THE W MASS - WHY THE HUBBUB?
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(SOME MATERIALS PROVIDED BY POUYA ASADI)
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)?

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.

$W^+$ decays into positron and electron neutrino.

Quarks fuse into a $W^+$ which is moving.
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

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

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

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

We can calculate this transverse mass and its max is the W mass
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
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).
WHY IS THIS INTERESTING?

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)
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 $x$,

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

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.
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, $G_F = 1.166 \times 10^{-5}$/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 (NONRENNORMALIZABLE TERMS)

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

Fan et.al.
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.
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!