THE W MASS -WHY THE HUBBUB?
SPENCER CHANG
U. OREGON QUARKNET 2022
(SOME MATERIALS PROVIDED BY POUYA ASADI)

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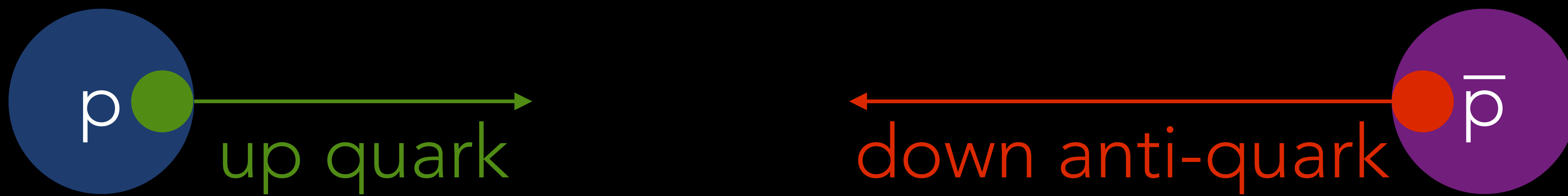
OUTLINE

- How is the W mass measured?
- Why is recent discrepancy potentially a problem?
- Aside: How to find new physics indirectly
- If result is confirmed, what could be the explanation?

HOW IS THE W MASS MEASURED AT A HADRON COLLIDER (E.G. LHC, TEVATRON)?



quarks fuse into a W^+ which is moving

W^+ decays into

Q: What can we infer about neutrino's momentum from conservation laws?

A: Since we don't know quark momenta, can only infer neutrino's transverse momentum

FIND IT DOWNSTAIRS....

INFERRING THE MASS

For a particle of mass m, we have Einstein's relation between energy, momentum and mass

$$E^2 - |\vec{p}|^2 c^2 = m^2 c^4$$

If neutrino was observable, we could add neutrino and positron E, $\vec{p}$ to get mass of W

However, we only know neutrino's transverse momentum

TRANSVERSE MASS

Define transverse energy, momentum for positron, electron neutrino

$\vec{p}_T \cong (p_x, p_y, 0)$, $E_T^2 \cong |\vec{p}_T|^2c^2 + m^2c^4 \approx |p_T|^2c^2$

Then we can use conservation of transverse momenta, to find the transverse energy and momenta of W particle

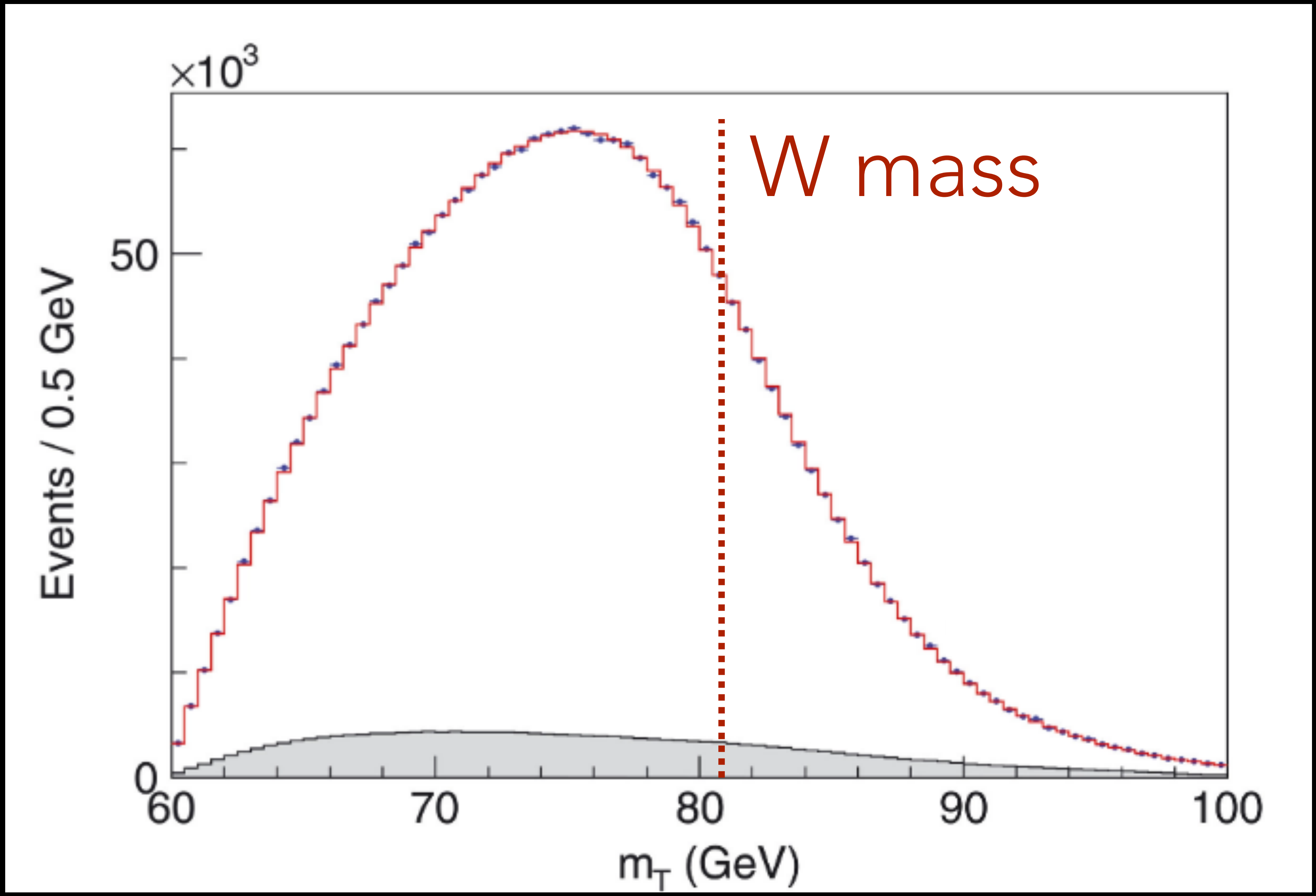
$$E_T^2 - |\vec{p}_T|^2c^2 \approx (|\vec{p}_{T,pos}|c + |\vec{p}_{T,neut}|c)^2$$
$$\leq (|\vec{p}_{pos}|c + |\vec{p}_{neut}|c)^2 \approx m_W^2c^2$$

