

Buon Compleanno, Bosone di Higgs!

R. Di Sipio, UniBo/ATLAS

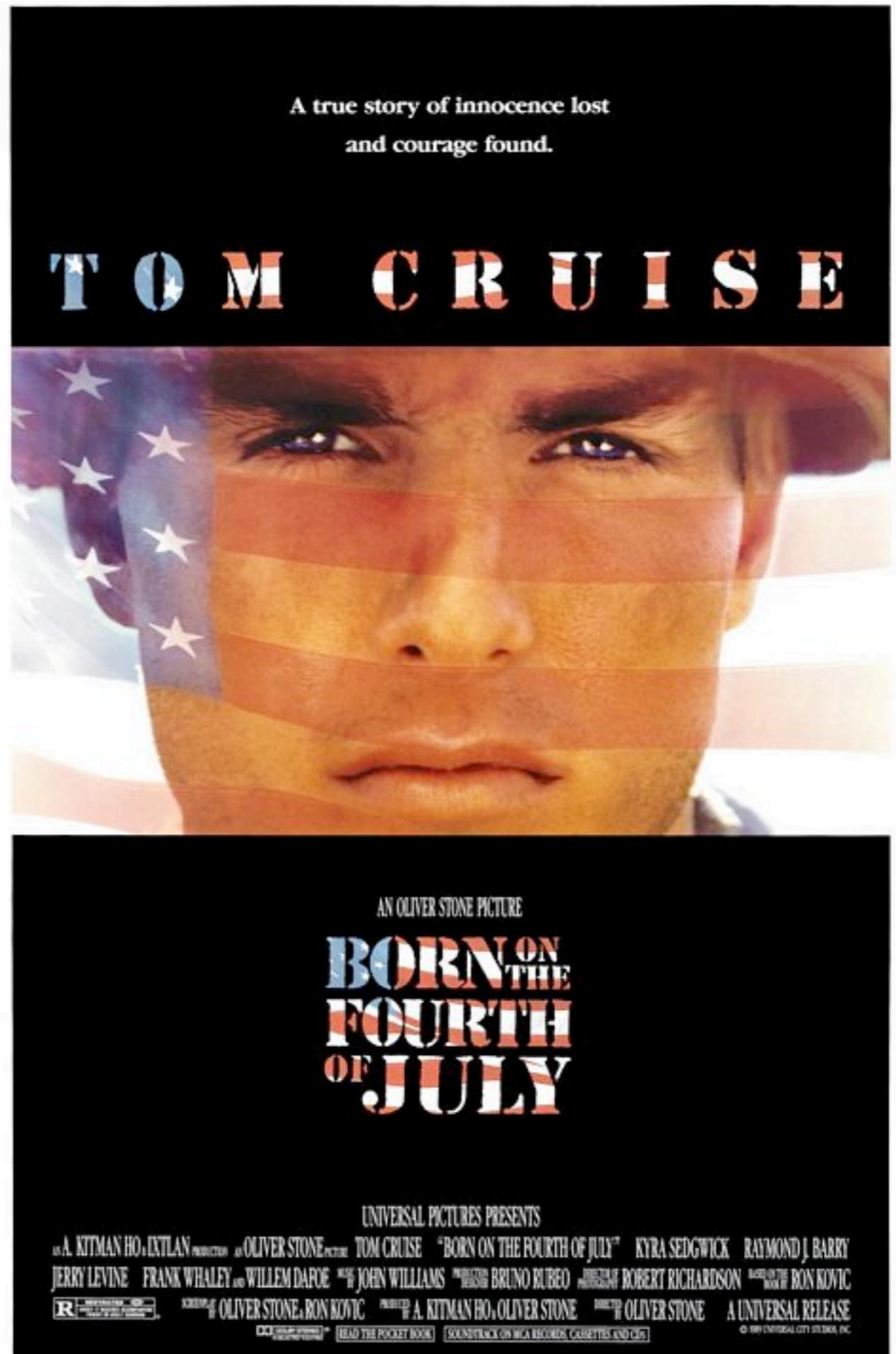
un film di successo!



Regia



Montaggio



idea per un sequel di successo!



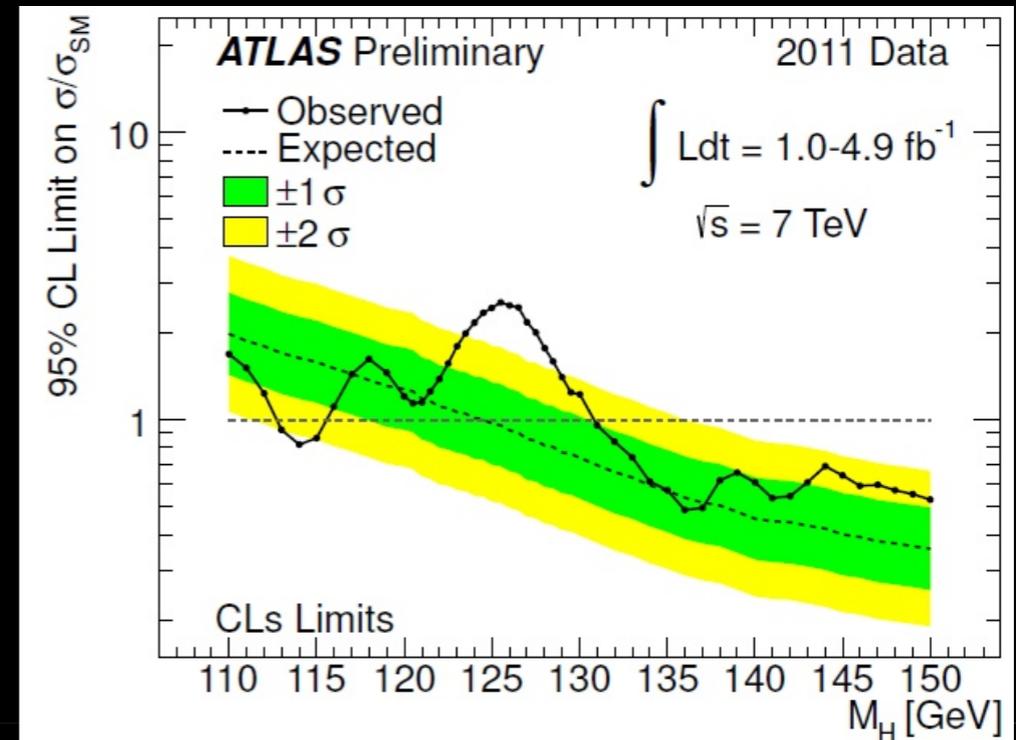
ATLAS



CMS

A true story of innocence lost
and courage found.

Higgs Boson



AN OLIVER STONE PICTURE

BORN ON THE FOURTH OF JULY

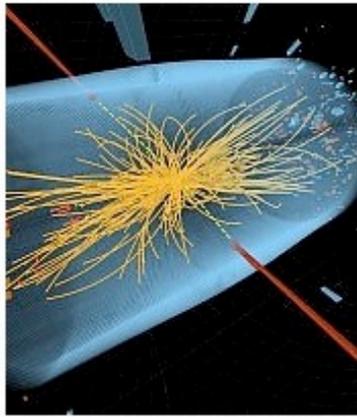
UNIVERSAL PICTURES PRESENTS

AS A KITMAN HO, EXTLAN PRODUCTION AN OLIVER STONE PICTURE TOM CRUISE "BORN ON THE FOURTH OF JULY" KYRA SEDGWICK RAYMOND J. BARRY
JERRY LEVINE FRANK WHALEY AND WILLEM DAFOE MUSIC BY JOHN WILLIAMS COSTUME DESIGNER BRUNO RUBEO EDITOR ROBERT RICHARDSON EXECUTIVE PRODUCERS
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CAMPAGNA FINANZIATA CON IL CONTRIBUTO DELL'UNIONE EUROPEA E DELLO STATO ITALIANO Reg. (UE) n.68



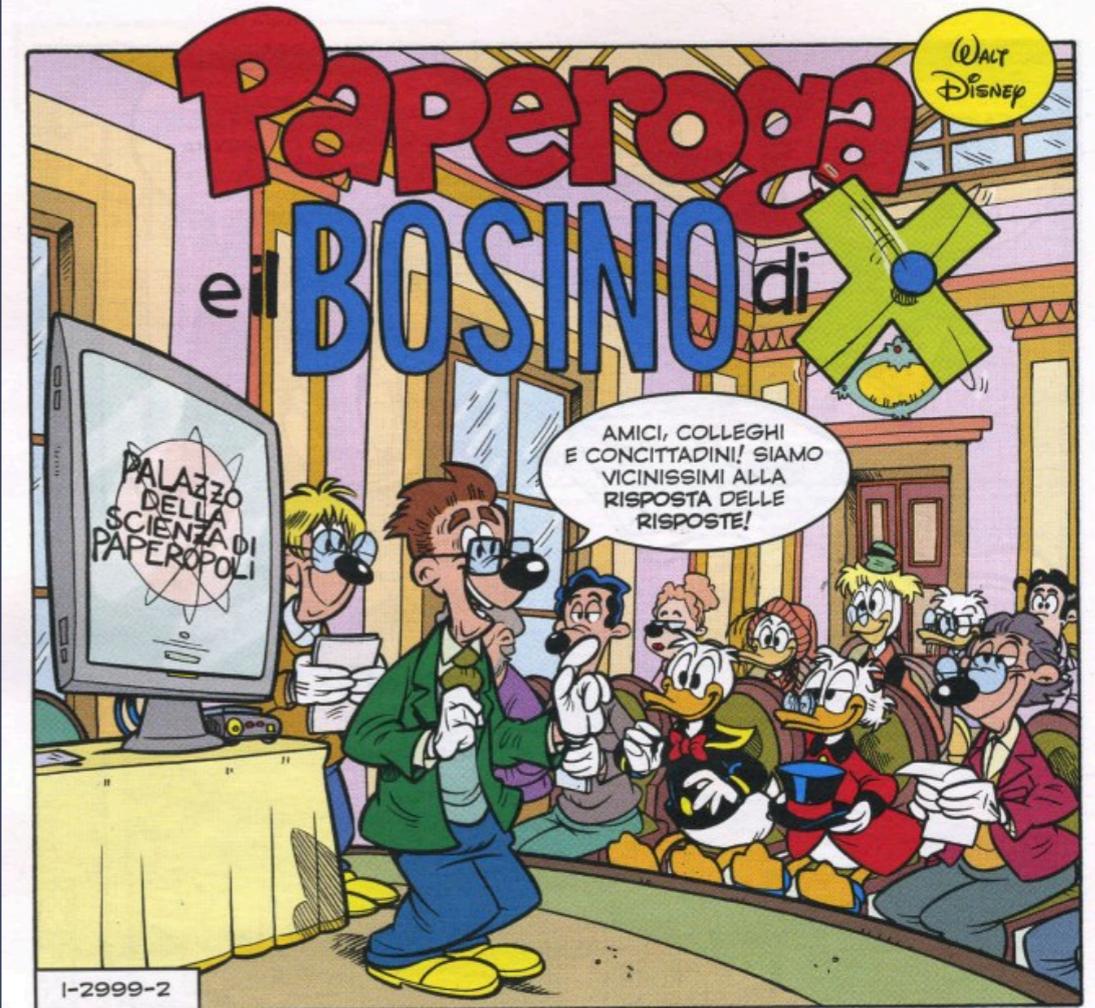
Ecco la "particella di Dio" diretta tv adesso l'universo è più stabile

Video Higgs, lacrime da premio Nobel

Scoperto al Cern di Ginevra il Bosone di Higgs, che spiega come mai tutte le cose nell'universo abbiano una massa. Teorizzato 48 anni fa dallo scienziato inglese, oggi 84enne e commosso dalla standing ovation che gli hanno riservato. Per lui si profila il riconoscimento più ambito *dall'inviato ELENA DUSI*

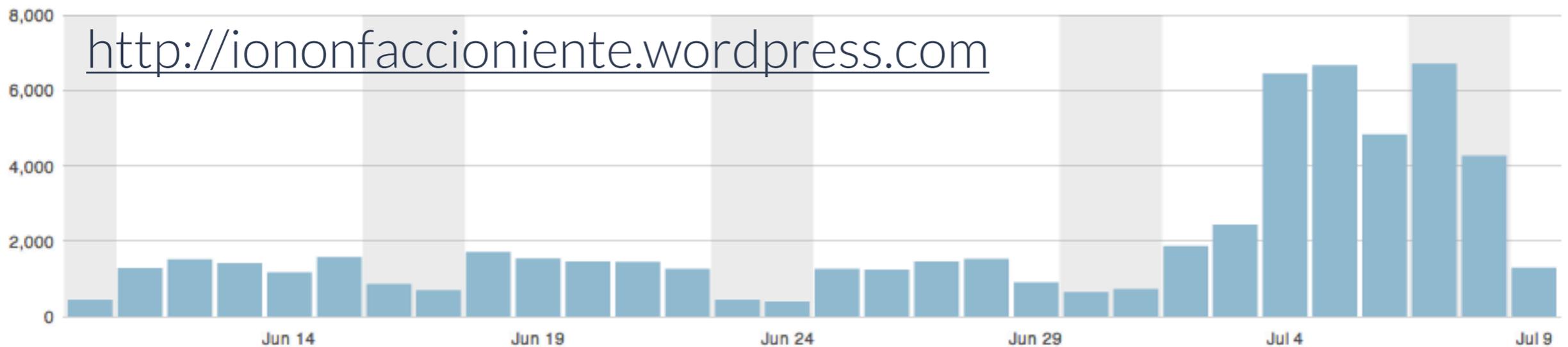
- ▶ **LA SCHEDE** Perché è importante questa particella [Video](#)
- ▶ Bertolucci, del Cern, anticipò la notizia alla Repubblica delle Idee
- ▶ **Video** Per errore l'annuncio esce sul sito del Centro

+ CONDIVIDI



1-2999-2

A colpo d'occhio Giorni Settimane Mesi



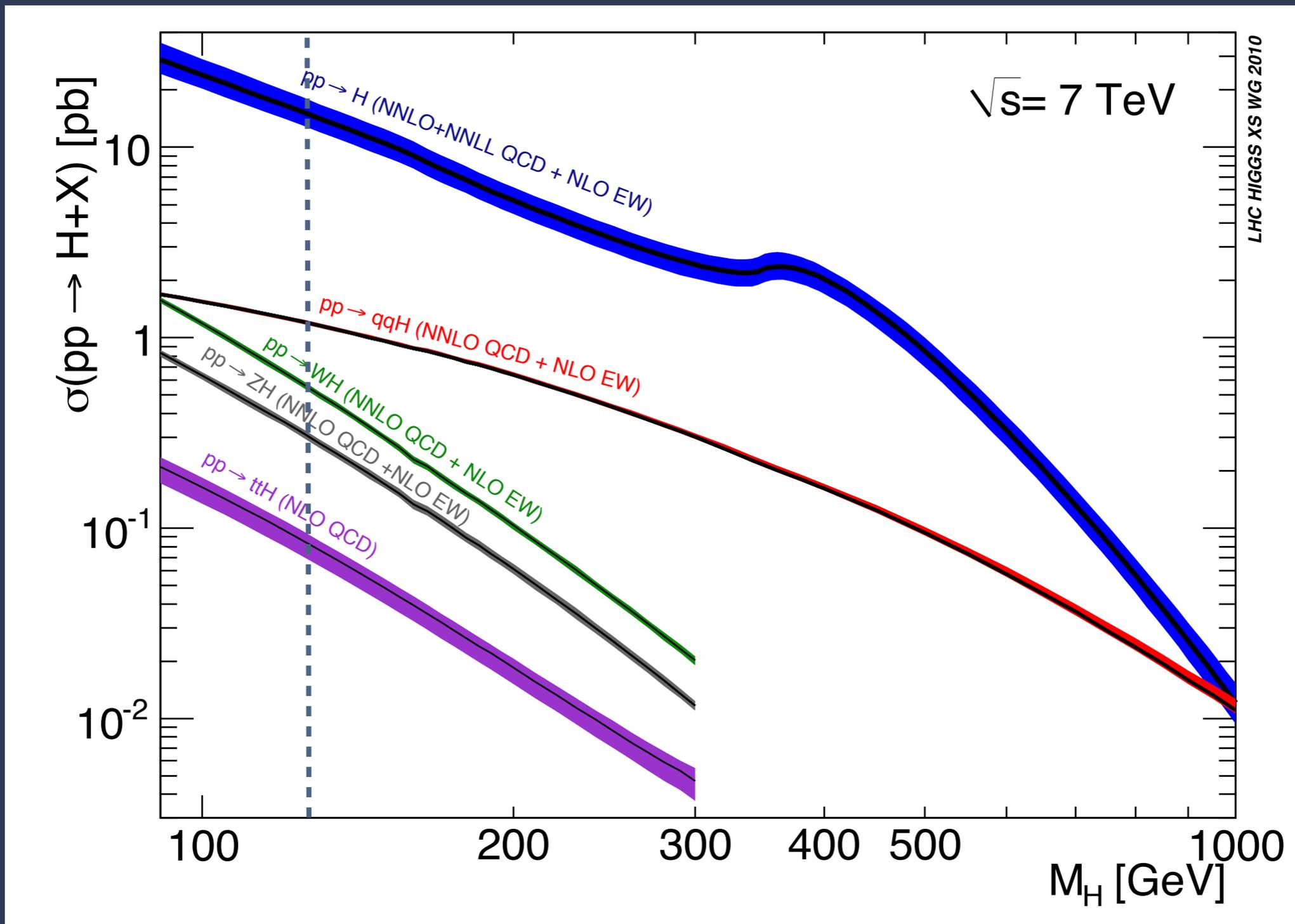
501.879
visite totali

1.288
visite odierne

6.702
visite nel vostro giorno con più traffico, July 7, 2012

[Tabelle di sintesi](#)

