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★ The gauge principle fixes the dynamics of QED, Weak and Strong interactions....gauge bosons discovered. (Energy/Precision/Theorists)

★ Hidden symmetry (aka spontaneous symmetry breaking) plays a role in some gauge dynamics.... boson associated with this discovered at CERN. (Energy/Theory)

★ Measured couplings of fermions to gauge bosons ....surprising differences in quark and lepton sectors. (Precision)

★ Cosmology has become a respectable science...many novel data and new puzzles. We can no longer make jokes about 100% error in exponents. (Cosmic)

- ⋆ The success of the gauge principle has led to many bold and sacrilgious speculations such as quark $\to$ lepton transitions, baryon- and lepton- number violation via gauge interactions.
- ⋆ Extrapolation of known physics by many orders of magnitude in energy. SUSY serves to make this extrapolation sensible.
- ⋆ Postulating large numbers of new states

Really, these ideas have been very beautiful and seductive. However, they come with their own theoretical issues.....such as fine-tuning, questions we never asked before.

The precise measurement of the Higgs boson mass (as well as the top quark mass) may be a window to high scale physics.

Of course, these windows are not a substitute for direct searches.

Despite years of many beautiful measurements, we have essentially no understanding of flavour or CP .....what different flavours are, and why the complex coupling matrix is what it is.

We know that the CP violation in the Standard Model is insufficient for the observed baryon asymmetry. We expect there is a source of CPV in other than the quark sector.

We should also keep in mind that the KM matrix <u>does not</u> encode all of flavour physics and CPV once we extend the SM.

Fortunately, many beautiful exeriments will probe flavour and CP violation and perhaps help break us free from the KM tyranny.

Dark Matter seems to be clearly present and (this is beyond my pay grade) not likely to be all primordial black holes.

Zwicky $\rightarrow$ Rubin and her friends $\rightarrow$ today

To me, the positron anomaly is the most tantalizing of the various pieces of evidence for something amiss. But we need to be able to distinguish DM from standard physics astrophysical processes occuring in unusual environments!

Data from AMS on $\bar{p}$ and $\overline{D}$ – also from the GAPS balloon experiment.

Planck satellite measurements

Perhaps even collider determination of DM density based on terrestrial measurements in the very far future if we are lucky.

Unprecedented connection between particle physics and cosmology

Field is healthy and vibrant for the next decade

However, a decade is not as long as it used to be.

On the Intensity frontier we have the LBNE program with the Liquid Argon TPC (surface/underground?). LAr may well be the technology of the long term future.

Flavour and CPV measurements

On the cosmic frontier, we have DE and DM experiments as well as measurments on the CMB. CMB studies can give far-reaching results, $e.g$ these can probe light DM particles that couple to photons and charged particles in the early Universe.

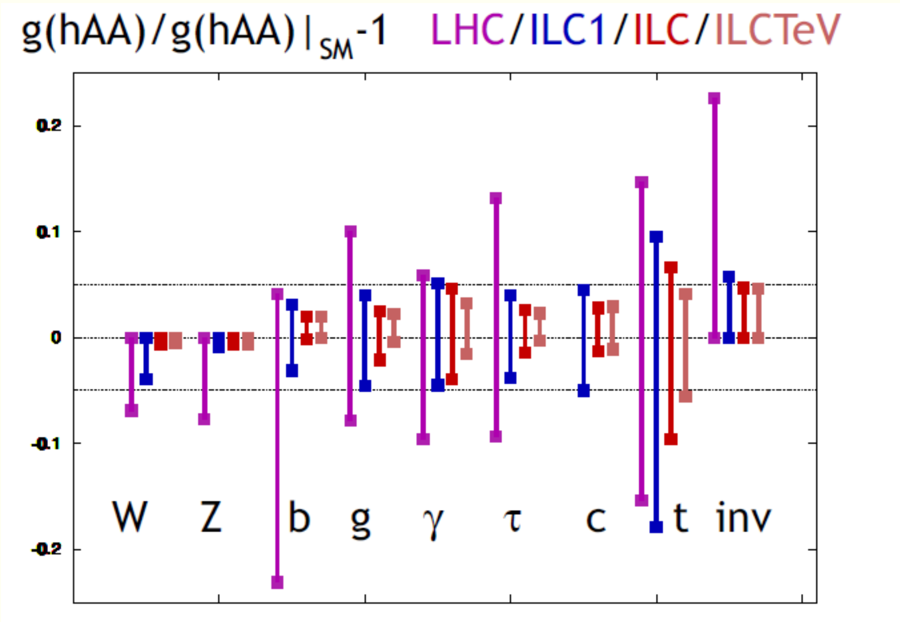
We have heard many negative things because of lack of new physics signals at LHC8. Personally, I think there was always much hype about "around the corner new physics" that has not panned out. Such build-up of expectations are not good for our field. However, data from LHC14 (or LHC 12 or LHC13) are going to be available in a finite time. <u>There is no substitute for energy, so please stay tuned.</u>

