

SUPERSYMMETRY

PRO AND CON

SUPERSYMMETRY IS A
VISION OF WHAT MAY BE
STORE IN PARTICLE PHYSICS...

THERE ARE SERIOUS PROS AND
CONS, i.e. REASONS TO BE

OPTIMISTIC OR LESS OPTIMISTIC

ABOUT SUPERSYMMETRY, AND I WANT

TO SURVEY SOME OF THEM TODAY

ON THE PLUS SIDE ARE SOME FAMILIAR ARGUMENTS:

* THE HIERARCHY PROBLEM

SMALLNESS OF M_W / M_{GUT}

* NOT JUST A TECHNICAL SOLUTION

- A UNIQUE NEW SYMMETRY AND PART OF A LARGER VISION OF PHYSICS

* VALUE OF $\sin^2 \theta_W$ AND SUSY GUTS

* NATURAL MECHANISM OF ELECTROWEAK SYMMETRY BREAKING

* COMPATIBLE WITH ELECTROWEAK TESTS

3

TO UNDERSTAND SOME OF THESE
POINTS, WE SHOULD RECALL

THAT IN FACT GRAND UNIFICATION

HAS SOME STRIKING MERITS:

* MAKE SENSE OF QUARK
AND LEPTON QUANTUM
NUMBERS

$$\begin{pmatrix} u \\ d \end{pmatrix}_{\frac{1}{3}} \oplus \bar{u}_{-\frac{4}{3}} \oplus \bar{d}_{\frac{2}{3}} \oplus \begin{pmatrix} \nu \\ e^- \end{pmatrix}_{-1} \oplus e^+_{\frac{2}{3}}$$

A SINGLE GENERATION IS NEATLY INTERPRETED AS $\bar{5} \oplus 10$ OF $SU(5)$ OR 16 OF $SO(10)$

* THE UNIFICATION SCALE M_{GUT} INFERRED FROM LOW ENERGY DATA IS RELATIVELY CLOSE TO THE PLANCK SCALE ... AND HIGH ENOUGH TO AVOID DISASTER WITH THE PROTON LIFETIME

* THE NEUTRINO MASS SCALE
SUGGESTED IN THE LATE 1970'S
BASED ON GUT'S

$$m_\nu \sim \frac{M_W^2}{M_{\text{GUT}}} \sim 10^{-2} \text{ eV}$$

HAS PROVED TO BE
ABOUT RIGHT

- 20 YEARS LATER.

* FITS NEATLY WITH STRINGS,
QUANTUM GRAVITY

* CMB FLUCTUATIONS AND GUT SCALE?

6

THESE SUCCESSES OF GUT'S ARE
ALSO HINTS OF SUPERSYMMETRY
AS THE OTHER PREDICTION OF
GUT'S - THE VALUE OF THE
WEAK ANGLE $\sin^2 \theta_w \approx .23$ -
WORKS OUT BEAUTIFULLY WITH
SUPERSYMMETRY, AND NOT
WITHOUT IT.

7

MOREOVER, GUTS NEED

SUPERSYMMETRY FOR OTHER REASONS:

THE PROTON LIFETIME AS ORIGINALLY

ESTIMATED FROM GUT'S TURNED

OUT TO BE TOO SHORT, BUT

SUPERSYMMETRY NATURALLY RAISES IT

AND SUPERSYMMETRY MOVES THE

UNIFICATION SCALE EVEN CLOSER TO

THE PLANCK SCALE, SHARPENING THE

HUNT OF A UNIFICATION WITH GRAVITY.

