ATLAS @ LHC – Prospective

In 2015 : √S = 7 TeV → 14 TeV

By 2021 : 300 fb^{-1} (~ * 12) ← end of approved running

By 203x : 3000 fb^{-1} (~ *10)

H_{SM}
$17. 10^{6}$
$170. 10^{6}$

Corinne Goy pour le groupe ATLAS – 03/10/2013

A year ago already !

Physics Letters B 716 (2012) 1–29

Contents lists available at SciVerse ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

ELSEVIER

Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC ☆

ATLAS Collaboration *

This paper is dedicated to the memory of our ATLAS colleagues who did not live to see the full impact and significance of their contributions to the experiment.

10 fb^{-1}

Contents lists available at SciVerse ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

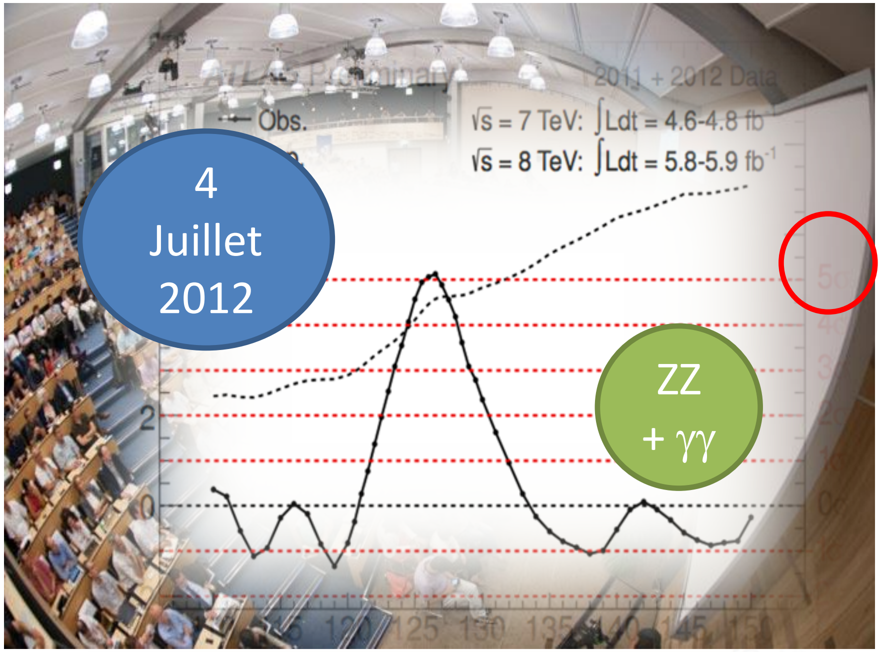
ELSEVIER

Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC ☆

CMS Collaboration *

CERN, Switzerland

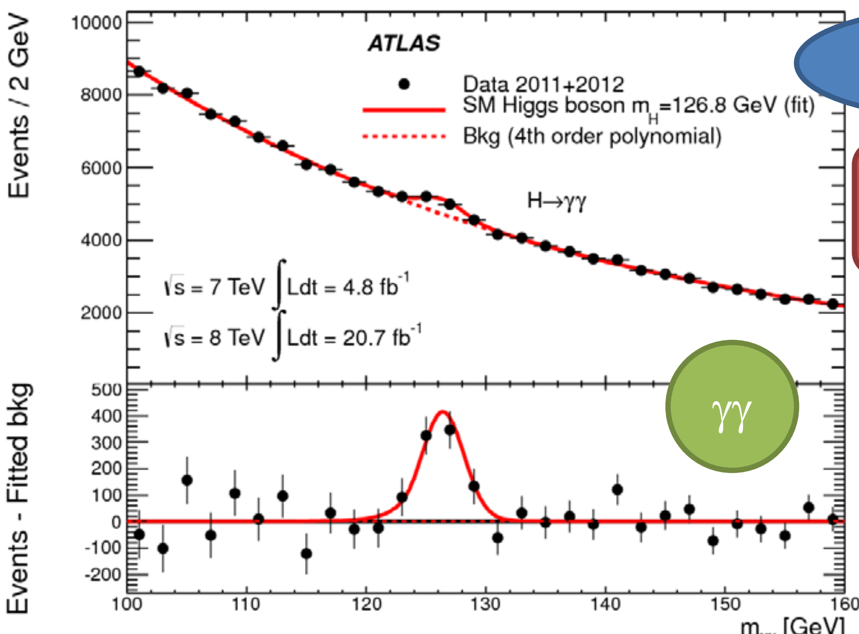
This paper is dedicated to the memory of our colleagues who worked on CMS but have since passed away. In recognition of their many contributions to the achievement of this observation.

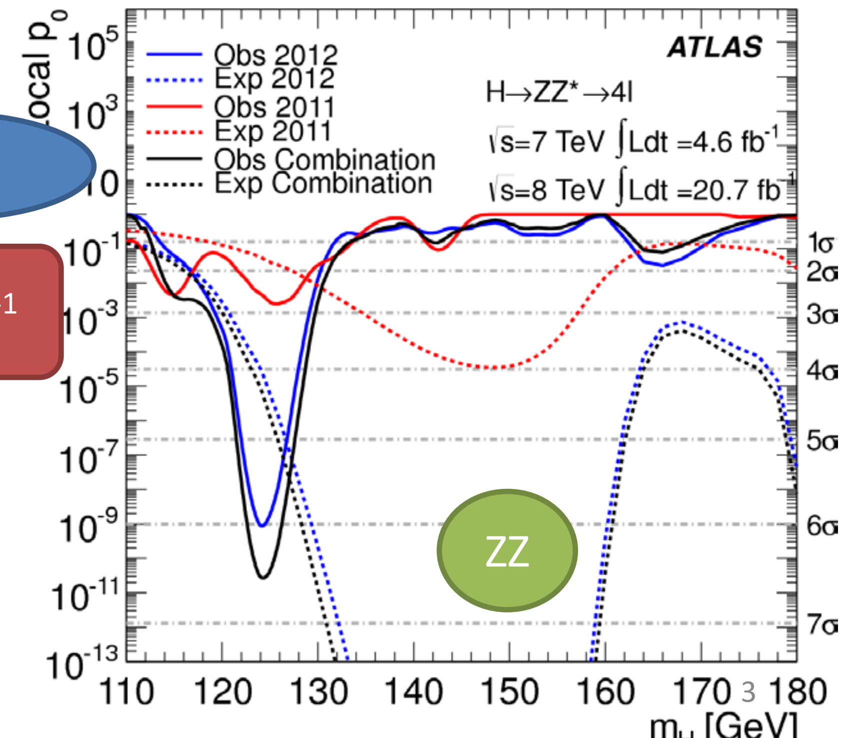


10 fb^{-1}
(# H $_{SM}$: 0.2 10^6)

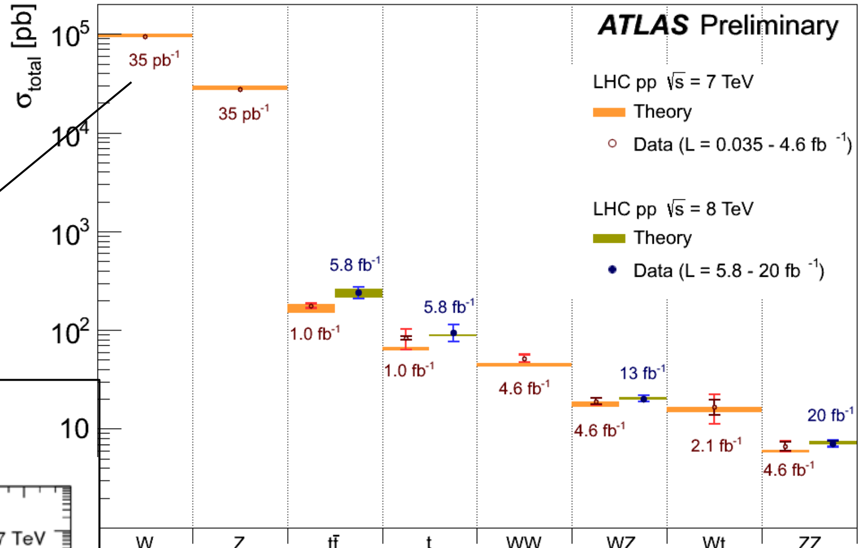
2013

25 fb^{-1}

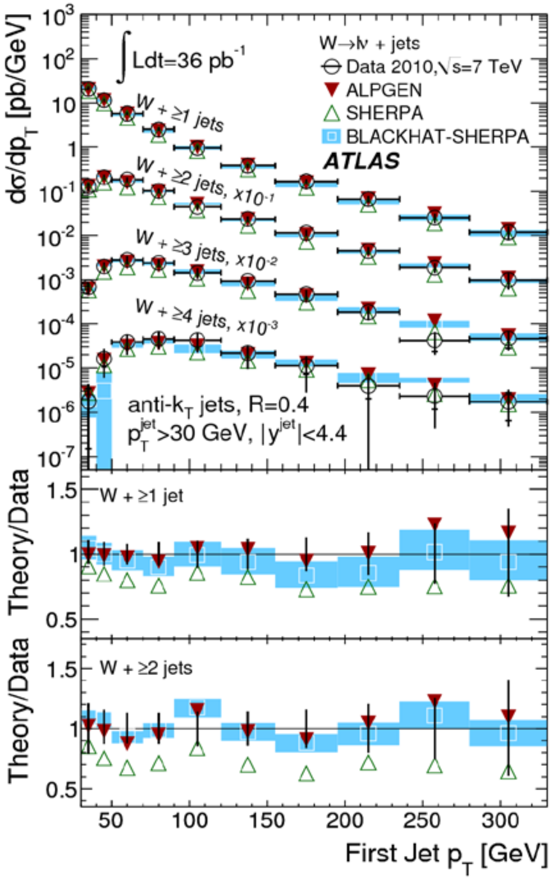




Standard model processes

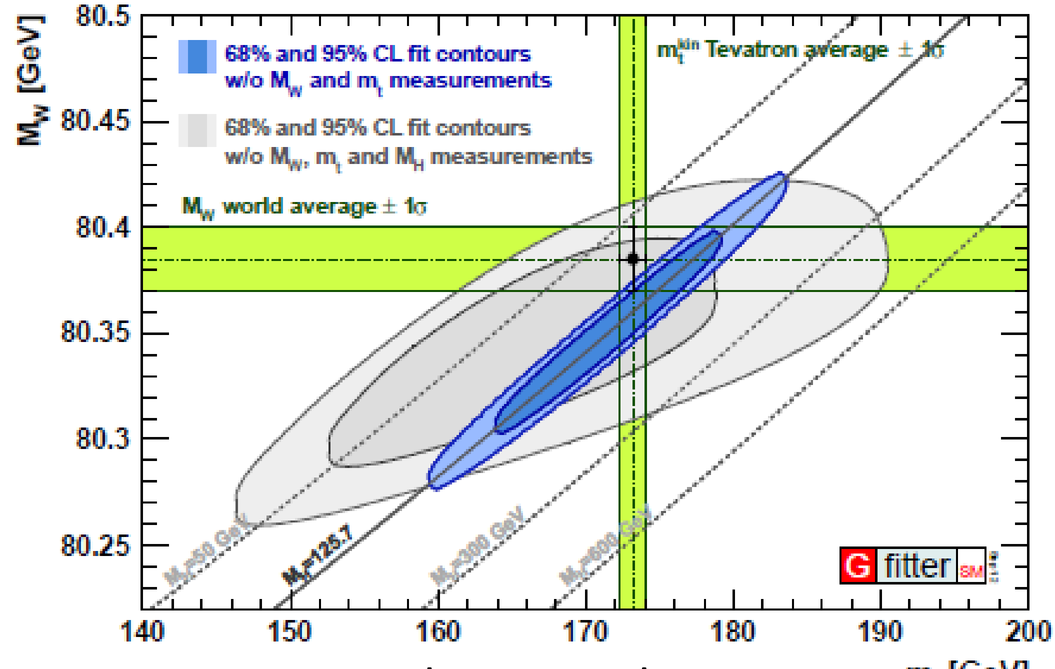


W + jets



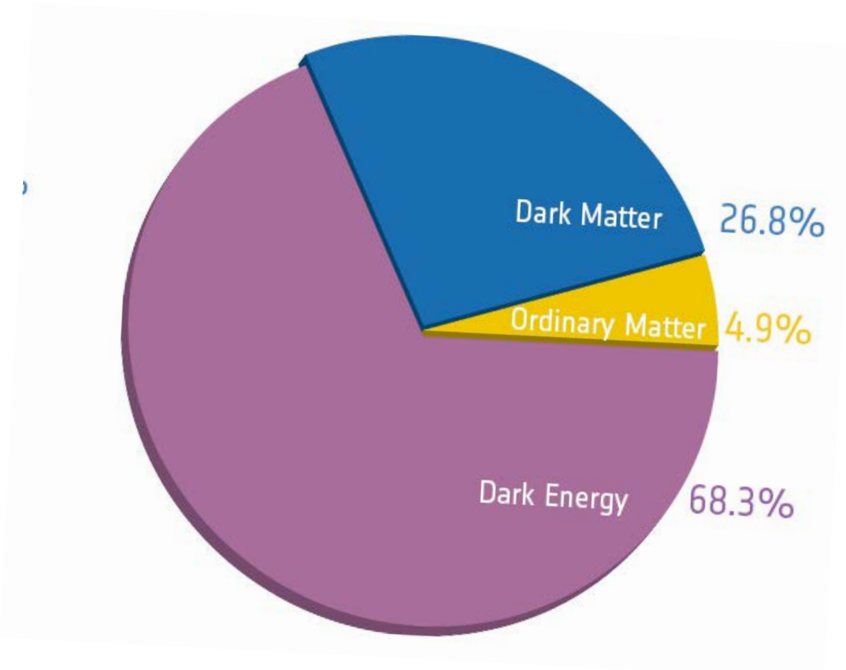
The SM holds !

