Some plots and tables on possible Heavy SM Higgses

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Introduction

- In the last discussion on Tuesday there were a few questions remaining on the issue What do we do if at LHC we see a Higgs with $m_h \approx 165$ GeV, consistent with the SM, and nothin gelse?
- First I have some remarks on EW precision data
- Then I was asked to show some ILC-related plots which could be interesting for heavier Higgs bosons
- Then I'll come back to the EW precision data

Introduction

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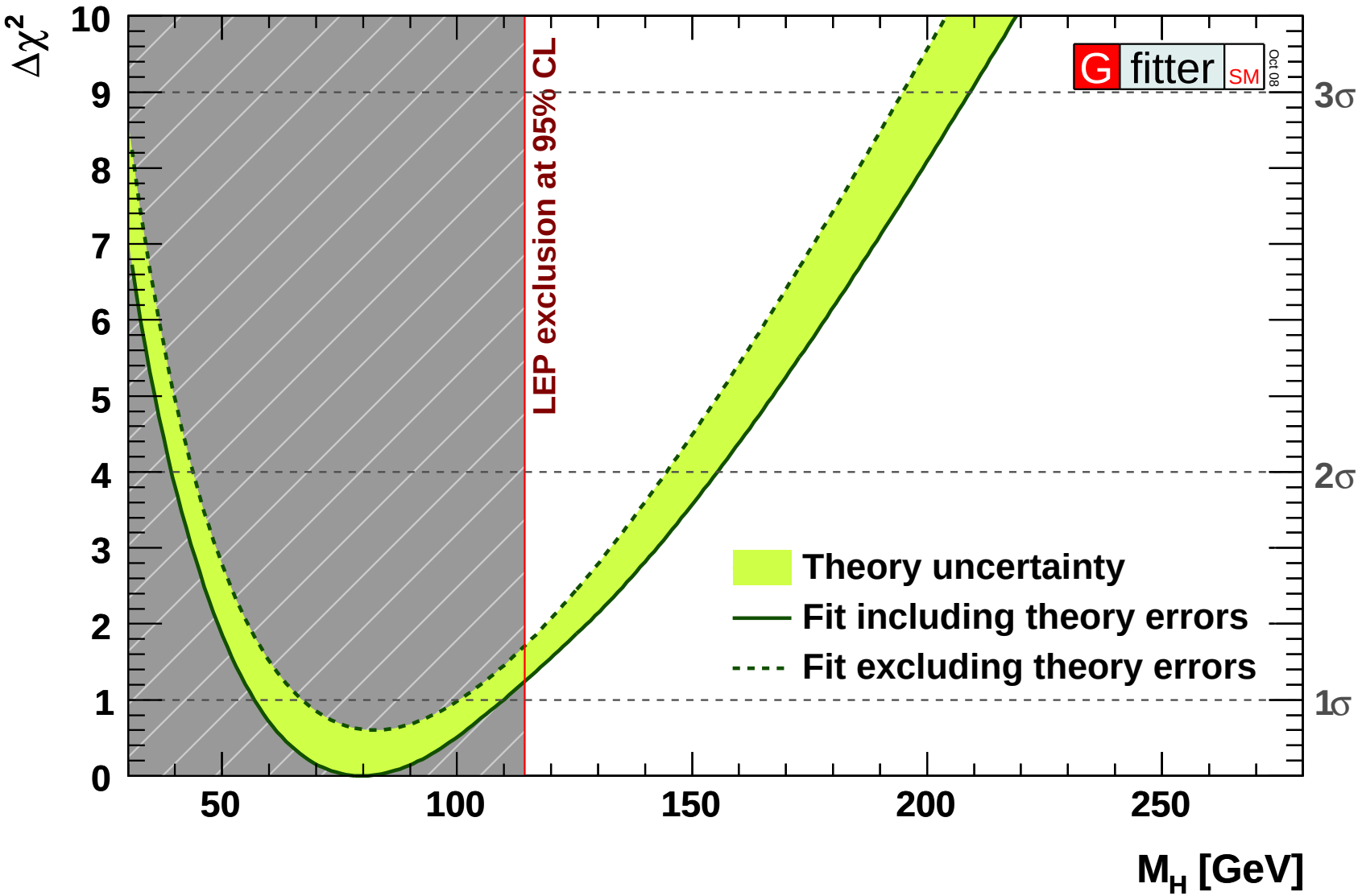
- Then I was asked to show some ILC-related plots which could be interesting for heavier Higgs bosons
- Then I'll come back to the EW precision data
- Most of the plots on ILC are indeed from the TESLA-TDR generation of studies
- However, many of these are currently repeated with
  - Full GEANT4 simulation including some cracks, support structures, insensitive regions, cables etc.
  - 20 Million SM events simulated + signals!
  - Overlay of beam backgrounds
  - etc . . .

  in the context of the International Large Detector concept (ILD)

Heavy SM Higgses and the SM Precision Data

- Finding a SM like Higgs at $m_h \approx 165$ GeV would put the SM under quite a bit of stress



