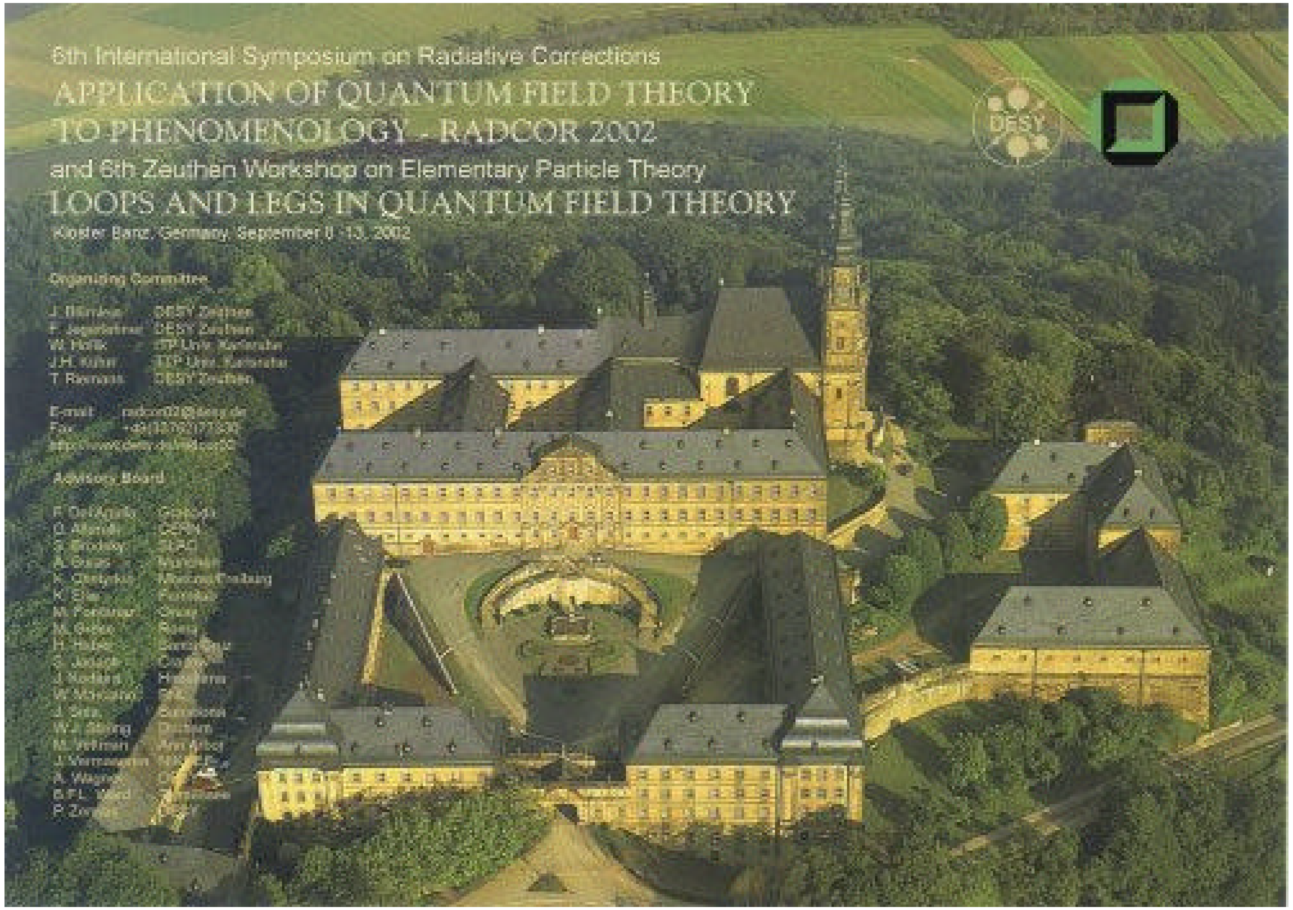
A New Tool for Science

Scientific Potential and Technical Challenges

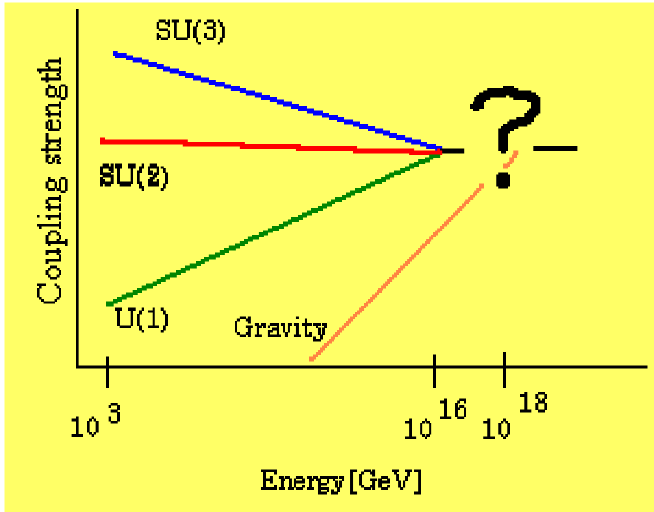


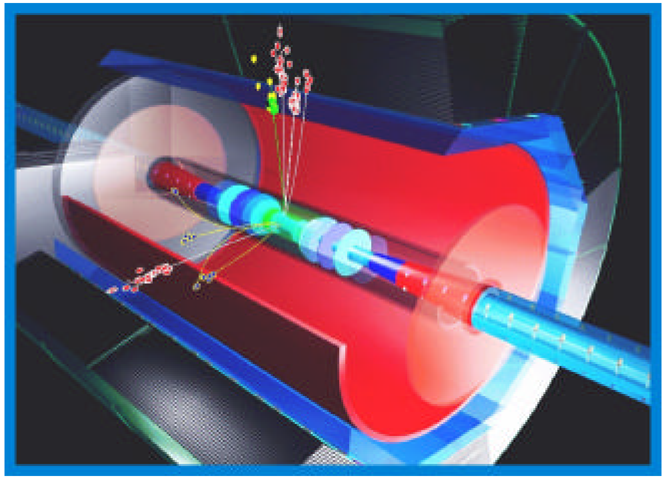
Key Questions of Particle Physics

- What is mass/matter ?

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

- Can the forces be unified?
- Fundamental symmetry of forces and building blocks?
- Can quantum physics and general relativity be united?
- Do we live in 4 dimensions?
- What happened in the very early universe ?
- Origin of dark matter



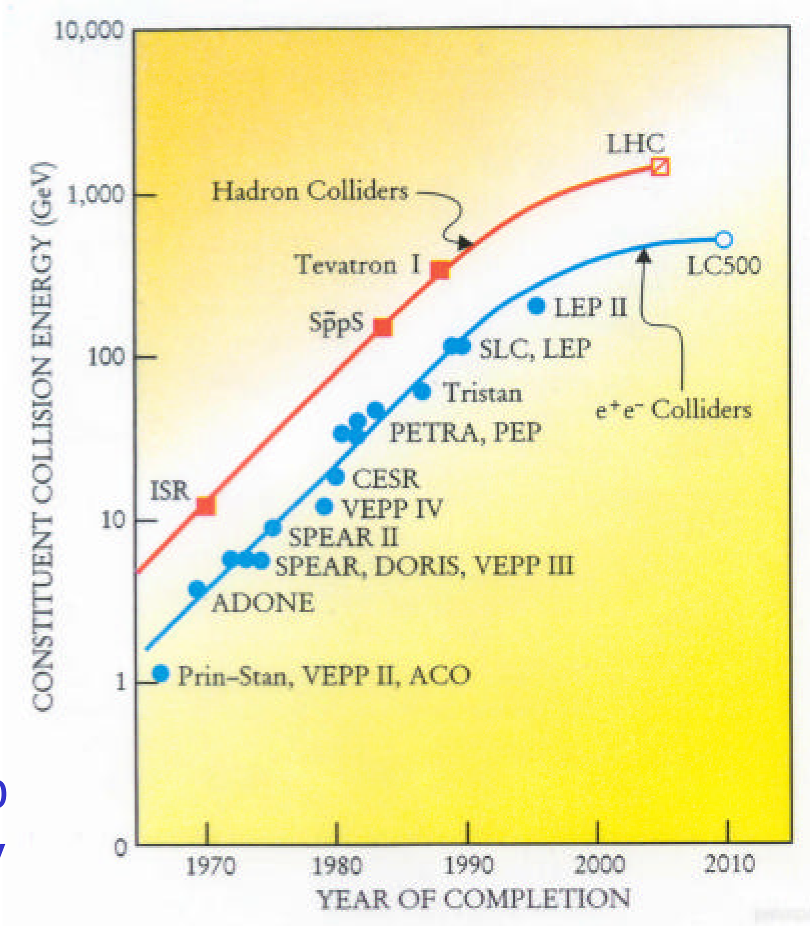


The Path to the Experimental Answers

- At high energies
  Hadron Colliders
  - LHC under construction at CERN

- In precision measurements (= high energy reach through virtual processes)
  Electron-Positron Collider
  - e.g. TESLA

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



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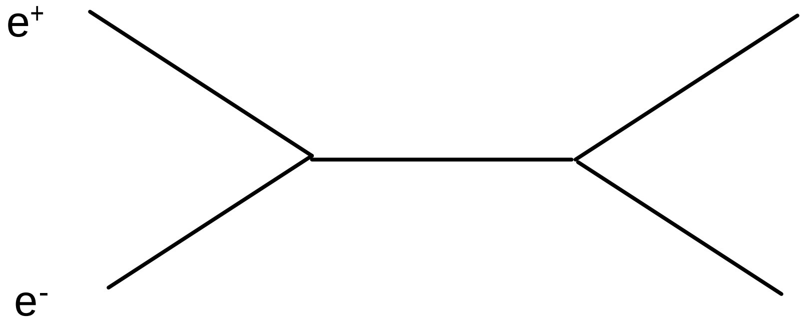
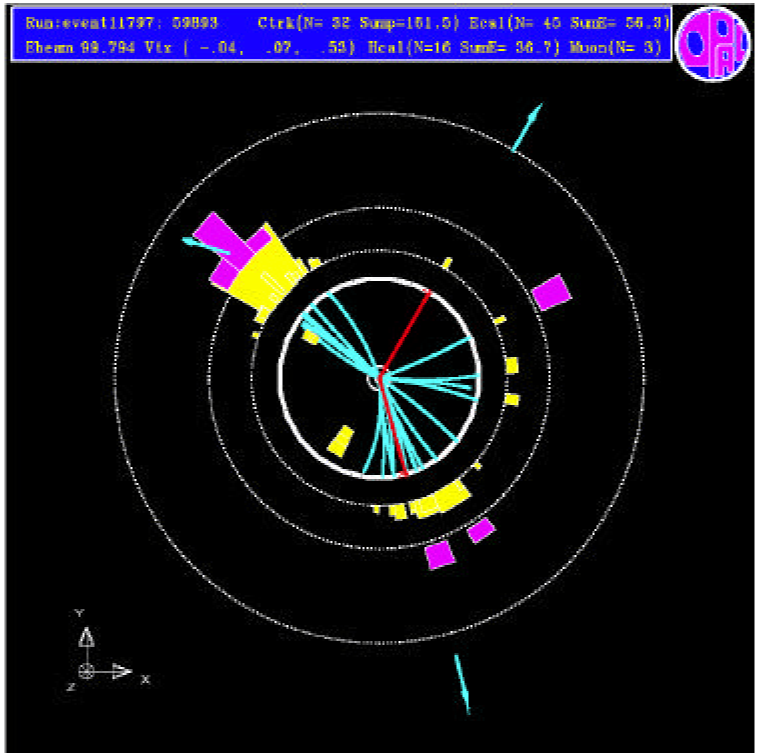
The Power of $e^+ e^-$ Colliders

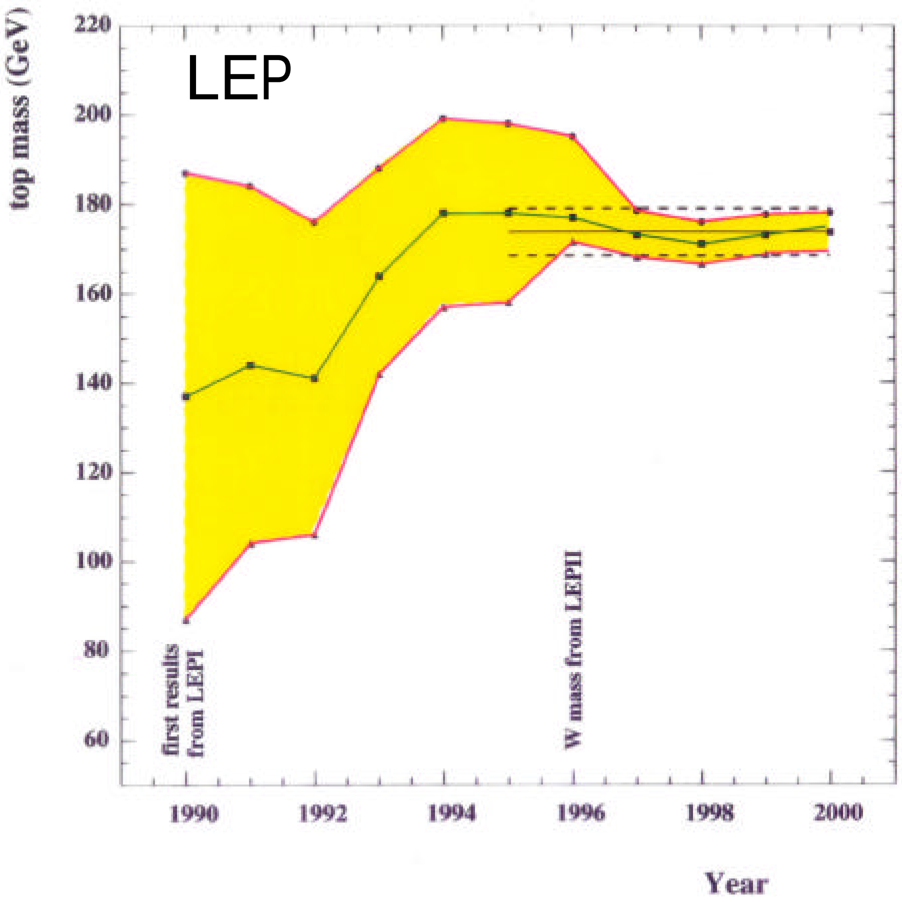
- well defined production process, simple kinematics
- precise knowledge of quantum numbers in initial state
- precise (<%) knowledge of the cross sections
- polarisation of e^- and e^+ beams possible
- energy and momentum of all partons known
- energy of system can be varied
- low background





q q μ μ

Test of the SM at the Level of Quantum Fluctuations



Indirect determination of the top mass

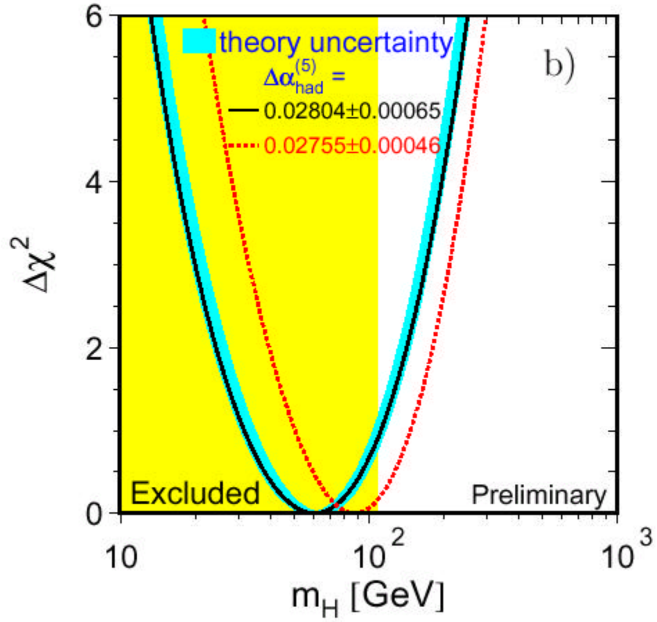
possible due to

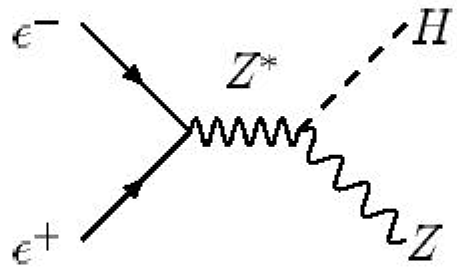
- precision measurements
- known higher order electroweak corrections