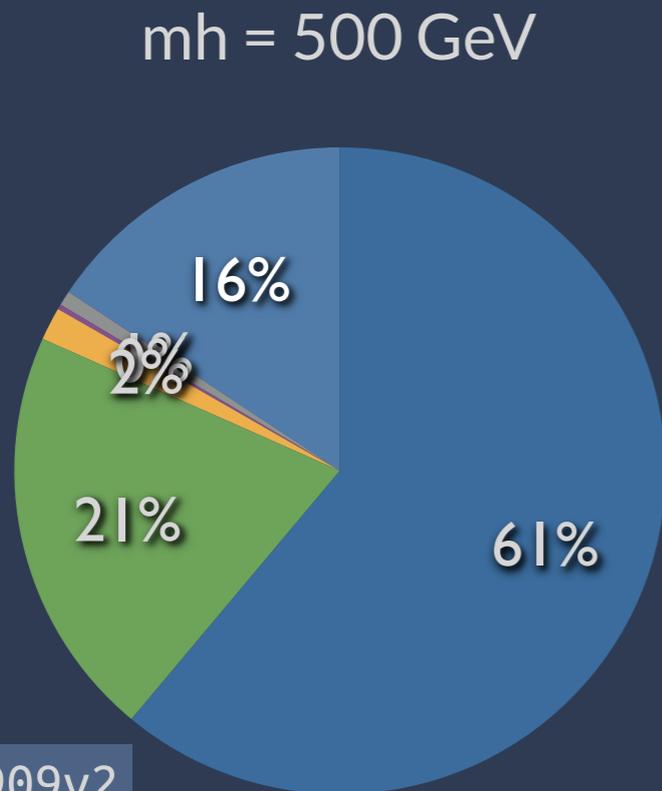
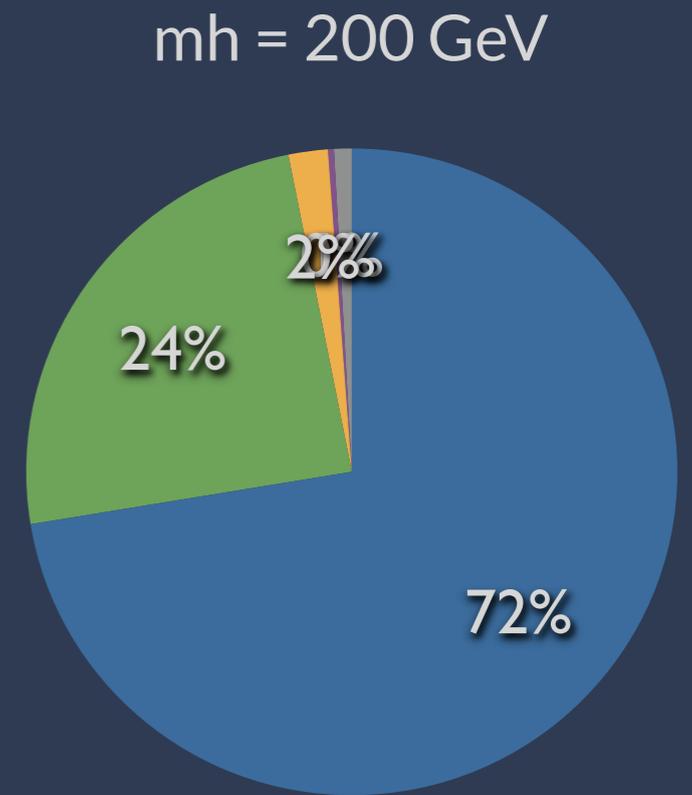
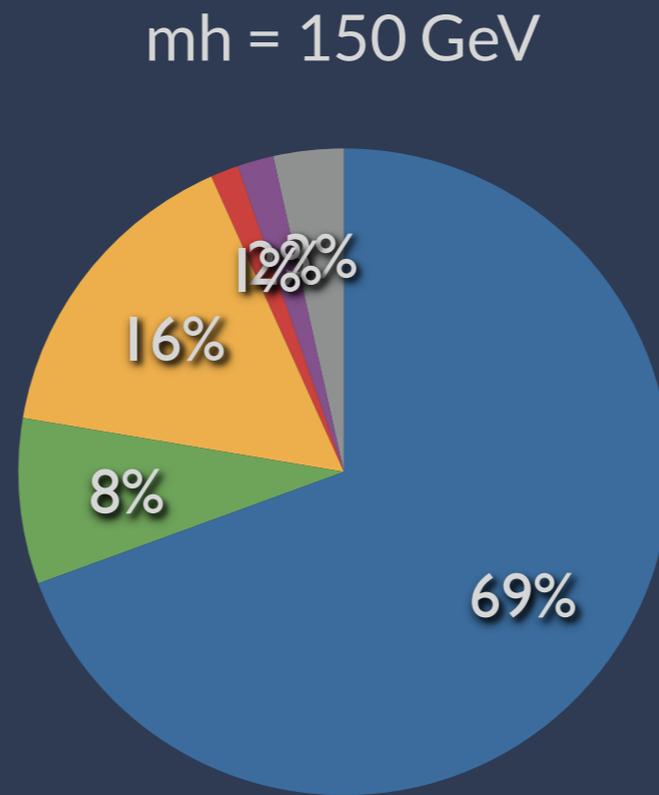
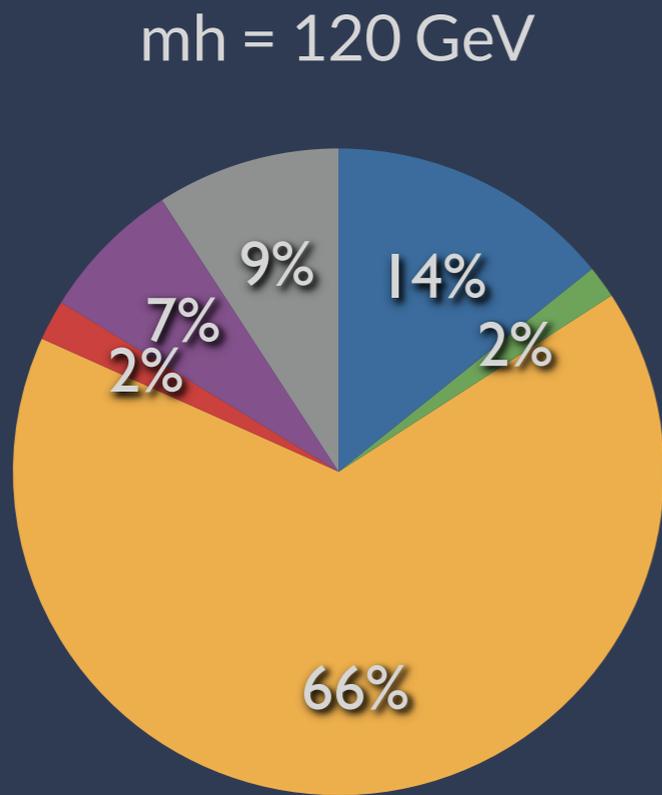
Produzione



- la sezione d'urto di produzione dipende dalla massa
- gluon-gluon fusion dominante
- WH/ZH tagging del bosone vettore (riduzione fondo)

Decadimento

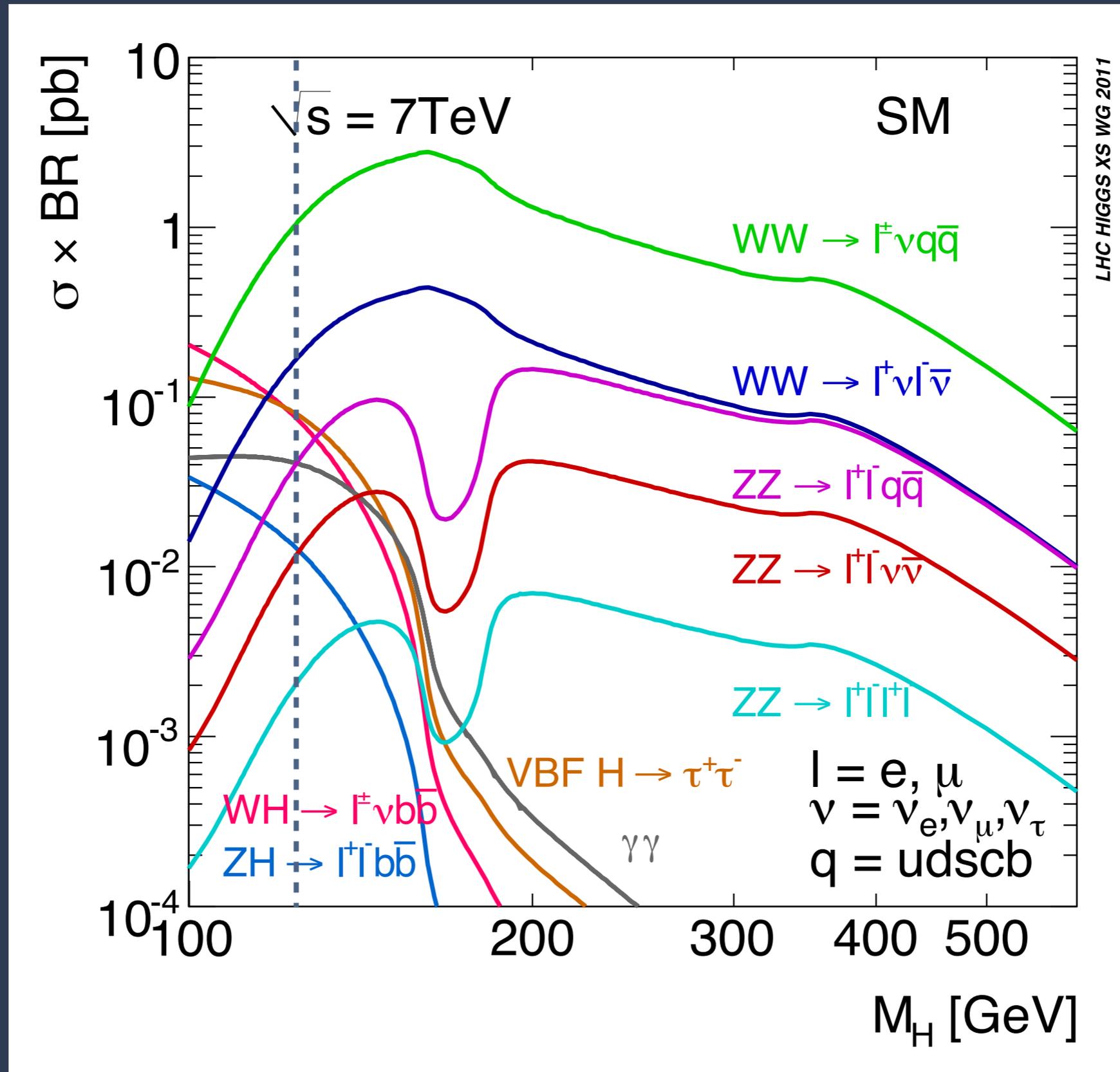
- WW
- ZZ
- bb
- YY
- TT
- gg
- tt



fenomenologia piuttosto differente a seconda del valore della massa!

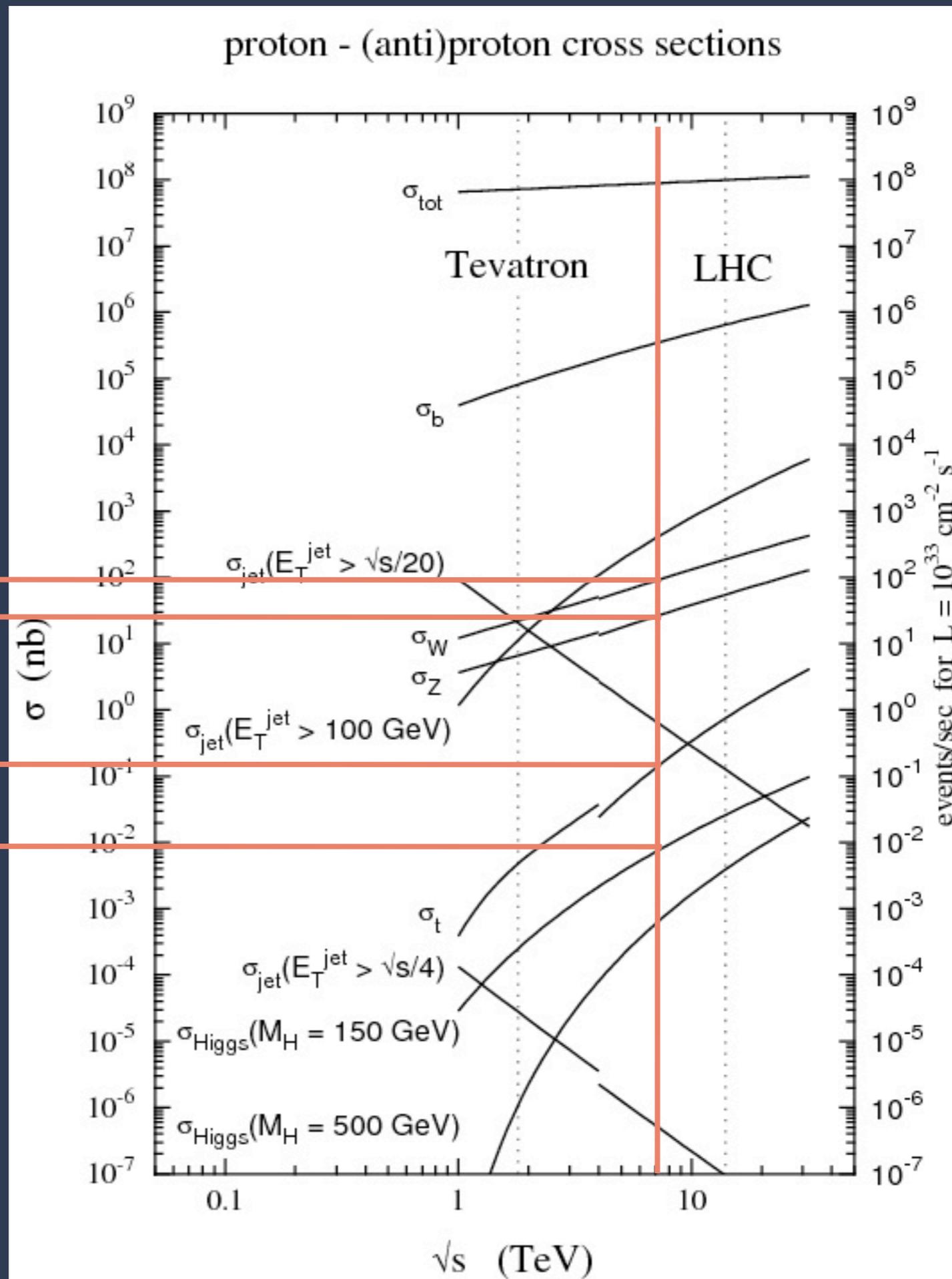
leggero *bb*
intermedio *WW*
pesante *WW, ZZ, tt*

mettendo tutto insieme: $\sigma \times BR$



fondi EW SM anche
 10^5 volte più grandi!

W
Z
top
higgs
(150 GeV)



$h \rightarrow \gamma\gamma$

Produzione

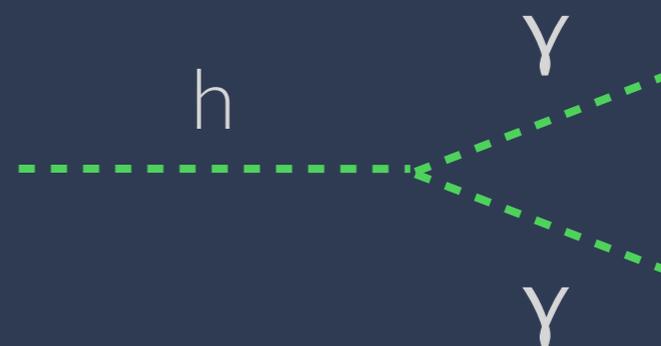
$$gg \rightarrow h$$

$$qq \rightarrow qq h \text{ (VBF)}$$

$$qq \rightarrow W/Z h$$

$$gg \rightarrow tt h$$

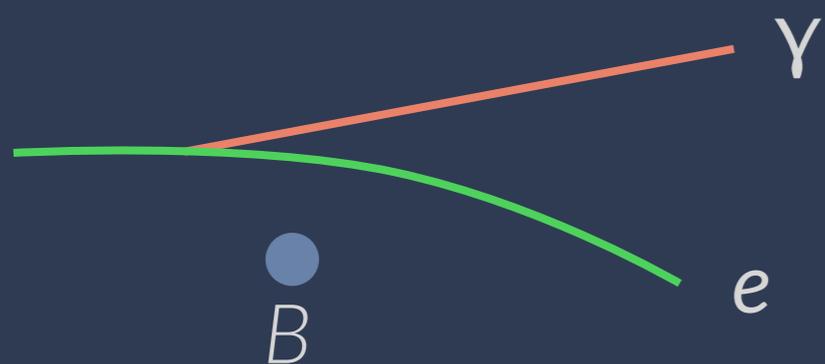
Decadimento



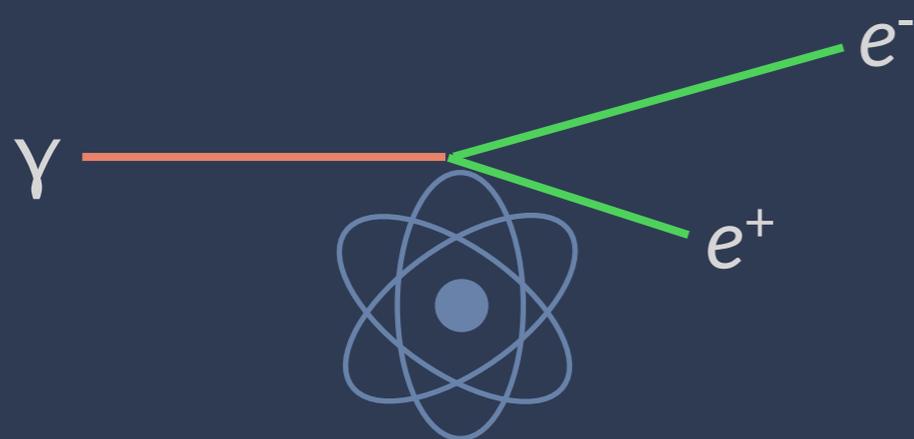
misuriamo la massa
invariante $\gamma\gamma$
(risoluzione \sim GeV)

Produzione	Stato finale	Segnatura
$gg \rightarrow h$	$\gamma\gamma, \gamma\gamma j$	fotoni, jet
VBF	$\gamma\gamma jj$	fotoni, jet
WH	$\gamma\gamma e/\mu^\pm \nu$	fotoni, leptone + E_T^{miss}
	$\gamma\gamma jj$	fotoni, jet+jet [m_W]
ZH	$\gamma\gamma e/\mu^\pm e/\mu^\pm$	fotoni, leptoni
	$\gamma\gamma jj$	fotoni, jet+jet [m_Z]
Fondi	$\gamma\gamma, \gamma^+ j, jj$	prompt / fake $\gamma, \pi^0 \rightarrow \gamma\gamma$

fotoni ricostruiti da depositi di energia (cluster) nel calorimetro EM



una carica accelerata emette radiazione (bremsstrahlung)
(falso positivo)

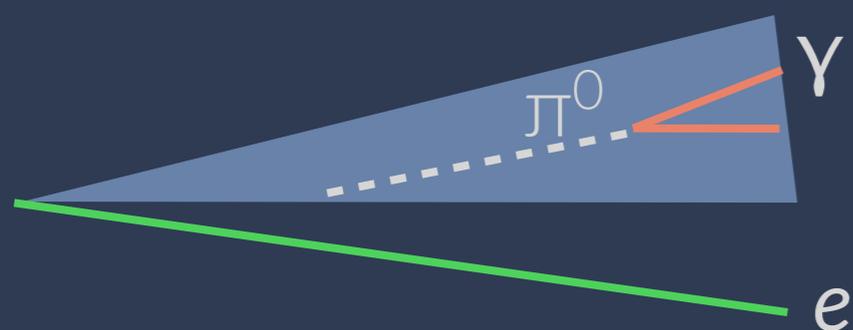


conversione fotone > 1 GeV in elettrone nell'ID (\sim metà delle volte):

