The International Linear Collider

A Telescope for the Terascale

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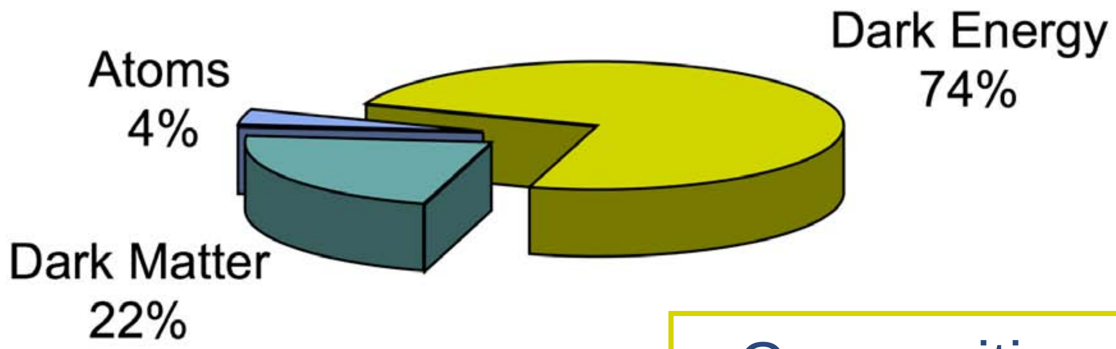
Johns Hopkins University
AAAS, San Francisco, 2/16/07

Revolution

- A revolution awaits at the Terascale
  - First hints appeared over 50 years ago
  - Recent discoveries have only increased our expectations



Composition of Universe

- It's exciting to finally have the tools we need!

Tools

- Today's accelerators are knocking on the door
  - Tevatron at Fermilab (proton-antiproton)
  - LEP at CERN (electron-positron)
  - SLC at SLAC (electron-positron)
- Tomorrow's accelerators will open it wide
  - LHC at CERN (proton-proton)
  - Proposed ILC (electron-positron)

A new era of discovery!

LHC

- The CERN LHC will lead the way
  - It has tremendous reach
- Protons are composed of quarks and gluons
  - Proton-proton collisions at 14 TeV ⇨

    Quark-quark, quark-gluon and gluon-gluon collisions at 0.5 - 5 TeV
  - Broad-band initial state!

ILC

- The ILC will offer a second view
  - It has tremendous precision
- Electrons are fundamental elementary particles
  - Electron-positron collisions with fixed energies, adjustable between 0.1 and 1.0 TeV
  - Clean and tightly controlled initial state!

LHC and ILC: Together, tools for the Terascale

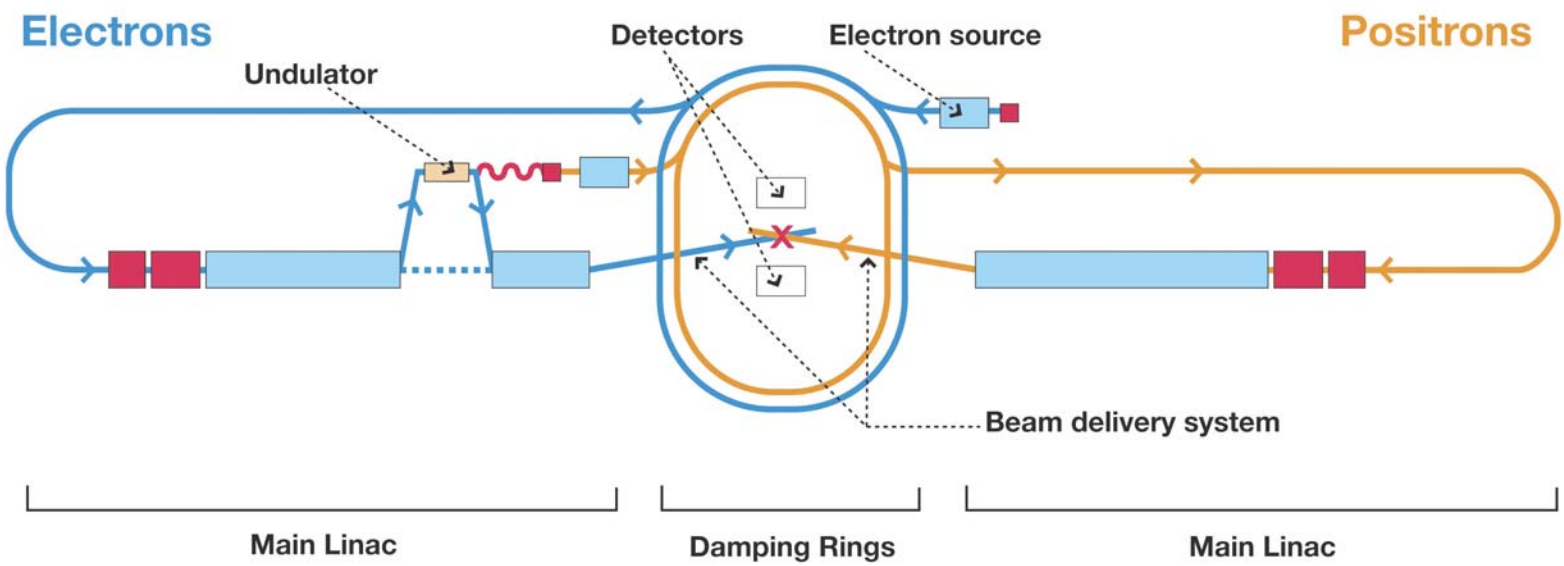
Outline

- The International Linear Collider
  - All three words are important

- In this talk …
  - I’ll tell you what it is
  - I’ll explain what it’s for
  - I’ll outline where the project stands

- And in the process, I’ll need all three words!

What is the ILC?



- Two linear accelerators, shooting intense beams of electrons and positrons, into head-on-head collisions. 30 km long; same size as LHC …
  - Initial phase 500 GeV, upgradeable to 1 TeV

Why electrons?

- What does the ILC's clean and well-characterized initial state bring to the table?
  - In short: a lot!
  - History is full of examples …
- With two independent probes – protons and electrons, we learn much more than we could learn with just one
  - Astronomers survey the universe in different wavelengths
  - Particle physicists use different initial states

Why is it linear?

