❷ Projects and Detectors

Projects for the next generation of lepton colliders:

- NLC: USA (SLAC)
- JLC: Asia (KEK)
- TESLA: international collaboration at DESY

Gross parameters of all projects:

- first phase: $\sqrt{s} \leq 500\,\mathrm{GeV}$
- upgrade: $\sqrt{s} \approx 1\,\mathrm{TeV}$
- tunnel length $\sim$ 30km
- physics start $\sim$ 2012

NLC/JLC:

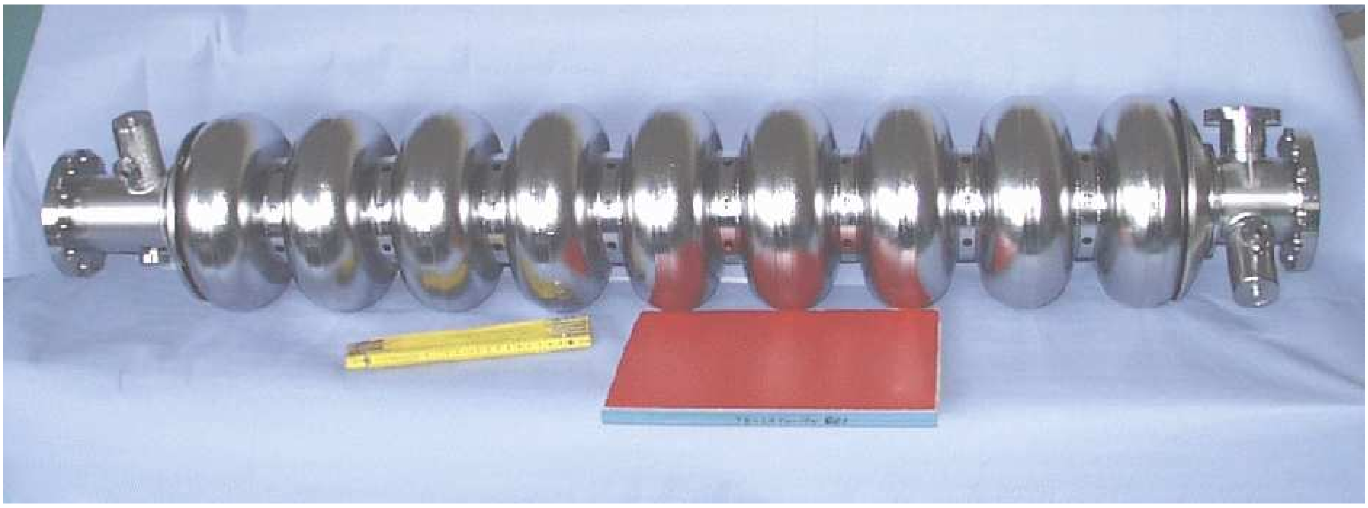
- normal conducting machines
- Luminosity $\mathcal{L} \approx 7 \cdot 10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$
- bunch trains of $\sim$ 100 bunches with $\sim$ 3ns bunch spacing
- repetition rate 120Hz
- small crossing angle at IP
- maximal energy $1 - 1.5\,\mathrm{TeV}$, limited by klystrons

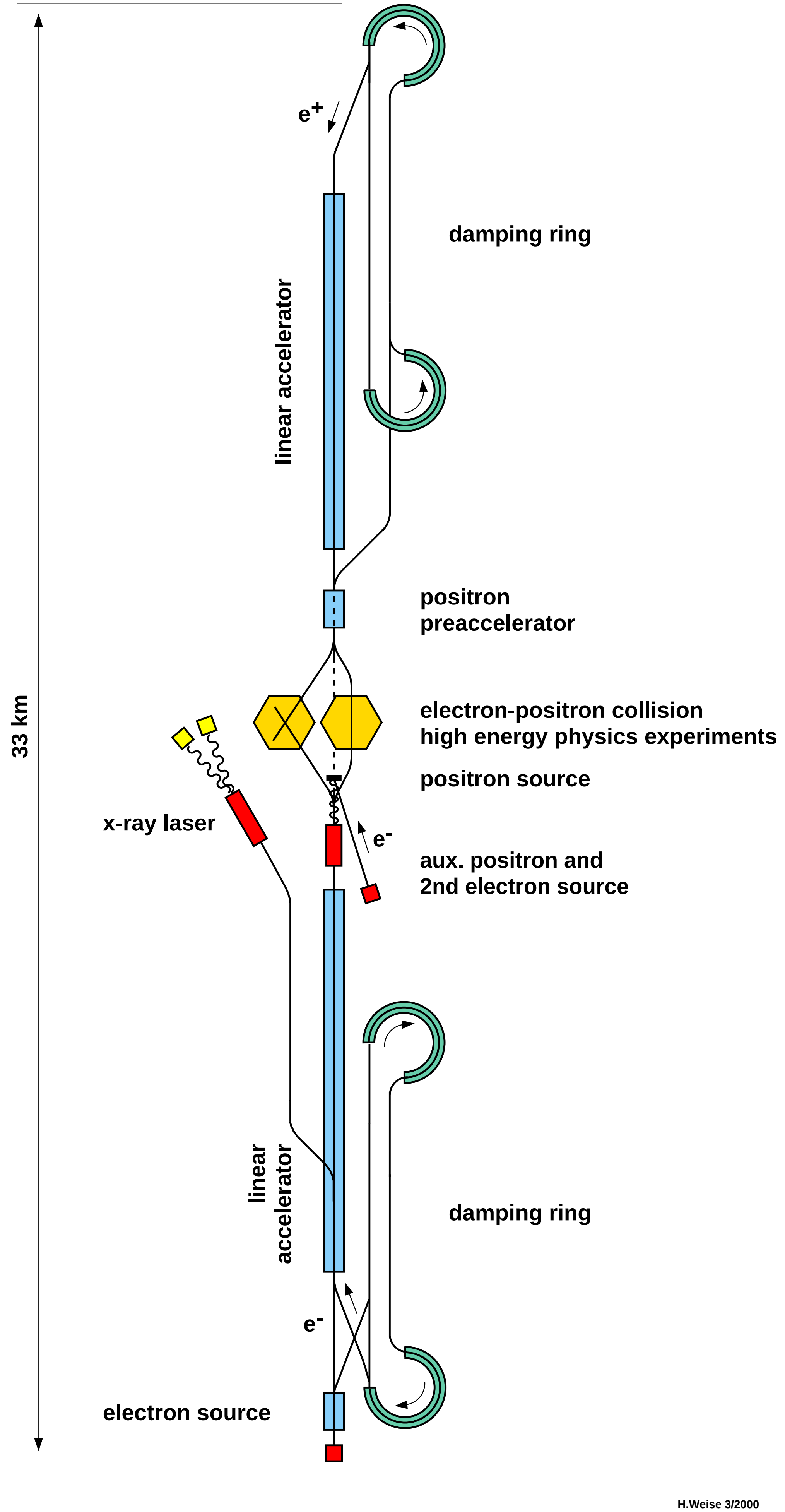
TESLA:→ plot

- superconducting machine
- Luminosity $\mathcal{L} \approx 3 - 5 \cdot 10^{34} \mathrm{cm}^{-2}\mathrm{s}^{-1}$ $\Rightarrow \sim 300 - 500\,\mathrm{fb}^{-1}/\mathrm{year}$
- bunch trains of ∼ 2800 bunches with ∼ 300ns bunch spacing
- repetition rate 5Hz
- head on collisions

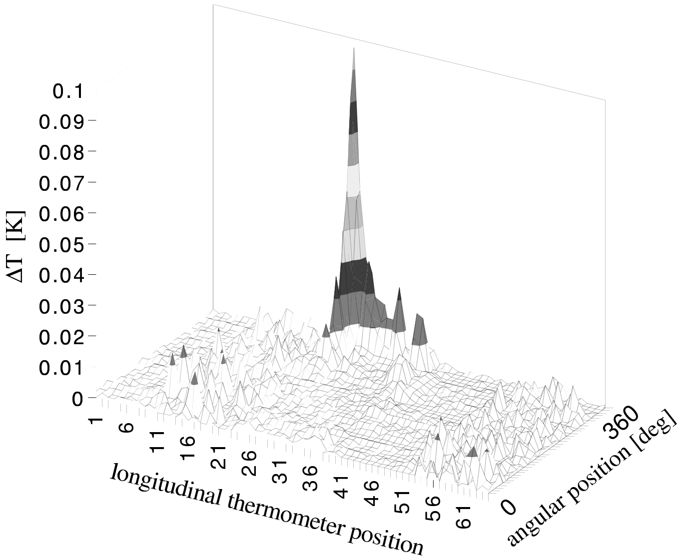
Challenge: Have to increase accelerating field at an affordable cost

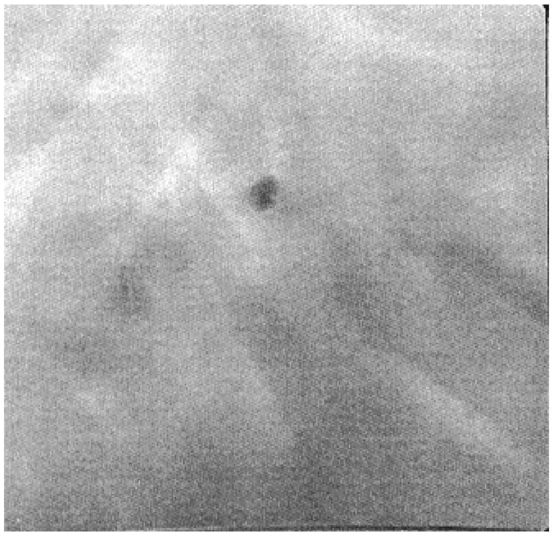
Basic structure: 9-cell niobium cavities



