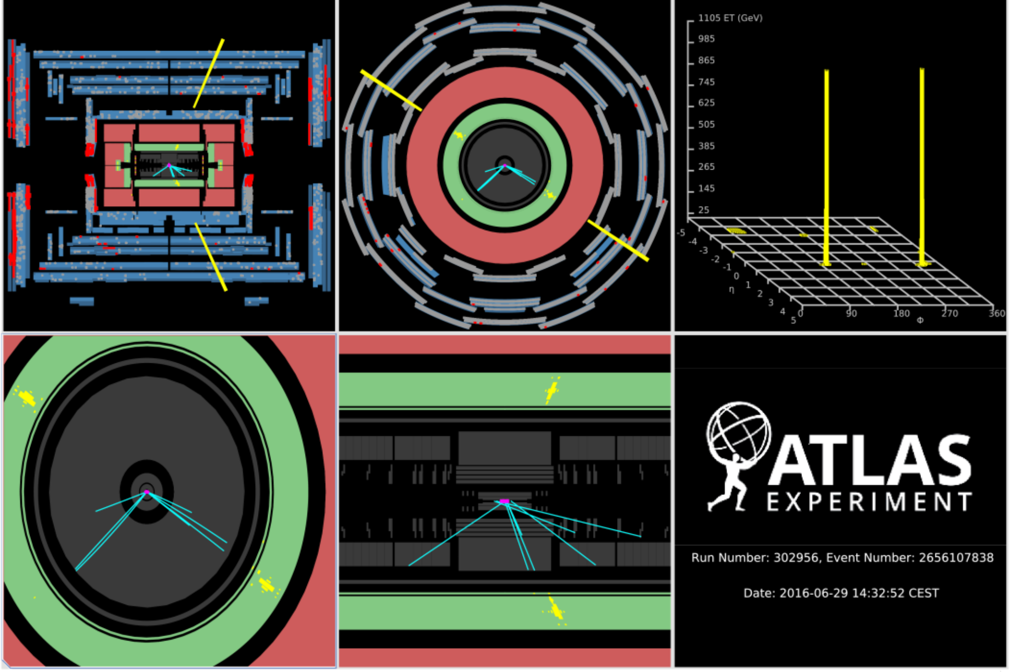
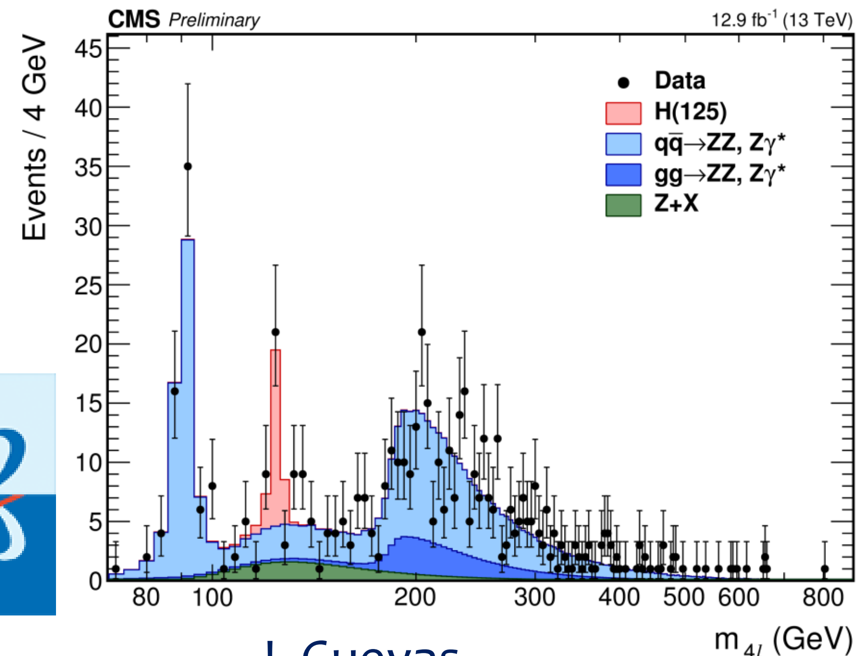
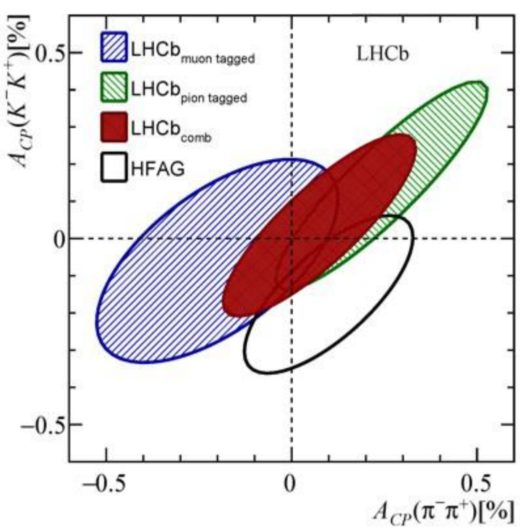


Recent Highlights from the LHC





J. Cuevas
U. Oviedo (Spain)
on behalf of the **ATLAS, CMS, and LHCb** collaborations

QCD@LHC 2016

22 - 26 August 2016, Zurich, Switzerland

Outline

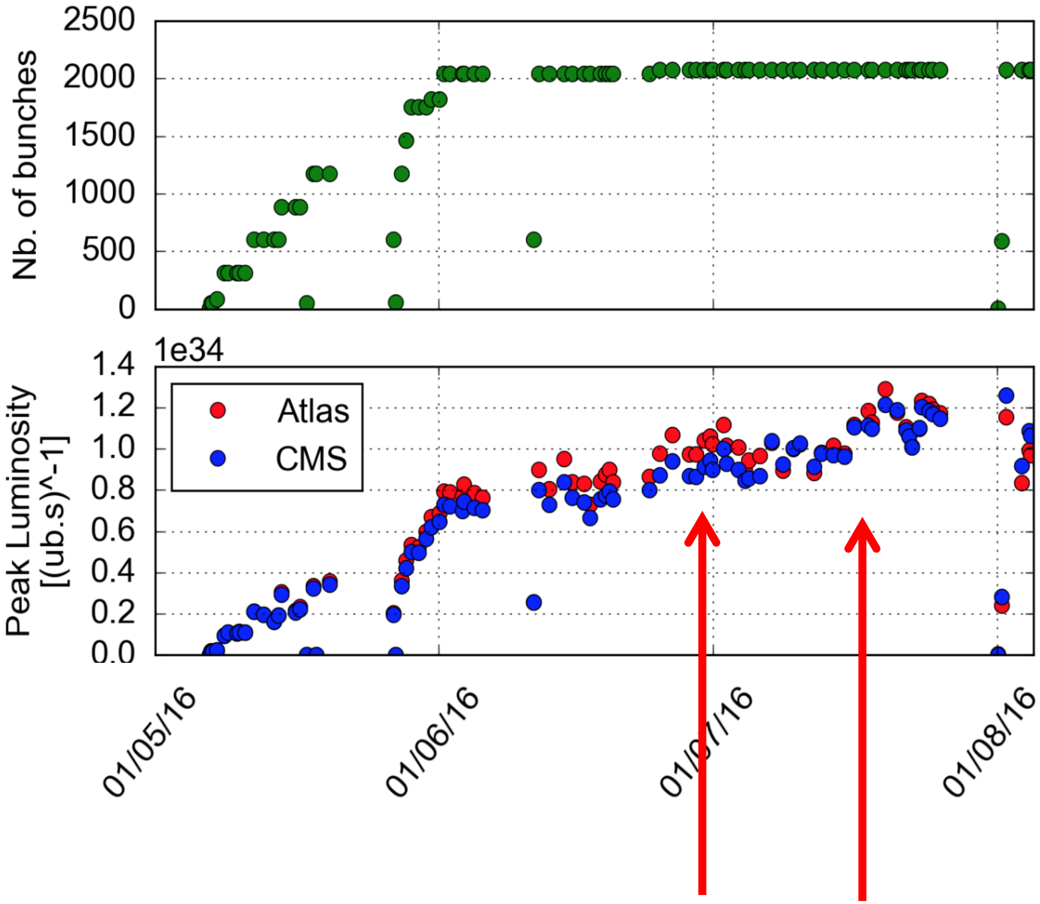
- **LHC** performance in 2016
- **CMS and ATLAS**: around 70 new results prepared in each case for summer conferences.
  - Searches for BSM physics, Supersymmetry and Exotica: exploring the new energy domain
  - Standard Model measurements: exploiting the sophistication of the detectors and exploring deeper the complexity of the Standard Model.
    - **Higgs boson**
    - **SM measurements: EWK** and **top-quark** related measurements

- CMS results: http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/ICHEP-2016.html
- ATLAS results: https://twiki.cern.ch/twiki/bin/view/AtlasPublic/Summer2016-13TeV

- **LHCb:** New probes of CP violation.
- LHCb results: http://lhcb.web.cern.ch/lhcb/

- Results at 13 TeV with 2016 dataset and some with 2015 dataset.
  - ATLAS and CMS have already recorded about 5 times more data in 2016 than in 2015.

LHC Peak luminosity



Reasonably quick ramp-up in number of bunches

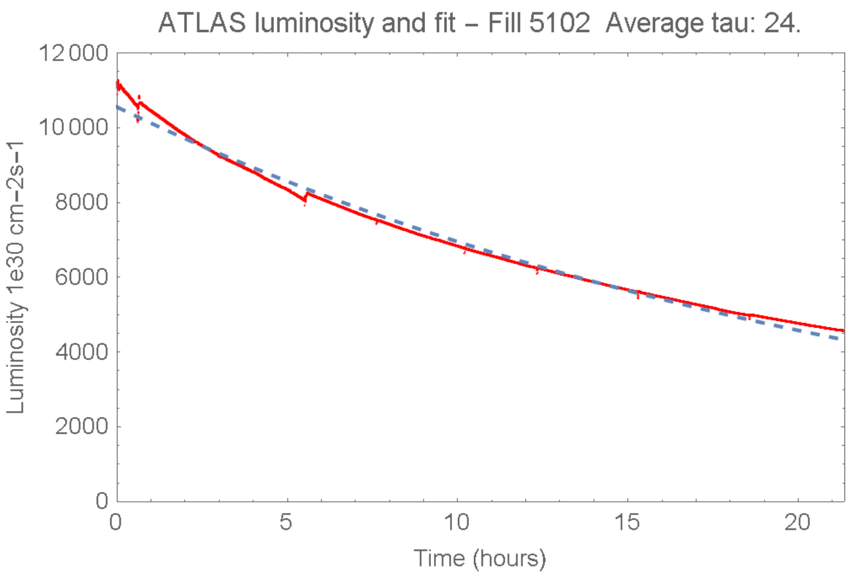
- Limited by SPS beam dump to ~2100
- Electron cloud still very much with us but effects under control
- Reduced beta* and lower transverse beam sizes from the injectors compensating the lower number of bunches

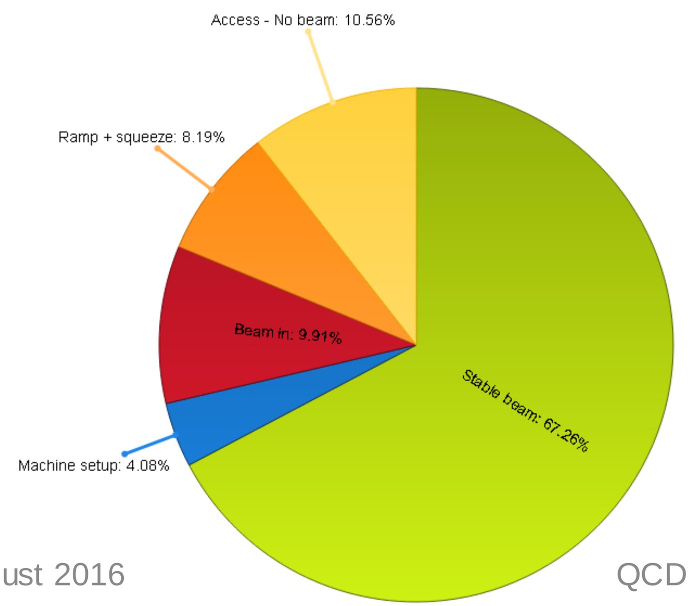
- **Design luminosity reached**

10^{34} **Lower emittance from injectors**

LHCb and ALICE: levelled operation at ~3×10^{32} and ~2×10^{30} $cm^{-2}s^{-1}$ respectively

LHC: Luminosity lifetime/Availability/Prospects





Excellent luminosity lifetime – main component - proton loss to inelastic collisions in ATLAS, CMS and LHCb

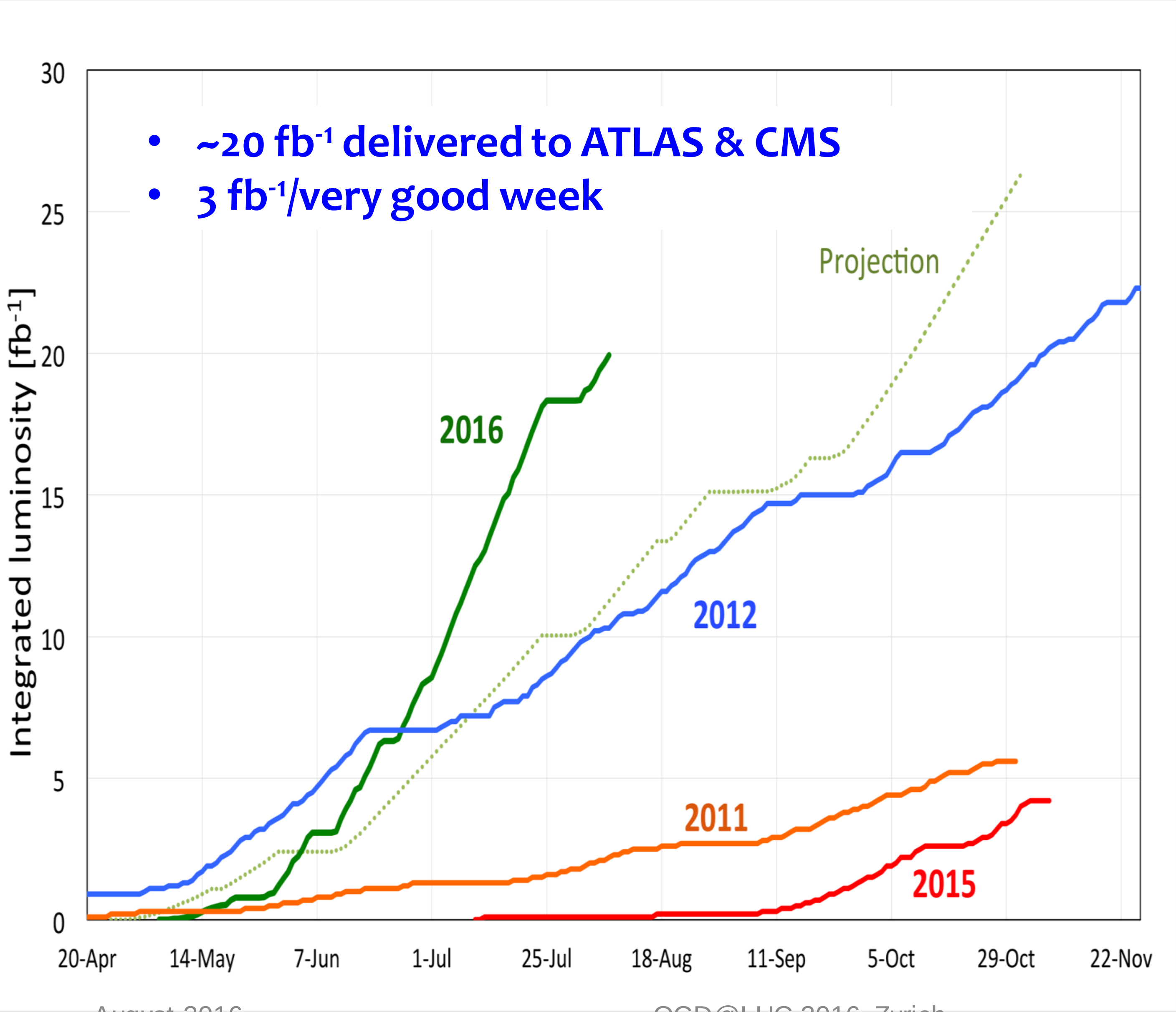
Good peak luminosity, excellent luminosity lifetime

Stunning availability

Sustained effort from hardware groups

- Peak luminosity limited to ~1.7e34 by inner triplets
- ~40 fb^{-1}/year in 2017 and 2018
- Prepare for HL-LHC and post-LS2 LIU era
- Prepare for 7 TeV operation

Integrated luminosity



LHC is enjoying the benefits of the decades long international design, construction, installation effort – foundations are good

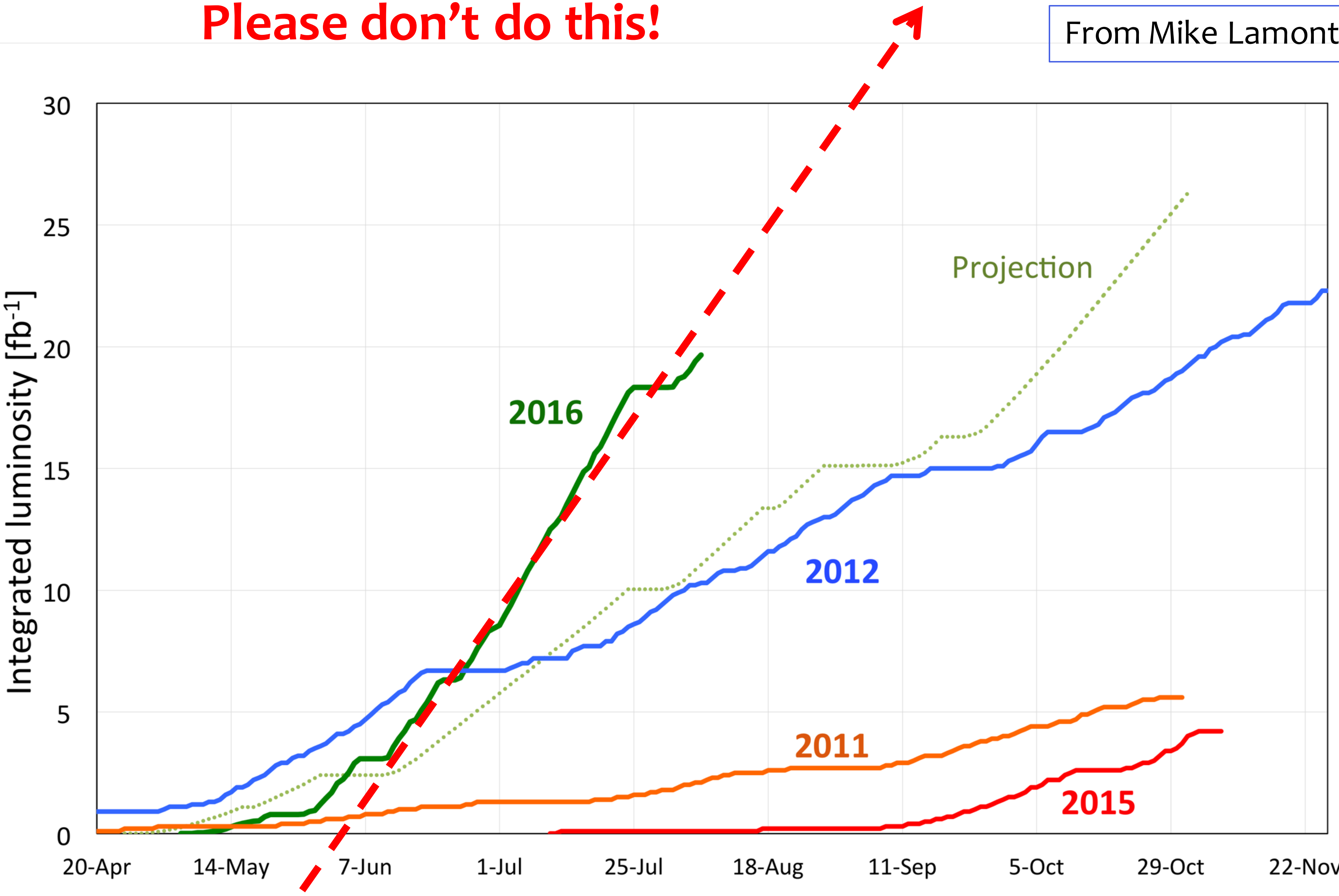
Huge amount of experience & understanding gained and fed-forward

Progress represents a phenomenal ongoing effort by all the teams involved.

Still margin for improvement in Run 2

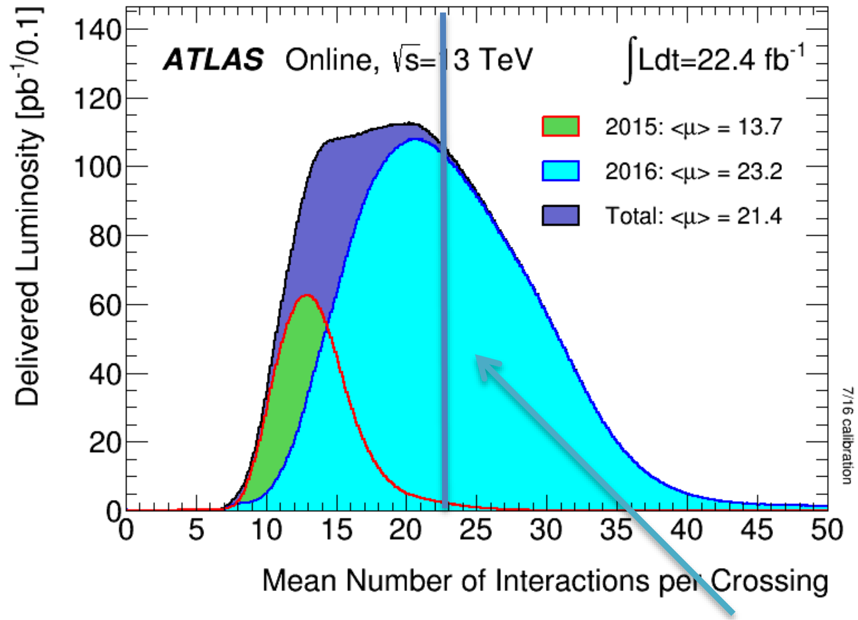
Please don’t do this!

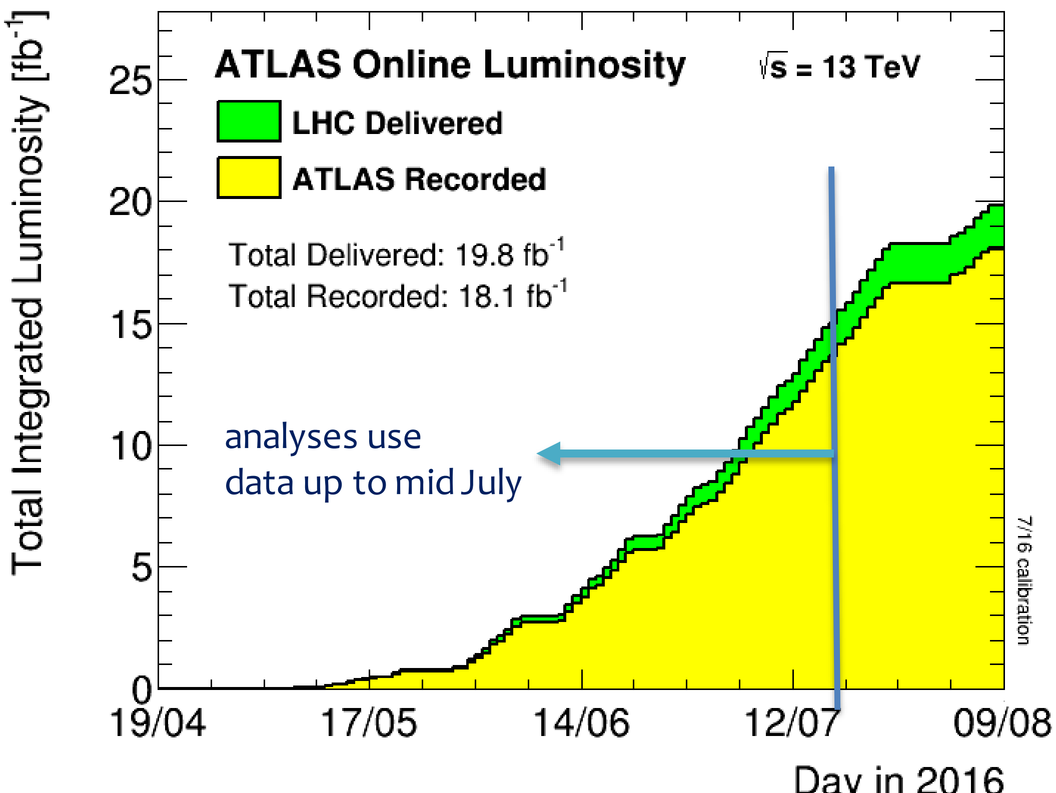
From Mike Lamont



ATLAS data samples

Exceptional LHC performance in 2016
following 13 TeV commissioning in 2015
(2015: 4.2 fb^{-1} delivered, 3.9 fb^{-1} collected)
Results reported with 3-15 fb^{-1}





Pileup often above LHC design in 2016

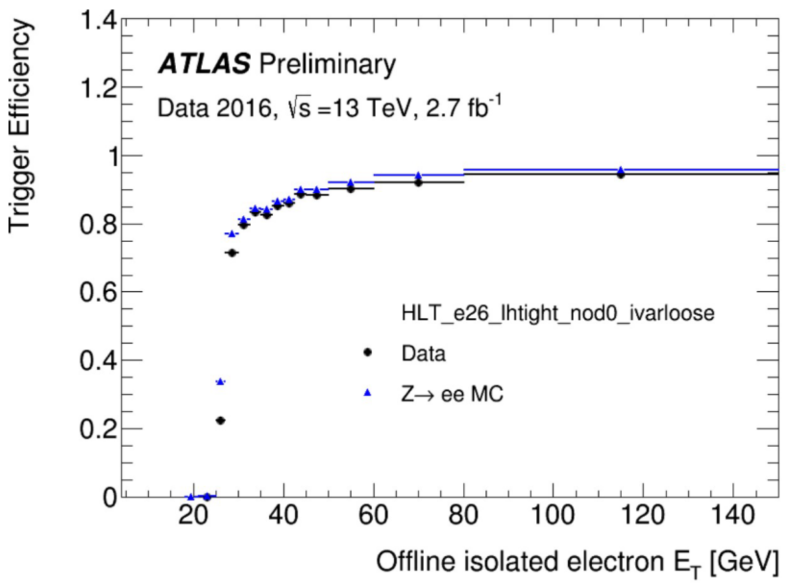
Luminosity uncertainty
- ±2.1% (2015)
- ±3.7% (2016, preliminary)
- ±2.9% (2015+2016, prel)

