



Higgs: what next?

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Summary

- Run I big summary
 - Higgs, massa, couplings, ...
- Higgs @ Run II
 - Nuove misure
 - ttH, HH
 - Misure template e differenziali
 - Higgs come strumento



Dall'annuncio ...

- 4 Luglio 2012 Annuncio scoperta Higgs boson $> 5\sigma$ significance

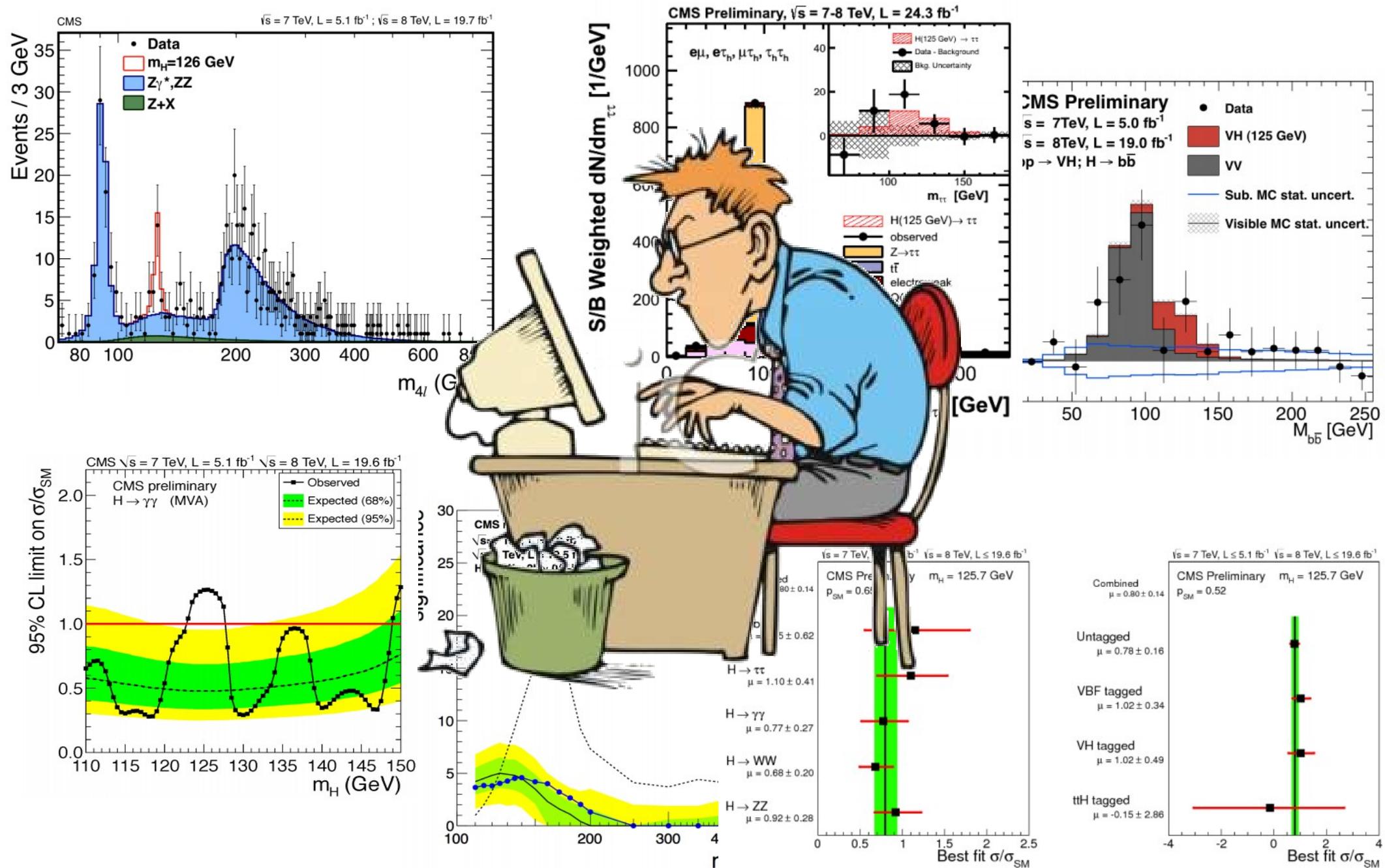




... **a** ...



... i mesi seguenti



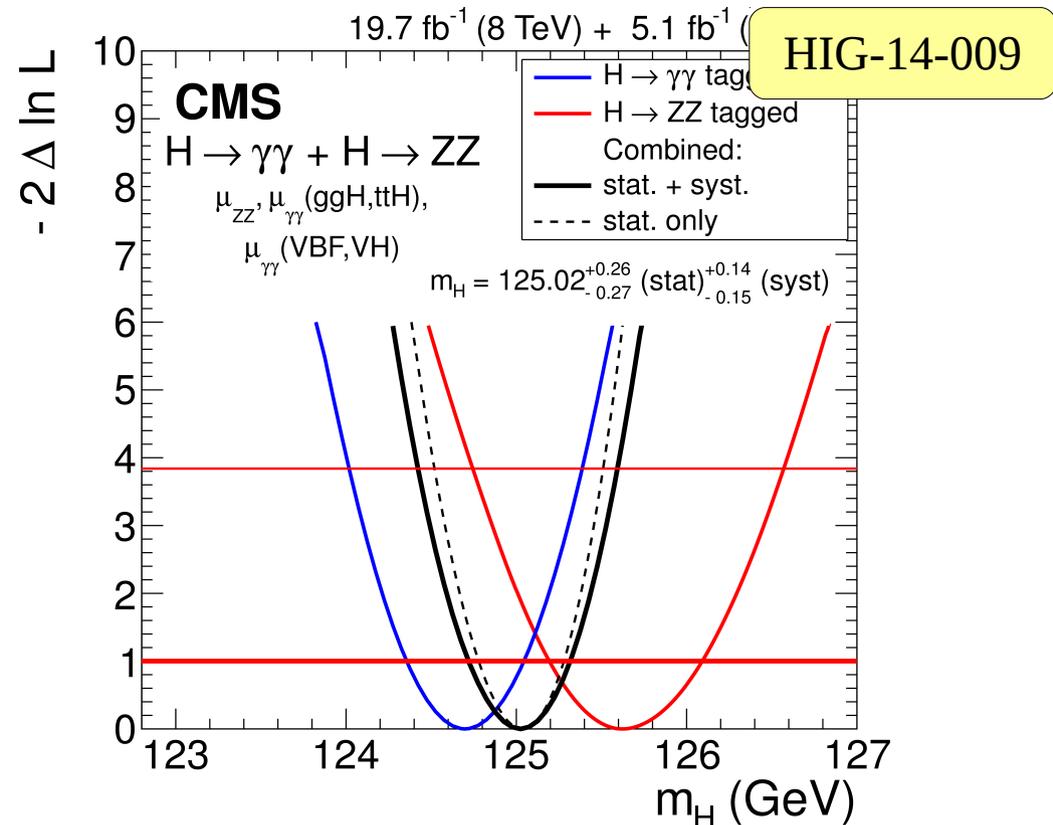
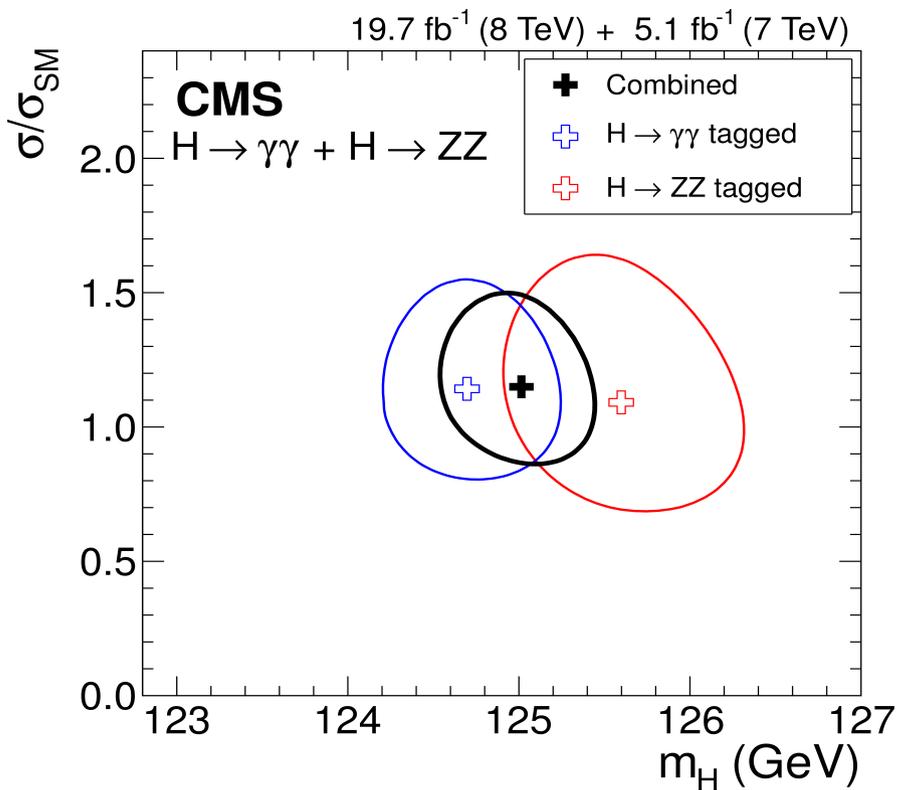