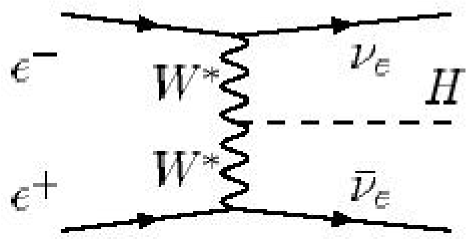
$$\propto \left(\frac{M_t}{M_W}\right)^2, \ln\left(\frac{M_h}{M_W}\right)$$

Proves high energy reach through virtual processes

The Higgs: Key to Understanding Mass





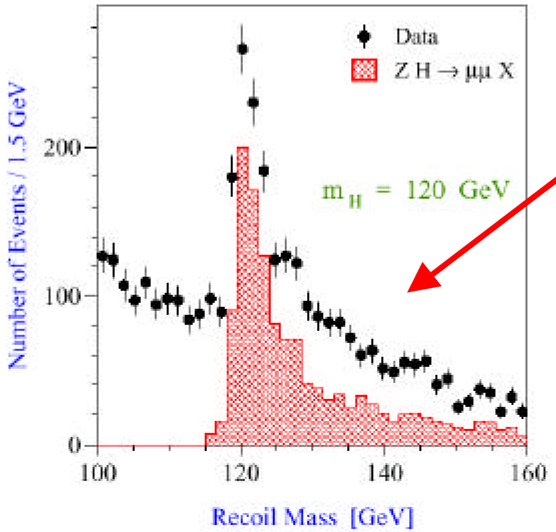


Where is the Higgs?

Mass limits for the Higgs

from precision tests of the SM

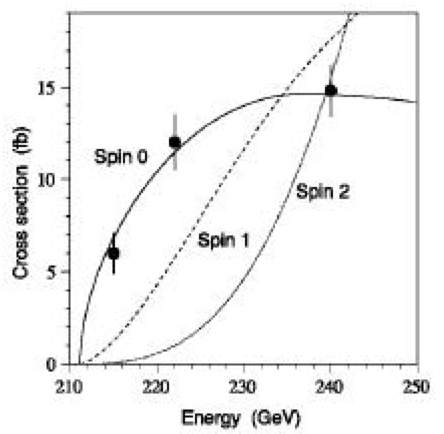
114 < m(H) < ~200 GeV (95 % CL)



A Linear Collider measures:

- mass
- quantum numbers
- lifetime
- couplings

= test the mechanism of mass generation



Higgs Mass Reconstruction in exclusive channels

Reconstruction in different channels:

$e^+e^- \to ZH \to$

$M_H = 120$ GeV:

a) $\to \; b\bar{b}q\bar{q}$

b) $\to \; q\bar{q}\ell^+\ell^-$

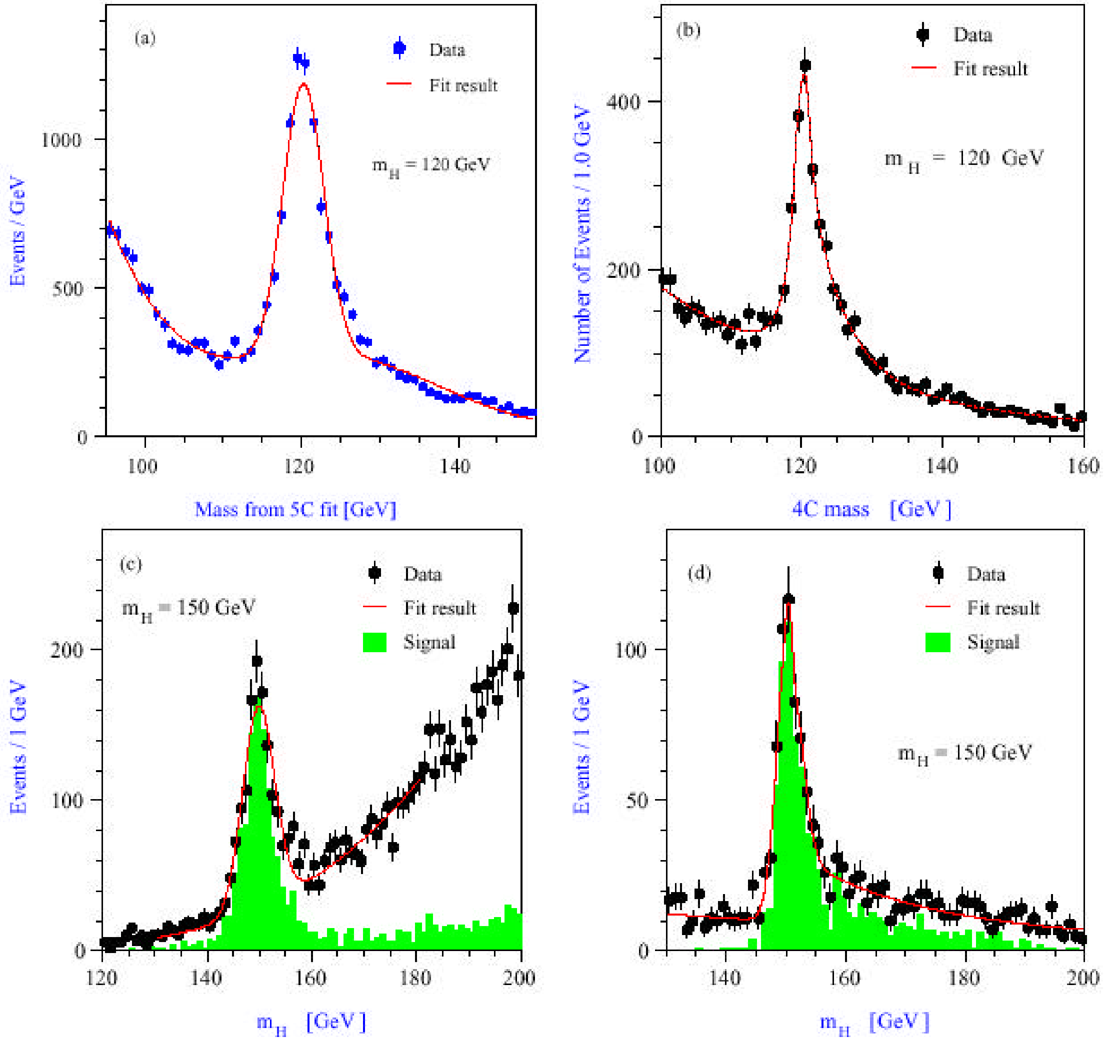
$M_H = 150$ GeV:

c) $\to \; W^+W^-q\bar{q}$

d) $\to \; W^+W^-\ell^+\ell^-$

500 fb-1 at

E= 350 GeV



$\Delta m_H =$ 40 MeV	70 MeV

Higgs Branching Ratios

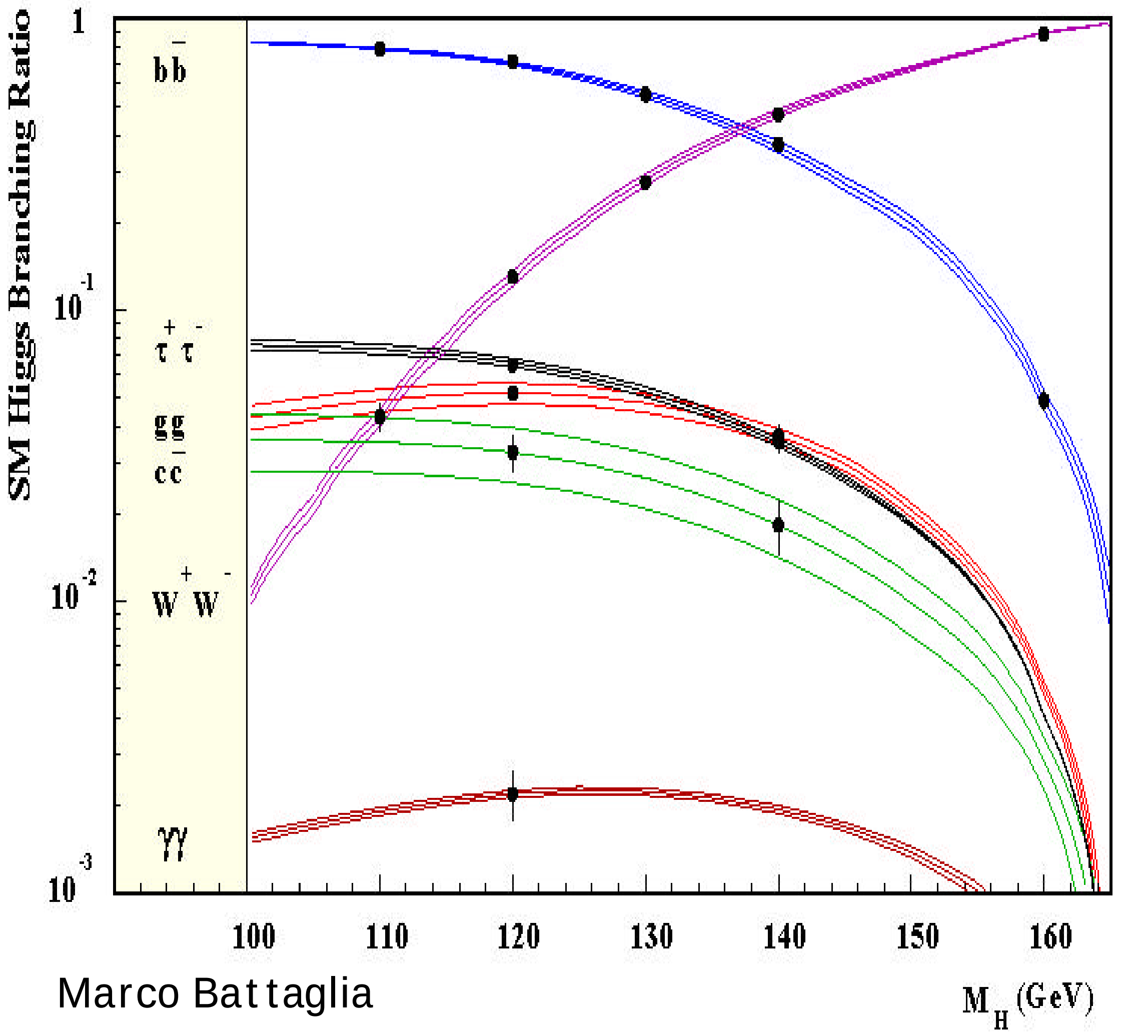
Branching ratios measure the Higgs coupling to fermions,

