Physics with next generation Linear Colliders

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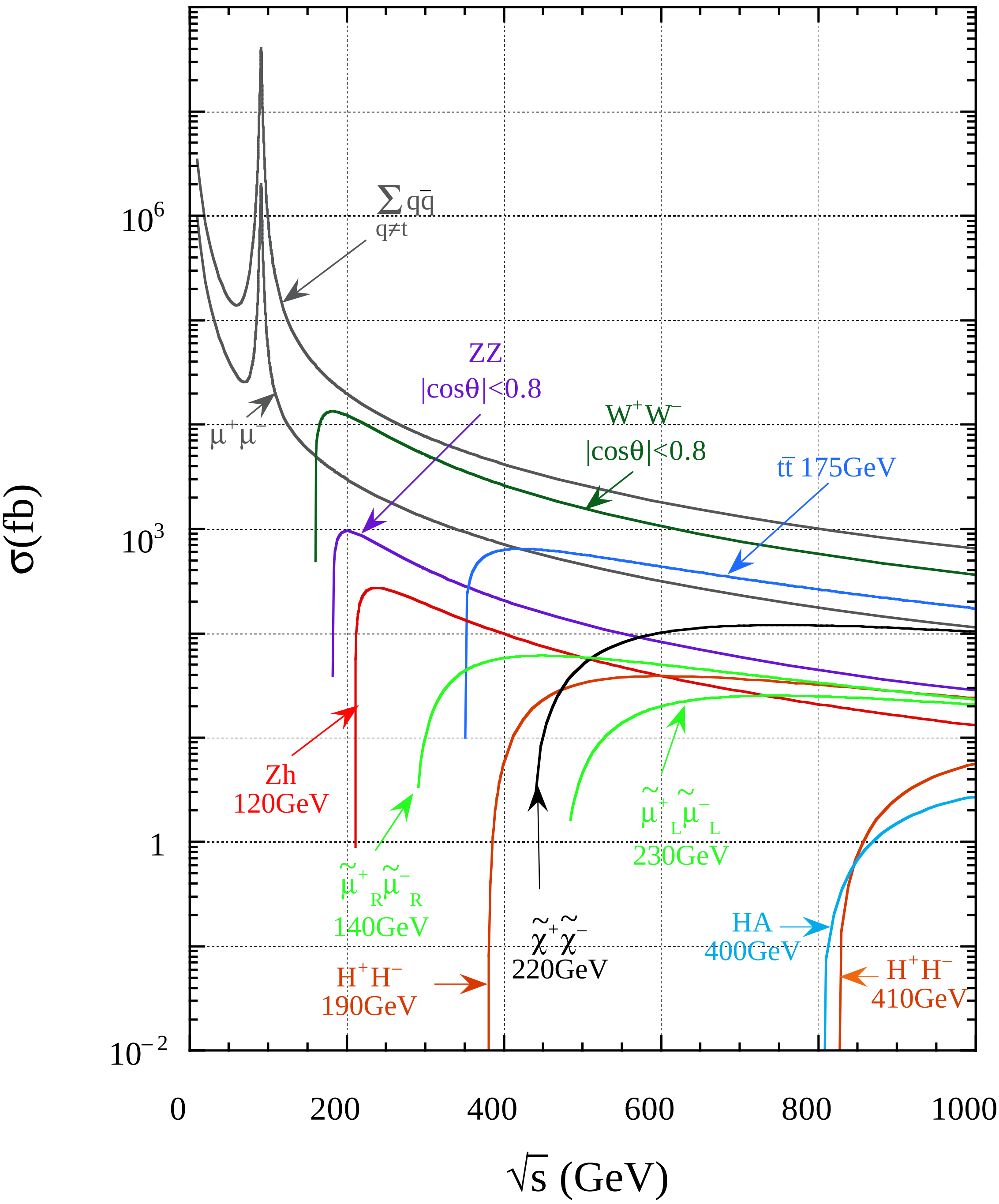
❶ Introduction

- Want to reach energy from LEP2 to ∼ 1 TeV
  ⇒ circular machines no longer possible
- Cross sections in range few fb to few pb



⇒ need luminosities of 10s to 100s fb^{-1}

LC (TESLA) parameters:

- energy range: 1st stage: $\sqrt{s} \leq 500\,\mathrm{GeV}$
  2nd stage: $\sqrt{s} \sim 1\,\mathrm{TeV}$
- Luminosity: $50(91\,\mathrm{GeV})-500(800\,\mathrm{GeV})\,\mathrm{fb}^{-1}/\mathrm{year}$
- start data taking ≥ 2012
- electron polarization $\sim 80\%$
- positron polarization of $40-60\%$ possible
- any LC can also be used as a $\gamma\gamma$-collider

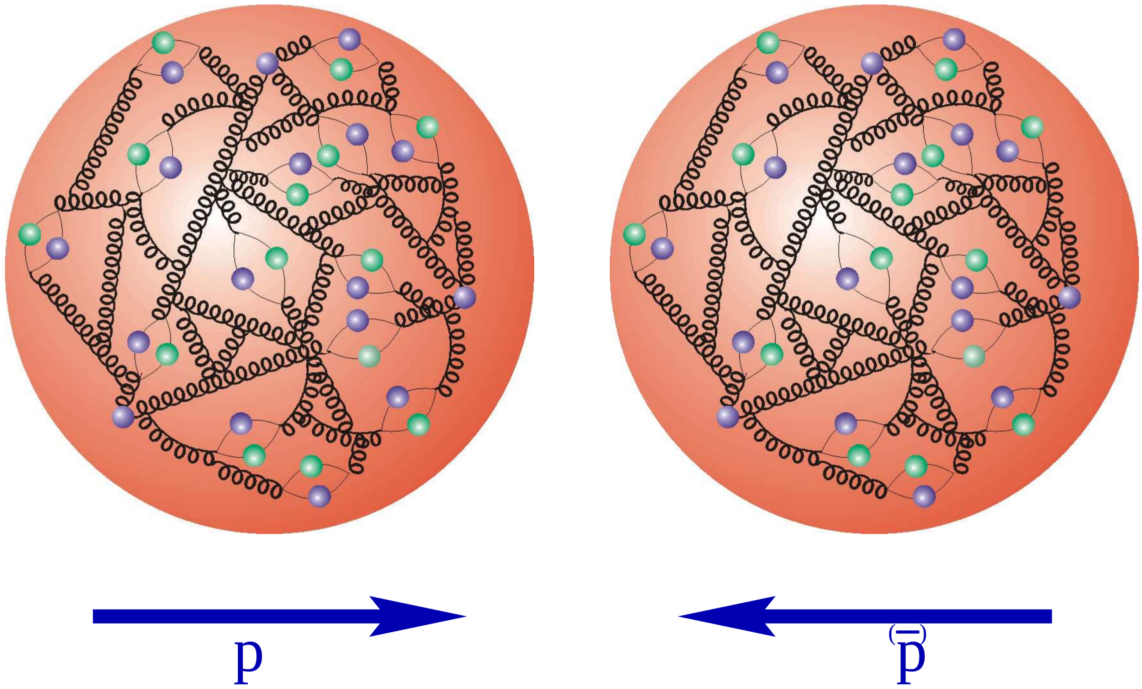
This means:

- few$\cdot 10^4$ $\mathrm{e^+e^-} \rightarrow HZ/\mathrm{year}$
  at $\sqrt{s} \approx 350\,\mathrm{GeV}$ $(m_\mathrm{H} \approx 120\,\mathrm{GeV})$
- 10^5 $\mathrm{e^+e^-} \rightarrow \mathrm{t\bar{t}}/\mathrm{year}$
  at $\sqrt{s} \approx 350\,\mathrm{GeV}$
- $5 \cdot 10^5$ $\mathrm{e^+e^-} \rightarrow \mathrm{q\bar{q}}/\mathrm{year}$
  at $\sqrt{s} \approx 500\,\mathrm{GeV}$ (no rad. ret)
- 10^5 $\mathrm{e^+e^-} \rightarrow \mu^+\mu^-/\mathrm{year}$
  at $\sqrt{s} \approx 500\,\mathrm{GeV}$ (no rad. ret)
- 10^6 $\mathrm{e^+e^-} \rightarrow \mathrm{W^+W^-}/\mathrm{year}$
  at $\sqrt{s} = 500 - 1000\,\mathrm{GeV}$
- 10^9 $\mathrm{e^+e^-} \rightarrow Z/\mathrm{year}$
  at $\sqrt{s} \approx 91\,\mathrm{GeV}$

