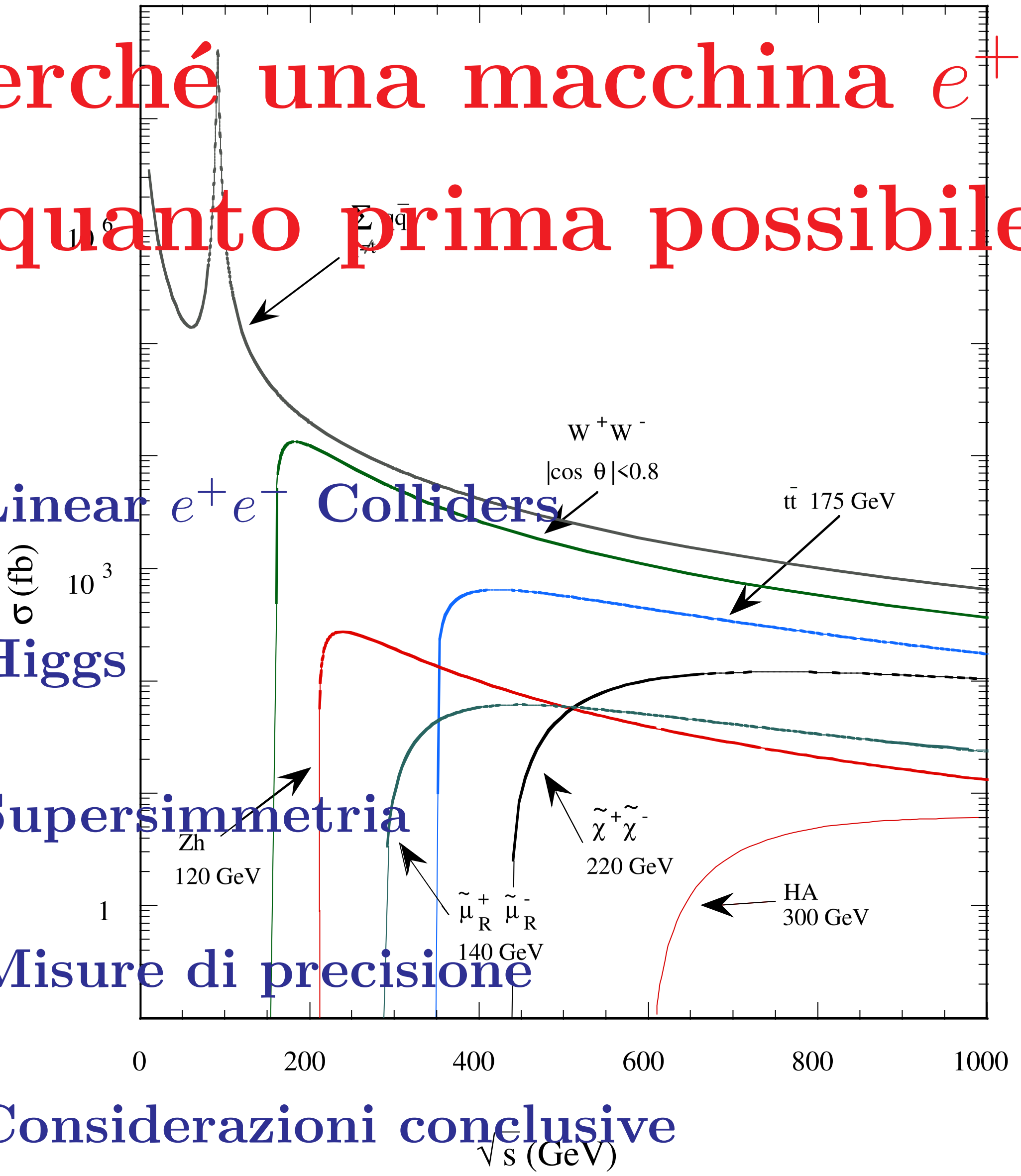
Linear e^+e^- Collider: Programma di ricerca

Ovvero:



Perché una macchina e^+e^- quanto prima possibile

- **Linear e^+e^- Colliders**
- **Higgs**
- **Supersimmetria**
- **Misure di precisione**
- **Considerazioni conclusive**

Linear Collider

Linear e^+e^- Colliders

- **Europa: TESLA**
  TDR 23-3-2001: **4 G Euro**
- **America: NLC**
  The Case for a 500 GeV e^+e^- Linear Collider
  hep-ex/0007022: **8 G \$ (da diminuire)**
- **Asia: JLC**
  design report 2003

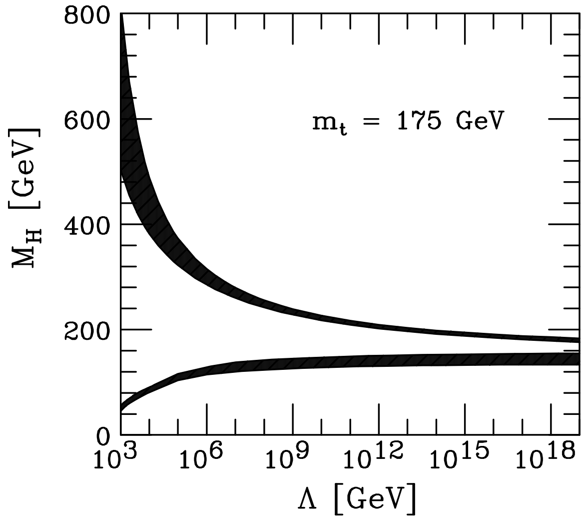
	TESLA	NLC/JLC-X	JLC-C
$\sqrt{s}$ (GeV)	500 (800)	500 (1000)	500
Gradient (MV/m)	22 (35)	50	34
$\mathcal{L}$ ($10^{34}cm^{-2}s^{-1}$)	3.4^a (5.8)	2.2 (3.4)	0.43
RF-freq. (GHz)	1.3	11.4	5.7
Bunch spacing (ns)	337	1.4	2.8
Bunch per pulse	2820 (4886)	190	72
Beamsstrahl. (%)	3.2 (4.4)	4.6 (8.8)	

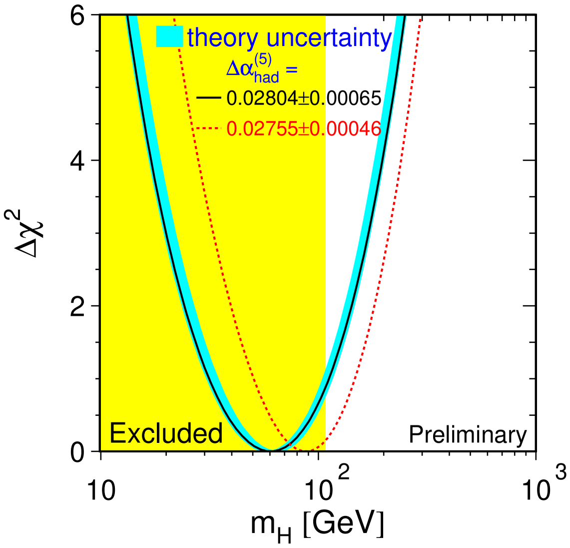
$+ \mathcal{P}$, GigaZ, $\gamma\gamma$, γe, e^-e^-, ep, XFEL

[a] $\int \mathcal{L}\, dt = 340 fb^{-1}$ per anno.