AS THIS ILLUSTRATES,

SUPERSYMMETRY ISN'T JUST A

TECHNICAL SOLUTION TO PROBLEMS

LIKE THE HIERARCHY PROBLEM

IT IS

- * A UNIQUE NEW SYMMETRY PRINCIPLE

- * PART OF AN ATTRACTIVE, LARGER PICTURE IN GUT'S

- * AN ESSENTIAL PART OF AN EVEN MORE AMBITIOUS PICTURE IN STRING THEORY

MOREOVER, WHILE SOME ALTERNATIVE THEORIES OF THE SMALLNESS OF THE ELECTROWEAK SCALE - LIKE MODELS OF COMPOSITE HIGGS BOSONS - HAVE REPEATEDLY HAD TROUBLE, SUPERSYMMETRY IS COMFORTABLY CONSISTENT WITH THE PRECISION ELECTROWEAK TESTS.

FINALLY, I THINK I SHOULD
ADD THAT WITH SUPERSYMMETRY
THERE IS AN ELEGANT
AND NATURAL MECHANISM -
FOUND 20 YEARS AGO AND STILL
ATTRACTIVE TODAY -
FOR ELECTROWEAK SYMMETRY
BREAKING
... SAME MODELS AS 20 YEARS AGO

BUT FOR TODAY, WE ARE
NOT GOING TO DWELL ON THESE
HAPPY THOUGHTS... WE ARE
GOING TO LOOK AT THE
DRAWBACKS OF SUPERSYMMETRY.

ONE OBVIOUS DRAWBACK OF
SUPERSYMMETRY IS SIMPLY THAT
IT HAS NOT BEEN FOUND YET

THIS IS DISAPPOINTING, BUT FOR
THE MOST PART PERHAPS NOT
REALLY SURPRISING

IF CHARGED SUPERPARTNERS ARE
JUST A LITTLE ABOVE M_Z , WE
WOULDN'T HAVE SEEN THEM YET

BUT THERE IS PERHAPS ONE MISSING
PARTICLE THAT IS A LITTLE
EMBARRASSING - THE HIGGS BOSON....

WITH THE MINIMAL SUPERSYMMETRIC
SPECTRUM, ONE HAS AT
TREE LEVEL

$$M_{HIGGS} \lesssim M_Z \sim 91 \text{ GeV}$$

COMPARED TO THE EXPERIMENTAL
BOUND

$$M_{HIGGS} \gtrsim 114 \text{ GeV}$$

ACTUALLY THERE IS A LARGE
RADIATIVE CORRECTION DUE TO
THE HEAVY TOP QUARK, AND THE
THEORETICAL BOUND ON THE HIGGS
MASS IS USUALLY QUOTED AS

$$M_{\text{HIGGS}} \lesssim 130 \text{ GeV}$$

SO THERE ISN'T QUITE A
CONTRADICTION ... BUT RATHER
OPTIMISTIC ASSUMPTIONS GO INTO
GETTING THE RADIATIVE CORRECTION SO
LARGE ...

ONE NEEDS COUPLINGS NOT
FAVORED BY MANY OF THE
MODELS AND/OR SUPERPARTNER
MASSES SO LARGE AS TO MAKE
THE SMALLNESS OF M_Z LOOK
A LITTLE UNNATURAL....

THOUGH THERE IS NO
CONTRADICTION YET, IT WOULD
CERTAINLY CLARIFY THINGS A
LOT TO KNOW WHAT M_{HIGGS} IS...

AND IT WOULD BE REALLY NICE
IF IT TURNED OUT TO BE

$$M_{\text{HIGGS}} \approx 115 \text{ GeV}$$

THE VALUE HINTED AT BY LEP.

(17)

AT A DIFFERENT LEVEL, SUPERSYMMETRY
WOULD HAVE BEEN MORE CONVINCING
IF IT HAD ACHIEVED SOME
SIMPLIFICATION IN THE STANDARD
MODEL ... FOR EXAMPLE,
COULD THE HIGGS BOSON BE
A SUPERPARTNER OF THE ELECTRON?
UNFORTUNATELY, NO: MODELS
THAT TRIED THINGS LIKE THAT
DIDN'T WORK.

THAT IS WHY THE "MINIMAL SUPERSYMMETRIC STANDARD MODEL" ESSENTIALLY DOUBLES THE STANDARD MODEL SPECTRUM.

