From FEL to TESLA

− From FEL to TESLA and Next Linear Collider

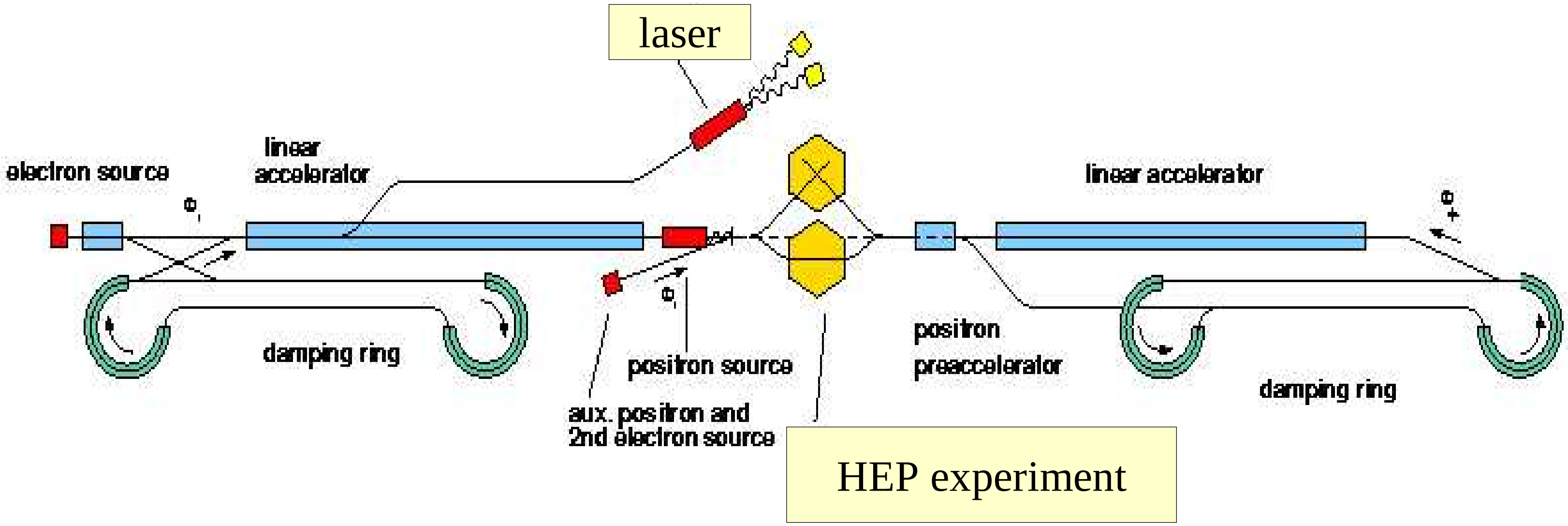
Ties Behnke, Deutsches Elektronen Synchroton, DESY, Hamburg

invited talk at the IEEE 2000, Lyon, France

- The Physics Case:
  - High energy physics at the energy frontier
  - Physics at the X−ray laser (FEL)
- The machine:
  - Linear Colliders
  - The Free Electron Laser
- The Instrumentation
  - Challenges

The TESLA Project

TESLA: Terra Electronvolt Superconducting Linear Accelerator



- a facility for particle physics (500 − 800 GeV electron positron collisions)
- a facility for synchroton radiation: Roentgenlaser

Linear Collider Projects

A number of projects exist worldwide:

USA: NLC
Japan JLC
Europe TESLA

particle physics:
three regional workshops/ studies

USA american LC workshop
Japan ACFA workshop
Europe ECFA/DESY workshop

2000 2001 2002 2003 2004 2010

Tesla TDR approval? start construction?

german science council

international definition

The Physics Case for TESLA

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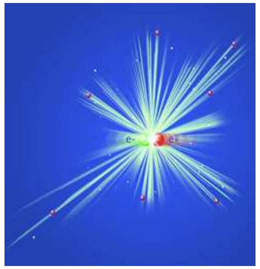
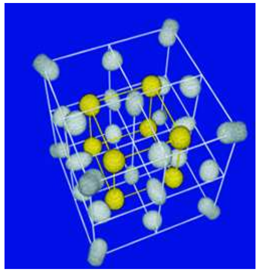


electron positron collisions at the highest energies

investigate the basic constituents of matter
understand the forces between particles
understand the structure of the vacuum

- The Higgs mechanism
- Physics beyond the SM
- SM physics at TESLA



Roentgenlaser at highest intensities

investigate the properties of materials, biological molecules, ...
understand dynamic in addition to static features

- solid state physics
- "life sciences"

TESLA Parameters

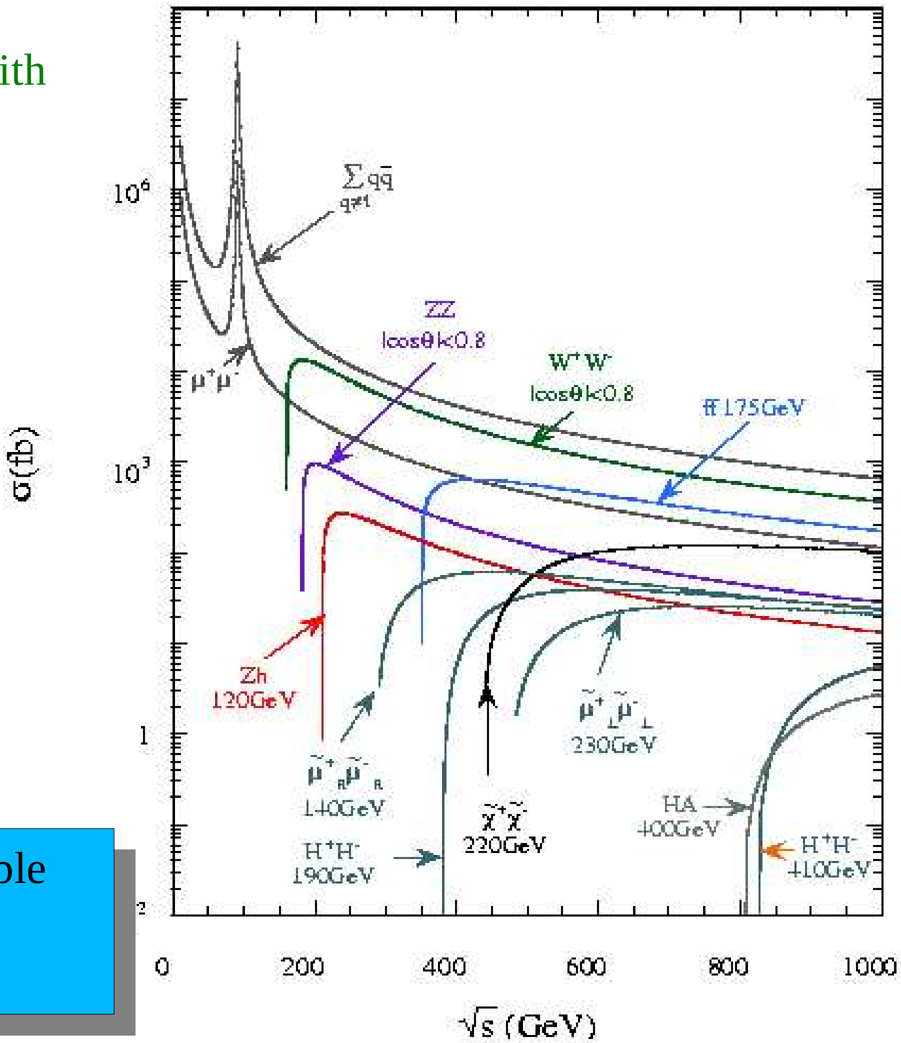
TESLA: electron positron linear accelerator with
an integrated X−Ray laser

luminosity: $5x10^{34}$ $cm^{-2}s^{-1}$

integrated luminosity 50−500 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



The Higgs Particle

Standard Model has been enormously successful, but:

Why do particles have a mass?

standard theory predicts all particles to be massless: m=0!

idea: David Miller
grahics: CERN

Higgs Bosons:

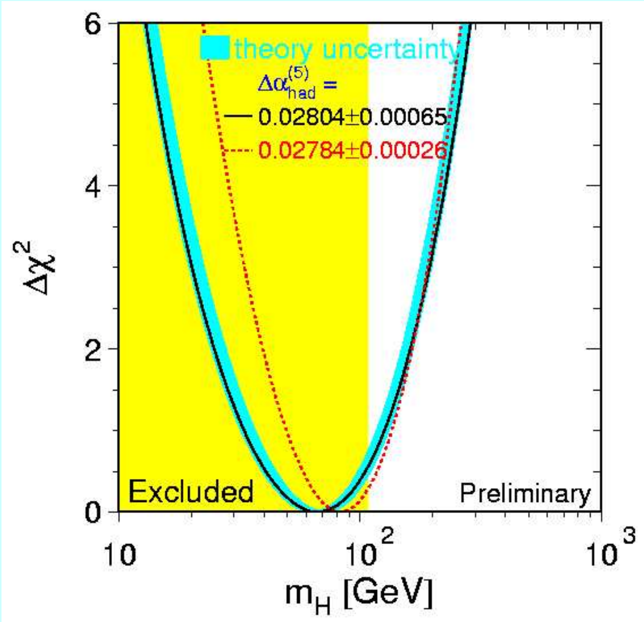
Particles acquire a mass through interaction with another particle: The Higgs Boson

- Higgs boson expected to be heavy
- so far no not seen experimentally

The Standard Model and the Higgs

- what do we know so far about the Higgs?

