Is Higgs enough?

or

Do we need something clearly beyond the standard model?

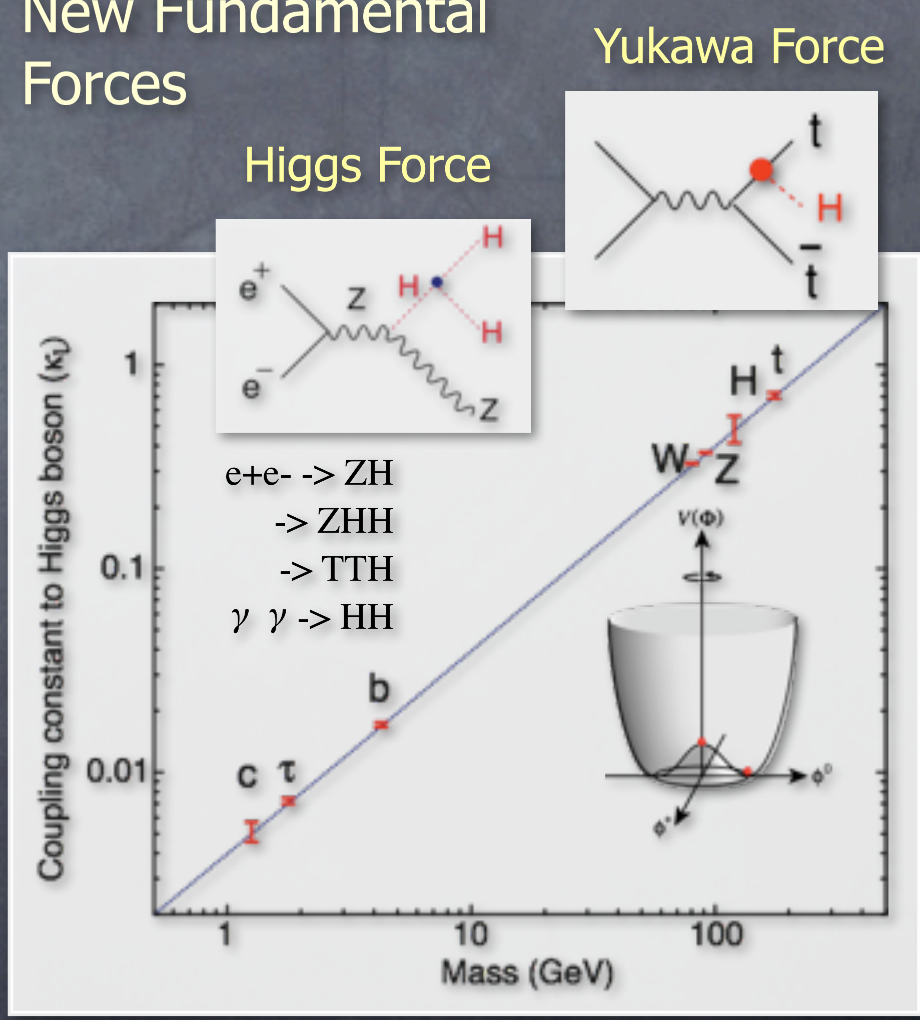
Keisuke Fujii (KEK)

What breaks EW symmetry?

- We know that something must have condensed in the vacuum and broken the electroweak gauge symmetry.
- This "something" supplies longitudinal components of W and Z and mixes left- and right-handed matter fermions, consequently generating mass and inducing flavor mixing among generations.
- We know it's there but other than that we know almost nothing about it.
- Once a SM Higgs-like object is found at the LHC, therefore, we need ILC to check it in detail to see if it has indeed all the required properties of the "something".

- We need to observe the force that makes the Higgs boson condense in the vacuum.
- We need to test the mass-coupling proportionality.

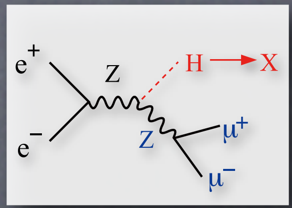
New Fundamental Forces



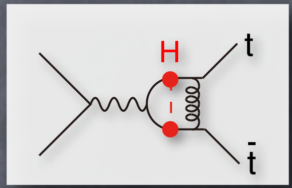
Why 500 GeV?

