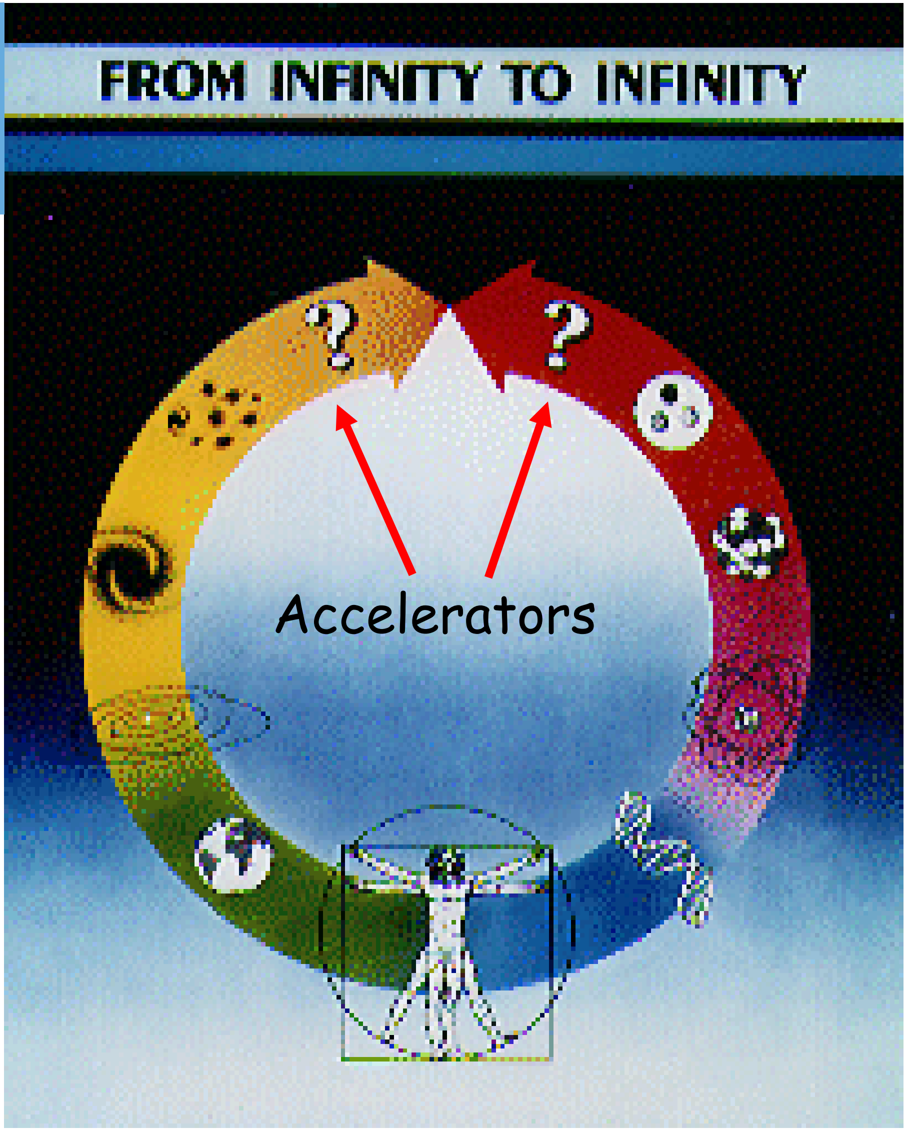
Pushing the Frontier: Tools for the Next Decade

EuroScience Open Forum 2004
Highlighting Science, Technology & Innovation in Europe



What do accelerators provide?

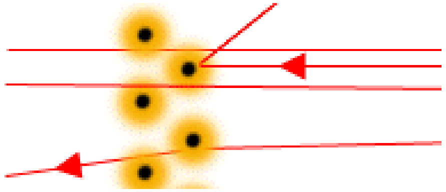
- The precision data
- The energy
- Combining energy and precision

Albrecht Wagner

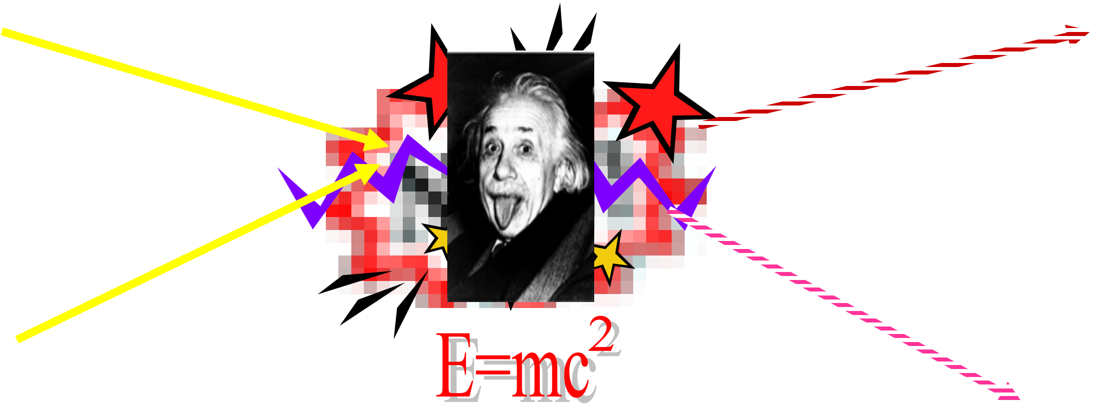
University of Hamburg and
Deutsches Elektronen-Synchrotron
DESY

Why do we need Accelerators?

To see the smallest things: $E = h\nu$



To generate heavy masses: $E = m c^2$



Key Questions of Particle Physics

- What is mass/matter ?

  why are carriers of weak force so heavy while the photon is massless?

- Can the forces be unified?

  Were all four forces equally strong immediately after the Big Bang?

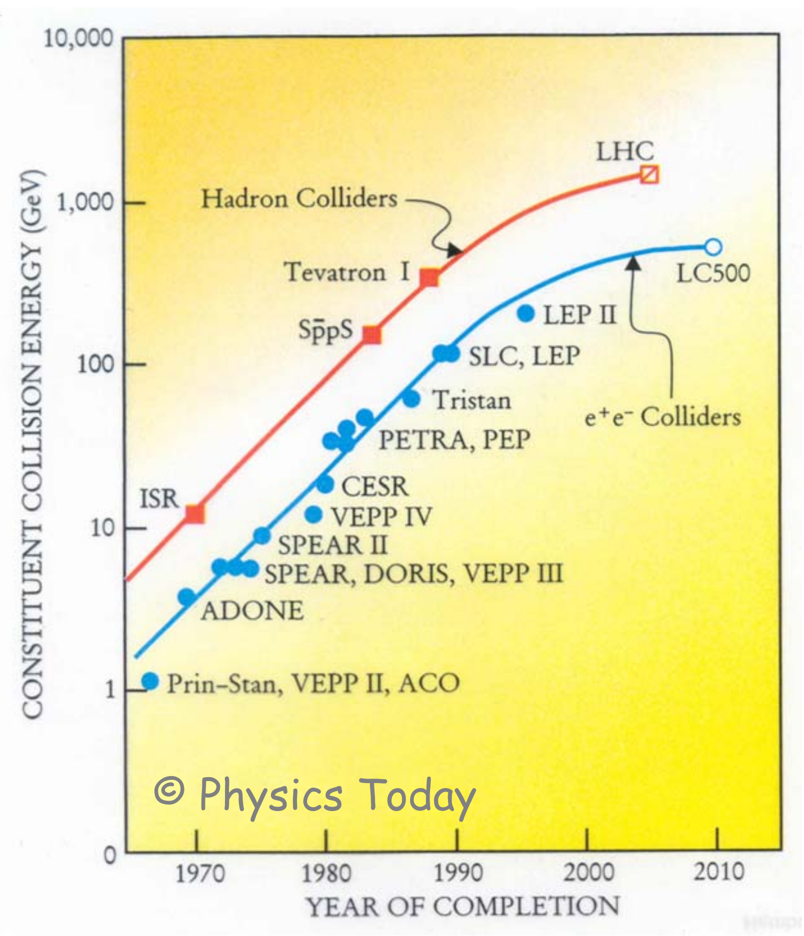
- Is there a fundamental symmetry of forces and building blocks?
- Can quantum physics and general relativity be united?
- Do we live in 4 dimensions?