- Circular machines suffer synchrotron radiation
  - Power loss:

$$\frac{dP}{dt} \propto \frac{E^4}{m^4 R^2}$$

  - Electrons are much lighter than protons, so synchrotron radiation is a show stopper for circular machines at Terascale energies
  - Three times the energy ⇨ nine times the radius!

How does it work?

1. Create dense swarms of 20 billion electrons and 20 billion positrons
2. Collect them into bunches and transport them to the ends of the linacs
3. Accelerate them to close to the speed of light
4. Focus the bunches to spots 5 nm high
5. Collide them at interaction point, where the matter and antimatter annihilate into bursts of pure energy

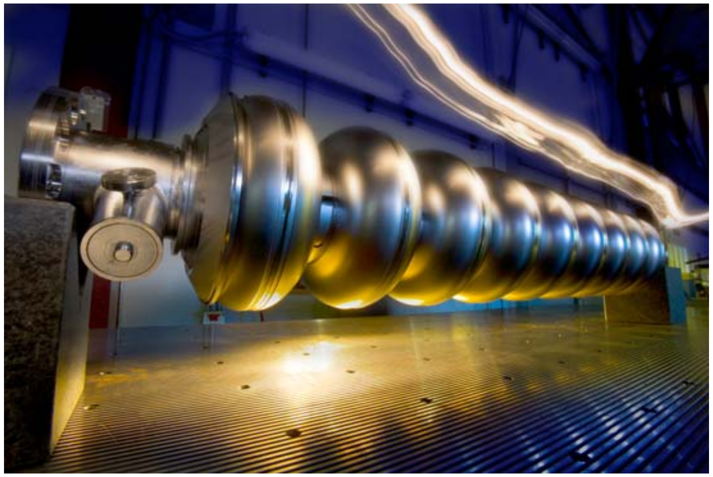
- Control the energy of the beam, the shape of the bunches, and the polarization of the electrons!

By the numbers

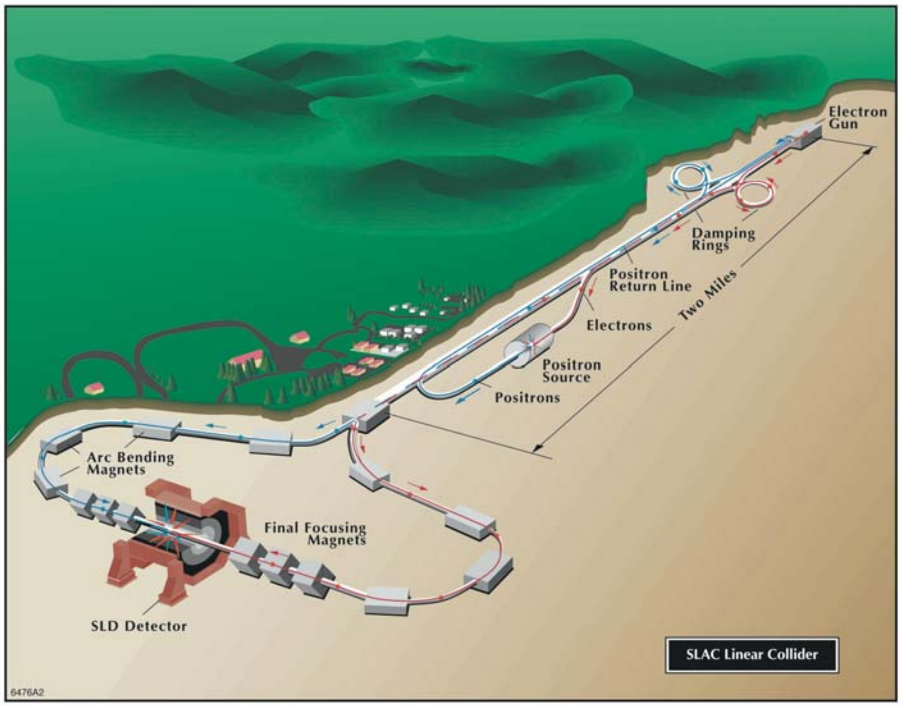
- Each beam contains 2625 bunches of 20 billion electrons or 20 billion positrons
  - Producing 14,000 collisions per second
- Each linac is built from 8000 superconducting niobium cavities, cooled to 1.8K
  - Accelerating particles 31.5 MV/meter
- Total power consumption:

  230 MWatt

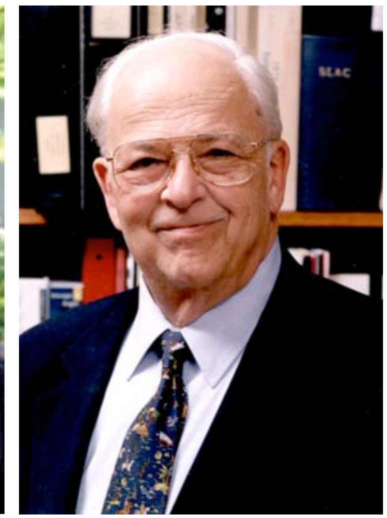
Tour de force!



Prototype: SLC



Stanford Linear Collider



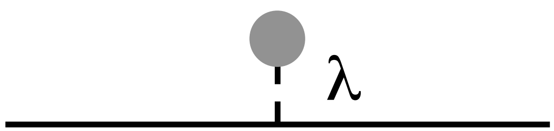
- One linear accelerator, boosting alternate bunches of electrons and positrons, brought by arcs into head-on-head collisions. 3 km long

Case studies

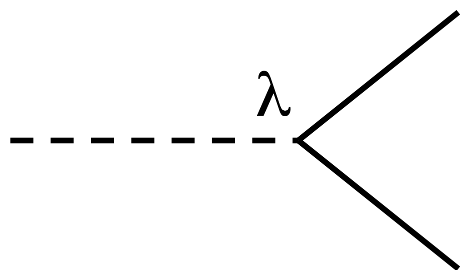
- The case for the ILC can be made by looking at various examples
  - Higgs and its Imposters
  - Extra Dimensions and their Avatars
  - Alchemy of Dark Matter
  - Ultimate Unification / Einstein's Dream
- In each case, the particles tell stories that go far beyond the particles themselves
  - And the ILC has an important role to play …

