

AFTER THE FIRST LHC PHASE

TWO MAIN MESSAGES

ARE THEY REALLY SHOCKING?

A HIGGS LIKE PARTICLE DISCOVERED (A PARTICLE THAT LOOKS VERY MUCH LIKE THE ELEMENTARY HIGGS BOSON OF THE SM)

FUNDAMENTAL DISCOVERY BUT...SOME OF US KNEW IT ALREADY 20 YEARS AGO

NO SIGNAL OF NEW PHYSICS

BUT... PRECISION LEP DATA, PRECISION FLAVOUR DATA,
WERE POINTING IN THAT DIRECTION

ONCE WE KNOW IT FOR SURE,

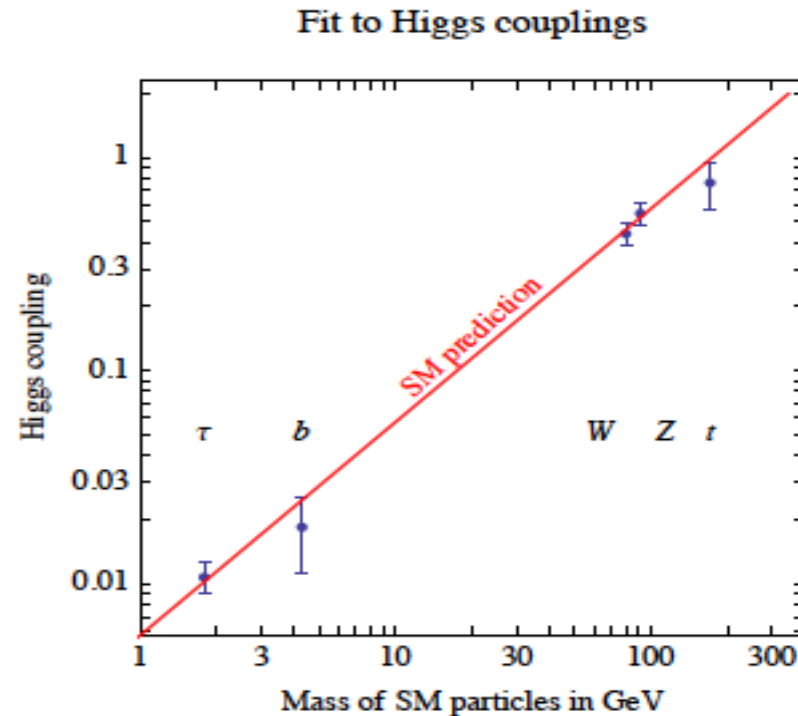
WHAT DOES IT MEAN FOR PARTICLE PHYSICS?

