



# Higgs exotics

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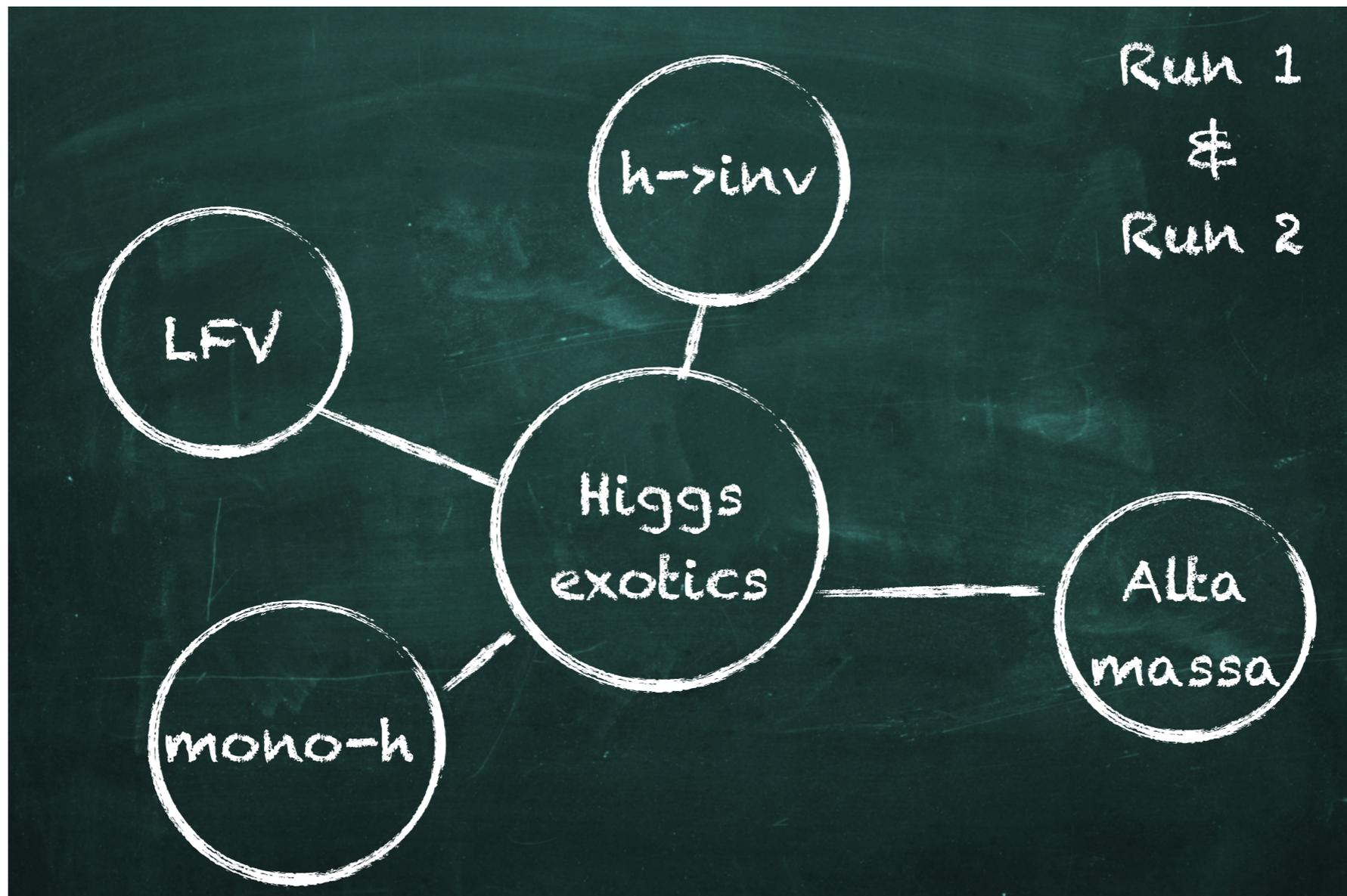
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*Per le collaborazioni ATLAS e CMS*

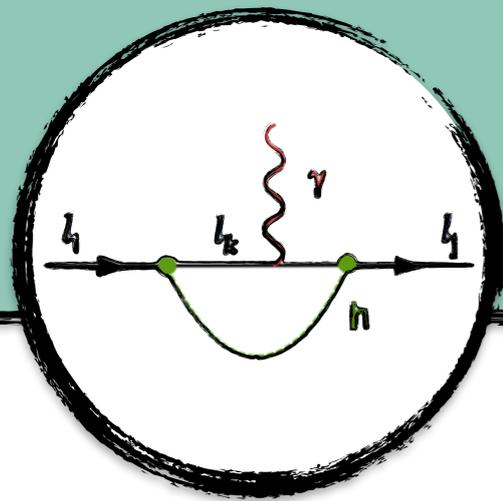


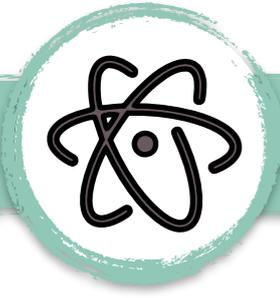
# Higgs exotics

- ▶ Settore di ricerca molto ampio che copre una vasta gamma di modelli teorici
  - Ricerche con Higgs Standard (h)
  - Ricerche con Higgs pesanti (H)



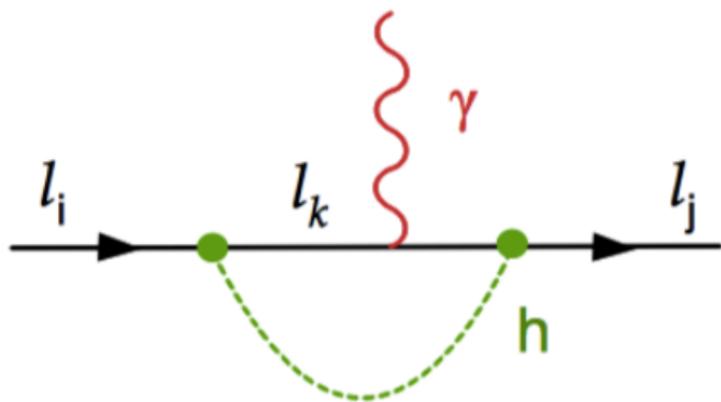
# Lepton Flavour Violation





# Lepton Flavour Violation (LFV)

- ▶ Il numero leptonico ed il sapore leptonico sono simmetrie accidentali dello SM.
- ▶ Decadimenti con LFV sono fortemente soppressi nello SM
- ▶ Permessi in teorie BSM(fino ad una certa mass scale): SUSY, 2HDM, composite Higgs boson models...



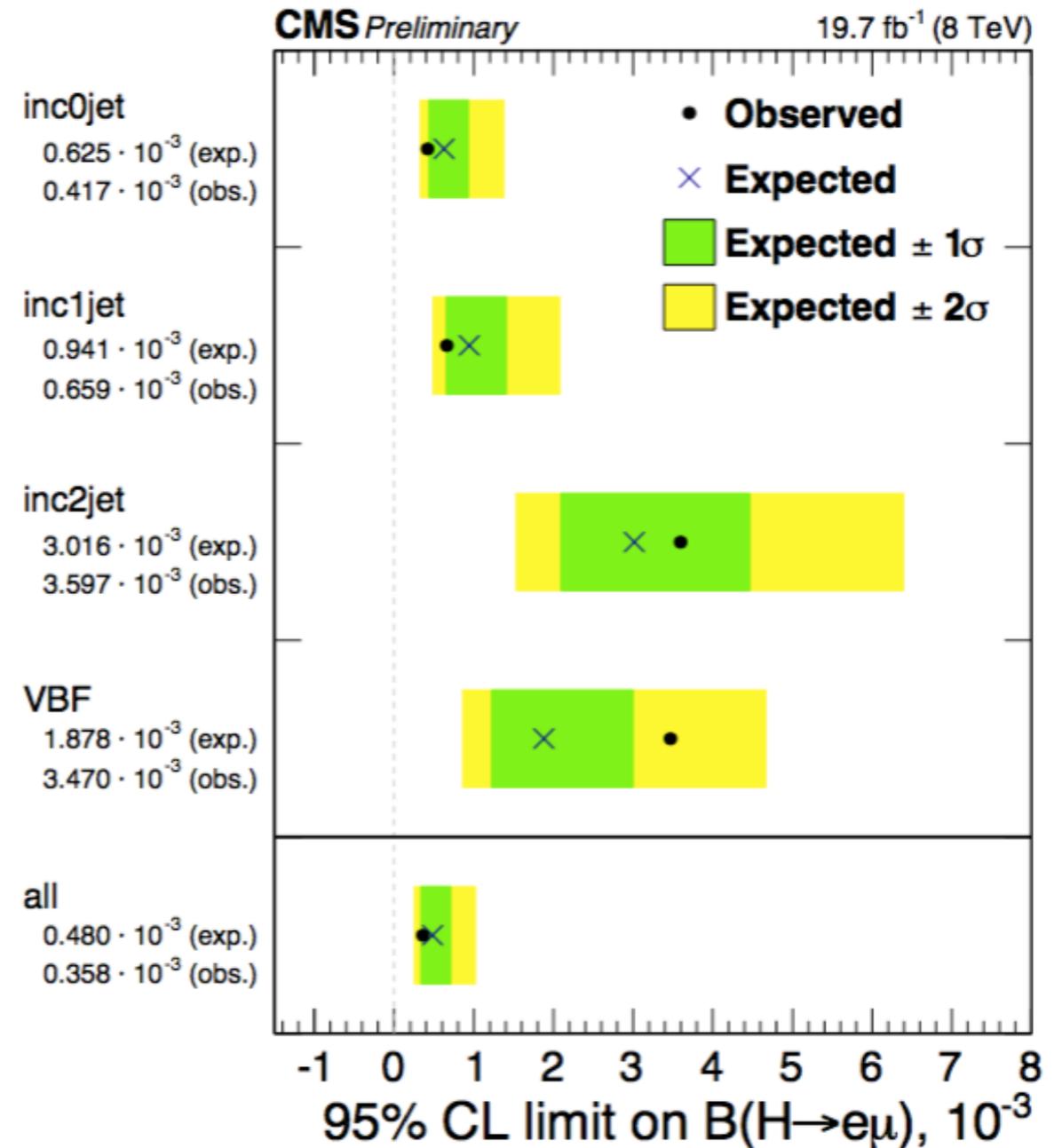
Transizioni con LFV possono avvenire tramite un bosone di Higgs virtuale in modelli BSM

	pre-LHC (da ricerche indirette)	ATLAS	CMS
$h \rightarrow \mu \tau_{had}$	<b>O(10%)</b>	✓	✓
$h \rightarrow e \tau_{lep}$		✓	✓
$h \rightarrow \mu \tau_{lep}$		Ricerca simultanea	✓
$h \rightarrow e \tau_{had}$		✓	✓
$h \rightarrow e \mu$		<b>O(10<sup>-8</sup>)</b>	X



# CMS $h \rightarrow e\mu$

- ▶ Selezionati leptoni con carica opposta
- ▶ Analisi suddivisa in categorie
  - Selezione con 0,1,2 jet
  - VBF
  - Nessun eccesso rispetto al fondo atteso è stato osservato



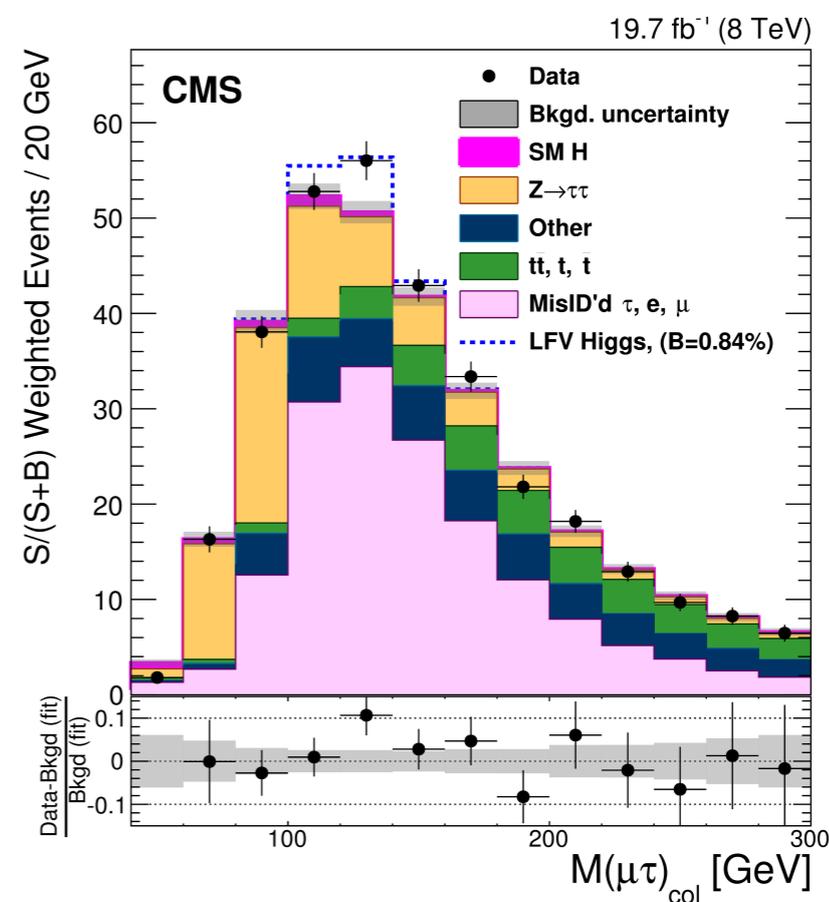
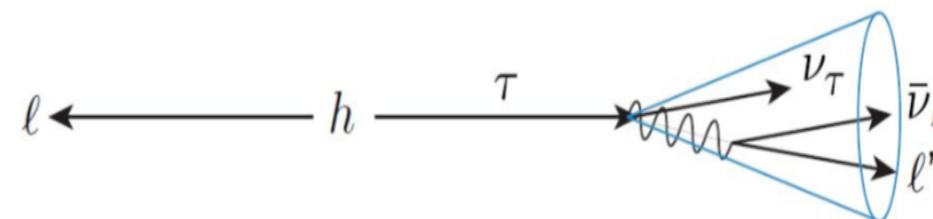
$B(H \rightarrow e\mu) < 0.036\% (0.0048\%) @ 95\% \text{ C.L.}$



# CMS $h \rightarrow \ell\tau$

- ▶ Analisi molto simili sia per il decadimento adronico che leptonico del tau
- ▶ Leptoni con carica opposta e ben separati
  - Si richiede che il leptone proveniente dal decadimento del tau abbia sapore diverso rispetto a quello proveniente dall'Higgs
- ▶ Analisi suddivisa in categorie a seconda del numero di jet: 0(ggF), 1(ggF, VH), 2(VBF)
- ▶ Criteri di selezione ottimizzati per ogni categoria
- ▶ Fondi principali:  $Z \rightarrow \tau\tau$ , leptoni erroneamente identificati in  $W$ +jets e QCD produzione multijet

## Massa collineare variabile discriminante



**Eccesso di  $2.4\sigma$  in  $H \rightarrow \mu\tau$   $Br(H \rightarrow \mu\tau) < 1.51\%$  (0.75%)**  
 **$Br(H \rightarrow e\tau) < 0.69\%$  (0.75%)**

$H \rightarrow \mu\tau$  CMS-HIG-14-005  
 $H \rightarrow e\tau$  CMS PAS HIG-14-040



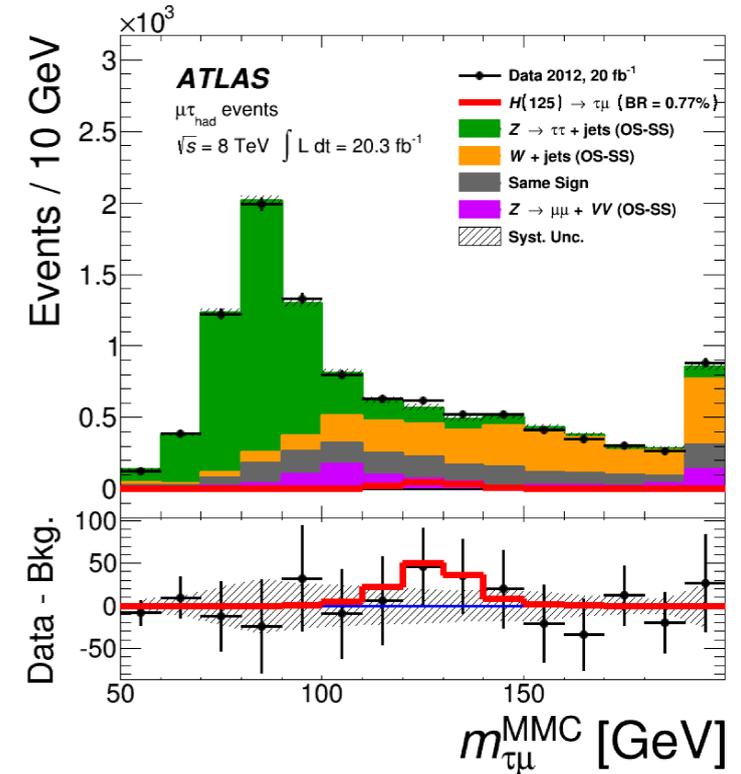
# ATLAS $h \rightarrow \ell\tau$

Approccio diverso per il decadimento adronico e leptonic del tau

## $H \rightarrow \ell\tau_{had}$

- ▶ Definite 2 regioni di segnale
  - Massa trasversa variabile principale dell'analisi
- ▶ Fondi principali:  $Z/\gamma^* \rightarrow \tau\tau$  (irriducibile),  $W$ +jets e  $Z/\gamma^* \rightarrow ll$

**Eccesso di  $1.3\sigma$  in  $h \rightarrow \mu\tau_{had}$   $Br(H \rightarrow \mu\tau_{had}) < 1.85\% (1.24\%) @ 95\% C.L.$   
 $Br(h \rightarrow e\tau_{had}) < 1.81\% (2.07\%) @ 95\% C.L.$**



## $H \rightarrow \ell\tau_{lep}$

Metodo data-driven: si assume che il fondo SM sia simmetrico per scambio  $e \leftrightarrow \mu$

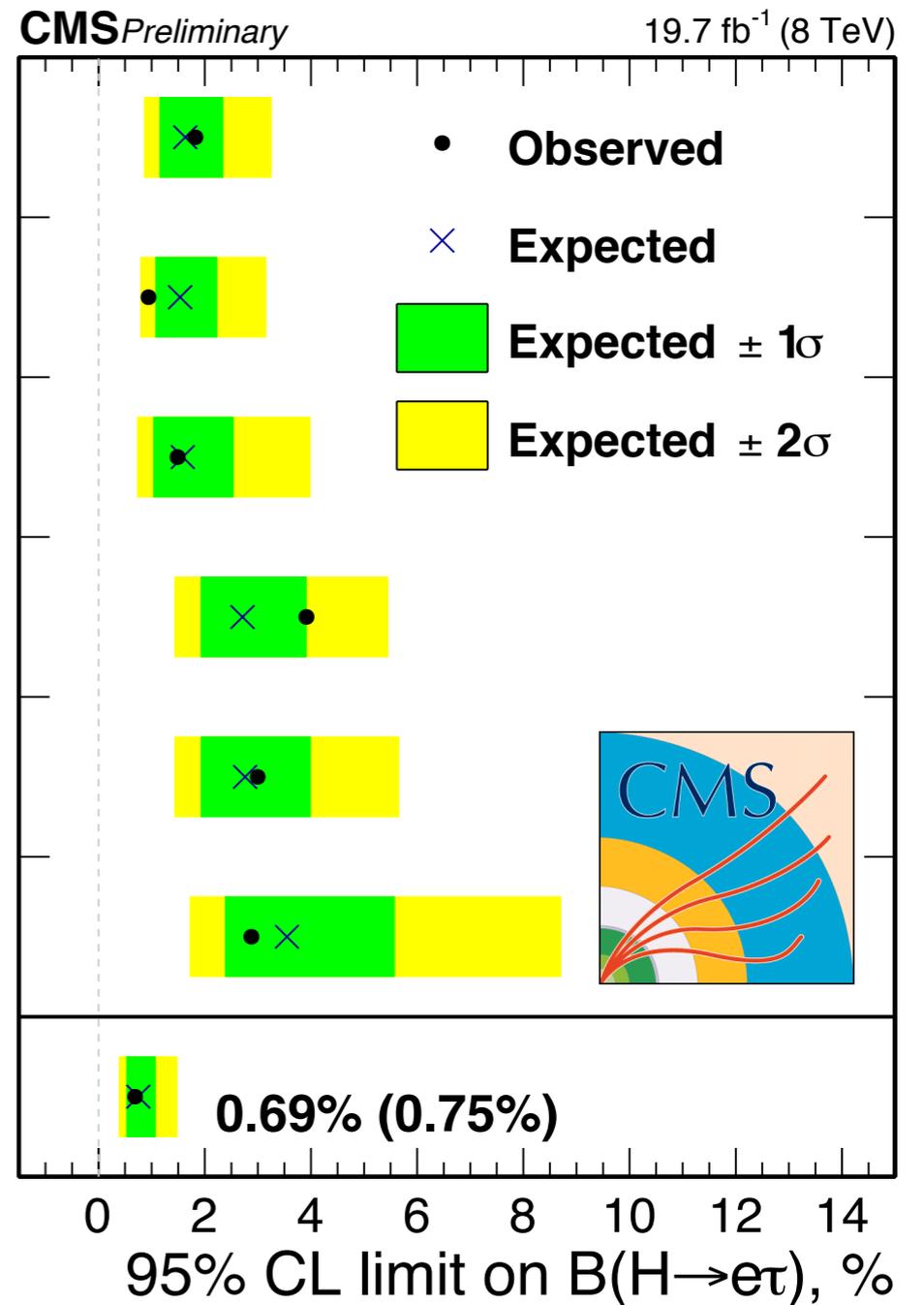
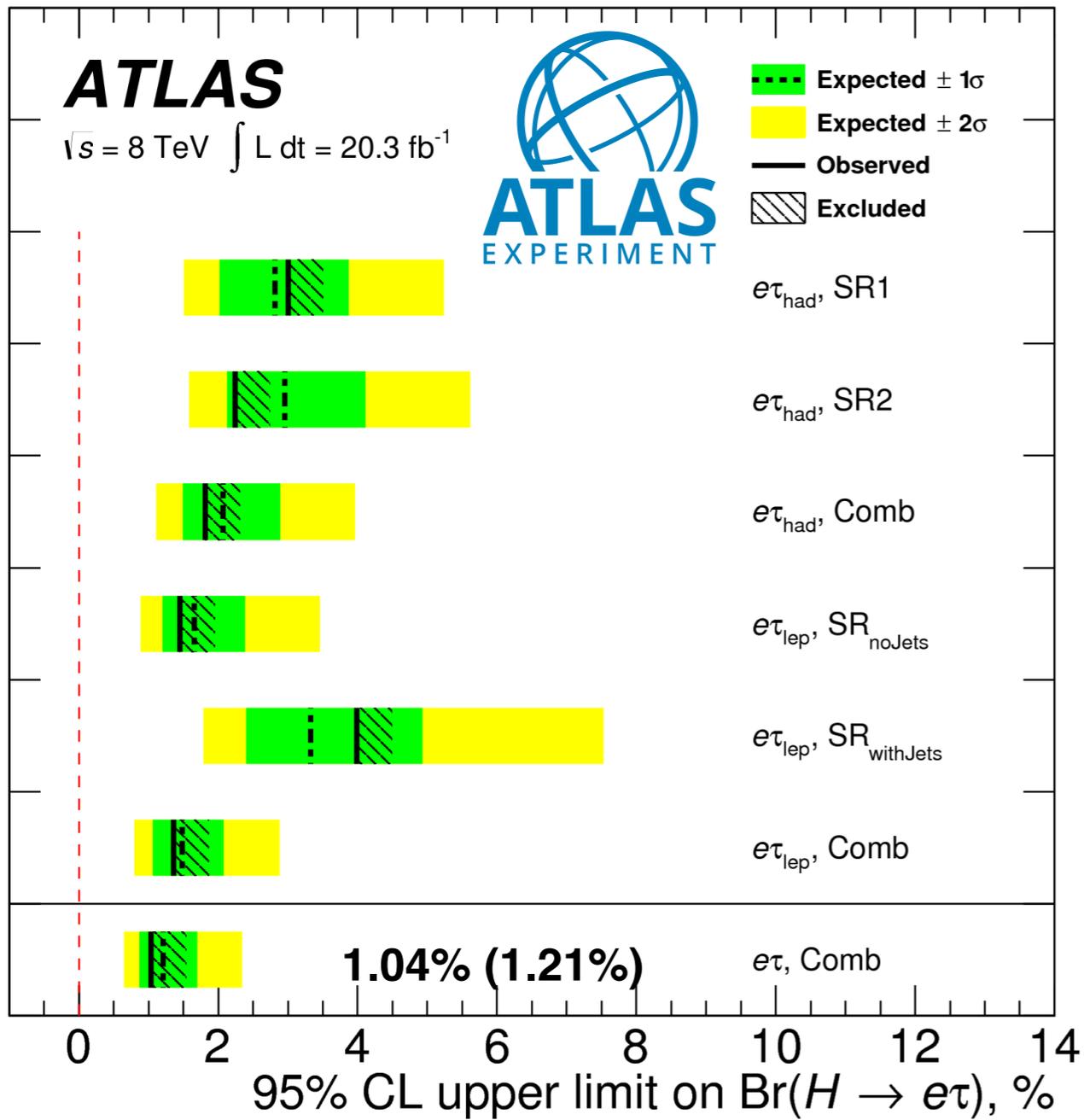
- ▶ 2 regioni di segnale: con e senza jets
- ▶ Si divide il campione  $e+\mu$  sample in due sotto campioni:  $e\mu$ , con  $pT(e) > pT(\mu)$ ,  $\mu e$ , con  $pT(e) < pT(\mu)$
- ▶ Stima del fondo  $H \rightarrow \mu\tau_e$  (presente solo in  $\mu e$ ) dal campione  $e\mu$  e viceversa.

**$Br(h \rightarrow e\tau_{lep}) < 1.36\% (1.48\%)$   
 $Br(h \rightarrow \mu\tau_{lep}) < 1.79\% (1.73\%)$**

JHEP11(2015)211  
 arXiv:1604.07730



# $h \rightarrow e\tau$ - ATLAS & CMS

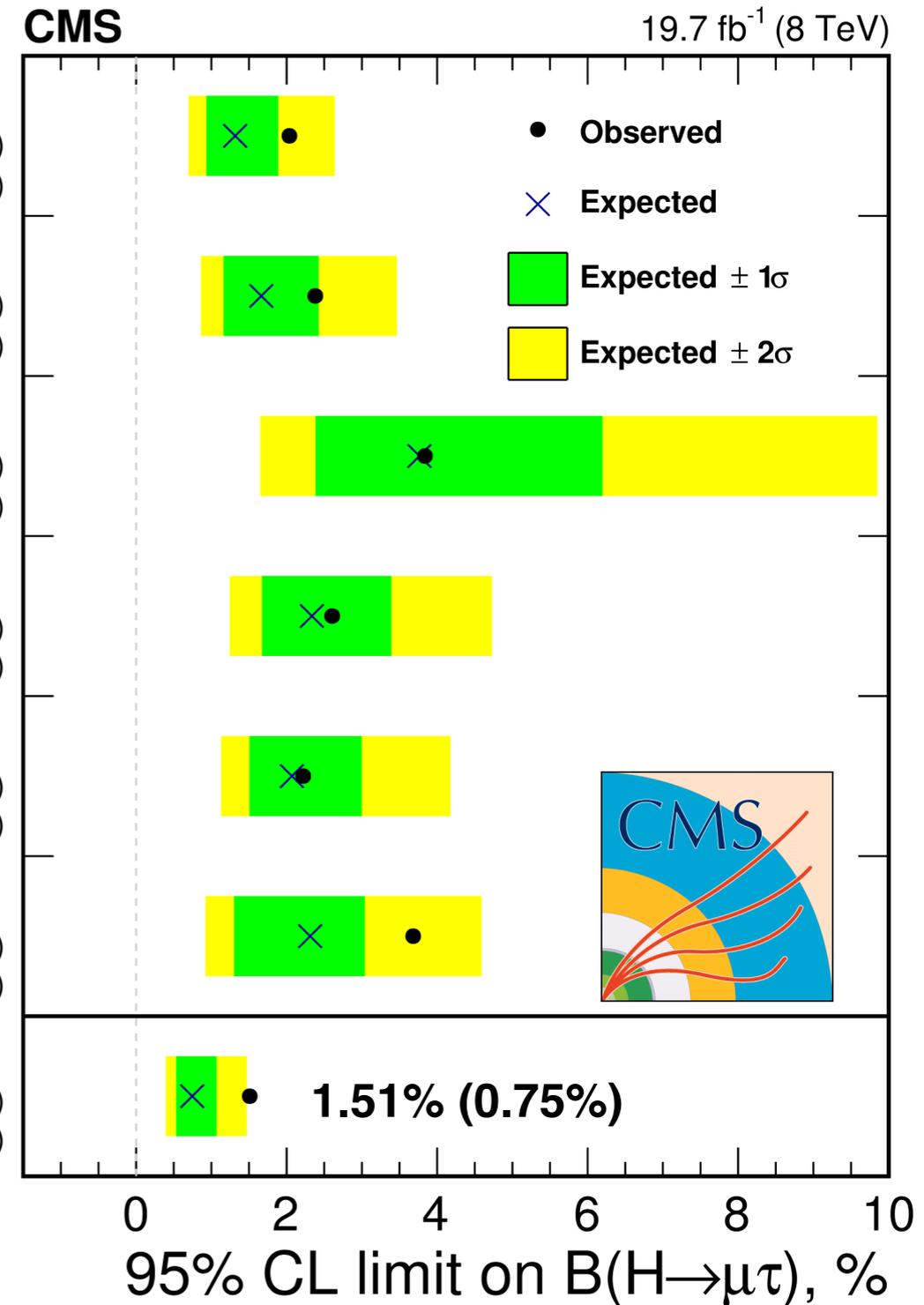
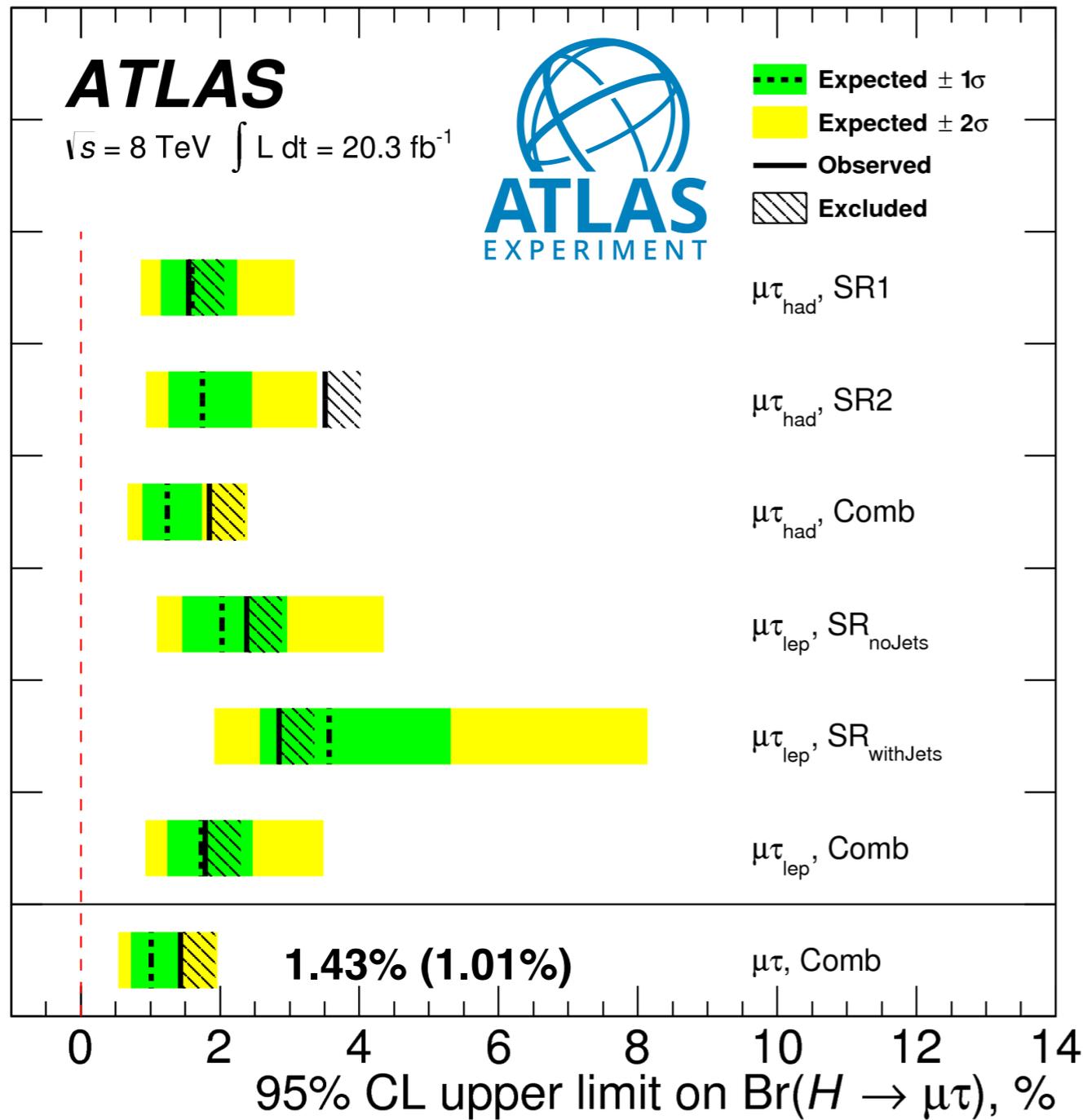