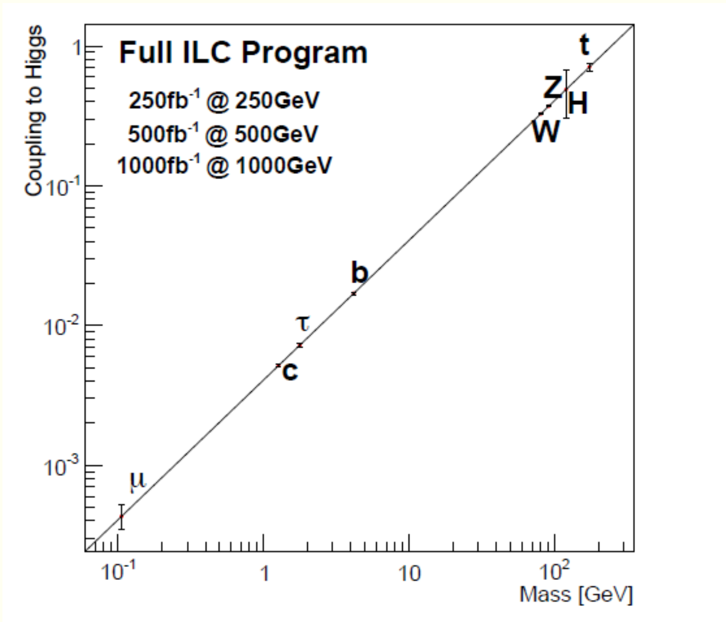
My feelings about a *LC have been dramatically altered by the Higgs discovery (evidence of the HZZ coupling is the key) as this gives us an energy target(s) that, in my view, was lacking.

Another bread-and-butter piece of physics for such a machine will be a study of the top quark threshold with unprecedented precision so it is necessary to run the machine there.

We also need to probe the couplings of the newly discovered Higgs particle — the $t\bar{t}H$ and, in a utopic world, also the triple Higgs coupling.

Peskin Plots





Notice the appearance of H in the frame on the right.

See http://lcsim.org/papers/DBDPhysics.pdf for details.

Recall early studies where we used to study upper bounds on m_h from the requirement that the couplings remain perturbative up to some very high scale. (e.g. Cabibbo, Maiani, Parisi and Petronzio). Up to gauge terms,