Data quality in 2016: >90% of data collected usable for analysis

ATLAS trigger

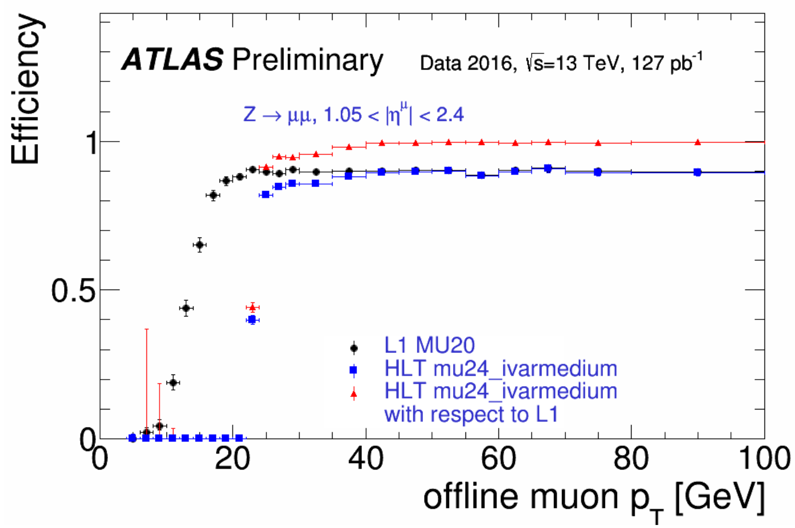
Complex trigger menu designed to meet varied physics, monitoring and performance requirements

- ~2000 active menu items
- Stable main primary triggers
- Level-1 running at ~85 kHz
- Average physics output rate ~1kHz



A few, example, trigger thresholds (GeV)

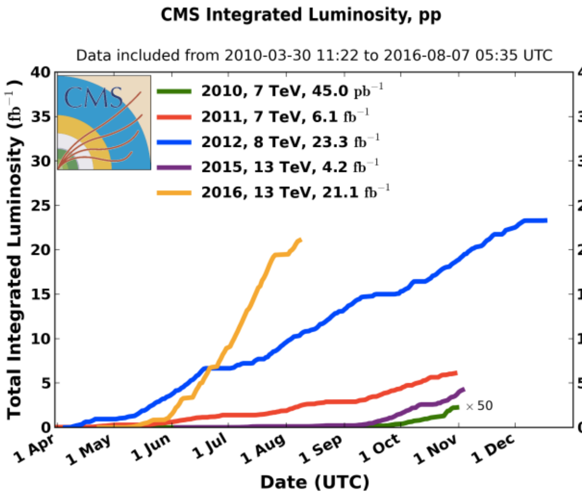
- $E_T(e) > 24$-26
- $p_T(\mu) > 24$-26
- $E_T^{miss} > 90$-110
- $E_T(jet) > 380$
- $E_T(\gamma) > 140$
- $p_T(\mu1,\mu2) > 6,6$ + topo/mass selections
- $E_T(\gamma1,\gamma2) > 35,25$

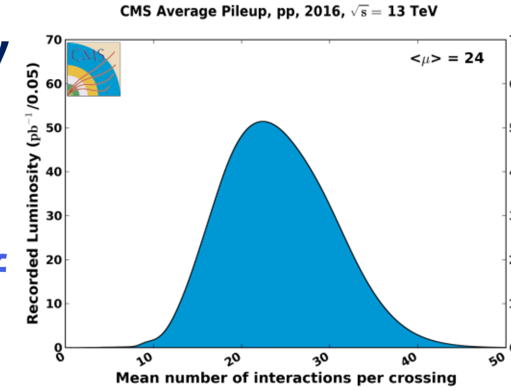


CMS:High luminosity

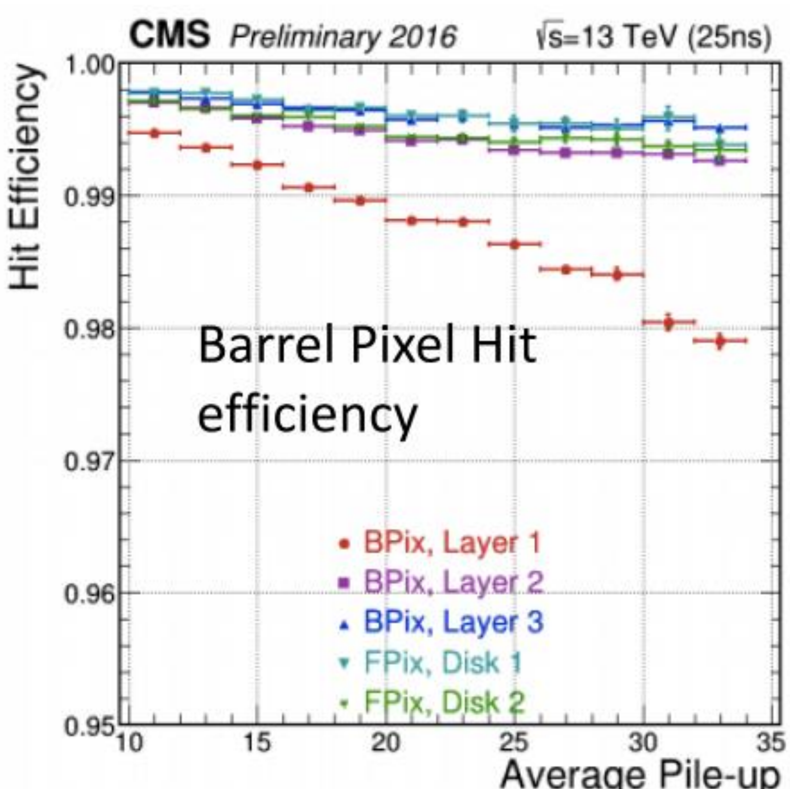
-> High Pileup

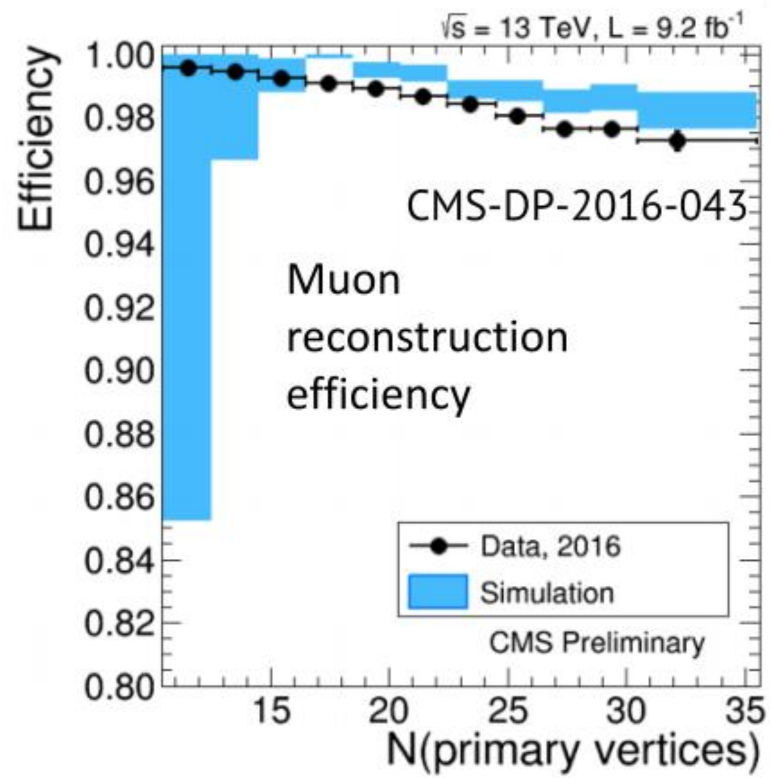
CMS livetime ~95% and > 94% of logged data usable for any physics analysis



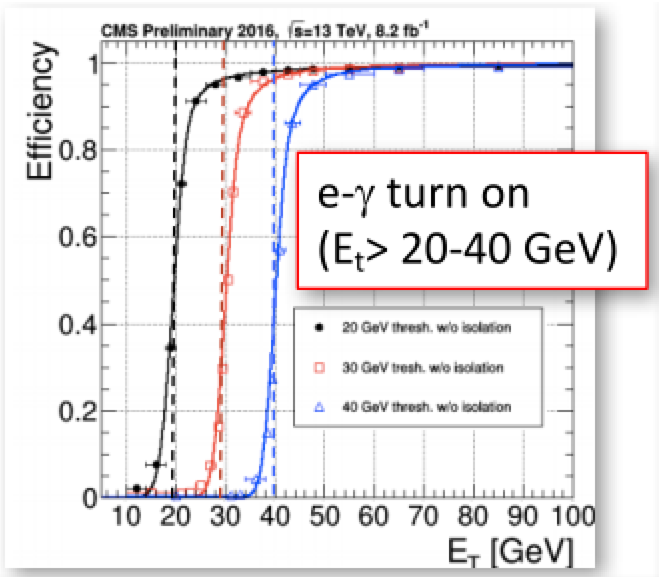


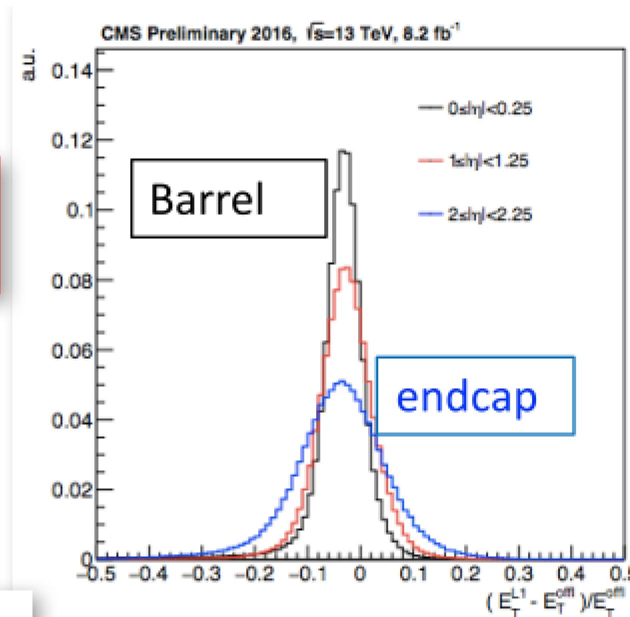
Dealing with Pileup close or above 40 is a challenge!

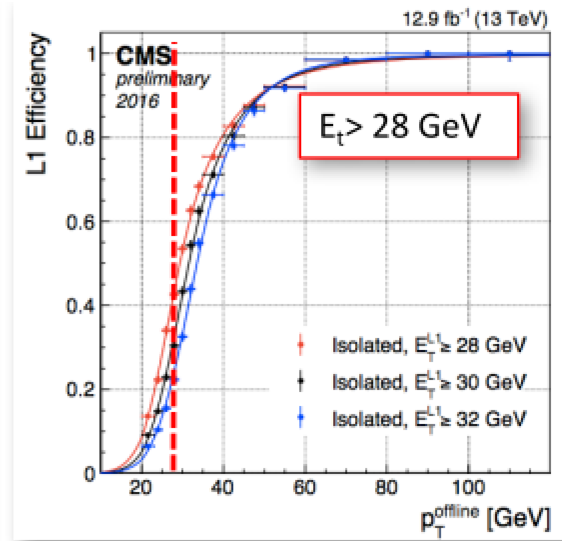


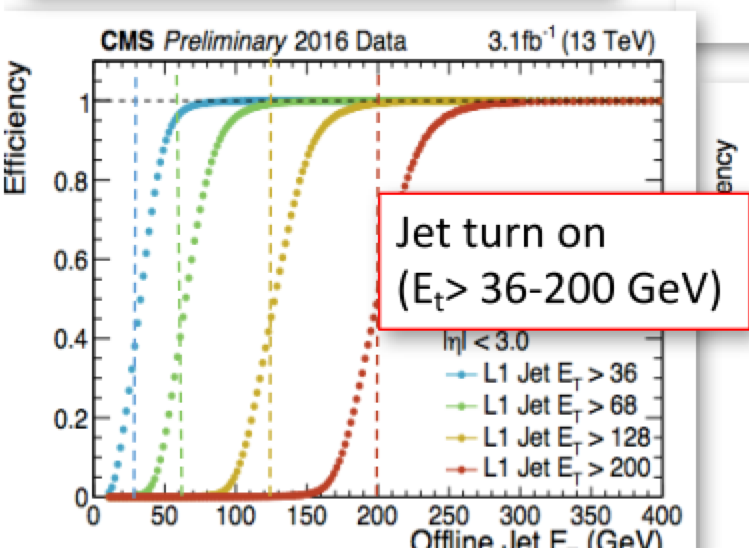


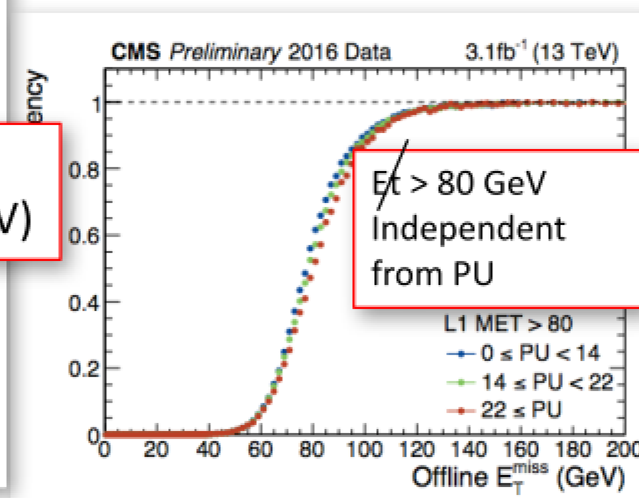
CMS: Trigger upgrade performance

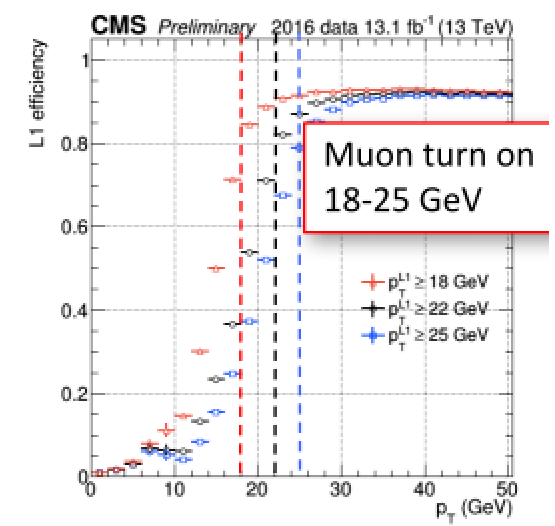






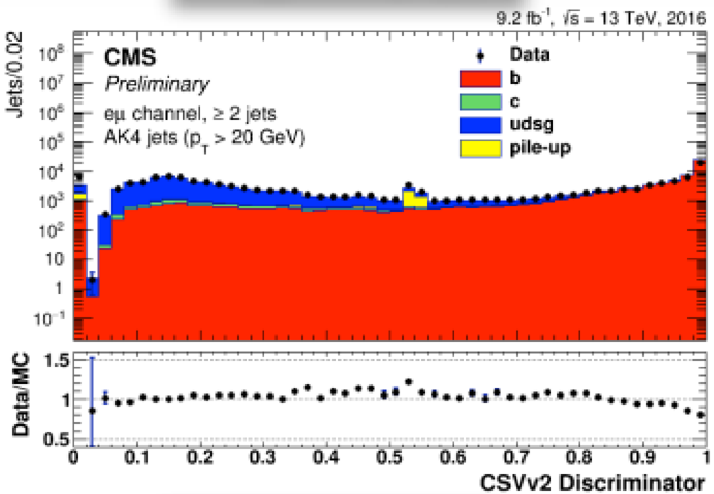




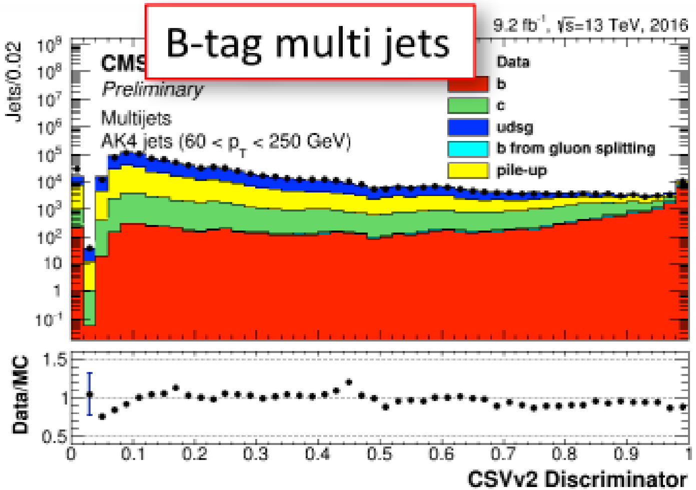


CMS: Physics Objects Performance

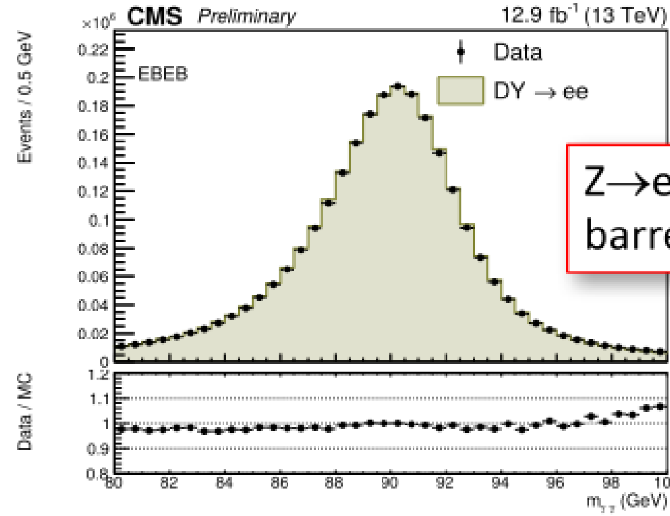
B-tag ttbar(e-μ)



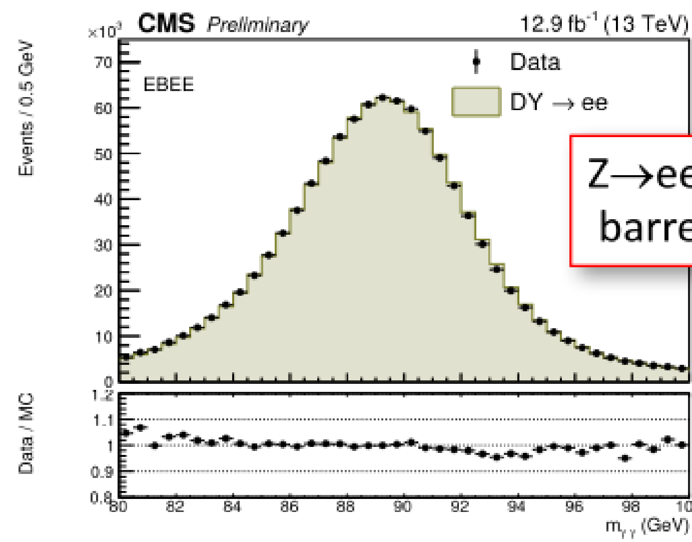
B-tag multi jets



CMS-DP-2016-042



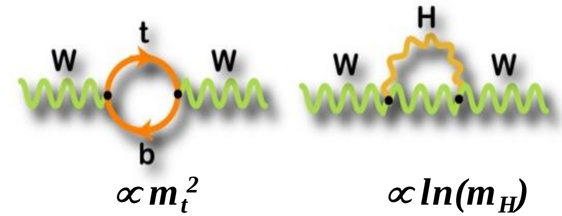
Z→ee
barrel



Z→ee
barrel-endcap

CMS-DP-2016-049

Top and Electroweak measurements: Constraining the SM

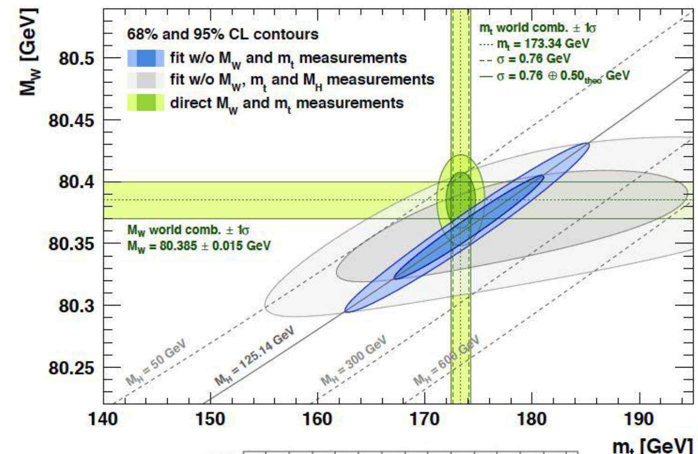


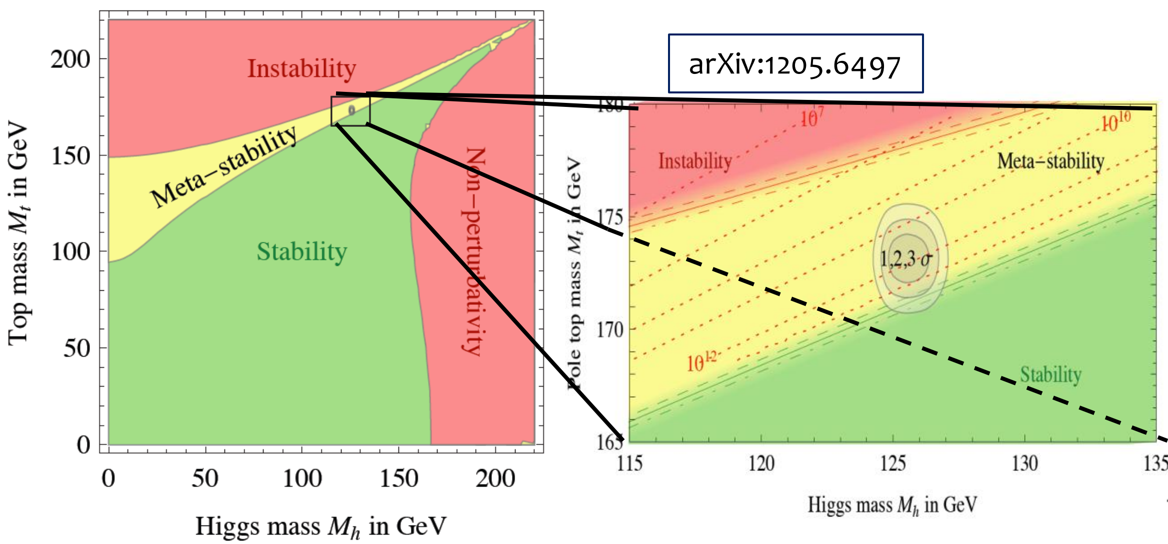
$m_W = m_W(m_t^2, \log(m_H))$

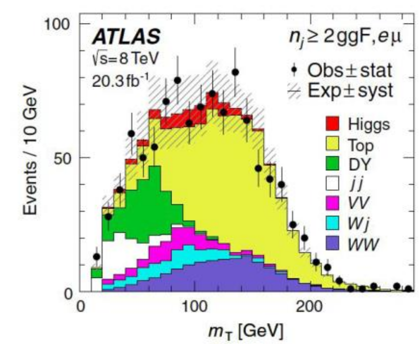
- Test self-consistency of the SM, and the stability of the EW vacuum.
- The Higgs/symmetry breaking sector can be explored with more insights coming from top physics

$$V(\phi) = -\mu^2 \phi^+\phi + \lambda (\phi^+\phi)^2 + Y^{ij} \psi_L^i \psi_R^j \phi$$

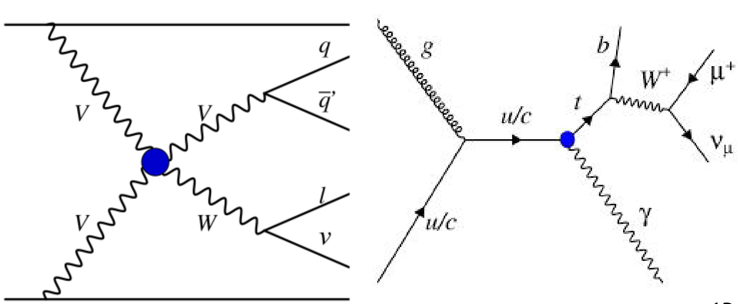
λ now known at NNLO QCD. Vacuum meta-stability when the minimum of $V(\Phi)$ is just local



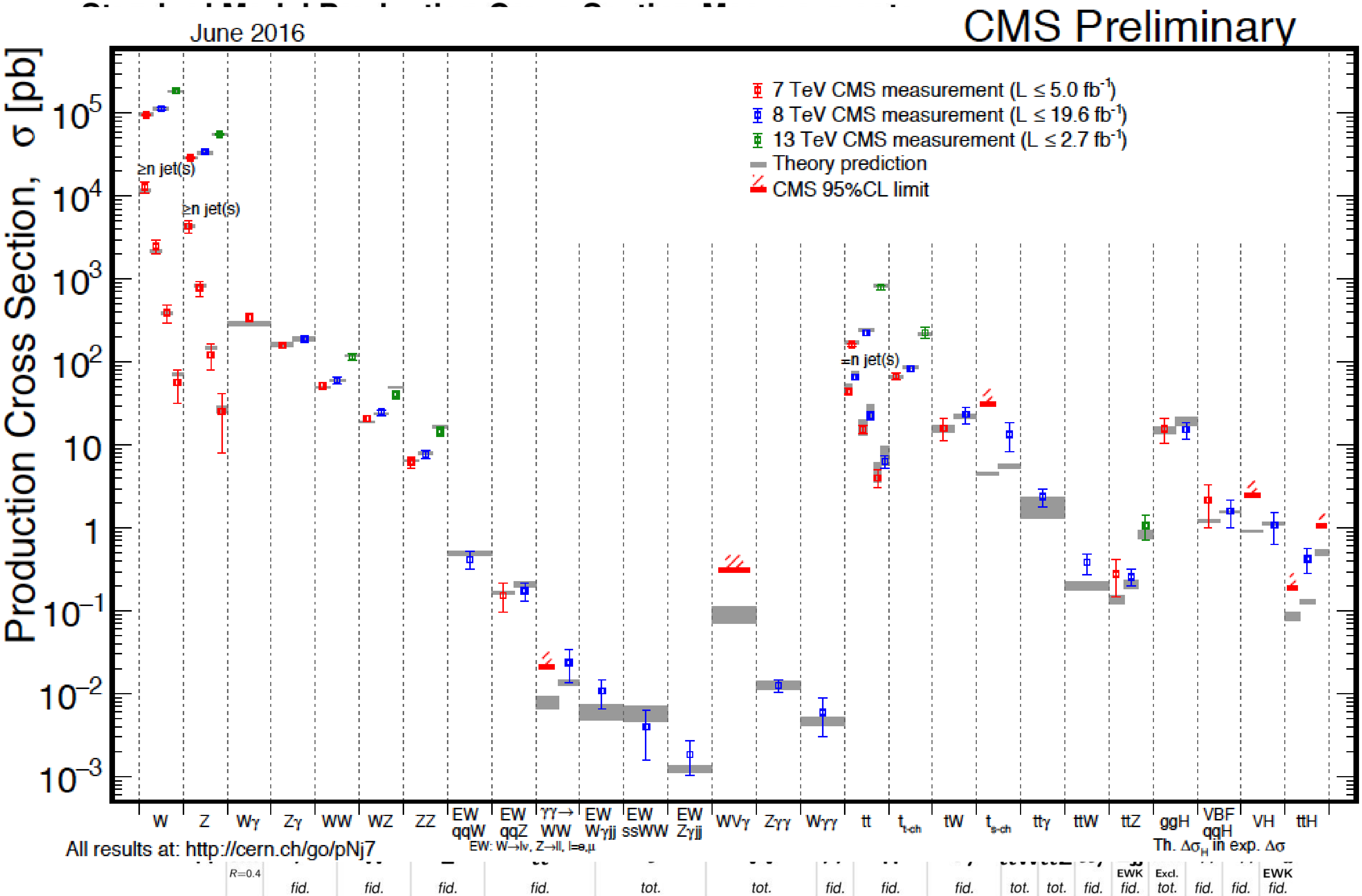




- Background to searches
- Test of gauge structure in the EW sector, New physics in couplings?

