Standard Model at ATLAS and CMS

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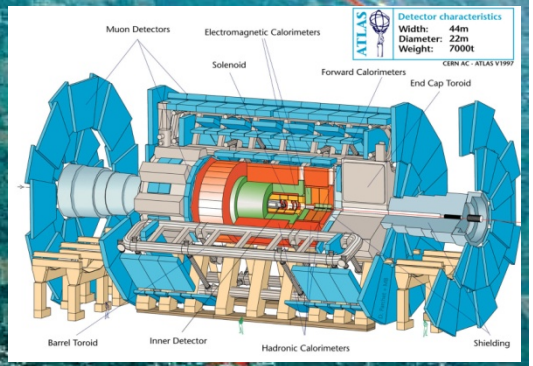
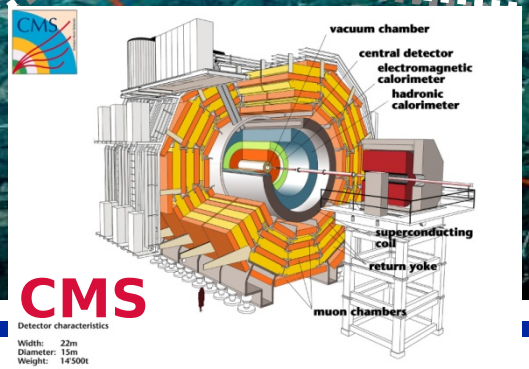
LBNL

Pheno-2015

ATLAS





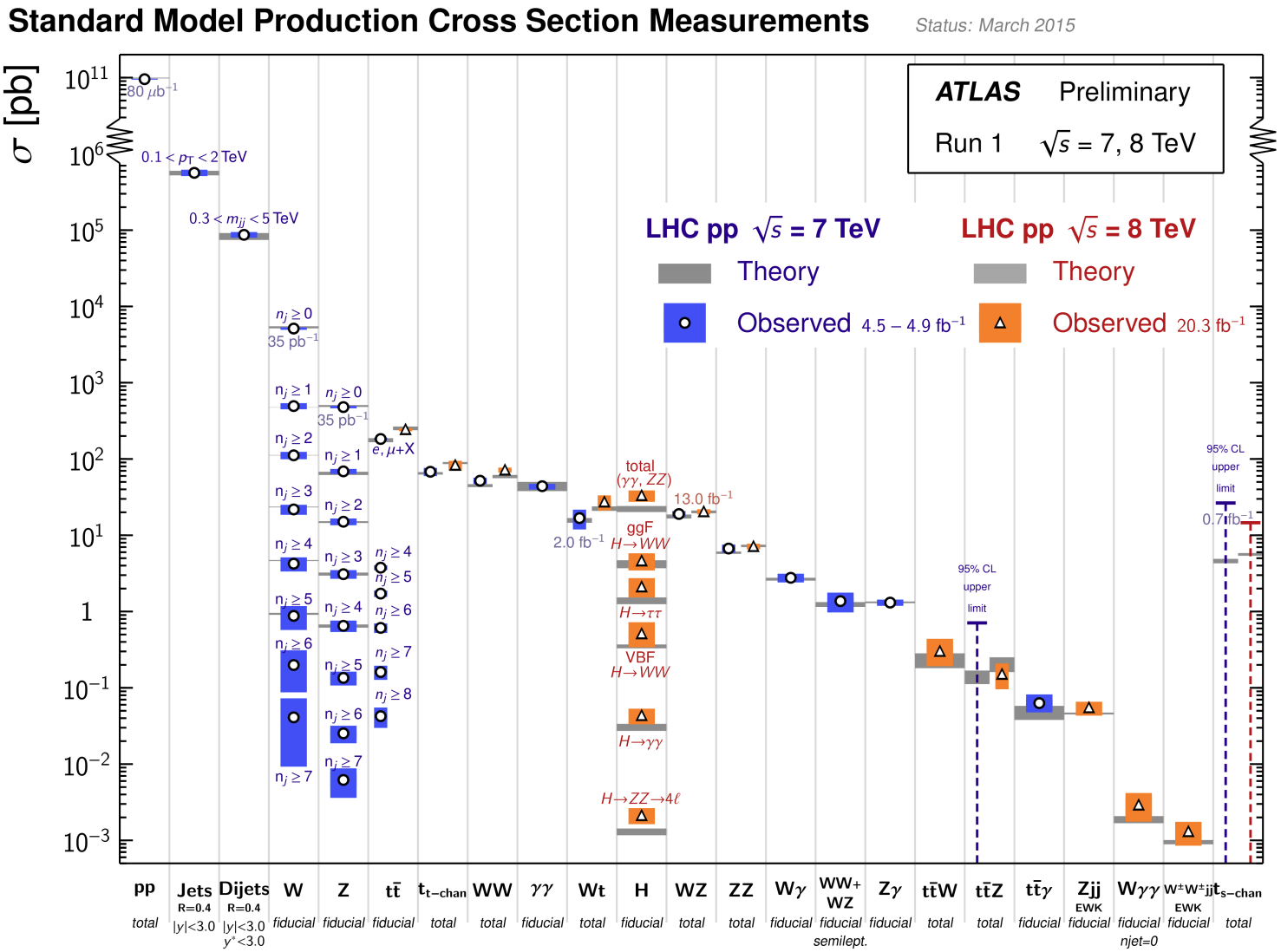
Standard Model at ATLAS and CMS

- Higgs
  - Mass
  - Couplings
  - production
- W/Z production
- Gauge boson pairs
  - QCD production
  - Electroweak production (VBF)
- Top mass and production
- QCD
  - Cannot cover PDF's
- Cannot cover B—Physics: no time
- Cannot cover details
  - Each topic would fill entire talk
- Note that there are more details in parallel sessions: List on next slide

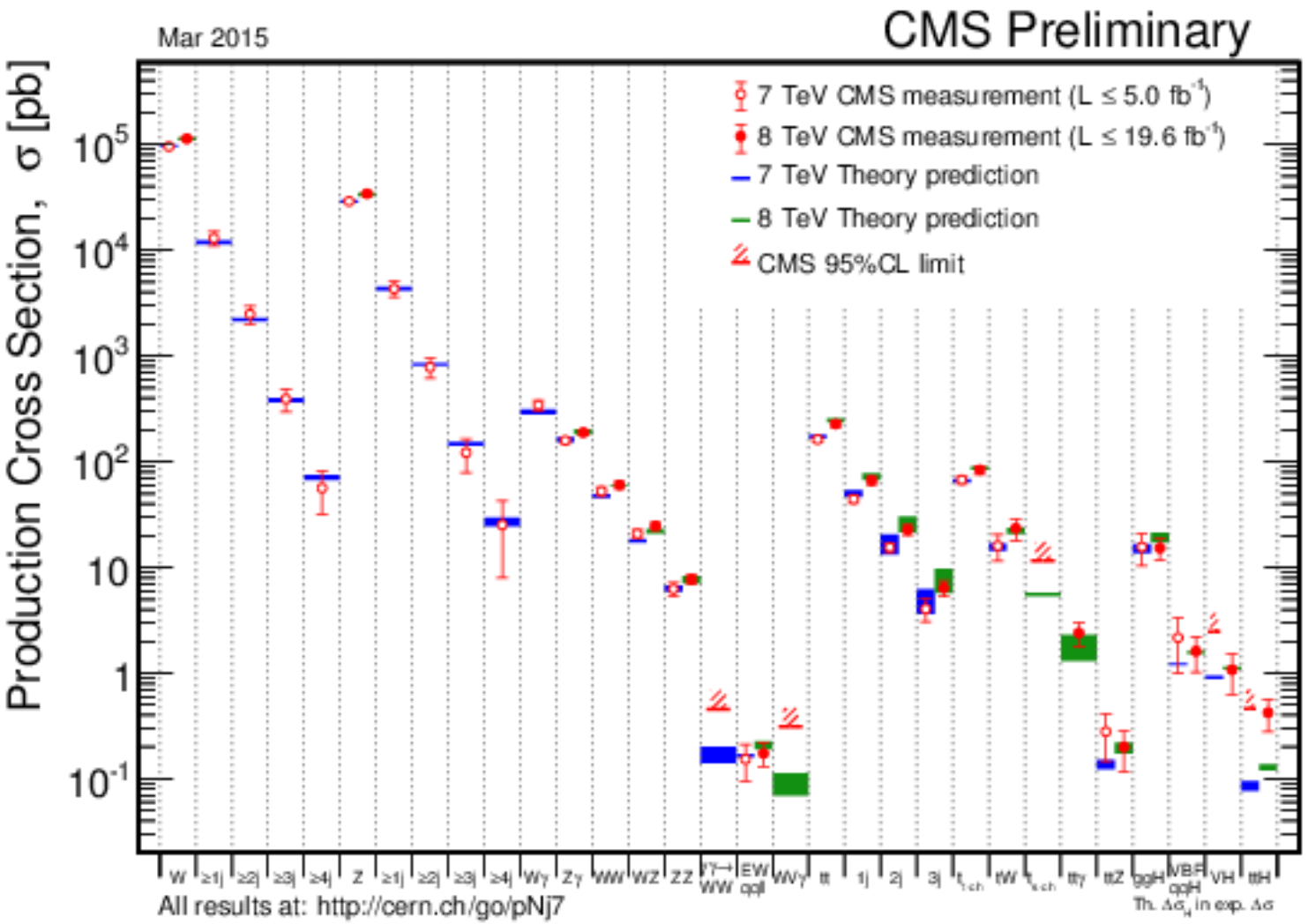
Related parallel session talks
Search talks not listed here

- **CMS:**
  - **PDF's and α_s: Fred Stober**
  - **Wtt and Ztt:Andrew Brinkerhoff**
- **ATLAS**
  - **QCD jets: Javier Llorente Merino**
  - **Quarkonia production: Benjamin Weinert**
  - **Electroweak results: Aparajita Dattagupta**
  - **Vector boson production: Samuel Webb**
  - **Top pair production:Ki Lei**
  - **Top Properties: Bruno Galhardo**
  - **Single Top: Kevin Sapp**
  - **Higgs boson properties: Jordan Webster**
  - **H+ttbar:Marine Kuna**
  - **Higgs couplings: Cecilia Taccini**

ATLAS overview: production rates



CMS overview: production rates



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  - **Couplings**
  - **production**

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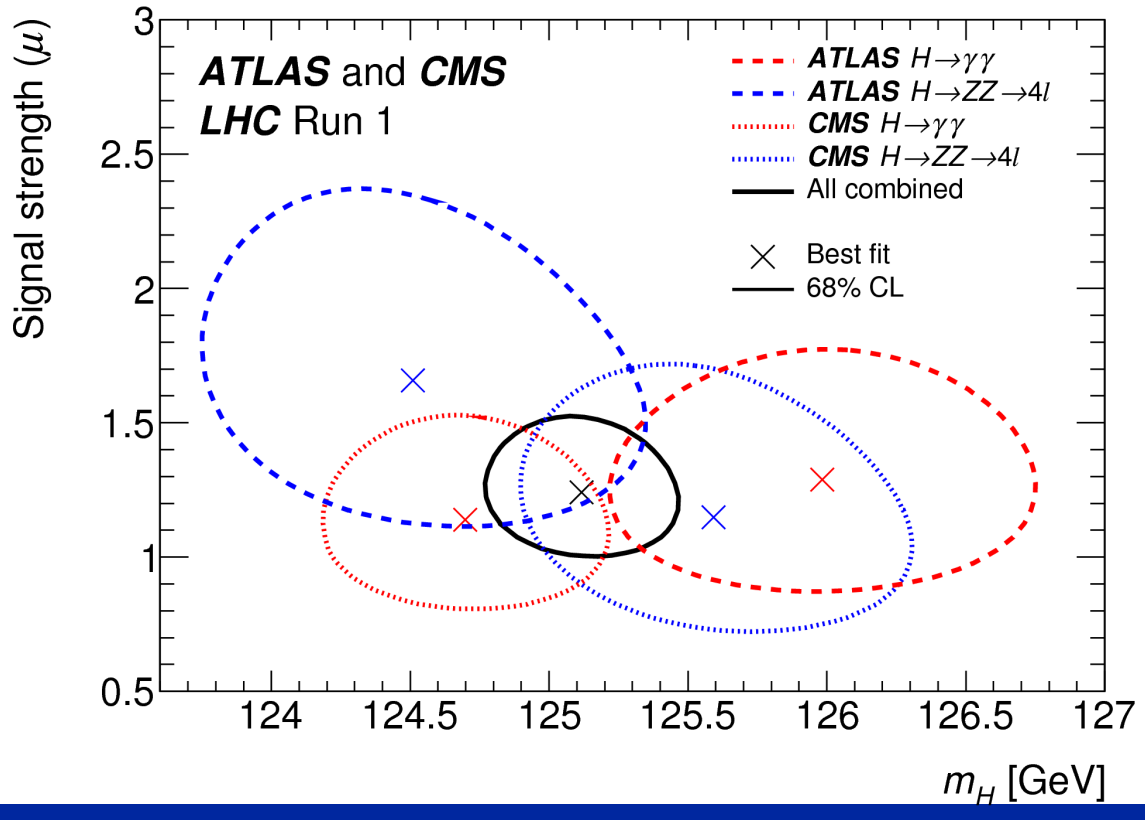
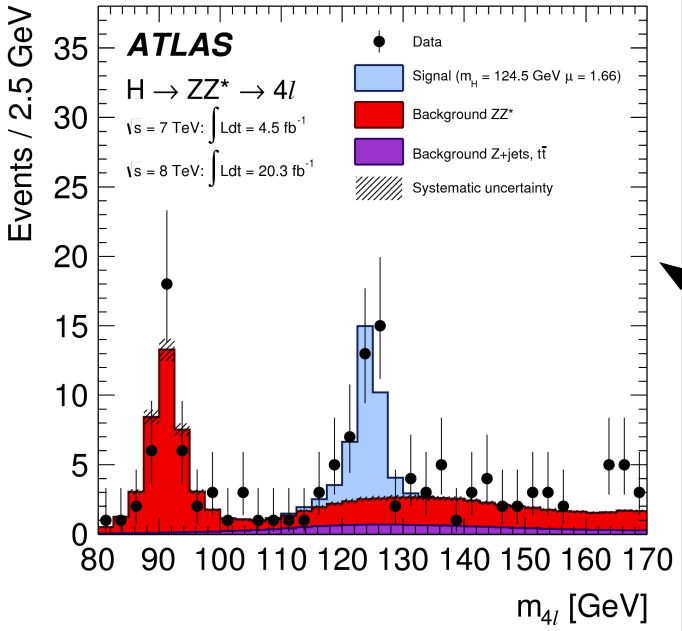
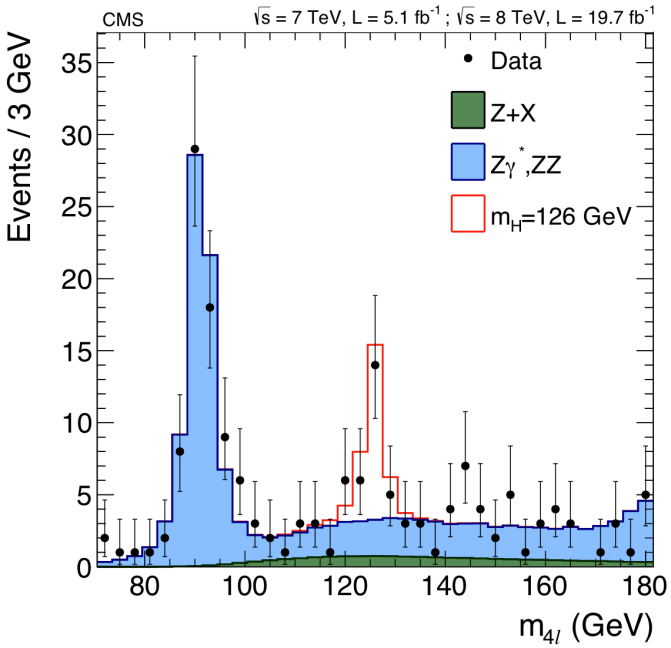
Higgs mass

