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 YEARES AGO

NO SIGNAL OF NEW PHYSICS

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

ONCE WE KNOW IT FOR SURE,

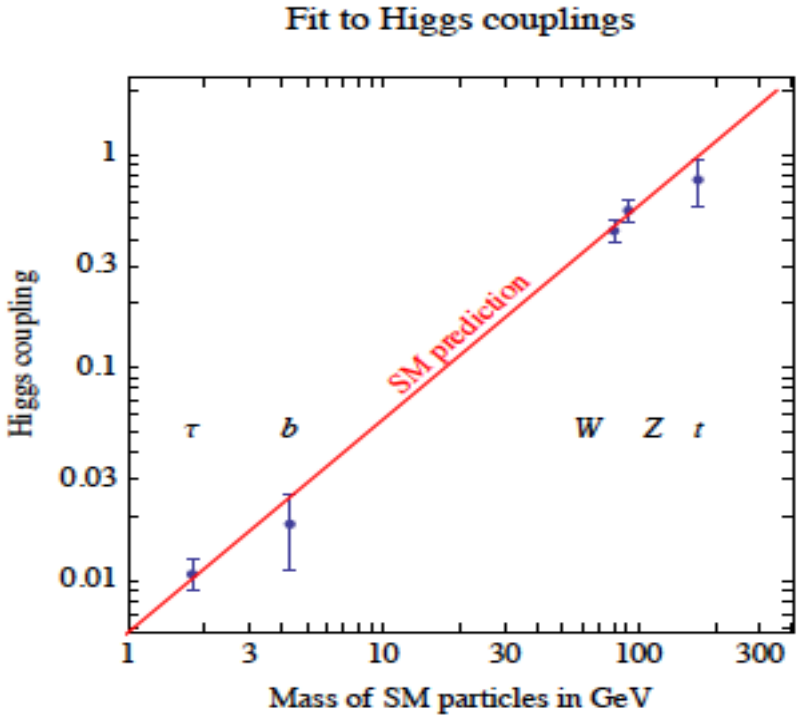
WHAT DOES IT MEAN FOR PARTICLE PHYSICS?

