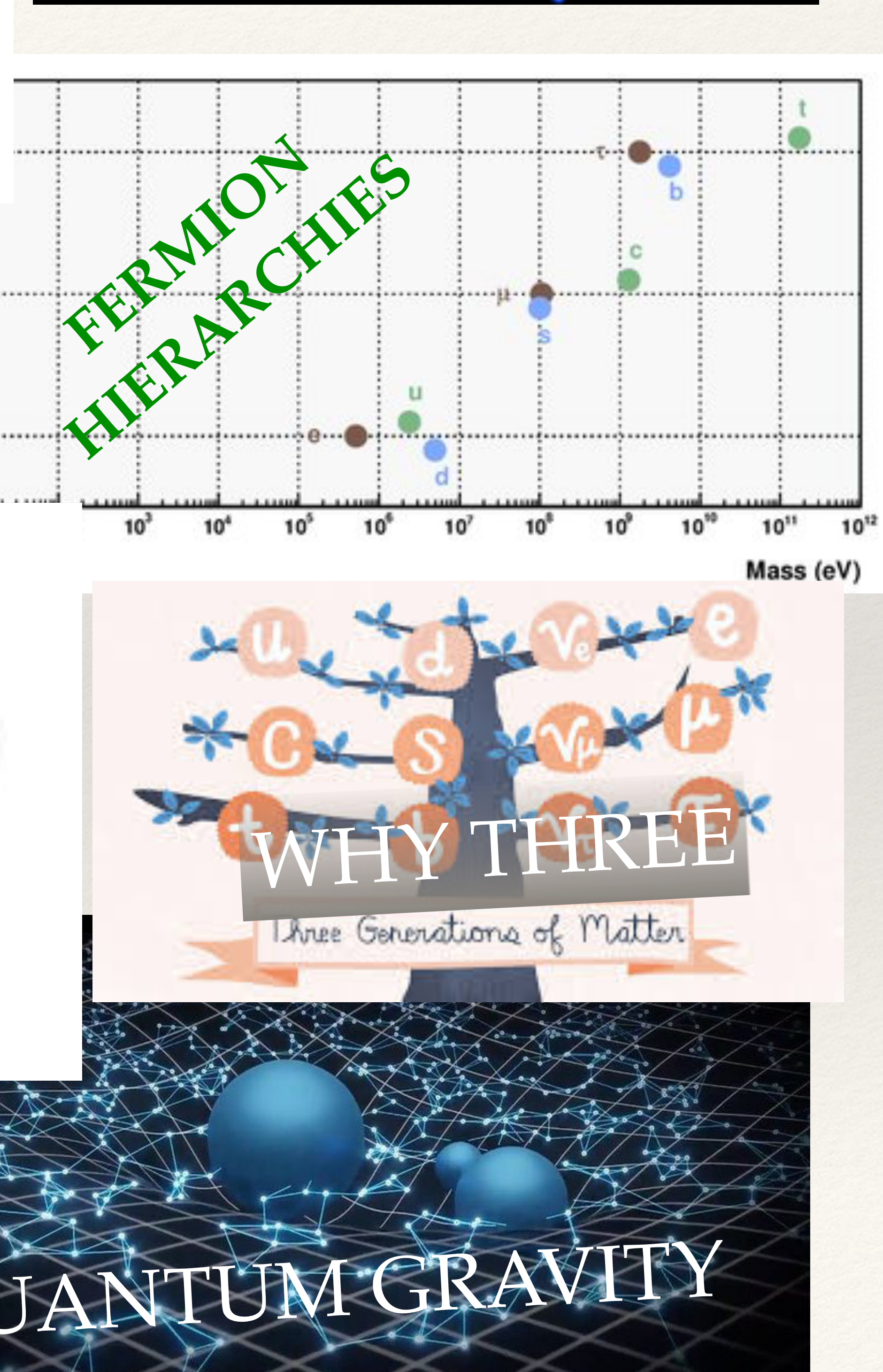
can predict Nature's behaviour
in a huge range of energies
with unparalleled precision
in many kinematic situations
involving numerous different particles

So why aren't we just happy?

Because that can’t be it







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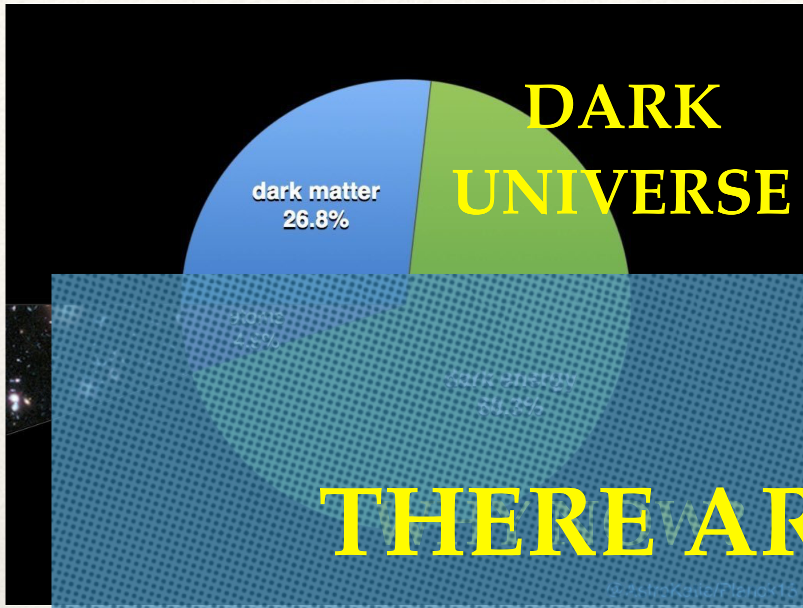
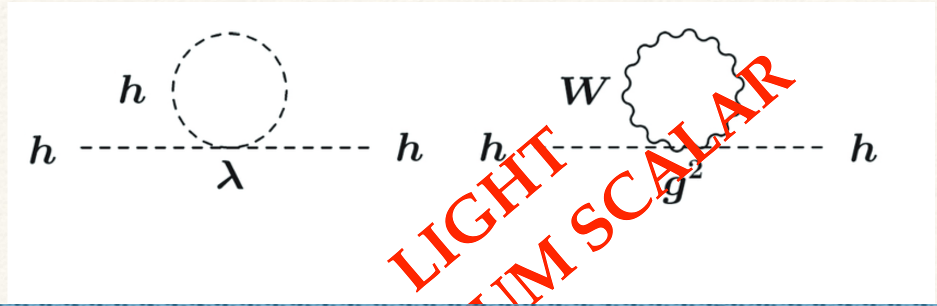
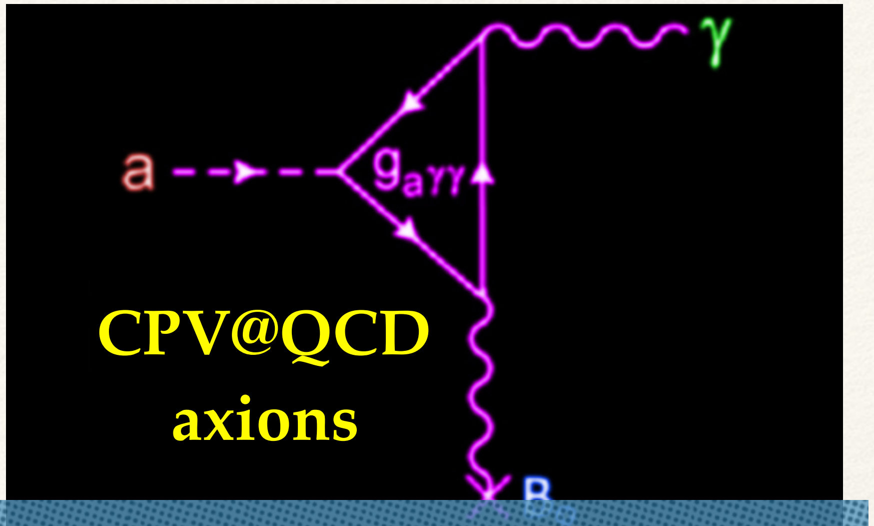