And is fully constrained



Electroweak Fit

Planck (2013): a summary



The SM tell us about ordinary matter :

- 5%
- Including 0.1% neutrinos ?

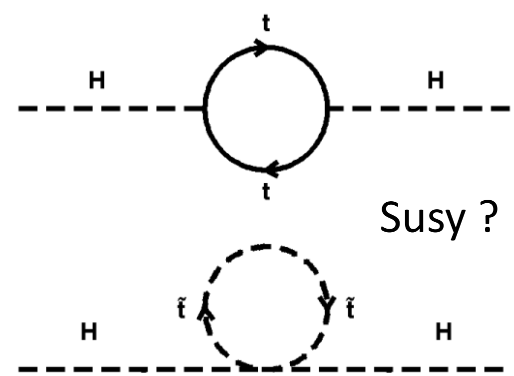
No clue of "what next" :

- Direct searches (√S)
- Precision measurements (L)

ElectroWeak Symmetry Breaking

- Is this really The Higgs boson?
  - Spin & Parity
  - Coupling to fermions
  - Coupling to gauge bosons
  - Higgs potential via triple & quartic H couplings

- Why 126 GeV ?
  - Fine tuning …
  - New physics …
    - Link with Dark Matter.



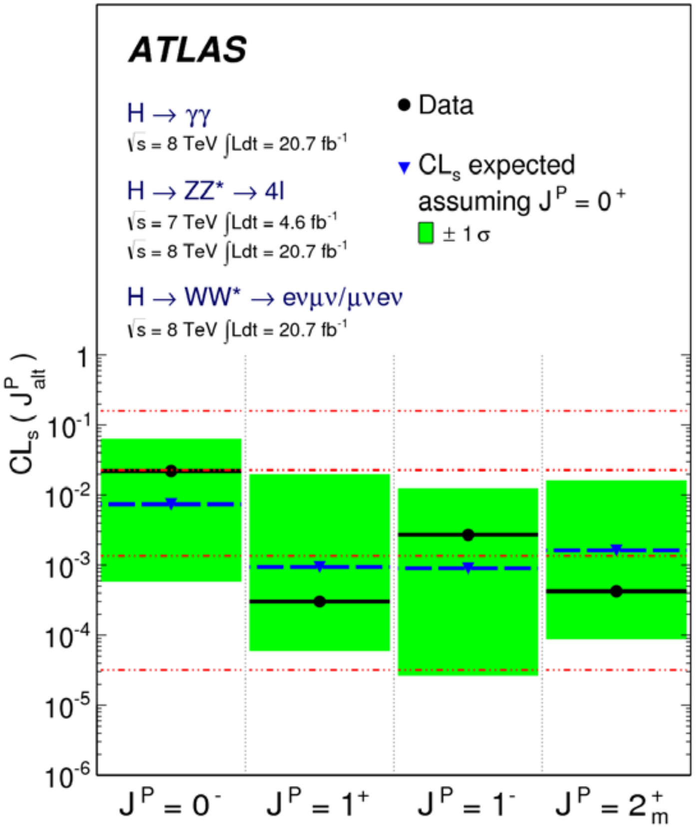
LHC planning

Luminosity

			Luminosity
2009		LHC startup, √s 900 GeV	
2010–2012		√s=7+8 TeV, L~6x10^{33}cm^{-2}s^{-1}, bunch spacing 50ns	Run 1 ~25 fb^{-1}
2013–2014	LS1	Go to design energy, nominal luminosity - Phase 0	
2015–2017		√s=13~14 TeV, L~1x10^{34}cm^{-2}s^{-1}, bunch spacing 25ns	~75-100 fb^{-1}
2018	LS2	Injector + LHC Phase I upgrade to ultimate design luminosity	
2019–2021		√s=14 TeV, L~2x10^{34}cm^{-2}s^{-1}, bunch spacing 25ns	300 fb-1
2022	LS3	HL-LHC Phase II upgrade: Interaction Region, crab cavities?	
2023 … 2030?		√s=14 TeV, L~5x10^{34}cm^{-2}s^{-1}, luminosity levelling	~3000 fb^{-1}

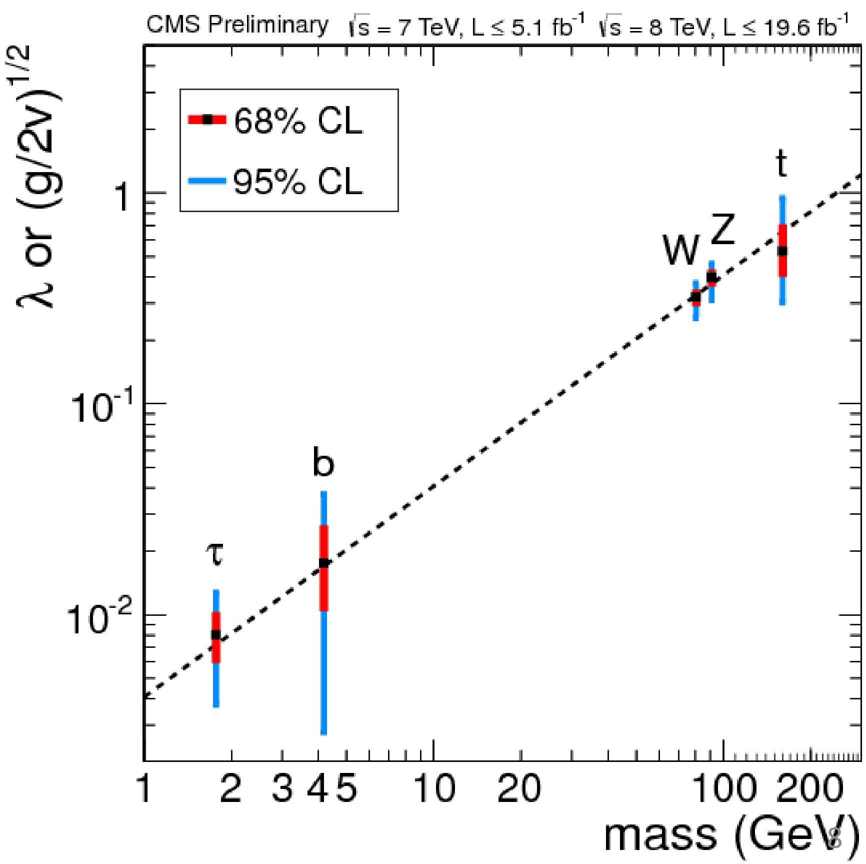
Approved ? → 3000 fb^{-1} / ~10 years (2033)

The new boson behaves like the SM Higgs boson



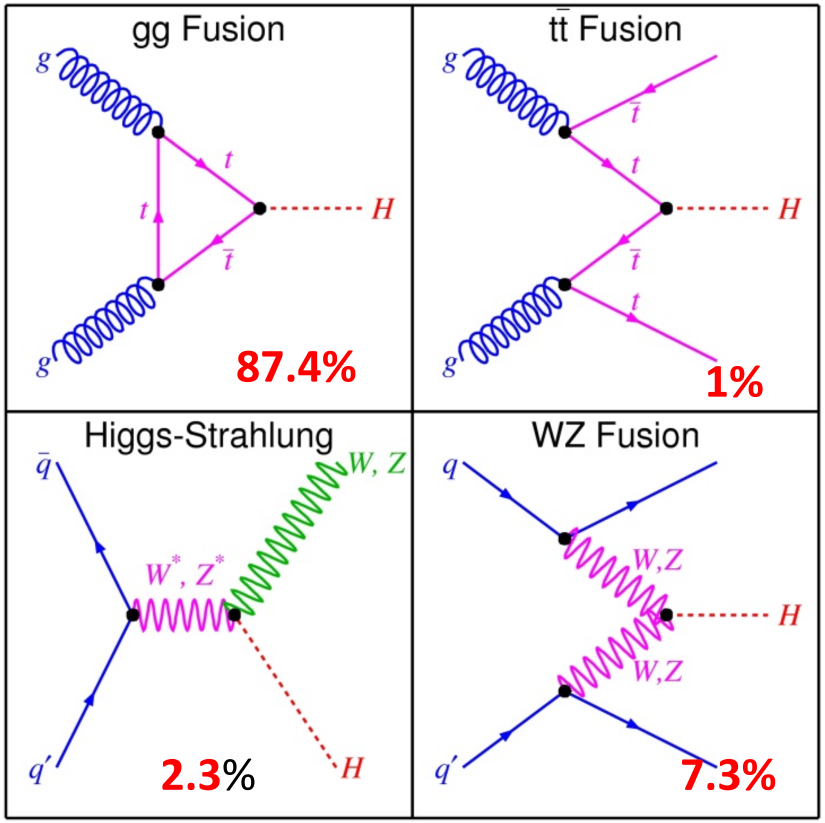
- $J^P = 0^+$
- Other hypothesis excluded by at least 2 sigmas

$$g_{Hf\bar{f}} = \frac{m_f}{v}, \qquad g_{HVV} = \frac{2m_V^2}{v},$$



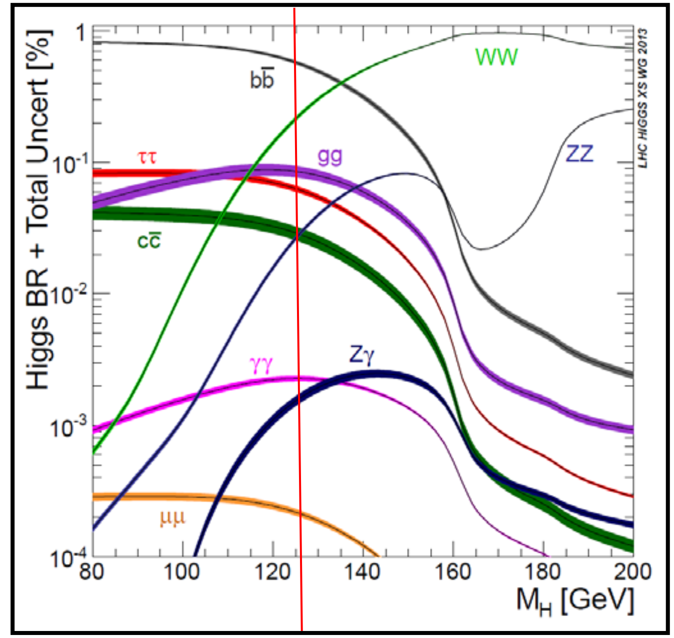
Couplings measurements

Production modes @ LHC (14 TeV) :