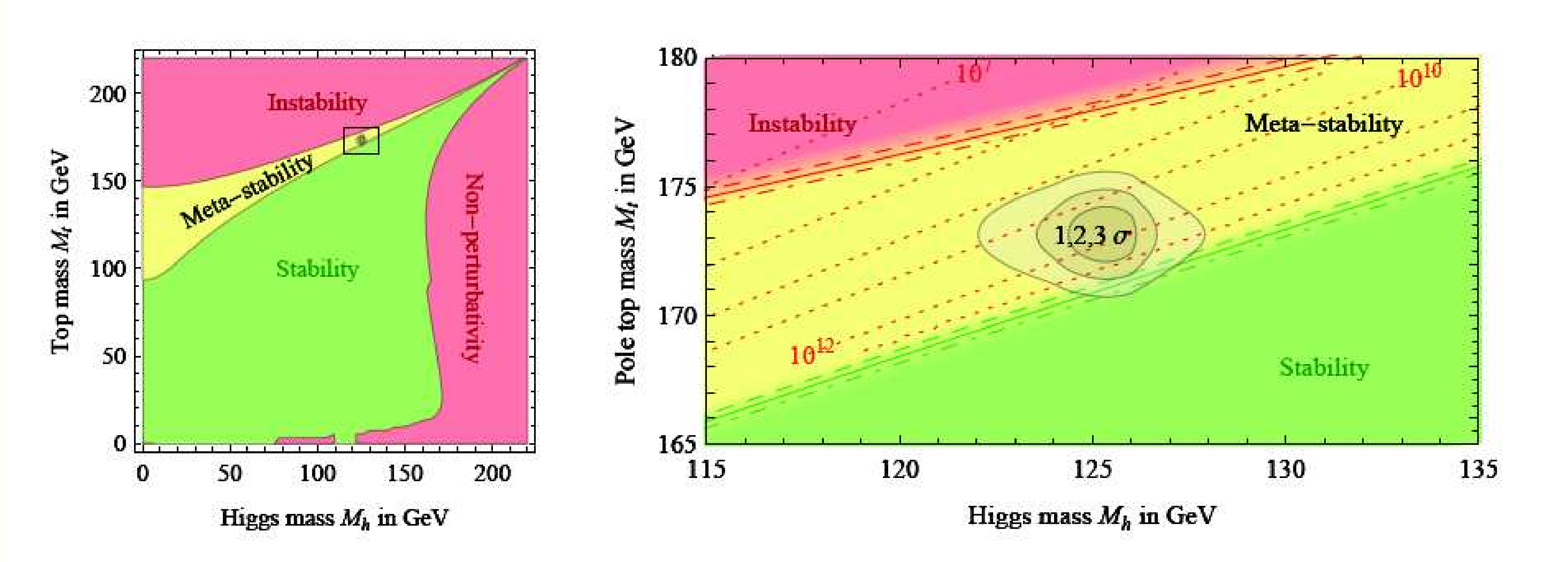
$$\frac{d\lambda}{dt} \propto 4\lambda^2 + 12\lambda h_t^2 - 36h_t^4.$$

Today, we know h_t.

- ⋆ If the Higgs boson is too heavy (too large a λ), the RHS is strongly positive and λ blows up before M_P or $M_{\rm GUT}$, or whatever we choose. In the Standard Model, this bound was $m_h \lesssim 175$ GeV
- ⋆ If Higgs boson is too light, the RHS is strongly negative, and λ becomes negative before our chosen scale. This is bad, because what we thought of our vacuum would become unstable!

Now that we know $m_h \sim 125$ GeV, our focus is on λ not being too small! Are we going to go poof because our vaccuum is unstable?

