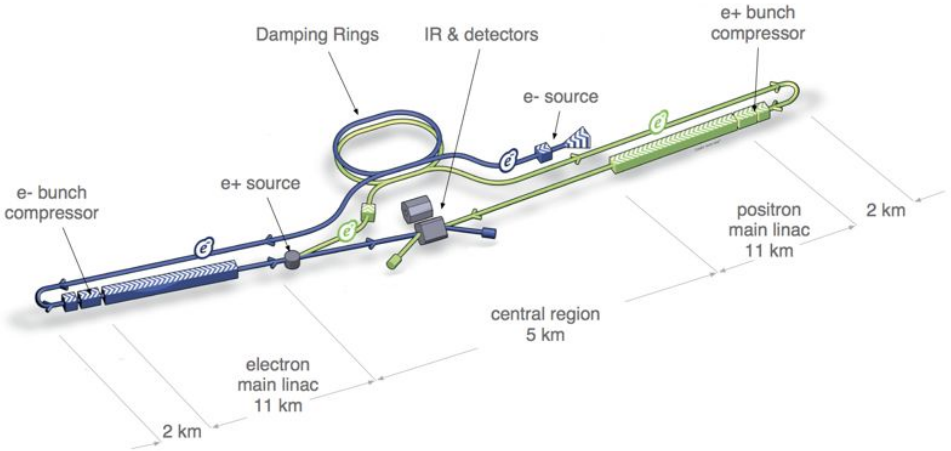
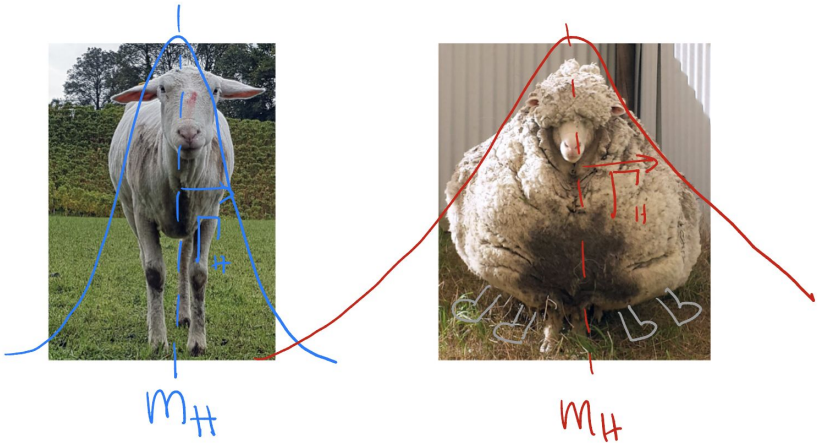
Measuring the Higgs Width at the ILC

Aleksandra, Anamika, Anna, Brian, Jordy, Thijs



What is the Higgs Width?!



- Natural width of Higgs
  - Unstable particle → Breit-Wigner mass shape
  - Width is related to life-time Γ = 1/τ
  - SM predicted width: ~ 4 MeV

- Why do we want to measure it?
  - The total width is affected by all Higgs decays, also the ones we cannot measure:

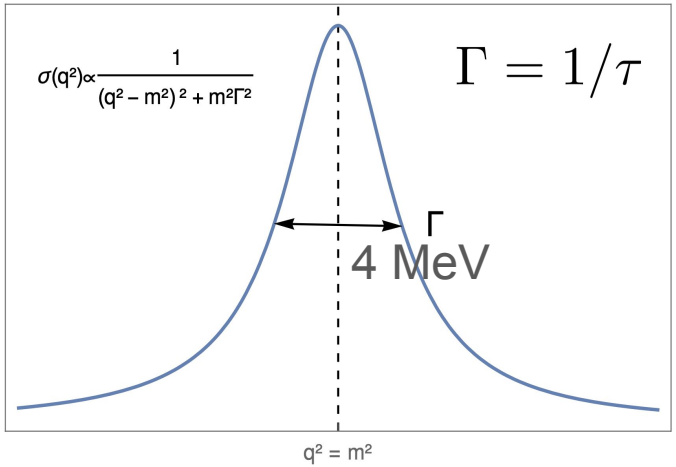
$$\Gamma_H = \Gamma_{H\to WW} + \Gamma_{H\to b\bar{b}} + \ldots + \Gamma^{?}_{BSM}$$

