Status of the LHC experiments and Standard Model results

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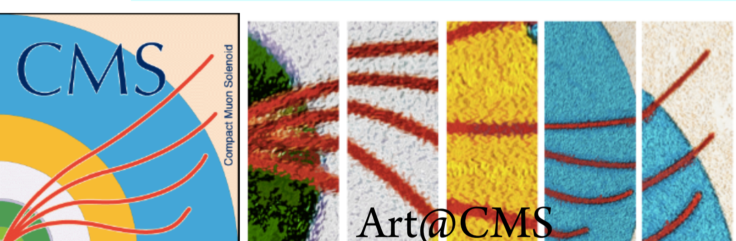
STARS2015 – 3° Caribbean Symposium on Cosmology, Gravitation, Nuclear and Astroparticle Physics

SMFNS2015 – 4° International Symposium on Strong Electromagnetic Fields and Neutron Stars

CUBA - May 10-16, 2015

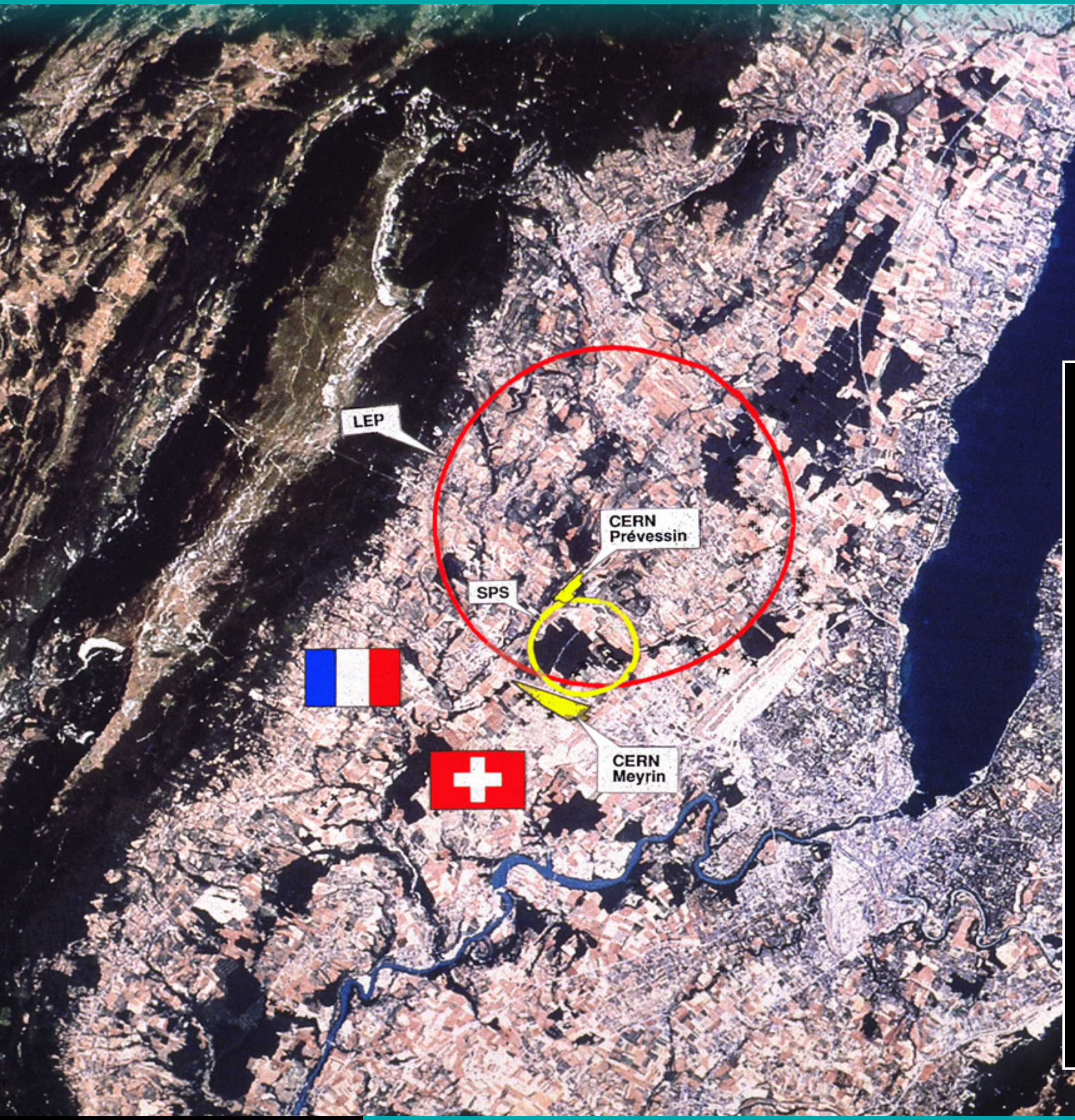


Outline

- **The first period of data taking at LHC**
- **Standard Model**
  - **Higgs boson discovery**
  - **W and Z boson physics**
  - **Top quark physics**
  - **Heavy Flavours: b and c physics**
  - **QCD highlights**
- **Conclusions and prospectives**

The Large Hadron Collider

The Large Hadron Collider is a 27 km long pp collider ring housed in a tunnel about 100 m underground near Geneva



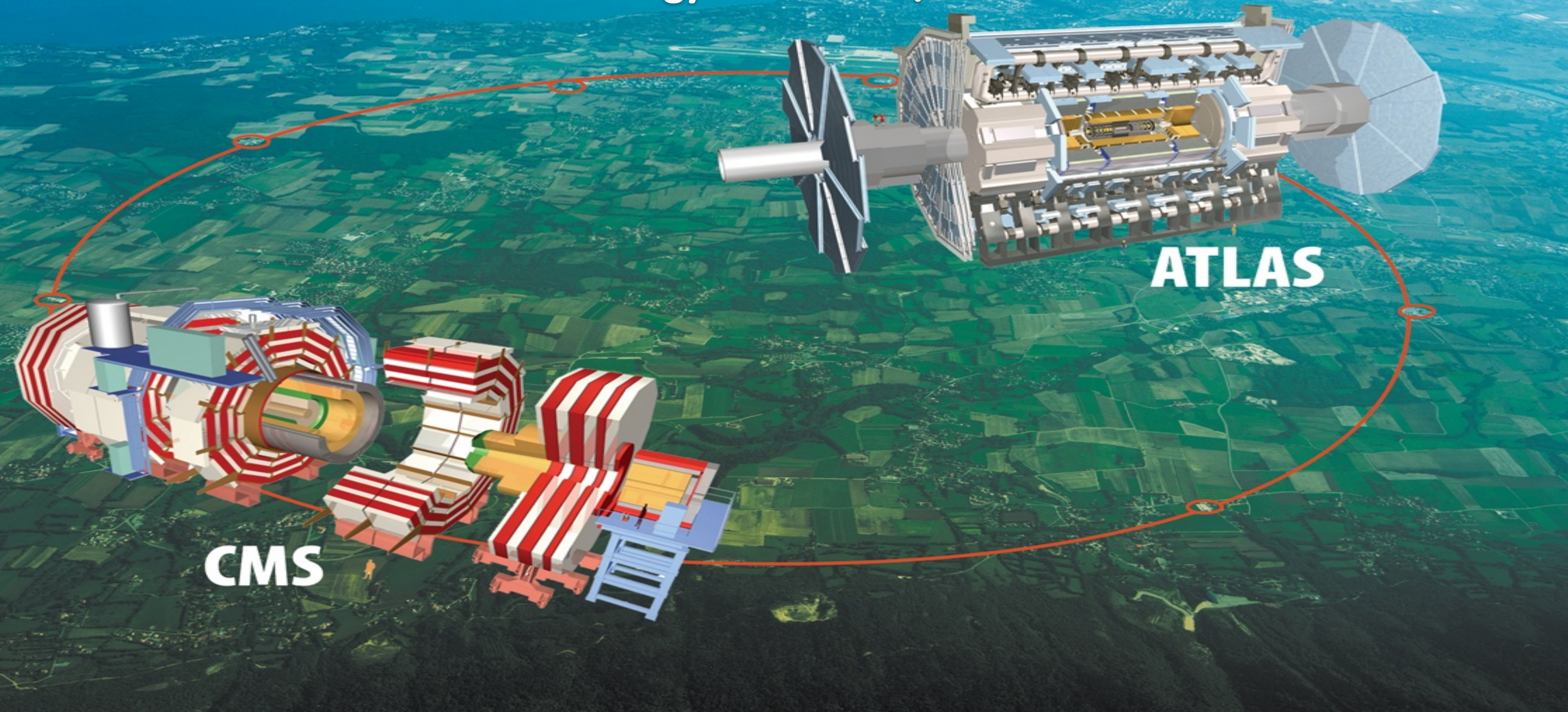
- Diameter 8.5 km
- Beam energy: 7 TeV
- Luminosity: 10^{34}
- Protons/bunch: 1.15×10^{11}
- Bunches: 2808
- Bunch spacing: 25 ns
- Machine current: 0.5 A
- Beam Stored energy: 362 MJ
- Operating temperature: 1.9 K
- Number of magnets: ~9300
- Magnet Stored Energy 8800 MJ
- Power consumption: ~120 MW
- Cost: 9.0×10^9 $

The LHC collider

Two general purpose detectors, designed to search for the Higgs Boson

The Large Hadron Collider (LHC), one of the largest and truly global scientific projects ever

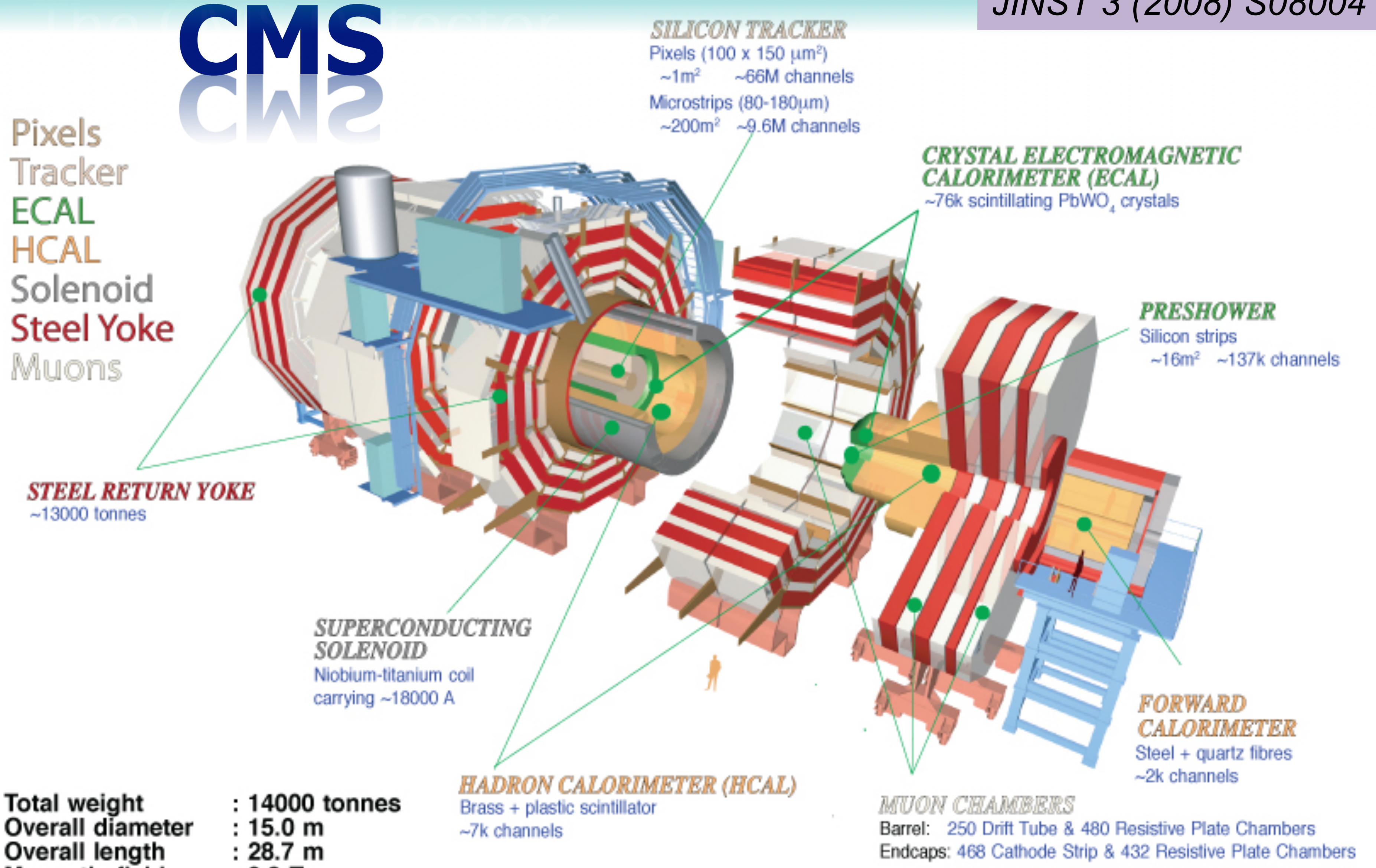
- pp collisions at a centre of mass energy of 7, 8 and 13 TeV
- PbPb collisions at a centre of mass energy of 2.76 TeV/nucleon



The CMS Detector

http://cms.web.cern.ch/

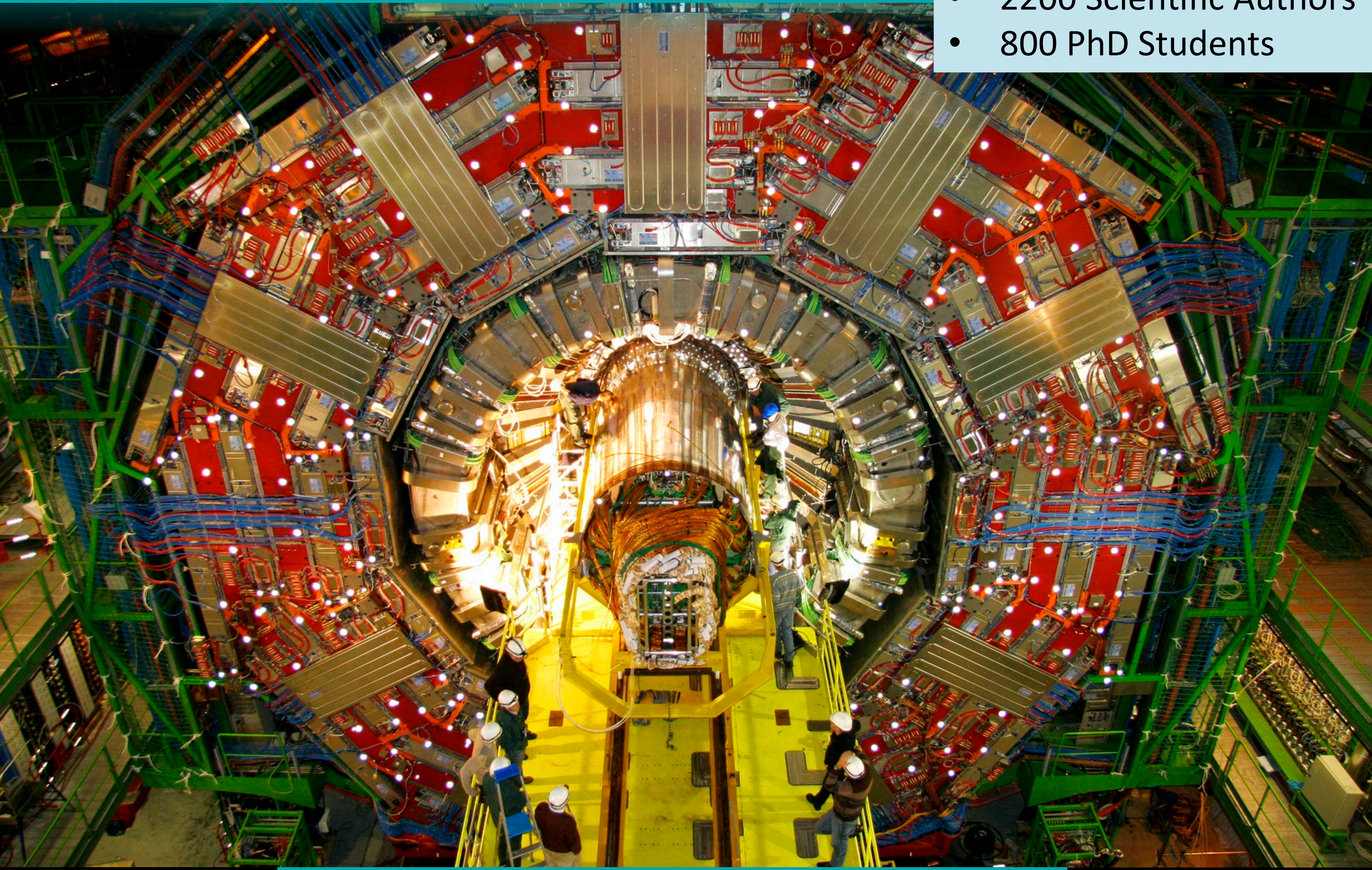
JINST 3 (2008) S08004



Total weight	**: 14000 tonnes**
Overall diameter	**: 15.0 m**
Overall length	**: 28.7 m**
Magnetic field	**: 3.8 T**

The CMS collaboration

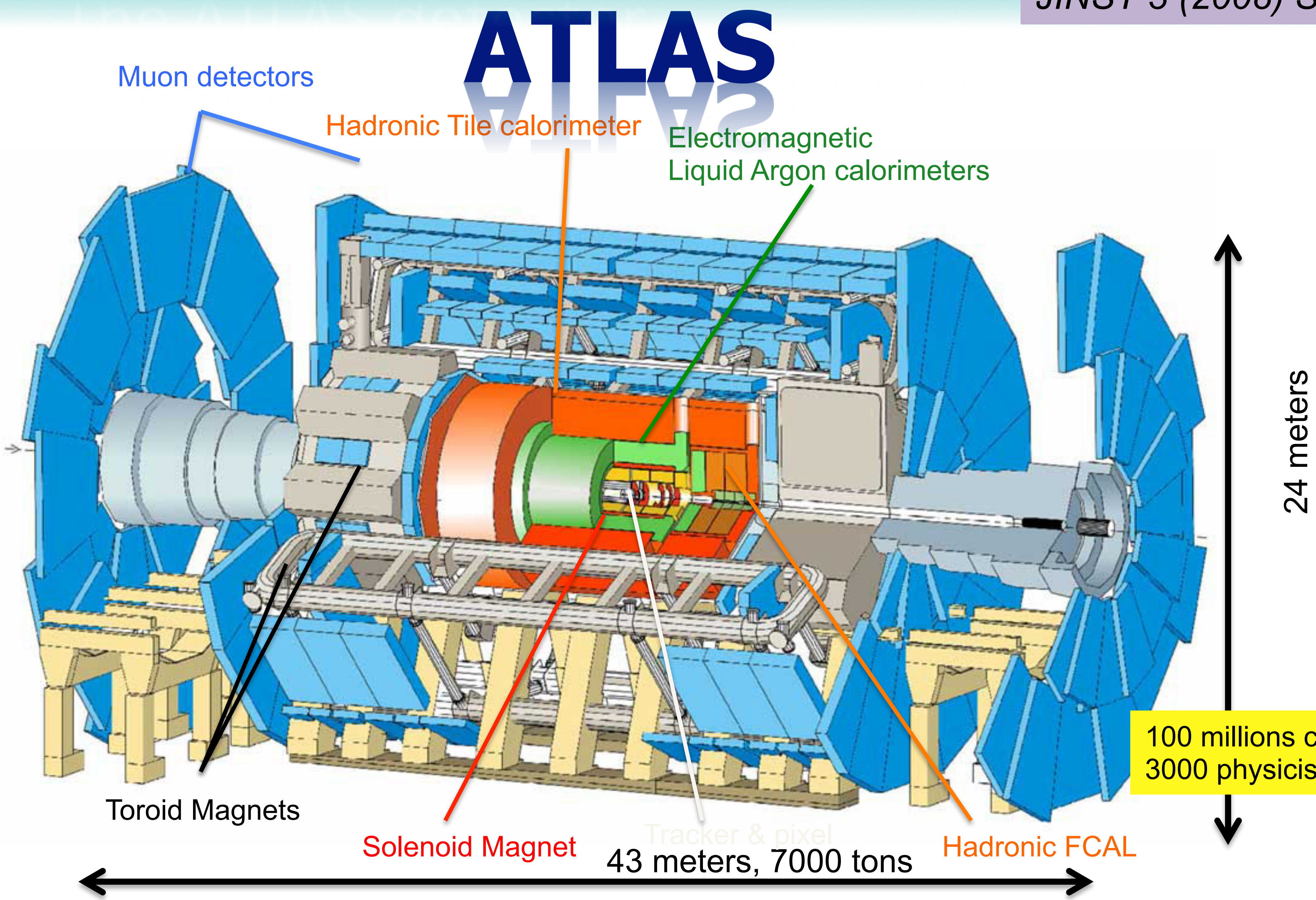
- 42 Countries
- 190 Institutions
- 2200 Scientific Authors
- 800 PhD Students



The ATLAS detector

http://atlas.web.cern.ch/

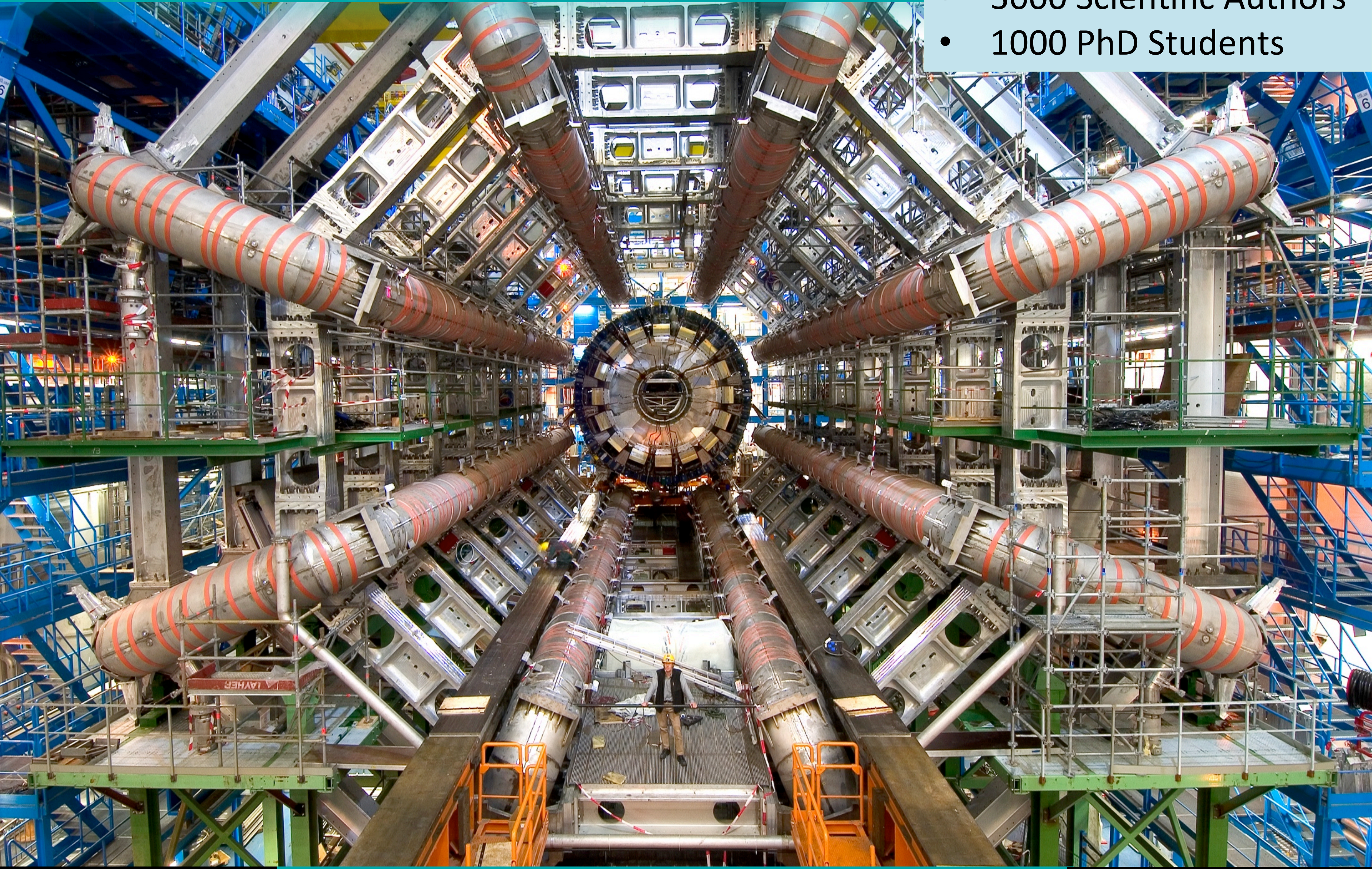
JINST 3 (2008) S08003



100 millions channels,
3000 physicists

The ATLAS collaboration

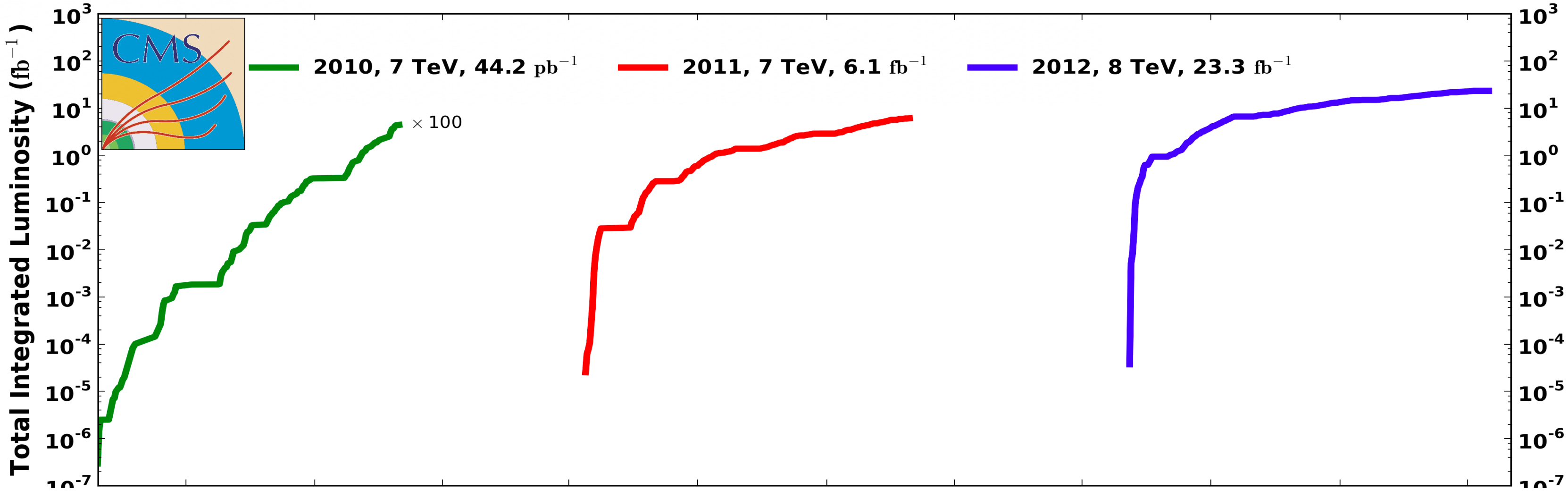
- 38 Countries
- 177 Institutions
- 3000 Scientific Authors
- 1000 PhD Students



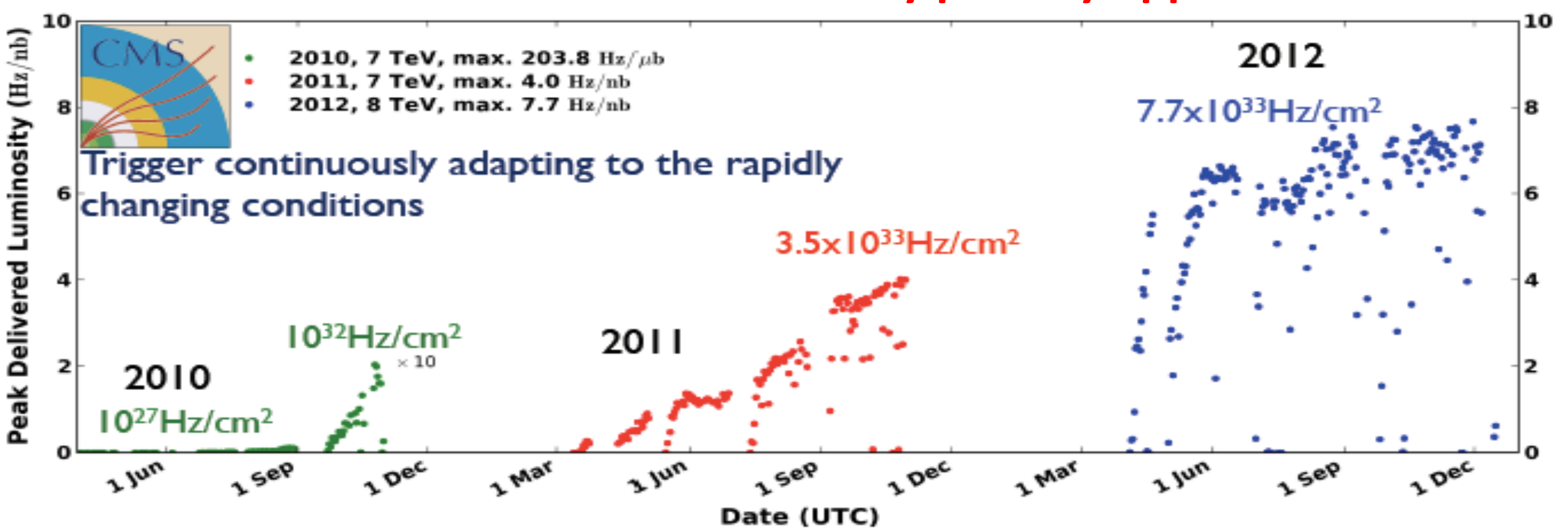
Three very successful years

Fantastic LHC performance!

CMS Integrated Luminosity per Day - pp

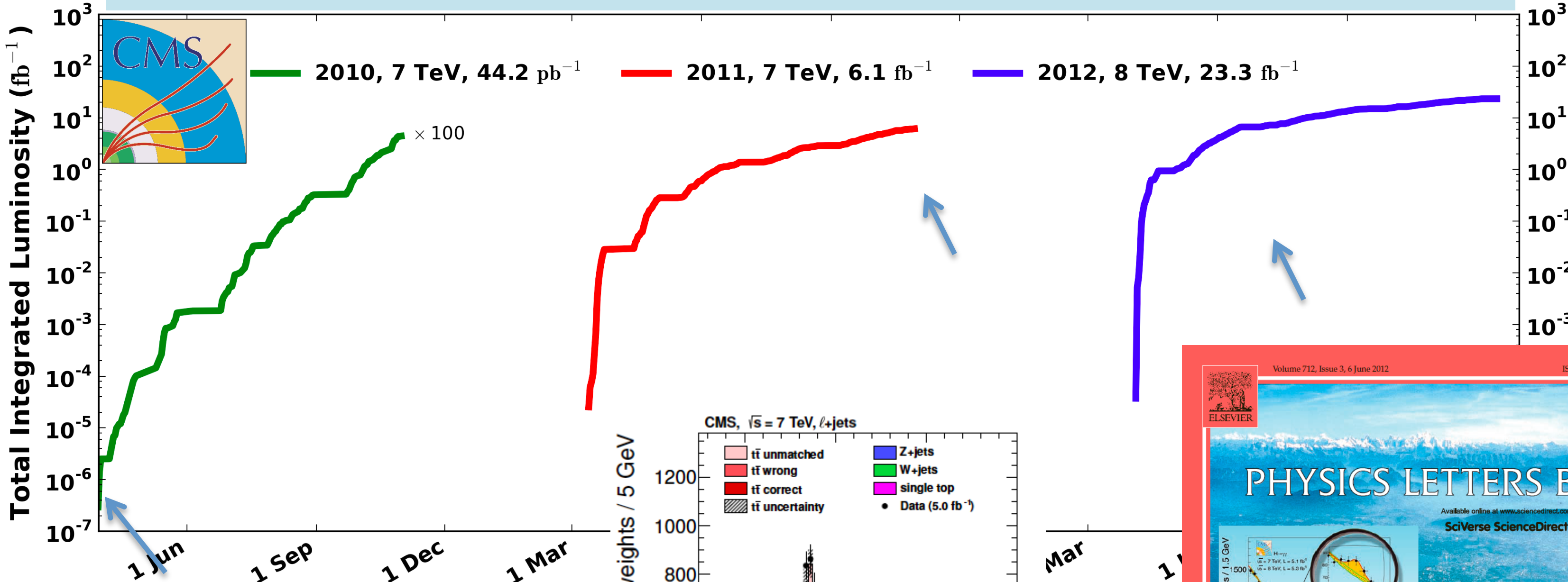


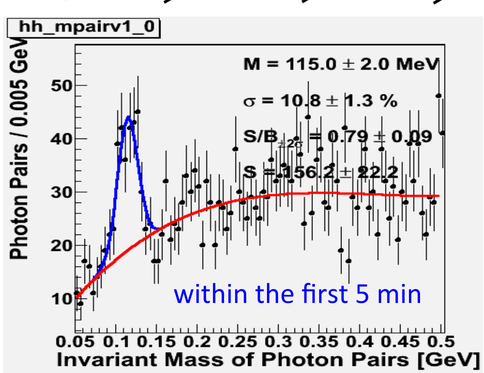
CMS Peak Luminosity per Day - pp

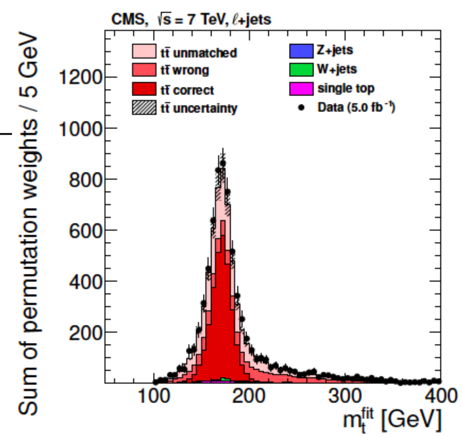


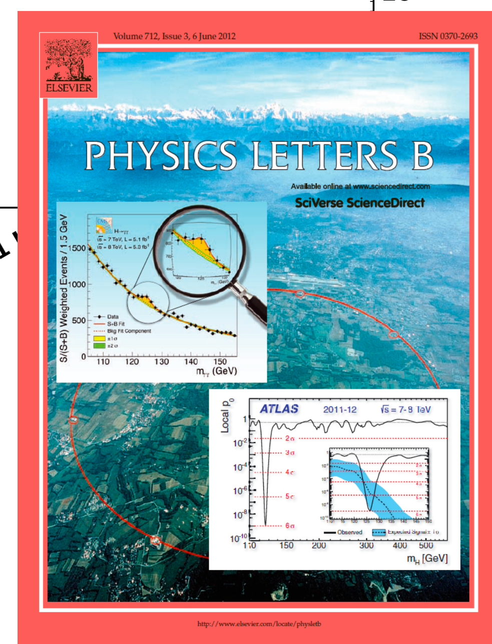
Three very successful years

From the first $\pi^0 \rightarrow \gamma\gamma$ reconstructed with the first LHC interactions, to precision SM measurements, to the first discovery…









Run1 pp data taking

Total $\mathcal{L}_{int}$(pp) ~ 30 fb^{-1}

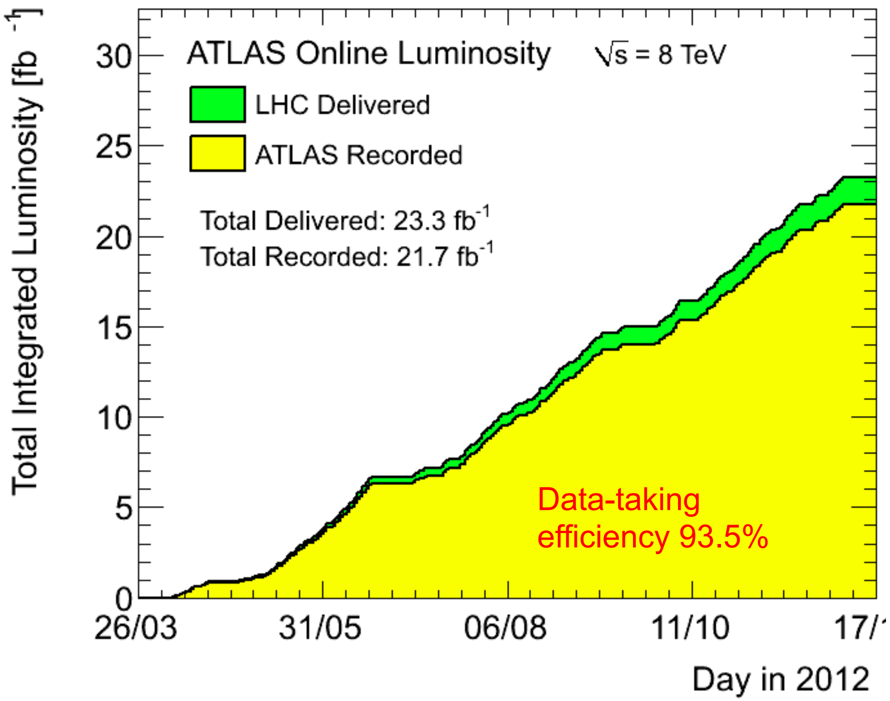
@7 TeV ~ 5 fb^{-1}

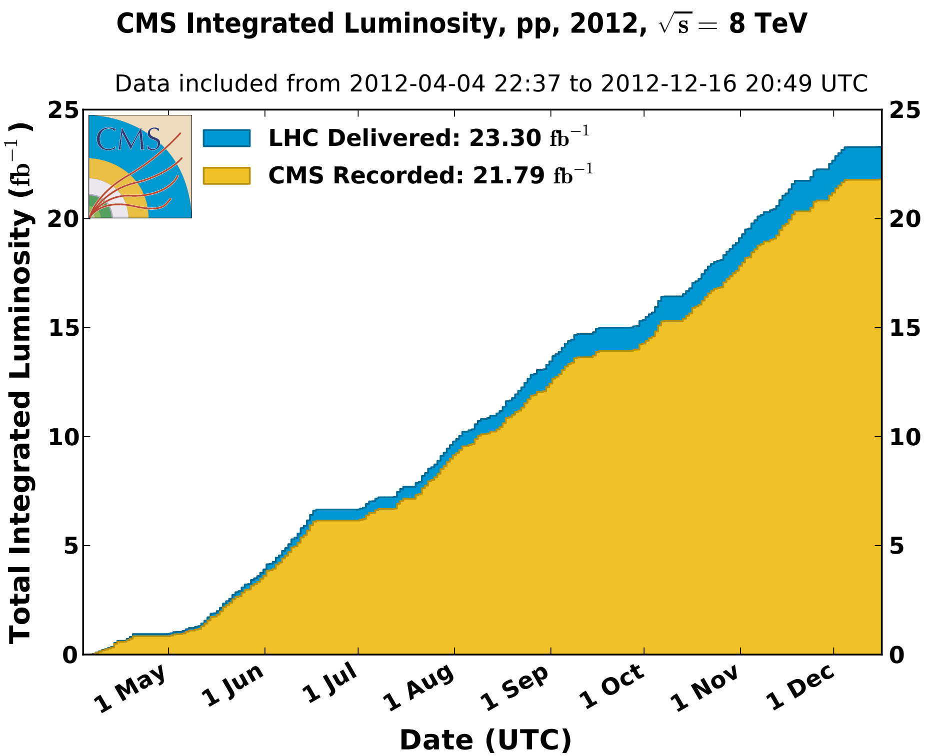
@8 TeV ~ 22 fb^{-1}

Excellent detectors performance:

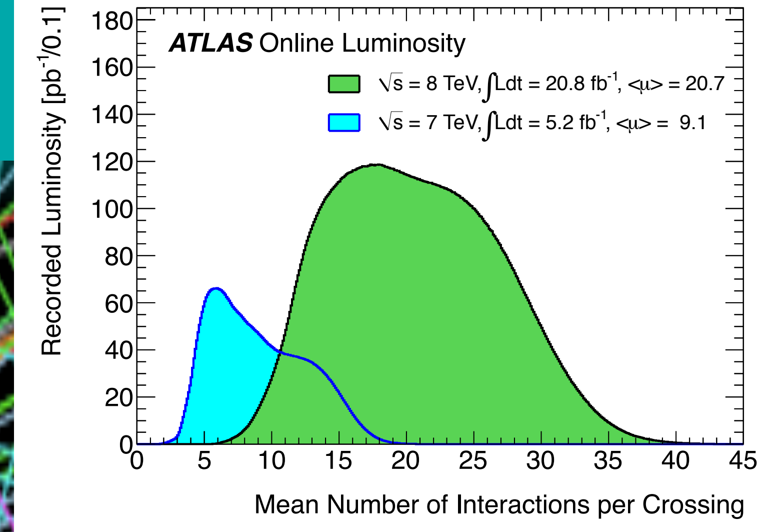
✓ Operational efficiency ~ 96%

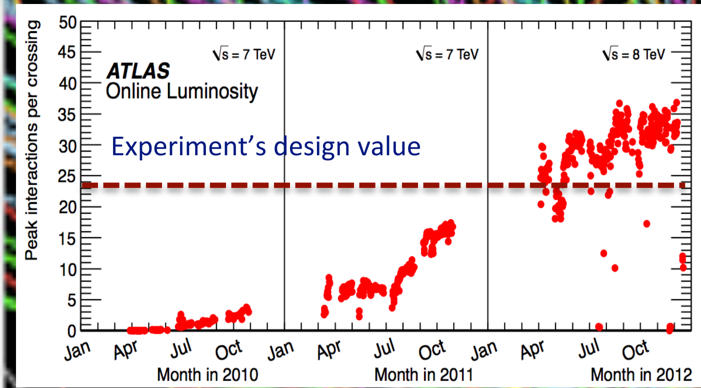
✓ High reconstruction efficiency also in presence of large pileup