- 2 channels contribute: $\gamma\gamma$ and ZZ* (to 4 leptons)
  - Others much less sensitive: $\tau\tau$, WW*
    - But these are consistent
- Signal strength is not correlated to mass measurements: strengths floated in fit
- Relative weights of measurements contributing to average: CMS $\gamma\gamma$ (40%), ZZ (23%): ATLAS $\gamma\gamma$ (19%), ZZ (18%)

arXiv:1503.07589



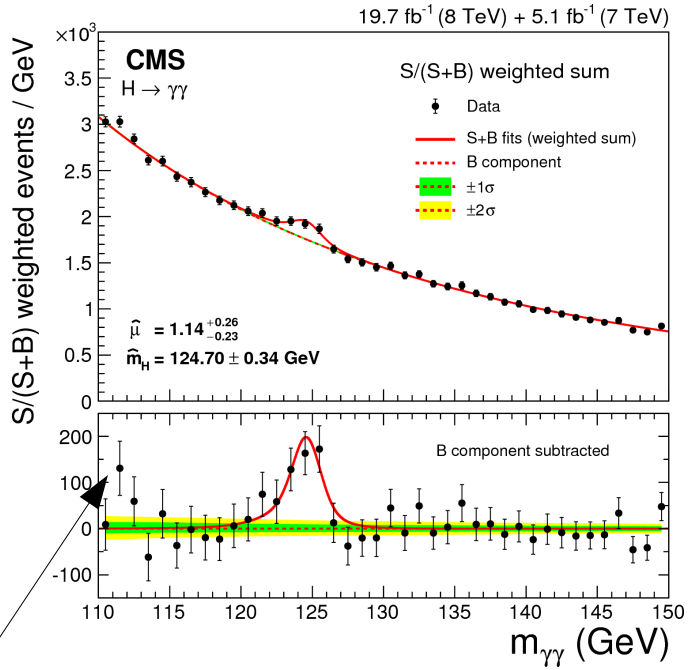

ATLAS
H → ZZ* → 4l
√s = 7 TeV: ∫Ldt = 4.5 fb-1
√s = 8 TeV: ∫Ldt = 20.3 fb-1
Data
Signal (mH = 124.5 GeV μ = 1.66)
Background ZZ*
Background Z+jets, tt̄
Systematic uncertainty
Events / 2.5 GeV
m4l [GeV]

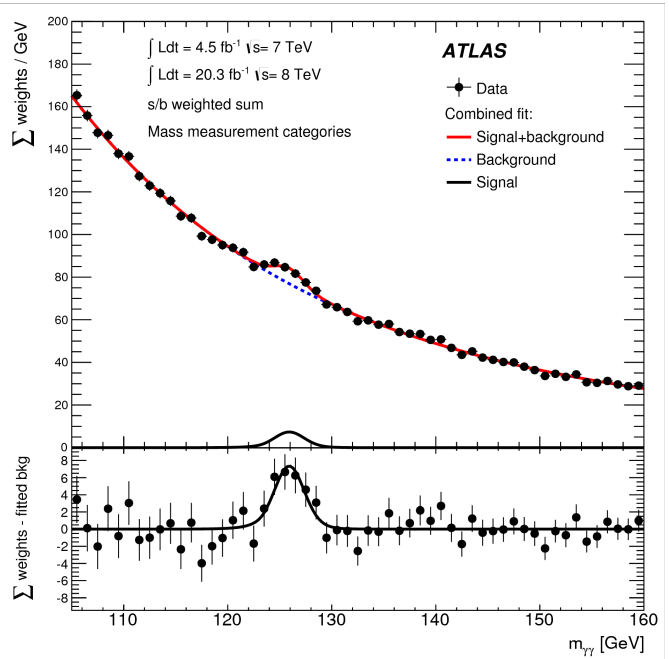

CMS
√s = 7 TeV, L = 5.1 fb-1 ; √s = 8 TeV, L = 19.7 fb-1
Data
Z+X
Zγ*,ZZ
mH=126 GeV
Events / 3 GeV
m4l (GeV)

inputs

ZZ

γγ

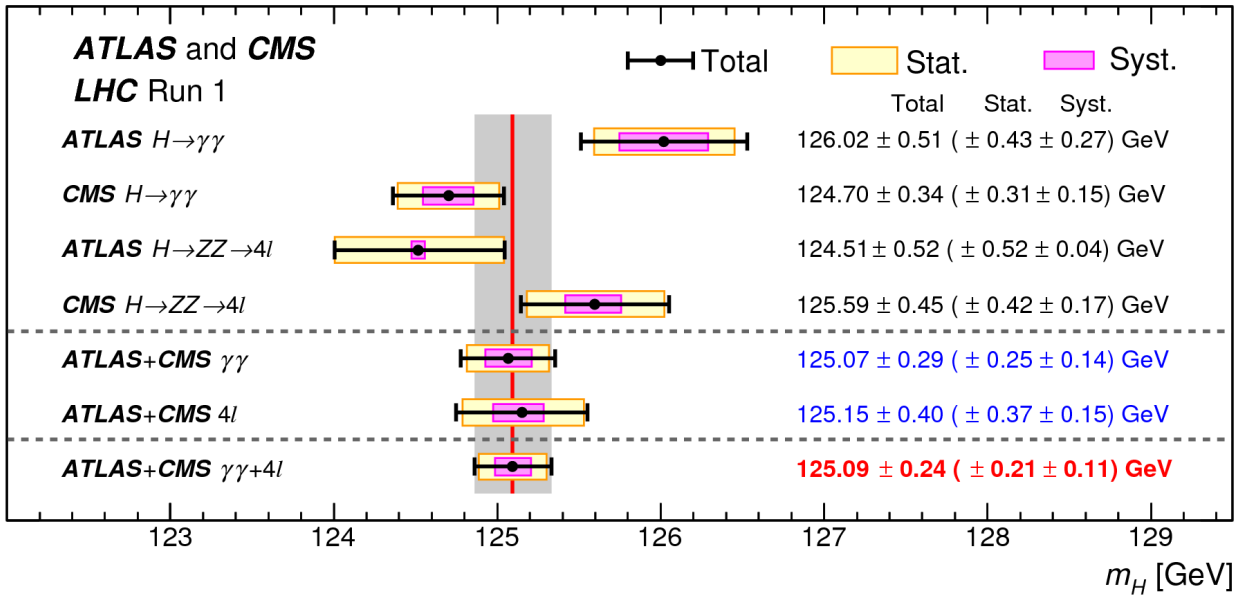

19.7 fb-1 (8 TeV) + 5.1 fb-1 (7 TeV)
CMS
H → γγ
S/(S+B) weighted sum
Data
S+B fits (weighted sum)
B component
±1σ
±2σ
μ̂ = 1.14 +0.26 −0.23
m̂H = 124.70 ± 0.34 GeV
S/(S+B) weighted events / GeV
B component subtracted
mγγ (GeV)


∫Ldt = 4.5 fb-1 √s= 7 TeV
∫Ldt = 20.3 fb-1 √s= 8 TeV
s/b weighted sum
Mass measurement categories
ATLAS
Data
Combined fit:
Signal+background
Background
Signal
Σ weights / GeV
Σ weights - fitted bkg
mγγ [GeV]

Higgs mass

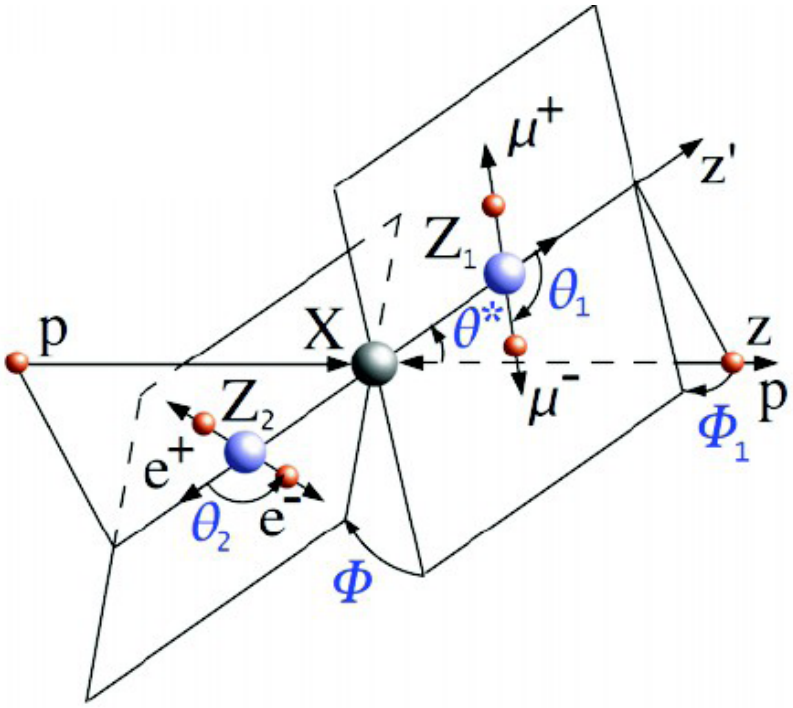
- **Combined mass**
  - **125.09 +/- 0.24 GeV**
    - **Statistical uncertainty dominates: 0.21 vs 0.11 systematic**
    - **Can therefore expect smaller uncertainty in Run 2**
  - **Some tension within experiments**
  - **Overall consistency good: overall compatibility ~10%: No evidence for more than one particle.**

arXiv:1503.07589



Higgs: Spin from decay kinematics

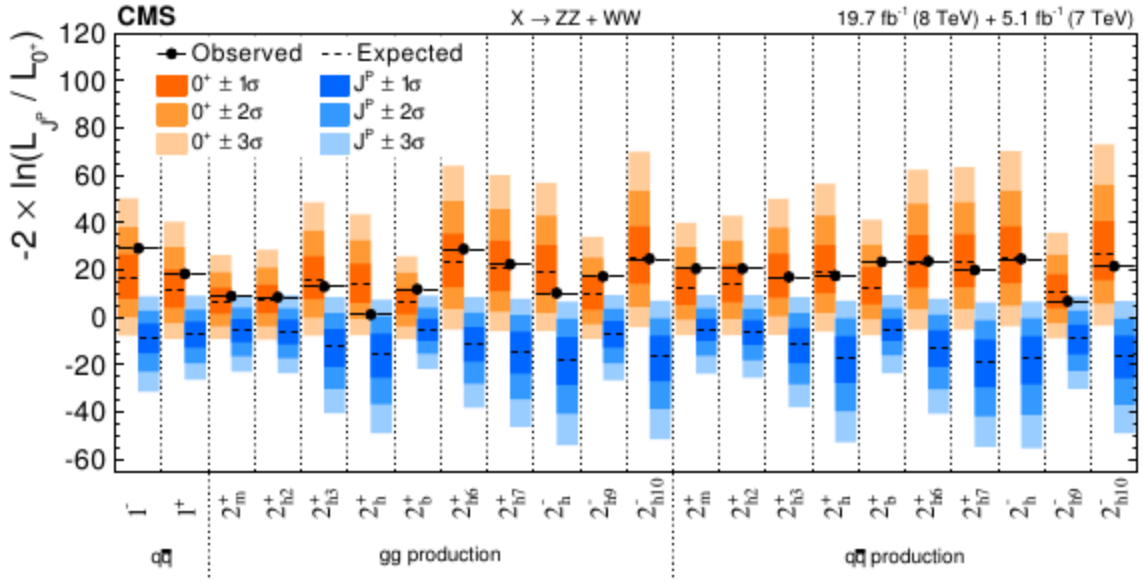
- Full Model independent spin parity determination needs more statistics in ZZ final state
  - Fully reconstructed
  - Does not depend on production mechanism
  - All decay angles measured



- Limited data allow models to be tested
  - Can also use $\gamma\gamma$ mode in this case
    - Dependence of decay angle on production
  - WW also be used
- Large number of spin-2 hypotheses with various couplings to qq and gg excluded at >95% CL

Higgs: Spin model hypotheses

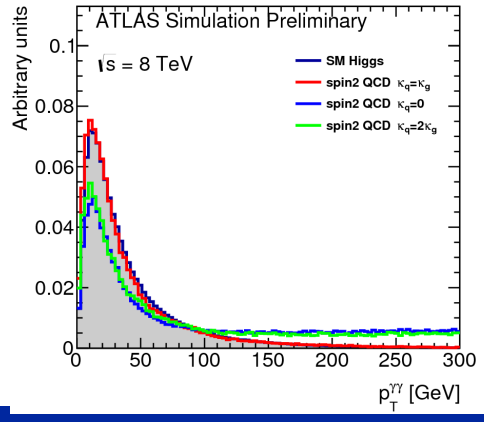
- **Measurements inconsistent with spin 1 and 2 hypotheses in ZZ and WW distributions**

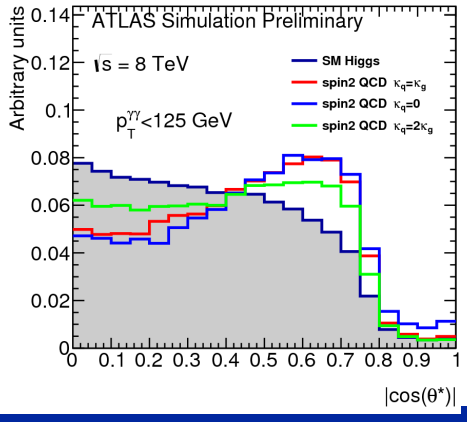


ArXiv: 1411.3441

- **Pt distribution of γγ system can test models: data not consistent with spin 2 models.**

ATLAS-CONF-2015-008

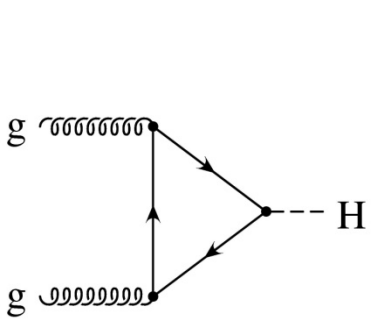


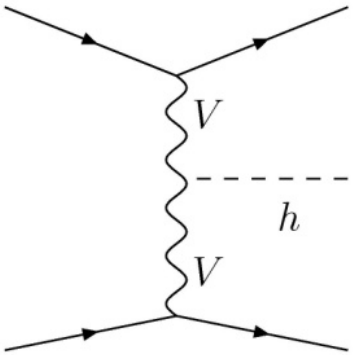


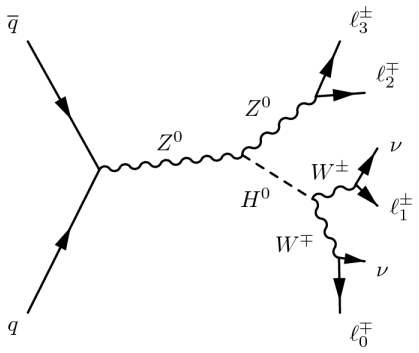
All data consistent with 0+
All other tested models excluded
Including 0-

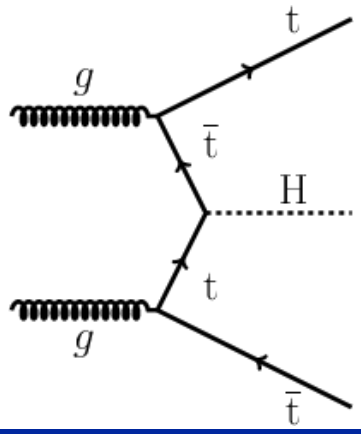
Higgs Properties: couplings

- No time to discuss general cases: will only address
  - "Are the measurements consistent with SM expectation?"
  - Final states investigated
    - WW, ZZ, γγ, ττ, μμ, ee,bbar,ttbar
  - Production mechanisms investigated
    - Gluon fusion
    - Vector boson fusion (VBF)
    - Associated
- Take away message:
  - Couplings proved to be non-universal (unlike other elementary states)
  - Looks like Standard Model Higgs
    - But precision is such that deviations could show up in Run2