EVEN SO, WHILE EXPLAINING THE SMALLNESS OF M_2/M_{GUT} AND THE VALUE OF $\sin^2 \theta_W$, SUPERSYMMETRY REOPENS SOME PROBLEMS THAT SEEMED SETTLED IN THE STANDARD MODEL

FOR EXAMPLE, ONE TRIUMPH OF THE STANDARD MODEL IS TO NATURALLY CONSERVE BARYON AND LEPTON NUMBER, BECAUSE THERE ARE NO RENORMALIZABLE (PERTURBATIVE) INTERACTIONS OF STANDARD MODEL FIELDS THAT VIOLATE THESE SYMMETRIES.

THIS IS LOST WITH SUPERSYMMETRY, WHERE RENORMALIZABLE INTERACTIONS

CAUSING CATASTROPHIC PROTON
DECAY ARE POSSIBLE

THE MOST COMMONLY ADOPTED
SOLUTION OF THIS PROBLEM IS
TO ASSUME A Z_2 -SYMMETRY
CALLED R-PARITY; THIS
IS POSSIBLE BUT NOT OBVIOUSLY
COMPELLING.

(21)

SUPERSYMMETRY ALSO INTRODUCES

AT THE GUT SCALE A NEW

SCENARIO OF PROTON DECAY

VIA DIMENSION FIVE OPERATORS

... TROUBLESOME FOR MANY MODELS

GIVEN MODERN EXPERIMENTAL BOUNDS

ON THE PROTON LIFETIME.

BROADLY SPEAKING, THERE ARE
TWO CLASSES OF MODELS OF
SUPERYSMMETRY BREAKING:

* GRAVITY MEDIATION

SUPERSYMMETRY BROKEN AT A
VERY HIGH SCALE AND SUSY
BREAKING MEDIATED TO STANDARD
MODEL VIA SUPERGRAVITY INTERACTION!

* GAUGE MEDIATION

SUPERSYMMETRY BREAKING AT
 $\lesssim 100$ TeV; COMMUNICATED TO
STANDARD MODEL VIA GAUGE FORCES

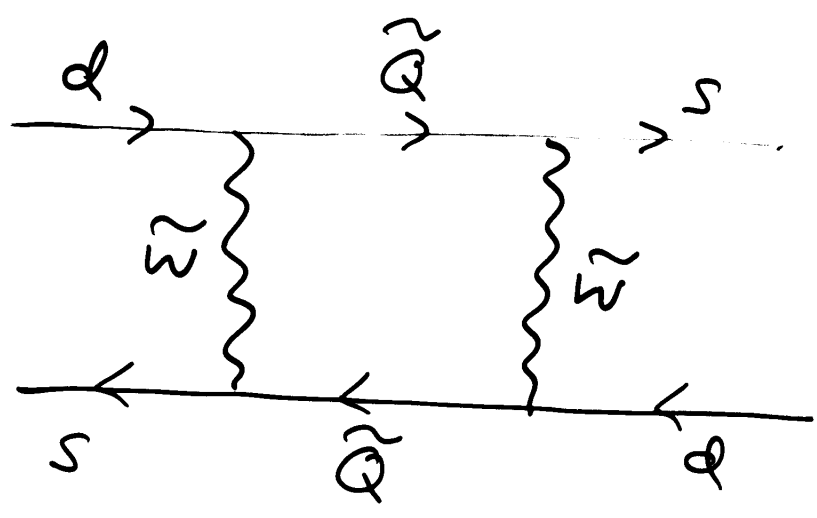
EACH TYPE OF MODEL HAS ITS VIRTUES, AND NONE HAS GIVEN A CLEAR PATH TO SOLVING ALL THE PROBLEMS.

FOR EXAMPLE, IF WE THINK ABOUT THE COSMOLOGICAL CONSTANT, WE MIGHT DECIDE WE FAVOR GRAVITY MEDIATION:

$$V = \left| \frac{DW}{D\phi_i} \right|^2 - G_N |W|^2$$

↑
Newton's constant.