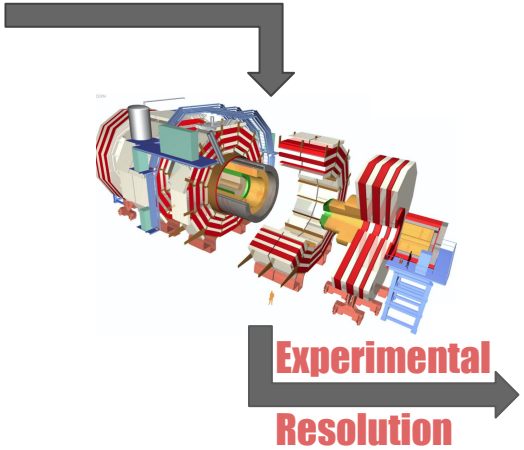
  - Enters in all Branching Ratios.
  - Any new Higgs decay (e.g. into Dark Matter) will enhance the width.

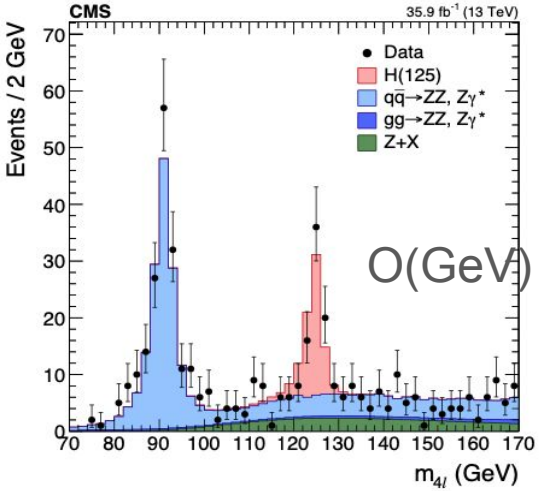
Attempts to measure it

From theory….

...to experiment!





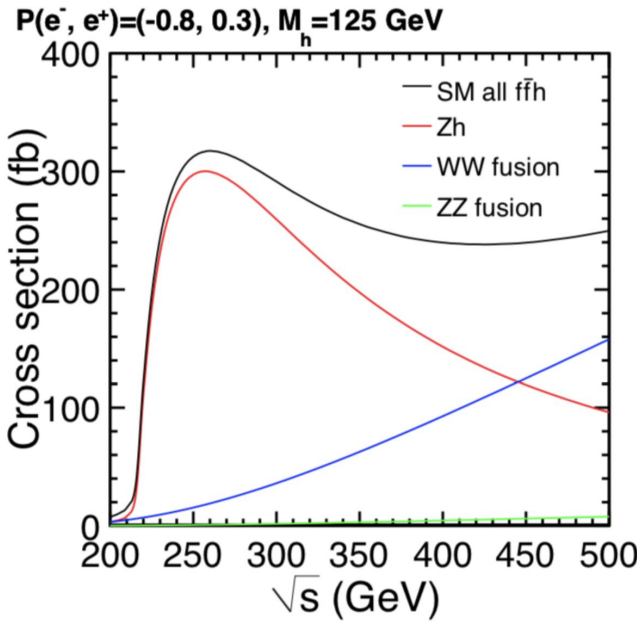


- Direct measurements (at the LHC) limited by resolution [factor 1000 missing]
- Indirect measurement can get close (but assumptions!)

Can we measure the width in a model independent way?