Linear Collider

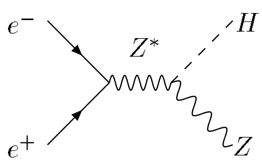
Fisica dell' Higgs

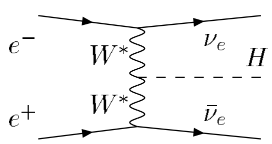




Produzione MS

Higgs-strahlung — Fusione WW/ZZ

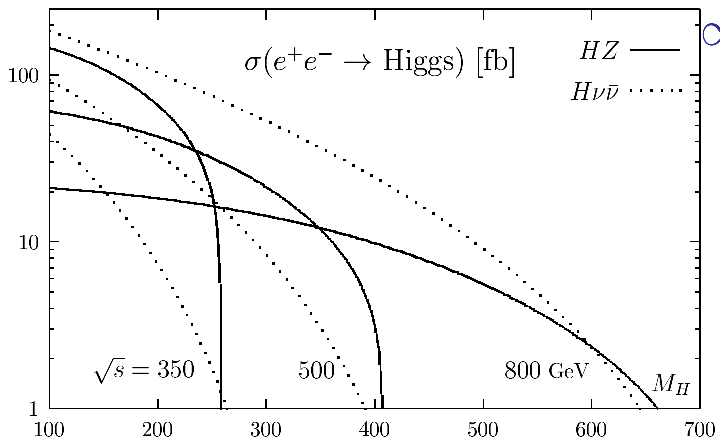




$$\sigma(e^+e^- \to ZH) = \frac{g^2_{ZZH}}{4\pi}\frac{G_F(v_e^2+a_e^2)}{96\sqrt{2}s}\beta_{HZ}\frac{\beta^2_{HZ}+12M_Z^2/s}{(1-M_Z^2/s)^2}$$

$$\sigma(e^+e^- \to \bar{\nu}_e\nu_e H) \to \frac{g^2_{WWH}}{4\pi}\frac{G_F^2}{8\pi^2}\left[\left(1+\frac{M_H^2}{s}\right)\log\frac{s}{M_H^2}-2\left(1-\frac{M_H^2}{s}\right)\right]$$

$$\propto \frac{g^2_{ZZH}}{s}$$



$$\propto g^2_{WWH} ln(s)$$

Linear Collider

Misura della massa

Higgs leggero (< 140 GeV)

- $H^0 Z \to q\bar{q}l^+l^-$

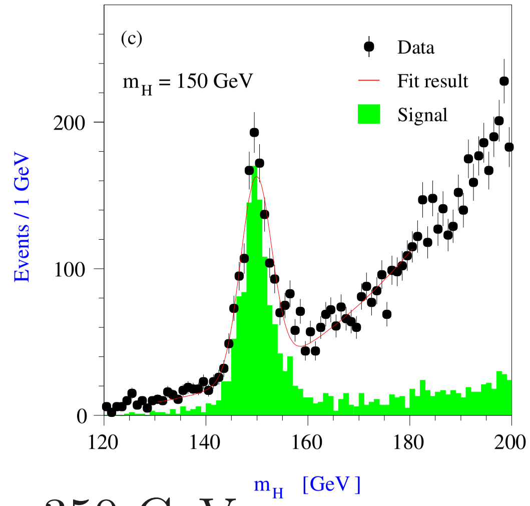
  Recoil mass (δM_H =110 MeV), 4-C fit

- $H^0 Z \to b\bar{b}q\bar{q}$

Higgs pesante (> 140 GeV)

- $H^0 Z \to W^+W^-l^+l^-$

- $H^0 Z \to W^+W^-q\bar{q}$



500 fb^{-1}, $\sqrt{s} = 350$ GeV

M_H (GeV)	Channel	δM_H (MeV)
120	$\ell\ell qq$	±70
120	$qqbb$	±50
120	Combined	±40
150	$\ell\ell$ Recoil	±90
150	$qqWW$	±130
150	Combined	±70
180	$\ell\ell$ Recoil	±100
180	$qqWW$	±150
180	Combined	±80

Nel MS: $M_H \Rightarrow$ profilo Higgs fissato

Linear Collider

Accoppiamenti e decadimenti nel MS

Fermioni

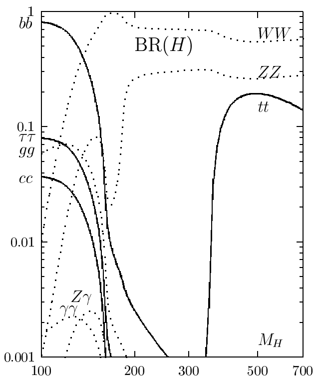
$$\Gamma(H^0 \to f\bar{f}) = \frac{g^2_{ffH}(M^2_H)}{4\pi}\frac{N_C}{2}M_H\left(1-\frac{4m^2_f}{M^2_H}\right)^{\frac{3}{2}}$$

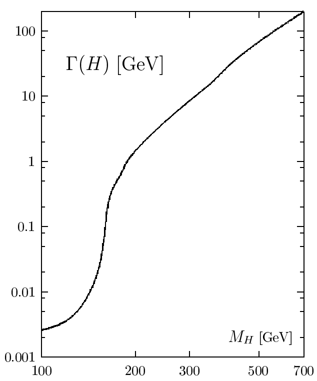
con $g_{ffH} = m_f/v,\ v{=}(\sqrt{2}G_F)^{-1/2} \Rightarrow \Gamma \propto m^2_f$

Bosoni di Gauge sopra soglia

$$\Gamma(H^0 \to VV) = \frac{g^2_{VVH}}{4\pi}\frac{3\delta_V}{8M_H}\left(1-\frac{M^2_H}{3M^2_V}+\frac{M^4_H}{12M^4_V}\right)\left(1-\frac{4M^2_V}{M^2_H}\right)^{\frac{1}{2}}$$

con $g_{VVH} = 2M^2_V/v,\ V = W, Z \Rightarrow \Gamma \to M^3_H$





Ma in MSSM

$$\frac{g_{h^0u\bar{u}}}{g_{ffH}} = \frac{cos\alpha}{sin\beta},\quad \frac{g_{h^0d\bar{d}}}{g_{ffH}} = -\frac{sin\alpha}{cos\beta},\quad \frac{g_{h^0VV}}{g_{VVH}} = sin(\beta-\alpha)$$

deviazioni in σ, B.R.

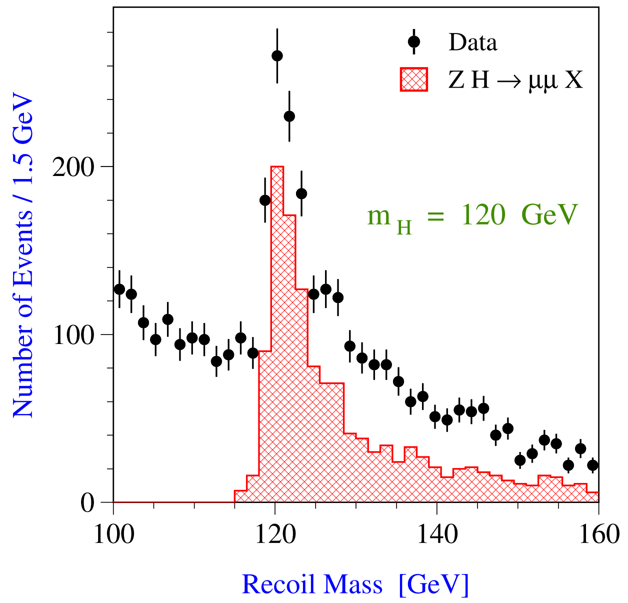
Molte strategie di misura per g

Capire la natura del Bosone di Higgs

Linear Collider

Misure g_{HZZ} e g_{HWW}

σ Higgs-strahlung misurabile indipendentemente dal decadimento H: massa di rinculo a $Z^0 \to l^+l^-$



