



# Is Nature Standard like the Model? Experimental results on SM and Higgs physics

19th April 2017

Andrea Massironi (Northeastern University) on behalf of the CMS and ATLAS collaborations

XVI Incontri di Fisica delle Alte Energie



April 2017

### Is Nature Standard like the Model?



### CMS Preliminary



19th April 2017

A. Massironi (Northeastern University)



April 2017



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<sup>19</sup>th April 2017

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- Many new results at 7/8/13 TeV from ATLAS and CMS
- How we usually proceed:





- Many new results at 7/8/13 TeV from ATLAS and CMS
- How we usually proceed:
  - Inclusive cross section

 $DATA = \sigma \times \int Luminosity$ 





### ... one step more

160

140

120

100

80

60

ATLAS s = 7 TeV, 4.6 fb

 Data ★ ABM12

🛟 CT14

HERAPDF2.0

da/d|y<sub>"</sub>| [pb]

7

STDM-2012-20



 $Z/\gamma^* \rightarrow I^+I^-$ 

p<sub>\_1</sub> > 20 GeV |η| < 2.5

66 < m<sub>u</sub> < 116 GeV

- Many new results at 7/8/13 TeV from ATLAS and CMS
- How we usually proceed:
  - Inclusive cross section ۲
  - Fiducial and differential cross section ۲

#### W



650



## Looking for the unknown







## Improving the precision

CMS

- Many new results at 7/8/13 TeV from ATLAS and CMS
- How we usually proceed:
  - Inclusive cross section
  - Fiducial and differential cross section
  - High energy regimes for anomalous couplings
  - If limited by systematics, ratio measurements to reduce systematic uncertainties







• Precise knowledge of Standard Model processes essential for modeling of backgrounds for new physics:

- W, Z, WW,  $\dots \rightarrow$  background for Higgs searches
- W, Z, ..., Higgs,  $\dots \rightarrow$  background for new physics
- Improvements in the ingredients for new physics
  - e.g. PDF knowledge from collider data  $\rightarrow$  positive feedback from jets,vector boson(s), ...

measurements





### **News from CMS and ATLAS**









- Since 2015 we are taking data at 13 TeV of center of mass energy
- Higher instantaneous luminosity  $\rightarrow$  higher pileup  $\rightarrow$  challenging environment







•  $Z \rightarrow \mu\mu$  and  $Z \rightarrow ee$ 

• Standard model *candle*: used for tag & probe, precision measurement, modeling for high energy resonances decaying into 2 leptons

•  $\sigma_{z \to II} \sim 6 \text{ nb}$  @ 13 TeV







## **Single Vector Boson production: W**







## Single Vector Boson production vs $\sqrt{s}$



















19th April 2017





- Clear signature  $\rightarrow$  e.g. 3 leptons
- High signal / background ratio
- $\sigma_{WZ \rightarrow 3lv} \sim 5 \text{ pb}$  @ 13 TeV



STDM-2015-19



SMP-16-002







- Both fully leptonic (2 neutrinos) and semi-leptonic decays considered
  - Good description of backgrounds essential for measurement
  - Usually 0-jet category to suppress tt contamination
- $\sigma_{WW \rightarrow lvlv} \sim 12 \text{ pb}$  @ 13 TeV