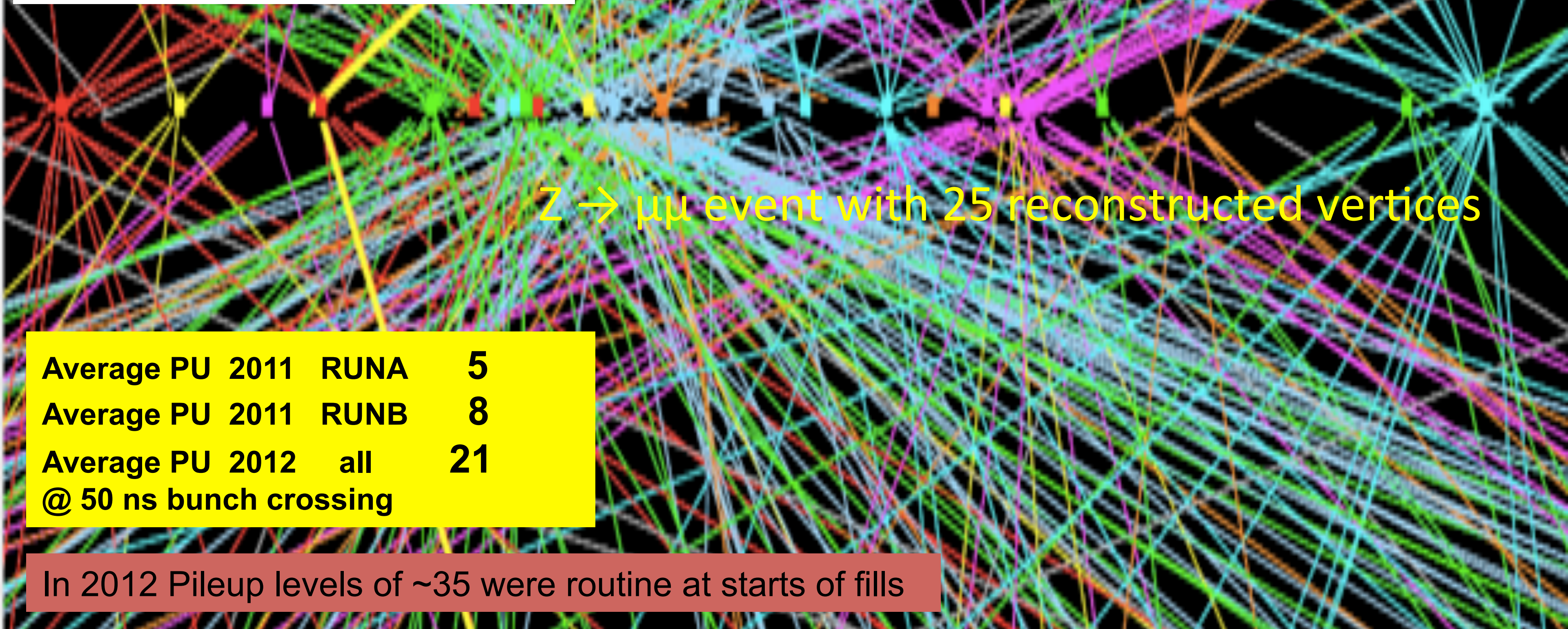




Pileup challenge



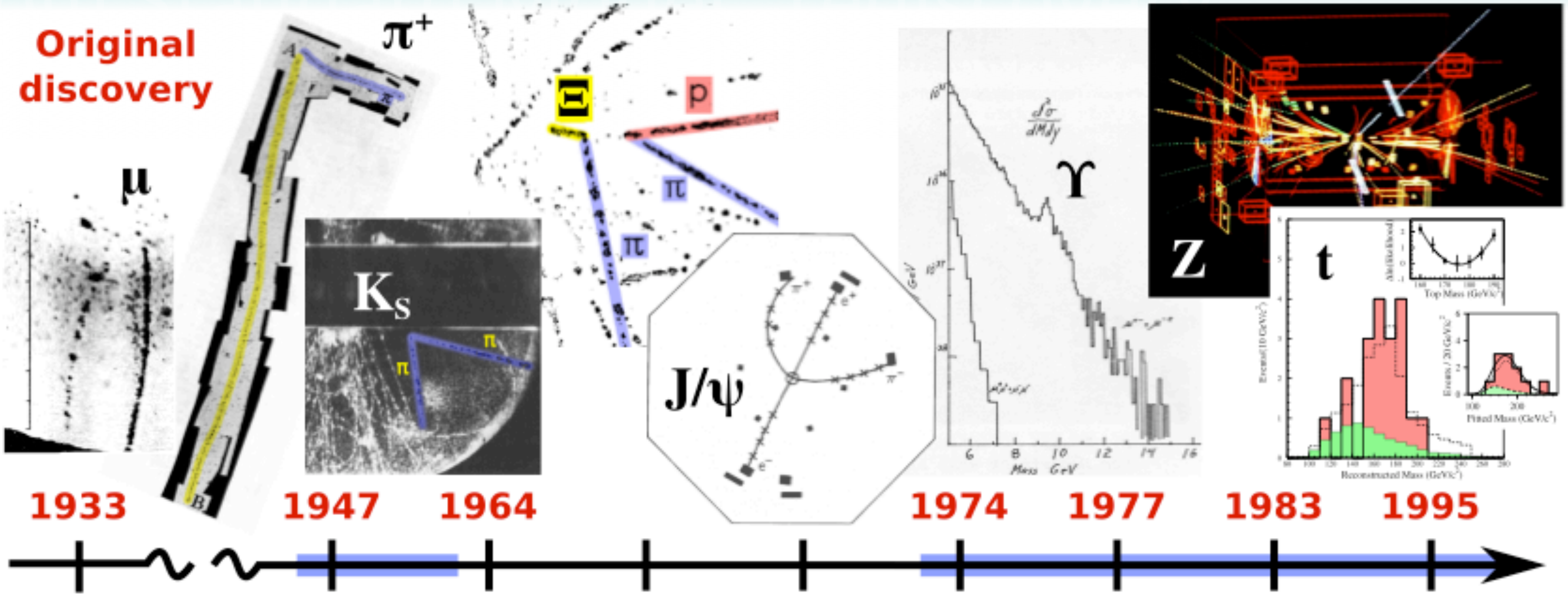




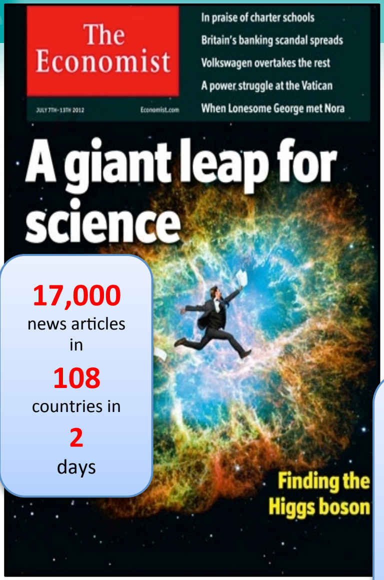
Average PU 2011 RUNA 5
Average PU 2011 RUNB 8
Average PU 2012 all 21
@ 50 ns bunch crossing

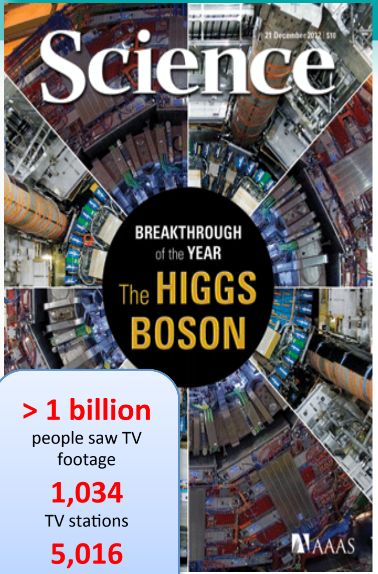
In 2012 Pileup levels of ~35 were routine at starts of fills

From Standard Model "rediscovery"…



… to Higgs Boson discovery…





17,000 news articles in **108** countries in **2** days

> 1 billion people saw TV footage

1,034 TV stations

5,016 Broadcasts

July 4rth 2012 @ CERN

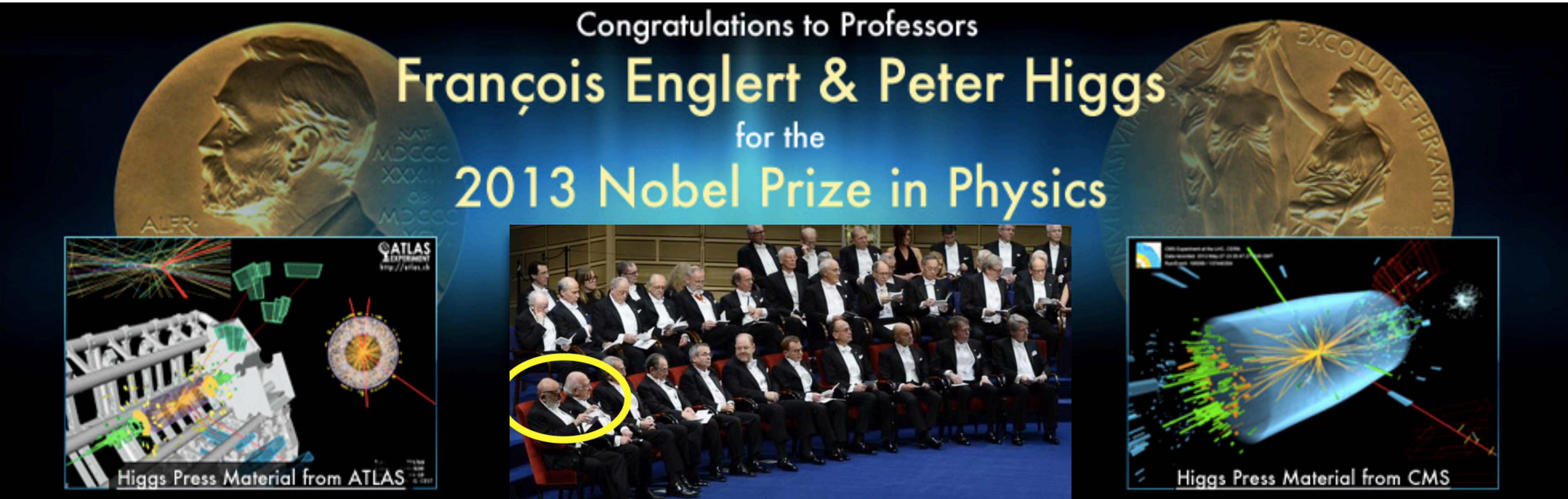
…and 2013 Nobel Prize in Physics

The Royal Swedish Academy of Sciences has decided to award the Nobel Prize in Physics for 2013 to

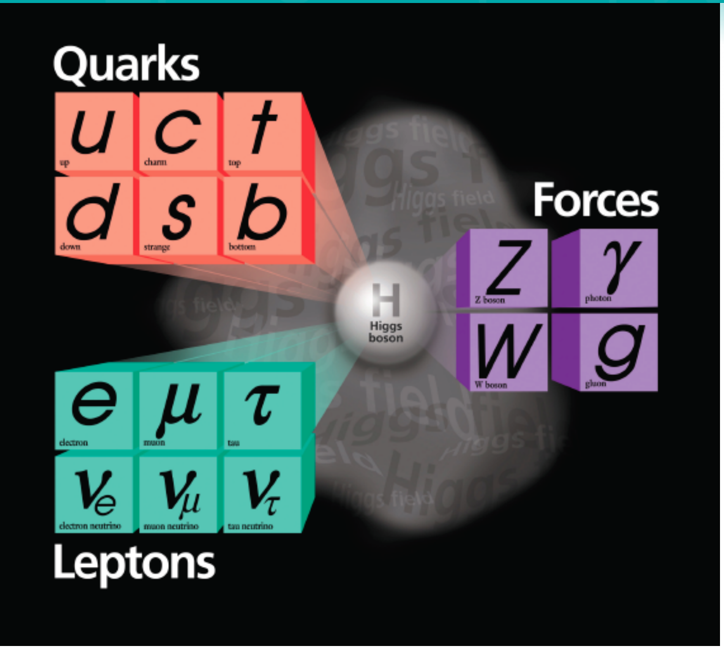
François Englert
Université Libre de Bruxelles, Brussels, Belgium

Peter W. Higgs
University of Edinburgh, UK

"for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's Large Hadron Collider"



The Standard Model of Particle Physics

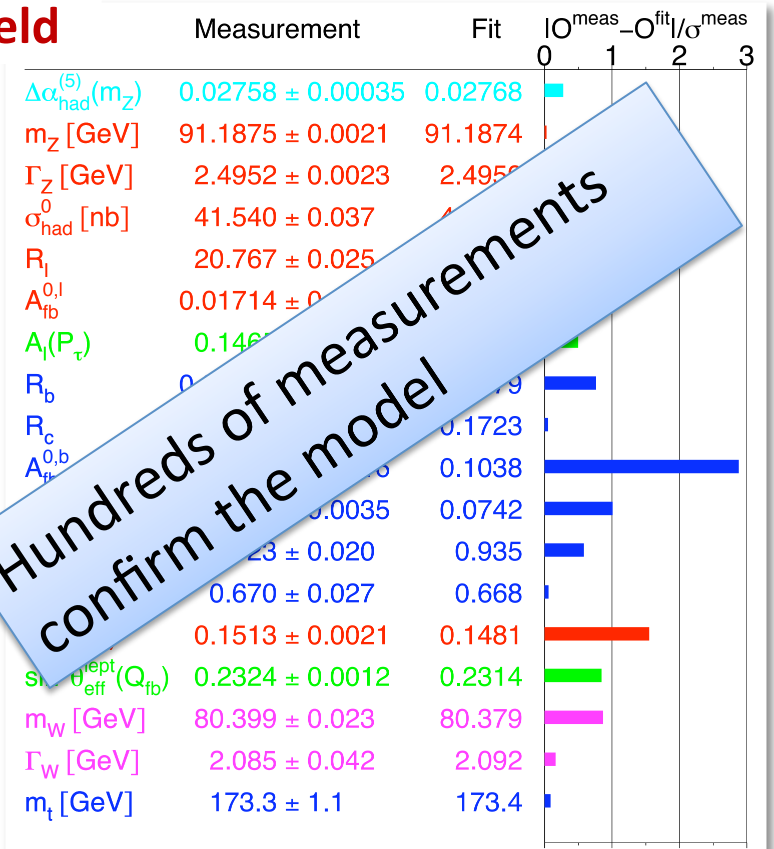


A sort of periodic table of fundamental particles:

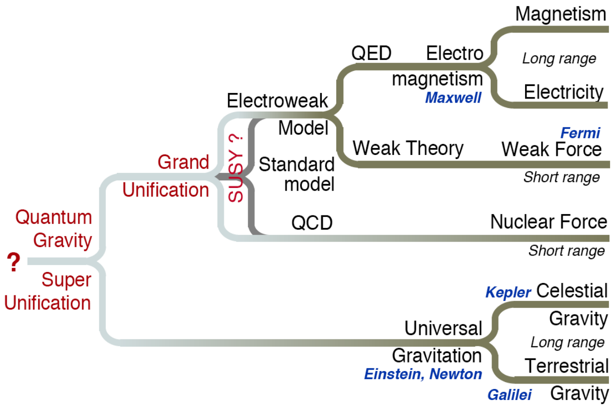
(i) Constituents of matter: quarks and leptons

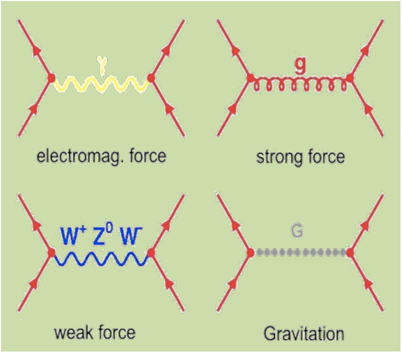
(ii) Four fundamental forces (described by quantum field theories, except gravitation)

(iii) The Higgs field

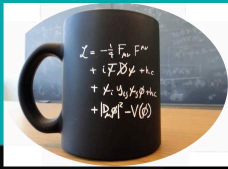


Unification of forces





The Standard Model of Particle Physics



$\mathcal{L}_{SM} =$

$$-\frac{1}{2}\partial_\nu g^a_\mu \partial_\nu g^a_\mu - g_s f^{abc}\partial_\mu g^a_\nu g^b_\mu g^c_\nu - \frac{1}{4} g_s^2 f^{abc} f^{ade} g^b_\mu g^c_\nu g^d_\mu g^e_\nu + \frac{1}{2} i g_s^2 (\bar{q}^\sigma_i \gamma^\mu q^\sigma_j) g^a_\mu + \bar{G}^a \partial^2 G^a + g_s f^{abc}\partial_\mu \bar{G}^a G^b g^c_\mu$$

$$-\partial_\nu W^+_\mu \partial_\nu W^-_\mu - M^2 W^+_\mu W^-_\mu - \frac{1}{2}\partial_\nu Z^0_\mu \partial_\nu Z^0_\mu - \frac{1}{2c_w^2} M^2 Z^0_\mu Z^0_\mu - \frac{1}{2}\partial_\mu A_\nu \partial_\mu A_\nu - \frac{1}{2}\partial_\mu H \partial_\mu H - \frac{1}{2} m_h^2 H^2 - \partial_\mu \phi^+ \partial_\mu \phi^-$$

$$-M^2 \phi^+ \phi^- - \frac{1}{2}\partial_\mu \phi^0 \partial_\mu \phi^0 - \frac{1}{2c_w^2} M \phi^0 \phi^0 - \beta_h \left[\frac{2M^2}{g^2} + \frac{2M}{g} H + \frac{1}{2}(H^2 + \phi^0\phi^0 + 2\phi^+\phi^-)\right] + \frac{2M^4}{g^2}\alpha_h$$

$$-igc_w \left[\partial_\nu Z^0_\mu (W^+_\mu W^-_\nu - W^+_\nu W^-_\mu) - Z^0_\nu (W^+_\mu \partial_\nu W^-_\mu - W^-_\mu \partial_\nu W^+_\mu) + Z^0_\mu (W^+_\nu \partial_\nu W^-_\mu - W^-_\nu \partial_\nu W^+_\mu)\right]$$

$$-igs_w \left[\partial_\nu A_\mu (W^+_\mu W^-_\nu - W^+_\nu W^-_\mu) - A_\nu (W^+_\mu \partial_\nu W^-_\mu - W^-_\mu \partial_\nu W^+_\mu) + A_\mu (W^+_\nu \partial_\nu W^-_\mu - W^-_\nu \partial_\nu W^+_\mu)\right]$$

$$-\frac{1}{2} g^2 W^+_\mu W^-_\mu W^+_\nu W^-_\nu + \frac{1}{2} g^2 W^+_\mu W^-_\nu W^+_\mu W^-_\nu + g^2 c_w^2 \left(Z^0_\mu W^+_\mu Z^0_\nu W^-_\nu - Z^0_\mu Z^0_\mu W^+_\nu W^-_\nu\right) + g^2 s_w^2 \left(A_\mu W^+_\mu A_\nu W^-_\nu - A_\mu A_\mu W^+_\nu W^-_\nu\right)$$

$$+g^2 s_w c_w \left[A_\mu Z^0_\nu (W^+_\mu W^-_\nu - W^+_\nu W^-_\mu) - 2A_\mu Z^0_\mu W^+_\nu W^-_\nu\right] - g\alpha \left[H^3 + H\phi^0\phi^0 + 2H\phi^+\phi^-\right]$$

$$-\frac{1}{8} g^2 \alpha_h \left[H^4 + (\phi^0)^4 + 4(\phi^+\phi^-)^2 + 4(\phi^0)^2\phi^+\phi^- + 4H^2\phi^+\phi^- + 2(\phi^0)^2 H^2\right] - gMW^+_\mu W^-_\mu H - \frac{1}{2} g \frac{M}{c_w^2} Z^0_\mu Z^0_\mu H$$

$$-\frac{1}{2} ig \left[W^+_\mu (\phi^0 \partial_\mu \phi^- - \phi^- \partial_\mu \phi^0) - W^-_\mu (\phi^0 \partial_\mu \phi^+ - \phi^+ \partial_\mu \phi^0)\right] + \frac{1}{2} g \left[W^+_\mu (H \partial_\mu \phi^- - \phi^- \partial_\mu H) - W^-_\mu (H \partial_\mu \phi^+ - \phi^+ \partial_\mu H)\right]$$

$$+\frac{1}{2} g \frac{1}{c_w} Z^0_\mu (H \partial_\mu \phi^0 - \phi^0 \partial_\mu H) - ig \frac{s_w^2}{c_w} M Z^0_\mu (W^+_\mu \phi^- - W^-_\mu \phi^+) + igs_w M A_\mu (W^+_\mu \phi^- - W^-_\mu \phi^+) - ig \frac{1 - 2c_w^2}{2c_w} Z^0_\mu (\phi^+ \partial_\mu \phi^-$$

$$-\phi^- \partial_\mu \phi^+) + igs_w A_\mu (\phi^+ \partial_\mu \phi^- - \phi^- \partial_\mu \phi^+) - \frac{1}{4} g^2 W^+_\mu W^-_\mu \left[H^2 + (\phi^0)^2 + 2\phi^+\phi^-\right] - \frac{1}{4} g^2 \frac{1}{c_w^2} Z^0_\mu Z^0_\mu [H^2 + (\phi^0)^2$$

$$+2(2s_w^2 - 1)^2 \phi^+\phi^-] - \frac{1}{2} g^2 \frac{s_w^2}{c_w} Z^0_\mu \phi^0 (W^+_\mu \phi^- + W^-_\mu \phi^+) - \frac{1}{2} ig^2 \frac{s_w^2}{c_w} Z^0_\mu H (W^+_\mu \phi^- - W^-_\mu \phi^+) + \frac{1}{2} g^2 s_w A_\mu \phi^0 (W^+_\mu \phi^- + W^-_\mu \phi^+)$$

$$+\frac{1}{2} ig^2 s_w A_\mu H (W^+_\mu \phi^- - W^-_\mu \phi^+) - g^2 \frac{s_w}{c_w} (2c_w^2 - 1) Z^0_\mu A_\mu \phi^+ \phi^- - g^1 s_w^2 A_\mu A_\mu \phi^+ \phi^- - \bar{e}^\lambda (\gamma\partial + m_e^\lambda) e^\lambda - \bar{\nu}^\lambda \gamma\partial \nu^\lambda$$

$$-\bar{u}^\lambda_j (\gamma\partial + m_u^\lambda) u^\lambda_j - \bar{d}^\lambda_j (\gamma\partial + m_d^\lambda) d^\lambda_j + igs_w A_\mu \left[-(\bar{e}^\lambda \gamma^\mu e^\lambda) + \frac{2}{3} (\bar{u}^\lambda_j \gamma^\mu u^\lambda_j) - \frac{1}{3} (\bar{d}^\lambda_j \gamma^\mu d^\lambda_j)\right]$$

$$+\frac{ig}{4c_w} Z^0_\mu \left[(\bar{\nu}^\lambda \gamma^\mu (1 + \gamma^5) \nu^\lambda) + (\bar{e}^\lambda \gamma^\mu (4s_w^2 - 1 - \gamma^5) e^\lambda) + (\bar{u}^\lambda_j \gamma^\mu (\tfrac{4}{3} s_w^2 - 1 - \gamma^5) u^\lambda_j) + (\bar{d}^\lambda_j \gamma^\mu (1 - \tfrac{8}{3} s_w^2 - \gamma^5) d^\lambda_j)\right]$$

$$+\frac{ig}{2\sqrt{2}} W^+_\mu \left[(\bar{\nu}^\lambda \gamma^\mu (1 + \gamma^5) e^\lambda) + (\bar{u}^\lambda_j \gamma^\mu (1 + \gamma^5) C_{\lambda\kappa} d^\kappa_j)\right] + \frac{ig}{2\sqrt{2}} W^-_\mu \left[(\bar{e}^\lambda \gamma^\mu (1 + \gamma^5) \nu^\lambda) + (\bar{d}^\kappa_j C^\dagger_{\lambda\kappa} \gamma^\mu (1 + \gamma^5) u^\lambda_j)\right]$$

$$+\frac{ig}{2\sqrt{2}} \frac{m_e^\lambda}{M} \left[-\phi^+ (\bar{\nu}^\lambda (1 - \gamma^5) e^\lambda) + \phi^- (\bar{e}^\lambda (1 + \gamma^5) \nu^\lambda)\right] - \frac{g}{2} \frac{m_e^\lambda}{M} \left[H (\bar{e}^\lambda e^\lambda) + i\phi^0 (\bar{e}^\lambda \gamma^5 e^\lambda)\right]$$

$$+\frac{ig}{2M\sqrt{2}} \phi^+ \left[-m_d^\kappa (\bar{u}^\lambda_j C_{\lambda\kappa} (1 - \gamma^5) d^\kappa_j) + m_u^\lambda (\bar{u}^\lambda_j C_{\lambda\kappa} (1 + \gamma^5) d^\kappa_j)\right] + \frac{ig}{2M\sqrt{2}} \phi^- \left[m_d^\lambda (\bar{d}^\lambda_j C^\dagger_{\lambda\kappa} (1 + \gamma^5) u^\kappa_j) - m_u^\kappa (\bar{d}^\lambda_j C^\dagger_{\lambda\kappa} (1 - \gamma^5) u^\kappa_j)\right]$$

$$-\frac{g}{2} \frac{m_u^\lambda}{M} H (\bar{u}^\lambda_j u^\lambda_j) - \frac{g}{2} \frac{m_d^\lambda}{M} H (\bar{d}^\lambda_j d^\lambda_j) + \frac{ig}{2} \frac{m_u^\lambda}{M} \phi^0 (\bar{u}^\lambda_j \gamma^5 u^\lambda_j) - \frac{ig}{2} \frac{m_d^\lambda}{M} \phi^0 (\bar{d}^\lambda_j \gamma^5 d^\lambda_j) + \bar{X}^+ (\partial^2 - M^2) X^+ + \bar{X}^- (\partial^2 - M^2) X^-$$

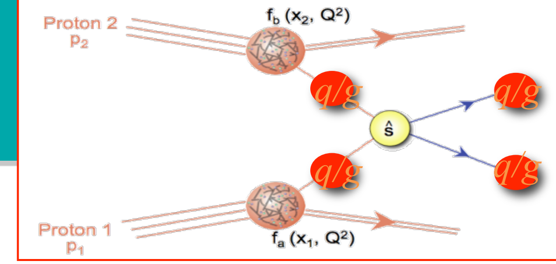
$$+\bar{X}^0 \left(\partial^2 - \frac{M^2}{c_w^2}\right) X^0 + \bar{Y} \partial^2 Y + igc_w W^+_\mu (\partial_\mu \bar{X}^0 X^- - \partial_\mu \bar{X}^+ X^0) + igs_w W^+_\mu (\partial_\mu \bar{Y} X^- - \partial_\mu \bar{X}^+ Y) + igc_w W^-_\mu (\partial_\mu \bar{X}^- X^0 - \partial_\mu \bar{X}^0 X^+)$$

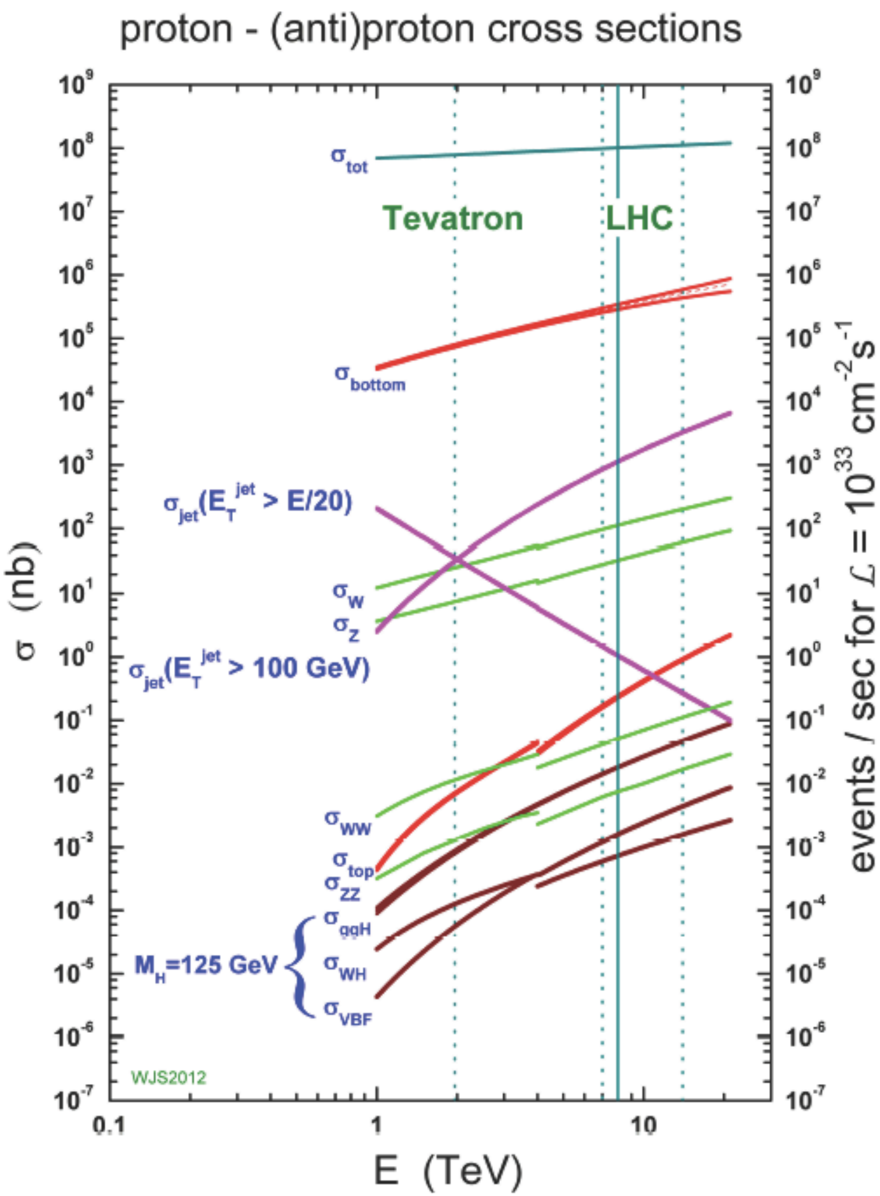
$$+igs_w W^-_\mu (\partial_\mu \bar{X}^- Y - \partial_\mu \bar{Y} X^+) + igc_w Z^0_\mu (\partial_\mu \bar{X}^+ X^+ - \partial_\mu \bar{X}^- X^-) + igs_w A_\mu (\partial_\mu \bar{X}^+ X^+ - \partial_\mu \bar{X}^- X^-) - \frac{1}{2} gM [\bar{X}^+ X^+ H + \bar{X}^- X^- H$$

$$+\frac{1}{c_w^2} \bar{X}^0 X^0 H] + \frac{1 - 2c_w^2}{2c_w} igM [\bar{X}^+ X^0 \phi^+ - \bar{X}^- X^0 \phi^-] + \frac{1}{2c_w} igM [\bar{X}^0 X^- \phi^+ - \bar{X}^0 X^+ \phi^-] + igMs_w [\bar{X}^0 X^- \phi^+ - \bar{X}^0 X^+ \phi^-]$$

$$+\frac{1}{2} igM [\bar{X}^+ X^+ \phi^0 - \bar{X}^- X^- \phi^0]$$

proton-proton cross sections

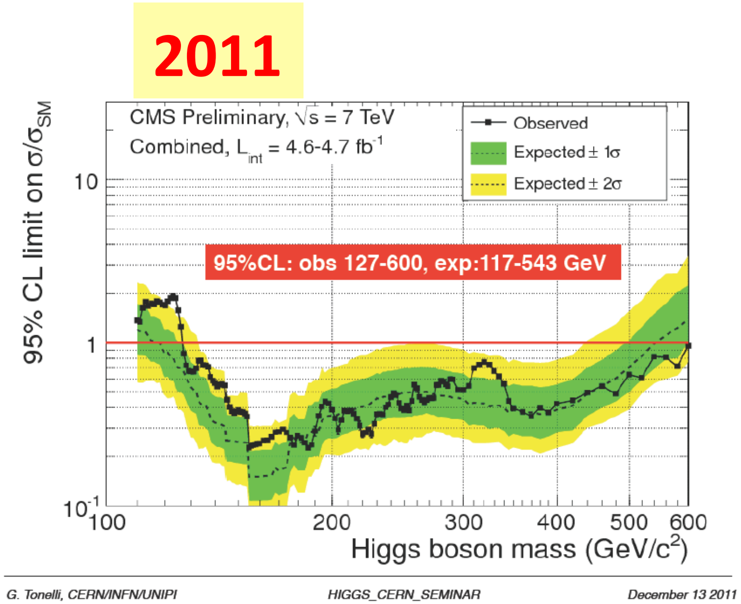


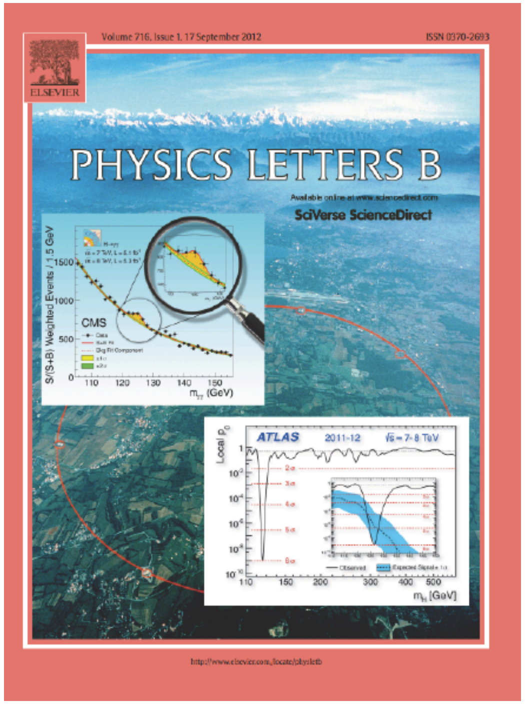


LHC @ 7-8 TeV; 13 TeV

- Hard scattering processes represent only a tiny fraction of the total inelastic pp cross section σ=o(100mb)
- b production cross section σ=o(100μb)
- Z production cross section σ=o(10nb)
- ttbar production cross section σ=o(100pb)
- SM Higgs production cross section σ=o(10pb)

i.e. $\sigma(pp \rightarrow W+X) \sim 150$ nb $\sim 2 \cdot 10^{-6}\, \sigma_{tot}(pp)$


2011
CMS Preliminary, √s = 7 TeV
Combined, L_int = 4.6-4.7 fb-1
Observed
Expected ± 1σ
Expected ± 2σ
95%CL: obs 127-600, exp:117-543 GeV
95% CL limit on σ/σSM
Higgs boson mass (GeV/c2)
G. Tonelli, CERN/INFN/UNIPI
HIGGS_CERN_SEMINAR
December 13 2011


Volume 716, Issue 1, 17 September 2012
ISSN 0370-2693
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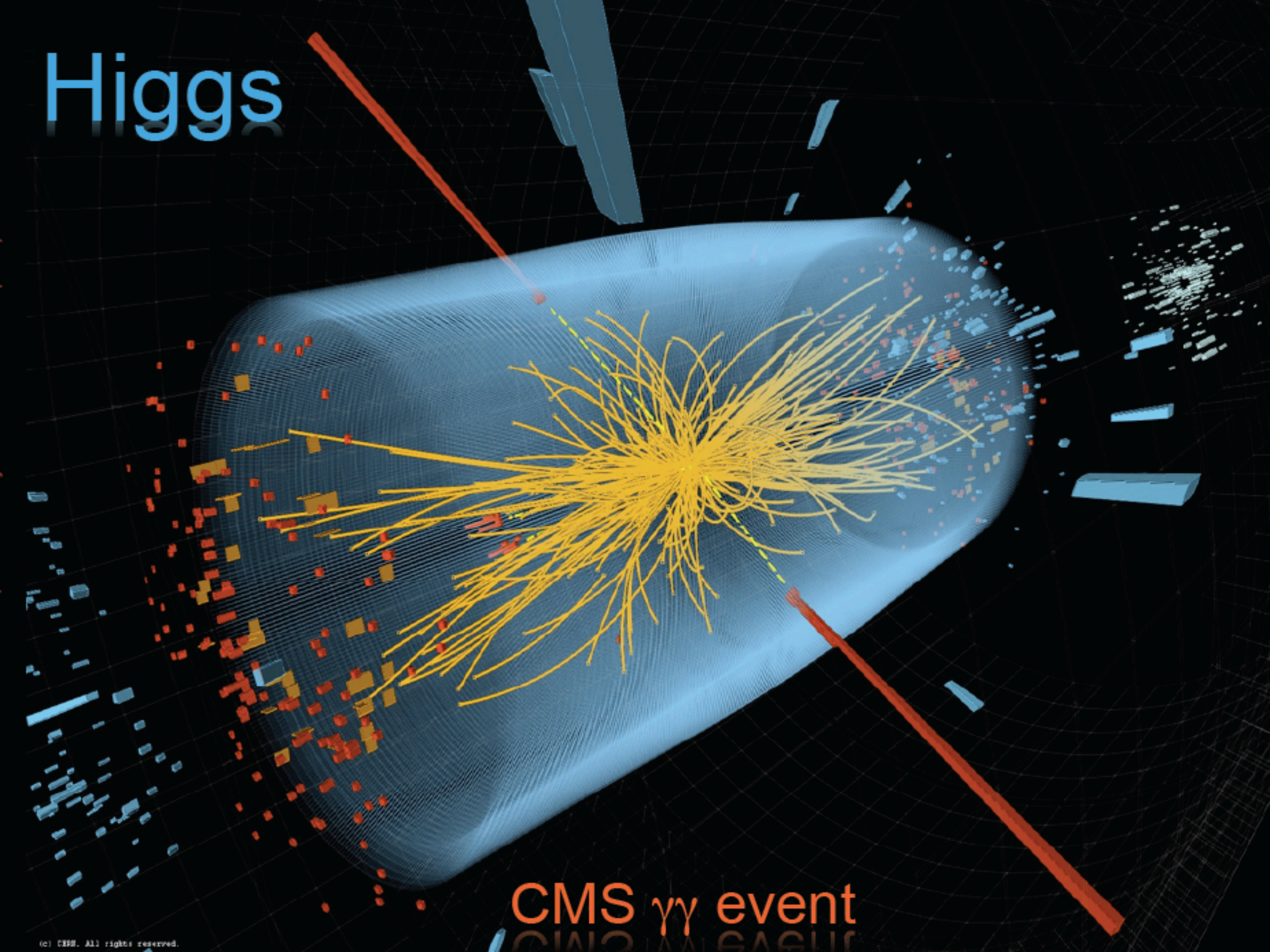
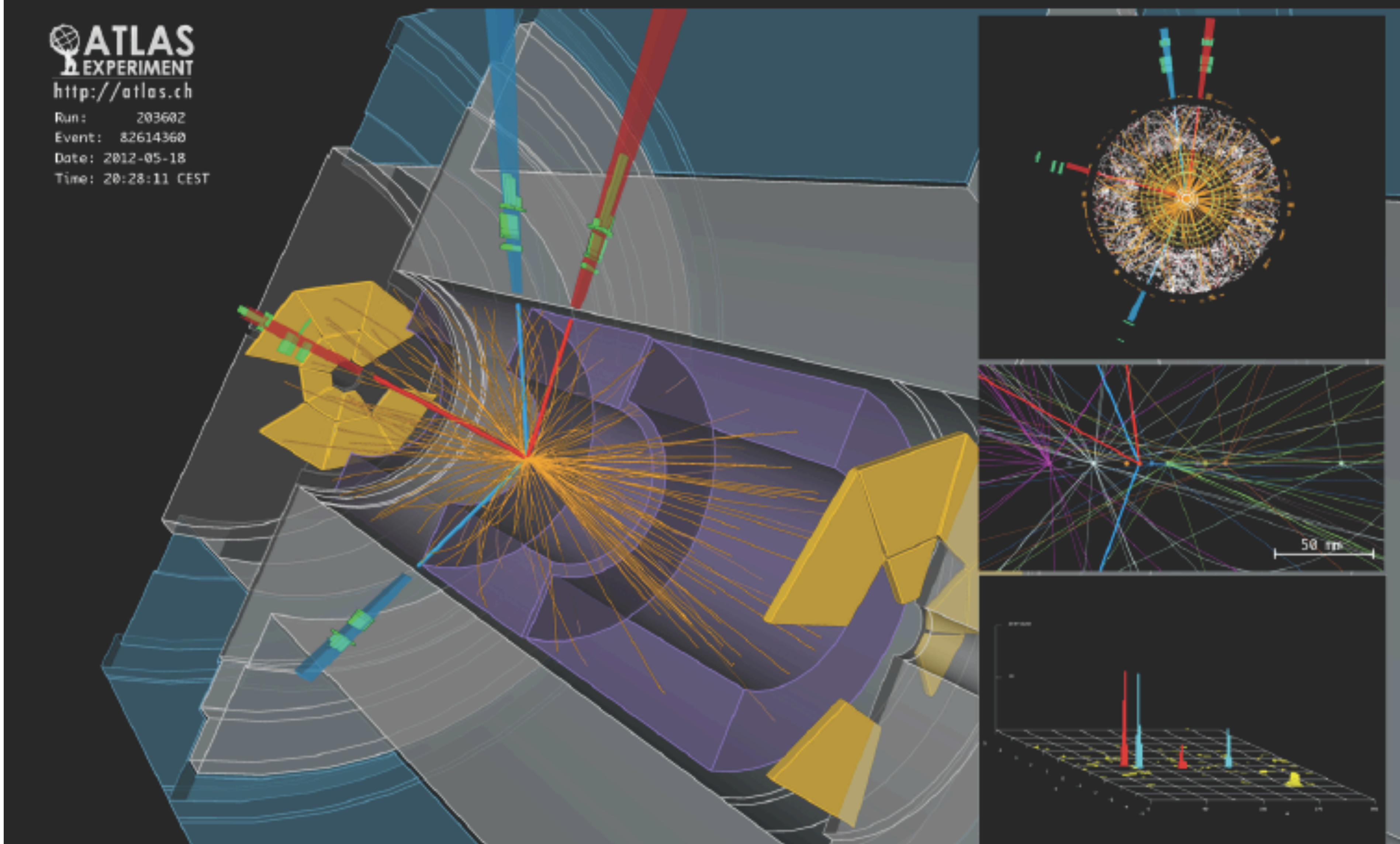
SciVerse ScienceDirect
CMS
ATLAS

