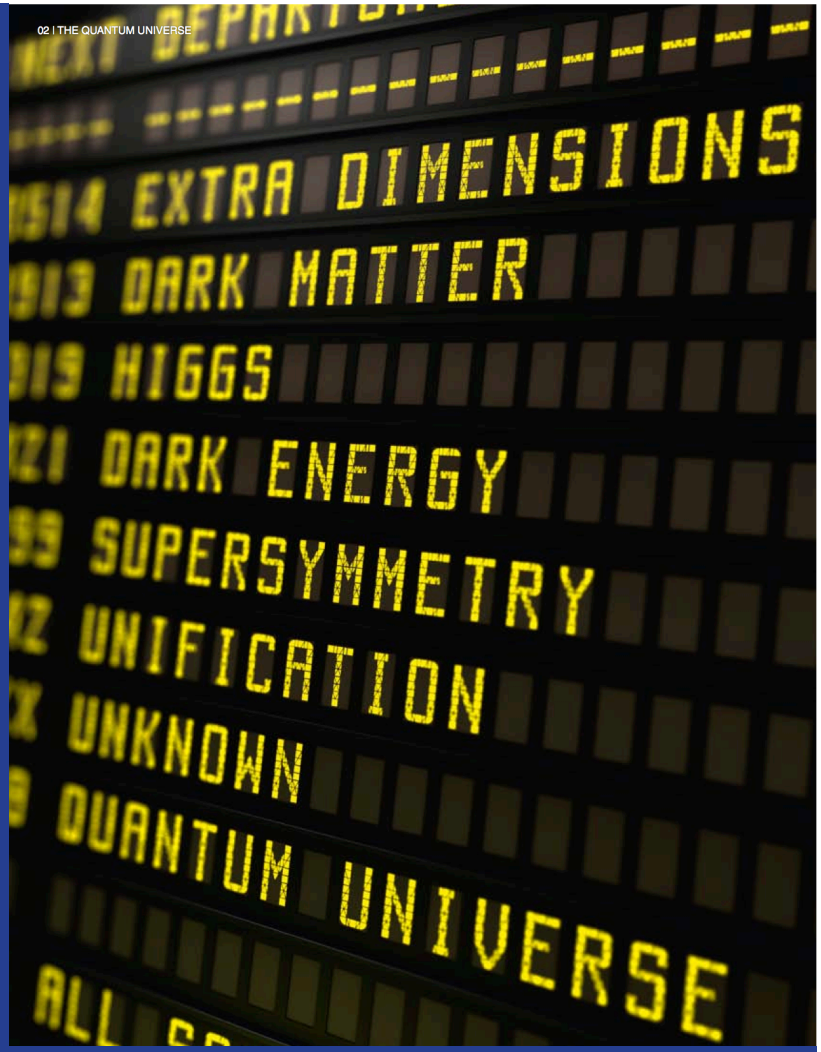
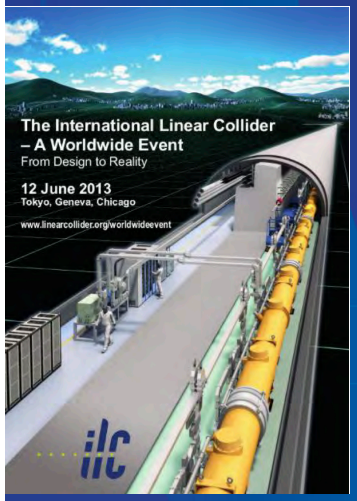
ILC Physics