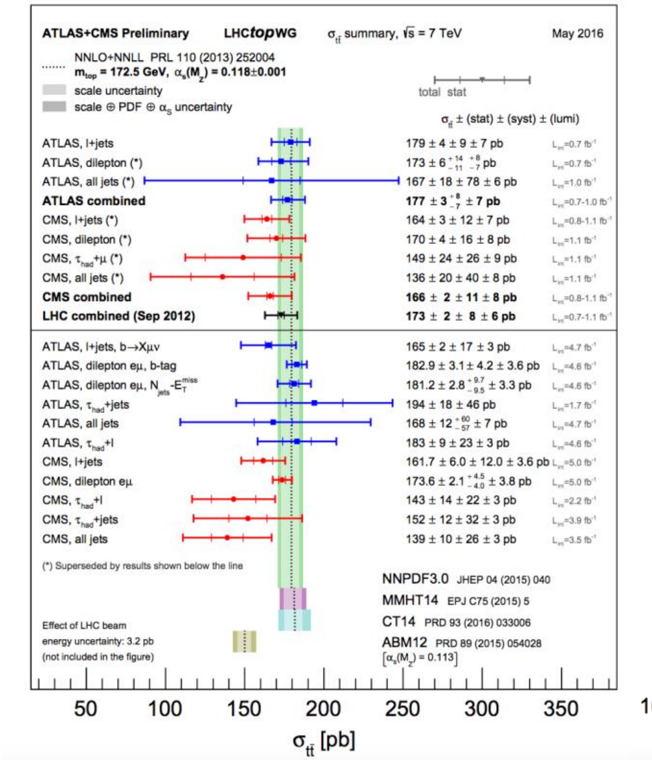


Top and Electroweak measurements

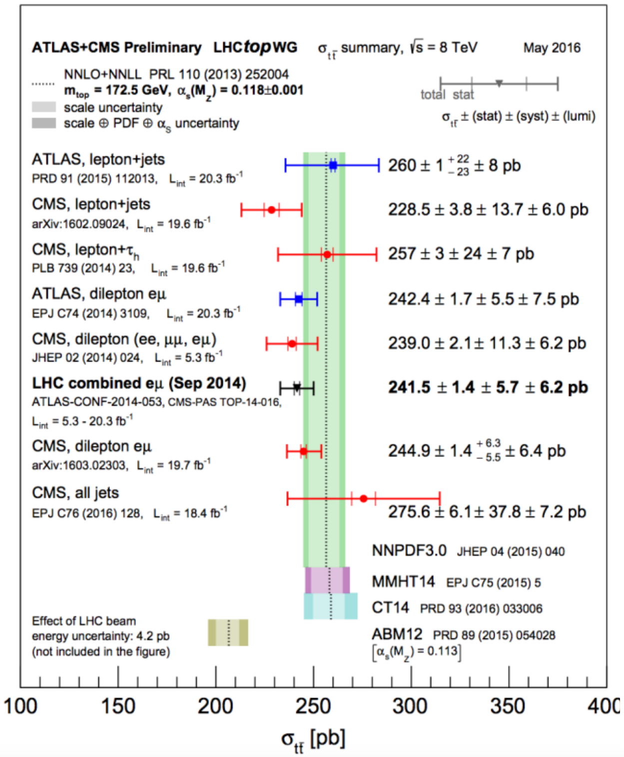


LHC: a Top quark factory

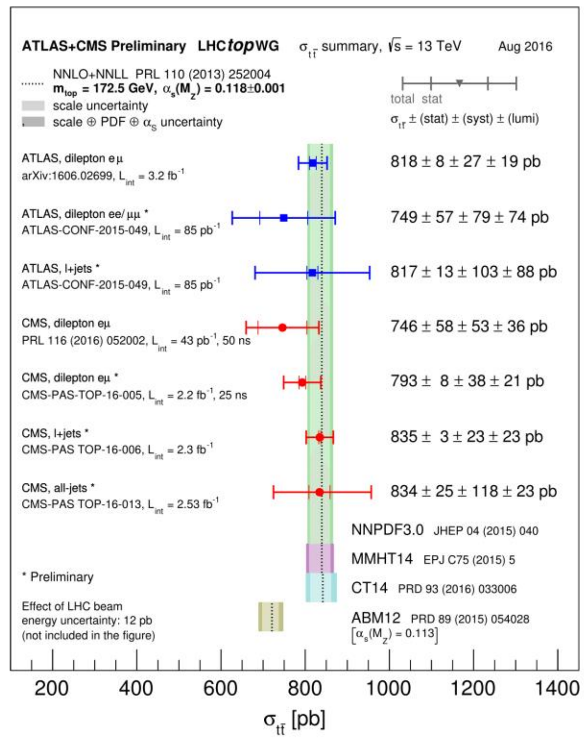
ATLAS and CMS 7 TeV



ATLAS and CMS 8TeV



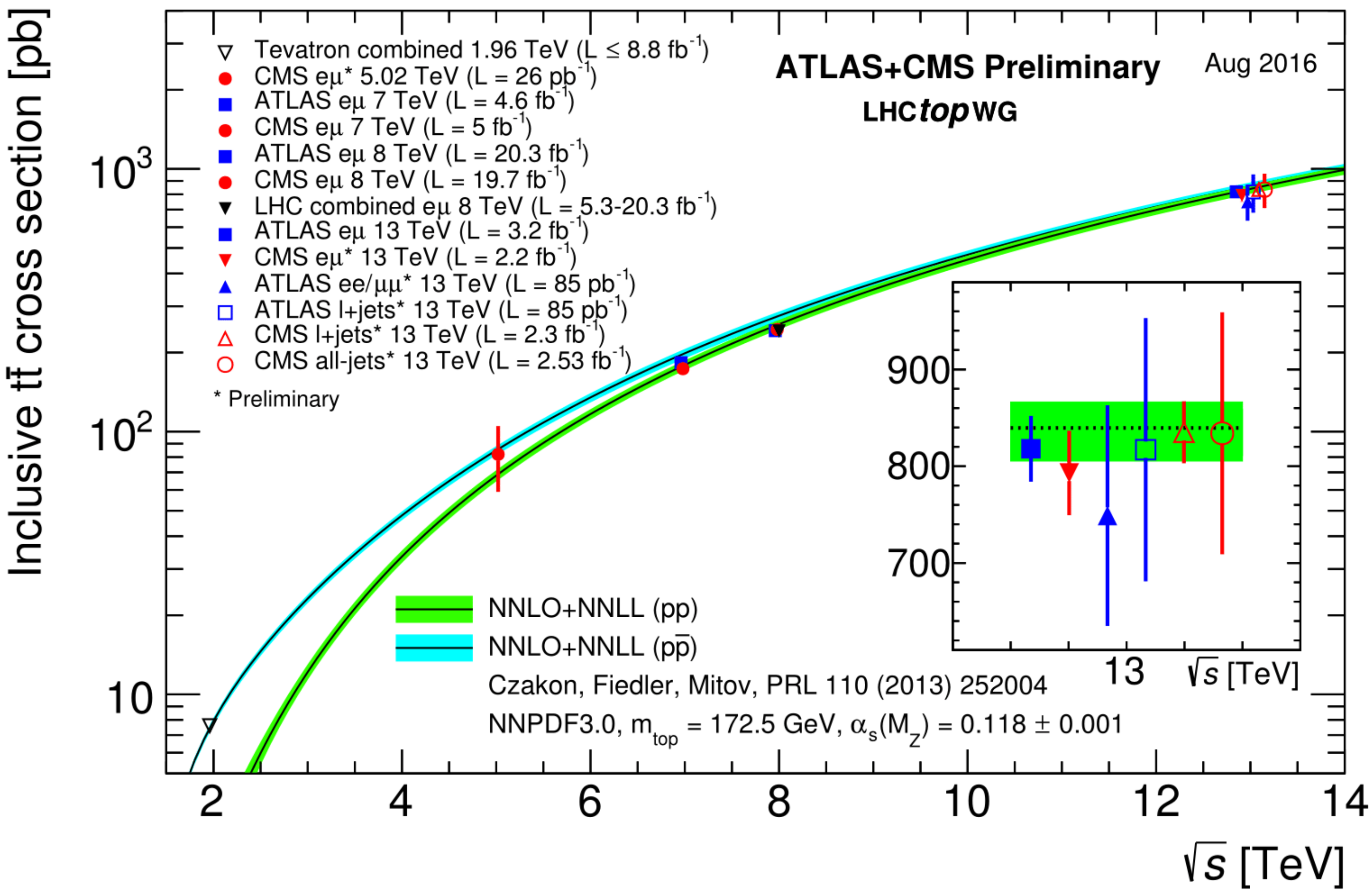
ATLAS and CMS 13 TeV



Precision of measuremet comparable to theory precision

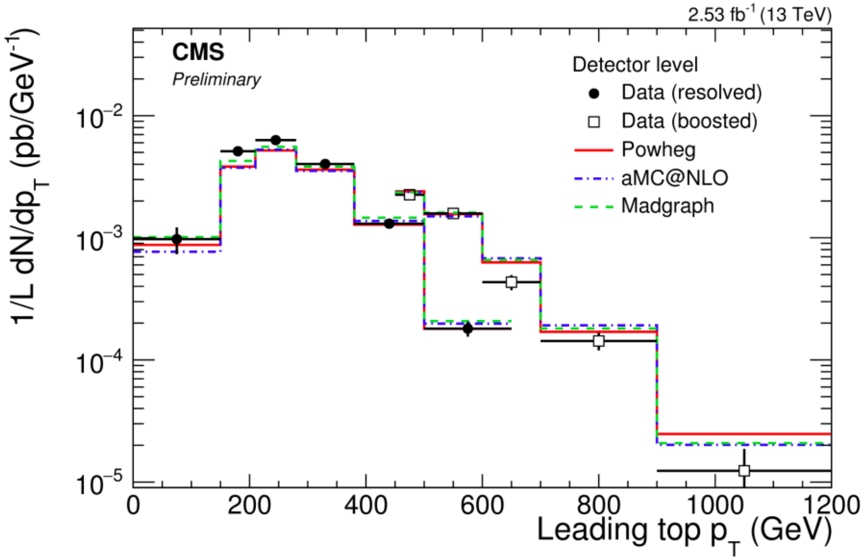
LHC and Tevatron results consistent and in agreement with NNLO+NNLL

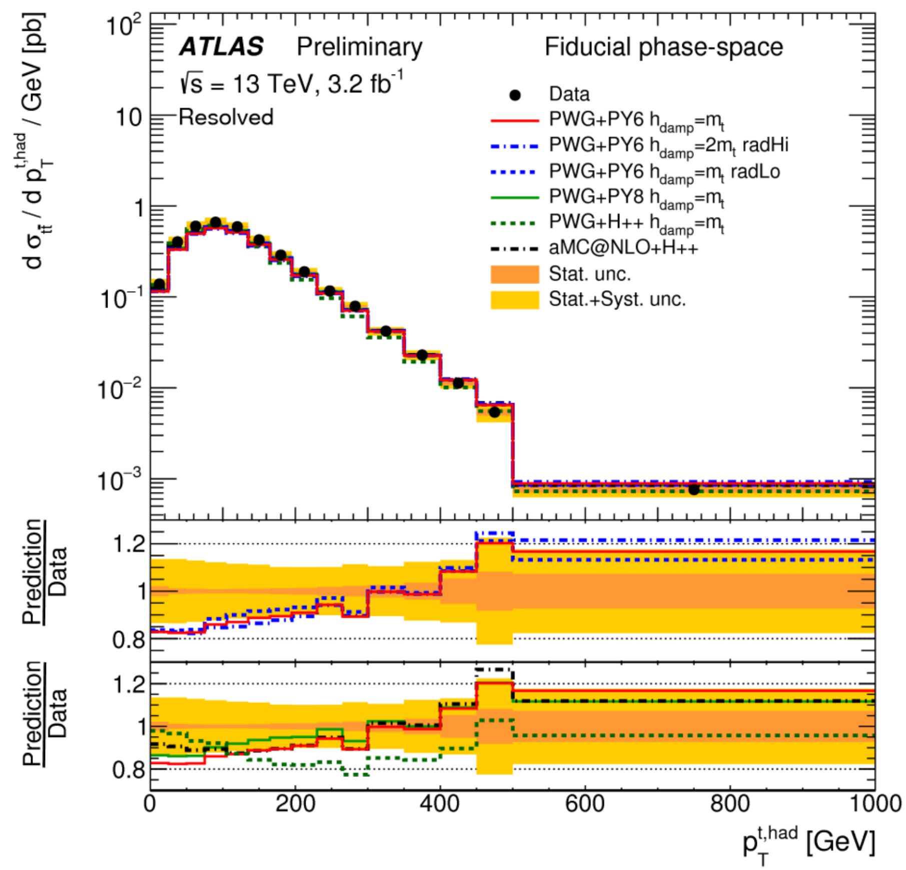
Top quark: Inclusive and differential cross-sections



LHC and Tevatron results consistent and in agreement with NNLO+NNLL over a large range of centre-of-mass energies

Top quark: Inclusive and differential cross-sections





CMS, 2.5fb^{-1},13TeV, all-jets, differential pT
Resolved & boosted, CMS-PAS-TOP-16-013

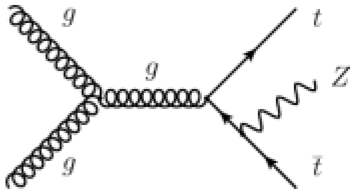
CMS, 2.5fb^{-1},13TeV, l+jets, differential pT
CMS-PAS-TOP-16-008

CMS, 2.2fb^{-1},13TeV, dilep, differential pT(t), y(t), y(tt),m(tt),ΔΦ(tt), CMS-PAS-TOP-16-007

Similar trends as in 8TeV. Top pT modelled too hard (improves with NNLO pQCD)

ATLAS, 3.2fb^{-1},13TeV, l+jets, differential pT
Resolved & boosted, ATLAS-CONF-2016-040
n(jets) in dileptons: ATLAS-CONF-2015-065
CMS, 2.3fb^{-1},13TeV, dilep, ttbb, ttjj
CMS-PAS-TOP-16-010

Top quark: other measurements



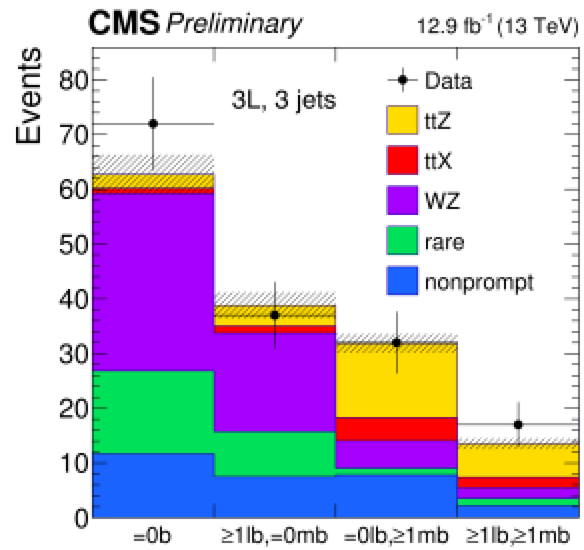
CMS ttZ and ttW

tt-Z coupling
Important backgrounds

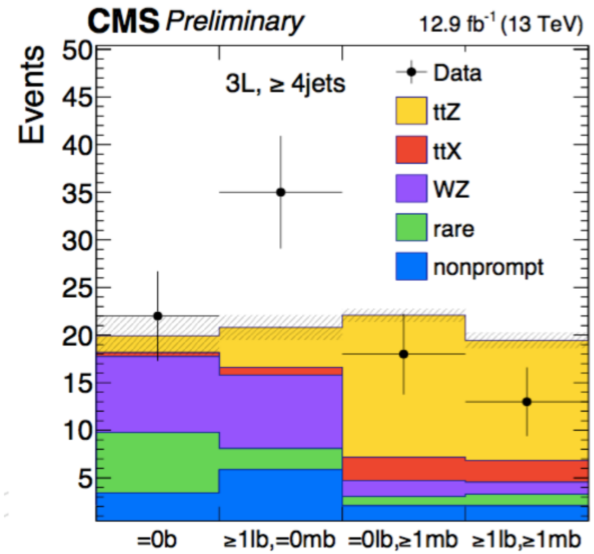
$\sigma(ttZ) = 0.70 \ {}^{+0.16}_{-0.15} \ {}^{+0.14}_{-0.12}$ pb

$\sigma(ttW) = 0.98 \ {}^{+0.23}_{-0.22} \ {}^{+0.22}_{-0.18}$ pb

(→ ttW: 3.9σ, ttZ: 4.6σ)



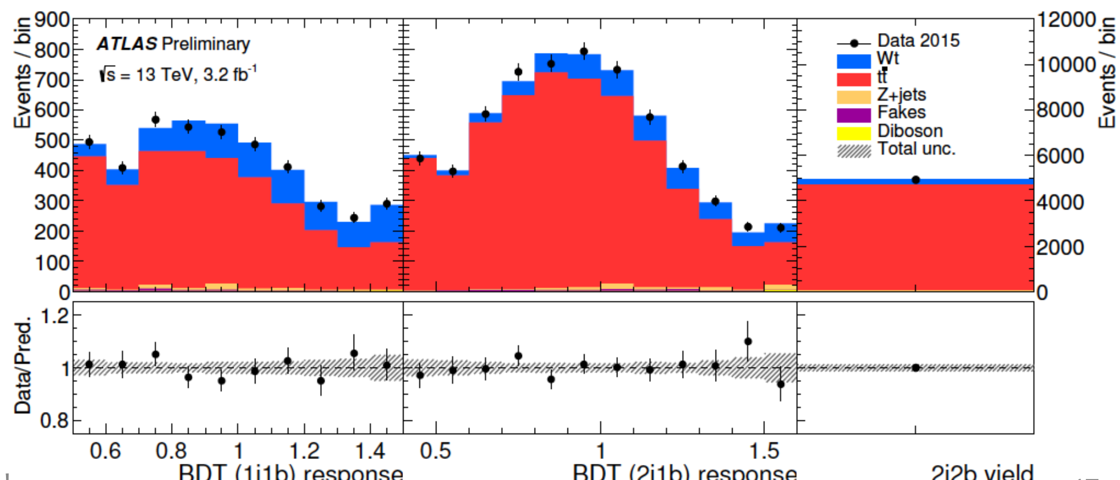
CMS, 12.9 fb^{-1}, 13TeV, ttZ, ttW, **CMS-PAS-TOP-16-017**



ATLAS 13TeV, Wt-channel

Binned profile LLH, on BDT,
σ(Wt) = 94 ±10+28-23 pb

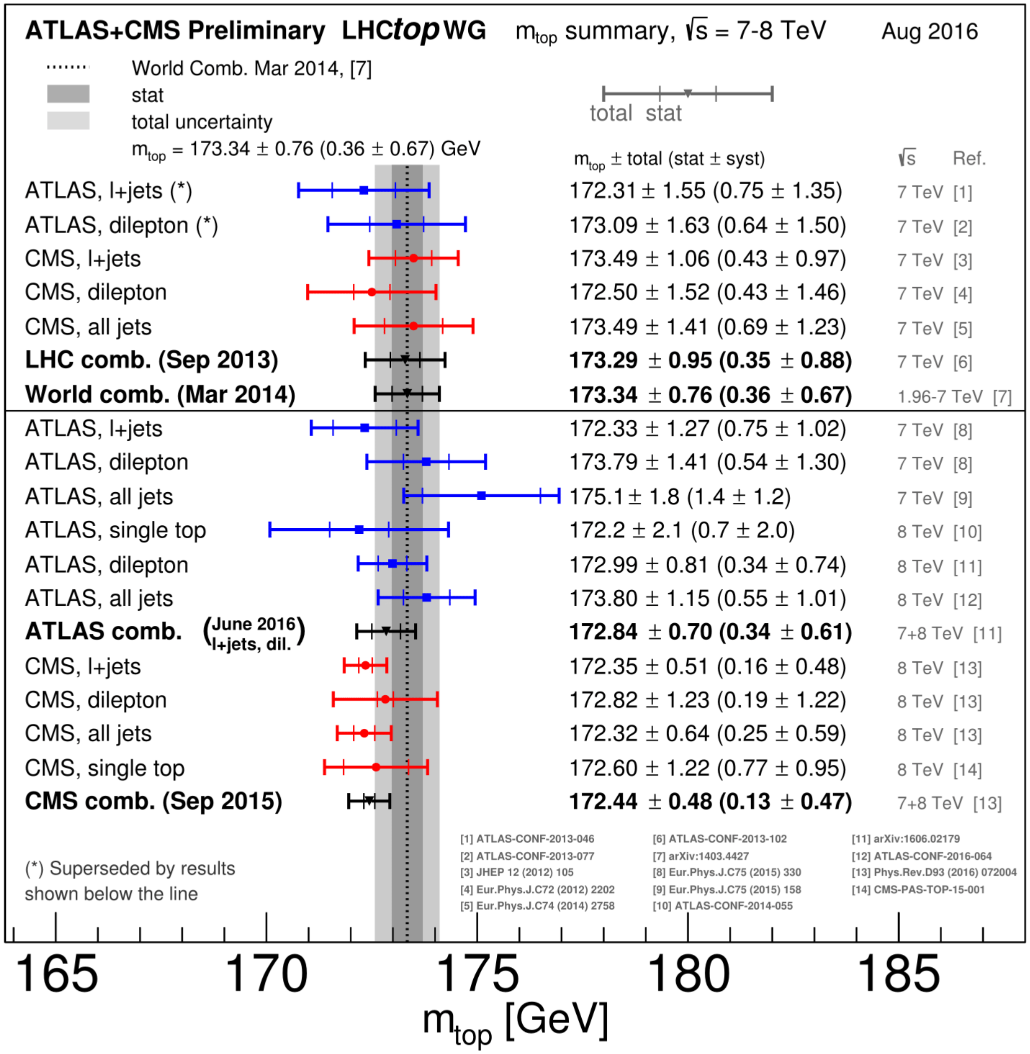
ATLAS, 3.2fb-1, 13 TeV, Wt-channel., **ATLAS-CONF-2016-065**

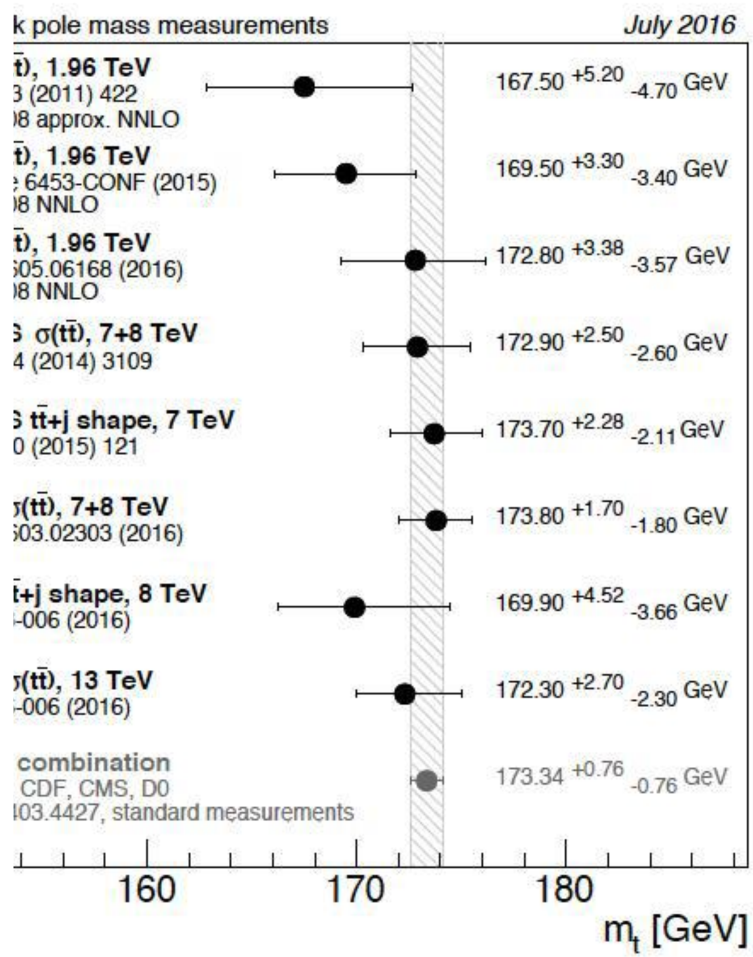


CMS + ATLAS m_{top}

LHC*top*WG precision of 0.3%

Indirect measurements of m_t^{pole} compatible with measured m_t^{MC} within precision of ± 2 GeV



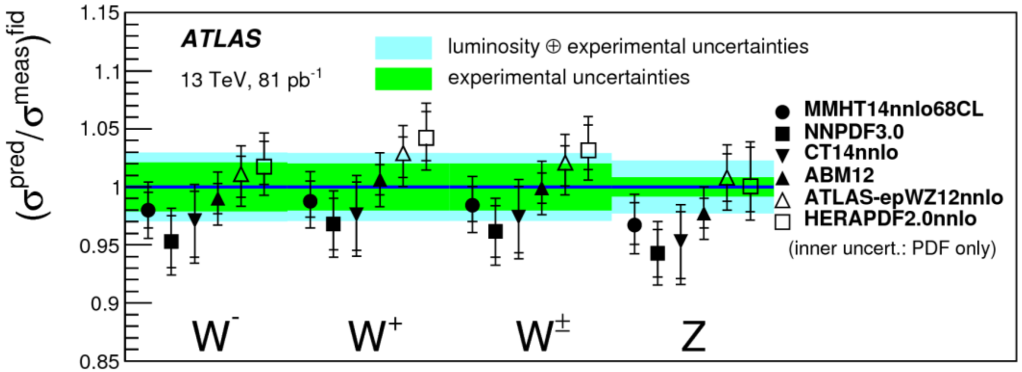


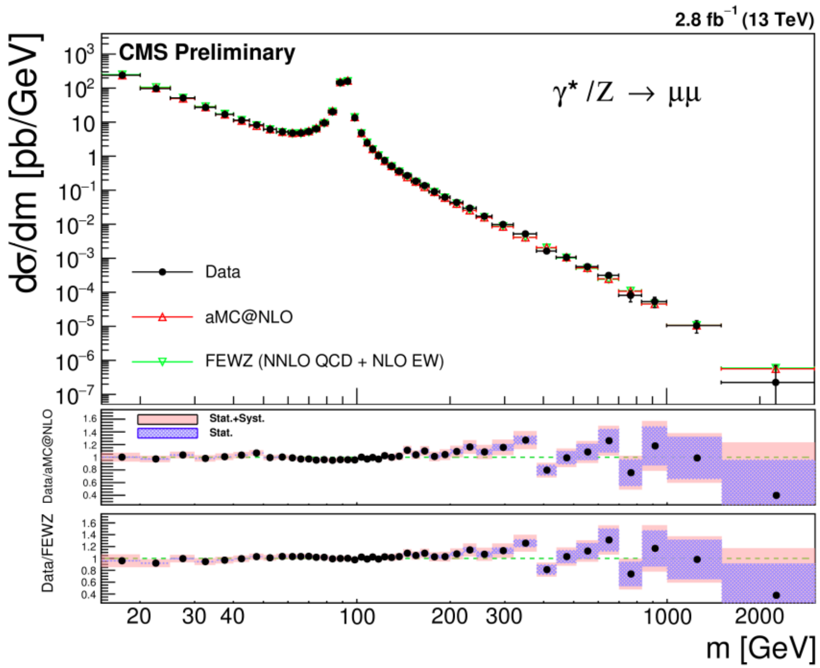
W and Z at 13TeV

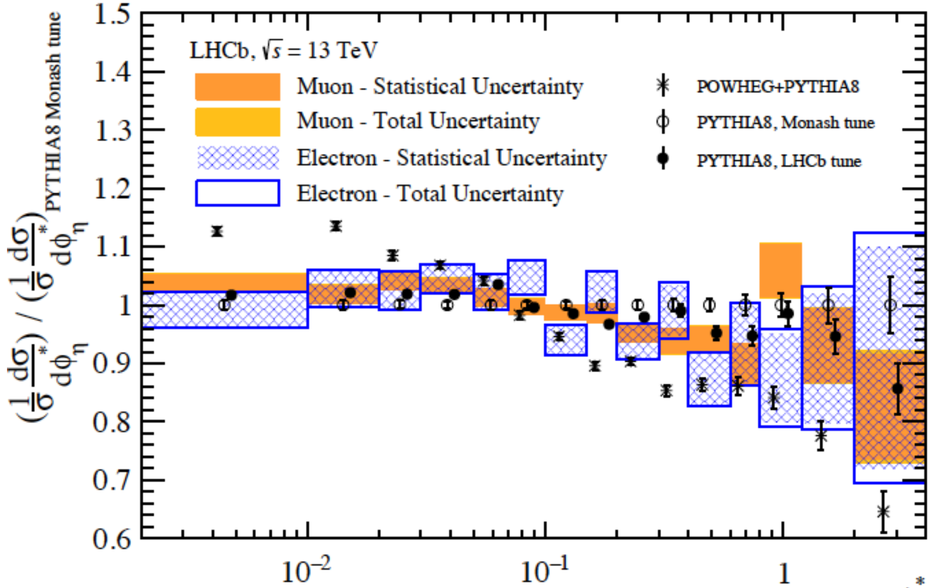
ATLAS , 81 pb^{-1}, 13TeV, W, Z, W+/W-, W/Z
Phys. Lett. B 759 (2016) 601

