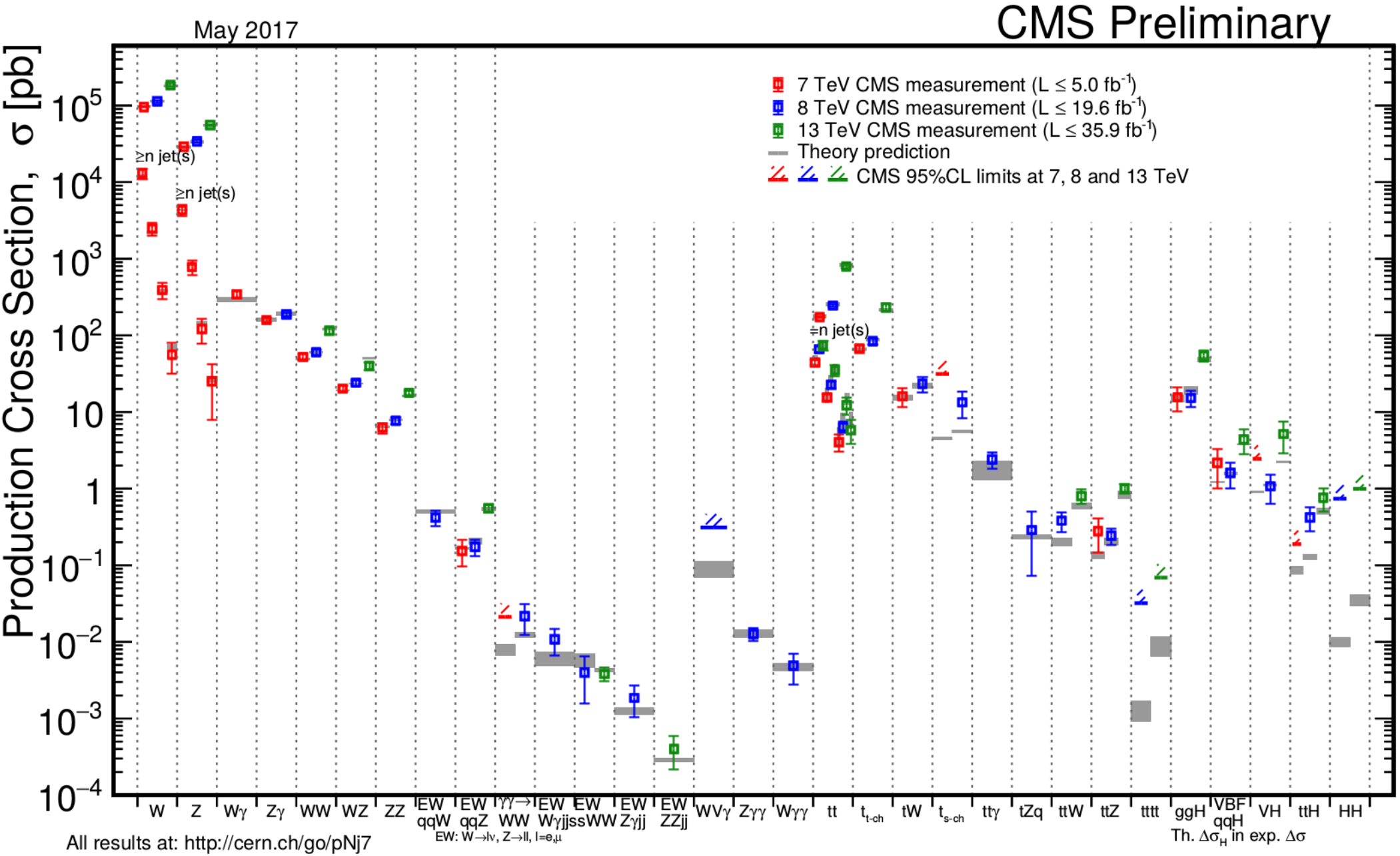
Overview of Standard Model and Higgs results at ATLAS and CMS

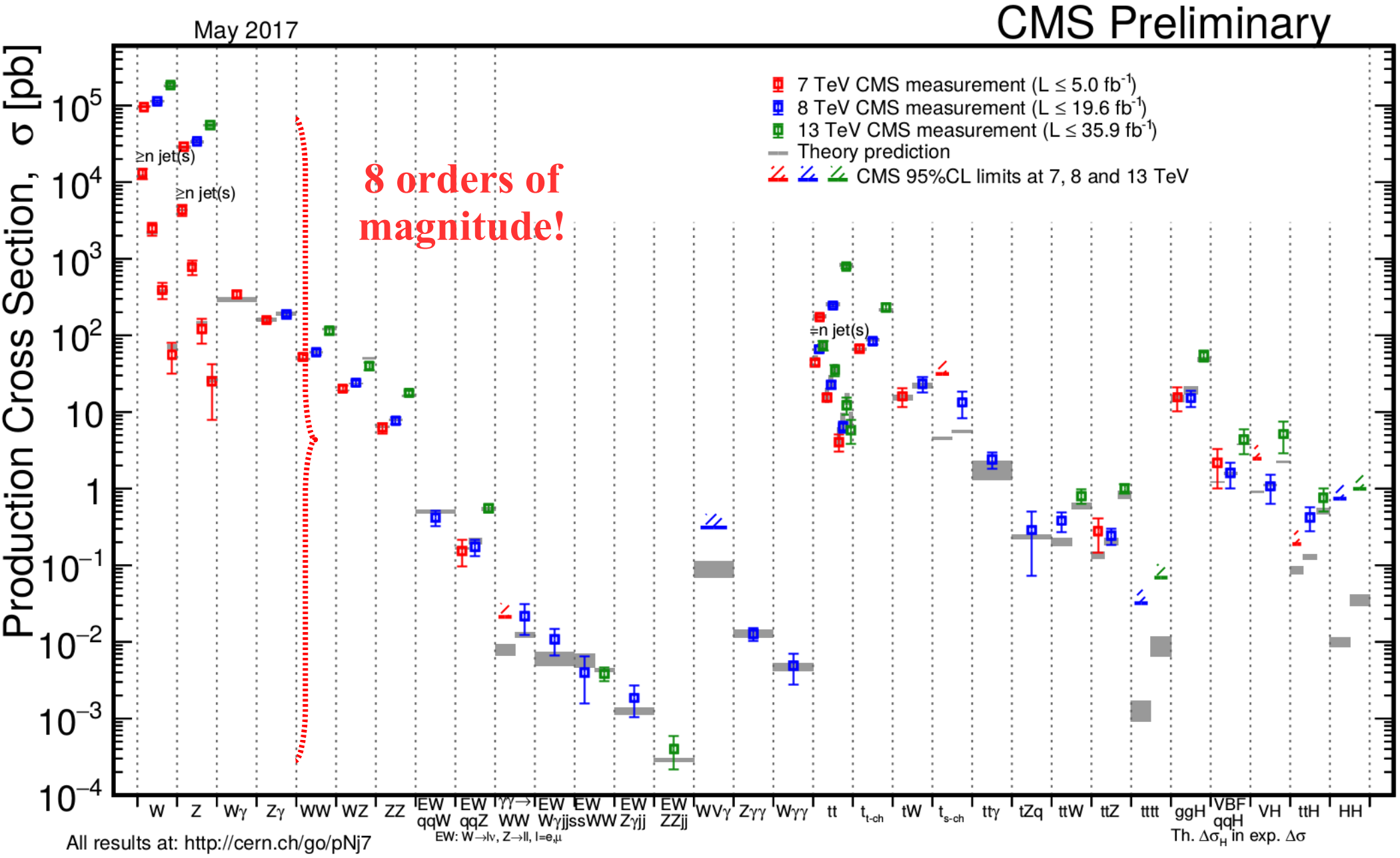
8th June 2017

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

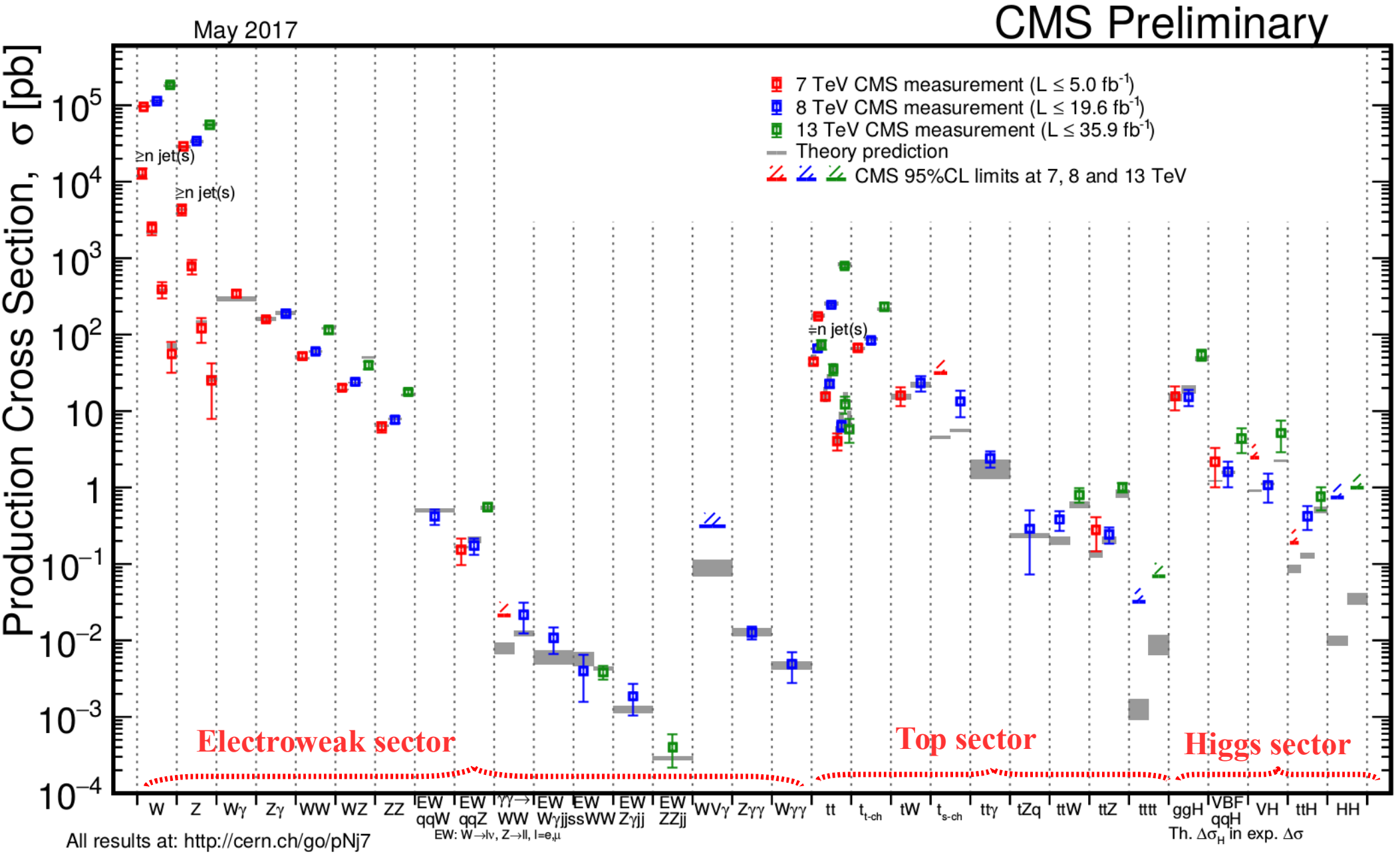
One picture to rule them all



Challenging analyses

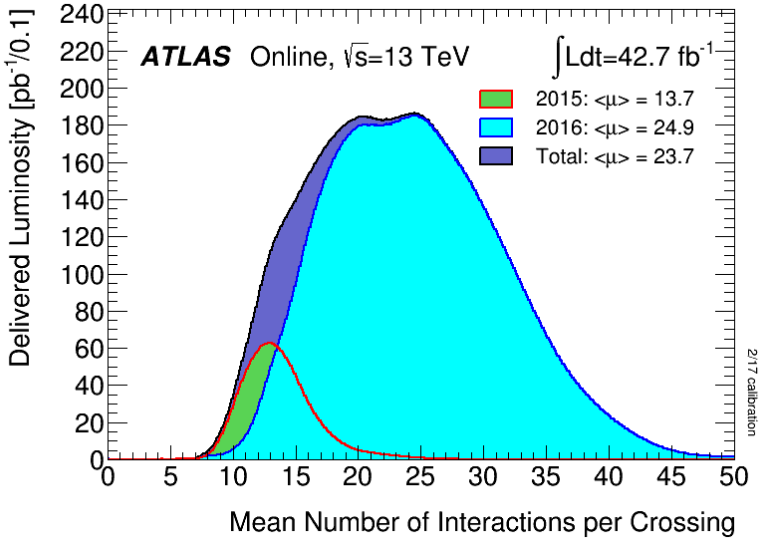


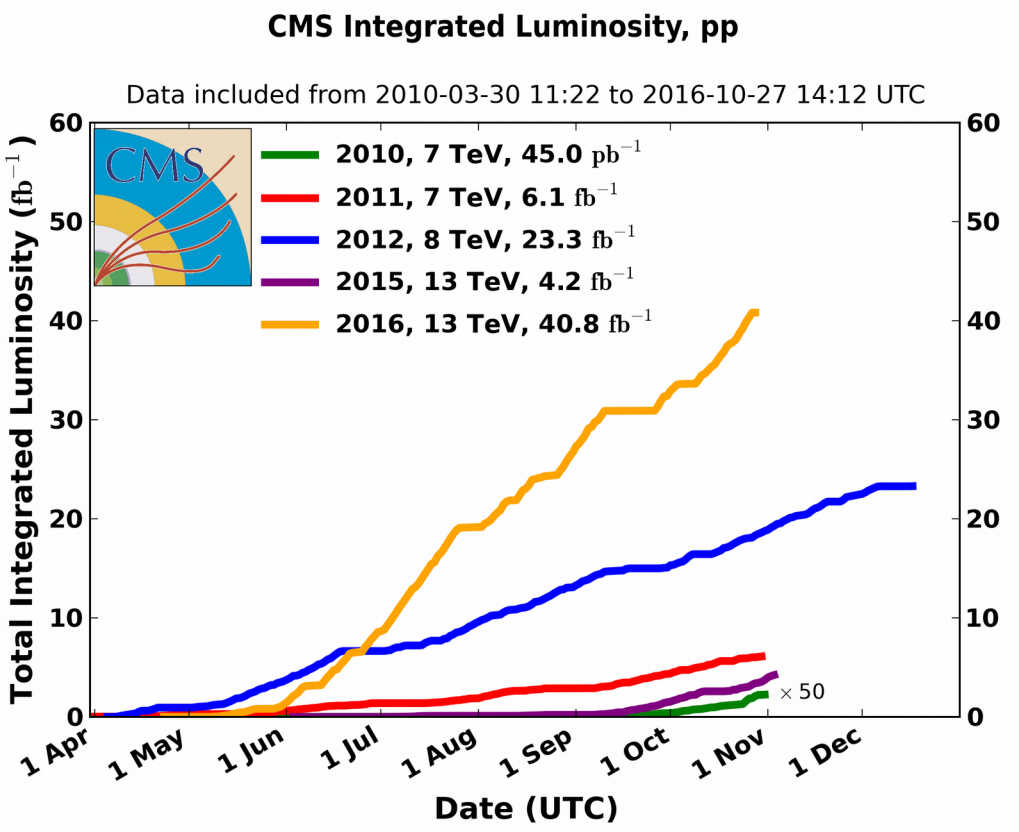
Looking everywhere

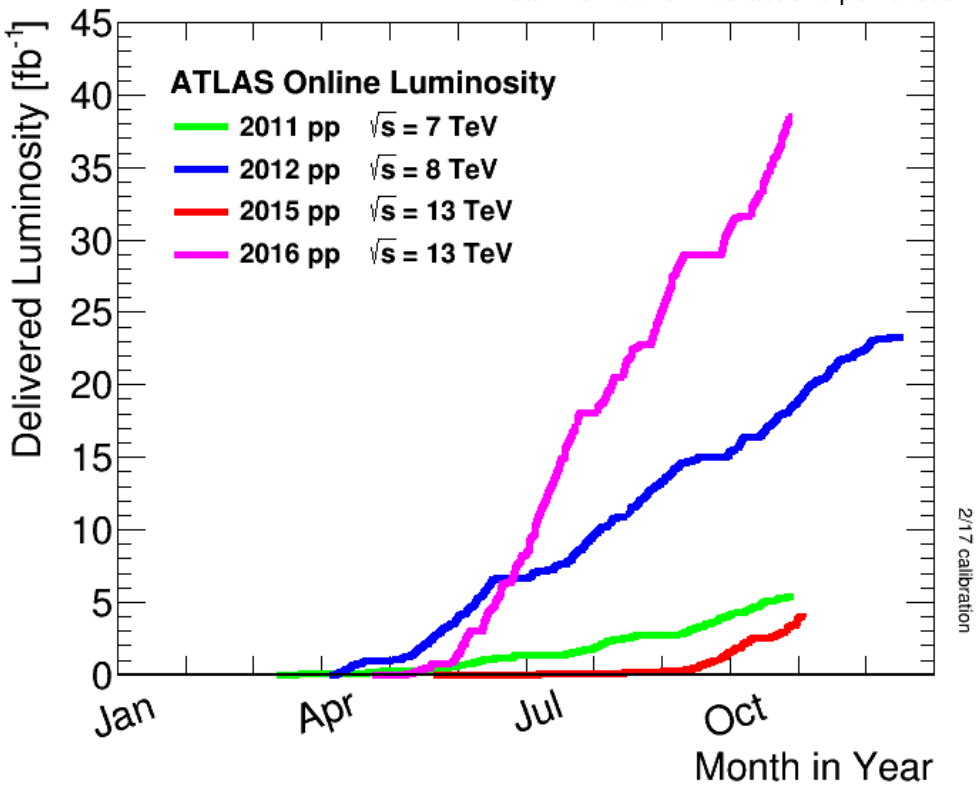


Thanks LHC

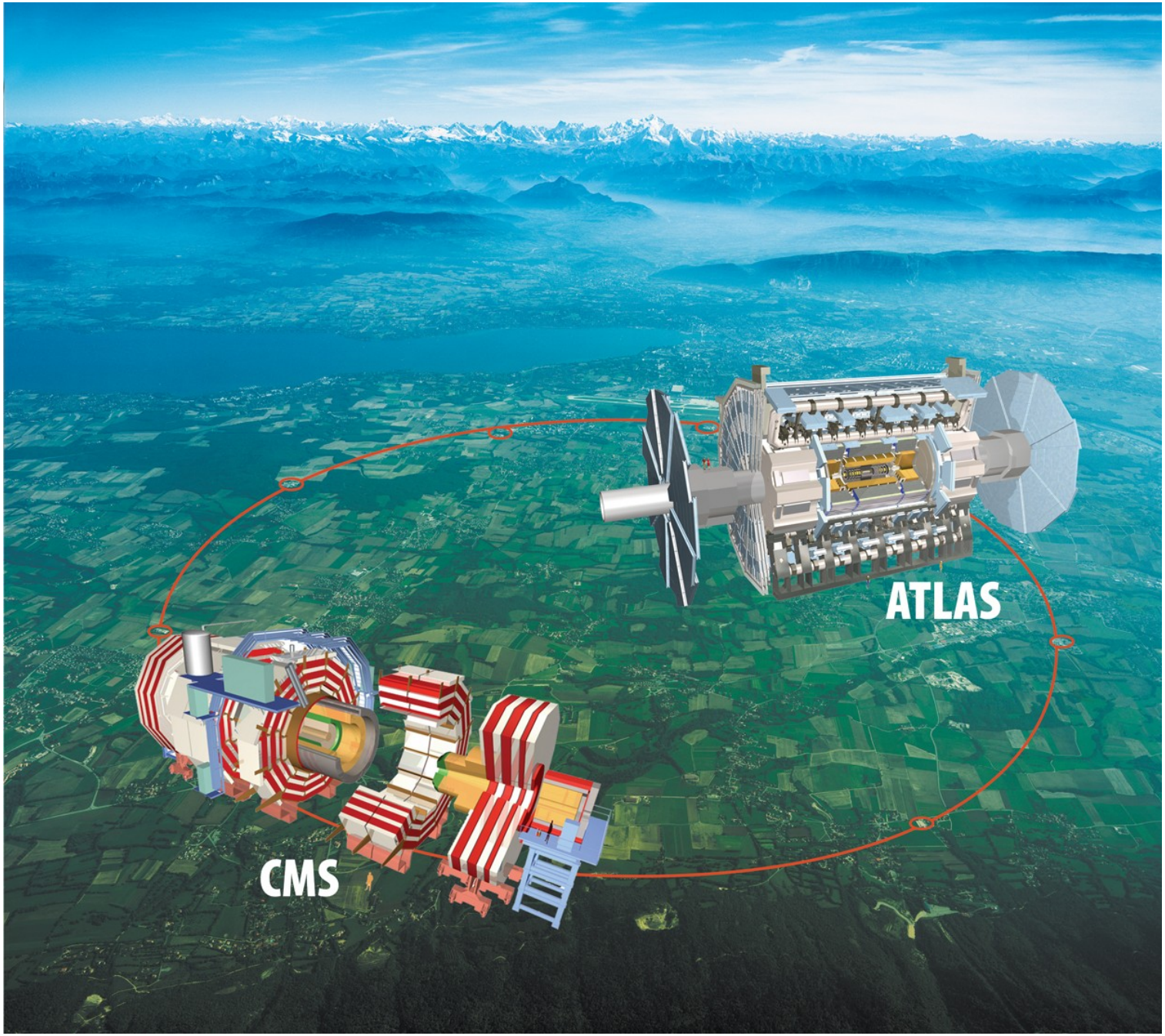
- Big thank to LHC for delivering so many pp collisions
- > 70 fb^{-1} so far … and more to come in 2017
- Higher pile-up scenarios → challenges for experiments







News from ATLAS and CMS



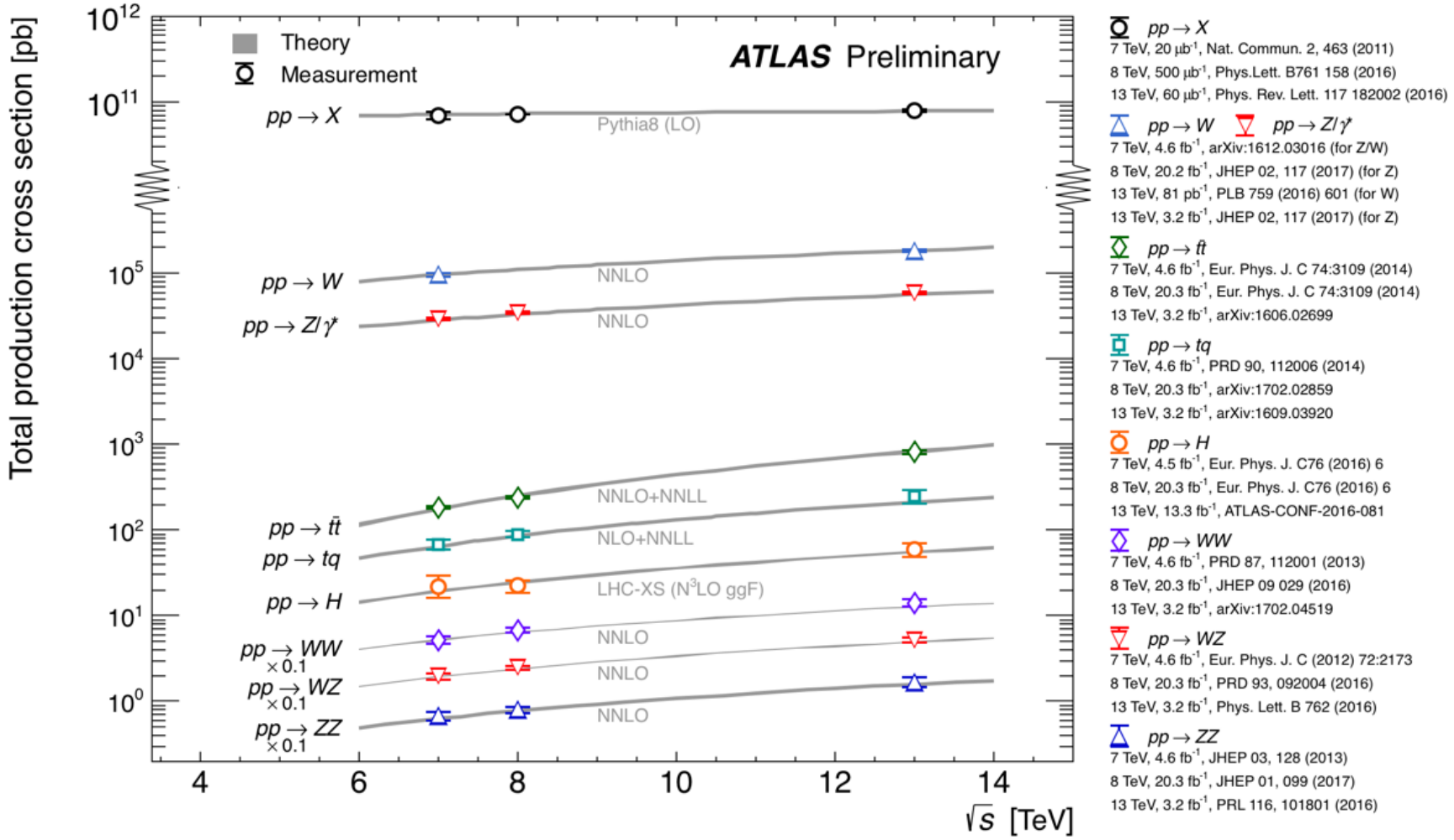
Strong interplay

Inclusive Cross Section

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

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

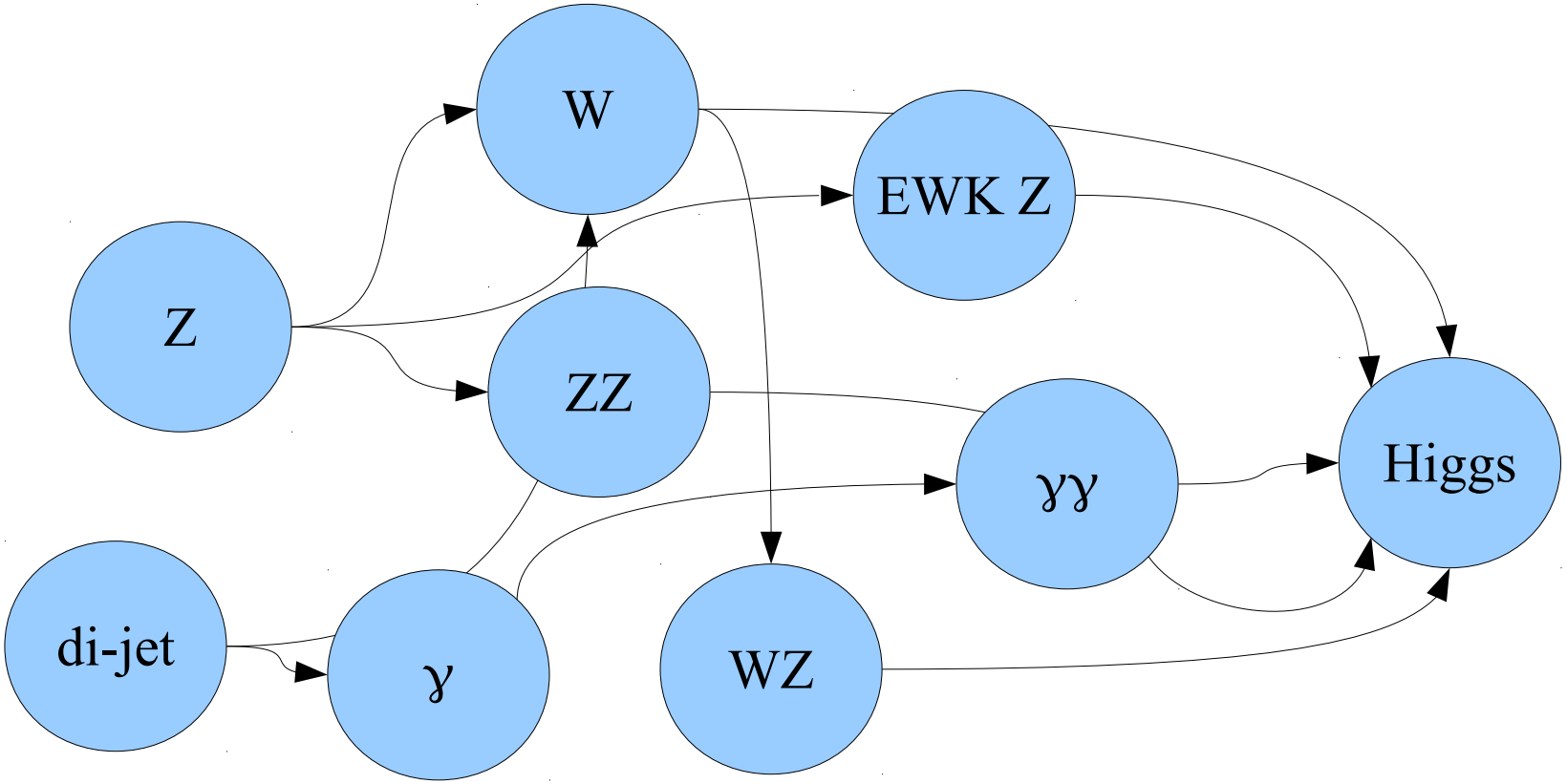
$$\sigma = \mathrm{DATA} / \int \mathrm{Luminosity}$$