a test of the Higgs mechanism

accuracy a few %

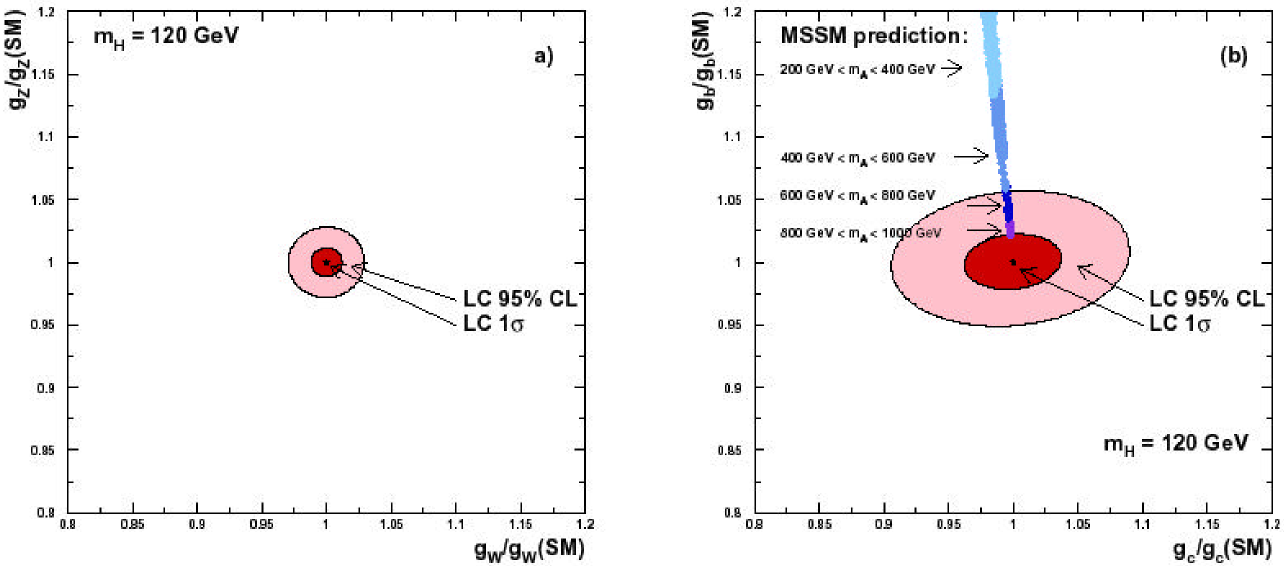
500 fb-1

at 350 GeV

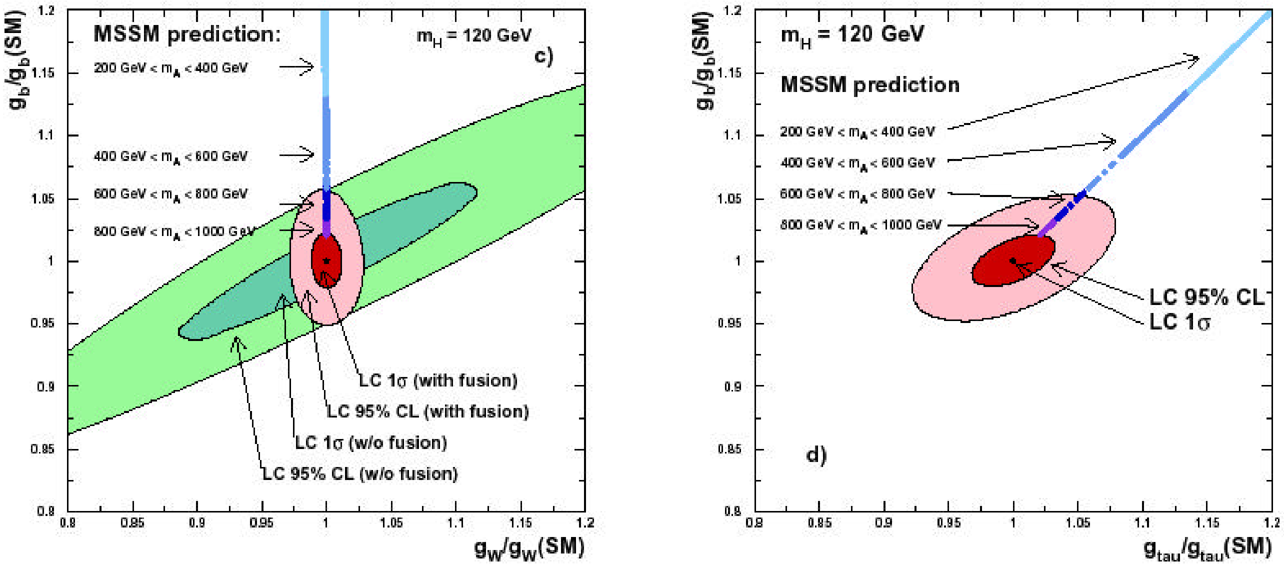


Marco Battaglia

Higgs Coupling Ratios



Ratios of couplings

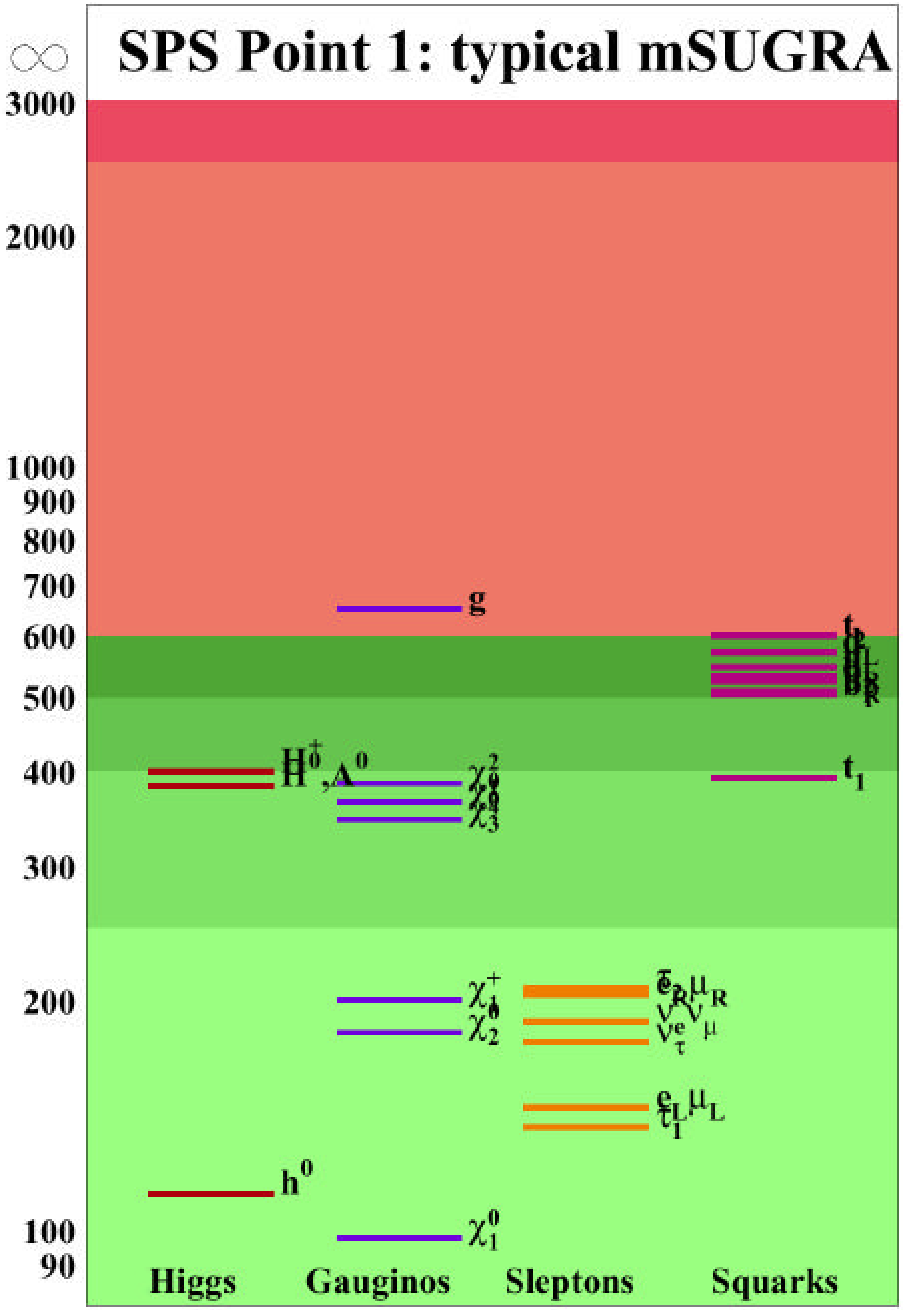


500 fb-1

m(H) = 120 GeV

Precise measurement of Higgs BRs probes non-SM nature of Higgs:

Is Higgs SM or MSSM?



SUSY Mass Spectra

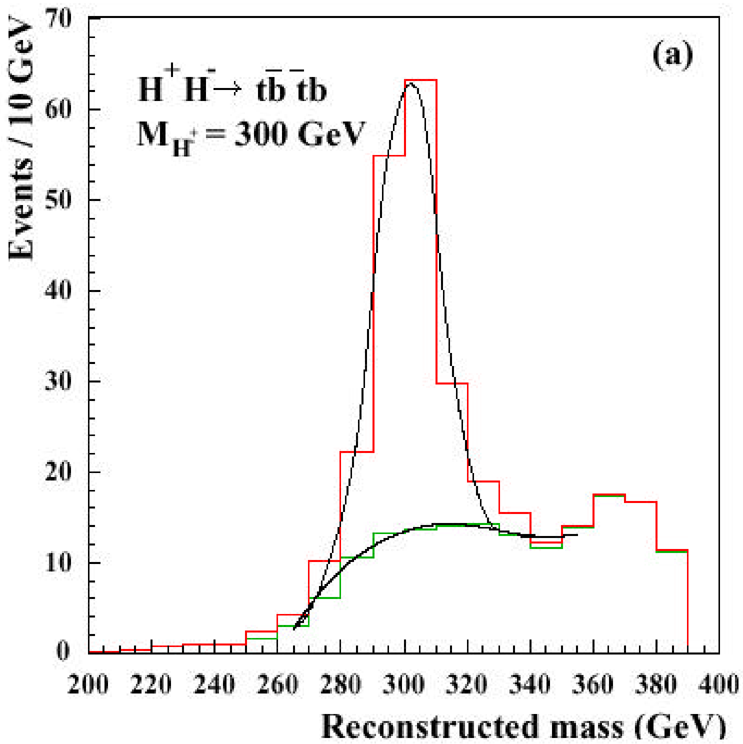
Mass spectra depend on choice of parameters...

A Linear Collider can measure supersymmetric particles:

- masses
- quantum numbers
- lifetimes
- decays

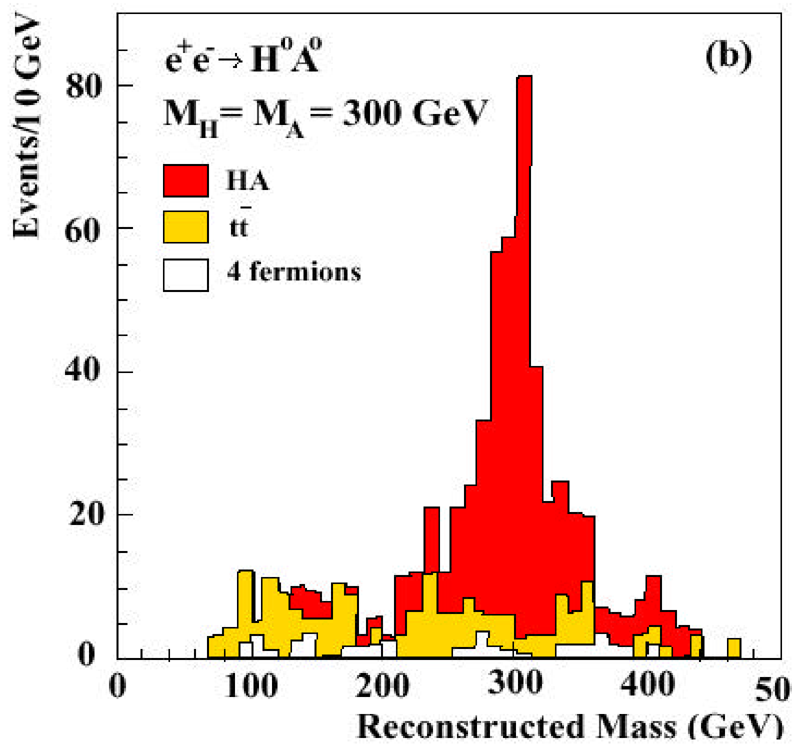
SUSY Higgs Bosons

SUSY extension to SM: additional doublets and singlets: h^0, H^0, A^0, H^+, H^-



Di-jet inv mass for $e^+e^- \to H^+H^- \to t\bar{b}\bar{t}b$

500 fb^{-1}, E = 800 GeV



Mass peak for $e^+e^- \to H^0A^0 \to b\bar{b}b\bar{b}$

50 fb^{-1}, E = 800 GeV

Sleptons

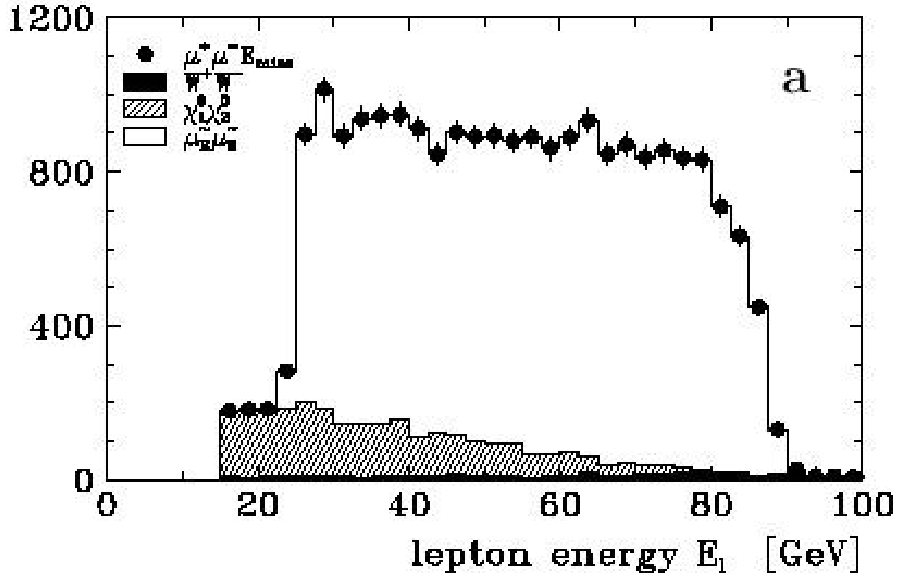
Production and decay of smuons:

$$e_R^- e_L^+ \;\rightarrow\; \tilde{\mu}_R \tilde{\mu}_R \;\rightarrow\; \mu^- \tilde{\chi}_1^0 \, \mu^+ \tilde{\chi}_1^0$$

160 fb-1

Mass errors (MeV):

	smuon	χ_1^0
end points:	300	300
threshold:	90	70



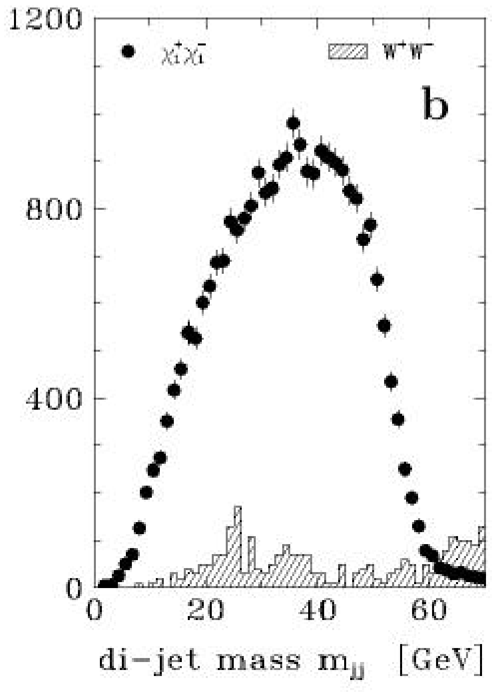
Energy spectrum of muons

Charginos

Produced in pairs

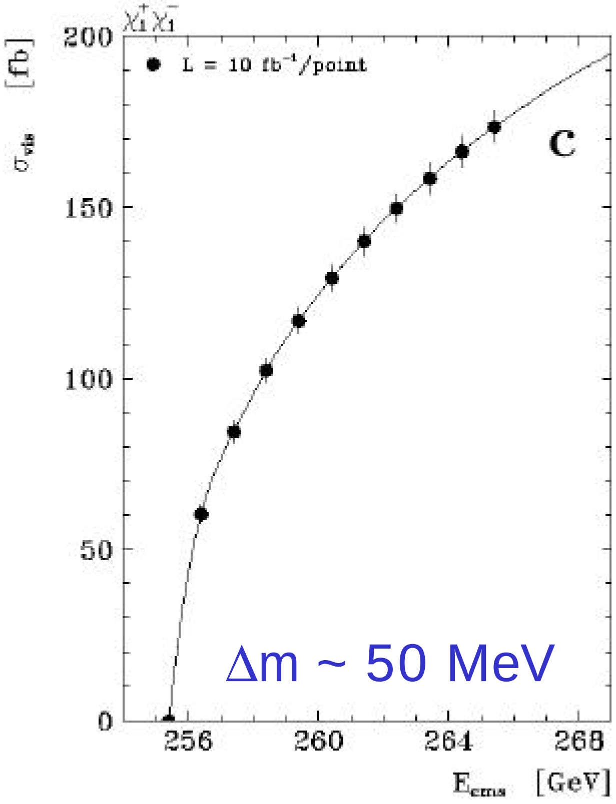
$$e_L^- e_R^+ \rightarrow \tilde{\chi}_1^- \tilde{\chi}_1^+ \rightarrow l^\pm \nu \tilde{\chi}_1^0 q\bar{q}' \tilde{\chi}_1^0$$