LHCb, 294 pb^{-1}, 13TeV, Forward Z 2.0 < |η| < 4.5
Φ*, ZpT, y(Z) arXiv:1607.06495
σ(Z->ll) = 194.3±0.9±3.3±7.6 pb

CMS , 2.8 fb^{-1}, 13TeV, m(Z)
CMS-PAS-SMP-16-009





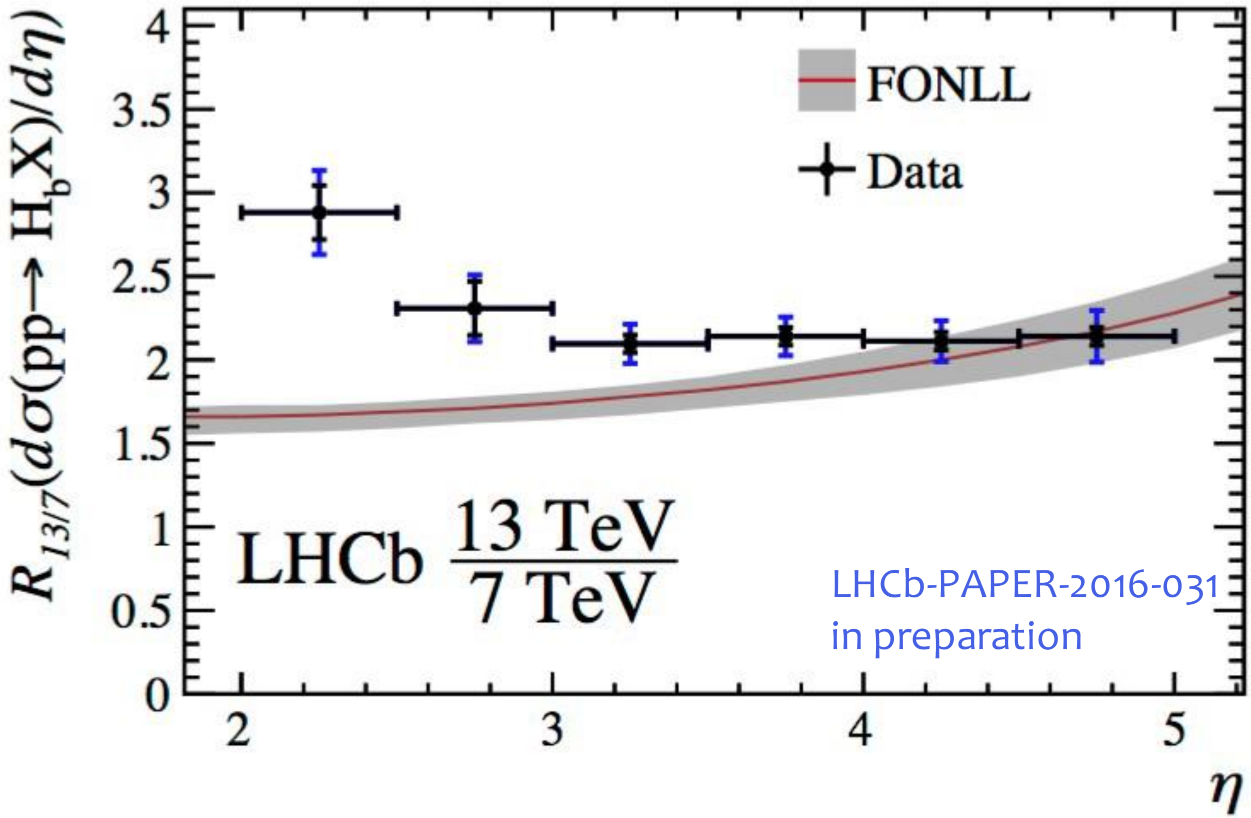


Inclusive (W,Z) and differential (Z) cross sections
→ Percentage-level precision, consistent with SM
Starting differential cross section measurements

bb Cross-Section at 7 and 13 TeV

LHCb has measured the cross-section for the process pp→bbX at both 7 and 13 TeV centre-of-mass energies, in the pseudorapidity range 2 < η < 5

- The measurement is made using semileptonic decays of b-hadrons



LHCb-PAPER-2016-031
in preparation

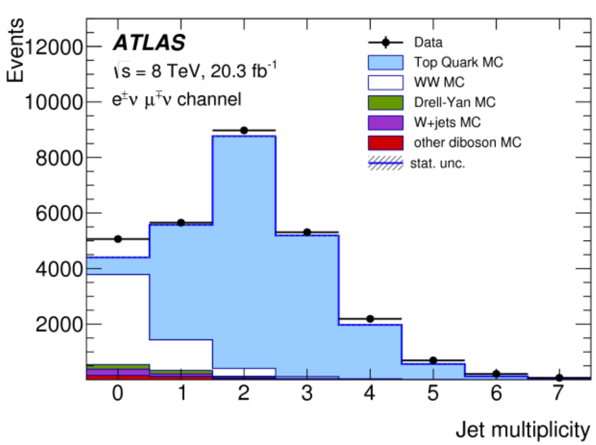
The ratio of **13 to 7 TeV cross-sections** appears to depart from FONLL theory predictions at low η, further theoretical progress needed

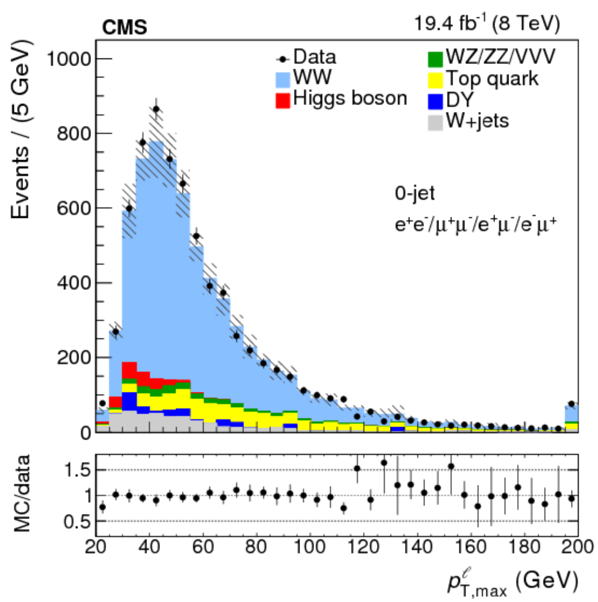
Multi Boson production: WW -> lνlν

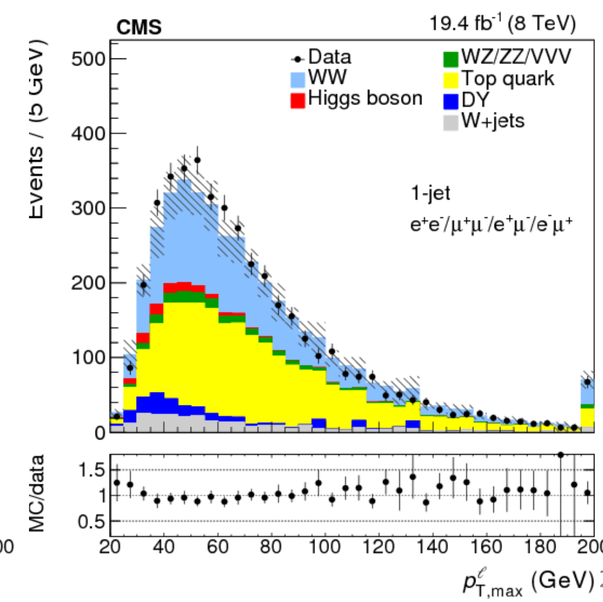
- Signal selection
  - Opposite-sign high-pT isolated leptons (ee, μμ, eμ)
  - Missing transverse energy (reduce Drell-Yan)
  - Jet veto (reduce ttbar), (outside the mZ mass window, if of same flavour). jet btagging. Either jet veto or 0 1 jet categorization.

ATLAS 20.3 fb^{-1}, 8TeV, WW, **arXiv:1603.01702, arXiv:1608.03086** (W^+W^- production in association with one jet)
CMS 19.7fb^{-1}, 8TeV, WW, **EPJC 76 (2016) 401**

- Background, total 15 – 30%,
  - Mainly ttbar / tW, W/Z+jets (measured with data), DY with MC normalized to data
  - W+jets: Control region with one nominal lepton and one loose lepton, **crucial for HWW**
  - Top: Jet multiplicity distribution in ttbar control region (using b-tagged jets)
  - WZ, ZZ and VVV are estimated from simulation
- **Excess in early cross section** measurements from **both ATLAS and CMS** has triggered a lot of theory papers about the NNLO calculations and further investigation on resummation effects at large logs
- **This measurement attracted a lot of attention**







Multi Boson production: WW -> lνlν

ATLAS: arXiv:1603.01702

Cross section measurement uncertainty is ~8.5 %
Dominant theory uncertainty in eμ comes from jet veto (3.4%), parton shower, hadronisation and underlying-event uncertainties (2.5%)

The combined total cross section is compatible with NNLO within 1.4σ

ATLAS: arXiv:1608.03086 (W+W- production in association with one jet)

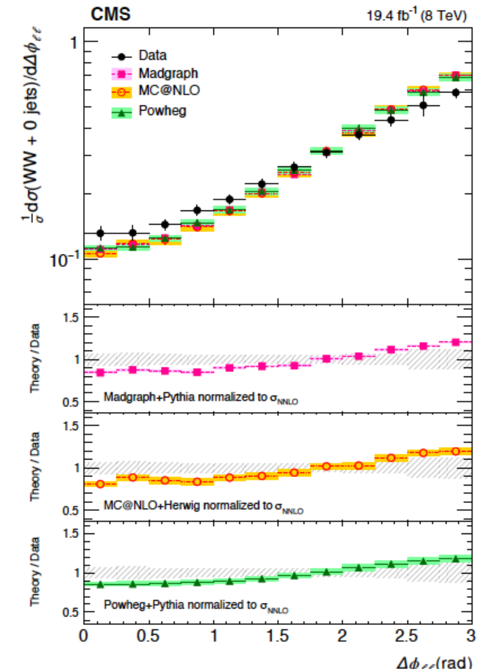
Extend the previous measurement to 1-jet final states. In combination with previous result provide a WW+≤ 1 jet fiducial cross section with reduced logarithmic dependence

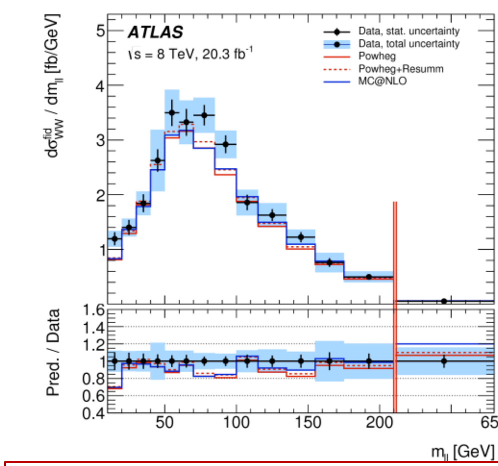
The result on total cross section is 12% more precise than the previous ATLAS measurement based on WW+0jet

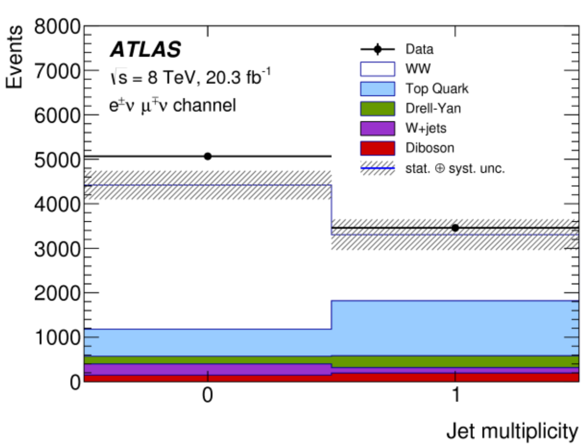
CMS: EPJC 76 (2016) 401:
Events with same-flavor and different-flavor lepton pair, with 0 and 1 associated jets, are used to measure the inclusive cross section.
p_T^{WW}-resummed calculation used for extrapolation to the full W-boson decay phase space.

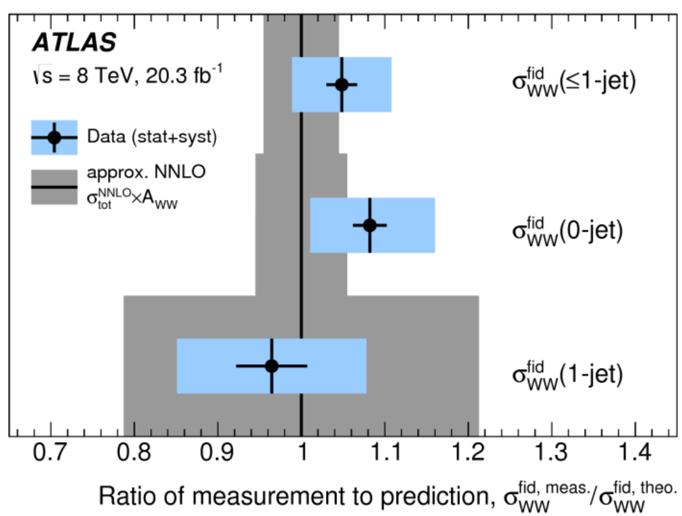
σ = 60.1 ± 0.9 (stat) ± 3.2 (exp) ± 3.1 (theo) ± 1.6 (lumi) pb

SM NNLO prediction: $59.8^{+1.3}_{-1.1}$ pb



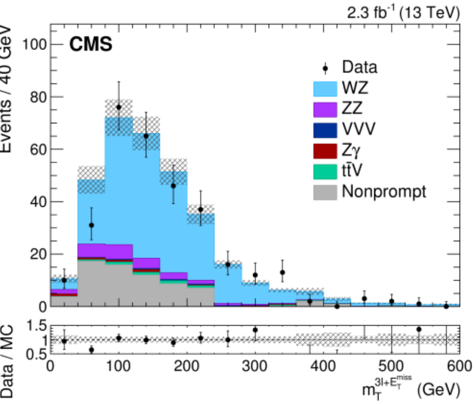


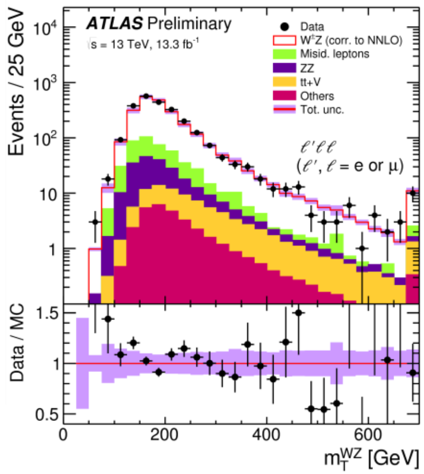


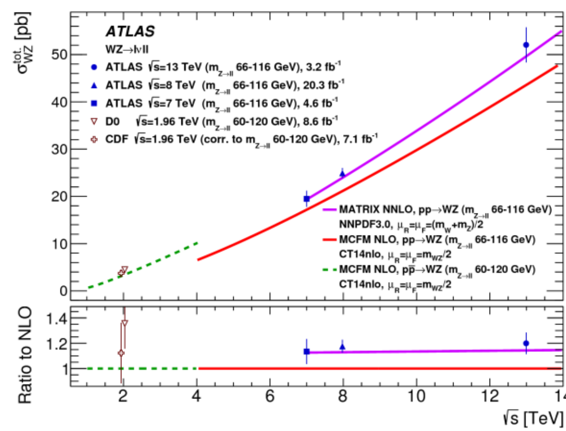


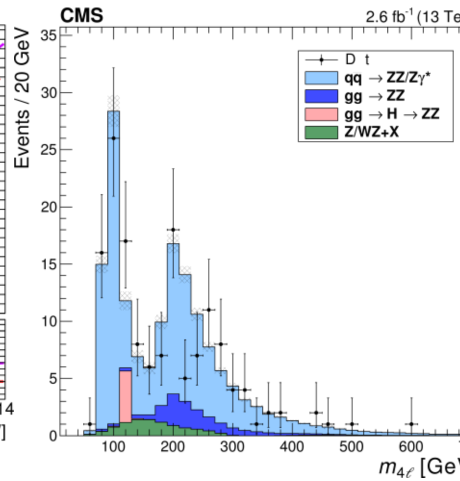
Shapes of the measured unfolded differential distributions agree with the predictions at the level of 15%

Multi Boson production, 13 TeV









Largest systematic uncertainty contribution from non-prompt background.

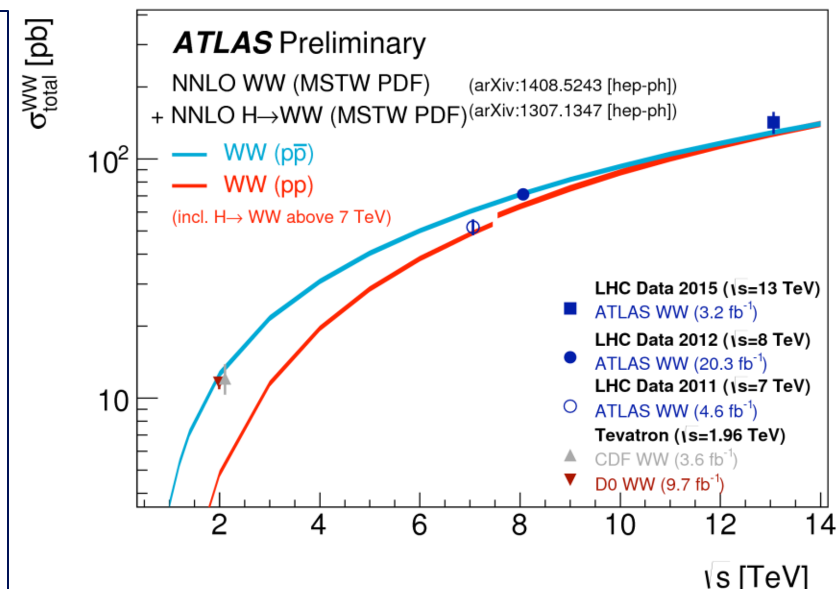
$$\sigma(pp \to WZ) = 39.9 \pm 3.2\,(\text{stat})^{+2.9}_{-3.1}\,(\text{syst}) \pm 0.4\,(\text{theo}) \pm 1.3\,(\text{lumi})\,\text{pb}.$$

SM NNLO prediction: $50.0^{+1.1}_{-1.0}$ pb

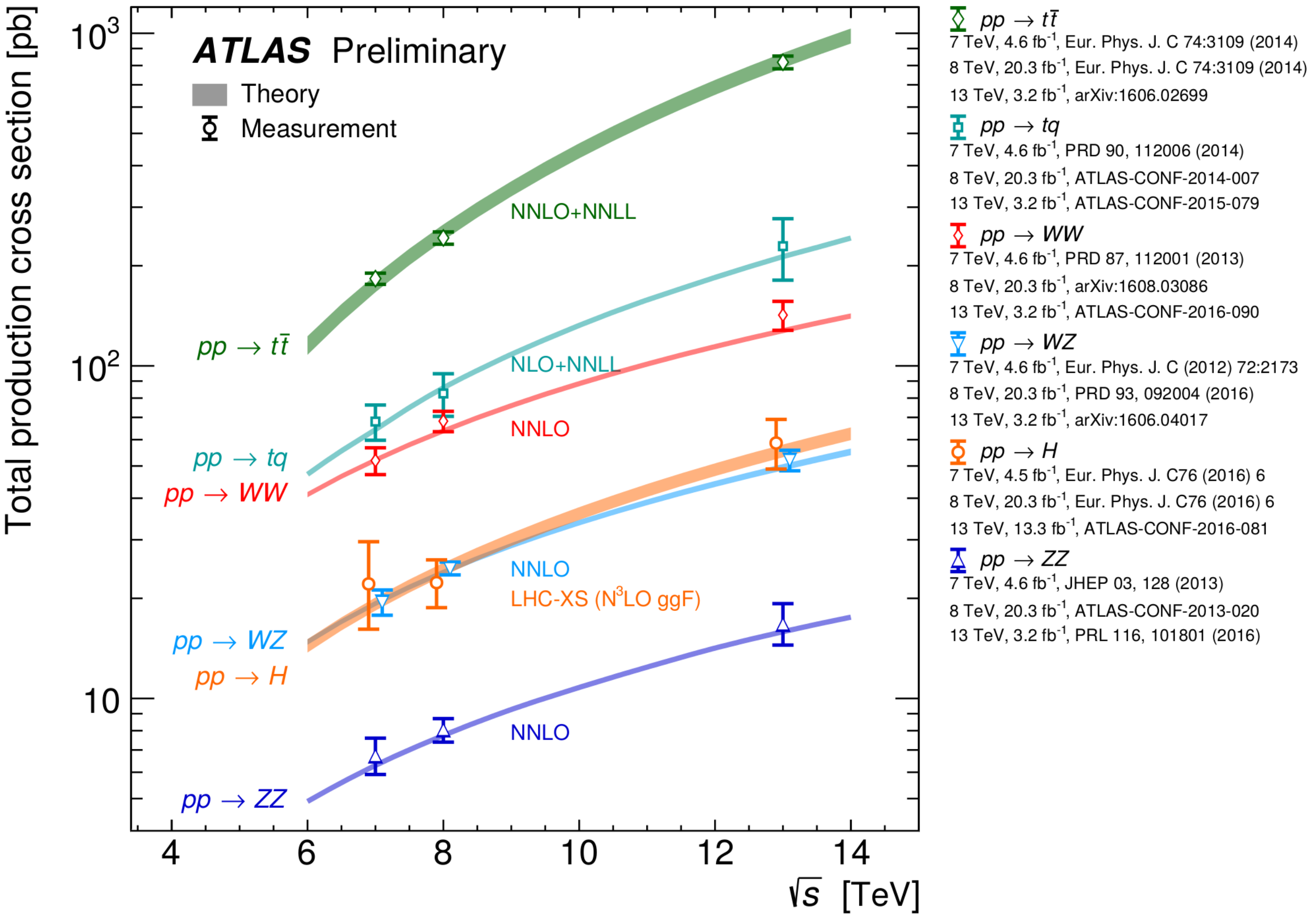
CMS , 2.3fb-1, 13TeV, WW, eμ+0/1jet
σ(WW) = 115.3 ± 10.9 pb
(↔ NNLO: 120±3±2pb)
(w/o H → WW)
CMS PAS-SMP-16-006

ATLAS , 3.2fb-1, 13TeV, WW, eμ, 0 jet
σ(WW) = 142 ±5±13±3 pb (↔ NNLO: 128 ± 4pb)
ATLAS-CONF-2016-090

- ***Both coll: WW cross section at 13 TeV, with 10% precision, sys. limited, consistent with NNLO***
- ***Both coll: ZZ cross section with 14% precision, statistically limited, consistent with NNLO (and NLO), CMS also Z->4l***
- **WZ ->3lnu results submitted to journal, ATLAS is compatible with the very recently calculated large NNLO corrections, while CMS below.**
- **Good agreement in general between measurements and recent NNLO predictions at both 8/13 TeV**
- **No deviations from SM observed in the search for Anomalous Triple Gauge**
- Couplings, limits start to surpass LEP results



Atlas summary on top and EWK results

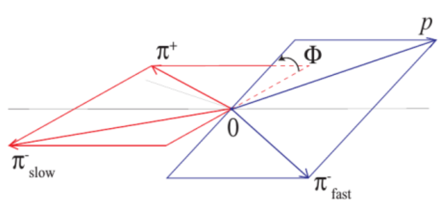


CP Violation at LHCb – Λ_b Decays

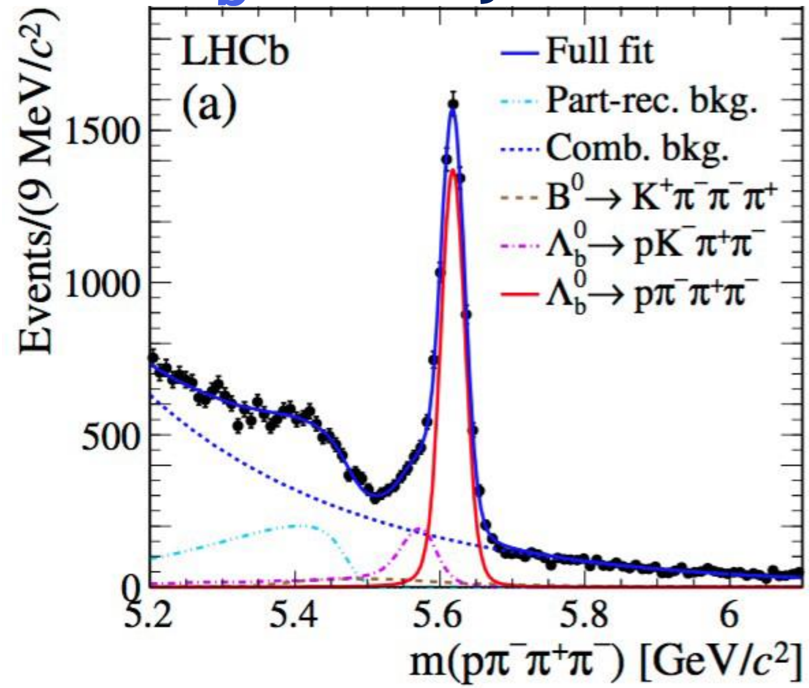
In the flavour sector, LHCb is, among many other measurements, probing CP violation in new processes

