Pheno 2021

LHC Phenomenology

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CSIC CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

LHC phenomenology

Current achievements
Tulika

← *a theorist's view* →

LHC's last frontier
Laura
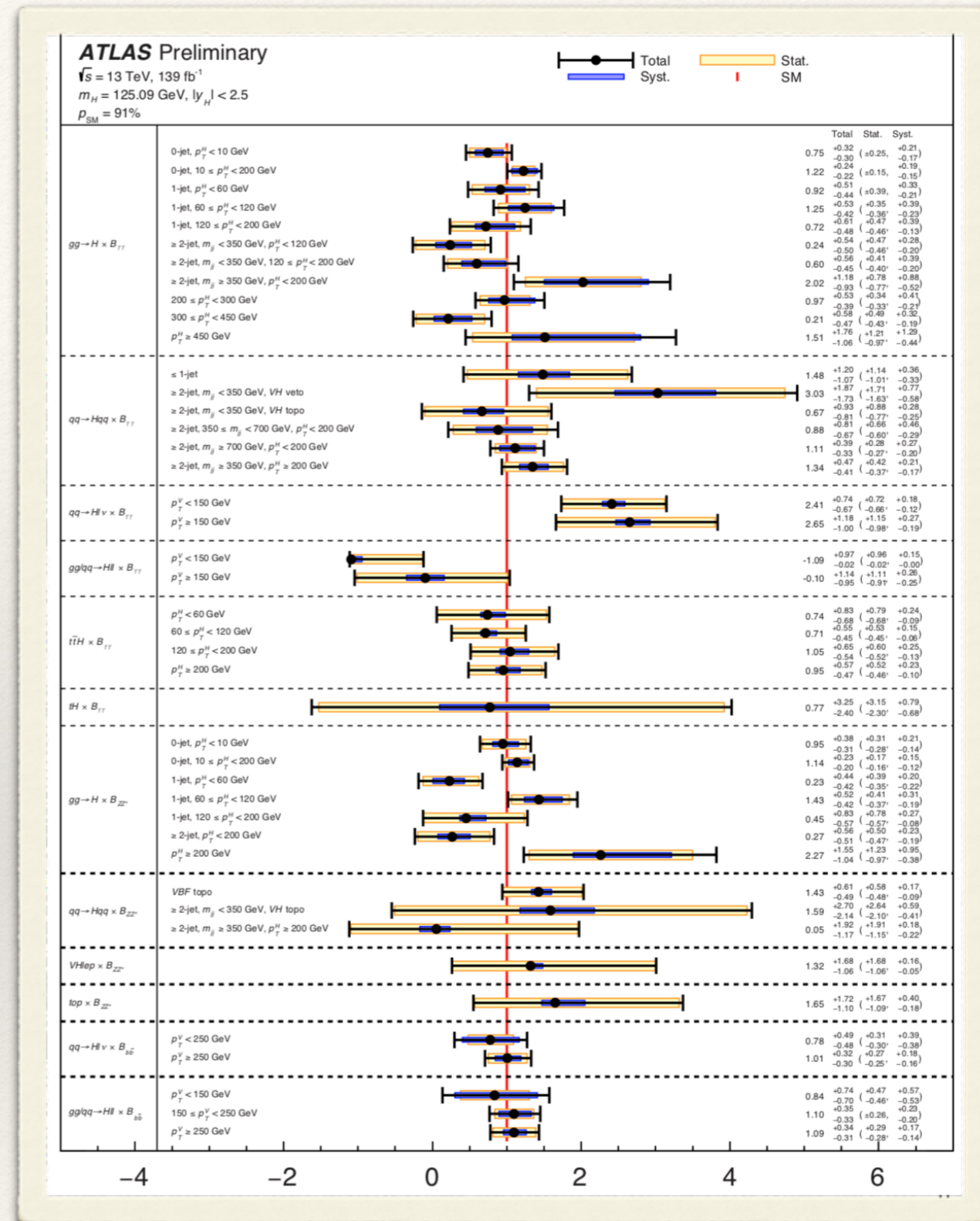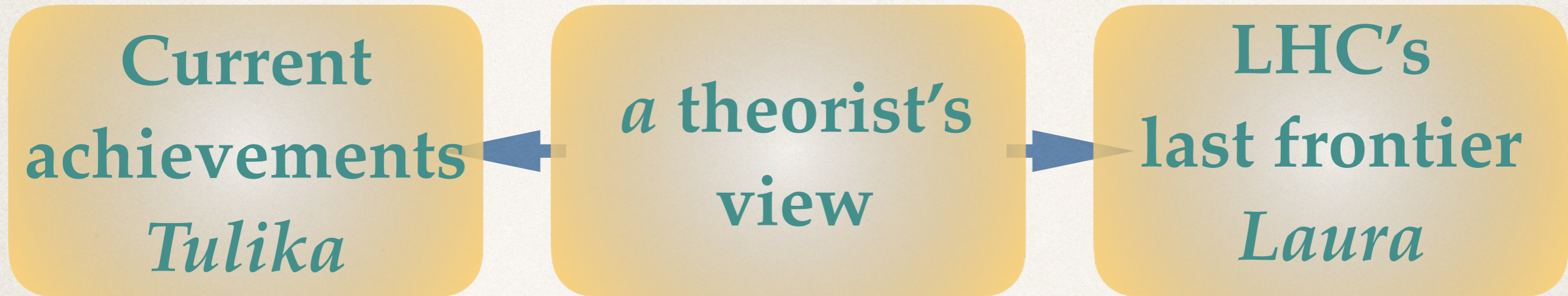
In this talk:

How the current results shape how we think about models for
Nature and the discovery potential of the LHC

Status of the SM
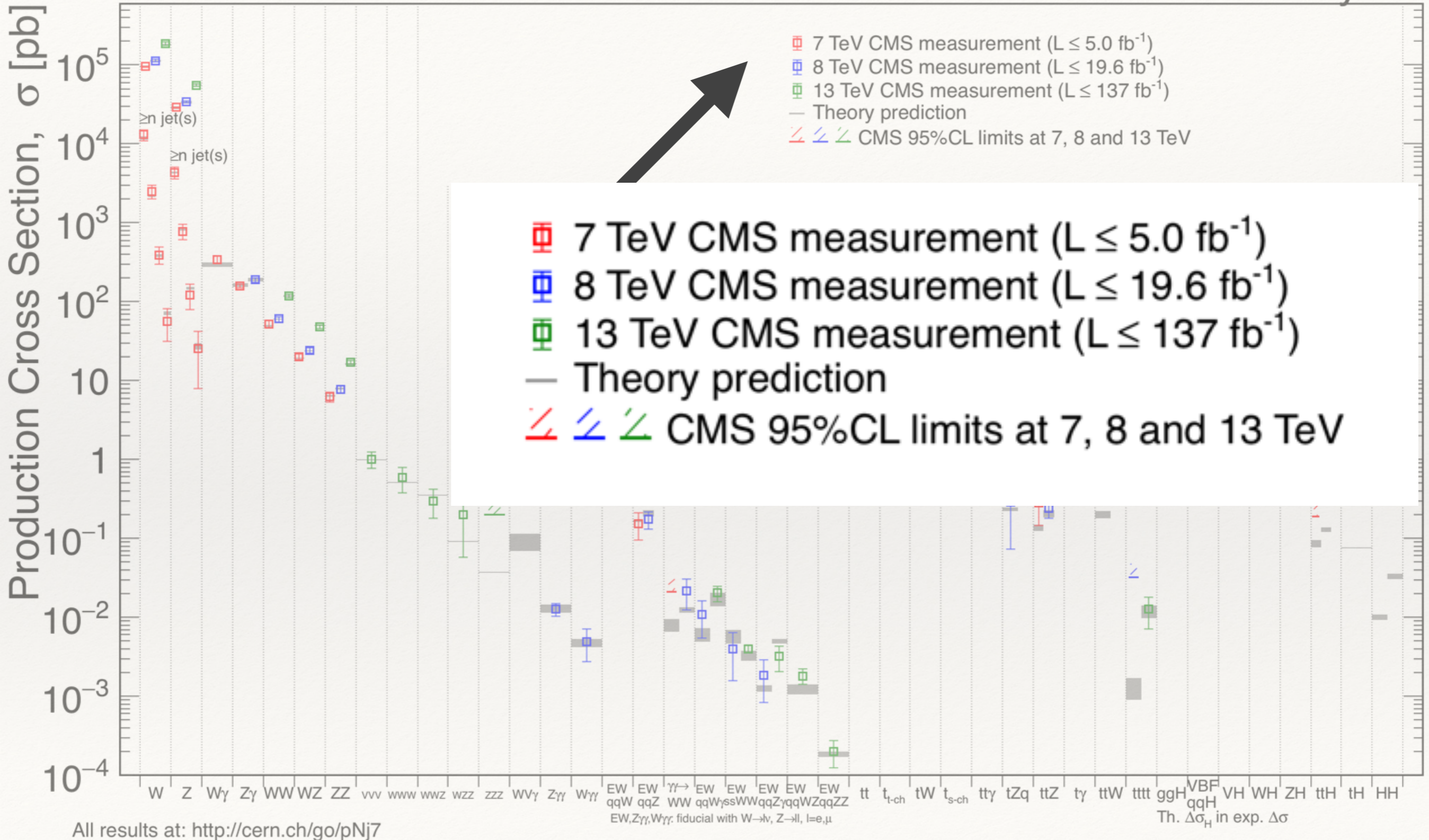Direct and indirect searches
Connecting ideas with experiments
Looking through different eyes