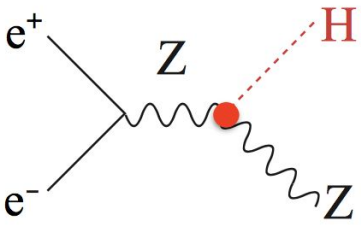
Higgs production at ILC

- International **Linear Collider**
- **e+ e-** Higgs factory with CM energy √s of **250 GeV** (500 GeV upgrade possible)
- Possibility to polarize beams (e.g. to enhance cross-sections)

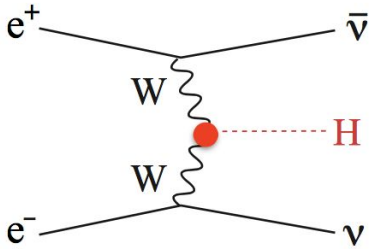


- Main Higgs production mechanisms:

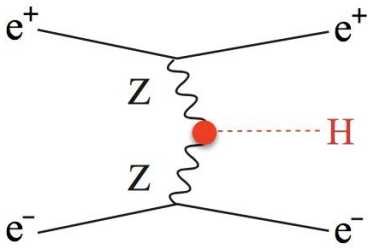
Higgs-strahlung (Zh)



WW fusion

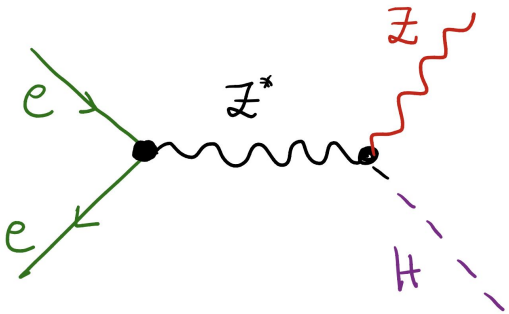


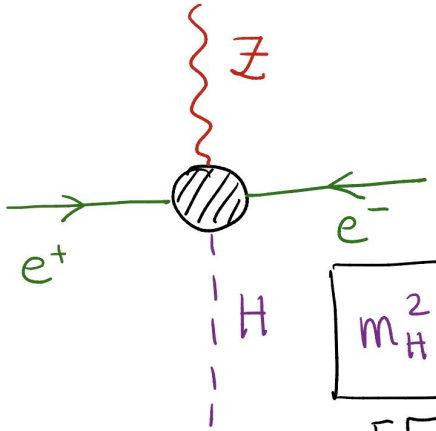
ZZ fusion



What does ILC bring to the picture?

- Knowledge of initial CM energy [we don't have this at the LHC!]
- Allows to measure the Higgs without looking at its decay products (from 4-momentum conservation)



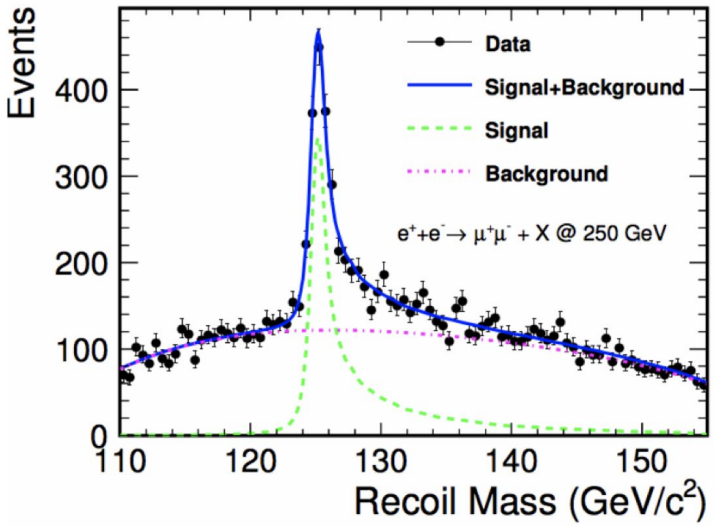


$$\left(p^{\mu}_{e^+} + p^{\mu}_{e^-}\right) = \left(p^{\mu}_{H} + p^{\mu}_{Z}\right)$$

$$\boxed{m_H^2 = s + M_Z^2 - 2\sqrt{s}\, E_Z}$$

$$\left[\sqrt{s} = E_{e^+} + E_{e^-}\right]$$

Is this enough to measure the width?