First evidence for CP violation in $\Lambda_b \rightarrow p\pi^- \pi^+\pi^-$

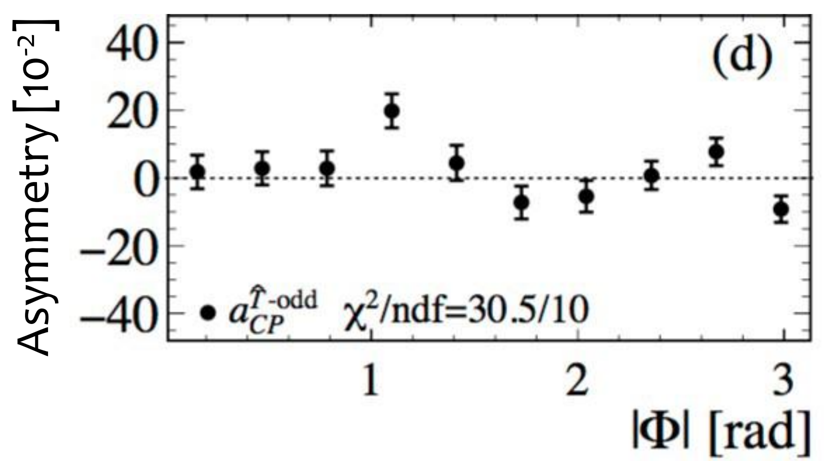
- Searching for local CP-violating effects in $\Lambda_b \rightarrow p\pi^-\pi^+\pi^-$ decays as a function of the relative orientation between the decay planes formed by the $p\pi^-$ and $\pi^+\pi^-$ systems (Φ)



- Evidence is found for CP violation at the 3.3σ level
- **First evidence of CP violation in the baryon sector**



LHCb-PAPER-2016-030 in preparation



Search for CP Violation in Charm Decays

CP violation in the charm sector is expected to be very small in the SM, but can be enhanced by new physics

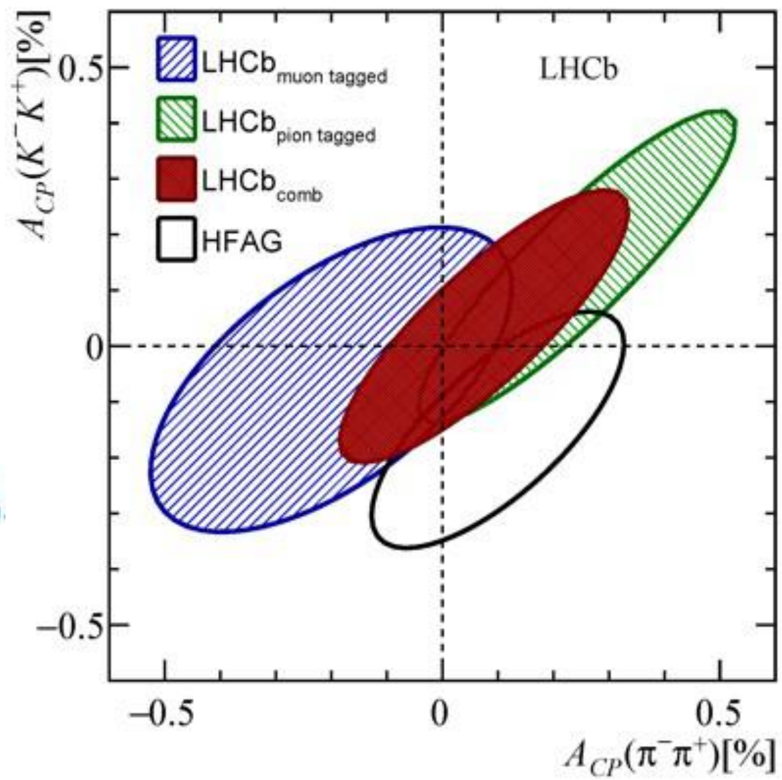
- Most precise measurement of $A_{CP}(D^0 \to K^+K^-)$

$$\frac{N(D^0 \to f) - N(\overline{D}^0 \to \bar{f})}{N(D^0 \to f) + N(\overline{D}^0 \to \bar{f})}$$ with $f=K^+K^-$

- Flavour of D^0 is tagged using the $\pi^\pm$ charge from $D^{*+} \to D^0(K^+K^-)\pi^+$ decays

$$A_{CP}(K^-K^+) = (0.14 \pm 0.15\,(\text{stat}) \pm 0.10\,(\text{syst}))\%$$

LHCb-PAPER-2016-035 in preparation



Combining this with a previous LHCb result using muon charge in semileptonic $B \to D\mu X$ decays as a tag, the most precise CP violation measurement from a charm meson decay from an individual experiment is obtained:

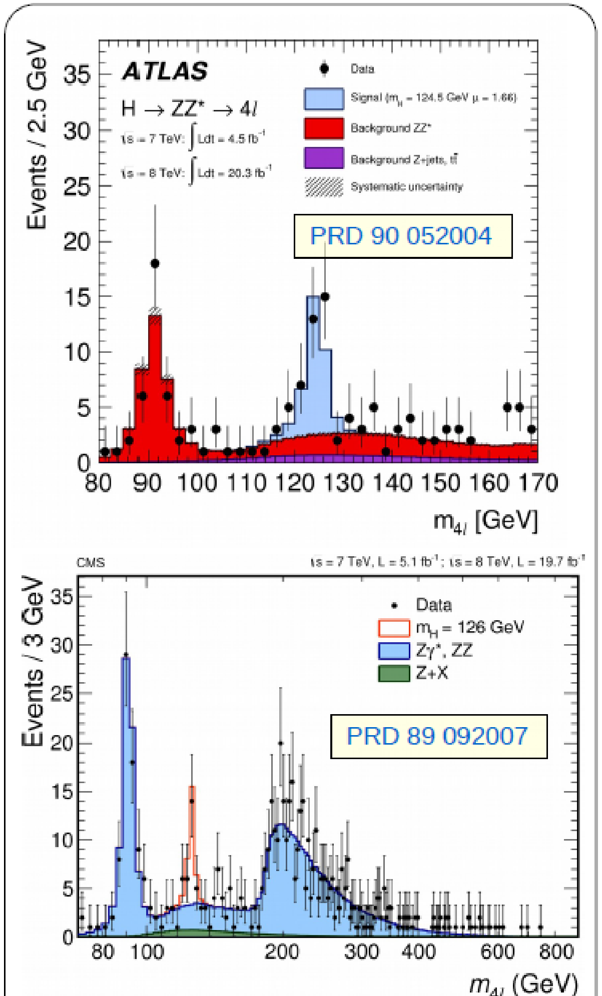
$$A_{CP}(K^-K^+) = (0.04 \pm 0.12\,(\text{stat}) \pm 0.10\,(\text{syst}))\%$$

HIGGS H(125) physics

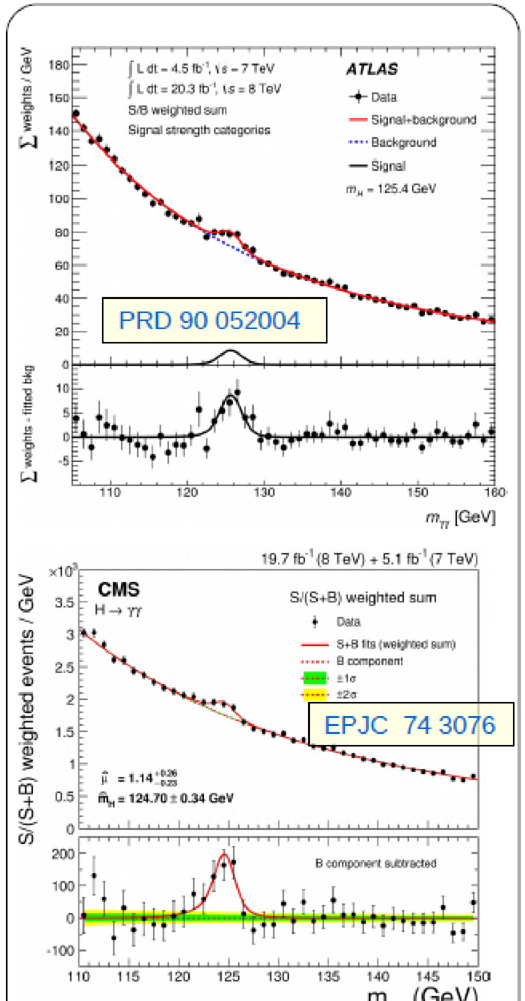
- Higgs boson at 125 GeV has opened up as many questions as it has answered
- Run-1: **Discovery**!
  - **its mass has been measured with high precision (±0.2%)** Phys. Rev. Lett. 114, 191803
  - Its spin-parity
  - production via gluon-fusion, vector-boson fusion, and associated with a W or Z, arXiv:1606.02266
  - decays to $\gamma\gamma$, WW, ZZ, and the fermionic decay to $\tau\tau$
- In Run-2: Consolidation and full study of its properties.
  - **Establish and measure at 13 TeV**: H->ZZ->4l (CMS-PAS-HIG-16-033, ATLAS-CONF-2016-079), H-> $\gamma\gamma$ (CMS-PAS-HIG-16-020, ATLAS-CONF-2016-067), H->WW (CMS-PAS-HIG-16-023), ATLAS combination (ATLAS-CONF-2016-081)
  - **Search for ttH production to probe ttH vertex directly** (ATLAS-CONF-2016-080, ATLAS-CONF-2016-058, ATLAS-CONF-2016-068, CMS-PAS-HIG-16-022, CMS-PAS-HIG-16-004)
  - Search for H $\longrightarrow$ bb decays (CMS-PAS-HIG-16-003, ATLAS-CONF-2016-091, 063)
  - Search for rare decays
  - Refine measurements of couplings (including HH), mass, etc
  - Expand use of H as a tool to find new physics (e.g. portal to Dark Matter)

Individual channels: H-> bosons

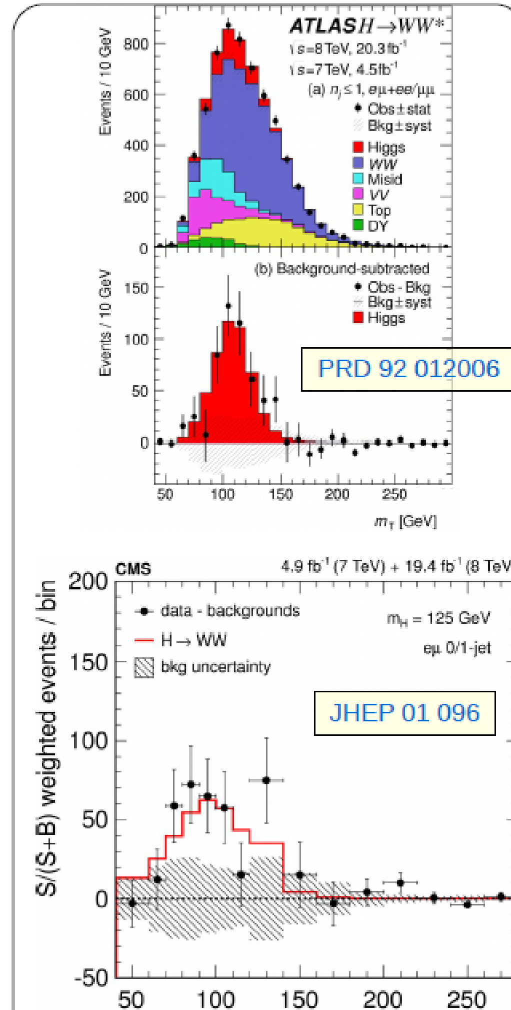
The original "discovery channels", updated to full run 1 luminosity, final and published



$H \to Z^{(*)}Z \to 4\ell$



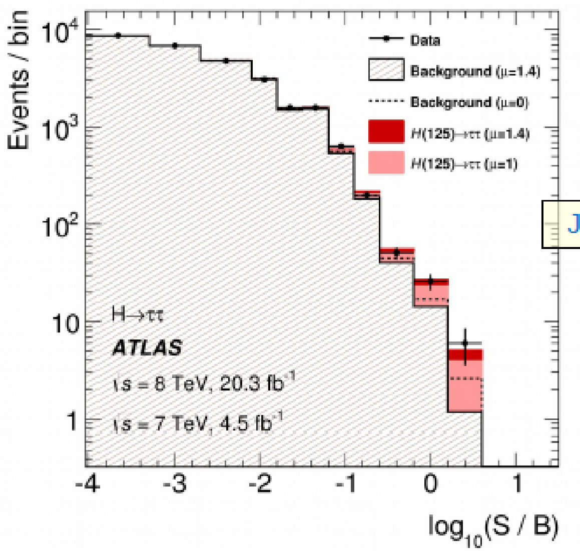
$H \to \gamma\gamma$



$H \to W^{(*)}W \to \ell\nu\ell\nu$

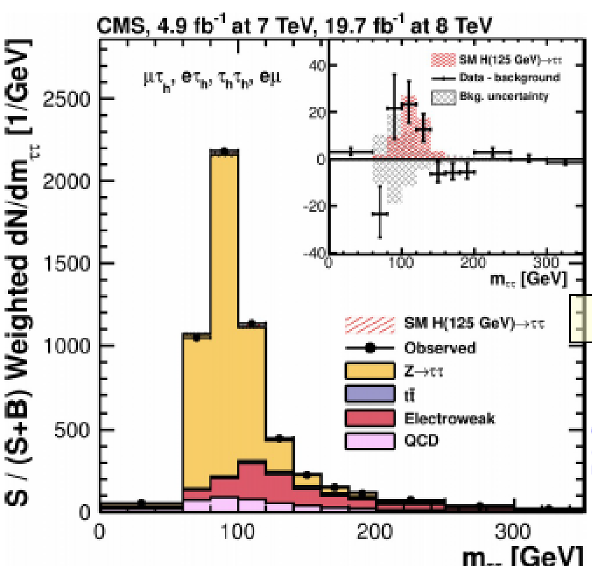
Individual channels: H-> fermions

$H \to \tau\tau$



JHEP 04 117

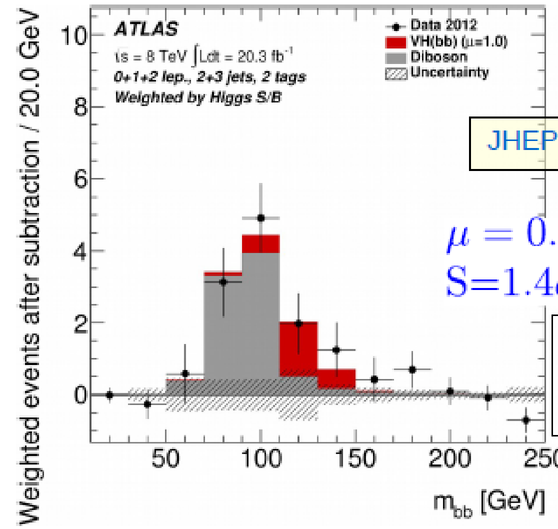
$\mu = 1.43^{+0.43}_{-0.37}$
$S = 4.5\sigma(3.4\sigma)$



JHEP 05 104

$\mu = 0.78 \pm .27$
$S = 3.2\sigma(3.7\sigma)$

VH/VBF, $H \to bb$

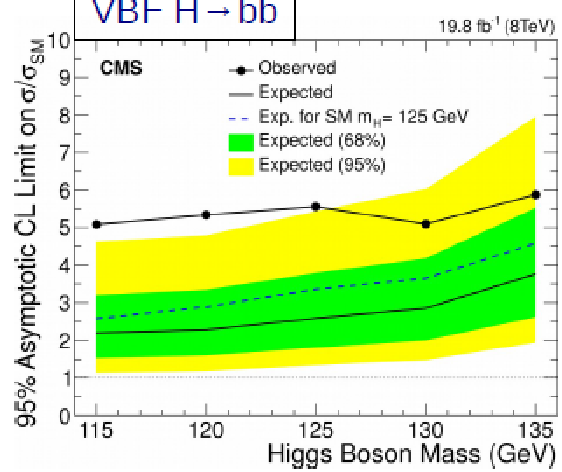


JHEP 01 069

$\mu = 0.52 \pm .32 \pm .24$
$S = 1.4\sigma(2.6\sigma)$

there is a deficit in 2011 data (not shown here)

VBF H→bb



subm. PRD arXiv:1506.01010

$\mu = 2.8^{+1.6}_{-1.4}$
$S = 2.2\sigma(0.8\sigma)$

combined with VH(bb) from

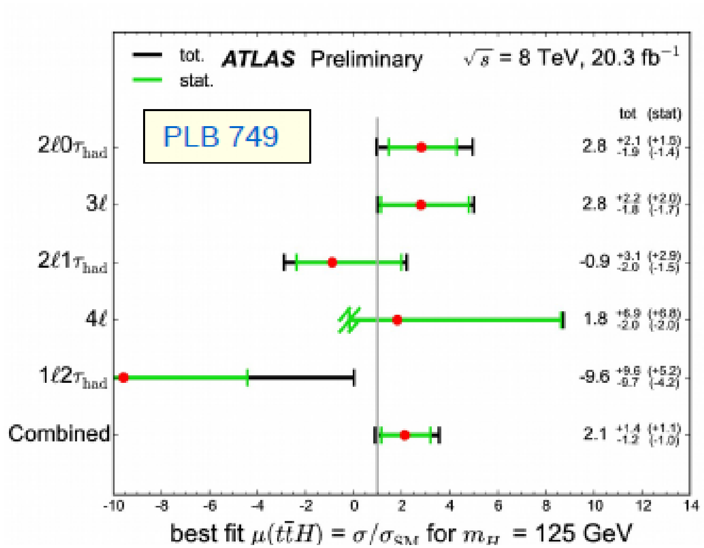
PRD 89 012003

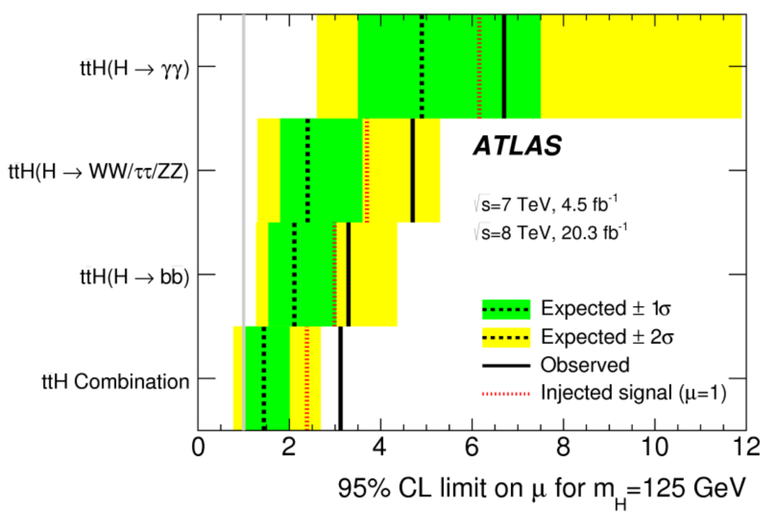
$\mu = 1.0 \pm .4$
$S = 2.6\sigma(2.7\sigma)$

Individual channels: ttH

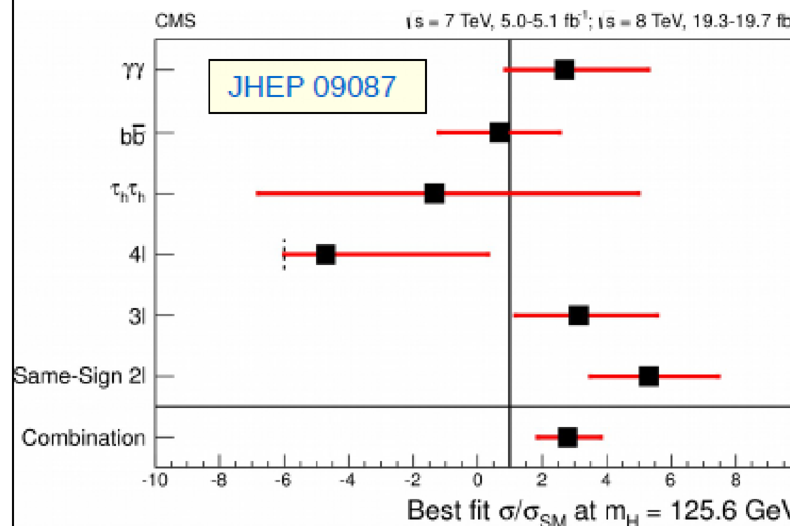
Directly probing the largest H coupling

$t\bar{t}H$, multi-leptons (WW, ZZ, ττ)





$t\bar{t}H$, H → hadrons, photons, leptons



$$\mu = 2.9^{+1.1}_{-0.9},\ \mu < 4.5(2.7)$$

$t\bar{t}H$, H → $b\bar{b}$, matrix element method

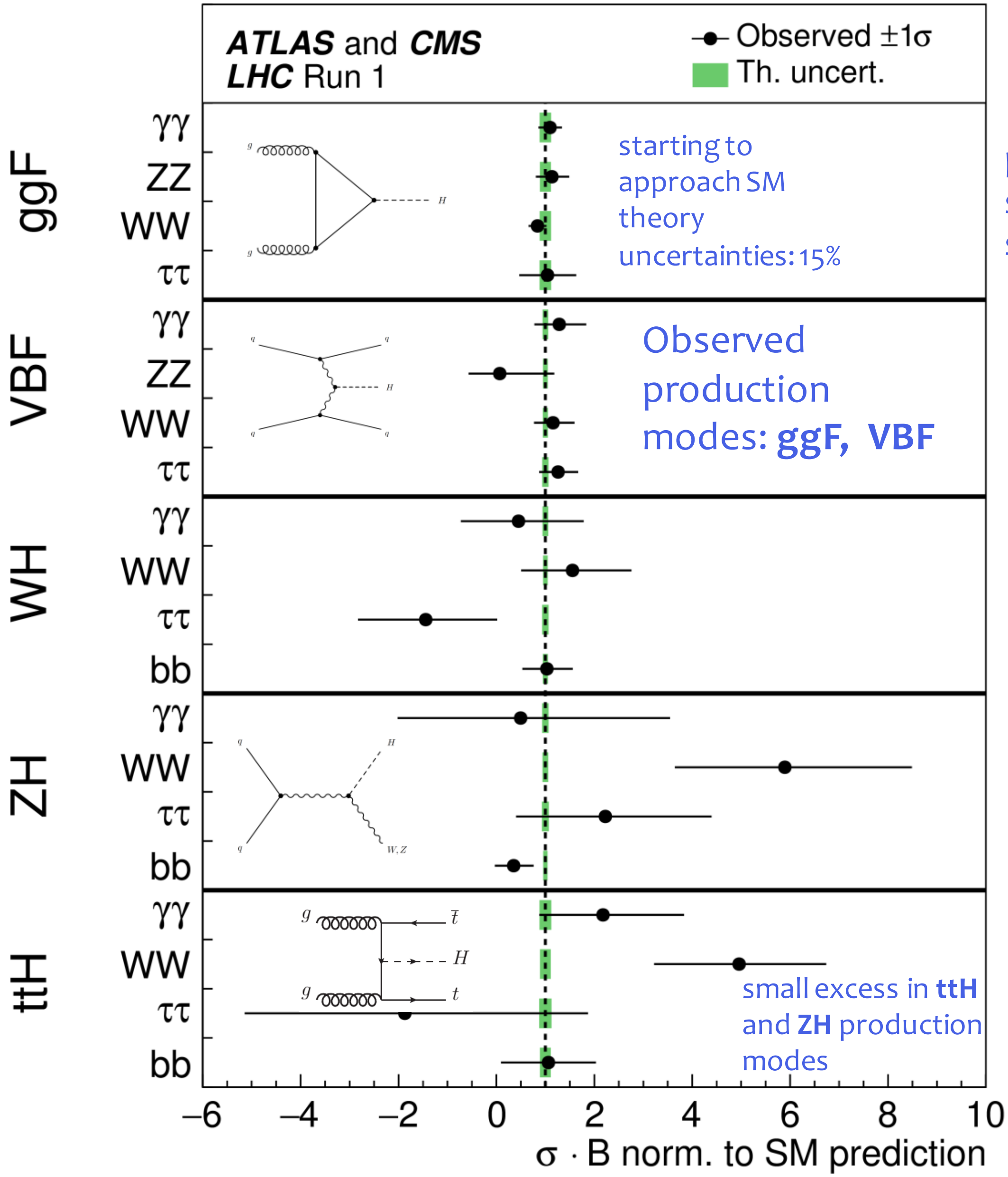
EPJC 75 251

$$\mu = 1.2^{+1.6}_{-1.5},\ \mu < 4.2(3.3)$$

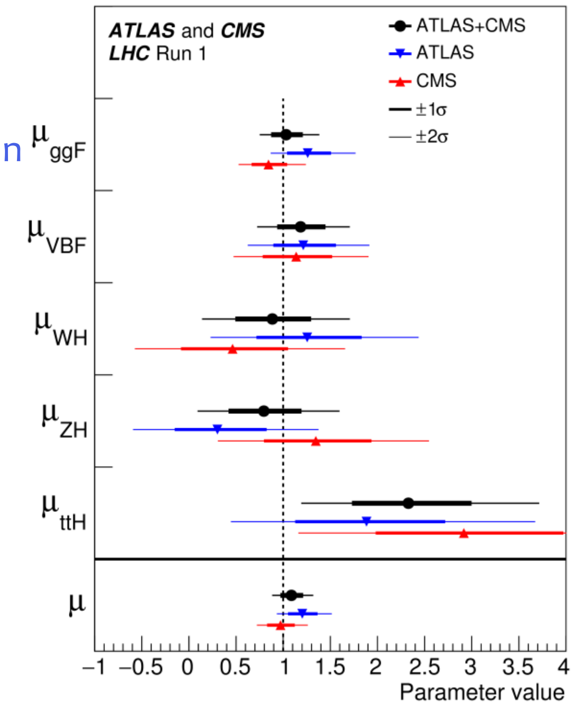
CMS

compatible with SM, but both experiments see an excess at the 2-3 σ level

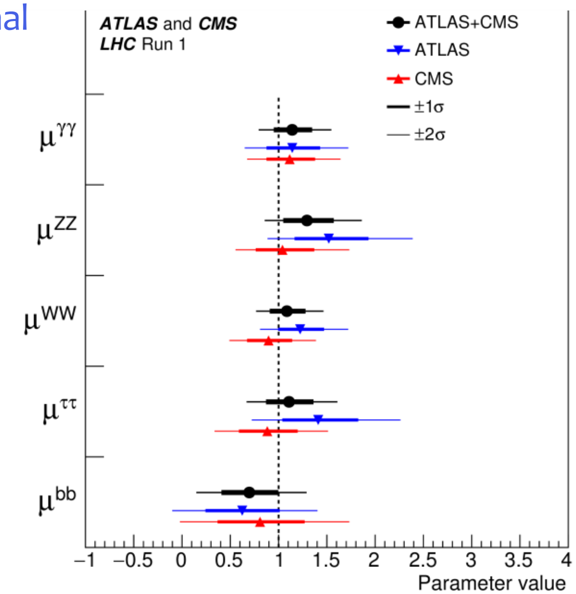
Individual channels: production/decay mode