JHEP11(2015)211  
 arXiv:1604.07730

$h \rightarrow \mu\tau$  CMS-HIG-14-005  
 $h \rightarrow e\tau$  CMS PAS HIG-14-04

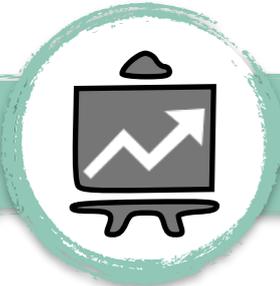


# $h \rightarrow \mu\tau$ - ATLAS & CMS

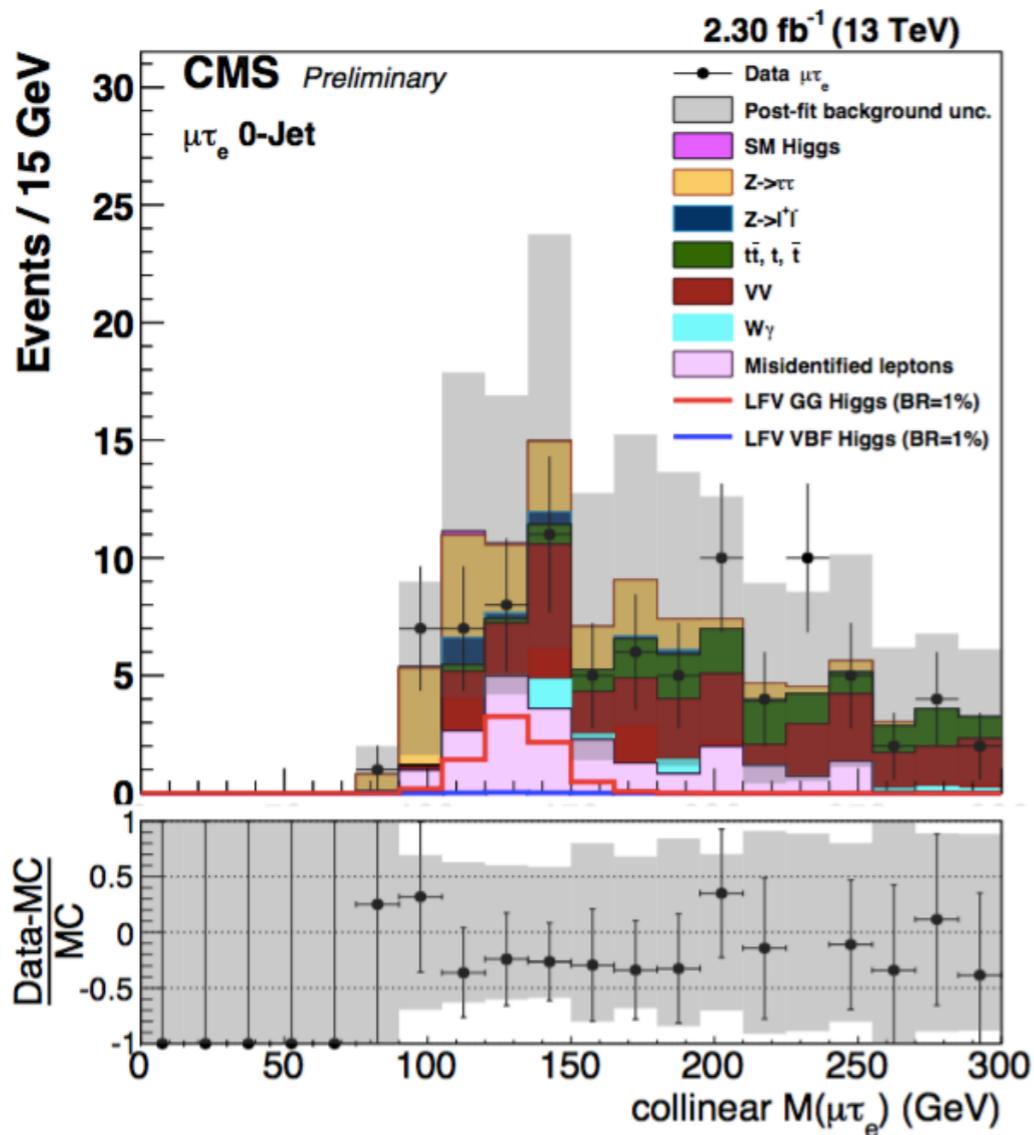


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arXiv:1604.07730

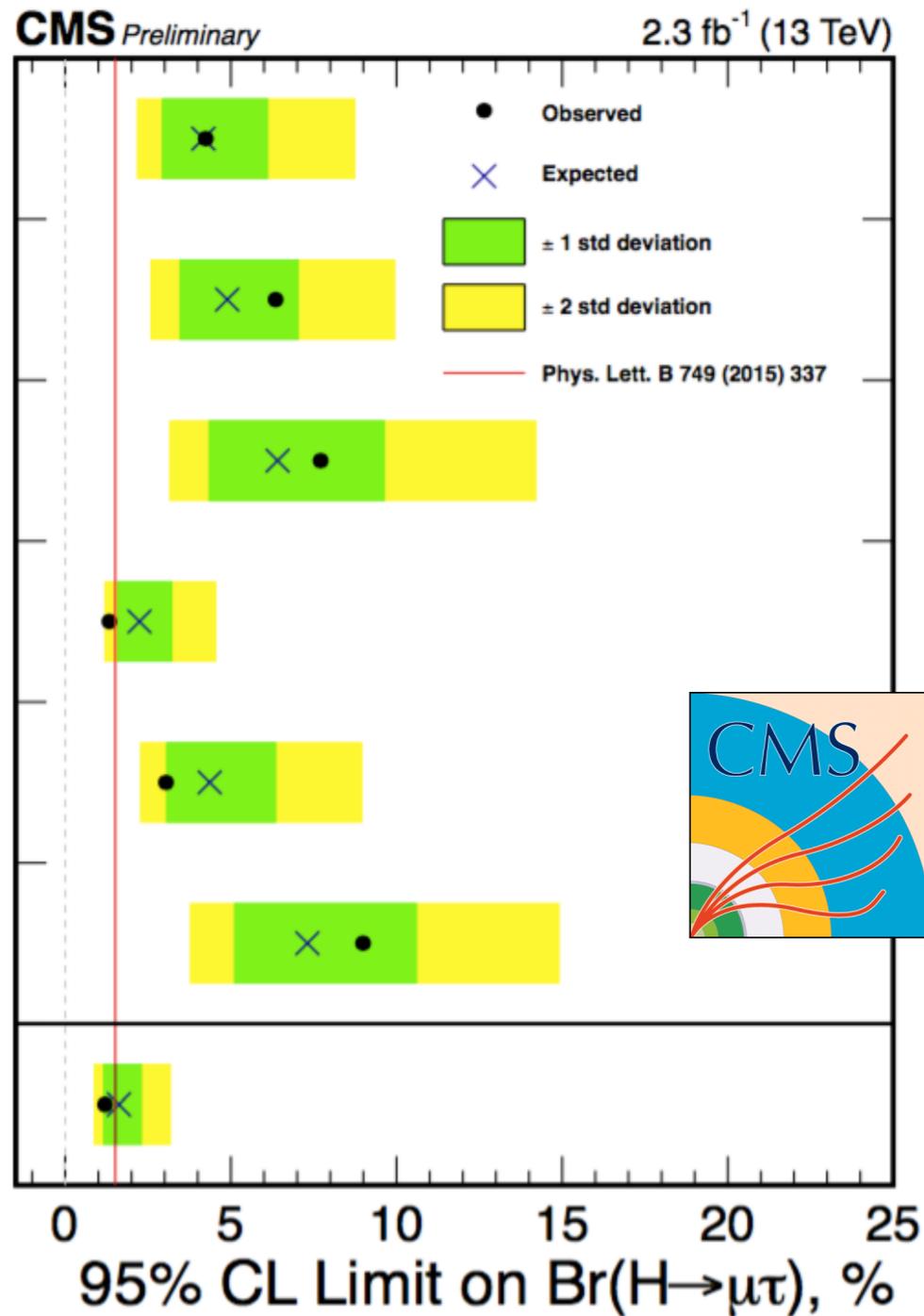
$h \rightarrow \mu\tau$  CMS-HIG-14-005  
 $h \rightarrow e\tau$  CMS PAS HIG-14-04



## Aggiornato solo canale muonico

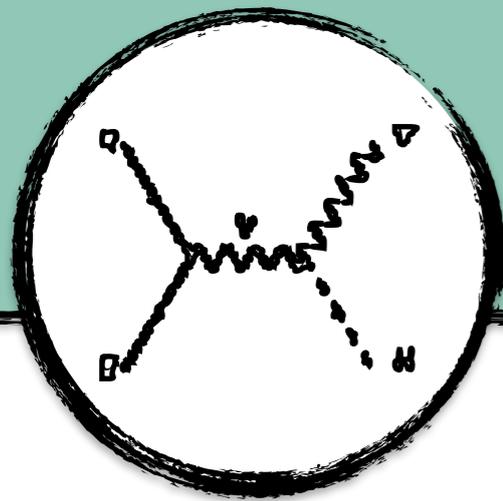


Strategia invariata rispetto Run1  
 Eccesso di  $2.4\sigma$  di Run1 non confermato

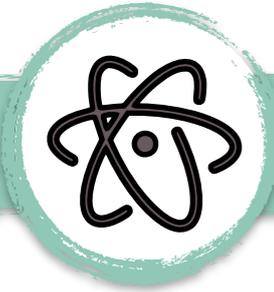


**$Br(H \rightarrow \mu\tau) < 1.20\%$  (1.62%)**



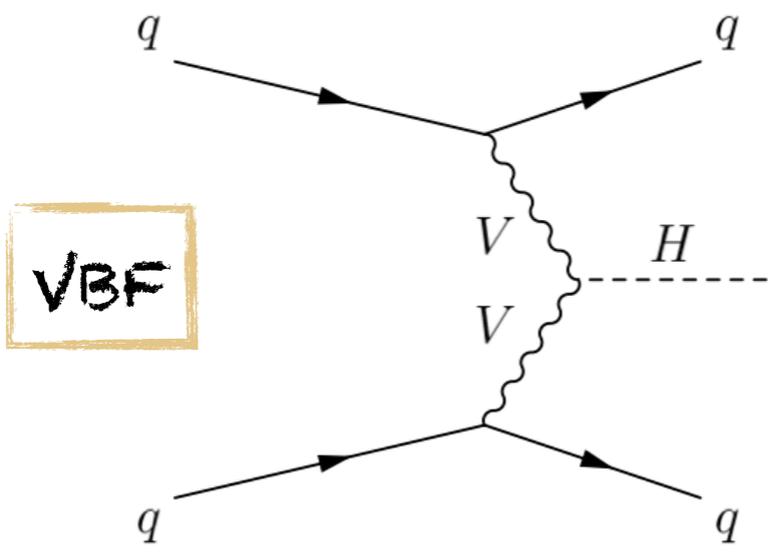
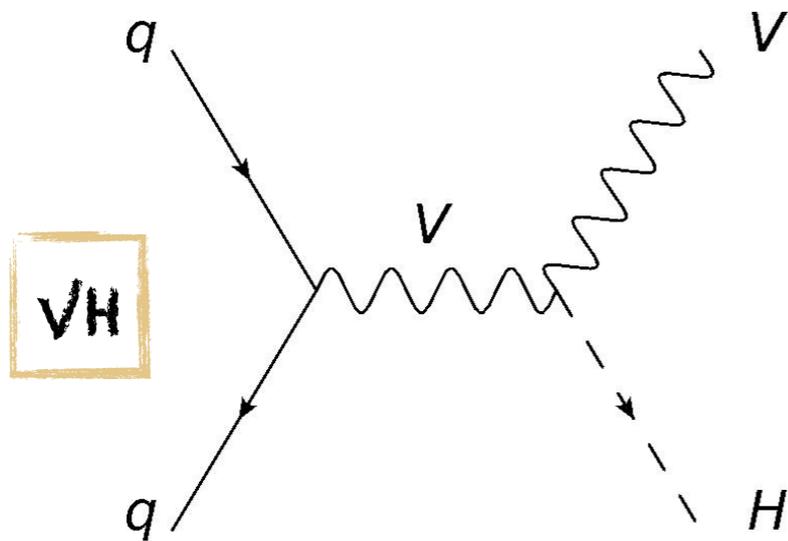


$h \rightarrow$  invisible



# $h \rightarrow$ Invisibile

- Modelli “Higgs-portal” con DM, SUSY neutralini, modelli graviscalars con dimensioni extra



<b>VH</b>	Z( $\rightarrow$ ll)H W/Z( $\rightarrow$ jj)H	Z( $\rightarrow$ ll)H Z( $\rightarrow$ bb)H
<b>VBF</b>	✓	✓



# $h \rightarrow \text{Invisible} - \nu H$

**Z( $\rightarrow \ell\ell$ )H:** leptoni con stesso sapore e carica opposta (elettroni o muoni) con alta energia mancante

## Fondi principali

- ☑ Z( $\ell\ell$ )Z( $\nu\nu$ ) fondo dominante e irriducibile, stimato con metodi MC
- ☑ W( $\ell\nu$ )Z( $\ell\ell$ ): stimato con metodi MC

ATLAS Z( $\rightarrow \ell\ell$ )h B(h  $\rightarrow$  inv.) < 0.75 [arXiv:1402.3244](#)

CMS Z( $\rightarrow \ell\ell$ )h B(h  $\rightarrow$  inv.) < 0.83 *Eur. Phys. J. C74 (2014) 2980*

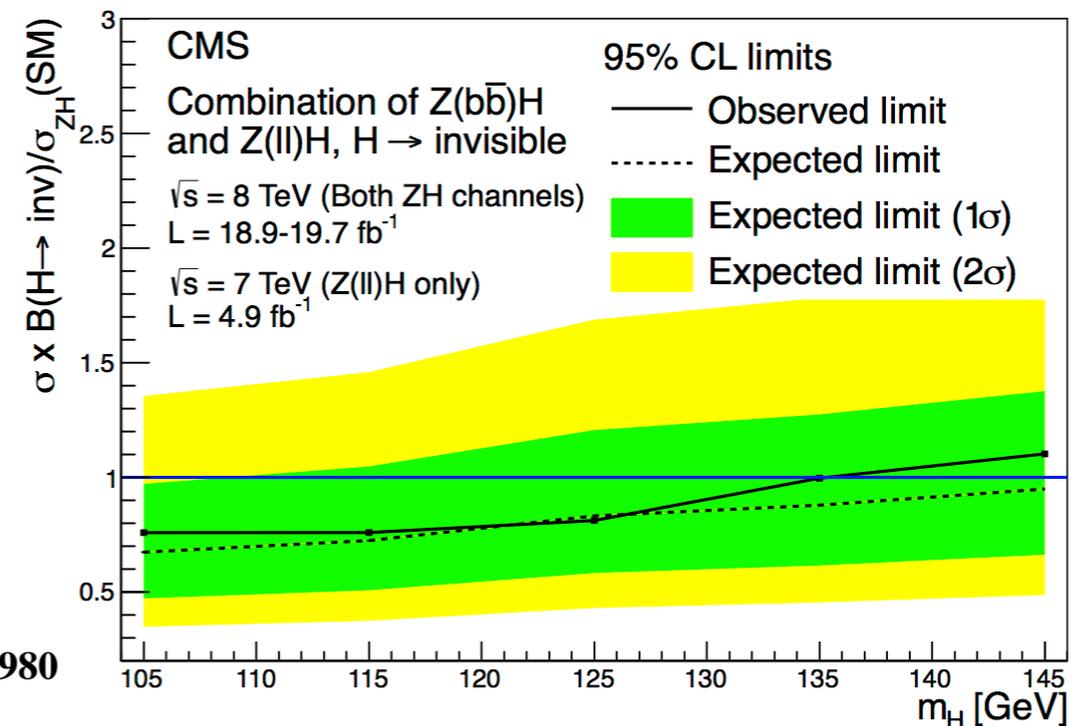
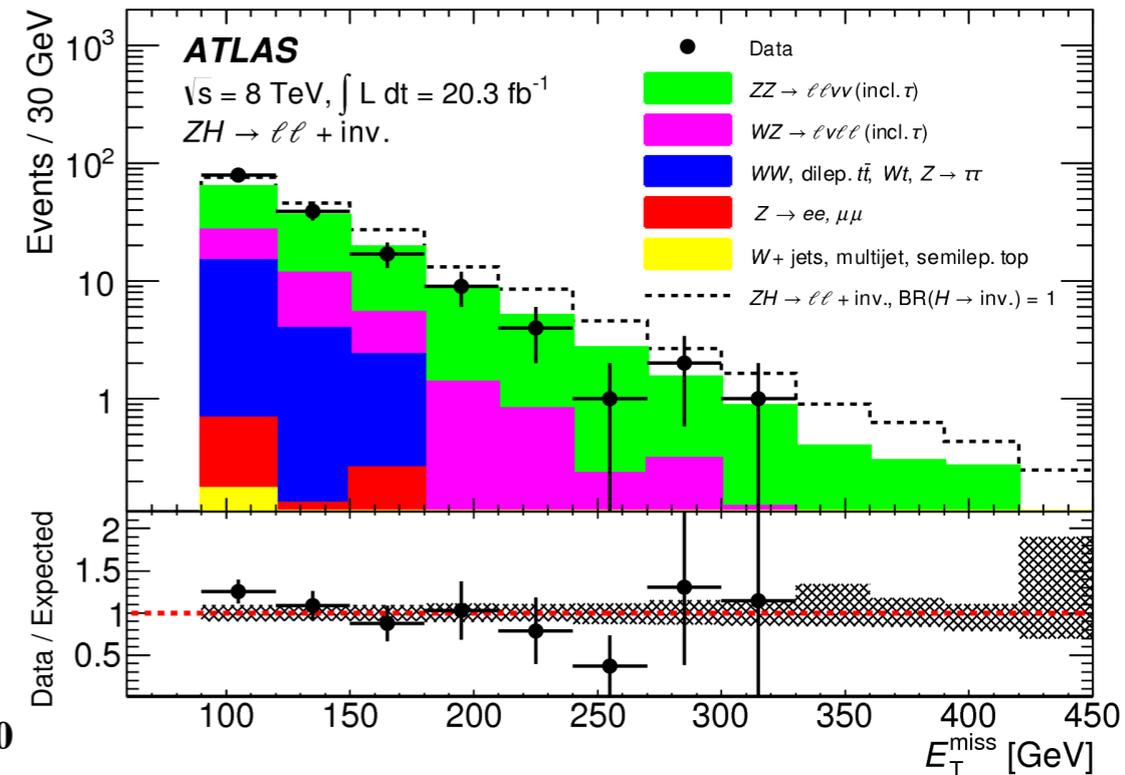
**V( $\rightarrow jj$ )H:** due jet la cui massa invariante  $m_{jj}$  sia consistente con la massa V e  $E_T^{miss}$

- ☑ Ricerche di ATLAS: W/Z( $\rightarrow jj$ )h
- ☑ Ricerche CMS Z( $\rightarrow bb$ )h

**Fondi principali:** (W/Z+jets,  $f t$ ) studiati con le control region

CMS Vh(comb) B(h  $\rightarrow$  inv.) < 0.81 *Eur. Phys. J. C74 (2014) 2980*

ATLAS Vh B(h  $\rightarrow$  inv.) < 0.78 *Eur. Phys. J. C (2015) 75:337*





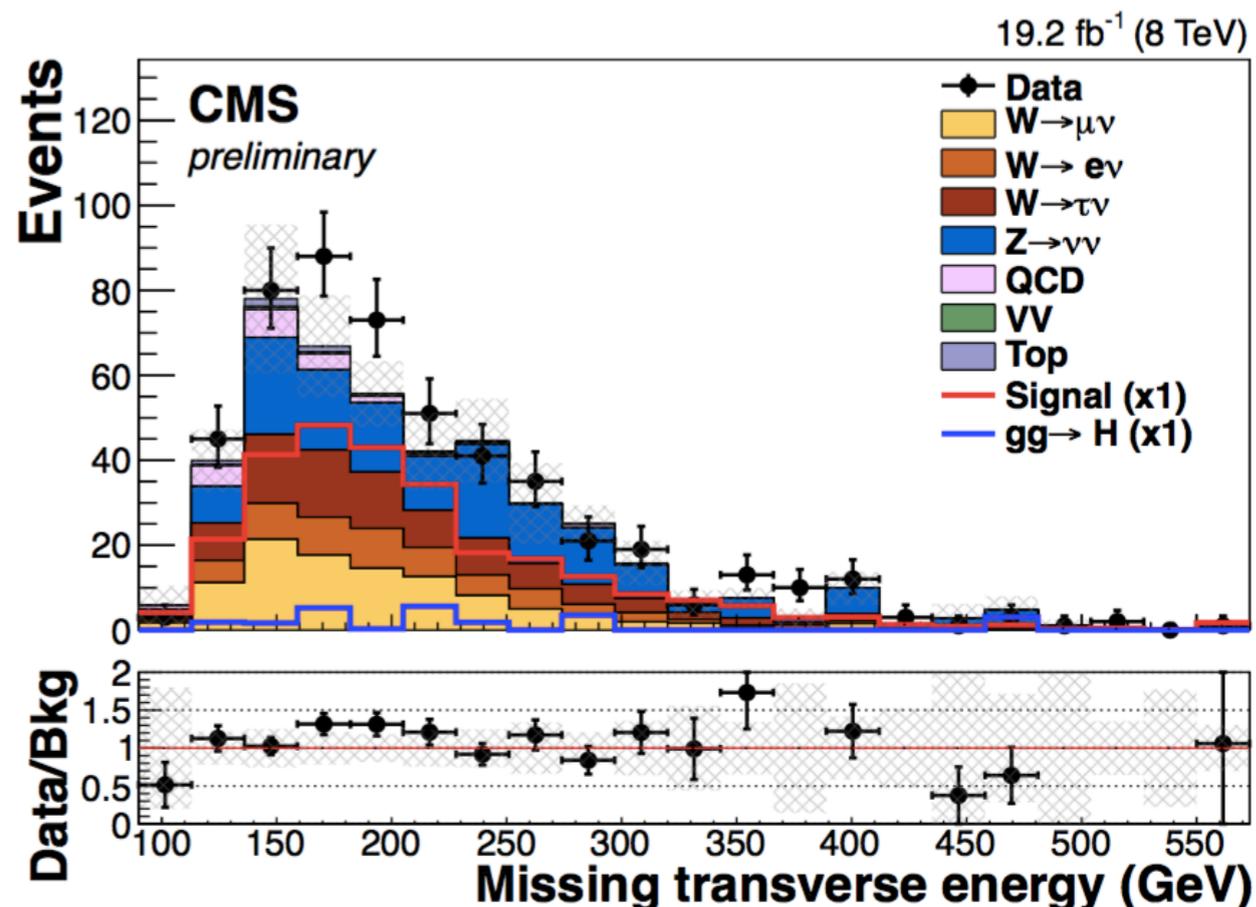
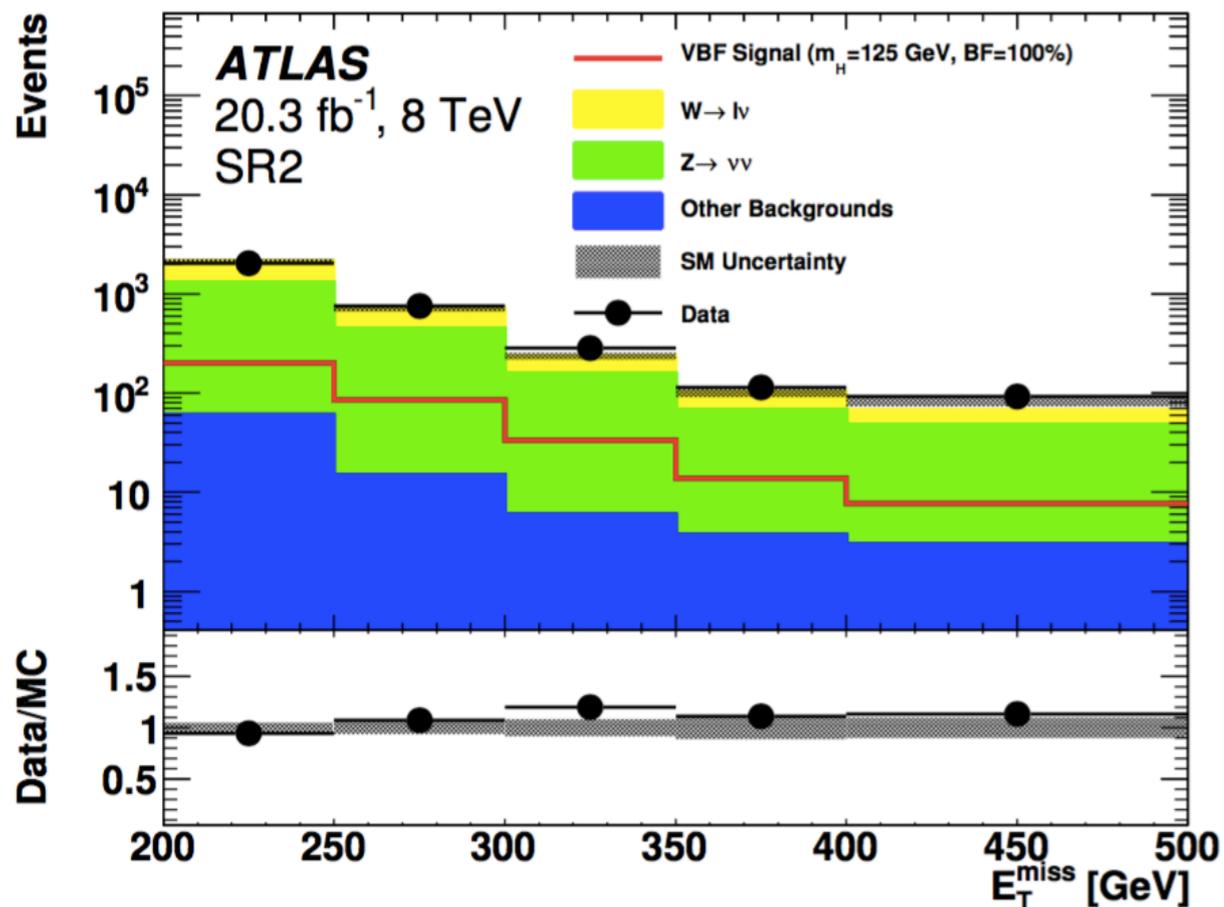
# $h \rightarrow$ Invisibile - VBF

**VBF:** due jet ben separati in pseudorapidità, con alta massa dijet e alta  $E_T^{\text{miss}}$

## Fondi:

Stima di W,Z+jets (main) usando CR  $Z \rightarrow ll$  e  $W \rightarrow lv$

Stima del fondo multijet con metodi di efficienza

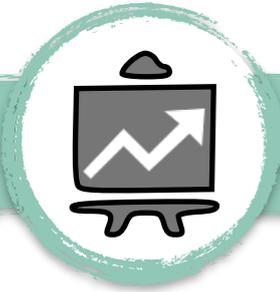


$B(h \rightarrow \text{inv.}) < 0.28$

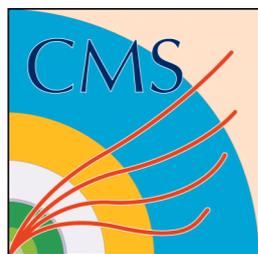
JHEP 01 (2016) 172

$B(h \rightarrow \text{inv.}) < 0.57$

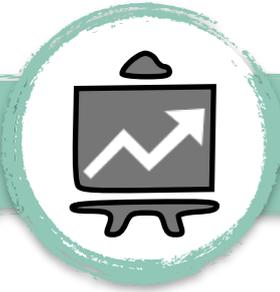
CMS PAS HIG-14-038



# $h \rightarrow$ Invisibile - risultati Run 1



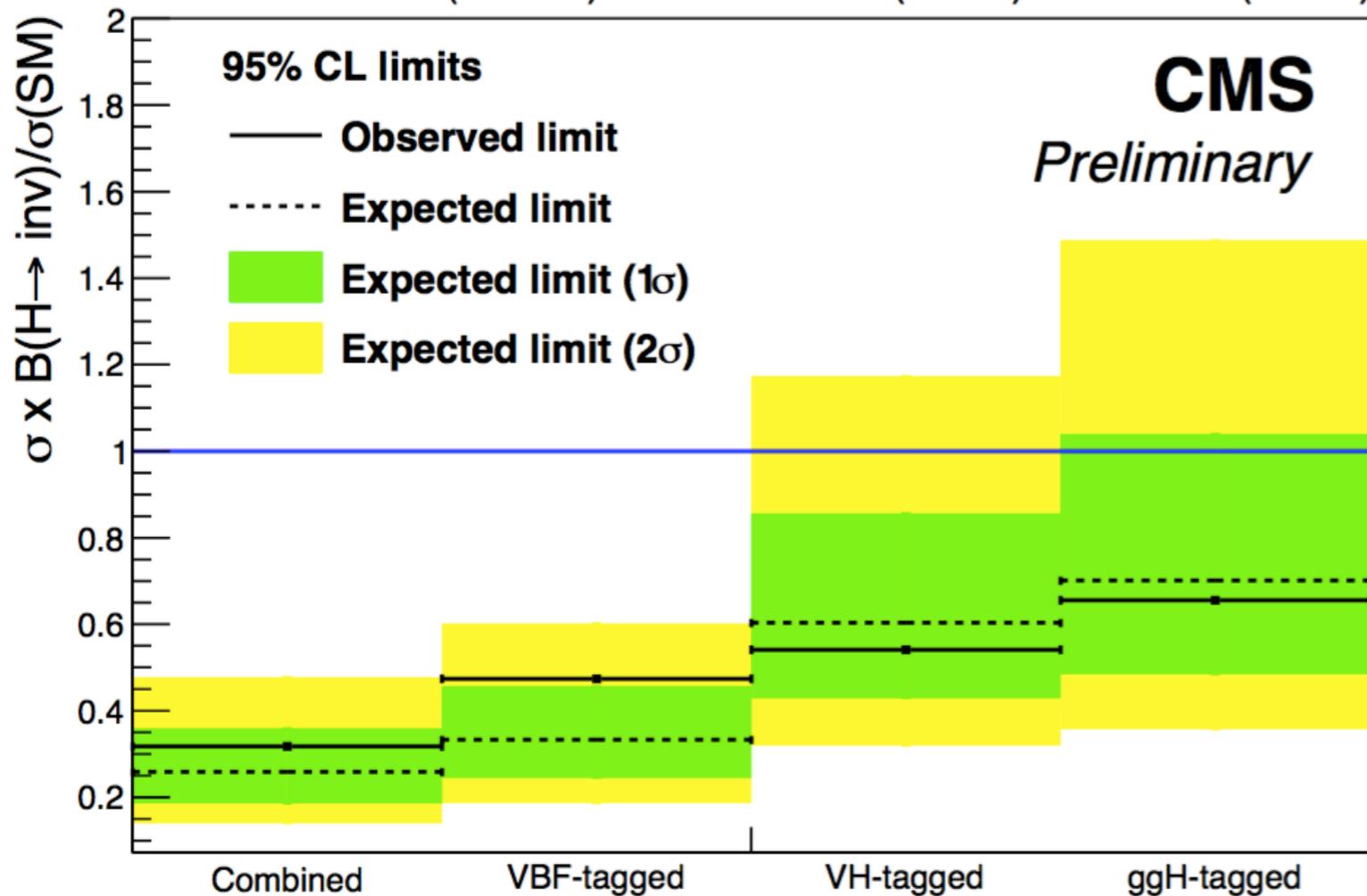
Canali	Obs.	Exp.	
$(Z \rightarrow \ell\ell)h$	0.75	0.62	arXiv:1402.3244
$(V \rightarrow qq)h$	0.78	0.86	<i>Eur. Phys. J. C (2015) 75:337</i>
VBF	0.28	0.31	<i>JHEP 01 (2016) 172</i>
Combinazione canali invisibile	0.25	0.27	<i>JHEP11(2015)206</i>
Combinazione tutti canali	0.23	0.24	<i>JHEP11(2015)206</i>
$Vh$	0.81	0.83	<i>Eur. Phys. J. C74 (2014) 2980</i>
VBF	0.57	0.40	CMS PAS HIG-14-038
Combinazione canali invisibile	0.36	0.30	CMS-PAS-HIG-15-012



# h → Invisible - Run 2

## Risultati pubblici solo da CMS

0-2.3 fb<sup>-1</sup> (13 TeV) + 18.9-19.7 fb<sup>-1</sup> (8 TeV) + 0-4.9 fb<sup>-1</sup> (7 TeV)



	Obs.	Exp.
(Z → ll)h	1.3	1.3
VBF	0.69	0.62
Combinazione (Run 1 + Run 2)	0.32	0.26

ZH CMS PAS HIG-16-008  
VBF CMS PAS HIG-16-009



Estensione del settore  
di Higgs



# Perché un secondo Higgs?

Estensioni del SM richiedono un settore dell'Higgs esteso, ad esempio:

- ▶ Supersimmetria, per preservare invarianza gauge
- ▶ Higgs composito, spettroscopia prevede altri stati

L'ipotesi *anticlimatica*:

- ▶ SM non é minimale
- ▶ SM prevede almeno un bosone di Higgs, ma può assorbirne di più (estensione del SM letterale...)

