Future Perspectives

LCWS11 Granada

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9/30/11

1946 Delahaye

Tevatron

- The case for the Standard Model was built at the Tevatron, LEP and SLC
  - After almost 30 years of service, the Tevatron is being shut down later today

- But rather than mourn its loss, more than 300 physicists from over 30 countries have gathered here in Granada to look to beyond it …
  - To the LHC and to the linear collider …

Linear Collider

- The case for a linear collider will be built at the LHC
  - Starting at 7 TeV, continuing at 14 TeV …
- We will soon know what that case might be
  - Hallelujah!
    - The long wait is over …
  - As a theorist, I can say it's exciting – and frightening – to finally learn the truth!

CLIC and ILC

- At present, we have two options:
  - ILC (International Linear Collider)
    - 1.3 GHz superconducting RF
    - 500 GeV – 1 TeV in the CM
  - CLIC (Compact Linear Collider)
    - 12 GHz warm copper RF, powered by drive beam
    - 500 GeV – 1 TeV – 3 TeV (?) in the CM
- Many common subsystems, with the ultimate energy limited by cost and wall plug power …

CLIC and ILC

- The ILC will be ready to propose in 2013
  - The GDE produced an RDR in 2008, and is preparing a TDR for late 2012
- CLIC will be ready at some later point
  - The CLIC Collaboration is preparing a CDR for late 2011, and is aiming for a PIP later in the decade, perhaps 2016
- The physics case is the same!

CLIC and ILC

- The eventual decision will be made on grounds of technical maturity, cost, and upgrade potential
  - Informed by LHC physics
- But for now, I'll focus on a first-stage linear collider …
  - With CM energies below 1 TeV
- Because that is all we can expect in the foreseeable future …

Linear Collider

- ILC base requirements
  - Physics between 200 and 500 GeV
  - Calibration at 91 GeV
  - Luminosity of 500 fb^{-1} in four years
  - Electron polarization > 80%
  - Stability at the 0.1% level
- These requirements are physics driven, so CLIC has similar requirements

Linear Collider

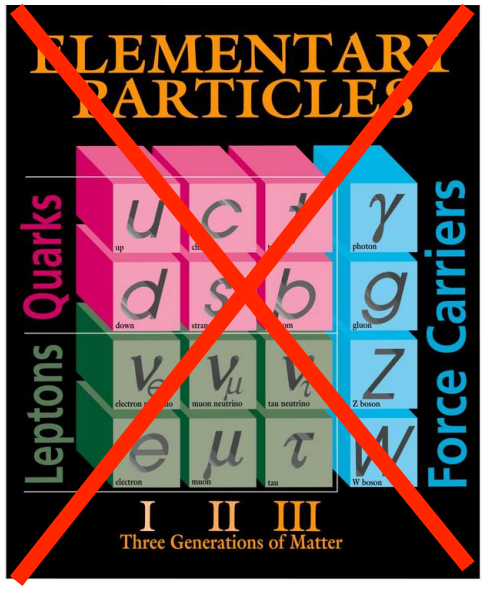
- ILC options
  - Upgradeable for physics up to 1 TeV
  - Positron polarization > 50%
  - GigaZ
  - e^-e^-
  - $e^-\gamma$ and $\gamma\gamma$
- And likewise for CLIC ...

Physics Case

- As of today, the physics case for a linear collider rests primarily on the Higgs
  - There may be other new physics in range of a 500 GeV machine, especially electroweak physics
  - But we are unlikely to know for sure based on results from the 7 TeV LHC
- We need to argue based on what we know
  - Discoveries beyond that are an added bonus!

Higgs Boson

- But that's OK: The Higgs is different!
  - It's not a quark, a lepton or a gauge boson …
  - It is a fundamental spin-zero boson that fills the vacuum
    - Bose-Einstein condensate…
    - Which implies that space itself is a superconductor!
- It is a radically new kind of particle
  - Last seen in the very early Universe!



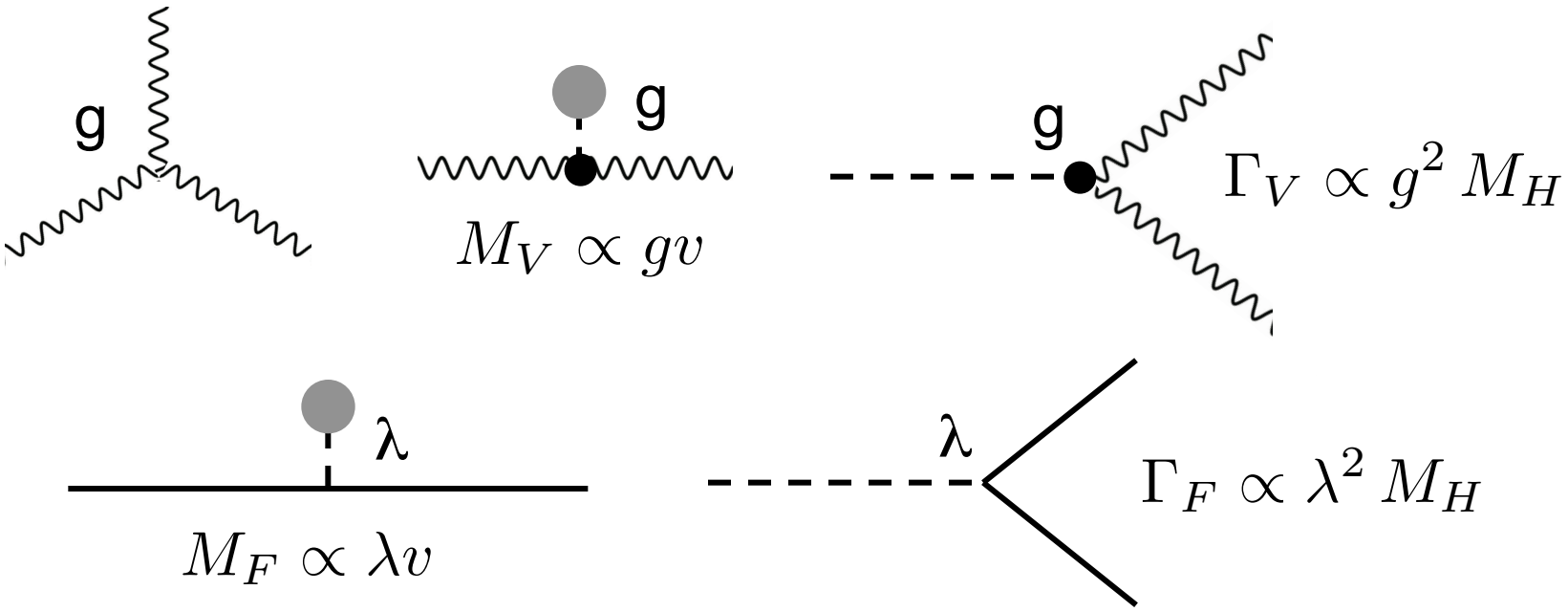
Higgs Boson

- To discover the Higgs …
  - What better way to celebrate the 100th anniversary of the discovery of superconductivity!

Kamerlingh Onnes
Nobel Prize, 1913

Higgs Boson

- For a Higgs to be *the* Higgs, it must obey some very special relations …



Masses and decay rates are related!