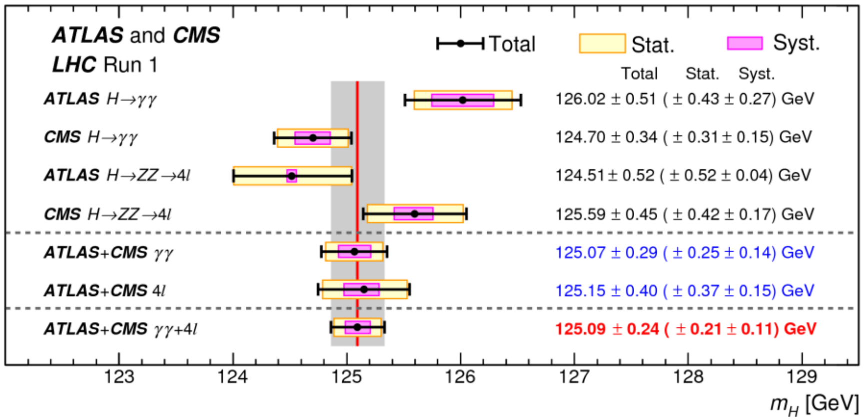
production signal strengths



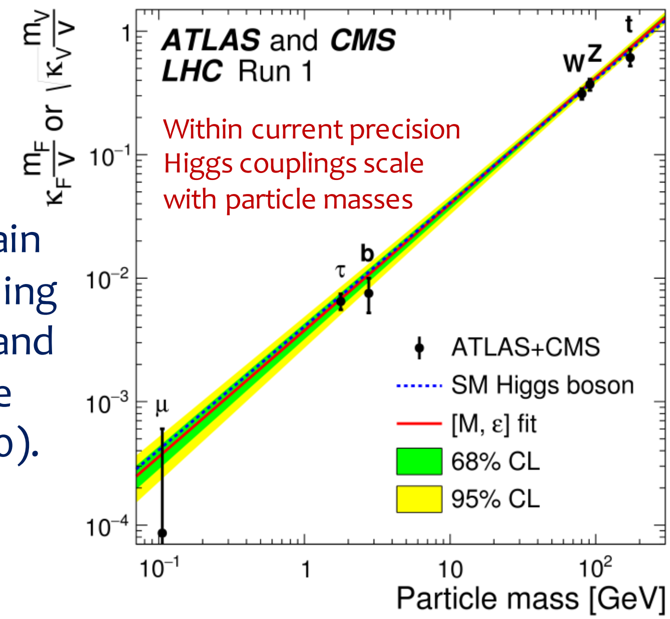
decay signal strengths



The BEH scalar (H(125))

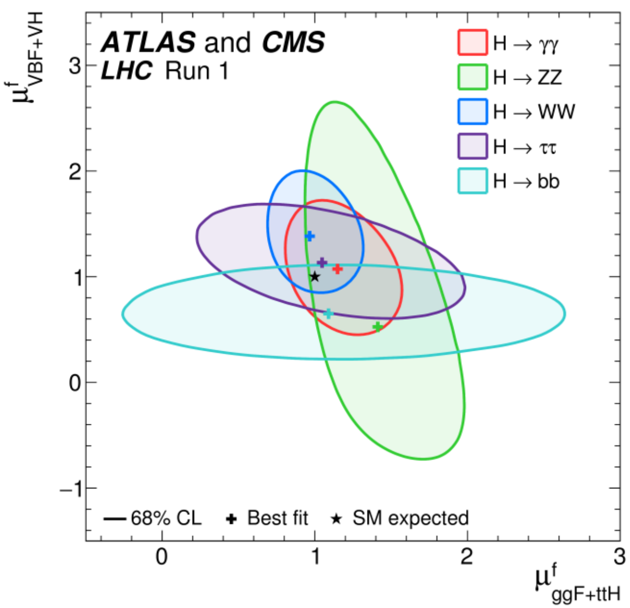


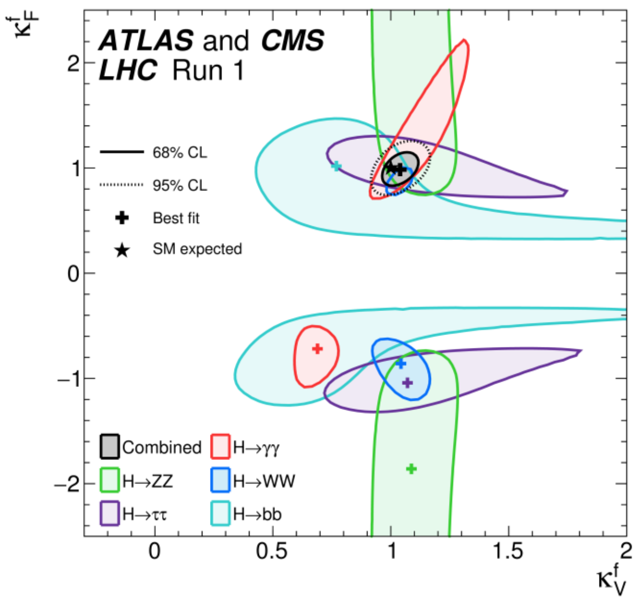
Fitting the 5 main tree level coupling modifiers + κ_μ and resolving all the loops (BR_{BSM} =0).

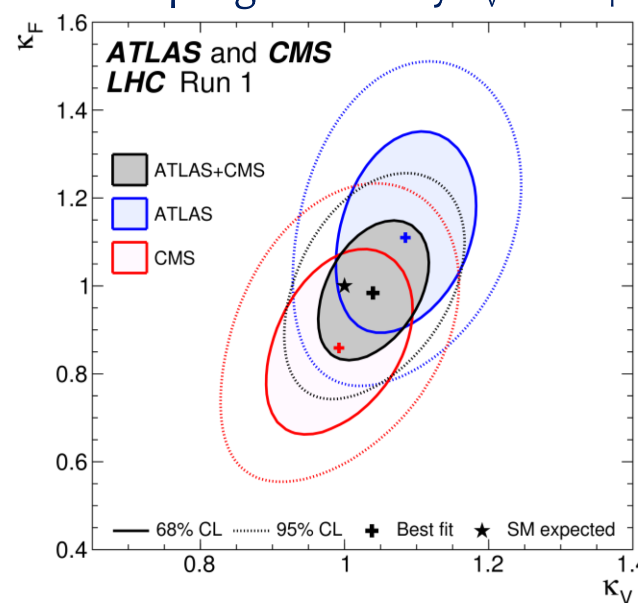


m_H = 125.09 ± 0.24 GeV= 125.09 ± 0.21 (stat) ± 0.11 (syst) GeV
$\Delta m_H/m_H$=0.2%

All vector and fermion couplings scaled by κ_V and κ_F

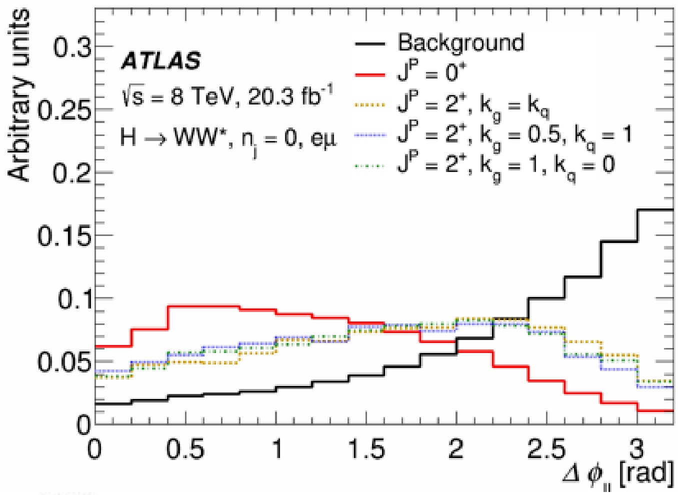


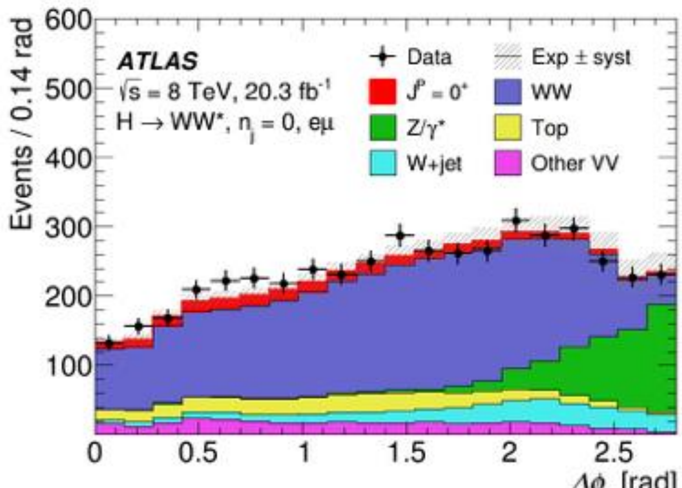




A scalar, beyond “reasonable” doubts

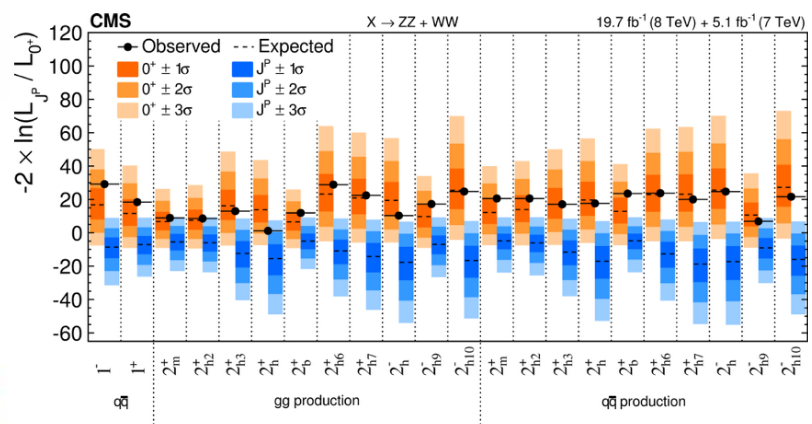
γγ, WW, ZZ modes

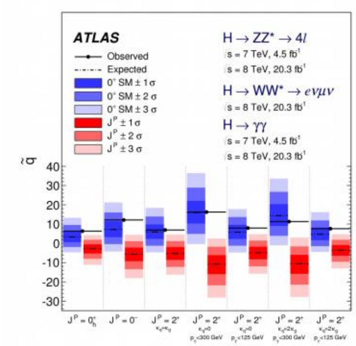


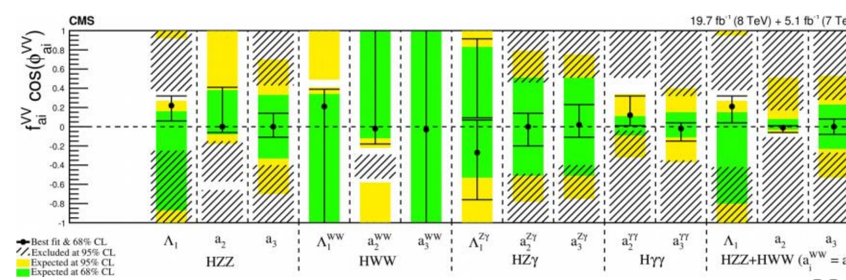


ATLAS and CMS exclude non-SM spin-0 models and spin-2 models with >99.9 % C.L.

constraints on non-SM contributions to the tensor structure of HVV coupling in $S^{CP}=0^+$ (parameterised as K_{HZZ}/K_{SM} , $K_{AZZ}/K_{SM}\cdot\tan\alpha$ (ATLAS) resp. Λ, a_1, a_1 (CMS))



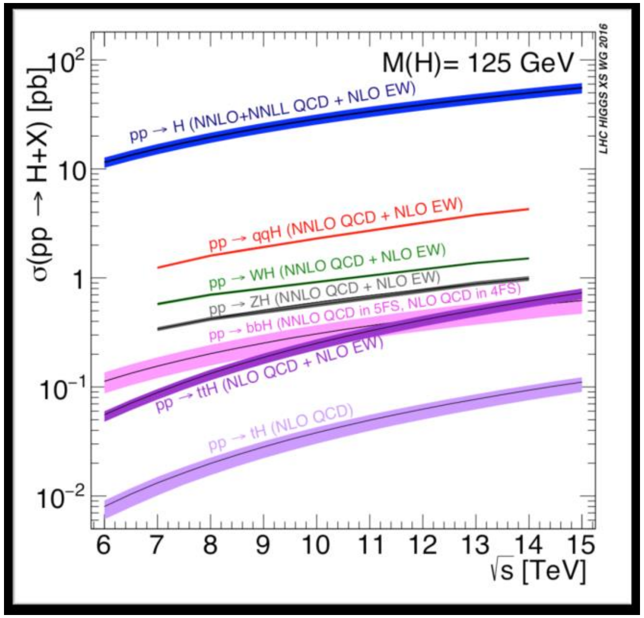




Alternatives tested: $0^\pm$, $1^\pm$ and $2^\pm$; Excluded at >99% CL

H(125) at 13 TeV

Many analyses in Run 2 follow closely the methods and strategies developed in Run 1



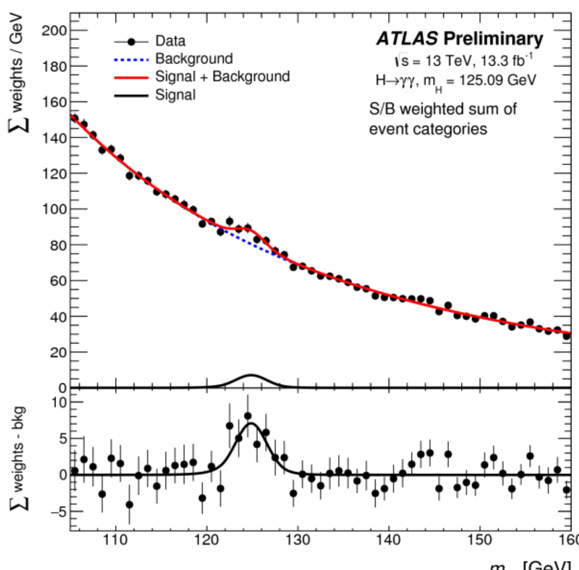
ggH (87.4%), 2.3 (σ_{13}/σ_8)
VBF (7.1%)
VH (4.9%)
ttH (0.6%), 3.9 (σ_{13}/σ_8)
Backgrounds:
tt 3.3 (σ_{13}/σ_8)

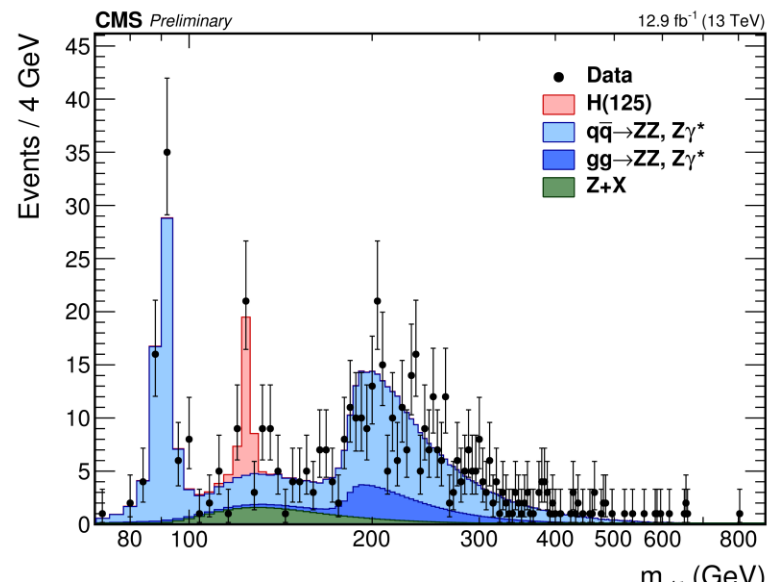
decay mode BR (%)
H->**bb** 58.1
H->**ττ** 6.3 S/B<1 ΔM/M ~ 10-20%

H->**WW** 21.5 S/B<1, ΔM/M ~ 30%
H->**ZZ** 2.6 S/B>>1, ΔM/M ~ 1-2%
H->**γγ** 0.23 S/B<1, ΔM/M ~ 1-2%

Given the luminosities collected (and used for the results presented here), in **2015: ~3 fb^{-1}** and in **2016: ~13 fb^{-1}**, **there are more Higgs bosons already in Run 2 than in Run 1!**

Higgs H(125) is re-discovered in the main decay channels used for the discovery at 7 and 8 TeV



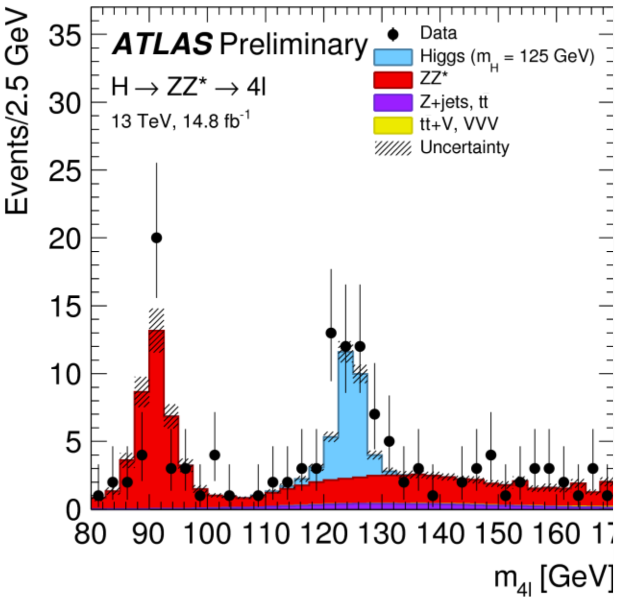


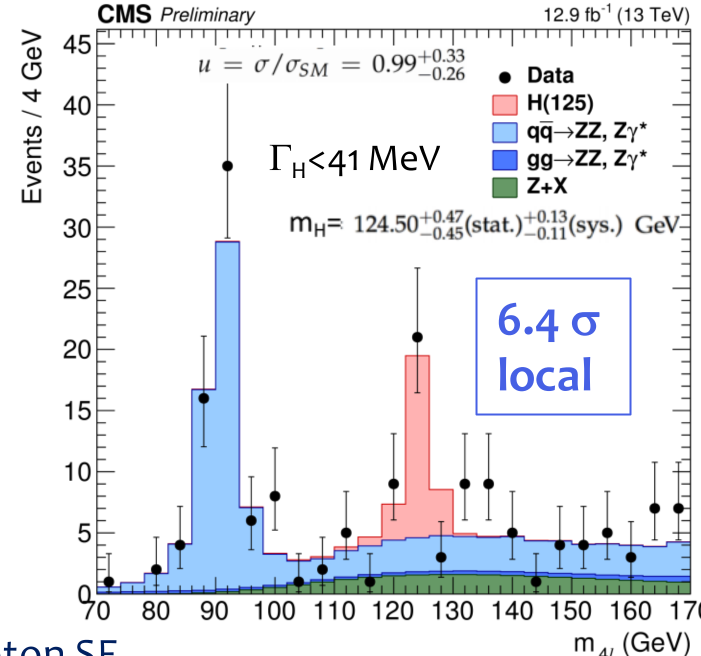
Higgs->ZZ*

ATLAS-CONF-2016-079
CMS-PAS-HIG-16-033

$H \to ZZ^* \to 4\ell$: Clear re-observation, rate consistent with SM H expectation (1.6σ high)

Extraction of signal through fit of m4l





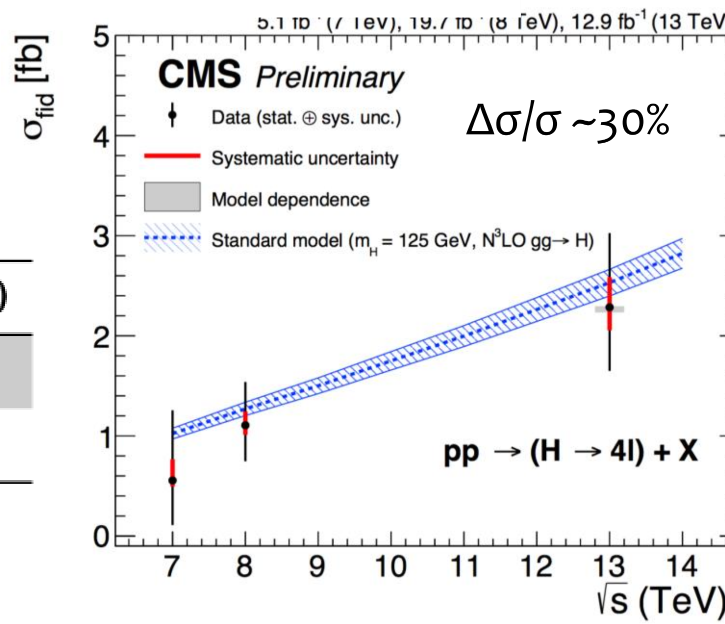
All production modes targeted ggF, VBF, VH, ttH events

Kinematic discriminant, MZ1, MZ2, 5 angles from decay chain, matrix element, used to enhance the signal purity of different production modes

Dominant systematic uncertainty: luminosity and lepton SF

Fiducial cross-section measurements:

13 TeV	Fiducial σ (fb)	SM prediction (fb)
ATLAS (14.8 fb^{-1})	$4.54^{+1.02}_{-0.90}$	$3.07^{+0.21}_{-0.25}$
CMS (12.9 fb^{-1})	$2.29^{+0.74}_{-0.64}(stat)^{+0.30}_{-0.23}(syst)$	2.53±0.13

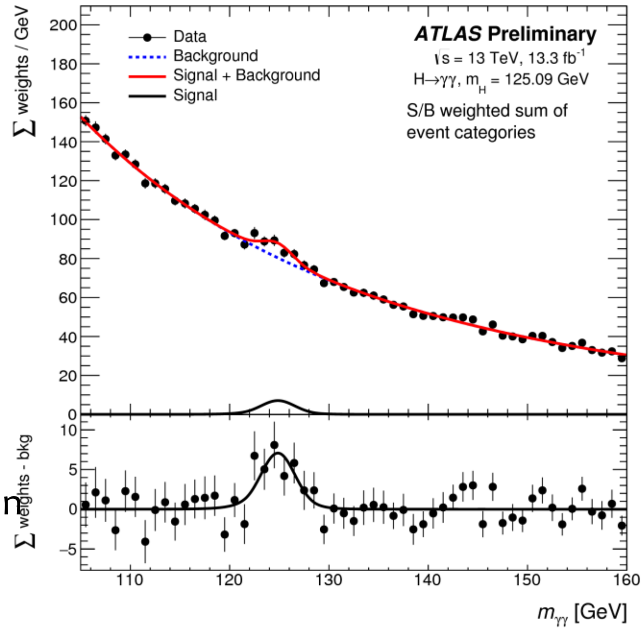


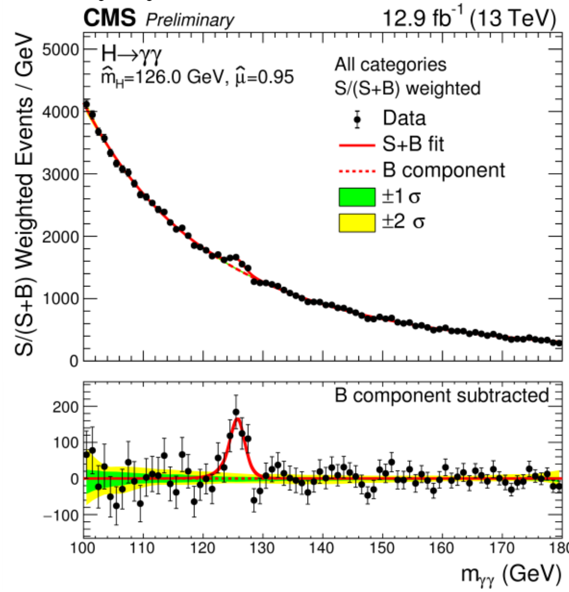
Higgs->γγ

ATLAS-CONF-2016-067
CMS-PAS-HIG-16-020

Event categories enhance sensitivity and help separate production modes

Signal extracted through fit of $m_{\gamma\gamma}$ in different event categories
- Main backgrounds: γγ and γ-jet production





All production modes targeted ggF, VBF, VH (only Atlas), ttH events

5.6σ at m_H=125.09 GeV

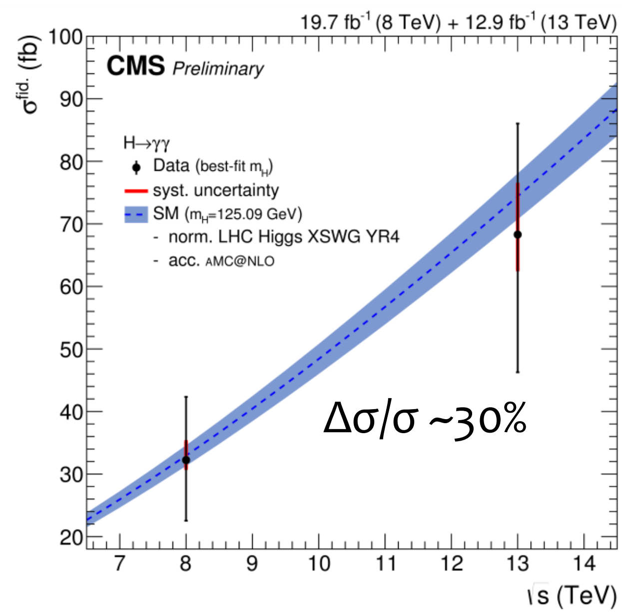
6.1 σ at m_H=126 GeV

$$\hat{\sigma}/\sigma_{SM} = 0.95^{+0.21}_{-0.19} = 0.95 \pm 0.17(stat.)^{+0.08}_{-0.05}(theo.)^{+0.10}_{-0.07}(syst.)$$

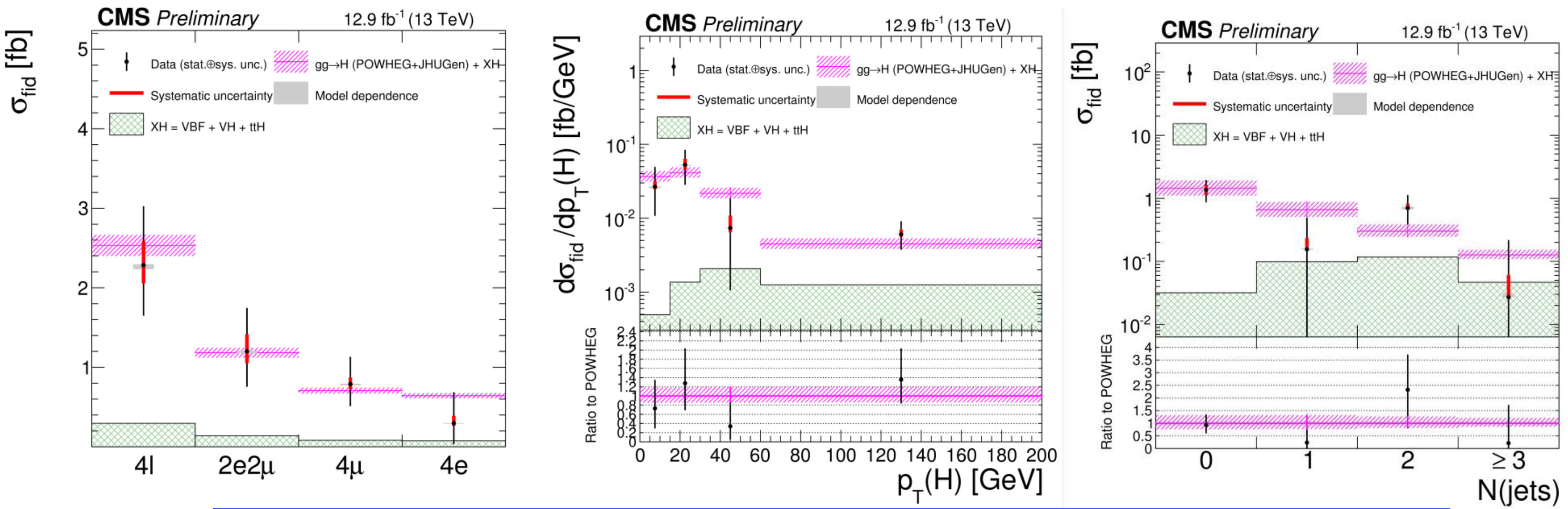
Dominant systematic uncertainty: photon energy scale and resolution and background choice bias