Run I post-scoperta

- Due linee guida
 - Misure di **precisione** ed esclusione di **modelli non SM**
 - **Combinazione** in **CMS** e combinazione **ATLAS+CMS**



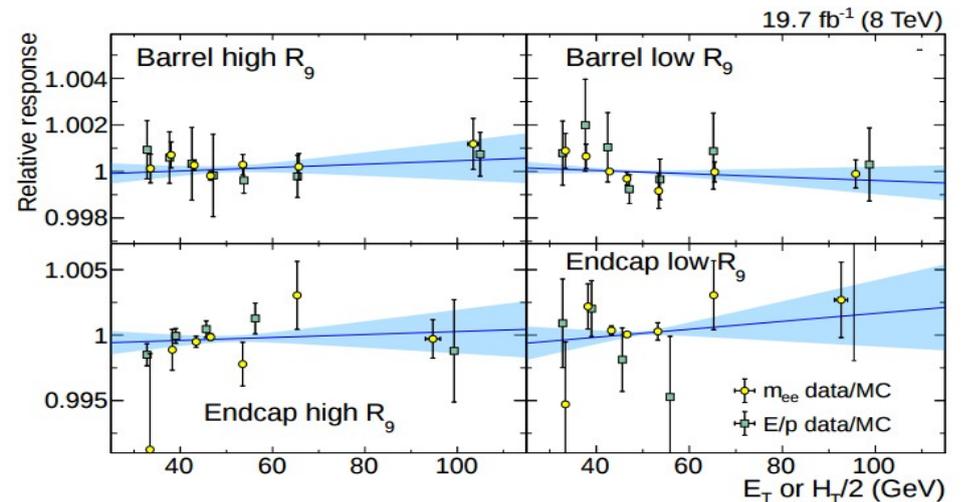
Massa



• $m_H = 125.02^{+0.26}_{-0.27}$ (stat)^{+0.14}_{-0.15} (syst) GeV

• Molto lavoro fatto per comprendere ogni singola sistemica

• e.g. energy scale e linearità

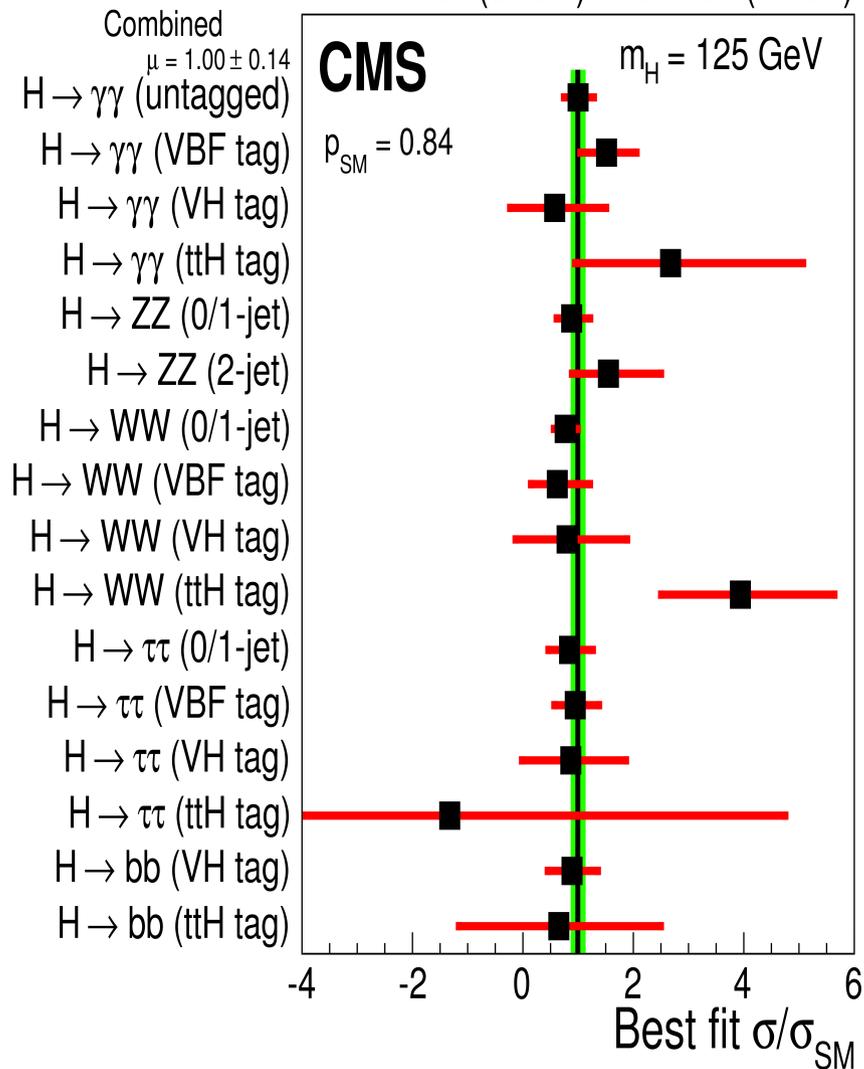




Couplings

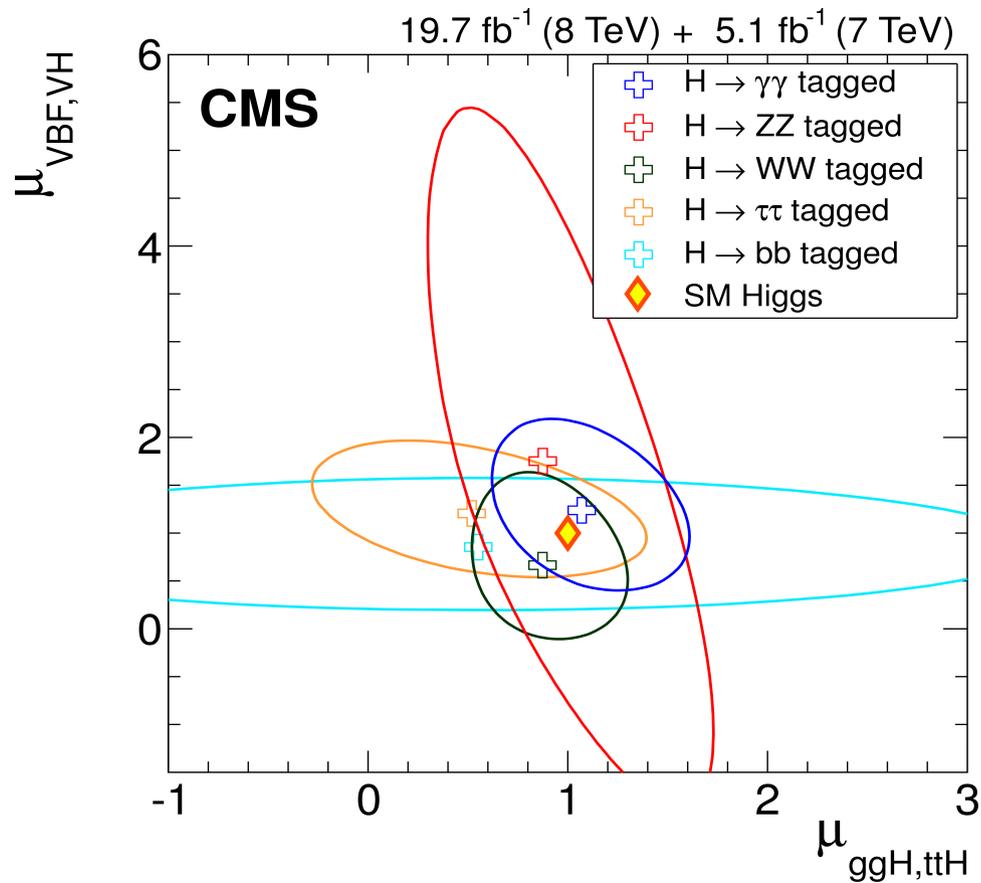
HIG-14-009

19.7 fb⁻¹ (8 TeV) + 5.1 fb⁻¹ (7 TeV)