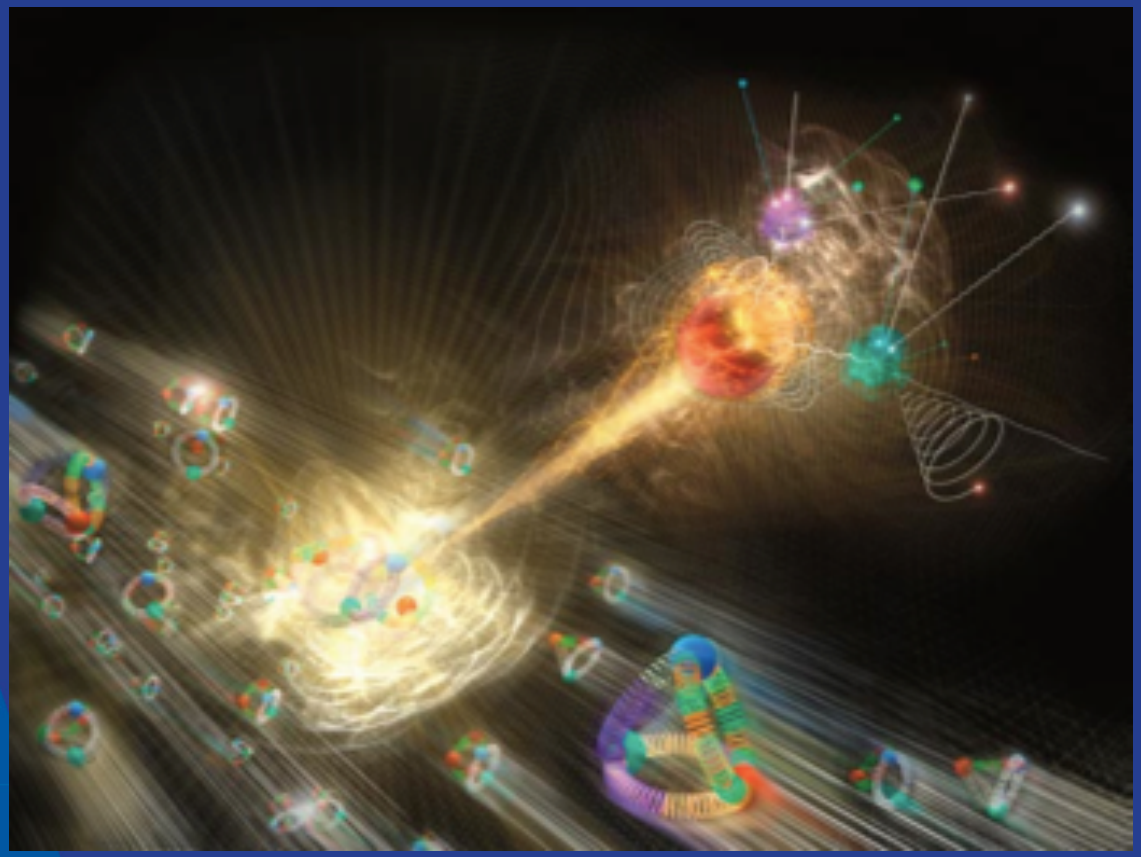
Joseph Lykken

ILC Worldwide Event, Fermilab 6/12/2013

U.S. DEPARTMENT OF ENERGY

Fermilab

A NEW AGE OF DISCOVERIES IN PARTICLE PHYSICS



The first time that the entire NYT Science section is devoted to a single story

Chasing the Higgs Boson | INTRODUCTION | PROMISED FIREBALLS | GAME OF BUMPS | STILL MISSING | OOZING INTO VIEW | OPENING THE BOX

Chasing the Higgs Boson

At the Large Hadron Collider near Geneva, two armies of scientists struggled to close in on physics' most elusive particle.

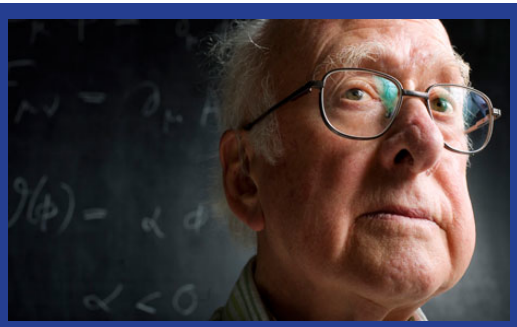
DENNIS OVERBYE
Published March 5, 2013 | 252 Comments

MEYRIN, Switzerland — Vivek Sharma missed his daughter.

