

Summary (and Outlook) : Colliders, PASCOS 2016

Whether/Wither Colliders?

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**PASCOS 2016: 22nd International Symposium on Particles,
Strings and Cosmology**

10-16 July 2016

XlIth Rencontres du Vietnam ICISE, Quy Nhon, Vietnam

Registration and program information: <https://indico.cern.ch/e/PASCOS2016>

The image is a promotional banner for the PASCOS 2016 symposium. It features a scenic landscape of Quy Nhon, Vietnam, with green mountains, a blue lake, and a sandy beach. A modern building is visible on the left. An inset map in the top right corner shows the location of Quy Nhon on the coast of Vietnam.

- 1) Few personal remarks on the current situation in HEP and colliders as well as outlook.

- 2) Substantiate it with what was said at the conference here!

Statement number 1:

”In the present state of physical science, therefore, a question of extreme interest arises: **Is there any principle on which an absolute thermometric scale can be founded?**”

Statement number 2:

”There is nothing new to be discovered in physics now, **All that remains is more and more precise measurement.**”

The rest is History as the saying goes!

1. Existence of a EW scale **stable under radiative corrections** revealed. **Is there a guiding principle on which the stability can be founded?** We 'thought' we knew!..may be our thinking is right but...may be not!
2. All that remains is **more and more precise measurement** of the **Higgs and top properties!** *OR Higher and higher energies?*

The rest (we hope) is future of HEP and the story of hunt for fundamental principles of nature!

To steal from 'Tale of two cities'

It is the **BEST** of the times ; it is the **WORST** of the times!

WHY?

Found the 'light' Higgs but **as yet NO** 'fundamental' understanding why is it so! No evidence for the physics that we **think must** exist to keep it so!

It is not as though we are only agonising over non discovery of one of our beautiful theories which we think must be realised in nature because of their aesthetic beauty!

We have MANY pragmatic reasons to expect physics beyond the SM : **either interactions or particles**

DM : the direct detection experiments and astrophysics both are challenging usual DM folklores just as much as LHC 'paradox' is challenging the 'hierarchy' folklore or 'fine tuning' folklore!

DM at the colliders is throwing out results that too we do not seem to understand!

Are we at a cusp and some people are asking the question whether it is time for a paradigm shift!

What is the way forward?

