ILC at the LHC Era:
Complementarity in revealing the Terascale physics

Tao Han
University of Wisconsin --- Madison

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HEP is entering a golden era

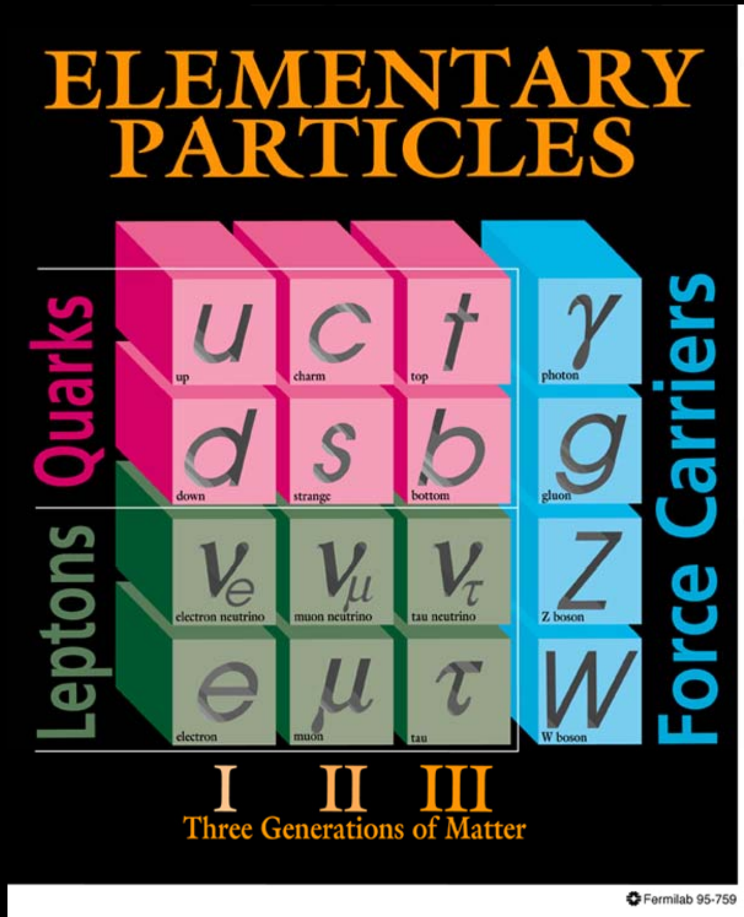
The exciting “coincidence”:

1. *We have a very accurate theory;*
2. *We know Terascale physics exists;*
3. *We will have the tools to uncover it!*

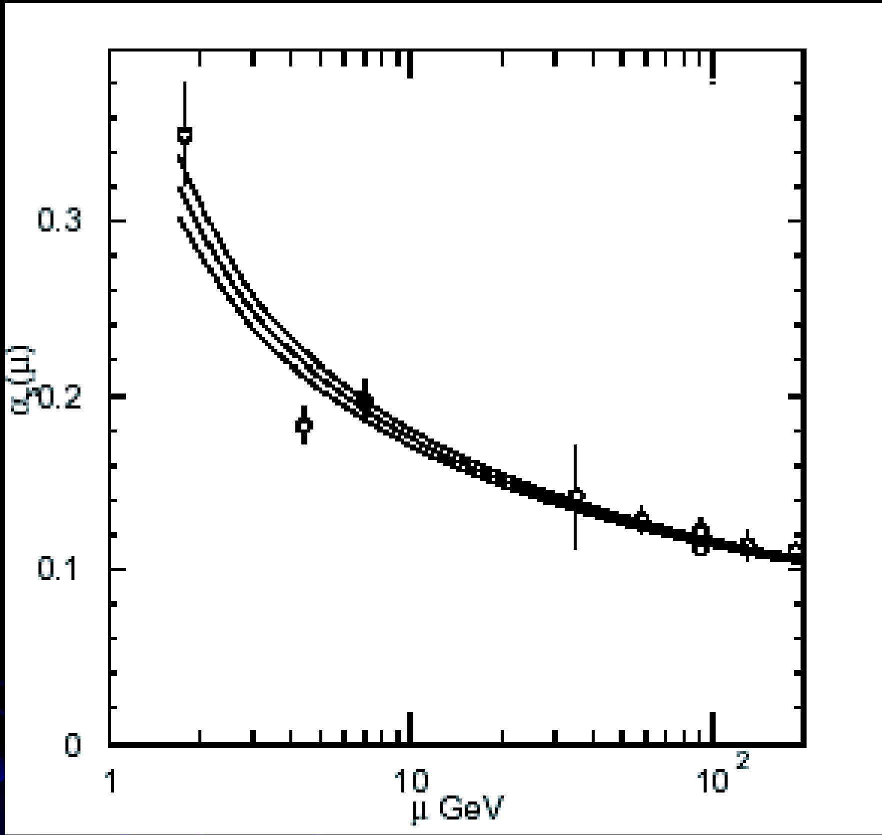
The talk is a broad-brush one.
More details in Parallels Sessions:
Morning of Feb.5.

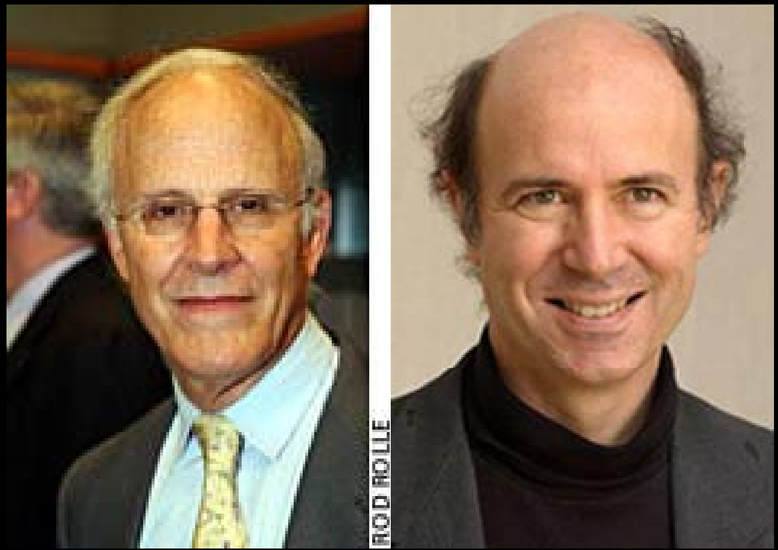
1. The elegant Standard Model

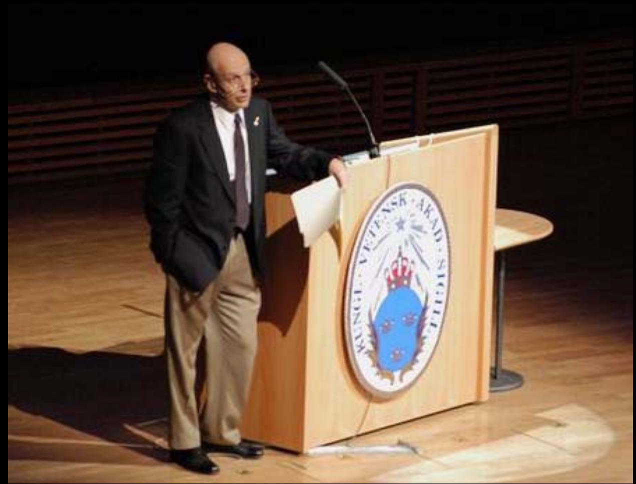
- Simple matter sector;
- Gauge principle to govern dynamics;
- Count for all HEP data;
- True triumph for physics and science !