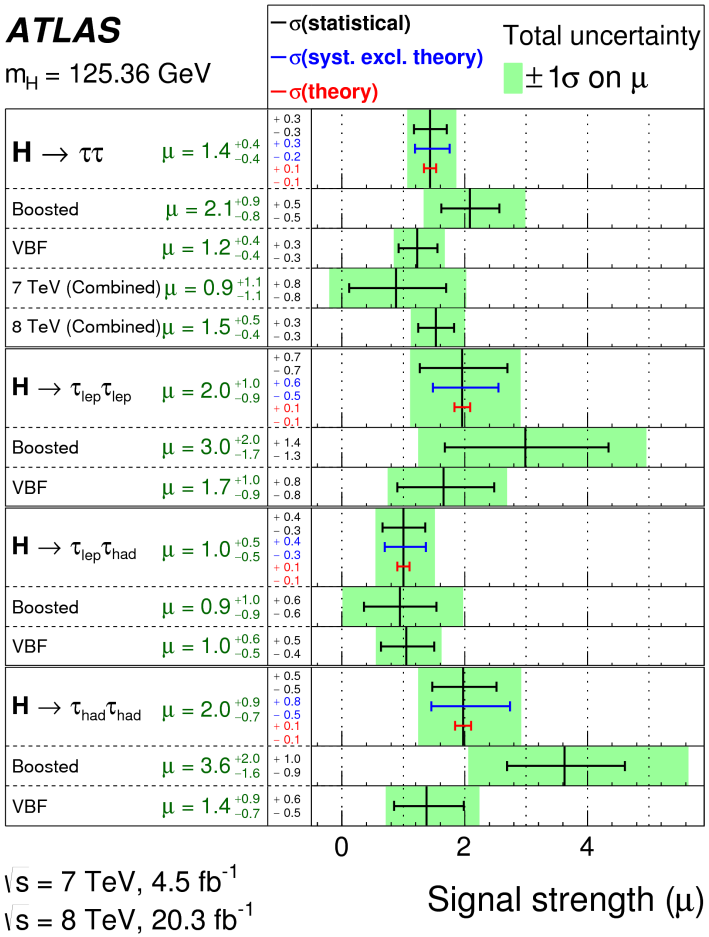


Higgs decay properties

- **Clear evidence for non universal leptonic couplings**
  - **Observations in ττ**
  - **Limits in ee and μμ**

arXiv:1501.04943

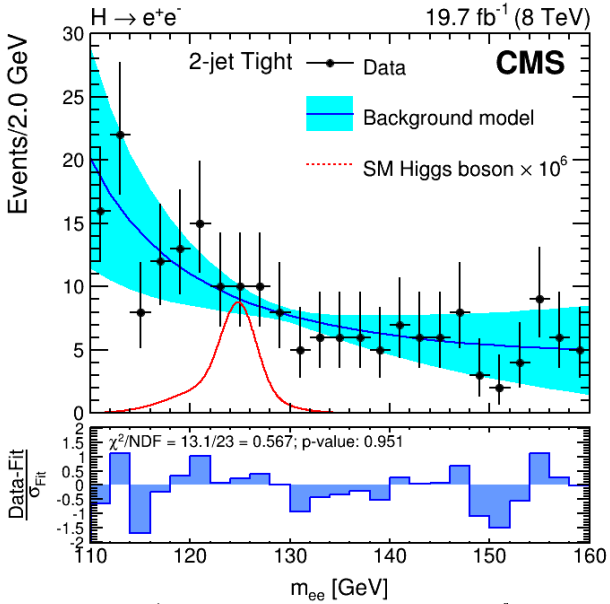
4.5σ excess in ττ

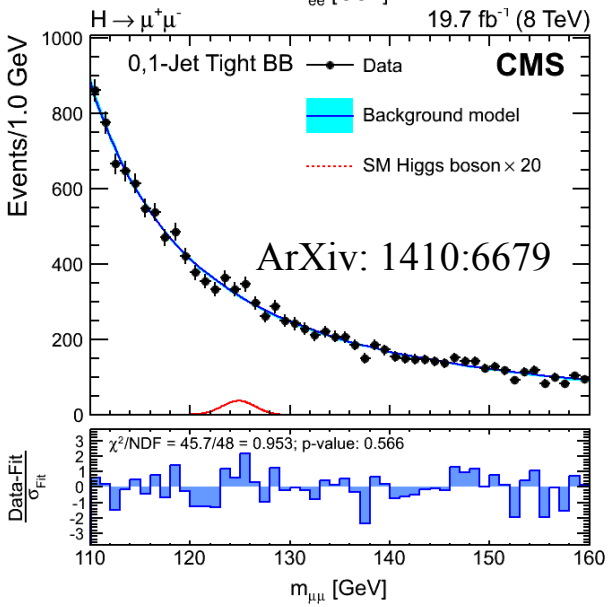


√s = 7 TeV, 4.5 fb^{-1}
√s = 8 TeV, 20.3 fb^{-1}

Drell Yan dominates

Note μμ is 220xSM for universal





Invisible Higgs width

- **VBF production: two jets +etmiss**
  - **Background dominated by Z and W**

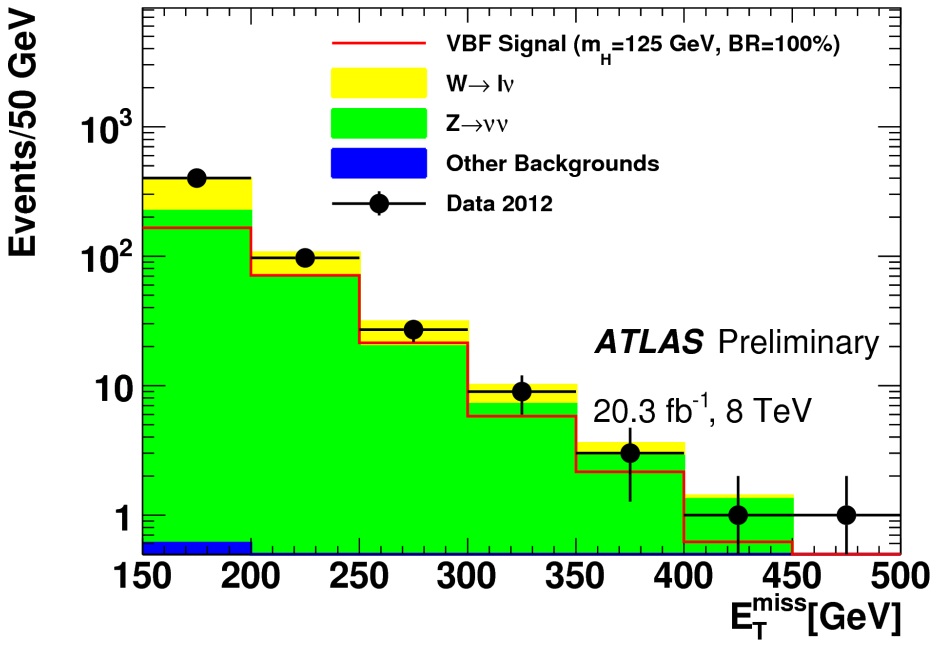
CMS

Process	Event yields
$Z \to \nu\nu$	$158.1 \pm 37.3 \pm 21.2$
$W \to \mu\nu$	$102.5 \pm 6.2 \pm 11.7$
$W \to e\nu$	$57.9 \pm 7.4 \pm 7.7$
$W \to \tau\nu$	$94.6 \pm 13.1 \pm 23.8$
top	5.5 ± 1.8
VV	3.9 ± 0.7
QCD multijet	17 ± 14
Total Background	$439.4 \pm 40.7 \pm 43.5$
Signal(VBF)	273.1 ± 31.2
Signal(ggH)	23.1 ± 15.9
Observed data	508

BR(H>Inv)<0.57 (95%CL)

CMS-PAS-HIG-14-038

ATLAS-CONF-2015-004



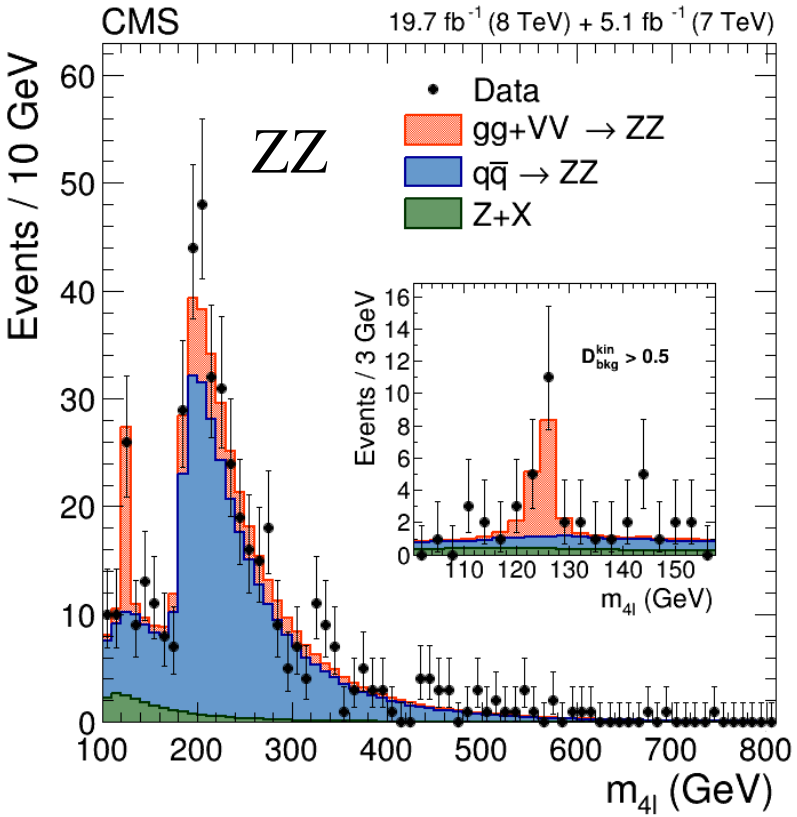
BR(H>Inv)<0.29 (95%CL)

- **Also results from ZH production results in unbalanced Z (etmiss)**
  - **Background from ZZ (mostly)**

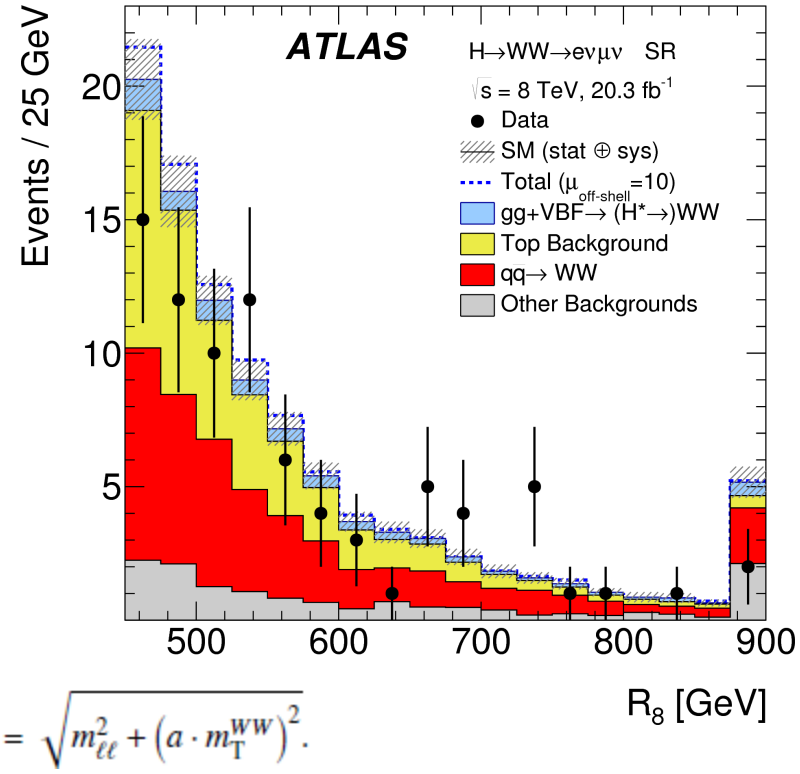
Higgs total width

- Cannot be measured directly from on shell data
- Must be extracted exploiting ZZ (or WW) cross section as function of mass
- Width <22 (23) MeV CMS (ATLAS), at 95% CL (7.5x SM expected value)

1405.3455



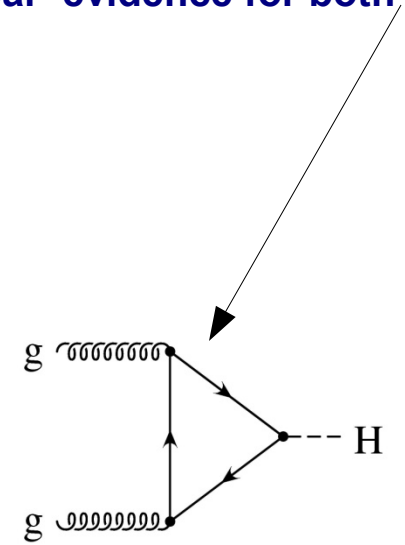
WW 1503.01060



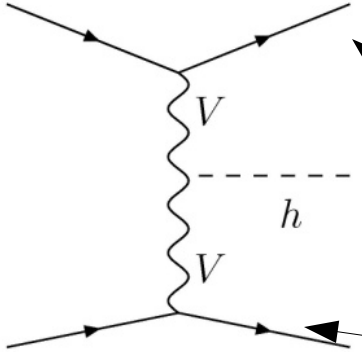
$$R_8 = \sqrt{m_{\ell\ell}^2 + \left(a \cdot m_T^{WW}\right)^2}.$$

Higgs production properties

- **Clear evidence for both gg and VBF production**



Sensitive to top coupling



Extra jets used as discriminant

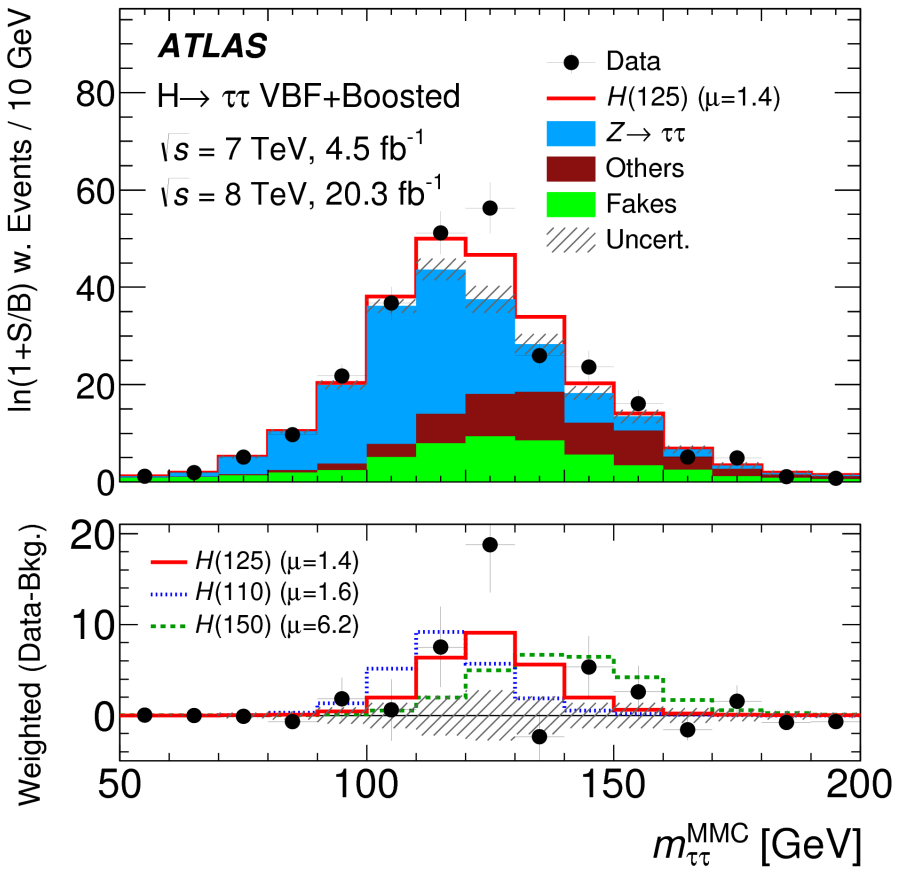
Powerful constraints in overall coupling fits