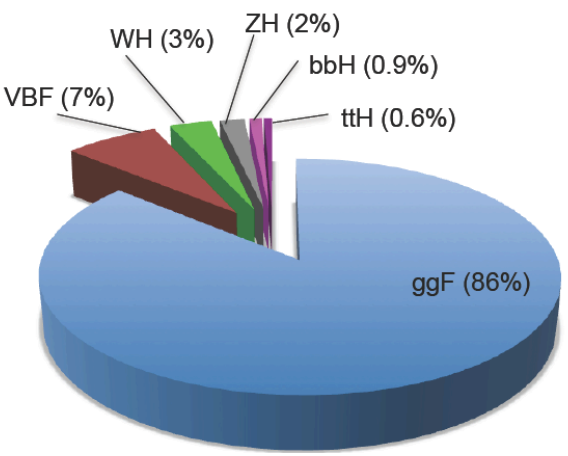
Higgs Boson

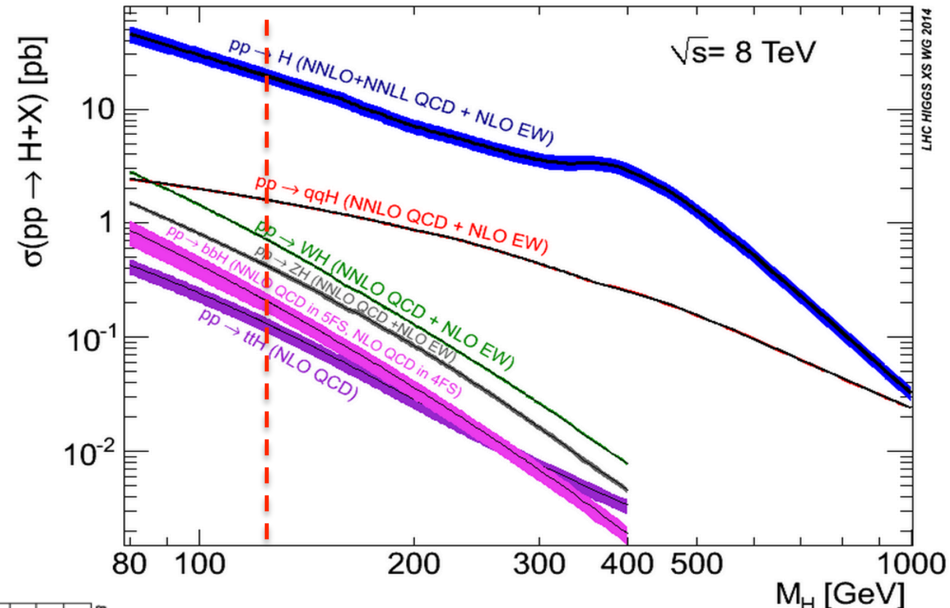

Higgs
CMS γγ event

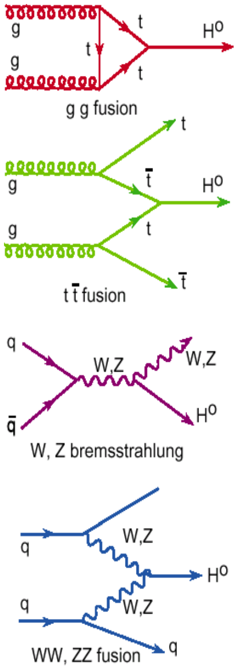
ATLAS: Higgs → ZZ → eeee event



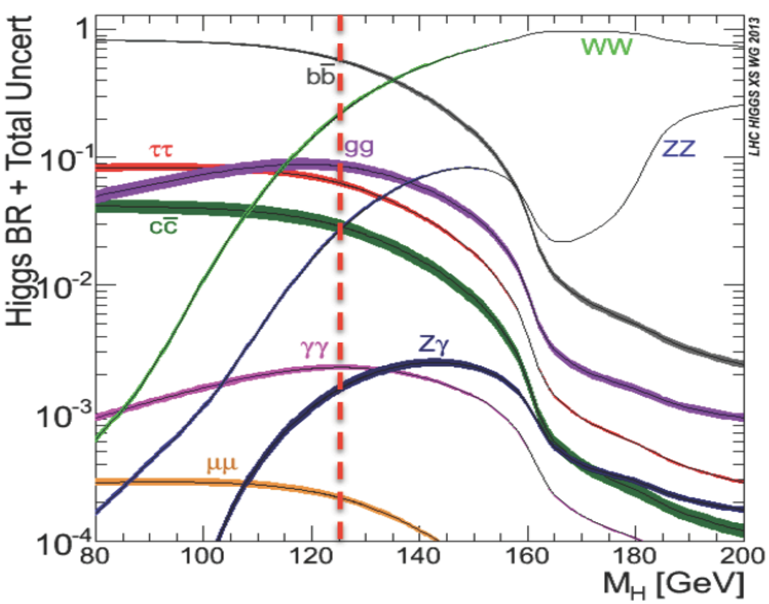
Higgs production and decay



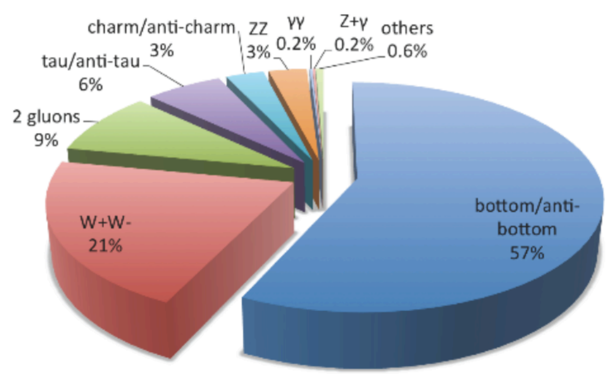




for m_H=125 GeV



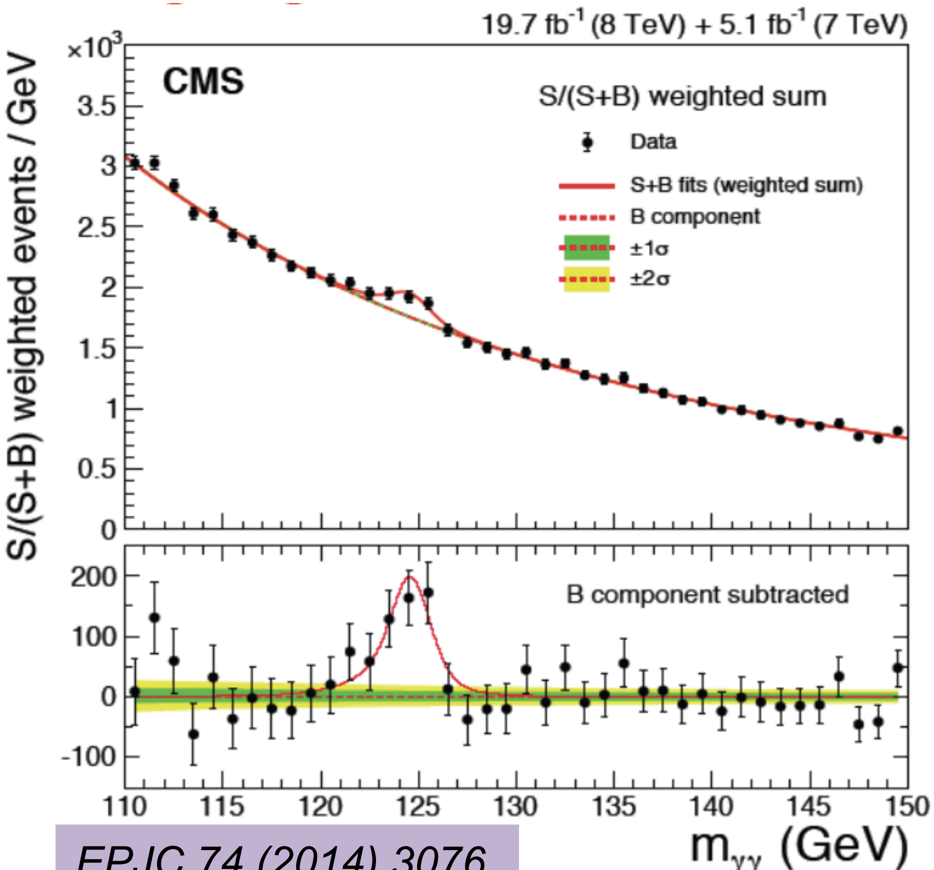
for m_H=125 GeV



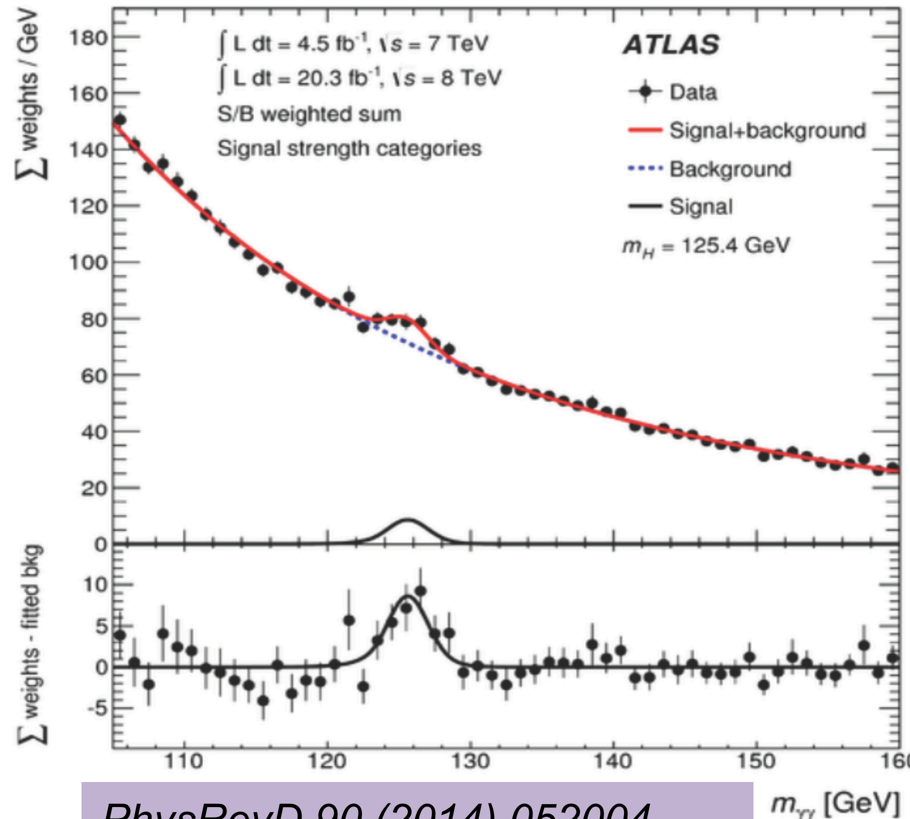
Most sensitive channels:

- H → ZZ* → 4l
- H → γγ
- H → WW → 2l2ν
- H → ττ
- H → bb

Higgs → γγ results



EPJC 74 (2014) 3076

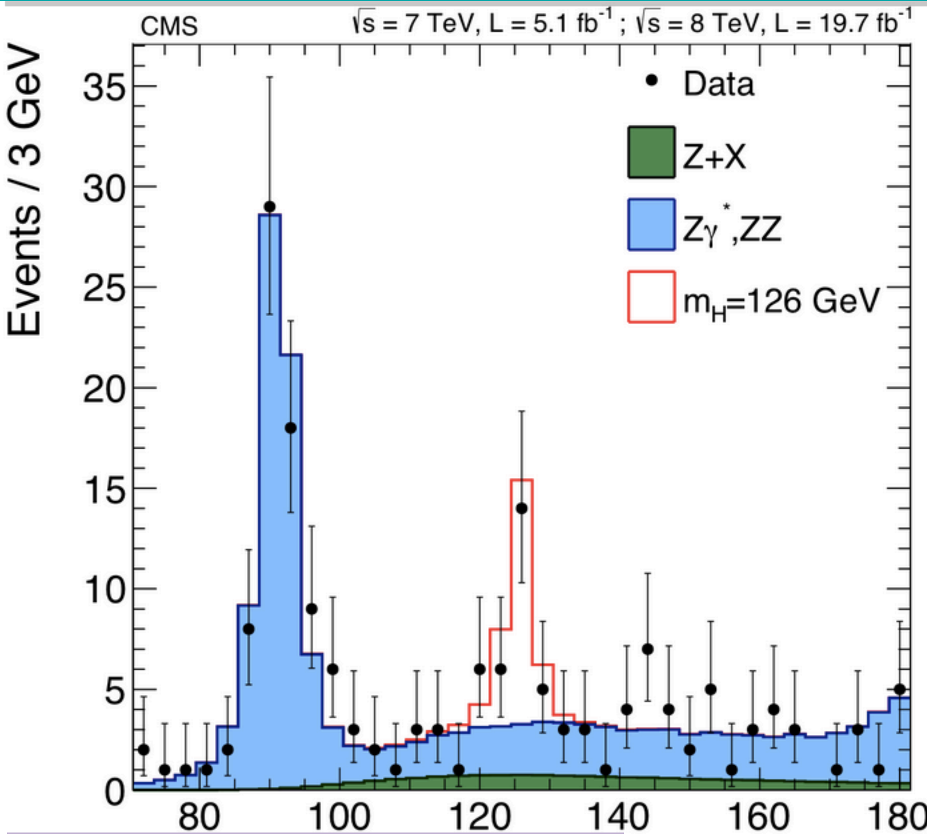


PhysRevD 90 (2014) 052004

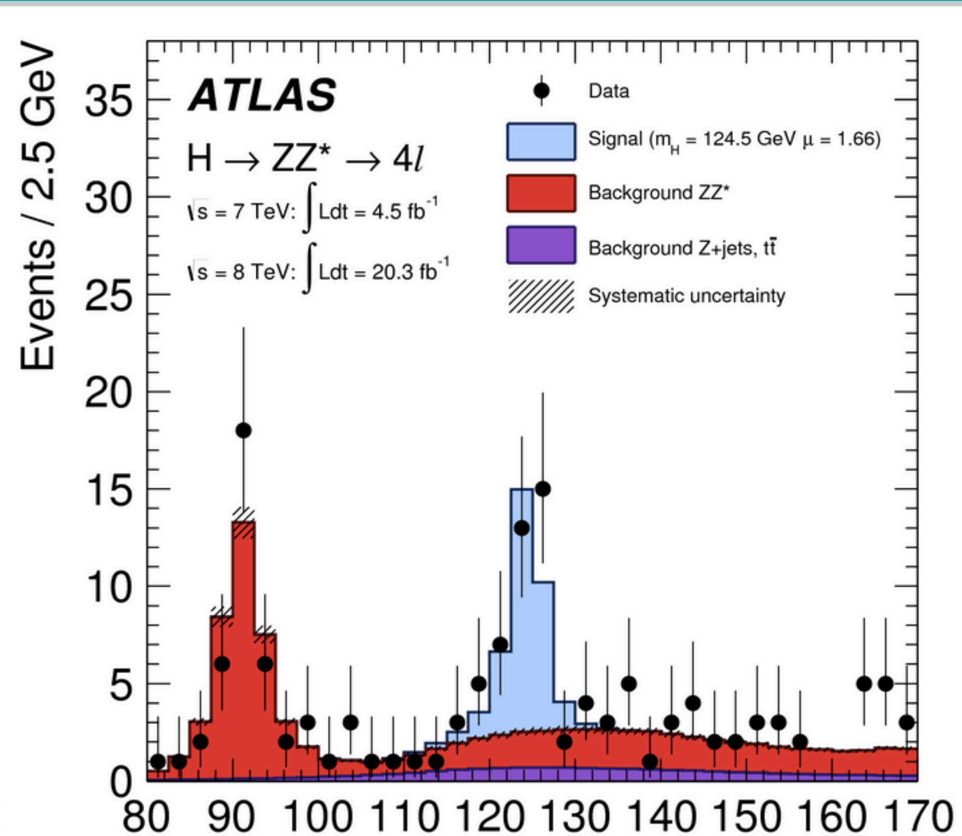
m_H = 124.7 ± 0.4 GeV
Significance = 5.7 (expected 5.2) σ
$\mu = \sigma\, BR/\sigma_{SM}\, BR_{SM}$= 1.14 + 0.26 – 0.23
Γ_H < 3.4 GeV @ 95% CL

m_H = 126.0 ± 0.5 GeV
Significance = 5.2 (expected 4.6) σ
$\mu = \sigma\, BR/\sigma_{SM}\, BR_{SM}$= 1.17 ± 0.27
Γ_H < 5.0 GeV @ 95% CL

Higgs → ZZ* → 4l results



PhysRevD 89 (2014) 092007



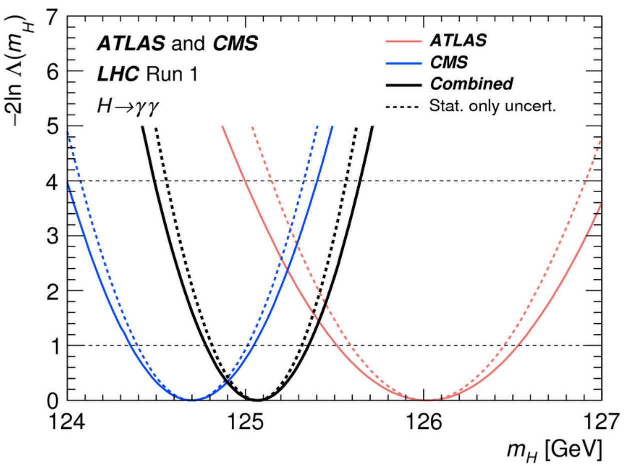
PhysRevD 90 (2014) 052004

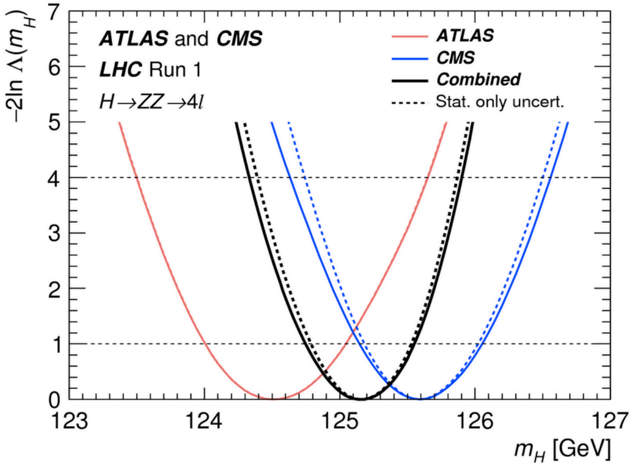
m_H = 125.6 ± 0.4 GeV
Significance = 6.7 (expected 7.2) σ
$\mu = \sigma\, BR/\sigma_{SM}\, BR_{SM}$ = 0.9 ± 0.3
Γ_H < 3.4 GeV @ 95% CL

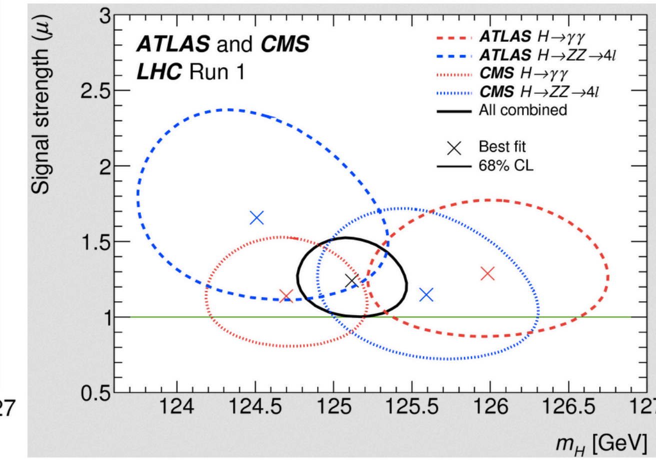
m_H = 124.5 ± 0.5 GeV
Significance = 8.2 (expected 5.8) σ
$\mu = \sigma\, BR/\sigma_{SM}\, BR_{SM}$ = 1.7 ± 0.4
Γ_H < 2.6 GeV @ 95% CL

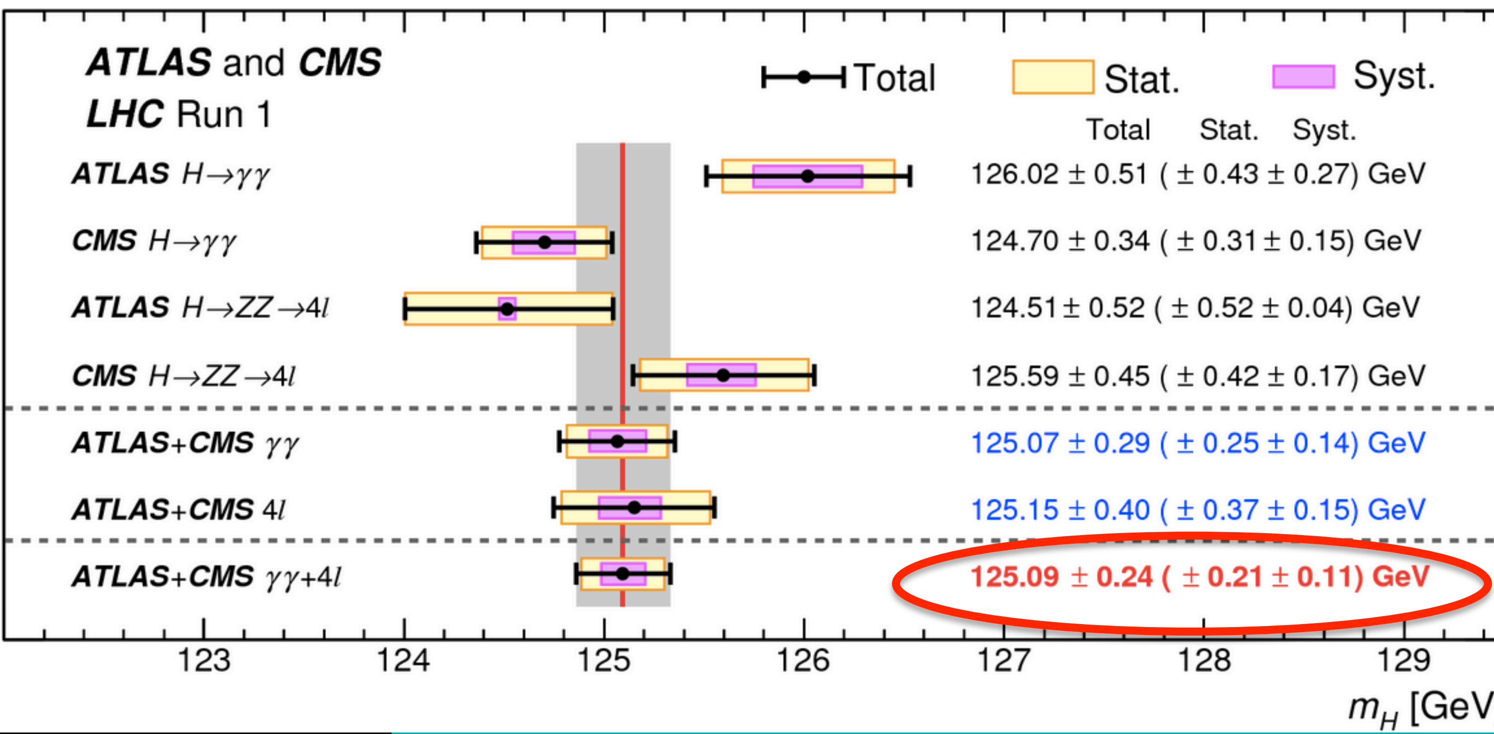
Higgs results combination: m_H

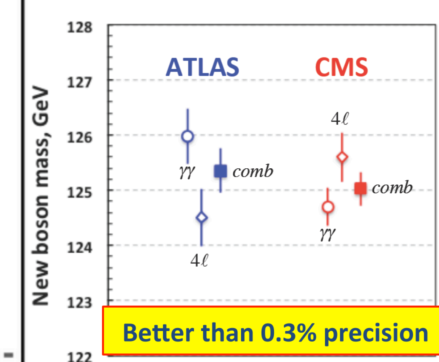
NEW







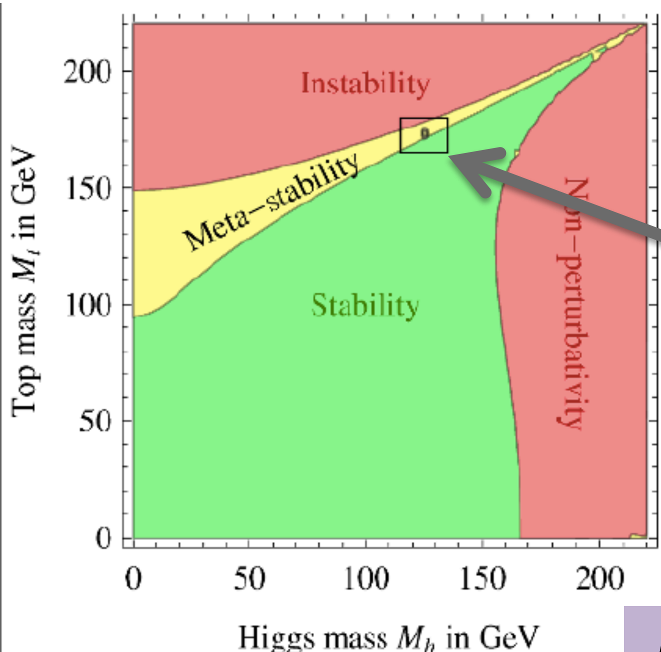


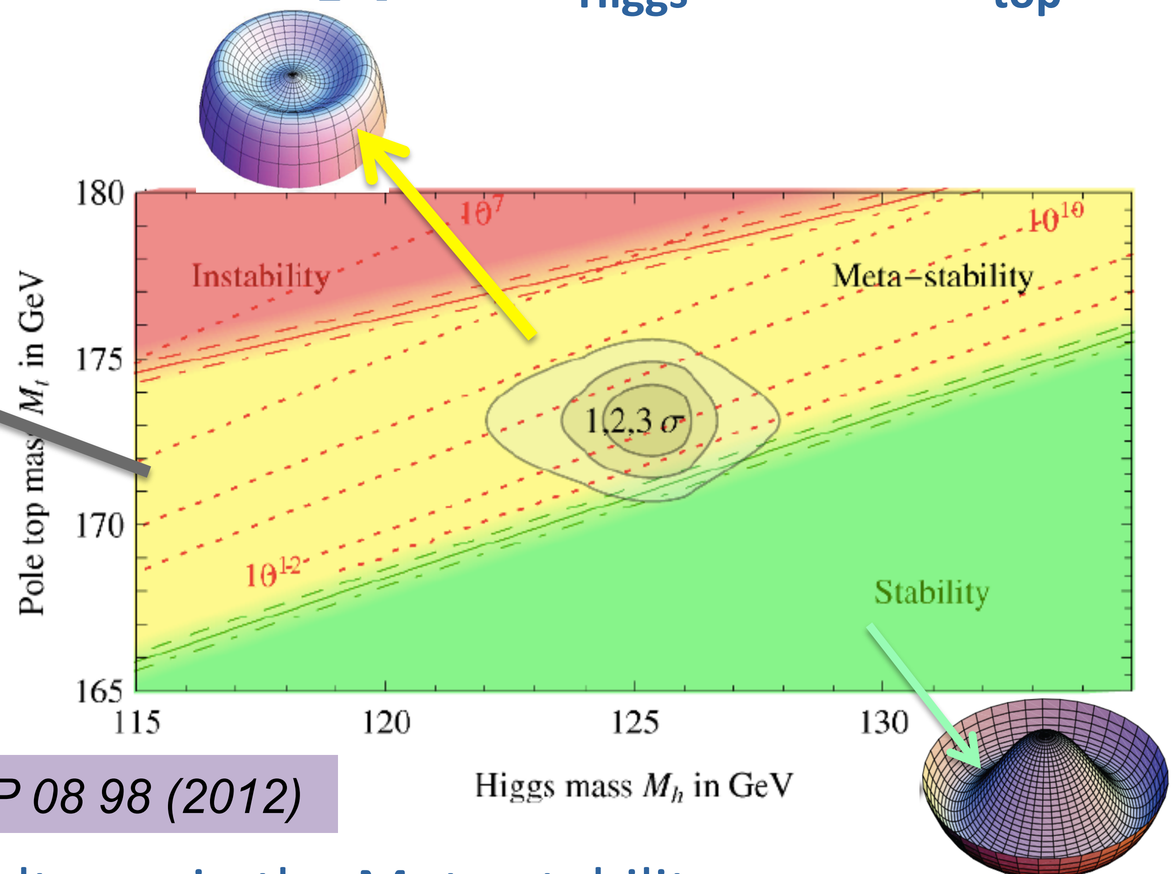


ATLAS&CMS:
arXiv:1503.07589
LHC combination

Higgs results and Vacuum stability

Vacuum stability depends strongly on m_{Higgs} and on m_{top} .





JHEP 08 98 (2012)

Our current results are in the Meta-stability zone:

M_{top} = 173. Gev ; M_{Higgs}= 125 GeV

but still compatible with stable and with unstable

Limits on total Higgs width

- From direct measurements are dominated by instrumental resolution:

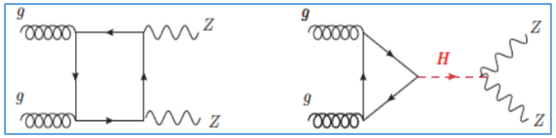
	CMS		ATLAS
$H \rightarrow \gamma\gamma$	Γ_H < 2.4 GeV @95% CL	$H \rightarrow \gamma\gamma$	Γ_H < 5.0 GeV @ 95% CL
$H \rightarrow ZZ \rightarrow 4l$	Γ_H < 3.4 GeV " "	$H \rightarrow ZZ \rightarrow 4l$	Γ_H < 2.6 GeV " "

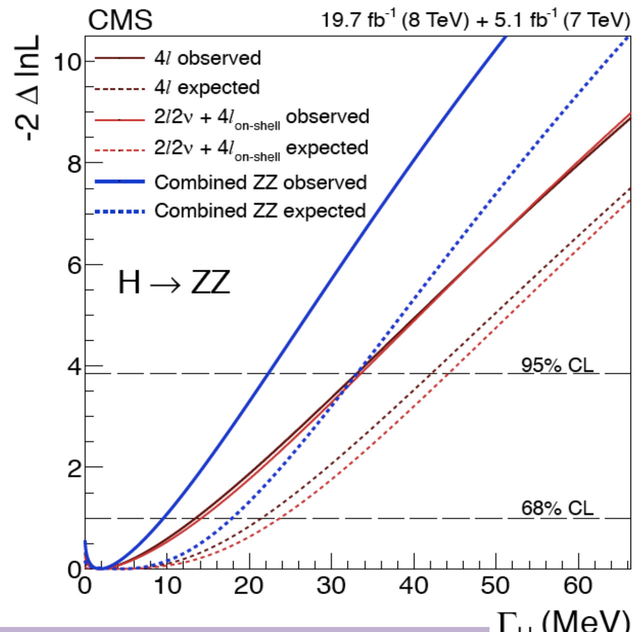
but SM expectations is: **Γ_{SM} = 4.15 MeV**!

- Indirect measurements based on comparison of *on-shell* and *off-shell* $H^* \rightarrow ZZ$. *Off-shell* to *on-shell* ratio is ~proportional to Γ_H

  *Should consider negative interference with box diagram

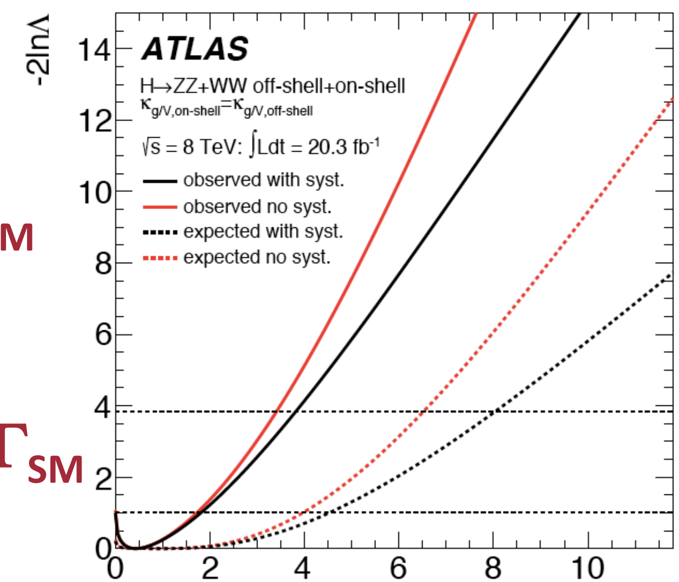
  *Assume that gg is the dominant production mechanism





CMS:
Γ_H < 22 MeV < 5.4 Γ_{SM}

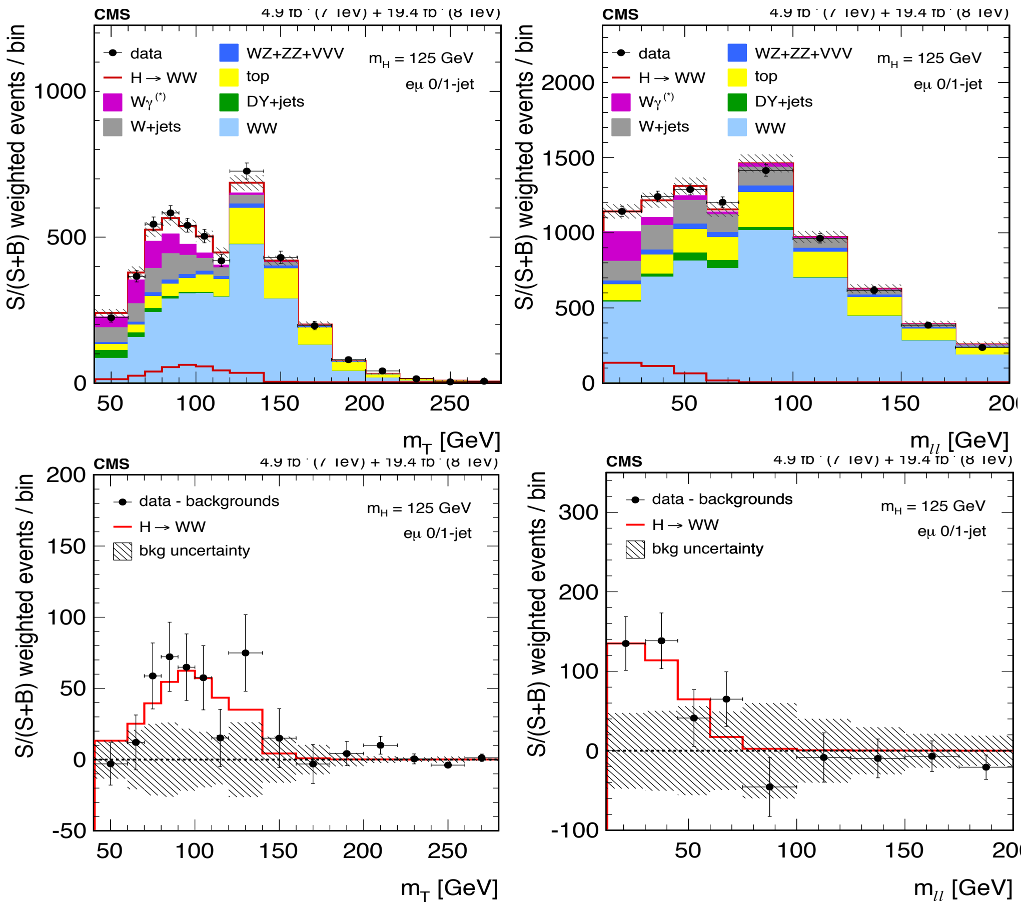
ATLAS:
Γ_H < 22.7 MeV < 5.5 Γ_{SM}



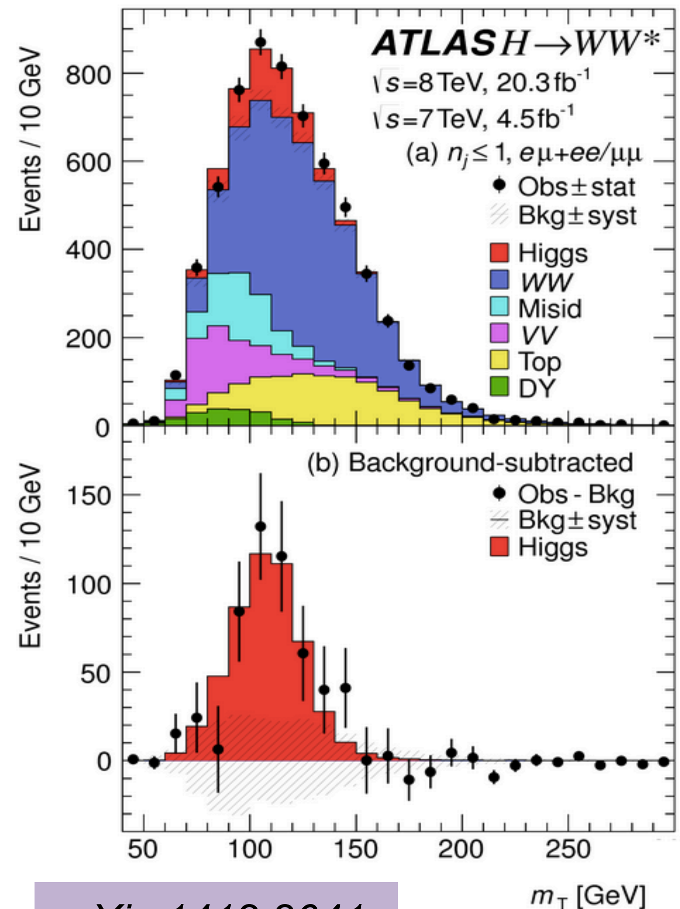
Phys.Lett. B 736(2014) 64

arXiv:1503.01060

Higgs → WW* → lνlν results



JHEP01(2014)096



arXiv:1412.2641

@m_H = 125.6 GeV

Significance = 4.3 (expected 5.8) σ

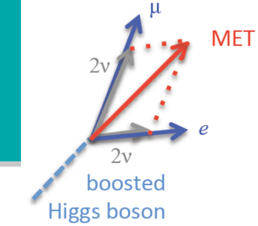
$\mu = \sigma\, BR/\sigma_{SM}\, BR_{SM} = 0.72 \pm 0.19$

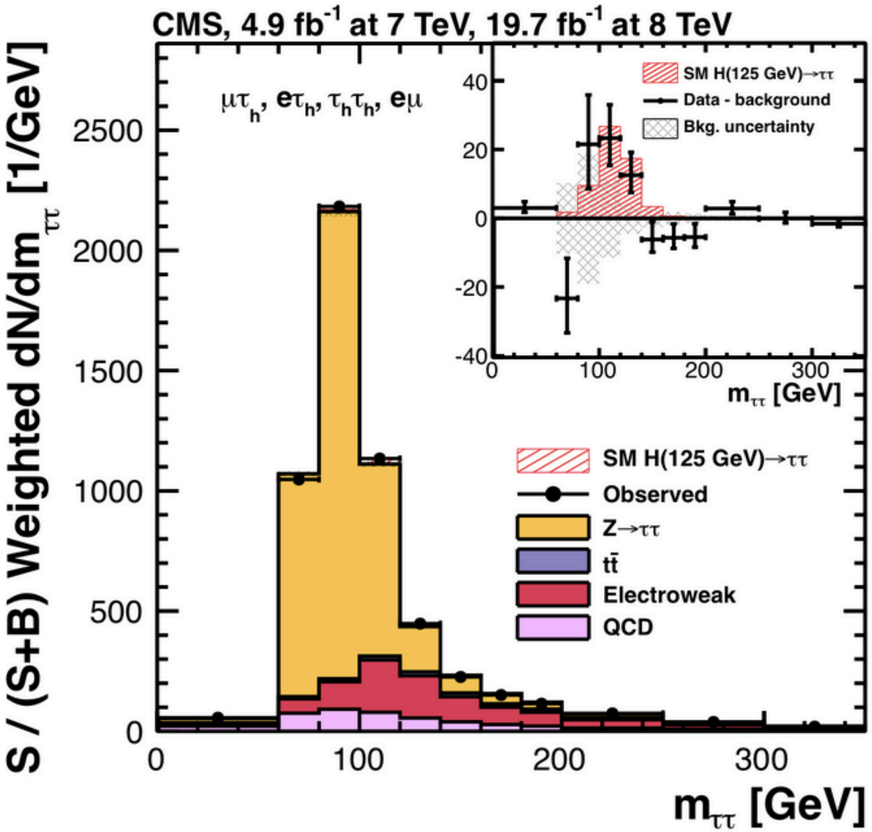
@m_H = 125.4 GeV

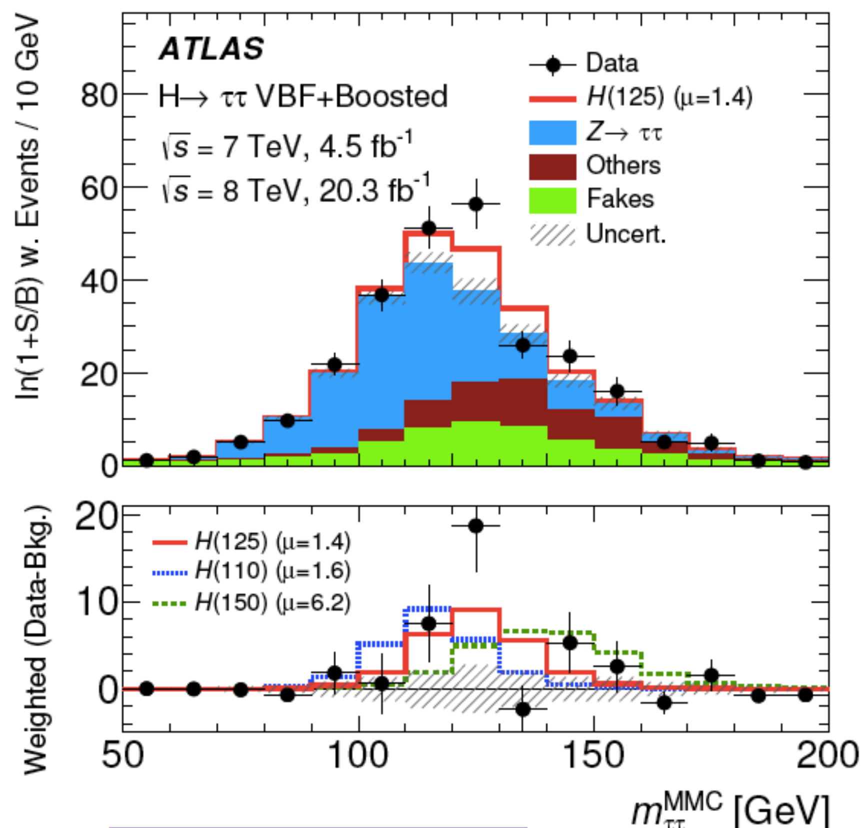
Significance = 6.1 (expected 5.8) σ

$\mu = \sigma\, BR/\sigma_{SM}\, BR_{SM} = 1.1 \pm 0.2$

Higgs → ττ results







arXiv:1401.5041 or JHEP05(2014)104

@m_H = 125 GeV

Significance = 3.2 (expected 3.7) σ

$\mu = \sigma/\sigma_{SM} = 0.78 \pm 0.27$

arxiv:1501.04943

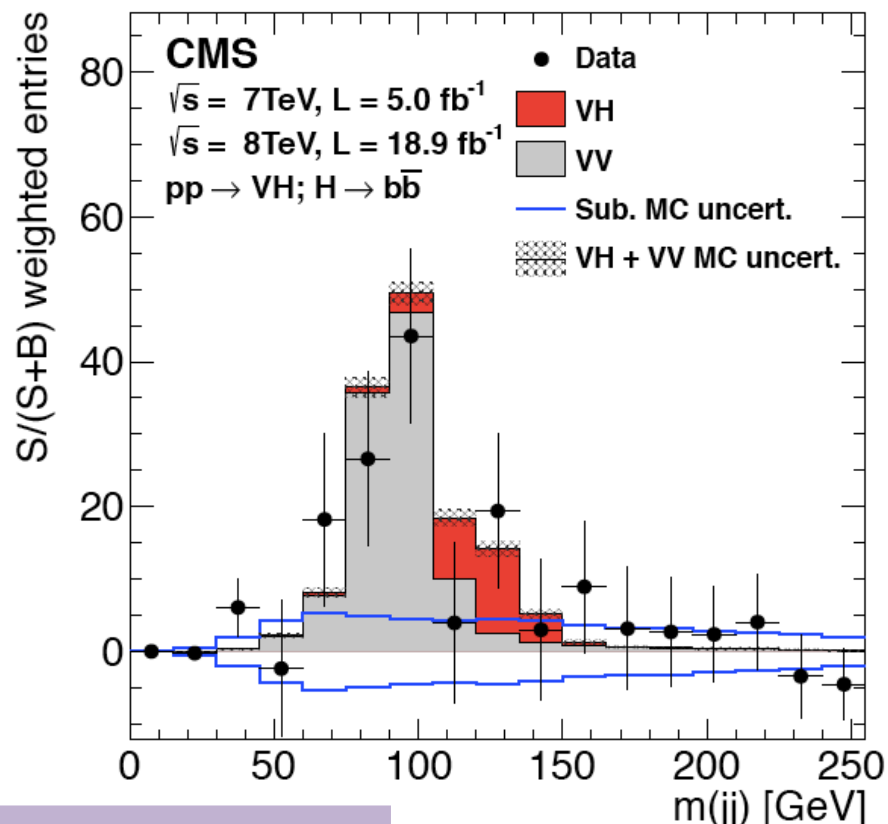
@m_H = 125.4 GeV

Significance = 4.5 (expected 3.4) σ

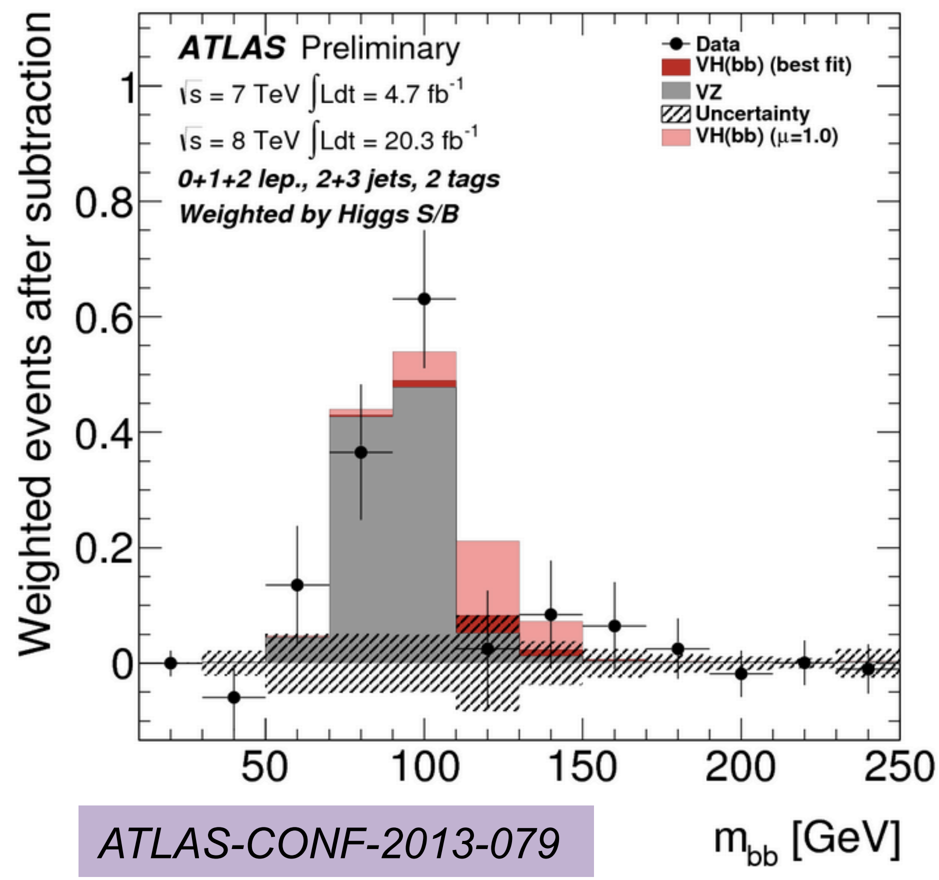
$\mu = \sigma/\sigma_{SM} = 1.4 \pm 0.4$

pp → VH ; Higgs → bb results

Very challenging at a hadron collider



arXiv:1310.3687v2



ATLAS-CONF-2013-079

@m_H = 125 GeV

Significance = 2.1 (expected 2.0) σ

$\mu = \sigma/\sigma_{SM} = 1.0 \pm 0.5$ x VB

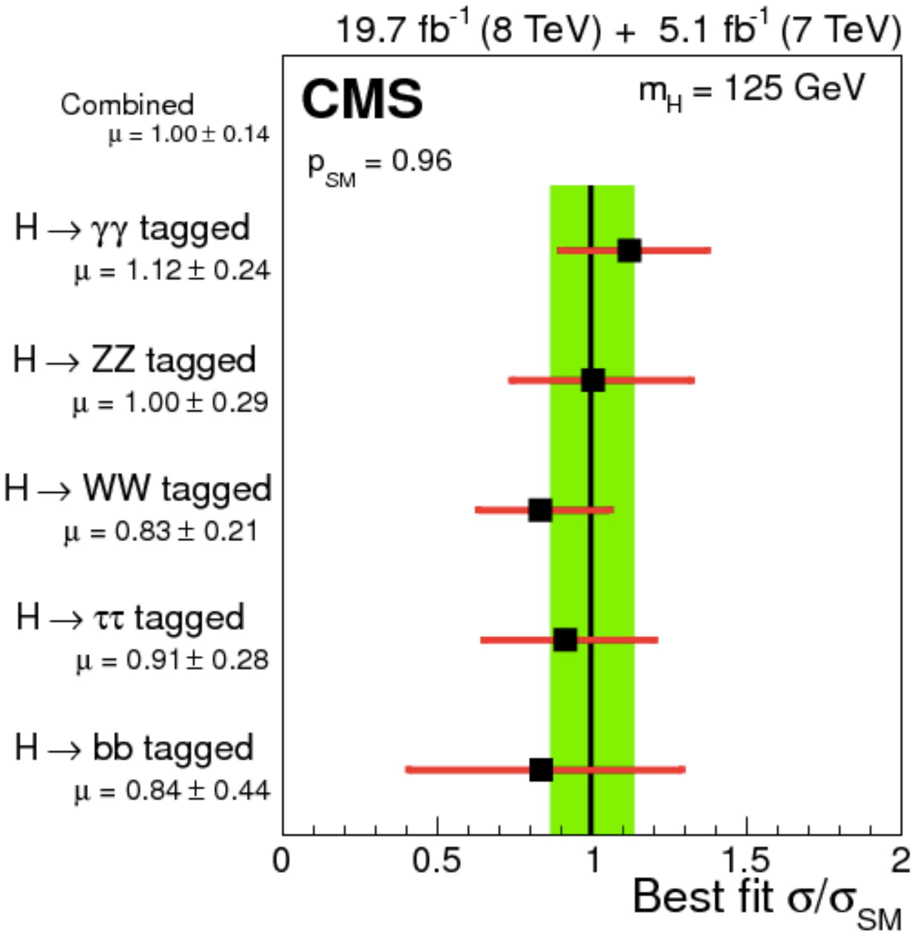
$\mu = \sigma/\sigma_{SM} = 0.9 \pm 1.9$ x VBF H→bb