The "strong force" becomes weaker



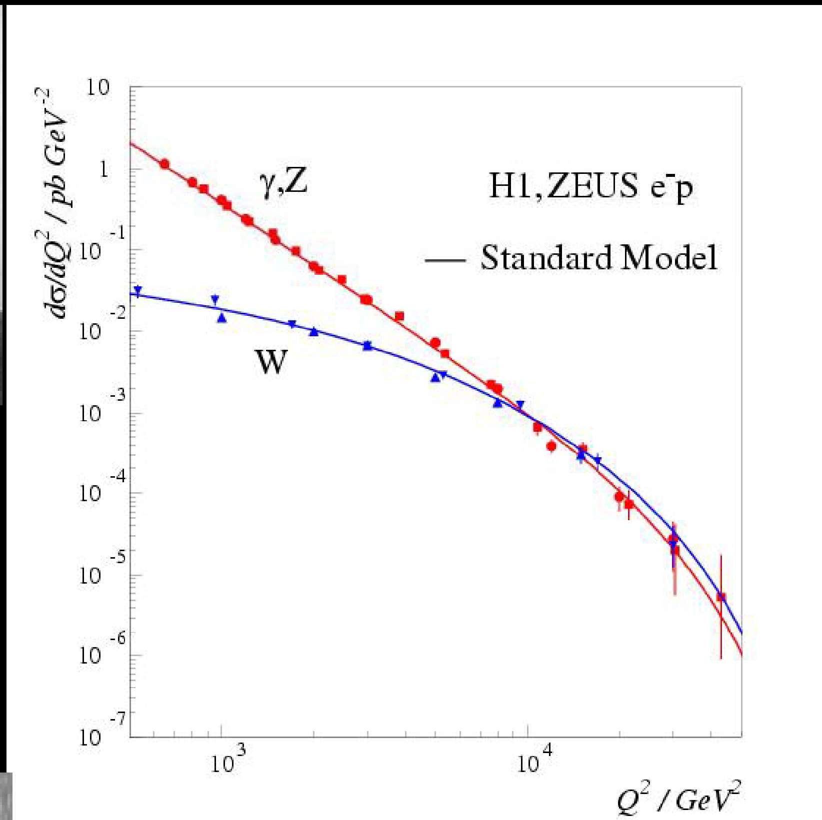




- Asymptotic freedom $\Longrightarrow$

Predictivity; "Higher" energy physics; Unification; The Early Universe

Toward a Fundamental Theory/Symmetry: Unification is a Guiding Theme



HERA

Neutral and Charged currents unify at 100 GeV

2. The Terascale Physics:

(A). Mass Quest:

Why the photon is so different from W/Z ?

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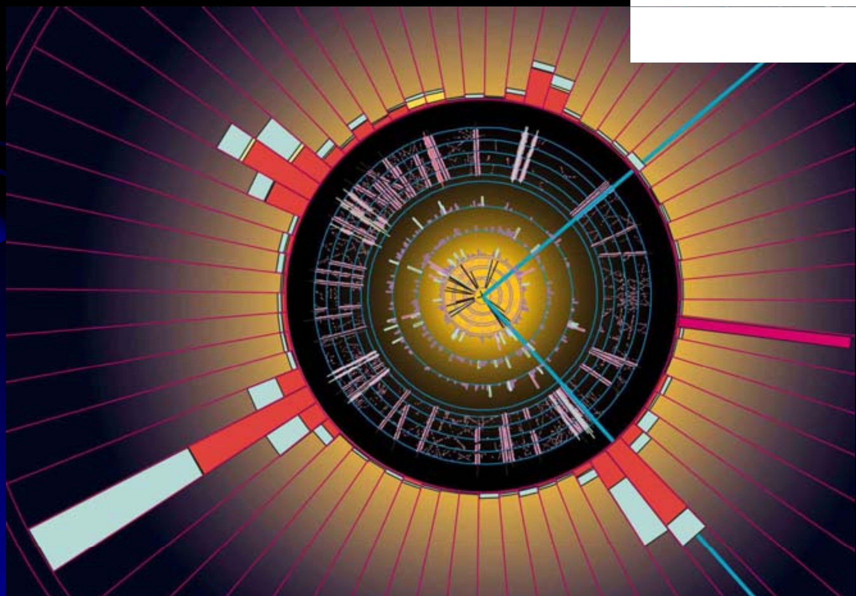

Why the top quark is as heavy as a gold atom, while neutrinos are nearly massless ?

CDF M_t=172.9 GeV

EW precision data: A light Higgs indeed?

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TIFF (LZW) decompressor
are needed to see this picture.

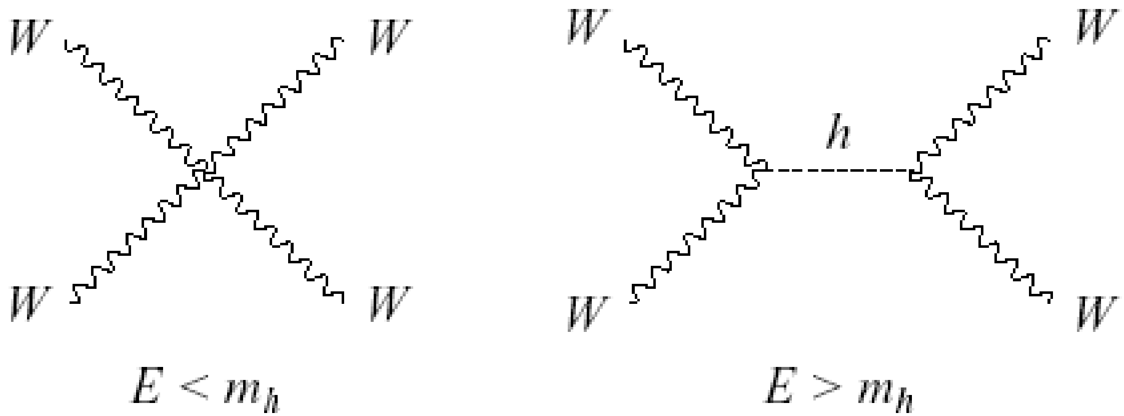
Or otherwise:

Partial-wave unitarity (probability conservation) demands:

$$m_h \text{ or alike } \lesssim \mathcal{O}(1\ \text{TeV}).$$

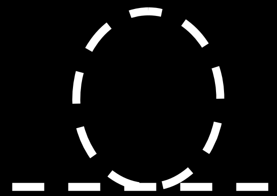
because:

- Consider the massive gauge boson scattering:



$$\mathcal{M}(W_L W_L \to W_L W_L) \sim \begin{cases} E_{cm}^2/v^2 & \text{no light Higgs,} \\ m_h^2/v^2 & \text{with a SM Higgs.} \end{cases}$$

(B). Is EW Scale Natural?



$$\delta M_H^2 \approx M_{Pl}^2$$

Quantum corrections drag weak scale to Planck scale

Tevatron/LHC Energies

To keep the Higgs boson naturally light, something else must set in below TeV.

Cancellation Mechanisms ?

- Super-symmetry (SUSY) (symmetry between *opposite* spin & statistics)

Natural cancellations: $\tilde{t}$ versus t

$\tilde{W}$ versus W

$\tilde{H}$ versus H

H_d versus H_u,

$$\Delta m_H^2 \sim (M_{SUSY}^2 - M_{SM}^2)\,\frac{\lambda_f^2}{16\pi^2}\ln\left(\frac{\Lambda}{M_{SUSY}}\right).$$

Weak scale SUSY is natural if $M_{SUSY} \sim \mathcal{O}(1\ \text{TeV})$.

- The Little Higgs idea – Strongly interacting dynamics:

  An alternative way to keep H light (naturally).