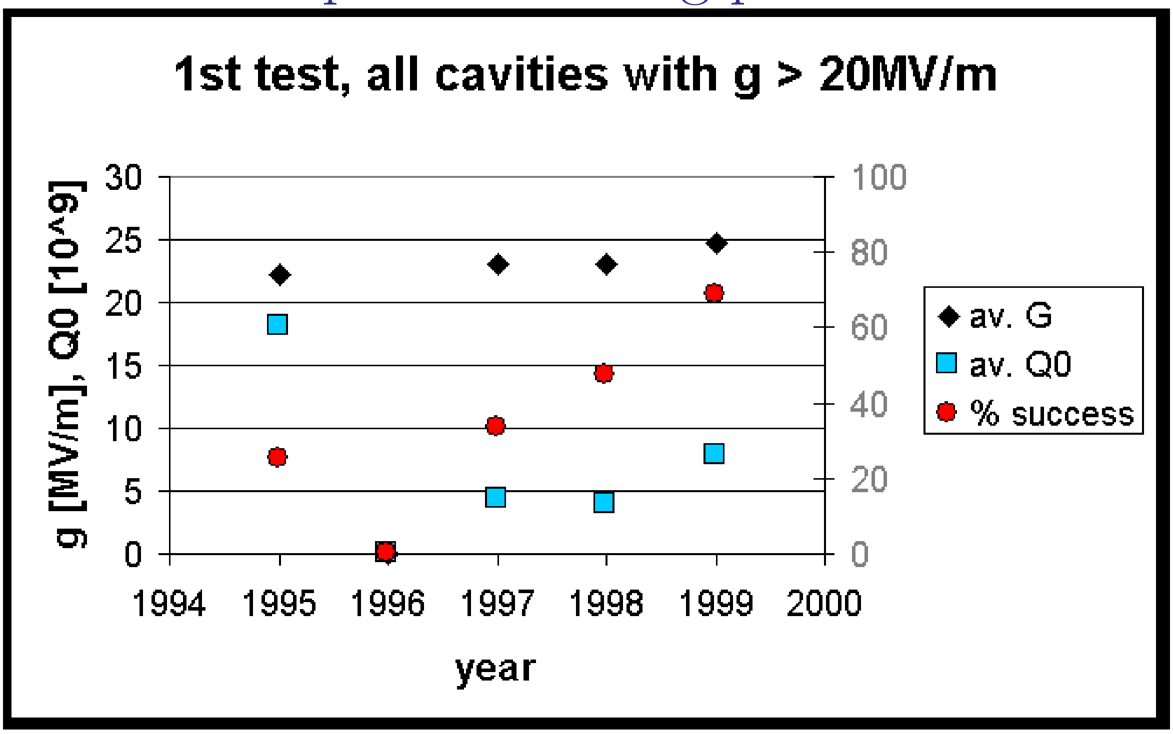

damping ring
linear accelerator
e+
positron
preaccelerator
electron-positron collision
high energy physics experiments
positron source
x-ray laser
e-
aux. positron and
2nd electron source
33 km
linear
accelerator
damping ring
e-
electron source
H.Weise 3/2000

- Limit from critical field of niobium: $E < 50\,\mathrm{MeV/m}$
- Practical limit: local impurities:





- solved with special cleaning processes



25 MeV/m is reached routinely

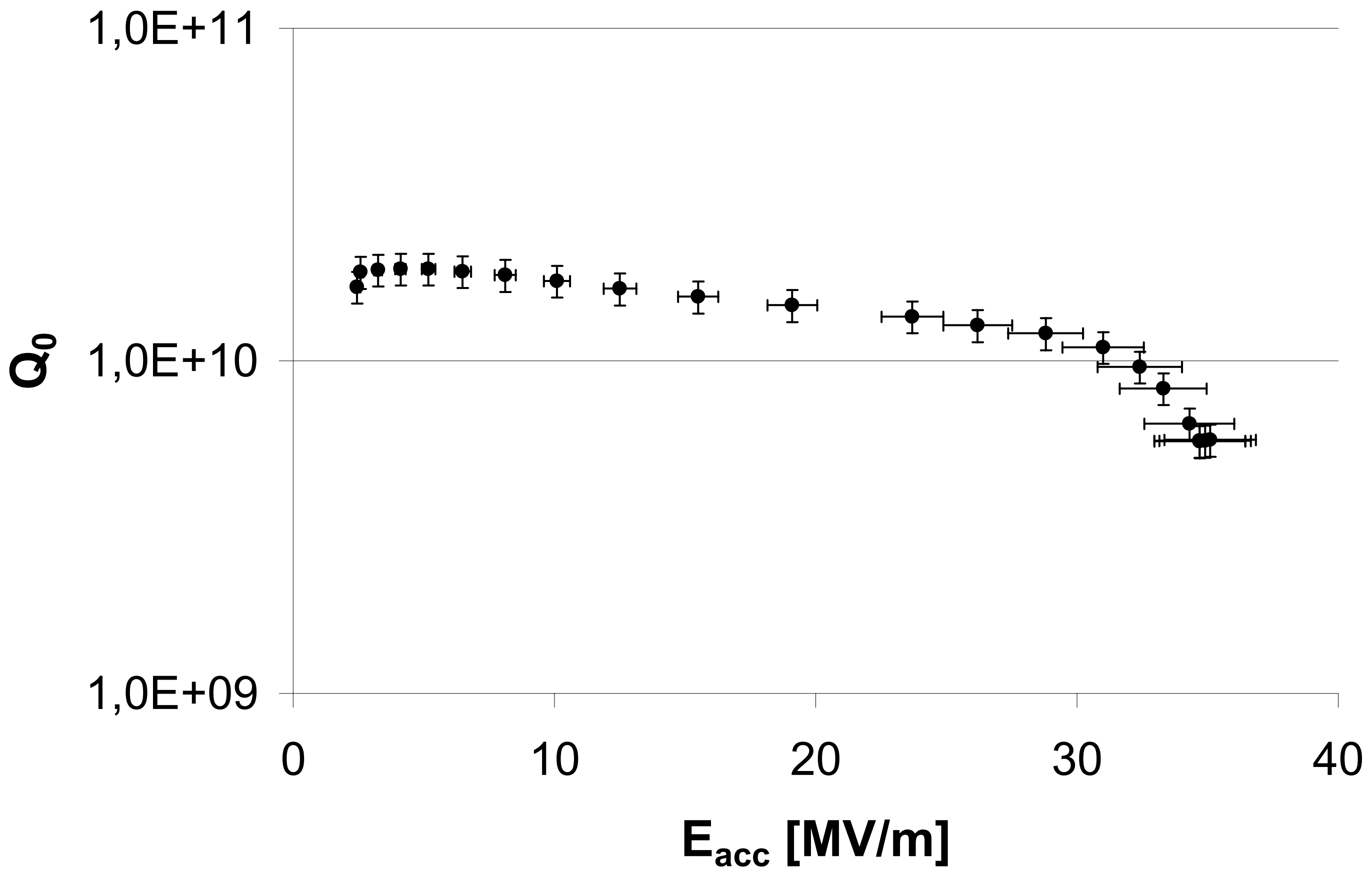
➠ sufficient for $\sqrt{s} = 500\,\mathrm{GeV}$

40 MeV/m reached for some single cell modules with electro-polishing

Standard

Electropolishing

35 MeV/m reached for the first multi-cell module



➠ $\sqrt{s} = 800$ GeV in reach

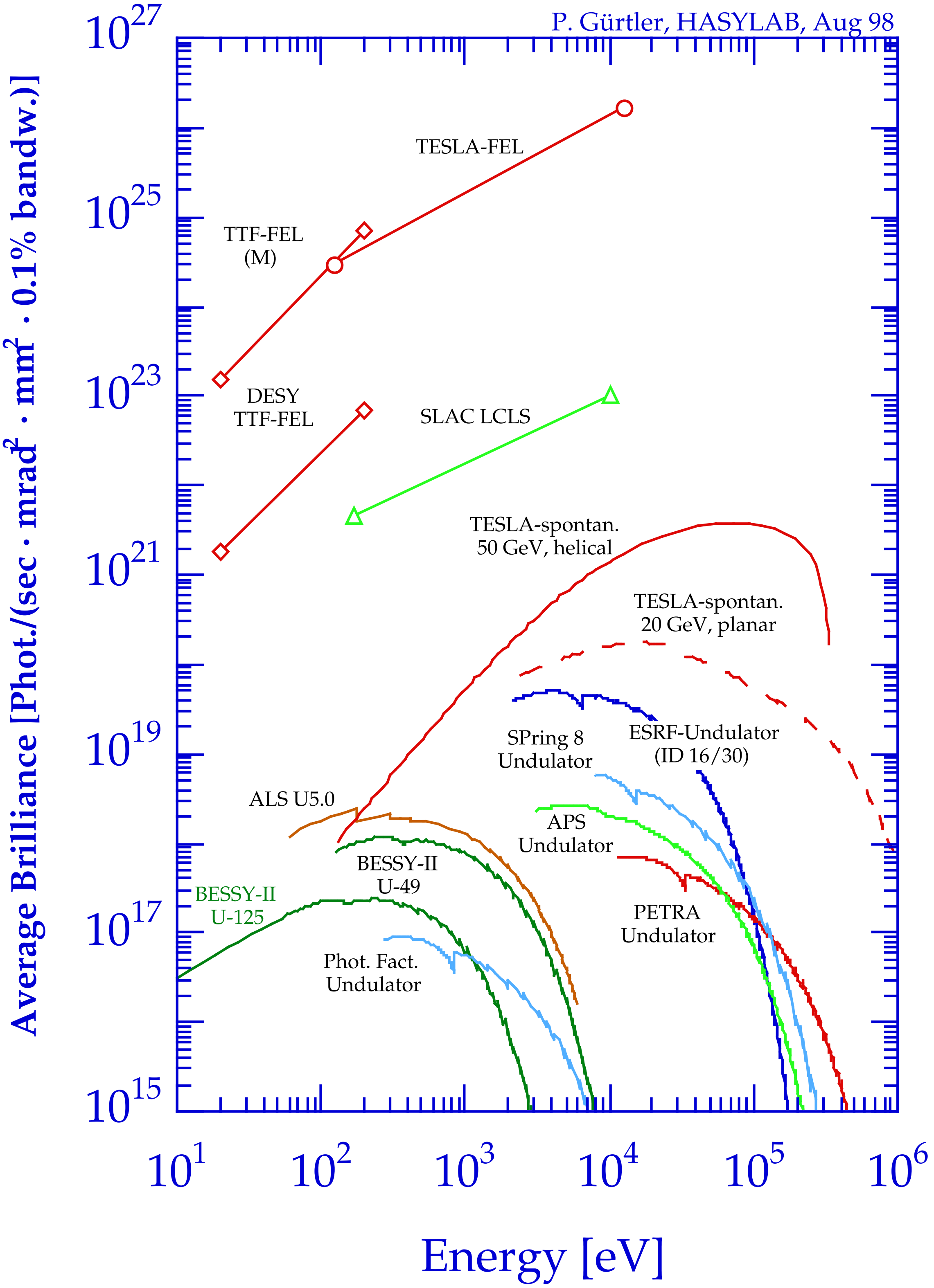
Comparison of machine types

Machine parameters at $\sqrt{s} = 500\,\mathrm{GeV}$

	TESLA	X-band
frequency [GHz]	1.3	11.4
gradient [MeV/m]	22	57
AC power [MW]	95	99
$\eta_{\mathrm{AC-to-beam}}$ [%]	23	8.8
Beamstrahlung δ_b [%]	3	4
σ_y at IP [nm]	5	5
Norm $\varepsilon_{x,y}$ at IP [10^{-6}m]	10,0.03	5,0.1
Luminosity [10^{33}]	31	7
Alignment tolerances:		
acc. structures [μm]	500	10
BPM resolution [μm]	10	1
quad pos. drift [μm]	0.5	0.01

- Higher gradient in normal conducting machines may allow higher energy
- Higher efficiency in superconducting machined allows higher luminosity
- Smaller wakefields for lower frequencies relax alignment tolerances
- X-band luminosities can be brought close to TESLA by increasing power and reducing tolerances

The TESLA design contains an integrated free electron laser with few nanometer wavelength to enlarge the user community (solid state physics, chemistry, biology etc.)



