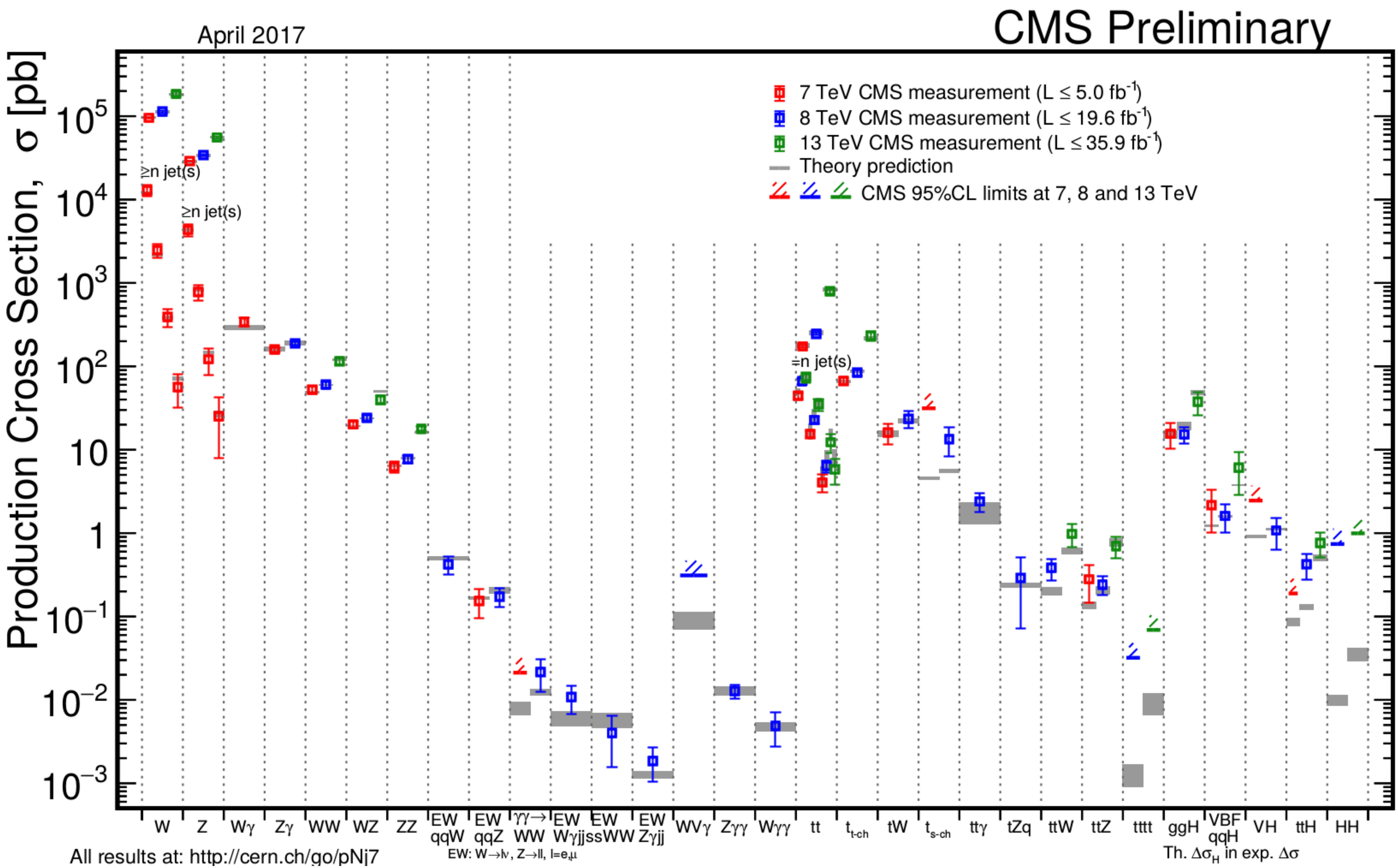
Is Nature Standard like the Model? Experimental results on SM and Higgs physics

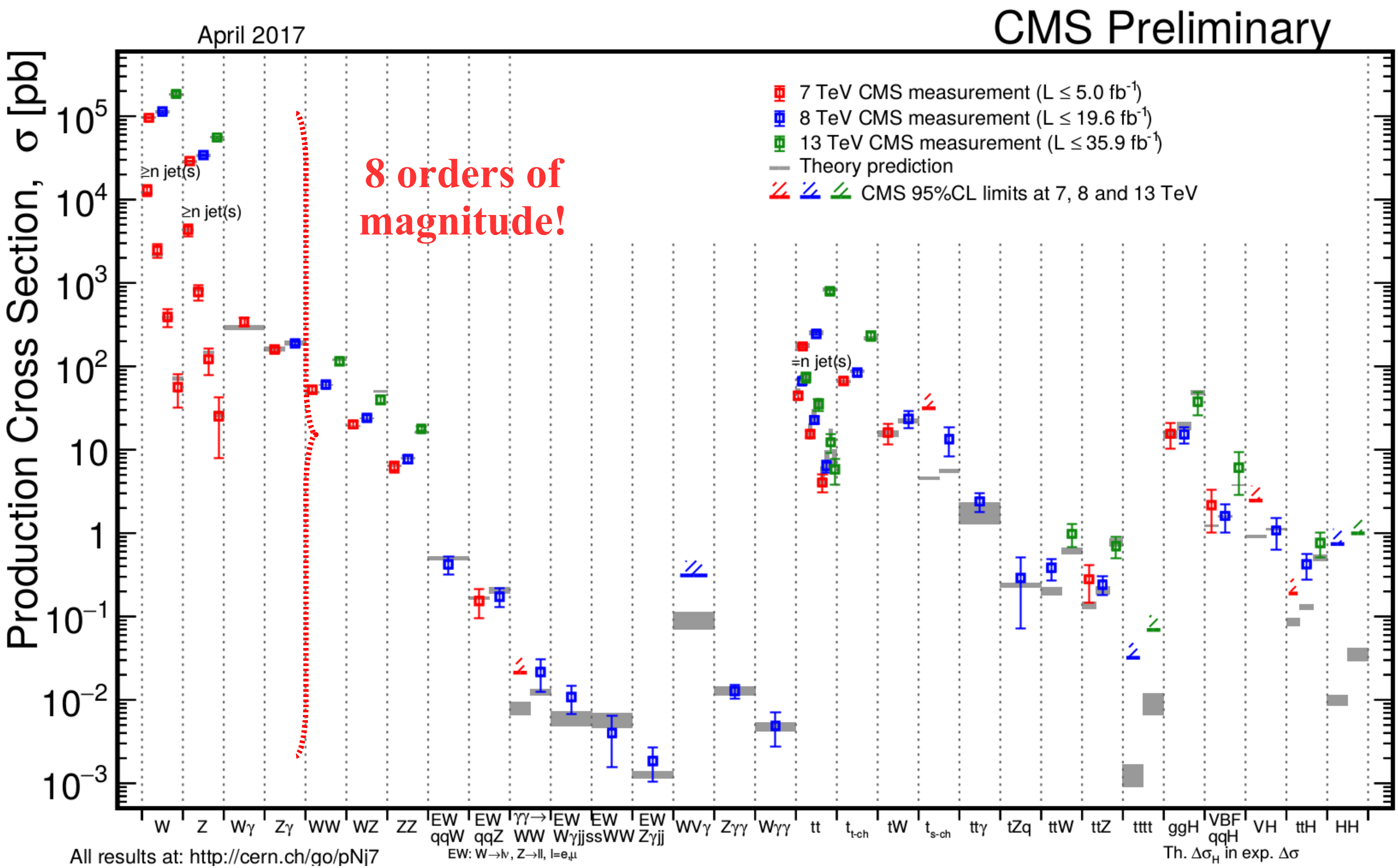
19th April 2017

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

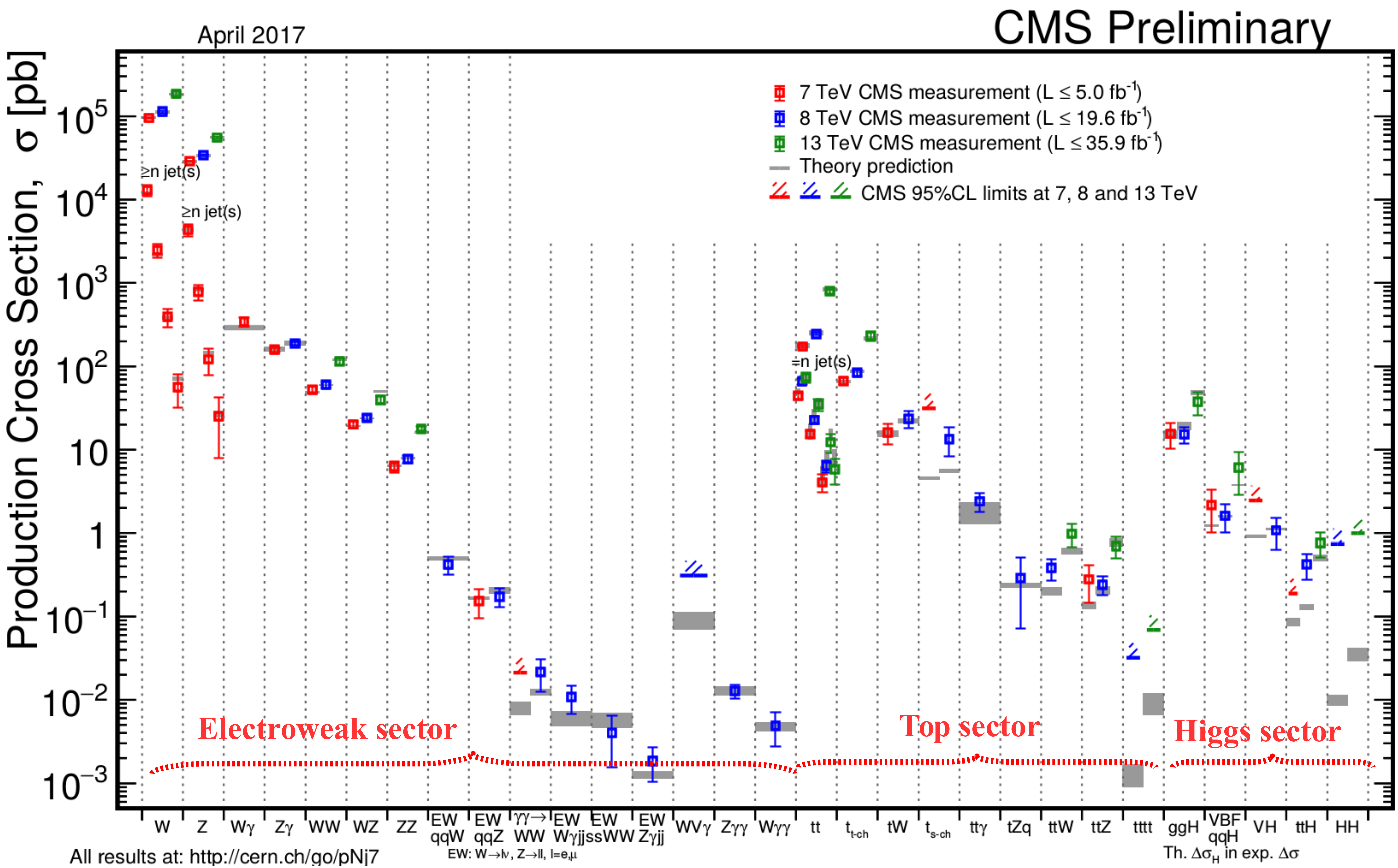
Is Nature Standard like the Model?



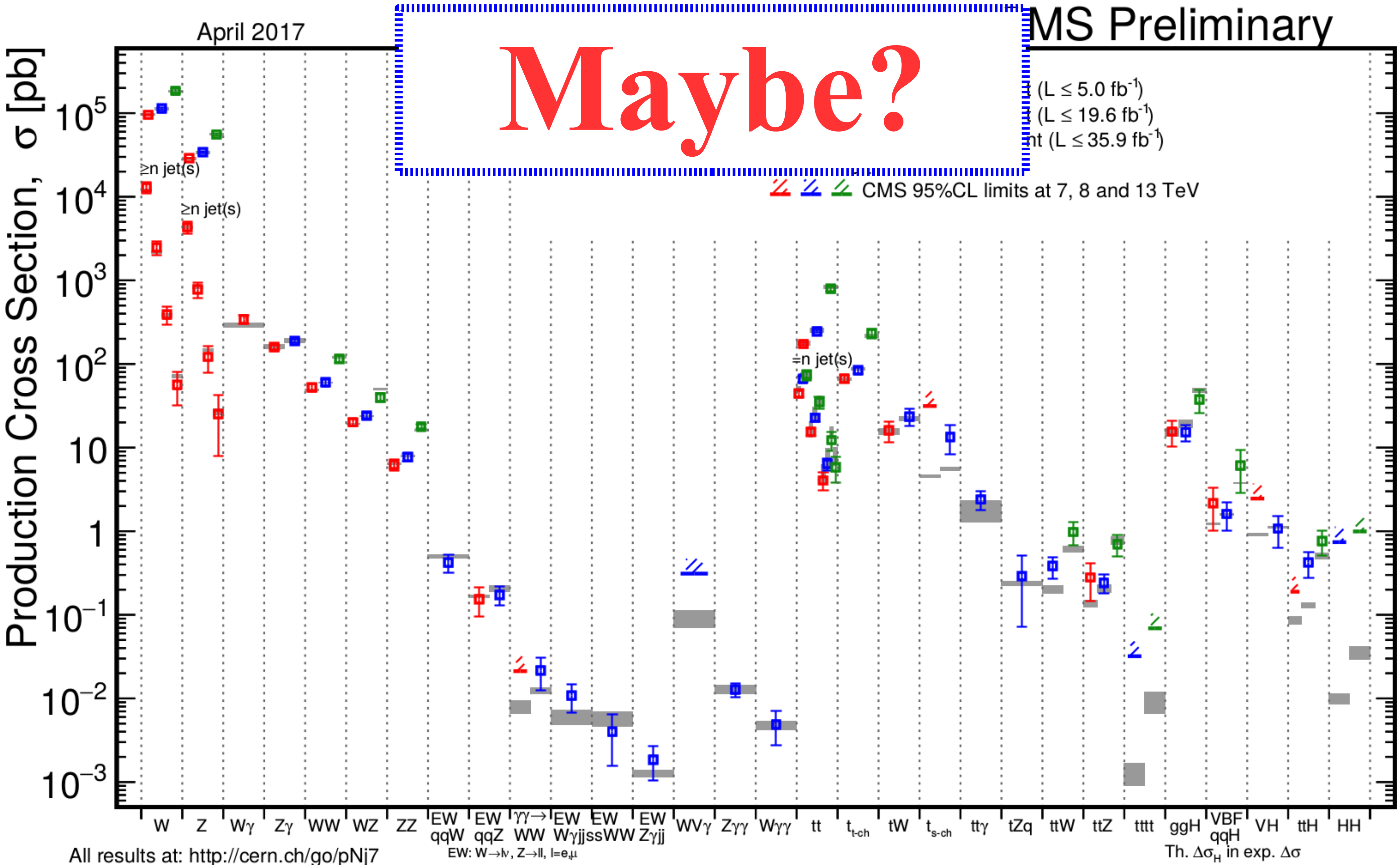
Is Nature Standard like the Model?



Is Nature Standard like the Model?



Is Nature Standard like the Model?



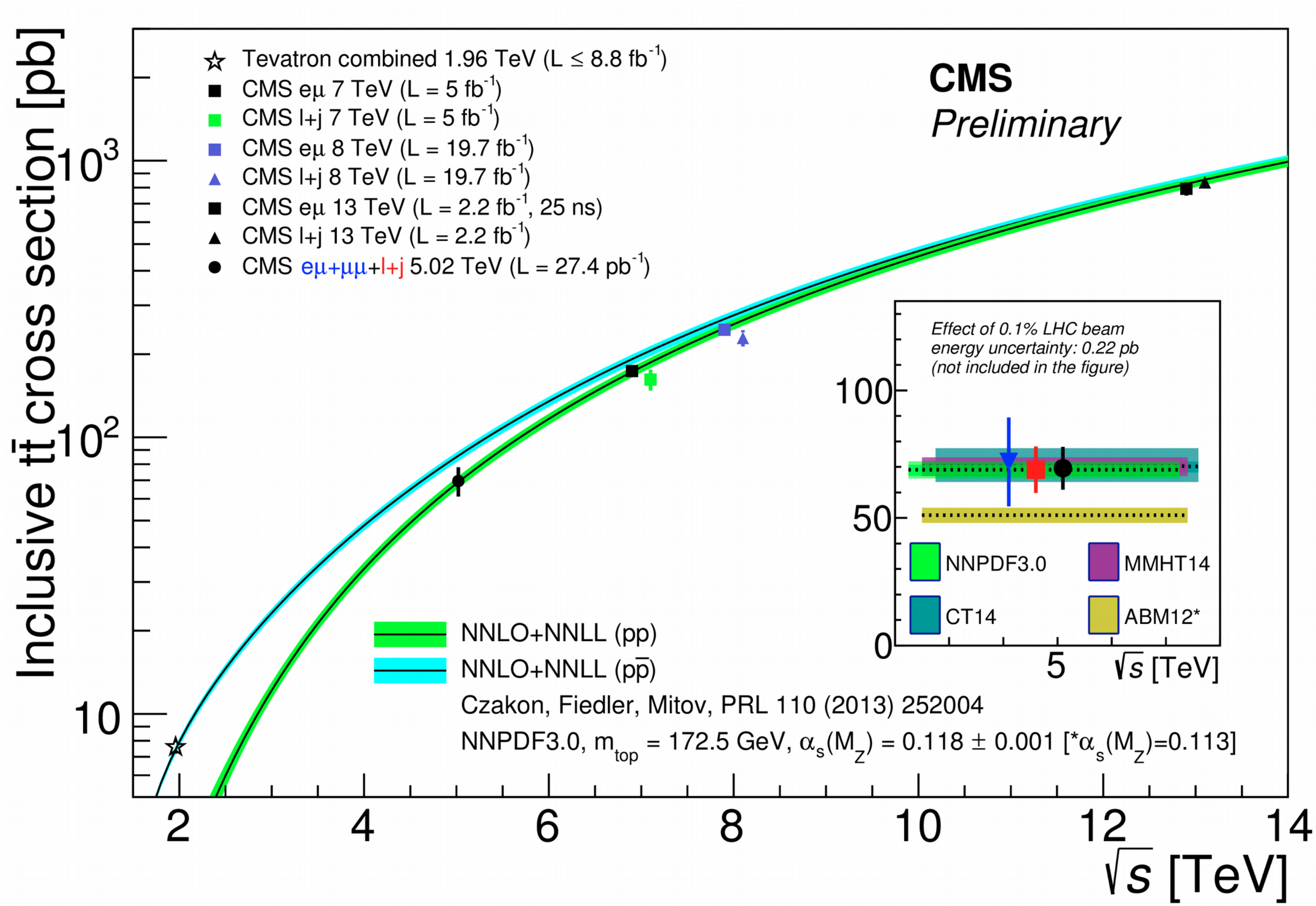
News from CMS and ATLAS

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

Steps towards measurements

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

$$\mathrm{DATA} = \sigma \times \int \mathrm{Luminosity}$$



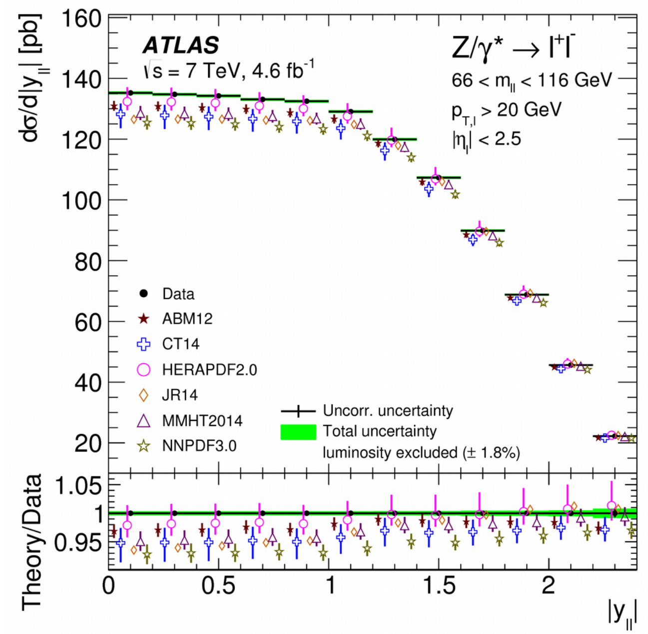
TOP-16-023

… one step more

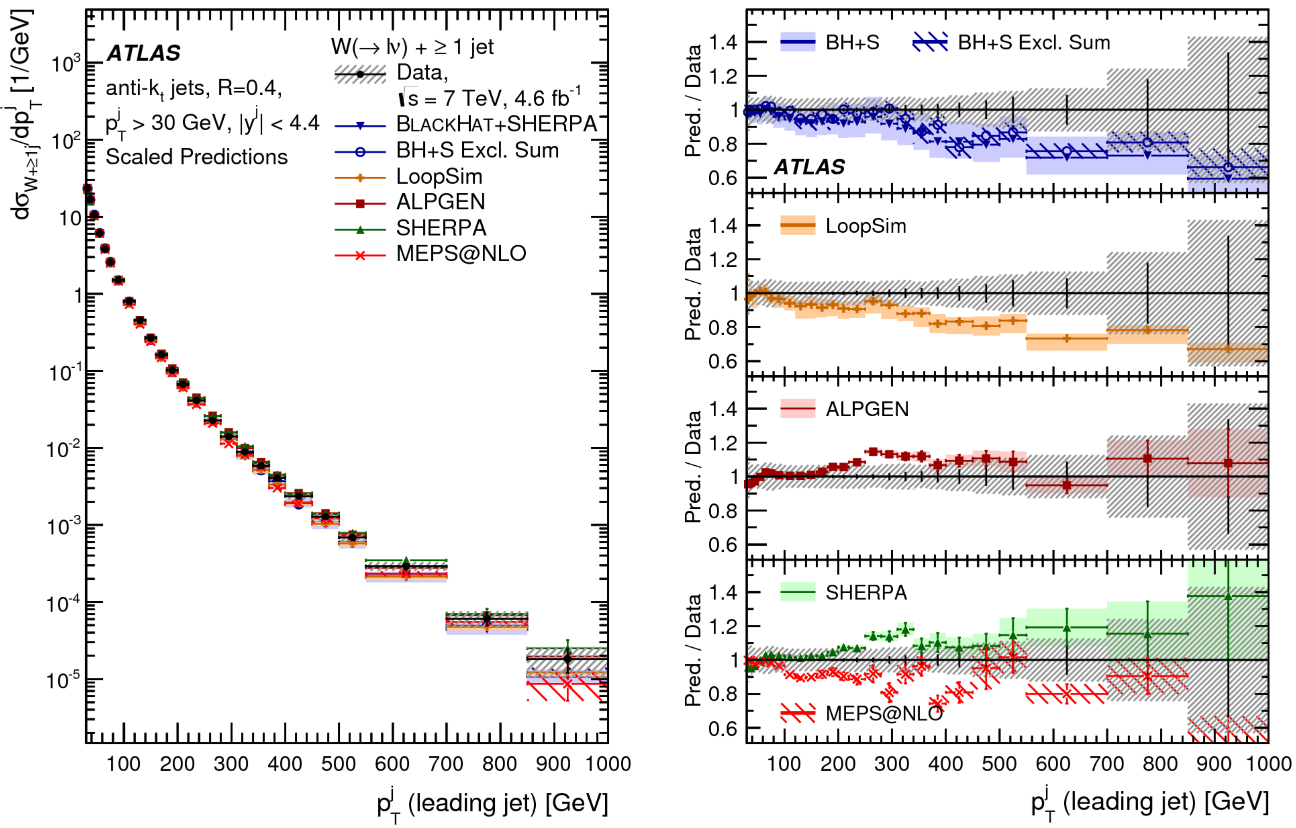
- Many new results at 7/8/13 TeV from ATLAS and CMS
- How we usually proceed:
  - Inclusive cross section
  - Fiducial and differential cross section

