Optimising ILC energy and beam parameters for precision Higgs boson measurements

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LC optimised luminosity $\rightarrow$ trade-off between

- total power $P_{electrical}$
- beamstrahlung emission δ_{BS}
- vertical emittance ε_y

(for given E_{CM} and power transfer efficiency η)

$$L \sim \frac{n_b N_e^2 f}{4\pi\sigma_x\sigma_y} H_D$$

SET $\sigma_z \lesssim \beta_y$

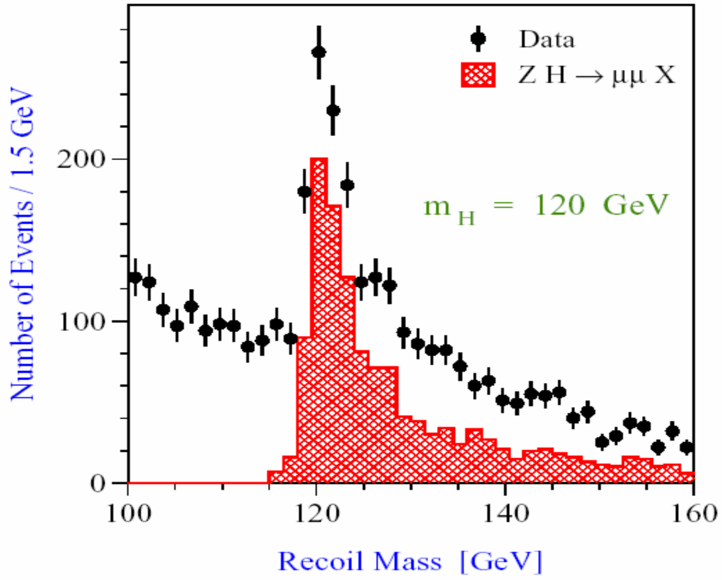
$$\delta_{BS} \sim \frac{N_e^2 E_{cm}}{\sigma_z(\sigma_x+\sigma_y)^2}$$

$$\sigma^2 = \varepsilon_n \beta / \gamma$$

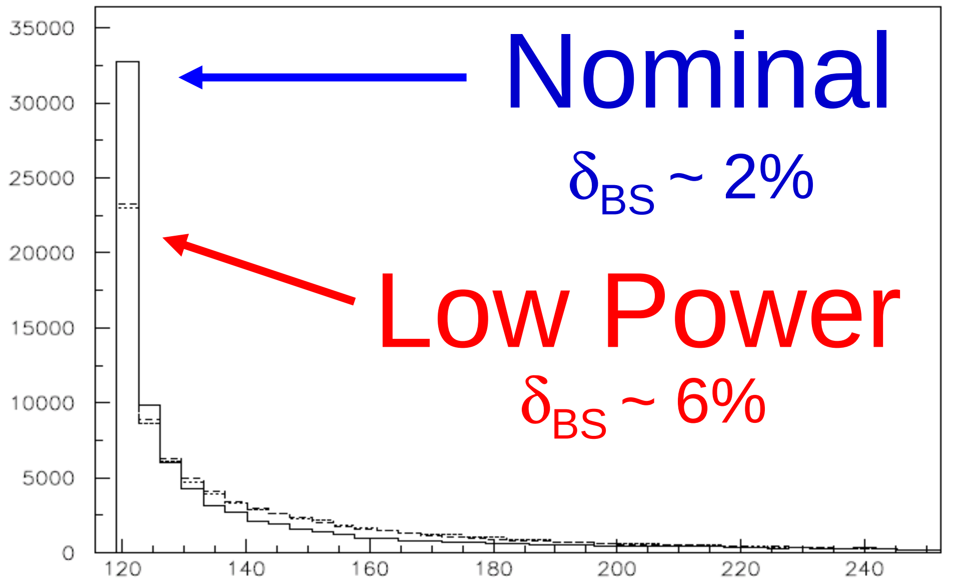
$$\rightarrow \quad L \sim \eta \frac{P_{electrical}}{E_{CM}} \sqrt{\frac{\delta_{BS}}{\varepsilon_{n,y}}} H_D$$

500 GeV CM	Nominal	Low P
N	$2\ 10^{10}$	$2\ 10^{10}$
bunches/train	**2820**	**1330**
σ_x [nm]	655	452
σ_y [nm]	5.7	3.8
σ_z [μm]	300	200
ε_{xN} [m.rad]	1.0 E-5	1.0 E-5
ε_{yN} [m.rad]	4.0 E-8	3.5 E-8
β_x [mm]	21.0	10.0
β_y [mm]	0.4	0.2
δ_{BS}	**0.02**	**0.06**
Luminosity [10^{34} $cm^{-2}s^{-1}$]	2.0	2.1