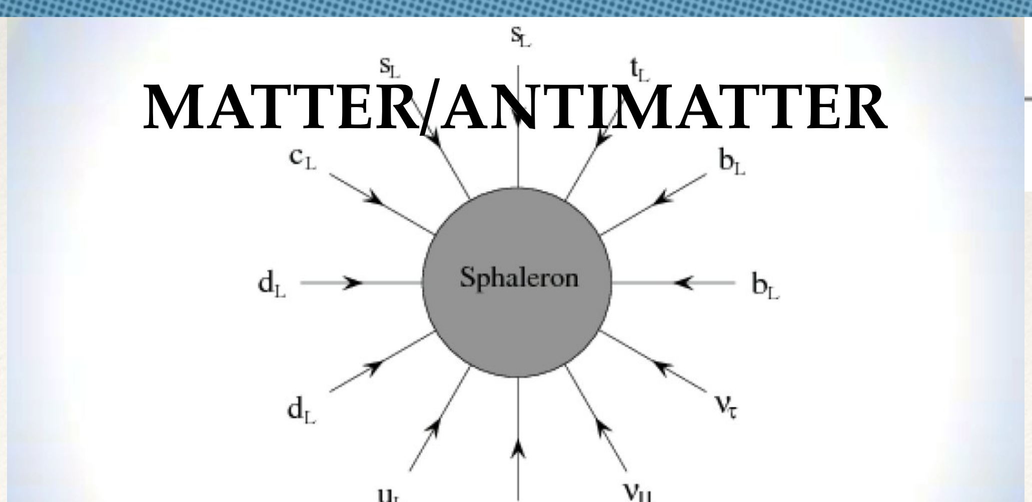
THERE ARE MANY MYSTERIES TO SOLVE

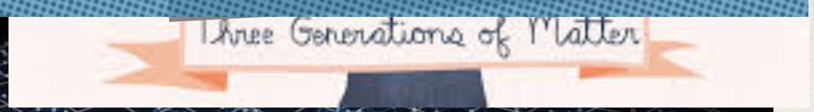
MANY *DISCOVERIES* TO BE MADE

the LHC's future is ensured through HL

exploit its potential for discovery

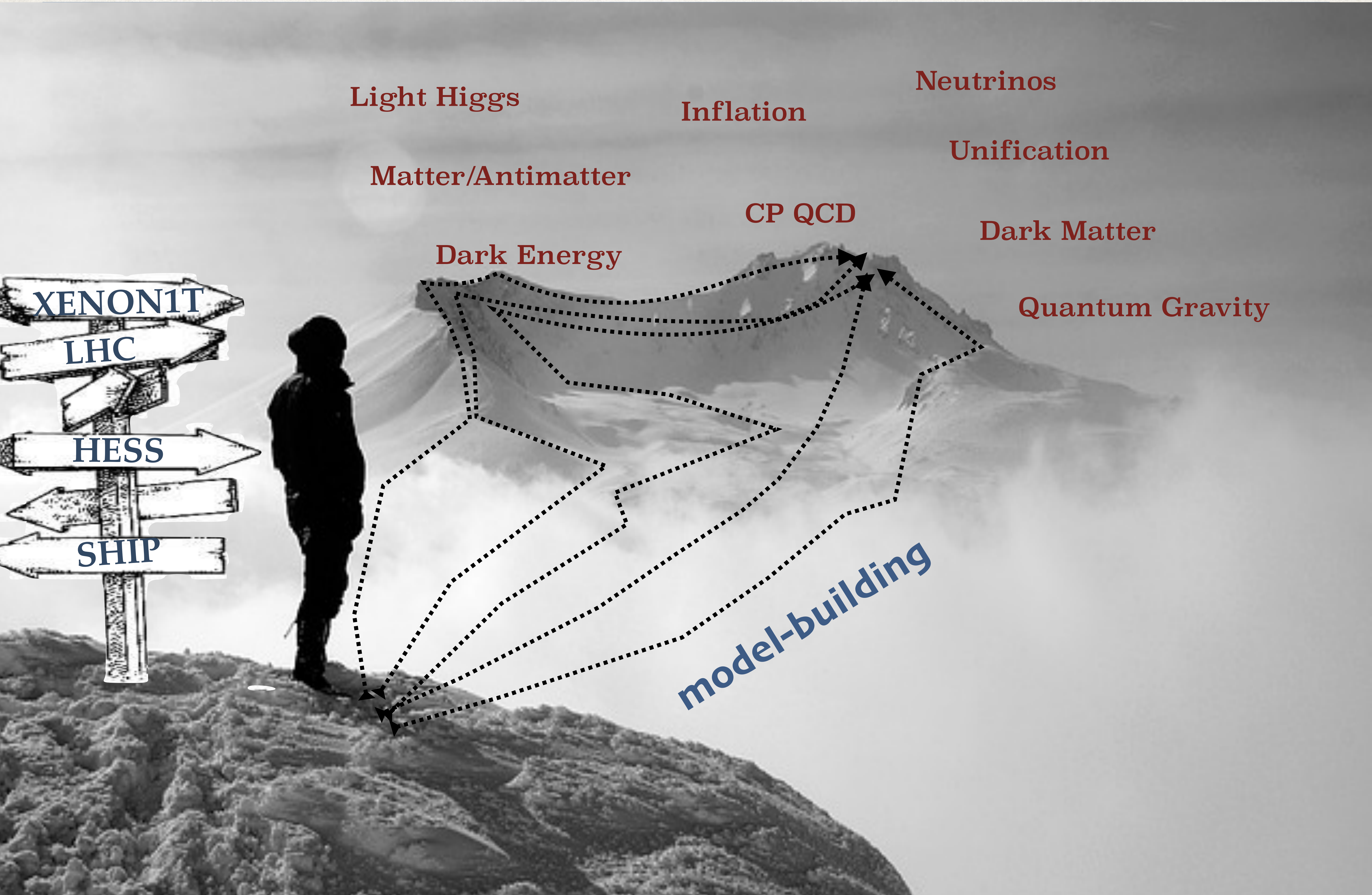
GAME ISN'T OVER



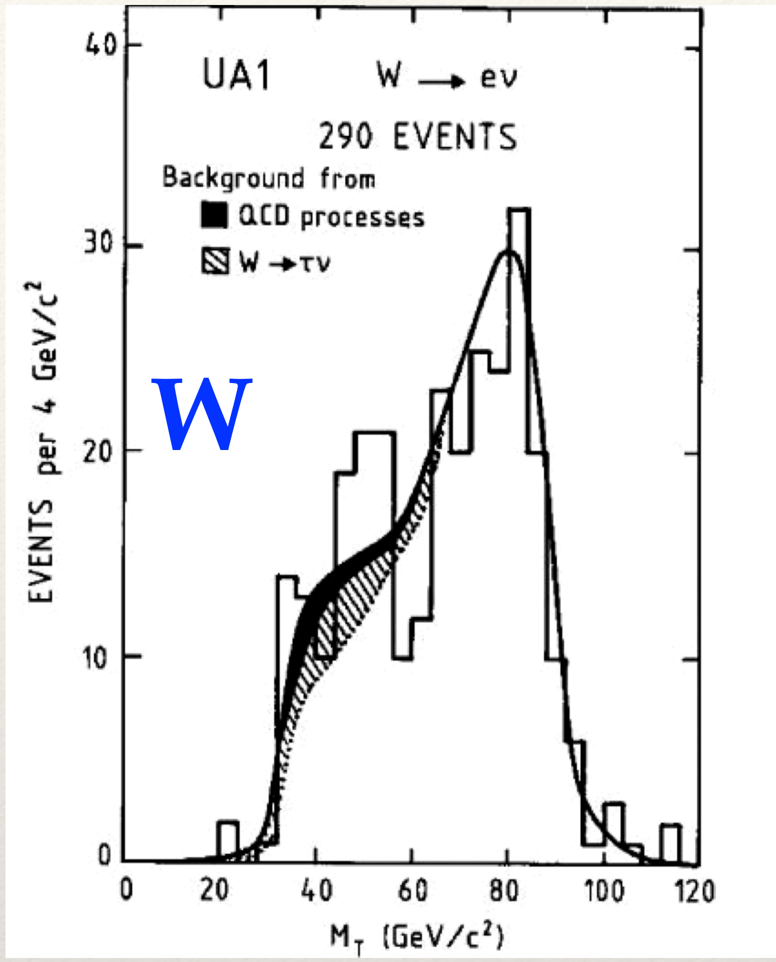