Current TESLA Reference Parameter Set

	500 GeV	800 GeV	
repetition rate	5	3	Hz
no. of bunches per pulse	2820	4500	
pulse length	950	850	usec
bunch spacing	337	189	nsec
bunch charge	2.0×10^{10}	1.4×10^{10}	1/e
pulse current	9.5	11.9	mA
AC power (2 linacs)	95	132	MW
normalised IP emittance (x,y)	10, 0.03	8, 0.01	$\times 10^{-6}$ m
IP beta-function (x,y)	15, 0.4	15, 0.3	mm
IP beam sizes (x,y)	553, 5	391, 2	nm
IP bunch length	0.4	0.3	mm
beamstrahlung dP/P	2.8	4.7	%
vertical disruption D_y	33	39	
luminosity	**3.1×10^{34}**	**5.0×10^{34}**	**$cm^{-2}s^{-1}$**

Beam polarization

- electrons should be polarizable to $\sim 80\%$ with the same technology as at SLC
- positron polarization:
  - positrons are made by sending the high energy electrons through a wiggler to produce photons which are shot on a target to produce positrons
  - if a helical undulator is used before the IP positron polarization of $50-60\%$ should be possible

Advantage of electron polarization:

- only e^-_L couple to $W^\pm$

➡ cross sections can be enhanced and backgrounds can be suppressed (e.g. W-pair production)

- in the unbroken symmetry only e^-_L couple to the W^0 while both helicities couple to the B

➡ in many channels completely different couplings are probed

Advantage of positron polarization:

- the effective polarization gets increased (e.g. for Z exchange: ($\mathcal{P}_{\text{eff}} = \frac{\mathcal{P}_+ + \mathcal{P}_-}{1+\mathcal{P}_+\mathcal{P}_-}$)
  $\mathcal{P}_+ = 50\%, \mathcal{P}_- = 80\% \Rightarrow \mathcal{P}_{\text{eff}} = 93\%$)
  and the error gets reduced (factor 3 for case above)
- the polarization can be measured with the Blondel scheme
- some backgrounds (e.g. single W) can only be suppressed with both beams polarized
- some analyzes (s-channel $\tilde{\nu}$-exchange, neutralino-production) profit from both beams being polarized

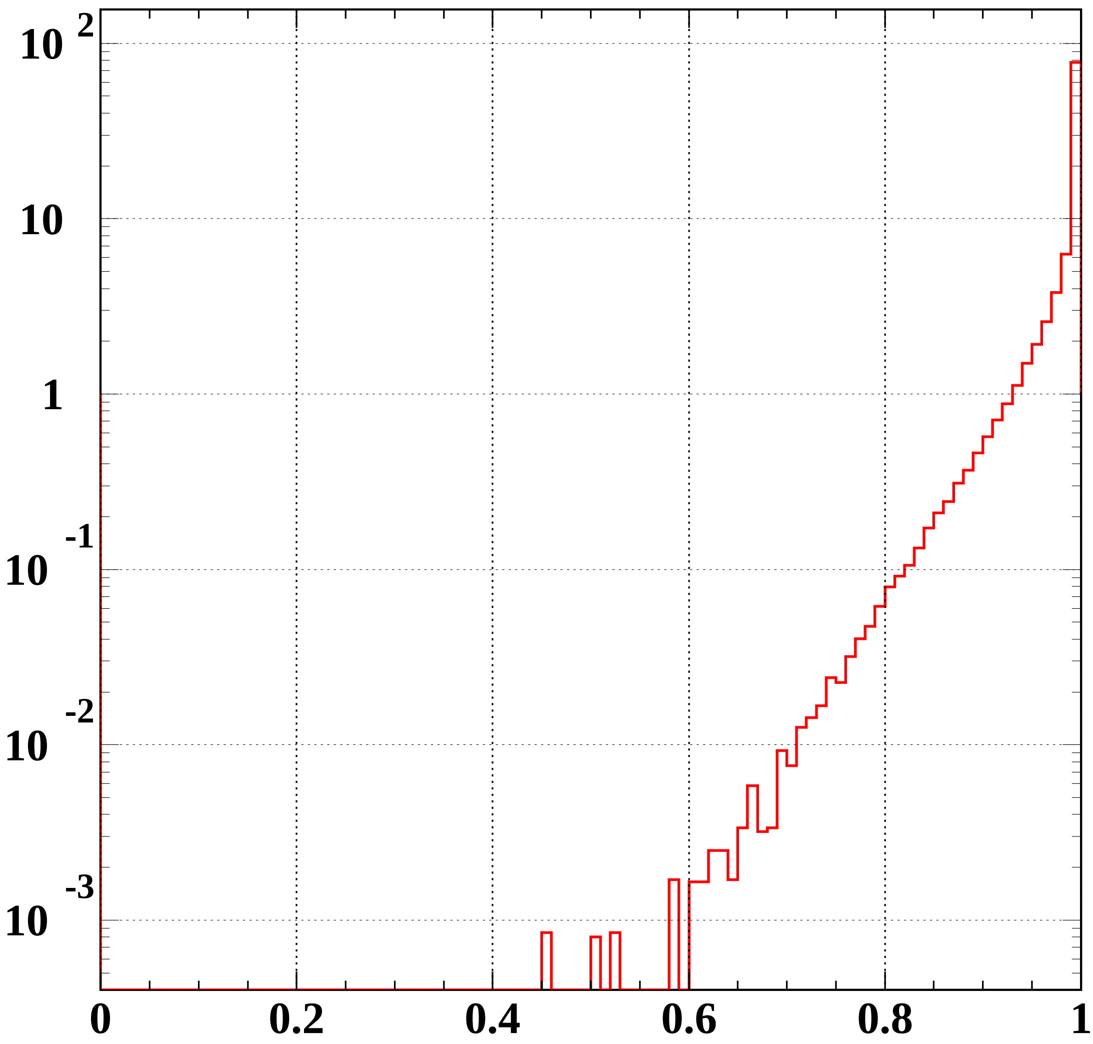
Common problem: beamstrahlung

Beams at IP are extremely collimated with many electrons/bunch

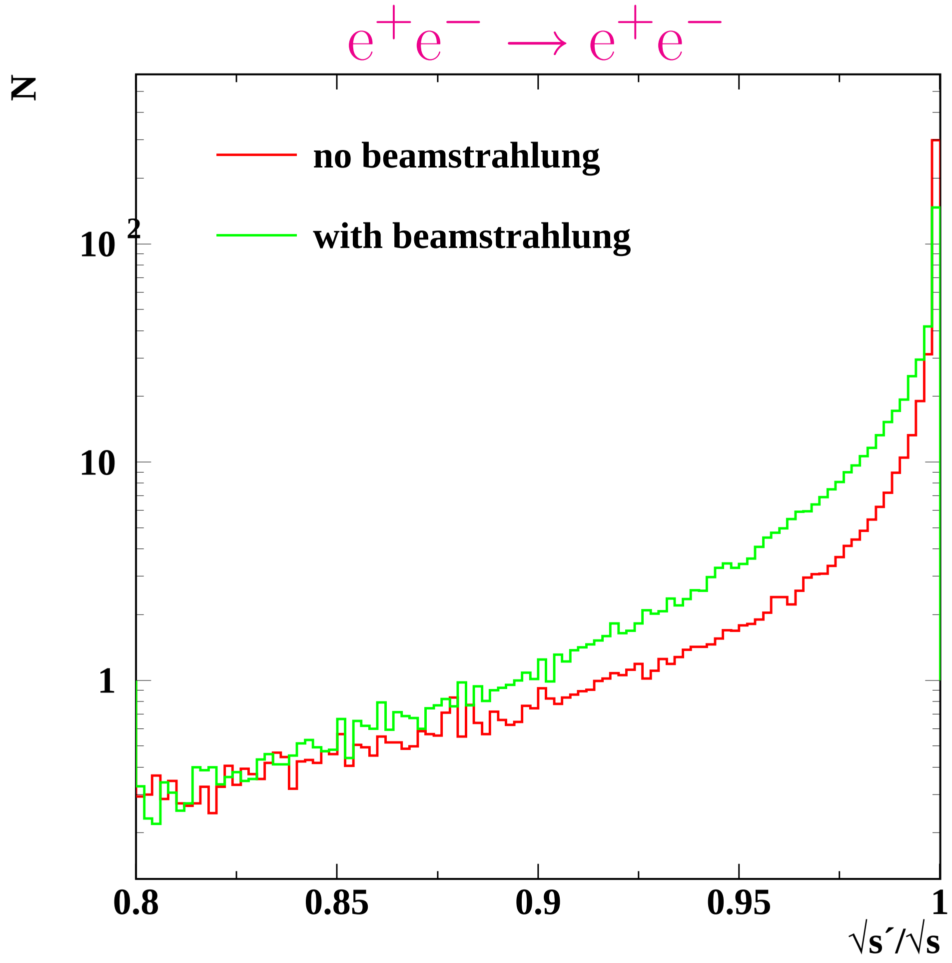
→ very high charge density

⇒ Electrons of one bunch radiate against the coherent field of the other bunch (Beamstrahlung)