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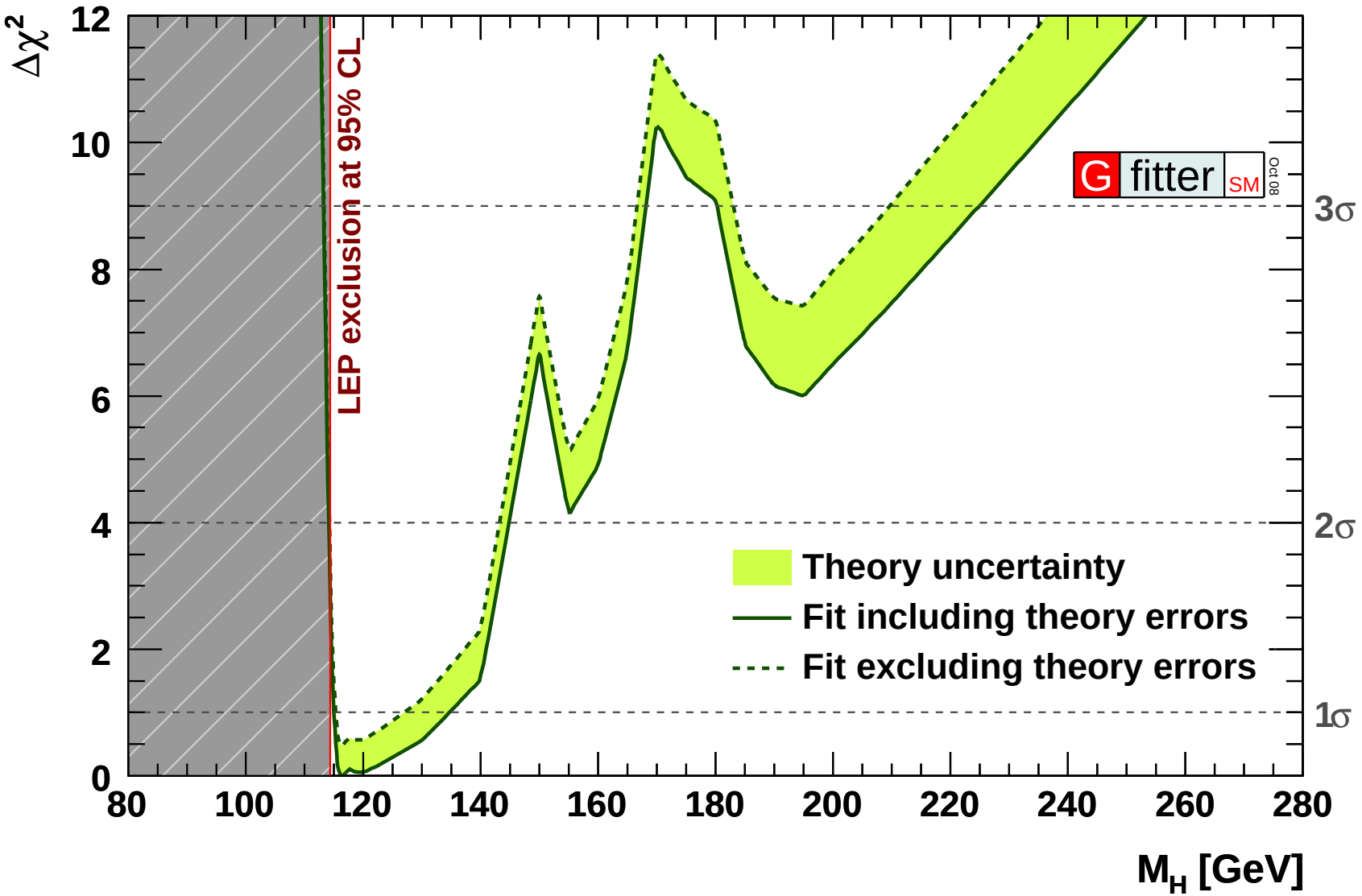
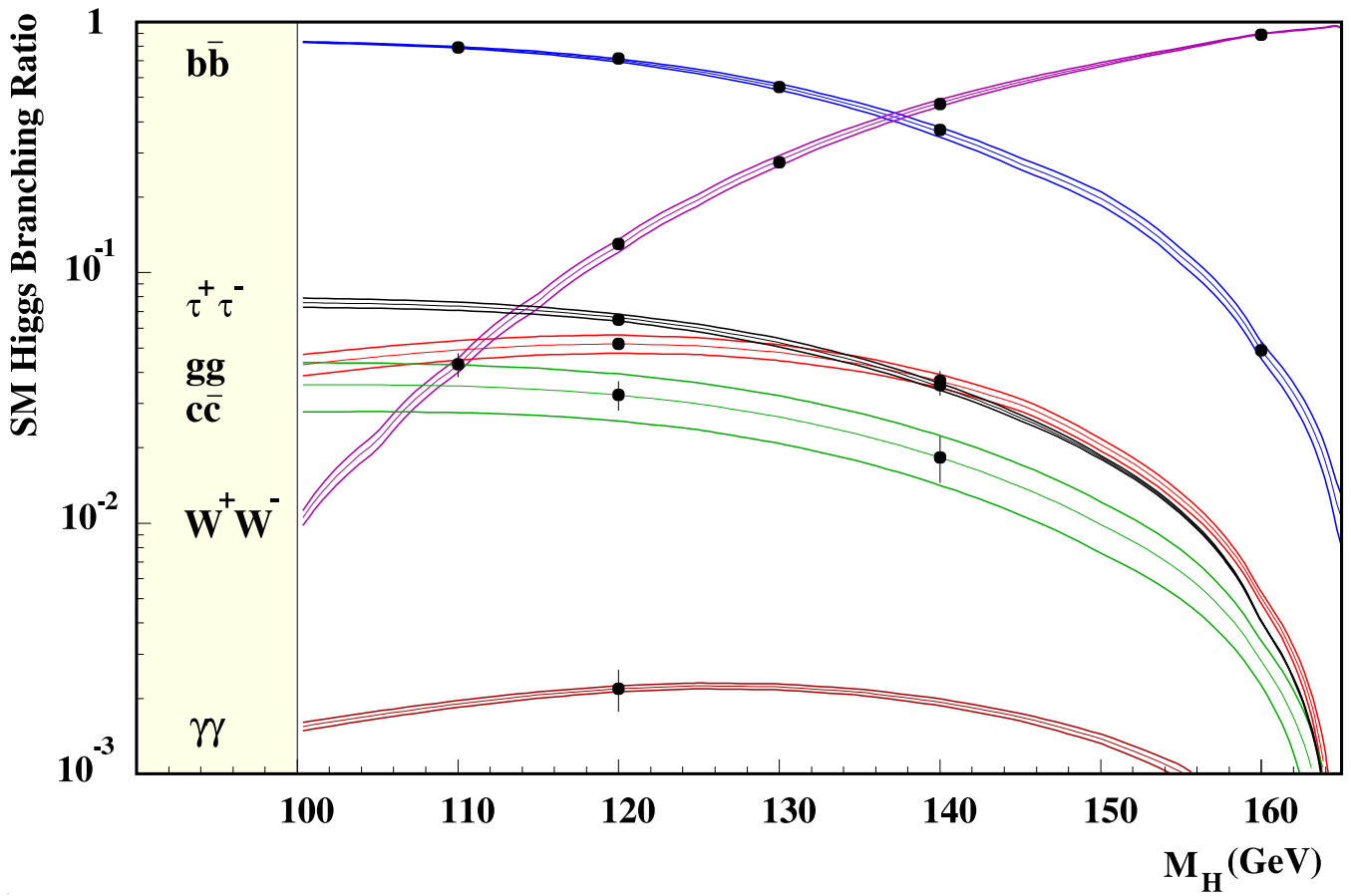