2HDM

Si aggiunge un doppietto EWK a quello esistente



$h, H, A, H^\pm$

$m_h, m_H, m_A, m_\pm, \tan\beta, \alpha$

$$\tan\beta = \frac{\langle \phi \rangle_0}{\langle \phi' \rangle_0}$$



parametro di mixing tra  $h$  e  $H$



# Accoppiamenti in 2HDM

Autostati di massa accoppiano tutti con  $h$  e  $H$  in tutti i modelli, ma accoppiamenti dipendono da modello

	Type I	Type II	Lepton-specific	Flipped
$\xi_h^u$	$\cos \alpha / \sin \beta$	$\cos \alpha / \sin \beta$	$\cos \alpha / \sin \beta$	$\cos \alpha / \sin \beta$
$\xi_h^d$	$\cos \alpha / \sin \beta$	$-\sin \alpha / \cos \beta$	$\cos \alpha / \sin \beta$	$-\sin \alpha / \cos \beta$
$\xi_h^\ell$	$\cos \alpha / \sin \beta$	$-\sin \alpha / \cos \beta$	$-\sin \alpha / \cos \beta$	$\cos \alpha / \sin \beta$
$\xi_H^u$	$\sin \alpha / \sin \beta$	$\sin \alpha / \sin \beta$	$\sin \alpha / \sin \beta$	$\sin \alpha / \sin \beta$
$\xi_H^d$	$\sin \alpha / \sin \beta$	$\cos \alpha / \cos \beta$	$\sin \alpha / \sin \beta$	$\cos \alpha / \cos \beta$
$\xi_H^\ell$	$\sin \alpha / \sin \beta$	$\cos \alpha / \cos \beta$	$\cos \alpha / \cos \beta$	$\sin \alpha / \sin \beta$

Diversa scala per  
"fermioni up e  
down"

Diversa scala per  
leptoni e quark

Diversa scala per  
quark up e down,  
per leptoni é  
invertita

$$g_{h,VV} \propto \sin(\beta - \alpha)$$

$$g_{H,VV} \propto \cos(\beta - \alpha)$$



# Topologie 2HDM

**h(125) →**

**VV** soppresso da  $\sin(\beta-\alpha)$

**bb e  $\tau\tau$**  necessari per distinguere tra scenari

**H →**

**VV** soppressi da  $\cos(\beta-\alpha)$

(...ormai MOLTO soppressi...)

Favorito  $m_H \gg m_h$ , decadimenti fermionici difficili (tranne  $tt$ )

**hh** possibile

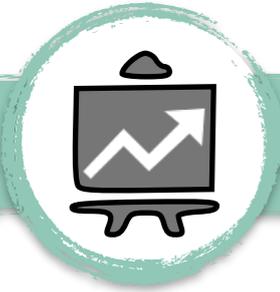
**Zh, ZA e AA** possibile

**A →**

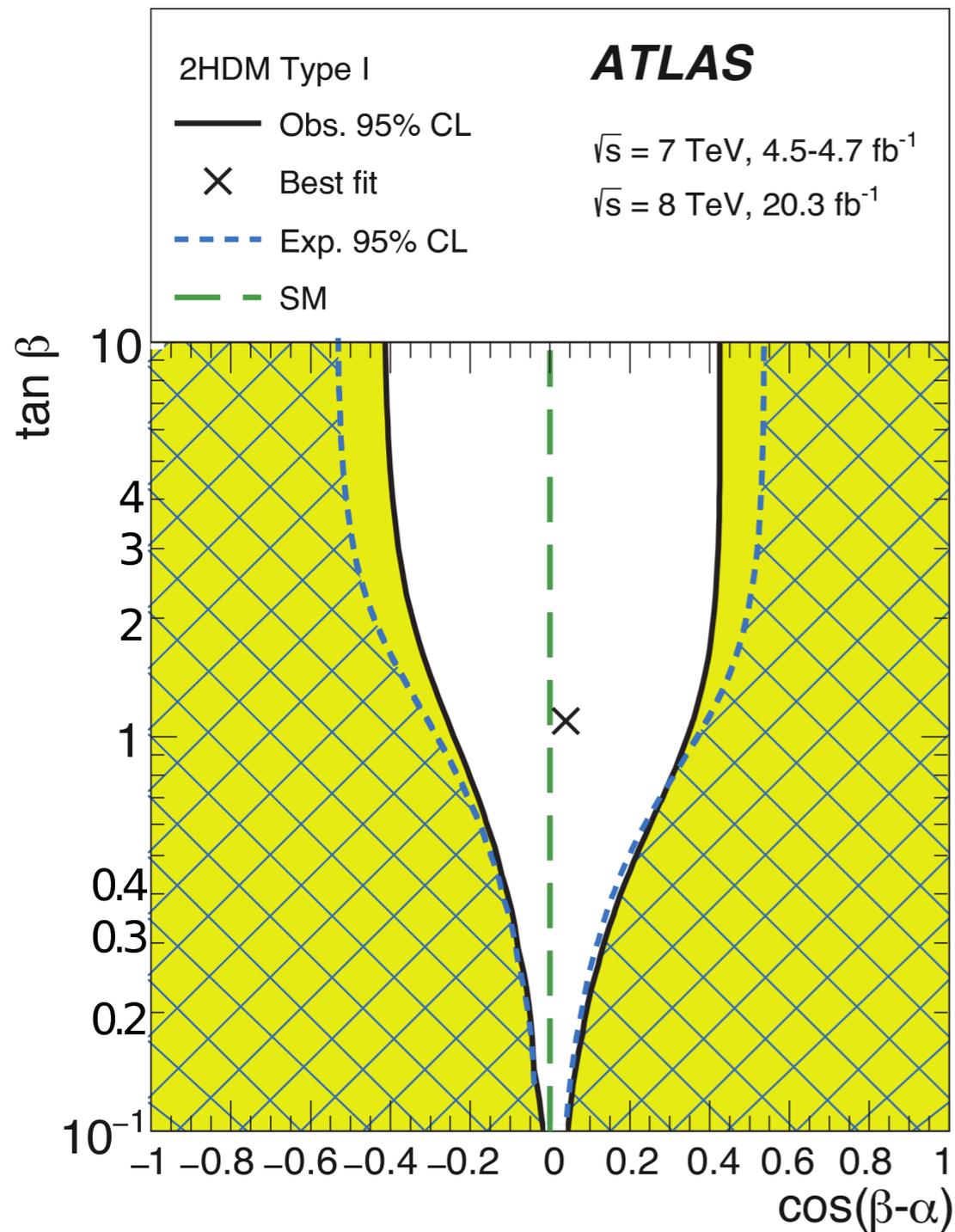
**VV** corrente soppressa al tree level

**bb e  $\tau\tau$**  canali principali per osservazione

**Zh o ZH** possibile



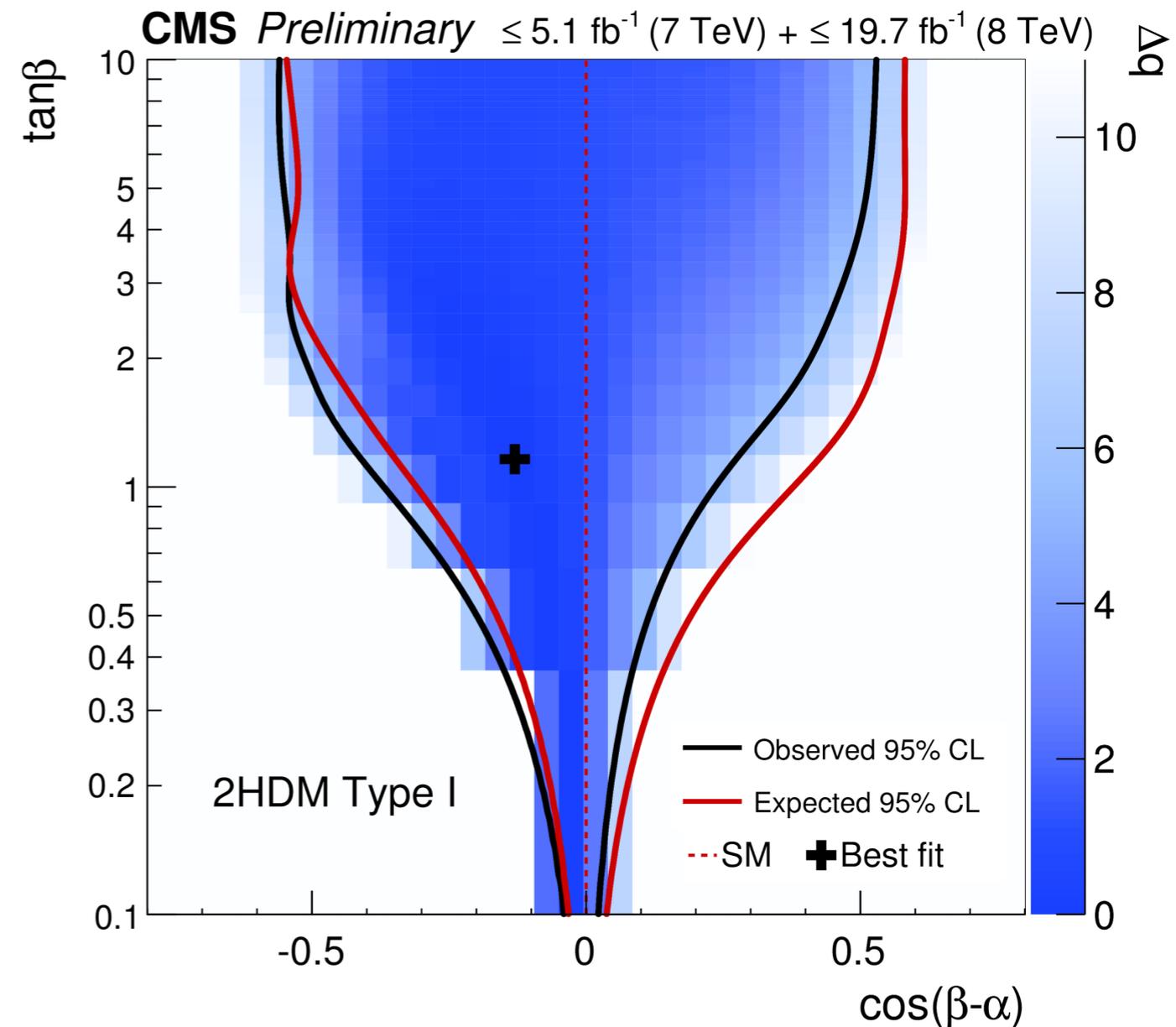
# Limiti allo spazio dei parametri



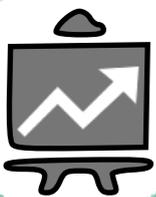
JHEP11(2015)206

Utilizzando i coupling di  $h_{125}$

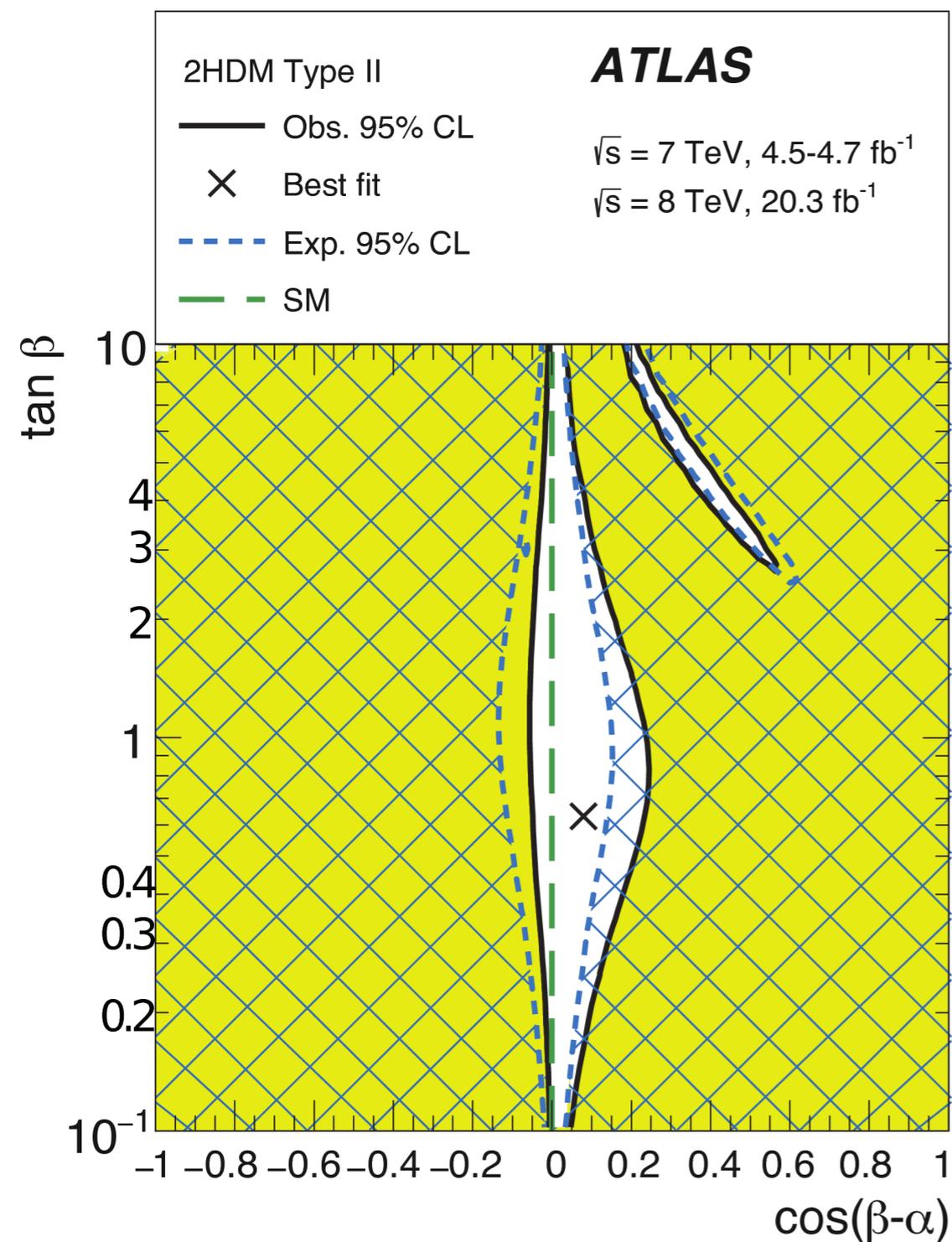
## Type-1



CMS-PAS-HIG-16-007



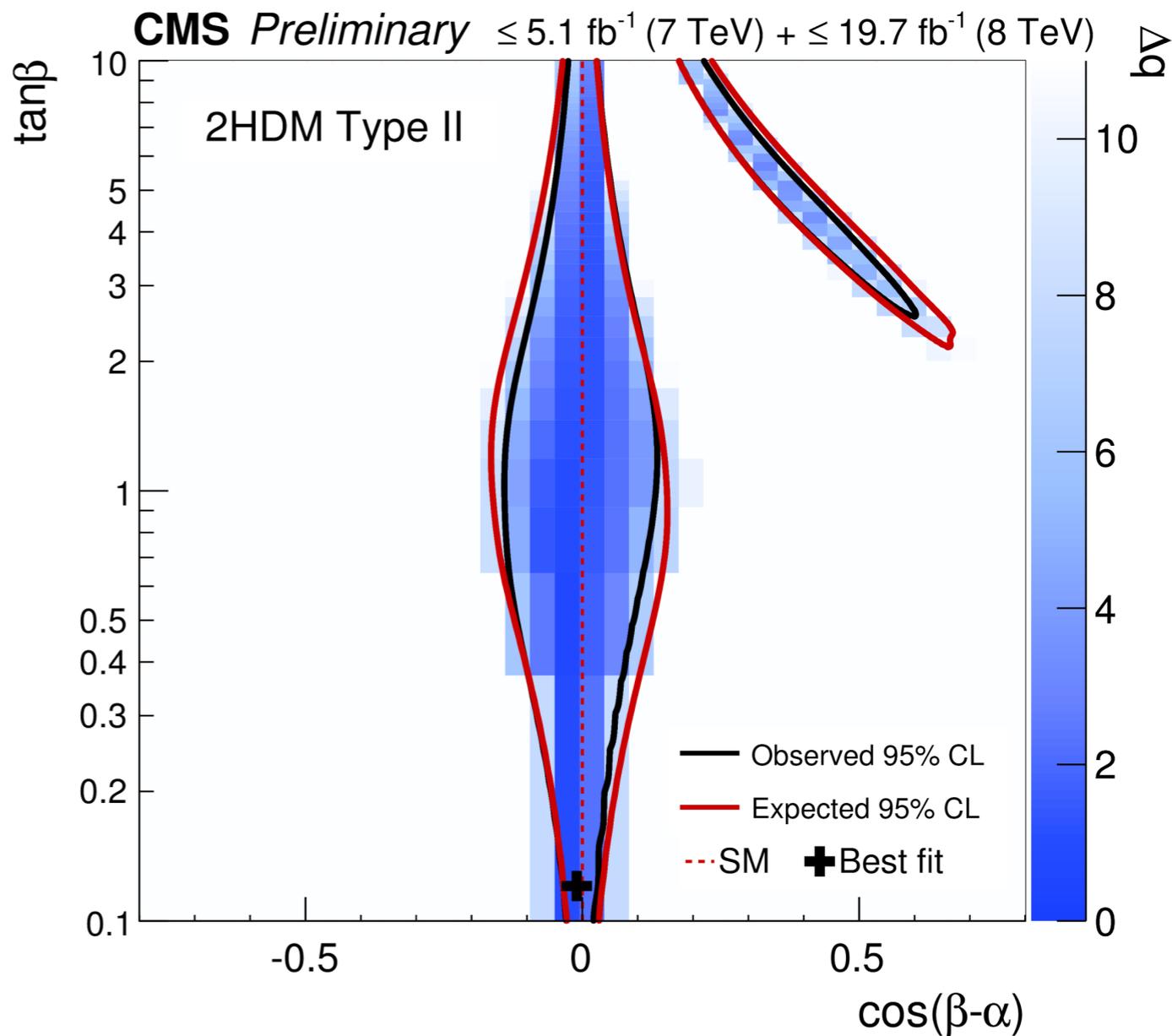
# Limiti allo spazio dei parametri



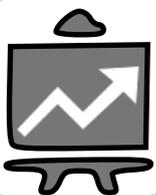
JHEP11(2015)206

Utilizzando i coupling di  $h_{125}$

## Type-2

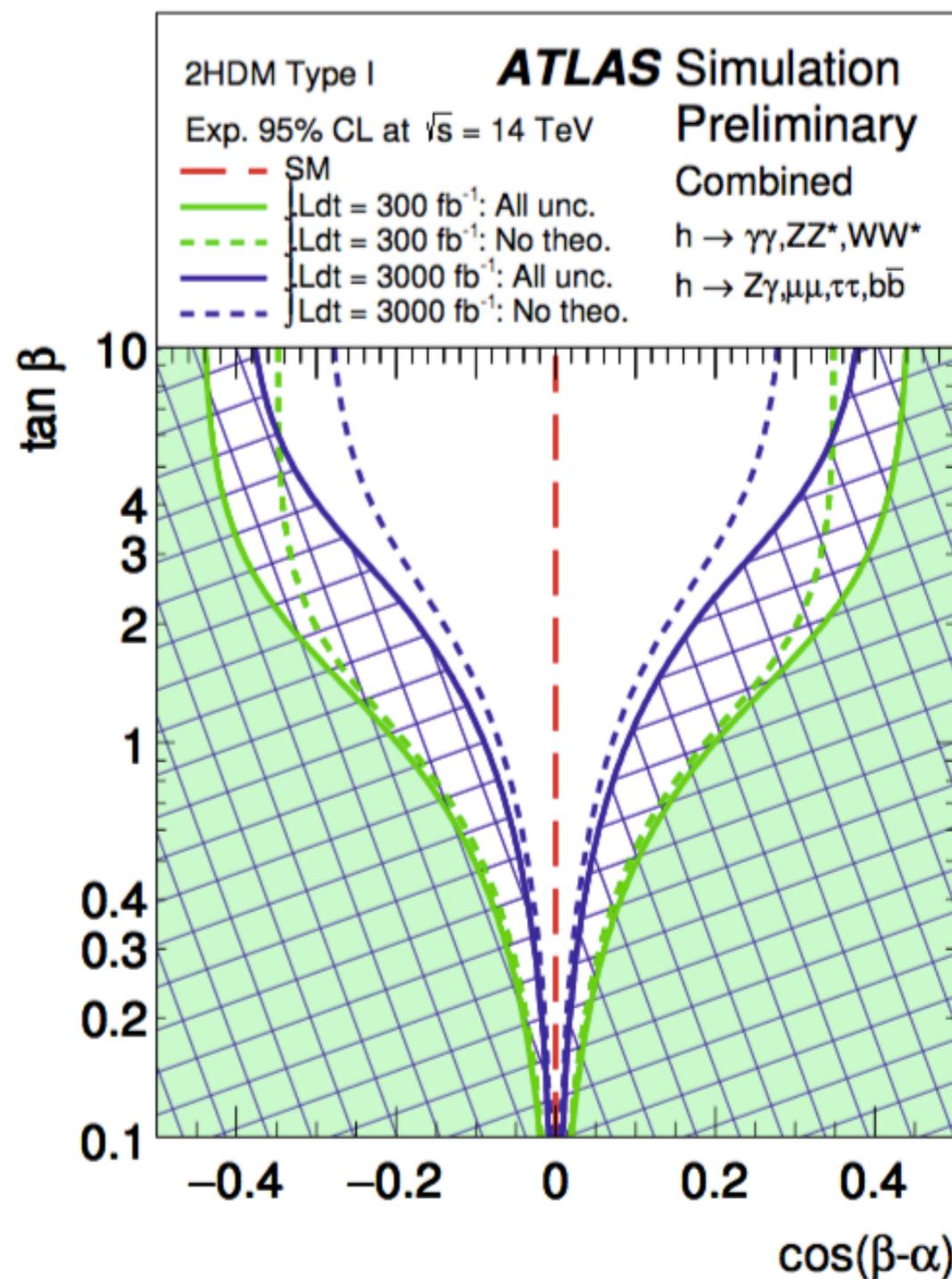
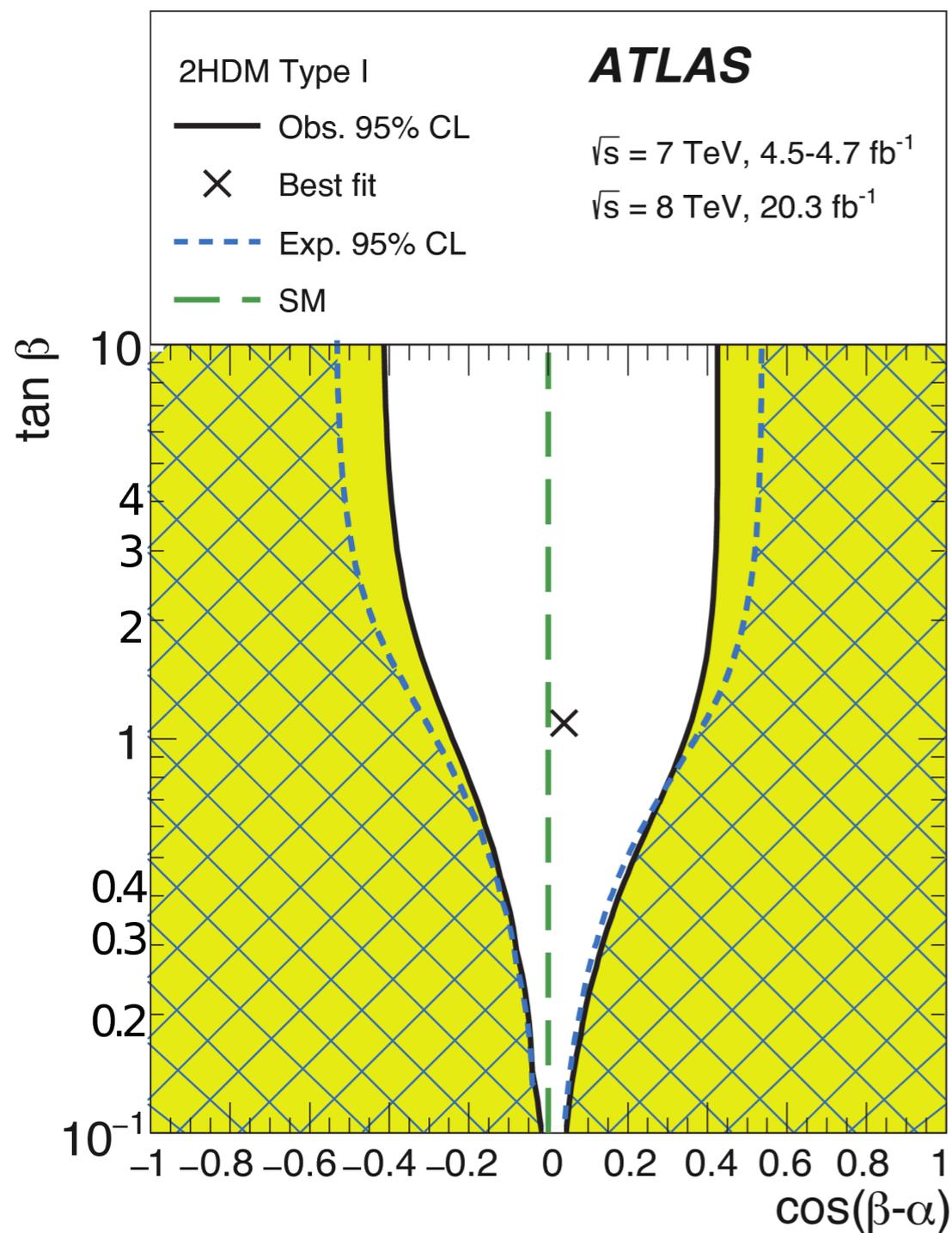