The background of your signal is my signal

$$\sigma = (\mathrm{DATA} - \mathrm{Background})/(\varepsilon \int \mathrm{Luminosity})$$

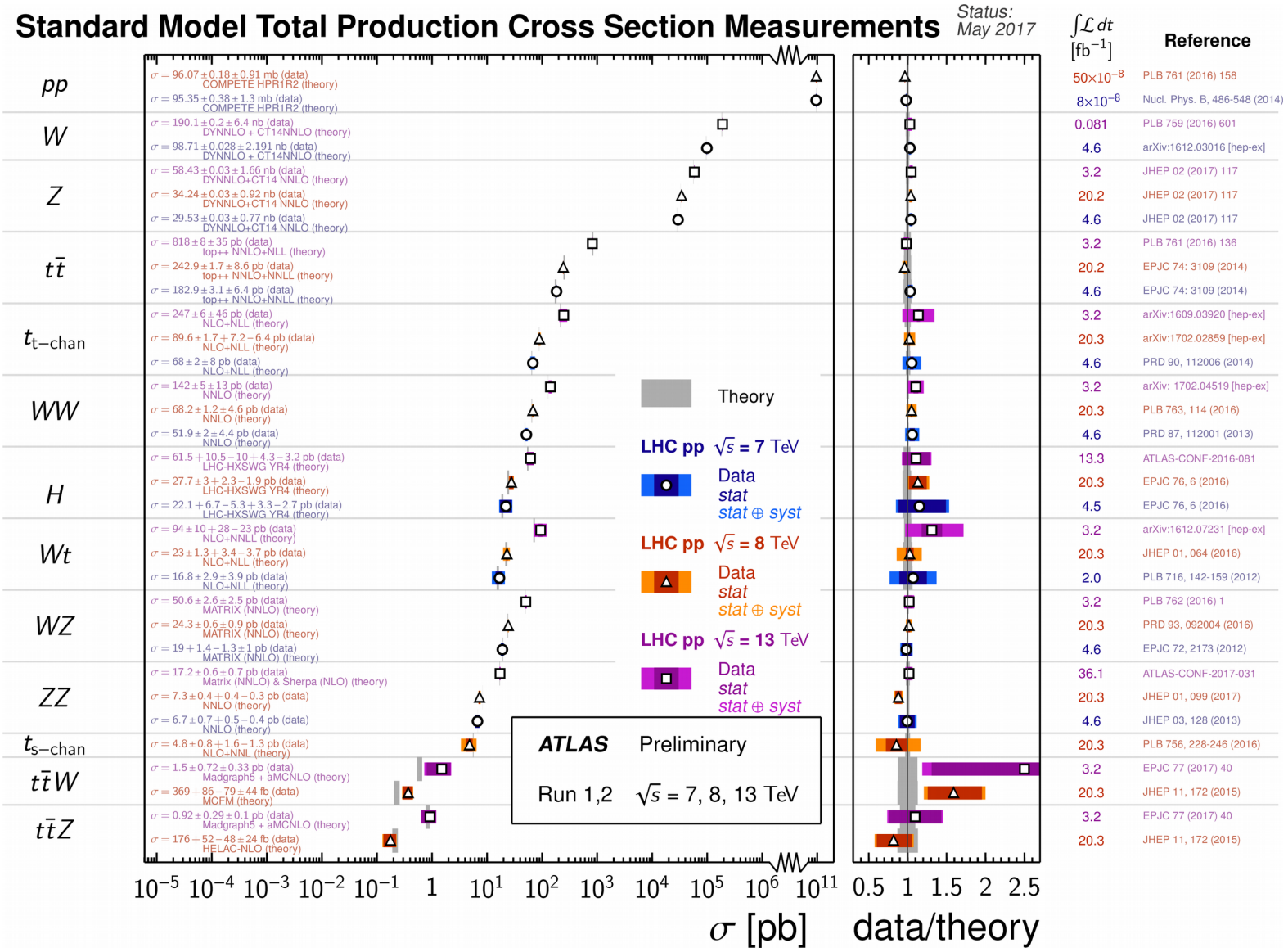
- Background estimation is essential for precision measurements
- Close connection analyses and improvements in description of a final state leads to reduction of uncertainties on background subtraction
- Standard model: jets, single vector boson, double vector bosons, … and Higgs



Standard Model measurements

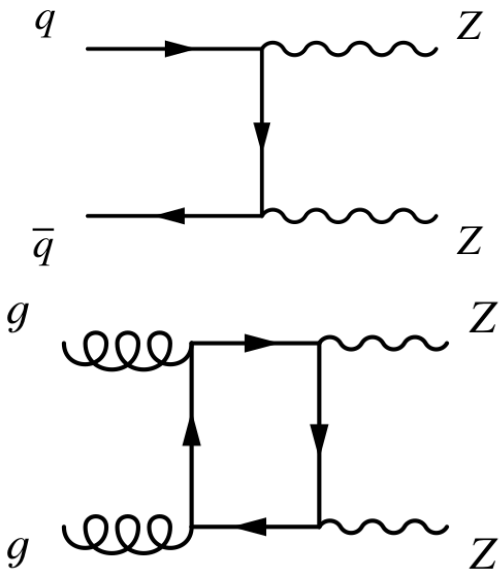
Many measurements

- Many measurements of SM processes in agreement with expectations
- New results in the following

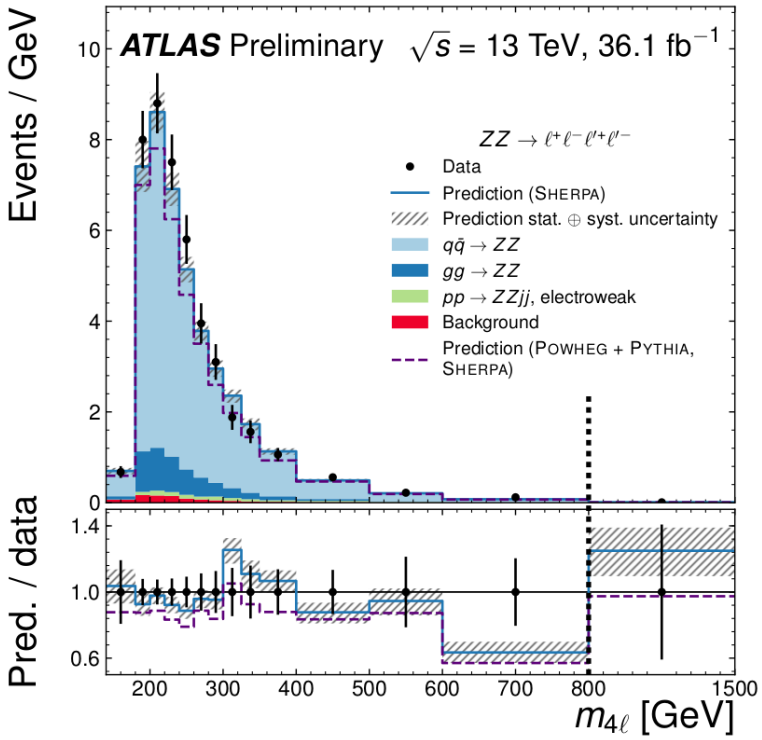


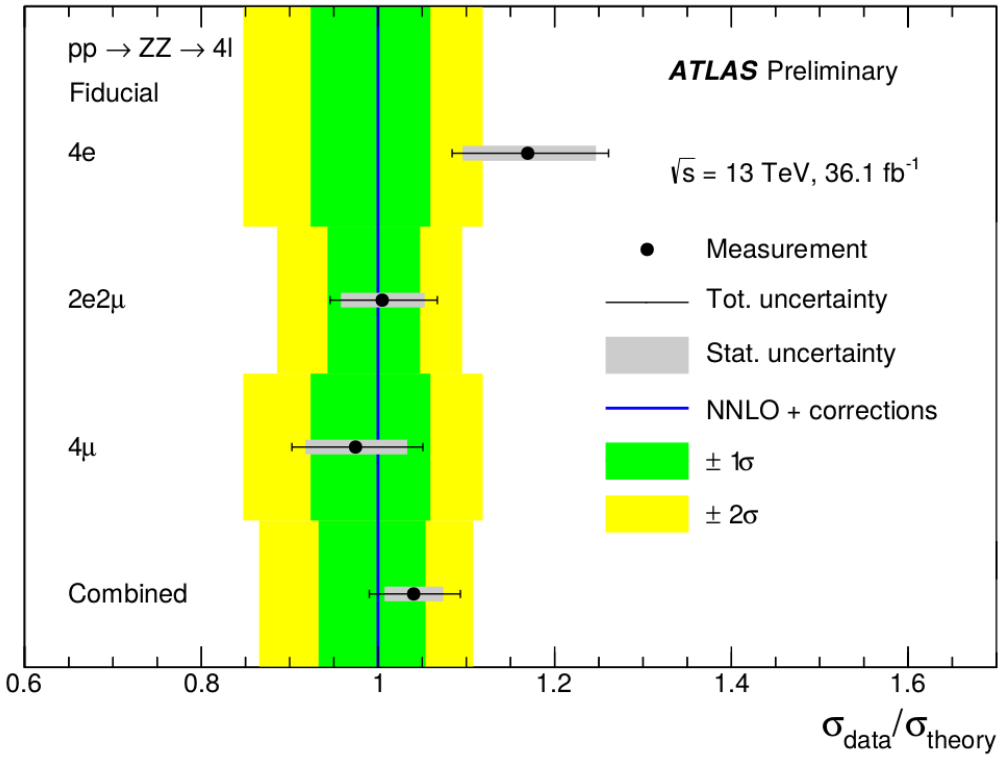
ZZ → 4 leptons

ATLAS-CONF-2017-031



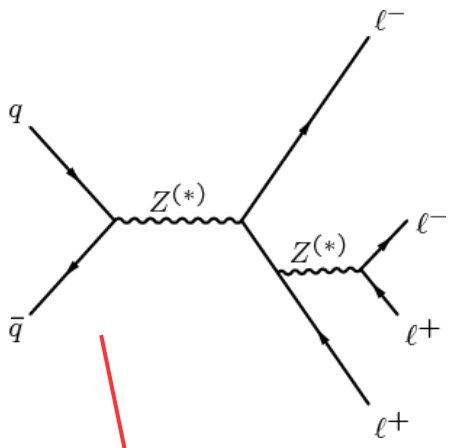
- 4 leptons: electrons/muons
  - Very clean experimental signature
- 66 GeV < M_Z < 116 GeV → on-shell Z
- Main background from non-prompt leptons
- Analysis statistically dominated
- Different final states (4e, 2e2μ, 4μ) and combination
- Good agreement with SM NNLO expectation



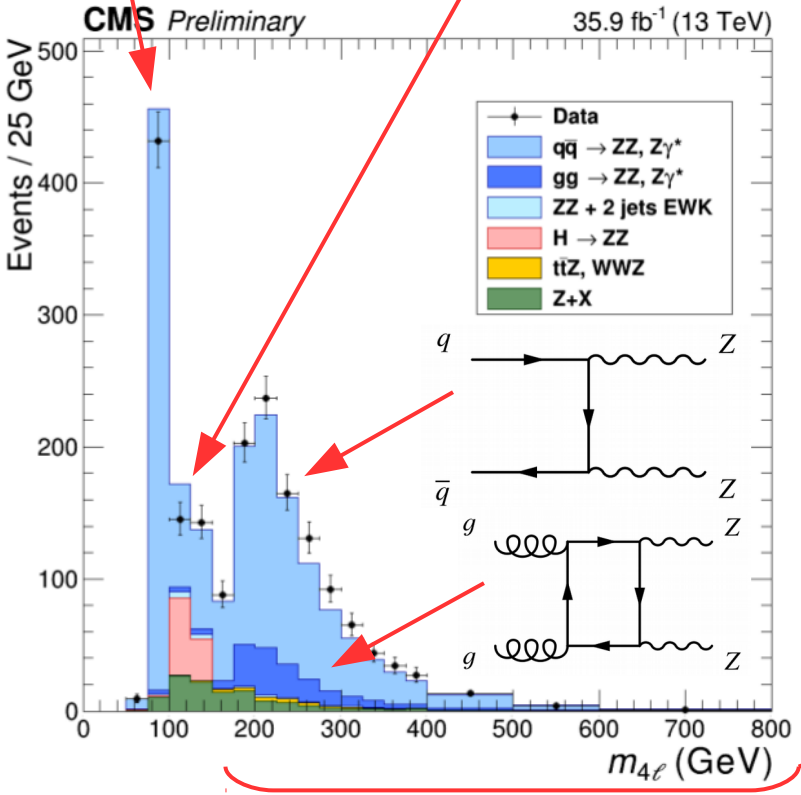


ZZ → 4 leptons

CMS-PAS-SMP-16-017



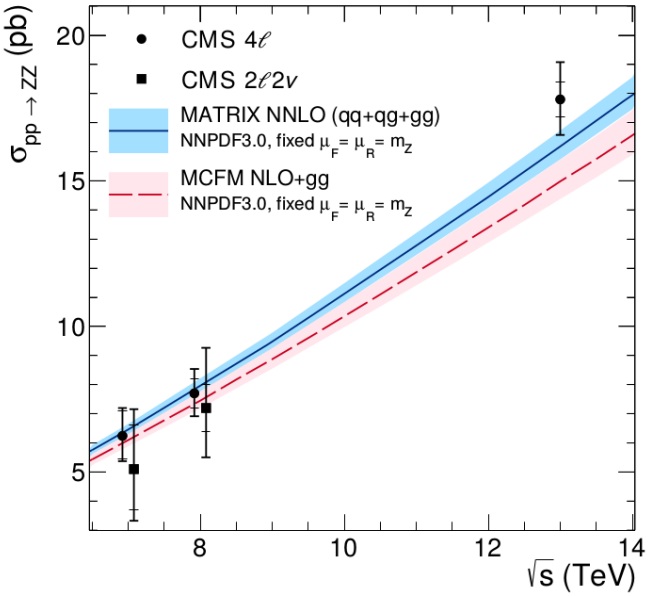
H → ZZ



- 4 leptons: electrons/muons

Final state	Expected $N_{4\ell}$	Background	Total expected	Observed
4μ	$196.0 \pm 1.2 \pm 14.9$	$3.9 \pm 1.0 \pm 1.5$	$199.9 \pm 1.6 \pm 15.0$	196
$2e2\mu$	$179.1 \pm 1.1 \pm 12.3$	$3.6 \pm 0.8 \pm 0.8$	$182.7 \pm 1.4 \pm 12.3$	167
$4e$	$59.1 \pm 0.6 \pm 6.7$	$2.4 \pm 0.4 \pm 1.0$	$61.4 \pm 0.8 \pm 6.8$	64
Total	$434.2 \pm 1.8 \pm 28.9$	$9.9 \pm 1.4 \pm 2.5$	$444.1 \pm 2.3 \pm 29.1$	427

- Measurement performed at different center of mass energies

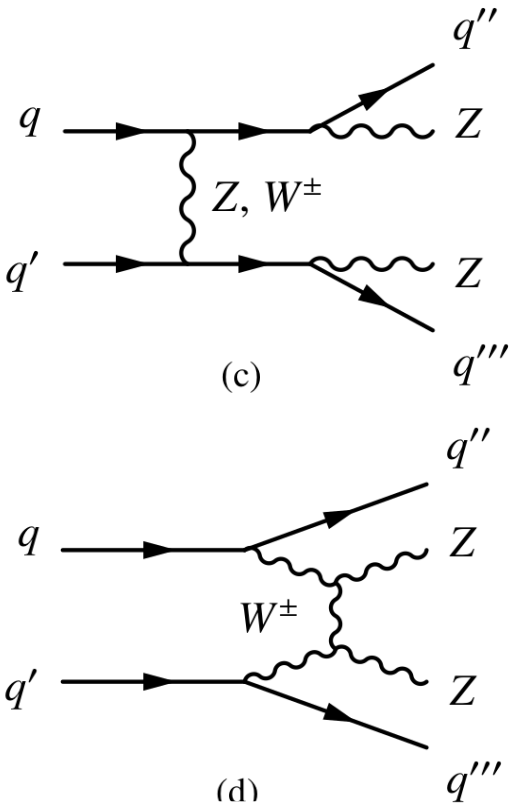


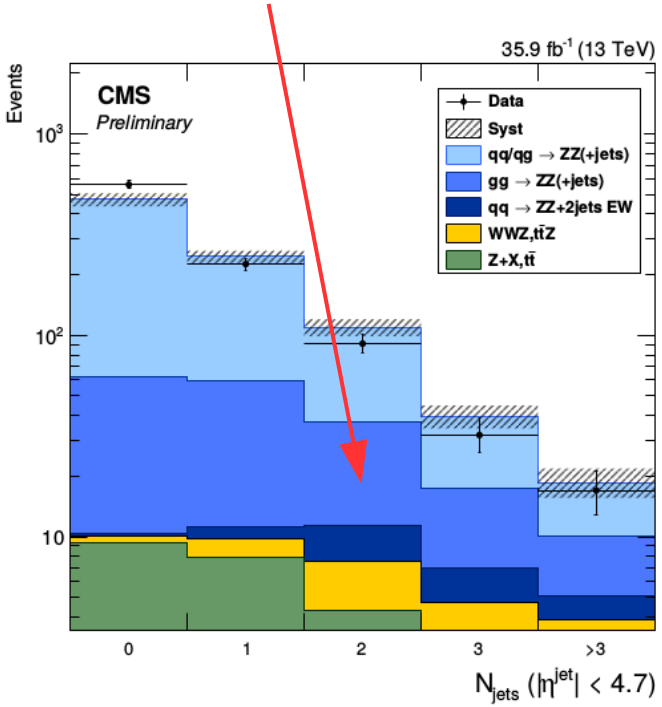
Decay channel	Expected $N_{4\ell}$	Background	Total expected	Observed
4μ	$265.5 \pm 1.3 \pm 8.4$	$5.2 \pm 0.8 \pm 1.5$	$270.7 \pm 1.5 \pm 8.6$	290
$2e2\mu$	$425.4 \pm 1.6 \pm 17.5$	$19.0 \pm 1.8 \pm 3.4$	$444.4 \pm 2.4 \pm 18.1$	465
$4e$	$165.3 \pm 1.0 \pm 10.9$	$11.8 \pm 1.5 \pm 2.2$	$177.2 \pm 1.8 \pm 11.4$	175
Total	$856.2 \pm 2.3 \pm 33.3$	$36.0 \pm 2.5 \pm 6.4$	$892.2 \pm 3.4 \pm 34.4$	930

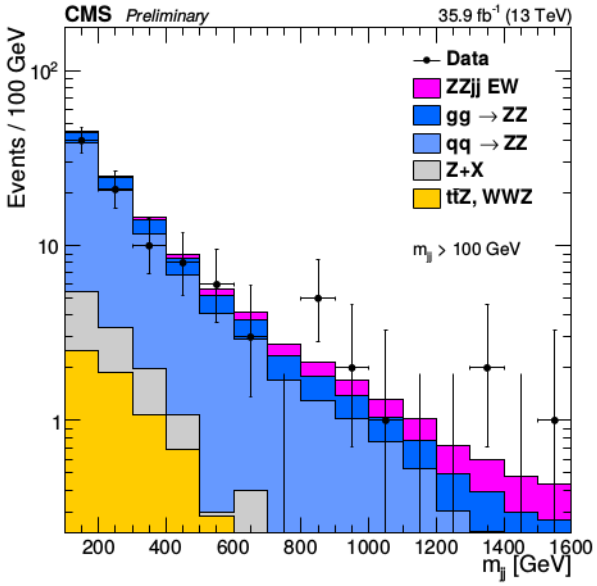
Electroweak ZZ

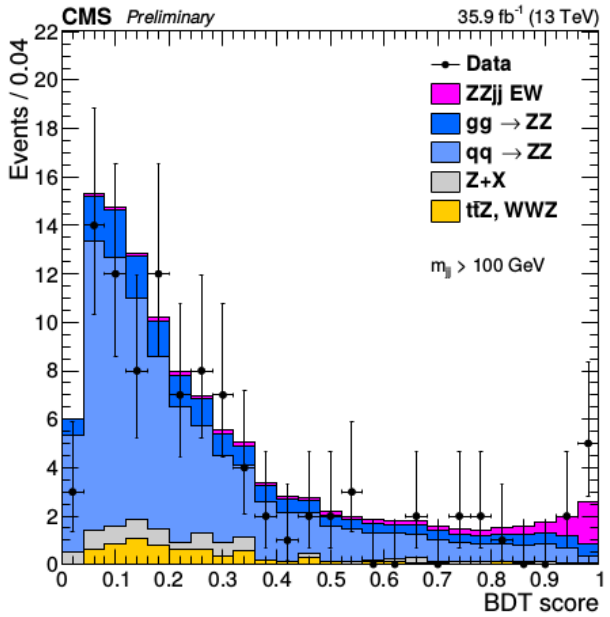
CMS-PAS-SMP-16-019

- 4 leptons: electrons/muons
- Electroweak production including Vector Boson Scattering









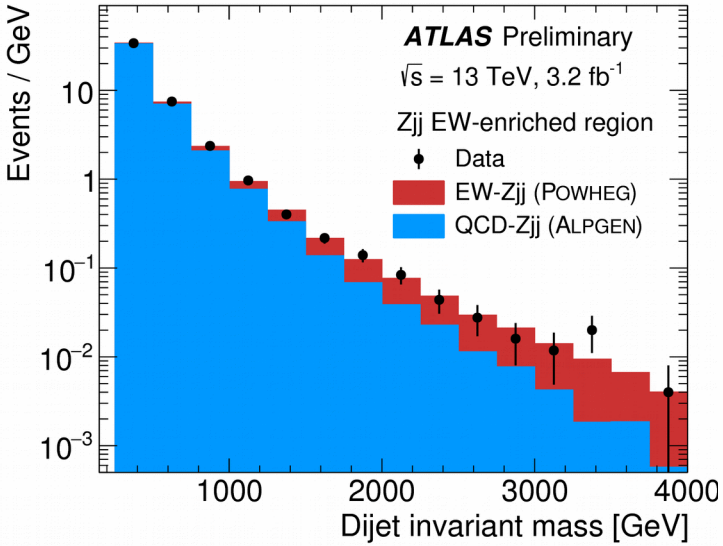
Selection	$t\bar{t}Z$ and WWZ	QCD ZZjj	Z+X	Total bkg.	EW ZZjj	Total expected	Data
ZZjj	7.1 ± 0.8	97 ± 14	6.6 ± 2.5	111 ± 14	6.2 ± 0.7	117 ± 14	99
VBS signal-enriched	0.9 ± 0.2	19 ± 4	0.7 ± 0.3	20 ± 4	4 ± 0.5	25 ± 4	19

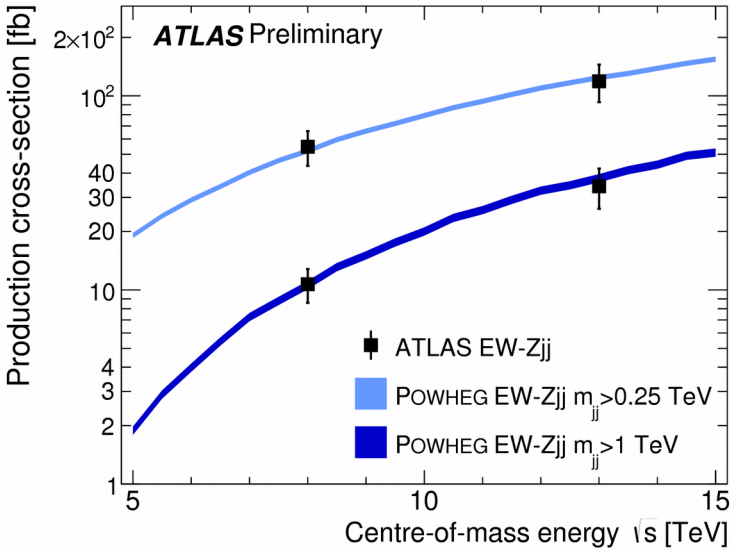
$M_{jj} > 400$ GeV, $|\Delta\eta_{jj}| > 2.4$

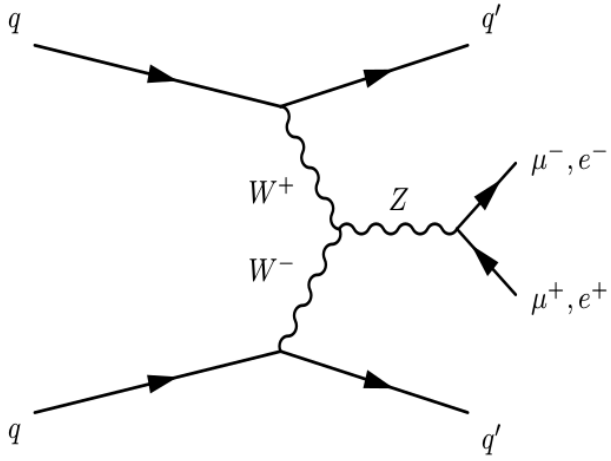
- High di-jet invariant mass
- Jets and leptons variables combined into a BDT
- $\sigma/\sigma_{SM} = 1.39^{+0.86}_{-0.65}$

Electroweak Z and Zγ

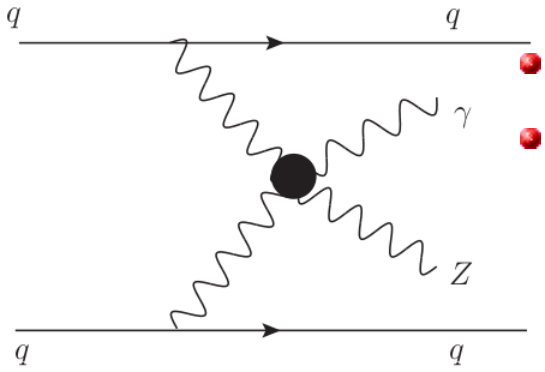
- **Electroweak Z + 2 jets:** Measurement of the cross-section for electroweak production of di-jets in association with a Z boson in pp collisions at √s = 13 TeV