• Signal strength

• $\mu = 1.00 \pm 0.09$ (stat) $^{+0.08}_{-0.07}$ (theo) ± 0.07 (syst)





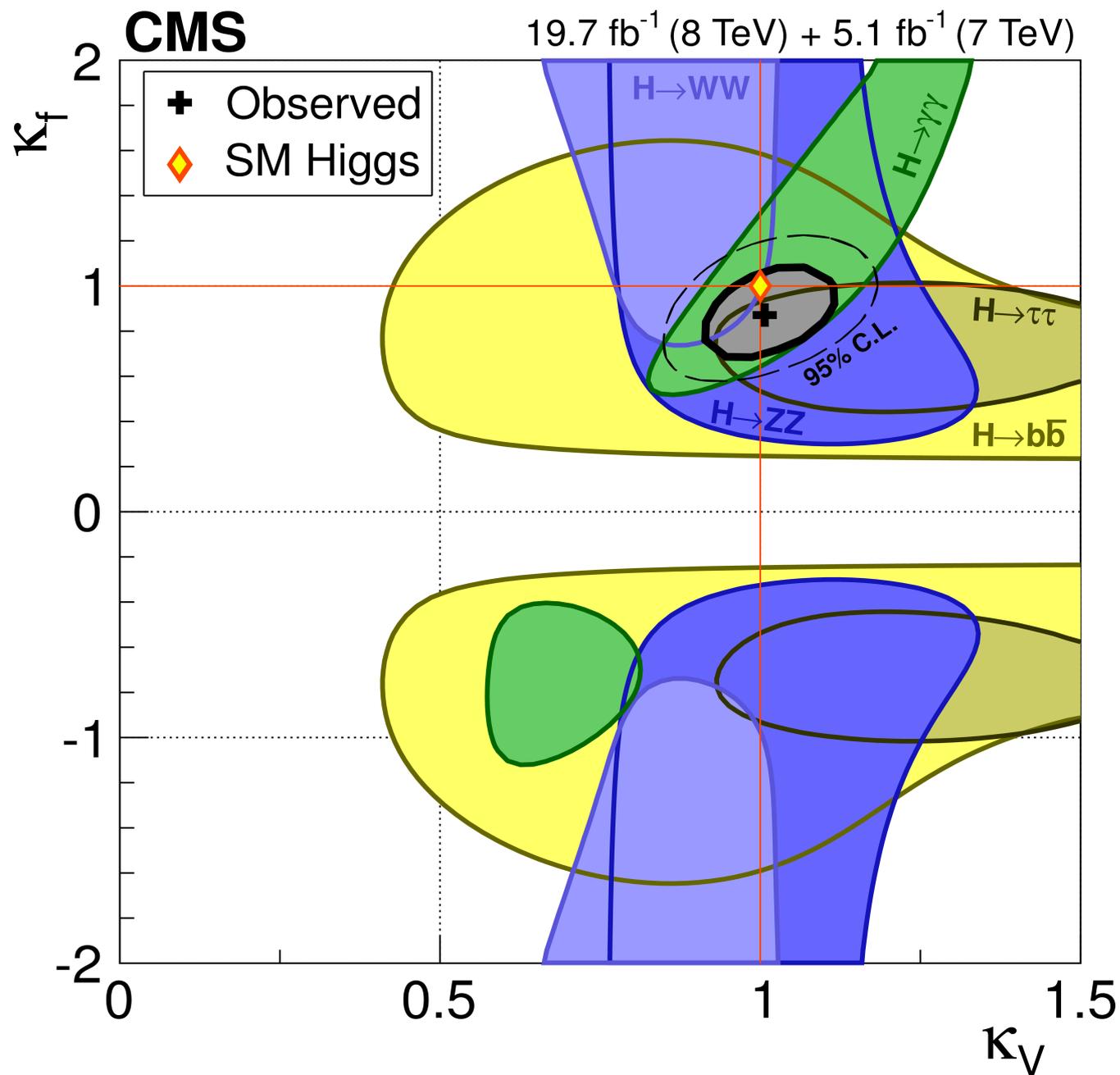
Couplings in un altro linguaggio

• Produzione

$$\kappa_i^2 = \sigma_i / \sigma_i^{\text{SM}}$$

• Decadimento

$$\kappa_i^2 = \Gamma_{ii} / \Gamma_{ii}^{\text{SM}}$$

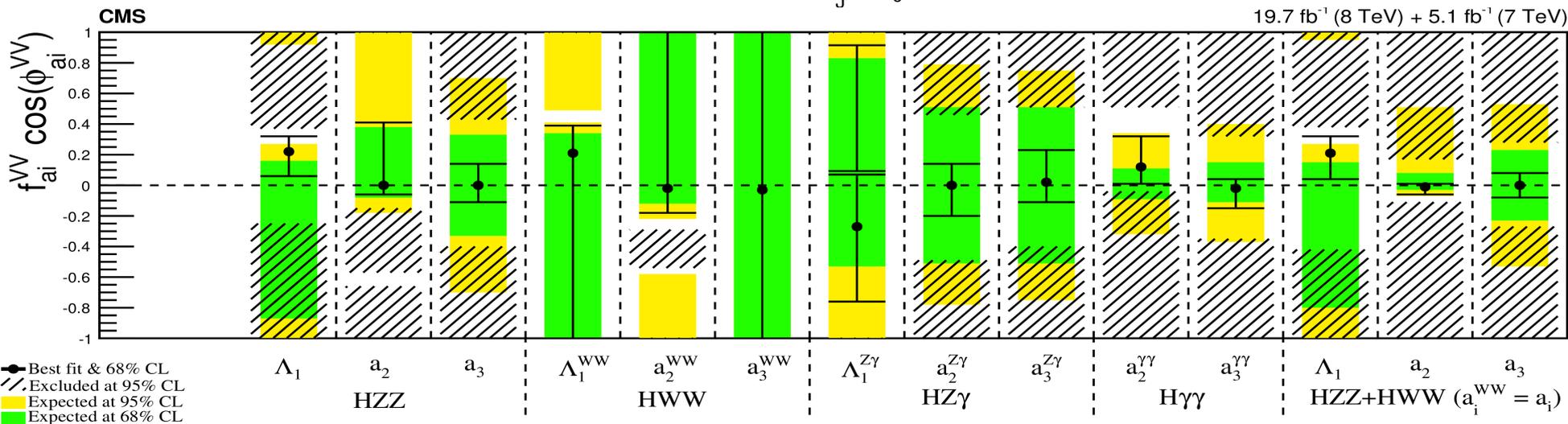
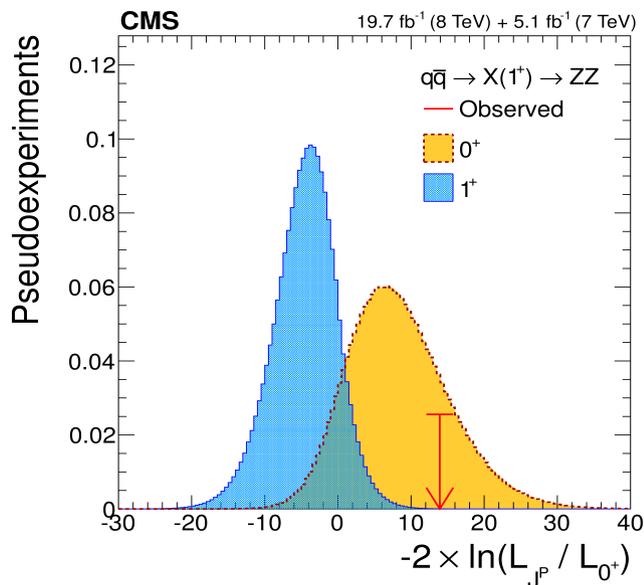
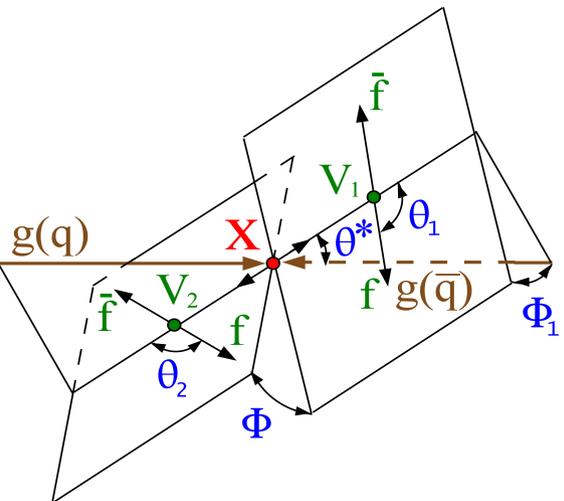