## Anomalous gauge couplings



√s

7 TeV

8 TeV

8 TeV

7,8 TeV

7,8 TeV

13 TeV

7 TeV

7 TeV

8 TeV

8 TeV

7,8 TeV

7,8 TeV

13 TeV

7 TeV

7 TeV

8 TeV

8 TeV

7.8 TeV

7,8 TeV

13 TeV

7 TeV

7 TeV

8 TeV

8 TeV

7,8 TeV

7,8 TeV

13 TeV

7 TeV

March 2017	CMS Central ATLAS Fit Value D0	Channel	l imits	ĺ/dt		March 2017	CMS ATLAS
			[-4 1e-01 4 6e-01]	4.6 fb <sup>-1</sup>	7 TeV	τγ	ATLAS+CMS
$\Delta \kappa_{\gamma}$		Wy	[-3.8e-01, 2.9e-01]	5.0 fb <sup>-1</sup>	7 TeV	1 <sub>4</sub>	·
		, 	[-1.2e-01, 1.7e-01]	20.3 fb <sup>-1</sup>	8 TeV		
		W/W	[-2.1e-01, 2.2e-01]	4.9 fb <sup>-1</sup>	7 TeV		i i i i i i i i i i i i i i i i i i i
	· · ·	\\\\\\	[-1.3e-01, 9.5e-02]	19.4 fb <sup>-1</sup>	8 TeV		, H
	· · ·	W/V/	[-2 1e-01 2 2e-01]	4.6 fb <sup>-1</sup>	7 TeV	٢Z	
	· · · ·	WV V	[-1 1e-01 1 4e-01]	5.0 fb <sup>-1</sup>	7 TeV	$I_{4}$	· · · · · · · · · · · · · · · · · · ·
	· '	VV V \\\\\\	[-4.4e-02.6.3e-02]	10 fb <sup>-1</sup>	8 TeV		
	· · · · ·	DO Comb	[-1.60-01, 2.50-01]	0.6 fb <sup>-1</sup>	1 96 TeV		
		LEB Comb	[-9.90-02.660-02]	0.0 ID	0.20 TeV		н
		LEF Comb.	[-6.50-02, 6.10-02]	0.7 ID	7 ToV	ñ	
$\lambda_{\gamma}$		VV y	[-0.5e-02, 0.1e-02]	4.0 ID		f <sub>5</sub>	·
		ννγ	[-5.00-02, 3.70-02]	5.0 fD			H
	Η	VVVV	[-1.9e-02, 1.9e-02]	20.3 fb			
		WW	[-4.8e-02, 4.8e-02]	4.9 fb			і ні
	let	WW	[-2.4e-02, 2.4e-02]	19.4 fb <sup>-</sup>	8 lev	7	
	H	WV	[-3.9e-02, 4.0e-02]	4.6 fb <sup>-1</sup>	7 TeV	$f_5^2$	
	H	WV	[-3.8e-02, 3.0e-02]	5.0 fb <sup>-1</sup>	7 TeV		· · ·
	н	WV	[-1.1e-02, 1.1e-02]	19 fb <sup>-1</sup>	8 TeV		H
	⊢●┥	D0 Comb.	[-3.6e-02, 4.4e-02]	8.6 fb <sup>-1</sup>	1.96 TeV		
	+++	LEP Comb.	[-5.9e-02, 1.7e-02]	0.7 fb <sup>-1</sup>	0.20 TeV		
_	0.5 0	0.5	1	1.5		-0.02	0
			aTGC Lir	nits @9	5% C.L.		



Channel

ZZ (4I,2I2v)

ZZ (41,212v)

ZZ (4I)

ZZ (4I)

ZZ (4I)

ZZ (4I)

ZZ (4I)

ZZ(2l2v)

ZZ (4I)

ZZ (4I)

ZZ (4I)

ZZ (2l2v)

ZZ (41,212v)

ZZ (4I,2I2v)

ZZ(41,212v)

ZZ (4I,2I2v)

ZZ (41,212v)

ZZ (4I,2I2v)

ZZ (2l2v)

ZZ (41,212v)

ZZ (41,212v)

ZZ (4I,2I2v)

ZZ (41,212v)

ZZ (2l2v)

ZZ (4I,2I2v)

ZZ (41,212v)

ZZ (4I,2I2v)

ZZ (41,212v)

Limits

[-1.5e-02, 1.5e-02]

[-3.8e-03, 3.8e-03]

[-5.0e-03, 5.0e-03]

[-3.6e-03, 3.2e-03]

[-3.0e-03, 2.6e-03

[-1.3e-03, 1.3e-03]

[-1.0e-02, 1.0e-02]

[-1.3e-02, 1.3e-02]

[-3.3e-03, 3.2e-03]

[-4.0e-03, 4.0e-03

[-2.7e-03, 3.2e-03

[-2.1e-03, 2.6e-03]

[-1.2e-03, 1.1e-03

[-8.7e-03, 9.1e-03

[-1.6e-02, 1.5e-02]

[-3.8e-03, 3.8e-03]

[-5.0e-03, 5.0e-03]

[-3.3e-03, 3.6e-03]

[-2.6e-03, 2.7e-03]

[-1.2e-03, 1.3e-03]

[-1.1e-02, 1.1e-02]

[-1.3e-02, 1.3e-02]

[-3.3e-03, 3.3e-03]

[-4.0e-03, 4.0e-03]

[-2.9e-03, 3.0e-03]

[-2.2e-03, 2.3e-03]

[-1.0e-03, 1.2e-03]

[-9.1e-03, 8.9e-03]

[Ldt

4.6 fb

20.3 fb<sup>-1</sup>

19.6 fb<sup>-1</sup>

24.7 fb

24.7 fb<sup>-1</sup>

35.9 fb<sup>-1</sup>

9.6 fb<sup>-1</sup>

4.6 fb<sup>-</sup>

20.3 fb<sup>-1</sup>

19.6 fb<sup>-1</sup>

24.7 fb<sup>-1</sup>

24.7 fb<sup>-1</sup>

35.9 fb<sup>-1</sup>

9.6 fb<sup>-1</sup>

4.6 fb

20.3 fb<sup>-1</sup>

19.6 fb<sup>-1</sup>

24.7 fb

24.7 fb

35.9 fb<sup>-1</sup>

9.6 fb<sup>-</sup>

4.6 fb<sup>-1</sup>

20.3 fb<sup>-1</sup>

19.6 fb<sup>-1</sup>

24.7 fb

24.7 fb<sup>-1</sup>

35.9 fb<sup>-1</sup>

9.6 fb<sup>-1</sup>

- Charged Anomalous Triple Gauge Couplings
- Neutral Anomalous Triple Gauge Couplings
- Anomalous Quartic Gauge Couplings