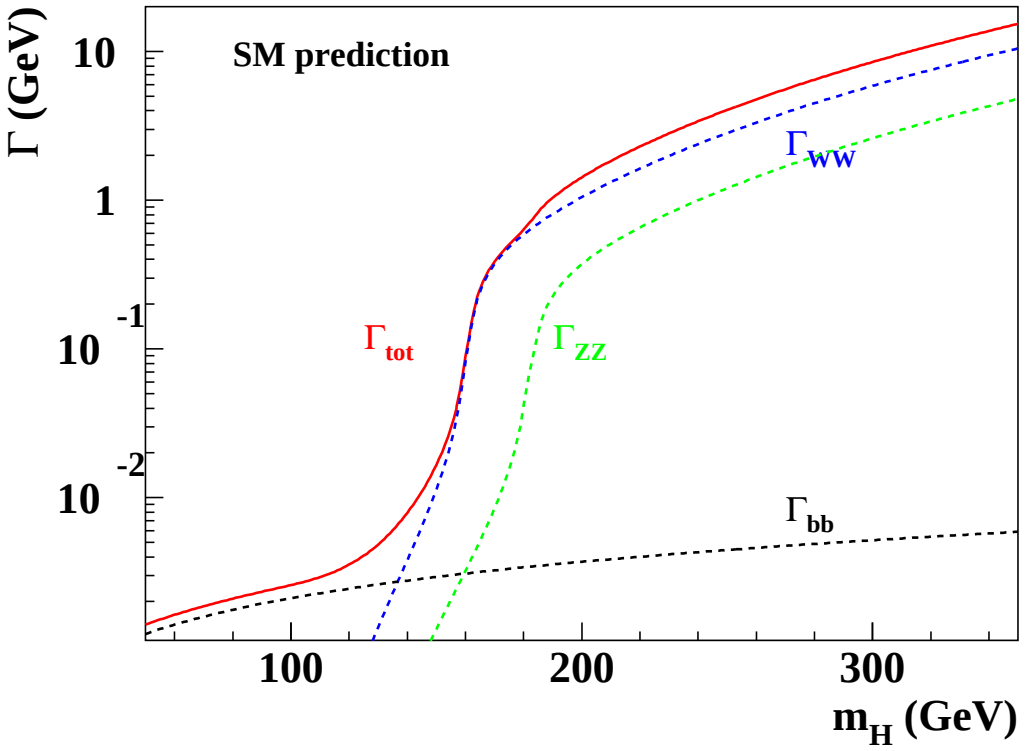
Higgs BR

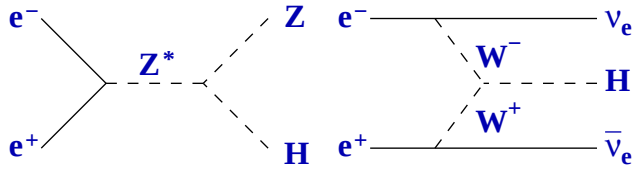


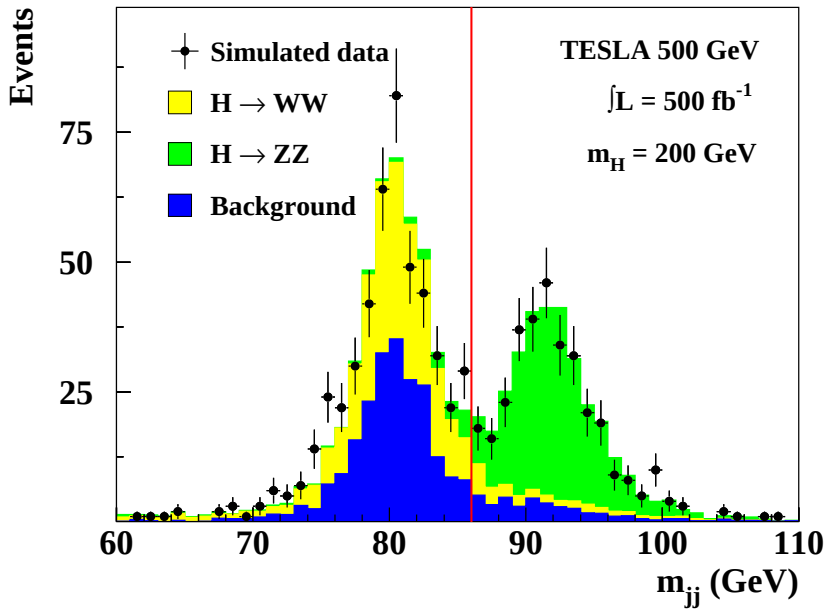
One of the design drivers of the experiments: need excellent vertexing!