IMPACT OF THE HIGGS DISCOVERY

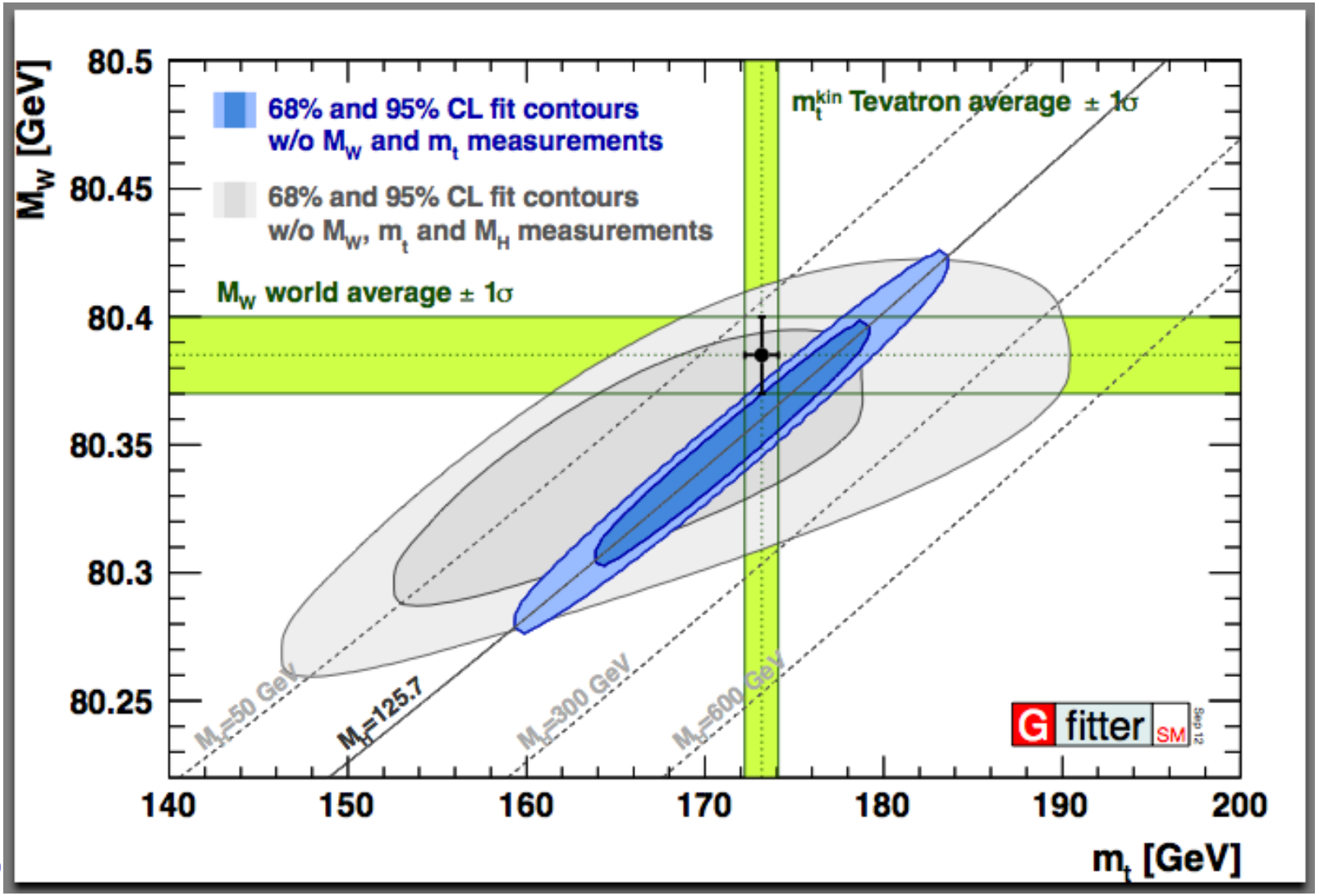
Mh=125 GeV

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


68% and 95% CL fit contours
w/o M_W and m_t measurements
68% and 95% CL fit contours
w/o M_W, m_t and M_H measurements
M_W world average ± 1σ
m_t^{kin} Tevatron average ± 1σ
M_H=50 GeV
M_H=125.7
M_H=300 GeV
M_H=600 GeV
G fitter SM
Sep 12
M_W [GeV]
m_t [GeV]
80.5
80.45
80.4
80.35
80.3
80.25
140
150
160
170
180
190
200

UNDERSTANDING THE FIT: CRUCIAL ROLE IS PLAYED BY THE

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

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

TWO POINTS:

1) ρ IS FINITE (NO RENORMALISATION SCALE DEPENDENCE) AND PERTURBATIVELY CALCULABLE;

THE SM IS RENORMALISABLE- NO DEPENDENCE ON THE POTENTIALLY EXISTING HIGHER MASS SCALES; WELL DEFINED HIGGS COUPLINGS ARE CRUCIAL FOR THIS

2) PERFECT NUMERICAL AGREEMENT FOR THE MEASURED MASSES

LIGHT SM LIKE HIGGS AND NO NEW PARTICLES=CONSISTENT PICTURE

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

➔

MOREOVER, REMARKABLY

HIGGS SELF-COUPLING

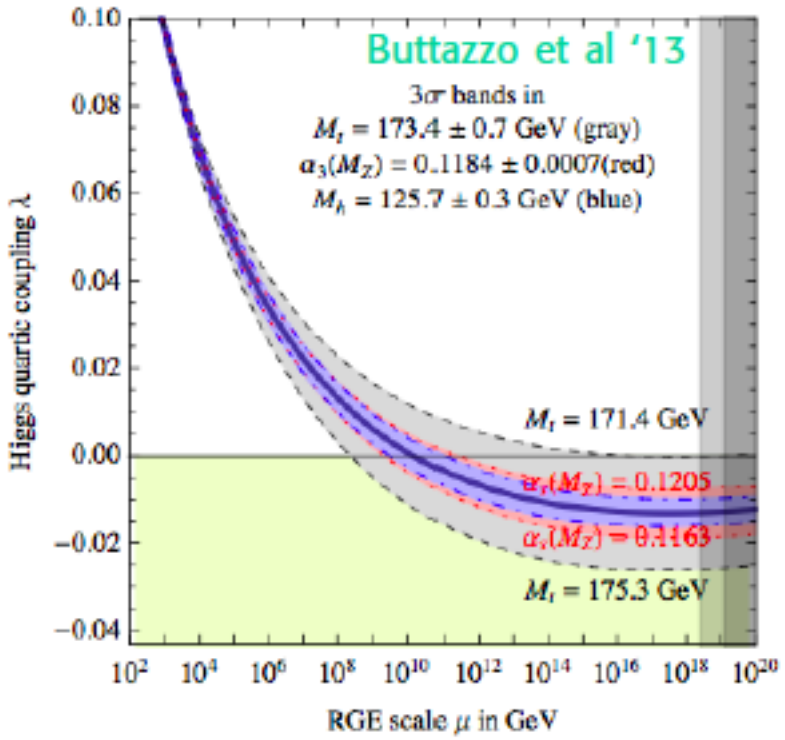
$$\lambda|H|^4 \qquad v = 246GeV \qquad \rightarrow \lambda = 0.12$$

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 $m_h = 125 GeV$ THE UNIVERSE BECOMES