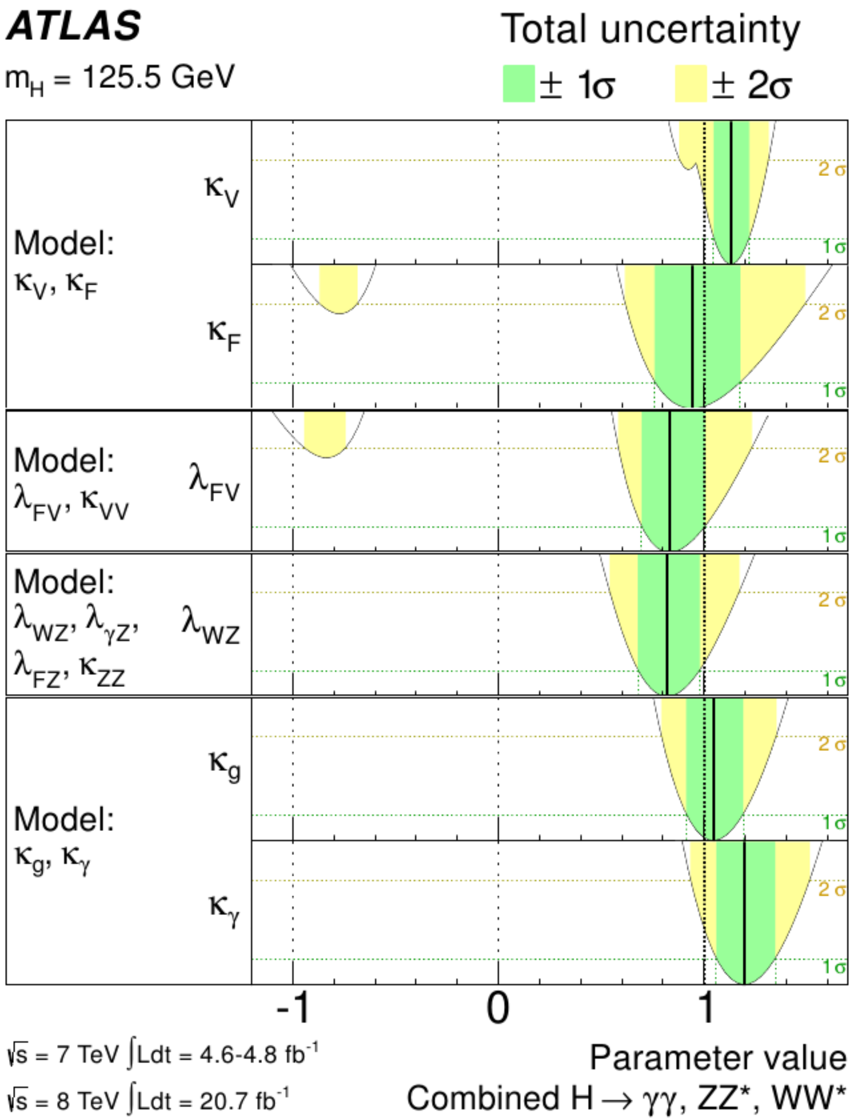
→ Access to the Top quark coupling to H

Decay modes @126 GeV :



%	bb	ττ	cc	μμ	WW	ZZ
	56.7	6.22	2.82	0.02	22.4	2.79
	gg	**γγ**	**Zγ**			
	8.52	0.228	0.159			

Coupling measurement with 25 fb^{-1}



$\kappa_i \equiv g_i / g_{iSM}$

$\lambda_{ij} \equiv \kappa_i / \kappa_j$

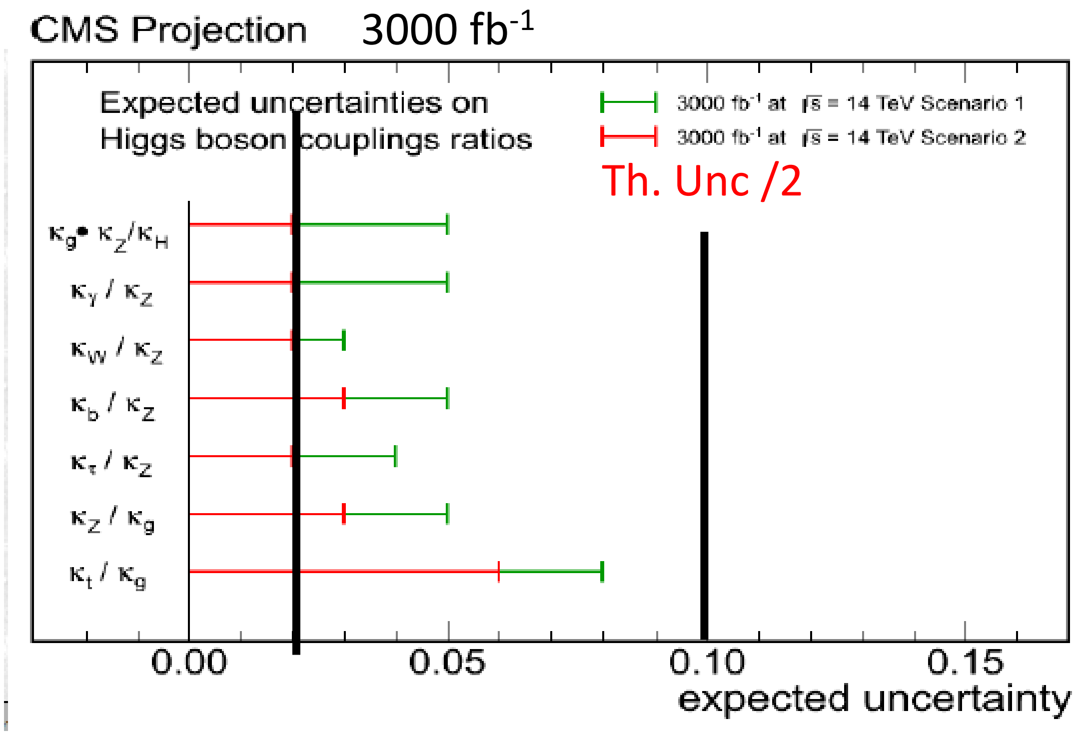
$\kappa_{ij} \equiv \kappa_i . \kappa_j / \kappa_H$

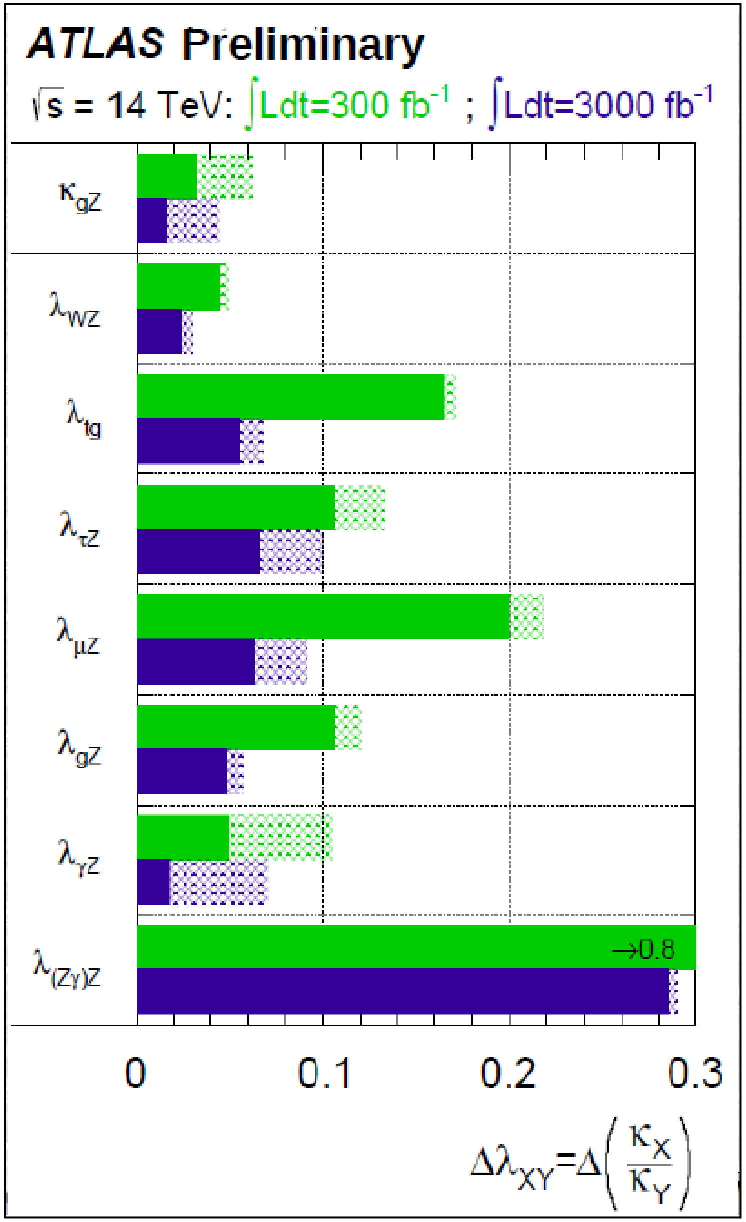
$$\sigma(i \to H).Br(H \to f) \sim (\kappa_i \kappa_f / \kappa_H)^2$$

Current uncertainties : > 20%

Only ratios are accessible at LHC

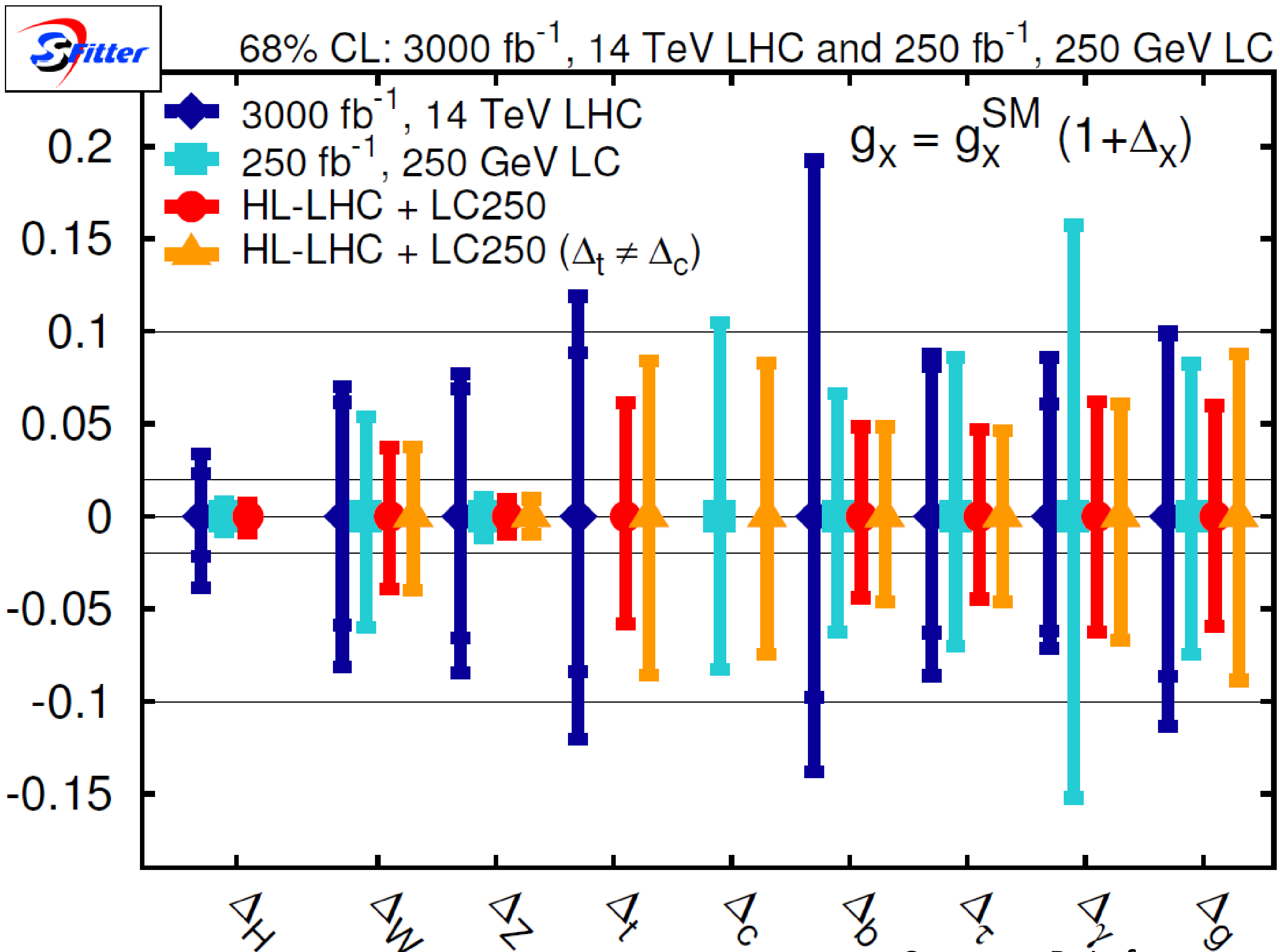
With 300 fb^{-1} and 3000 fb^{-1}





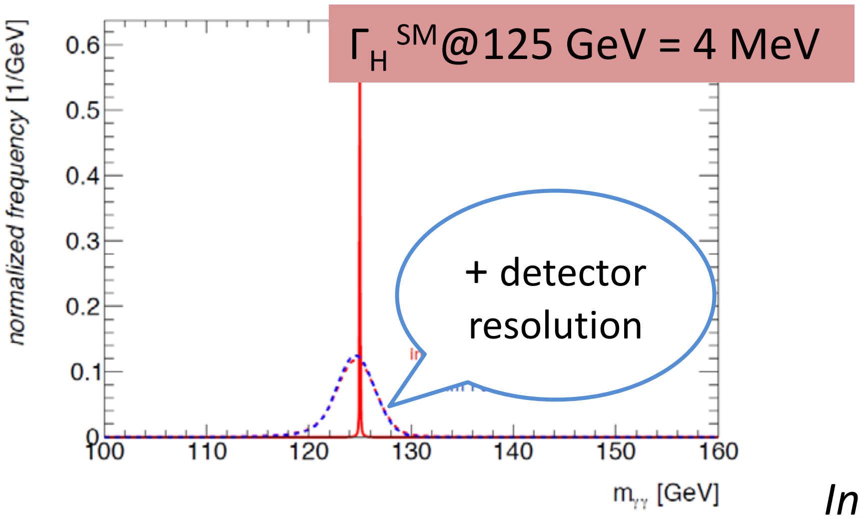
- With 3000 fb^{-1},
  - a factor ~2 improvement is expected .
  - → 2 to 10 %
- Theoretical uncertainties (QCD scale, PDF, higher orders, non perturbative, electroweak)