- Up to $m_h < 210\ GeV$: With $\mathcal{L}^{int} = 1\ \text{ab}^{-1}$, better than 17 % accuracy on $BR(h \rightarrow bb)$
- It would be fundamental new information to see the Yukawa process! (indep. of gauge sector!)

Heavier Higgs: Total Width



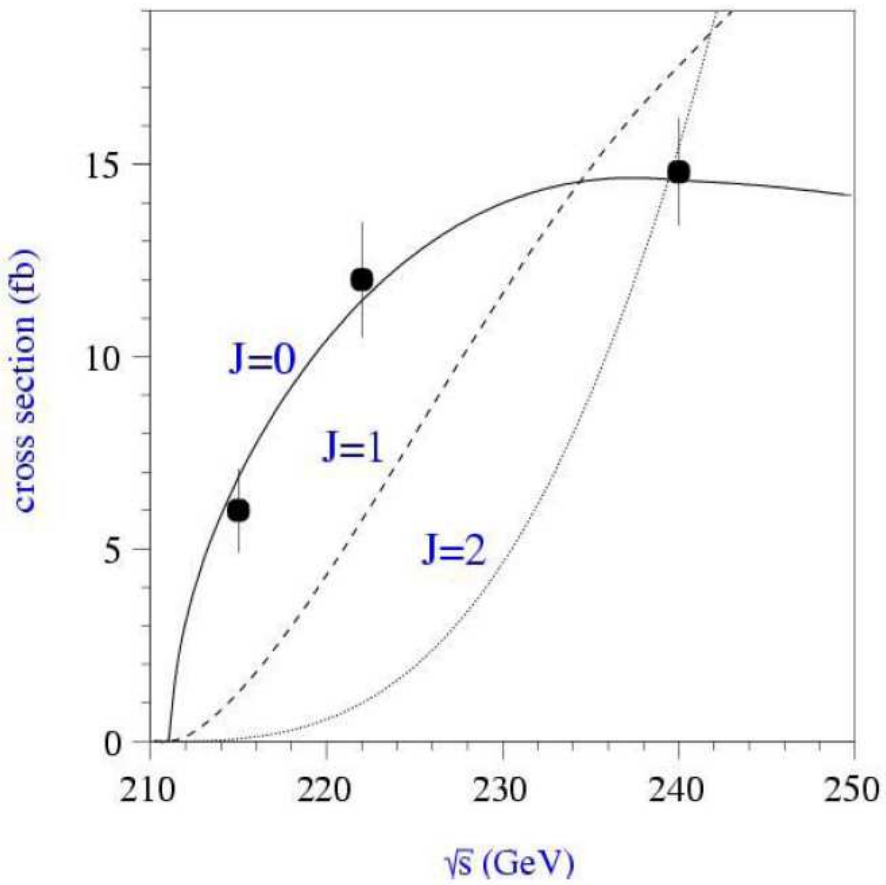




- For large m_h: Measure exp. width directly, from $WW \longrightarrow h \longrightarrow WW$ or maybe use threshold scan

m_{H}	$\frac{\Delta N}{N}$	$\frac{\Delta m}{m}$	$\frac{\Delta\Gamma}{\Gamma}$	$\frac{\Delta \mathrm{BR}_{\mathrm{H}\to\mathrm{WW}}}{\mathrm{BR}_{\mathrm{H}\to\mathrm{WW}}}$	$\frac{\Delta \mathrm{BR}_{\mathrm{H}\to\mathrm{ZZ}}}{\mathrm{BR}_{\mathrm{H}\to\mathrm{ZZ}}}$
200 GeV	3.6 %	0.11 %	34.0 %	3.5 %	9.9 %
240 GeV	3.8 %	0.17 %	26.8 %	5.0 %	10.8 %
280 GeV	4.4 %	0.24 %	22.7 %	7.7 %	16.2 %
320 GeV	6.3 %	0.36 %	26.4 %	8.6 %	17.3 %