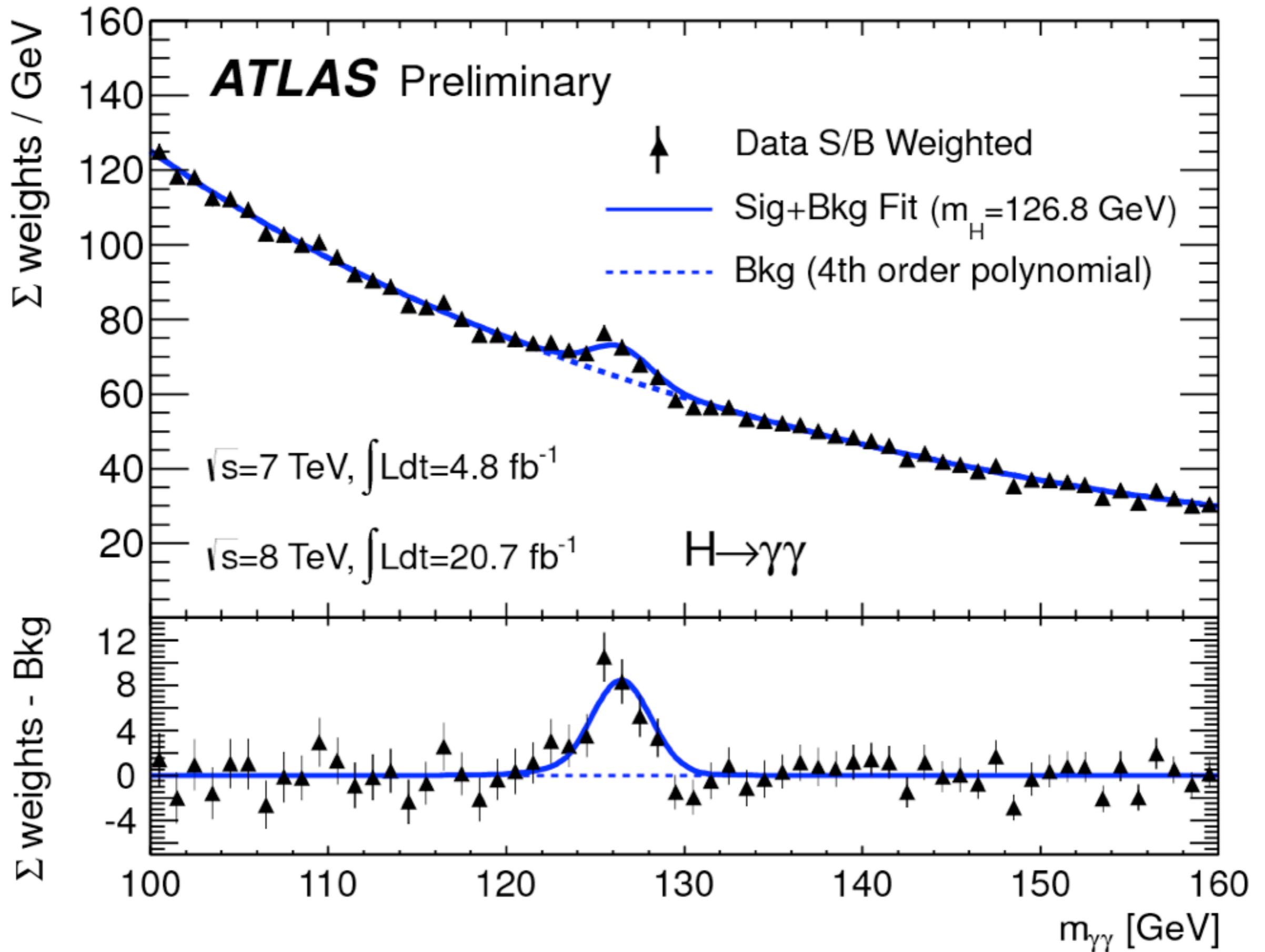
$$\frac{d\sigma}{dx} = \frac{A}{X_0 N_A} \left(1 - \frac{4}{3}x(1-x)\right)$$

impulso asimmetrico
tracce deboli “perse”

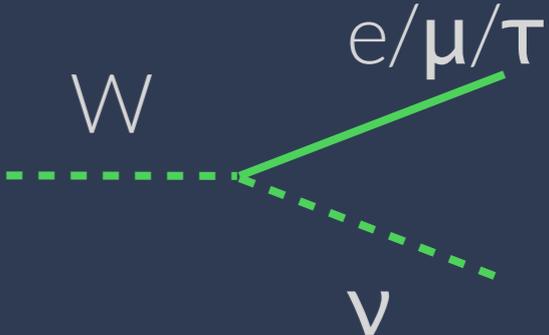
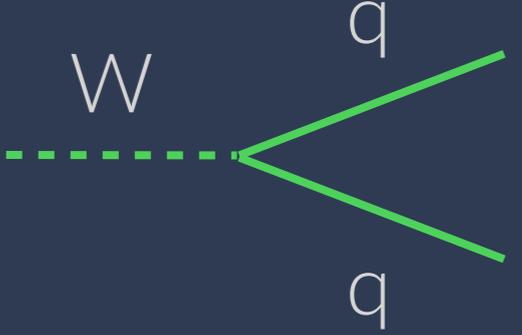
(falso negativo)



$\pi^0 \rightarrow \gamma\gamma$ collimati in un jet
(ATLAS: high-granularity η strips)
(falso positivo)



$h \rightarrow WW^* \rightarrow |v|v$

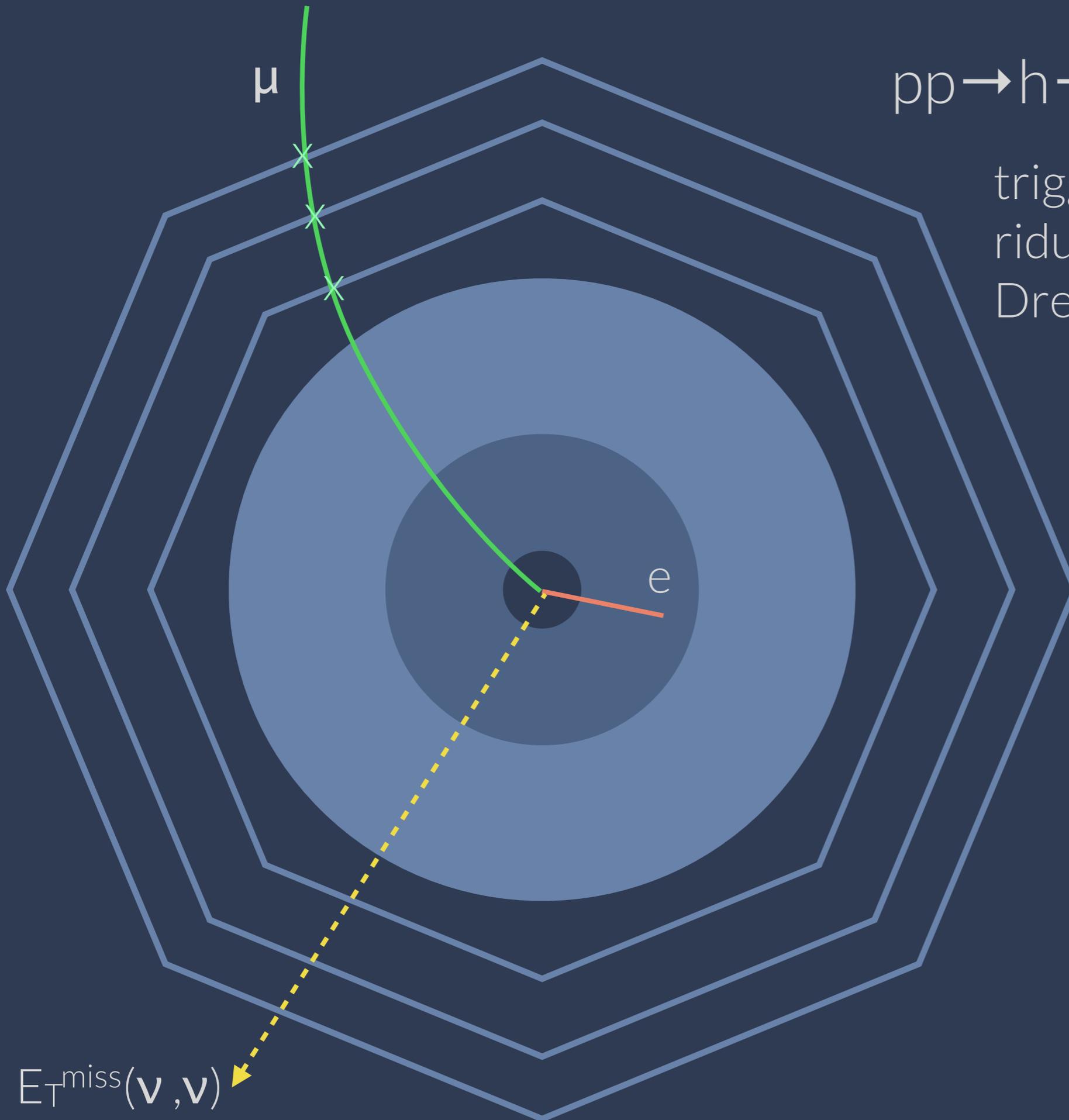
Produzione	Decadimento	
$gg \rightarrow h$		leptonico (33%) 
$qq \rightarrow qq h$ (VBF)		adronico (66%) 
$qq \rightarrow W/Z h$		
$gg \rightarrow tt h$		

quale canale?

canale	statistica	reco cinematica	fondi	risoluzione massa
qqqq			hopeless!!	solo BSM?
lvqq		1 neutrino		alta massa [600-1000]
lvlv ($e\nu\mu\nu$)		2 neutrini	WW, top, $Z/\gamma^* \rightarrow l^+l^-, W\gamma$	bassa massa [115-600]

$pp \rightarrow h \rightarrow WW \rightarrow e\nu \mu\nu$

trigger sui leptoni
riduzione fondo irriducibile
Drell-Yan \Rightarrow canale $e\mu$

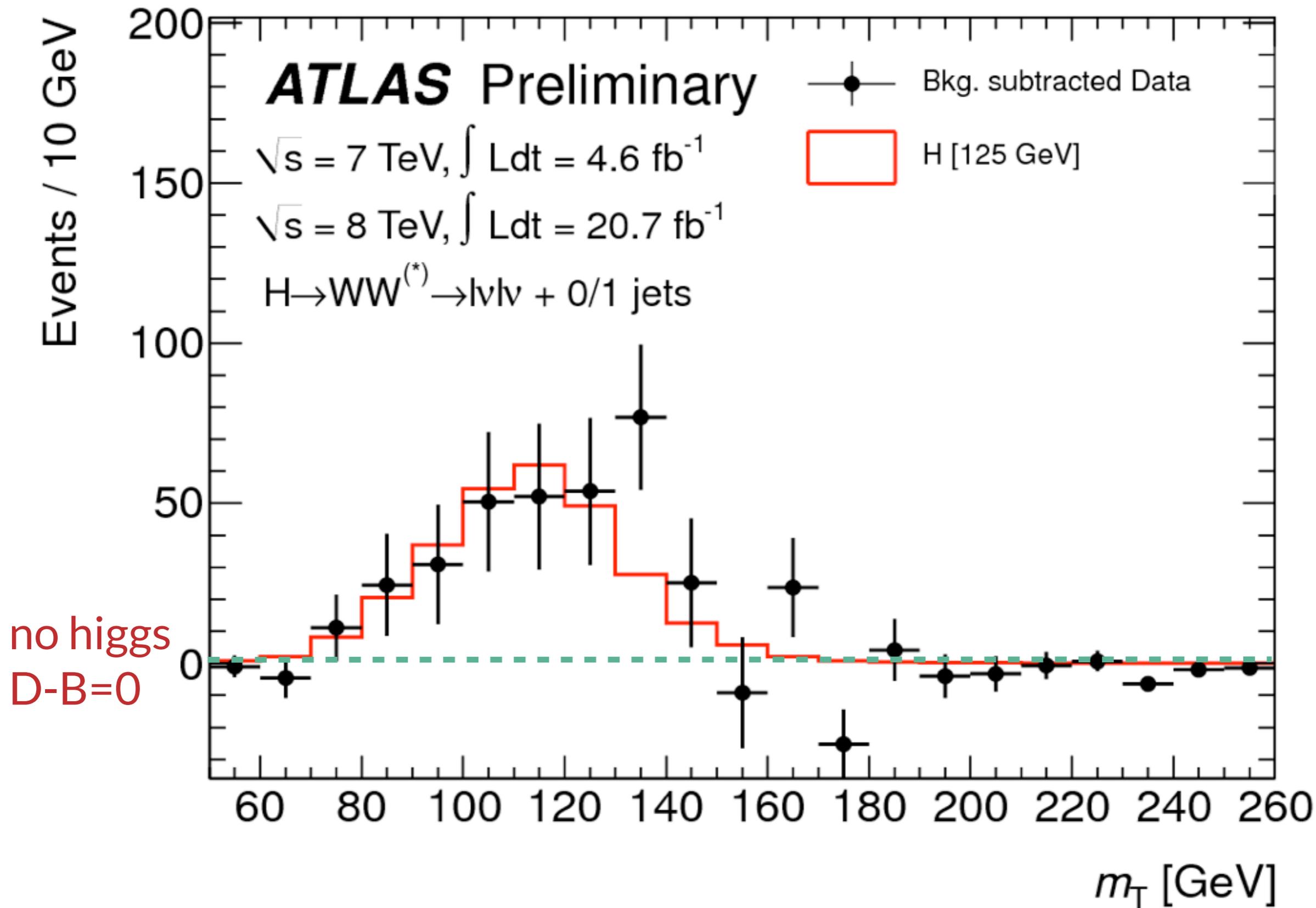


non è possibile ricostruire
completamente la
cinematica (neutrini!)

$$m_T^2 = E_T^2 - p_T^2$$

$$m_{l+l-}$$

$$\Delta\phi(E_T^{\text{miss}}, l^+l^-)$$



higgs or non higgs?

Un higgs o l'Higgs?

- Higgs = *unica particella scalare che dà massa*
- *bosoni vettori con coupling $c_V = 1$*
 - *custodial symmetry: $c_V = c_W = c_Z$*
- *fermioni con yukawa coupling λ_i caratteristici*

$$\mathcal{L}_1 = c_V \frac{h}{v} [2m_W^2 |W_\mu|^2 + m_Z^2 (Z_\mu)^2]$$

Impronte digitali

- Proprietà che vogliamo studiare:
 - Sezione d'urto totale
 - Branching ratio dei vari canali
 - Accoppiamenti a bosoni e fermioni
 - Spin-parità

- Impostori:
 - Miscela di 2 o più doppietti EW (2HDM, SUSY)
 - Miscela CP-odd CP-even
 - Composto (cooper pair)
- Oppure unico scalare, ma:
 - 4 generazioni di fermioni
 - Non-standard BR
 - Decadimenti “esotici” (dark matter?)

Canali di ricerca

	h	VBF	Wh	Zh	tth
WW	evidence/excess		no evidence (yet)	no evidence (yet)	no evidence (yet)
ZZ	observation				
Z γ	no evidence (yet)				
$\gamma\gamma$	observation	evidence/excess			no evidence (yet)
$\tau\tau$	no evidence (yet)	no evidence (yet)	no evidence (yet)		
$\mu\mu$		no evidence (yet)	no evidence (yet)	no evidence (yet)	
bb	hopeless	hopeless	no evidence (yet)	no evidence (yet)	no evidence (yet)
cc	hopeless	hopeless	hopeless	hopeless	hopeless
gg	hopeless	hopeless	hopeless	hopeless	hopeless
??	hopeless			no evidence (yet)	

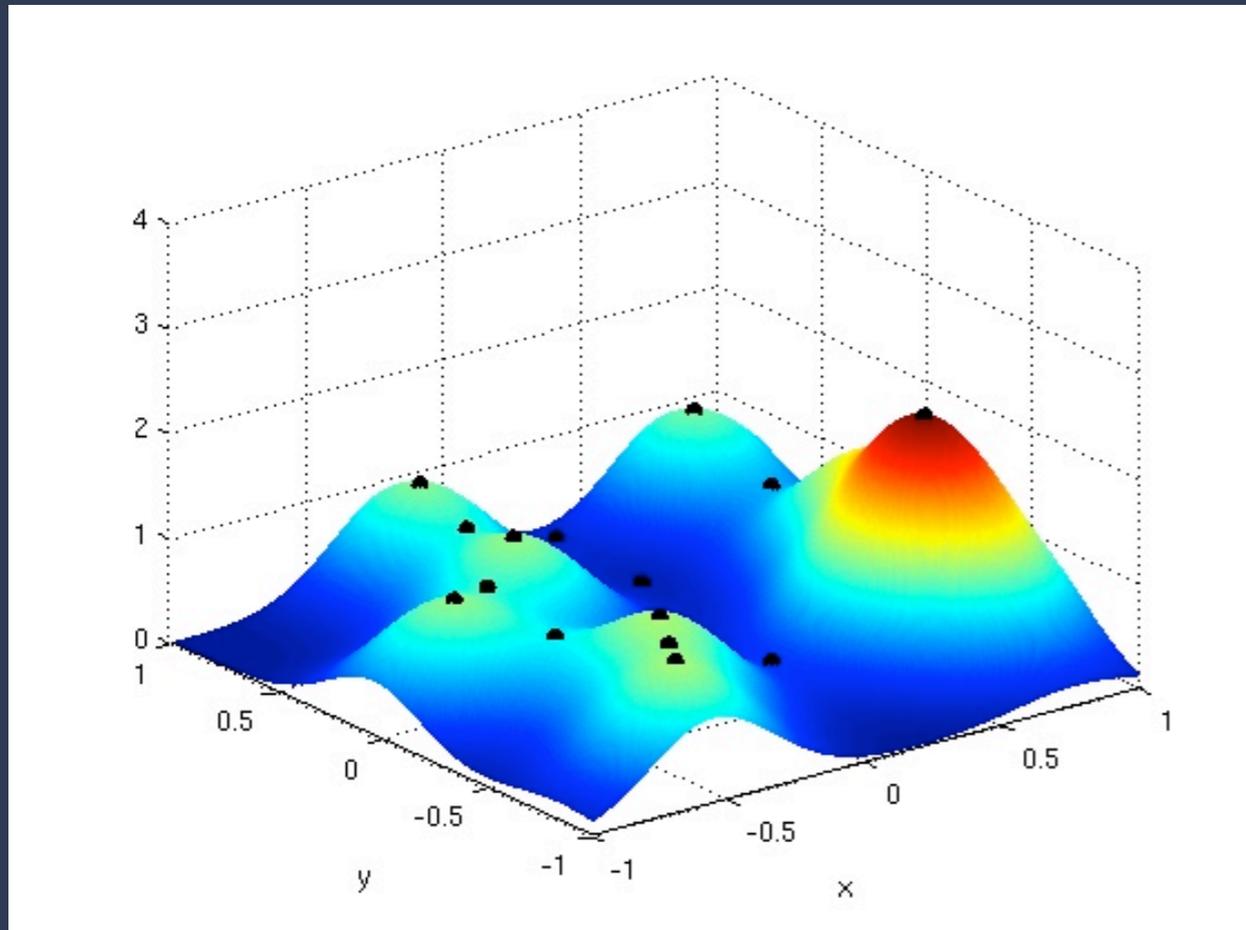
- observation
- evidence/excess
- no evidence (yet)
- hopeless

possiamo mettere
insieme tutte
queste
informazioni?

