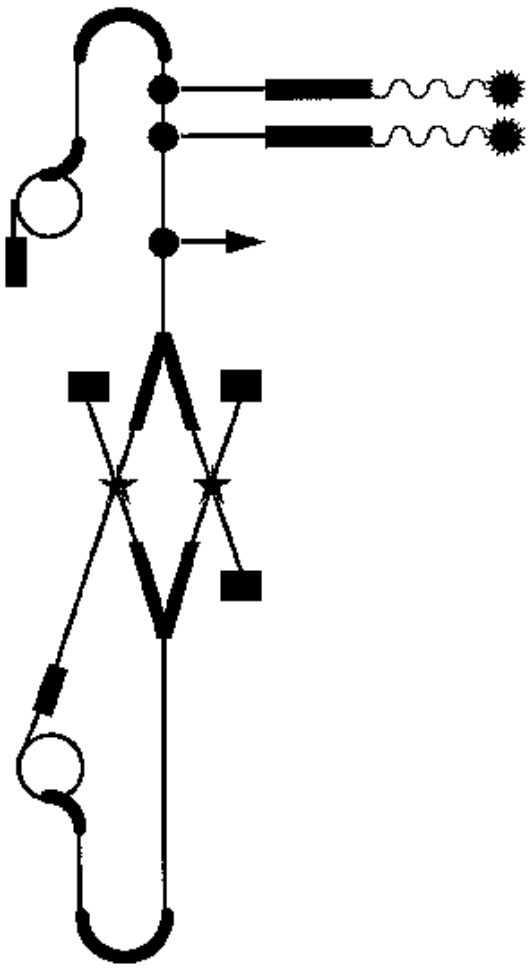
T. GREENSHAW

Future Physics with a Linear Collider



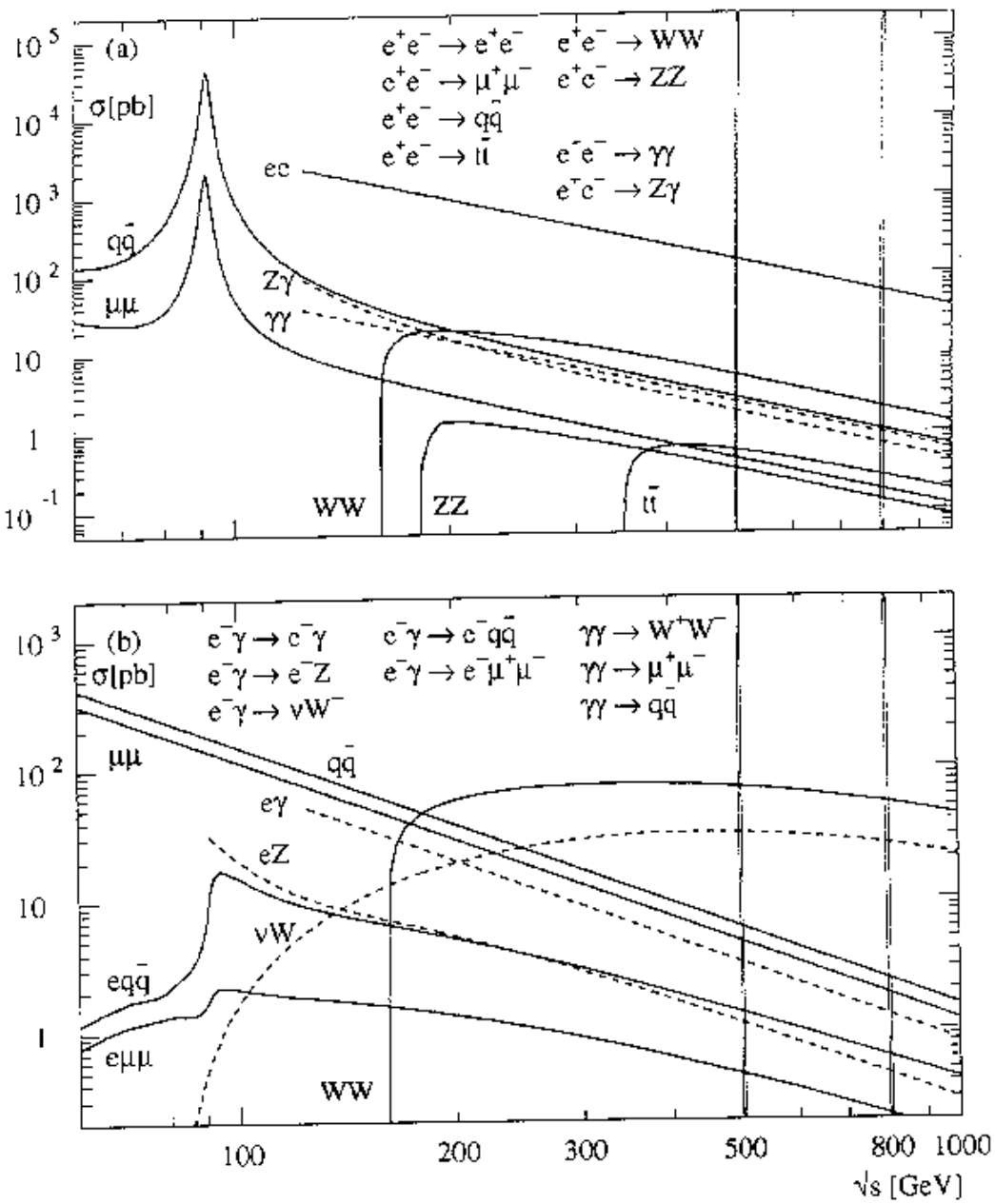
- Why a LC as well as the LHC?
- The TESLA collider.
- Calorimetry and muon detection.
- Optional extras.

Why a LC?

- Take two examples:
  - The SM Higgs.
  - SUSY
- How well can LC do relevant measurements?
- Consider $\sqrt{s} \sim 500\,\text{GeV}$, $\int \mathcal{L} \sim 50\text{pb}^{-1}$.
- Where does LC provide different information to LHC?

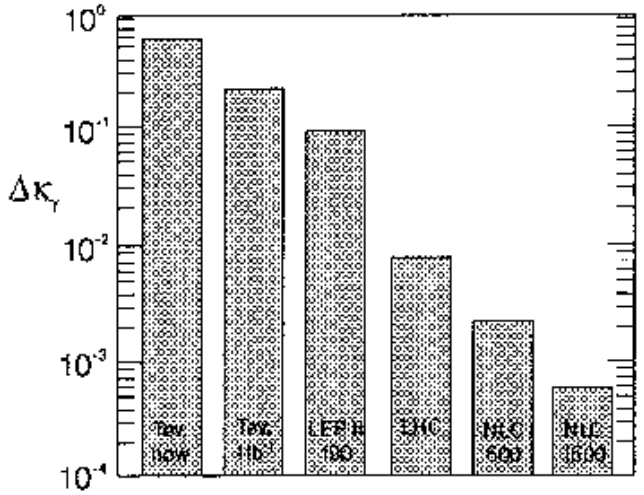
- For more, and more detail, see:
  http://www.desy.de:8888/~schreibr/cdr/cdr.html

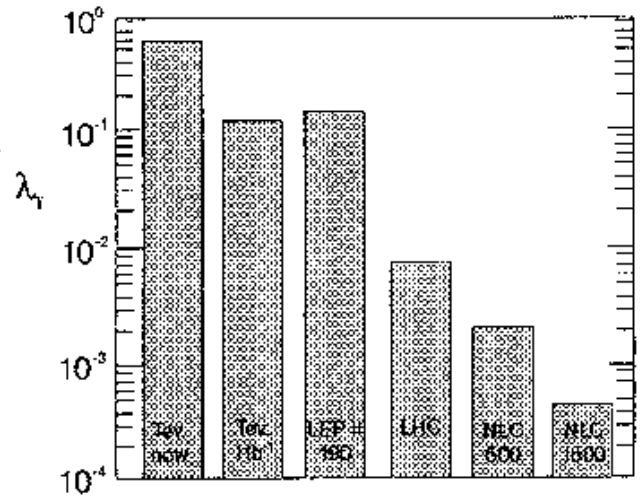
Rates of SM Processes



Triple Gauge Couplings

- Comparison of measurements at various colliders.