Eventi $e^+e^- \to H^0 Z \to q\bar{q}l^+l^-$ $(l = e, \mu)$ con 500 fb^{-1}

M_H (GeV)	$\sqrt{s} = 350$ GeV	500 GeV	800 GeV
120	4670	2020	740
140	4120	1910	707
160	3560	1780	685
180	2960	1650	667
200	2320	1500	645
250	230	1110	575
Max M_H (GeV)	258	407	639

$$\frac{\delta(\sigma)}{\sigma} \text{ (stat) } 2.5\text{-}3\%$$

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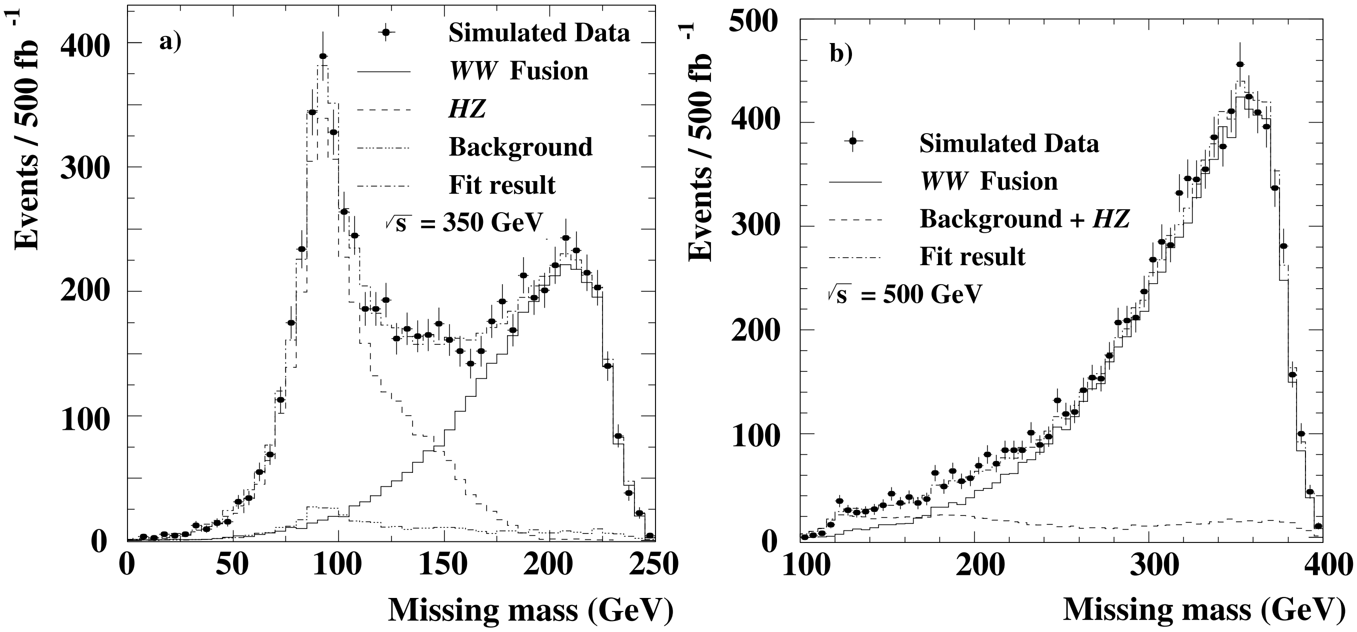
Fusione: σ_{WWH} da stato finale $b\bar{b}\nu\bar{\nu}$

500 fb^{-1}



$$\frac{\delta(\sigma)}{\sigma} \text{ (stat) } 2.8\text{-}13\%$$

B.R. WW^* (ZZ^*) Da Higgs-strahlung cercando decadimenti adronici e semileptonici del W (Z^0)

$M_H = 120$ (GeV)	120	140	160
$H \to WW^*$	± 0.051	± 0.025	± 0.021
$H \to ZZ^*$			± 0.169

$$\sigma_{WWH} \Rightarrow g_{HWW} \Rightarrow \Gamma(H \to WW) + \text{B.R. } WW^*$$

$$\Downarrow$$

$$\Gamma_{tot} \ \mathbf{4\text{-}13\%}$$

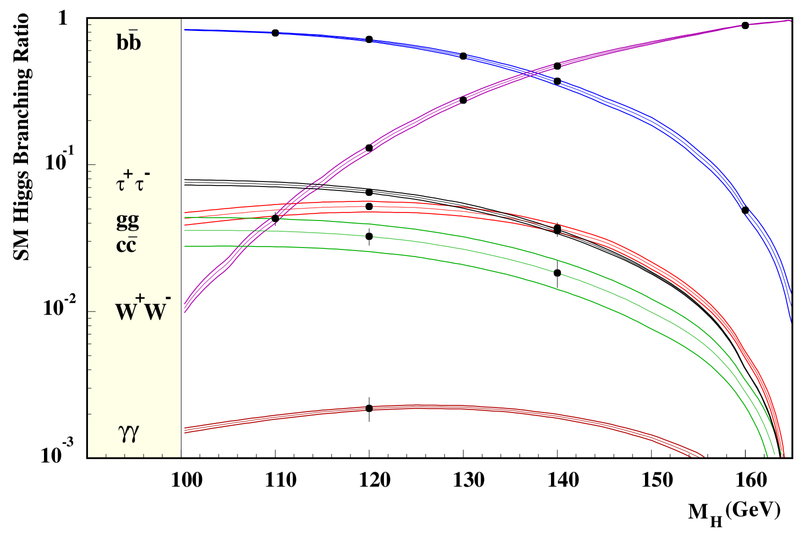
Linear Collider

Misure g_{ffH}

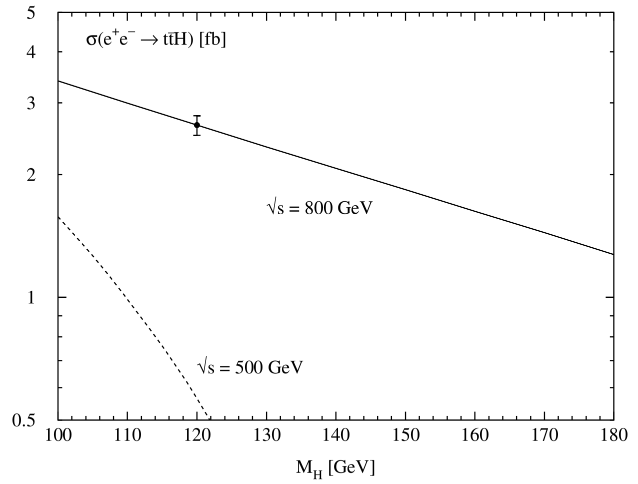
- decadimenti adronici dell'Higgs:
  frazioni di $b\bar{b}$ e $c\bar{c}$ (e di gg) mediante
  jet flavour tagging $\Rightarrow$ eccellente rivelatore di vertice
  controllo con eventi ZZ

- $H/h^0 \rightarrow \tau^+\tau^-$ da molteplicità, massa jet ...