These questions are also questions of cosmology:

- What happened in the very early universe ?
- Origin of dark matter?

The Path to the Experimental Answers

Particle physics has always successfully pursued two complementary strategies in parallel for gaining new understanding



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HIGH ENERGY

direct discovery of new phenomena
i.e. accelerators operating at the energy scale of the new particle

HIGH PRECISION

Discoveries and access to new physics at high energies through the precision measurement of phenomena at lower scales

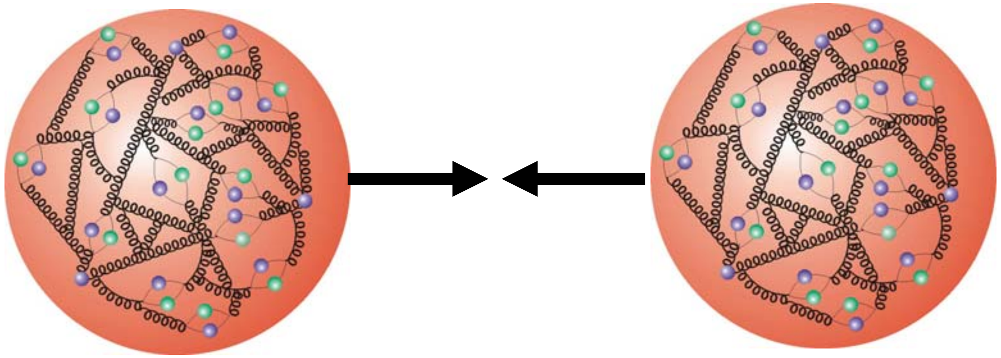
High Resolution (as special case)

Probing the structure of matter by colliding point-like electrons with protons

The Power of Proton Colliders

- Relatively easy to obtain very high energies, as protons don't loose energy through radiation while being accelerated
- Large cross sections

but



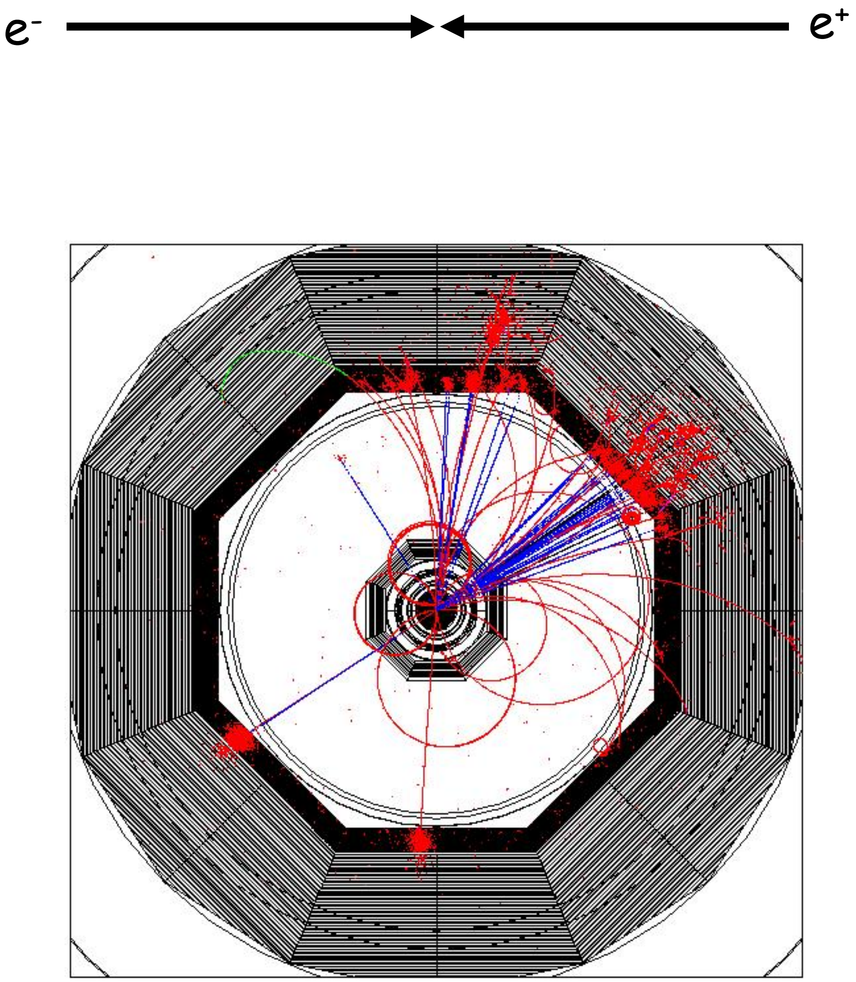
- energy and momentum of colliding particles can not be chosen, as protons are complex objects, composed of quarks and gluons
- high background

R. Feynman:

Colliding two grand pianos and listening…

The Power of $e^+ e^-$ Colliders

- well defined production process, simple kinematics
- precise knowledge of quantum numbers in initial state
- precise (<%) knowledge of the cross sections
- polarisation of e^- and e^+ beams possible
- energy and momentum of all particles known
- energy of system can be varied
- low background



Precision

Precision measurements in particle physics have become a main tool for

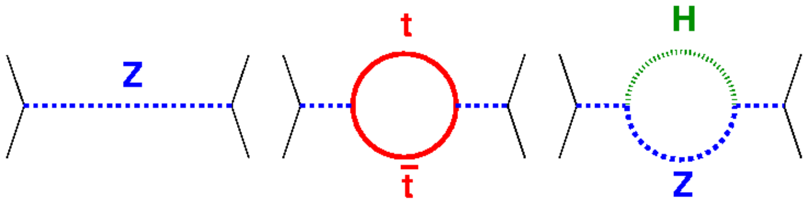
- testing the Standard Model (e.g. at LEP, HERA, Tevatron)
- searching for physics beyond the SM
- searching for the origins of the matter-antimatter asymmetry in the universe (e.g. at b-meson factories at KEK and SLAC)

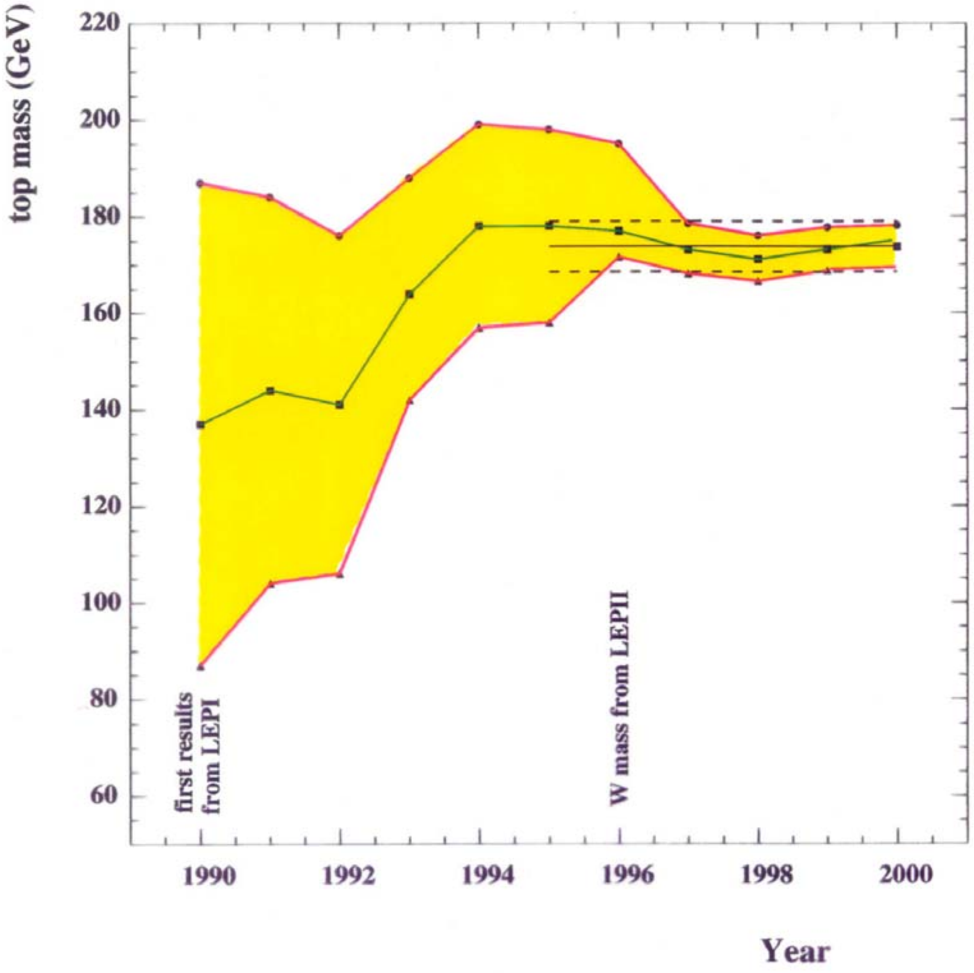
Precision measurements became possible through

- Innovative design of modern accelerators (colliders), leading to unprecedented data rates
- detailed theoretical calculations
- precision detectors, low background

Predictive Power of Precision Measurements

Example: Search for the Top Quark





Mass of top quark was determined *indirectly* before it was observed in *direct* measurements.