IMPACT OF THE HIGGS DISCOVERY

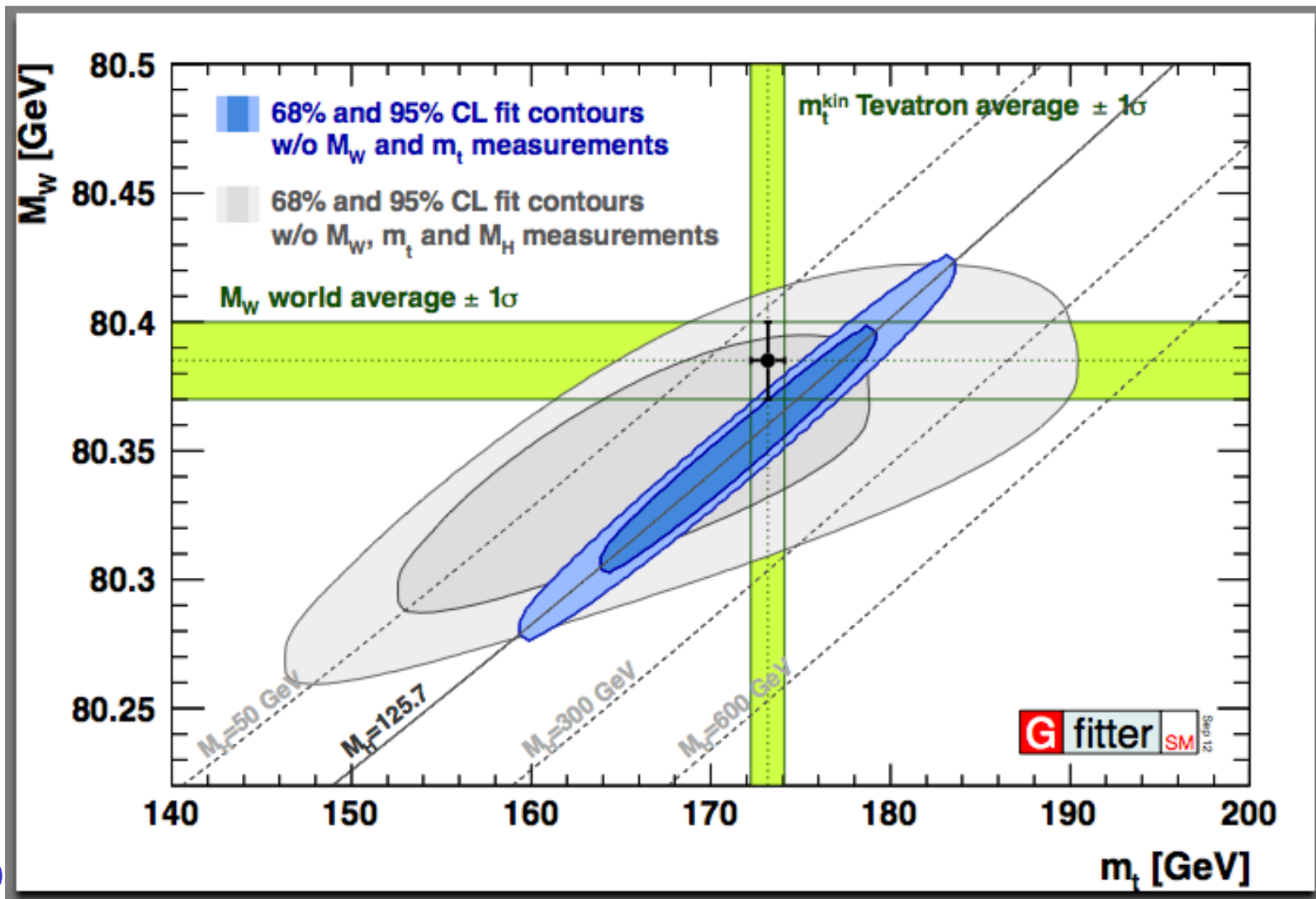
Mh=125 GeV

ITS COUPLINGS ARE WITHIN ~20% CONSISTENT WITH THE SM COUPLINGS

GIARDINO ET AL.'13



CONSISTENCY WITH THE EW PRECISION DATA (FITS IN THE SM); NO CONSPIRACY BETWEEN A HEAVY HIGGS AND NEW PHYSICS EFFECTS



THE BEAUTY OF THE SM IS BEST ILLUSTRATED BY ITS PREDICTION FOR

ρ PARAMETER (RELATIVE STRENGTH OF THE NEUTRAL TO CHARGE CURRENT INTERACTION)

$$\Delta\rho \equiv \rho - 1 \sim c_1 g^2 \frac{m_t^2}{M_W^2} - c_2 g'^2 \ln \frac{m_h^2}{M_W^2}$$

- 1) THE SM IS RENORMALISABLE- NO DEPENDENCE ON THE POTENTIALLY EXISTING HIGHER MASS SCALES (LIKE QED VS SM); WELL DEFINED HIGGS COUPLINGS ARE CRUCIAL FOR THIS
- 2) ρ IS FINITE (NO RENORMALISATION SCALE DEPENDENCE) AND PERTURBATIVELY CALCULABLE;
- 3) PERFECT NUMERICAL AGREEMENT FOR THE MEASURED MASSES

