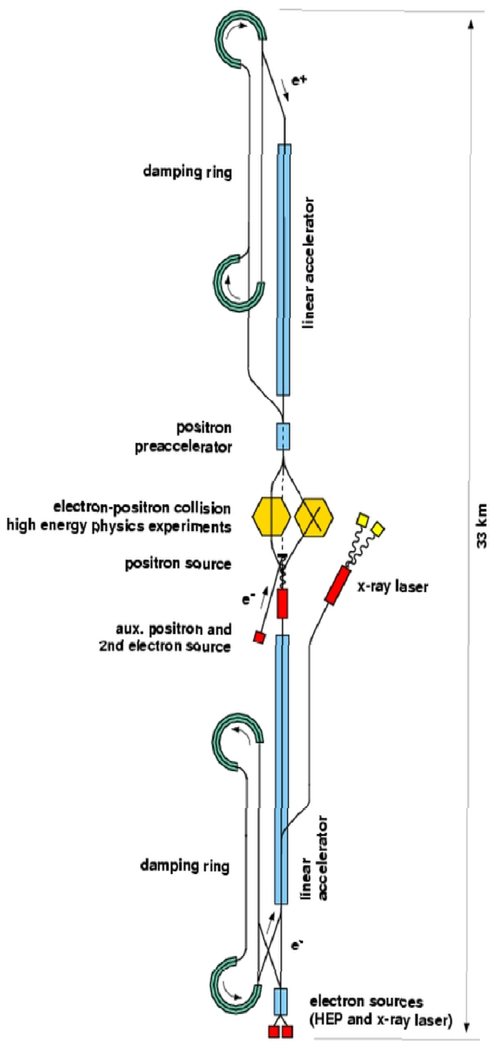
TESLA: The Physics Program

Ties Behnke, DESY Hamburg
28−08−2001

- TESLA: The project
- Particle Physics at TESLA
- Physics with the Free Electron Laser
- The Road to TESLA

The TESLA Project



Max energy 500–800 GeV
$\mathscr{L} = 5\ 10^{33}\ cm^{-2} s^{-1}$

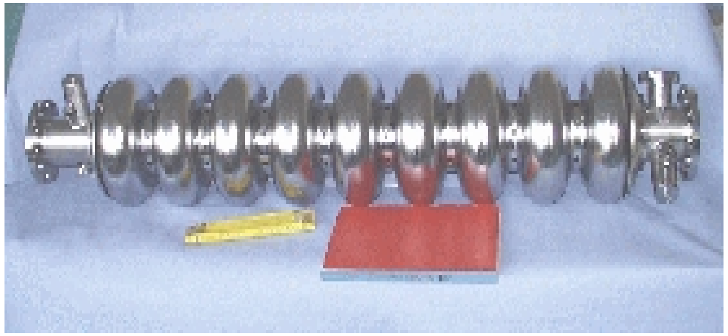
Integrated Luminosity:
$500\ fb^{-1}$ /year

Site length: 33km

Integrated facility for
electron positron accelerator
and Free Electron Laser

TESLA: TDR submitted 3/01

1134 authors from 304 Institutes
in 36 countries



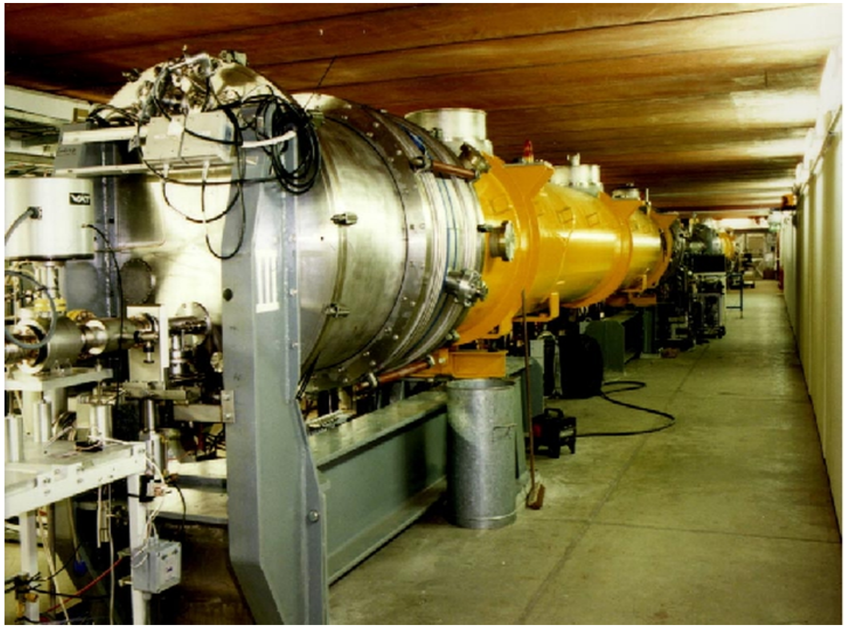
Superconducting cavity:
gradient > 25 MV/m

The TESLA site near Hamburg

TESLA

TESLA

- a machine concept: superconducting acceleration modules
- a collaboration:
  build and operate a test accelerator TTF
- a proposal to build such a machine



The TESLA Test Facility TTFI

The TESLA Collaboration

IHEP
Academia Sinica, Beijing
Tsinghua-University, Beijing

SEFT
University of Helsinki

CEA/DSM
(DAPNIA, CE-Saclay)
IN2P3
(INP Orsay + LAL Orsay)

Max-Born-Institut, Berlin-Adlershof
DESY, Hamburg und Zeuthen
GH Wuppertal
Fachbereich Physik
IAP, University of Frankfurt
GKSS, Geesthacht
FZ Karlsruhe
IfH, TU Darmstadt
ITE, TU Berlin
IKK, TU Dresden
RWTH Aachen III
Uni Hamburg
Uni Rostok
BESSY Berlin

INFN Legnaro
INFN Frascati
INFN Milano
INFN Roma II

Polish Academy of Science
Warsaw (IF PAN)
University of Warsaw,
Inst. of Exp. Physics
University of Cracow (INP)
Univ. of Mining & Metallurgy, Cracow
Polish Atomic Energy Agency, Cracow
Soltan Institute for Nuclear Studies, Otwock-Swierk

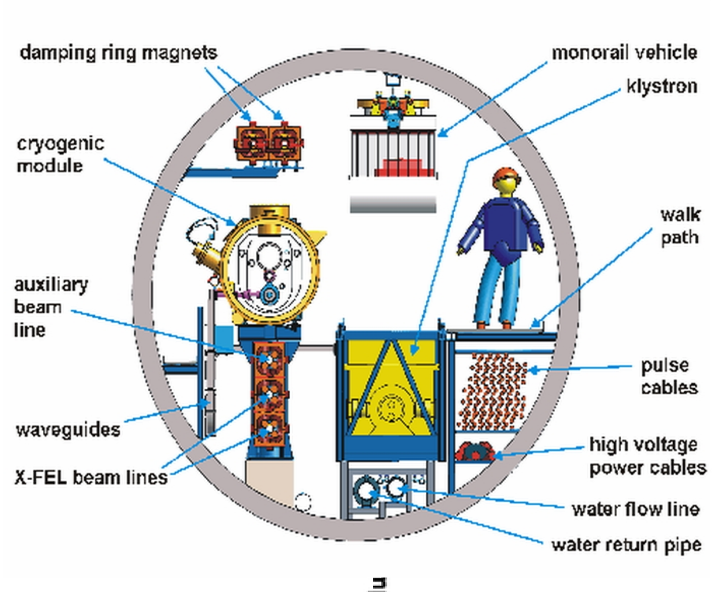
JINR Dubna
INR Troitsk
IHEP Protvino
MEPhI Moscow
INP Novosibirs

Cornell University
Newman Lab. Ithaca NY
Fermilab
Batavia IL
UCLA
Los Angeles CA
ANL

Yerevan Physics Institut

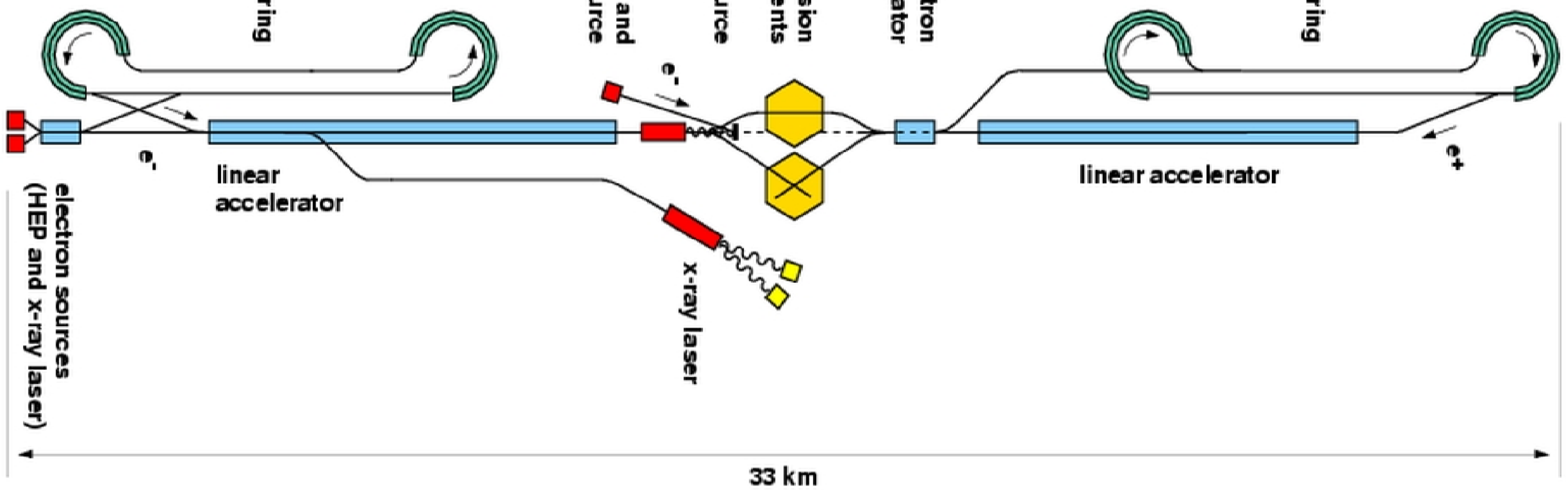
Overall TESLA Layout

TESLA tunnel: diameter 5.50 m



- Overall collider layout:

DESY



TESLA Parameters

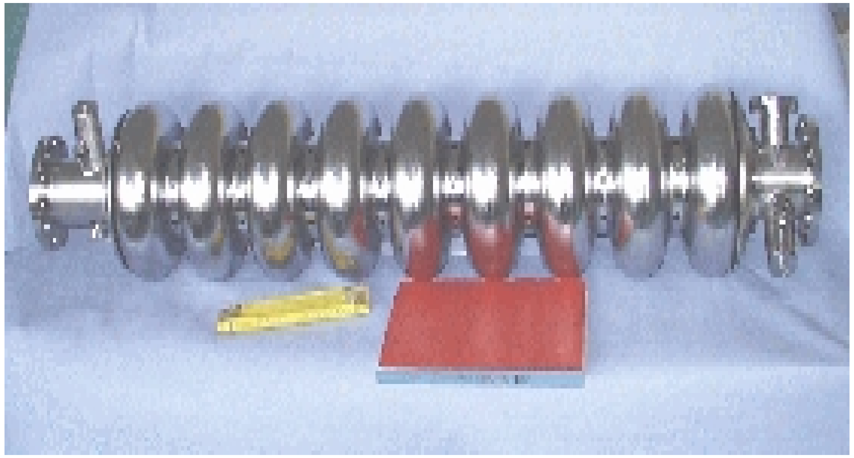
TESLA 500 GeV parameters

		TESLA-500
Accelerating gradient	E_{acc} [MV/m]	23.4
RF-frequency	f_{RF} [GHz]	1.3
Fill factor		0.747
Total site length	L_{tot} [km]	33
Active length	[km]	21.8
No. of accelerator structures		21024
No. of klystrons		584
Klystron peak power	[MW]	9.5
Repetition rate	f_{rep} [Hz]	5
Beam pulse length	T_P [μs]	950
RF-pulse length	T_{RF} [μs]	1370
No. of bunches per pulse	n_b	2820
Bunch spacing	Δt_b [ns]	337
Charge per bunch	N_e [10^{10}]	2
Emittance at IP	$\gamma\epsilon_{x,y}$ [10^{-6}m]	10, 0.03
Beta at IP	$\beta^*_{x,y}$ [mm]	15, 0.4
Beam size at IP	$\sigma^*_{x,y}$ [nm]	553, 5
Bunch length at IP	σ_z [mm]	0.3
Beamstrahlung	δ_E [%]	3.2
Luminosity	L_{e+e-} [10^{34}cm^{-2}s^{-1}]	3.4
Power per beam	$P_b/2$ [MW]	11.3
Two-linac primary electric power (main linac RF and cryogenic systems)	P_{AC} [MW]	97
e^-e^- collision mode:		
Beamstrahlung	$\delta_{E,e-e-}$ [%]	2.0
Luminosity	L_{e-e-} [10^{34}cm^{-2}s^{-1}]	0.47

TESLA 800 GeV parameters

		TESLA-800
Accelerating gradient	E_{acc} [MV/m]	35
Fill factor		0.79
Repetition rate	f_{rep} [Hz]	4
Beam pulse length	T_P [μs]	860
No. of bunches per pulse	n_b	4886
Bunch spacing	Δt_b [ns]	176
Charge per bunch	N_e [10^{10}]	1.4
Emittance at IP	$\gamma\epsilon_{x,y}$ [10^{-6}m]	8, 0.015
Beta at IP	$\beta^*_{x,y}$ [mm]	15, 0.4
Beam size at IP	$\sigma^*_{x,y}$ [nm]	391, 2.8
Bunch length at IP	σ_z [mm]	0.3
Beamstrahlung	δ_E [%]	4.3
Luminosity	L [10^{34}cm^{-2}s^{-1}]	5.8
No. of klystrons		1240
Power per beam	$P_b/2$ [MW]	17
Two-linac primary electric power	P_{AC} [MW]	≈150

TESLA Basic Concept



- superconducting solid Nb cavities
  - E(acc) ~ 25 MV/m, T=2K
- Long RF pulses (~ 1 ms)
  - ➔ low RF peak power (200 kW/m)
  - ➔ long bunch train with large interbunch spacing
- Low RF frequency (1.3 GHz)
  - ➔ small wakefields
- Overall design compatible with E(cms) = 91 .... 800 GeV
  - baseline design and parameters for 500 GeV

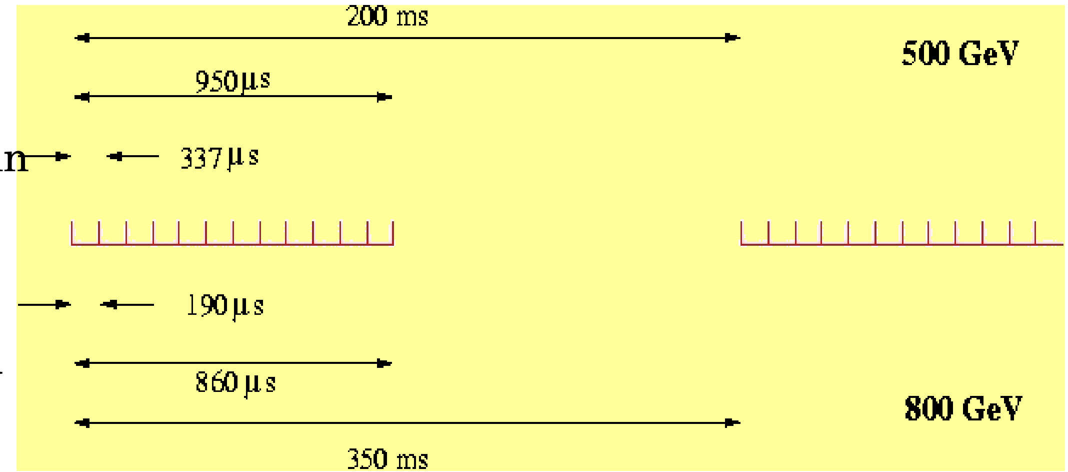
The TESLA acceleration structures:

module geometry	***module length***	***V(acc)***	***Fill factor***	***RF/module***
9−cell structure	1.04	23.40	78.00%	219
4x7 superstructure	3.23	22.00	89.00%	675

TESLA Bunch Structure

- Main characteristics:
  - long bunch trains, even longer times between bunch trains

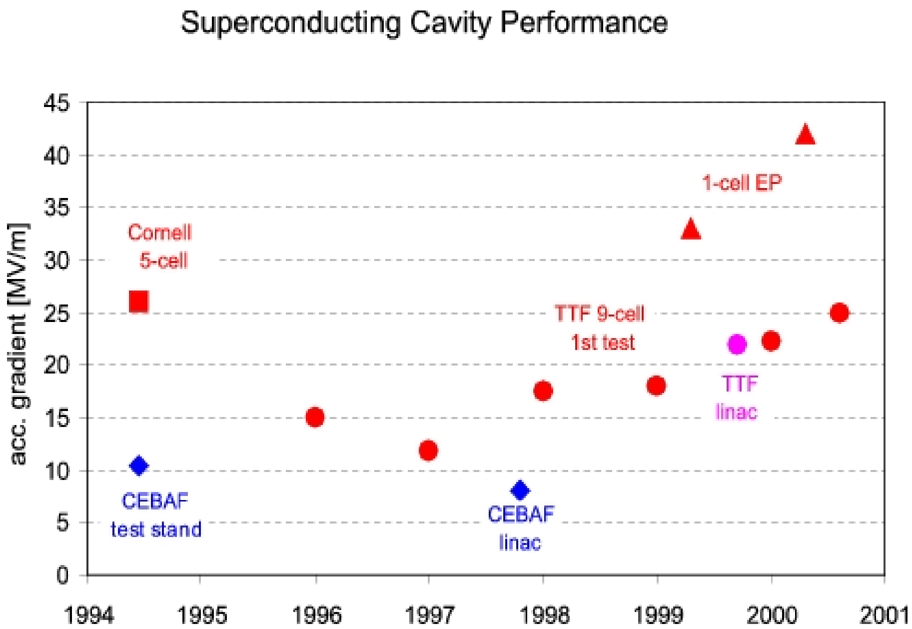
500 GeV	5 Hz x 2820 x 2.0 10^{10}
800 GeV	3 Hz x 4568 x 1.4 10^{10}



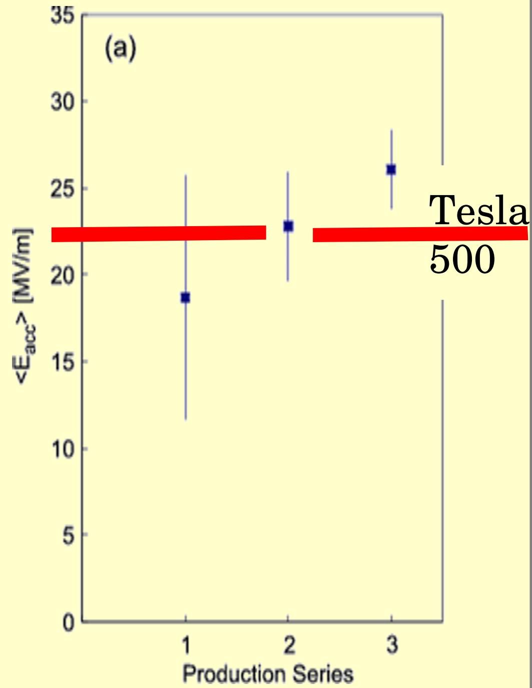
- possibility of orbit corrections within single bunch train (fast feedback system)
- Head on collisions are possible
- Bunch collisions are well separated in detector

Status of Cavities Development

- TESLA Test Facility (TTF) Goals:
  - Phase I:
    - development of acceleration modules
    - proof of principle of operation of SC linac at high (> 22.5 GeV) gradient
    - proof of principle for SASE FEL in the VUV (60 nm)



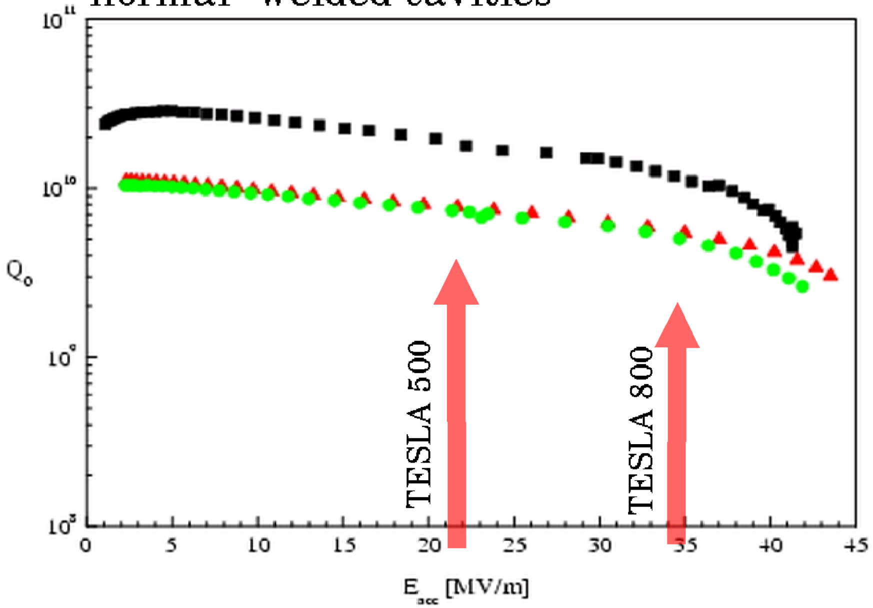
cavity performance per production series



Single Cell Cavities

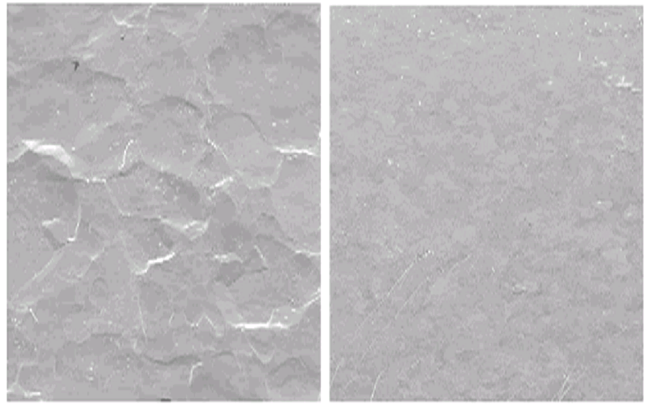
- Further improvement of gradient: electropolishing

"normal" welded cavities

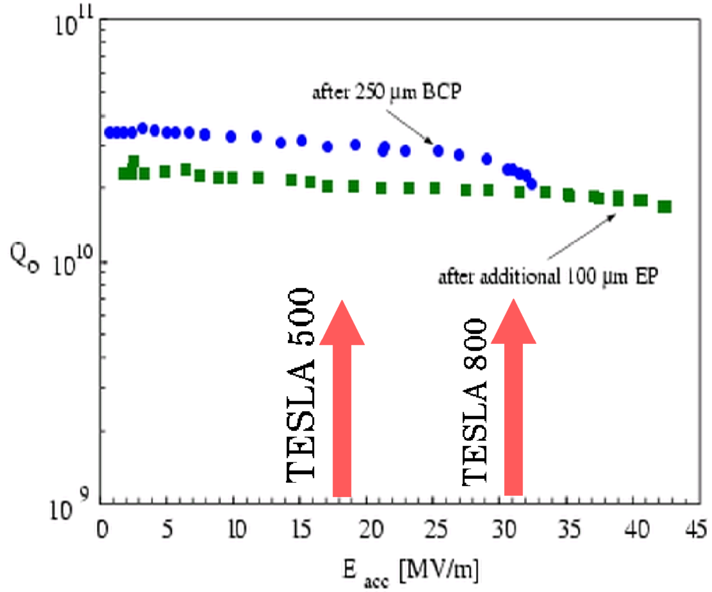


Gradients in excess of 40MV/m
in single cell cavities

Chemically polished Electropolished



Hydroformed cavities:



- Overall development looks very encouraging
- Clear path to larger energies (800 GeV at least)

RF Power: Klystrons

TH 1801 multi beam Klystron

- High power (10 MW peak)
- Low voltage (117 kV)
- High efficiency (65 %)
- Long pulse (1.5 ms)

System has been fabricated in industry

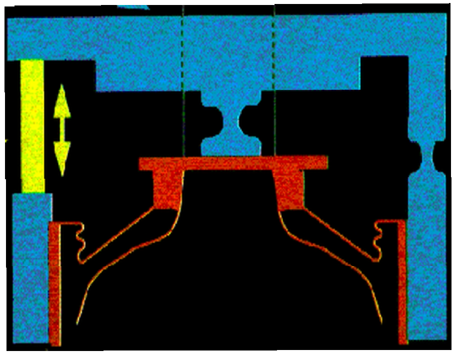
Is now being used at the TTF LINAC

Lorentz Force Deformation

- Problem: Cavity deform under the Lorentz force at high gradient
  - Cavity changes its shape
  - cavity is detuned

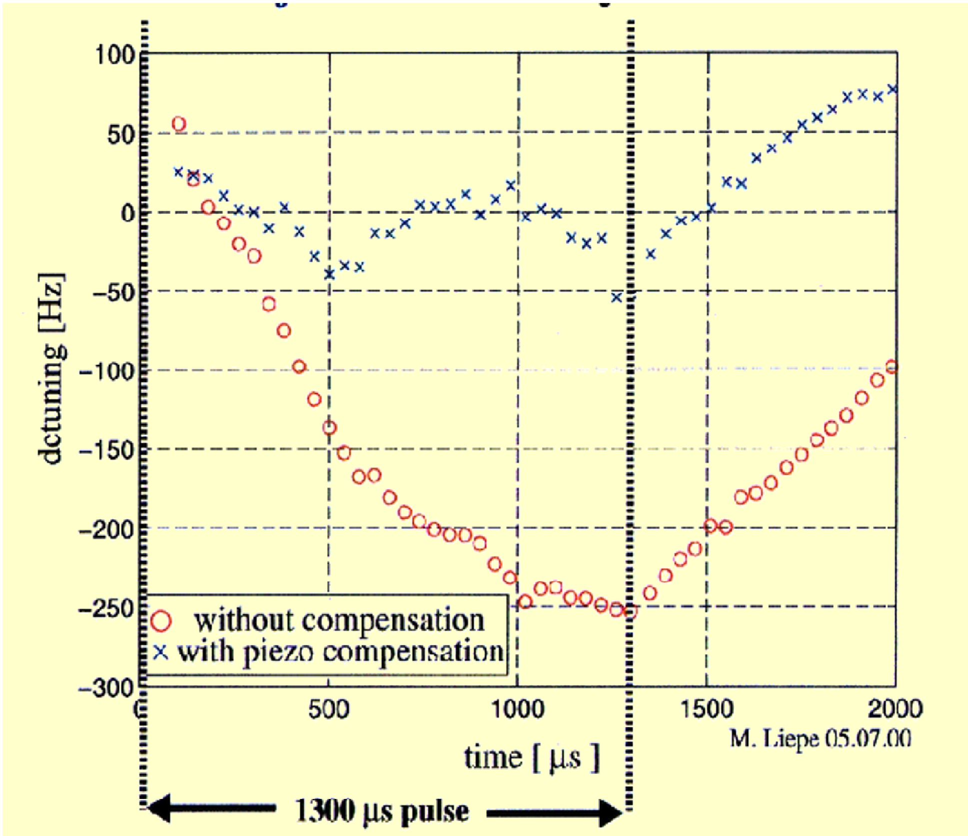
- solution:
  - active compensation using piezo–crystal

l = 39mm
V(max)= 150 V
f(max) = 500 Hz



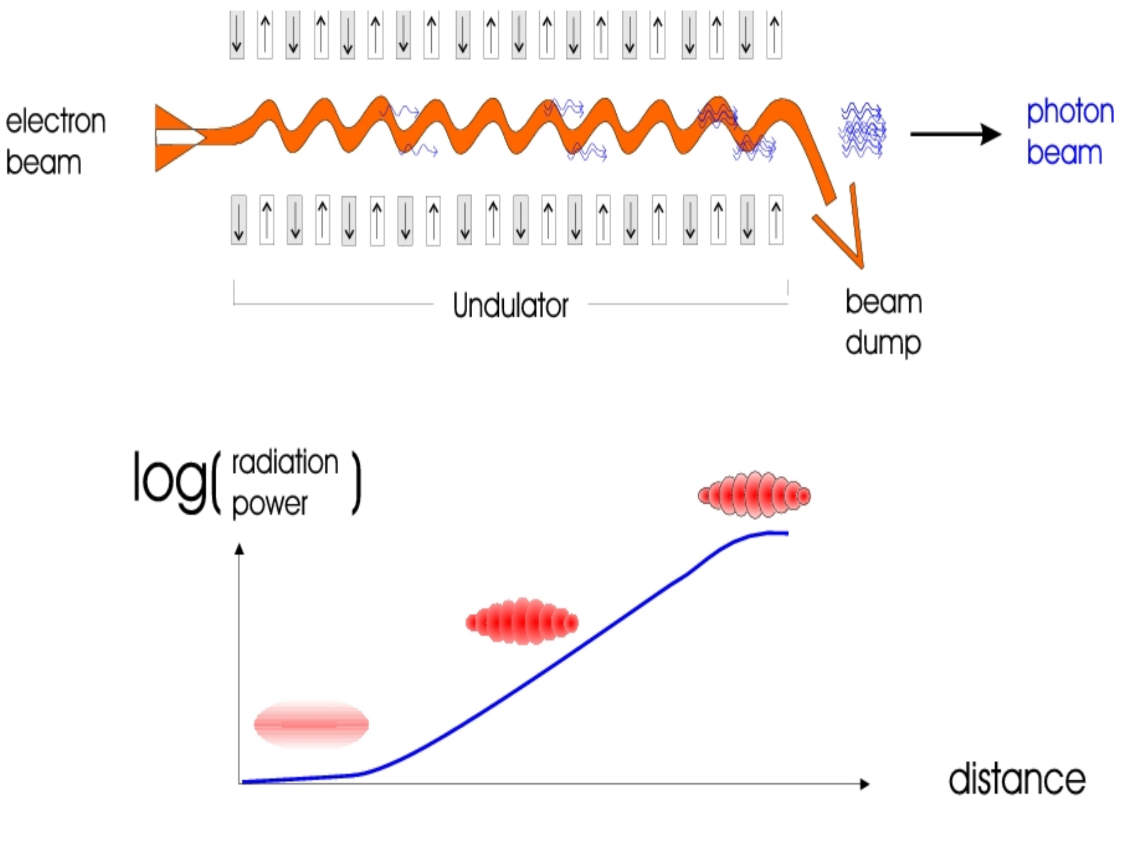
piezo actuator

first successful test on cavity C45 at 20 MV/m



The Free Electron Laser at TTF

- TTF LINAC is used to drive a SASE FEL
  - Goal I: Proof of Principle for VUV FEL
  - Goal II: Operation of user facility after 2003