Possible due to quantum fluctuations, and

- precision measurements
- calculation of higher order electroweak corrections

$$\propto \left(\frac{\boxed{M_t}}{M_W}\right)^2, \ln\left(\frac{\boxed{M_h}}{M_W}\right)$$

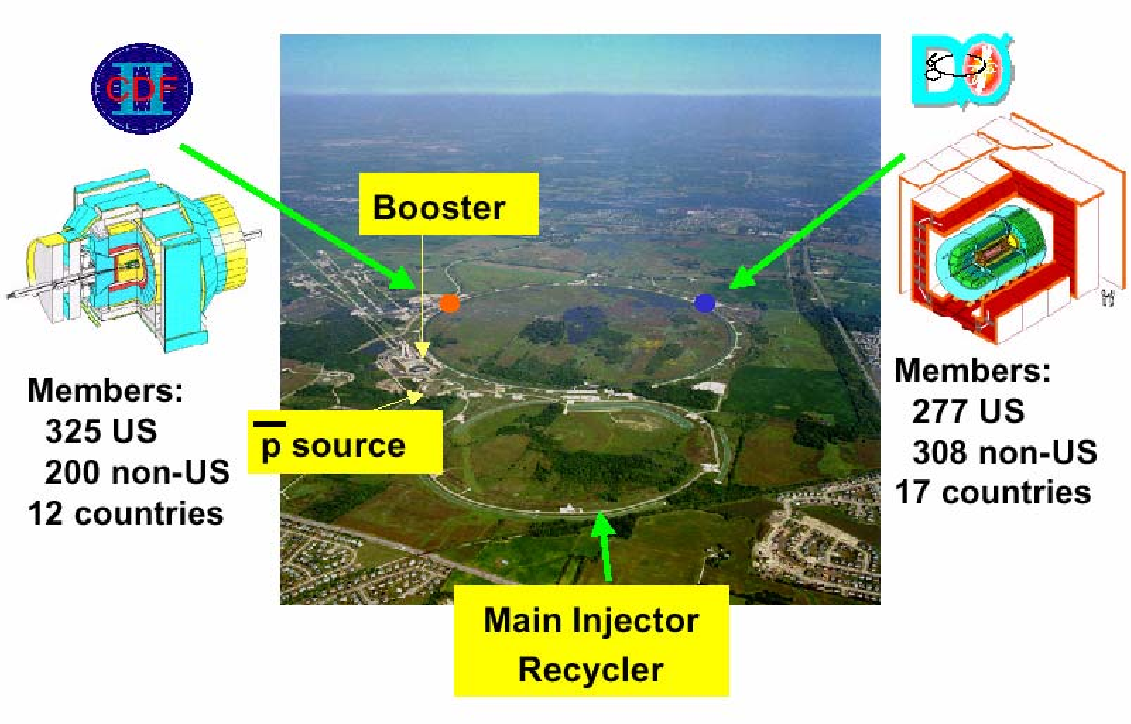
Energy

Running now: Tevatron at Fermilab

proton – antiproton collider

Energy:

$E_{beam} = 1$ TeV



Members:
325 US
200 non-US
12 countries

Members:
277 US
308 non-US
17 countries

Energy : The Next Step

Under construction: The Large Hadron Collider at CERN

proton-proton collider,

in the LEP tunnel

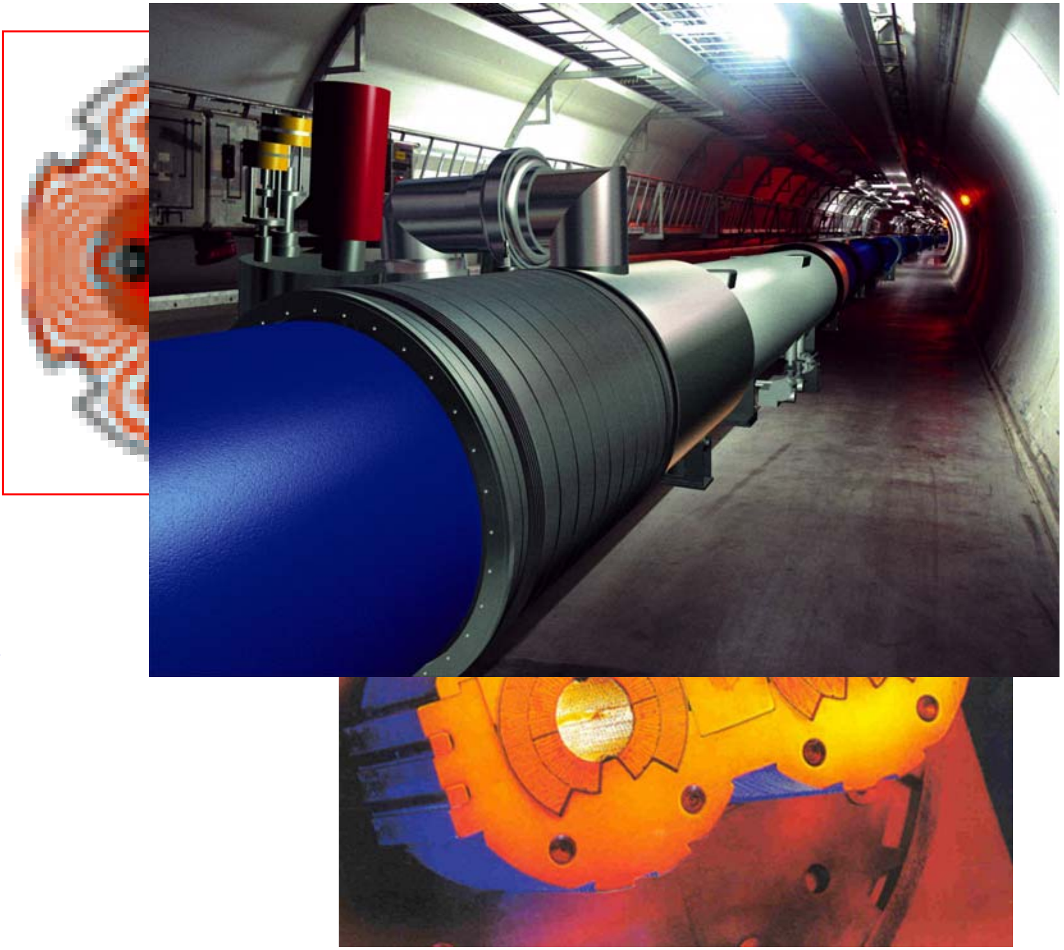
(27 km circumference)

first luminosity in 2007

Energy:

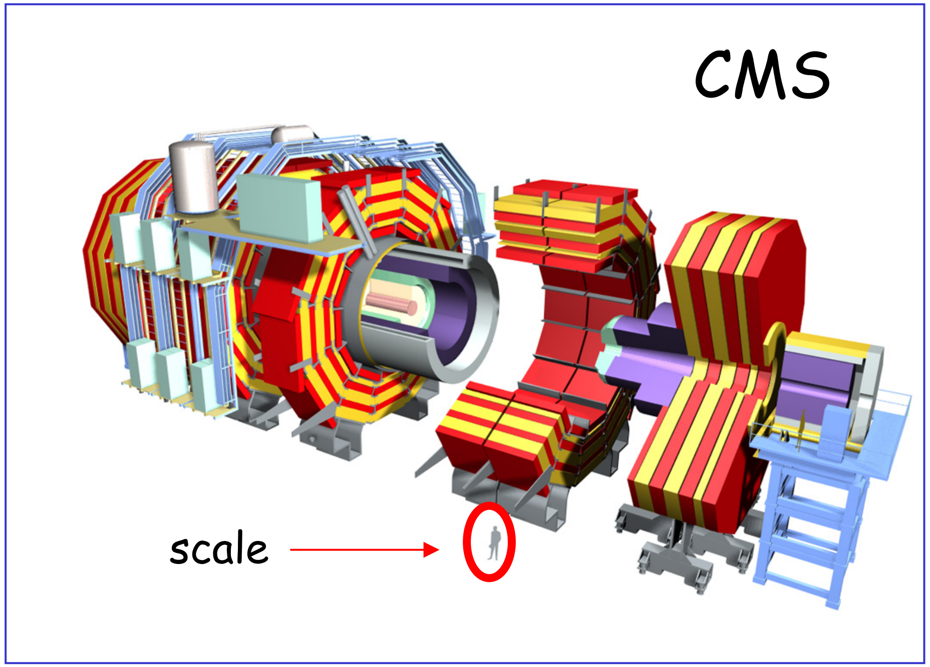
$E_{beam} = 7$ TeV

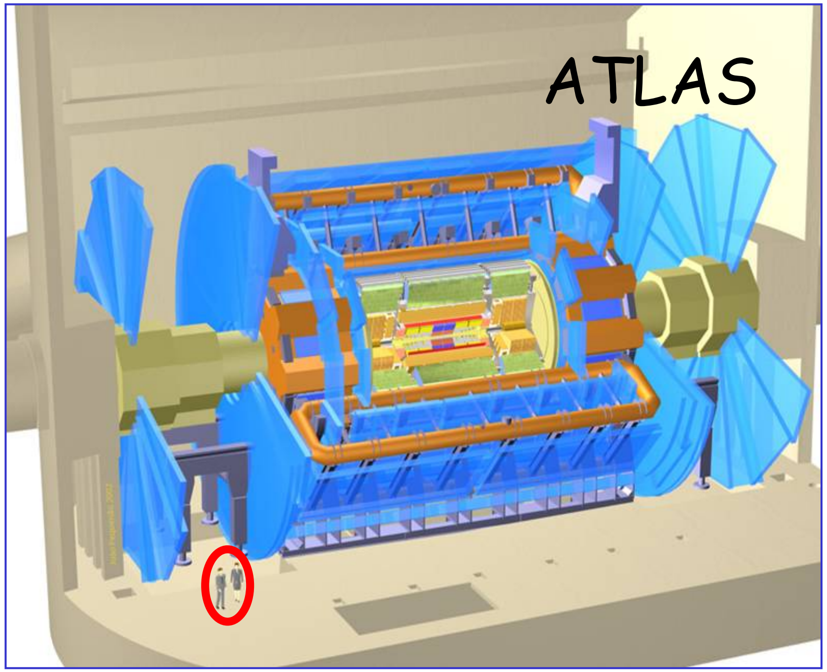
Will collide also heavy ions

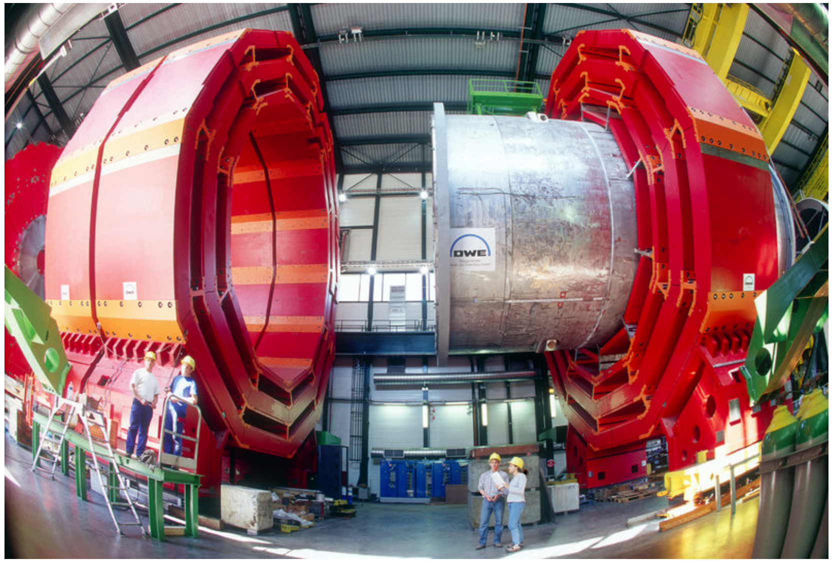


LHC Dipole Magnets

LHC Detectors

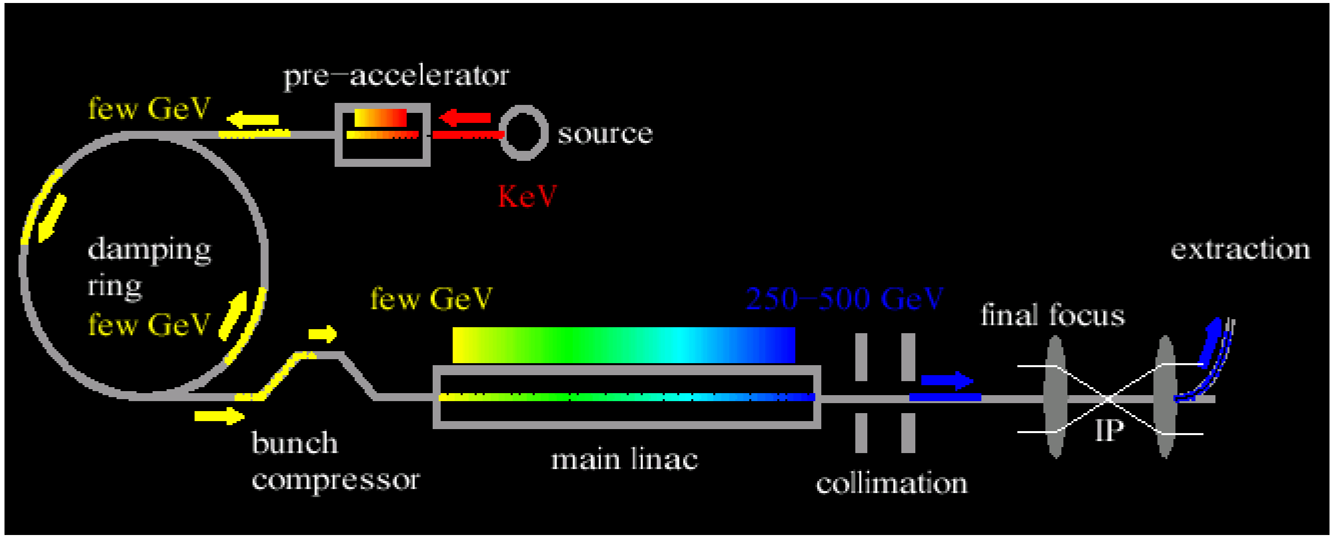






Combining Energy and Precision: e+e- Colliders

In order to reach E > 200 GeV one needs to build linear colliders because of energy loss due to synchrotron radiation