Fiducial cross-section measurements:

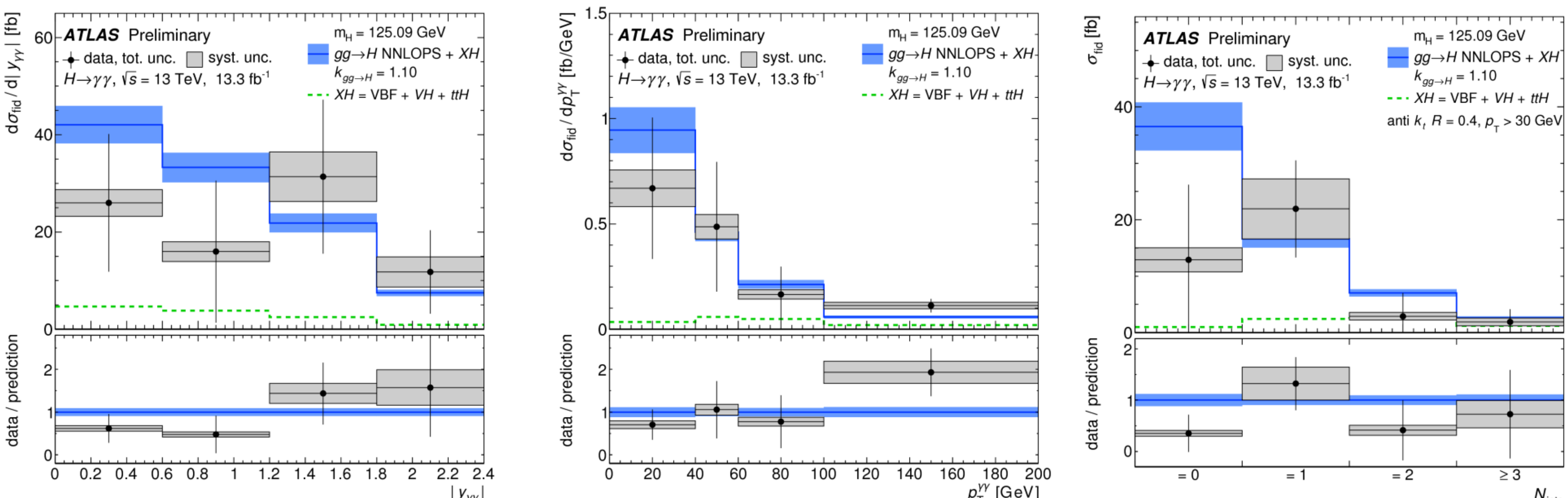
13 TeV	Fiducial σ (fb)	SM prediction (fb)
ATLAS (13.3 fb^{-1})	43.2±14.9(stat)±4.9(syst)	$62.8^{+3.4}_{-4.4}$ (N^3LO+XH)
CMS (12.9 fb^{-1})	69^{+16}_{-22}(stat)$^{+8}_{-6}$(syst)	73.8±3.8



… differential measurements in H-> γγ and H-> ZZ*



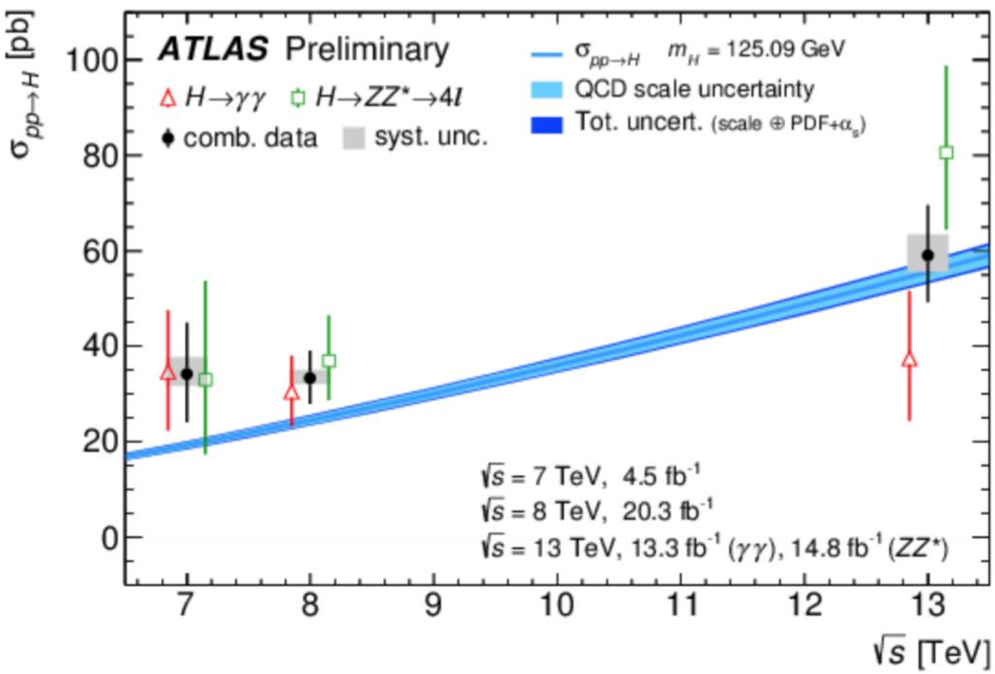
very useful to improve MC codes and reduce systematic uncertainties

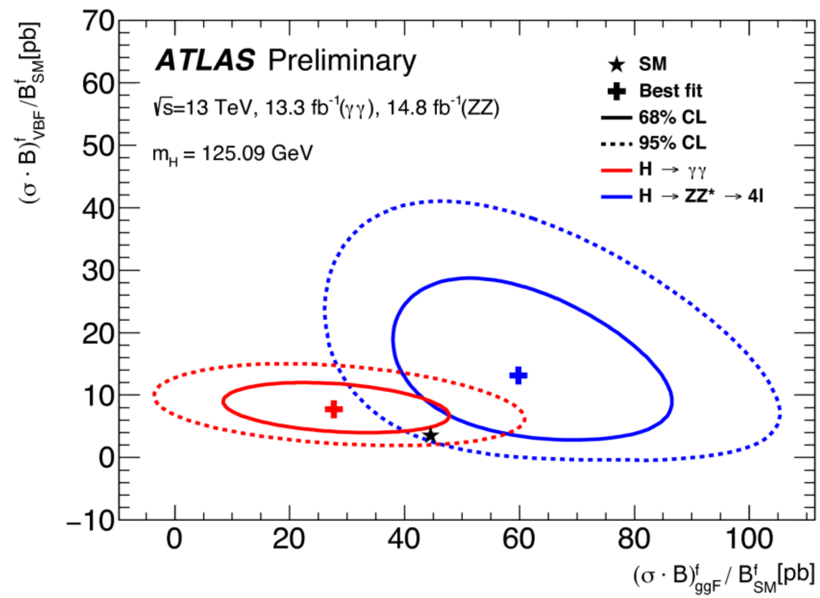


… combination of H-> γγ and H-> ZZ* (ATLAS-CONF-2016-081)

Combination of H->γγ and H->Z->4l inclusive samples, with no categorization

Higgs production is observed with **10σ significance (8.6σ expected) with 13 TeV** data in agreement with SM expectations

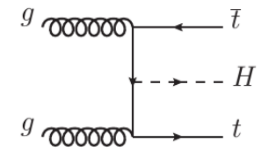




Precision already comparable to Run 1

	Measurement at 13 TeV	SM prediction at 13 TeV
σ (pb)	$59.0^{+9.7}_{-9.2}$(stat)$^{+4.4}_{-3.5}$(syst)	$55.5^{+2.4}_{-3.4}$
μ	$1.13^{+0.18}_{-0.17}$	1

ttH production
(establish this mode at 13 TeV)



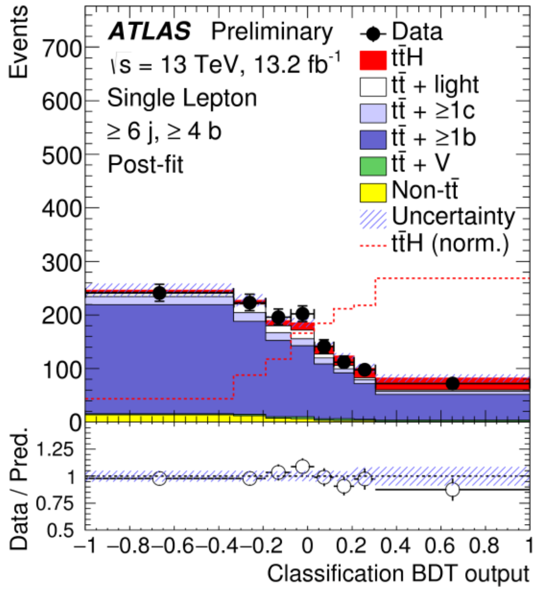
ATLAS-CONF-2016-080
CMS-PAS-HIG-16-004
CMS-PAS-HIG-16-022
ATLAS-CONF-2016-058

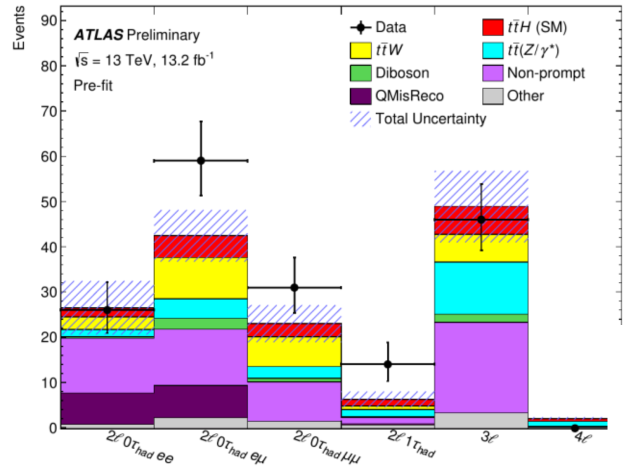
- **Direct probe of top Yukawa coupling**

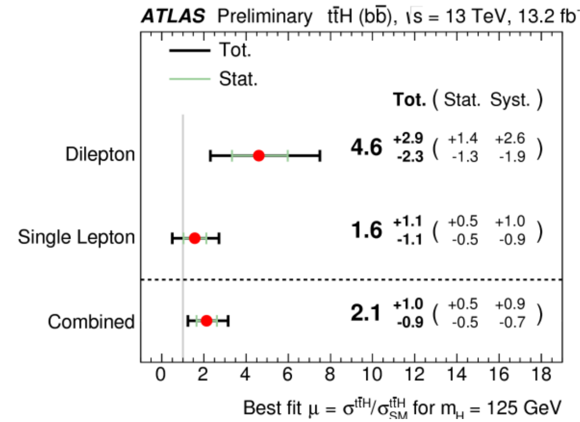
- Cross-section at 13 TeV ~4 times that at 8 TeV
- Results with 2015,2016 data for:
  - ttH, H→bb: categorize events according to amount of leptons, jets, b-jets, main background tt+heavy flavour production
    - ATLAS uses BDT to reconstruct Higgs and separate signal and background for each category
    - CMS includes now a boosted category and 2D matrix-element and BDT
    - Dominant systematic uncertainty: signal and background modeling and normalization
  - ttH, multilepton final states H-> WW, ZZ, ττ
    - 2-4 leptons, 2 or more jets, and at least 1 b-tagged jet. Allows at least one τ_{had}
    - ATLAS cut and count analysis in main different category regions
    - CMS BDT based discriminants including matrix element weights
    - Dominant systematic uncertainty: fake-rate measurements and non-prompt background estimates
  - ttH, H→γγ through H→γγ event categorisation

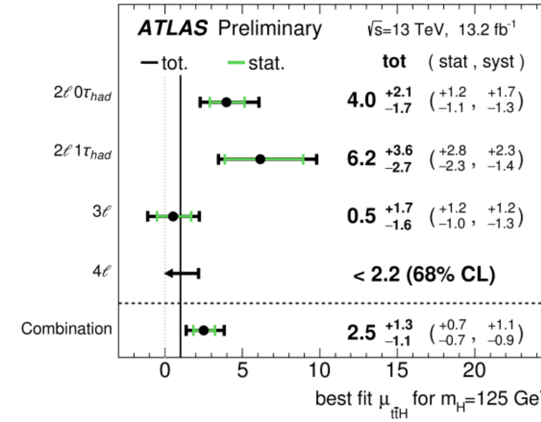
ttH production

ATLAS-CONF-2016-080, 058, 068
CMS-PAS-HIG-16-004, 022

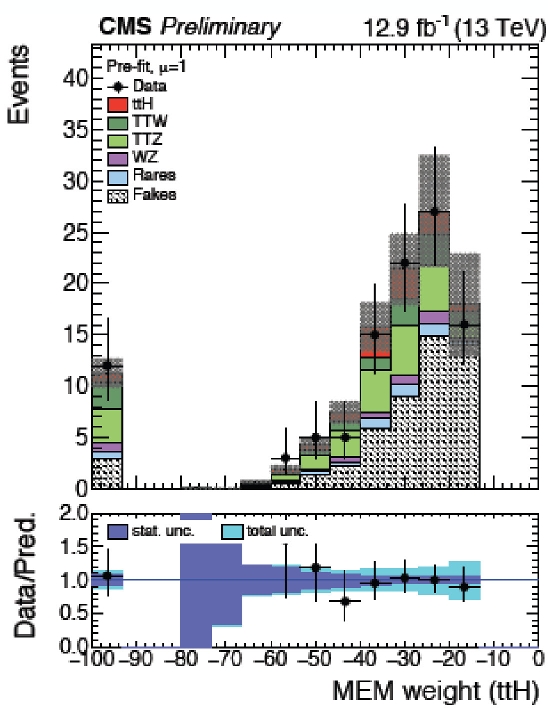


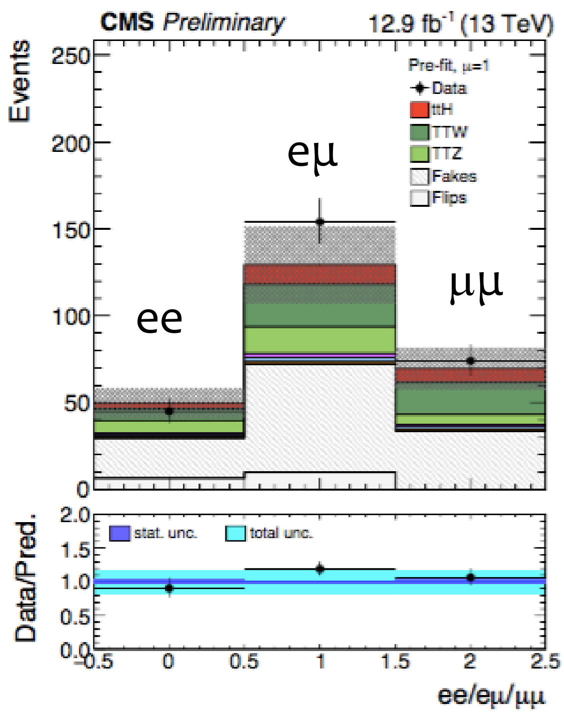


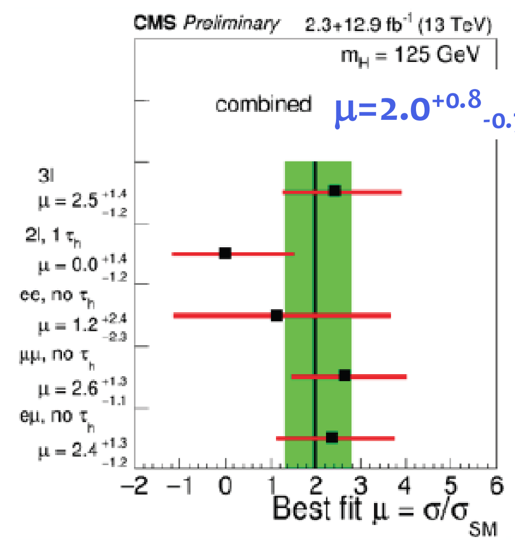




ATLAS ttH combination, μ=1.8±0.7





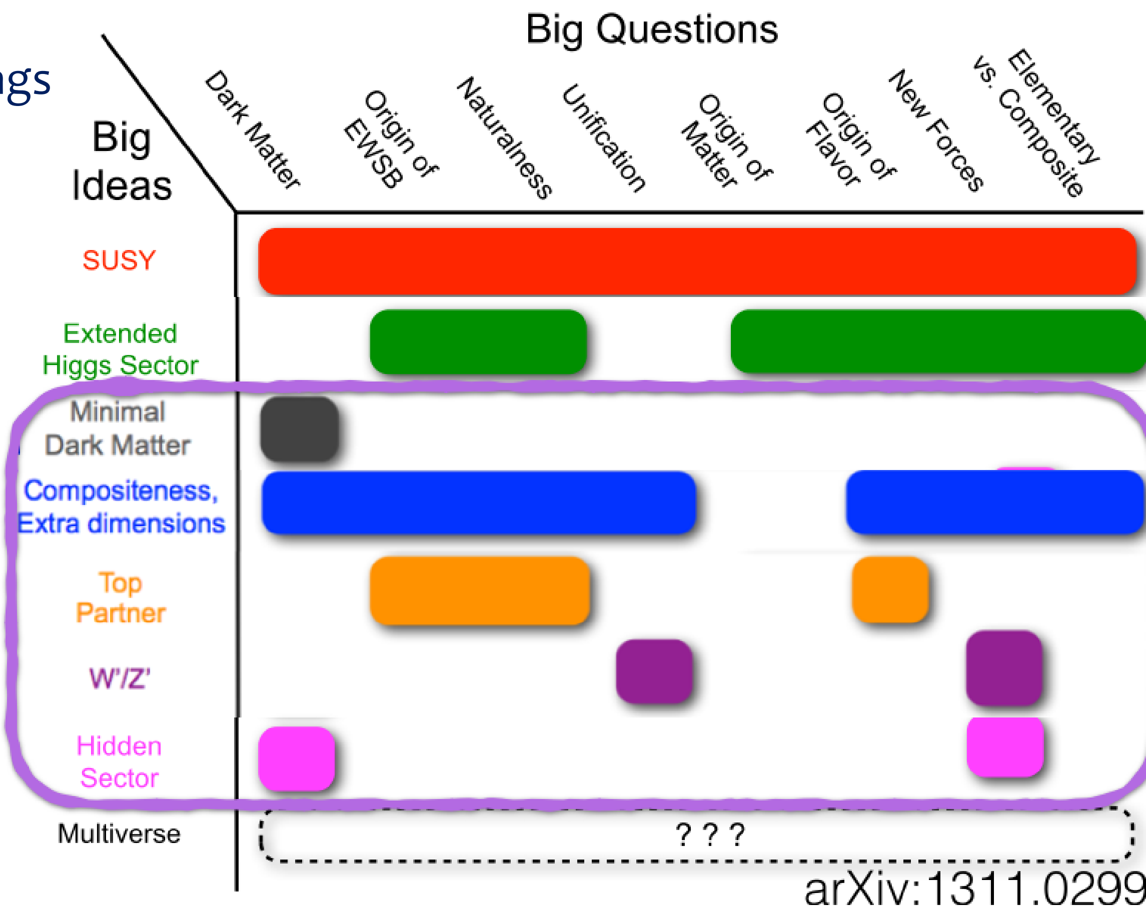


Searches: SUSY and Exotica

Major extension of reach compared to Run-1, and they probe well into the TeV, and even multi-TeV, mass scale range

Main motivations to look for **SUSY** remain after run 1 results,

- **Hierarchy problem (low-mass top squarks may cancel SM contributions to mH),**
- lightest SUSY particle can be stable, weekly interacting and massive (DM candidate),
- unification of gauge couplings



- **Exotica:**
- Many Big Questions beyond the SM to be answered at TeV scale
- Big Ideas highly constrained from theory and observed phenomena

SUSY in run 2 at 13 TeV

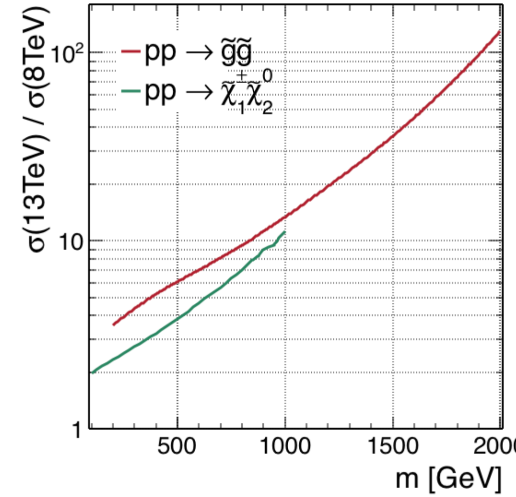
- **Substantially higher cross sections w.r.t. 7/8 TeV in Run1**
  - in particular for gluon-gluon processes
  - most important gain for the highest masses
  - For many SUSY searches higher than for dominant SM backgrounds (W/Z+jets, tt)

three main scenarios

R-parity conserving (lightest SUSY particle=$\tilde{\chi}_1^0$)
- provides DM candidate
- "classical" SUSY signatures with high missing ET (MET)
- strong or electroweak production

R-parity violating, different LSPs
- couplings strongly constrained (proton stability)
- loose MET handle for bkg reduction
- alternative signatures like high jet multiplicity

Gauge mediated SUSY breaking
- decay chains terminate with (low-mass, invisible)
- Typical signature: MET+ $\tilde{G}$ photons or Zs from last decay step



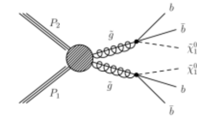
Focus on specific signatures, **simplified models guide optimisation**

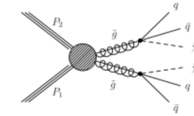
Data-driven backgrounds: multiple control regions to constrain MC predictions and systematic uncertainties

Validation regions: verify background descriptions

Signal regions: sensitivity!

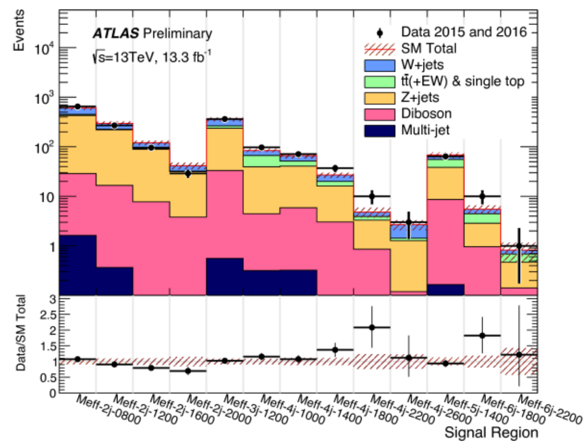
Gluino decays to qq/bb/tt+LSP

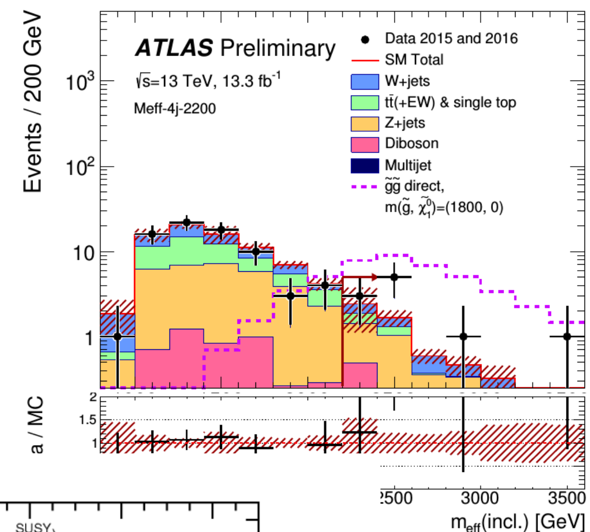




CMS-SUS-16-014, 015, 016, ATLAS-CONF-2016-078, 052, 037

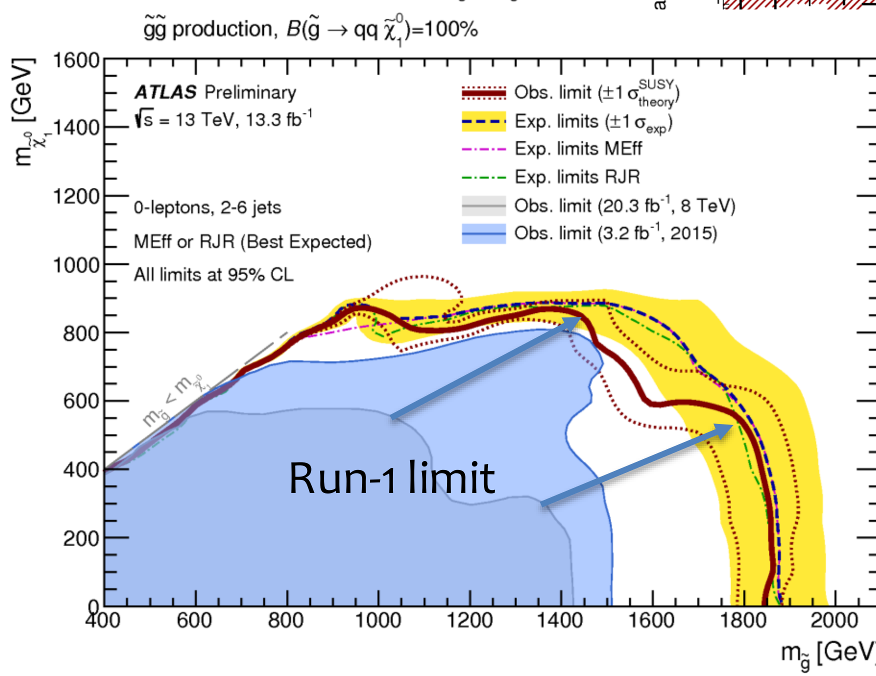
- Gluinos: highest SUSY production cross section, give access to other sparticles via decay chains





- 2-6 jets and veto isolated leptons
- Total of 30 signal regions with different m_{eff} ($m_{eff} = E_T^{miss} + \Sigma |pT(\text{jet})|$) cuts
- Main backgrounds Z/W+jets and *tt*
- Sensitive to *g* and *q* production
- Largest excess 1.6σ

- **No significant excesses overall**



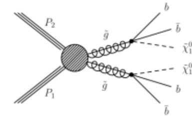
m(g) limit (low-mass χ_1^0)

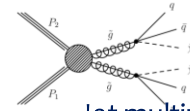
(Run-1) 1.4 TeV → (Run-2) 1.86 TeV

Gluino decays to qq/bb/tt+LSP

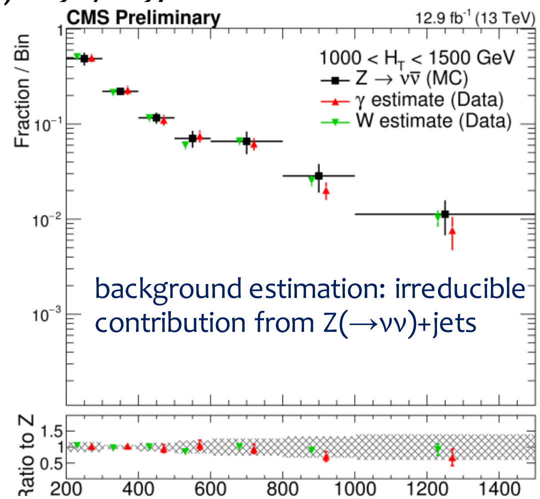
CMS-SUS-16-014, 015, 016, ATLAS-CONF-2016-078, 052, 037

- Hadronic search
- key variables: M_{T2}, or missing H_T, binned in #jets, #b-jets, H_T.