CMS-PAS-HIG-16-007



# Limiti allo spazio dei parametri - Prospettive

## Type-1

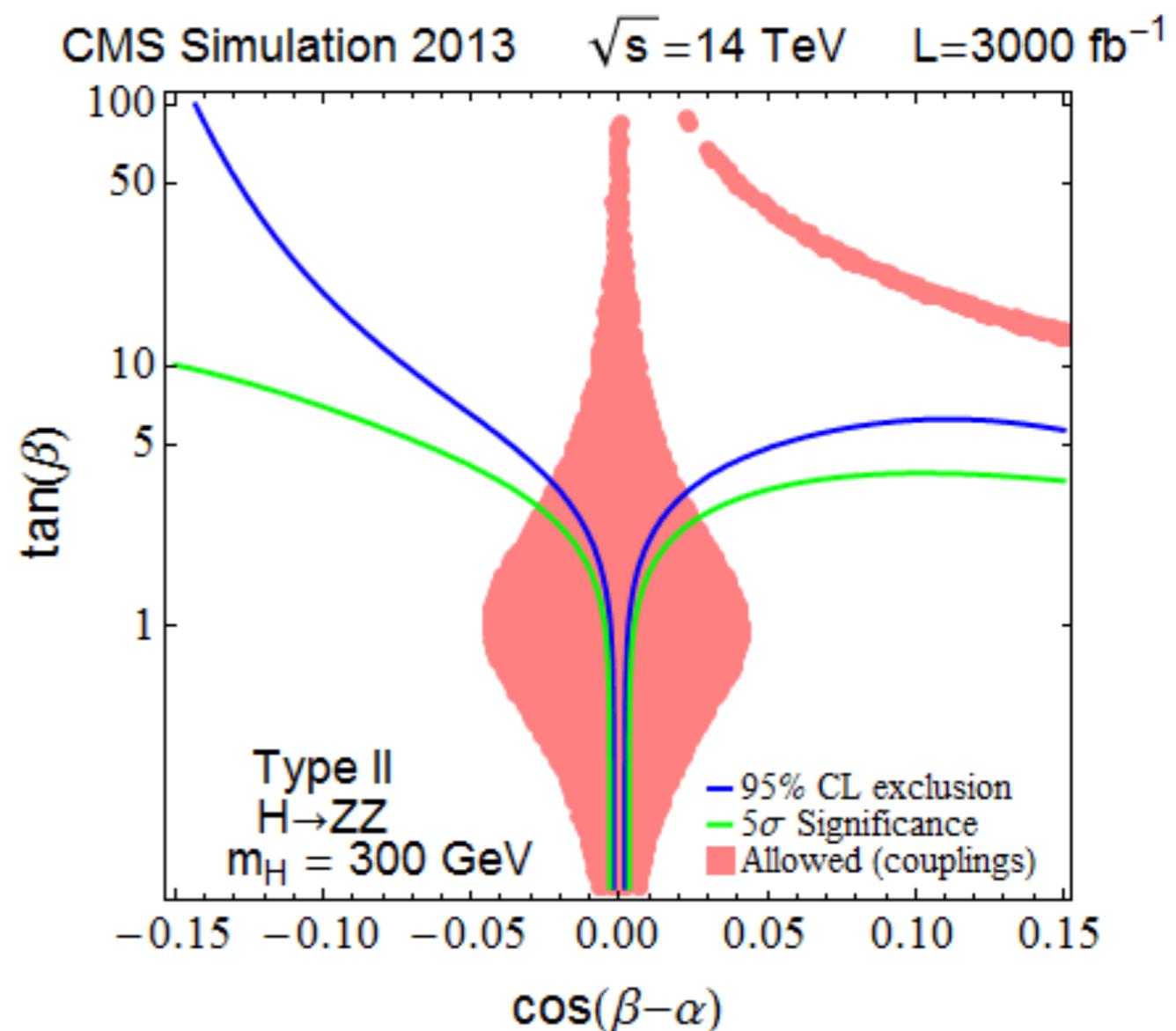
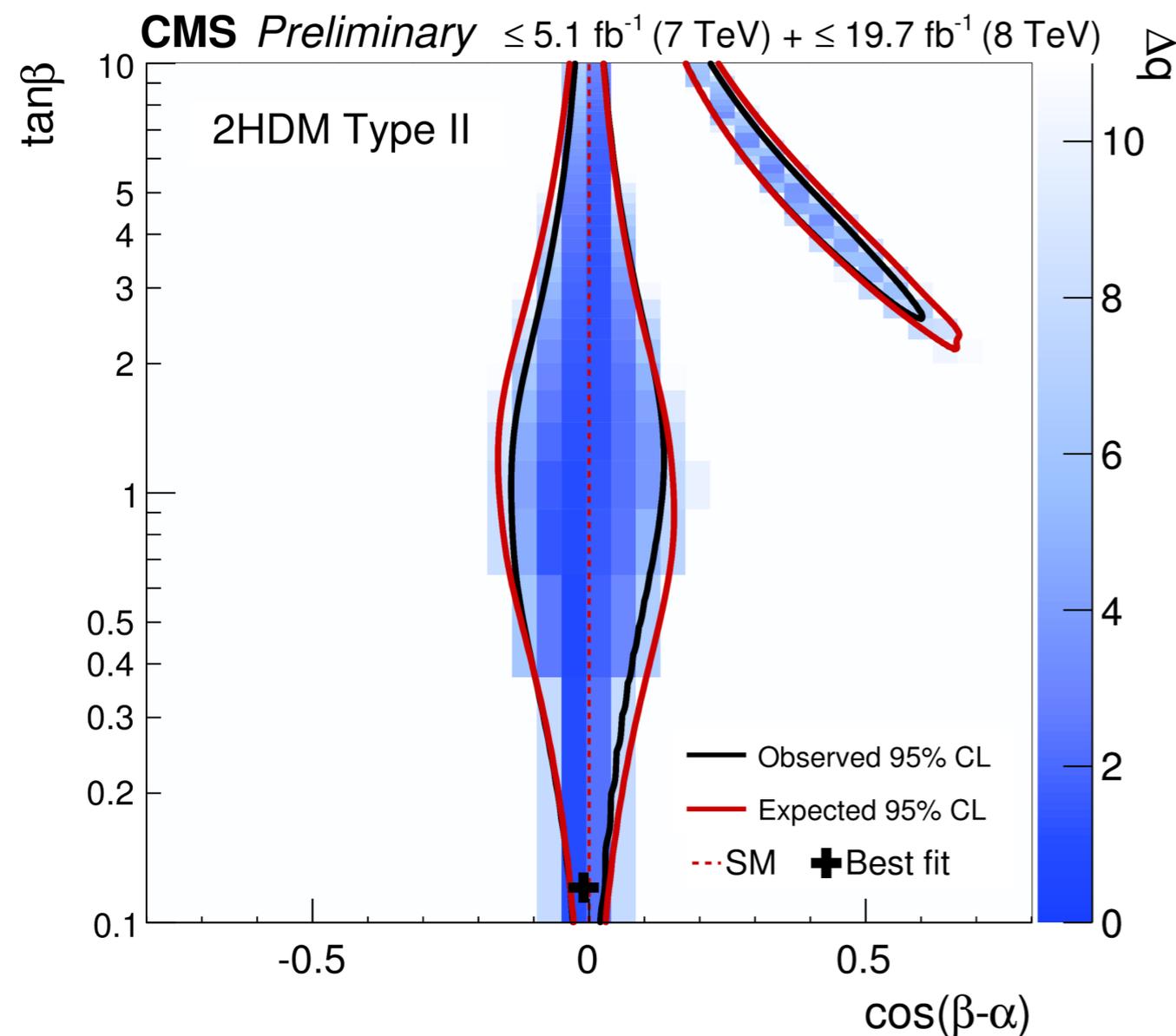


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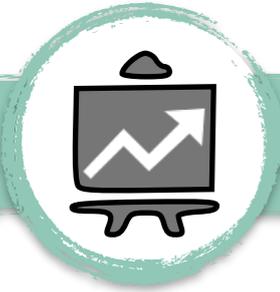


# Limiti allo spazio dei parametri - Prospettive

## Type-2



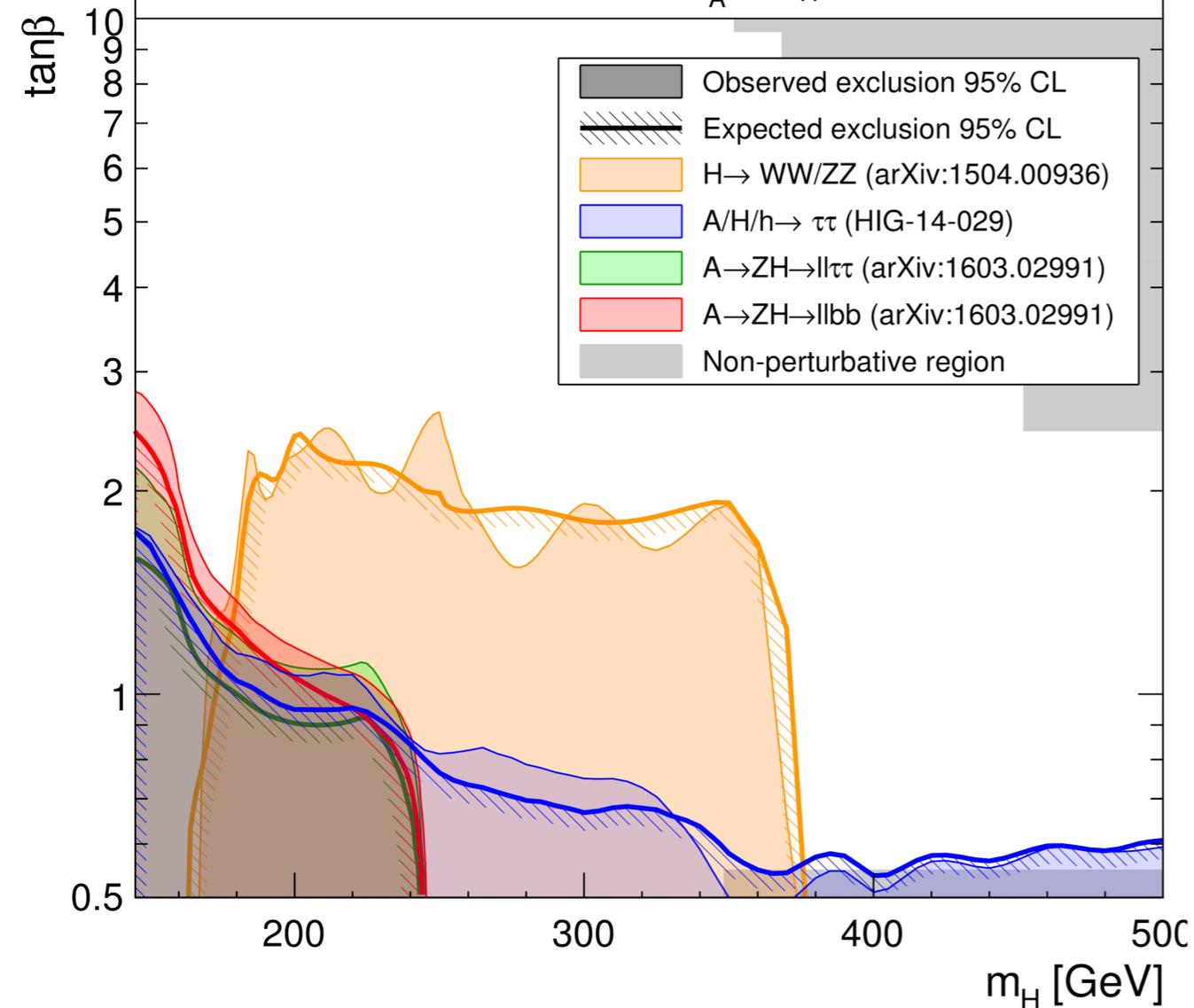
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# Limiti allo spazio dei parametri

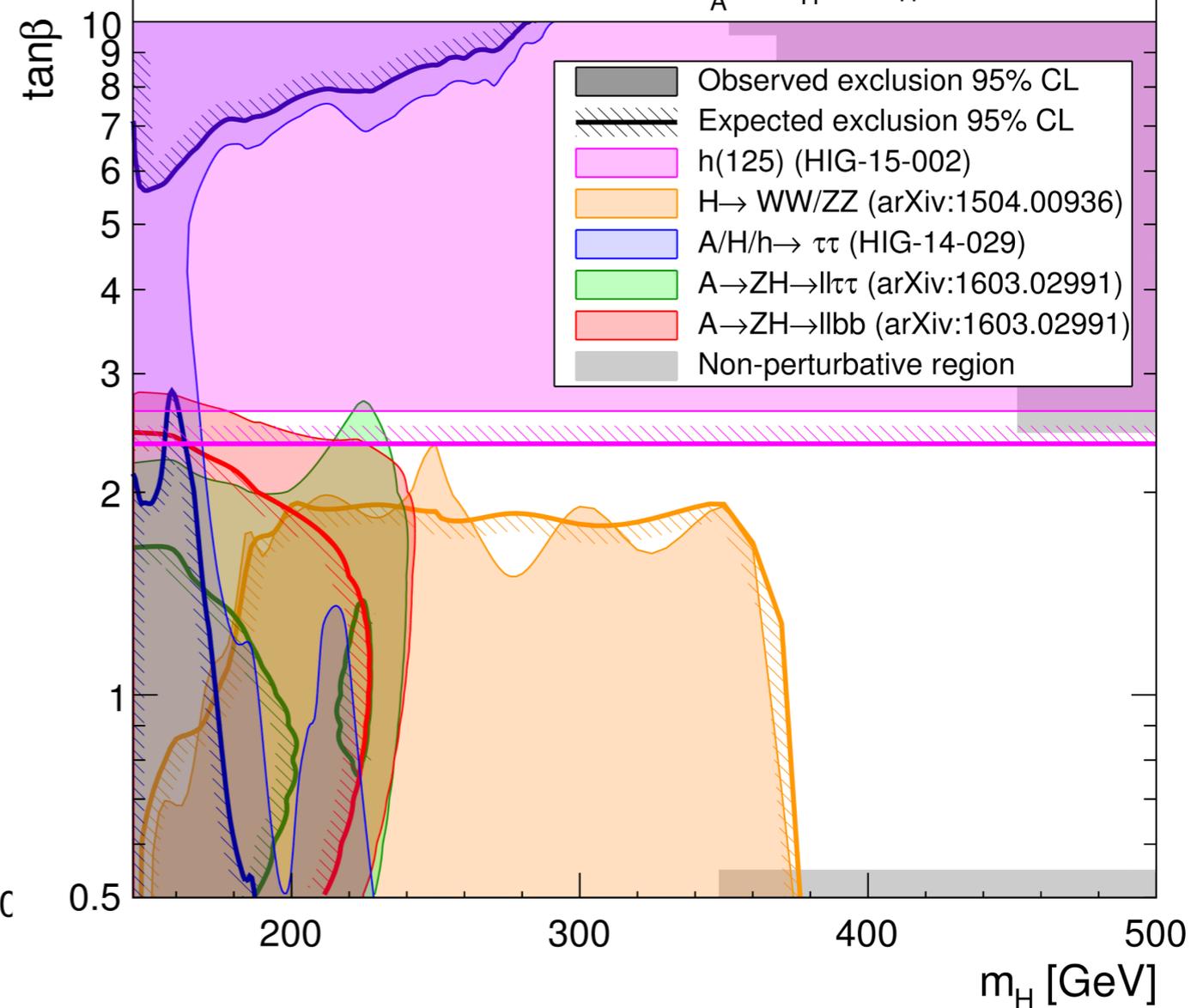
**CMS Preliminary**  $\leq 5.1 \text{ fb}^{-1}$  (7 TeV) +  $\leq 19.7 \text{ fb}^{-1}$  (8 TeV)

2HDM Type I,  $\cos(\beta-\alpha)=0.1$ ,  $m_A = m_{H^\pm} = m_H + 100 \text{ GeV}$

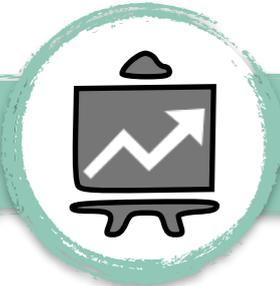


**CMS Preliminary**  $\leq 5.1 \text{ fb}^{-1}$  (7 TeV) +  $\leq 19.7 \text{ fb}^{-1}$  (8 TeV)

2HDM Type II,  $\cos(\beta-\alpha)=0.1$ ,  $m_A = m_{H^\pm} = m_H + 100 \text{ GeV}$

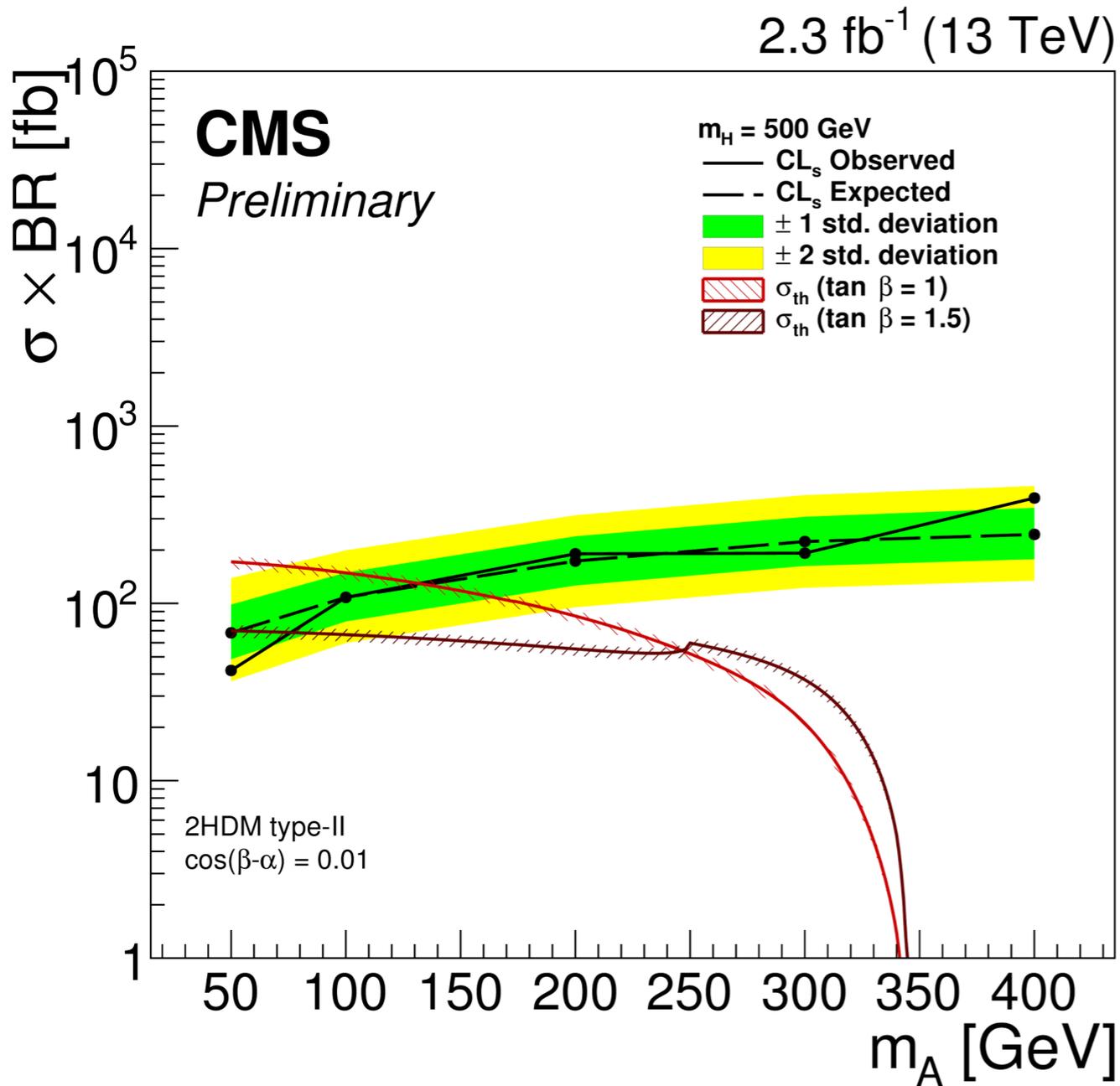


CMS-PAS-HIG-16-007



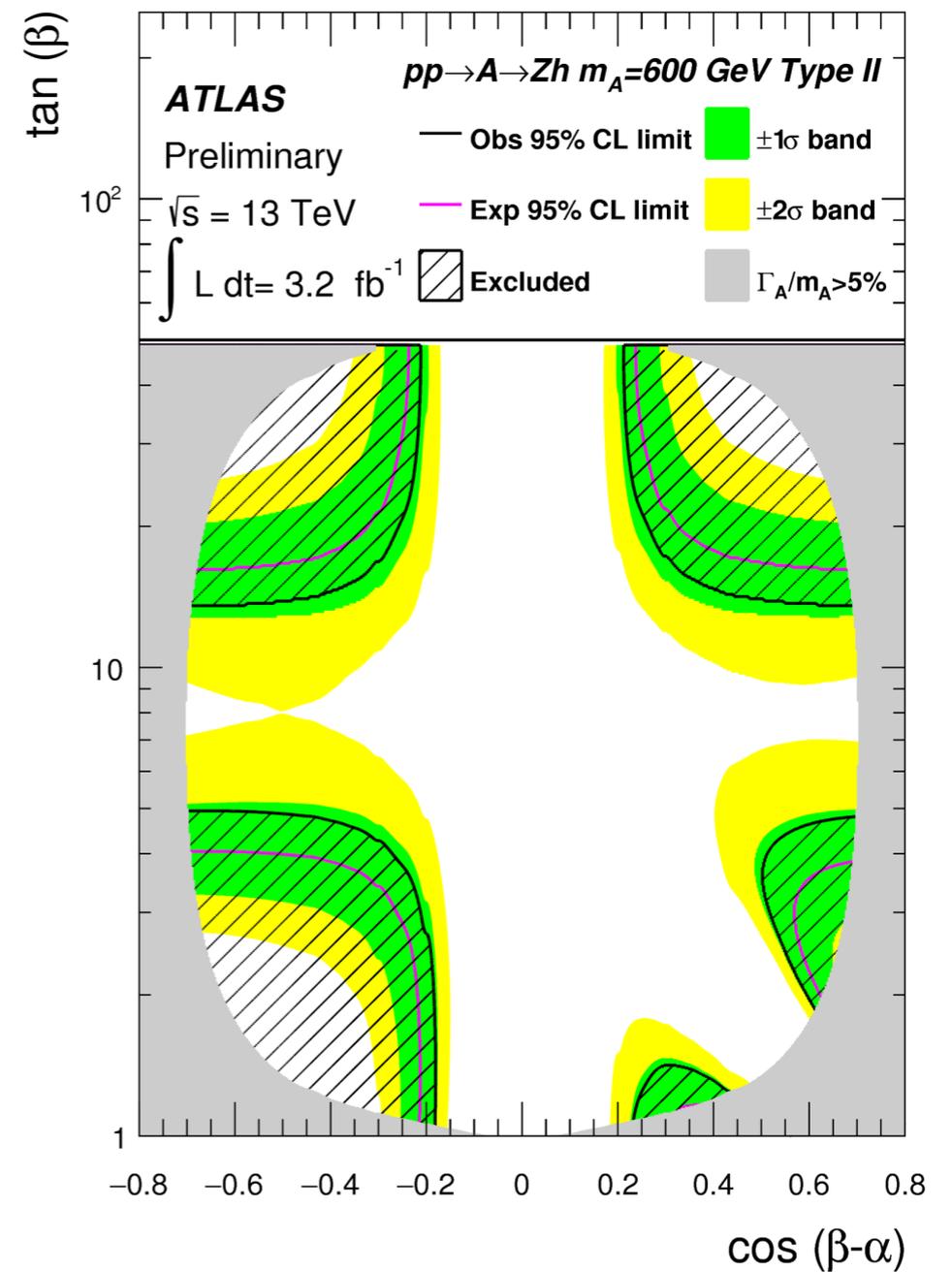
# Run2: ricerche con pseudoscalari

## CMS: $H \rightarrow ZA \rightarrow l^+l^- bb$

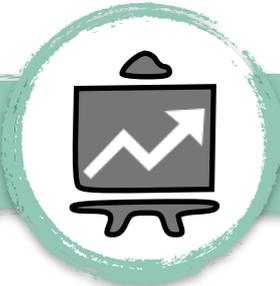


CMS-PAS-HIG-16-010

## ATLAS: $A \rightarrow Zh \rightarrow l^+l^- bb$



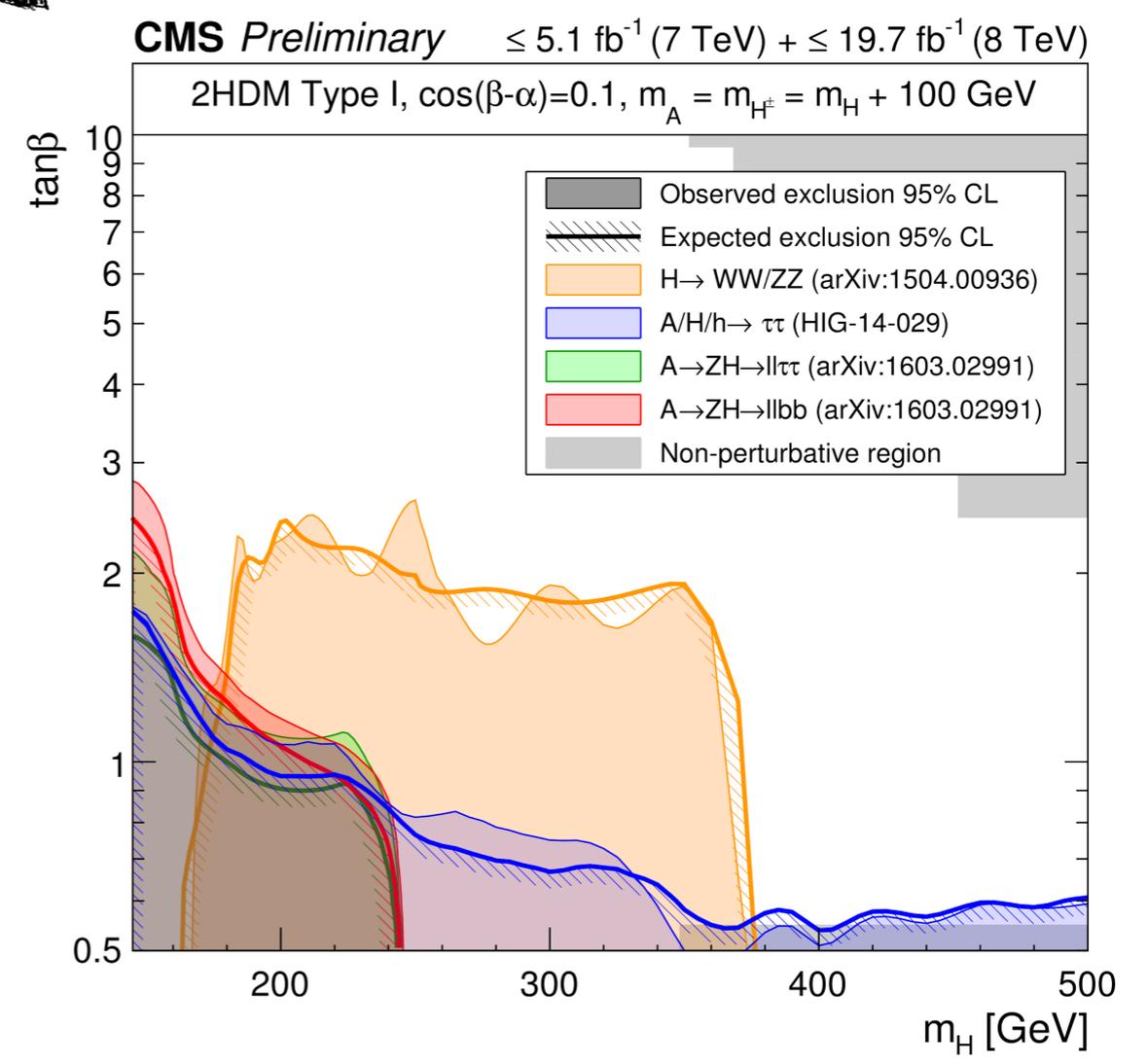
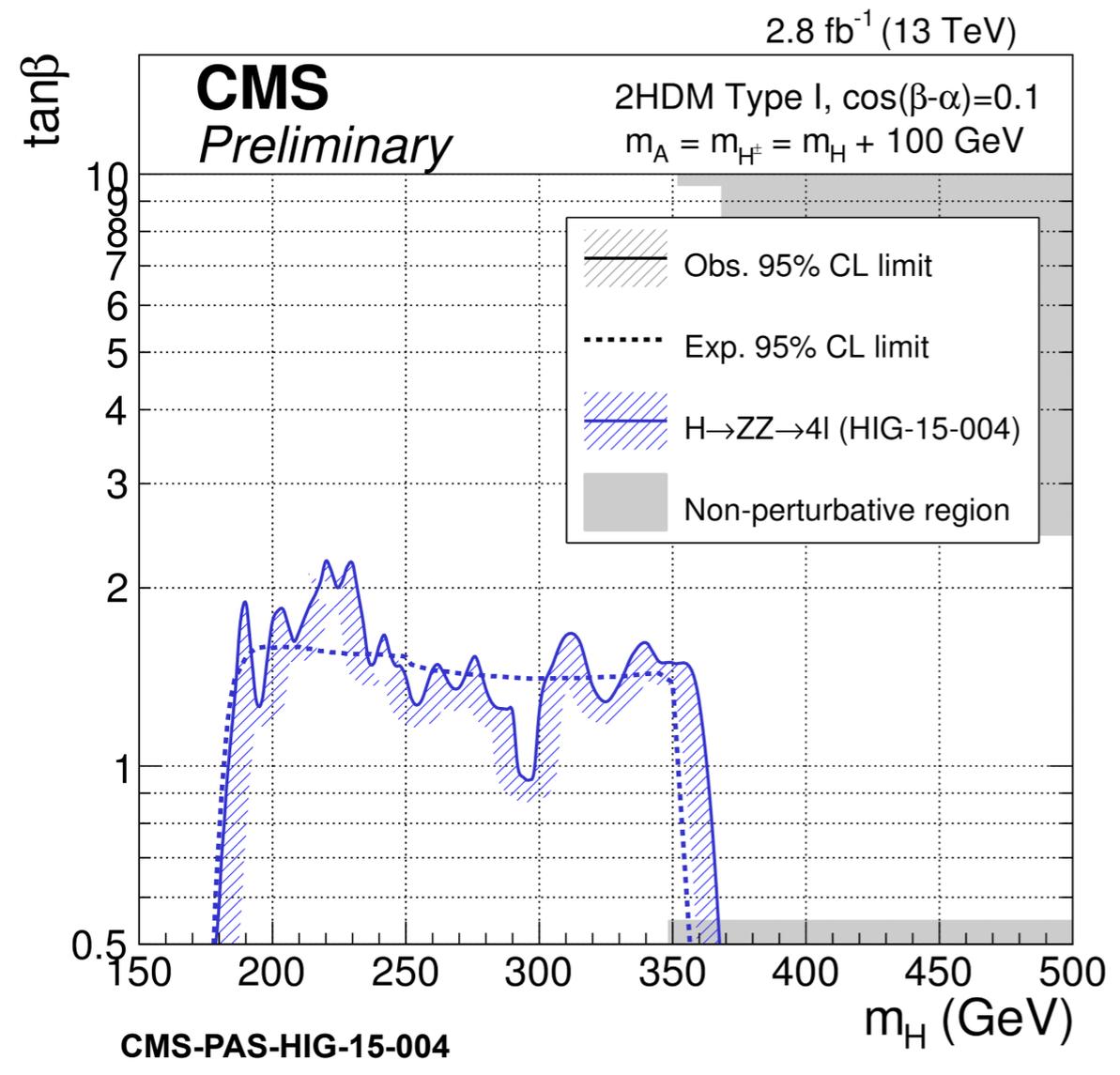
ATLAS-CONF-2016-015

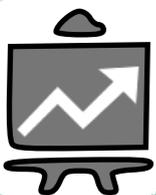


# Run2: ricerche $H \rightarrow \nu\nu$

	CMS	ATLAS
$H \rightarrow ZZ \rightarrow 4l$	✓	✓ ( $X \rightarrow ZZ$ )
$H \rightarrow ZZ \rightarrow 2l2\nu$	✓	✓
$H \rightarrow ZZ \rightarrow 2l2q$	X	✓
$H \rightarrow ZZ \rightarrow 2l2q / 2l2\nu$	X	✓

Serve più statistica!