Well Known Thresholds

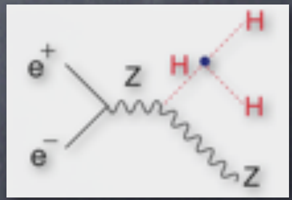
- ZH @ 230 GeV (=mZ+mH+20GeV)
  - mh, gamma_h, JCP
  - Gauge quantum numbers -> Yukawa couplings except for top
  - absolute measurement of ZZH coupling (Recoil mass)
  - BR(h->VV,qq,ll,invisible) : V=W/Z(direct), g,A(loop)



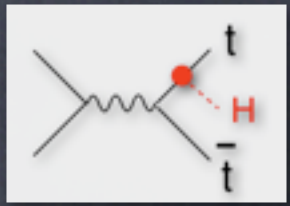
- ttbar @ 340-350GeV (~2mt) : solid threshold
  - threshold scan -> Indirect top Yukawa meas.
  - AFB, momentum distribution
  - Form factor measurements



- ZHH @ 500GeV (~mZ+2mH+170GeV)
  - cross section peak at around 500GeV -> Higgs self-coupling

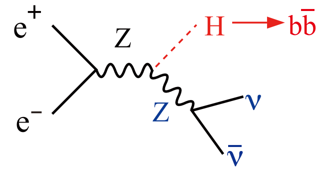


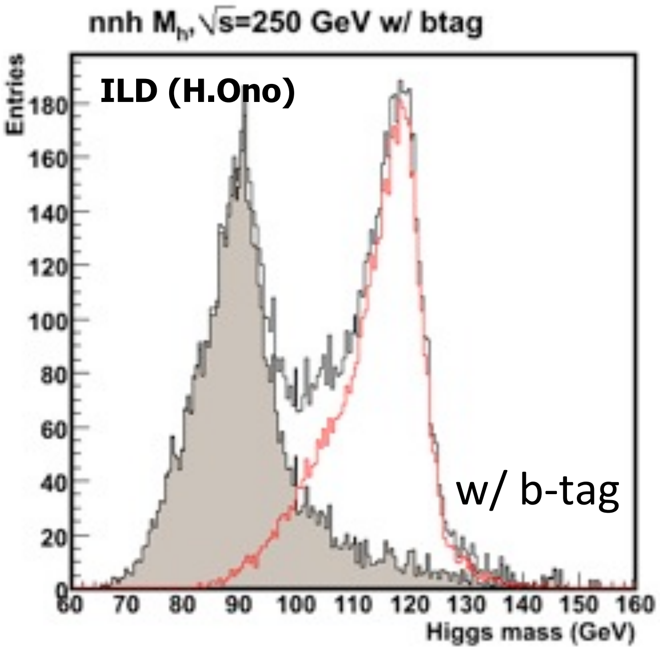
- ttbarH @ 500GeV (~2mt+mH+30GeV)
  - Optimum at around 700GeV but QCD enhancement allows measurement concurrent to ZHH -> Direct top Yukawa meas.



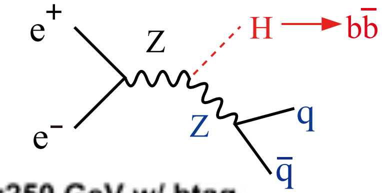
The mass-coupling plot can be completed with ILC500 !