Spin & anomalous couplings

HIG-14-018

- $H \rightarrow ZZ$
- $H \rightarrow WW$
- $H \rightarrow \gamma\gamma$
- Test di diversi modelli non SM O^{++}
- Anomalous couplings



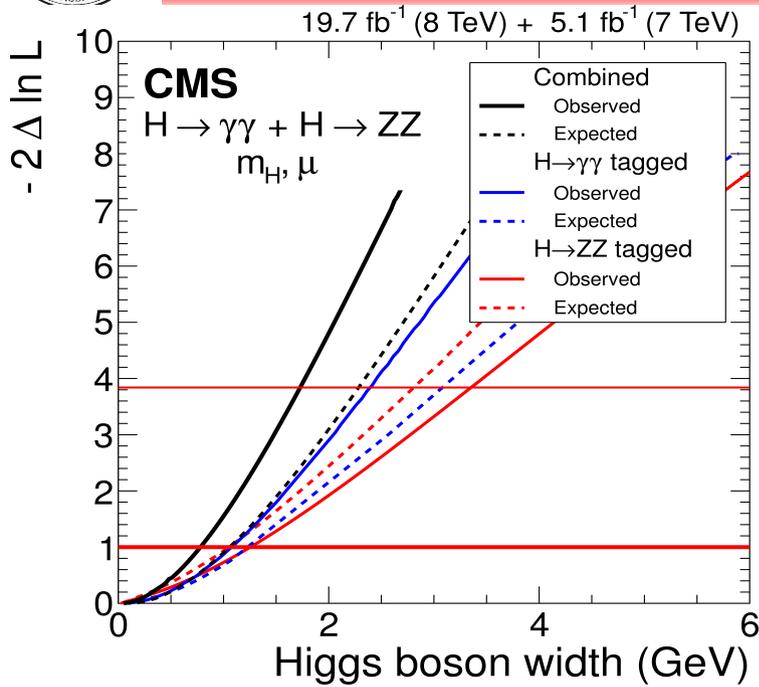
$$A(HV_1V_2) \sim \left[a_1^{V_1V_2} + \frac{\kappa_1^{V_1V_2} q_{V_1}^2 + \kappa_2^{V_1V_2} q_{V_2}^2}{\left(\Lambda_1^{V_1V_2}\right)^2} \right] m_V^2 \epsilon_{V_1}^* \epsilon_{V_2}^* + a_2^{V_1V_2} f_{\mu\nu}^{*(V_1)} f^{*(V_2),\mu\nu} + a_3^{V_1V_2} f_{\mu\nu}^{*(V_1)} \tilde{f}^{*(V_2),\mu\nu}$$

Λ₁ term
leading momentum expansion
a₂ term
CP even state
a₃ term
CP odd state



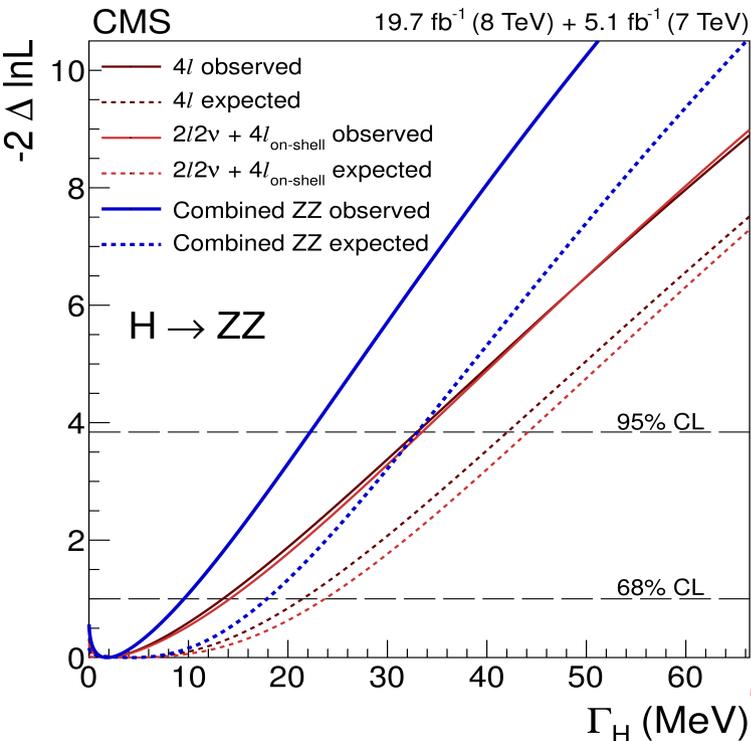
Higgs width $\Gamma_H \sim 4 \text{ MeV}$ @SM

HIG-14-009
HIG-14-002
HIG-14-036
HIG-14-032



- Misura diretta da **HZZ + Hγγ**
- Misura indiretta da **HZZ + HWW**

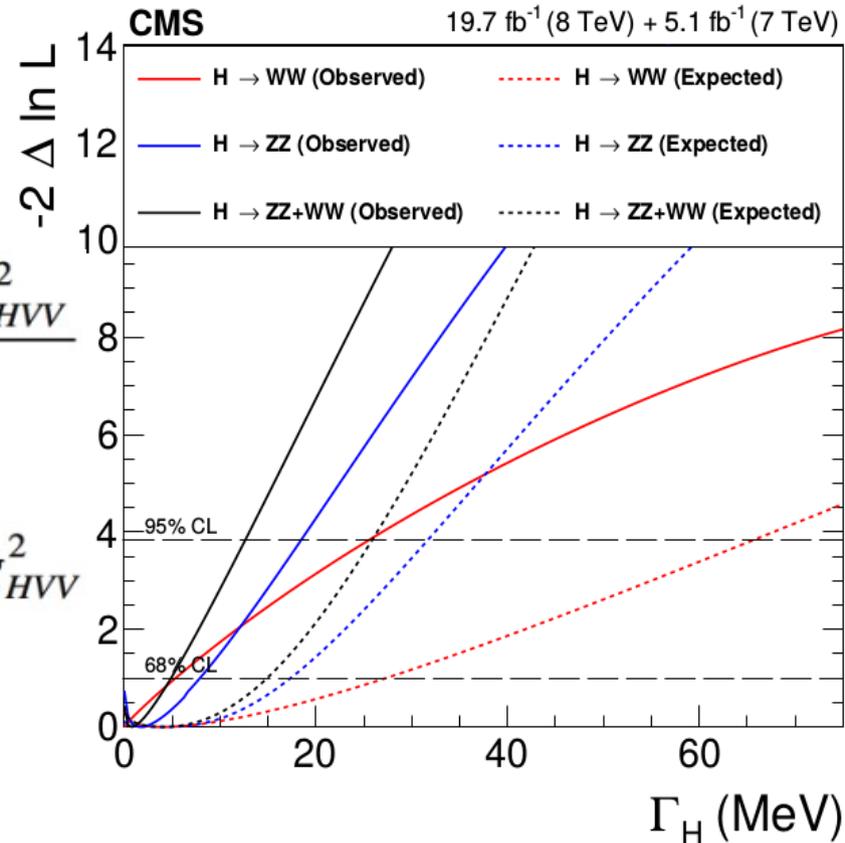
$$\frac{d\sigma_{gg \rightarrow H \rightarrow VV}}{dm_{VV}^2} \propto g_{ggH}^2 g_{HVV}^2 \frac{F(m_{VV})}{(m_{VV}^2 - m_H^2)^2 + m_H^2 \Gamma_H^2}$$



