Physics Perspectives at the Next e^+e^- Linear Collider

[Marc Winter – IReS, Strasbourg]

- Introduction
- Advantages of e^+e^- colliders
- Experimental aspects
- Research and Characterisation of the Higgs boson(s)
- Research and Characterisation of physics beyond the Standard Model
- Standard precision measurements
- What if the Higgs is heavy or ignored by Nature ?
- Summary – Conclusions

Advantages of e^+e^- colliders

- initial state quantum numbers well defined

- E_{cm} well known ($O(10^{-4} - 10^{-5})$) and tunable
  ⇒ scan resonances & kinematical thresholds

- tunable polarisation of the beams:
  - $P_- = -80\% / 0 / +80\%$ $P_+ = -60\% / 0 / +60\%$
  - essential for spin analyses and (des)activating processes

- e^+e^- annihilation is democratique
  ⇒ access to a large variety of final states

- signals well defined, easy to separate from backgrounds

- beam background of modest influence

- beam luminosity well known: $O(10^{-2} - 10^{-4})$
  ⇒ essential for cross-section measurements

Experimentation quite easy

- other collisions accessible
  e^-e^-, $e^-\gamma$, $\gamma\gamma$, e^-N and e^-A

- **Projects under study**

Parameters at $\sqrt{s} = 500$ GeV

	TESLA	NLC	JLC-X	JLC-C
f_{rep} [Hz]	5	120	150	100
N_b	2820	190	190	142
ΔT_b [ns]	337	1.4	1.4	2.8
bunch crossing	head on	angle	angle	angle
N_e/bunch [10^{10}]	2	0.75	0.7	1.1
$\sigma^*_{x/y}$ [nm]	553/5	245/2.7	239/2.6	318/4.3
δ_E [%]	3.2	4.7	5.3	3.9
$\mathcal{L}$ [$10^{34} cm^{-2} s^{-1}$]	3.4	2.	2.6	1.3
P_{beam} [MW]	22.6	13.2	17.6	12.6
P_{AC}(linacs) [MW]	97	132	141	220
G_{acc} [MV/m]	23.5	48	50	36
total length [km]	33	30	16	linac 19

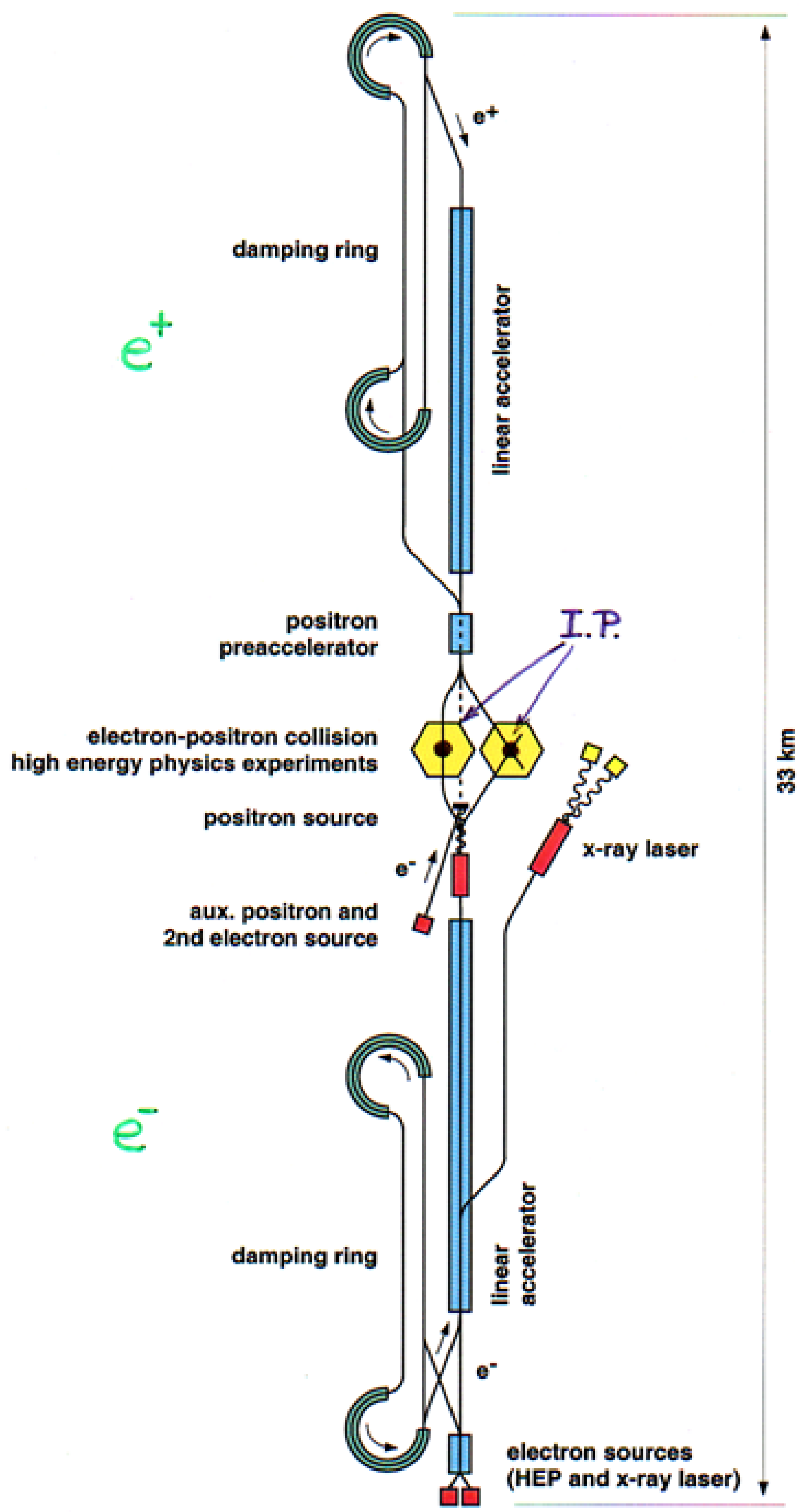
Some achievments (see TESLA-TDR : March 2001)

Super Conducting Cavities (TESLA):

- 23.5 MV/m needed for 500 GeV routinely achieved in industry
- 35 MV/m needed for 800 GeV → 42 MV/m achieved outside TTF
- XFEL delivers ~ 100 nm beam

↳ TDR (machine design, beam bg, detector design, exhaustive ϕ's case)

Sketch of the TESLA overall layout



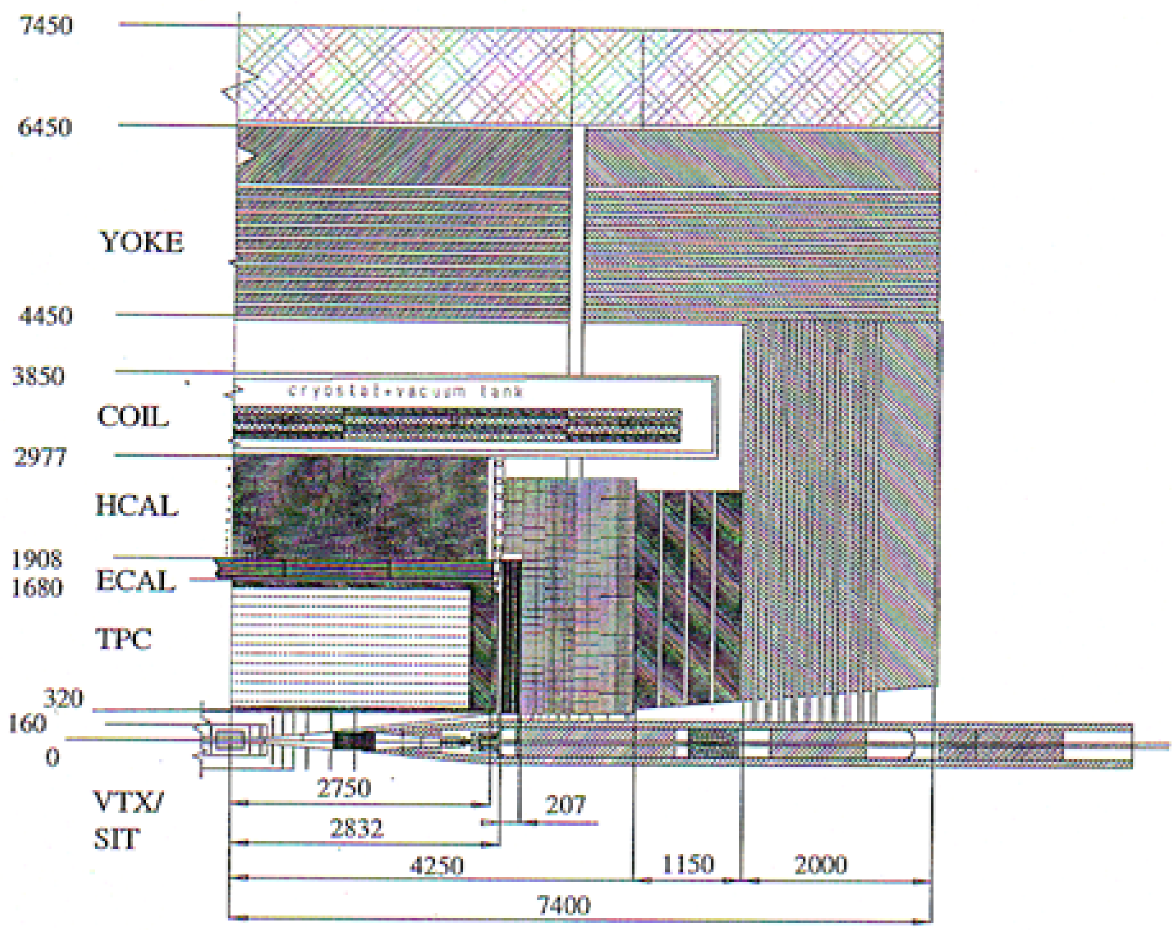
HERA

Machine properties & Event rates

	TESLA parameters	
Center of mass energy	0.5 TeV	0.8 TeV
Beam properties		
Luminosity $[10^{34} cm^{-2} s^{-1}]$	3.4	5.8
Trains/s	5	4
Bunches/train	2820	4886
Interbunch spacing [ns]	337	176
Bunch sizes		
σ_x / σ_y [nm]	553/5	391/2.8
σ_z [mm]	0.3	0.3
Backgrounds		
$\gamma\gamma$ ev./BX ($p_t^{min} = 2.2$ GeV/c)	0.02	0.1
Physics events		
Bhabha ($\theta > 20$ mrad) $[s^{-1}]$	350	240
W^+W^- $[h^{-1}]$	930	810
$q\bar{q}$ $[h^{-1}]$	330	210
$t\bar{t}$ $[h^{-1}]$	70	54
$\nu\bar{\nu} H_{SM}$ ($M_H = 120$ GeV/c^2)	10	35
$Z H_{SM}$ (" " " ")	7	4

THE DETECTOR

similar to LEP detectors
with much higher performances

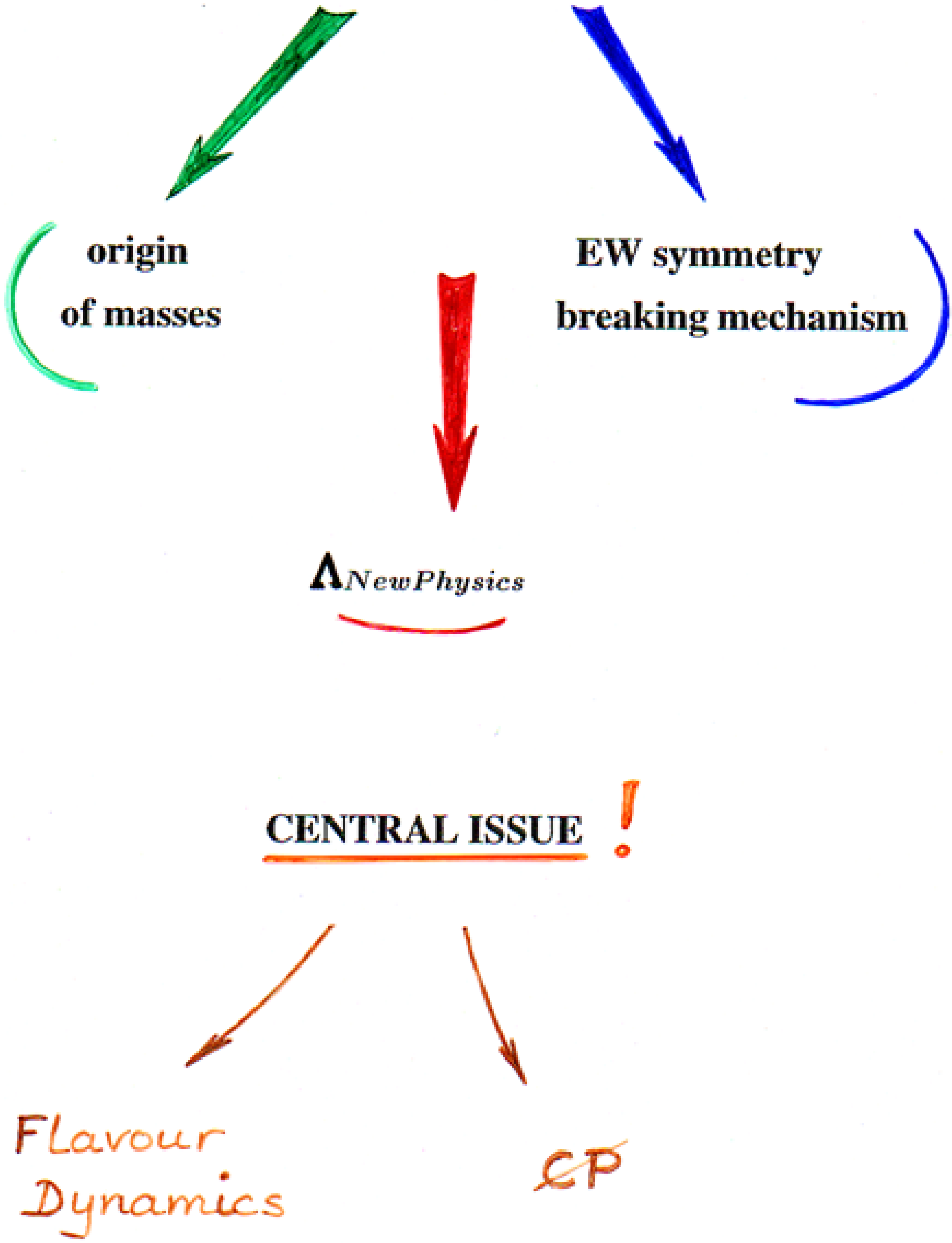


► Some strong features:

- $\Delta_{IP} \sim 5\text{-}10\,\mu m$
- M_H / M_Z separation: tracking ~ 10× better than LEP
- E.M. calorimeter: very granular & hermetic
- geometrical acceptance: $\Theta \gtrsim 5$ mrad (~ no hole)

■ **SEARCH / CHARACTERISE the LIGHT HIGGS BOSON**

(standard, supersym., different, fundamental, ...)