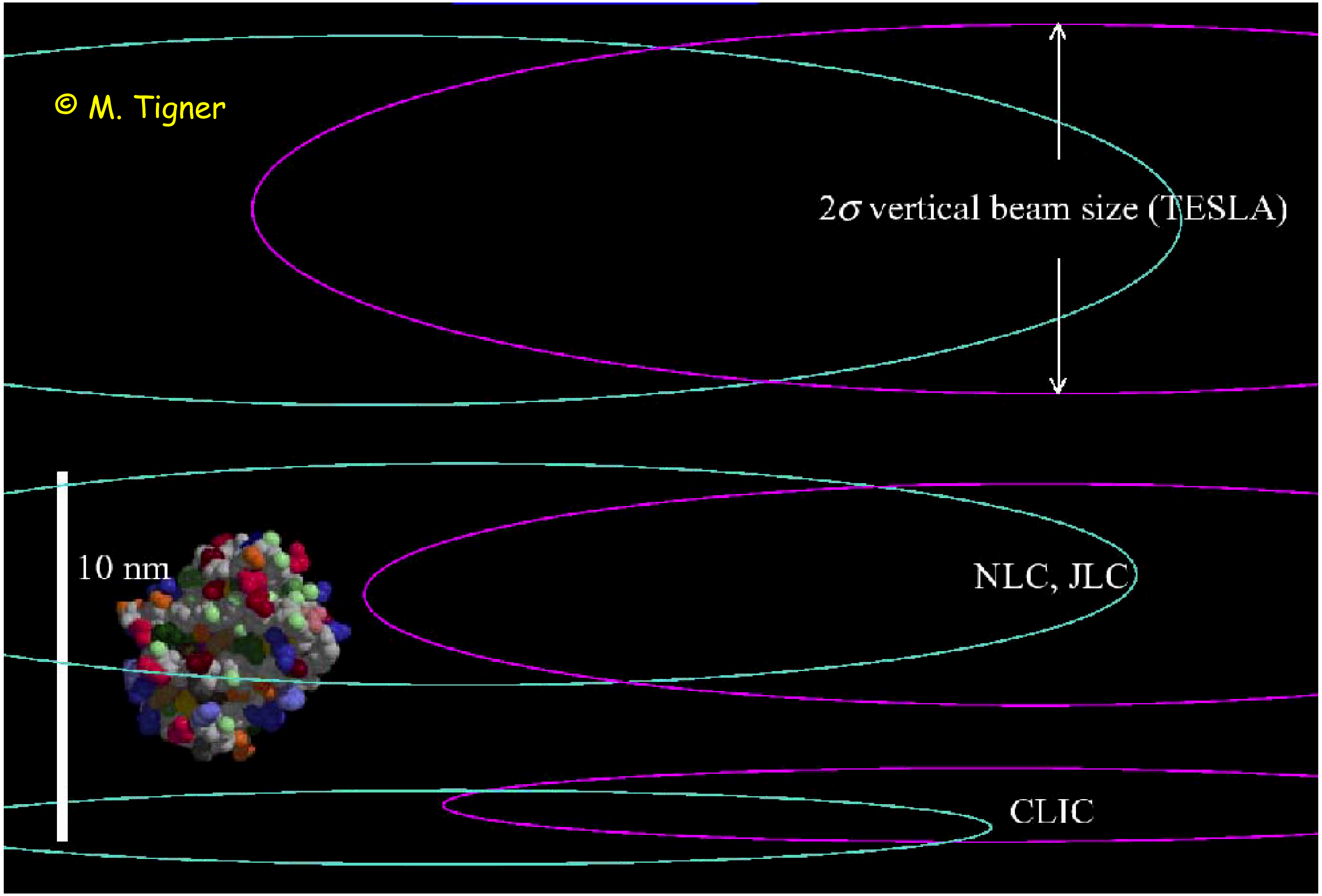
Poof of principle:

SLC at Stanford

Challenges:

Source:	produce large number of electrons/positrons (10^{10})
Damping Rings:	Make very small, well collimated beams (emittance)
Energy:	assure rapid acceleration (gradient)
Final Focus:	focus beam to tiny size (5*500 nm) →

Beam Sizes



The Choice of Technology

All major laboratories have worked during the last ~ 15 years on the development of the adequate accelerator technology, following different routes.

As the technologies have now matured one needed to decide which technology to chose for the global project, the International Linear Collider (ILC).

A international panel was charged with this recommendation.

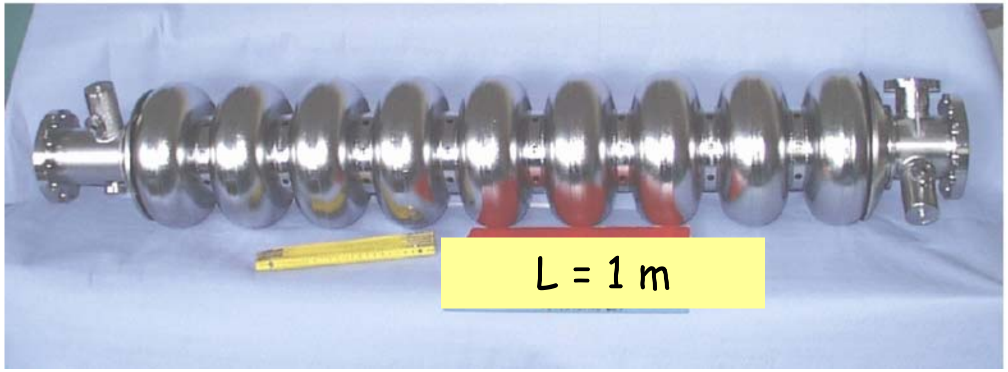
It made this recommendation in August to the International Committee for Future Accelerators (ICFA) which unanimously endorsed the recommendation:

"We recommend that the linear collider be based on superconducting RF technology"

For details see: http://www.interactions.org/linearcollider

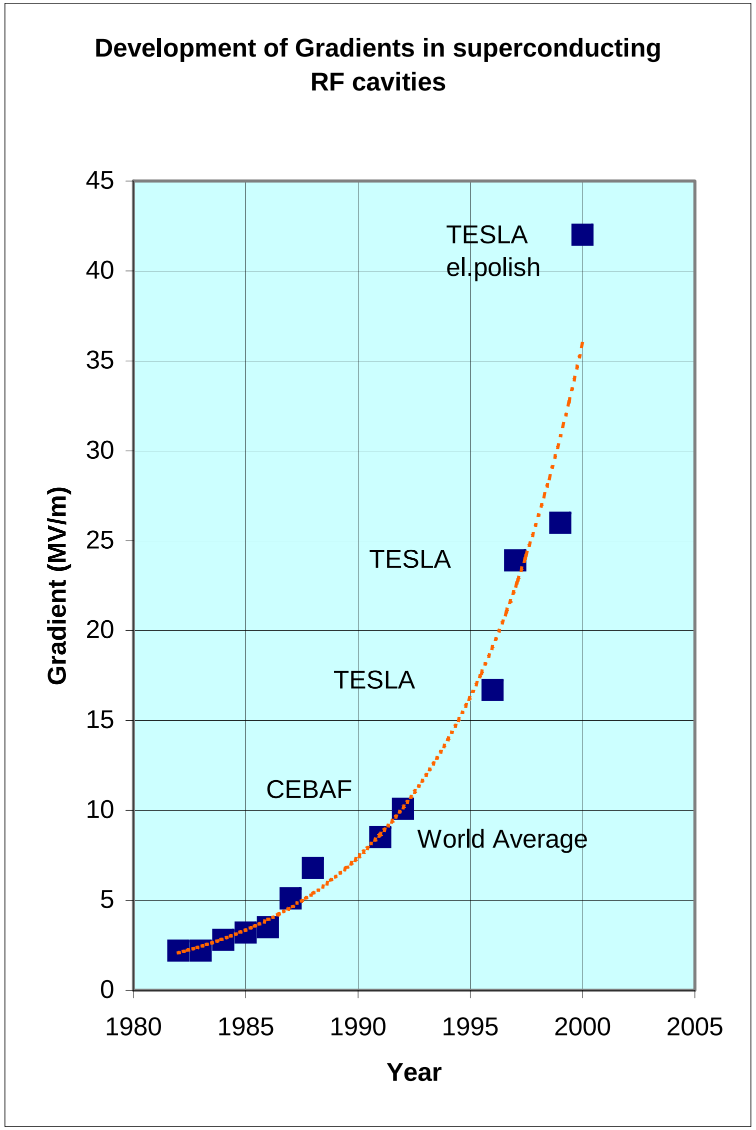
The Story of SC Cavities

SC RF structures for accelerators were developed in many countries



The challenge of high gradients needed for high energy Linear Colliders has attracted the world expertise in SC, thus leading to major progress