Z

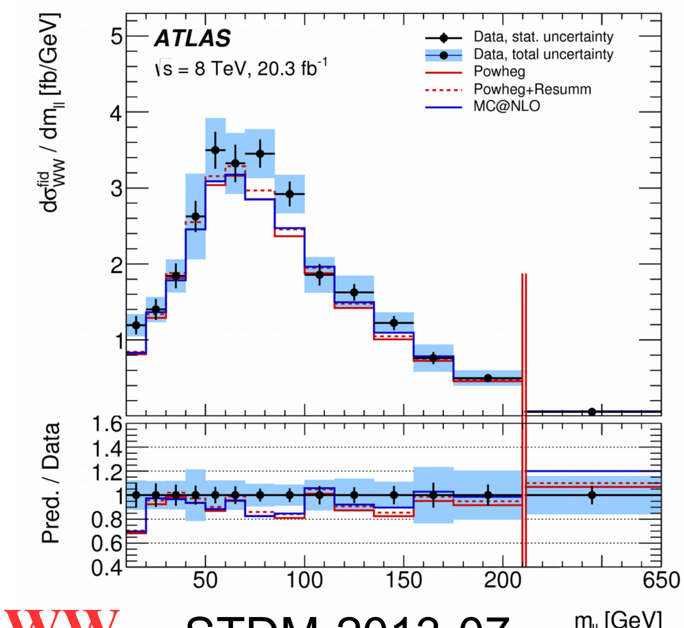
STDM-2012-20



W



STDM-2012-24

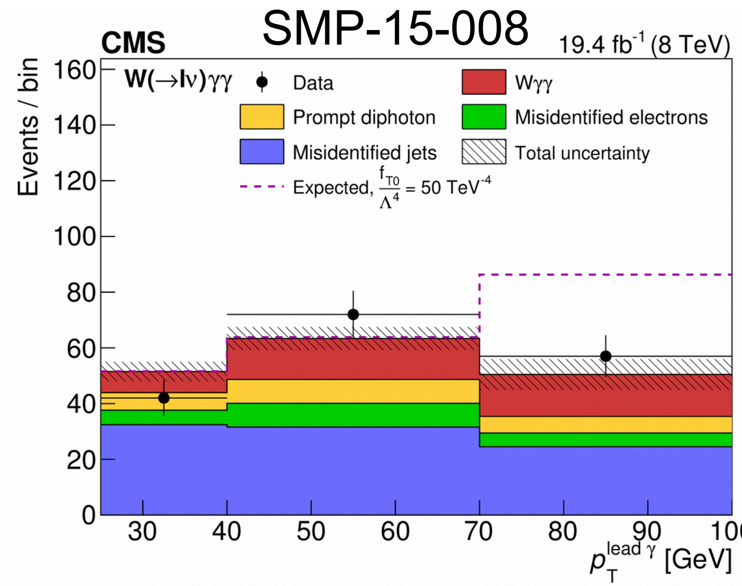


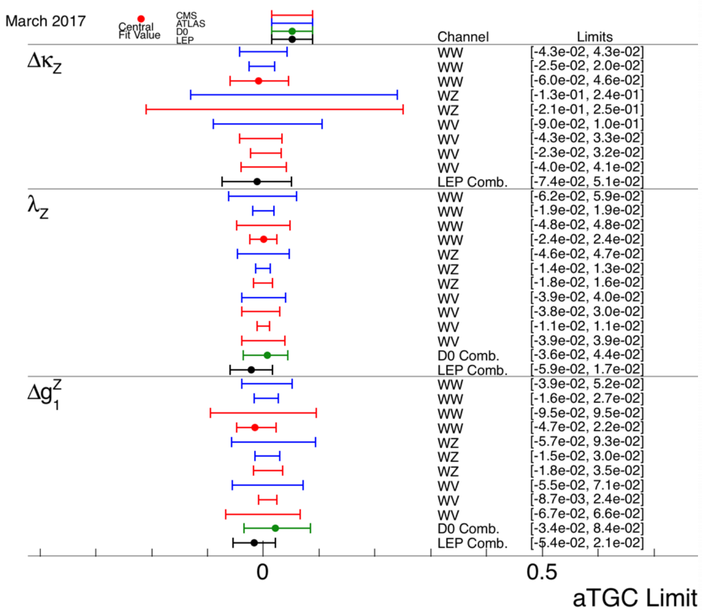
WW

STDM-2013-07

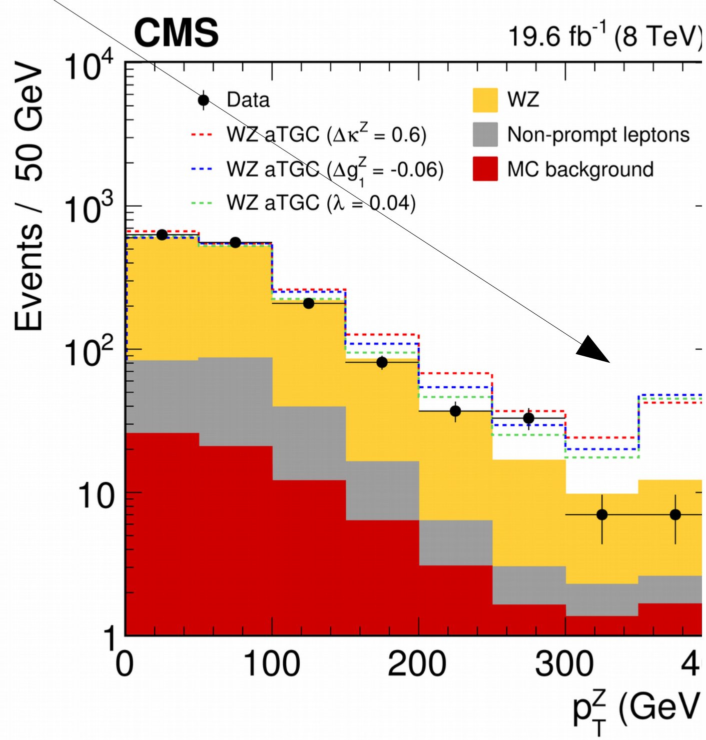
Looking for the unknown

- 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

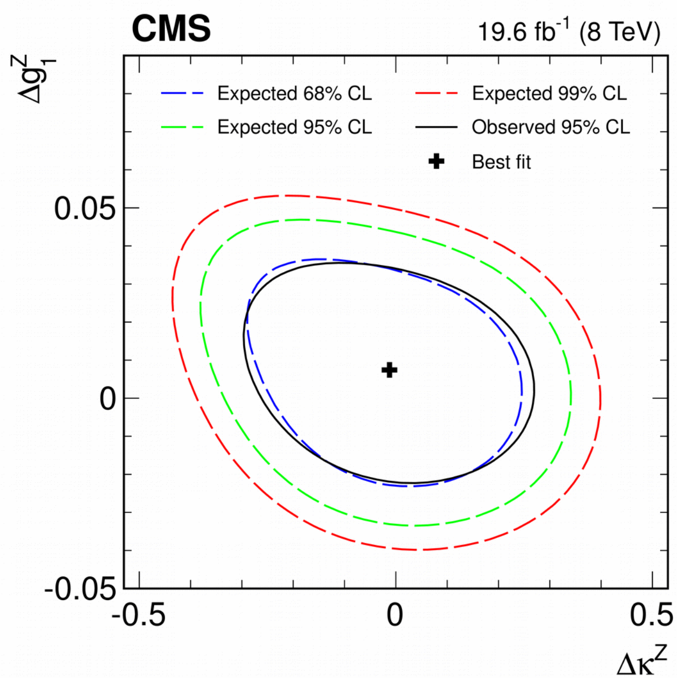




SMP-14-016



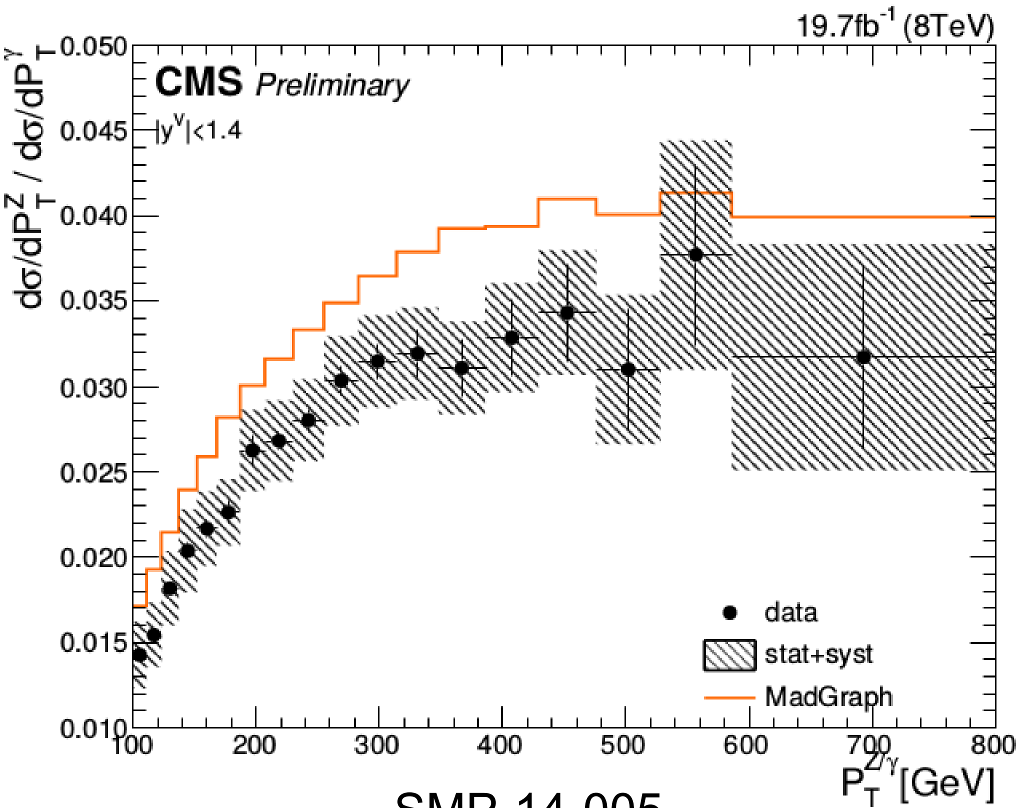
SMP-14-014



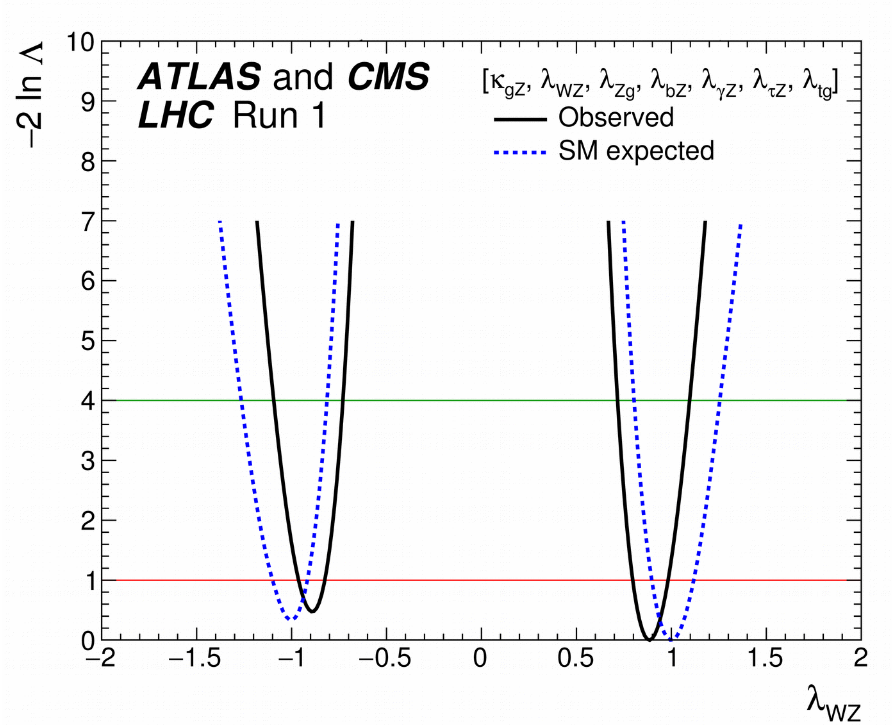
SMP-14-014

Improving the precision

- 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



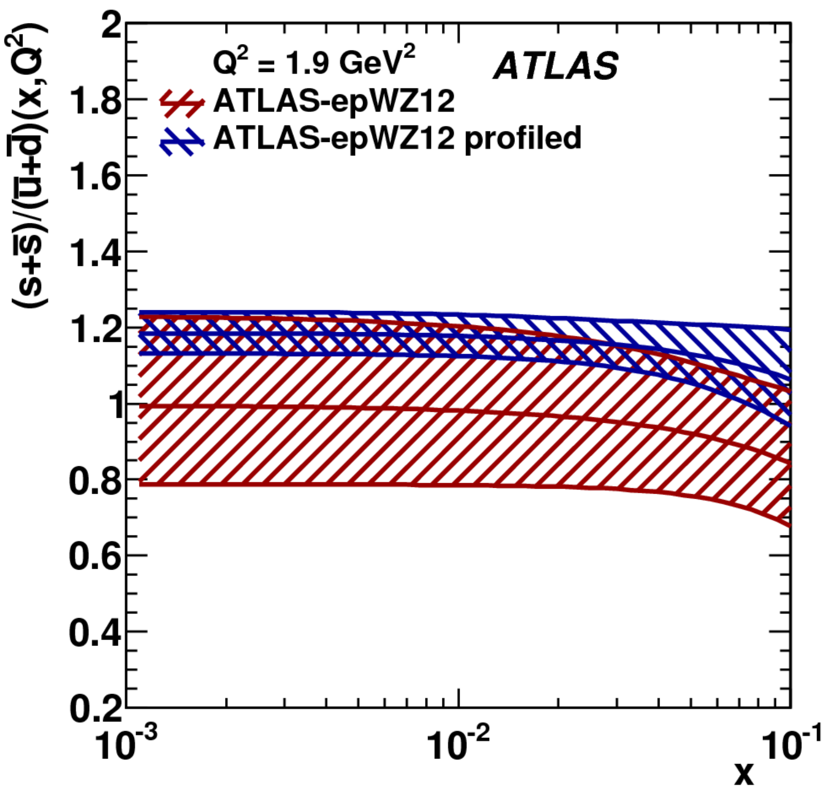
SMP-14-005



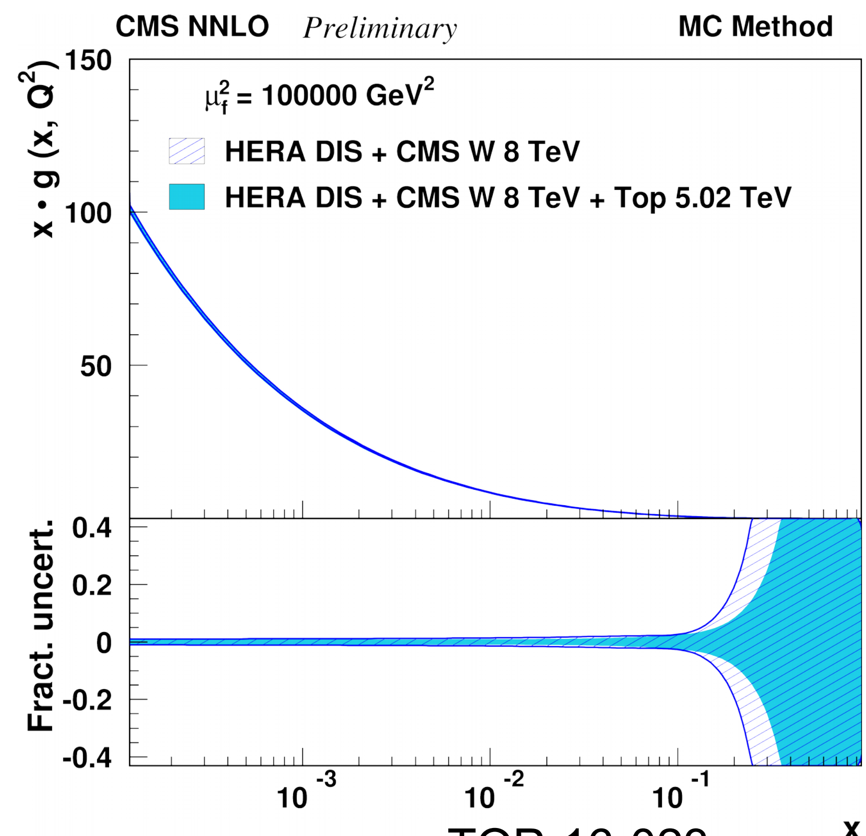
HIG-15-002

Interplay between analyses

- Precise knowledge of Standard Model processes essential for modeling of backgrounds for new physics:
  - W, Z, WW, … → background for Higgs searches
  - W, Z, …, Higgs, … → background for new physics
- Improvements in the ingredients for new physics
  - e.g. PDF knowledge from collider data → positive feedback from jets,vector boson(s), ... measurements

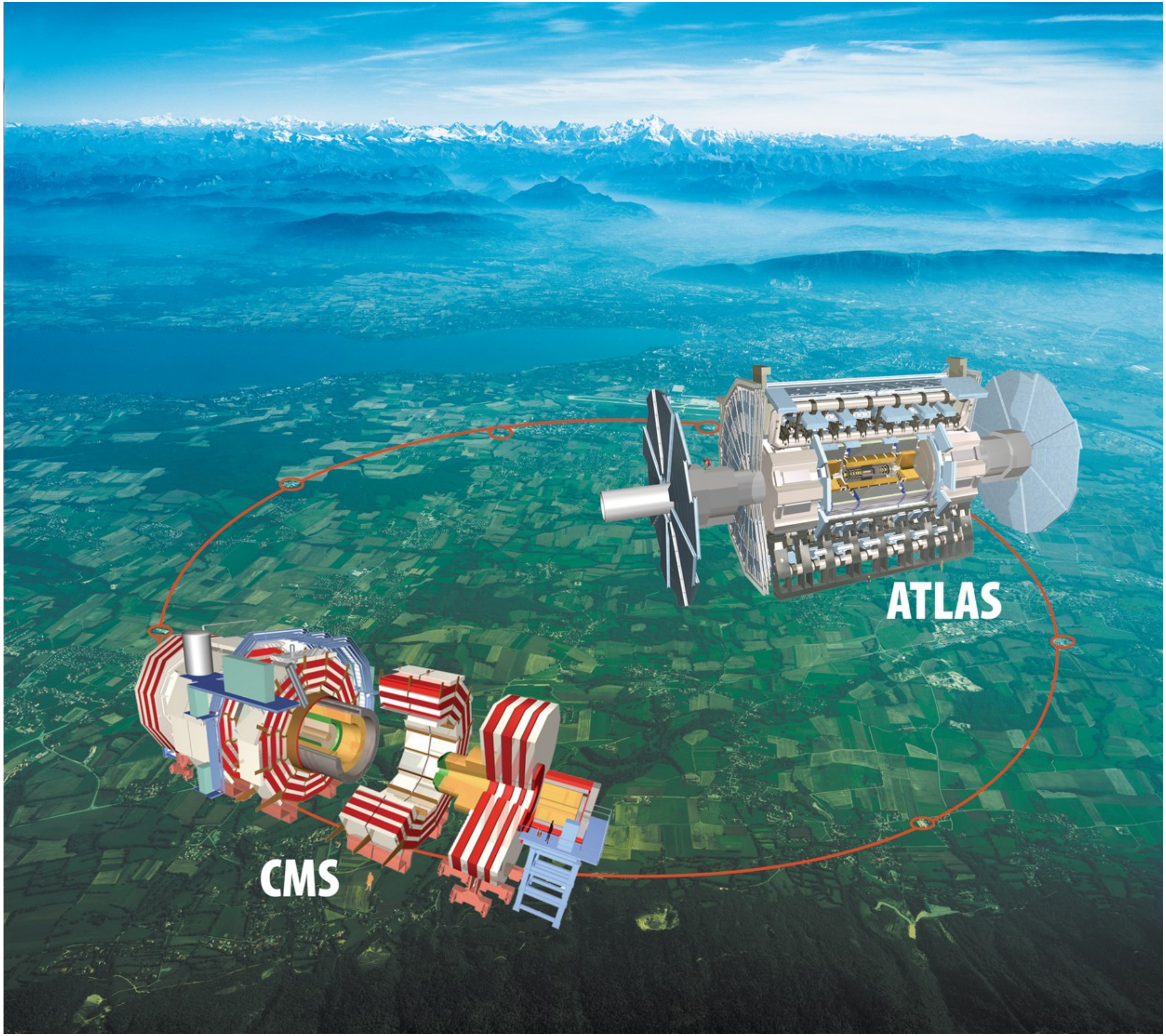


STDM-2012-20



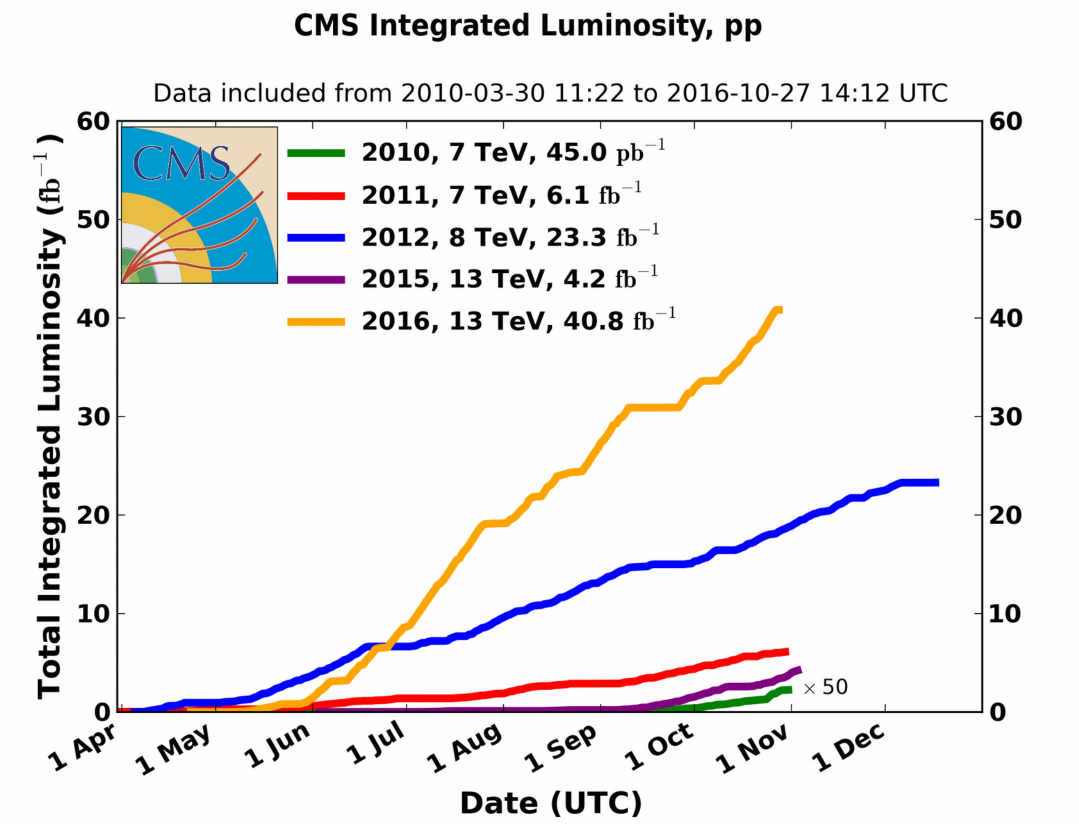
TOP-16-023

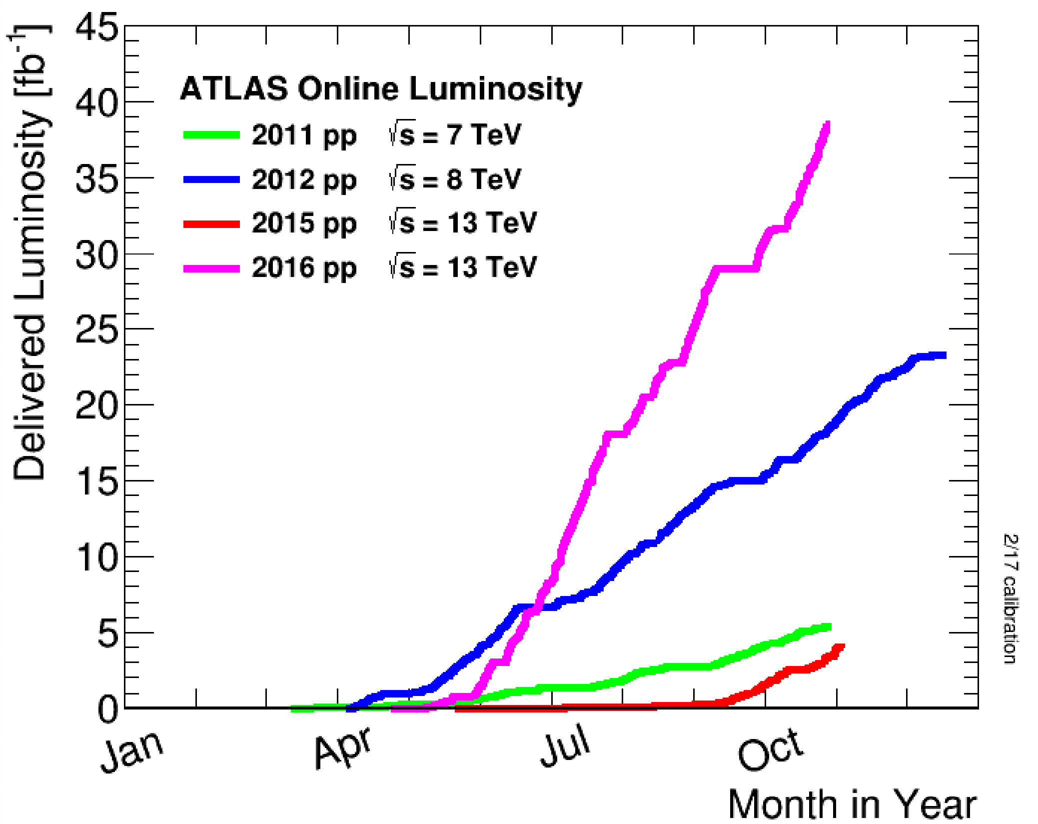
News from CMS and ATLAS



LHC, CMS, ATLAS in one slide

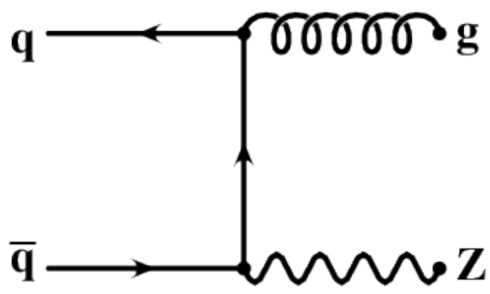
- Since 2015 we are taking data at 13 TeV of center of mass energy
- Higher instantaneous luminosity → higher pileup → challenging environment





Single Vector Boson production: Z

- $Z \rightarrow \mu\mu$ and $Z \rightarrow ee$
- Standard model *candle*: used for tag & probe, precision measurement, modeling for high energy resonances decaying into 2 leptons
  - $\sigma_{Z\rightarrow ll} \sim 6$ nb @ 13 TeV



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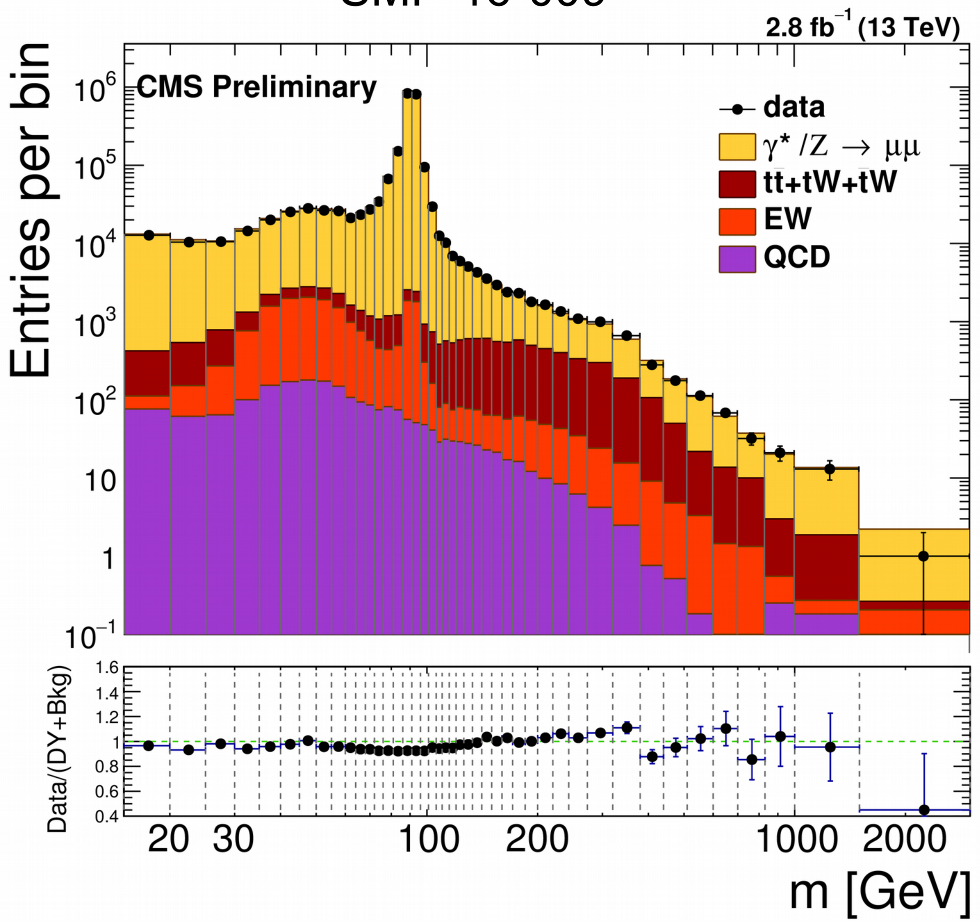
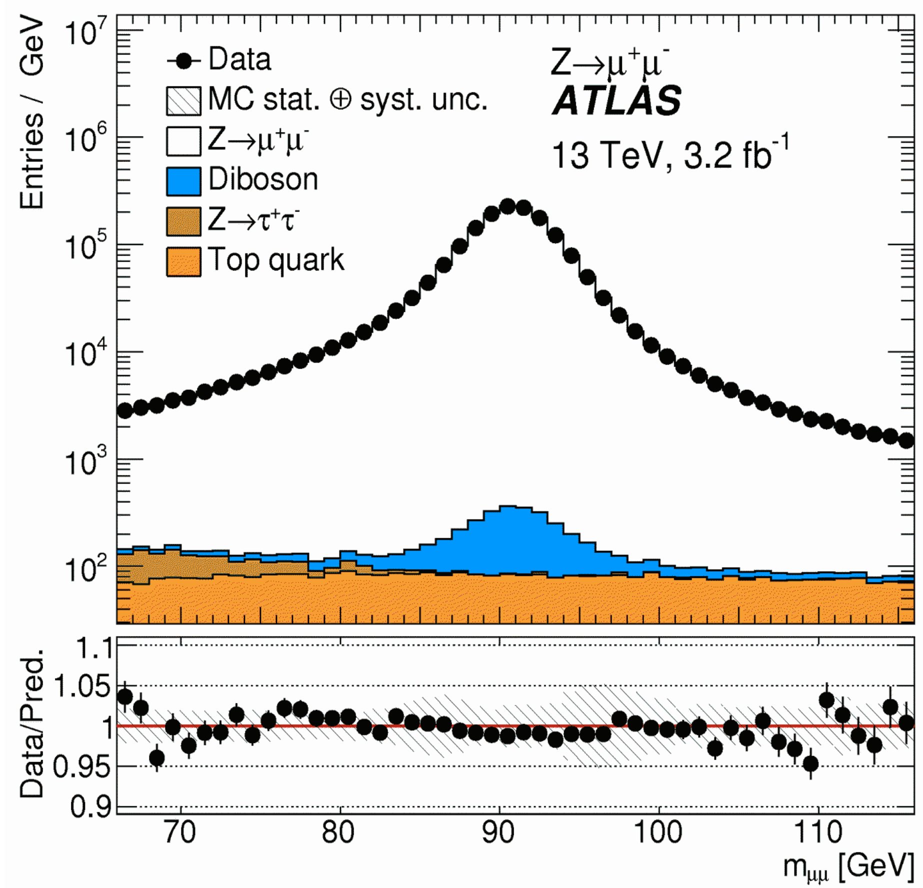
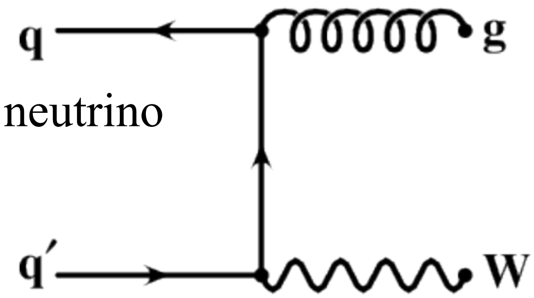