Motivations for a light Higgs boson

- **Standard Model**: Unitarity, Triviality, vacuum Stability
  - $130 \lesssim M_H \lesssim 180$ GeV if $\Lambda_{NP} \sim M_{Pl}$
  - $M_H \lesssim 700-800$ GeV if $\Lambda_{NP} \sim \mathcal{O}$ (TeV)

- experimental evidence for genuine E.W corrections attributable to the standard Higgs boson:

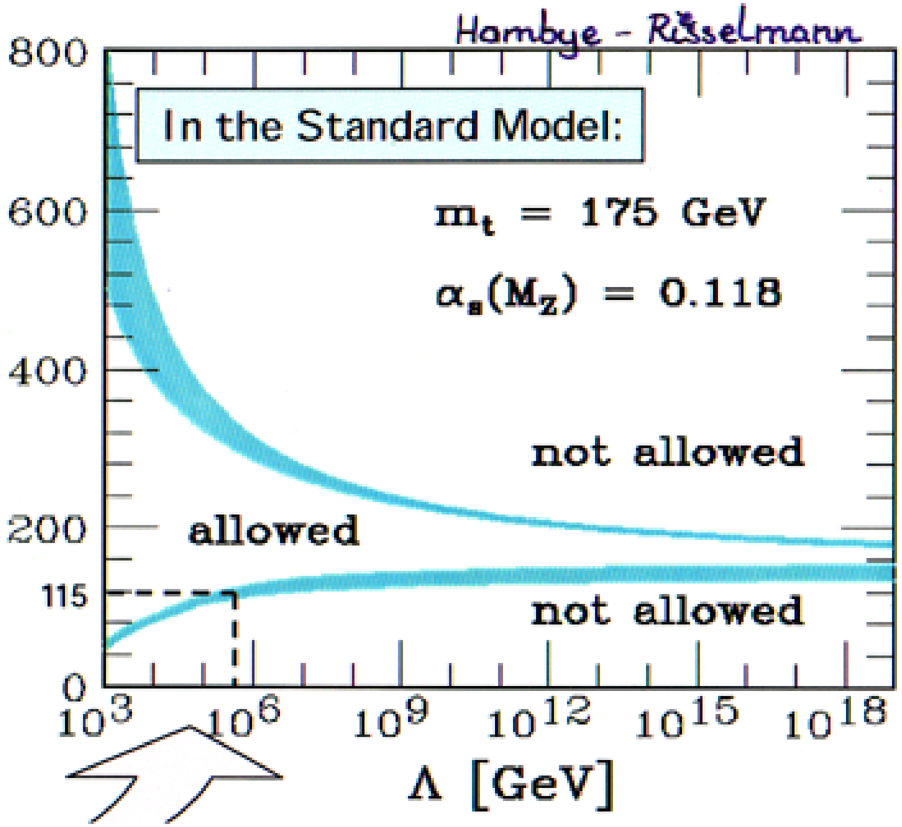
$$M_H = 88^{+53}_{-35} \text{ GeV}$$

$\hookrightarrow M_H < 196/222$ GeV (95% C.L.) or 270 GeV (99% C.L.)

- direct search of Higgs boson at LEP:
  $M_H \gtrsim 114$ GeV (95% C.L.)

- Supersymmetry:
  - minimal: $M_h \lesssim 135$ GeV
  - very general: $M_h \lesssim 205$ GeV

■ Standard Higgs Search (1)



- Higgs potential ⟶ M_H

$$V(\phi) = \frac{\lambda}{3}\left[\phi\bar{\phi} - \frac{v^2}{2}\right] \quad (v \sim 246 \text{ GeV})$$

$$= \frac{1}{2}\frac{\lambda v^2}{3}H^2 + \frac{\lambda v}{3!}H^3 + \frac{\lambda}{4!}H^4 \quad \text{near minimum}$$

$$M_H = v\sqrt{\frac{\lambda}{3}}$$ ⟵ "running" constant

window towards very large values of Λ

Theoretical constraints on M_H:

$$0 \leq \lambda(\Lambda) < \infty$$

vacuum stability — triviality

Λ: energy scale where S.M. stops being valid

Global Fit

- using LEP1, LEP2, SLC, Tevatron, APV data and constraint on $\Delta\alpha_{udscb} = \Delta\alpha^{(5)}_{had}$ (2 options)

	LEP including LEP-2 M_W	all data except M_W and m_t	all data except M_W	all data except m_t	all data
m_t (GeV)	186^{+13}_{-11}	169^{+12}_{-9}	$173.3^{+4.7}_{-4.6}$	181^{+11}_{-9}	$175.8^{+4.4}_{-4.3}$
M_H (GeV)	260^{+404}_{-155}	81^{+109}_{40}	108^{+70}_{-44}	126^{+182}_{-69}	88^{+53}_{-35}
$\log(M_H$ /GeV)	$2.42^{+0.41}_{-0.39}$	$1.91^{+0.37}_{0.29}$	$2.03^{+0.22}_{-0.23}$	$2.10^{+0.39}_{-0.34}$	$1.94^{+0.21}_{-0.22}$
χ^2/d.o.f.	15.5/8	18.9/12	19.1/13	22.6/14	22.9/15 (9%)
$\sin^2\theta^{lept}_{eff}$	0.23162	0.23150	0.23151	0.23139	0.23136
	± 0.00018	± 0.00016	± 0.00016	± 0.00015	± 0.00014
$\sin^2\theta_W$	0.22282	0.22333	0.22313	0.22248	0.22263
	± 0.00051	± 0.00063	± 0.00045	± 0.00045	± 0.00036
M_W (GeV)	80.389 ± 0.026	80.363 ± 0.032	80.373 ± 0.023	80.406 ± 0.023	80.398 ± 0.019

all data: $\kappa = 1.0371 \pm 0.0027$

$\rho_L = 1.00501 \pm 0.00075$ → 6.5 st.dev. evidence for genuine EW corr.

$\Delta r_W = -0.0246 \pm 0.0022$

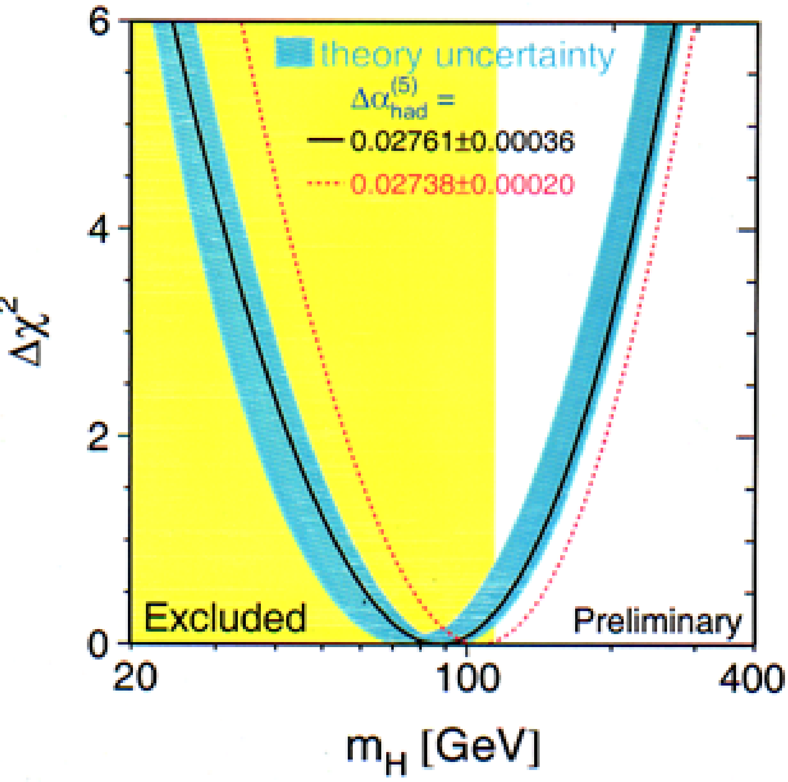
$\Delta r = 0.0360 \pm 0.0020$

Higgs mass:

$M_H = 88^{+53}_{-35}$ GeV

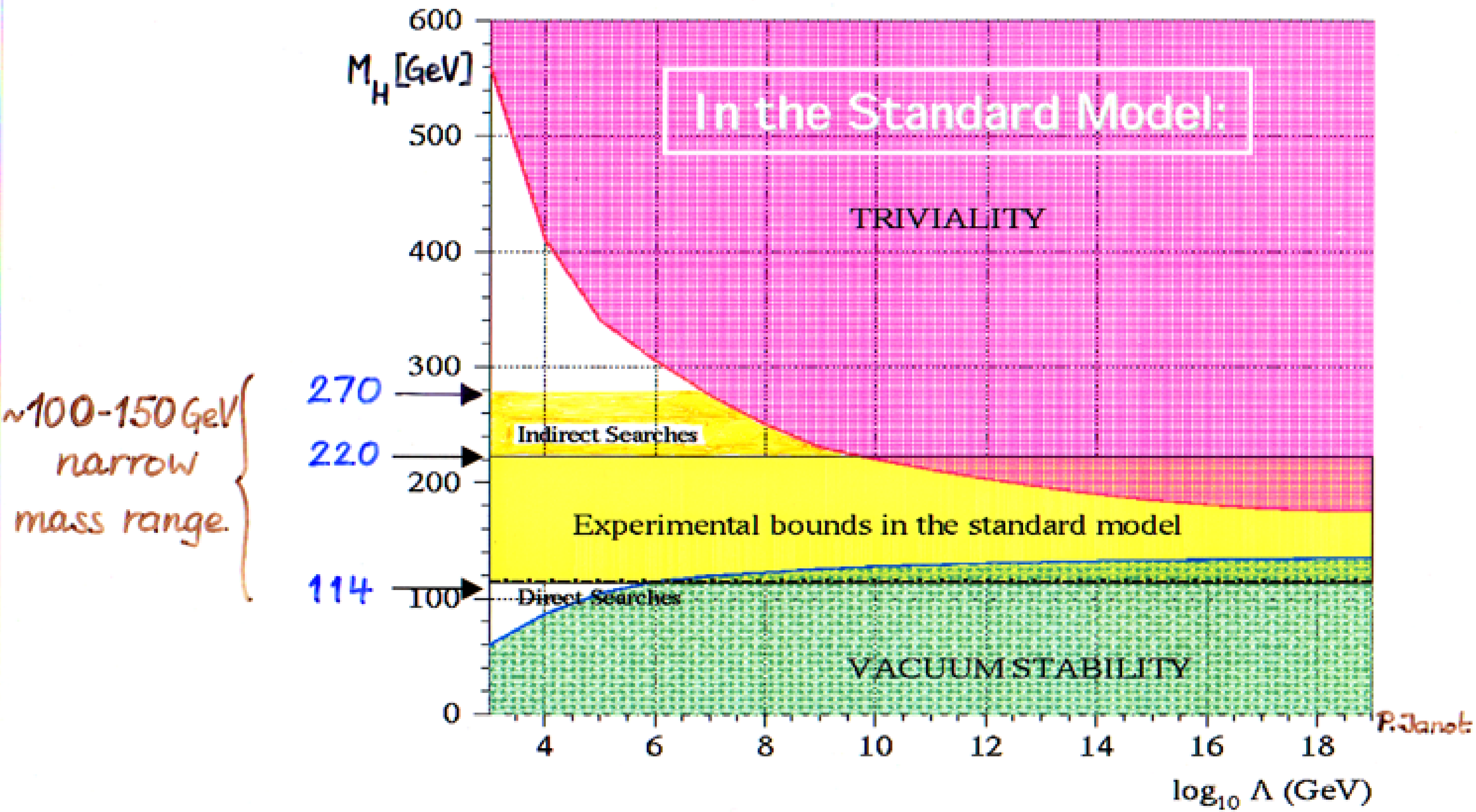
$M_H < 196\text{-}222$ GeV (95% C.L.)

$M_H < 270$ GeV (99% C.L.)



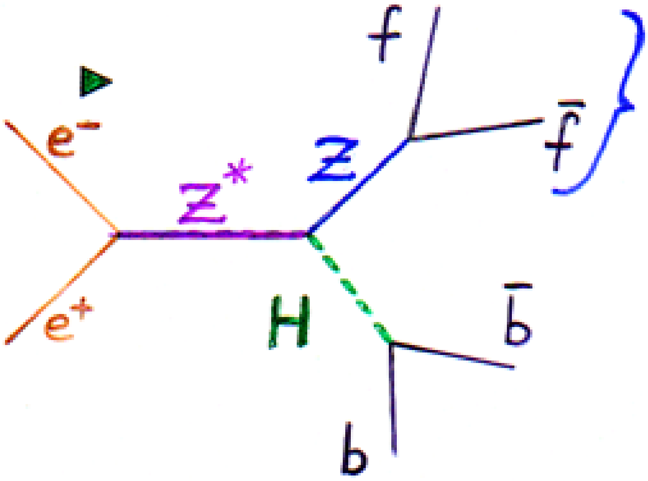
- Summary of constraints on M_H^{SM}

$114 < M_H < 220\text{–}270$ GeV



■ Making evidence of the Higgs boson

▶



Recoil Mass:

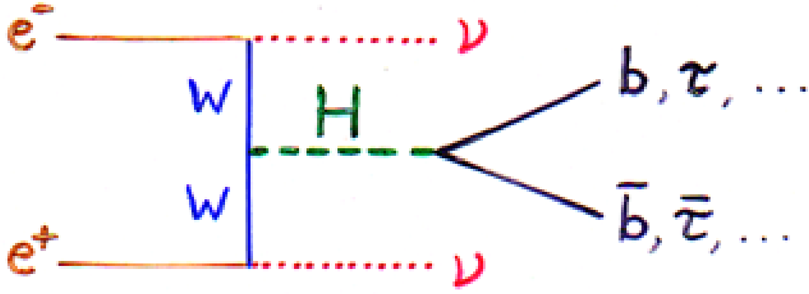
$$M_H^2 = s - 2\sqrt{s}E_Z + M_Z^2$$

$$\Delta M_H \leq 50 MeV$$

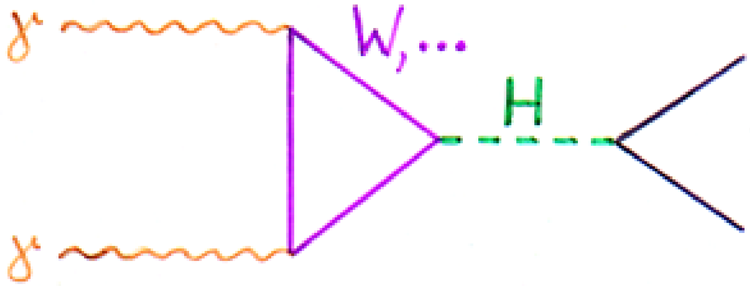
Fig. →

→ M_H observable and characterisable for any Higgs decay (even invisible)

▶ WW fusion (dominates if $\sqrt{s} \geq 500\ GeV$)