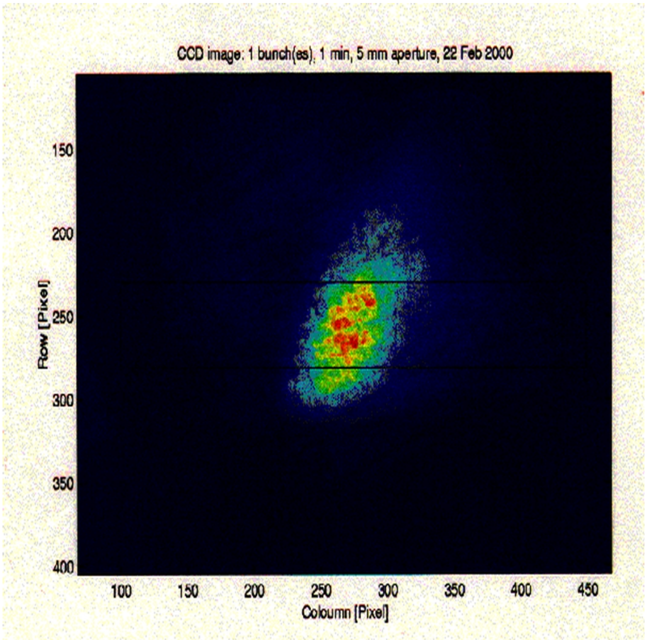


Free Electron Laser in the Self Amplified Spontaneous Emission (SASE) mode

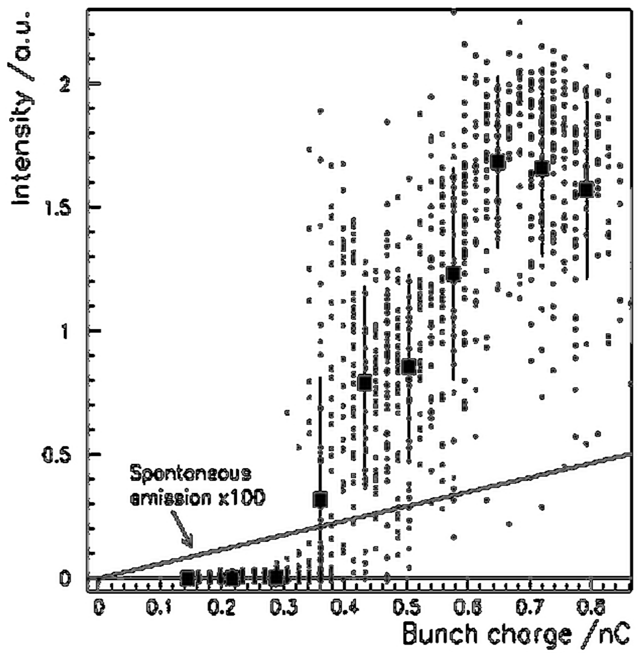
The TTF FEL

- February 2000: observe first lasing at <100 nm
- Since then: systematic studies
  - ➨ very reliable and reproducible behaviour
  - ➨ continuous reduction of the frequency
  - ➨ Main radiation characteristics have been found

CCD image of the FEL beam:



Signal development

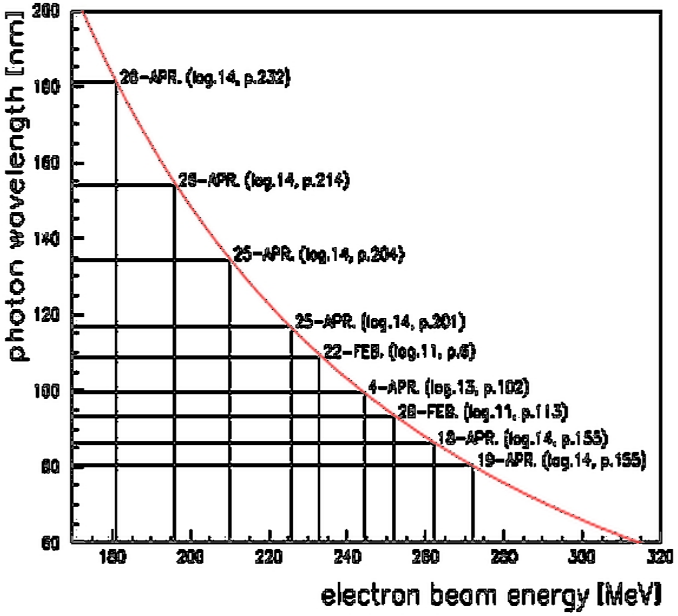


The TTF FEL

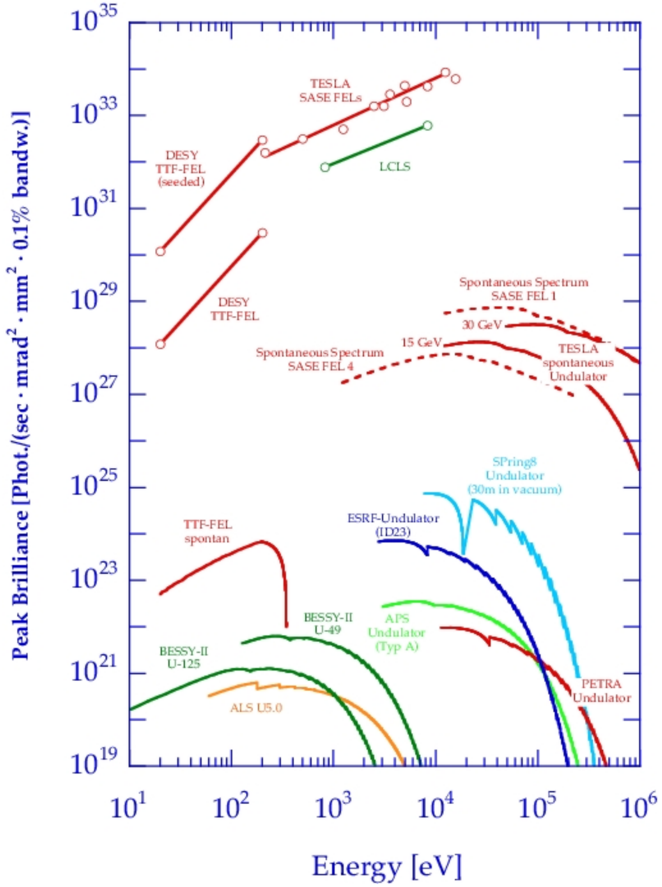
Since observation of first lasing:
continuous further development of the system towards:

Smaller wavelength
better reproducibility
higher brilliance

Development of X–ray energy



FEL operation: brilliance vs energy

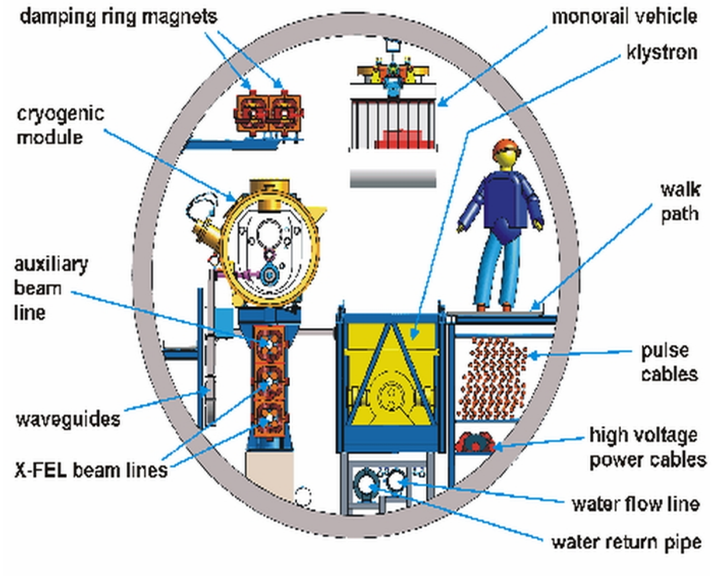


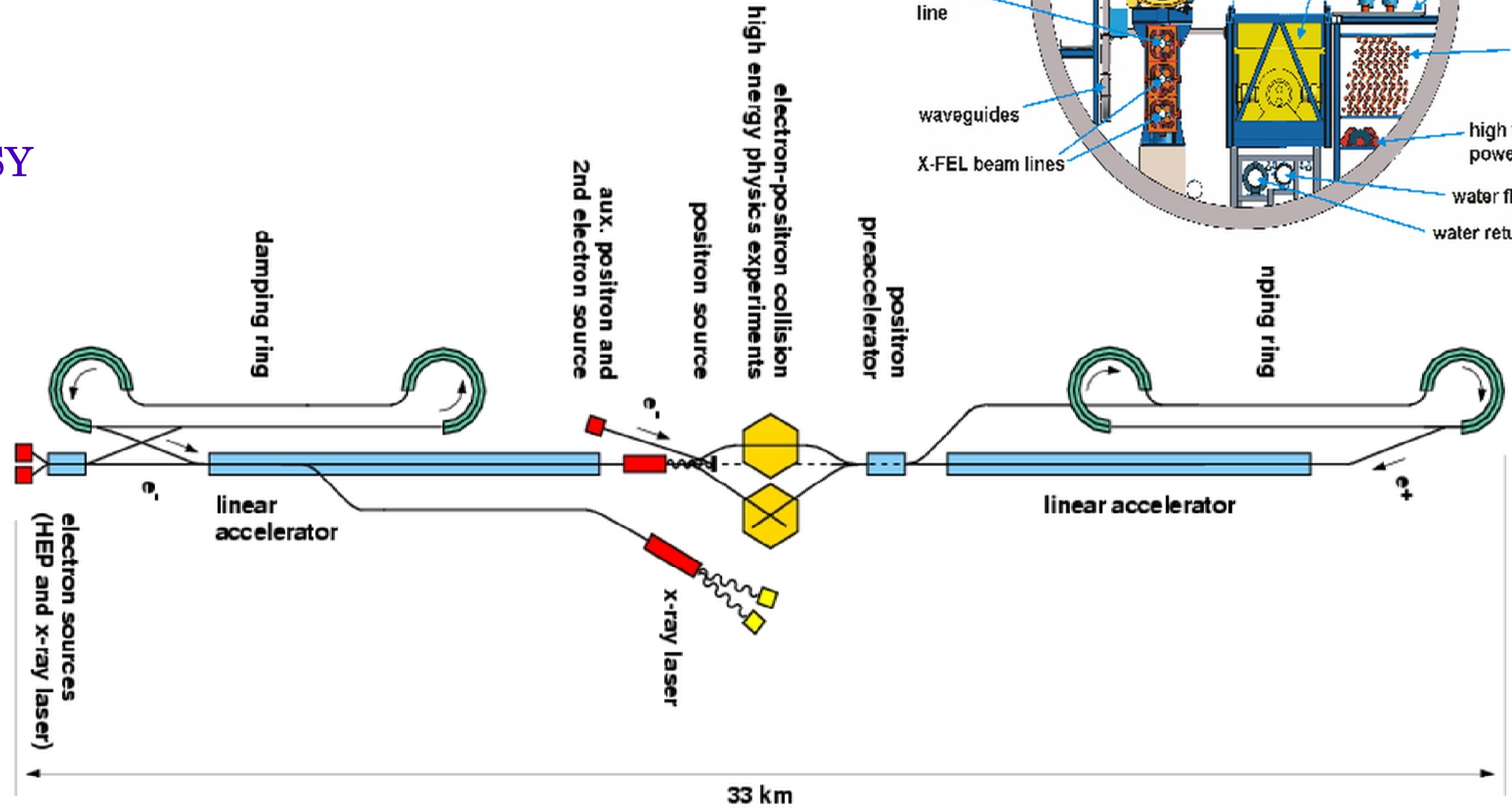
Overall TESLA Layout

- Overall collider layout:

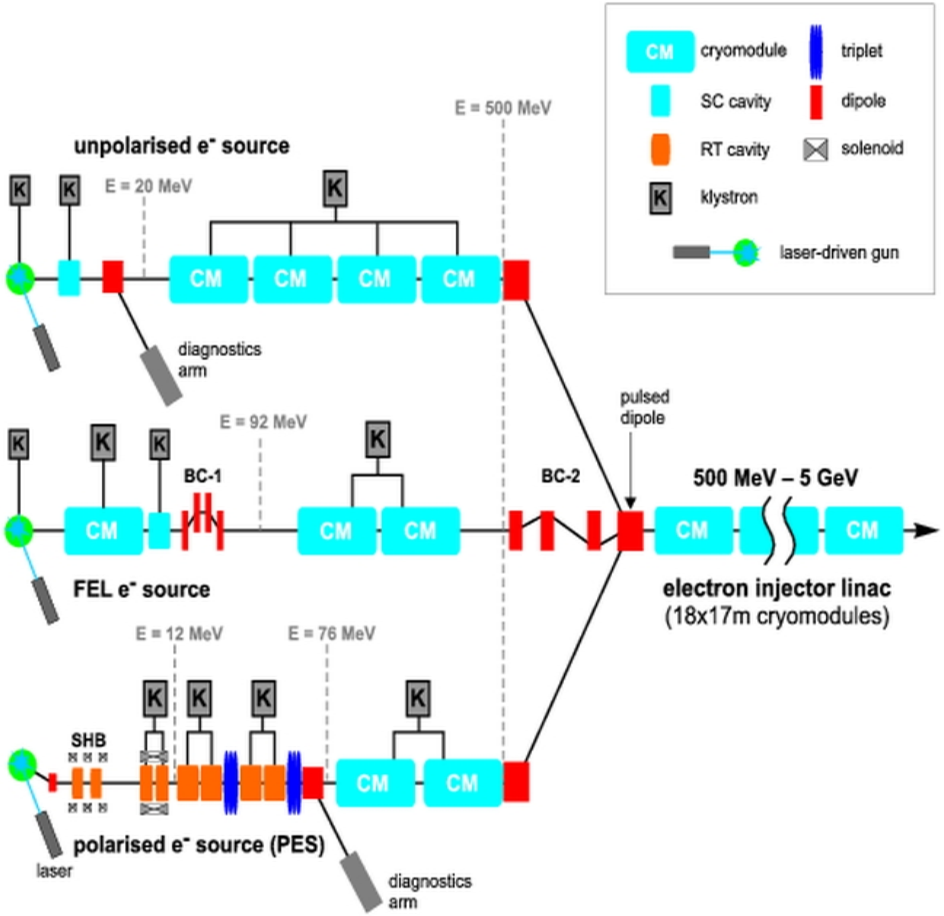
DESY

TESLA tunnel: diameter 5.50 m





TESLA injector complex:

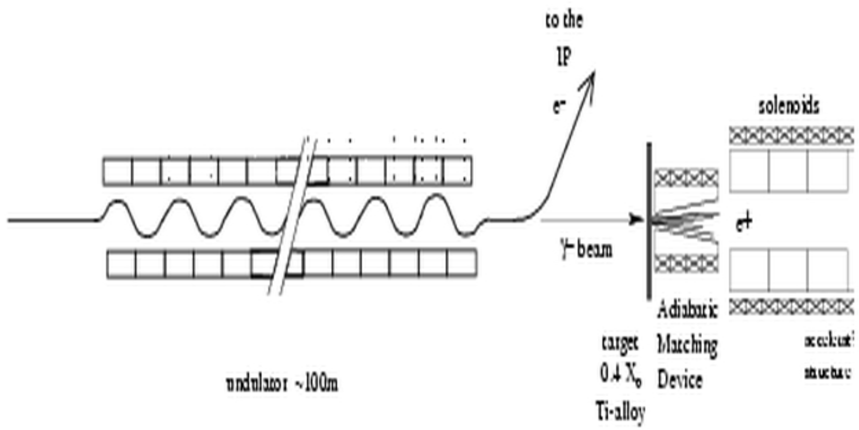


- Laser driven electron guns
- Three separate guns for
  - Unpolarised
  - Polarised
  - FEL beam

- Electron polarisation is part of the baseline program

Collider Layout: Positron Source

- Positron source: use incoming electron beam as a source of photons produce positrons
- Small degradation of quality of beam is acceptable



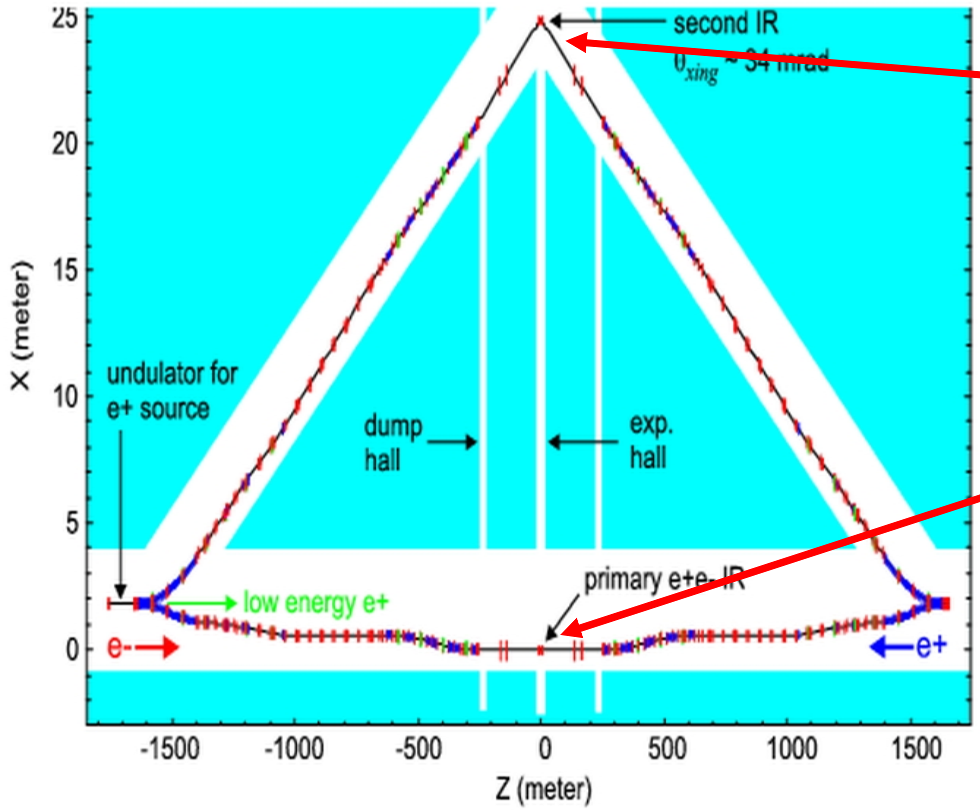
- Allows very high positron currents
- Possibility of positron polarisation

	SLC	TESLA
No of positron per pulse	4.00E+010	5.60E+013
No of bunches per pulse	1	2820
Pulse duration	3 ps	0.95 ms
Bunch spacing	8.3 ms	337 ns
Repetition frequency	120 Hz	5 Hz

- Expected positron polarisation: between 45 and 60% at (nearly) full intensity
- Need to build a helical undulator (technologically challenging)
- Positron Polarisation is not part of the baseline design

The Interaction Region

Conceptual layout of the interaction region(s):



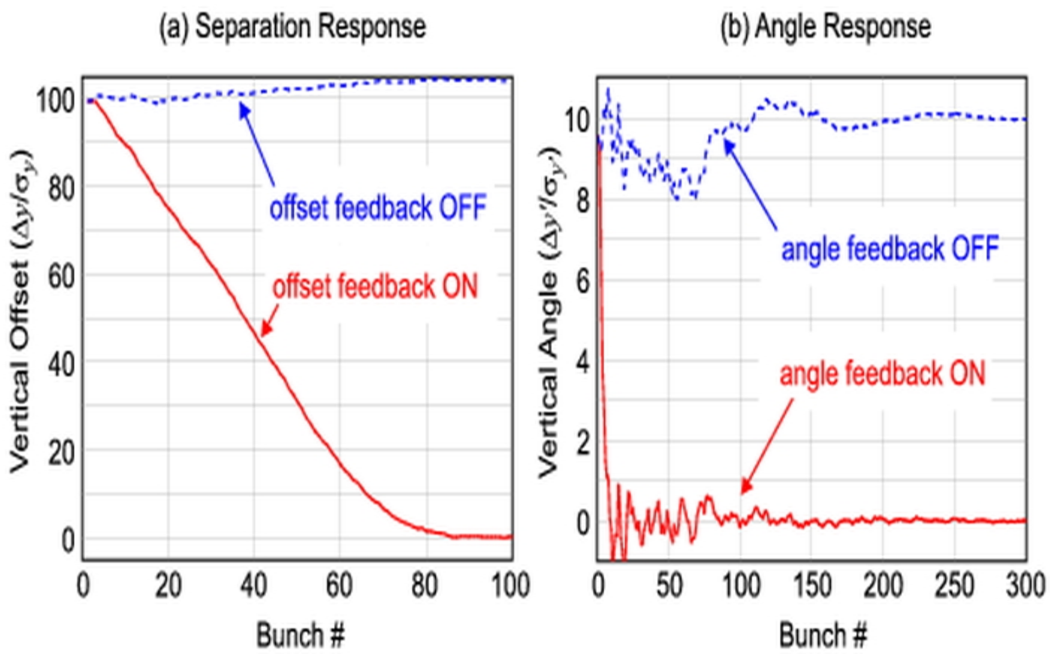
2. IR not part of baseline design

IR for gamma gamma
electron gamma
electron electron
electron positron
34 mrad crossing angle

IR for primary electron positron program (or electron electron)
no crossing angle

Fast Feedback at the IP

- Long bunch trains, long times between bunches:
  - ➡ Feedback system within bunch train possible to stabilise the luminosity

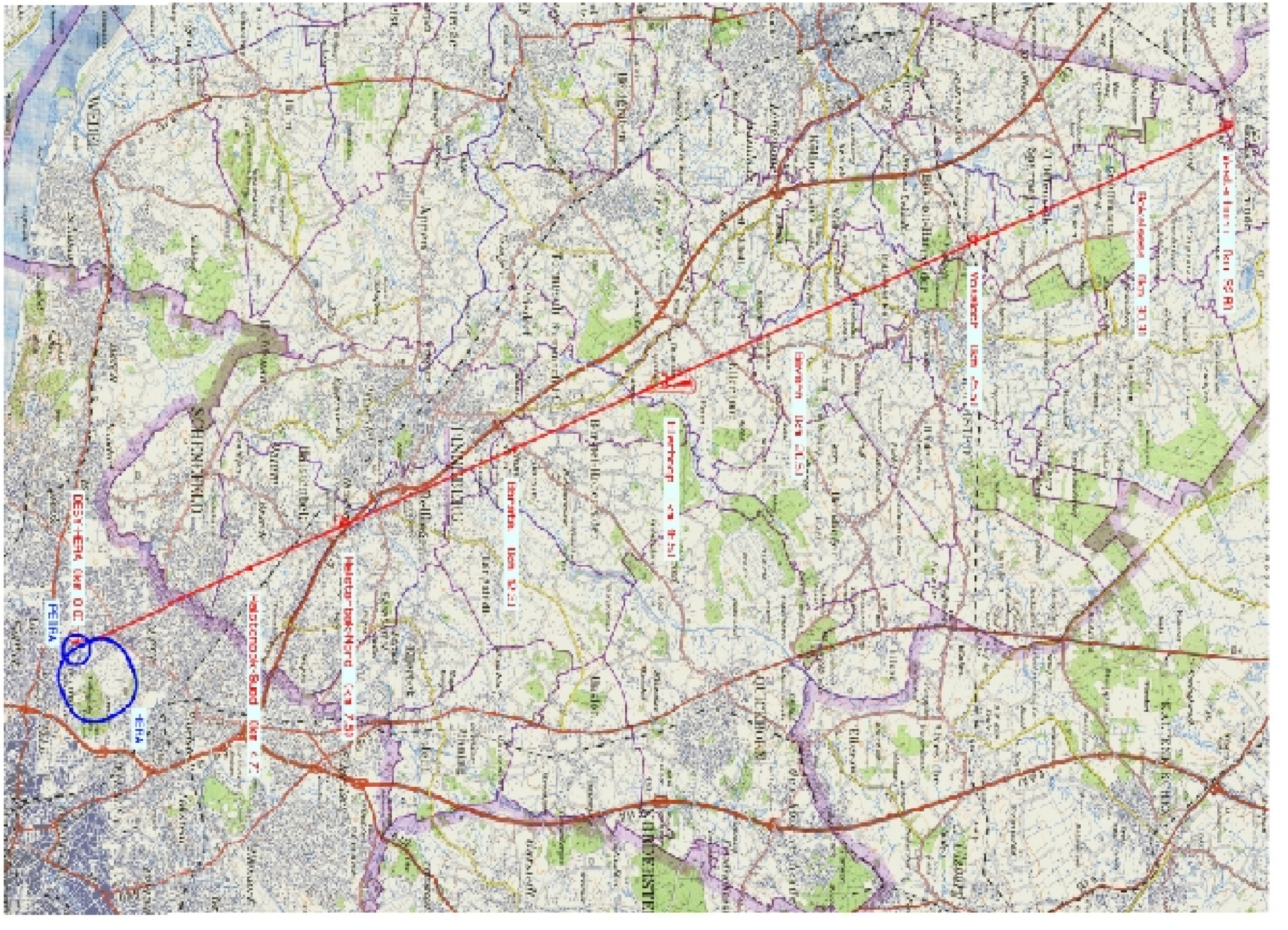


- Act on angle
- Act on offset

- After about 90 bunches: reduction by factor 1000

- Train to train tolerance of final doublet limiting the luminosity loss to 10%: 200nm

A TESLA Site near Hamburg



Summary TESLA Collider

- The TESLA collider is in a rather good state:
  - technology is in hands
  - serious industrial studies about production have been finished successfully
  - so far no major show stoppers have been found

  - of course many detailed technical question still need to be solved
  - the energy upgrade potential needs to be firmed up:
    - 800 GeV seems do–able already now, though more cavity development is needed
    - beyond 800 GeV up to 1 TeV seems in reach if better cavities can be made
    - beyond 1 TeV:
      - up to 1.2 TeV by making the machine asymmetric (extend one side only)
      - higher energies by extending both arms of the machine

- competing technologies:
  - American/ Japanese warm machine (X–Band):
    intense development ongoing, but serious problems with cavities. Final proof of operation not yet done
  - Japanese proposal for a "low energy" machine (350 GeV, top and Higgs factory)
    warm technology, similar problems with cavities, though (due to lower gradient) not as serious

- next generation technology: CLIC
  - estimated 10 years of basic research needed before a proposal can be made
  - a machine for the time after LHC/ TESLA to explore the multi–TeV regime

TESLA Parameters

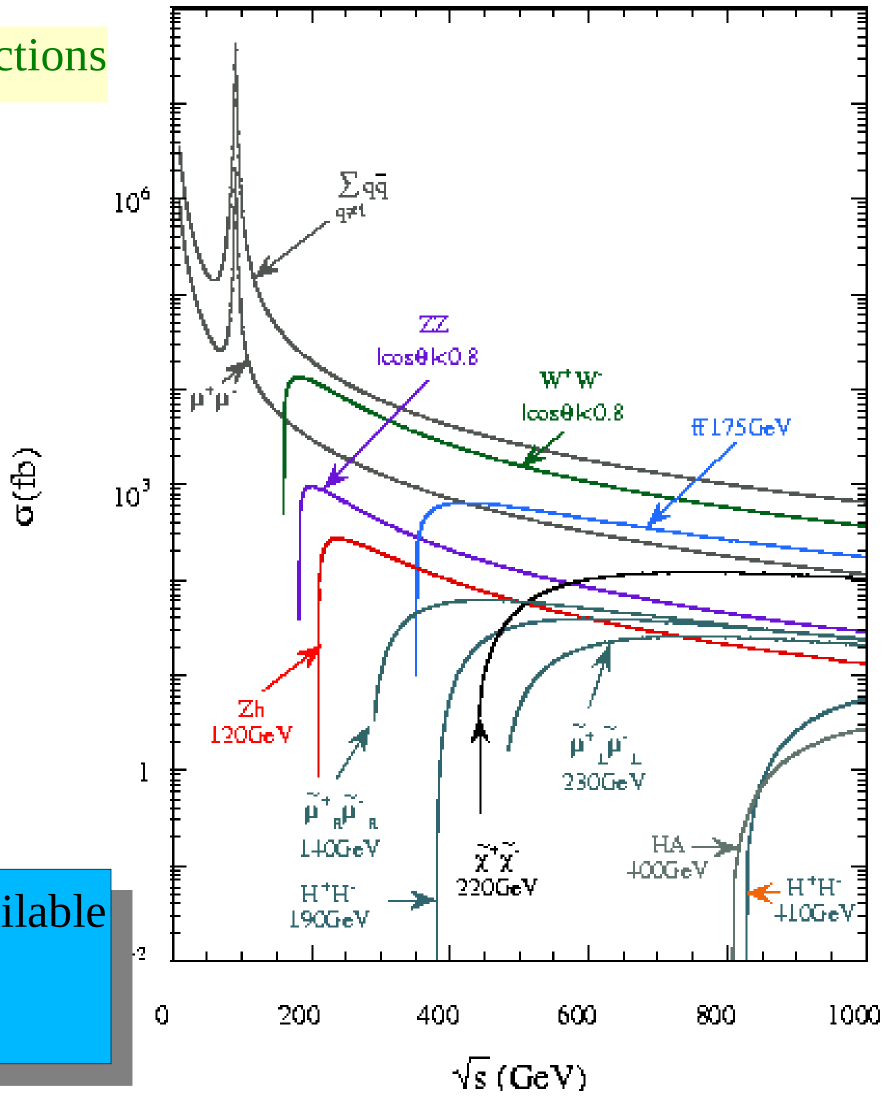
TESLA: expected cross sections for some reactions