500 fb^{-1}, $\sqrt{s} = 350$ GeV



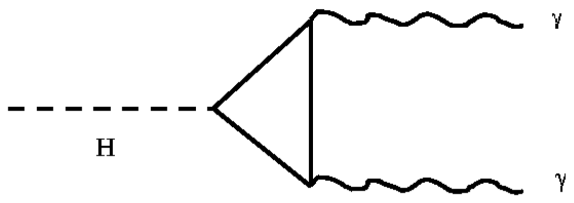
- g_{ttH} se $M_H < 2m_t$ da $e^+e^- \rightarrow t\bar{t}H$ ($\sqrt{s} = 800$ GeV)



Linear Collider

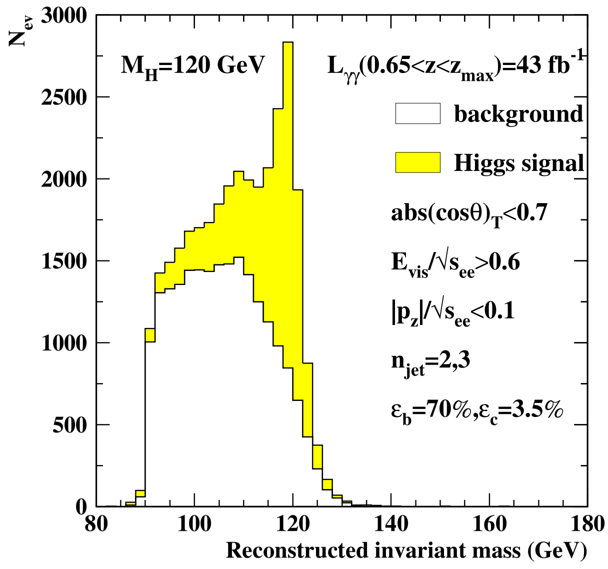
Accoppiamento ai fotoni

- Mediato da :



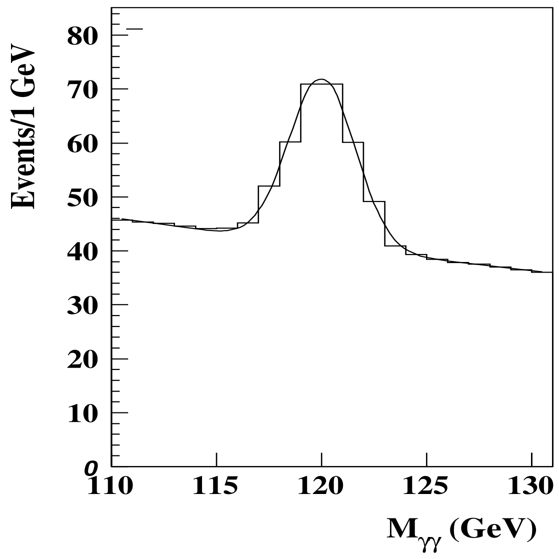
+ analoghi

- misurabile da:
  $\sigma(\gamma\gamma \rightarrow H)$
  in $\gamma\gamma$ collider



$$e^+e^- \rightarrow \nu\bar{\nu}H \rightarrow \nu\bar{\nu}\gamma\gamma$$

$$\sqrt{s} = 500 \text{ GeV } 1000 \text{ fb}^{-1}$$



B.R.$(H \rightarrow \gamma\gamma)$:
$\nu\bar{\nu}\gamma\gamma$ +
$q\bar{q}\gamma\gamma$

$\Downarrow$

δB.R.$\sim$ 23%

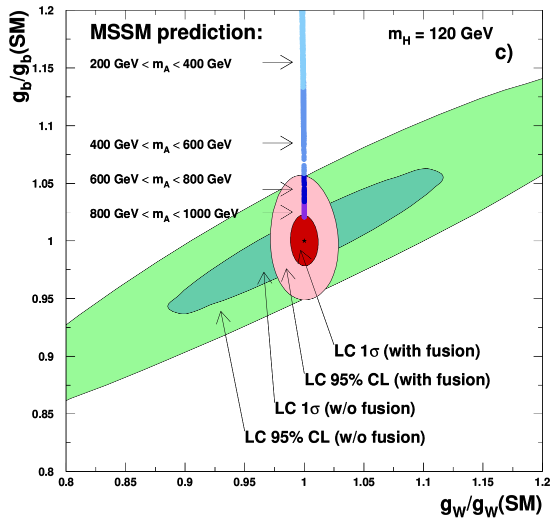
Linear Collider

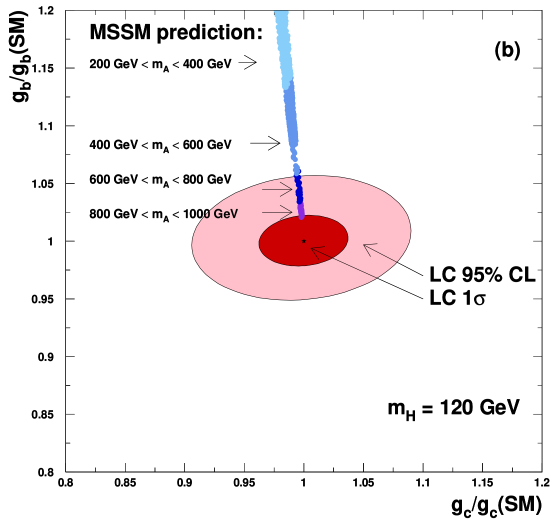
Fit globale alle misure ($\sigma_{HZ}, \sigma_{H\nu\bar{\nu}}$, B.R., correlazioni): fornisce accoppiamenti *model-independent*

$$\Gamma^{MSSM}_{b\bar{b}} \propto \Gamma^{MS}_{b\bar{b}} \left(\frac{sin^2\alpha}{cos^2\beta}\right)$$
$$\Gamma^{MSSM}_{c\bar{c}} \propto \Gamma^{MS}_{c\bar{c}} \left(\frac{cos^2\alpha}{sin^2\beta}\right)$$
$$\frac{\Gamma^{MSSM}_{c\bar{c}}}{\Gamma^{MSSM}_{b\bar{b}}} \propto \frac{\Gamma^{MS}_{c\bar{c}}}{\Gamma^{MS}_{b\bar{b}}} \frac{1}{tan^2\alpha \; tan^2\beta} \simeq \simeq \frac{(M_h^2 - M_A^2)^2}{(M_Z^2 + M_A^2)^2}$$

500 fb^{-1}, $\sqrt{s} = 500$ GeV

Coupling	$M_H = 120$ GeV	140 GeV
g_{HWW}	$\pm$ 0.012	$\pm$ 0.020
g_{HZZ}	$\pm$ 0.012	$\pm$ 0.013
g_{Htt} [a]	$\pm$ 0.030	$\pm$ 0.061
g_{Hbb}	$\pm$ 0.022	$\pm$ 0.022
g_{Hcc}	$\pm$ 0.037	$\pm$ 0.102
$g_{H\tau\tau}$	$\pm$ 0.033	$\pm$ 0.048
g_{HWW}/g_{HZZ}	$\pm$ 0.017	$\pm$ 0.024
g_{Htt}/g_{HWW}	$\pm$ 0.029	$\pm$ 0.052
g_{Hbb}/g_{HWW}	$\pm$ 0.012	$\pm$ 0.022
$g_{H\tau\tau}/g_{HWW}$	$\pm$ 0.033	$\pm$ 0.041
g_{Htt}/g_{Hbb}	$\pm$ 0.026	$\pm$ 0.057
g_{Hcc}/g_{Hbb}	$\pm$ 0.041	$\pm$ 0.100
$g_{H\tau\tau}/g_{Hbb}$	$\pm$ 0.027	$\pm$ 0.042