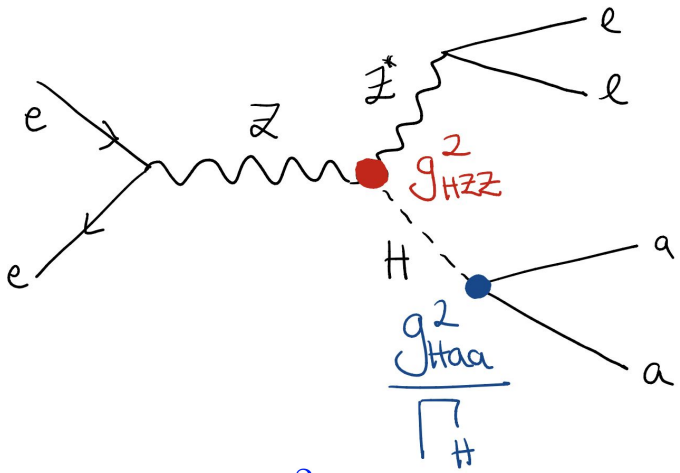
No, <u>direct measurement</u> is still limited by detector resolution to O(GeV)
[same as for LHC]

But then, what did we gain?

We can perform indirect measurements without assumptions!

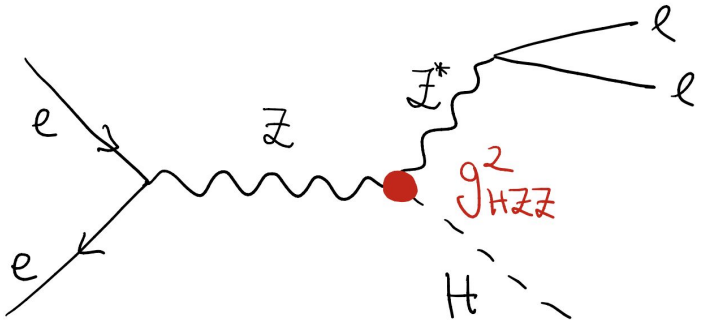
But then, what did we gain?

Exclusive final states (a la LHC)



$$\text{rate} \sim g^2_{HZZ} \times \frac{g^2_{Haa}}{\Gamma_H}$$

Inclusive final states (new at ILC)

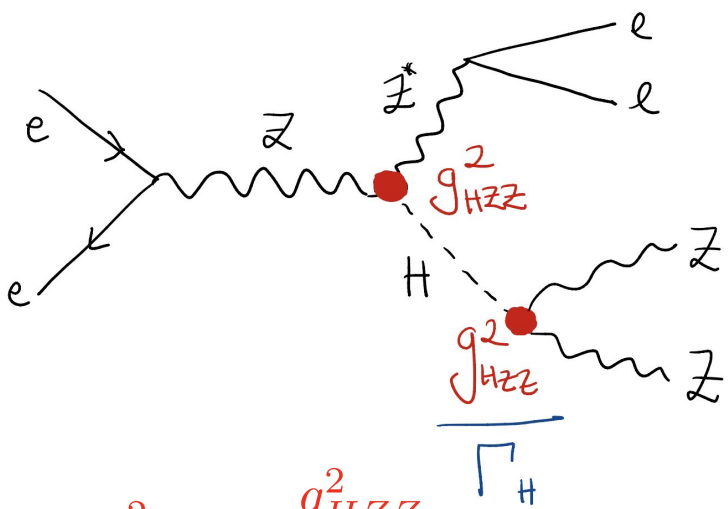


$$\text{rate} \sim g^2_{HZZ}$$

Measure g_{HZZ} and g_{Haa} and infer Γ_H from ratio of the two rates

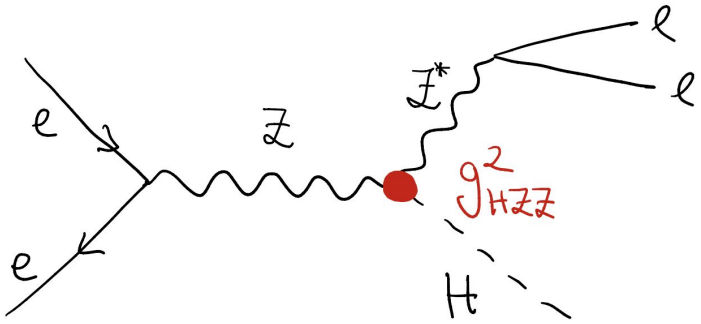
But then, what did we gain?