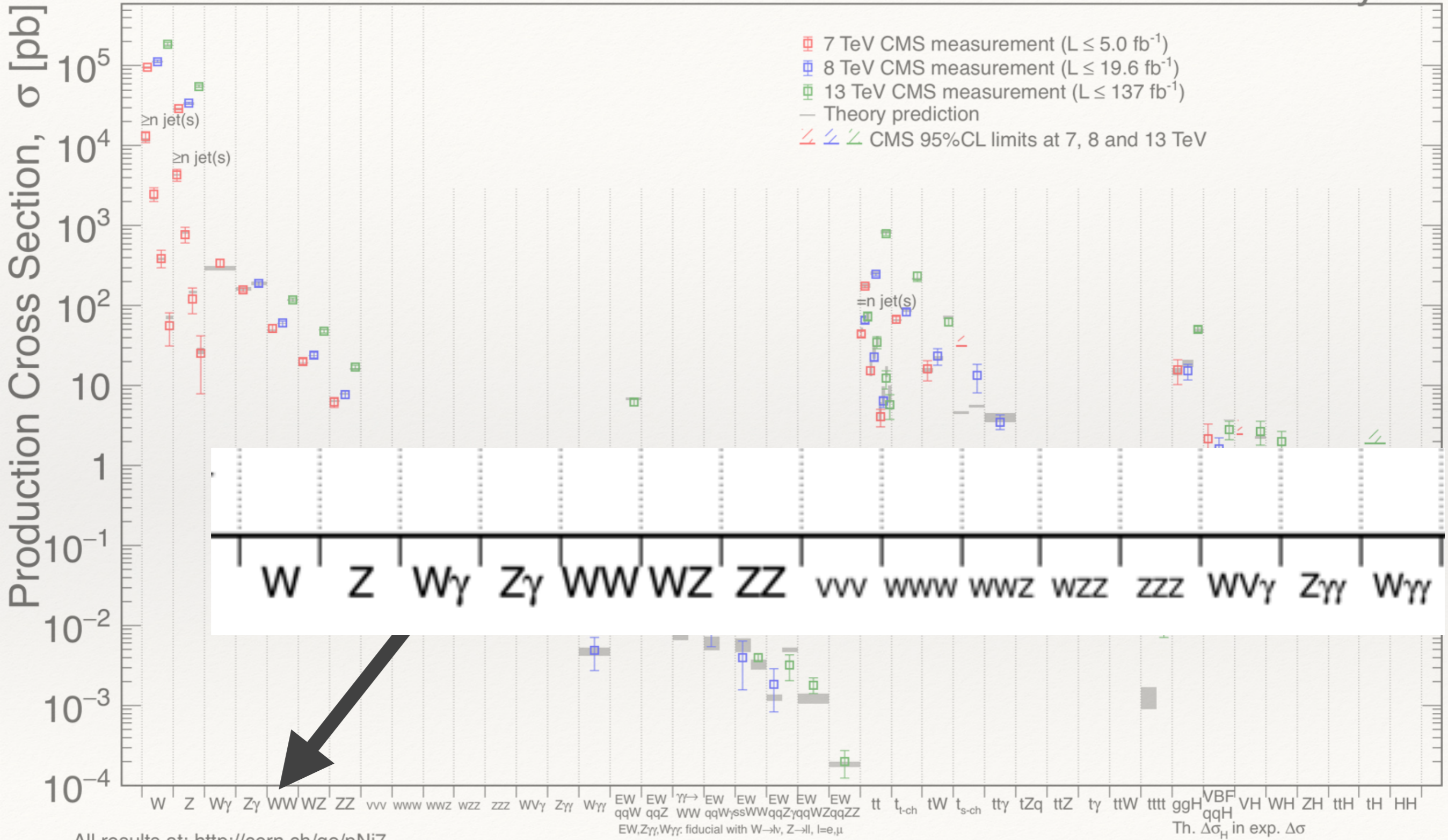# The status of the SM

Testing the Standard Model

Snapshot of CMS results

Testing the Standard Model

Testing the Standard Model

Testing the Standard Model

Testing the Standard Model

Testing the Standard Model

Testing the Standard Model

May 2020

CMS Preliminary

Production Cross Section, σ [pb]

$\geq$n jet(s)

$\geq$n jet(s)

☐ 7 TeV CMS measurement (L ≤ 5.0 fb⁻¹)
☐ 8 TeV CMS measurement (L ≤ 19.6 fb⁻¹)
☐ 13 TeV CMS measurement (L ≤ 137 fb⁻¹)
— Theory prediction
◿ ◿ ◿ CMS 95%CL limits at 7, 8 and 13 TeV

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]

W Z Wγ Zγ WW WZ ZZ vvv www wwz wzz zzz WVγ Zγγ Wγγ EW qqW EW qqZ γγ→ WW EW qqWγ ssWW EW qqZγ EW qqWZ EW qqZZ tt t_t-ch tW t_s-ch ttγ tZq ttZ tγ ttW tttt ggH VBF qqH VH WH ZH ttH tH HH