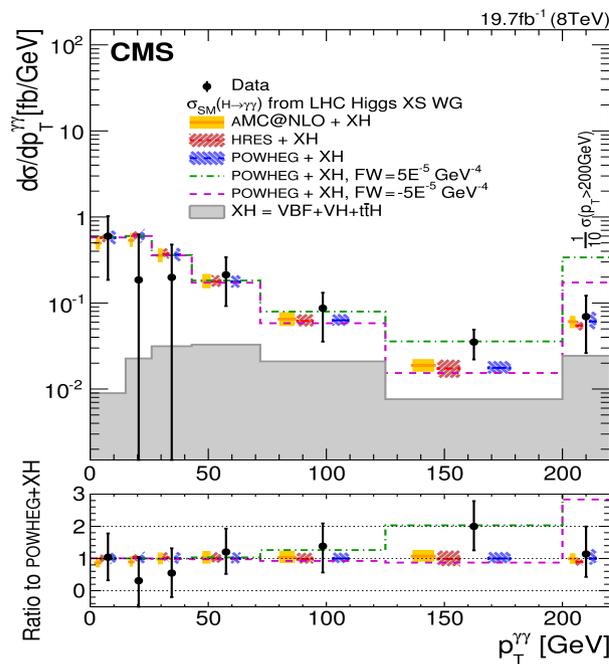
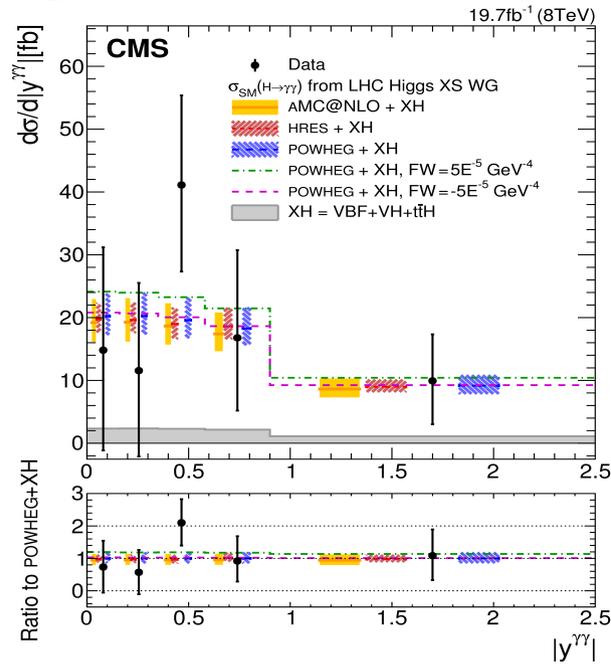
$$\frac{d\sigma_{gg \rightarrow H \rightarrow VV}^{on-shell}}{dm_{VV}} \propto \frac{g_{ggH}^2 g_{HVV}^2}{\Gamma_H}$$

$$\frac{d\sigma_{gg \rightarrow H \rightarrow VV}^{off-shell}}{dm_{VV}} \propto g_{ggH}^2 g_{HVV}^2$$

$\Gamma_H < 13 \text{ MeV}$



Misure fiduciali e differenziali

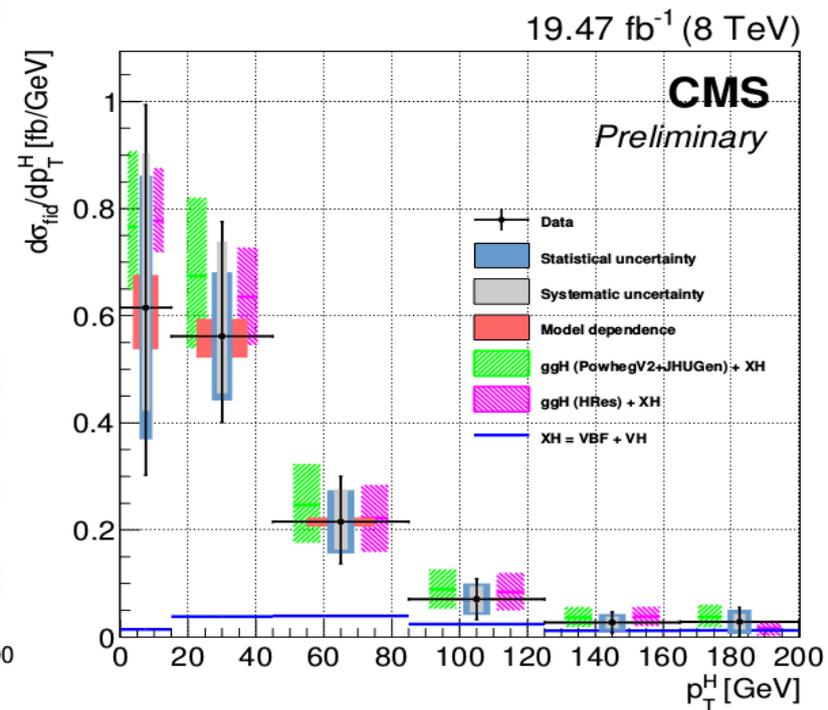
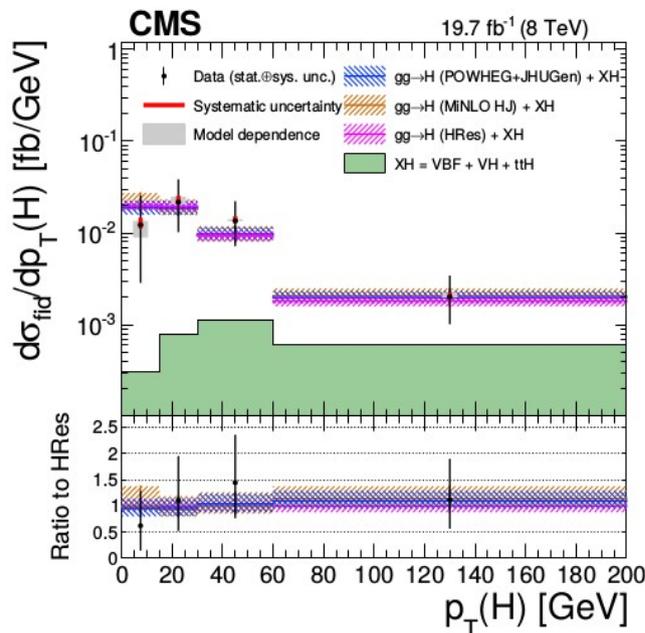
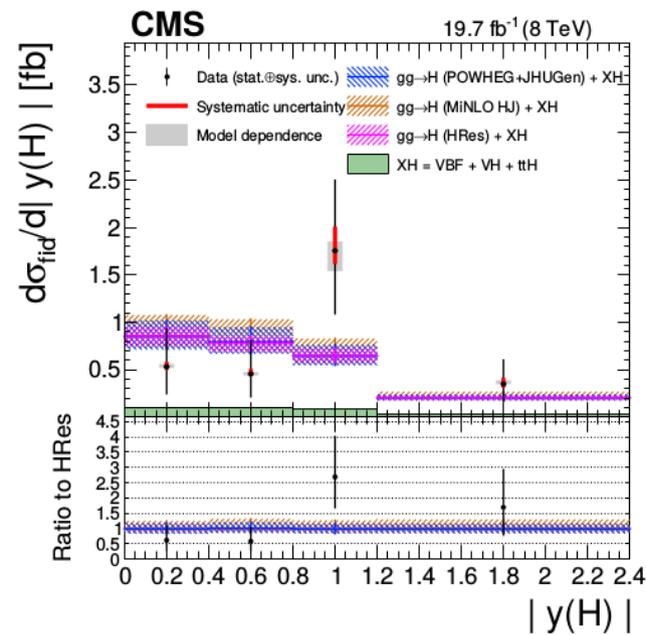