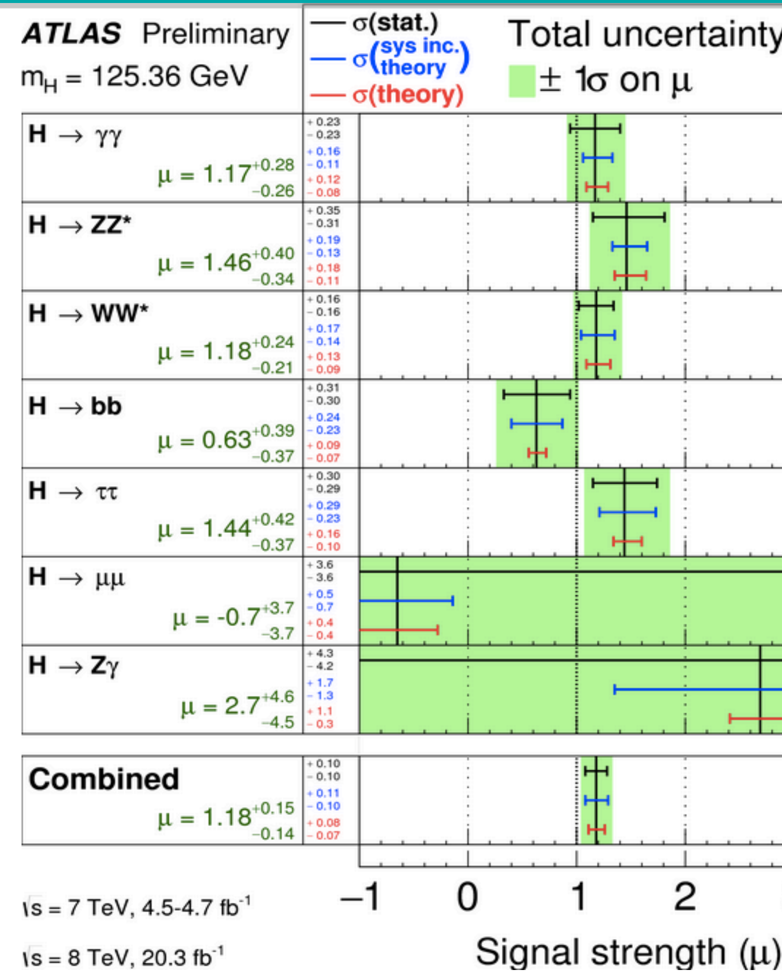
@m_H = 125.4 GeV

Significance = 1.4 (expected 2.6) σ

$\mu = \sigma/\sigma_{SM} = 0.5 \pm 0.4$

Main 5 channels: couplings and SM compatibility





*without most recent results

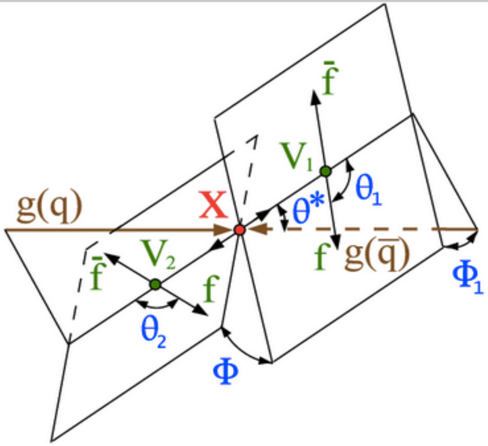
arXiv:1412.8662

ATLAS-CONF-2015-007

$\mu = \sigma\, BR/\sigma_{SM}\, BR_{SM} = 1.00 \pm 0.09(stat) \pm 0.07(syst) \pm 0.08(theor)$ CMS

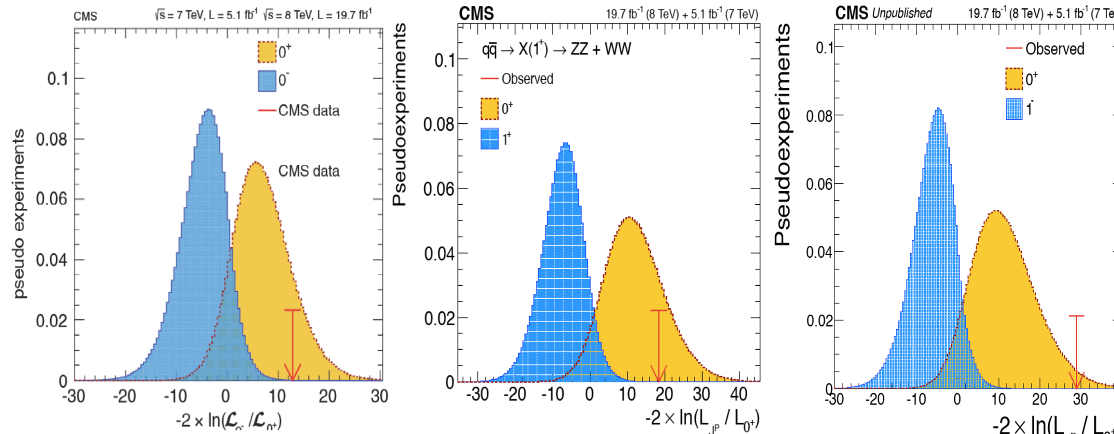
$\mu = \sigma\, BR/\sigma_{SM}\, BR_{SM} = 1.18 \pm 0.10(stat) \pm 0.09(syst) \pm 0.10(theor)$ ATLAS*

Spin parity test/analysis



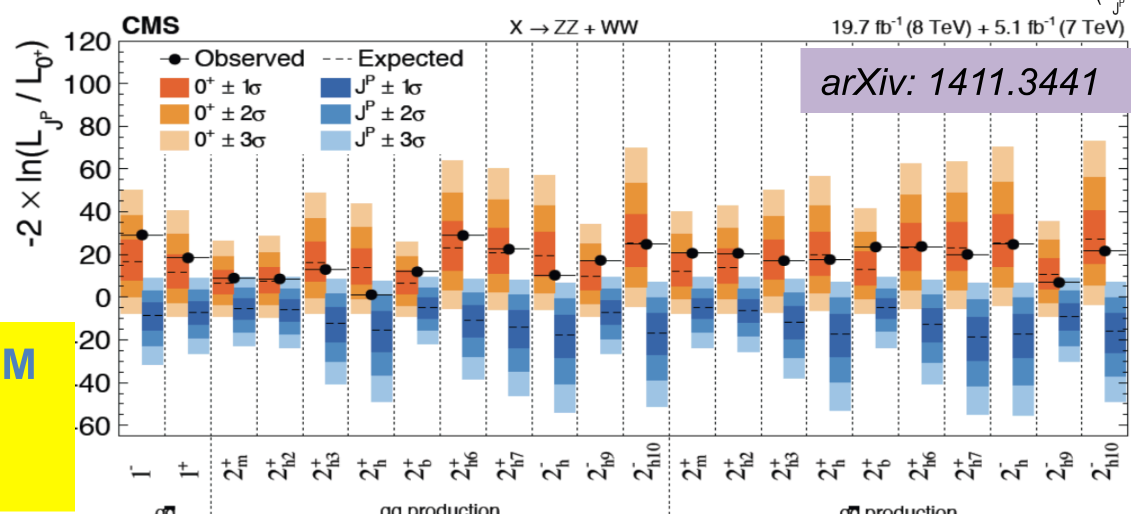
Use ZZ(m_{Z1},m_{Z2}, 5 angles), WW(M_{ll},$\Delta\phi_{LL}$) and $\gamma\gamma$($\cos\theta^*$) decays:

- the particle is a Boson
- Spin 1 is excluded because of H→ γγ [Landau-Yang theorem]
- $J^P = 0^+$(SM), 0^-, 2^+,2^-



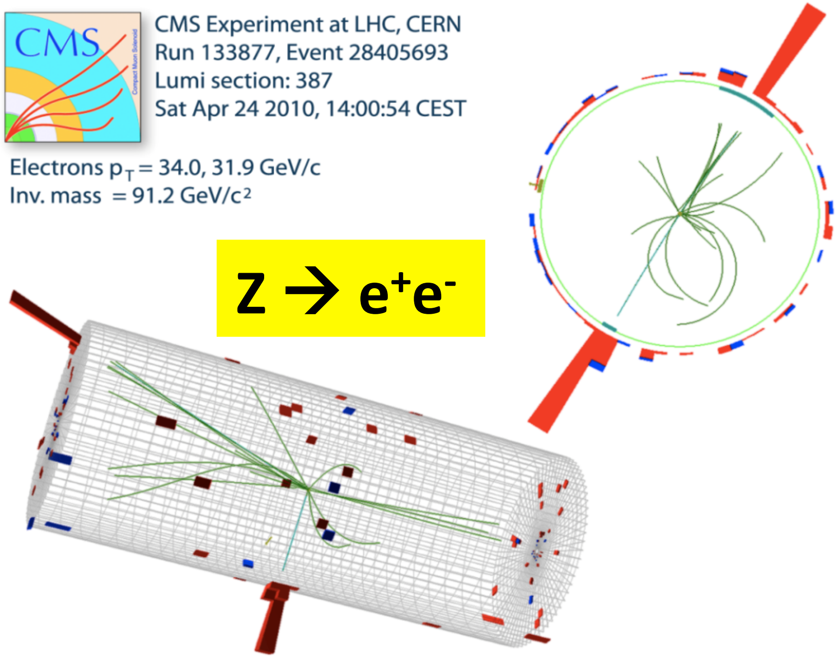
ATLAS: *PhysLett B 726 (2013)120*

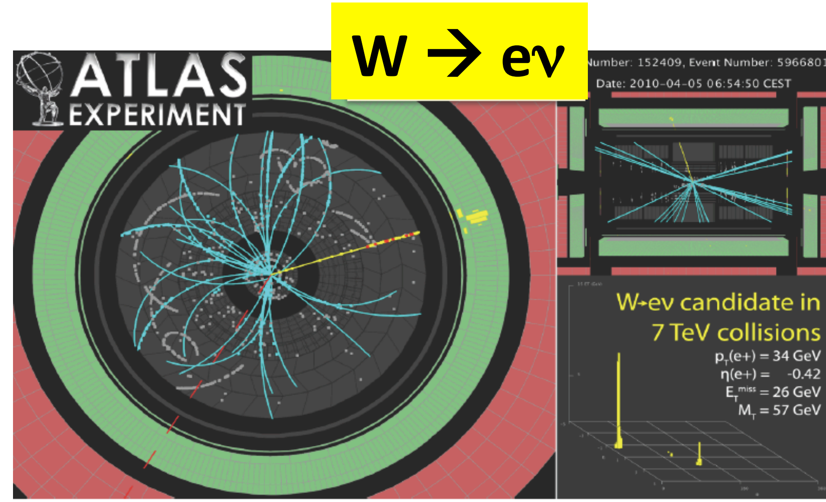
JP	Channels	CL[%]
0-	ZZ	97.8
1+	ZZ,WW	99.97
1-	ZZ,WW	99.7
2+	γγ,ZZ,WW	99.99



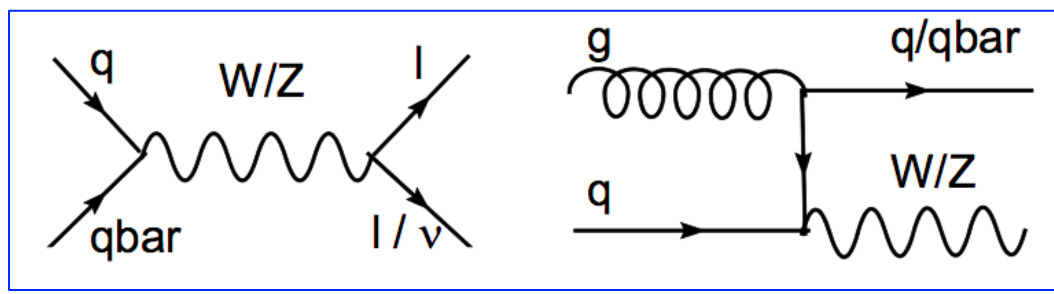
arXiv: 1411.3441

Both experiments consistent with SM $J^P = 0^+$. Several hypotheses considered excluded @ 99%CL



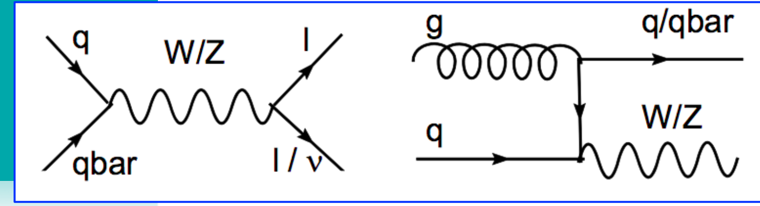


W and Z bosons



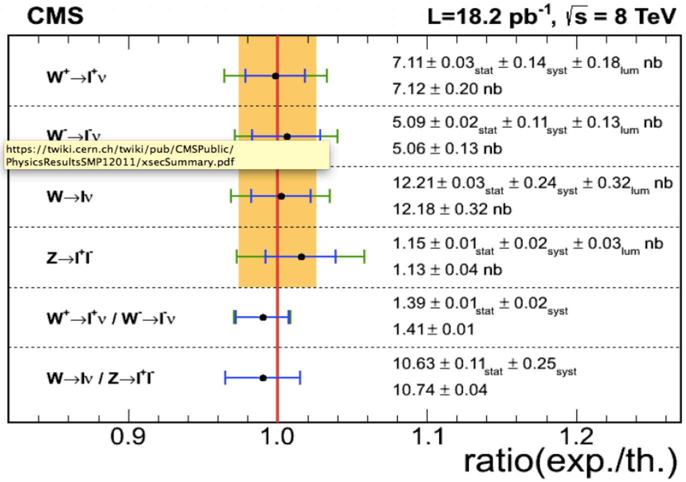
LO (Drell-Yan) + NLO

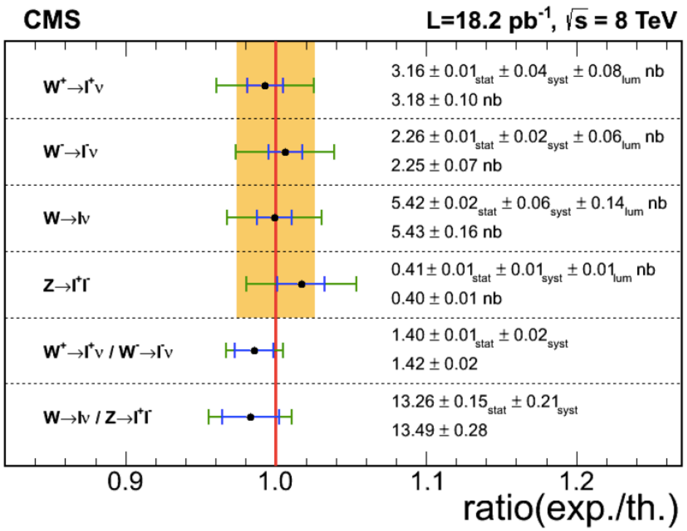
W and Z productions vs. √s



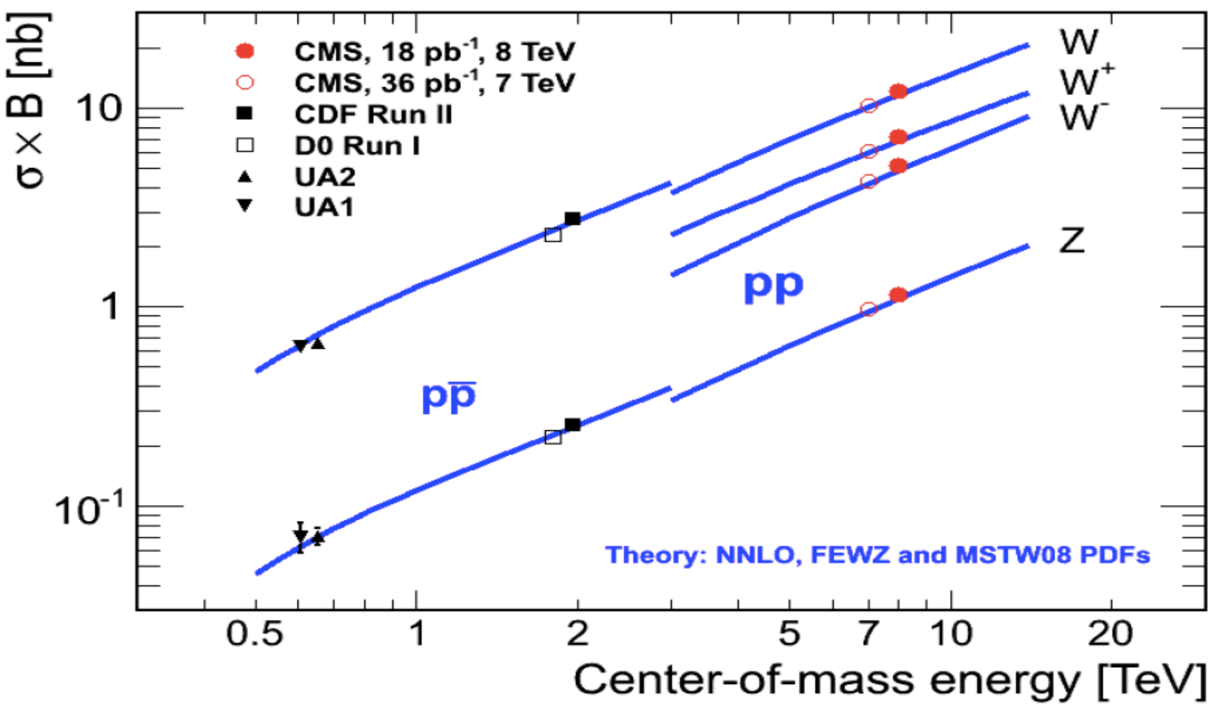
LO (Drell-Yan) + NLO

8TeV Inclusive





Precise measurements already with ~ 10 pb^{-1}



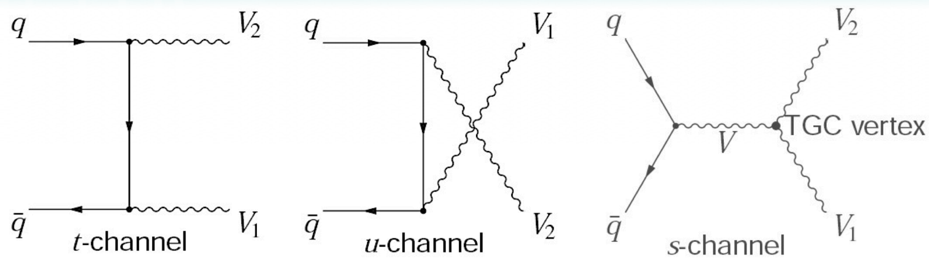
CMS-SMP-12-011

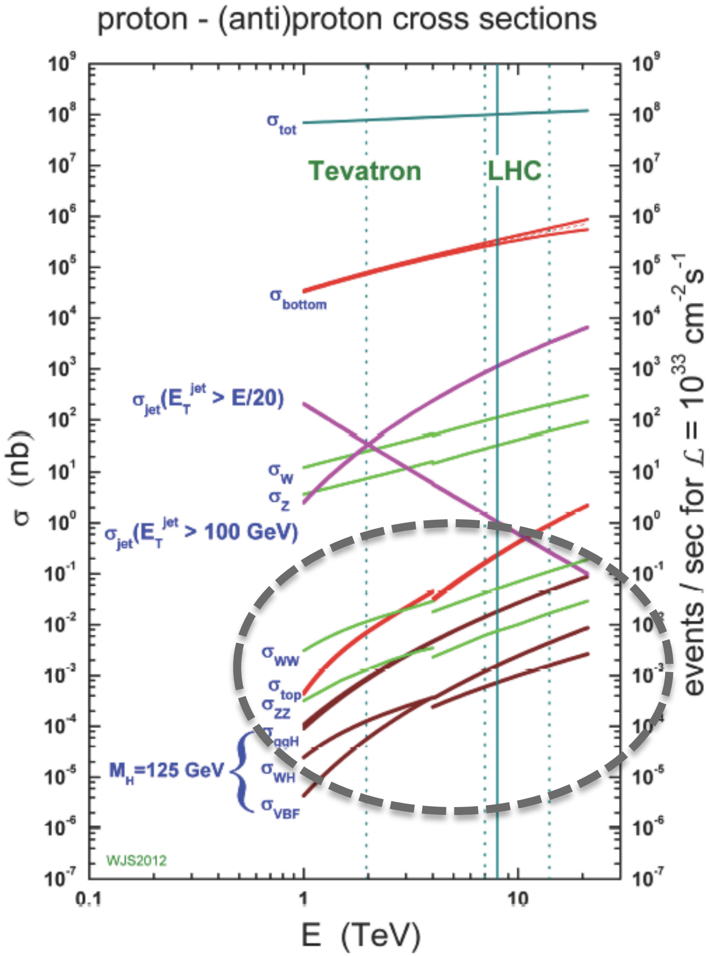
8TeV

Vector boson production is an important benchmark for QCD. EWK Deviations from SM would indicate New Physics.

Di-Boson production at LHC

Standard di-boson production:
γγ, Wγ, Zγ, WW, WZ, ZZ
is competing with Higgs production



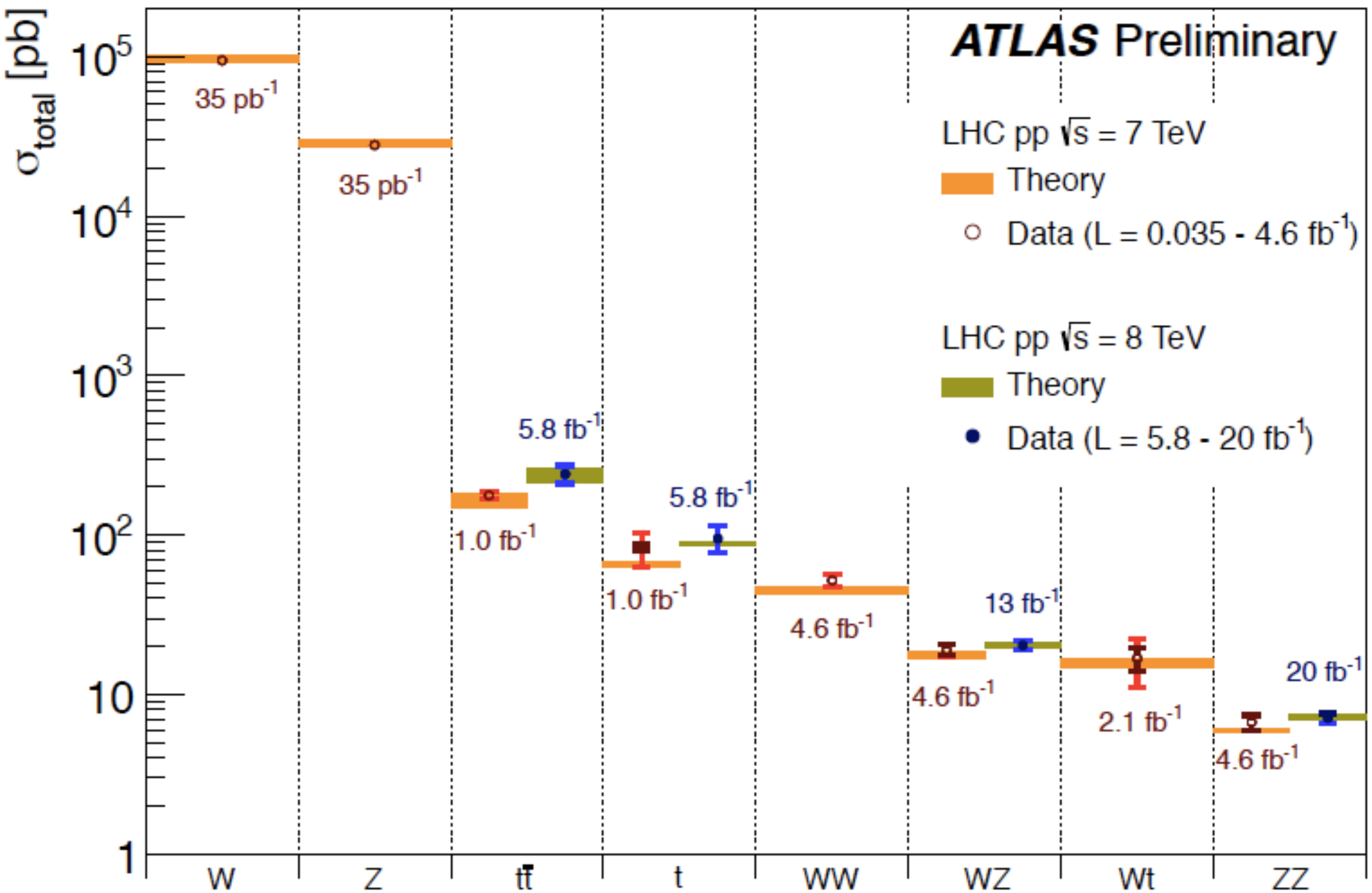


Cross section measurements of multi-boson production:

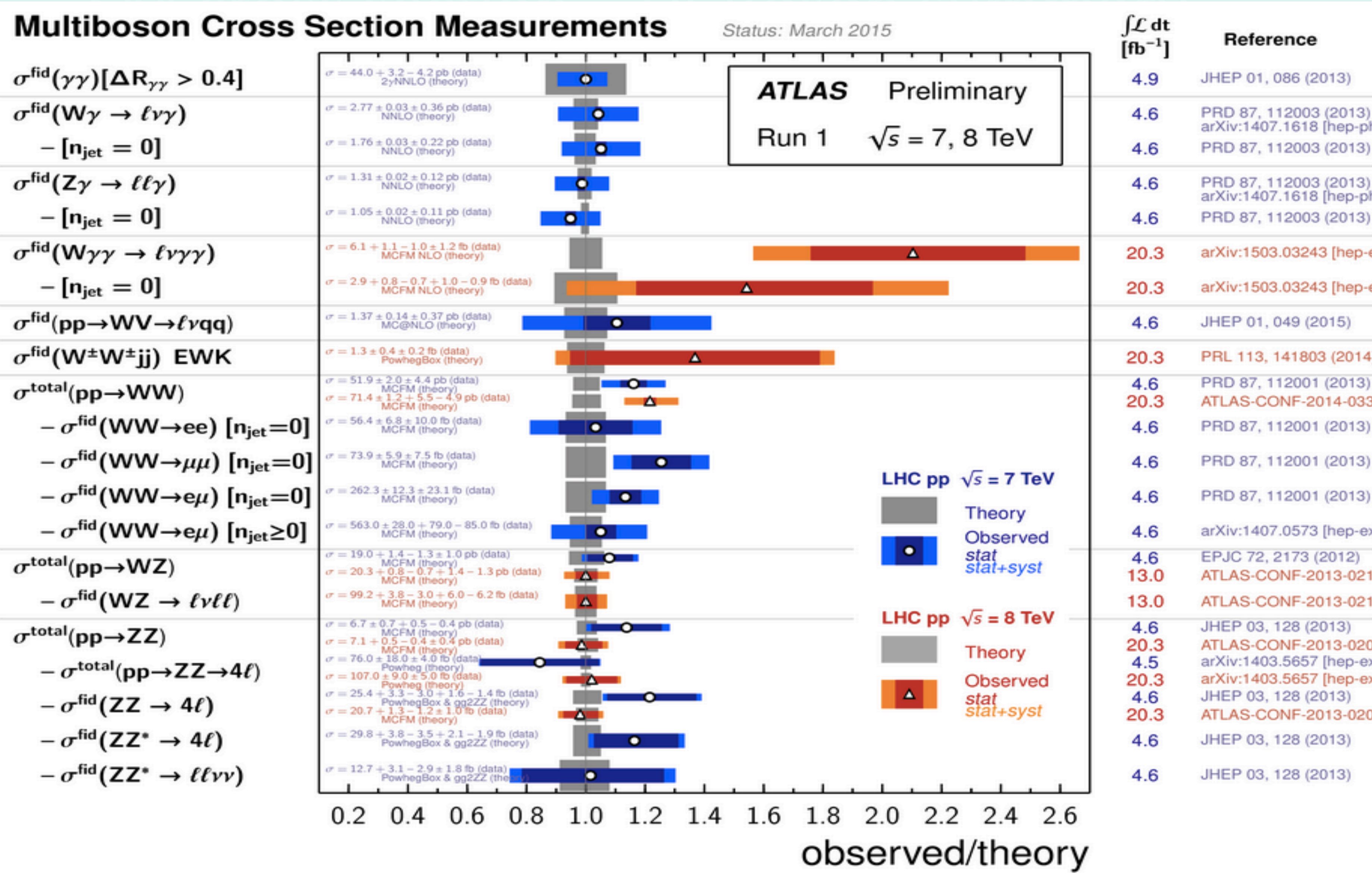
- Fundamental test of the Standard Model (SM) at the TeV scale
- Probe vector-boson self-interaction. Anomalous Triple (TGC) and Quartic Gauge Couplings (QGC) are probes of new physics.
- Irreducible background for Higgs boson studies and many beyond SM searches

Summary of W & Z cross sections

ATLAS and CMS have measured the diboson production cross sections of Wγ, Zγ, WW, WZ and ZZ at √s = 7 and 8 TeV

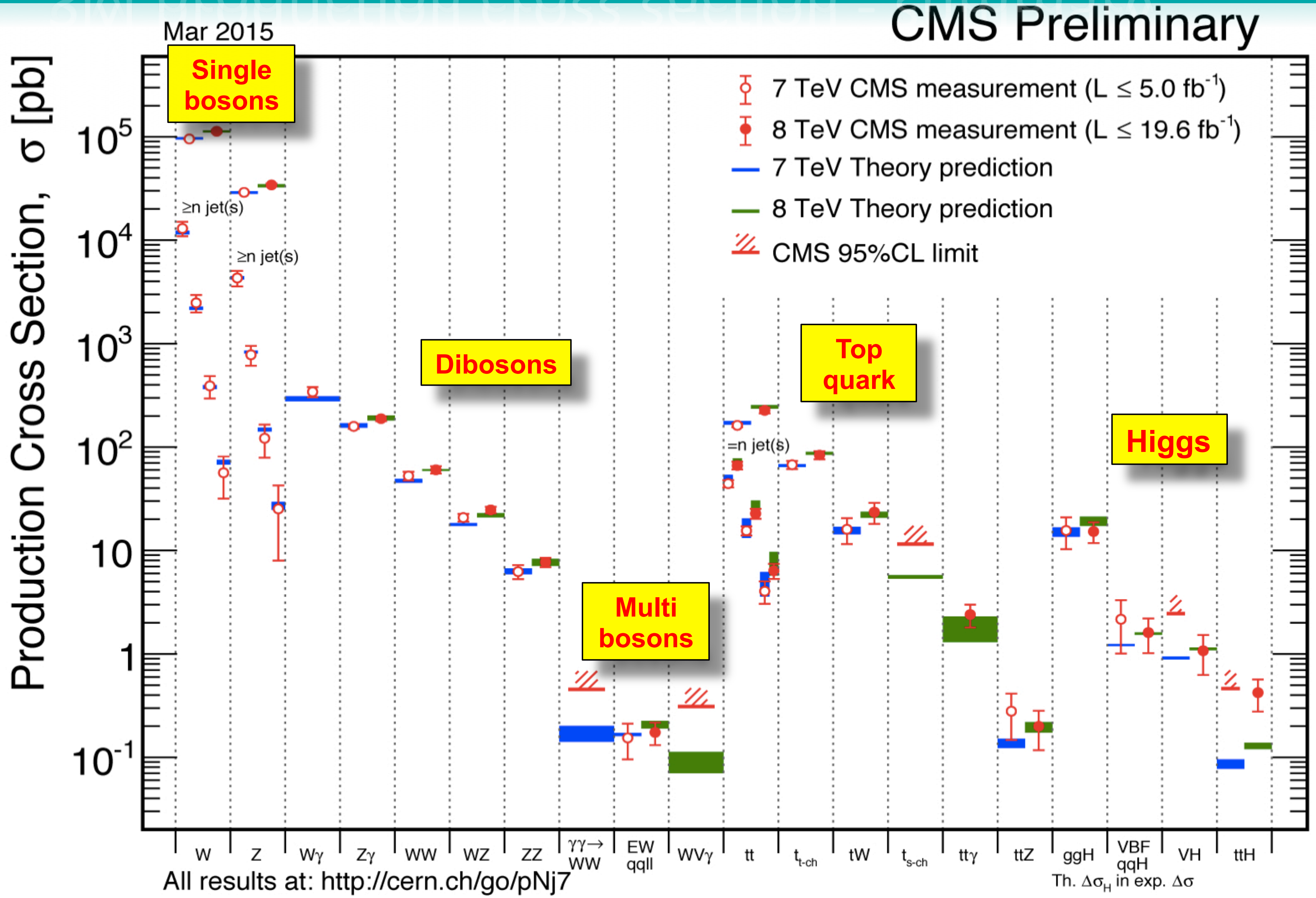


SM cross section – Di-Boson summary

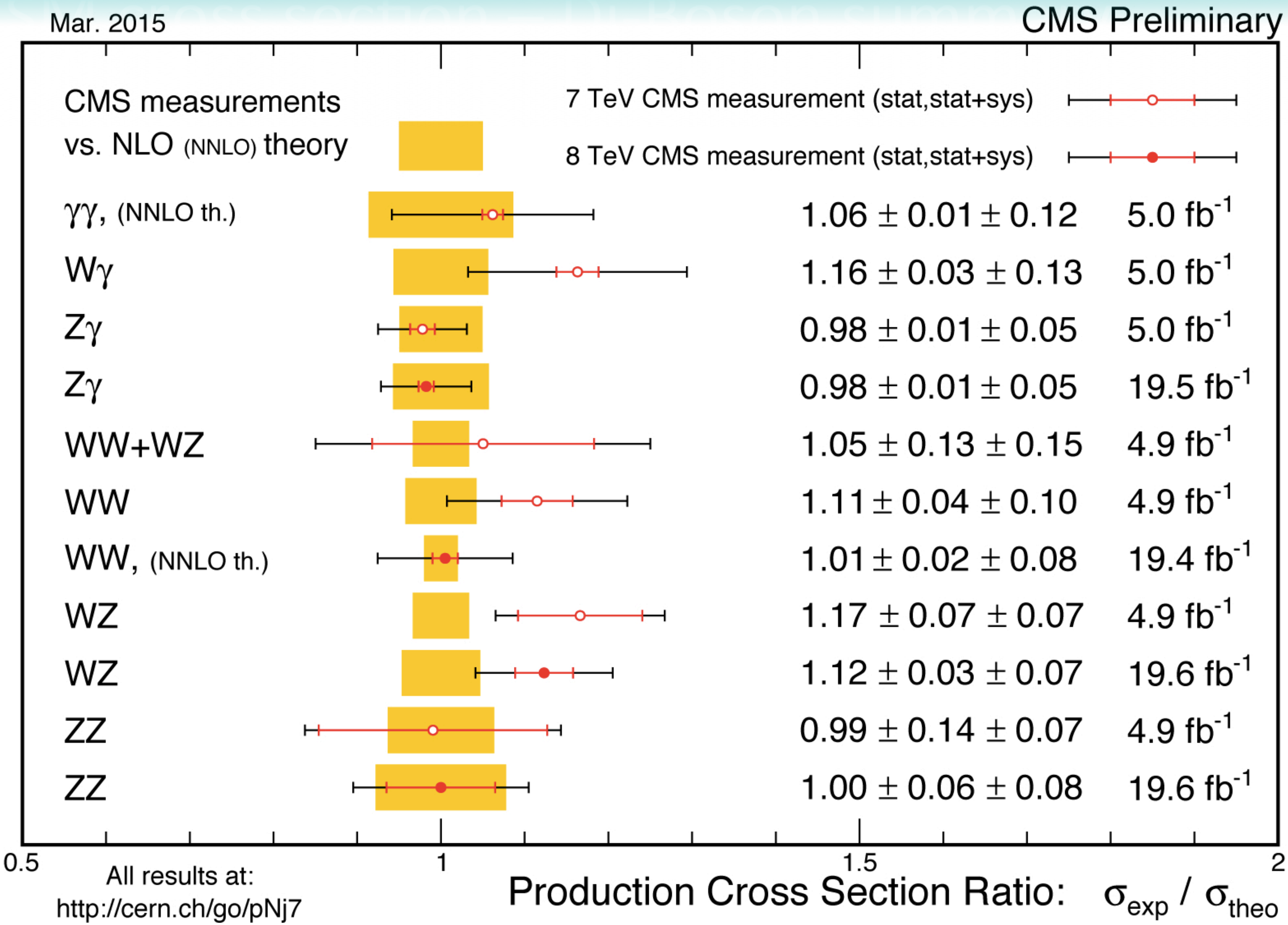


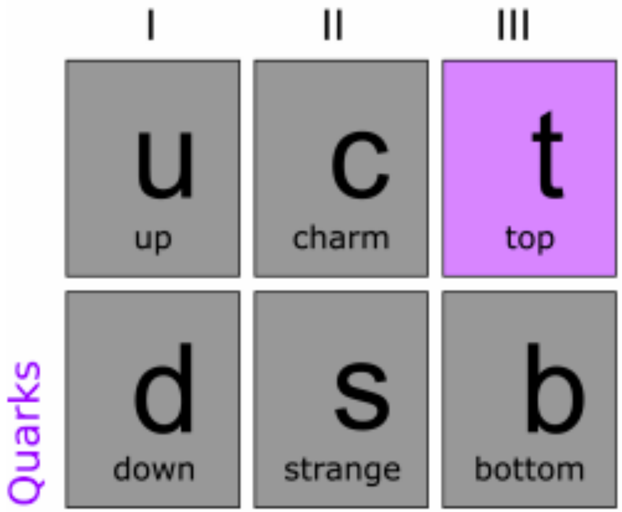
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsCombined

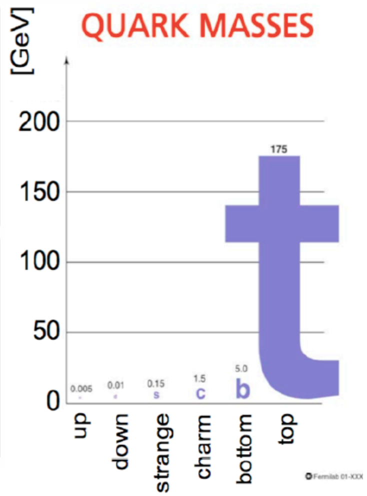
SM production cross section - summary

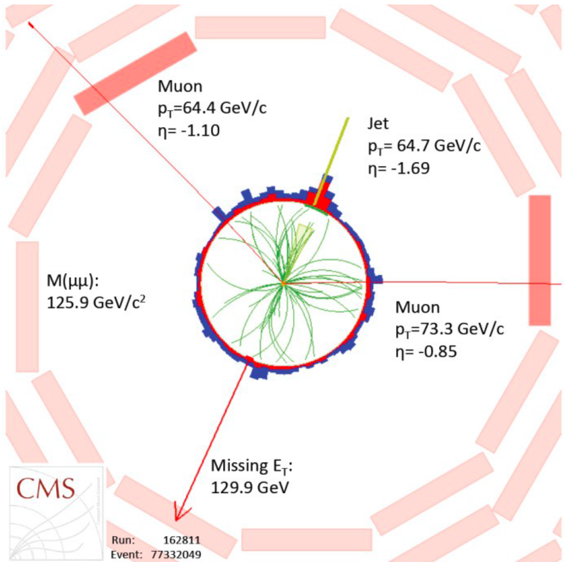


SM cross section – Di-Boson summary



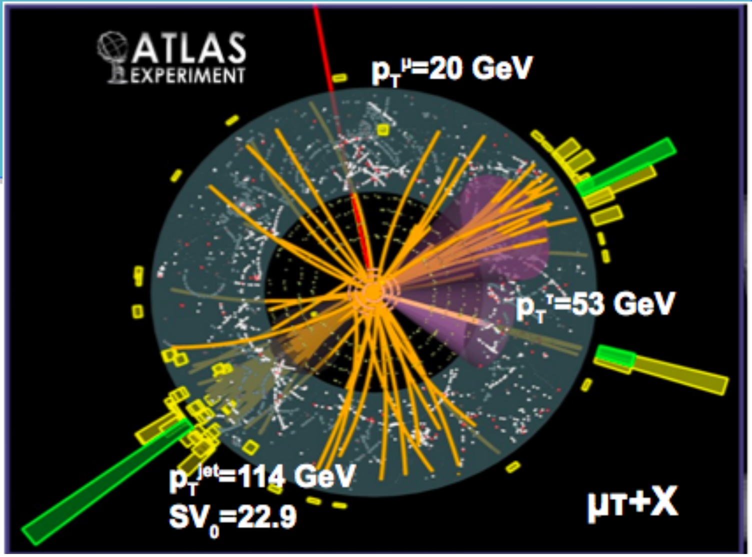






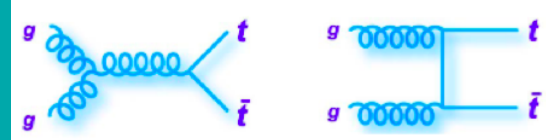
Heavy Flavour Physics – Top quark

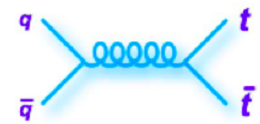
LHC is a top factory!