ATLAS-STDM-2016-09

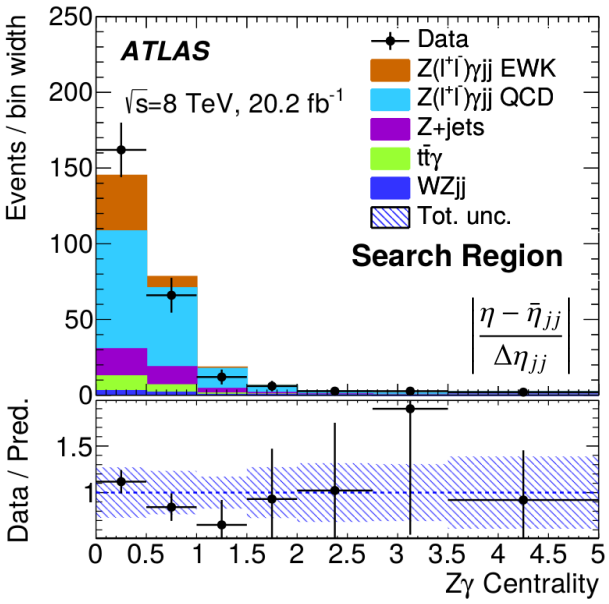


- **Electroweak Zγ + 2 jets**
- Significance = 2.0σ (1.8σ) observed (expected)
- Z → ll and Z → νν used

$$\sigma^{\text{VBFNLO,EWK}}_{Z\gamma jj} = 0.94 \pm 0.09 \text{ fb}$$

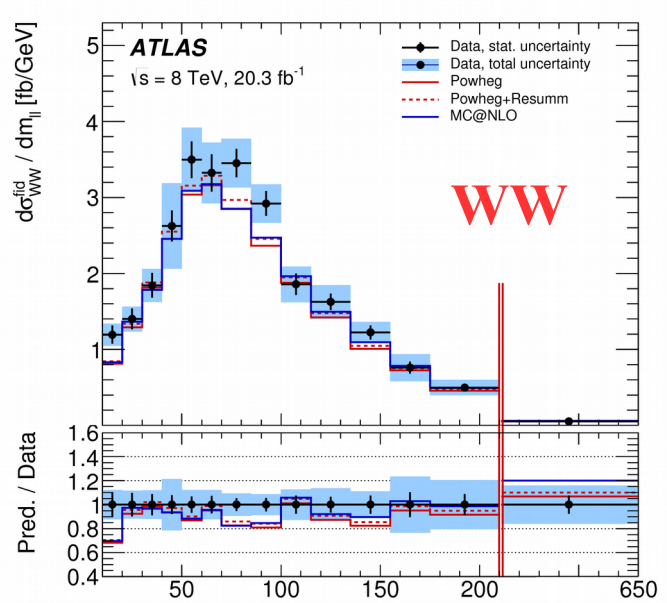
$$\sigma^{\text{EWK}}_{Z\gamma jj} = 1.1 \pm 0.5 \text{ (stat)} \pm 0.4 \text{ (syst) fb} = 1.1 \pm 0.6 \text{ fb}$$

STDM-2015-21
arXiv:1705.01966



Fiducial and Differential Cross Section

- Many new results at 7/8/13 TeV from ATLAS and CMS
- How we usually proceed:
  - Inclusive cross section
  - Fiducial and differential cross section
- Reduced **theoretical uncertainty** on experimental results
- **Less model dependent** results
- Allow **comparison** with several MC calculations



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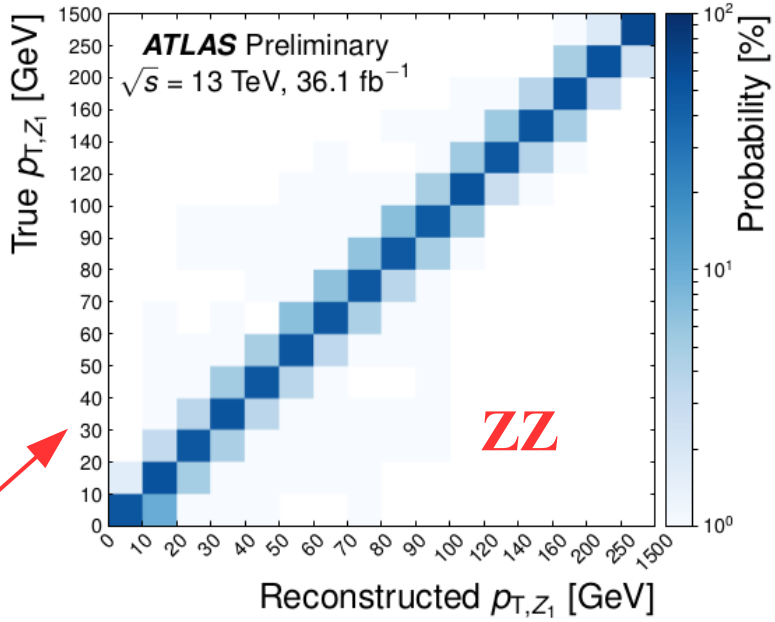
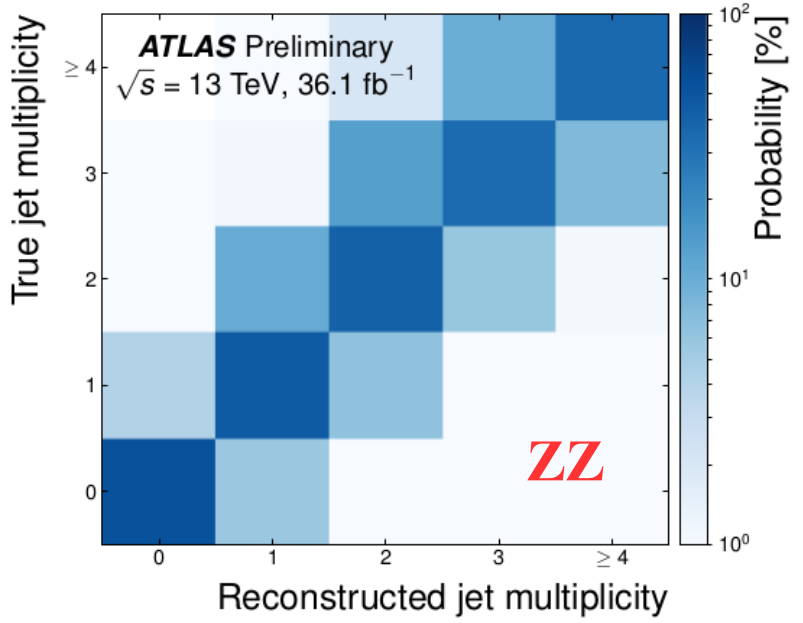
- **Fiducial** phase space:
  - Mimic kinematic acceptance of detector
- **Unfolding** procedure: usually regularized distribution
  - Bayesian, SVD regularization
  - Response matrix

ATLAS-CONF-2017-031





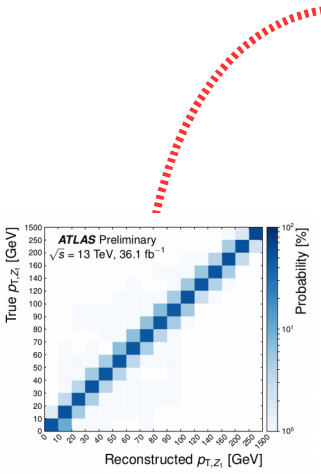
A complete menu

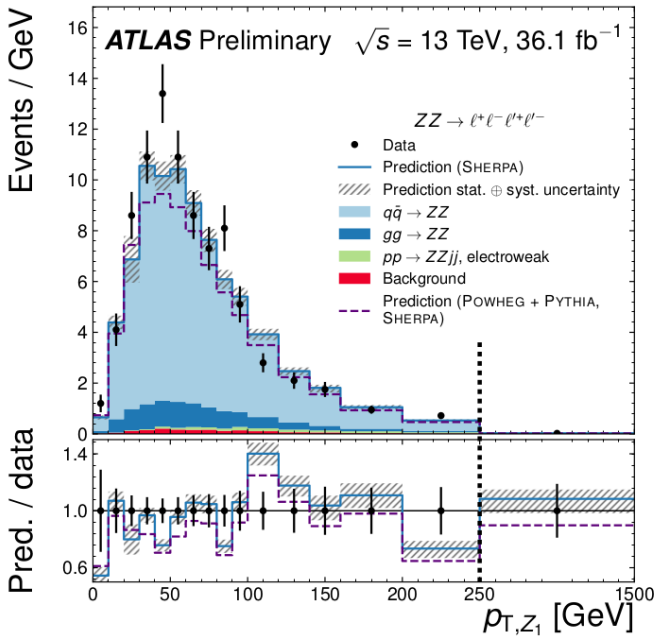
- Many measurements performed by ATLAS and CMS
  - Single jet
  - Di-jet
  - Single Vector Boson
    - W
    - Z
  - Double Vector Boson
    - WW
    - WZ
    - ZZ
    - W/Z + γ
  - Triple Vector Boson
  - Vector Boson Scattering

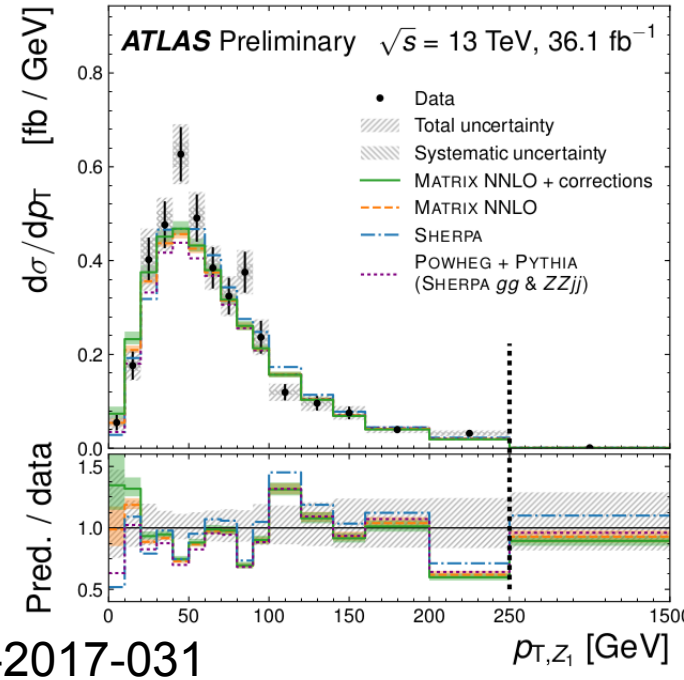
- **Differential ZZ → 4 leptons**
  - Fiducial phase space

Type	Input or requirement
Leptons (e, μ)	Prompt Dressed with prompt photons within $\Delta R = 0.1$ $p_T > 5$ GeV $\|\eta\| < 2.7$
Quadruplets	Two same-flavor opposite-charge lepton pairs Three leading-p_T leptons satisfy $p_T > 20$ GeV, 15 GeV, 10 GeV
Events	Only quadruplet minimizing $\|m_{\ell\ell} - m_Z\| + \|m_{\ell'\ell'} - m_Z\|$ is considered Any same-flavor opposite-charge dilepton has mass $m_{\ell\ell} > 5$ GeV $\Delta R > 0.1$ (0.2) between all same-flavor (different-flavor) leptons Dileptons minimizing $\|m_{\ell\ell} - m_Z\| + \|m_{\ell'\ell'} - m_Z\|$ are taken as Z boson candidates Z boson candidates have mass 66 GeV < $m_{\ell\ell}$ < 116 GeV
Jets	Clustered from all non-prompt particles Anti-k_t algorithm with $R = 0.4$ $p_T > 30$ GeV $\|\eta\| < 4.5$ Rejected if within $\Delta R = 0.4$ of a fiducial lepton

  - 20 variables, including jet related ones



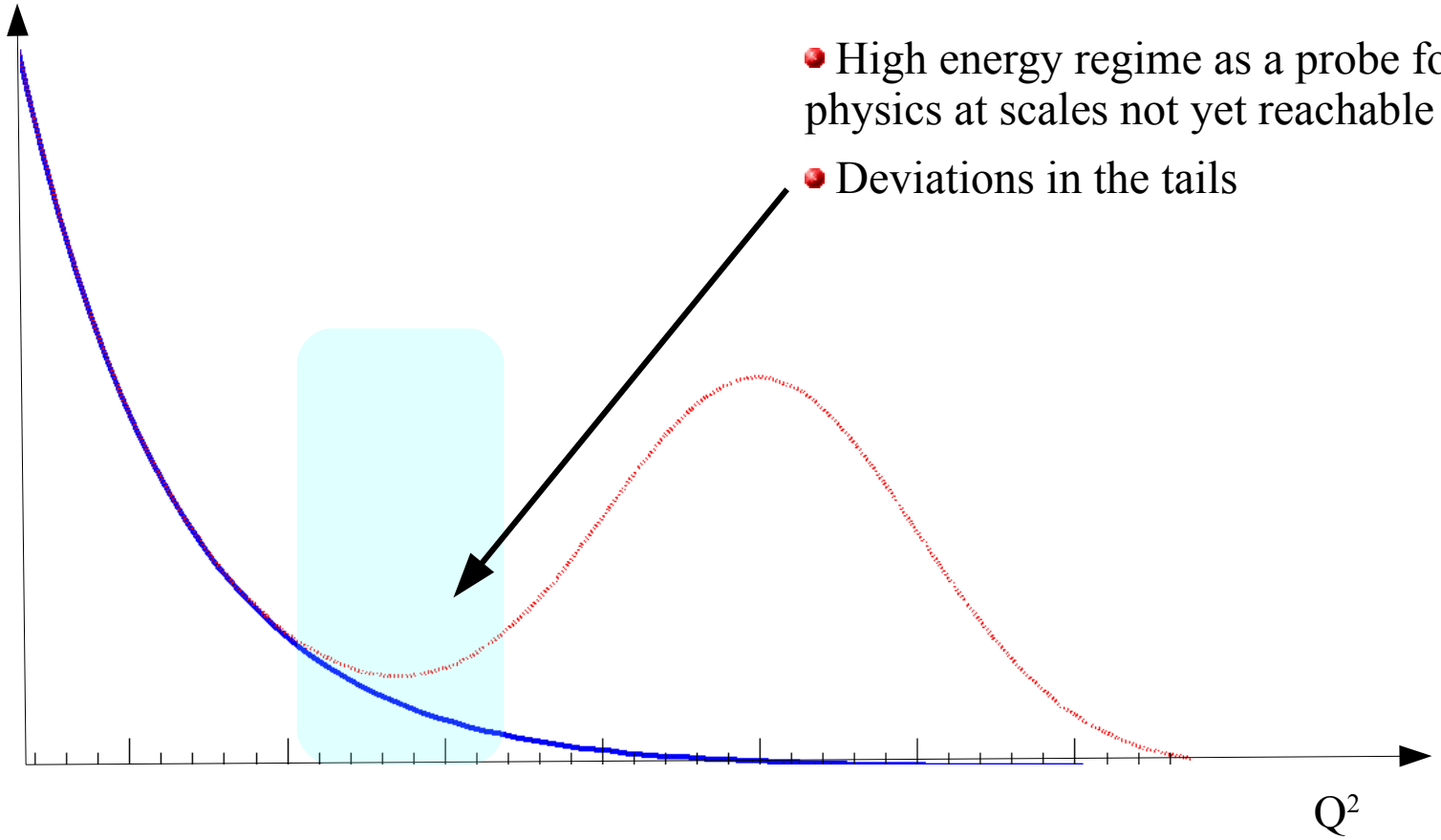




ATLAS-CONF-2017-031

Looking for deviations

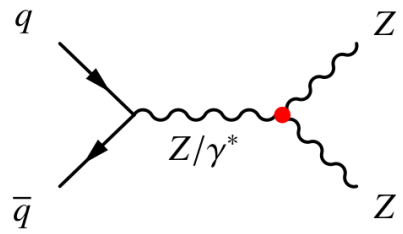
- Many new results at 7/8/13 TeV from ATLAS and CMS
- How we usually proceed:
  - Inclusive cross section
  - Fiducial and differential cross section
  - High energy regimes for anomalous couplings



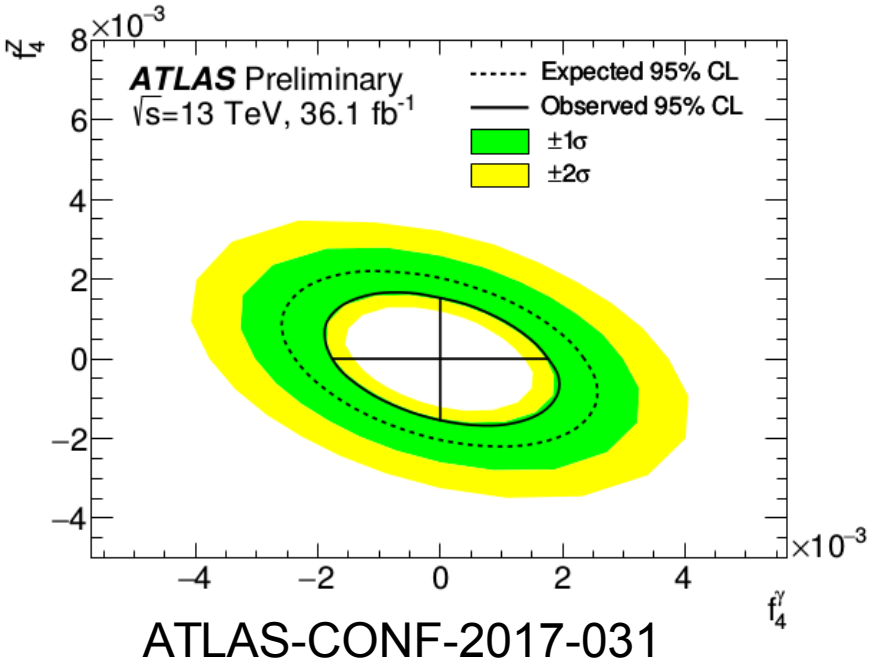
- High energy regime as a probe for new physics at scales not yet reachable directly
- Deviations in the tails

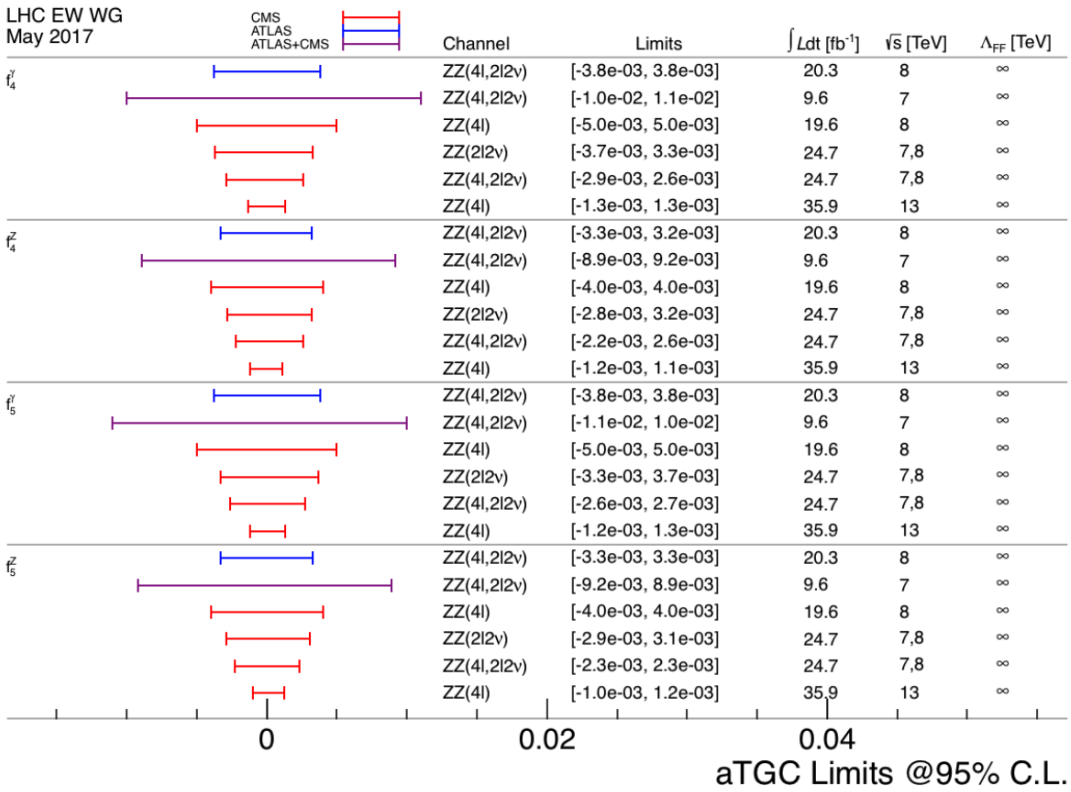
Anomalous Couplings

- Charged Anomalous Triple Gauge Couplings: charged aTGC
- Neutral Anomalous Triple Gauge Couplings: neutral aTGC
- Anomalous Quartic Gauge Couplings: aQGC



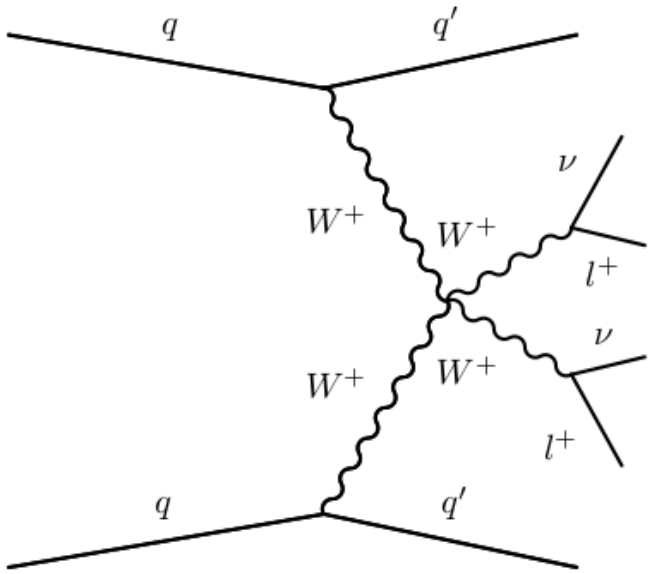
- Vertices not allowed in SM at tree-level
- Different kinematic distributions due to changes in the couplings

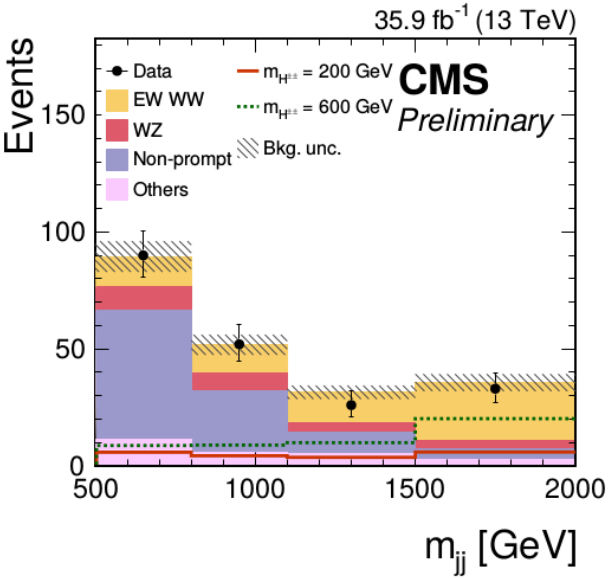


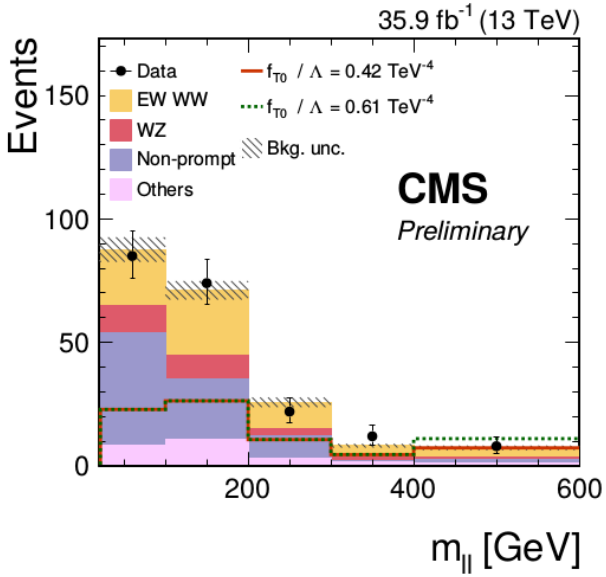


$W^{\pm}W^{\pm}$ + 2jets

- **Vector Boson Scattering WW**
  - **Same sign** → reduced background
  - High di-jet invariant mass
- Observation with **5.5 standard deviations** (5.7 expected)
- Fiducial region:
  - $p_T^{Lep} > 20$ GeV, $|\eta^{Lep}|<2.5$
  - $p_T^{Jet} > 30$ GeV, $|\eta^{Jet}|<5.0$, $|\Delta\eta_{jj}|>2.5$, $M_{jj} > 500$ GeV
- $\sigma_{fid}(W^{\pm}W^{\pm}jj) = 3.83 \pm 0.66\,(stat) \pm 0.35\,(syst)$ fb
- Sensitive to anomalous quartic gauge coupling





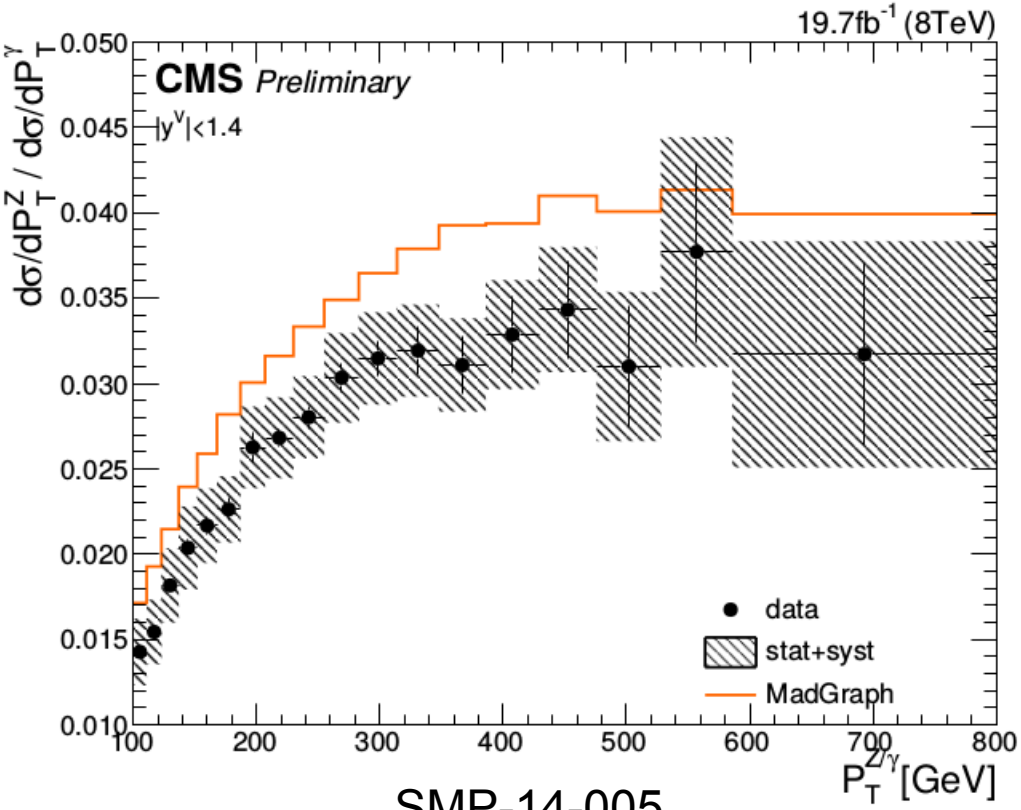


	Observed limits (TeV $^{-4}$)	Expected limits (TeV $^{-4}$)	Run-I limits (TeV $^{-4}$)
f_{S0}/Λ	[-7.7, 7.7]	[-7.0, 7.2]	[-38 , 40] [11]
f_{S1}/Λ	[-21.6,21.8]	[-19.9,20.2]	[-118 , 120] [11]
f_{M0}/Λ	[-6.0, 5.9]	[-5.6, 5.5]	[-4.6 , 4.6] [29]
f_{M1}/Λ	[-8.7 ,9.1]	[-7.9, 8.5]	[-17 , 17] [29]
f_{M6}/Λ	[-11.9,11.8]	[-11.1,11.0]	[-65 , 63] [11]
f_{M7}/Λ	[-13.3,12.9]	[-12.4,11.8]	[-70 , 66] [11]
f_{T0}/Λ	[-0.62,0.65]	[-0.58,0.61]	[-3.8 , 3.4] [30]
f_{T1}/Λ	[-0.28,0.31]	[-0.26,0.29]	[-1.9 , 2.2] [11]
f_{T2}/Λ	[-0.89,1.02]	[-0.80,0.95]	[-5.2 , 6.4] [11]