  Again, predicting new states:

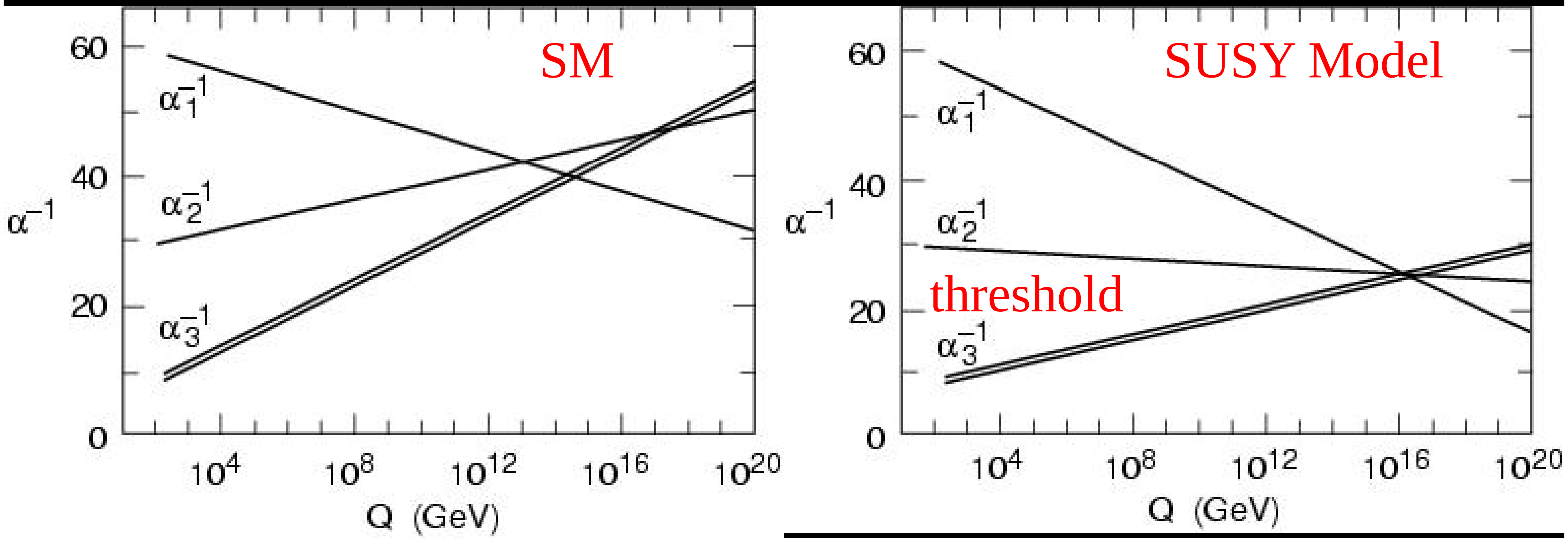
$$W^{\pm}, Z, B \leftrightarrow W_H^{\pm}, Z_H, B_H; \quad t \leftrightarrow T; \quad H \leftrightarrow \Phi.$$

(cancellation among same spin states!)

Natural EW theory predicts TeV scale new physics!

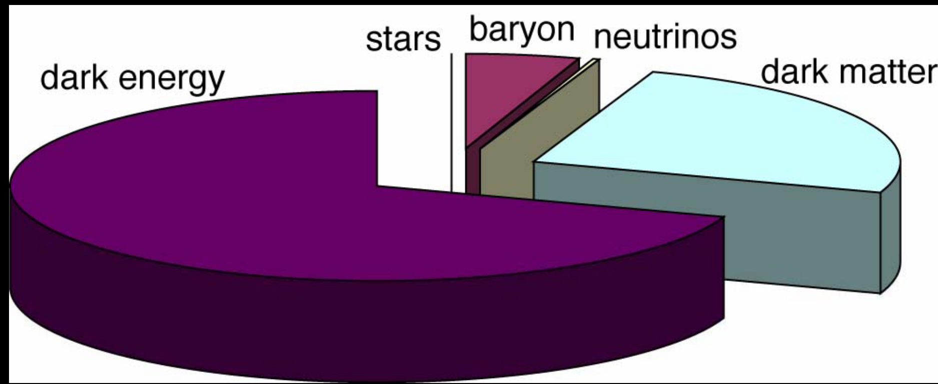
(C). Einstein's Dream of Unification

- Running of the coupling constants needs a Terascale threshold to unify.