We can calculate this transverse mass and its max is the W mass

SAMPLE HISTOGRAM

In reality, it doesn't end at W mass due to backgrounds & events where W gets created with a QCD jet

In practice, shape of histogram gives W mass

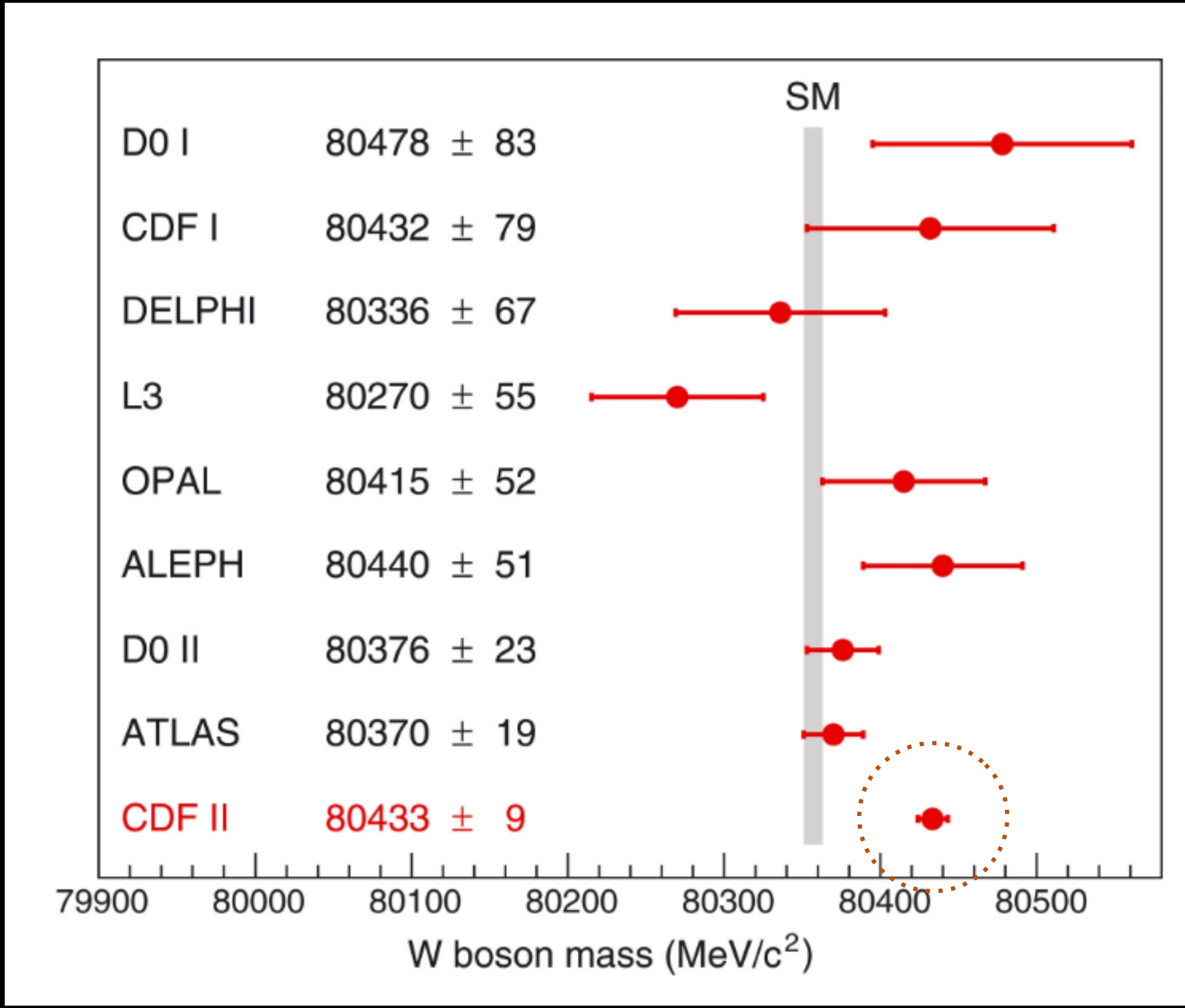


Credit: CDFII

LATEST RESULTS