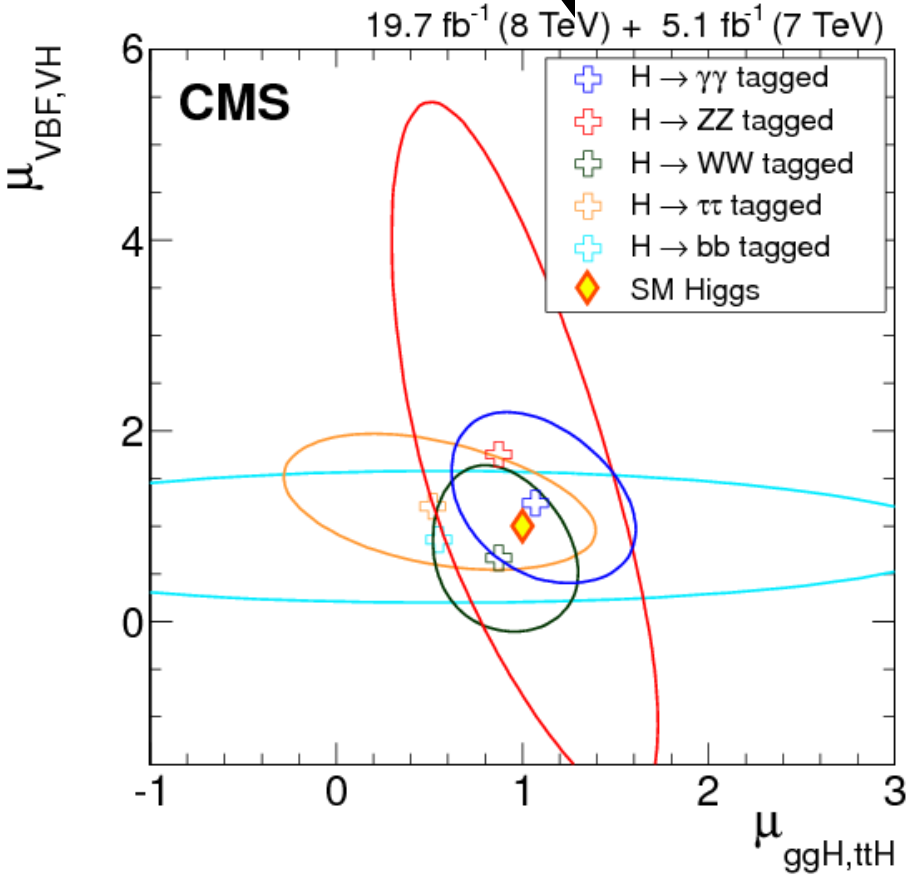
Higgs production properties

- signal in $\tau\tau$

Overall fit

Note excellent separation in $\tau\tau$ and $\gamma\gamma$



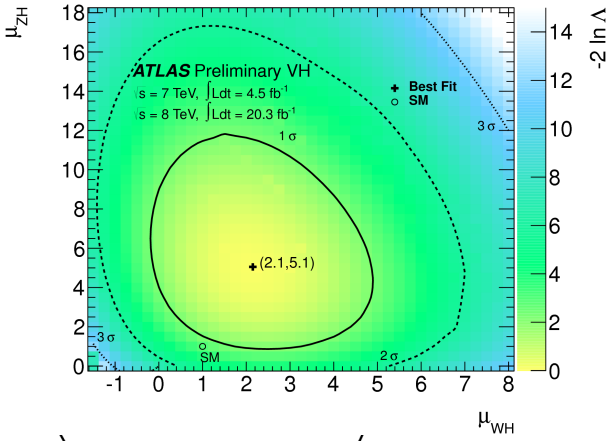


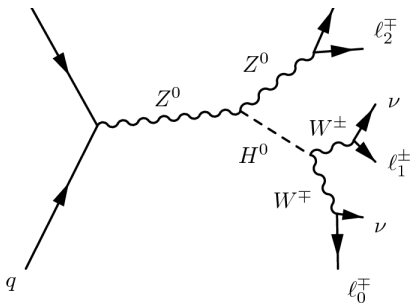
Associated Higgs production

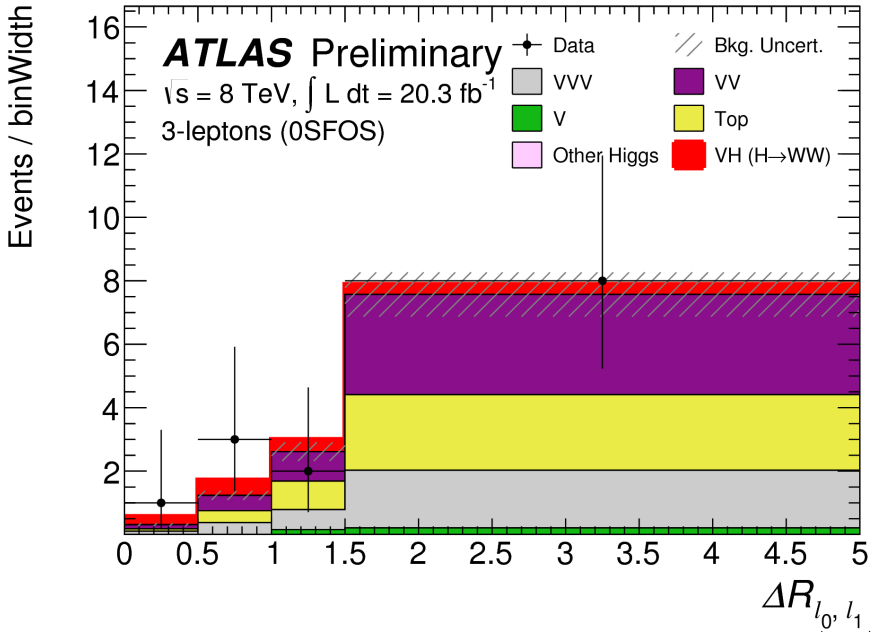
- ZH and WH

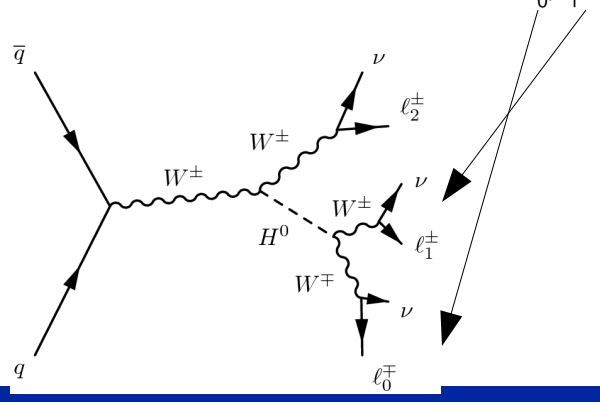
ATLAS-CONF-2015-005

- Events selected with 2 or 3 isolated leptons
- Statistics limited: 13 TeV needed
- Also results in H to bbar



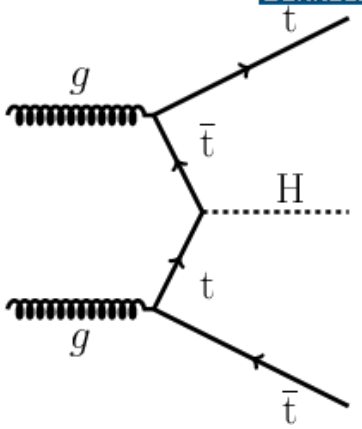


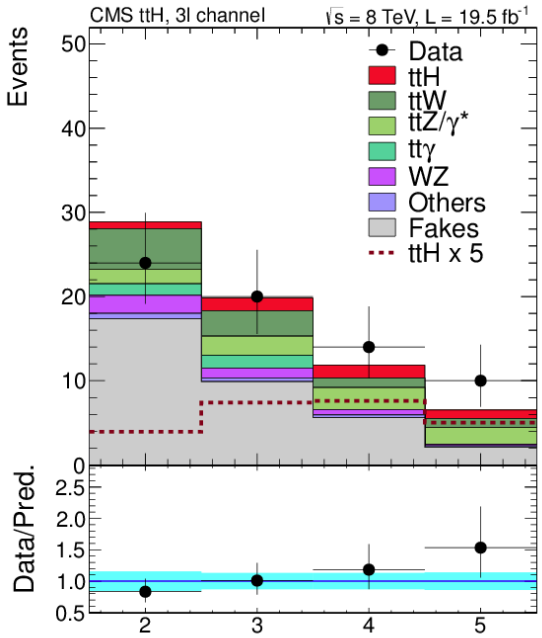


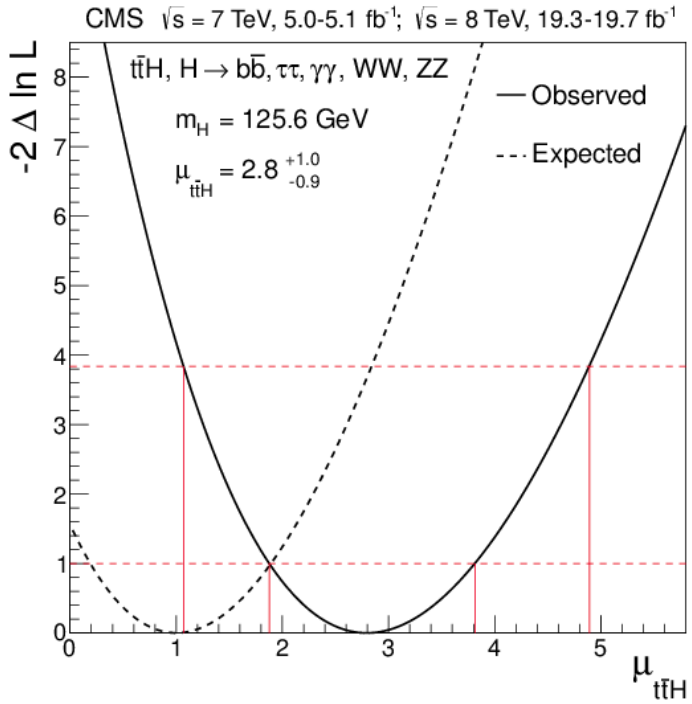


Associated Higgs production

- Htt: direct probe of top coupling
  - Small signal and large backgrounds
- Small rate: many channels combined (list incomplete)
  - Lepton+ > N Jets + >M btags
  - 3 leptons
  - 2 leptons + jets + btags
- Much larger cross section in Run 2



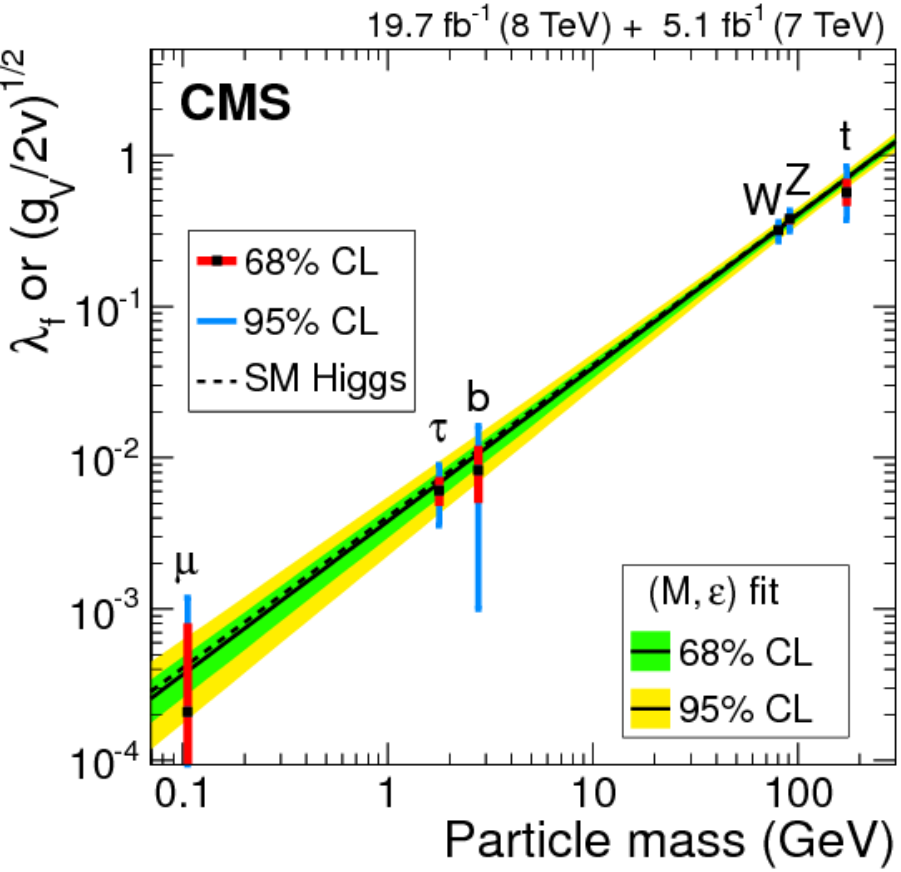


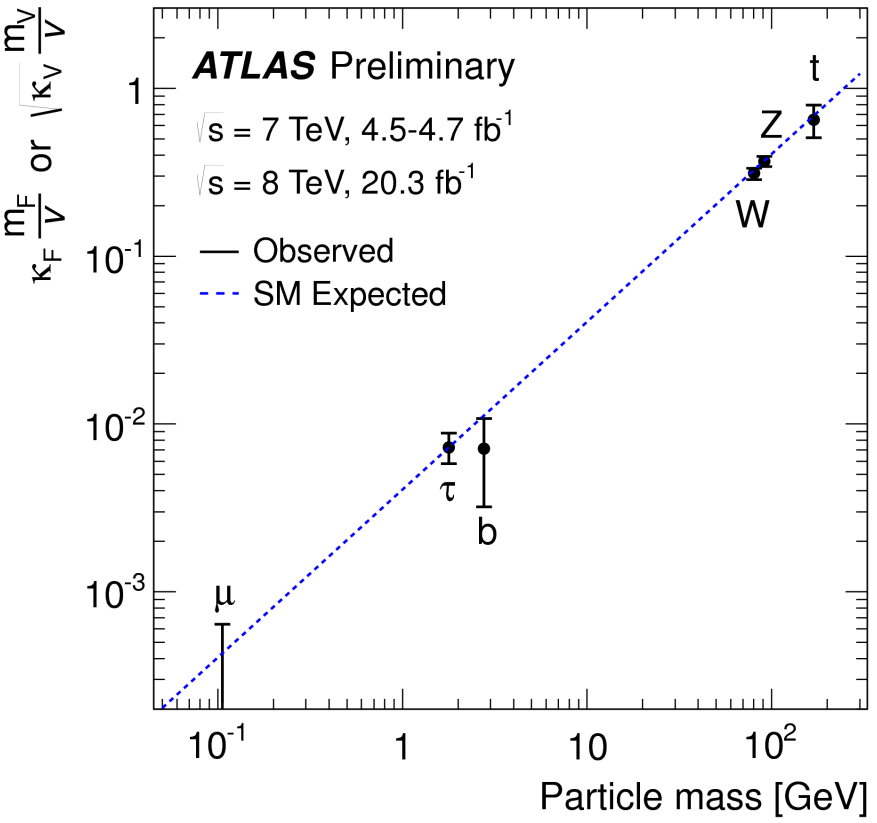


http://arxiv.org/pdf/1408.1682.pdf

Higgs Summary

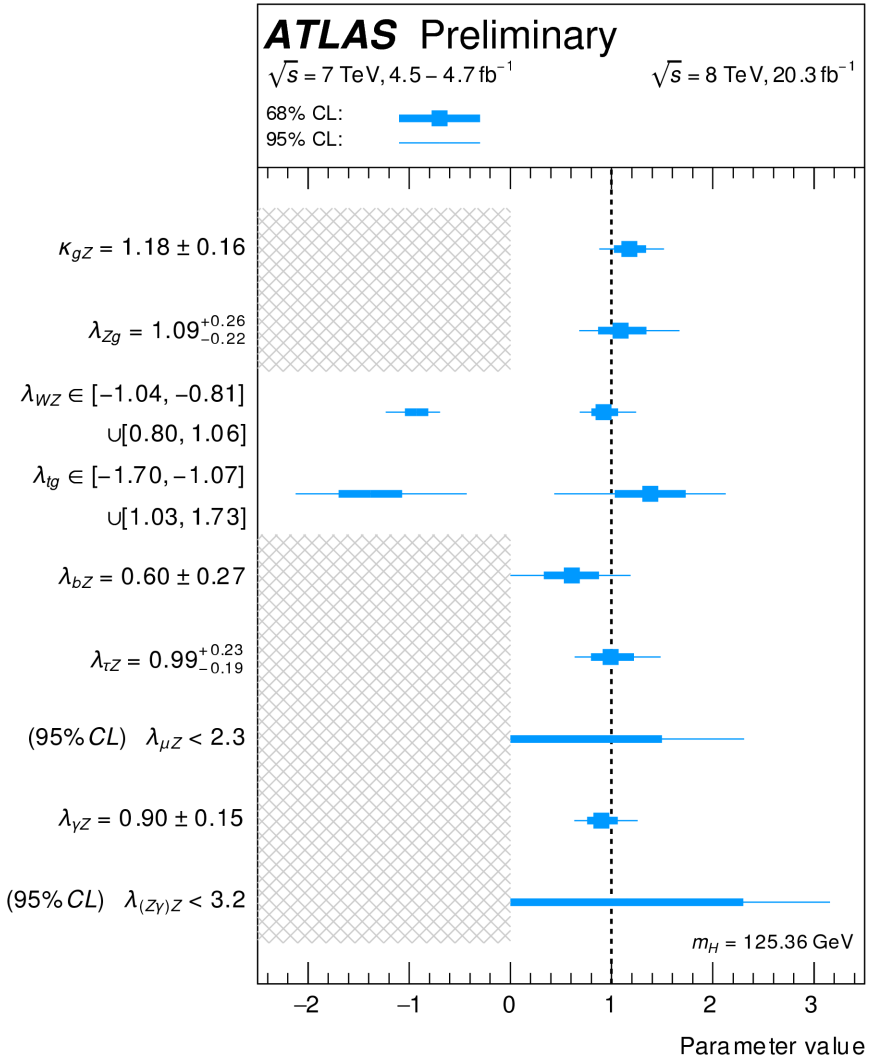
- **Very good consistency of all data with standard model Higgs of mass 125.09 GeV**