Higgs Spin

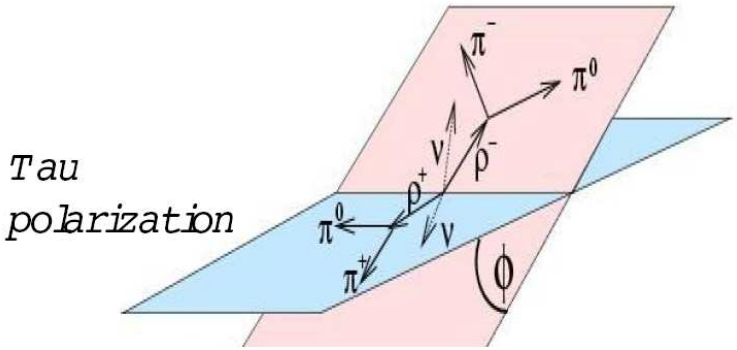


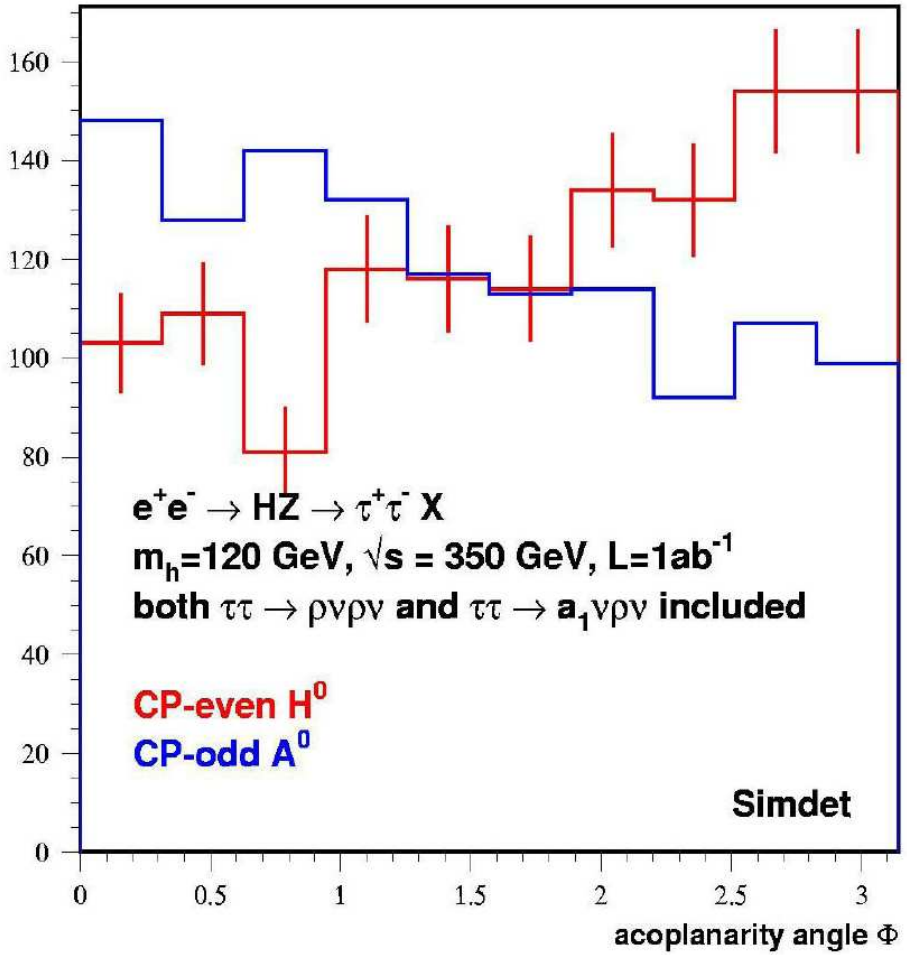
- Higgs would be the first fundamental scalar
- Need to confirm its spin
- Can use a threshold scan

Higgs *CP*

- Here studied for a light Higgs, but that should also work for $h \rightarrow WW$

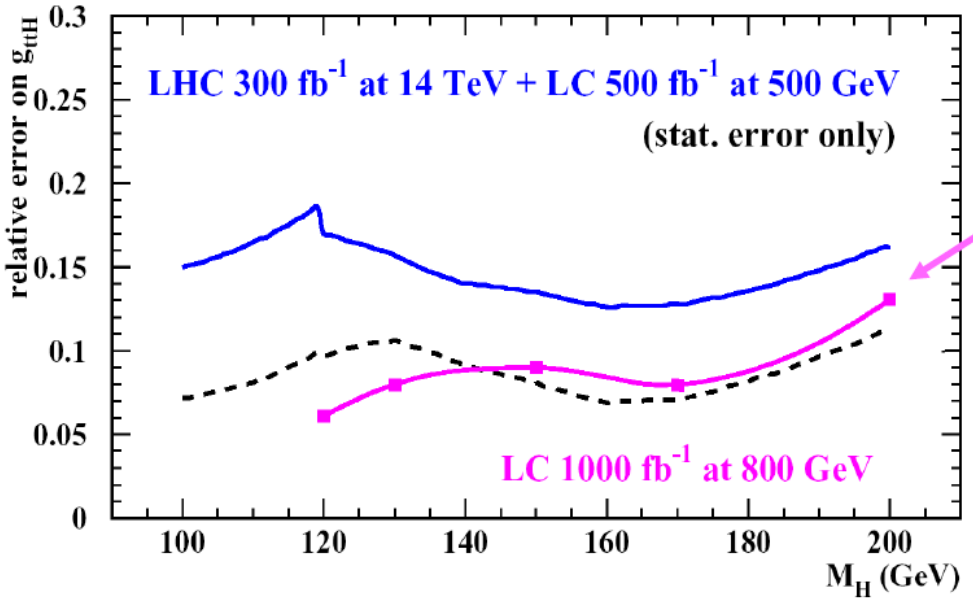
- SM Higgs is CP even
- Confirm that, using spin correlations in $h \rightarrow \tau\tau$ decays