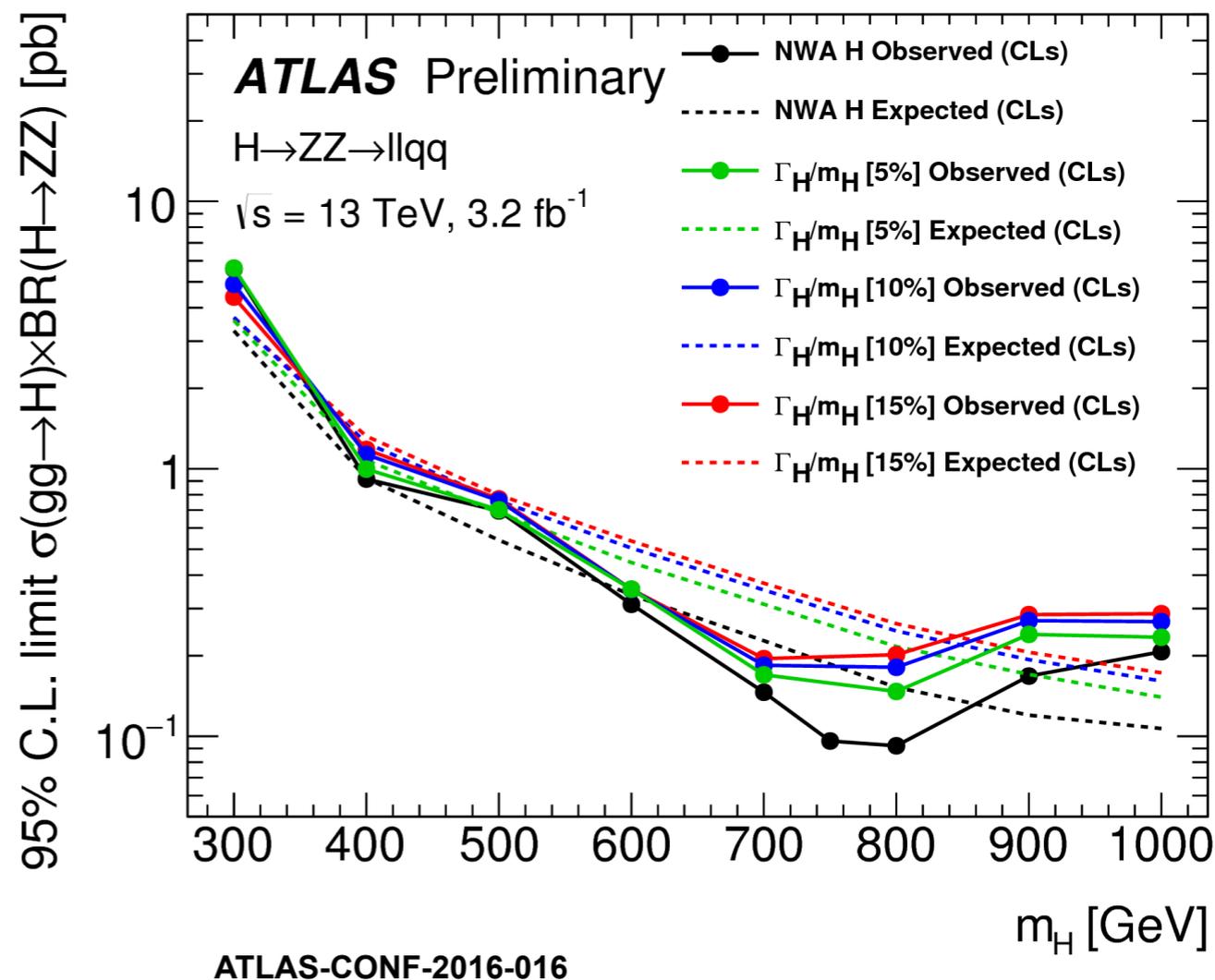
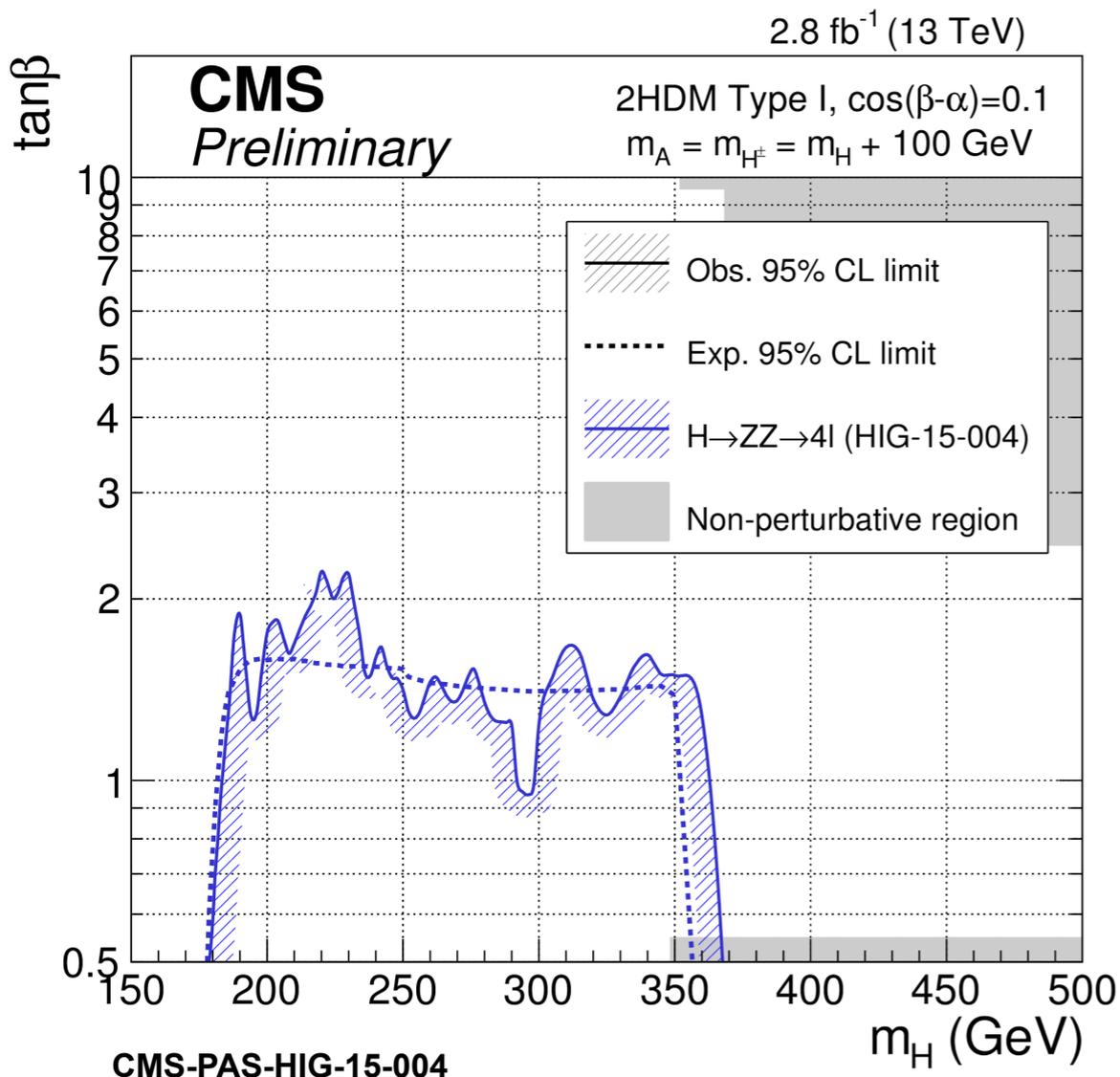


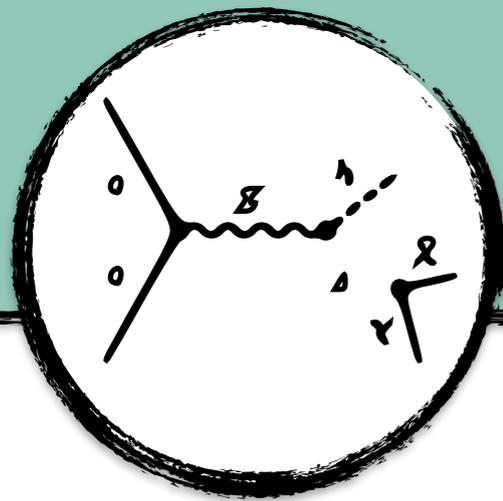


# Run2: ricerche $H \rightarrow \nu\nu$

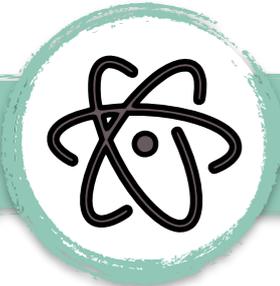
	CMS	ATLAS
$H \rightarrow ZZ \rightarrow 4l$	✓	✓ ( $X \rightarrow ZZ$ )
$H \rightarrow ZZ \rightarrow 2l2\nu$	✓	✓
$H \rightarrow ZZ \rightarrow 2l2q$	X	✓
$H \rightarrow ZZ \rightarrow 2l2q / 2l2\nu$	X	✓

Limite per diverse larghezze:  
interpretazione più facile in  
diversi modelli (in genere  
preferito da comunità teorica)





Моно-н



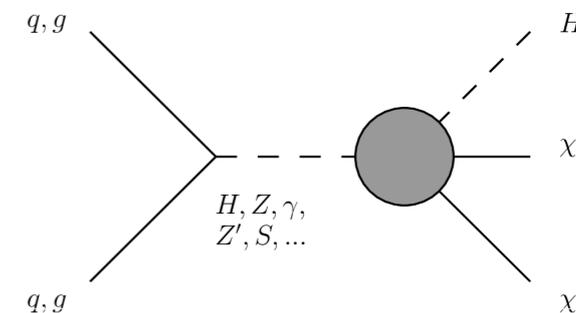
## Ricerche di materia oscura (DM)



## Studio accoppiamento SM - DM

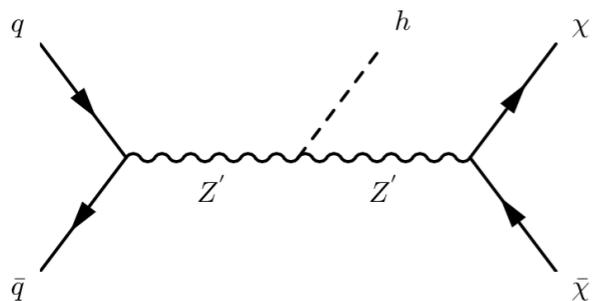
### EFT

- approccio principale nel Run-1
- Utilizzo di operatori di differenti dimensioni
- Confronto immediato con esperimenti "direct detection"
- Sensitività espressa in termini della scala di interazione  $\Lambda$  e alla massa della DM  $m_\chi$



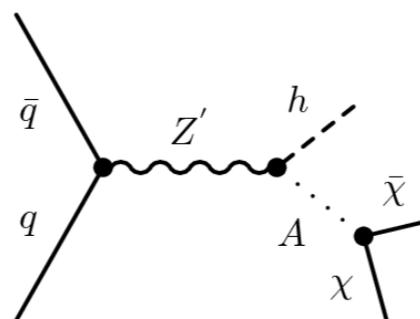
### Modelli semplificati

- Dipendenza da più parametri
- Mediatore scalare o vettoriale



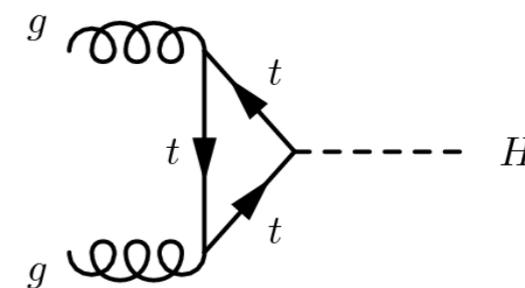
### Z'-2HDM

- Si assume un modello 2HDM per l'accoppiamento con la DM
- 2 parametri: accoppiamento  $g_{Z'}$  e  $\tan\beta$



### Modelli con Higgs massivo

- Si assume un modello 2HDM che ha come mediatore un Higgs massivo



Risultati pubblici Run-1 e Run-2 solo da ATLAS per  $h \rightarrow \gamma\gamma$ ,  $h \rightarrow b\bar{b}$ ,  $h \rightarrow ZZ \rightarrow 4\ell$

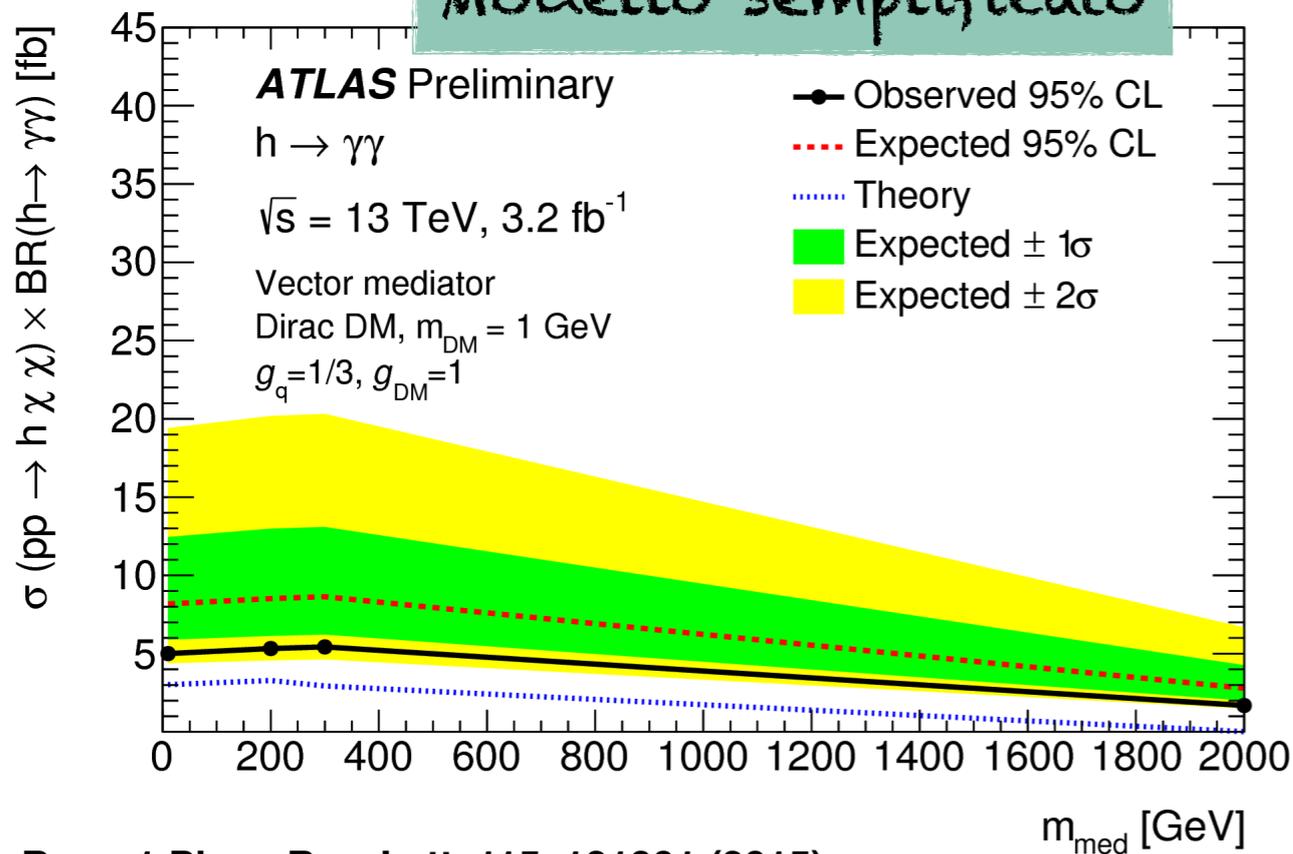


# Mono-h( $\rightarrow\gamma\gamma$ )

Analisi Run 1 e Run 2 molto simili

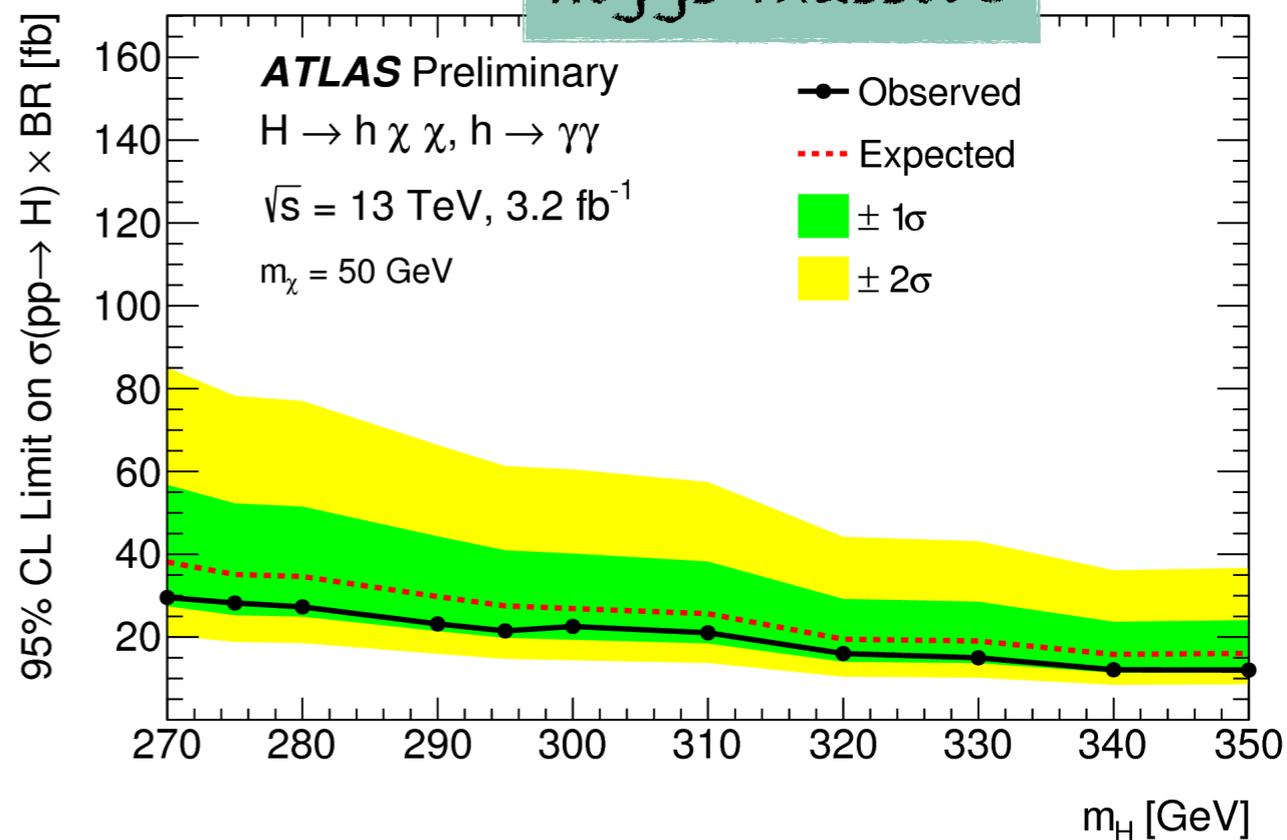
- ▶ 2 fotoni
- ▶ Taglio sulla MET
- ▶ Nel Run 2 introdotte 4 regioni ottimizzate per i modelli teorici studiati
- ▶ VH(Run 1), produzione non risonante in difotoni come fondi principali

## Modello semplificato



Run - 1 Phys. Rev. Lett. 115, 131801 (2015)  
Run - 2 ATLAS-CONF-2016-011

## Higgs massivo



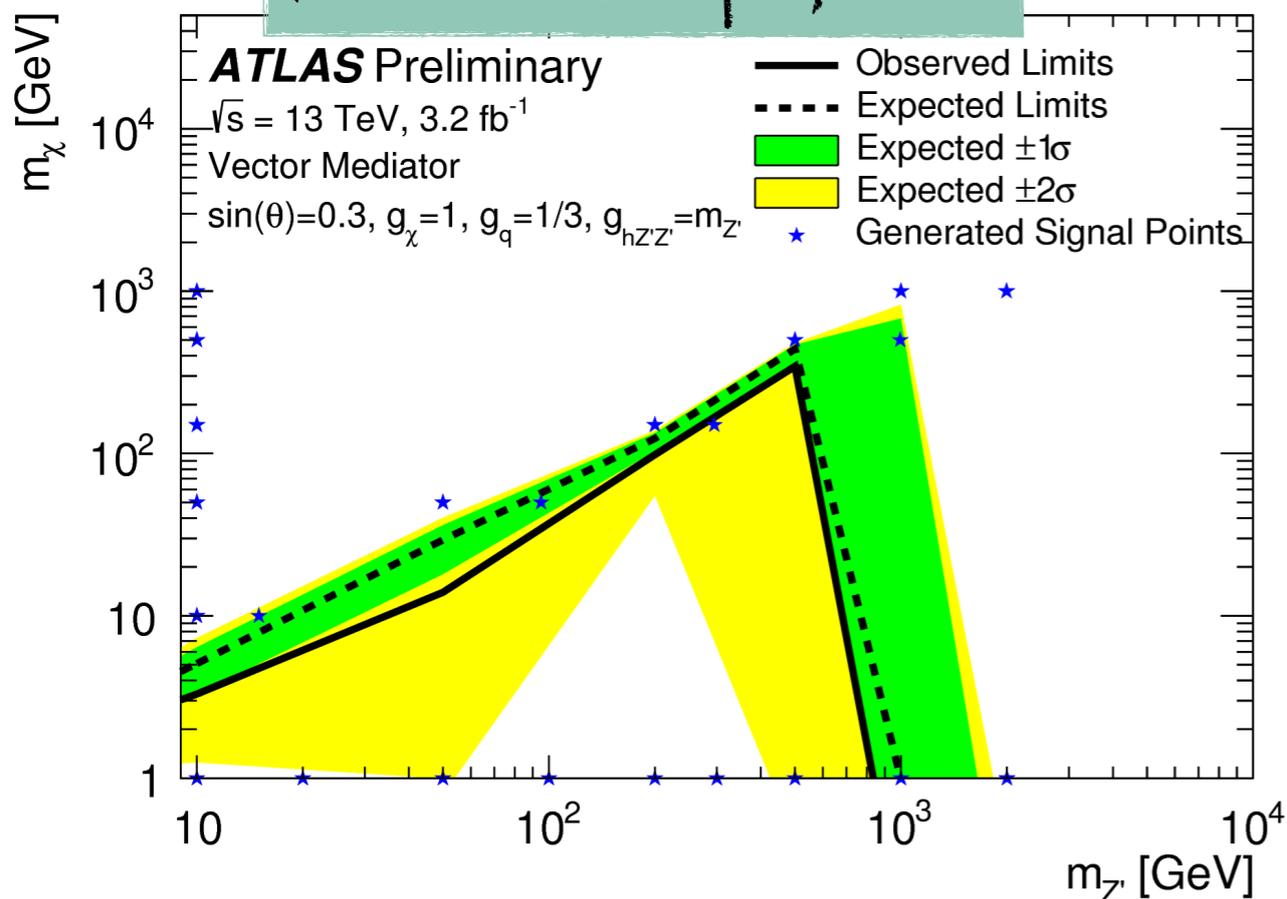


# Mono- $h(\rightarrow b\bar{b})$

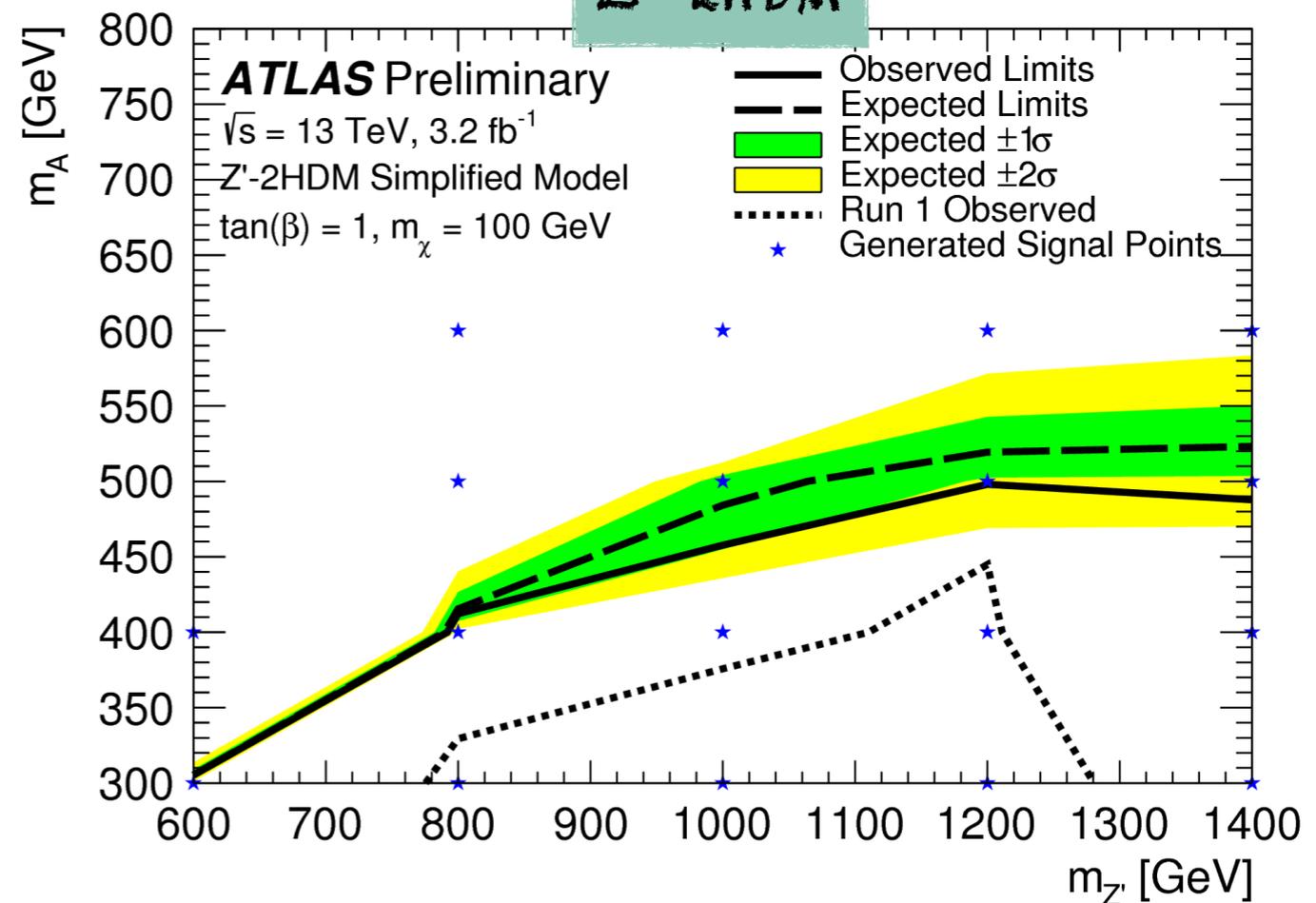
## Canale di decadimento favorito del bosone di Higgs

- ▶ Analisi divisa nelle categorie resolved e boosted
  - Classificazione in base al numero di b-jets
  - Maggiore sensibilità nella regioni con alta MET e 2 b-jets
- ▶  $m(jj)$  o  $m(j)$  variabile discriminante nelle regioni resolved e boosted
- ▶  $W/z$  + jets e  $t\bar{t}$  fondi dominanti

### Modello semplificato



### Z'-2HDM



ATLAS-CONF-2016-019

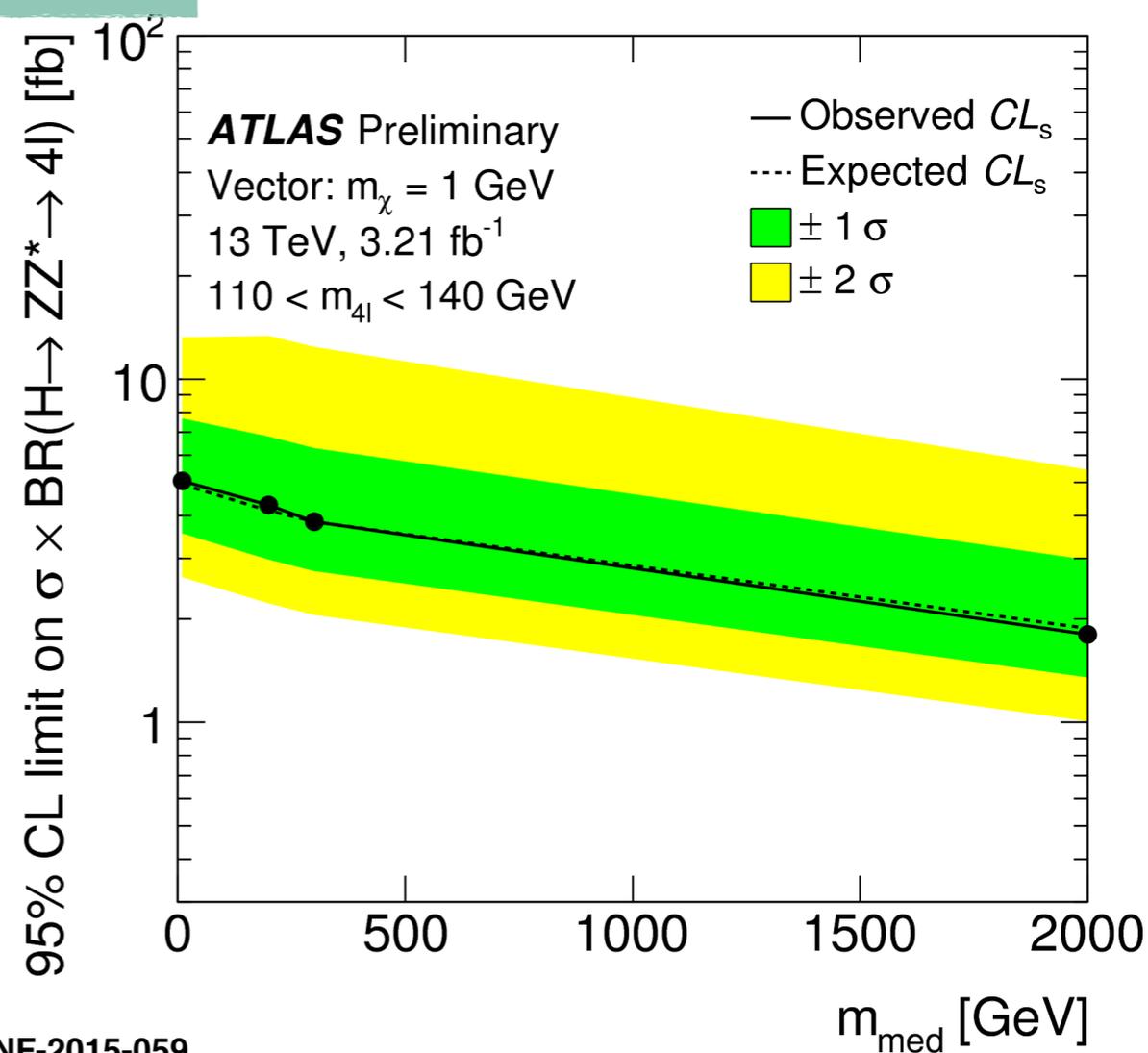
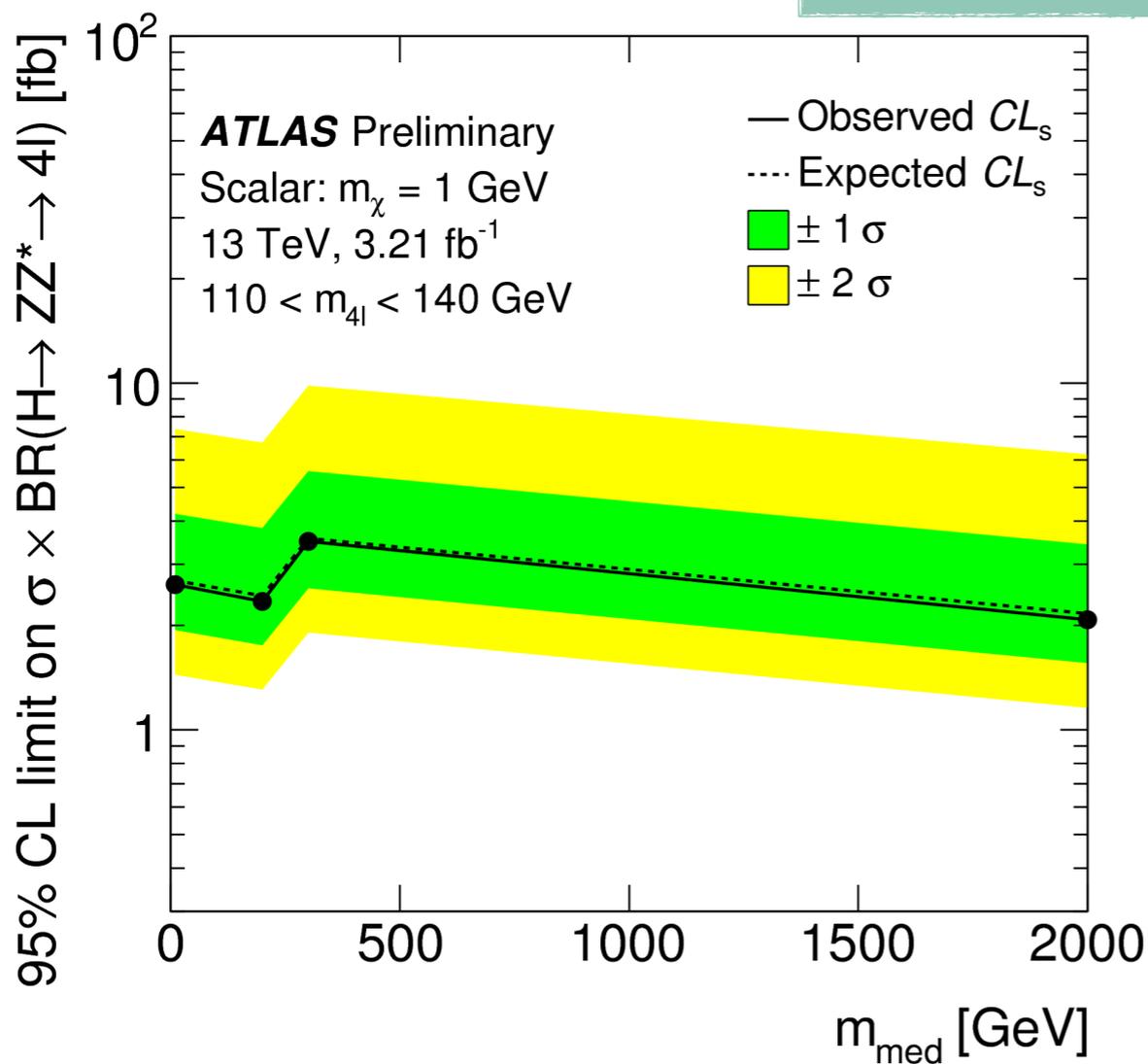


# Mono- $h(\rightarrow ZZ \rightarrow 4\ell)$

## Segnatura sperimentale chiara

- ▶ Sensitività attesa inferiore all'analisi  $h \rightarrow \gamma\gamma$  (di un fattore 3)
- ▶ MET usata come variabile discriminante
  - ▶ SR con MET > 100 GeV, CR con MET < 100 GeV
- ▶ ZZ, Z+jets,  $t\bar{t}$ ,  $ZH(\rightarrow WW \rightarrow \ell\nu\ell\nu)$ , meccanismi di produzione dell'Higgs