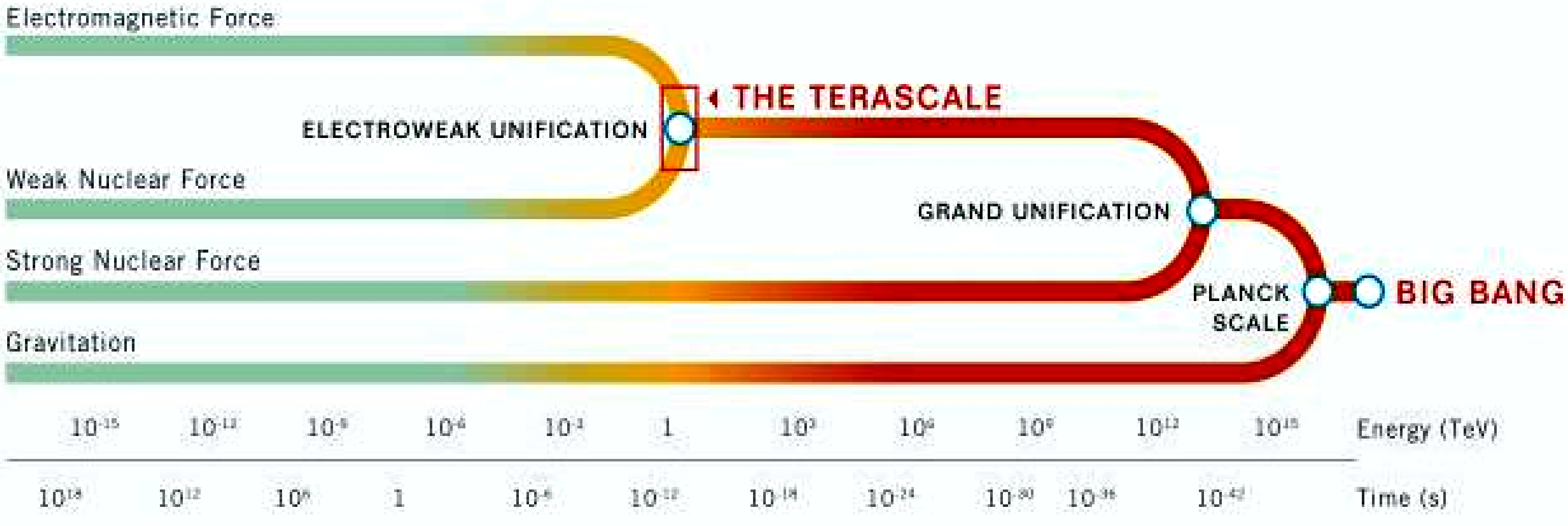
(D). The Cosmic Quests

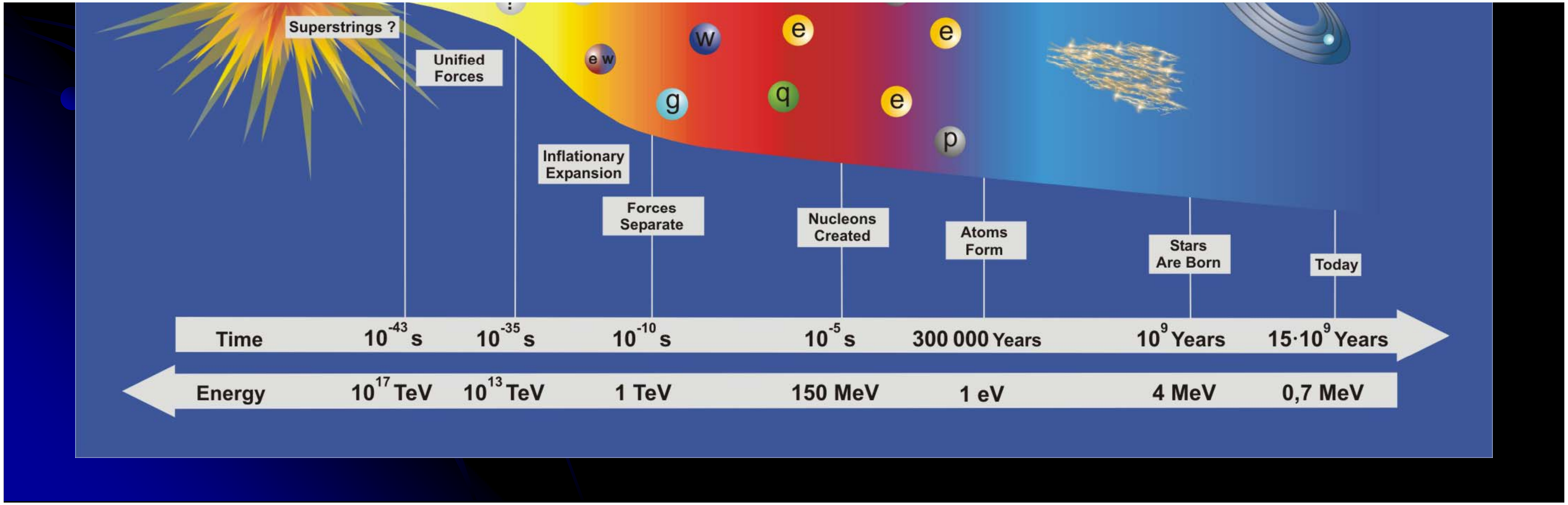
- What is Dark Matter?
  - No candidate in the Standard Model
- What is Dark Energy?
  - SM can't explain this either



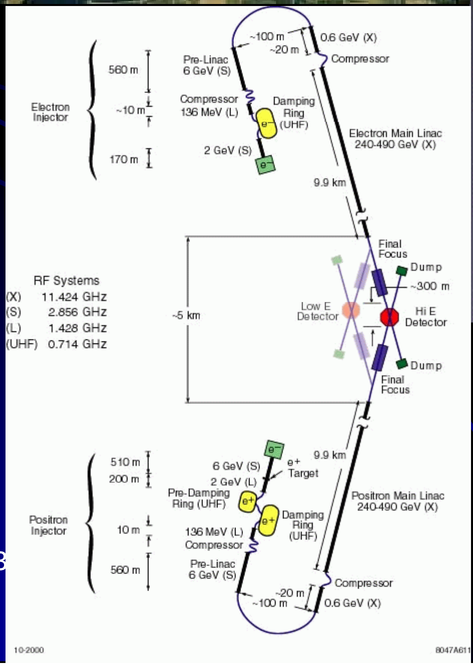
Natural DM candidates: WIMPs

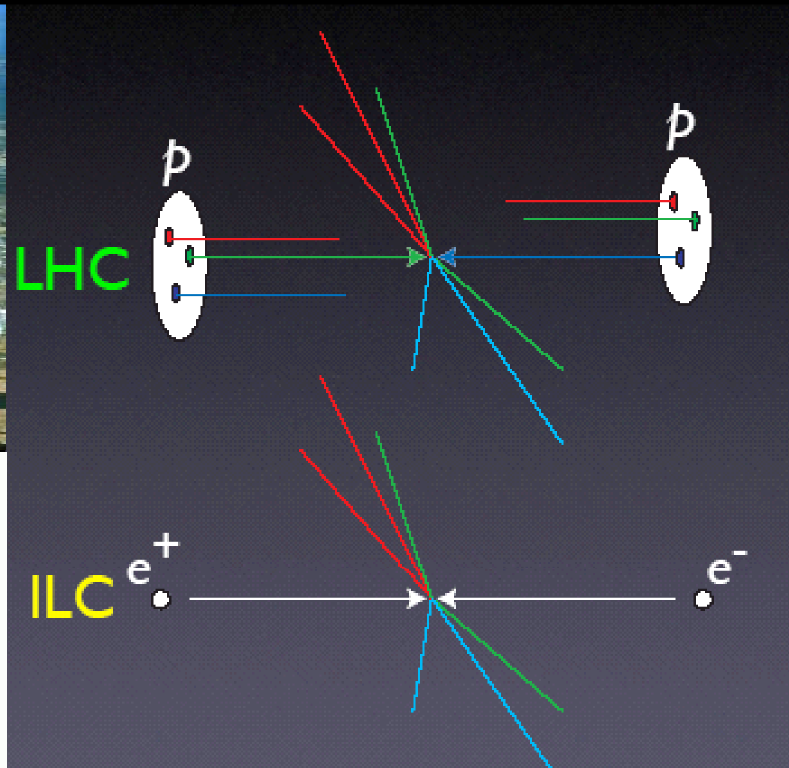
Terascale (neutral stable) particles


Electromagnetic Force
ELECTROWEAK UNIFICATION
THE TERASCALE
Weak Nuclear Force
GRAND UNIFICATION
Strong Nuclear Force
PLANCK SCALE
BIG BANG
Gravitation
10^{-15} 10^{-12} 10^{-9} 10^{-6} 10^{-3} 1 10^{3} 10^{6} 10^{9} 10^{12} 10^{15} Energy (TeV)
10^{18} 10^{12} 10^{6} 1 10^{-6} 10^{-12} 10^{-18} 10^{-24} 10^{-30} 10^{-36} 10^{-42} Time (s)


Superstrings ?
Unified Forces
Inflationary Expansion
Forces Separate
Nucleons Created
Atoms Form
Stars Are Born
Today
e w
w
e
g
q
e
p
Time 10^{-43} s 10^{-35} s 10^{-10} s 10^{-5} s 300 000 Years 10^{9} Years $15 \cdot 10^{9}$ Years
Energy 10^{17} TeV 10^{13} TeV 1 TeV 150 MeV 1 eV 4 MeV 0,7 MeV

