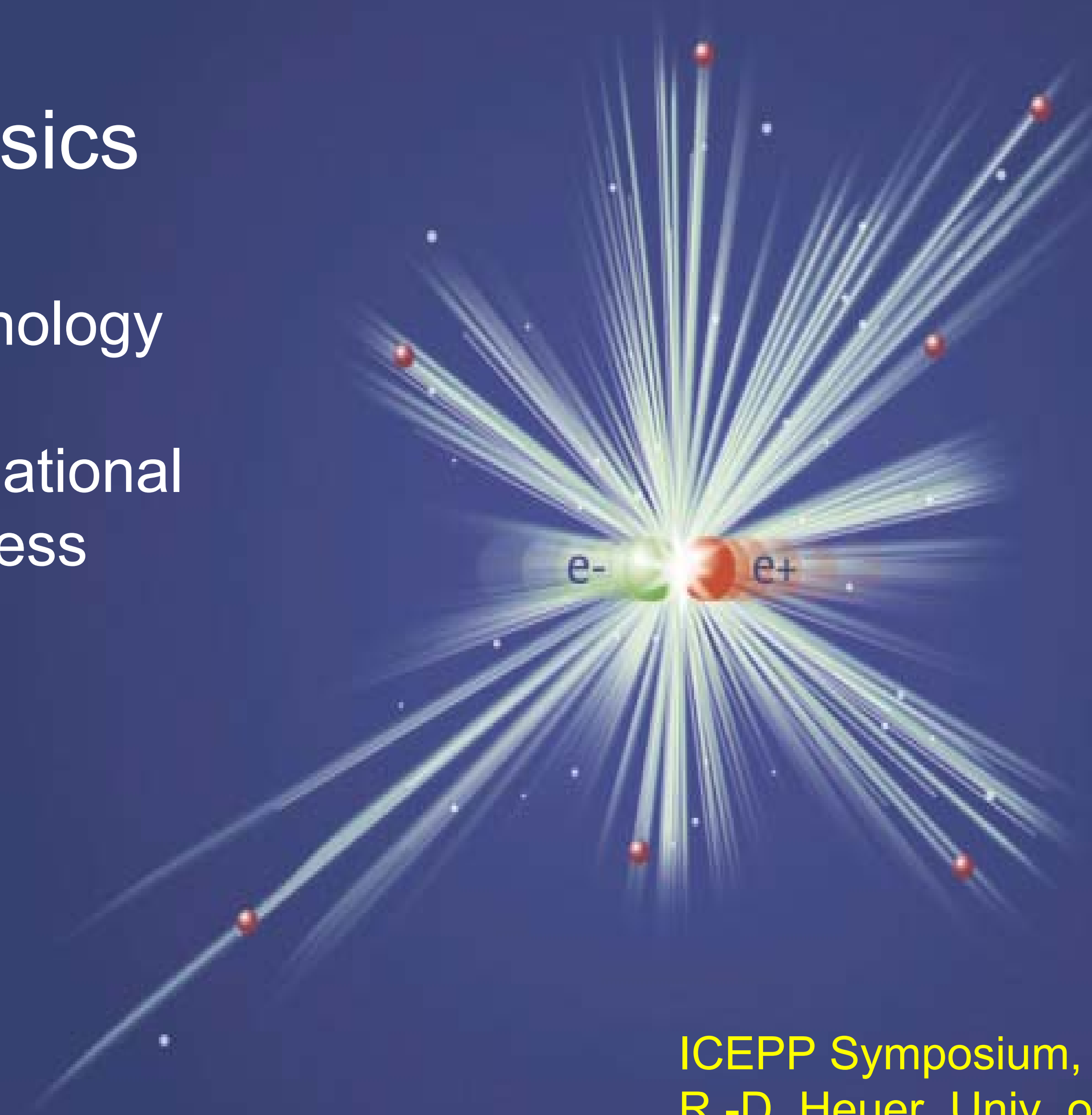
The Linear Collider Project

- Physics

- Technology

- International
  Progress



ICEPP Symposium, Hakuba, Feb. 2004
R.-D. Heuer, Univ. of Hamburg

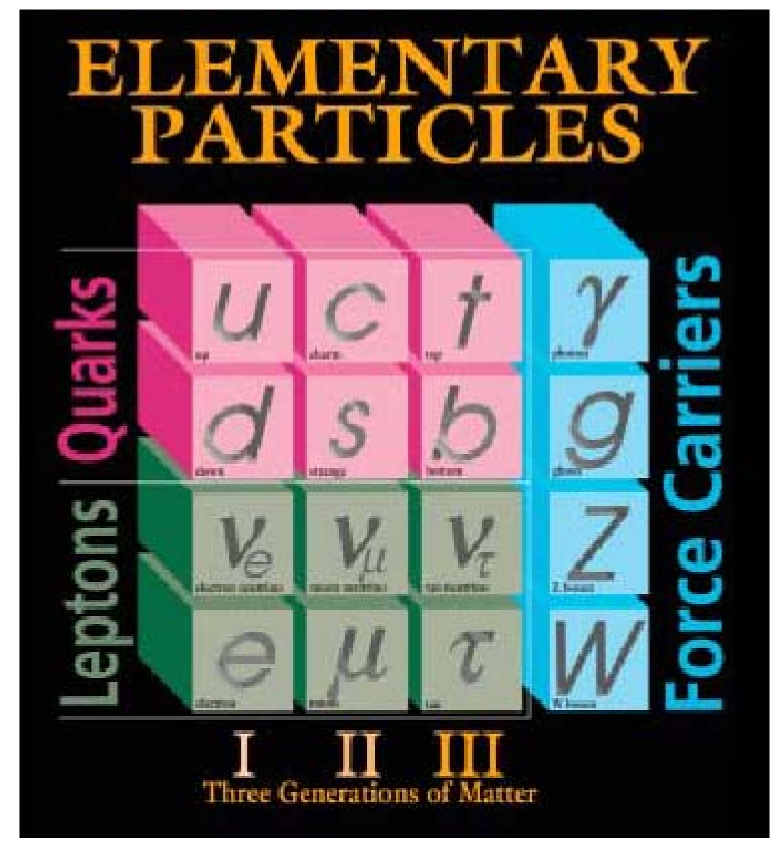
What have we learned the last 50 years
or
Status of the **Standard Model**

The physical world is

composed of
Quarks and Leptons

interacting via
force carriers
(Gauge Bosons)

Last entries: top-quark 1995
tau-neutrino 2000



Standard Model

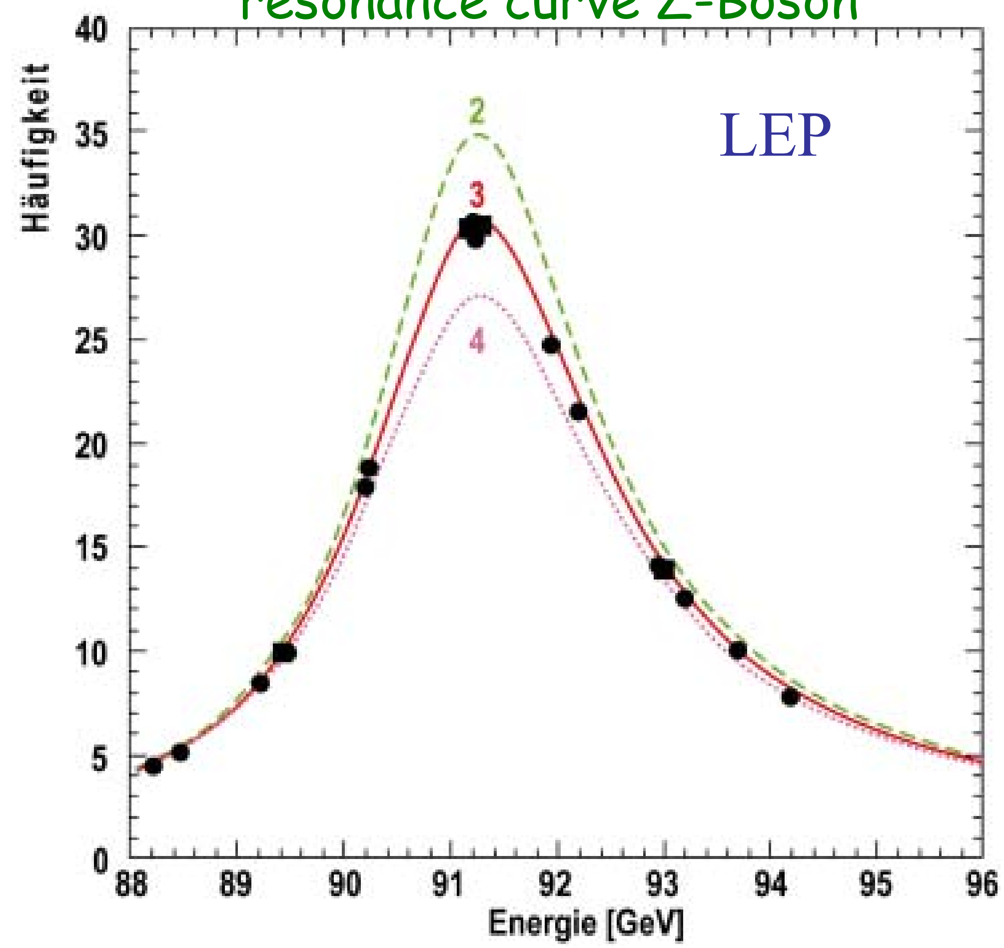
$e^+e^- \rightarrow Z^0 \rightarrow f\,\bar{f}$
where $f = q, l, \nu$

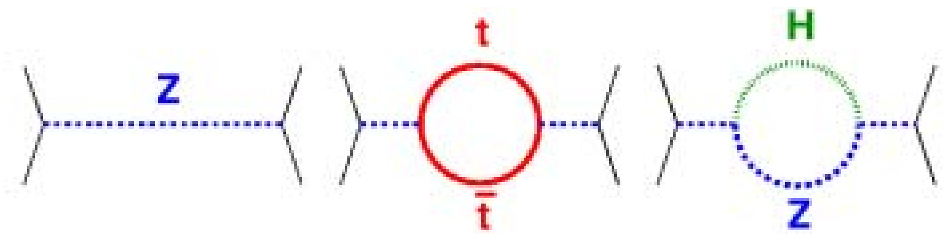
σ_Z and Γ_Z depend on number of (light) neutrinos

number of families:

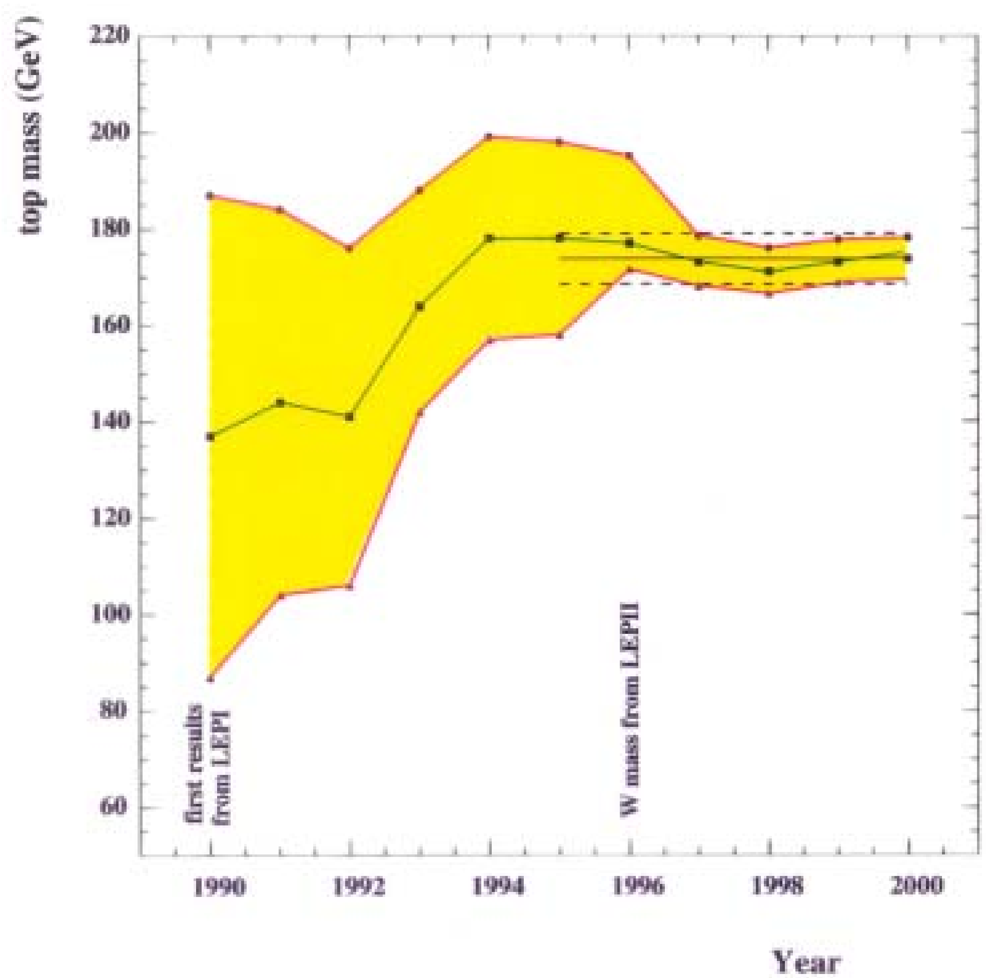
N = 2.994 +– 0.012

resonance curve Z-Boson





Standard Model:
Testing Quantum Fluctuations



LEP:

Indirect determination of the top mass

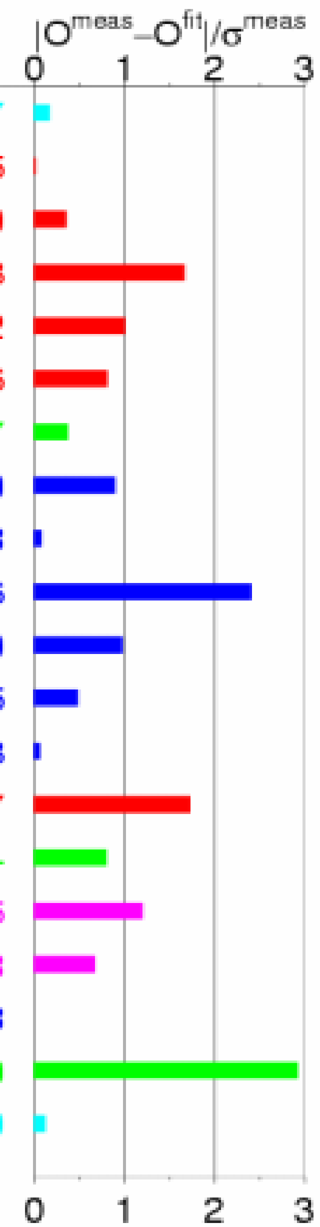
possible due to

- precision measurements
- known higher order electroweak corrections

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

Summer 2003

	Measurement	Fit
$\Delta\alpha_{had}^{(5)}(m_Z)$	0.02761 ± 0.00036	0.02767
m_Z [GeV]	91.1875 ± 0.0021	91.1875
Γ_Z [GeV]	2.4952 ± 0.0023	2.4960
σ_{had}^0 [nb]	41.540 ± 0.037	41.478
R_l	20.767 ± 0.025	20.742
$A_{fb}^{0,l}$	0.01714 ± 0.00095	0.01636
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1477
R_b	0.21638 ± 0.00066	0.21579
R_c	0.1720 ± 0.0030	0.1723
$A_{fb}^{0,b}$	0.0997 ± 0.0016	0.1036
$A_{fb}^{0,c}$	0.0706 ± 0.0035	0.0740
A_b	0.925 ± 0.020	0.935
A_c	0.670 ± 0.026	0.668
A_l(SLD)	0.1513 ± 0.0021	0.1477
$\sin^2\theta_{eff}^{lept}(Q_{fb})$	0.2324 ± 0.0012	0.2314
m_W [GeV]	80.426 ± 0.034	80.385
Γ_W [GeV]	2.139 ± 0.069	2.093
m_t [GeV]	174.3 ± 5.1	174.3
$\sin^2\theta_W(\nu N)$	0.2277 ± 0.0016	0.2229
Q_W(Cs)	-72.84 ± 0.46	-72.90



Standard Model today enormously successful:

- tested at quantum level
- (sub)permille accuracy

precise and quantitative description of subatomic physics,
valid to the 0.1% level

Standard Model

Success of the Standard Model:

Describes matter and interactions of observed particles consistently up to the Planck scale

But:

Origin of Electro-Weak Symmetry Breaking (EWSB) not revealed, Higgs-Boson not found yet

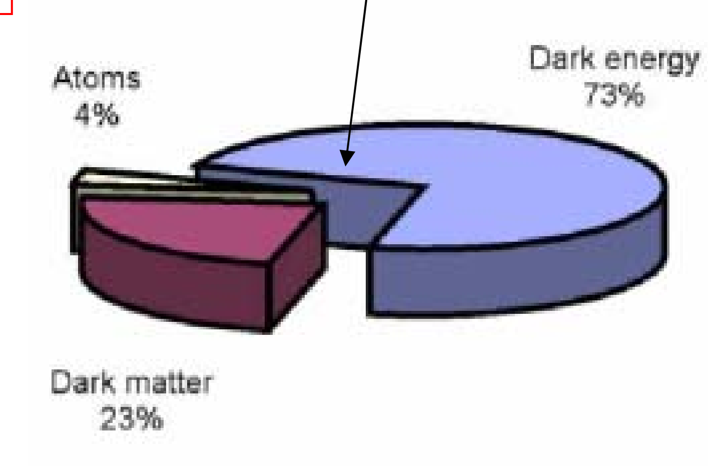
The SM is unstable:

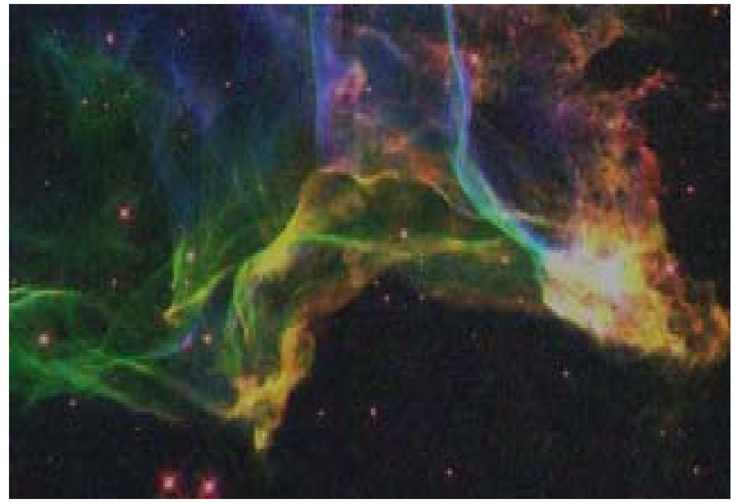
Higgs mass not protected against very large corrections

$200^2 = (10^{19})^2 - (10^{19})^2$ strange…

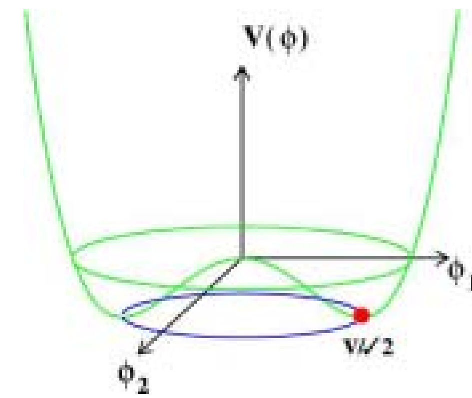
The SM is incomplete:

95% of the total energy of the Universe does not appear in the SM

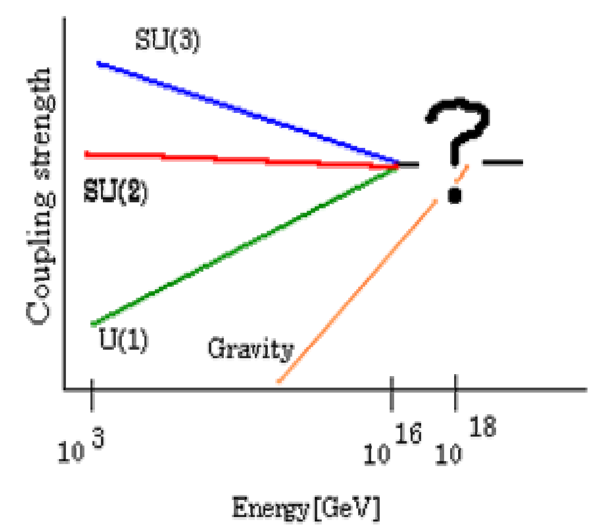




Key Questions of Particle Physics and Cosmology



- What is the origin of mass
-
- Are there more than four space-time dimensions
- What is the quantum theory of gravity
-
- Do the forces unify, at what scale
- Are there new forces
-
- What is dark matter
- What is dark energy
- What happened to antimatter
- • • •



Towards the Answers

To find answers to these questions
at the frontiers of the very complex, very large, and the very small
there is a variety of very different experimental approaches :

- Astrophysics (SN, CMB, cosmic rays, WIMP searches)
- Neutrino Physics (cosmic, solar, atmospheric, reactors, accelerators)
- High precision experiments at low energy (B-Factories, g-2, $\mu \rightarrow e\gamma$, …)

and

- Colliders at the energy frontier

Next steps at the energy frontier

There are two distinct and complementary strategies for gaining new understanding of matter, space and time at future particle accelerators:

Towards highest energies

Hadron Colliders

- LHC under construction at CERN

Towards precision measurements

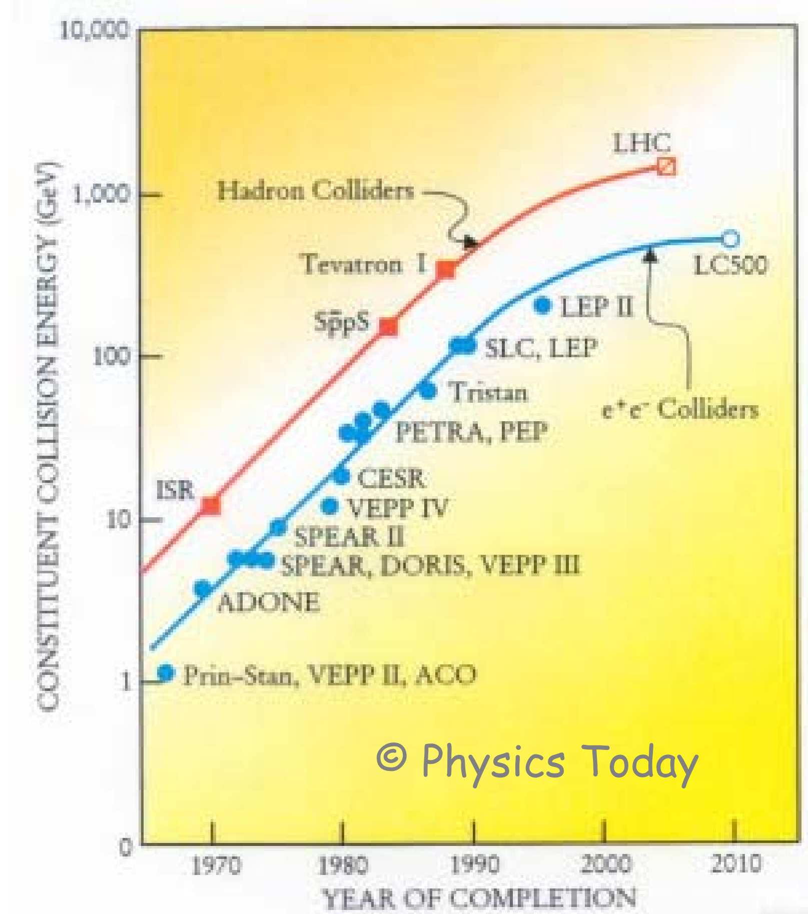
Electron-Positron Colliders

- e.g. GLC, NLC, TESLA

Physics and experience teach us that we need these different tools to answer the open questions and that they complement each other

prime example: LEP / Tevatron

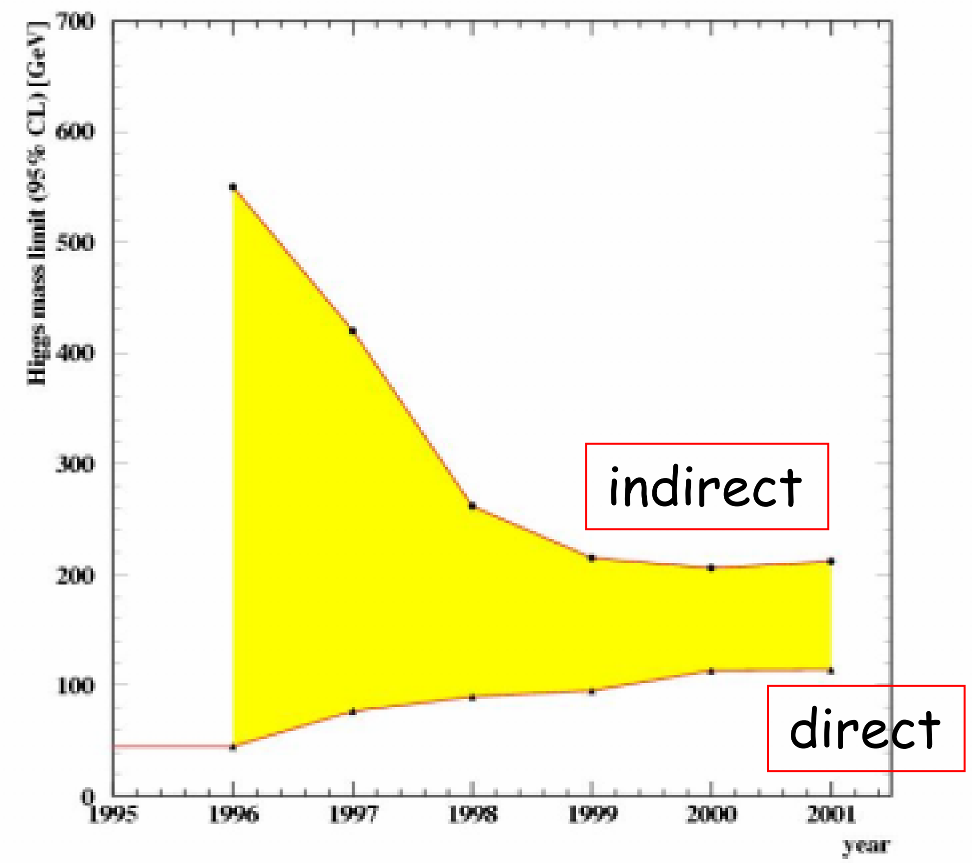
accelerator development



The next steps

We know enough now to predict with great certainty that fundamental new understanding of how forces are related, and the way that mass is given to all particles, will be found with the LHC and a Linear Collider operating at an energy of at least 500 GeV.