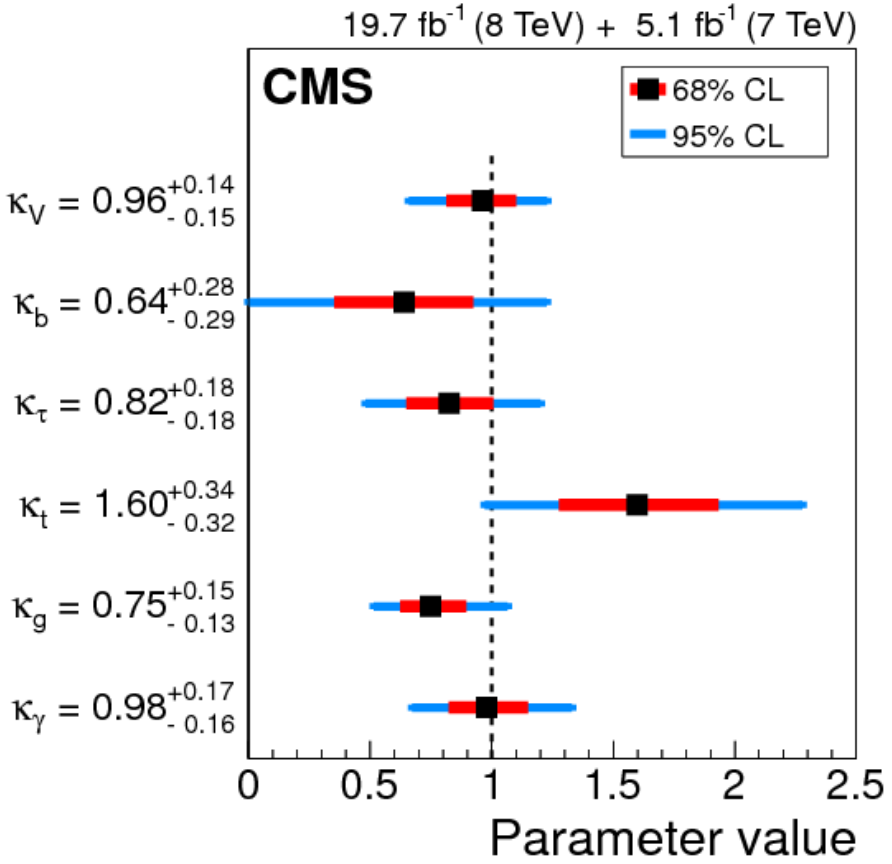




Higgs Summary

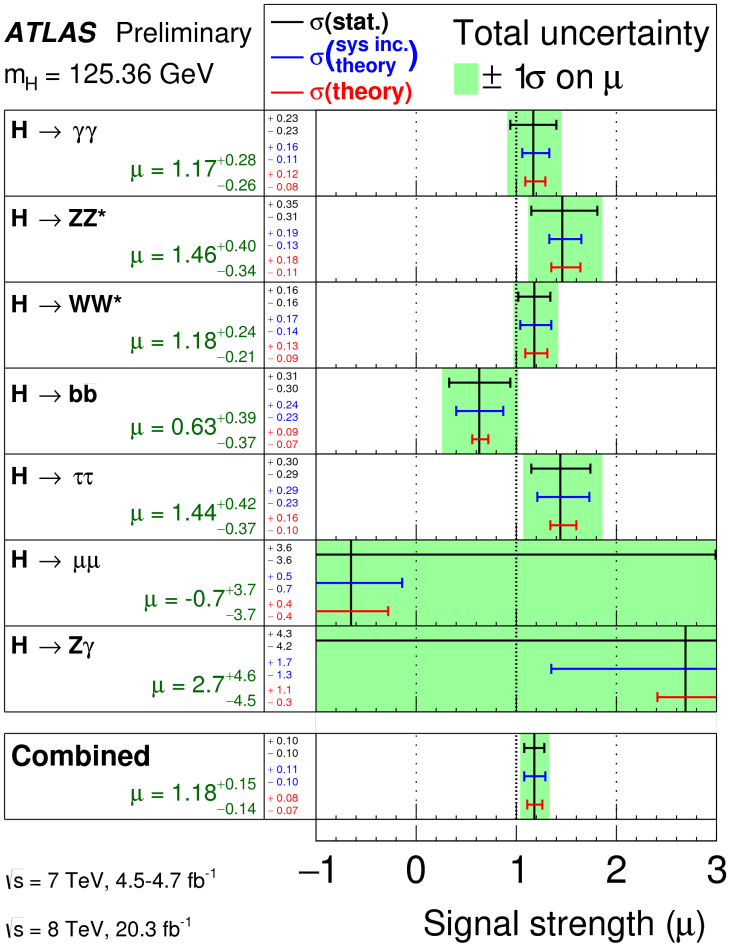
- **No evidence for BSM here**



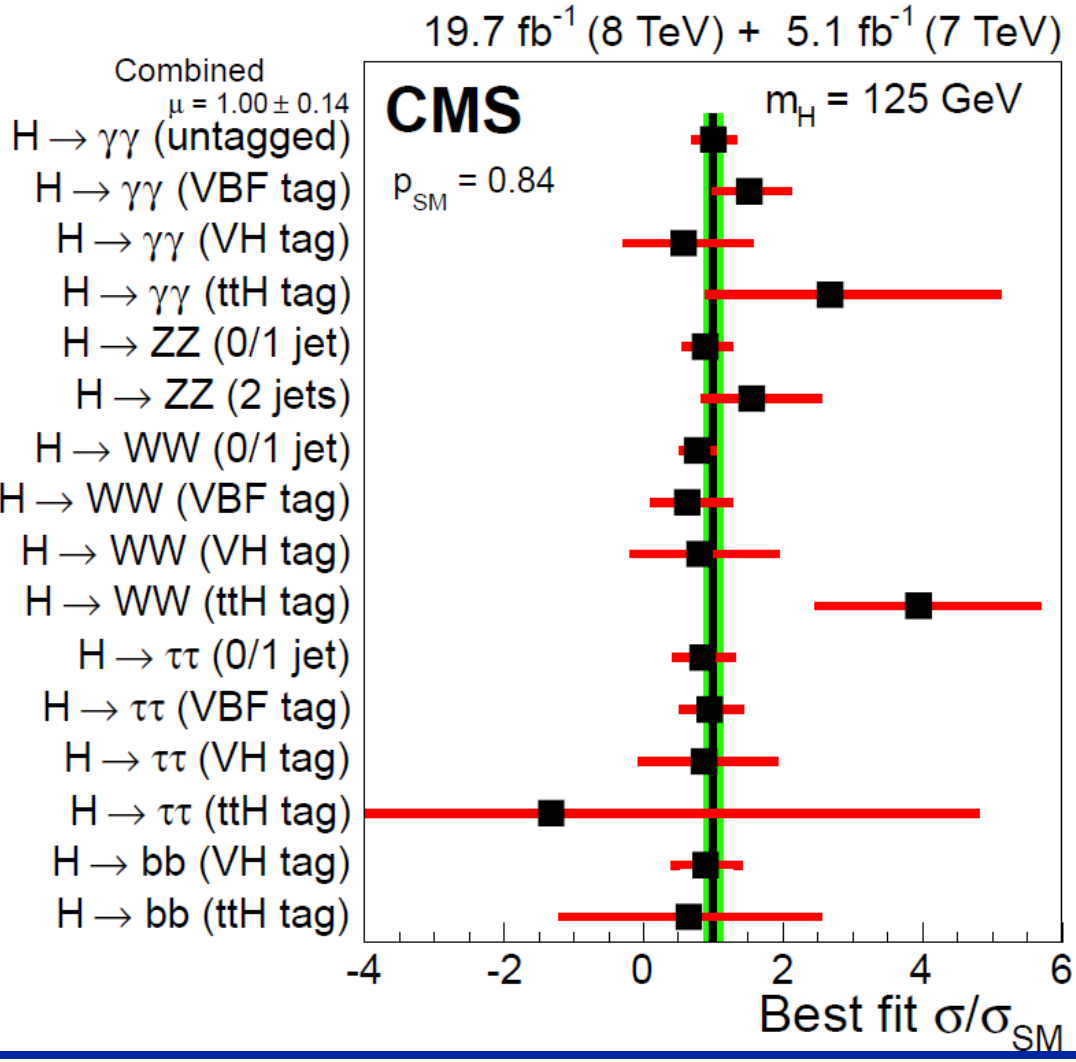


Higgs coupling Summary

ATLAS-CONF-2015-007



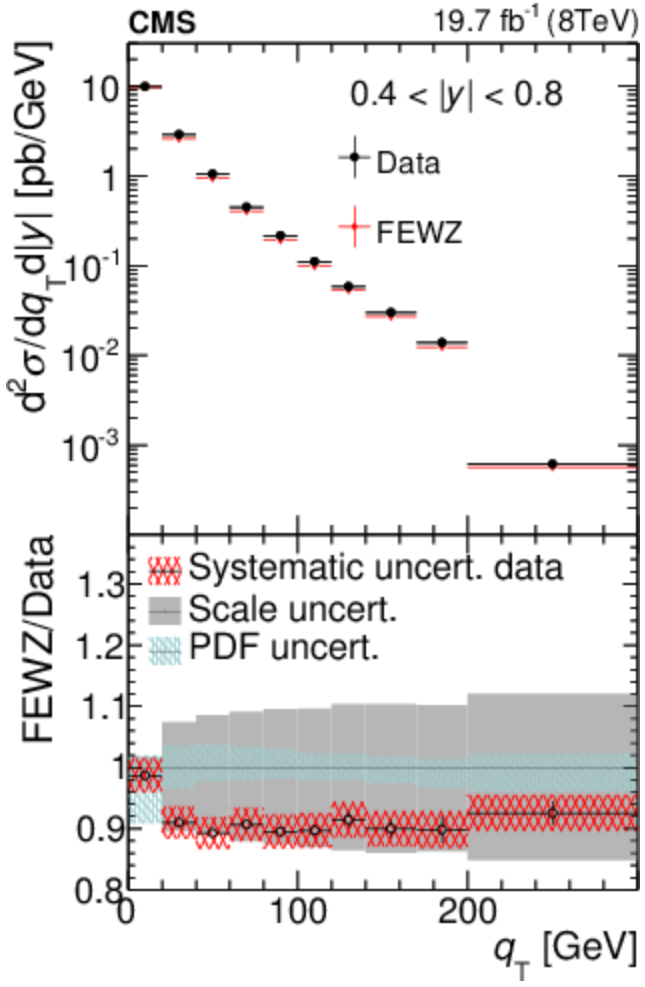
ArXiv:1412:8662



Standard Model at ATLAS and CMS

- Higgs
  - Mass
  - Couplings
  - production
- **W/Z production**
- Gauge boson pairs
  - QCD production
  - Electroweak production (VBF)
- Top mass and production
- QCD

Z production properties



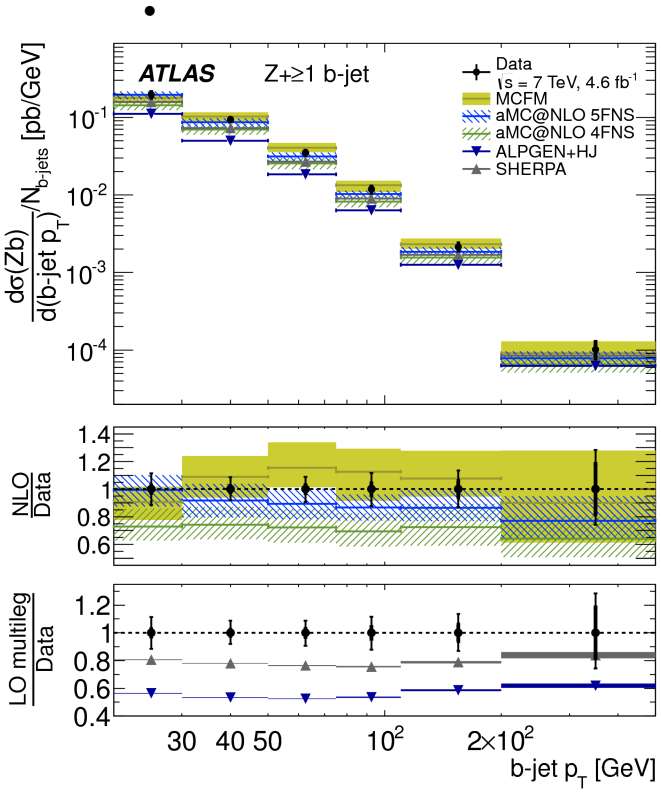
Arxiv:1504:03511

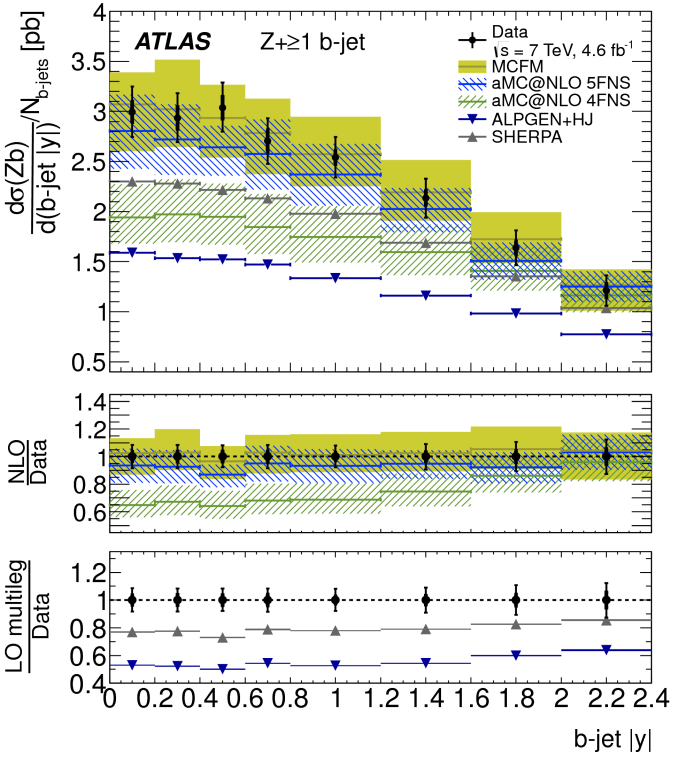
Pt distribution of Z: measured in μμ and ee

Theory good to 10% over range of 10^4

But some room for improvements here

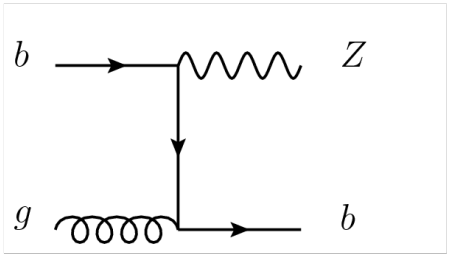
Z production with b jets





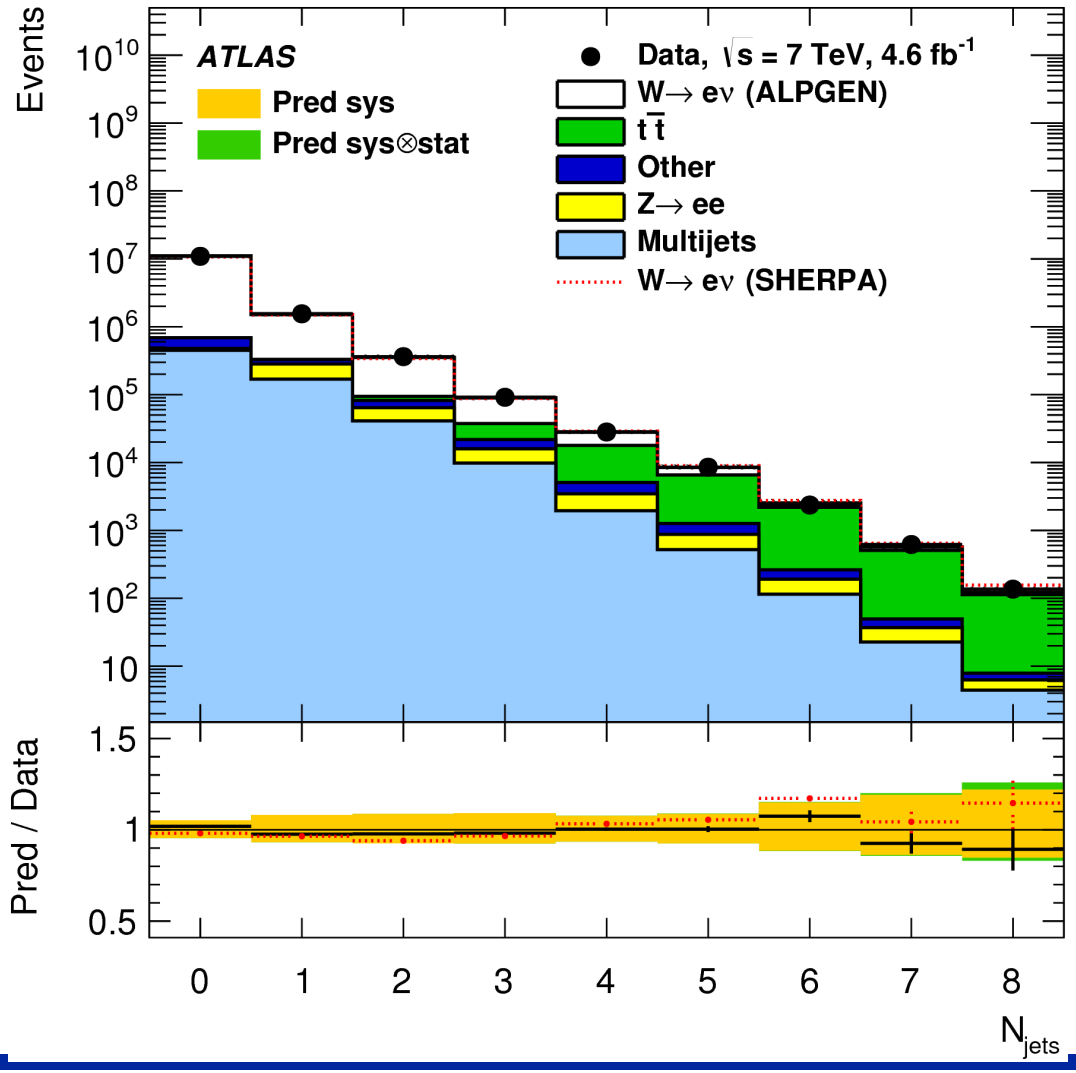
Some differences in models
MCFM agrees (after hadronization correction)