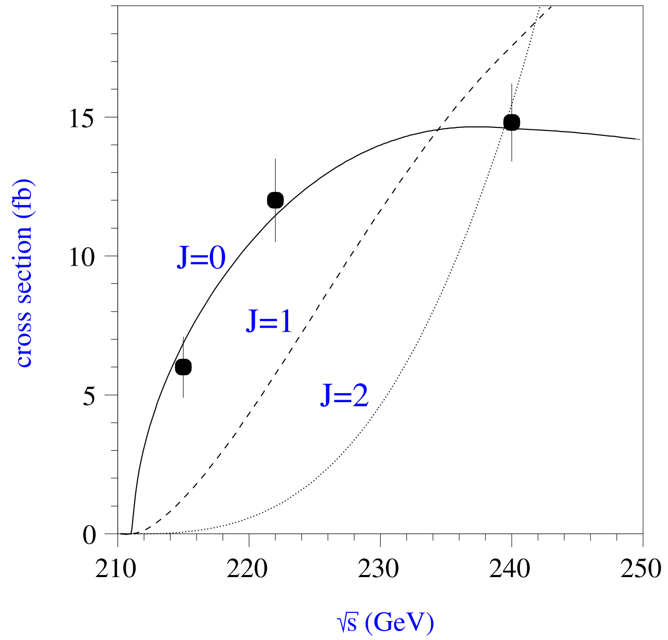


[a] 1000 fb^{-1}, $\sqrt{s} = 800$ GeV

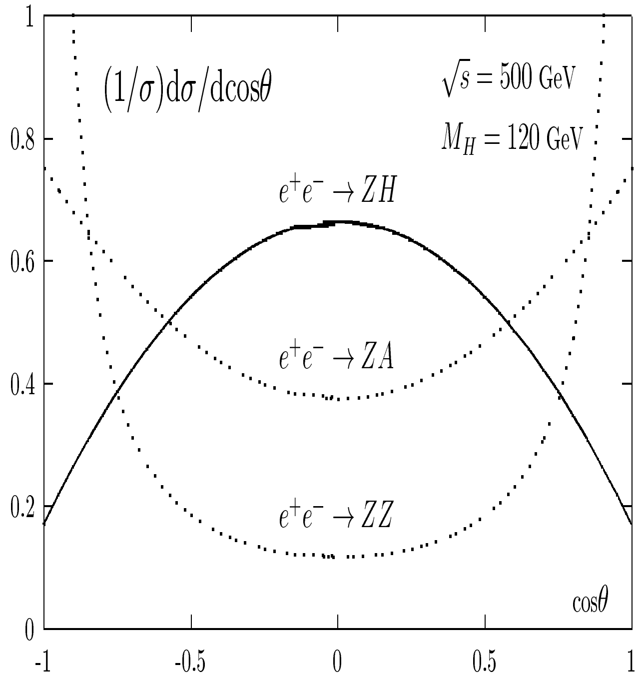
Linear Collider

Numeri quantici

- In soglia $\sigma \propto \beta$ solo per J=0



- Nel continuo possibile distinguere gli stati con diversa parità (o combinazioni $\not{C}\not{P}$)



Linear Collider

Altri stati di Higgs

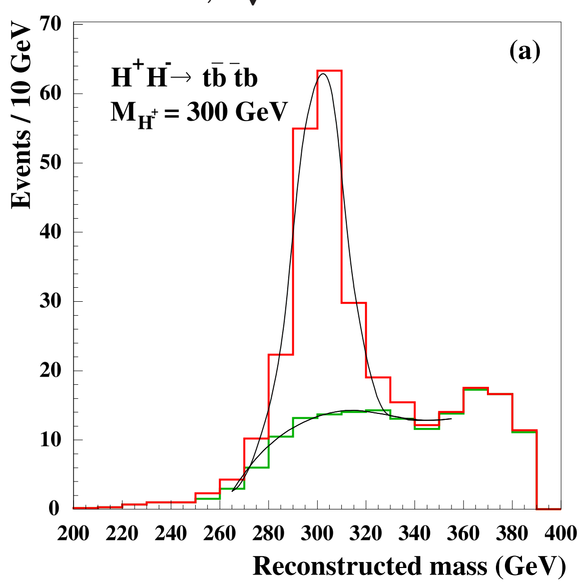
- Presenti in tutti le estensioni del MS:

  $H^{\pm}, H^0, A^0$

- *decoupling limit*: pesanti, decadono in quark pesanti

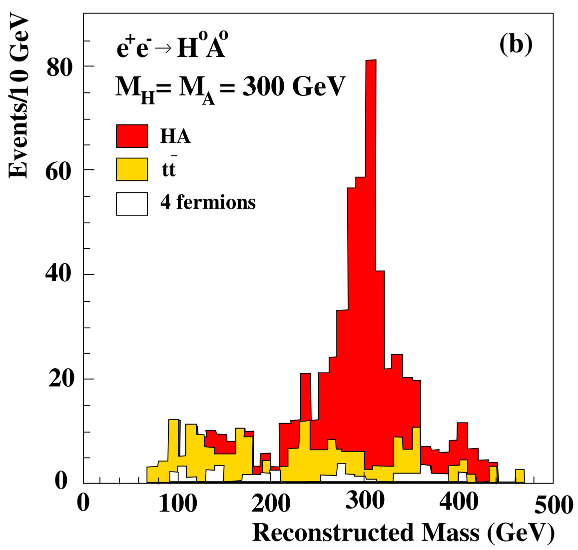
  $e^+e^- \to H^+H^- \to t\bar{b}\bar{t}b \quad e^+e^- \to H^0A^0 \to b\bar{b}b\bar{b}$

$500\ \mathrm{fb}^{-1}, \sqrt{s} = 800$ GeV



δM_{H^+} 1 GeV

$50\ \mathrm{fb}^{-1}, \sqrt{s} = 800$ GeV



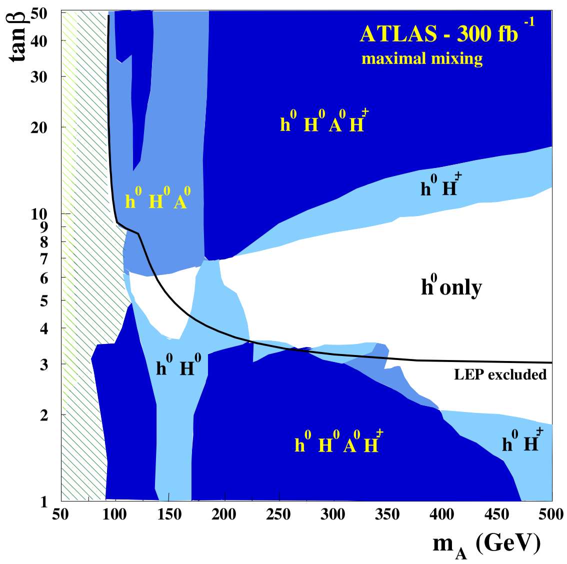
$\frac{\delta M_A}{M_A}$ (200 fb^{-1}) 0.2-0.4%

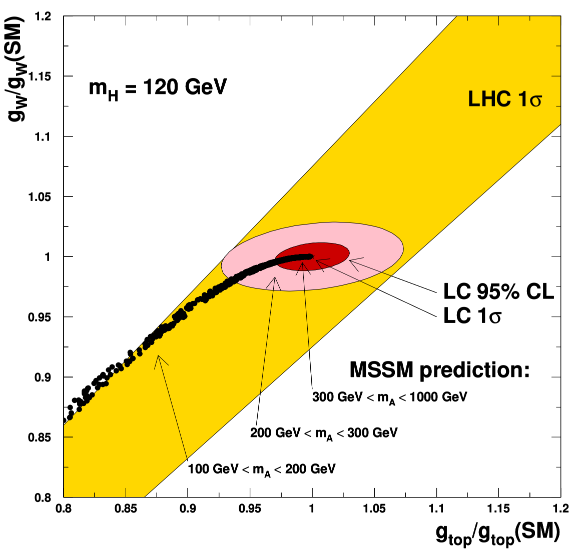
260 $< M_A <$ 340 GeV

Linear Collider

Confronto con LHC

	M_H (GeV)	$\delta(X)/X$ LHC $2 \times 300\,\mathrm{fb}^{-1}$	$\delta(X)/X$ LC $500\,\mathrm{fb}^{-1}$
M_H	120	9×10^{-4}	3×10^{-4}
M_H	160	10×10^{-4}	4×10^{-4}
Γ_{tot}	120-140	-	0.04 - 0.06
$g_{Hu\bar{u}}$	120-140	-	0.02 - 0.04
$g_{Hd\bar{d}}$	120-140	-	0.01 - 0.02
g_{HWW}	120-140	-	0.01 - 0.03
$\frac{g_{Hu\bar{u}}}{g_{Hd\bar{d}}}$	120-140	-	0.023-0.052
$\frac{g_{Hb\bar{b}}}{g_{HWW}}$	120-140	-	0.012-0.022
$\frac{g_{Ht\bar{t}}}{g_{HWW}}$	120	0.070	0.023
$\frac{g_{HZZ}}{g_{HWW}}$	160	0.050	0.022
$\mathcal{CP}$ test	120	-	0.03
λ_{HHH}	120	-	0.22