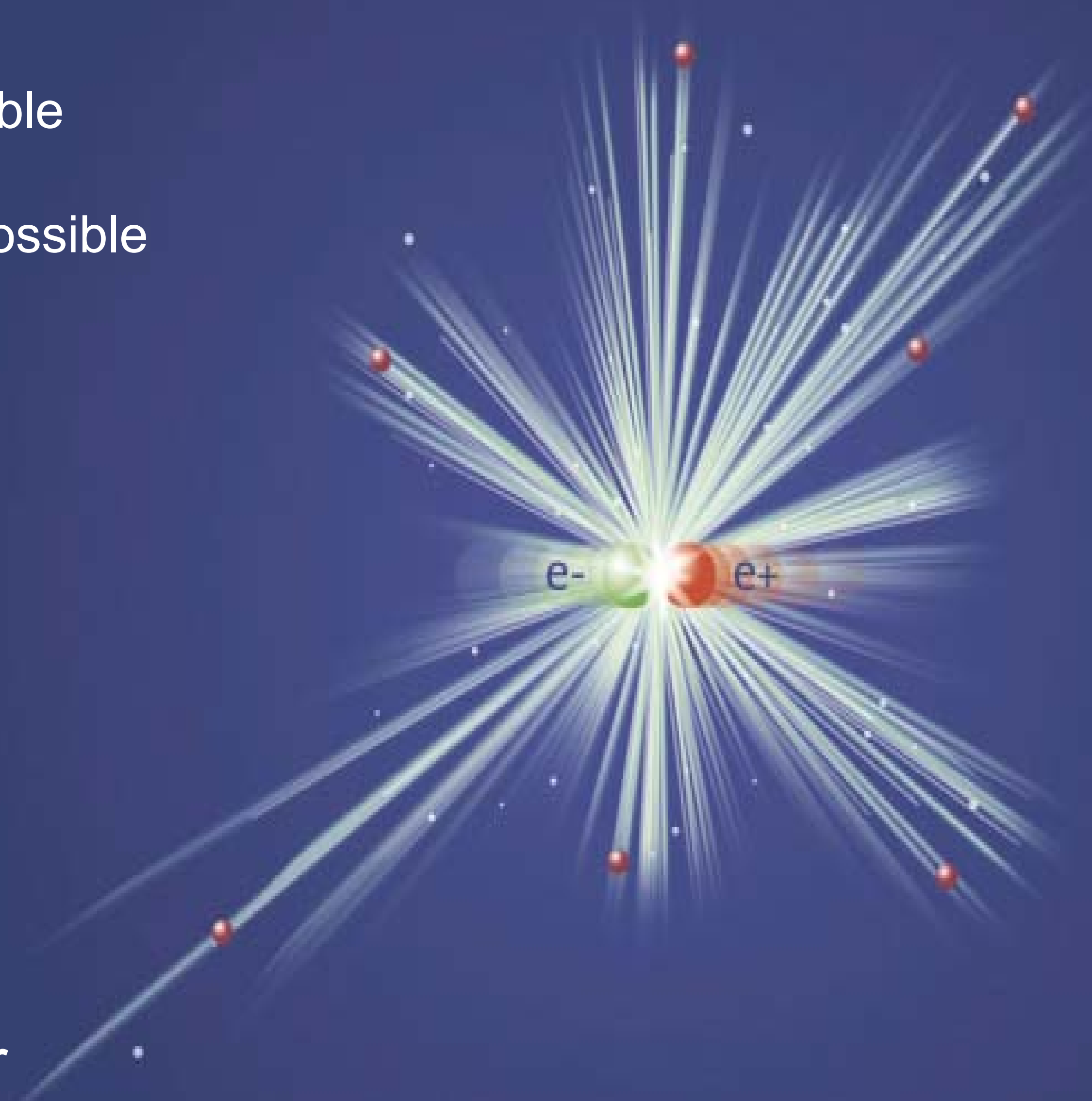
Experimental limits on the Higgs boson mass



M_H *between 114 and ~210 GeV*

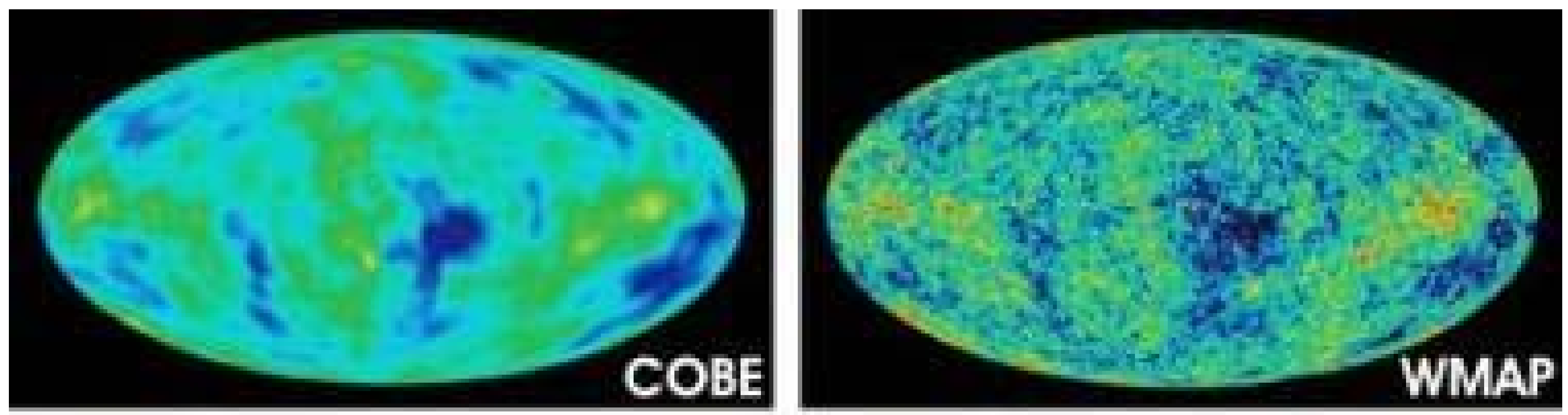
Electron-Positron Linear Collider offers

- well defined initial state
  - $\sqrt{s}$ well defined and tuneable
  - quantum numbers known
  - polarisation of e^+ and e^- possible
- clean environment
  - collision of pointlike particles
  - → low backgrounds
- precise knowledge of cross sections



⇒ Machine for **Discoveries and Precision Measurements**

An Analogy: What precision does for you ...



The Role of Electron Positron Colliders

Explore new Physics through high precision at high energy

microscopic

telescopic

$$e^+e^- \to X_{new}(+Y_{SM})$$

$$e^+e^- \to SM$$

Study the properties of new particles (cross sections, BR's, quantum numbers)

Study known SM processes to look for tiny deviations through virtual effects (needs ultimate precision of measurements and theoretical predictions)

Reason: low experimental backgrounds,
weakly interacting initial state → high precision predictions

Linear Collider Parameters
international consensus (30/9/2003)

(1) baseline machine

200 GeV < $\sqrt{s}$ < 500 GeV

integrated luminosity ~ 500 fb^{-1} in 4 years

electron polarisation ~ 80%

(2) energy upgrade

to $\sqrt{s}$ ~ 1 TeV

integrated luminosity ~ 1 ab^{-1} in 3 years

(3) options

positron polarisation of ~ 50%

high luminosity running at M_Z and W-pair threshold

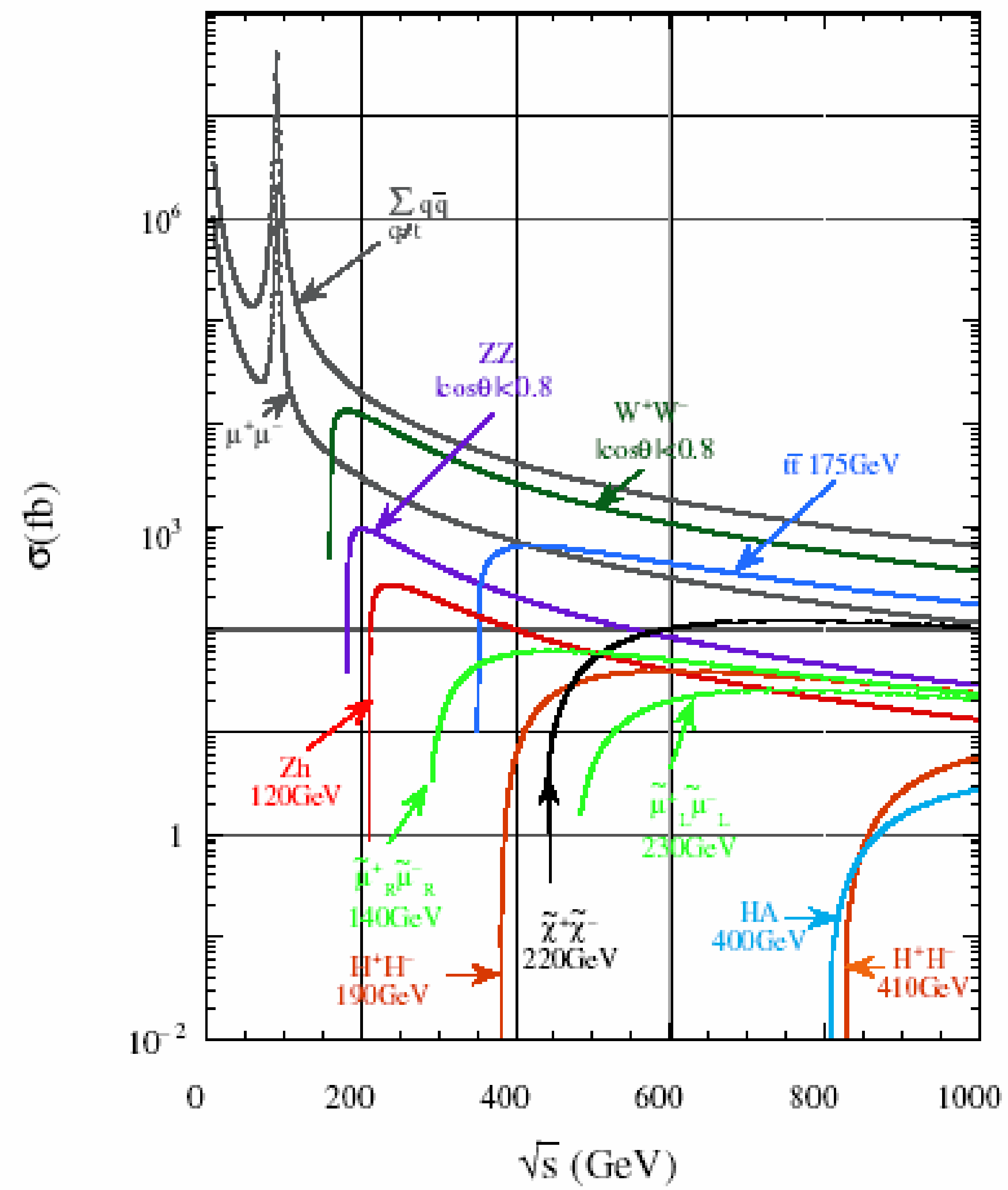
e^-e^-, $e\gamma$, $\gamma\gamma$ collisions

! Times quoted for data taking cover only part of program !

Physics

Comprehensive
and
high precision
coverage
of energy range from
M_Z to ~ 1 TeV

cross sections few *fb* to few *pb*
→ e.g. *O*(10,000) HZ/yr



Driving Physics

1. Electroweak symmetry breaking

   light Higgs

   no Higgs ← and many(!) new models in between

2. Hierarchy and Unification

   SUSY

   Extra Dimensions

   and much more…

3. Flavour physics

EWSB: Higgs

The Higgs-Boson is a new form of matter

a fundamental scalar

a new force coupling to mass

Discovery and first measurements at LHC

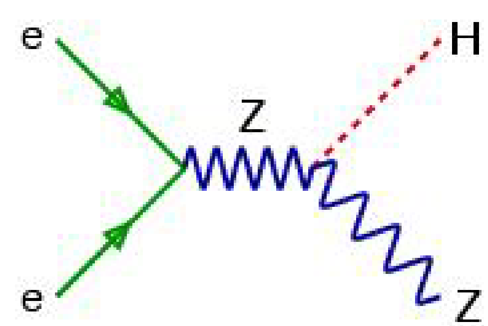
Task at the Linear Collider:

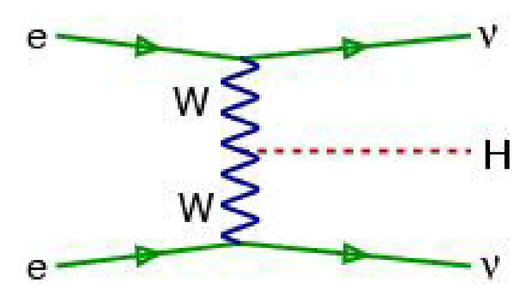
Establish Higgs mechanism as the mechanism responsible for electro-weak symmetry breaking

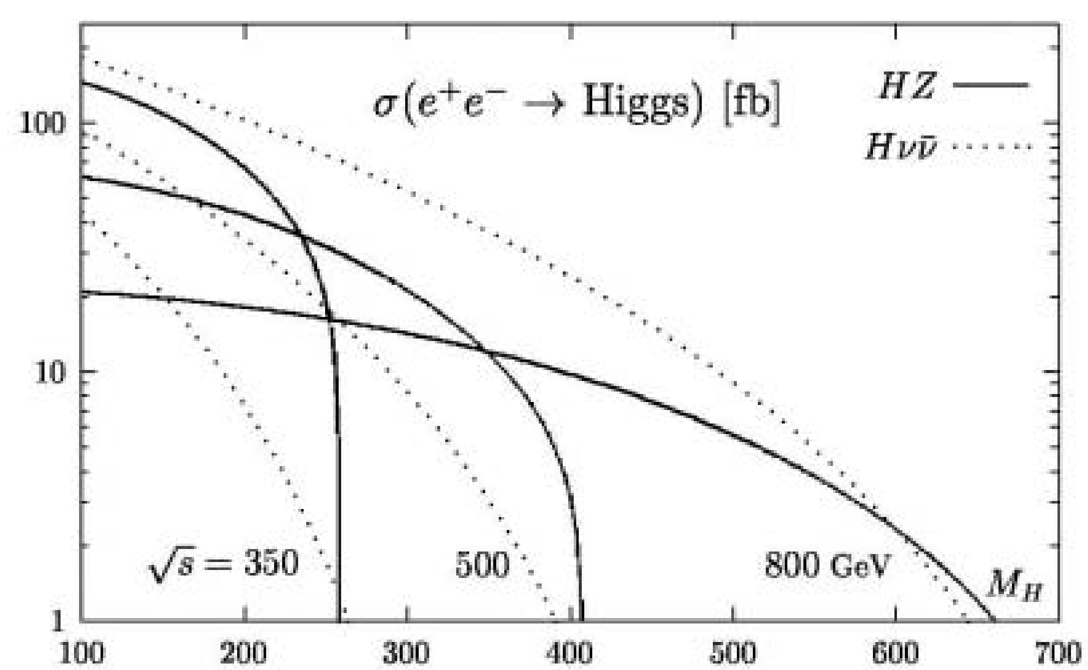
- Is it a Higgs-Boson ?
- Is it responsible for mass generation ?
- Does the Higgs field have a non-zero v.e.v. ?
- Structure of Higgs sector !

EWSB: Precision physics of Higgs bosons

Dominant production processes at LC:







Task at the LC:

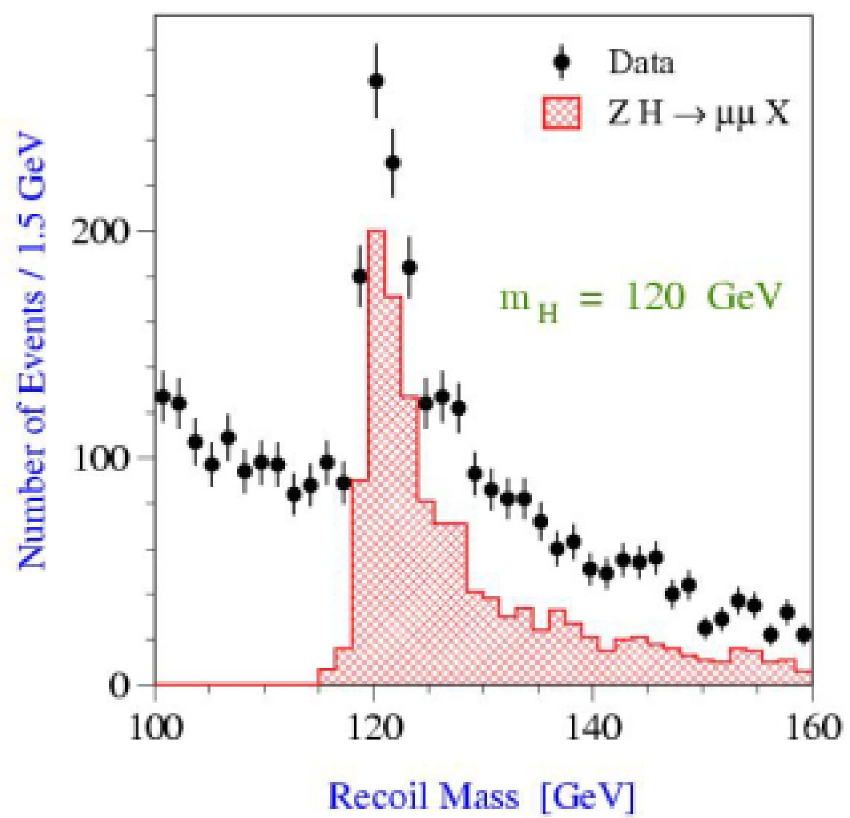
determine properties of the Higgs-boson

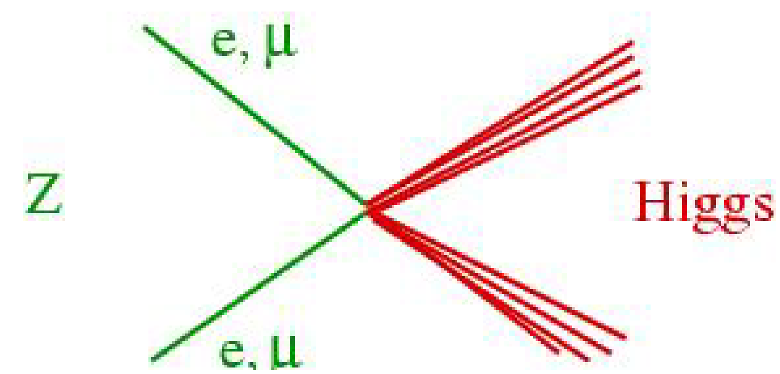
establish Higgs mechanism responsible for the origin of mass