5 flavor (blue) preferred



JHEP10(2014)141

W production properties

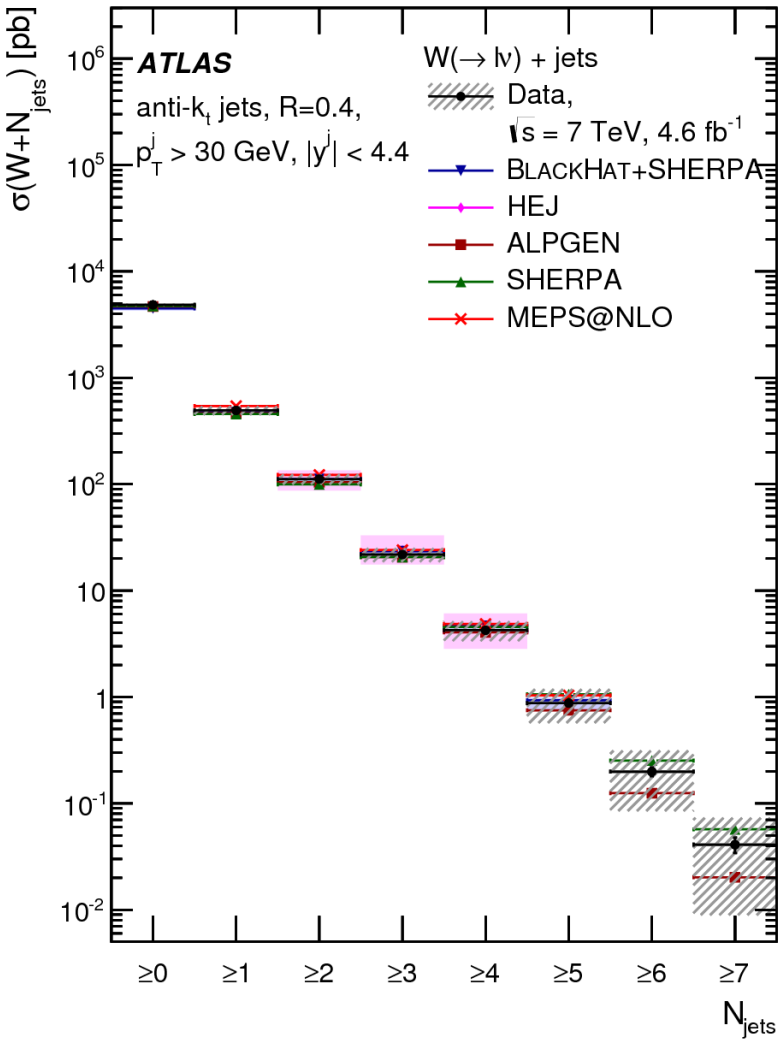


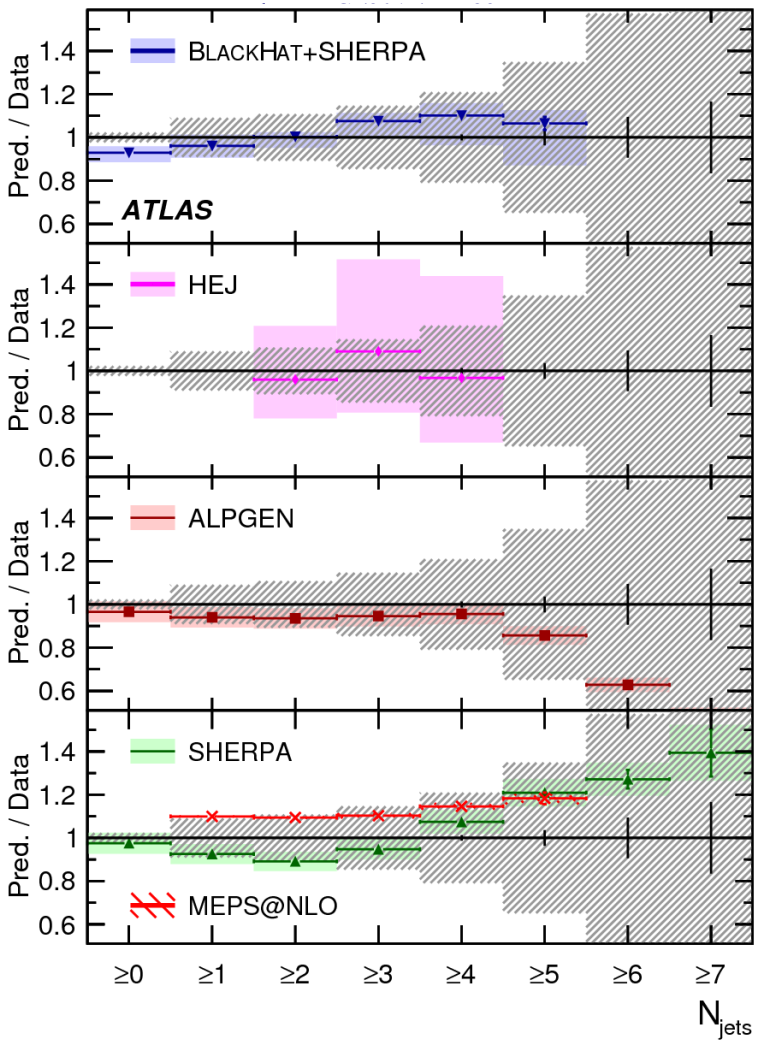
Eur. Phys. J. C (2015) 75:82

Events selected using lepton and etmiss
Jets have pt>30 GeV eta<4.4
Note large top contribution as high multplicity
Top measured from sub-sample requiring b-tag – extrapolated using MC

Jet multiplicity distribution
Excellent theory agreement

W production properties

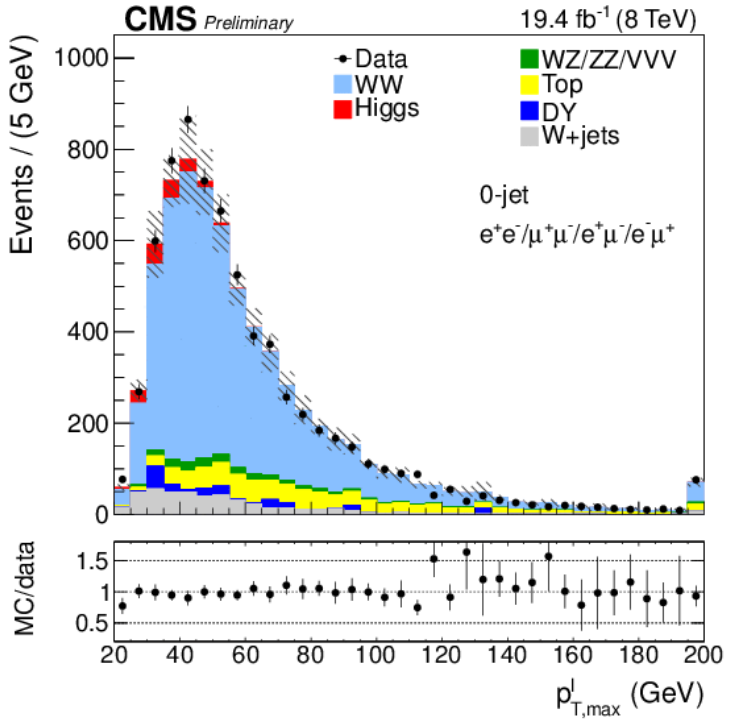


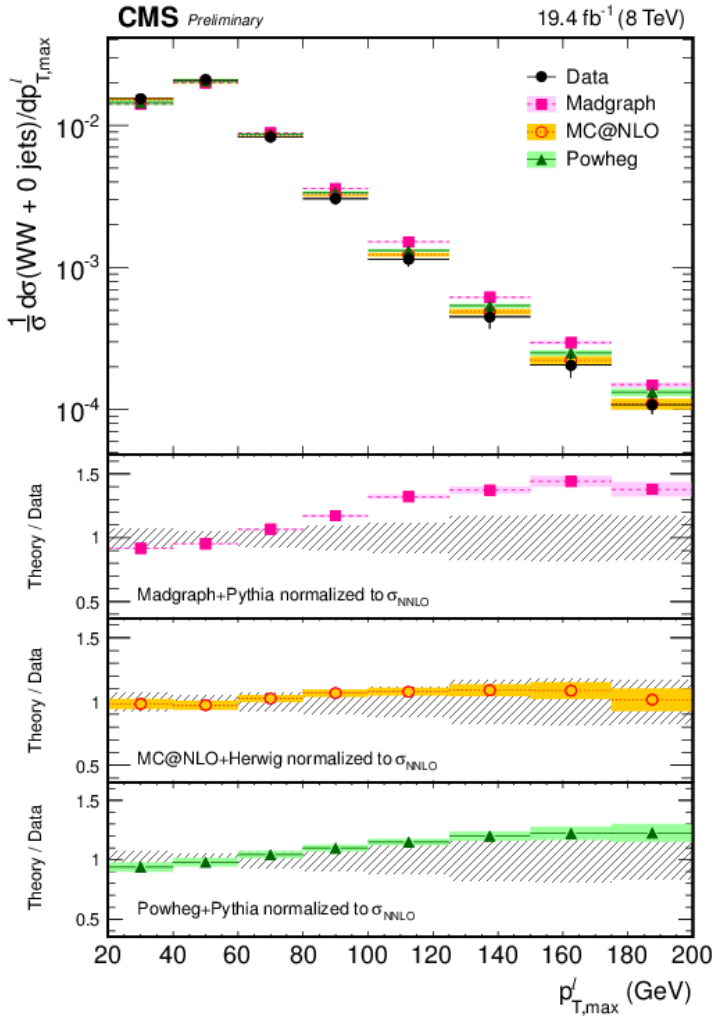


WW production properties

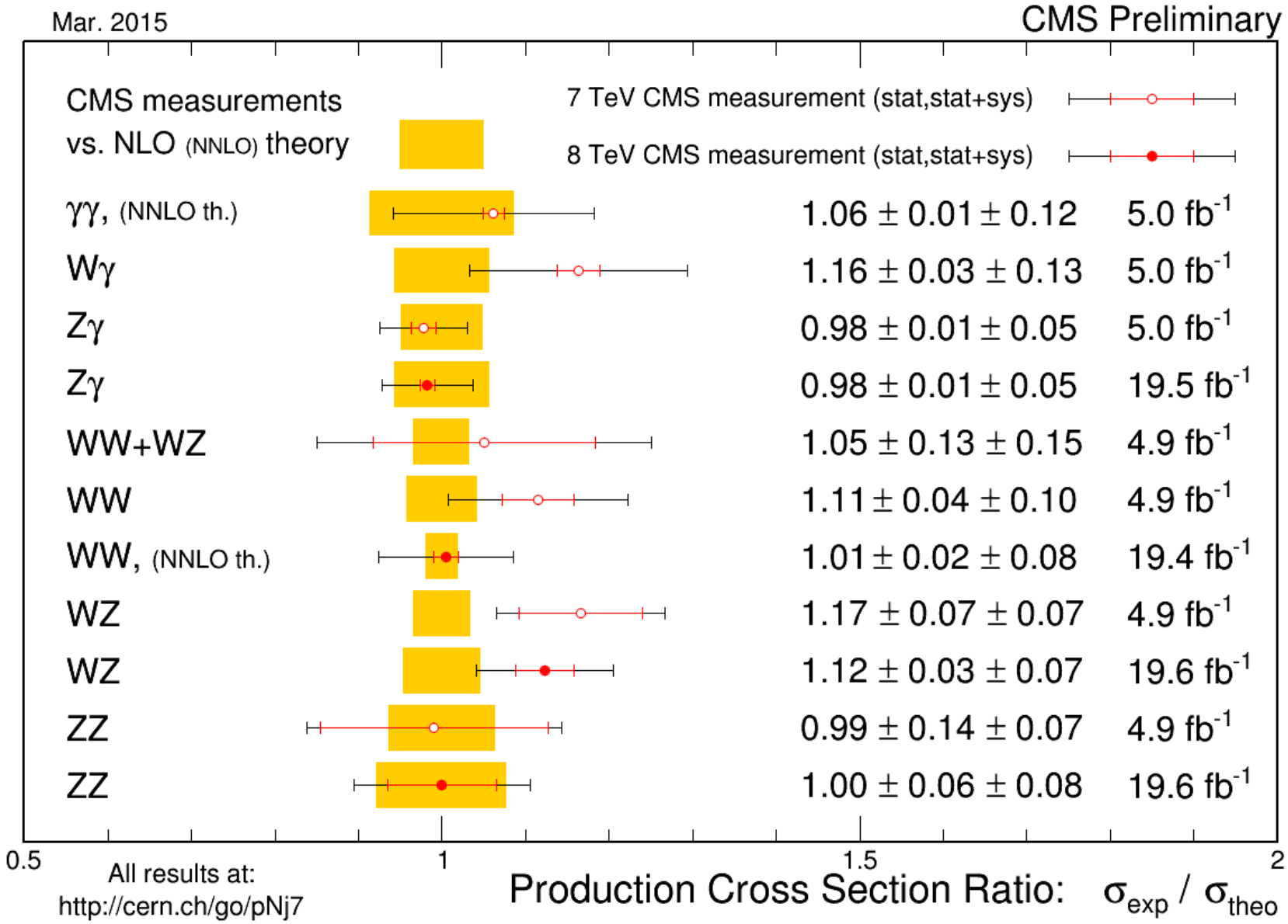
Large background from ttbar
Use 0-jet channel for good S/B
Good agreement at 8TeV with theory

CMS-PAS-SMP-14-016

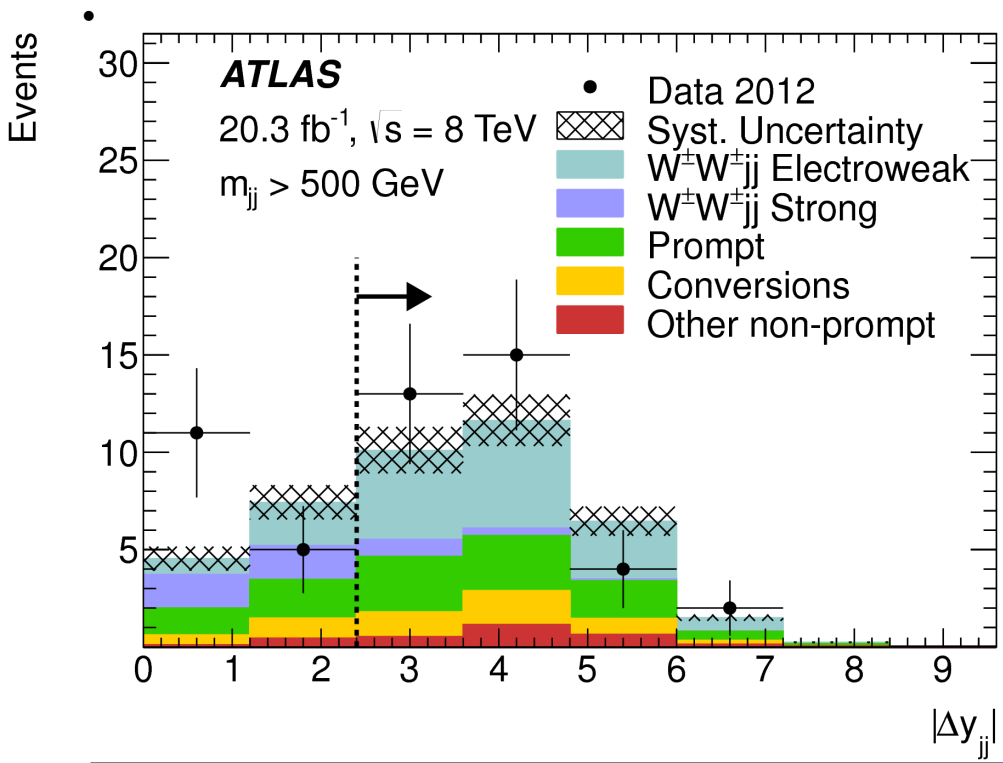




Pair production rates

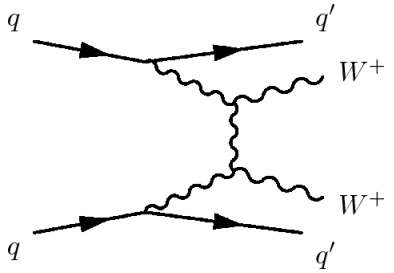


W^+W^+ electro weak production (VBF)



