Study of the Higgs properties at a muon collider.

M. Greco
Univ. and INFN - Roma Tre

RAL, June 25th, 2015

Motivation and Summary

- The discovery of the Higgs is a success of the SM, and also demanding a detailed knowledge of the properties of this particle.
- Various types of electron and muon colliders have been proposed for precision studies of the total and partial widths in the various decay channels.
- In the case of a Higgs factory through a muon collider, sizeable radiative effects - of order of 50% or larger - must be carefully taken into account for a precise measurement of the total and partial widths of the Higgs particle.

The LHC discovery of the Higgs at 125 GeV

- ATLAS: $m = 125.5 \pm 0.2$ (stat) ± 0.6 (sys) GeV
- CMS: $m = 125.8 \pm 0.4$ (stat) ± 0.4 (sys) GeV

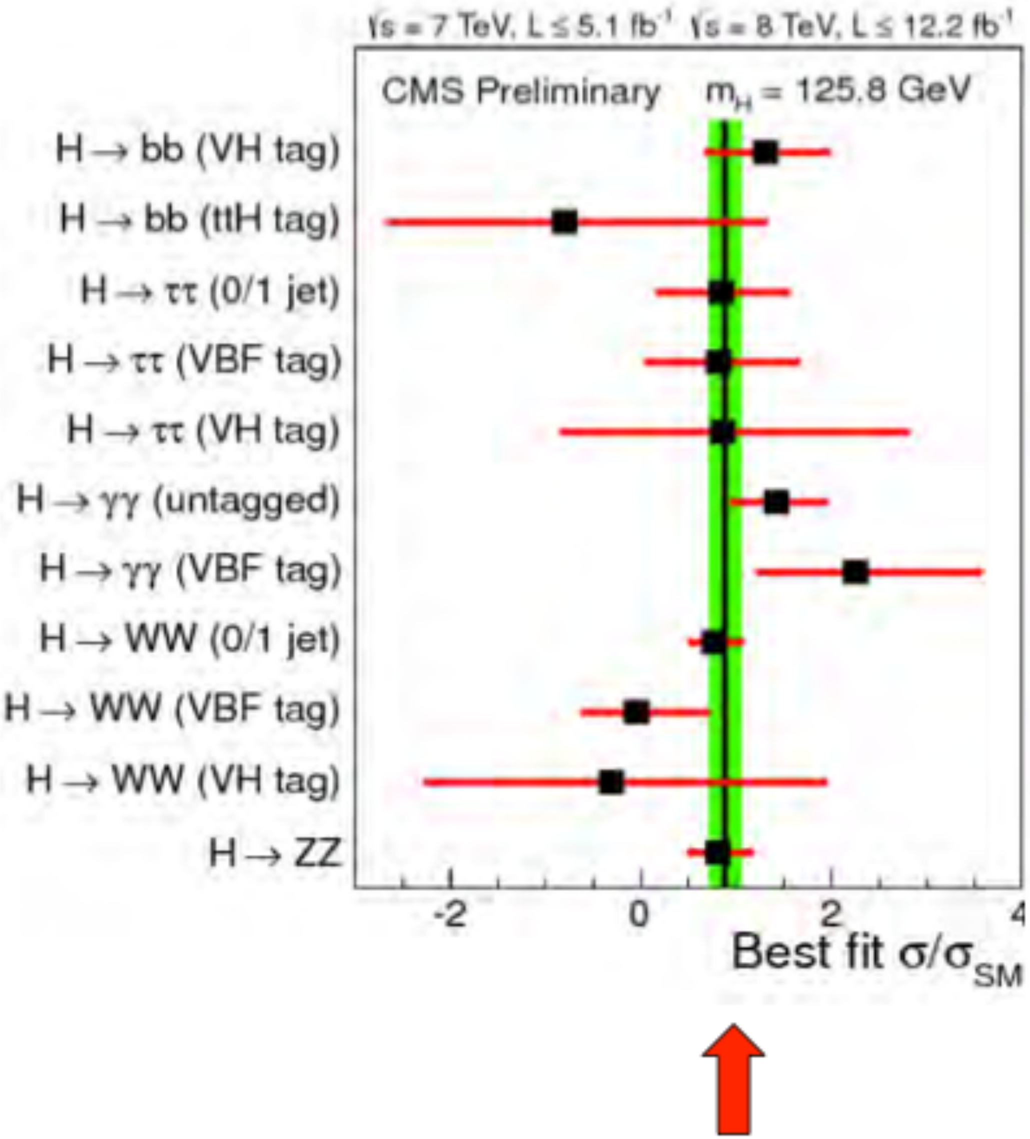
- CMS and Atlas have observed a narrow line of high significance at about 125 GeV mass, compatible with the Standard Model Higgs boson.