EWSB: Precision physics of Higgs bosons

"seeing it without looking at it":
decay-mode independent observation

Recoil mass spectrum
ee -> HZ with Z -> l^+l^-



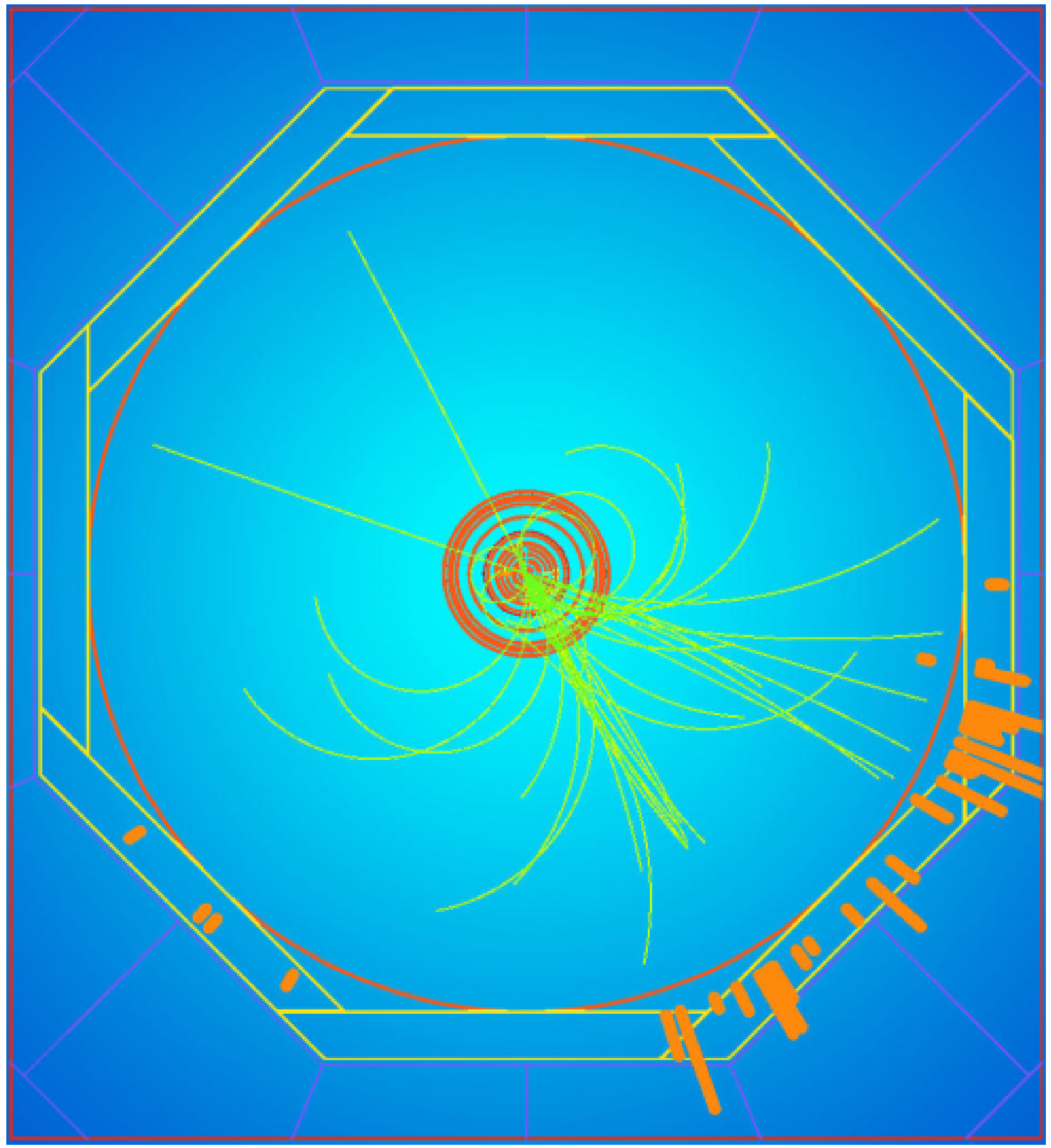


$\Delta\sigma$ ~ 3%

model independent measurement

Δm ~ 50 MeV

sub-permille precision



ee -> HZ
Z -> l l
H -> qq

EWSB: Precision physics of Higgs bosons

ee -> HZ
diff. decay channels

m_H = 120 GeV

$\rightarrow b\bar{b}q\bar{q}$

$\rightarrow q\bar{q}\ell^+\ell^-$

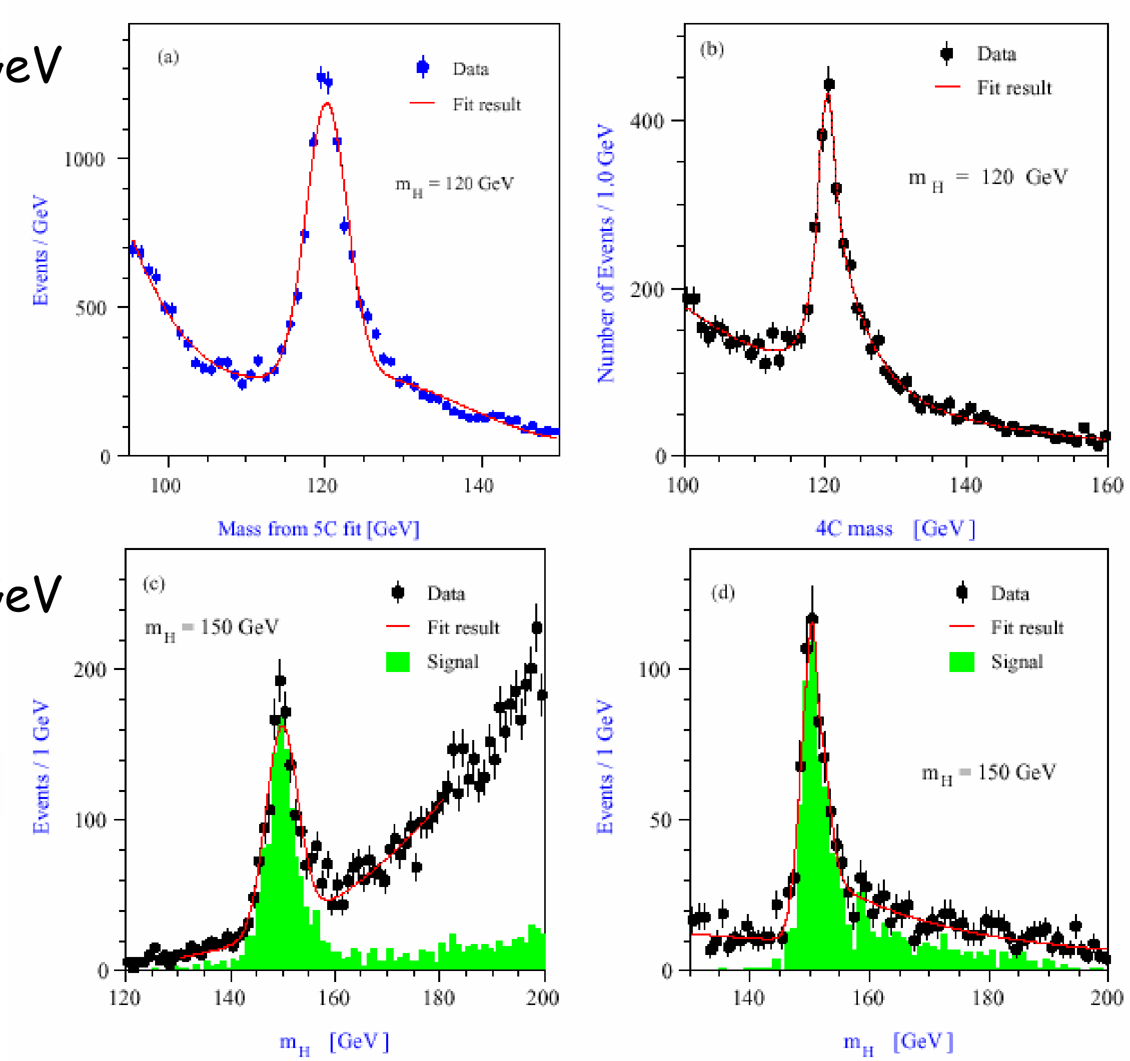
Δm_H = 40 MeV

m_H = 150 GeV

$\rightarrow W^+W^-q\bar{q}$

$\rightarrow W^+W^-\ell^+\ell^-$

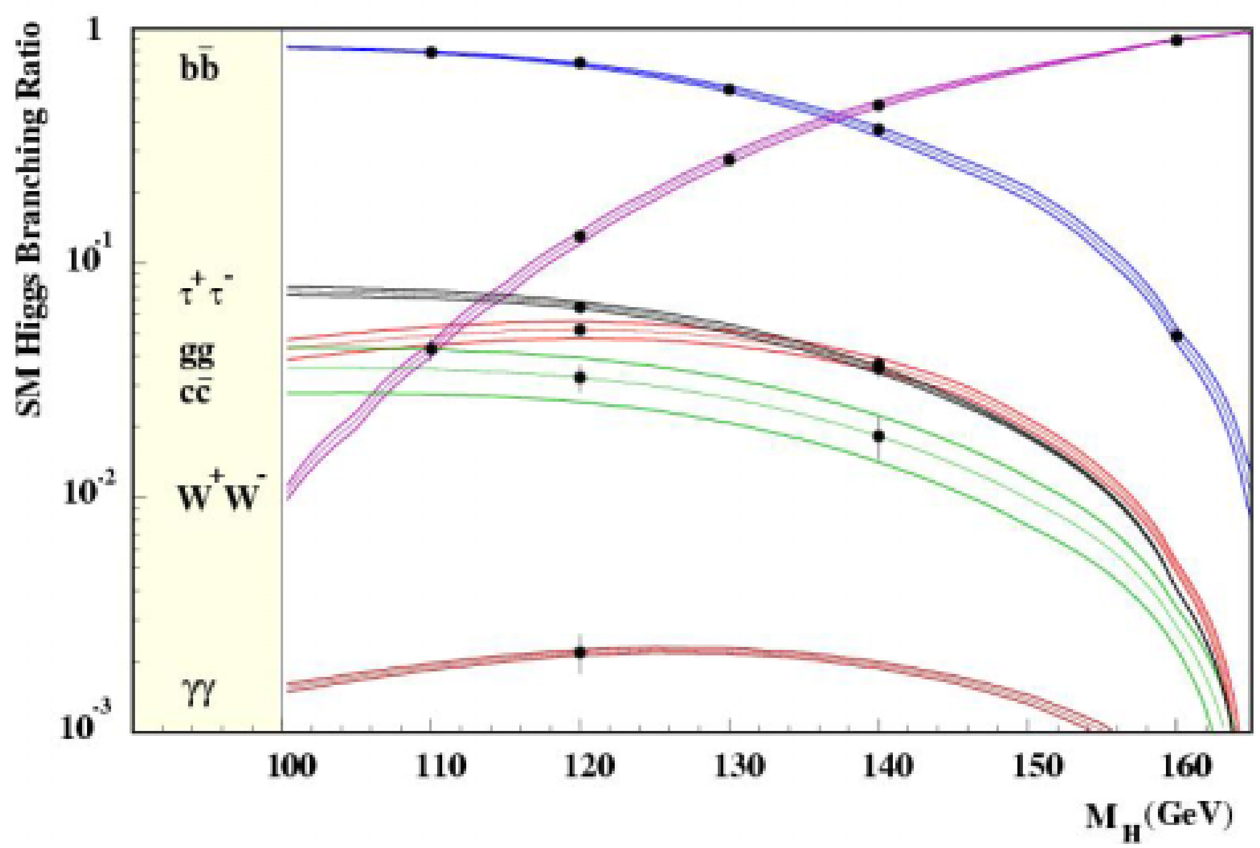
Δm_H = 70 MeV



EWSB: Precision physics of Higgs bosons

Higgs field responsible for particle masses
→ couplings proportional to masses

Precision analysis
of Higgs decays



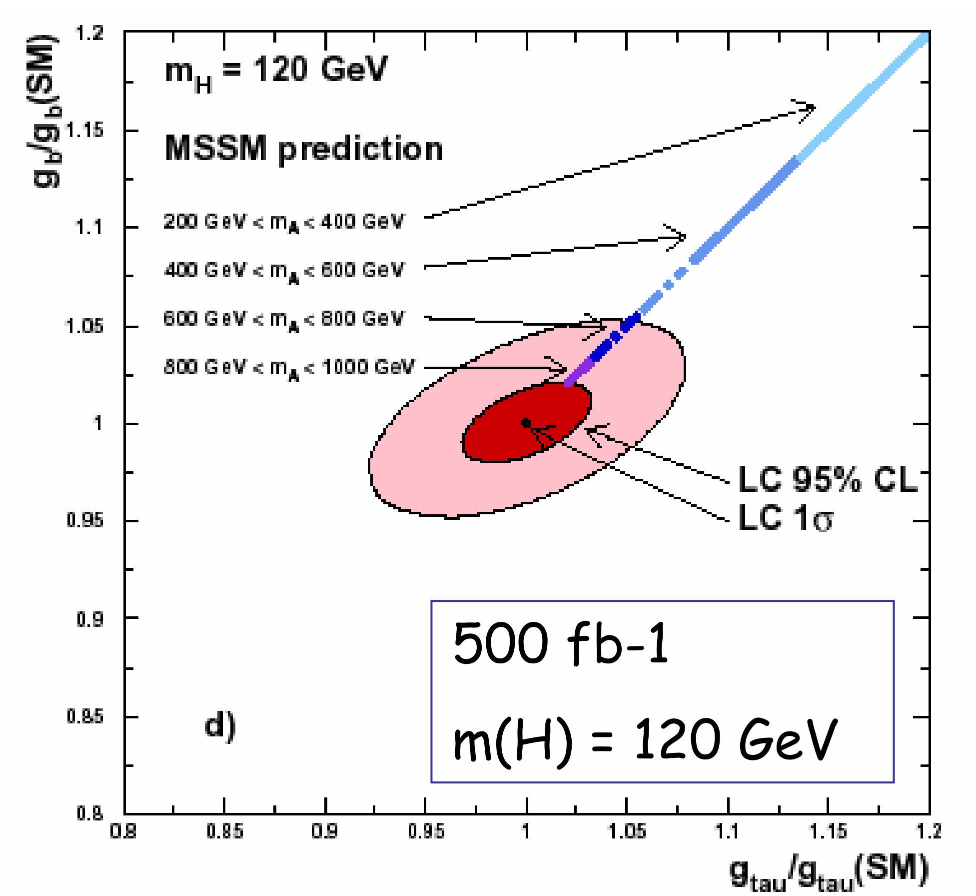
ΔBR/BR

bb	2.4%
cc	8.3%
gg	5.5%
tt	6.0%
gg	23.0%
WW	5.4%

For 500 fb^{-1}
M_H = 120 GeV

EWSB: Precision physics of Higgs bosons

High precision measurement of Higgs branching ratios
allows sensitivity to new effects, e.g. additional heavy Higgs bosons



Global fit to measured cross sections and BRs yields

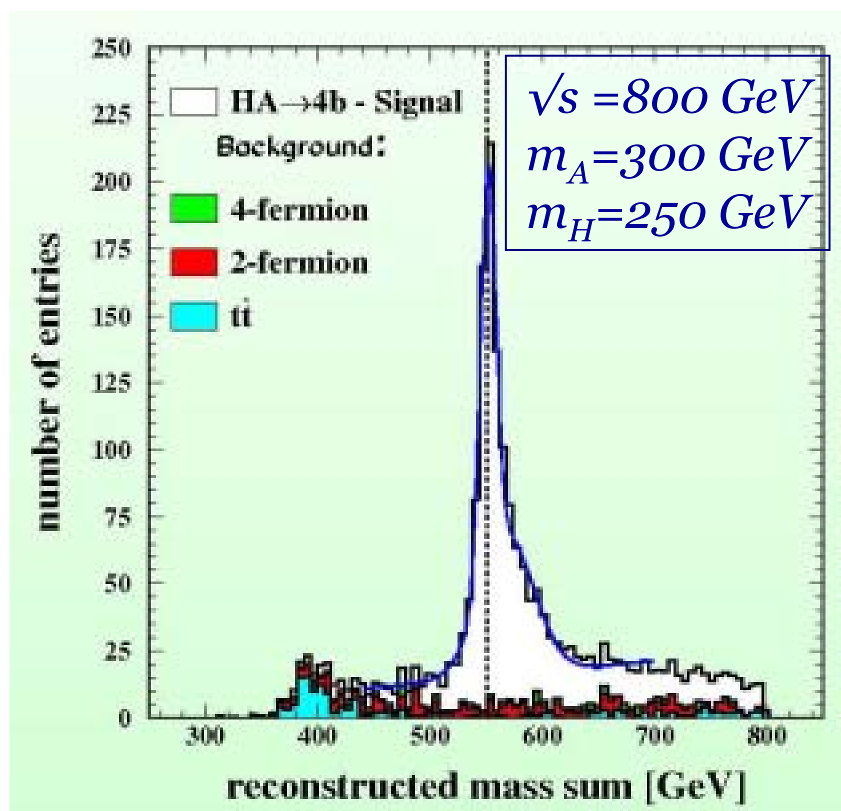
Higgs couplings,

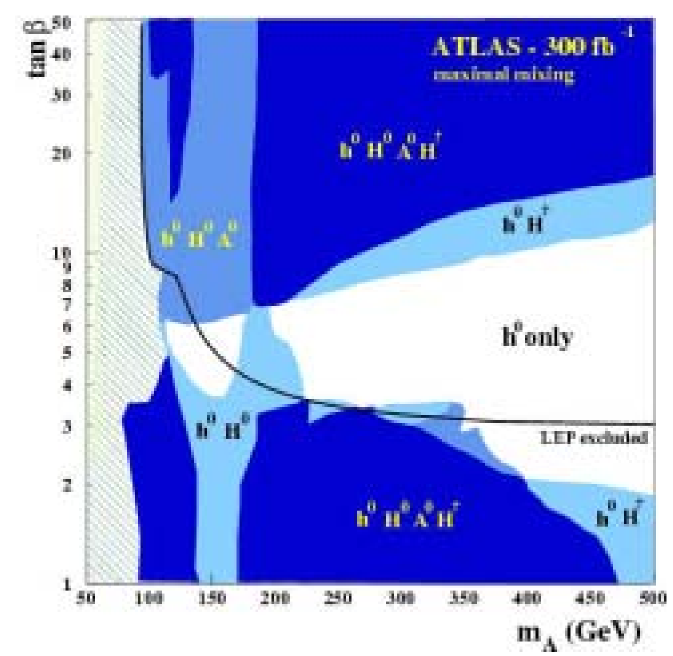
e.g. g(Hbb) and g(Hττ)

example:
Standard Model Higgs
vs
MSSM Higgs

EWSB: Heavy SUSY-Higgs

Heavy SUSY Higgs bosons:
observation and mass/BR/width(?) measurements
deep into the LHC wedge region at 800-1000 GeV LC

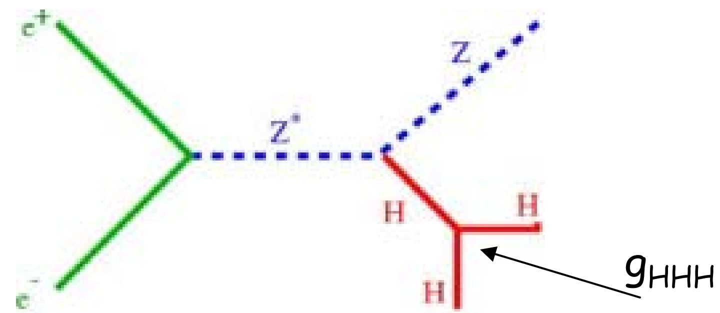




HA → bbbb and HA → bbττ/ττbb observable

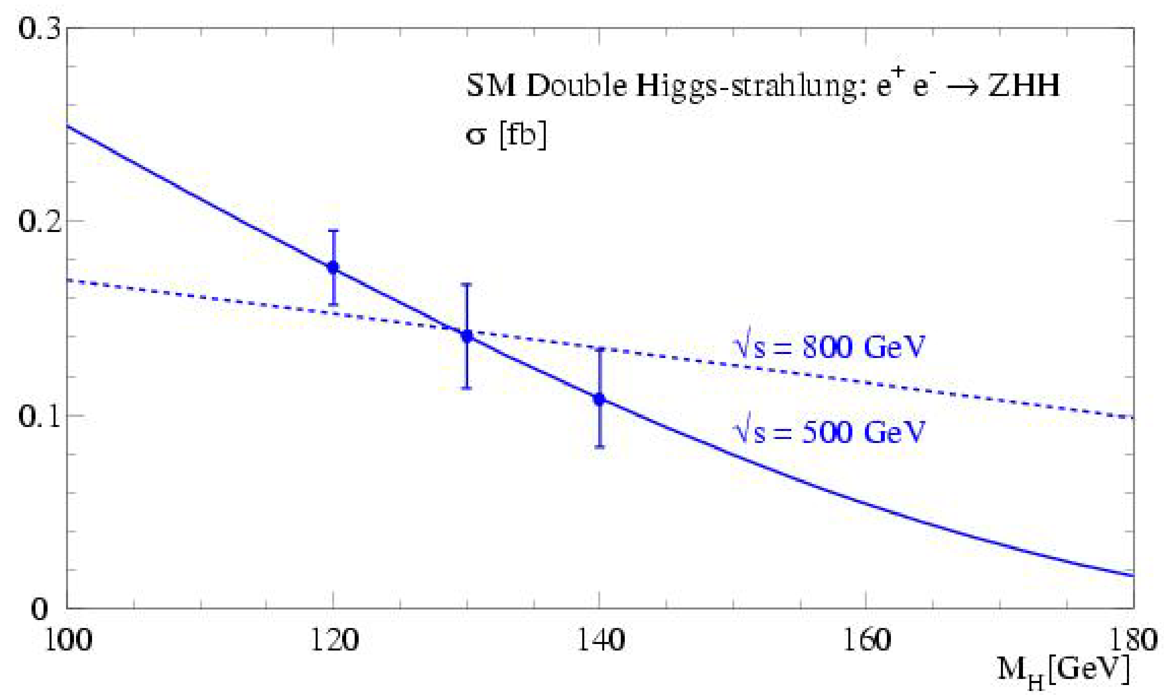
HA: 5σ discovery possible up to Σm = √s – 30 GeV

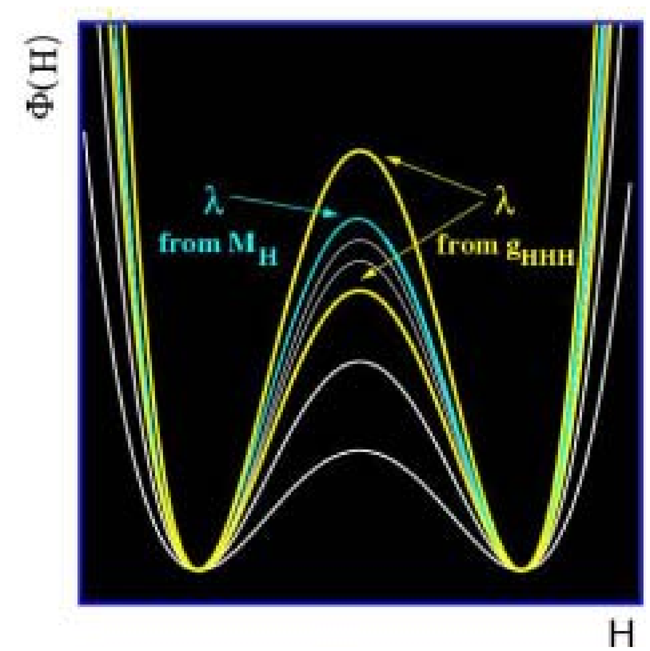
EWSB: Reconstruction of the Higgs-potential



$\Phi(H) = \lambda v^2 H^2 + \lambda v H^3 + 1/4 \lambda H^4$

SM: $g_{HHH} = 6\lambda v$, fixed by M_H





$\Delta\lambda / \lambda \cong 20\%$

(1 ab^{-1})

EWSB: No Higgs boson(s) found….

→ divergent $W_L W_L \rightarrow W_L W_L$ amplitude in SM at $\Lambda^2 = o\left(\frac{4\pi\sqrt{2}}{G_F}\right) \approx (1.2TeV)^2$

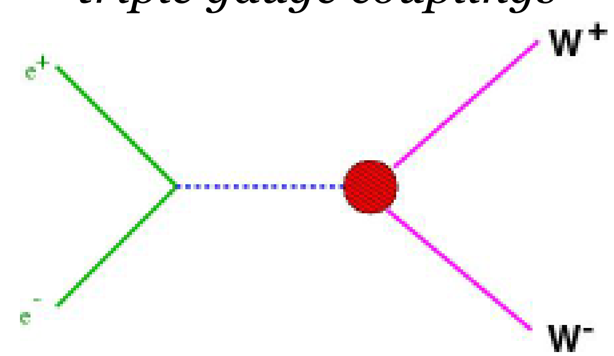
→ SM becomes inconsistent unless a new strong QCD-like interaction sets on

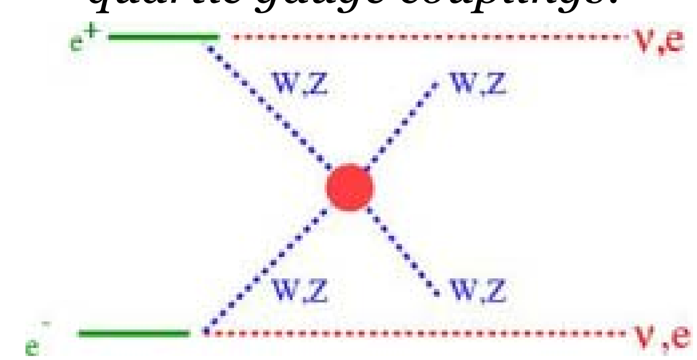
→ Goldstone bosons ("Pions") = W states ("technicolor")

→ no calculable theory until today in agreement with precision data

Experimental consequences: *deviations in*

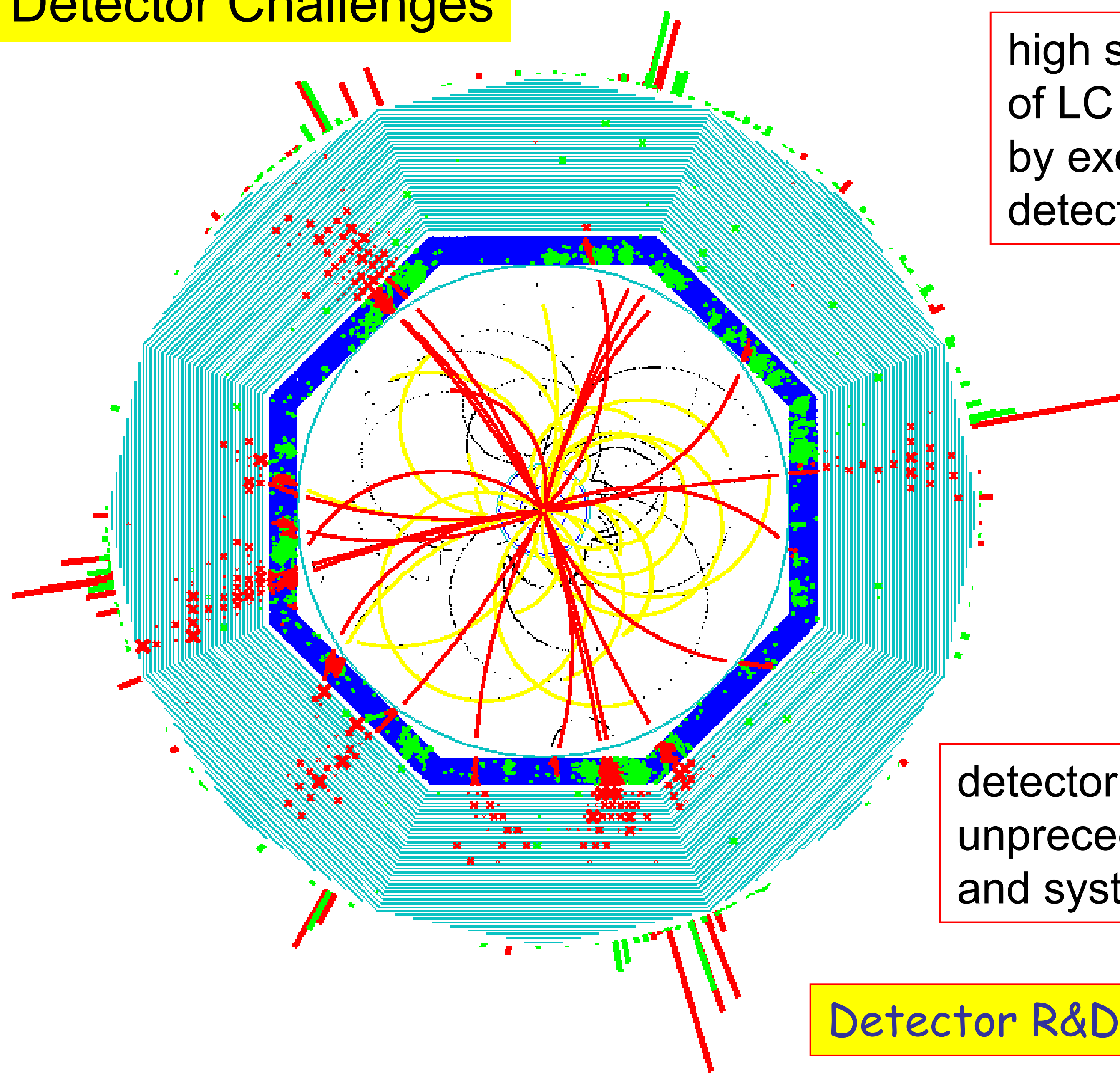
triple gauge couplings *quartic gauge couplings:*





LC (800 GeV): sensitivity to energy scale Λ:
triple gauge couplings: ~ 8 TeV
quartic gauge couplings: ~ 3 TeV ⇨ *complete threshold region covered*

Detector Challenges



high statistical power of LC has to be met by excellent detector performance

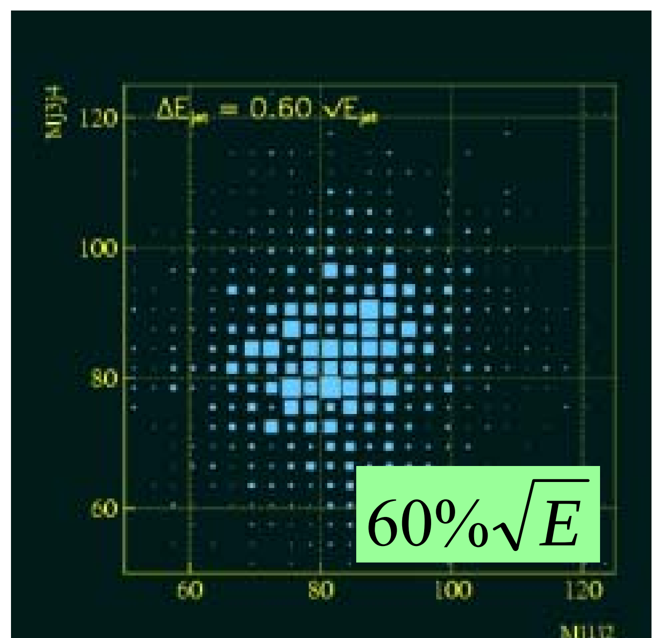
detector design challenging unprecedented resolution and systematics

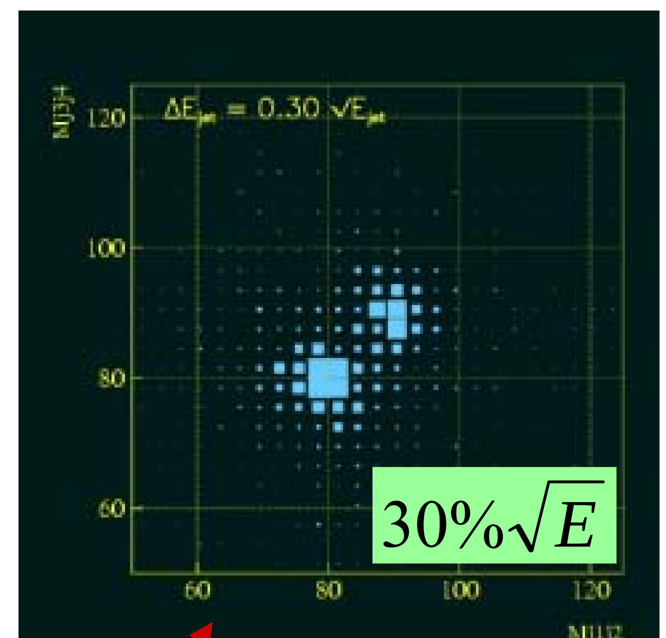
Detector R&D needed now

Detector Challenges

- Goal: distinguish W and Z in their hadronic decay modes
- Example: Jet energy resolution (Particle Flow)

$$e^+e^- \to WW\nu\bar{\nu} \quad , \quad e^+e^- \to ZZ\nu\bar{\nu}$$





LEP-like resolution

LC goal

Detector R&D ongoing in international proto-collaborations

Summary: EWSB

All(?) models of EWSB require study of
Higgs Bosons or longitudinal Gauge Bosons

- precision measurements at the Linear Collider together with the results from LHC are crucial to establish the Higgs mechanism responsible for the origin of mass and for revealing the character of the Higgs boson

- if the electroweak symmetry is broken differently or in a more complicated way then foreseen in the Standard Model, the LC measurements strongly constrain the alternative model

Beyond the Higgs

Why are electroweak scale (10^2 GeV) and the Planck scale (10^{19} GeV) so disparate ?