In April, CDF released their final measurement of W mass

It is more precise than any other analysis (incl. LHC expts) and is far off from the Standard Model value (7 sigma)



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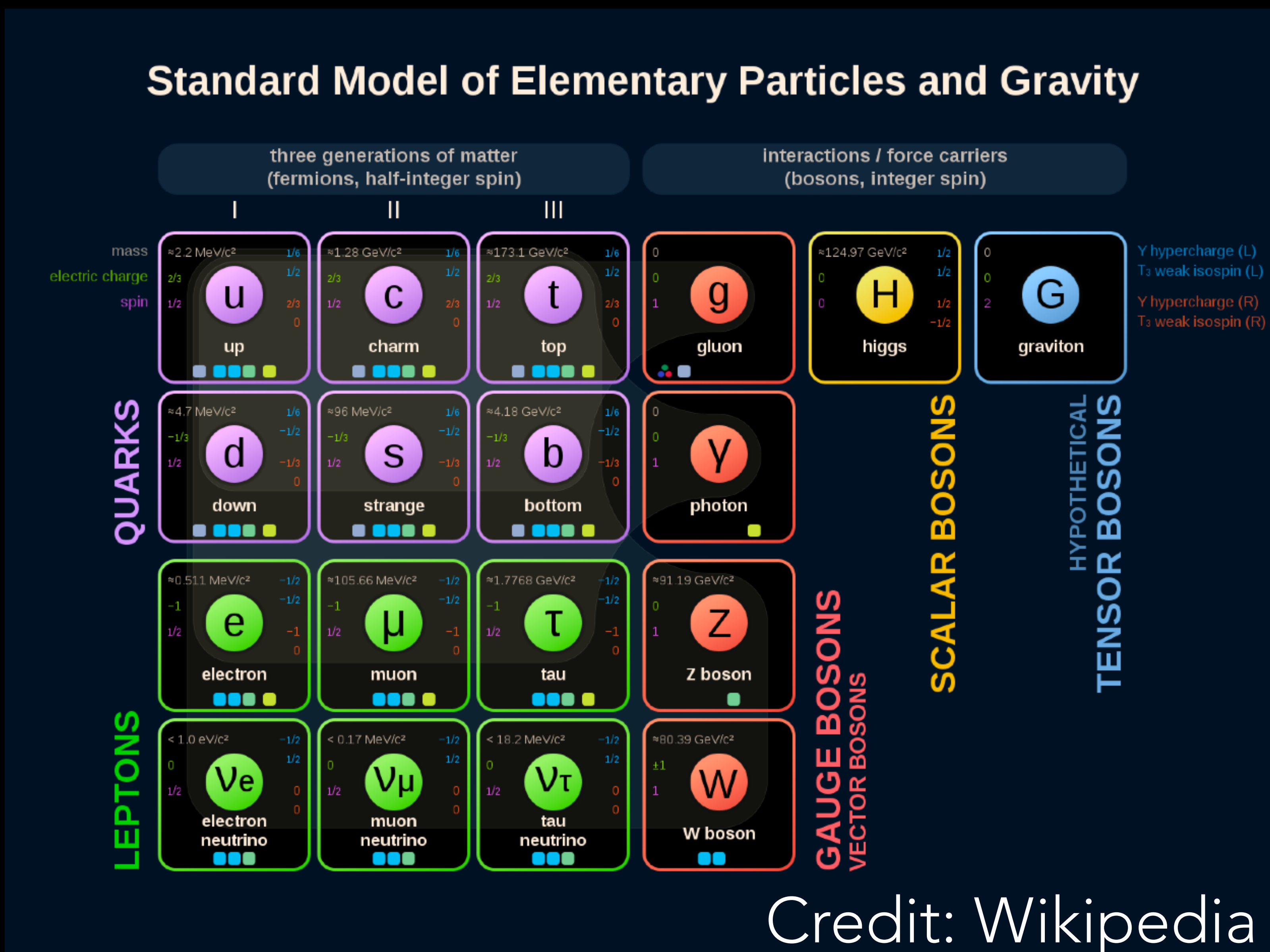
WHY IS THIS INTERESTING?