Average energy loss for colliding e^+e^--pairs at 500 GeV: $\sim 1.5\%$



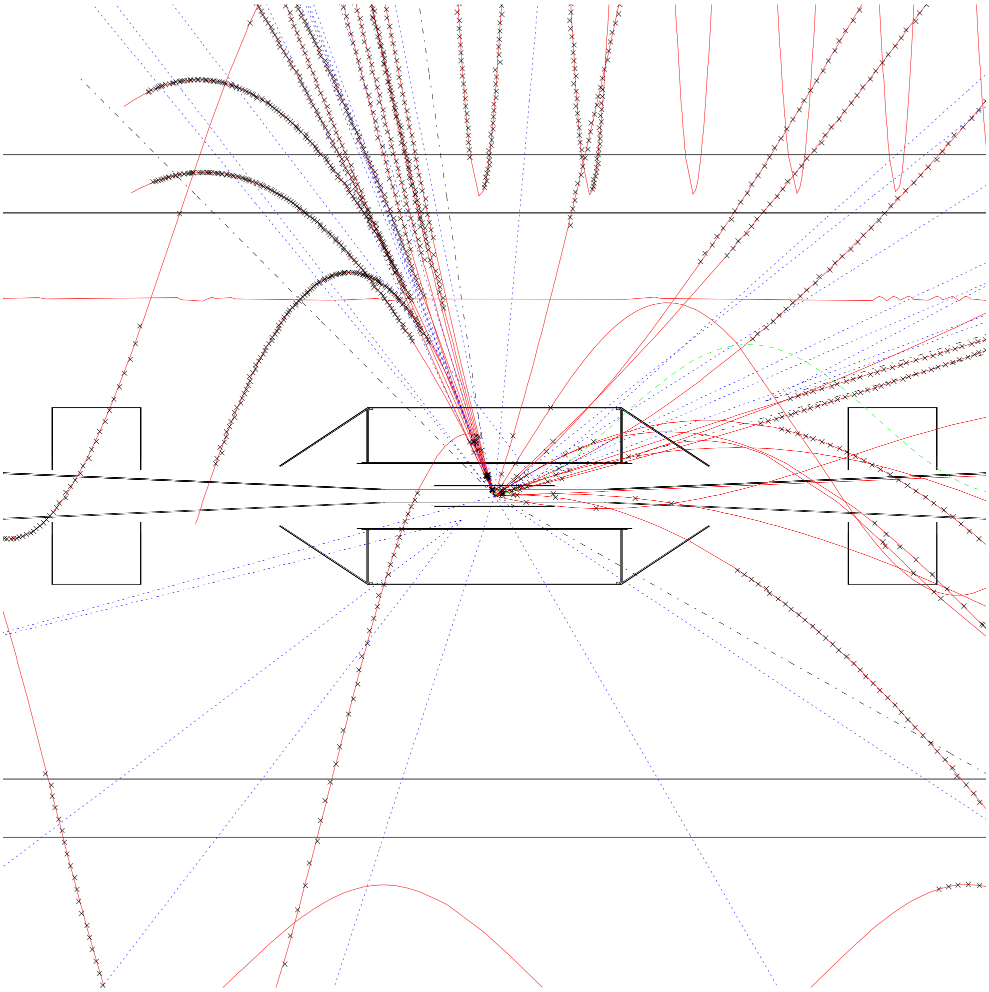
- For continuum processes beamstrahlung comparable to ISR, however with shorter tails



- beamstrahl spectrum can be measured on the 10^{-4} level from the acolinearity of Bhabha-events in the forward ($7° - 25°$) region
- in general beamstrahlung is not a problem in the analyzes

$\gamma\gamma$-background

- at the LC $\gamma\gamma$-background originates from the usual e^+e^--process and from beamstrahlung
- at TESLA luminosities the overlap probability for a $\gamma\gamma$-event with a physics event is on the few % level

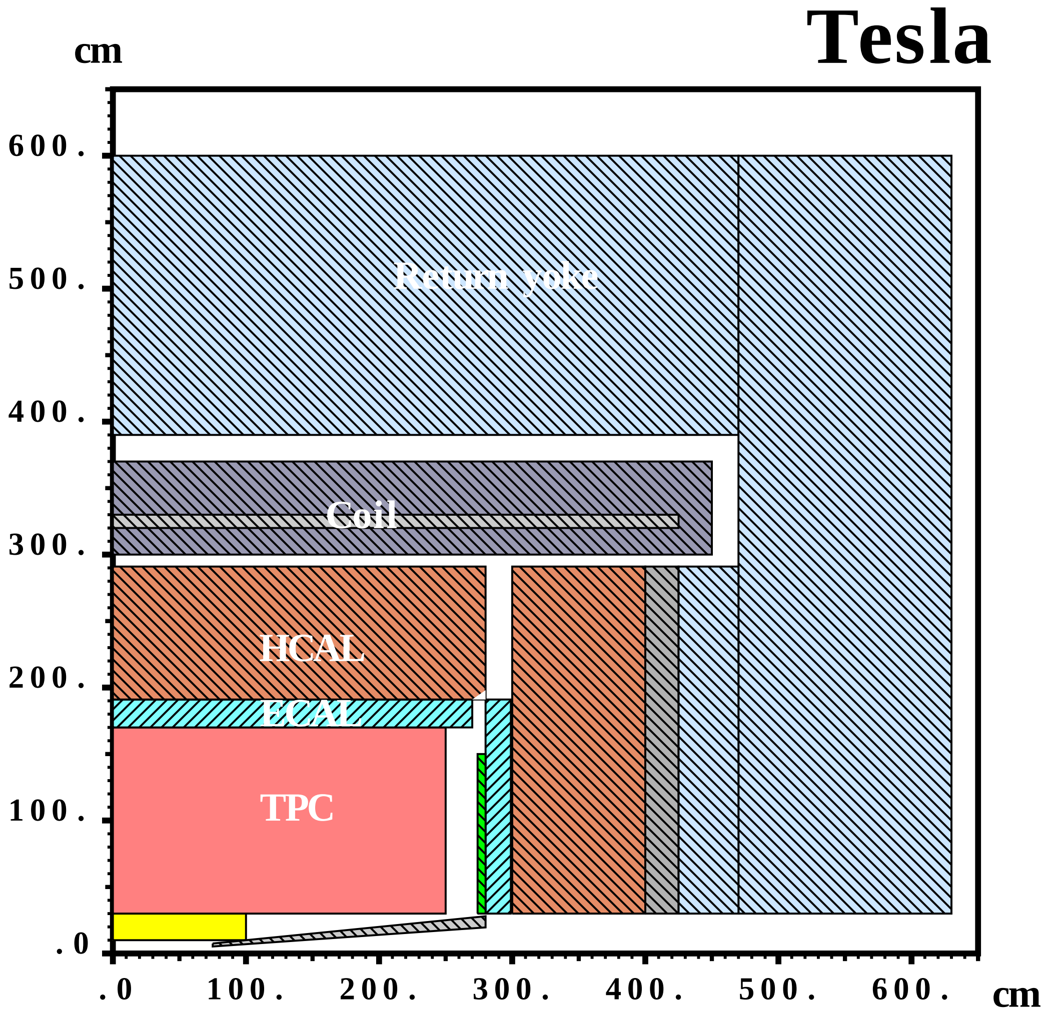


- events with $\gamma\gamma$-overlap can be tagged by a displaced vertex in z and by topological variables
- first studies indicate that they will be no serious problem for physics

A possible Detector for TESLA

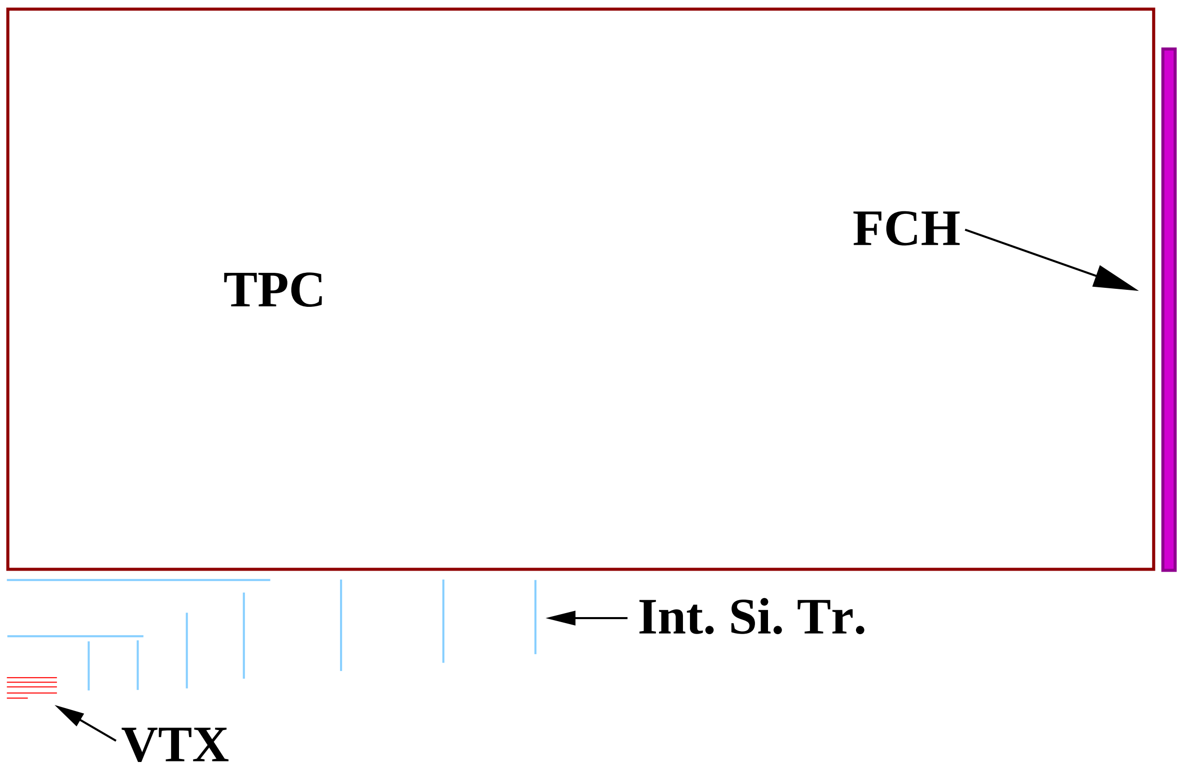
- For the TESLA TDR a possible detector has been designed
- This is meant as a proof that the required detector can be built with the (almost) available technology and with an affordable cost
- The US and Asian detectors are very similar, so only the TESLA detector will be described