Higgs

- The Higgs is different
  - A spin-zero boson that fills the vacuum
    - Bose-Einstein condensate!
- It is a radically new kind of particle
  - Responsible for the microphysical origin of mass



$$m_f \propto \lambda v$$

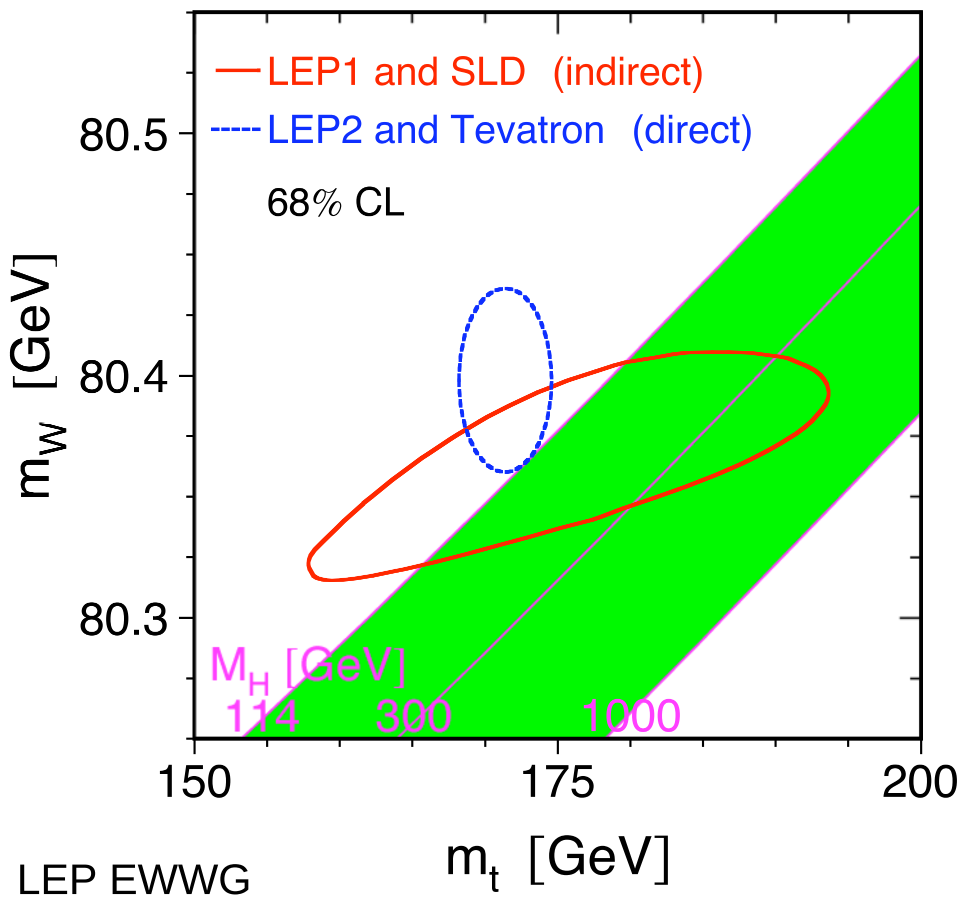


$$\Gamma_f \propto \frac{\lambda^2}{M}$$

Masses and decay rates are related!

Higgs

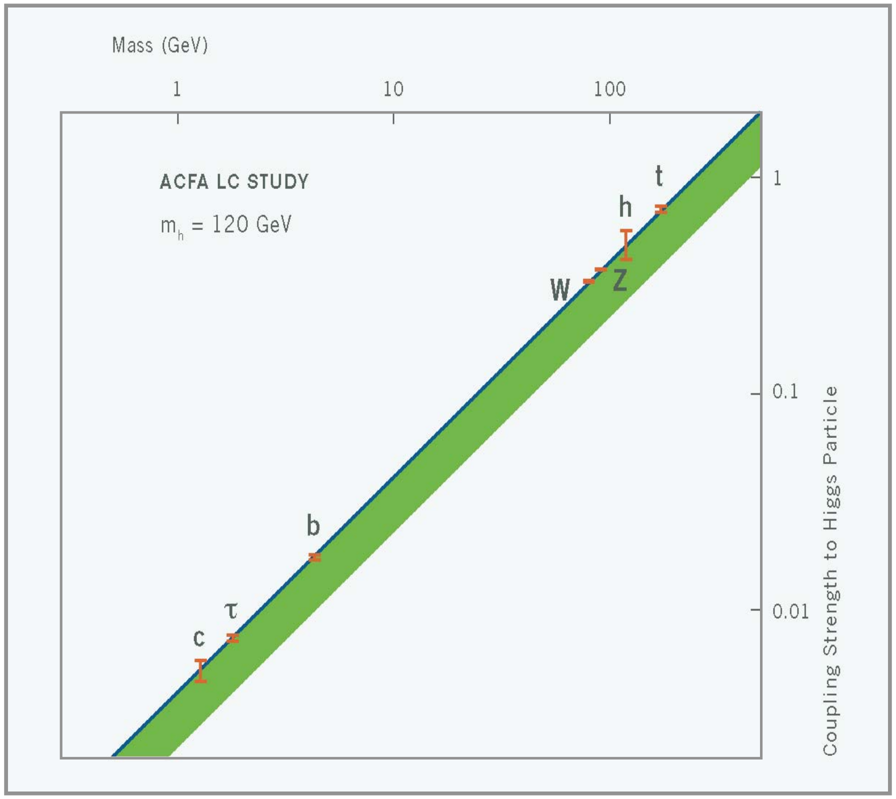
Precision Measurements



LEP EWWG

- Present-day experiments suggest that the Higgs is close at hand
  - Its mass is below 200 GeV
- Well within range of the 500 GeV ILC …