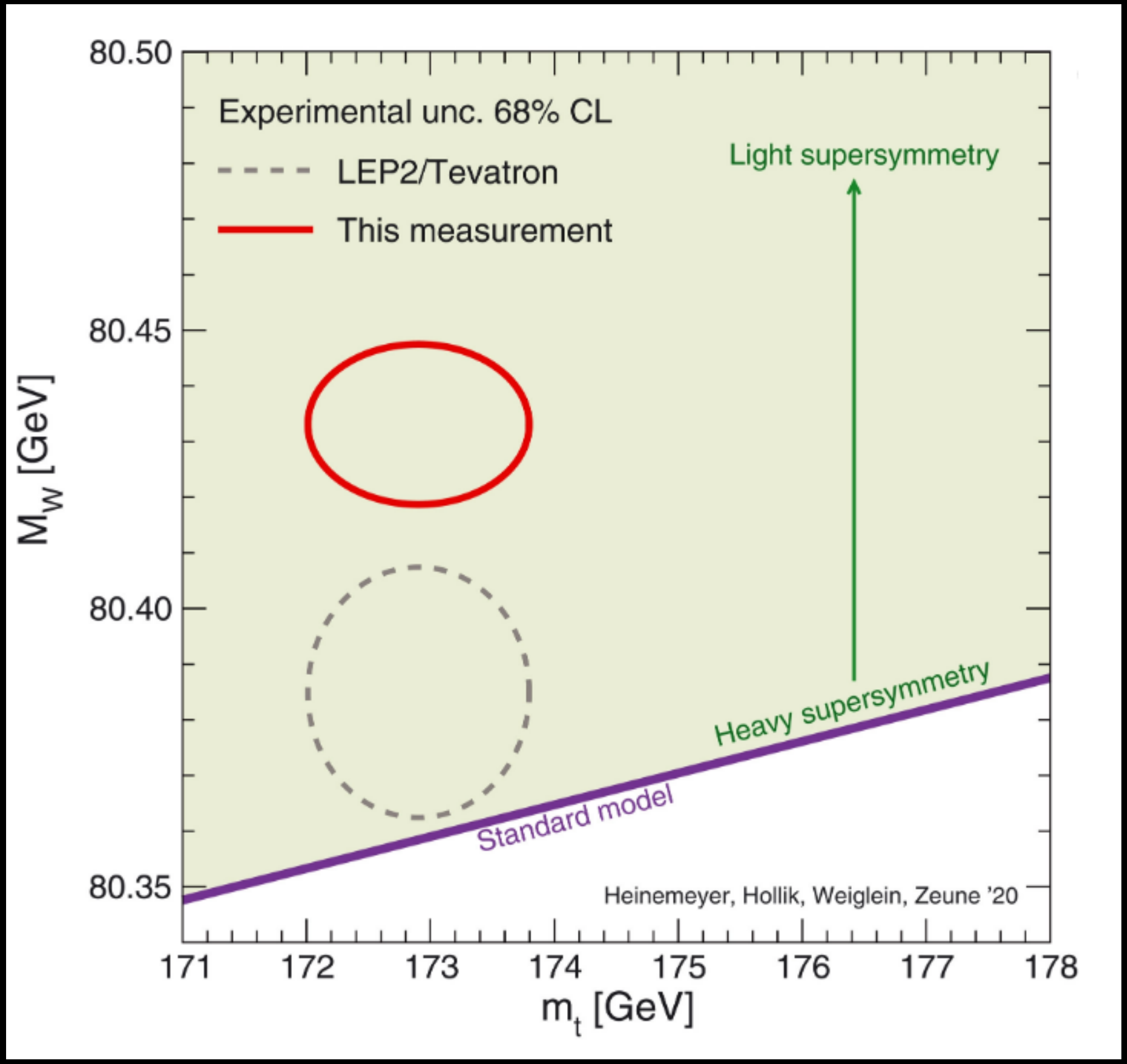
Credit: Wikipedia

Common lore:
Standard Model is most precisely tested theory

Ignoring neutrino mass, has 18 parameters

These parameters are predict all observables, including W mass, so if it is incorrect, must be new physics (W/Z masses determined by weak, electromagnetic interaction strengths)

FOR EXAMPLE...