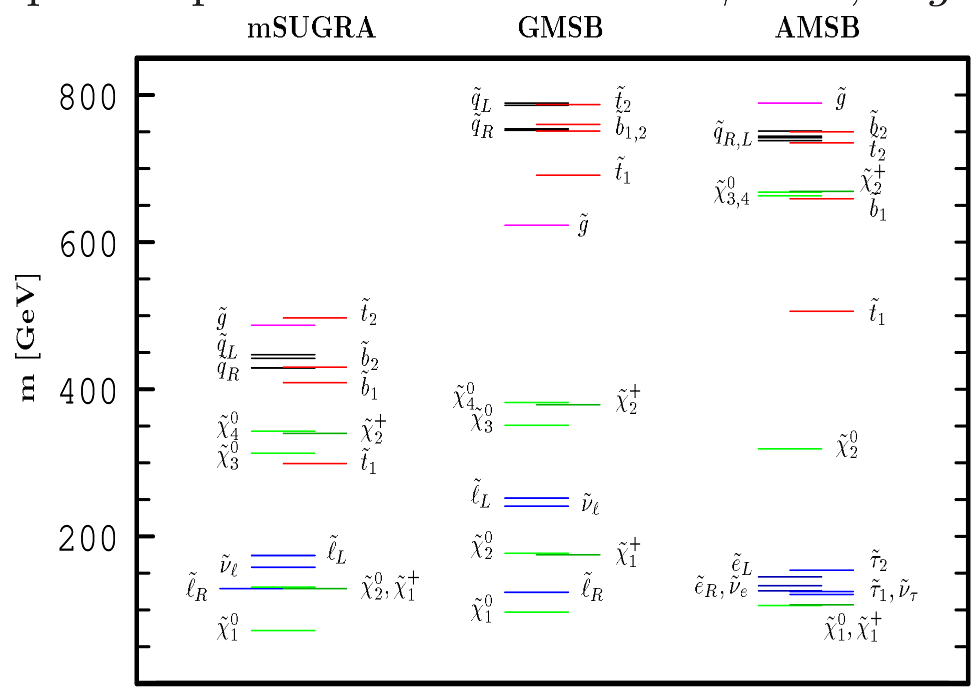
LC: studia bosone di Higgs con alta precisione in tutti i suoi aspetti e può chiudere eventuali buchi nel potenziale di scoperta di LHC.

Linear Collider

Studio della Supersimmetria

- Se LHC scopre la Supersimmetria
  LC macchina per studiarne le caratteristiche e determinarne i parametri fondamentali

Esempio di spettro di massa con tan$\beta = 3$, *sign* μ>0



Ruolo fondamentale della polarizzazione:

$\mathcal{P}_- = 80\%$

per numeri quantici deboli, accoppiamenti, mixing

$\mathcal{P}_+ = 60\%$

precisione parametri, sensibilità decadimenti rari,...

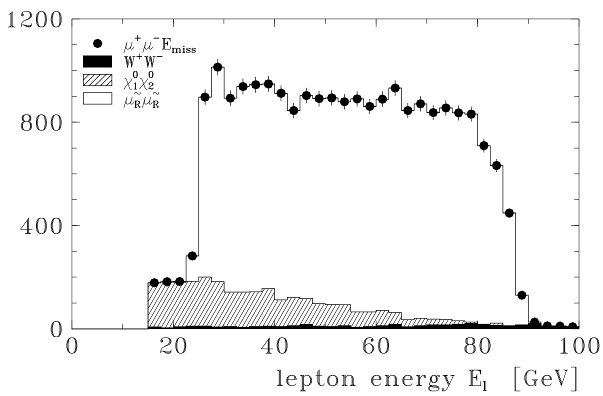
Linear Collider

Sleptoni

- Rivelazione, misura massa, larghezza

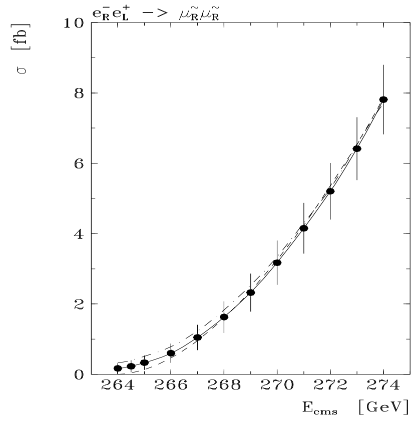
$$\text{es: } e_R^- e_L^+ \rightarrow \tilde{\mu}_R \tilde{\mu}_R \rightarrow \mu^- \tilde{\chi}_1^0 \mu^+ \tilde{\chi}_1^0$$

μ end-point



$\delta m \sim 0.3\%$

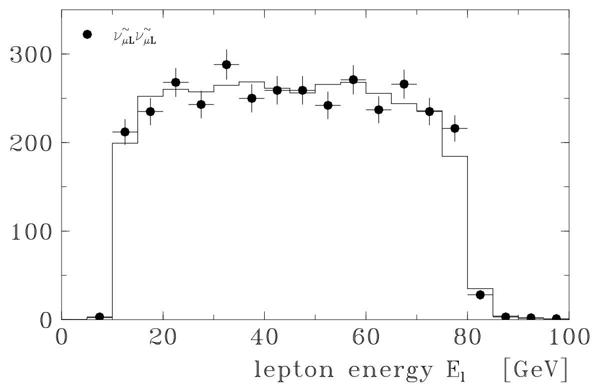
produzione in soglia



δm<0.1 $\delta\Gamma \sim 0.1$ GeV

$$\text{es: } e_L^- e_R^+ \rightarrow \tilde{\nu}_\mu \bar{\tilde{\nu}}_\mu \rightarrow \mu^- \tilde{\chi}_1^+ \mu^+ \tilde{\chi}_1^-$$
$$\tilde{\chi}_1^\pm \rightarrow \mu^\pm \nu_l \tilde{\chi}_1^0,\ q\bar{q}\prime\tilde{\chi}_1^0$$

δm<0.3%



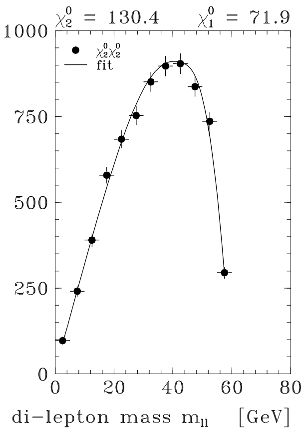
$$m_{\tilde{l}_L}^2 - m_{\tilde{\nu}_l}^2 = -M_W^2 \cos 2\beta \Rightarrow \tan\beta = 3.0 \pm 0.1 \div 10 \pm 5$$

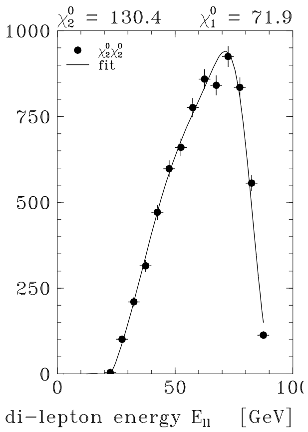
Linear Collider

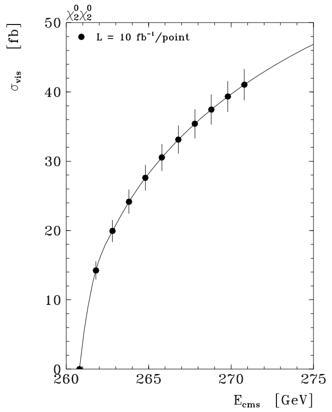
Chargini e Neutralini

- Rivelazione, misura massa, proprietà

$$e_L^- e_R^+ \rightarrow \tilde{\chi}_2^0 \tilde{\chi}_2^0 \text{ con } \tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 l^+ l^-$$