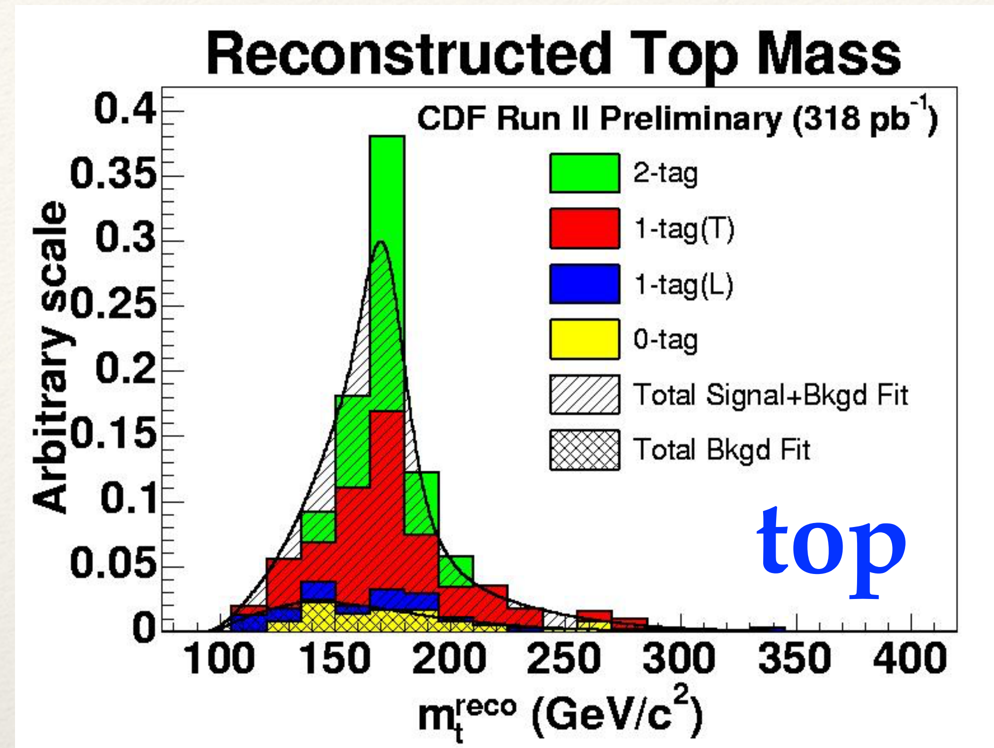
So here we are

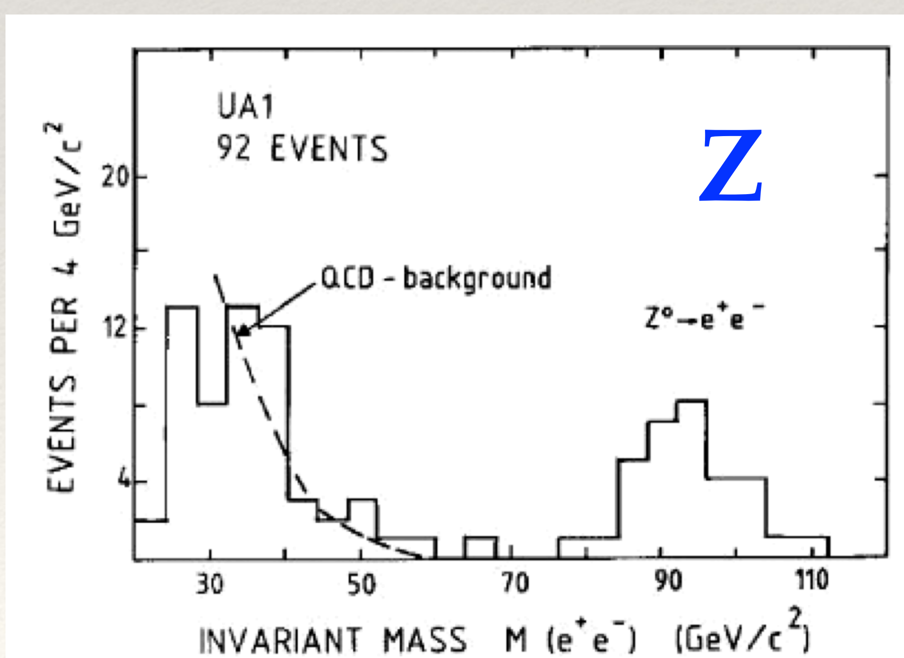
Empirical science

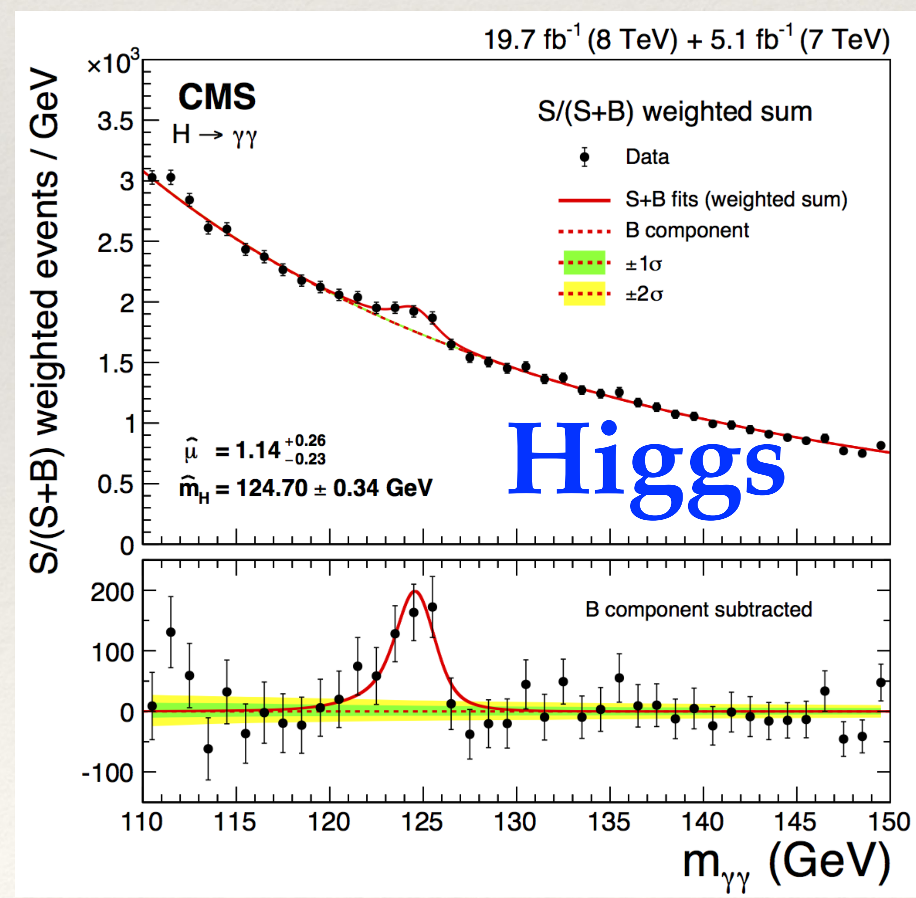


Discoveries = Resonances?

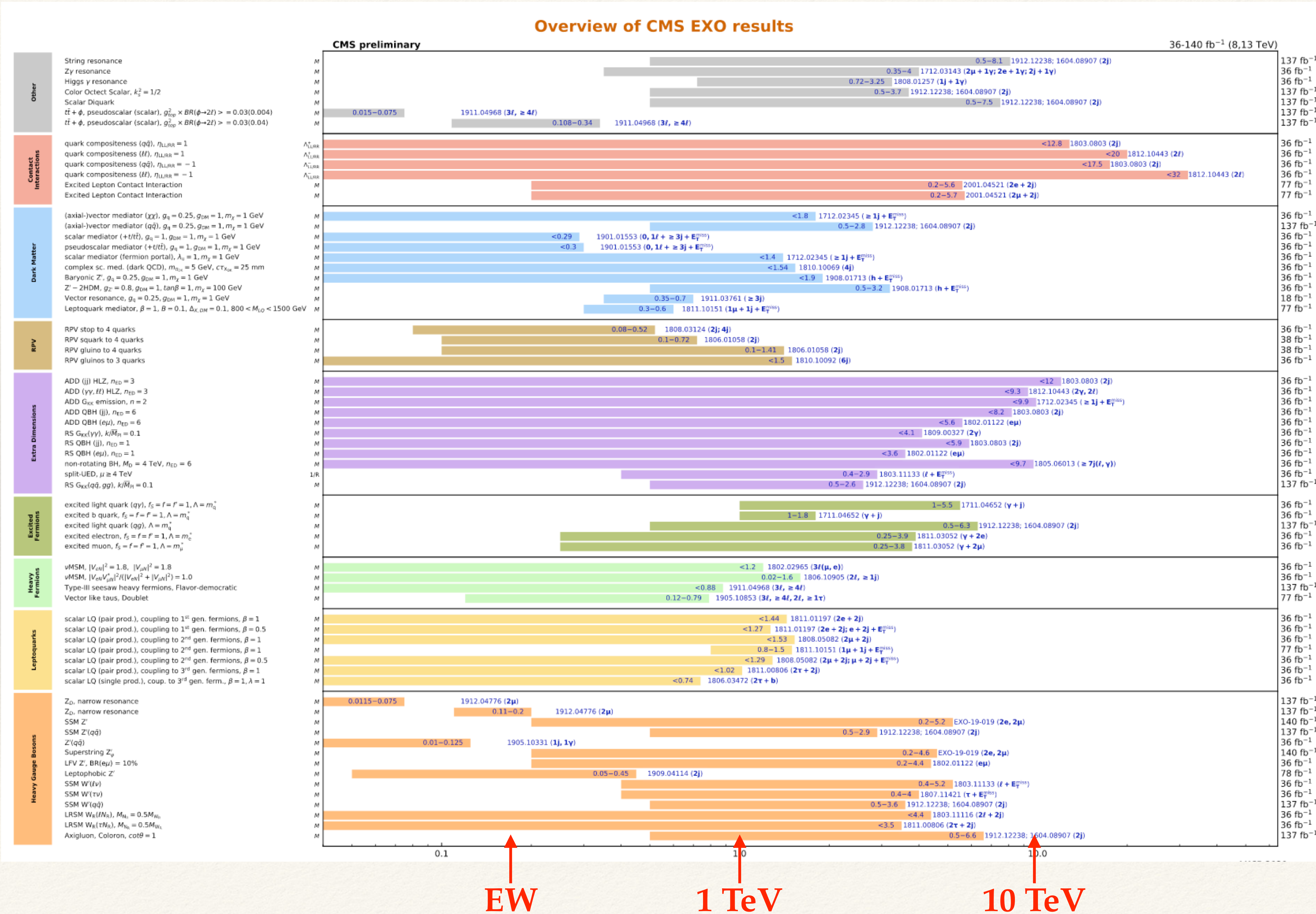








And resonances have been searched for, indeed!