Luminosity: $5\times10^{34}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$

bunch trains of 2820 bunches
time between bunches 337 ns

integrated luminosity/year $500\ \mathrm{fb}^{-1}$

100000 Higgs/year
300000 tt / year
1000000 WW/year



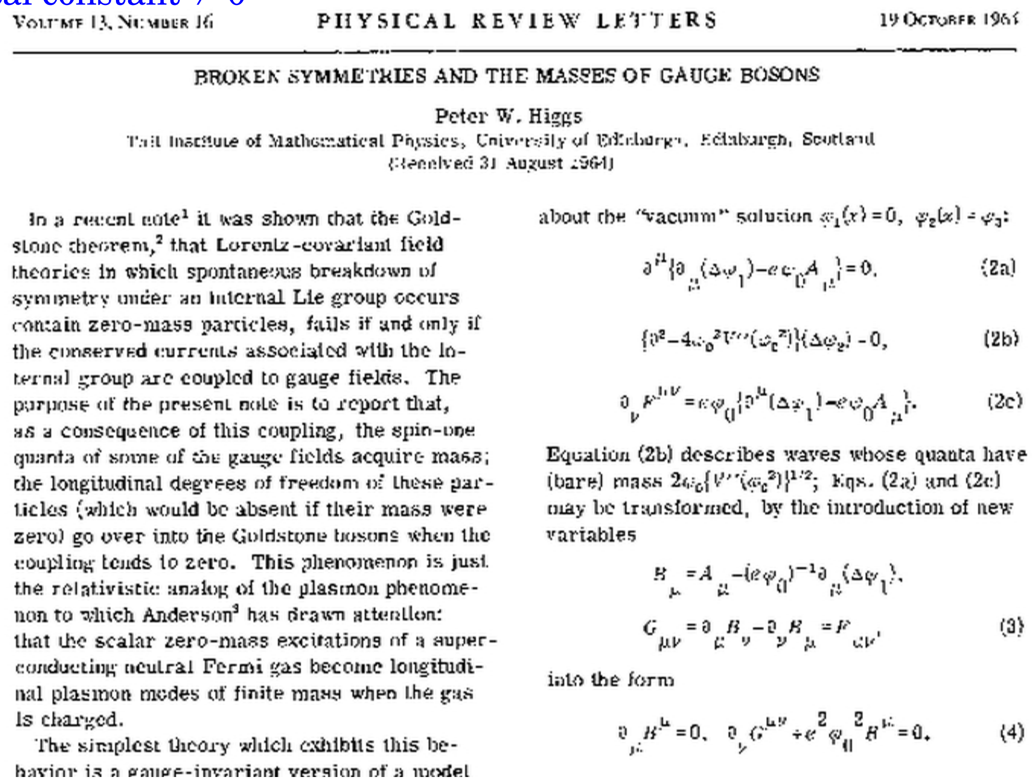
enormous quantities of data will be available
at the highest energies!
Precision physics will be possible

Key Questions in Particle Physics

- What is the origin of the symmetry breaking in the electroweak sector
  - Which mechanism gives mass to fundamental particles?
- Can the four fundamental forces of nature, the electromagnetic, the weak, the strong force and gravity, be unified in a comprehensive theory?
- Where do quark and lepton flavour come from?
  - why 3 generations? CP violation? Mixing
- What are the unseen elements of the universe
  - dark matter, dark energy, cosmological constant $\neq 0$

Papers:

Peter P.Higgs:	9
Papers with Higgs in the title:	5286



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BROKEN SYMMETRIES AND THE MASSES OF GAUGE BOSONS

Peter W. Higgs

Tait Institute of Mathematical Physics, University of Edinburgh, Edinburgh, Scotland

(Received 31 August 1964)

In a recent note[1] it was shown that the Goldstone theorem,[2] that Lorentz-covariant field theories in which spontaneous breakdown of symmetry under an internal Lie group occurs contain zero-mass particles, fails if and only if the conserved currents associated with the internal group are coupled to gauge fields. The purpose of the present note is to report that, as a consequence of this coupling, the spin-one quanta of some of the gauge fields acquire mass; the longitudinal degrees of freedom of these particles (which would be absent if their mass were zero) go over into the Goldstone bosons when the coupling tends to zero. This phenomenon is just the relativistic analog of the plasmon phenomenon to which Anderson[3] has drawn attention: that the scalar zero-mass excitations of a superconducting neutral Fermi gas become longitudinal plasmon modes of finite mass when the gas is charged.

The simplest theory which exhibits this behavior is a gauge-invariant version of a model

about the "vacuum" solution $\varphi_1(x)=0$, $\varphi_2(x)=\varphi_0$:

$$\partial^\mu\{\partial_\mu(\Delta\varphi_1)-e\varphi_0A_\mu\}=0, \qquad (2a)$$

$$\{\partial^2-4\varphi_0^2V''(\varphi_0^2)\}(\Delta\varphi_2)=0, \qquad (2b)$$

$$\partial_\nu F^{\mu\nu}=e\varphi_0\{\partial^\mu(\Delta\varphi_1)-e\varphi_0A_\mu\}. \qquad (2c)$$

Equation (2b) describes waves whose quanta have (bare) mass $2\varphi_0\{V''(\varphi_0^2)\}^{1/2}$; Eqs. (2a) and (2c) may be transformed, by the introduction of new variables

$$B_\mu=A_\mu-(e\varphi_0)^{-1}\partial_\mu(\Delta\varphi_1),$$

$$G_{\mu\nu}=\partial_\mu B_\nu-\partial_\nu B_\mu=F_{\mu\nu}, \qquad (3)$$

into the form

$$\partial_\mu B^\mu=0, \quad \partial_\nu G^{\mu\nu}+e^2\varphi_0^2B^\mu=0. \qquad (4)$$

EW Symmetry Breaking

- central question for the next generation of colliders:
  - understand the nature of the electroweak symmetry breaking mechanism (EWSB)

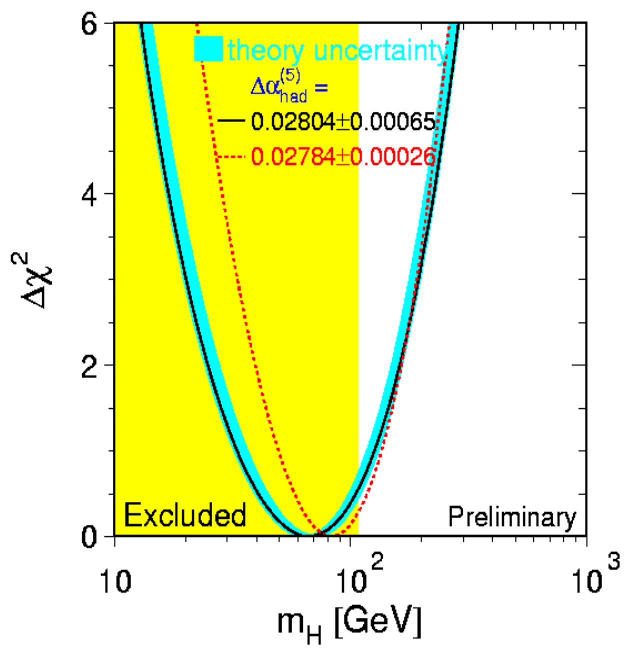
- currently three main routes to EWSB are discussed:

1. An elementary Higgs boson exists → search for the Higgs boson
2. the Higgs boson is composite → search for the substructure
3. there is no Higgs boson → new strong force must exist at some scale

The Case for an Elementary Higgs

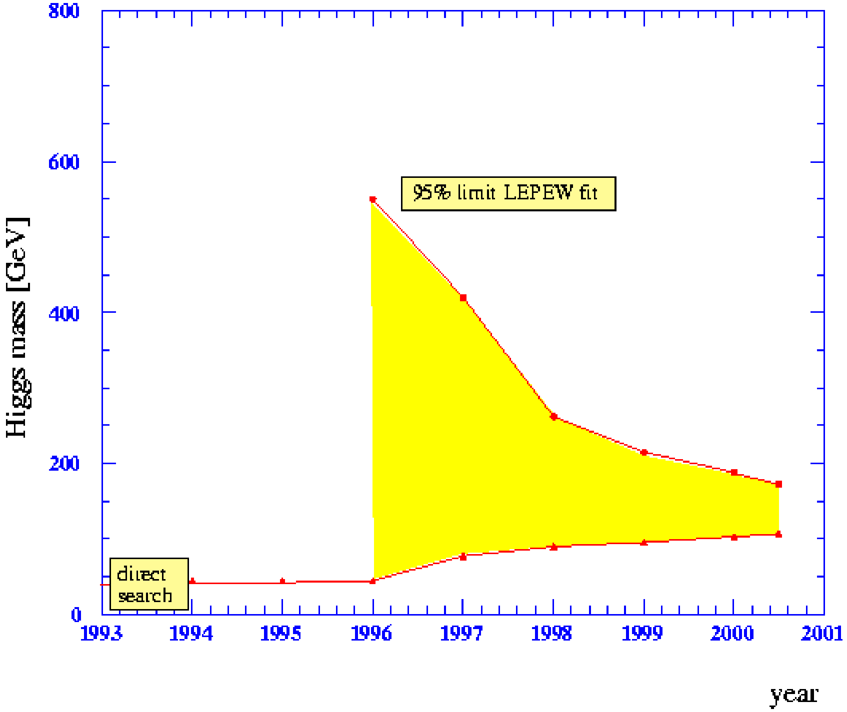
If the Higgs is elementary:

indirect limits from LEP



M < 188 GeV@95% CL

development of limits over time:



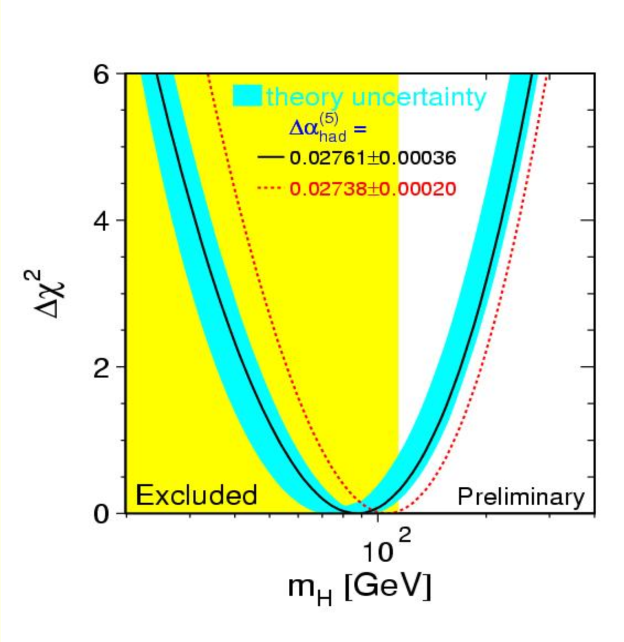
- light elementary Higgs very much favoured
- other (theoretical) constraints

validity of perturbation theory:	< 500 GeV
GUT constraints (naive)	< 180 GeV
SUSY models	< 205 GeV
Model independent studies	< 300 GeV

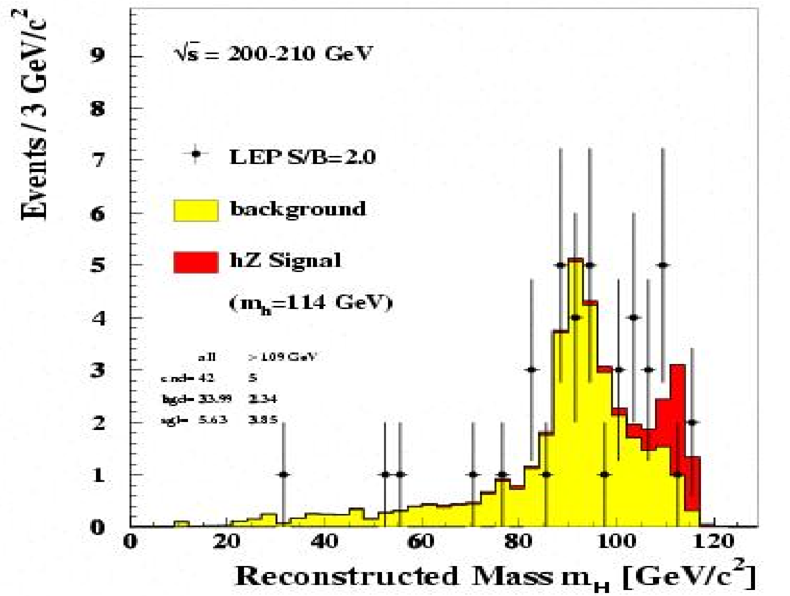
The Case for an Elementary Higgs

If the Higgs is elementary:

indirect limits from LEP



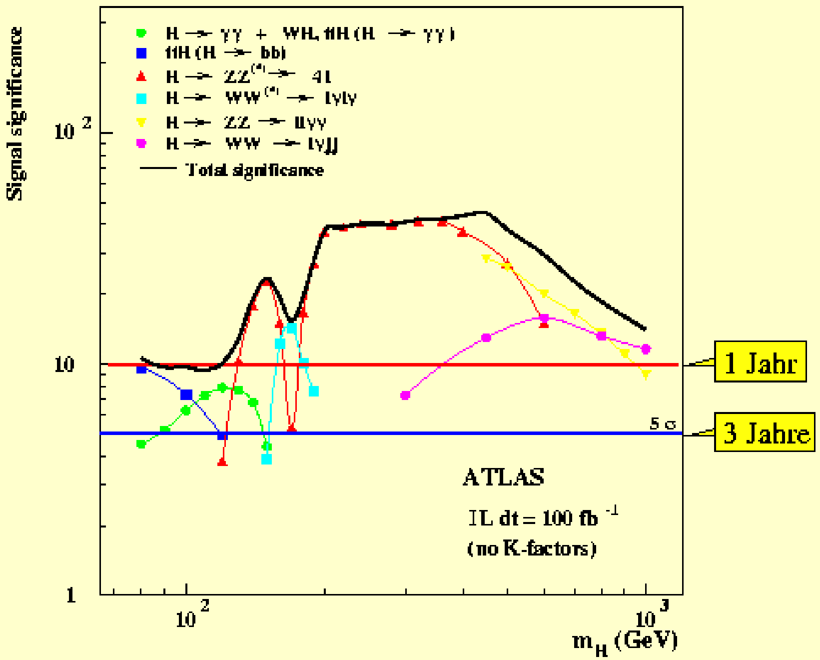
M < 212 GeV@95% CL



LEP data from September 2000:
some excess observed (~ 2.1 sigma)
at M(higgs) ~ 115 GeV

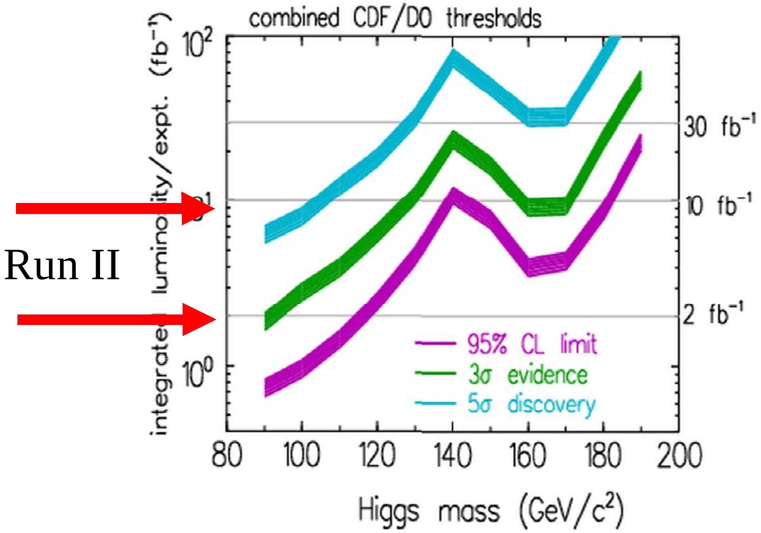
- light elementary Higgs very much favoured
  other (theoretical) constraints
  - validity of perturbation theory: < 500 GeV
  - GUT constraints (naive) < 180 GeV
  - SUSY models < 205 GeV
  - Model independent studies < 300 GeV

Possible Discovery of the Higgs



LHC: convincing signals after approx. 3 years
if the Higgs is light
faster, if the Higgs is heavy

Tevatron reach for run II:



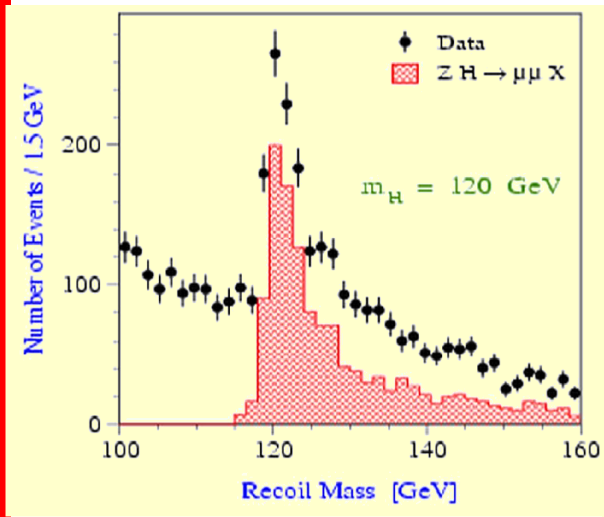
Either Tevatron or LHC will likely find
the Higgs if it is there,
and if LEP has not already found it

Higgs at TESLA

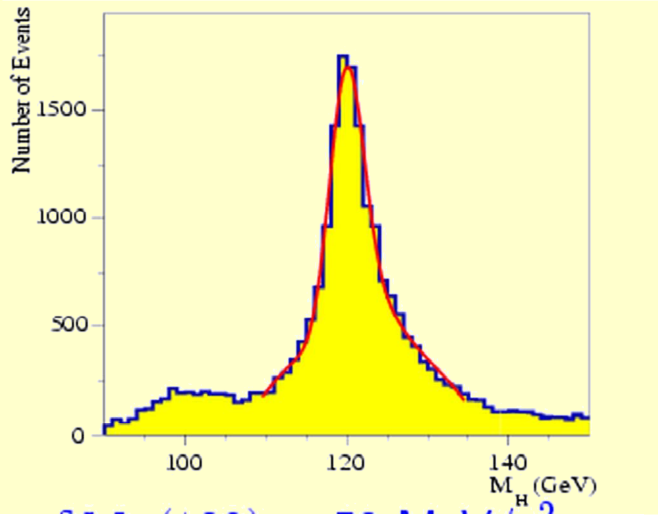
Determination of mass of Higgs:

direct reconstruction of Higgs in a number of decay channels possible,
most favourable ee → Z → HZ

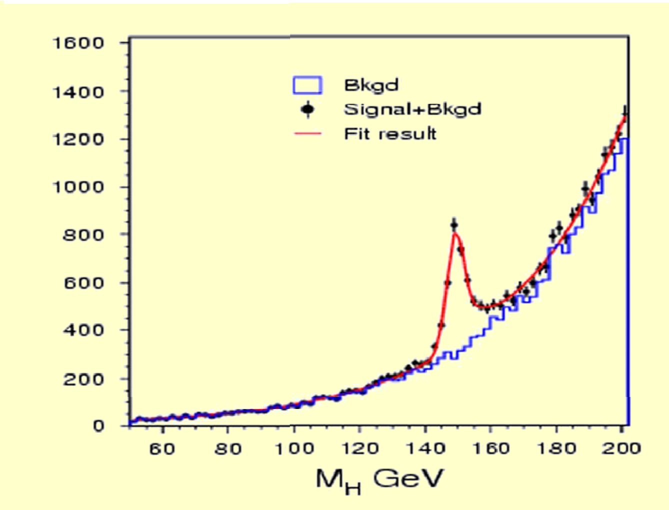
ZH → μμX



ZH → qqbb



ZH → WW qq



Clear signals in many channels:

mass		width:
M(Higgs)	dM	
120 GeV	40 MeV	to 5–10%
150 GeV	70 MeV	
180 GeV	90 MeV	

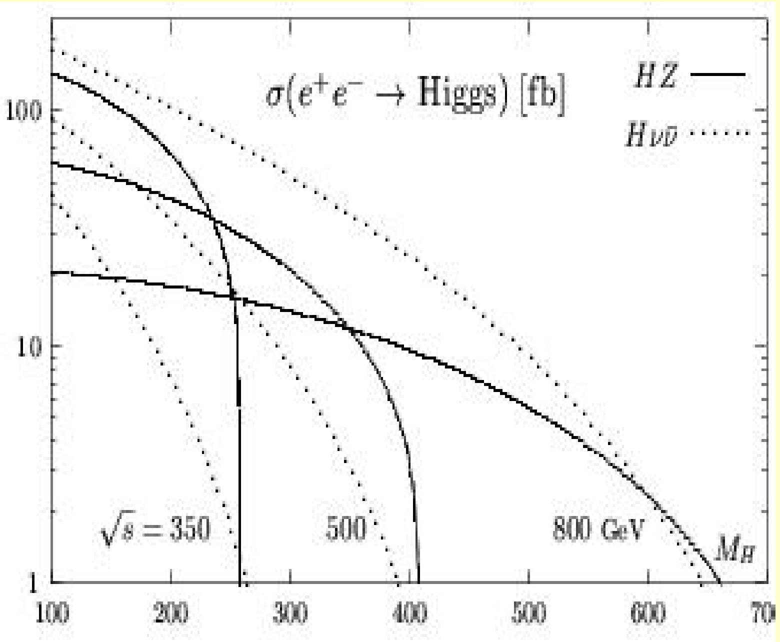
Higgs Properties

Once "signals" are found:

- Determine mass and width
- measure quantum numbers J^{PC}
- determine the couplings to fermions (mass)
- measure Higgs self–coupling, determine the potential
- separate SM Higgs from SUSY Higgs or other models

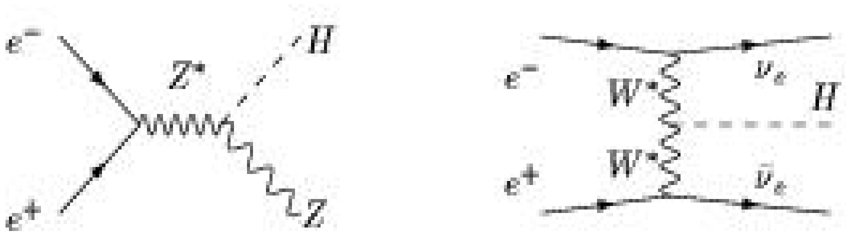
Need whole series of measurement to fully establish nature of Higgs mechanism

Higgs production cross section (SM)



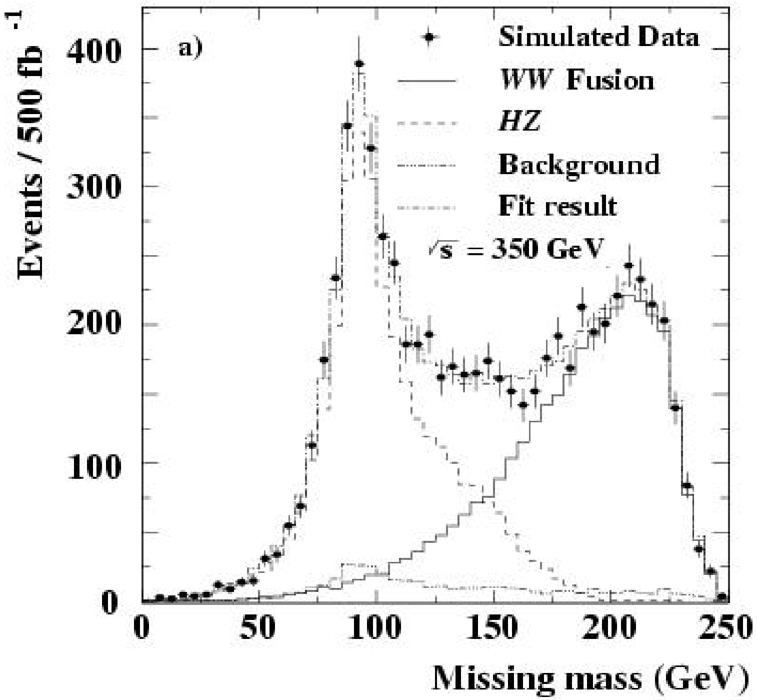
Higgs production II

Alternative channel: WW fusion



Main interest:
determine the width of the Higgs Boson:

Method	120 GeV	160 GeV
WW	0.061	0.140
$\gamma\gamma$	0.230	



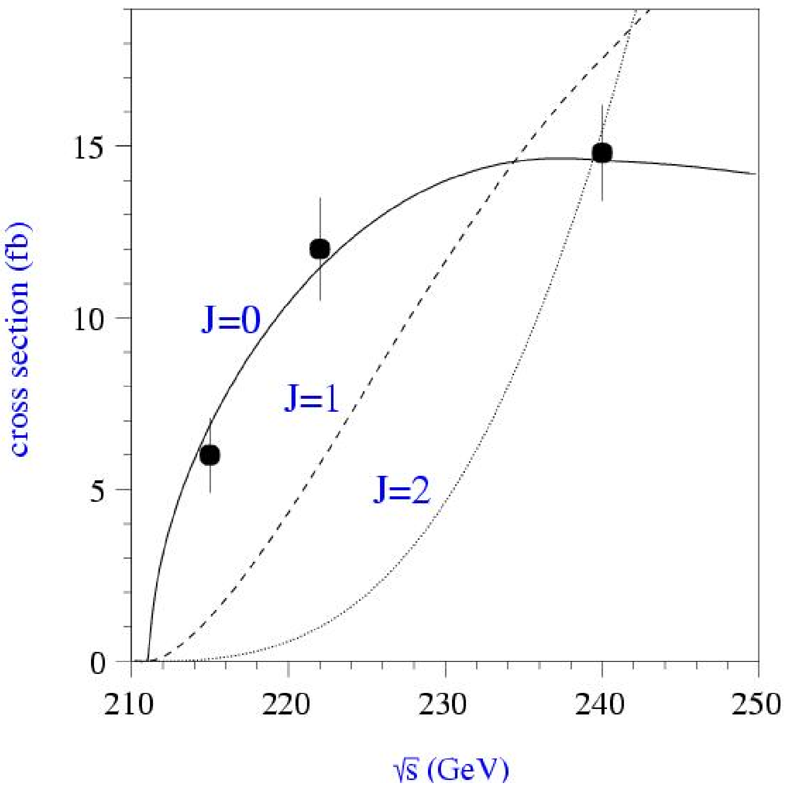
Polarisation of lepton beam is very important to turn on / off the SM backgrounds

Higgs Quantum Numbers

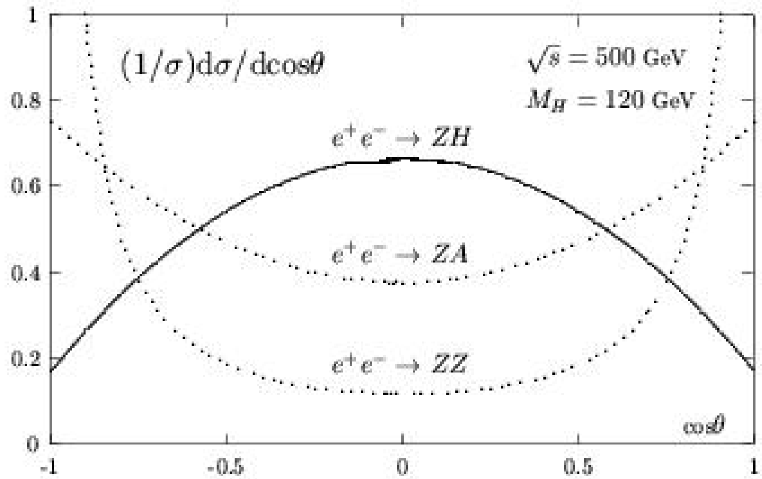
Have to determine the quantum numbers of the Higgs particle

- Spin J
- Study the nature of the candidate (SM, MSSM, ...)