EW,Zγγ,Wγγ: fiducial with W→lν, Z→ll, l=e,μ

Th. $\Delta\sigma_H$ in exp. $\Delta\sigma$

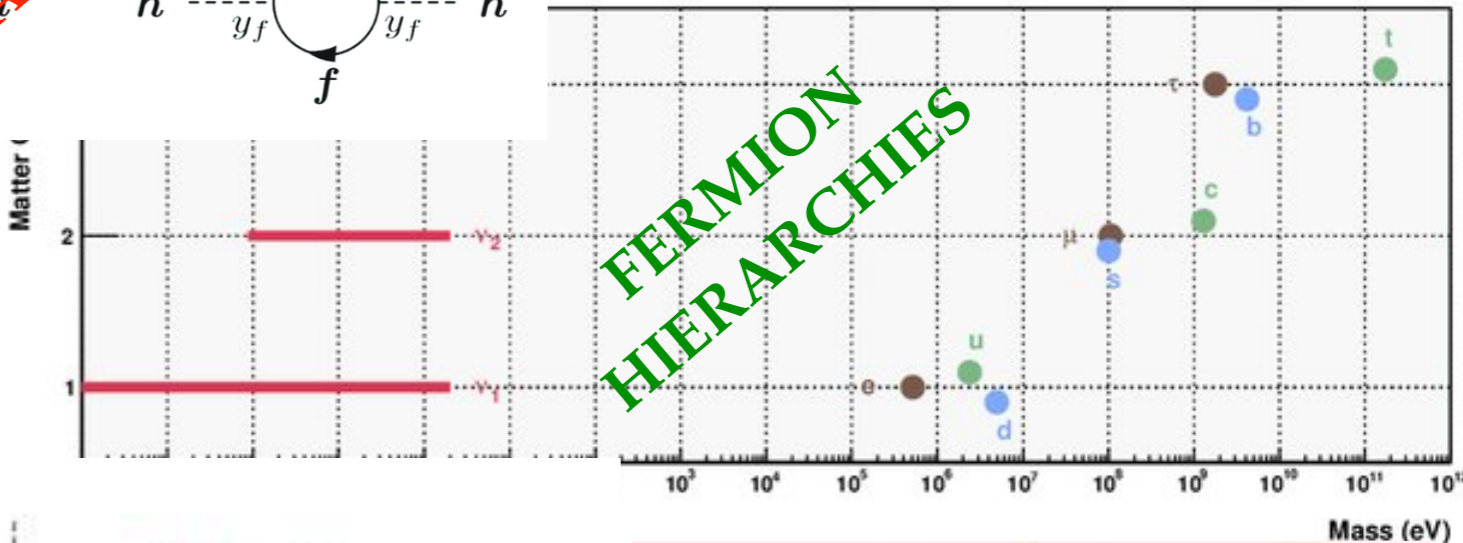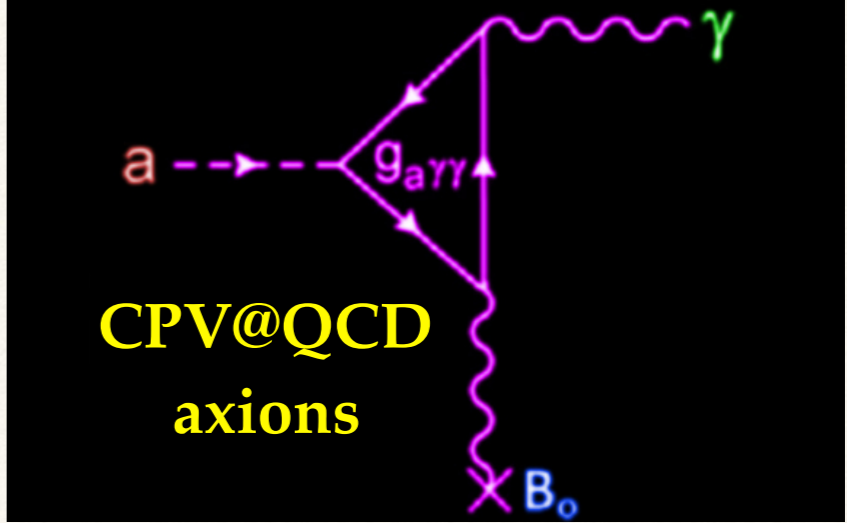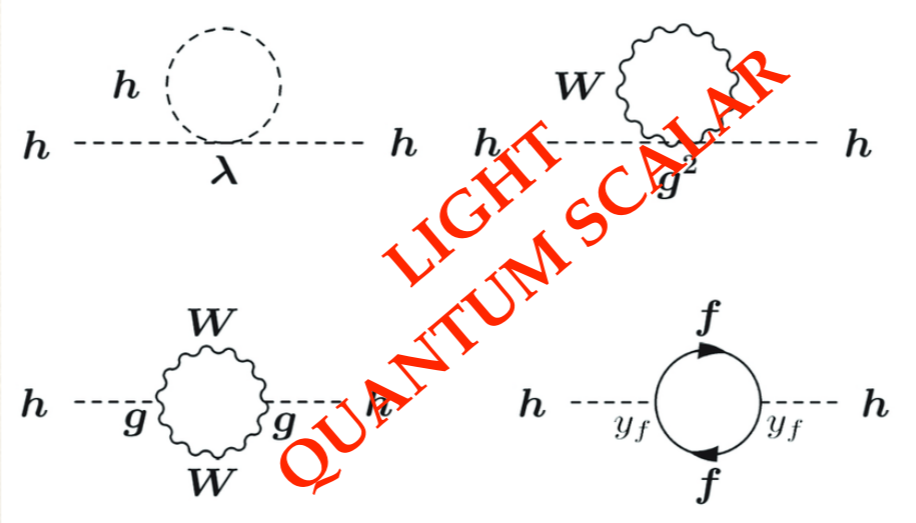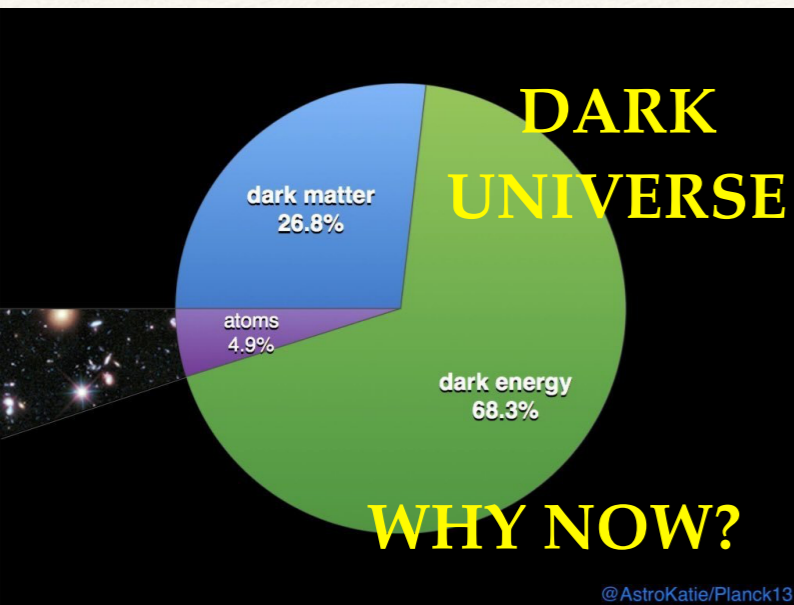All results at: http://cern.ch/go/pNj7

Celebrating the Standard Model

Those are impressive achievements

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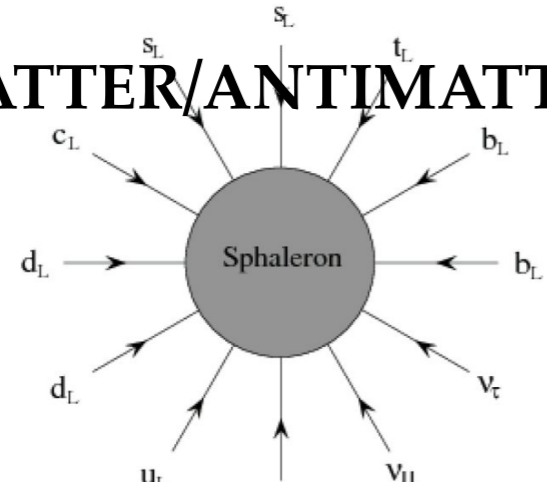based on rather simple building blocks

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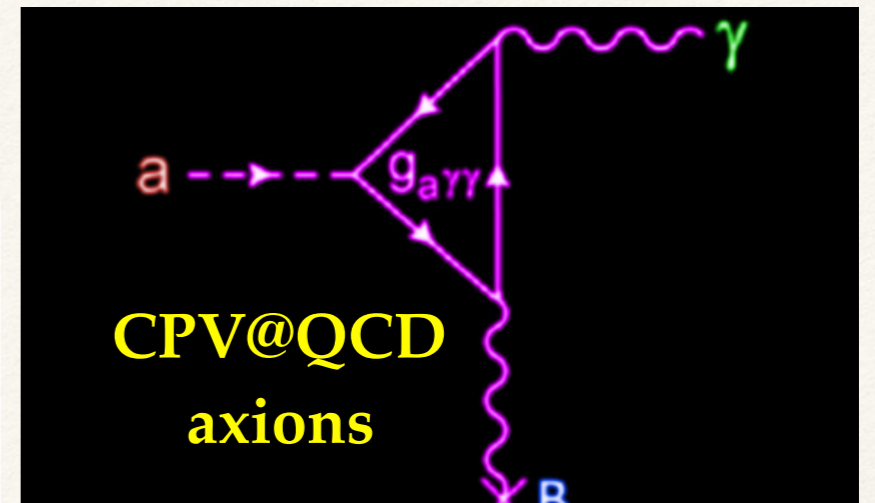involving numerous different particles

So why aren't we just happy?

Because that can't be it

DARK UNIVERSE

WHY NOW?

LIGHT QUANTUM SCALAR

CPV@QCD axions

FERMION HIERARCHIES

Theories of Dark Matter ?