$\Delta m_{\tilde{\chi}_2^0 - \tilde{\chi}_1^0} < 50\text{MeV}$ δm<0.2% δm $\sim$ 50 MeV

- Analogamente

$$e_L^- e_R^+ \rightarrow \tilde{\chi}_1^+ \tilde{\chi}_1^- \longrightarrow l^{\pm} \nu \tilde{\chi}_1^0 q \bar{q}' \tilde{\chi}_1^0$$

- Da masse e sezioni d'urto ⇒ parametri SUSY

500 fb^{-1} con $\mathcal{P}$ e^-

	input RR1	fit value	input RR2	fit value
M_2	152 GeV	152 ± 1.8 GeV	150 GeV	150 ± 1.2 GeV
μ	316 GeV	316 ± 0.9 GeV	263 GeV	263 ± 0.7 GeV
$\tan\beta$	3	3 ± 0.7	30	> 20
M_1	78.7 GeV	78.7 ± 0.7 GeV	78.0 GeV	78.0 ± 0.4 GeV

Linear Collider

Complementarietà con LHC

particle	m [GeV]	δm [GeV] LHC	δm [GeV] LHC+LC
h^0	109	0.2	0.05
A^0	259	3	1.5
χ_1^+	133	3	0.11
χ_1^0	72.6	3	0.15
$\tilde{\nu}_e$	233	3	0.1
$\tilde{e}_1$	217	3	0.15
$\tilde{\nu}_\tau$	214	3	0.8
$\tilde{\tau}_1$	154	3	0.7
$\tilde{u}_1$	466	10	3
$\tilde{t}_1$	377	10	3
$\tilde{g}$	470	10	10

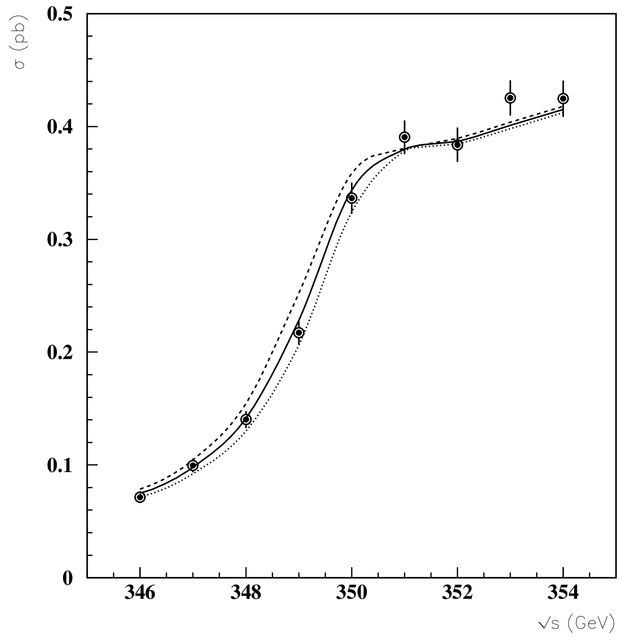
- SUSY a *basse* energie $\Rightarrow$ scoperta a LHC
  maggior potenziale di scoperta
- LC determina con precisione:
  - masse, larghezze e B.R.
  - accoppiamenti
  - parametri di mixing per chargino/neutralino
  - angoli di mixing nei settori $\tilde{t}$, $\tilde{\tau}$
  - tanβ dal settore $\tilde{\tau}$ per tanβ>10
  - spin, numeri quantici, fasi $\not{C}P$
  - Parametri SUSY in modo model independent

Linear Collider

Misure di Precisione Elettrodeboli

Misura della massa del top

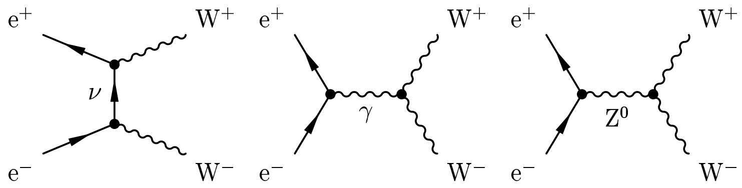
- Produzione $t\bar{t}$ in soglia
- $t \rightarrow b + W$
- Massa: $\delta m_t \sim 120$ MeV (ora teoria: ~ 0.2 GeV)



+ Fisica del top: 10^5 $t\bar{t}/100$ fb^{-1}

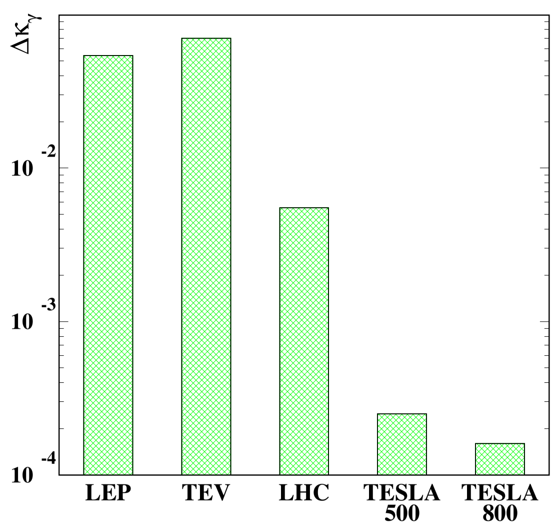
Linear Collider

Accoppiamenti VWW (V=Z,γ)



- sensibili a modelli
  con rottura forte della
  simmetria elettrodebole;
  maggiore precisione
  ad alta energia.
  $\mathcal{P}_{e^-} = 80\%$, $\mathcal{P}_{e^+} = 60\%$

	500 fb^{-1}	1000 fb^{-1}
coupling	error $\times 10^{-4}$	
	$\sqrt{s} = 500$ GeV	$\sqrt{s} = 800$ GeV
C,P-conserving, SU(2) $\times$ U(1) relations:		
Δg_1^Z	2.8	1.8
$\Delta\kappa_\gamma$	3.1	1.9
λ_γ	4.3	2.6
C,P-conserving, no relations:		
Δg_1^Z	15.5	12.6
$\Delta\kappa_\gamma$	3.3	1.9
λ_γ	5.9	3.3
$\Delta\kappa_Z$	3.2	1.9
λ_Z	6.7	3.0
not C or P conserving:		
g_5^Z	16.5	14.4
g_4^Z	45.9	18.3
$\tilde{\kappa}_Z$	39.0	14.3
$\tilde{\lambda}_Z$	7.5	3.0