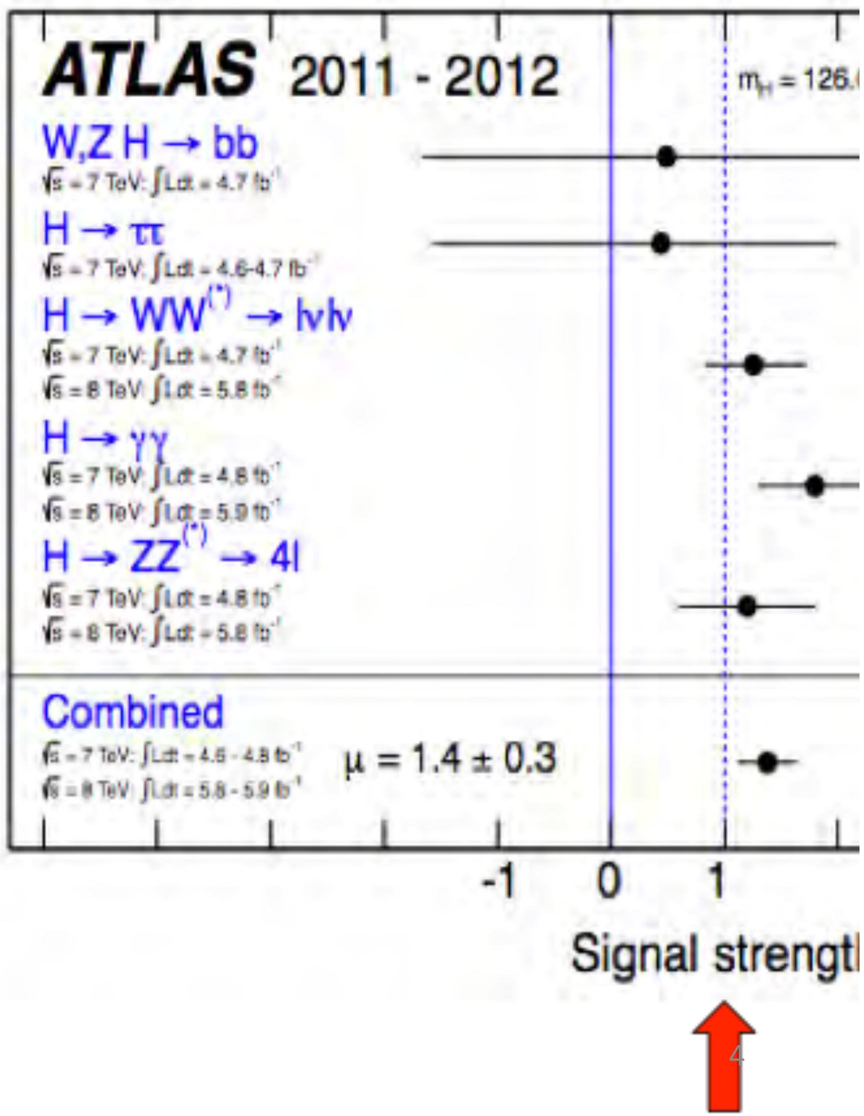
- Their data are consistent with fermionic and bosonic couplings expected from a SM Higgs particle. Searches have been performed in several decay modes.

- Experimental energy resolutions have been so far much wider of the expected intrinsic Higgs width of about 4 MeV.

- ATLAS and CMS and also CDF also exclude other SM Higgs bosons up to approximately 600 GeV.