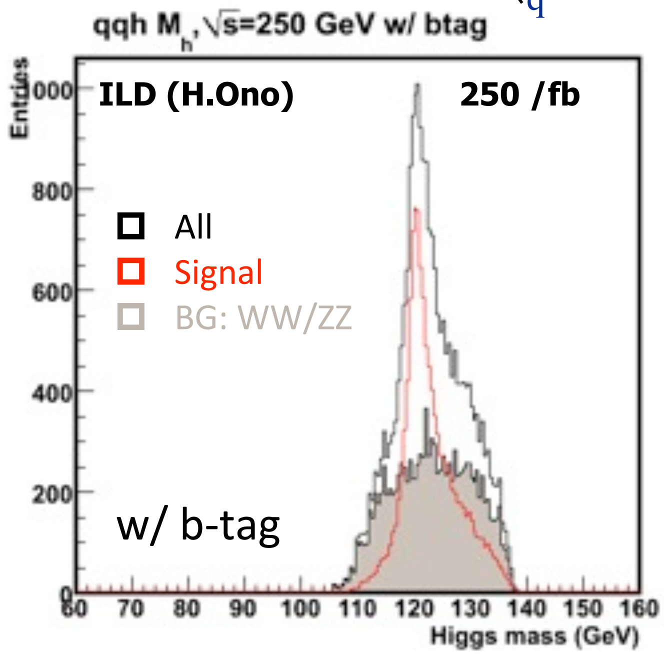
ννH





qqH



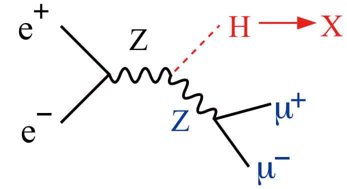


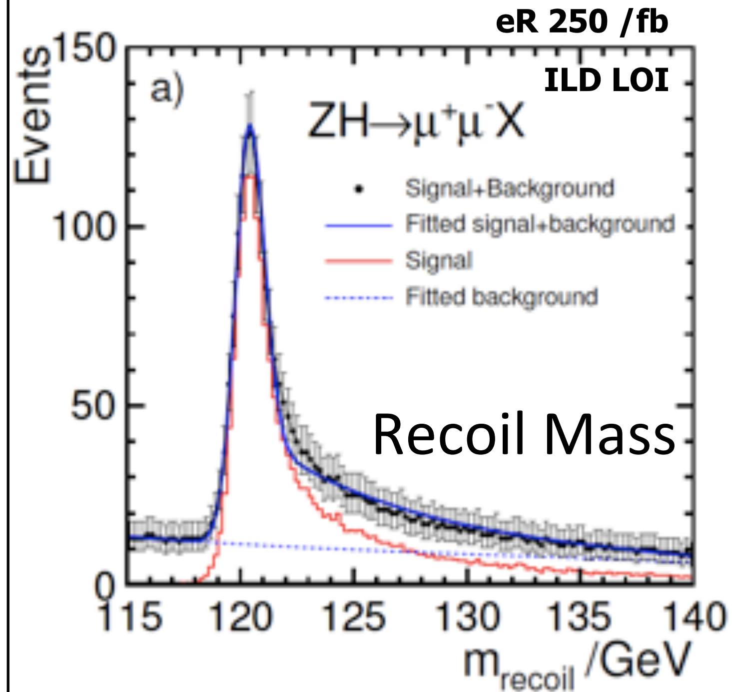
Higgs mass	120 GeV				140 GeV		
Cross section	σ=354.3 fb				σ=203.1 fb		
Higgs decay	BR	σxBR	ΔBR/BR		BR	σxBR	ΔBR/BR
			ILD : Now	ILD : LOI			Scaled
H→bb	66.5%	235.6	2.7% (2.7%)	2.7%	33.0%	67.1	7%
H→cc	2.9%	10.4	8.9% (7.7%)	12%	1.5%	3.0	16.2%
H→WW*	13.6%	48.3	15.7%		49.2%	99.8	10.9%
H→gg	8.2%	29.2	10.2% (8.2%)	29%	5.7%	11.5	17.8%

Very Preliminary

New ILD results are preliminarily combined with ννH and qqH at 250 GeV (350GeV) w/250fb^{-1}, WW* from hep/ph1011.5805v2; σ_{ZH} uncertainty is included for ILD (2.5%)

llH





We can detect it even if it decays 100% invisibly!

$$\Delta m_H < 40\,\mathrm{MeV}$$

$$\Delta\sigma_{ZH}/\sigma_{ZH} = 2.5\%$$

Absolute measurement of ZHH coupling!

Absolute BR measurement possible!

HHH Coupling with current analysis technology

Polarization: (e-,e+)=(-0.8,0.3) $e^+ + e^- \rightarrow ZHH$ $M(H) = 120\text{GeV}$ $\int Ldt = 2\text{ab}^{-1}$

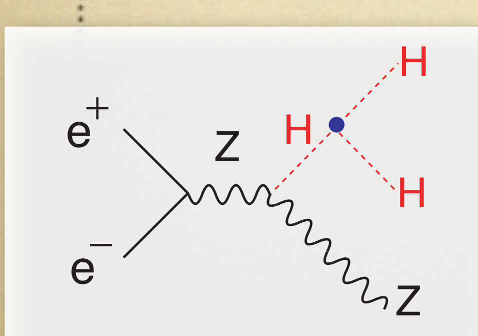
Energy (GeV)	Modes	signal	background	significance	
				excess (I)	measurement (II)
500	(ll)(bb)(bb)	6.4	6.7	2.1σ	1.7σ
500	(νν)(bb)(bb)	5.2	7.0	1.7σ	1.4σ
500	(qq)(bb)(bb)	8.5	11.7	2.2σ	1.9σ
		16.6	129	1.4σ	1.3σ