Standa	rd Model Total Produ	ction Cross S	ection Measur	ements March 2017	∫£ dt [fb <sup>−1</sup> ]	Reference
nn	$\sigma = 96.07 \pm 0.18 \pm 0.91 \text{ mb (data)}$ COMPETE HPR1R2 (theory)		Δ		50×10 <sup>-8</sup>	PLB 761 (2016) 158
PP	$\sigma = 95.35 \pm 0.38 \pm 1.3$ mb (data) COMPETE HPR1B2 (theory)		0	•	8×10 <sup>-8</sup>	Nucl. Phys. B, 486-548 (201
۱۸/	$\sigma = 190.1 \pm 0.2 \pm 6.4 \text{ nb (data)}$ DYNNLO + CT14NNLO (theory)		¢		0.081	PLB 759 (2016) 601
vv	$\sigma = 98.71 \pm 0.028 \pm 2.191 \text{ nb (data)}$ DYNNLO + CT14NNLO (theory)		0	•	4.6	arXiv:1612.03016 [hep-ex]
	$\sigma = 58.43 \pm 0.03 \pm 1.66$ nb (data) DYNNLO+CT14 NNLO (theory)		¢	Þ	3.2	JHEP 02 (2017) 117
Z	$\sigma = 34.24 \pm 0.03 \pm 0.92 \text{ nb (data)}$ DYNNLO+CT14 NNLO (theory)		Δ		20.2	JHEP 02 (2017) 117
	$\sigma = 29.53 \pm 0.03 \pm 0.77 \text{ nb (data)}$ DYNNLO+CT14 NNLO (theory)		0	o	4.6	JHEP 02 (2017) 117
	$\sigma = 818 \pm 8 \pm 35 \text{ pb (data)}$ top++ NNLO+NLL (theory)	¢		0	3.2	PLB 761 (2016) 136
tĪ	$\sigma = 242.9 \pm 1.7 \pm 8.6 \text{ pb (data)}$	Ą			20.2	EPJC 74: 3109 (2014)
	$\sigma = 182.9 \pm 3.1 \pm 6.4 \text{ pb (data)}$	0		•	4.6	EPJC 74: 3109 (2014)
	$\sigma = 247 \pm 6 \pm 46 \text{ pb (data)}$ NLQ+NLL (theory)	0			3.2	arXiv:1609.03920 [hep-ex]
t <sub>t-chan</sub>	$\sigma = 89.6 \pm 1.7 + 7.2 - 6.4 \text{ pb} (data)$ NLO+NL (theory)	4			20.3	arXiv:1702.02859 [hep-ex]
	$\sigma = 68 \pm 2 \pm 8 \text{ pb (data)}$	0			4.6	PRD 90, 112006 (2014)
	$\sigma = 142 \pm 5 \pm 13 \text{ pb (data)}$ NNI O (theory)	¢	Theory		3.2	arXiv: 1702.04519 [hep-ex]
WW	$\sigma = 68.2 \pm 1.2 \pm 4.6 \text{ p} \text{ (data)}$	4	Theory		20.3	PLB 763, 114 (2016)
	$\sigma = 51.9 \pm 2 \pm 4.4 \text{ pb} (data)$	0			4.6	PRD 87, 112001 (2013)
	$\sigma = 61.5 + 10.5 + 10.4 \times 10^{-10}$	b	LHC pp $\gamma s = 7$ TeV =		13.3	ATLAS-CONF-2016-081
	$\sigma = 27.7 \pm 3 + 2.3 - 1.9 \text{ pb (data)}$	<b>A</b>	• Data		20.3	EPJC 76, 6 (2016)
н	$\sigma = 22.1 + 6.7 - 5.3 + 3.3 - 2.7 \text{ pb} (\text{data})$	Þ	stat ⊕ syst		4.5	EPJC 76, 6 (2016)
	$\sigma = 94 \pm 10 + 28 - 23 \text{ pb (data)}$				3.2	arXiv:1612.07231 [hep-ex]
Wt	$\sigma = 23 \pm 1.3 + 3.4 - 3.7 \text{ pb} (\text{data})$	4	LHC pp √s = 8 TeV		20.3	JHEP 01, 064 (2016)
	$\sigma = 16.8 \pm 2.9 \pm 3.9 \text{ pb} (\text{data})$	þ	Data		2.0	PLB 716, 142-159 (2012)
	$\sigma = 50.6 \pm 2.6 \pm 2.5 \text{ pb} (\text{data})$	¢	stat ⊕ svst	i i i i i i i i i i i i i i i i i i i	3.2	PLB 762 (2016) 1
WZ	$\sigma = 24.3 \pm 0.6 \pm 0.9 \text{ pb} (\text{data})$	$\Delta$	3iai ⊕ 3y3i		20.3	PRD 93, 092004 (2016)
	$\sigma = 19 + 1.4 - 1.3 \pm 10 \text{ (data)}$	•	LHC pp √s = 13 TeV		4.6	EPJC 72, 2173 (2012)
	$\sigma = 16.7 + 2.2 - 2 + 1.3 - 1 \text{ pb (data)}$	0	Data		3.2	PRL 116, 101801 (2016)
ZZ	$\sigma = 7.3 \pm 0.4 + 0.4 - 0.3 \text{ pb (data)}$	4	stat		20.3	JHEP 01, 099 (2017)
	$\sigma = 6.7 \pm 0.7 + 0.5 - 0.4$ pb (data)	•	stat 🕁 syst		4.6	JHEP 03, 128 (2013)
t <sub>s-chan</sub>	$\sigma = 4.8 \pm 0.8 + 1.6 - 1.3 \text{ pb (data)}$	ATLAS	Preliminary		20.3	PLB 756, 228-246 (2016)
	$\sigma = 1.5 \pm 0.72 \pm 0.39 \text{ (data)}$				3.2	EPJC 77 (2017) 40
ttvv	$\sigma = 369 + 86 - 79 \pm 44 \text{ (b) (data)}$	Run 1.2	$\sqrt{s} = 7.8.13$ TeV		20.3	JHEP 11, 172 (2015)
	$\sigma = 0.92 \pm 0.29 \pm 0.1 \text{ pb} \text{ (data)}$		<b>v</b> , , , , , , , , , , , , , , , , , , ,		3.2	EPJC 77 (2017) 40
ttΖ	$\sigma = 176 + 52 - 480 + 10 (data)$ HELAC-NLO (theory)	- 			20.3	JHEP 11, 172 (2015)
	$10^{-5} \ 10^{-4} \ 10^{-3} \ 10^{-2} \ 10^{-1}$	1 10 <sup>1</sup> 10 <sup>2</sup> 10 <sup>3</sup>	$10^4 \ 10^5 \ 10^6 \ 10^1$	$^{1}$ 0.5 1 1.5 2 2.5		
			$\sigma$ [pb]	data/theory		