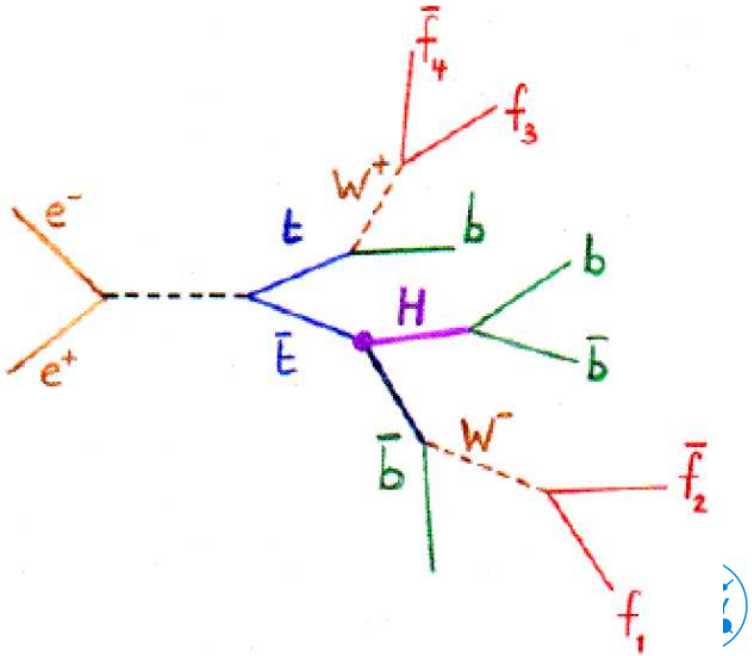




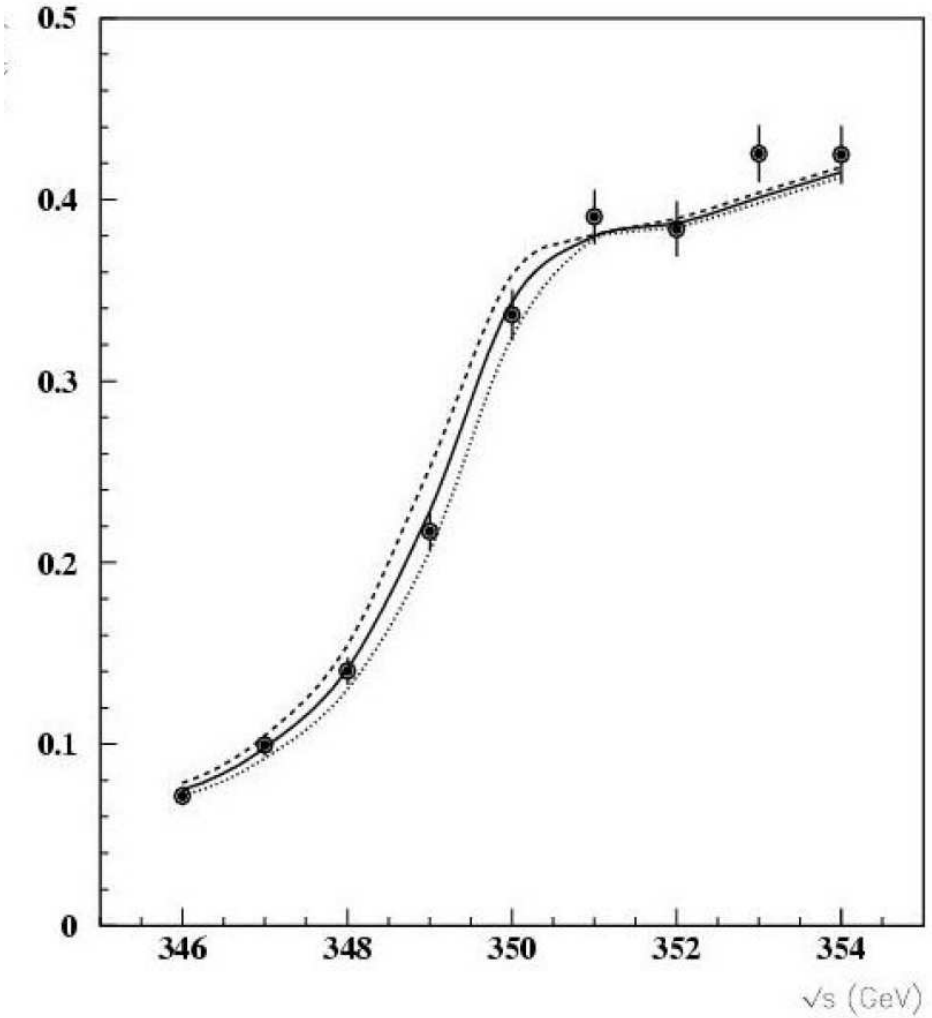
Higgs Top Yukawa Coupling

- Want: absolute top Yukawa coupling
- Study underway to show that with $h \rightarrow WW$
- Use combined information from ILC500 and LHC:
  - From LHC: rate of $gg, qq \rightarrow tt\,h$; $(h \rightarrow bb, WW)$ is proportional to $g_{tt} \times g_{bb/WW}$
  - From ILC500: $\mathcal{B}(h \rightarrow bb, WW)$ absulte measurement of g_{bb}, g_{WW}
- Or simply use ILC1000 . . .





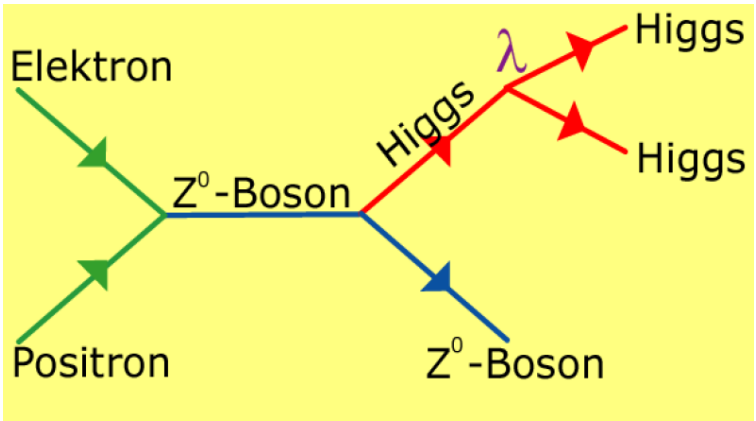
Cross-checking with Precise top Mass Measurement



- Check g_{htt} vs. SM expectation
- Need: A very precise top quark mass measurement!
- Achieve this via threshold scan ($50\,\mathrm{MeV}$ uncertainty)
- Width uncertainty $\approx 3\,\%$
- This is very important:
  - Presently the largest source of uncertainty of many SM calculations
  - Top quark might be an interesting window towards new physics, due to its extremely large mass (and $g_{htt} \approx 1$)