Easy detection
through their decays



350 GeV

160 fb^{-1}

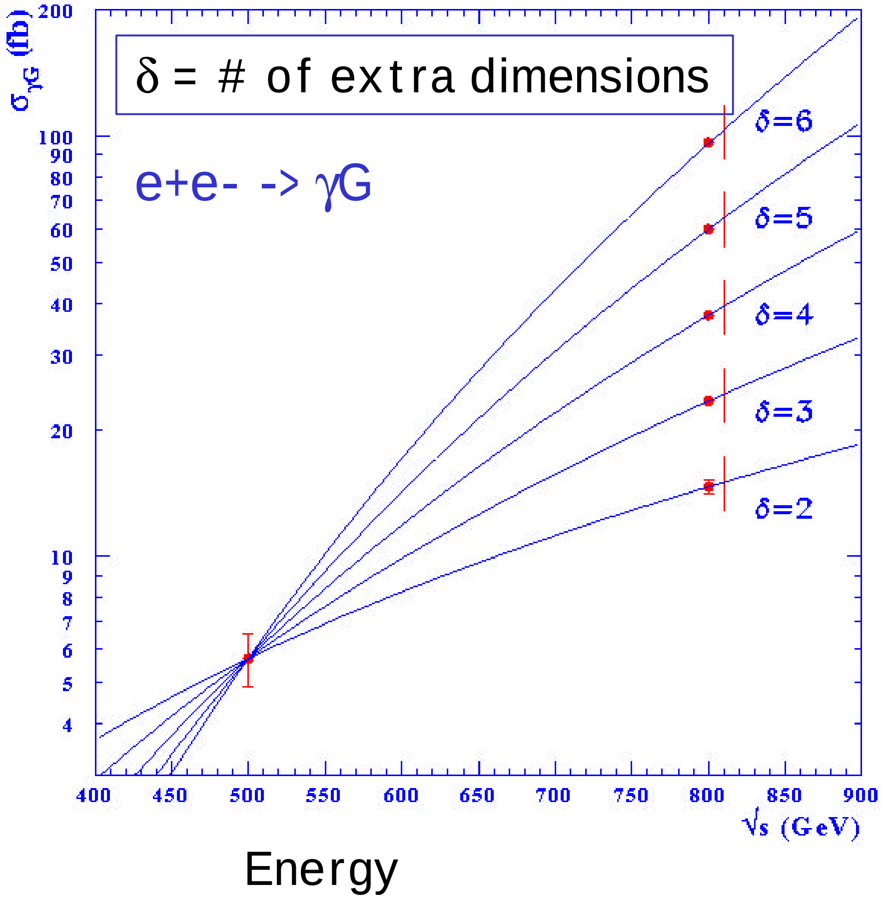


Cross section rises as $\sigma_{\chi\chi} \propto \beta$

Shape of X-section -> spin

Extra Dimensions

cross section for anomalous single photon production



- In how many dimensions do we live?

Emission of gravitons into extra dimensions

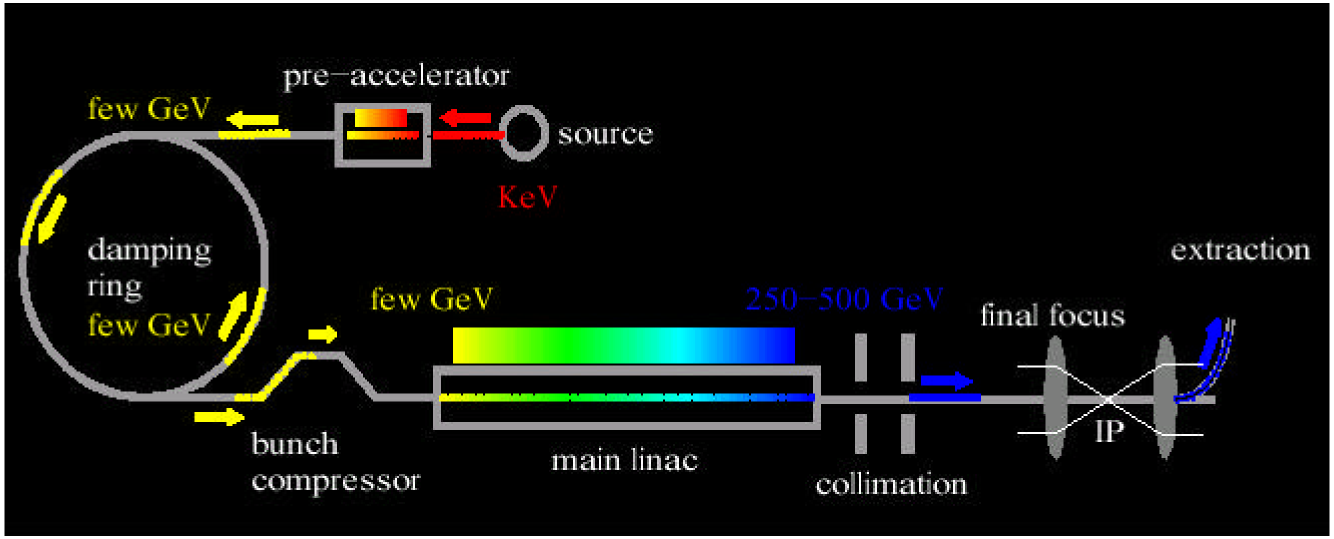
+ emission of γ or a jet

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)

e+e- Colliders: The Challenges



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 (5*500 nm) (final focus)

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

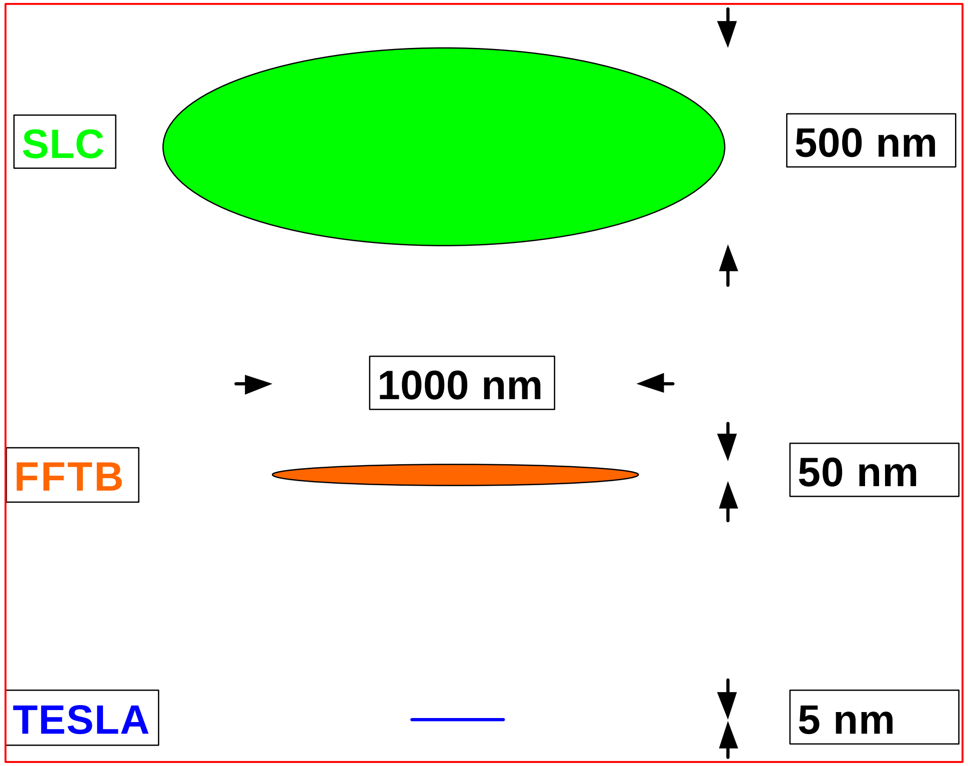
To meet these challenges: A lot of R&D on LC's world-wide

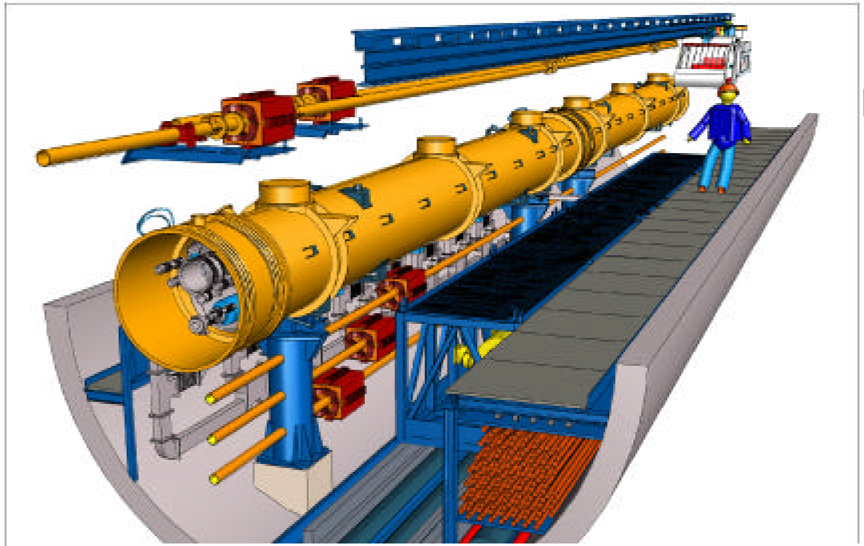
From SLC to TESLA

	SLC	TESLA	
Energy E_{cm}	100	500 (→ ~1000)	GeV
Beam Power	0.04	~10	MW
Spot size IP	500 (~50§)	~5	nm
Luminosity	$3{\cdot}10^{-4}$	3	10^{34} cm^{-2} s^{-1}

Main challenges:

- Luminosity
- Energy



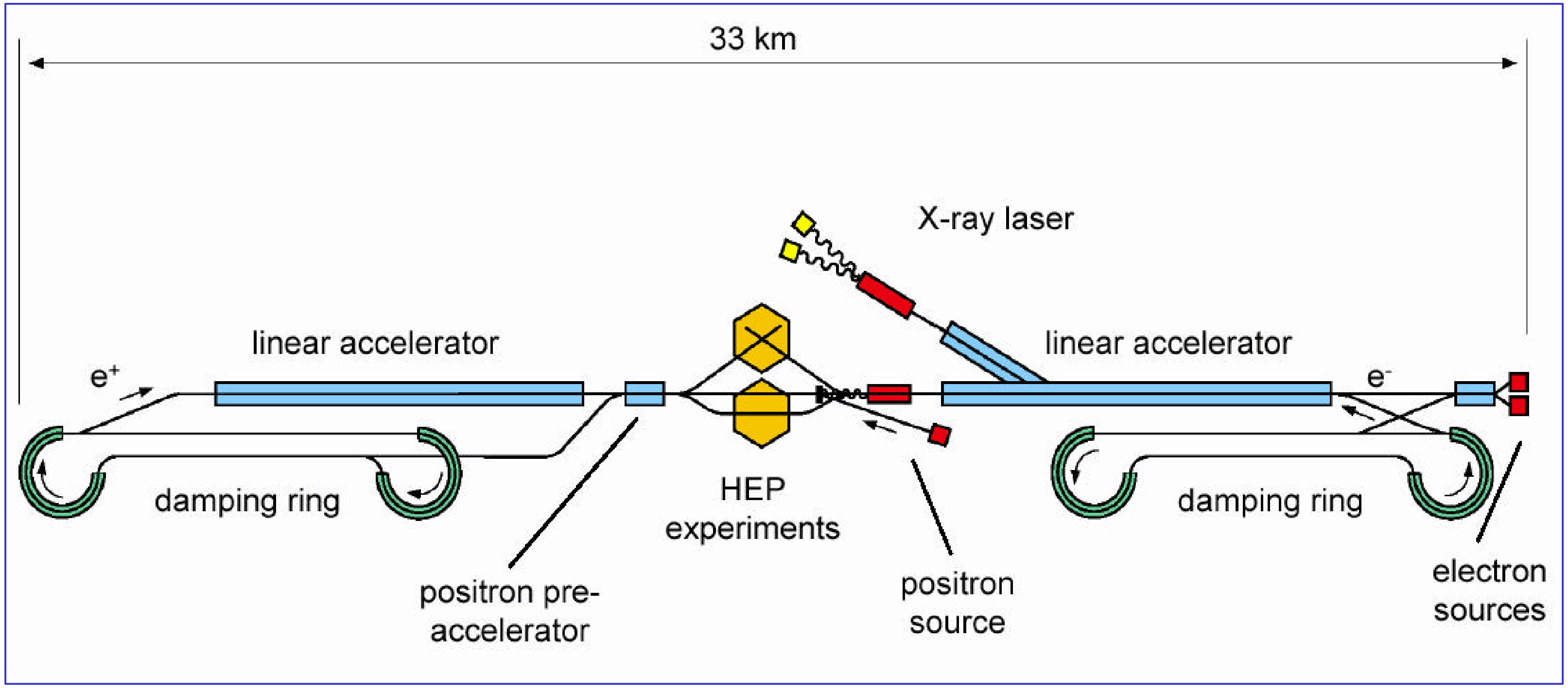


The Technical Design Report was published in March 2001

TESLA

International project for fundamental science:

- Electron-Positron collider
- X-ray laser laboratory



The TESLA Collaboration

- The TESLA Collaboration:

\- 44 Institutes in 11 countries

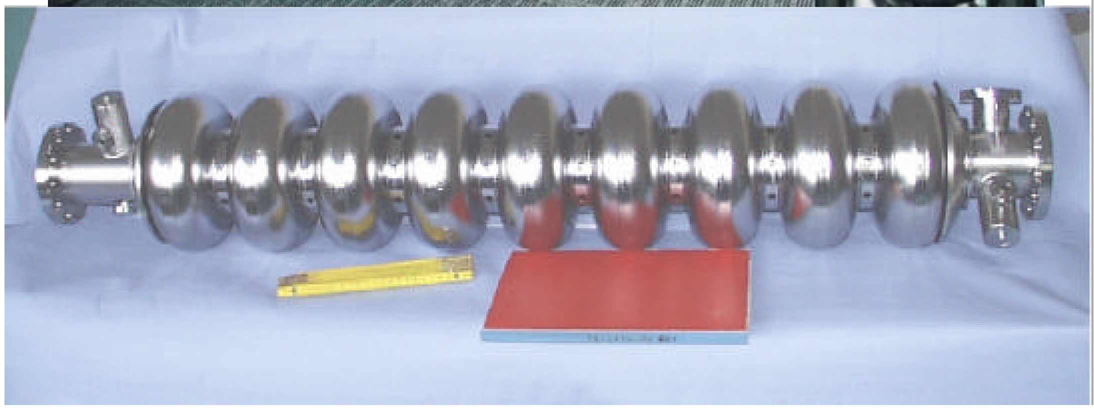
(still growing)

UK (CCLRC) has just joined

\- major hardware contributions from abroad by France, Italy, USA

- Co-operation with CERN and KEK on SC cavities

The Choice of Technology



The TESLA collaboration, led by B. Wiik, has selected in 1991 the Superconducting Linac Technology for its high potential:

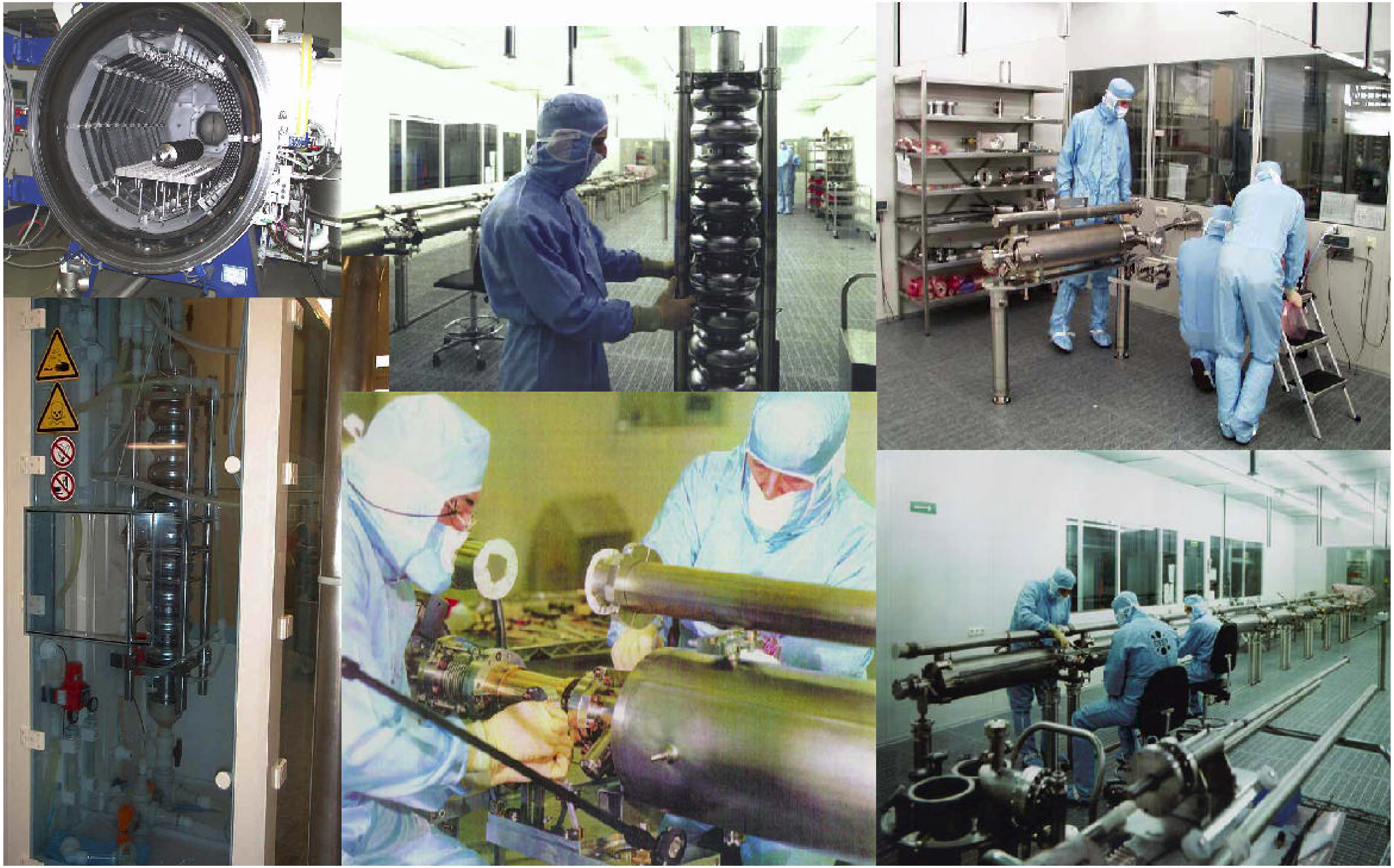
high luminosity
high power efficiency
relatively relaxed tolerances

Challenges:

high acceleration gradients
cost effective realisation

Superconducting solid Nb cavities
T=2K

Preparation of TESLA Cavities



Accelerator Milestones

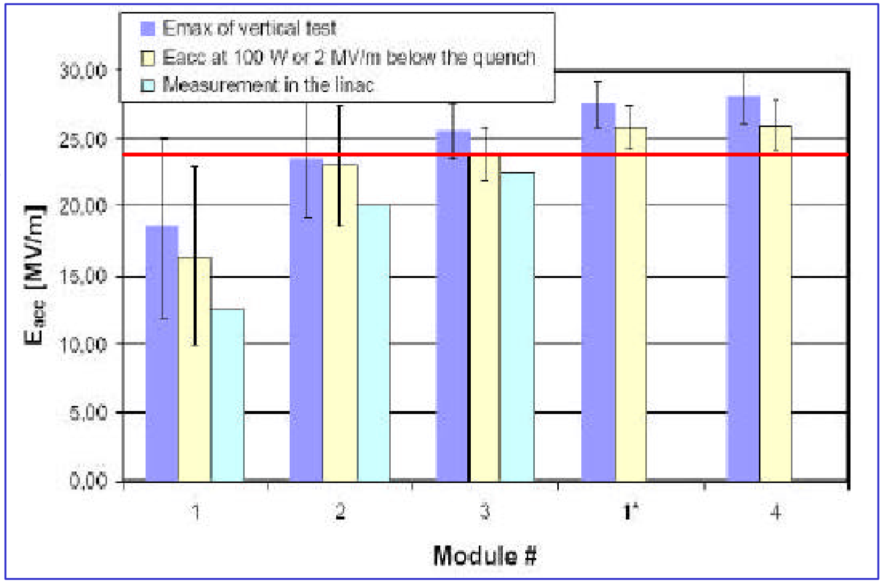
Since 1992 the TESLA Collaboration was able to increase the performance of SC cavities by a factor 4-5, while reducing the cost by a factor 4

- Routine production of cavities exceeding 25 MV/m
- New surface treatment, gradients of > 40 MV/m -> clear energy upgrade

Successful development of other components like klystrons and RF couplers

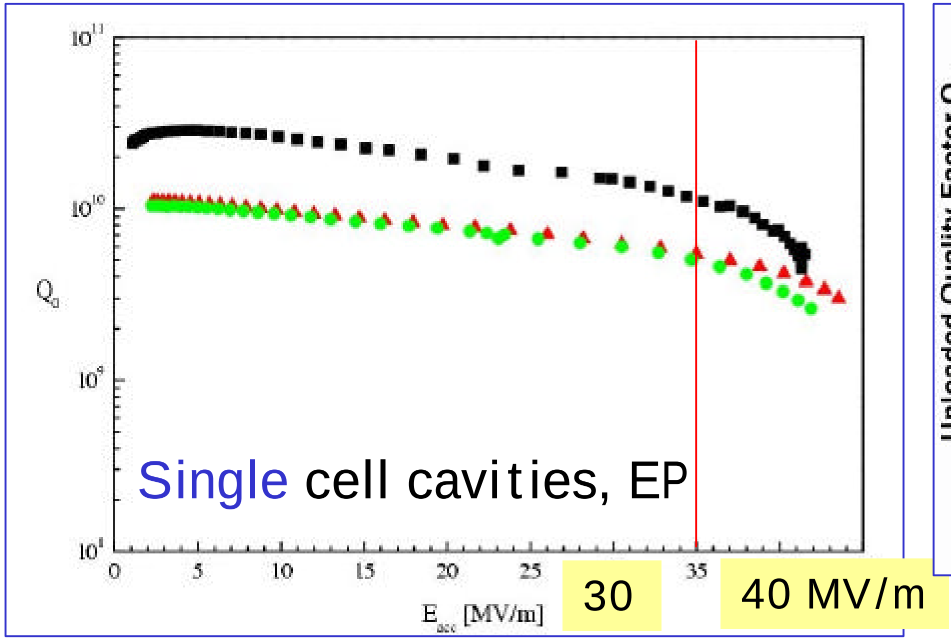
Built so far:	
~100	9-cell cavities
22	1-cell cavities
6	7-cell cavites
etc	

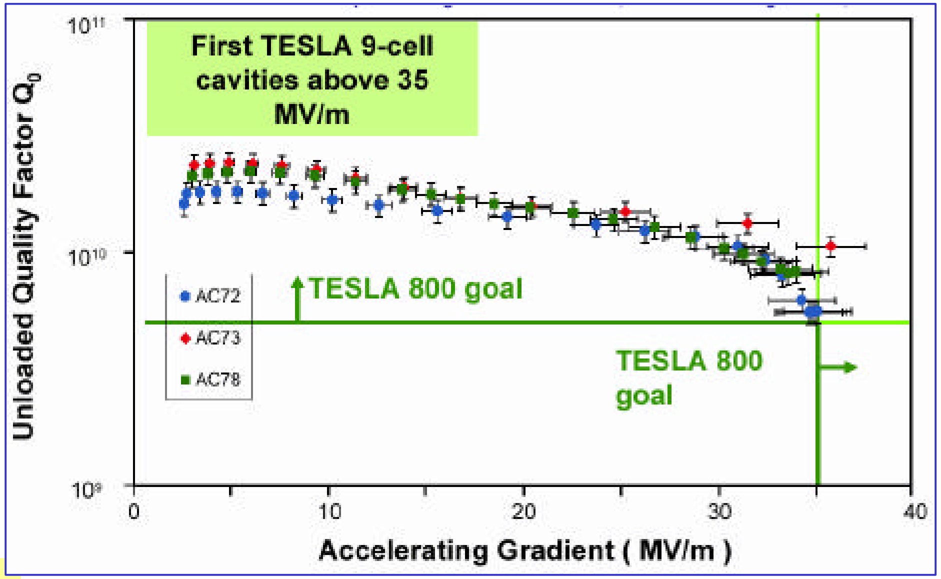
cavity performance per module



The Way to 35 MV/m – and 800 GeV

Improvement of surface quality with electro-polishing





CERN/KEK/Saclay/DESY collaboration

Transition from single-cell results to multi-cell results has again been successful

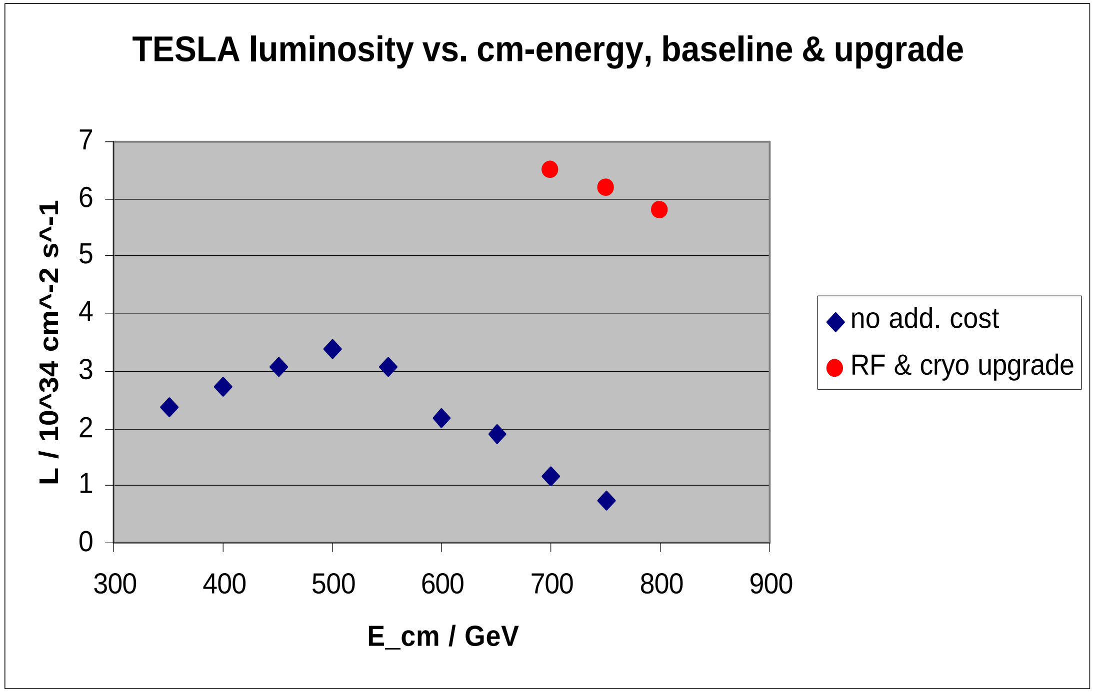
TESLA Energy Strategy

TDR (March 2001)