STDM-2016-01



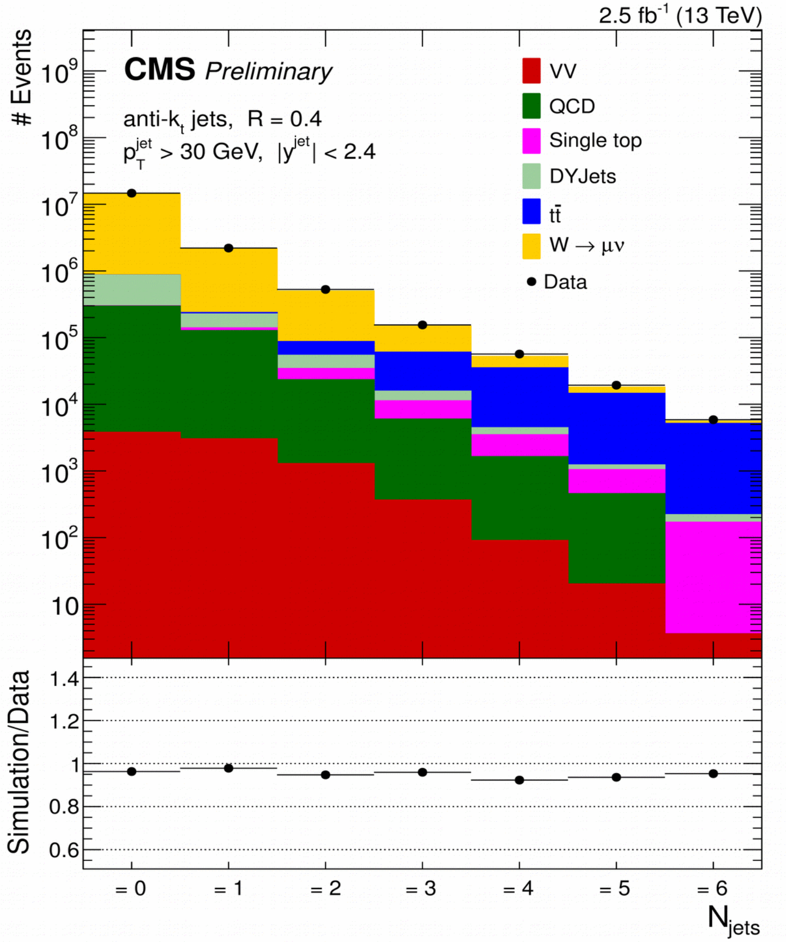
Single Vector Boson production: W

- $W \to \mu\nu$ and $W \to e\nu$
  - Missing transverse momentum from neutrino
    $\to$ transverse mass distribution
  - $\sigma_{W\to l\nu} \sim 61$ nb @ 13 TeV

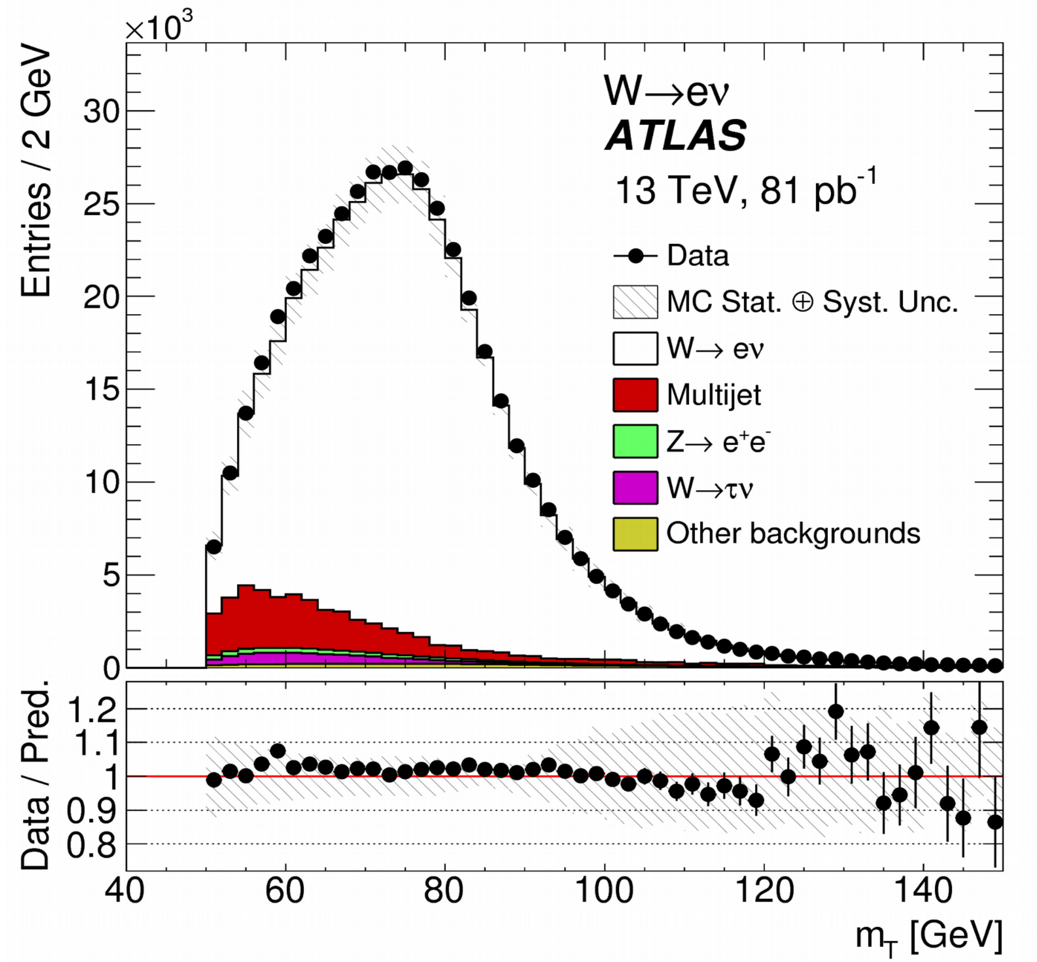


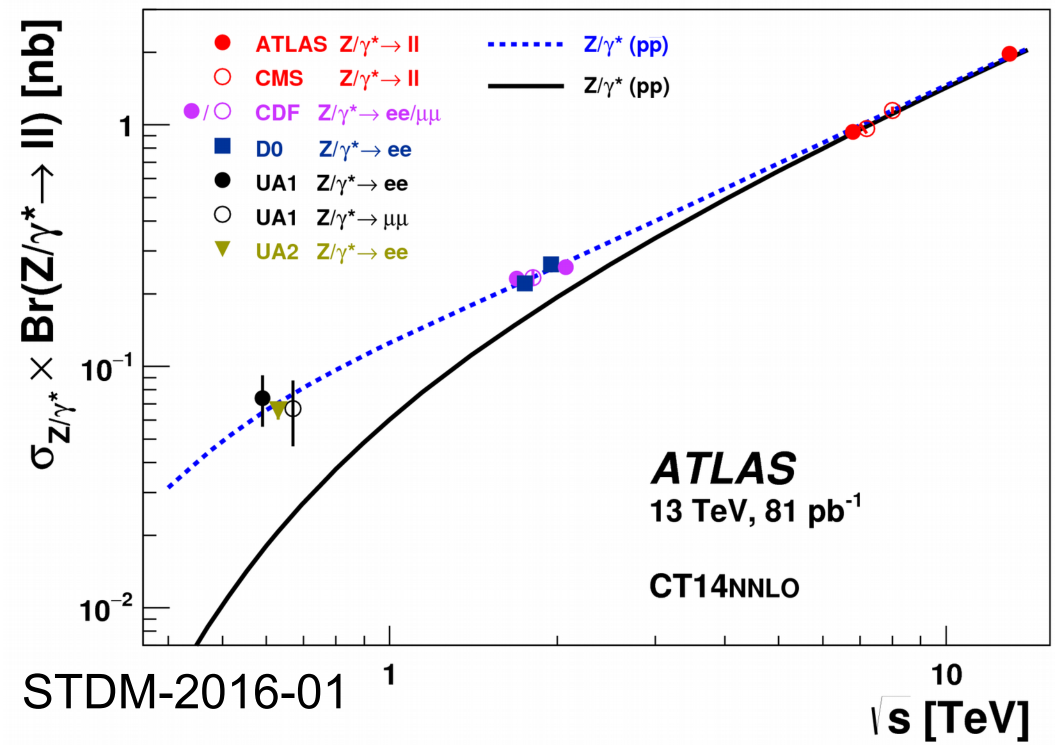
Prospects for a precise measurement of the W mass at LHC with the CMS detector
Elisabetta Manca

SMP-16-005



STDM-2016-02

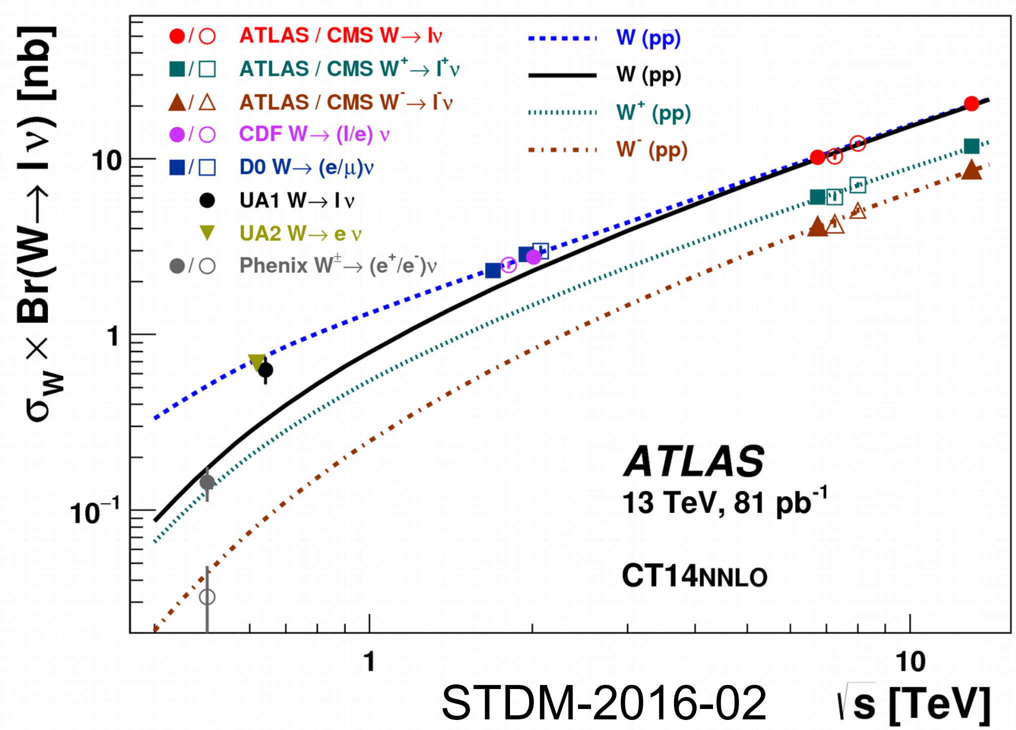




- Test of cross section at different center of mass energies
- Good prediction over different order of magnitudes

$$Z \rightarrow ll$$

$$W \rightarrow l\nu$$

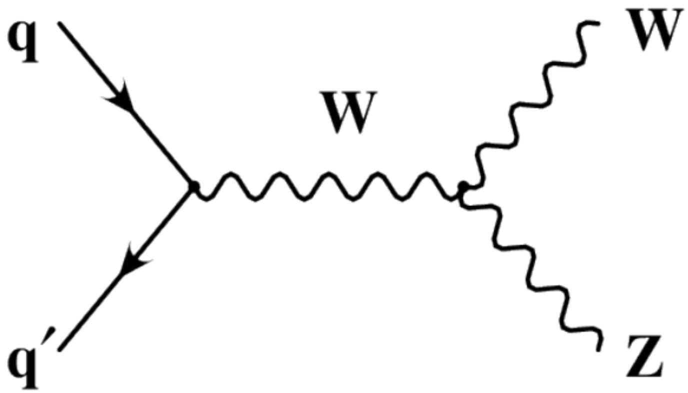


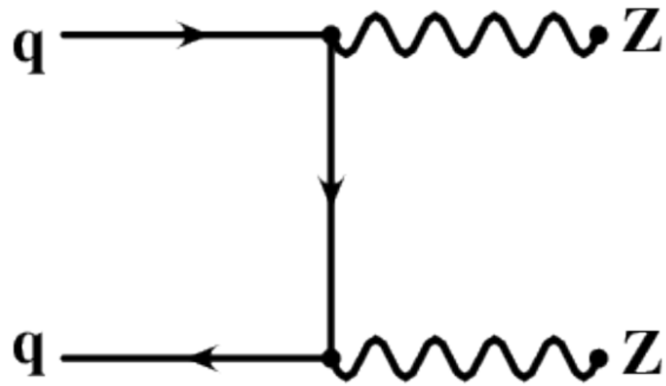
Misure di precisione

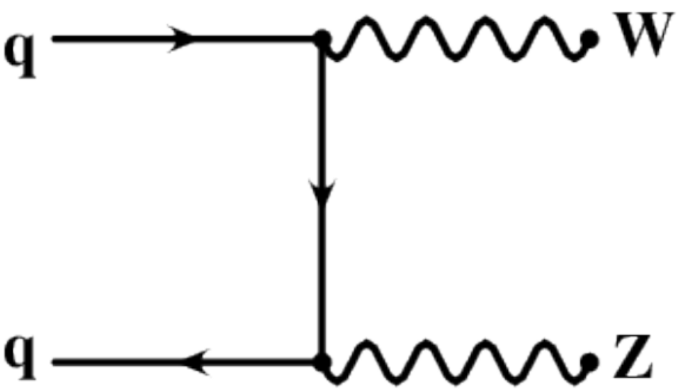
dei bosoni vettori W e Z ad ATLAS

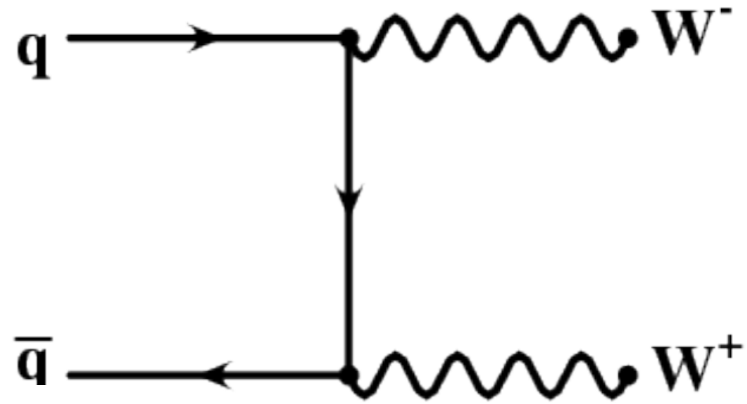
Camilla Vittori

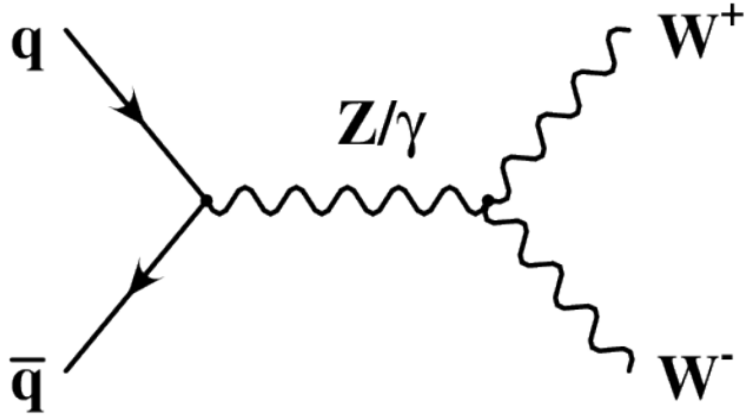
Vector Bosons production





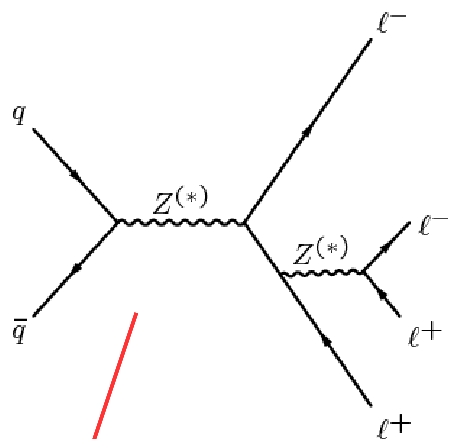


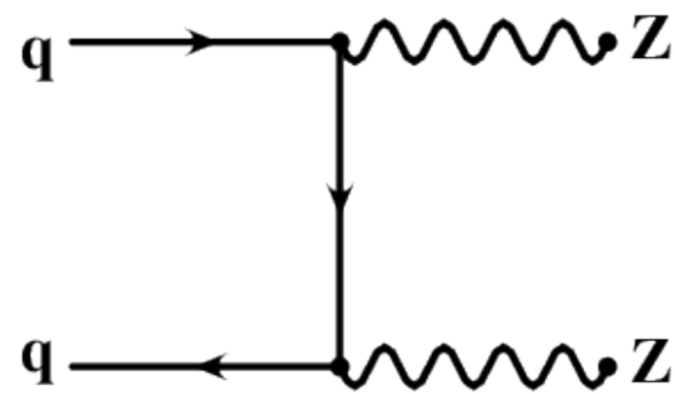




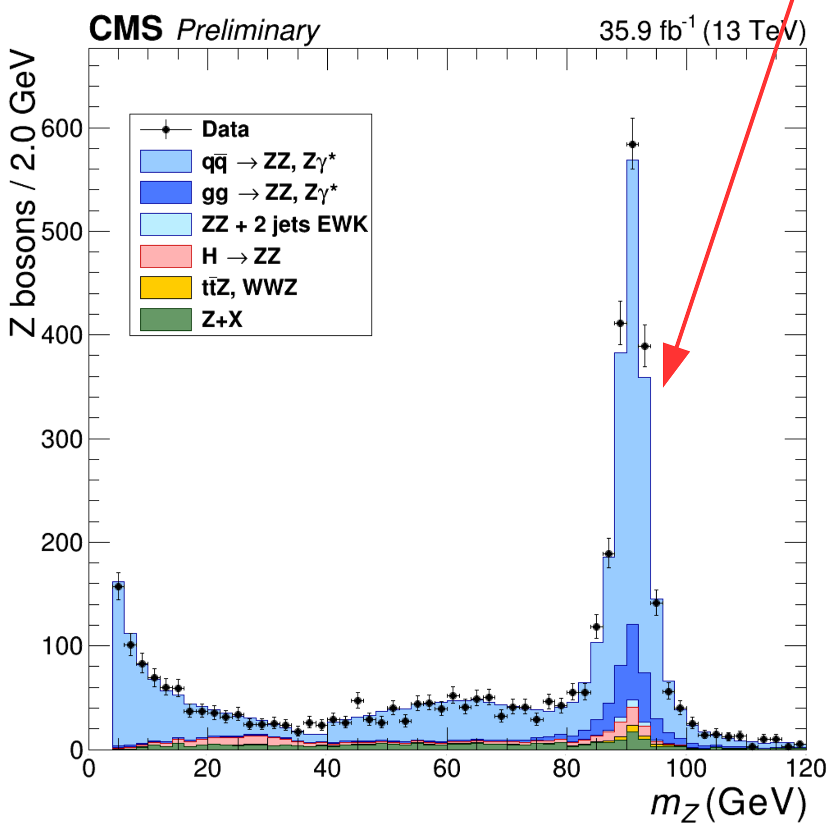
ZZ

- Clear signature → e.g. 4 leptons
- High signal / background ratio
- $\sigma_{ZZ\to 4l} \sim 1.2$ pb @ 13 TeV

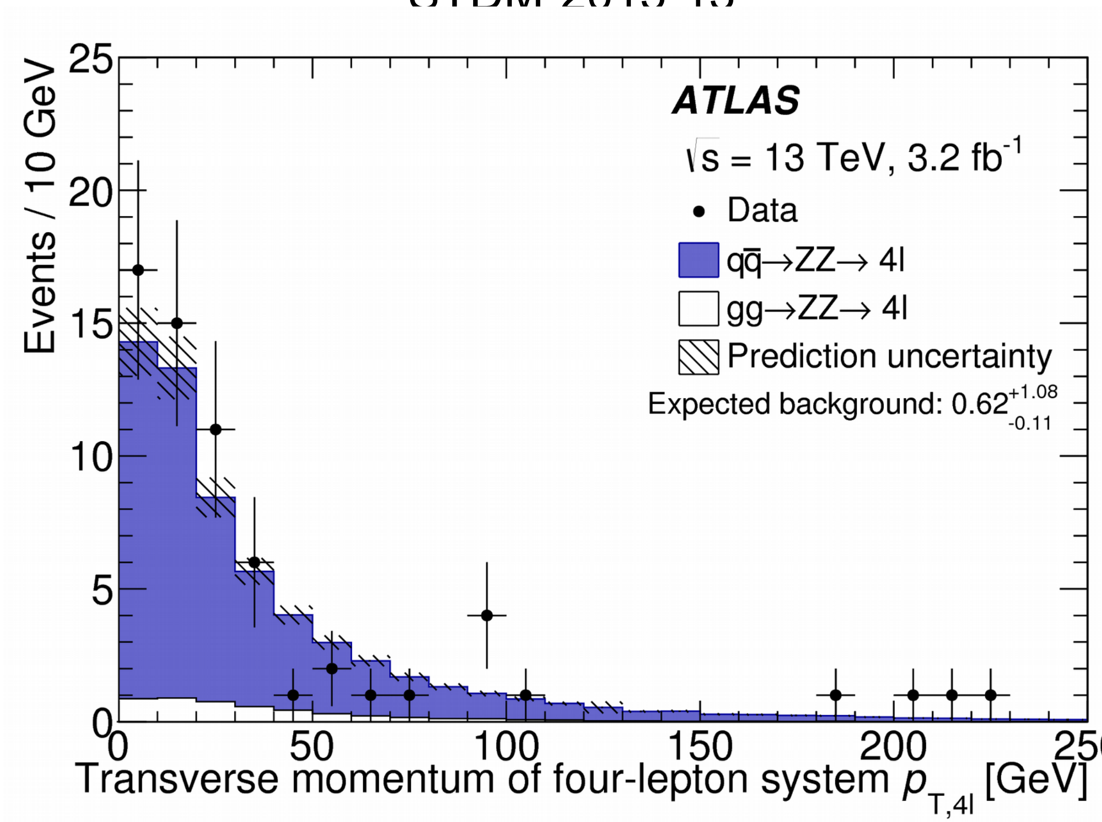




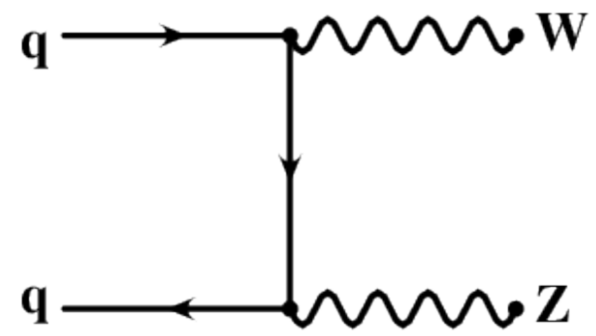
SMP-16-017



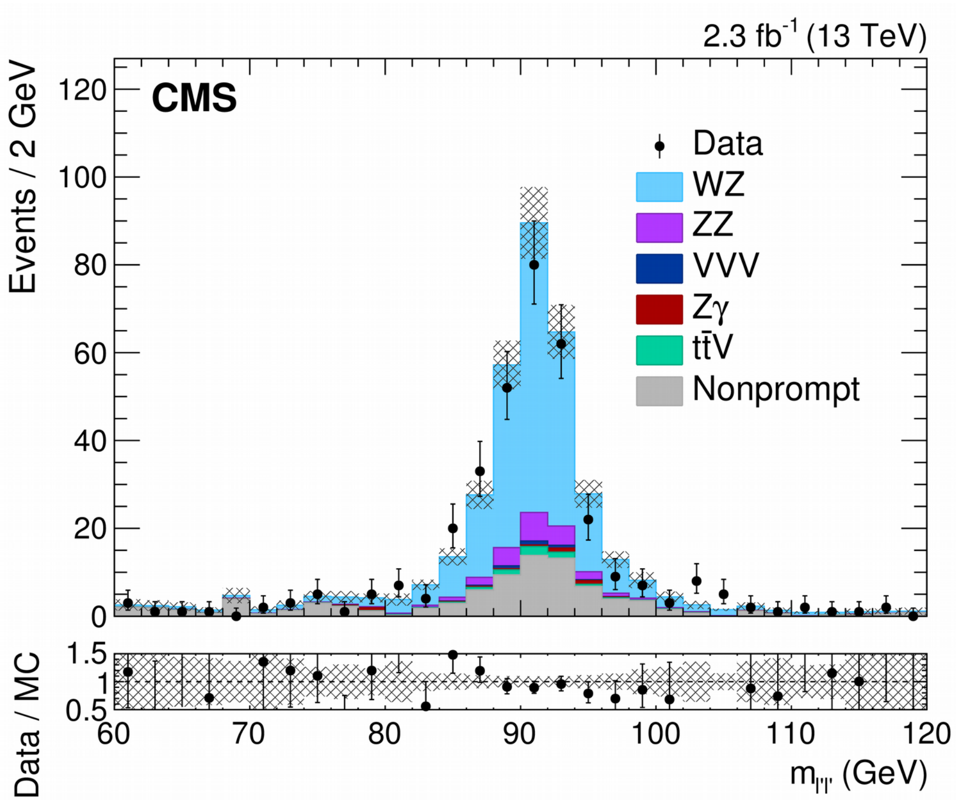
STDM-2015-13



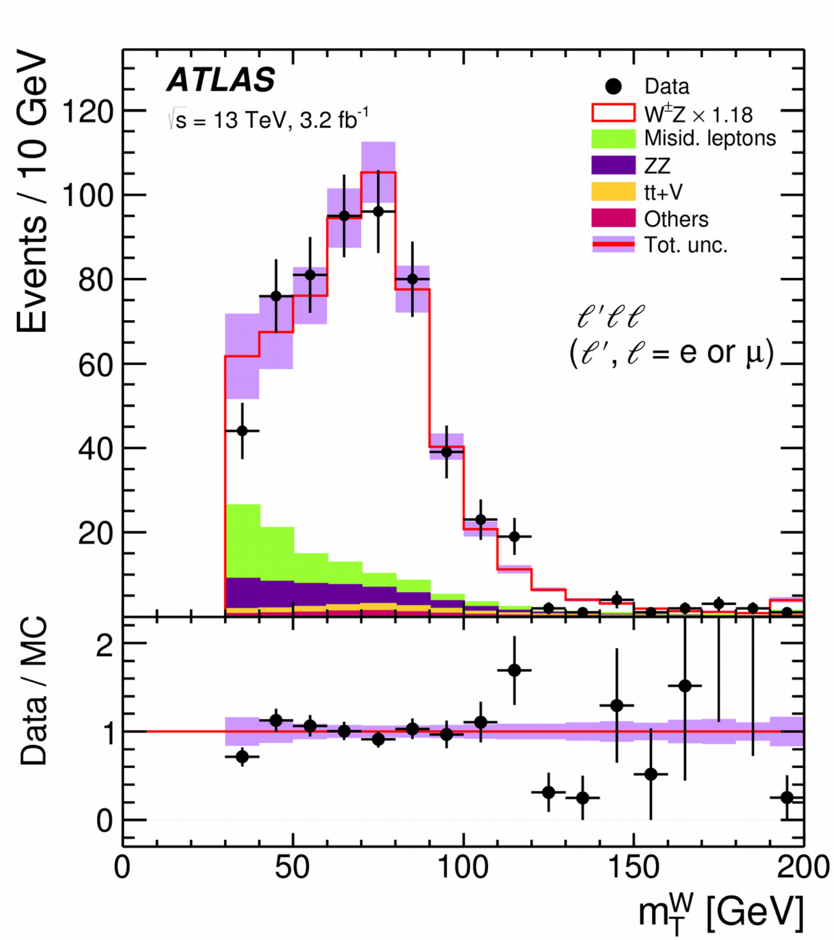
- Clear signature → e.g. 3 leptons
- High signal / background ratio
- $\sigma_{WZ \rightarrow 3l\nu} \sim 5$ pb @ 13 TeV