Accordo dati-previsione

funzione N-dimensionale
dei parametri (*likelihood*)

$$L(\mu, \theta) = \prod_j P(\mu S_j + B_j | D_j) \prod_s N(\theta_s)$$



- massa Higgs
- signal strength μ
- sezioni d'urto ggF, VBF, ...
- branching ratio ($h \rightarrow \gamma\gamma, \dots$)
- incertezze sistematiche

profile likelihood ratio:

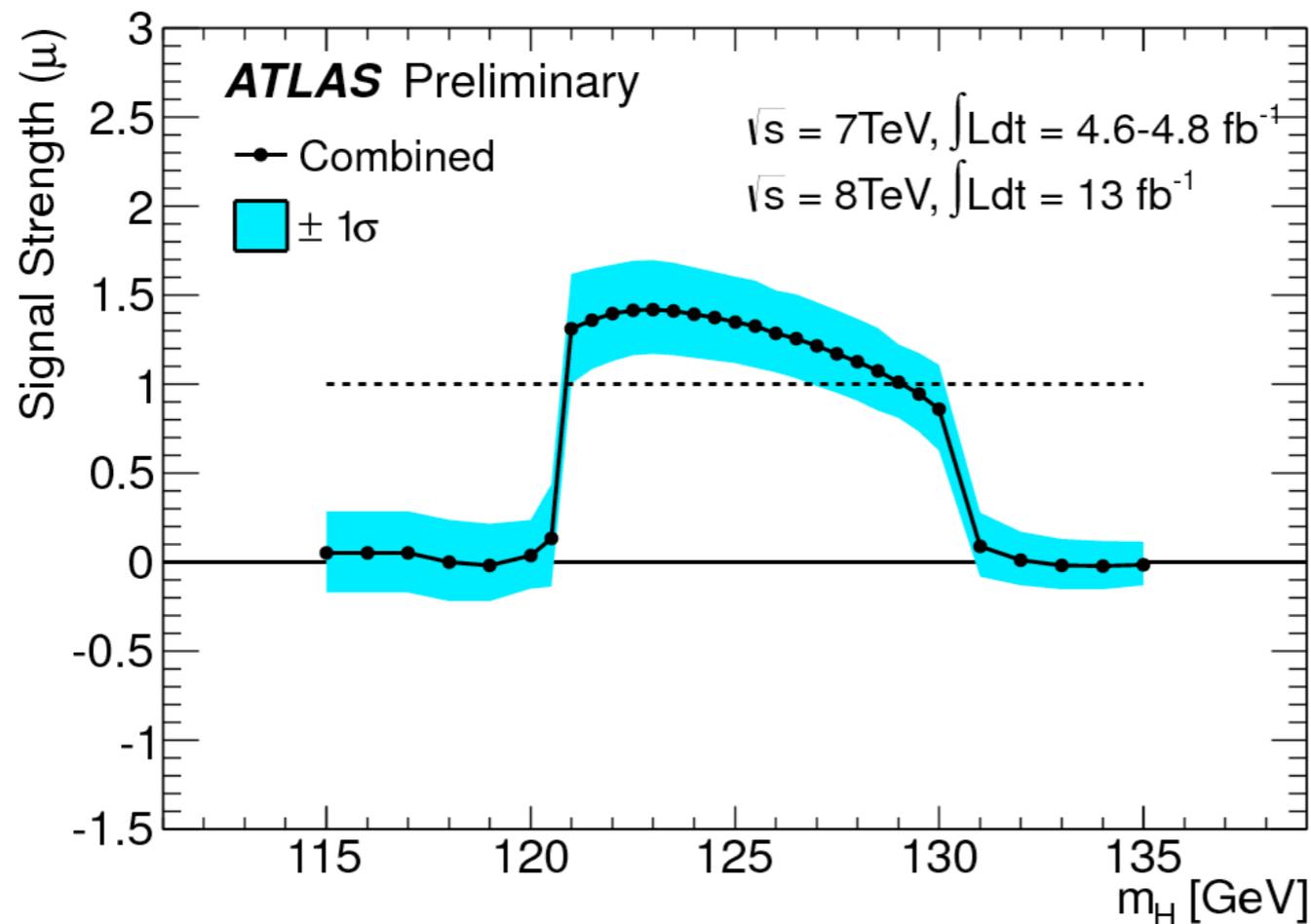
$$\lambda(\mu) = \frac{L(\mu, \hat{\hat{\theta}})}{L(\hat{\mu}, \hat{\theta})}$$

metodo statistico per estrapolare il
valore di *best-fit* di uno dei parametri
“marginalizzando” gli altri

Signal Strength

riscalda la previsione sul segnale

- solo fondo: $\mu = 0$
- Standard Model: $\mu = 1$, ma per quale m_H ?

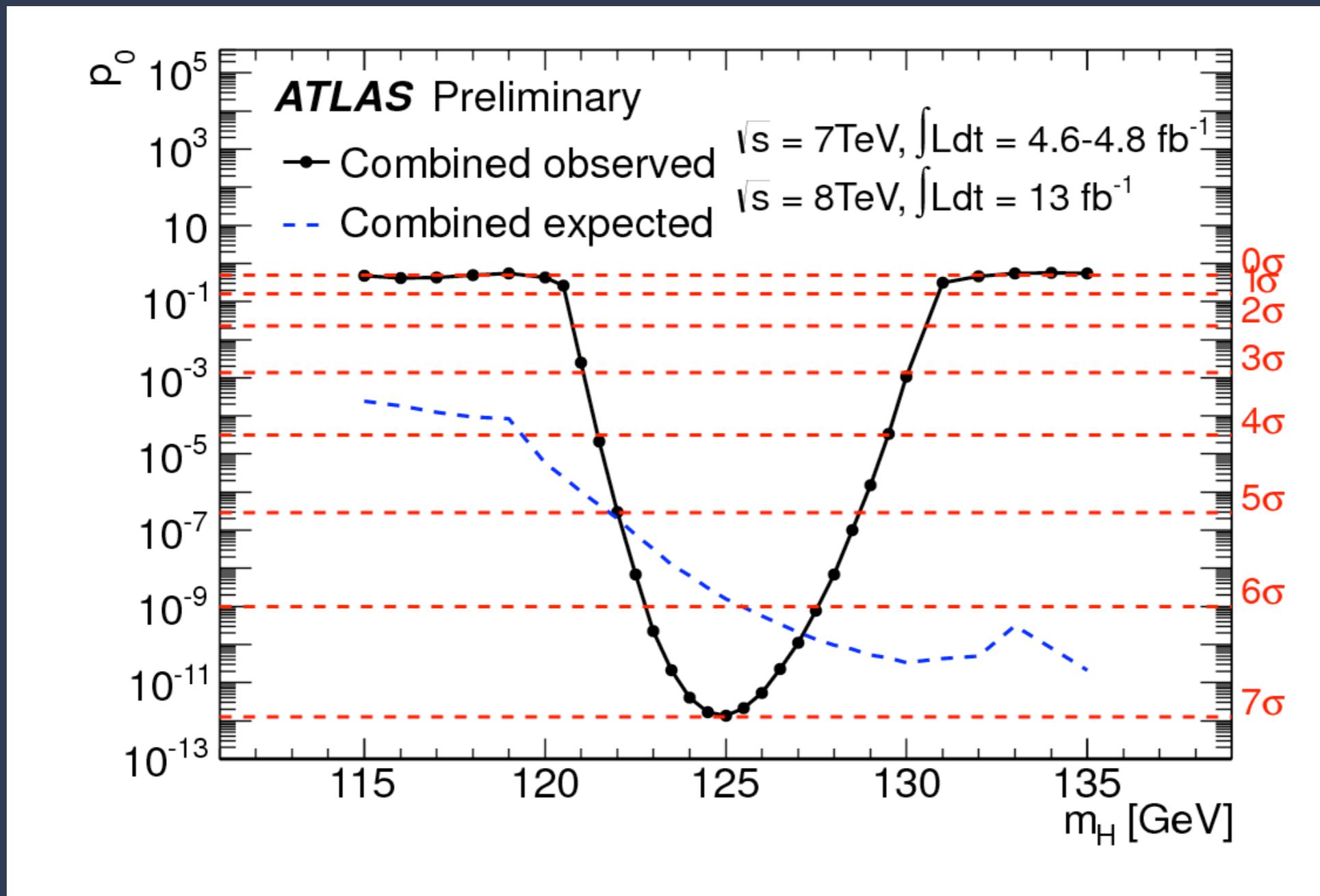


ideale: Dirac delta

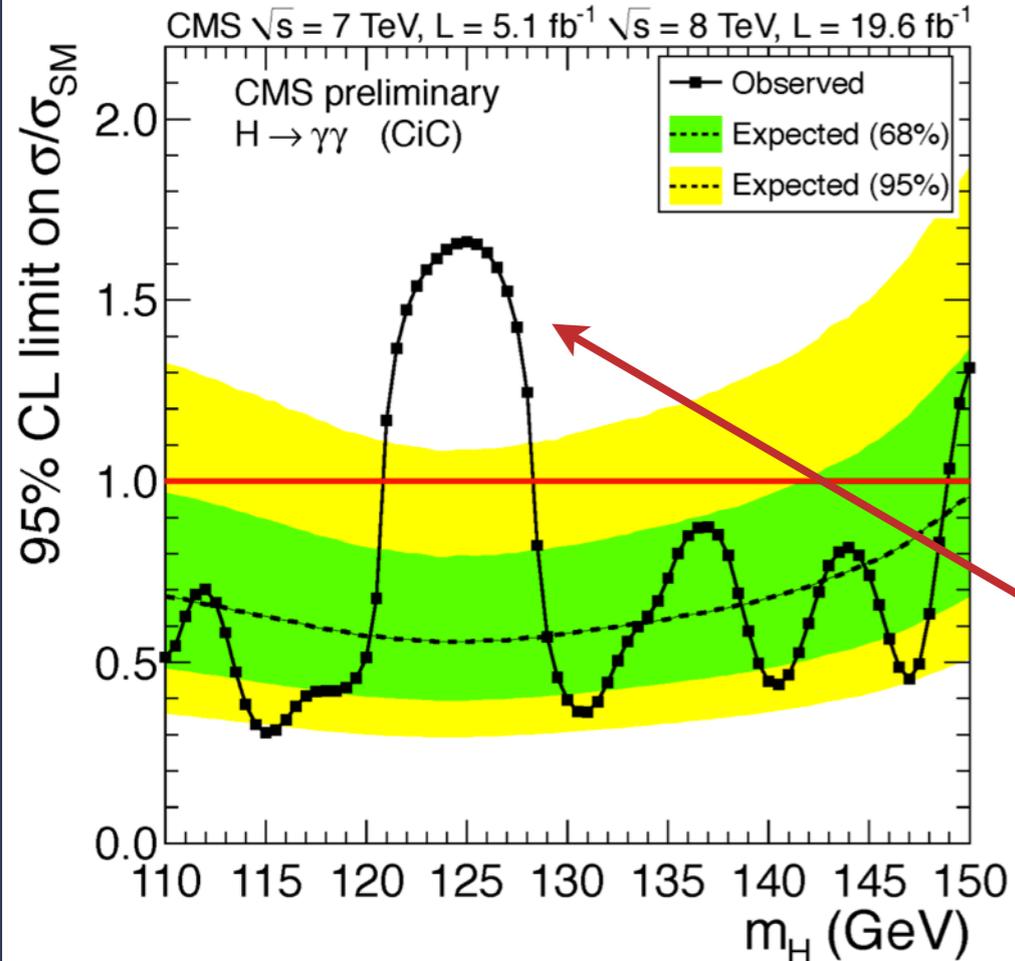
detector/analisi:
distribuzione larga

è davvero un segnale?

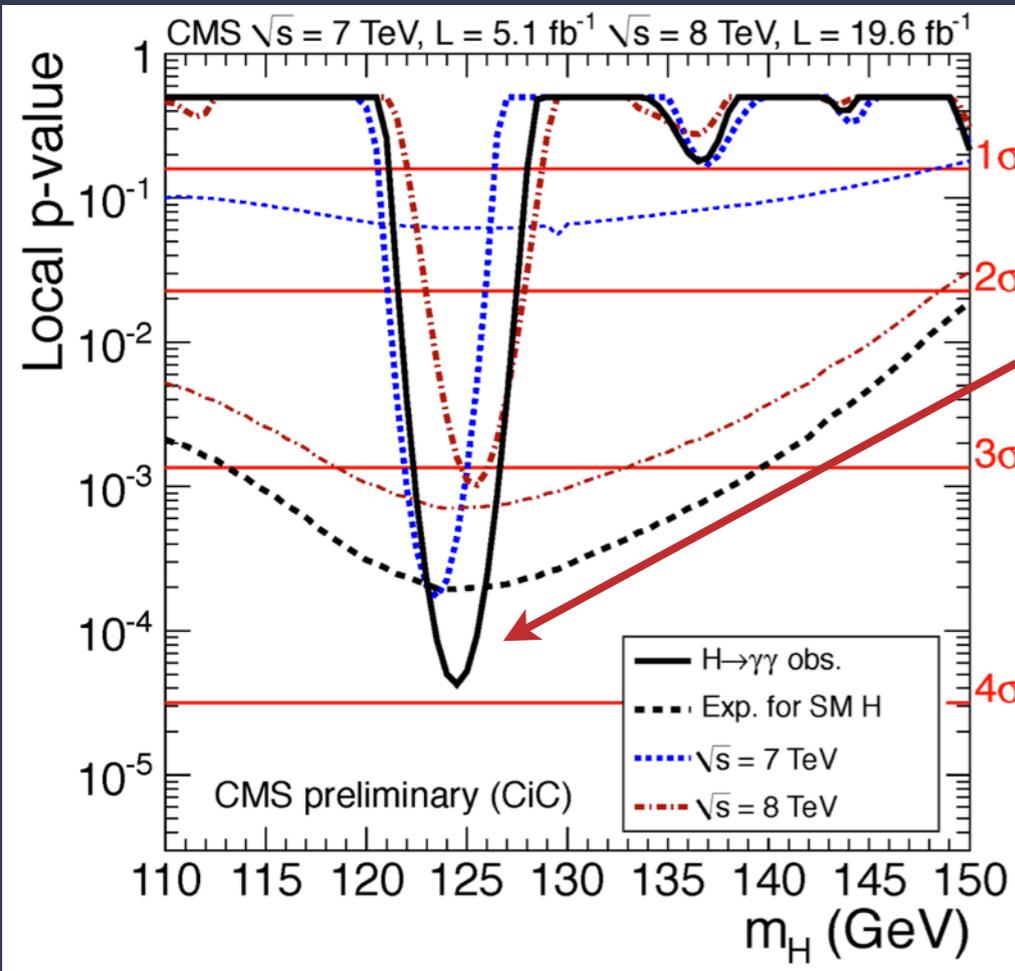
stima della probabilità (p -value) che il **solo fondo** fluttui tanto da **sembrare un segnale con $\mu(m_H)$** osservata



p -value \Rightarrow deviazioni standard (σ) sotto ipotesi di gaussianità $Z = \Phi^{-1}(1-p)$

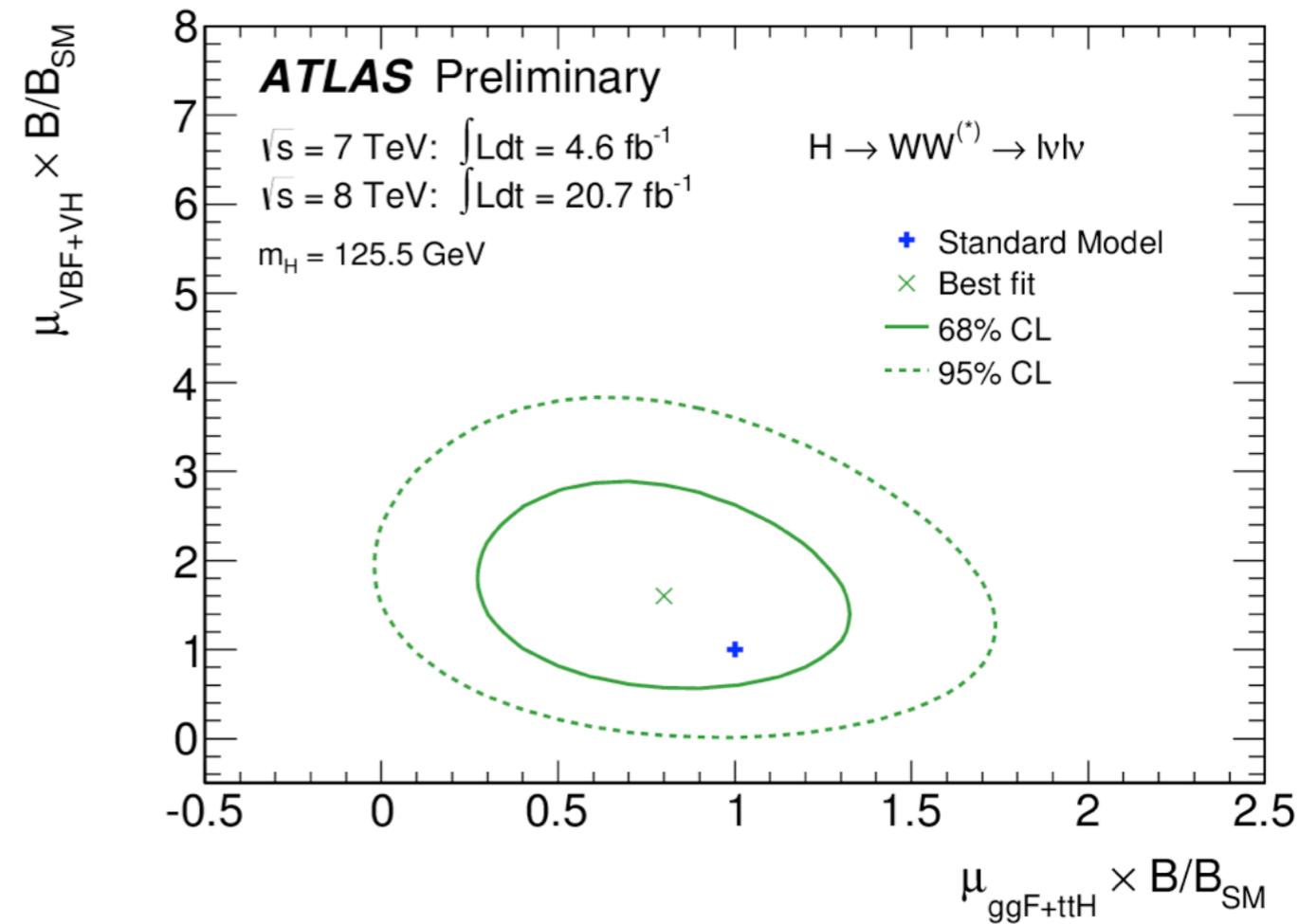
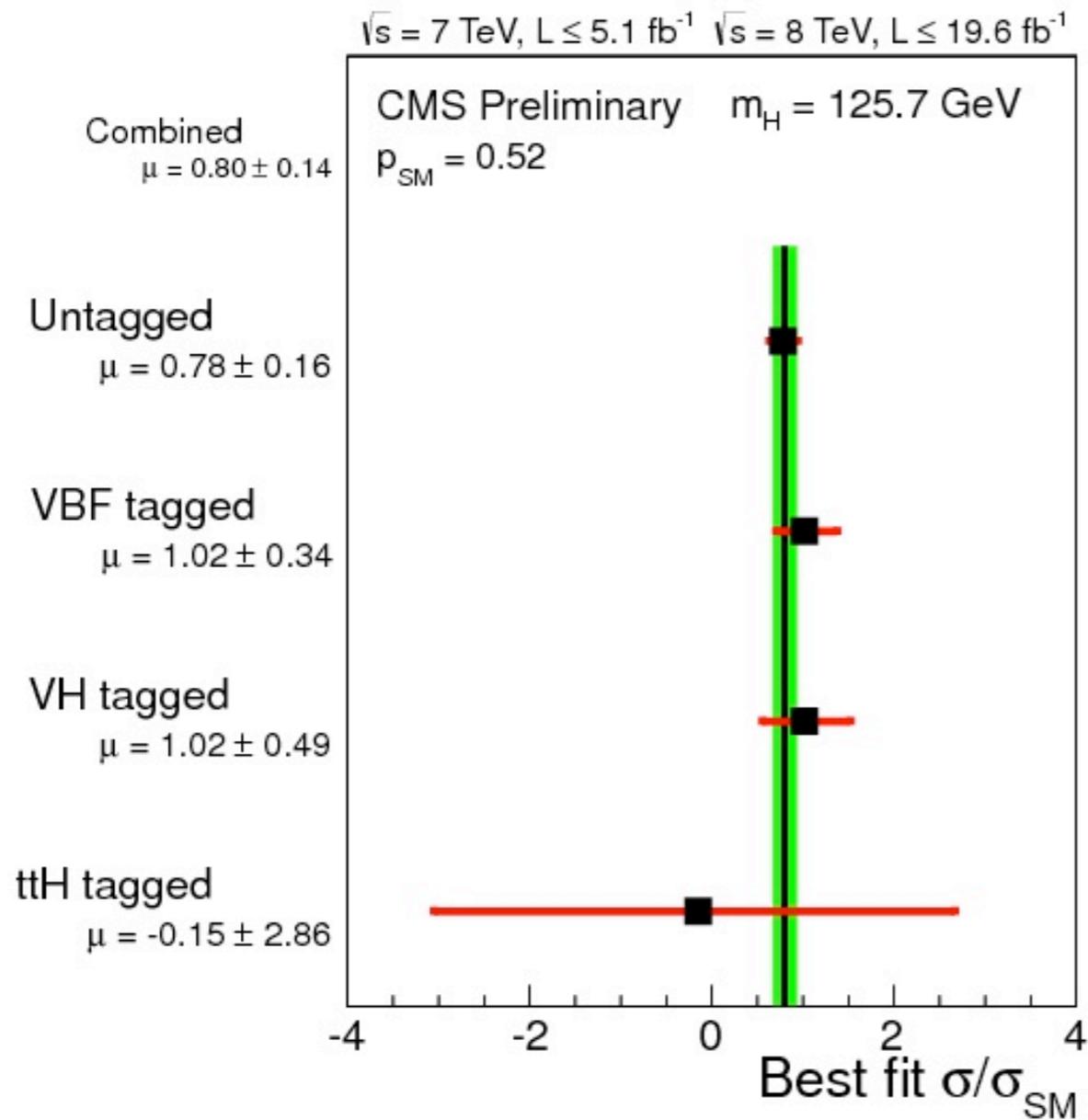


si possono tradurre questi limiti in termini di sezioni d'urto rispetto a quelle previste dal Modello Standard $\sigma/\sigma_{\text{SM}}$