indirect limits from LEP



m < 188 GeV
@ 95% CL

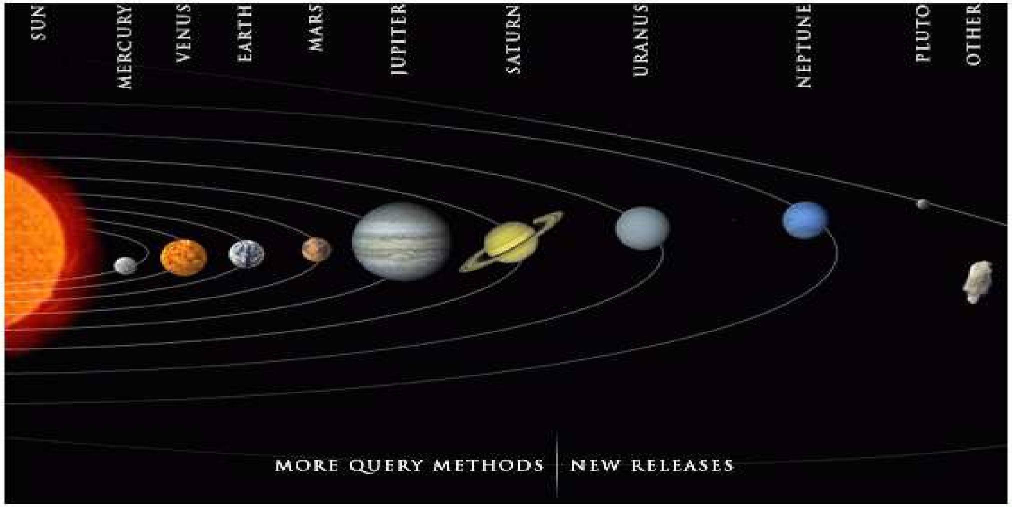
result of global fit,
inputs from
- LEP
- SLD
- Tevatron
- Neutrino Experiments

light Higgs is clearly favoured in SM

Precision has played an important role in physics for previous discoveries:

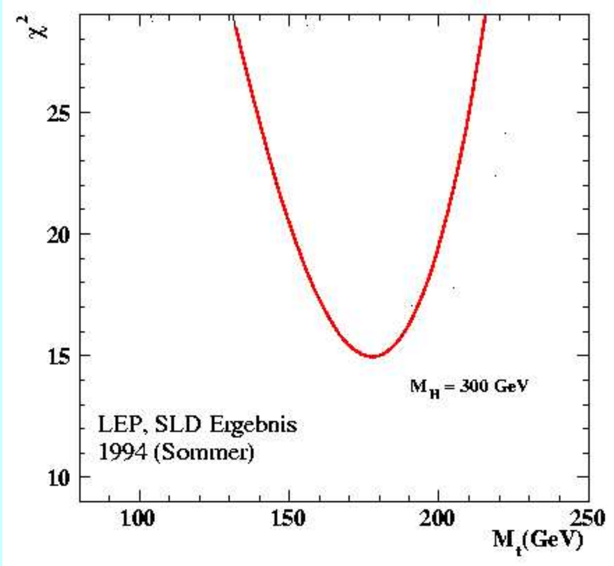
Precision in Physics

example: astronomy



observed: small deviations from the expected trajectories of the planets
predicted: an additional planet can explain the observation
discovery: PLUTO was found

example: Particle physics



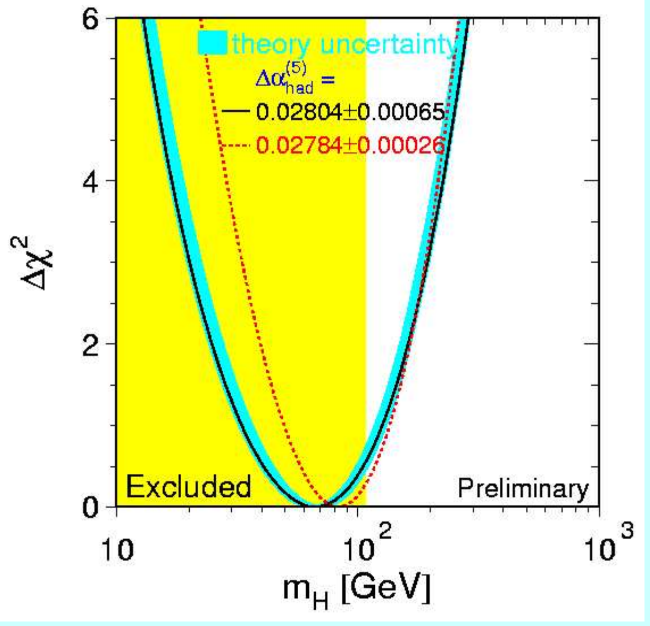
indirect limit for the top quark

discovery: 1995, Tevatron (USA) at the predicted mass

The Standard Model and the Higgs

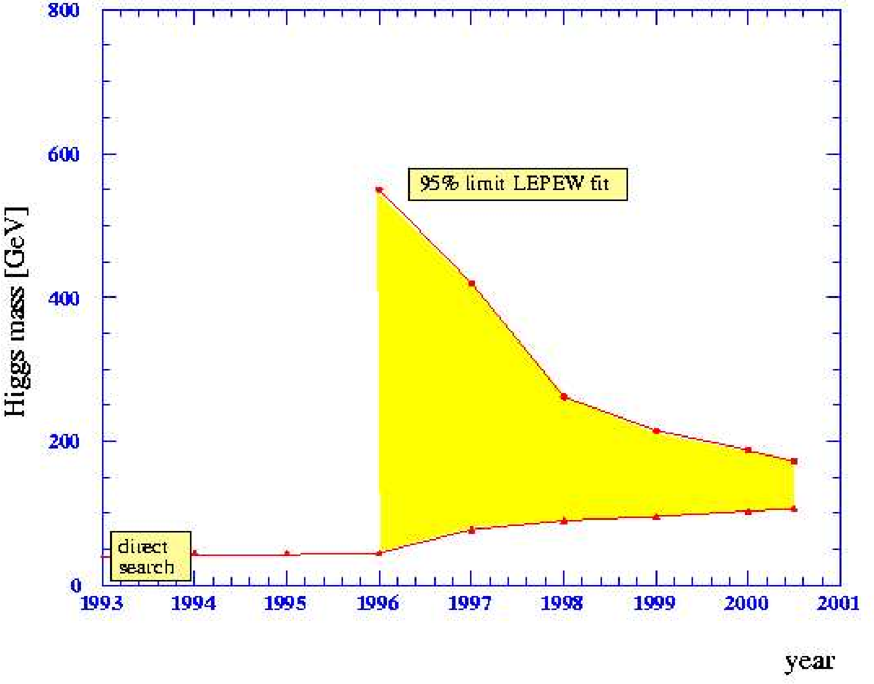
The indirect limits from world data:

indirect limits from LEP



m < 188 GeV
@ 95% CL

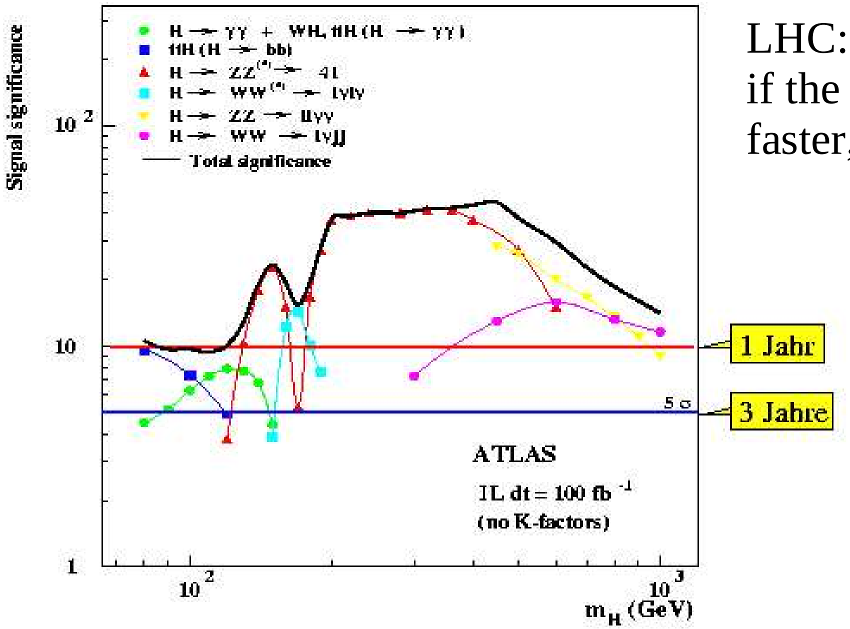
development of limits over time:



A 500−800 GeV linear collider is well suited to see and investigate the Higgs

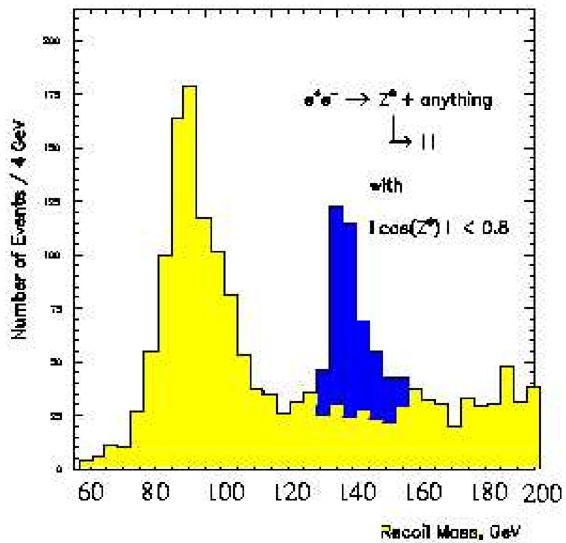
Possible Discovery of the Higgs

- Most likely scenario: Discovery of the Higgs at the LHC (if LEP does not find it...)



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

after one month
at TESLA:

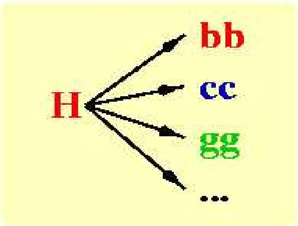


At high lumi approx. 10^5 Higgs Bosons per year: Precision!