Inflation Reheating

$V(\phi)$

ϕ

MATTER/ANTIMATTER

Sphaleron

WHY THREE

Three Generations of Matter

QUANTUM GRAVITY

Because that can't be it
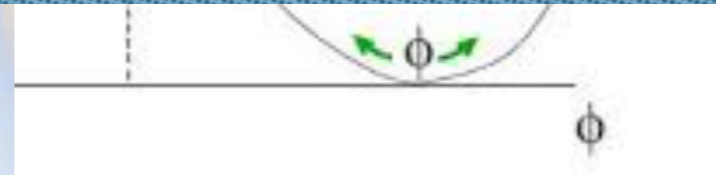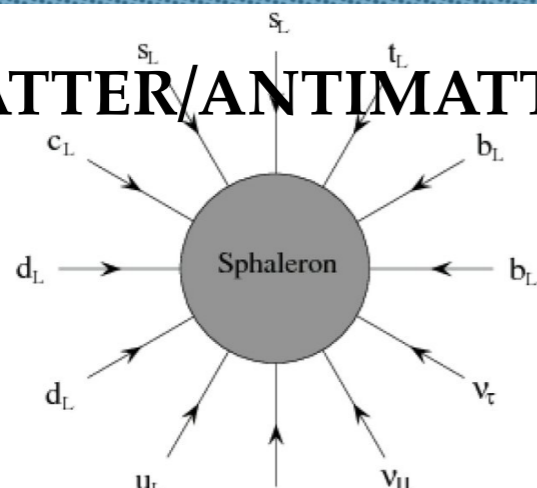

DARK UNIVERSE

LIGHT QUANTUM SCALAR

CPV@QCD axions
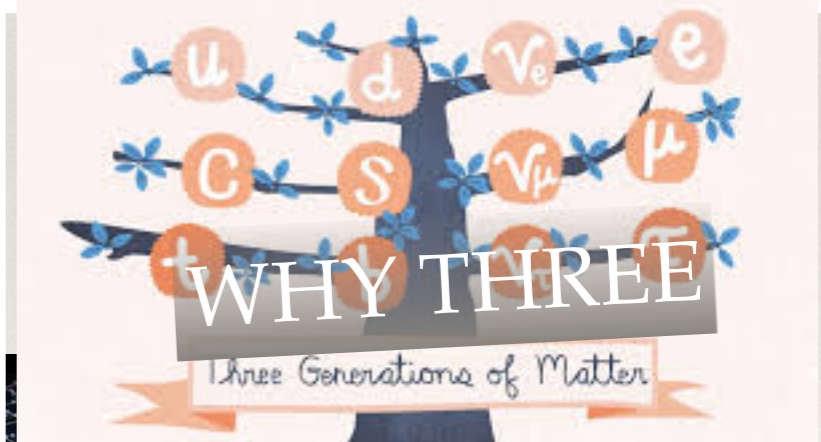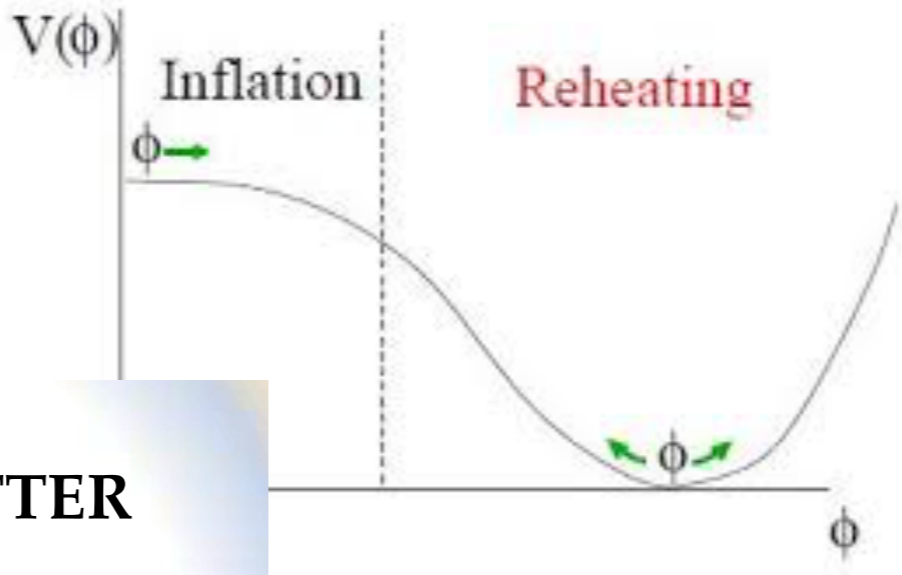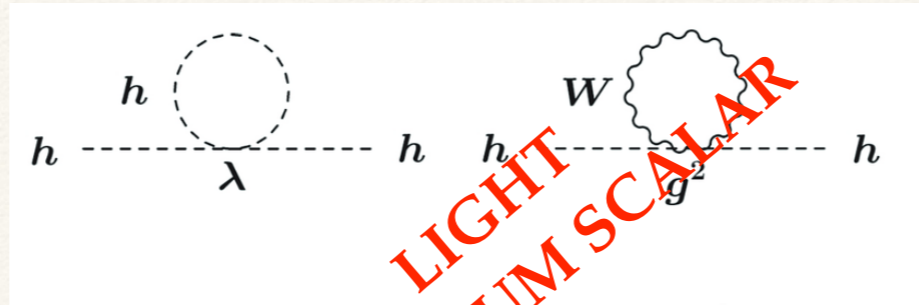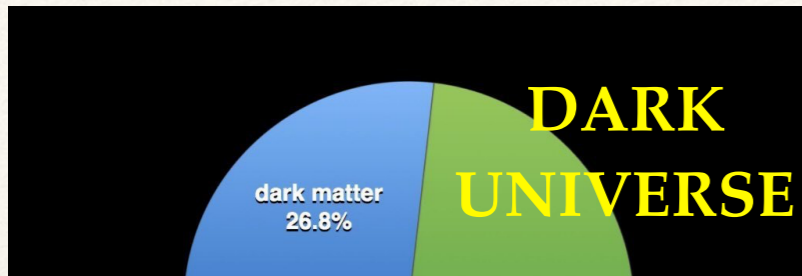
THERE ARE MANY MYSTERIES TO SOLVE
MANY DISCOVERIES TO BE MADE
PHENO21 with 150 talks, 7 parallel sessions
impressive amount of new ideas
exploiting the LHC potential for discovery
GAME ISN'T OVER