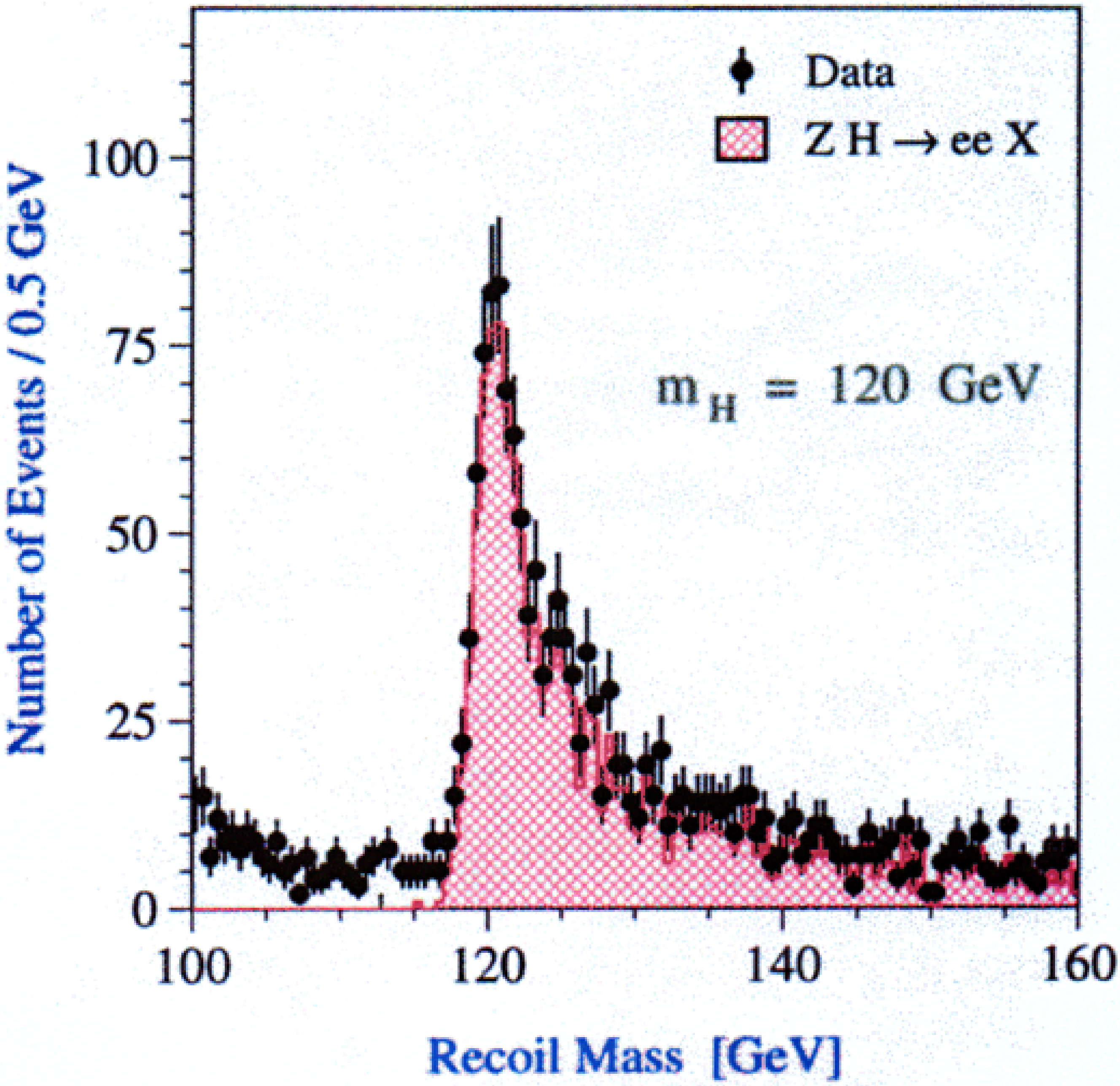
▶ $\gamma\gamma$ collisions



sensitive to virtual effects from New Physics

Recoil Mass

The recoil mass spectrum from e^+e^-

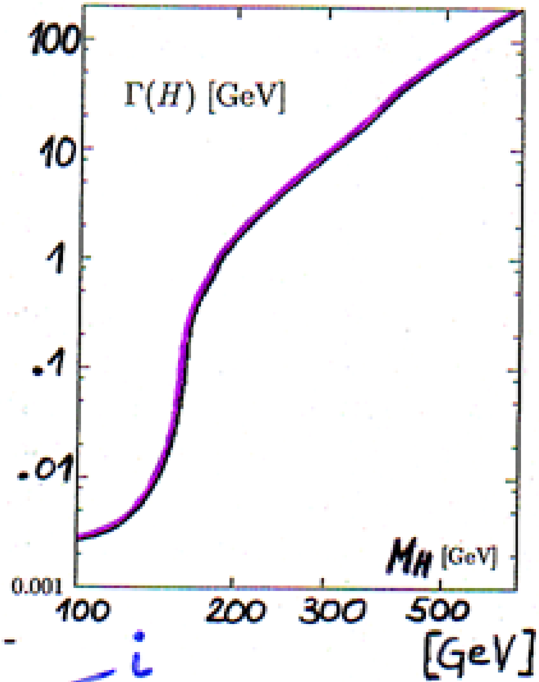


$\Delta\sigma/\sigma \approx 4\,\%$

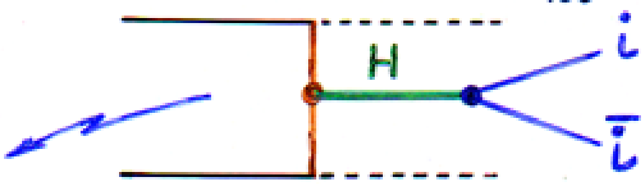
$\Delta M_H \approx 150$ MeV

Measurement of the Higgs total width

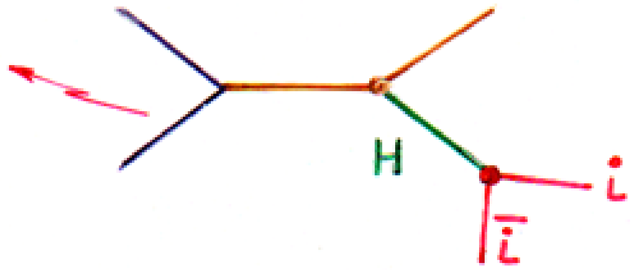
* Γ_H directly measurable
  only if $M_H \geq 200$ GeV
  ($\Gamma_H \leq$10 MeV if $M_H \leq$140 GeV)



→ if $M_H \leq 200$ GeV:



$$\Gamma_H = \frac{\Gamma_i}{Br_i}$$



$M_H \geq 115$ GeV:

$$\Gamma_H = \frac{\Gamma_{WW^*} \cdot Br(H \to b\bar{b})}{Br(H \to WW^*) \cdot Br(H \to b\bar{b})}$$

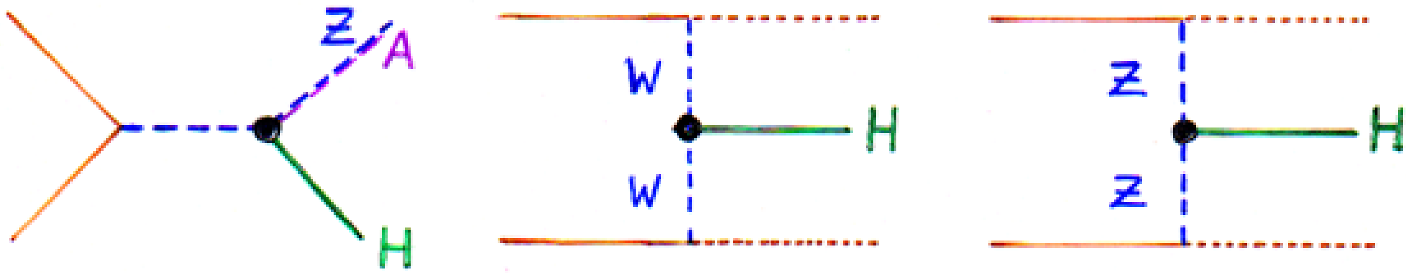
$M_H \geq 140$ GeV:

($\gamma\gamma$ coll.)

$$\Gamma_H = \frac{\Gamma_{\gamma\gamma} \cdot Br(H \to b\bar{b})}{Br(H \to \gamma\gamma) \cdot Br(H \to b\bar{b})}$$

→ $\Delta\Gamma/\Gamma \sim$ few % for any M_H

Measurement of Higgs production cross-sections



→ access to the Higgs <u>couplings</u>

- <u>MS</u>: $\Delta\sigma/\sigma \sim 1\%$ for $M_H \leq 0.7\sqrt{s}$
  (detectable for $M_H \leq \sqrt{s} - M_Z$)

- <u>SUSY</u>: sensitivity to h^0 for $M_{h^0} \leq 0.7\sqrt{s}$
  sensitivity to $A, H^0, H^{\pm}$ for M $\leq 0.5\sqrt{s}$ (or $\sqrt{s} - M_h$)

■ **Measurement of the branching ratios → g_{HVV}, Y_{Hff}**

→ **check if:**

- $g_{HVV} = 2\ (\sqrt{s}\, G_F)^{1/2} M_V^2$
- $g_{Hff} = (\sqrt{s}\, G_F)^{1/2}\, m_f$ **for each flavour**

⟶ nature of Higgs : S.M. , SUSY, or ?

→ **compare Γ_H and $\Sigma\, Br_i$**

⟶ "missing" final states ?

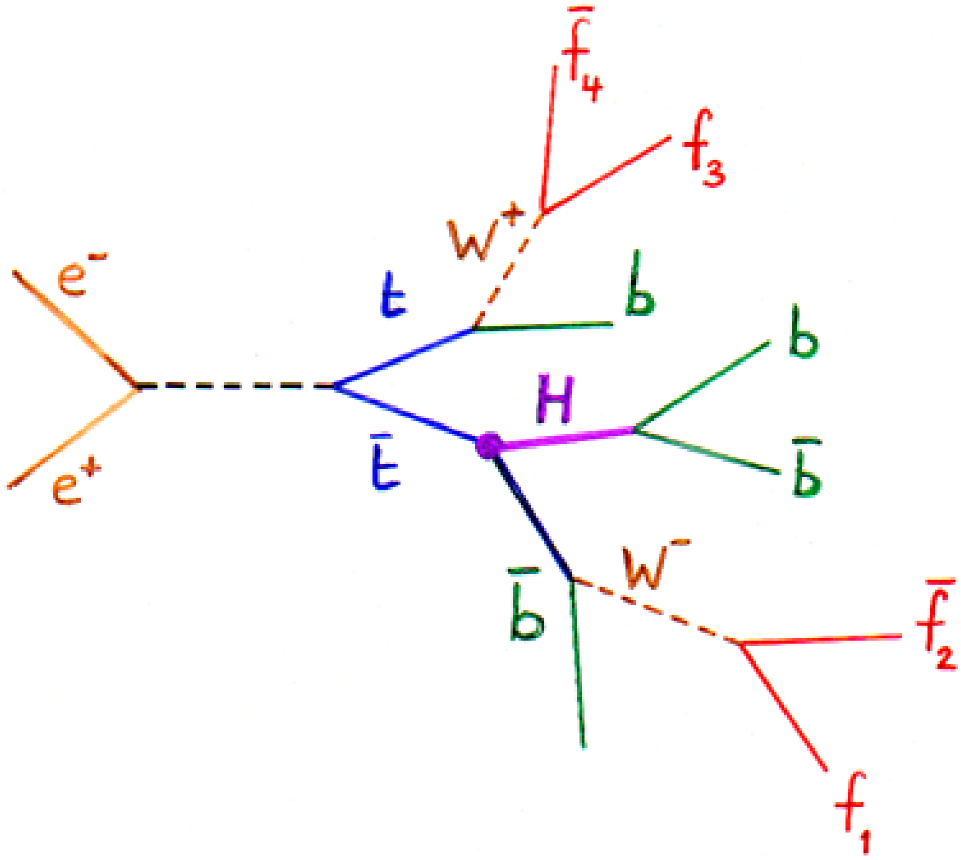
- light Higgs coupling measurements :

M_H [GeV]	120	140
g_{HZZ}	1%	1%
g_{HWW}	1%	2%
g_{Hbb}	2%	2%
g_{Hcc}	3%	10%
g_{Htt}	$\gtrsim$ 3%	$\gtrsim$ 6%
g_{Hgg}	~5%	
λ_{HHH}	$\lesssim$20%	$\lesssim$30%

Measurement of Y_{Htt}

- role of top quark in EW symmetry breaking ?
  ($m_t > M_W, M_Z$)

- how to measure Y_{Htt} when $M_H \leq 200 GeV$?



$$\sigma_{Htt} \sim 1\text{-}3\ fb$$

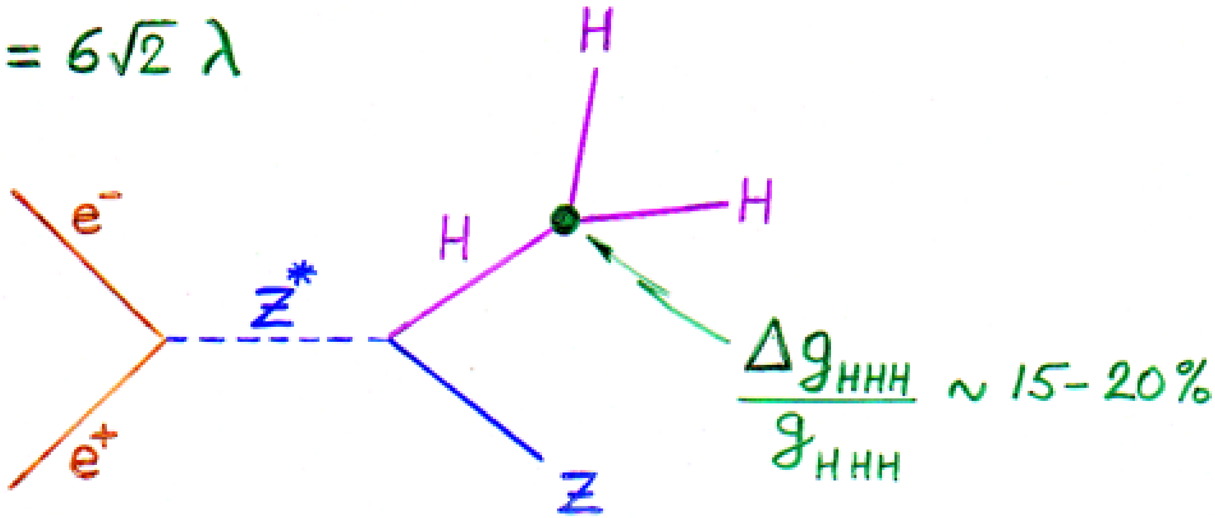
$$\frac{\Delta y_{Htt}}{y_{Htt}} \sim 5\text{-}10\%$$

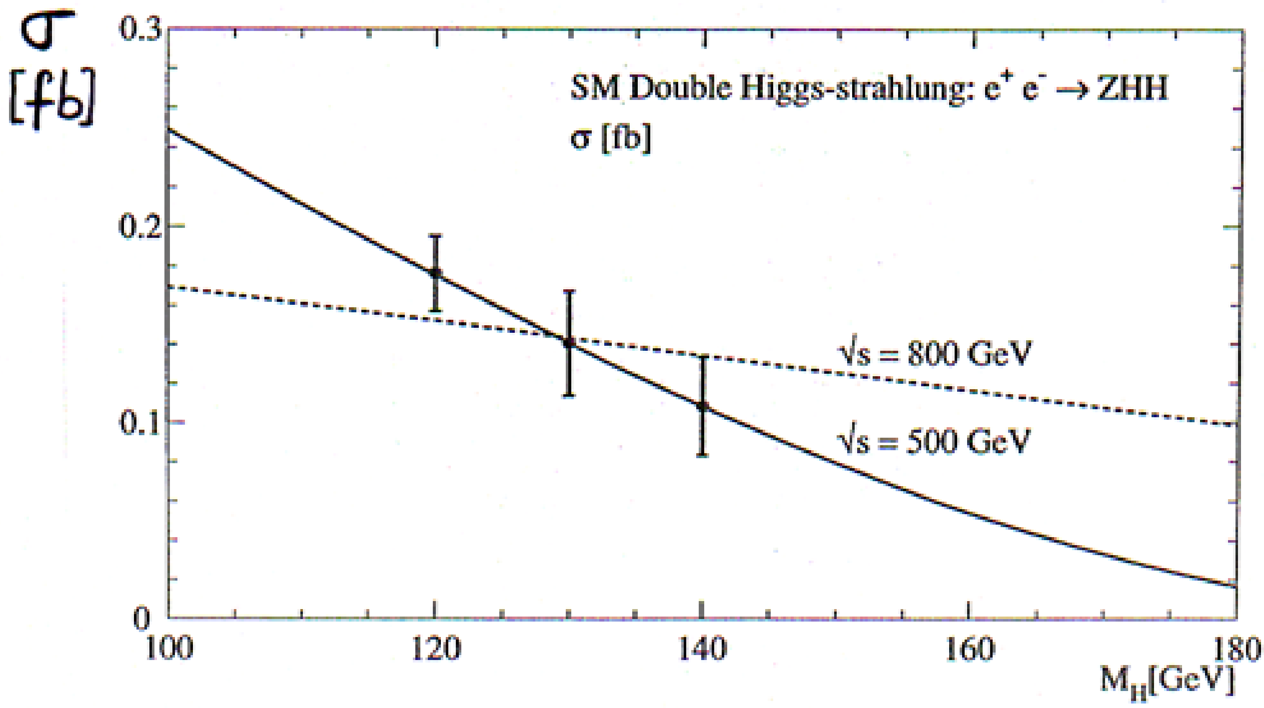
Reconstruct the Higgs potential

- $V = \lambda \left(|\varphi|^2 - \frac{1}{2} v^2\right)^2$

$$= \lambda v^2 H^2 + \lambda v H^3 + \frac{1}{4} \lambda H^4$$

- $M_H = \sqrt{2\lambda}\, v$
- $g_{HHH} = 6\sqrt{2}\,\lambda$



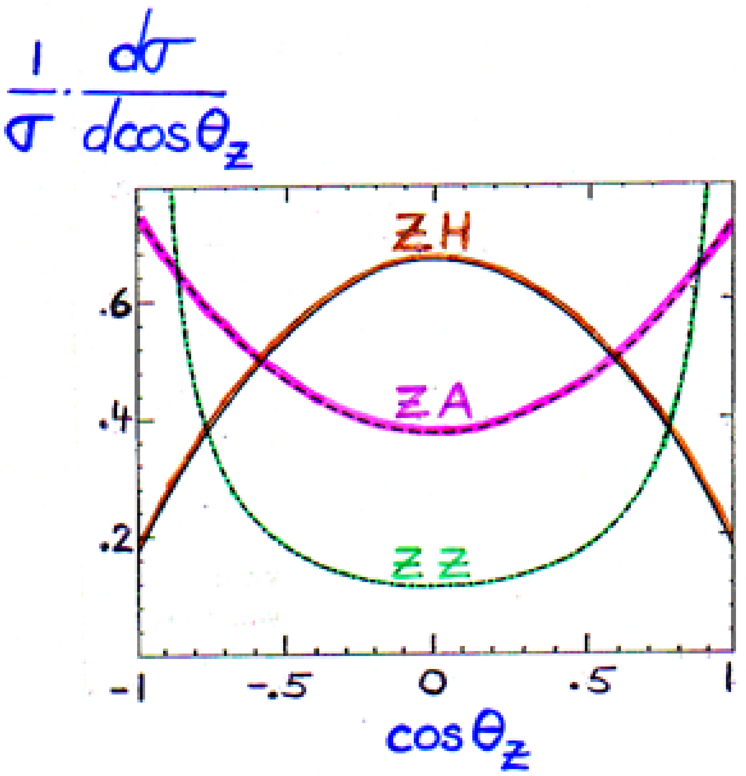


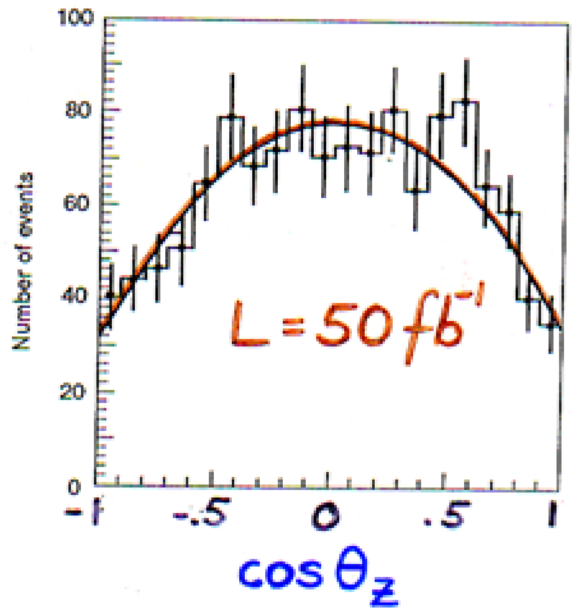
Determination of J^{PC}

- **M.S:** $d\sigma / d\cos\theta \sim \lambda \sin^2\theta + 8M^2/s$ **(P = +1)**