Higgs

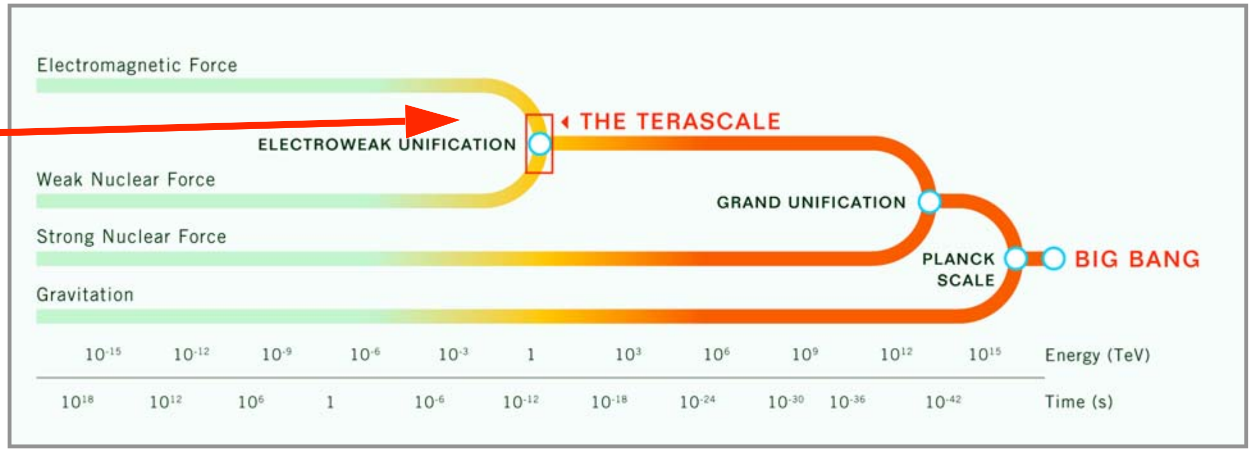


Higgs Couplings at ILC

- But is a "Higgs" the Higgs? Is it the *only* Higgs?
  - Does it have the correct spin?
  - Does it have the correct couplings?
  - Does it mix with other spin-zero particles – such as radions?
- We need experiments to know for sure!

Extra Dimensions

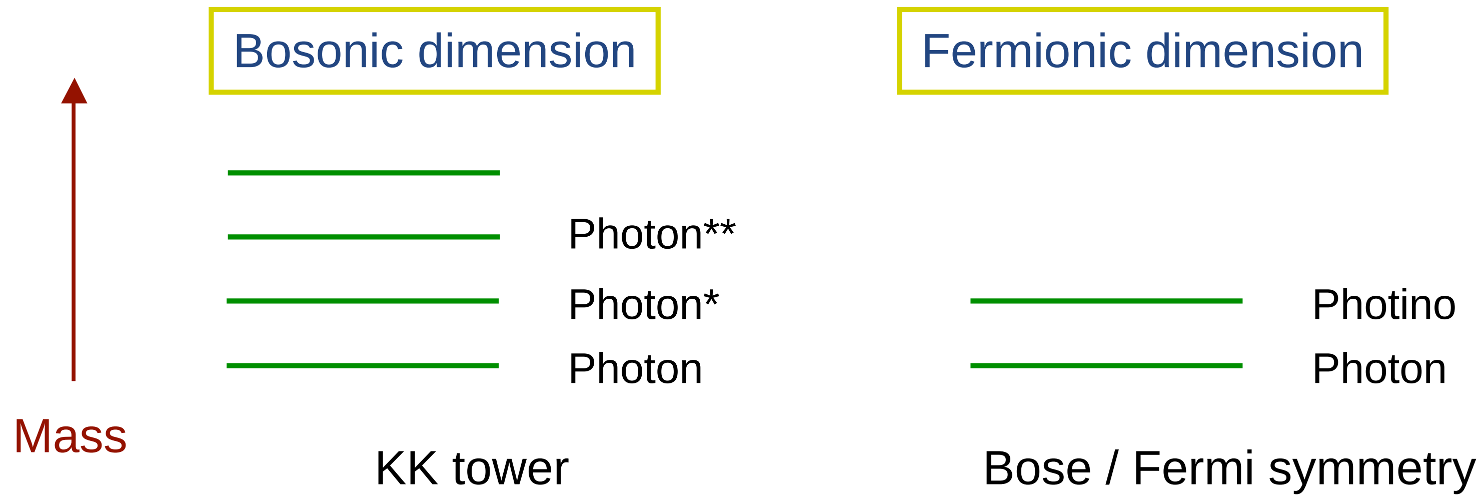
Terascale



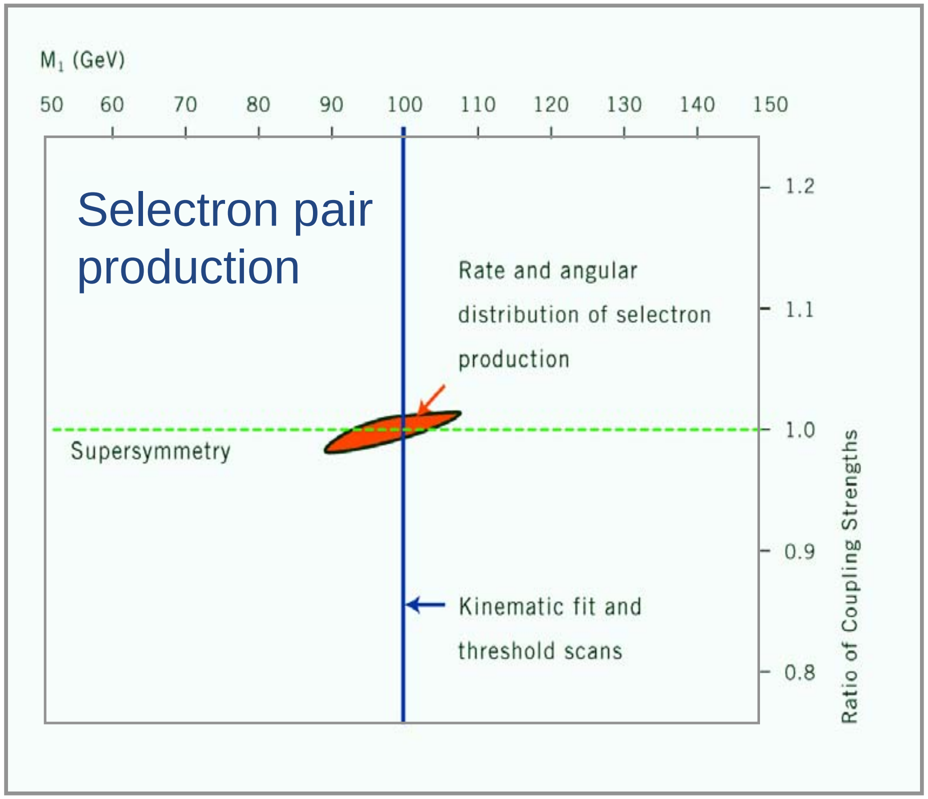
- The Terascale is where EW unification occurs
  - Of course, the Higgs. But is there more?
- Many theories of EW unification involve exotic new physics
  - Even new dimensions of space …

Extra Dimensions

- Extra dimensions come in two types:
  - Fermionic ⇨ Supersymmetric partners
  - Bosonic ⇨ Kaluza-Klein partners
- In each case, they show up as new particles!