Exclusive final states (a la LHC)



$$\text{rate} \sim g^2_{HZZ} \times \frac{g^2_{HZZ}}{\Gamma_H}$$

Inclusive final states (new at ILC)



$$\text{rate} \sim g^2_{HZZ}$$

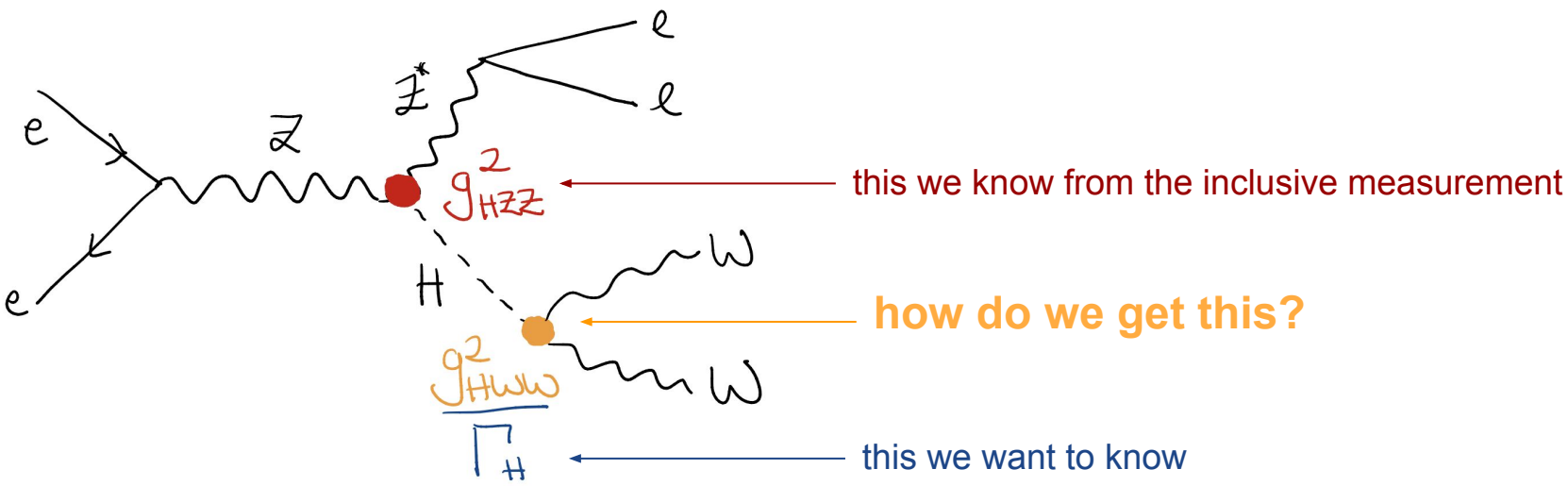
Can measure g_{HZZ} model indep.ly and infer Γ_H from ratio of the two rates

But..

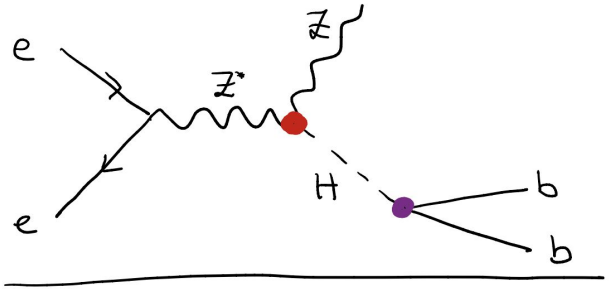
H→ZZ BR is tiny (2.6%, not yet requiring leptons) ⟶ limited statistics, high unc.!

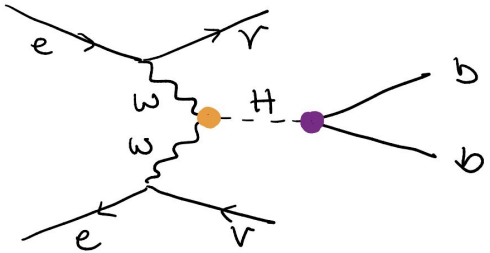
Idea: Use H → WW [higher BR of 21.4%]

How to **actually** measure the width?