3. Major Discoveries Ahead --- Collider experiments





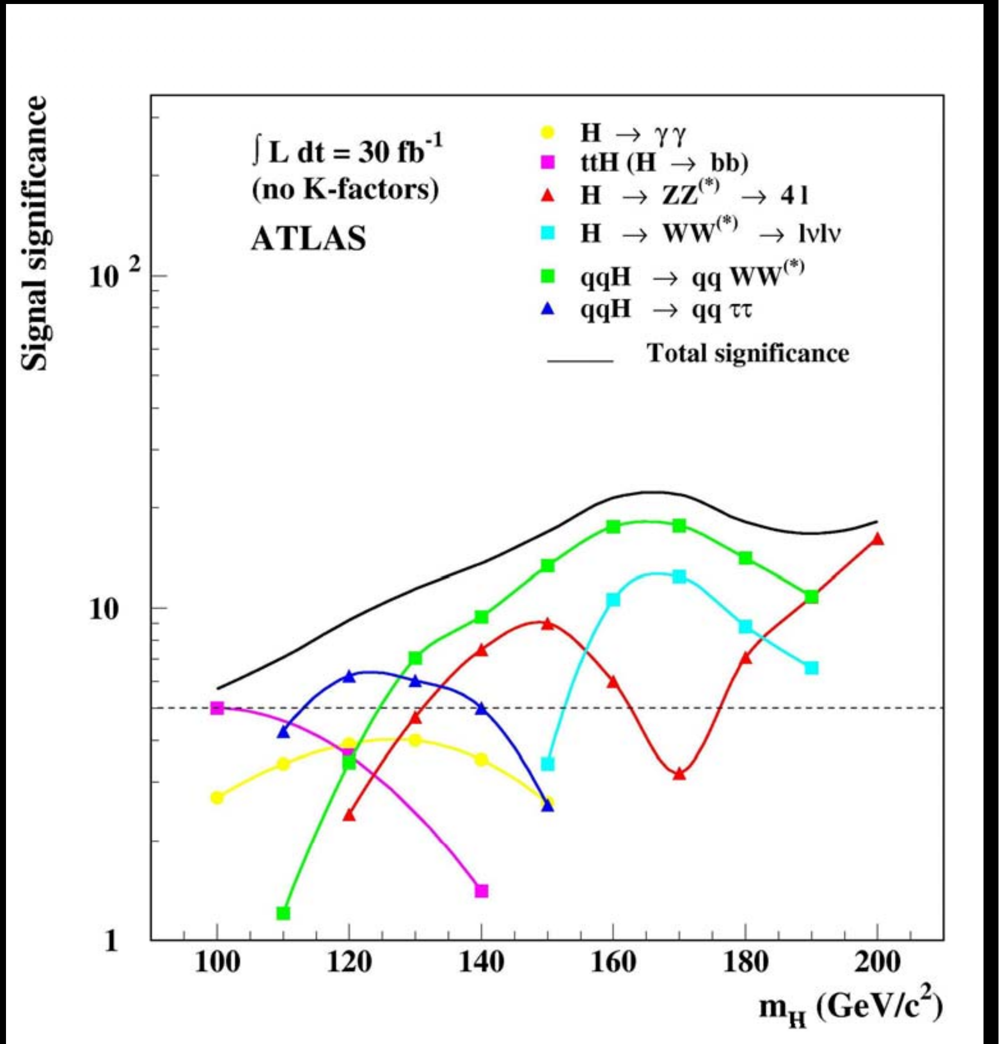
High energy;
High luminosity;
Multi-channels;
Strong force;
…

Precision physics;
Clean experiments;
Beam polarization;
…

Great complementarity !

Answer to (A): *The Higgs*

- LHC will discover SM Higgs boson if it exists
- Sensitive to m_h from 100-1000 GeV
- Higgs signal in just a few channels



More to ask:

- Is this a Higgs or something else?
- We must know:
  - mass for W,Z?
  - mass for fermions?
  - Higgs its own mass?

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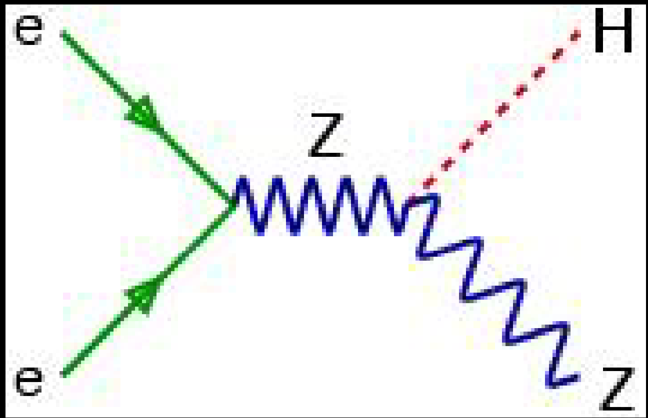
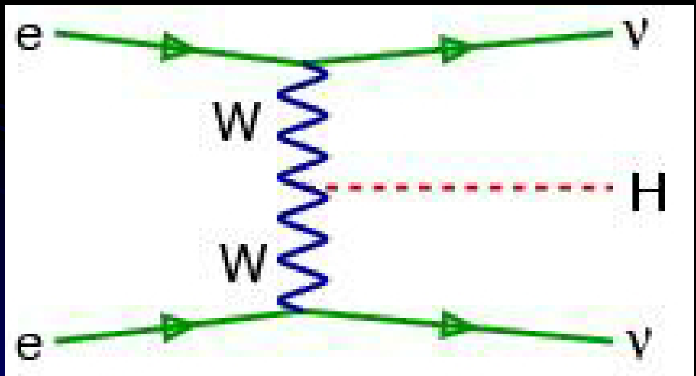
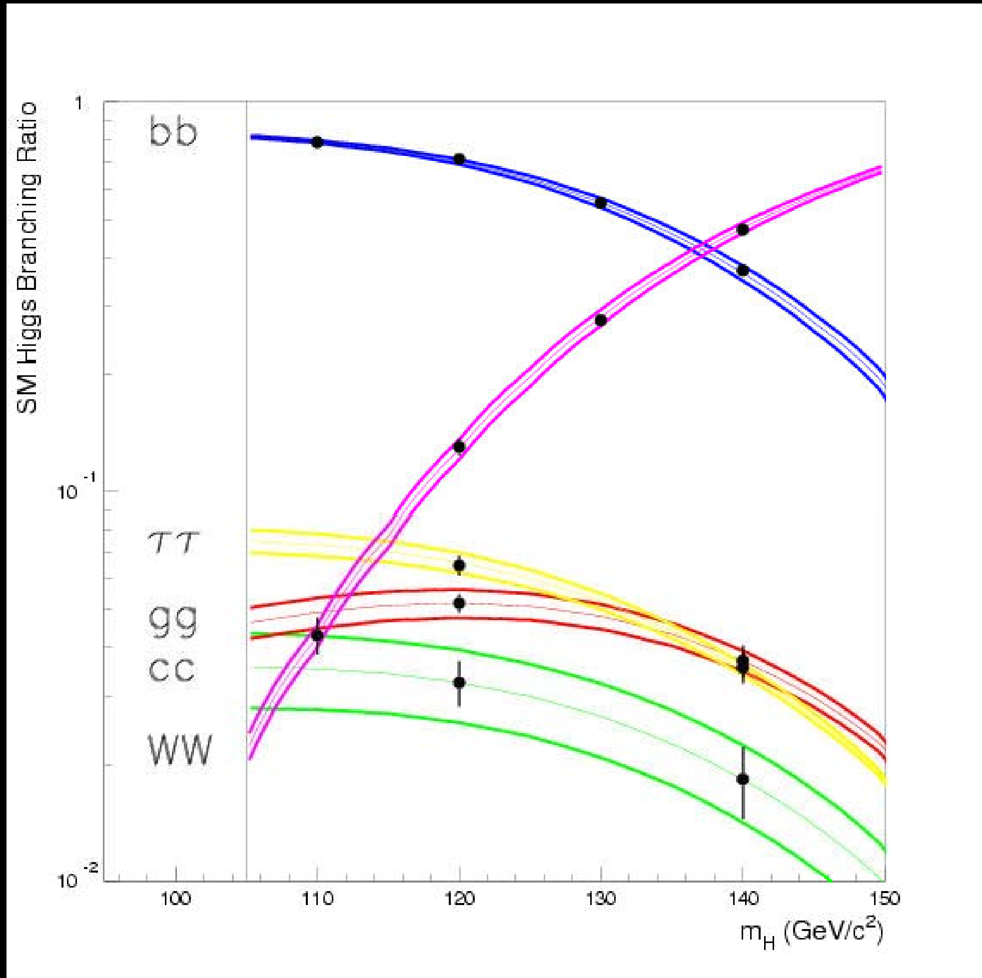
TIFF (LZW) decompressor
are needed to see this picture.