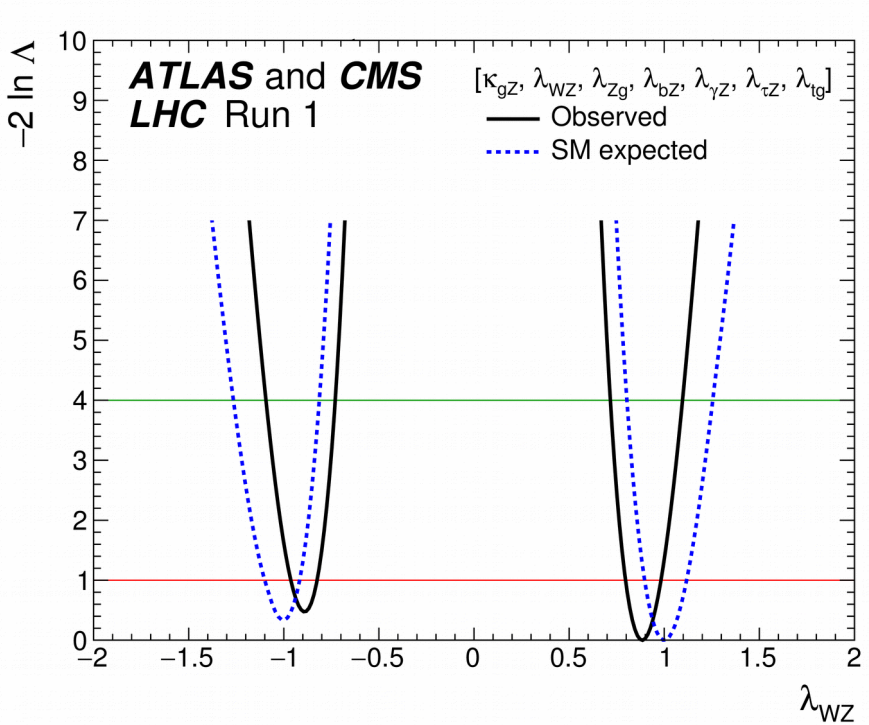
CMS-PAS-SMP-17-004

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



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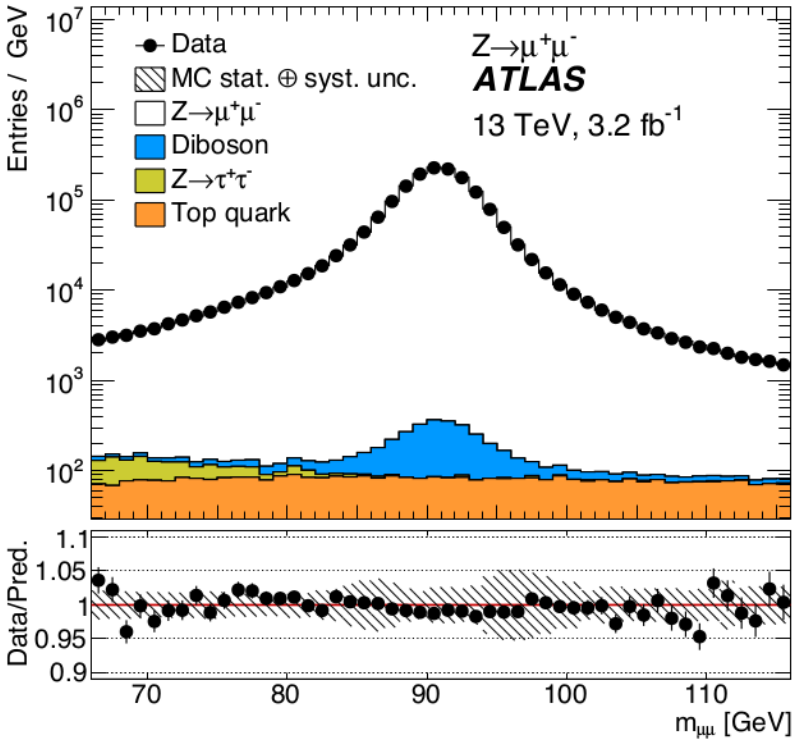
$t\bar{t}$ / Z

- Measuring **ratios** of experimental observables some systematic uncertainties cancel out
  - e.g. luminosity uncertainty
- Ratios also with respect to different center of mass energies results



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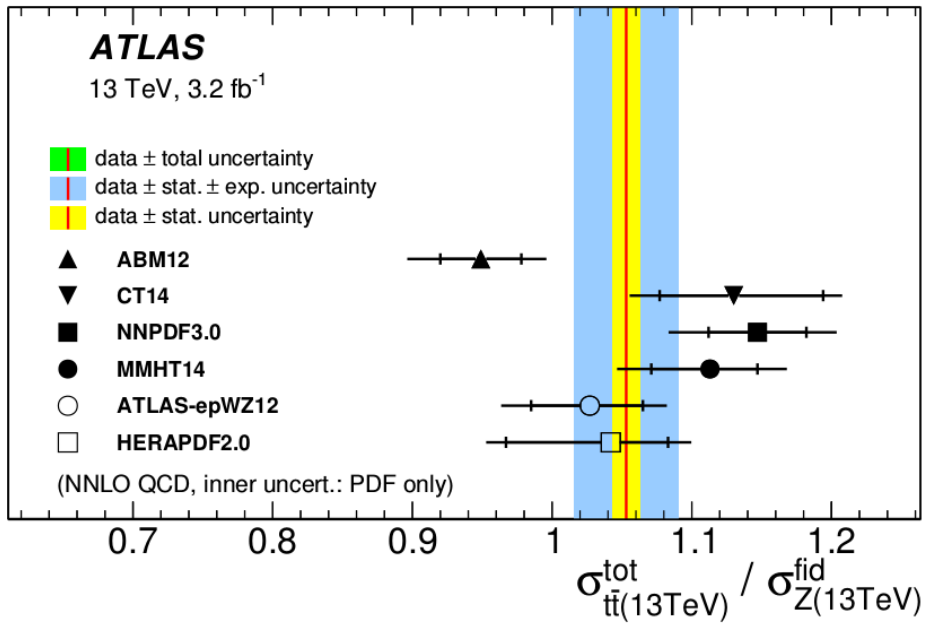
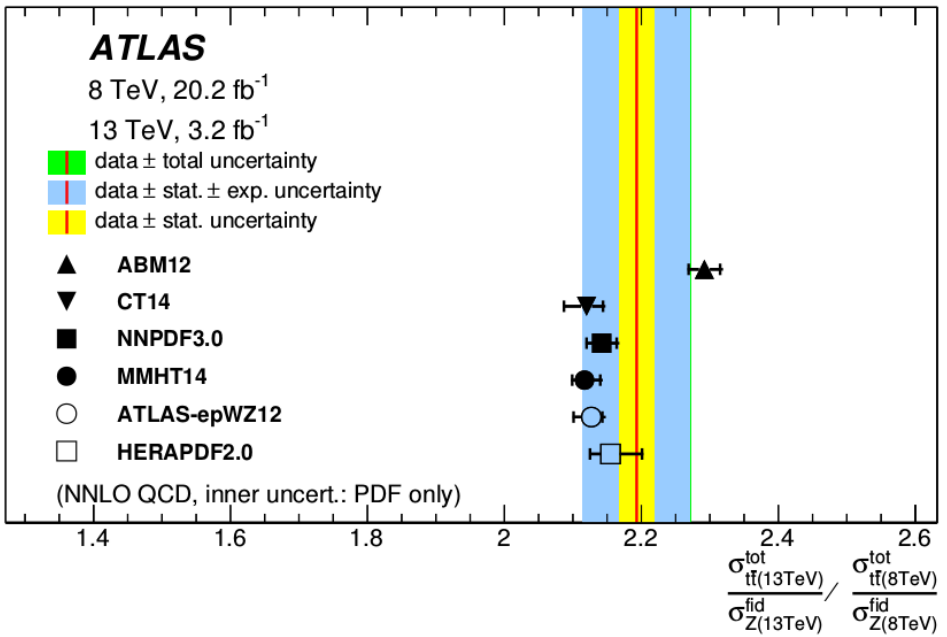
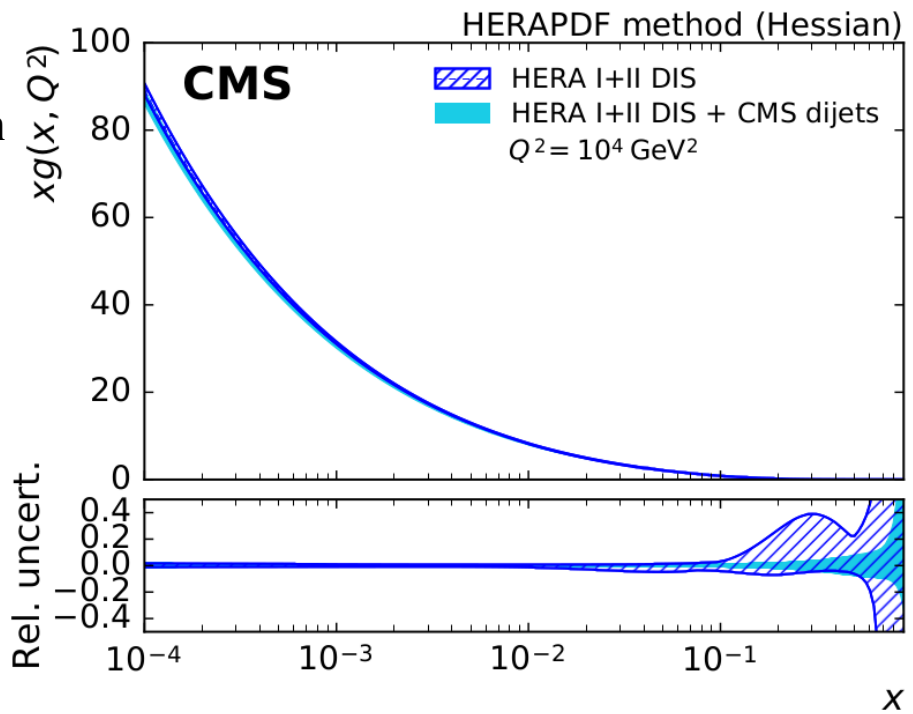


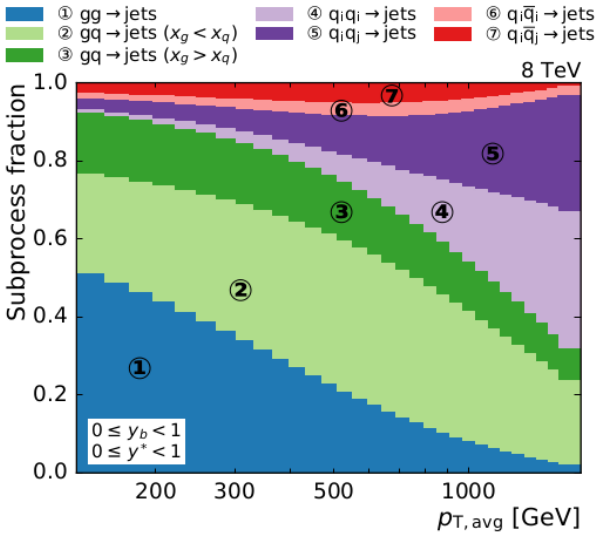


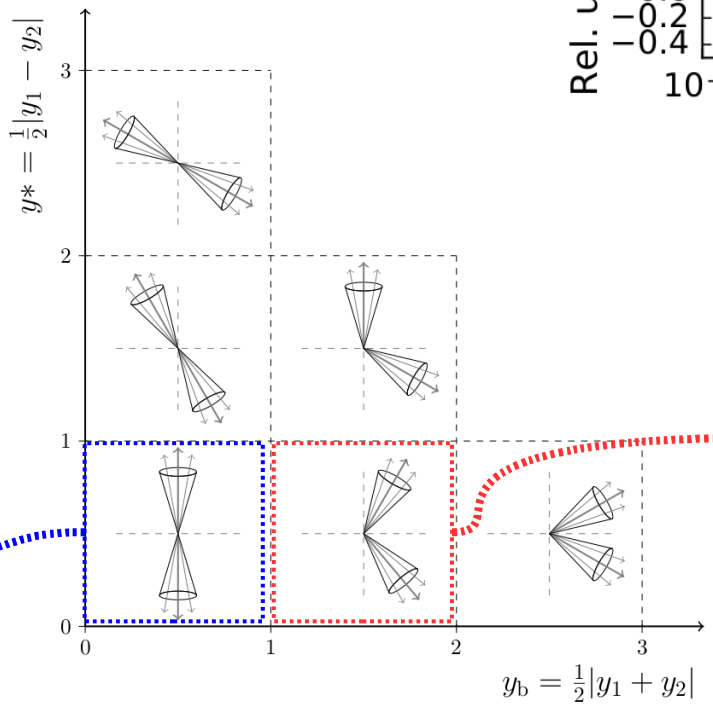
More ...

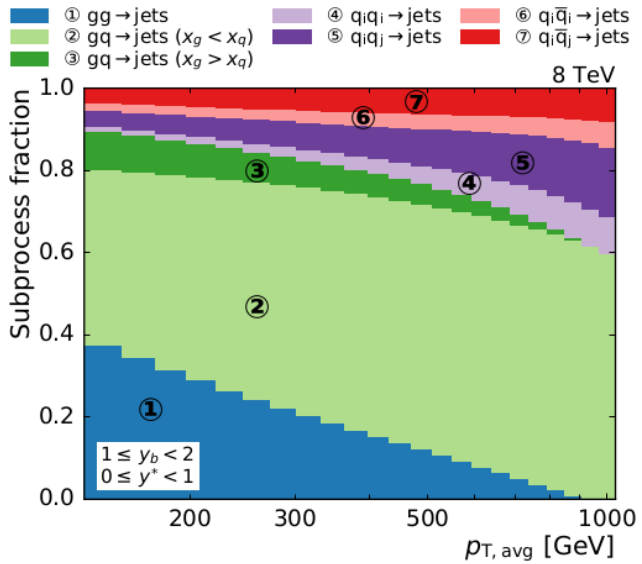
- Use LHC based results to constraint knowledge on **proton PDF**, measurement of **strong coupling constant α_s**
- Measurement of the **triple-differential di-jet cross section**
  - p_T, Δy, boost (y_b)
  - Different phase spaces probed → sensitive to different PDF components
- Important to **reduce systematic uncertainty in precision measurements and searches**

CMS-PAS-SMP-16-011



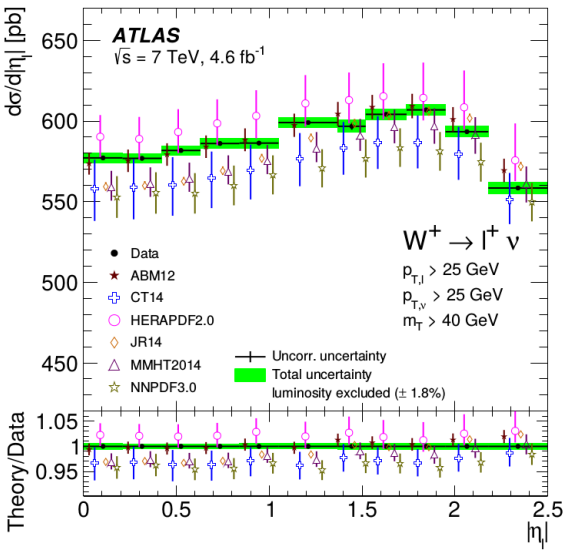


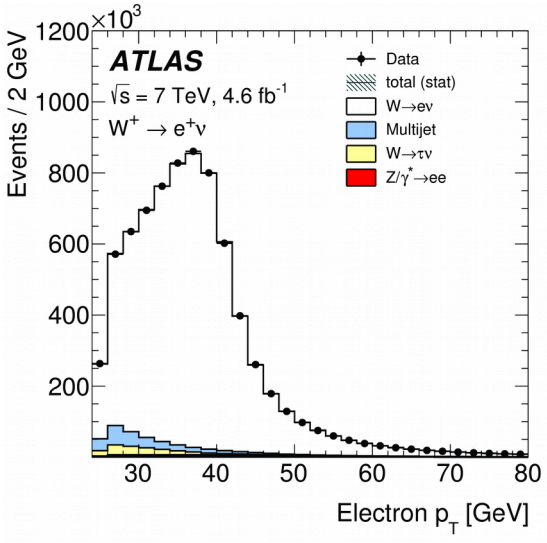


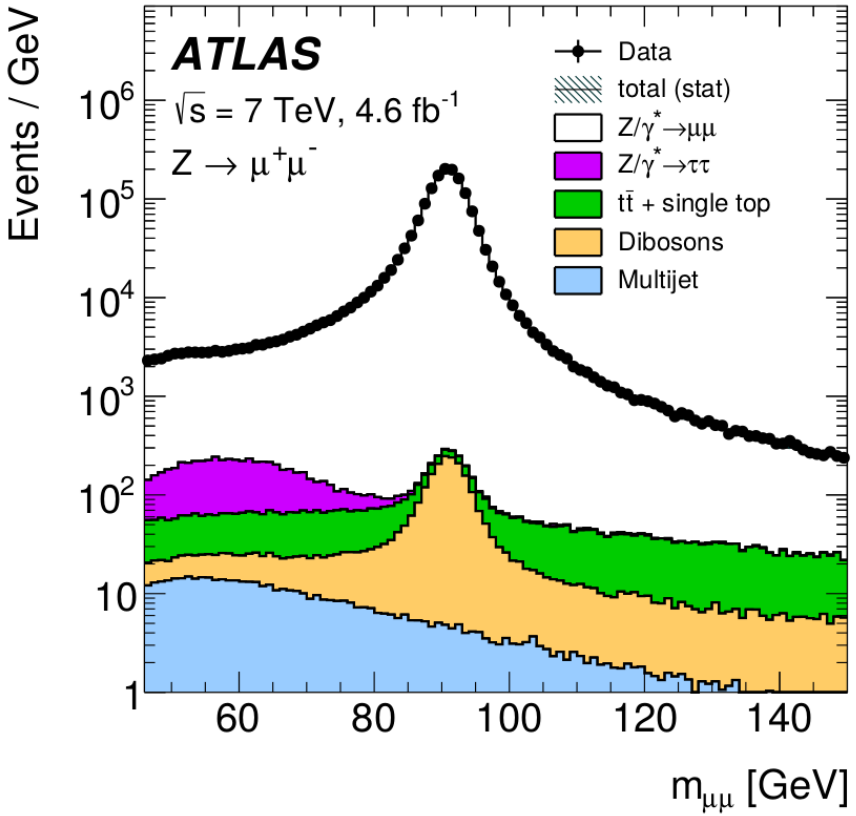


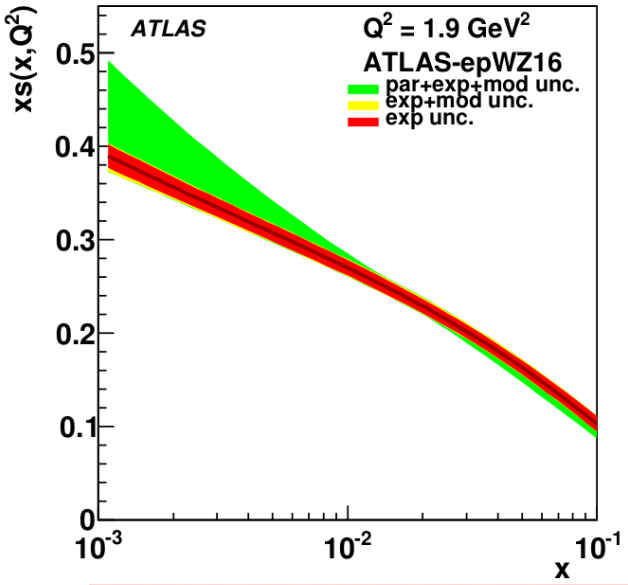
Precision measurement W^+, W^- and Z/γ^*

- From precision measurement of single vector boson production → **proton PDF**, measurement of **strange quark density**, measurement of CKM matrix elements $|V_{cs}|$



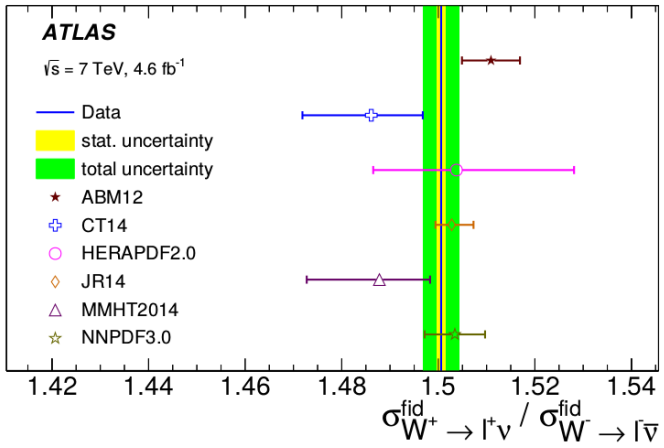






- Inclusive cross section
- Differential cross section
- ratios between different final states
- comparison with different PDF sets, precision measurements
- …

STDM-2012-20



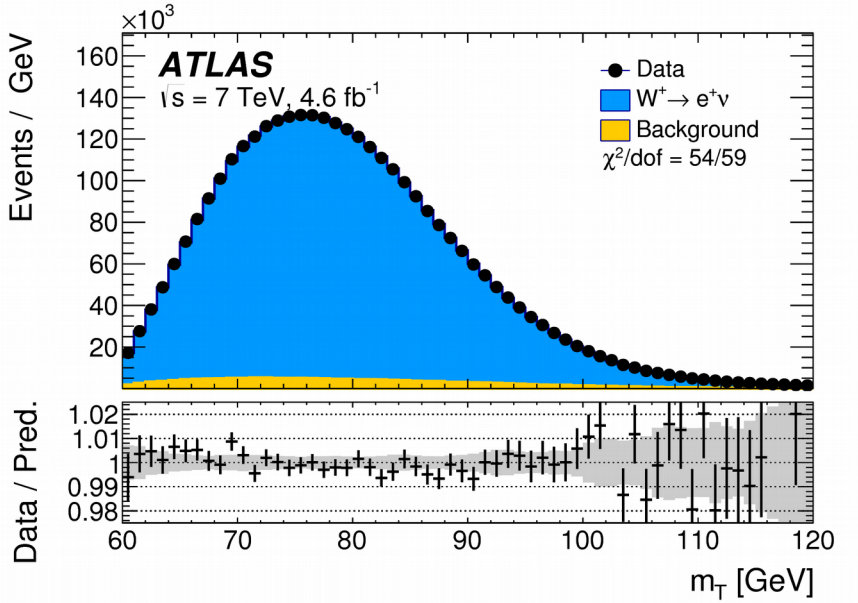
Precision measurements: W mass

- Precision measurement at LHC STDM-2014-18
  - W-mass

$M_W = 80370 \pm 7\ (\text{stat.}) \pm 11\ (\text{exp. syst.}) \pm 14\ (\text{mod. Syst.})$ MeV

$= \mathbf{80370 \pm 19\ MeV}$

- Extensive work to keep experimental and theoretical uncertainties as small as possible

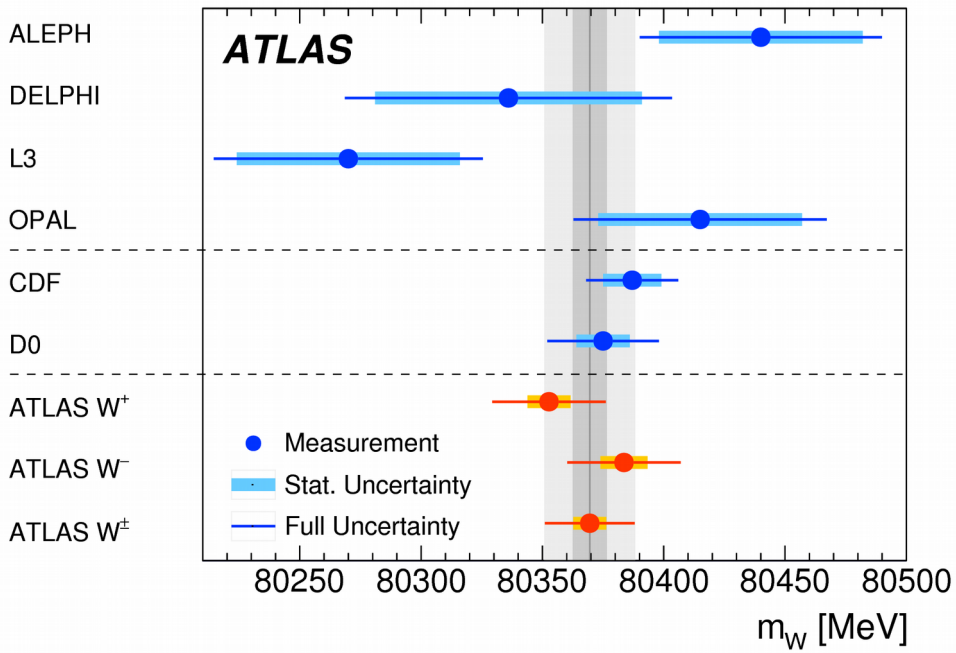


W→ eν

$\lvert\eta_\ell\rvert$ range	[0.0, 0.6]		[0.6, 1.2]		[1.82, 2.4]		Combined	
Kinematic distribution	p_T^ℓ	m_T	p_T^ℓ	m_T	p_T^ℓ	m_T	p_T^ℓ	m_T
δm_W [MeV]								
Energy scale	10.4	10.3	10.8	10.1	16.1	17.1	8.1	8.0
Energy resolution	5.0	6.0	7.3	6.7	10.4	15.5	3.5	5.5
Energy linearity	2.2	4.2	5.8	8.9	8.6	10.6	3.4	5.5
Energy tails	2.3	3.3	2.3	3.3	2.3	3.3	2.3	3.3
Reconstruction efficiency	10.5	8.8	9.9	7.8	14.5	11.0	7.2	6.0
Identification efficiency	10.4	7.7	11.7	8.8	16.7	12.1	7.3	5.6
Trigger and isolation efficiencies	0.2	0.5	0.3	0.5	2.0	2.2	0.8	0.9
Charge mismeasurement	0.2	0.2	0.2	0.2	1.5	1.5	0.1	0.1
Total	19.0	17.5	21.1	19.4	30.7	30.5	14.2	14.3