Top pair production

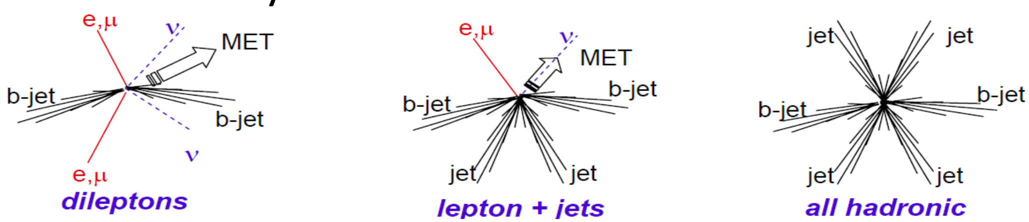
- Top is the heaviest quark
- Large mass, coupling to the Higgs ~1 → no hadronization
- ttbar and single top processes are significant backgrounds to Higgs and for many BSM searches



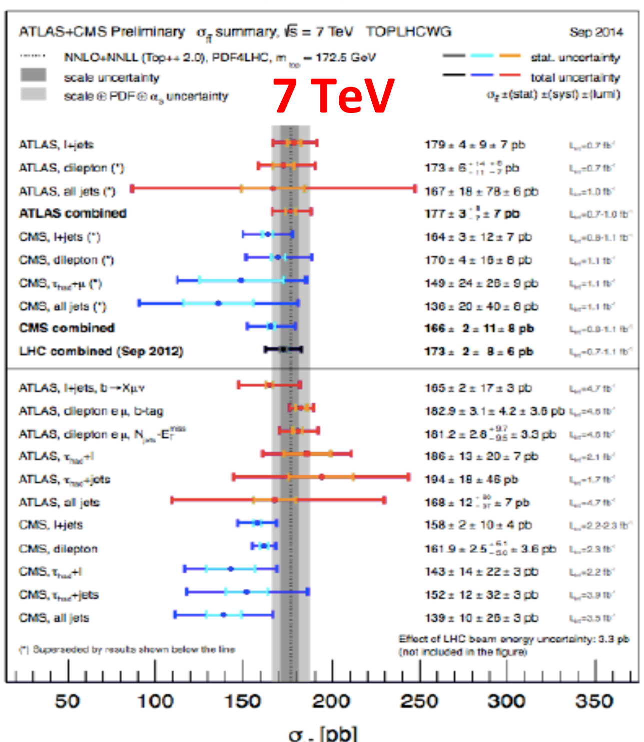


	LHC (7TeV)	Tevatron
gg	~80%	~15%
$q\bar{q}$	~20%	~85%

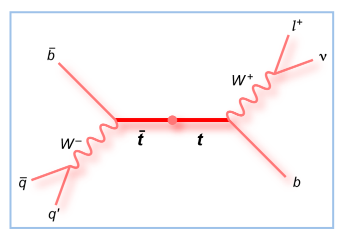
tt production dominated by gluon fusion at LHC (~90%)

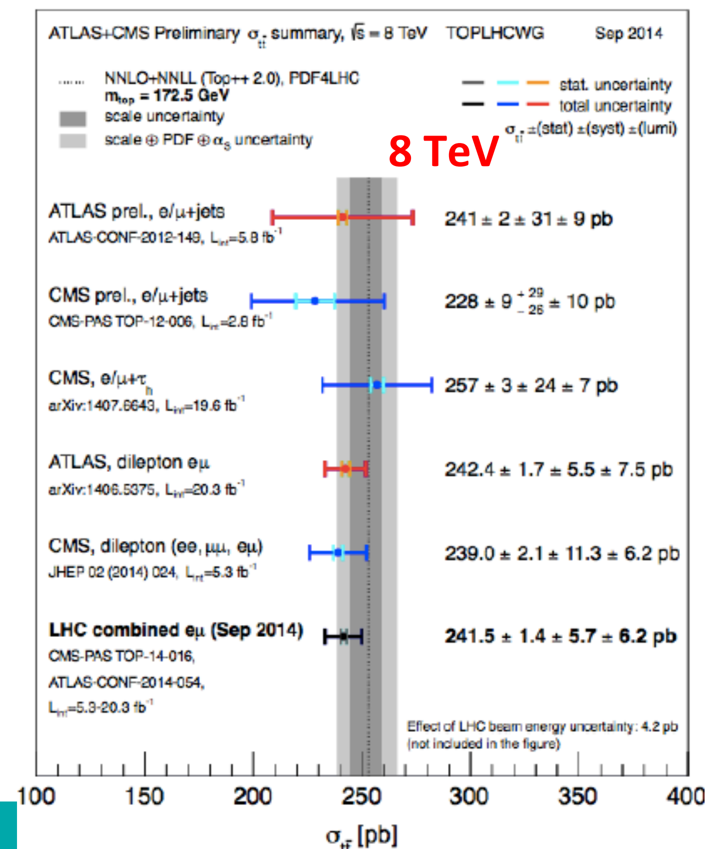


dileptons	lepton + jets	all hadronic
BR(μ,e)~6%	BR(μ,e)~34%	BR~46%
Bg: Z+jets	Bg: W+jets	Bg: QCD



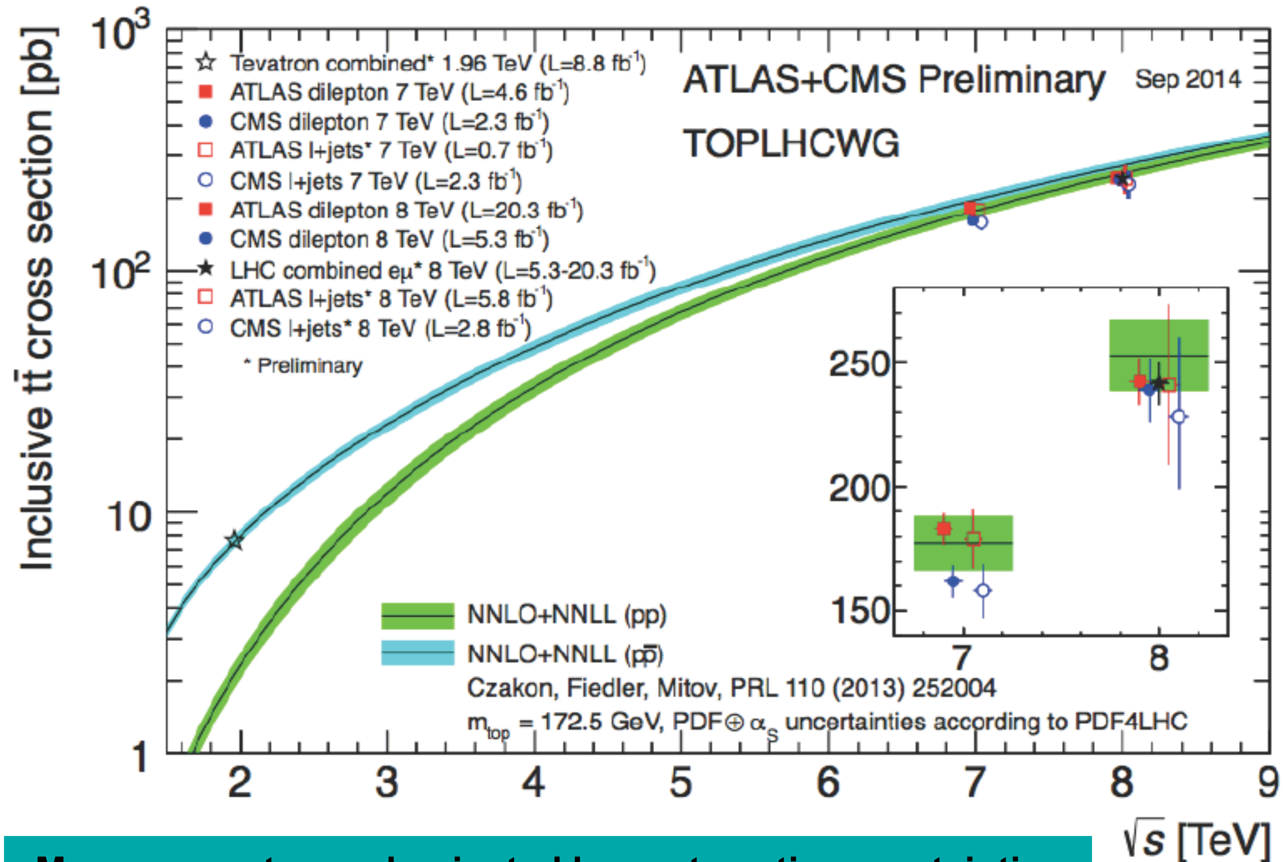
In SM:
BR(t → W+b) ~100%
→ W decay modes define top states





Top pair cross section

– Cross-check using different final channels and reconstruction techniques



ATLAS: EPJ C74 (2014) 3109

CMS: JHEP 02 (2014); JHEP 11 (2012) 067

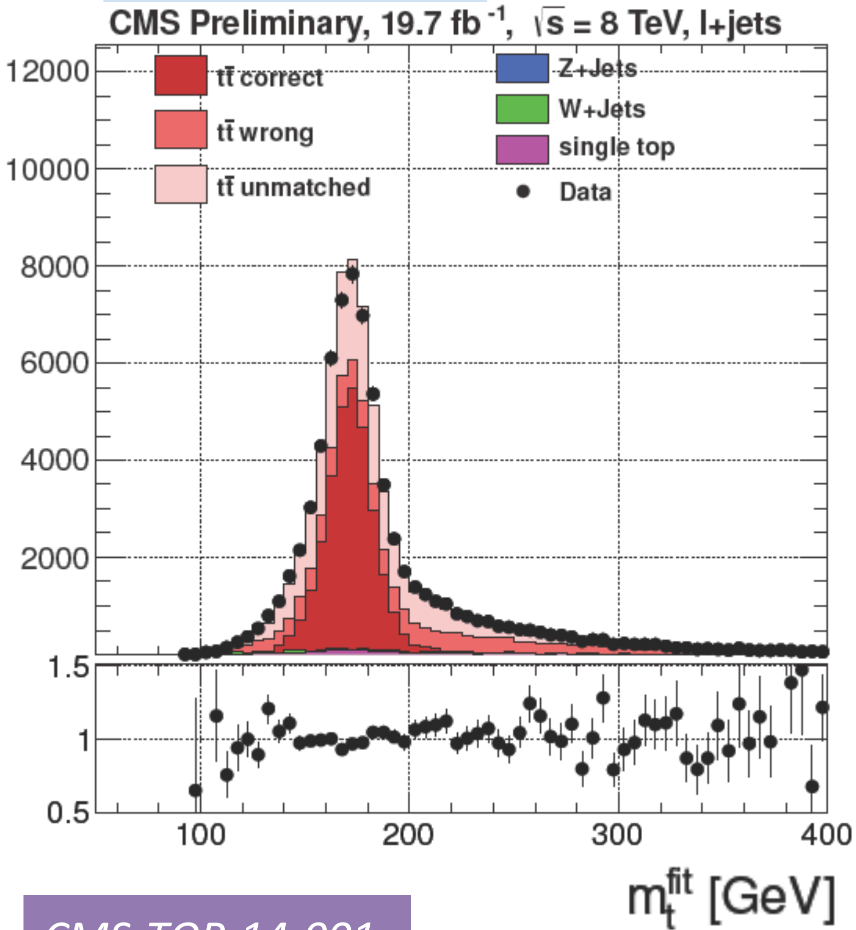
Measurements are dominated by systematic uncertainties

ATLAS: new results in arXiv:1504.04251

ATLAS and CMS 7/8 TeV results are compatible between them and in agreement with theoretical predictions (approx. NNLO): $\sigma_{t\bar{t}}$(8TeV) = 241.5 ± 8.5 pb

Top quark mass: two most precise measurements

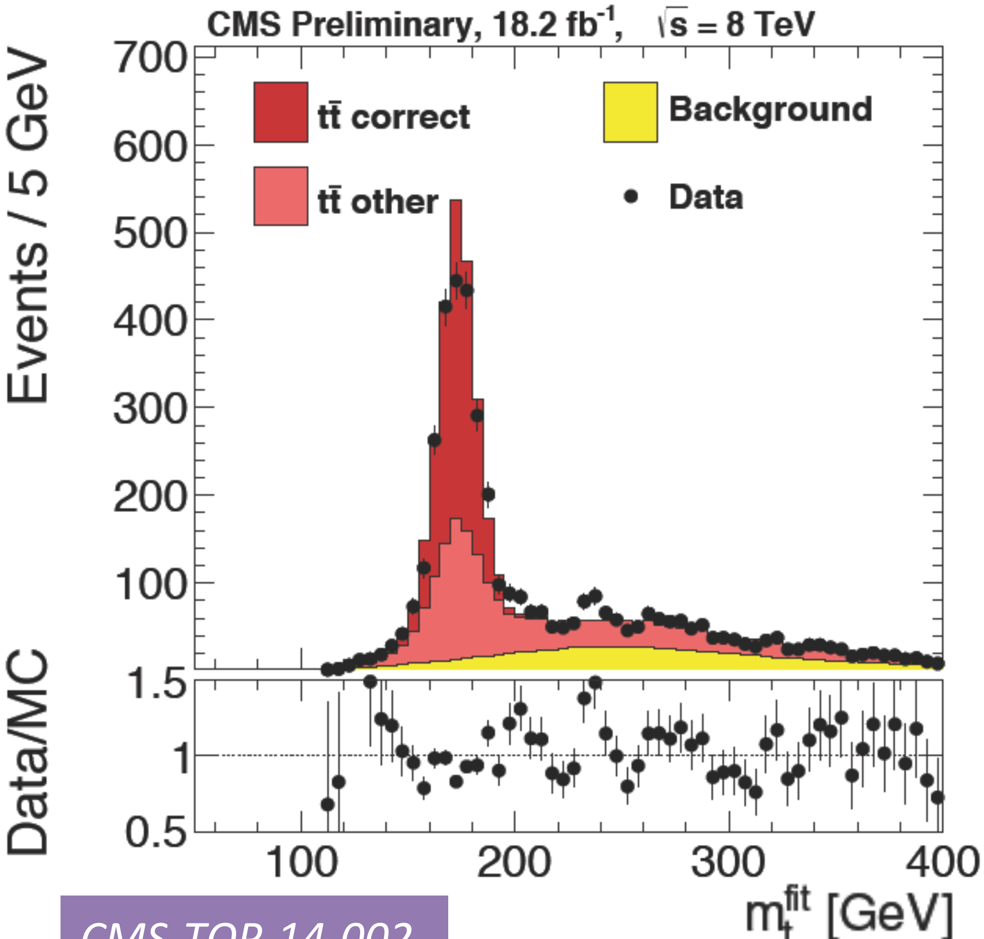
Lepton+Jets



CMS-TOP-14-001

$$m_t = 172.04 \pm 0.19_{stat} \pm 0.75_{syst}\ \text{GeV}$$

Hadronic



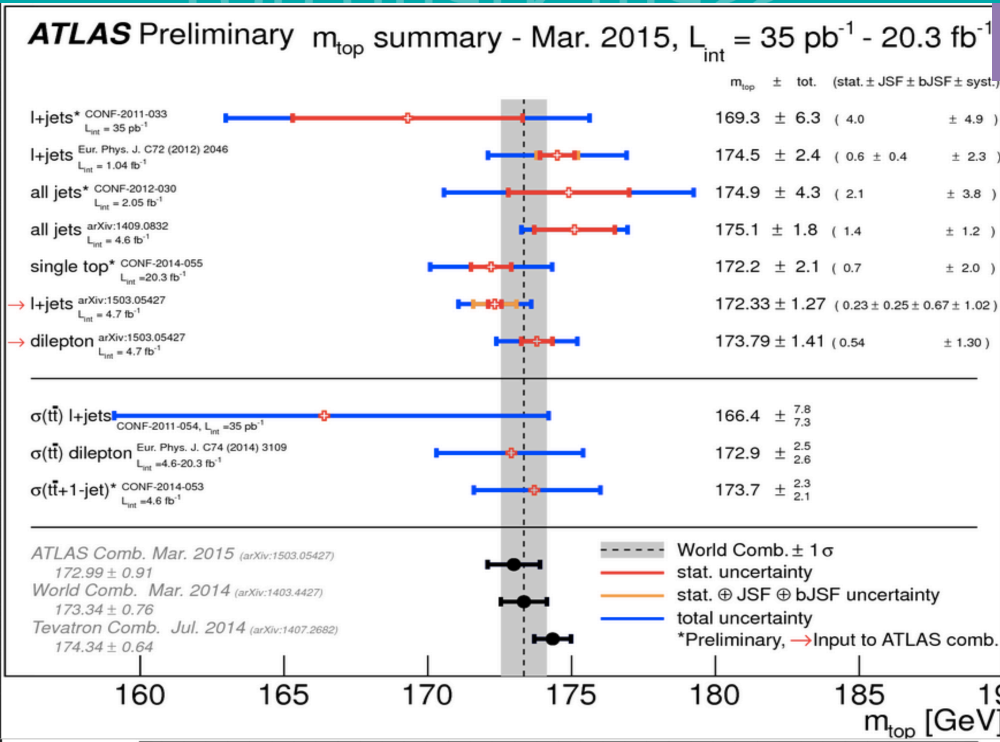
CMS-TOP-14-002

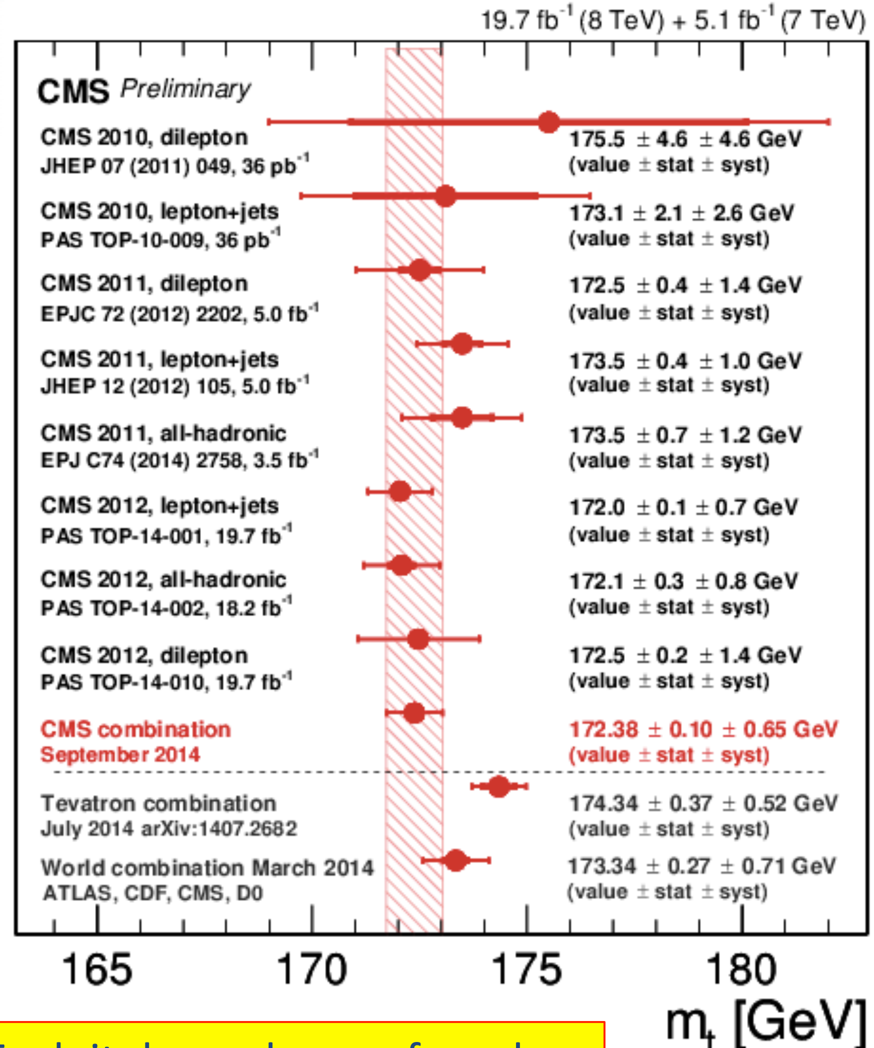
$$m_t = 172.08 \pm 0.36_{stat} \pm 0.83_{syst}\ \text{GeV}$$

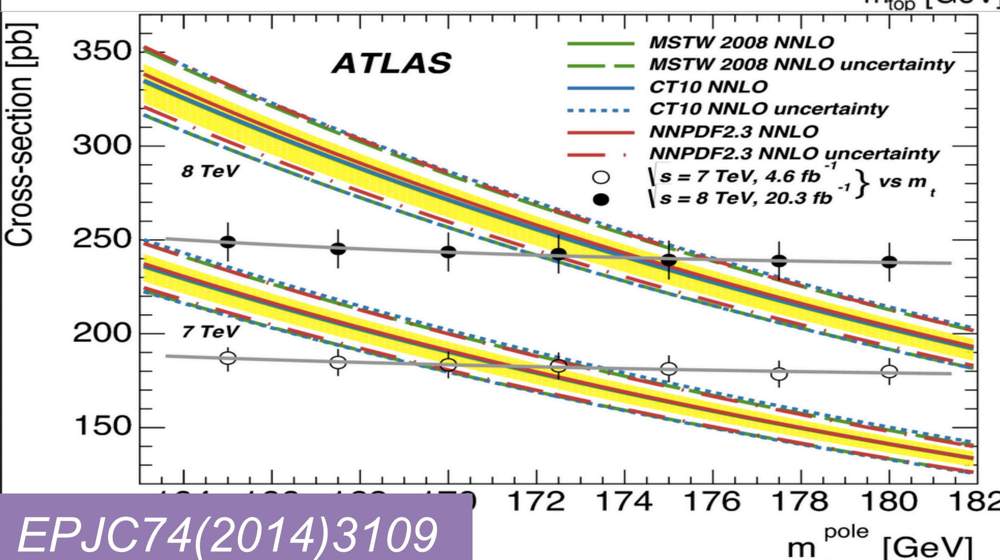
Top quark mass

arXiv:1503.05427

CMS-PAS-TOP-14-015





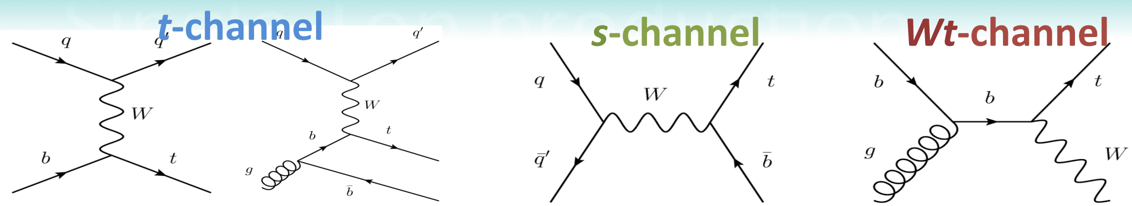


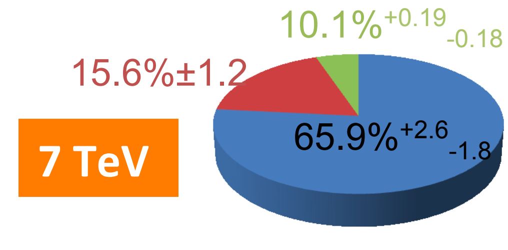
EPJC74(2014)3109

Exploit dependence of production cross section on top mass

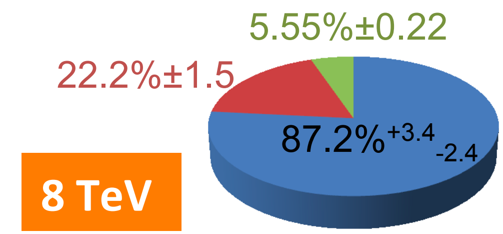
Single Top production

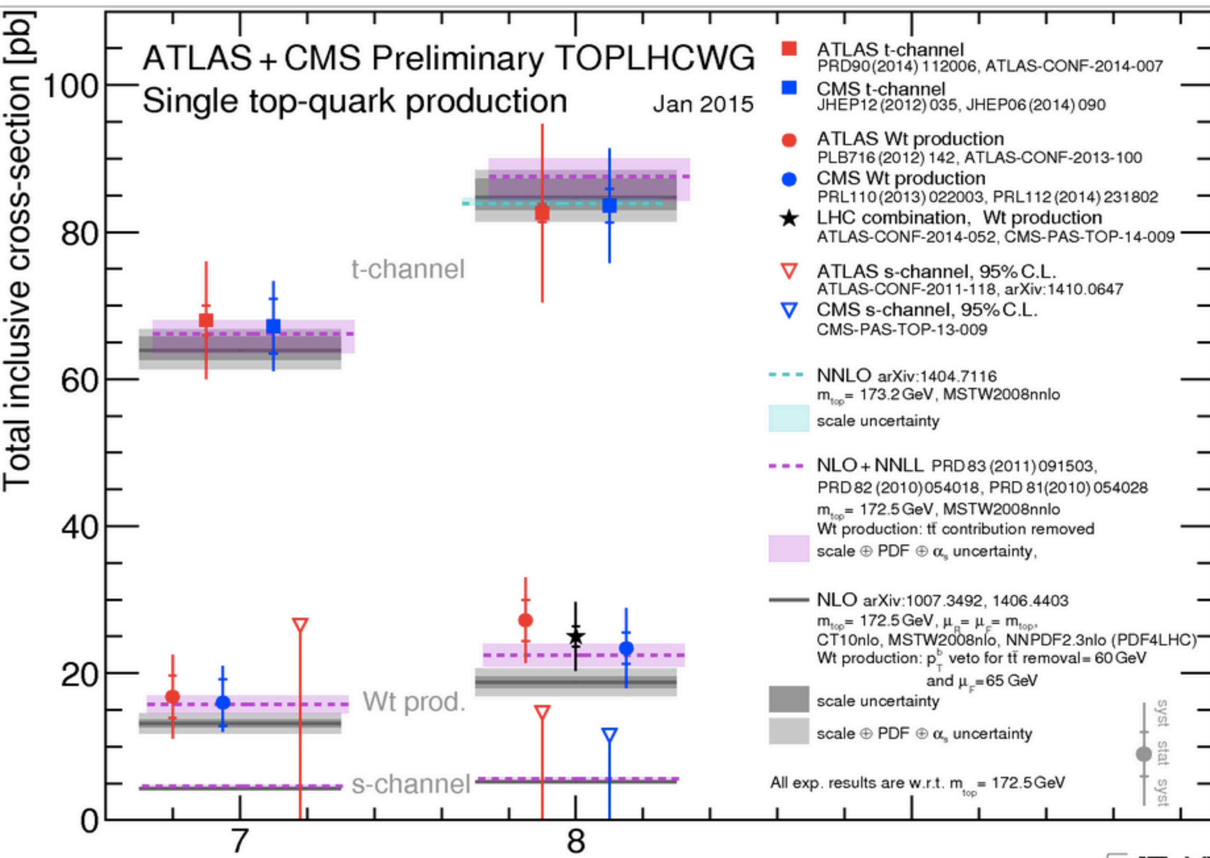
Collider	s-channel σ_{tb}	t-channel σ_{tqb}	tW-channel σ_{tW}
Tevatron $p\bar{p}$ (1.96 TeV)	1.05 pb	2.08 pb	0.22 pb
LHC pp (7 TeV)	4.63 pb	64.6 pb	15.7 pb
LHC pp (8 TeV)	5.55 pb	87.1 pb	22.2 pb

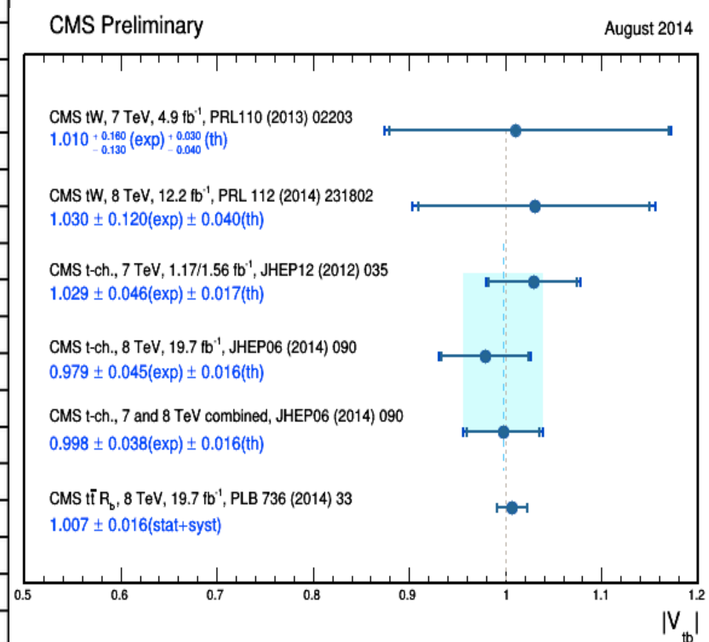


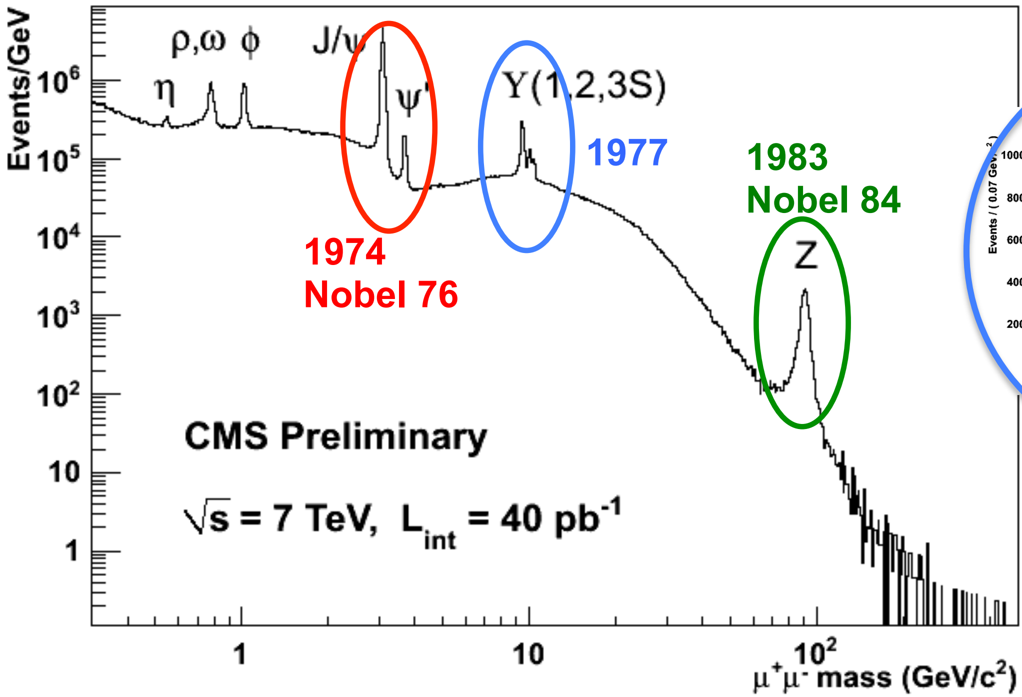


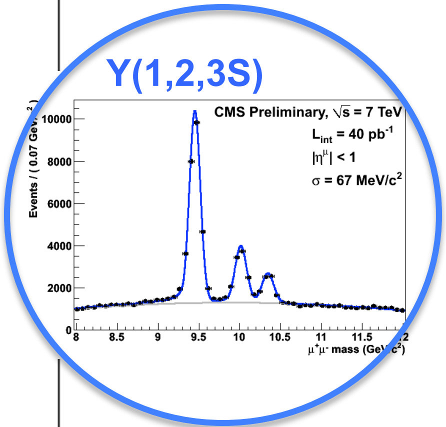
- Cross-sections for each channel (σ_t, σ_s, and σ_{Wt})
- Matrix Element / Couplings (V_{tb})







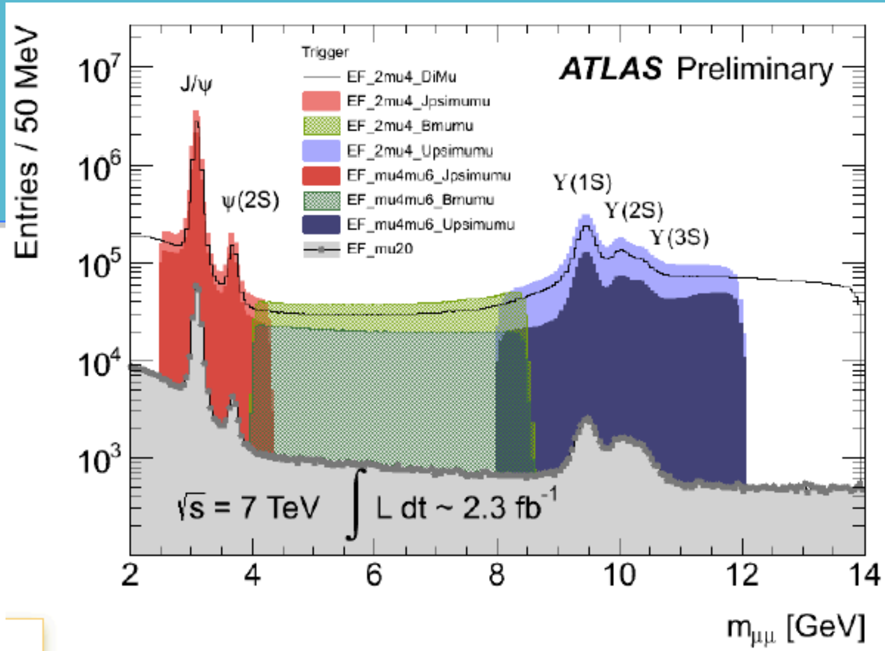




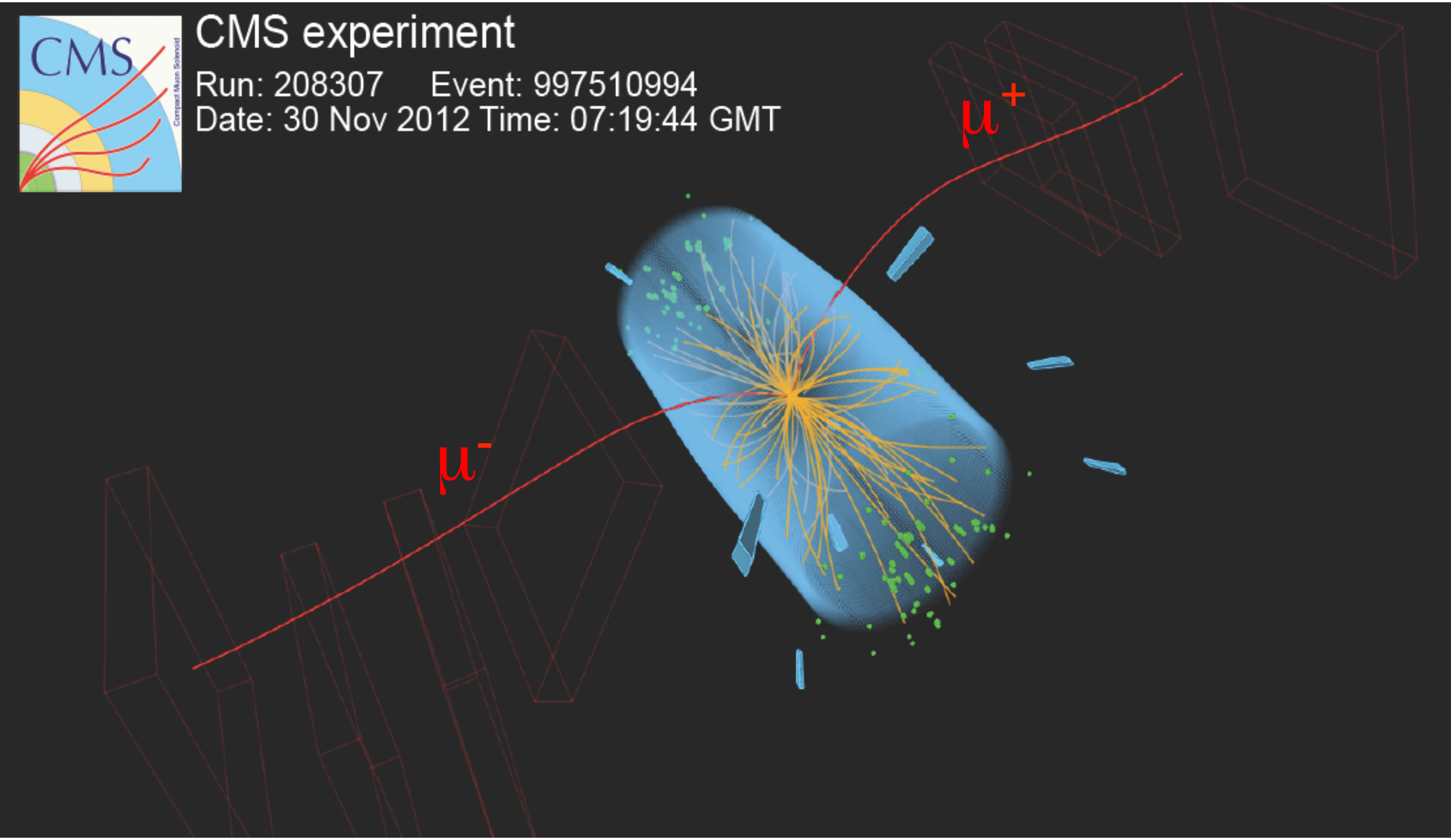
Heavy Flavour Physics – b & c quarks

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

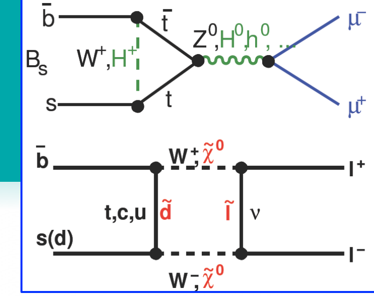
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/BPhysPublicResults



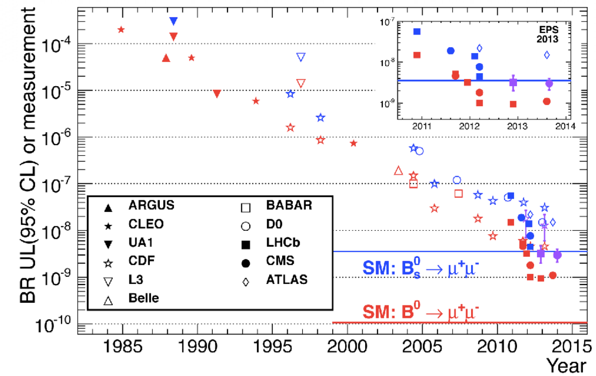
Observation of $B_s \rightarrow \mu^+\mu^-$



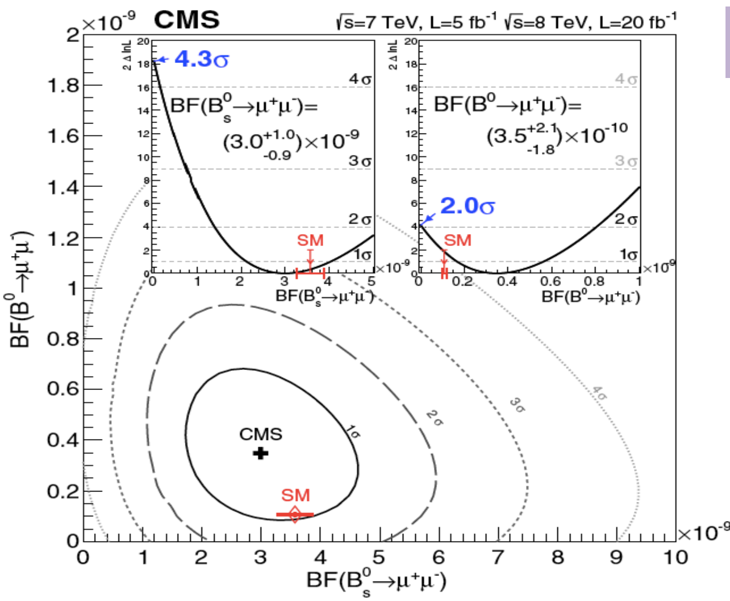
Search for $B_{s,d} \rightarrow \mu^+\mu^-$