A professor at the University of California, San Diego, Dr. Sharma had to spend months at a time away from home, coordinating a team of physicists at the Large Hadron Collider, here just outside Geneva. But on April 15, 2011, Meera Sharma's 7th birthday, he flew to

Illustration by Sean McCabe/Photographs by Daniel Auf der Mauer, Toni Albir, Fabrice Coffrini, Fred Merz
Peter Higgs, center, of the University of Edinburgh, was one of the first to propose the particle's existence. From left, physicists at CERN who helped lead the hunt for it: Sau Lan Wu, Joe Incandela, Guido Tonelli and Fabiola Gianotti.

Higgs Big Questions



- How many Higgs bosons are there
- Does the Higgs couple to matter particles proportional to their masses
- Is the electroweak scale stabilized by new symmetries, new forces, new particles

Already this makes it pretty obvious what you need:

- Direct searches for new particles: LHC
- Indirect searches for new particles: g-2 etc.
- Precision measurements of Higgs and other particle properties: ILC

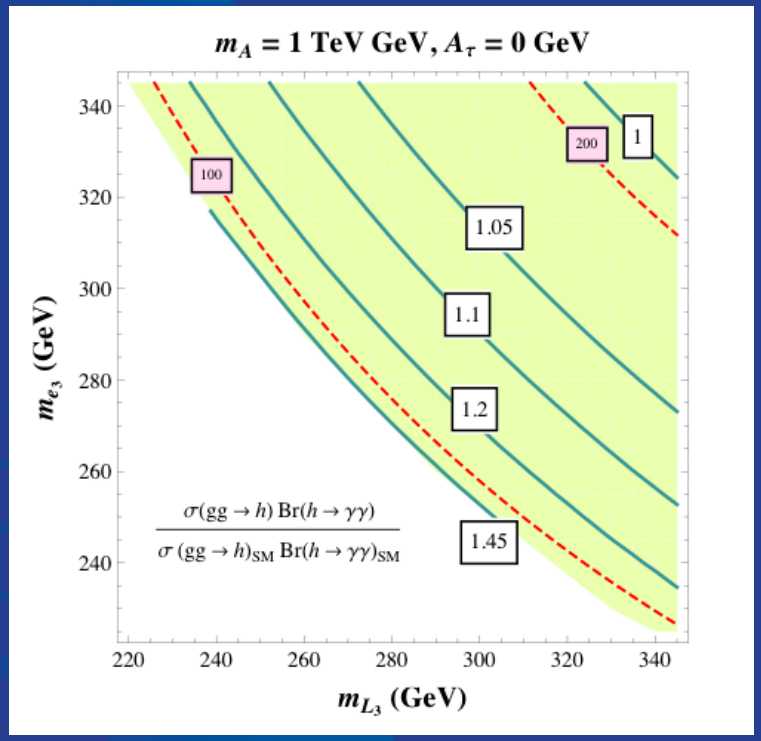
Higgs Connections

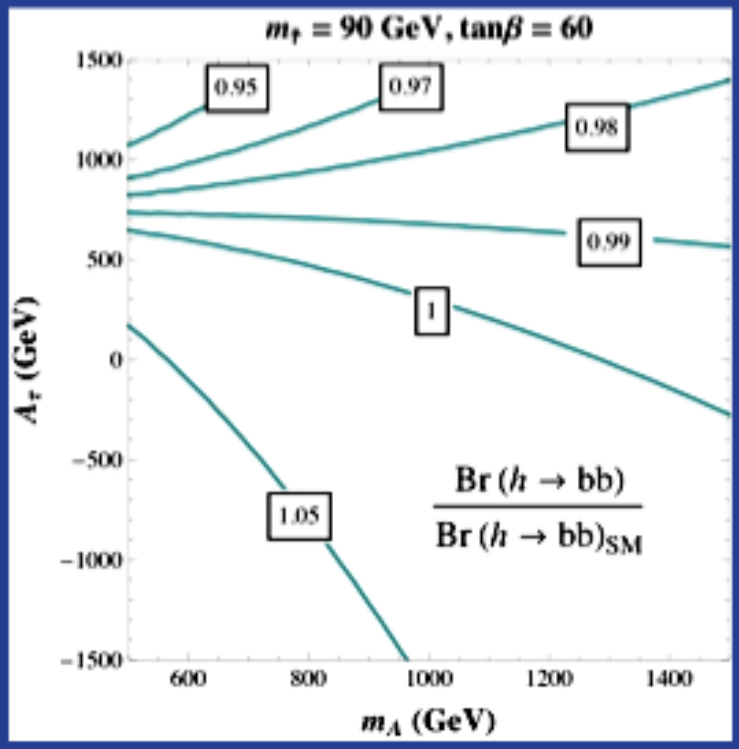
- Is there a Higgs portal to dark matter