SMP-16-002

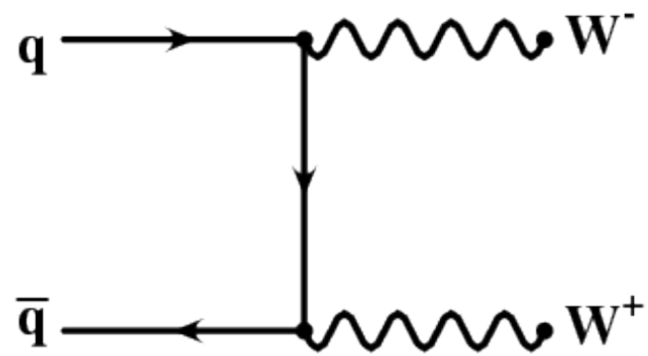


STDM-2015-19



WW

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



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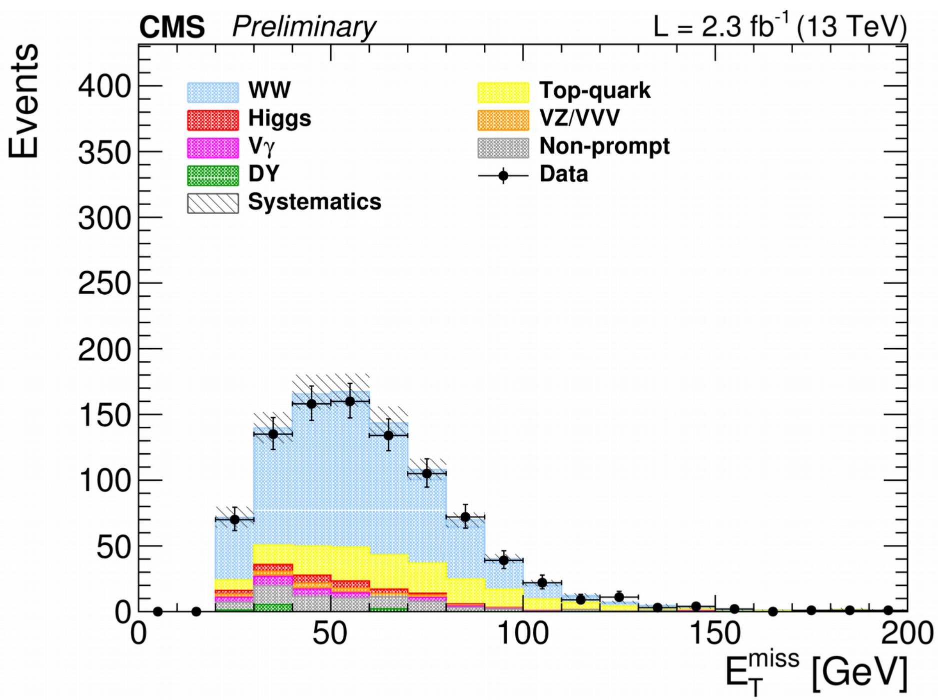
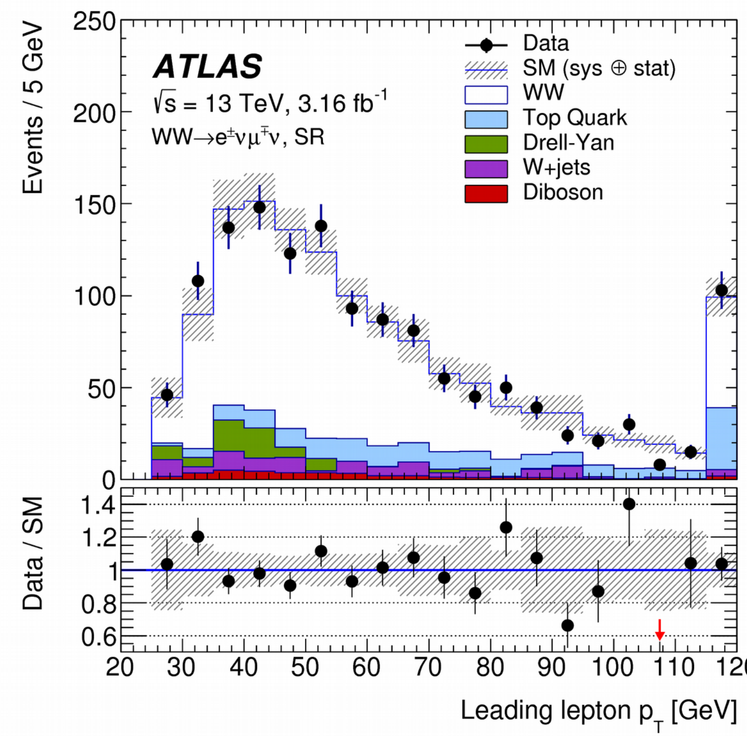
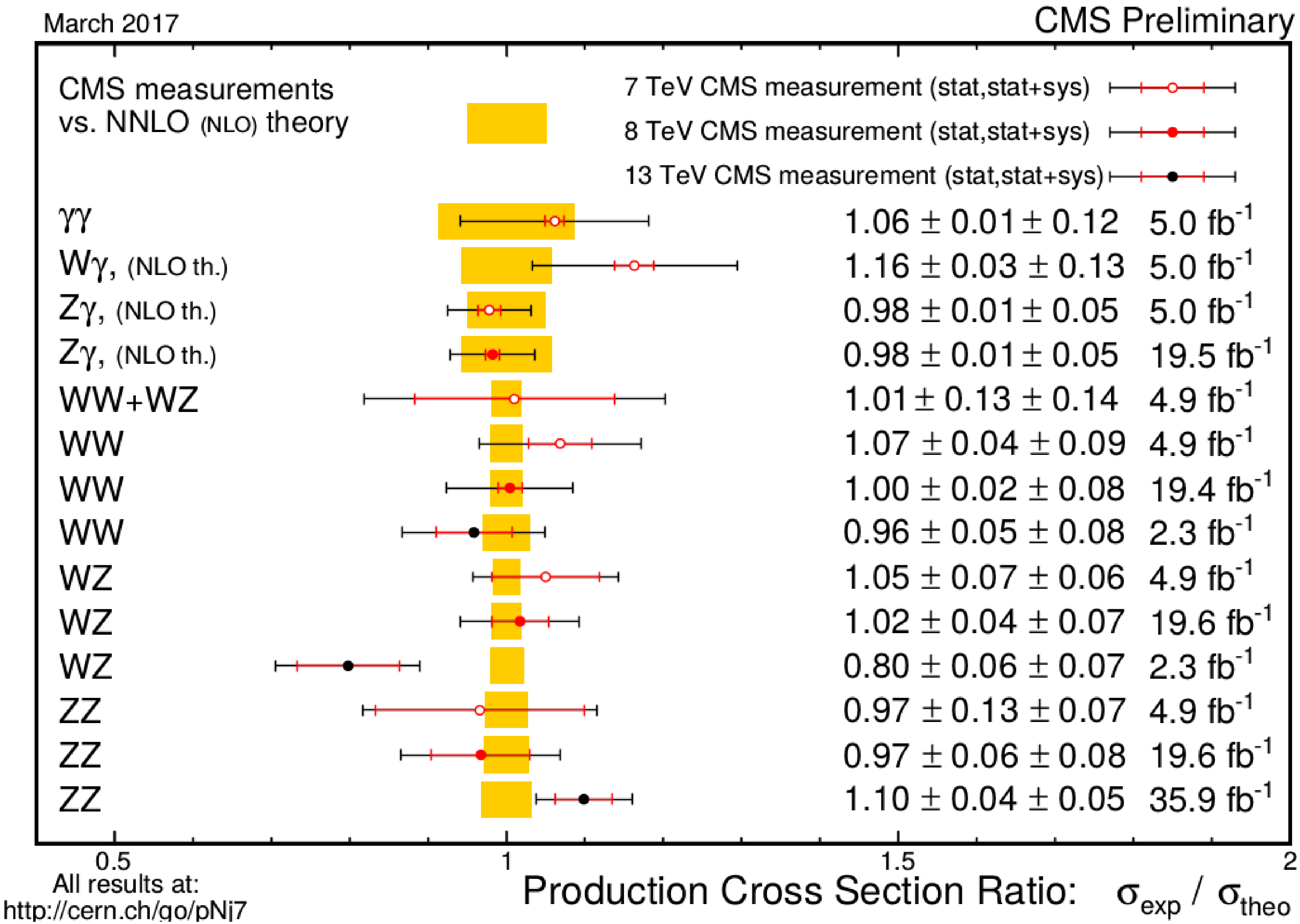


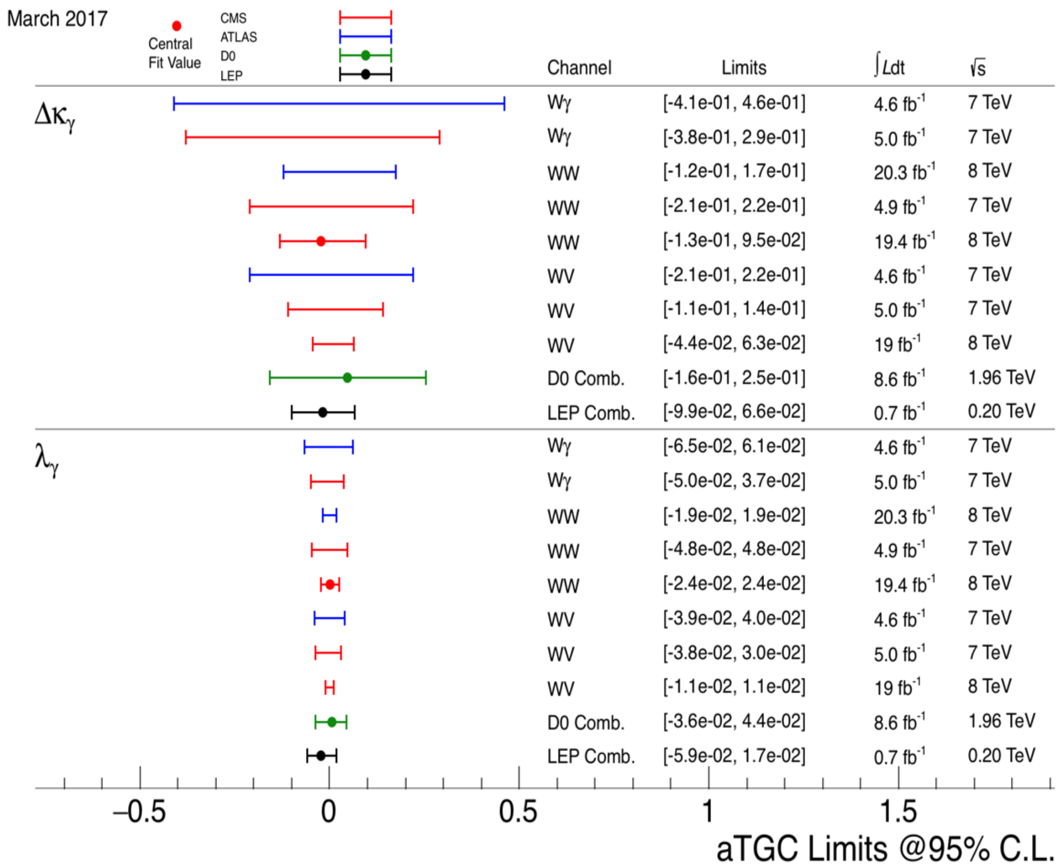
STDM-2015-20

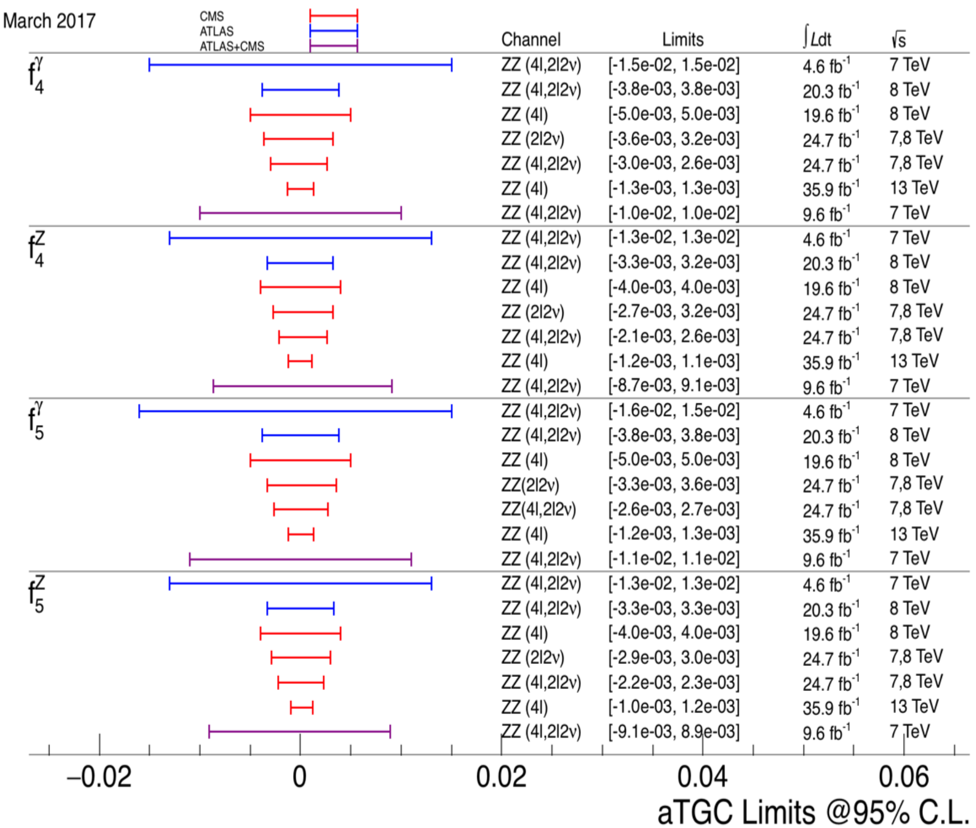


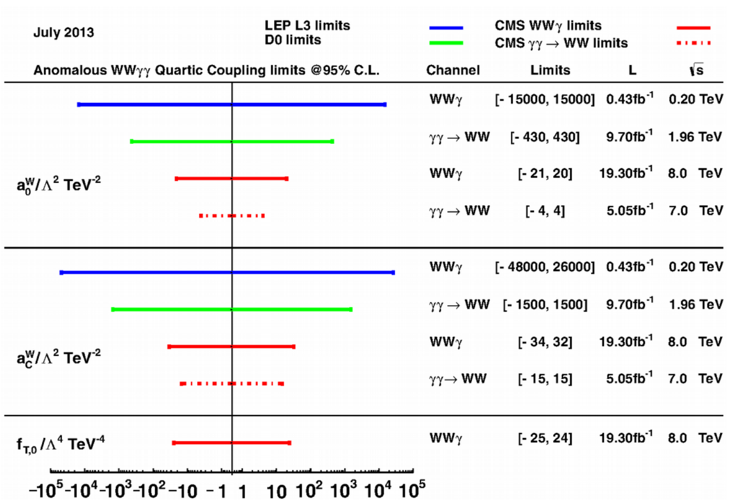
Big summary table



Anomalous gauge couplings

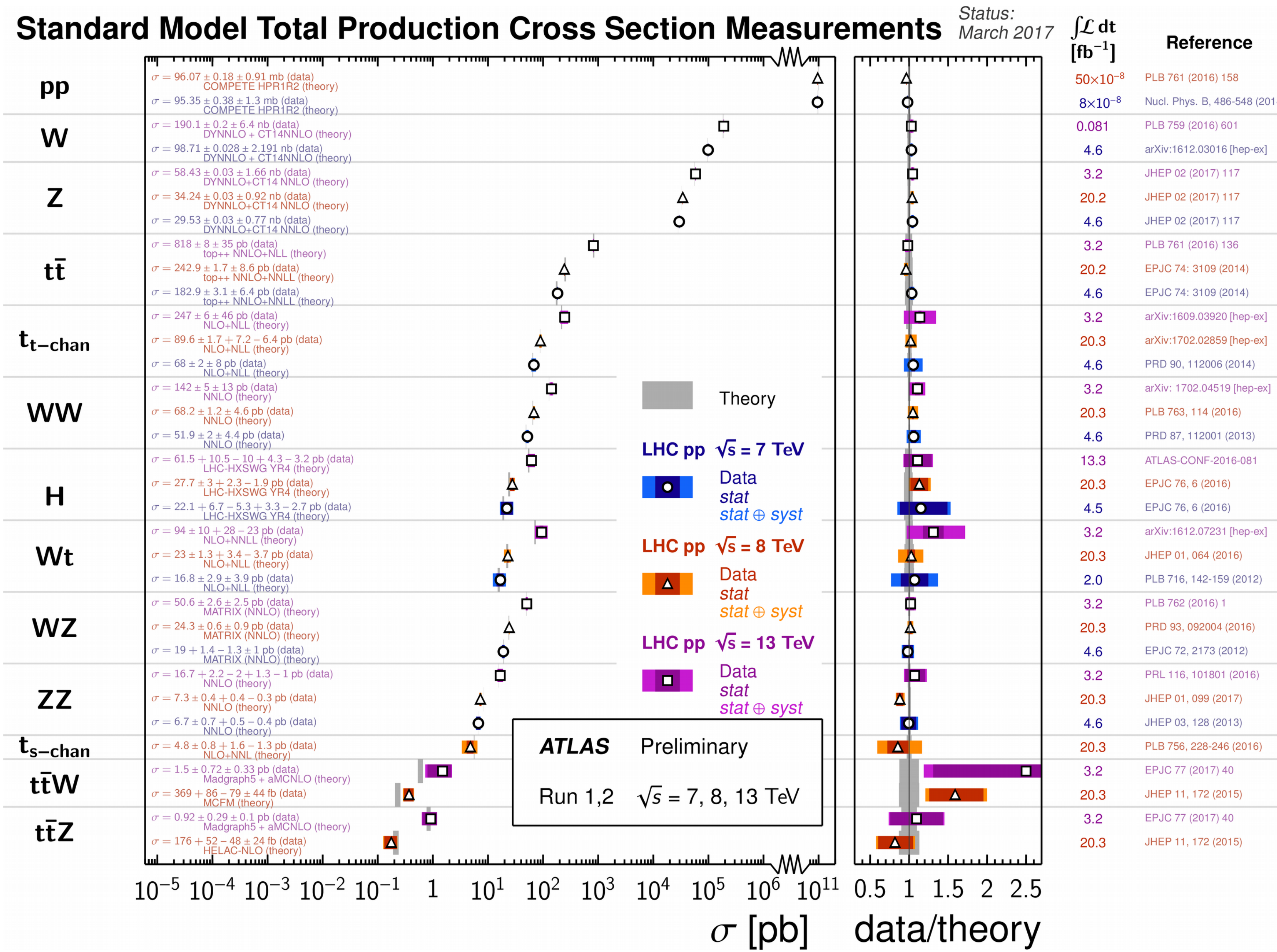






- Charged Anomalous Triple Gauge Couplings
- Neutral Anomalous Triple Gauge Couplings
- Anomalous Quartic Gauge Couplings

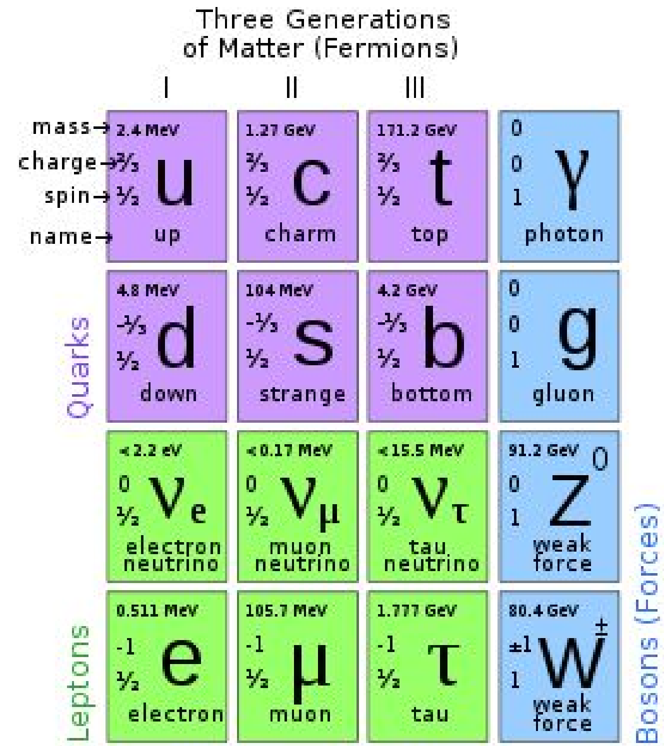
Big summary table (cont)

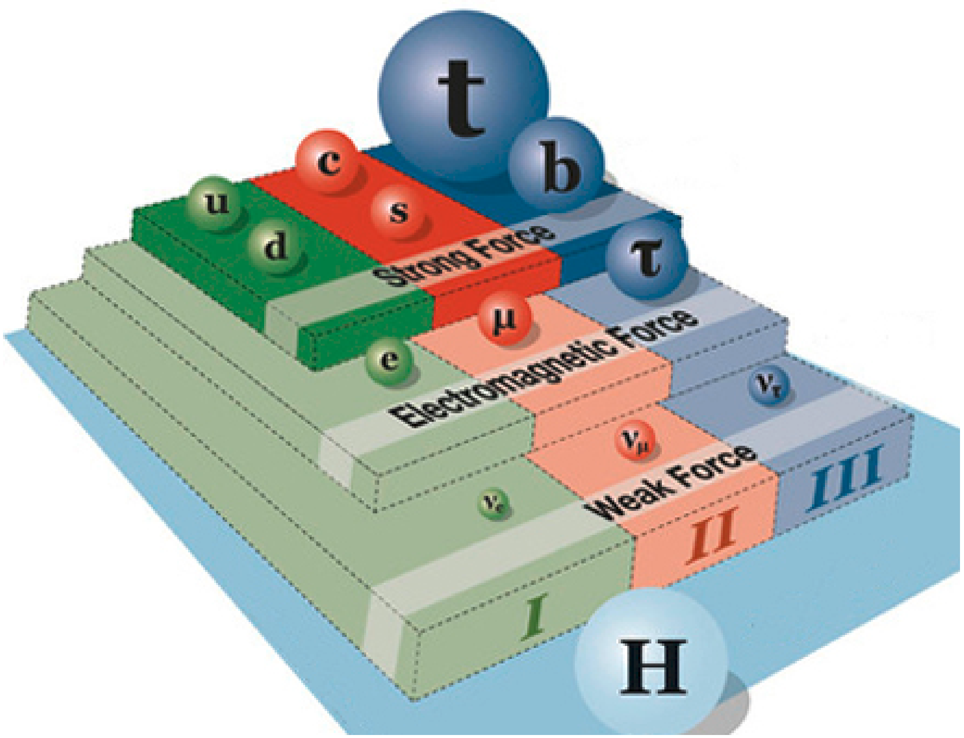


Top

- Heaviest quark ~ **172 GeV**
- Rather "young" particle: 22 years old since discovery
- Studied in different collider environments (pp, $p\bar{p}$)

  and at different center of mass energies
- Precision measurement and hints for new physics from discrepancies between predictions and observations



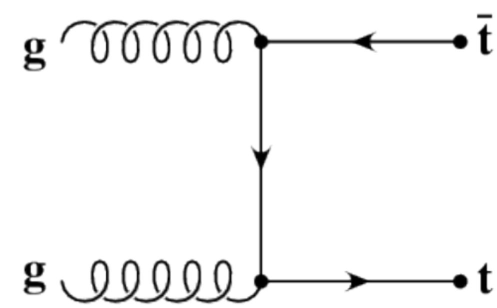


Top quark mass measurement
with soft muons from b-hadron decay
Maurizio De Santis

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

$t\bar{t}$

- Fully leptonic, semi-leptonic and all-hadronic decays considered
- $\sigma_{tt\rightarrow l\nu l\nu bb} \sim 87$ pb @ 13 TeV
- Many measurements: cross section, inclusive, differential and fiducial, top mass, polarization, asymmetries, width, rare decays, ...