Getting g_{HWW}

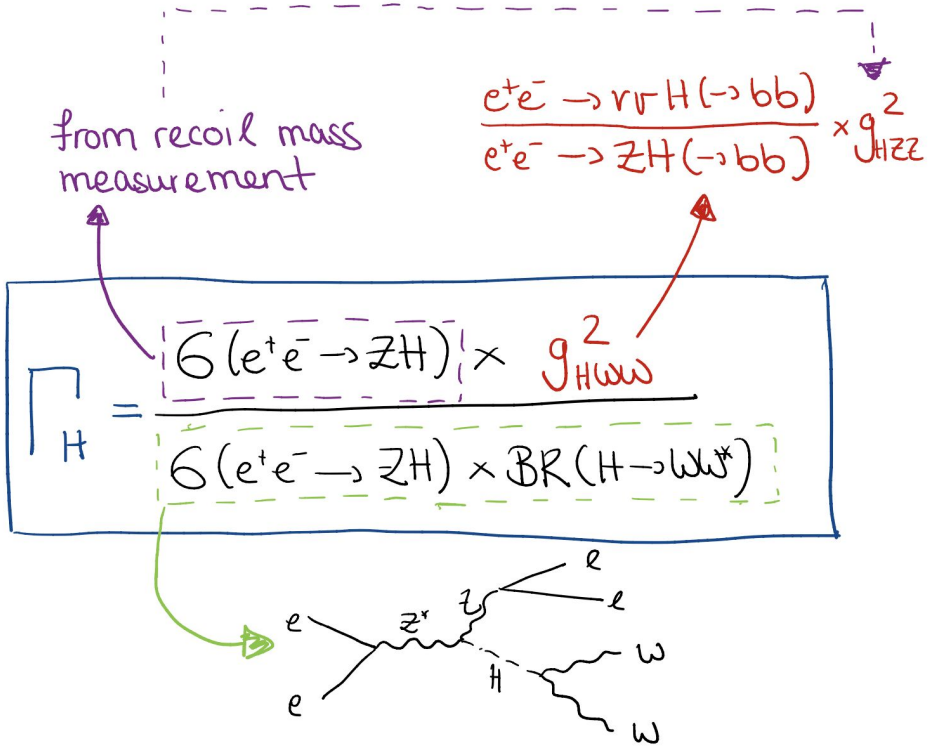




this we know from the inclusive measurement

$$\sim \frac{g_{HZZ}^2 \times \frac{g_{Hbb}^2}{\Gamma_H}}{g_{HWW}^2 \times \frac{g_{Hbb}^2}{\Gamma_H}}$$

Putting it together



Which precision can we achieve?

1.) ILC @ 250 GeV

2/ab luminosity [O(15y) running]