W→ μν

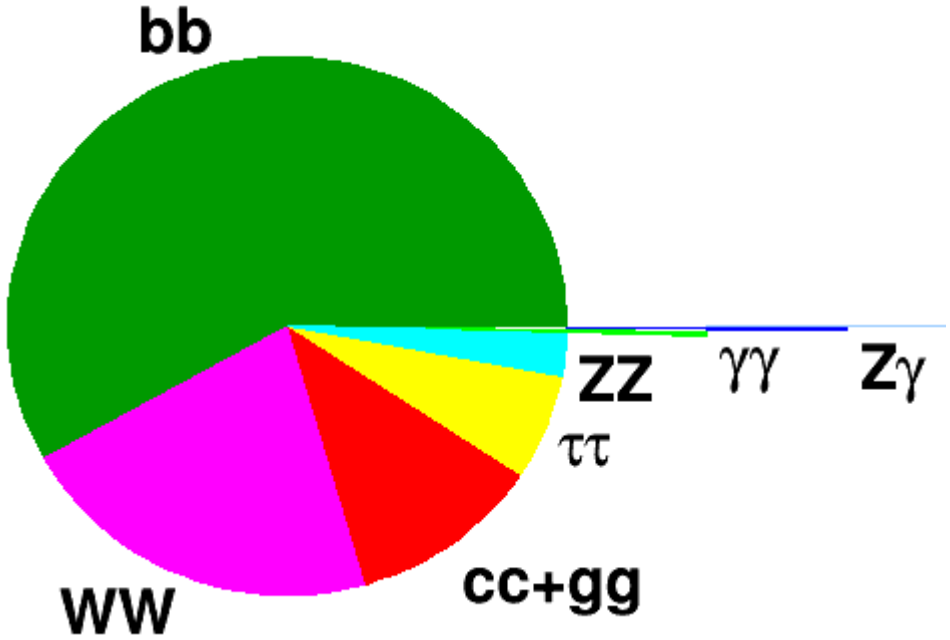
$\lvert\eta_\ell\rvert$ range	[0.0, 0.8]		[0.8, 1.4]		[1.4, 2.0]		[2.0, 2.4]		Combined	
Kinematic distribution	p_T^ℓ	m_T	p_T^ℓ	m_T	p_T^ℓ	m_T	p_T^ℓ	m_T	p_T^ℓ	m_T
δm_W [MeV]										
Momentum scale	8.9	9.3	14.2	15.6	27.4	29.2	111.0	115.4	8.4	8.8
Momentum resolution	1.8	2.0	1.9	1.7	1.5	2.2	3.4	3.8	1.0	1.2
Sagitta bias	0.7	0.8	1.7	1.7	3.1	3.1	4.5	4.3	0.6	0.6
Reconstruction and isolation efficiencies	4.0	3.6	5.1	3.7	4.7	3.5	6.4	5.5	2.7	2.2
Trigger efficiency	5.6	5.0	7.1	5.0	11.8	9.1	12.1	9.9	4.1	3.2
Total	11.4	11.4	16.9	17.0	30.4	31.0	112.0	116.1	9.8	9.7



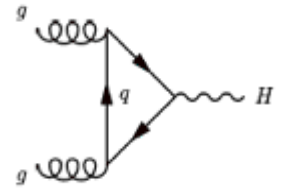
Higgs measurements

The Higgs

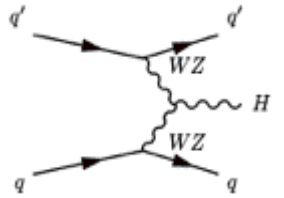
- Similar path as SM measurements
- Lower signal / background ratio
  - More *challenging*!
- New particle at LHC:
  - Full spectrum diagnosis of the new boson
  - Check of different production mechanisms
  - Check of different decays
  - Check for anomalous couplings and deviations vs theory



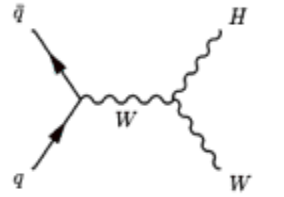
ggH 48.58 pb



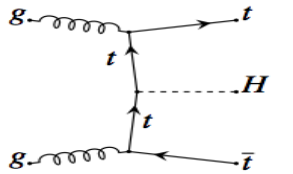
qqH 3.78 pb

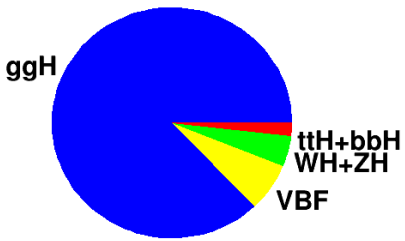


WH+ZH 2.26 pb



ttH+bbH 1.0 pb

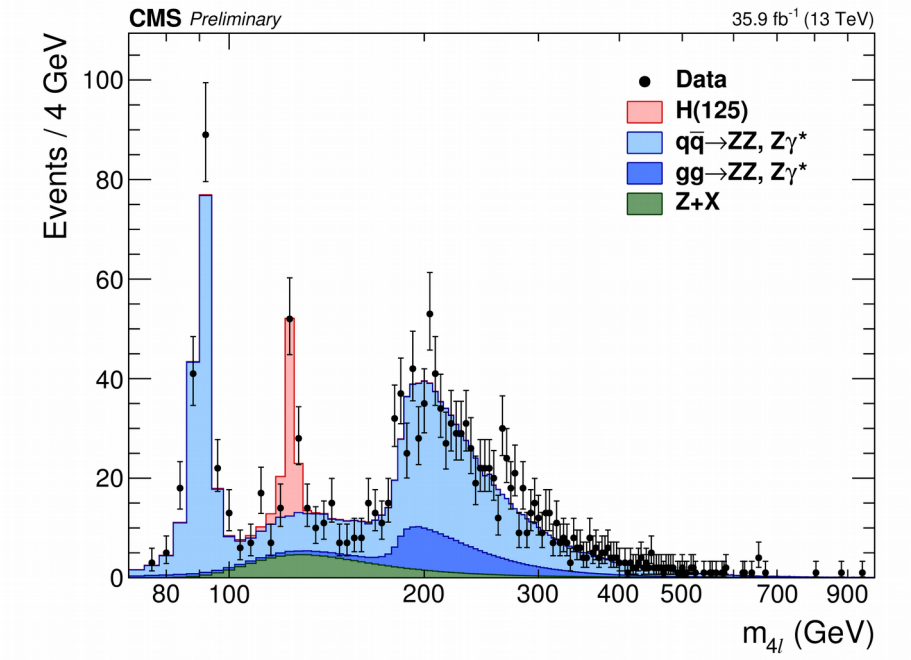




m_H = 125 GeV
13 TeV

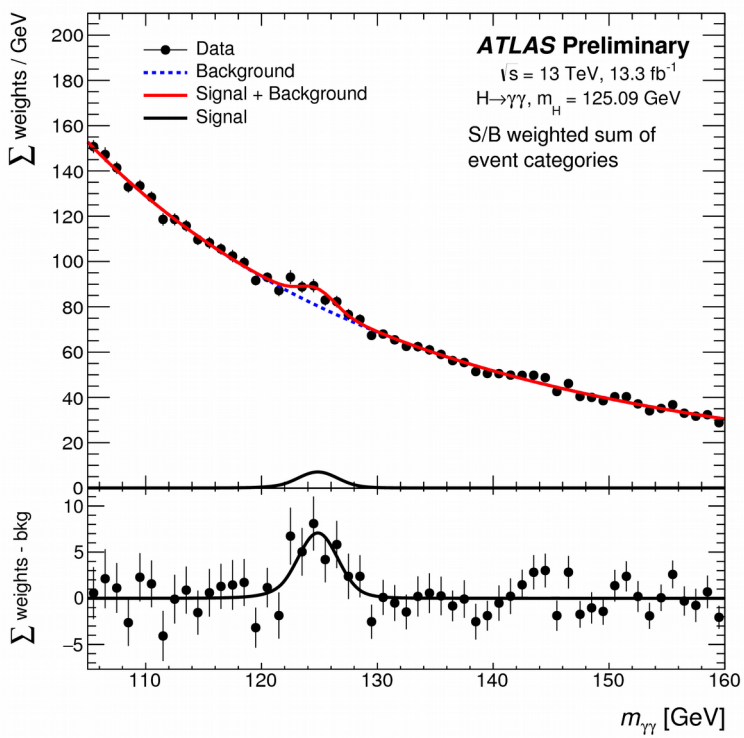
H → ZZ / γγ

- "golden channels"
  - Inclusive cross sections
  - Fiducial and differential measurements
  - Higgs mass measurement
  - Anomalous couplings



CMS-HIG-16-041
CMS-HIG-17-011

ATLAS-CONF-2017-032
ATLAS-CONF-2016-079



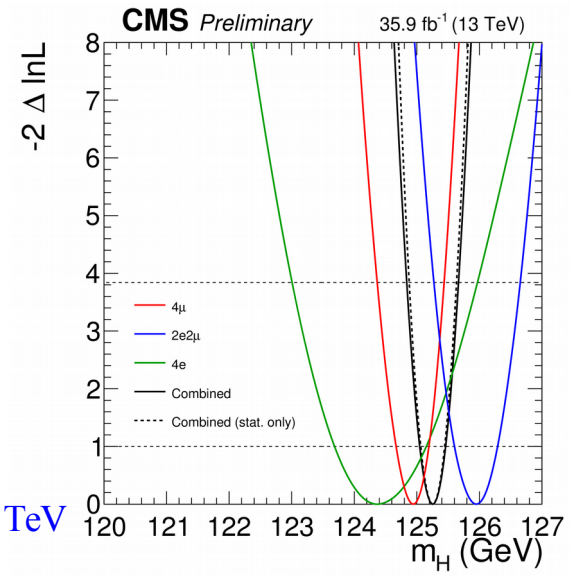
CMS-HIG-16-040
CMS-HIG-17-015
ATLAS-CONF-2016-067

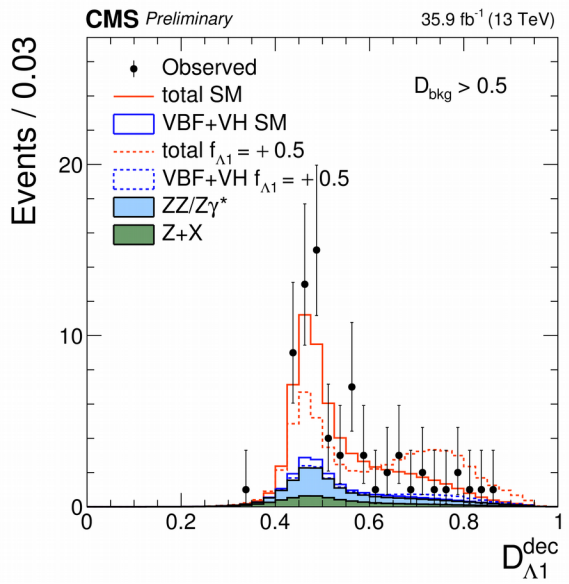
H → ZZ

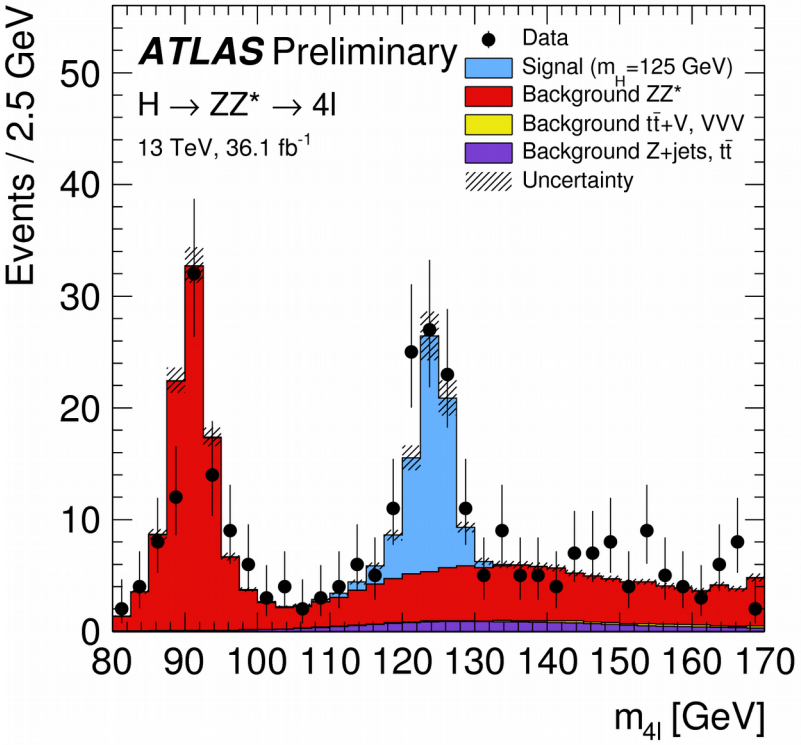
- Low BR but clean signature → full kinematic of Higgs decay reconstructed
- Very high signal/background ratio
- Differential measurements, Higgs couplings, mass measurement, ...

m_H 125.26 ± 0.20 (stat.) ± 0.08 (syst.) CMS ZZ @ 13 TeV

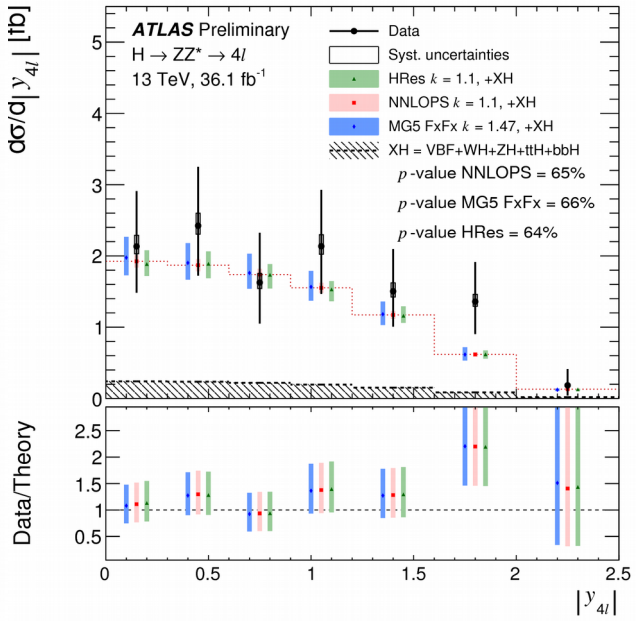
m_H = 125.09 ± 0.21 (stat.) ± 0.11 (syst.) ATLAS + CMS @ 7+8 TeV



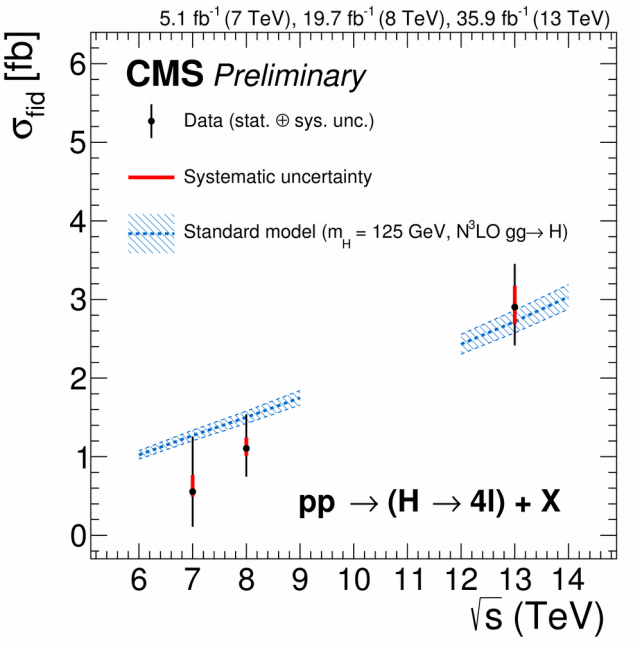




CMS-HIG-16-041
CMS-HIG-17-011

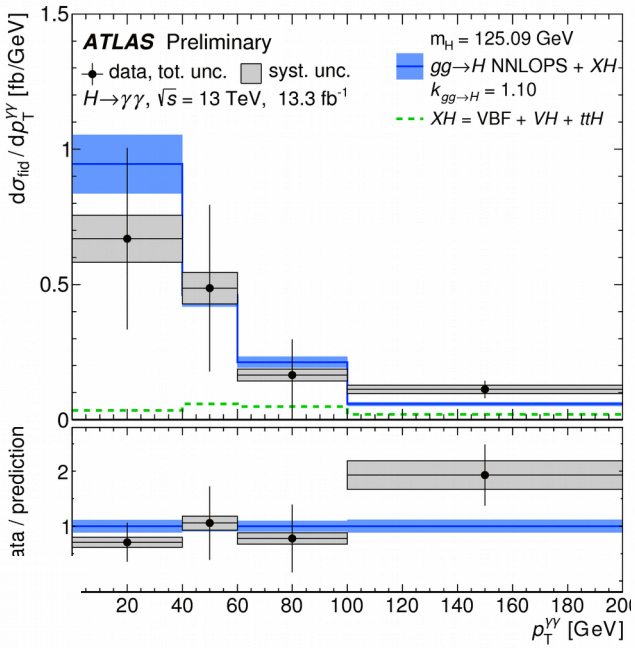


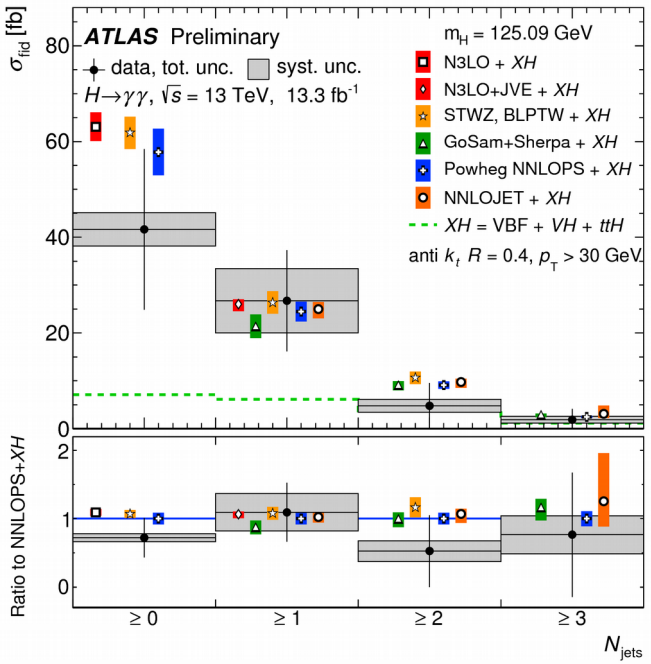
ATLAS-CONF-2017-032
ATLAS-CONF-2016-079

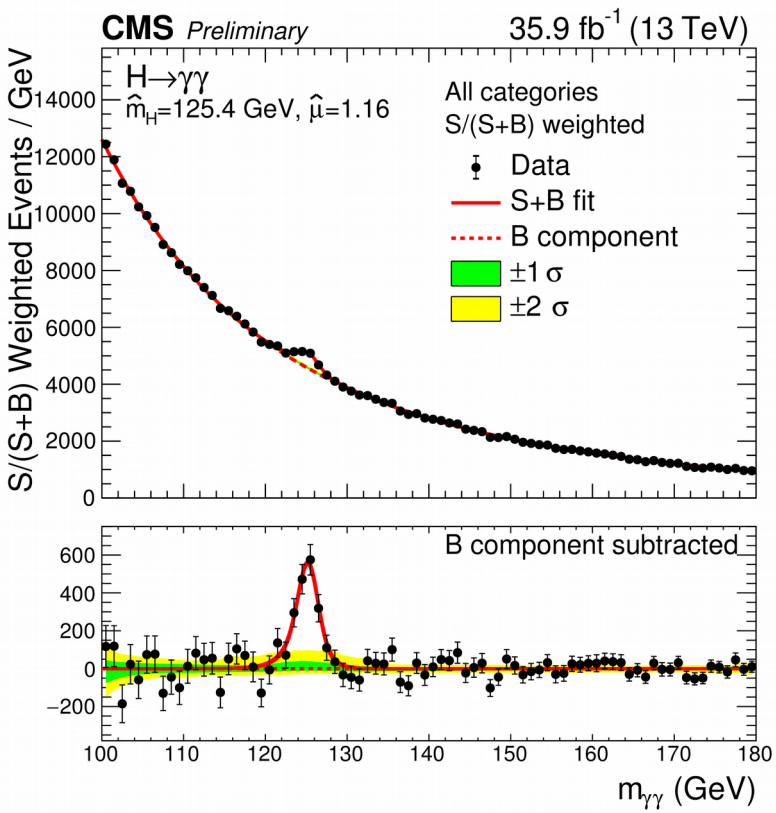


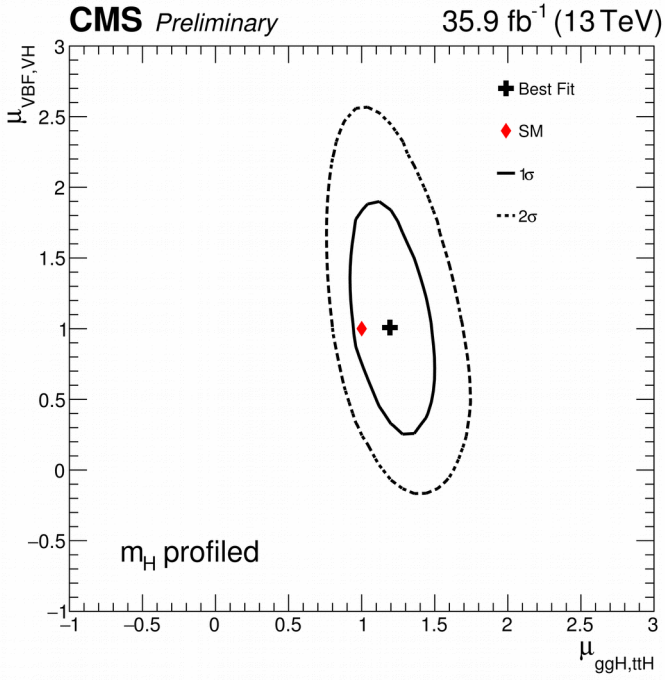
H → γγ

- Low BR ~ 0.2% but clean signature
- Differential measurements and different production mechanisms









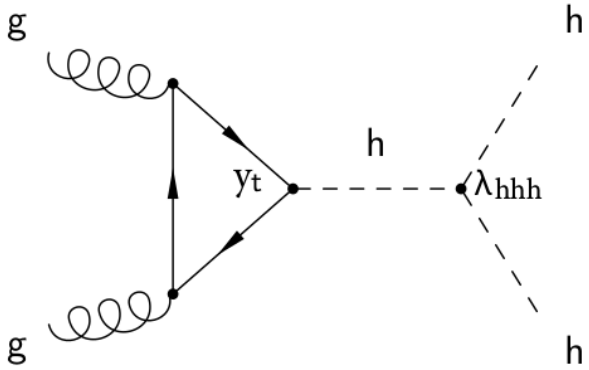
CMS-HIG-16-040

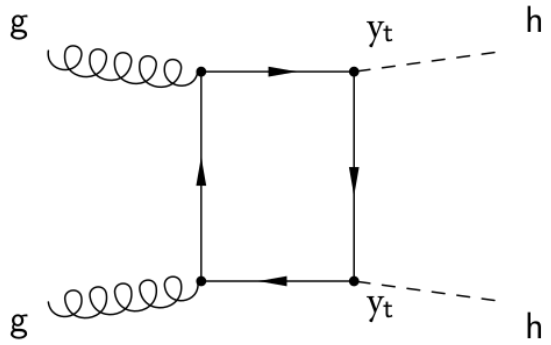
CMS-HIG-17-015

ATLAS-CONF-2016-067

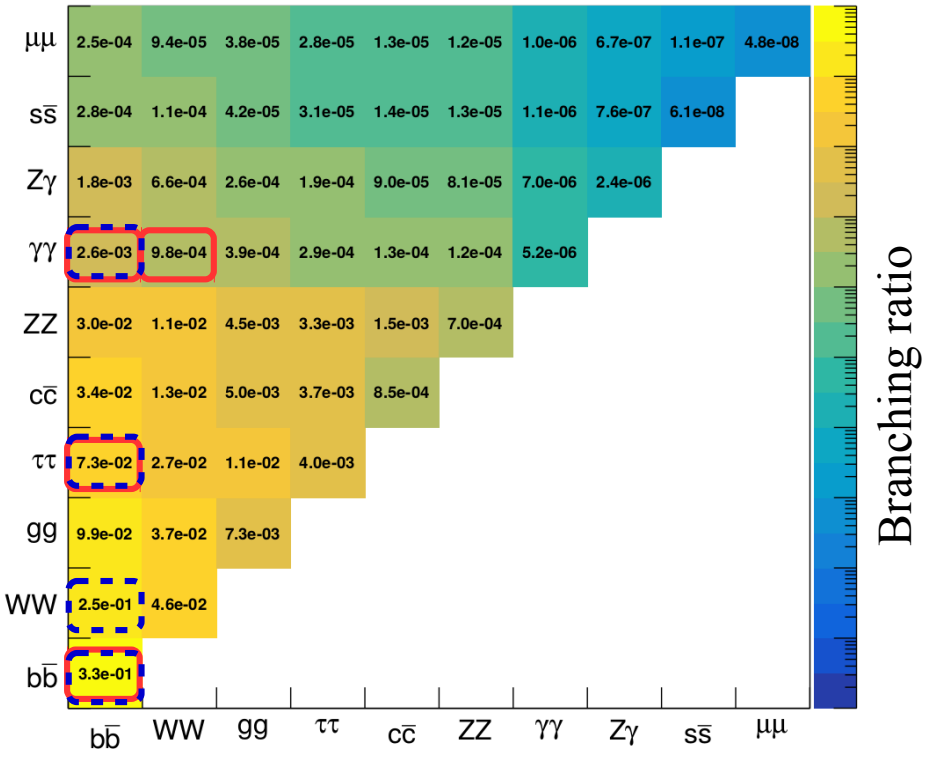
2 is better than 1: di-Higgs searches

- **Rarer** processes being investigated: σ_{HH} =33 fb (σ_{ggH} = 49 pb) at $\sqrt{s}$ = 13 TeV
  - Destructive interference between diagrams





- Cross section enhanced by BSM:
  - Non-resonant: anomalous couplings
  - Resonant: e.g. 2HDM or Randall-Sundrum gravitons
- Different final states considered
  - ATLAS
  - CMS



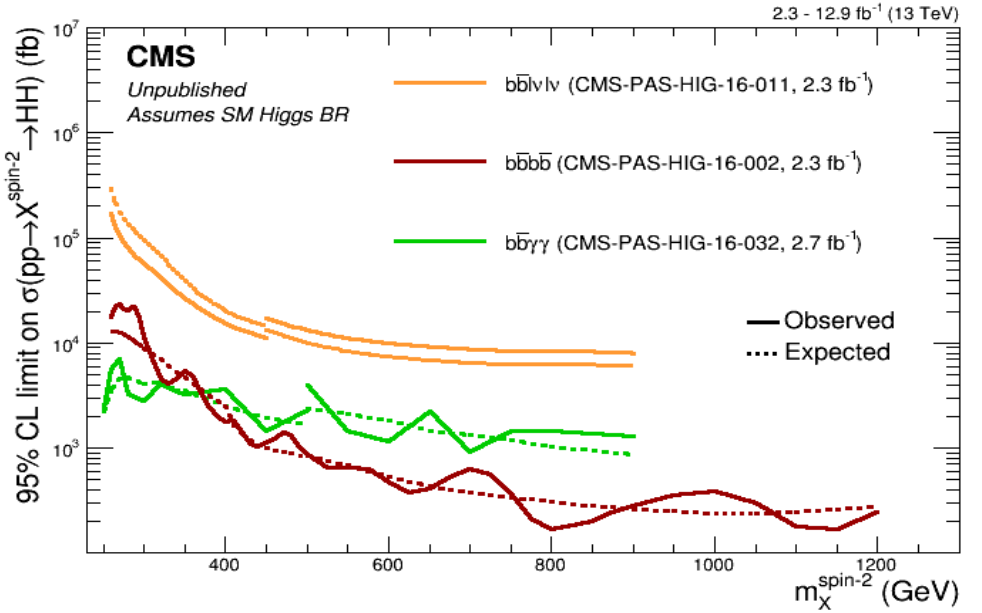
Di-Higgs searches

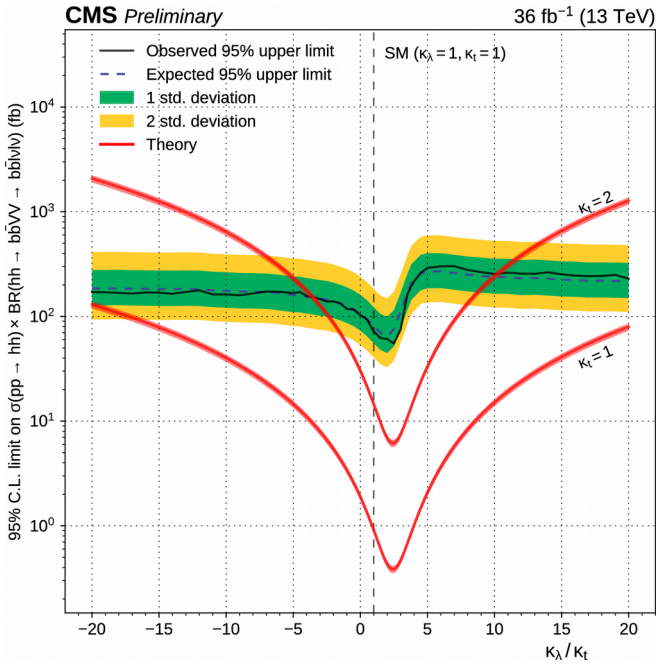
- No X → HH resonances found (so far)
- Sensitive to new physics → so far no deviations with respect to SM observed