combined significance of ZHH excess: **3.9σ**

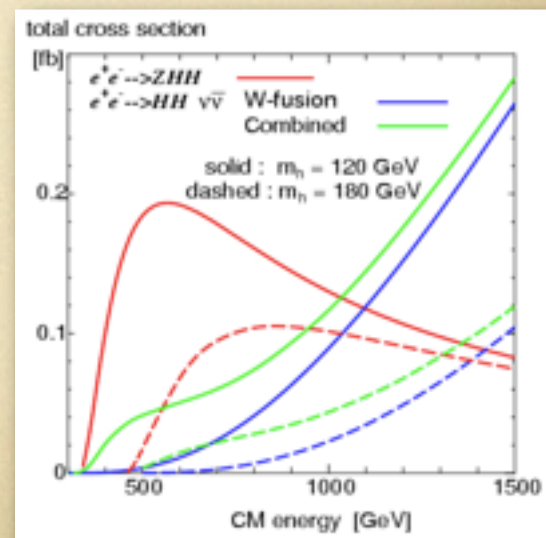
$$\sigma_{ZHH} = 0.22 \pm 0.07 \quad \text{fb}$$

precision of cross section: **32%**

precision of Higgs self-coupling: **57%**

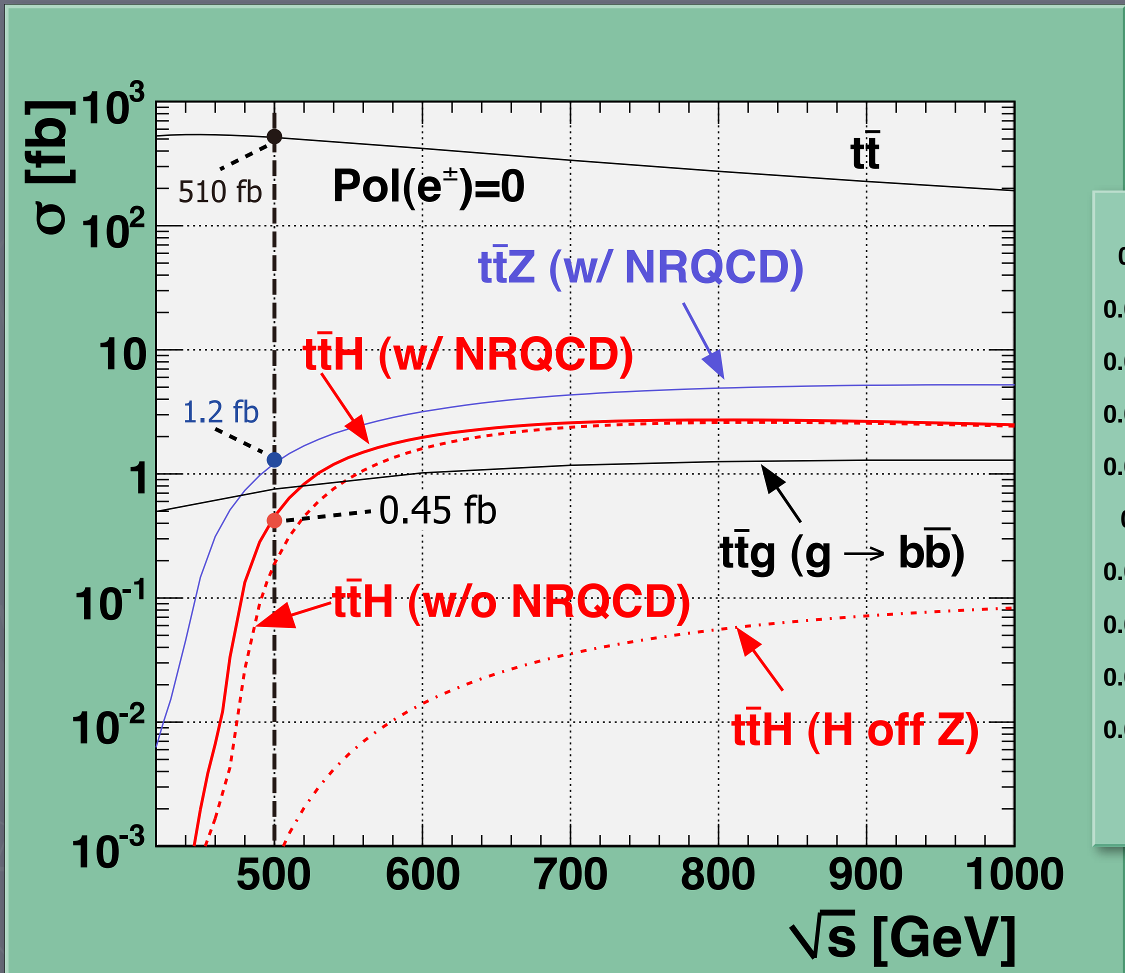


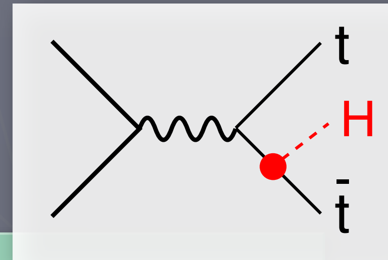
ILD (ACFA Higgs WG: J. Tian et al)

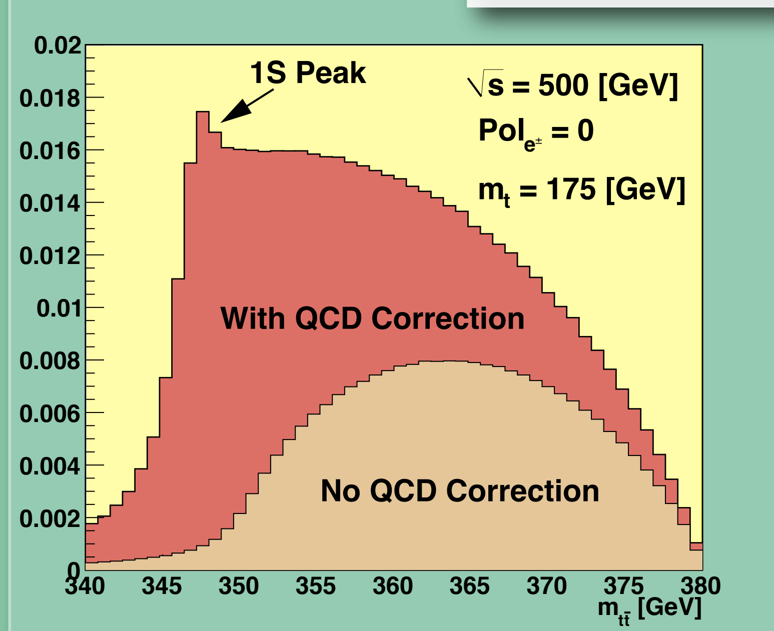


Top Yukawa Couping

The largest among matter fermions







x2 Enhancement by NR QCD correction to the ttbar system

Fast simulation: P.R.D84, 014033 (2011)

$$\Delta g_Y(t)/g_Y(t) \simeq 10\,\%$$