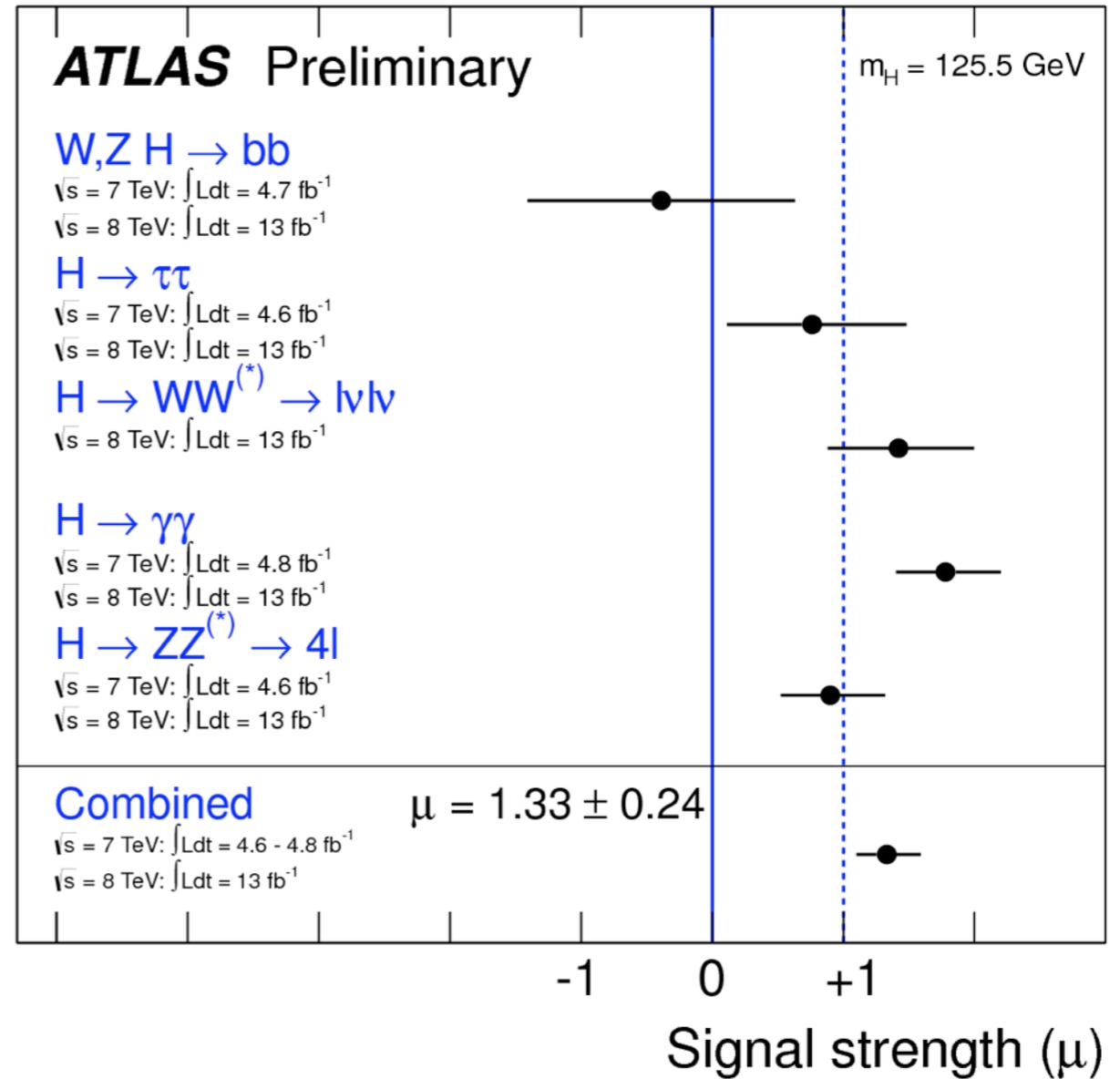
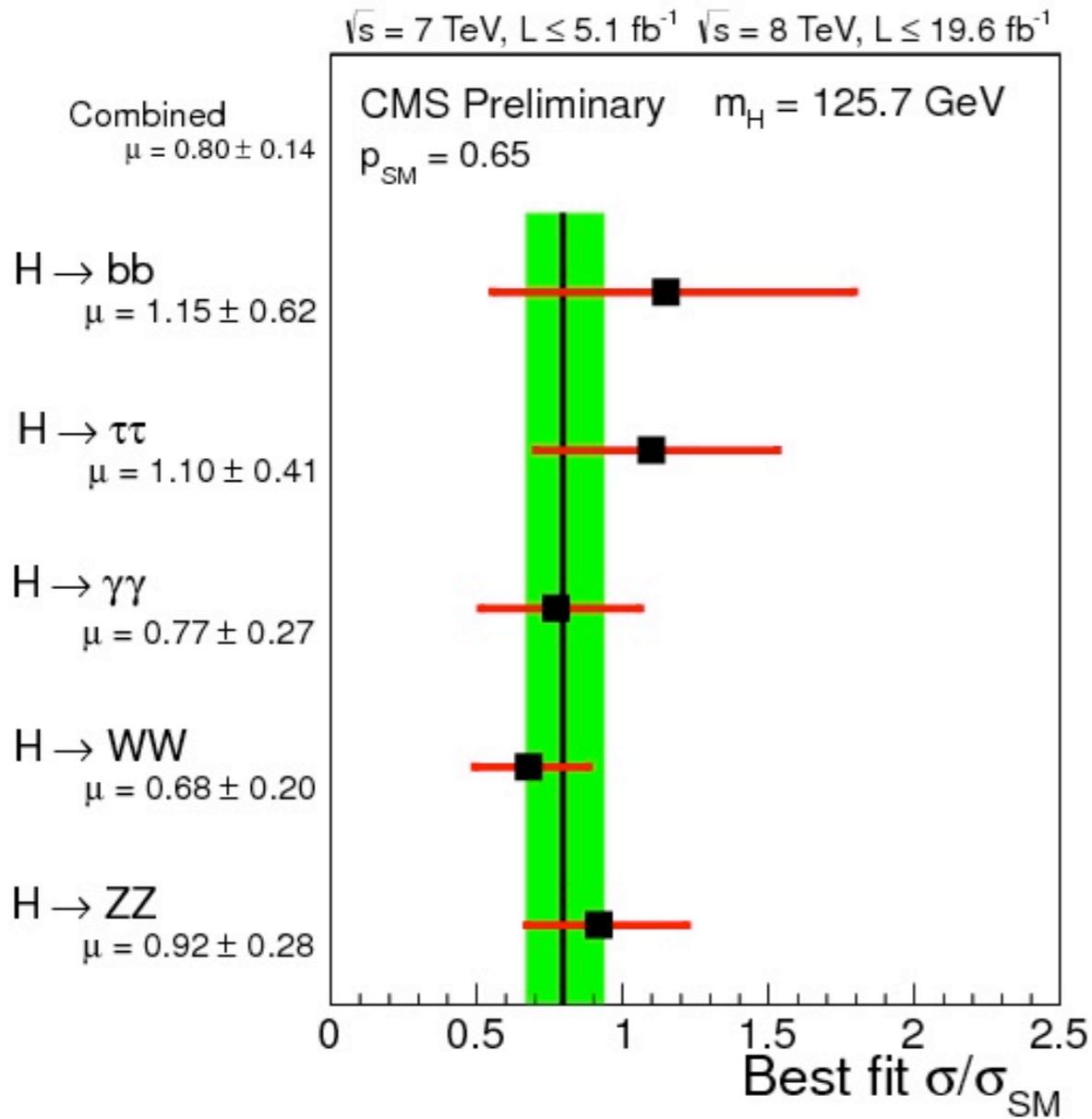
osservazione $h \rightarrow \gamma\gamma$
 superate 3 deviazioni standard!

Produzione



no grandi deviazioni dallo SM

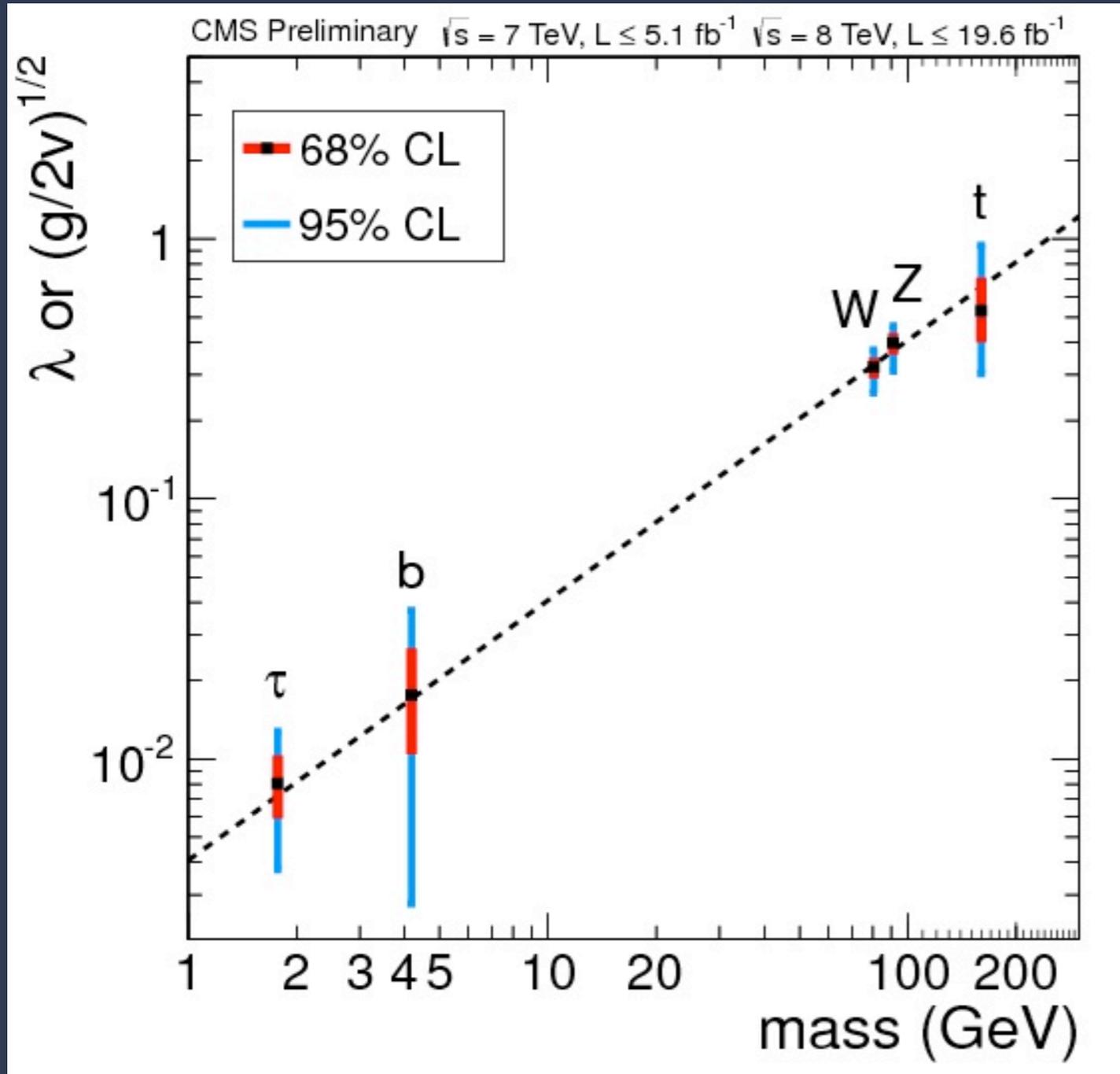
Decadimento



ATLAS e CMS marginalmente compatibili

no grandi deviazioni dallo SM

Accoppiamenti



accoppiamento alle masse:

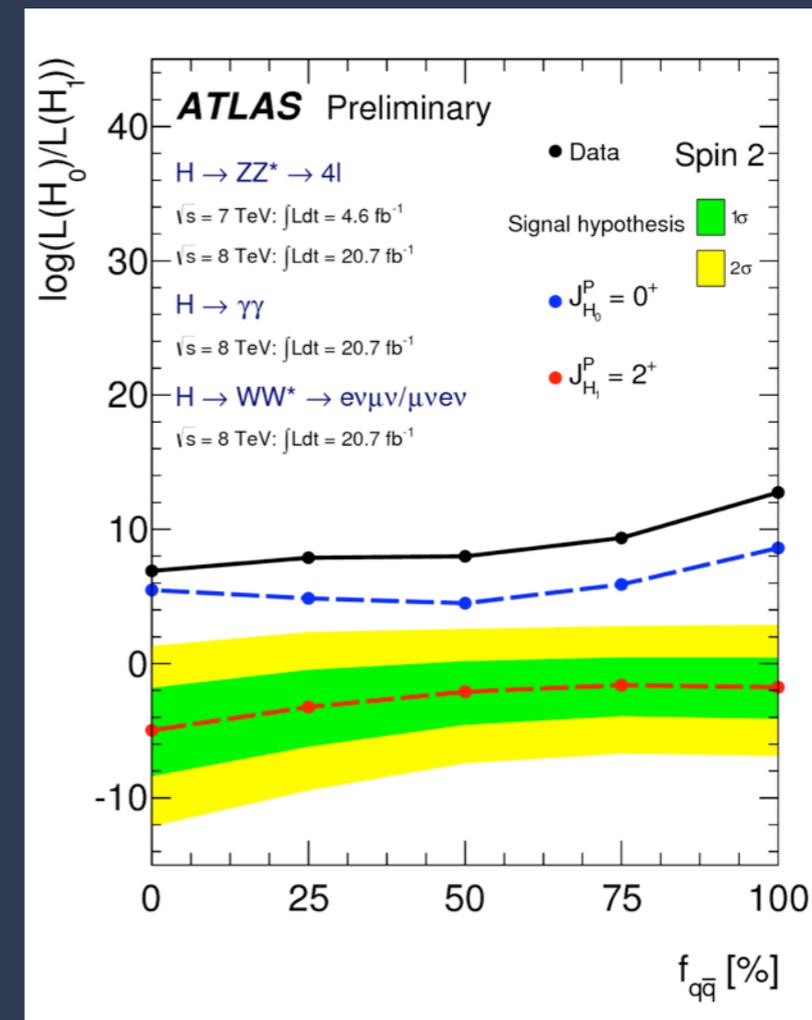
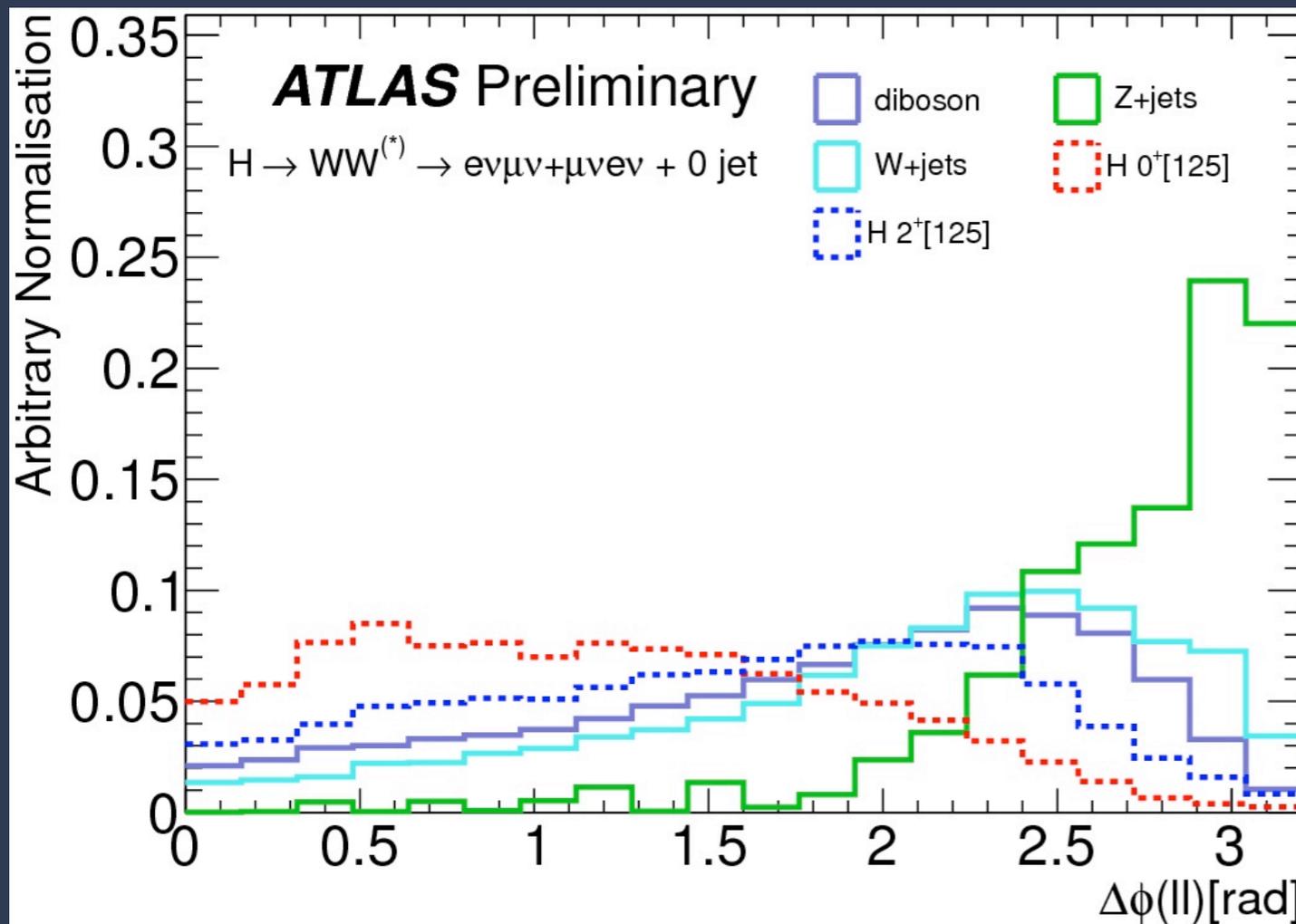
- bosoni $\sim (g/2v)^{1/2}$
- fermioni $\sim \lambda_i$ (Yukawa)

no grandi deviazioni dallo SM

Spin-parità

- Standard Model: $J^P = 0^+$
- E' un bosone!
 - Osservato $h \rightarrow \gamma\gamma$
 - Teorema di Landau-Yang: *una particella vettoriale massiva non può decadere in due bosoni vettori con massa nulla*
- Non basta! scalare ($J=0$)? tensoriale ($J=2$)?