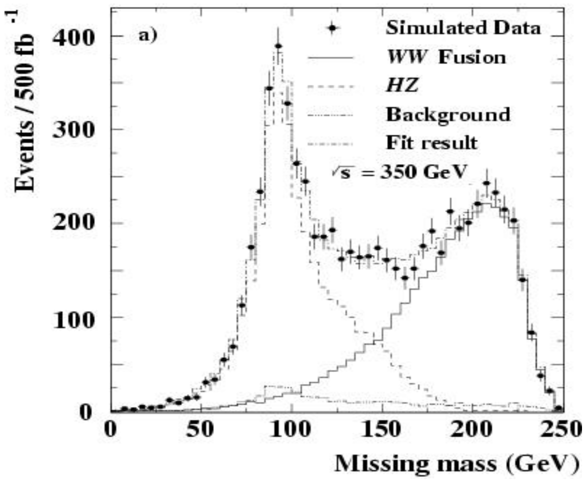
Threshold behaviour

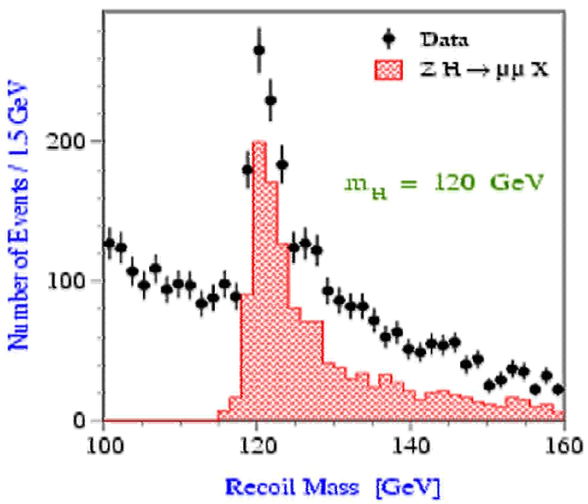


Angular distribution



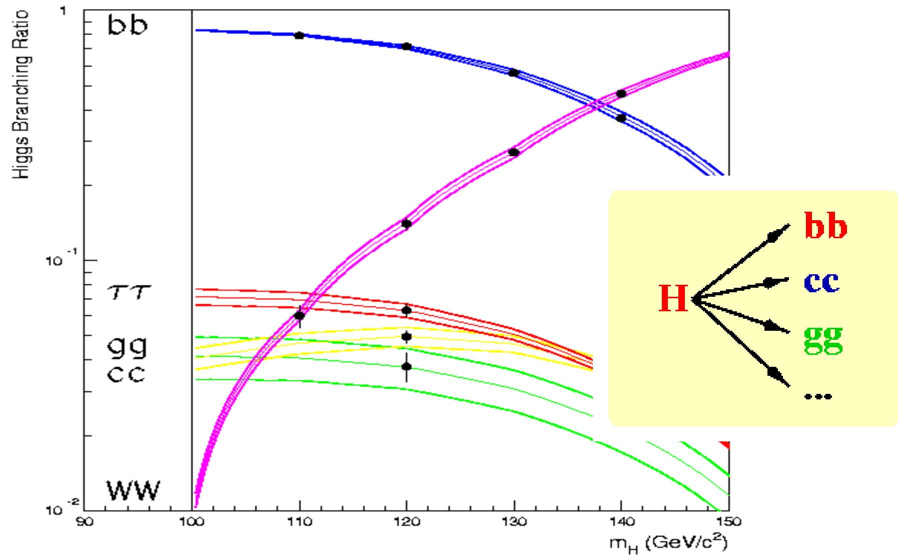
Beyond a Discovery





- complete test of our understanding of mass
  - can the Higgs explain the Z/W−mass? is the existence of the Higgs enough?
  - Can the Higgs explain the mass of the fermions

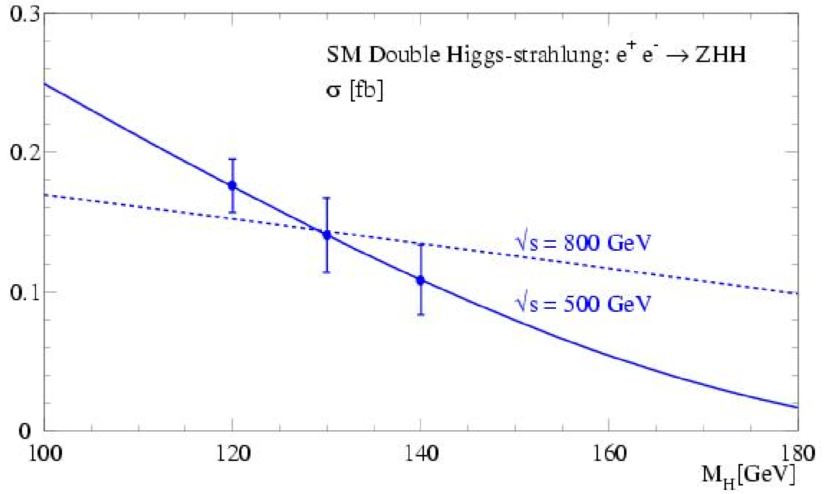
Couplings to fermions:



Higgs Self Coupling

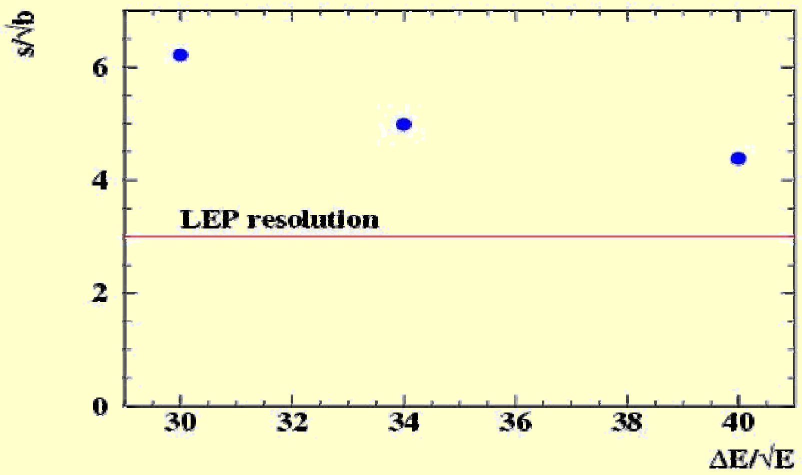
The most difficult question:
is the Higgs Potential the one we think it is ("Mexican Hat")?

Higgs self couplings: Higgs Potential



Can measure the Higgs Potential
to 10–20%

Role of the detector resolution in this:
significance as a function of different
energy flow resolution values

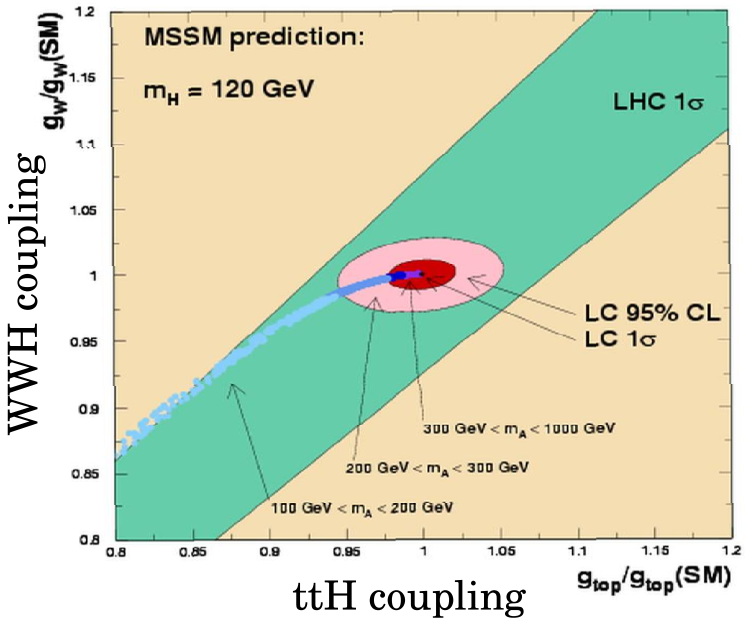


Beyond the Standard Model Higgs

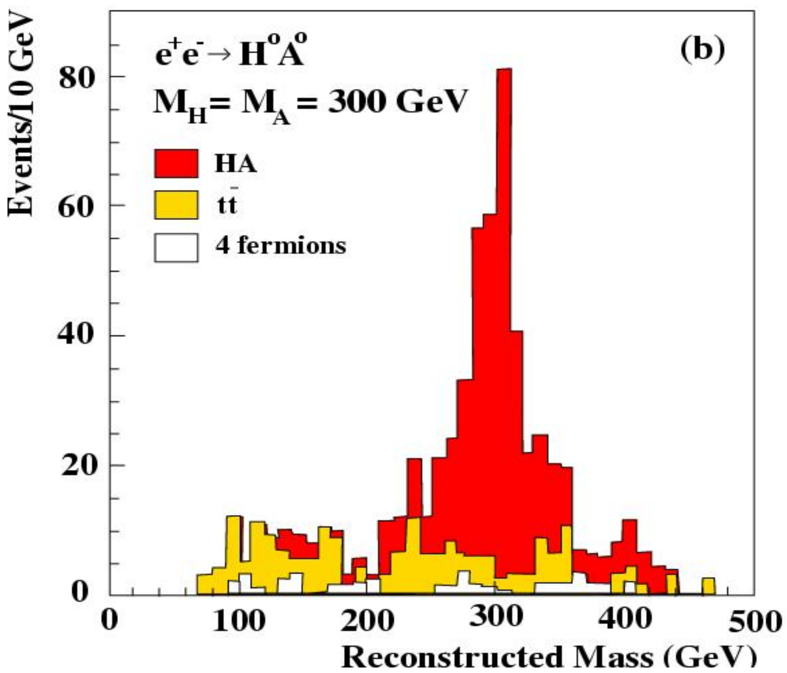
Is the Higgs the SM Higgs?
Is the Higgs a supersymmetric Higgs?
Is the Higgs something completely different?

Answering these questions requires a detailed and precise investigation of the Higgs properties

Example: Distinction SM Higgs from MSSM Higgs



Signal for supersymmetric Higgs ($50\ fb^{-1}$, 4b final state)

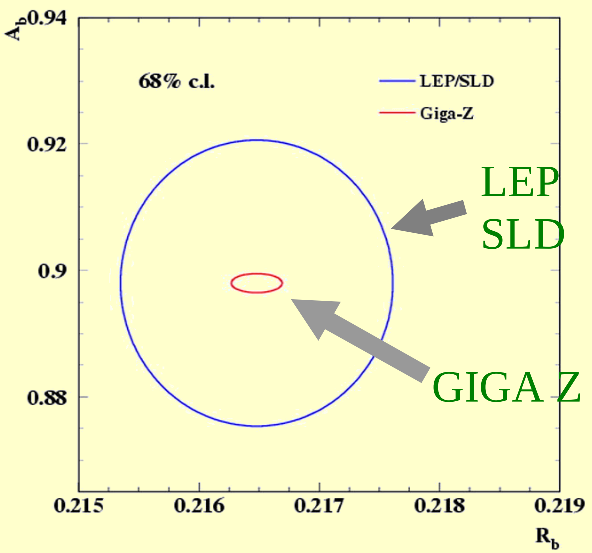


"GIGA Z"

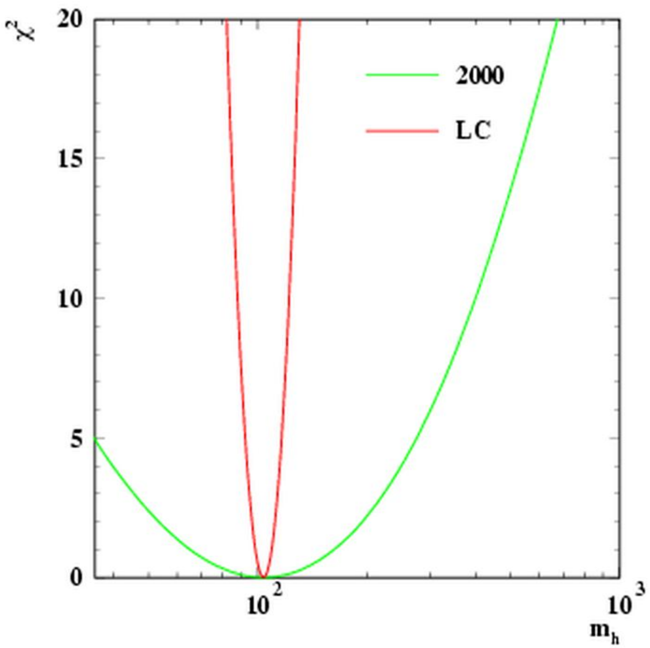
• if light Higgs is not found: return to lower energies as a first step!

GIGA Z:
operate TESLA at 91 GeV
very high luminosity
1 billion Z bosons possible

improve the precision electroweak measurement from LEP



• redo the indirect Higgs "limits" using GIGA Z:
  • get much more stringent information
  • if there is an inconsistency somewhere, it will show up here



try to see indications of where to go for new physics before going there!

Comparison to LHC

- Finding the Higgs Boson

  LHC / Tevatron should discover the Higgs
  measure its mass
  (exception: Higgs decays dominantely invisibly, then LC finds it)

- Measuring total width, couplings

  LHC will not measure Γ(tot) (or very poorly)
  LHC will measure ratios of some couplings to ~20%
  LC will measure width and couplings on the % level

- Measure the quantum numbers

  LHC will not do, LC will do easily

- explore the Higgs potential

  LHC will not do, LC will do with sufficient luminosity

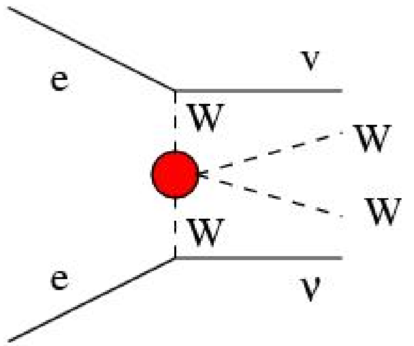
LHC should discover a Higgs candidate

LC should discover, what this really is

We will need both!

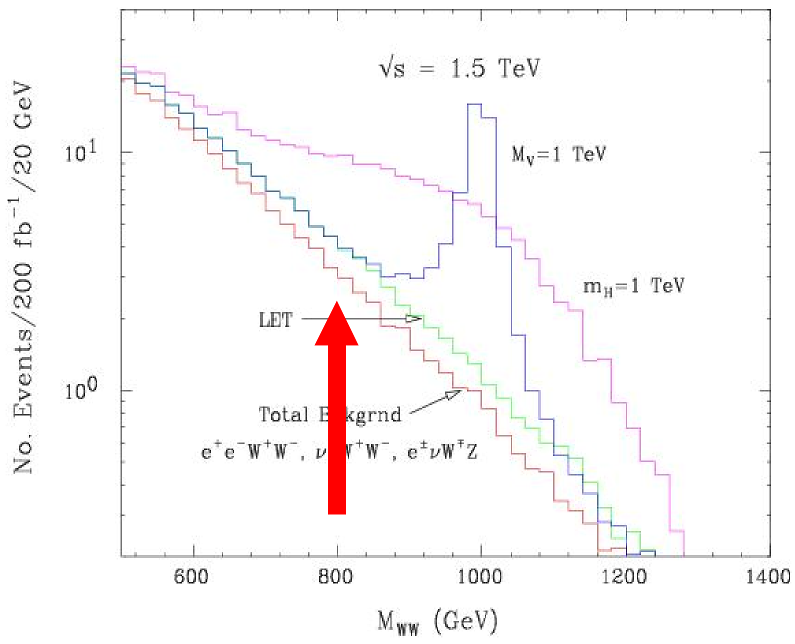
The Higgs does not exist...

- if no Higgs is found at LEP, Tevatron, LHC, LC:
  - very fundamental arguments require: something must happen on the TeV scale (otherwise unitary in WW scattering is violated)
  - one possibility: a new strong interaction (WW rescattering) plays the role of the Higgs
    there are no fundamental scalars in nature, "fermioncentric" world,
    either no Higgs exists, or the Higgs is composite



- main access: study of WW scattering
- effects already visible at "low" energies

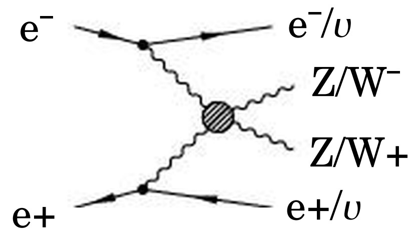
consistent models for this type are difficult

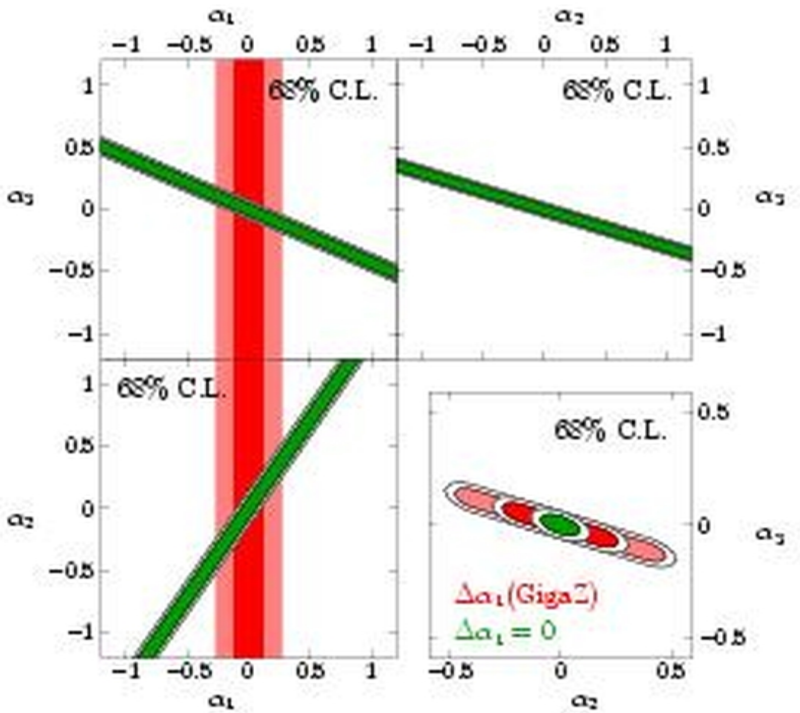


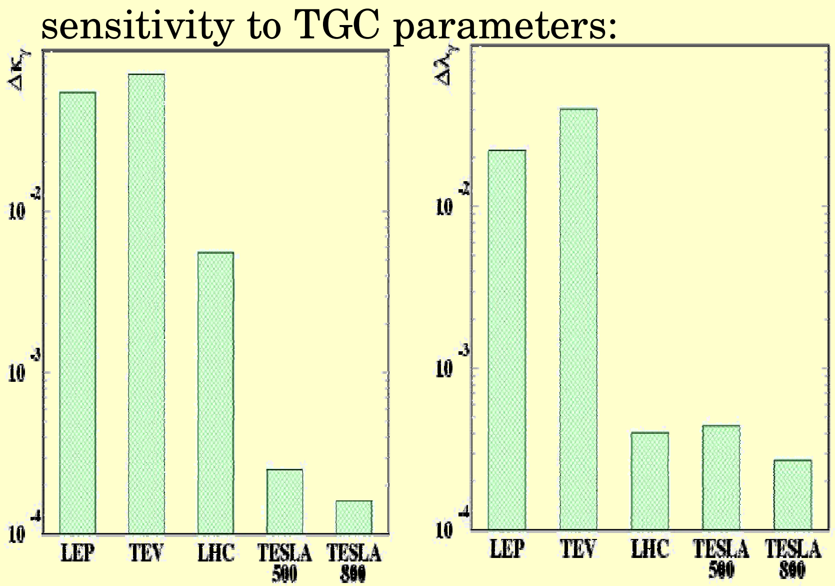
Strong WW scattering

Detailed investigation of the "tripple Gauge couplings" TGC

- a detailed investigation needs high statistics (800 GeV, 1000 fb^{-1}) plus lepton polarisation (P(e−)=80%, P(e+)=60%)
- need additionally data from Giga Z to determine $\alpha(3)$





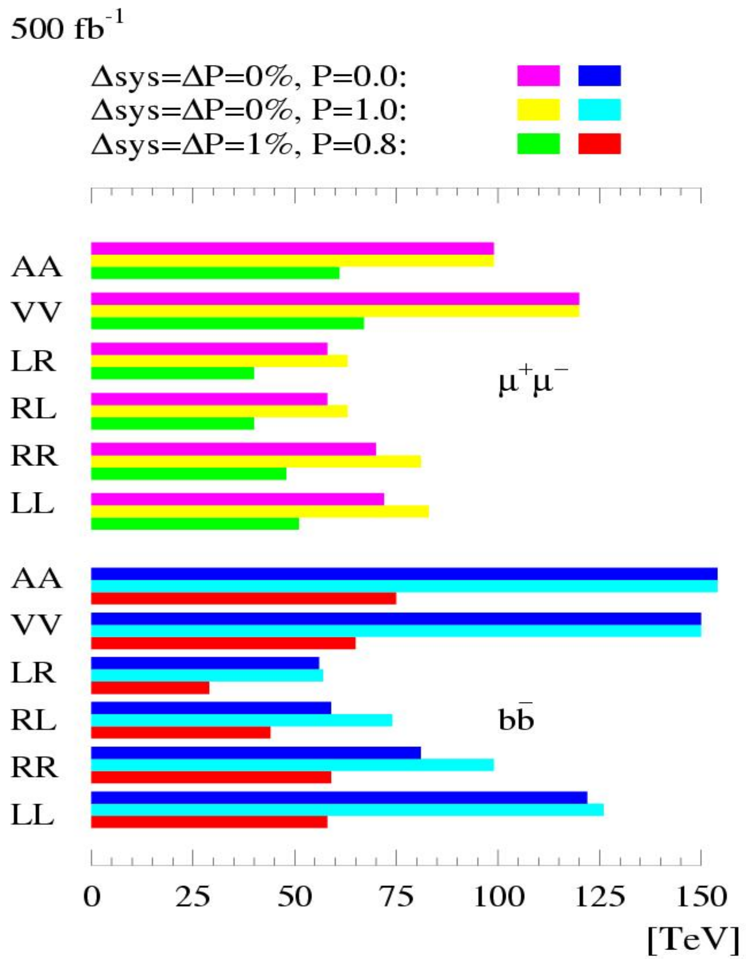


Substructure

- is there a structure below the known one
  - new heavy Z–like bosons
  - Leptoquarks?
  - exotic spin 2 exchange particles?
  - ...

- best studied in the reaction: $e^+e^- \rightarrow f\bar{f}$

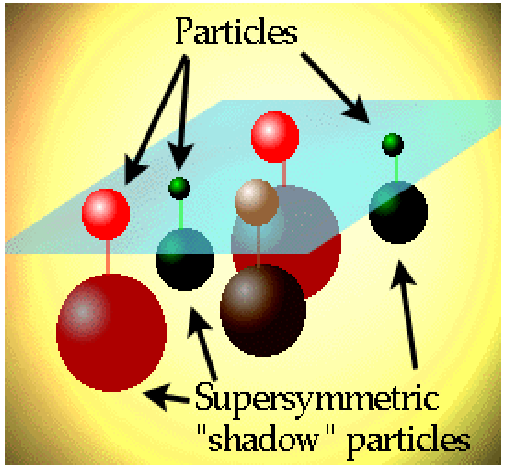
the scale of substructure can be probed well beyond the energy of the collider



Physics beyond the Standard Model

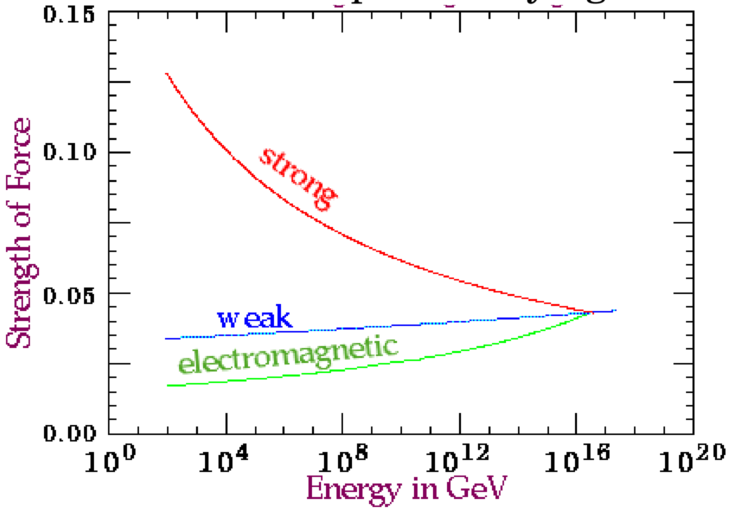
- "there must be something more than just the Standard Model..."
  SUPERSYMMETRY?

just one possible model of many
but experimental signatures of most
models are similar



SUSY: fundamental symmetry between fermions and bosons
doubles number of particles
particles must be heavy, since no observation so far
SUSY must be "broken"

SUSY helps in unifying forces at large energies

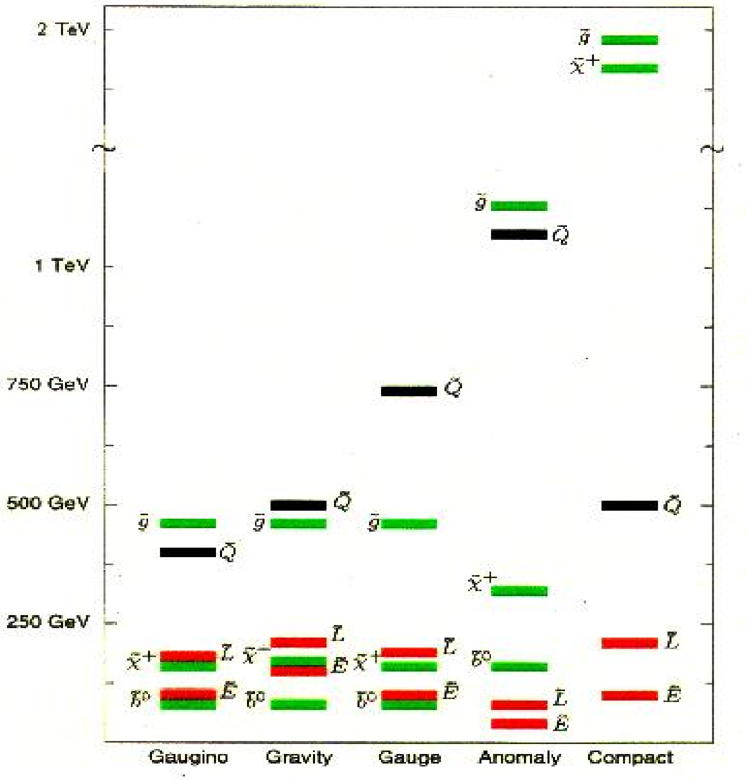


- Supersymmetry extends the SM, does not replace it (example: quantum mechanics extends classical mechanics, does not replace it)
- so far no experimental evidence for SUSY

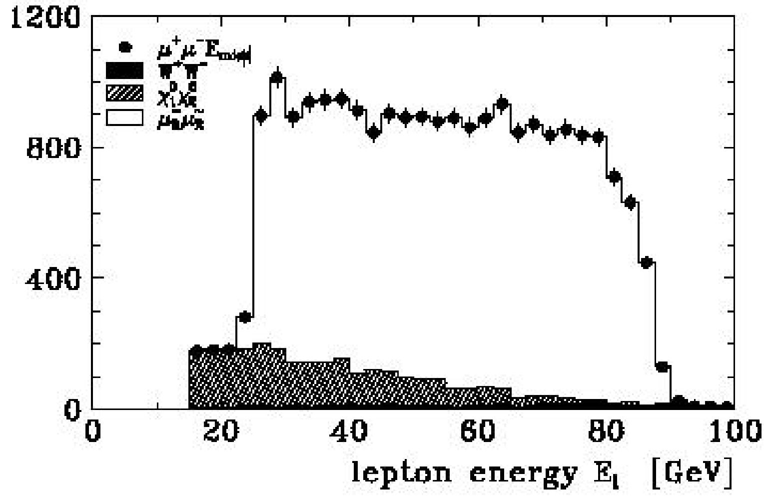
Supersymmetry

- key to Supersymmetry:
  - discovery
  - spectroscopy to select the correct model

- in "all" models: expect at least some of the SUSY partners at few 100 GeV ("no loose theorem", nearly model–independent)



smuon observed mass spectrum



spectacular signals for SUSY partners if in the kinematic reach at LC

TESLA will be able to contribute significantly to the knowledge about SUSY, if SUSY exists

Supersymmetry

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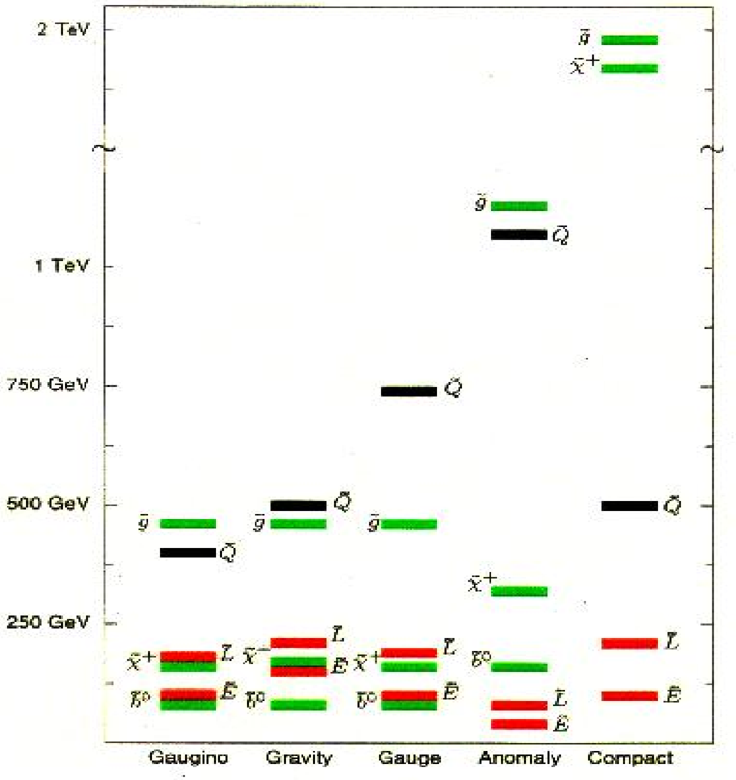
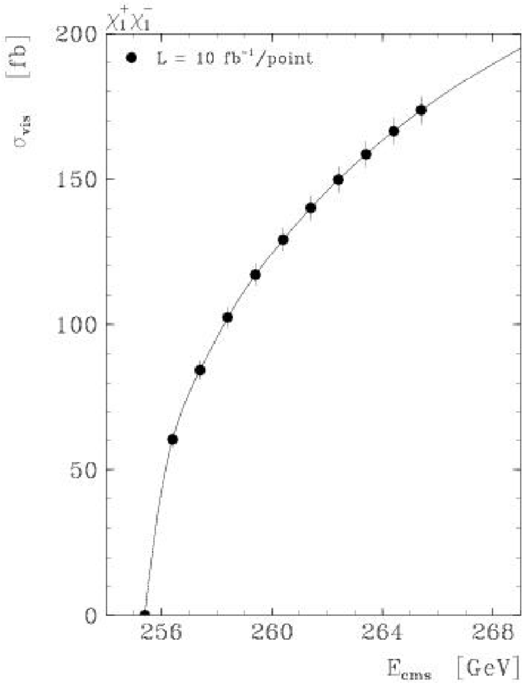