$$\text{with } 1\,\text{ab}^{-1}\,@\,500\,\text{GeV}$$

Summary

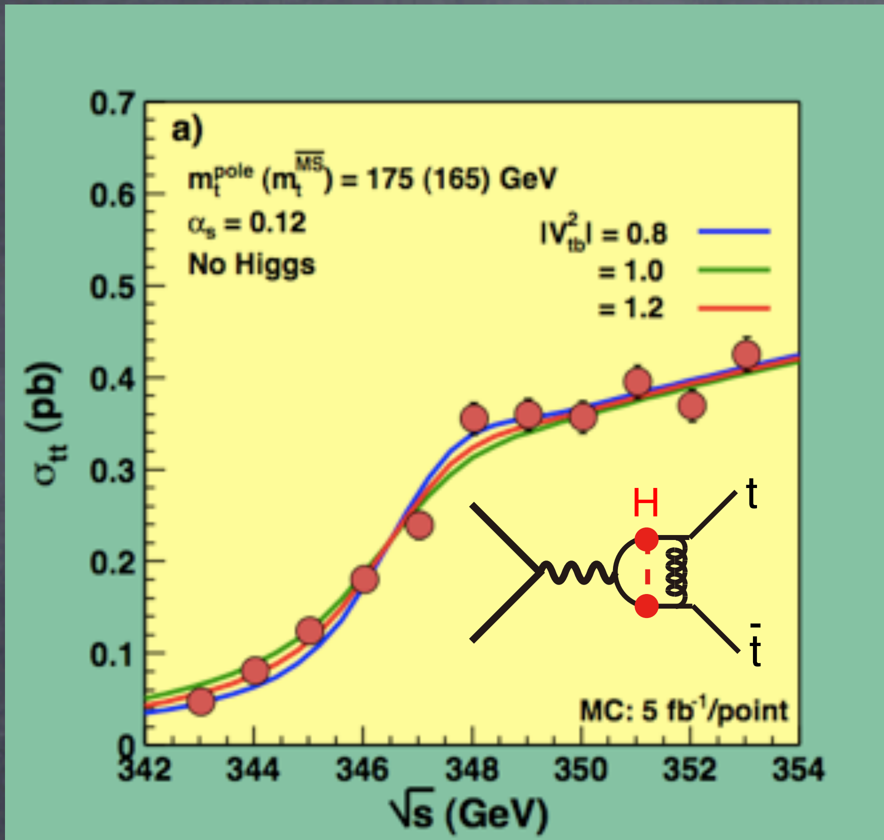
- The primary goal of the ILC 500 is to uncover the secret of the EW symmetry breaking.
- For this we need self-contained precision Higgs studies to complete the mass-coupling plot
  - starting from e+e- -> ZH at Ecm = mZ+mH+20GeV,
  - then ttbar at around 350GeV,
  - and then ZHH and ttbarH at the highest energy of 500GeV.
- A 500GeV ILC is absolutely necessary to carry out this mission and we can do this with staging starting from Ecm=250GeV.