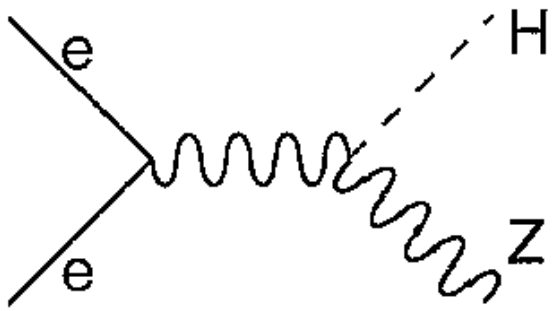


SM Higgs

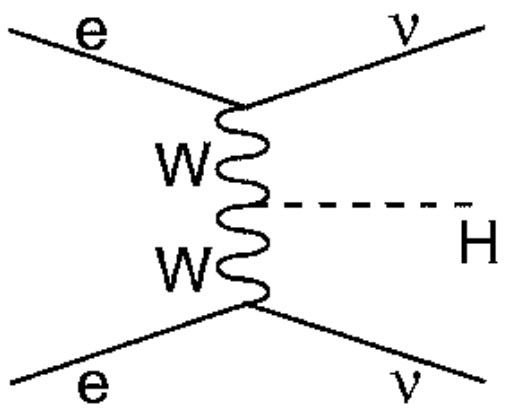
- Essential to SM, but no experimental evidence!
- To understand must find Higgs boson and measure:
  - Mass.
  - Spin.
  - Parity.
  - Lifetime.
  - Couplings to W, Z, q, l.
  - Self-couplings.
- Electroweak data suggest $70 < M_H < 320\,\text{GeV}$

SM Higgs Mass

- Production at LC:
  - Higgs-strahlung.

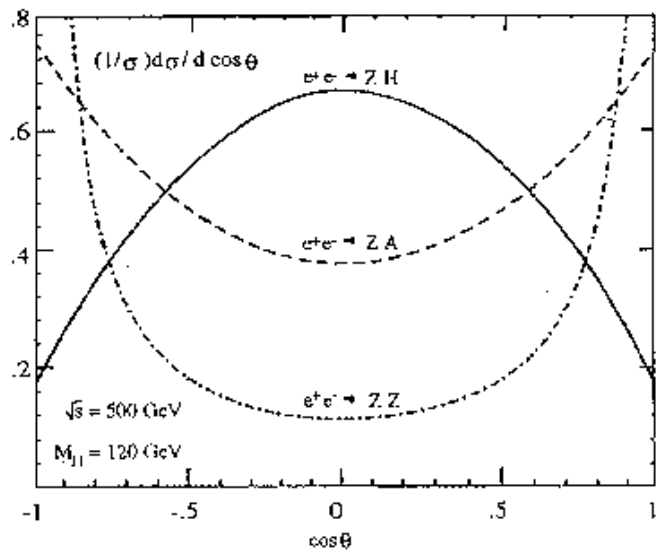


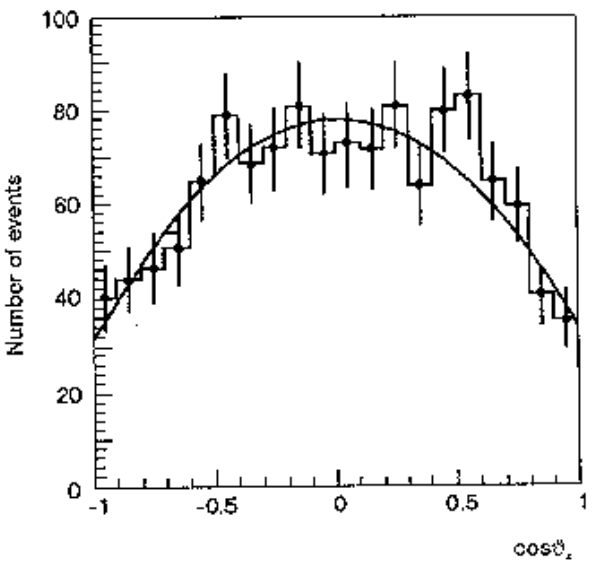
  - M_H via recoil mass.
  - Reconstruct from final state.
- Fusion mechanism



SM Higgs External Quantum Numbers

- Spin, Parity from angular distribution of Z, H bosons in Higgs-strahlung.





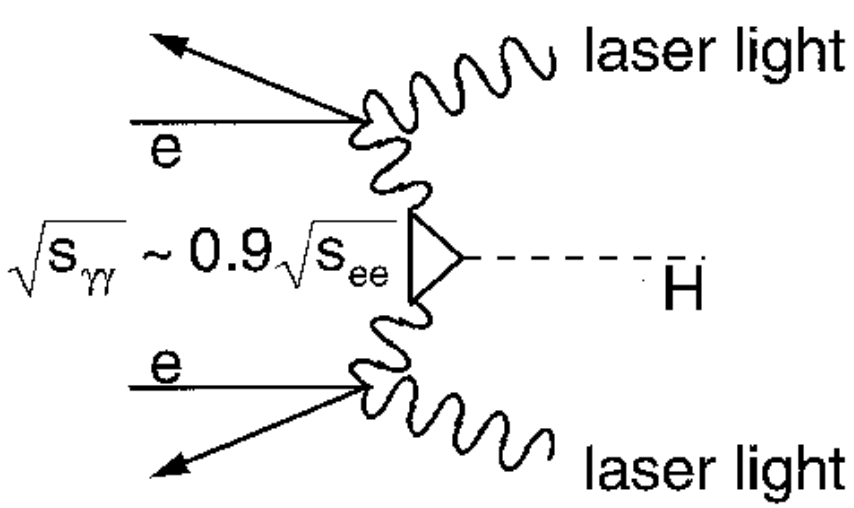
Higgs Lifetime

- Width directly measureable where large, i.e. if $M_H > 2 \times M_Z$.
- Small mass, width < resolution:
  - Measure

$$BR(H \to \gamma\gamma) = \frac{\Gamma(H \to \gamma\gamma)}{\Gamma(H)}$$

  - From LC in $\gamma\gamma$ mode get

$$\sigma(\gamma\gamma \to H) = \frac{16\pi^2}{M_H} \Gamma(H \to \gamma\gamma) \times BW$$

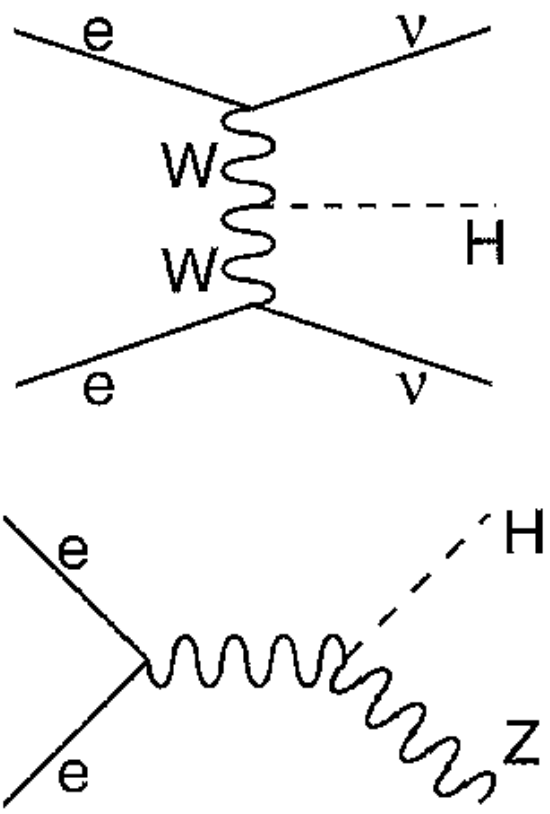


Higgs lifetime cont.

- Similarly for intermediate mass, using:
  - BR($H \to ZZ$), BR($H \to WW$).
  - $\sigma(ee \to HZ)$, $\sigma(ee \to \nu\nu H)$.
- Can determine τ_H for all M_H using ee and $\gamma\gamma$ collider.

Higgs Couplings

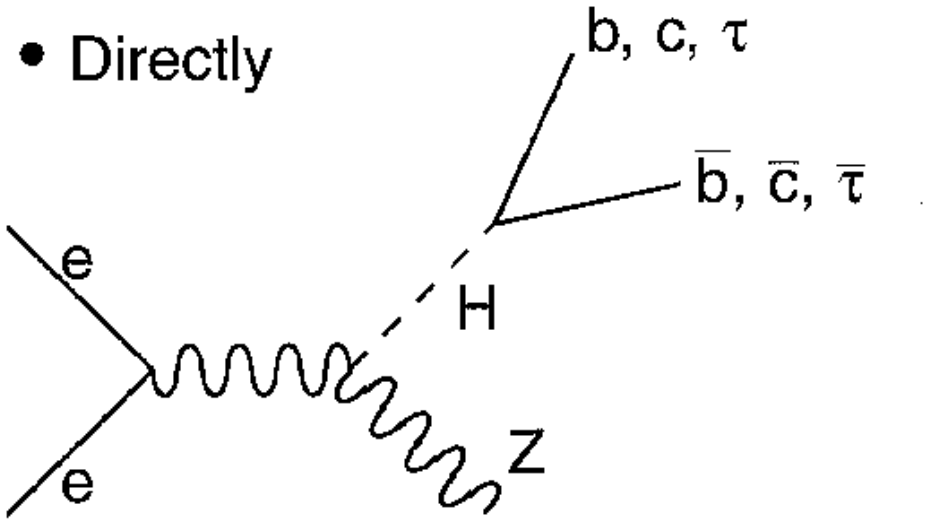
- To W, Z, bosons, via cross-sections:



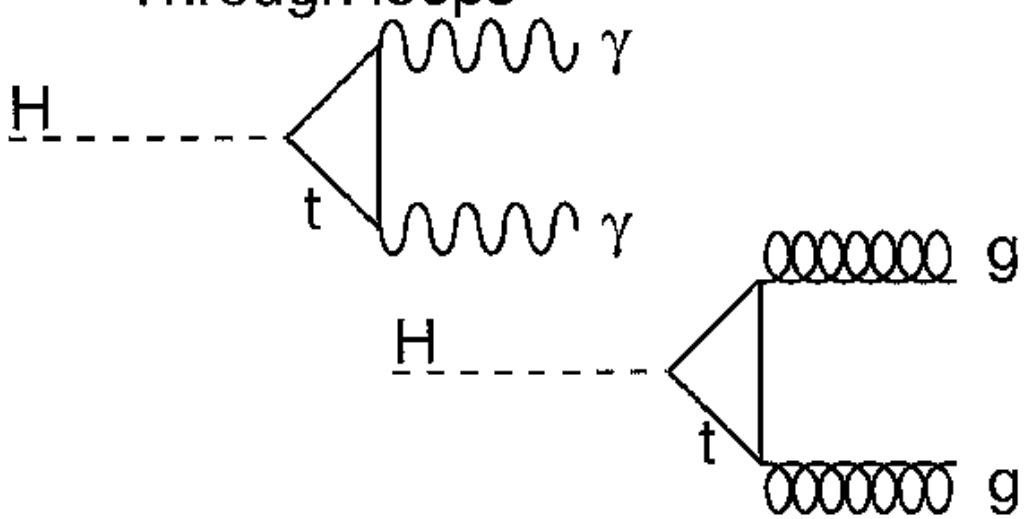
- Accuracy ~ 3%

Higgs couplings cont.

- To fermions, via branching ratios, either:
  - Directly

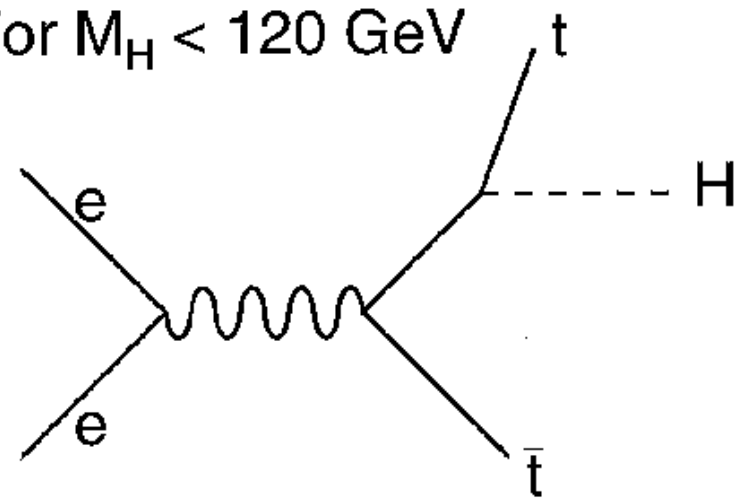


  - Through loops

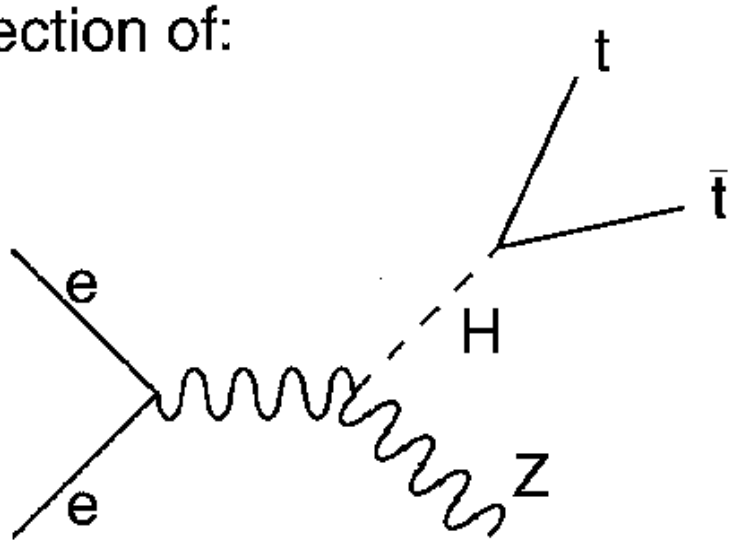


Higgs couplings cont.

- To top
  - For $M_H < 120$ GeV

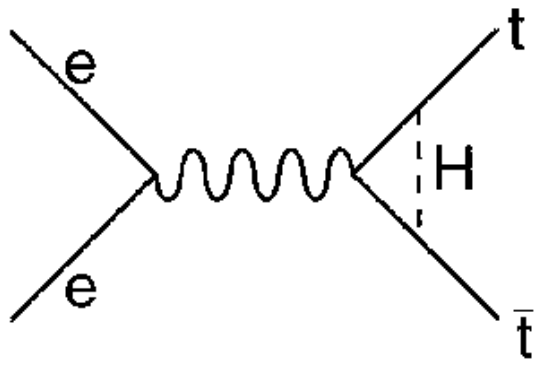


  - For $M_H > 2 \times M_t$, effects on cross-section of:

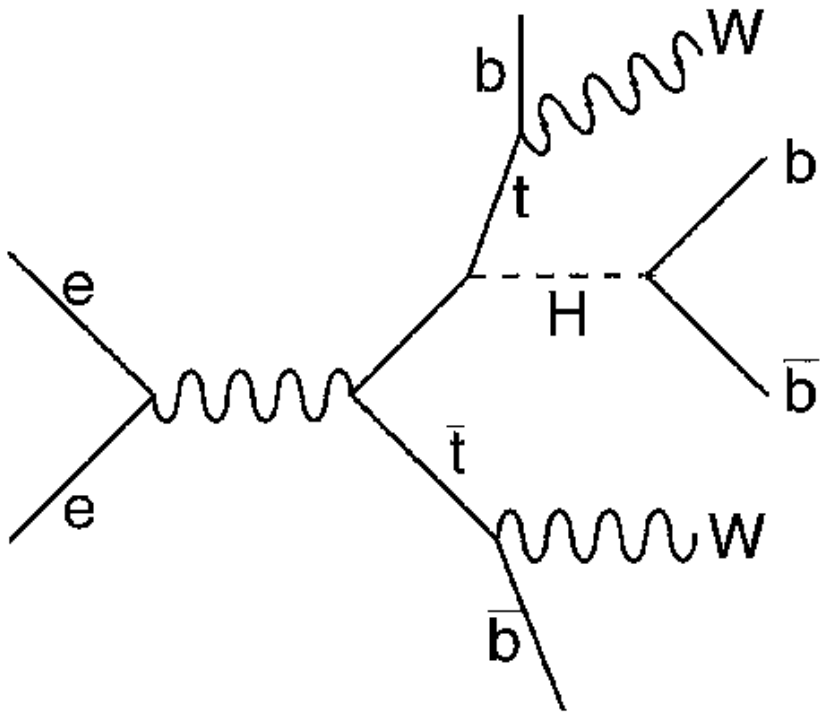


Higgs couplings cont.

- Also study effects on t production of:

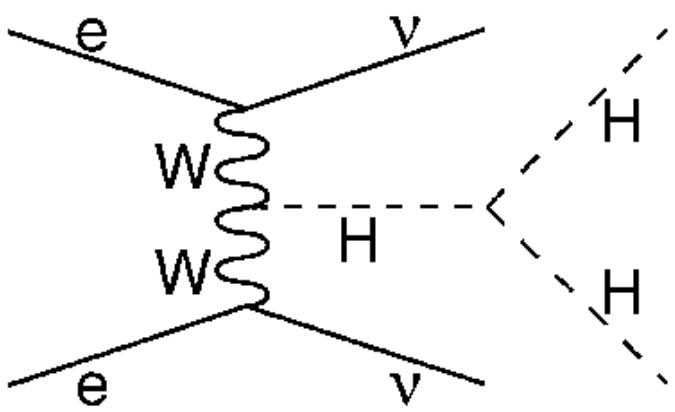


- Note complexity of final states!