Projection by an independent group

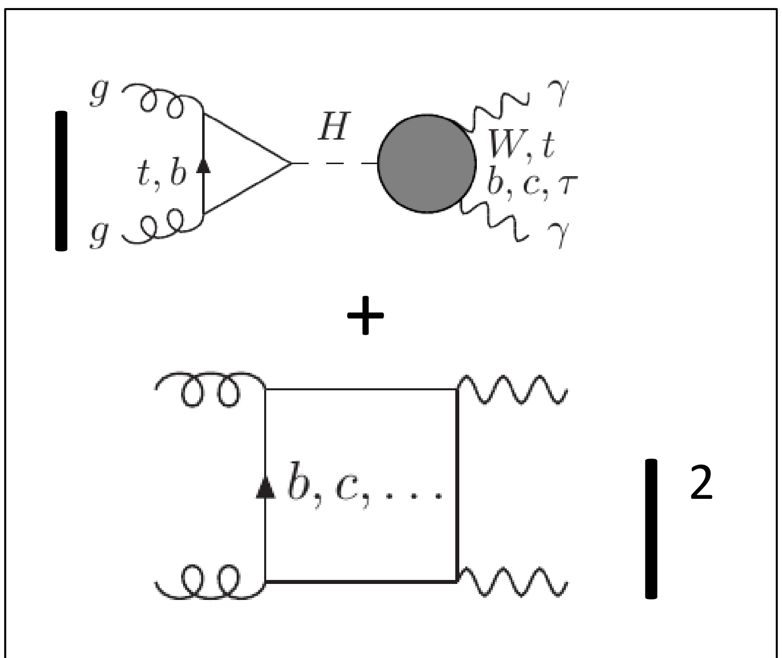


Courtesy R. Lafaye

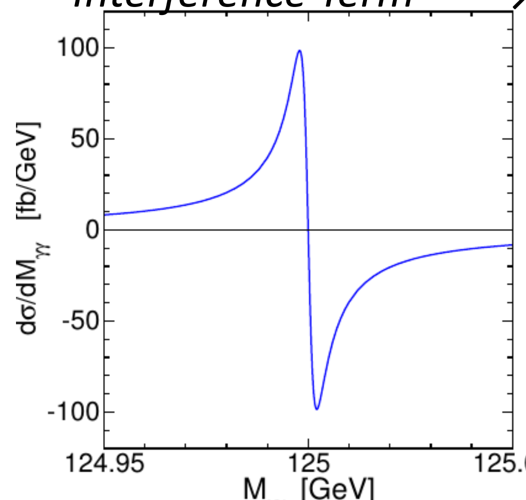
Measuring the Total Width

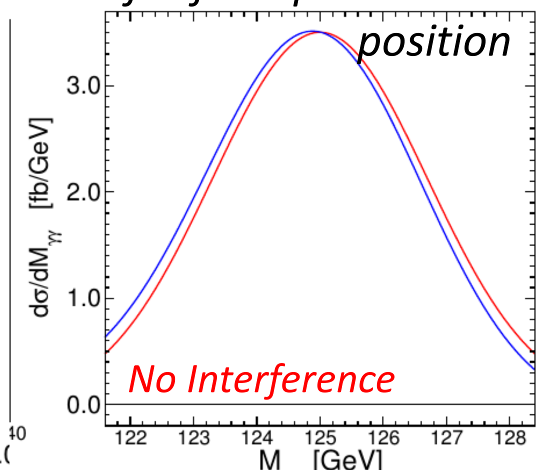


- Direct measurement is limited by the detector resolution.
- Current limits :
  - 6.9GeV (CMS)
- Expected at the end of Run 1 :
  - ~ 2GeV (syst. limited)



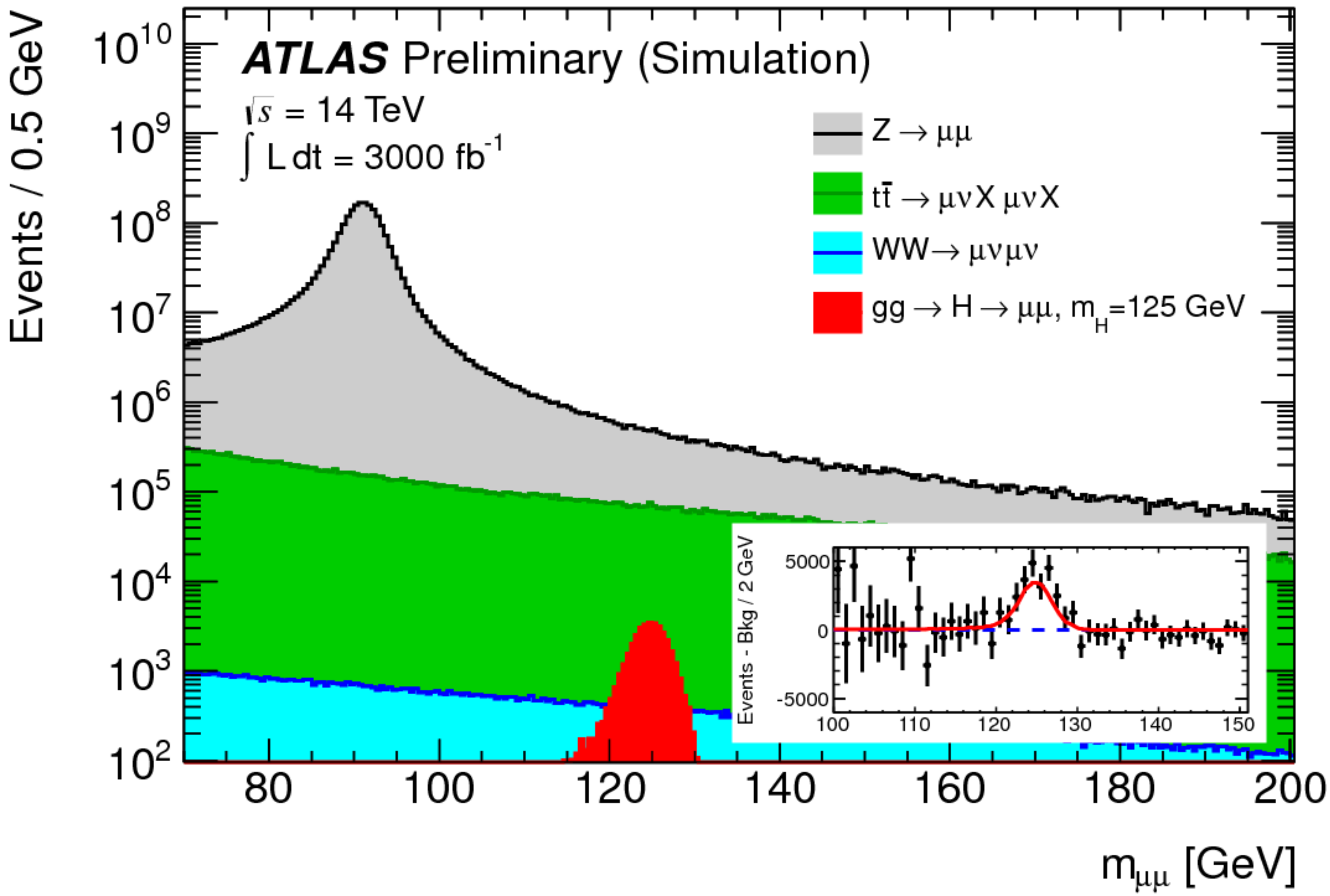
Interference Term → *Shift of the peak position*





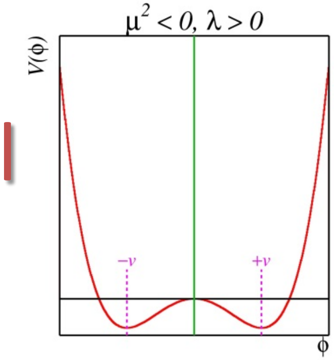
- Expected at the end of Run 2 : ~ 200 to 400 MeV
- Stat. limited.

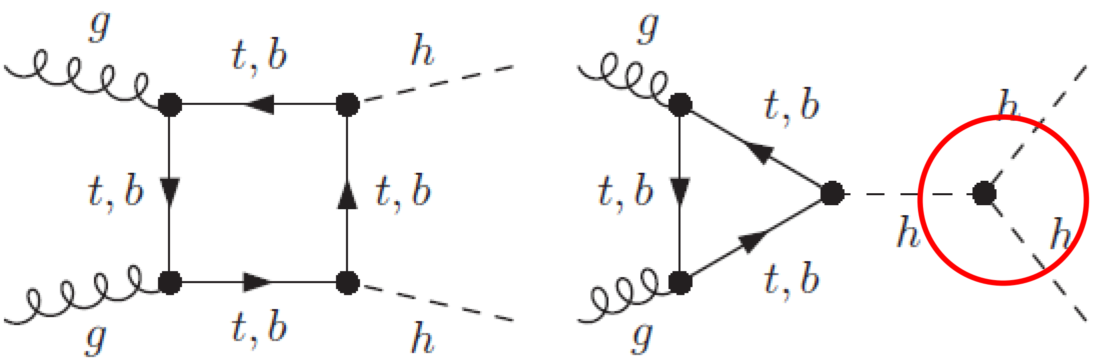
Rare Mode : H →μμ (2nd lepton)



A few thousand events expected with 3000 fb^{-1}

Triple & Quartic H coupling
→ The Higgs Potential





Within SM :

- Difficult, even at ILC/CLIC
- Explored channel:
  - bbγγ
  - bbWW
  - bbττ /bb bb (th. studies)

$\sqrt{S}$ = 14 TeV	gg→H	gg→HH
σ (fb)	49850	33

With 3000 fb^{-1}

30 % ?