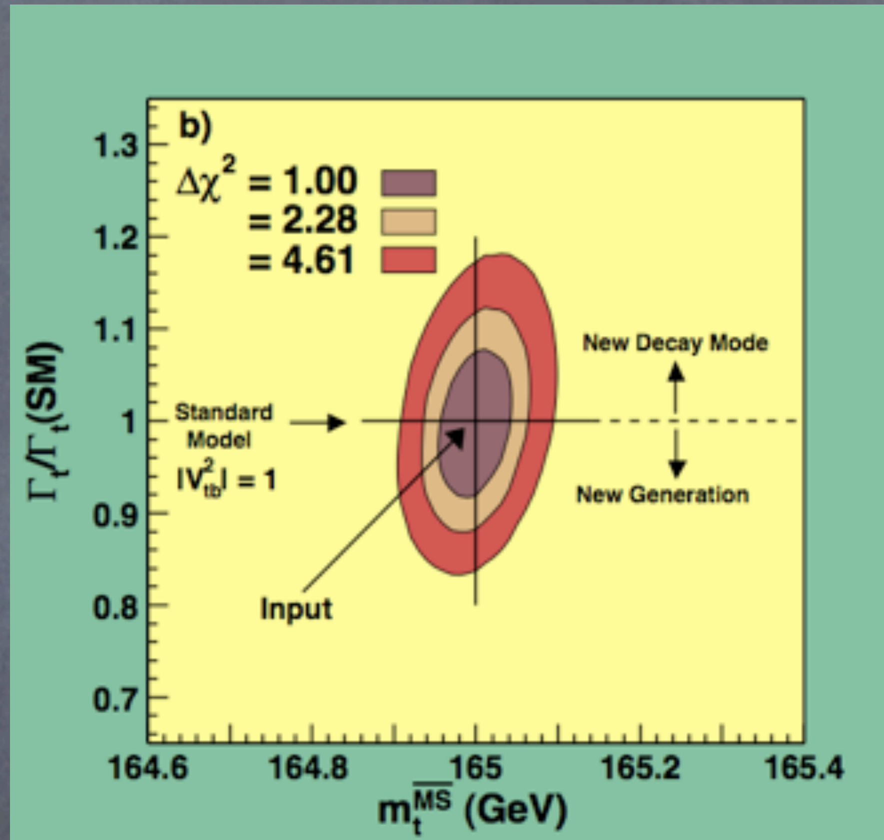
Conclusion

- Question:
  - Is Higgs enough?
- My answer:
  - It is surely enough and we definitely need ILC!
  - I would go so far as to say that we need ILC even if no Higgs-like object will be found at LHC.
  - This is because we need ILC to make sure that the Higgs is really not there. If it is indeed not there, we have to investigate the longitudinal components of W and Z in great detail, since we know that they are from the “something” in the vacuum, which is totally unknown, breaking the EW symmetry. We will then need a W/Z factory.