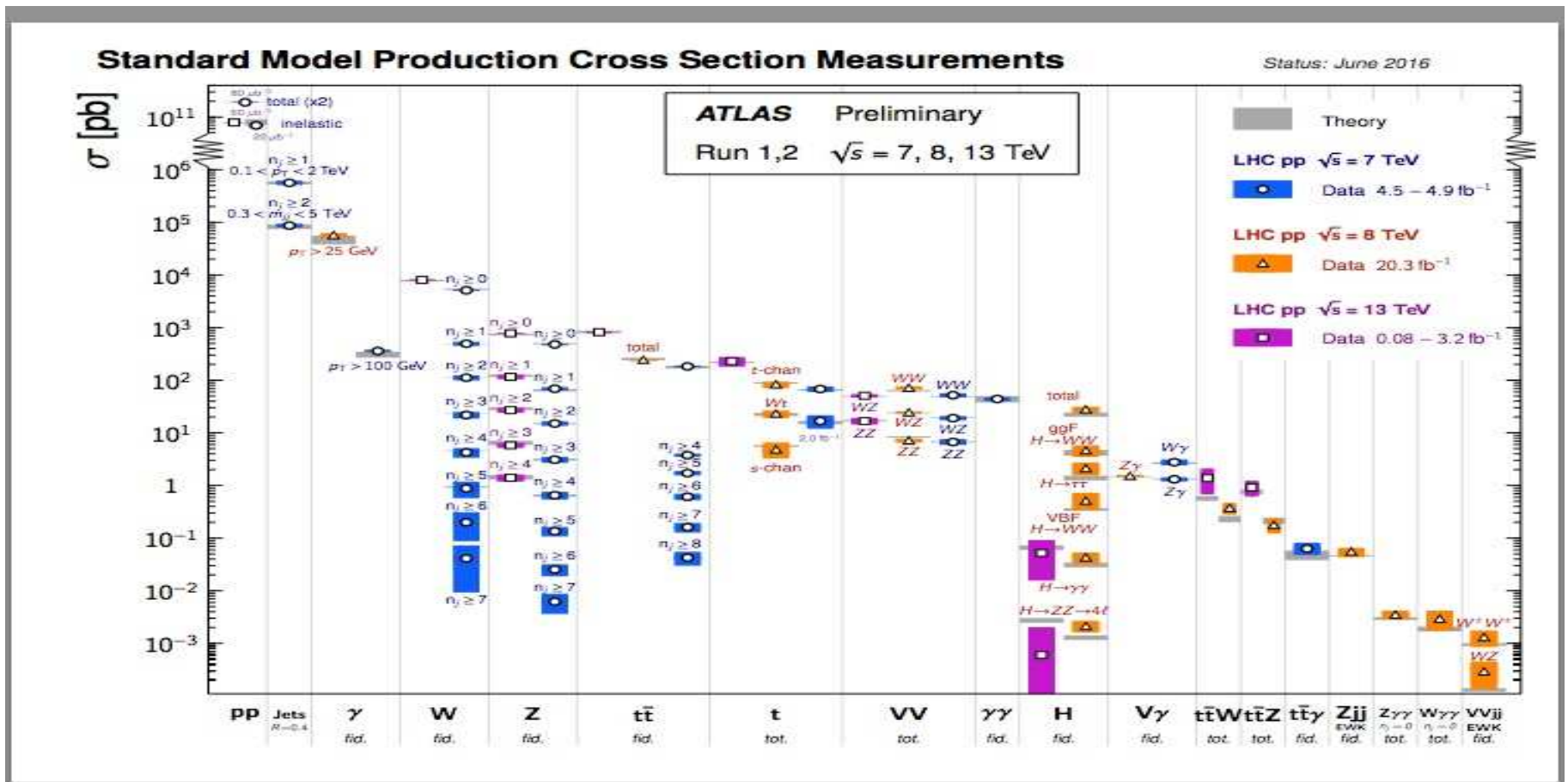


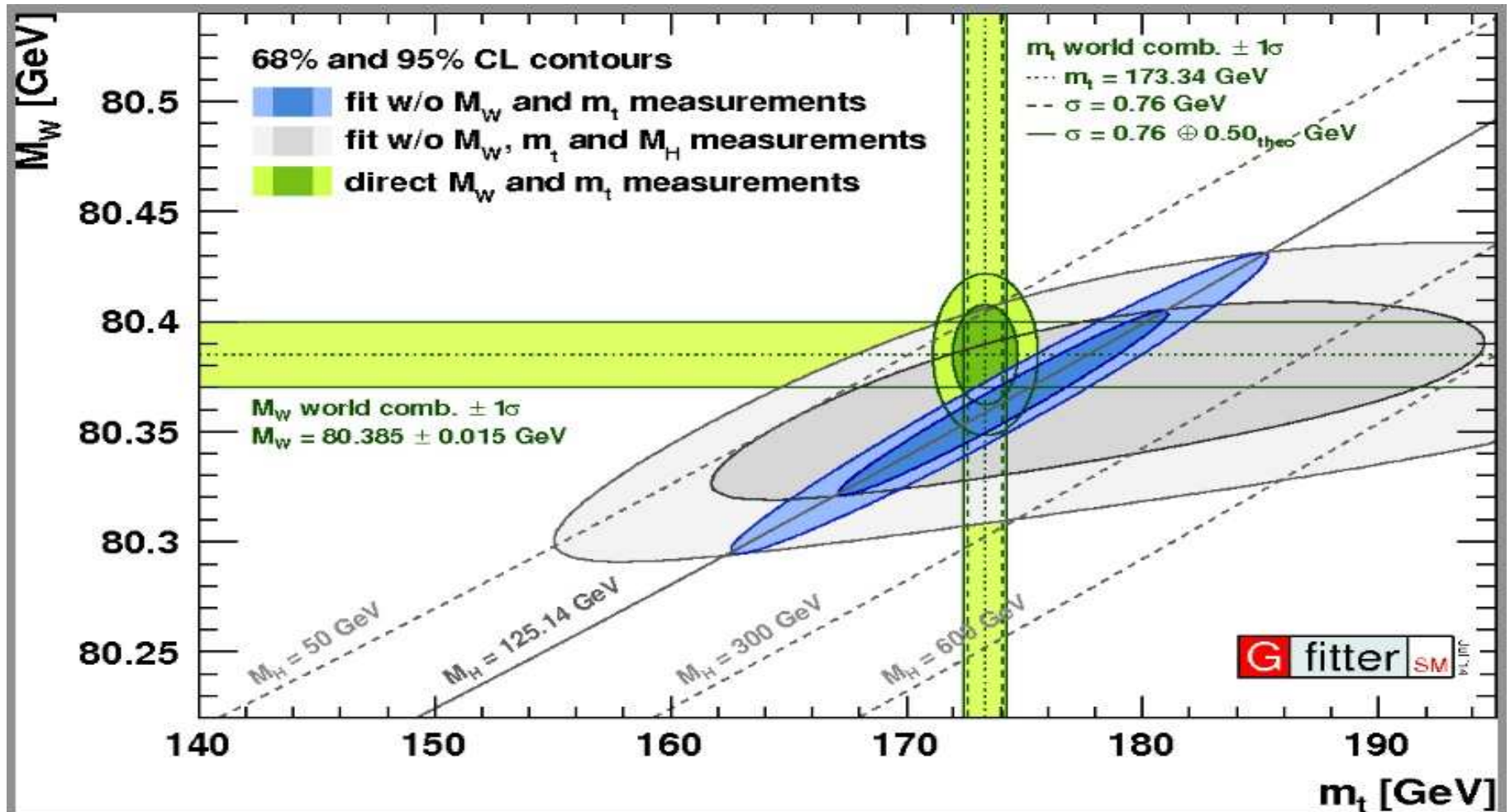
David Gross argued that either way one is led to the need of TeV energy collider(s)!

Mihoko Nojiri stressed the importance of asking meaningful and basic questions, to justify the need of these expensive instruments we need to continue our explorations!

At the same time Xerxes told us that we need to be careful before we start concluding that 'nature' is not 'natural'!

Aurelio Juste, Andreas Jung and Alberto Belloni told us how well the SM works!





SM rocks! *At LOOP level*

Precision measurements require precision calculations!

Active and strong interaction between theorists and experimentalists essential!

Stressed by all the speakers!

LHC Seems to have found the light Higgs consistent with the top mass implied by EW precision tests

BUT So far no evidence/indication for the different BSM particles.

The mass and the couplings of this light state and top might be the window through which we can get a view of BSM at present!



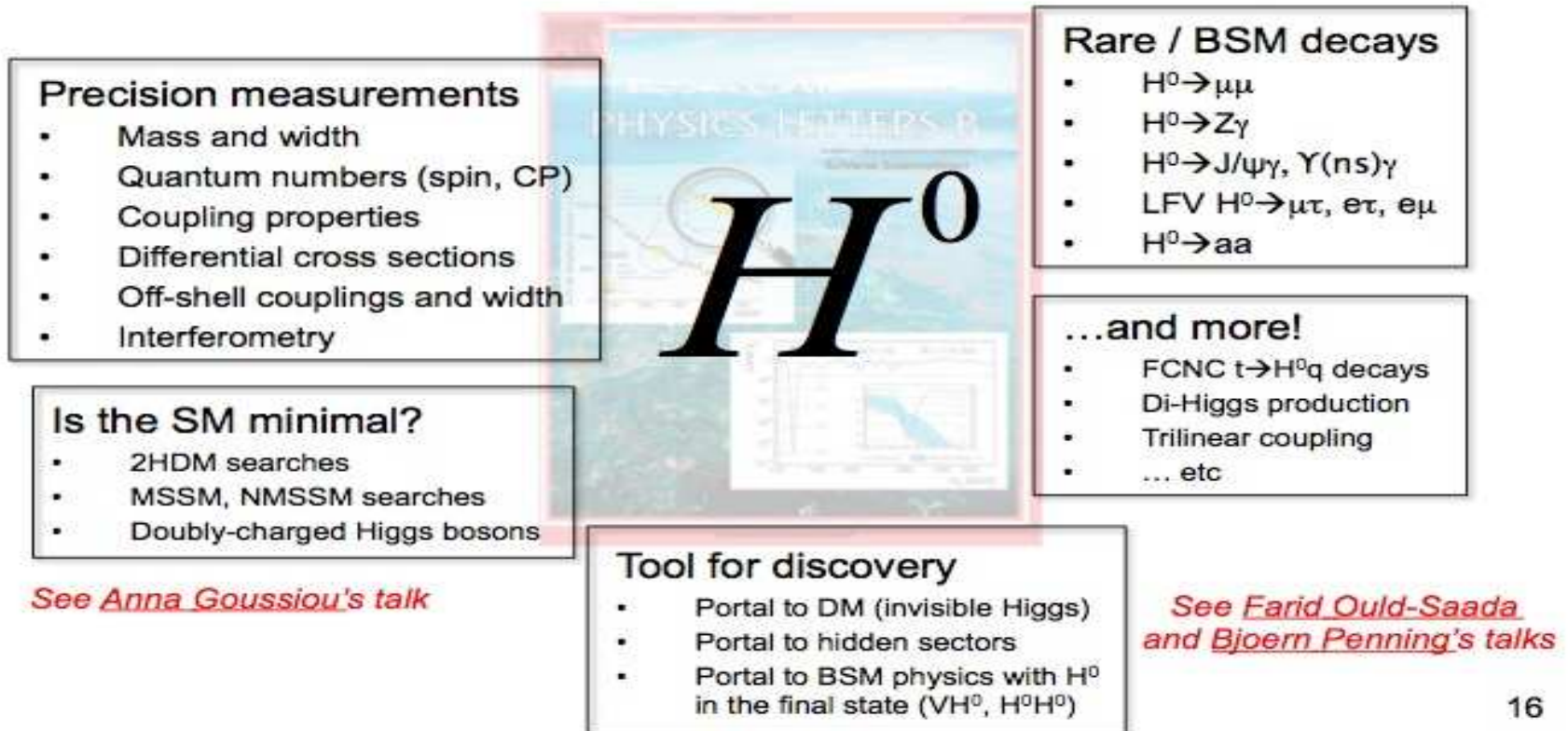
Peeping through the Higgs window!