⟶ **3.9%** precision

2.) + ILC @ 500 GeV

assuming 4/ab additional lumi

higher W-fusion cross-section

⟶ **1.7%** precision

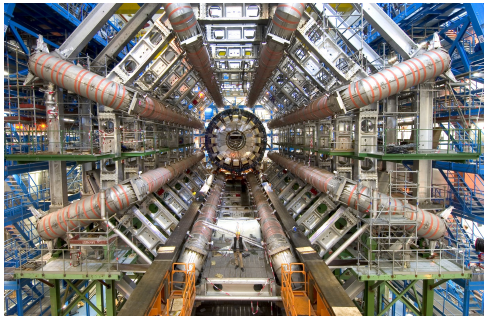
Backup

Precision estimates

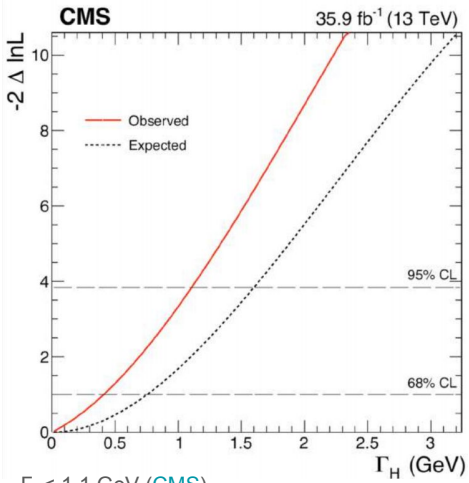
	ILC250		+ILC500	
	κ fit	EFT fit	κ fit	EFT fit
$g(hbb)$	1.8	1.1	0.60	0.58
$g(hcc)$	2.4	1.9	1.2	1.2
$g(hgg)$	2.2	1.7	0.97	0.95
$g(hWW)$	1.8	0.67	0.40	0.34
$g(h\tau\tau)$	1.9	1.2	0.80	0.74
$g(hZZ)$	0.38	0.68	0.30	0.35
$g(h\gamma\gamma)$	1.1	1.2	1.0	1.0
$g(h\mu\mu)$	5.6	5.6	5.1	5.1
$g(h\gamma Z)$	16	6.6	16	2.6
$g(hbb)/g(hWW)$	0.88	0.86	0.47	0.46
$g(h\tau\tau)/g(hWW)$	1.0	1.0	0.65	0.65
$g(hWW)/g(hZZ)$	1.7	0.07	0.26	0.05
Γ_h	3.9	2.5	1.7	1.6
$BR(h \to inv)$	0.32	0.32	0.29	0.29
$BR(h \to other)$	1.6	1.6	1.3	1.2

LHC & Higgs width

- Famous discovery of Higgs boson in 2012
- Measurement difficulties: relatively small mass resolution
- Direct strategies
  - Convolution experimental mass resolution and natural width
    - Γ_H< 2.6 GeV (ATLAS), Γ_H< 1.1 GeV (CMS) 95% CL
  - From lifetime
    - Γ_H> 3.5 e-3 eV (CMS) 95% CL



Our favourite current Higgs experiment ;)



Γ_H< 1.1 GeV (CMS)

LHC & Higgs width

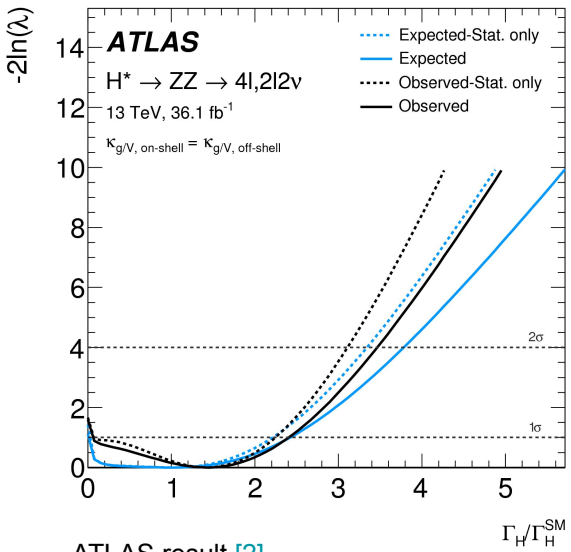
- Indirect strategy Higgs decay: on-shell / off-shell

$$\sigma_{\text{on}} \sim \int \frac{\mathrm{d}s}{(s-m_Z^2)^2+\Gamma_Z^2 m_Z^2} \propto \frac{1}{\Gamma_Z}$$

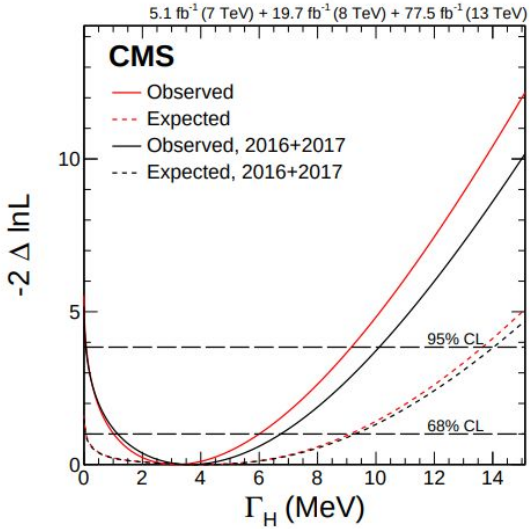
$$\sigma_{\text{off}} \sim \int_{s \gg m_Z^2} \frac{\mathrm{d}s}{(s-m_Z^2)^2+\cancel{\Gamma_Z^2 m_Z^2}}$$

approx.

$$\Gamma \propto \frac{\sigma_{\text{off}}}{\sigma_{\text{on}}}$$



ATLAS result [2]



CMS result [3]