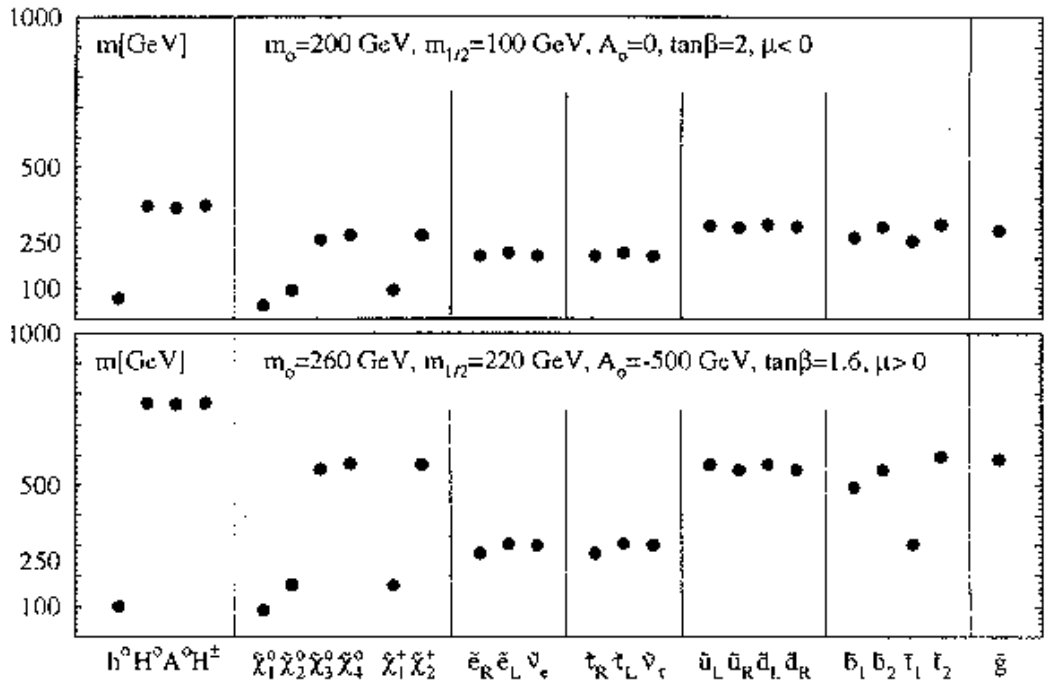
Higgs Self-Couplings

- Difficult!
  - Need $\sqrt{s} \sim 1.6\,\text{TeV}$, $L \sim 1000\,\text{fb}^{-1}$.



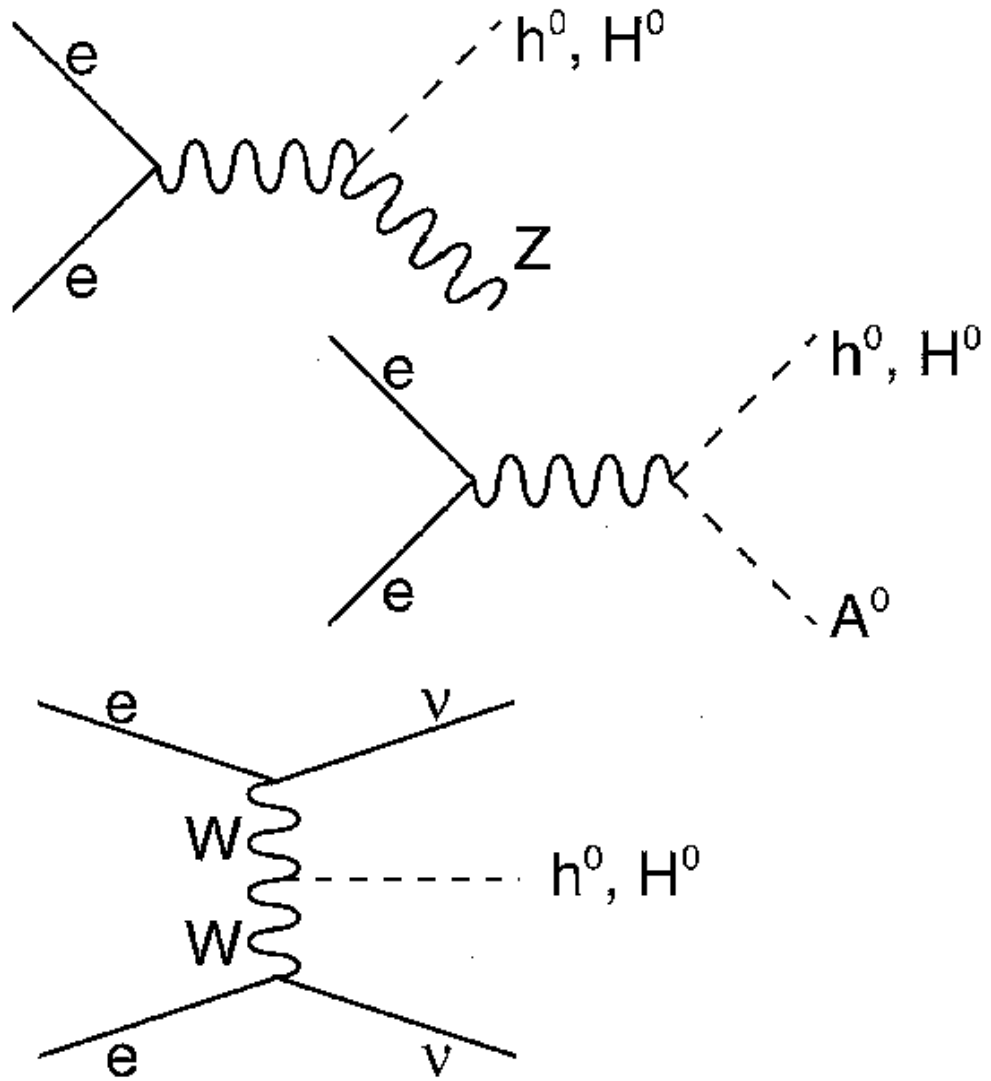
The LC and SUSY

- "Typical" MSSM particle masses.



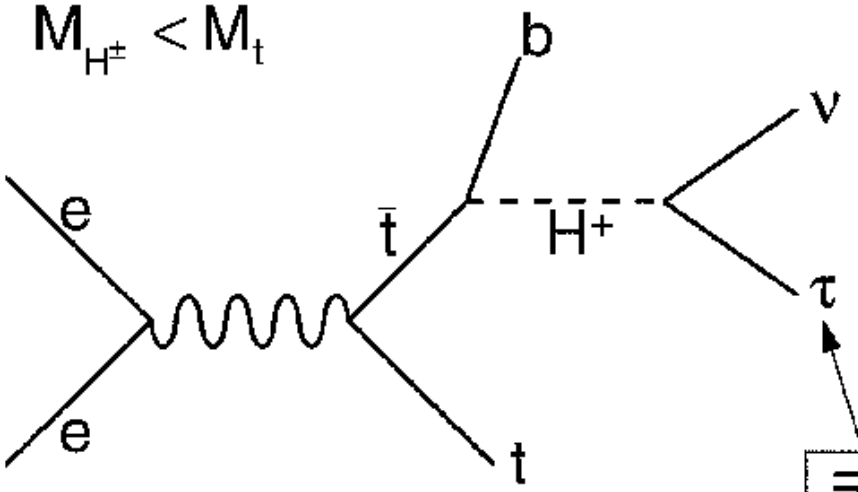
Production of SUSY Higgs

- Higgs bosons are h^0, H^0, A^0, $H^{\pm}$.
- Lightest h^0, $M_h < 150\,GeV$.
- Production mechanisms



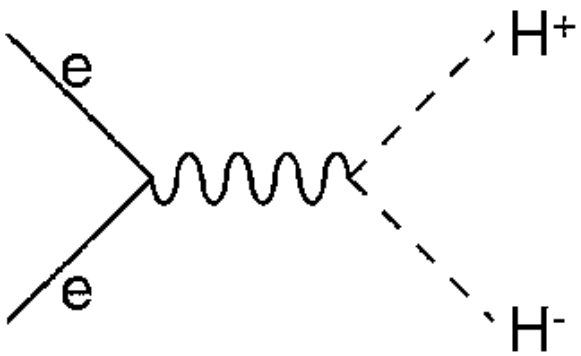
Production of SUSY Higgs cont.

- If $M_{H^\pm} < M_t$



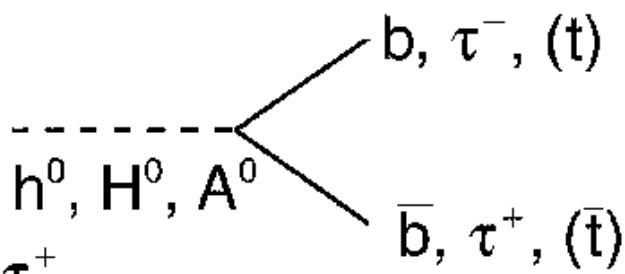
more τ than e, μ in top final states!