Are there

new particles ? $\rightarrow$ supersymmetry

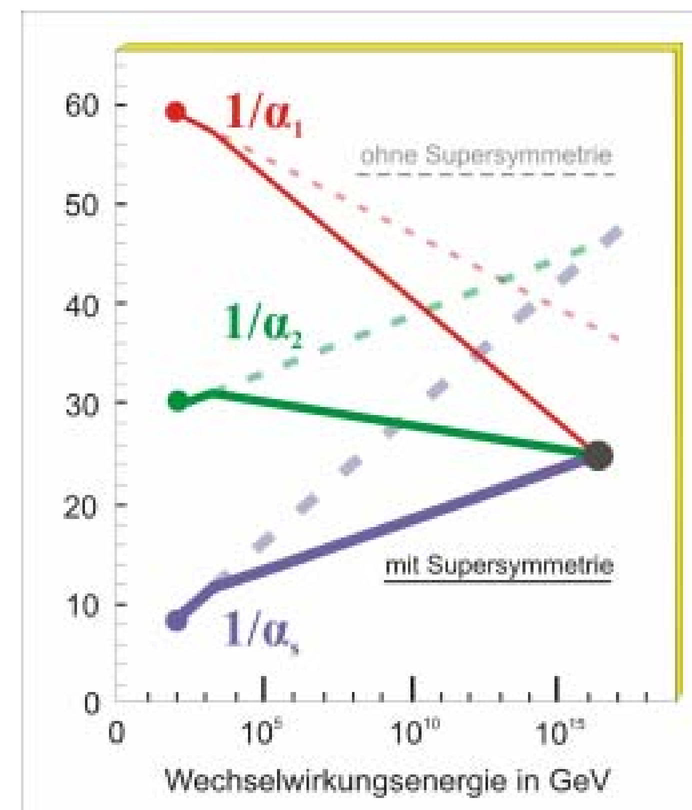
hidden dimensions ?

Supersymmetry

- unifies matter with forces

  for each particle a supersymmetric partner (*sparticle*) of opposite statistics is introduced

- allows to unify strong and electroweak forces →



- provides a link to string theories

Supersymmetry

- Predicts
  - light Higgs boson (+ additional heavier Higgs bosons)
  - spectrum of sparticles (→doubling number of particles)
- Contains
  - many new parameters connected to SUSY breaking
- Provides
  - dark matter candidate

⇒ LC task for SUSY

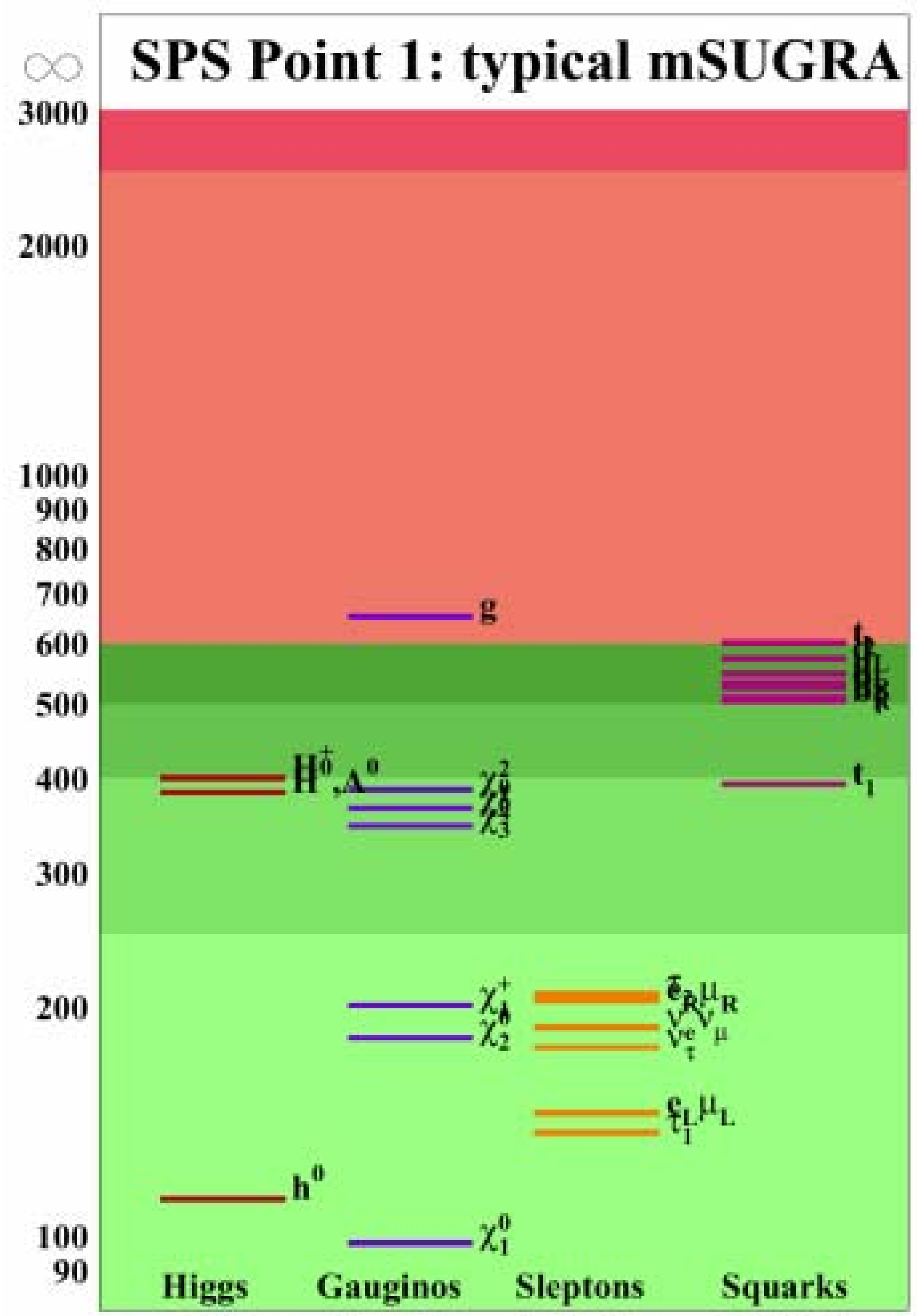
High precision measurements of

- masses
- couplings
- quantum numbers

needed to

- extract fundamental parameters (few)
- determine the way Supersymmetry is broken
  i.e the underlying supersymmetric model

Supersymmetry



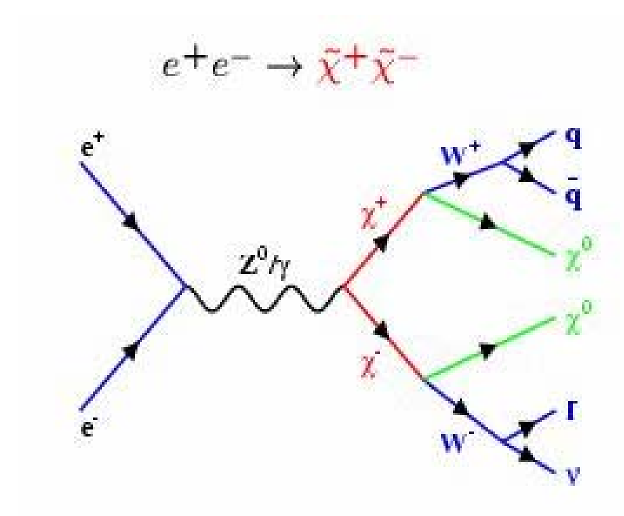
Mass spectra depend on choice of models and parameters...

well measureable at LHC

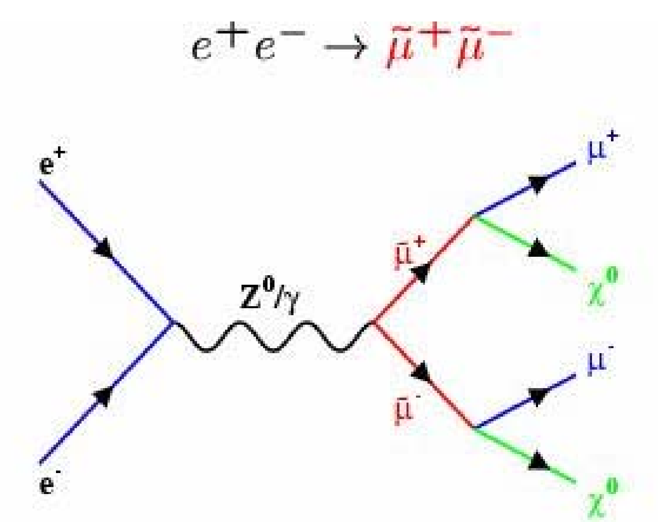
precise spectroscopy at the Linear Collider

Supersymmetry

Production and decay of supersymmetric particles at e^+e^- colliders



charginos



s-muons

Lightest supersymmetric particle stable in most models

candidate for dark matter

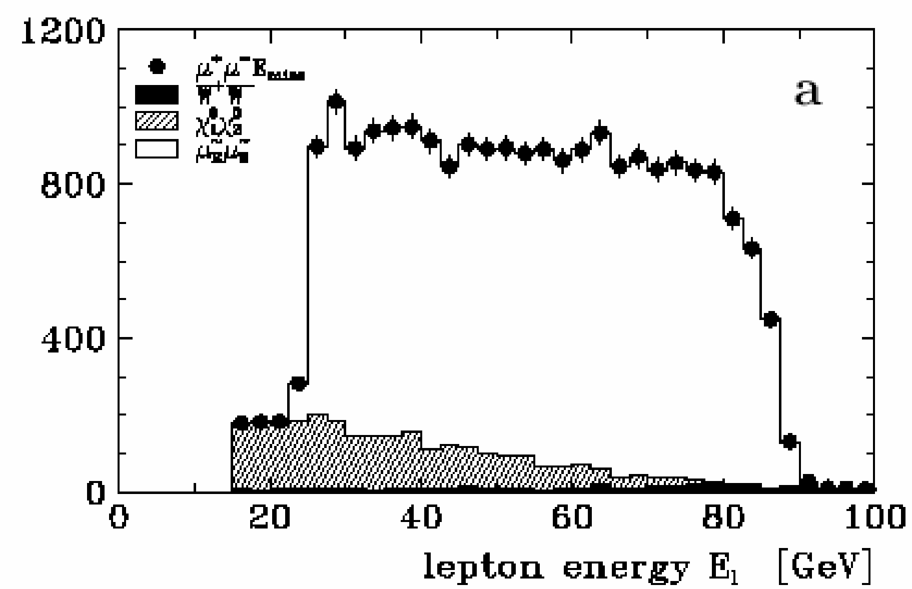
Experimental signature: missing energy

Supersymmetry

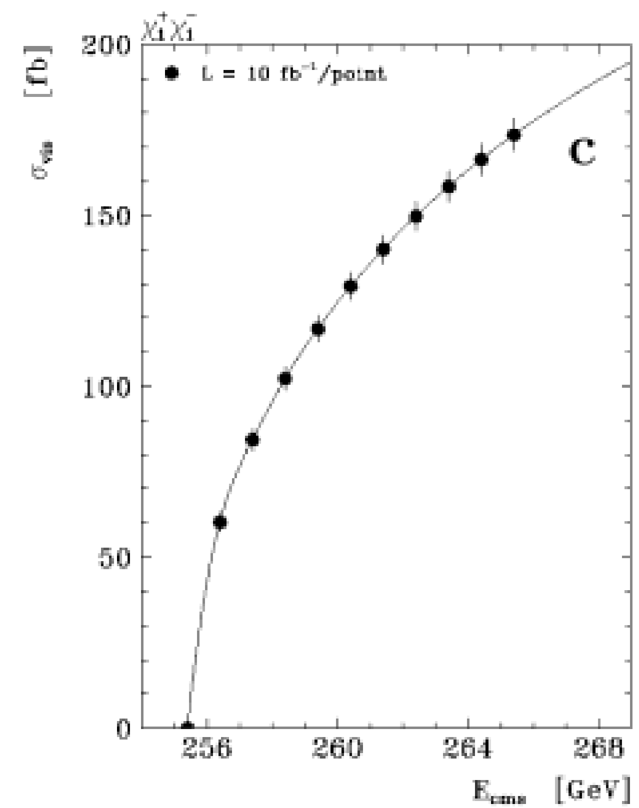
Measurement of sparticle masses

ex: Sleptons

lepton energy spectrum in continuum



ex: Charginos threshold scan



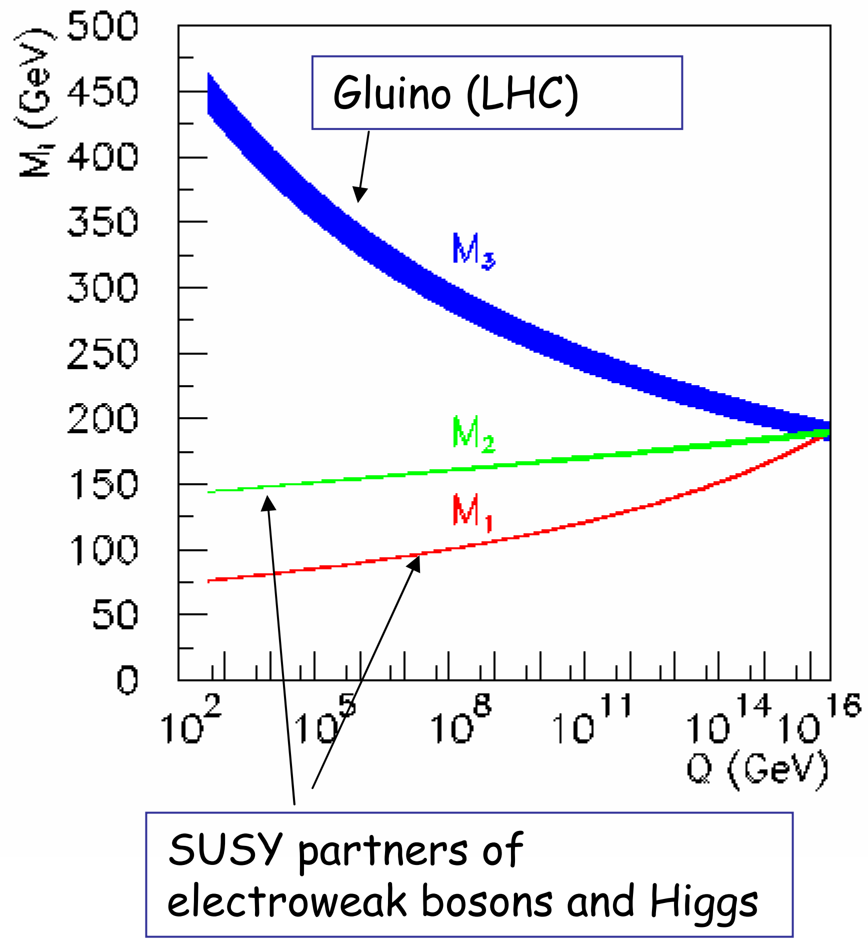
achievable accuracy:

$\delta m/m \sim 10^{-3}$

Supersymmetry

Extrapolation to GUT scale

If there is a line of sight from EW to GUT/Planck scale physics in Nature, the LC has precise enough focus and sufficient aperture to observe the signals!



Extrapolation of SUSY parameters from weak to GUT scale (within mSUGRA)

Gauge couplings unify at high energies,

Gaugino masses unify at same scale

Precision provided by LC for slepton, charginos and neutralinos will allow to test if masses unify at same scale as forces

Summary: Supersymmetry

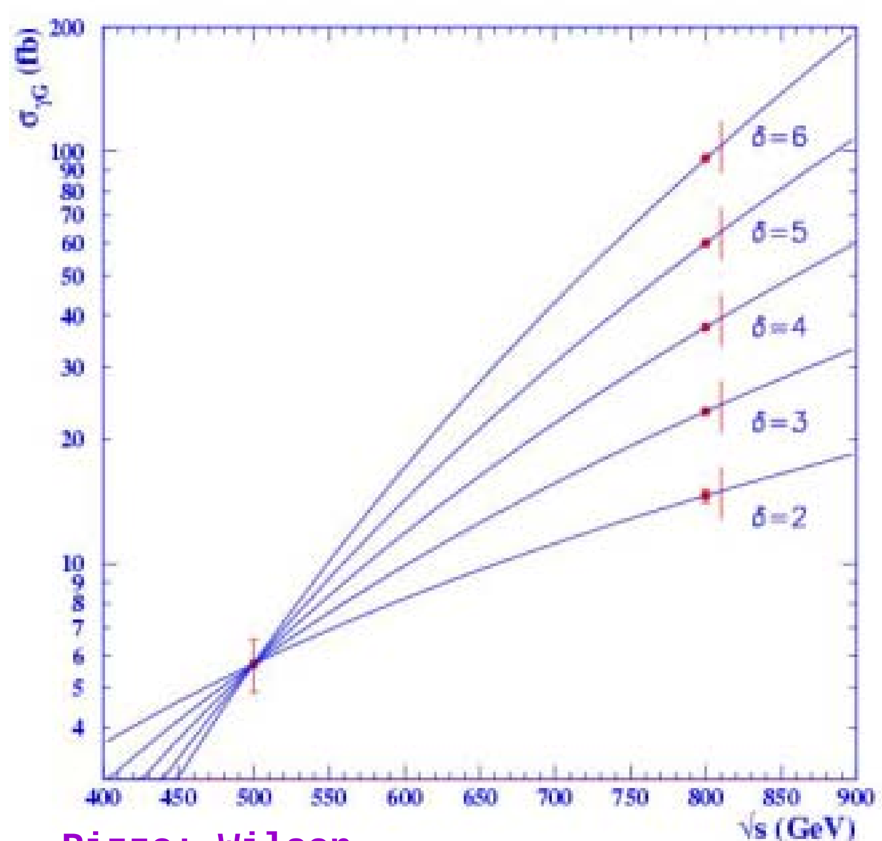
The Linear Collider will be a unique tool
for high precision measurements

- model independent determination of SUSY parameters
- learn about SUSY breaking mechanism
- extrapolation to GUT scale possible

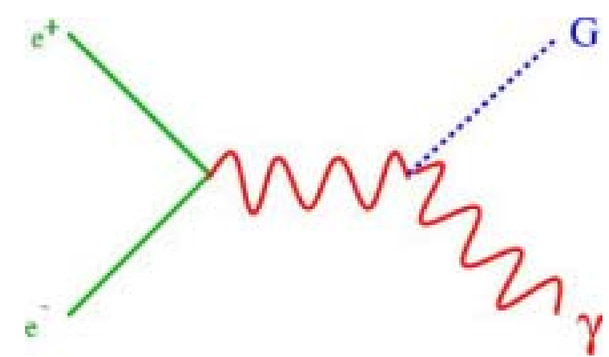
but what if ……

Extra Dimensions

Effects from real graviton emission:



Rizzo; Wilson



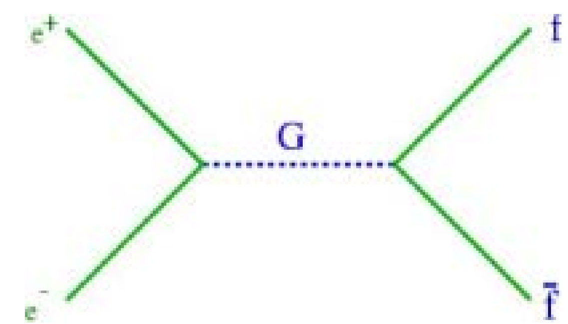
measures the number
of extra dimensions!

polarisation important to
reduce background!

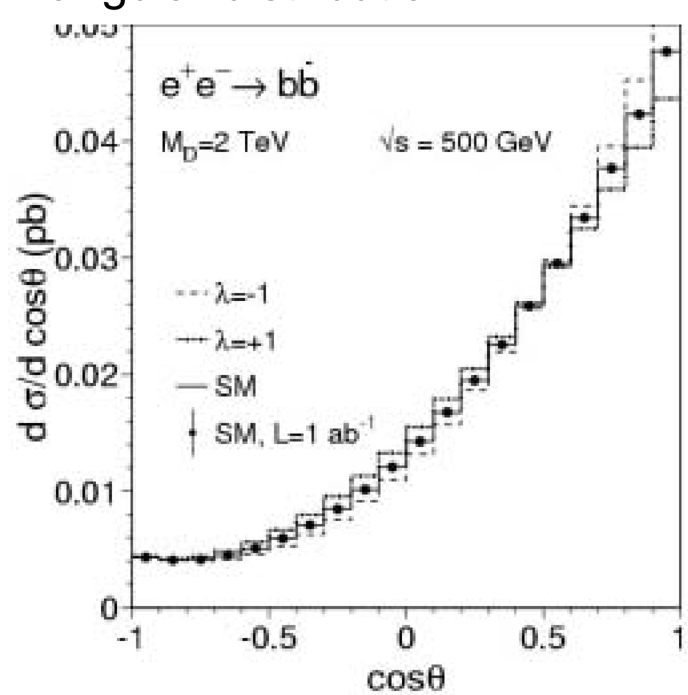
Extra Dimensions

Effects from virtual graviton exchange:

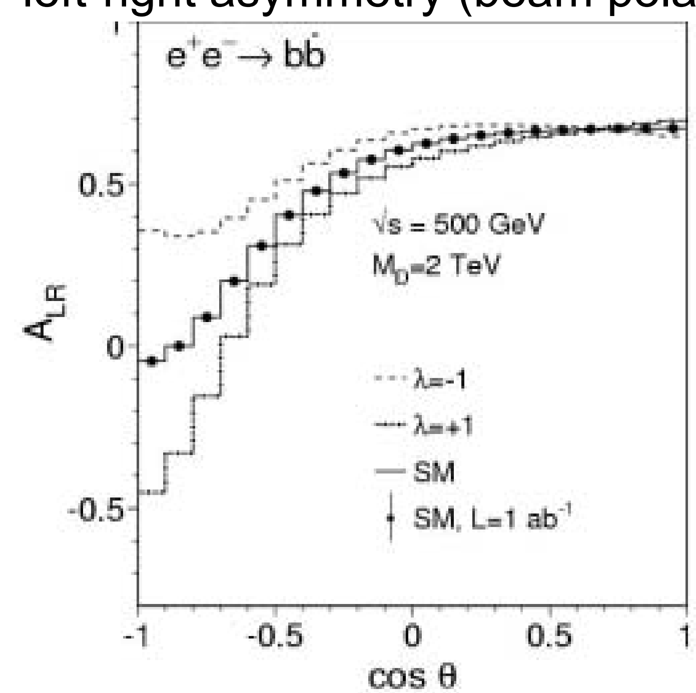
can prove Spin-2 exchange!



angular distribution

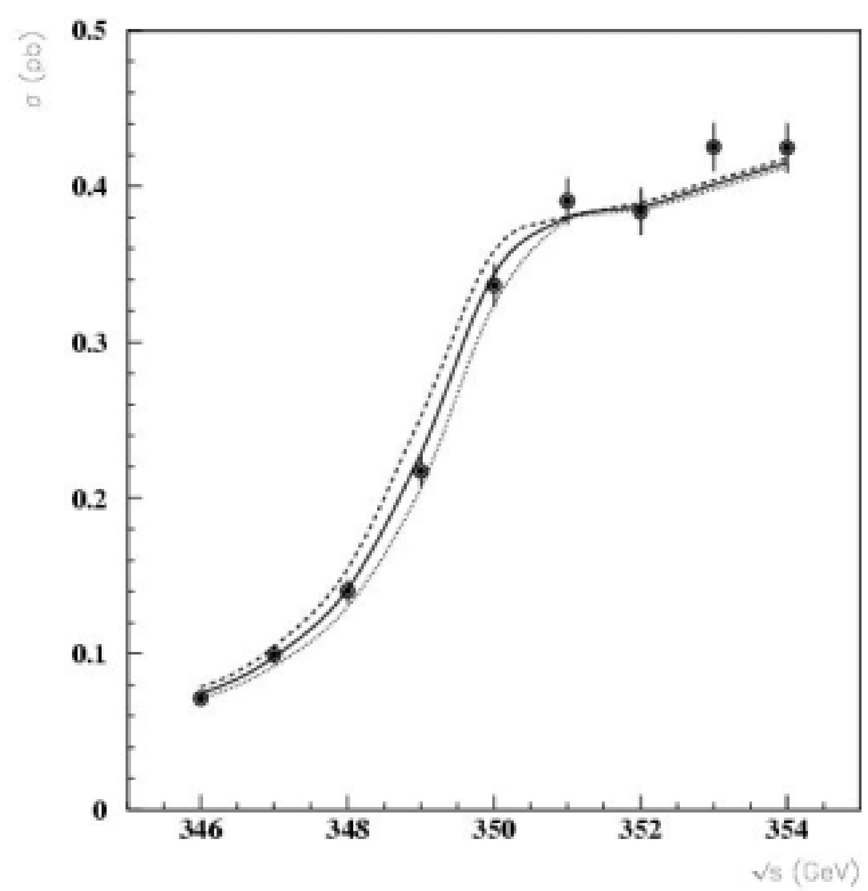


left-right asymmetry (beam polarisation!)