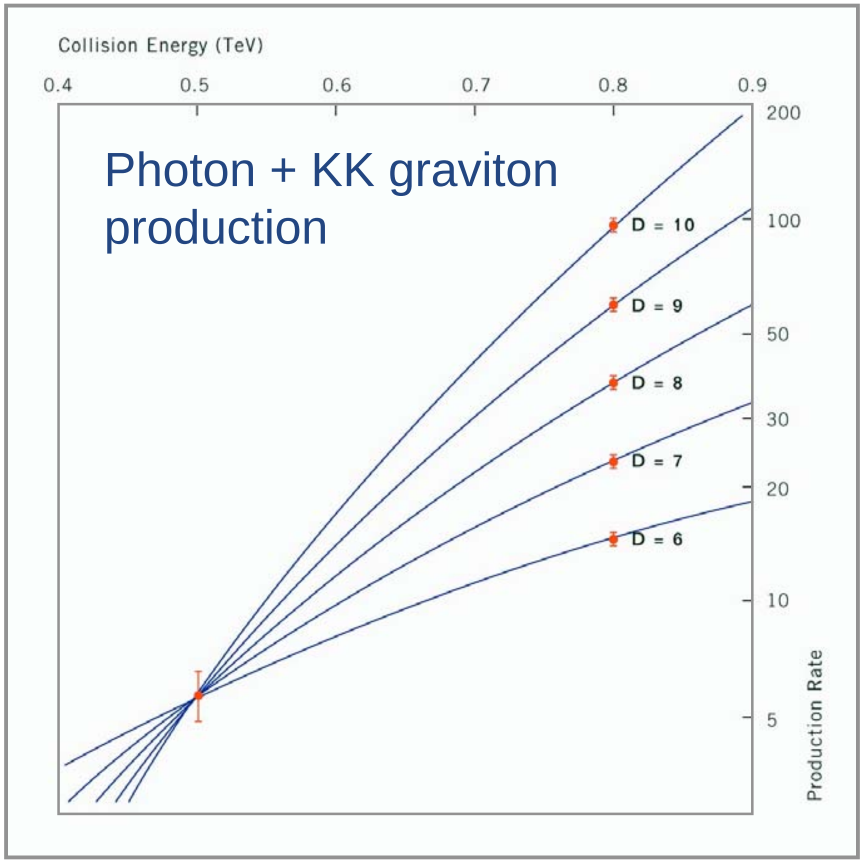
Supersymmetry



SUSY Couplings at ILC

- But are they SUSY?
  - Does they have the correct spins?
  - Does they have the correct couplings?
  - What are their masses?
- The ILC makes model-independent measurements. It is well-suited to SUSY signatures!

Bosonic Dimensions



Dimension Counting at ILC

- But are they the sign of a new dimension?
  - Does they have the correct spins?
  - Does they have the correct couplings?
  - What are their masses?
- How many hidden dimensions are there?
- The ILC is well-suited to missing-energy signatures

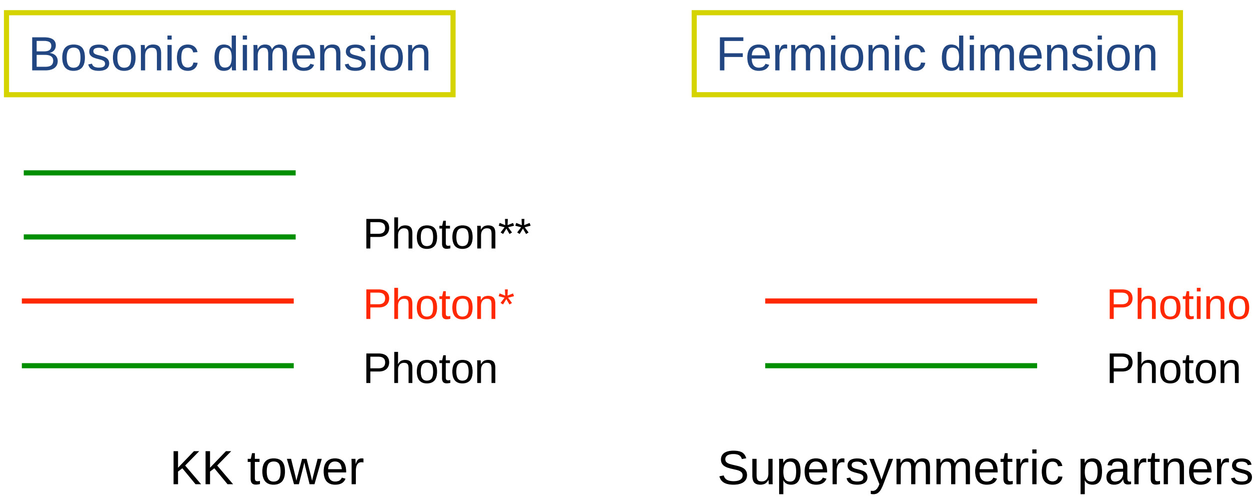
Dark Matter

- The astrophysical and cosmological evidence for dark matter is overwhelming. But what is it?