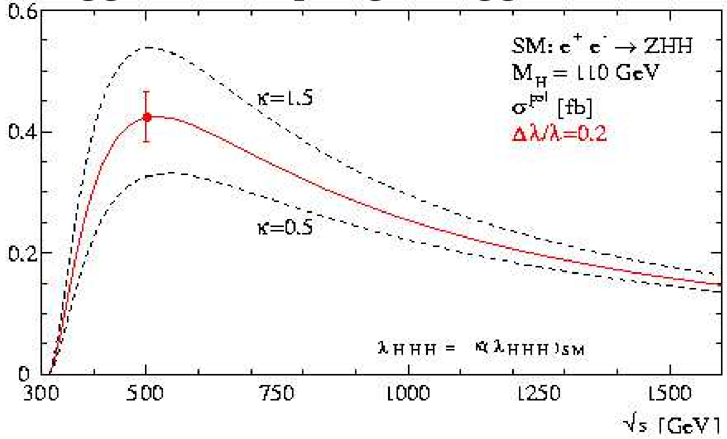
Beyond a Discovery

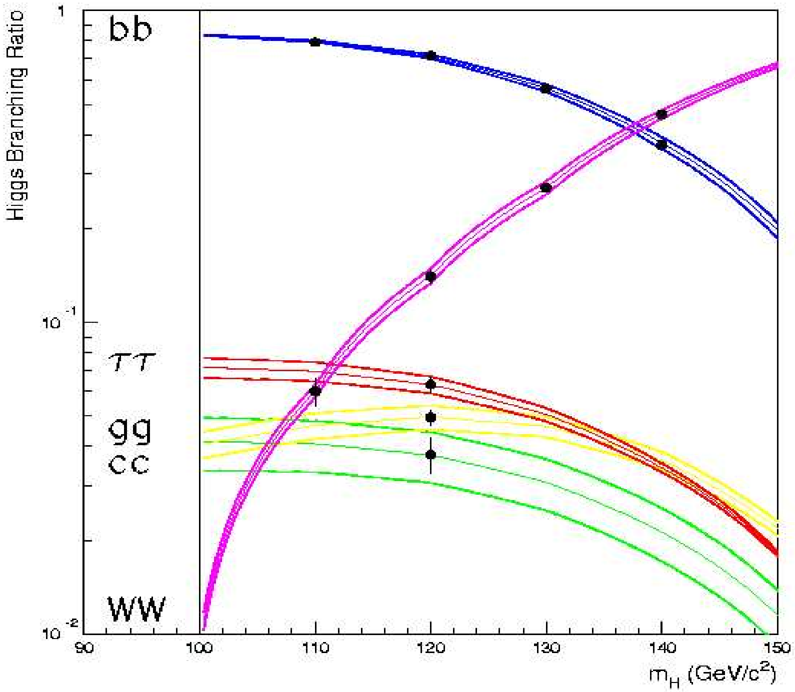
- complete test of our understanding of mass

  - can the Higgs explain the Z−mass?
    is the existence of the Higgs enough?



Higgs self couplings: Higgs Potential



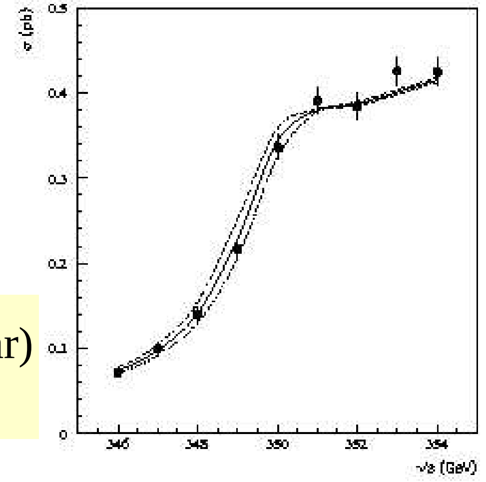


Precision measurement of the Higgs properties to a few percent!

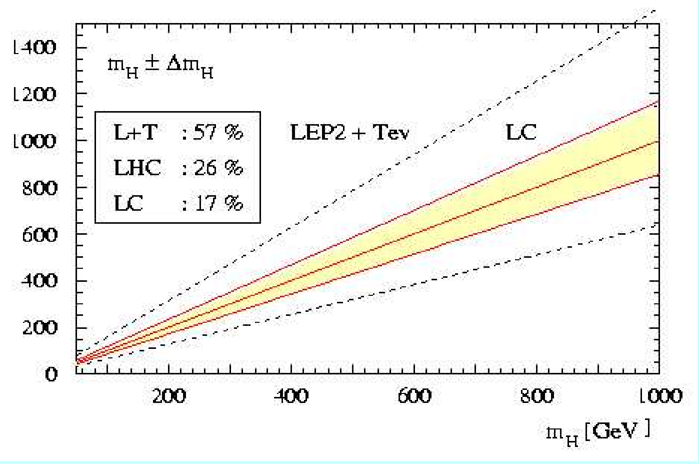
TOP Physics

- 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

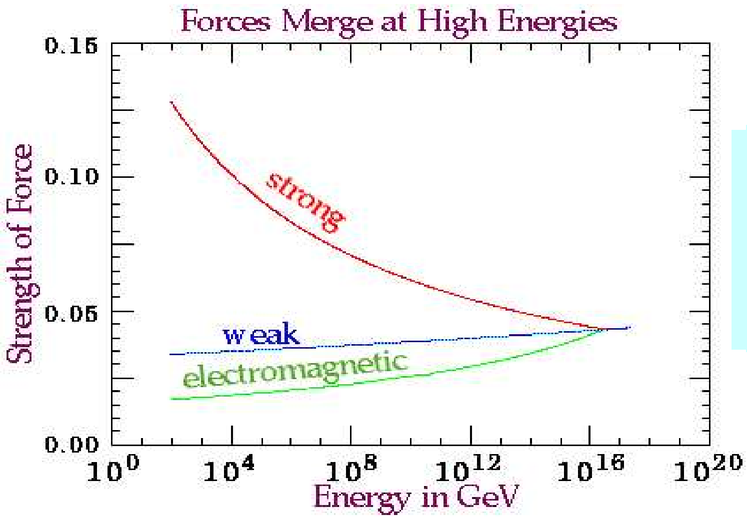


- allows stringent consistency checks of the Standard Model

Precision Tests of the Standard Model

Physics beyond the Standard Model

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



unification of forces is made easier
by Supersymmetry

- 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

A linear collider with
energy up to 1 TeV
should be able to
contribute to the solution of this problem!

Summary Particle Physics

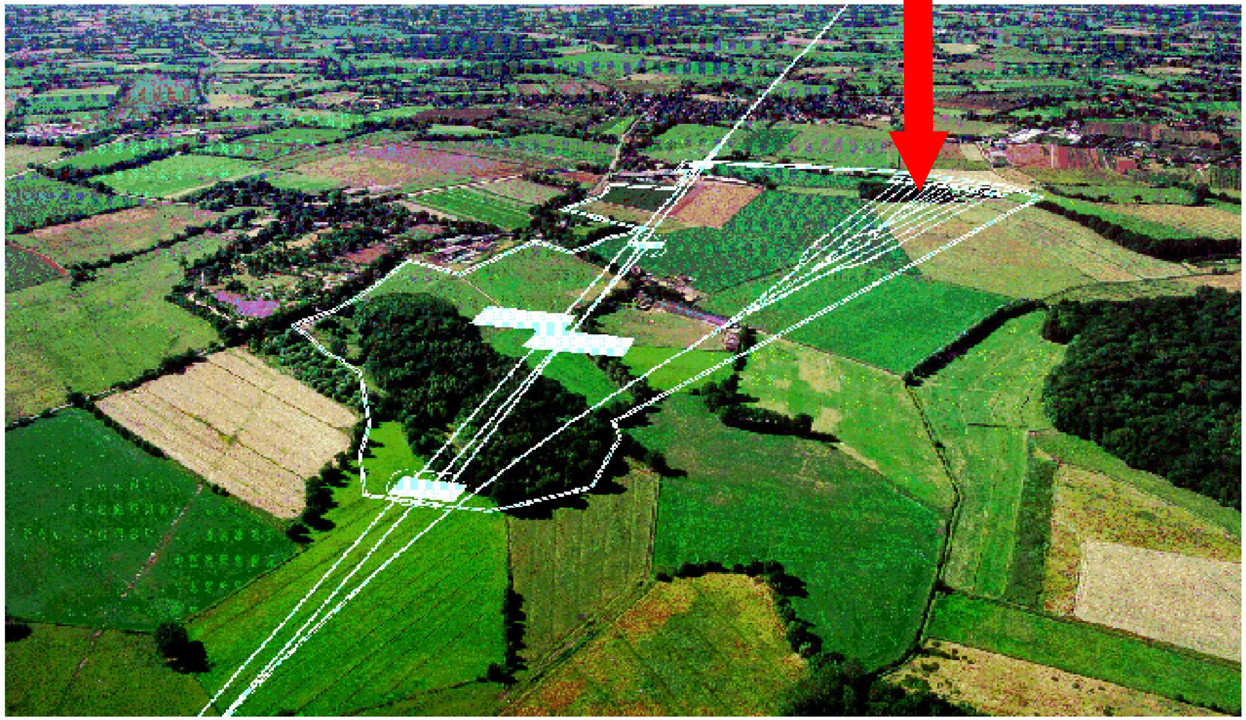
- A linear electron positron collider is a machine to do
  - Precision physics
  - Discovery physics on the mass scale up to E(cms)

- Selected topics:
  - Higgs Physics
  - Standard Model Physics
  - Searches for Supersymmetry
  - Searches for physics beyond the Standard Model

The Free Electron Laser

- The free electron laser is an integral part of the TESLA project

FEL experimental area



FEL: a X−ray laser
(1−10 A) of
extreme brilliance
extremely short pulses

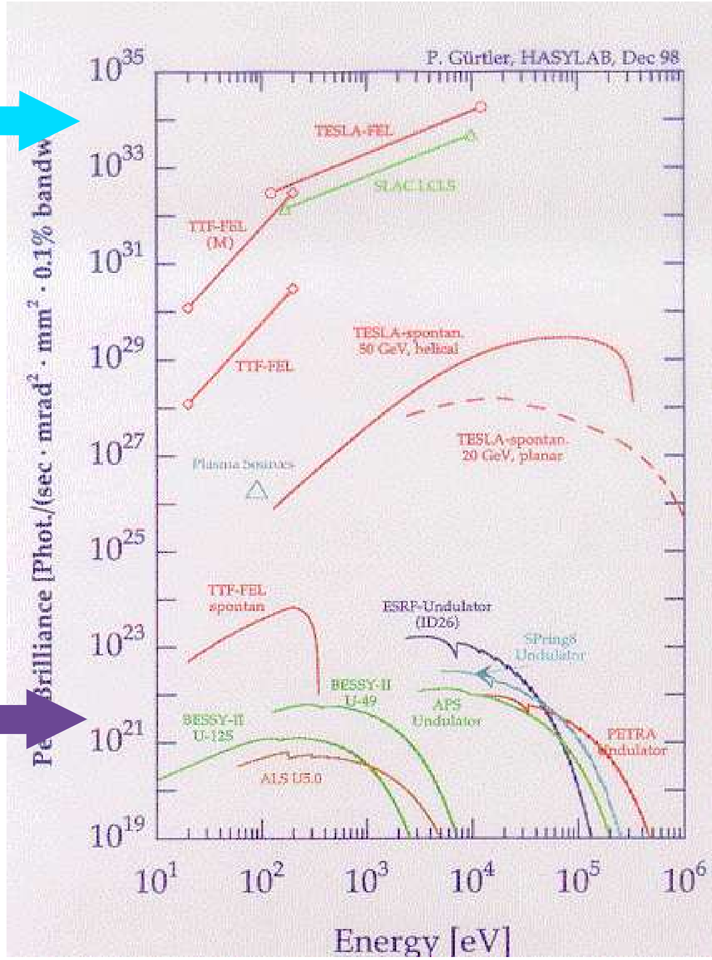
Parameters of the TESLA−FEL

Brilliance of different sources:

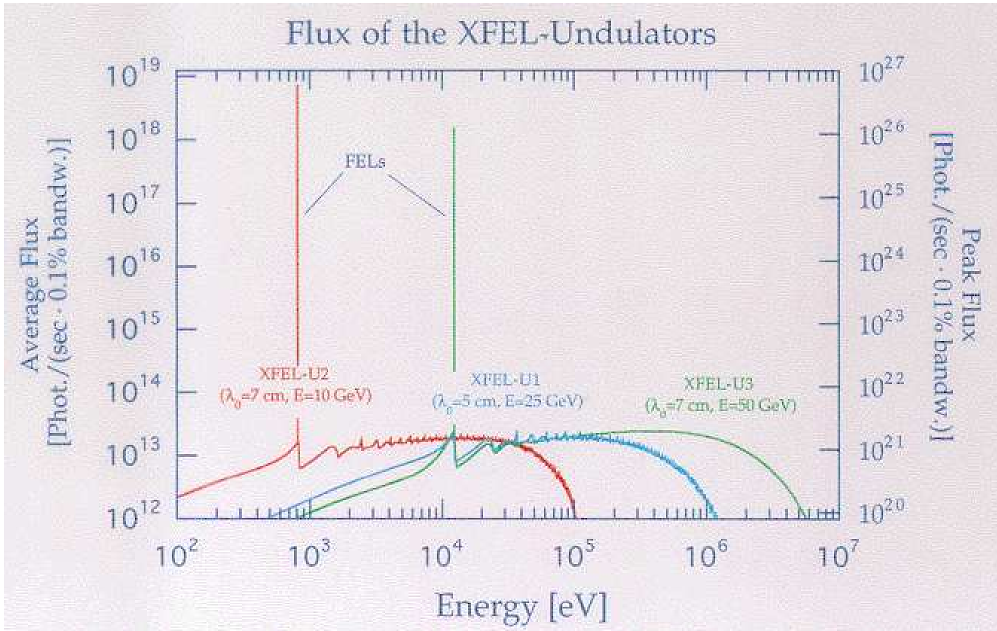
TESLA FEL

SLAC FEL

current

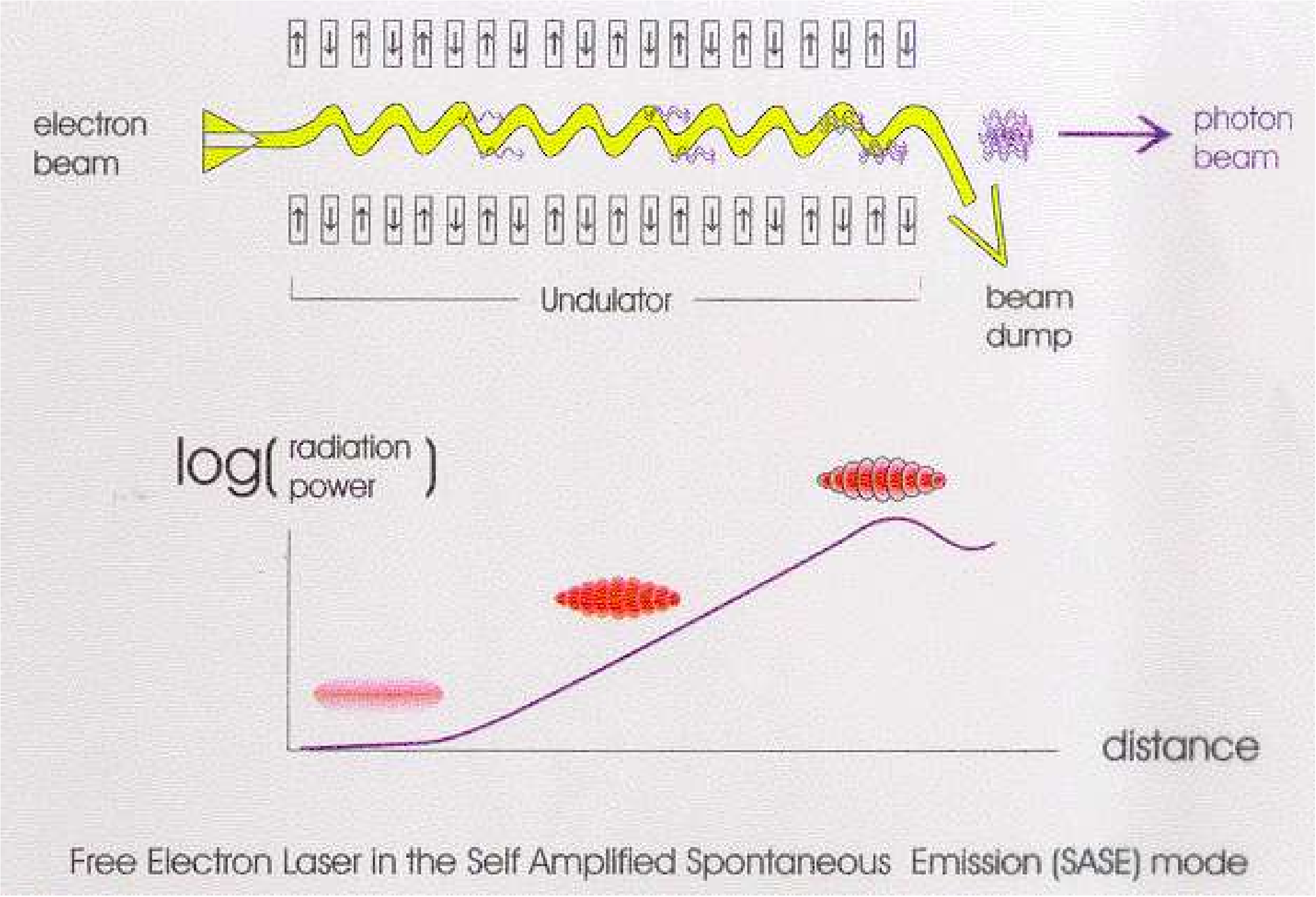


expected Photon Flux for XFEL

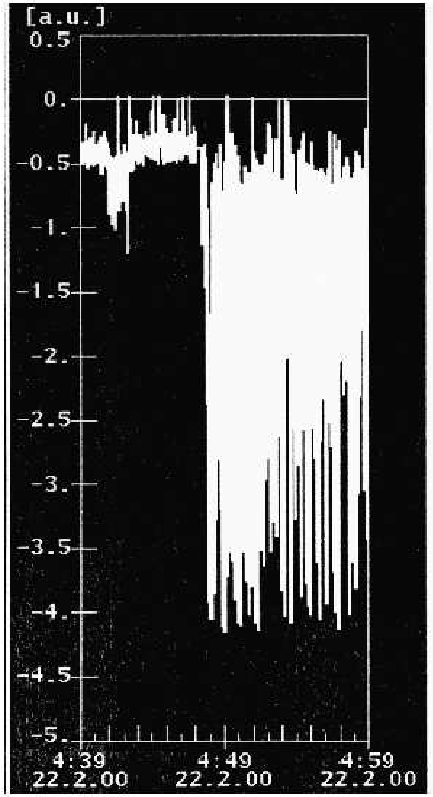


The SASE Principle

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



first lasing observed
at DESY February 2000



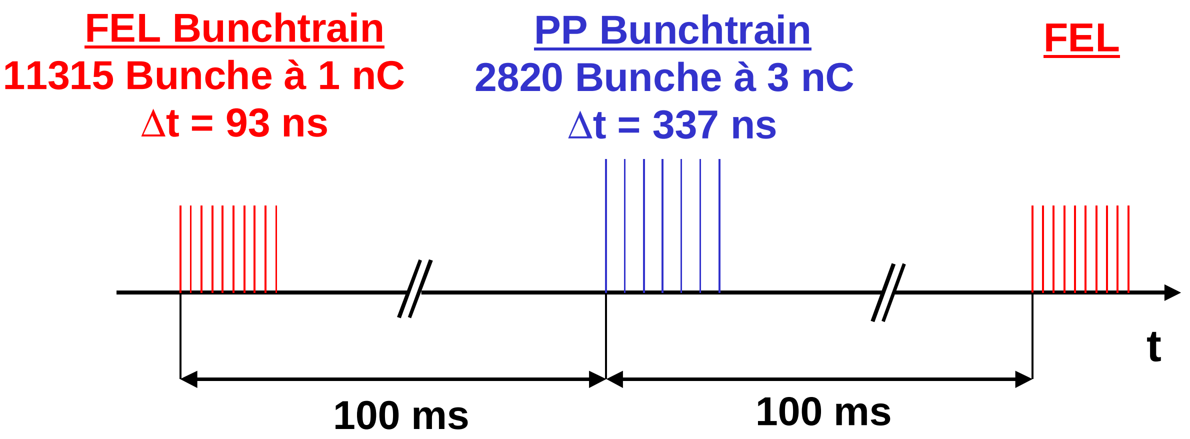
Properties of X−FEL Radiation at TESLA

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



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

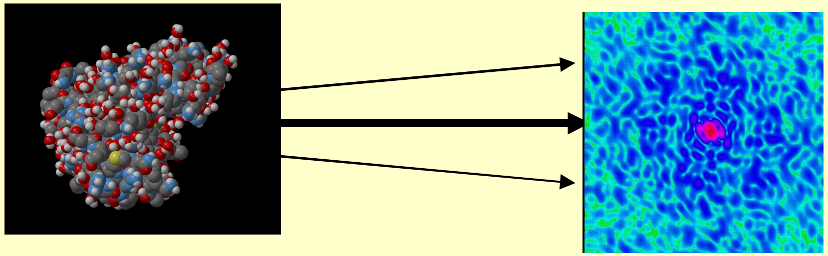
The XFEL pulse is extremely energetic:

- 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

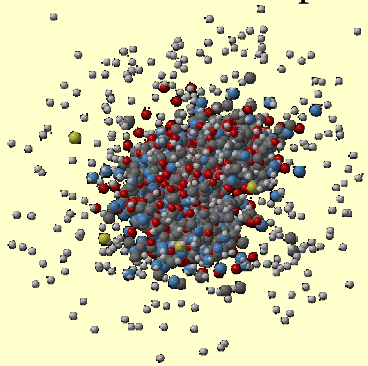
example: X−ray diffraction of single protein molecule:

J. Arthur, Stanford

t=100 fs



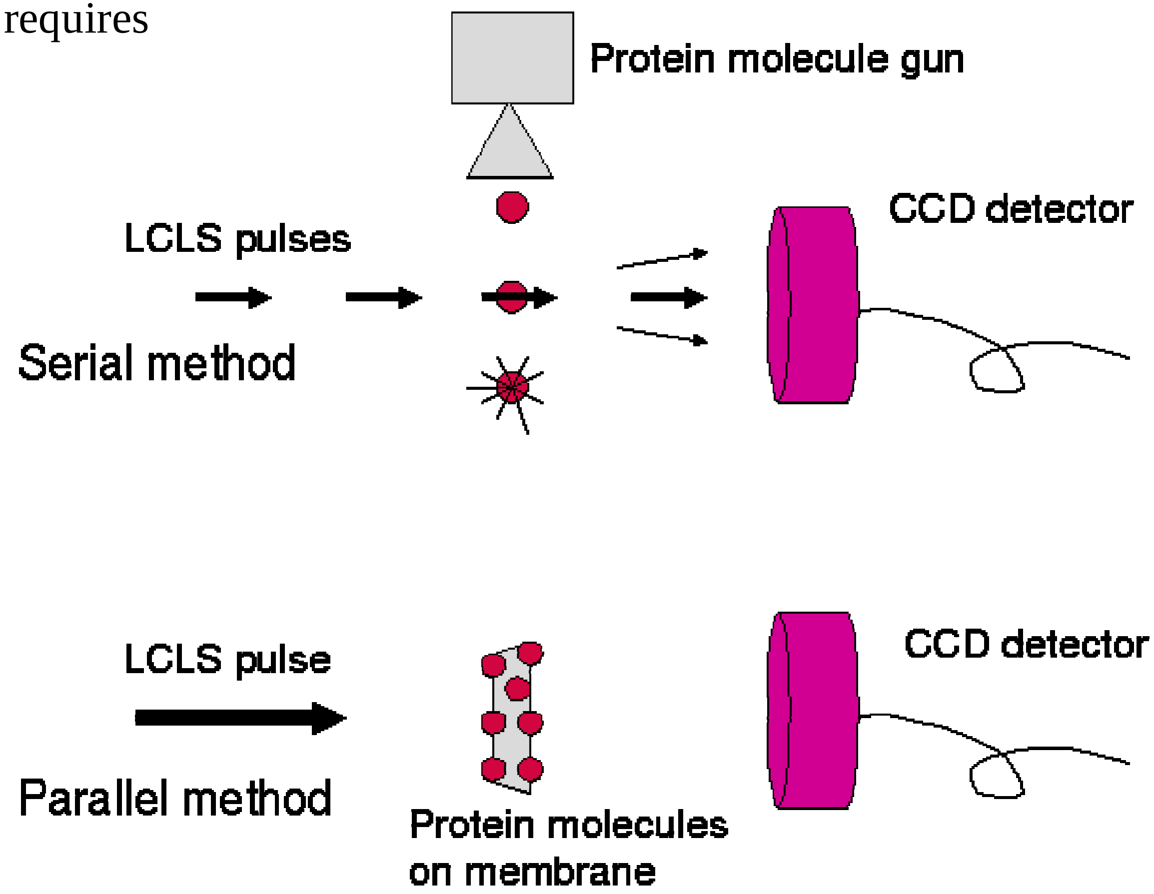
t>7ps



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

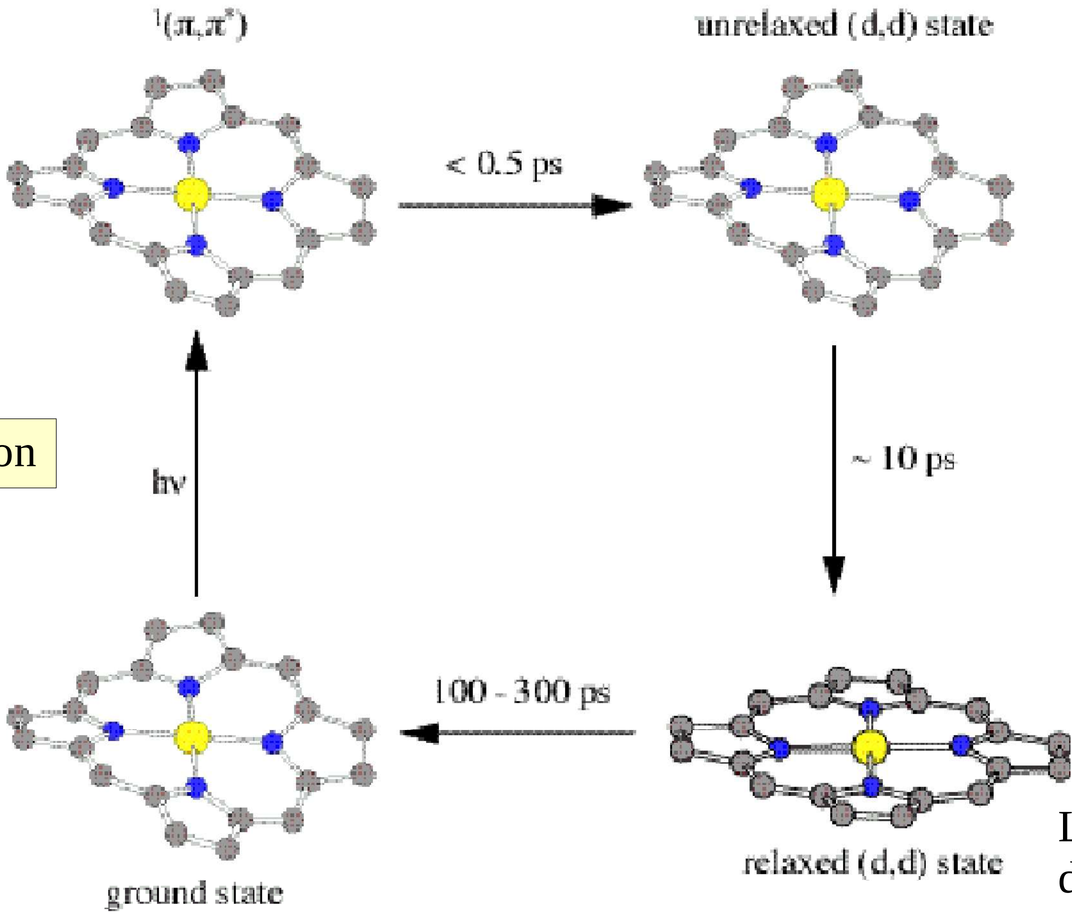


J.Arthur, Stanford

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 Physics Case

A linear electron positron collider has an exciting physics program:

Elementary Particle Physics:

- Precision tests of the electroweak model
- Understanding of the mechanism to break the EW symmetry
- Search for new physics beyond the SM

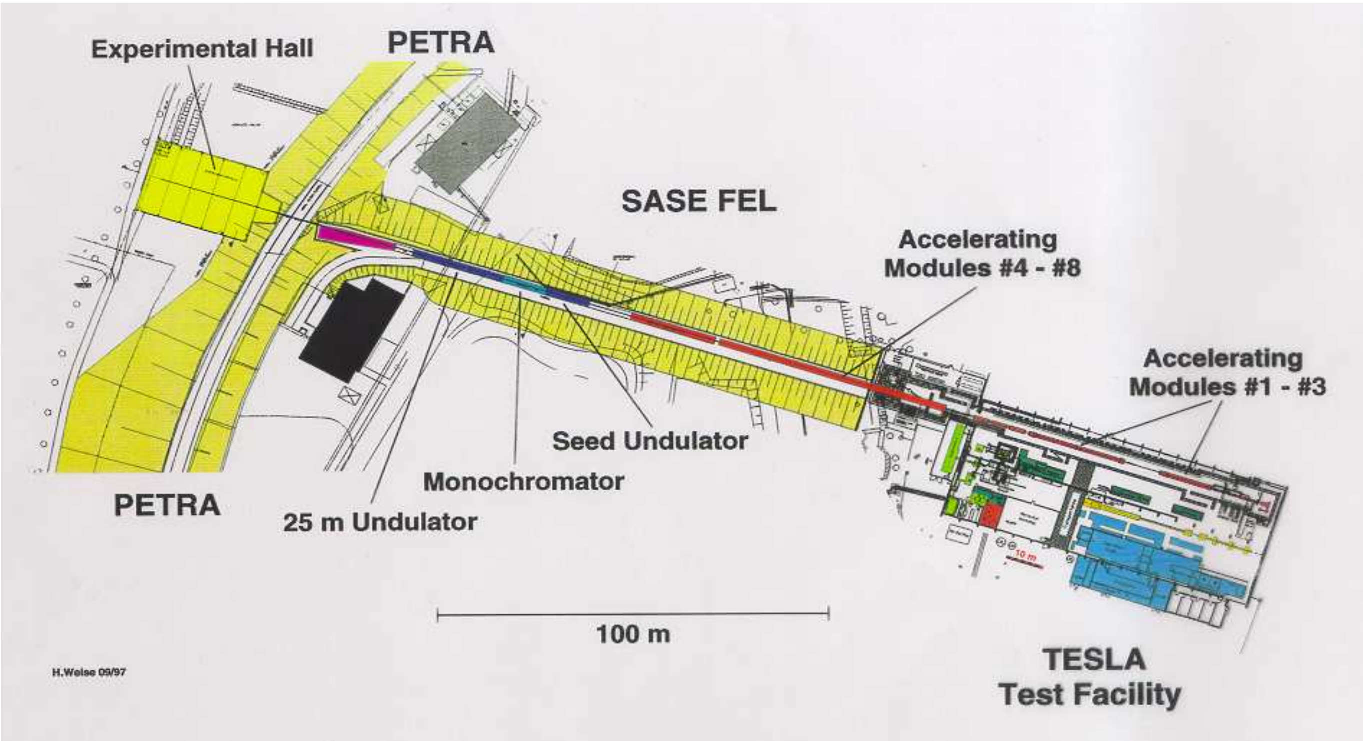
Physics at the free electron laser

- Look at the dynamics of processes on an atomic scale
- Study single molecules, e.g. biological molecules

A LC has an exciting and rich physics program which supplements and adds to the one from other facilities (LHC, Synchroton Light Sources, ...)