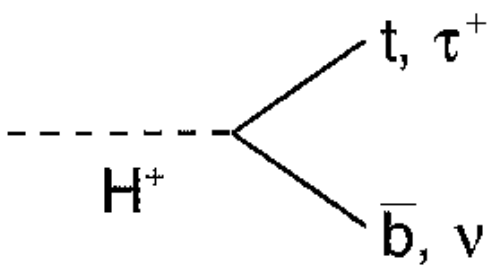
- If $H^\pm$ heavy



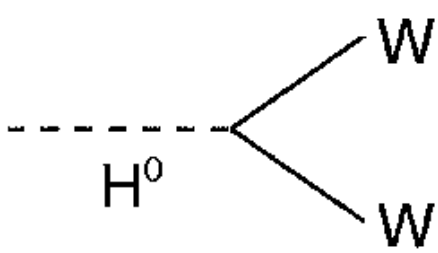
SUSY Higgs decays

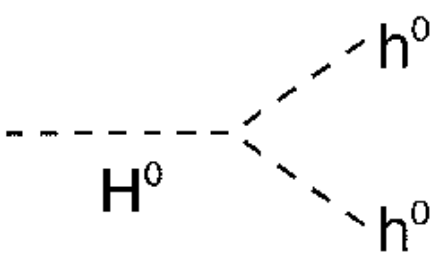
- To fermions

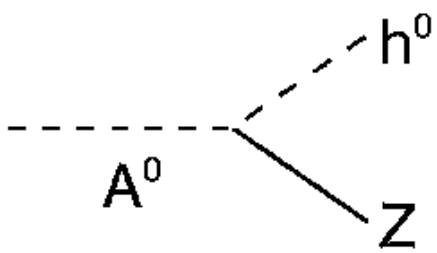


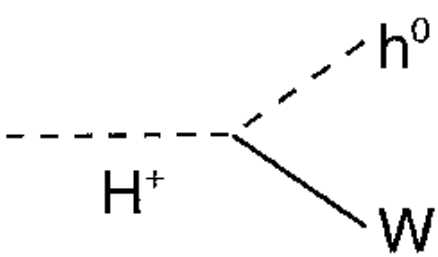


- To bosons



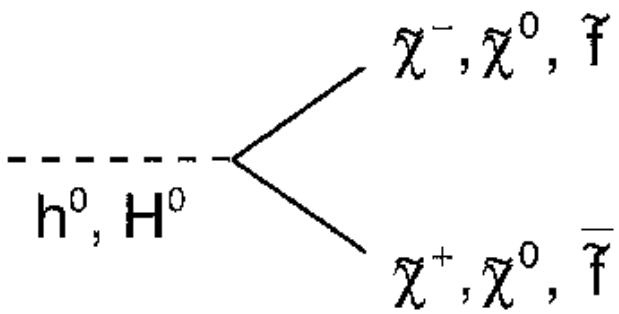






SUSY Higgs decays cont.

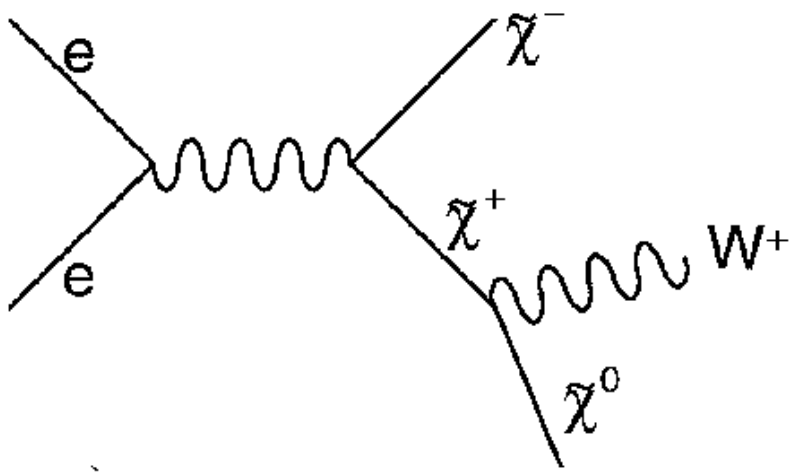
- To sparticles



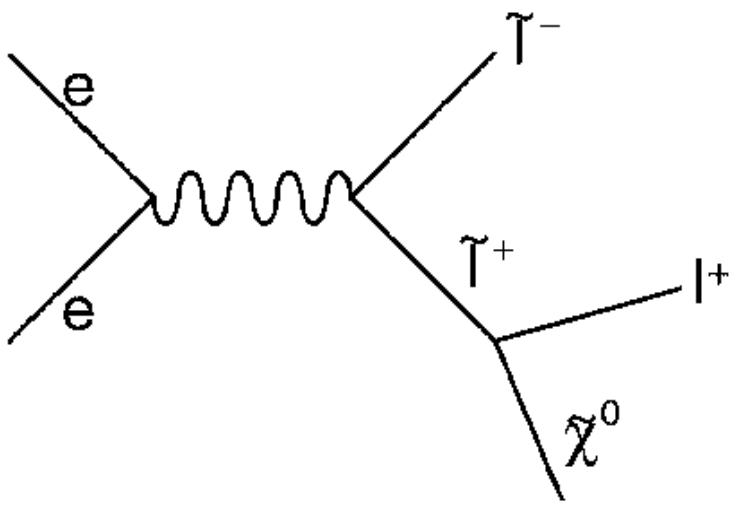
- To summarise.
  - h^0 *always* found at LC.
  - If $M_{H^0}, M_{A^0}, M_{H^\pm} < \frac{\sqrt{s}}{2}$ also get $H^0, A^0, H^\pm$.

Sparticles

- Charginos, neutralinos.

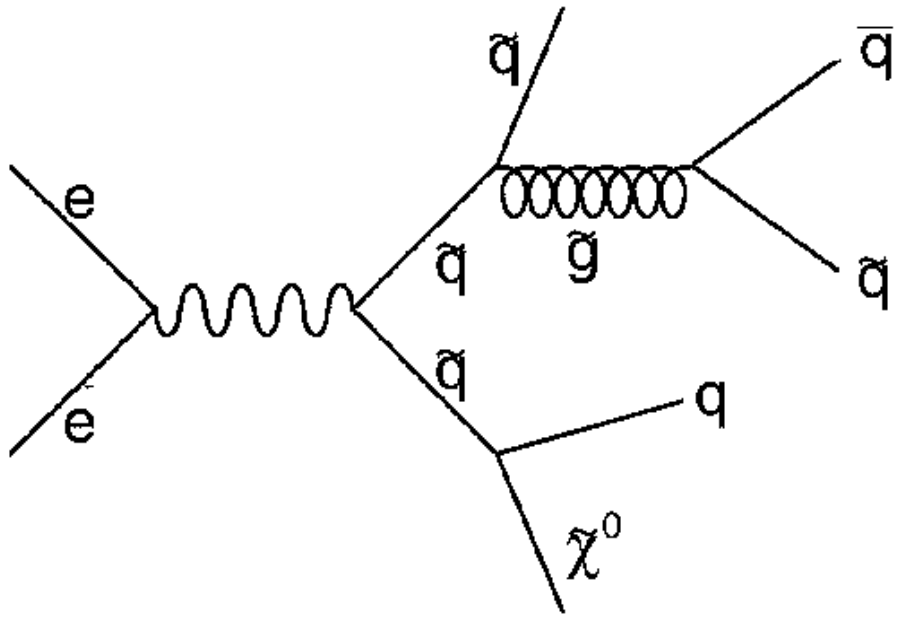


- Sleptons



Sparticles cont.