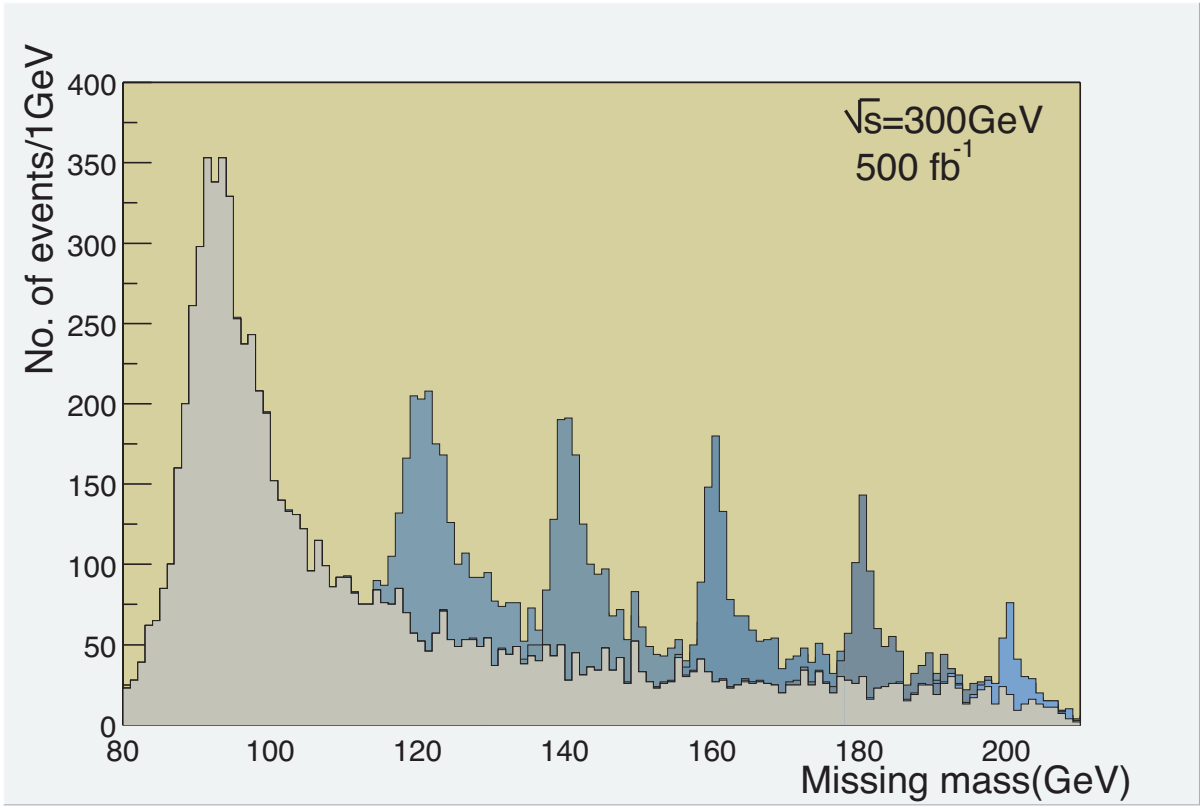
Higgs Boson

- Great claims demand great evidence …
  - To separate fact from fiction. That's the basis of science!
- Therefore, given a candidate Higgs, we need to determine its properties – to learn what it is – and to learn how it works
  - Is a Higgs is *the* Higgs, or is it an imposter?
  - To answer the question, we need to measure its mass, spin, couplings …

Higgs Boson

- At a linear collider, the Higgs can't hide!

  $e^+e^- \rightarrow ZH \rightarrow \mu^+\mu^- X$

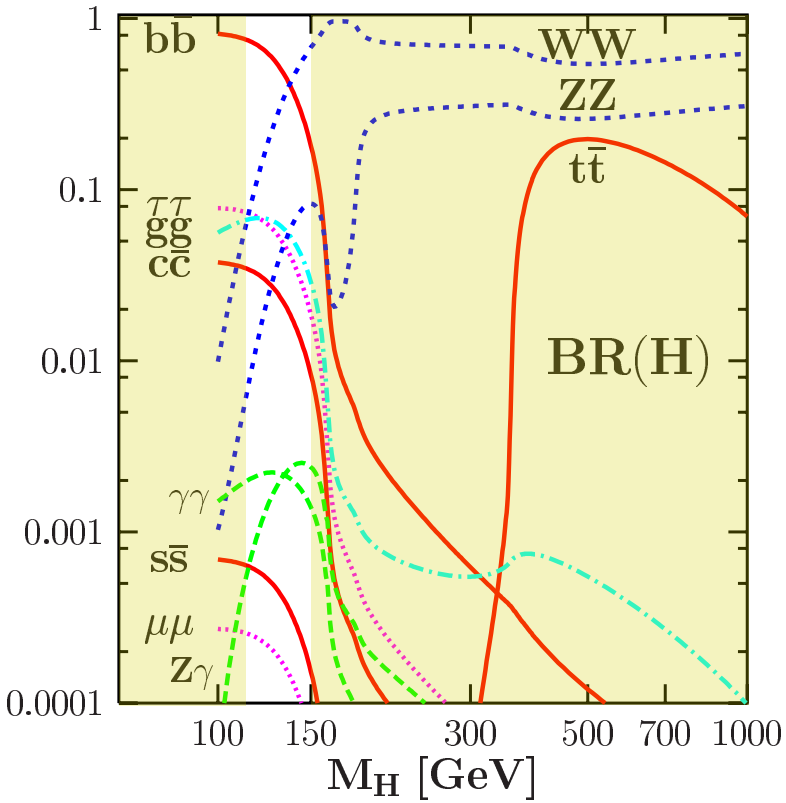


From Z recoil!

Higgs Boson

- Higgs decays depend on the Higgs mass

  Allowed region: $115 < M_H < 150$ GeV



Higgs Boson

- Measure Higgs mass

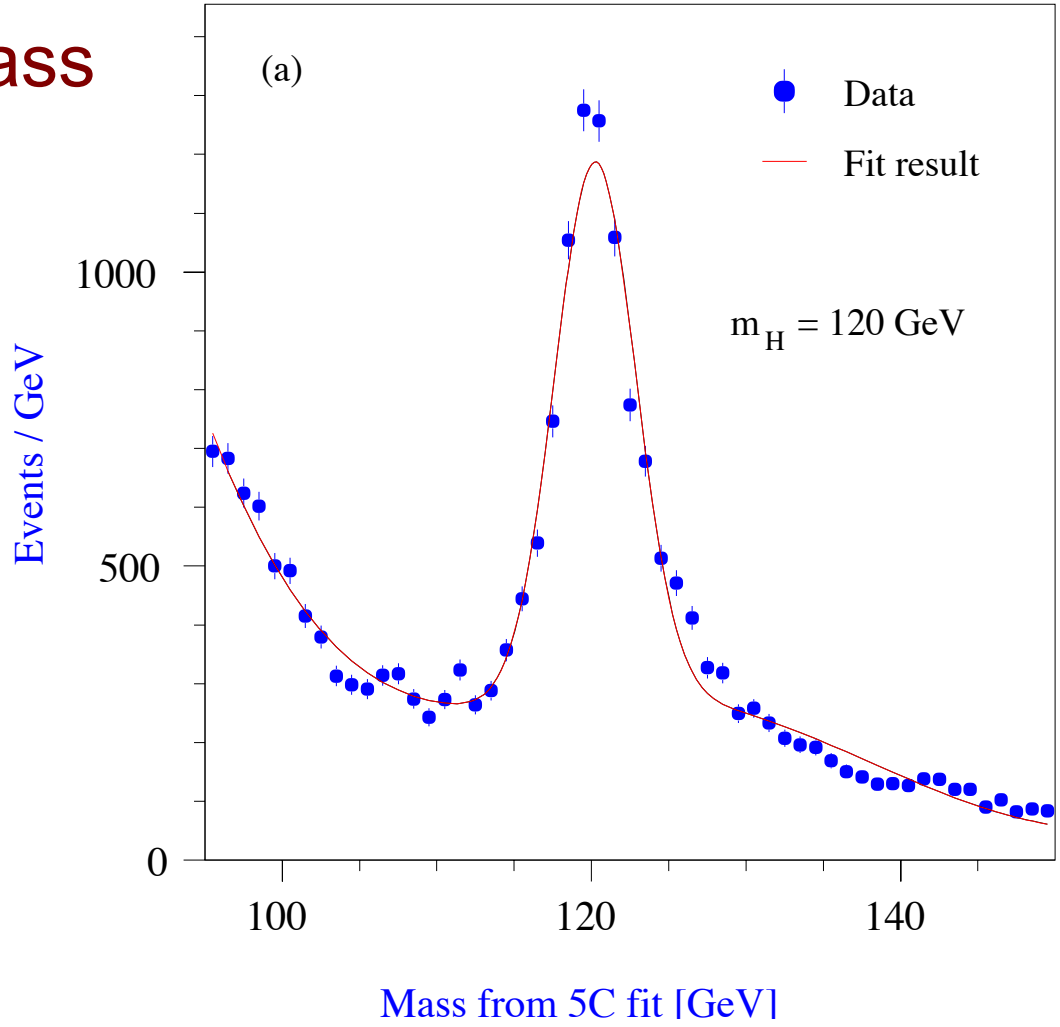
  $\Delta M_H \approx \pm 40$ MeV

  This plot:

  $e^+e^- \rightarrow b\bar{b}q\bar{q}$

  $\sqrt{s} = 350$ GeV

  $L = 500$ fb^{-1}



Higgs Boson

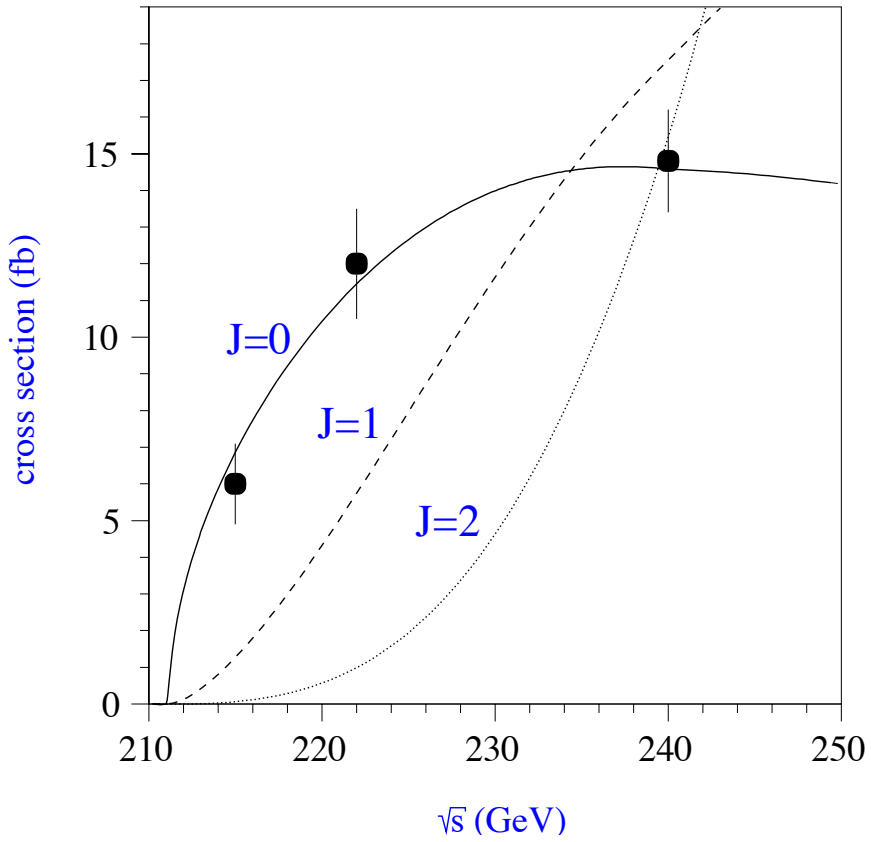
- Determine Higgs spin

  Threshold energy scan

    Spin 0!

  This plot:

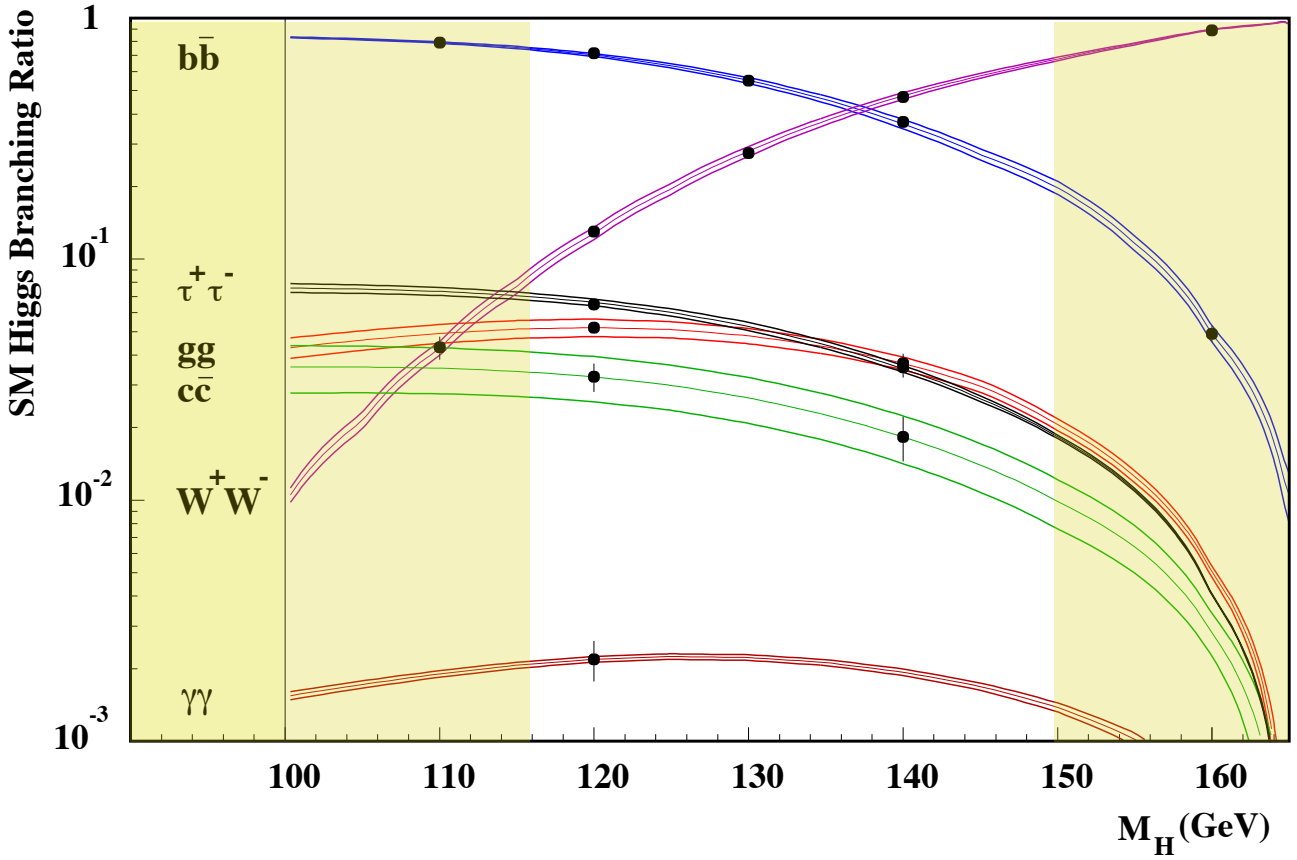
    L = 20 fb^{-1} per point



Higgs Boson

- Measure Higgs branching ratios

  This plot: $\sqrt{s}$ = 350 GeV, L = 500 fb^{-1}



Higgs Boson

- Determine Higgs couplings

  g_{HWW} and g_{HZZ}

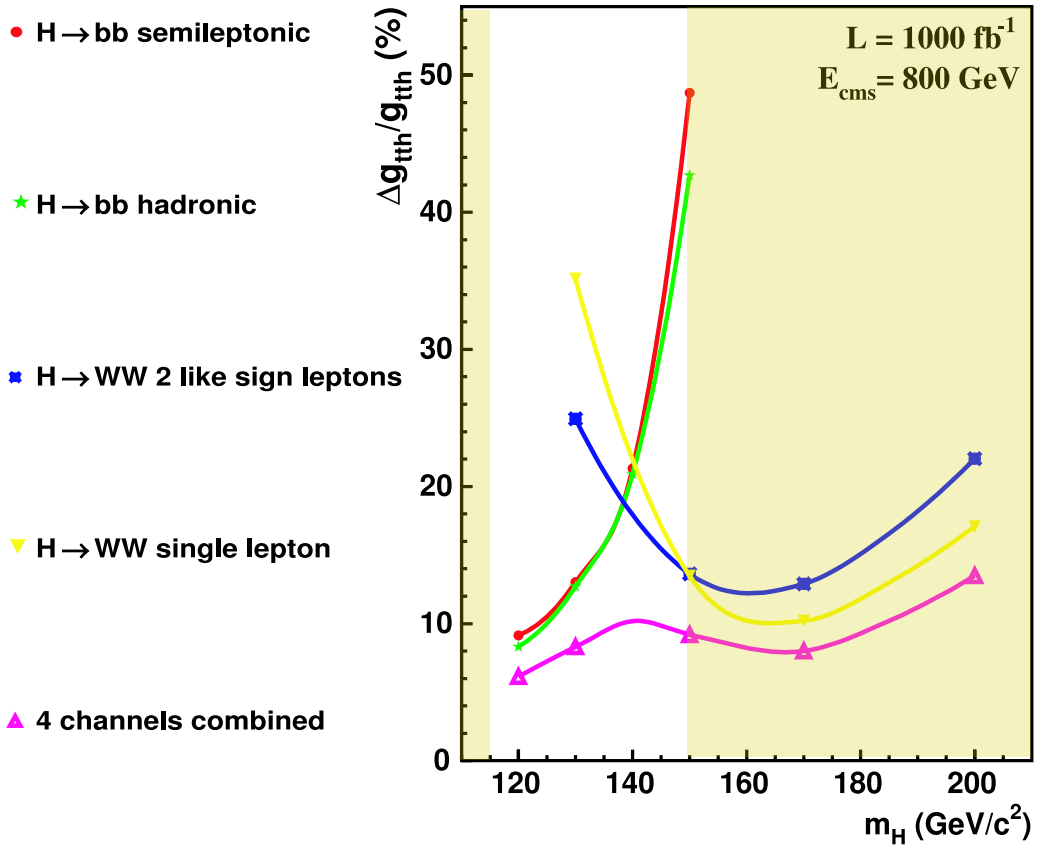
  to 1 – 2 %

  Sensitive test!