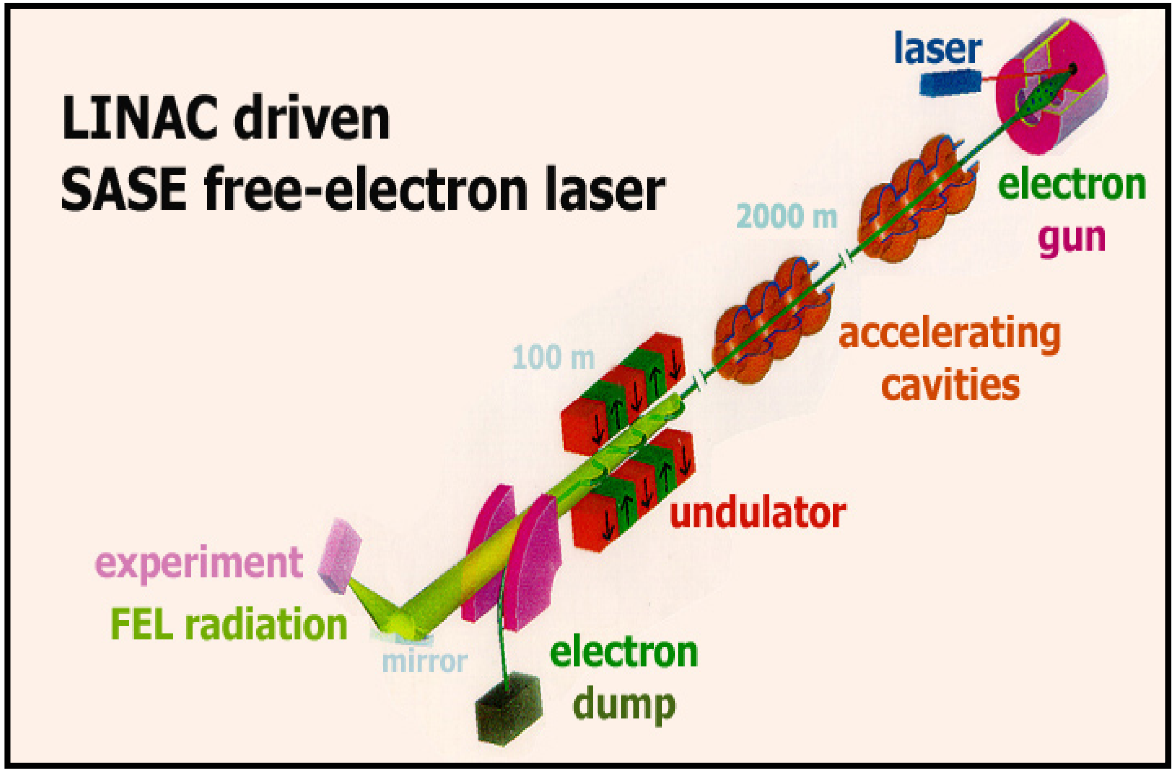
(TESLA collaboration of 55 institutes in 12 counties, based at DESY).



Impact of Accelerator Development on Other Fields

XFEL - a Revolutionary Photon Source

The excellent beam properties in the superconducting LINAC allow to use the SASE (Self Amplifying Spontaneous Emission) principle to build a new powerful photon source



Brillance:
gain ~ 10^9 compared to existing facilities

Photon beam:

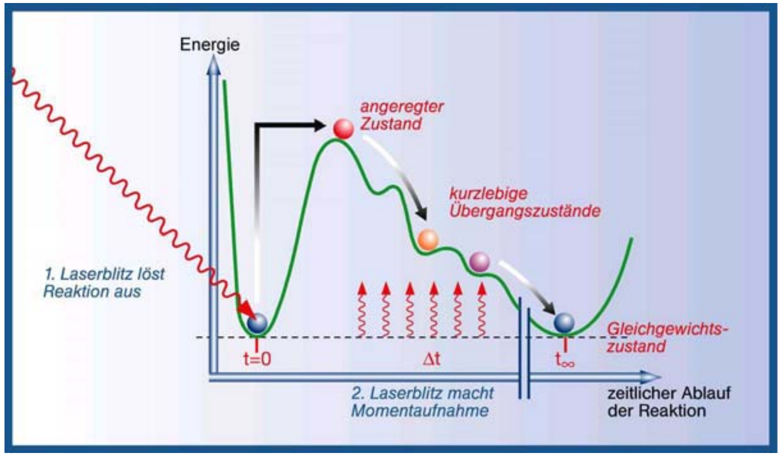
- X-rays at 0.1 nm
- Full coherence (Laser)
- Pulse length < 100 fs (time scale of chemical reactions)
- Energy tuneable

Science with the X-FEL

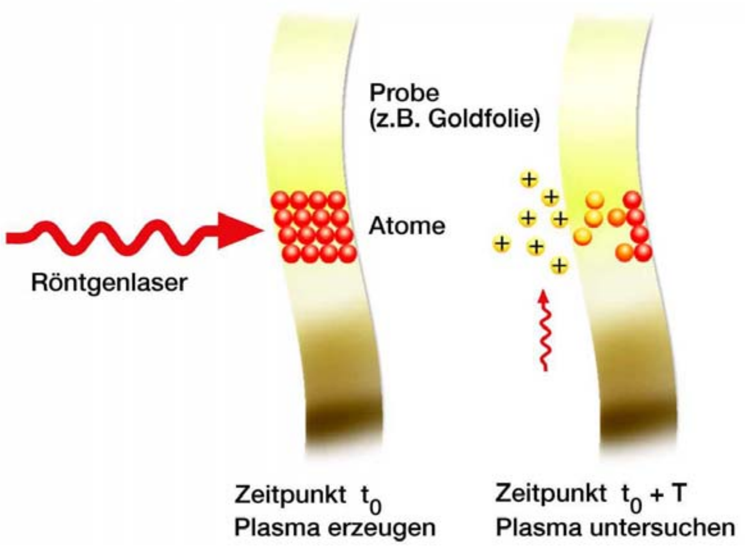
Main fields of research with the X-FEL:

- atomic, molecular and cluster phenomena, plasma physics
- non-linear processes and quantum optics
- condensed matter physics and materials science
- ultra-fast chemistry and life-sciences

Movies of chemical reactions



Plasma physics



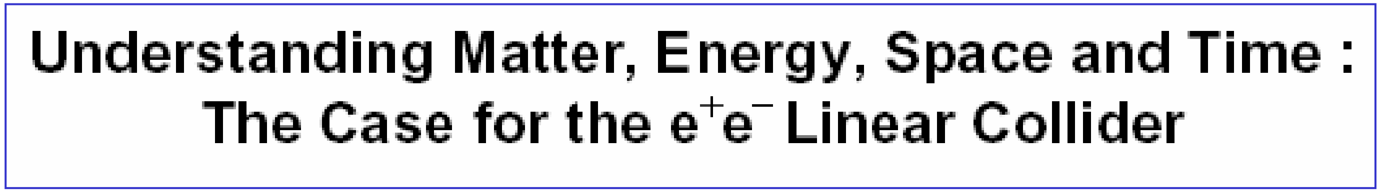
The World Road Map of Particle Physics

In-depth studies were performed in Asia, Europe, and the US

As a result a world-wide consensus has formed for a baseline LC project in which *positrons* collide with *electrons* at energies up to 500 GeV, with *luminosity* above 10^{34} cm^{-2}s^{-1}.

The energy should be upgradable to about 1 TeV.

Substantial overlap in running with LHC recommended



Understanding Matter, Energy, Space and Time :
The Case for the e^+e^- Linear Collider

The document has been signed by ~ 2700 scientists from all around the world.

The Higgs: Key to Understanding Mass

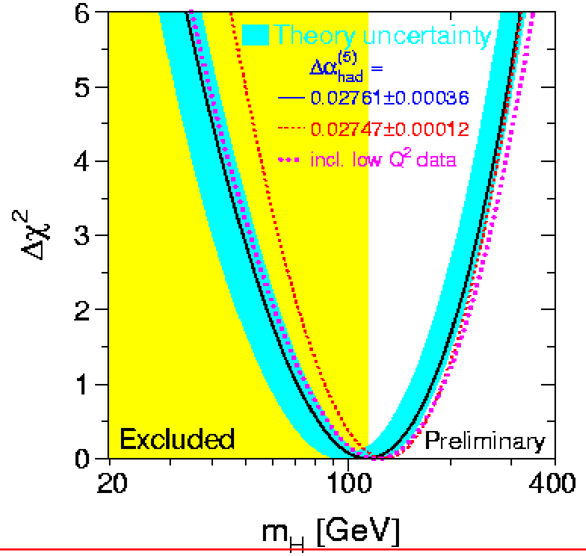
The Higgs particle is the last missing piece of the SM

Where is the Higgs?