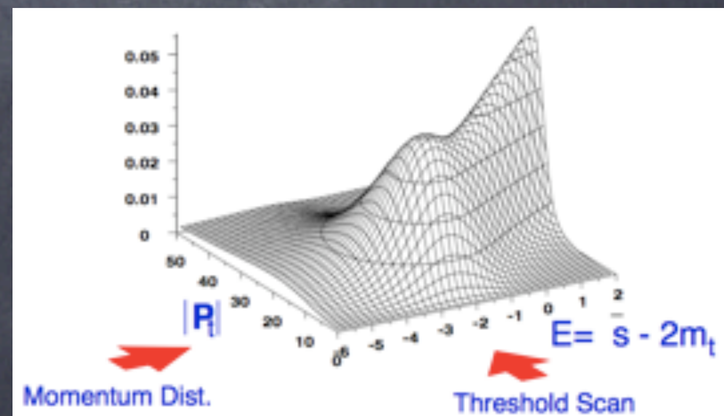
Backup

TTbar Threshold





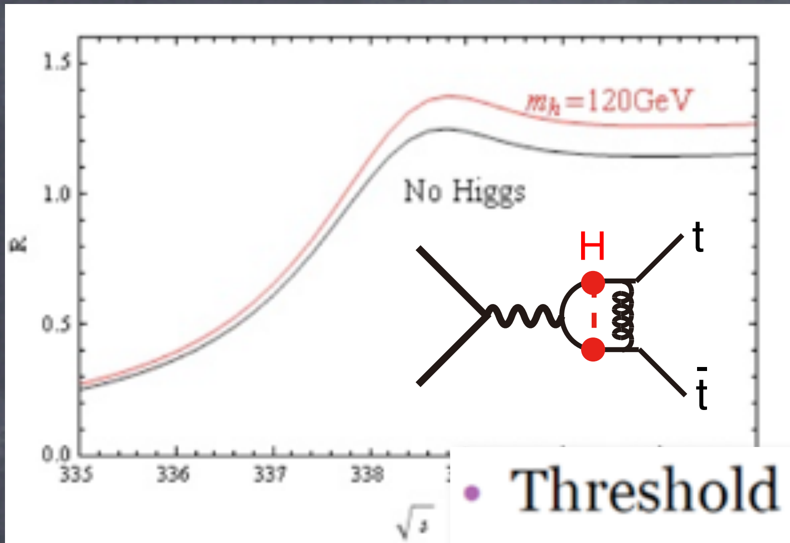
$$\Delta m_t \lesssim 100\,\mathrm{MeV}$$



Theoretical ambiguity of mt could be improved to < 50MeV in the future

Normalization ambiguity could also be significantly reduced in the future

Reducing Theoretical Ambiguities



9% effect on the X-section

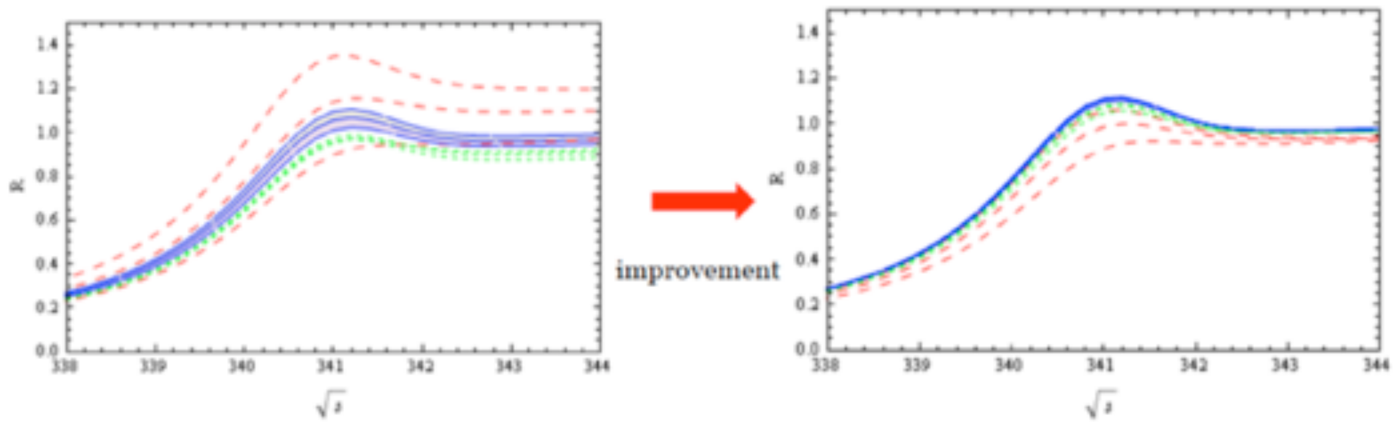
Normalization ambiguity due to the QCD enhancement has been an obstacle to do this measurement

- Threshold enhancement is due to Coulomb resummation

  ⇓

  RG improved potential to reach high accuracy
- Below RG improvement is applied to QCD static potential.