- Squarks, gluinos

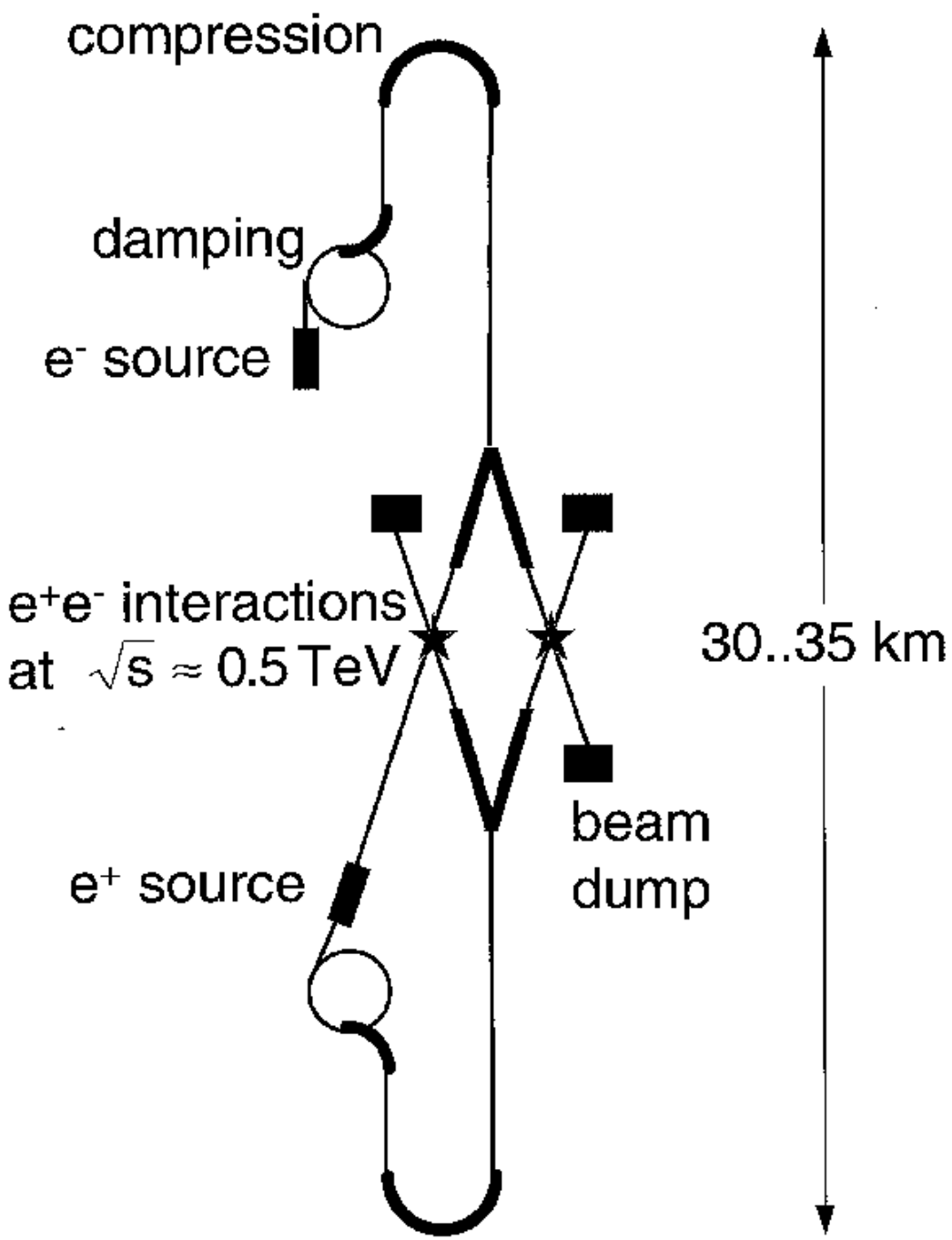


- To summarise:
  - Colourless sparticles good at LC, coloured at LHC.
  - Can determine masses, spins, couplings of produced charginos, sleptons...

Summary

- "...it is apparent that the rich structures at the TeV scale cannot be uncovered in total by hadron machines. However, combined analyses at the LHC and e^+e^- colliders can provide us with a coherent picture of this domain..."

The LC


compression
damping
e⁻ source
e⁺e⁻ interactions
at $\sqrt{s} \approx 0.5\,\mathrm{TeV}$
beam
dump
e⁺ source
30..35 km

LC Operation

- Need lots of P to get E.
- ...and large $\mathcal{L}$ to combat 1/s

$$\mathcal{L} = \frac{nNf}{4\pi\sigma_x\sigma_y} H_D$$

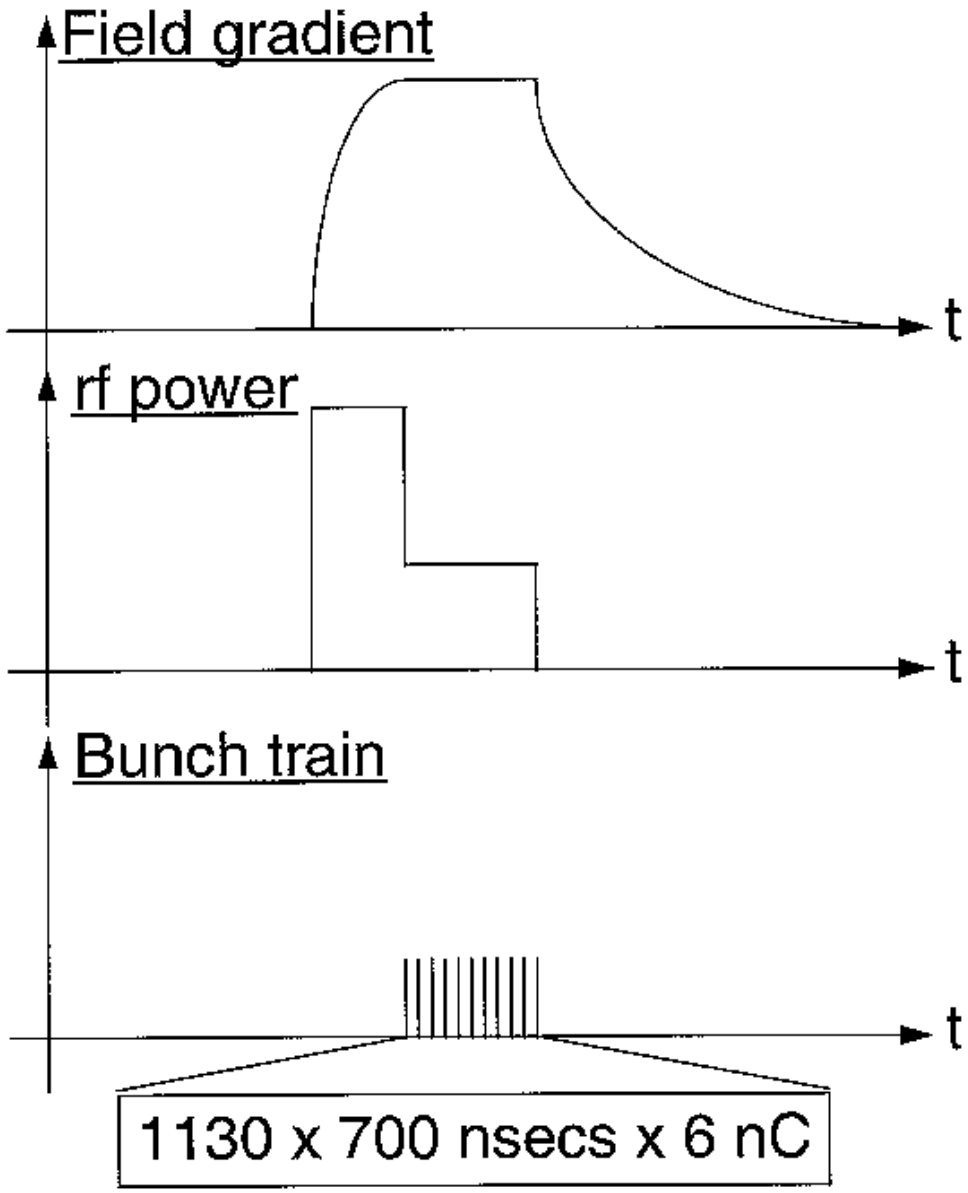
So accererator must:

- be efficient (wall to beam);
- high current;
- bang tiny beams together.

- TESLA provides above using SC cavities.
- Several advantages for experiments.

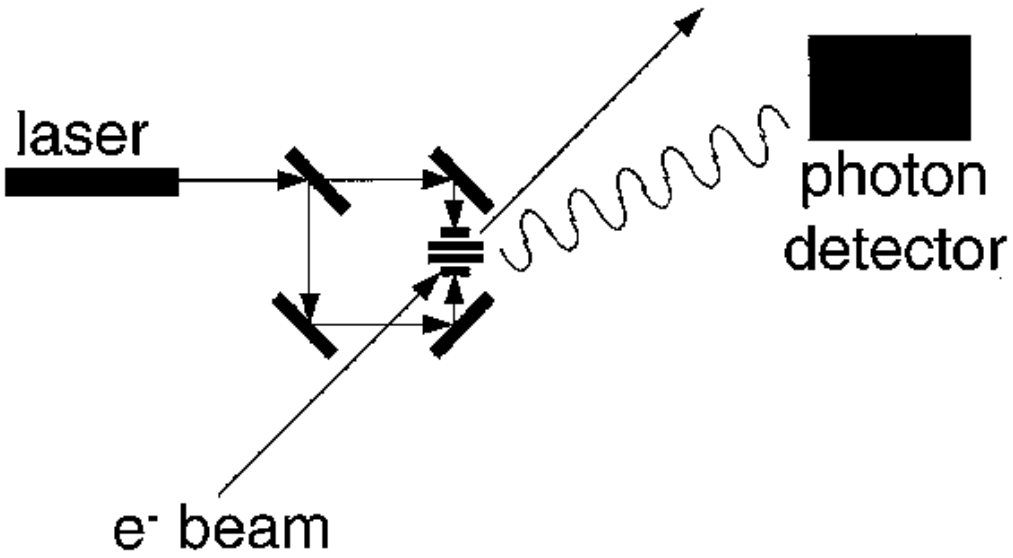
Advantages of SC

- Time structure of bunch trains and rf.