Mass limits for the Higgs are derived from precision tests of the SM

114 < m(H) < 237 GeV (95 % CL)

Therefore expect to find Higgs 'around the corner'



Hadron collider will most likely see the Higgs first:

- High sensitivity over wide mass range

Linear Collider measures Higgs properties with high precision (e.g.):

- quantum numbers
- Couplings (test the mechanism of mass generation)

Supersymmetry

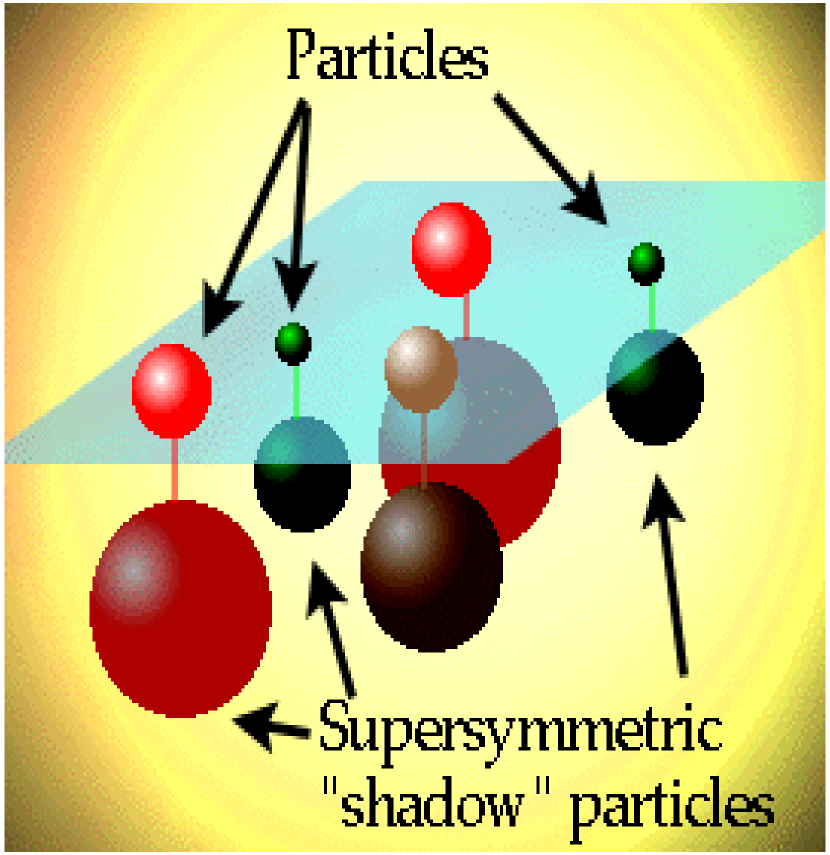
Supersymmetry is the favoured theory beyond the SM

- Calculable theory with no divergencies
- Unification of particles and forces
- Part of quantum theory of gravitation

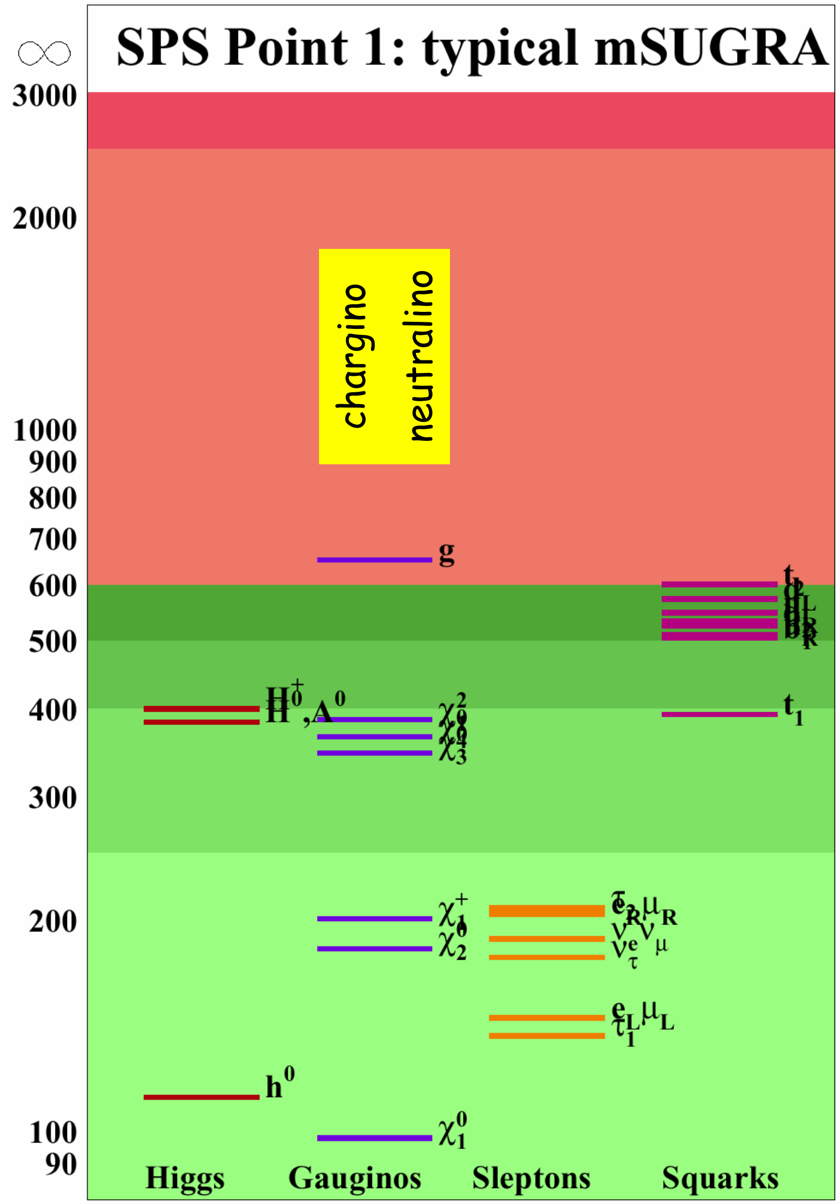
- Many arguments/measurements supporting SUSY

- consequence: many new particles every known particle has a supersymmetric partner

- possible link to dark matter



Seeing Supersymmetric Particles



LHC will see many of these new particles

especially those carrying colour

A Linear Collider can measure detailed properties of supersymmetric particles:

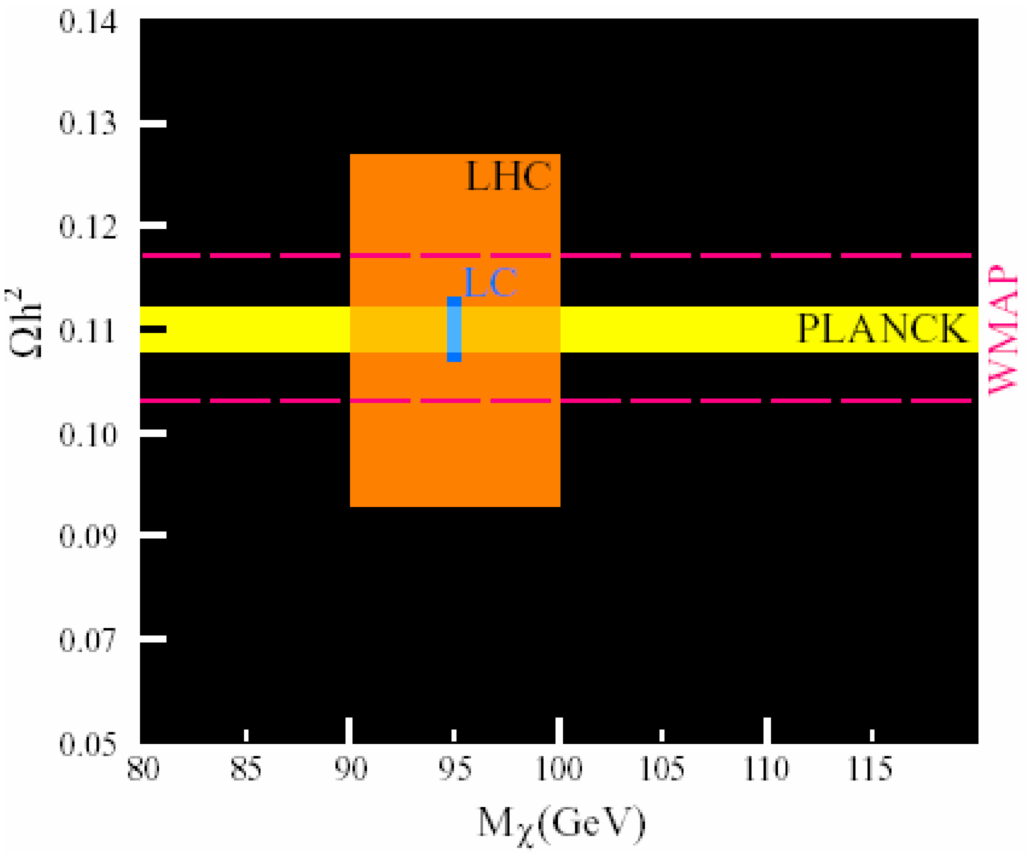
- masses
- quantum numbers
- lifetimes
- decays