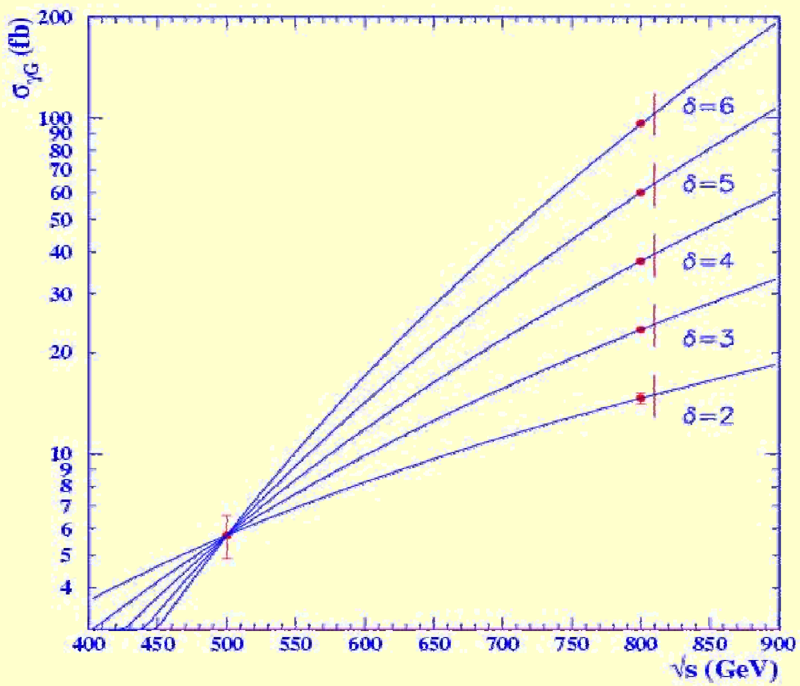
spectacular signals for SUSY partners if in the kinematic reach at LC

TESLA will be able to contribute significantly to the knowledge about SUSY, if SUSY exists

Extra Dimensions

Novel recent approach to solve the gauge hierarchy problem: large extra dimensions

many theoretical models exist with striking predictions



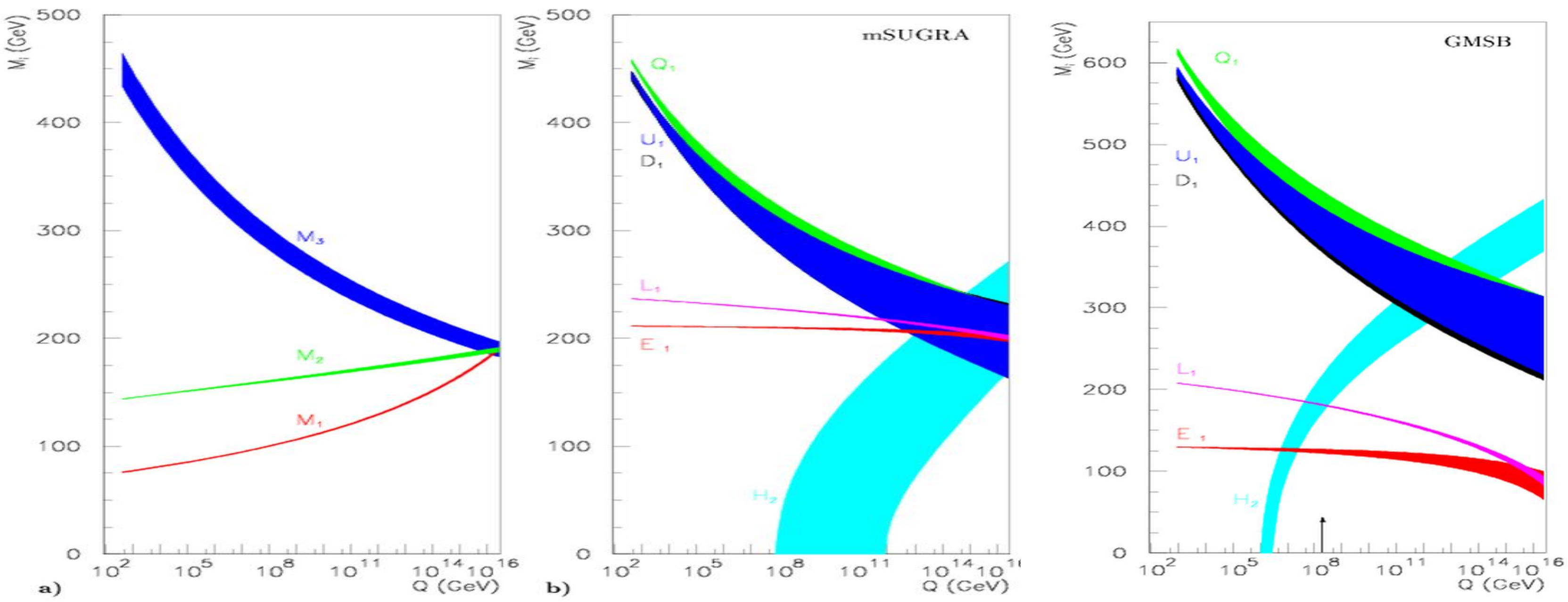
number of extra dimensions determined at TESLA at 500 and 800 GeV in anomalous direct photon events

discovery reach at LHC and TESLA

δ	2	3	4	5	6
LHC	4.0—7.5	4.5—5.9	5.0—5.3	none	none
TESLA	0.5—7.9	0.5—5.6	0.5—4.2	0.5—3.4	0.5—2.9

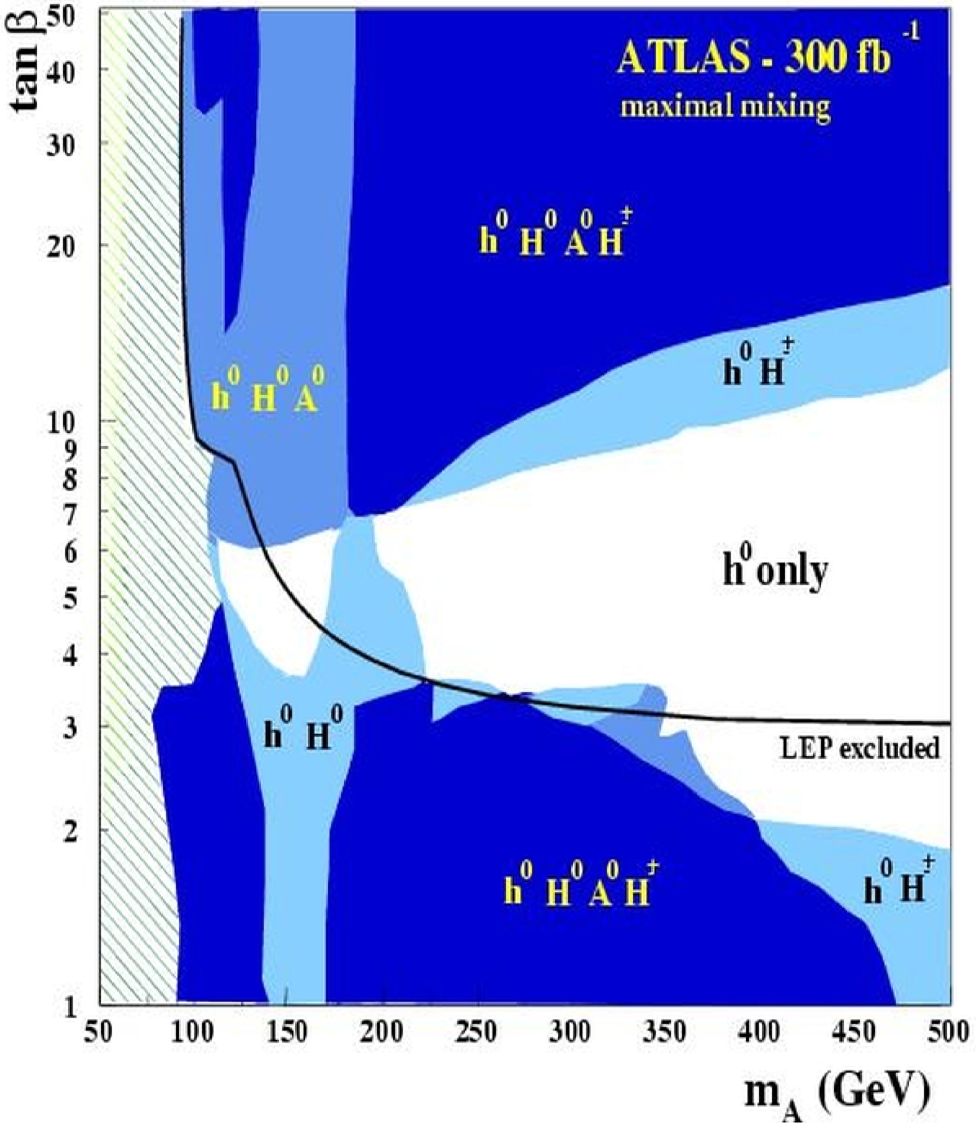
SUSY at very high energies

precision measurements allow the extrapolation to high energies with good precision:
  learn about the high energy behaviour
  use this to distinguish models



This might be the only way to access these extremely high energies experimentally!

SUSY: LC vs LHC



Mass reach of LHC larger

precision reach of LC better (if
within mass reach)
access to anything beyond the mass
essentially only at LC

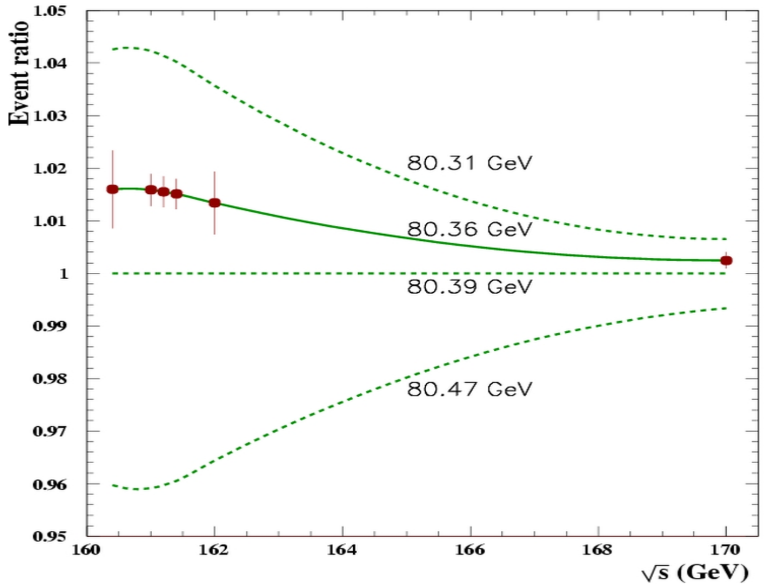
separation of different SUSY particles
difficult at LHC

Remark: polarisation of lepton beams
is an important ingredient to determine
the sparticle properties

Precision Physics

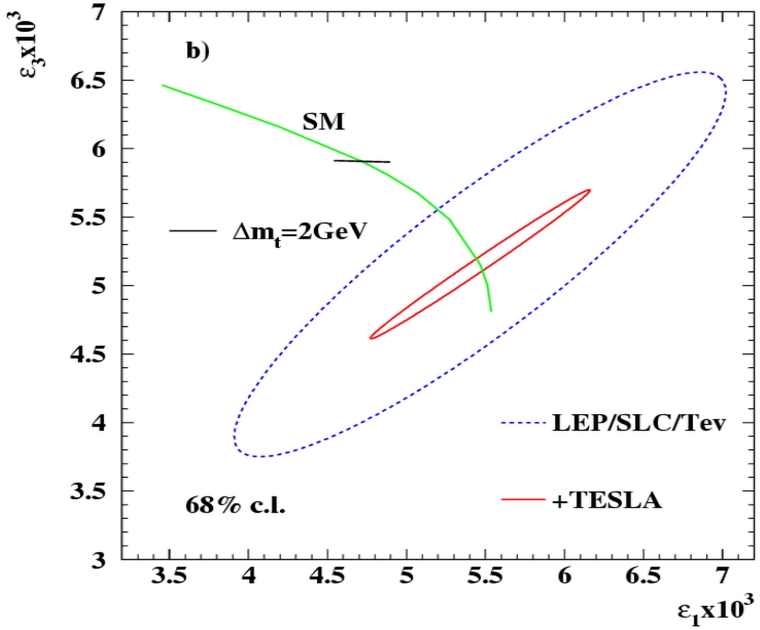
- High luminosity and clean event structure:
  ➡ TESLA allows precision Standard Model physics

- W−mass determination



other measurements:
  electroweak gauge bosons
  top mass
  CKM matrix elements

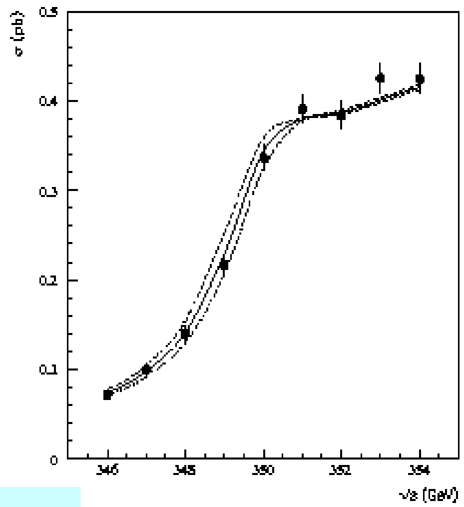
Interpretation of precision data in the SM context:



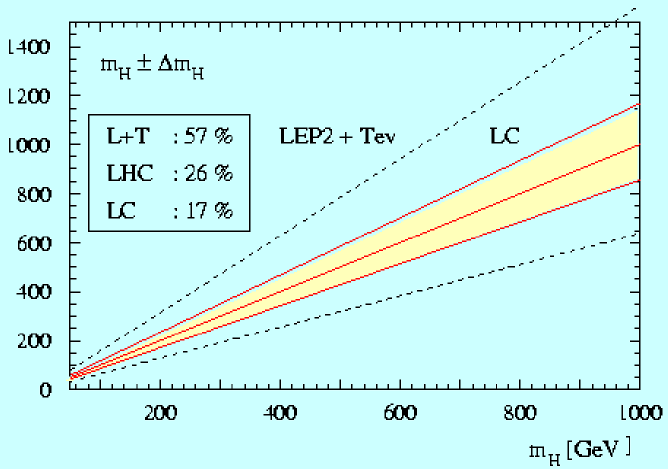
TOP Physics

- A linear collider with E>350 GeV is a top factory
- allows precision studies of the top system
  - top is the heaviest known fermion
  - top−Higgs coupling is very interesting if it exists (Higgs couples to mass)

top threshold scan



Based on 500 fb^{-1} of integrated luminosity (1 year)
error: m =±100±(100–200) MeV



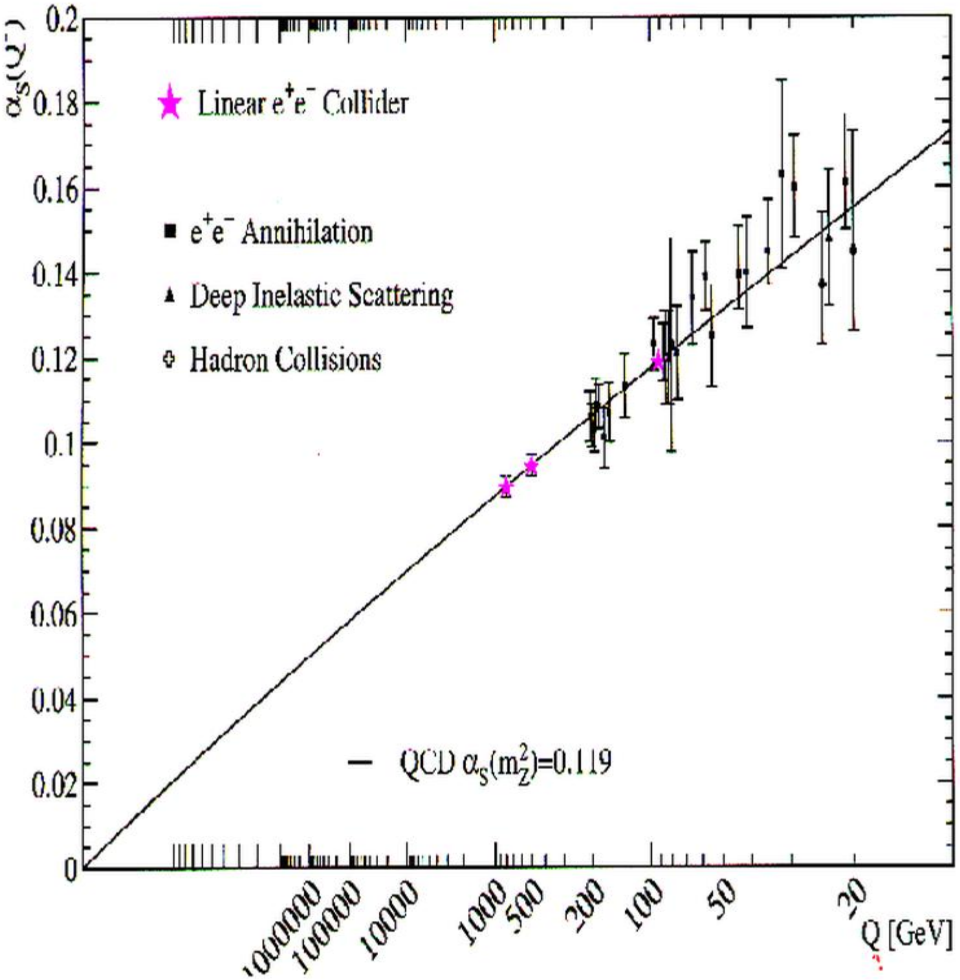
Allows stringent consistency checks of the Standard Model

Precision Tests of the Standard Model

Quantum Chromo Dynamics at LC

Strong coupling constant including LC information:

- add precise α(strong) measurements at three energies (91, 500, 800 GeV)
- do consistent (one experiment!) check of the running of α(strong)
- needs improved theoretical understanding
- could much improve the extrapolation to the GUT scale



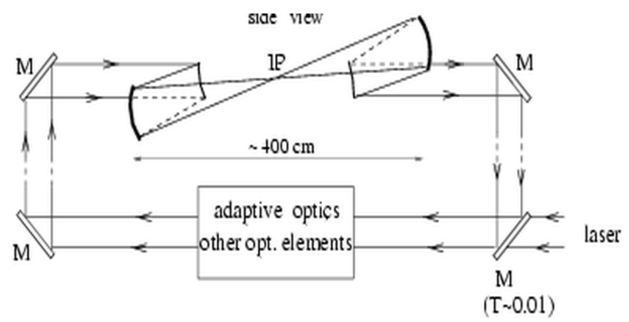
Photon Photon Collider @ TESLA

Alternative: Collide Photons with Photons

- produce scalar Higgs bosons singly (larger discovery reach)
- C=+1 states are produced (C=−1 in e+e− collisions)
- large cross section for pairs of charged hadrons

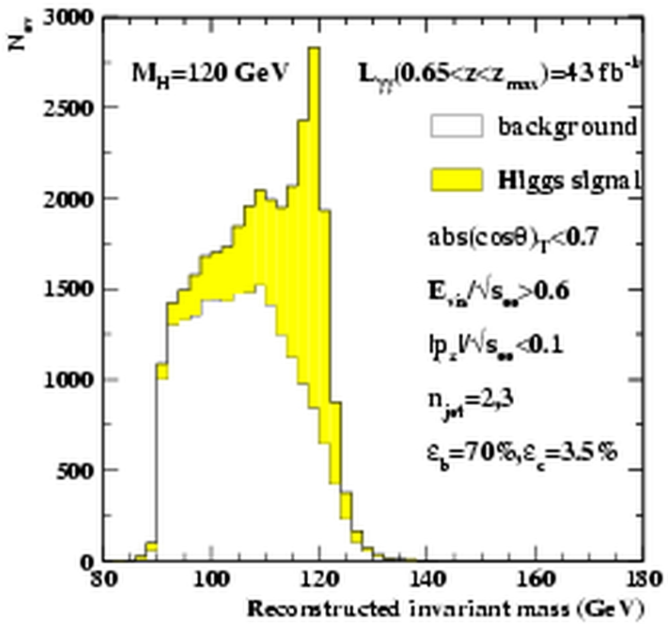
- initial collision energy less well defined
- need complicated laser installation in interaction point

proposed laser scheme (optical cavity)



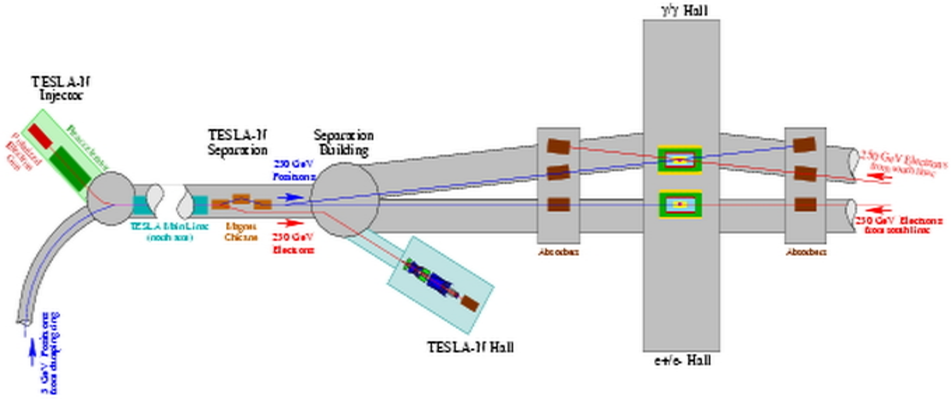
Laser installation technically challenging
Investigations into realisation are starting

Higgs signal in $H\rightarrow\gamma\gamma$

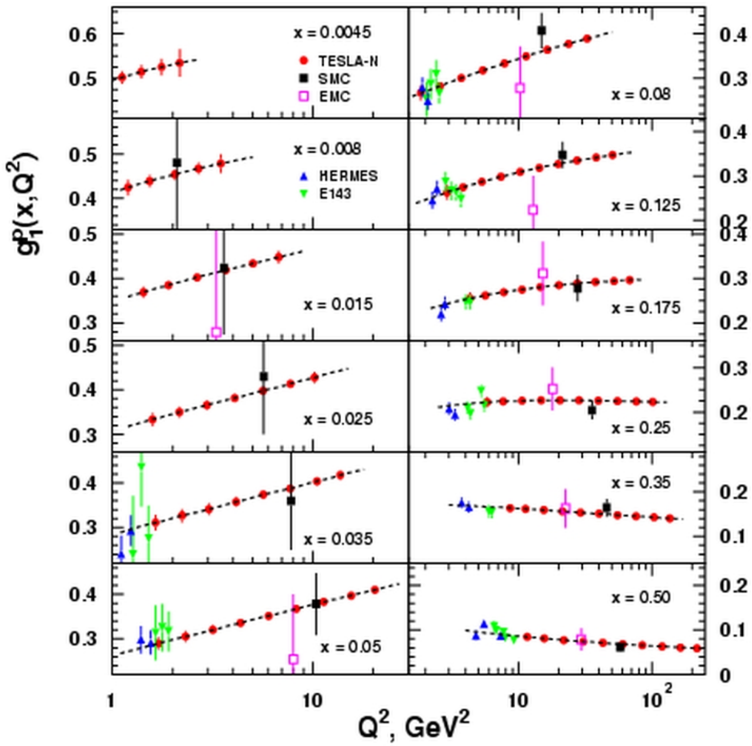


TESLA−N

polarised electron – nucleon scattering
using electrons from TESLA

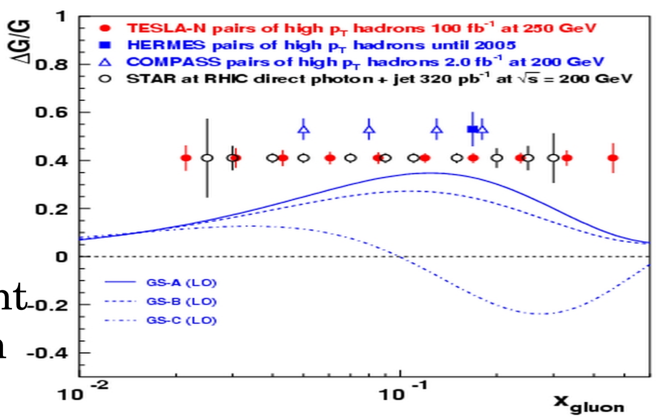


use low intensity electron bunches in between the HEP bunches: no interference to HEP running



Complete mapping of the Q^2 and x–dependance of both the helicity and the transversity distributions Δq and δq will become available.

projected precision of measurement of gluon contribution to the proton spin



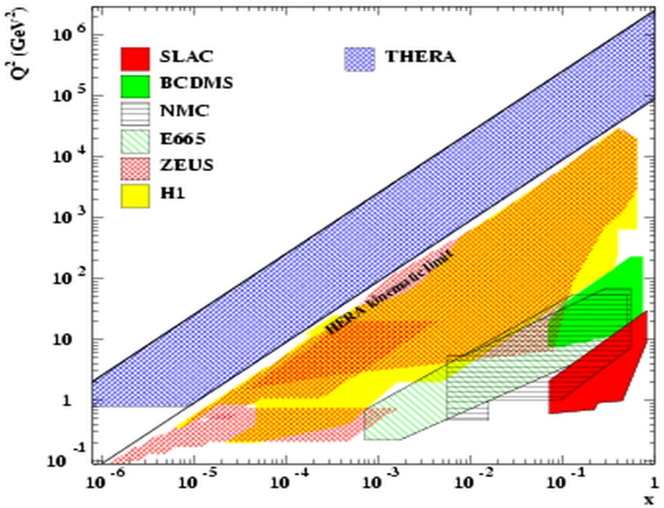
THERA

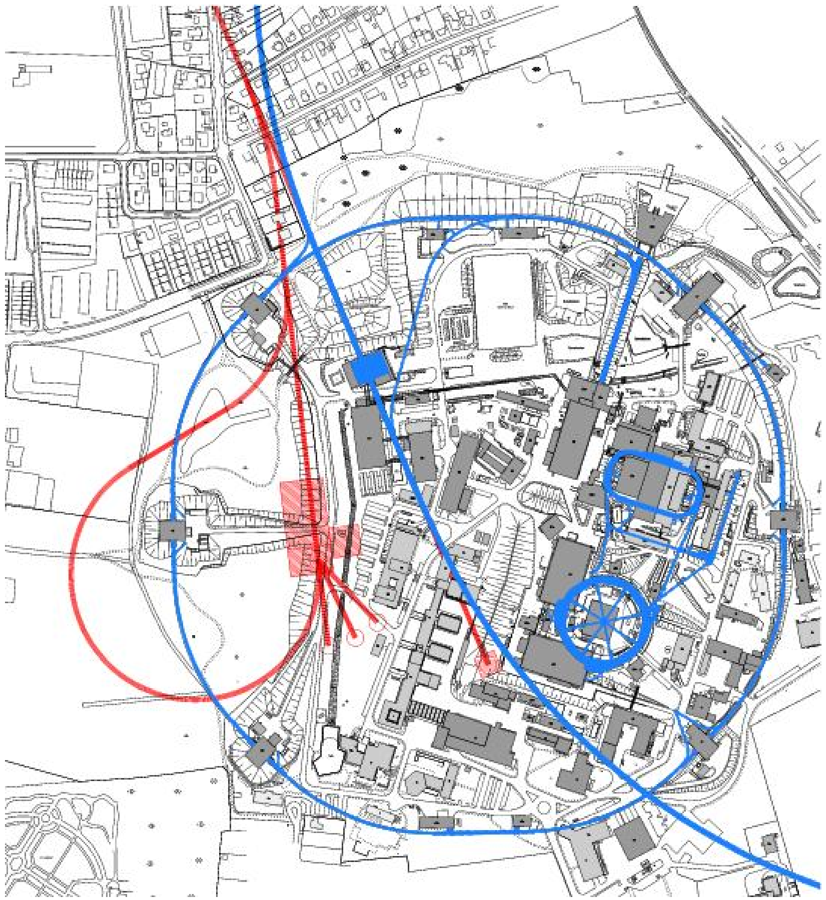
THERA: Collide electrons from TESLA with protons in HERA

expected performance:

electron energy	250 GeV
proton energy	1 TeV
luminosity	$4.1 \cdot 10^{30} cm^{-2} s^{-1}$