The most probable scene at the high energy frontier at the startup of a linear collider will be:

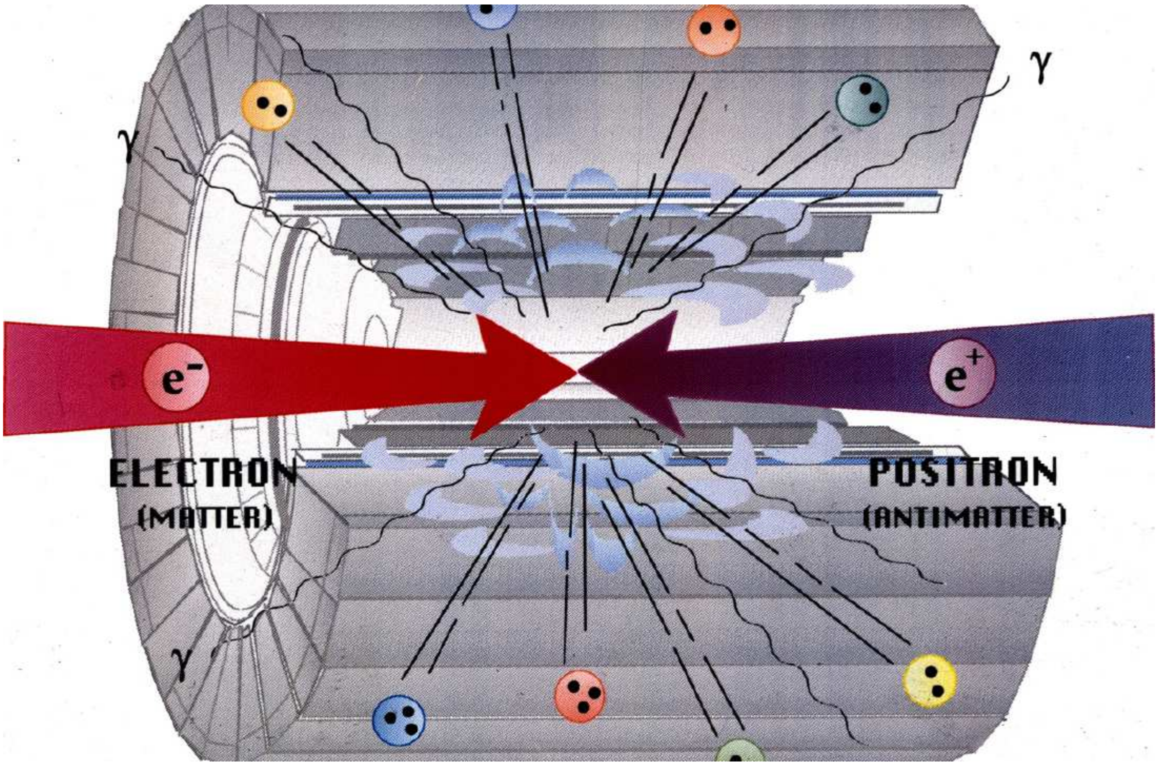
- LEP completed
- TEVATRON run II completed
- LHC has taken several years of data

Hadron collider



- Because of the high proton mass heigh energies are reachable
- however protons are composite particles:
  - parton energies are much lower than proton energy
  - interaction on the parton level is unknown
  - proton remnant disappears in beam-pipe
    $\Rightarrow$ kinematics must be reconstructed from the decay products
- protons have strong interactions
  - high background
  - not all processes can be reconstructed
- hadron collider are "discovery machines"