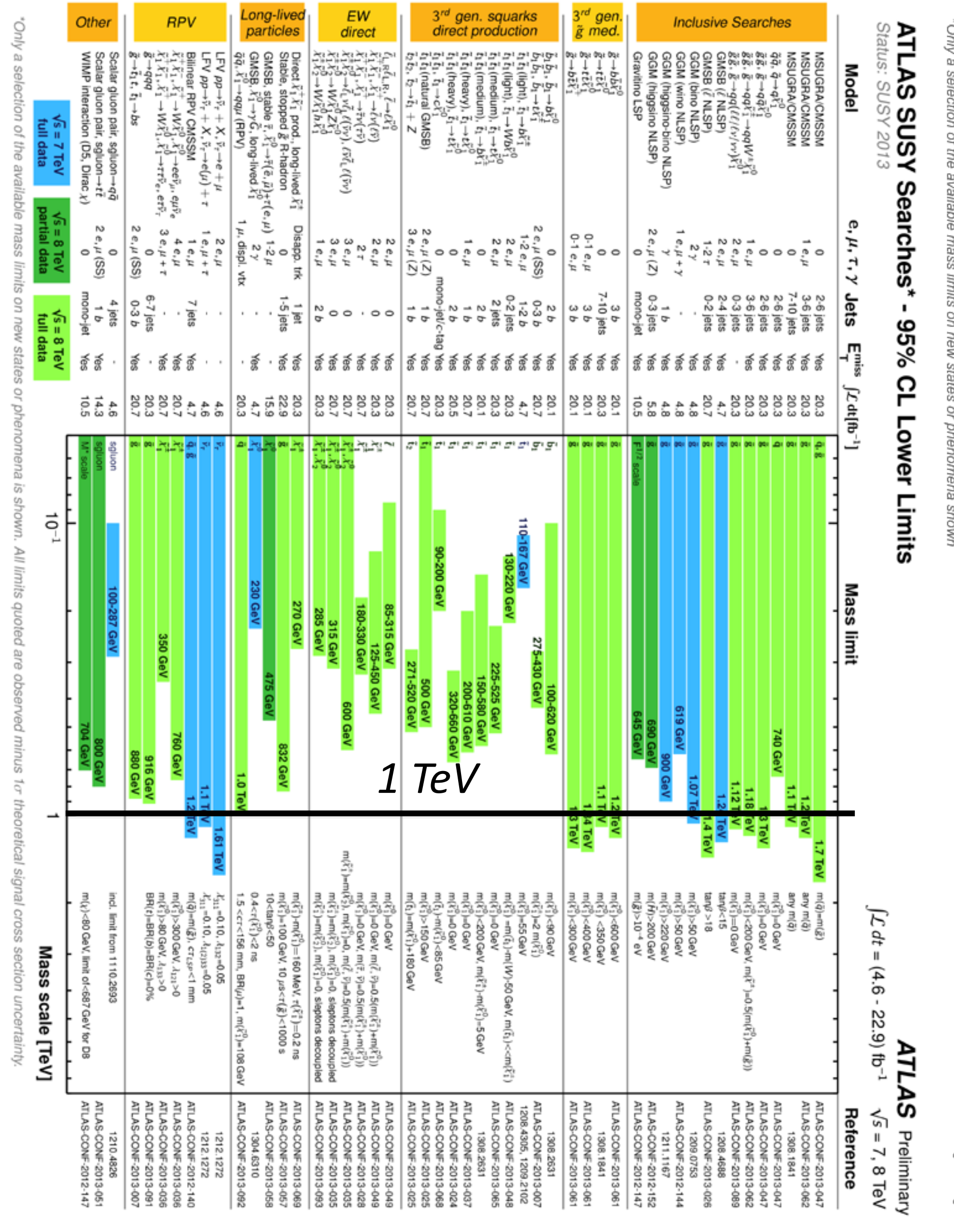
Exploiting the bb final state is a necessity

Beyond the Standard Model

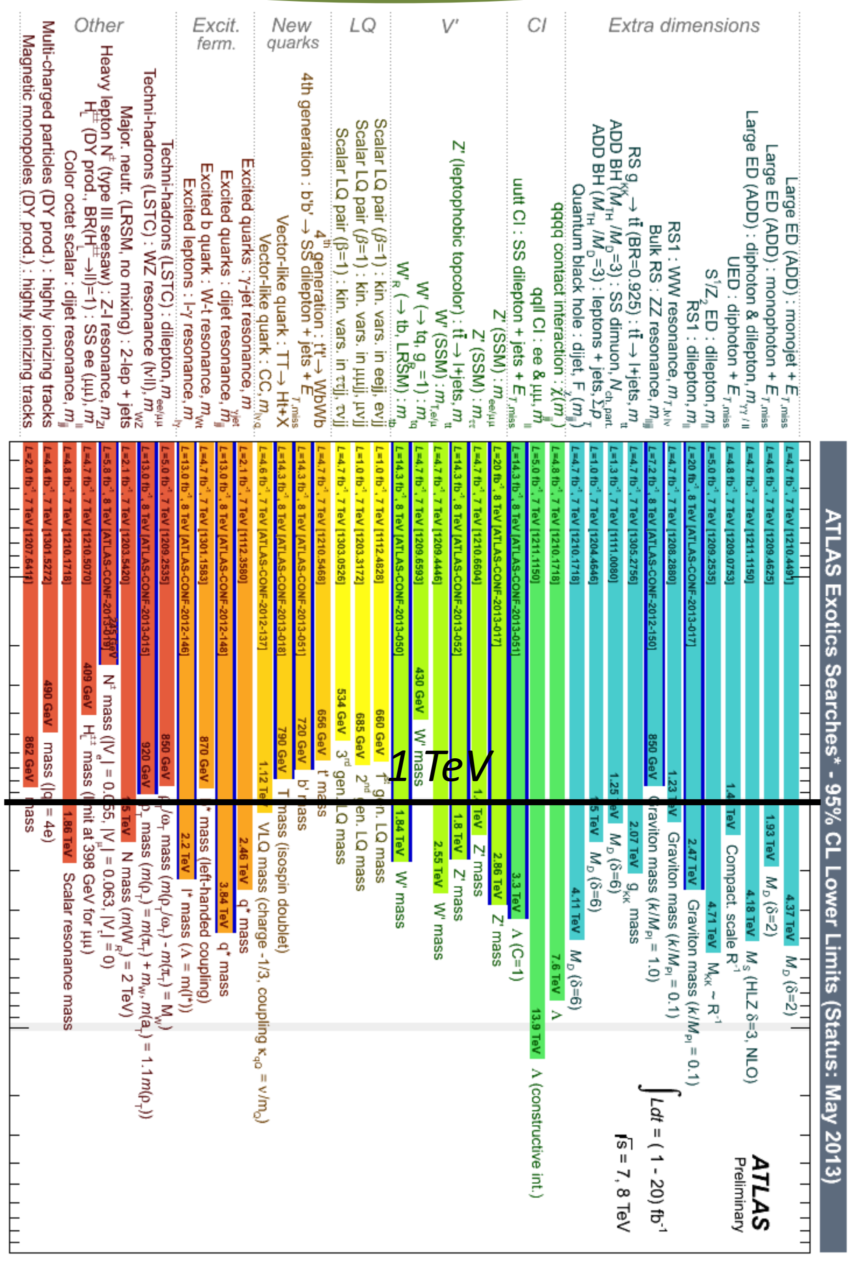
SUperSYmmetry, Compositeness, Extra-dimensions, New Gauge bosons, New families

…

SUSY

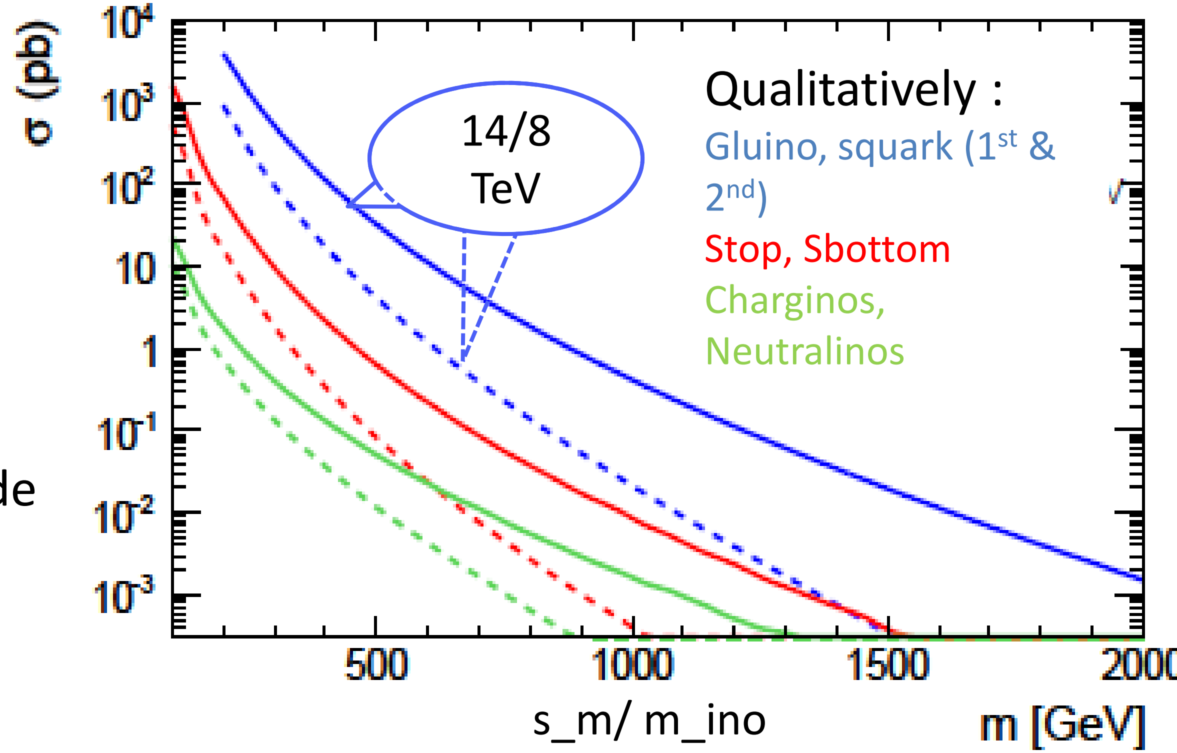


Non – SUSY

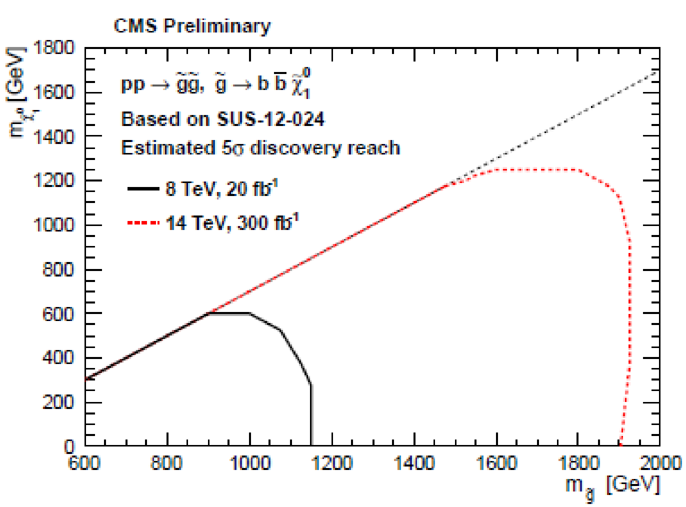


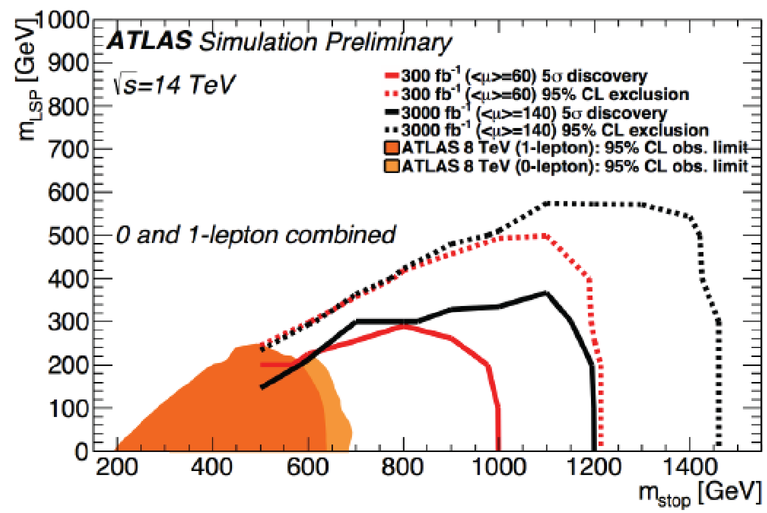
$\sqrt{S}$: 7 TeV → 14 TeV

- A substantial increase of the cross-section
- roughly an order of magnitude



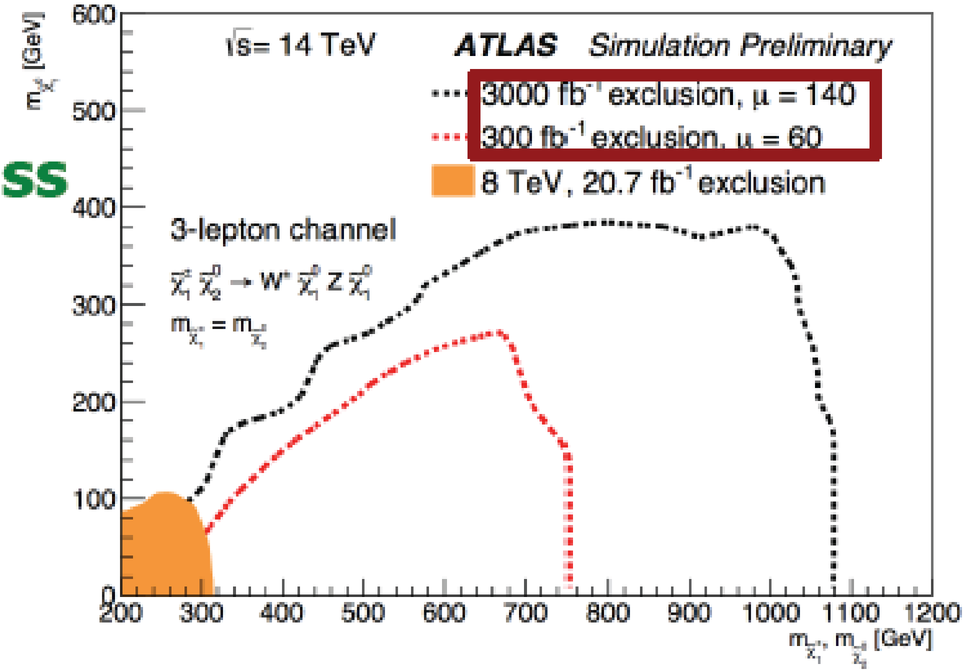
- **Gluino/Squark : ~ 2 TeV**
- **Stop/Sbottom : 800 GeV – 1 TeV**