Murayama LP03

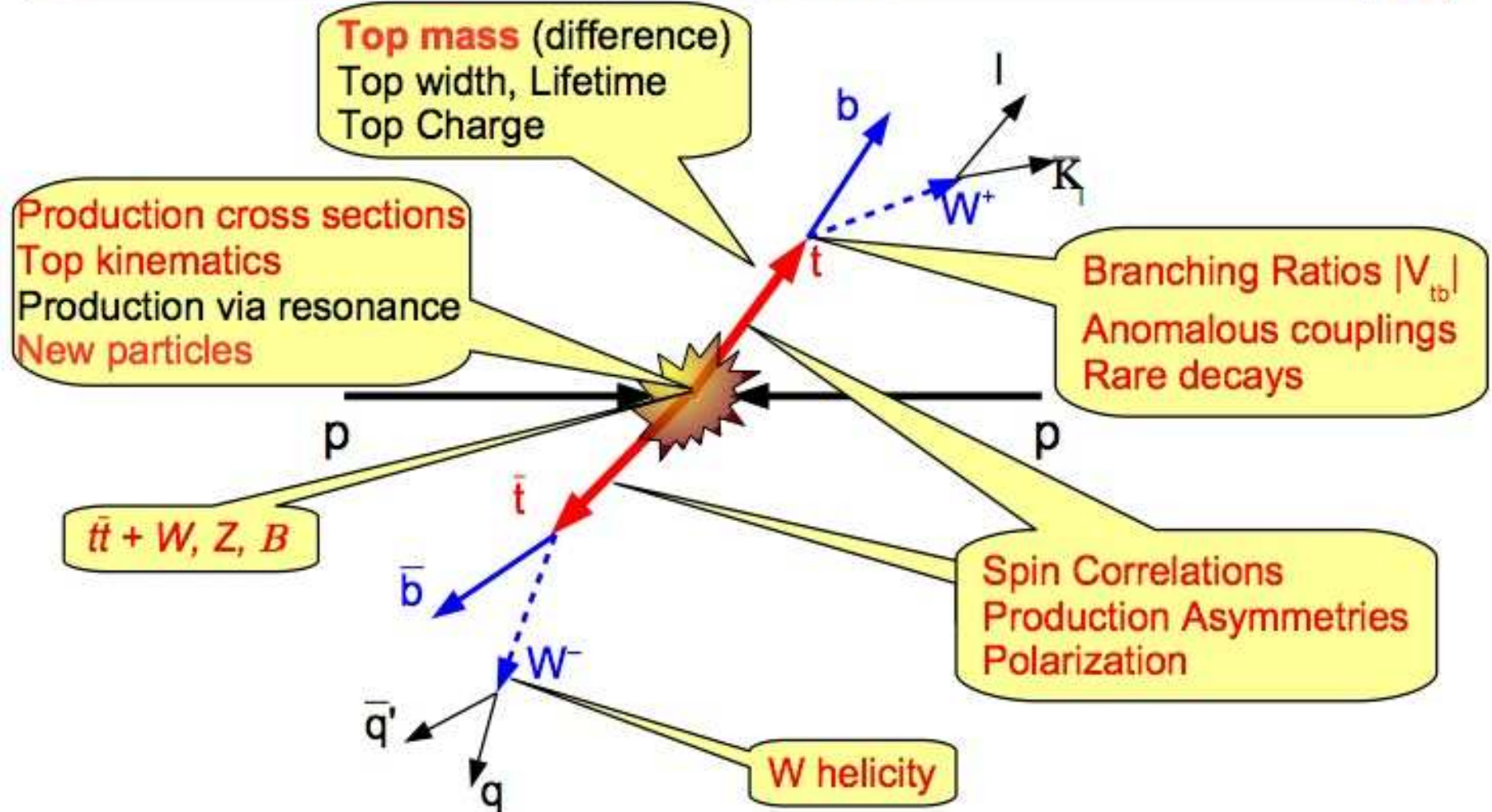
Explosion of the Higgs Physics Landscape!

- Since the discovery of the Higgs boson, an entire new field has emerged.