Linear Collider

Giga Z

- **Alta Luminosità**

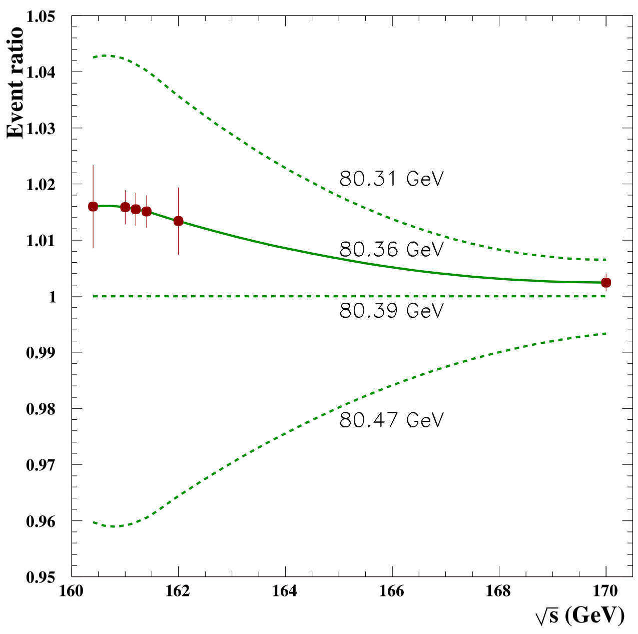
  10^9 Z^0 in $50 \div 100$ giorni di run
- **Polarizzazione** $\Rightarrow$ $A_{LR} = \frac{1}{\mathcal{P}} \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R}$

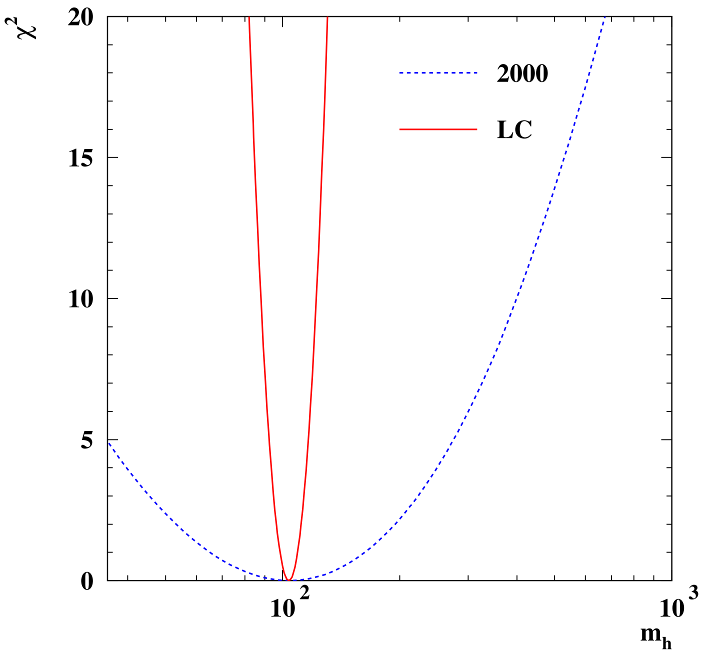
  $\frac{\sigma}{\sigma_u} = 1 - \mathcal{P}_{e^+}\mathcal{P}_{e^-} + A_{LR}(\mathcal{P}_{e^+}\mathcal{P}_{e^-})$
- **Blondel-scheme:**

  $A_{LR} = \sqrt{\frac{(\sigma_{++}+\sigma_{-+}-\sigma_{+-}-\sigma_{--})(-\sigma_{++}+\sigma_{-+}-\sigma_{+-}+\sigma_{--})}{(\sigma_{++}+\sigma_{-+}+\sigma_{+-}+\sigma_{--})(-\sigma_{++}+\sigma_{-+}+\sigma_{+-}-\sigma_{--})}}$
- $\Delta A_{LR} \sim 10^{-4} \Rightarrow \Delta sin^2_{eff}\theta = 1.3 \cdot 10^{-5}$
- **Simile $\mathcal{L}$ per W sopra soglia**

	LEP/SLD	TESLA
$sin^2_{eff}\theta$	0.23146 ± 0.00017	± 0.000013
M_Z	91.1875 ± 0.0021 GeV	± 0.0021 GeV
$\alpha_s(M_Z^2)$	0.1183 ± 0.0027	± 0.0009
$\Delta\rho_l$	$(0.55 \pm 0.10) \cdot 10^{-2}$	$\pm 0.05 \cdot 10^{-2}$
N_ν	2.984 ± 0.008	± 0.004
$\mathcal{A}_b$	0.898 ± 0.015	± 0.001
R_b^0	0.21653 ± 0.00069	± 0.00014
M_W	80.436 ± 0.036 GeV	± 0.006 GeV

Linear Collider





Extended gauge theories

	LHC	TESLA
Z' masses	$M_{Z'} \leq 5$ TeV	$M_{Z'} \leq 15$ TeV
Z' couplings	?	$\mathcal{O}(10\%)$
SSM W' masses	$M_{W'} \leq 5$ TeV	$M_{W'} \leq 6$ TeV
W' couplings	?	$\mathcal{O}(10\%)$
SO(10), E_6 ferminons	quarks	leptons

Linear Collider

Considerazioni Riassuntive

Se al Tevatron/LHC...

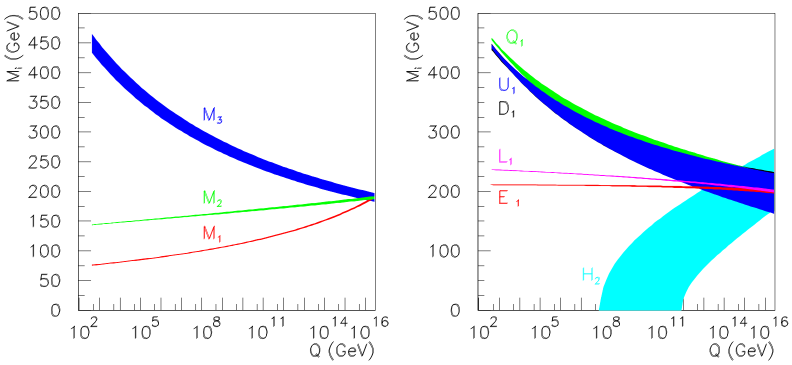
1. Trovato Higgs leggero ($\leq$ 140 GeV) e SUSY

$$\sqrt{s} \leq 500 \text{ GeV}$$

- misura proprietà Higgs (m, Γ, B.R., numeri quantici..)
- misura tutte le $\tilde{p}$ accessibili (massa, numeri quantici, mixing)

$$\sqrt{s} \text{ 800 GeV - 1 TeV}$$

- trova e misura le altre $\tilde{p}$ e Higgs pesanti e determina i parametri di SUSY con estrapolazione alla fisica alle scale più alte



Linear Collider

2. Trovato Higgs ma non SUSY

$\sqrt{s} \leq 500$ GeV

- misura proprietà Higgs con la massima precisione: indispensabile per effetti oltre MS direttamente dal settore di Higgs.
  NB: se $M_H > 180$ discrepanza con fit MS ma difficili B.R. fermionici (LC non peggiore di LHC).

a basse energie

- misure di alta precisione alla Z^0 e alla soglia WW per ulteriori indicazioni di Fisica oltre MS

$\sqrt{s}$ 800 GeV - 1 TeV

- studia accoppiamento ttH, deviazioni WW scattering, nuove evidenze ....

3. Trovato nulla

$\sqrt{s} \leq 500$ GeV

- tappa i buchi per l'Higgs a LHC
- studia accoppiamenti WWV
- studia accoppiamenti top

a basse energie

- misure di alta precisione alla Z^0 e alla soglia WW per capire dove il MS non funziona

4. Trovato Higgs, SUSY e altro....

Linear Collider

Conclusioni

In nessuno degli scenari precedenti un Linear Collider si rivelerebbe inutile.

Energia di partenza sotto i 500 GeV , alta luminosità, polarizzazione, precisione (anche del rivelatore) sono requisiti fondamentali.

Uno dei tre progetti (non importa dove, può importare quale per la garanzia di buon funzionamento) deve partire appena possibile (2003) tenendo conto dei tempi di realizzazione ($\sim$ 8 anni).

Sulla base di quanto detto l'obiezione che prima di far partire una tale impresa si debbano aspettare i risultati di LHC è infondata.

Dati l'entità del progetto ci vuole una comunità HEP unita .