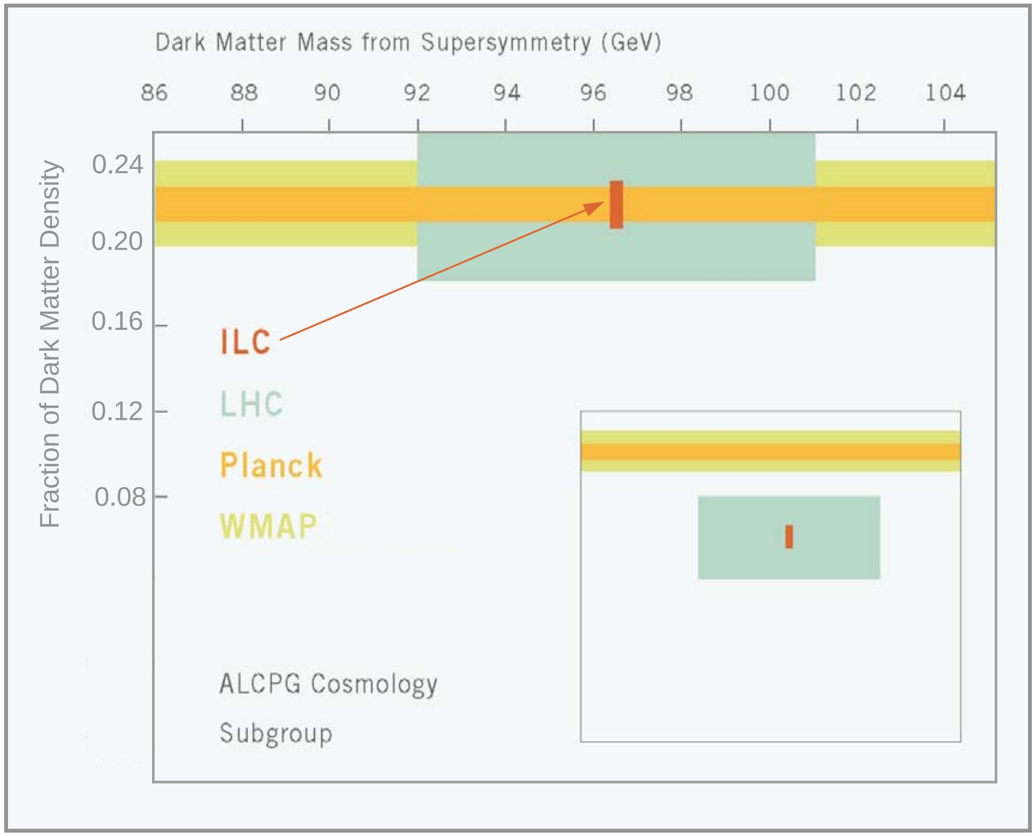
Chandra / Hubble
⇨ X-ray / optical synergy!

Dark Matter

- Most theories of EW unification have viable dark matter candidates
- For example, the lightest KK particle or the lightest SUSY particle can do the job



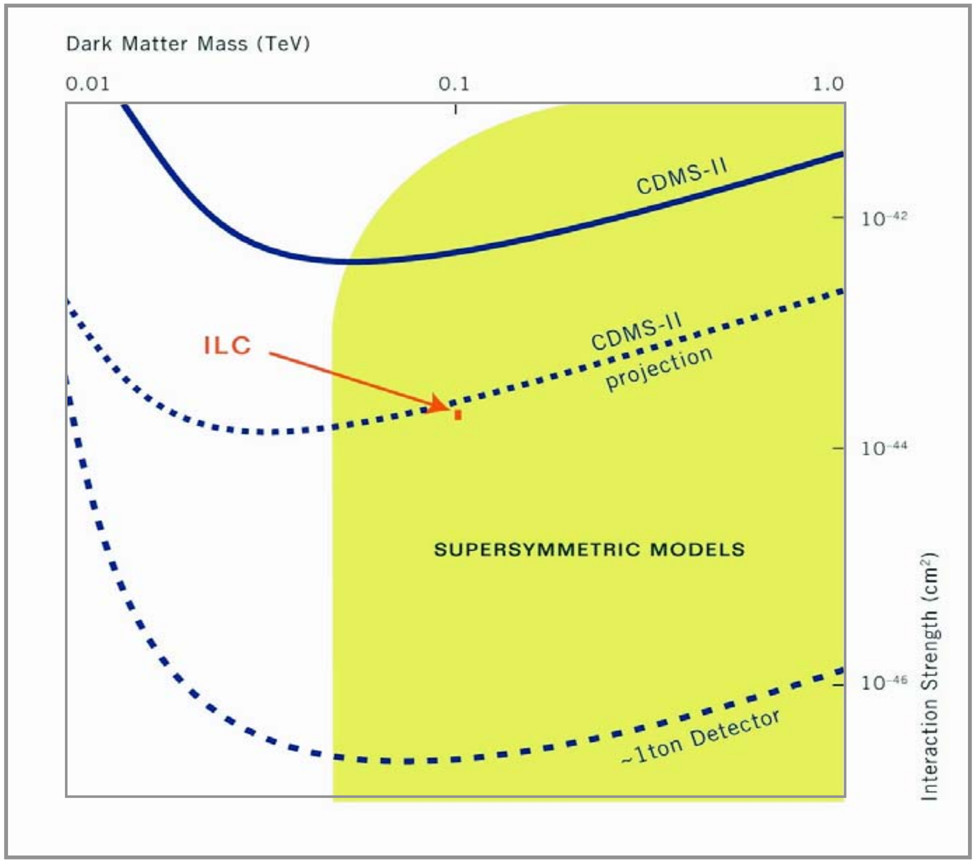
Dark Matter



Cosmic Concordance

- But are they official dark matter particles?
  - What are their masses?
  - What are their cross sections?
- How much of the dark matter would they make up?
- As before, the ILC is well-suited to the task

Dark Matter

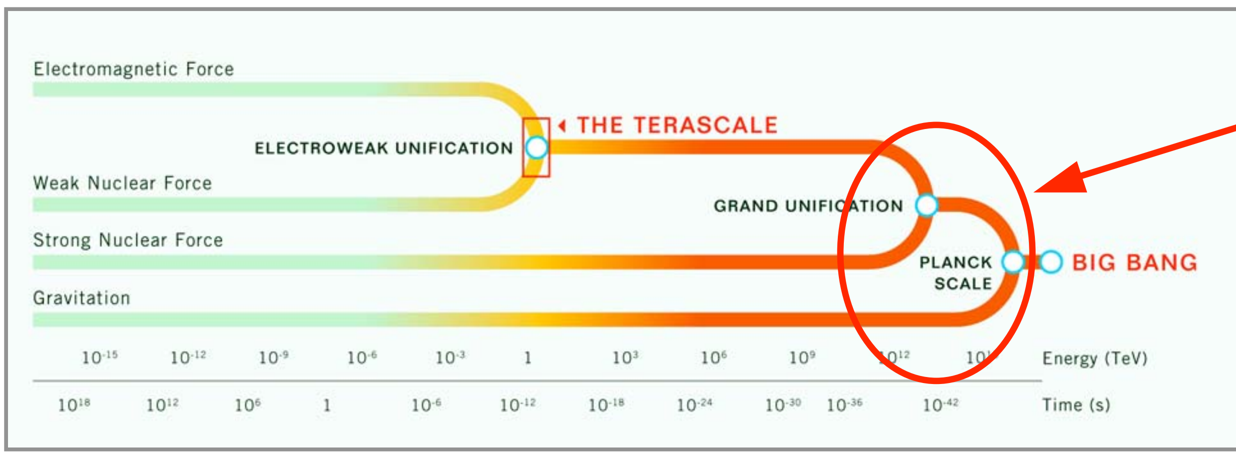


Dark Matter Direct Detection

- Of course, one wants a triple check:
  - Astrophysics and cosmology
  - Accelerator production
  - Direct detection
- Is the dark matter candidate actually in our galactic halo?