- Heaviest quark ~ 172 GeV
- Rather "young" particle: 22 years old since discovery
- Studied in different collider environments (pp, pp)
   and at different center of mass energies
- Precision measurement and hints for new physics from discrepancies between predictions and observations





Top quark mass measurement with soft muons from b-hadron decay *Maurizio De Santis* 

Fisica del top a LHC: misura di sezioni d'urto di produzione e proprieta' *Serena Palazzo* 



•  $\sigma_{tt \rightarrow lvlvbb} \sim 87 \text{ pb}$  @ 13 TeV

Many measurements: cross section, inclusive, differential and

fiducial, top mass, polarization, asymmetries, width, rare decays, ...





tt



### **Recent result:** $t\bar{t}$



- Special topic:  $\sqrt{s} = 5.02$  TeV
- Just 27 pb<sup>-1</sup> of data
- Fully leptonic and semileptonic measurement
- Good for PDF fitting because it offers different sensitivity than higher energy measurements





### Many more



• Single top, tW, differential, top mass measurement, top – antitop mass difference, tt +  $\gamma$ , tt +V, ...







- Top Higgs
  - Top Yukawa coupling
  - x 4 in cross section at 13 TeV w.r.t. 8 TeV
  - New physics ... answer the original question









- ttH searches
- Multileptons final state (H  $\rightarrow$  WW, ZZ,  $\tau\tau$ ), H  $\rightarrow \tau\tau$ , H  $\rightarrow$  bb, H $\rightarrow \gamma\gamma$
- Signal strength in multileptons:  $CMS = 1.5 \pm 0.5$  ATLAS =  $2.5 \pm 1.3$
- ~  $3\sigma$  (1.7 $\sigma$ ) significance observed (expected)

ATLAS-CONF-2016-058







Higgs world



3.5





- Higgs  $\rightarrow \gamma \gamma$
- Low BR ~ 0.2% but clean signature
- Differential measurements

Study of the decays of the Higgs boson to boson pairs at Run-II with the ATLAS experiment *Marco Sessa* 

#### CMS-PAS-HIG-17-015





19th April 2017



GeV

Events/2.5

35

30

25

20

15

10

5

0

80

90

 $H \to ZZ^* \to 4I$ 

13 TeV. 14.8 fb<sup>-1</sup>

## $H \rightarrow ZZ$



- Higgs  $\rightarrow$  ZZ
- Low BR but clean signature  $\rightarrow$  full kinematic of Higgs decay reconstructed
- Very high signal/background ratio
- Differential measurements, Higgs couplings, mass measurement, ...

Study of the production modes of the Higgs boson and EFT interpretations in the H -> ZZ\* -> 41 decay channel at 13 TeV center of mass energy with the ATLAS detector at LHC Giada Mancini



#### ATLAS-CONF-2016-079

19th April 2017





SM (sys

Other VV

Other Higgs

7 Linte

W+iet

Top

ww

ATLAS-CONF-2016-112

ATLAS Preliminary

 $\sqrt{s} = 13 \text{ TeV}, 5.81 \text{ fb}^{-1}$ 

 $H \rightarrow WW \rightarrow e\mu + \mu e (VBF)$ 

350

300E

250

Events / bin

- Higgs  $\rightarrow$  WW, bb,  $\tau\tau$ ,  $\mu\mu$ , rare decays
- Control of most of SM backgrounds is fundamental
  - Close interplay with SM precision measurements



19th April 2017



## **Properties**



- Higgs mass, Higgs couplings, ...
- Higgs physics towards precision measurement









- Is Nature Standard like the Model? So far it seems ... but ...
- More data needed to reduce statistical and systematic uncertainty
- Great positive feedback from Theory community in the last years on improved MC generators (NLO is now the basis!), higher order calculations, reduced uncertainties, ...
- Rarer and rarer processes are currently under study
  - e.g. di-higgs searches
- More results based on 2016 data are coming
- ... and more data in 2017!