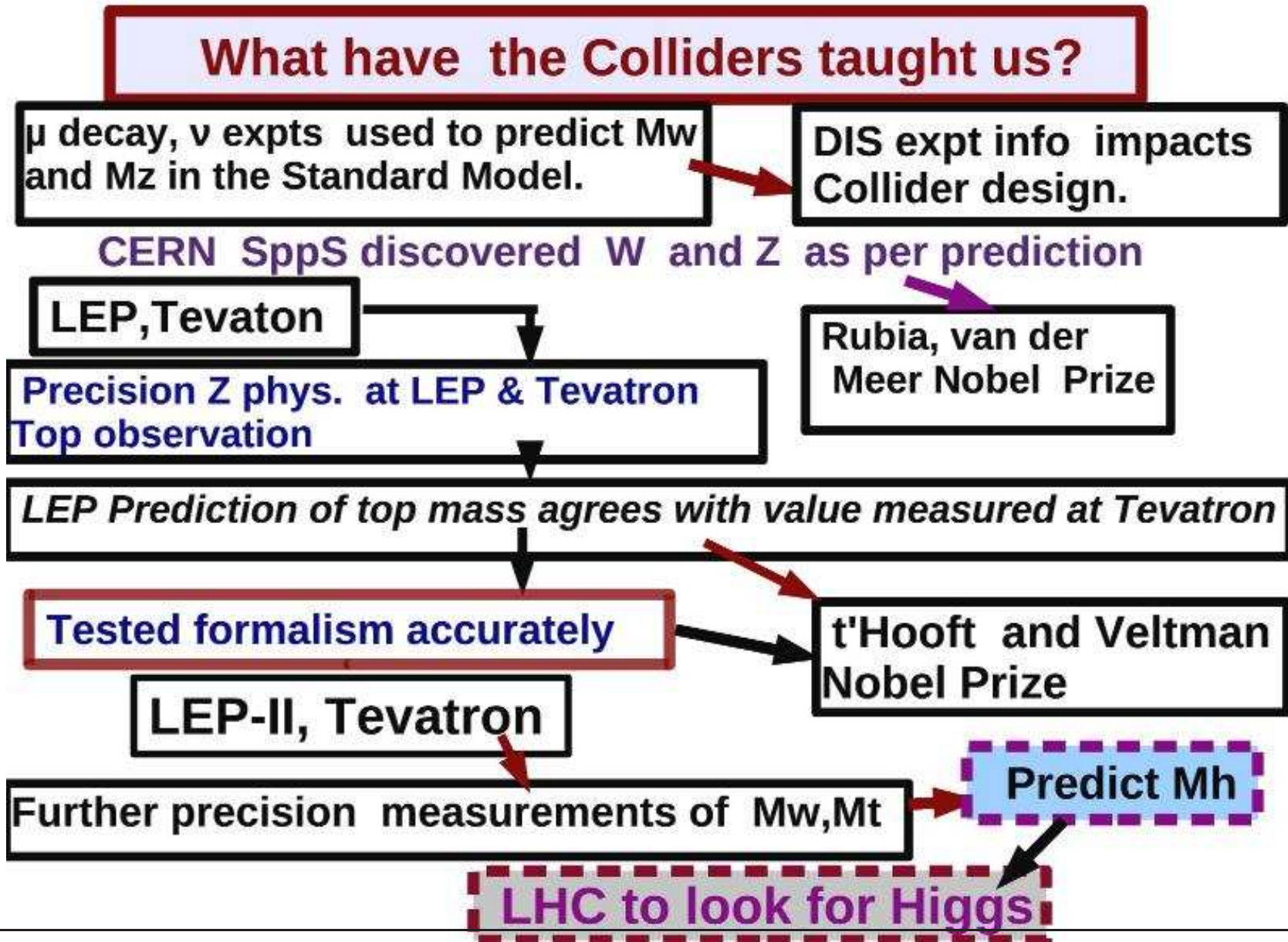


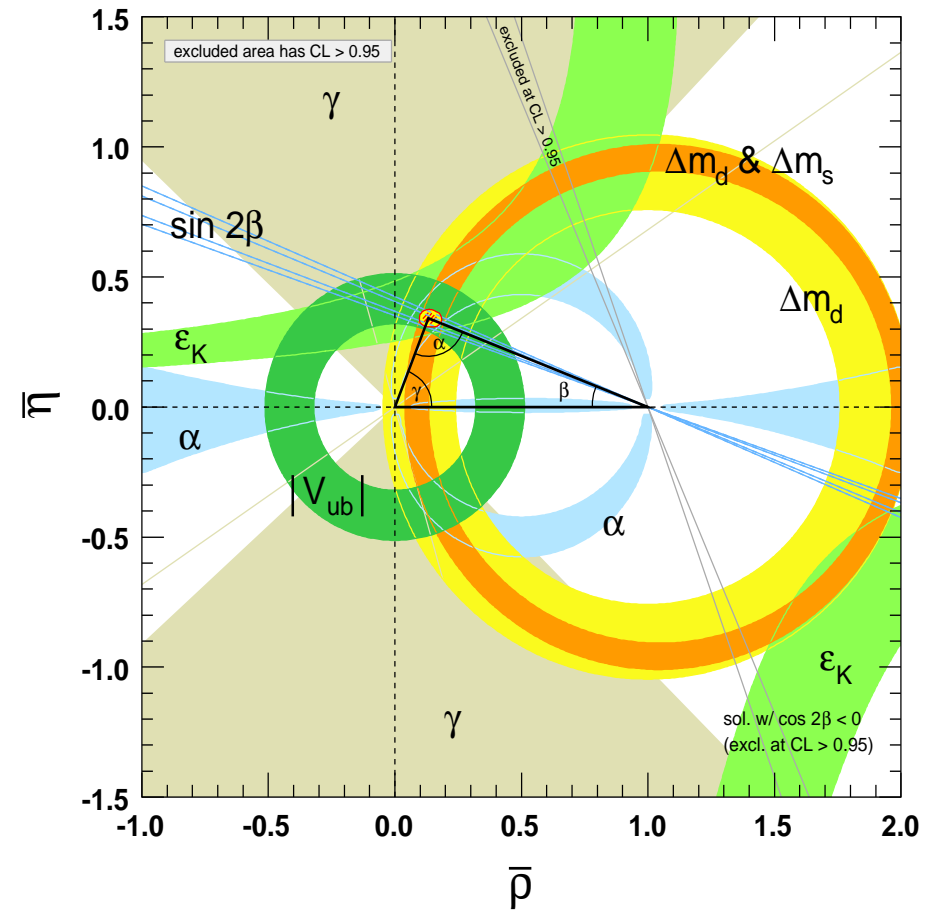
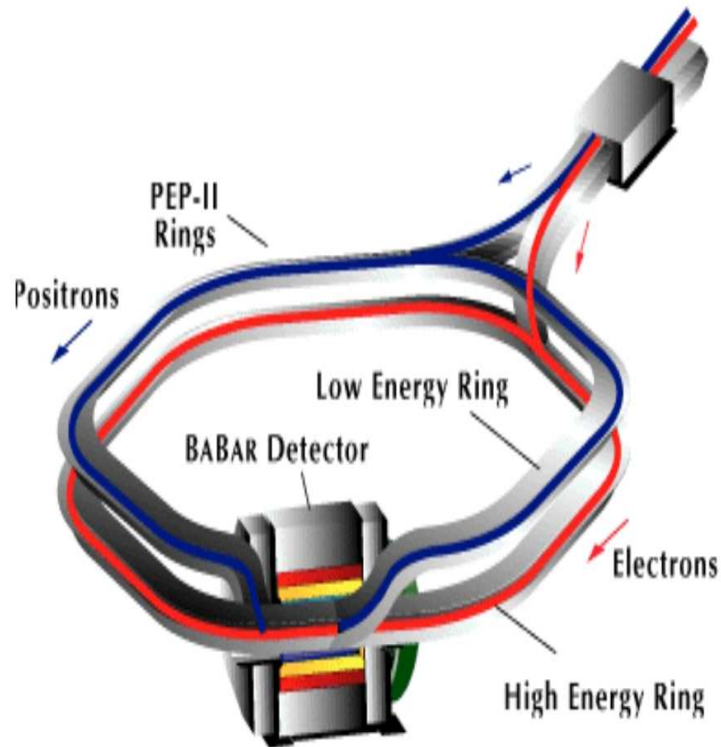


Content



Same from B physics: LHCb and BABAR, CLFV.... Many discussions here!