  Top quarks too:

  $\lambda_{Ht\bar{t}}$

  to < 10%



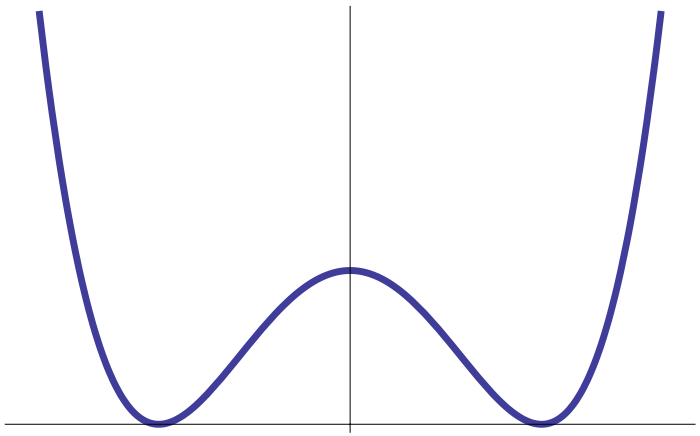
Higgs Boson

- Measure Higgs trilinear self-coupling

  λ_{HHH}

  to 12%

  for M_H = 120 GeV, $\sqrt{s}$ = 1000 GeV, L = 1000 fb^{-1}



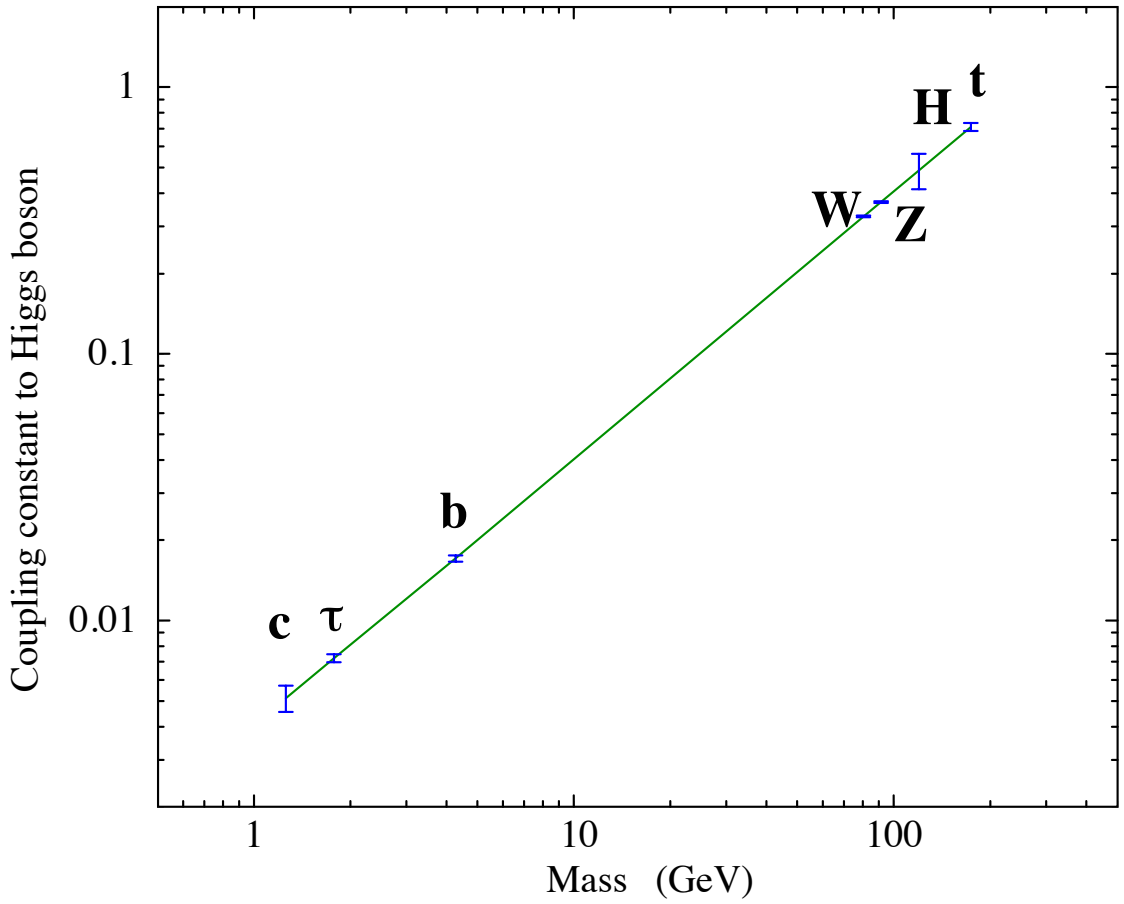
Test of Higgs potential

$\lambda_{HHH} = \sqrt{2}\, M_H$

$$V(H) = \frac{1}{2} M_H^2 H^2 + \sqrt{2}\, M_H H^3 + \cdots$$

Higgs Boson

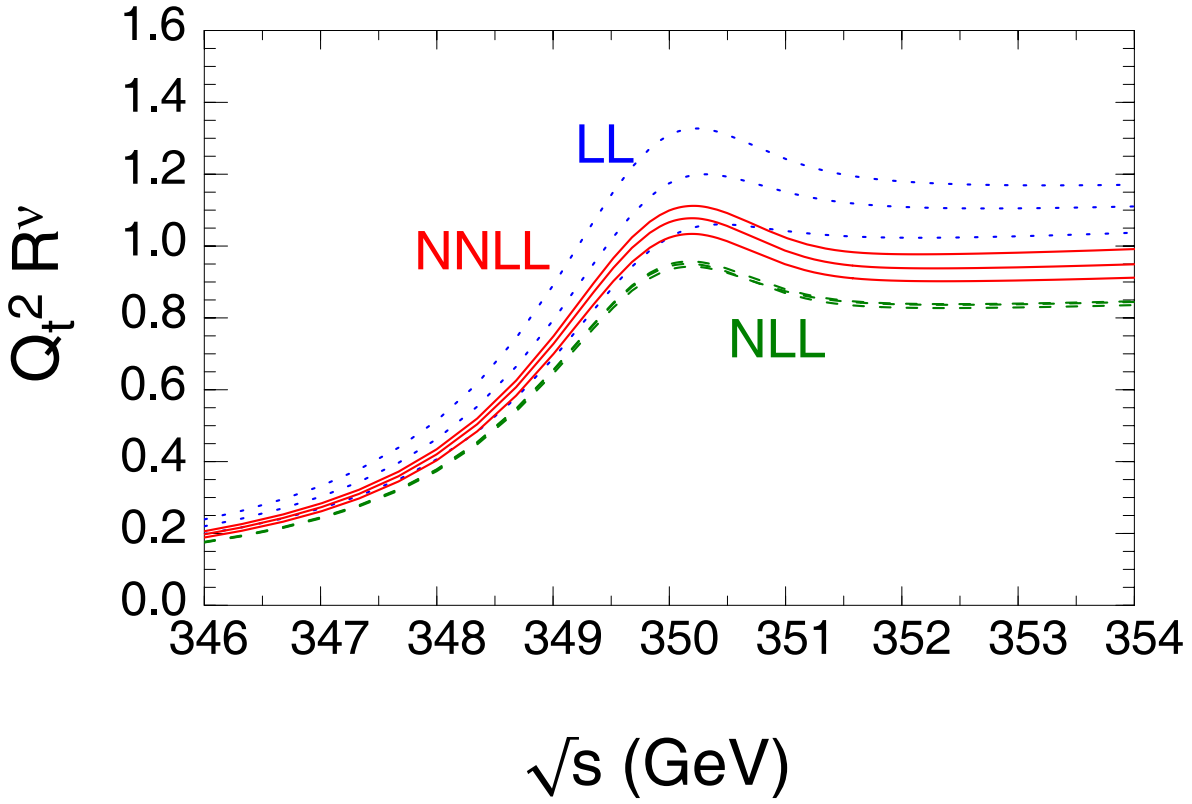
- Is a Higgs *the* Higgs? The ultimate test …