All Higgs results





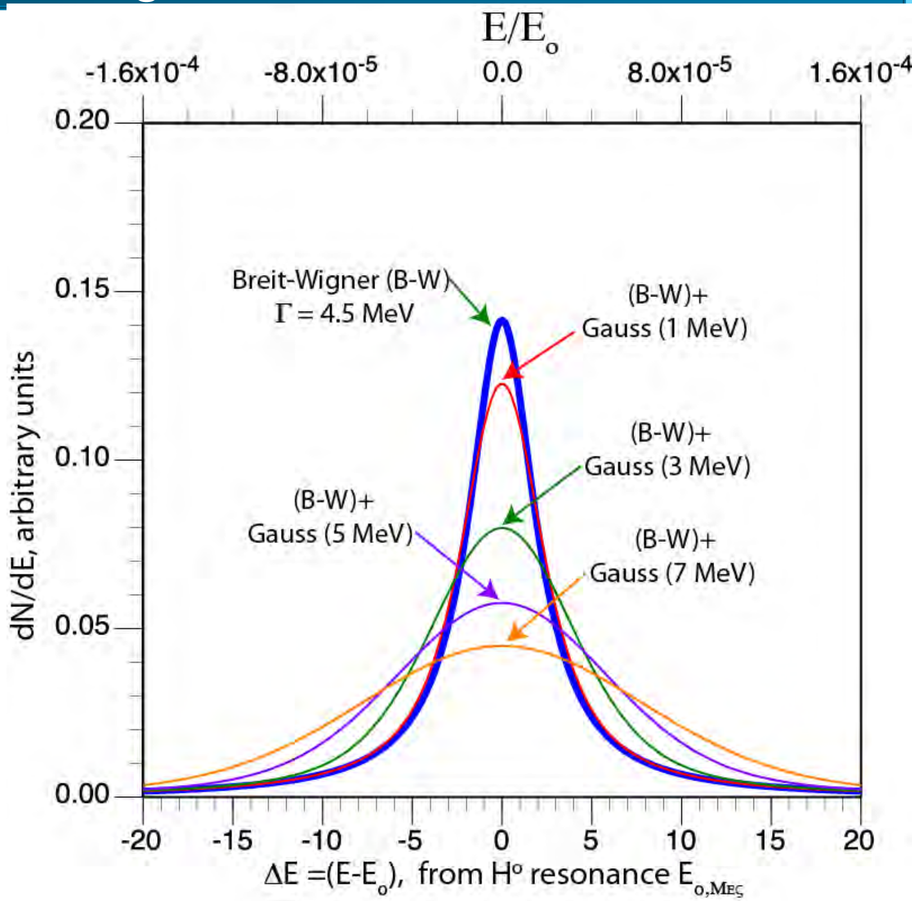
- From the available data it cannot be concluded yet that we have found the SM Higgs and not one of the scalars postulated within the possible extensions of the SM.

- Therefore a detailed study of the properties of this particle is highly required.

- In particular the Higgs width's measurement is essential to determine the partial widths and couplings to fermions and bosons.

The Higgs width according to the Standard Model

- Like in the case of the Zo, the determination of the H_o width will be crucial in the determination of the nature of the particle and the underlying theory
- Cross section is shown here, convoluted with a Gaussian beam distribution.
- Signal is not affected only if the rms beam energy width is ≲ a few MeV.



4.5 MeV wdth:A very demanding resolution R ≈ 0.003% is required

C. Rubbia, Venice, March 2015

The need of a better precision

- What precision is needed in order to search for possible additional deviations from the SM, even under the assumption that there is no other additional "Higgs" state at the LHC ?
- Predicted ultimate LHC accuracies for "exotic" alternatives

R.S. Gupta et al.	ΔhVV	$\Delta h\bar{t}t$	Δhbb
Mixed-in Singlet	6%	6%	6%
Composite Higgs	8%	tens of %	tens of %
Minimal Supersymmetry	< 1%	3%	10%[a],
LHC 14 TeV, 3 ab^{-1}	8%	10%	15%

Ultimate at LHC
1 ab= 10^{-42} cm^2

$$\frac{g_{hbb}}{g_{h_{SM}bb}} = \frac{g_{h\tau\tau}}{g_{h_{SM}\tau\tau}} \simeq 1 + 1.7\% \left(\frac{1\ \mathrm{TeV}}{m_A}\right)^2$$

SUSY tan(β)>5

$$\frac{g_{hff}}{g_{h_{SM}ff}} \quad \frac{g_{hVV}}{g_{h_{SM}VV}} \simeq 1 - 3\% \left(\frac{1\ \mathrm{TeV}}{f}\right)^2$$

Composite Higgs

$$\frac{g_{hgg}}{g_{h_{SM}gg}} \simeq 1 + 2.9\% \left(\frac{1\ \mathrm{TeV}}{m_T}\right)^2, \qquad \frac{g_{h\gamma\gamma}}{g_{h_{SM}\gamma\gamma}} \simeq 1 - 0.8\% \left(\frac{1\ \mathrm{TeV}}{m_T}\right)^2$$

Top partners

- Sensitivity to "TeV" new physics for "5 sigma" discoveries may need 1 per-cent to sub 1-per-cent σ accuracies on rates.

arXiv:1206.3560v3 [hep-ph] 27 Sep 2012

The quest for Higgs Factories

- Two possible future alternatives:

> A e^+e^- collider at L > 10^{34} and a *$Z+H_o$ signal* of *≈ 200 fb.* The circumference of a new, LEP-like ring is of about ≈ 80 km or of a Linear Collider of 31 km.