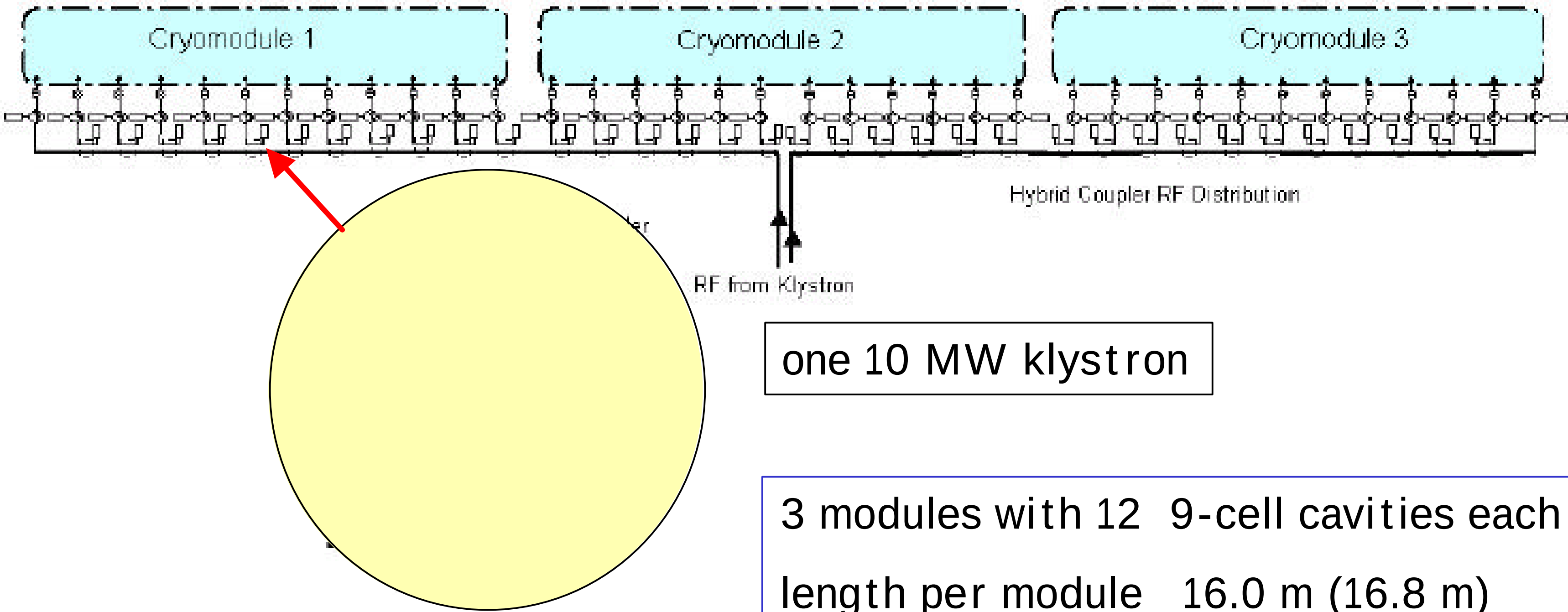
Base line design for 500 GeV, upgrade possibility outlined

- initially operate at an energy of about 500 GeV, to explore the Higgs and related phenomena, and then
- increasing the energy to 800-1,000 GeV, to more fully explore the TeV energy scale.

Assuming that cavities will reach 35 MV/m:



Basic Unit of the Main Linac (5 - 250 GeV)



one 10 MW klystron

3 modules with 12 9-cell cavities each

length per module 16.0 m (16.8 m)

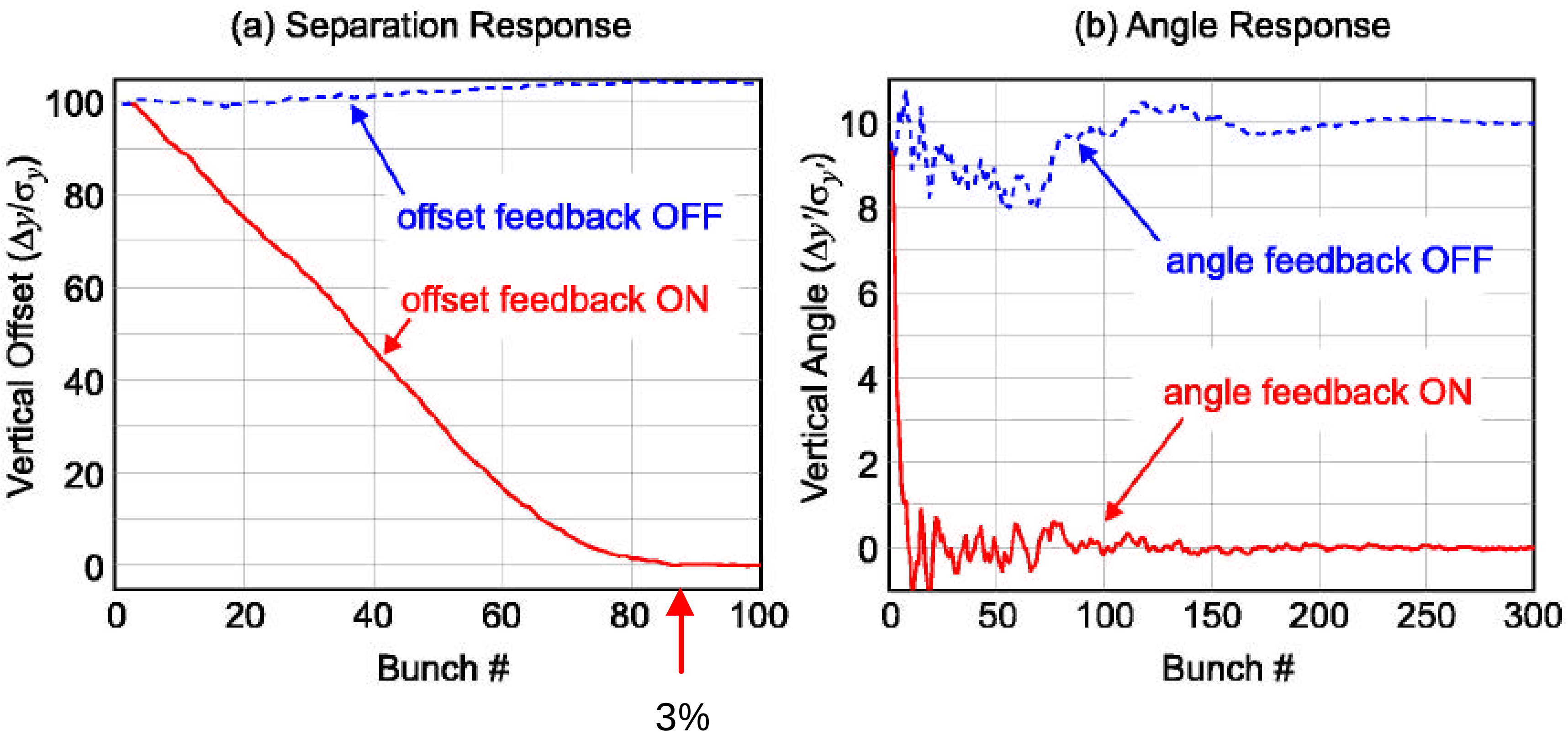
per linac:

- 858 modules (12 cavities)
- 286 klystrons, providing 2% energy overhead @23.4MV/m
- total length 14.4km (fill factor 74%)

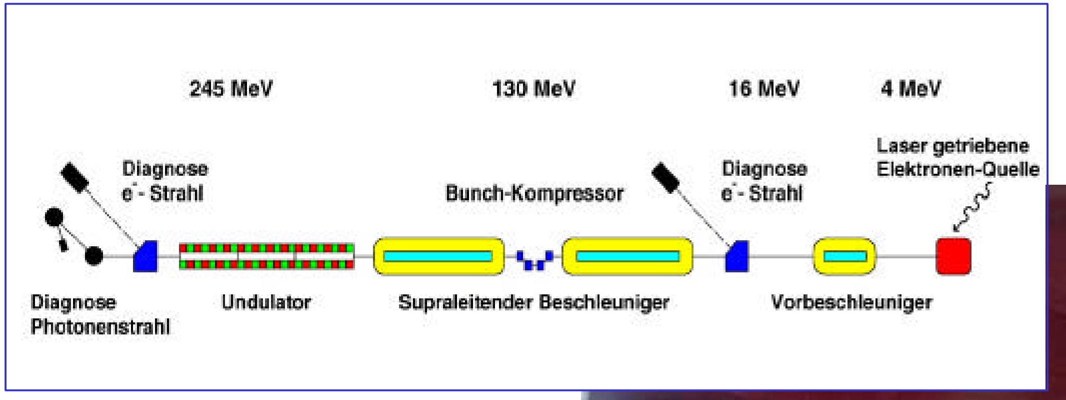
Fast Feedback Kicker

Long bunch trains, large time gap between bunches:

Feedback system within bunch train to stabilise the luminosity



The TESLA Test Facility



Construction of a prototype accelerator:

Tasks:

Test of all components

Operation for > 13 000 h

Base for costing

Proof of laser

Conclusion:

The technical readiness has been demonstrated

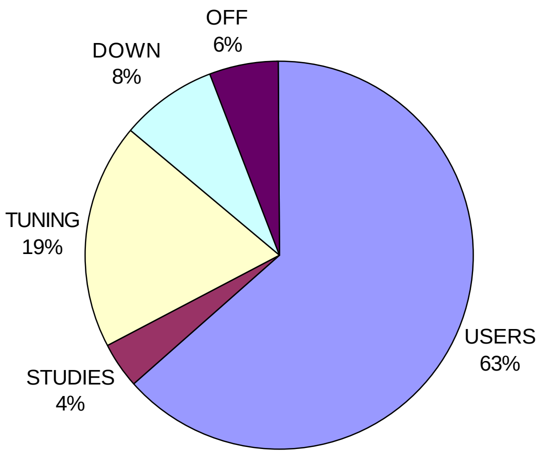
TESLA

TTF Operation for Experiments and Beam Studies

Overview of TTF Operation from August 2001 to May 2002:

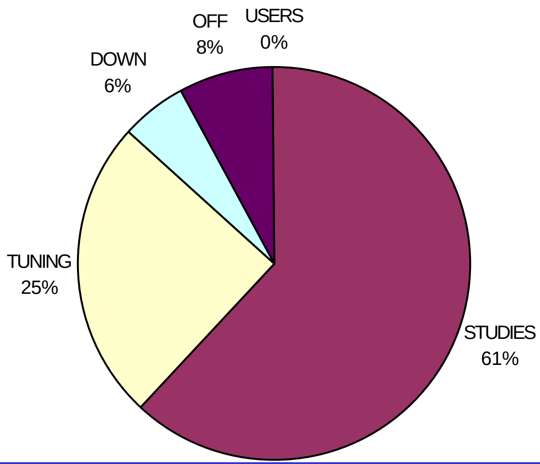
Total hours of operation: **4080**

Beam Uptime = hours allocated to the users, accelerator studies, and overall tuning: 89% (after October 2001)



FEL experiments

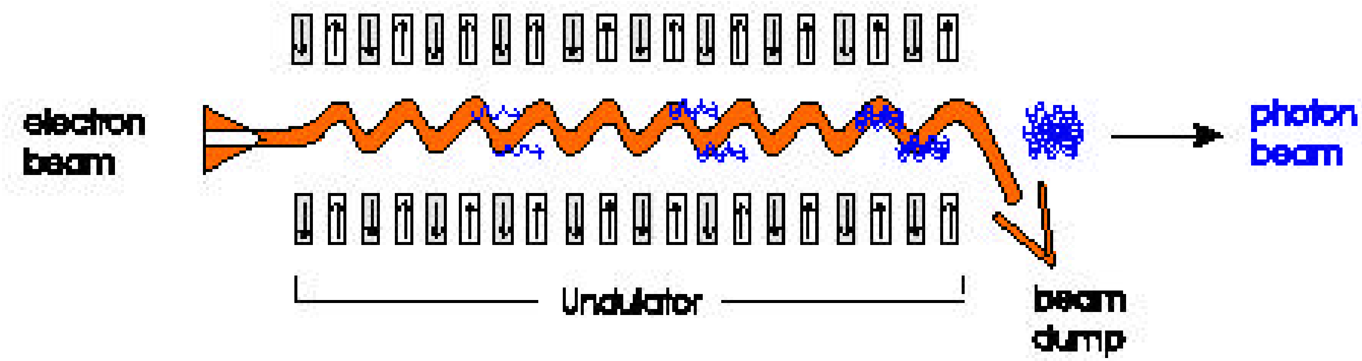
14.01.02 - 20.01.02



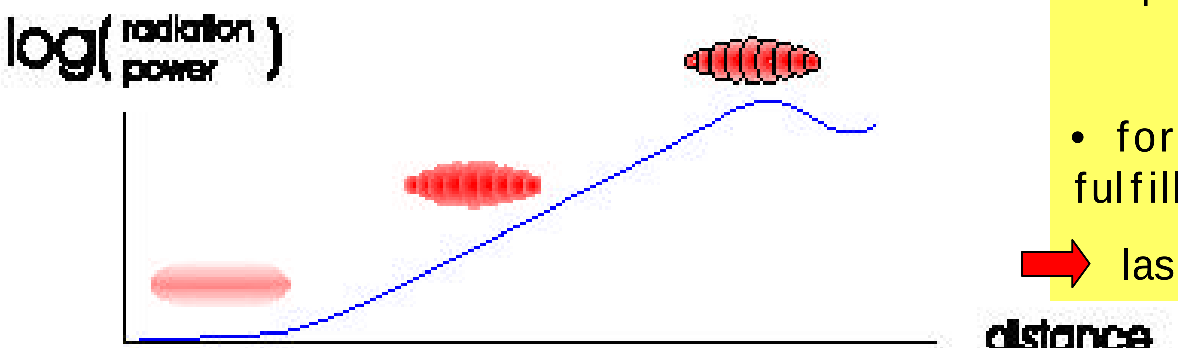
Linac studies

11.02.02 - 17.02.02

SC Linac as Base for an X-FEL

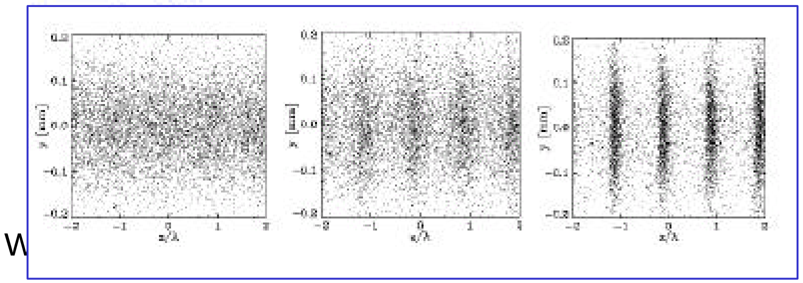


Self
Amplified
Spontaneous
Emission
(Kondratenko, Saldin 1980)