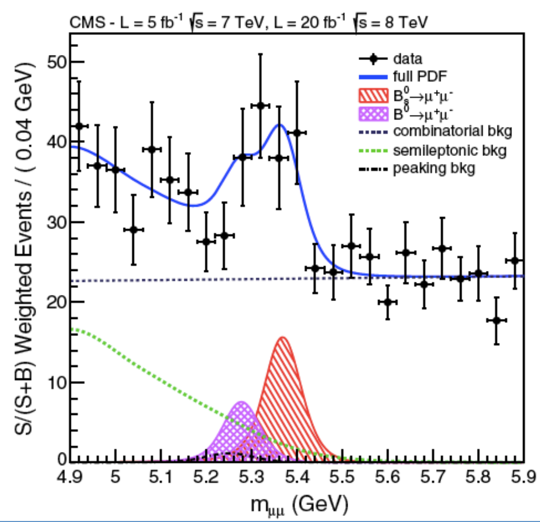


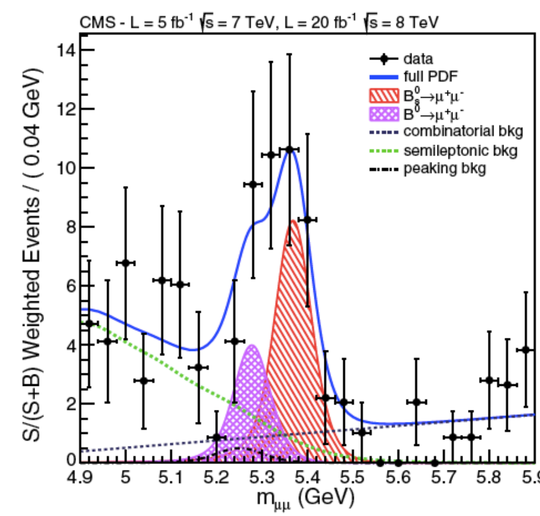
- Decay suppressed: forbidden at tree level, b→ s(d) FCNC transition through penguin or box diagrams
- SM predictions: $BR(B_s \rightarrow \mu\mu) = (3.65 \pm 0.23)\ 10^{-9}$
  $BR(B^0 \rightarrow \mu\mu) = (1.07 \pm 0.10)\ 10^{-10}$



PRL111 (2013) 101804





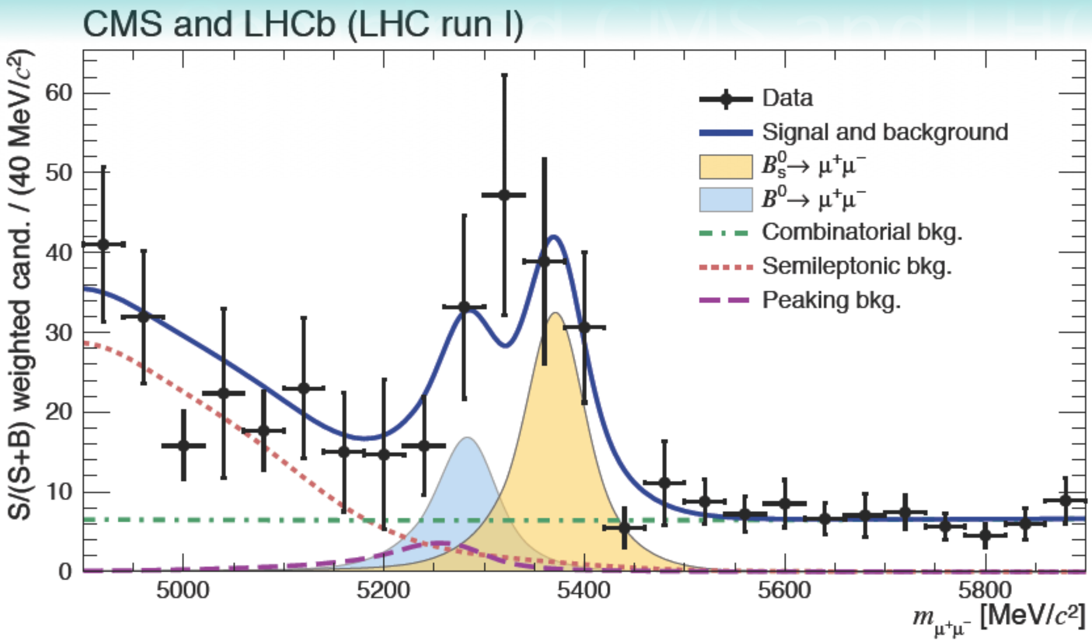


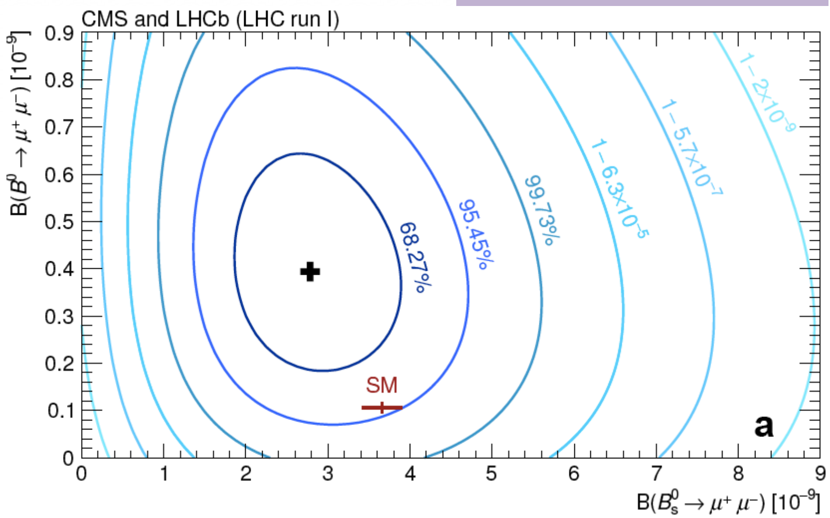
$BR(B_s \rightarrow \mu\mu) = (3.0\ ^{+0.9}_{-0.8}\ \text{stat}\ ^{+0.6}_{-0.4}\ \text{syst})\ 10^{-9}$; 4.3 σ (expected 4.8 σ)

$BR(B^0 \rightarrow \mu\mu) = (3.5\ ^{+2.1}_{-1.8}\ \text{stat\&syst})\ 10^{-10}$; 2 σ

Combined CMS and LHCb analysis

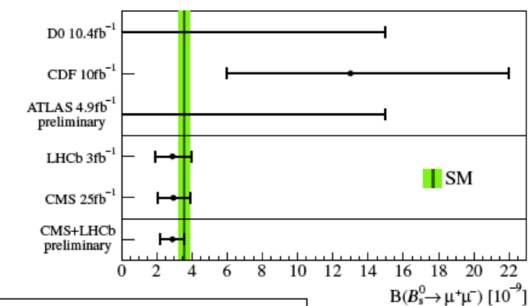
arXiv: 1411.4413

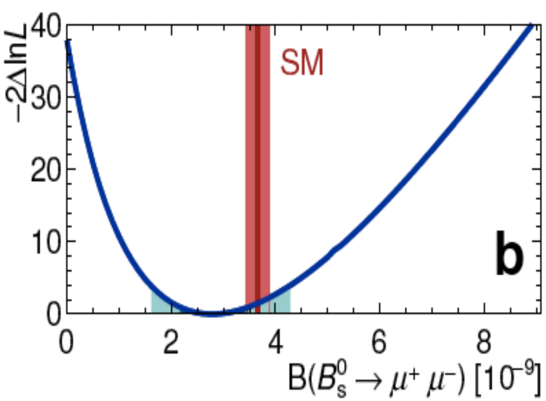


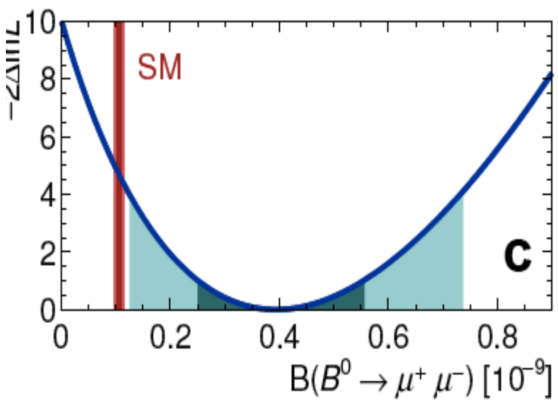


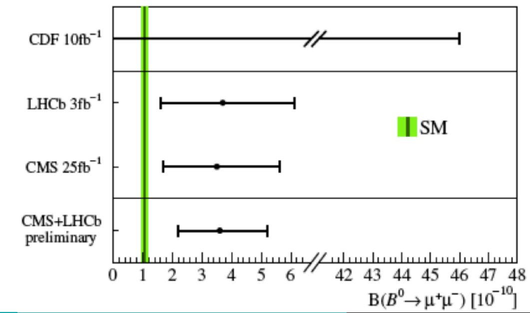
$BR(B_s \to \mu\mu)=(2.8\ ^{+0.7}_{-0.6})\ 10^{-9}$ (6.2 σ) stat. signif.

$BR(B^0 \to \mu\mu)=(3.9\ ^{+1.6}_{-1.4})\ 10^{-10}$ (3.2 σ)

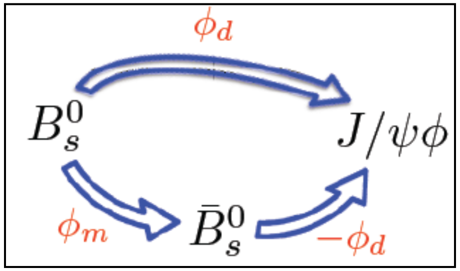


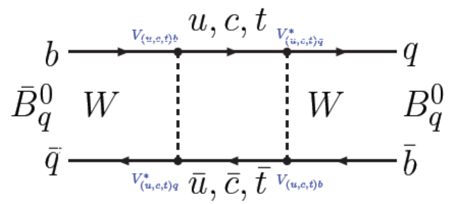






Mixing Induced CPV



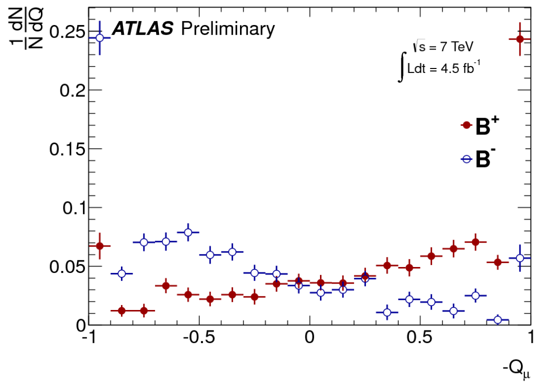


- Consider here the decay

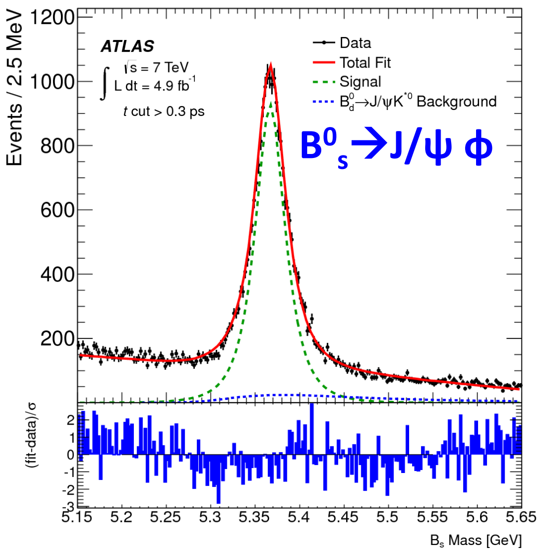
  $B^0_s \rightarrow J/\psi\ \phi$
- Interference between mixing and decay gives rise to a CPV phase:

  $\varphi_s = \varphi_m - 2\varphi_d$
- Mixing phase φ_m from $\Delta B=2$ box diagram → sensitive to NP

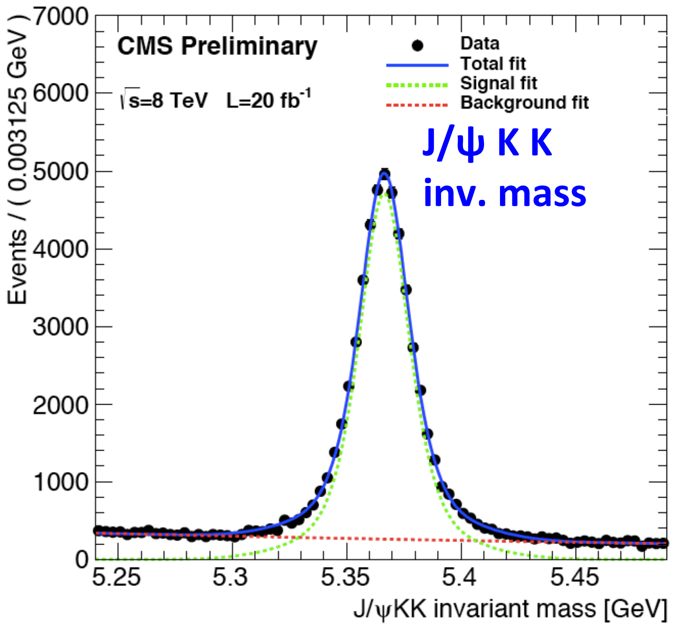
OS tagging calibration on $B^+ \rightarrow J/psi\ K^+$



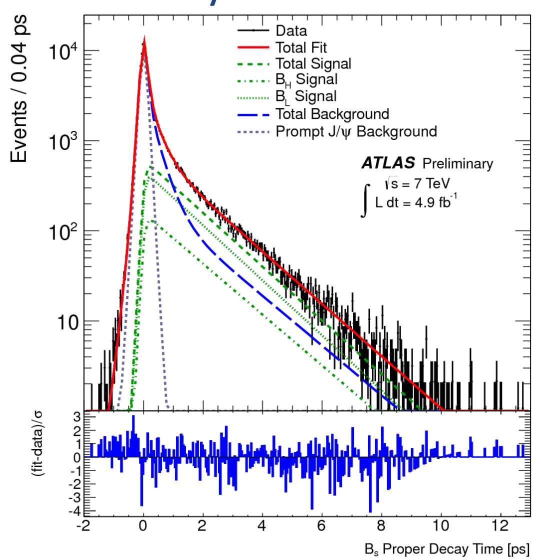
CMS-PAS-BPH-13-012; PRD 90 (2014) 052007



Fit projection on $m(B_s)$



Likelihood fit projection on decay time

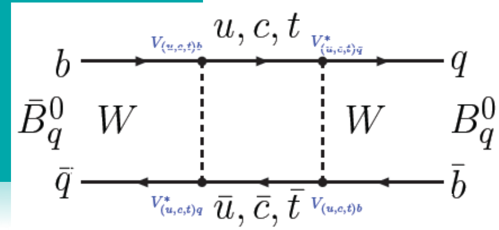


Mixing Induced CPV

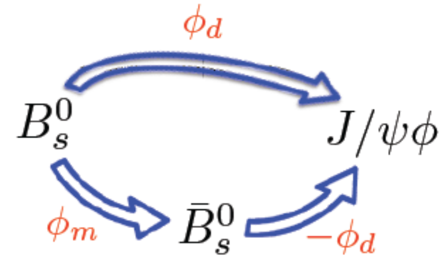
$$\phi_s^{SM} = -2arg\left(\frac{V_{ts}V_{tb}^*}{V_{cs}V_{cb}^*}\right) = -0.036 \pm 0.002\,\mathrm{rad}$$

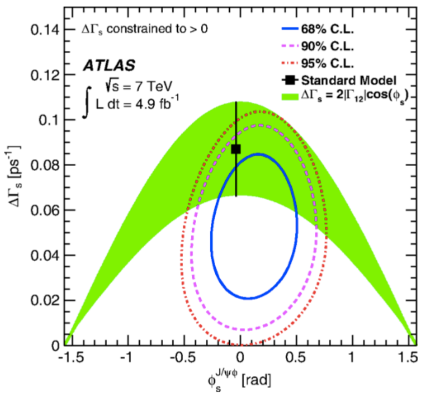
$$\Delta\Gamma_s = 0.087 \pm 0.021\ \mathrm{ps}^{-1}$$

SM predictions

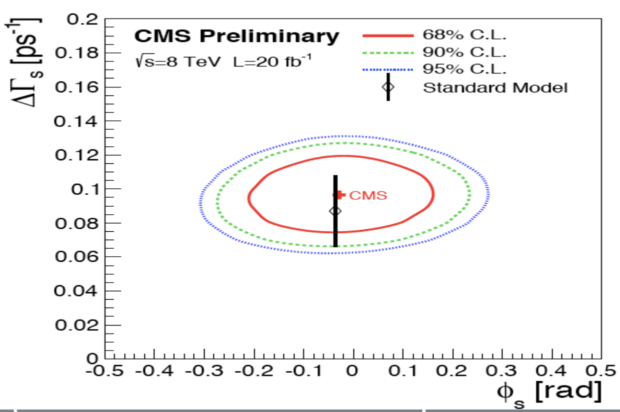


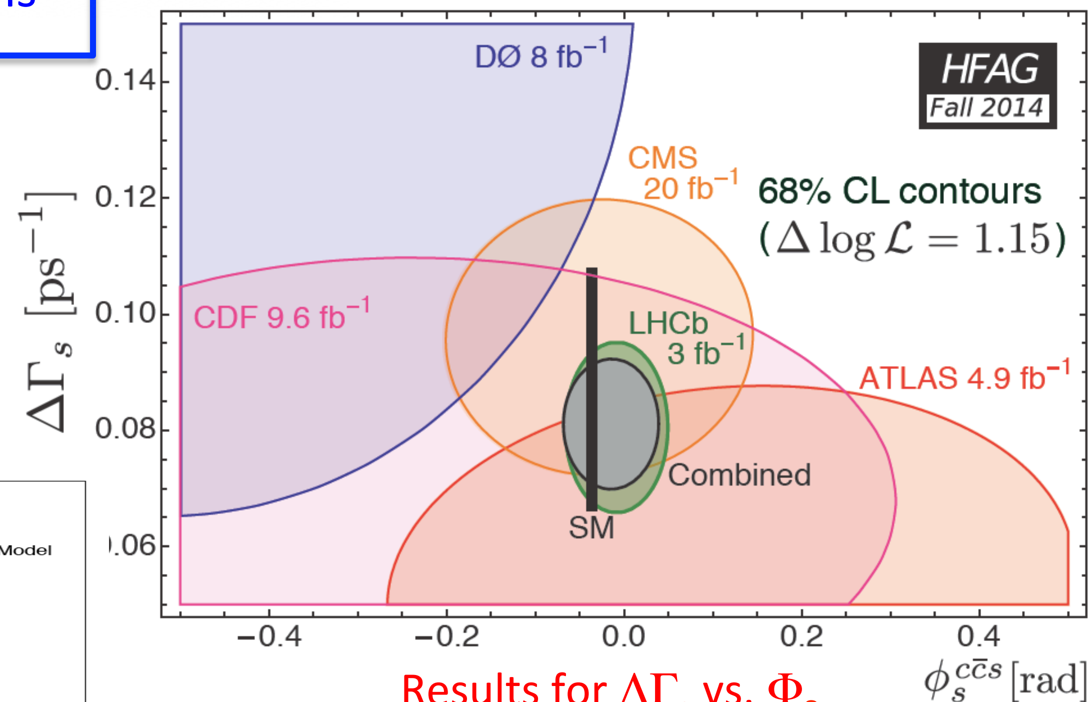
$B^0_s \rightarrow J/\psi\ \phi$





Likelihood fit projection on decay time (no selection on decay time in this analysis)





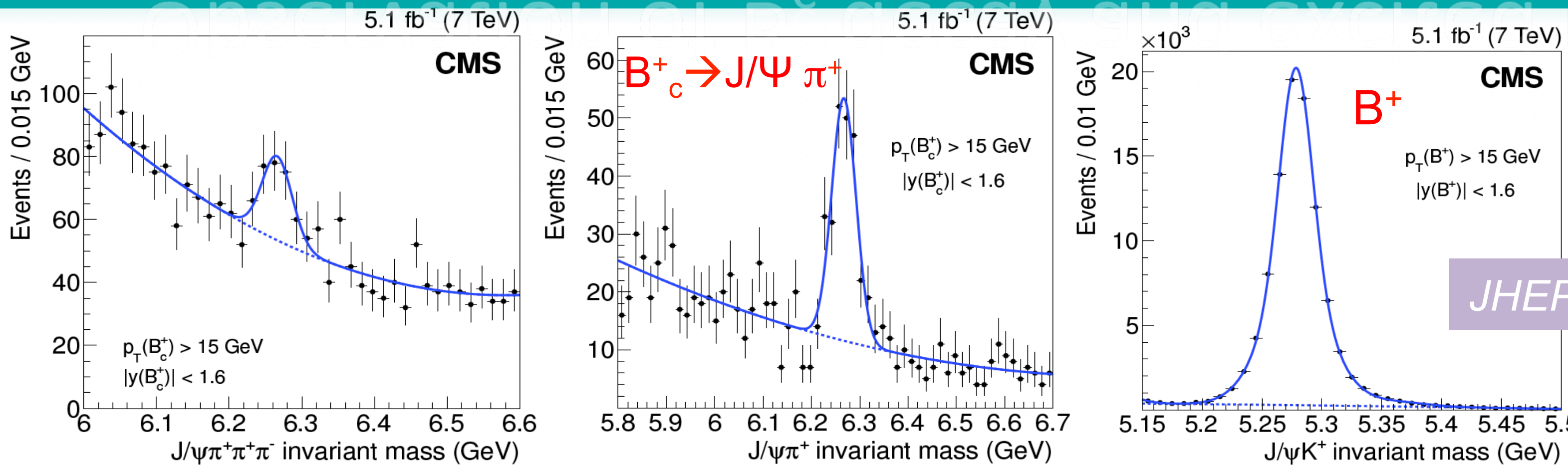
Results for $\Delta\Gamma_s$ vs. Φ_s

Experiment	$\Delta\Gamma_s$ (ps^{-1})	ϕ_s (rad)
ATLAS (4.9/fb)	0.053±0.021±0.010 *	0.12±0.25±0.05 *
CMS (20/fb)	0.096±0.014±0.007	−0.03±0.11±0.03
LHCb (3/fb)	0.0805±0.0091±0.0032	−0.058±0.049±0.006

Result in agreement with SM within current uncertainties

*ATLAS result with full statistics expected soon

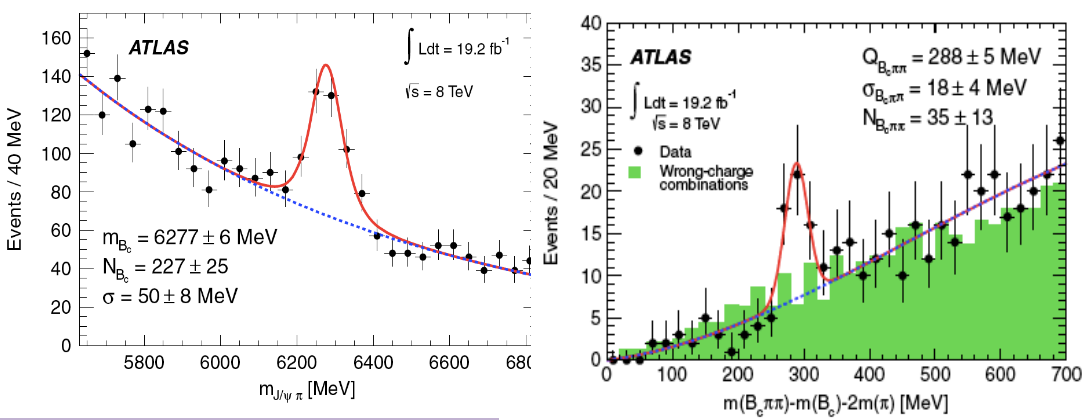
Observation of B_c decay and excited $B_c(2S)$



JHEP 01 (2015) 063

$\sigma(B^+_c)BR(B^+_c \rightarrow J/\Psi\ \pi^+)/\sigma(B^+)BR(B^+ \rightarrow J/\Psi\ K^+) = (0.48 \pm 0.05\ (stat) \pm 0.03\ (syst)\ \pm 0.05\ (\tau_{Bc}))\%$

$BR(B^+_c \rightarrow J/\Psi\ \pi^+\pi^+\pi^+)/BR(B^+ \rightarrow J/\Psi\ \pi^+) = (2.55 \pm 0.80\ (stat) \pm 0.33\ (syst)\ +0.04/-0.01\ (\tau_{Bc}))\%$

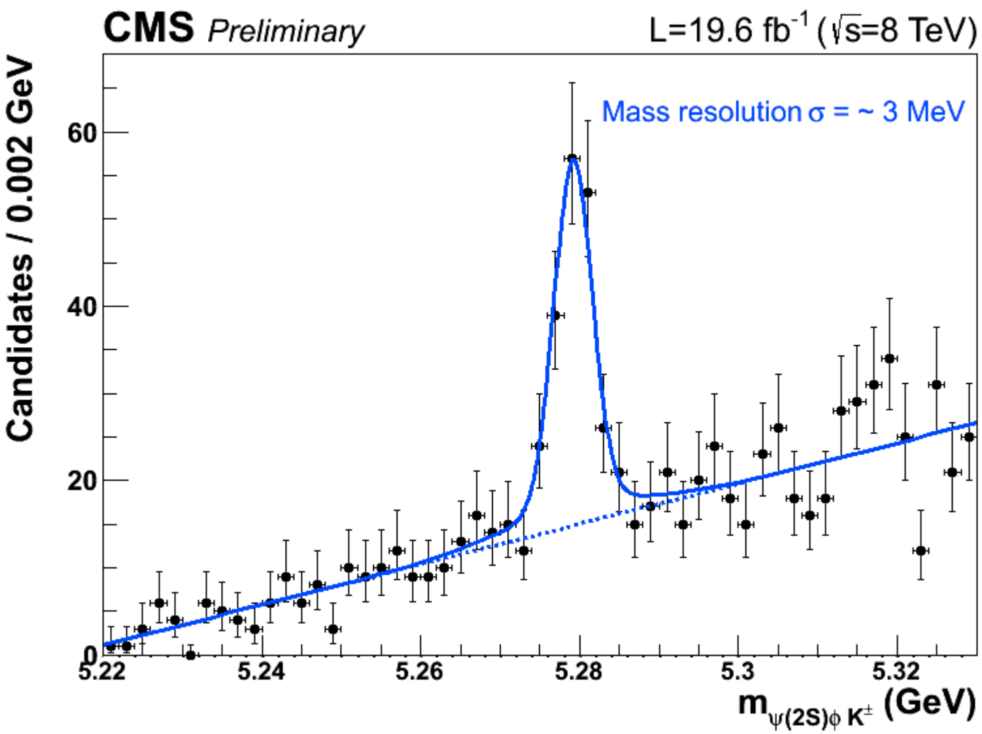


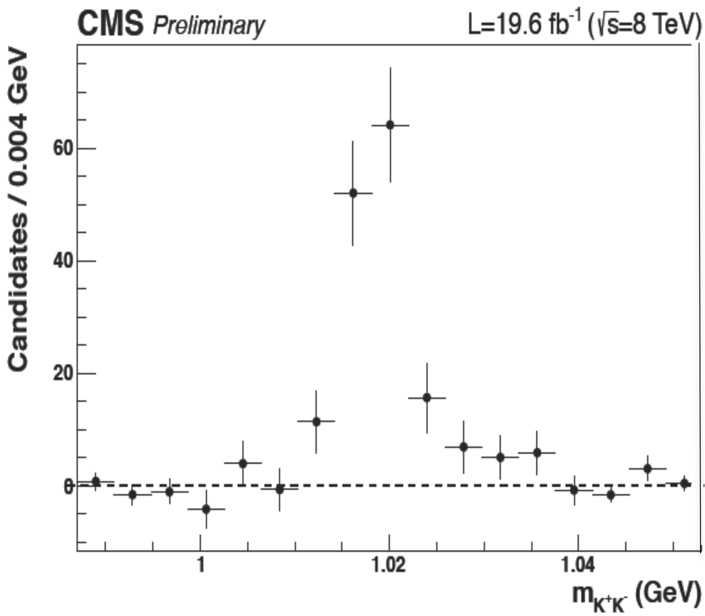
PRL 113 (2014) 212004

- Excited state of the $B^{\pm}_c$ meson observed in the its hadronic transition to the ground state $B^{\pm}_c \rightarrow J/\psi\pi^{\pm}$.
- 5.2 σ significance
- Mass of the observed state is 6842±4±5 MeV, consistent with expectations for $B^{\pm}_c(2S)$ meson.

Observation of B±→ψ(2S)Φ K±

NEW





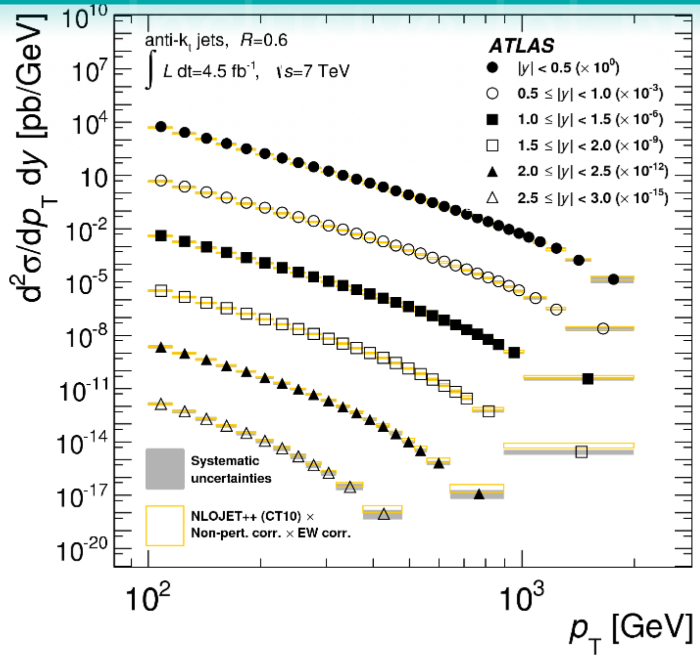
- About 144 candidates
- From $B^{\pm} \rightarrow J/\psi\ \Phi\ K^{\pm}$ decays study → first observation of the $B^{\pm} \rightarrow \psi(2S)\ \Phi\ K^{\pm}$ rare decay.
- BR measurement on going.

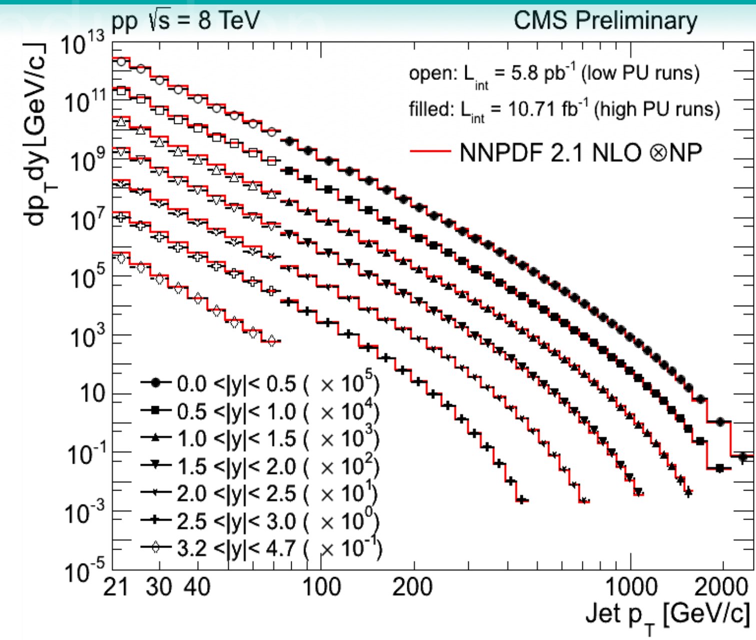
CMS-BPH-13-009

QCD Highlights

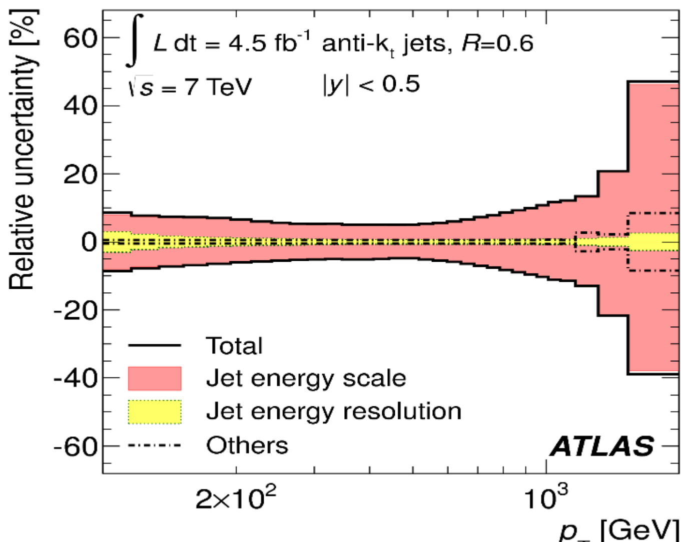
Inclusive Jet production

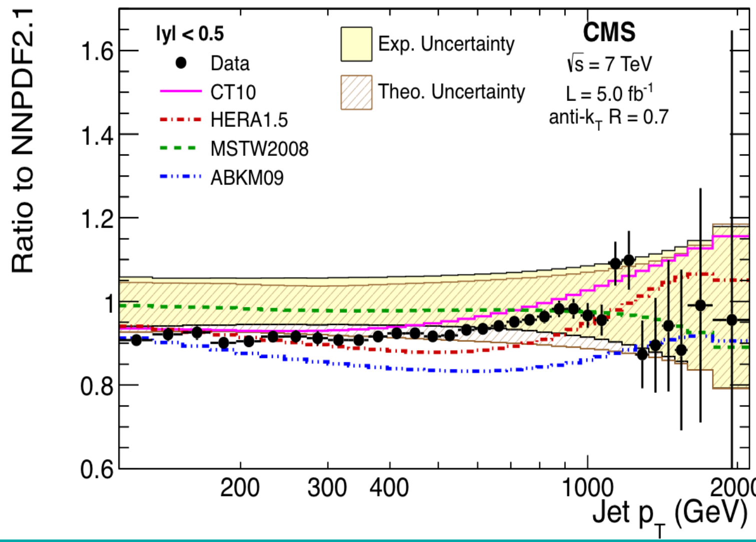
$$\frac{d^2\sigma}{dp_T dy} = \frac{1}{e \times L_{int}} \frac{N_{jets}}{\Delta p_T \Delta |y|}$$





Agreement with NLO QCD predictions over many orders of magnitude and up to 2 TeV in jet p_T





Very important for PDF constraints.

PRD 87 (2013) 112002
CMS-PAS-SMP-12-012
CMS-PAS-FSQ-12-031
arXiv:1410.8857

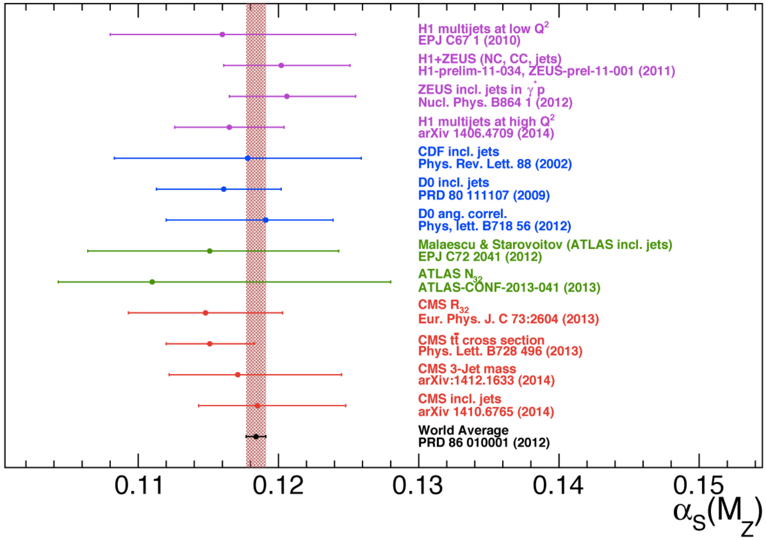
The strong coupling α_s

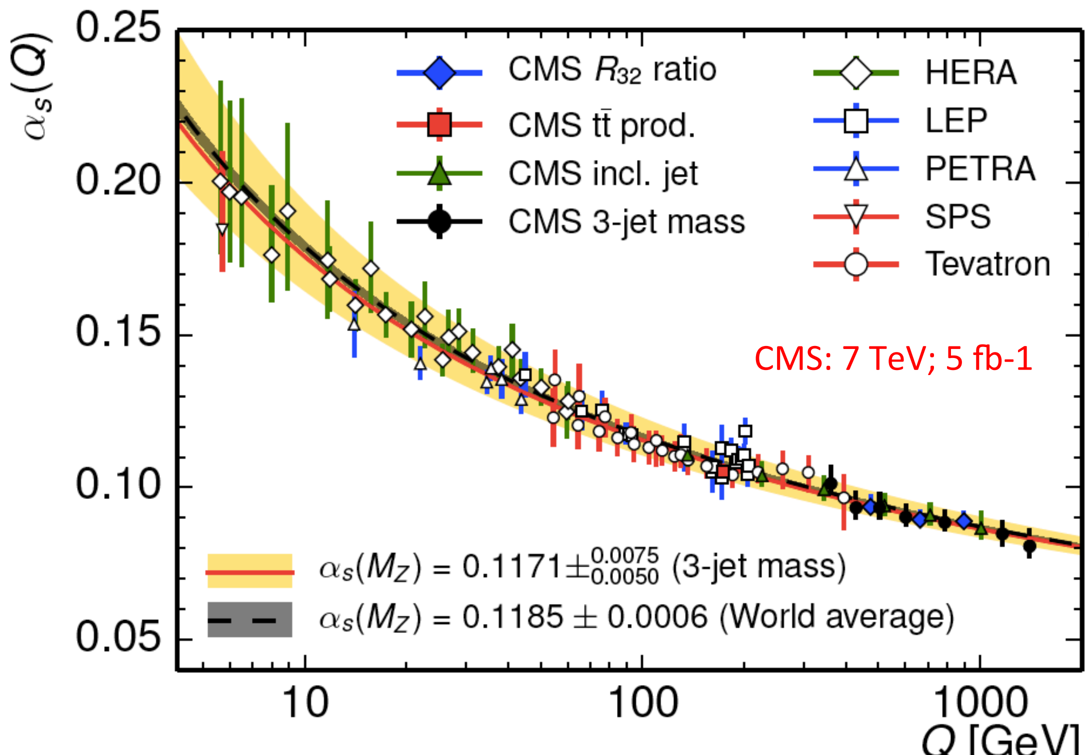
$$R_{32} = \frac{d\sigma_{3+}/dp_{\mathrm{T}}}{d\sigma_{2+}/dp_{\mathrm{T}}} \propto \alpha_s(Q)$$

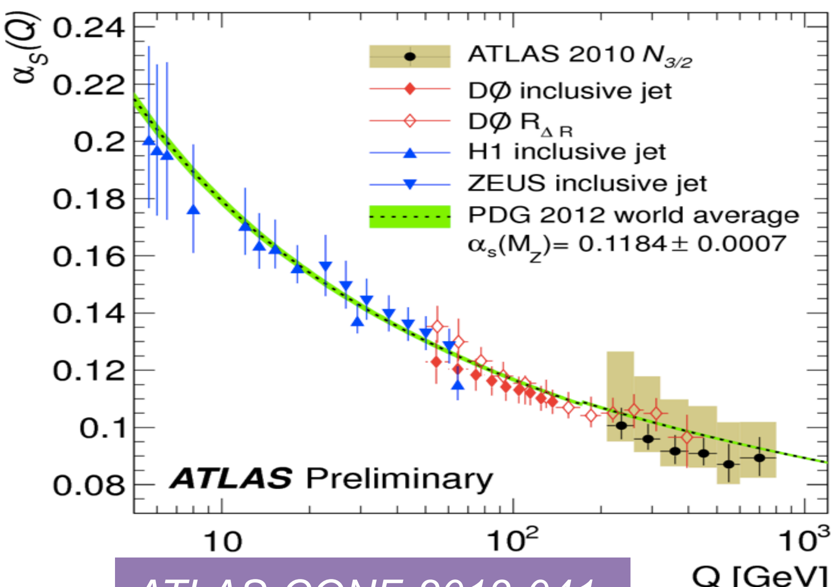
3-jet to 2-jet cross section ratio is sensitive to the strong coupling constant and mostly insensitive to many theor. and exp. systematic uncertainties

– avoids direct dependence on PDFs

– eliminates dependence from luminosity normalization







arXiv:1412.1633; CERN-PH-EP-2014-28; EPJC soon

ATLAS-CONF-2013-041

Conclusions (1)

- Three exciting years: from the first $\pi^0 \rightarrow \gamma\gamma$ reconstructed with the first LHC interactions, to precision SM measurements, to the first big discovery…
- From search to discovery to measurement and, so far, all measurements of the 125 GeV Higgs boson agree with SM predictions.
- The Higgs is already being used to search for exotica.

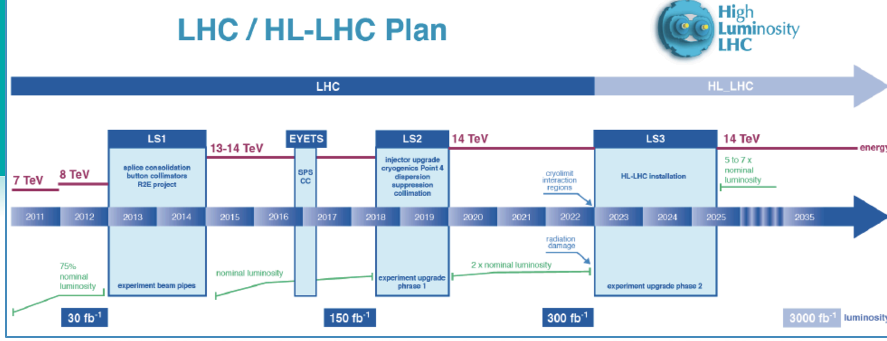
The LHC and the LHC detectors have performed extremely well, even above expectations.

- With the discovery of the Higgs boson the SM is now complete.
- The SM provides an accurate de-scription of experiments.
- Standard Model processes holding up remarkably well to scrutiny from up to $\sqrt{s}$ = 8 TeV over several orders of magnitude in production cross sections but we are just at the begin-ning of the "TeV" scale exploration.