Making Beams Collide

- Shintake monitor



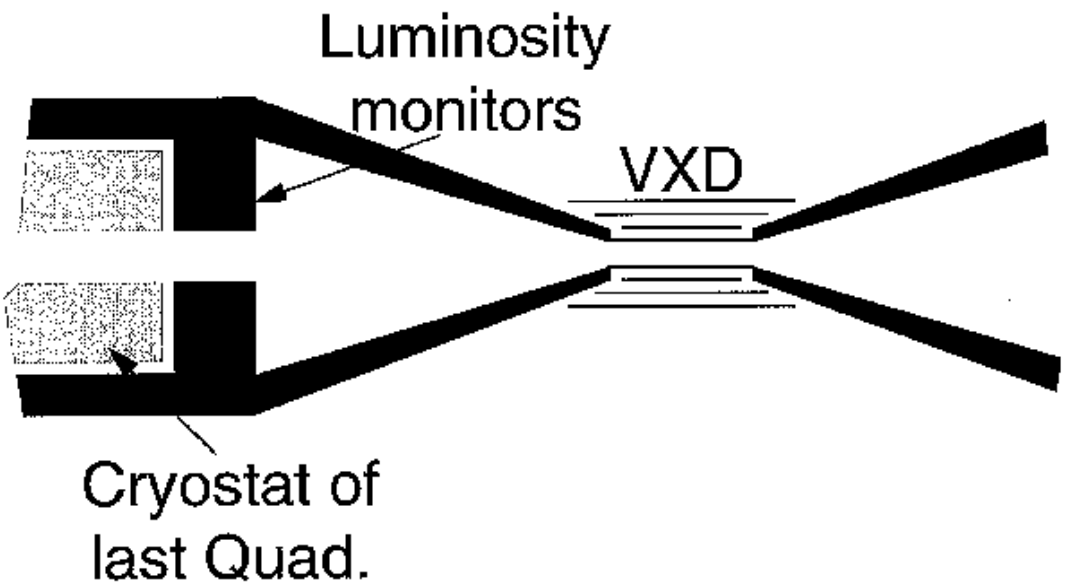
- Laser wires, Shintake monitors to bring beams to collision.
- Fine tune beams using information from first bunch crossings in bunch train.

LC Detector

- Big new problem, beam-strahlung.

- Gives rise to:
  - Copious e^+e^- production (curl up in strong B-field).
  - Reduction and spread of $\sqrt{s}$. (measure using asymmetric Bhabhas).
  - Focussing of beams.

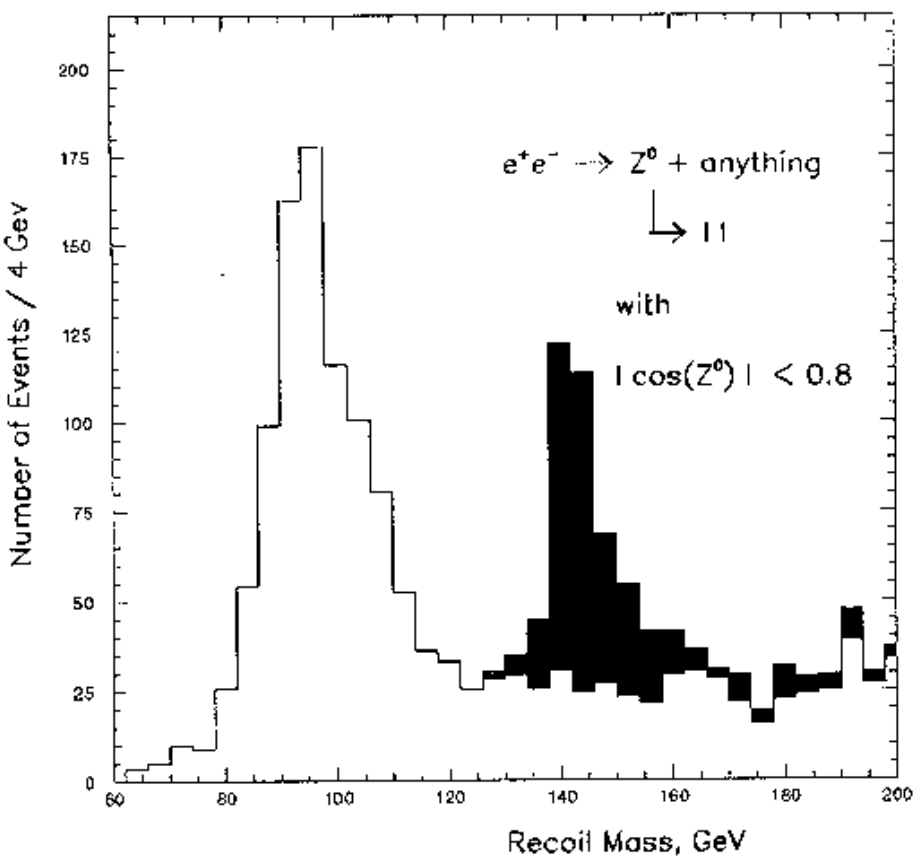
Synchrotron Radiation Masks



- Limits angular coverage of central tracking to $\theta > 80$ mrad.
- Limits minimum radius of VXD to about 20 mm.

Necessary Resolution

- Very good vertexing for charm, beauty coupling to Higgs.
- Good tracking and calorimetry for "recoil mass" measurment of Higgs.



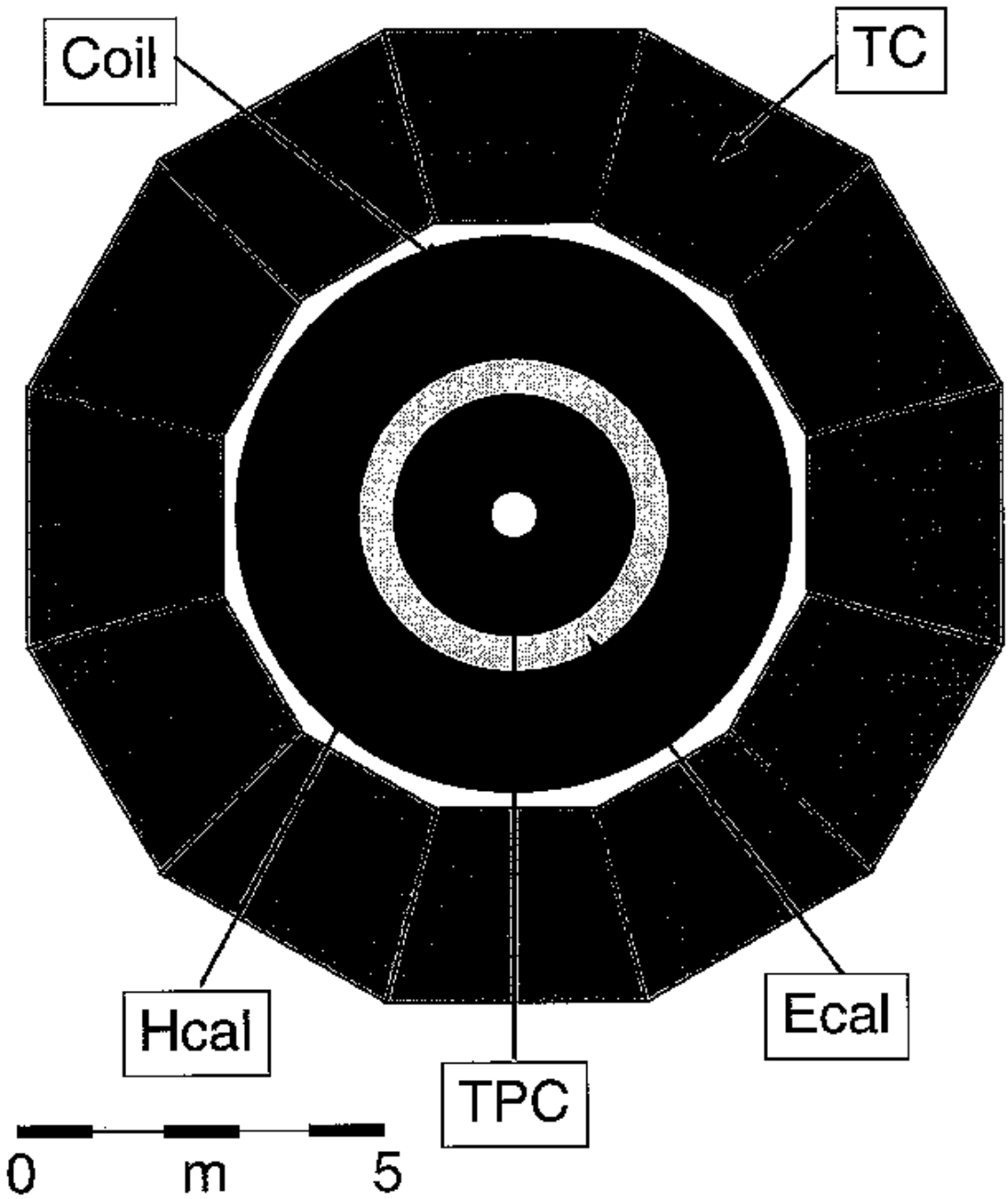
Necessary resolution cont.