Scalare(?)



dati

ipotesi 0^+

ipotesi 2^+

- 2^+ produzione mista $gg + qq$ ($f_{qq} [\%]$)
- 0^+ favorito su 2^+ ($>3\div 4 \sigma$) combinando:
 - $h \rightarrow \gamma\gamma$
 - $h \rightarrow WW^* \rightarrow |v|v$
 - $h \rightarrow ZZ^* \rightarrow 4l$

molto difficile misurare la parità

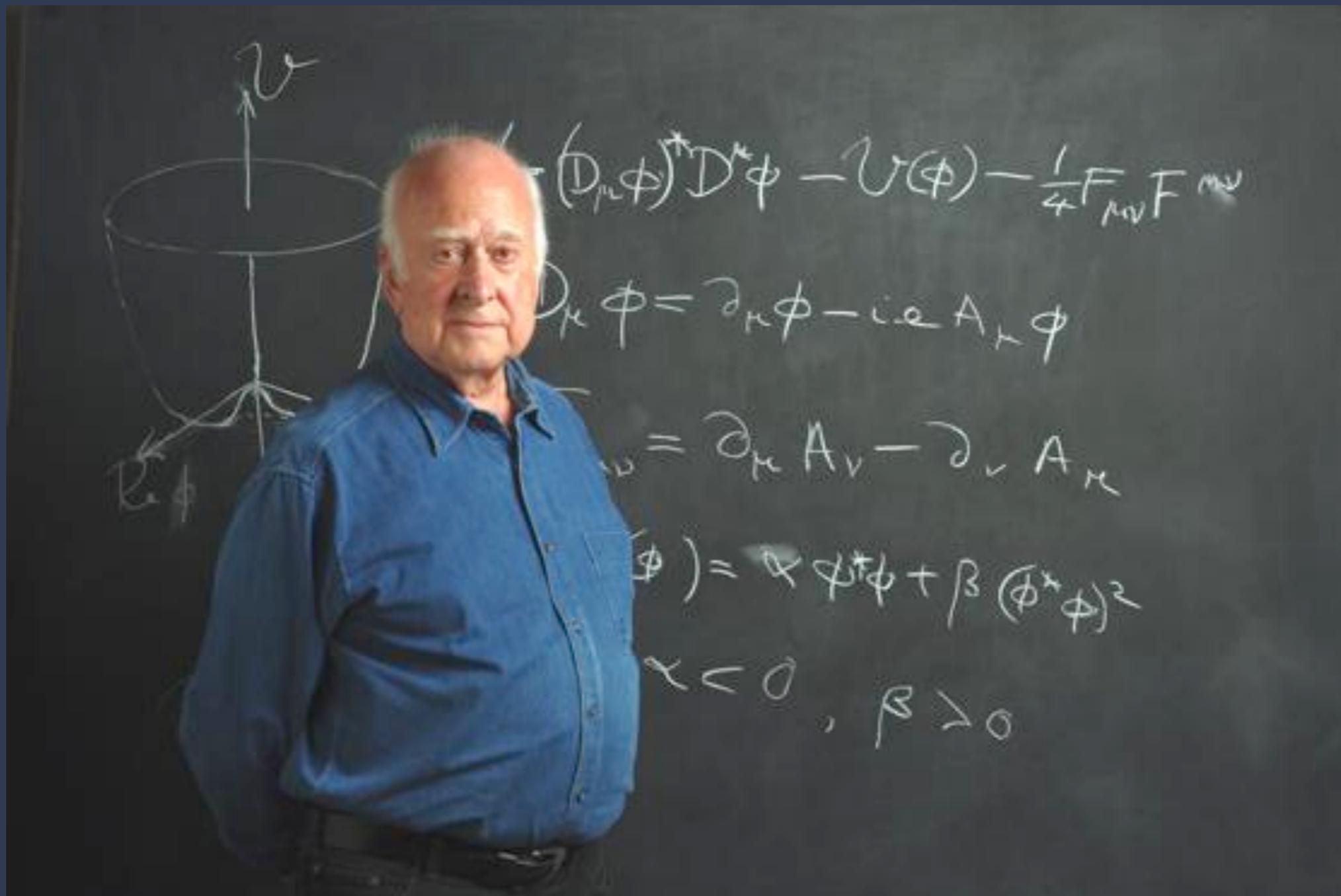
Conclusioni

- Nuova particella scalare compatibile con il bosone di Higgs scoperta (4.7.2012)
- Dopo un anno sappiamo che:
 - è un bosone \sim scalare ($J=0$)
 - accoppiamenti compatibili con Higgs SM
 - nessuna deviazione *davvero* intrigante

Conclusioni?

- Nuova particella scalare compatibile con il bosone di Higgs scoperta (4.7.2012)
- Dopo un anno *non* sappiamo se:
 - ce ne sono altri?
 - decadimenti esotici (dark matter)? *
 - accoppiamenti non-standard ai fermioni? *

* incertezze ancora grandi



I'm glad it happened in my lifetime

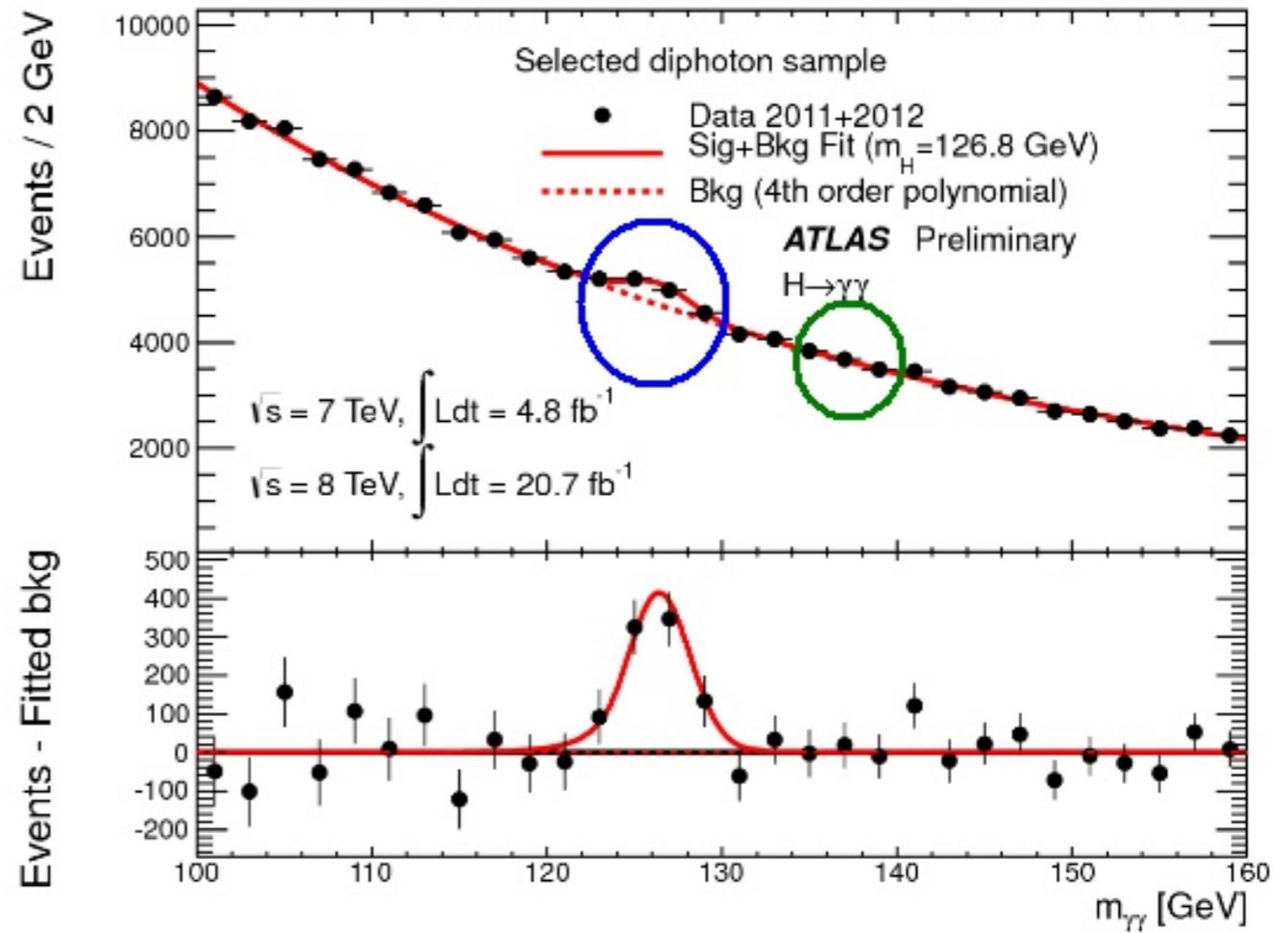
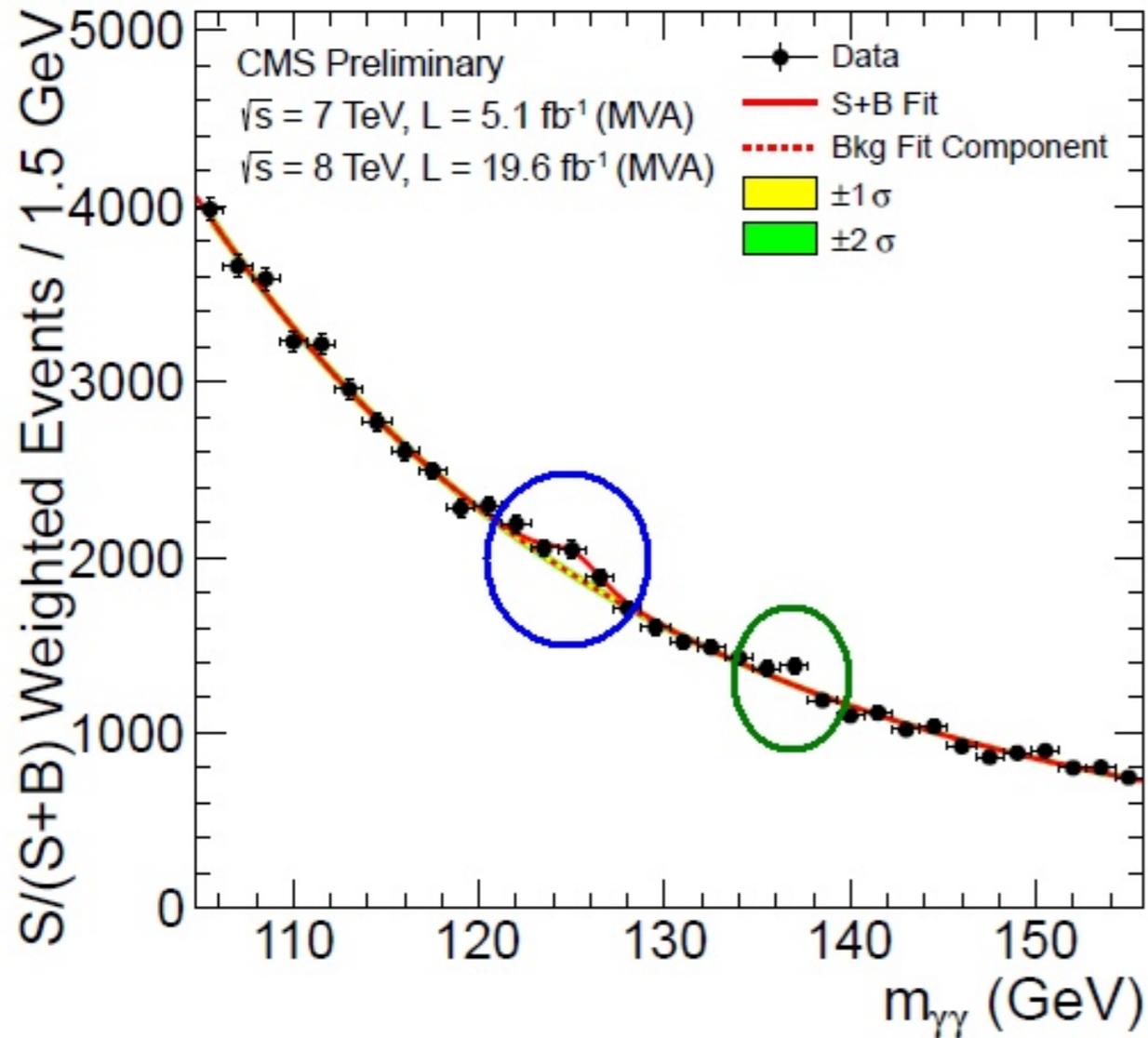
{P. Higgs}

Me, too

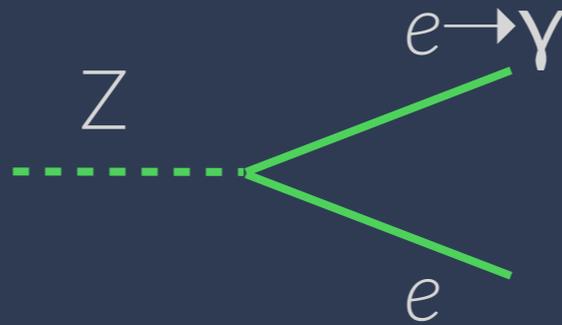
{R. Di Sipio}

backup

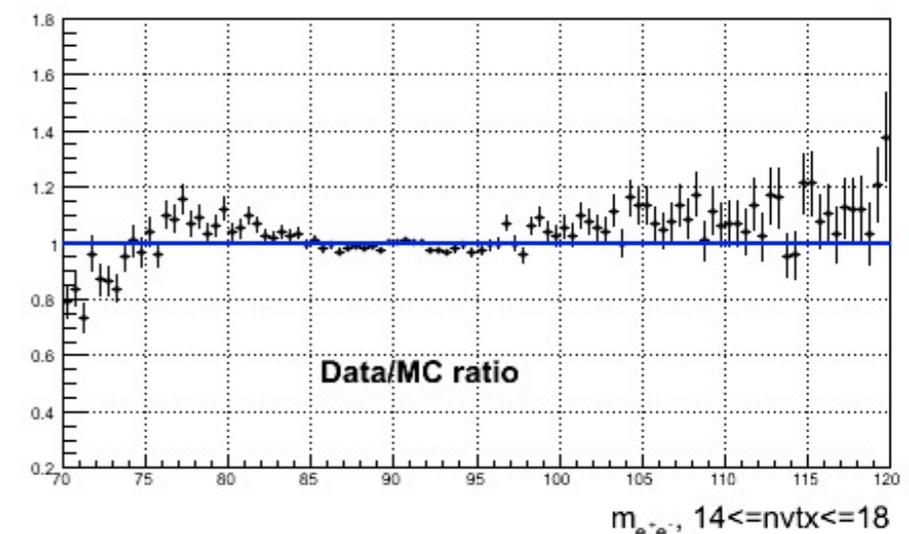
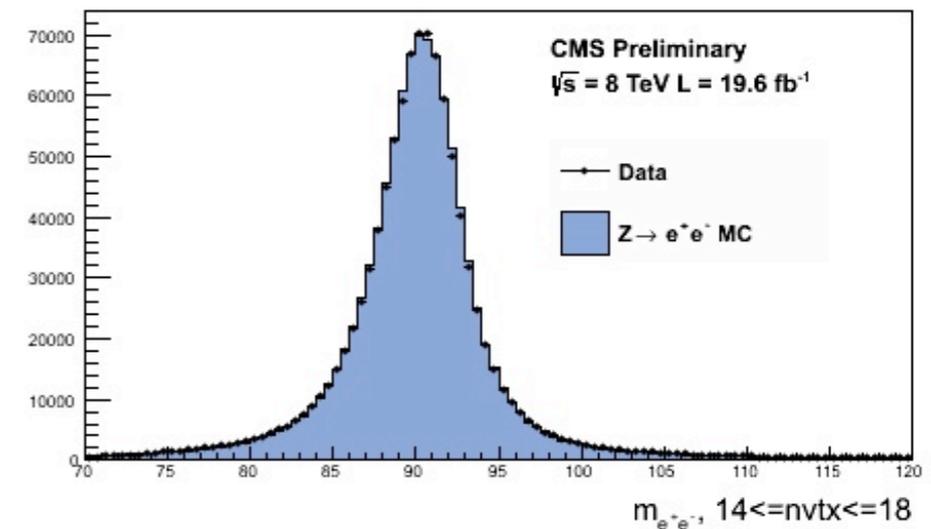
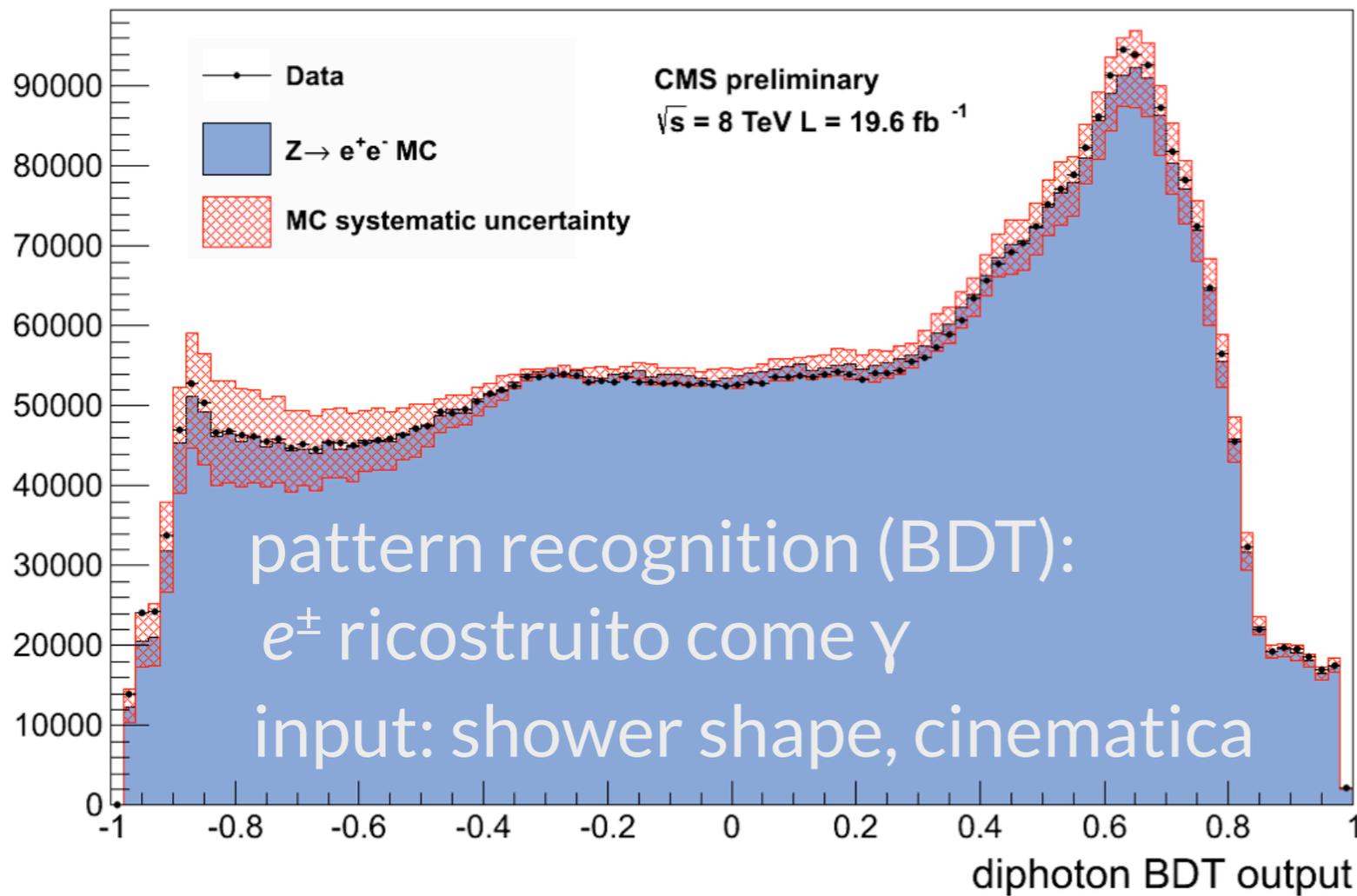
due higgs?