Top Quark – the Key to Flavour Physics?

scan of the threshold for $e^+e^- \rightarrow t\,t$



precise mass measurement
(100 MeV)

very important ingredient to
for precise theoretical predictions

(need to know SM parameters
if we want to see beyond-SM
physics!)

Precision electroweak tests

high luminosity running at the Z-pole

Giga Z (10^9 Z/year) ≈ 1000 x "LEP" in 3 months

with e^- and e^+ polarisation

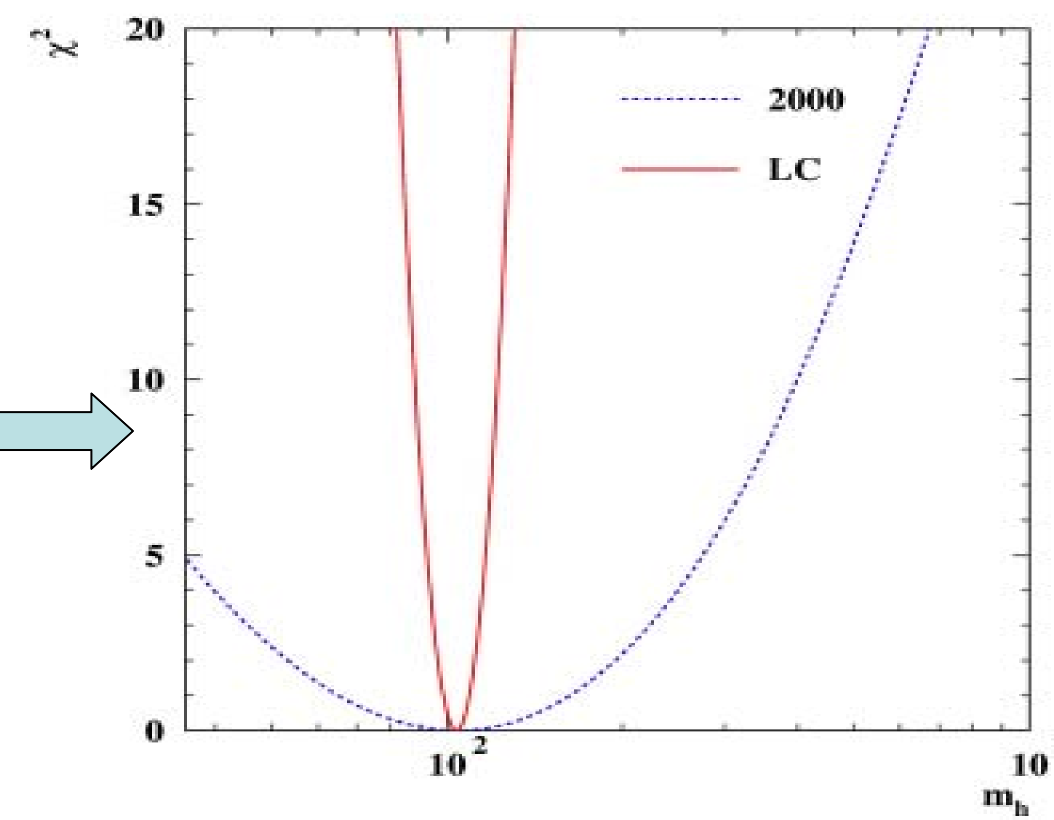
$\Delta \sin\Theta_W = 0.000013$

together with

$\Delta M_W = 7$ MeV
(threshold scan)

And

$\Delta M_{top} = 100$ MeV



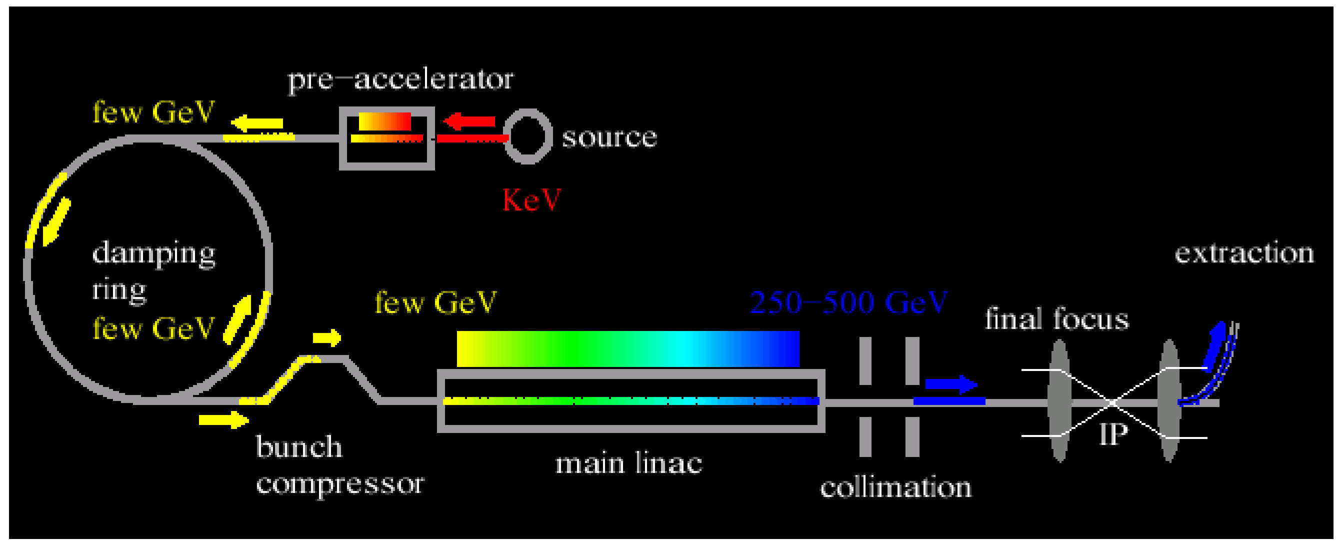
Physics Conclusion

LC with $\sqrt{s} \leq 1$ TeV and high luminosity allows

- most stringent test of electroweak Standard Model
- to establish Higgs mechanism in its essential elements
- to explore SUSY sector with high accuracy, model independent
- extrapolations beyond kinematically accessible region
- ….

World-wide consensus on physics case:
http://sbhep1.physics.sunysb.edu/~grannis/lc_consensus.html

General layout of a Linear Collider



For E > 200 GeV need to build linear colliders

Proof of principle:

SLC

The challenges:

Luminosity: high charge density (10^{10}), > 10,000 bunches/s

very small vertical emittance (damping rings, linac)

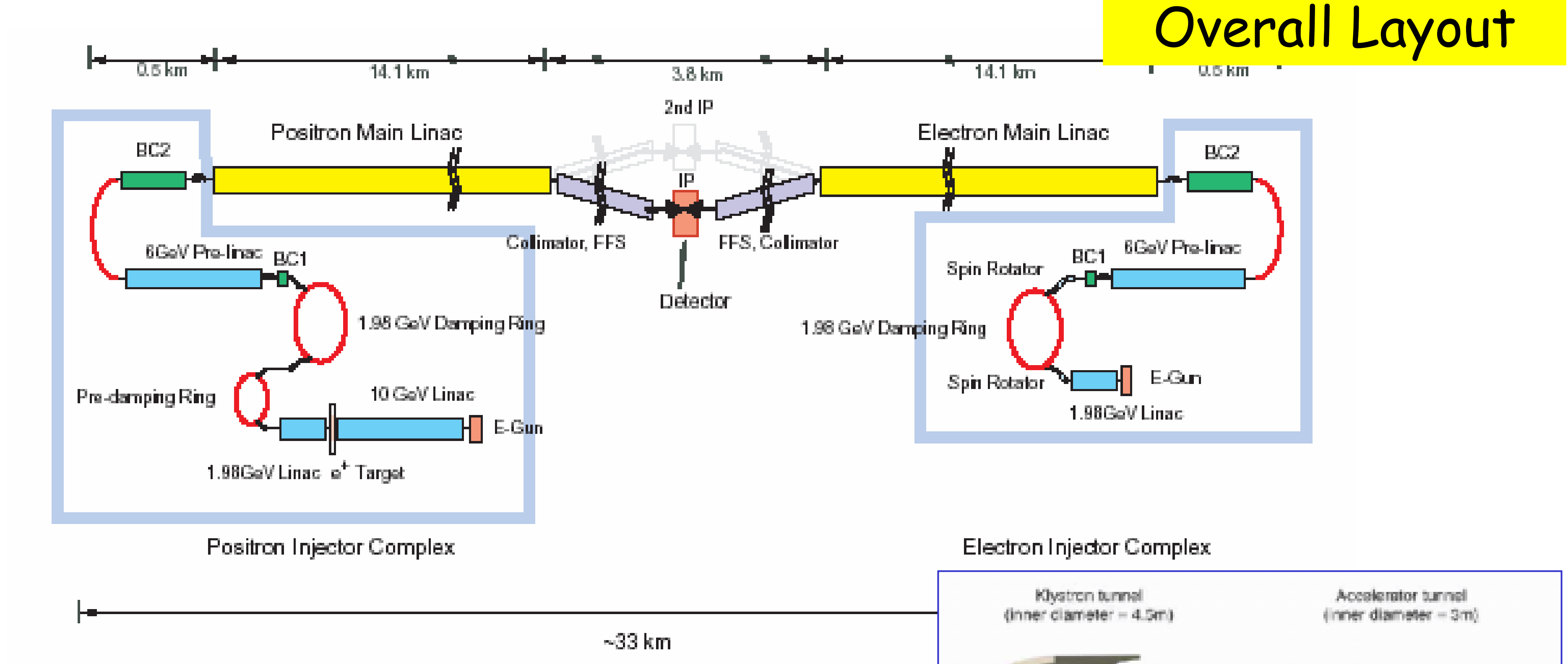
tiny beam size (5x500 nm) (final focus)

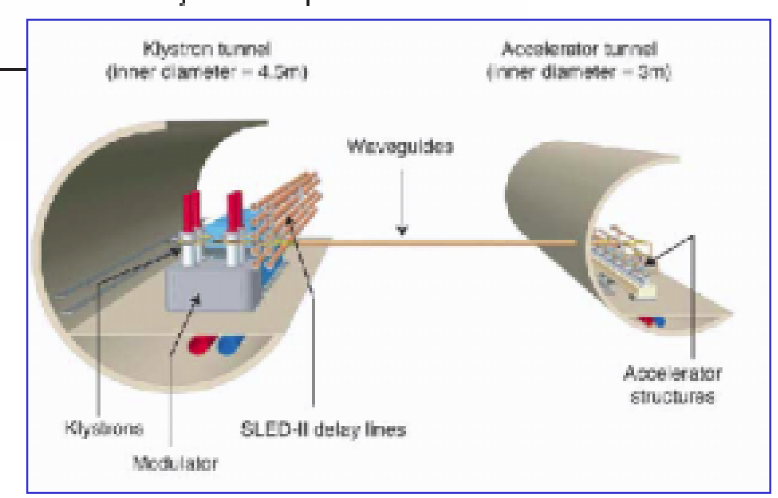
Energy: high accelerating gradient (> 25 MV/m, 500 - 1000 GeV)

To meet these challenges: A lot of R&D on LC's world-wide

different technologies: GLC/NLC…..TESLA……(CLIC)

GLC/(NLC) Overall Layout



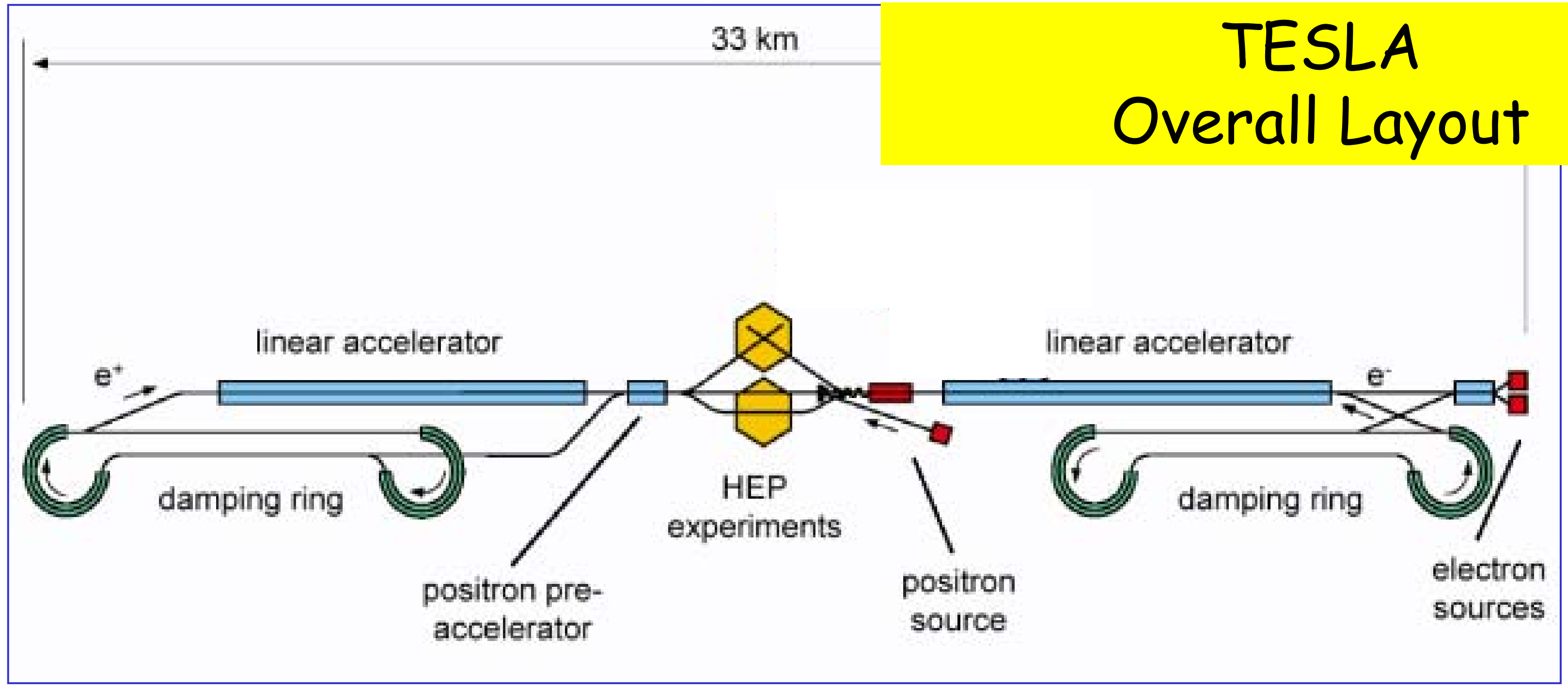


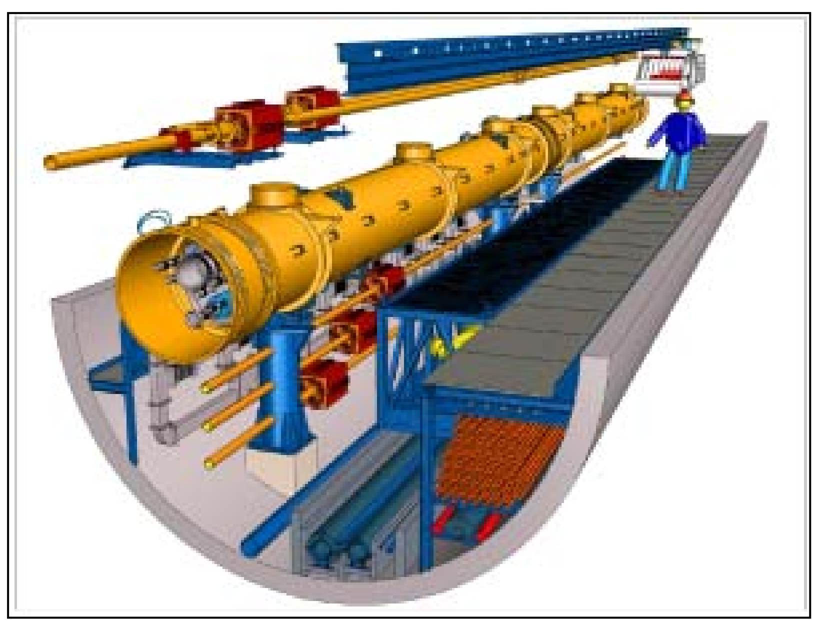
Warm RF, 11.4 GHz

Loaded gradient 50 MV/m

For site length 33 km: E_{cm} = 1.-1.3 TeV

TESLA
Overall Layout





Superconducting RF, 1.3 GHz

Loaded gradient up to 35 MV/m

For site length 33 km: E_{cm} = 800 GeV

The Technical Design Report incl. cost
was published in March 2001

Elektron-Positron Linear Collider (TeV region)

some design parameters at 500 GeV c.m.

	JLC/NLC	TESLA	SLC
L X 10^{33} ($cm^{-2}s^{-1}$)	**25**	**34**	$3x10^{-3}$
P_{AC} (MW)	**195**	**140**	
σ_y^* (nm)	**3**	**5**	500
bunch separation (ns)	**1.4**	**337**	
G_{acc} (MV/m), 500GeV	**50**	**23.5**	
800GeV	50	35	

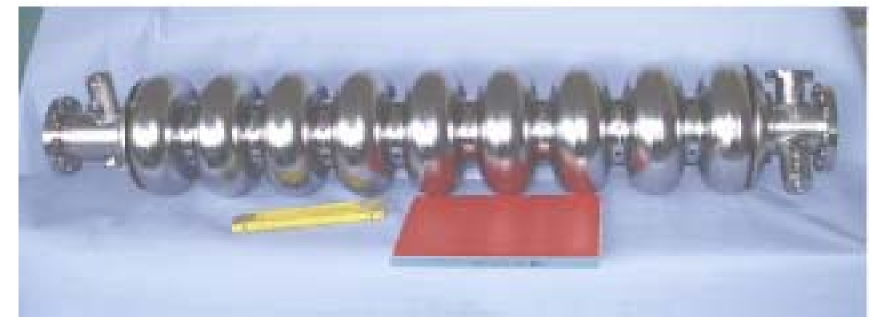
TESLA Test Facility
at DESY

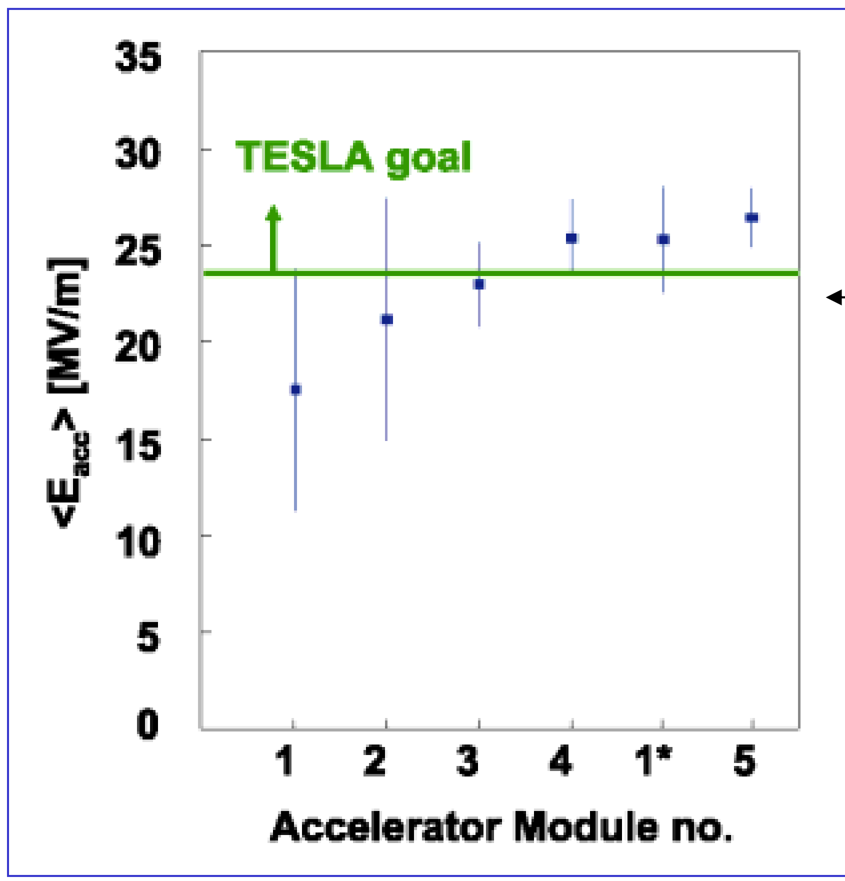
Operation for >13,000 h

Base for Project Proposal
TDR (March 2001)

Technical readiness
demonstrated

TESLA

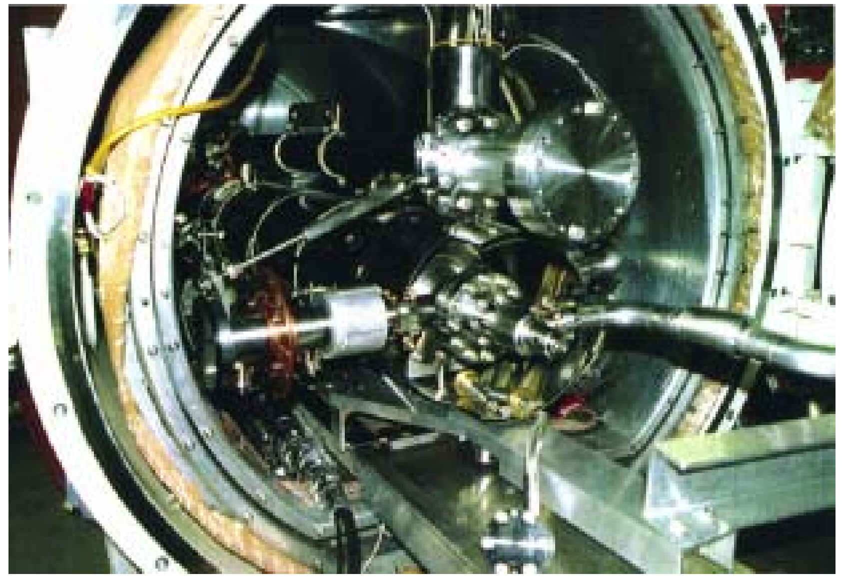




Routine production of cavities
exceeding 25 MV/m
(TESLA goal for 500 GeV)