CDF has a provocative plot in their W mass paper, showing how it is incompatible with the Standard Model, but could be explained (indirectly) by supersymmetry

MORE PRECISELY...

What people mean by Standard Model is a truncation of its most general form

Historically, when quantum field theory was being developed, a premium was placed on the theory being "renormalizable"

Analogy, it is like saying we have a Taylor series for general function of x,

$$f(x) = c_0 + c_1 x + c_2 x^2 + c_3 x^3 + c_4 x^4 + \ldots$$

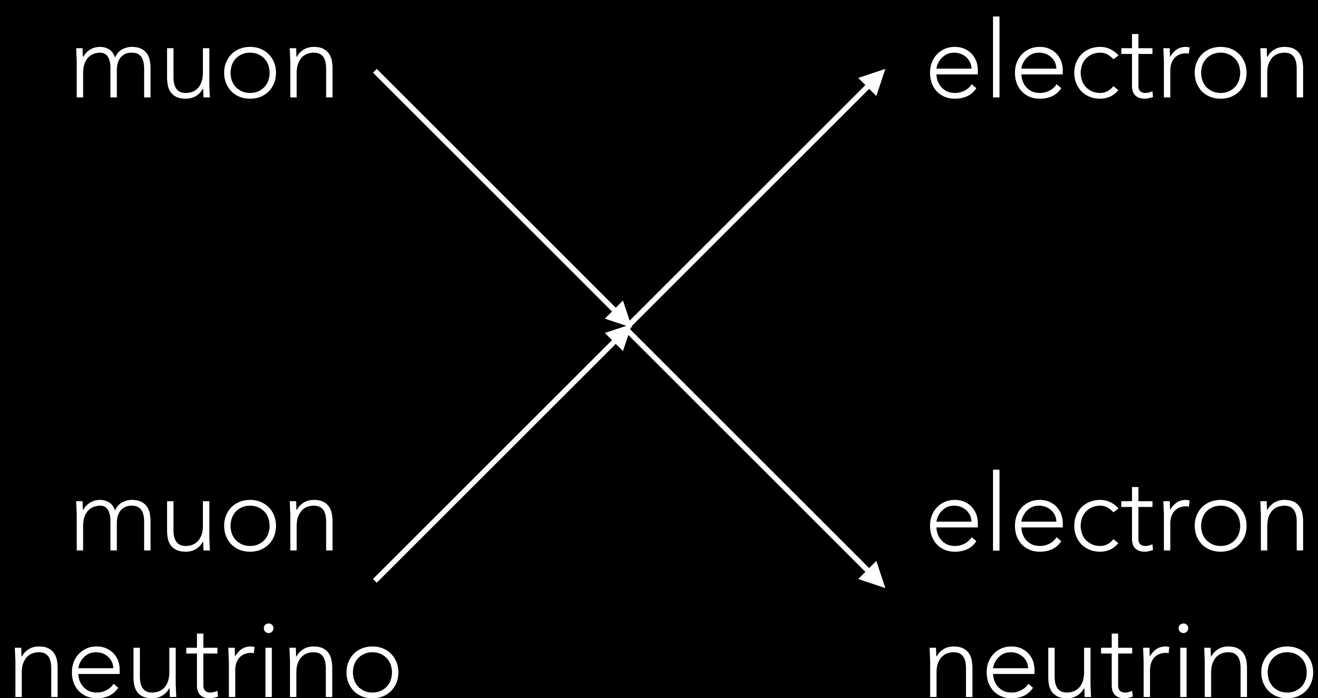
and we don't allow terms of x^5 and higher. In this analogy, these lower terms are the parameters of SM

Higher terms are extra parameters and change predictions

NONRENORMALIZABLE (NR) INTERACTIONS (BETA DECAY)