- Does the Higgs make the universe unstable
- Did the Higgs trigger the genesis of matter
- How does the Higgs talk to neutrinos
- Is the Higgs related to inflation or dark energy (extra credit)

  - These ambitious questions motivate a multi-decade worldwide experimental program across all of the frontiers of particle physics
  - ILC, integrating and extending the discoveries of this global program, will be a key unlocking the deepest secrets of Nature

what Higgs precision do we need?

- There could be one or more large deviations (10 – 30%) in Higgs decay branchings vs SM
- Typically implies new particles within direct reach of ILC, and smaller deviations in other Higgs BRs

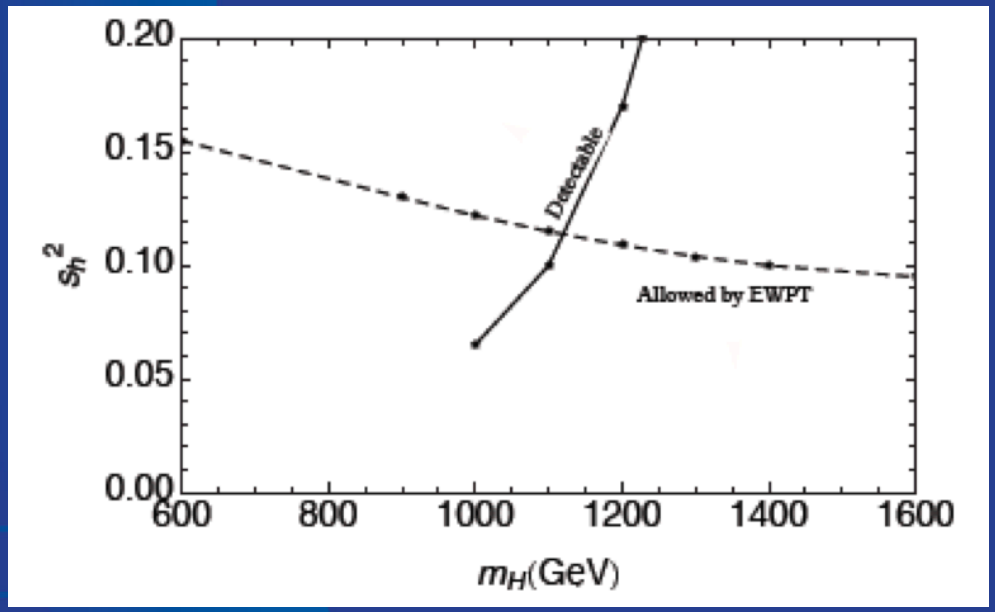




M. Carena, S. Gori, C. Wagner, L-T Wang

what Higgs precision do we need?

- Higgs mixings already constrained by EWPO
- LHC may or may not discover heavy Higgs directly
- Will need ILC precision to decipher the full Higgs sector



R. Gupta, H. Rzehak, J. Wells

Example: a SM singlet that mixes with the Higgs

$$g_{hxx}/g_{H_{\rm SM}xx} \simeq 1 - 6\%$$

ILC TDR Volume 2

what Higgs precision do we need?