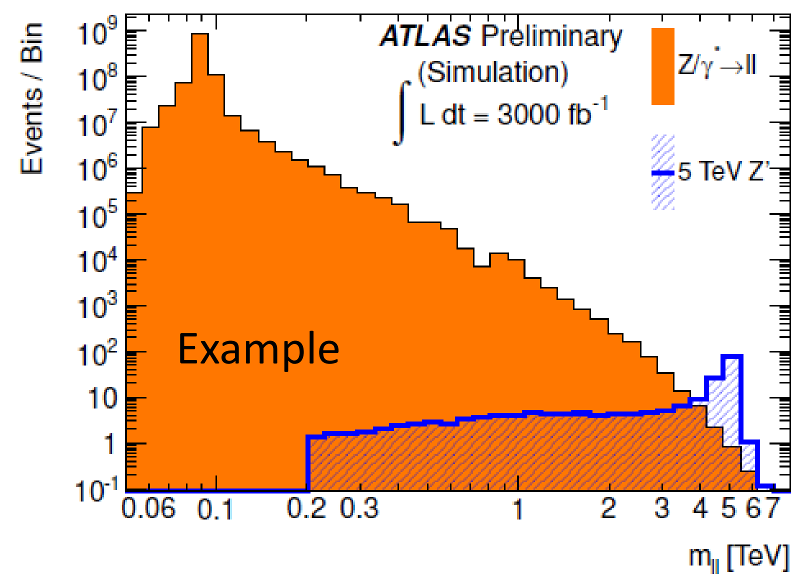
From 300 fb^{-1} to 3000 fb^{-1}

- **Charginos :**
  - **Exclusion to 1 TeV**

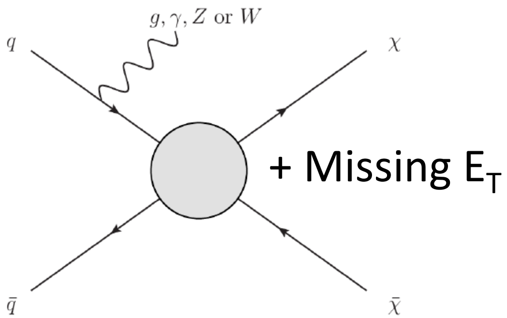


- Improvement of sensitivity by :
  - 400 GeV (squarks, gluinos)
  - 200 GeV (stop, sbottom)
  - 1 TeV (resonances)

model	300 fb^{-1}	1000 fb^{-1}	3000 fb^{-1}
$Z'_{SSM} \to ee$	6.5	7.2	7.8
$Z'_{SSM} \to \mu\mu$	6.4	7.1	7.6

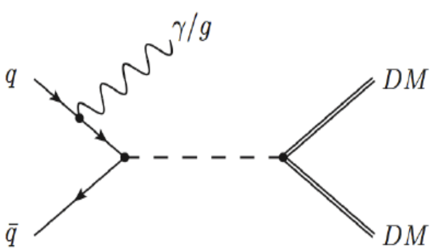


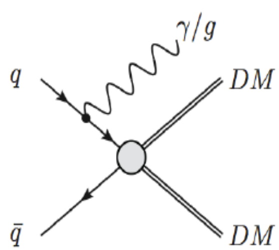
Dark Matter

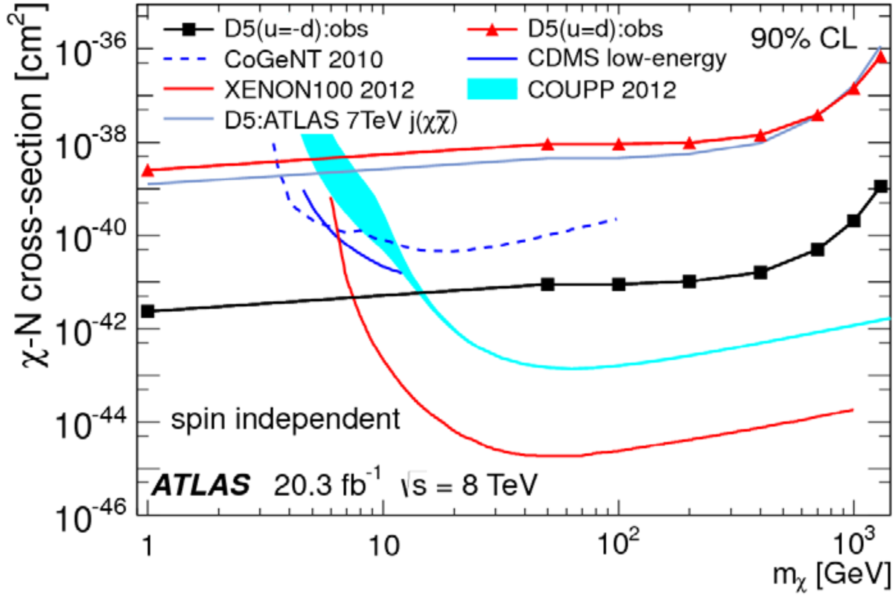


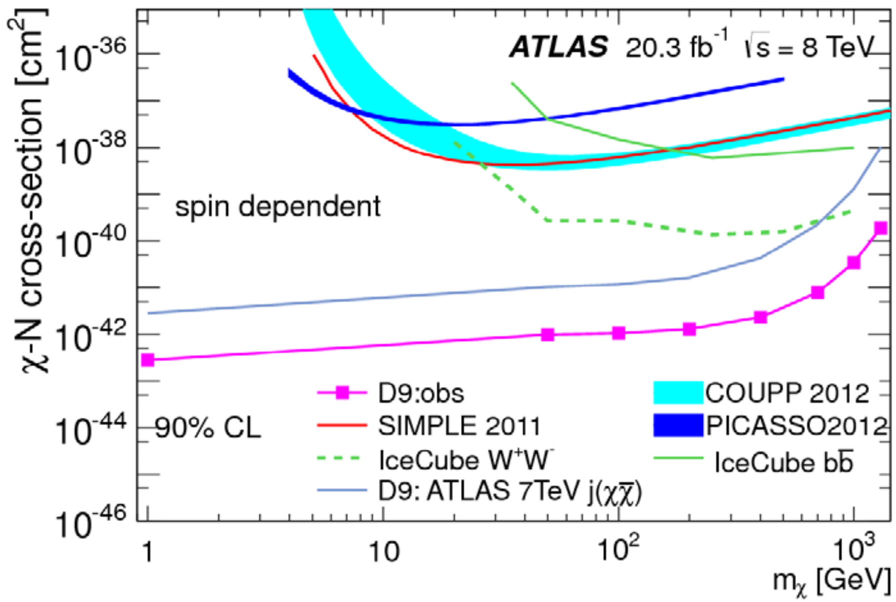
- Effective field theory (EFT) operators
- Competitive limits with direct searches
  - In the low masse range.
  - Spin dependent

- *CAVEAT : EFT may not hold*



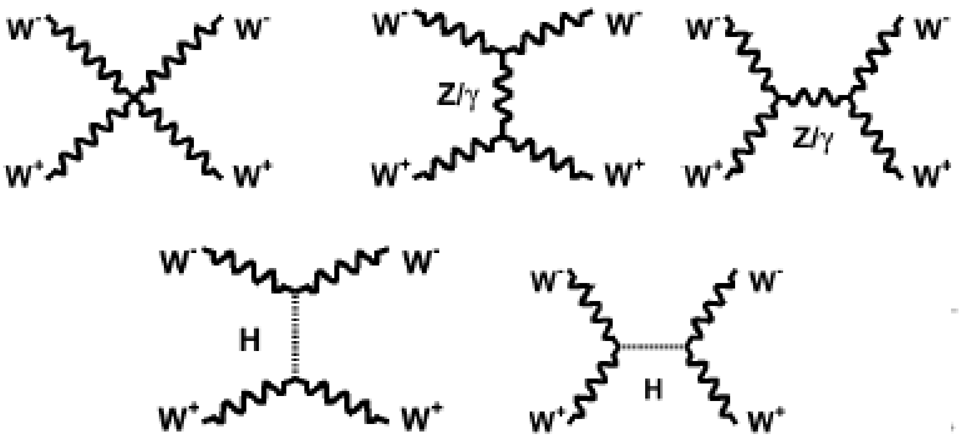






Multi Boson Final States :

Vector Boson Scattering –Triple Gauge Coupling –
Quartic Gauge Coupling

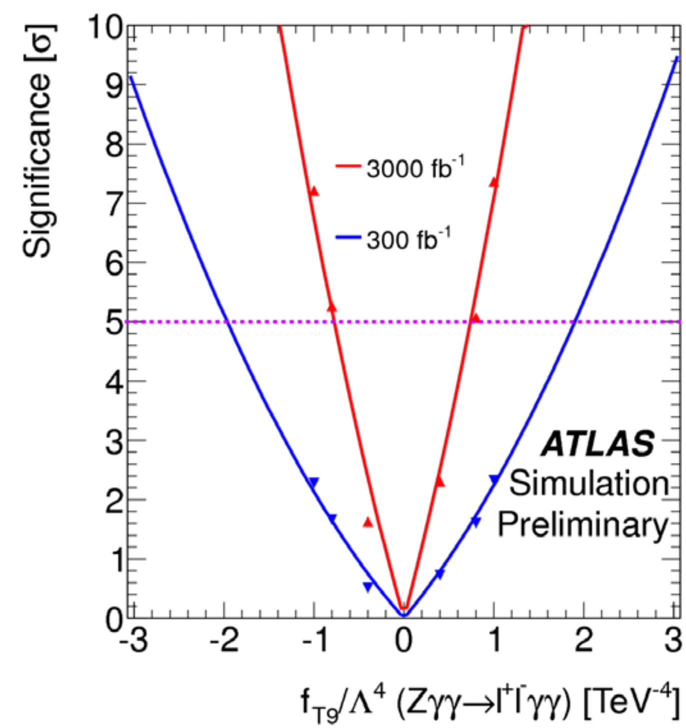


Non Abelian Structure of SM :

- In particular access to QGC

EWSB :

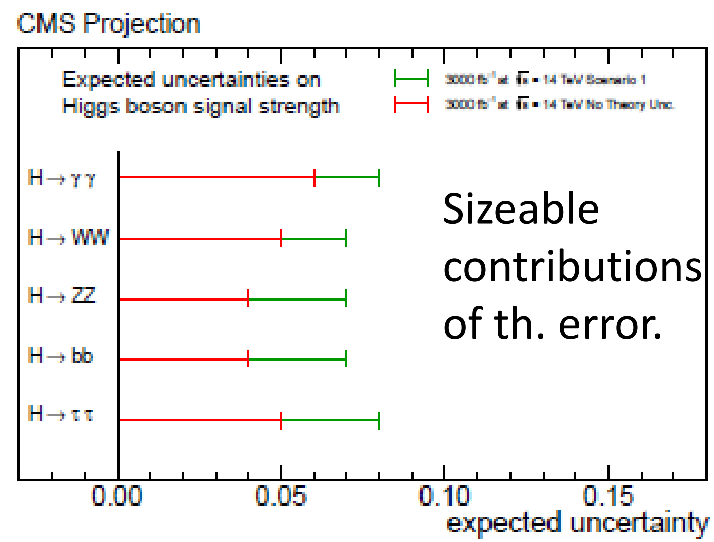
- Does the "Higgs" behave as expected ?