However, history has shown it is okay to have nonrenormalizable terms

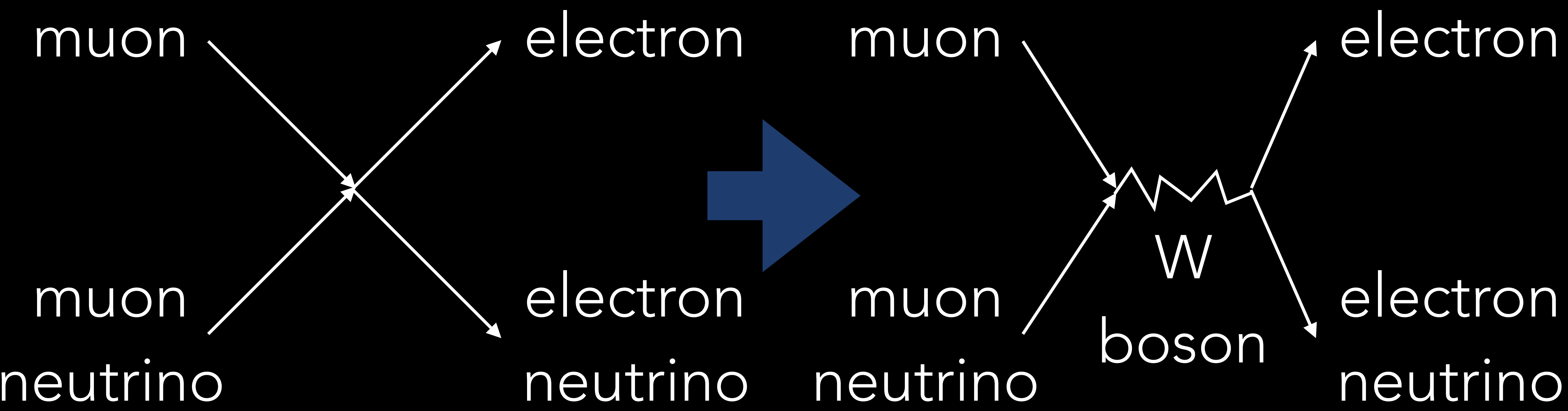
Muon decay ($\mu \rightarrow e\bar{\nu}_e \nu_\mu$)was described by NR interaction due to Fermi



With additional parameter, $G_F = 1.166 \times 10^{-5}/\text{GeV}^2$, can describe this phenomenon even though it is nonrenormalizable

NONRENORMALIZABLE INTERACTIONS INDIRECTLY POINT TO NEW PHYSICS!

NR parameters have dimension $1/E^n$, thus lead to problems at high energies, requiring new physics



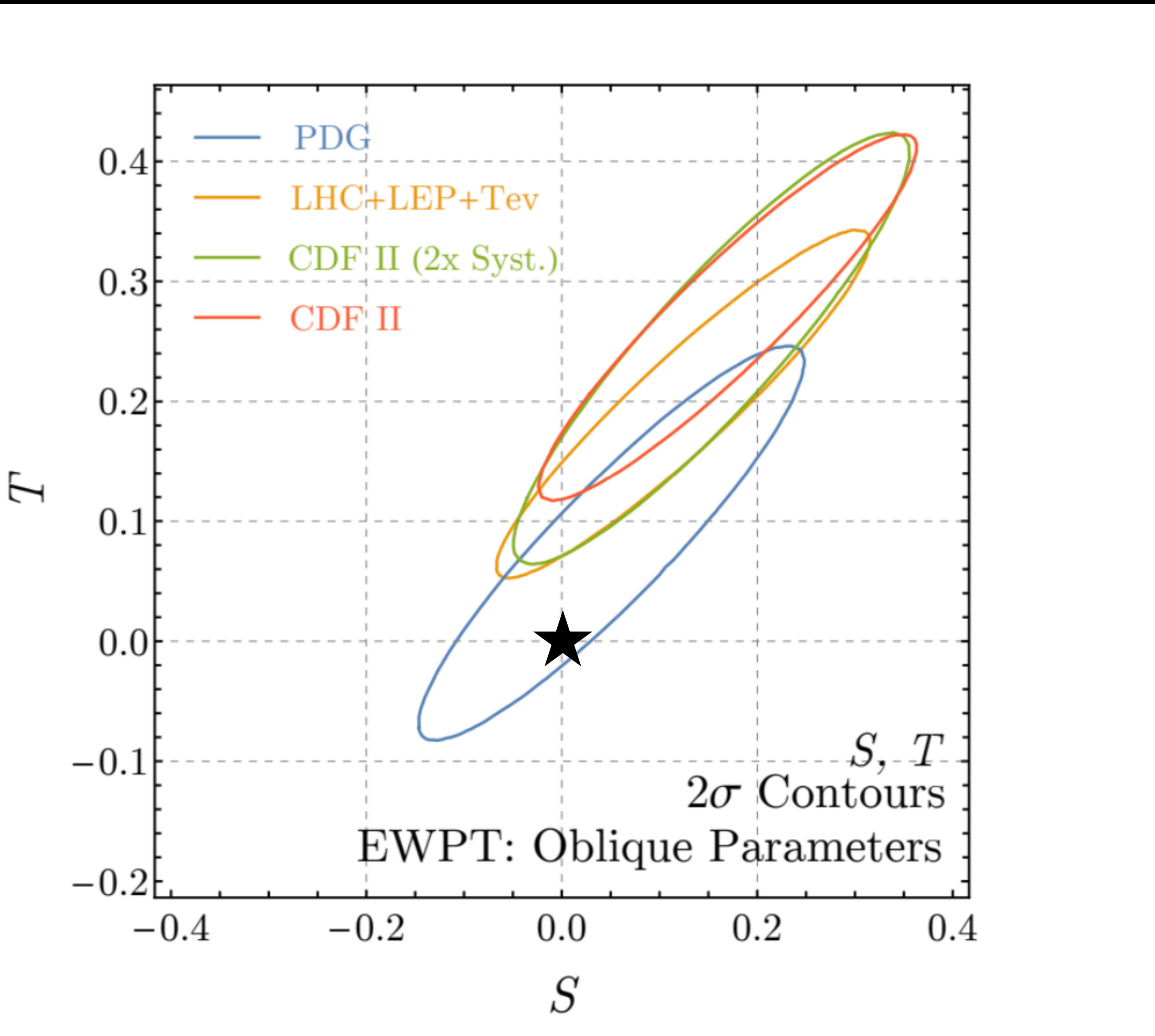
Other examples: Neutrino mass? Anomalous muon magnetic dipole moment? If we observe proton decay, nonstandard Higgs couplings, neutrinoless double beta decay...