• Misure fiduciali e differenziali

- H → γγ
- H → ZZ
- H → WW

HIG-14-016
HIG-14-028
HIG-15-010

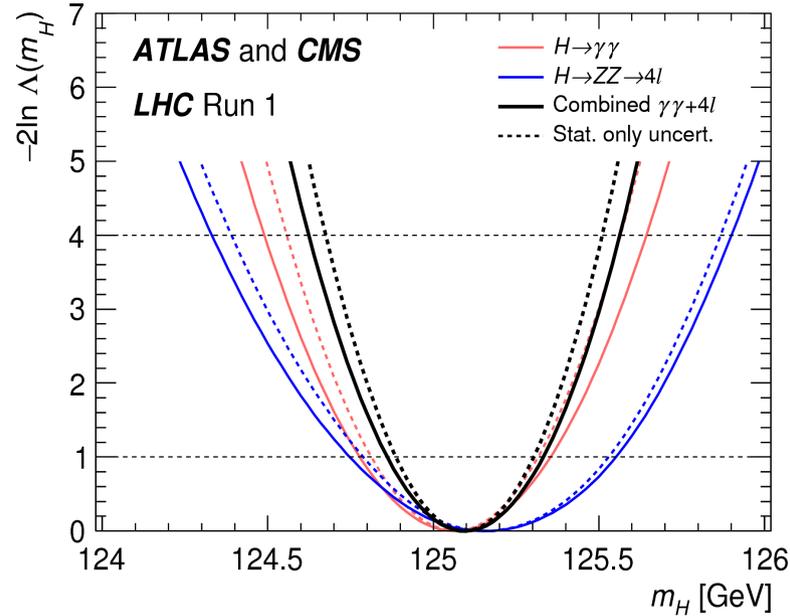
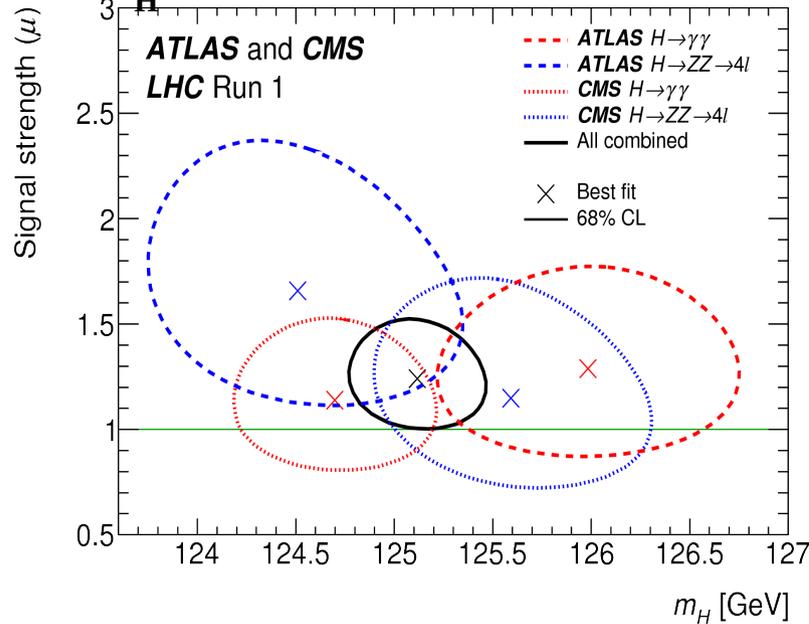
• Indipendenza da modelli





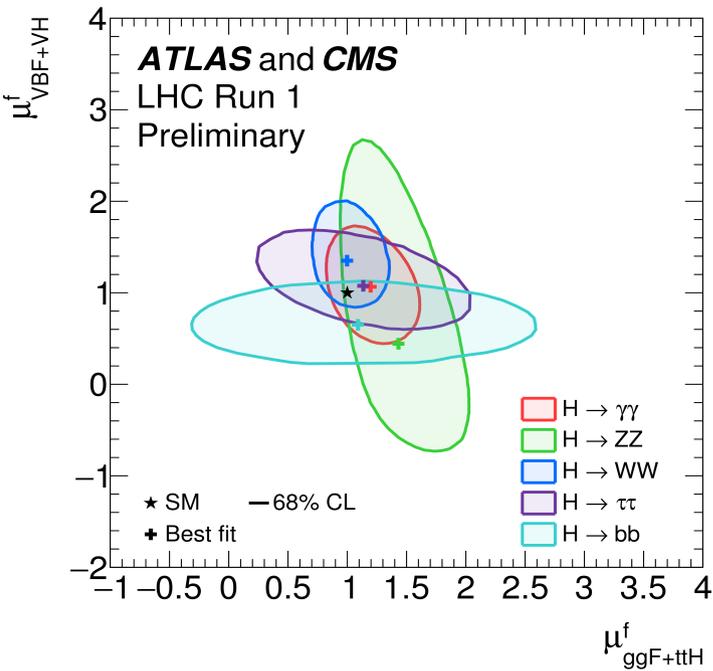
Combinazione ATLAS + CMS Run I

$$m_H = 125.09 \pm 0.24 \text{ GeV} = 125.09 \pm 0.21 \text{ (stat)} \pm 0.11 \text{ (syst)} \text{ GeV}$$



HIG-14-042
HIG-15-002

- ATLAS + CMS
- Massa
- Couplings



- Molto lavoro su cosa **correlare** e su cosa **non correlare**
- Combinando miglioriamo per un fattore statistico
- Possiamo migliorare ulteriormente correlando in maniera corretta le incertezze
- e.g. pdf uncertainty per il segnale è correlata tra ATLAS e CMS

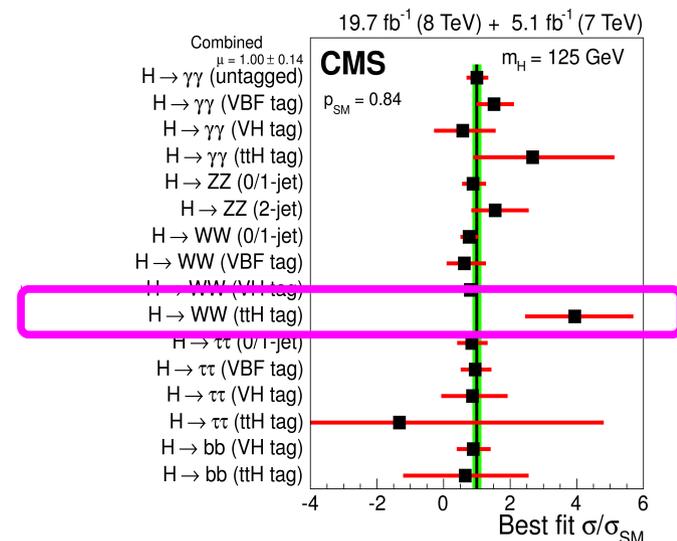
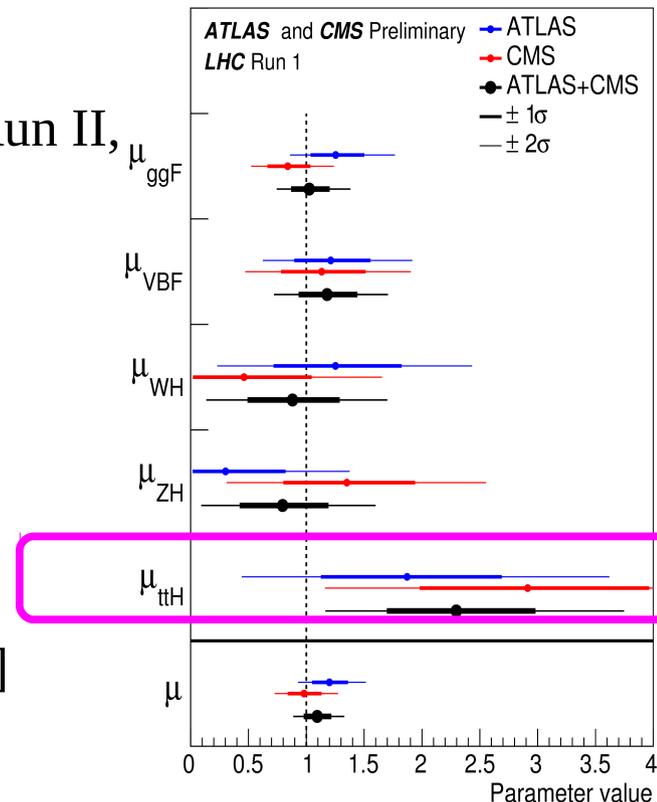
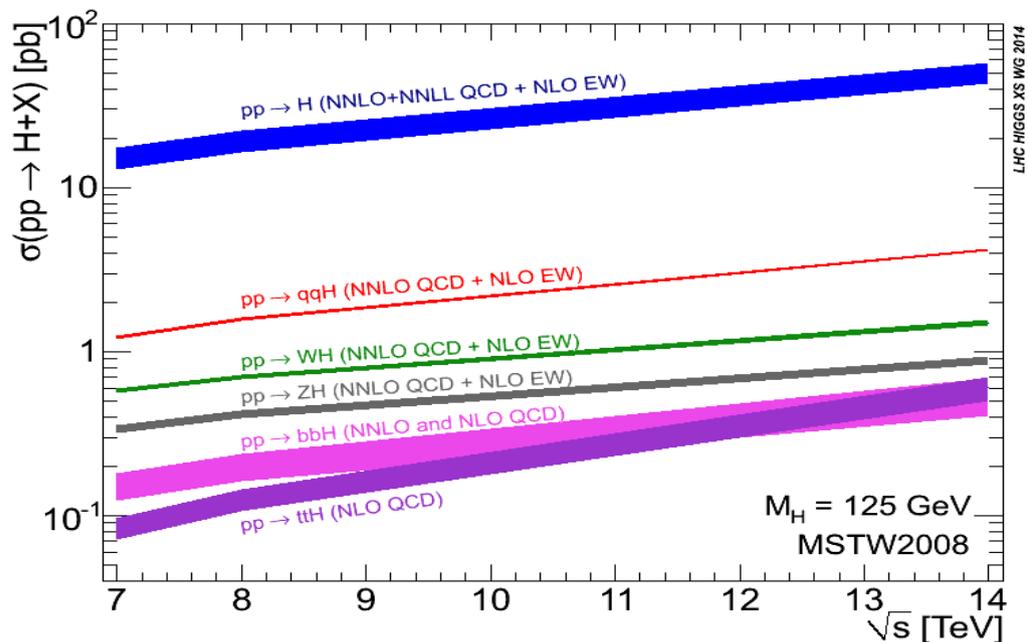


Higgs @ Run II

- Alcune **deviazioni** @Run I
- Interessante verificare se sono statisticamente significative @Run II, se compatibile con SM o ...