- **MSSM: distinguish h^0 from A (P = -1)**
  $1 + \cos^2\theta$

→ analyse the angular distribution of the recoil Z





SEARCH/CHARACTERISE the PHYSICS BEYOND the STANDARD MODEL

- Supersymmetry
- Low Scale Quantum Gravity
- Technicolour
- Extended Gauge Theories

Supersymmetry:

▷ perhaps the best candidate to go beyond the S.M.

coherent, perturbative theory ⇒ predictive:

- $sin^2\theta_W(GUT)$
- $M_h < 135 - 205 GeV$

▷ favoured by present experimental observations:

- $sin^2\theta_W^{eff} = 0.23136 \pm 0.00014$
- $100 \leq M_h \leq 300$ GeV

Supersymmetry:

▶ e^+e^- collisions are unique for:

- discovering $\chi^+, \chi^0, \tilde{l}\ (\tilde{\tau}, \tilde{\nu}\ !), \tilde{t}_R, ...$
- characterising all particles accessible (usually $m \leq E_b$) with the precision needed to understand which supersymmetric theory was retained in Nature:

1) $m, cos\theta_{mix}, ...$ ⟶ $M_1, M_2, tg\beta, \mu, ...$

$O(10^{-2} - 10^{-3})$

2) nature of the breaking of SUSY

$mSUGRA, GMSB, AMSB, ..., \not{R}_p$?

▶ e^+e^- collisions allow to investigate complicated scenarios (e.g. dense mass spectrum)

⟹ characterisation of the new particles (e.g. spin !) and reduction of backgrounds (from SUSY !) achievable due to (tunable) beam polarisations and flexible beam energy

■ **SUSY: prod. of sfermions (MSSM)** $e^+e^- \rightarrow \tilde{f}\bar{\tilde{f}}$

▶ **sleptons:** $\tilde{l}^{\pm}_{L,R}$, $\tilde{\nu}$

- **masses of** $\tilde{l}^{\pm}_{L,R} \rightarrow \chi^0 l^{\pm}$
  - distribution of $p_{l^{\pm}}$
  - scan of σ_{Thresh}

Fig →

$$\frac{\Delta m}{m} \sim 10^{-2} - 10^{-3}$$

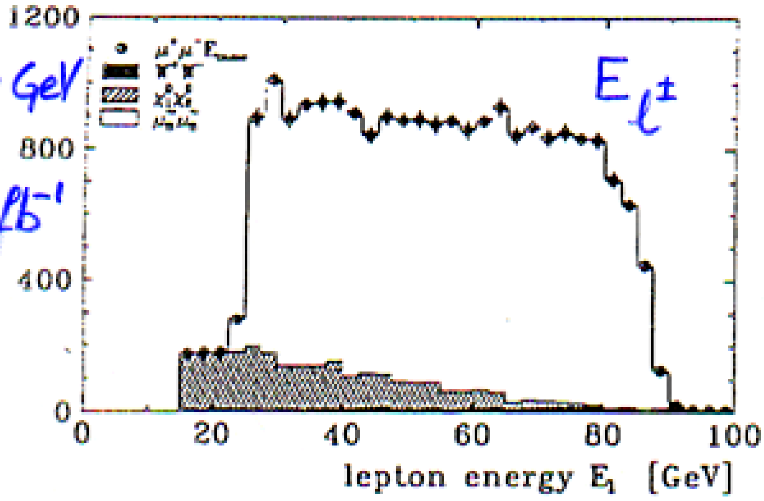
- **properties:**
  - $\sigma_{Thresh} \sim \beta^3$
  - $d\sigma/dcos\theta_{l^{\pm}}$

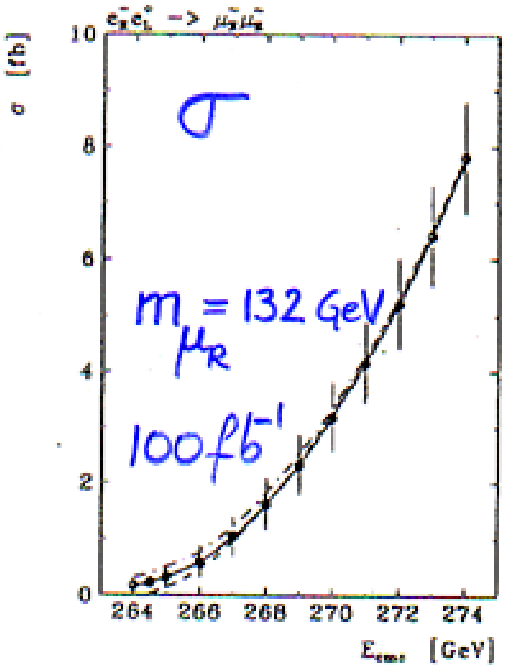
spin (0!), Br, $\theta_{mix} \sim O(10^{-2})$

$1/\ e^-_R e^+_L \longrightarrow \tilde{\mu}_R \tilde{\mu}_R \longrightarrow \mu^- \chi^0_1 \mu^+ \chi^0_1$

$\sqrt{s} = 320$ GeV

$L = 160\ fb^{-1}$

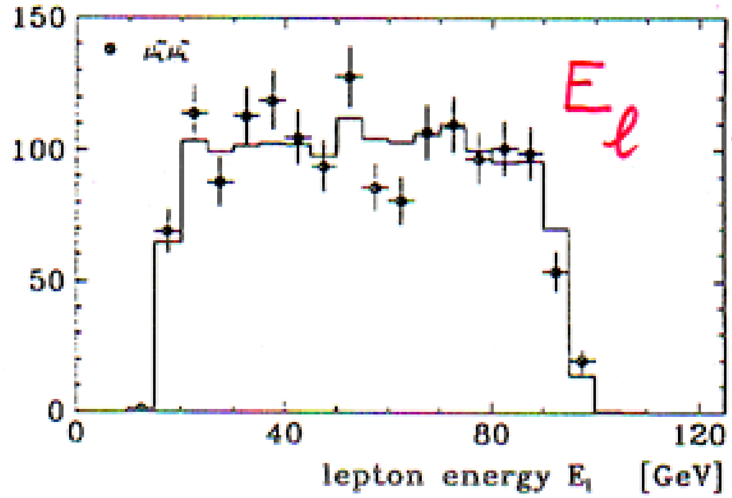




$2/\ e^-_L e^+_R \longrightarrow \tilde{\mu}_L \tilde{\mu}_L \longrightarrow \mu^- \chi^0_2 \mu^+ \chi^0_2 \quad (\chi^0_2 \rightarrow \ell^+ \ell^- \chi^0_1)$

$\sqrt{s} = 500$ GeV

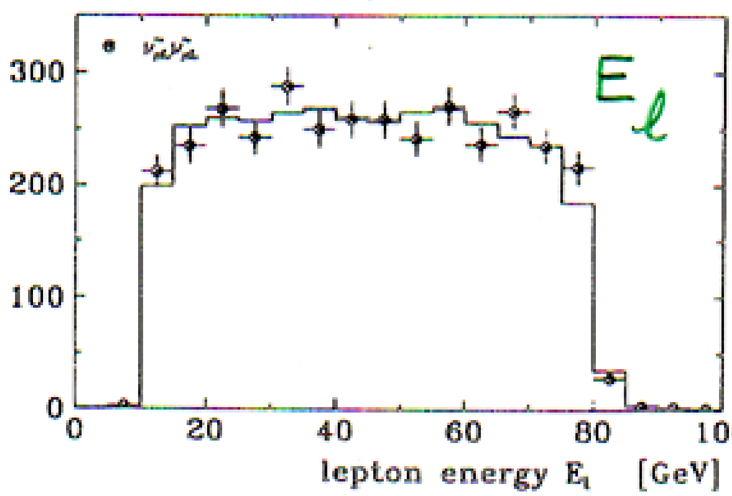
$L = 250\ fb^{-1}$



$3/\ e^-_L e^+_R \longrightarrow \tilde{\nu}_\mu \tilde{\nu}_\mu \longrightarrow \mu^- \chi^+_1 \mu^+ \chi^-_1 \quad (\chi^+_1 \longrightarrow \ell^\pm \nu_\ell \chi^0_1)$

$\sqrt{s} = 500$ GeV

$L = 250\ fb^{-1}$



SUSY: prod. of sfermions (MSSM) $e^+e^- \rightarrow \tilde{f}\bar{\tilde{f}}$

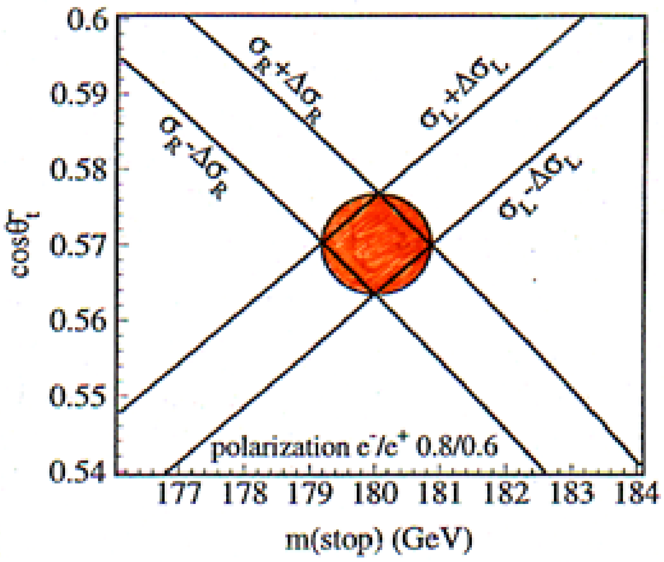
- **squarks:** $\tilde{t}, \tilde{b}, \ldots$

  - **characterise the $\tilde{t}_1$ and its mixing angle :**

$$\frac{d\sigma}{d\sqrt{s}} \; ; \; A_{LR} = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R}$$

$$\rightarrow \frac{\Delta m_{\tilde{t}_1}}{m_{\tilde{t}_1}} \sim \text{few } 10^{-3}$$

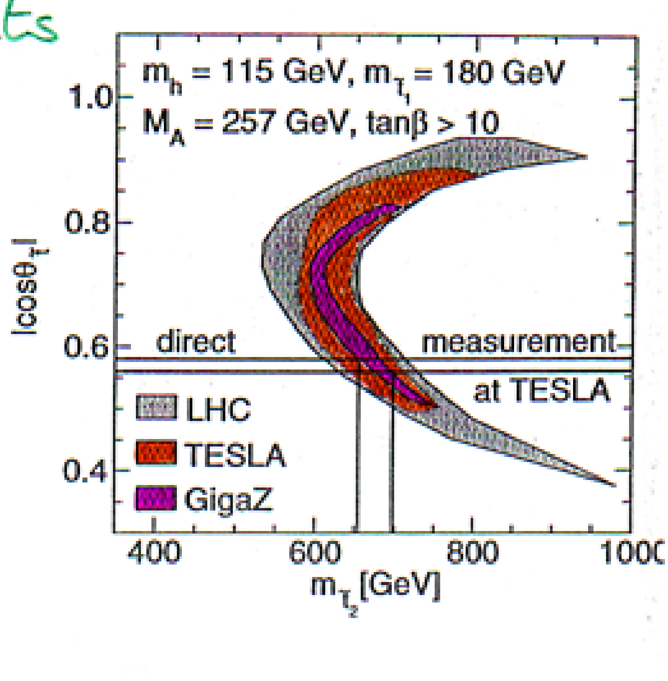
$$\Delta \cos\theta_{\tilde{t}} \sim O(10^{-3})$$



using precise measurements of M_{h^0}, M_W and $\sin^2\theta_W^{eff}$

↓

derive $m_{\tilde{t}_2}$



SUSY: prod. of charginos and neutralinos

▶ **Observation:**

$$e^+e^- \rightarrow \chi_2^0\chi_2^0 \rightarrow 4l^\pm + \not{E}(\chi_1^0)$$

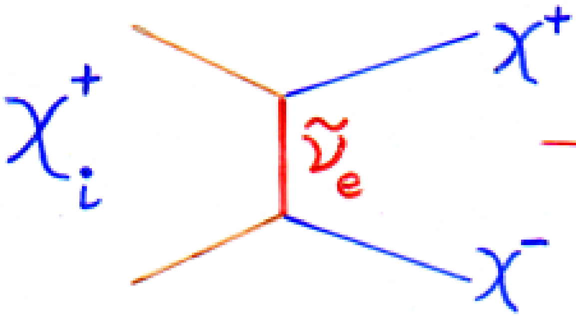
$$e^+e^- \rightarrow \chi_1^+\chi_1^+ \rightarrow l^\pm \nu q q' + \not{E}(\chi_1^0)$$

▶ **Masses:** $M_{l^+l^-,\,qq'}, E_{l^+l^-,\,qq'}, \sigma_{Thresh} \sim \beta$

Fig →

$$\rightarrow \frac{\Delta M_\chi}{M_\chi} \lesssim 10^{-3}$$

▶ **Properties:** $\sigma.Br(e)$, A^e_{FB}



→ $m_{\tilde{\nu}_e} \pm 10$ GeV up to $\sqrt{s}$

→ mixing angles (ϕ_L, ϕ_R) within $O(10^{-3})$

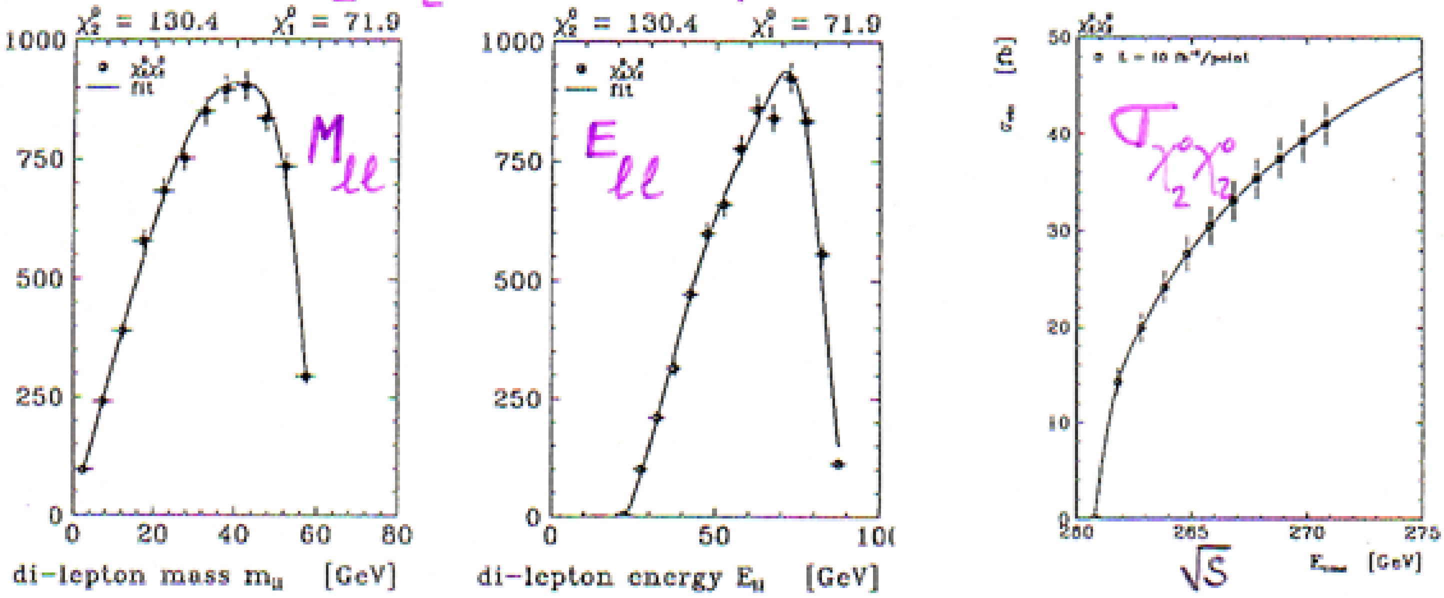
χ_i^0: access to $M_1, M_2, \mu, tg\beta$ $(\mathbb{P}_\pm!)$

also : $\gamma e^- \rightarrow \tilde{e}^-_{L,R}\chi_1^0 \rightarrow e^-\chi_1^0\chi_2^0 \rightarrow \frac{\Delta M_1}{M_1} \lesssim O(10^{-2})$