Status of the TESLA Project

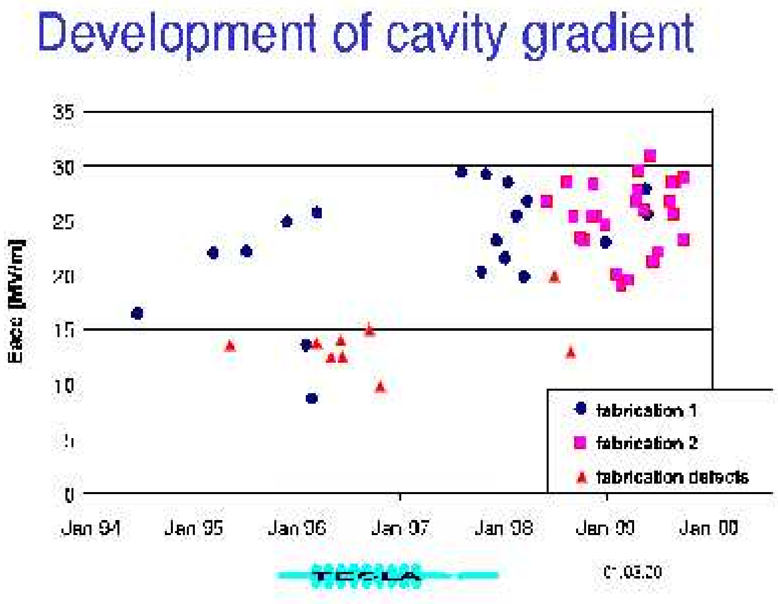
- Under construction: Tesla Test Facility Phase TTF II



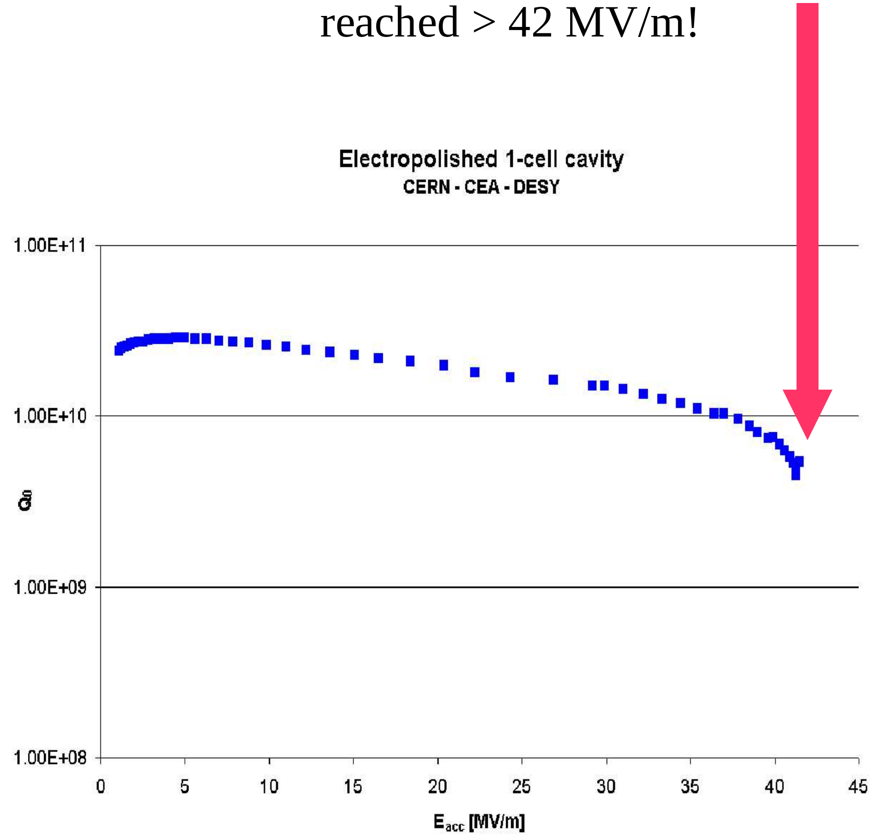
Goal: −demonstrate the superconducting technology (TTF I, done)
− demonstrate the SASE principle in the <100nm range (done)
−gain experience operating a superconducting linac and FEL
−>2003: user facility for Roentgenlaser

Status of Cavity Development

500 GeV Tesla: approx. 22 MV/m needed



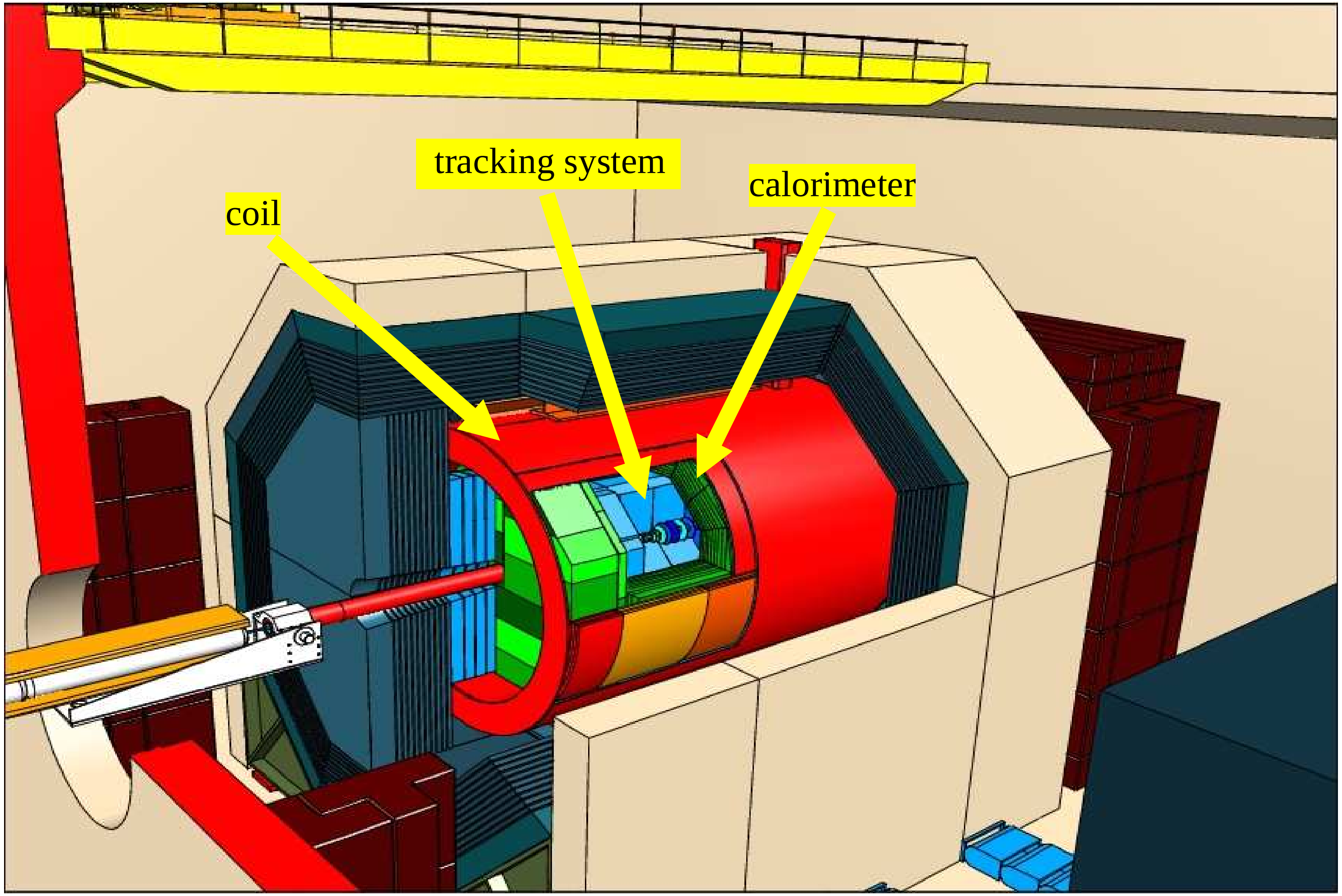
in single cell cavities:
reached > 42 MV/m!