BABAR/BELLE/LHCb helped us get here!

To quote Michelangelo Mangano

- The days of “guaranteed” discoveries or of no-lose theorems in particle physics are over, at least for the time being
- but the big questions of our field remain wild open (hierarchy problem, flavour, neutrinos, DM, BAU,)
- This simply implies that, more than for the past 30 years, future HEP’s progress is to be driven by experimental exploration, possibly renouncing/reviewing deeply rooted theoretical bias

BSM will perhaps appear as anomaly, as a 'blip' over SM bkgds!

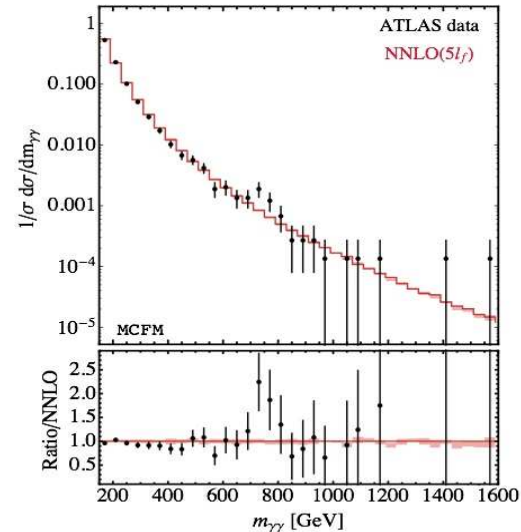
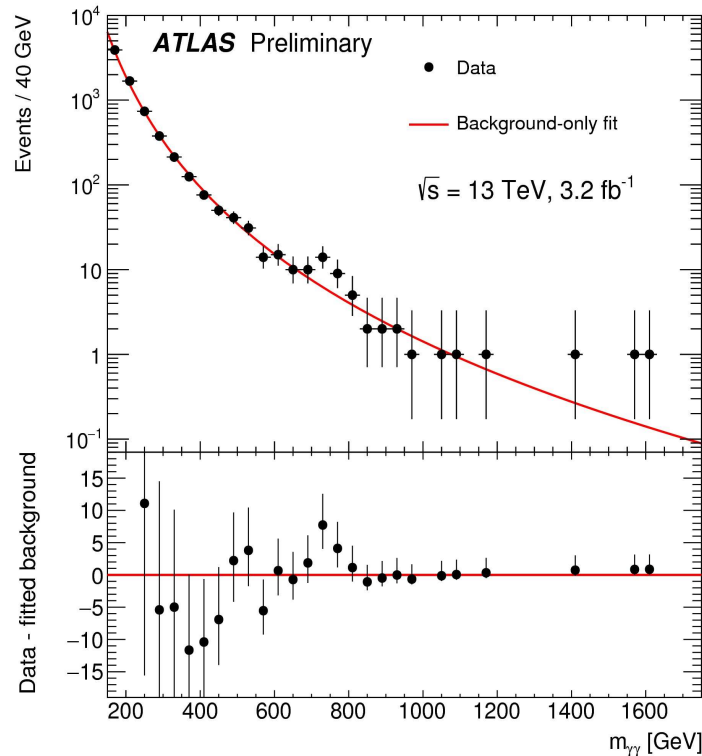


Figure 11. The rate-normalized shapes of the $m_{\gamma\gamma}$ distribution from the ATLAS collaboration and the MCFM NNLO prediction for $\mu = m_{\gamma\gamma}$. The lower panel indicates the ratio of the data to the NNLO prediction.

750 GeV Fitted ATLAS bkgd!

N²LO QCD calculation!

At least the excess is not a 'loose wire' effect!

At present we do not quite know the answer to the question 'Whither next' ?

Following the 'discovery ' of the Higgs at the LHC, next logical step is to make **precision** studies of the properties of the Higgs.

Just like **precision study** of all the other particles in the SM gave information on **the missing piece the Higgs**, now one can learn about **Beyond the SM(BSM)** physics.

Can LHC offer **high enough** precision in the studies of the properties (mass, spin, parity) of the Higgs.

The energy scale for BSM seems to be high (initial LHC results) ☹

Historically baton has passed from hadronic to leptonic colliders and vice versa. So then **may be** it is the turn of high energy e^+e^- colliders.

The mass of the observed state very very interesting from a lot of points of view!

Small enough to keep us still thinking of a mechanism like SUSY to stabilize it (case for a higher energy pp machine?)

and

Large enough to make us wonder whether SM is the ONLY thing all the way to the Planck Scale! (strengthened by absence of any BSM signal!)**case for precision measurement?**

and

A unique value where decays into almost all final states are substantial**Good for precision measurement**

13/14 TeV LHC!

High Luminosity **HL** 13/14 TeV : 3000 fb^{-1}

Far future: **HE** 100 TeV?

ILC: 250 GeV, 500 GeV and 1 TeV: Interesting developments in Japan!

FCC: future circular colliders: FCC(ee) upto 350 GeV

Same tunnel : 100 TeV pp and also high energy eP?

CEPC: Moving on very seriously about the circular colliders!!

On the intensity front : Super Belle, Kaons.... Will provide precision information on flavor physics!

US: Snowmass studies.

Comparisons of HL LHC, FCC(ee) , ILC and CLIC!

FCC(ee) : Lower energy than ILC, can cover precision study of Higgs and $t\bar{t}$ in the second stage. Extension to higher energy to cover $t\bar{t}h$ seems a bit too expensive for the circular option.

Higher luminosity, so precisions for FCC(ee) almost always better than even ILC.

FCC (hh) requires magnetic fields of about 15-20 Tesla. This is about twice the values currently achieved.

CEPC is looking at (right now) only the option with energy unto 240 GeV.

Remember:

More than two decades required to achieve the performance for the beam and acceleration gradient that is required for the ILC to deliver!

This is the typical time scale!