Search for the Higgs boson pair production at sqrt=13 TeV with the ATLAS detector *Monica Verducci* 

> Ricerca di produzione risonante di coppie HH nel canale 4b con l'esperimento CMS a 13 TeV *Leonardo Giannini*

Search for the Higgs boson pair production in the WWbb final state at sqrt(s)=13 TeV with the ATLAS detector *Muhammad Sohail* 



19th April 2017







(for real)



## References



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- https://twiki.cern.ch/twiki/bin/view/AtlasPublic/TopPublicResults























- Higgs  $\rightarrow \gamma \gamma$
- Low BR ~ 0.2% but clean signature
- Differential measurements







March 2017				ſ.,	_
	ATLAS+CMS	Channel	Limits	J <i>L</i> dt	Vs.
f		ZZ (4I,2I2v)	[-1.5e-02, 1.5e-02]	4.6 fb <sup>-1</sup>	7 TeV
'4	<b>⊢−−−−−</b>	ZZ (4I,2I2v)	[-3.8e-03, 3.8e-03]	20.3 fb <sup>-1</sup>	8 TeV
	<b>⊢</b>	ZZ (4I)	[-5.0e-03, 5.0e-03]	19.6 fb <sup>-1</sup>	8 TeV
	F	ZZ (2l2v)	[-3.6e-03, 3.2e-03]	24.7 fb <sup>-1</sup>	7,8 TeV
	<b>⊢−−−−</b> {	ZZ (4I,2I2v)	[-3.0e-03, 2.6e-03]	24.7 fb <sup>-1</sup>	7,8 TeV
	H	ZZ (4I)	[-1.3e-03, 1.3e-03]	35.9 fb <sup>-1</sup>	13 TeV
	<b>├</b> ────┤	ZZ (4I,2I2v)	[-1.0e-02, 1.0e-02]	9.6 fb <sup>-1</sup>	7 TeV
fΖ		ZZ (4I,2I2v)	[-1.3e-02, 1.3e-02]	4.6 fb <sup>-1</sup>	7 TeV
4	<b>⊢−−−−1</b>	ZZ (4I,2I2v)	[-3.3e-03, 3.2e-03]	20.3 fb <sup>-1</sup>	8 TeV
	<b>├</b> ────┥	ZZ (4I)	[-4.0e-03, 4.0e-03]	19.6 fb <sup>-1</sup>	8 TeV
	<b>⊢−−−−</b>	ZZ (2l2v)	[-2.7e-03, 3.2e-03]	24.7 fb <sup>-1</sup>	7,8 TeV
	<b>⊢−−−</b>	ZZ (4I,2I2v)	[-2.1e-03, 2.6e-03]	24.7 fb <sup>-1</sup>	7,8 TeV
	H	ZZ (4I)	[-1.2e-03, 1.1e-03]	35.9 fb <sup>-1</sup>	13 TeV
		ZZ (4I,2I2v)	[-8.7e-03, 9.1e-03]	9.6 fb <sup>-1</sup>	7 TeV
$f^{\gamma}$		ZZ (4I,2I2v)	[-1.6e-02, 1.5e-02]	4.6 fb <sup>-1</sup>	7 TeV
<b>'</b> 5	⊢	ZZ (4I,2I2v)	[-3.8e-03, 3.8e-03]	20.3 fb <sup>-1</sup>	8 TeV
	<b>⊢−−−−−− </b>	ZZ (4I)	[-5.0e-03, 5.0e-03]	19.6 fb <sup>-1</sup>	8 TeV
	<b>⊢−−−− </b>	ZZ(2l2v)	[-3.3e-03, 3.6e-03]	24.7 fb <sup>-1</sup>	7,8 TeV
	<b>⊢−−−</b> 1	ZZ(4I,2I2v)	[-2.6e-03, 2.7e-03]	24.7 fb <sup>-1</sup>	7,8 TeV
	H	ZZ (4I)	[-1.2e-03, 1.3e-03]	35.9 fb <sup>-1</sup>	13 TeV
		ZZ (4I,2I2v)	[-1.1e-02, 1.1e-02]	9.6 fb <sup>-1</sup>	7 TeV
۴Z		ZZ (4I,2I2v)	[-1.3e-02, 1.3e-02]	4.6 fb <sup>-1</sup>	7 TeV
<b>'</b> 5	<b>⊢−−−−</b> ↓	ZZ (4I,2I2v)	[-3.3e-03, 3.3e-03]	20.3 fb <sup>-1</sup>	8 TeV
	<b>⊢−−−−− </b>	ZZ (4I)	[-4.0e-03, 4.0e-03]	19.6 fb <sup>-1</sup>	8 TeV
	<b>⊢−−−−</b>	ZZ (2l2v)	[-2.9e-03, 3.0e-03]	24.7 fb <sup>-1</sup>	7,8 TeV
	<b>⊢−−−</b>	ZZ (4I,2I2v)	[-2.2e-03, 2.3e-03]	24.7 fb <sup>-1</sup>	7,8 TeV
	H	ZZ (4I)	[-1.0e-03, 1.2e-03]	35.9 fb <sup>-1</sup>	13 TeV
. 1		ZZ (4I,2I2v)	[-9.1e-03, 8.9e-03]	9.6 fb <sup>-1</sup>	7 <mark>T</mark> eV
-0.0	0	0.02	0.04		0.06
			aTGC Li	mits @95	5% C.L.