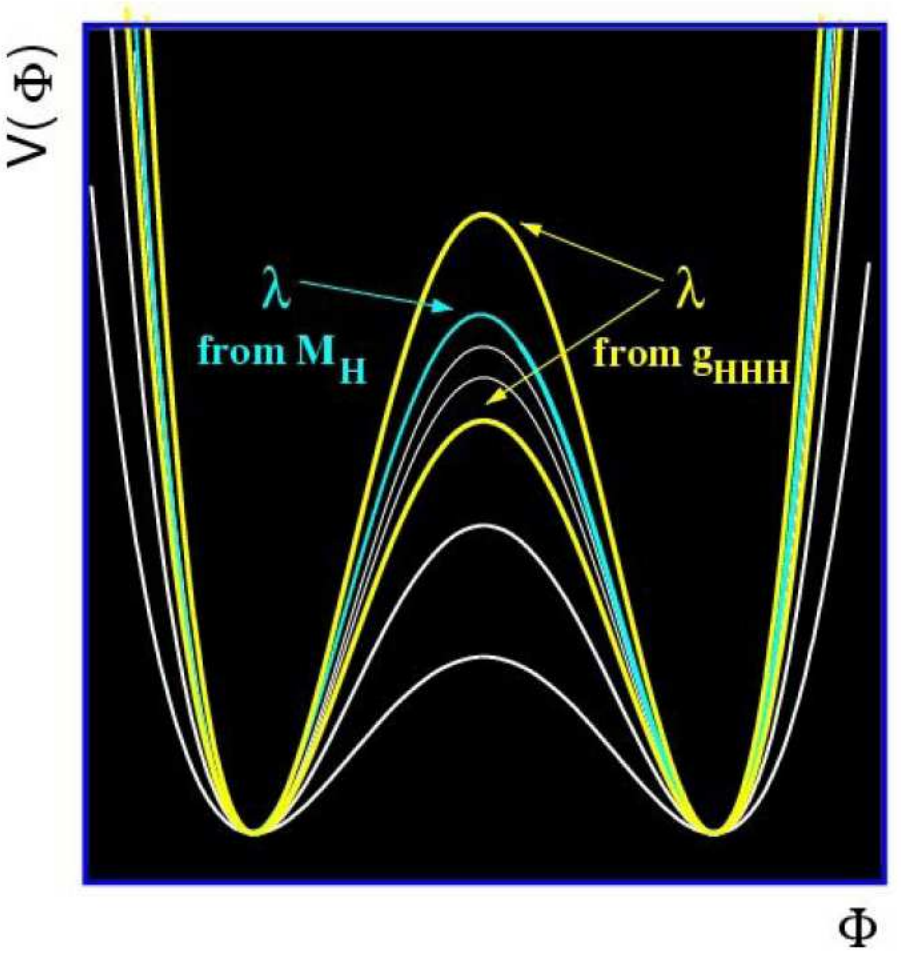
Finally: Higgs Self-Coupling ???

- Again: Measure precisely whether the observed particle is the SM Higgs
- Check $\lambda = m_h^2/(2v^2)$



- We need highest energies ($1\,\mathrm{TeV}$), highest luminosities ($1\,\mathrm{ab}^1$) and best detectors for that!

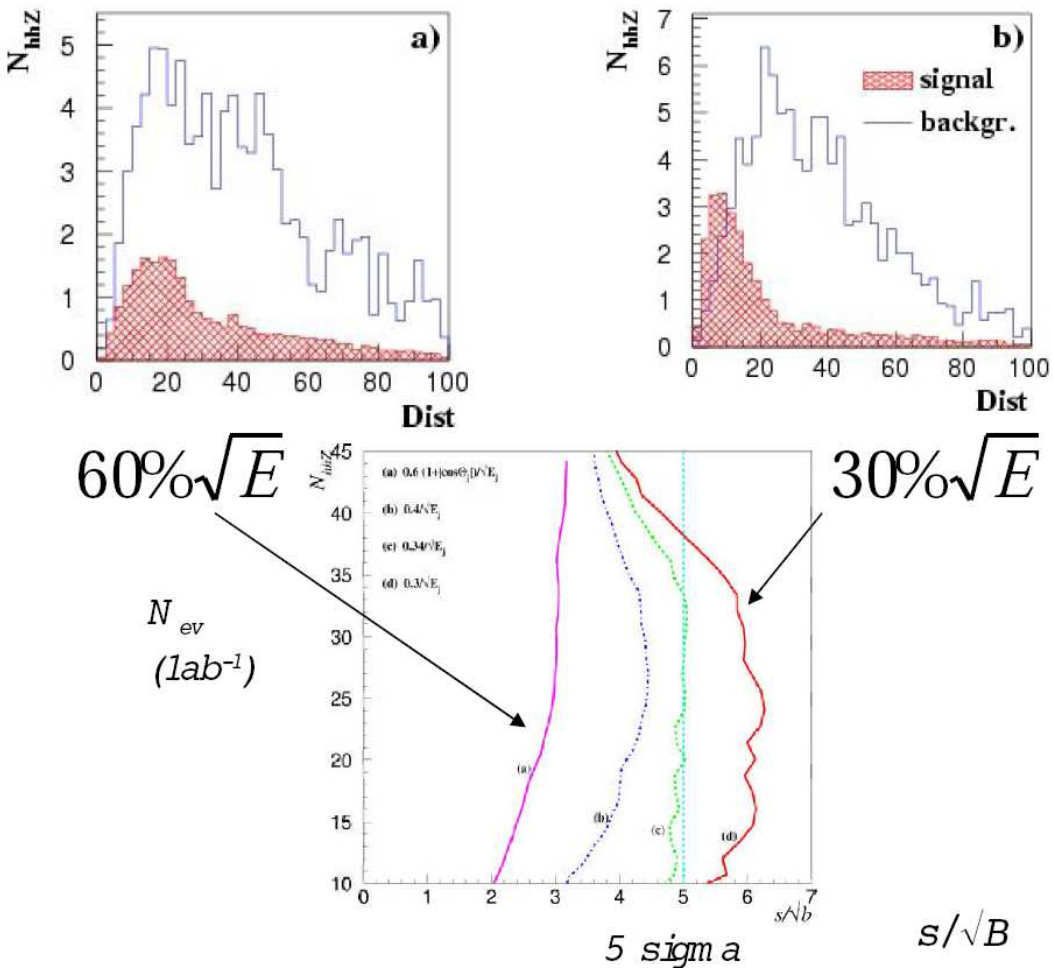
Overconstrain this!



$$V(\Phi) = -\mu^2|\Phi|^2 + \lambda|\Phi|^4$$

Higgs-Self-Coupling Signal ?