MATTER/ANTIMATTER

Sphaleron

Three Generations of Matter

QUANTUM GRAVITY

So here we are

Light Higgs

Inflation

Neutrinos

Unification

Matter/Antimatter
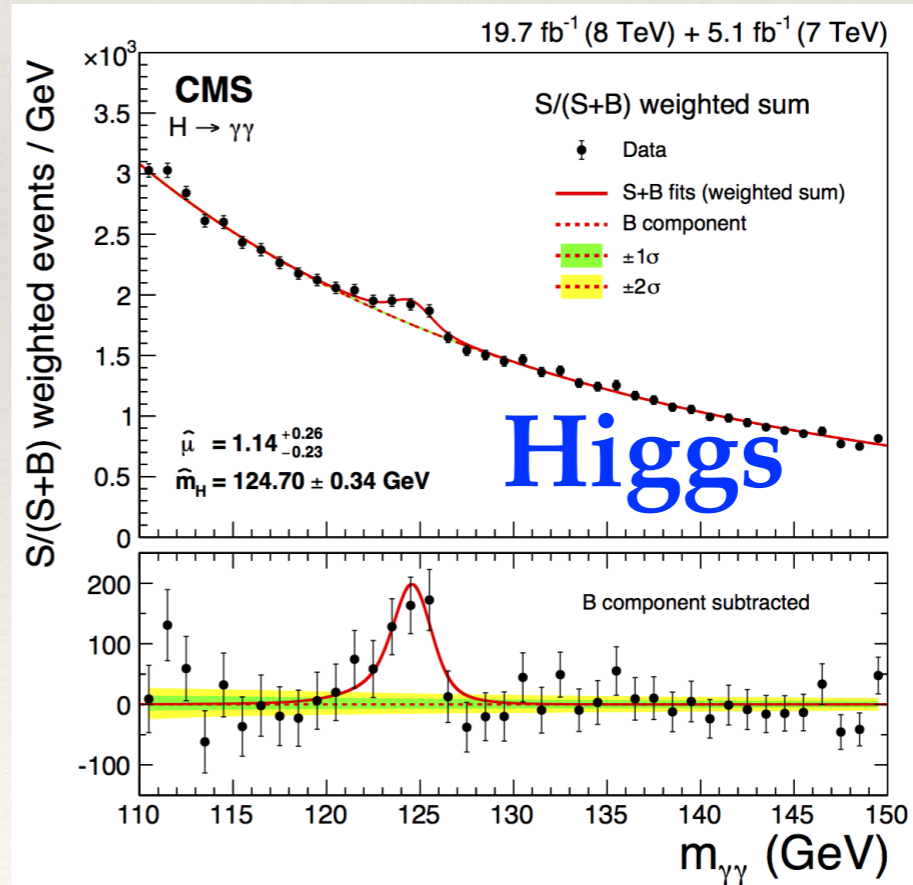
CP QCD

Dark Matter

Dark Energy

Quantum Gravity

finding our path through **SYMMETRIES & DYNAMICS**

aiming for a **UNIFIED FRAMEWORK**

SM+GR

Direct versus indirect searches

Discoveries = Resonances?
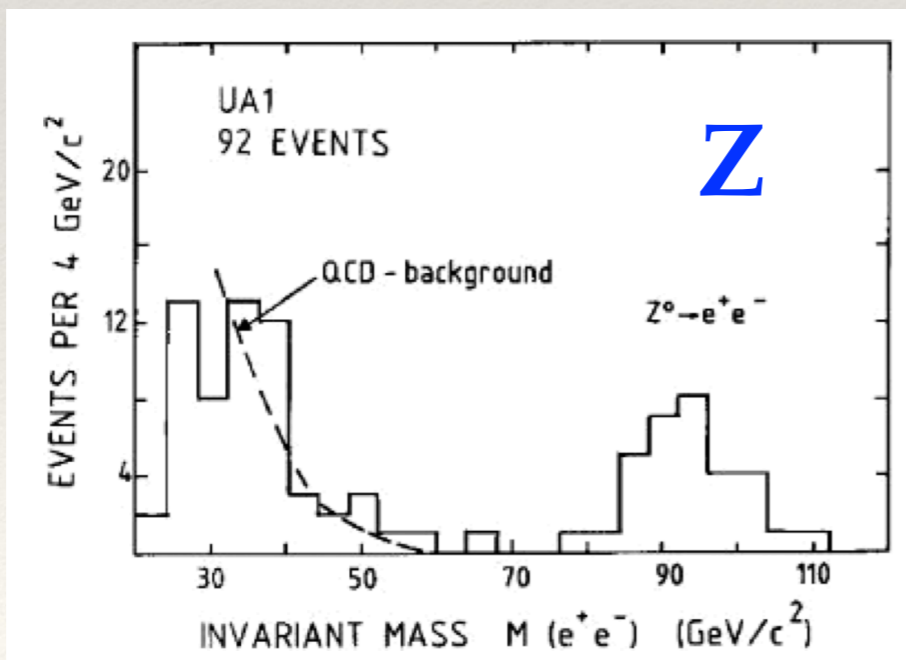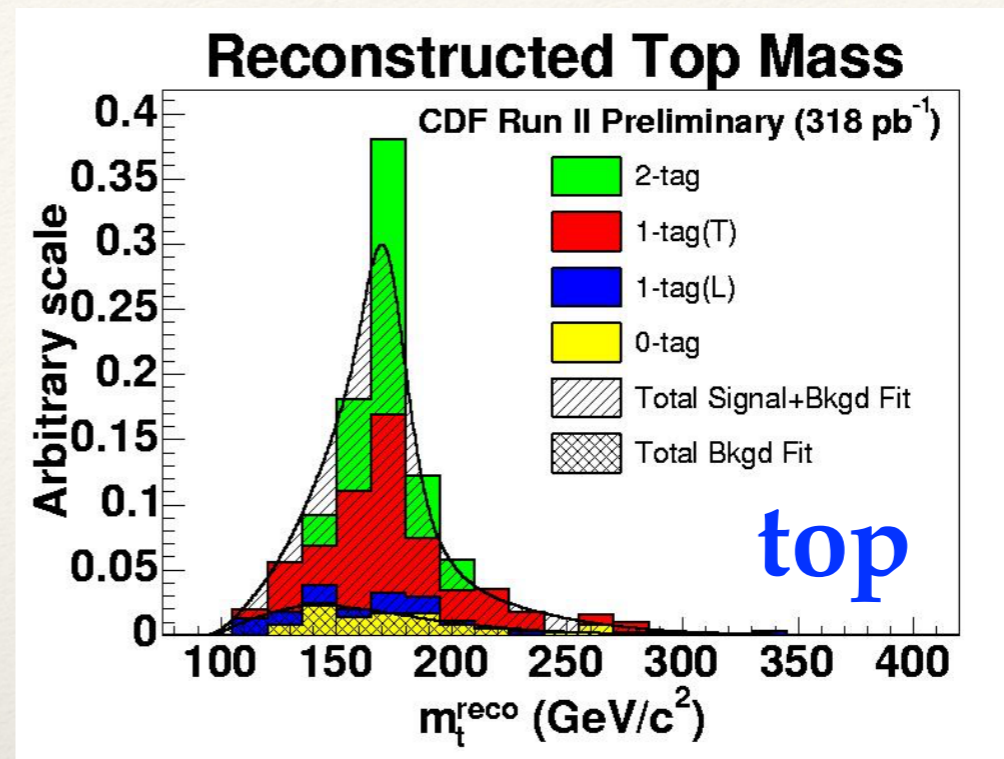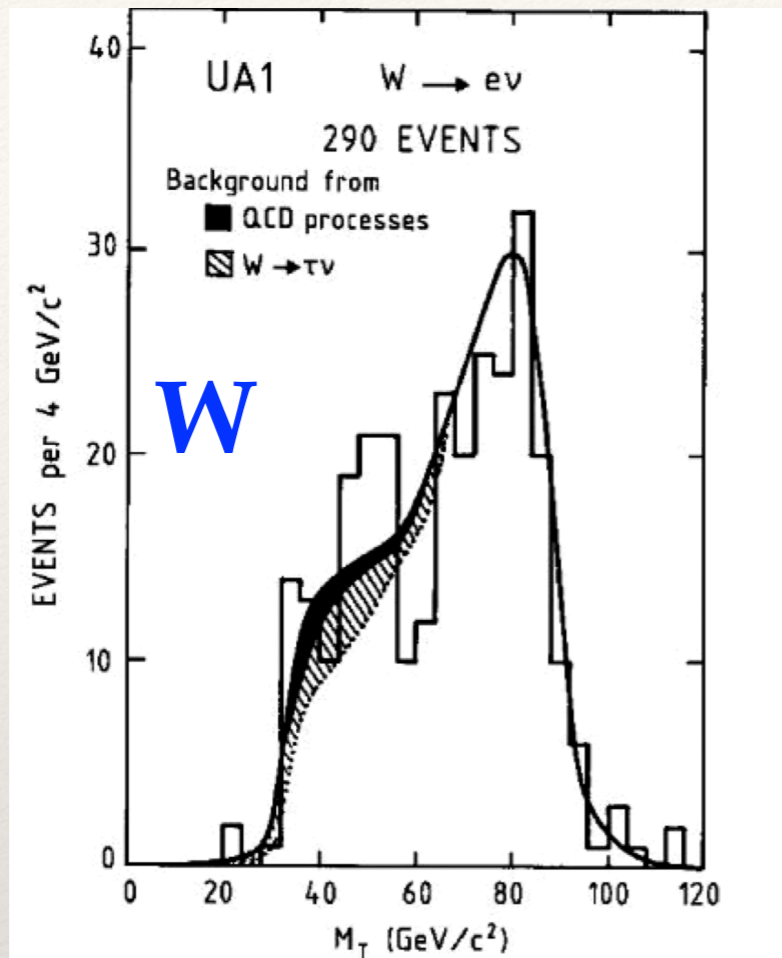
Coloured states to the very exotic