→ THE SM, WITH ITS SIMPLEST VERSION
OF THE HIGGS MECHANISM, IS AT LEAST
A GOOD EFFECTIVE THEORY

MOREOVER, REMARKABLY

HIGGS SELF-COUPLING

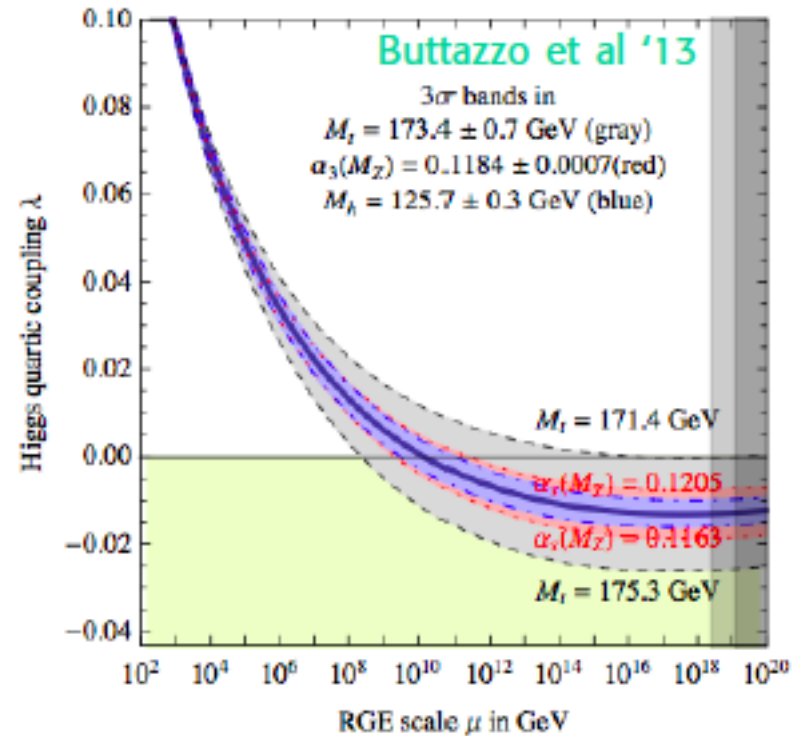
$$\lambda |H|^4 \quad v = 246 \text{ GeV} \quad \rightarrow \lambda = 0.12$$

WELL WITHIN PERTURBATIVE REGIME!

VACUUM STABILITY IN SM

$$V = \frac{\lambda(\mu)}{4} h^4$$

$$\lambda_0 = \frac{m_h^2}{4v^2}$$



IN THE ABSENCE OF NEW PHYSICS, FOR $m_h = 125 \text{ GeV}$ THE UNIVERSE BECOMES

METASTABLE AT $\Lambda \approx 10^{10} - 12 \text{ GeV}$

BUT WITH SUFFICIENTLY LONG LIFE TIME! SM COULD BE A CONSISTENT THEORY UP TO THE PLANCK SCALE

BUT,

DONT RUSH TO TOO QUICK CONCLUSIONS ABOUT THE VALIDITY OF THE SM TO VERY HIGH ENERGIES BECAUSE,

HIGGS COUPLINGS VERSUS NEW SCALES:

$$M = 1TeV$$



less than (3- 5) % deviations
from the SM couplings

VERY CHALLENGING: DEVIATIONS MAY BE OF THE ORDER OF THE PRESENT UNCERTAINTIES IN THE SM PREDICTIONS

(ALMEIDA, LEE, SP, WELLS 1311.6721)

NO MATTER HOW CHALLENGING IT MAY BE
TO SEE BSM PHYSICS THAT WAY,

**PRECISION HIGGS (AND TOP) PHYSICS
LOOKS NOW LIKE A MUST!**

(CLIC, ILC, TLEP?)

**GIVEN THAT APPARENT FINAL SUCCESS OF THE SM
AND THE ABSENCE OF ANY EVIDENCE FOR NEW
PARTICLES (SO FAR)—**

HAS THE CASE FOR BSM PHYSICS CHANGED?

**THE MOTIVATION REMAINS INTACT:
IT IS THE QUESTION ABOUT THE ORIGIN OF THE FERMION CONSTANT**

**CAN THE W MASS BE SENSIBLY CALCULATED IN A DEEPER THEORY?
CAN WE „DERIVE” EWSB?**

**SENSIBLY=WITHOUT EXCESSIVE FINE TUNING OF THE PARAMETERS
(HIERARCHY PROBLEM)**

EMPIRICAL EVIDENCE FOR BSM:

NEUTRINO MASSES AND MIXING

DARK MATTER

**THEY CAN IN PRINCIPLE BE EXPLAINED BY „SMALL ADDITIONS”
TO THE SM.**

**FOR DARK MATTER, A „SMALL ADDITION” MAY MEAN A WHOLE NEW
HIDDEN WORLD...**

BUT THEY MAY, AS WELL, BE LINKED TO A BROADER DEEPER THEORY

ONE CANNOT OVERESTIMATE THE SIGNIFICANCE OF
DISCOVERING DARK MATTER PARTICLE(S), NOT ONLY FOR ITS
OWN SAKE BUT ALSO FOR CONSTRUCTING A DEEPER THEORY OF
THE FERMI SCALE

WE MAY GET AN EMPIRICAL HINT FOR SUCH A THEORY OR JUST
FOR A „SMALL ADDITION” TO THE SM.