The fate of our vaccuum arXiv: 1205.6497

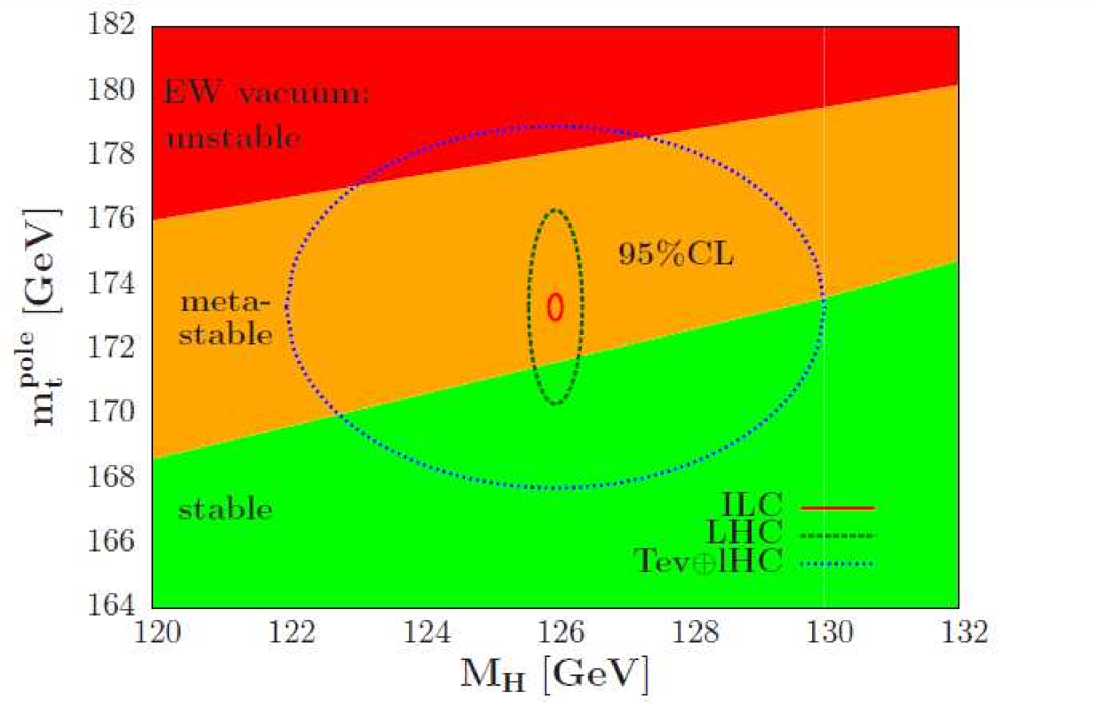


What I have told you would require us to live in the green region.

We apparently do not live there as the blow-up shows.

Luckily, the estimated lifetime of our vacuum because of quantum (not thermal) fluctuations exceeds 14 GY. However, consequences of the shift of this plot, especially in the vertical direction, are drastic.

Given the import of these considerations, Alekhin, Djouadi, Moch, arXiv:1207.0980 have critiqued whether the kinematically extracted mass of the top is indeed the needed pole mass. They argue that there is better theoretical control on the $\overline{\rm MS}$ mass extracted from the cross section, but this has large errors.



Measurements at the *LC will measure the $\overline{\rm MS}$ mass precisely and so tell us whether the measured value of m_h requires new physics to intervene before the Planck scale.

- ⋆ On the time scale of 10-15 years, we have a vibrant program with a strong connection between theory and experiment (both components are essential) from which we will truly get important information. Analysis of LHC14 data, or data from the sky may be game-changing, as could data that conclusively break us out of the KM picture! Cannot, of course, promise new discoveries but we should look and analysis should focus on discovery and not "better bounds".

- ⋆ Cosmology and particle physics are being inter-connected at a level never before conceived. However, we need to learn to speak a common language and understand one another better.

- ⋆ The Higgs particle we have discovered can be exquisitely studied at the *LC. We may learn if it is SM-like beyond reasonable doubt, or whether it has fatter cousins.....beyond what can be learnt at LHC14.

- ⋆ The Higgs boson appears to lie at an interesting mass and the *LC may give us yet more evidence to believe there is physics beyond the Standard Model.

★ I did not talk about this here, but I think obituaries of SUSY are premature. Natural models necessarily require light higgsinos that will reveal themselves at an electron-positron collider, if concomitant small mass gaps can be probed over backgrounds from two photon physics.

★ Although the desire and dreams for a broad band search machine such as a LaSGNA to explore the unknown remain, the case for the *LC is very strong. We now know a qualitatively new particle exists. A study of this may yield surprises. Of course, this facility can also explore many other things.

★ The theory community has played, and will continue to play, a vital role in the HEP enterprise.