So we have:

LHC: 13 TeV: current

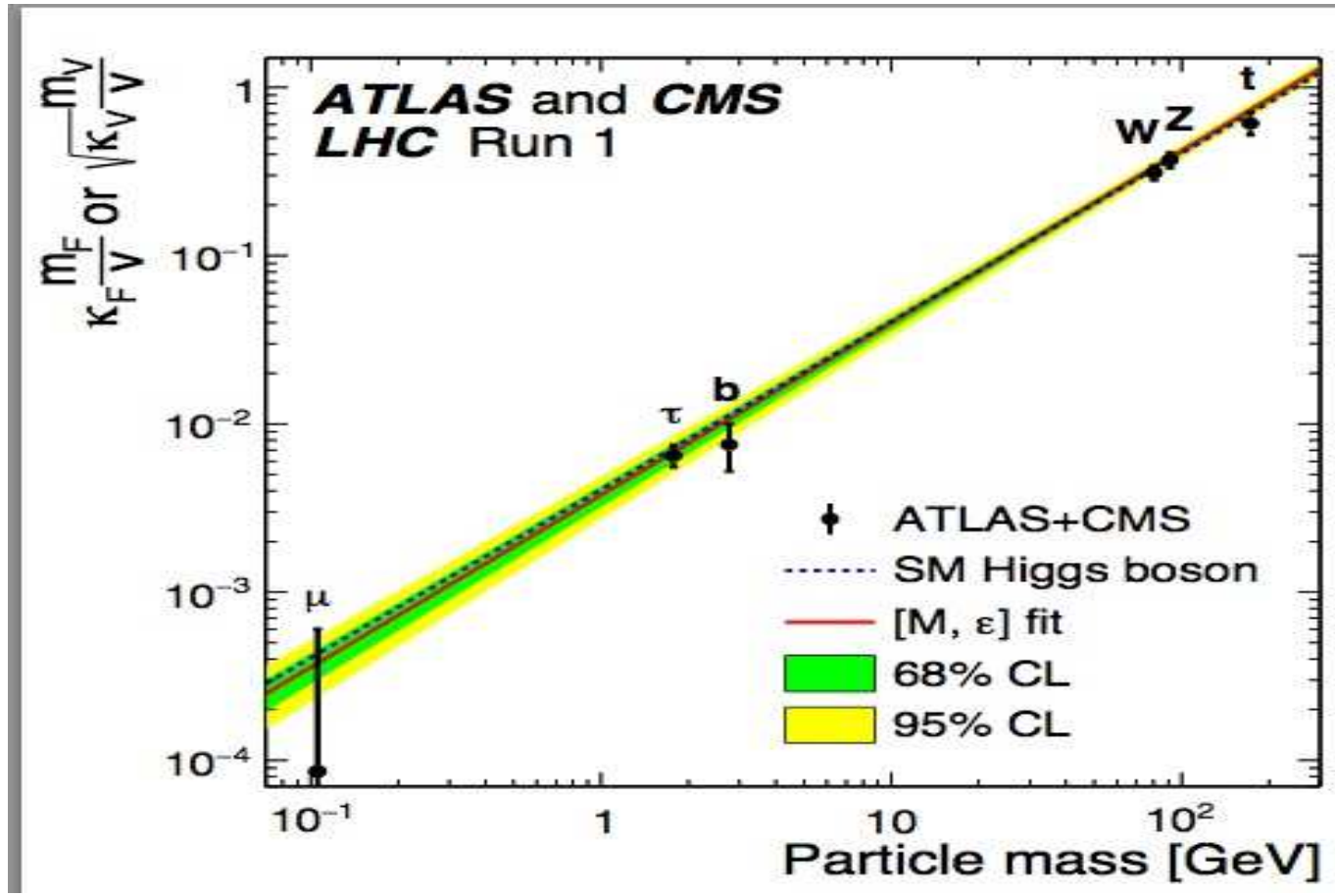
SuperBelle : certain.

LHC(HL): Quite certain

ILC: Technology proven, developed and can be undertaken once money is available.

FCC (ee), CEPC seem more the 'future' machines and FCC(hh) even further!

CEPC : Work done for ILC is helping..so may be lead time will be less!



Information on the fermion higgs coupling. [coupling values in the SM!](#). Is it **the** Higgs?

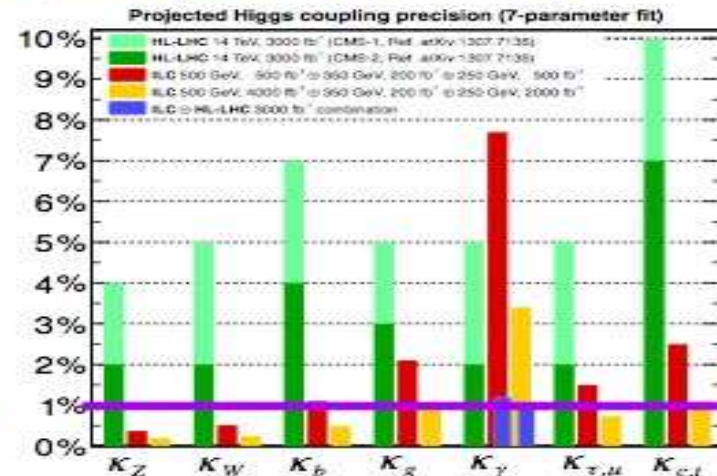
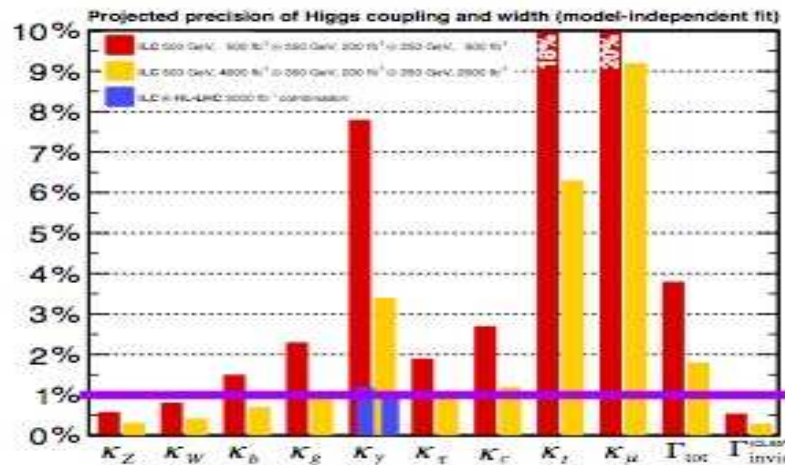
Talk by Tanabe:

Higgs Couplings

Model-Independent:
Only possible at e^+e^-

Model-Dependent:
Compare with LHC

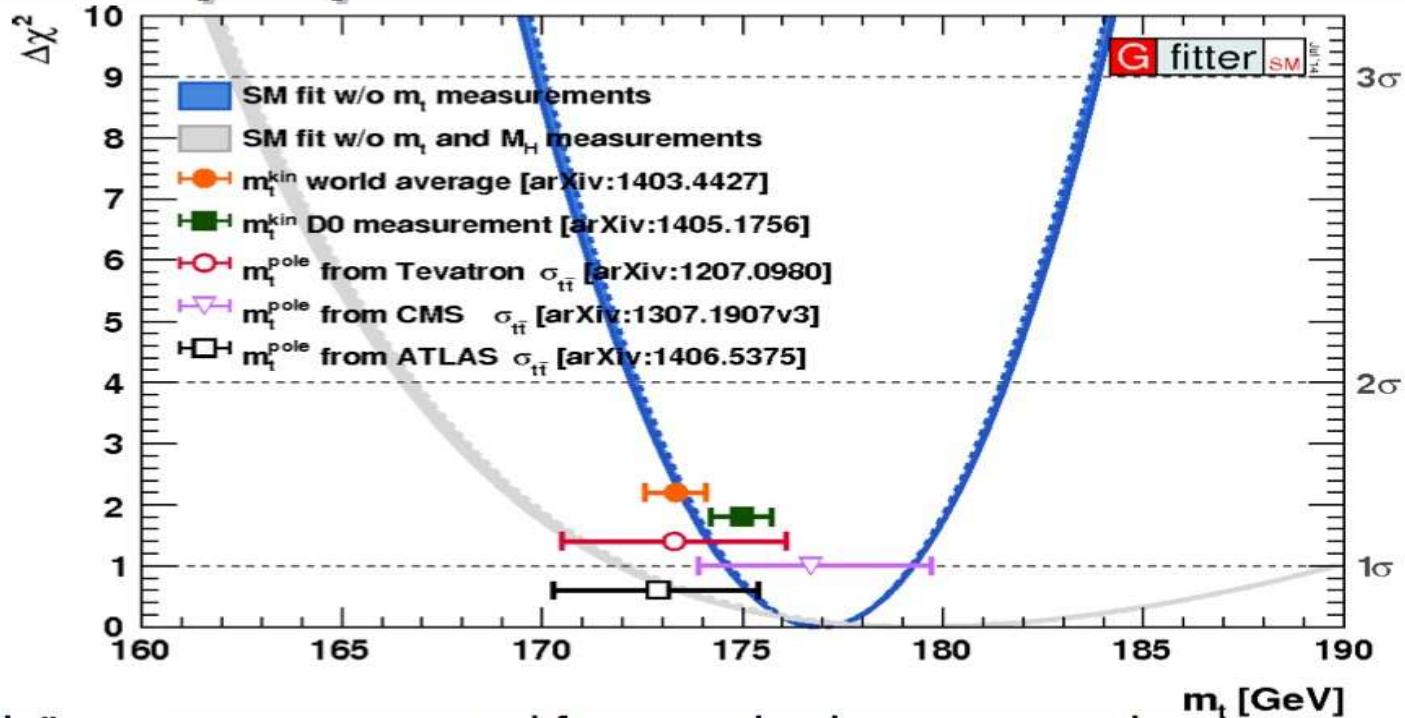
Including systematic uncertainties [arXiv:1506.05992]



Sub-percent precision fit on most Higgs couplings with full ILC500 program



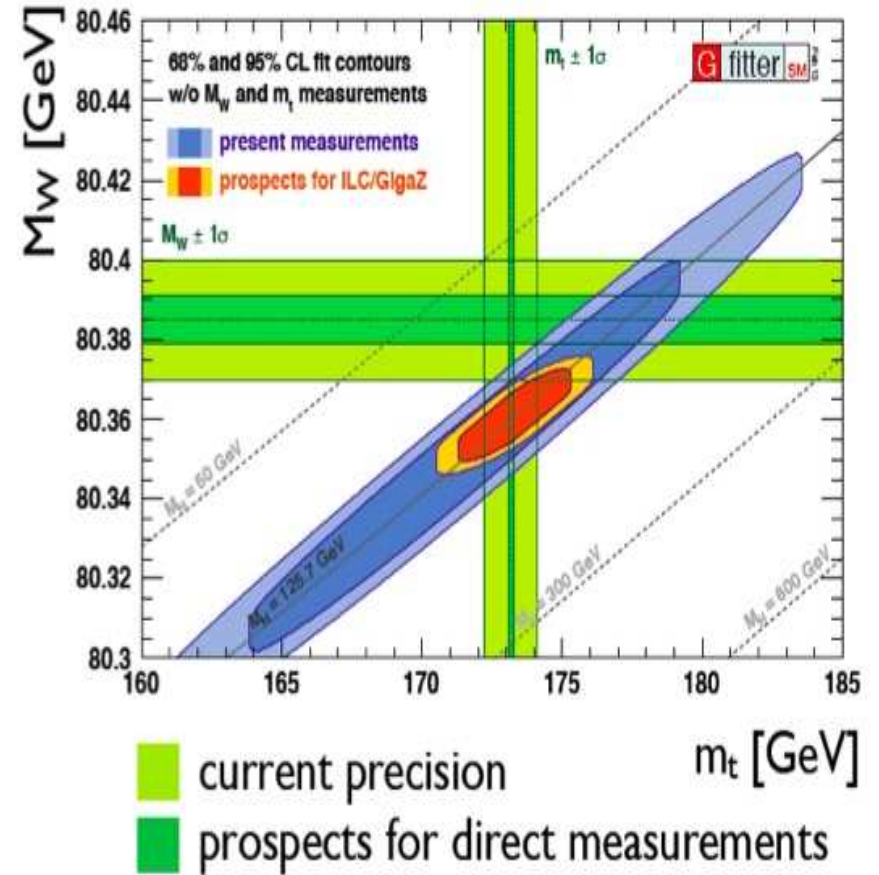
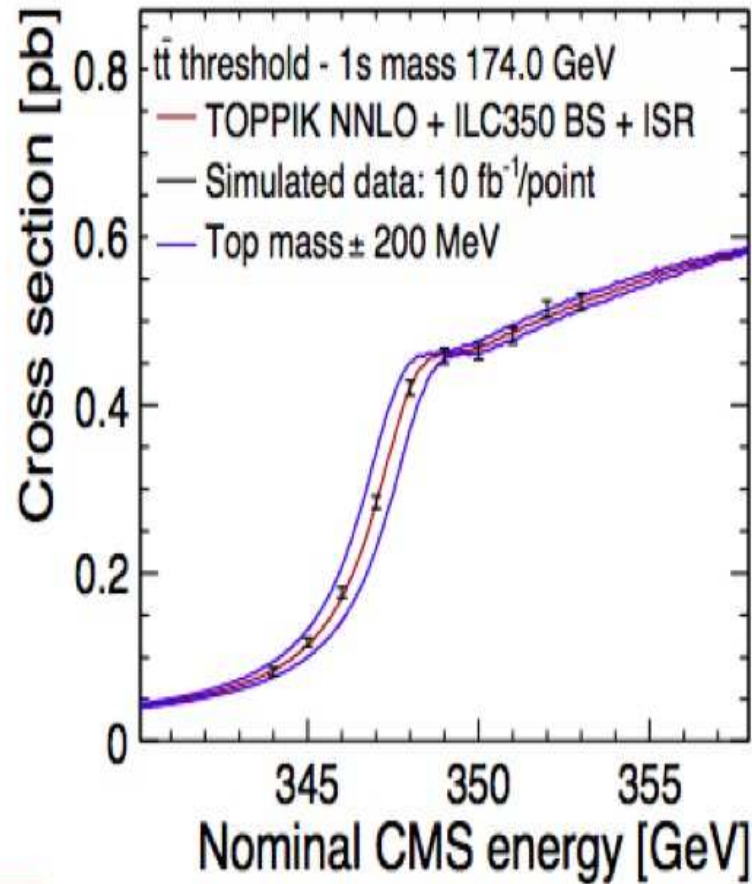
Top quark mass