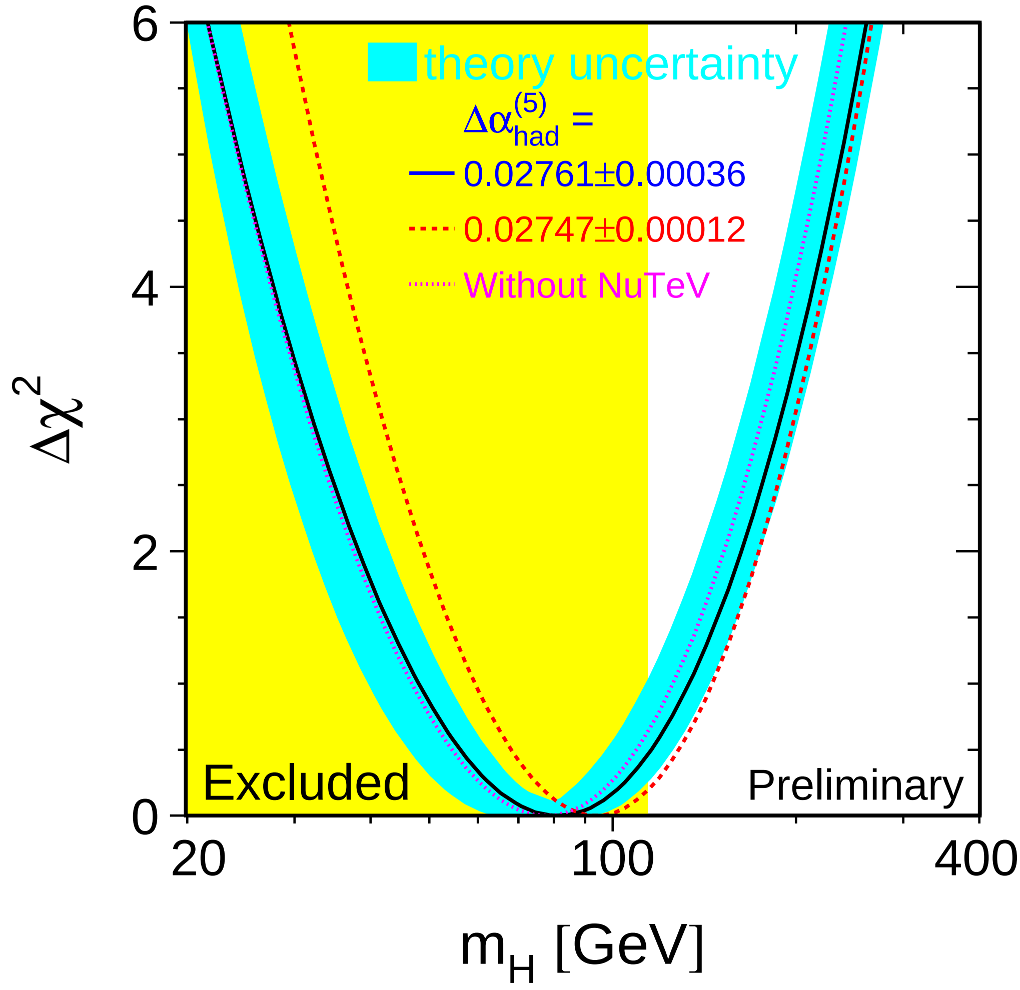
Lepton collider



- Because of the smaller e-mass it is more difficult to reach high energies (synchrotron radiation)
- electrons are point like
  - interaction energy = e^+e^--energy
  - energy-momentum conservation can be used to reconstruct the event kinematics
- electrons have no strong interactions
  - low backgrounds
  - all events can be reconstructed
- lepton-collider are “precision machines”