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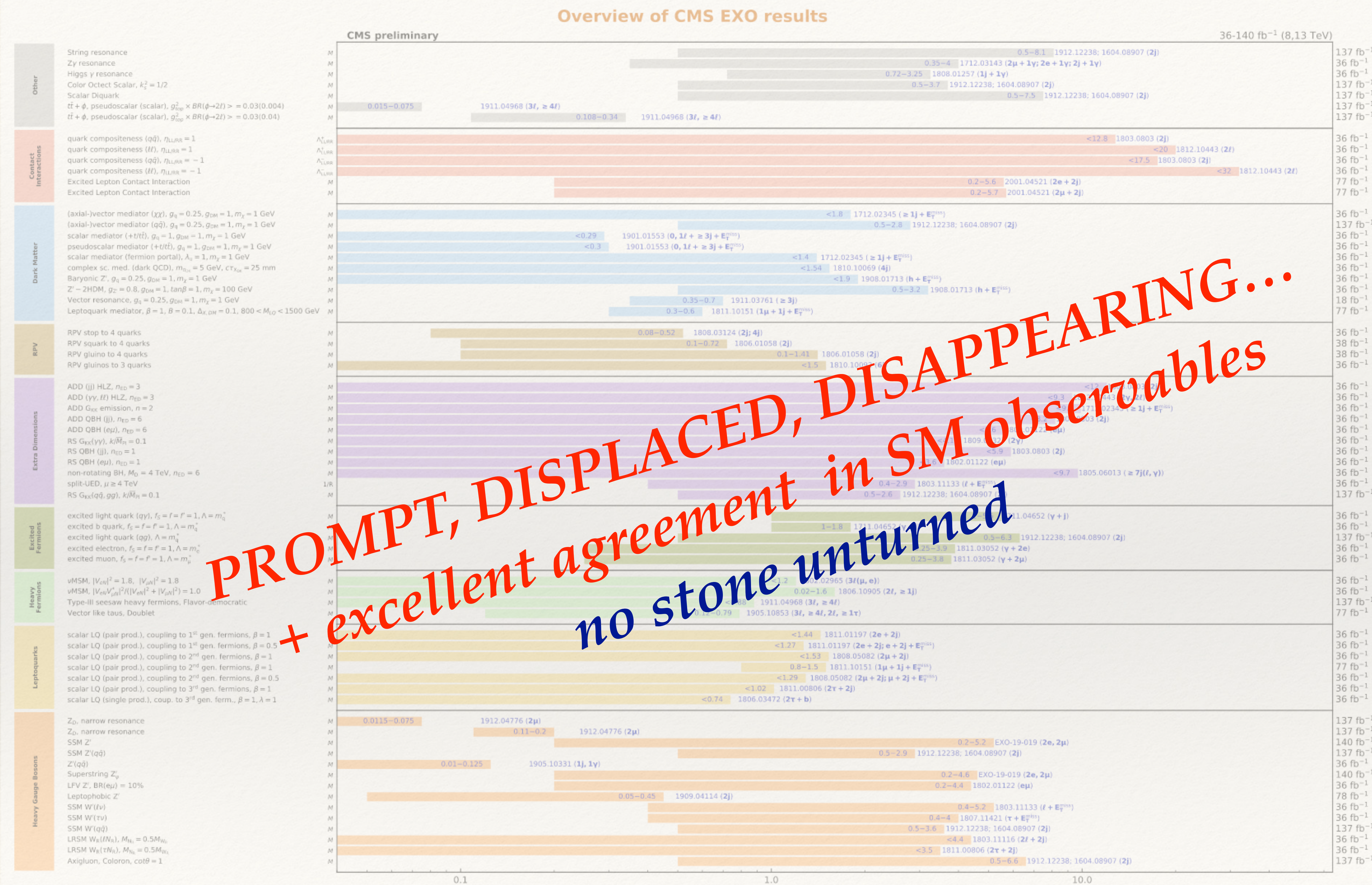


PROMPT, DISPLACED, DISAPPEARING…

+ excellent agreement in SM observables

no stone unturned

Angst, anyone?

War absolutely sucks but good example of group's ability for mobilising people and resources driven by a big idea (preservation)

Thanks to the LHC, we have witnessed a large-scale mobilisation of talent behind the idea of understanding Nature

a selfless, intellectual drive

It is a remarkable success and its continuation requires re-focusing as we learn more about Nature

Scenarios for new physics at the TeV-scale are evolving

Then what?

Connecting ideas with experiments

A cosmological Higgs

HIGGS

Dark Matter
Higgs portal
Higgs DM mediator

UV sensitivity
Naturalness
heavy new physics
Relaxation

Inflation
Higgs inflation
Inflaton vs Higgs

Phase transitions
Baryogenesis
gravitational waves

Fate of the Universe
Stability

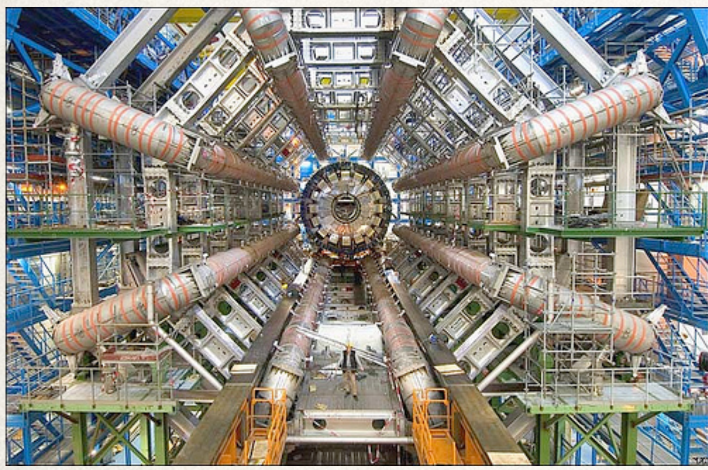
The LHC provides the **most precise, controlled** way of studying the Higgs and direct access to TeV scales
Exploiting complementarity with cosmo/astro probes