April 2016	CMS ATLAS			c	
	CDF	Channel	Limits	∫ <i>L</i> dt	√s
h <sup>y</sup>		Ζγ(ΙΙγ,ννγ)	[-1.5e-02, 1.6e-02]	4.6 fb <sup>-1</sup>	7 TeV
3	н	Ζγ(ΙΙγ,ννγ)	[-9.5e-04, 9.9e-04]	20.3 fb <sup>-1</sup>	8 TeV
	<b>⊢</b>	Ζγ(ΙΙγ,ννγ)	[-2.9e-03, 2.9e-03]	5.0 fb <sup>-1</sup>	7 TeV
	<b>⊢−−−−</b> ↓	Zγ(IIγ)	[-4.6e-03, 4.6e-03]	19.5 fb <sup>-1</sup>	8 TeV
	н	Ζγ(ννγ)	[-1.1e-03, 9.0e-04]	19.6 fb <sup>-1</sup>	8 TeV
	<b>├</b> ────┤	Ζγ(ΙΙγ,ννγ)	[-2.2e-02, 2.0e-02]	5.1 fb <sup>-1</sup>	1.96 TeV
h <sup>Z</sup>		Ζγ(ΙΙγ,ννγ)	[-1.3e-02, 1.4e-02]	4.6 fb <sup>-1</sup>	7 TeV
''3	н	Ζγ(ΙΙγ,ννγ)	[-7.8e-04, 8.6e-04]	20.3 fb <sup>-1</sup>	8 TeV
	<b>⊢</b> −−1	Ζγ(ΙΙγ,ννγ)	[-2.7e-03, 2.7e-03]	5.0 fb <sup>-1</sup>	7 TeV
	H	Zγ(IIγ)	[-3.8e-03, 3.7e-03]	19.5 fb <sup>-1</sup>	8 TeV
	н	Ζγ(ννγ)	[-1.5e-03, 1.6e-03]	19.6 fb <sup>-1</sup>	8 TeV
	<b>├</b> ────┤	Ζγ(ΙΙγ,ννγ)	[-2.0e-02, 2.1e-02]	5.1 fb <sup>-1</sup>	1.96 TeV
h <sup>γ</sup>		Ζγ(ΙΙγ,ννγ)	[-9.4e-05, 9.2e-05]	4.6 fb <sup>-1</sup>	7 TeV
··4	н	Ζγ(ΙΙγ,ννγ)	[-3.2e-06, 3.2e-06]	20.3 fb <sup>-1</sup>	8 TeV
	н	Ζγ(ΙΙγ,ννγ)	[-1.5e-05, 1.5e-05]	5.0 fb <sup>-1</sup>	7 TeV
	<b>⊢−−−−</b>	Zγ(IIγ)	[-3.6e-05, 3.5e-05]	19.5 fb <sup>-1</sup>	8 TeV
	Н	Ζγ(ννγ)	[-3.8e-06, 4.3e-06]	19.6 fb <sup>-1</sup>	8 TeV
h <sup>Z</sup>		Ζγ(ΙΙγ,ννγ)	[-8.7e-05, 8.7e-05]	4.6 fb <sup>-1</sup>	7 TeV
"4	н	Ζγ(ΙΙγ,ννγ)	[-3.0e-06, 2.9e-06]	20.3 fb <sup>-1</sup>	8 TeV
	н	Ζγ(ΙΙγ,ννγ)	[-1.3e-05, 1.3e-05]	5.0 fb <sup>-1</sup>	7 TeV
	<b>⊢</b> −−−	Zγ(IIγ)	[-3.1e-05, 3.0e-05]	19.5 fb <sup>-1</sup>	8 TeV
	<mark>Н</mark>	Ζγ(ννγ)	[-3.9e-06, 4.5e-06]	19.6 fb <sup>-1</sup>	8 TeV
	-0.2 0 0.2	0.	4 0.6	0	.8 x10 <sup>-1</sup> (h.)
		aTO	C Limits @95	% C.L.	x10 <sup>-3</sup> (h