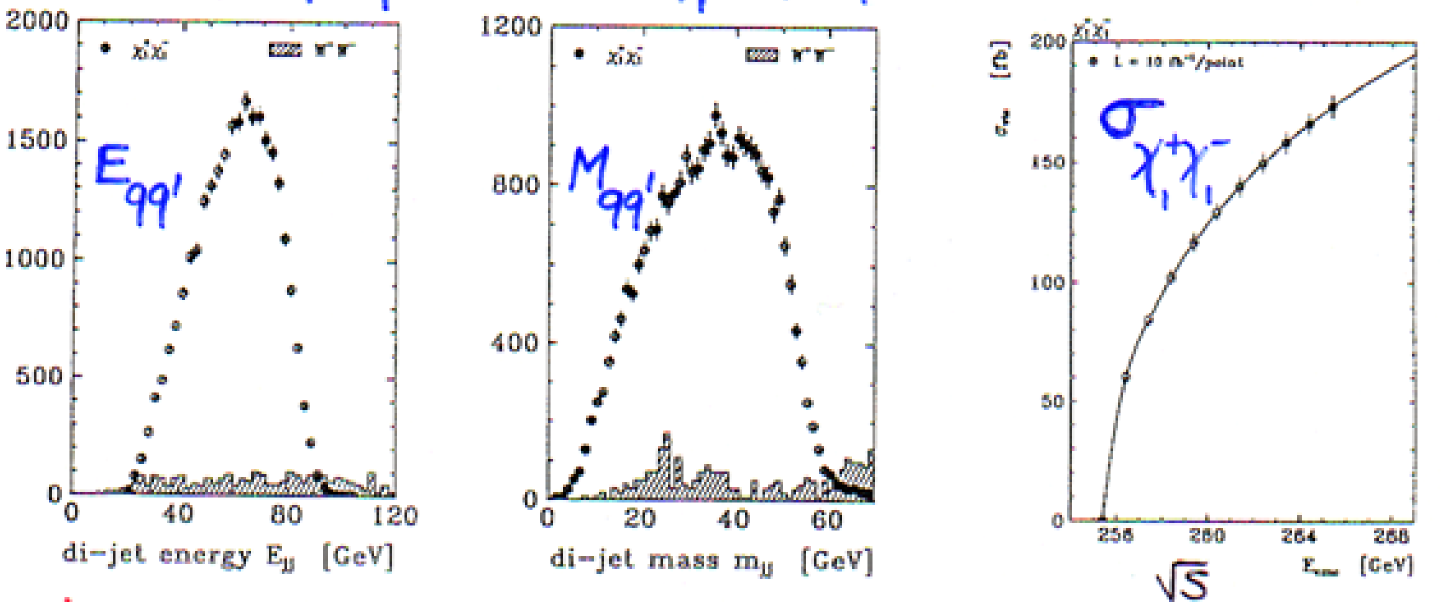
Fig →

→ check if $M_1/M_2 = \frac{5}{3} tg^2\theta_W$

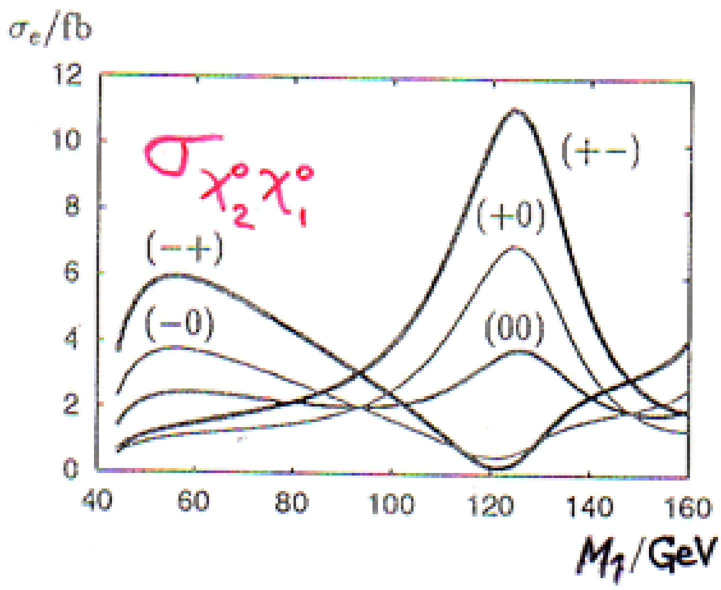
• $e^-_L e^+_R \longrightarrow \chi^0_2 \chi^0_2 \longrightarrow \ell^+\ell^-\chi^0_1 \; \ell^+\ell^-\chi^0_1$



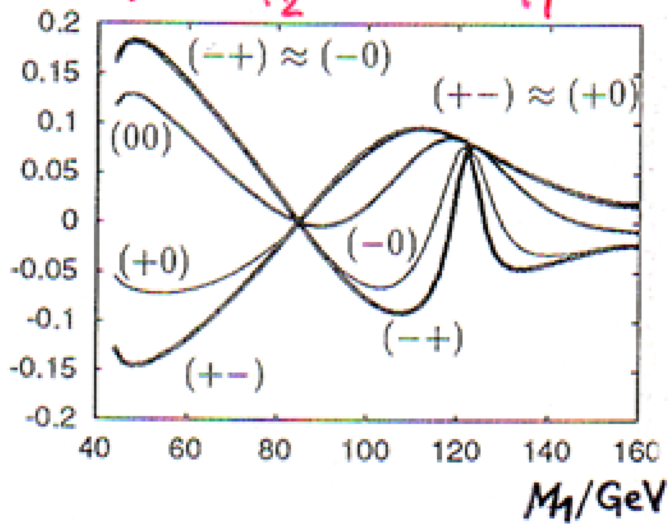
• $e^-_L e^+_R \longrightarrow \chi^+_1 \chi^-_1 \longrightarrow \ell^\pm \nu \chi^0_1 q q' \chi^0_1$



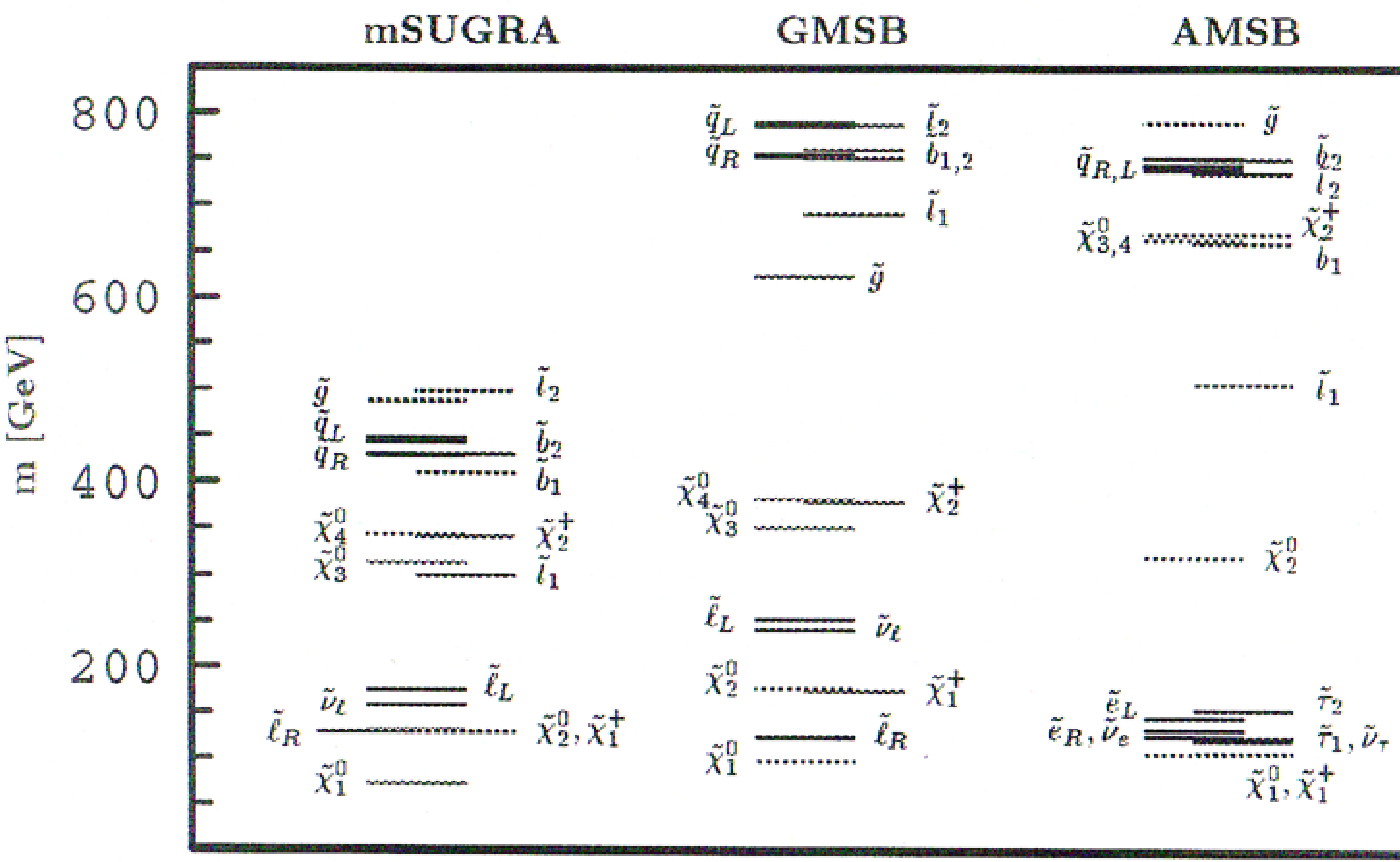
• $e^+e^- \longrightarrow \chi^0_2 \chi^0_1$ @ $\sqrt{s} = m_{\chi^0_1} + m_{\chi^0_2} + 30$ GeV



A_{FB} (e^-) de $\chi^0_2 \to e^+e^-\chi^0_1$



Spectre de Masse des Sparticules en Fonction de la Brisure de SUSY



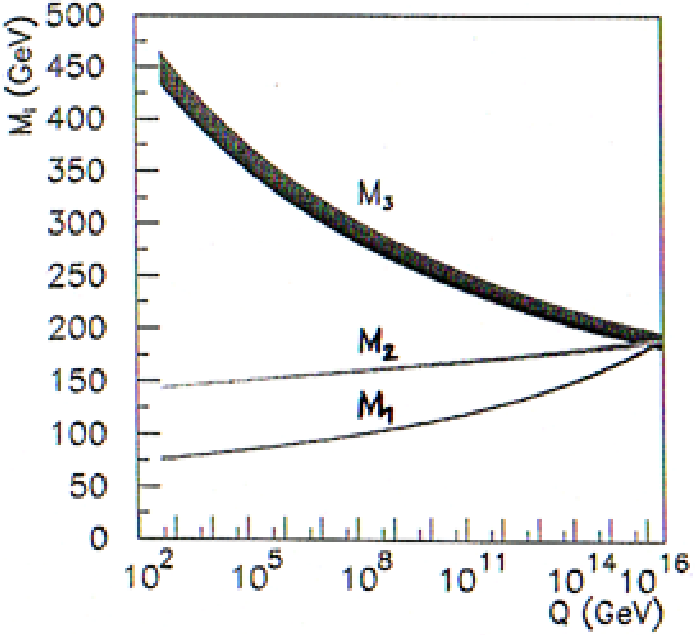
- Investigate the Breaking of Supersymmetry

→ evolution (RGE) of the fundamental parameters

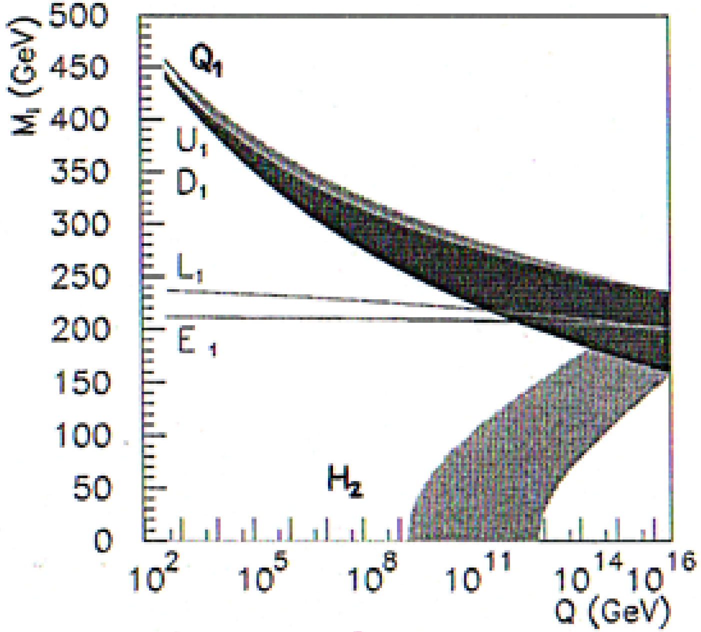
▶ mSUGRA

▶ GMSB

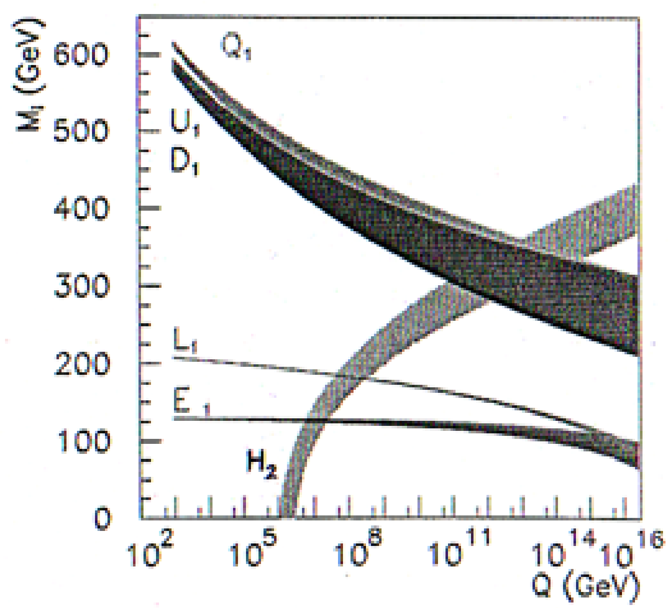
gauginos



sfermions



sfermions



* precision is essential for the extrapolation

How sensitive are $e^+e^- \to f\bar{f}$, W^+W^- or $\gamma\gamma$ to physics beyond the Standard Model?

1 - There may be a single gauge group describing all subatomic forces in a unified framework at high energy
$\longrightarrow$ new gauge bosons (Z', Z_R, W_R, ...)