Similar story for Axions and ALPs, scalars are versatile

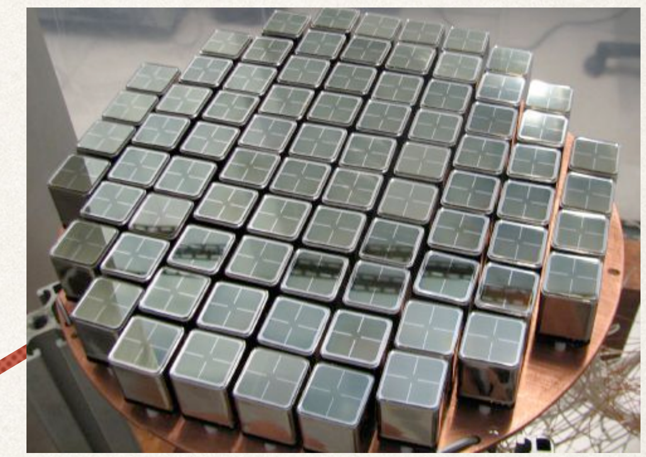
Many faces of Dark Matter

THEORY
Discrete symmetries
Dynamical stability
self-interactions
Link to Higgs…

COLLIDERS

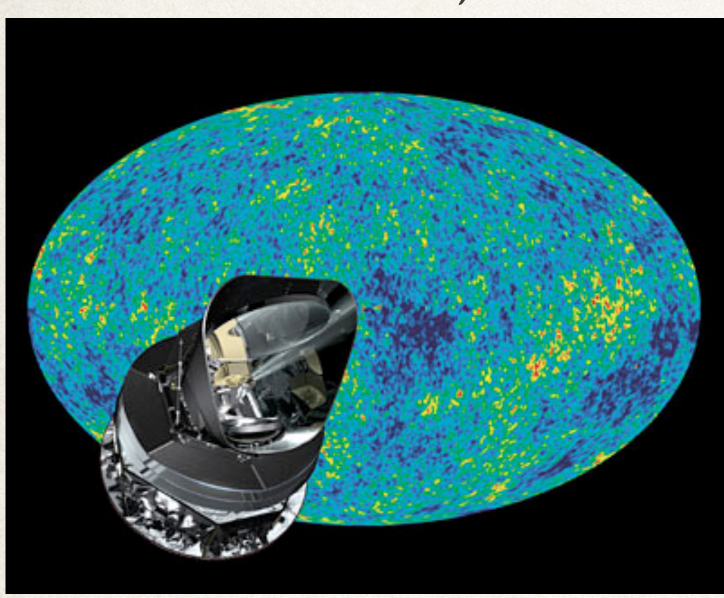


DIRECT DETECTION

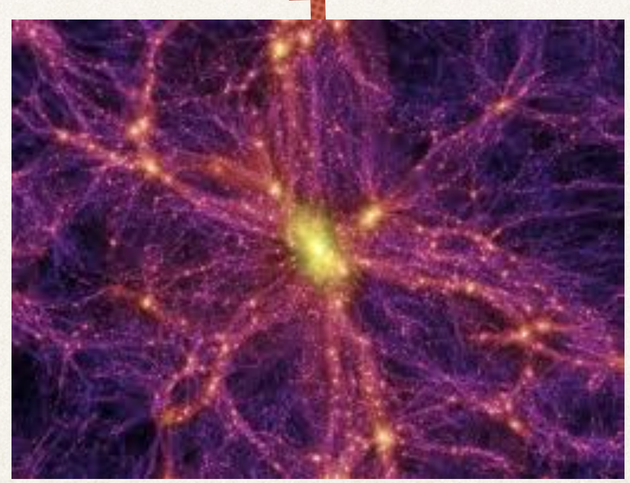


DARK MATTER

CMB: relic, tilt



INDIRECT DETECTION

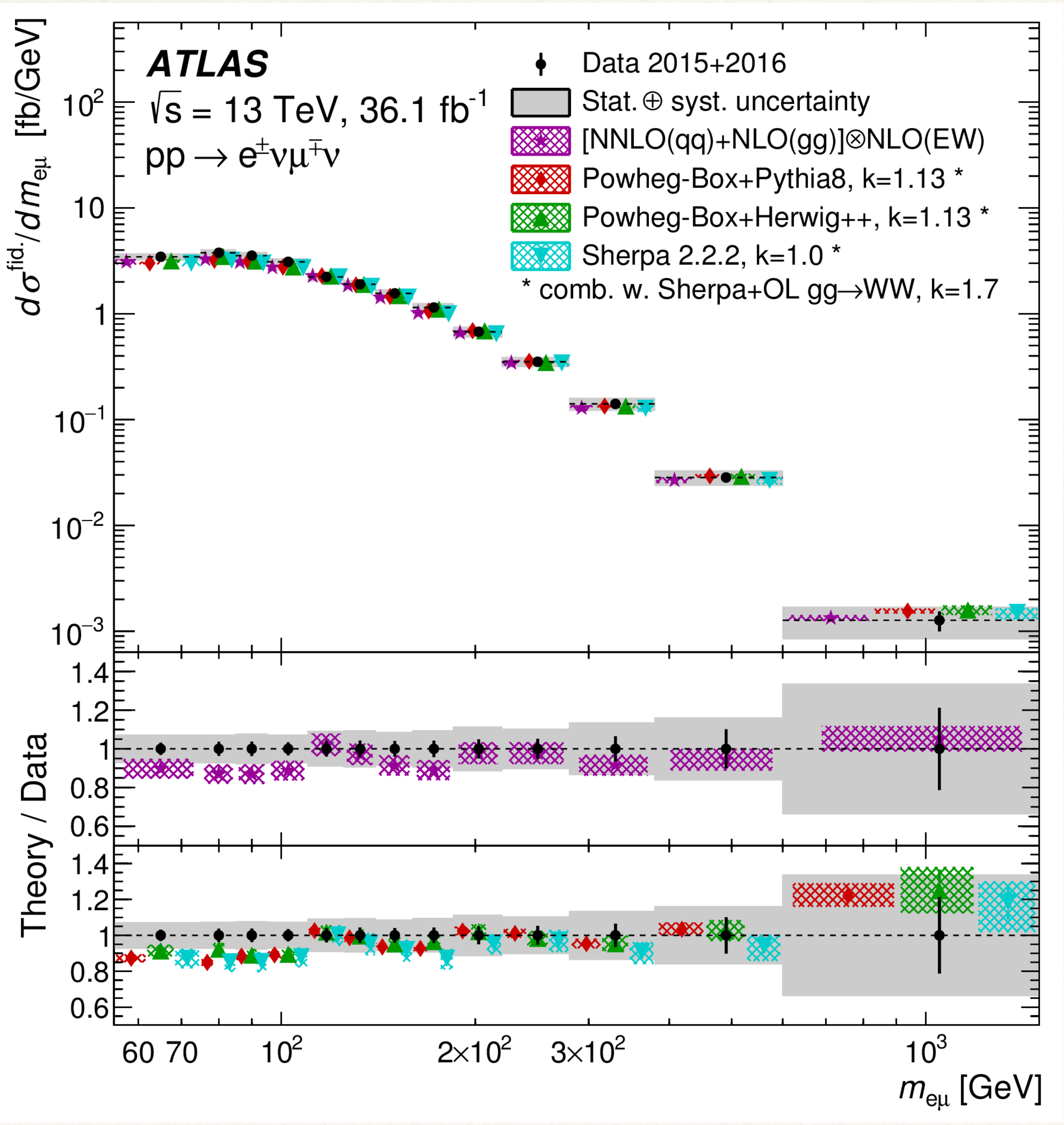


SIMULATIONS

New opportunities at the LHC

Run3 and beyond

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



Precision LHC-> new opportunity

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

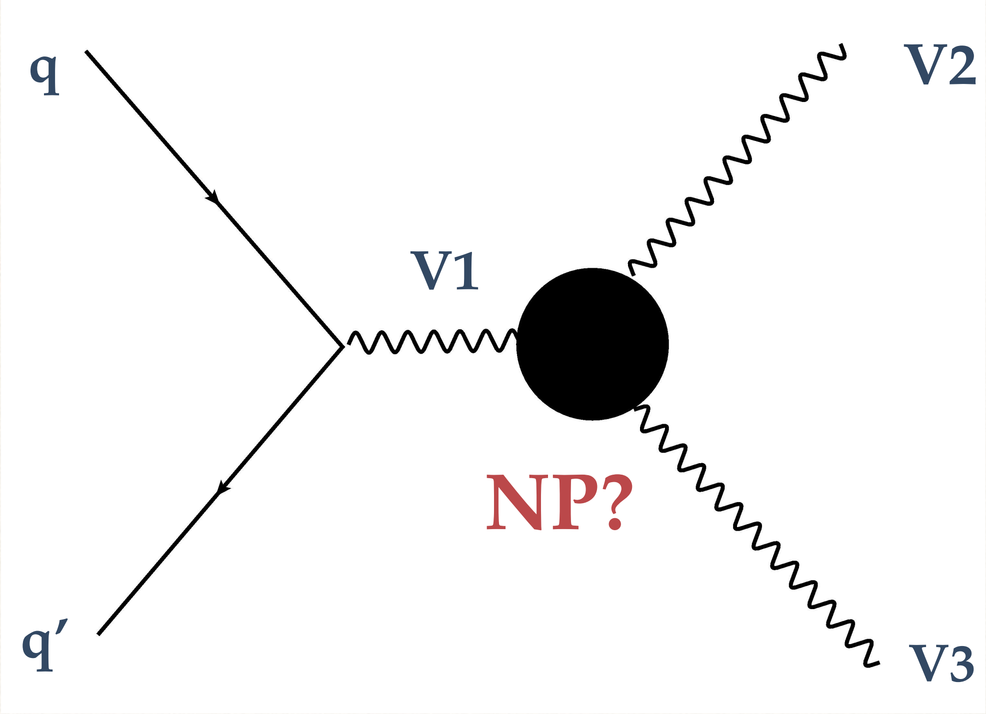
Let's embrace this state-of-affairs to perform different searches for new phenomena, beyond resonances

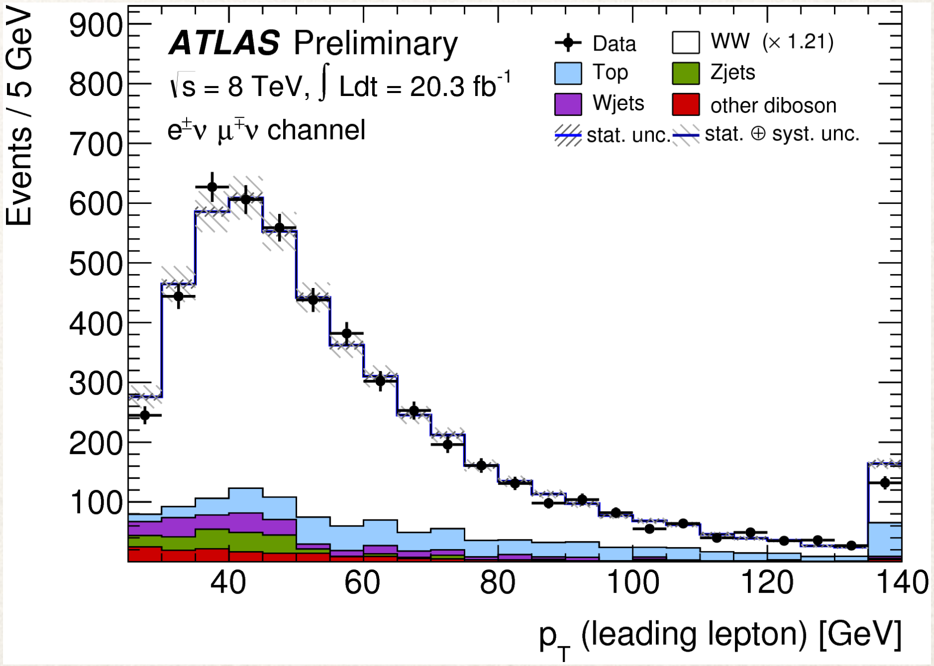
Change in paradigm: Indirect searches

Focus on SM particles' behaviour
precise determination of couplings and kinematics
comparison with SM,
search for deviations