Ultimate Unification

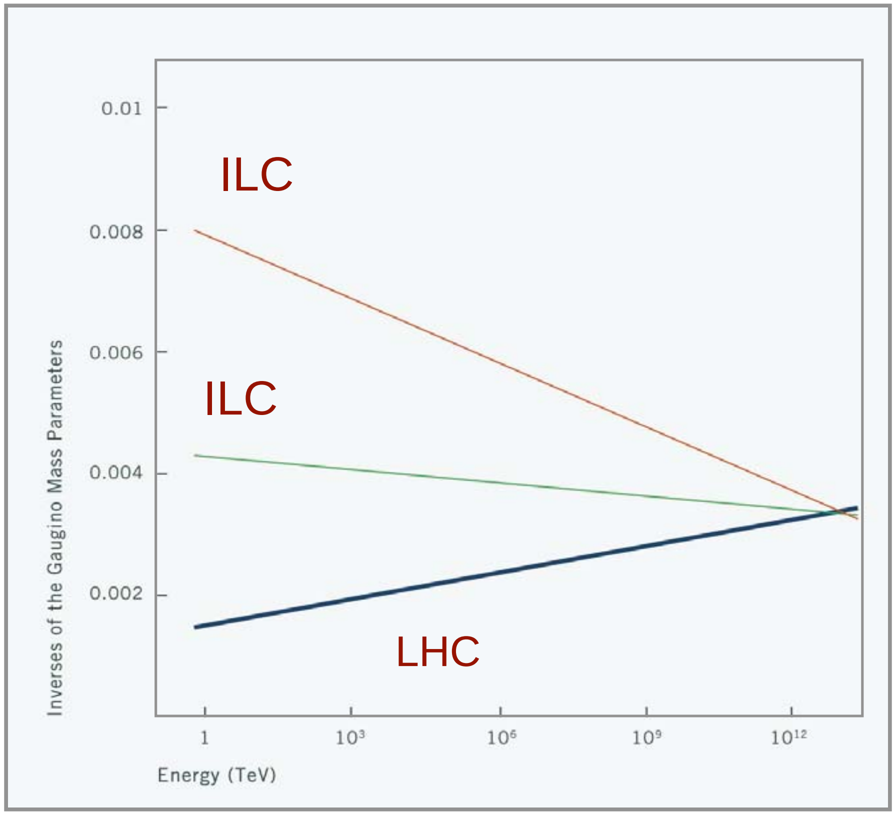
- Because of its great precision, the ILC is sensitive to tiny quantum effects that let it act as a telescope to energies way past the Terascale
  - It can probe physics far beyond 1 TeV



Ultimate Unification!

- Unification exhibits LHC / ILC synergy!

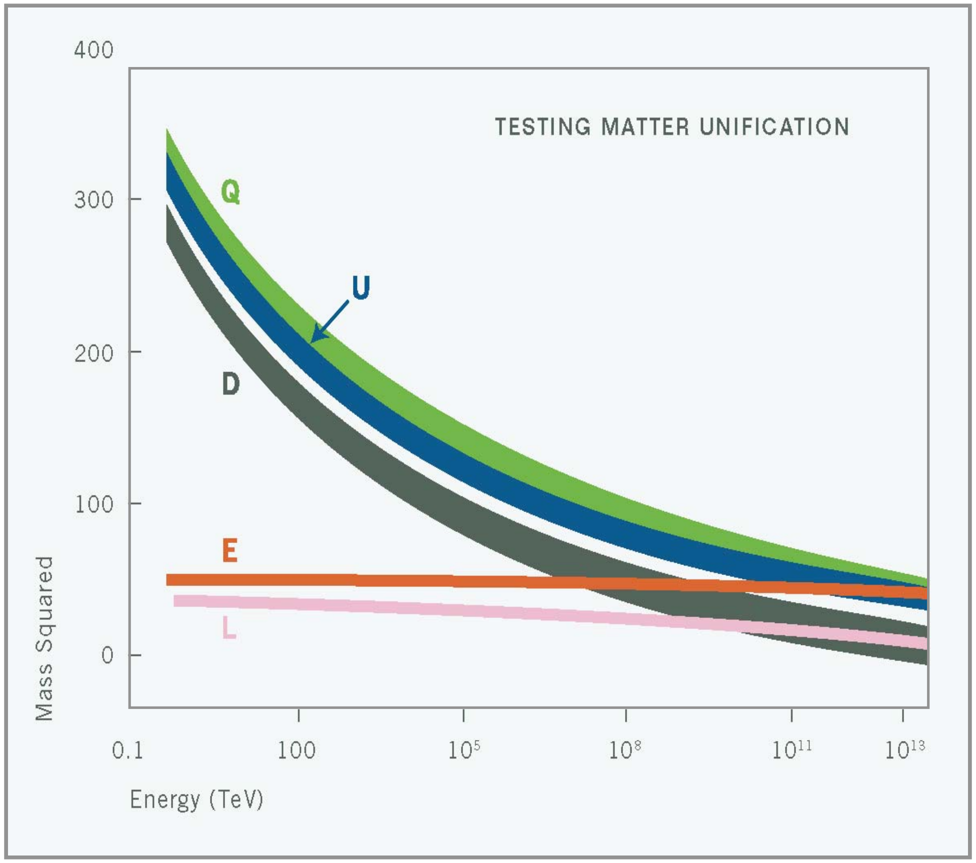
Ultimate Unification



SUSY Gaugino Unification

- In SUSY, the gauge couplings unify. Do the gaugino masses?
  - LHC ⇨ gluino
  - ILC ⇨ wino, zino, photino
- Together, the LHC and the ILC can illuminate physics far beyond the Terascale