### Modello semplificato



ATLAS-CONF-2015-059



# Conclusioni



# Conclusioni

L'ombrello di "Higgs esotico" ricopre due possibili percorsi:

- ▶ Decadimenti di  $h_{125}$
- ▶ Ricerca di ulteriori stati ad alta massa

Per Run2, aggiornamento delle analisi "di punta" a 13 TeV

- ▶ In molti casi, (comprensibile) ritardo in attesa di sensibilità compatibile a 8 TeV
  - Tempo dedicato alla riottimizzazione delle analisi
  - Specialmente vero per gli studi di  $h_{125}$
- ▶ In Run2, aumentato notevolmente lo spettro di topologie con interpretazione nel settore dell'Higgs
  - Filosofia leave no stone unturned
- ▶ L'approccio di base e' identificare topologie e scenari di benchmark condivisi
- ▶ Importante lavoro di razionalizzazione nello YR4 dell'HXSWG

**Cosa ci manca?**



# Desiderata

## Decadimenti esotici di $h_{125}$ :

- ▶  $q\bar{q}$  con mesoni leggeri, come  $h \rightarrow \phi\gamma$ 
  - Limitazione principale e' ovviamente il trigger
  - Alcuni forse possibili, ma necessari studi (manpower)
- ▶  $h_{125} \rightarrow 2 \text{ scalari} \rightarrow 4f$ 
  - Nulla e' perduto fuorché 4b
- ▶ Decadimenti a vita media "lunga"
  - Anche qui il trigger e' il collo di bottiglia
  - Stati finali leptonici favoriti

## $t\bar{t}$ :

- ▶ Forse il solo canale in grado di distinguere diversi scenari di 2HDM
- ▶  $H \rightarrow VV$  soppresso da  $h_{125}$ ,  $t\bar{t}$  non necessariamente
- ▶  $m_{tt} \sim 750 \text{ GeV}...$
- ▶ Due problemi per affrontarlo:
  - Abbondante fondo  $t\bar{t}$
  - Piu' importante: input teorico (interferenza segnale-fondo)

# BSM Higgs searches

## Discussione

Claudio Caputo, Paolo Francavilla  
INFN, Univ. Studi di Bari & CNRS ILP/LPNHE Paris

May 17, 2016

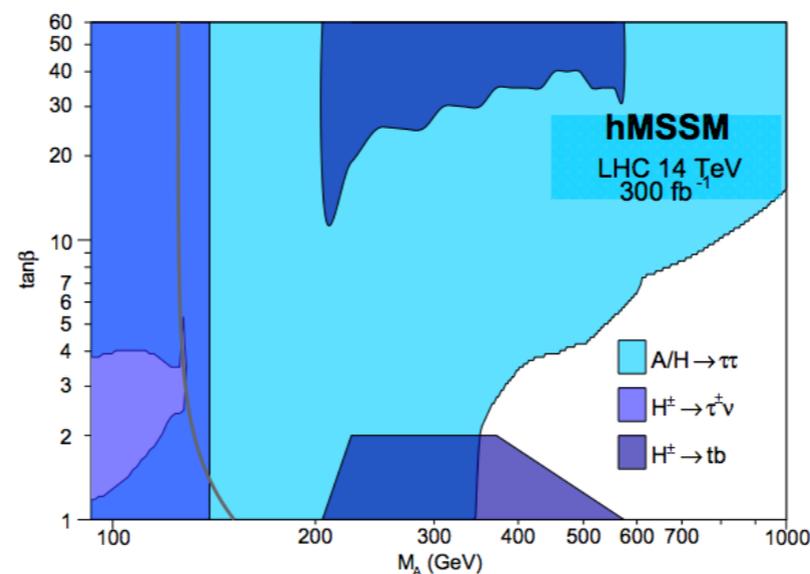
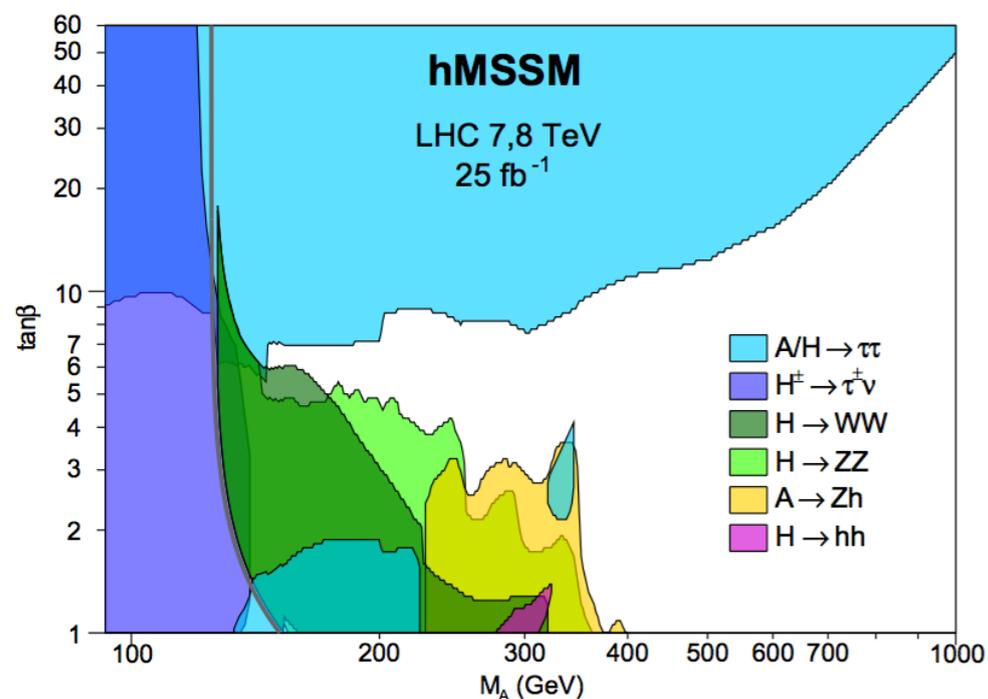
PP @ LHC 2016

VII Workshop italiano sulla fisica pp a LHC

# Projections - Fermions

14 TeV - 300 fb<sup>-1</sup>

Run 1



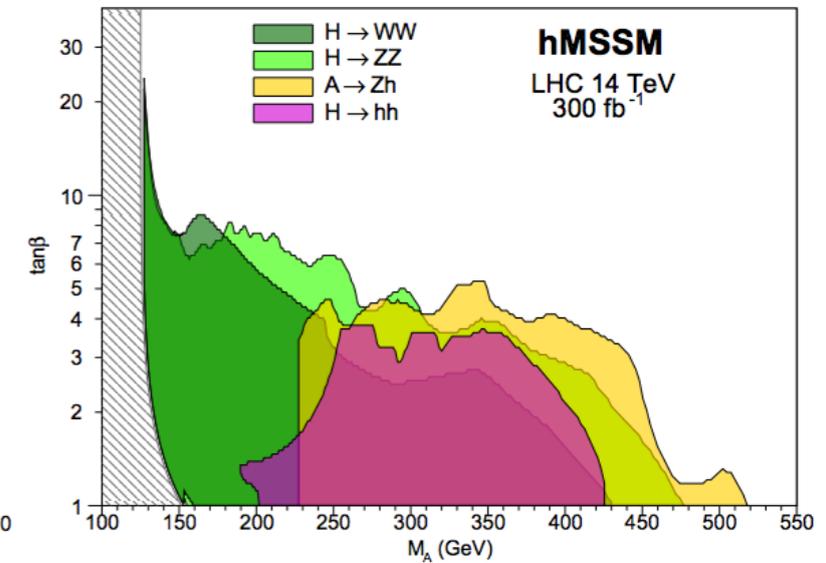
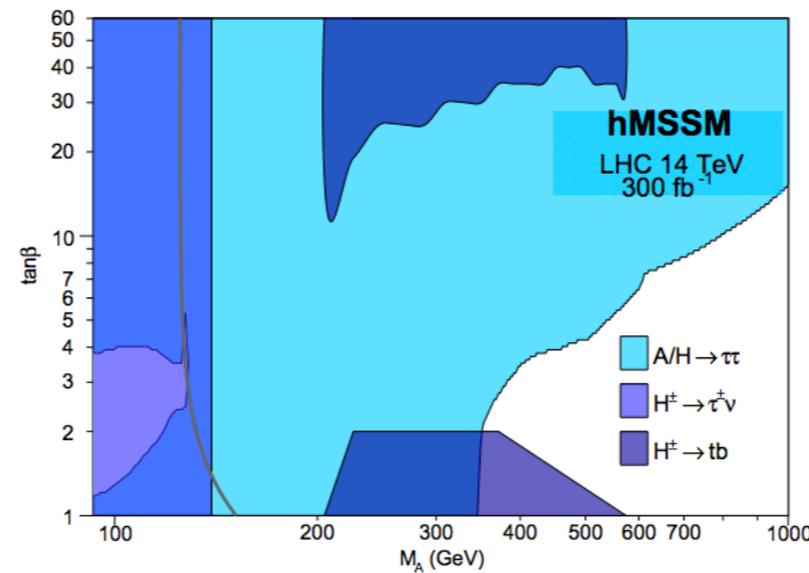
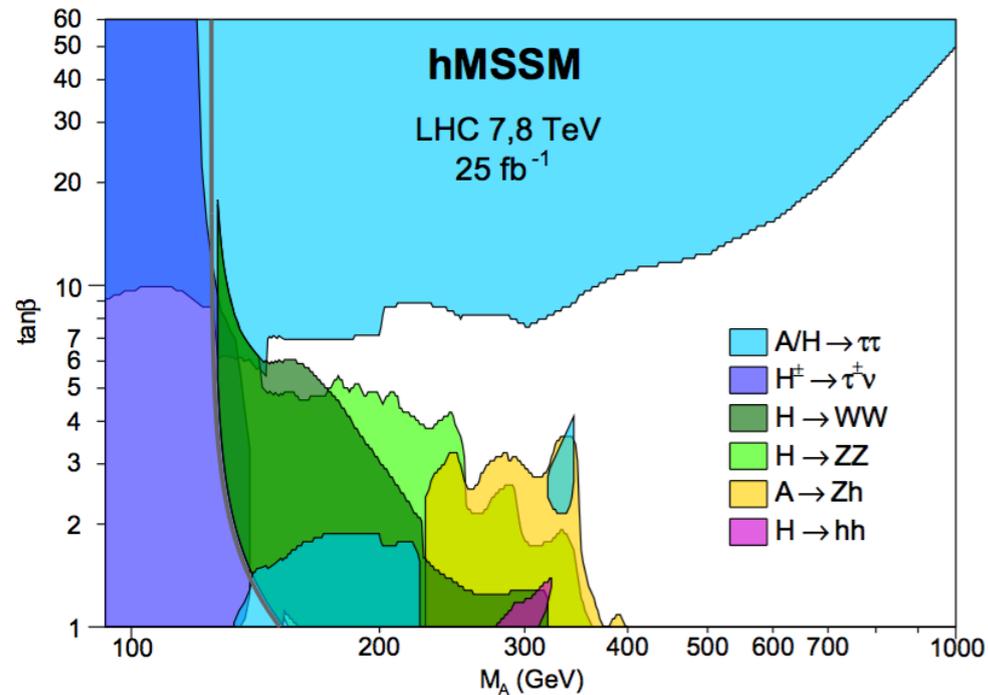
A/H- $\rightarrow\tau\tau$  will cover alone good part of the phase space

Run1 searches already covering the majority of the phase space for  $m_A < 2m_{\text{top}}$

# Projections - Bosons

14 TeV - 300 fb<sup>-1</sup>

Run 1



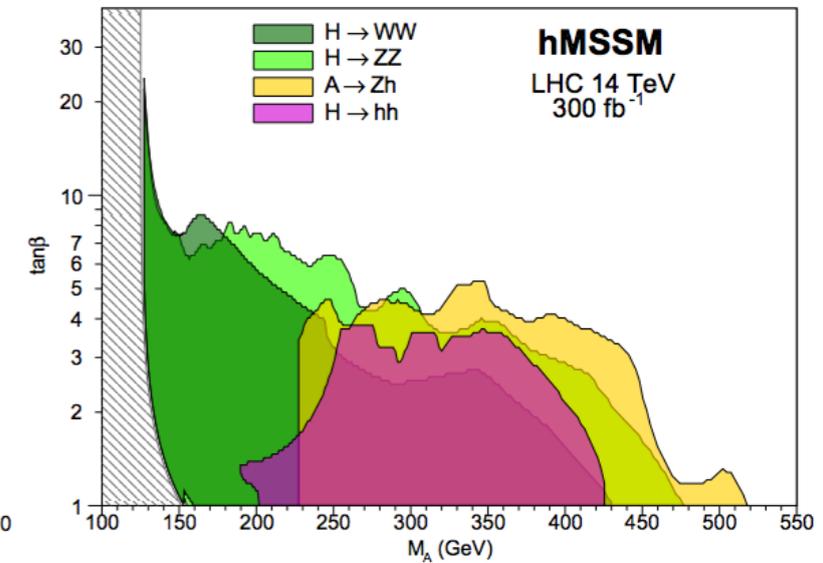
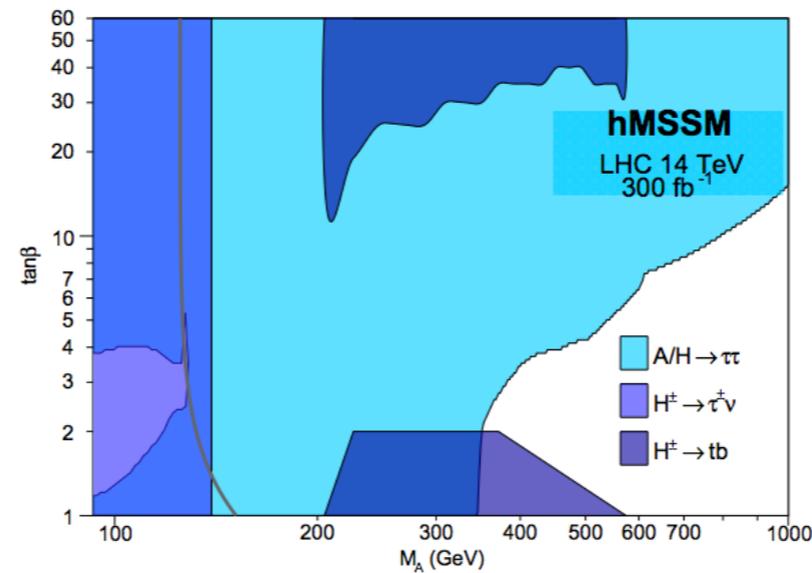
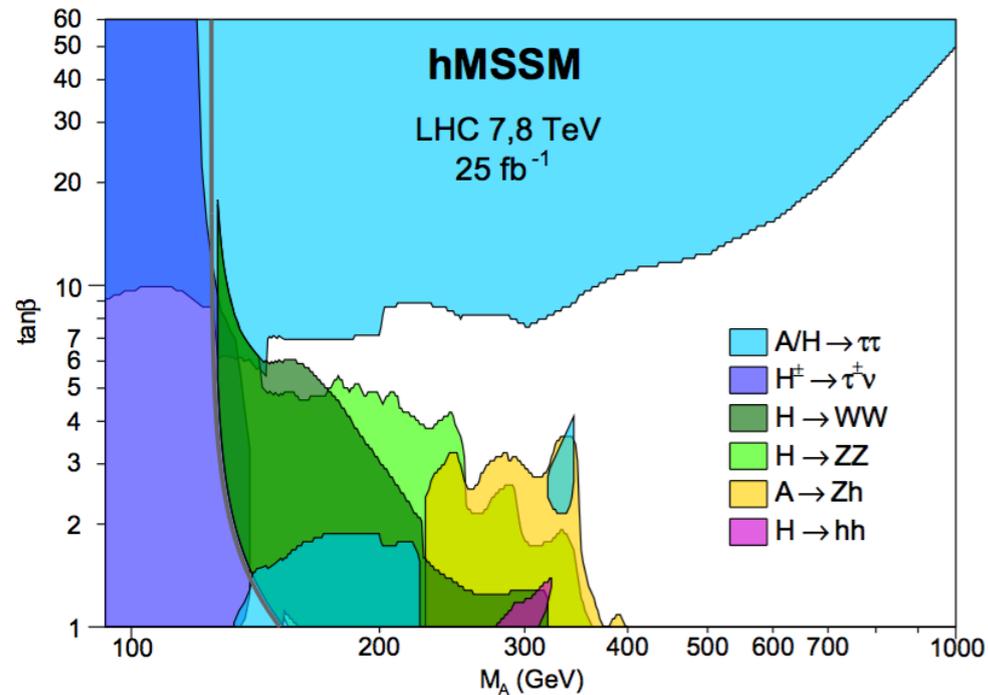
A/H- $\rightarrow\tau\tau$  will cover alone good part of the phase space

Run1 searches already covering the majority of the phase space for  $m_A < 2m_{\text{top}}$

# Projections

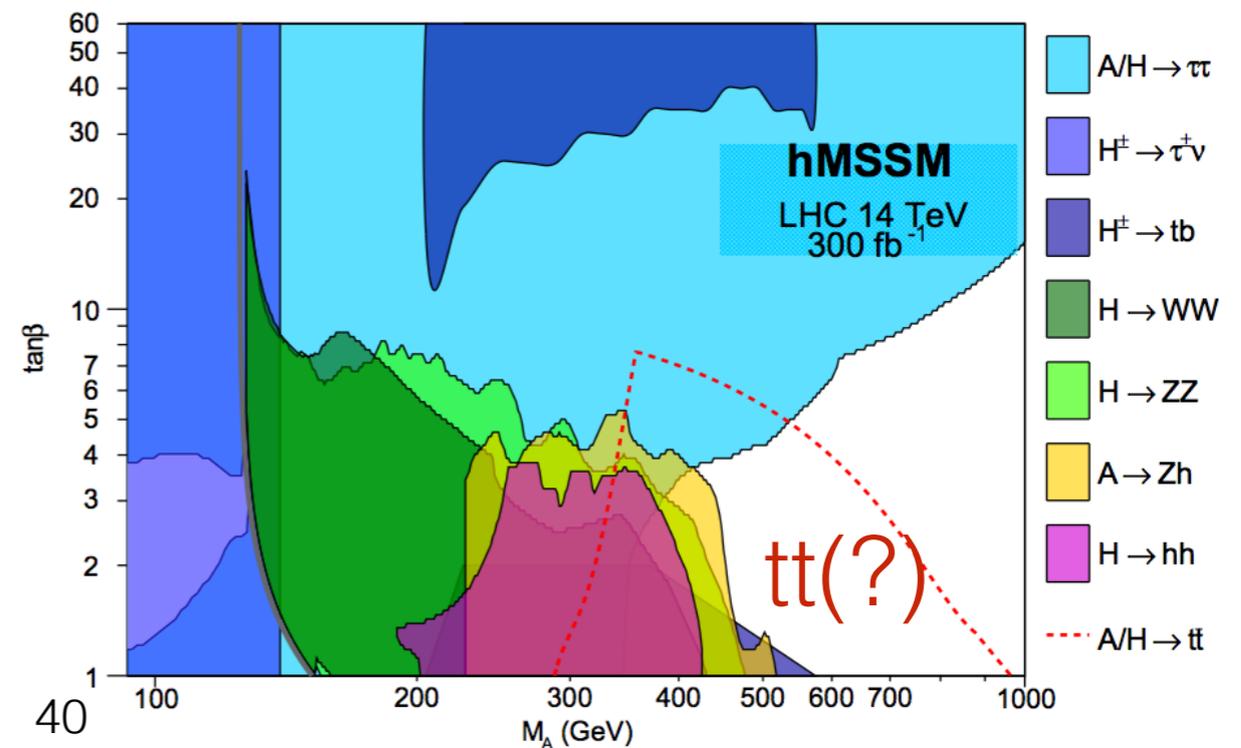
14 TeV - 300 fb<sup>-1</sup>

Run 1



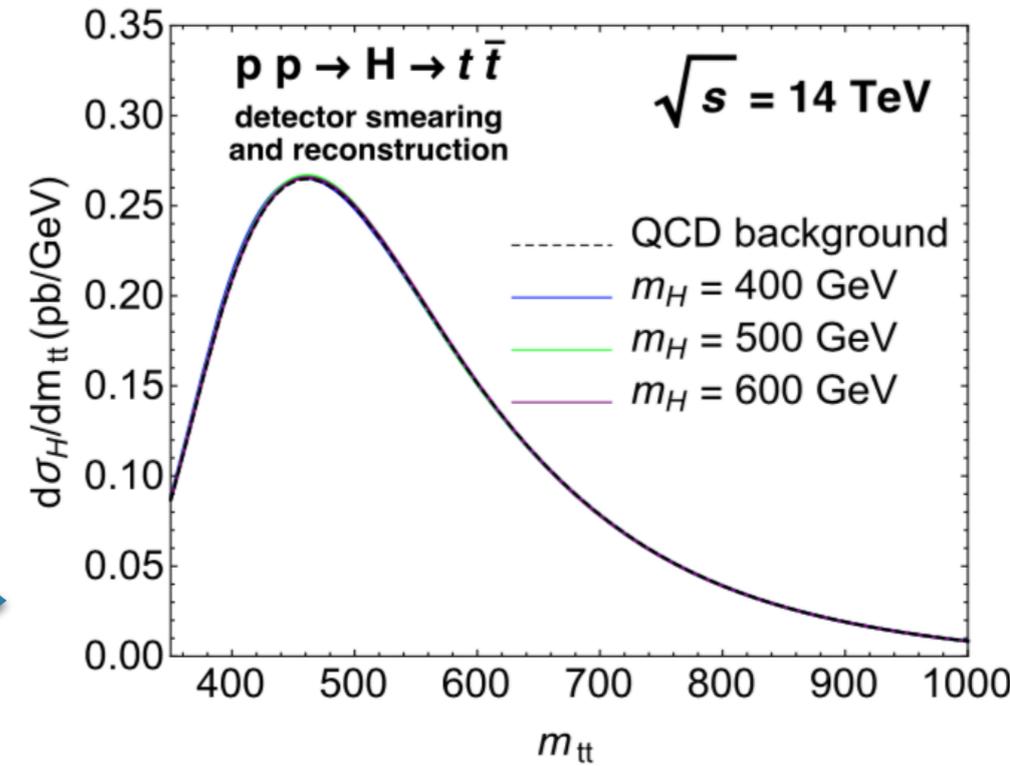
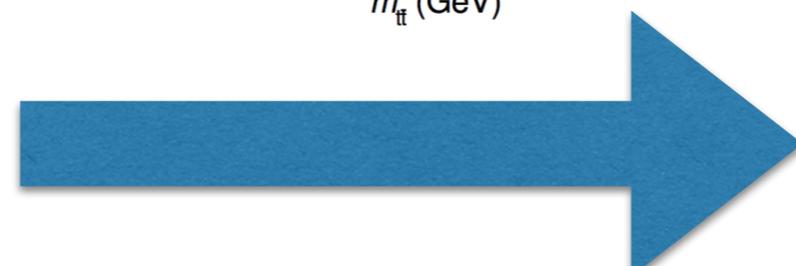
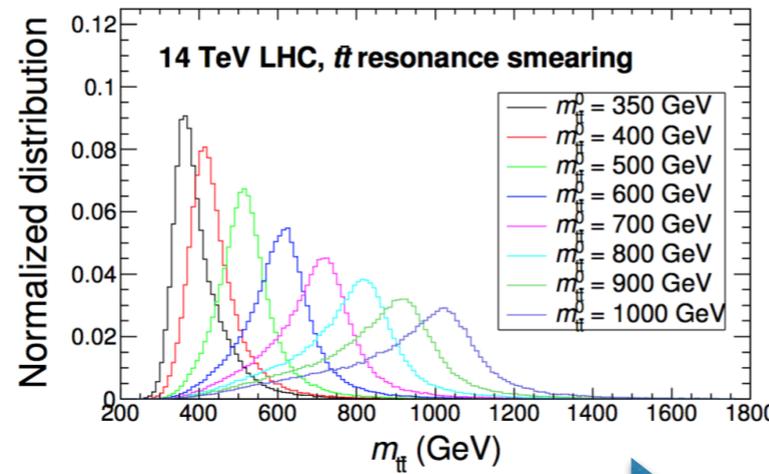
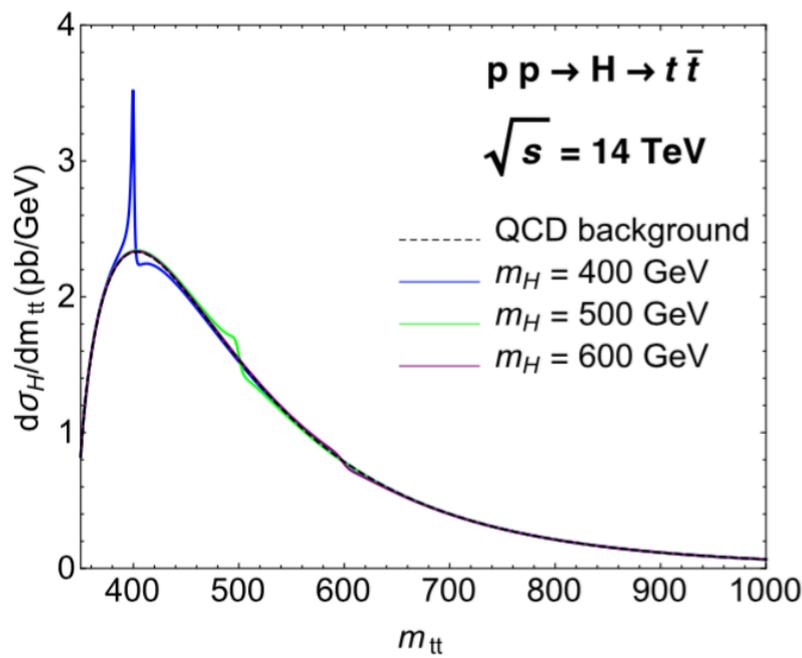
A/H- $\rightarrow\tau\tau$  will cover alone good part of the phase space

Run1 searches already covering the majority of the phase space for  $m_A < 2m_{\text{top}}$

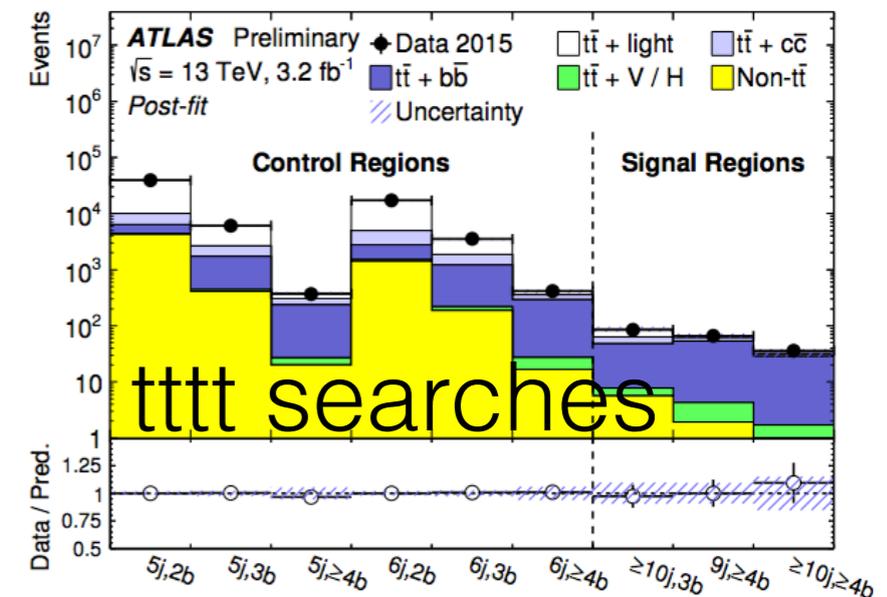


# A/H- > ttbar?

- The ATLAS and CMS performed searches for Spin1 heavy states decaying into  $t\bar{t}$  pairs
- More complicated Higgs situation: Interference with QCD  $t\bar{t}$  production.



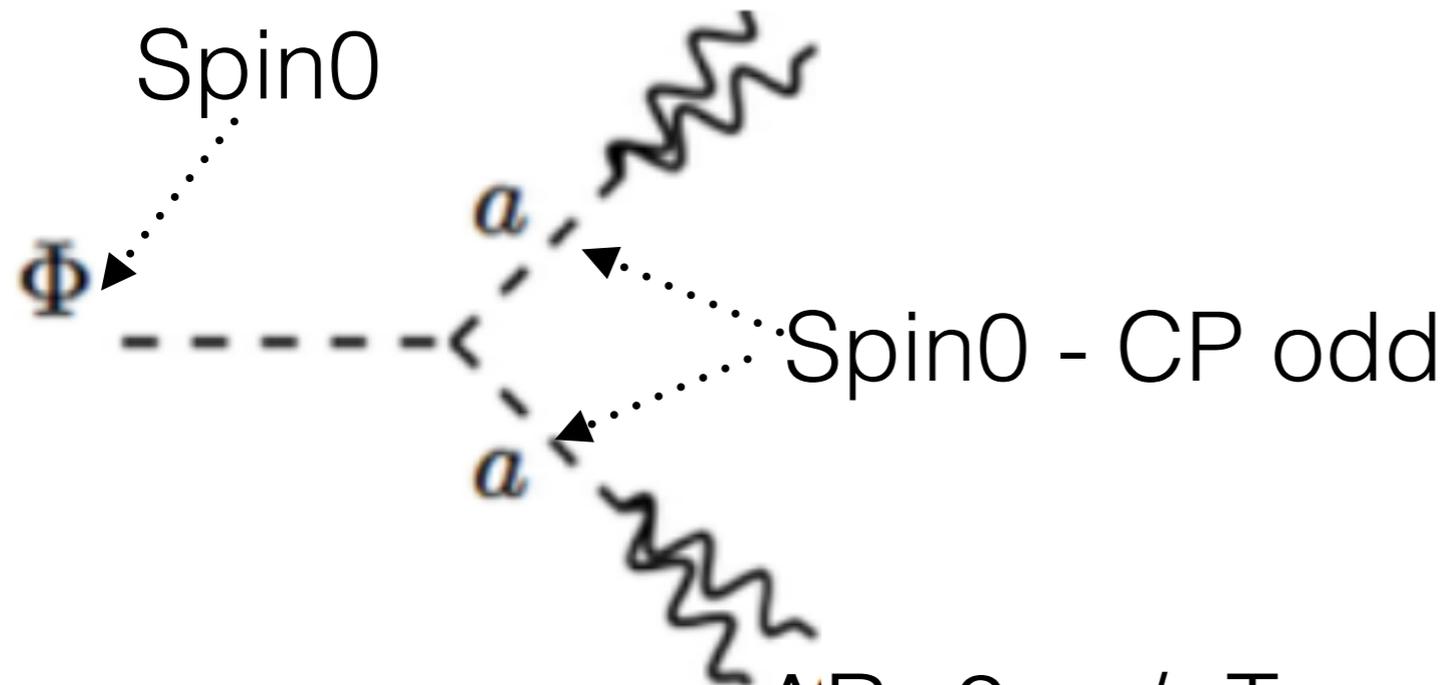
- Any chance?
- Other production mechanisms?
  - $t\bar{t}t\bar{t}$  ( $m_H=700$  GeV,  $\tan\beta=1$  -> 5 fb)?



# X(750 GeV) in NMSSM

1602.07691v2

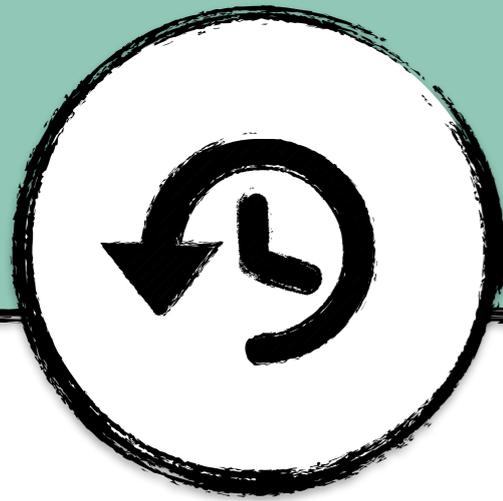
1602.00949



neutral spin 0 in NMSSM:  
3 CP even  $h_1, h_2, h_3$ , 2 CP odd  $A, a$

$$\Delta R = 2ma/pT \rightarrow ma < 0.1 - 10 \text{ GeV}$$

- Can we (ATLAS/CMS) distinguish them from single photons?
- Run1 ATLAS  $H \rightarrow aa \rightarrow \gamma\gamma\gamma\gamma$ :
  - Limits for  $10 < ma < 440 \text{ GeV}$ ,  $mH < 900 \text{ GeV}$
- Other channels?
  - $X(750) \rightarrow aa \rightarrow 4\mu$ ?
  - $a \rightarrow 2e$ ?