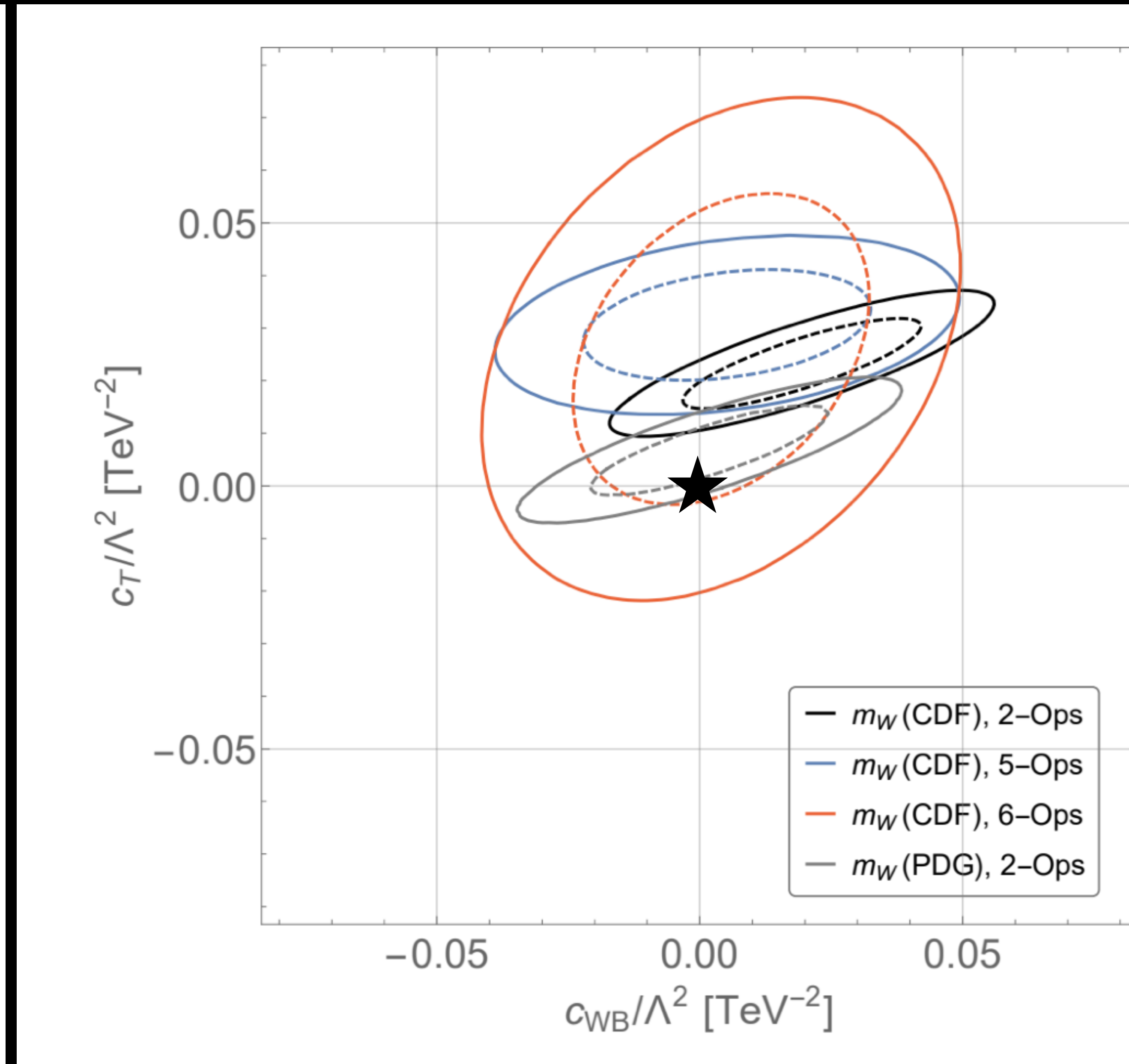
W MASS, A SIGN OF NEW PHYSICS?