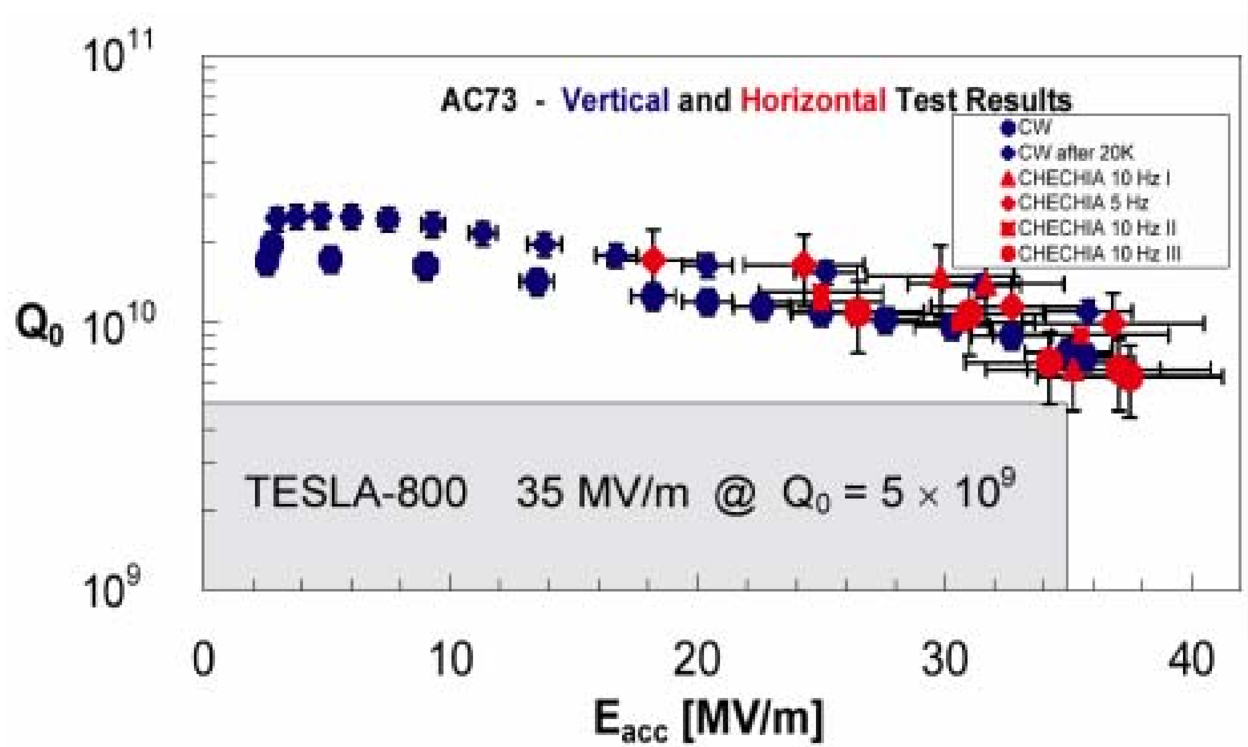
New surface treatment,
gradients of
> 40 MV/m (single cells)
-> clear energy upgrade

High Power Test of a Complete EP nine-cell Cavity



Several single cell cavities reached > 40 MV/m

- 1/8th of a TESLA cryomodule
- 5 Hz, 500 ms fill, 800 ms flat-top
- 33-> >35 MV/m with no interruption related to cavity-coupler-klystron for more than 1000 hours
- > 50 h at 36 MV/m
- No field emission



Two cavities tested

Global Organisation

New large scale accelerators need to be global efforts

⇓

Need to go new ways in international collaborations in order to advance science

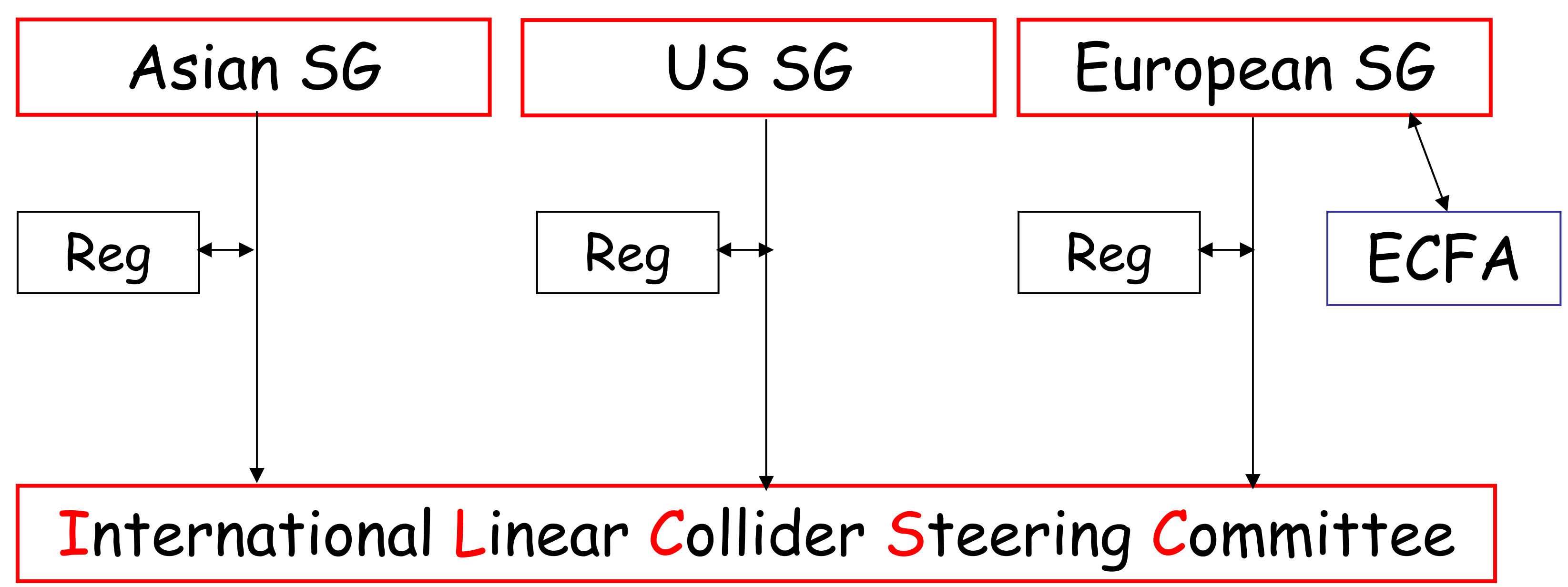
⇓

Collaboration of interested accelerator laboratories and institutes world-wide with the goal to design, build, operate and utilise a large new accelerator:

Global **A**ccelerator **N**etwork

How to arrive at a Linear Collider as a World-Project

ICFA Initiative for an international Coordination:



active since Aug. 2002

What has Happened recently?

- OECD Global Science Forum (2002 and continuing)
- ILCSC and regional steering group
- WG's on organisational matters
- International LC Technical Review Committee
  (established R&D list for both technologies)
- Parameter list has been established
- US: Facilities for the Future of Science
- International technology recommendation panel (ITRP)
- Technology progress
- Discussion among funding agencies
- OECD science ministers' statement

…a lot

Next Milestones towards a Linear Collider as a World-Project

2004	Selection of Collider Technology (warm or cold)
	setting up of an international project team with branches in America, Asia and Europe
	Continuation of discussion between funding agencies
	Further studies of organisational structures
2005	Start of work of project teams
2006	Completion of the project layout including costing
2007	Decision in principle by governments to go ahead with LC
2015	Start of commissioning

Summary + Outlook

- Linear Electron Positron Collider in the range 500-1000 GeV has excellent scientific potential
- Worldwide consensus: LC next large HEP project – soon
- HEP community wants to build the LC as truly global project – choice of technology by end 2004
- Activities on political level started – Think global

Supersymmetry

- best motivated extension of SM
  grand unification – connection to gravity – light Higgs – $\sin^2\Theta_W$
  dark matter candidate – ….

- mass spectrum depends on the unknown breaking scheme

- LC task for SUSY
  reconstruction of kinematically accessible sparticle spectrum
  i.e. measure sparticle properties (masses, Xsections, spin-parity)

  extract fundamental parameters (mass parameters, mixings, couplings)
  at the weak scale

  extrapolate to GUT scale using RGEs

  → determine underlying supersymmetric model

Global Accelerator Network

- make best use of world-wide competence, ideas, resources

- Well defined roles and obligations of all partners

- make projects part of the national programs of the participating countries

- create a visible presence of activities in all participating countries

- keep culture of accelerator development (scientific and technical) alive in laboratories and universities and be attractive for young scientists

- not an international permanent institution but an international project of limited duration

Global Accelerator Network

- Follows major detector collaboration in particle physics
- Partners contribute in full responsibility through components or subsystems
- Facility is common property
- Responsibility, cost are shared
- Remote operation

Remote Operation : Social Aspects

- how much manpower is needed in host lab to operate accelerator etc.
- how much manpower is needed as user support
- how much manpower is needed in home labs
- which are the necessary qualifications of the staff
- how to achieve the desired 'corporate identity‘, i.e. the common identification with the project
- how to maintain the 'scientific social life'

Towards a global project

International Linear Collider Technical Review Committee

ILC-TRC (chair Greg Loew)

- To assess the present technology status of the LC designs at hand, and their potential for meeting the advertised parameters at 500 GeV c.m.
- Use common criteria, definitions, computer codes, etc., for the assessments
- To assess the potential of each design for reaching energies above 500 GeV c.m.
- To establish, for each design, the R&D work that remains to be done in the next few years
- Categorise (rank) the R&D items
- To suggest future areas of collaboration

ILC-TRC Rankings Score Sheet

	TESLA		JLC/NLC	
E_{cm}	500	800	500	1000
R1	0	+1	2	+0
R2	7	+4	3	+0
R3	10	+3	11	+0
R4	1	+0	2	2

Report by the
ILC-TRC
(420 pages)

endorsed by
ICFA
in February 2003

ILC-TRC The Rankings for R&D

R1 R&D needed for feasibility demonstration of the machine

TESLA 800 GeV	● Building and testing of a cryomodule (8 cavities) at 35 MV/m and measurements of dark current
JLC/NLC 500 GeV	● Test of complete accelerator structure at design gradient with detuning and damping, including study of breakdown and dark current ● Demonstration of SLED-II pulse compressor at full power

R2 R&D needed to finalize design choices and ensure reliability

R3 R&D needed before starting production of systems and components

R4 R&D desirable for technical or cost optimisation

ILC-TRC Report

"TESLA has essentially demonstrated its main linac rf performance specifications for 500 GeV c.m.
In 2004, one will hopefully know if TESLA can reach 800 GeV c.m. by testing of the cryomodules at 35 MV/m."

{ Note: cms-energy above 800 GeV achievable by appropriate choice of length and site of the interaction region }

TESLA

Statement by the German Government on LC

Dr. H. Schunck, EPS HEP conference in Aachen, July 2003:

“The TESLA linear collider has been one of the proposals evaluated by the Wissenschaftsrat. The judgement of the Wissenschaftsrat on the scientific perspectives of the project has indeed been very positive. The Wissenschaftsrat has strongly suggested hat the linear collider should be realized as a genuine global project.

The German government has decided to follow this and as a consequence not to proceed nationally and at this moment not to propose a German site for TESLA. We have to wait for the international development. But we will continue our efforts to be able to participate in a global linear collider project. Let me underline: my government is the first one to have announced to be principally committed to participating in the project. “

US 20-Year Outlook
Facilities for the Future of Science

Near-Term (Priority ↓)

Priority	Office	Facility
1	FES	ITER
2	ASCR	UltraScale Scientific Computing Capability
Tie for 3	HEP	Joint Dark Energy Mission
	BES	Linac Coherent Light Source
	BER	Protein Production and Tags
	NP	Rare Isotope Accelerator
Tie for 7	BER	Characterization and Imaging
	NP	CEBAF Upgrade
	ASCR	Esnet Upgrade
	ASCR	NERSC Upgrade
	BES	Transmission Electron Achromatic Microscope
12	HEP	BTeV

Mid-Term (Priority ↓)

Priority	Office	Facility
13	HEP	Linear Collider
Tie for 14	BER	Analysis and Modeling of Cellular Systems
	BES	SNS 2-4 MW Upgrade
	BES	SNS Second Target Station
	BER	Whole Proteome Analysis
Tie for 18	NP	Double Beta Decay Underground Detector
	FES	Next Step Spherical Tokamak
	NP	RHIC II

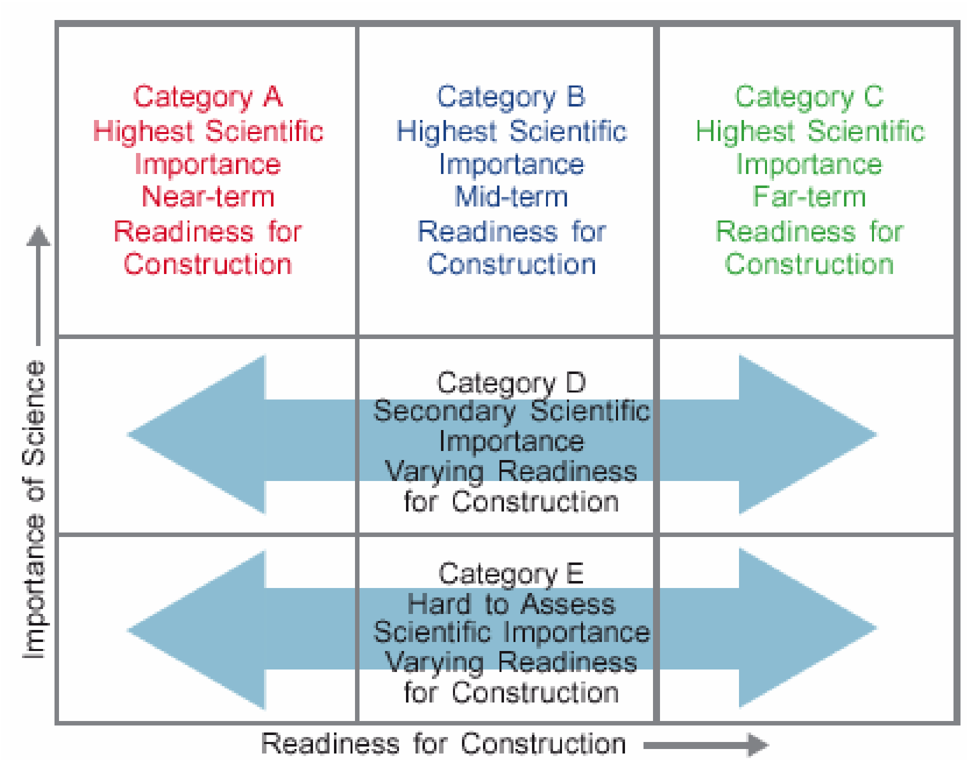
Mid Term Readiness for construction (time line?!)

Near Term Readiness for construction

HEPAP: "The intrinsic science potential of the Linear Collider and the capability of the facility to achieve that science are *absolutely central.* Presently in an advanced *R&D phase* on an international basis, with the formation of an international design team it would enter the project engineering and design phase in 2006."

US 20-Year Outlook
Facilities for the Future of Science

Prioritisation process:



http://www.sc.doe.gov/Sub/Facilities_for_future/20-Year-Outlook-screen.pdf

The DoE Advisory Committees recommended 53 major facilities for construction, and assessed each according to two criteria:

- scientific importance and
- readiness for construction.

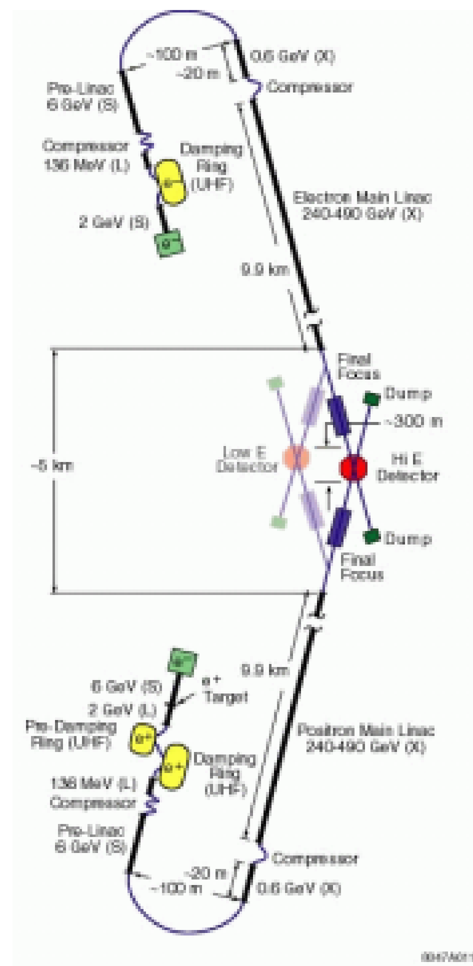
Of the 53 facilities initially proposed by the Advisory Committees, 28 made the list of most important facilities that will be needed over the next 20 years to support the Nation's research needs in areas that have been the traditional responsibility of the DOE.

Linear Collider Technology

Two different concepts for a 500-1000 GeV LC:

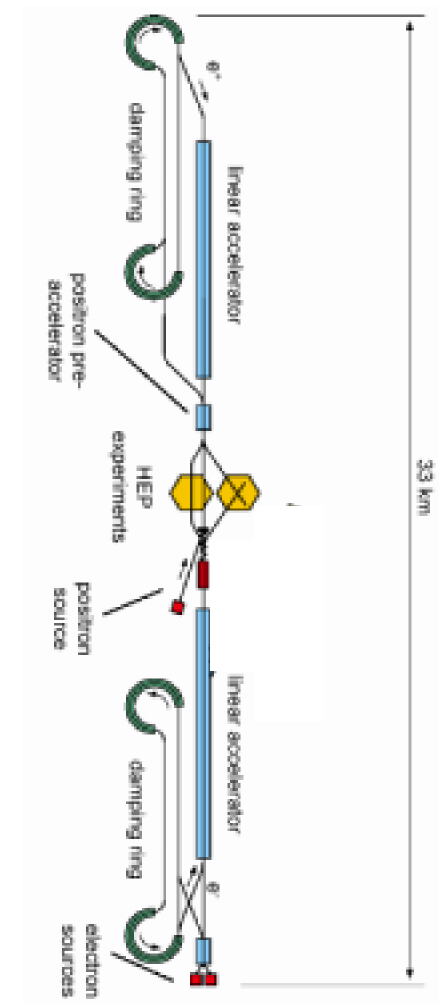
NLC/GLC

normal-conducting resonators



TESLA

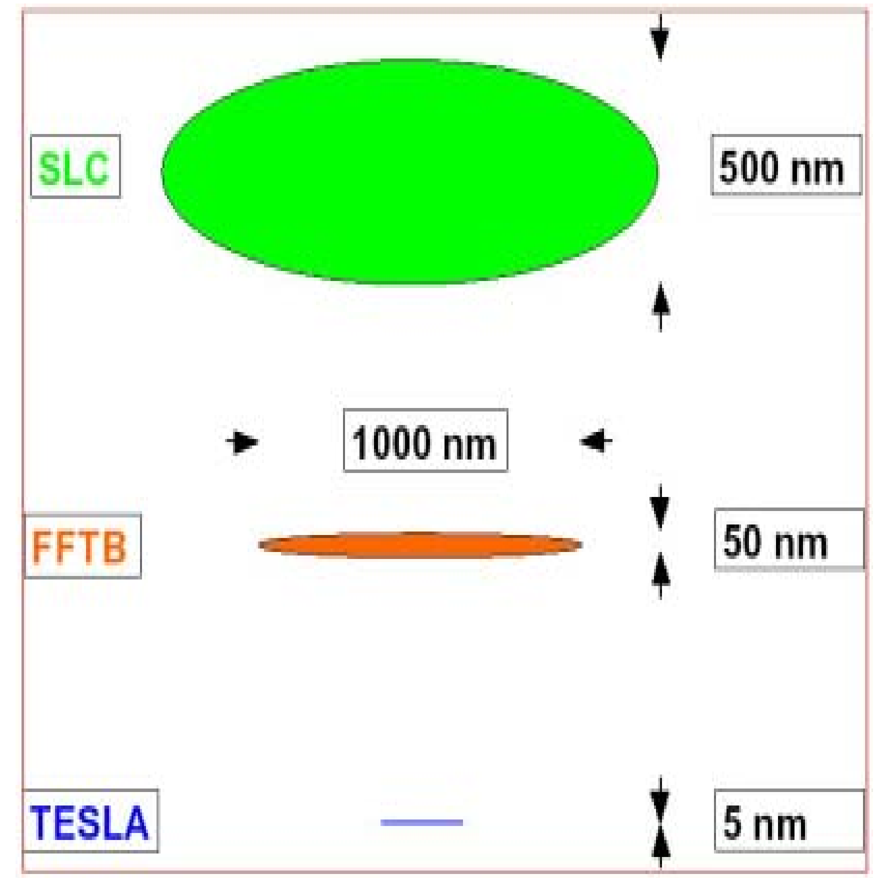
super-conducting resonators



final choice still to be made

Linear Collider Challenges

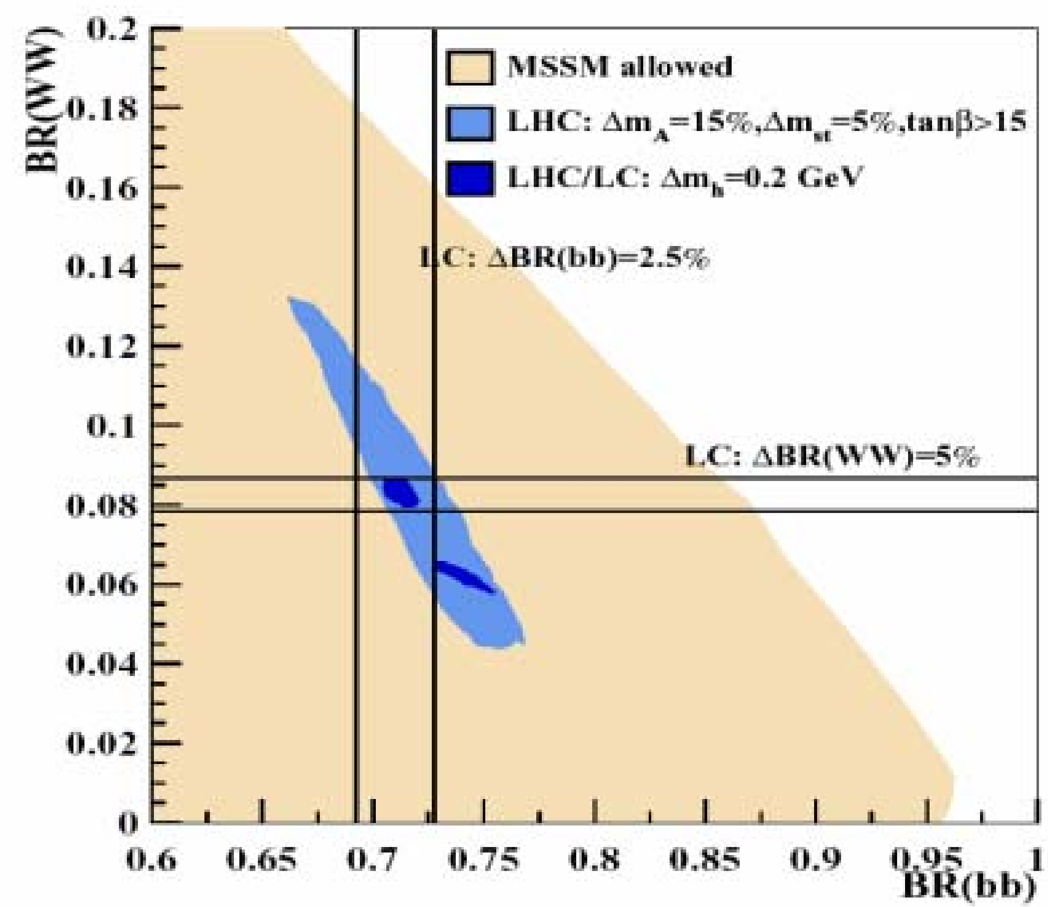
Challenge of a tiny beam size :



intense R&D program on
beam delivery system including
final focus

Strong involvement of
UK machine and particle physicists

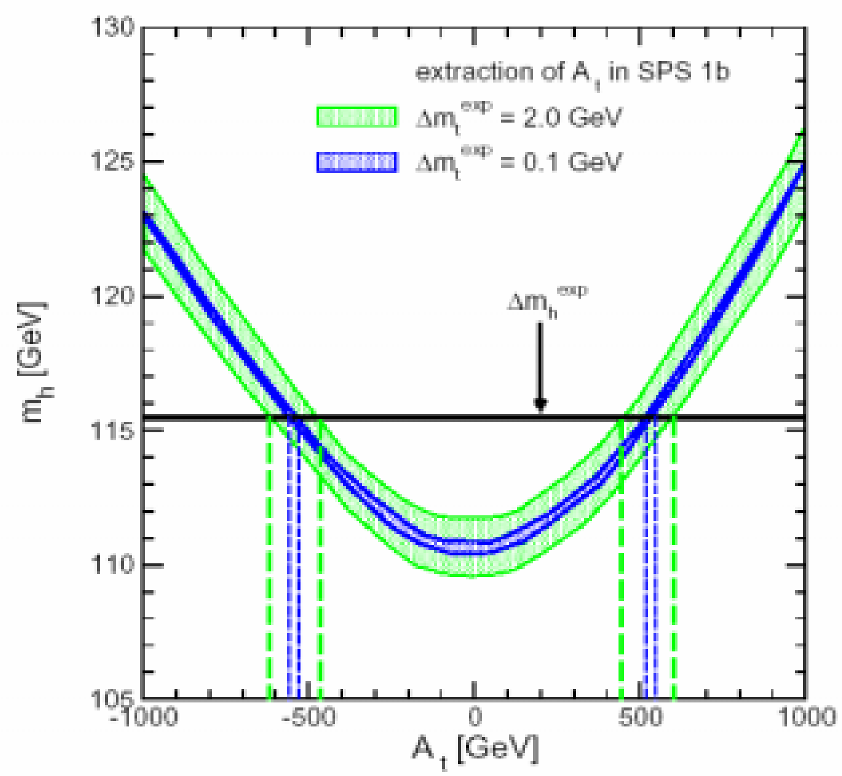
LHC+LC: SUSY Higgs parameter determination

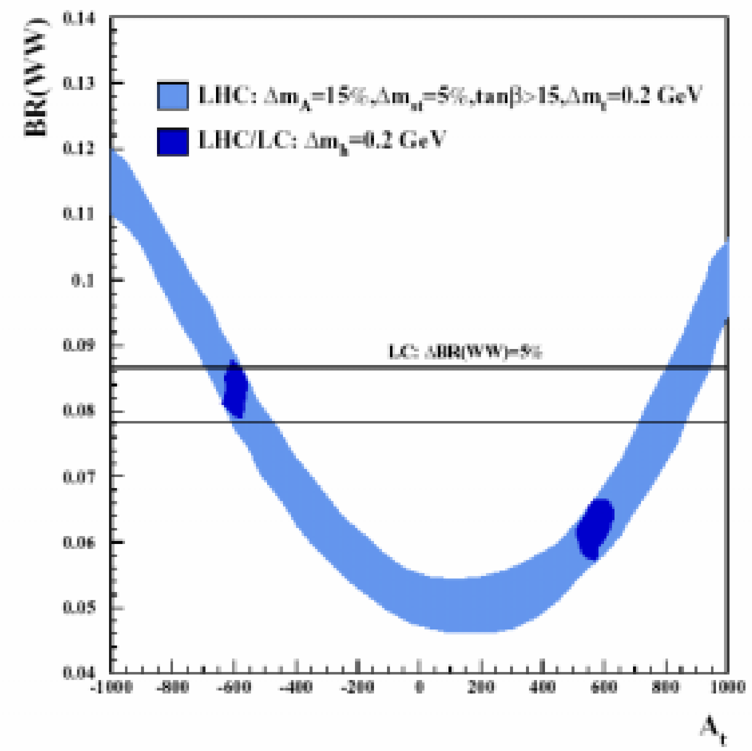


⇒ Comparison of MSSM prediction based on assumed inputs with BR's measured at the LC yields very sensitive test of the model

LHC+LC: SUSY Higgs parameter determination

⇒ Indirect determination of trilinear coupling A_t:





Precise measurement of m_t at the LC crucial, $\delta m_t \lesssim 100$ MeV

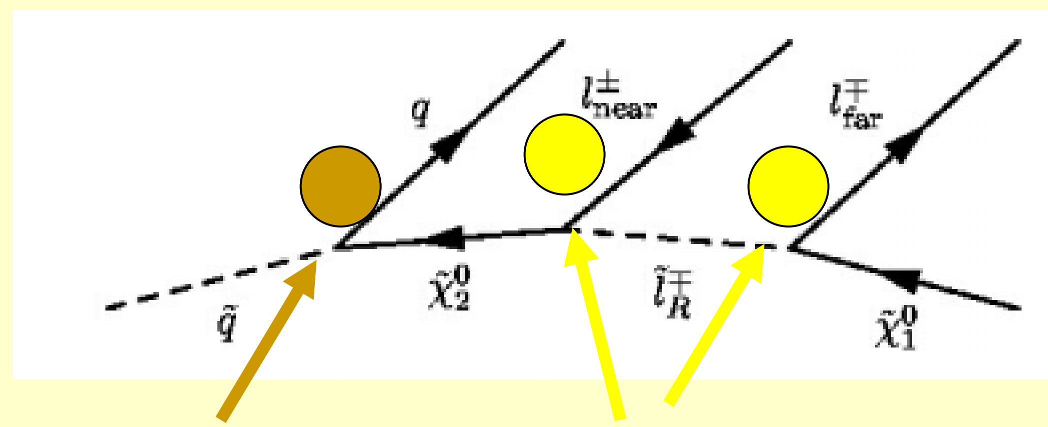
Δm_t^{LC} vs. Δm_t^{LHC} ⇒ accuracy of A_t determination improved by factor 3

Physics: Join Forces: LHC + LC

Example: SUSY

Cascade decays of squarks: if heavy, only accessible at LHC
hard to measure properties, if massess and BR's of lower members of decay chain unknown.