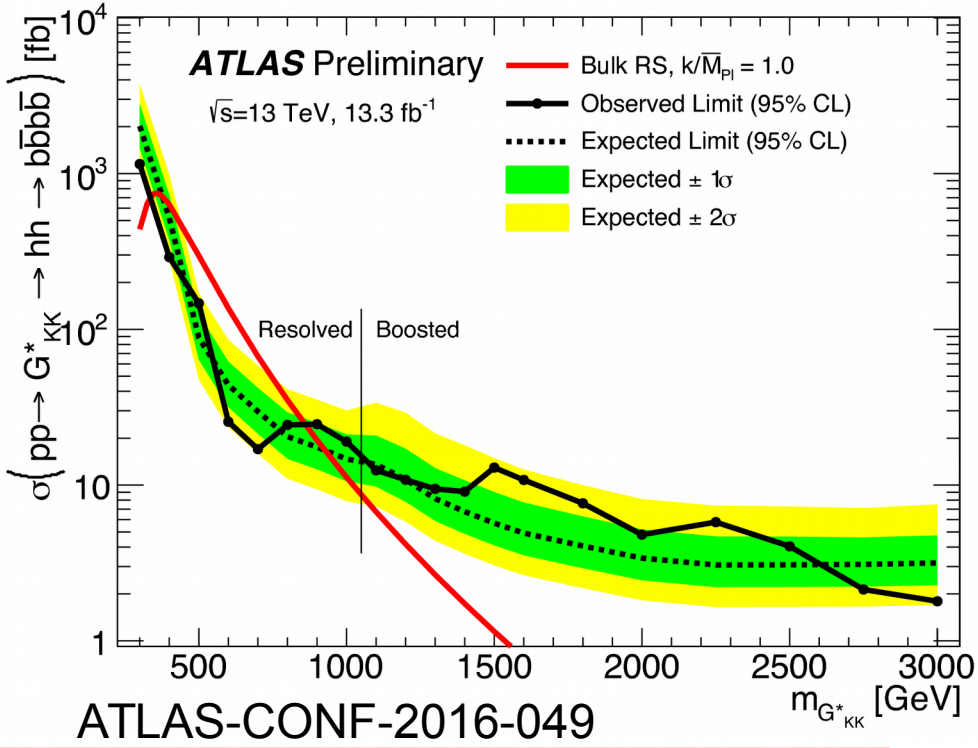
https://twiki.cern.ch/twiki/bin/view/CMSPublic/SummaryResultsHIG

channel	CMS		ATLAS	
	limit σ/σ_{SM}	luminosity	limit σ/σ_{SM}	luminosity
bb$\tau\tau$	28 (25)	35.9 fb^{-1}	-	-
bbWW	79 (89)	35.9 fb^{-1}	-	-
bb$\gamma\gamma$	91 (90)	2.7 fb^{-1}	117 (161)	3.2 fb^{-1}
bbbb	342 (308)	2.3-2.7 fb^{-1}	29 (38)	13 fb^{-1}
$\gamma\gamma$WW	-	-	749 (386)	13 fb^{-1}

- SM HH limits set
- Limits on anomalous couplings

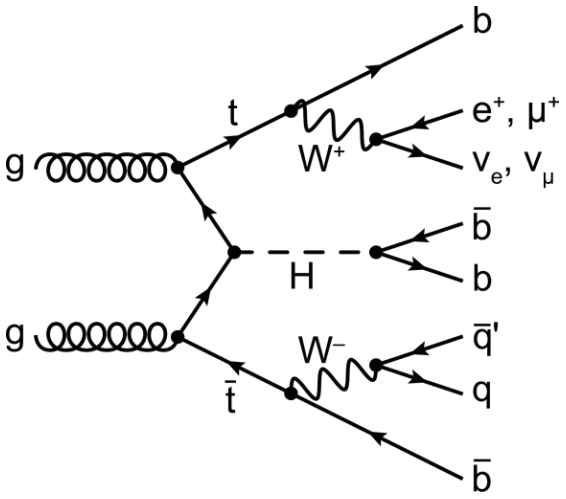






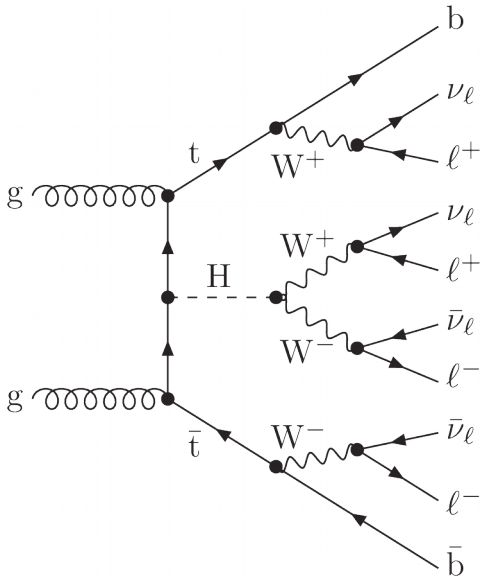
Rare is good: ttH

- ttH: $\sigma_{ttH} = 0.5$ pb ($\sigma_{ggH} = 49$ pb)
- **Multileptons** final state (H → WW, ZZ, ττ), **H → ττ**, **H → bb**, **H→ γγ**



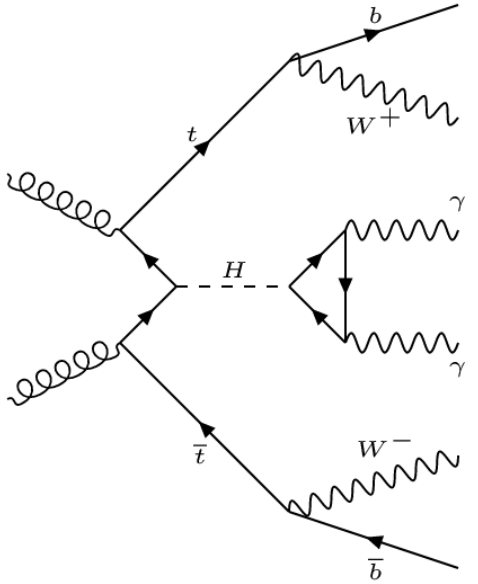
Systematically limited

Increased cross section



Increased purity

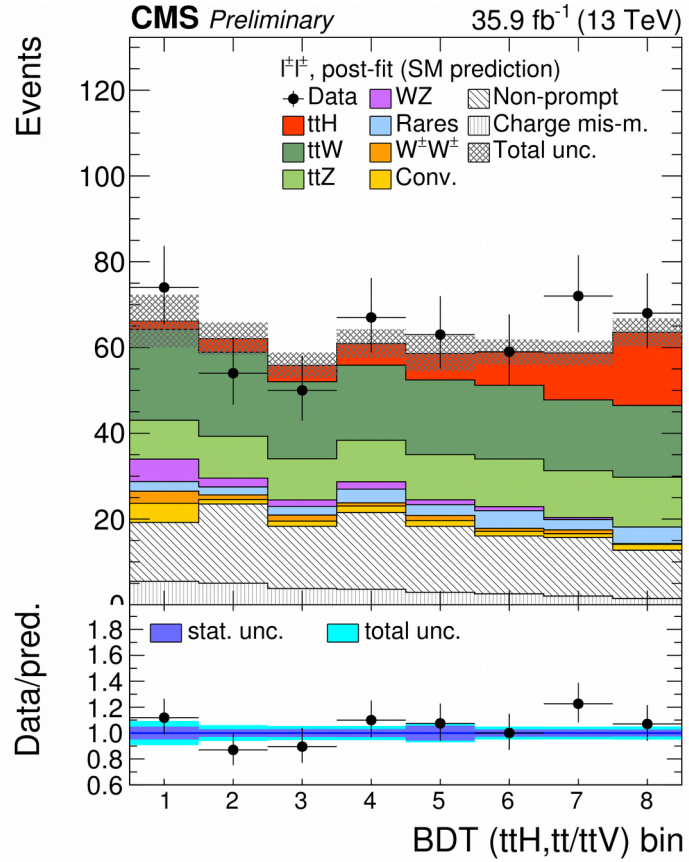
Statistically limited

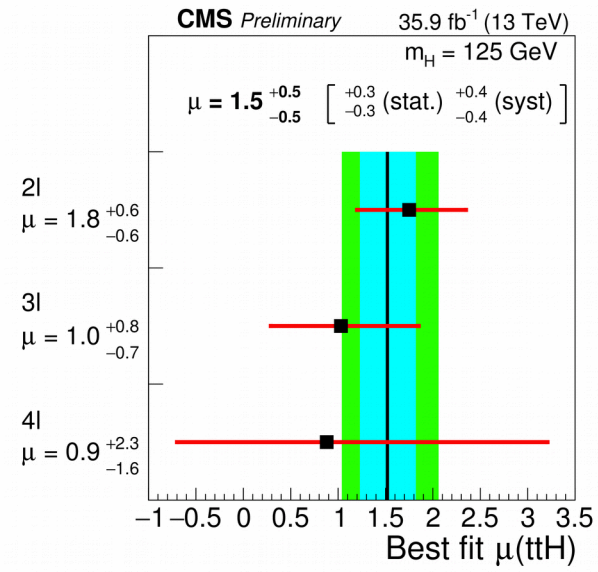


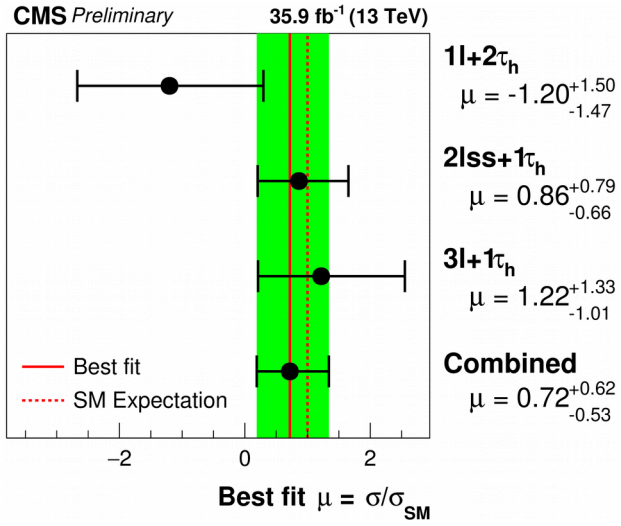
ttH → different final states

- Multivariate analysis techniques used
- More data needed to reach 5σ discovery

HIG-17-004

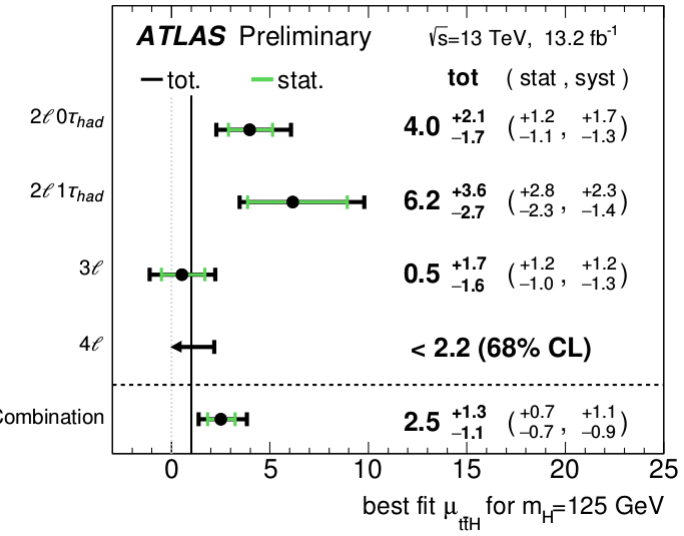




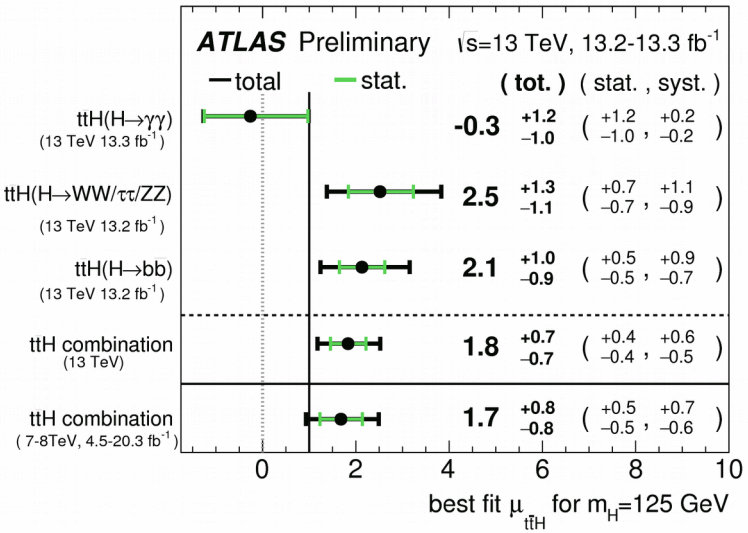


HIG-17-003

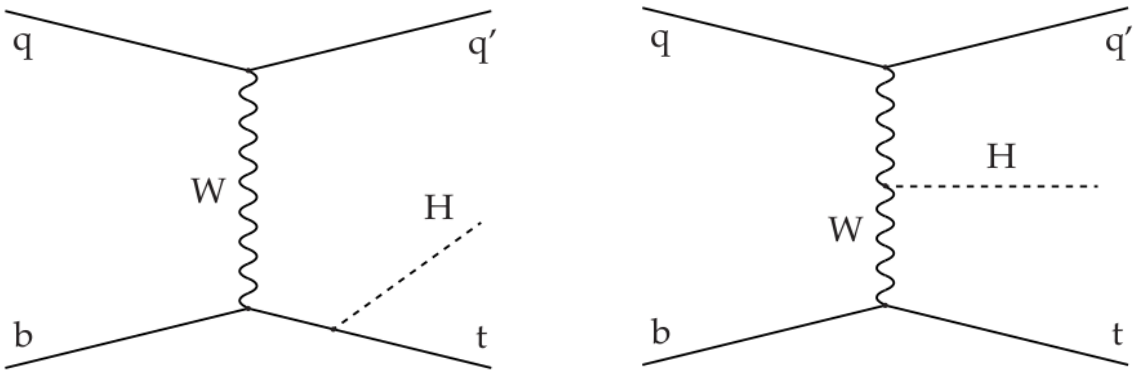
ATLAS-CONF-2016-058



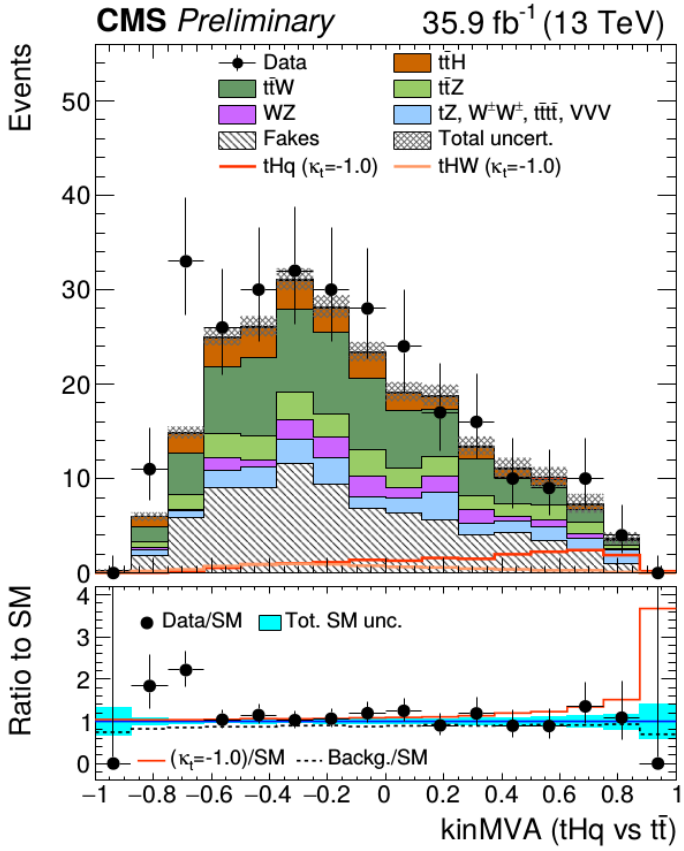
ATLAS-CONF-2016-068



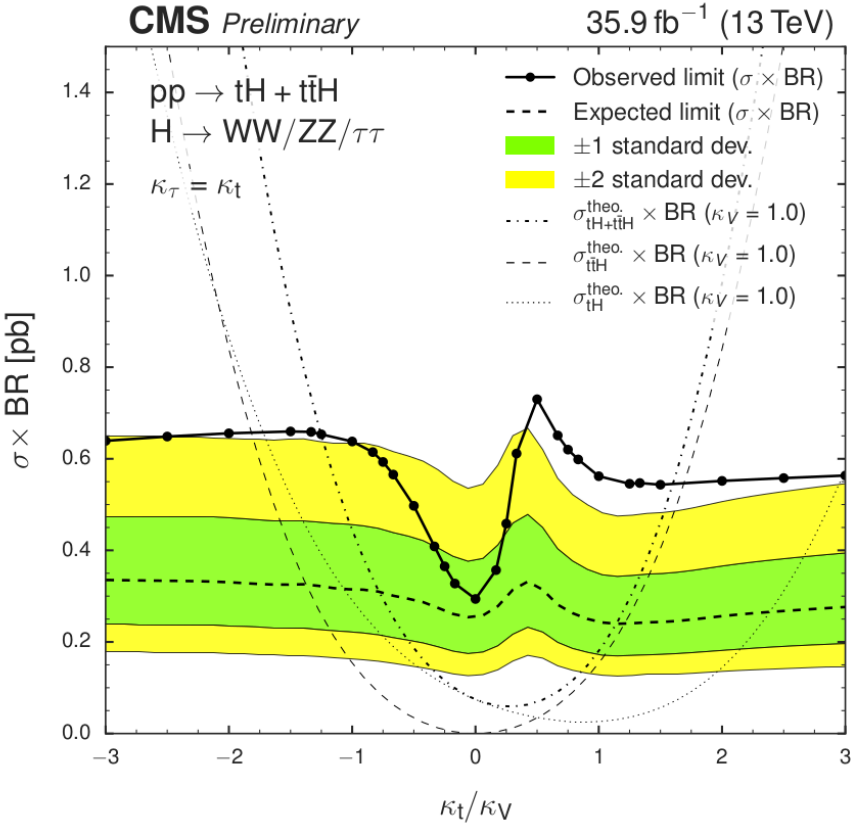
Even rarer: tHq and anomalous couplings



- Strong interference in SM scenario
  - σ_{tHq} = 0.07 pb
- With k_t/k_V != 1 = SM, *14x* larger tHq production
- Most SM measurements are sensitive to $|k_t|$ → here we probe the sign too

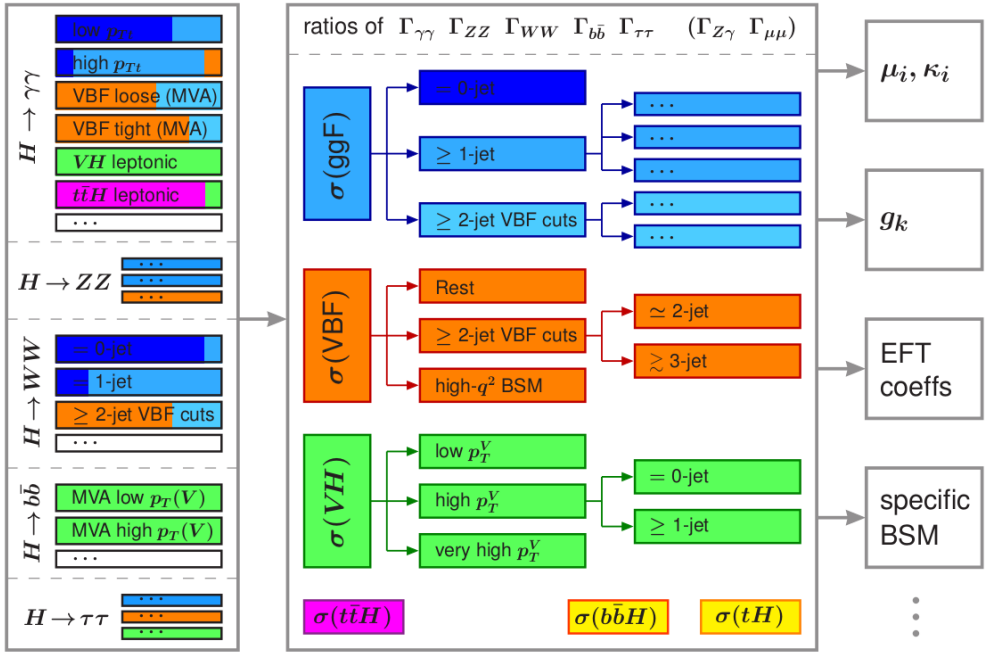


HIG-17-005

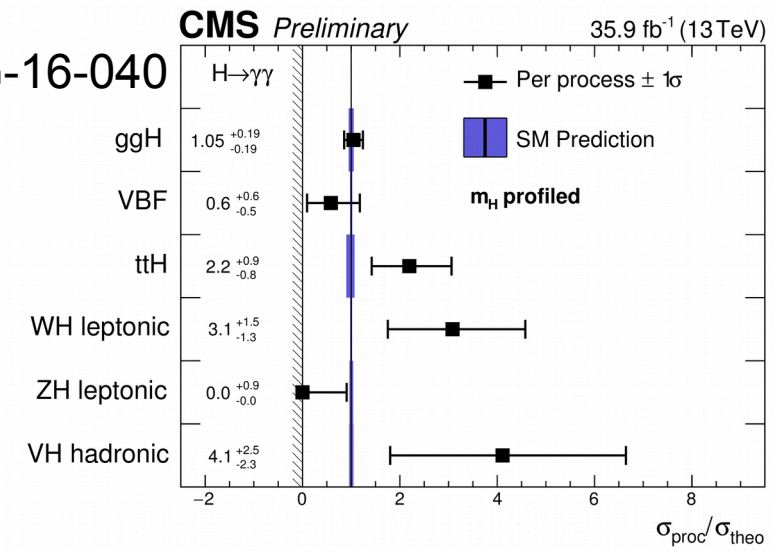


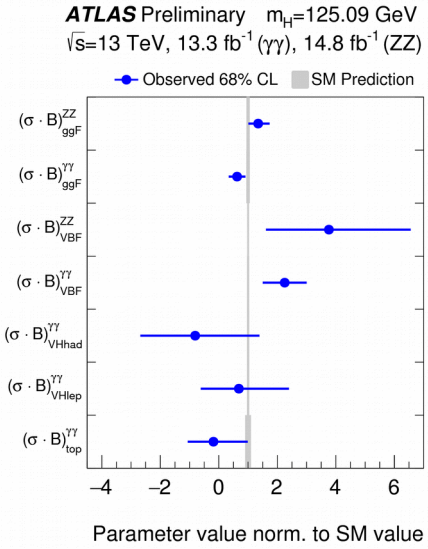
Simplified Template Cross Section

- Reduce main theoretical uncertainties in the Simplified Template Cross Section (STXS), arXiv:1610.07922
  - Common phase spaces defined by ATLAS, CMS and Theorists
  - Possible re-interpretation of experimental results given new theoretical predictions



CMS-HIG-16-040



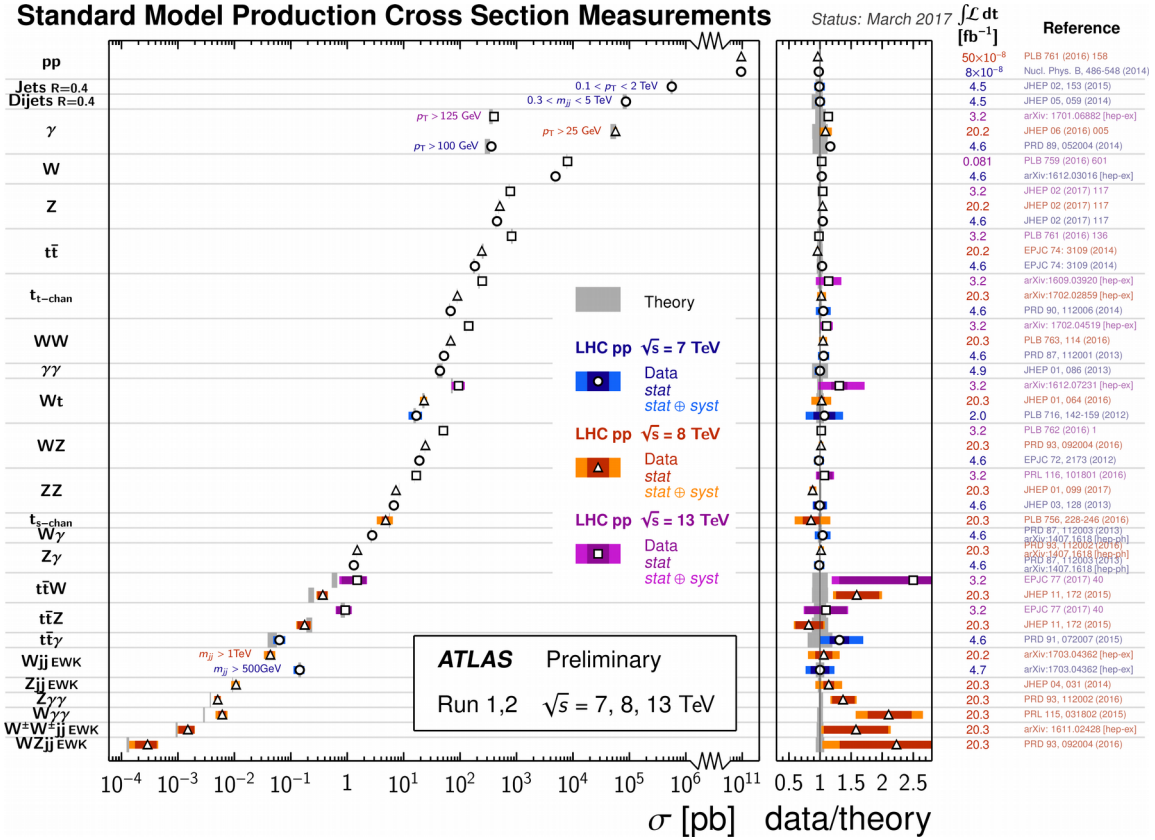


ATLAS-CONF-2016-067
ATLAS-CONF-2016-081

$$\sigma_{ggH} \times \mathcal{B}(H \to \gamma\gamma) = 63\ ^{+30}_{-29}\ \text{fb}$$
$$\sigma_{\text{VBF}} \times \mathcal{B}(H \to \gamma\gamma) = 17.8\ ^{+6.3}_{-5.7}\ \text{fb}$$
$$\sigma_{\text{VHlep}} \times \mathcal{B}(H \to \gamma\gamma) = 1.0\ ^{+2.5}_{-1.9}\ \text{fb}$$
$$\sigma_{\text{VHhad}} \times \mathcal{B}(H \to \gamma\gamma) = -2.3\ ^{+6.8}_{-5.8}\ \text{fb}$$
$$\sigma_{t\bar{t}H} \times \mathcal{B}(H \to \gamma\gamma) = -0.3\ ^{+1.4}_{-1.1}\ \text{fb}$$