Global detector concept



Relatively similar to a LEP detector

Tracking



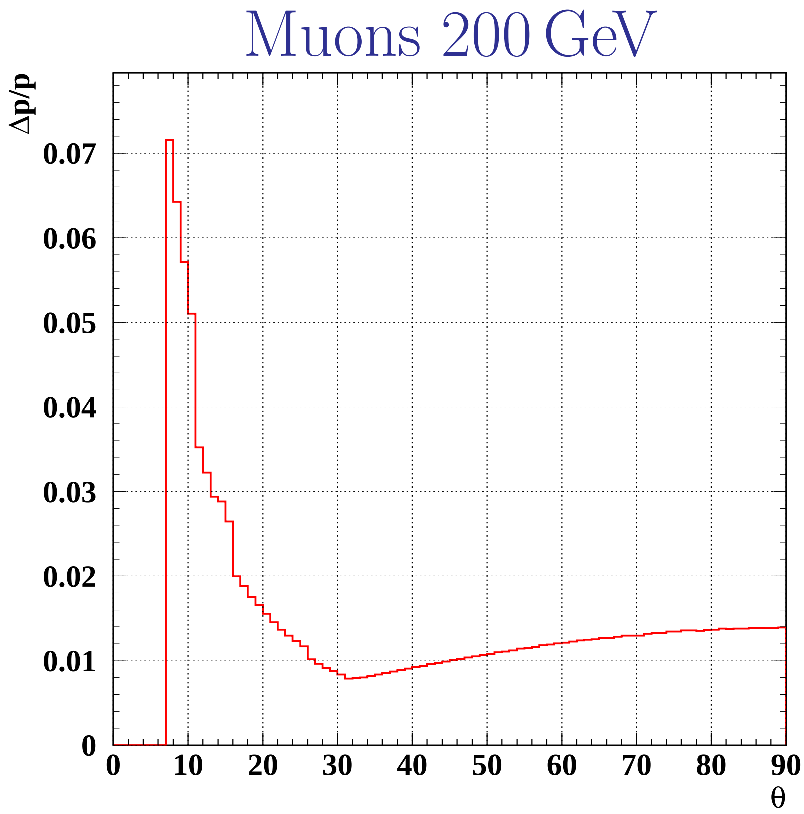
- Superconducting solenoid with $B = 3 - 4T$
- Vertex detector $\rightarrow$ later
- Main tracker: TPC
- silicon tracker inside TPC consisting of barrel cylinders and forward discs
- forward chamber behind TPC

R&D issues for the main tracker

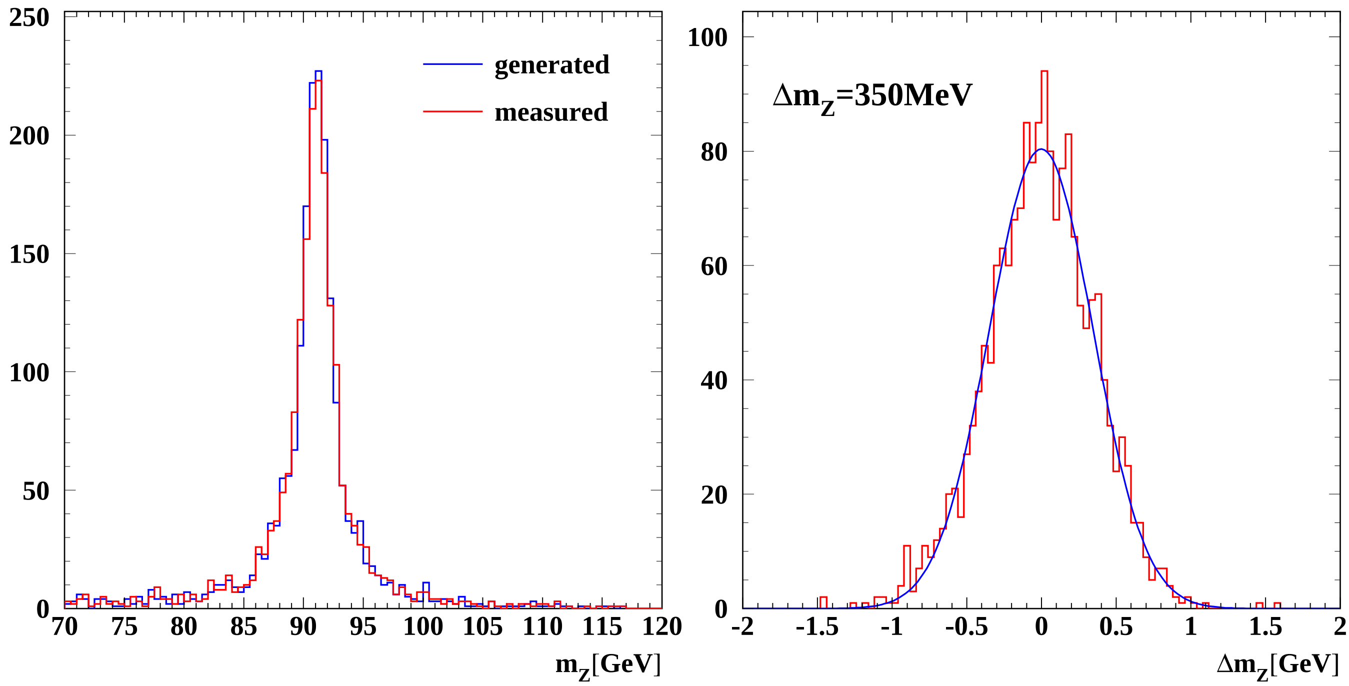
Mainly TPC:

- to cope with larger backgrounds many more pad rows than at LEP (> 150) are needed
- alternative readout schemes like GEMs under study:
  - charge cloud doesn't spread over several pads, how to get good point resolution?
  - how to avoid ion flow back into the sensitive volume?
- dense packing of electronics
- design of a very thin field cages and endplate

Tracking system gives excellent momentum resolution for $\theta > 7°$



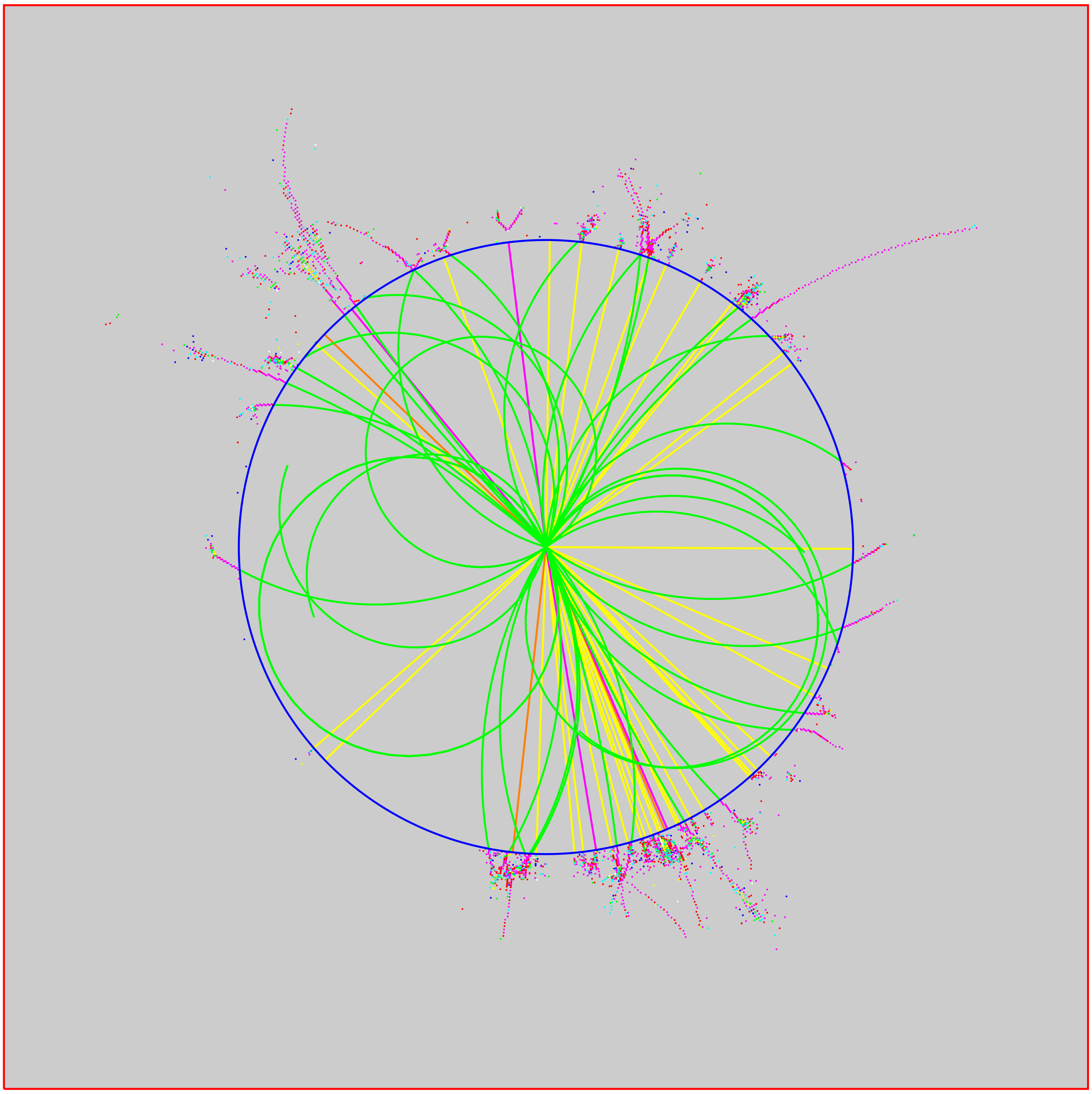
E.g. Z-mass resolution for $e^+e^- \rightarrow HZ, Z \rightarrow \mu^+\mu^-$ totally dominated by intrinsic Z-width



Calorimetry:

- To improve resolution main part of hadron-calorimeter will be inside coil
- Energy flow will be calculated à la LEP ($E_{\text{tot}} = E_{\text{charged}} + E_\gamma + E_{n,K^0_L}$)
  $\Rightarrow$ Spatial resolution is more important than energy resolution
- Aim for
  - ECAL: $\frac{\Delta E}{E} = \frac{0.10}{\sqrt{E}} \oplus 0.01$
  - HCAL: $\frac{\Delta E}{E} = \frac{0.50}{\sqrt{E}} \oplus 0.04$
- several technologies under study
  - shashlik
  - scintillating tiles
  - Si-W (EM only) clearly the best option, if affordable
  - small cells ($1 \times 1\text{cm}^2$) with binary readout (hadron only) might be superior to scintillator because of better separation of nearby showers

Hadronic event in the SiW-Calorimeter



R&D issues in for the calorimeter

General:

- Energy flow concept requires very sophisticated reconstruction algorithms

SiW:

- minimization of silicon cost
- dense packing of channels
- fabrication of homogeneous tungsten surfaces

Scintillating tiles:

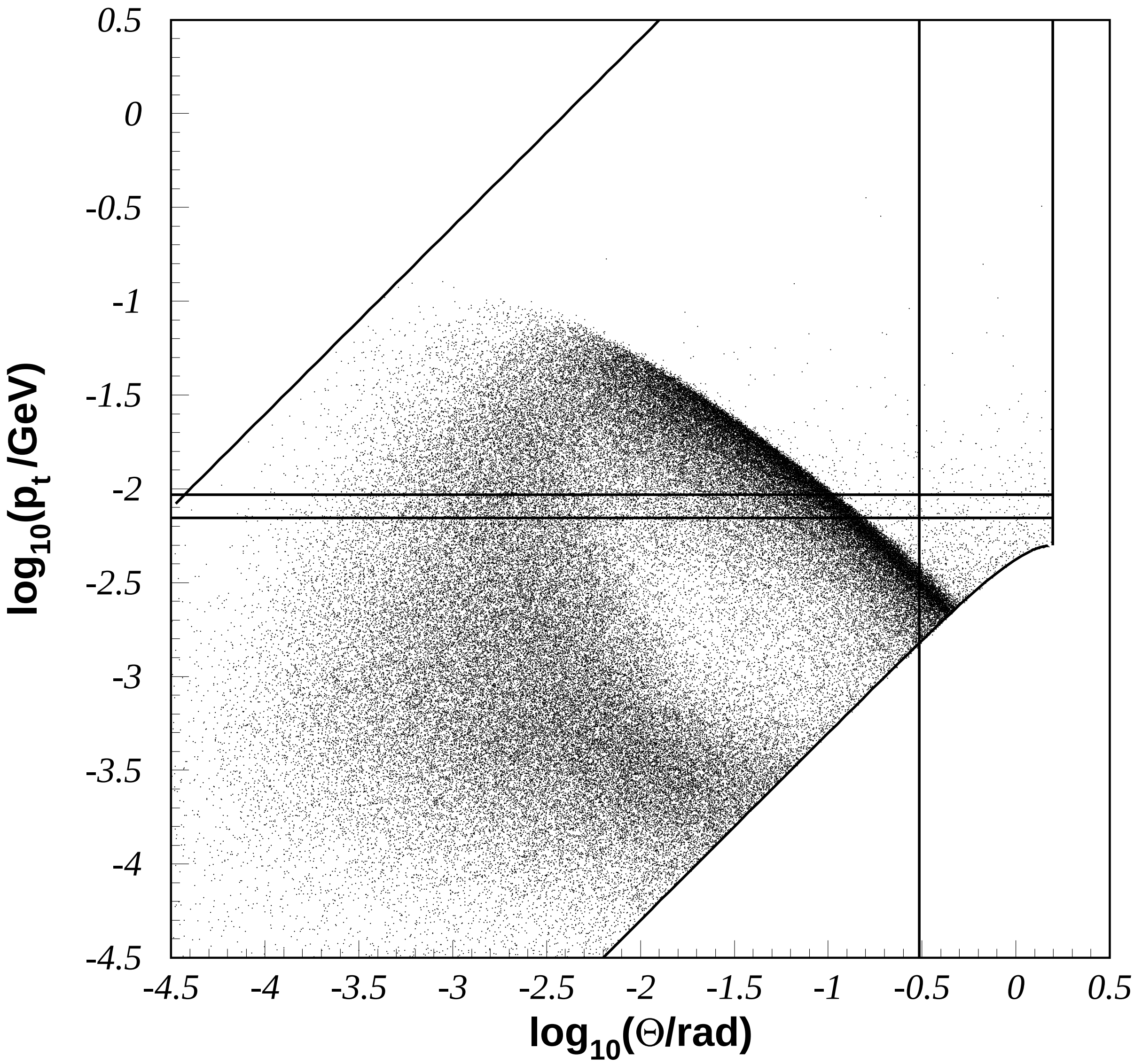
- minimization of tiles (fiber coupling)
- cheap fiber readout

Digital calorimeter:

- cost minimization of readout channel ($5 \cdot 10^7$ channels!!!)

Vertex detector

Main issue: e^+e^- pairs from beamstrahlung



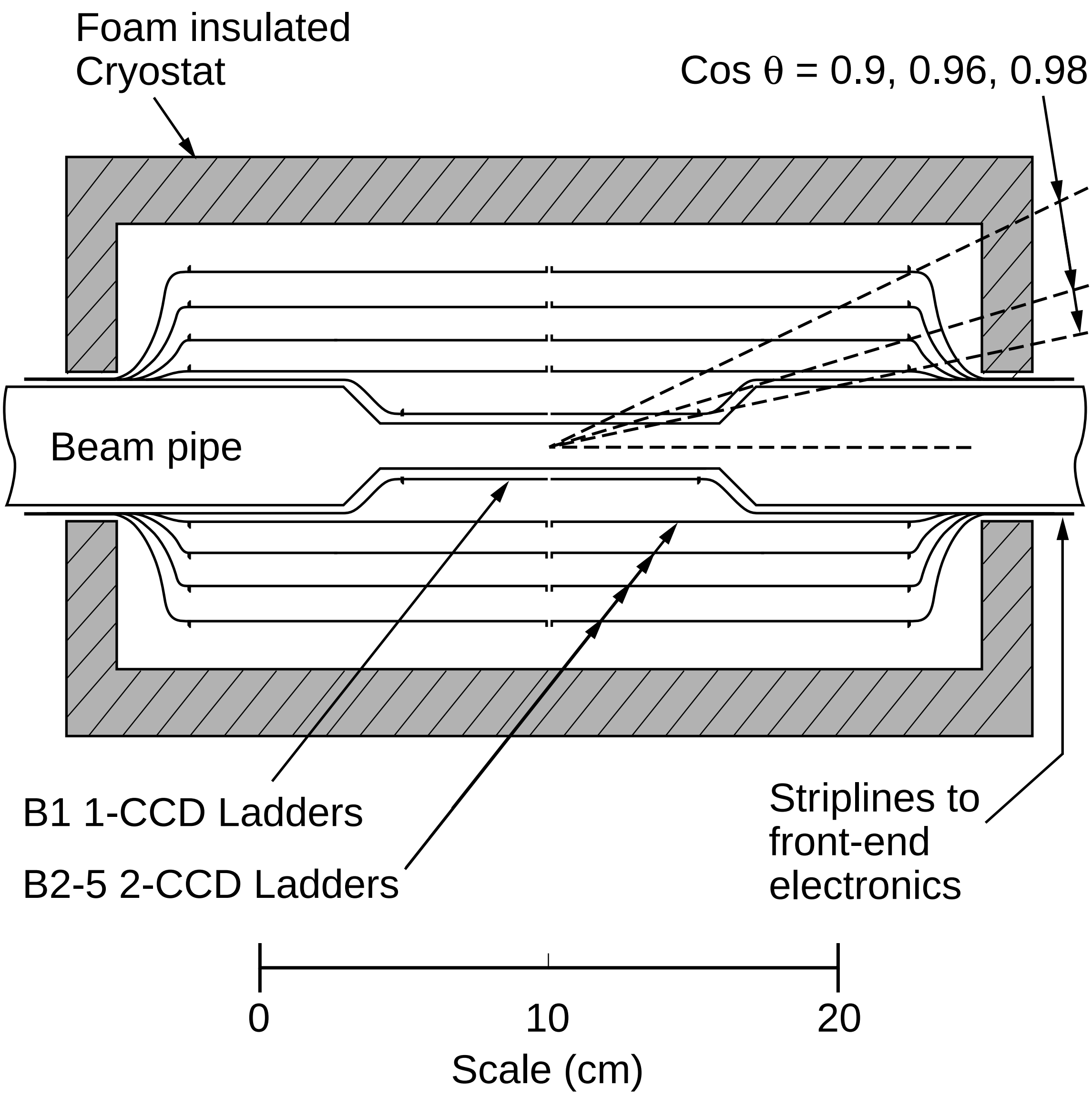
For a given B field p_t translates into a maximum radius

At TESLA $B = 3T$, $r = 1.5$cm corresponds to 0.03 hit/mm^2/BX

Technologies:

- Pixels à la ATLAS
- CMOS-Pixels (very attractive idea)
- CCDs (pioneered at SLD)

CCDs



- point resolution: $\sigma_p \approx 3.5\mu\text{m}$
- layer thickness: $\sim 0.12\% X_0$

$\Rightarrow$ IP resolution $\sigma_{IP} \sim 2\mu\text{m} \oplus \dfrac{10\mu\text{m}}{p\sin^{3/2}\theta}$

R&D issues for the vertex detector

CCDs:

- currently the readout time is very long accumulating background over many bunch crossings
  - column parallel readout
  - readout frequency 50 MHz
  - readout detector continuously

  ⇒ One complete readout extends over ~ 100 bunch crossings ➟ 3 hits/mm^2/BX
- thinning of layers

Pixels:

- need to make detector much thinner
- need to improve resolution (floating pixels)

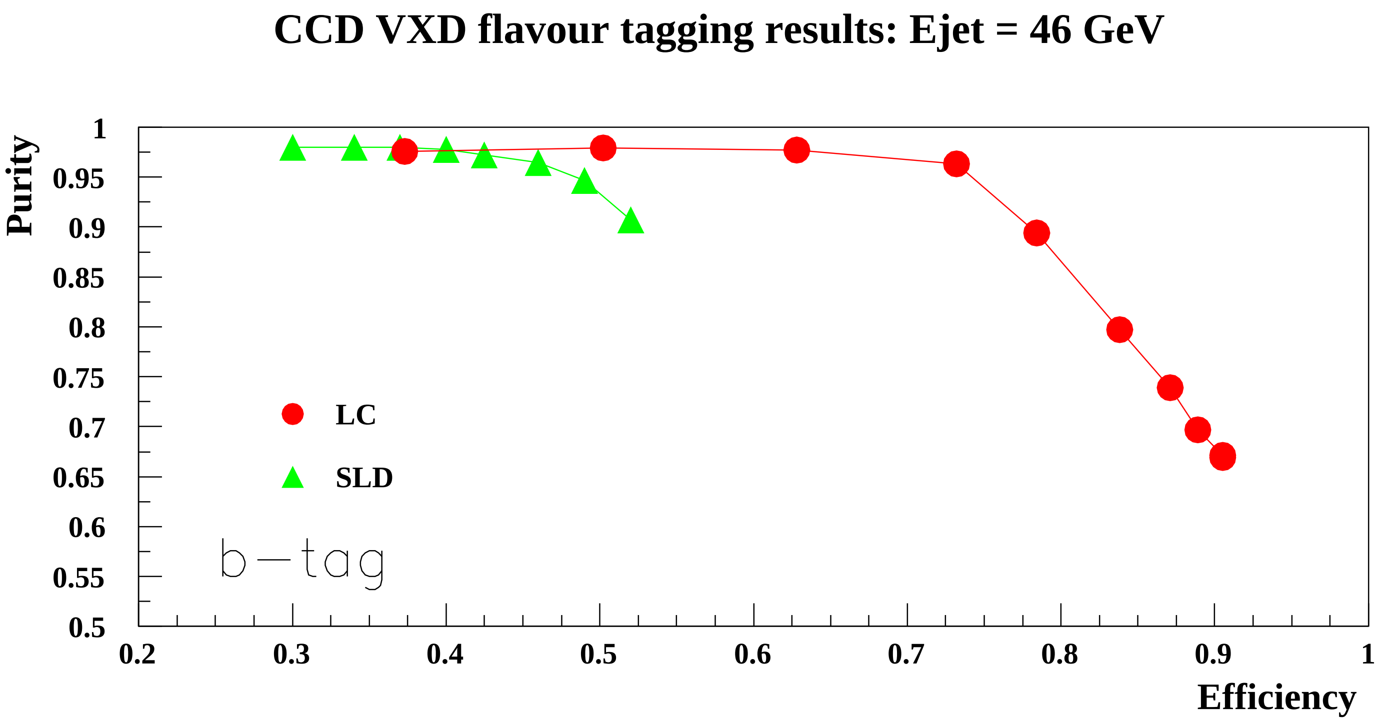
CMOS:

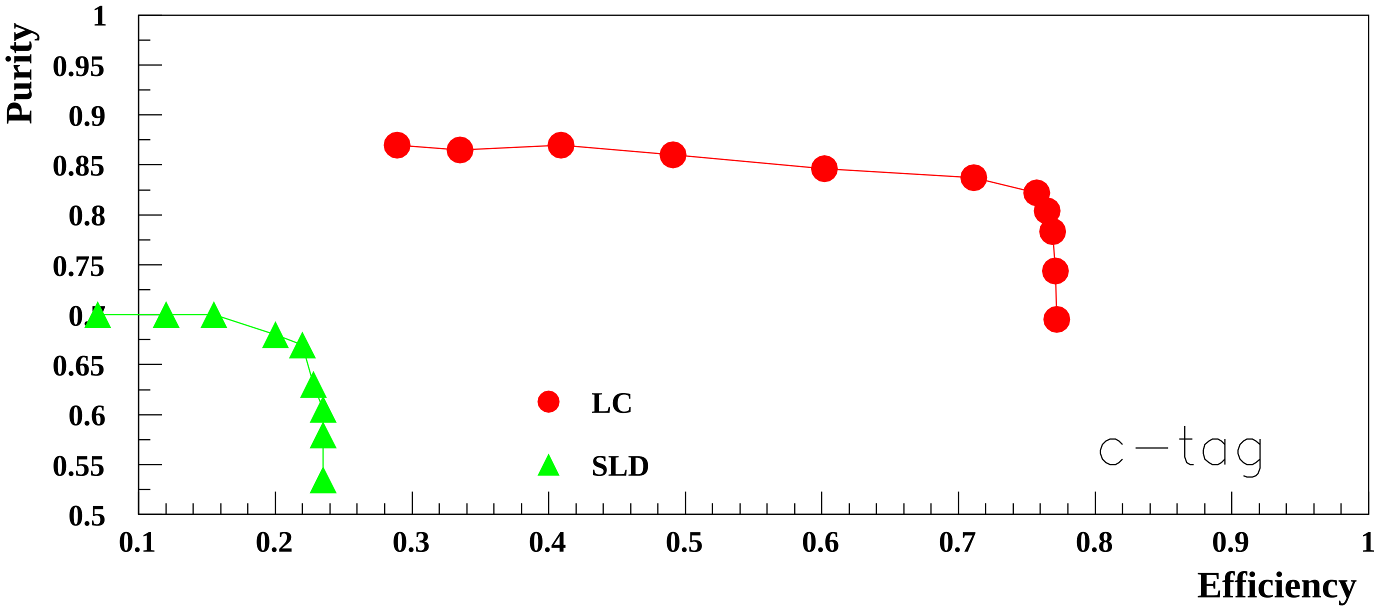
(same technology as in cheap video cameras, potential to be fast and cheap)

- first promising results on small test chips but no running large scale system yet

B-tagging:

Very good results with SLD-like algorithm



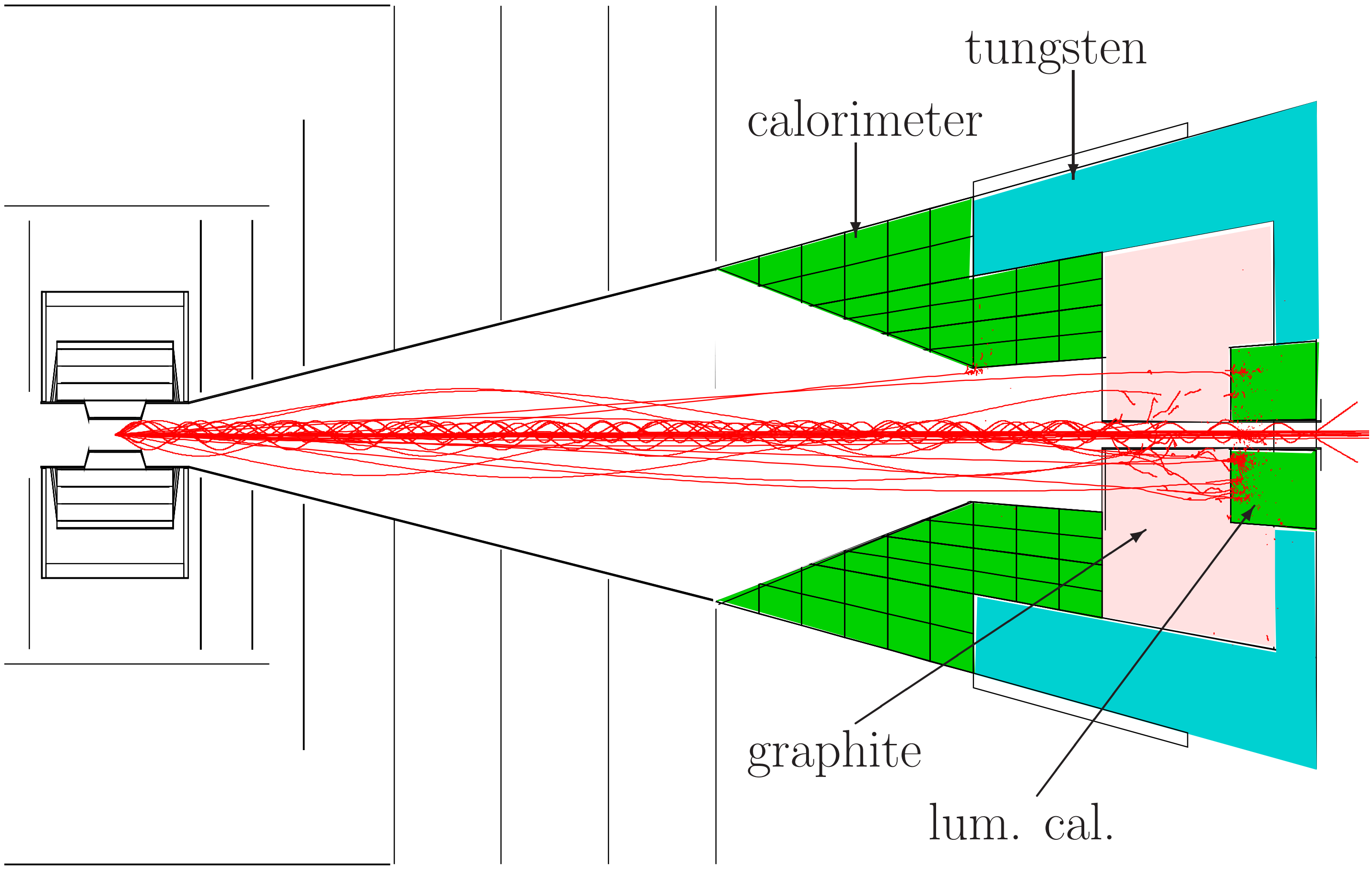


- Very high b-efficiency ⇒ important for multi-b final states with low σ (ZHH,$t\bar{t}$H)
- Good c-efficiency/purity ⇒ important for BR(H $\rightarrow c\bar{c}$)

Very forward region:

- Pairs give large background in very forward region
- Also lots of neutrons in this region

➡ Need mask at $\theta < 5^\circ$



- Environment clean enough above $\theta = 1.5^\circ$ to install hermeticity calorimeters for searches and precision luminosity
- Below 1.5° only luminosity calorimeter for machine tuning and limited tagging for searches
- R&D needed for radiation hardness of LCAL

Trigger

- detector is designed without any hardware trigger
- a full bunch train is read out and send to a PC farm
- bandwidth not larger than level 2 at LHC
- the system is completely deadtime free
- the full detector information can be used to select complicated new physics channels
- no need to include fast detectors for triggering

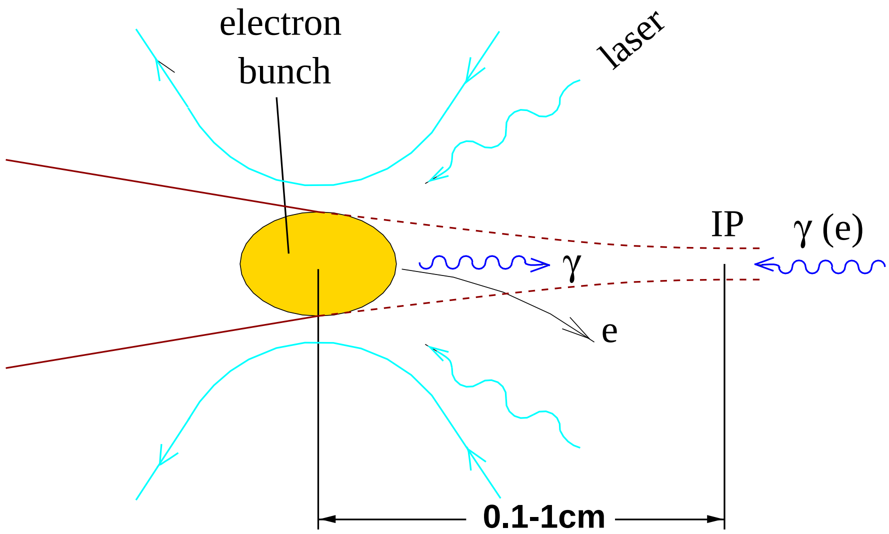
Other collider modes

e^-e^--collider:

- to run an e^+e^--collider in e^-e^- mode should be a relatively simple modification
- since the pinch-effect turns into an anti-pinch-effect luminosity can be about an order of magnitude lower
- the interaction region can stay the same
- physics interest:
  - precision measurement of Møller-scattering
  - precision measurement of the selectron mass (β instead of β^3 suppression due to χ^0 t-channel production)
  - access to the $I = 2$ amplitude in WW-scattering
  - some exotic models, e.g. with doubly charged leptons

$\gamma\gamma$ and eγ collider

- high energy γs can be produced by Compton backscattering with laser light close to the IP



- Maximal photon energy ω_m:

$$\omega_m = \frac{x}{x+1} E_0$$

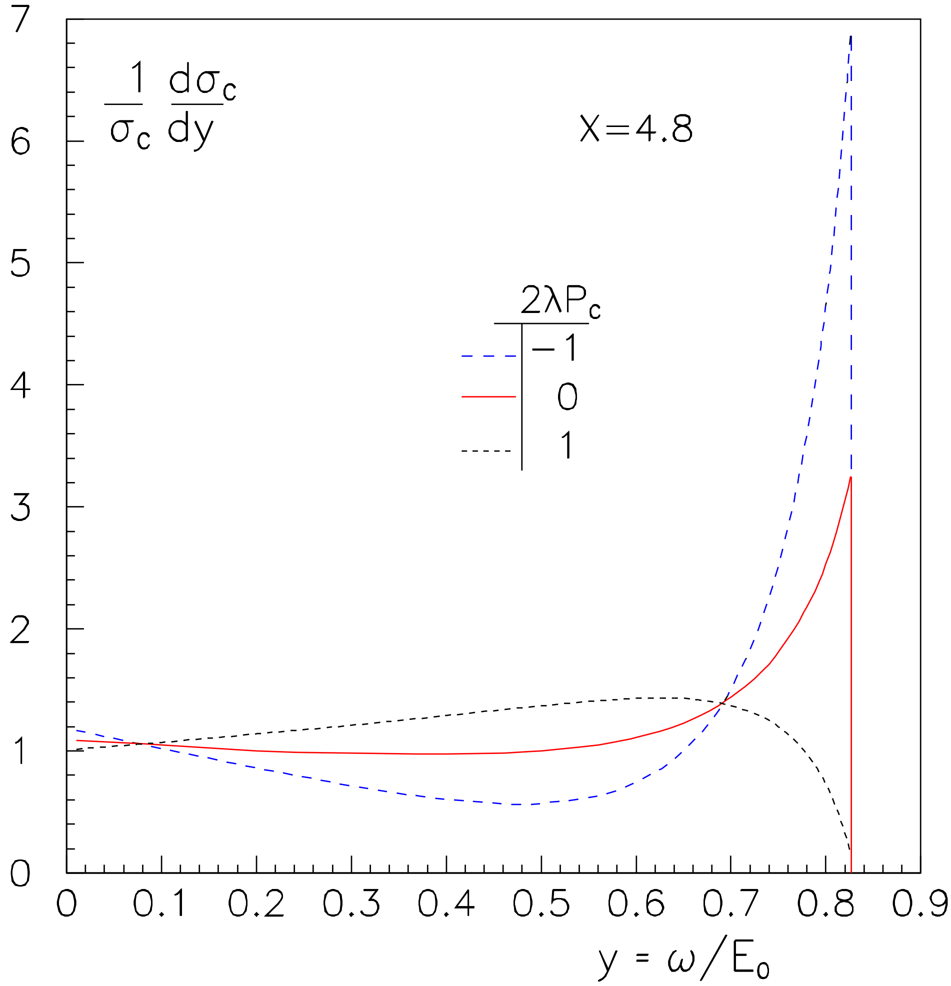
$$x = \frac{4E_0\omega_0}{m^2c^4} \simeq 15.3 \left[\frac{E_0}{\mathrm{TeV}}\right]\left[\frac{\omega_0}{eV}\right]$$

($\omega_0(E_0)$ = laser (beam) energy)

have to keep $x < 4.8$ to avoid $\gamma\gamma \rightarrow e^+e^-$ in the laser interaction region $\Rightarrow$ $\omega_m \approx 0.8 E_0$

- γ energy spectrum depends on product of electron and laser polarization

γ-energy spectrum for different polarization products

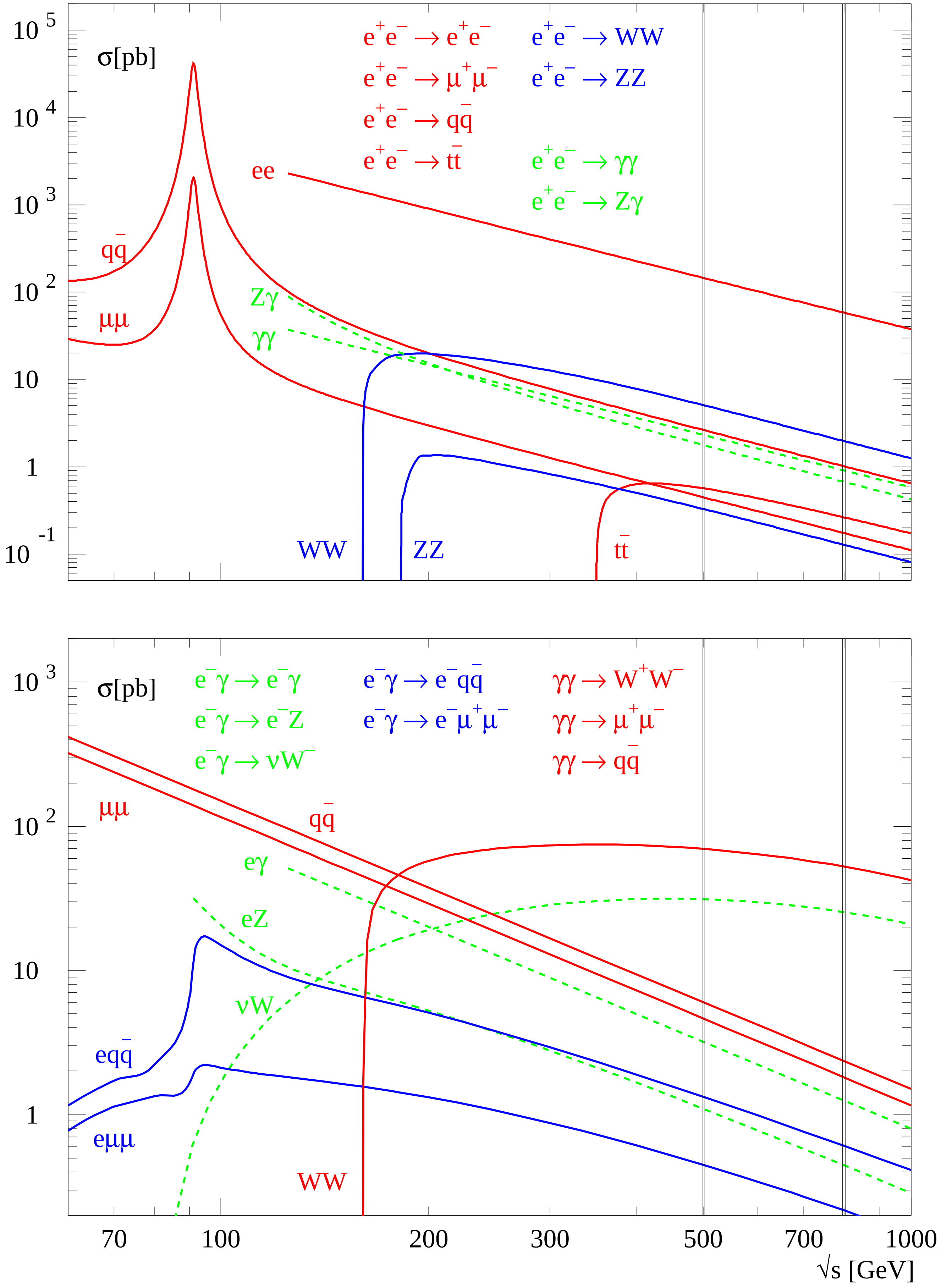


- luminosity for $\gamma\gamma$, $e\gamma$-colliders factor 5-10 lower than for e$^+$e$^-$-colliders for identical beam parameters (can be brought to 40% by optimizing parameters)
- to separate used photon beam from incoming beam a crossing angle is needed
- background situation is similar to e$^+$e$^-$-mode
- however $\sim$ 1.5 underlying events from low energy $\gamma\gamma$ collisions

Physics interest:

- some cross sections involving gauge bosons are larger than in e^+e^- $\rightarrow$ plot
- coupling to photons can be measured without ambiguities from Z-couplings
- a $\gamma\gamma$-collider can measure cleanly the partial width $H \rightarrow \gamma\gamma$ $\rightarrow$ later
- the mass reach for some particles (Higgses, SUSY-particles, W') can be higher than in e^+e^-
- an $e\gamma$-collider is an ideal place to measure the photon structure

SM cross sections is e^+e^-, $e\gamma$, $\gamma\gamma$



A possible roadmap to an LC (TESLA)

- All regions agree that we need one TeV-class LC in the world as the highest priority project in HEP
- Wherever it will be build we will all collaborate
- the TESLA "Technical Design Report" has been submitted in march 2001
- the project has reviewed by the German science council
- a first reaction from the German government exists
- The projected cost of TESLA is:
  - 500 GeV linear collider: 3.1 GEURO
  - addition for FEL: 0.5 GEURO
  - HEP detector: 0.2 GEURO
- A realistic estimate of the German contribution is $\mathcal{O}(50\%)$.
- The rest has to come as international contribution
- TESLA will be organized as a temporary international organization.
- total construction time 8 years
- we could start data taking in 2012

Recent press release by the German government

A new free electron laser is to be built at the DESY research centre in Hamburg. In view of the locational advantage, Germany is prepared to cover half of the investment costs amounting to 673 million Euro. Talks on European cooperation will soon start so that it will be possible to take a decision on construction within about two years. The construction period will be approximately six years.

No German site is at present proposed for the TESLA linear accelerator. The reason is that the accelerator project will be an international collaboration. International developments must therefore be taken into account. An independent initiative by Germany concerning the site of the accelerator is neither appropriate nor necessary. DESY will, however, be able to continue its international research work so that German participation in a future global project will be possible.