This plot is even more interesting if the Higgs is not “standard”

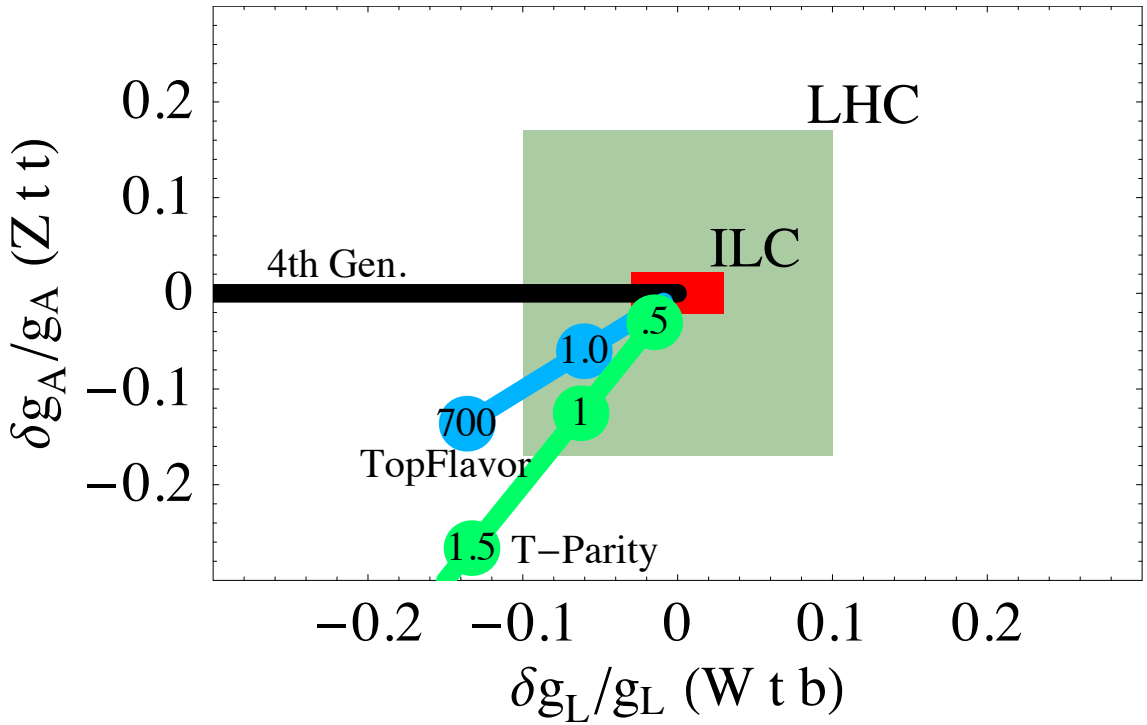
Top Quark

- A threshold scan can determine the top quark mass to 100 – 200 MeV



Top Quark

- Top quark couplings are an excellent place to search for new physics



This plot:

$e^+e^- \rightarrow l^\pm$ + jets

$\sqrt{s}$ = 500 GeV

L = 100 fb^{-1}

$P(e^-)$ = 0.8

New Physics

- A linear collider is so precise and so versatile that it has a role to play in any scenario of new physics – provided the physics is within reach …
  - New Force: Z'
  - Supersymmetry: charginos, neutralinos, sleptons
  - Extra dimensions: KK gravitons, photons, leptons
  - Little Higgs: New tops, Higgs particles, gauge bosons
  - Dark Matter: WIMPS …

New Force

- A LC can search for Z' bosons up to very high energies

This plot:

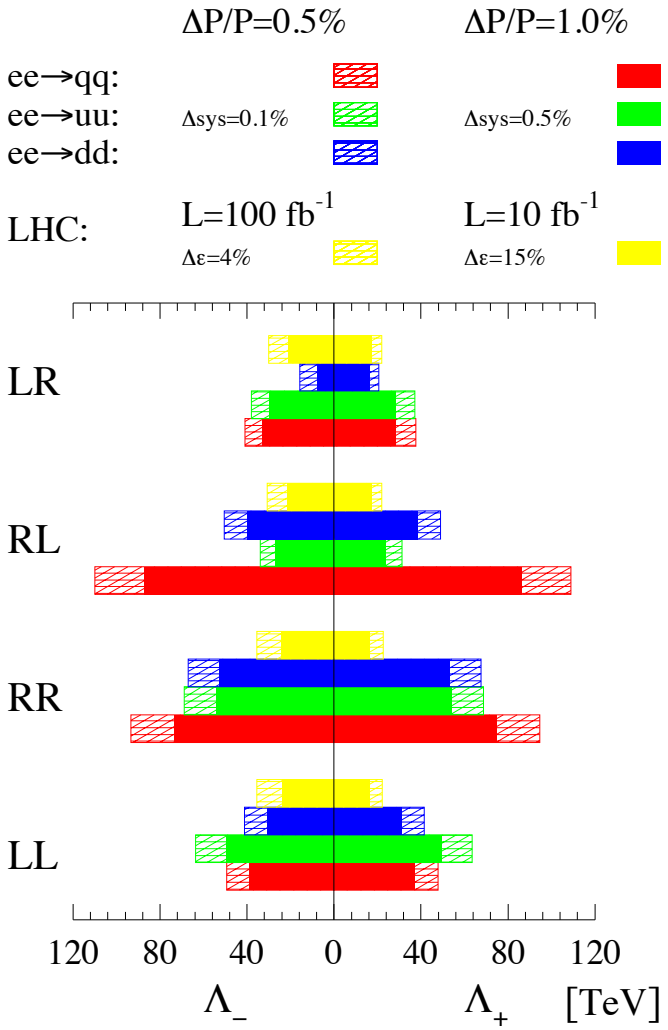
$e^+e^- \rightarrow$ hadrons

$\sqrt{s}$ = 500 GeV

L = 1000 fb^{-1}

$P(e^-) = 0.8$

$P(e^+) = 0.6$



New Force

- It can probe couplings that are inaccessible to the LHC

This plot:

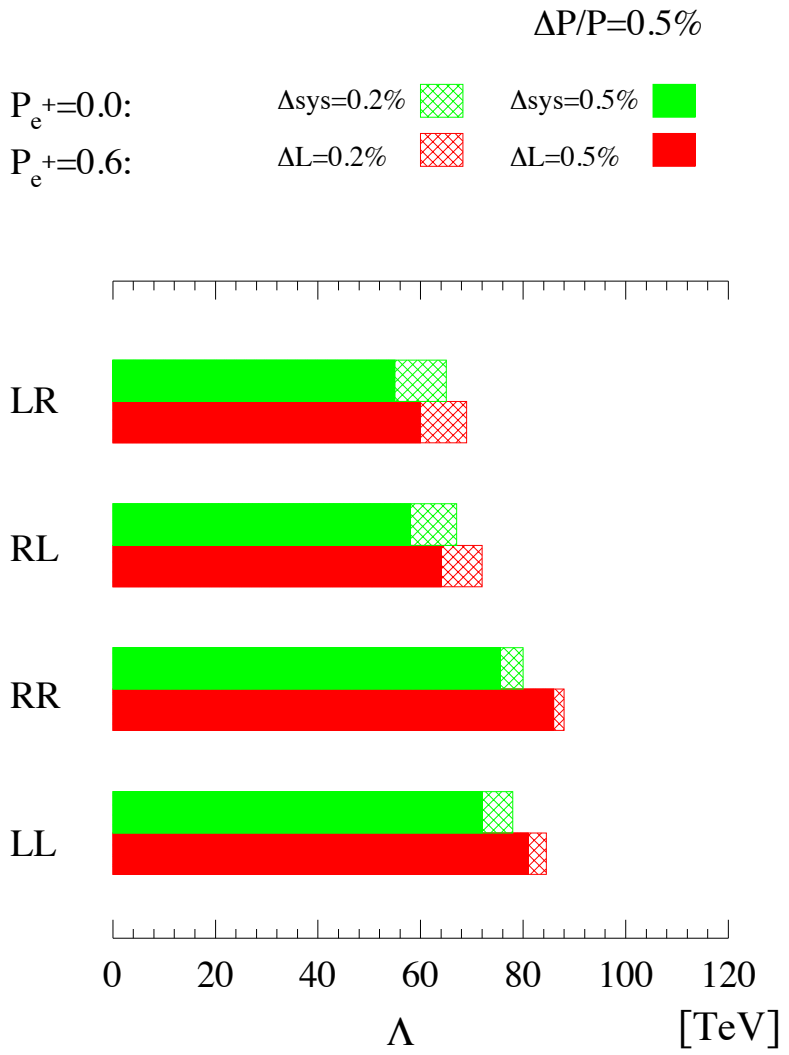
$e^+e^- \rightarrow \mu^+\mu^-$

$\sqrt{s}$ = 500 GeV

L = 1000 fb^{-1}

$P(e^-) = 0.8$

$P(e^+) = 0.0, 0.6$



New Force

- A LC can distinguish one Z' from another …

This plot:

3 TeV Z'

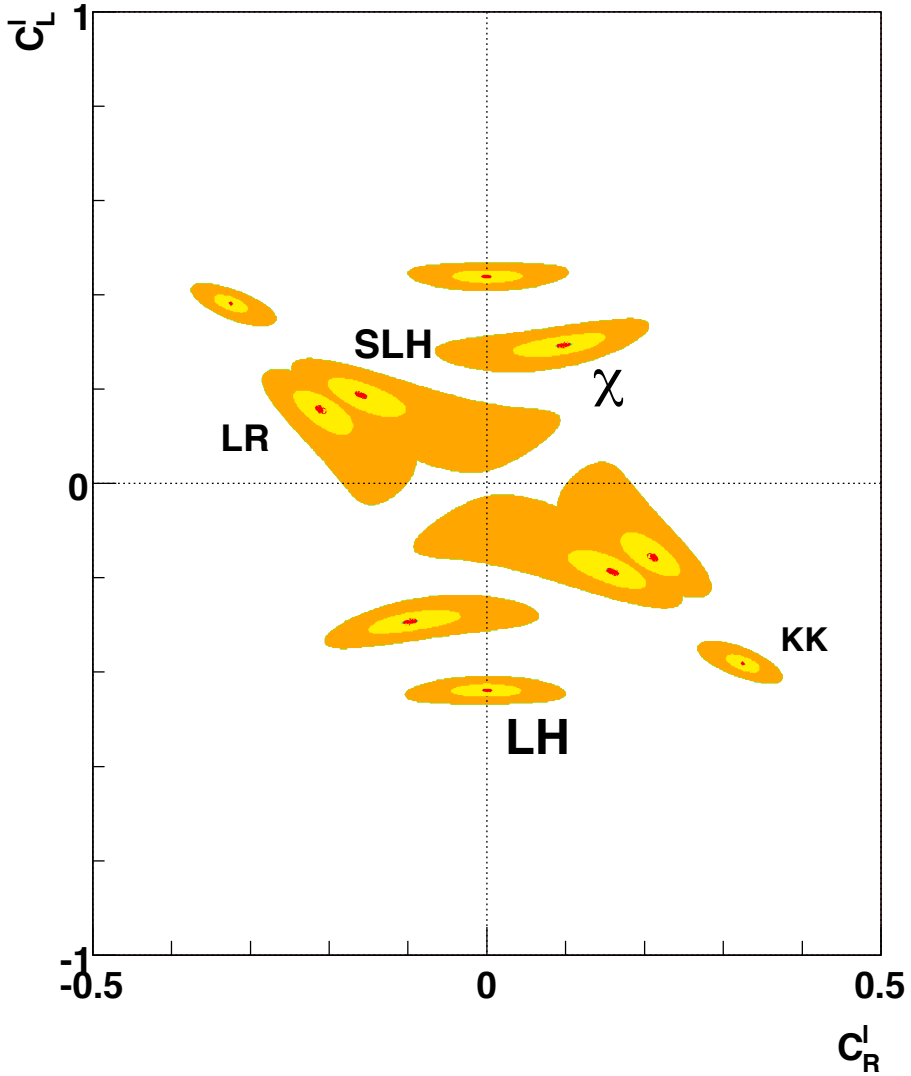
$e^+e^- \rightarrow$ fermions

$\sqrt{s}$ = 500 GeV

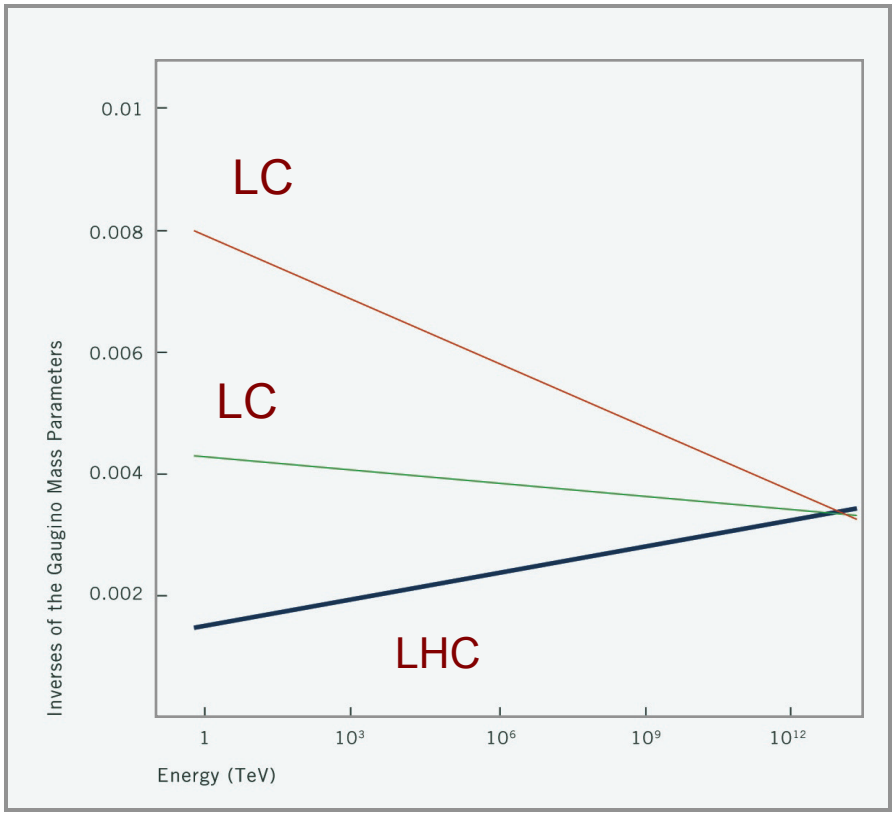
L = 1000 fb^{-1}

P(e^-) = 0.8

P(e^+) = 0.6



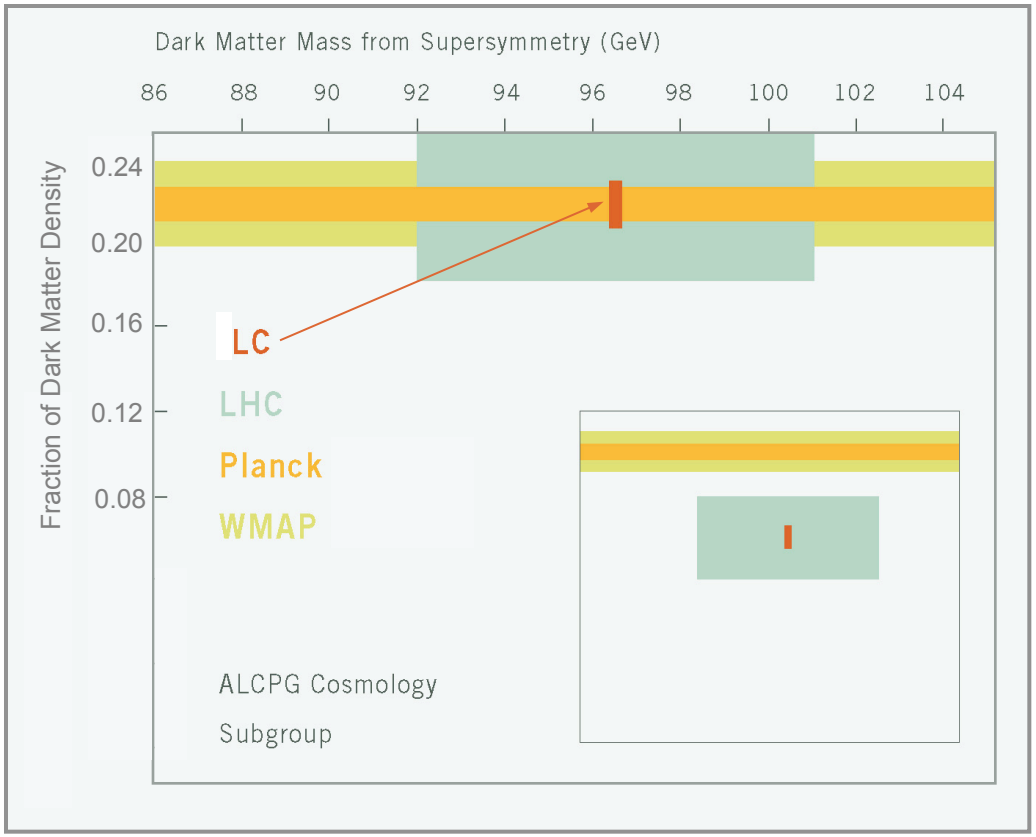
Ultimate Unification



Gaugino Unification

- In supersymmetry, gauge couplings unify. Do gaugino masses?
  - LHC ⇨ gluino
  - ILC ⇨ wino, zino, photino
- Together, the LHC and a linear collider can reveal the physics of grand unification!

Dark Matter



Cosmic Concordance

- Is a "WIMP" an official dark matter particle?
  - What is its mass?
  - What is its cross section?
- How much of the dark matter would it make up?
- A linear collider is well-suited to the task

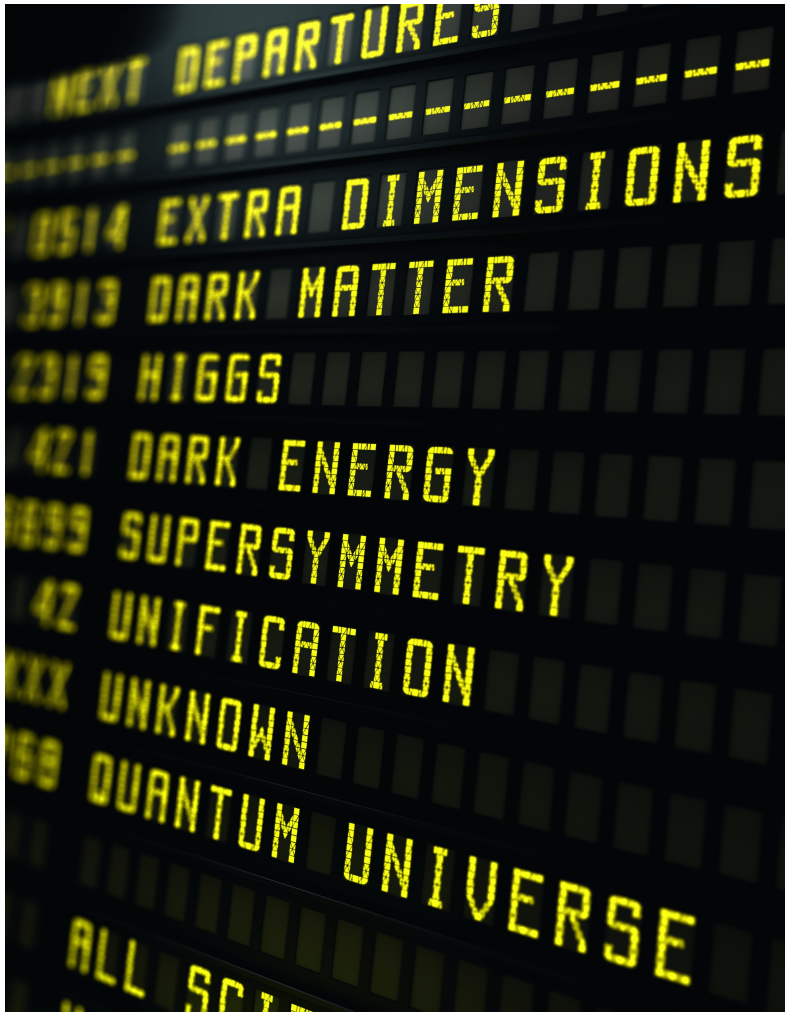
Precision Physics

- These measurements require *great precision …* in both the accelerator and the detectors …
  - To elucidate the Higgs
  - To probe the top quark
  - To find new forces well beyond 1 TeV
  - And even to search for unification …

The hallmark of a linear collider!

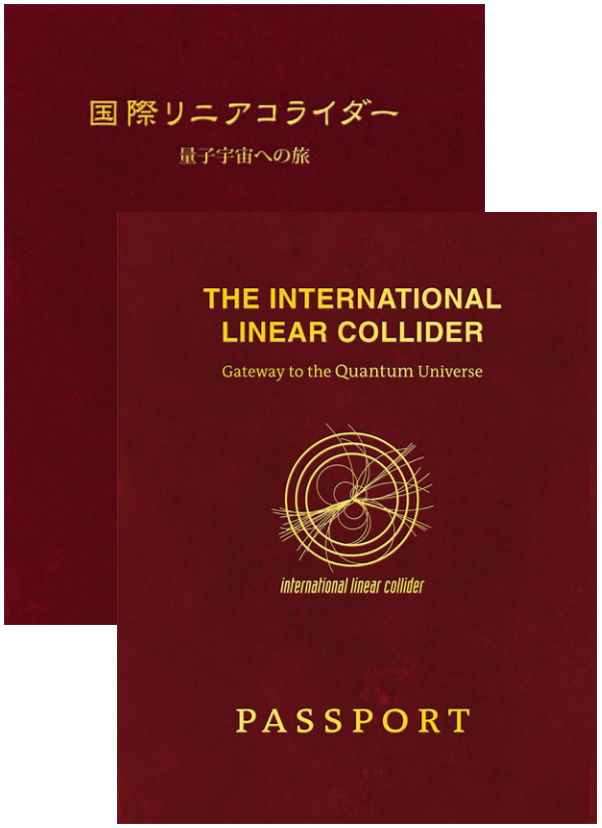
Path Forward

- Do great science
  - Celebrate the LHC and all its success!
- Be strategic
  - Rocky global economy
- Prepare for 2012 +
  - R&D on accelerators *and* detectors…



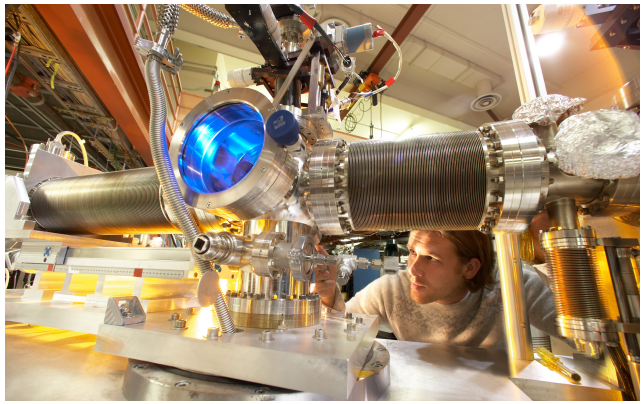
Public Outreach

- But doing great science will not be enough …
  - To realize a linear collider, we need to engage the public
    - Francois Richard!
  - The world faces many challenges
    - Finance and trade
    - Natural disasters
    - Energy and environment
    - Medicine and public health
  - The public is paying for our science



Public Outreach

- Fortunately, our field has a legacy of broad impacts
  - From medical technology to the world wide web
- What are benefits of accelerator and detector research?
  - We need crisp and clear answers!
    - Wolfgang Lohmann



YAHOO!