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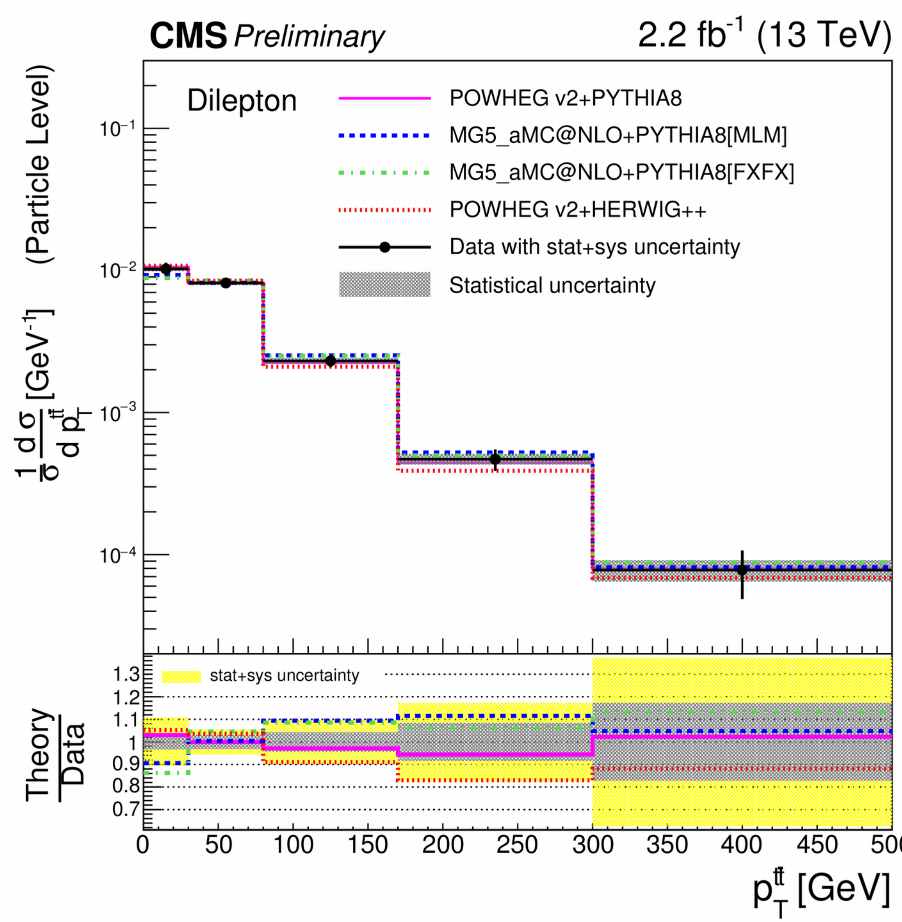
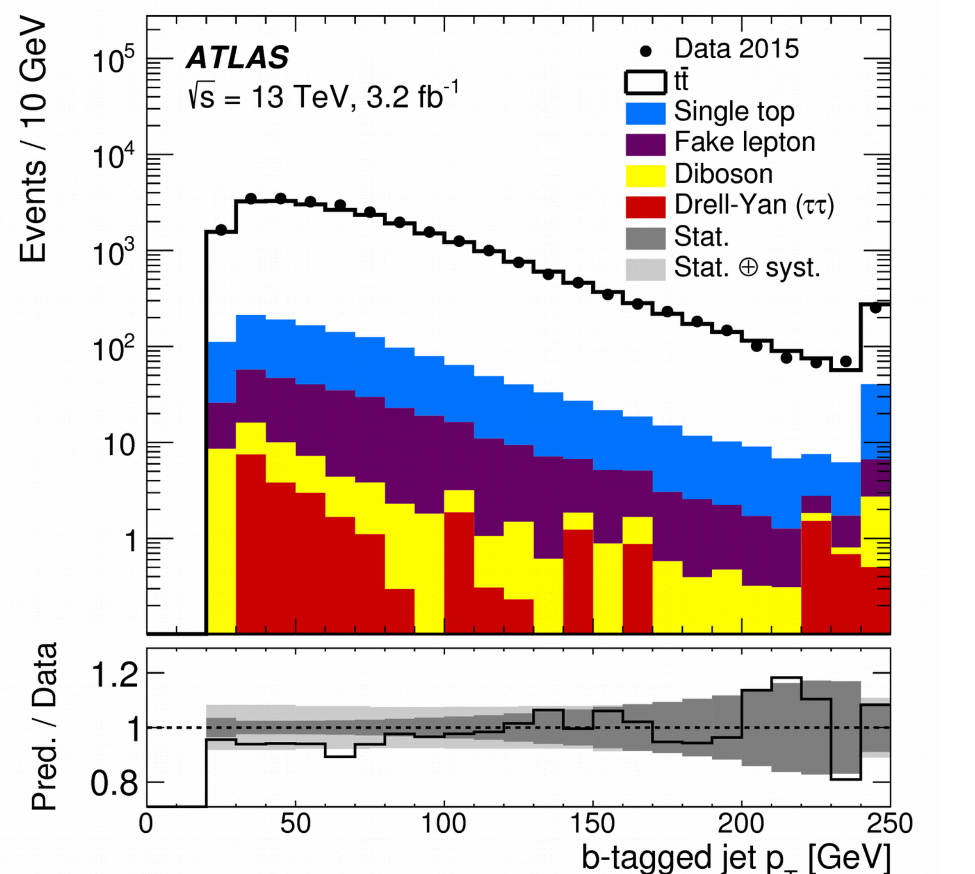
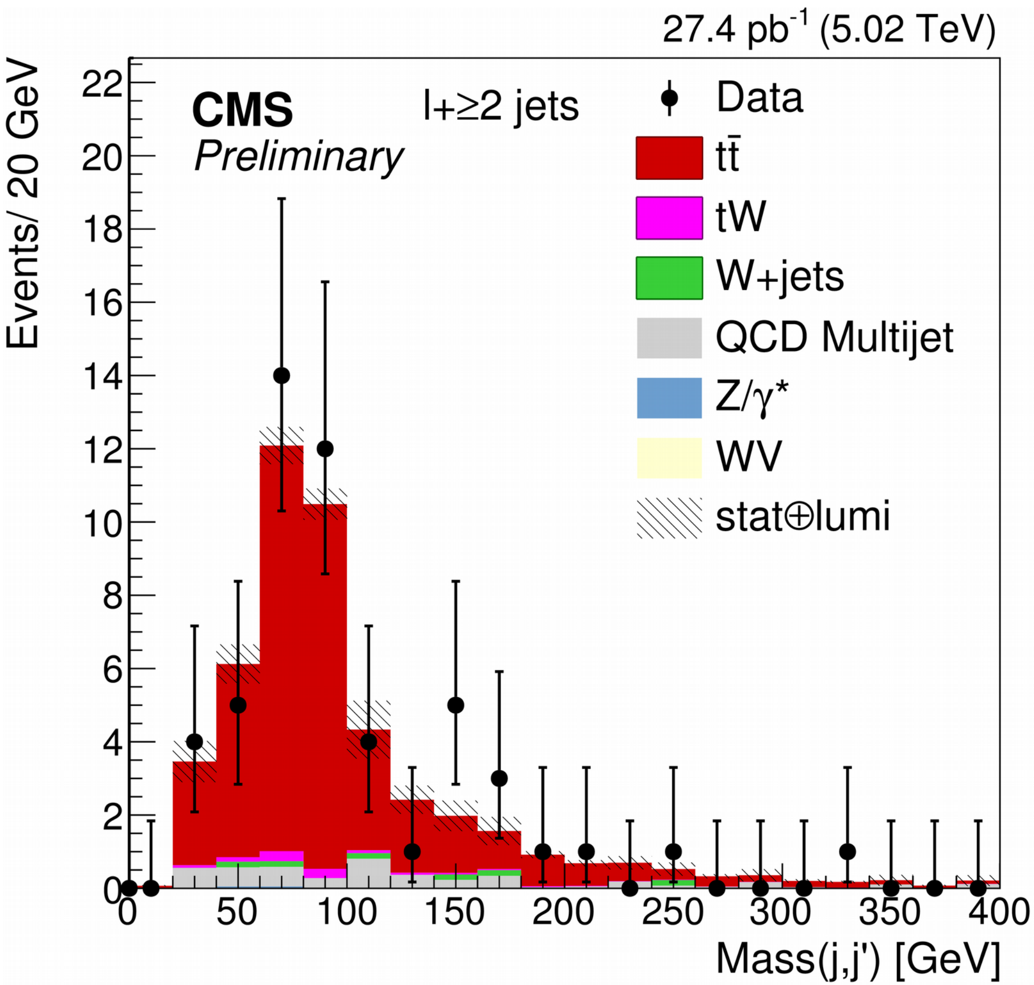


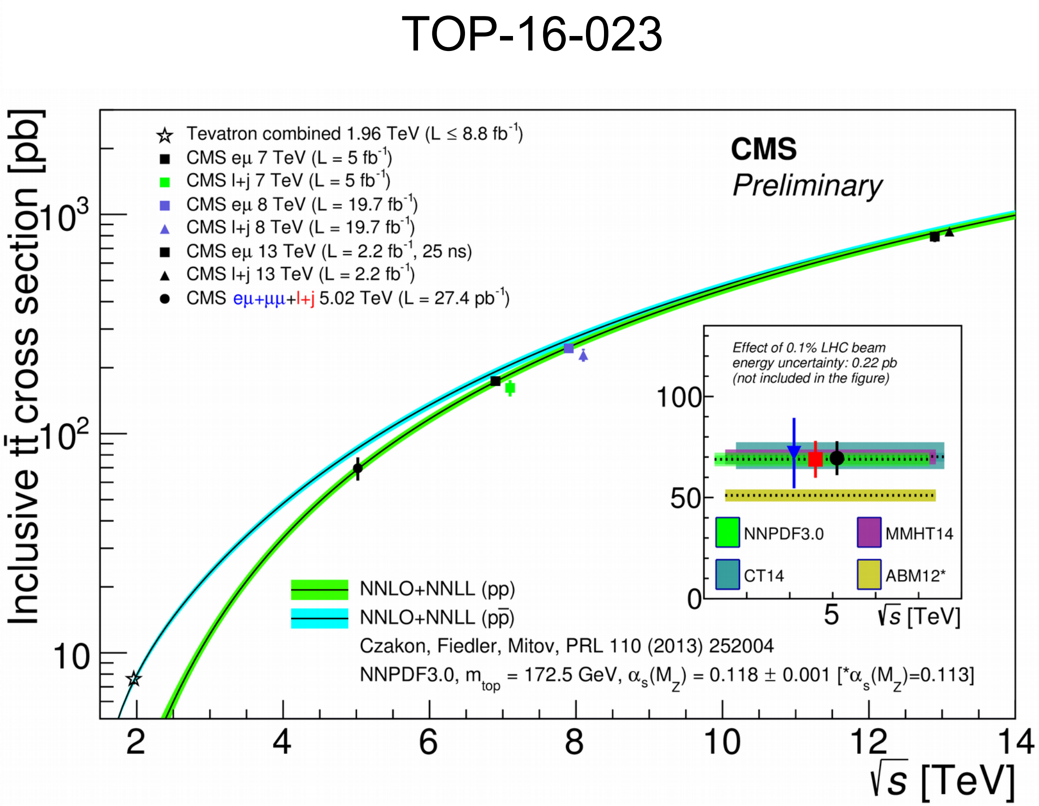
TOPQ-2016-04



Recent result: $t\bar{t}$

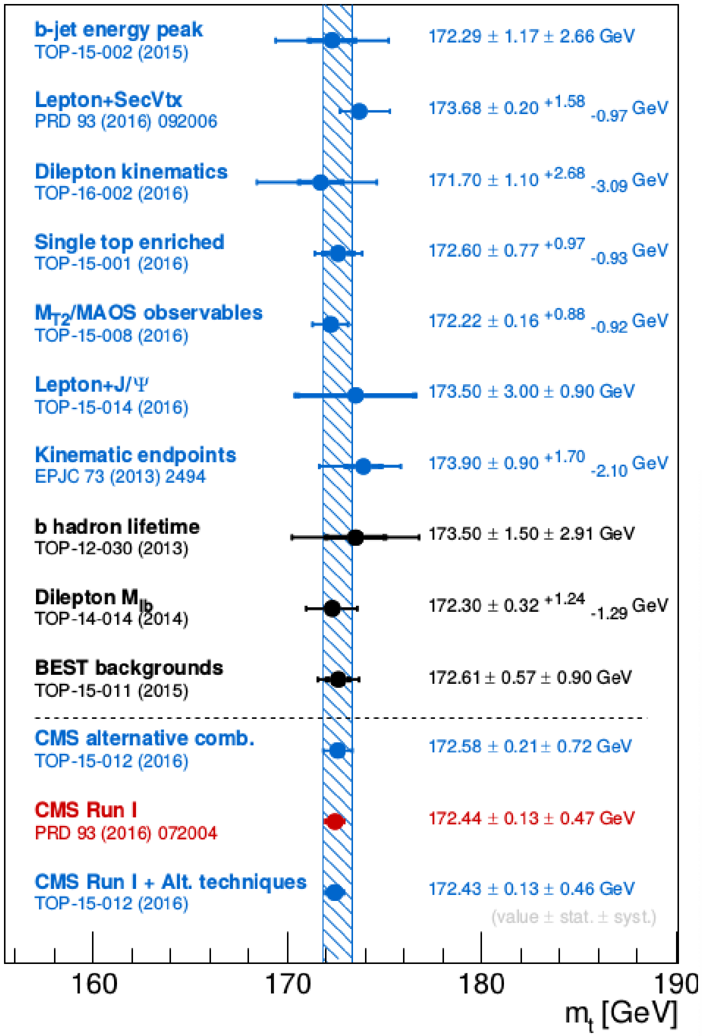
- Special topic: $\sqrt{s}$ = **5.02** TeV
- Just 27 pb^{-1} of data
- Fully leptonic and semileptonic measurement
- Good for PDF fitting because it offers different sensitivity than higher energy measurements

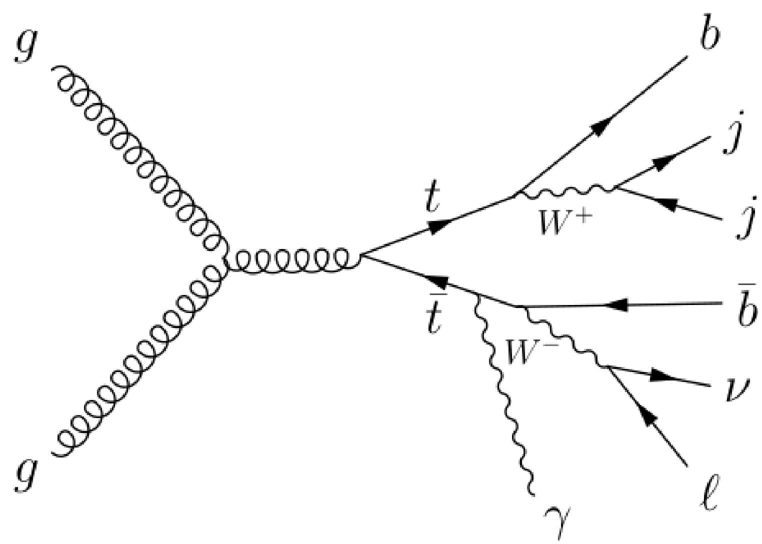


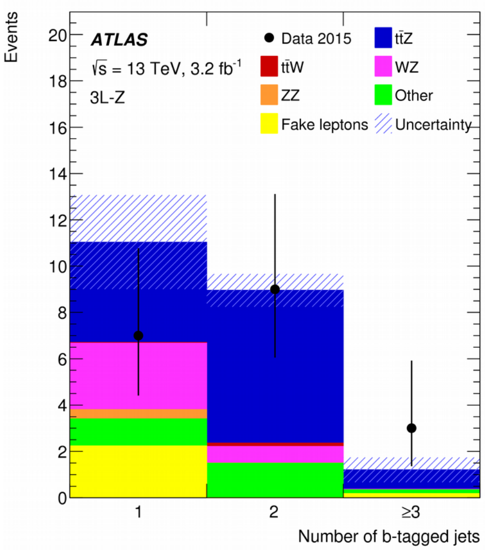


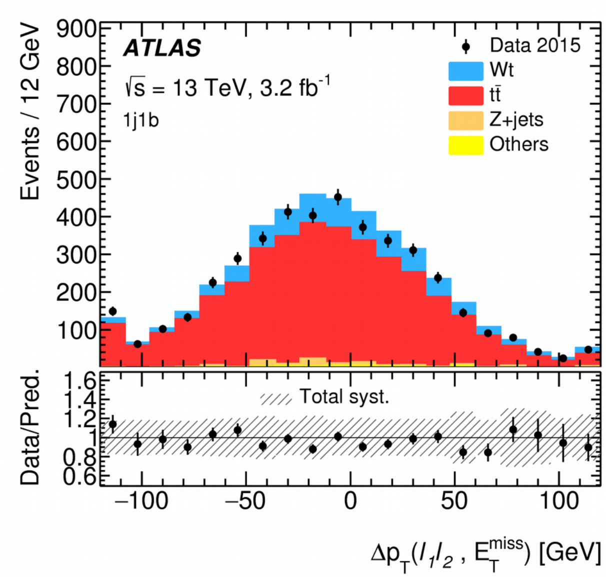
Many more

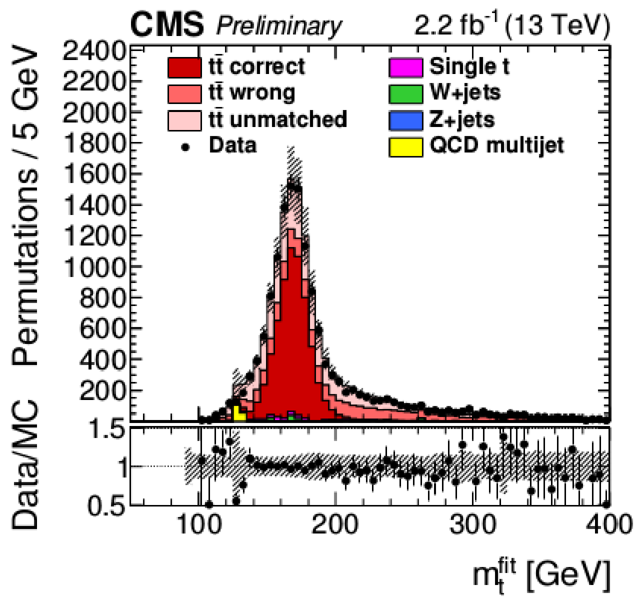
- Single top, tW, differential, top mass measurement, top – antitop mass difference, tt + γ, tt +V, ...





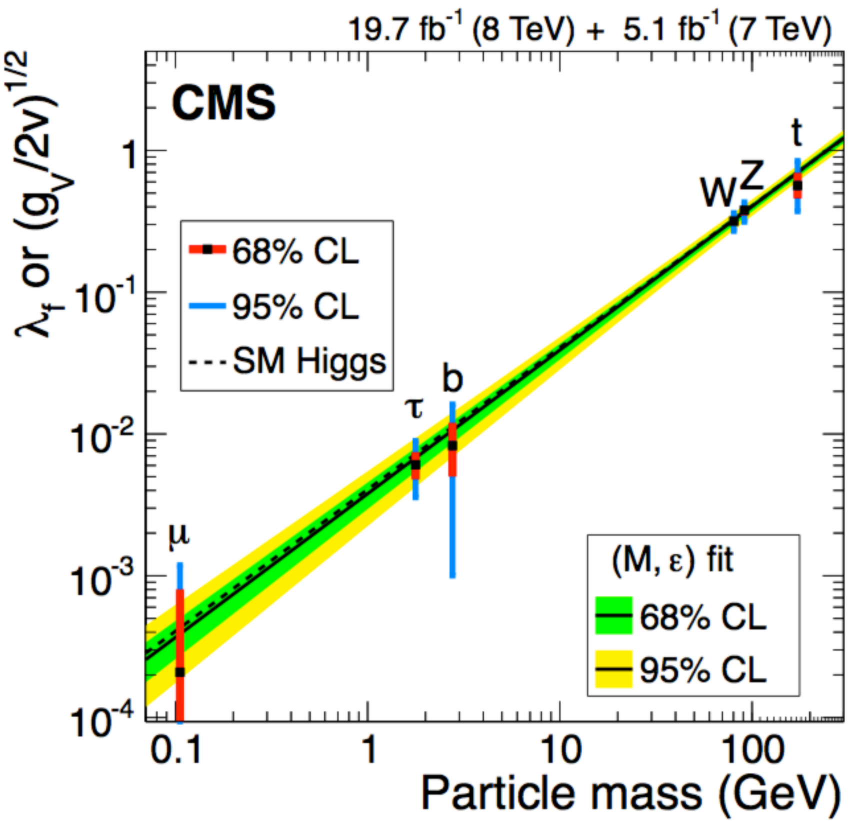




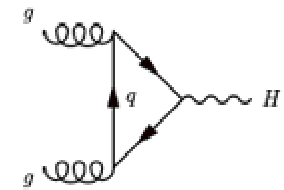


Cross over: top & Higgs

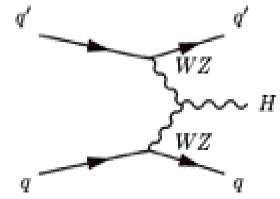
- Top – Higgs
  - Top Yukawa coupling
  - x 4 in cross section at 13 TeV w.r.t. 8 TeV
  - New physics … answer the original question



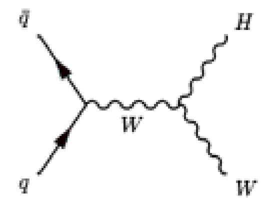
ggH 48.58 pb



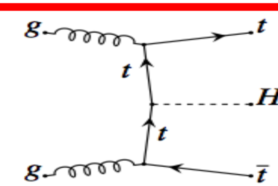
qqH 3.78 pb

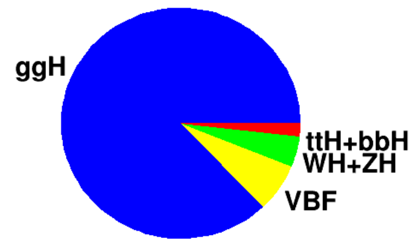


WH+ZH 2.38 pb



ttH+bbH 1.0 pb

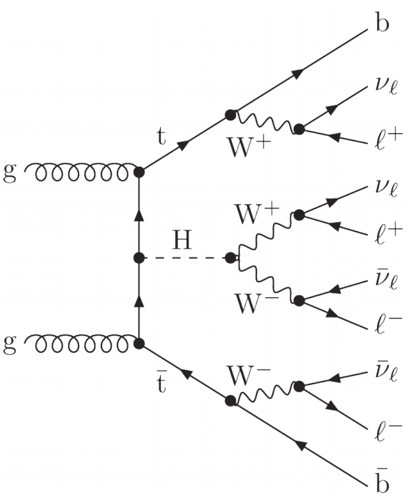




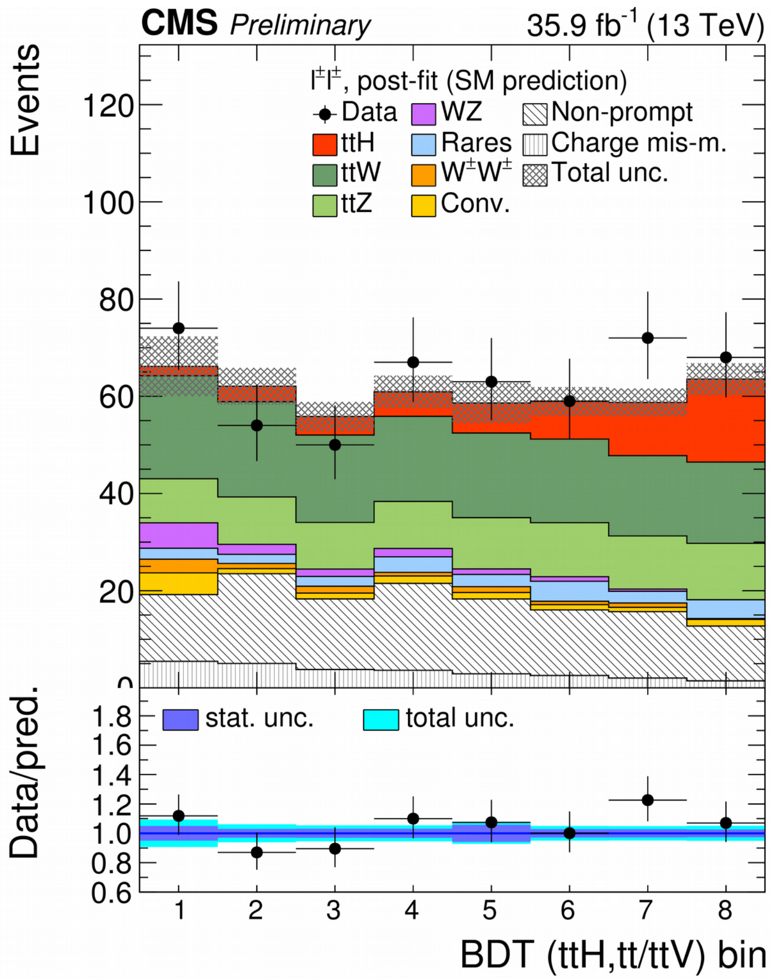
m_H = 125 GeV
13 TeV

Cross over: top & Higgs

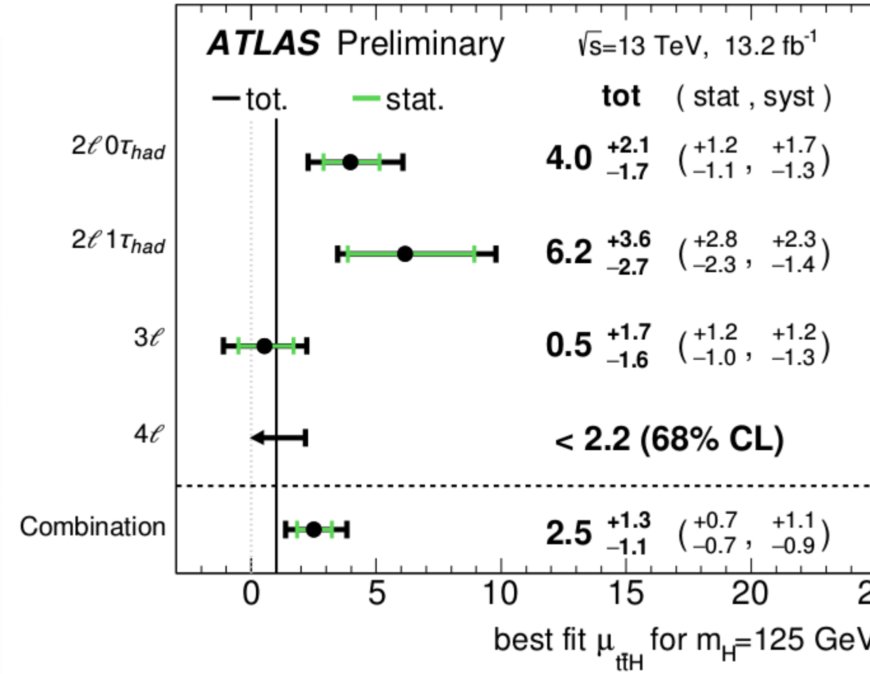
- **ttH** searches
- Multileptons final state (H → WW, ZZ, ττ), H → ττ, H → bb, H→ γγ
- Signal strength in multileptons: CMS = 1.5 ± 0.5 ATLAS = 2.5 ± 1.3
- ~ 3σ (1.7σ) significance observed (expected)