Cavity development has been
very successful:
international effort!
Cavities for TESLA can be built

A Detector for TESLA

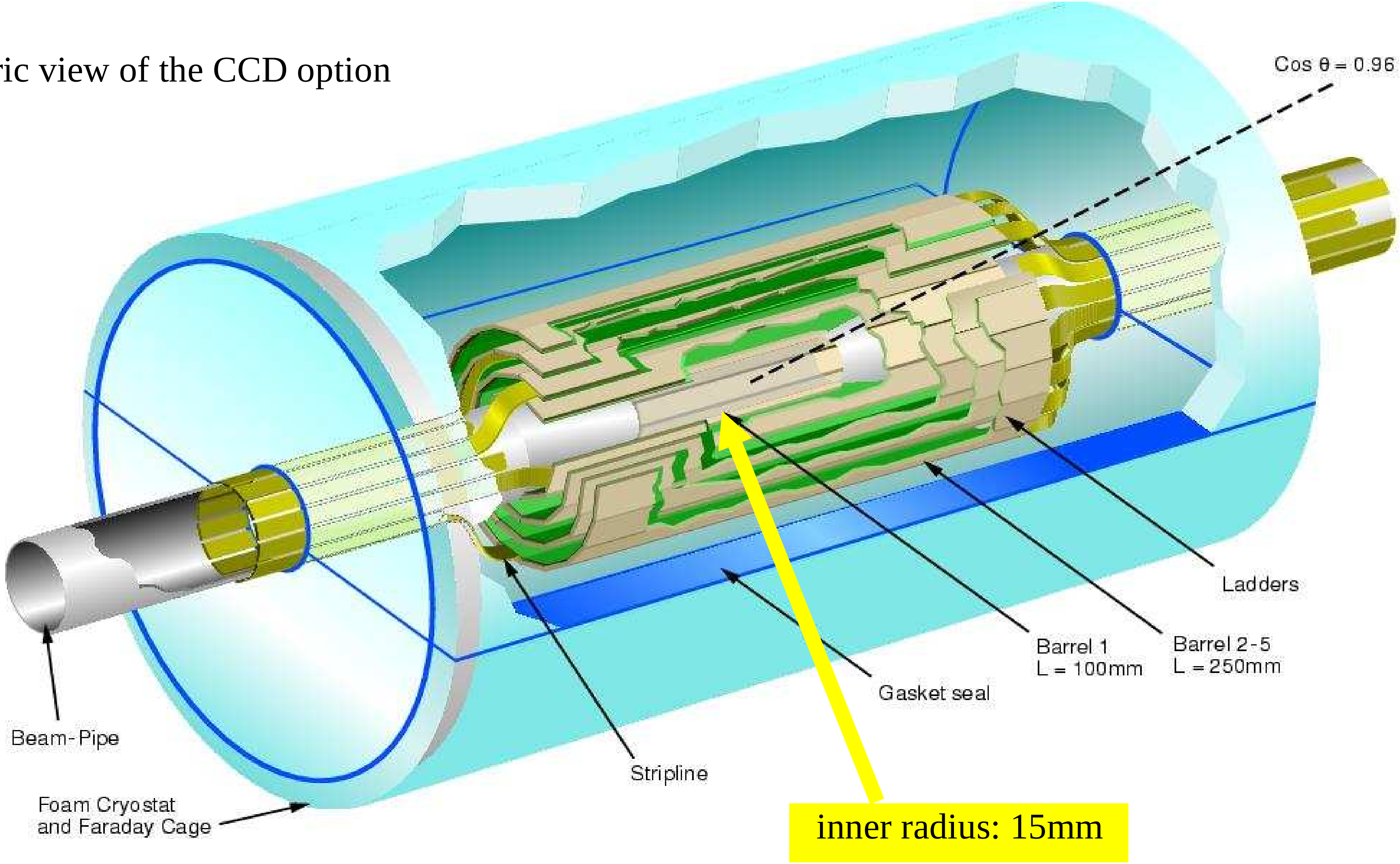
view of a proposed detector for TESLA



ECFA−DESY linear collider study

Vertex Detector

isometric view of the CCD option



Vertex Detector

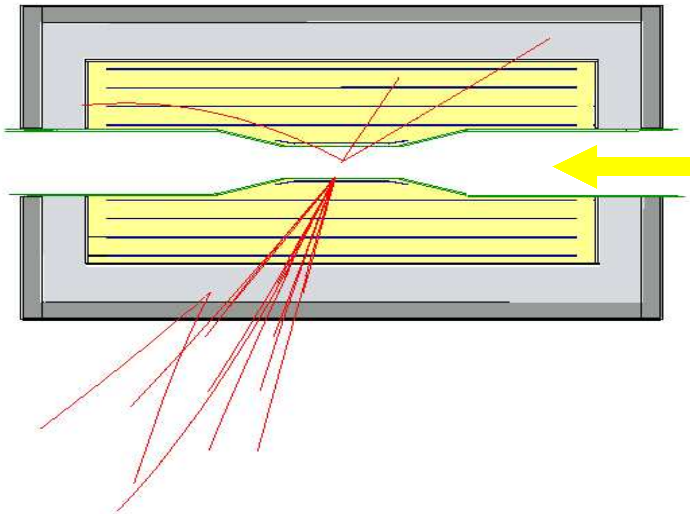
Vertex detector:

several options under discussion

requirements:

- extremely good precision
- radiation hard
- fast
- high granularity

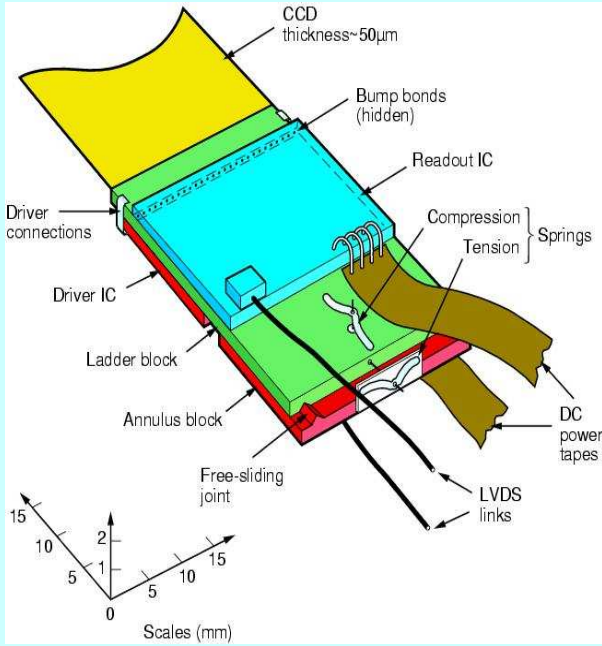
physics case: B−physics: detached vertices



1.5 cm beampipe

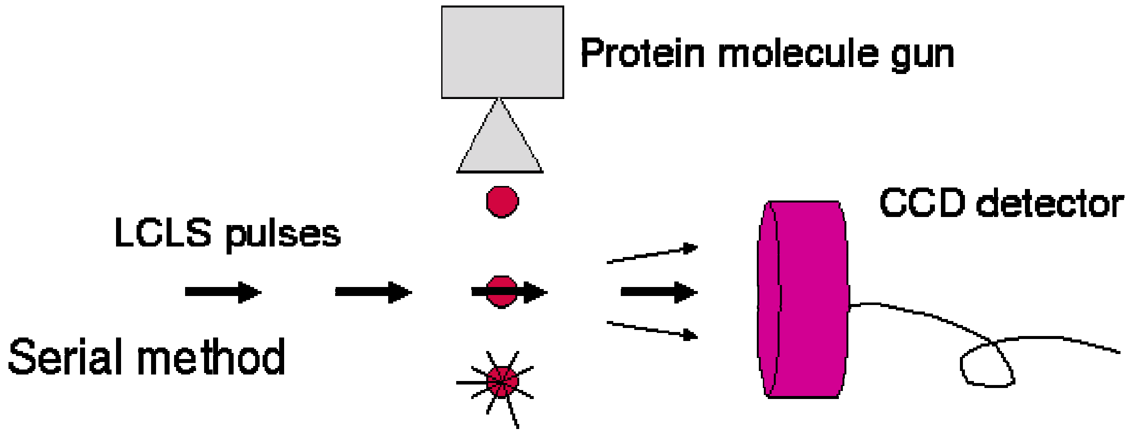
construction detail:

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

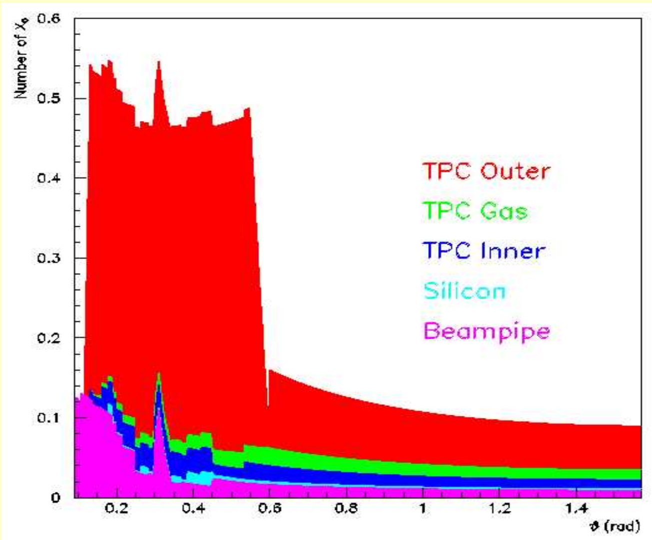
Development of experimental techniques at the FEL is starting
Both HEP and FEL will profit from their respective experiences

TPC tracking System

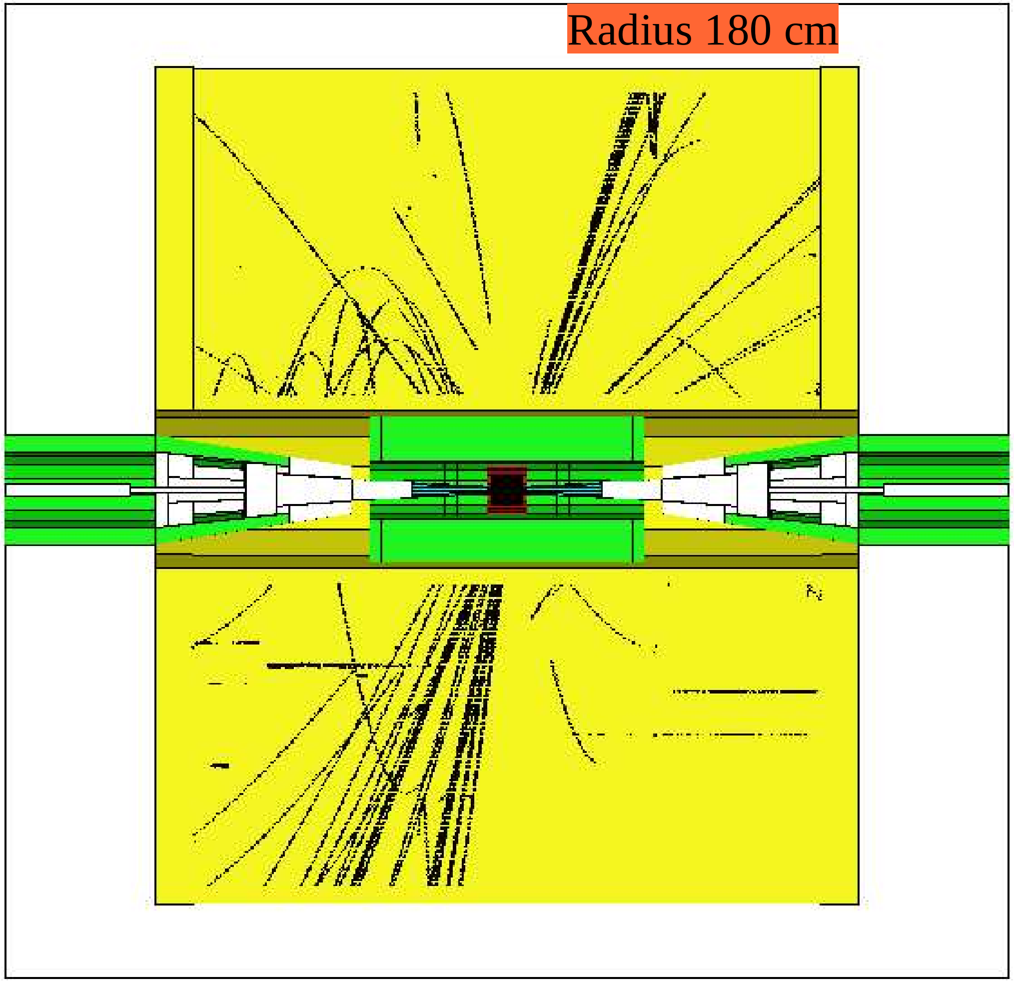
TPC: Time Projection Chamber

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

material budget:

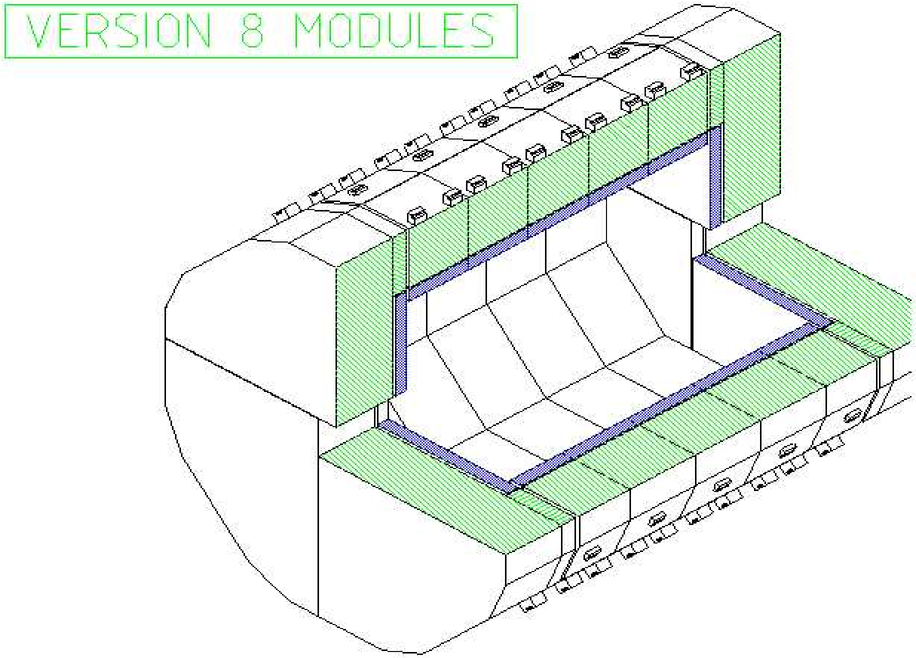


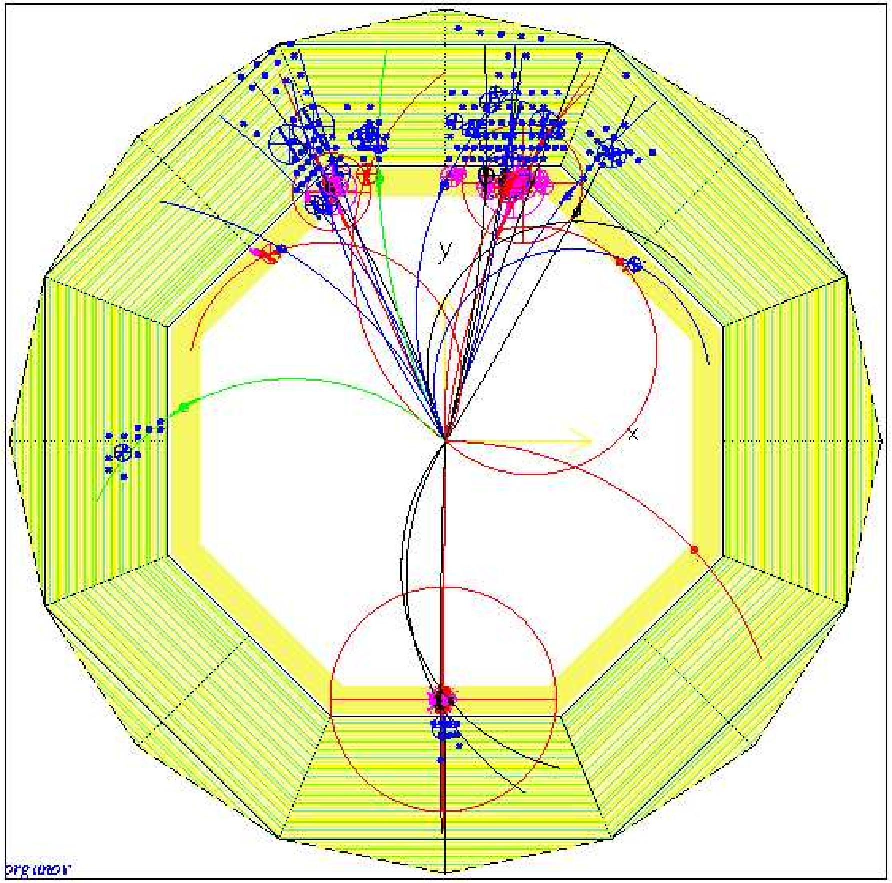
a simulated dd event



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)





The TESLA Project

- DESY is doing a detailed site study for TESLA close to the existing DESY laboratory

- tunnel length: 33km
- depth 20−30 m below ground
- tunnel diameter 5m

- TESLA is planned as an international project
- Current TESLA collaboration: some 10 nations
- Future Vision: operate these big machines similar to HEP experiment as truly international facilities: Global Accelerator Network

Summary and Outlook

- TESLA is an integrated facility for FEL and HEP
  - other communities have expressed an interest
    nuclear physics: ELFE at TESLA
    fixed target experimentation

- large physics potential for HEP and FEL
- a machine to really do precision and discovery physics

- Milestones reached:
  - reached the gradient >20 MV/m
  - have operated a superconducting machine for >5000h
  - have demonstrated the FEL principle below 100nm

- next steps:
  - TDR is being prepared for publication in March 2001
  - fully costed design of the machine
  - fully costed design of a HEP detector for TESLA
  - discussions within the international community about TESLA/ NLC / JLC

- 2010: earliest date such a facility could start operation

Roentgen Sources for time resolved Investigations

Comparison of available and planned Roentgen Sources around the world:

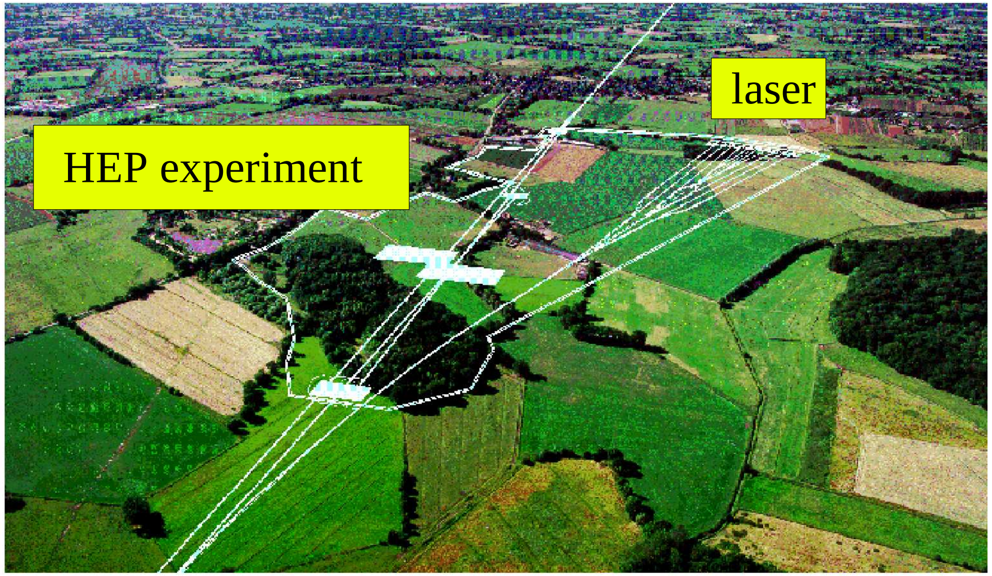
Source	Wave-length (Å)	Photons per Pulse per 0.1% Bandw.	Flux in Photons/sec/0.1% Bandwidth		Brilliance (Photons/sec/mrad^2 /mm^2/0.1% Bandwidth	
			Average	Peak	Average	Peak
PETRA-Undulator	0.8	1×10^9 in 140 ps	8×10^{14}	1×10^{19}	7×10^{17}	1×10^{22}
TESLA -FEL	1.0	7×10^{12} in 80 fs	6×10^{17}	5×10^{25}	2×10^{26}	2×10^{34}
Laser-Induced Plasma	7	1×10^5 in 100 fs	1×10^6	1×10^{18}	3×10^5	3×10^{17}
Thomson Scattering	0.4	2×10^8 in 300 fs	2×10^{10}	6×10^{20}	3×10^{10}	1×10^{21}
Higher Harmonic Generation	300 100-150 30-40	10^8 in 10 fs 10^6 in 10 fs 10^4 in 10 fs	10^{11} 10^9 10^7	10^{22} 10^{20} 10^{18}	4×10^{13} 4×10^{11} 4×10^9	4×10^{24} 4×10^{22} 4×10^{20}

(Peter Gürtler, 09.06.00)

The TESLA facility

aerial view of the planned facility:

to Westerhorn



to Hamburg

- one laboratory for both laser and HEP

- current site planning:
  - close to Hamburg
  - total length 33 km
  - laboratory at km 16.5

- current state of the project:
  - TDR is being prepared
  - decision making process will start 2001/2002
  - decision maybe in 2002/2003