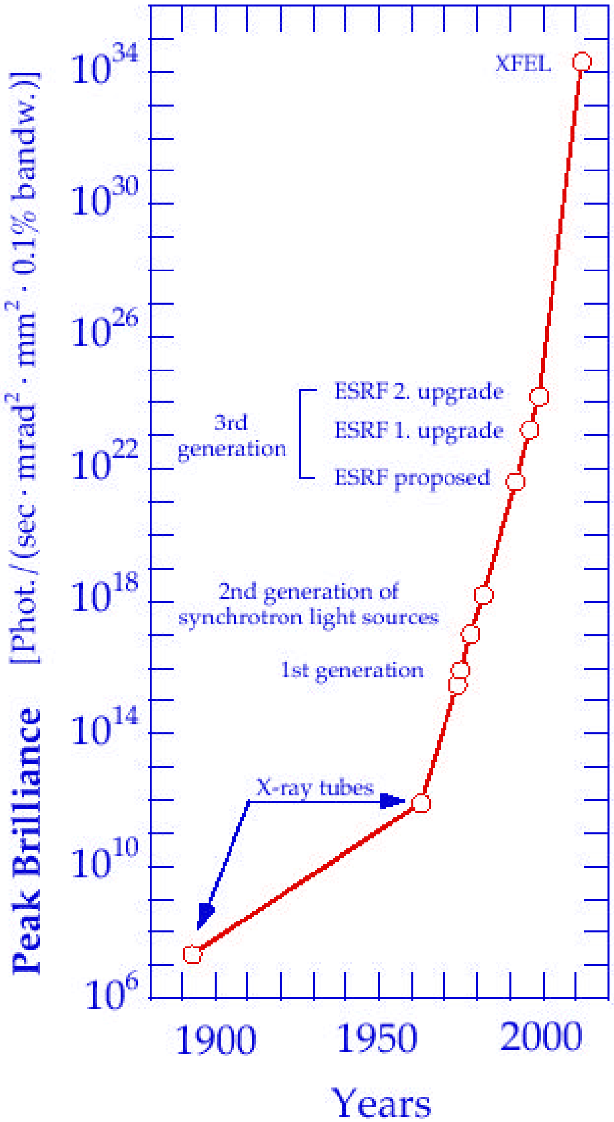
- Spont. Emission
- for certain wave lenghts, fulfilling a resonance condition

➡ lasing



requires small emittance electron beam

Properties of the X-ray Laser



- Wavelength of atomic dimensions

  > 0.1 nm
- Highest brilliance

  ~ 10^9 times that of sources of the 3. generation
- Very short pulselength

  100 fs
- Tunable in wavelength
- Coherence

Synchrotron radiation power P of an incoherent electron distribution: $P \sim N_e$

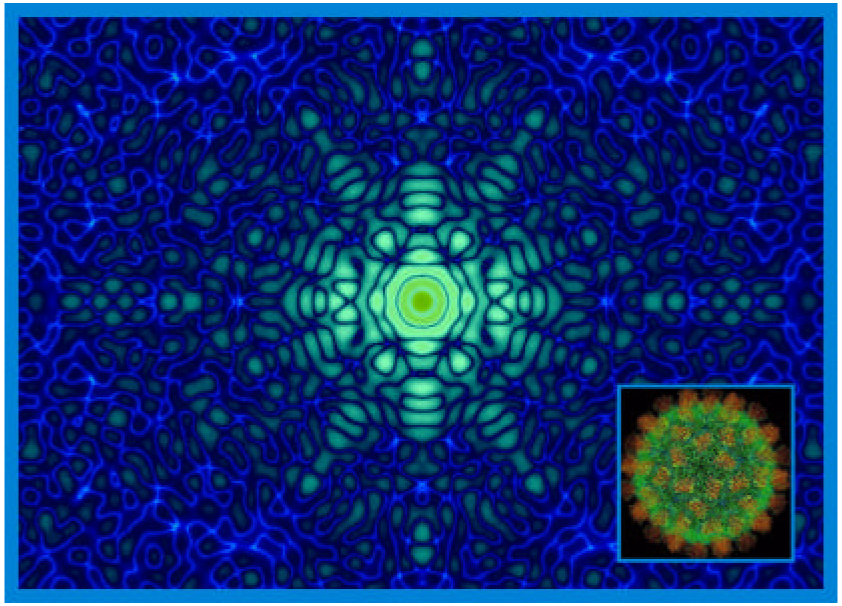
Radiation from a point charge (bunch length < $\lambda_{radiation}$): $P \sim N_e^2$

Gain: $\sim N_e = 10^9 \ldots 10^{10}$

Scientific Applications of a 0.1 nm Laser

The applications make use of the different features of the laser

- Atomic and molecular physics
- Biology
- Chemistry
- Material science
- High field- and plasma physics



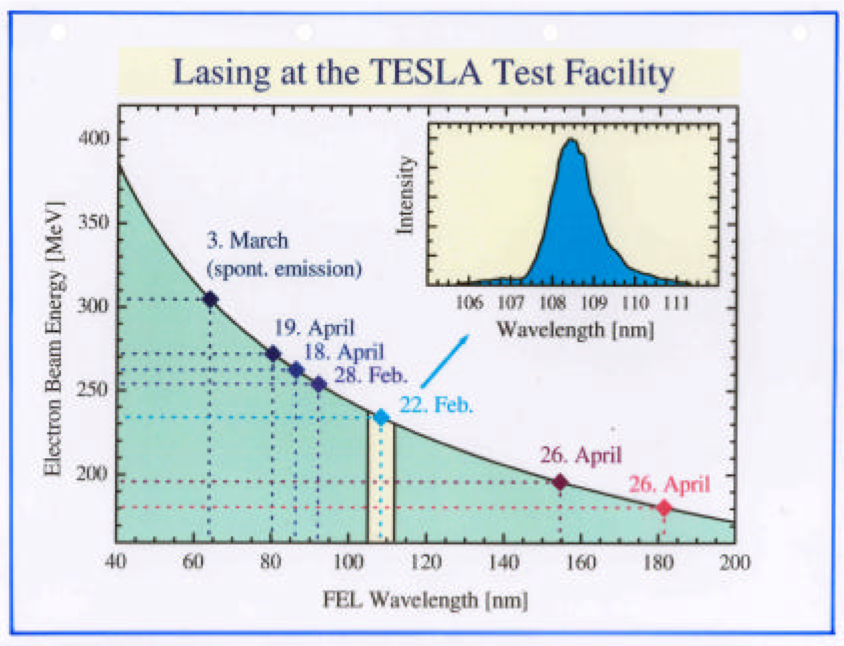
movies of chemical reactions

real-time studies of formation of condensed matter

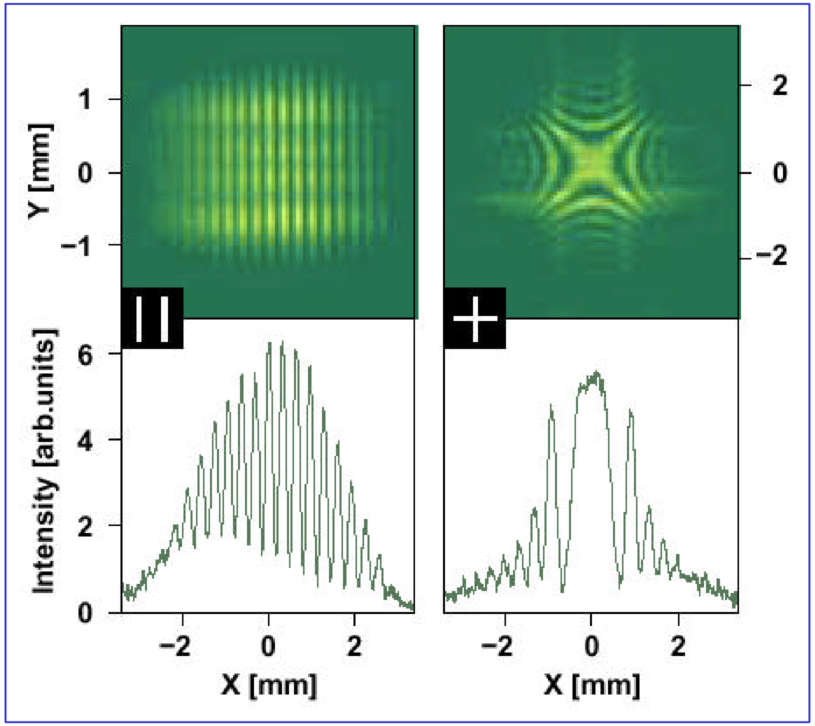
imaging of bio-molecular assemblies with atomic resolution

Key role for pump-and-probe experiments

Tunability and Coherence



$$l \propto 1/E^2$$



→Transverse coherence

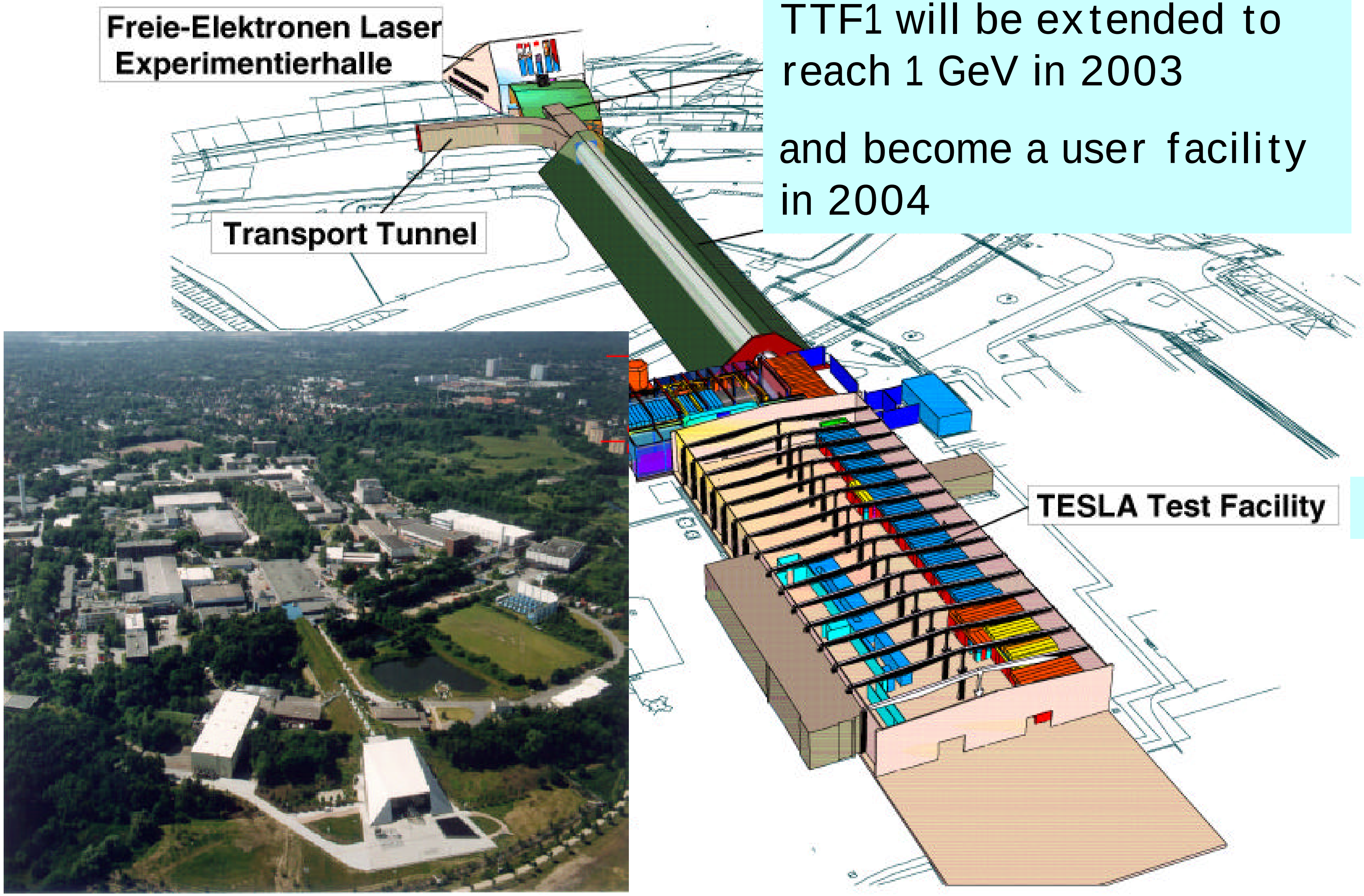
Also seen in opening angle of radiation at saturation

Slit distance: 3 mm

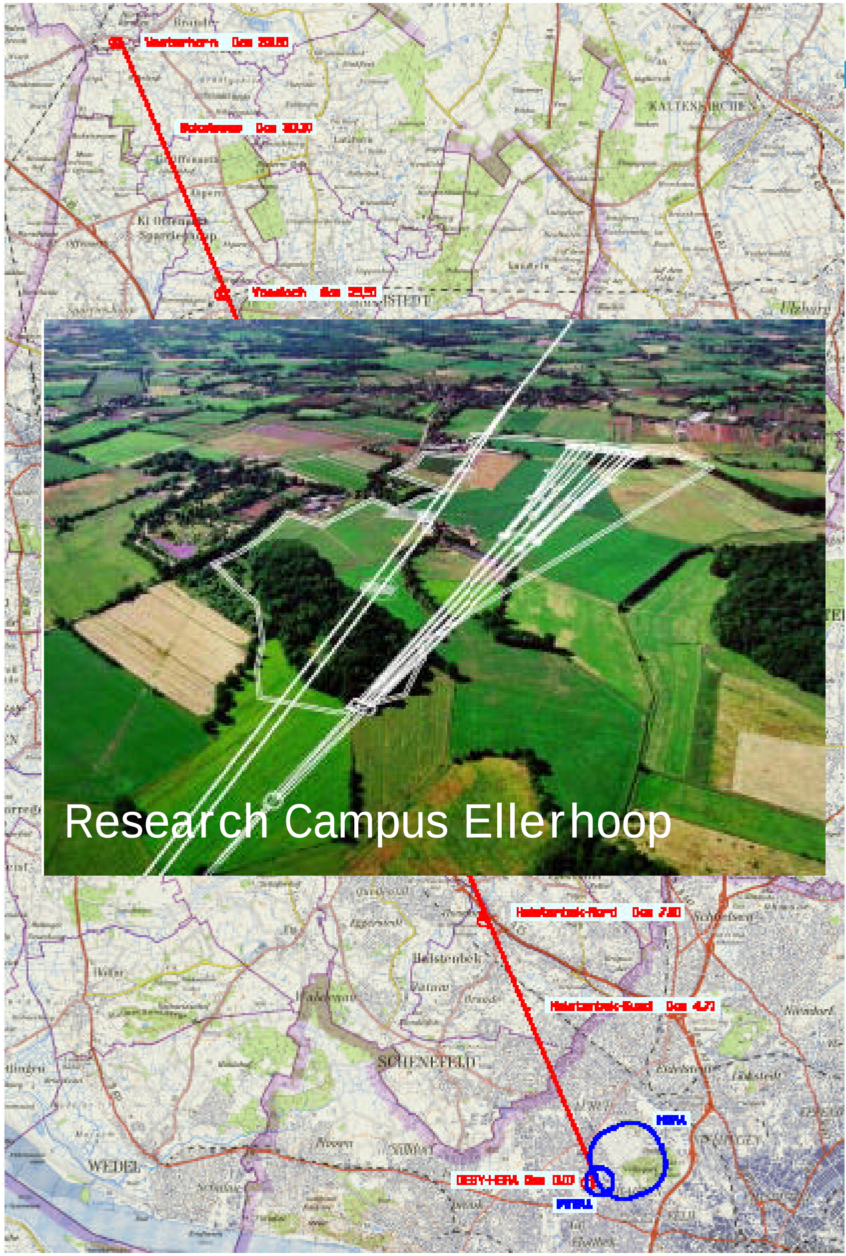
TTF2 VUV FEL

TTF1 will be extended to reach 1 GeV in 2003

and become a user facility in 2004



TTF1



Site Planning Status

Agreement between the states Schleswig-Holstein and Hamburg for joint legal procedure