ILC merits:

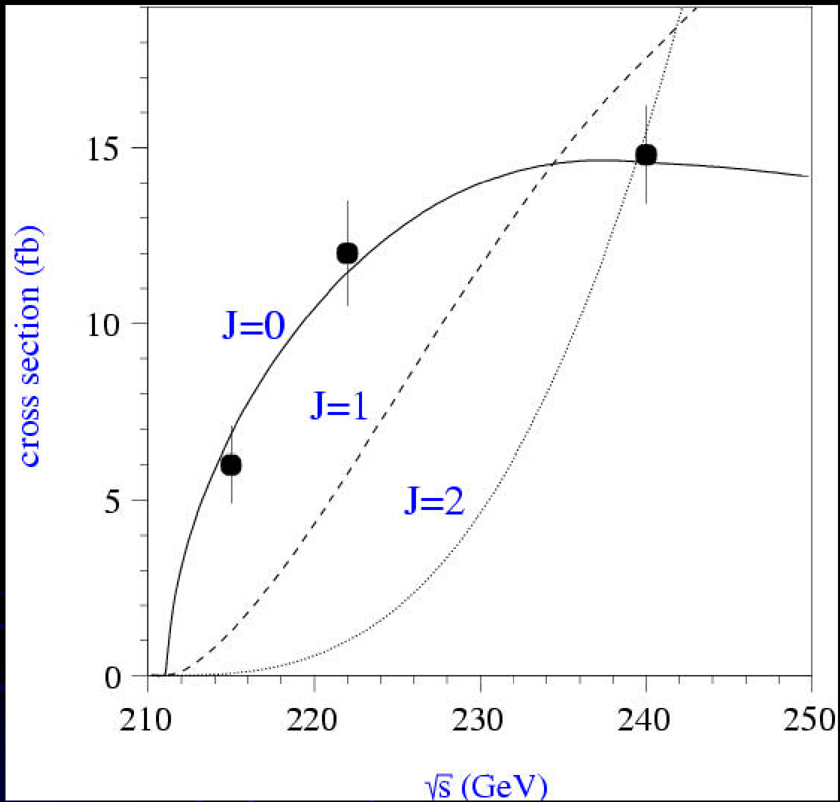






Linear Collider is the place to measure Higgs couplings!

Threshold behavior measures spin



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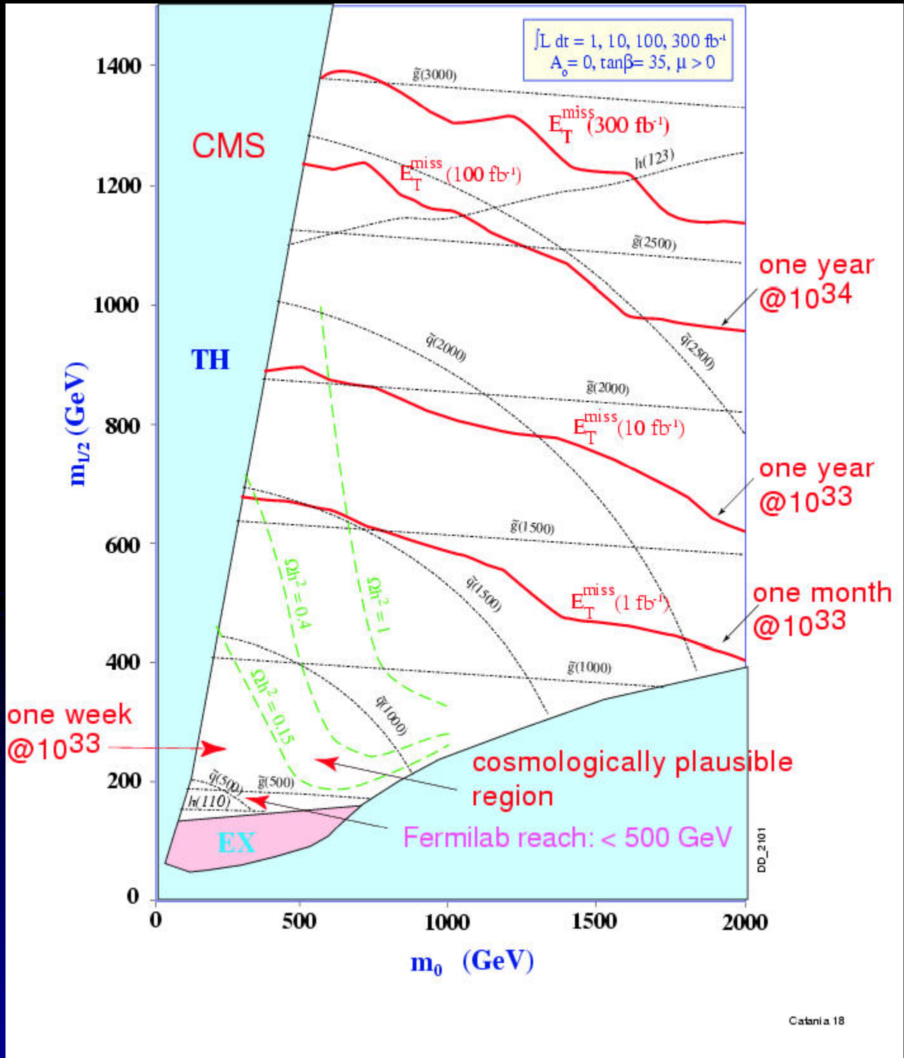
Linear collider can change initial state energy to do energy scans

Very hard to do at the LHC

Answer to (B):
TeV scale new particles



If there, discovery of SUSY signal is not TOO hard.

- Untangling spectrum is difficult $\Rightarrow$ all particles produced together:

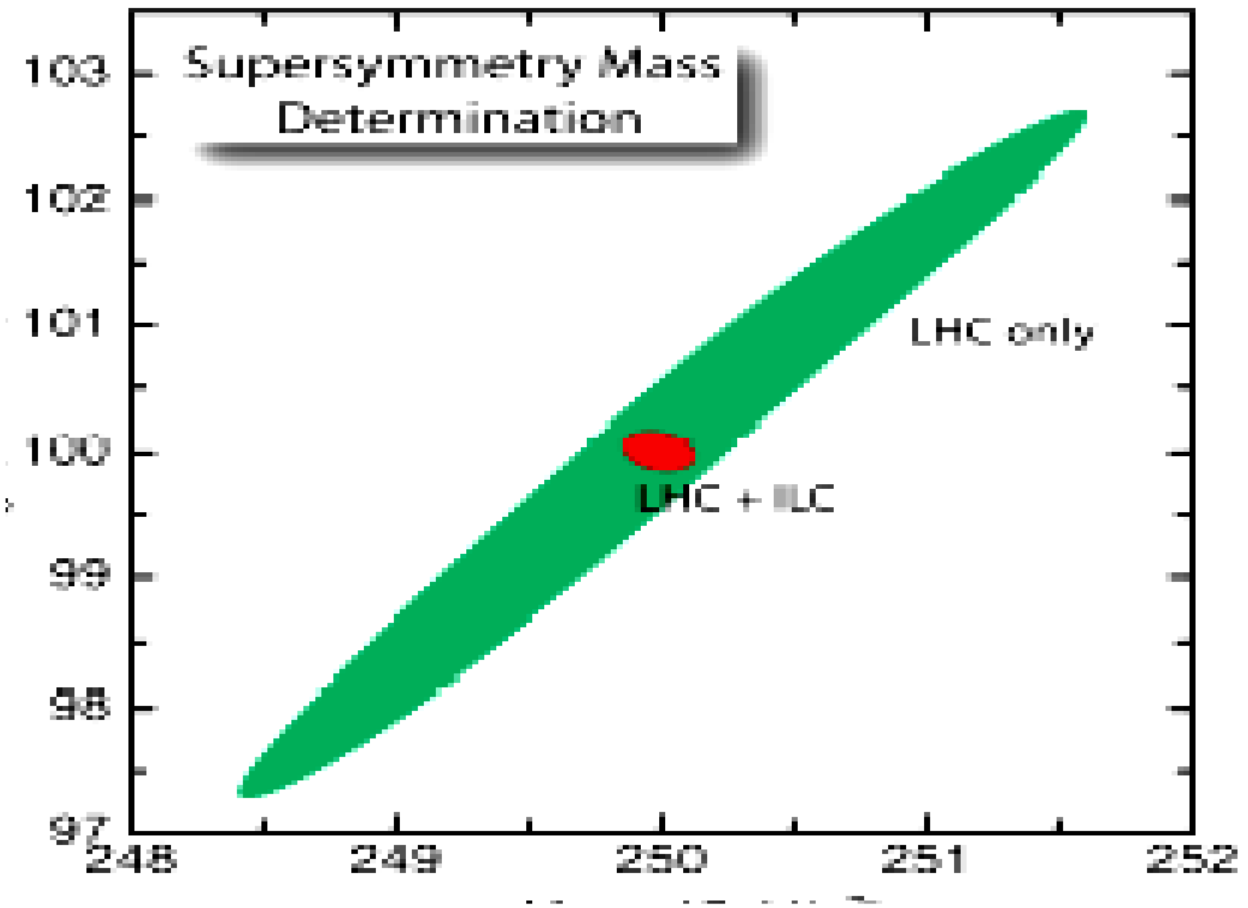
  "Inclusive signatures".