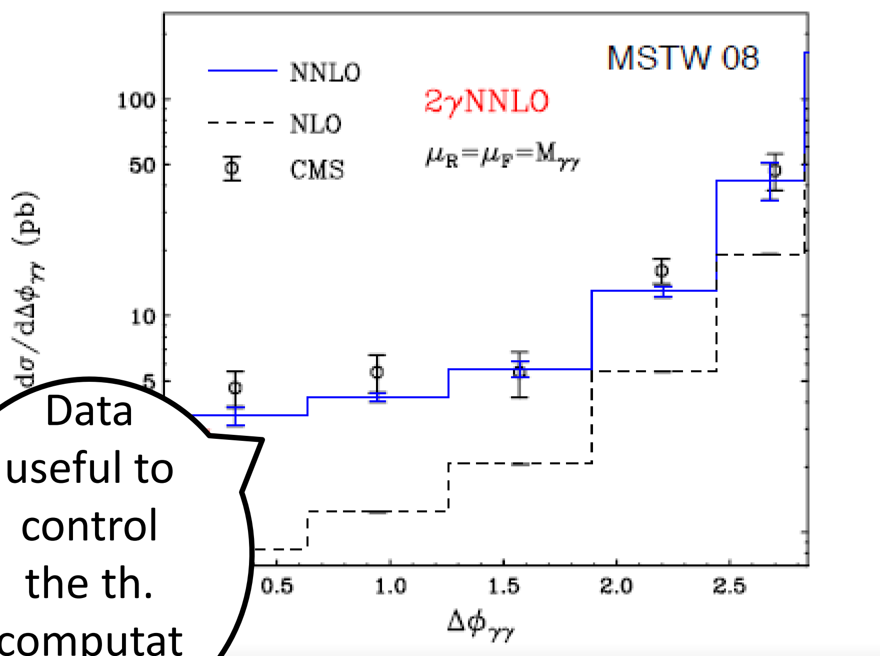
Theoretical Uncertainties and Precision Measurements

Theoretical uncertainties :

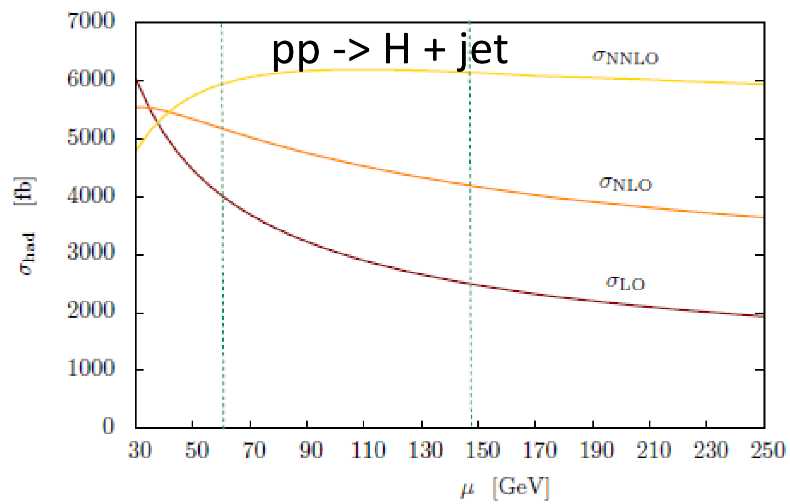
- PDFs, α_S
- Non pertubative computation
- Higher orders
  - NLO done
  - **NNLO is the new frontier …**
- **EW corrections (5%)**



Sizeable contributions of th. error.



Data useful to control the th. computations



→Scale uncertainty reduced from 40% to 4%

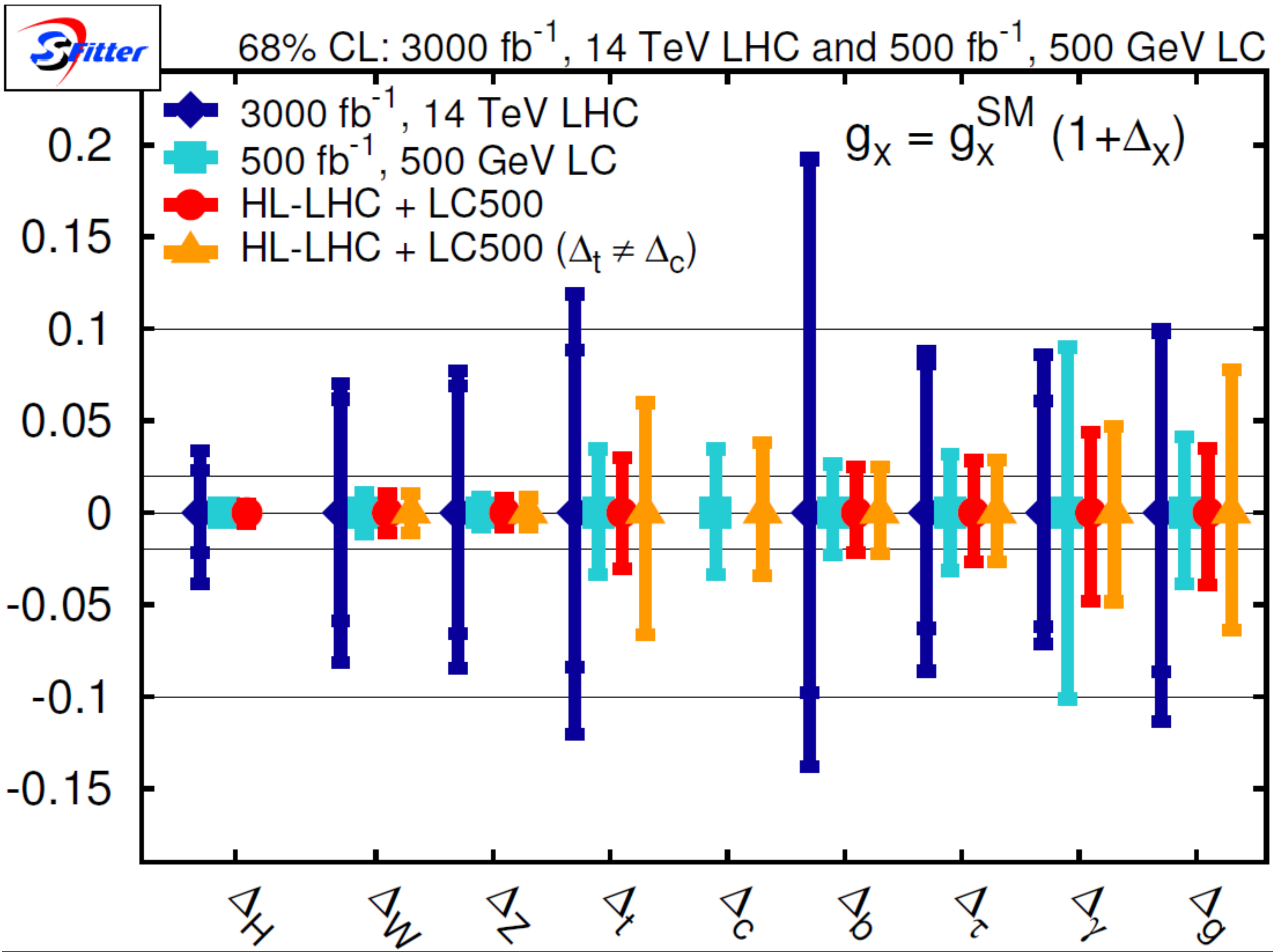
Prospects with 3000 fb^{-1}

- **New discovery / Better limits**

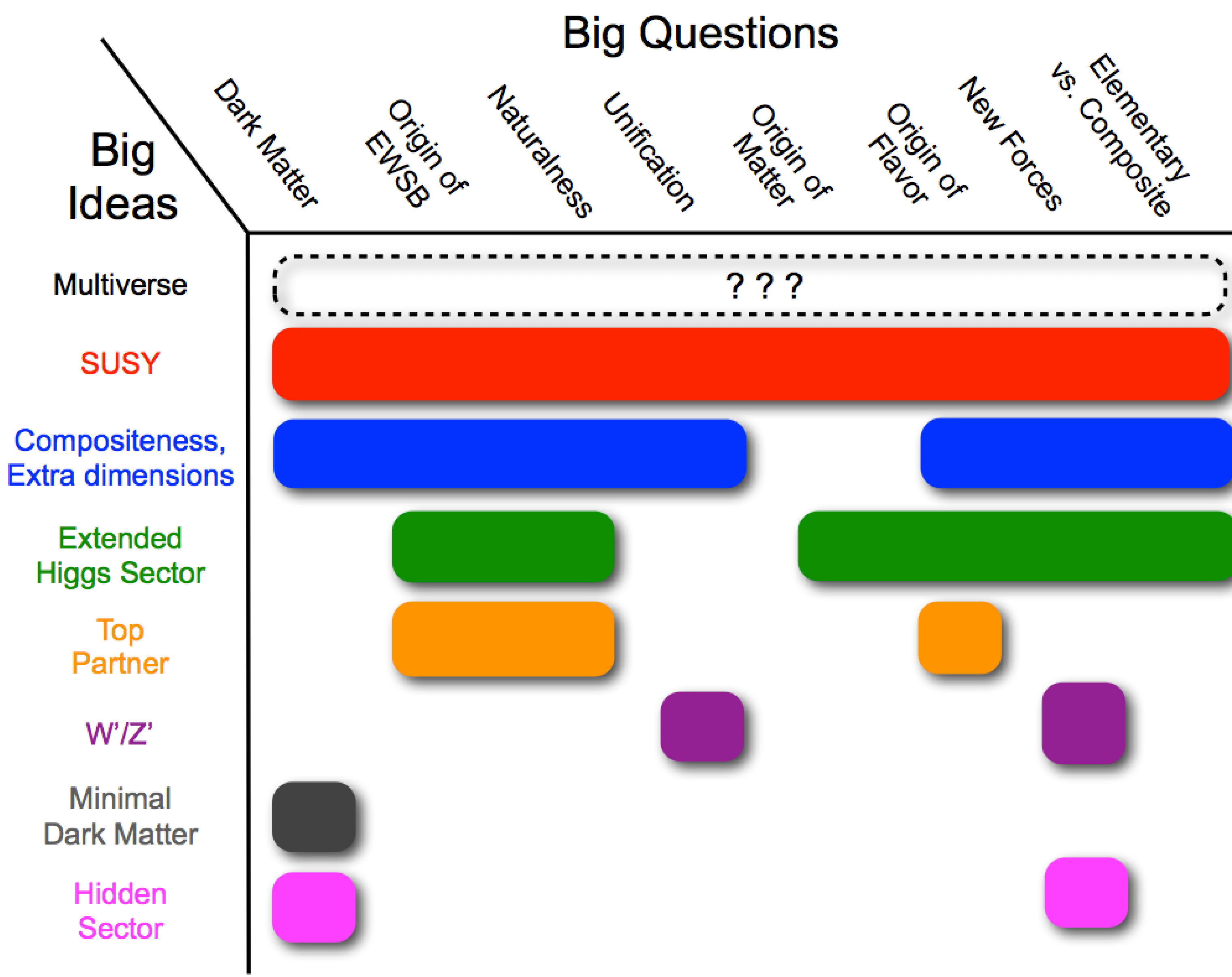
- **Era of precision Higgs physics :**
  - Mass ~ 50 MeV
  - Couplings de 2 a 10% (ratio)
  - Rare decays (Zγ, μμ)
  - Triple H coupling ?
  - Width :
    - Via the interference with bkg graphs in the mode H → γγ
    - Sensitivity : ~400 MeV
      - SM : 4 MeV , current limit ~ 7 GeV

- **Precision SM measurements :**
  - Multi boson phenomenology
  - + $\sin^2(\theta_W)$, M_{Top} , M_W …

To cope with the event rate, event pile-up and radiation level expected in Phase I and II of LHC, it is needed to upgrade the detectors → next talk.