  (In the plots below we neglected other corrections as a first study)



$M_{t,PS}$ =170GeV, LO(Red)/NLO(Green)/NNLO(Blue) for μ=20, 30, 40GeV

Yuichiro Kiyo @ LCWS10

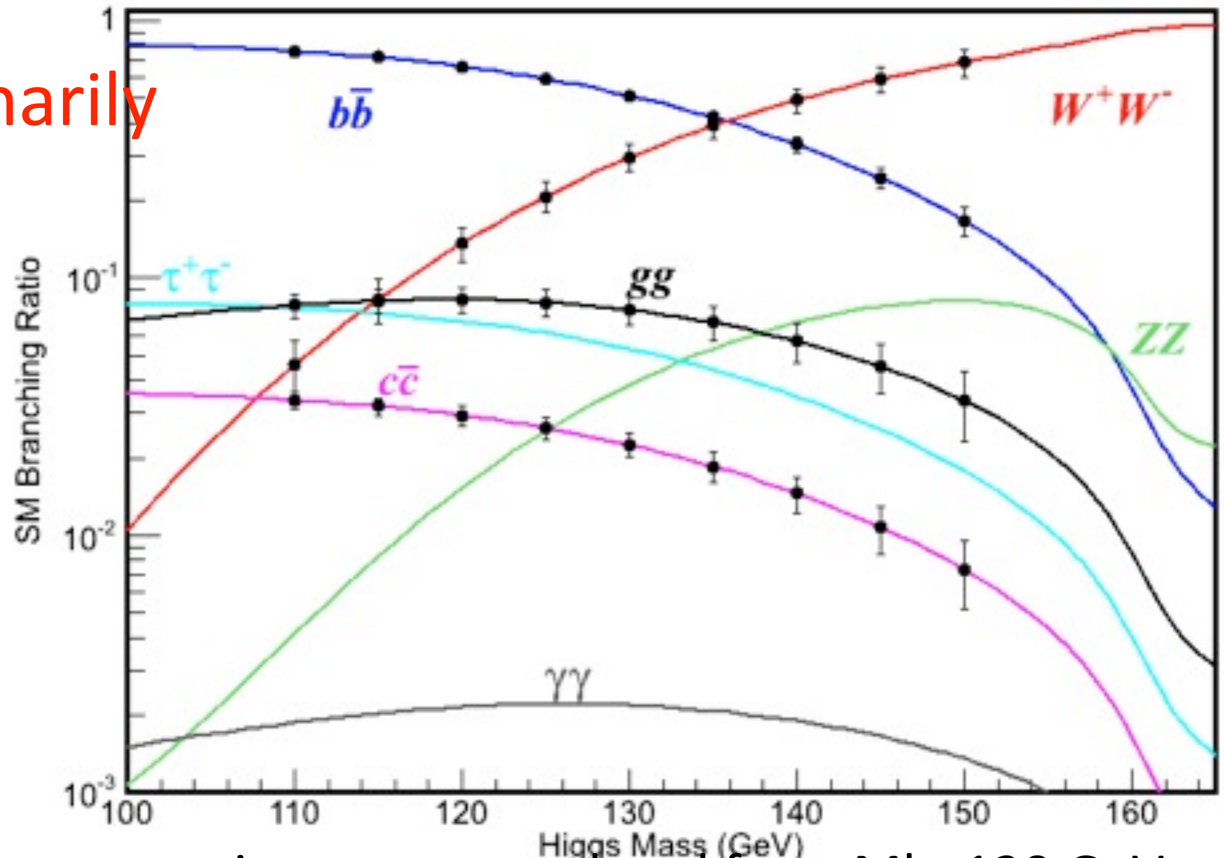
Use of the RG improved potential can significantly improve the situation!

Still preliminary but prospect is bright!

Higgs BR measurement accuracy in low Higgs mass region

Ecm=250 GeV, L=250 fb^{-1}, Beam pol(e^+,e^-)=(+30%, -80%)

preliminarily



Measurement accuracies are extrapolated from Mh=120 GeV results.

Better to analyze full simulation sample directly to evaluate including efficiency

→Higgs mass of 130, 140 GeV @ Ecm=250GeV samples are ready