Higgs boson selection through recoil mass (model-independent)



E_{CM} = 350 GeV M_{Higgs} = 120 GeV
500 fb^{-1}



$$M_H^2 = (E_{CM} - E_Z)^2 - P_Z^2$$

(K. Mönig)

di-muon recoil mass in $e^+e^- \to H^0Z \to X\,\mu^+\mu^-$

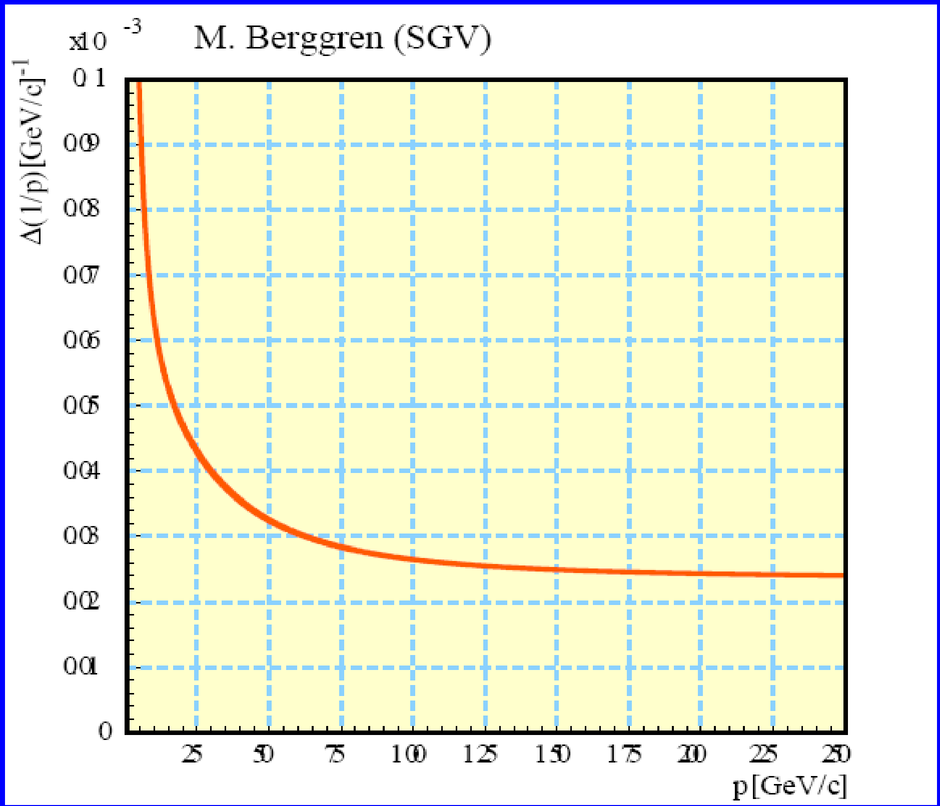
Lower peak for Low Power → estimate need 1.8 times more luminosity to recover “precision” at 350 GeV

Too simplistic ! Must consider muon momentum and Higgs mass resolutions

Higgs mass measurement (model-independent)

Example : $H^0Z \rightarrow X + (\mu^+\mu^- \text{ or } e^+e^-)$

Momentum resolution : $\delta p \sim k\, p^2$
$k \sim 5\ 10^{-5}\ \text{GeV}^{-1}$ (TESLA TDR)