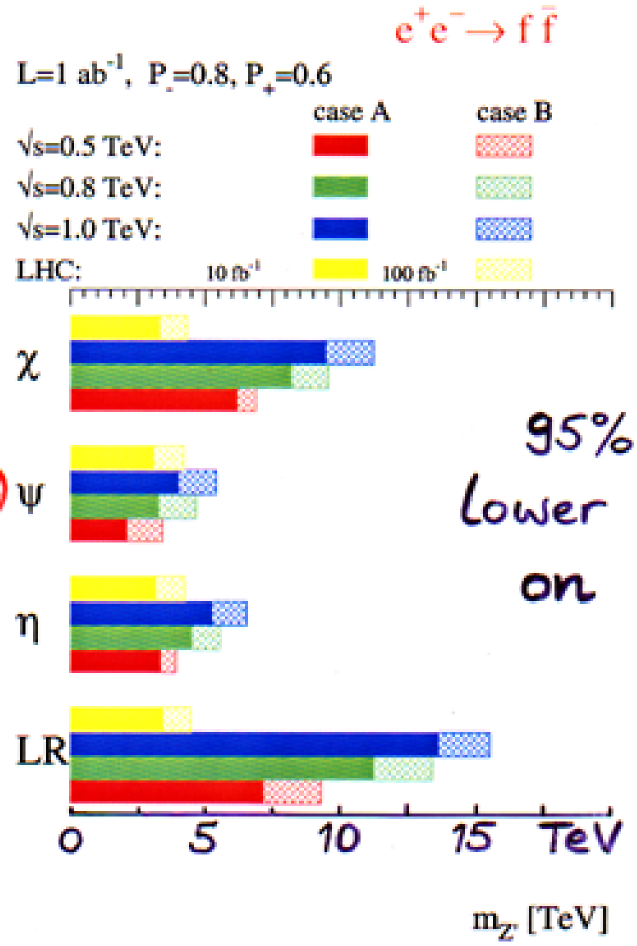
e^+e^- interactions at TESLA are sensitive to Z' bosons of mass $\gg E_{cm}$

ex: $e^+e^- \longrightarrow f\bar{f}$

the sensitivity depends on the gauge group considered (χ, ψ, η, LR)

$\equiv Z', Z_R$ couplings

$\rightarrow M_{Z'} \lesssim 4-12$ TeV

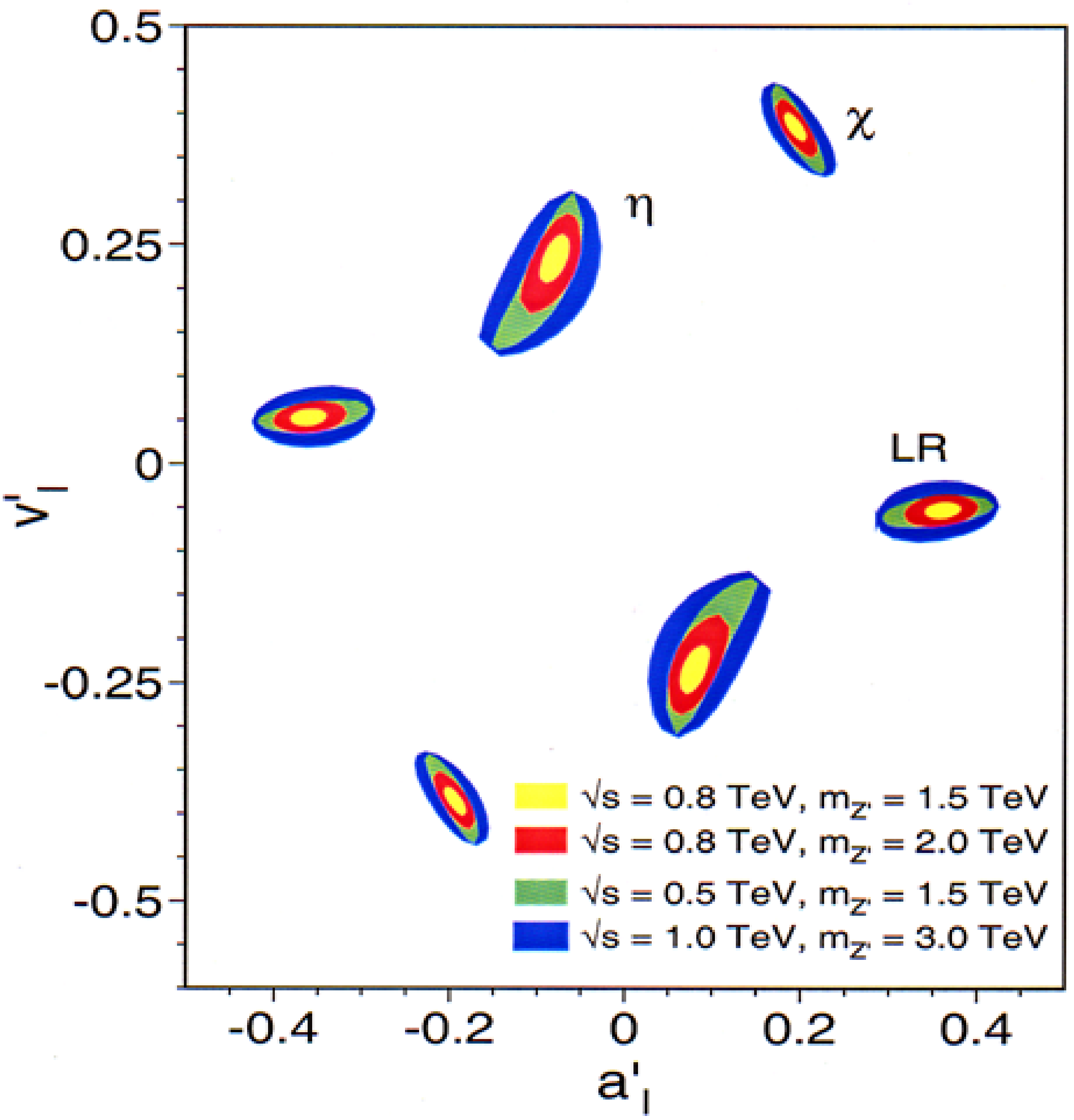


$e^+e^- \longrightarrow \ell^+\ell^-$: determine Z' couplings $\sim O(10\%)$
crucial for Z' seen at LHC

Characterizing a Z′ observed at LHC

$e^+e^- \longrightarrow l^+l^-$ (polarised beams)

extract $a_l^N = a_l' \sqrt{\frac{s}{M_{Z'}^2 - s}}$ $\quad v_l^N = v_l' \sqrt{\frac{s}{M_{Z'}^2 - s}}$



2.- Low Scale Quantum Gravity :

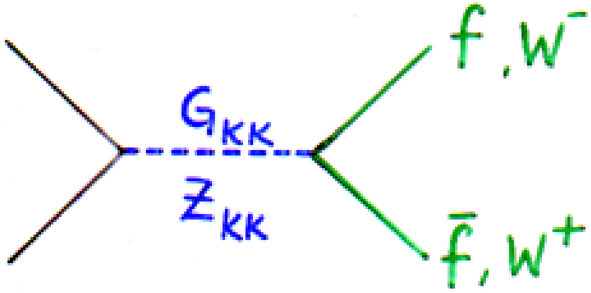
- direct effects : $e^+e^- \longrightarrow \gamma\, G_{KK}$

  (G_{KK} ↙) energy-momentum "not conserved"

$$M_{PL}^2 = V_\delta M_D^{2+\delta}$$

$\delta =$	2	3	4	5	6	
M_D[TeV] =	10.4	6.9	5.1	4.0	3.3	(95% C.L.)

- virtual effects :



$\longrightarrow$ modifies $\frac{d\sigma}{d\Omega_{f,W}}$, A_{LR}

sensitivity up to $M_D \sim 8$ TeV

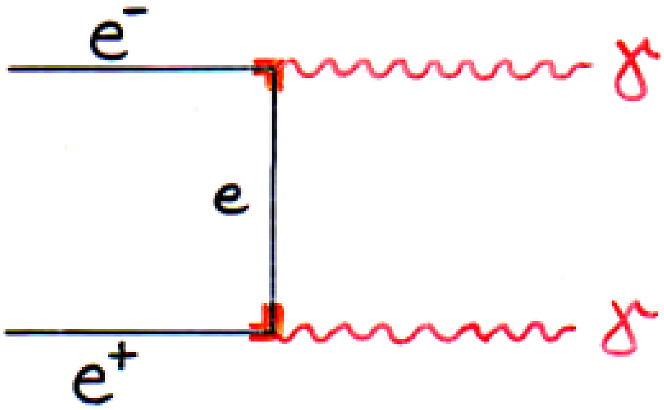
* for certain classes of models [Antoniadis et al.]

$e^+e^- \longrightarrow \mu^+\mu^-$ sensitive up to $\frac{1}{R_{comp.}} \sim 10$ TeV

($\Longleftrightarrow$ $M_D \sim 45$ TeV, $\delta = 6$)

- are matter constituants elementary?

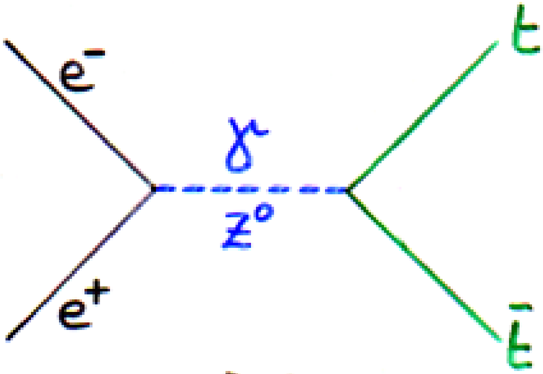
ex: testing the electron structure



$\frac{d\sigma}{d\Omega_\gamma}$ sensitive to $r_e \sim 10^{-18}$ cm

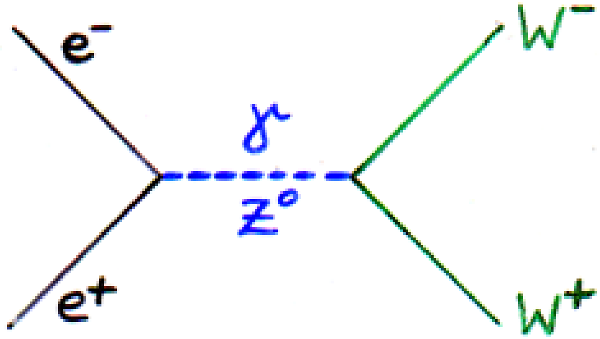
($\Leftrightarrow$ energy scale $\Lambda_c \sim 150$ TeV)

Standard precision measurements at TESLA are mainly based on:



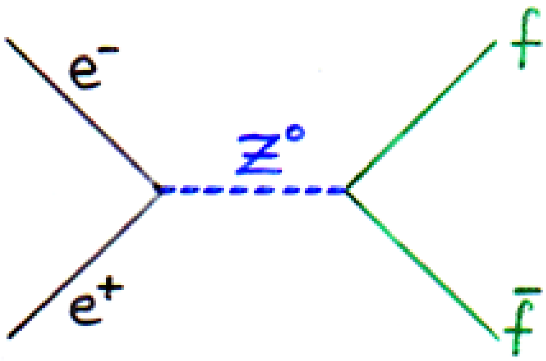
$E_{cm} \gtrsim 350$ GeV

$\sim 10^6\, t\bar{t}$



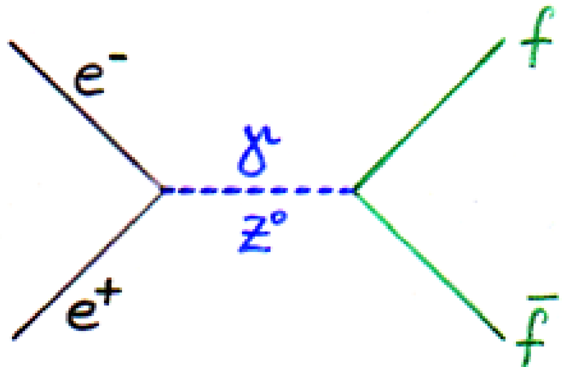
$E_{cm} \gtrsim 160$ GeV

$> 10^6\, W^+W^-$



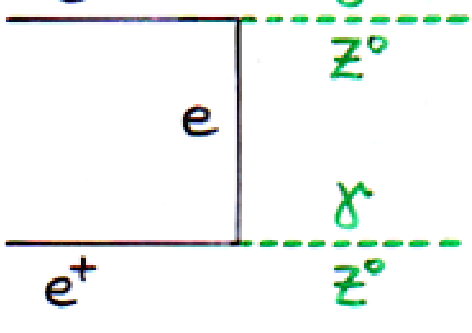
$E_{cm} \sim 91$ GeV

$> 10^9\, Z^0$

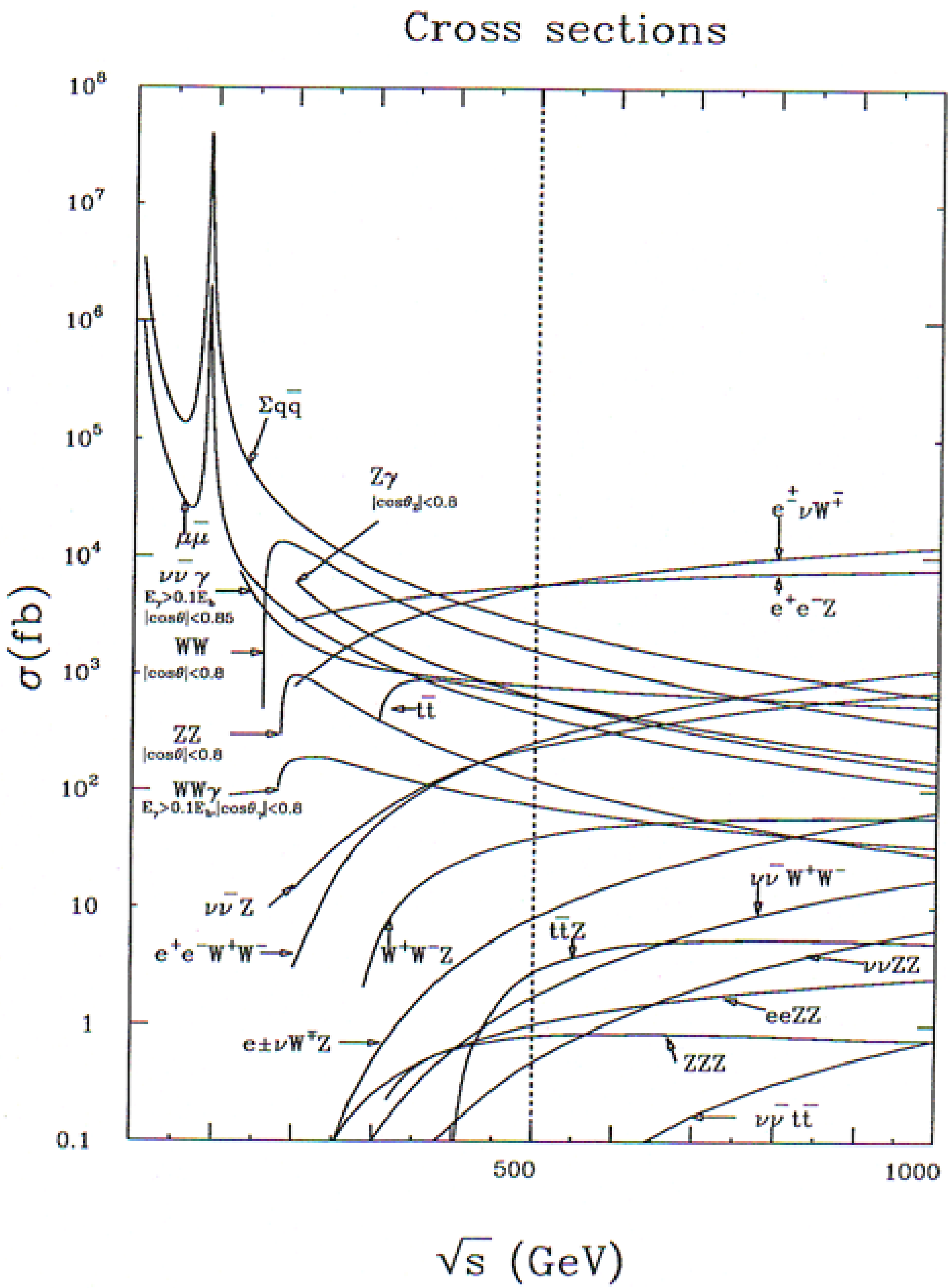


$E_{cm} \gtrsim 500$ GeV

$\sim 10^7\, f\bar{f}$



$E_{cm} \gtrsim 500$ GeV



Cross sections
σ(fb)
√s (GeV)
10⁸
10⁷
10⁶
10⁵
10⁴
10³
10²
10
1
0.1
500
1000
Σqq̄
μμ̄
Zγ
|cosθ_z|<0.8
νν̄ γ
E_γ>0.1E_b
|cosθ|<0.85
WW
|cosθ|<0.8
tt̄
ZZ
|cosθ|<0.8
WWγ
E_γ>0.1E_b |cosθ_γ|<0.8
e⁺̄ νW⁻̄⁺
e⁺e⁻Z
νν̄ Z
e⁺e⁻W⁺W⁻
W⁺W⁻Z
νν̄ W⁺W⁻
tt̄Z
ννZZ
eeZZ
e±νW∓Z
ZZZ
νν̄ tt̄

What is the Higgs mass ?