SO, CAN WE „SENSIBLY” CALCULATE THE FERMI
CONSTANT OR IT IS A FREE PARAMETER OF THE THEORY
AND WE MUST TAKE IT FROM EXPERIMENT ?

NATURALNESS (HIERARCHY PROBLEM) – a vague concept

IT IS NOT THE PROBLEM OF QUADRATIC DIVERGENCES IN THE SM:
SM IS A RENORMALISABLE THEORY.

Thus if one ignores the hierarchy problem it is completely
finite and predictive
If you do not care about fine tuning you are not punished!!

(GUIDO ALTARELLI)

ONLY WHEN YOU CARE TO PREDICT M_W , YOU FACE THE QUESTION!

ANY SHORT DISTANCE PHYSICS THAT COUPLES TO THE HIGGS
(RH NEUTRINO, GUT PARTICLES..) WOULD INTRODUCE
QUADRATIC SENSITIVITY OF M_W TO THOSE SCALES

UNLESS... WE DO SOMETHING ABOUT THAT

WITH THE ABOVE GUIDELINE, THERE ARE TWO MAIN DIRECTIONS:

SUPERSYMMETRY

COMPOSITE HIGGS MODELS

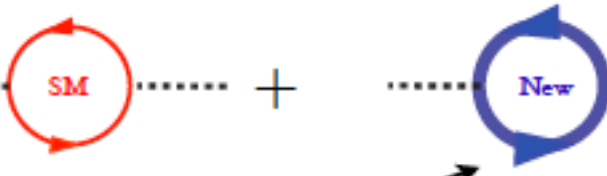
**(HIGGS DOUBLET AS A NAMBU- GOLDSTONE
BOSON OF A NEW STRONG SECTOR)**

BOTH

- **LINK THE FERMI SCALE TO THE LARGE TOP QUARK YUKAWA COUPLING AND NEW MASS SCALE (SO THE QUESTION ABOUT NATURALNESS IS LEGITIMATE)**
- **CAN ACCOMMODATE 125 GeV MASS**

Supersymmetry

$$\delta m_H^2 = \text{---} \textcircled{\text{SM}} \text{---} + \text{---} \textcircled{\text{New}} \text{---} \sim \tilde{m} \ln \Lambda$$



 s-particles

UNIQUE FEATURE:
 ALSO CANCELLATION OF QUADRATIC SENSITIVITY TO MUCH HIGHER SCALES

$$\text{---} \textcircled{M} \text{---} + \text{---} \textcircled{M + \tilde{m}} \text{---} \sim \tilde{m} \ln \Lambda$$

EFFECTIVE COMPOSITE MODELS CAN ACCOMMODATE 125
GeV HIGGS BOSON

BUT,

A LOT OF ARBITRARINESS , NO EASY UV COMPLETION,

ELECTROWEAK SECTOR LINKED TO NON-PERTURBATIVE
PHYSICS

ALL THAT CAN BE CONFRONTED WITH THE WELL KNOWN
VIRTUES OF SUPERSYMMETRY

AN EXAMPLE OF THE DIFFERENCE BETWEEN THE TWO APPROACHES:

Generic features of the scalar sector in extensions of the SM with elementary (2HDM, supersymmetry) or composite scalars

- more than one scalar
- none of the scalars couple to WW and to fermions exactly like the SM Higgs boson (because of the mixing between them)
- ONLY $O(1\%)$ EFFECTS FOR 1 TeV NEW MASS SCALE

HOWEVER, THERE IS A QUESTION OF PRINCIPLE THAT DISTINGUISHES THE TWO APPROACHES

SUPPOSE THE „HIGGS” COUPLINGS TO THE GAUGE BOSONS ARE MODIFIED

$$g \rightarrow g\left(1 - \frac{v^2}{\Lambda^2}\right)$$

Interpretation of the scale Λ depends on BSM:

IT IS THE MASS OF THE HEAVY HIGGS IN SUSY AND THE SCALE OF THE ON-SET OF NON-PERTURBATIVE PHYSICS IN COMPOSITE MODELS

Effects on precision tests

$$\Delta\rho \sim g'^2 \left(\ln \frac{m_h^2}{M_W^2} + \frac{v^2}{\Lambda^2} \ln \frac{\Lambda^2}{m_h^2} \right) + \dots$$

EXTENDED SCALAR SECTORS , LIKE SUSY-
predictivity and perturbativity remains, ρ still finite,
approaching SM value in the decoupling limit (1 Tev for
the superpartner mass is enough)

COMPOSITE HIGGS IN STRONGLY INTERACTING MODELS –
NONRENOMALISABLE ELECTROWEAK SECTOR, DOES NOT DECOUPLE
FROM NEW STRONG DYNAMICS; ρ
CANNOT BE CALCULATED PERTURBATIVELY

LACK OF SIMPLICITY AND OF PERTURBATIVITY PUTS COMPOSITE MODELS ON
DEFENSIVE

THE PROBLEM IS THAT BOTH LOOK A BIT FINE TUNED NOW
STILL, WE HAVE PLENTY OF MODELS THAT REDUCE FINE TUNING FROM 10^{14}
TO 10^2 OR 10^3 . IS IT MUCH WORSE THAN 10?

THE LESSON FROM THE LHC: BE MORE OPEN MINDED ON FINE-TUNING; THE STANDARD MEASURES OF FT MAY BE MISLEADING: THE EXPECTATION TO HAVE A NEW MASS SCALE **BELOW** 1TeV WAS NOT BASED ON ANY STRONG ARGUMENT;

WHERE IS M_{susy} ? IT CAN STILL BE **AROUND** 1 TeV

FLAVOUR PHYSICS- SENSITIVE TO HIGH SCALES

	PRESENT EXP BOUND	SM
$\mu \rightarrow e\gamma$	10^{-13}	10^{-54}
$EDMS_{\text{NEUTRON}}$	10^{-26}	10^{-32}
ELECTRON	?	
$K_L \rightarrow \pi^0 \nu \bar{\nu}$	10^{-8}	10^{-11}
$K^+ \rightarrow \pi^+ \nu \bar{\nu}$	3x SM	
$B_d \rightarrow \mu^+ \mu^-$	5xSM	
$B_S \rightarrow K^* \nu \bar{\nu}$	2xSM	
$t \rightarrow c\gamma$		

**LET'S BE AMBITIOUS AND
TRY TO EXPLAIN IN A BSM THE FERMION
MASS SPECTRUM**

**New sources of FCNC and CP violation,
controlled by the proposed theory of fermion
masses**

SUMMARY

THE HIGGS DISCOVERY MAKES THE SM LOOKING AS A CONSISTENT THEORY UP TO VERY HIGH ENERGIES:

„SMALL” ADDITIONS CAN EXPLAIN NEUTRINO MASSES;
DARK MATTER SECTOR MAY NOT DESTROY ITS VALIDITY ALL THE WAY UP (HIDDEN SECTOR?)

BUT IS THE FERMI CONSTANT (THE VEV OF THE VACUUM) REALLY ANOTHER, UNEXPLAINABLE , FUNDAMENTAL PARAMETER OF NATURE - ANTHROPIC PRINCIPLE?

FLAVOUR PUZZLE- MASSES, MIXING? EVERYTHING ANTHROPIC?!

HARD TO BELIEVE... AFTER THE HIGGS DISCOVERY THERE IS CERTAINLY STILL A LOT OF ROOM FOR NEW PHYSICS „NEARBY” THAT COULD EXPLAIN ALL THAT

SUMMARY

NO REASON YET TO

GIVE UP THE QUESTION ABOUT THE ORIGIN OF THE FERMI SCALE AS A GUIDING PRINCIPLE FOR THE BSM PHYSICS AND TO RUSH TO THE LANDSCAPE PICTURE

THE EXPERIMENTAL EXPLORATION OF THE TeV SCALE IS STILL IN A VERY PRELIMINARY

NEW GENERATION OF PRECISION DATA, FLAVOR AND DARK MATTER SECTORS MAY ALSO GIVE CRUCIAL HINTS, PARTICULARLY IF THE NEW SCALE IS A BIT HIGH FOR ITS DIRECT DETECTION

END