Dark Matter, LHC and LC

If within reach, LHC and LC will measure mass of LSP and couplings

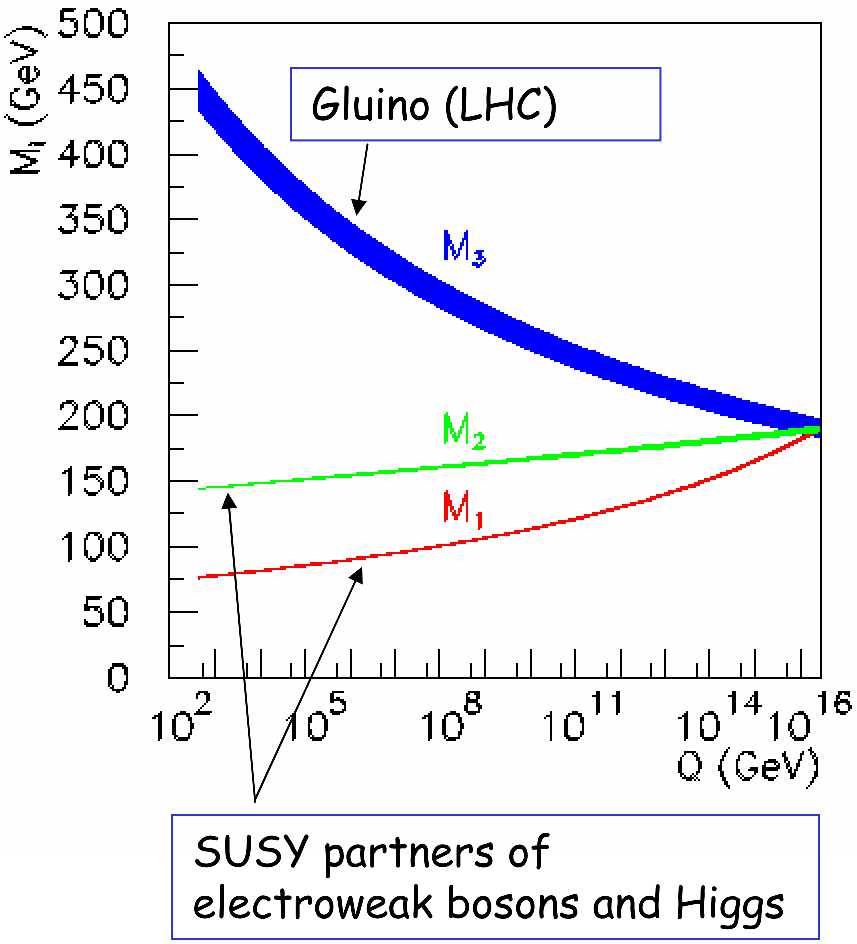
-> input for cosmology

-> will allow to interpret non-accelerator searches for DM



ACCURACY of WMAP, LHC and linear collider in determining the mass of the neutralino, a dark matter candidate, and so constraining its contribution to the energy density of the universe.

Test of Unification


Gluino (LHC)

SUSY partners of electroweak bosons and Higgs

Extrapolation of SUSY parameters from weak to GUT scale

Couplings unify at high energies,

Gaugino masses unify at same scale

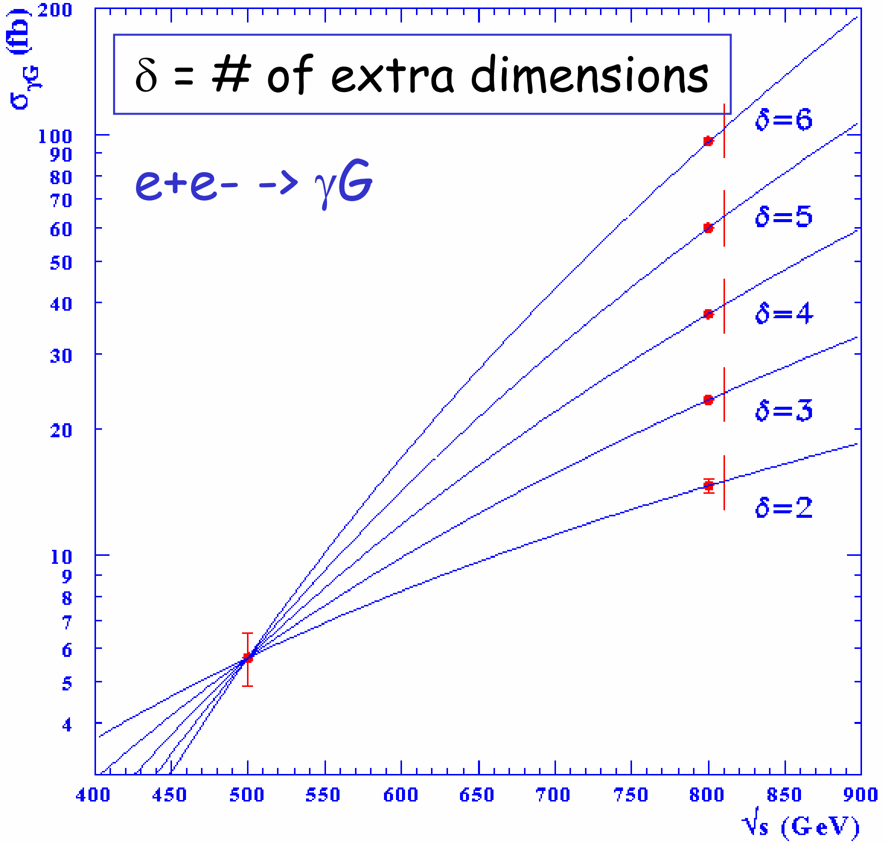
Precision provided by

LHC for gluinos and

LC for sleptons, charginos and neutralinos will allow to test if masses unify at same scale as forces

Extra Spatial Dimensions

cross section for anomalous single photon production

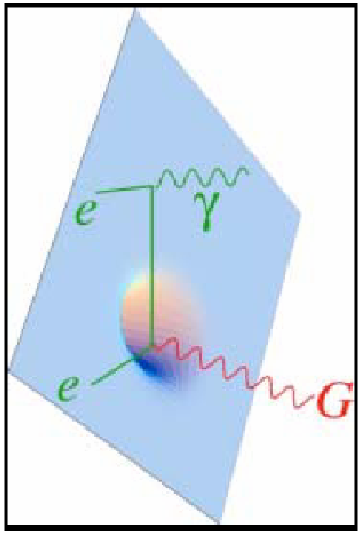


Energy

•In how many dimensions do we live?

Emission of gravitons into extra dimensions

+ emission of γ
(or one jet)



measurement of cross sections at different energies allows to determine number and scale of extra dimensions

Possible Road Map towards a Global Linear Collider

2004 Selection of Collider Technology (warm or cold)

Setting up of an international project team with branches in America, Asia and Europe (‚Global Design Initiative')

2005 Start of work of project teams

2007 Submission of TDR to governments to go ahead with LC

~2009/10 Start major construction

2015 Start of commissioning

Particle Physics World-Wide

Time scale, size, complexity and cost of future projects in particle physics require a new, globally coordinated, joint approach

The LC is likely the first step in this direction

Conclusions

Accelerator-based particle physics has put our understanding of the microscopic world on a firm foundation

The answers to the open questions are most likely ‚around the corner'

The next project (LHC) is under construction

There exists a world-wide consensus, that LHC must be supplemented with an e^+e^- Linear Collider

The size of new accelerators requires new approaches for their realisation

The link between particle physics and cosmology is very strong

Accelerator R&D for particle physics is important for other fields

From all we know: Next generation of accelerators (LHC and LC) ->
major breakthrough in our understanding,
not only incremental increase in knowledge