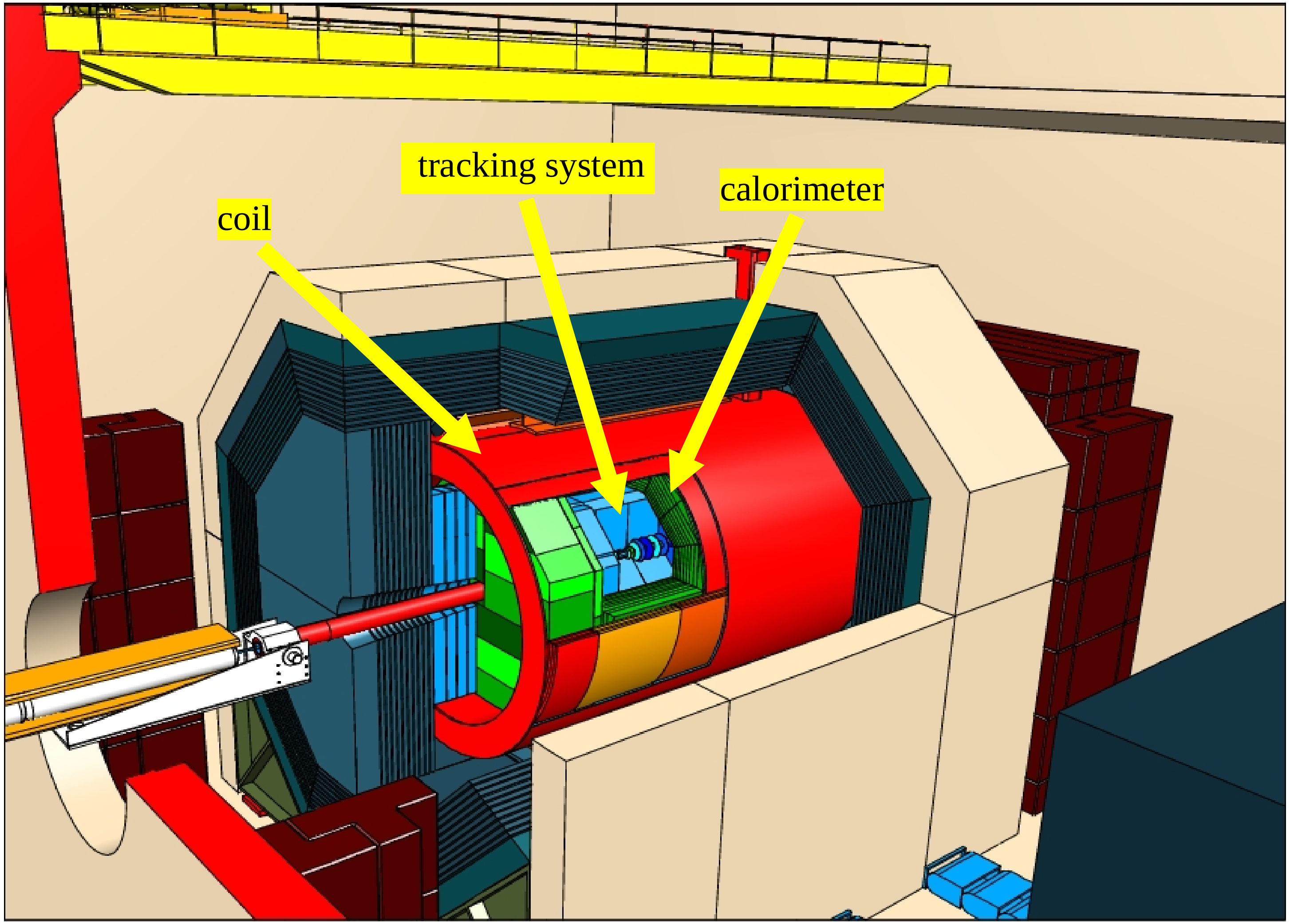
reach in x–Q² plane





A Detector for TESLA

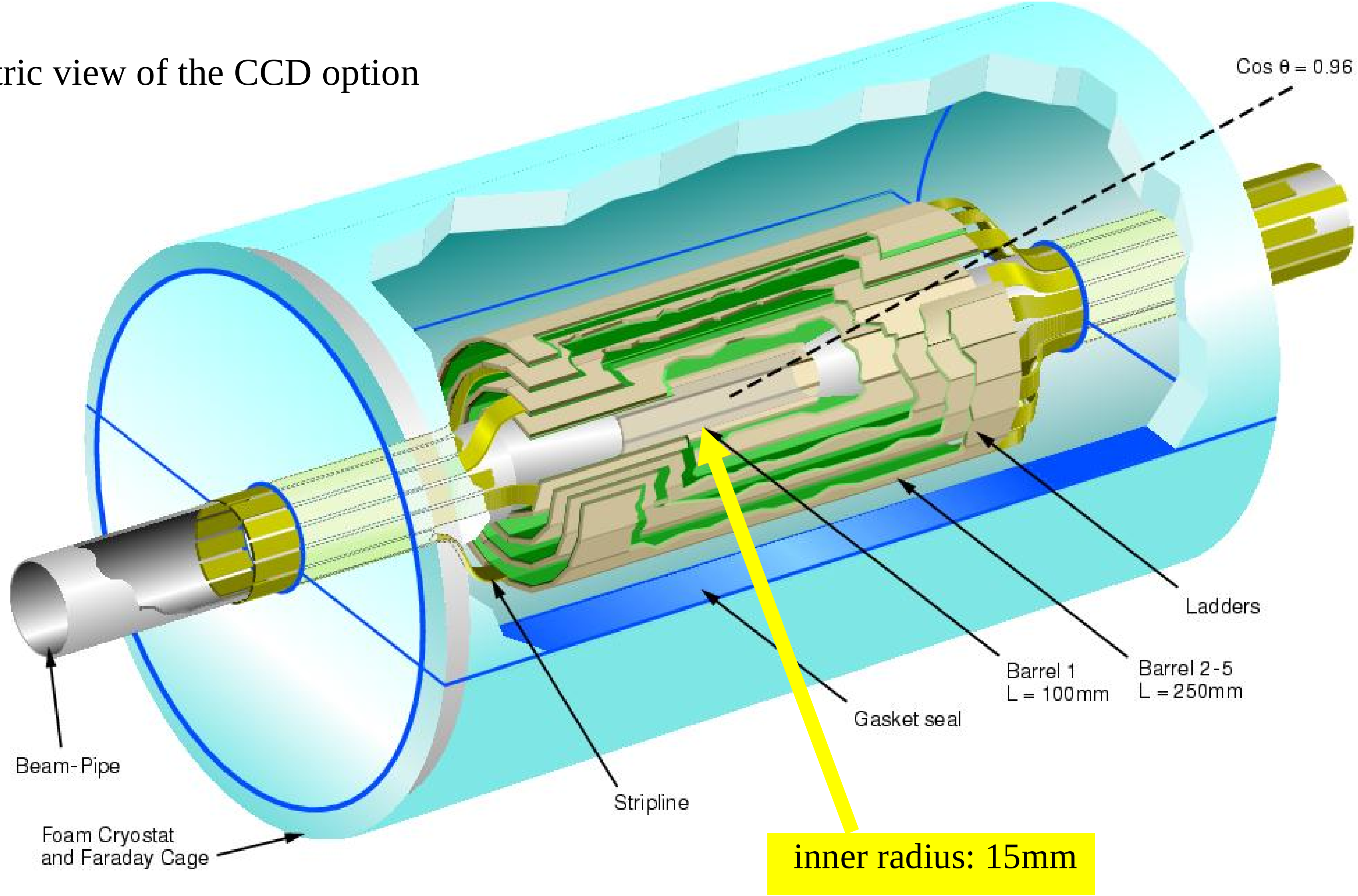
view of a proposed detector for TESLA



ECFA−DESY linear collider study

Vertex Detector

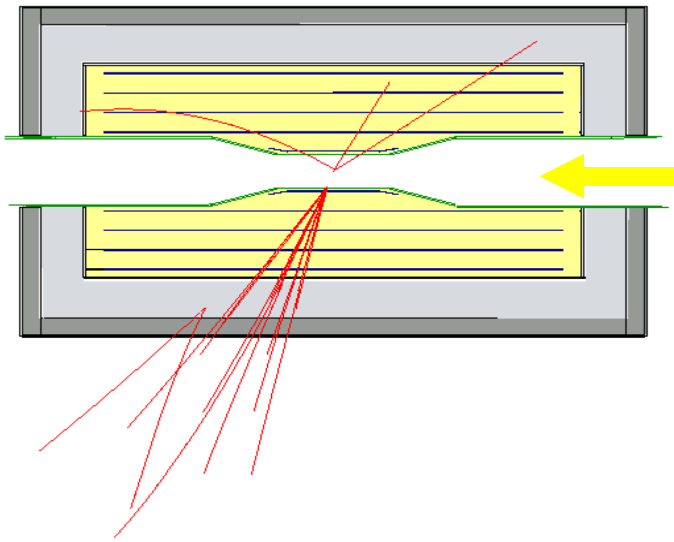
isometric view of the CCD option



Vertex Detector

Vertex detector:
several options under discussion
requirements:
extremely good precision
radiation hard
fast
high granularity

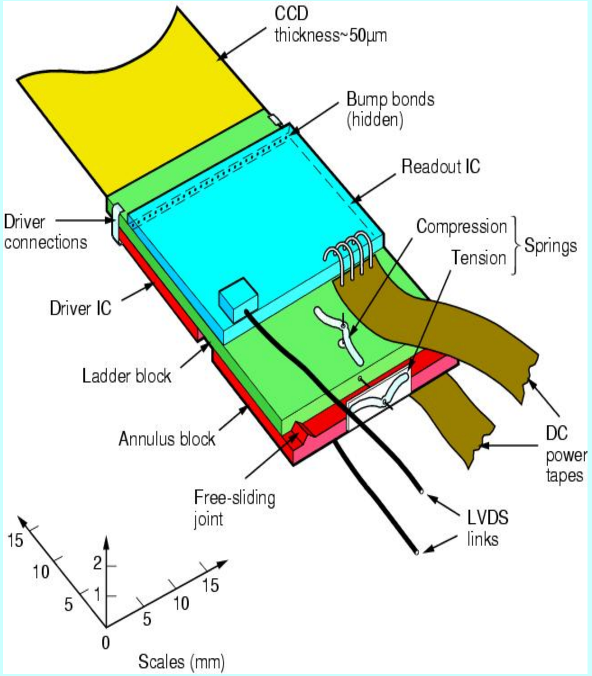
physics case: B−physics: detached vertices



1.5 cm beampipe

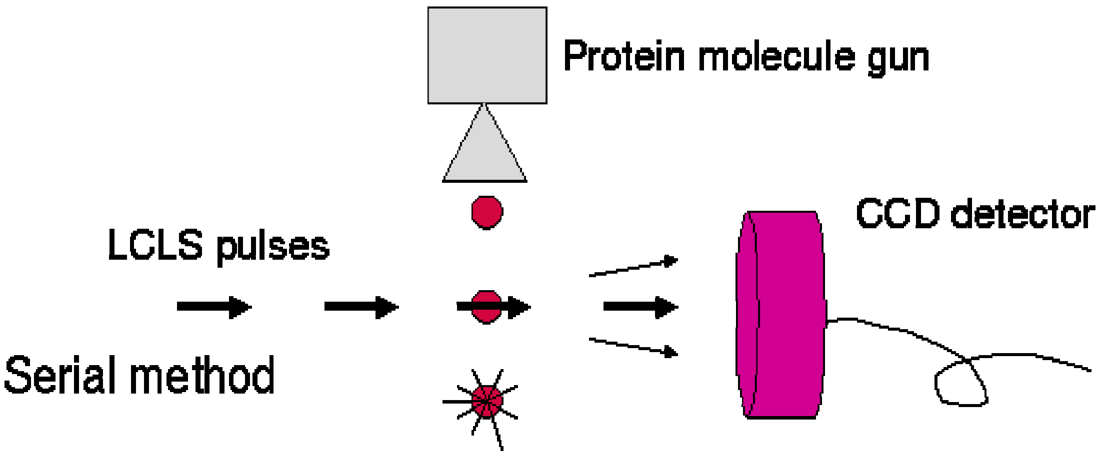
construction detail:

extremely thin ladder (50 um)
ladders are "stretched" from two sides



CCD Detector at the FEL

FEL will require improved and
new experimental methods:



needed: fast, precise detector: CCD

fast recording of diffraction picture from individual molecules

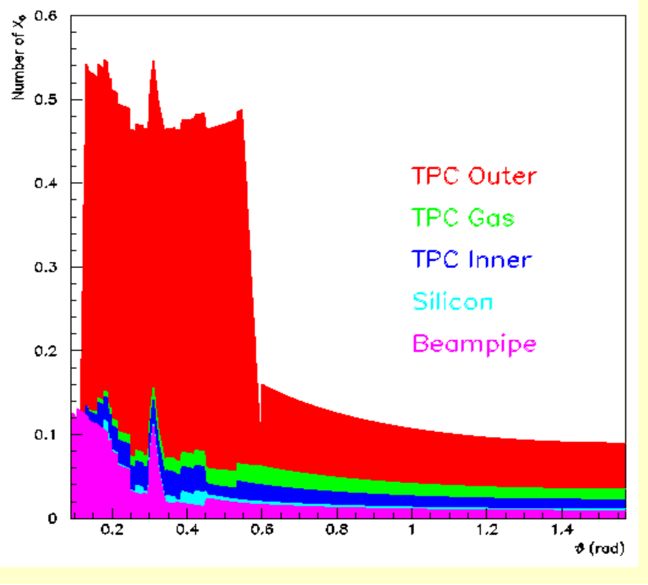
Development of experimental techniques at the FEL is starting
Both HEP and FEL will profit from their respective experiences

TPC tracking System

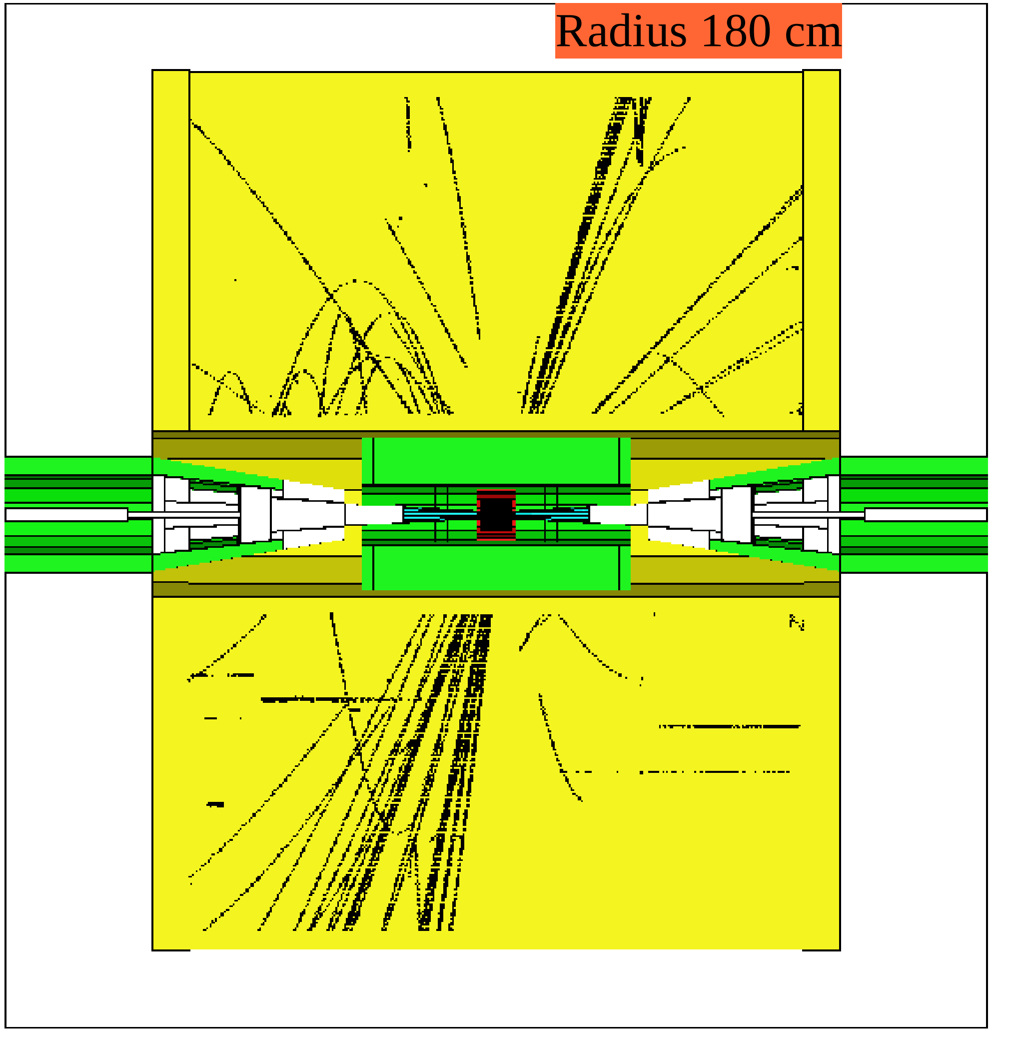
TPC: Time Projection Chamber

large gasfilled system
little material
true 3−D reconstruction possible
large granularity

material budget:

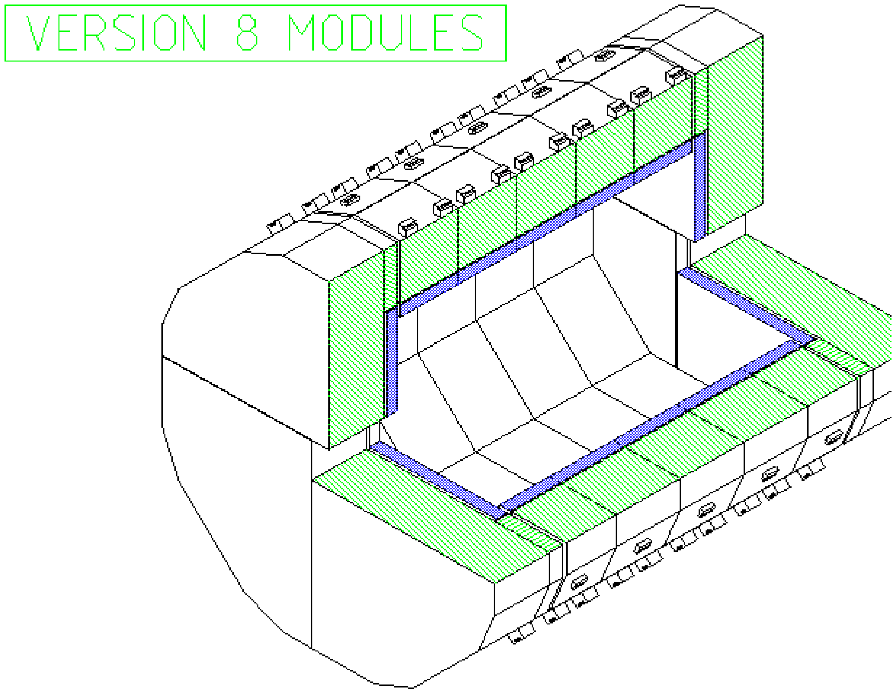


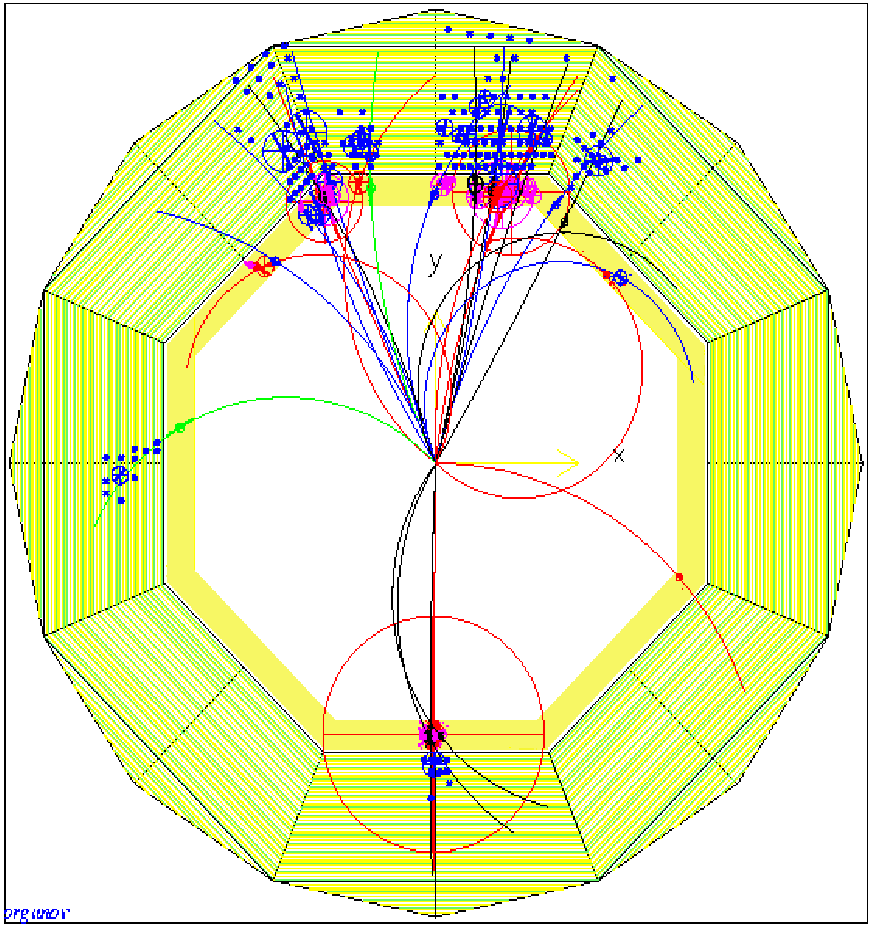
a simulated dd event



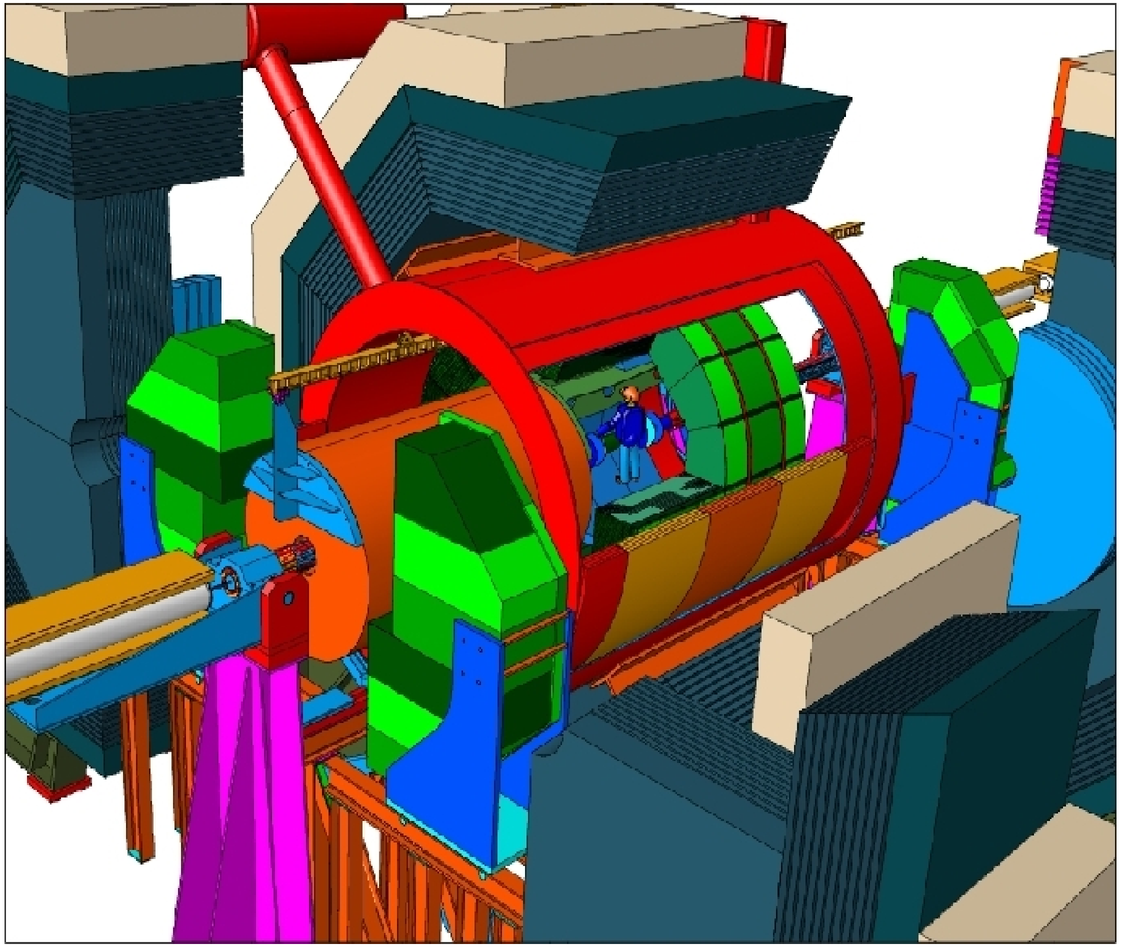
Calorimetry

- calorimeter at E>500 GeV will be very important
- TESLA concept:
  - a high precision, "tracking" calorimeter
  - W absorbers, SI sensors (1x1 cm^2 pad)



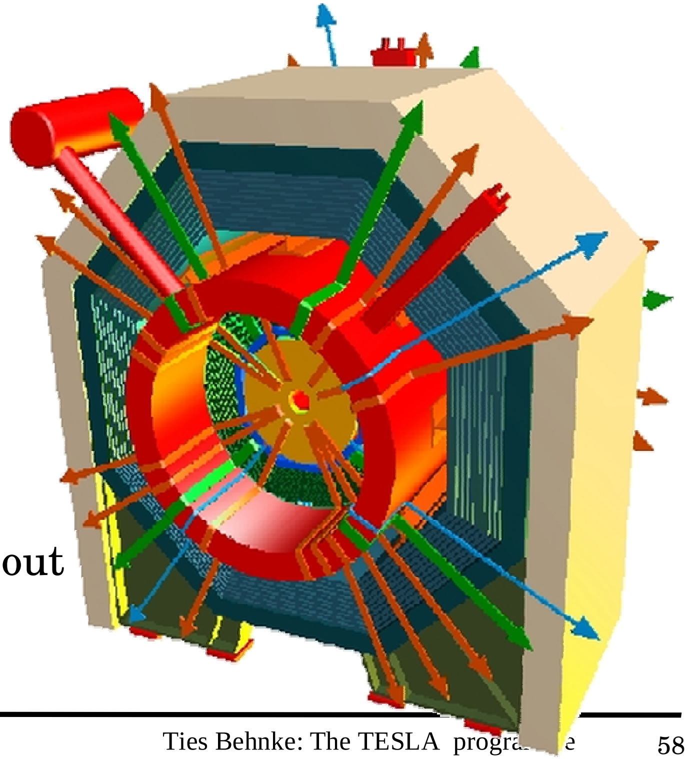


Detector Mechanics



First conceptual version of detector moving and installation:

- Open the endcap Yoke
- Retract the endcap calorimeters
- Move the TPC along z
- Acces the inner detectors



Proposed cable routes out of the detector

Summary Particle Physics

- a linear collider with E= 500 to 800 GeV offers a rich physics program

- EWSB: major insights expected
  - Higgs precision measurements
  - SUSY (or similar) precision study
  - model independent search for alternative scenarios

very strong hints for physics at a few 100 GeV!

- many precision measurements to significantly extend our present knowledge
  - electroweak precision measurements
  - W mass measurement
  - top mass and properties
  - QCD physics
  - ....

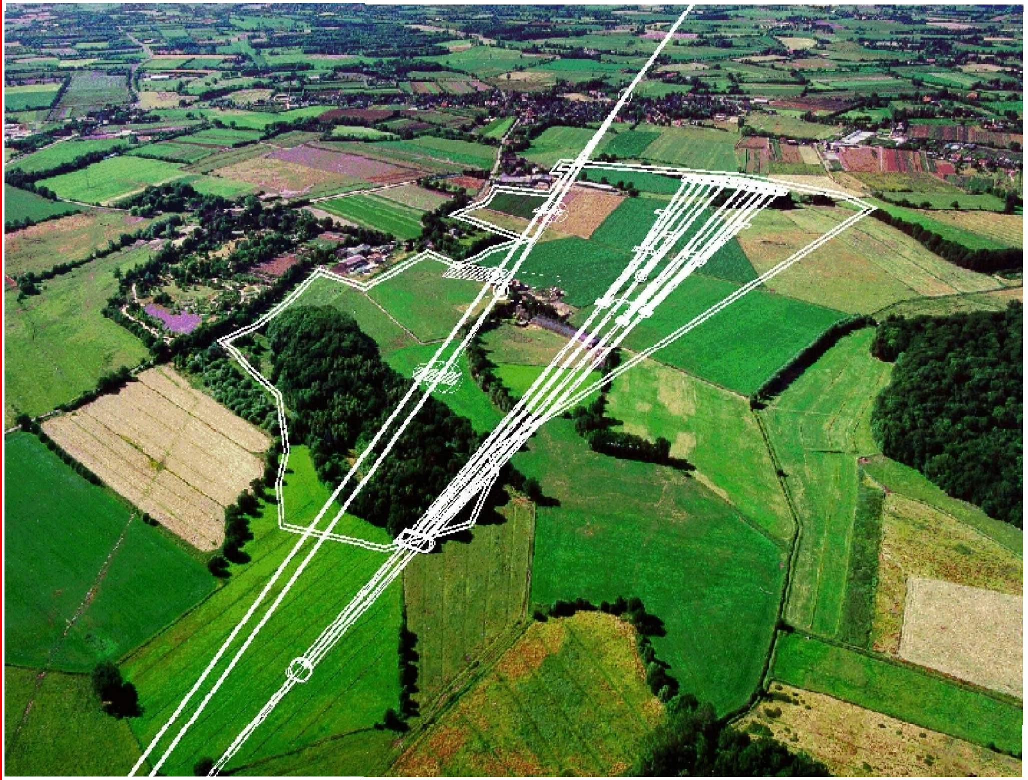
results feed back into EWSB understanding

- a linear collider will also search for the totally unexpected
  - substructure?
  - completely new physics: extra dimensions?
  - ...