> A $\mu^+\mu^-$ collider at L > 10^{32} and a *H_o signal in the s-state* of ≈ *20'000 fb*. The collider radius is much smaller, only ≈ 50 m, but the novel "muon cooling" facility is required.

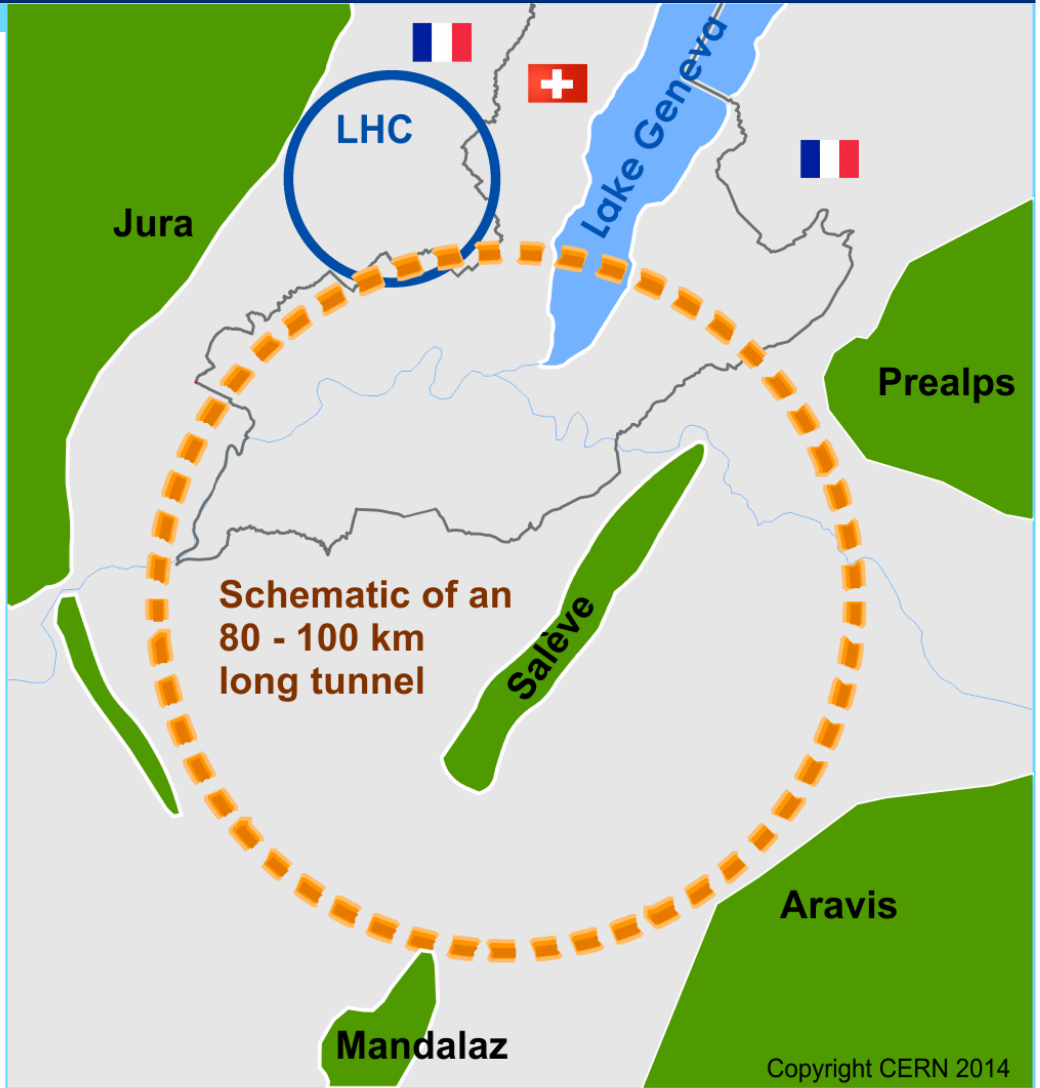
M I C E

"muon cooling": C. Rubbia, "A complete demonstrator of a muon cooled Higgs factory" , **arXiv:1308.6612** . Also Venice and Cern, 2015