- If new particles with TeV mass, effects on Higgs couplings are small, need ILC precision to confirm and decipher them
  - Little Higgs models with TeV scale partners

$$\frac{g_{hgg}}{g_{h_{\rm SM}gg}} = 1-(5\%\sim 9\%)$$
$$\frac{g_{h\gamma\gamma}}{g_{h_{\rm SM}\gamma\gamma}} = 1-(5\%\sim 6\%)$$

  - Heavy Higgs effects

$$\frac{g_{hbb}}{g_{h_{\rm SM}bb}} = \frac{g_{h\tau\tau}}{g_{h_{\rm SM}\tau\tau}} \simeq 1+1.7\%\left(\frac{1\ \text{TeV}}{m_A}\right)^2$$

  - Scalar top partner effects

$$\frac{g_{hgg}}{g_{h_{\rm SM}gg}} \simeq 1+1.4\%\left(\frac{1\ \text{TeV}}{m_T}\right)^2, \qquad \frac{g_{h\gamma\gamma}}{g_{h_{\rm SM}\gamma\gamma}} \simeq 1-0.4\%\left(\frac{1\ \text{TeV}}{m_T}\right)^2$$

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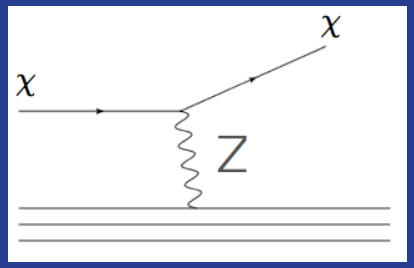
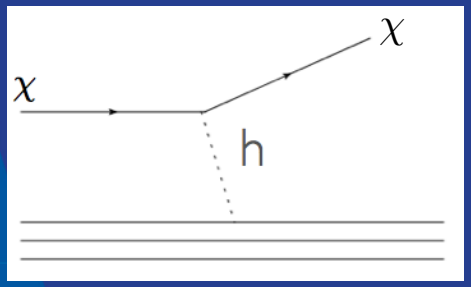
Higgs portal to dark matter

- How does dark matter interact with baryonic matter?