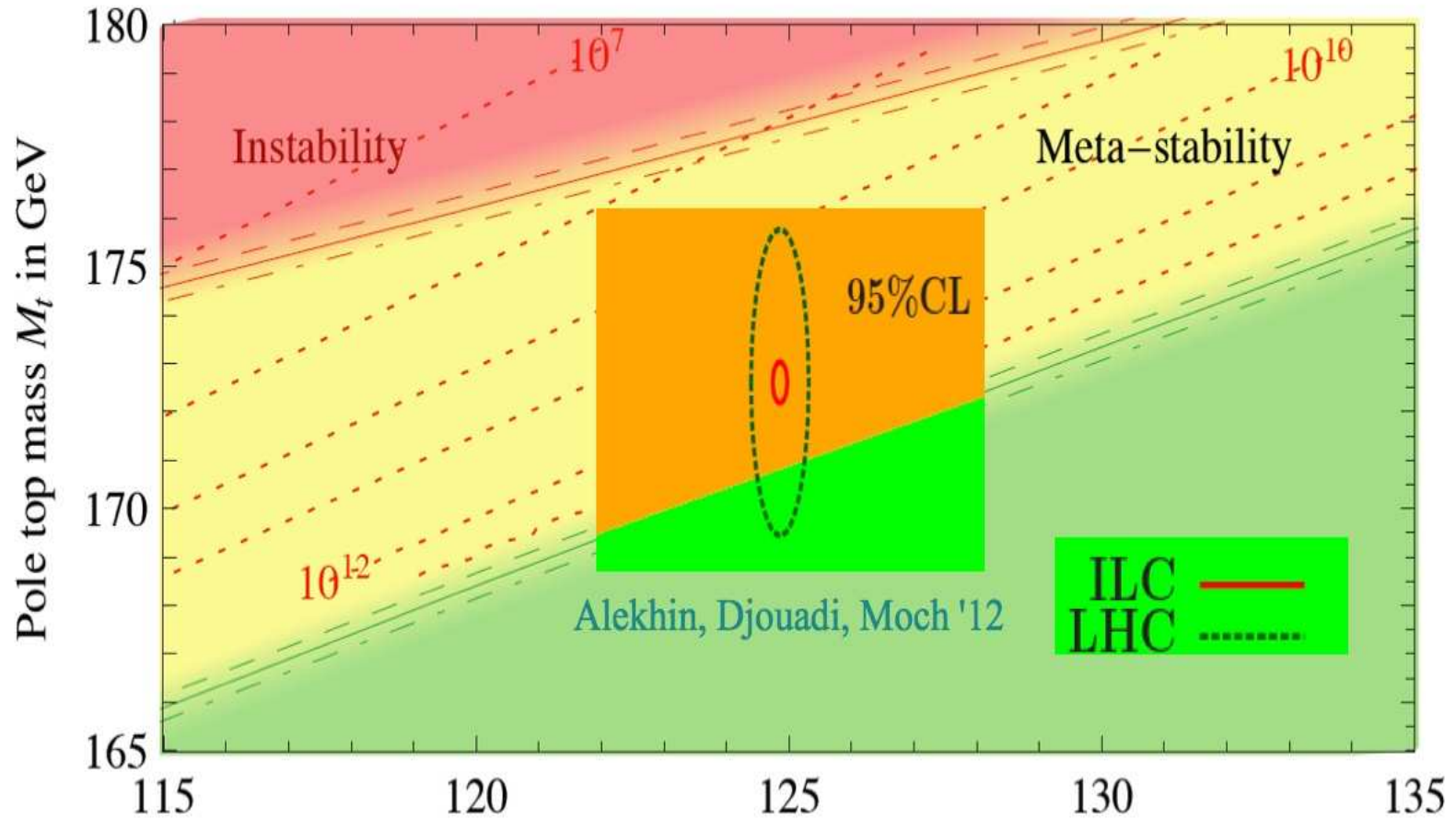
- “pole”
- “kin”

means extracted from production cross sections
 means direct measurements, e.g. matrix element method

Precision at LHC (With 80 million top pairs as told by Andreas) :
 500 MeV, Ultimately 200 MeV may be possible!



Precision: $\simeq 100$ MeV!



LHC: 13 TeV: current

SuperBelle : certain.

LHC(HL): Quite certain

ILC: Technology available and can be undertaken once money is available. CLIC technology studies in advanced stage. (Linear Collider Board: LCB)

FCC (ee) and FCC(hh) seem more the 'future' machines: two or three decades in future.

Results from LHC 13 will play a role in deciding what we do!. May be in a few months we will have forgotten that we were agonizing over this 'absence' of new physics at LHC!

One thing for sure: we need precision calculations and precision measurements!

Connections with Cosmology : Some can be tested through precision measurements at the Colliders! for example the **Invisible branching ratio** of the Higgs.

The Higgs mass and (in)stability of the Vacuum may say something about high scale physics and *MAY* have connections to some Planck Scale physics ideas!

The progress has to come through the joint investigations on the earth and in the sky!



So Colliders will do their bit! By precision measurements: either at hadronic colliders or at leptonic colliders!

The road may be very long but 'physics case' for colliders is not 'withering' just yet!