Most likely explanation is that CDF W mass measurement has some experiment/theory error
If so, hopefully LHC experiments can resolve this

However, if it holds up experimentally, then it can be another new nonrenormalizable interaction, opening the door for new physics explanations...

MODEL-INDEPENDENT FITS TO NEW PHYSICS (NONRENORMALIZABLE TERMS)





Asadi et.al.

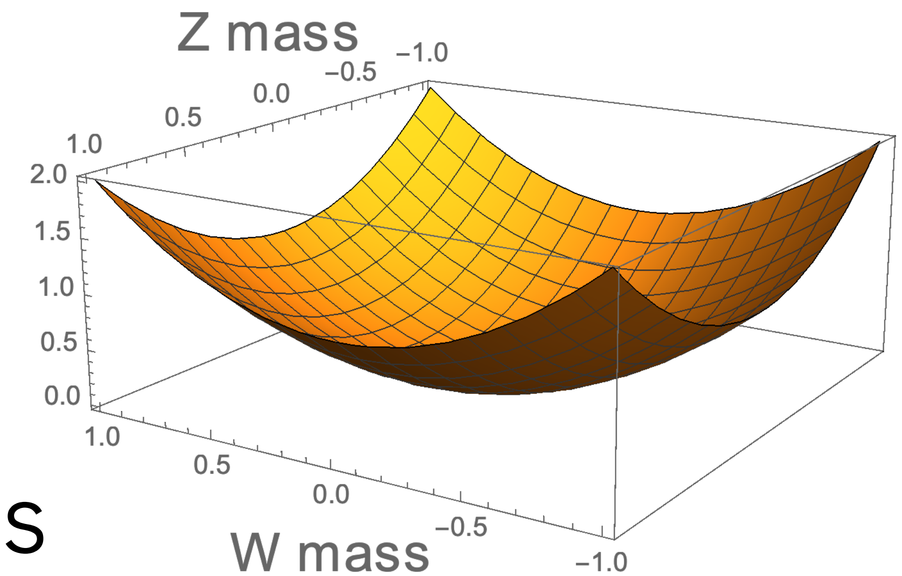
Fan et.al.

CDF ellipses not overlapping origin (star), suggests new physics at energy scale ~ 7 TeV (slightly beyond LHC)

WHAT COULD IT BE?

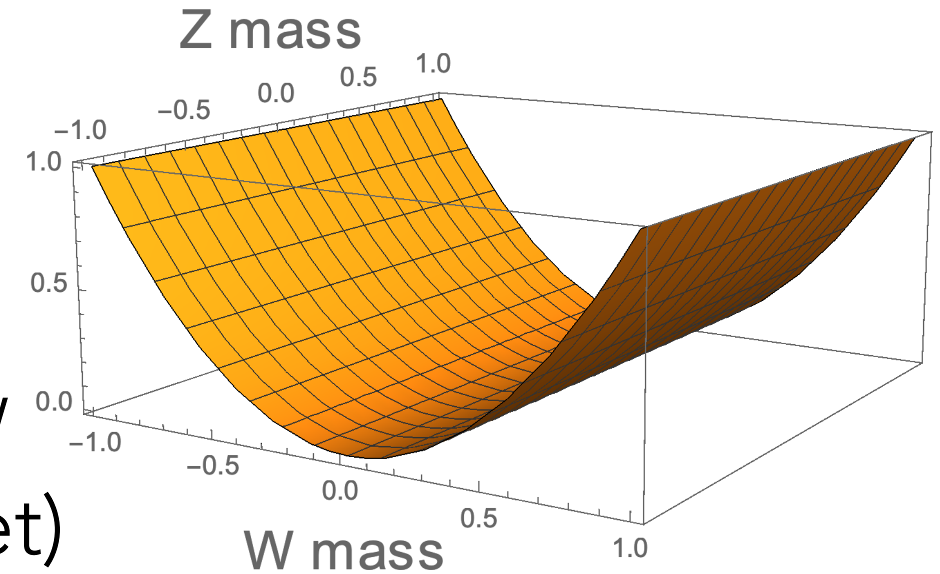
Lots of things... certainly exotic things like supersymmetry, where we should keep looking for new particles

Could be something much more simple, like a new source of electroweak symmetry breaking beyond the standard Higgs mechanism, which can alter Higgs couplings



Higgs

New (Triplet)



CONCLUSIONS

- Measuring things we know well precisely, e.g. W mass, can indirectly point to new physics
- Will it hold up experimentally? If so, it provides a hint of what new physics is responsible...
- We should know more soon as ATLAS/CMS update their W mass analyses and we get more data from the LHC

THANKS FOR YOUR TIME!