Example:



only accessible at LHC *if these are known from LC*

Improvement of squark mass by ~factor 3-4!

ongoing work... LHC/LC study group

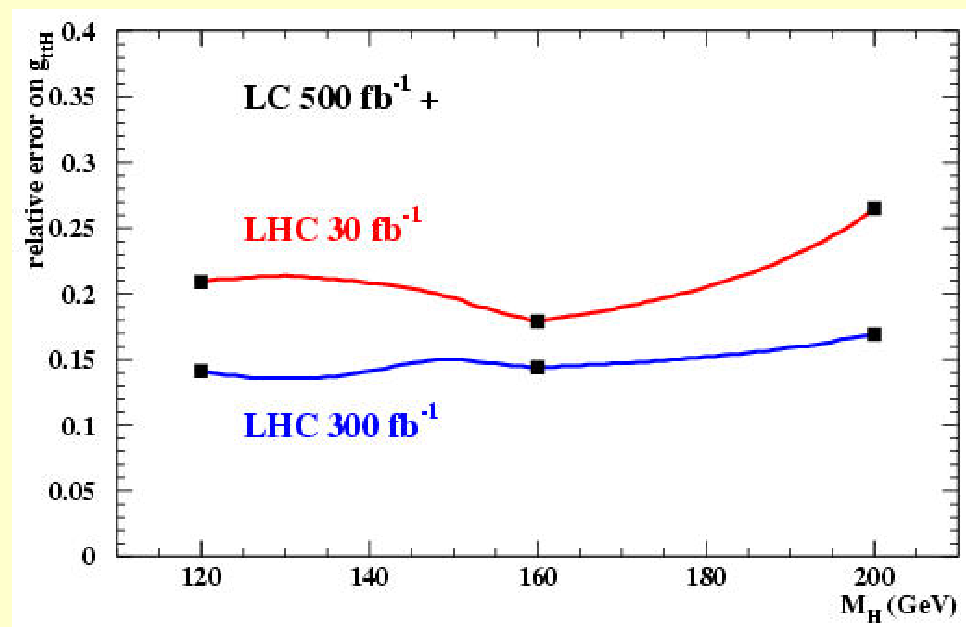
www.ippp.dur.ac.uk/~georg/lhclc

Physics: Join Forces LHC + LC

Worldwide LHC/LC working group to explore the synergy between both machines, in general, and in particular when overlapping in time.

Work out cases where LC input improves LHC analyses

Example: absolute top Yukawa coupling from
gg,qq →ttH (H →bb,WW) (@LHC) (rate ~ $(g_t\, g_{b/W})^2$) *and*
BR(H →bb,WW) (@LC) (absolute measurement of $g_{b/W}$)



LHC+LC: SUSY Higgs parameter determination

Combination of LHC data on heavy Higgs states with LC data on the light $\mathcal{CP}$-even Higgs

[K. Desch, S. Heinemeyer, G.W.]

Assume: LHC information on M_A, $\tan\beta \oplus$ (LHC $\otimes$ LC) information on stop/sbottom masses $\oplus$ LHC / LC measurement of m_h:

M_A: 15% accuracy, $m_{\tilde{t}_1}, m_{\tilde{t}_2}, m_{\tilde{b}_1}, m_{\tilde{b}_2}$: 5% accuracy, $\tan\beta > 15$

BR($h \to b\bar{b}$): 2.5% accuracy, BR($h \to WW^*$): 5% accuracy

TESLA

Technology Choice

The International Linear Collider Steering Committee (ILCSC) has successfully completed the selection of the twelve members of the International Technology Recommendation Panel (ITRP):

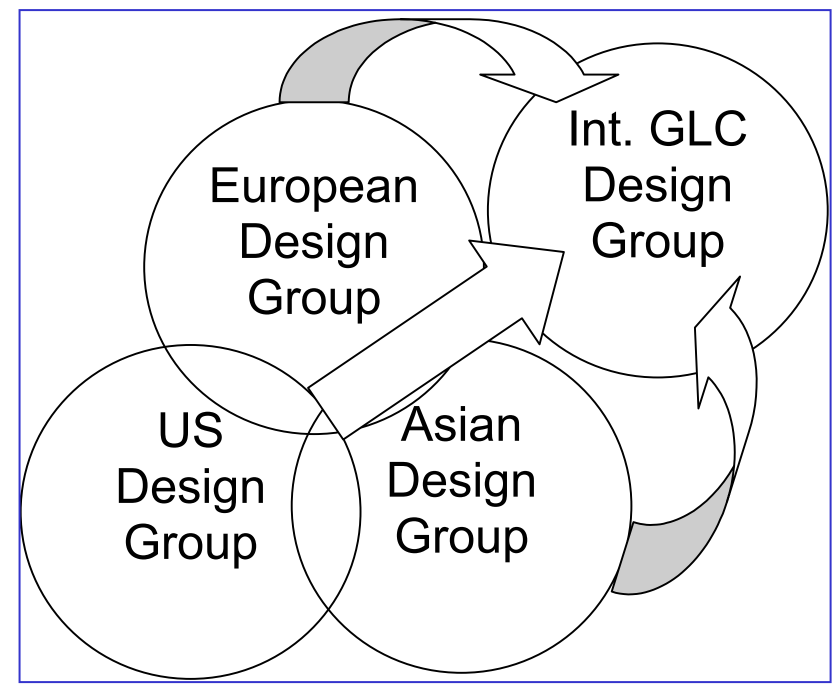
Asia:	Europe:	North America:
G.S. Lee	J-E Augustin	J. Bagger
A. Masaike	G. Bellettini	B. Barish (Chair)
K. Oide	G. Kalmus	P. Grannis
H. Sugaware	V. Soergel	N. Holtkamp

Recommendation of one technology before end of 2004

Global Design Organisation

Task force is preparing a Global Design Organisation. Main thrust of present thinking:

- The ILC Global Design Organization (GDO) to be established as an inter-regional entity as soon as the International Technical Recommendation Committee establishes their choice of the basic technology.
- The first mission of the GDO is to turn the technology choice to conceptual design of the machine (parameters, layout, roadmap, R&D)
- The GDO will consist of a Central Team and three Regional Teams, representing Asia, Europe and North America. (EU Design Study)



Global Accelerator Network

- project should have a minimal administrative structure, with mainly management oversight functions

- well defined roles and obligations of all partners

- coherent and transparent process for reaching decisions (consensus) inside collaboration

- financial stability combined with necessary flexibility

- not an international permanent institution but an international project of limited duration

Remote Operation : Technical Aspects

- remote controls and access, multiple control rooms
- protection against un-authorised access
- communication (speech, visual, computer)

- standardisation of systems & software, common documentation
- the role of GRID
- modular components and good spare parts

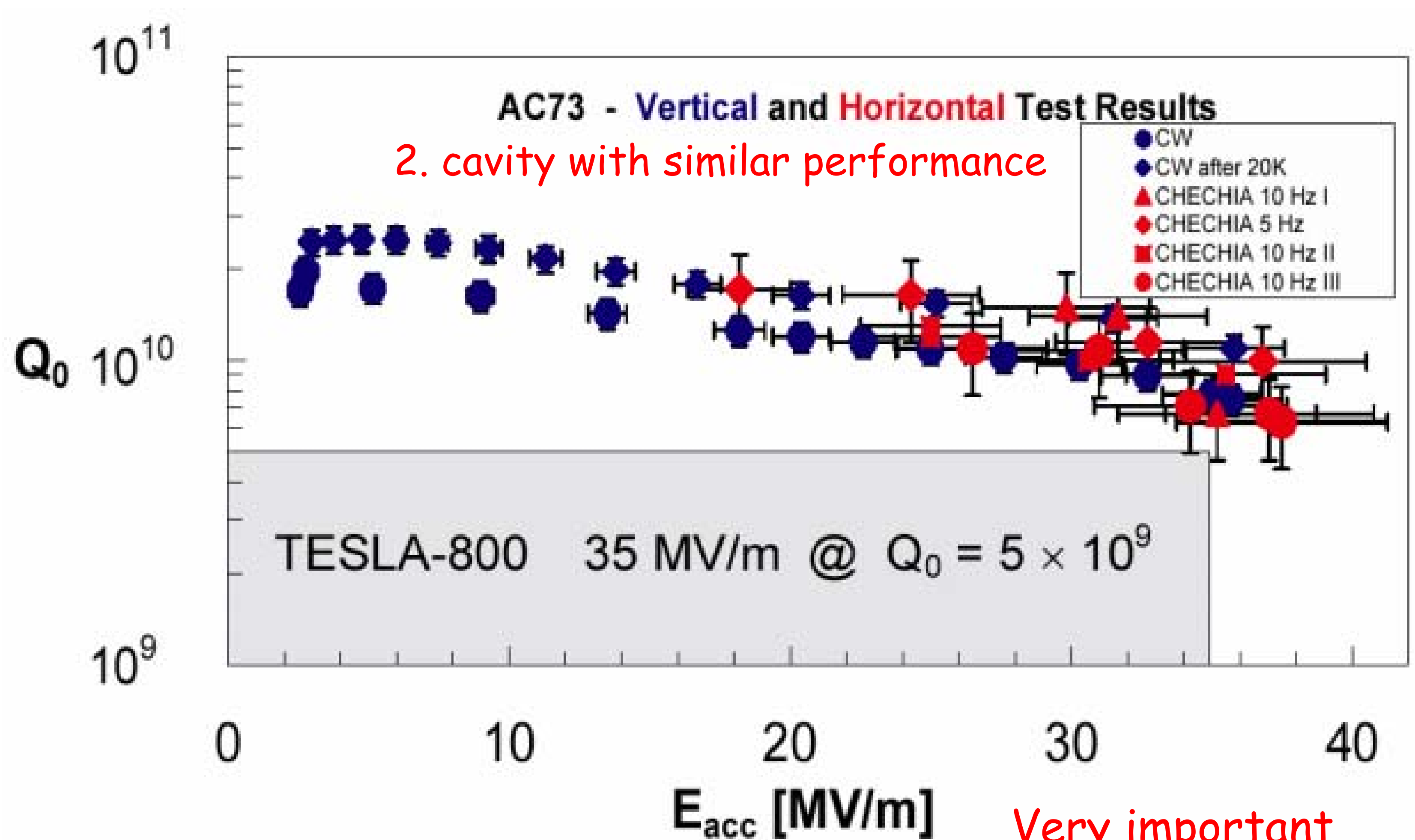
Plans for testing the remote operation concept are being pursued in the framework of existing facilities (TTF,...)

TESLA

Outlook

- Strong world enthusiasm for a LC continues and grows
- The HEP community has demonstrated the will to join behind one technology and to build the LC jointly. It has the capability of getting organised
- The reason: „The next discoveries will have a disproportionate impact of our understanding of Nature".
- We have convinced many people outside our community, but we need to get our own community more on board
- Need to go new ways in international collaborations in order to advance science and to maintain the strong existing centres
- Most important: we need to keep focused on reaching the next milestones while looking at the same time further ahead

High Gradients

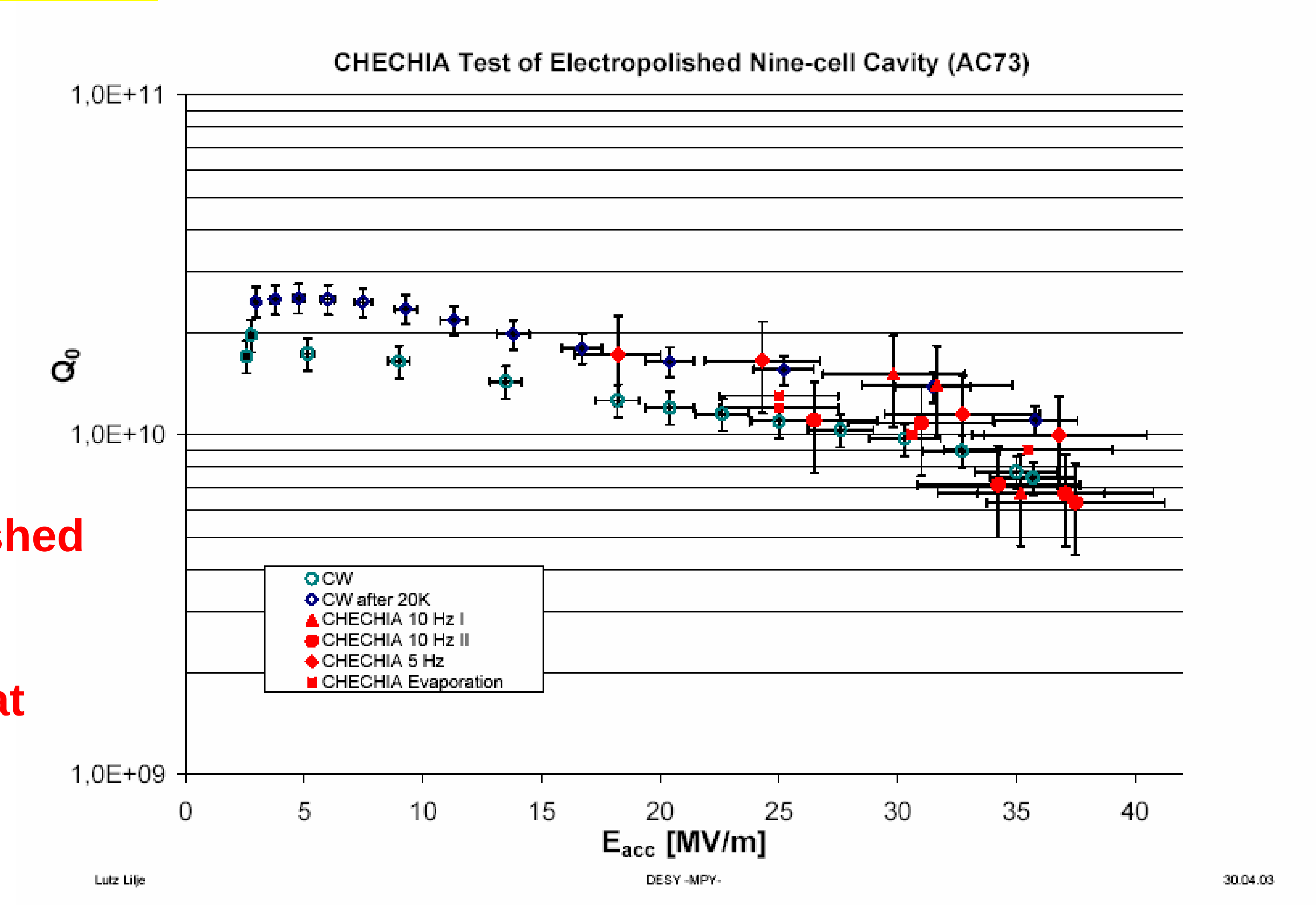


Very important for choice of technology

TESLA

The path to higher energies….

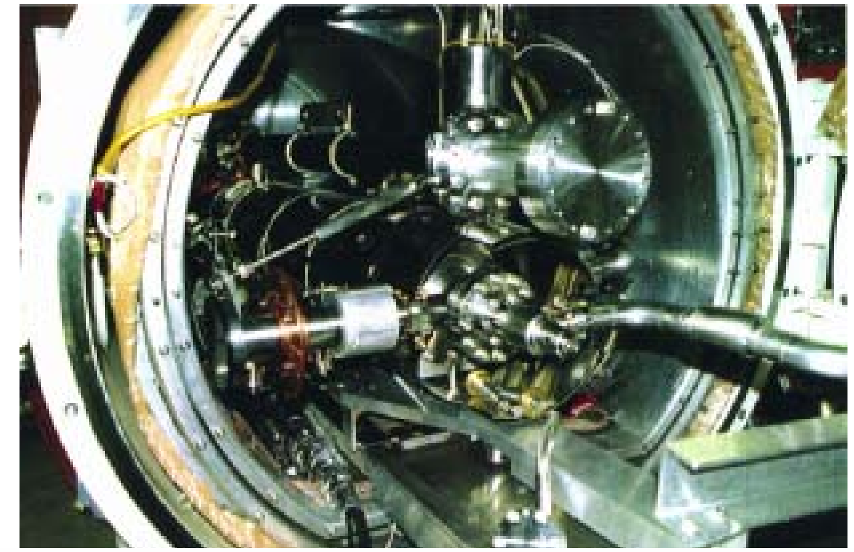
High power test of electropolished nine-cell Cavity
> 1100 hrs at 35 MV/m



April 2003: 38 MV/m

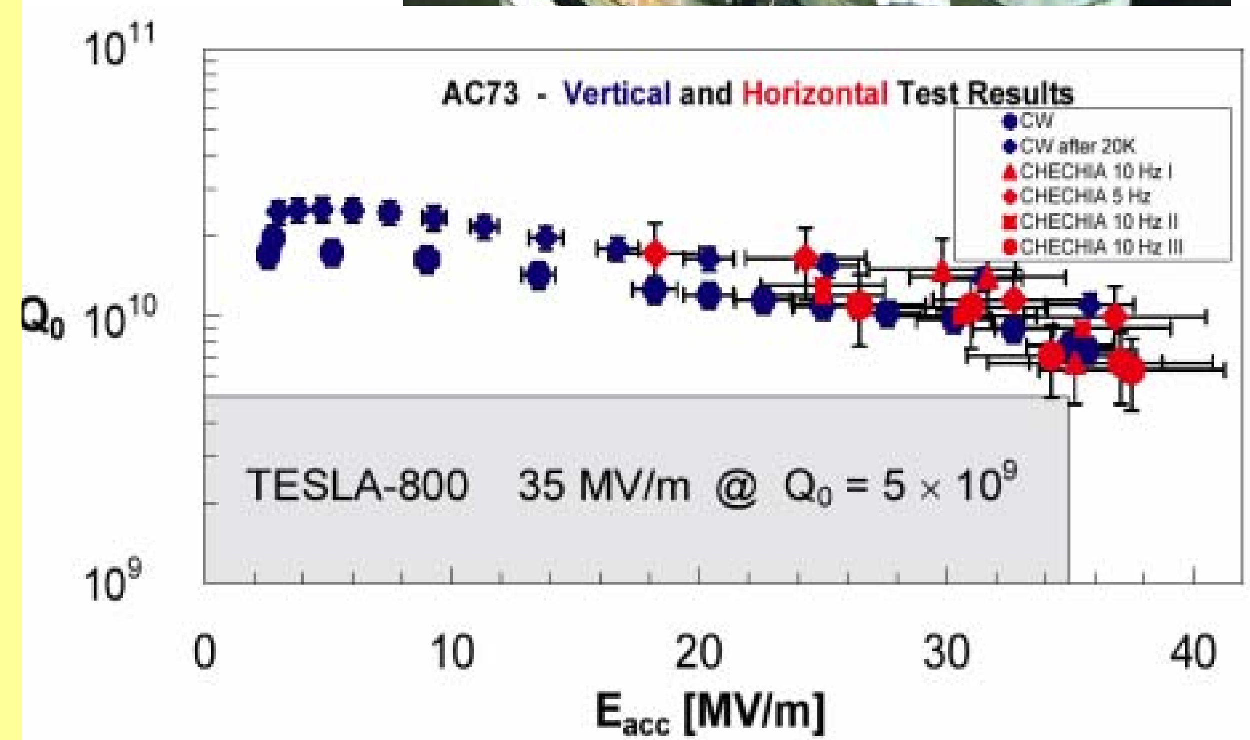
High Power Test of a Complete EP nine-cell Cavity

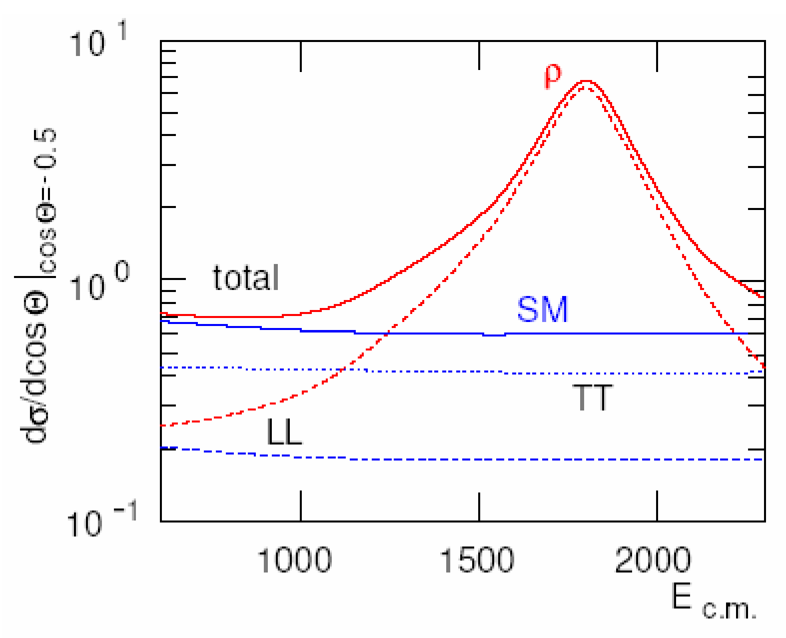
Several single cell cavities reached > 40 MV/m



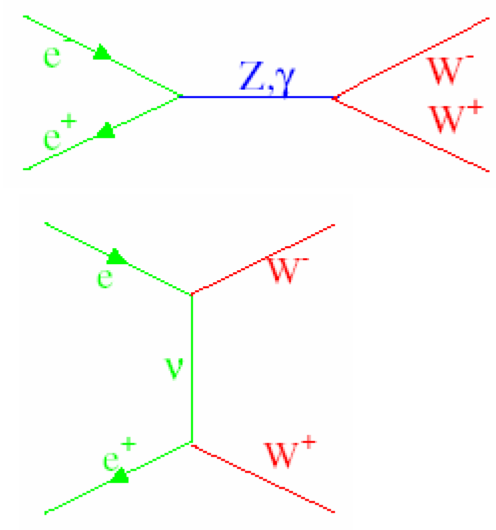
- 1/8th of a TESLA cryomodule
- 5 Hz, 500 μs fill, 800 μs flat-top
- 33-> >35 MV/m

  with no interruption related to cavity-coupler-klystron for more than 1000 hours
- > 50 h at 36 MV/m
- No field emission