- **ttH** sotto i riflettori

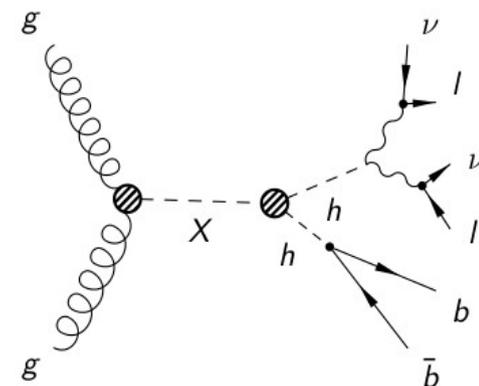
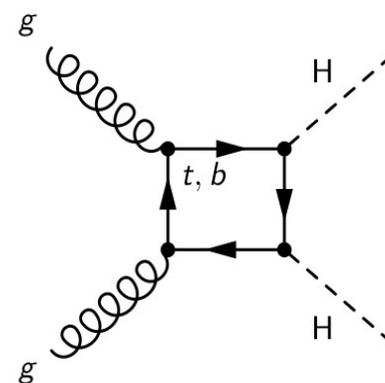
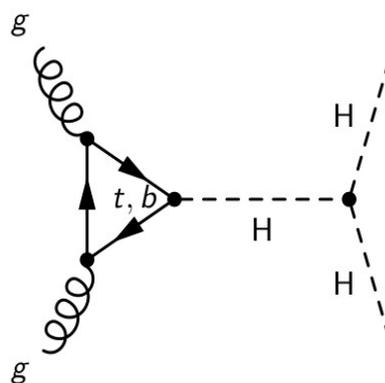
- Sezione d'urto ttH **x4** da 8 → 13 TeV
- 2/fb @ 13 TeV ~ 8/fb @13 TeV
- + miglioramenti = ~ expected performance [<http://cern.ch/go/k6lw>]



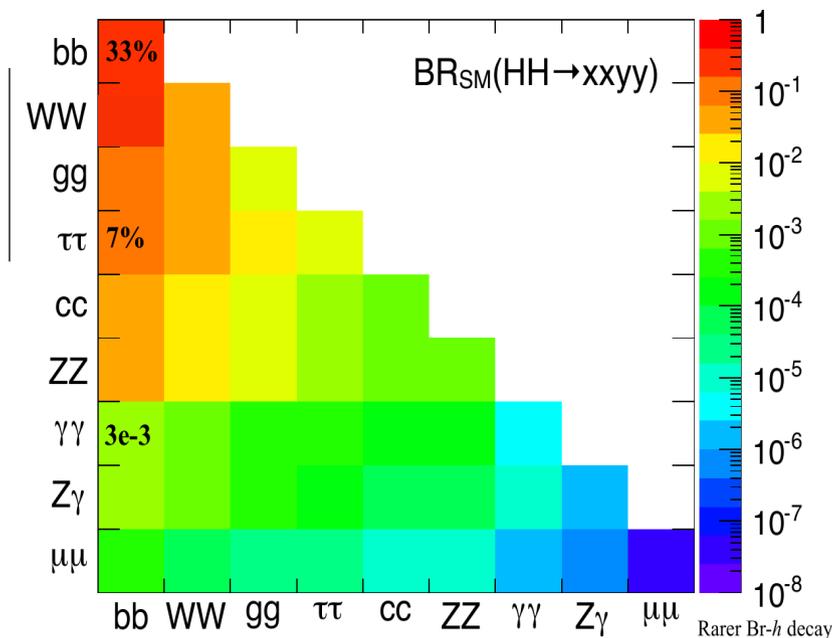
Higgs self-coupling ... long term project (?)

• Higgs self coupling → Produzione HH

- $\sigma(ggHH) \sim 34 \text{ fb @ } 13 \text{ TeV}$
- Interferenza distruttiva in SM
- Aumento della sezione d'urto se
 - Piccole deviazioni vs SM
 - Presenza di particelle massive che decadono in HH



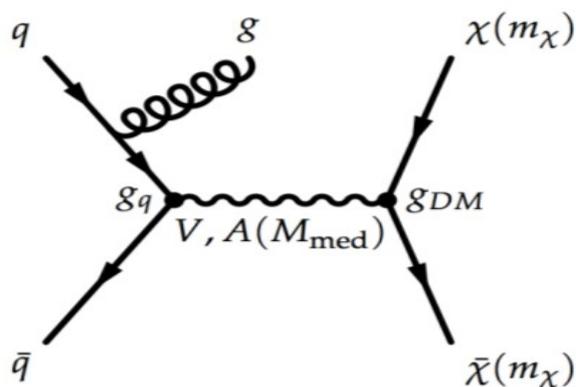
- Diversi stati finali
 - $HH \rightarrow \mathbf{bbbb}$
 - $HH \rightarrow \mathbf{bb\gamma\gamma}$
 - $HH \rightarrow \mathbf{bb\tau\tau}$
 - $HH \rightarrow \mathbf{WWbb}$





Higgs come strumento

- Higgs come strumento per nuova fisica
- **Dark Matter e mono-Higgs**
 - CMS EXO workshop in Venezia inizio Nov [<https://agenda.infn.it/conferenceDisplay.py?confId=9973>]



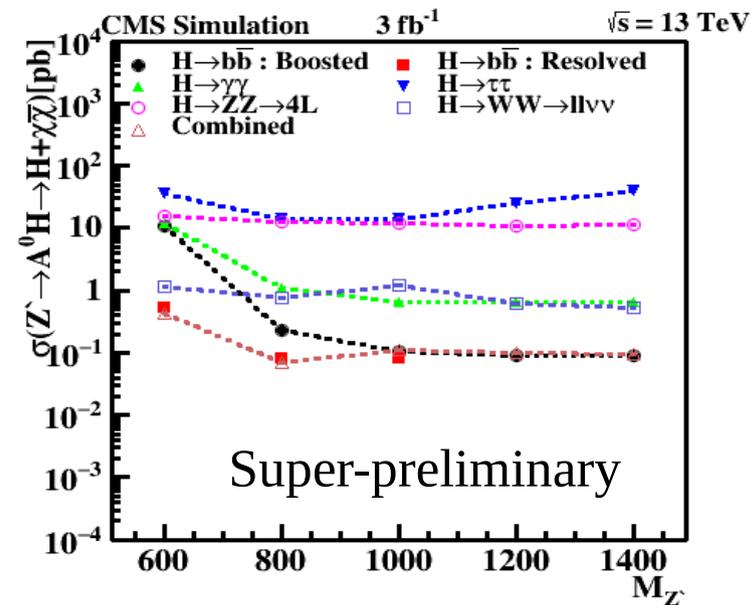
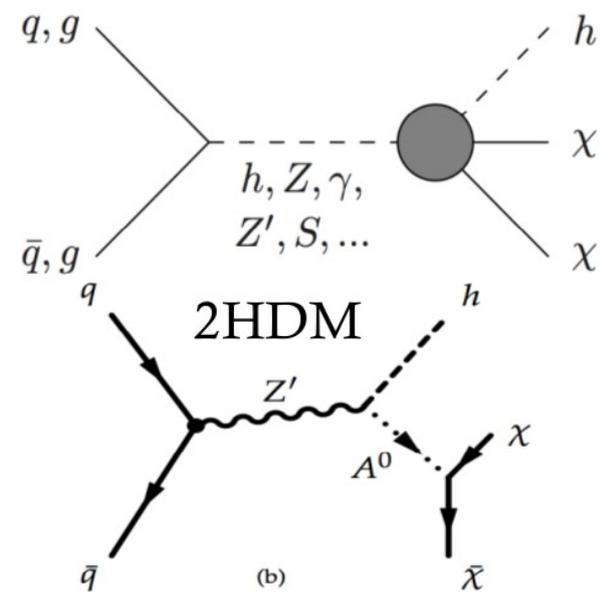
Mono-“X” searches