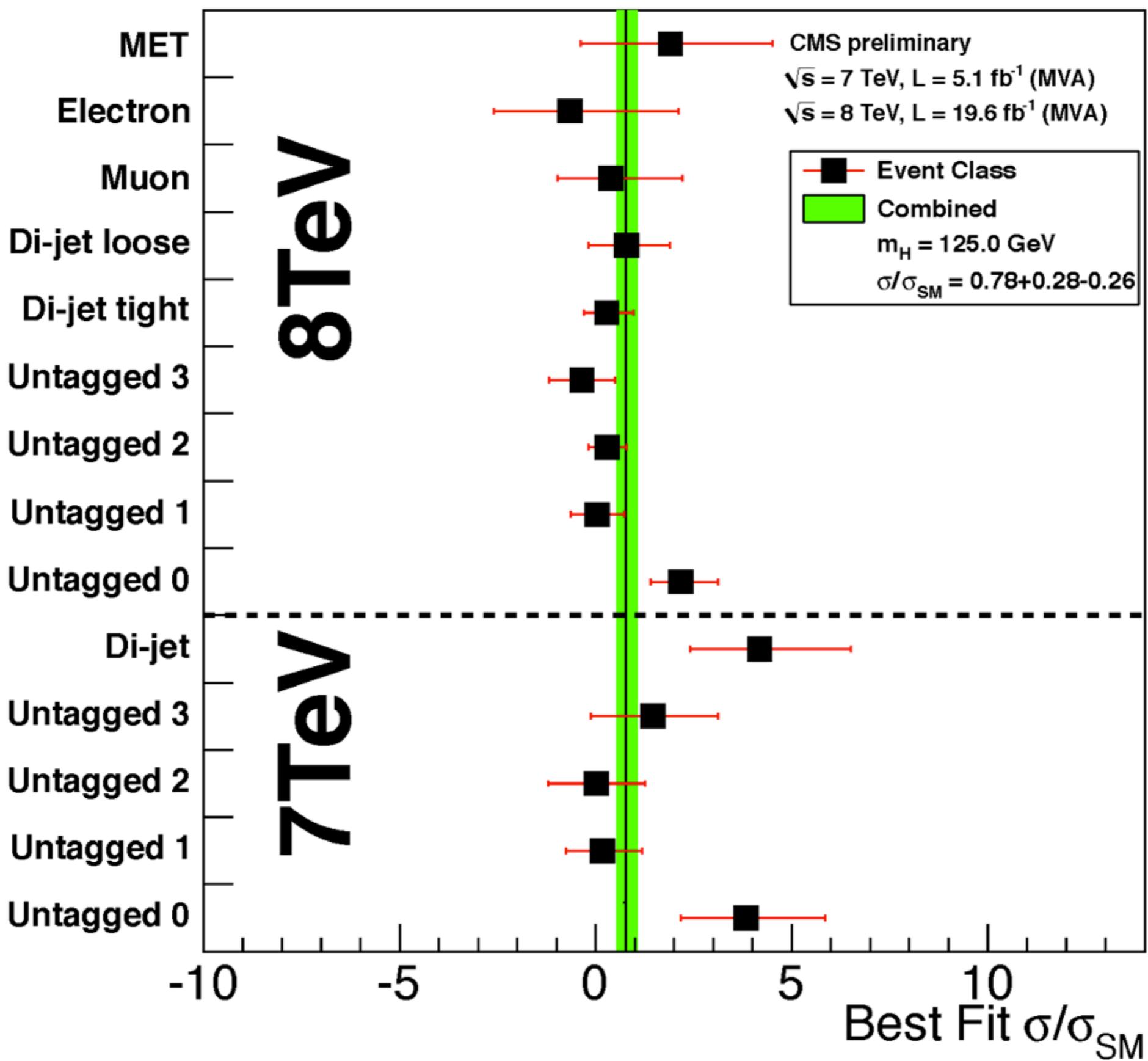
calibrazione $Z \rightarrow e^+e^-$

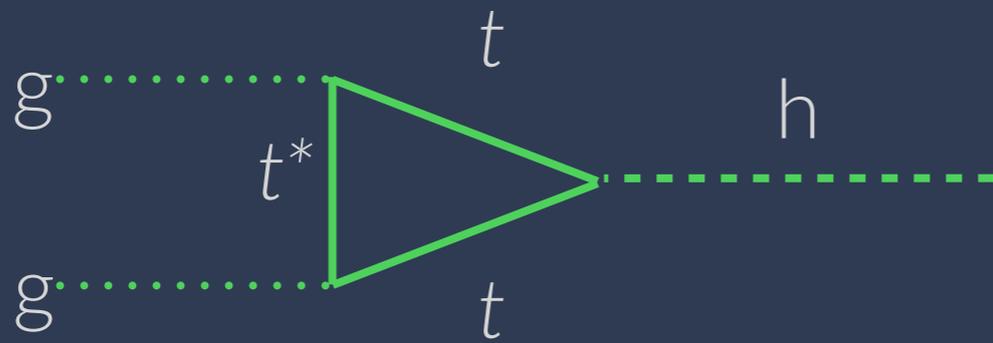


- vertice conversione
- vertice primario $\Upsilon\Upsilon$

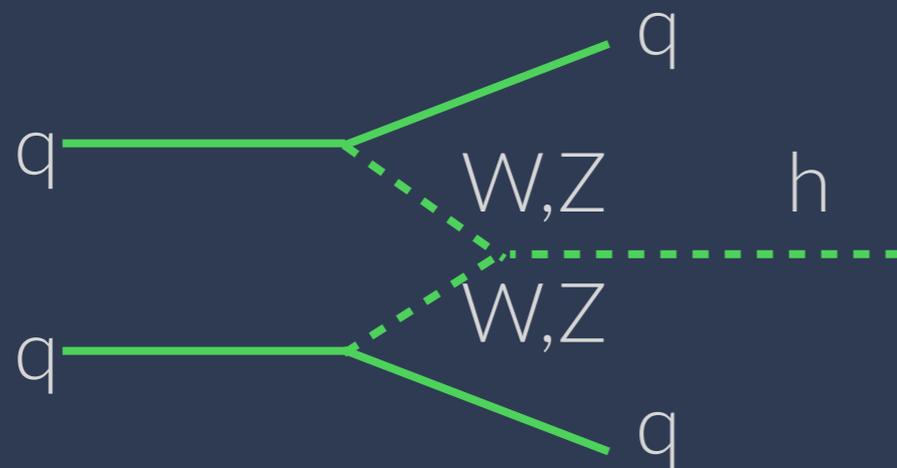


cosa cercare?





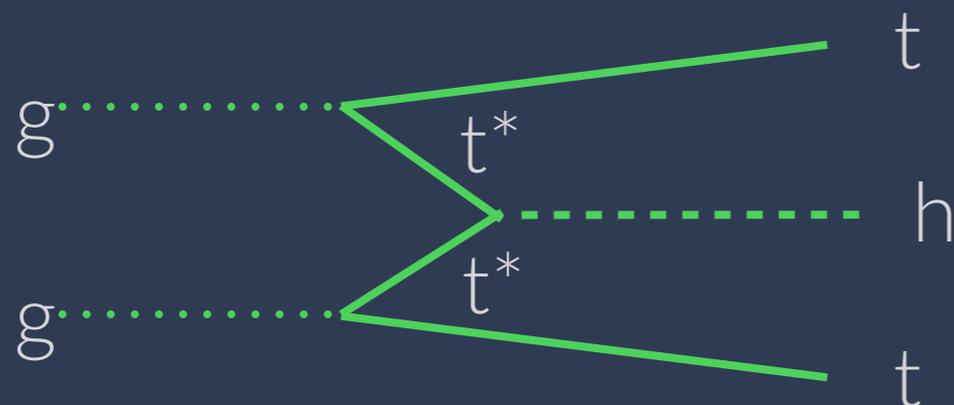
gluon-gluon fusion



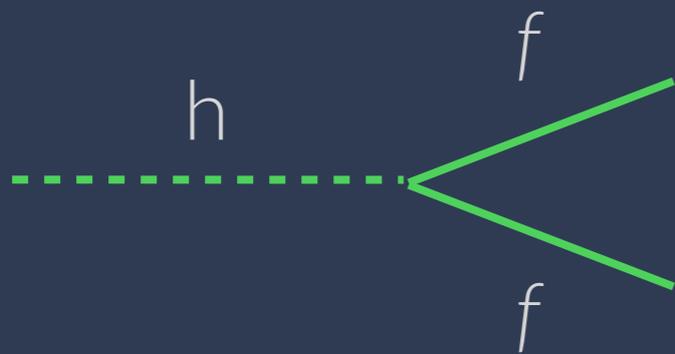
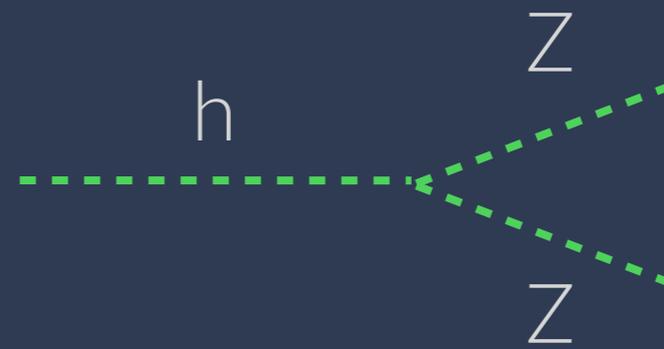
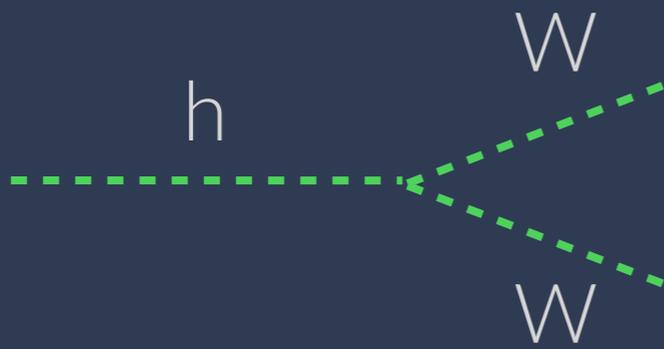
Vector boson fusion



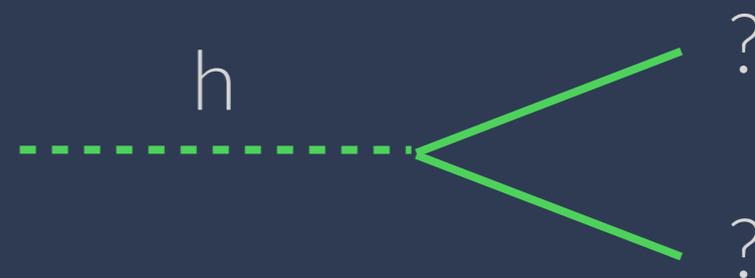
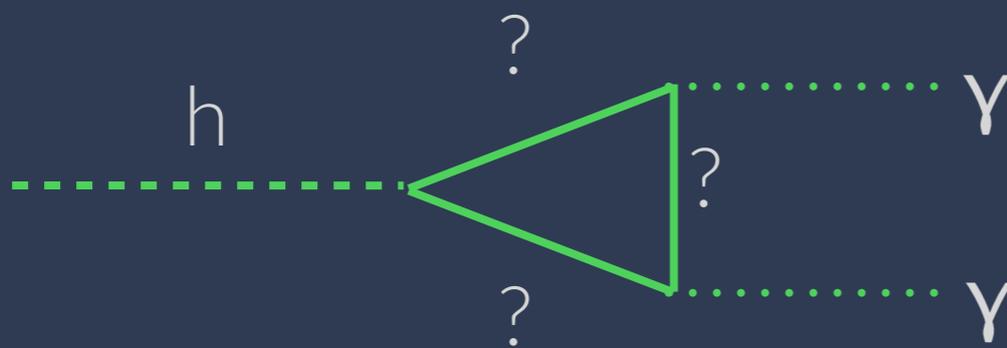
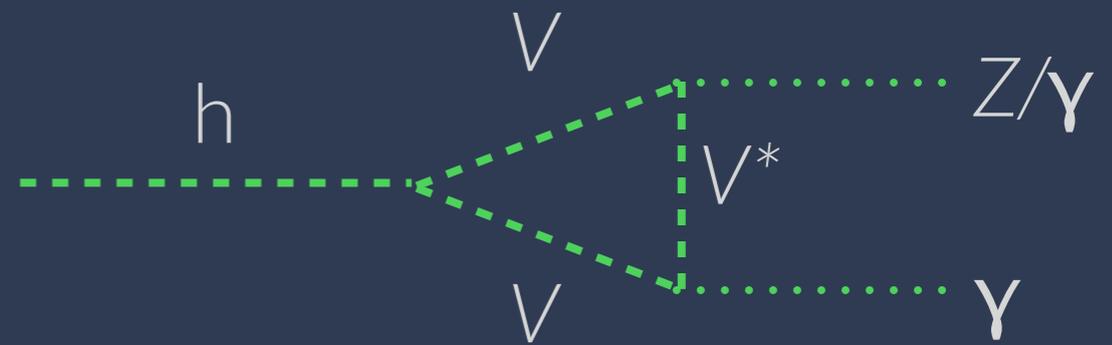
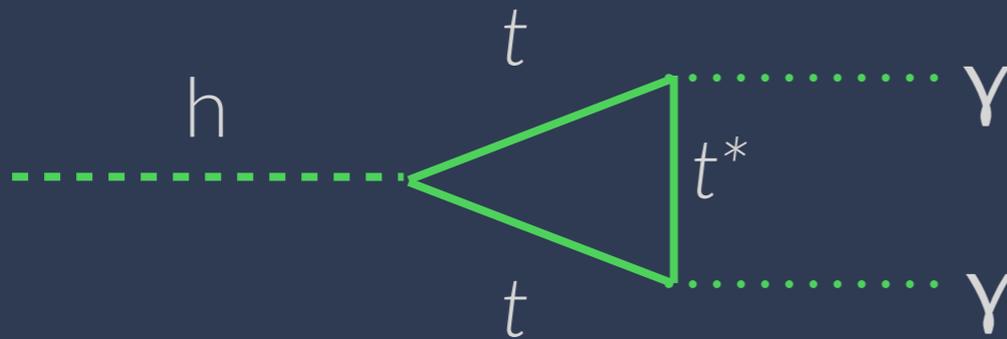
higgs-strahlung



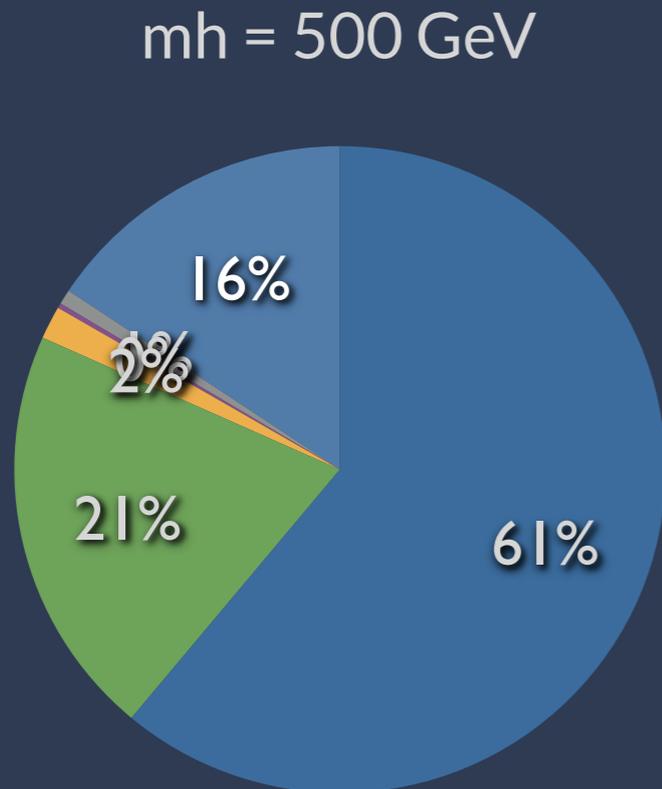
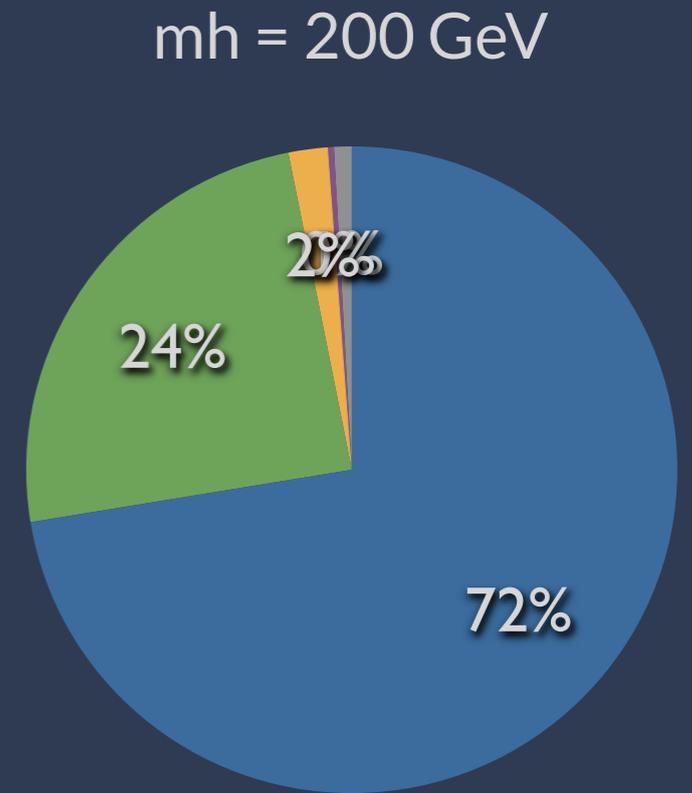
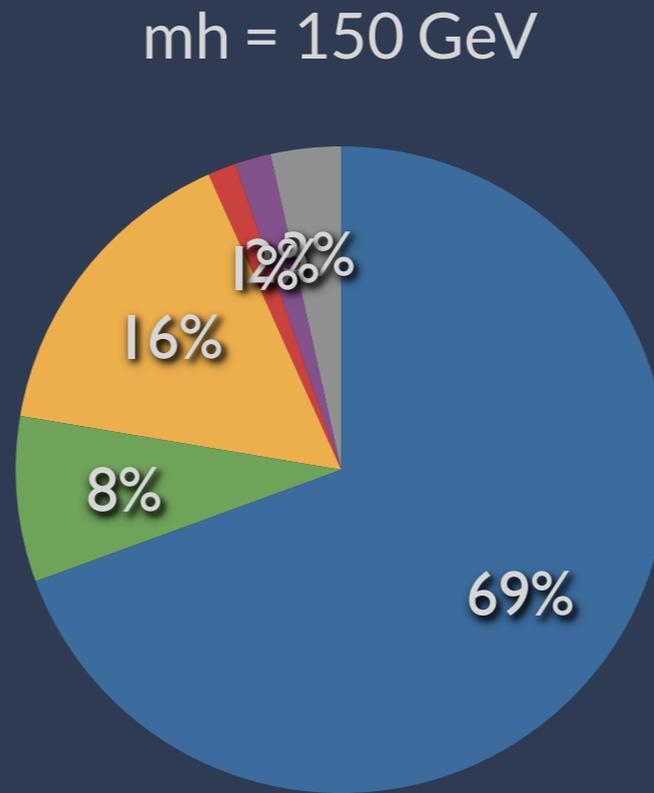
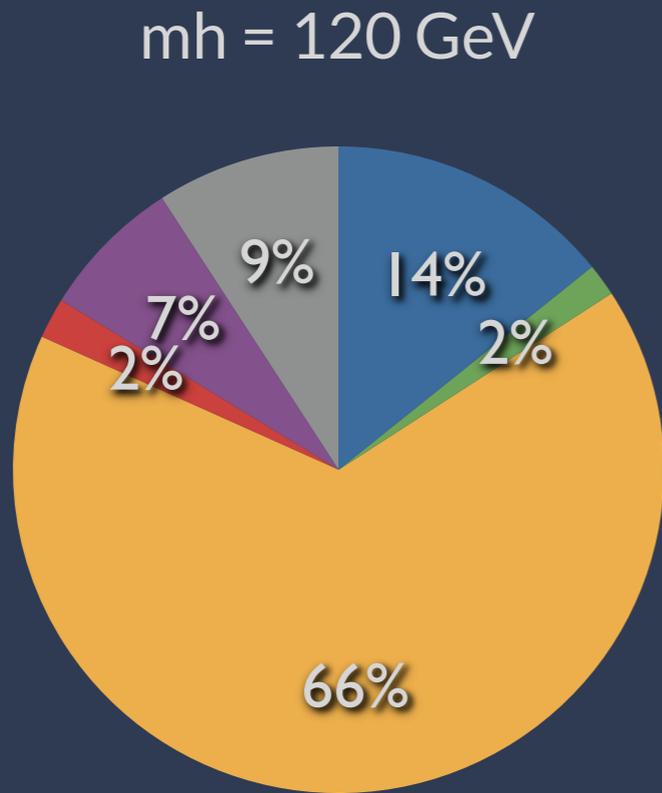
tt+h associated production