- May learn SUSY mass differences from complex decay chains:

How to "Invert the signal?"

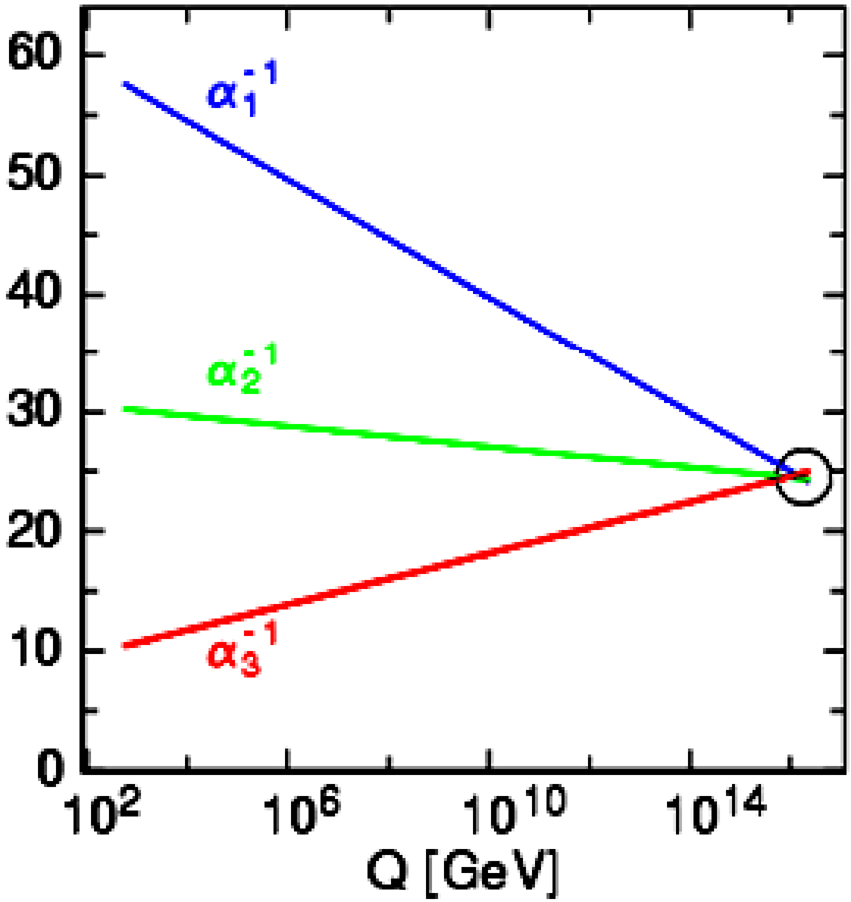
With the help of ILC:

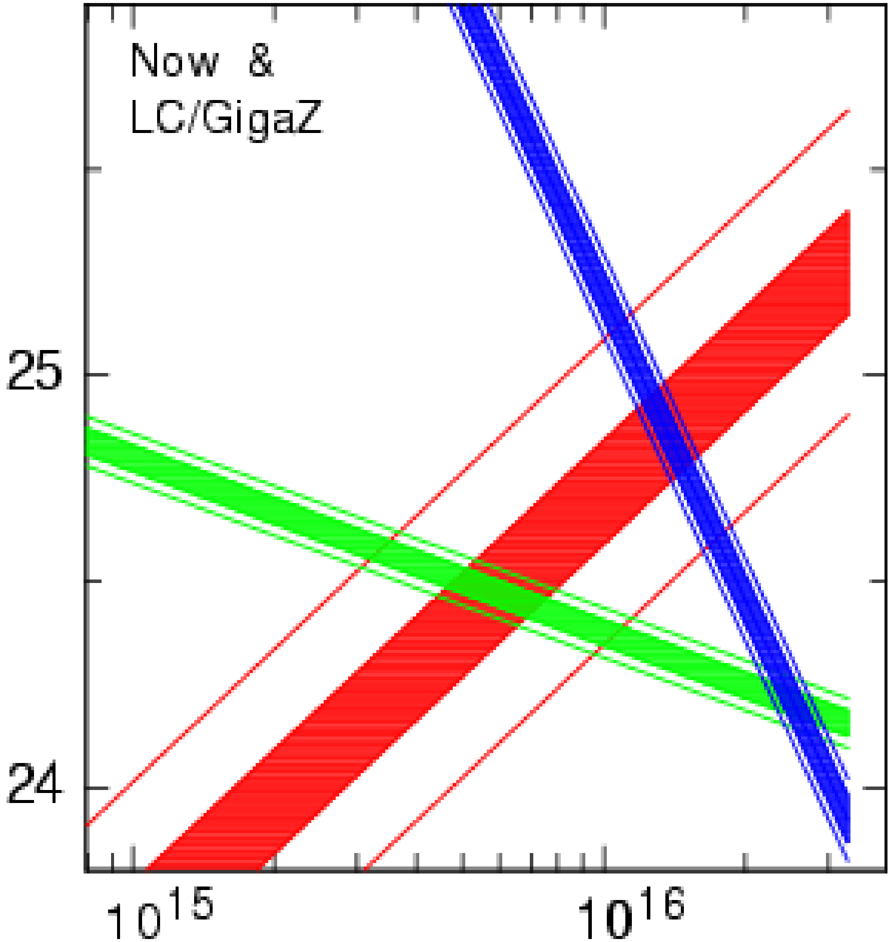
$M_{1/2}$



M_0

Answer to (C)
Consistency check for GUTs





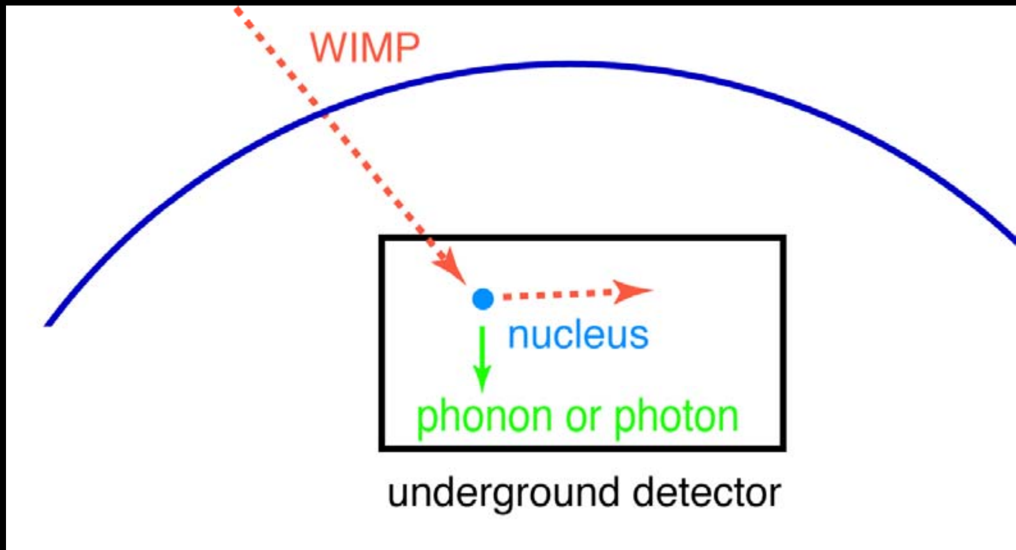
Answer to (D)