Phys. Rev. Lett. 113, 141803

Rare process
Evidence seen
Forward jets required



	Inclusive Region			VBS Region		
	$e^{\pm}e^{\pm}$	$e^{\pm}\mu^{\pm}$	$\mu^{\pm}\mu^{\pm}$	$e^{\pm}e^{\pm}$	$e^{\pm}\mu^{\pm}$	$\mu^{\pm}\mu^{\pm}$
Prompt	3.0 ± 0.7	6.1 ± 1.3	2.6 ± 0.6	2.2 ± 0.5	4.2 ± 1.0	1.9 ± 0.5
Conversions	3.2 ± 0.7	2.4 ± 0.8	–	2.1 ± 0.5	1.9 ± 0.7	–
Other non-prompt	0.61 ± 0.30	1.9 ± 0.8	0.41 ± 0.22	0.50 ± 0.26	1.5 ± 0.6	0.34 ± 0.19
$W^{\pm}W^{\pm}jj$ Strong	0.89 ± 0.15	2.5 ± 0.4	1.42 ± 0.23	0.25 ± 0.06	0.71 ± 0.14	0.38 ± 0.08
$W^{\pm}W^{\pm}jj$ Electroweak	3.07 ± 0.30	9.0 ± 0.8	4.9 ± 0.5	2.55 ± 0.25	7.3 ± 0.6	4.0 ± 0.4
Total background	6.8 ± 1.2	10.3 ± 2.0	3.0 ± 0.6	5.0 ± 0.9	8.3 ± 1.6	2.6 ± 0.5
Total predicted	10.7 ± 1.4	21.7 ± 2.6	9.3 ± 1.0	7.6 ± 1.0	15.6 ± 2.0	6.6 ± 0.8
Data	12	26	12	6	18	10

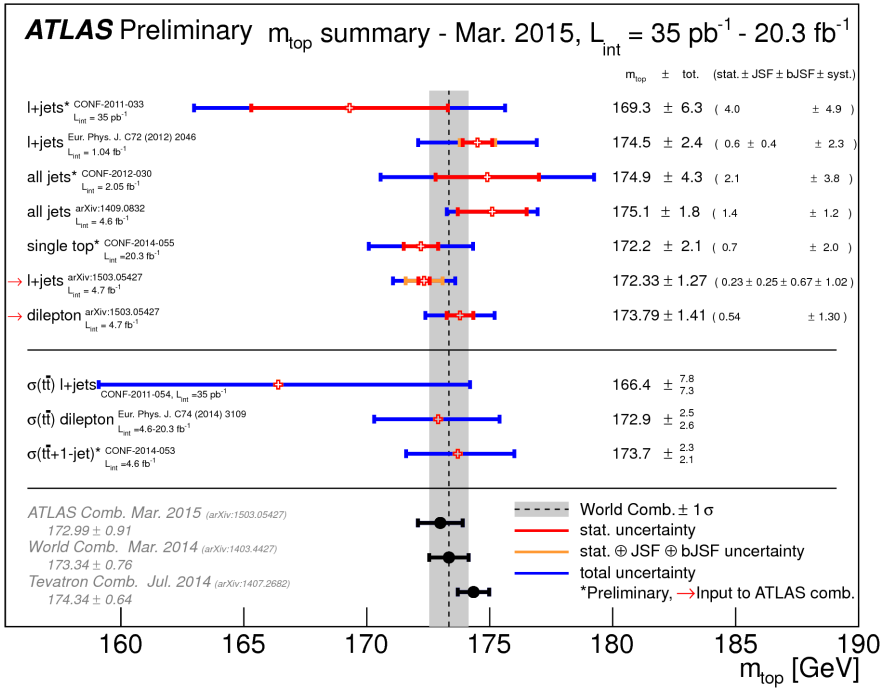
See also CMS
arXiv:1410.6315

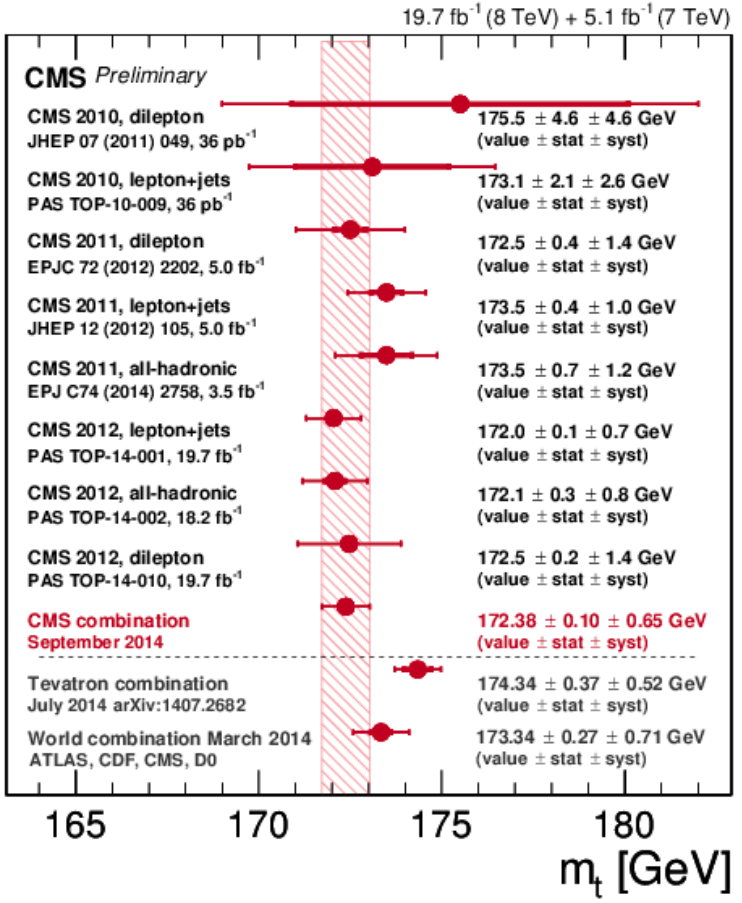
Standard Model at ATLAS and CMS

- Higgs
  - Mass
  - Couplings
  - production
- W/Z production
- Gauge boson pairs
  - QCD production
  - Electroweak production (VBF)
- **Top mass and production**
- QCD
-

Top mass

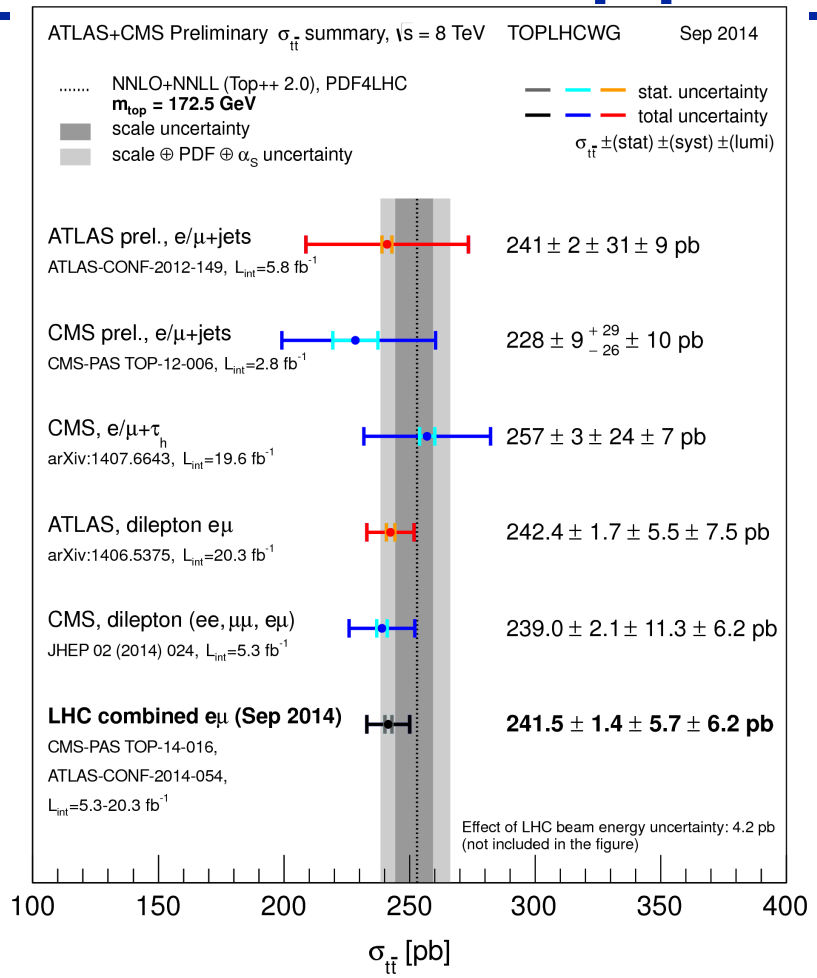
- Measurements from many channels
  - All jet
  - Lepton +jet
  - Dilepton
- Systematics important
  - "What is top mass?"
    - Theory problem



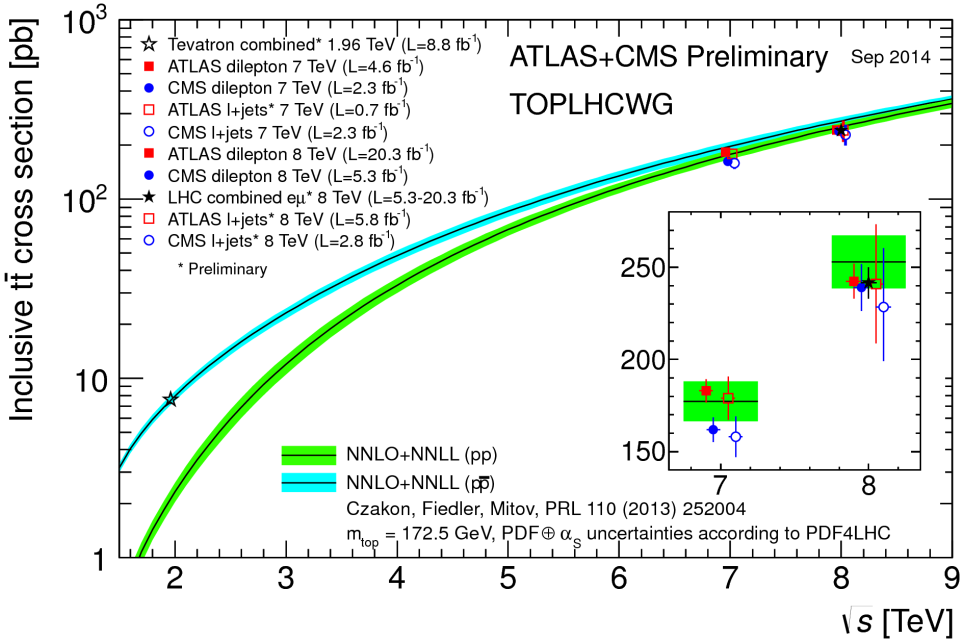


Jet energy scale dominates systematics

Top production



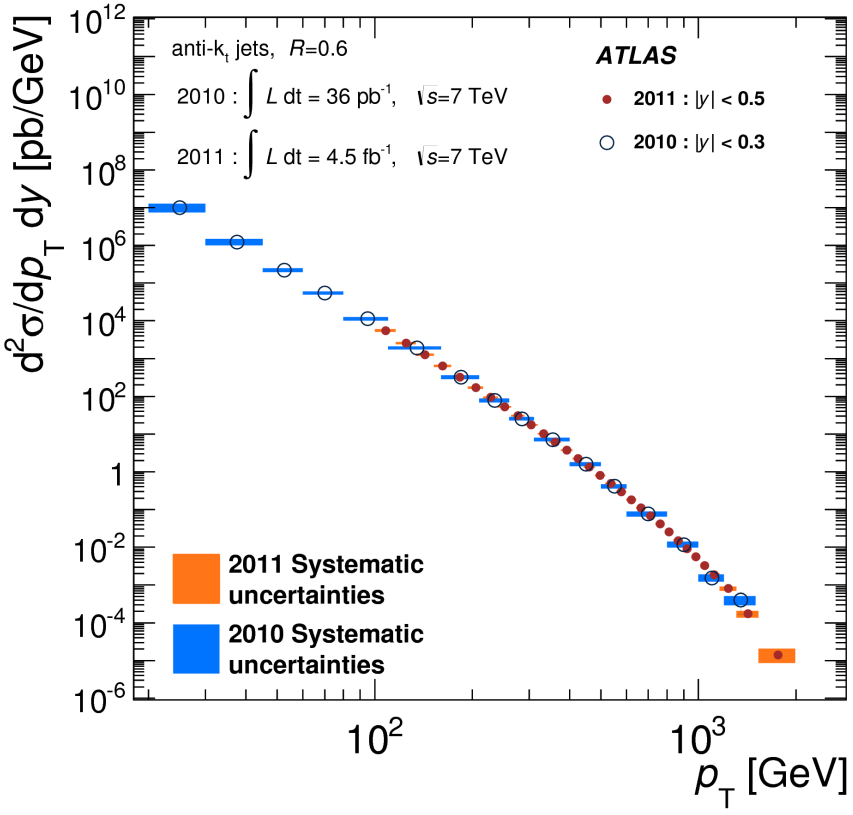
Measured in several final states
Well described by QCD

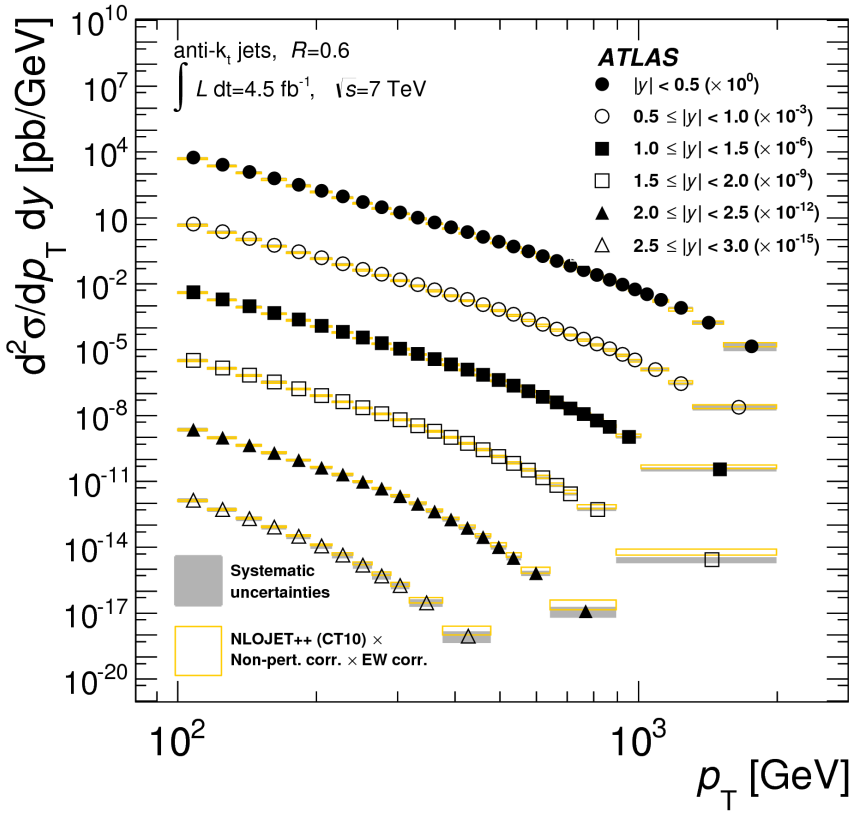


Standard Model at ATLAS and CMS

- Higgs
  - Mass
  - Couplings
  - production
- W/Z production
- Gauge boson pairs
  - QCD production
  - Electroweak production (VBF)
- Top mass and production
- QCD