Conclusions

- LHC results from **ATLAS** and **CMS**
  - So far mostly compatible with **SM** predictions
  - **Precision measurement** era started
- **More data** needed to reduce statistical and systematic uncertainty
  - **2016** results still coming + **2017** data taking just started
- Lepton Flavour Violation in Higgs-land → be patient and wait 30 minutes for **Higgs flavor specific decays at ATLAS and CMS** by Colin Jessop



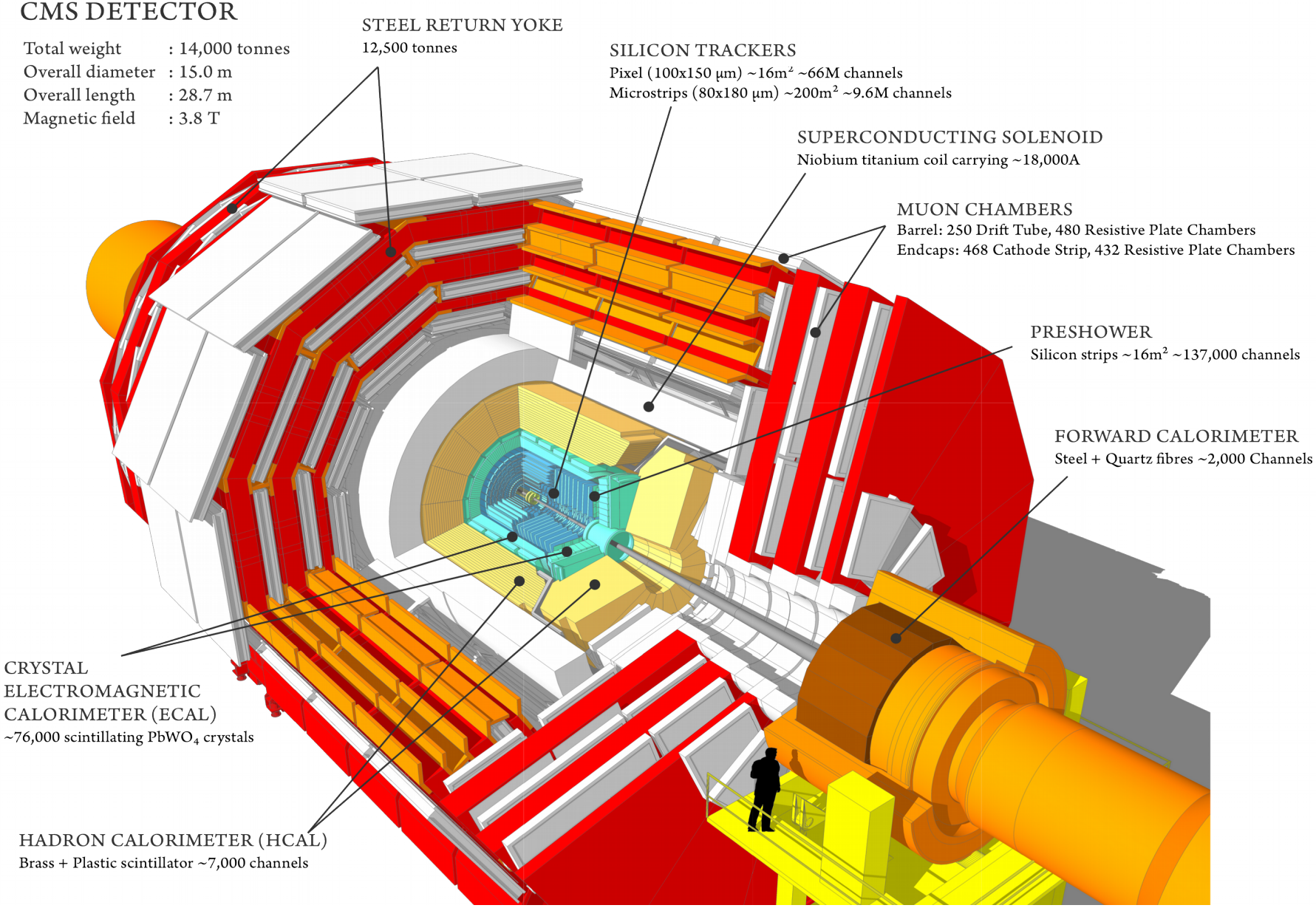

BACKUP

References

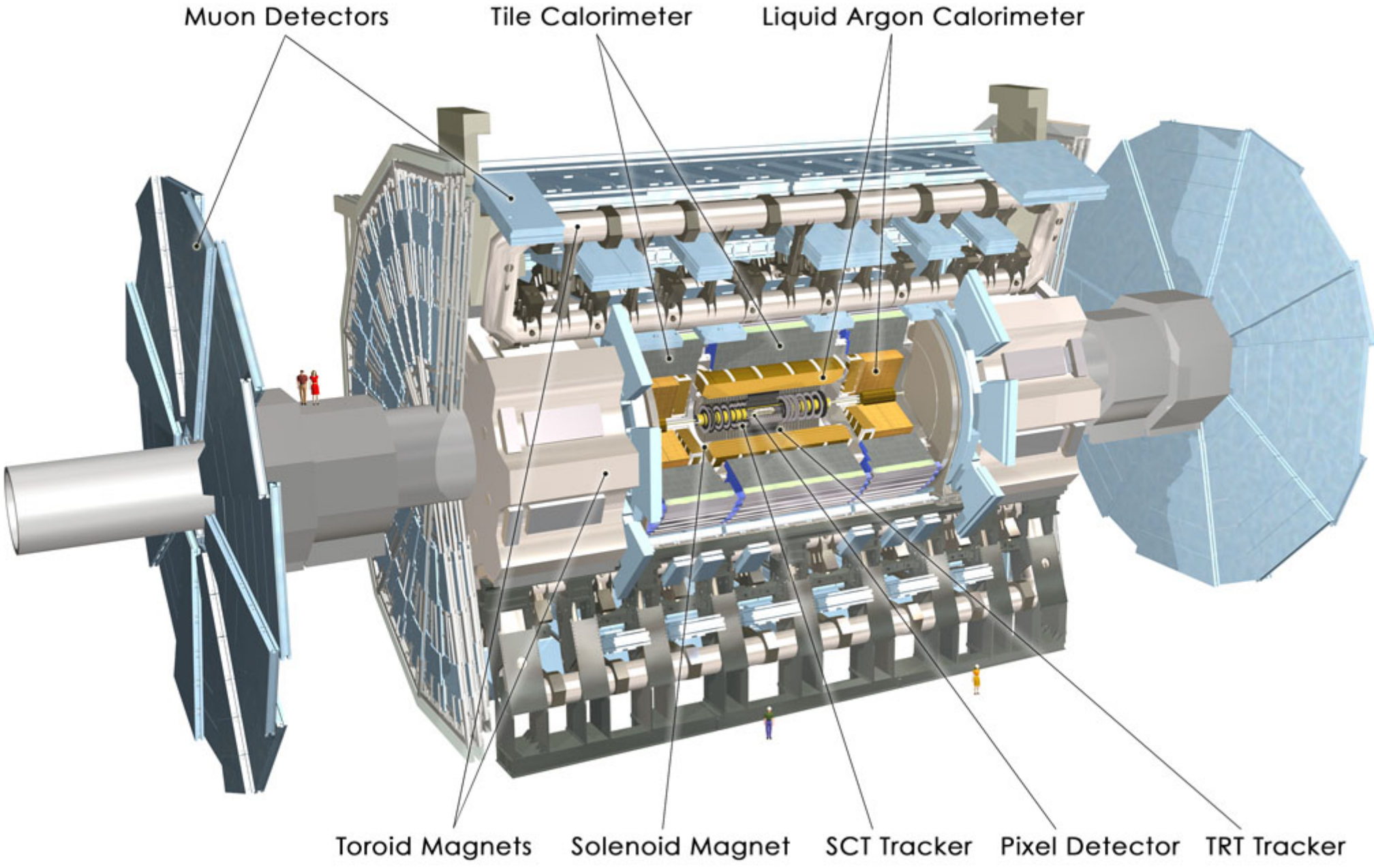
- CMS
- http://cms-results.web.cern.ch/cms-results/public-results/publications/
- http://cms-results.web.cern.ch/cms-results/public-results/publications/HIG/index.html
- http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/HIG/index.html
- http://cms-results.web.cern.ch/cms-results/public-results/publications/SMP/index.html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

- ATLAS
- 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://twiki.cern.ch/twiki/bin/view/AtlasPublic/HiggsPublicResults
- https://twiki.cern.ch/twiki/bin/view/AtlasPublic/StandardModelPublicResults

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

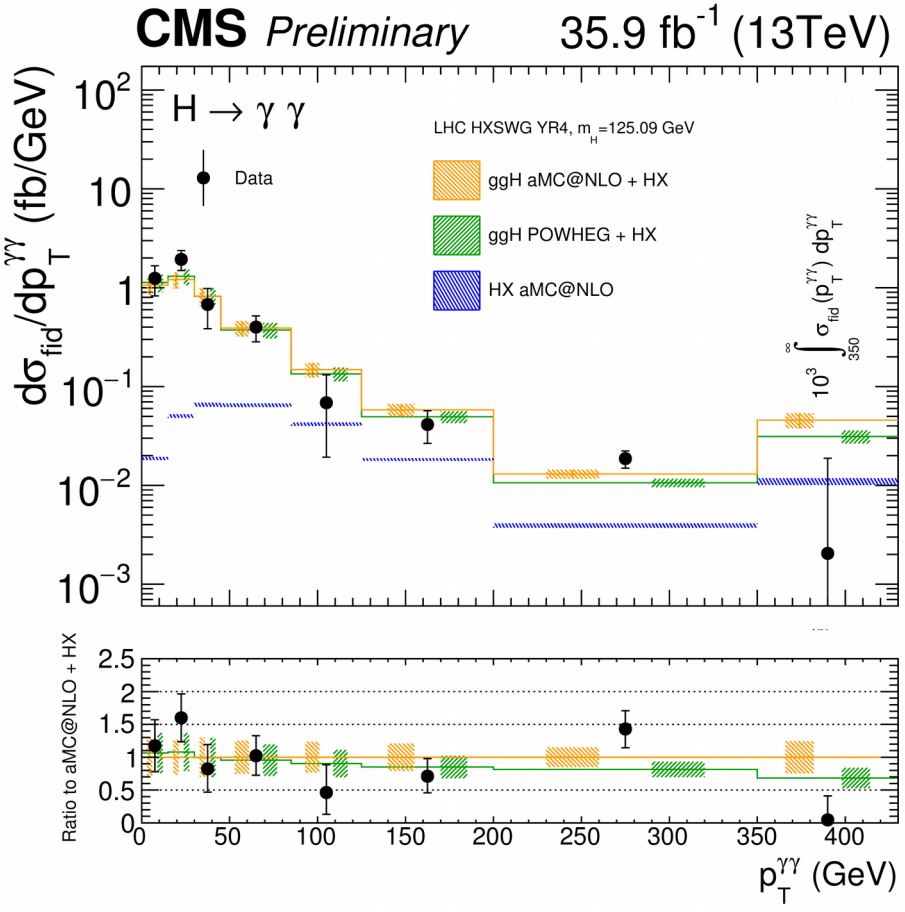
ATLAS


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

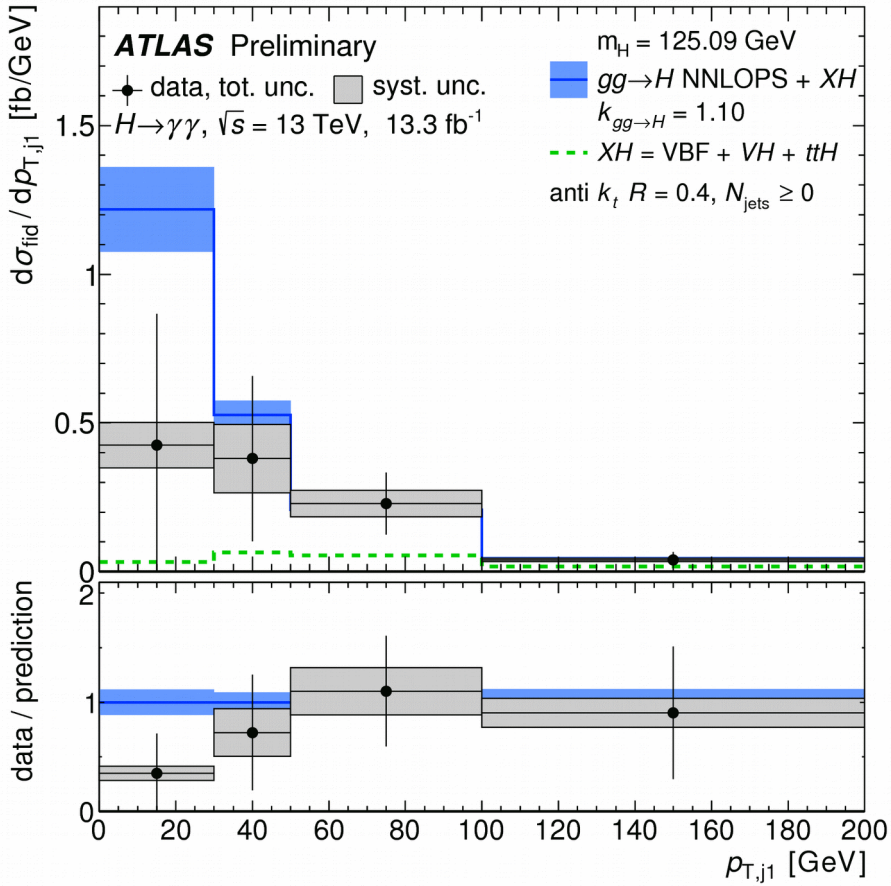
H → γγ

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

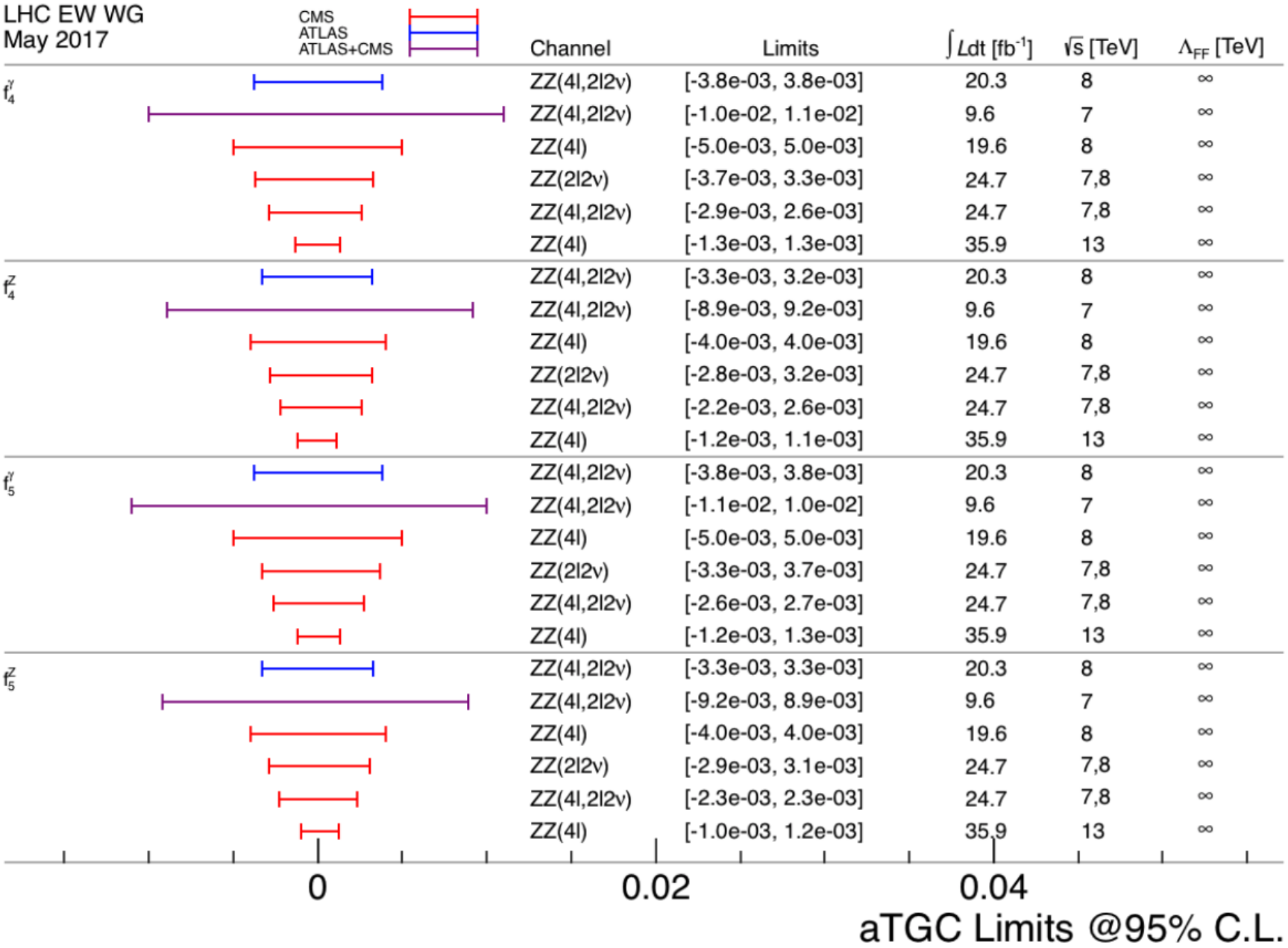
CMS-PAS-HIG-17-015



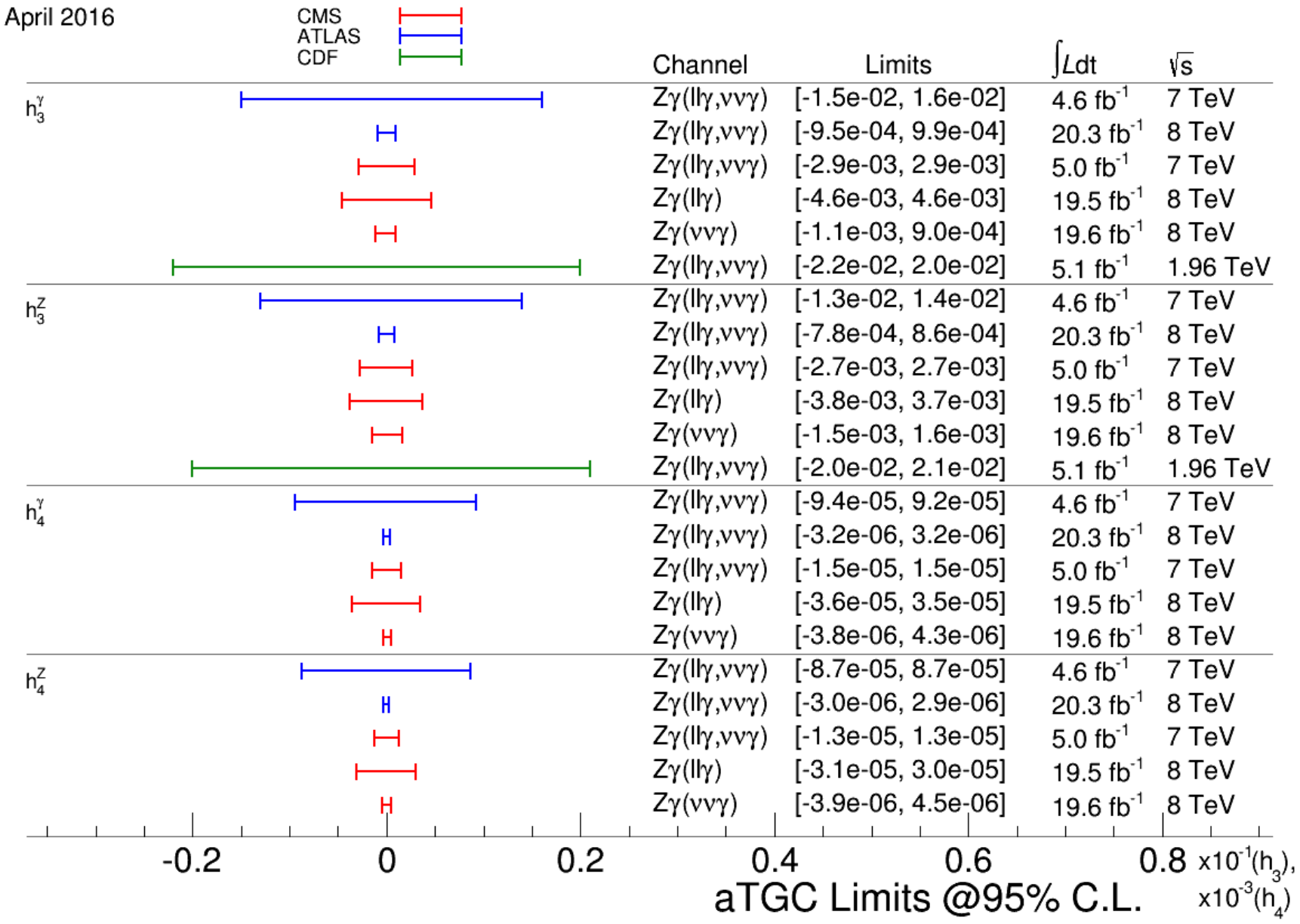
ATLAS-CONF-2016-067



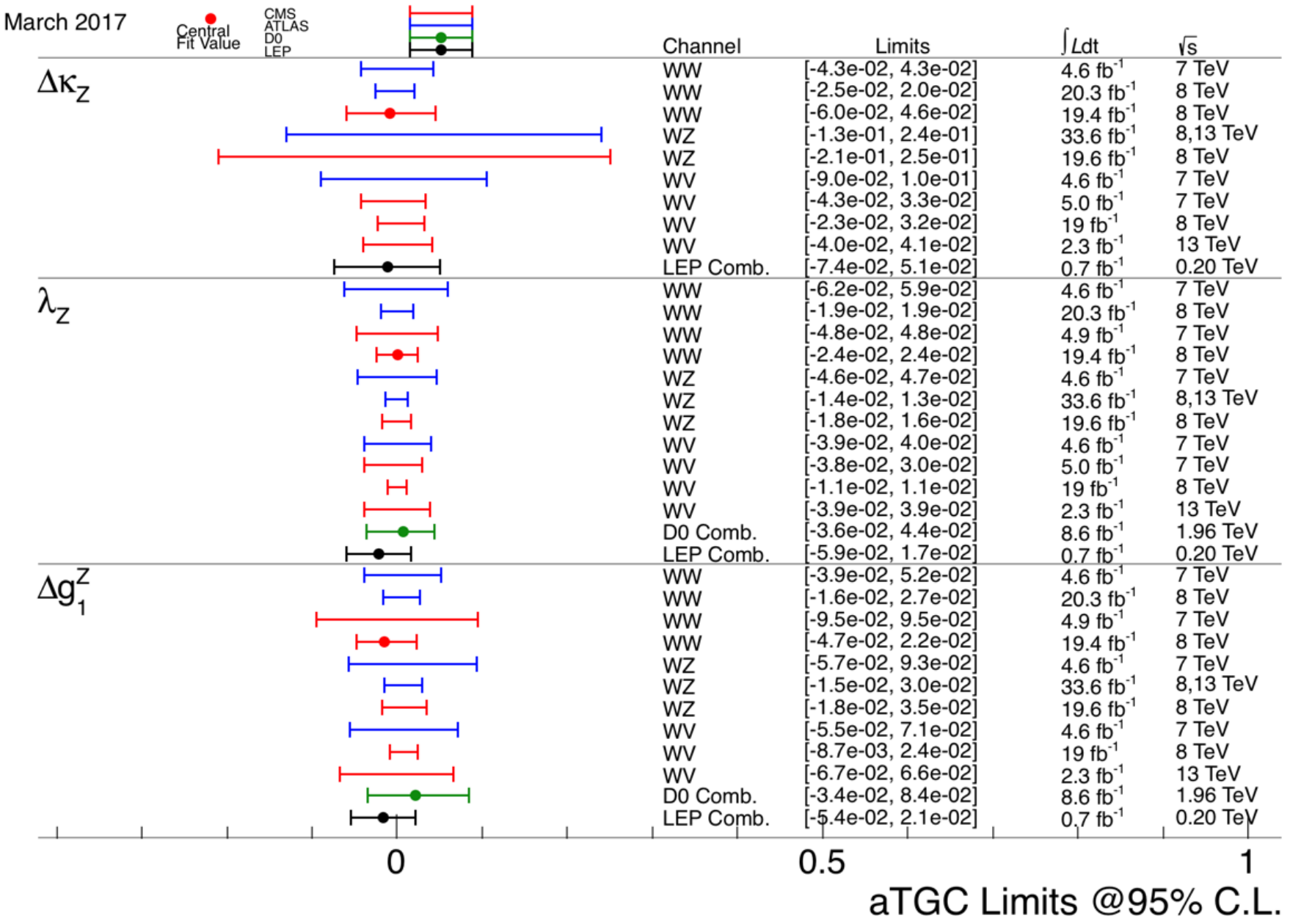
Neutral anomalous triple gauge couplings



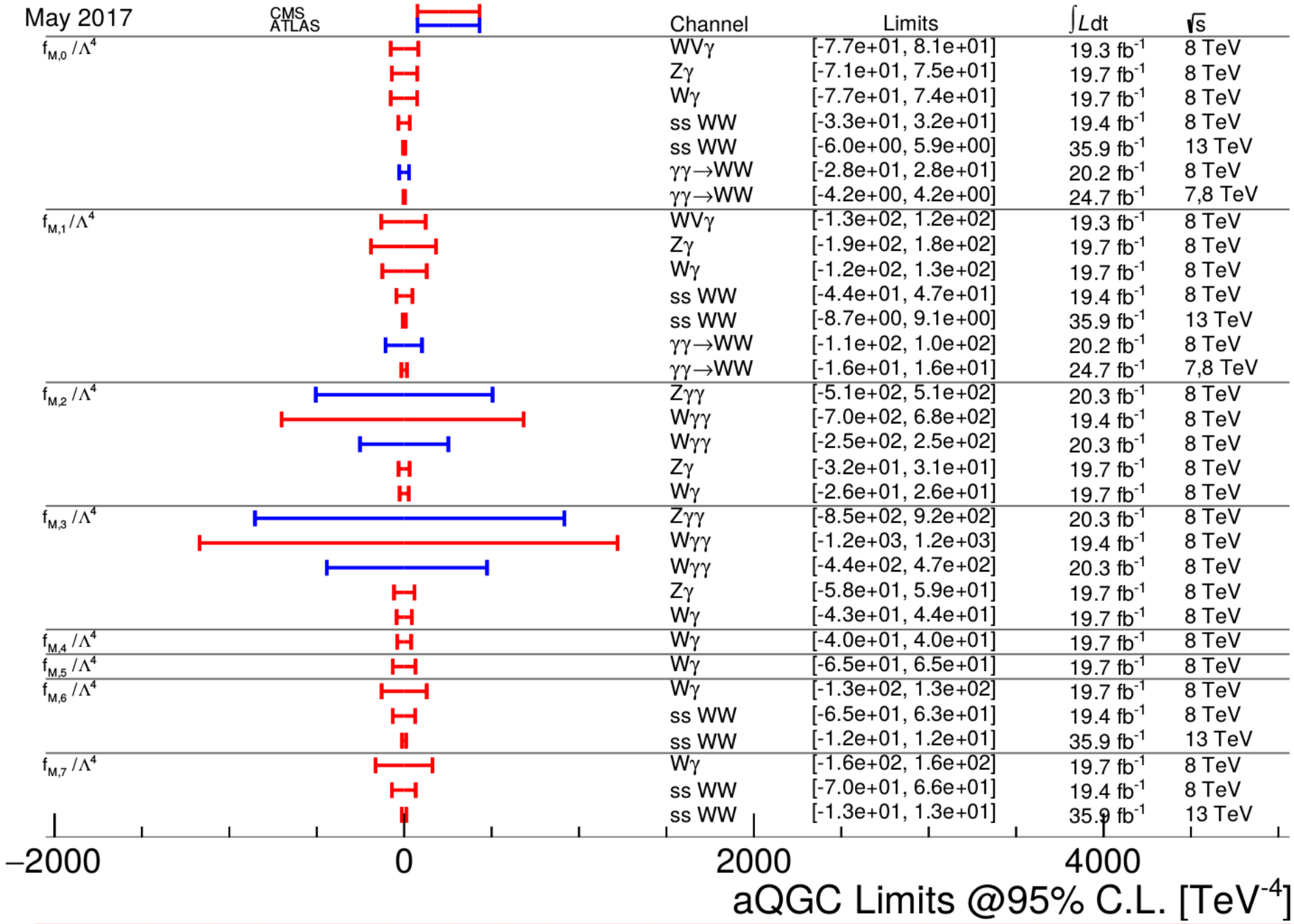
Neutral anomalous triple gauge couplings