HIG-17-004



ATLAS-CONF-2016-058

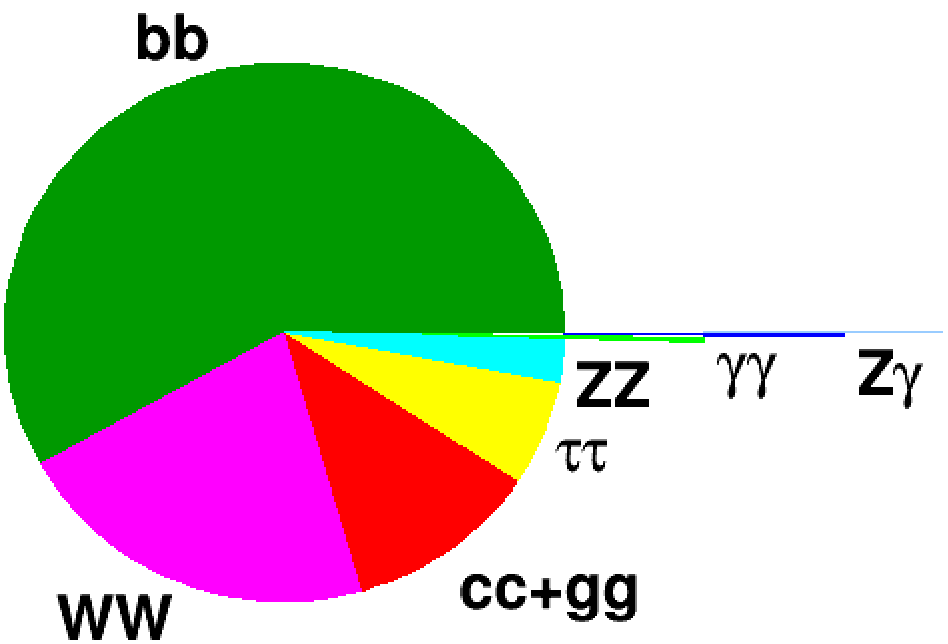


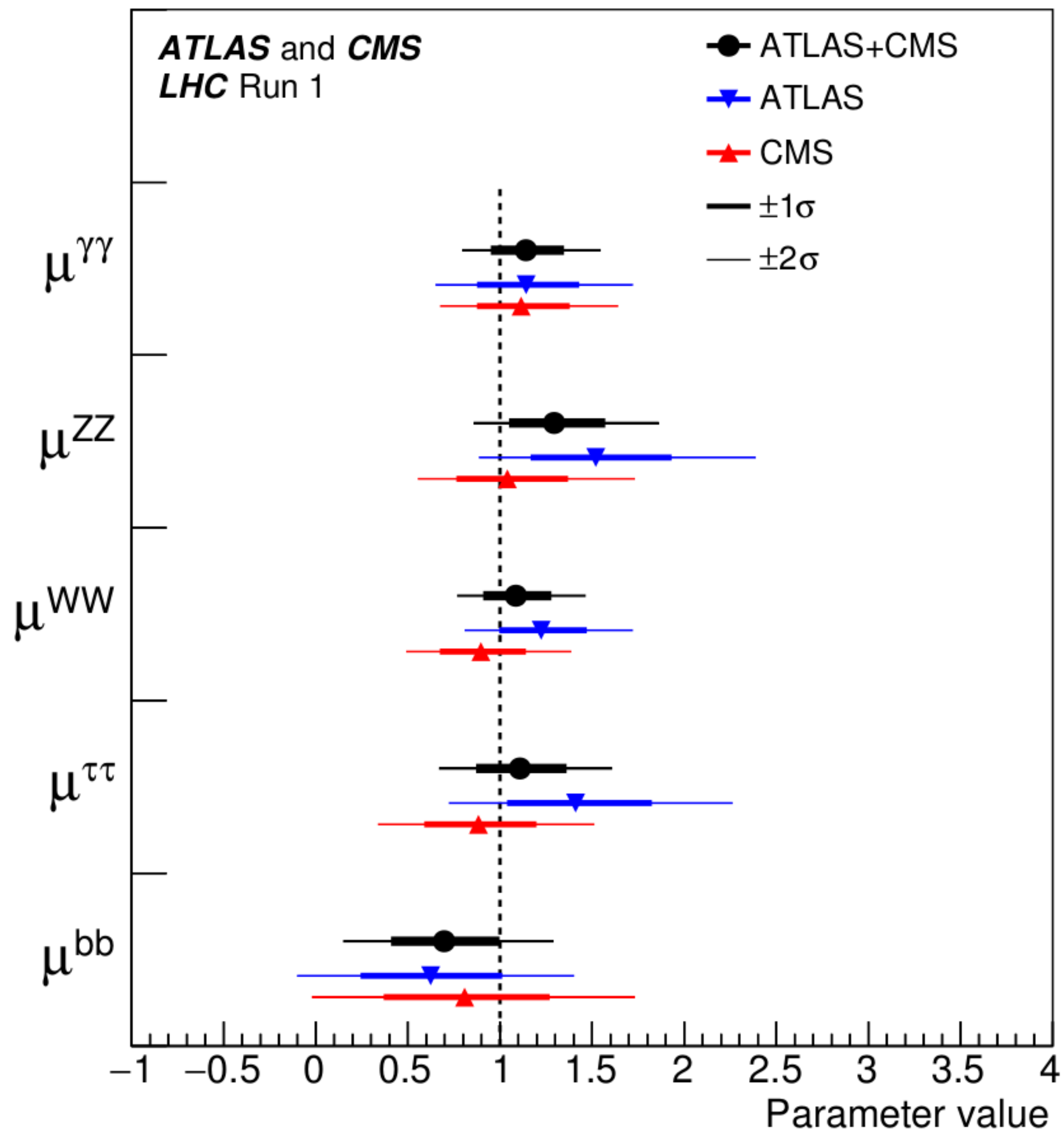
Search for the associated production
of the Higgs boson with a top quark pair
at the ATLAS experiment
Silvia Biondi

Many production mechanisms, many decays

- Higgs world
  - Many production mechanisms and many decays modes
  - Different signal/background ratios
  - Legacy Run I results combination ATLAS+CMS

JHEP 08 (2016) 045



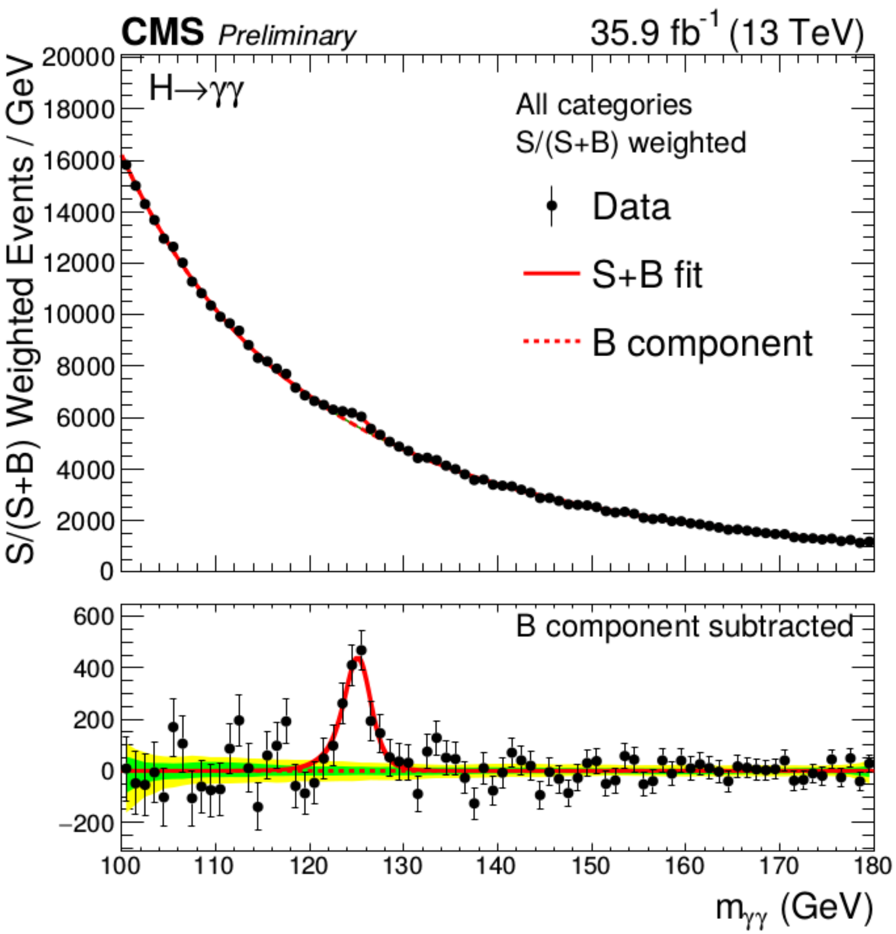


H → γγ

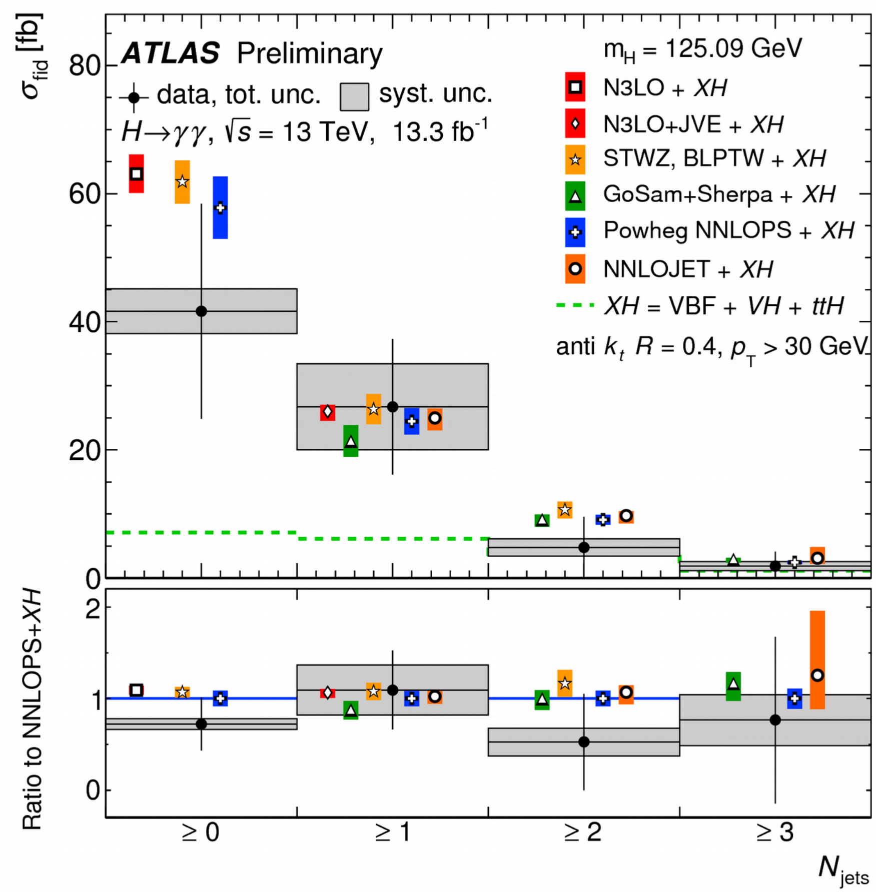
- Higgs → γγ
- Low BR ~ 0.2% but clean signature
- Differential measurements

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



ATLAS-CONF-2016-067

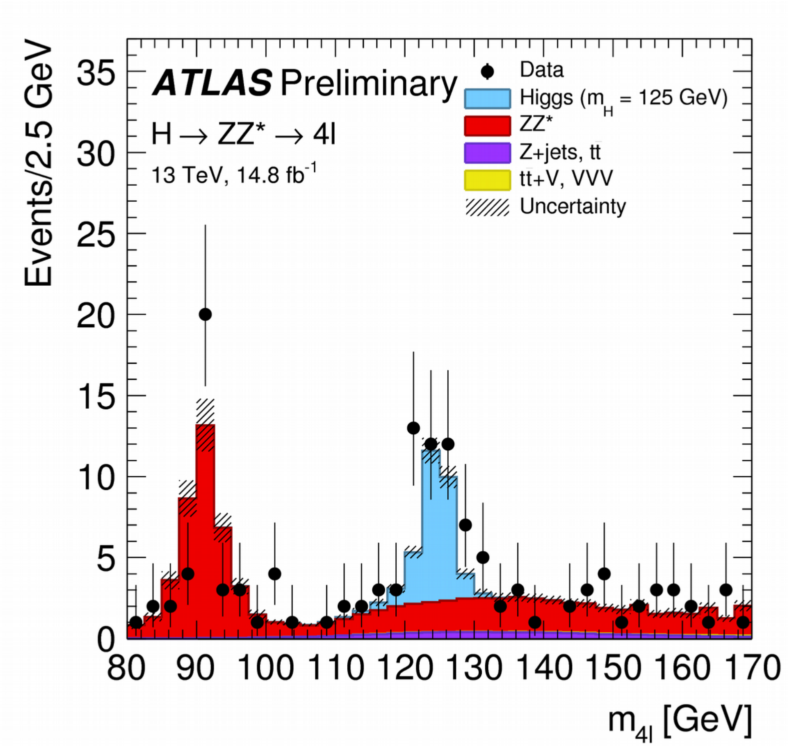


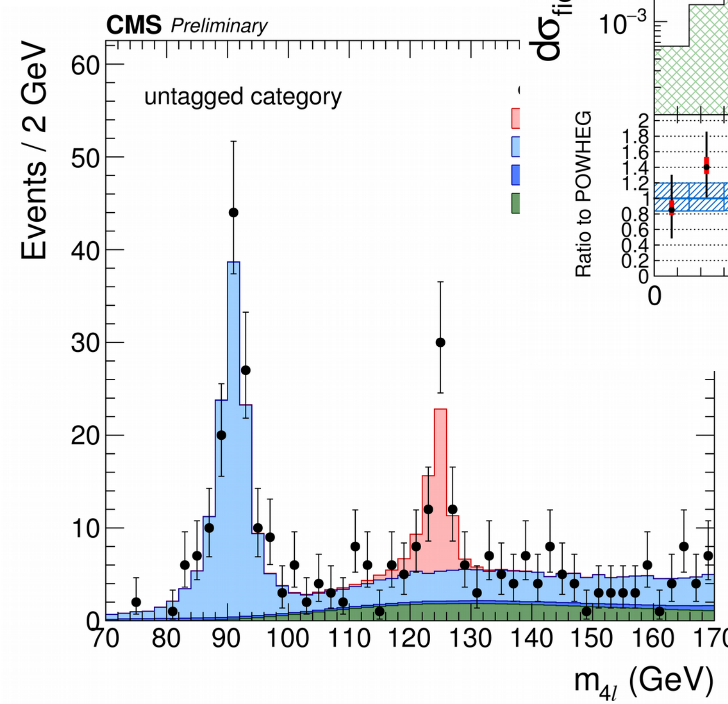
H → ZZ

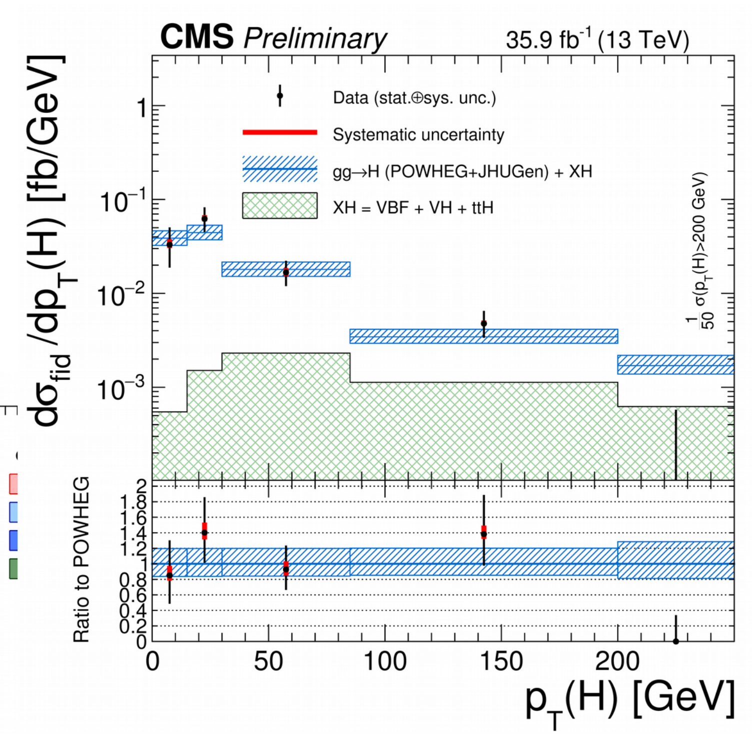
- Higgs → ZZ
- Low BR but clean signature → full kinematic of Higgs decay reconstructed
- Very high signal/background ratio
- Differential measurements, Higgs couplings, mass measurement, ...

Study of the production modes of the Higgs boson
and EFT interpretations in the H -> ZZ* -> 4l decay channel
at 13 TeV center of mass energy with the ATLAS detector at LHC
Giada Mancini

ATLAS-CONF-2016-079



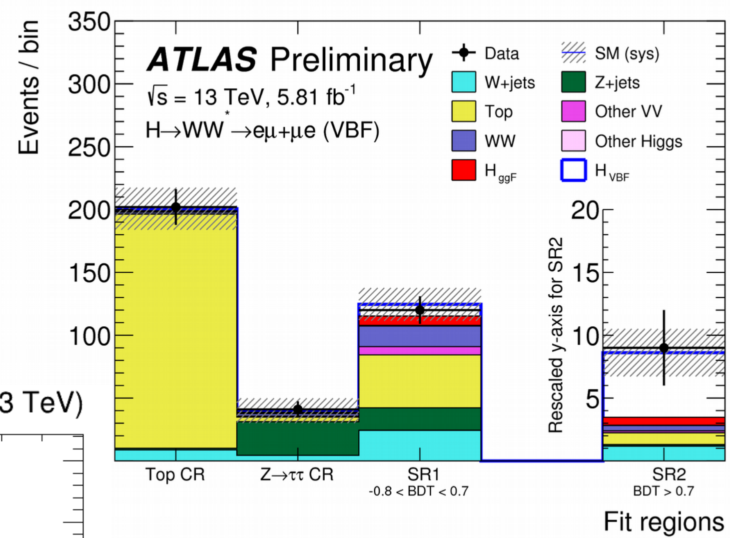




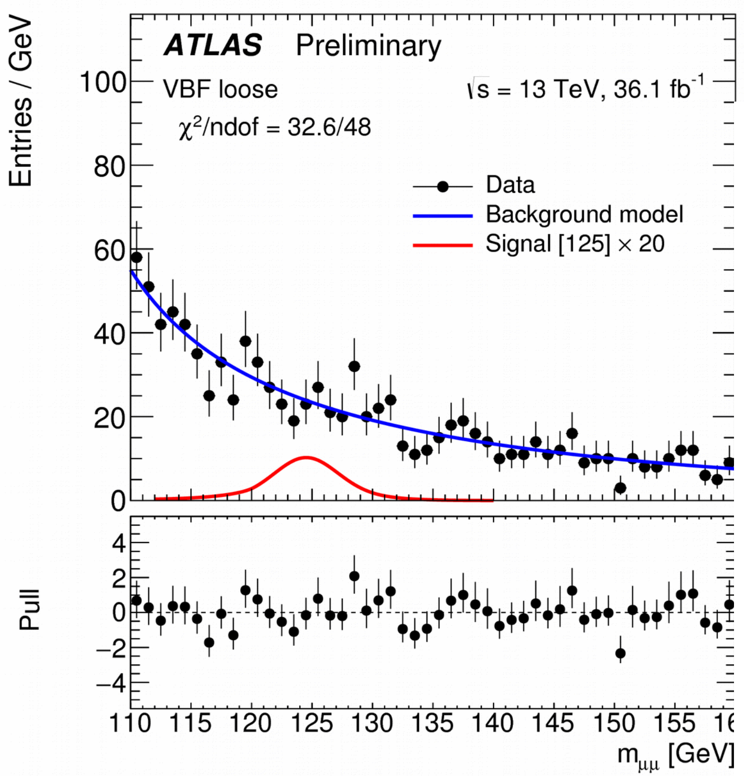
HIG-16-041

- Higgs → WW, bb, ττ, μμ, rare decays
- Control of most of SM backgrounds is fundamental
  - Close interplay with SM precision measurements

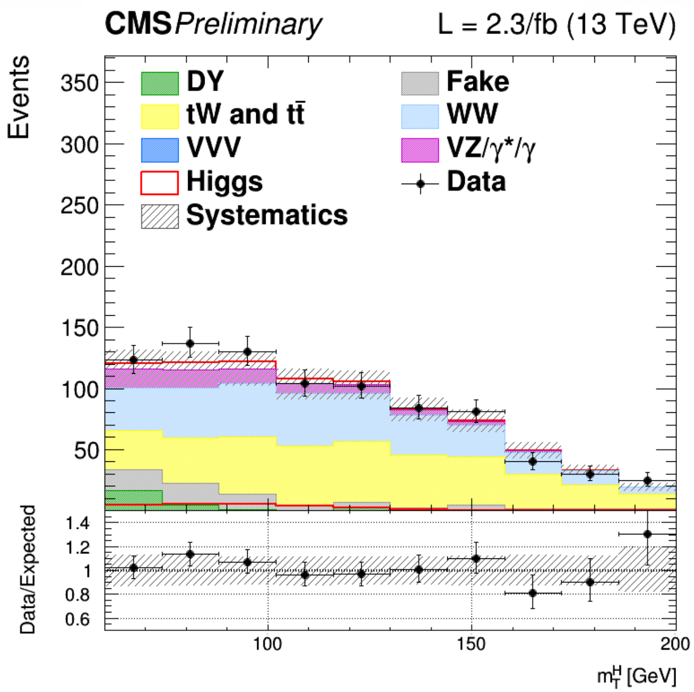
ATLAS-CONF-2016-112



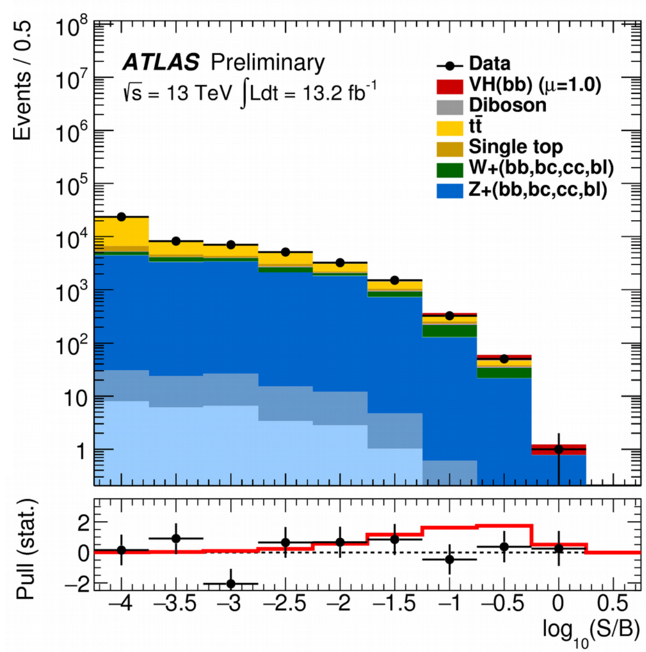
ATLAS-CONF-2017-014



CMS-PAS-HIG-15-003



ATLAS-CONF-2016-091

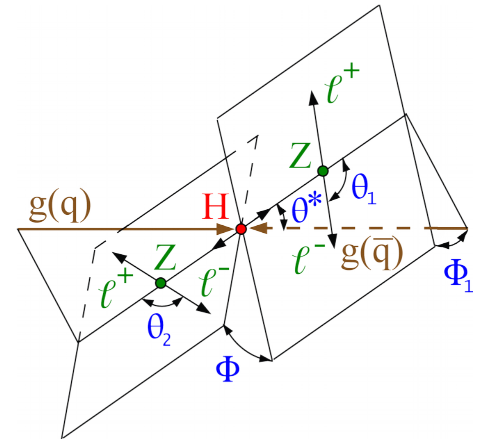


Search for the vector boson fusion produced Standard Model Higgs boson decaying to bottom-quarks with the ATLAS detector
Carlo Varni

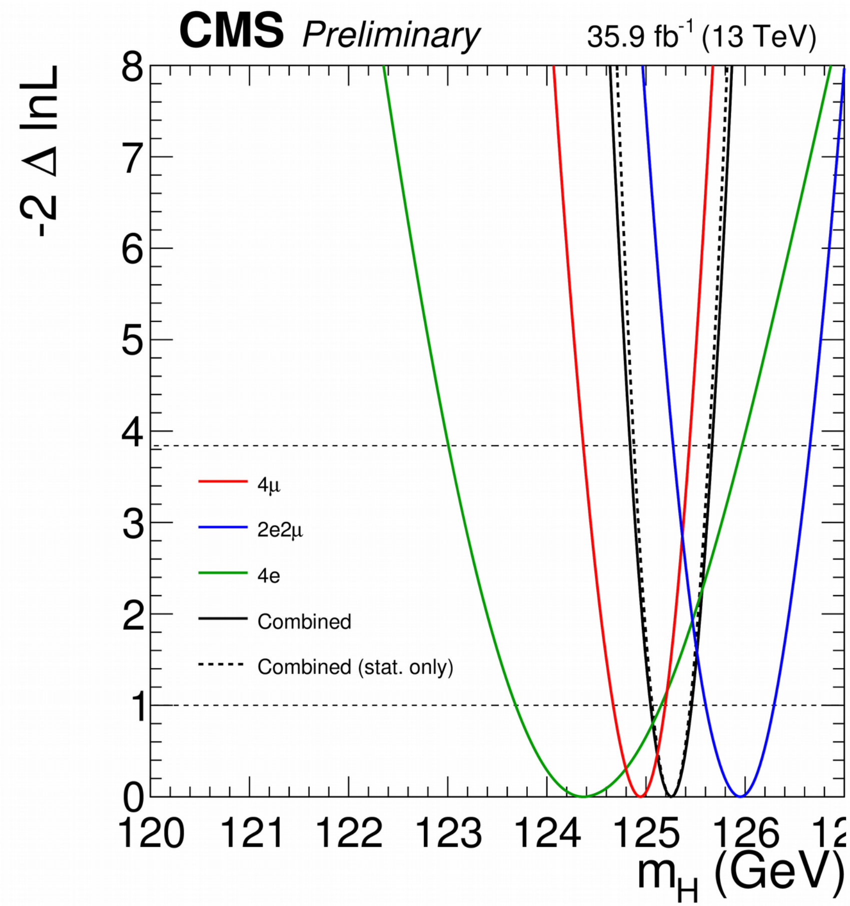
Properties

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

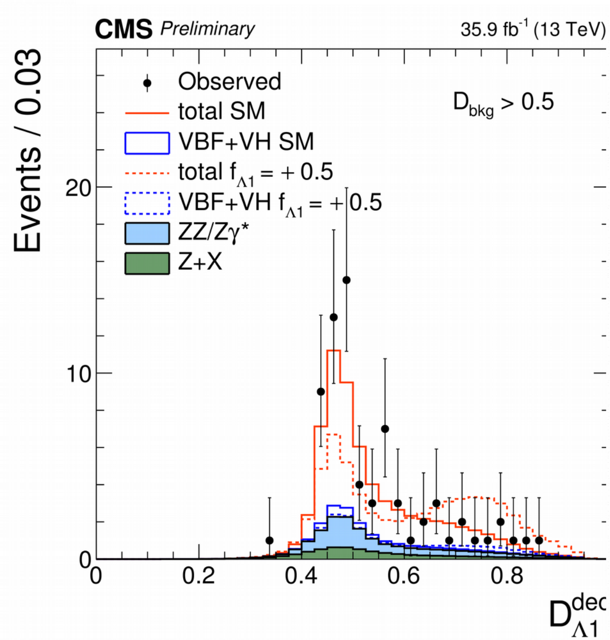
HIG-17-011

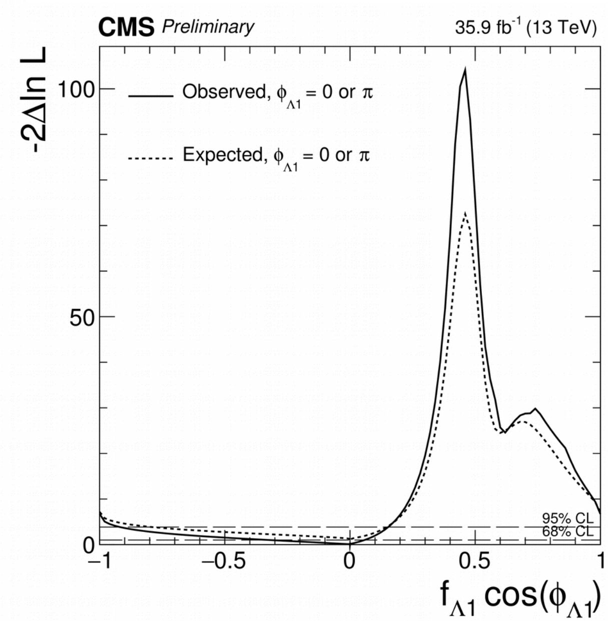


HIG-16-041



$$\left[a_1^{VV} + \frac{\kappa_1^{VV} q_1^2 + \kappa_2^{VV} q_2^2}{\left(\Lambda_1^{VV}\right)^2} + \frac{\kappa_3^{VV} (q_1+q_2)^2}{\left(\Lambda_Q^{VV}\right)^2} \right] m_{V1}^2 \epsilon_{V1}^* \epsilon_{V2}^* + a_2^{VV} f_{\mu\nu}^{*(1)} f^{*(2),\mu\nu} + a_3^{VV} f_{\mu\nu}^{*(1)} \tilde{f}^{*(2),\mu\nu}$$