IF INSTEAD WE THINK ABOUT
FLAVOR-CHANGING NEUTRAL
CURRENTS, WHERE SUSY
AGAW INTRODUCES NEW
TROUBLESOME POSSIBILITIES



WE MIGHT DECIDE WE FAVOR
GAUGE MEDIATION.

ALONG WITH BARYON, LEPTON,
AND FLAVOR SYMMETRIES, WE
SHOULD ALSO WORRY ABOUT CP,
AS WE WERE REMINDED EARLIER
THIS AFTERNOON.

HERE IN FACT THE STANDARD MODEL
ISN'T ENTIRELY SATISFACTORY
BECAUSE OF THE STRONG CP
PROBLEM — WHY IS THE NEUTRON
ELECTRIC DIPOLE MOMENT SO SMALL?

THE "AXION" IS AN ELEGANT SOLUTION
AND HERE ACTUALLY IS ONE OF THE
TRIUMPHS OF STRING THEORY:

IN FIELD THEORY, THE IDEA OF
THE AXION SEEMS TECHNICALLY
NATURAL BUT PERHAPS CONTRIVED,
WHILE STRING THEORY FORCES
AXIONS UPON US, ALONG WITH
QUANTUM GRAVITY, EXTRA DIMENSIONS,
AND ALL THE REST.

HOWEVER ...

(27)

TeV SCALE SUSY + AXION "a"

IMPLY EXISTENCE OF A SCALAR

PARTNER "s" OF a

a COUPLES TO TWO GLUONS, SO

s DOES ALSO

$$a \text{ Tr } F_{\mu\nu} \tilde{F}^{\mu\nu} + s \text{ Tr } F_{\mu\nu} F^{\mu\nu}$$

UNIFICATION \Rightarrow a AND s COUPLE

TO TWO PHOTONS OR TWO W, Z

BOSONS ALSO.

(28)

THE MEASURED GAUGE COUPLINGS
WILL DEPEND UPON THE VACUUM
EXPECTATION VALUE $\langle S \rangle$

AND THIS ADDS TO THE BURDEN
THAT MUST BE BORNE BY A
SUPERSYMMETRY BREAKING SCHEME:

GENERATE A POTENTIAL FOR S

WITH A SENSIBLE MINIMUM,

NO RUNAWAY,

"IN FOR A PENNY, IN FOR A POUND"

TO OUR LIST OF DRAWBACKS
OF SUSY, WE SHOULD ADD
THAT SUSY ALSO INTRODUCES
NEW AND POTENTIALLY TOO BIG
SOURCES OF POSSIBLE CP VIOLATION,
AS IT DOES WITH BARYON AND
LEPTON NUMBER AND FLAVOR
QUANTUM NUMBERS.

TO ME, THE CENTRAL DRAWBACK OF SUPERSYMMETRY IS THAT WE DON'T HAVE A CONVINCING, WORKABLE PICTURE OF WHAT THE TEV SUPERWORLD WOULD REALLY LOOK LIKE.

IF WE HAD SUCH A PICTURE, WE'D BE MORE CONFIDENT OF FINDING SUPERSYMMETRY, BUT WE'D HAVE LESS TO LEARN BY DOING SO.

MY PURPOSE IN DWELLING ON
THE DRAWBACKS OF SUPERSYMMETRY
IS NOT TO CONVINCCE YOU THAT
IT IS WRONG.

SUPERSYMMETRY ALSO HAS
BIG PLUSES, AS SKETCHED IN THE
FIRST PART OF THE TALK!

BUT THE DRAWBACKS ARE
ENOUGH THAT IT WOULD BE
QUITE DRAMATIC TO LEARN THAT
NATURE DID SOLVE ALL THOSE
PROBLEMS...

AND IF SO, EACH PROBLEM I'VE
DESCRIBED WOULD TURN INTO AN
OPPORTUNITY TO LEARN A
FUNDAMENTAL NEW LESSON
ABOUT NATURE