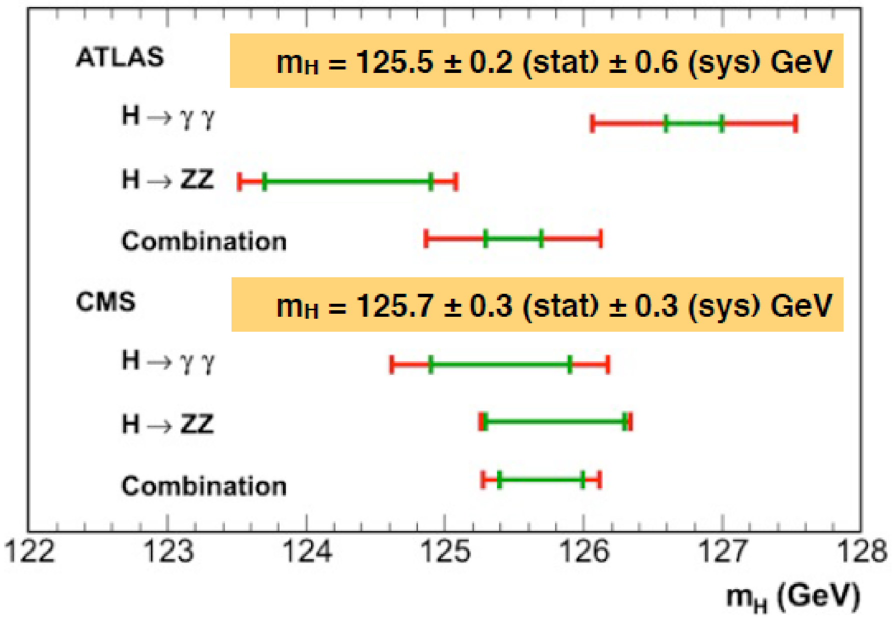


SFitter
68% CL: 3000 fb-1, 14 TeV LHC and 500 fb-1, 500 GeV LC
3000 fb-1, 14 TeV LHC
500 fb-1, 500 GeV LC
HL-LHC + LC500
HL-LHC + LC500 (Δt ≠ Δc)
gx = gxSM (1+Δx)
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
ΔH
ΔW
ΔZ
Δt
Δc
Δb
Δτ
Δγ
Δg


Big Questions
Big Ideas
Dark Matter
Origin of EWSB
Naturalness
Unification
Origin of Matter
Origin of Flavor
New Forces
Elementary vs. Composite
Multiverse
? ? ?
SUSY
Compositeness, Extra dimensions
Extended Higgs Sector
Top Partner
W'/Z'
Minimal Dark Matter
Hidden Sector

Higgs Boson Mass Measurement

High resolution channel H → γγ and H → ZZ* → 4l



ATLAS 115 GeV < m_{4l} < 125 GeV

	total signal full mass range	signal	$ZZ^{(*)}$	$Z + \text{jets}, t\bar{t}$	S/B	expected	observed
4μ	6.8 ± 0.8	6.3 ± 0.8	2.8 ± 0.1	0.55 ± 0.15	1.9	9.6 ± 1.0	13
$2\mu 2e$	3.4 ± 0.5	3.0 ± 0.4	1.4 ± 0.1	1.56 ± 0.33	1.0	6.0 ± 0.8	5
$2e2\mu$	4.7 ± 0.6	4.0 ± 0.5	2.1 ± 0.1	0.55 ± 0.17	1.5	6.6 ± 0.8	8
$4e$	[illegible]	2.6 ± 0.4	1.2 ± 0.1	1.11 ± 0.28	1.1	4.9 ± 0.8	6
total	18.2 ± 2.4	[illegible]5.9 ± 2.1	7.4 ± 0.4	3.74 ± 0.93	1.4	27.1 ± 3.4	32

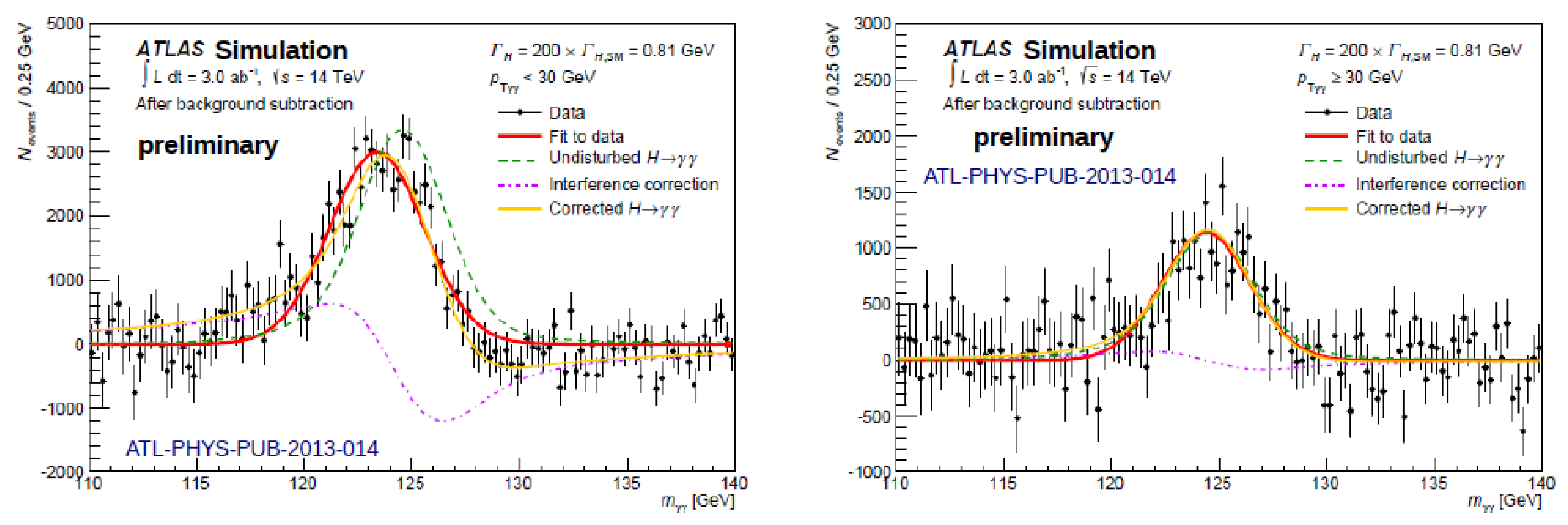
CMS 110 GeV < m_{4l} < 160 GeV

Channel	4e	4μ	$2e2\mu$	4ℓ
ZZ background	6.6 ±0.8	13.8 ±1.0	18.1 ±1.3	38.5 ±1.8
Z+ X	2.5 ± 1.0	1.6 ± 0.6	4.0 ± 1.6	8.1 ±2.0
All background expected	9.1 ± 1.3	15.4 ± 1.2	22.0 ± 2.0	46.5 ±2.7
m_H = 125 GeV	3.5 ±0.5	6.8 ±0.8	8.9 ±1.0	19.2 ±1.4
m_H = 126 GeV	3.9 ±0.6	7.4 ±0.9	9.8 ±1.1	21.1 ±1.5
Observed	16	23	32	71

Δm of 100(50) MeV achievable for 300(3000) fb^{-1}

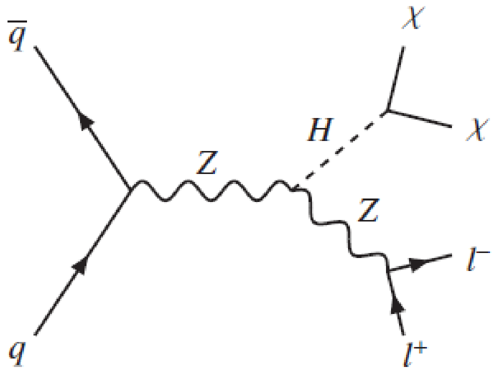
Higgs width in γγ

- Interference depends on s/b & hence p_T
- Compare H→γγ divided at p_T=30GeV

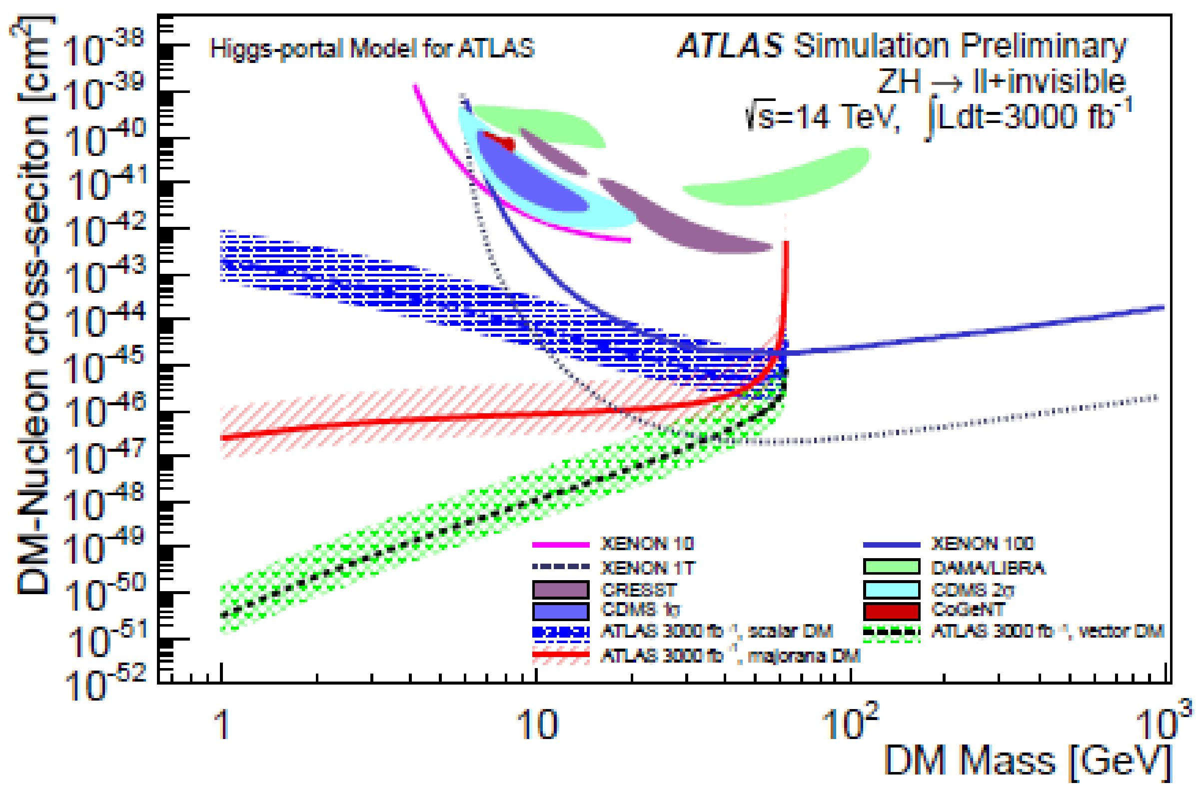


- Comparing peak positions gives sensitivity:
  - Γ_H<920MeV from 300fb^{-1}, 200MeV from 3ab^{-1} (full)
  - Γ_H<880MeV from 300fb^{-1}, 160MeV from 3ab^{-1} (stat)
- Systematic errors not dominating

Another Portal to DM



- From Missing Et distribution
- Sensitivity to Br $_{Inv}$: ~ 10% with 3000 fb^{-1}



Vector Boson Scattering – Summary

- HL-LHC enhances discovery range for new higher-dimension electroweak operators by more than a factor of two

Parameter	dimension	channel	Λ_{UV} [TeV]	300 fb^{-1}		3000 fb^{-1}	
				5σ	95% CL	5σ	95% CL
$c_{\phi W}/\Lambda^2$	6	ZZ	1.9	34 TeV^{-2}	20 TeV^{-2}	16 TeV^{-2}	9.3 TeV^{-2}
f_{S0}/Λ^4	8	$W^\pm W^\pm$	2.0	10 TeV^{-4}	6.8 TeV^{-4}	4.5 TeV^{-4}	0.8 TeV^{-4}
f_{T1}/Λ^4	8	WZ	3.7	1.3 TeV^{-4}	0.7 TeV^{-4}	0.6 TeV^{-4}	0.3 TeV^{-4}
f_{T8}/Λ^4	8	$Z\gamma\gamma$	12	0.9 TeV^{-4}	0.5 TeV^{-4}	0.4 TeV^{-4}	0.2 TeV^{-4}
f_{T9}/Λ^4	8	$Z\gamma\gamma$	13	2.0 TeV^{-4}	0.9 TeV^{-4}	0.7 TeV^{-4}	0.3 TeV^{-4}

Λ_{UV}: unitarity violation bound corresponding to the sensitivity with 3000 fb^{-1}

SM discovery expected with 185 fb^{-1}

BSM contribution at TeV Scale might be observed at 300 fb^{-1}!

If BSM discovered in 300 fb^{-1} dataset, then the coefficients on the new operators could be measured to 5% precision with 3000 fb^{-1}