Future Circular Collider Study - SCOPE
CDR and cost review for the next ESU (2018)

Form an international collaboration to study:

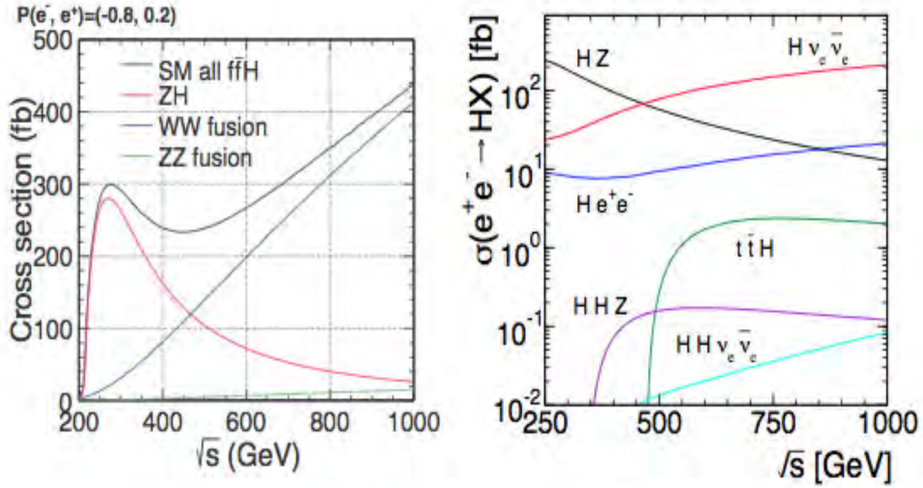
- ***pp*-collider (*FCC-hh*)**
  → defining infrastructure requirements
- **e^+e^- collider (*FCC-ee*)** as potential intermediate step
  → Study Z, W, H, top
- ***p-e* (*FCC-he*) option**
- **80-100 km infrastructure** in Geneva area.
- CEPC-SppC in China

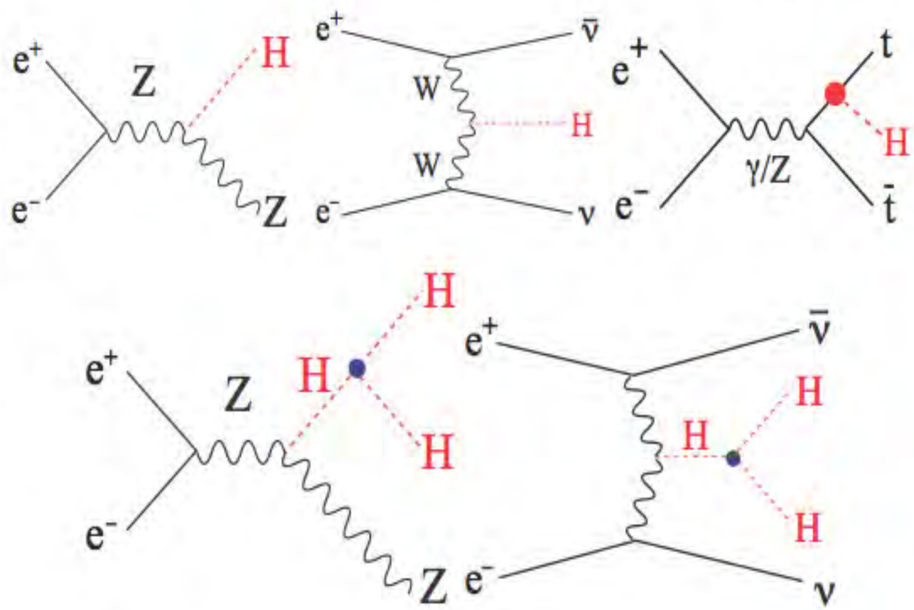


M. Koratzinos, La Thuile, 2015

Production cross sections at the e+ e- collider

- The production cross sections of the Higgs boson with the mass of 125 GeV for e+-e- as a function of the energy √s.
- The cross sections of the production processes as a function of the √s collision energy.
- The Higgs-strahlung diagram (Left), the W-boson fusion process (Middle) and the top-quark association (Right).
- Double Higgs boson diagrams via off-shell Higgs-strahlung (Left) and W-boson fusion (Right) processes





The second option: a $\mu^+\mu^-$ collider ?