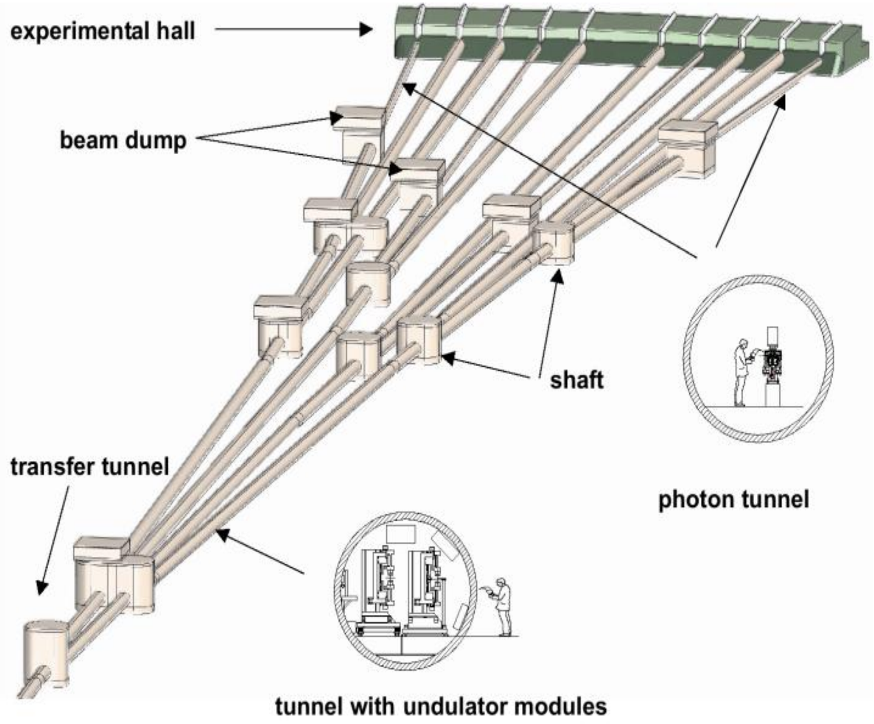
- the linear collider will complement the physics program of the LHC. Only together can we hope to understand the fundamental problem of electroweak symmetry breaking!

The TESLA FEL: Overall Layout

Aerial view of the Ellerhoop Campus:

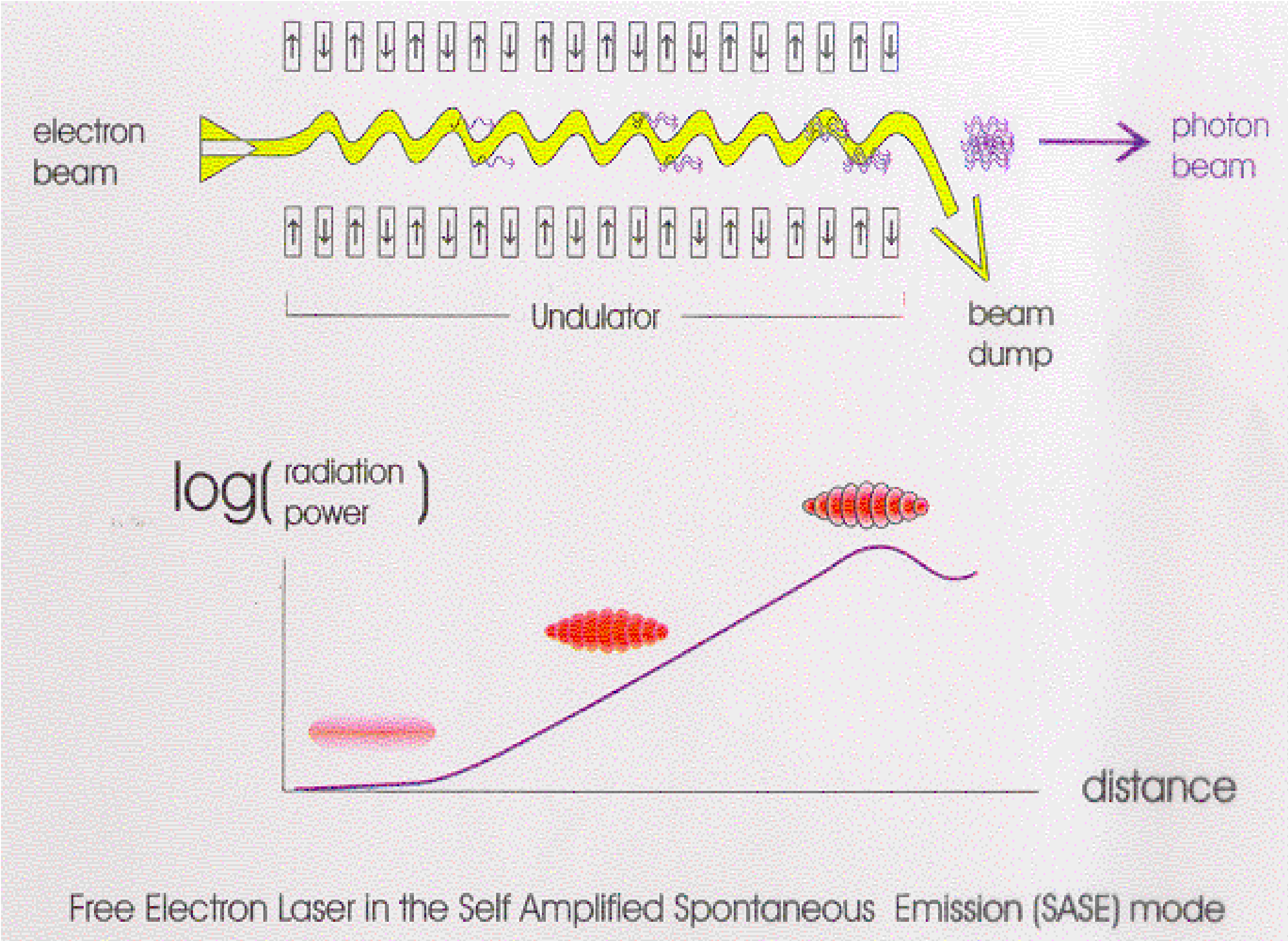


Layout of FEL beamlines

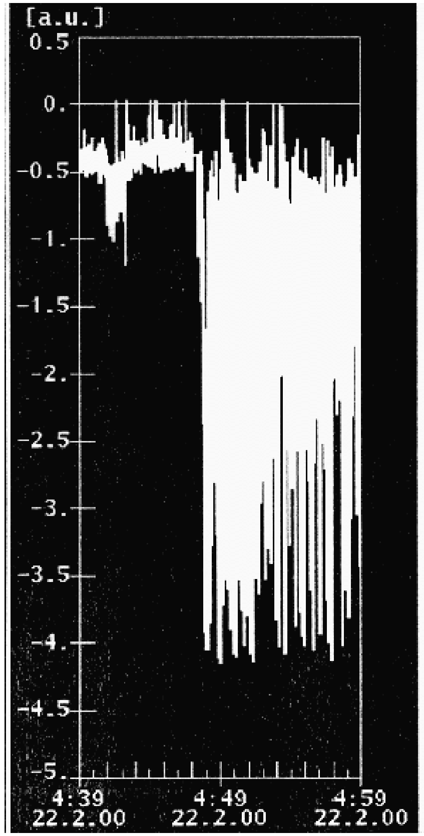


The SASE Principle

- electron beam is sent through undulator
- coherent emission of laser light:



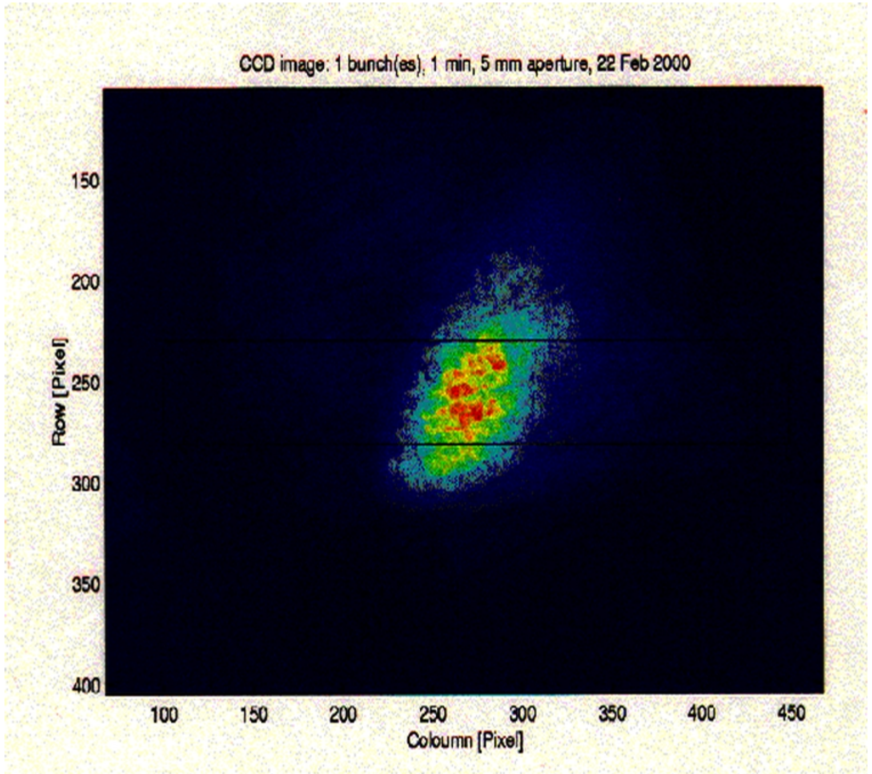
first lasing observed
at DESY February 2000



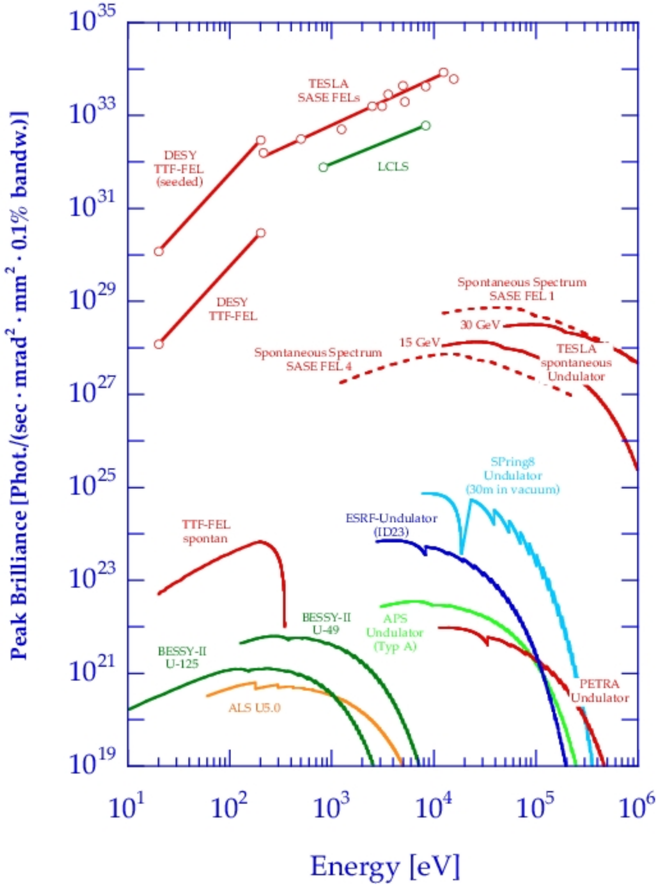
The TESLA FEL

First lasing at <100 nm observed 02–2000

Since then: continuous improvement and optimisation



FEL operation: brilliance vs energy

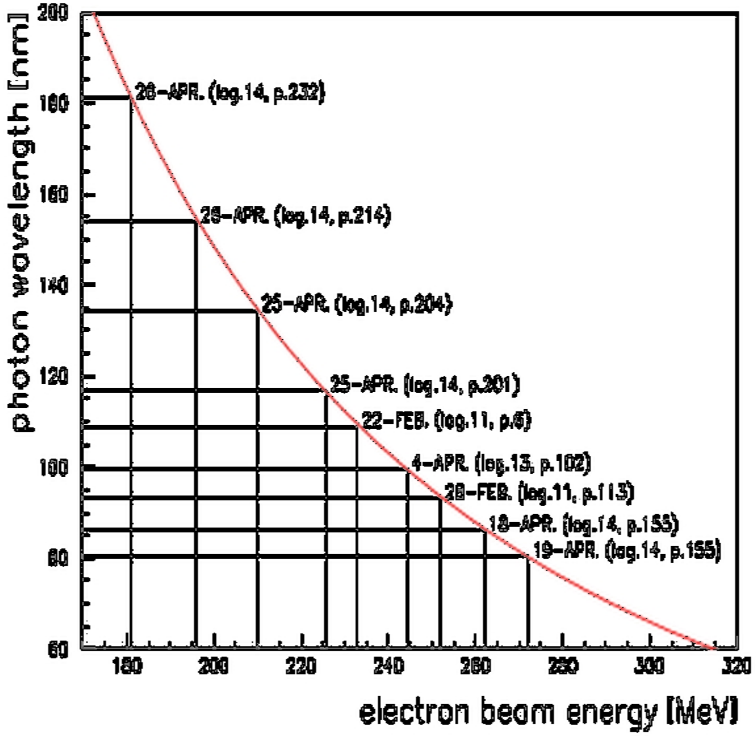


The TESLA FEL

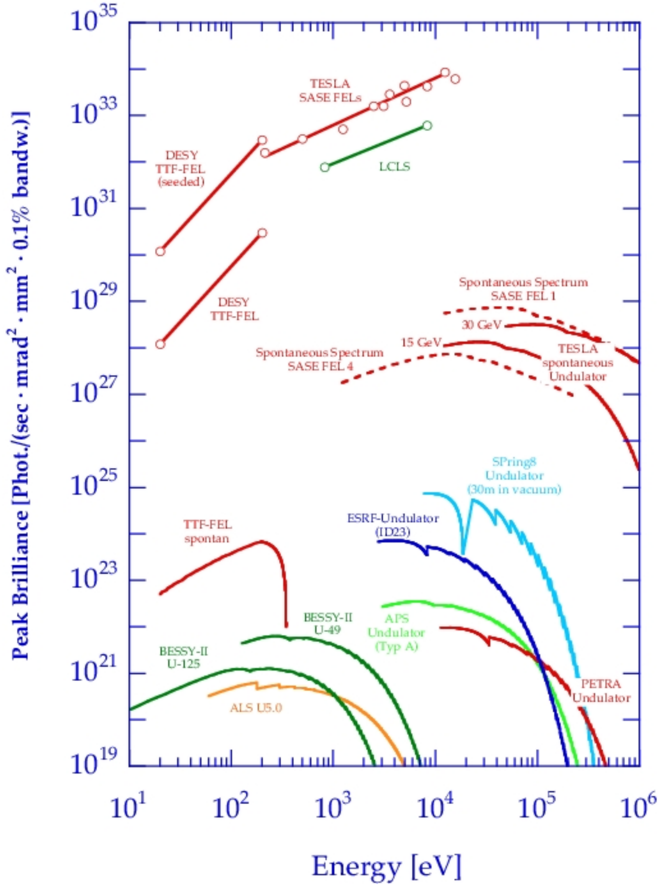
First lasing at <100 nm observed 02–2000

Since then: continuous improvement and optimisation

Smaller wavelength
tunable wavelength
higher brilliance



FEL operation: brilliance vs energy



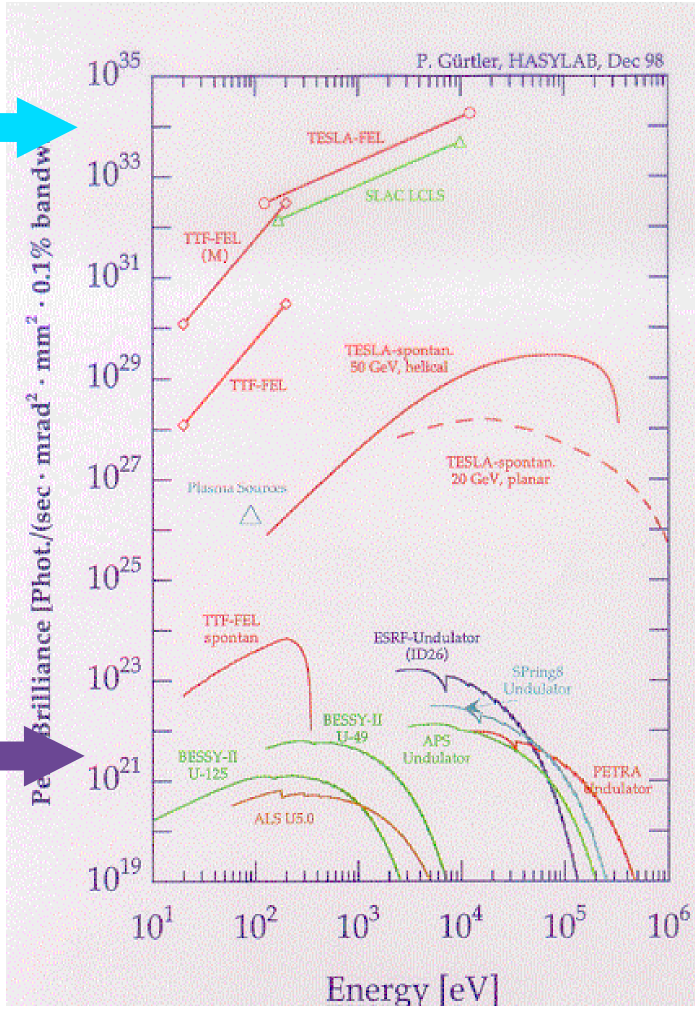
Parameters of the TESLA−FEL

Brilliance of different sources:

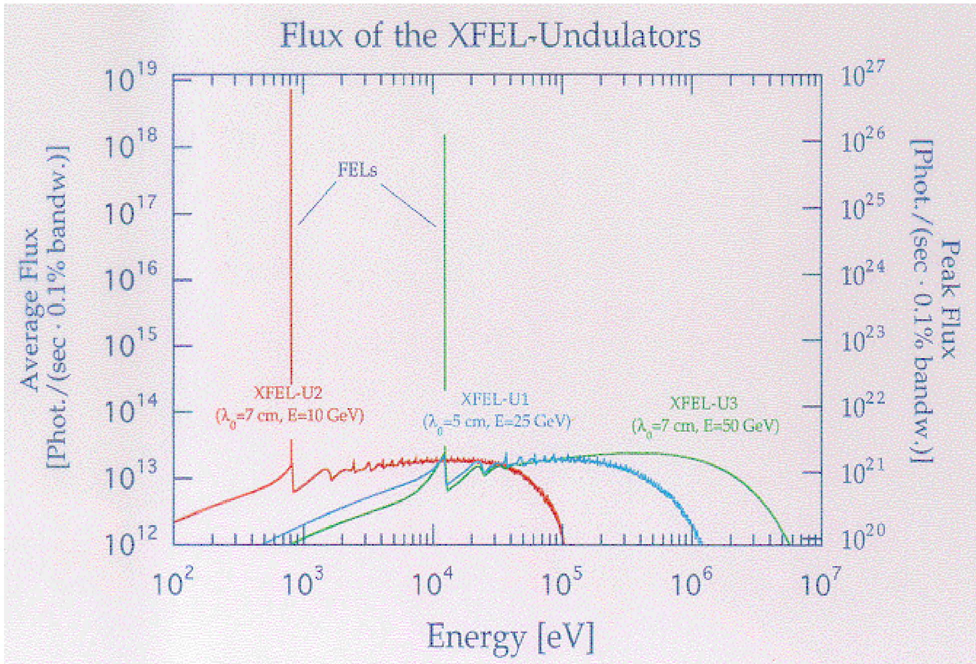
TESLA FEL

SLAC FEL

current



expected Photon Flux for XFEL



Properties of X−FEL Radiation at TESLA

Electron Beam

- energy: 15−50 GeV
- frequency 5 Hz
- Charge/bunch 1 nC
- Bunchlength 80 fs
- Bunchtrain 11315 bunches

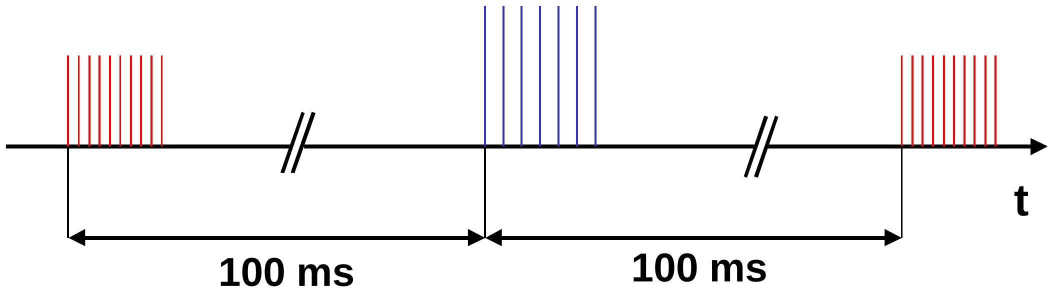
Photon Beam

- wavelength 20−1 A
- ‘peak brilliance’ 2×10^{34}
- photons/ pulse 7×10^{12}
- bandwidth 0.1%
- beam divergence ~ 1 µrad

FEL Bunchtrain
11315 Bunche à 1 nC
Δt = 93 ns

PP Bunchtrain
2820 Bunche à 3 nC
Δt = 337 ns

FEL



Research at FEL's

• atomic physics, interaction with matter, plasmaphysics

intensity, short pulses

• femtosecond chemistry, structural biology

short pulses

• spectroscopy: dynamics of complex systems, holography on a atomic scale

coherent lightsource

This list is extremely incomplete and can only touch upon the different areas of research possible

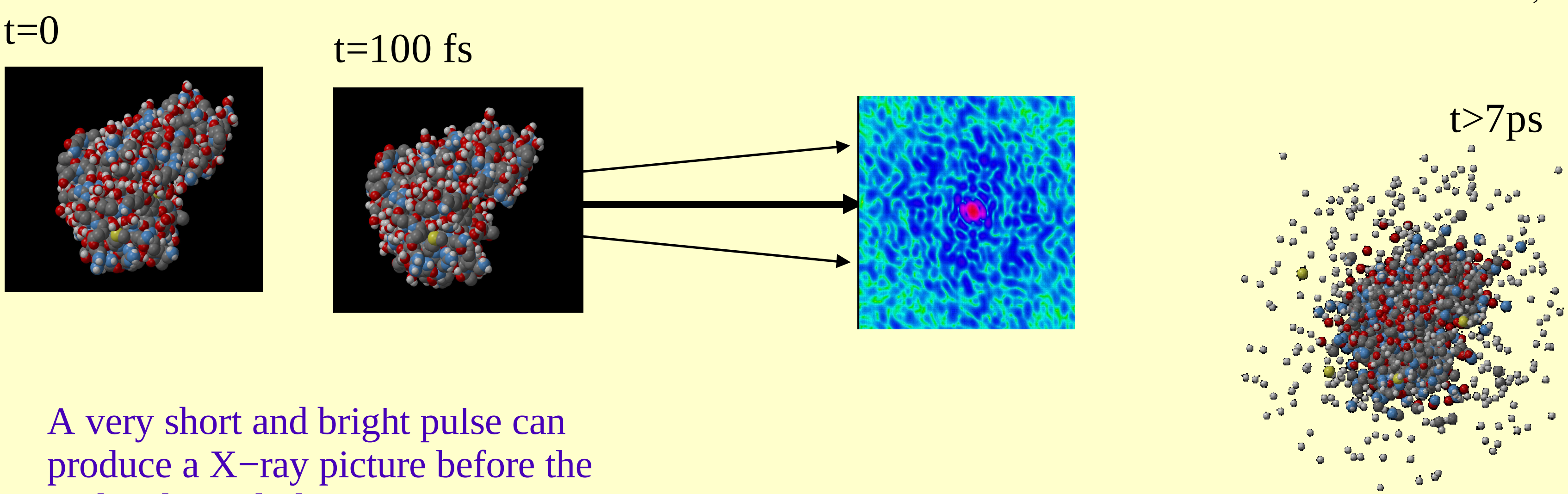
Interaction with Matter

The XFEL pulse is extremely energetic:

- per pulse $>10^{12}$ photons
- average power density 1000W/ cm^2
- ‘peak power’ TW/ cm^2
- focussed to 100nm another increase by 10^7
- most materials will evaporate....
- the exact behaviour of matter in under such conditions is not known

example: X−ray diffraction of single protein molecule:

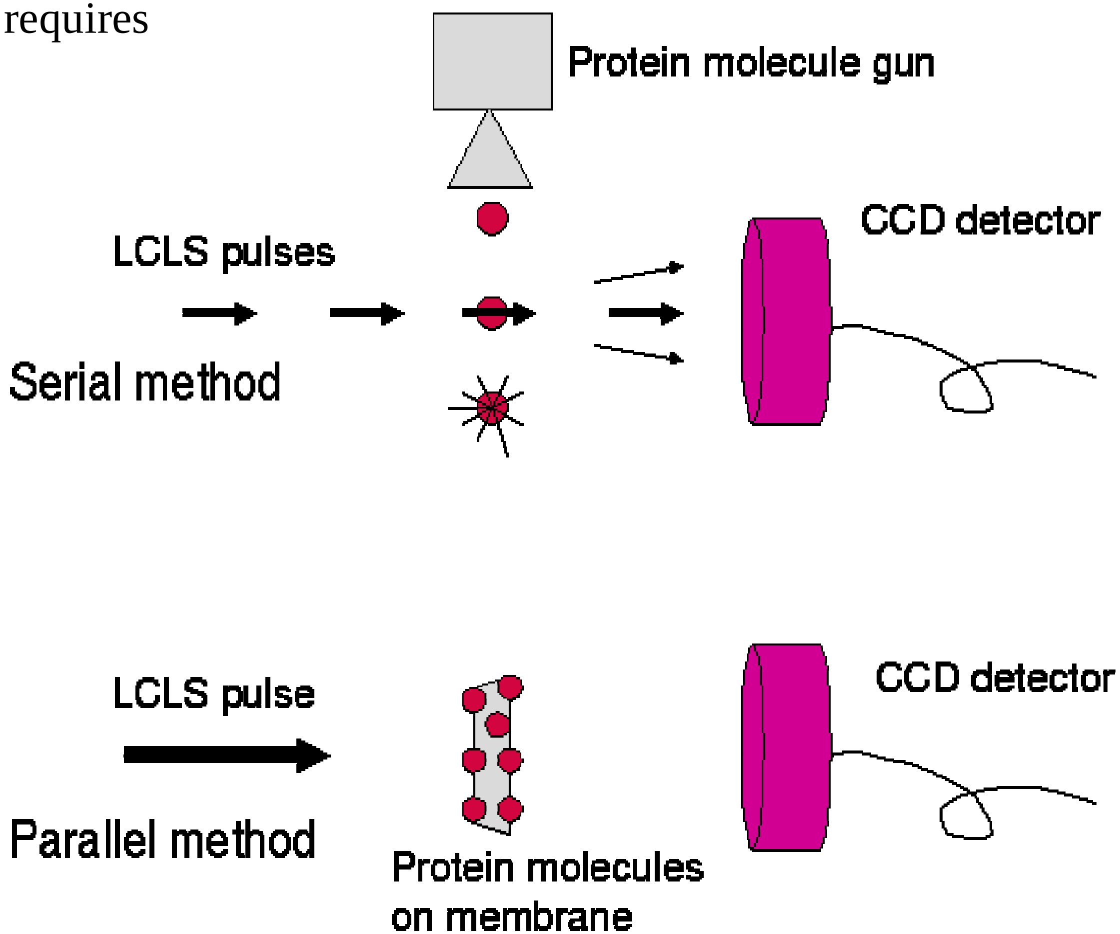
J. Arthur, Stanford



A very short and bright pulse can produce a X−ray picture before the molecule explodes