A - determine m_t, M_W at kinematical threshold :

1/ measure $\frac{d\sigma}{dE_{cm}}(e^+e^- \longrightarrow t\bar{t}, W^+W^-)$

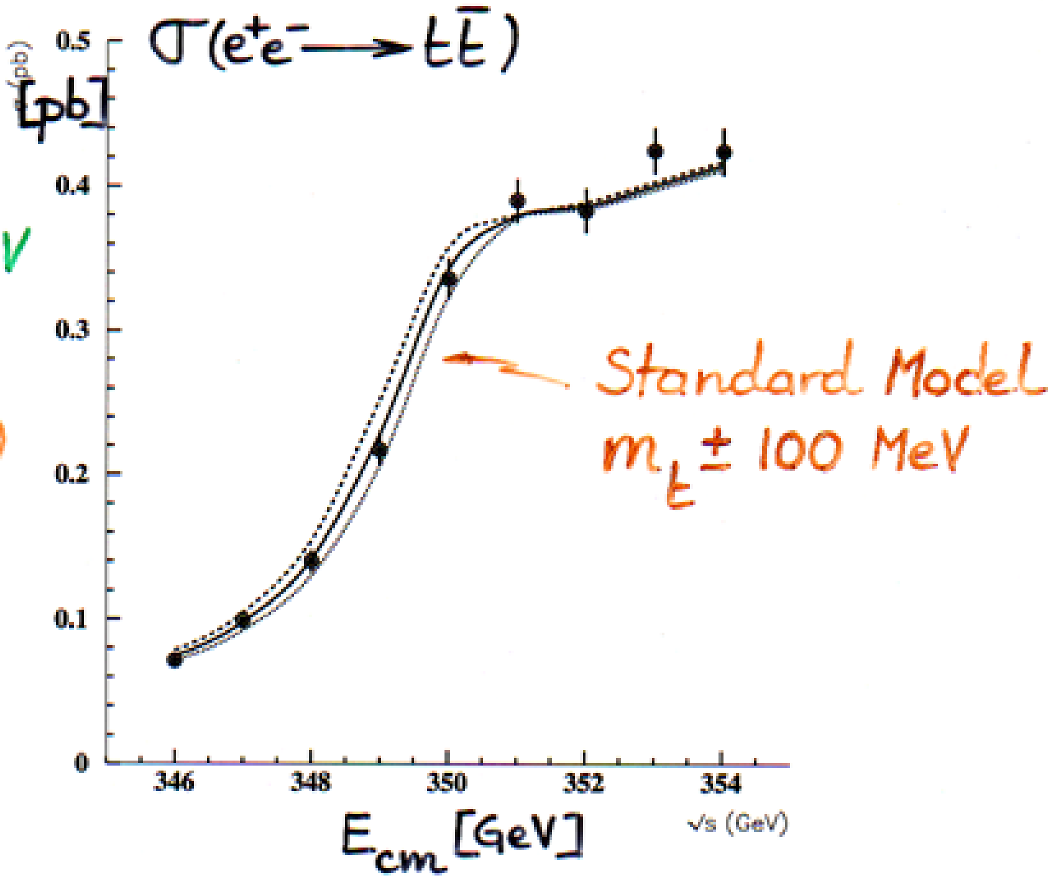
2/ determine for which value of m_t, M_W :

$$\frac{d\sigma}{dE_{cm}}(\text{standard Model}) = \frac{d\sigma}{dE_{cm}}(\text{exp})$$

- top mass :

  $\Delta m_t < 200$ MeV

  (LHC : 1.3-2.0 GeV)



- W mass :

  $\Delta M_W \sim 6$ MeV

  (LHC : 15-25 MeV)

B - determine $\sin^2\theta_W^{eff}$ from $e^+e^- \longrightarrow f\bar{f}$

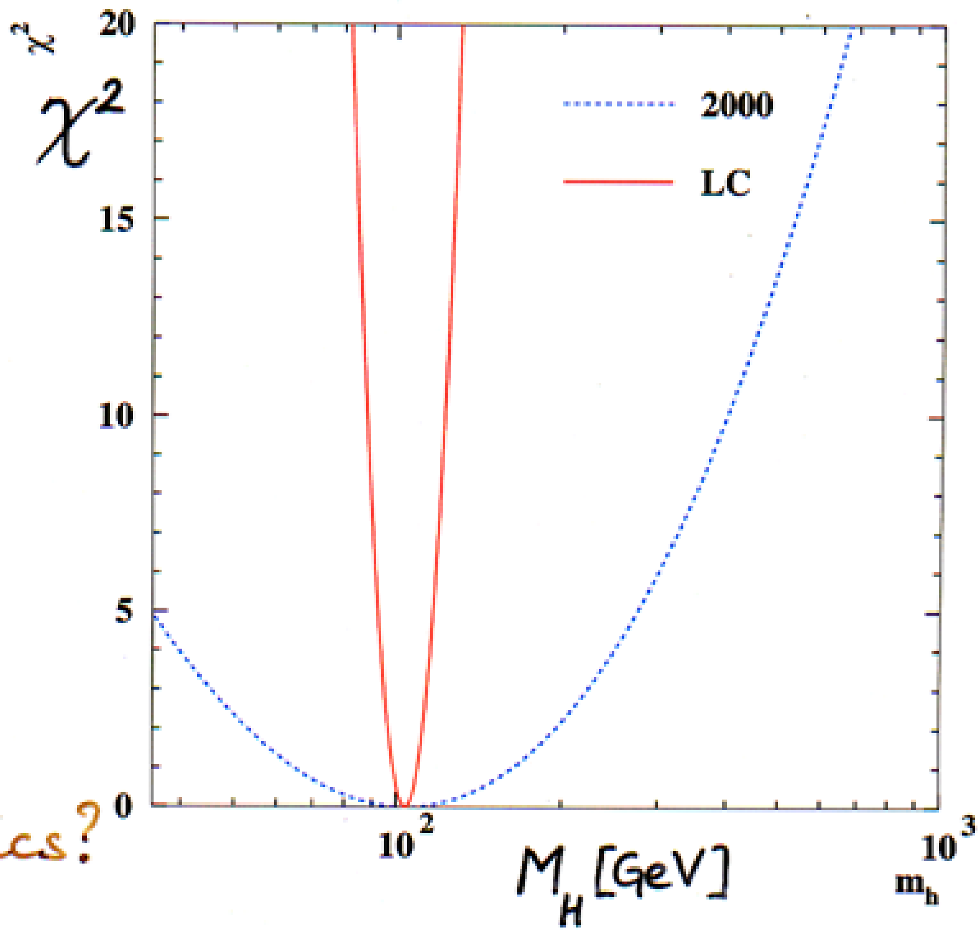
($E_{cm} \sim 91$ GeV)

measure $A_{LR} \approx \frac{1}{\text{Polar.}} \cdot \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R}$

Standard Model: $A_{LR} \simeq \frac{2\,(1-4\sin^2\theta_W^{eff})}{1+(1-4\sin^2\theta_W^{eff})^2}$

precision expected : $\frac{\Delta \sin^2\theta_W^{eff}}{\sin^2\theta_W^{eff}} \lesssim 0.01\%$

$\frac{\Delta M_H}{M_H} \sim 5\%$



$M_H^{indirect} \overset{?}{=} M_H^{direct}$

↓

room for New Physics?

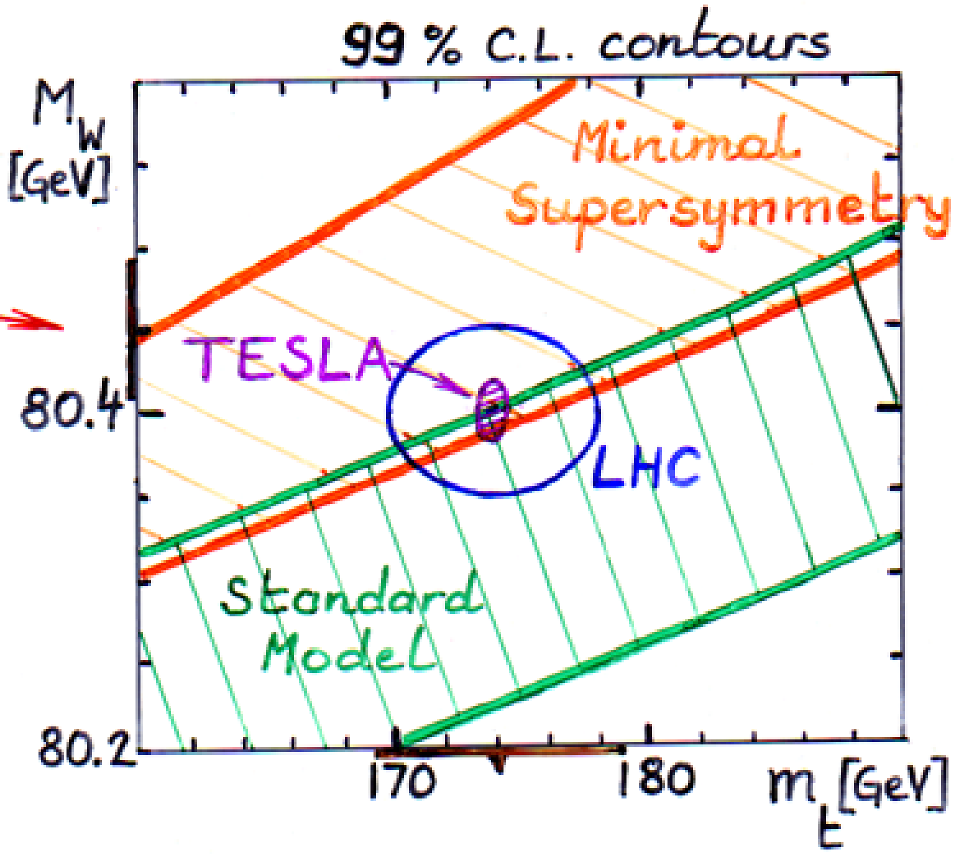
What is the Nature of the Physics beyond the Standard Model?

- example of Supersymmetry

quantum corrections due to new physics will modify the values of $\sin^2\theta_W$ and M_W

TESLA will severely constrain the values of the parameters associated to the Minimal Supersymmetric Model

ex: M_W versus m_t →



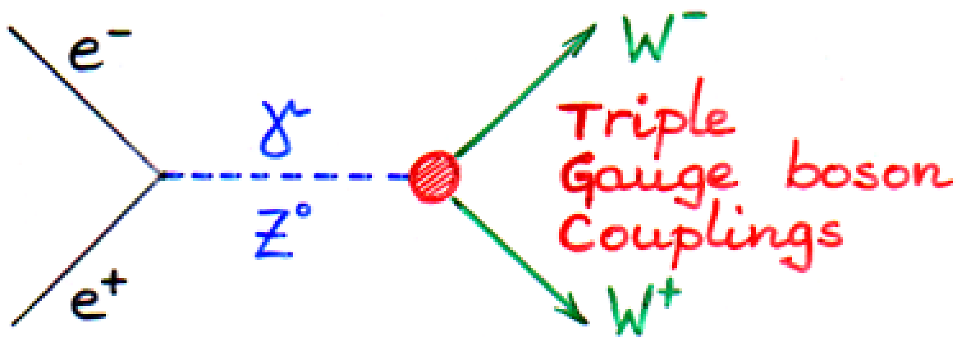
Top Quark profile

- the top quark is special ...
  - $m_t \gg m_{f \neq t}$
    → does m_t set an energy scale in flavour dynamics ?
  - $m_t > M_W, M_Z$
    → does top play a role in the electroweak symmetry breaking?

- measure all possible characteristics of top:
  - magnetic and electric dipole moments:
    $\sim O(\%)$ $\sim 10^{-18}$ e.cm
  - electroweak couplings $v_t, a_t \sim O(\%)$
  - etc.

Gauge Boson Interactions

- are sensitive to physics beyond Standard Model



- influence $\frac{d\sigma}{d\cos\theta_W}(e^+e^- \rightarrow W^+W^-)$, A_{LR}^W, ...

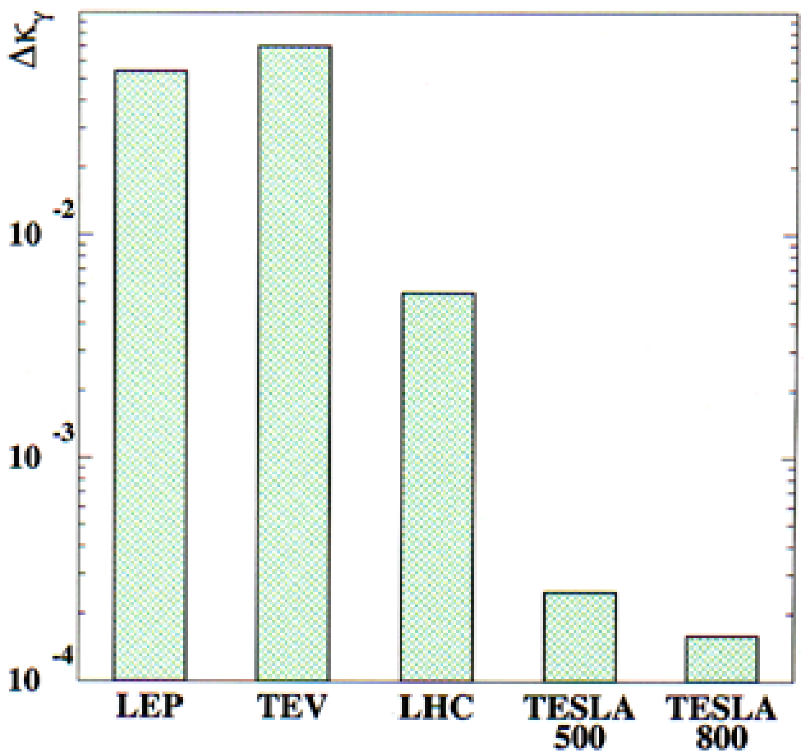
- 2 × 3 parameters : $g_\gamma, \Delta\kappa_\gamma, \lambda_\gamma ; g_Z, \Delta\kappa_Z, \lambda_Z$

  Standard Model : e , 0 , 0 , $e\,\mathrm{cotg}\,\theta_W$, 0 , 0

  quantum corrections $\sim O(10^{-4})$

- precision at TESLA $\sim O(10^{-4})$

  LHC : $\sim O(10^{-3})$



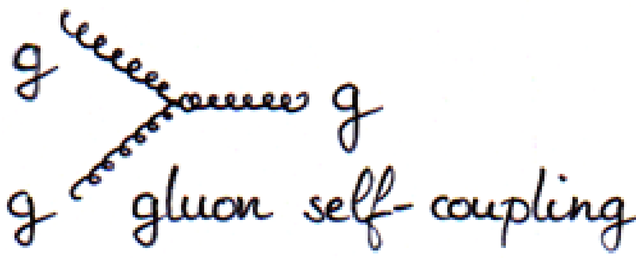
The knowledge of the strong coupling constant