March 2017	Central				f	_
	Fit value	LÉP <b>H</b>	Channel	Limits	J Ldt	<u>Vs</u>
Δκ			WW	[-4.3e-02, 4.3e-02]	4.6 fb <sup>-</sup>	/ IeV
ΔĸZ		, <b>F</b> -4	WW	[-2.5e-02, 2.0e-02]	20.3 fb	8 lev
		· · · · · · ·	WW	[-6.0e-02, 4.6e-02]	19.4 fb	8 lev
			WZ	[-1.3e-01, 2.4e-01]	33.6 fb <sup>-</sup>	8,13 lev
			WZ	[-2.1e-01, 2.5e-01]	19.6 fb <sup>-</sup> '	8 leV
		H	WV	[-9.0e-02, 1.0e-01]	4.6 fb <sup>-</sup>	7 TeV
		<b>⊢−−−−</b>	WV	[-4.3e-02, 3.3e-02]	5.0 fb <sup>-1</sup>	7 TeV
		<b>⊢</b> −−	WV	[-2.3e-02, 3.2e-02]	19 fb <sup>-1</sup>	8 TeV
		<b>⊢−−−</b> 4	WV	[-4.0e-02, 4.1e-02]	2.3 fb <sup>-1</sup>	13 TeV
		⊢_●	LEP Comb.	[-7.4e-02, 5.1e-02]	0.7 fb <sup>-1</sup>	0.20 TeV
2		<b>⊢</b> −−−−−−	WW	[-6.2e-02, 5.9e-02]	4.6 fb <sup>-1</sup>	7 TeV
$^{\Lambda}Z$		H	WW	[-1.9e-02, 1.9e-02]	20.3 fb <sup>-1</sup>	8 TeV
-		⊢	WW	[-4.8e-02, 4.8e-02]	4.9 fb <sup>-1</sup>	7 TeV
		⊢●┥	WW	[-2.4e-02, 2.4e-02]	19.4 fb <sup>-1</sup>	8 TeV
		<b>⊢−−−−</b>	WZ	[-4.6e-02, 4.7e-02]	4.6 fb <sup>-1</sup>	7 TeV
		H	WZ	[-1.4e-02, 1.3e-02]	33.6 fb <sup>-1</sup>	8,13 TeV
		⊢-I	WZ	[-1.8e-02, 1.6e-02]	19.6 fb <sup>-1</sup>	8 TeV
		<b>⊢−−−−</b>	WV	[-3.9e-02, 4.0e-02]	4.6 fb <sup>-1</sup>	7 TeV
		<b>⊢−−−</b> 4	ŴV	[-3.8e-02, 3.0e-02]	5.0 fb <sup>-1</sup>	7 TeV
		н	WV	[-1.1e-02, 1.1e-02]	19 fb <sup>-1</sup>	8 TeV
		<b>⊢−−−−</b> ↓	WV	[-3.9e-02, 3.9e-02]	2.3 fb <sup>-1</sup>	13 TeV
		<b>⊢</b> ●−1	D0 Comb.	[-3.6e-02, 4.4e-02]	8.6 fb <sup>-1</sup>	1.96 TeV
		⊢●	LEP Comb.	[-5.9e-02, 1.7e-02]	0.7 fb <sup>-1</sup>	0.20 TeV
A a Z			WW	[-3.9e-02, 5.2e-02]	4.6 fb <sup>-1</sup>	7 TeV
∆g_		H-I	WW	[-1.6e-02, 2.7e-02]	20.3 fb <sup>-1</sup>	8 TeV
- 1		<b>—</b>	ŴŴ	[-9.5e-02, 9.5e-02]	4.9 fb <sup>-1</sup>	7 TeV
		· <b>⊢</b> ●–↓ ·	WW	[-4.7e-02, 2.2e-02]	19.4 fb <sup>-1</sup>	8 TeV
		<u> </u>	WZ	[-5.7e-02, 9.3e-02]	$4.6 \text{ fb}^{-1}$	7 TeV
		· ⊢ ·	WZ	[-1.5e-02, 3.0e-02]	33.6 fb <sup>-1</sup>	8,13 TeV
		i i i i i i i i i i i i i i i i i i i	WZ	[-1.8e-02, 3.5e-02]	19.6 fb <sup>-1</sup>	8 TeV
			ŴV	[-5.5e-02, 7.1e-02]	$4.6 \text{ fb}^{-1}$	7 TeV
		· H	ŴV	-8.7e-03, 2.4e-021	19 fb <sup>-1</sup>	8 TeV
		· · ·	ŴV	[-6.7e-02, 6.6e-02]	$2.3 \text{ fb}^{-1}$	13 TeV
		· · · · · · · · · · · · · · · · · · ·	D0 Comb	[-3.4e-02, 8.4e-02]	8.6 fb <sup>-1</sup>	1.96 TeV
		, ⊢∙+I	LEP Comb.	[-5.4e-02, 2.1e-02]	0,7 fb <sup>-1</sup>	0.20 Teγ
				0.5		
		0		0.5		I
				aTGC Lii	nits @9	5% C.L.