Production of particle dark matter

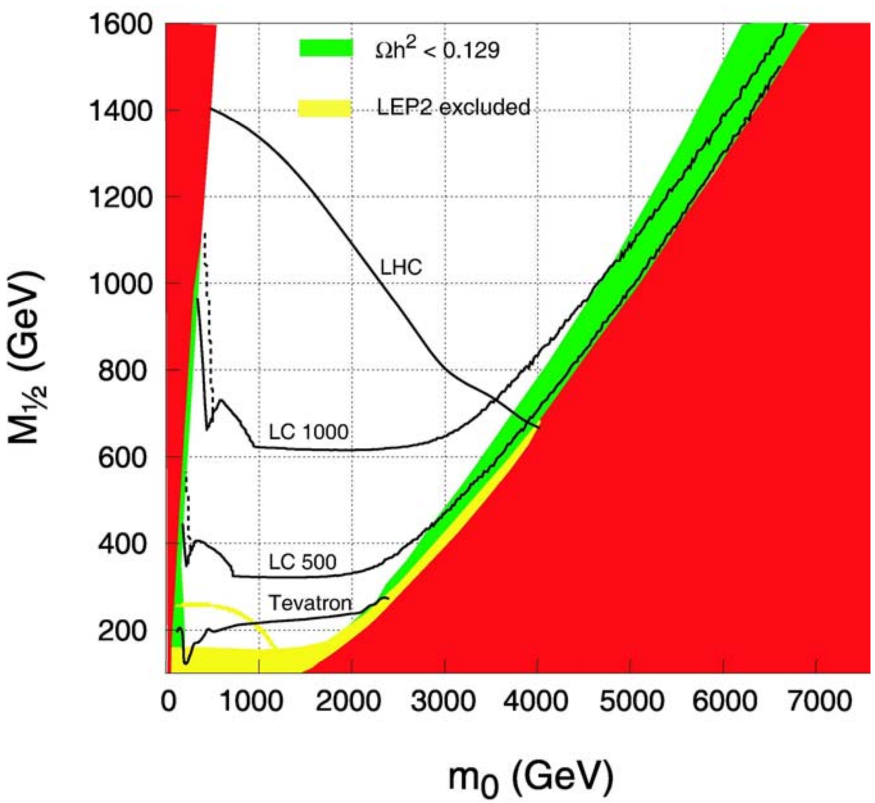
- We'd like to detect dark matter in the lab
  - To show they're in the galactic halo …
- And to produce them at an accelerator
  - To measure their properties …

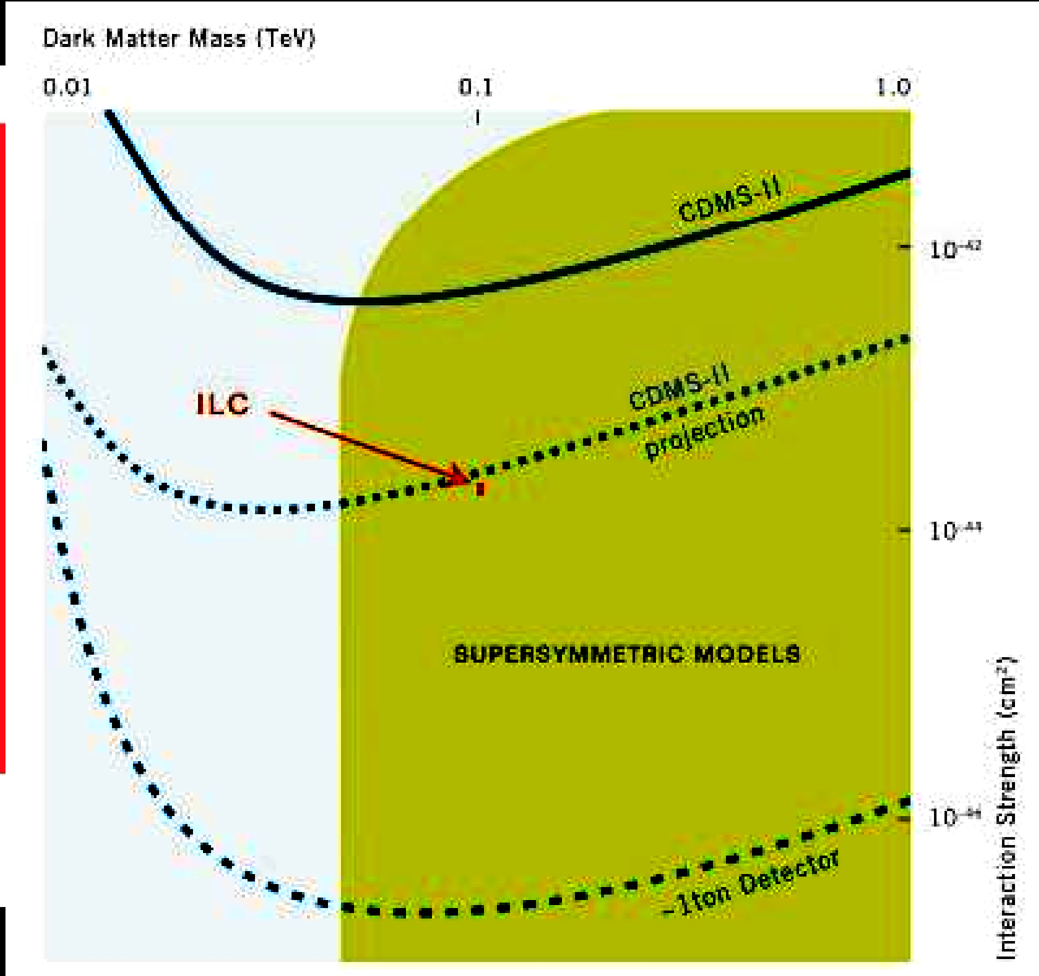
WIMP: Weakly Interacting Massive Particle

--- dark matter candidate



If LSP is dark matter, LHC and LC will complement the direct DM searches:





This has covered a lot!

The more observed at the *LHC,*

the more exciting the *ILC* would be!

However, I don't pretend to know
What exactly the LHC will find …

What IF … ?

(E). Precision measurements

Indirect searches:

Example I: *ttZ coupling*

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are needed to see this picture.

Indirect Searches:

Example II: *EW parameters / SUSY*

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TIFF (LZW) decompressor
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Indirect Searches:

Example III: *Contact interactions*

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Sensitity to

$\Lambda \sim 100$ TeV,

$\lambda \sim 10^{-19}$ cm !

Indirect Searches:

Example IV:

Anomalous WW couplings

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Conclusions

- HEP theory (SM) on solid ground;
- Terascale new physics strongly motivated;
- LHC will lead to discovery;
- ILC will be needed to sort out the picture.

ILC crucial in the LHC era !
But Keep up the hard work!