gravity



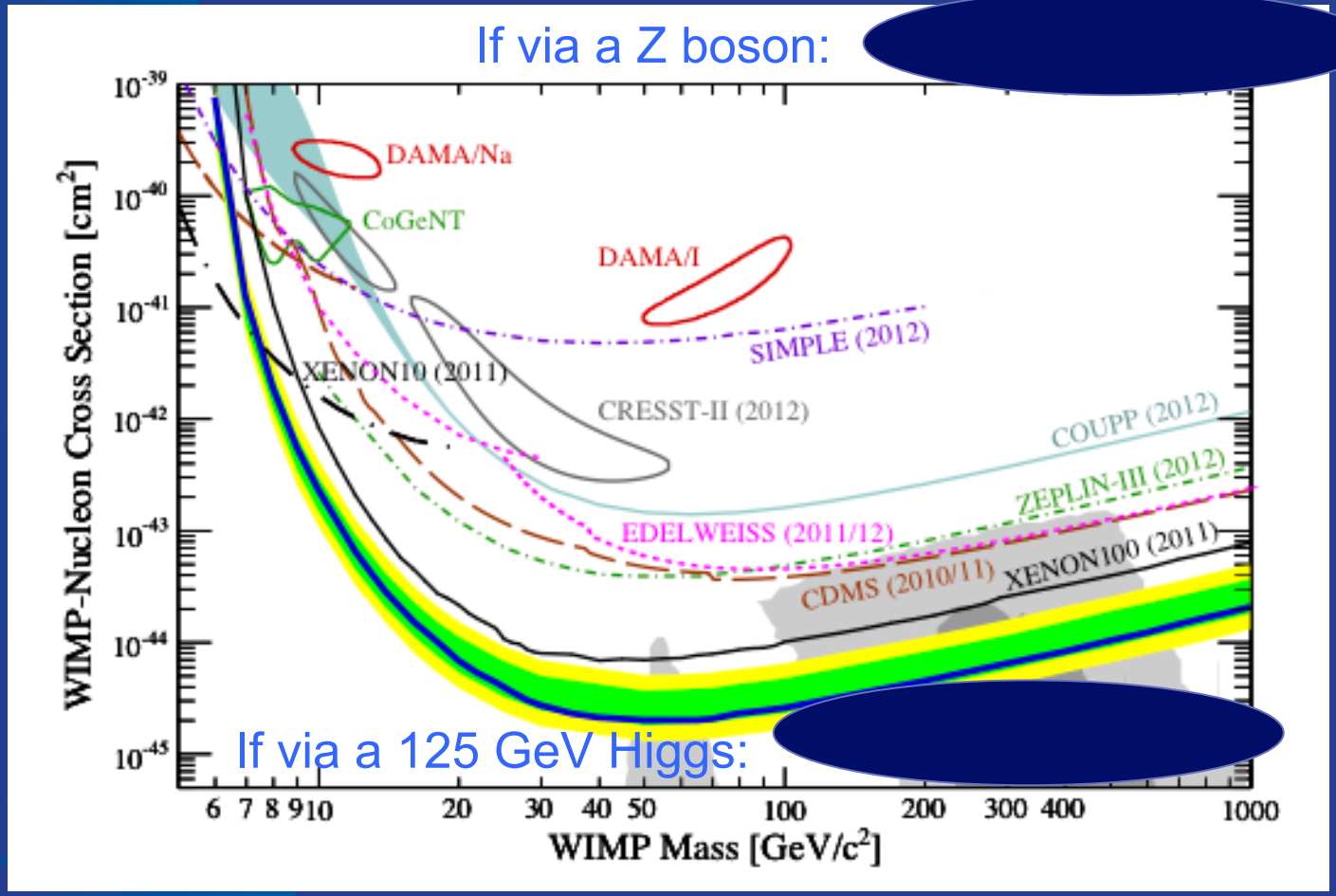
Z exchange?



Higgs exchange?

What can DM direct detection experiments tell us?

If via a Z boson:



If via a 125 GeV Higgs:

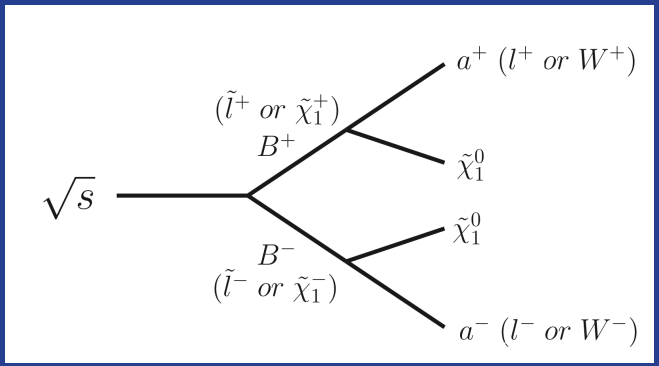
Next generation DM experiments can see this

If via a 500 GeV Higgs:

Adapted from AAAS slide by N. Weiner

ILC and dark matter

- If the DM is light enough, ILC will produce it directly
- Or from decays of partners (e.g. charginos, sleptons)
- Or from Higgs decays