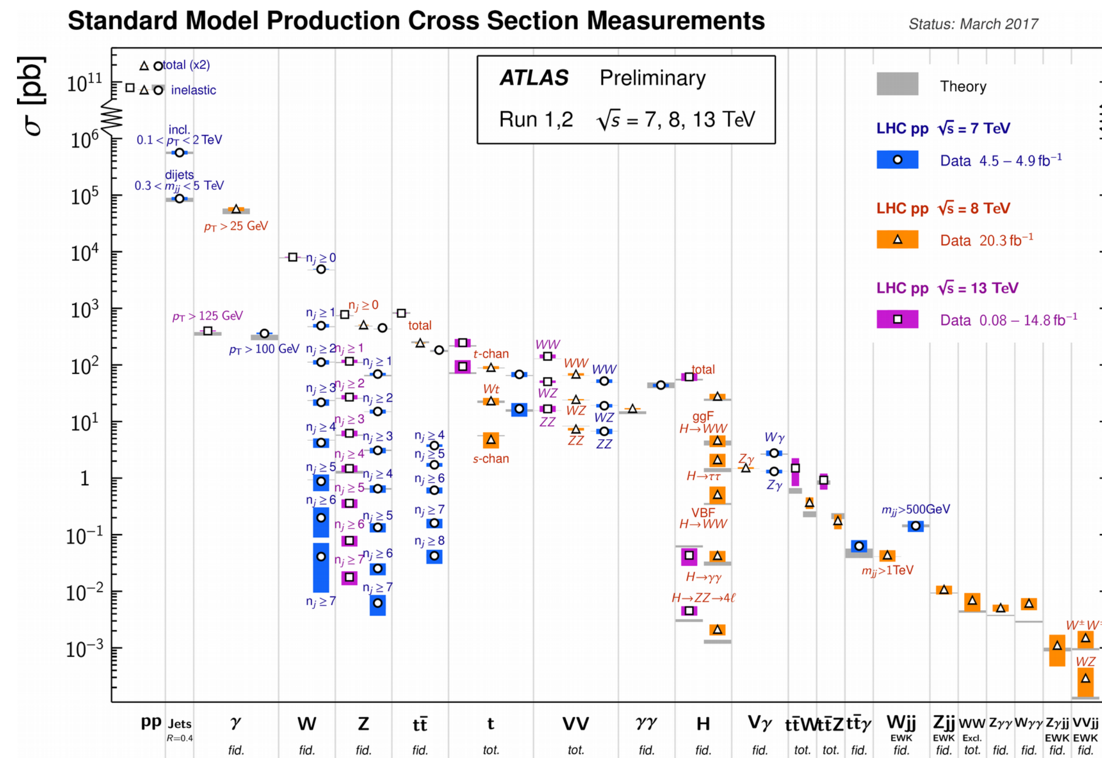
… the end?

- 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



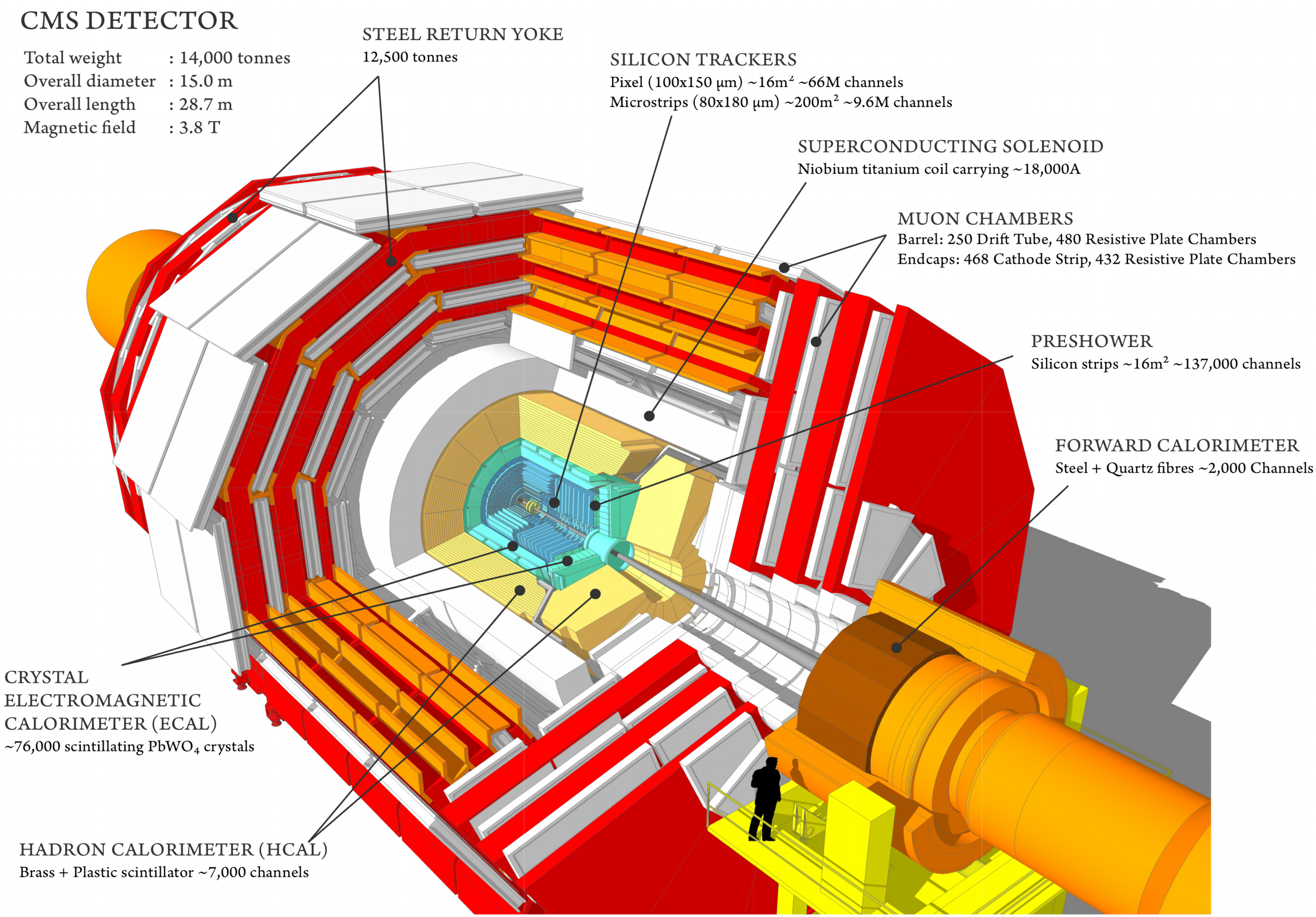
(for real)

References

- http://cms-results.web.cern.ch/cms-results/public-results/publications/
- http://cms-results.web.cern.ch/cms-results/public-results/publications/HIG/index.html
- http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/HIG/index.html
- http://cms-results.web.cern.ch/cms-results/public-results/publications/SMP/index.html
- http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/SMP/index.html
- http://cms-results.web.cern.ch/cms-results/public-results/publications/TOP/index.html
- http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/TOP/index.html

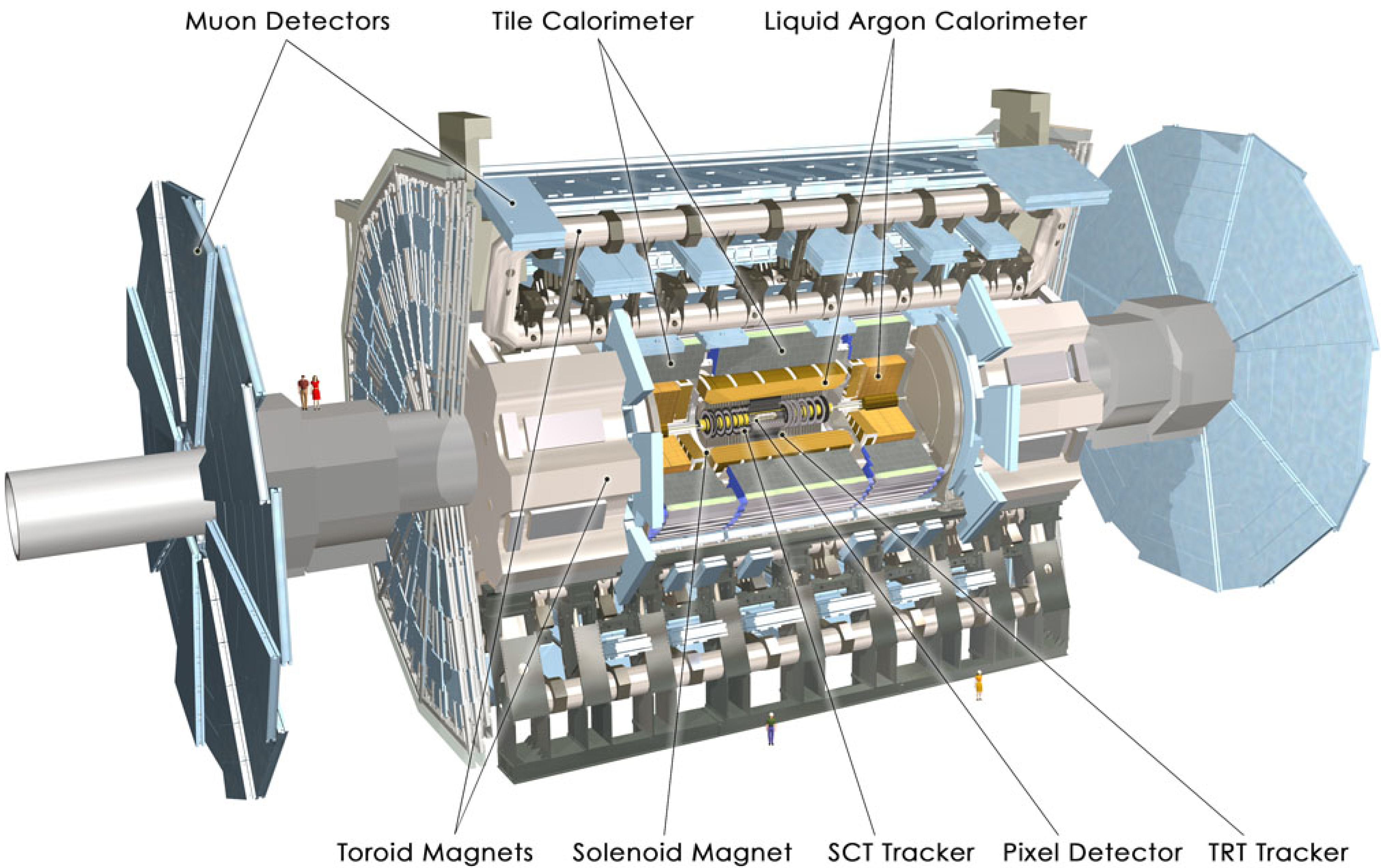
- https://twiki.cern.ch/twiki/bin/view/AtlasPublic
- https://twiki.cern.ch/twiki/bin/view/AtlasPublic/Winter201713TeV
- https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CombinedSummaryPlots/SM/
- https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CombinedSummaryPlots/HIGGS/
- https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CombinedSummaryPlots/TOP/
- https://twiki.cern.ch/twiki/bin/view/AtlasPublic/HiggsPublicResults
- https://twiki.cern.ch/twiki/bin/view/AtlasPublic/StandardModelPublicResults
- https://twiki.cern.ch/twiki/bin/view/AtlasPublic/TopPublicResults

CMS



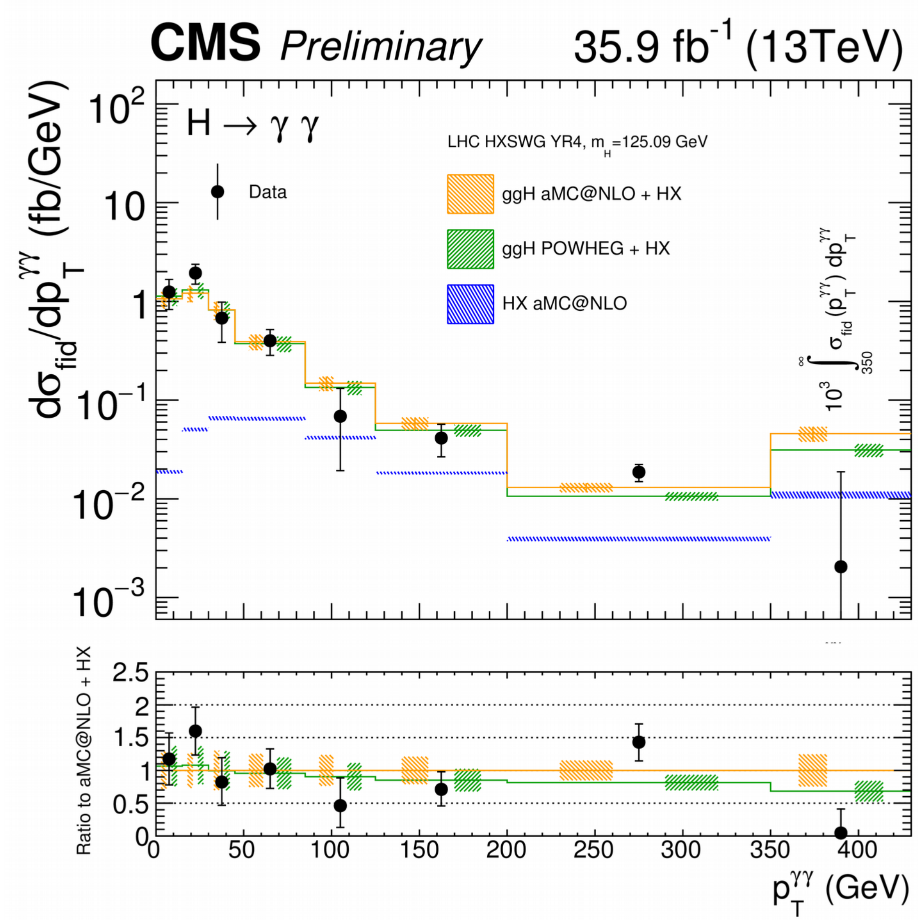
CMS DETECTOR
Total weight : 14,000 tonnes
Overall diameter : 15.0 m
Overall length : 28.7 m
Magnetic field : 3.8 T
STEEL RETURN YOKE
12,500 tonnes
SILICON TRACKERS
Pixel (100x150 μm) ~16m² ~66M channels
Microstrips (80x180 μm) ~200m² ~9.6M channels
SUPERCONDUCTING SOLENOID
Niobium titanium coil carrying ~18,000A
MUON CHAMBERS
Barrel: 250 Drift Tube, 480 Resistive Plate Chambers
Endcaps: 468 Cathode Strip, 432 Resistive Plate Chambers
PRESHOWER
Silicon strips ~16m² ~137,000 channels
FORWARD CALORIMETER
Steel + Quartz fibres ~2,000 Channels
CRYSTAL ELECTROMAGNETIC CALORIMETER (ECAL)
~76,000 scintillating PbWO4 crystals
HADRON CALORIMETER (HCAL)
Brass + Plastic scintillator ~7,000 channels

ATLAS

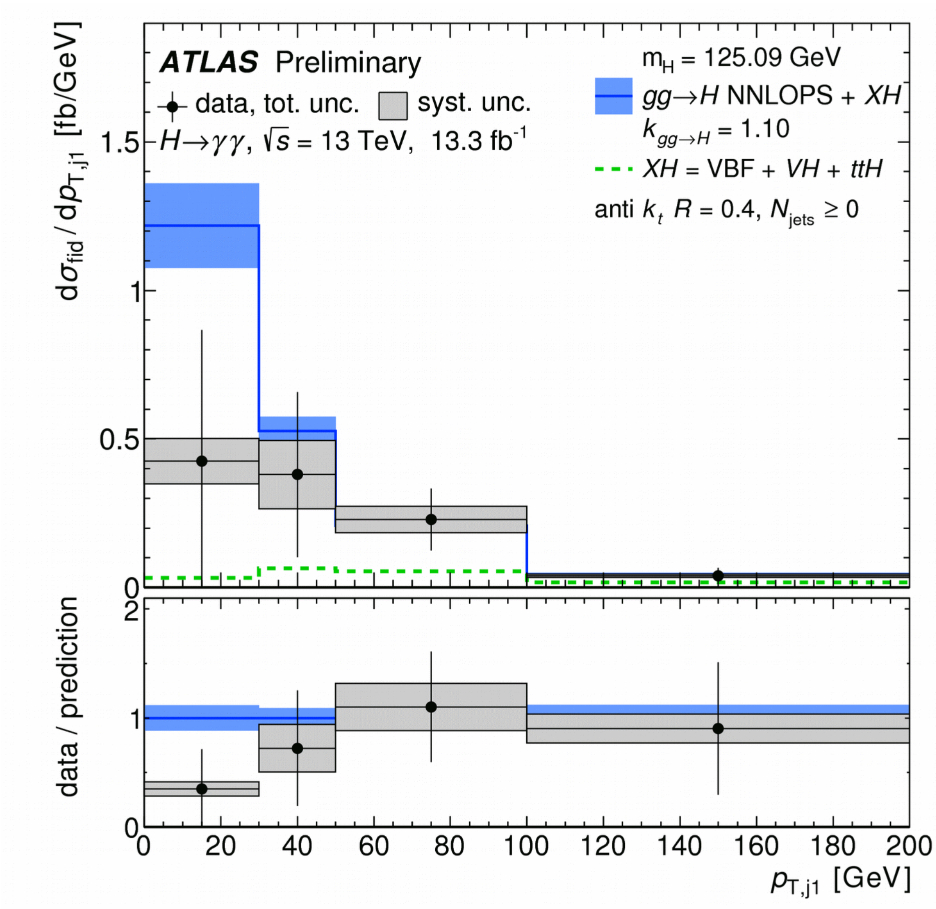

Muon Detectors
Tile Calorimeter
Liquid Argon Calorimeter
Toroid Magnets
Solenoid Magnet
SCT Tracker
Pixel Detector
TRT Tracker

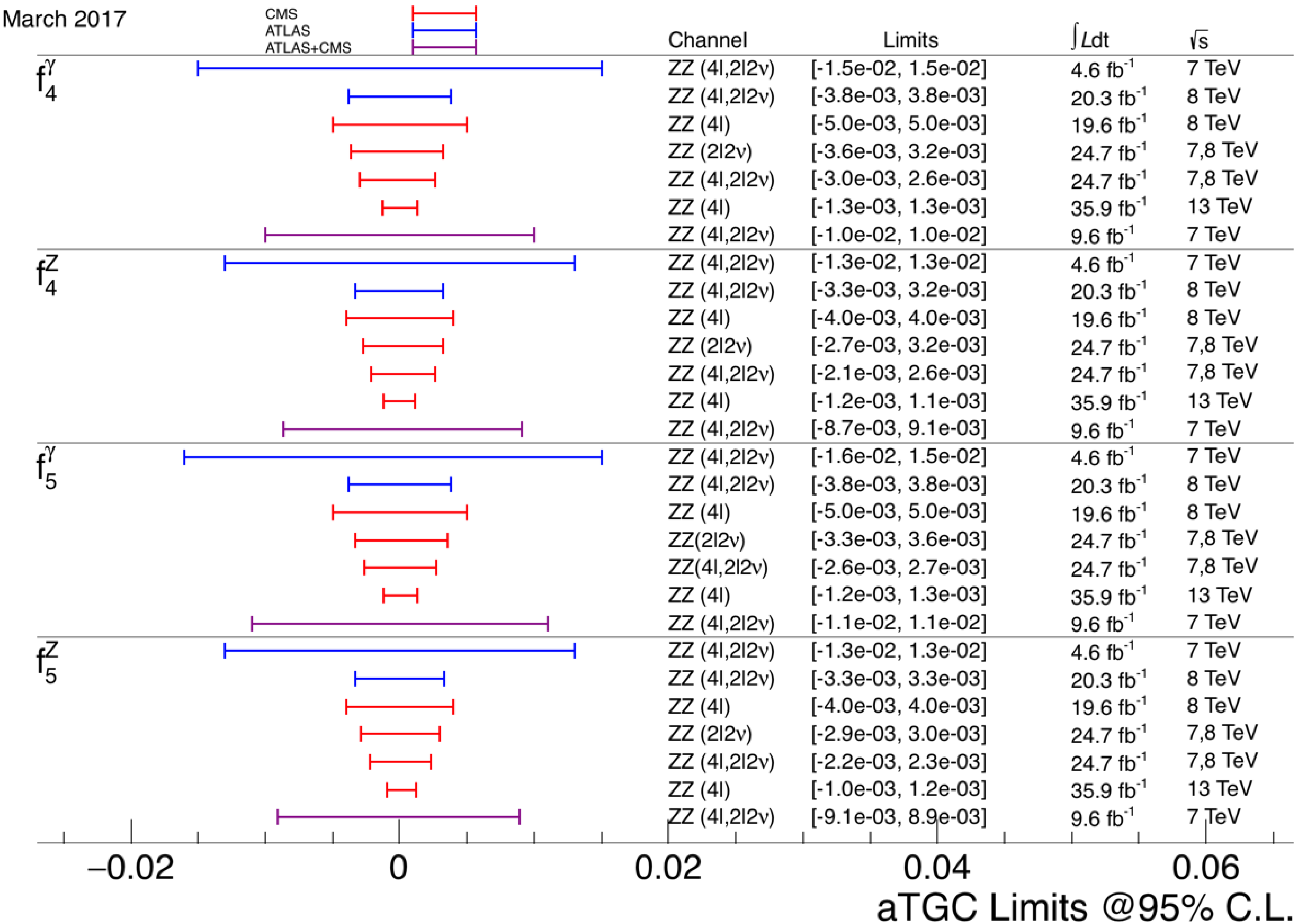
- Higgs $\to$ $\gamma\gamma$
- Low BR ~ 0.2% but clean signature
- Differential measurements