SUSY Benchmark   **Jets+MET**   **some-SUSY**   **HSCPs**
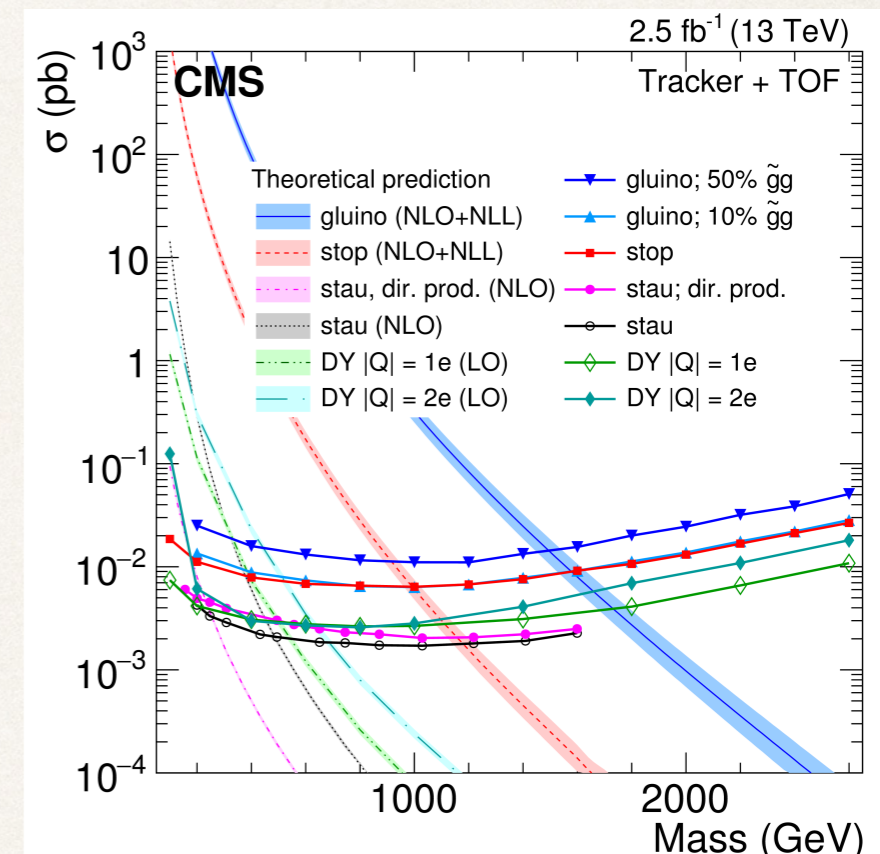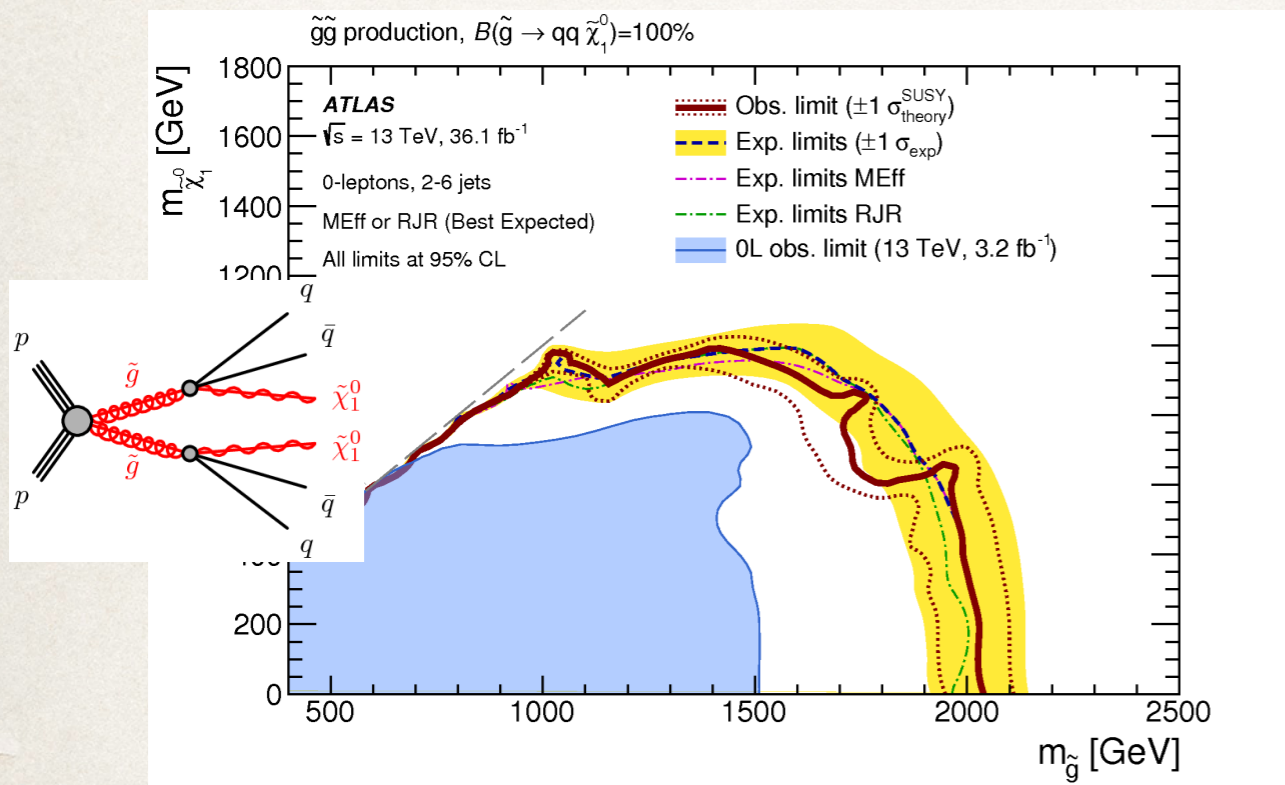
It's a long way since LHC7

Simplified models, model-agnostic resonance searches

better presentation of results (xsec*BR, fiducial)

Communication with theorists is excellent

recasting has never been simpler

Run3 and beyond

The LHC is a hadron machine, a **discovery** machine
yet it had to re-invent itself to become a **precision** machine
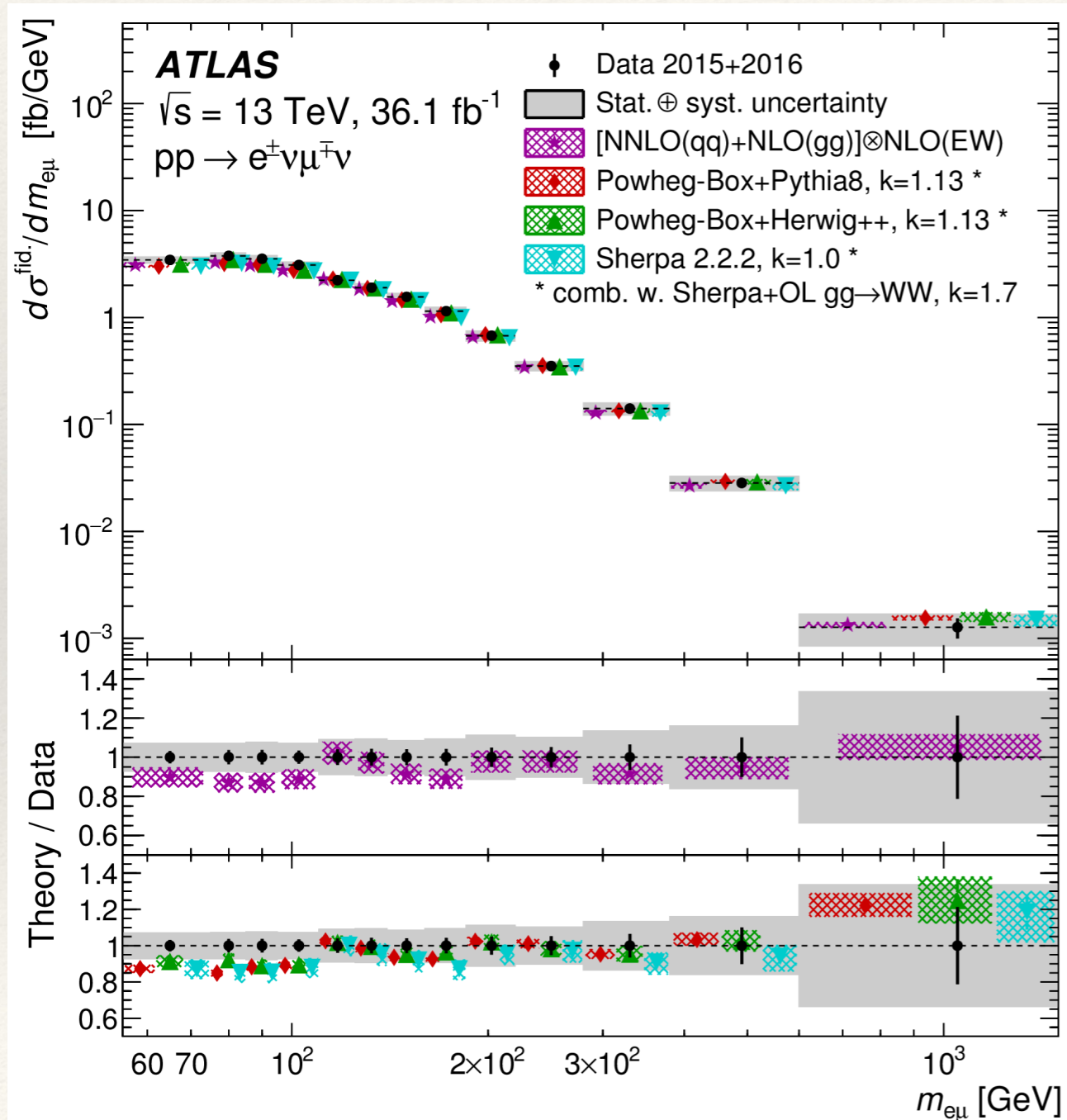
Traditional resonant searches have been so far unfruitful