Ultimate Unification

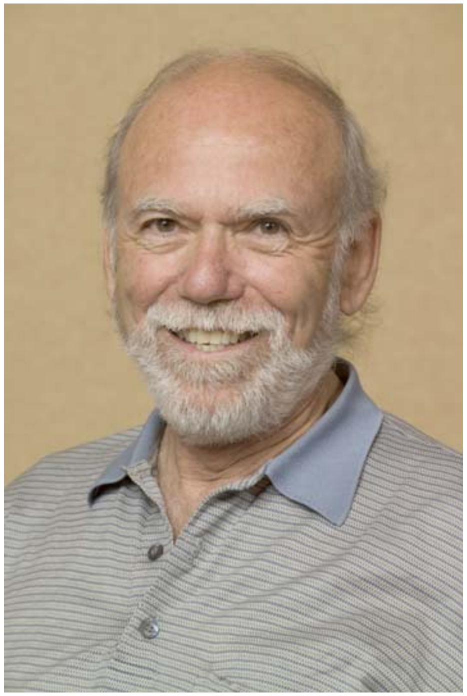


Quark and Lepton Unification

- Do the quark and lepton couplings unify as well?
  - Q, U, E
  - L, D
- They had better! It's an essential feature of most unified theories …
  - Test enabled by the ILC

Next steps

- The ILC is an international project, proposed by physicists from Europe, Asia and the Americas
  - The scope of the project is too large for any one country or region
- It is being run by a Global Design Effort, led by Barry Barish of Caltech
  - The GDE directs over 100 universities and laboratories around the world on ILC R&D. It involves over 1000 physicists in its work



Next steps

- The GDE has just met in Beijing, where it released its Reference Design Report, with a preliminary cost for this global project
  - Shared Value
    - 4.9B ILC Value Units*
  - Site Dependent Value
    - 1.8B ILC Value Units
  - Labor
    - 13k person-years

* 1 ILC Value Unit = 1 US$ on 1/1/07

Major Accomplishment!

In the news!

Le Monde.fr

Sciences

Un effort mondial est requis pour le dernier des accélérateurs géants

LE MONDE | 15.02.07 | 15h52 • Mis à jour le 15.02.07 | 15h52

INTERNATIONAL Herald Tribune

宇宙創生解明へ、巨大粒子加速器は７７８０億円

YOMIURI ONLINE | 読売新聞

DIE ZEIT

Physicists plan costly look at the beginnings of the universe

国际科学家联合发布最新一代高能加速器设计报告

Wer soll das bezahlen?

5,5 Milliarden kostet einem neuen Bericht zufolge der modernste Teilchenbeschleuniger der Welt. Deutsche Physiker würden ihn gerne nahe Hamburg aufbauen. *Von Björn Schwentker*

Un accélérateur pour éclairer le big bang

CYRILLE VANLERBERGHE.
Publié le 10 février 2007
Actualisé le 10 février 2007 : 22h22

Science AAAS

WIRED NEWS

NEWS OF THE WEEK

PHYSICS:
International Team Releases Design, Cost for Next Great Particle Smasher
Adrian Cho

Nachrichten > Wissen > Forschung

TEILCHENPHYSIK DIE NÄCHSTE GENERATION DER LINEAR-BES

Milliarden-Projekt für Hamburg?

全球物理学家准备共建新一代高能加速器

Next steps

- The cost is presently being validated by an international team of experts
- It will then be translated into the different national accounting schemes
- The GDE is proposing to have an Engineering Design Report ready by 2010
- Much R&D remains to be done by the international community …

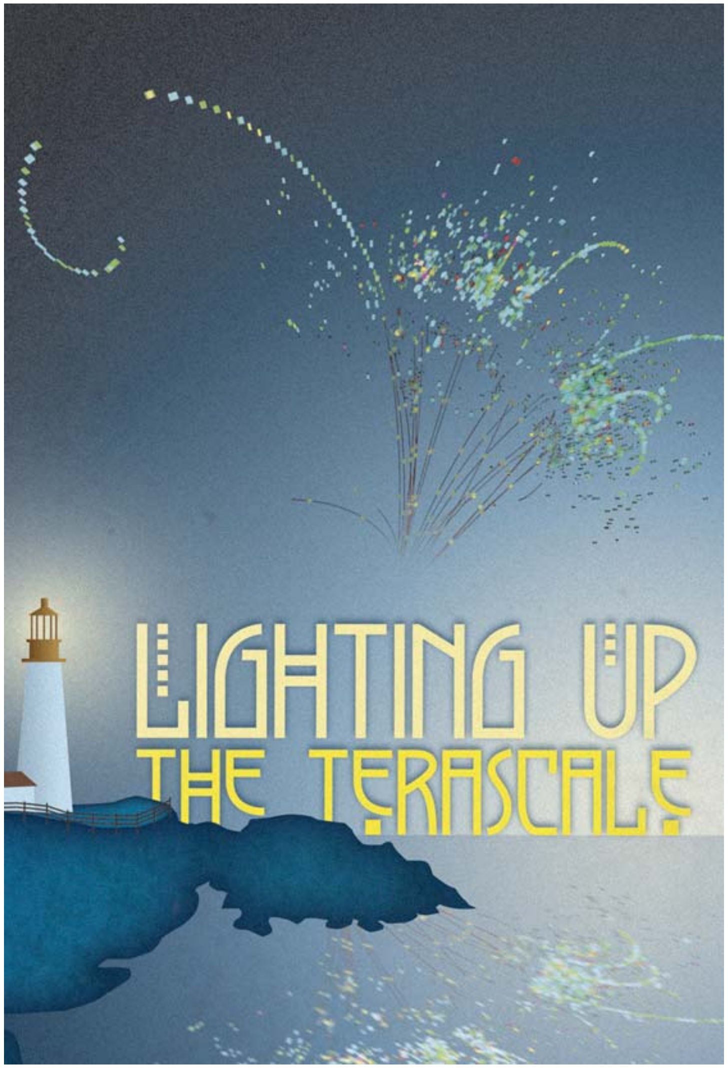
Next steps

- Then, with initial results from the LHC, and with more information on the design, site and cost, the world will be in position to decide whether to proceed with ILC construction
- And if all goes well, perhaps late in the next decade, physicists will begin to use the ILC to explore the mysteries of the …

Quantum Universe!

Information

- For more information, visit
  - www.interactions.org/quantumuniverse/
  - www.linearcollider.org/



All unattributed plots are taken from *Discovering the Quantum Universe,* available at interactions.org