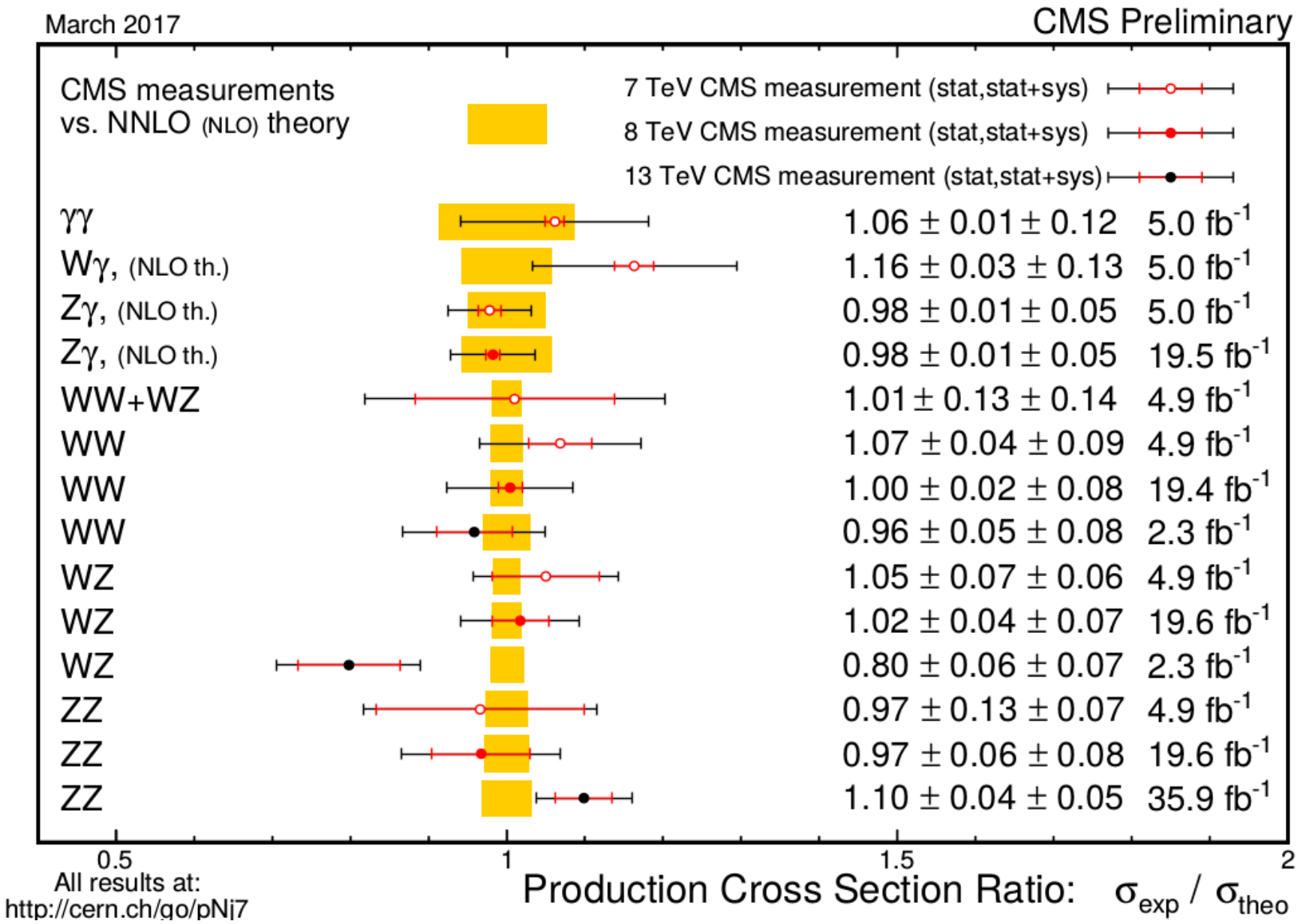
Charged anomalous triple gauge couplings



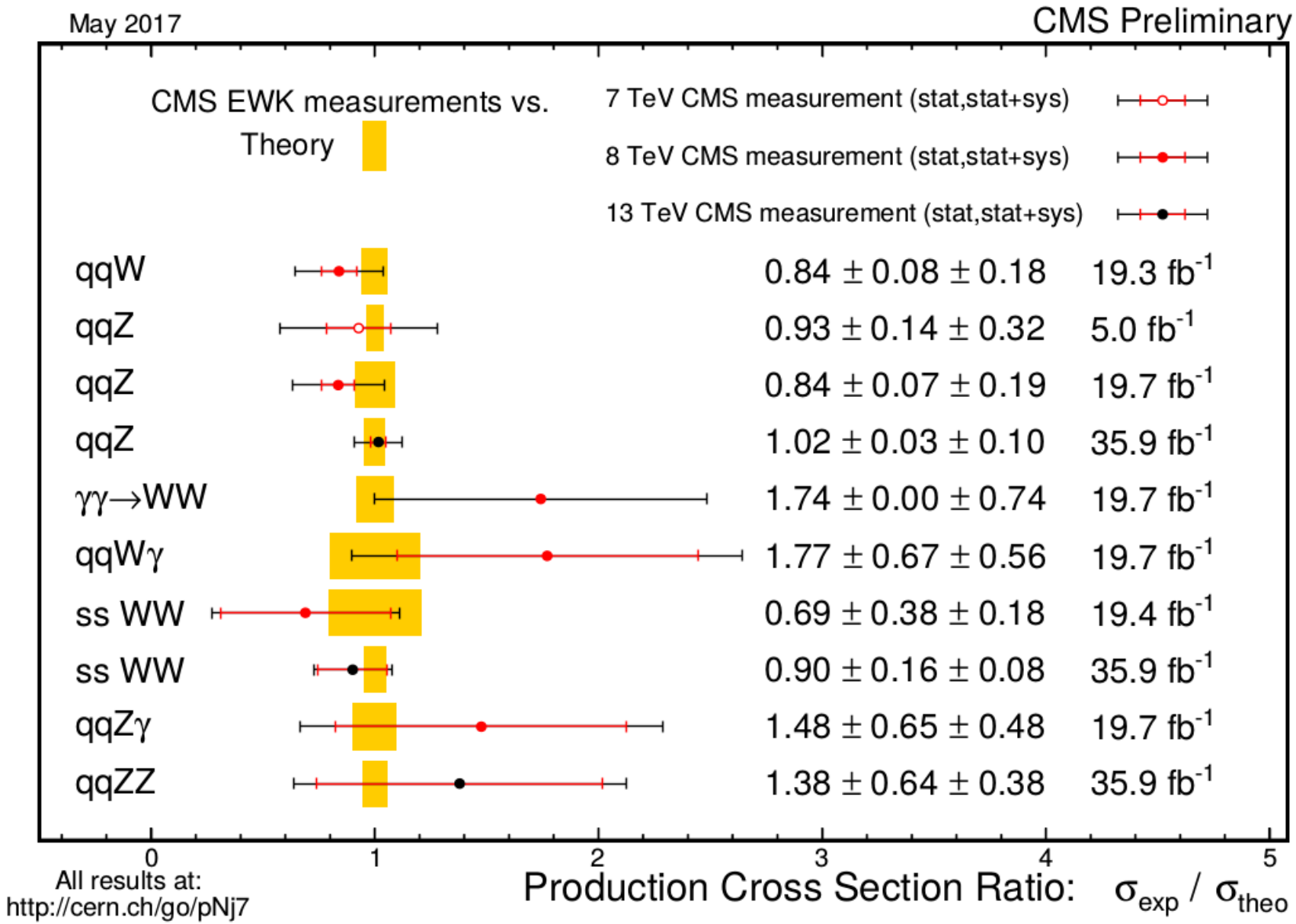
Anomalous quartic gauge couplings



Big summary table

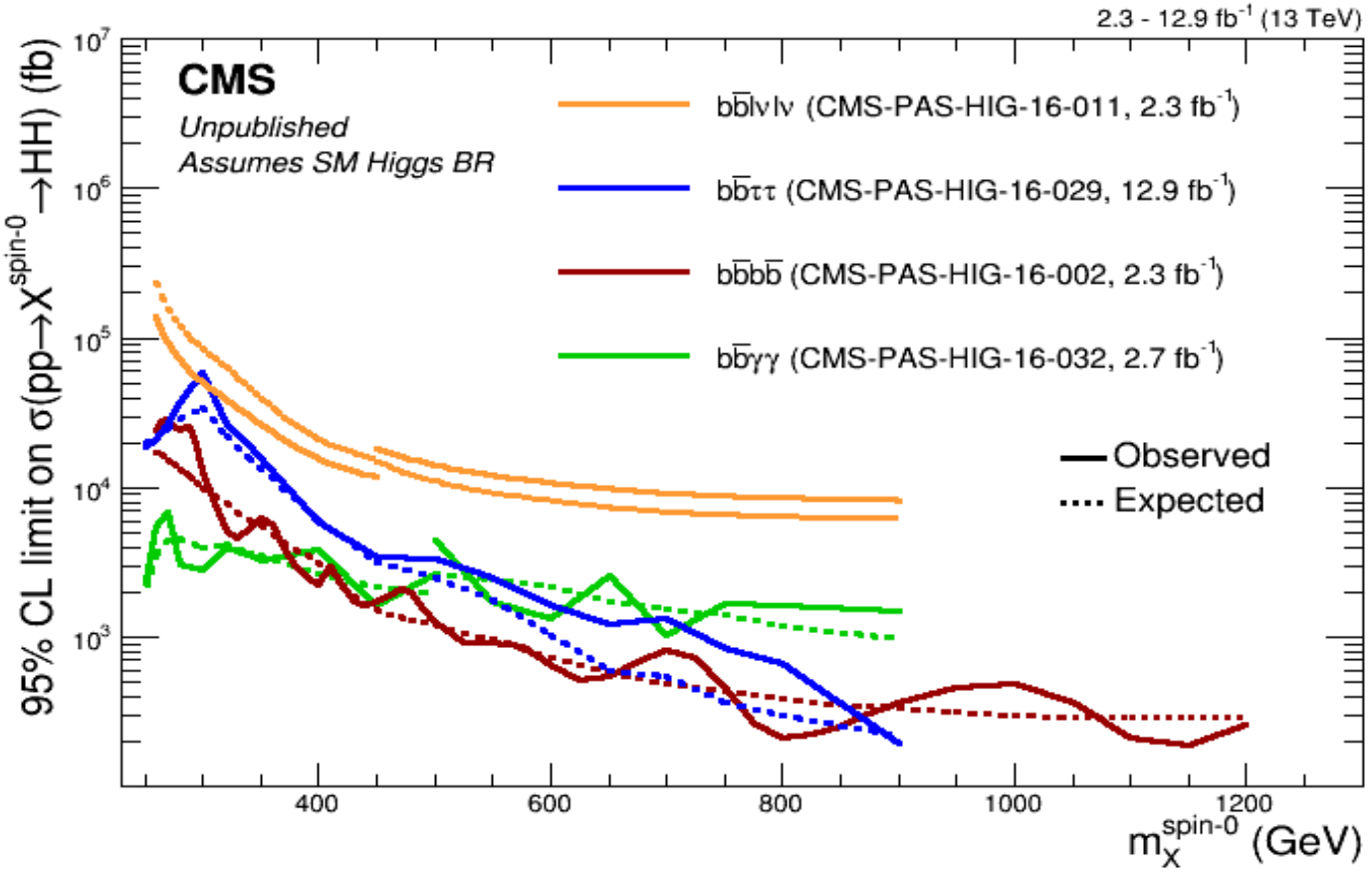


Big summary table (cont)



Di-Higgs searches

- Spin 0 limit: X → HH



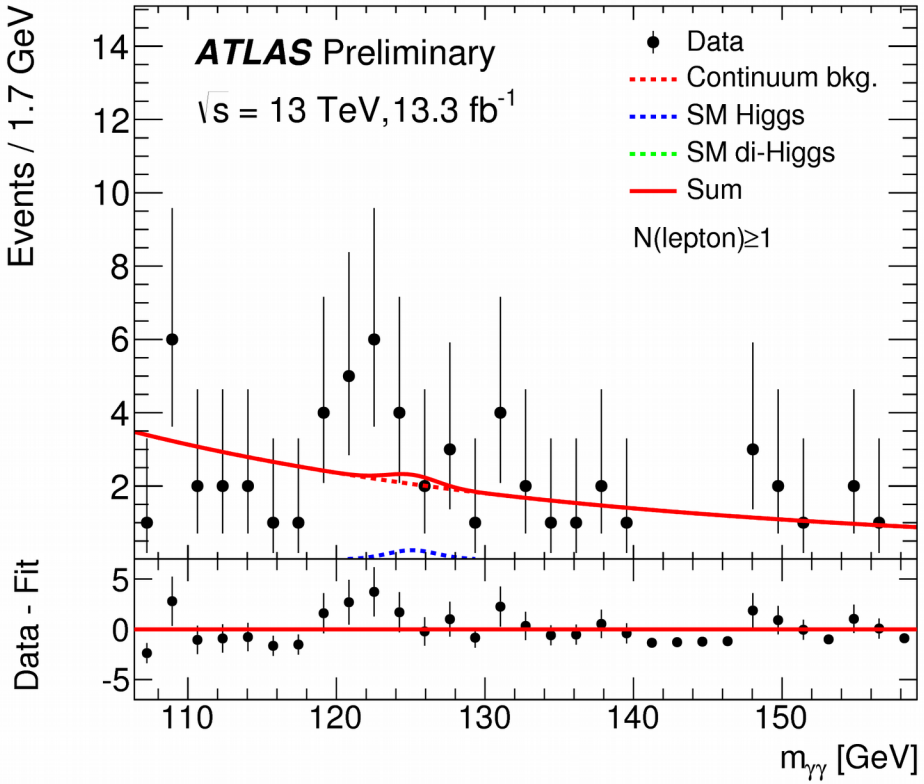
https://twiki.cern.ch/twiki/bin/view/CMSPublic/SummaryResultsHIG

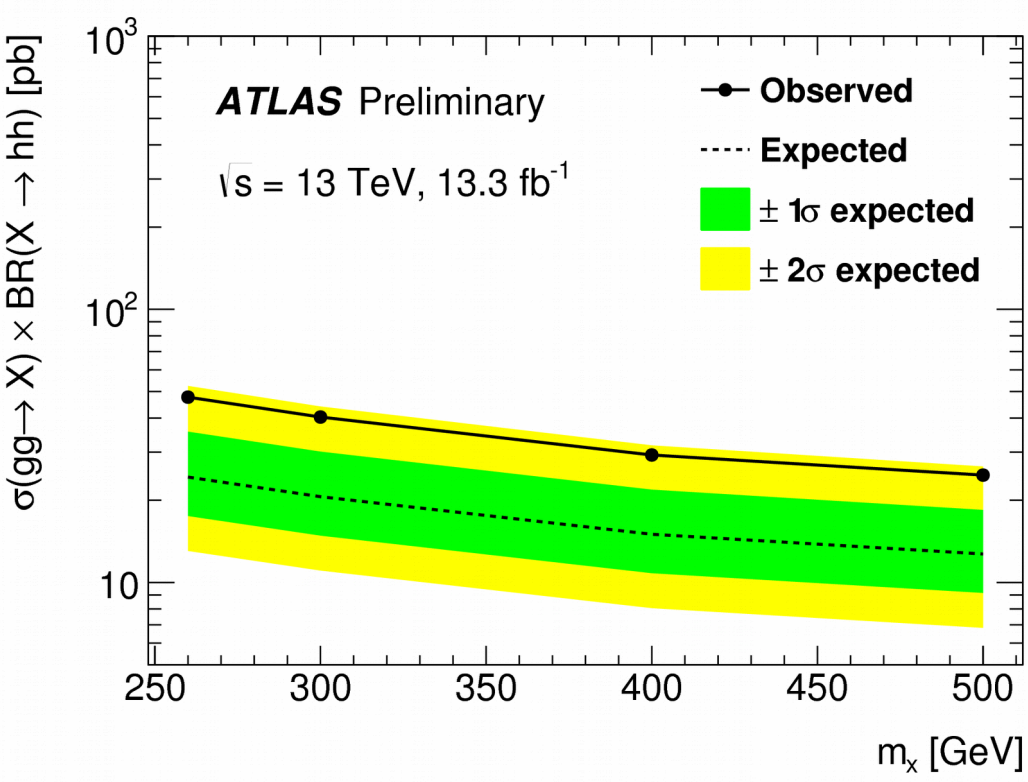
Di-Higgs searches: WWγγ

- HH → WW γγ
  - WW → lνjj
  - Events in signal region
  - 0 lepton control region → sideband for signal region (>= 1 lepton)

ATLAS-CONF-2016-071

Process	Number of events	
Continuum background	7.26	± 1.23
SM single-Higgs	0.616	± 0.115
SM di-Higgs	0.0187	± 0.002 24
Observed		15

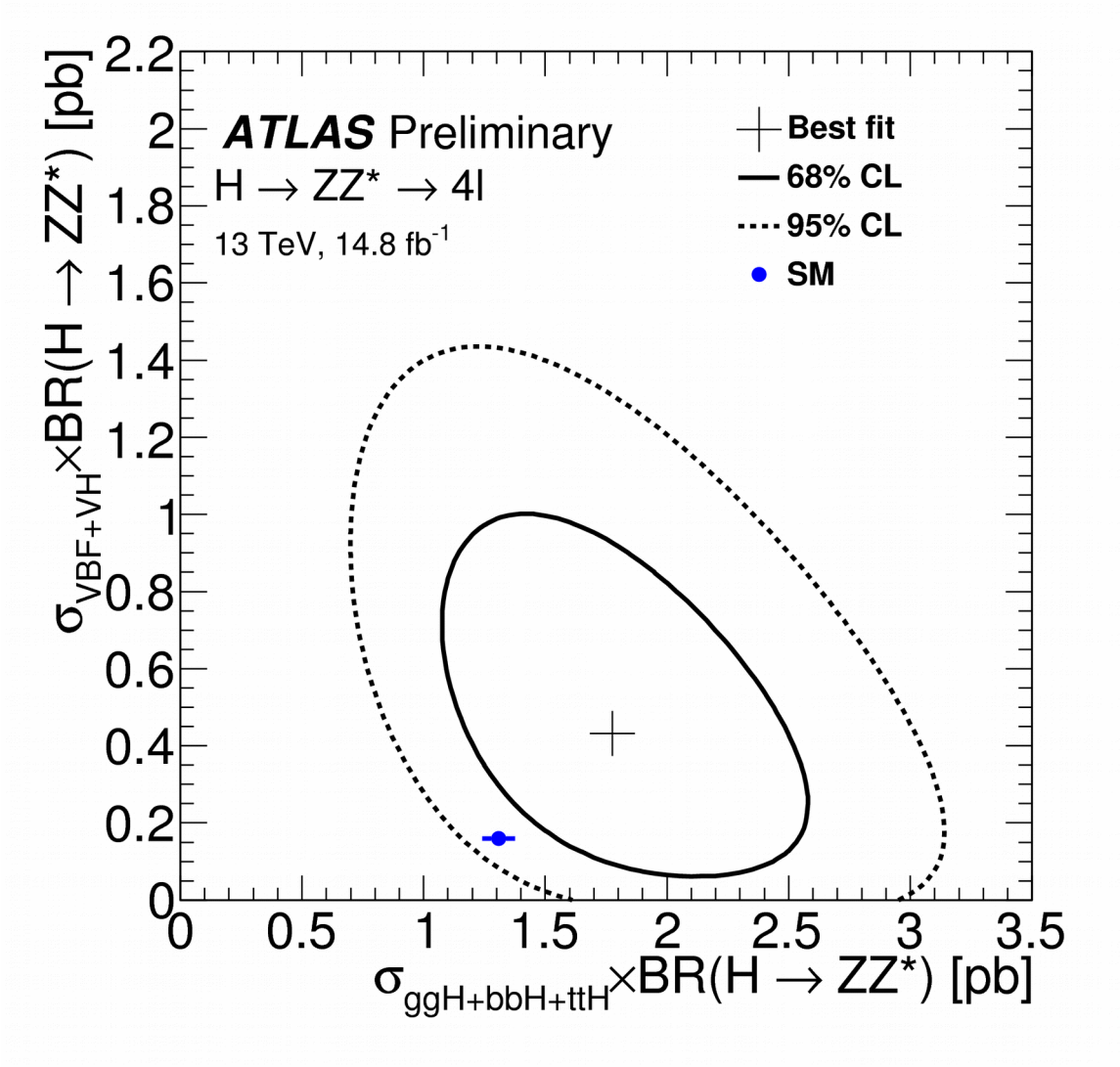




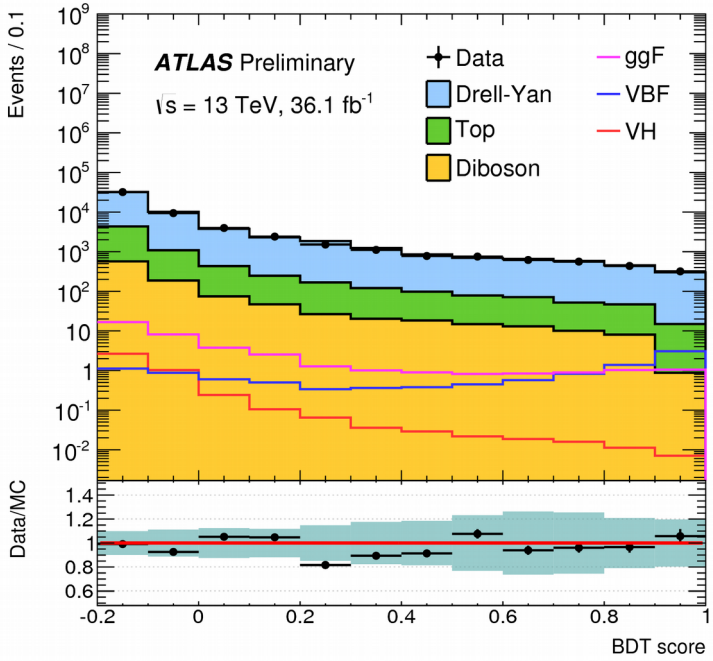
H → ZZ

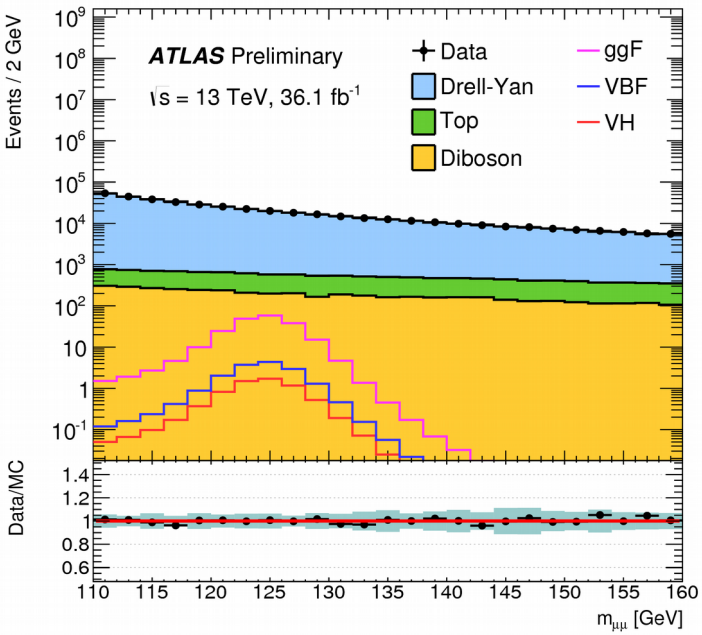
- Different production mechanisms

CMS-HIG-16-041
CMS-HIG-17-011
ATLAS-CONF-2017-032
ATLAS-CONF-2016-079

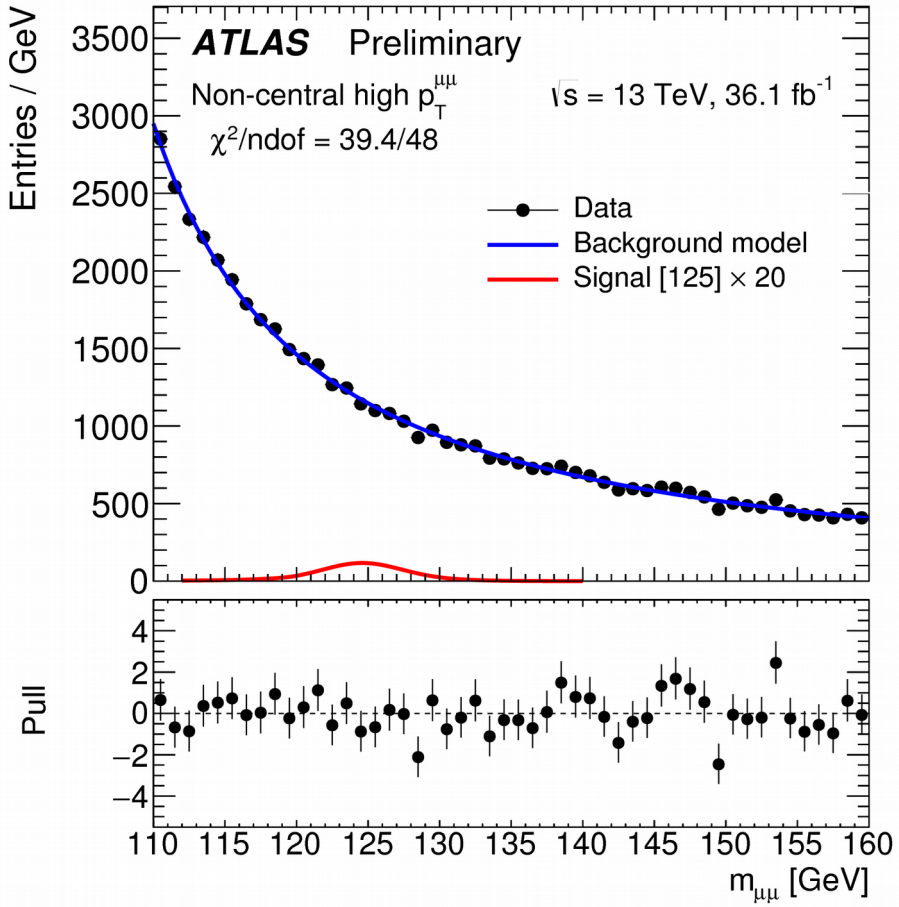


H → μμ





- Very rare final state: BR H→μμ = 2.18 x 10^{-4}
- Observed (expected) upper limit is 2.8 (2.9) times the Standard Model prediction



ATLAS-CONF-2017-014