CMS-PAS-HIG-17-015



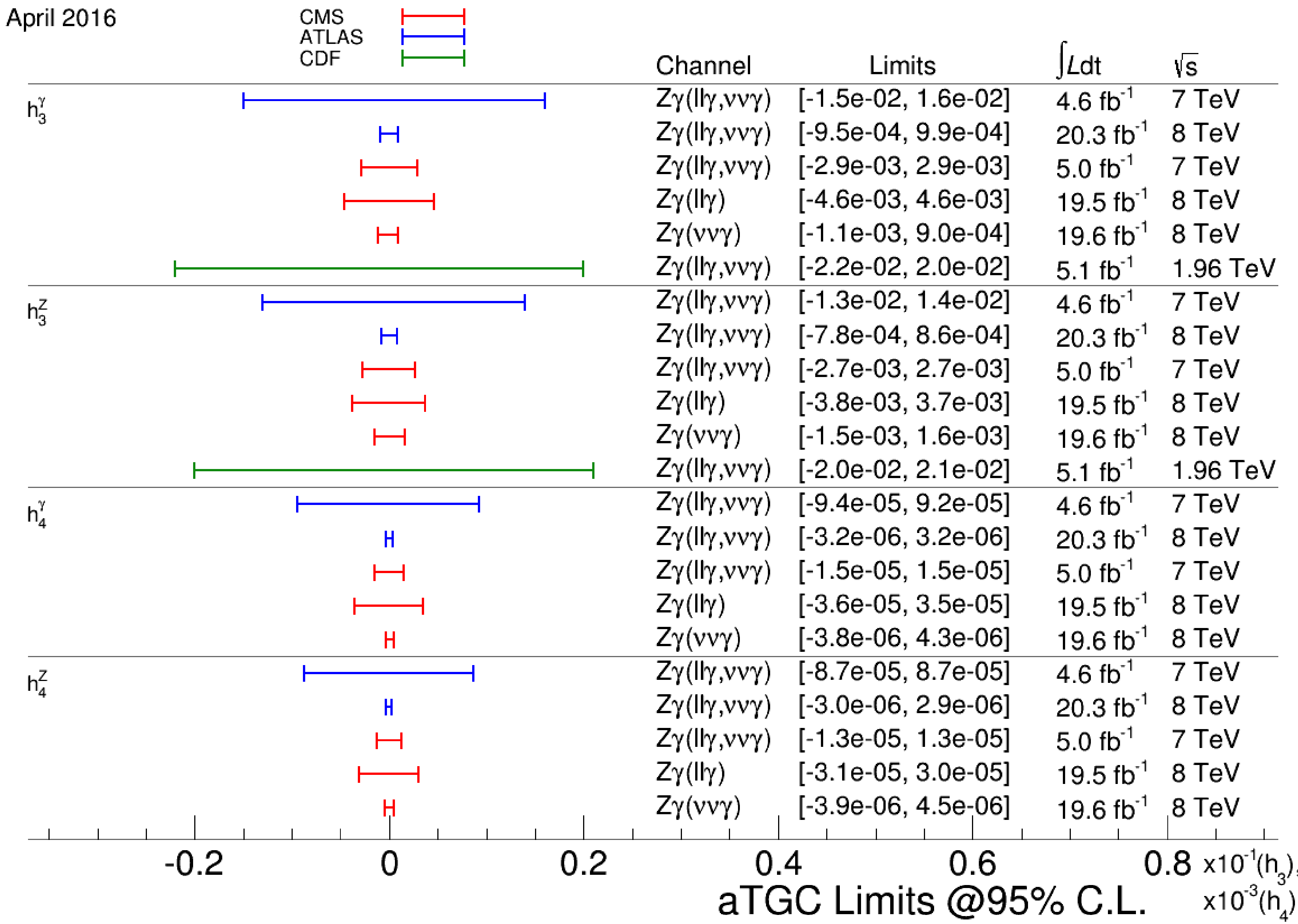
ATLAS-CONF-2016-067

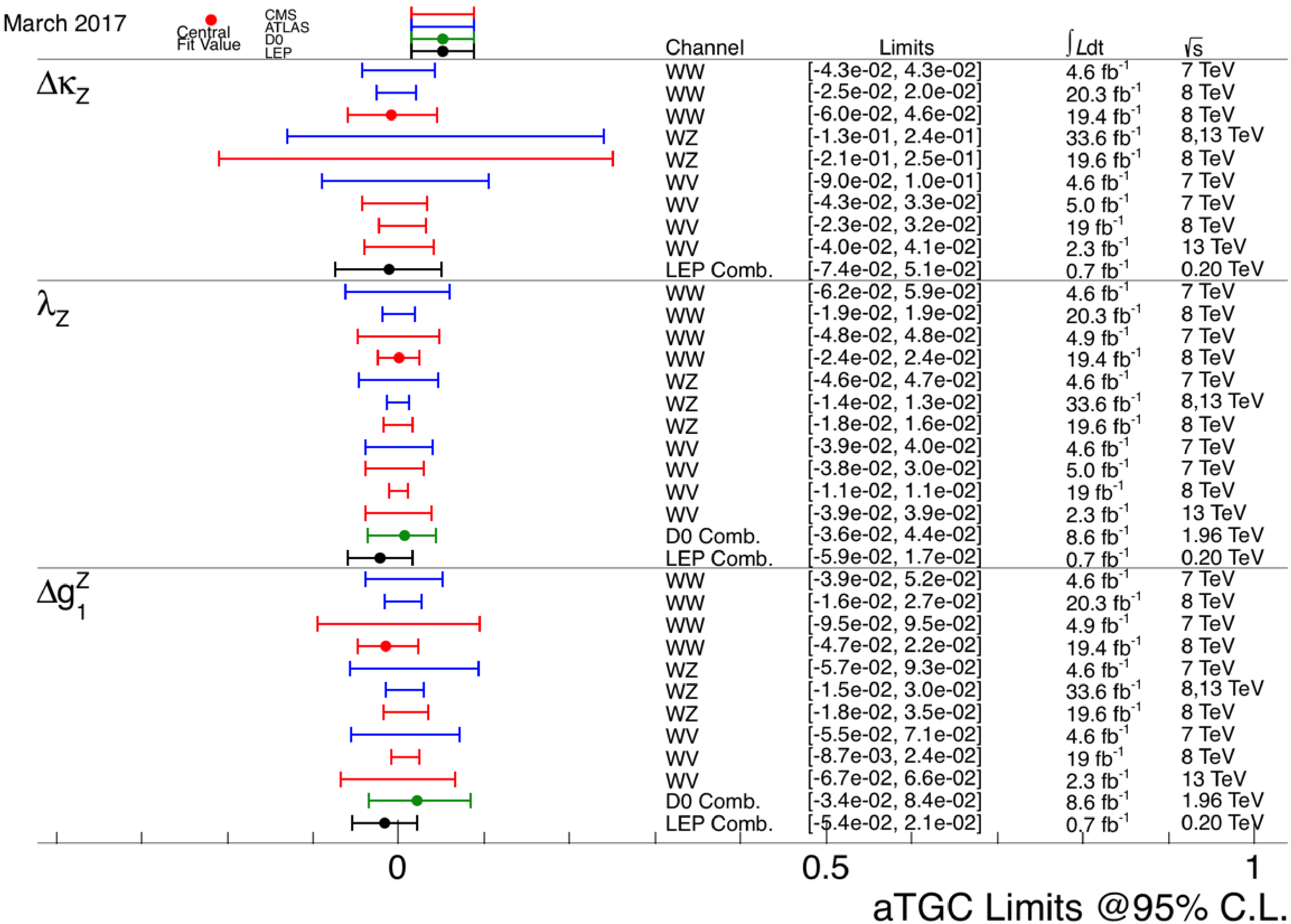




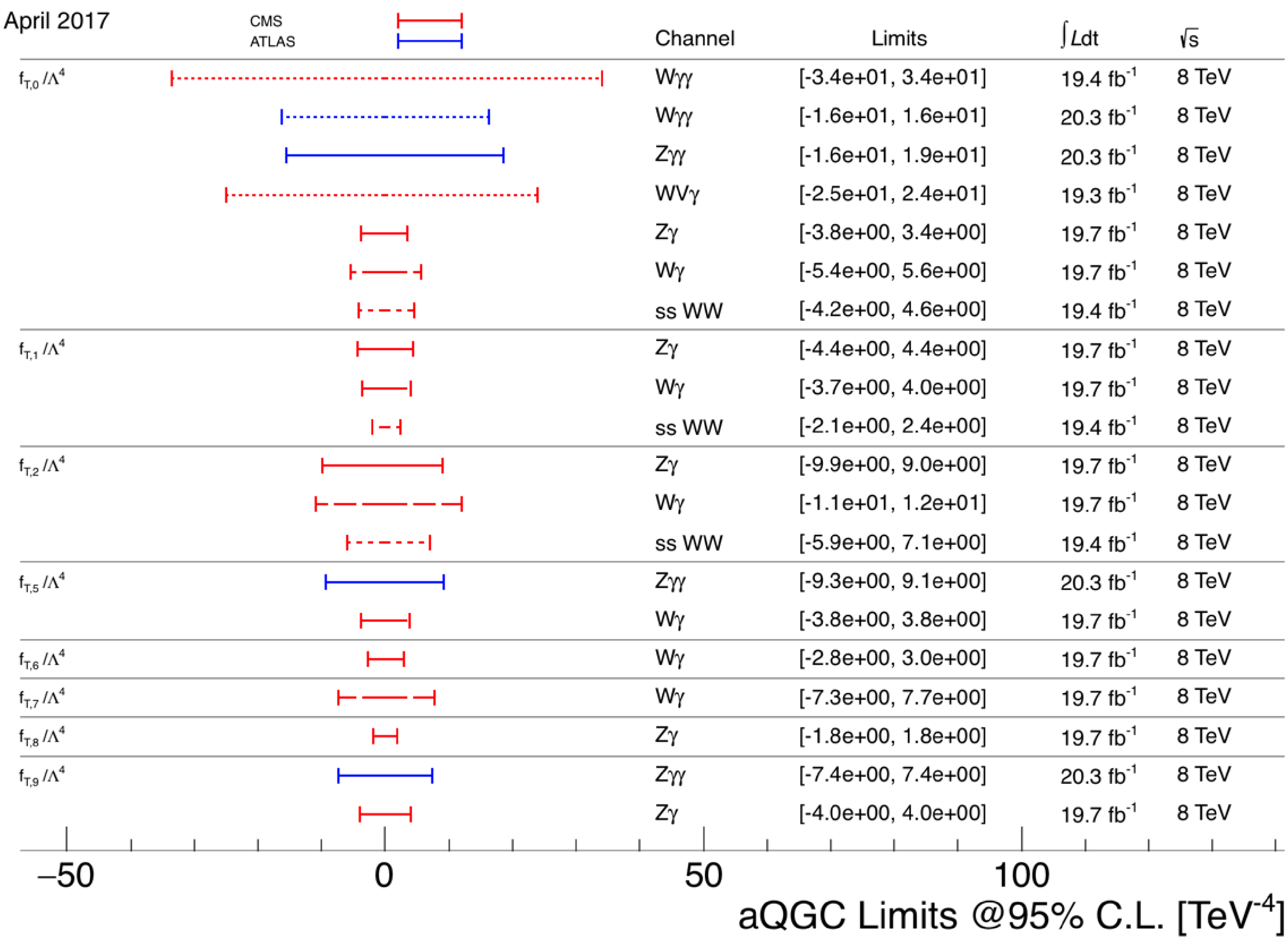
Coupling	Channel	Limits	$\int Ldt$	$\sqrt{s}$
f_4^γ	ZZ (4l,2l2ν)	[-1.5e-02, 1.5e-02]	4.6 fb^{-1}	7 TeV
	ZZ (4l,2l2ν)	[-3.8e-03, 3.8e-03]	20.3 fb^{-1}	8 TeV
	ZZ (4l)	[-5.0e-03, 5.0e-03]	19.6 fb^{-1}	8 TeV
	ZZ (2l2ν)	[-3.6e-03, 3.2e-03]	24.7 fb^{-1}	7,8 TeV
	ZZ (4l,2l2ν)	[-3.0e-03, 2.6e-03]	24.7 fb^{-1}	7,8 TeV
	ZZ (4l)	[-1.3e-03, 1.3e-03]	35.9 fb^{-1}	13 TeV
	ZZ (4l,2l2ν)	[-1.0e-02, 1.0e-02]	9.6 fb^{-1}	7 TeV
f_4^Z	ZZ (4l,2l2ν)	[-1.3e-02, 1.3e-02]	4.6 fb^{-1}	7 TeV
	ZZ (4l,2l2ν)	[-3.3e-03, 3.2e-03]	20.3 fb^{-1}	8 TeV
	ZZ (4l)	[-4.0e-03, 4.0e-03]	19.6 fb^{-1}	8 TeV
	ZZ (2l2ν)	[-2.7e-03, 3.2e-03]	24.7 fb^{-1}	7,8 TeV
	ZZ (4l,2l2ν)	[-2.1e-03, 2.6e-03]	24.7 fb^{-1}	7,8 TeV
	ZZ (4l)	[-1.2e-03, 1.1e-03]	35.9 fb^{-1}	13 TeV
	ZZ (4l,2l2ν)	[-8.7e-03, 9.1e-03]	9.6 fb^{-1}	7 TeV
f_5^γ	ZZ (4l,2l2ν)	[-1.6e-02, 1.5e-02]	4.6 fb^{-1}	7 TeV
	ZZ (4l,2l2ν)	[-3.8e-03, 3.8e-03]	20.3 fb^{-1}	8 TeV
	ZZ (4l)	[-5.0e-03, 5.0e-03]	19.6 fb^{-1}	8 TeV
	ZZ(2l2ν)	[-3.3e-03, 3.6e-03]	24.7 fb^{-1}	7,8 TeV
	ZZ(4l,2l2ν)	[-2.6e-03, 2.7e-03]	24.7 fb^{-1}	7,8 TeV
	ZZ (4l)	[-1.2e-03, 1.3e-03]	35.9 fb^{-1}	13 TeV
	ZZ (4l,2l2ν)	[-1.1e-02, 1.1e-02]	9.6 fb^{-1}	7 TeV
f_5^Z	ZZ (4l,2l2ν)	[-1.3e-02, 1.3e-02]	4.6 fb^{-1}	7 TeV
	ZZ (4l,2l2ν)	[-3.3e-03, 3.3e-03]	20.3 fb^{-1}	8 TeV
	ZZ (4l)	[-4.0e-03, 4.0e-03]	19.6 fb^{-1}	8 TeV
	ZZ (2l2ν)	[-2.9e-03, 3.0e-03]	24.7 fb^{-1}	7,8 TeV
	ZZ (4l,2l2ν)	[-2.2e-03, 2.3e-03]	24.7 fb^{-1}	7,8 TeV
	ZZ (4l)	[-1.0e-03, 1.2e-03]	35.9 fb^{-1}	13 TeV
	ZZ (4l,2l2ν)	[-9.1e-03, 8.9e-03]	9.6 fb^{-1}	7 TeV

Neutral anomalous triple gauge couplings




March 2017
Central Fit Value
CMS
ATLAS
D0
LEP
Channel
Limits
∫Ldt
√s
Δκ_Z
WW [-4.3e-02, 4.3e-02] 4.6 fb-1 7 TeV
WW [-2.5e-02, 2.0e-02] 20.3 fb-1 8 TeV
WW [-6.0e-02, 4.6e-02] 19.4 fb-1 8 TeV
WZ [-1.3e-01, 2.4e-01] 33.6 fb-1 8,13 TeV
WZ [-2.1e-01, 2.5e-01] 19.6 fb-1 8 TeV
WV [-9.0e-02, 1.0e-01] 4.6 fb-1 7 TeV
WV [-4.3e-02, 3.3e-02] 5.0 fb-1 7 TeV
WV [-2.3e-02, 3.2e-02] 19 fb-1 8 TeV
WV [-4.0e-02, 4.1e-02] 2.3 fb-1 13 TeV
LEP Comb. [-7.4e-02, 5.1e-02] 0.7 fb-1 0.20 TeV
λ_Z
WW [-6.2e-02, 5.9e-02] 4.6 fb-1 7 TeV
WW [-1.9e-02, 1.9e-02] 20.3 fb-1 8 TeV
WW [-4.8e-02, 4.8e-02] 4.9 fb-1 7 TeV
WW [-2.4e-02, 2.4e-02] 19.4 fb-1 8 TeV
WZ [-4.6e-02, 4.7e-02] 4.6 fb-1 7 TeV
WZ [-1.4e-02, 1.3e-02] 33.6 fb-1 8,13 TeV
WZ [-1.8e-02, 1.6e-02] 19.6 fb-1 8 TeV
WV [-3.9e-02, 4.0e-02] 4.6 fb-1 7 TeV
WV [-3.8e-02, 3.0e-02] 5.0 fb-1 7 TeV
WV [-1.1e-02, 1.1e-02] 19 fb-1 8 TeV
WV [-3.9e-02, 3.9e-02] 2.3 fb-1 13 TeV
D0 Comb. [-3.6e-02, 4.4e-02] 8.6 fb-1 1.96 TeV
LEP Comb. [-5.9e-02, 1.7e-02] 0.7 fb-1 0.20 TeV
Δg^Z_1
WW [-3.9e-02, 5.2e-02] 4.6 fb-1 7 TeV
WW [-1.6e-02, 2.7e-02] 20.3 fb-1 8 TeV
WW [-9.5e-02, 9.5e-02] 4.9 fb-1 7 TeV
WW [-4.7e-02, 2.2e-02] 19.4 fb-1 8 TeV
WZ [-5.7e-02, 9.3e-02] 4.6 fb-1 7 TeV
WZ [-1.5e-02, 3.0e-02] 33.6 fb-1 8,13 TeV
WZ [-1.8e-02, 3.5e-02] 19.6 fb-1 8 TeV
WV [-5.5e-02, 7.1e-02] 4.6 fb-1 7 TeV
WV [-8.7e-03, 2.4e-02] 19 fb-1 8 TeV
WV [-6.7e-02, 6.6e-02] 2.3 fb-1 13 TeV
D0 Comb. [-3.4e-02, 8.4e-02] 8.6 fb-1 1.96 TeV
LEP Comb. [-5.4e-02, 2.1e-02] 0.7 fb-1 0.20 TeV
0
0.5
1
aTGC Limits @95% C.L.

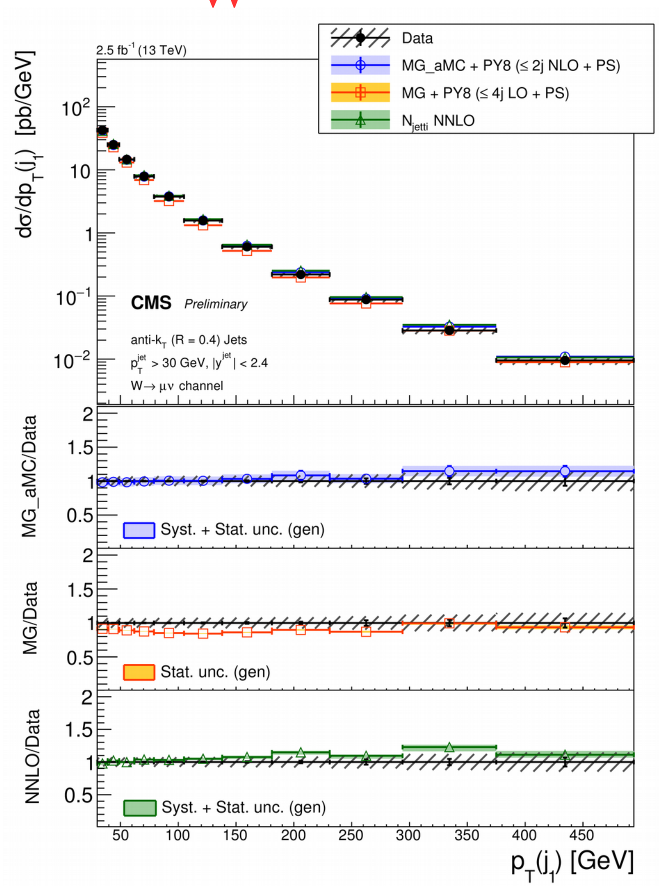
Anomalous quartic gauge couplings



… one step more (mirror image)

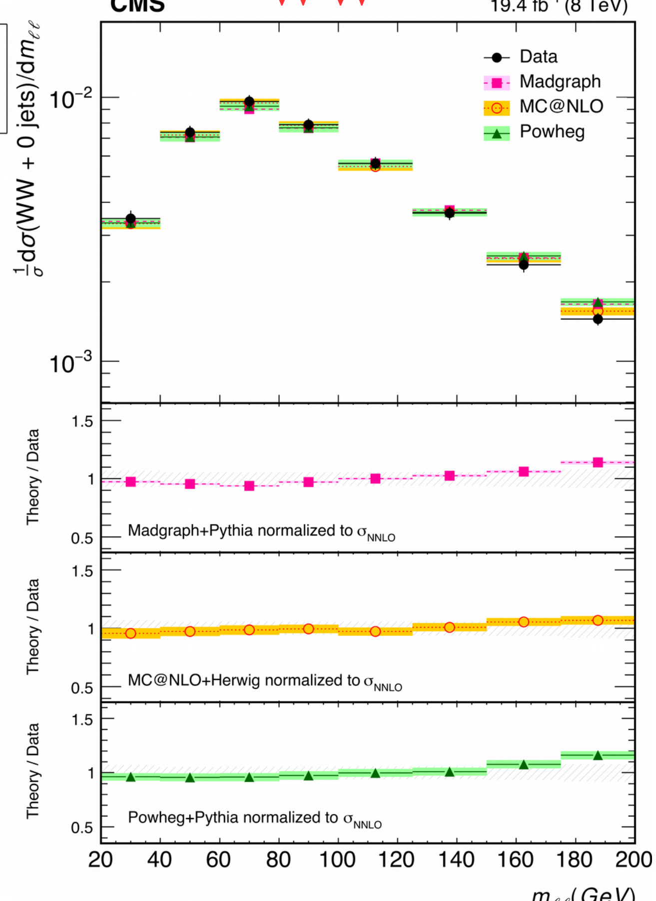
- Many new results at 7/8/13 TeV from ATLAS and CMS
- How we usually proceed:
  - Inclusive cross section
  - Fiducial and differential cross section

W



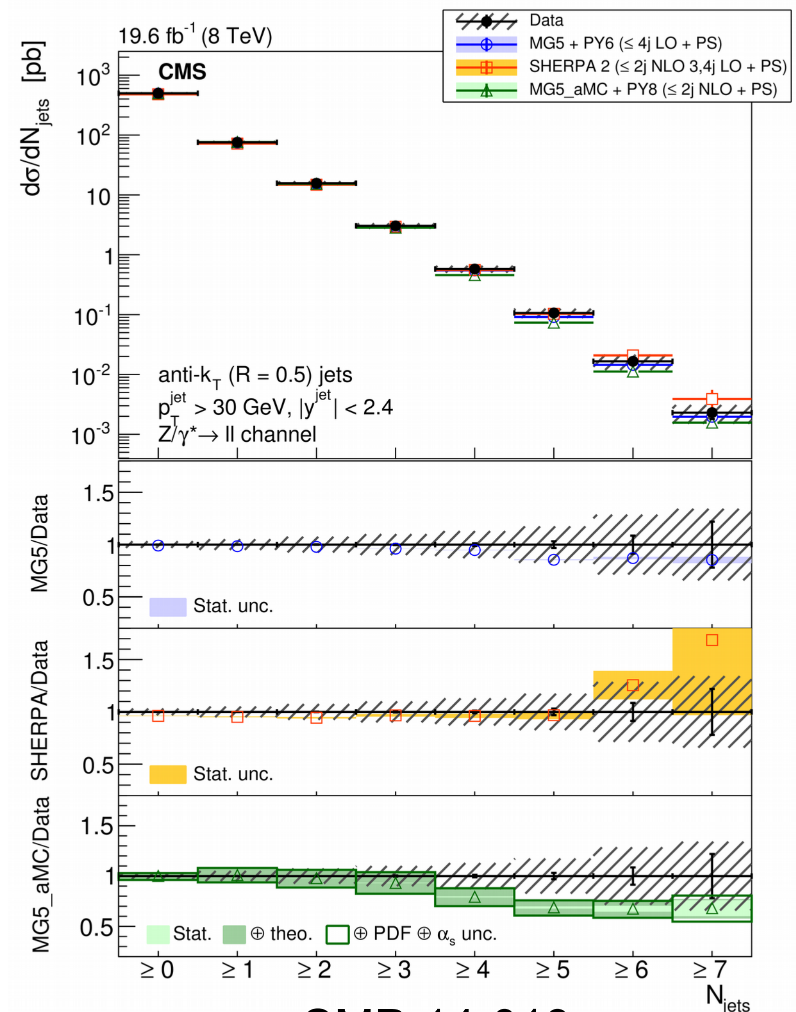
SMP-16-005

WW



SMP-14-016

Z

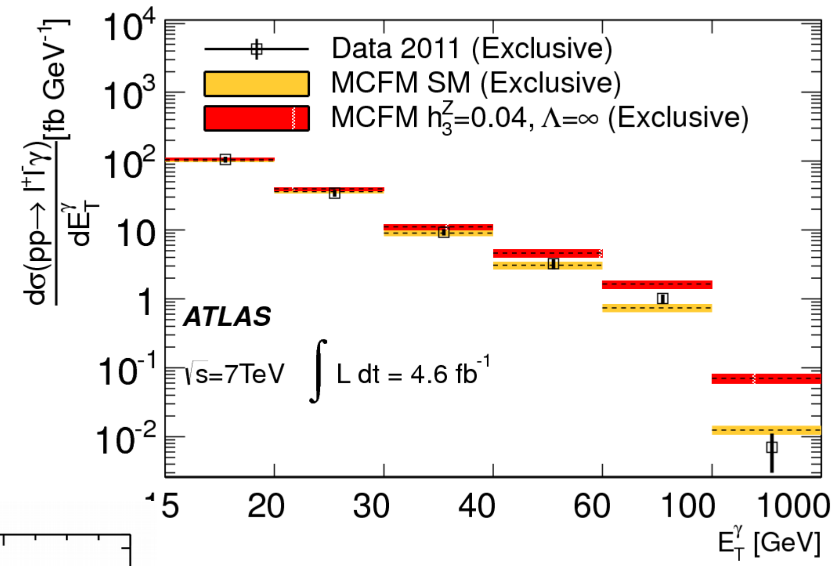


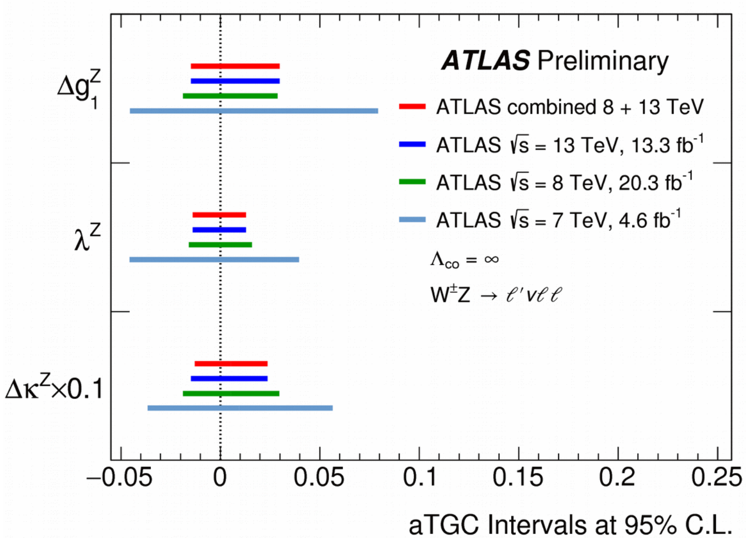
SMP-14-013

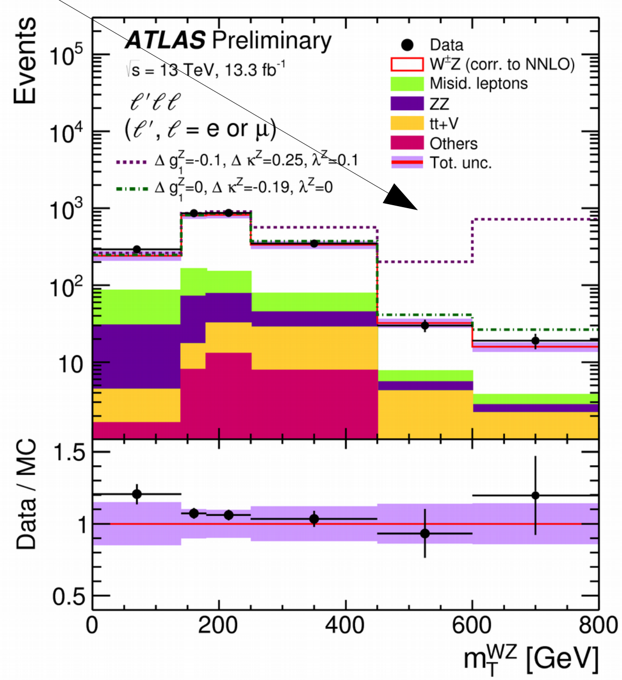
Looking for the unknown (mirror image)

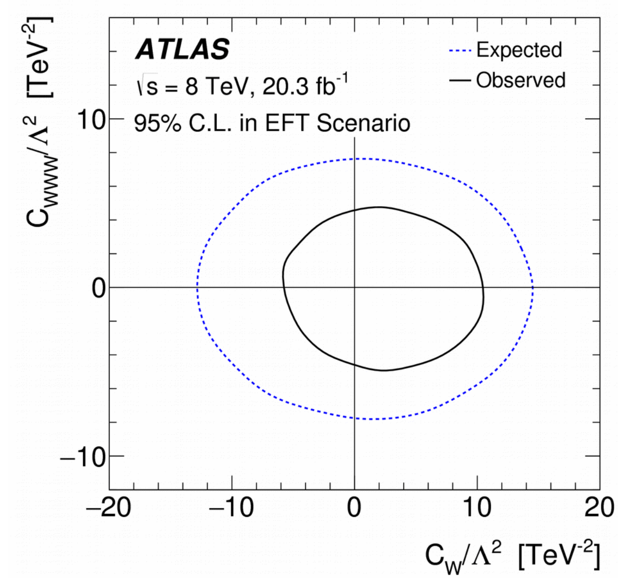
- Many new results at 7/8/13 TeV from ATLAS and CMS
- How we usually proceed:
  - Inclusive cross section
  - Fiducial and differential cross section
  - High energy regimes for anomalous couplings

STDM-2012-07









ATLAS-CONF-2016-043

STDM-2013-07