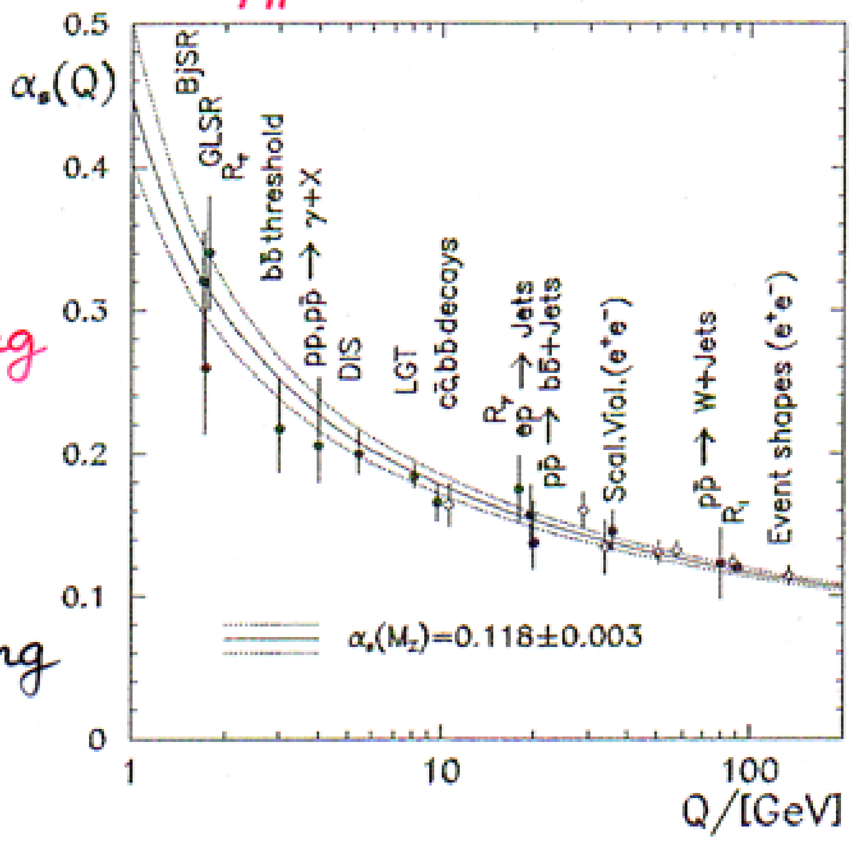
- is essential for accurate electroweak and perturbative Quantum Chromodynamics (QCD) predictions. Ex: $\frac{d\sigma}{dE_{cm}}(e^+e^- \longrightarrow t\bar{t})$

- test the "evolution" of $\alpha_s = \frac{g_s^2}{4\pi}$ with Q^2

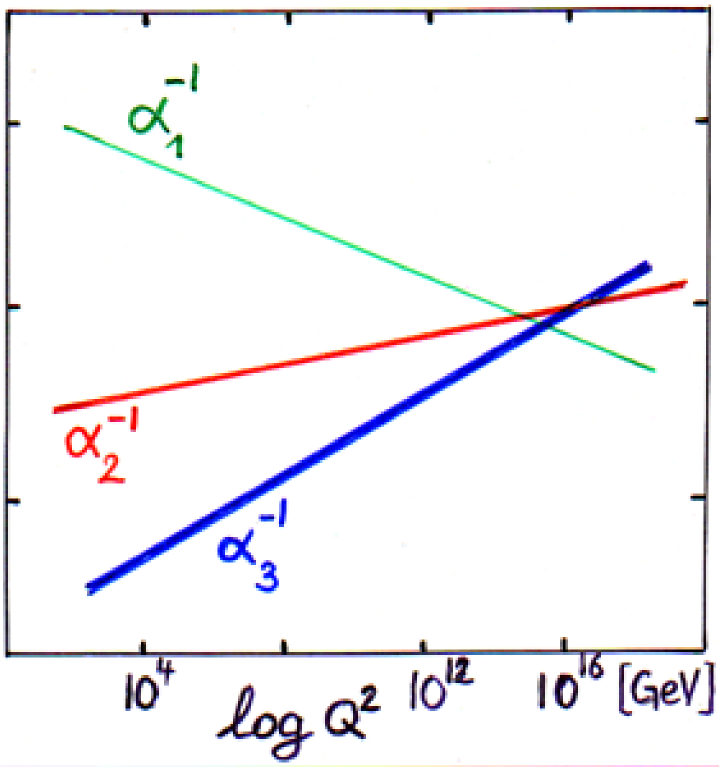
QCD : $\frac{d\alpha_s}{d\ln Q^2} < 0$

due to non-abelian structure of the strong interaction :





- extrapolate $\alpha_s(Q^2)$ to very high energy in order to estimate a potential Grand Unification energy scale.



- TESLA: $\frac{\Delta\alpha_s}{\alpha_s} \sim 0.5\%$

(today : $\sim 2\%$)

If the Higgs boson was not light ...

1- Explain why the electroweak observables suggest a light Higgs ($M_H < 300$ GeV)

- it could be that

$$\sin^2\theta_W^{exp} = \sin^2\theta_W^{SM}(M_H \sim 100\,\mathrm{GeV}) + a \log\frac{M_H}{100} + b \cdot F_{New\ Physics}$$

$\Rightarrow$ new physics ($\neq$ supersym.) ... ~ 0!

- fit $\{a, b, M_H\}$ to $\{\sin^2\theta_W, m_t, M_W\}$ measured at LEP, SLC, Tevatron for various New Physics hypotheses ($\Leftrightarrow$ various F_{NP}):

  $M_H \lesssim 500$ GeV $\Longrightarrow$ it will be seen at TESLA

  $\Lambda_{NP} \lesssim O(\mathrm{TeV})$ $\Longrightarrow$ effects will be observed at TESLA in $e^+e^- \longrightarrow f\bar{f}, W^+W^-, \ldots$

- fits of $\{a, b, M_H\}$ to $\{\sin^2\theta_W, m_t, M_W\}$ measured at TESLA will severely constrain M_H and the new physics parameters

if Nature ignores the Higgs boson ...

- $\{\sin^2\theta_W, M_W, m_t\}$ will become more and more constraining / essential

- also major consequences on WW, ZZ ... production

  $\sigma(e^+e^- \longrightarrow W^+W^-, Z^\circ Z^\circ) \xrightarrow{E_{cm} \sim O(\text{TeV})} \infty$ NOT PHYSICAL

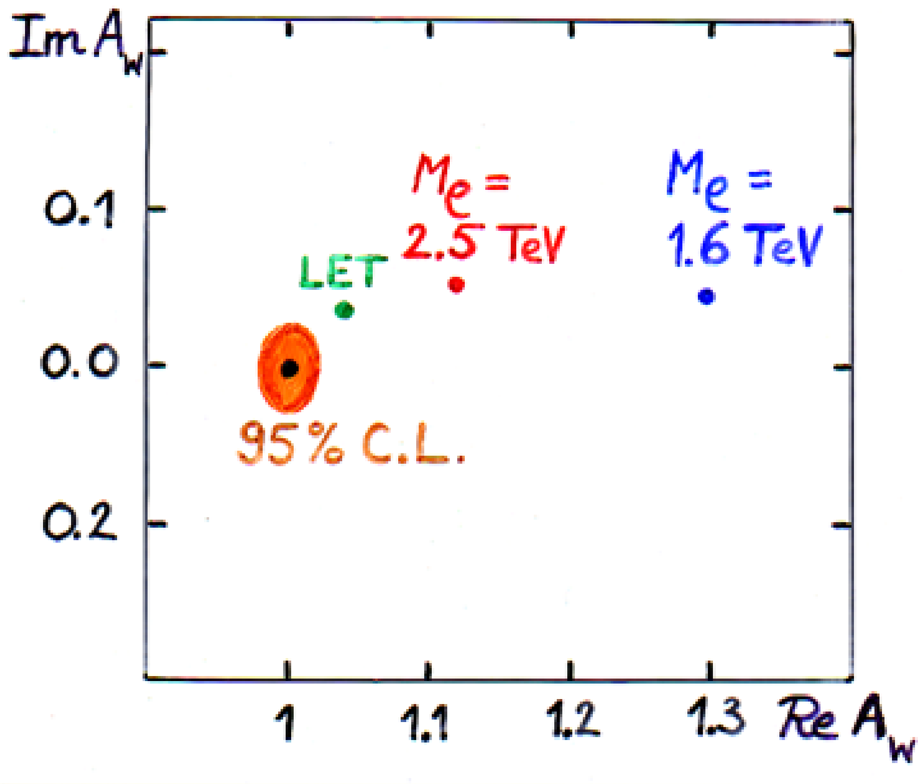
  some new phenomenon will avoid the divergence

  → measure $\sigma(e^+e^- \longrightarrow {WW \atop ZZ} \nu\bar{\nu})$, $\frac{d\sigma}{d\Omega}(e^+e^- \longrightarrow WW)$, A^W_{LR}

- in general : TESLA observables are sensitive to new energy scale $\lesssim$ 5-15 TeV

- in case of new vector resonances (ex: ρ_{TC})

  the sensitivity covers any $M_{\rho_{TC}}$



… no Higgs but a strongly inter. EW sector

- ex. of BESS model (⊃ certain Technic. models)
  dynamical EW sym. breaking ⇒ new gauge bosons
  ⟹ new parameters: M_V, g'', b

- measure $e^+e^- \longrightarrow f\bar{f}, W^+W^-$
  ↳ $\frac{d\sigma}{d\cos\theta_{f,W}}$, $A_{LR}^{f\bar{f}, W^+W^-}$, …

  and adjust (M_V) g'', b in theoretical expressions
  in order to reproduce measured values

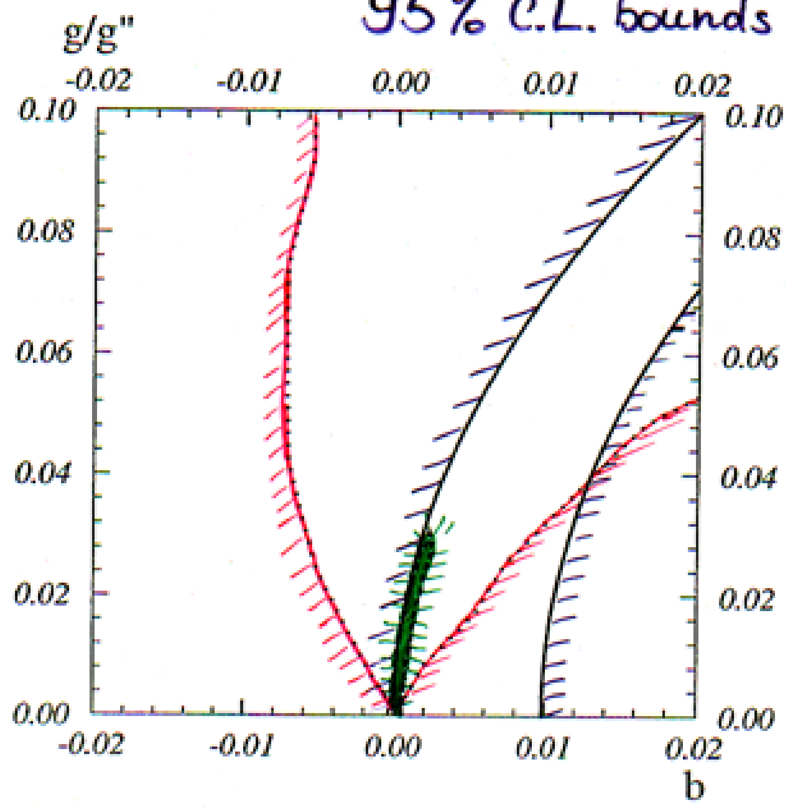
⇓

95% C.L. bounds

present limits ———

LHC (M_V = 2TeV) ———

TESLA (M_V = 2TeV) ———
$\sqrt{s}$ = 800 GeV; L = 1000 fb^{-1}



SUMMARY – CONCLUSION

- technology is ready for e^+e^- collisions at 500 – 800 ... GeV $\left(\begin{array}{l} L \sim 3\text{-}6\ 10^{34} cm^{-2} s^{-1} \\ P_- = 80\% \ ;\ P_+ = 60\% \end{array} \right)$

- high physics potential:
  - discover and understand EW sym. breaking
  - " " " Physics > S.M.

also:
- top physics ($\sim 10^6\ t\bar{t}$)
- τ physics ($\sim 10^7\ \tau\bar{\tau}$)
- $\not{CP}_B$
- QCD studies

⟹ complementary to LHC: possibility of running Future L.C. in // with LHC is very tempting

- let's join our efforts and do it!

TESLA / LHC complementarity

		TESLA	LHC
$\frac{\Delta\alpha_s}{\alpha_s}$		0.5%	-
$\frac{\Delta\sin^2\theta_W}{\sin^2\theta_W}$		$\sim 10^{-4}$	-
ΔM_W		6 MeV	15-25 MeV
Δm_t		< 200 MeV	1.3 - 2.0 GeV
top quark profile		O(%) ← different param. →	O(%)
TGC		$\gtrsim O(10^{-4})$	$\sim O(10^{-3})$
virtual effects from New Phys.	$M_{Z'}$:	4-12 TeV	~ 4 TeV
	$Z'f\bar{f}$:	O(10%)	-
	V_{KK}:	> 10 TeV	$\lesssim$ 6 TeV
heavy Higgs		H characterized New Physics constrained	?
no Higgs		$\Lambda_{NP} \sim$ 5-15 TeV New Physics constrained	$\Lambda_{NP} <$ 10 TeV

Beam Energy Measurement

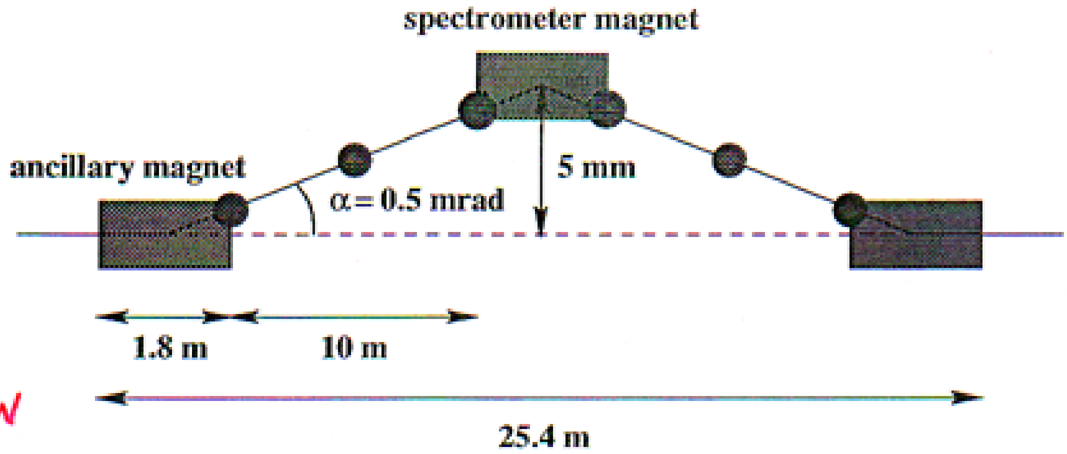
- accurate knowledge needed for m_t, $\sin^2\theta_W$

1- Magnetic spectrometer:

$$\frac{\Delta E_b}{E_b} \approx 10^{-4}$$

(like LEP)

OK for m_t, M_W

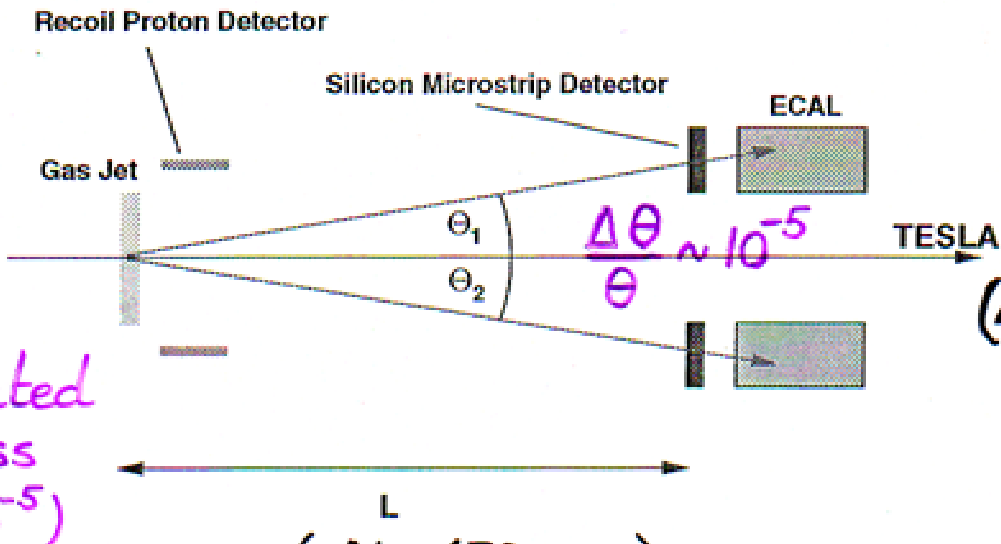


2- Möller scattering spectrometer:

$$\frac{\Delta E_b}{E_b} \approx 10^{-5}$$

cross-calibrated with Z^0 mass ($\pm 2\ 10^{-5}$)

OK for $\sin^2\theta_W^{eff}$



$\frac{\Delta\theta}{\theta} \sim 10^{-5}$

$(\Delta d \sim 1\,\mu m)$

$(\Delta L \sim 150\,\mu m)$