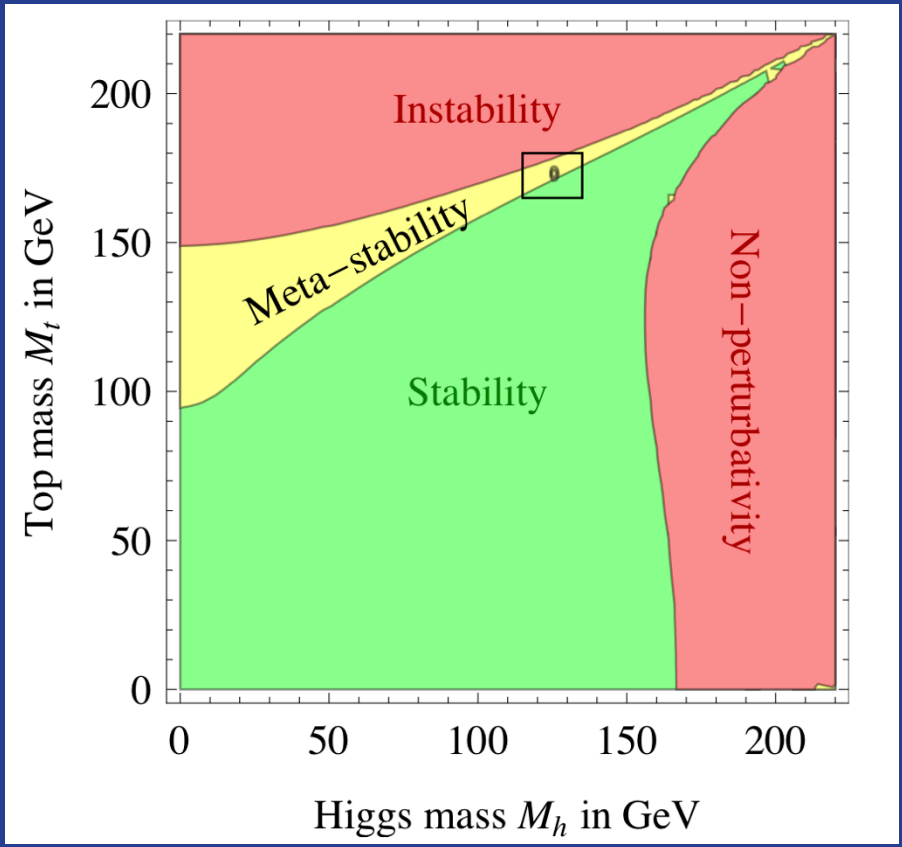
Together with results from direct + indirect detection + LHC, ILC can "close the circle" on dark matter

- Do measured DM properties account for its relic density?
- What is the relation of dark matter to ordinary matter?

Higgs and the Fate of the Universe

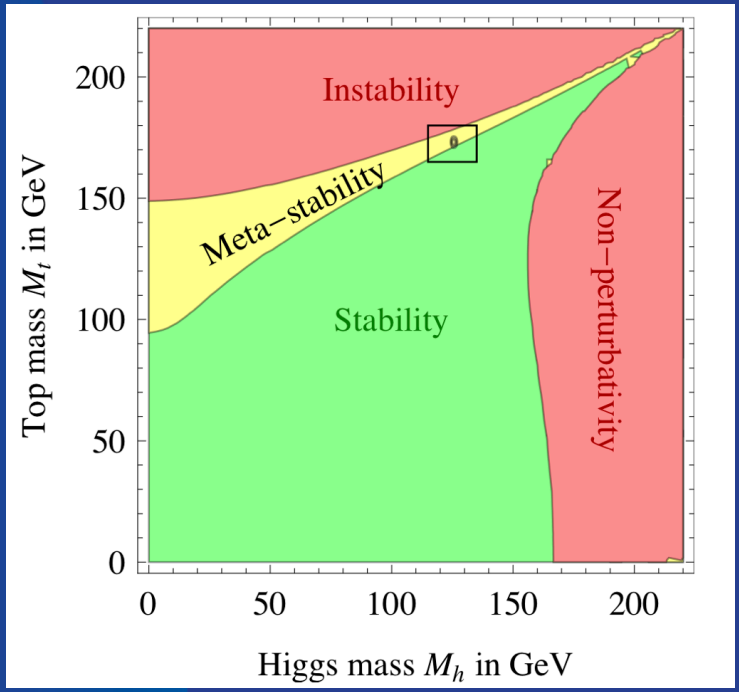
Knowing the Higgs mass we can now compute the SM Higgs potential, and check if the EW-breaking vacuum is the global minimum of the potential…