Google™

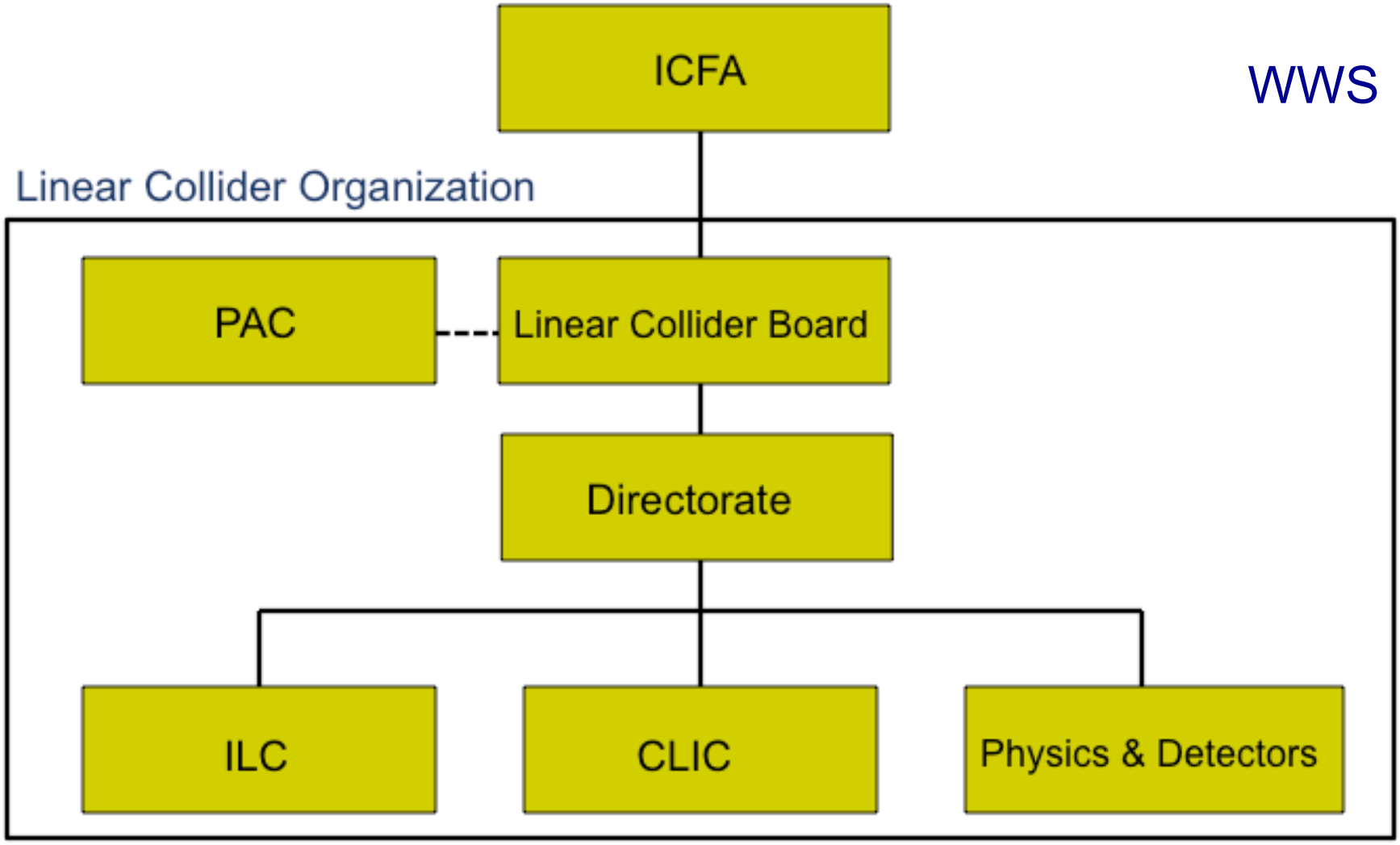
Post 2012

- The mandates of the ILCSC, the GDE and the RD all expire at the end of 2012
  - This is an opportunity for us to take the next step towards a linear collider
- Of course, we'd like to start a construction project at that time …
  - But given political reality, it's likely we won't have that choice …

Post 2012

- The ILCSC is preparing to propose to ICFA a transitional Linear Collider Organization, charged with preparing a single world-wide linear collider proposal, with technology based on the physics revealed by the LHC
  - This organization would exist for 3 – 6 years, as required
  - It would bring ILC, CLIC and the RD into a single entity, with a single Director, who would speak with one voice for the global linear collider community

Possible Organization



Path Forward

- For ILC, before 2012
  - Finish TDR / DBD for accelerator and detectors
    - Balance cost, risk, operations and physics
    - Contain costs while retaining essential capability
    - Prepare Project Implementation Planning document
- For CLIC, before 2012
  - Finish CDR
    - Aggressively pursue essential R&D

Path Forward

- For ILC, post 2012
  - Continue work on accelerator and detectors

    Especially systems tests, higher gradient cavities, value engineering, change control and detector development
- For CLIC, post 2012
  - Push towards a PIP in 2016
- For ILC and CLIC
  - Prepare for news from the LHC
    - Be ready to move quickly – when the time is right

Path Forward

- For ILC and CLIC, now and in the future …
  - Engage our funding agencies
    - Through ICFA, FALC and local efforts
  - Reach out to the public and fellow scientists
    - We need them on our side
  - Above all, stay together
    - We are one global community

Path Forward

- The next few years will require nerves of steel …
  - We must be nimble to adapt quickly to a rapidly changing landscape
  - In this way we can marshal support for the linear collider we know we need …

    Be it ILC or CLIC

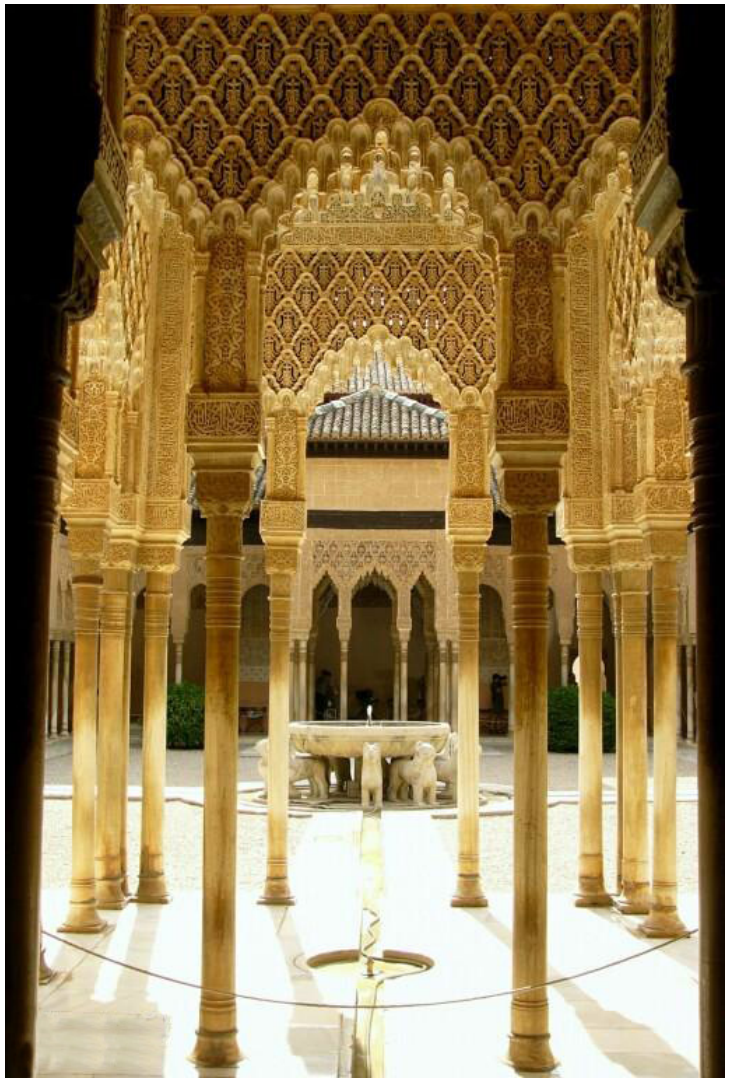
    … to explore the Terascale …

    … and create an enduring monument to our humanity …

Information

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

All unattributed plots are taken from the ILC RDR, available at interactions.org



INTERNATIONAL WORKSHOP ON FUTURE

LINEAR COLLIDERS

LCWS11

GRANADA _ SPAIN

26-30 SEPTEMBER 2011

On behalf of us all, I would like to thank the organizers – particularly Fernando Cornet, Juan Fuster and Alberto Ruiz – for all they have done to welcome us to Granada, and for making the conference such a success!

LCWS 2012

The University of Texas at Arlington
October 22-26, 2012