Vertexing	$\delta(IP_{r\phi}) \leq 10\,\mu m \oplus \frac{30\,\mu m\,\mathrm{GeV}/c}{p\sin^{3/2}\theta}$ $\delta(IP_z) \leq 20\,\mu m \oplus \frac{30\,\mu m\,\mathrm{GeV}/c}{p\sin^{5/2}\theta}$
Forward Tracking	$\frac{\delta p}{p} < 20\,\%$, $\delta_\theta < 200\,\mu$rad for 100–250 GeV particles down to lowest polar angle θ.
Tracking	$\frac{\delta p_t}{p_t^2} \leq 1 \cdot 10^{-4}(\frac{\mathrm{GeV}}{c})^{-1}$ Good particle identification.
Electromagnetic Calorimeter	$\frac{\delta E}{E} \leq 0.10\frac{1}{\sqrt{E}} \oplus 0.01$ (E in GeV) Granularity $0.9° \times 0.9°$, at least 3 samples in depth.
Hadronic Calorimeter	$\frac{\delta E}{E} \leq 0.50\frac{1}{\sqrt{E}} \oplus 0.04$ (E in GeV) Granularity $2° \times 2°$, at least 3 samples in depth.
Muon Detector	Fe yoke instrumented as tail catcher and muon tracker. Toroid momentum analysis for forward muons ($\theta < 15°$), $\frac{\delta p}{p} < 20\,\%$.
Energy Flow	$\frac{\delta E}{E} \simeq 0.3\frac{1}{\sqrt{E}}$ (E in GeV)
Hermetic Coverage	$\lvert\cos\theta\rvert < 0.99$

Large Coil LC Detector

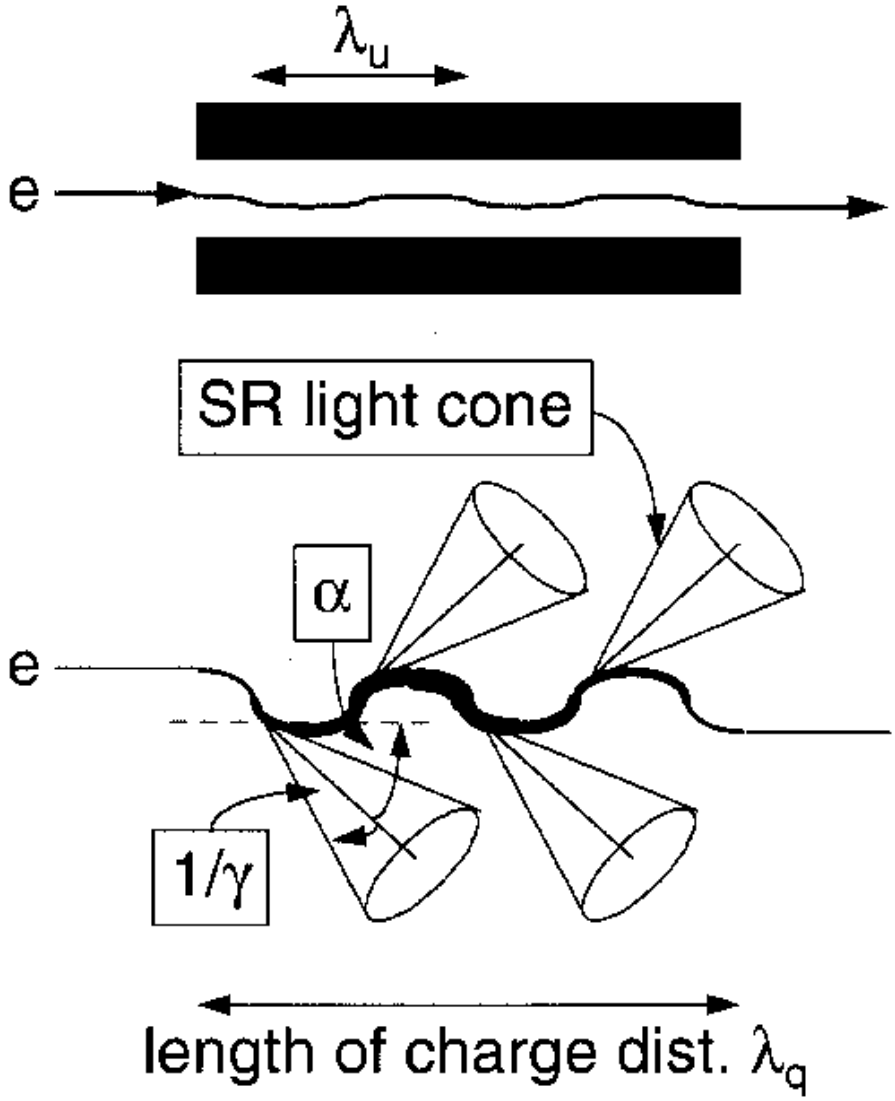
- B-field 3T.
- CCD (with "fast clear") or Si Pixel VXD.
- Intermediate tracker (hexagonal straw tubes?)
- Si layer.
- TPC.
- Pb/Scint Shashlik EM Cal.
- Cu/Scint Shashlik Had. Cal.
- Coil (radius ~ 3.5m).
- Instrumented Fe return yoke (~2m thick).
- Additional intrumentation in forward region to determine momentum (or at least charge) of forward muons.
- Total diam. ~ 13m.

LC Detector, End View

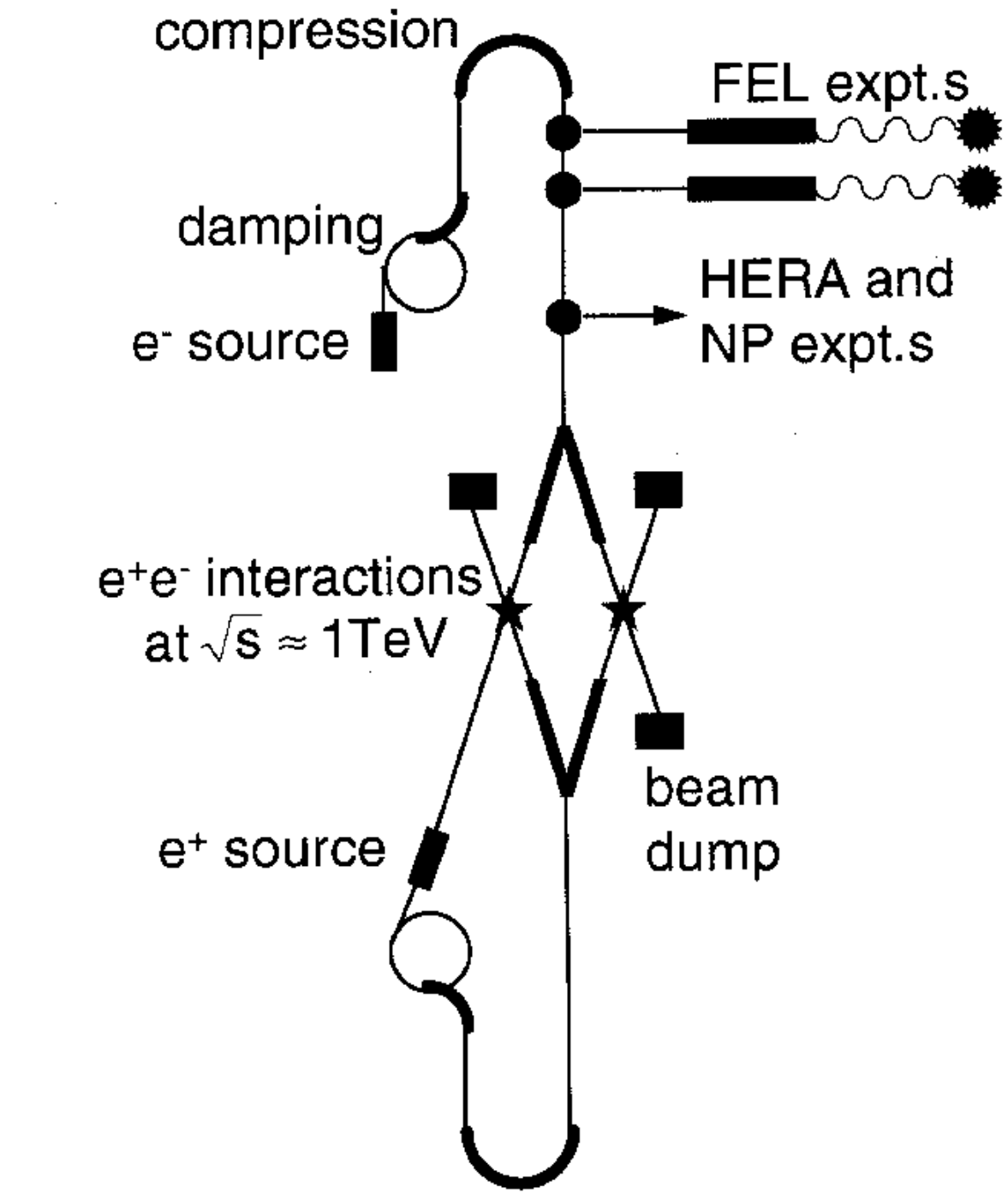


Free Electron Laser

- Synchrotron Radiation emitted by e beam passing through magnets:



Updated Schematic Collider Design



Conclusions

- LC complements LHC perfectly, much exciting physics to be done.
- Can build LC with state-of-the-art technology.
- Can build LC detector with current technology.
- What are we waiting for!