- Diversi stati finali

- $H > b\bar{b}$
- $H > \tau\tau$
- $H > \gamma\gamma$
- $H > WW$
- $H > ZZ$

- Model-independent

- Model-dependent





Come produrre risultati duraturi e robusti

↑
semplicità

- **Signal strength** → 100% dipendente da SM: solo sezione d'urto misurata
- Couplings o $\mu_{\text{VBF}}/\mu_{\text{ggH}}$, ... → più parametri liberi, meno dipendenza da SM
 - Ma nella produzione ggH, SM è assunto!
- **Misura differenziale** → 100% indipendente da SM ... ma ... statistica MOLTO elevata è richiesta

↓
Indipendenza SM

- Pseudo-observables ~ **Template (a.k.a. simplified) cross sections**
 - Definire “segnali” da misurare non solo come ggH, VBF, ... ma più dettagliati
 - e.g. **ggH+0 jet, ggH+1jet, ggH+2jet, ...**
 - Liberarsi da alcune *assunzioni* teoriche
 - Liberarsi da alcune *sistematiche* teoriche (e.g. jet binning)
- Coordinazione tra **ATLAS e CMS** e comunità **teorica** → YR4



Higgs è ancora sulla cresta dell'onda

- Higgs @ Run I

- LA nuova particella scoperta finora a LHC
- **Molte analisi, molti risultati**
- **Caratterizzazione** della nuova particella

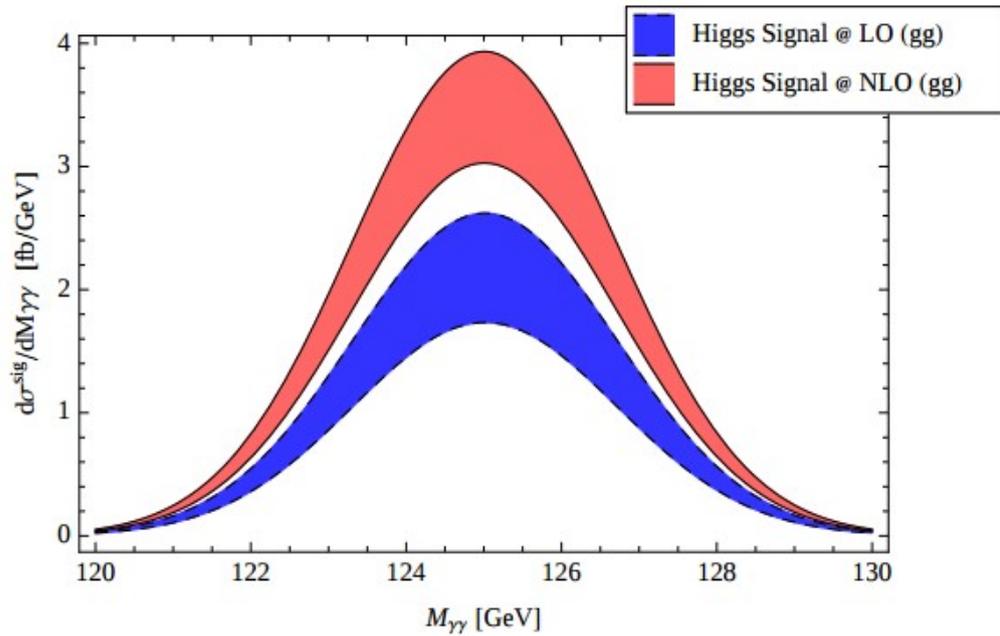
- Higgs @ Run II

- Riscoperta Higgs: sezione d'urto come SM?
- Continua caratterizzazione
- Riflettori puntati su deviazioni osservate @ Run I
- **ttH**
- La maggior parte delle analisi Higgs hanno come target *Moriond* o *Summer16*
 - **$H\gamma\gamma$, Hbb , HZZ , HWW , $H\tau\tau$**
- Nuove strategie di misura: template analyses & misure differenziali
- Piani per Run II:
 - Higgs Self coupling & **HH**
- HIG-EXO workshop 3-4 dicembre [<https://indico.cern.ch/event/462120/>]

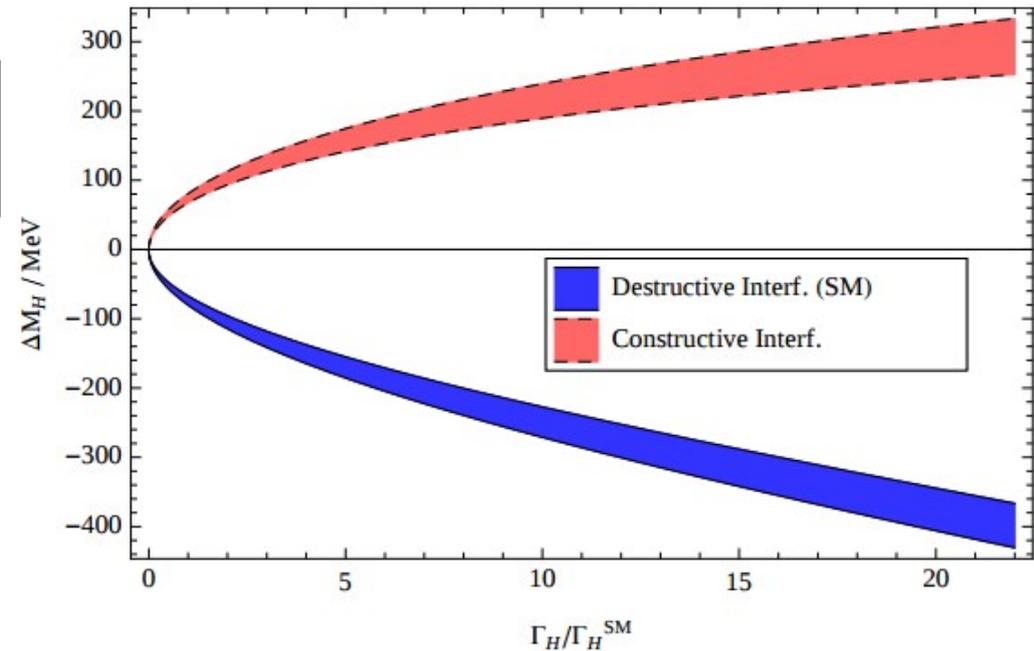
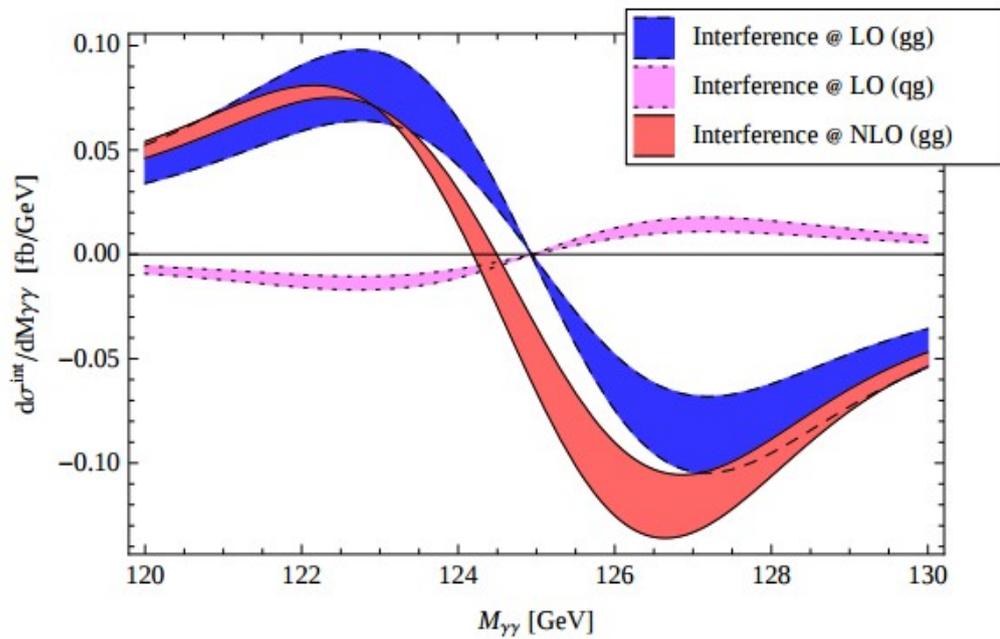




Higgs width $\Gamma_H \sim 4 \text{ MeV} @\text{SM}$



- $H\gamma\gamma$
- Higgs width via interferometry
- ggH vs VBF





EXO Higgs

- Higgs in canali esotici
 - Molte molte molte ... molte ... analisi
 - <http://cms-results.web.cern.ch/cms-results/public-results/publications/HIG/EXO.html>
 - Diverse analisi Run I in fase di completamento