$M_H^2 = -\,4\, E_b\, E_Z + M_Z^2$

$E_Z = E_b - (M_H^2 - M_Z^2)\,/\,4\, E_b$

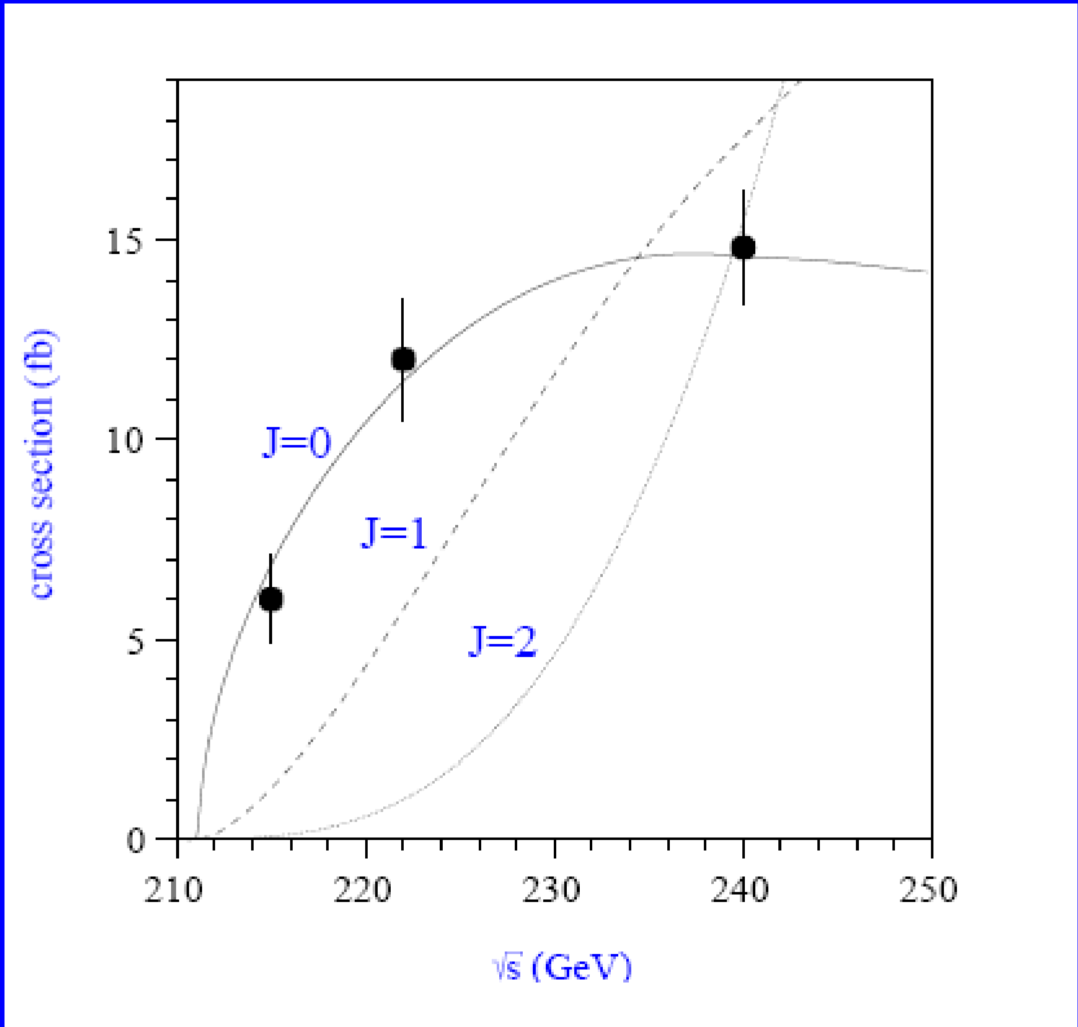
$\delta M_H^2 \sim 4\, E_b\, \delta E_Z$
$\sim 8\, E_b\, k\, P_{lep}^2$
$\sim 2\, E_b^3\, k$

Single event Higgs mass resolution best near production threshold

Improved 1/p resolution expected including outer silicon detectors

Higgs mass measurement (model-independent)

Example : $H^0Z \to X + (\mu^+\mu^- \text{ or } e^+e^-)$



Higgs production cross-section largest just above threshold

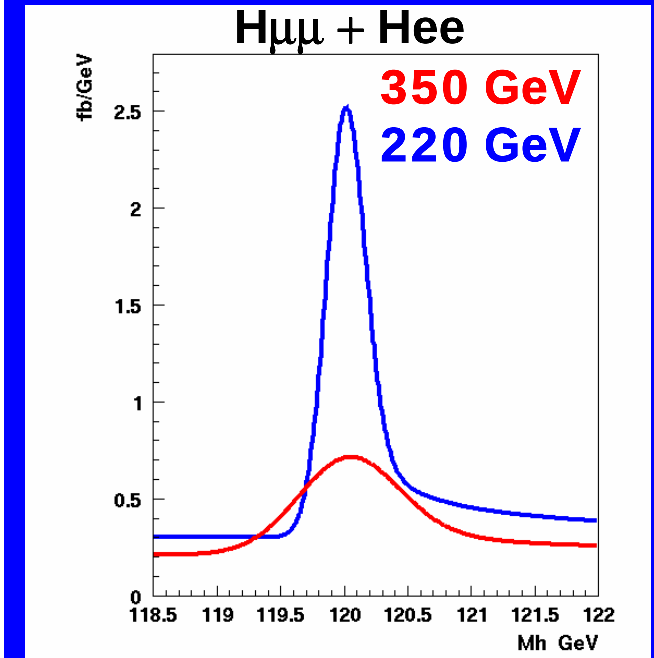
σ_{HZ} (230 GeV)

$\Downarrow$

σ_{HZ} (350 GeV) $\times$ 2

Higgs mass measurement (model-independent)