Indirect searches using the Higgs
since 2012, relatively new
Higgs as a window to NP
expect deviations in its behaviour
Run2 data and beyond
precision Higgs Physics

e.g. Anomalous trilinear gauge couplings, aka **TGCs**





LEP, Tevatron, LHC

EFT is the new black

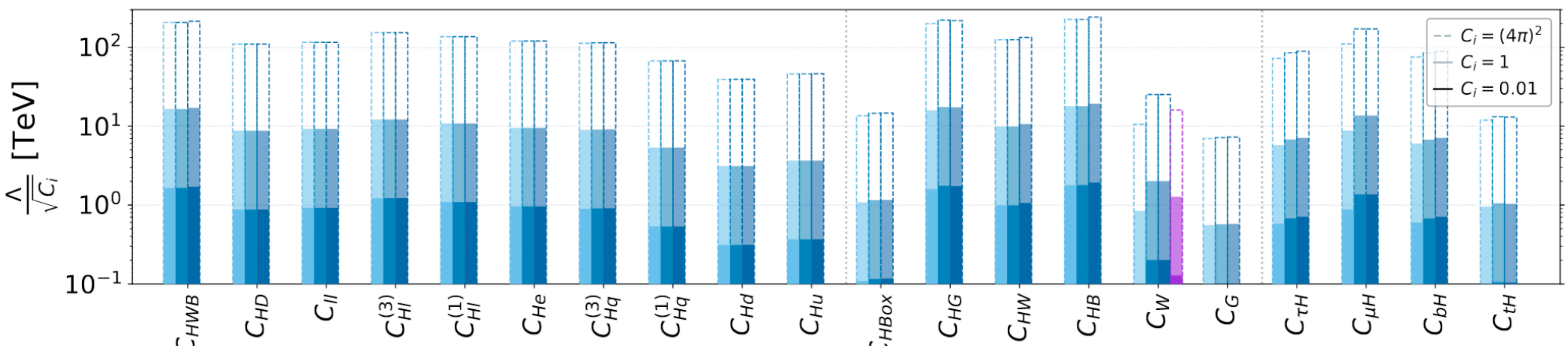
I assume you roughly know what is SMEFT
and also know this is a word increasingly present in LHC analyses

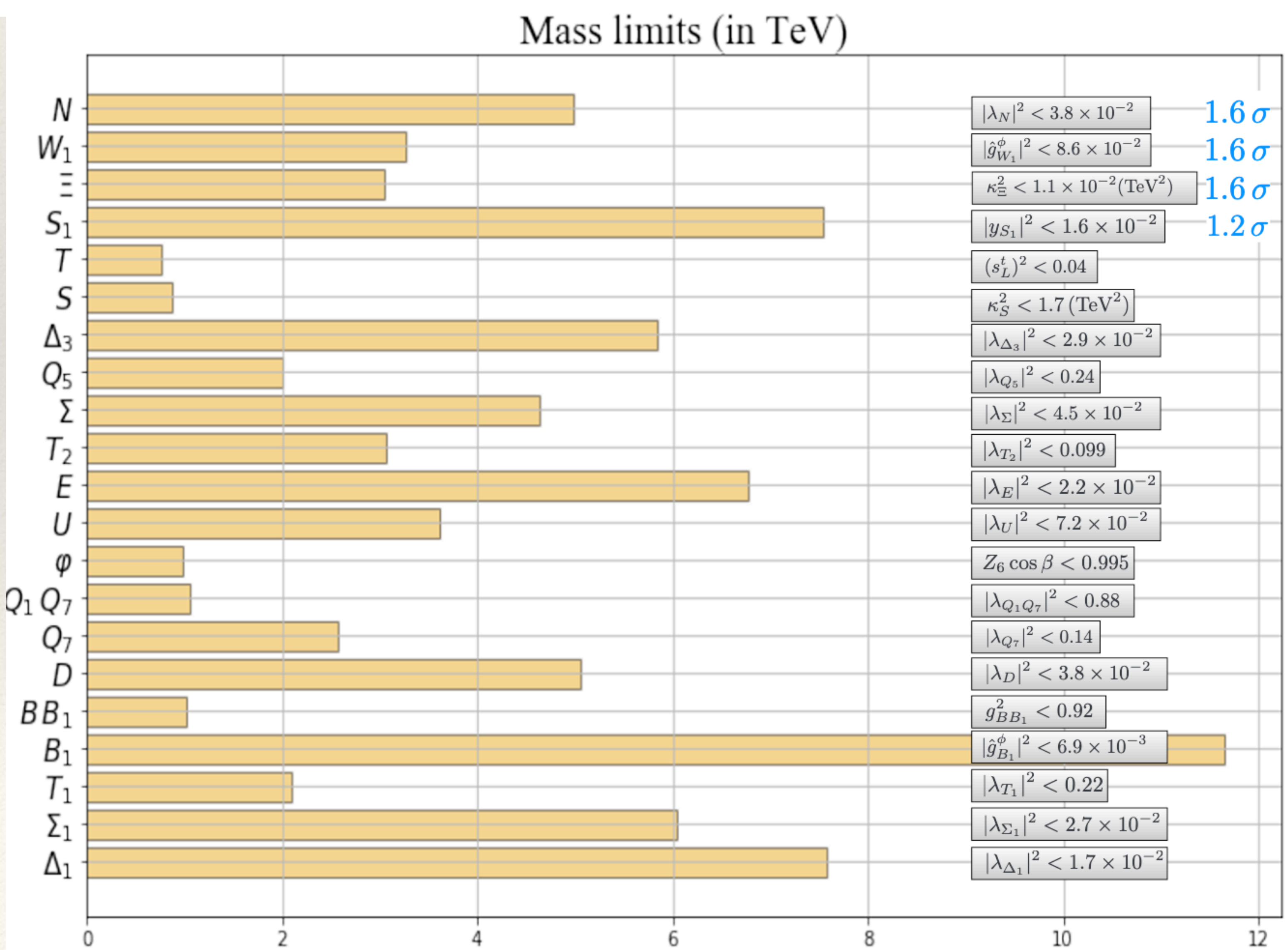
There are good theoretical reasons to adopt (NOW) an EFT interpretation of the LHC data
no light NP, nice/tractable framework…

And experiments, after lots of tensioning and some reticence, are also adopting it as a default option to re-interpret SM measurements

Current SMEFT constraints reach the TeV for most of t he param space

Ellis, Madigan, Mimasu, VS, You
2012.02779, JHEP





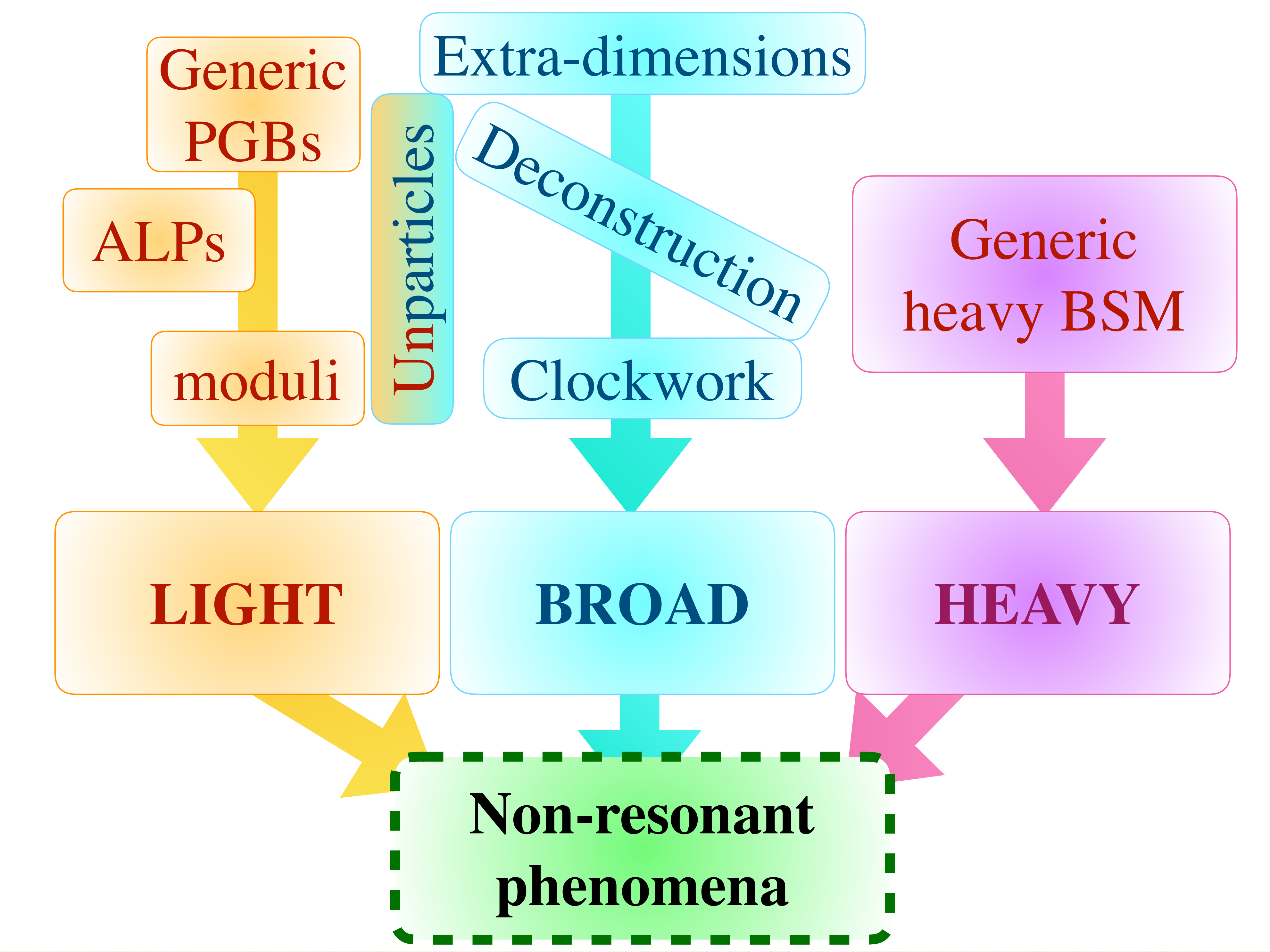
And when translated into vanilla extensions of the SM, the mass limits are also probing the TeV scale