X−Ray Diffraction

resolving Å structure requires
many molecules:
molecular beam

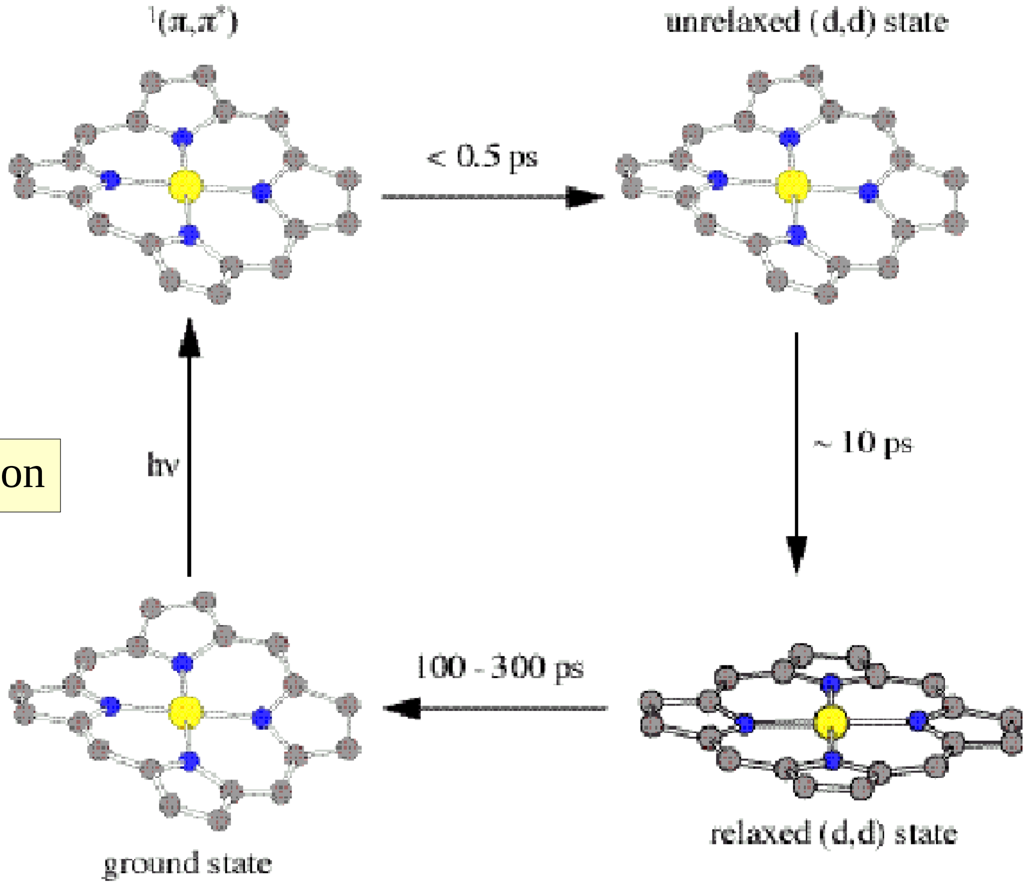


J.Arthur, Stanford

Femtosecond Chemistry

Goal: Study the sequence of dynamical changes on sub−ps time scale following an external disturbance

excitation



Look at dynamic behaviour of systems

Low−spin Nickel(II) Prophyrins deactivation pathway

J. Arthur, Stanford

Conclusion X−FEL Physics Case

A linear electron positron collider has an exciting physics program:

Physics at the free electron laser

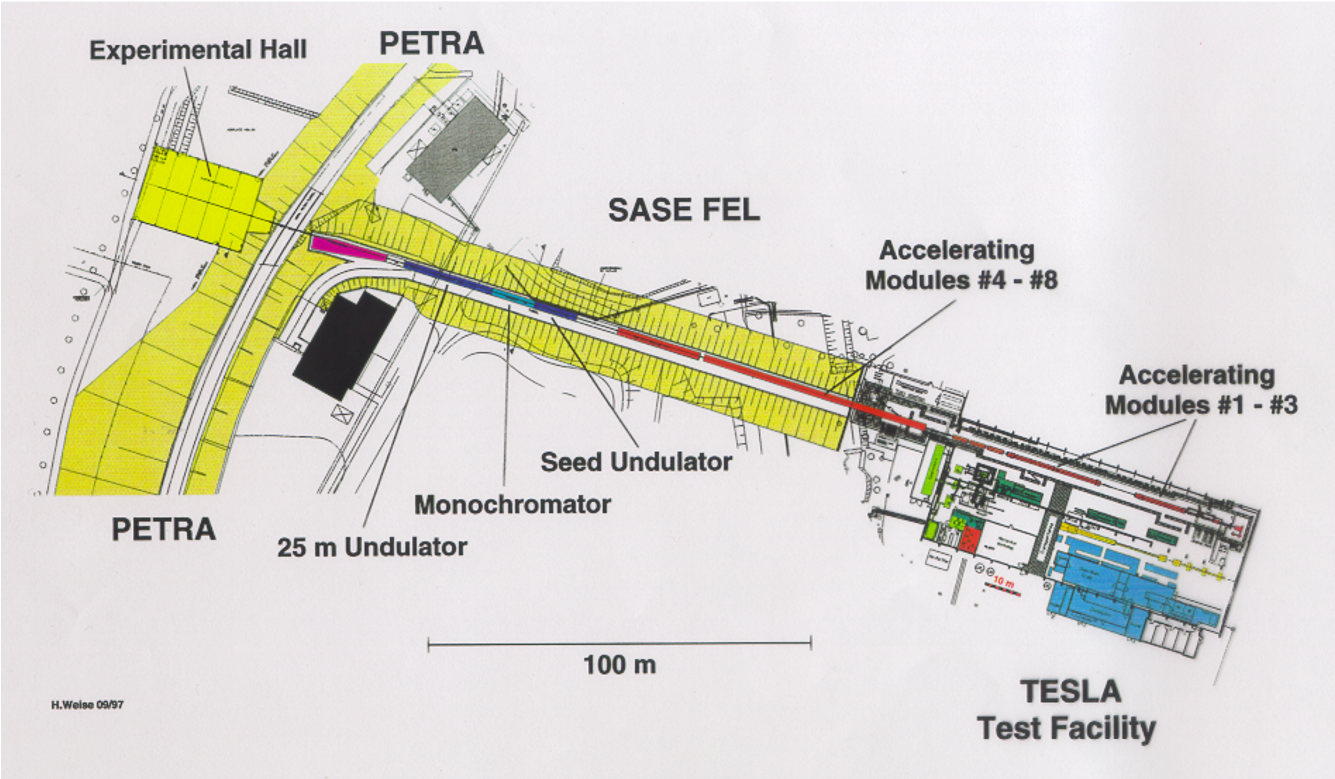
- Look at the dynamics of processes on an atomic scale
- Study single molecules, e.g. biological molecules
- Contributions to many areas of
  - Solid State Physics
  - Atomic Physics
  - Plasma Physics
  - Biology
  - ...

  are expected

A X–FEL has many exciting applications and is carried by a wide and diverse community of physicists. Its an unprecedented example of an interdisciplinary research center

Status of the TESLA Project

• Under construction: Tesla Test Facility Phase TTF II



Goal: −demonstrate the superconducting technology (TTF I, done)

− demonstrate the SASE principle in the <100nm range (done)

−gain experience operating a superconducting linac and FEL

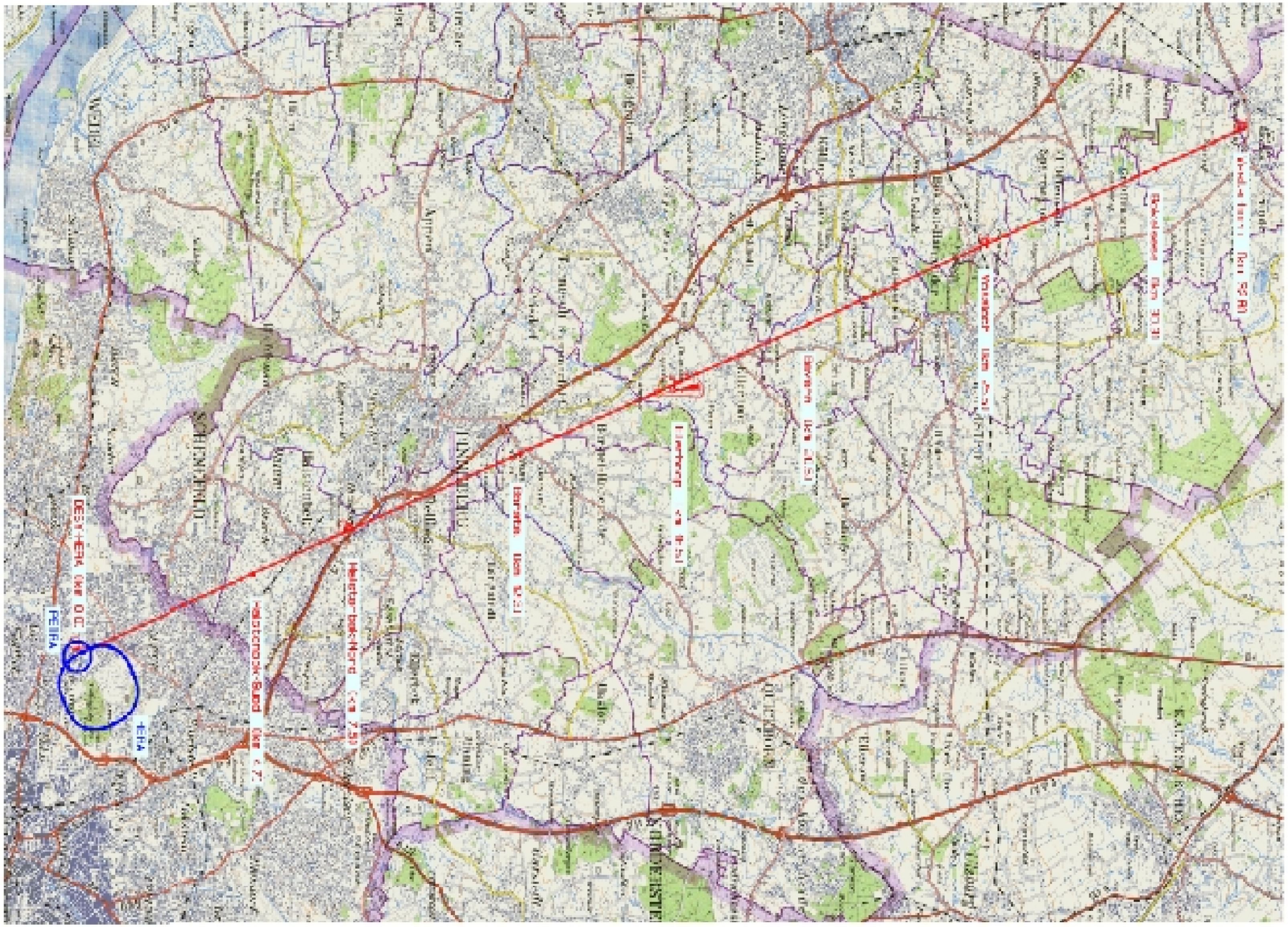
−>2003: user facility for Roentgenlaser

The TESLA TDR

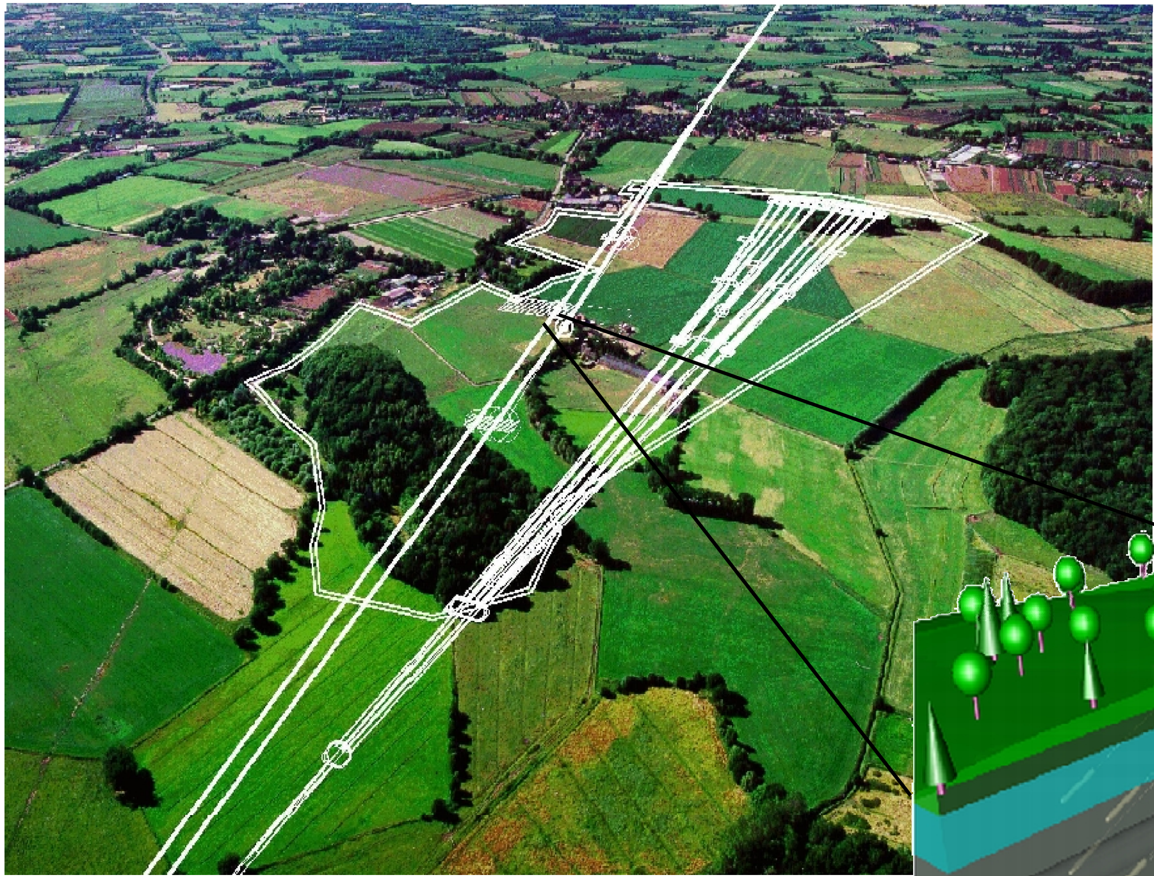
The TESLA TDR: published March 2001
see http://tesla.desy.de/tdr

Presented to the public at the
TESLA scientific colloquium, 23/24 March 2001
in DESY Hamburg

A TESLA Site near Hamburg



The TESLA Research Campus

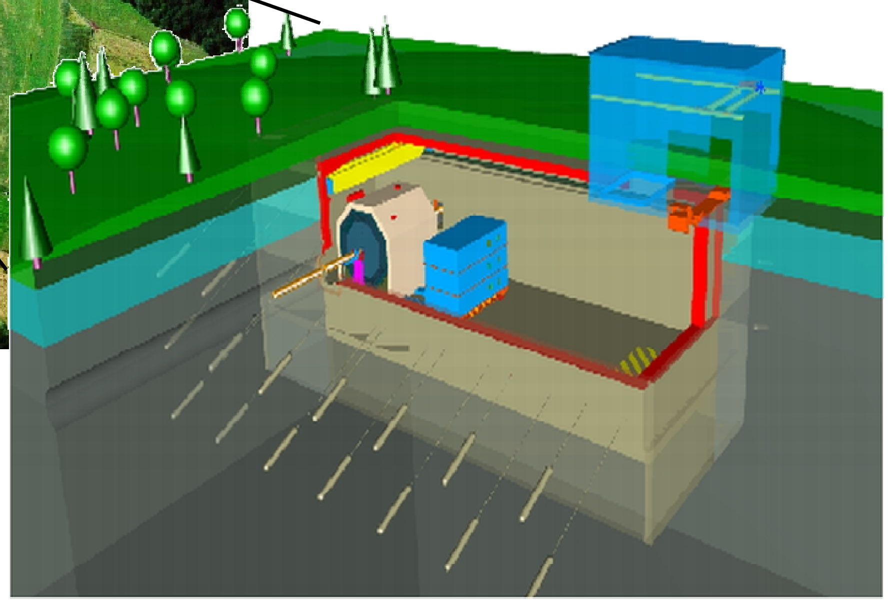


Aerial view of Ellerhoop

Central laboratory site at km15

HEP experiment(s)
XFEL laboratory

Artists drawing of the HEP hall



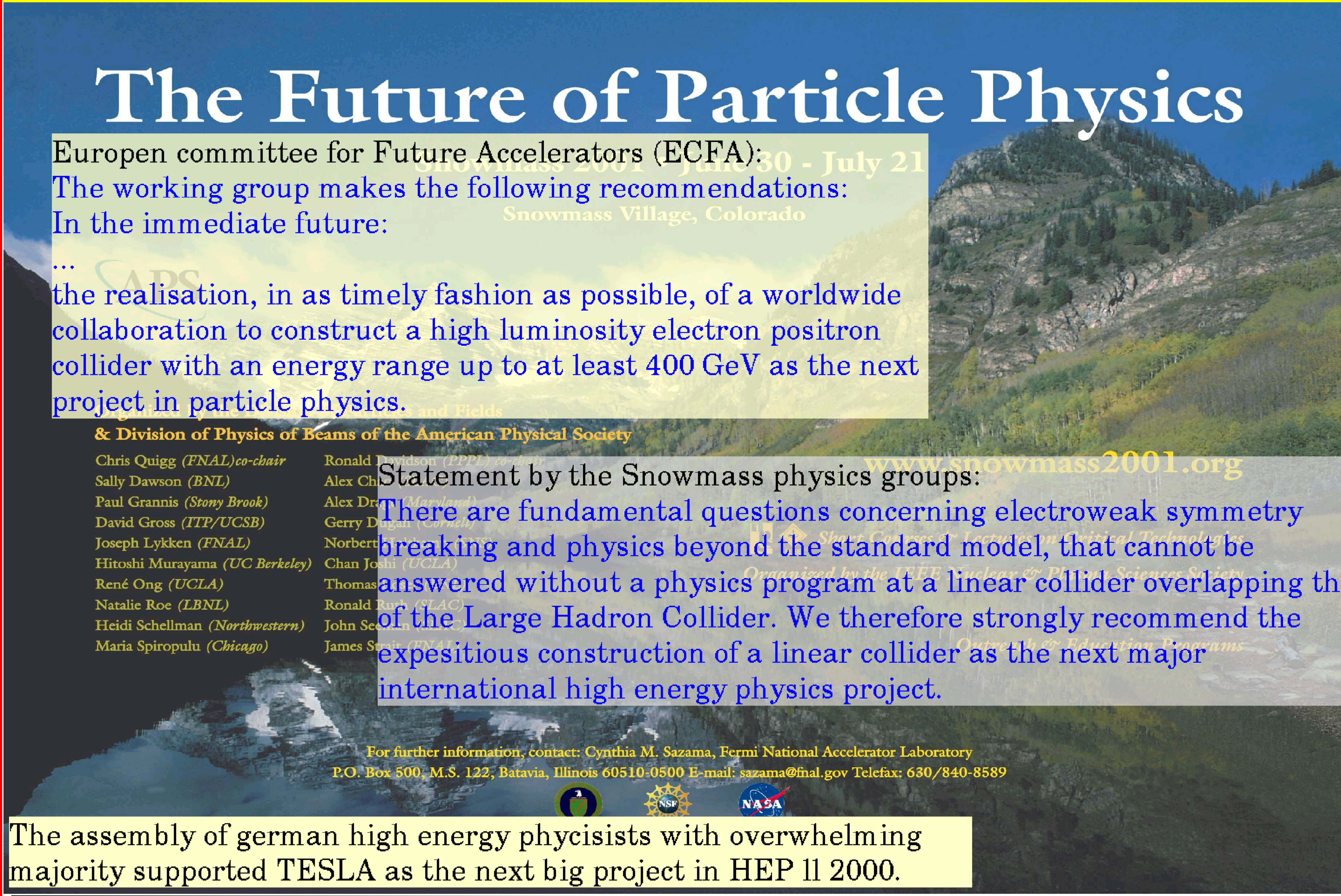
TESLA: Goals and Milestones

- Goals:
  - Develop superconducting technology
  - Use LINAC as driver for X–FEL

- Milestones reached:
  - Routine production of cavities with > 25MV/m
  - Cavities with >40MV/m as single cell cavities
  - Construction and operation of TTF I
    - Stable operation for > 8600 h
    - Demonstrate SASE principle at <100 nm
  - Successful development of klystrons, RF couplers, etc

- Development of the Physics Case
  - 2 ECFA/DESY workshops with large and international attendance (total >10 workshop meetings)
  - Milestone reached: TESLA TDR Part III (physics), PartIV (detector), Part VI (other research options)
  - Continuation for two more years to
    - Develop the physics studies further
    - React to new developments
    - Continue work on the detector (R&D efforts are starting)
    - Continue the work on machine/ detector interface

Situation worldwide



Europen committee for Future Accelerators (ECFA):
The working group makes the following recommendations:
In the immediate future:
...
the realisation, in as timely fashion as possible, of a worldwide collaboration to construct a high luminosity electron positron collider with an energy range up to at least 400 GeV as the next project in particle physics.

Statement by the Snowmass physics groups:
There are fundamental questions concerning electroweak symmetry breaking and physics beyond the standard model, that cannot be answered without a physics program at a linear collider overlapping that of the Large Hadron Collider. We therefore strongly recommend the expesitious construction of a linear collider as the next major international high energy physics project.

The assembly of german high energy phycisists with overwhelming majority supported TESLA as the next big project in HEP 11 2000.

A Global Accelerator Network

Construct and operate future large accelerators in the framework of a global network

- Make projects part of the national programs of the participating countries
- Maintain the scientific and technical culture and know how in home labes, remain attractive for young people, yet contribute to and participate in large, unique projects
- Maintain and run accelerators to a large extend from participating labs
- Pull together world–wide competence, ideas, resources

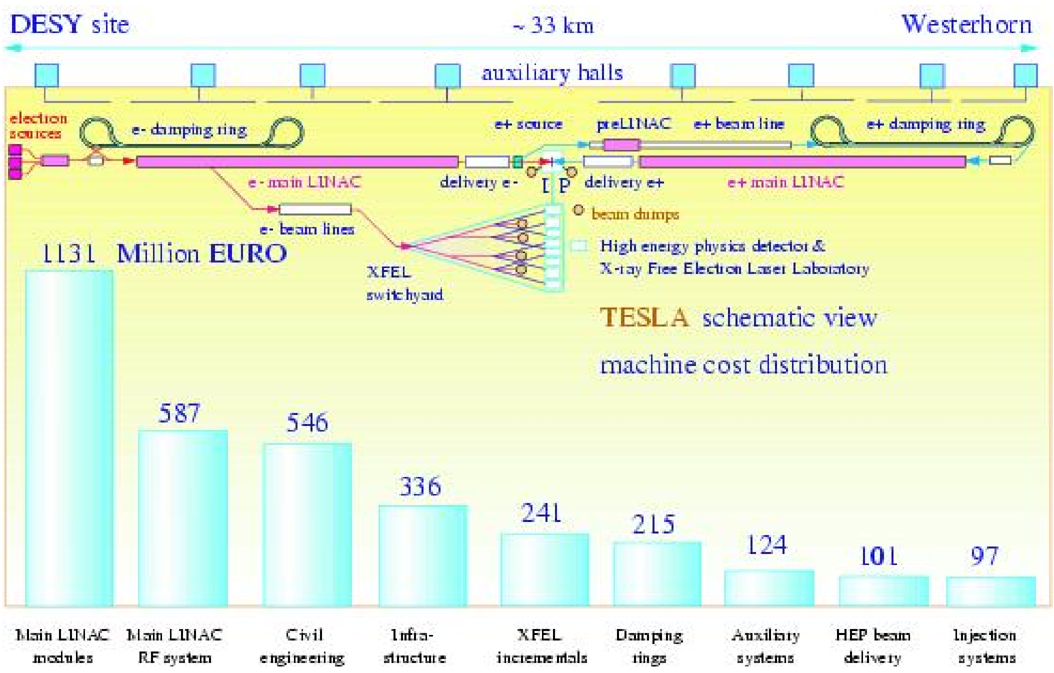
- Capital investment is done at home
- Site selections becomes a less critical issue
- Put accelerator close to an existing laboratory:
  - Make optimal use of existing experience, manpower, and infrastructure
  - Specific financial obligations for the host country

ICFA study findings:

Global considerations:
- Need laboratory structure
- Host nation is essential
- Will bear a major fraction of the cost

Technical considerations:
- Project requires central management
- Host lab will have safety responsibility
- Remote operation is in principle feasible
- Local staff of approx. 200 is needed

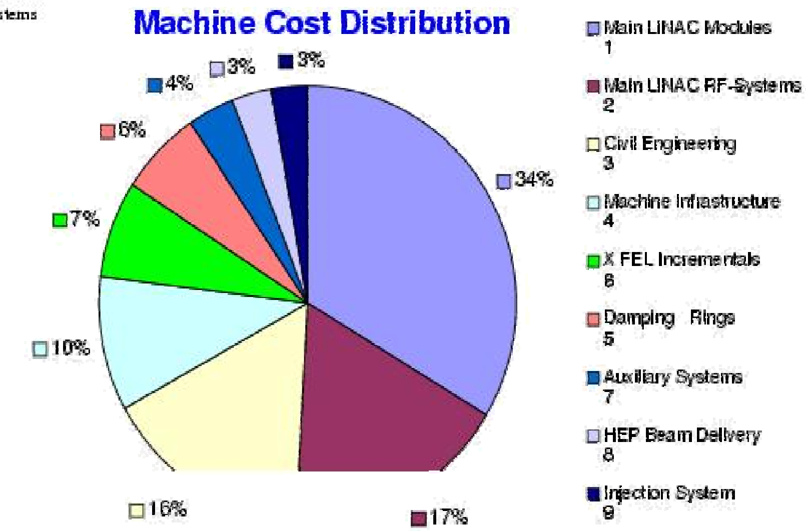
Costs and schedules



Total estimated TESLA cost:
3136 million Euro

X–FEL additional machine elements:
241 million Euro

Cost of particle physics detector:
about 200 million Euro



Installation schedule:

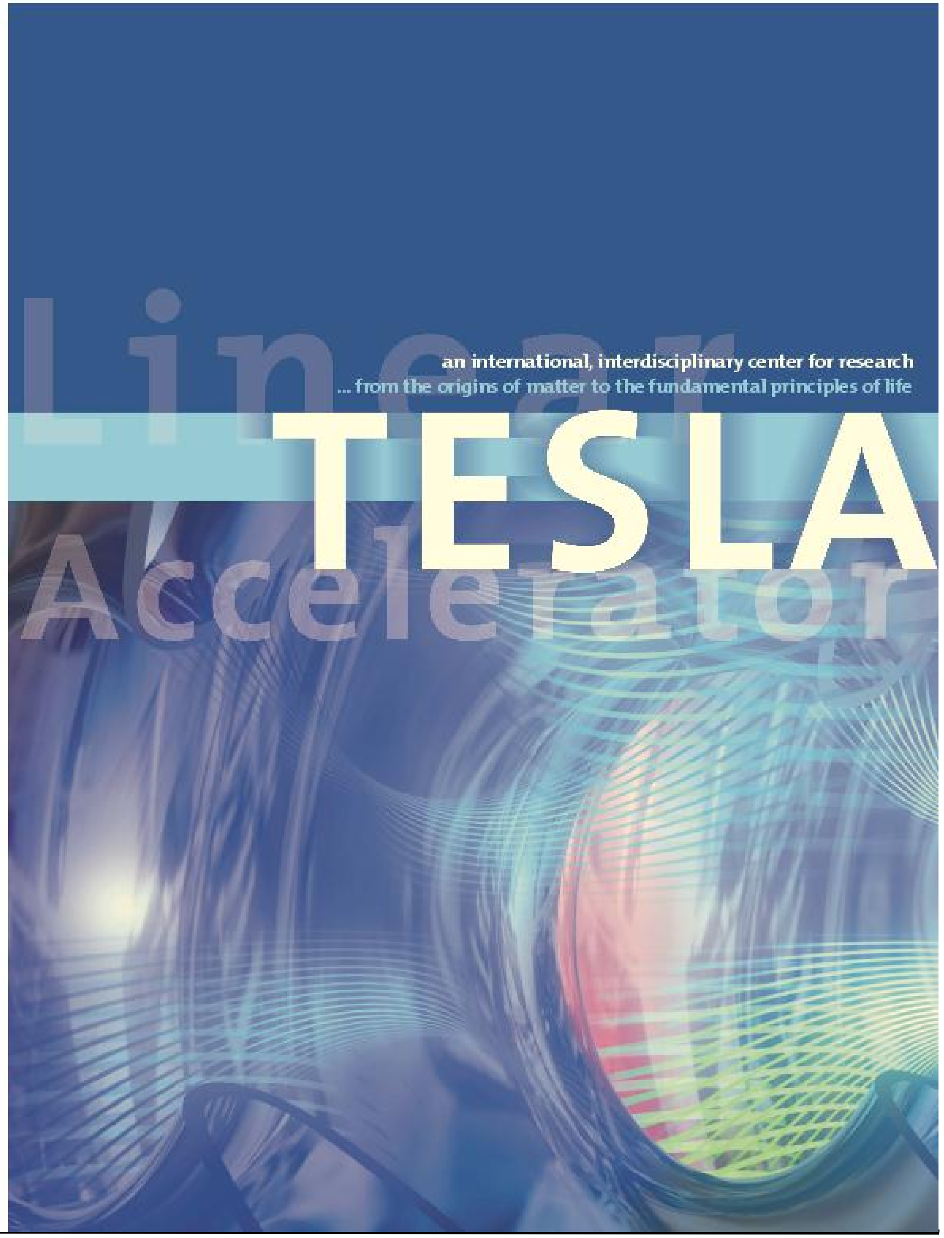
total construction time after approval:
8 years
4 years to drill the tunnel
4 years to fill the tunnel

Conclusions

- TESLA: a proposal for a new large interdisciplinary research cent
- Most technical problem are solved
- 500 GeV baseline design is "conservati
- Energy upgrade potential is real

- HEP experimentation at TESLA is challenging
- Needs serious and significant Detector R&D
- Combination of HEP and FEL offers exciting new perspectives

- Plans:
  - TESLA TDR now
  - German Wissenschaftsrat: 2002
  - International technical review?



Conclusion

- TESLA is an exciting new project connecting HEP and many other areas of science
- TESLA is in a state where we are confident that it can be build as proposed and within cost
- TESLA is a serious contender in the international competition about the next generation of HEP machines
- TESLA is ideally suited to complement the LHC
- TESLA opens completly new avenues of research in the synchroton radiation community
- The concept of a Global Accelerator Network is a very attractive scheme to realise such a machine

Now is the right time to move ahead and start with TESLA. Lets do it!