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

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 CHALLANGING: DEVIATIONS MAY BE OF THE ORDER OF THE PRESENT UNCERTAINITIES IN THE SM PREDICTIONS

(ALMEIDA, LEE, SP, WELLS 1311.6721)

NO MATTER HOW CHALLANGING 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 FERMI CONSTANT

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

**HAVE WE LOST OUR GUIDING PRINCIPLE BASED ON
THE (UN)NATURALNESS OF THE SM HIGGS POTENTIAL ?**

EMPIRICAL EVIDENCE FOR BSM:

NEUTRINO MASSES AND MIXING

DARK MATTER

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

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

FOR DARK MATTER, A „SMALL ADDITION" MAY MEAN A WHOLE NEW HIDDEN WORLD…

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

ONCE WE DISCOVER THE DARK MATTER PARTICLE OUR PERSPECTIVE MAY CHANGE..
E.G. IF WE LEARN IT IS A WIMP

NATURALNESS – a vague concept

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**

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

Generic features of the scalar sector in (perturbative or non-perturbative) 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)

BUT 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

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

Interpretation of the scale Λ depends on BSM

Effects on precision tests

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

The cutoff scale may have different interpretations (e.g. the mass of the next scalar)

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 FERMI SCALE „PREDICTED" AND NATURALNESS?- YES, BUT PERHAPS ONE SHOULD BE MORE OPEN MINDED.

THIS SEEMS TO BE THE LESSON FROM THE LHC. CERTAINLY A CHANGE OF PERSPECTIVE BUT THE PREVIOUS ONE WAS NOT BASED ON ANY STRONG ARGUMENTS.

FLAVOUR PHYSICS- SENSITIVE TO HIGH SCALES

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

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 DISTROY 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:

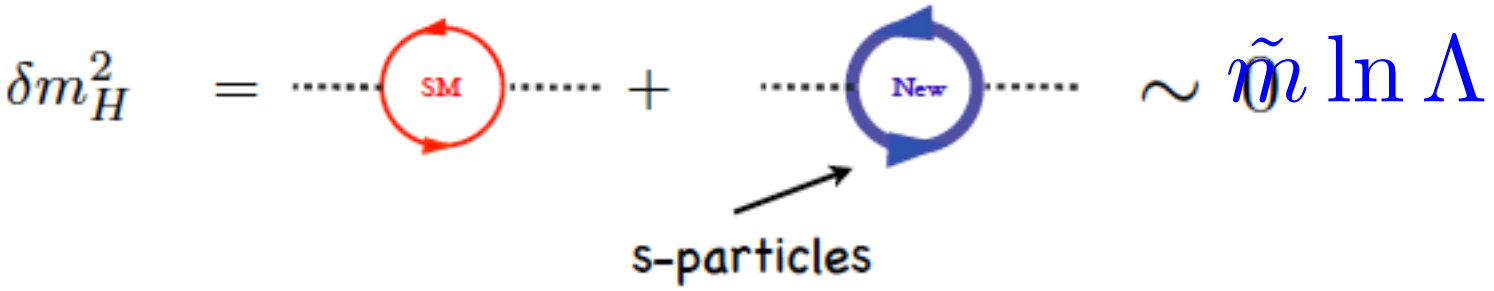
- GIVE UP THE QUESTION ABOUT THE ORIGIN OF THE FERMI SCALE AS A GUIDING PRINCIPLE FOR THE BSM PHYSICS
- TO RUSH TO THE LANDSCAPE PICTURE FOR THE FERMI SCALE

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

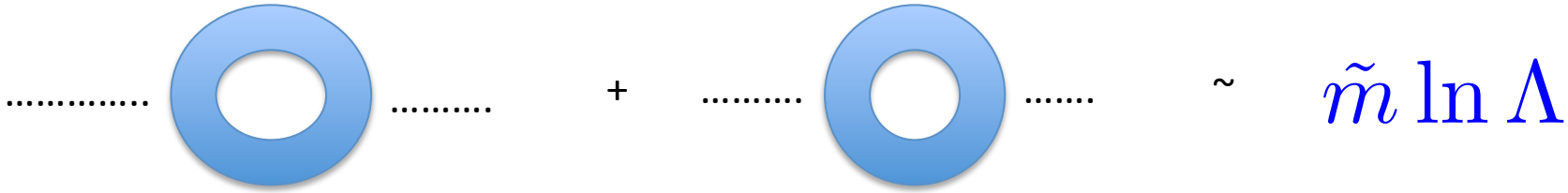
END

Supersymmetry



UNIQUE FEATURE:

ALSO CANCELLATION OF QUADRATIC SENSITIVITY TO MUCH HIGHER SCALES



The Higgs boson as a pseudoGolsdtone

(like the π in QCD)