Lots of work needed to advance this area: higher-order calculations, optimisation of strategies, better exp understanding of correlations…

Many scenarios beyond EFT

Folgado, VS.
2005.06492, AdvHEP

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



The light case: pseudo-Goldstone

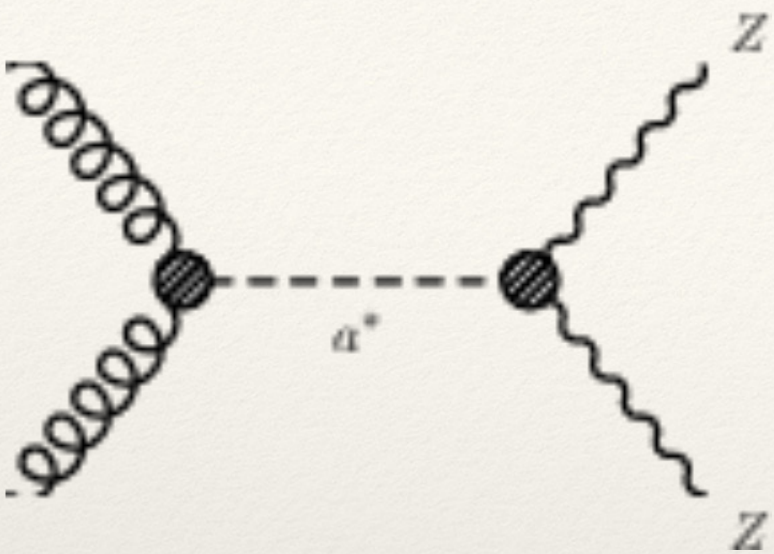
What if your new sector was very light?
imagine, for example, you are looking for a particle
which decays into photons with mass << GeV

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

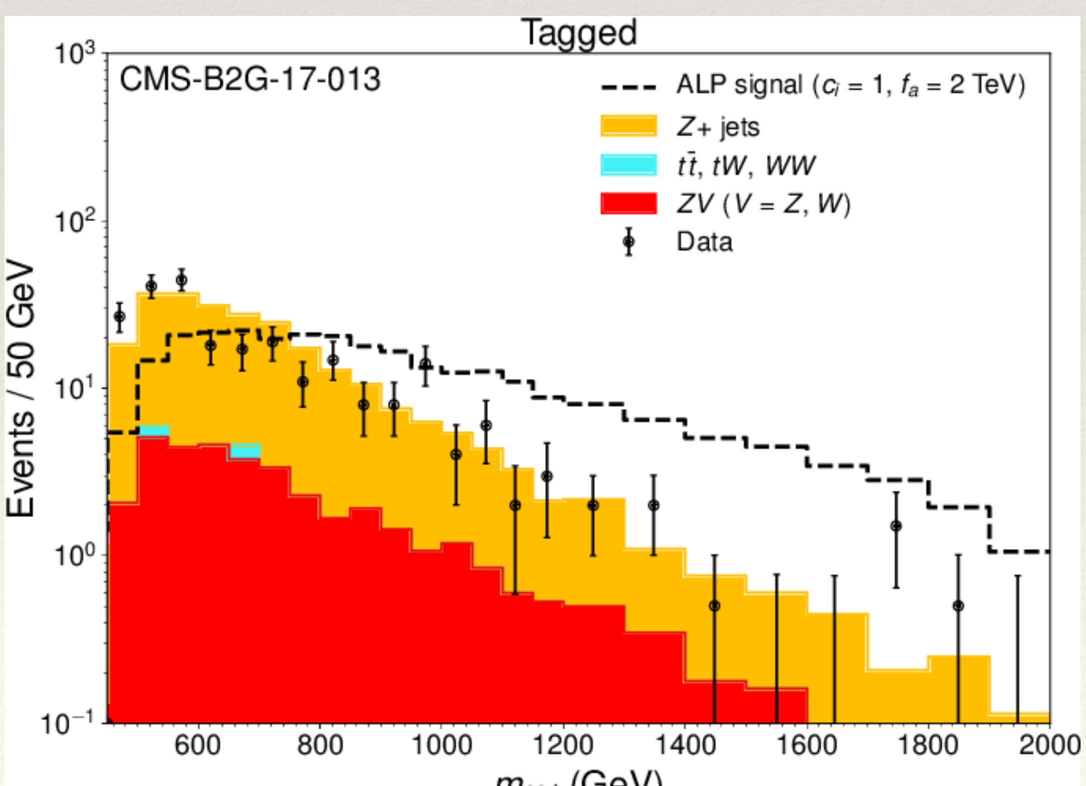
This particle can't be searched for a high-energy collider like the LHC

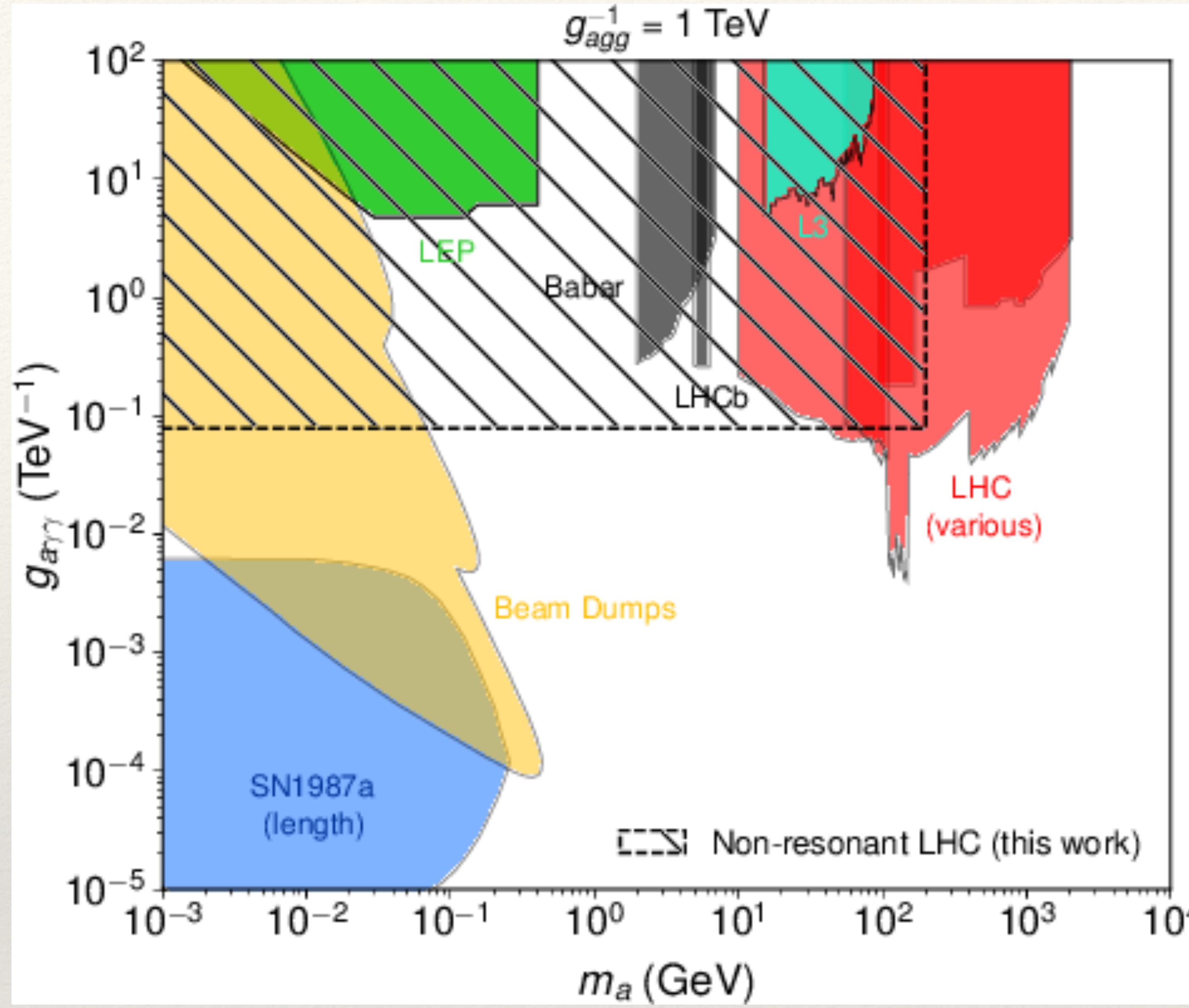
BUT
what if your new particle was a pseudo-Goldstone boson?
its couplings to SM particle would grow with energy
we may not see the particle as a resonance but feel its effect
in high-energy tails