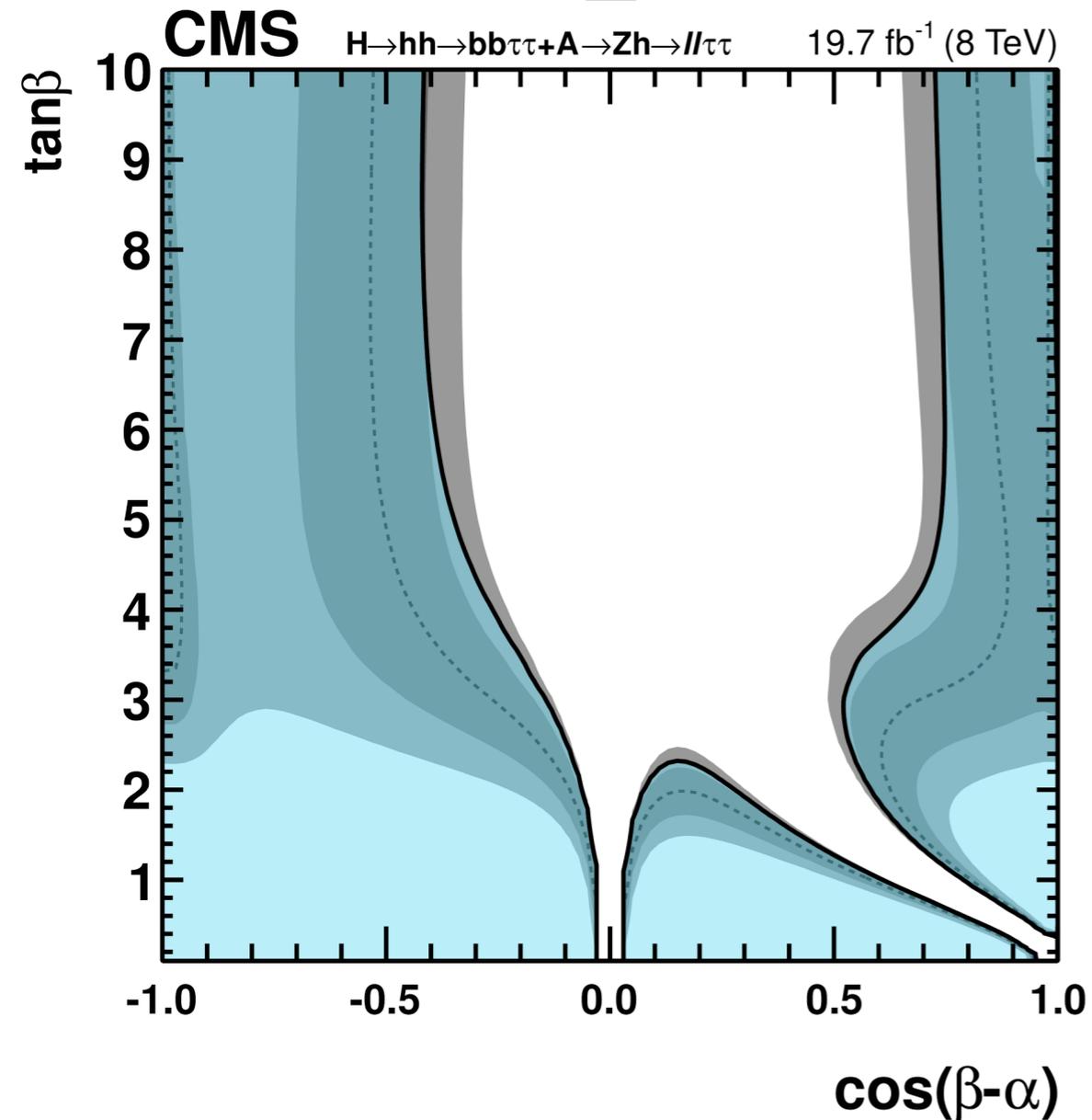
Backup

# Run1: Risultati 2HDM/hh per CMS

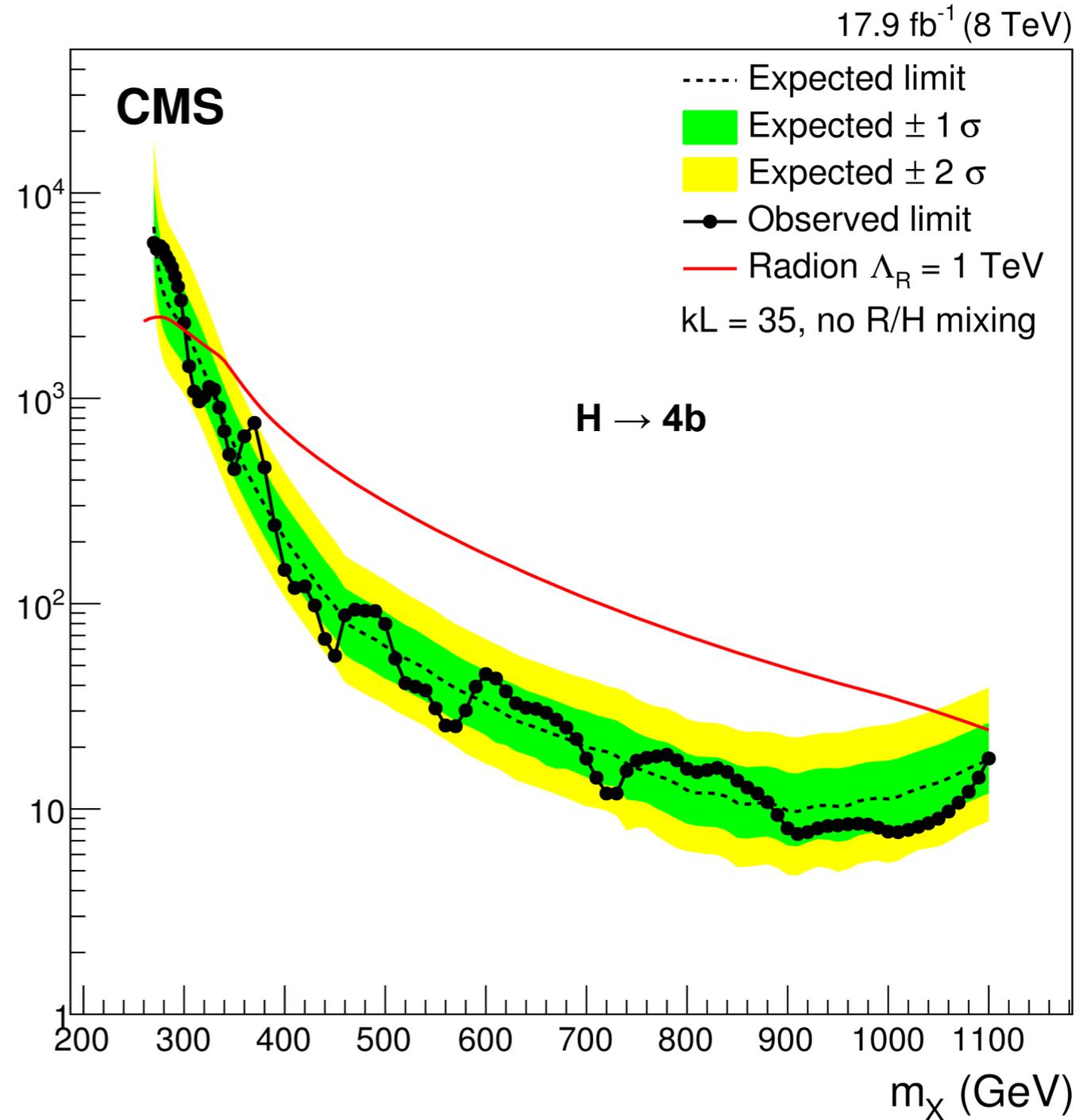
2HDM type-II,  $m_A = m_H = 300$  GeV

95% CL Excluded:

- Observed
- $\pm 1\sigma$  Expected
- Expected
- $\pm 2\sigma$  Expected



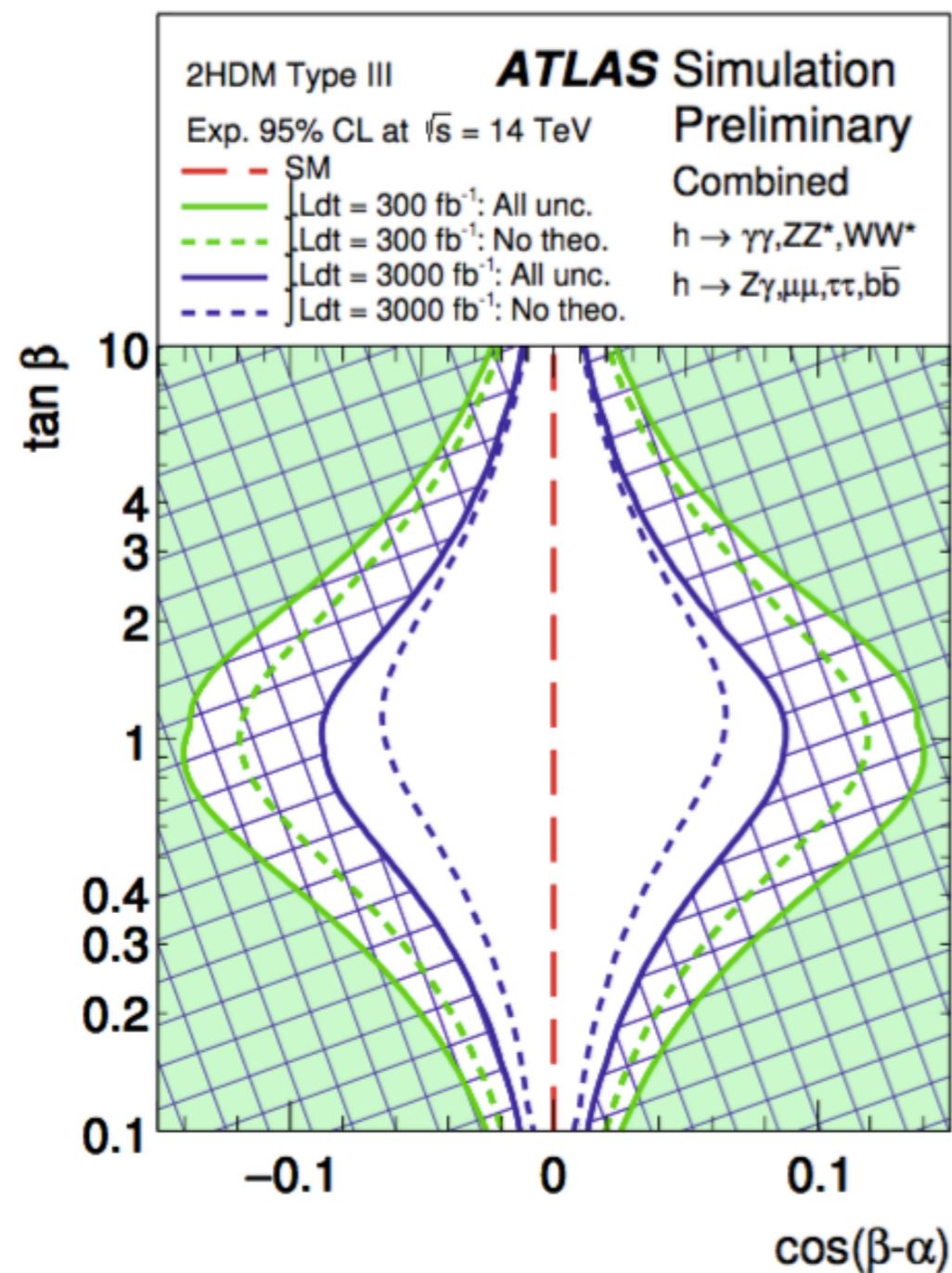
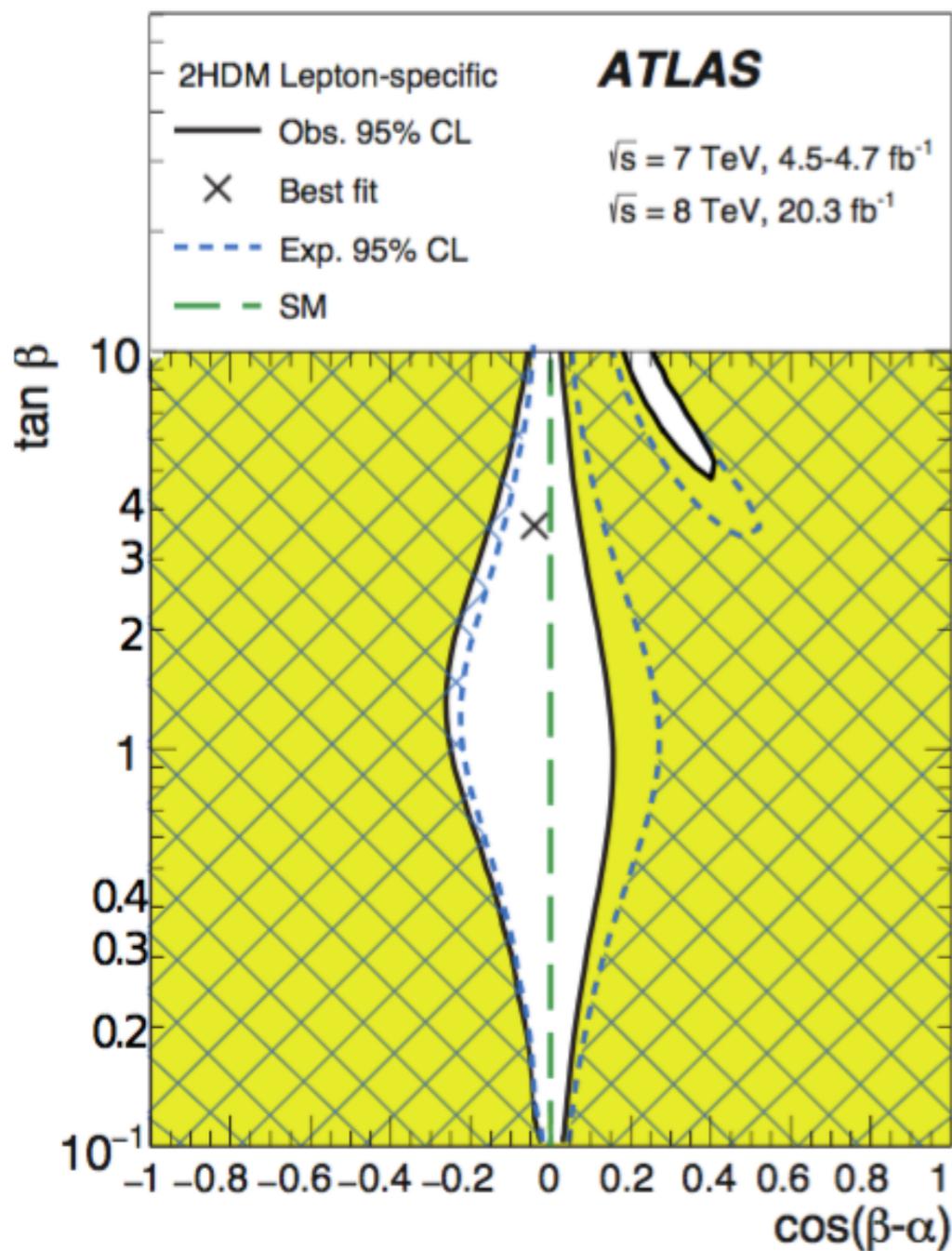
95% CL<sub>S</sub> limit on  $\sigma$  ( $pp \rightarrow X \rightarrow HH \rightarrow b\bar{b}b\bar{b}$ ) (fb)





# Limiti allo spazio dei parametri

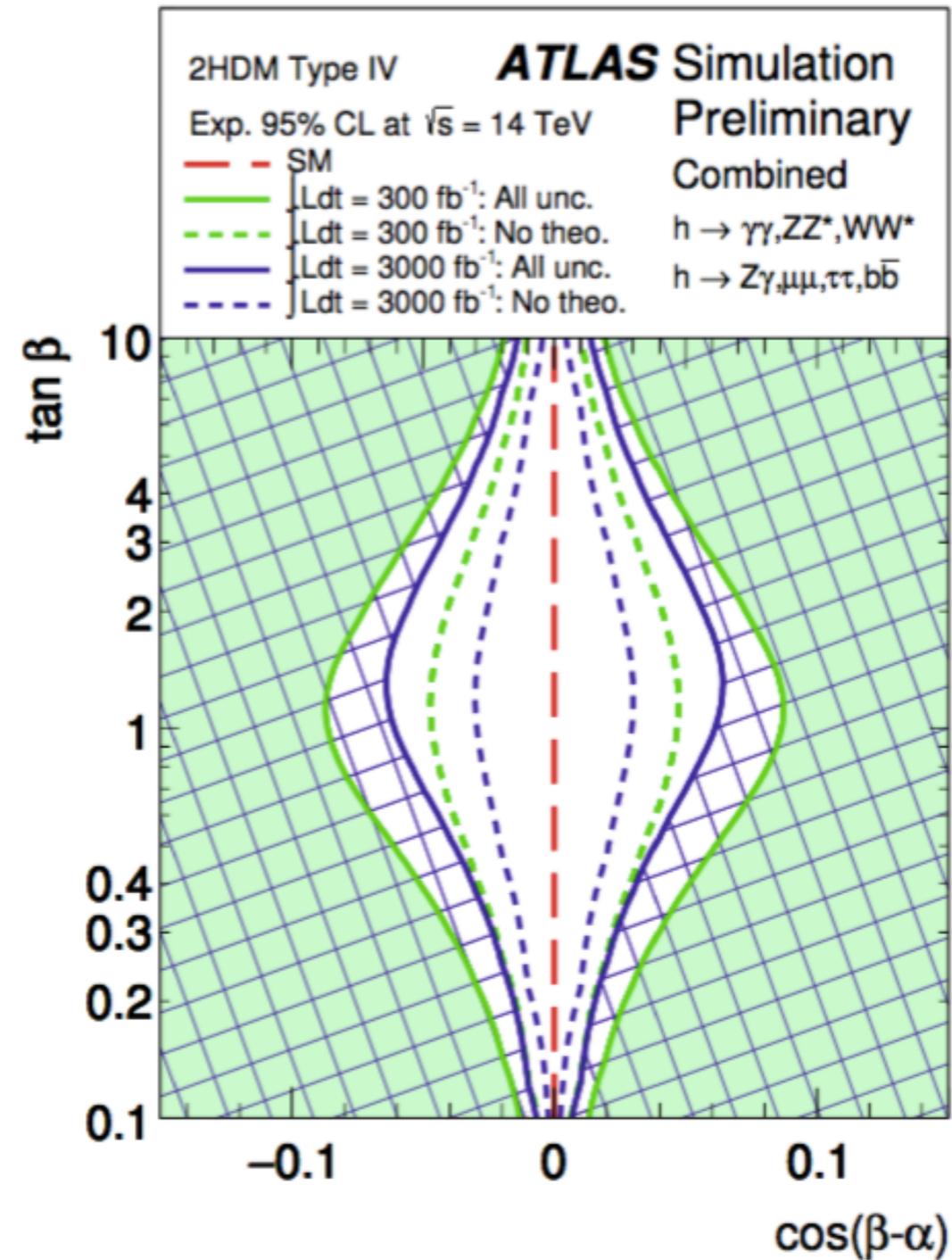
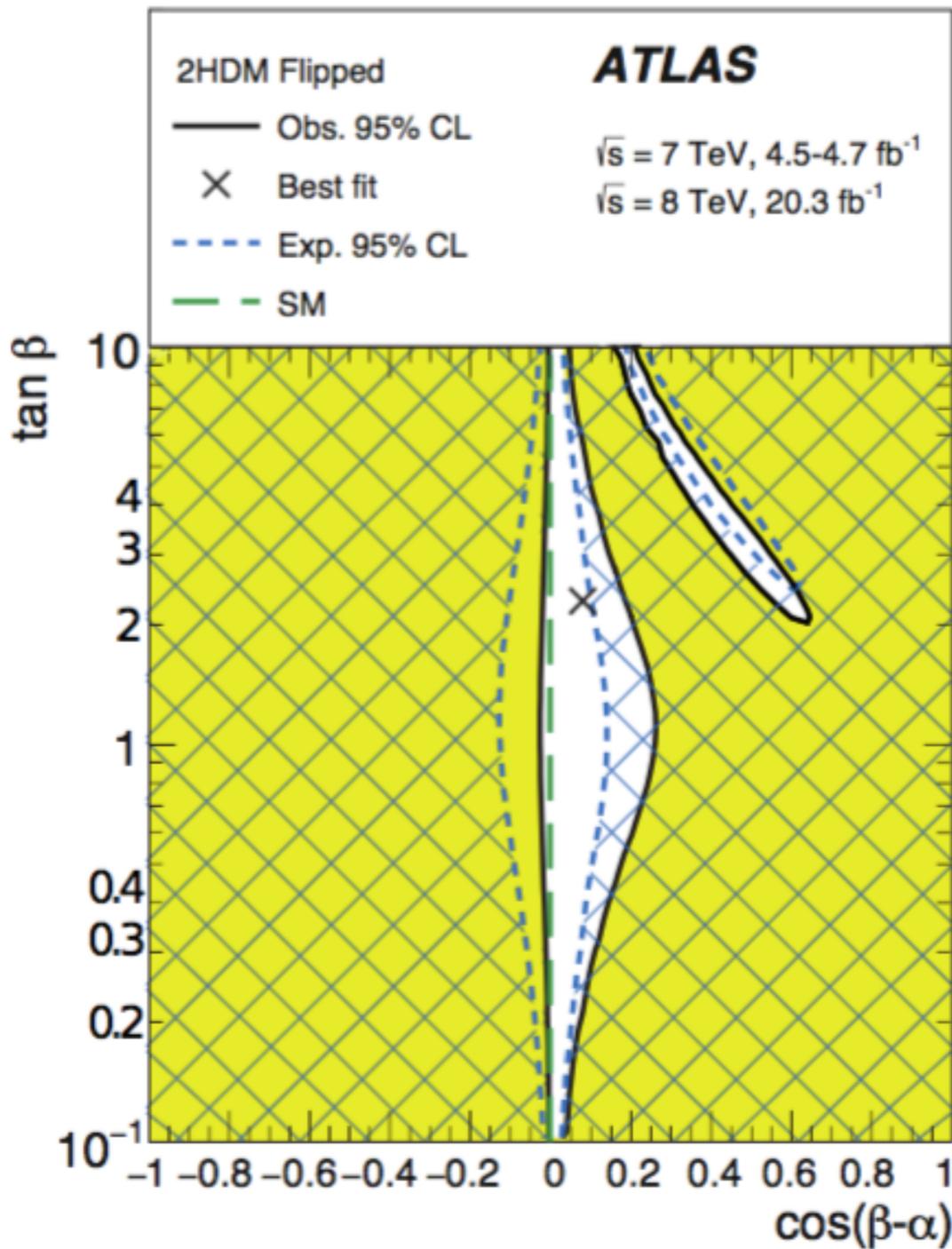
## Lepton Specific





# Limiti allo spazio dei parametri

## Flipped



# Search for $H \rightarrow ZA$ , $Z \rightarrow LL$ and $A \rightarrow bb$

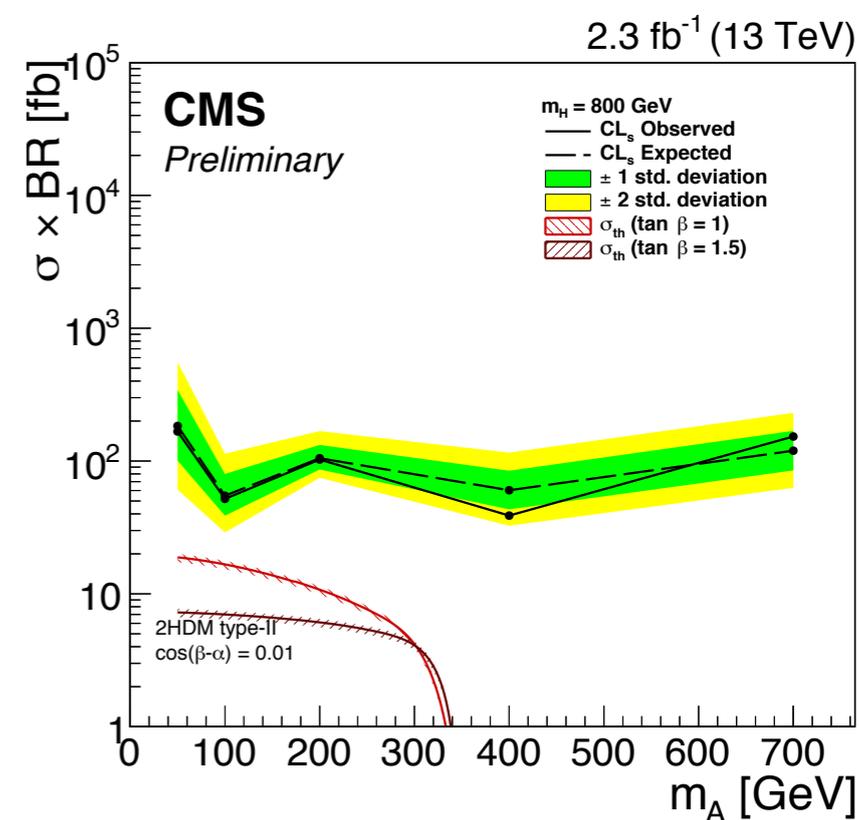
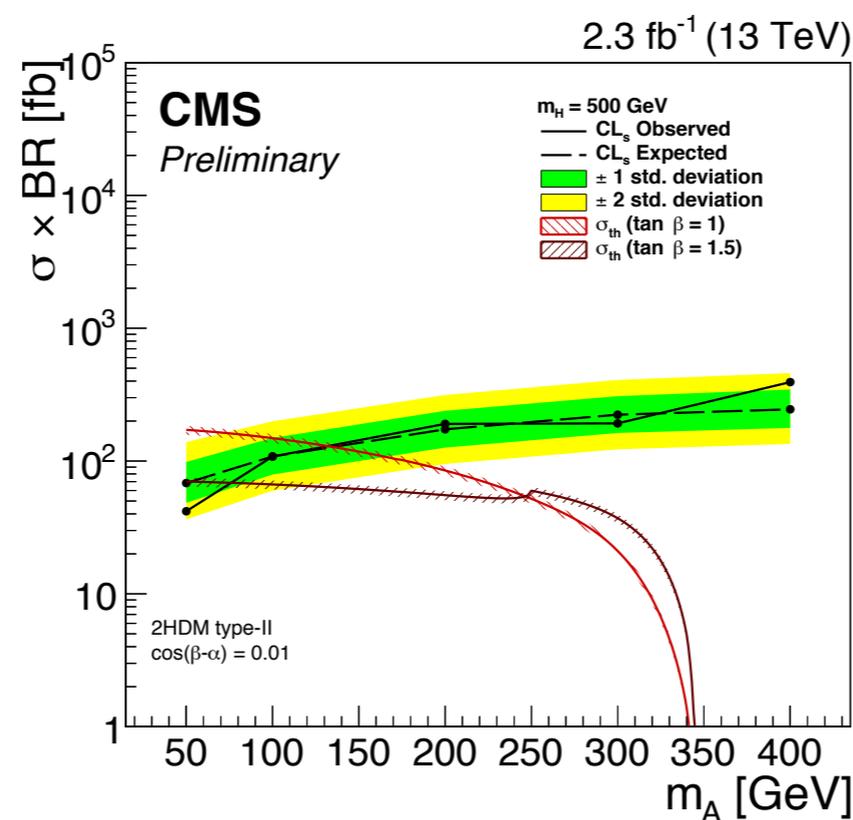
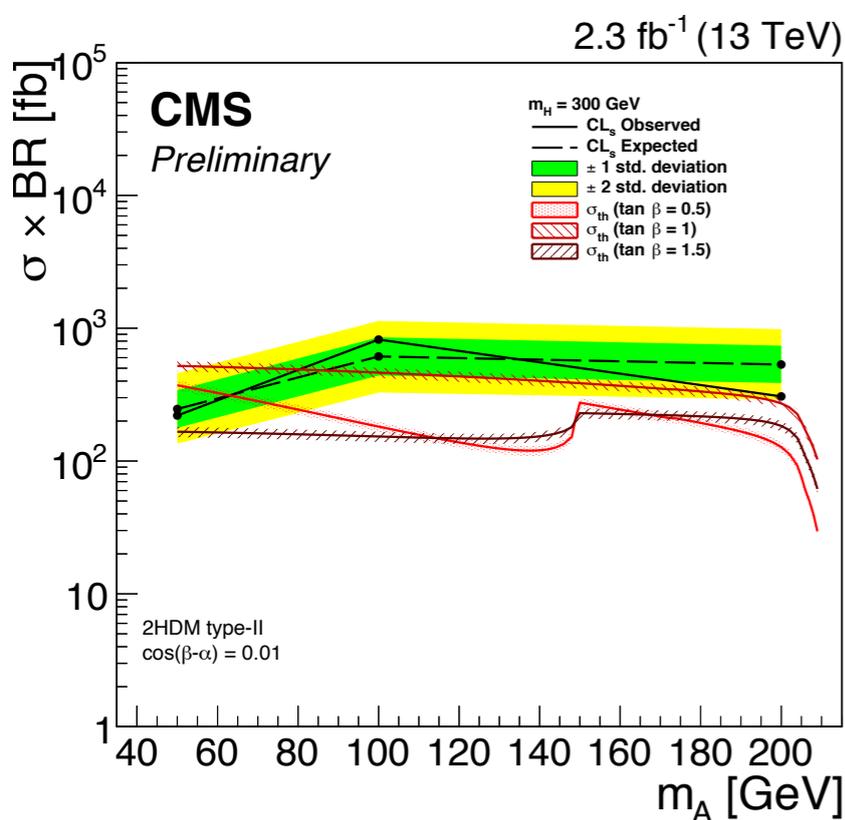
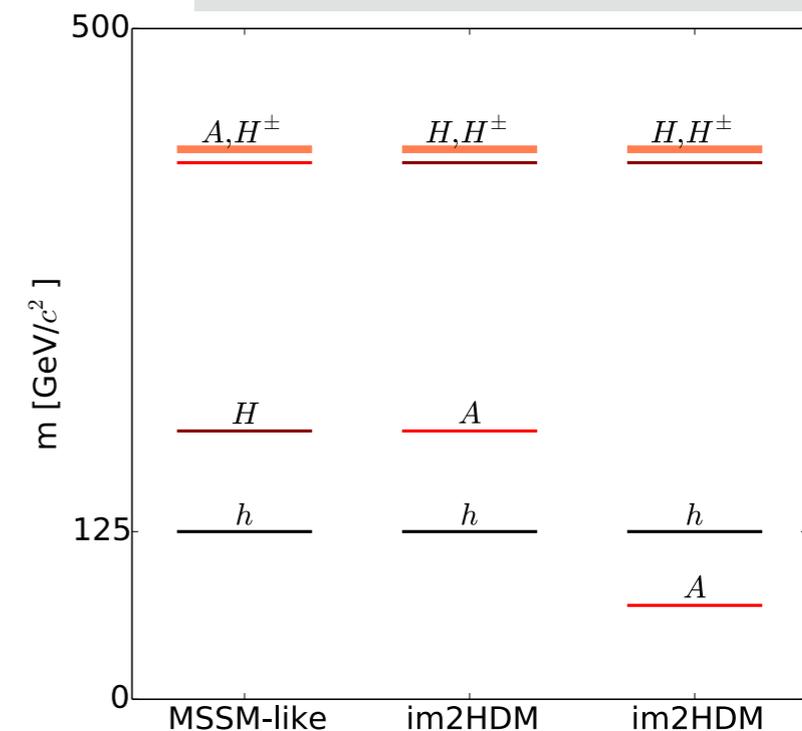
CMS: [CMS-PAS-HIG-16-010](#)

Motivated by 2HDM with twisted custodial symmetry, which gives a heavier scalar  $H$  and a lighter pseudoscalar  $A$  boson.