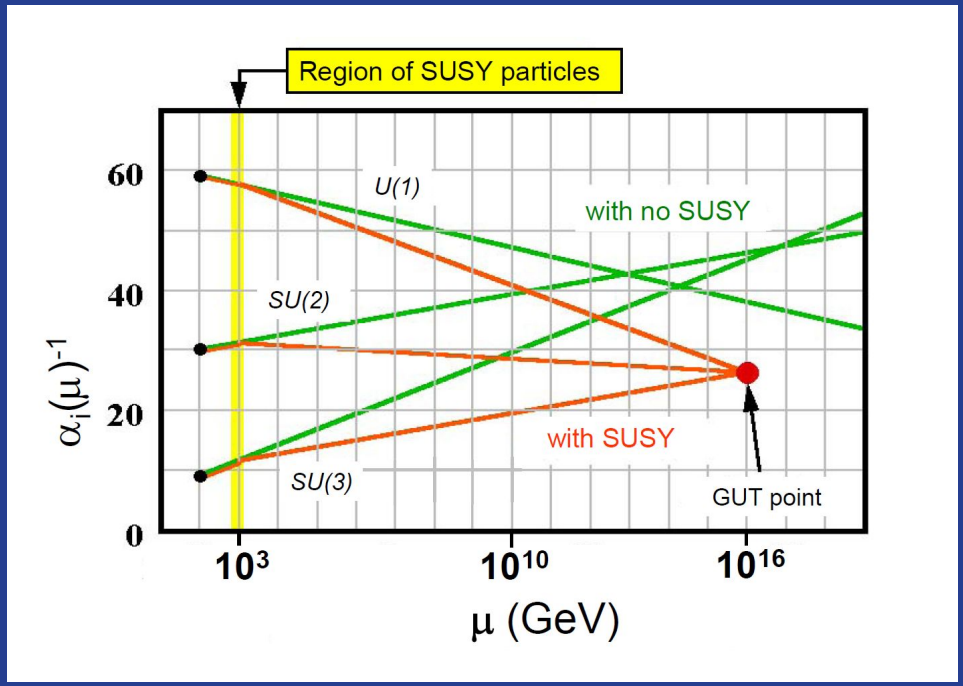
Why are we on the ragged edge of doom?



A. Strumia

If the Standard Model is correct, the Higgs mass and the top quark mass put us right on the edge of vacuum stability



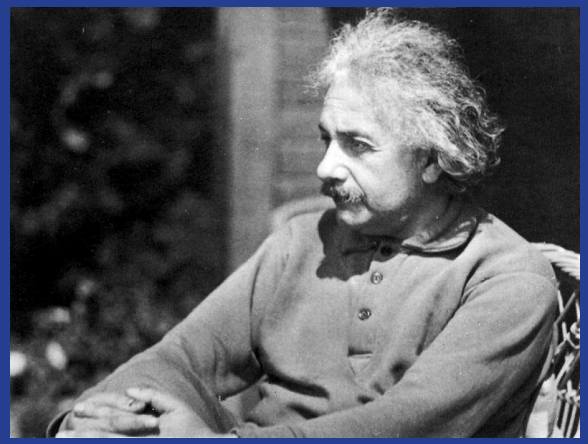


- One of these (or both) is a (few percent) coincidence
- The other may be a profound hint of new fundamental physics
- How will we ever know?

ILC and ultimate unification

- If SUSY, measure lighter gauginos at ILC well enough to test unification
- Combine ILC with neutrino + CLFV + quark flavor + proton decay data to get clues about unification and the origins of flavor at superheavy scales
- If SM only, or SM+dark matter only, ILC provides needed precision on the key parameters, e.g. the top quark mass
- Combine (we hope) with theory insights to get a new paradigm

Ambitious, but this is the realization of Einstein's dream



ILC on the launchpad

- The Higgs discovery marks the dawn of a new era
- ILC, fueled by a global program on many fronts, can get us to a new paradigm of fundamental physics