April 2017	CMS ATLAS	Channel	Limits	∫ <i>L</i> dt	√s
$f_{T,0} / \Lambda^4$		Wγγ	[-3.4e+01, 3.4e+01]	19.4 fb <sup>-1</sup>	8 TeV
	II	Wγγ	[-1.6e+01, 1.6e+01]	20.3 fb <sup>-1</sup>	8 TeV
	FI	Ζγγ	[-1.6e+01, 1.9e+01]	20.3 fb <sup>-1</sup>	8 TeV
	ll	WVγ	[-2.5e+01, 2.4e+01]	19.3 fb <sup>-1</sup>	8 TeV
	<b>⊢</b> −−1	Ζγ	[-3.8e+00, 3.4e+00]	19.7 fb <sup>-1</sup>	8 TeV
	F +	Wγ	[-5.4e+00, 5.6e+00]	19.7 fb <sup>-1</sup>	8 TeV
	F4	ss WW	[-4.2e+00, 4.6e+00]	19.4 fb <sup>-1</sup>	8 TeV
$f_{T,1} / \Lambda^4$	<b>⊢</b> −−−1	Ζγ	[-4.4e+00, 4.4e+00]	19.7 fb <sup>-1</sup>	8 TeV
	<b>⊢−−−1</b>	Wγ	[-3.7e+00, 4.0e+00]	19.7 fb <sup>-1</sup>	8 TeV
	1-4	ss WW	[-2.1e+00, 2.4e+00]	19.4 fb <sup>-1</sup>	8 TeV
$f_{T,2}/\Lambda^4$	F	Ζγ	[-9.9e+00, 9.0e+00]	19.7 fb <sup>-1</sup>	8 TeV
	⊢ — — — →	Wγ	[-1.1e+01, 1.2e+01]	19.7 fb <sup>-1</sup>	8 TeV
	FI	ss WW	[-5.9e+00, 7.1e+00]	19.4 fb <sup>-1</sup>	8 TeV
$f_{T,5}/\Lambda^4$	HH	Ζγγ	[-9.3e+00, 9.1e+00]	20.3 fb <sup>-1</sup>	8 TeV
	<b>⊢−−−1</b>	Wγ	[-3.8e+00, 3.8e+00]	19.7 fb <sup>-1</sup>	8 TeV
$f_{T,6}/\Lambda^4$	⊢I	Wγ	[-2.8e+00, 3.0e+00]	19.7 fb <sup>-1</sup>	8 TeV
$f_{T,7}/\Lambda^4$	⊢	Wγ	[-7.3e+00, 7.7e+00]	19.7 fb <sup>-1</sup>	8 TeV
$f_{T,8}/\Lambda^4$	н	Ζγ	[-1.8e+00, 1.8e+00]	19.7 fb <sup>-1</sup>	8 TeV
$f_{T,9}/\Lambda^4$	<b>⊢−−−−1</b>	Ζγγ	[-7.4e+00, 7.4e+00]	20.3 fb <sup>-1</sup>	8 TeV
1	H	Zγ	[-4.0e+00, 4.0e+00]	19.7 fb <sup>-1</sup>	8 TeV
		<b>50</b>			
-50	0	50			<b>1 1 1 1</b>
		a	QGC Limits @9	5% C.L	. [ IeV <sup>-</sup> ]





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- Many new results at 7/8/13 TeV from ATLAS and CMS
- How we usually proceed:
  - Inclusive cross section
  - Fiducial and differential cross section





## Looking for the unknown (mirror image)



STDM-2012-07 • Many new results at 7/8/13 TeV from ATLAS and CMS 10<sup>4</sup>  $\frac{d\sigma(pp \rightarrow l^+ l^- \gamma)}{dE_T^{\gamma}} [fb \text{ GeV}^{-1}]$ Data 2011 (Exclusive) • How we usually proceed: MCFM SM (Exclusive) 10<sup>3</sup> MCFM  $h_2^Z = 0.04$ ,  $\Lambda = \infty$  (Exclusive) Inclusive cross section ۲  $10^{2}$ Fiducial and differential cross section 10 High energy regimes for anomalous couplings ATLAS 10<sup>-1</sup> √s=7TeV  $L dt = 4.6 \text{ fb}^{-1}$ 10<sup>-2</sup> 30 15 20 40 60 100 1000  $E_{\tau}^{\gamma}$  [GeV] Events **ATLAS** Preliminary Data 10<sup>5</sup> W<sup>±</sup>Z (corr. to NNLO) 13 TeV. 13.3 fb Misid. leptons ZZ C<sub>www</sub>/Λ<sup>2</sup> [TeV<sup>-2</sup>] ATLAS ATLAS Preliminary tt+V  $\ell = e \text{ or } \mu$ Expected  $10^{4}$  $\Delta g_{\perp}^{Z}$ Others \s = 8 TeV, 20.3 fb<sup>-1</sup> Observed  $-0.1. \Delta \kappa^{Z} = 0.25. \lambda$ Tot unc ATLAS combined 8 + 13 TeV 10- 95% C.L. in EFT Scenario  $10^{3}$ — ATLAS √s = 13 TeV, 13.3 fb<sup>-1</sup> - ATLAS √s = 8 TeV, 20.3 fb<sup>-1</sup> 10<sup>2</sup> - ATLAS  $\sqrt{s} = 7$  TeV, 4.6 fb<sup>-1</sup>  $\lambda^{Z}$  $\Lambda_{co} = \infty$  $W^{\pm}Z \rightarrow \ell' v \ell \ell$ 10  $\Delta \kappa^{Z} \times 0.1$ Data / MC 1.5 -10-0.050 0.05 0.25 0.1 0.150.2 -20-10 0 10 20 aTGC Intervals at 95% C.L. 0.5 ō 200 400 600 800  $C_w/\Lambda^2$  [TeV<sup>-2</sup>] m<sup>WZ</sup> [GeV]

ATLAS-CONF-2016-043

#### STDM-2013-07

19th April 2017