Example : $H^0Z \rightarrow X + (\mu^+\mu^- \text{ or } e^+e^-)$



Semi-analytical evaluation

$\delta M_H^2 \sim \sqrt{2}\, k\, P_{lep}\, (4\, E_b\, P_{lep} + M_Z^2)$

$\sigma_{M_H} = \delta M_H / \sqrt{p}\, \sqrt{N_{evt}}$

Includes internal (ISR and FSR) and external (from material) radiative effects

Can be further improved with 4C kinematic fit

Example: σ_{M_H} = 85 MeV with 500 fb^{-1} at E_{CM} = 350 GeV
Garcia-Abbia et al. Eur.Phys.J.C (2005)

(σ_{M_H}= 110 MeV)

E_{CM}	σ(Hμμ) fb No ISR	P lepton GeV	δ_{M_H} MeV	Muon Radcor	Electron Radcor	$\mathcal{L}$(2%) fb^{-1} μμ+ee
500	2.0	122	2450	0.51	0.34	2000
350	4.6	83	780	0.43	0.26	500
230	9.1	54	300	0.39	0.21	50

Higgs mass measurement (model-independent)

Example : $H^0Z \rightarrow X$ + hadrons

Jet resolution : $\delta p \sim A \sqrt{p}$ with $A \sim 0.30\ \mathrm{GeV}^{1/2}$
(expected from energy flow algorithms)

$$M_H^2 = - 4\, E_b\, E_Z + M_Z^2$$

Can improve mass resolution without looking at Higgs decays (model independent) with kinematic constraint:

$$M_Z^2 = 2\, P_1\, P_2\, (1 - \cos\theta_{12})$$

$$\delta M_H^2 \sim 4\, E_b\, A\, \sqrt{P_1}\, (1 - P_2 / P_1) + E\, (\Gamma_Z)$$

Factor 2-3 better single event Higgs mass resolution found at 230 compared to 350 GeV with 1C kinematic constraint

(to be checked with Monte Carlo simulation)

Beam parameter optimisation at 220 GeV

$$L \sim \frac{n_b N_e^2 f}{4\pi\sigma_x\sigma_y} H_D$$

$$\delta_{BS} \sim \frac{N_e^2 E_{cm}}{\sigma_z(\sigma_x+\sigma_y)^2}$$

$$L \sim \eta \frac{P_{\text{electrical}}}{E_{CM}} \sqrt{\frac{\delta_{BS}}{\varepsilon_{n,y}}} H_D$$

SET $\sigma_z \lesssim \beta_y$ $\quad \sigma^2 = \varepsilon_n \beta / \gamma$

β_x [mm]	β_y[mm]	σ_z[μm]	L[10^{34}cm^{-1}s^{-1}]	$\delta\sqrt{s}/\sqrt{s}$ [%]	L in 0.5 GeV	
21	0.4	300	2.09	1.05	1.09	← 500 GeV
21	0.4	300	0.92	0.24	0.73	220 GeV
18	0.4	300	1.01	0.28	0.77	220 GeV
15	0.4	300	1.13	0.34	0.83	220 GeV
12	0.4	300	1.30	0.43	0.90	220 GeV
9	0.4	300	1.55	0.61	0.98	220 GeV
21	0.2	200	1.10	0.33	0.84	220 GeV
18	0.2	200	1.20	0.39	0.88	220 GeV
15	0.2	200	1.34	0.47	0.94	220 GeV
12	0.2	200	1.54	0.59	1.02	220 GeV
9	0.2	200	1.84	0.80	1.10	220 GeV

- Optimisation actually favours increasing the luminosity through tighter focusing (as “Low Power”), even if beamstrahlung is enhanced
- However, optimisation is not very critical…
- Increased beamstrahlung also not expected to be a problem in the extraction line due to the lower energy
- Feasibility of $\beta_x = 10$mm β_y 0.2 mm $\sigma_z = 200\ \mu$m ?

$\Rightarrow$ What are possibilities to run at $E_{CM} = 230$ GeV given that e+ require $E_{e-} = 150$ GeV ?

$\Rightarrow$ Are there (luminosity) issues related to decelerating the e- beam from 150 to 115 GeV ?

Conclusion

- Strong advantage to operate just above Higgs boson production threshold to measure the mass
- Kinematic fitting (4C,5C) can help at all energies but model-independence crucial strength of ILC ($\neq$ LHC)

example: H $\rightarrow$ invisible decays, e.g. neutralinos, occur in many BSM scenarii

- Higgs boson width and spin also best near threshold
- Higgs BRs should be checked not to be worse
- “Low Power” like parameters helpful but not crucially
- $\exists$ strong operational constraints from e+ production ?

Prospects

- More quantitative simulation studies