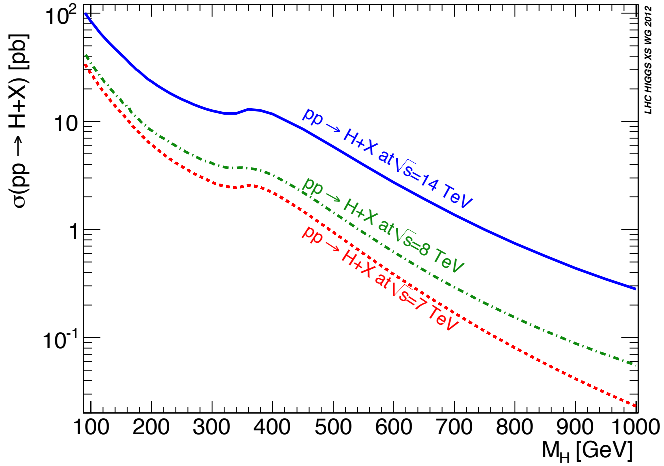
ATLAS & CMS: from Run 1 several hundreds of publications

Conclusions (2)

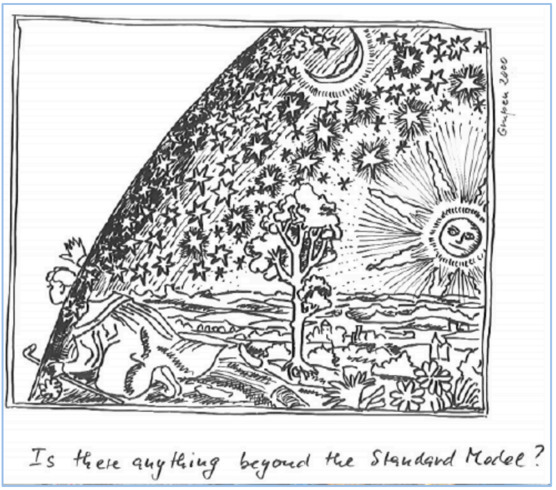
We have exploited the Run1 data: the majority of searches and analysis are published.



The LHC has so far produced only 1% of its ultimate data sample.
Furthermore, the operation at full energy (13 TeV) and high luminosity will increase the power of searches by a factor ten…. we will again explore new frontiers.



https://twiki.cern.ch/twiki/bin/view/LHCPhysics/CrossSections

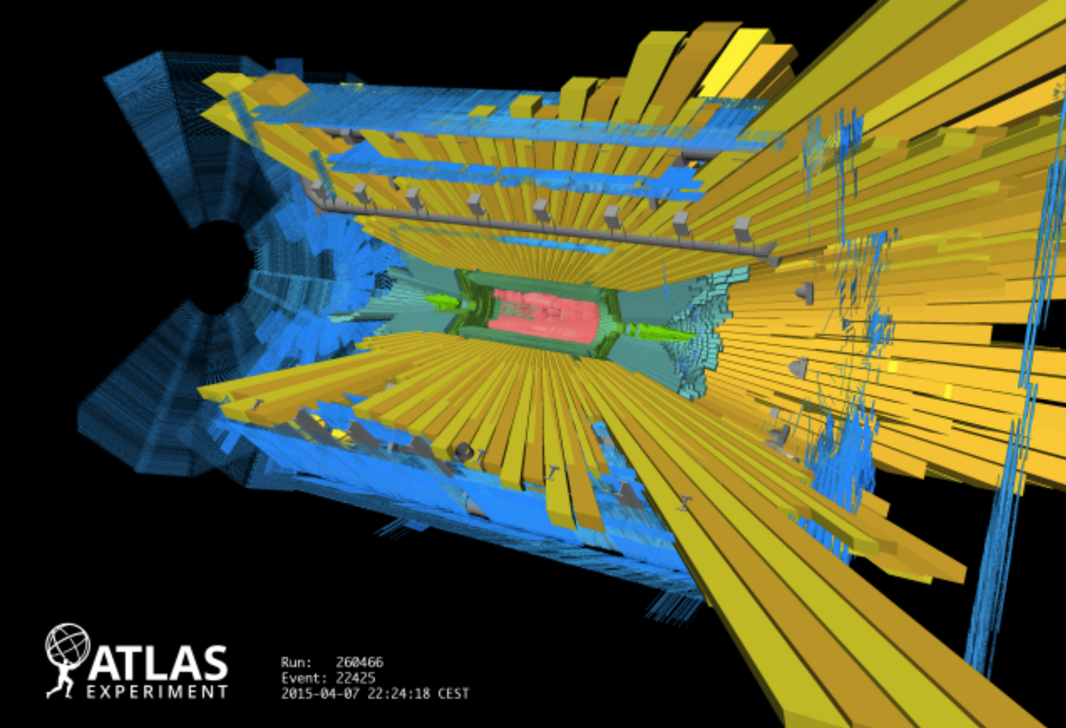


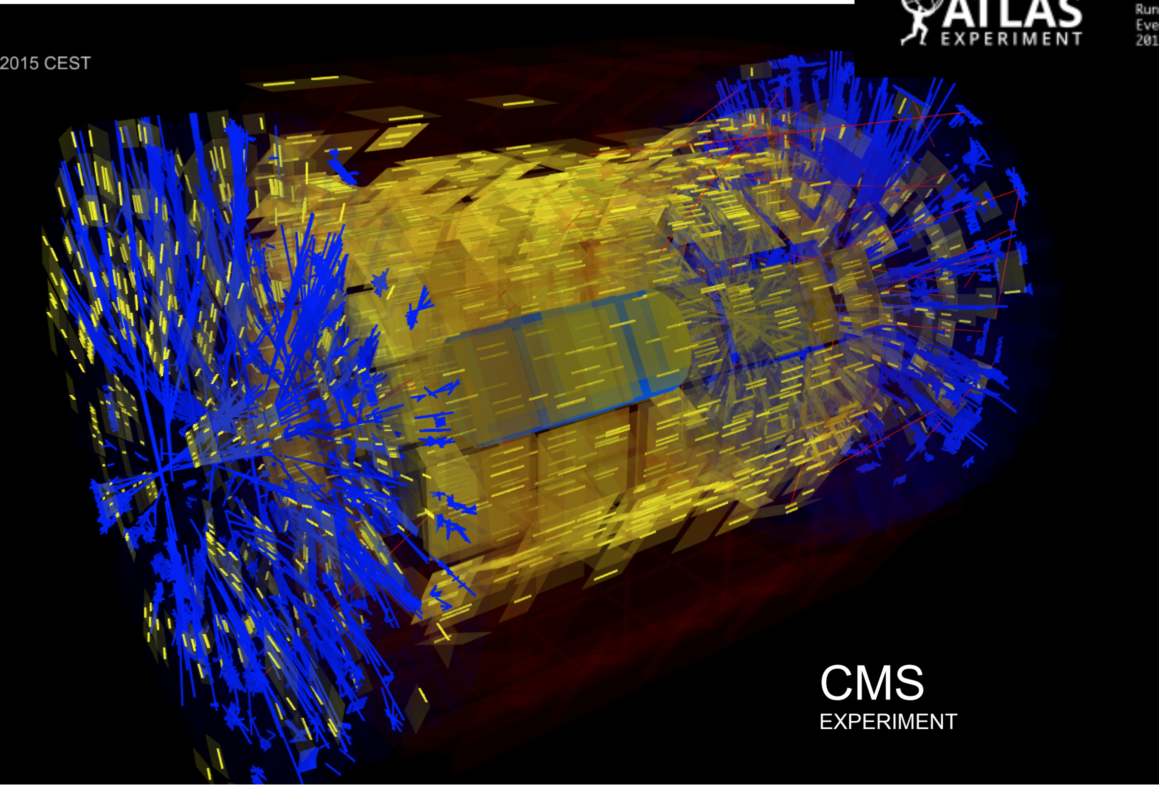
The study of the Standard Model at 13 TeV will be one of the first points to tackle at the new energy. The first QCD and Electroweak Studies will be done with much less than a fb^{-1}

We are now concentrating on the preparation for Run2 that will start in one month….

2015 - Fist beams in LHC

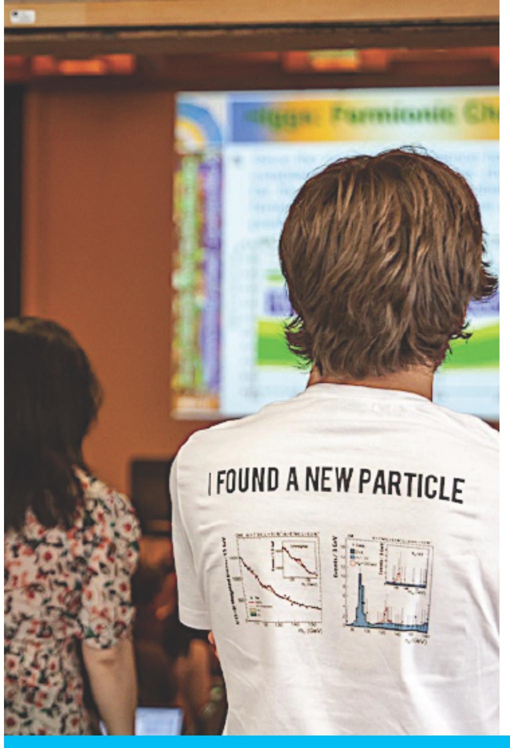
Getting ready for RUN2





Splashes events: LHC beam on collimators.

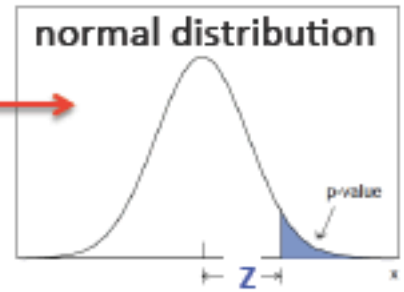
First synchronous signals of 2015!



Thank you

p-value and significance (Z)

$$p\text{-value} = P(\, n \geq n_{obs} \mid b \,)$$



p-value	Z
2.3 x 10^{-2}	2
1.4 x 10^{-3}	3
3.2 x 10^{-5}	4
2.9 x 10^{-7}	5
1.0 x 10^{-9}	6
1.3 x 10^{-12}	7

signal strength (μ) – common scale factor for signal event yields

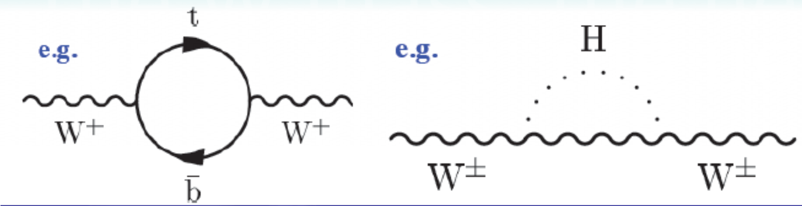
$$n_{\text{expected}} = \mu \cdot [\, \sigma_{\text{SM H}} \cdot B(\text{H}_{\text{SM}} \to xx) \cdot L \cdot \varepsilon \,] + n_{\text{background}}$$

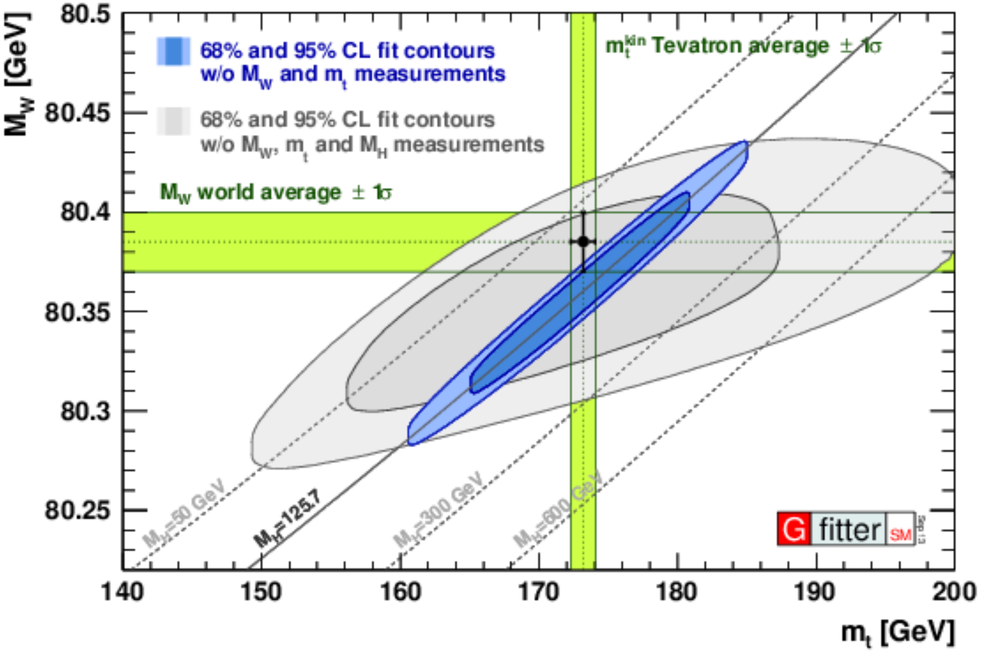
95% CL limits on signal strength (in absence of a significant excess):

μ is excluded at 95% CL, if :

$$\frac{P(\, n \leq n_{obs} \mid b + \mu \cdot s \,)}{P(\, n \leq n_{obs} \mid b \,)} < 0.05$$

The W mass: the next step





LHC can check VERY precisely the SM as it has the potential to measure the fundamental masses of the SM: Top, Higgs, W. The M_w is the biggest challenge

ΔM_W [MeV]	LHC		
$\sqrt{s}$ [TeV]	8	[illegible]	14
$\mathcal{L}[\mathrm{fb}^{-1}]$	[illegible]	[illegible]	[illegible]000
PDF	[illegible]	[illegible]	3
QED rad[illegible]	[illegible]	3	2
p_T(W[illegible]	2	1	1
oth[illegible]cs	10	5	3
W sta[illegible]s	1	0.2	0
Total	15	8	5

Stay posted: the goal is ambitious

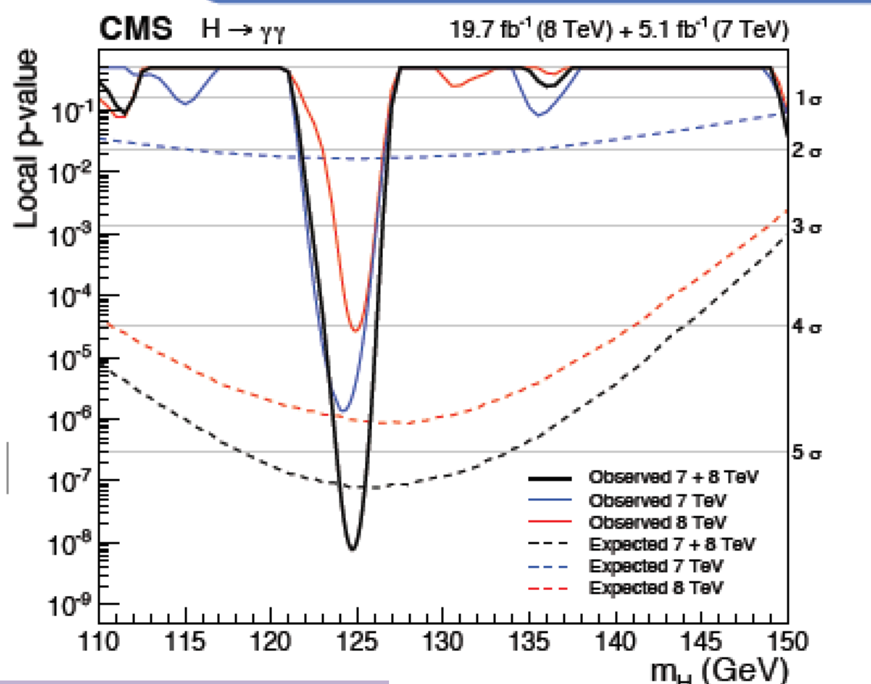
- Biggest three obstacles to surmount:
  - PDFs: sea quarks play a much stronger role than at the Tevatron. **Need at least 2X better PDFs.**
  - Momentum scale
  - Recoil model/MET

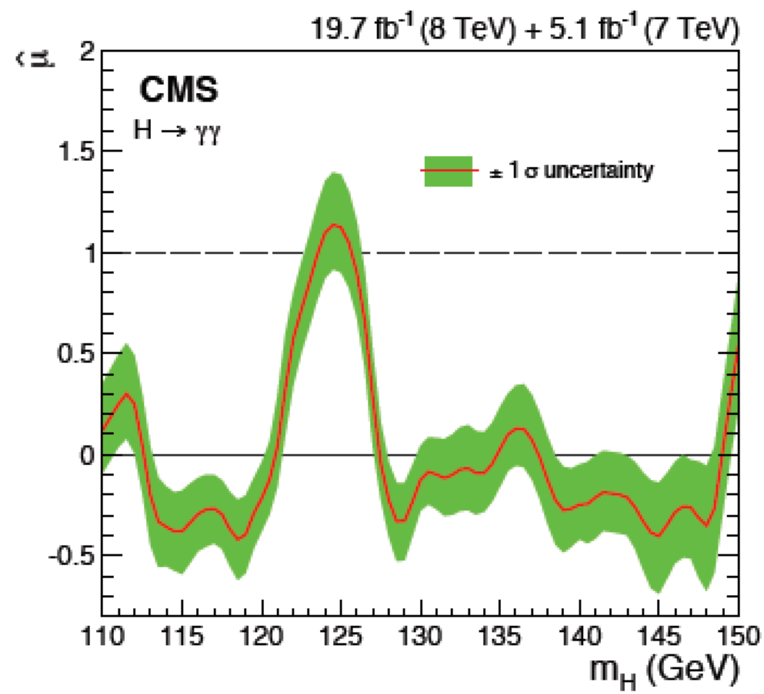
Higgs → γγ results

Signal Strength:

Dataset	Significance (obs)	σ/σ_{SM}	m_H (GeV)
7 TeV	4.7σ	$2.22^{+0.62}_{-0.55}$	124.2
8 TeV	4.0σ	$0.90^{+0.26}_{-0.23}$	124.9
7 + 8 TeV	**5.7σ**	$\mathbf{1.14^{+0.26}_{-0.23}}$	**124.7**

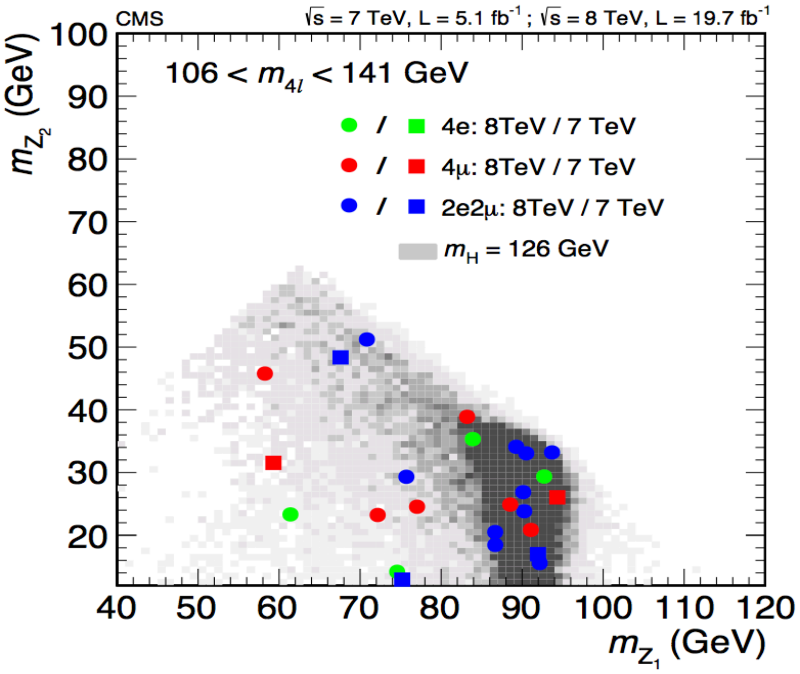
$$\sigma/\sigma_{SM} = 1.14^{+0.26}_{-0.23}\left[{}^{+0.21}_{-0.21}(\text{stat.})^{+0.09}_{-0.05}(\text{syst.})^{+0.13}_{-0.09}(\text{th.})\right]$$



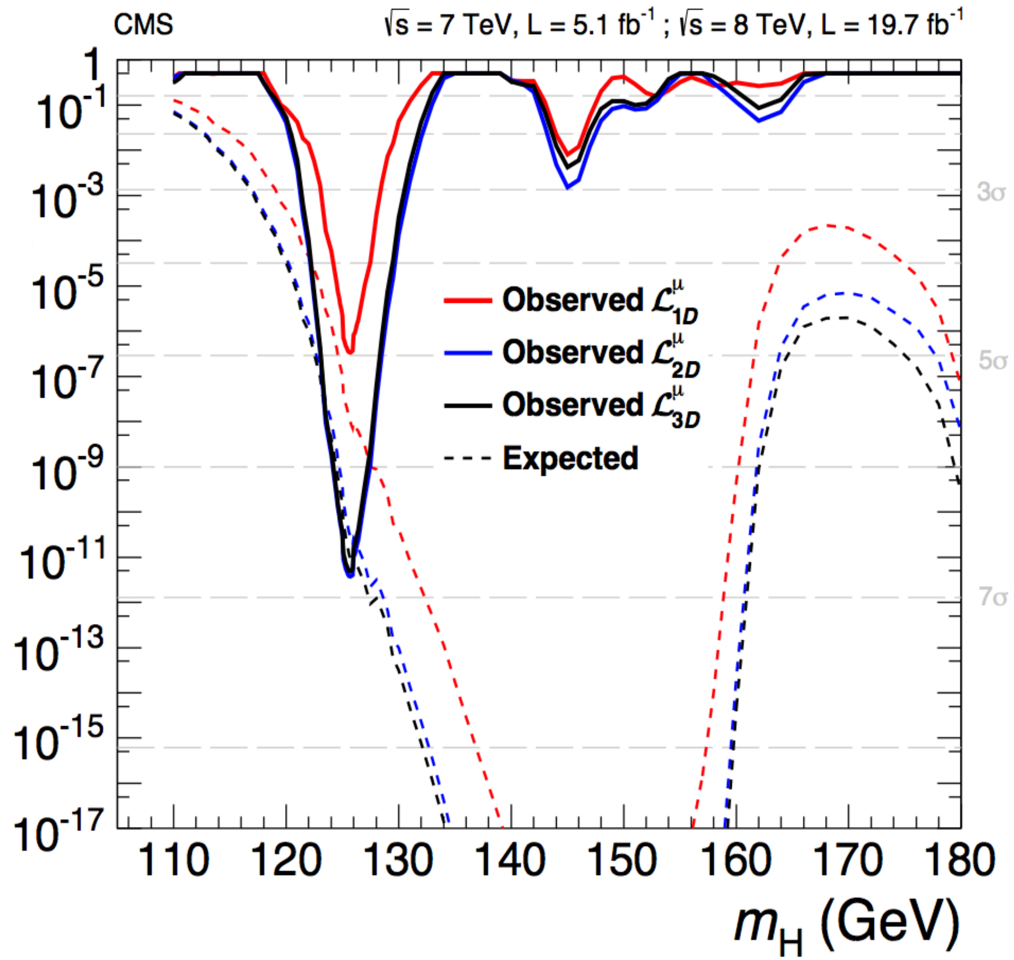


EPJ C 74 (2014) 3076

Higgs → ZZ → 4l results



Significance is well over 6 standard deviations



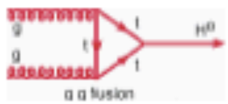
CMS: Expected: 6.7σ

Observed: 6.8σ

$\rightarrow \mu = 0.93^{+0.29}_{-0.24}$

SM Higgs events yield (per experiment)

Total number of inelastic pp-collisions produced in Run I:	1.5×10^{15}
Total produced Higgs bosons (m_H=125 GeV):	560,000



	m_H=125 GeV (l=e/μ)		ggF (86%)	VBF (7%)	VH (5%)	bbH (0.9%)	ttH (0.6%)
✓	H → ZZ → 4l	0.013%	72				
✓	H → γγ	0.23%	1,300				
✓	H → WW → lνlν	1.1%	6,100				
✓	H → ττ	6.3%	35,000				
?	H → bb	58%	✗ 270,000	42,000			
–	H → μμ	0.022%	120				
–	H → Zγ → 2l γ	0.010%	56				
–	H → J/ψγ → μμ γ	1.7×10^{-7}	0.1				
–	invisible	0.11%	✗ 590 (too small S/B at LHC, unless there is BSM H→inv)				
–	all others	37%	✗ 200,000 (deemed not feasible at LHC)				

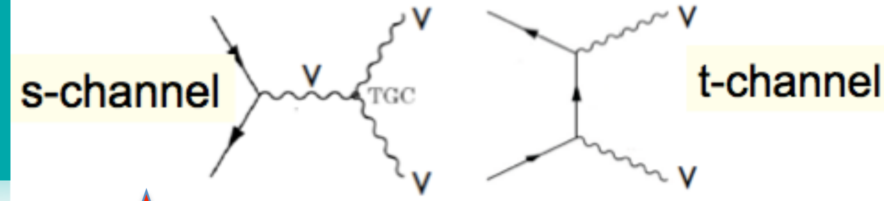
all event counts are before:
- detector acceptance
- reconstruction efficiency
- event selection efficiency

References

new results from the last 6 months are highlighted in pink

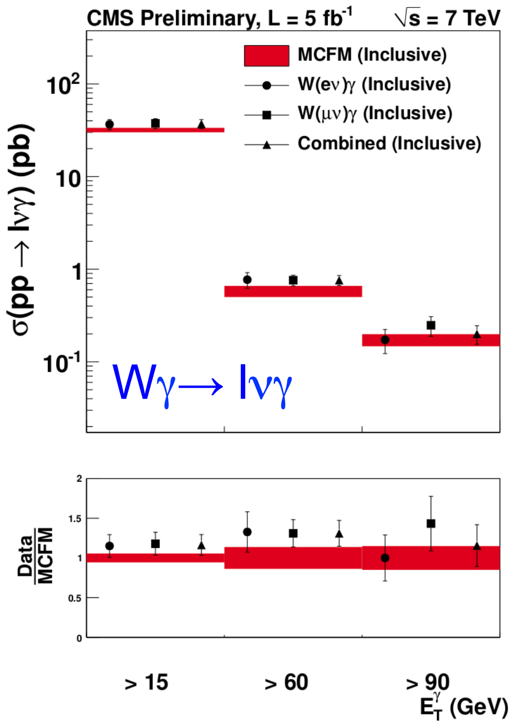
Analysis	ATLAS	CMS
ZZ → 4l	Phys. Rev. D91 (2014) 012006	Phys. Rev. D89 (2014) 092007
γγ	Phys. Rev. D90 (2014) 112015	Eur. Phys. J. C74 (2014) 10, 3076
WW → 2l2ν	arXiv:1412.2641	JHEP 1401 (2014) 096
ττ	arXiv:1501.04943	JHEP 1405 (2014) 104
bb	JHEP 01 (2015) 069	Phys.Rev. D89 (2014) 012003, CMS PAS HIG-13-011
μμ	Phys. Lett. B738 (2014) 68	arXiv:1410.6679
Zγ	Phys. Lett. B732 (2014) 8	Phys. Lett. B726 (2013) 587
invisible	Phys. Rev. Lett. 112 (2014) 201802	Eur. Phys. J. C74 (2014) 2980
Qγ [Q=J/ψ, Υ]	arXiv:1501.03276	
> ttH	Phys. Lett. B740 (2015) 222, ATLAS-CONF-2014-011	JHEP 1409 (2014) 087, arXiv:1502.02485
> tHq		CMS PAS HIG-14-001, CMS PAS HIG-14-015
s	Phys.Rev. D90 (2014) 052004	arXiv:1412.8662
bination (couplings, BSM)	update is coming soon	arXiv:1412.8662
-parity	Phys.Lett. B726 (2013) 120	arXiv:1411.3441, Phys. Rev. D89 (2014) 092007
malous decay amplitudes	coming soon	arXiv:1411.3441
th via off-shell production	ATLAS-CONF-2014-042	Phys. Lett. B736 (2014) 64
erential cross sections	JHEP 09 (2014) 112, Phys. Lett. B738 (2014) 234	coming soon

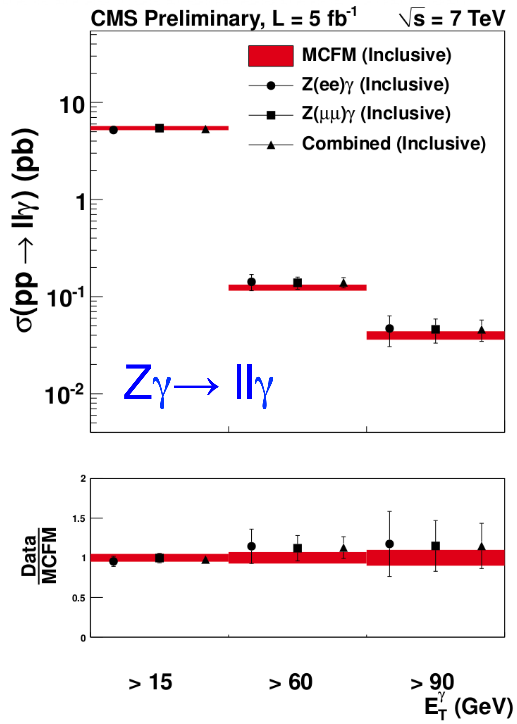
Wγ and Zγ production

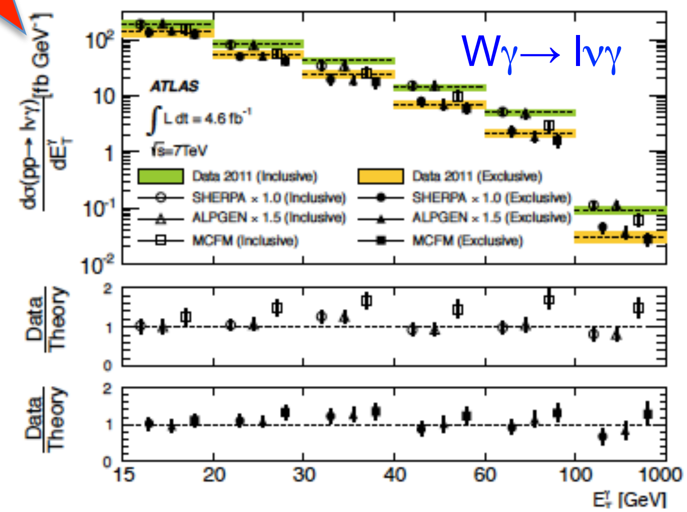


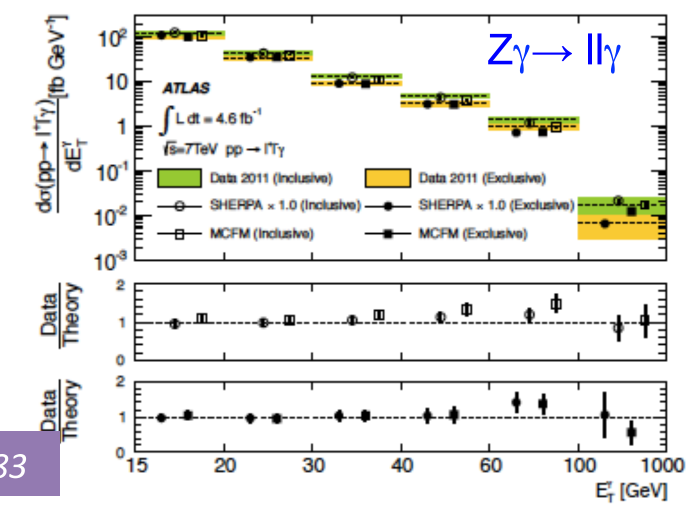
NEW

CMS-PAS-EWK-11-009







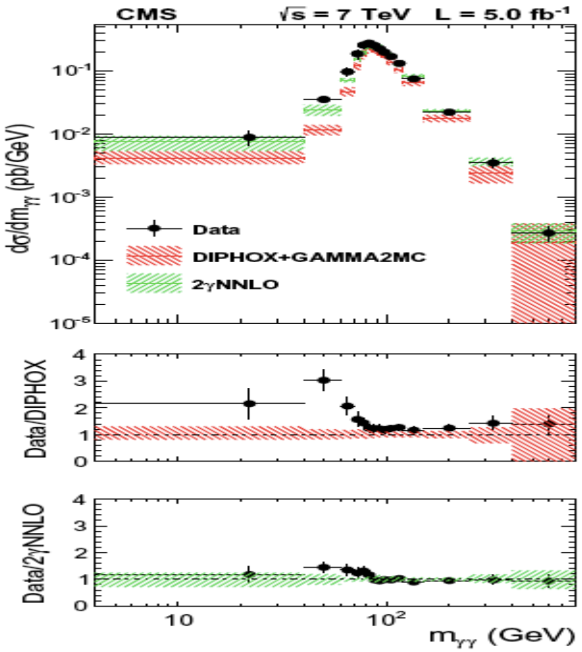


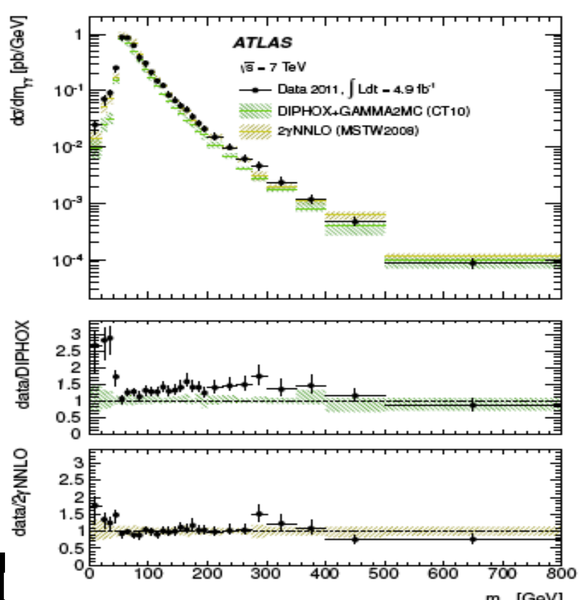
Analyses of lνγ, llγ, and ννγ final states

- Inclusive Wγ cross sections above theory (MCFM NLO)
- Fair agreement for Zγ

ATLAS arXiv:1302.1283

Di-photon production





- Measurement of diphoton production @ 7 TeV, 5 fb^{-1}
- Major background for H->γγ and BSM searches
- Main background from jets misidentified as photons
- CMS probing a phase space with asymmetric p_T selection to enhance sensitivity to the higher order diagrams:

CMS-PAS-SMP-13-001
Eur. Phys. J. C 74 (2014) 3129

two isolated photons,
$p_{T,\gamma 1} > 40$ GeV,
$p_{T,\gamma 2} > 25$ GeV,
$|\eta_\gamma| < 1.44$
or $1.57 < |\eta_\gamma| < 2.5$,
$\Delta R(\gamma_1, \gamma_2) > 0.45$)

CMS result :

$\sigma(pp \rightarrow \gamma\gamma + X)$ =

17.2 ± 0.2(stat.) ± 1.9(syst.) ± 0.4(lum.) pb

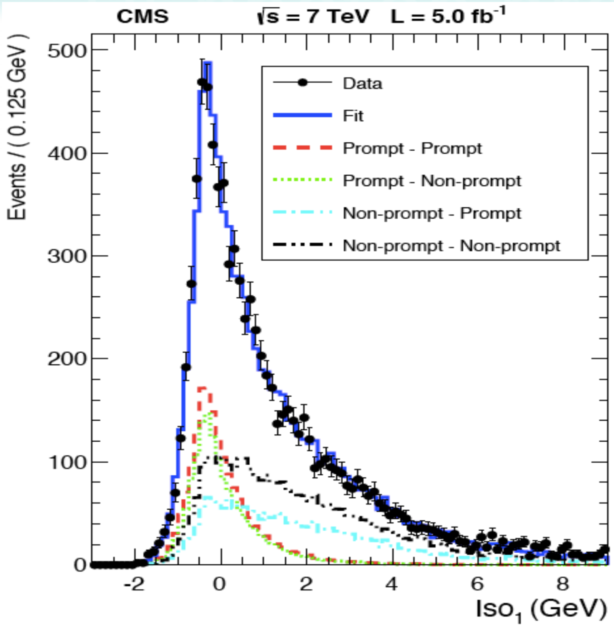
$\sigma(2\gamma NNLO) = 16.2_{-1.3}^{+1.5}$ (scale) pb

ATLAS result *(different p_T, η, ΔR selections)*:

44+3.2/-4.2 pb ; 2γNNLO= 44+6/-5 pb

ATLAS: JHEP01 (2013) 086

Di-photon production



- Measurement of diphoton production @ 7 TeV, 5 fb^{-1}
- Major background for H->γγ and BSM searches
- Main background from jets misidentified as photons
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CMS-PAS-SMP-13-001
Eur. Phys. J. C 74 (2014) 3129

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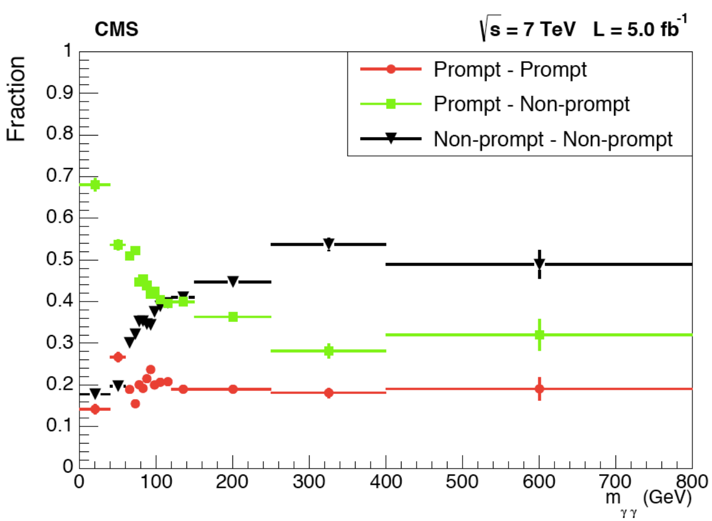


CMS result :

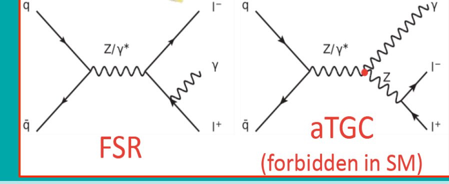
$\sigma(pp \rightarrow \gamma\gamma + X) =$

$17.2 \pm 0.2(\text{stat.}) \pm 1.9(\text{syst.}) \pm 0.4(\text{lum.})$ pb

$\sigma(2\gamma\text{NNLO}) = 16.2_{-1.3}^{+1.5}$ (scale) pb

ATLAS: JHEP01 (2013) 086

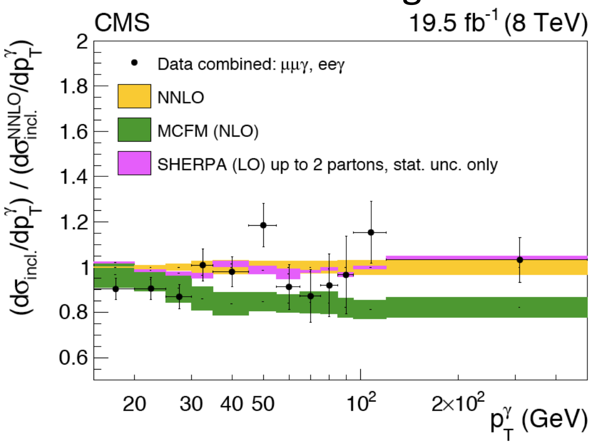
Zγ production and aTGC



- Measurement of the Zγ production cross section in electron and muon channels, with 19.5 fb^{-1} at 8 TeV
- Kinematic range: $p_T^l > 20$ GeV, $M_{ll} > 50$ GeV, $E_T^\gamma > 15$ GeV, $\Delta R(l,\gamma) > 0.7$, lept. and photon in fiducial area
- The dominant background is DY+jets: non-prompt photons from π^0 or η decays or misidentified hadrons

Uncertainties dominated by template statistics and FSR contamination. Best agreement with NNLO and SHERPA at high $p_{T\gamma}$

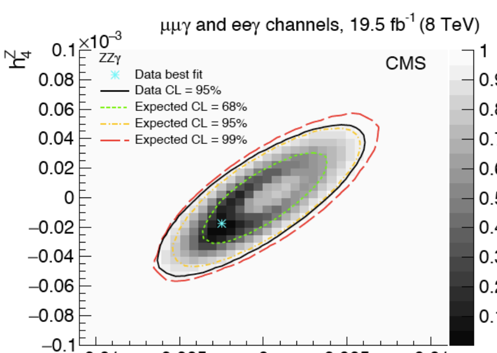
σ(NLO) = 2100 ± 120 fb (MCFM)
σ(NNLO) = 2241 ± 22 fb (M. Grazzini et al. *arXiv:1309.7000.*)



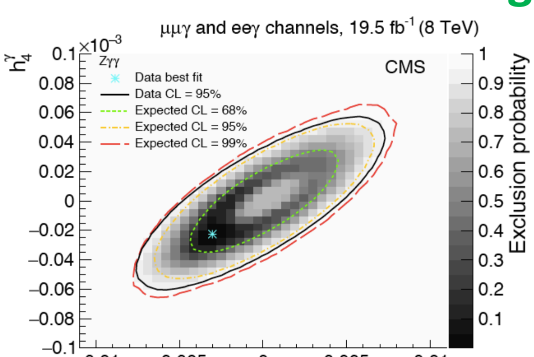
CMS: σ(incl) = 2063 ± 19 (stat.) ± 98 (syst.) ± 54 (lumi.) fb

NEW

Extraction on the limits (95%CL) on the strenght of ZZγ and Zγγ aTGC.
<u>Improvement by a factor 3 with respect to previous results.</u>
Good agreement with SM expectations



ZZγ coupling



Zγγ coupling

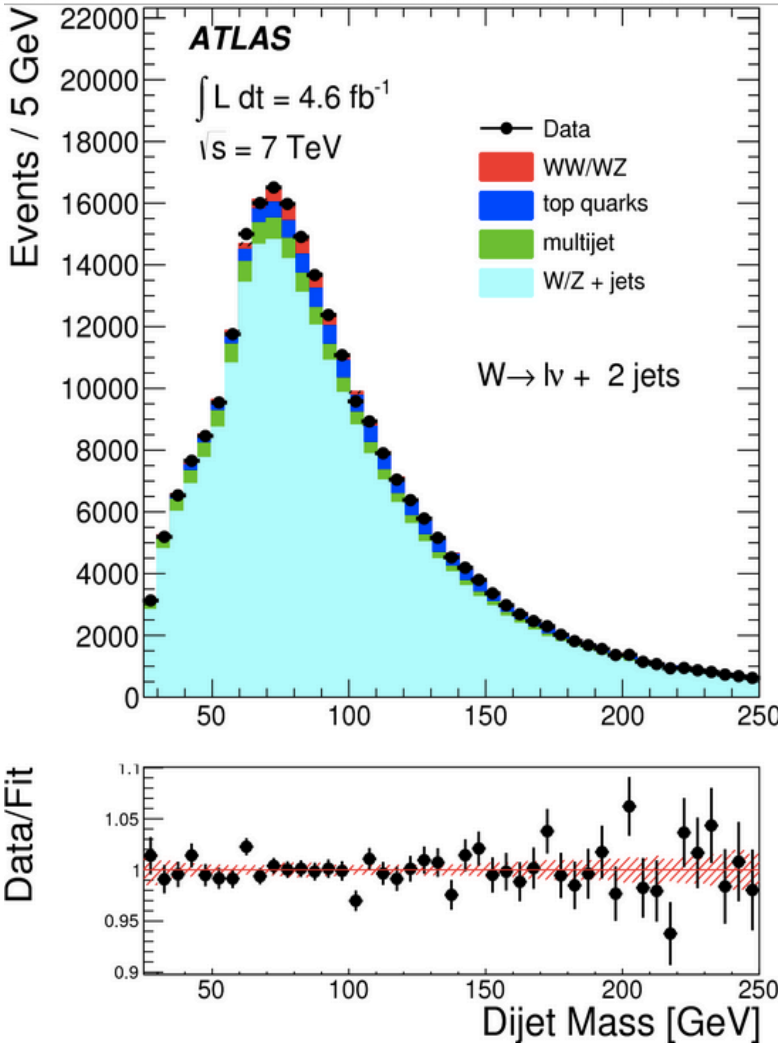
$$-3.8 \times 10^{-3} < h_3^Z < 3.7 \times 10^{-3}$$
$$-3.1 \times 10^{-5} < h_4^Z < 3.0 \times 10^{-5}$$
$$-4.6 \times 10^{-3} < h_3^\gamma < 4.6 \times 10^{-3}$$
$$-3.6 \times 10^{-5} < h_4^\gamma < 3.5 \times 10^{-5}$$

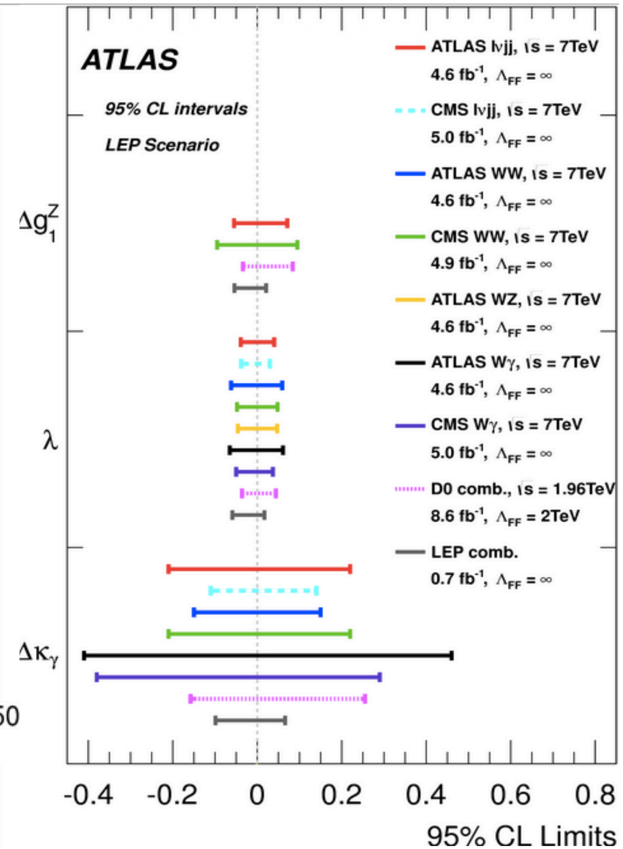
arXiv: 1502.05664
accepted by JHEP

WW+WZ production and aTGC

NEW

Final state : WW+WZ → lν qq (e/μ E_T^{miss} two jets)





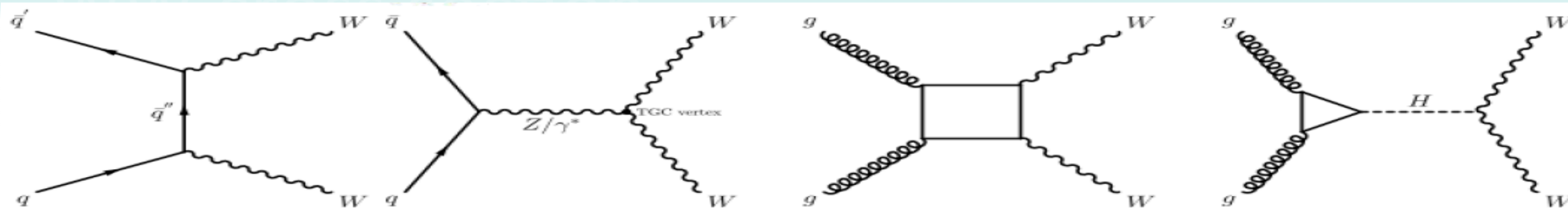
Template fit used to extract σ.
Measured cross section consistent with SM prediction.
Systematic uncertainty ~30%.