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

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
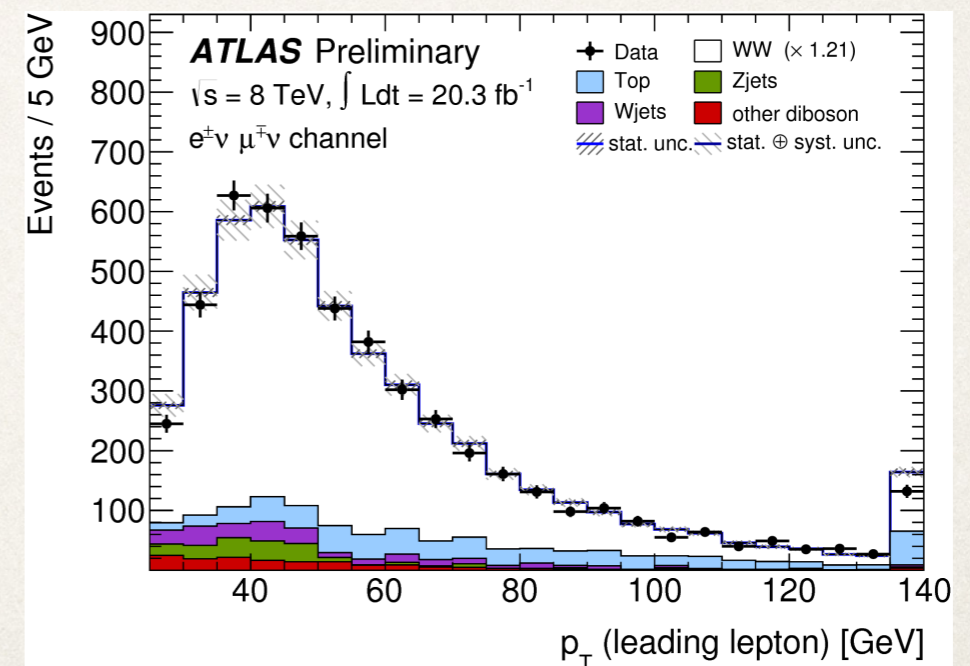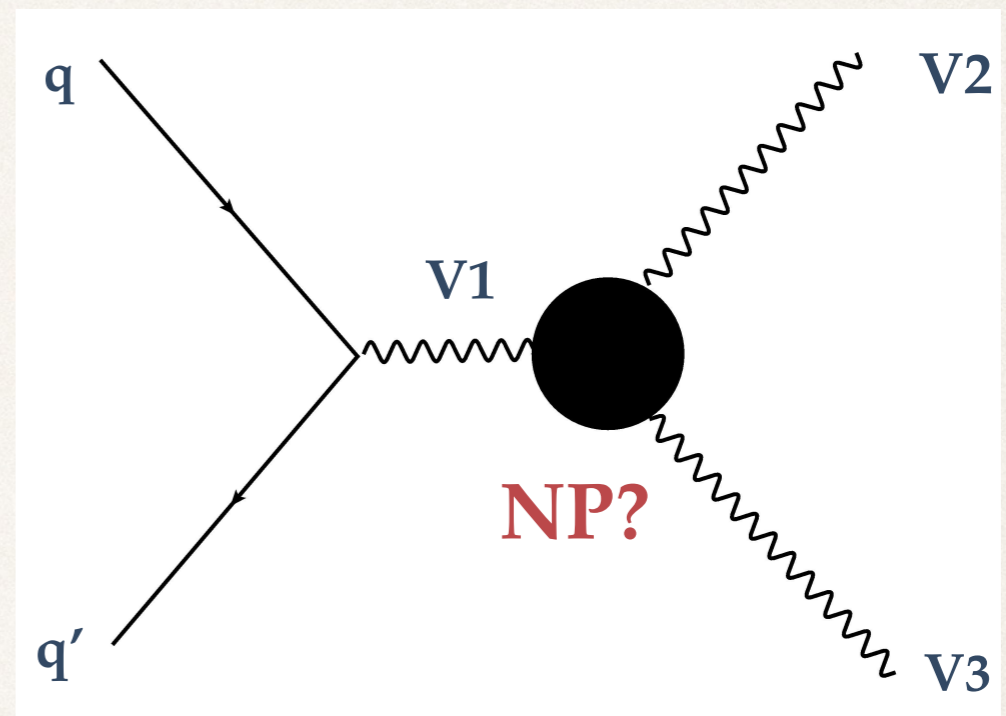
EFT is the new black

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

Advantages

- **Combination**: LHC Higgs and EW production, low energy, EWPTs
- **Precision:** higher-order EW and QCD, dimension-eight, chiral logs
- **Consistency:** Backgrounds and signal
- **Reduces model biases:** explore theories beyond known paradigms
- **Matching:** Direct connection to models

Disadvantages

- **Assumptions**: Only SM light states
- **Complexity:** Large number of parameters
- **Validity:** EFT cannot be used in regions of energies ~ scale of new resonances

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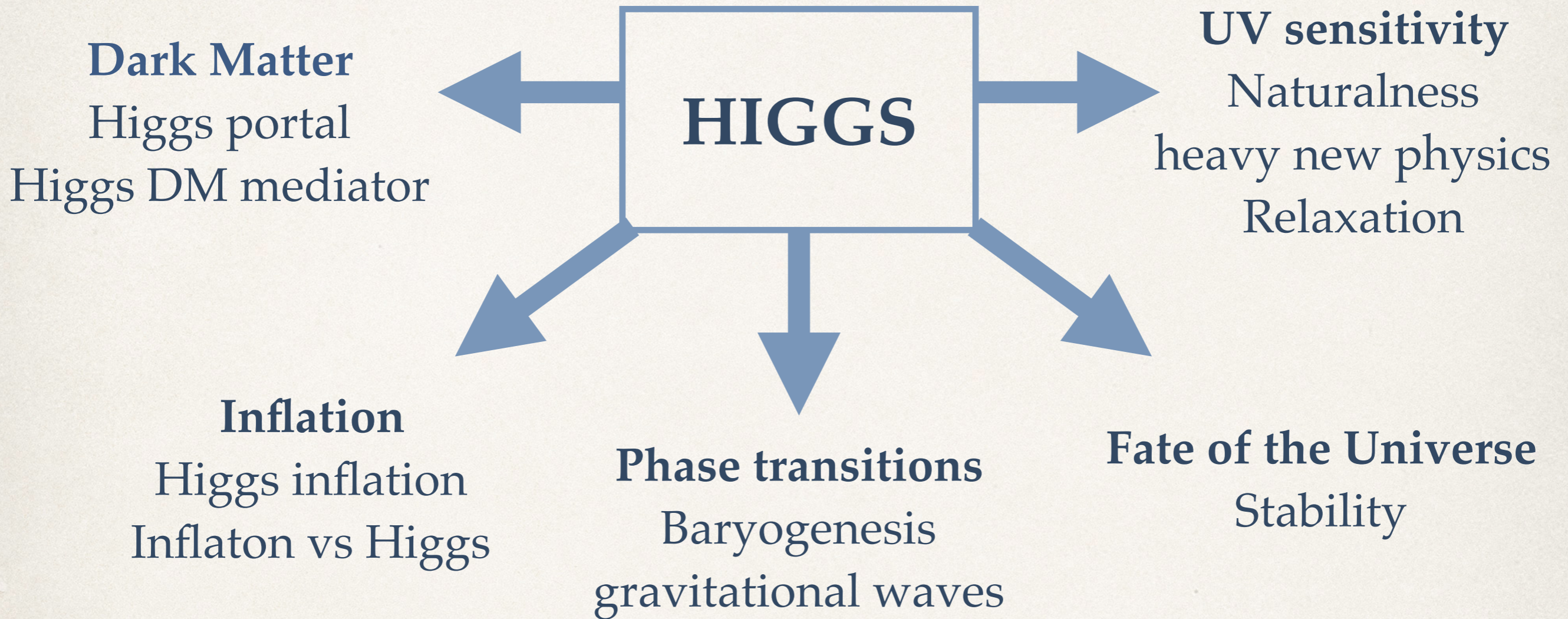
The LHC provides the most precise, controlled way of studying
the Higgs and direct access to TeV scales
Exploiting complementarity with cosmo/astro probes