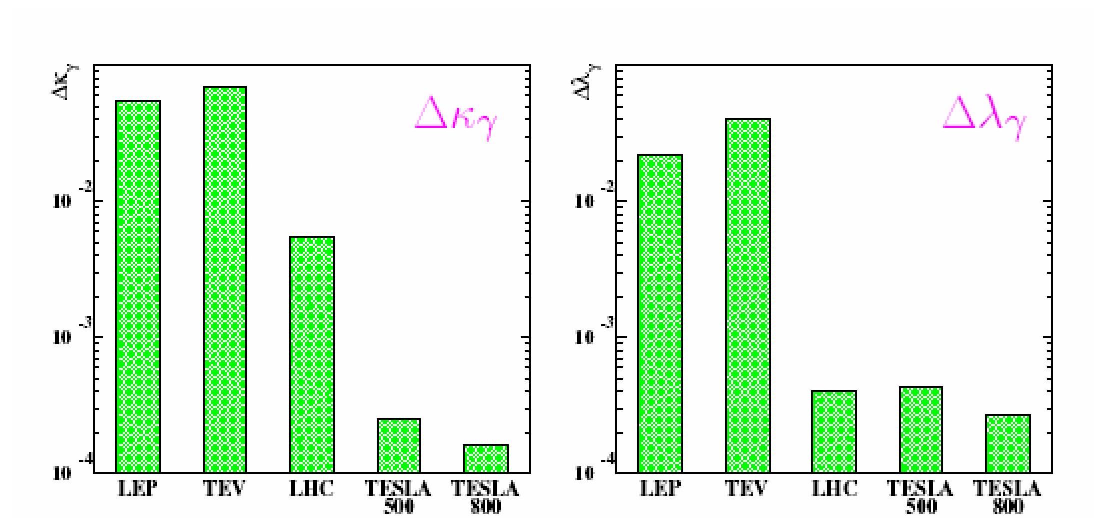




10^{1}
10^{0}
10^{-1}
ρ
total
SM
TT
LL
1000
1500
2000
E c.m.
dσ/dcos Θ |cos Θ= - 0.5



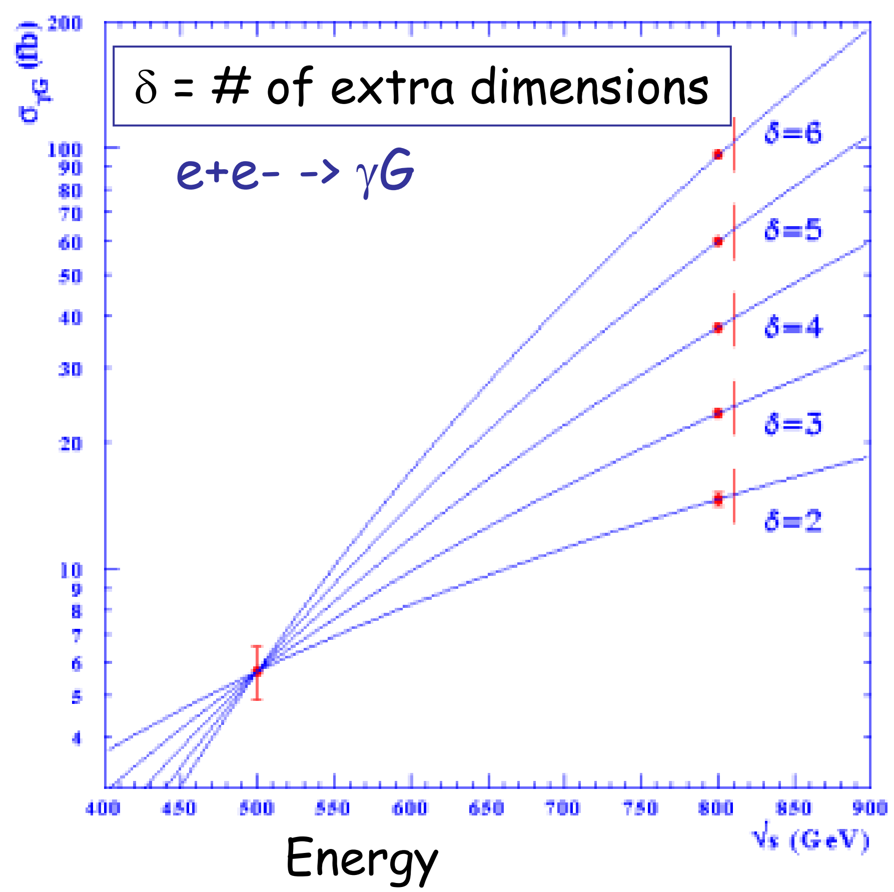
e⁻
e⁺
Z,γ
W⁻
W⁺
ν



Δκγ
Δλγ
LEP
TEV
LHC
TESLA 500
TESLA 800

Hidden dimensions

cross section for anomalous single photon production



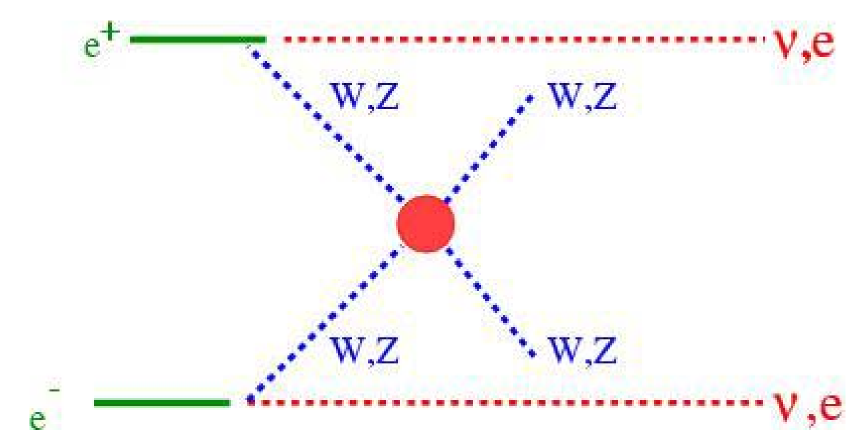
measurement of cross sections at different energies allows to determine number and scale of extra dimensions

(500 fb-1 at 500 GeV,

1000 fb-1 at 800 GeV)

No Higgs boson(s) found….

$W_L W_L$ scattering:



Standard Model mathematically inconsistent unless new physics at about 1.3 TeV

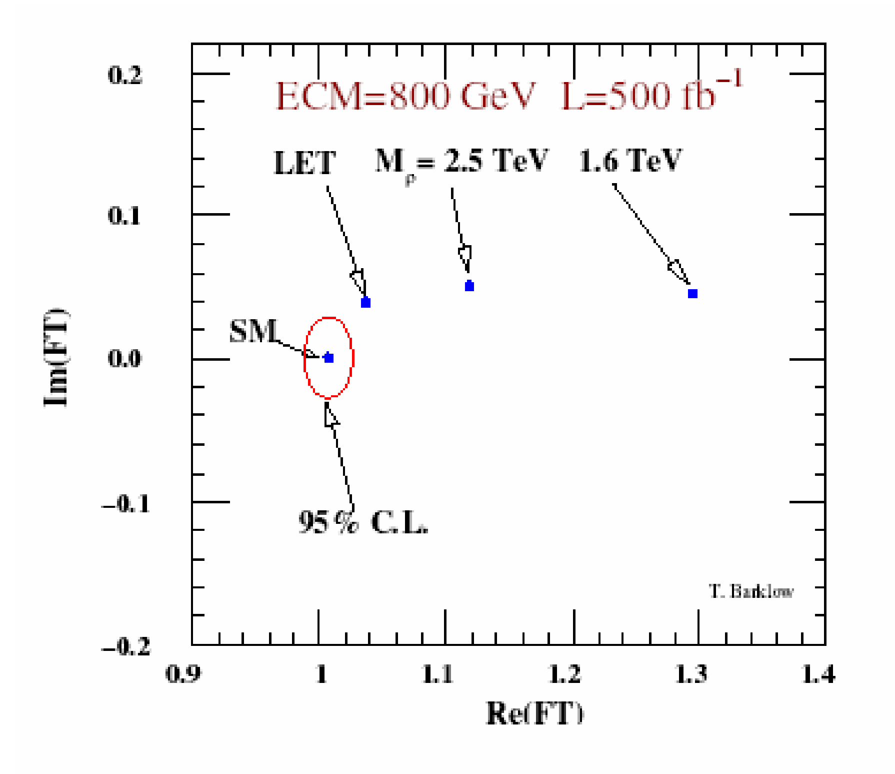
Experimental consequence: New strong interaction measurable in triple and quartic gauge boson couplings

Sensitivity at a 800-1000 Gev Linear Collider: ~ 8 TeV (TGC)
~ 3 TeV (QGC)

→ *complete threshold region covered*

No Higgs boson(s) found….

Analysis of ee → WW within technicolour models:

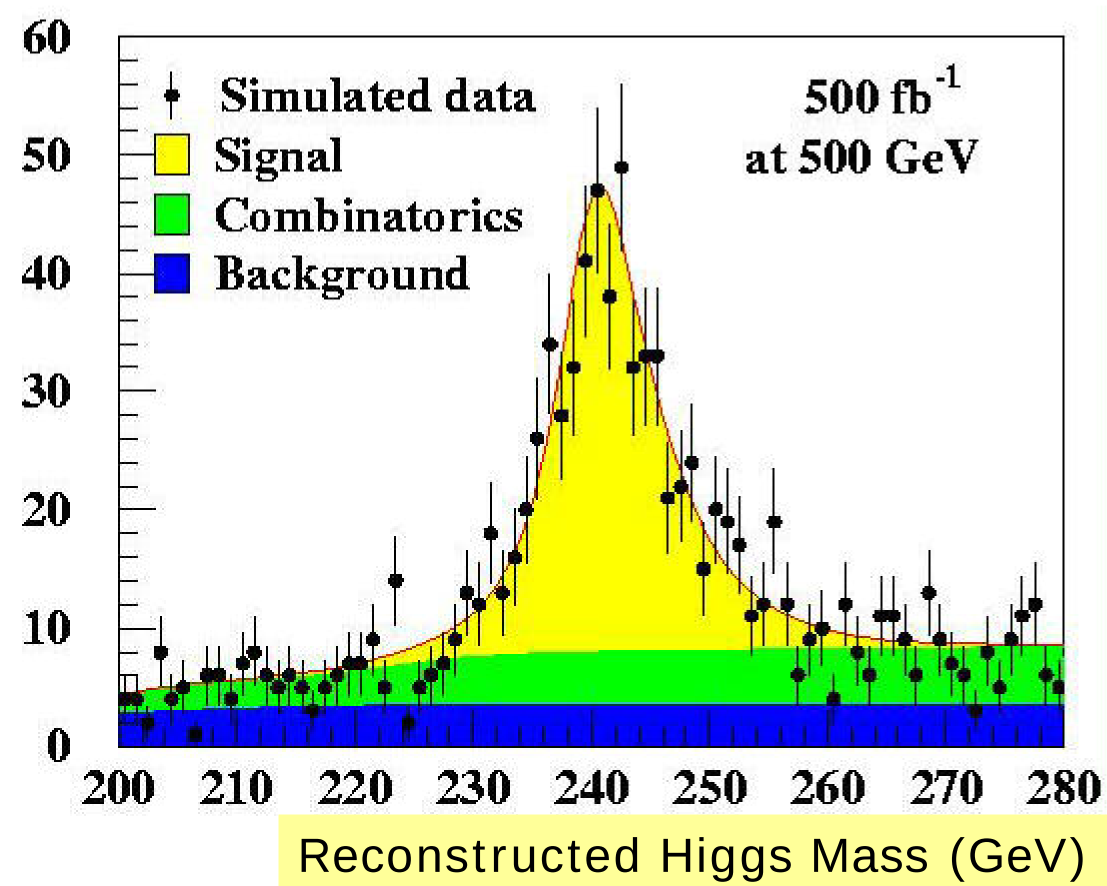


Linear Collider sensitive
to masses up to ~ 2.5 TeV
and can distinguish LET from SM

Precision physics of Higgs bosons

$e^+e^- \to ZH \to \ell^+\ell^- q\bar{q}q\bar{q}$

m_H=240 GeV



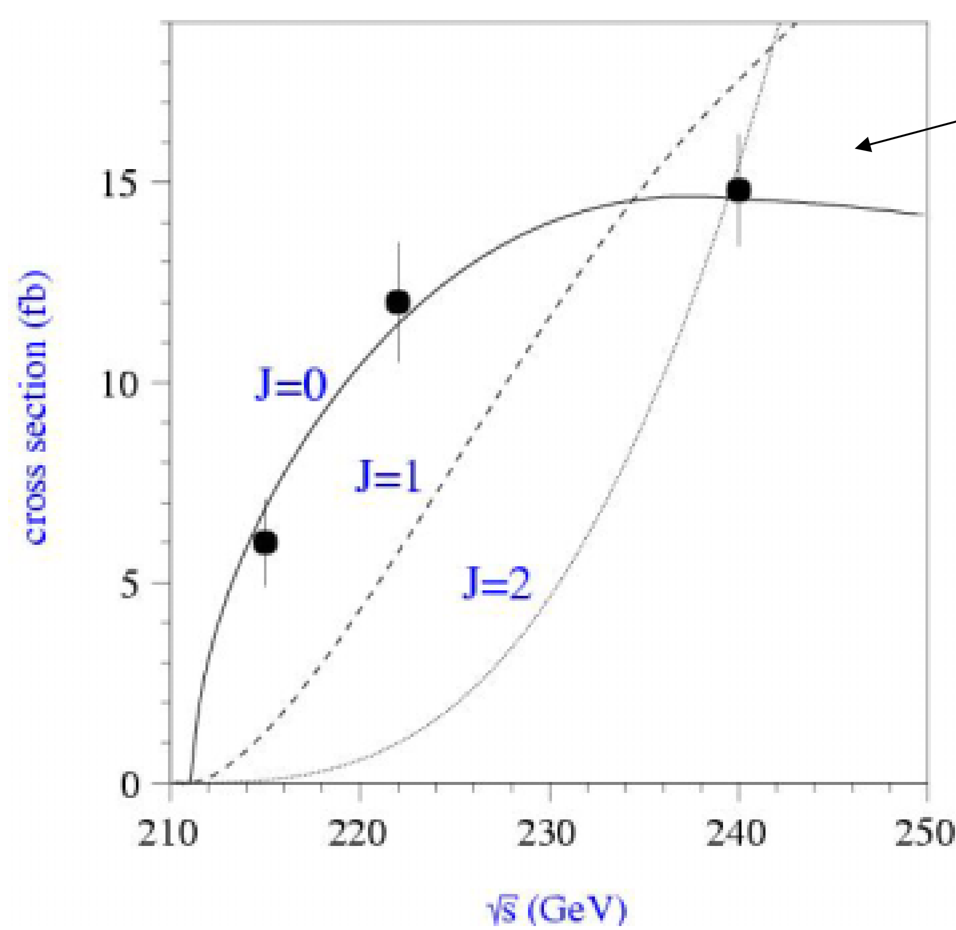
Δm_H = 400 MeV (0.2%)

$\Delta\ \sigma$ (HZ) = 4%

Results available for M_H up to 320 GeV

Precision physics of Higgs bosons

Determination of quantum numbers

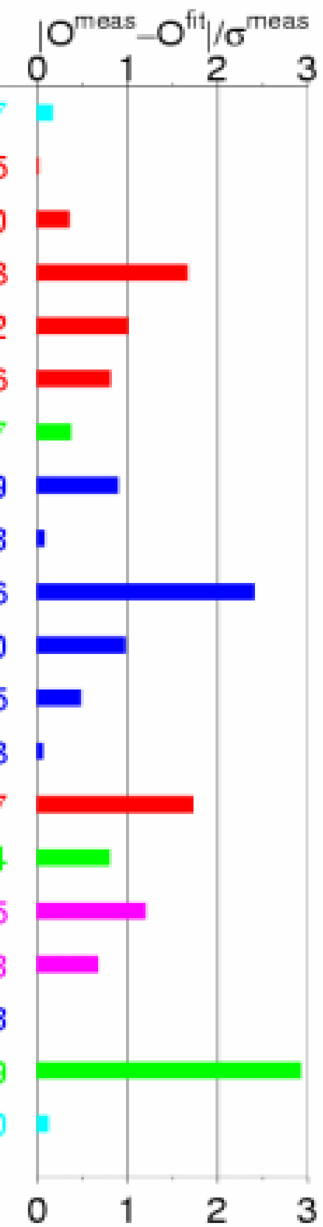


Spin from threshold measurement

CP-quantum numbers
from
H,Z angular distributions
or
polarisation analysis
of Higgs decays to taus

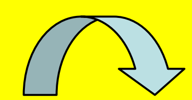
Summer 2003

	Measurement	Fit
$\Delta\alpha^{(5)}_{had}(m_Z)$	0.02761 ± 0.00036	0.02767
m_Z [GeV]	91.1875 ± 0.0021	91.1875
Γ_Z [GeV]	2.4952 ± 0.0023	2.4960
σ^0_{had} [nb]	41.540 ± 0.037	41.478
R_l	20.767 ± 0.025	20.742
$A^{0,l}_{fb}$	0.01714 ± 0.00095	0.01636
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1477
R_b	0.21638 ± 0.00066	0.21579
R_c	0.1720 ± 0.0030	0.1723
$A^{0,b}_{fb}$	0.0997 ± 0.0016	0.1036
$A^{0,c}_{fb}$	0.0706 ± 0.0035	0.0740
A_b	0.925 ± 0.020	0.935
A_c	0.670 ± 0.026	0.668
A_l(SLD)	0.1513 ± 0.0021	0.1477
$\sin^2\theta^{lept}_{eff}(Q_{fb})$	0.2324 ± 0.0012	0.2314
m_W [GeV]	80.426 ± 0.034	80.385
Γ_W [GeV]	2.139 ± 0.069	2.093
m_t [GeV]	174.3 ± 5.1	174.3
$\sin^2\theta_W(\nu N)$	0.2277 ± 0.0016	0.2229
Q_W(Cs)	-72.84 ± 0.46	-72.90



Standard Model today enormously successful:

- tested at quantum level
- (sub)permille accuracy



precise and quantitative description of subatomic physics,
valid to the 0.1% level

But:
many key questions open

Particle Physics and Cosmology

Particle Physics and Cosmology
both point to New Physics at the TeV scale

Electroweak unification

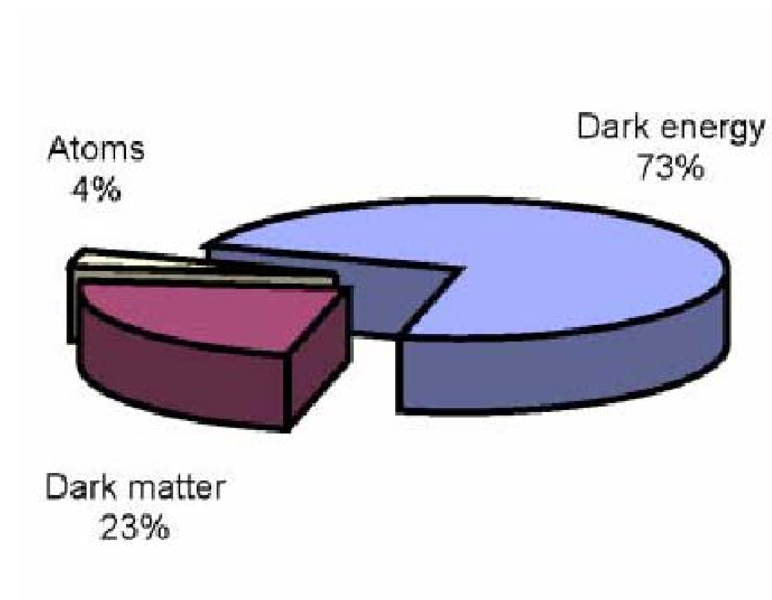
Dark Matter

Dark Energy

Inflation

Neutrino Masses

CP Violation



The next steps at the energy frontier

There are two distinct and complementary strategies
for gaining new understanding of matter, space and time
at future particle accelerators

HIGH ENERGY

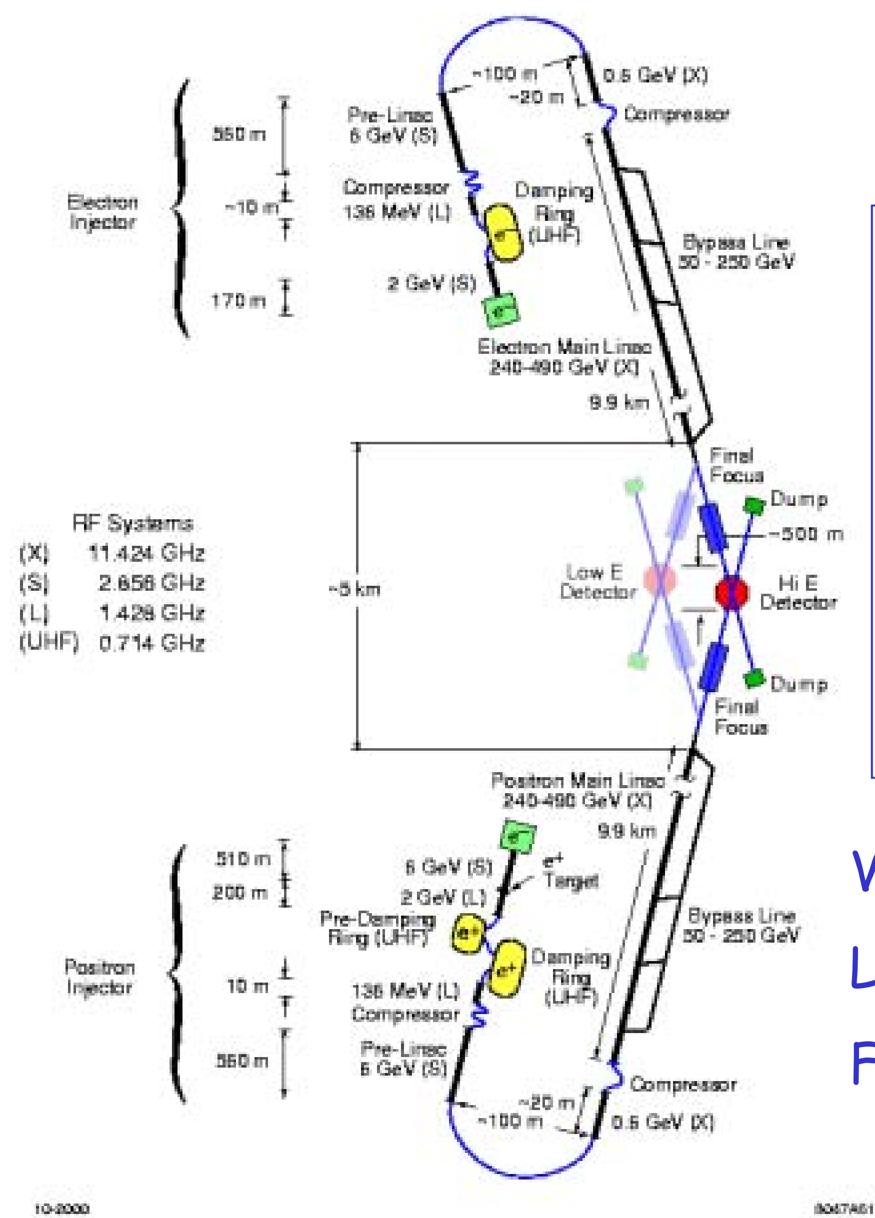
direct discovery of new phenomena
i.e. accelerators operating at the energy scale of the new particle

HIGH PRECISION

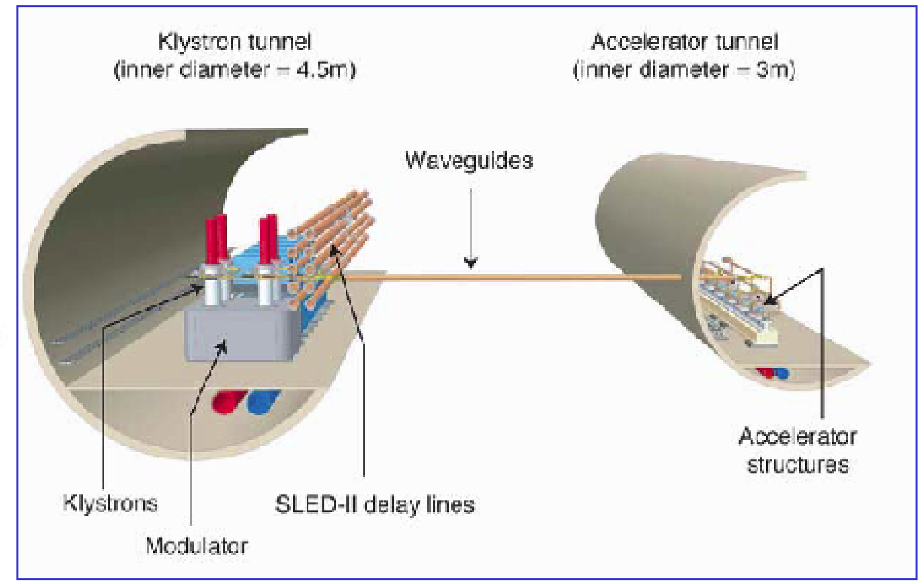
interference of new physics at high energies through the precision
measurement of phenomena at lower scales

Both strategies have worked well together
→ much more complete understanding than from either one alone

prime example: LEP / Tevatron



(GLC)/NLC Overall Layout



Warm RF, 11.4 GHz

Loaded gradient 50 MV/m

For site length 33 km: E_{cm} = 1.–1.3 TeV