The light case: pseudo-Goldstone



Gavela, No, VS, Troconiz.
1905.12953, PRL





A lot more to explore for
LHC probes of TeV-scale pGB:
more channels, controlling high-pT,
combination, interplay with other
probes (low-E, GWs…)

The broad case

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

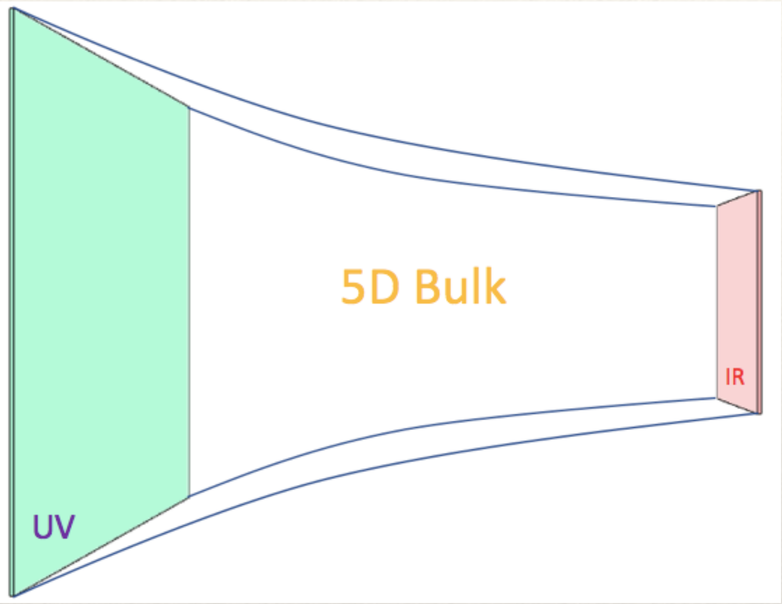
Remember that in QCD at large-Nc *expect* a tower of resonances
example: s=1 rho, rho'… and a whole tower until LambdaQCD
width ~ 1/Nc^2
but Nc=3 not a large number, so rho and rho' are relatively narrow
but after that we got a continuum of the "rho-tower"
mesonic QCD in the intermediate region is non-resonant

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

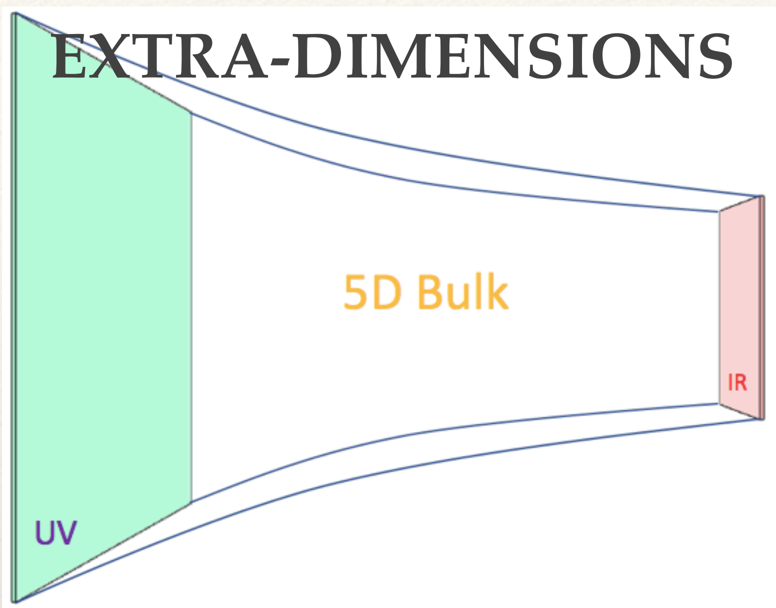
Unavoidable: KK-gravitons coupled to SM particles via the stress-tensor
mass and 1/coupling ~ TeV

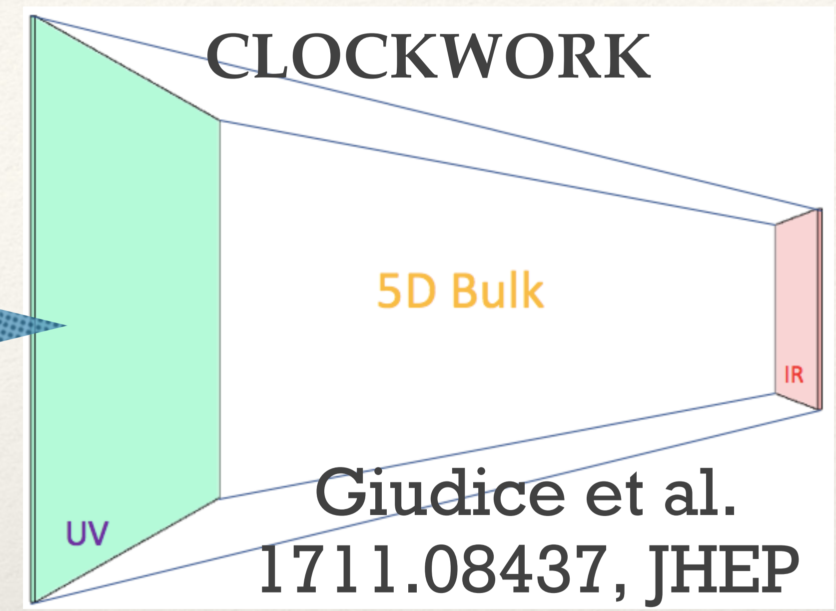
$$\mathcal{L} = -\frac{1}{\Lambda}\sum_{n=1}^{\infty} h^n_{\mu\nu}(x)T^{\mu\nu}(x),$$

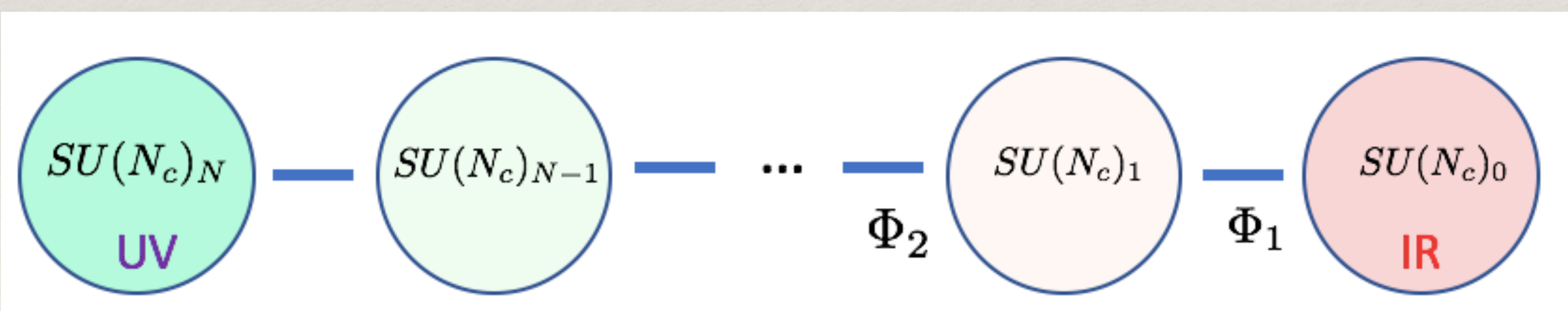
This tower's resonances could be close-by and produce a continuum would **evade resonant searches**
KK-gravitons could be much lighter than typical limits (>~ TeV) and only discovered by analysis of tails

The broad case

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







MOOSE/DECONSTRUCTION

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

This is a rather unexplored area
more work needed on modelling, and reinterpretation from EFTs

Summary

LHC quo vadis? or how do we make the best use of what is coming next? (~ E, more lumi)

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Direct searches will continue testing broader sets of models
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New opportunities in the precision era for the LHC
are there any blind spots in experimental searches?
model-building exploration could inspire them
e.g., *Reece's talk today on SUSY leftovers*
the LHC can probe TeV scale new physics via non-resonant searches, they cover a wide range of models,
more theoretical effort needed here