QCD jets:inclusive





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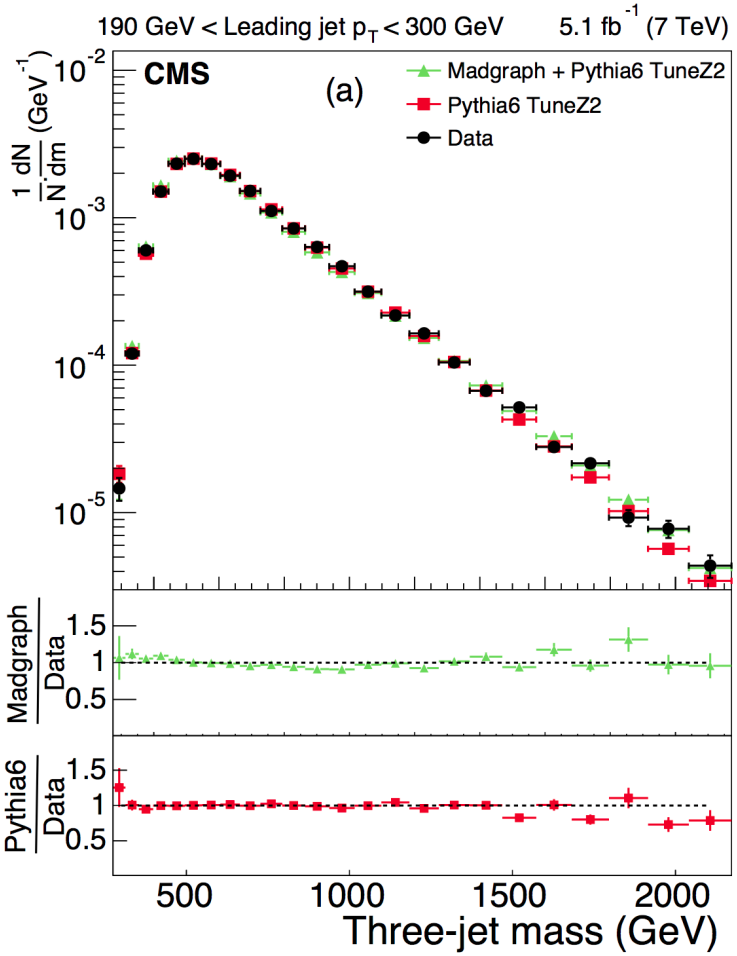
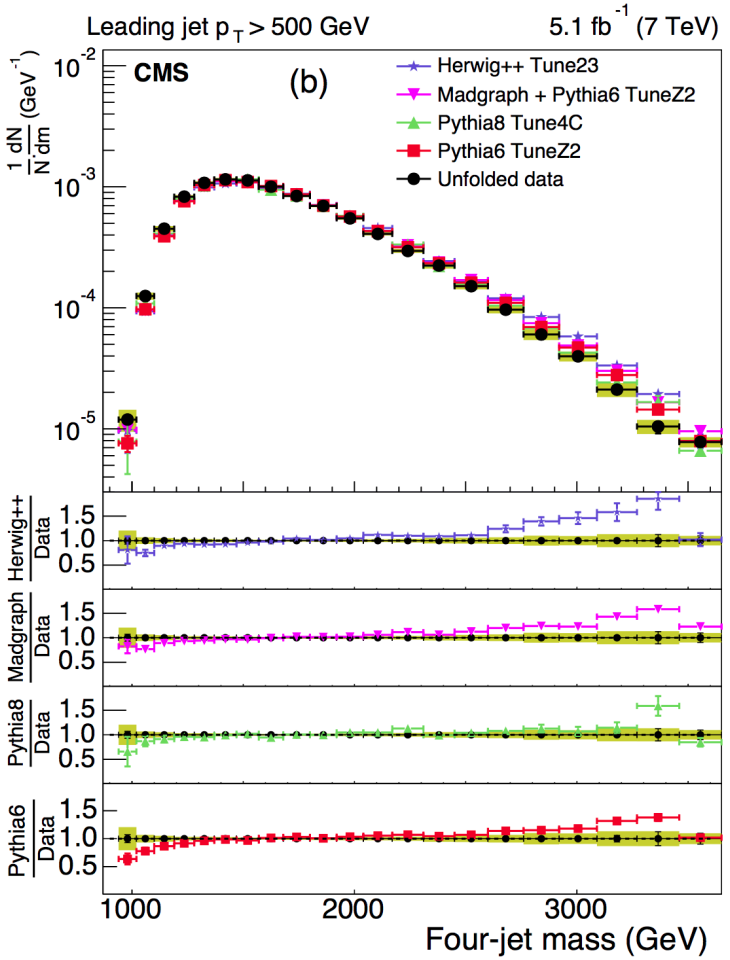
Theory agrees over 12 orders of magnitude

QCD multi-jets: mass distributions





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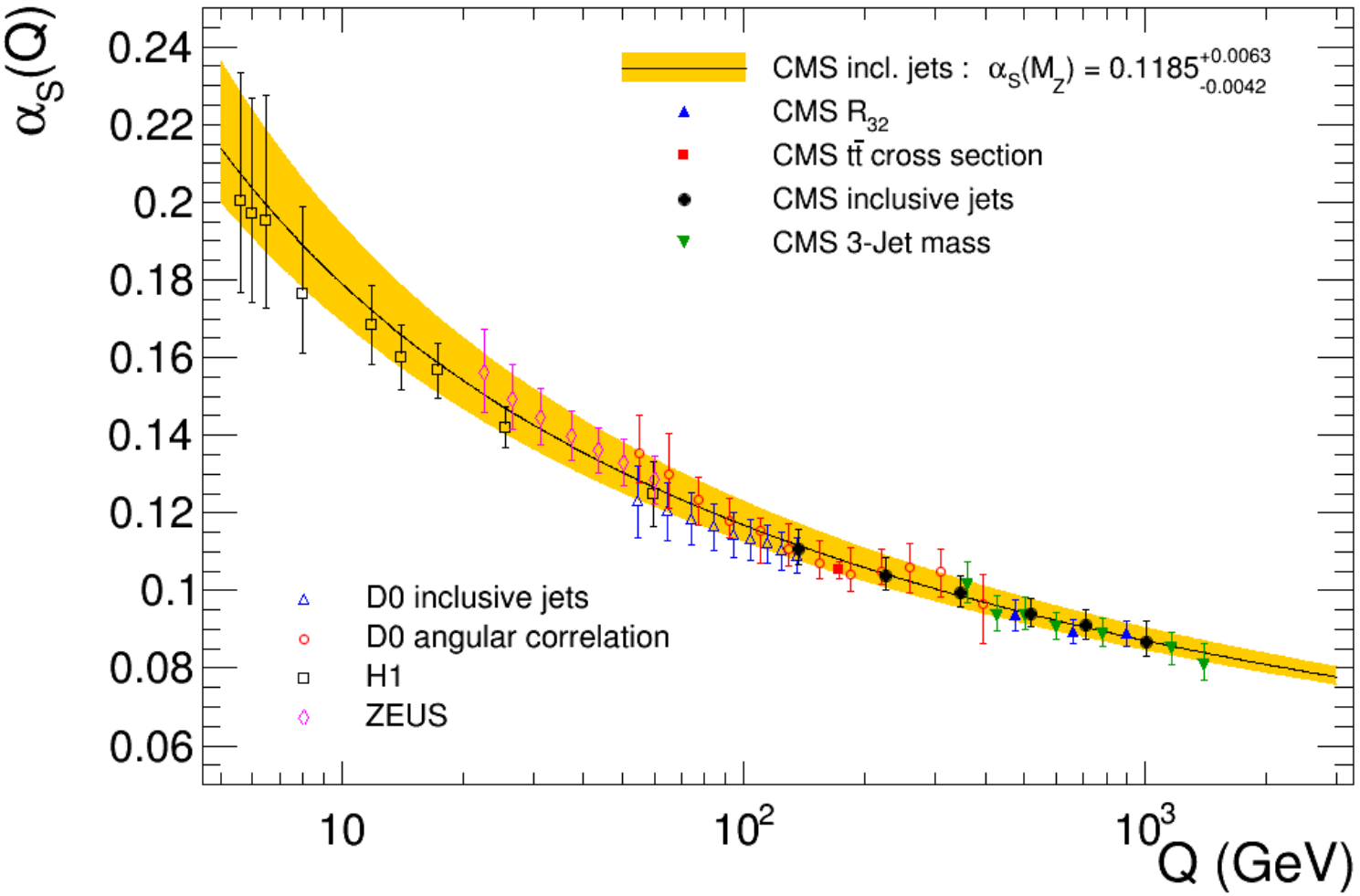
QCD coupling from rates

- QCD processes depend on α_s
- Given sufficiently precise data and controlled theory systematic errors
  - PDF N^{n}LO etc
- Λ extracted and running tested as several scale are involved



53

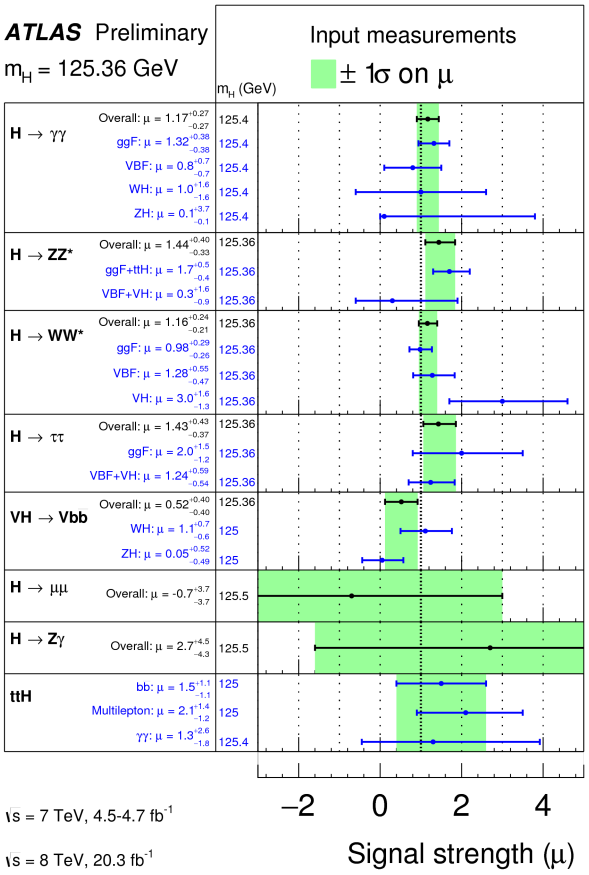
Summary

-
- Higgs has mass 125.09+/- 0.24 GeV
- All expected modes seen at correct rate
  - Looks like SM Higgs
  - More precision with Run 2
- QCD modeling works exceptionally well
  - Many processes
  - Large multiplicities
  - Great confidence in a priori background estimates
    - Even if they are not used!
-

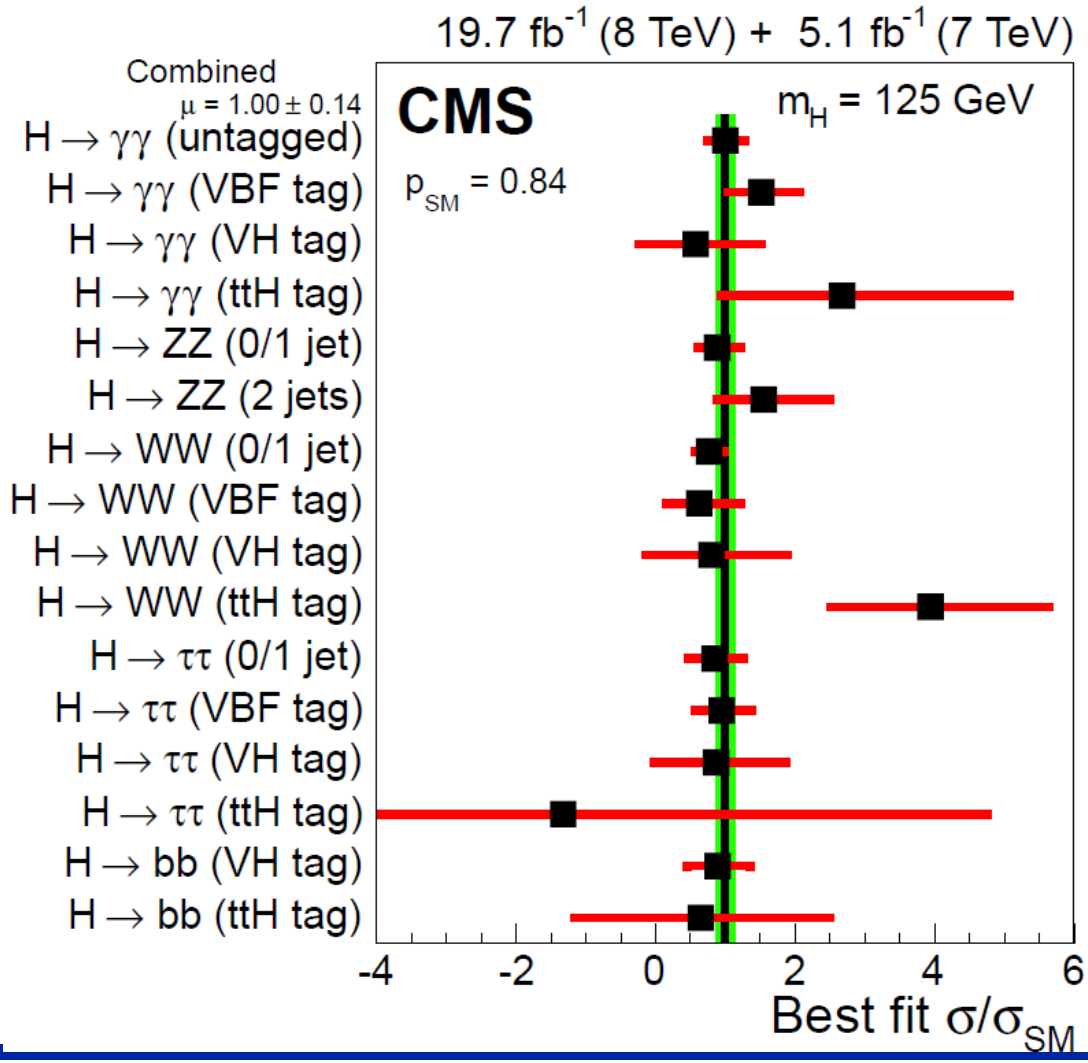
Backup

Higgs coupling Summary

ATLAS-CONF-2015-007



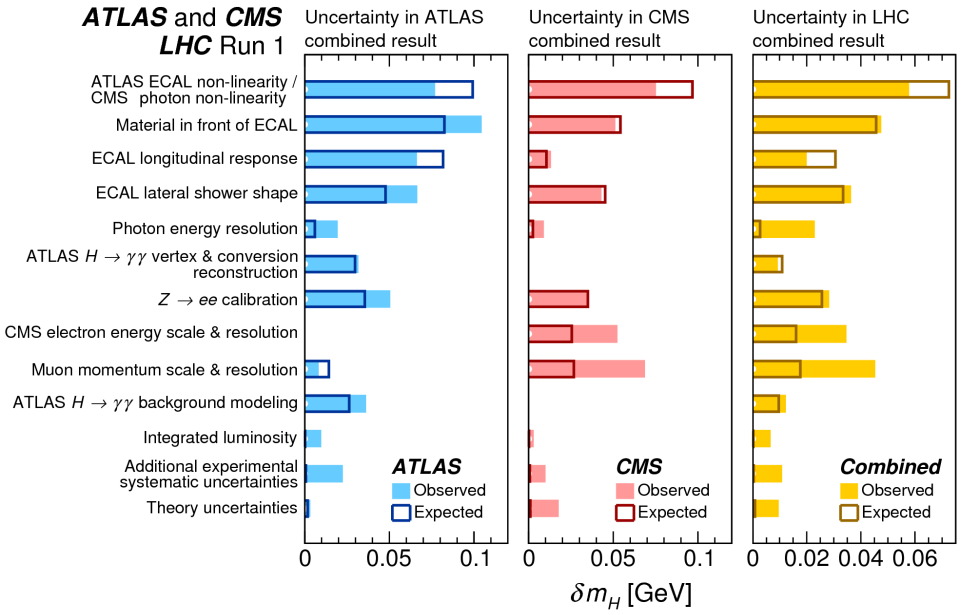
ArXiv:1412:8662

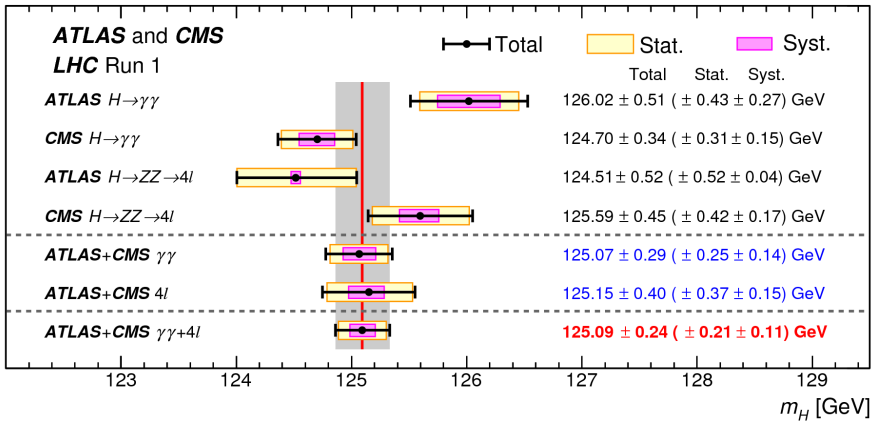


Higgs mass

- **Combined mass**
  - **125.09 +/- 0.24 GeV**
    - **Statistical uncertainty dominates: 0.21 vs 0.11 systematic**
    - **Can therefore expect smaller uncertainty in Run 2**
  - **Some tension within experiments**
  - **Overall consistency good: overall compatibility ~10%: No evidence for more than one particle.**

arXiv:1503.07589





Higgs coupIng to b-bbar

- **Associated ZH and WH used**
- **Multivariate method used to optimize**
- **Several channels combined**

arXiv:1503.07589