## Analysis Strategy

- ▶ A signal region (S) is defined for each  $m_A$ - $m_H$  hypothesis in the plane of  $m_{bb}$ - $m_{llbb}$
- ▶ The final limit is calculated from the single bin of S.

Limits for three  $m_H$  hypotheses, as a function of  $m_A$ .



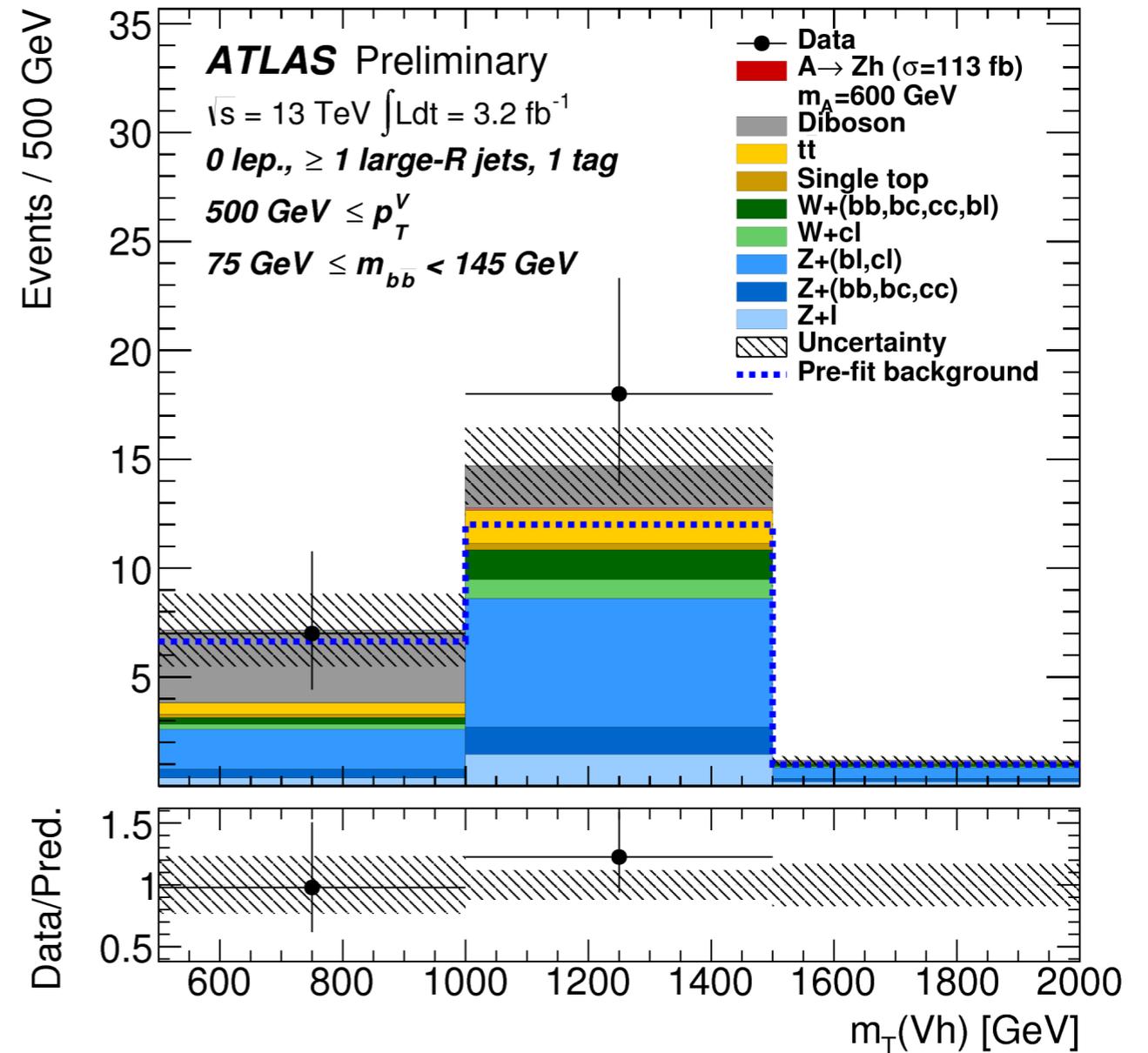
# Search for $A \rightarrow Zh, h \rightarrow bb$

Searching for an additional pseudoscalar boson, as predicted in 2HDM.

The search is for a narrow resonance of  $m_H = 200\text{-}2000$  GeV.

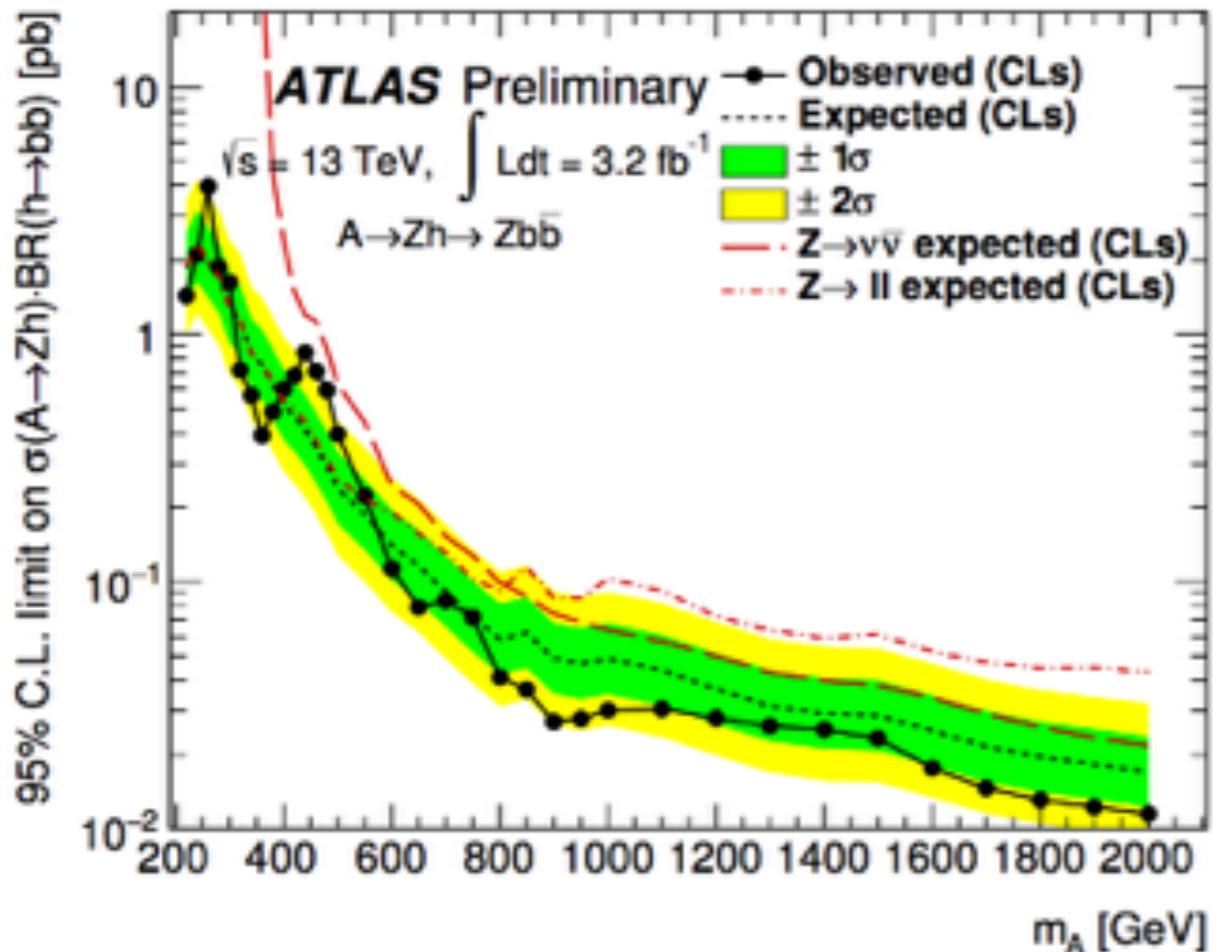
- ▶ Targeting  $A \rightarrow Zh \rightarrow \nu\nu bb / ll bb$
- ▶ Makes use of categories:
  - ▶ 0/2-leptons
  - ▶  $p_T^Z < \text{or} > 500$  GeV (defining the resolved/ T boosted transition)
  - ▶ 1/2 b-tagged jets
- ▶ Final discriminant:
  - ▶ 2- lepton invariant  $m_{llbb}$  for
  - ▶ 0-lepton:

$$m_T^{Zh} = \sqrt{(E_T^h + E_T^{\text{miss}})^2 - (\vec{p}_T^h + \vec{E}_T^{\text{miss}})^2}$$

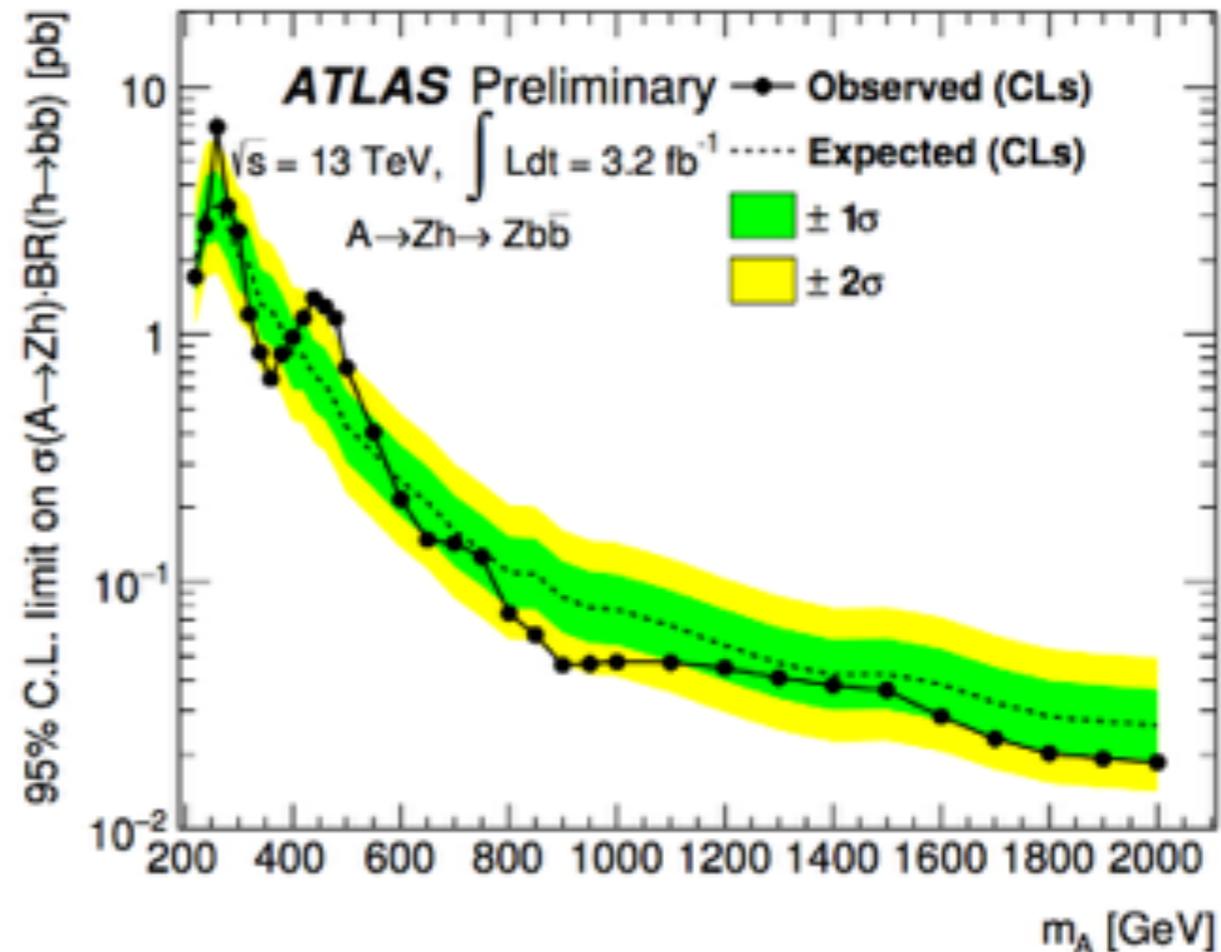


ATLAS: [ATLAS-CONF-2016-015](https://atlas.conf.cern.ch/ATLAS-CONF-2016-015)

# Search for $A \rightarrow Zh, h \rightarrow bb$



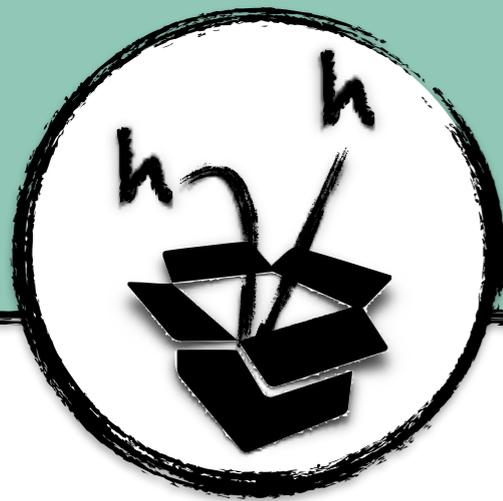
(a) Pure gluon fusion production



(b) Pure  $b$ -quark associated production

Limits on ggF and  $b$ -associated production from simultaneous binned-likelihood fit for signal and control regions.

ATLAS: [ATLAS-CONF-2016-015](https://atlas.conf.cern.ch/ATLAS-CONF-2016-015)



Ricerca h-h



# Produzione di di-Higgs risonante

Possibile in diversi scenari:

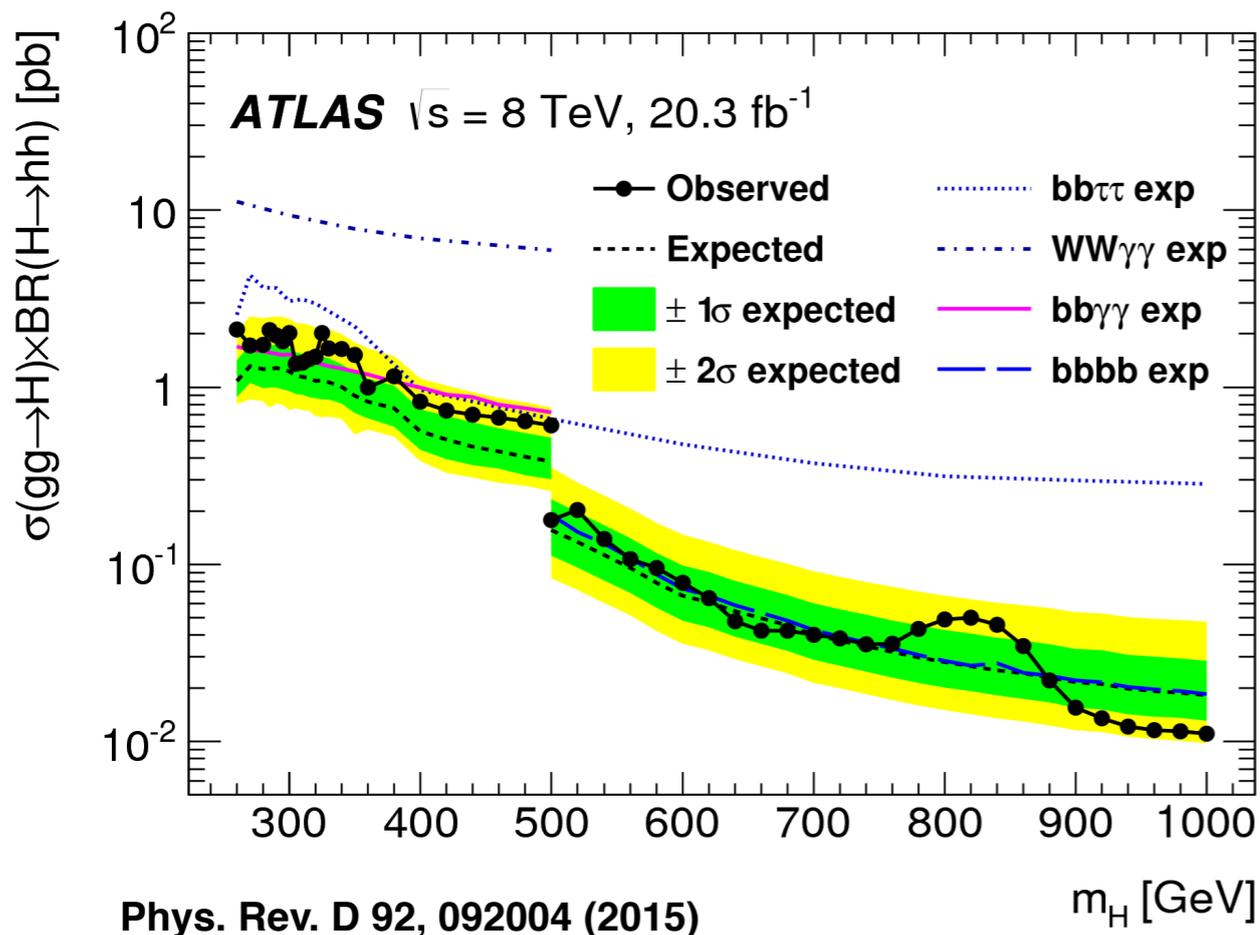
- ▶ Estensione del settore dell'Higgs nel SM:  $H \rightarrow hh$
- ▶ Decadimenti mediatore gravità
  - Radion, RS, K-K, etc...

Ricca combinazione di stati finali, sia in CMS che ATLAS

	<b>CMS (Run1)</b>	<b>ATLAS</b>	<b>CMS (Run2)</b>	<b>ATLAS</b>
<b>2b2<math>\gamma</math></b>	✓	✓	X	✓
<b>2b2<math>\tau</math></b>	✓	✓	✓	X
<b>4b</b>	✓	✓	✓	✓
<b>2<math>\gamma</math>2W</b>	X	✓	X	X
<b>2b2W</b>	X	X	✓	X



# Run1: Combinazioni e confronto

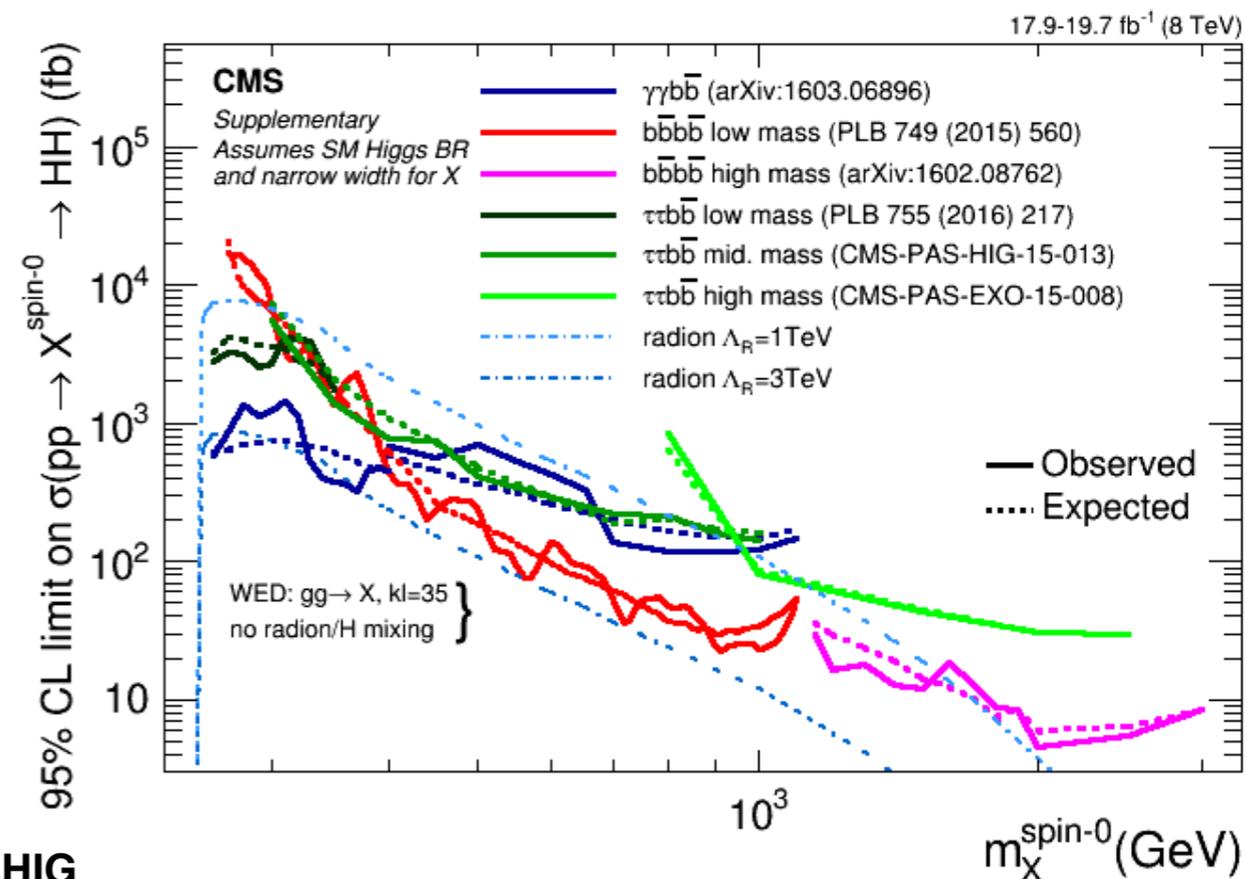


**ATLAS**  
 Combinazione di tutti i risultati di Run1:  $2b2\gamma$ ,  $2b2\tau$ ,  $4b$  e  $2\gamma 2W$

## CMS

Sovrapposizione dei risultati

- Selezione dedicata per i diversi regimi di massa
- Ricerca sopra alla soglia  $m_X > 1 \text{ TeV}$



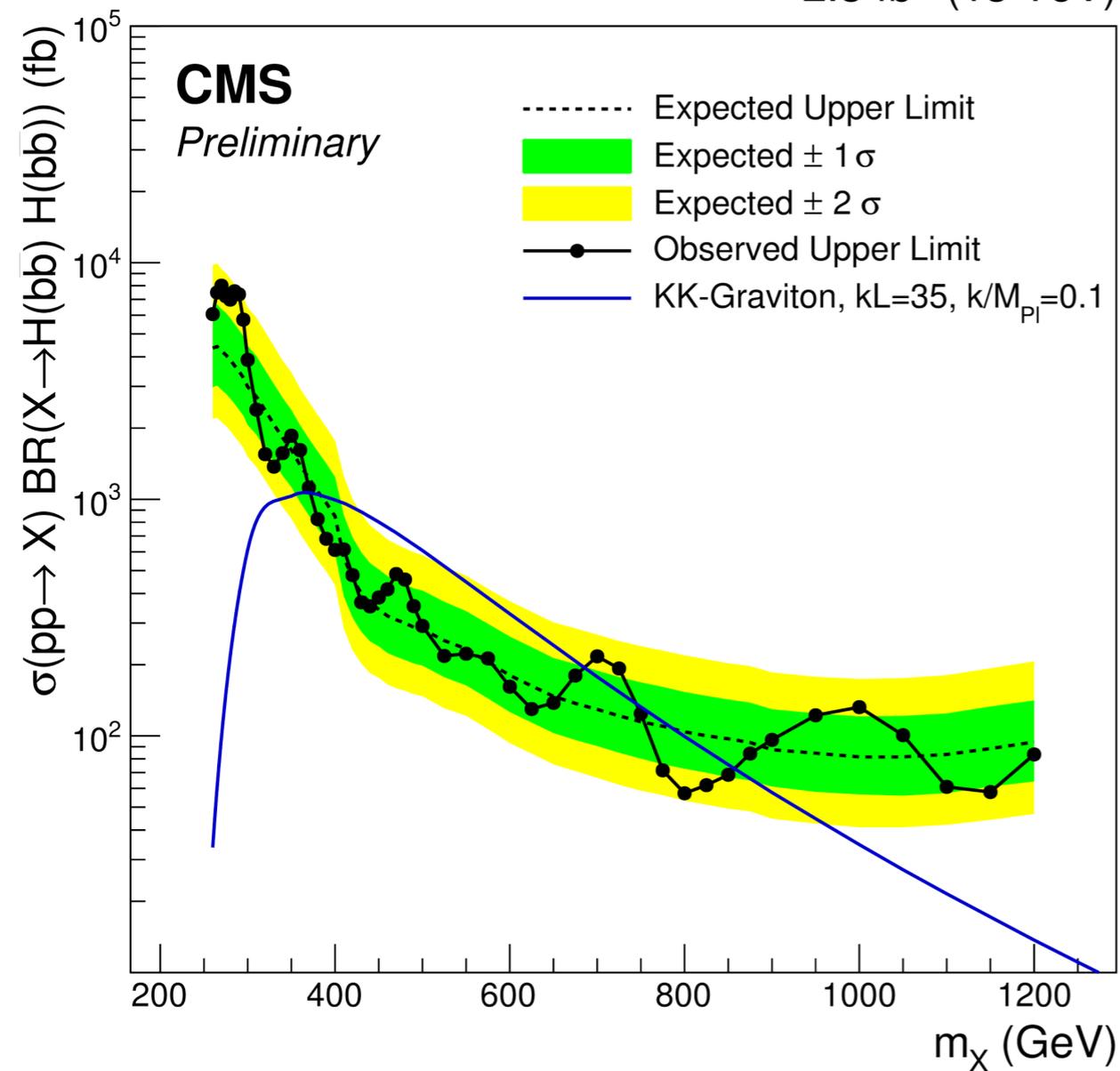
<https://twiki.cern.ch/twiki/bin/viewauth/CMSPublic/SummaryResultsHIG>



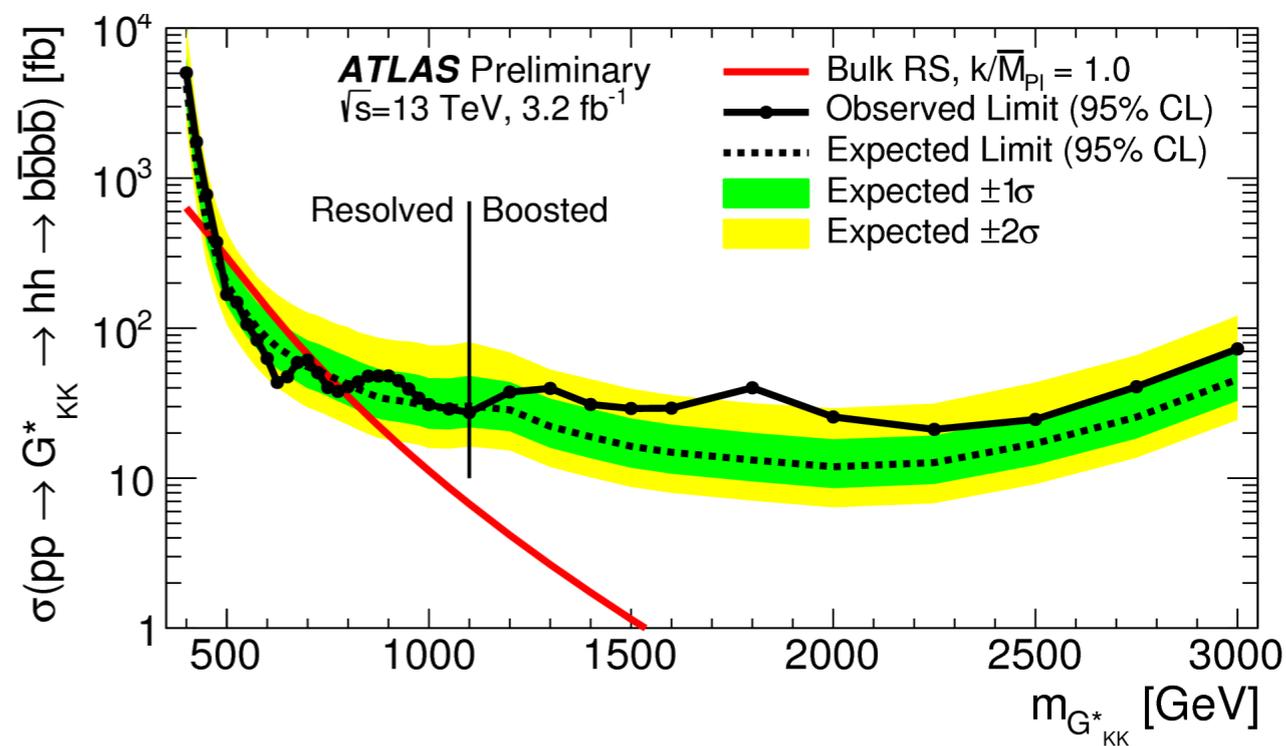
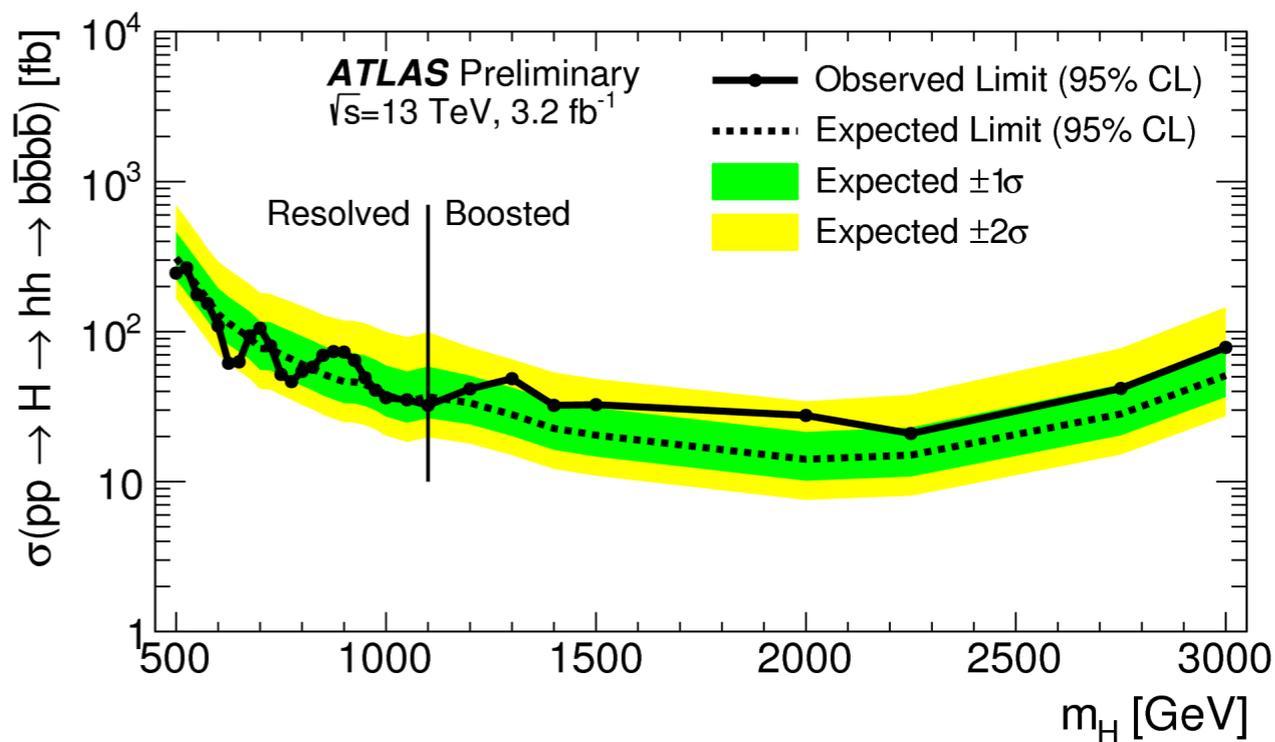
# Run2: risultati recenti

## Entrambe le analisi oltre il TeV

2.3 fb<sup>-1</sup> (13 TeV)



CMS-PAS-HIG-16-002



ATLAS-CONF-2016-017