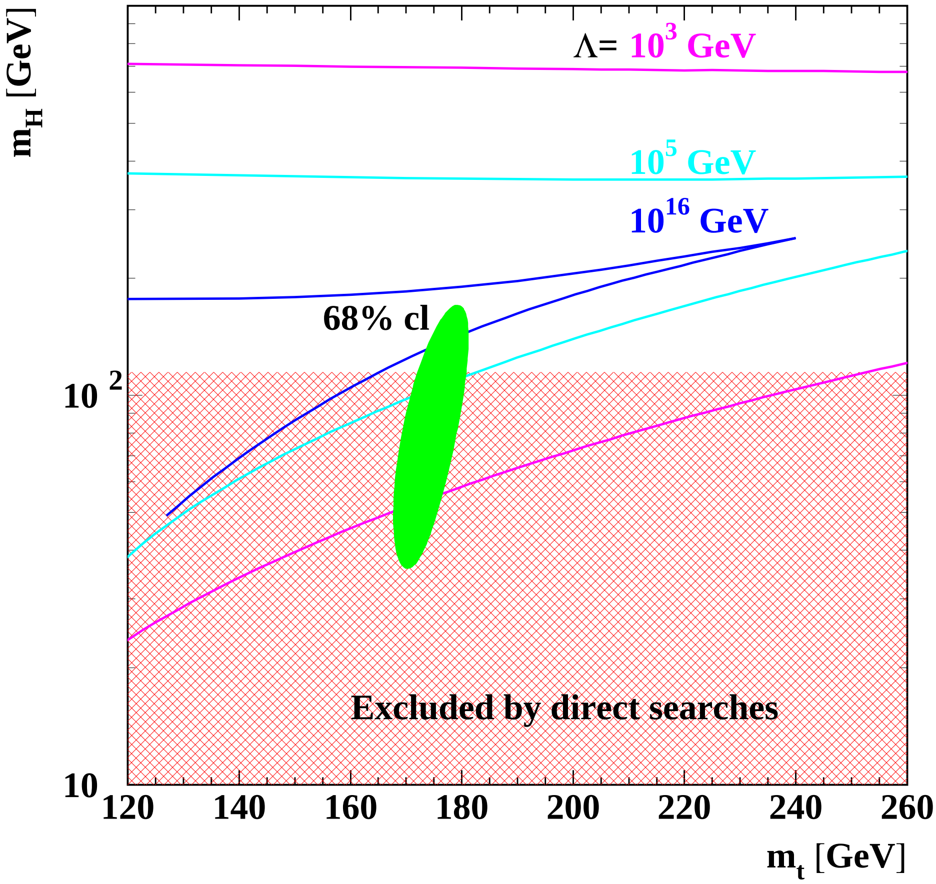
The physics possibilities:

- The Standard Model is the final theory:
  - LEP,SLD,TEVATRON indicate that the Higgs is light



$\Rightarrow m_{\mathrm{H}} < 200\,\mathrm{GeV} \quad (95\%\mathrm{c.l.})$

...which is perfectly consistent with the SM being the final theory:



- At least LHC should have seen the Higgs

➡ The Higgs is in the reach of the LC phase 1 and the LC can determine the Higgs properties in detail

- The world is supersymmetric:
  - at least the light Higgs (h) has been seen by at least the LHC
  - probably some supersymmetric particles (squarks) are seen by LHC
  - at least the h has to be in the LC range

- there is a high chance that (some) sleptons and gauginos are seen by the LC as well

➡ (Some) SUSY parameters can be measured at the LC with good precision

- The gauge group is larger than $SU(3) \times SU(2) \times U(1)$
  - LHC can directly see Z',W' until few TeV
  - LC has a comparable reach by precision measurements via Z'-Z-, Z'-γ-interference
  - if LHC measures the Z' mass, LC can measure its couplings
- Symmetry breaking is realized by a strongly interacting scenario:
  - no Higgs is seen at any machine
  - new resonances (if they exist) might be outside the reach for LHC and LC
  - both machines have a chance to see effects in triple/quartic gauge-boson couplings
- Whatever happens the LC is the first machine to do a precise exploration of the top-threshold

In general:

Whatever the scenario is, the LHC is the ideal machine to discover it, but has problems to measure its detailed properties

On the contrary an e^+e^- collider is the best machine to do precision measurements, especially if it is known, where to look

In these lectures I would like to convince you that we need the combination LHC-LC to really understand the physics at the TeV scale

Useful Web pages

- DESY/ECFA workshop on linear colliders:
  http://www.desy.de/conferences/ecfa-desy-lcext.htm
- TESLA TDR
  http://tesla.desy.de/tdr
- Linear Collider Physics Resource Book for Snowmass 2001:
  http://www.slac.stanford.edu/grp/th/LCBook/
- Snowmass 2001 "The future of particle physics"
  http:http://www.slac.stanford.edu/econf/C010630/pr
- This lecture
  http://www.ifh.de/www_users/zeus
  /moenig/academic_training/