- The direct H^o cross section is greatly enhanced in a $\mu^+\mu^-$ collider when compared to an e^+e^- collider, since the s-channel coupling to a scalar is proportional to the lepton mass.
- Like in the well known case of the Z^0 production, the H^o scalar production in the s-state offers conditions of unique cleanliness .
- An unique feature of such process — if of an appropriate luminosity — is that its actual mass, its very narrow width and most decay channels may be directly measured with accuracy.
- Therefore the properties of the Higgs boson can be detailed over a larger fraction of model parameter space than at any other proposed accelerator method.
- A particularly important conclusion is that it will have greater potentials for distinguishing between a standard SM and the SM-like H_o of SUSY or of other than any other collider.

Venice,March.2015 Slide# : 19

The realization of a cooling demonstrator (C. Rubbia) is essential.
At Cern? Elsewhere?

Radiative effects

- In the case of a Higgs factory through a muon collider, sizeable QED radiative effects - of order of 50% - must be carefully taken into account for a precise measurement of the leptonic and total widths of the Higgs particle.
- Those effects do not apply in the case of Higgs production in electron-positron colliders.
- Effects similar to J/Psi, Z, … production in e+e- annihilation.

More details

- Correction factor $\propto (\Gamma/M)^{(4\alpha/\pi)\log(2E/m)}$ modifies the lowest order cross section o(50%).

- By defining: $\beta_i = \frac{4\alpha}{\pi}\left[\log\frac{W}{m_i} - \frac{1}{2}\right]$, $\begin{aligned} y &= W - M \\ \tan\delta_R(W) &= \frac{1}{2}\Gamma/(-y) \end{aligned}$

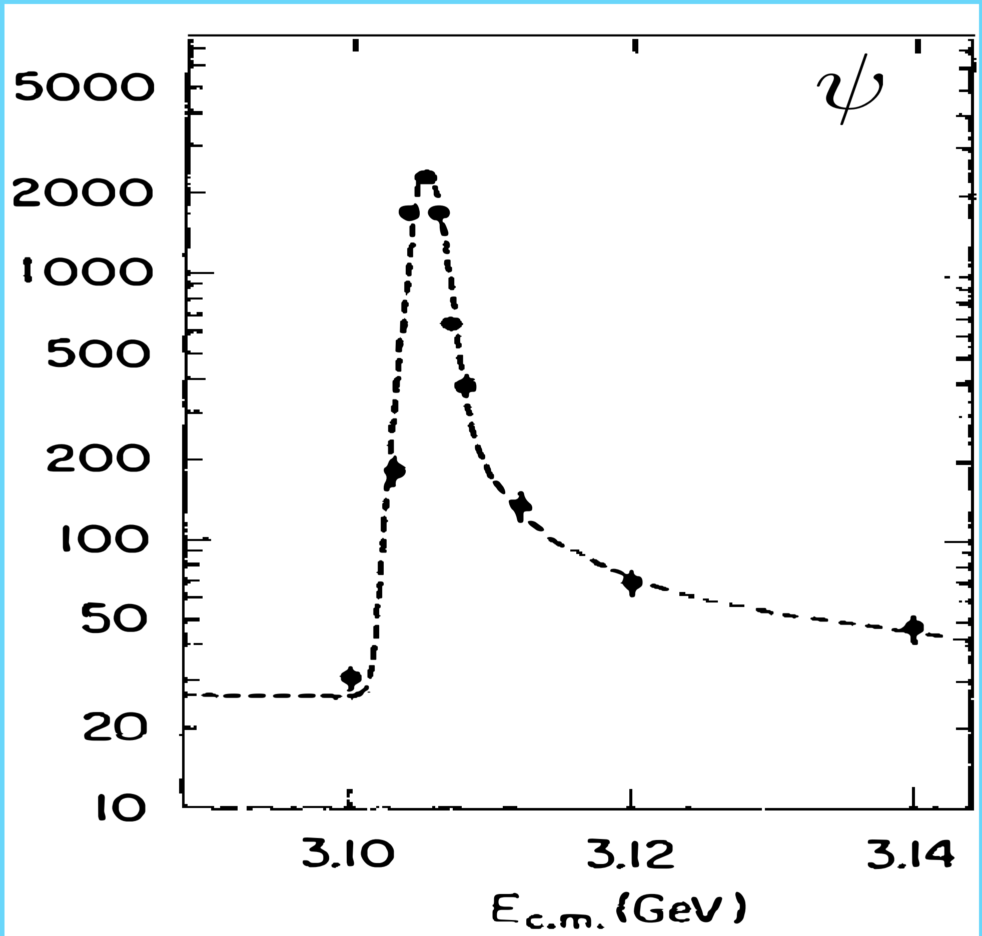
Infrared factor modifies Born cross section as:

M.G., Pancheri, Srivastava, Nucl. Phys. B101, 1975 and B171, 1980.

$$C^{res}_{infra} = \left(\frac{y^2 + (\Gamma/2)^2}{(M/2)^2}\right)^{\beta_i/2}\left[1 + \beta_i\frac{y}{\Gamma/2}\delta_R\right]$$

- At W=2E=M_Higgs, $\beta_i = 0.061$ $C^{res}_{infra} = (\Gamma/M)^{\beta_i} = 0.53,$

The situation is very similar to J/Psi production in e+e- annih. a part from the background.



- Since the resonance is quite narrow, one has to integrate over the machine resolution

$$G(W' - W) = \frac{1}{\sqrt{2\pi\sigma}} e^{-(W'-W)^2/(2\sigma^2)}$$

$$\tilde{\sigma}(W) = \int G(W' - W) dW' \sigma(W')$$

- Then the observed cross section at the peak is, to o(1%) accuracy:

$$\tilde{\sigma}(M) = \frac{2\pi^2 \Gamma_i \Gamma_f}{\sqrt{2}\pi\sigma M^2 \Gamma} \left(\frac{\Gamma}{M}\right)^{\beta_i} e^{\left(\frac{\Gamma}{2\sqrt{2}\sigma}\right)^2} \left\{ ercf\left(\frac{\Gamma}{2\sqrt{2}\sigma}\right) + \frac{1}{2}\beta_i E_1\left(\frac{\Gamma^2}{8\sigma^2}\right) \right\}$$

-> Numerical results for Higgs. The correction factor C is:

C = 0.47 , 0.37 , 0.30 , 0.20

$\sigma = 1$ MeV, 2 MeV, 3 MeV, 4 MeV,

-> Important corrections to the Born Higgs signal.

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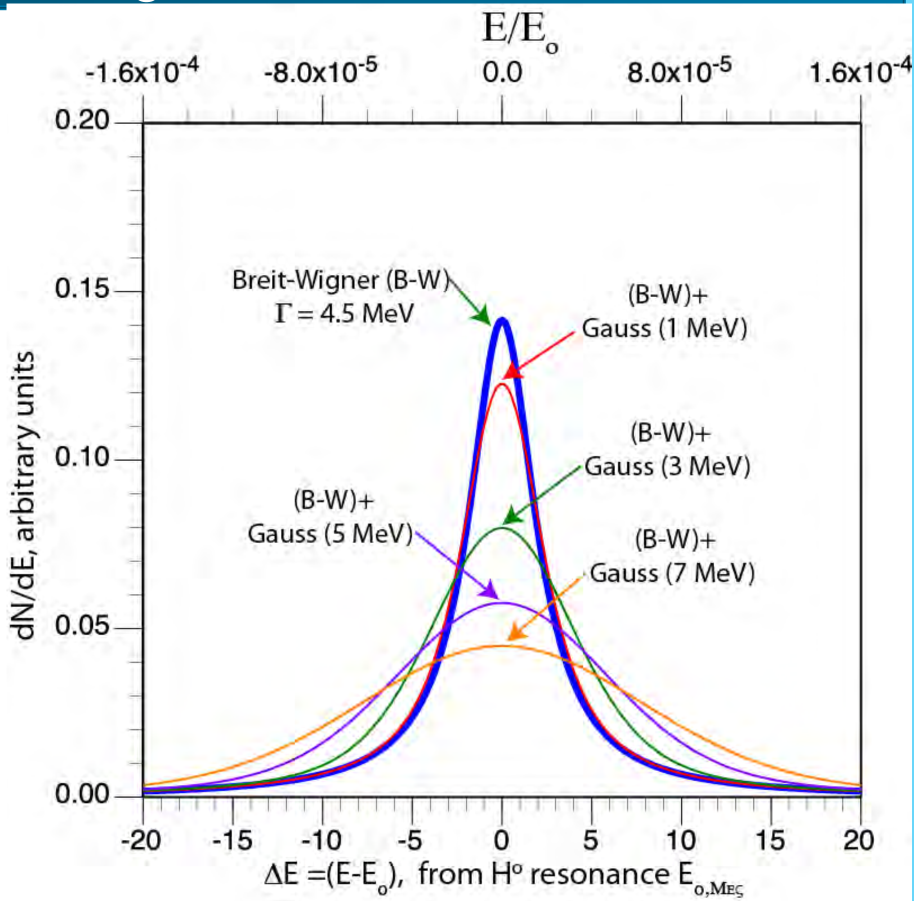

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-> Ratio Signal/Background affected as a function of beams spread.