$f = u/d/s/c, b, e, \mu, \tau$



- WW
- ZZ
- bb
- YY
- TT
- gg
- tt

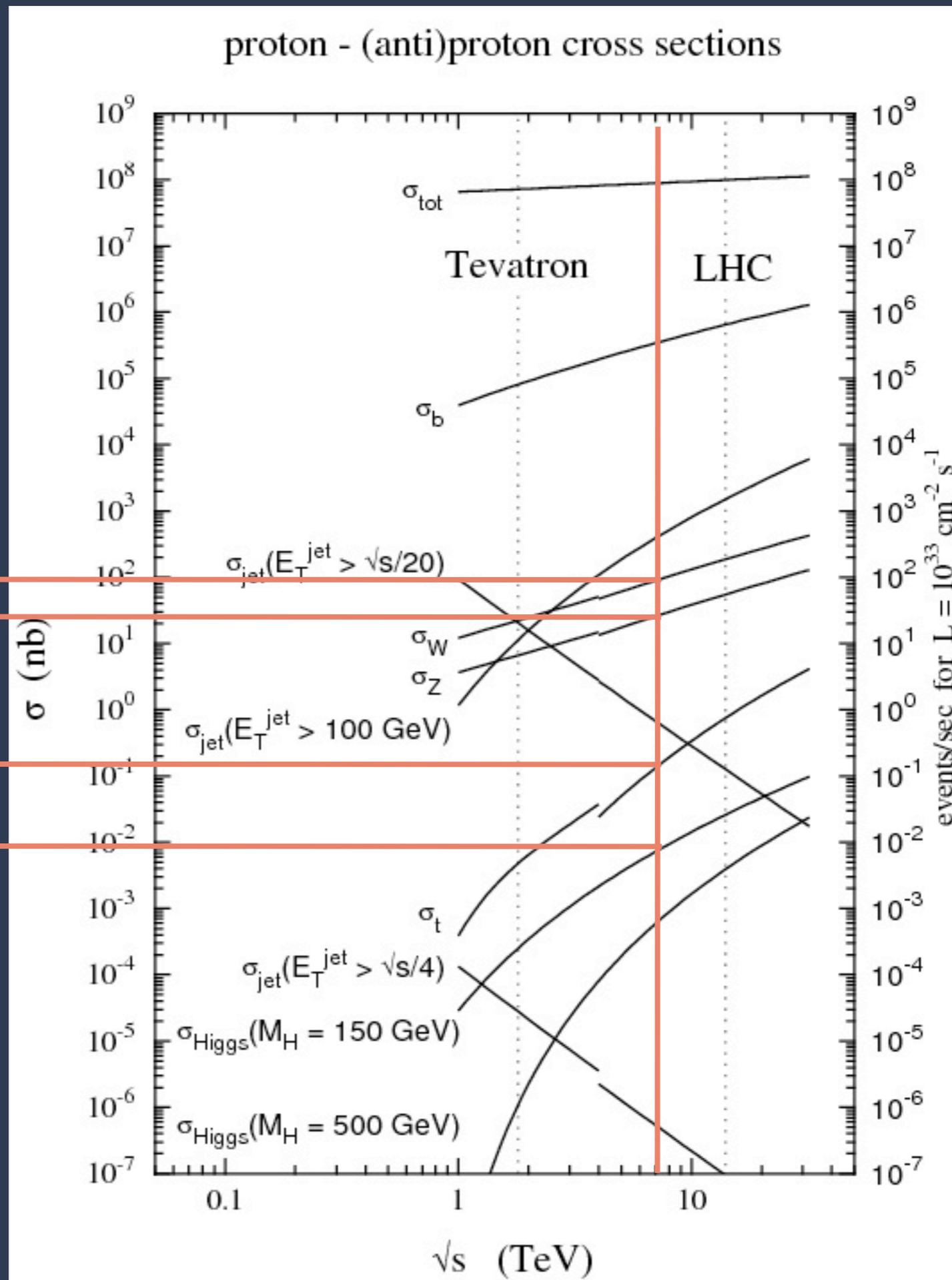


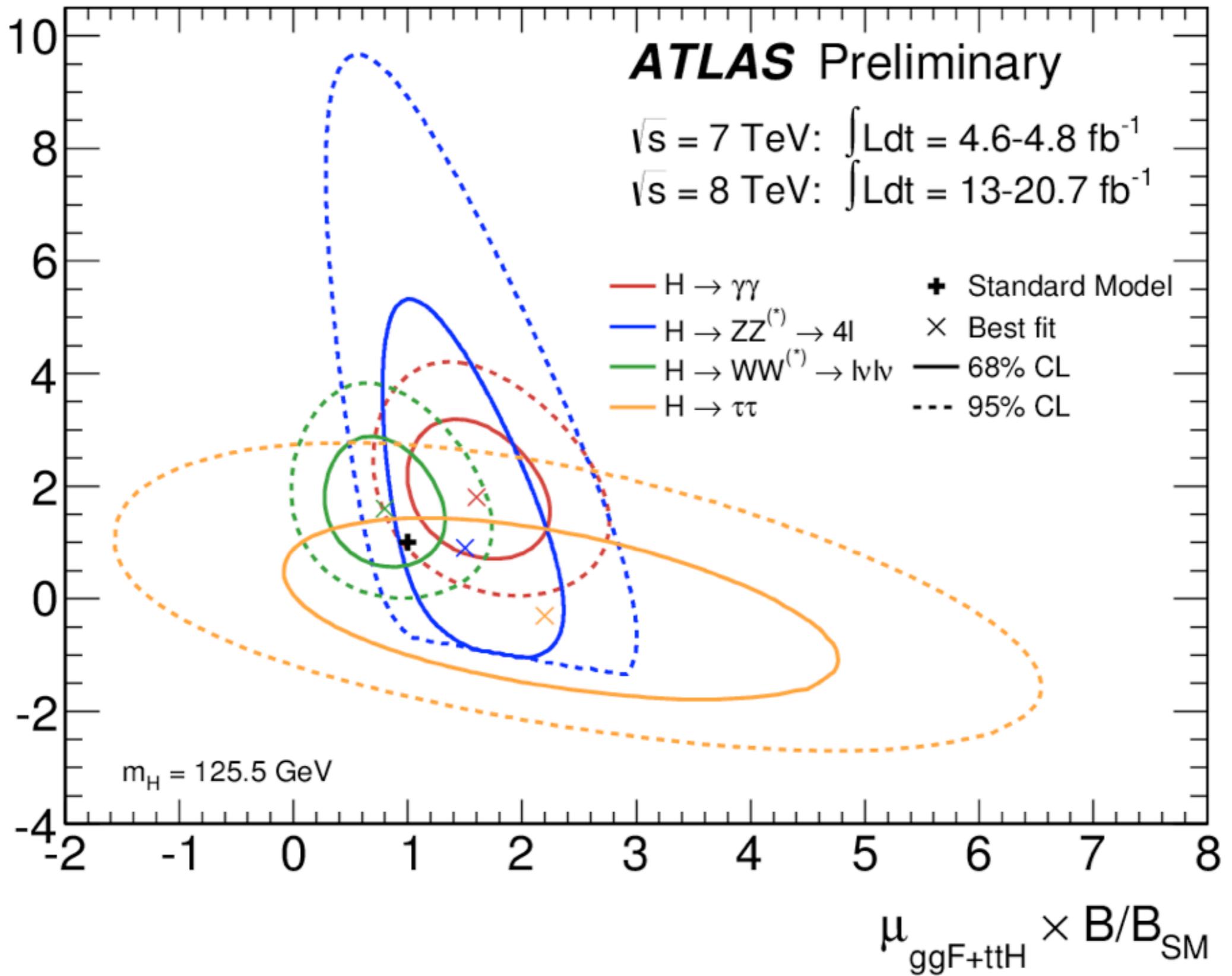
fenomenologia piuttosto differente a seconda del valore della massa!

leggero bb
intermedio WW
pesante WW, ZZ, tt

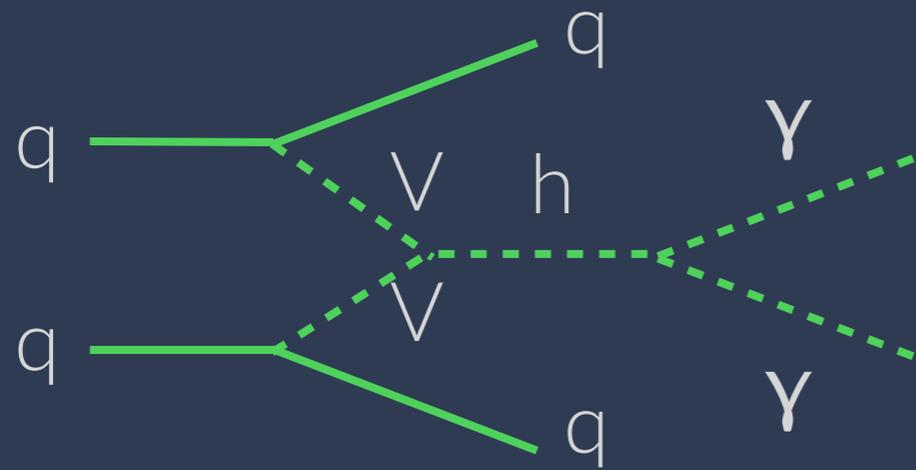
fondi EW SM anche
 10^5 volte più grandi!

W
 Z
 top
 higgs
 (150 GeV)

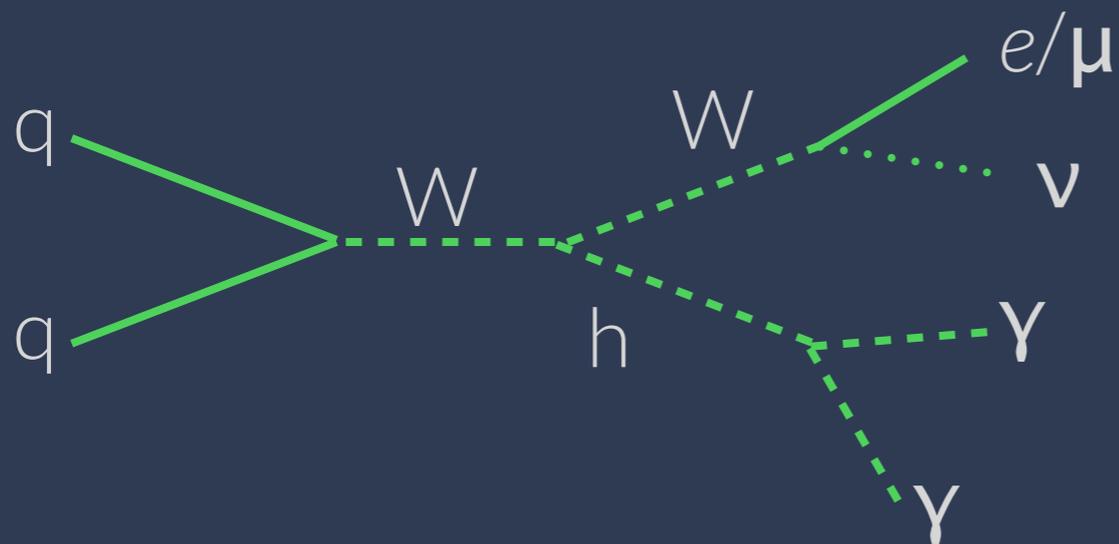


$\mu_{\text{VBF+VH}} \times \text{B/B}_{\text{SM}}$ 

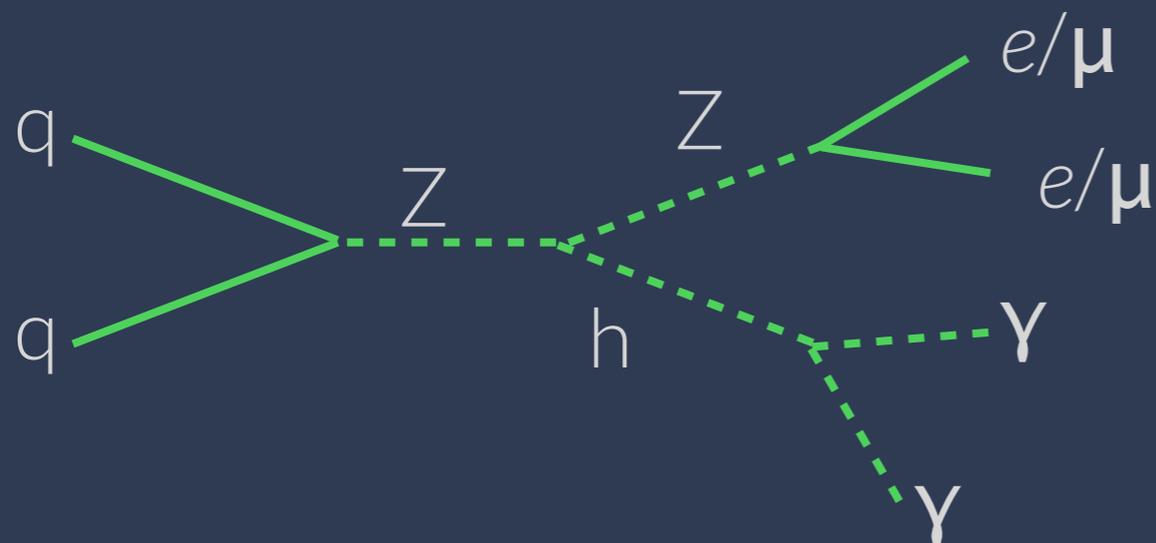
ggF vs VBF: ok, ma occhio a $h \rightarrow \gamma\gamma$



VBF: due jet in avanti con grande separazione angolare

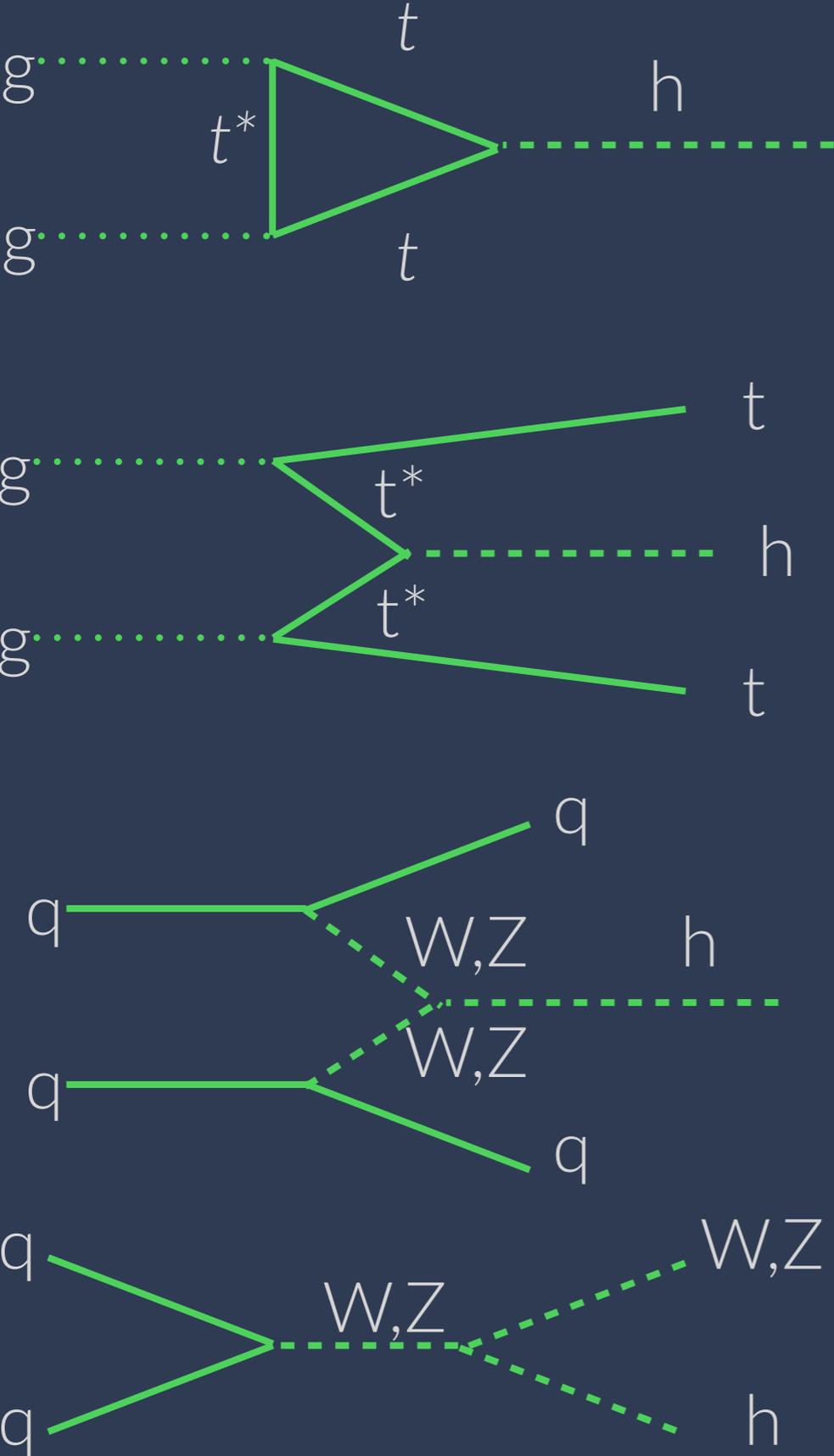


WH: leptone carico, energia trasversa mancante



ZH: due leptoni carichi

produzione



decadimento