Environmental impact study is completed. It includes evaluations of

- noise protection
- electromagnetic pollution
- radiological risks
- hydro-geology

We prepare to start the legal procedure required for an implementation at the site in November 02, as part of the overall feasibility study

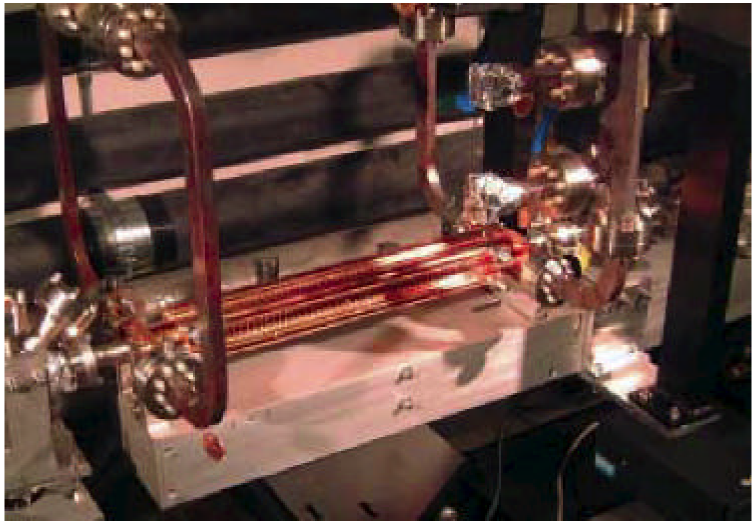
Other Linear Collider Projects

The following other collider projects are in under study:

At Stanford Linear Accelerator Centre: NLC

At KEK: JLC

Both use higher RF frequencies operated at room temperature.



Technical Review Board is active

Goal:

- critical review of all features of the different technologies
- No recommendation on technology
- Experts learn details about alternate designs (basis for collaboration)

Oral report due in Oct 2002

How to Realise Big Accelerator Projects?

Global Accelerator Network

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

- 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
- Project of limited duration (~ 25 years)

Important to work out the detailed management issues

TESLA

Enabling Future Large Projects

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

- 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

- make new projects attractive for young scientists, who can contribute to and participate in large, unique projects make site selection less important and controversial

- make site selection less important and controversial

GAN

Remote operation will very likely be of key importance for the future operation of large facilities.

Key issues:

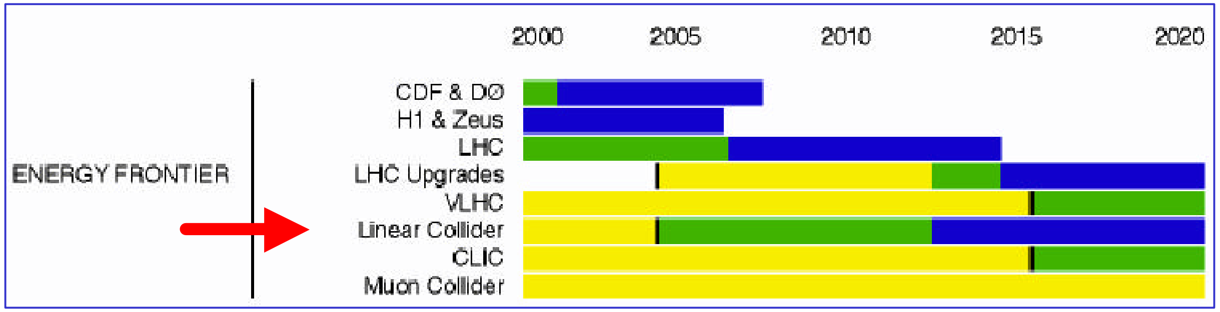
- social aspects
- identify exciting issues, challenges

Tests in this area are ongoing or planned (TTF, A0, LINX, PI3...)

The GAN workshop series is an important start for an in-depth study of the critical issues and for real experiments

The Road Map towards the LC

We must keep the time line in mind in our next steps:



The synergy between the LHC and the linear collider argues for an early start. The linear collider should be ready to begin construction in 2005.

Need to converge towards one project soon to meet challenges

International technical review helps to clarify issues, but will not provide a recommendation

What can we do to be able to begin construction in 2005?

TESLA

OECD Consultative Group

Principal Conclusions Regarding the Road Map:

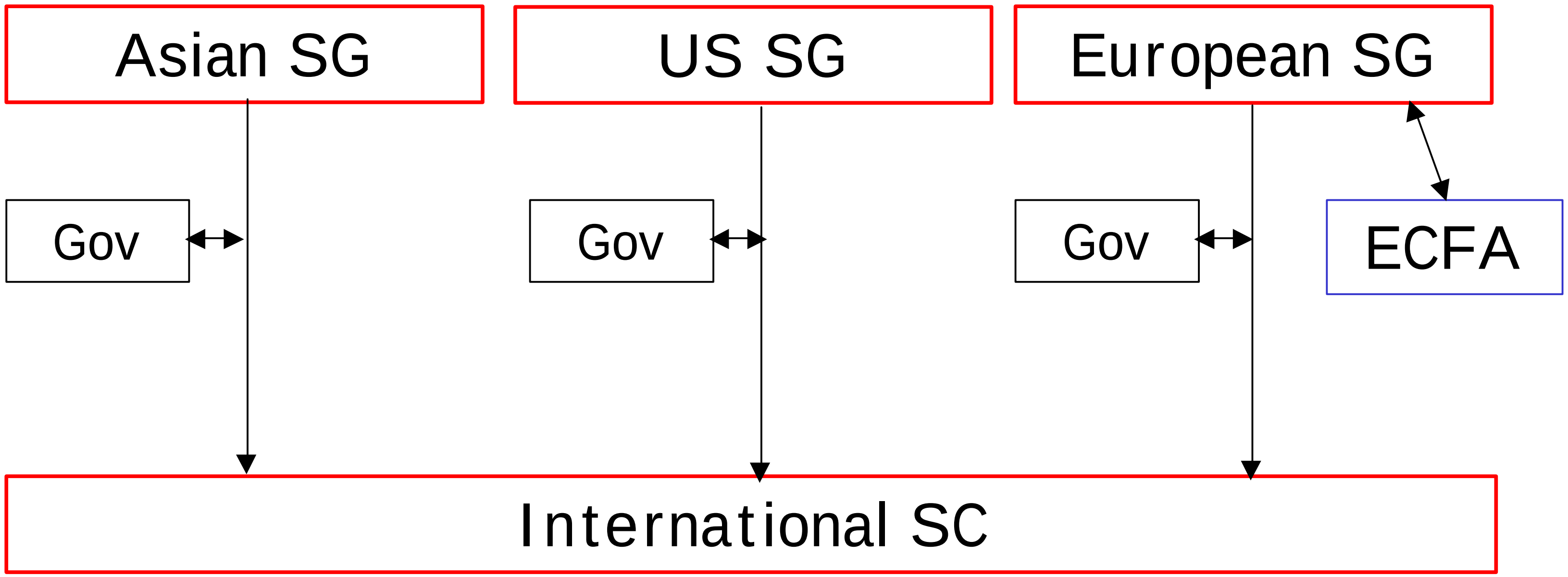
- The Consultative Group concurs with the world-wide consensus … that a high-energy electron-positron linear collider is the next facility.

- There should be a significant period of concurrent running of the LHC and the LC, requiring the LC to start operating before 2015. Given the long lead times for decision-making and for construction, consultations among interested countries should begin at a suitably-chosen time in the near future.

- The cost of the LC will be broadly comparable to that of the LHC, and can be accommodated if the historical pattern of expenditure on particle physics … l resources that … ide.

Proposal by GSF to continue the group in one form or the other after summer 2002

ICFA initiative:



WR-Statements concerning the LC

Evaluation of TESLA by the German Science Council (Wissenschaftsrat)

The scientific questions addressed by the Linear Collider TESLA promise an exceptionally high gain in knowledge for fundamental questions of the micro- and macro cosmos. ...

... The general feasibility of the superconducting accelerator technology has been convincingly demonstrated by the TSLA Test Facility, operated at DESY. ...

The Wissenschaftsrat asks the Federal Government,
after the submission of a project proposal which is more concrete in terms of international financing and international cooperation
to make as soon as possible a binding commitment for a German contribution

WR-Statements concerning the X-FEL

Due to the high brilliance and time resolution of the X-FEL one can expect a new quality of experiments in many fields of natural sciences, life science, geo-science and material science. The high coherence of the photon beam allows for the first time the complete analysis of structural and dynamic properties of matter ...

... Key theoretical and experimental developments as well as major technological innovations have been made at the TESLA Test Facility and more are to be expected.

The Wissenschaftsrat asks the Federal Government,

after the submission of a revised project proposal

to make as soon as possible a binding commitment for a German participation in the TESLA X-FEL.

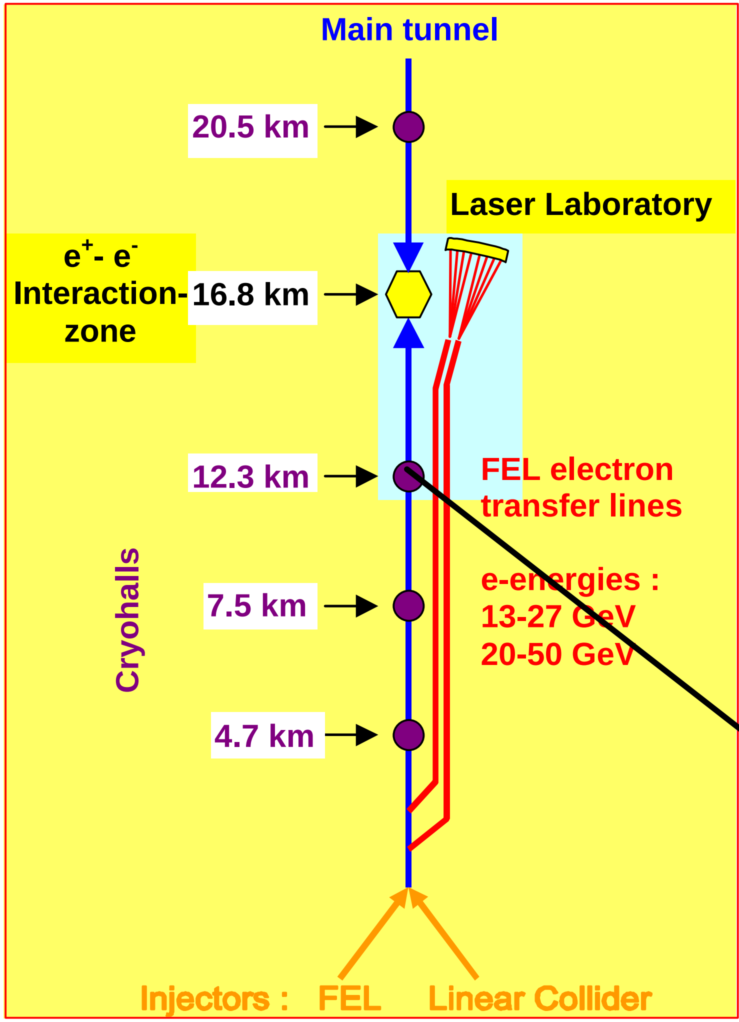
TESLA

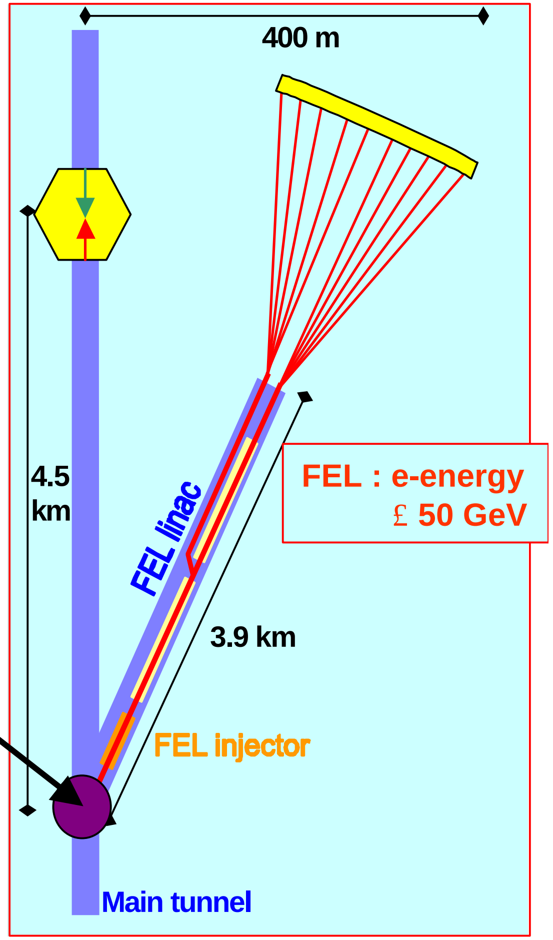
The X-FEL

TDR:

Collider and FEL use jointly the first section of the SC linac.

Following the recommendation by the Science Council, the planning is based on separate linac for X-FEL, using same technology and infrastructure





New scheme for implementation

Conclusions X-FEL

A new laser principle has been fully verified down to 80 nm, an important step towards X-ray lasers (0.1 nm) with very high peak brilliance, < 100 fs pulse duration

Many fields of science will enormously benefit

Superconducting technology is very well suited to serve as driver for an X-FEL laboratory

There will be more than one X-FEL facility around the world, probably one per region

Close collaboration between US and Europe, will expand much further

A German international review (German Science Council) gives the project very good marks

In Germany: Scientific recommendation on XFEL in 2002/3

Political decision expected in 2003

Conclusions LC

In particle physics a world consensus has emerged that a LC has the highest priority and should overlap with the LHC

As a result of a strong international collaboration, superconducting technology provides excellent experimental conditions and is mature and cost effective, an international Technical Review is looking at all LC technologies

The international community has set up a LC steering committee

New concepts of international collaboration and joint partnership have been developed and are being analysed

A German international review (German Science Council) gives the project very good marks

In Germany: Scientific recommendation on LC in 2002/3

Political decision expected in 2003