Signal/Background studies

- T. Han and Z. Liu (arXiv:1210.7803v2)

R (%)	$\mu^+\mu^- \to h$	$h \to b\bar{b}$		$h \to WW^*$	
	$\sigma_{\rm eff}$ (pb)	σ_{Sig}	σ_{Bkg}	σ_{Sig}	σ_{Bkg}
0.01	16	7.6	15	3.7	0.051
0.003	38	18		5.5	

Effective cross sections (in pb) at the resonance for two choices of beam energy resolutions R and two leading decay channels, with the SM branching fractions. No radiative effects included.

→ Further work is needed.

- No similar effects for e+e- colliders

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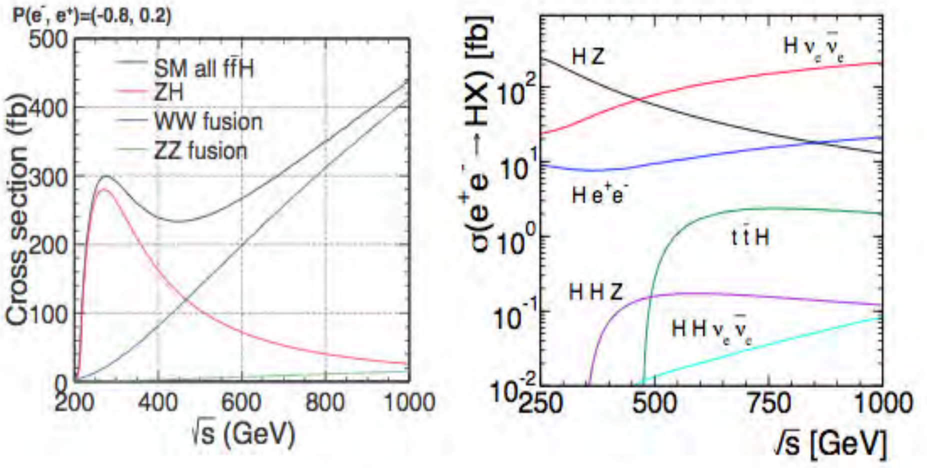

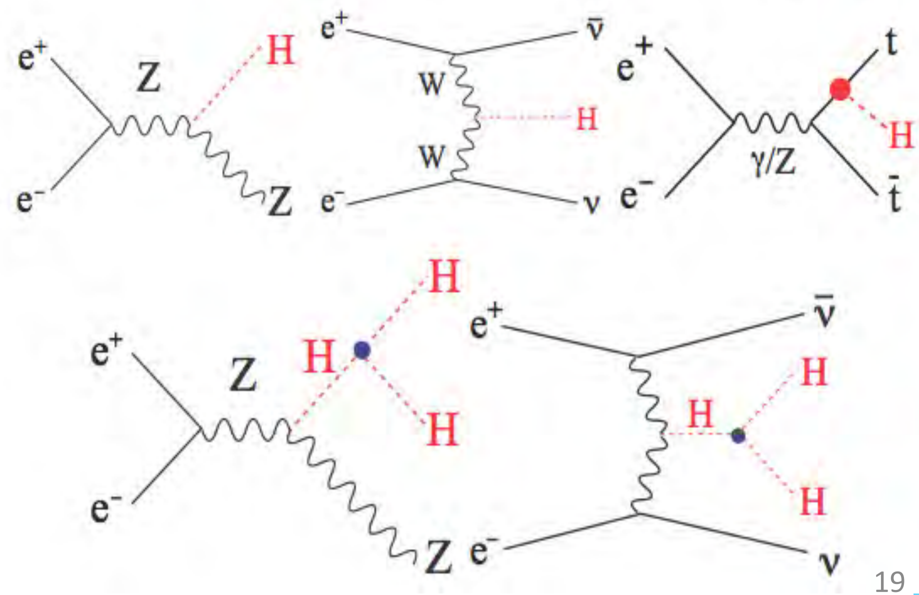

Conclusions

- Precision studies of the properties of the Higgs are mandatory.
- Various proposals of electron and muon colliders have been put forward.
- Muon colliders seem more appropriate for measuring the Higgs width and couplings. Sizeable radiative effects – of order 50% or larger – must be carefully taken into account for precision measurements.

Thank you !