Similar story for Axions and ALPs, scalars are versatile

# Many faces of Dark Matter

COLLIDERS

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

DIRECT DETECTION

DARK MATTER

CMB: relic, tilt

INDIRECT DETECTION

SIMULATIONS
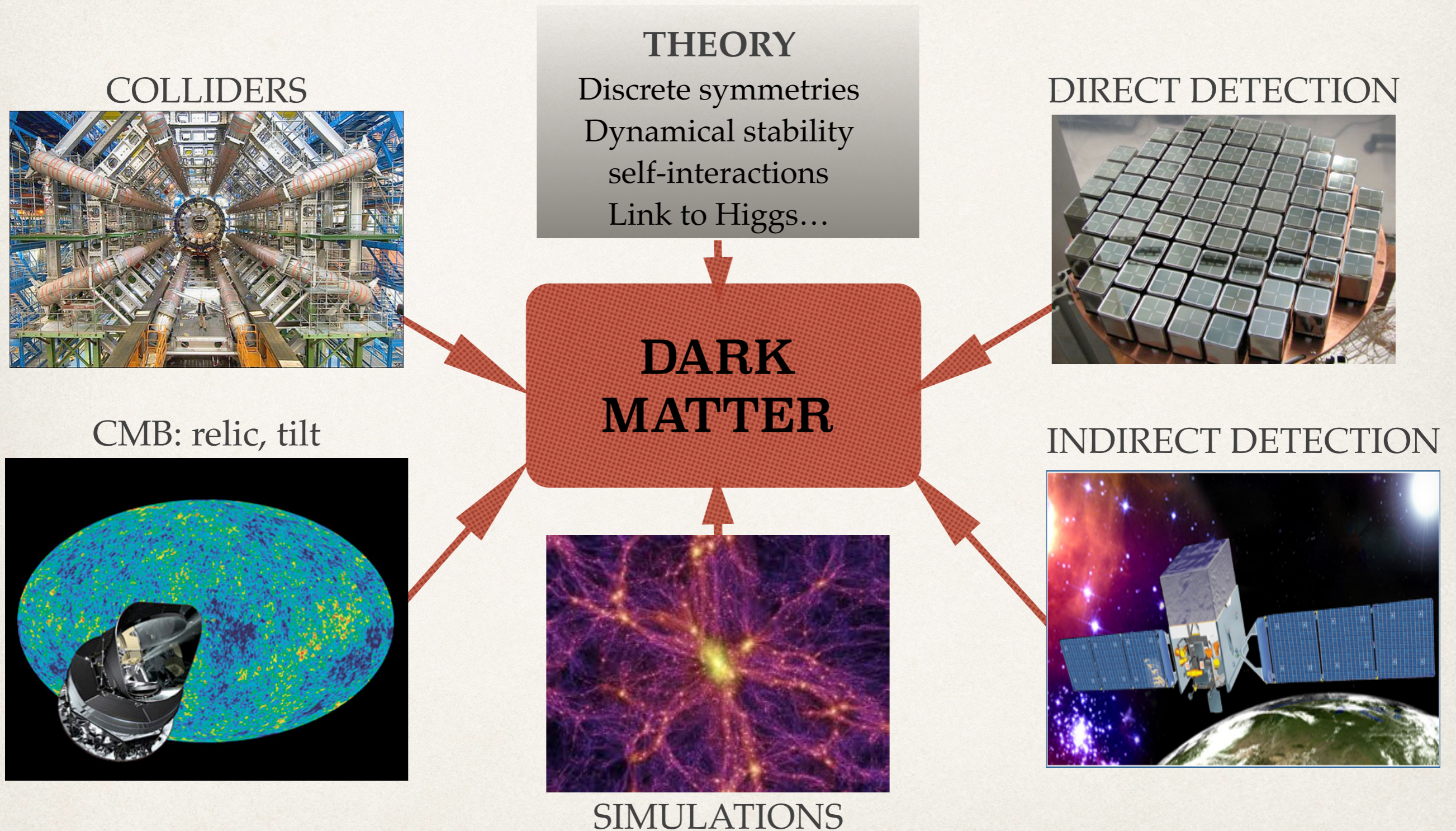
Looking through different eyes

These days we think a lot more about **complementarity**

One idea can be tested by many experiments beyond LHC *neutrino observatories/reactors, high-intensity/precision at low energies (flavour, g-2), gravitational waves…*
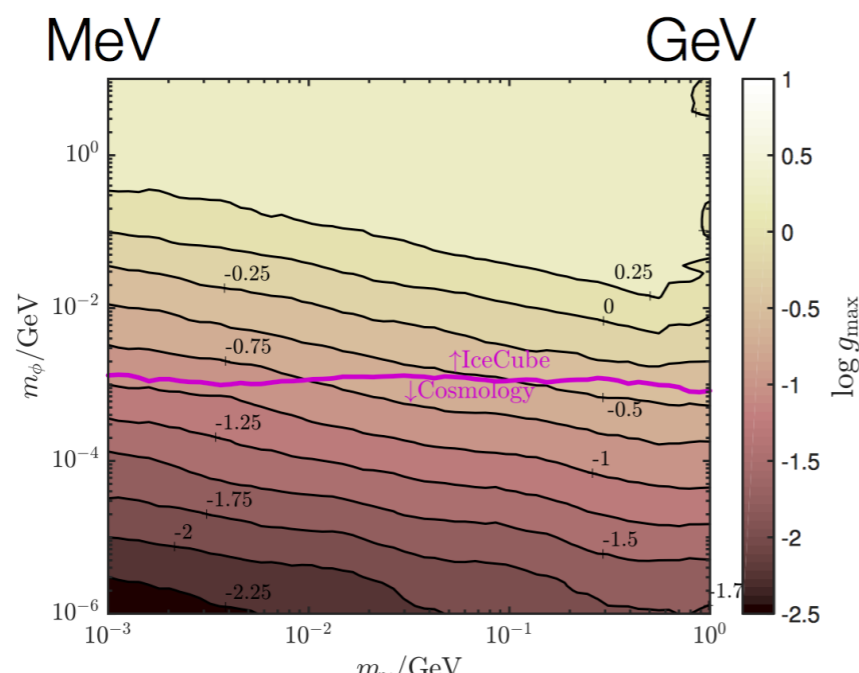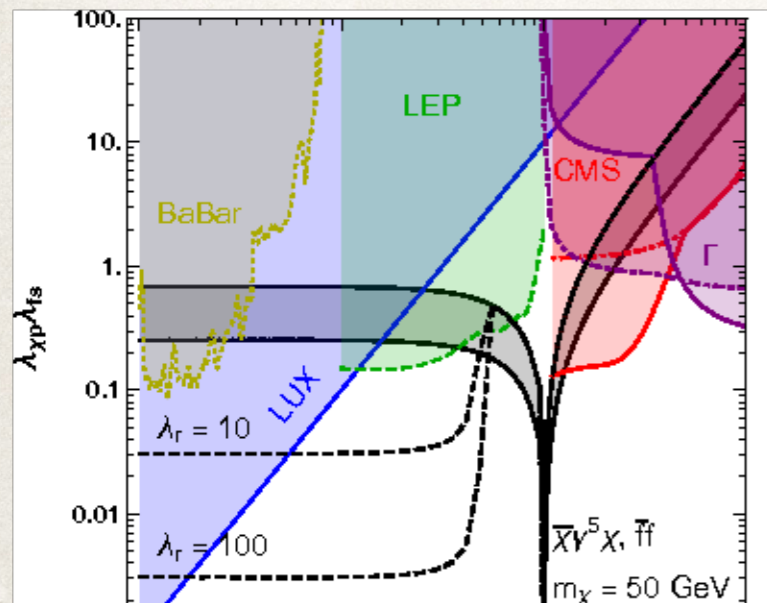
1. New experiments, ways they present results, access to data

2. Simple straw-man models

3. Development of public tools, or recasting, so we can tackle complex processes and focus on the fundamental ideas

Smaller experiments may be key

LHC is our best probe into the SM but
other, smaller and narrower-focus experiments are also important
cheaper, shorter time-scale
develop creative experimental techniques
often enlarge the initial physics focus

Summary

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

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what is coming next? (~ E, more lumi)

Direct searches will continue testing broader sets of models
Indirect searches for NP have gained a lot of traction at the LHC
but advancement requires more intense thy/exp communication

Summary

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As theorists our task is to continue exploiting the LHC capabilities for discovery,
guided by ideas and exploring complementarity with other probes

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As theorists our task is to continue exploiting the LHC capabilities for discovery,
guided by ideas and exploring complementarity with other probes

But in a time where the experimental landscape is so complex, and we
are entrusted with reinterpretation ,we have to remind ourselves that
our job is also to explore crazy, blue skies ideas with no immediate
testable consequences. Those are the seeds for the future of the field.

Have fun!