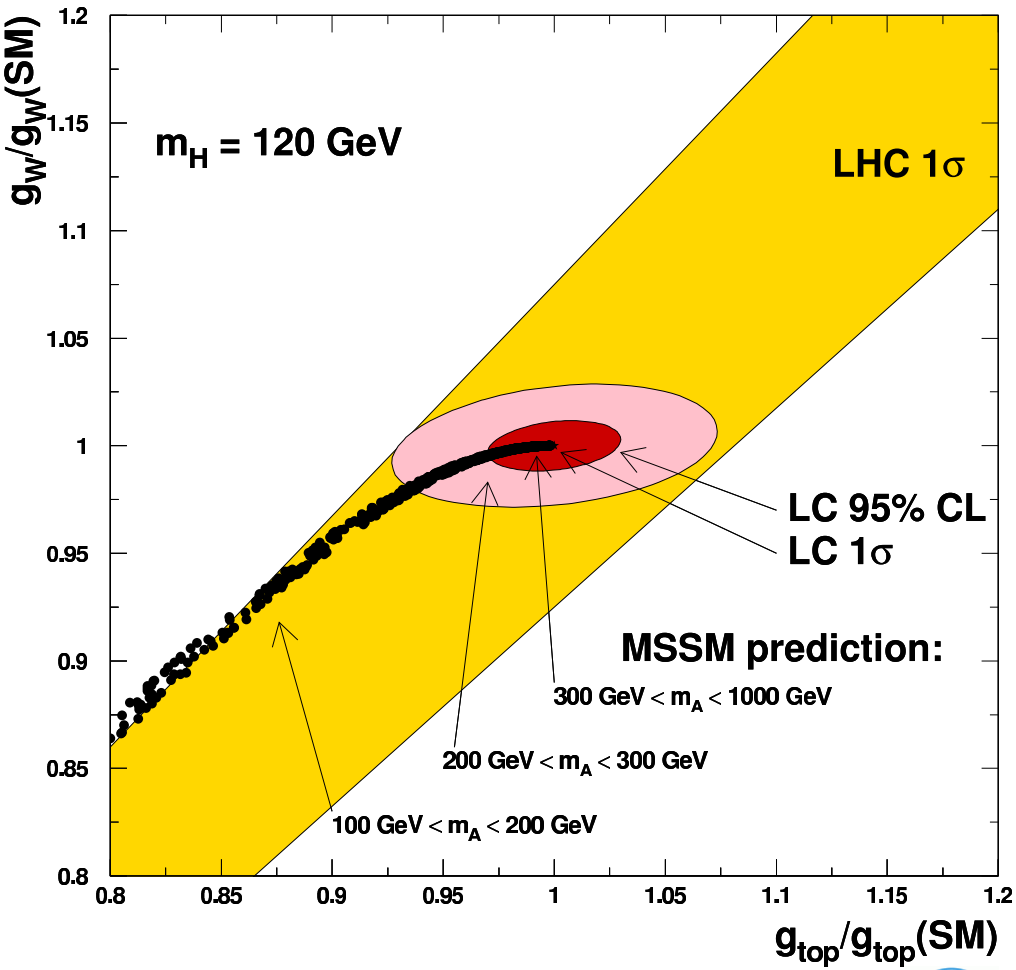
- Probably that would be very difficult for $m_h \approx 165$ GeV
- Con: Smaller σ
- Pro: Less combinatorics?
- At ILC use
  $e^+e^- \rightarrow hhZ \rightarrow 6j$
- Calculate
  $$Dist = \sqrt{\sum_{i=1}^{3}(m_{jj}^{i,rec} - m^{i,target})^2}$$
- Only a few tens of events for $\int \mathcal{L} = 1\,\mathrm{ab}^{-1}$
- Need highest precision calorimetry in dense 6 jet environment
- Or $WW \rightarrow h \rightarrow hh$???
  Studied somewhere?
  CLIC?



Precision: Combining the Information

- And for Higgs bosons with $m_h < 160$ GeV:
- Assume one Higgs is found and nothing else
- How precisely do we know it's the SM Higgs?

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



Other Directions?
GigaZ and the slower path to higher Energies

- The most natural first stage of an ILC: GigaZ/TeraZ/MegaW . . .
- Roughly 2.5-3km accelerator on each side for $\sqrt{s} = 91.2$ GeV

Quantity	Present	Expected uncertainty LHC	ILC	GigaZ (ILC)
M_W [MeV]	25	15	15	6
m_t [GeV]	1.2	1.0	0.2	0.1
$\sin^2\theta^\ell_{\rm eff}$ $[10^{-5}]$	17	17	17	1.3
R^0_ℓ $[10^{-2}]$	2.5	2.5	2.5	0.4
$\Delta\alpha^{(5)}_{\rm had}(M_Z^2)$ $[10^{-5}]$	22 (7)	22 (7)	22 (7)	22 (7)
$M_H(= 120$ GeV) [GeV]	$^{+56}_{-40}$ $(^{+52}_{-39})$ $[^{+39}_{-31}]$	$^{+45}_{-35}$ $(^{+42}_{-33})$ $[^{+30}_{-25}]$	$^{+42}_{-33}$ $(^{+39}_{-31})$ $[^{+28}_{-23}]$	$^{+27}_{-23}$ $(^{+20}_{-18})$ $[^{+8}_{-7}]$
$\alpha_S(M_Z^2)$ $[10^{-4}]$	28	28	27	6

- Here GigaZ includes MegaW at $\sqrt{s} \approx 150 - 170$ GeV
- From there one could gradually move to a top factory at $\sqrt{s} \approx 360$ GeV
- Then we got the Higgs, too . . .

Other Directions?
GigaZ and the slower path to higher Energies

- Keep in mind that for this plot $\langle m_h \rangle$ has been moved to 120 GeV!