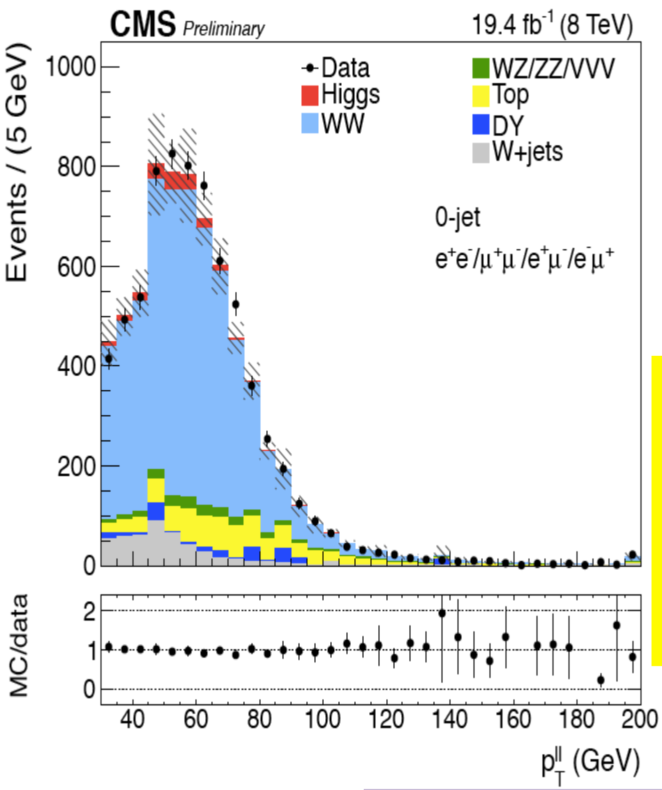
JHEP 01 (2015) 049

ATLAS: σ = 68 ± 7 (stat.) ± 19 (syst.) pb

NLO SM prediction: σ = 61.1 ± 2.2) pb

WW cross section





NLO* SM prediction @7 TeV: σ = 47.0 ± 2.0) pb
NLO* SM prediction @8 TeV: σ = 59.8 ± 2.2) pb

CMS@7 TeV: σ = 52.4 ± 2.0 (stat.) ± 4.5 (syst.) ± 1.2 (lum.) pb
CMS@8 TeV: σ = 60.1 ± 3.2 (stat.) ± 3.1 (syst.) ± 1.6 (lum.) pb

ATLAS@7TeV: $\sigma = 71.4\,^{+1.2}_{-1.2}\,(\text{stat.})\,^{+5.0}_{-4.4}\,(\text{syst.})\,^{+2.2}_{-2.1}\,(\text{lum.})$ pb

ATLAS result about 2 σ higher than SM prediction.

ATLAS-CONF-2014-033; Phys.Lett.B721(2013) 190; CMS-PAS-SMP-14-016

ZZ → 4l cross section

NEW

- Inclusive and differential ZZ->lll'l' cross sections (l = e, μ; l' = e, μ, τ)
- Mutually exclusive sets of 4e, 4μ, 2e2μ and llττ, with 60 < m_Z <120 GeV
- Simultaneous fit to include all final states in cross section calculation
- Differential cross section measured, 4e, 4μ, 2e2μ decays combined
- Good agreement with the SM

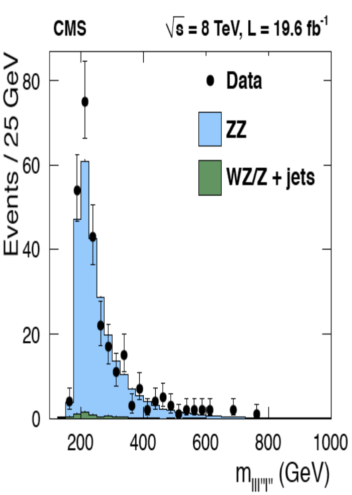
Theoretical value of 7.7 ± 0.6 pb

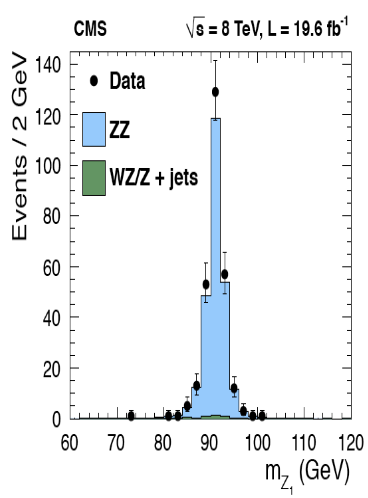
σ(pp → ZZ) @ 8 TeV

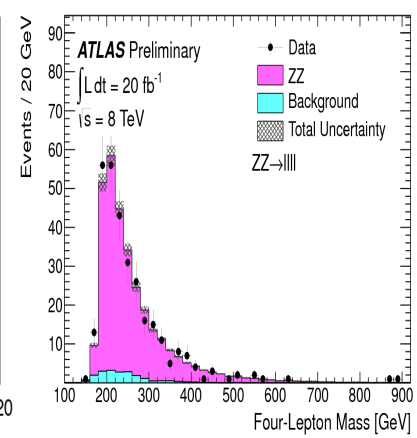
CMS = 7.7 ± 0.5 (stat.) +0.5-0.4 (syst.) ±0.4 (theo.) ±0.2 (lum.) pb

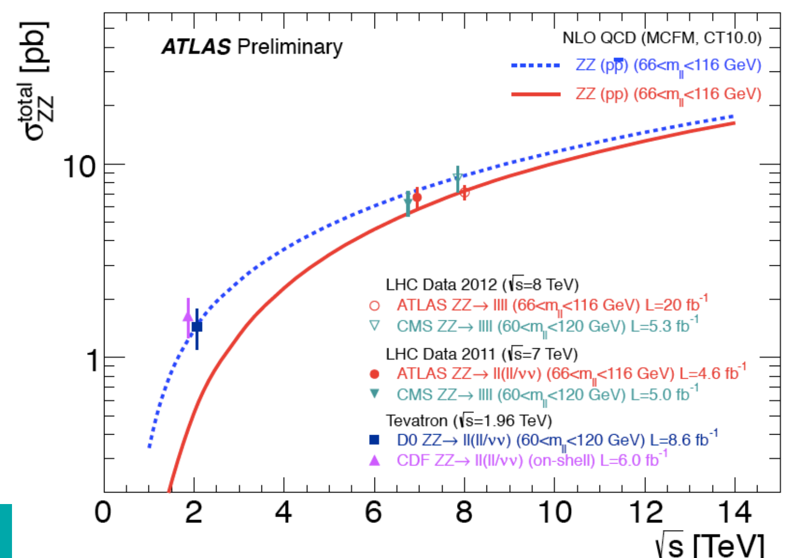
ATLAS = 7.1 +0.5-0.4 (stat.) ±0.3(syst.) ±0.2 (lum.) pb

NB Different definitions: CMS has Higgs subtracted, for ATLAS its part of measurement.







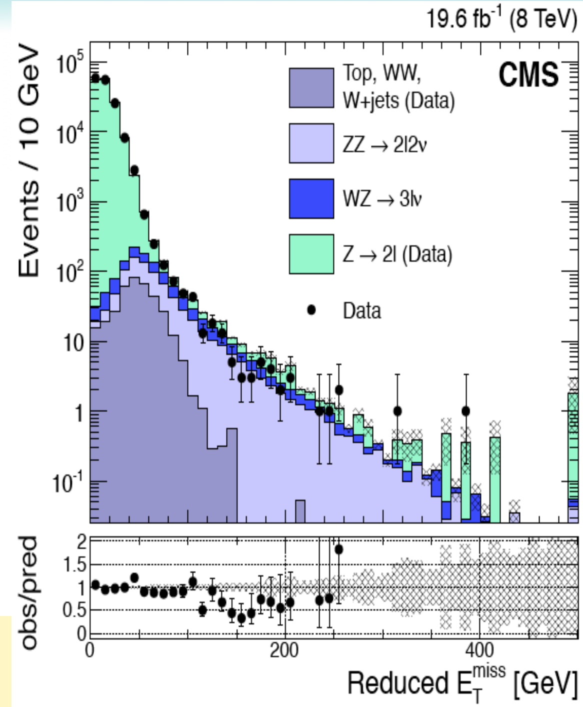


Phys. Lett. B 740 (2015) 250; ATLAS-CONF-2013-020

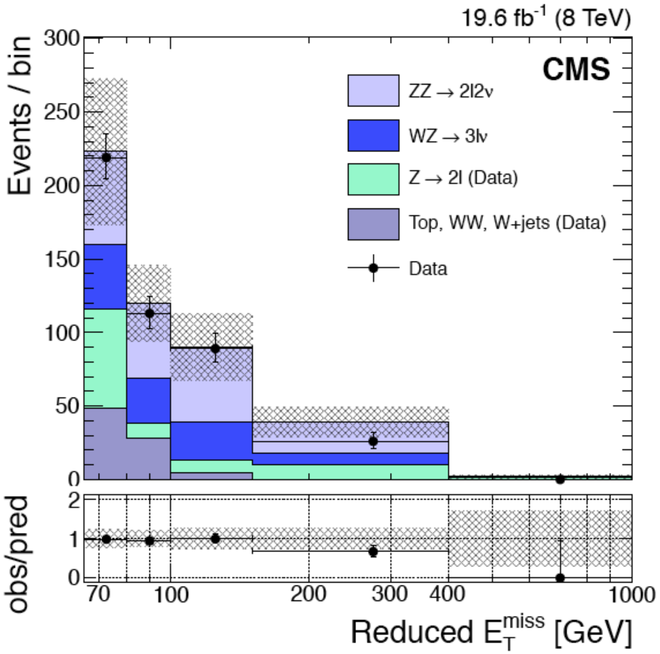
ZZ → 2l2ν production

NEW

- Inclusive cross-section measurement, 7TeV ($4.9 fb^{-1}$) and 8TeV ($19.6 fb^{-1}$)
- BR is 6x larger than ZZ→4l, large background yields (DY, WW and top)
- MET reconstruction is crucial, distinctive w.r.p. to DY process.



Theoretical value@7(8)TeV
6.2 +0.3-0.2 (7.6+0.4-0.3)pb

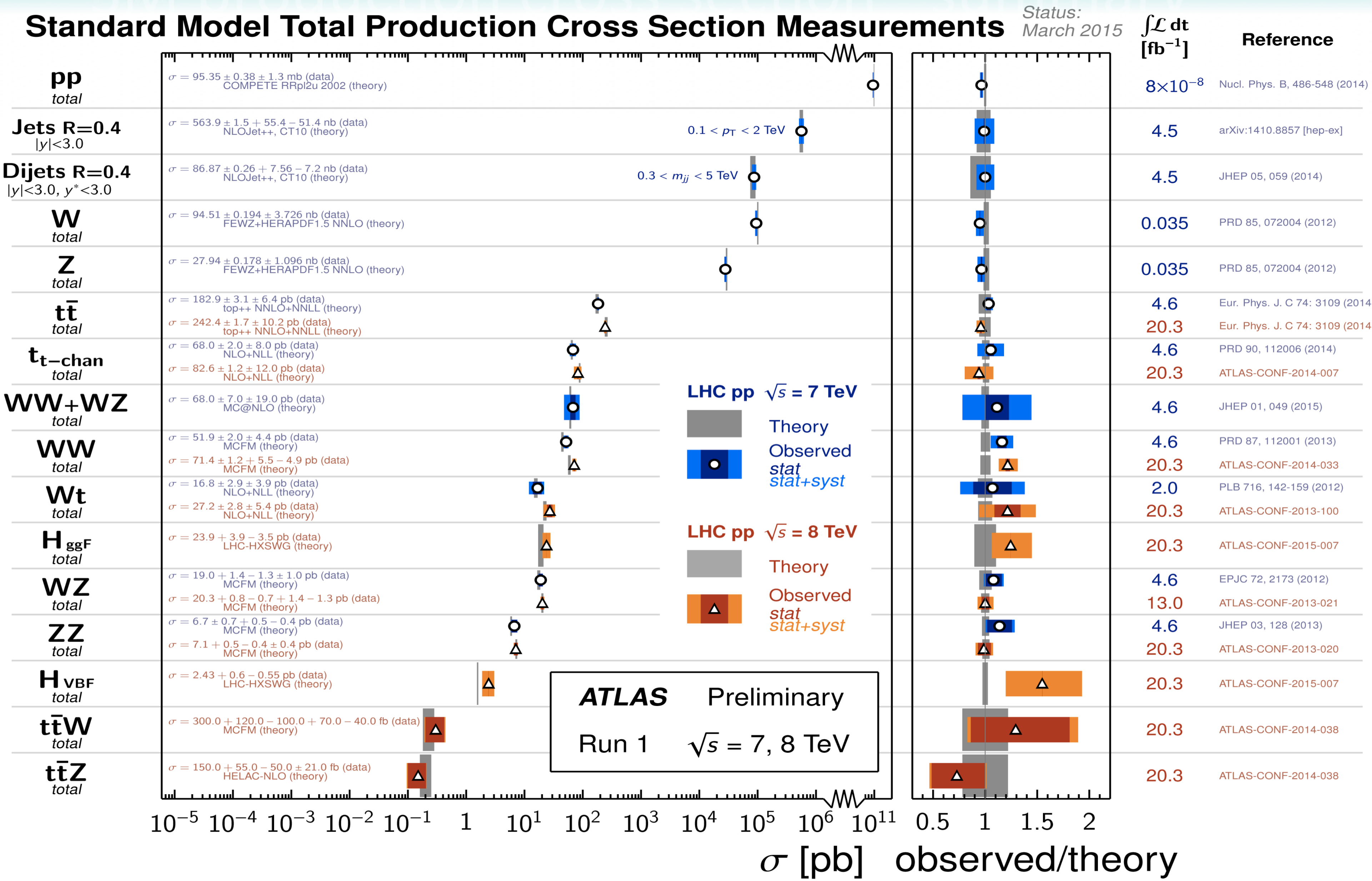


CMS@7TeV:
σ = 5.2 +1.5-1.4 (stat) +1.4-1.1(syst.) ±0.2 (lum.) pb
CMS@8TeV:
σ = 6.9 ±0.8 (stat) +1.8-1.4(syst.) ±0.3 (lum.) pb

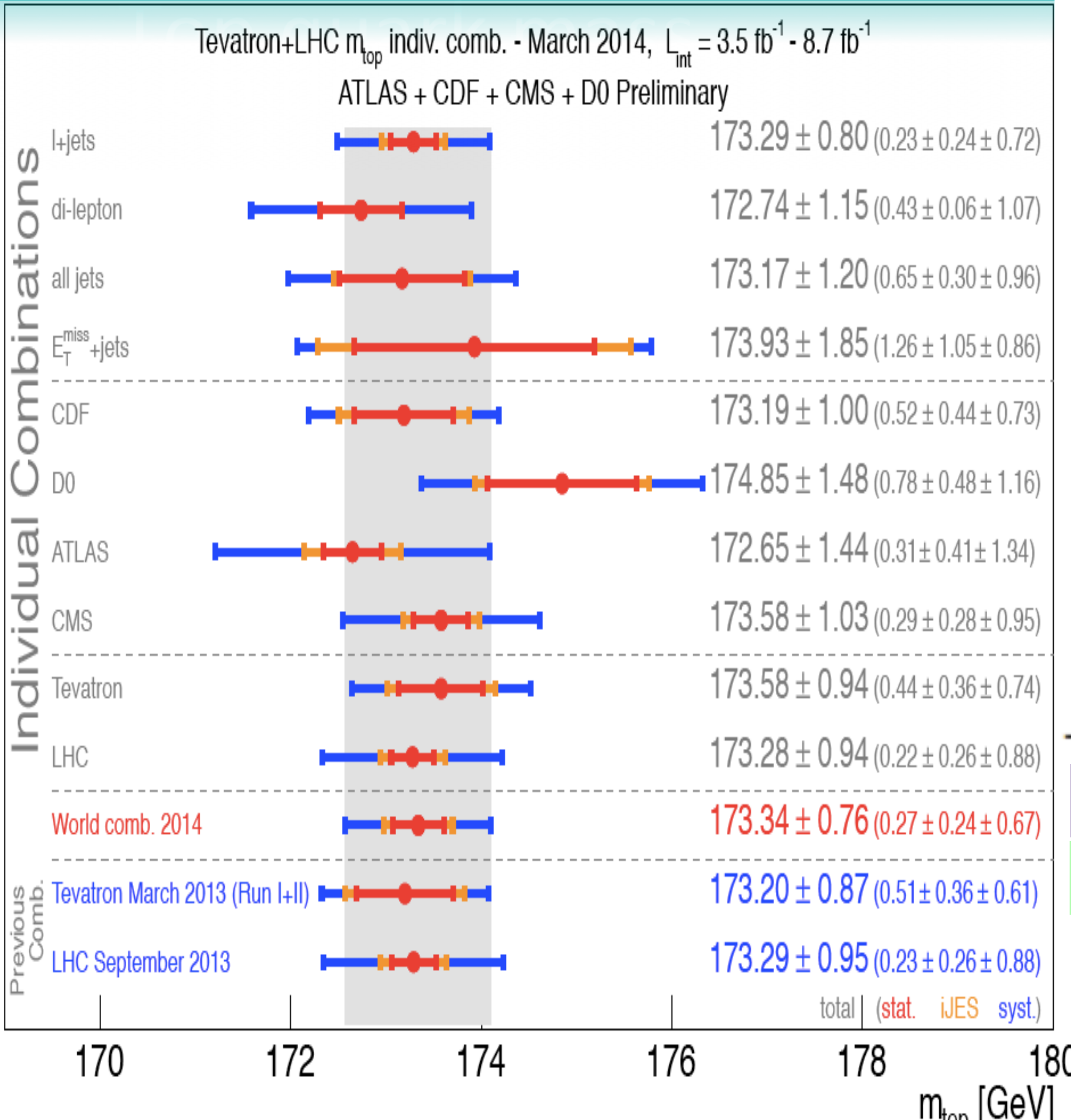
$$\text{reduced-}E_T^{\text{miss}\,i} = -q_T^i - R^i_{c/u}$$

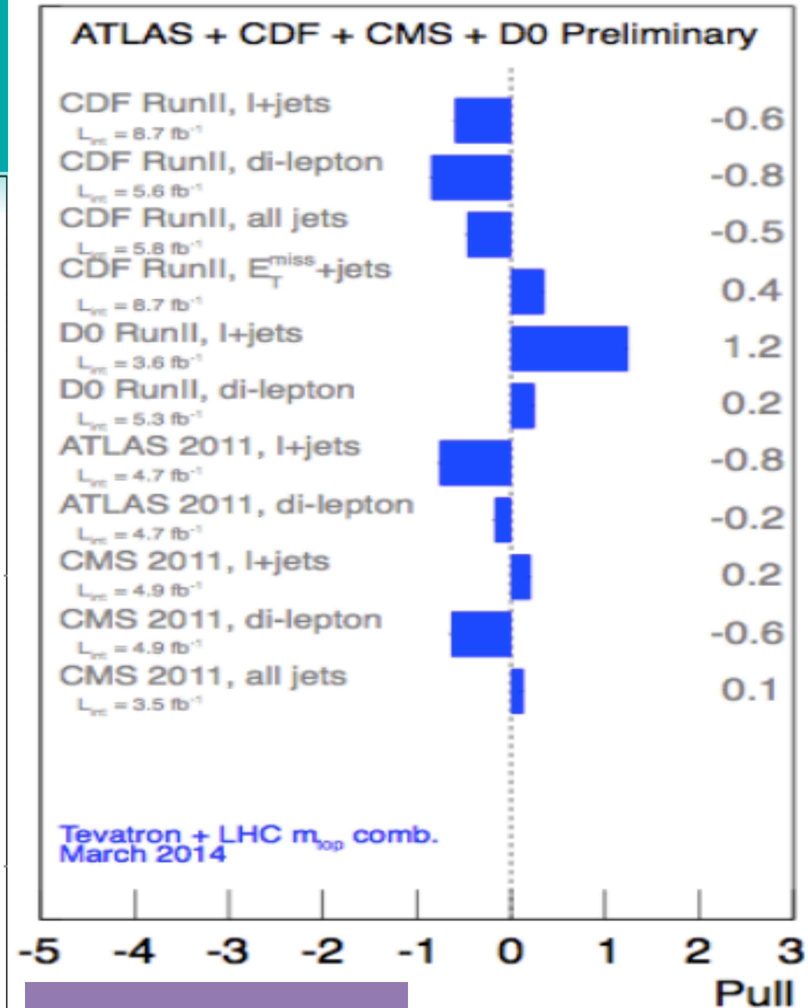
arXiv.1503.05467; CERN-PH-EP-2015-029

SM production cross section - summary



Top quark mass





arXiv: 1403.4427

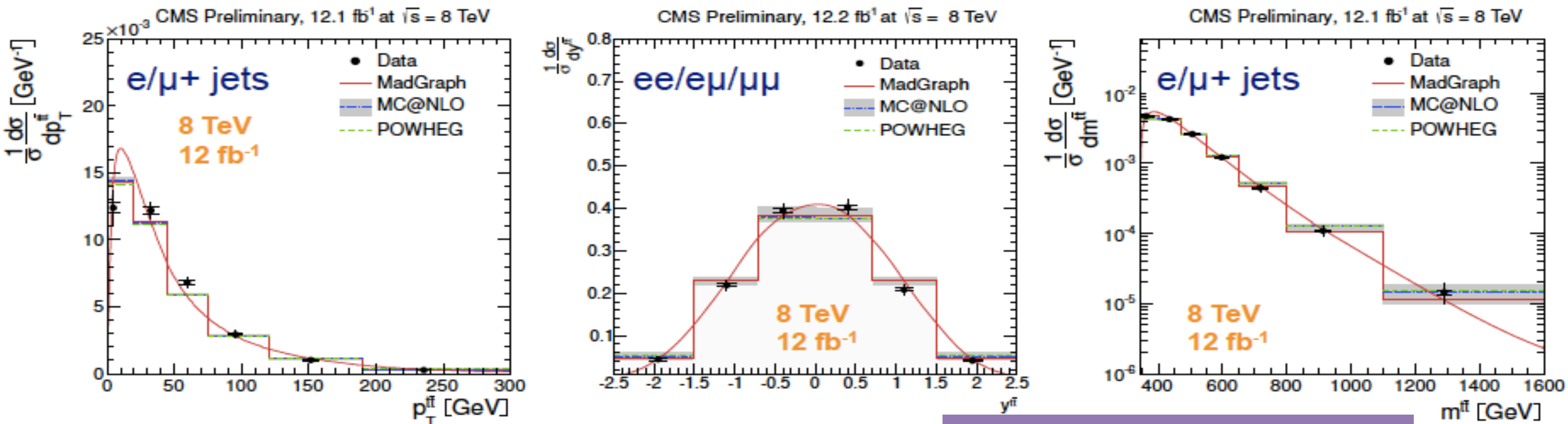
$$m_t = 173.34 \pm 0.27_{stat} \pm 0.67_{syst}\ \text{GeV}$$

CMS - top anti-top mass difference:

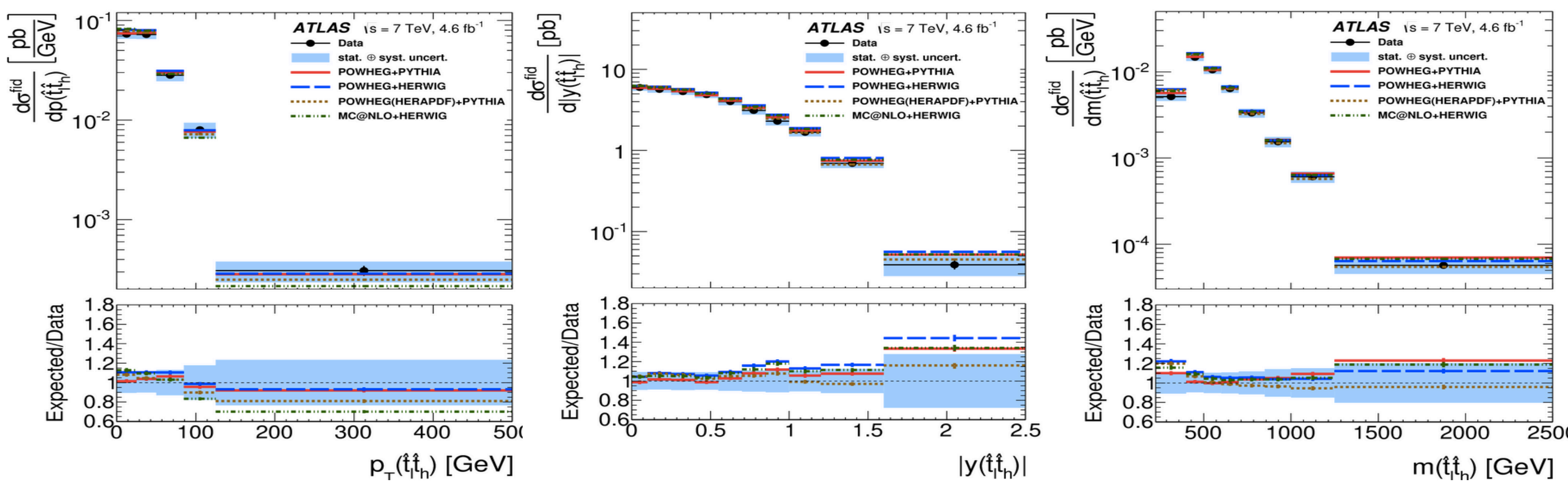
$$\Delta m_t = -272 \pm 196_{stat} \pm 122_{syst}\ \text{MeV}$$

Top quark pair differential cross section

$$\frac{1}{\sigma}\frac{d\sigma(x_i)}{dx_i}$$



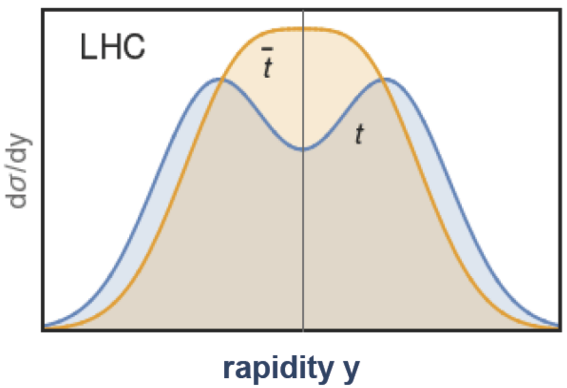
CMS: EPJ C 73 (2013) 2339



No significant deviation from SM observed

ATLAS: arXiv: 1502.05923

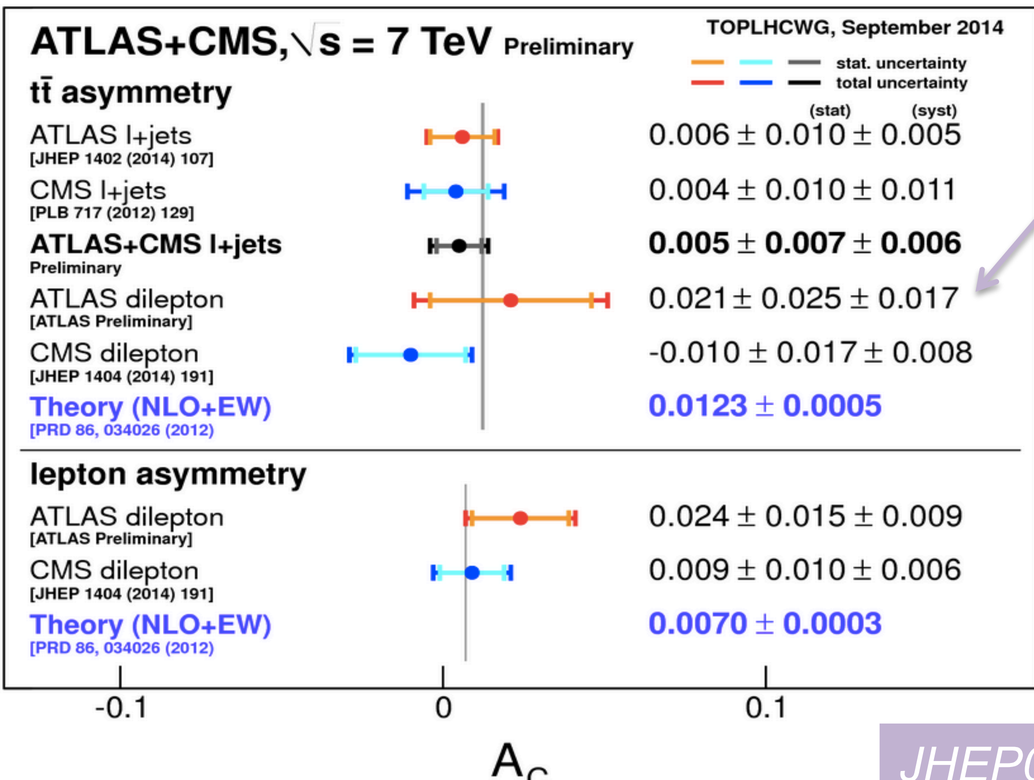
Top pair charge asymmetry

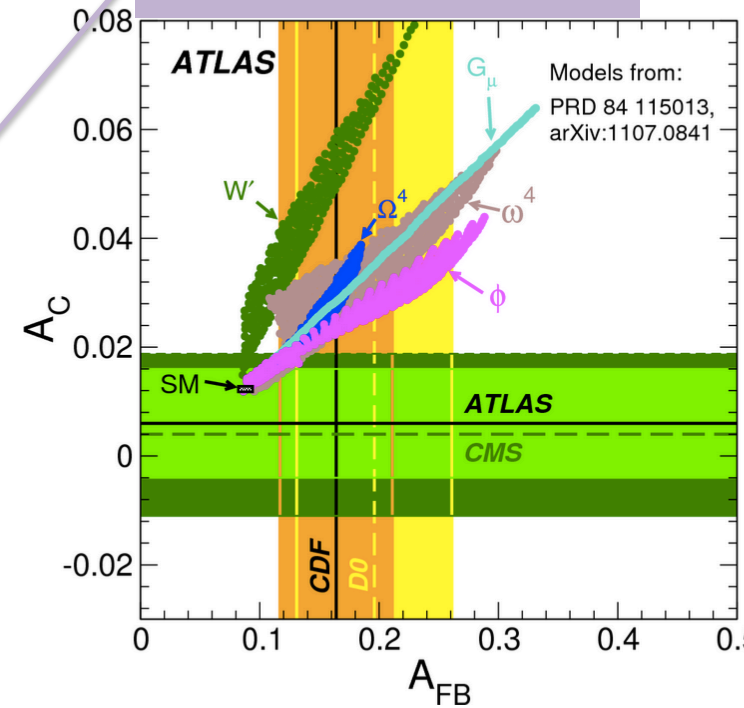


$$A_C = \frac{N(\Delta|y| > 0) - N(\Delta|y| < 0)}{N(\Delta|y| > 0) + N(\Delta|y| < 0)}$$

$$\Delta|y| = |y_t| - |y_{\bar{t}}|$$

NEW arXiv:1501.07383



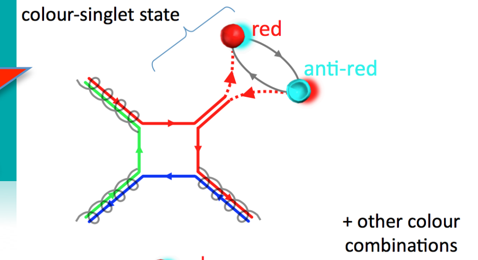


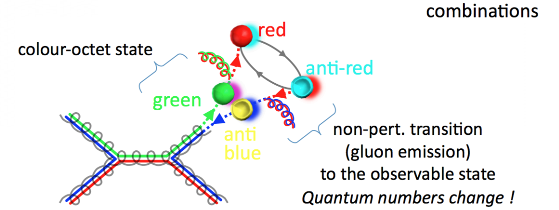
JHEP04(2014)191

JHEP 02 (2014) 107

J/psi + Z associate production

NEW



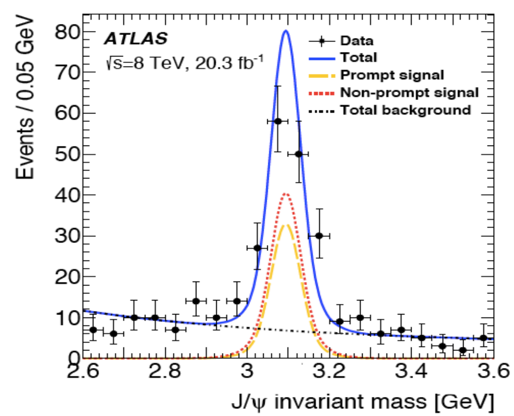


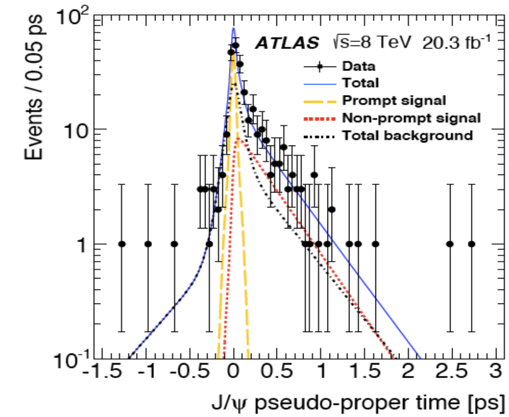
Production model for quarkonia may require a q-qbar state produced as color-singlet in the lowest order Feynman diagram (Color Singlet Model), or may ask a q-qbar pair being produced in any color, subsequently removed with soft gluon irradiation.

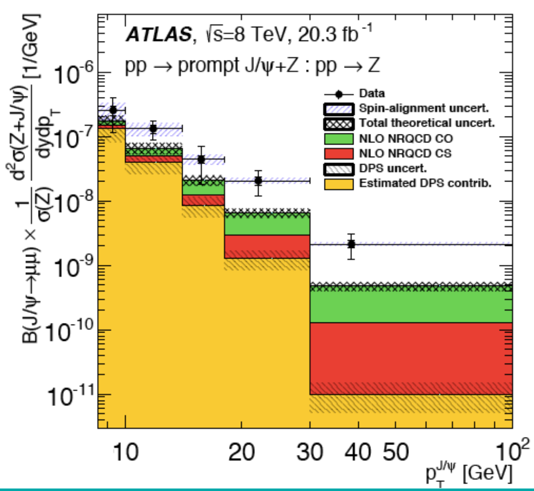
In associated production J/psi + W/Z, the lowest order diagrams suggest that a better discrimination between the models may be possible. Requiring the formation of W/Z sets a high energy scale for the scattering process that improves the perturbative calculation convergence.

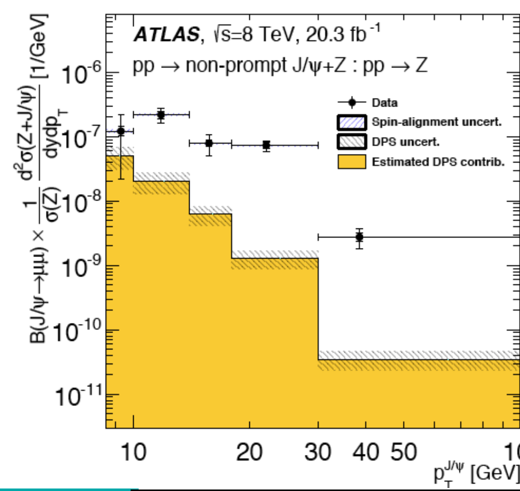
- First observation of:
  Z + prompt J/psi (significance 5σ) and
  Z + non-prompt J/psi (significance 9σ)
- Observed production ratehigher than predictions by one order of magnitude.

arXiv: 1412.6428

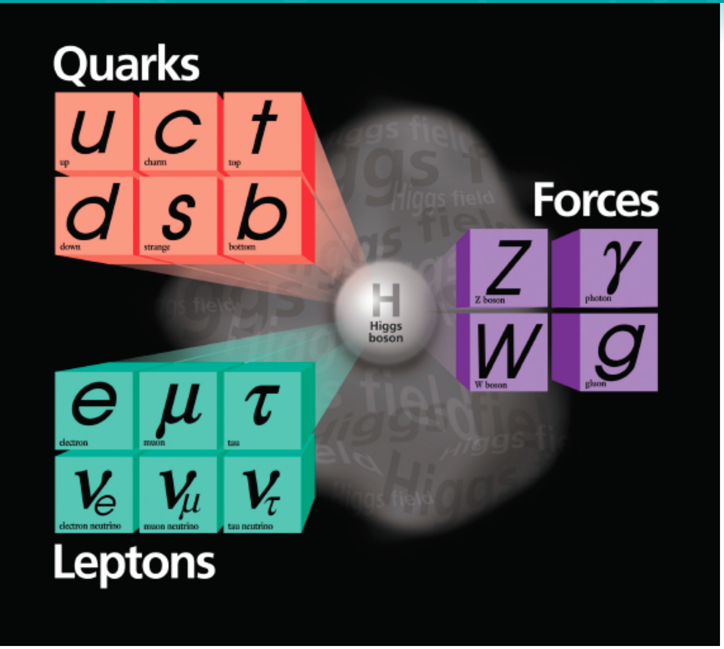








The Standard Model of Particle Physics

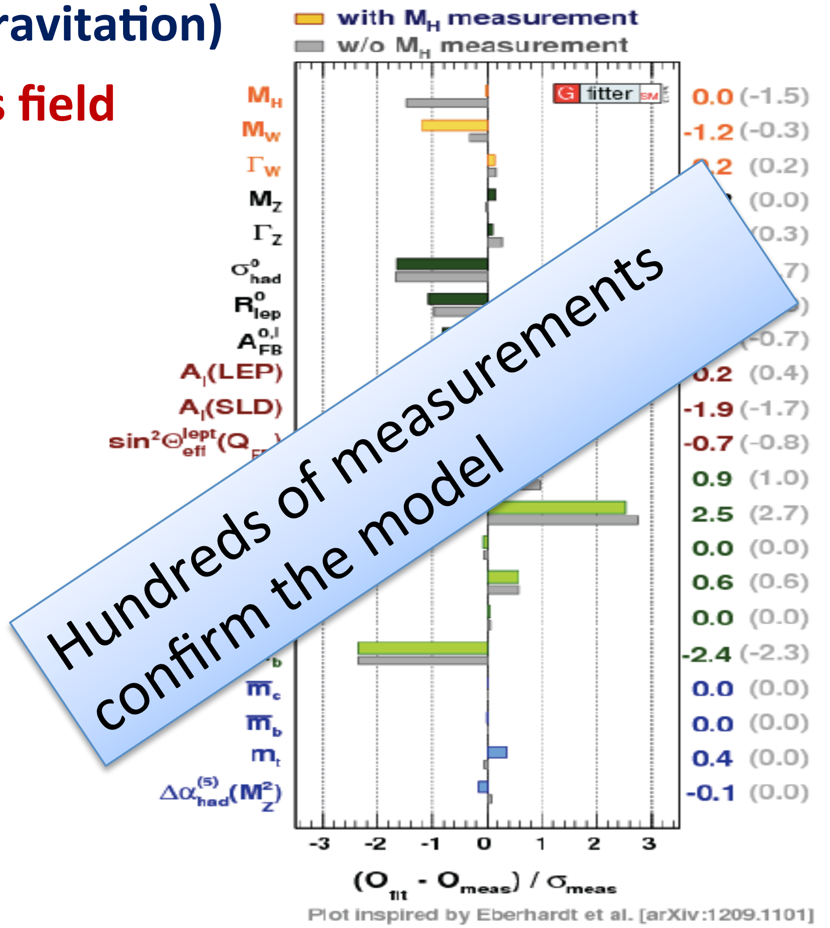


A sort of periodic table of fundamental particles:

(i) Constituents of matter: quarks and leptons

(ii) Four fundamental forces (described by quantum field theories, except gravitation)

(iii) The Higgs field



Unification of forces