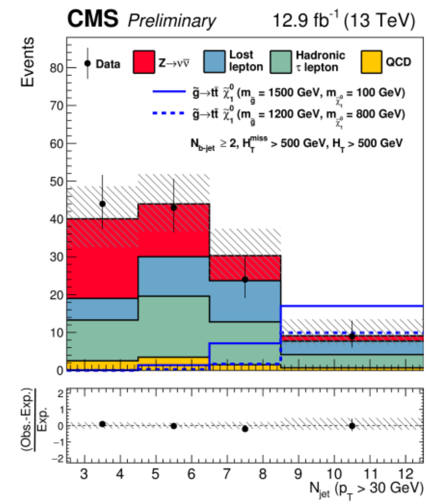


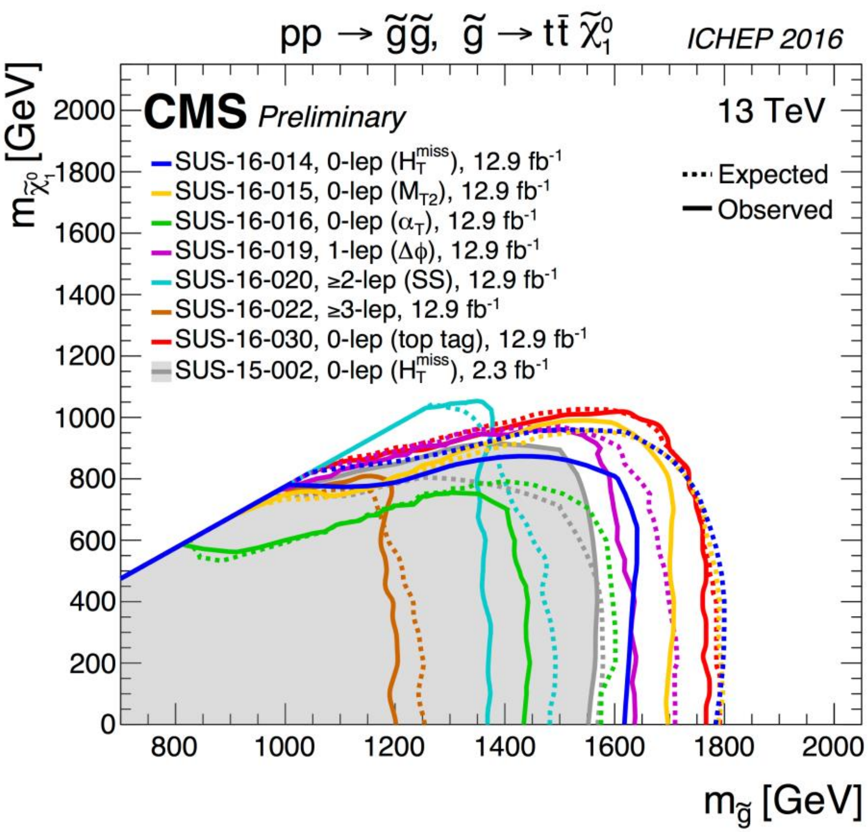


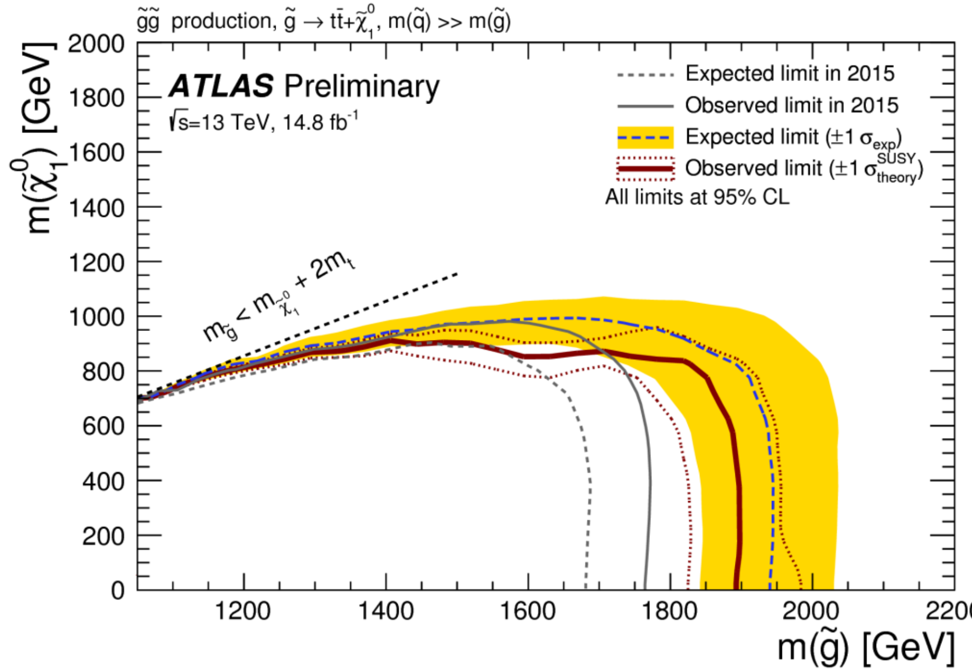
Jet multiplicity for a signal-enriched region



background estimation: irreducible contribution from Z(→νν)+jets

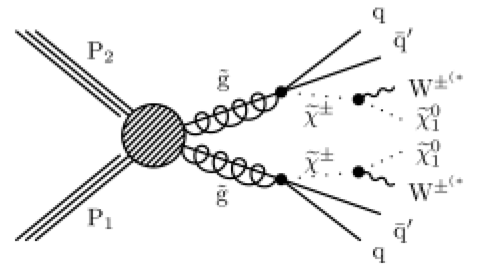






Gluino production / chargino

CMS-SUS-16-014, 019, 020, 022, ATLAS-CONF-2016-078, 054, 037

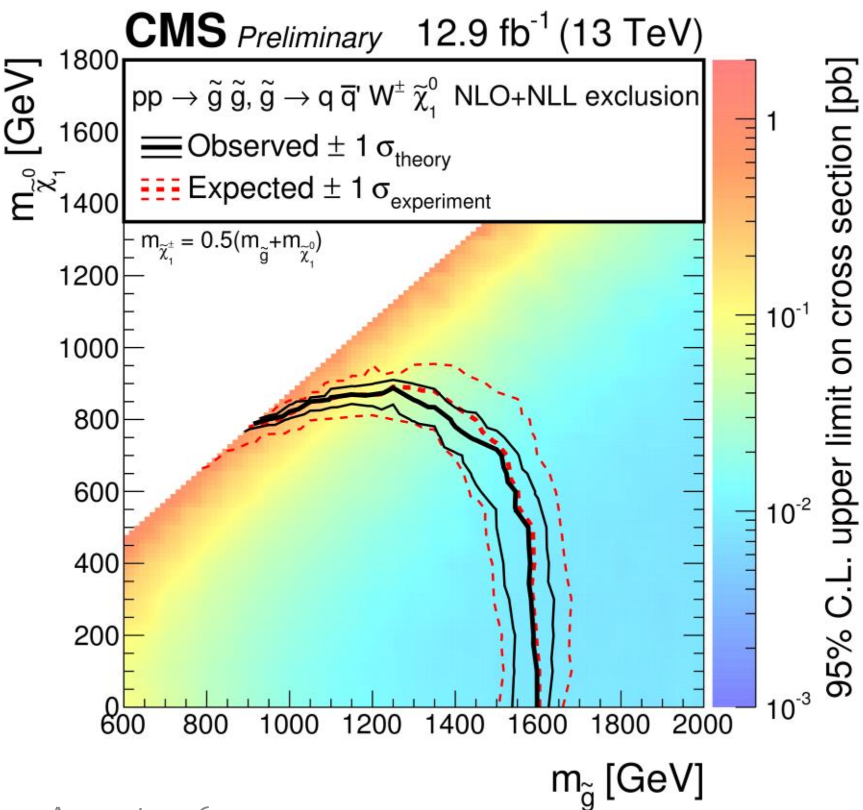


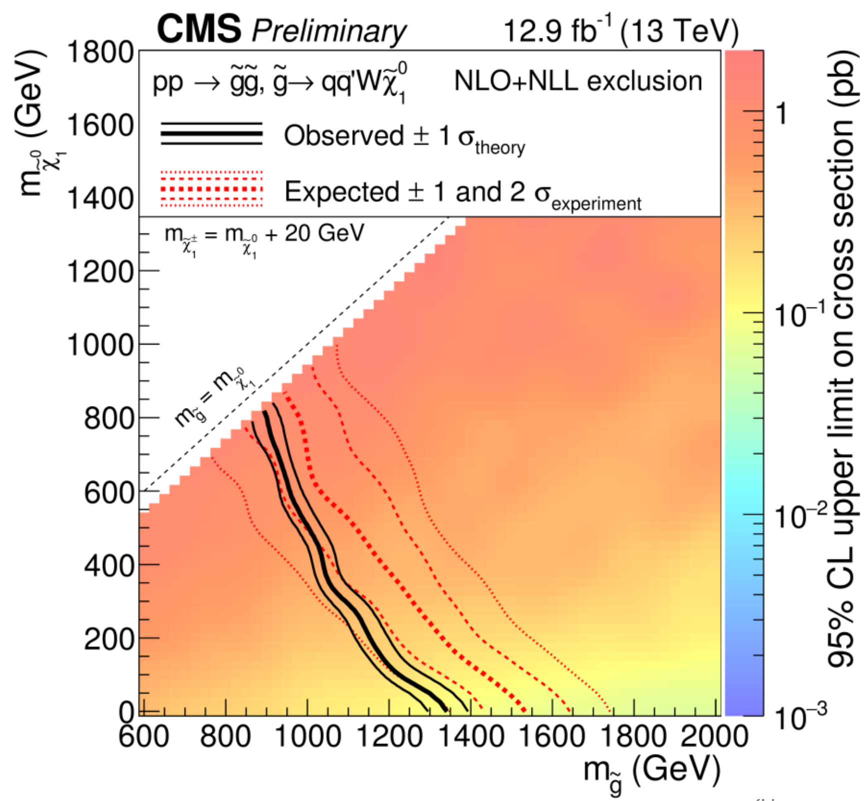
Decay chains in gluino production via a chargino and a W*

- **Single lepton search**
  - 1 lepton, jets, no b-jets
  - HT, MET, W pT , Δφ(W,lepton)

Same-sign dileptons

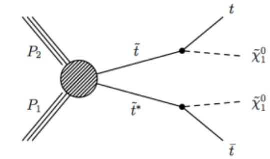
- small SM backgrounds (multi-boson, fake leptons, charge flip)
- binned in pT(l),mT, MET,HT, #jets





Top squarks

Low-mass top squarks required for natural models



CMS-SUS-16-029, 025 ATLAS-CONF-2016-050

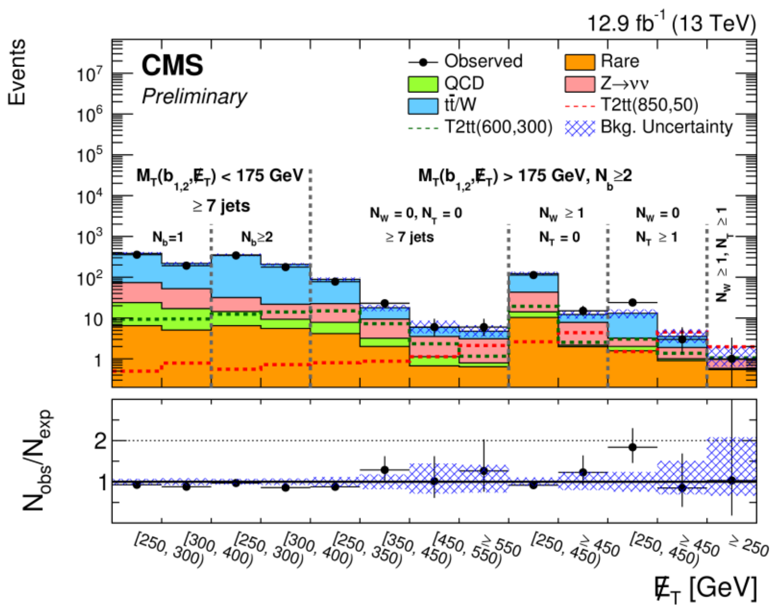
- favored decay via t(*) and LSP: final states classified according to W decay mode
  - Event topology: WbWb+MET (0l, 1l, 2l, τ)
  - approaches SM tt signature for $\Delta m \approx m(t)$ and low LSP mass
- if chargino is accessible: alternative decay to b-chargino

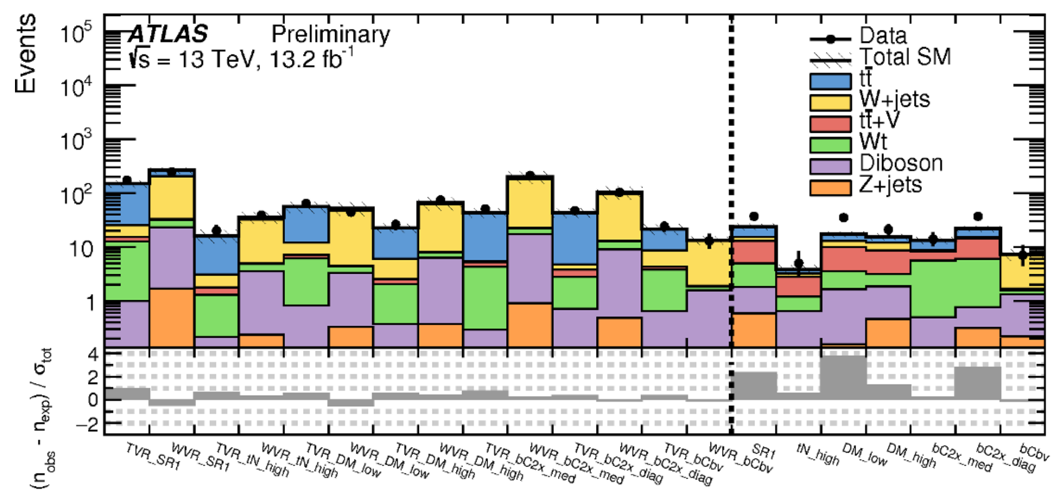
CMS: Hadronic search

- optimizations for low and high Δm
- high Δm: using #jets, #b-jets, mT(b), and MET; #tops and #Ws from jet substructure

ATLAS: 1l, in total, 35 signal regions

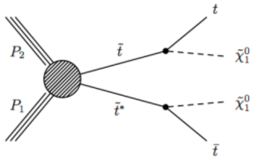
- basic selection on jets, b-jets, MET
- Aiming to cover $m(\chi_1^0)$ vs m(t) plane
- Largest excess 3.3σ



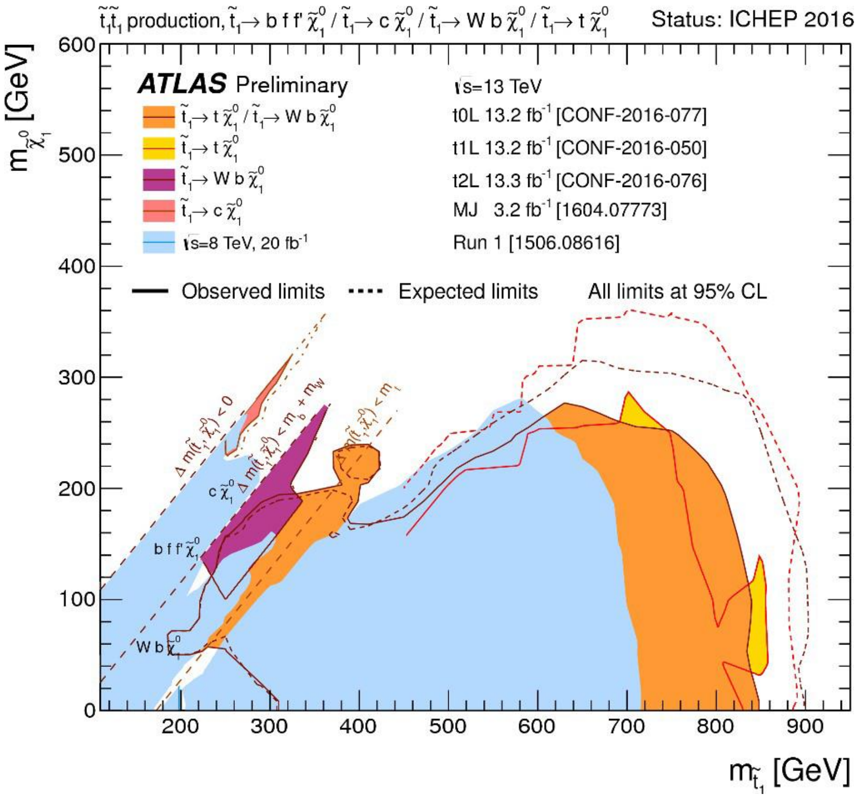


validation regions signal regions

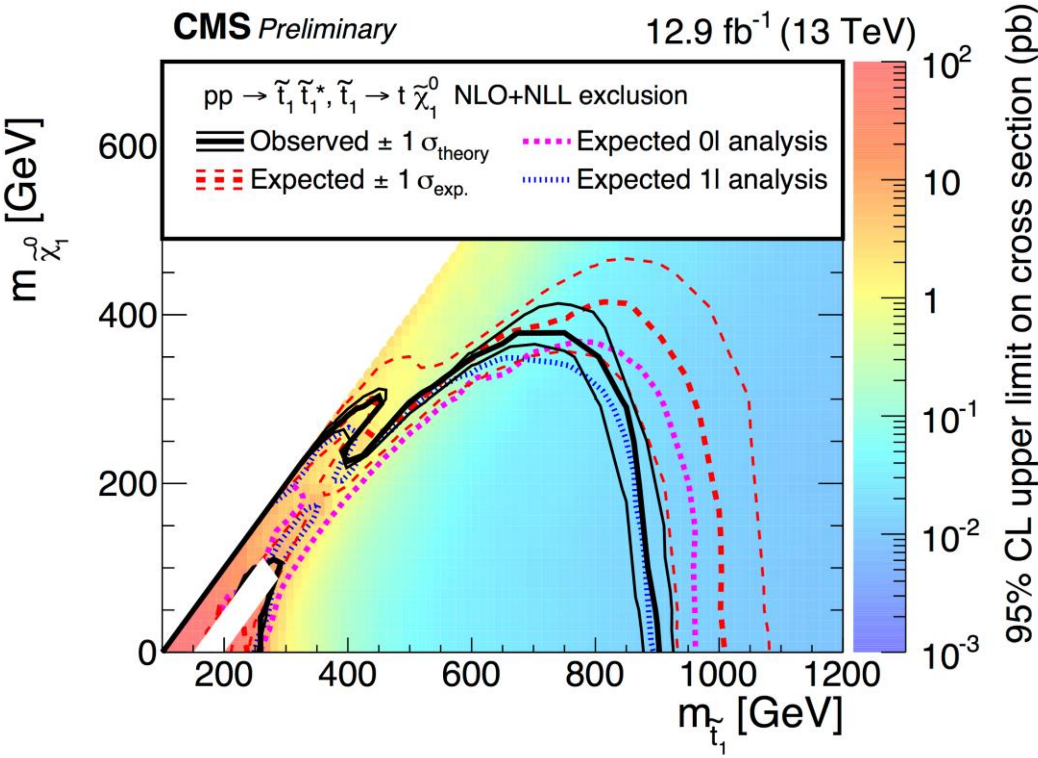
Top squarks



ATLAS summary



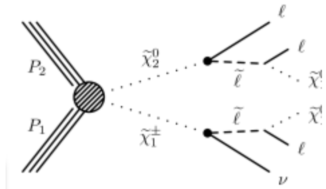
CMS 0l+1l combination for 2-/3-body decay



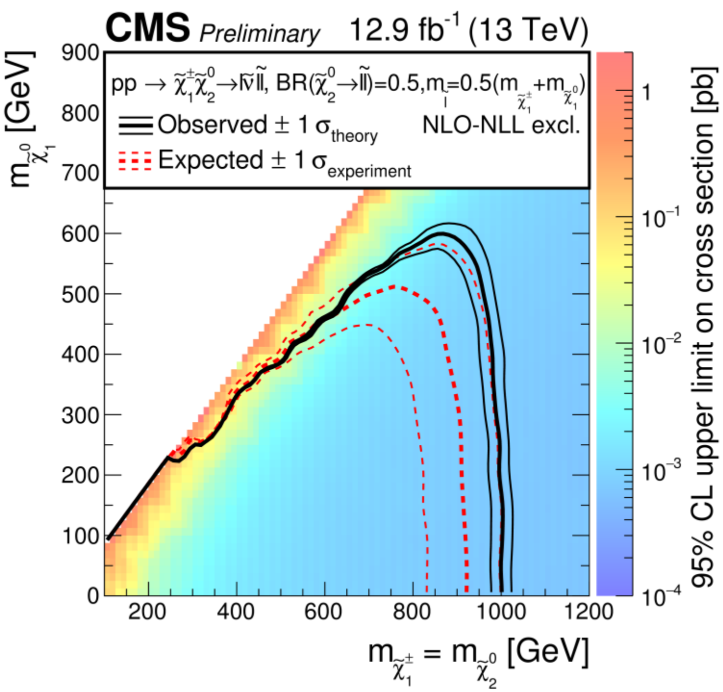
For **m(χ$_1^0$) < 200 GeV**, **m(t) < 800 GeV excluded** except in rather small regions

Electroweak Production

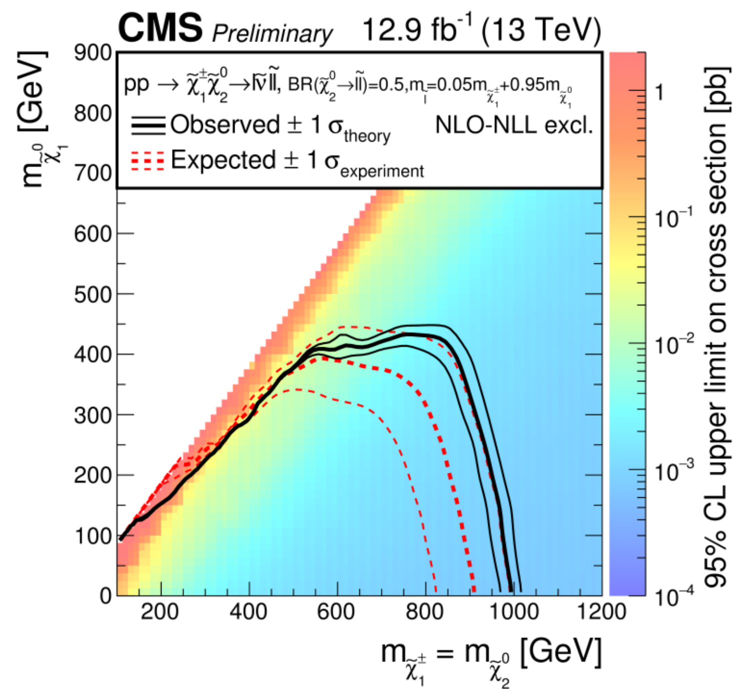
CMS-SUS-16-024



- **Direct production of "electroweakino" pairs**
  - Decays via sleptons/sneutrinos
  - Using benchmarks to illustrate different scenarios (depend on mixings and nature of lightest slepton)
- **Multilepton searches**
  - 3 (or 4) leptons (includes combinations with 1 or 2 hadronically decaying τs)
  - SRs binned in flavour&charge combination, MET, m(ll)/pT(ll)



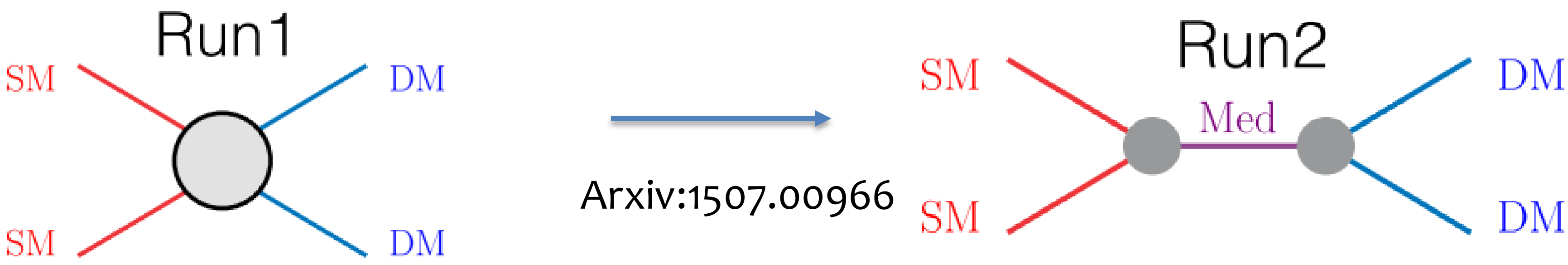
Electroweak production: In flavor democratic scenario we exclude Chargino masses **up to 1 TeV (previous Run1 limit was 750 GeV)**



3l + same-sign 2l

Exotica: Dark Matter Search

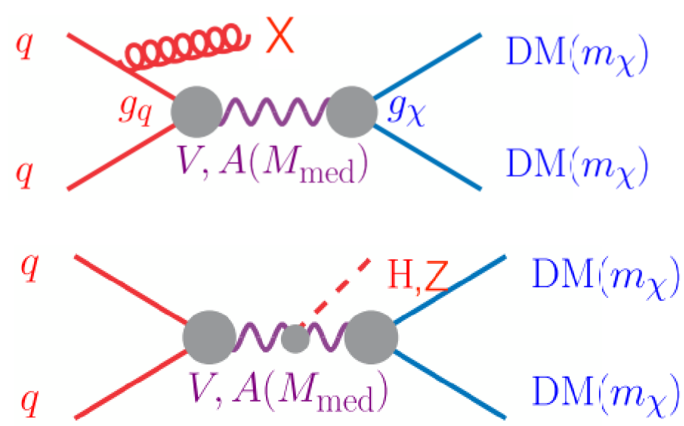
ATLAS/CMS searches assuming that DM is a WIMP

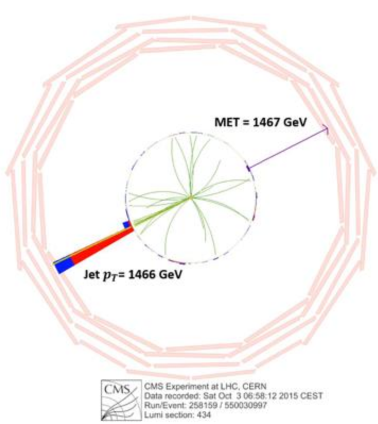


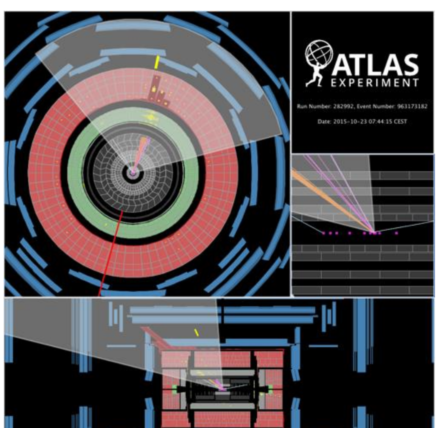
Arxiv:1507.00966

Collider Dark Matter Signature - Mono-X:
ET miss +X a.k.a. Mono-X

- **X from ISR jet, b, t, γ, W, Z**
- **X from mixing with mediator**







DM interpretation using simplified model to avoid EFT validity concerns

Exotica: Dark Matter Search, Mono-jet/b-jets/top

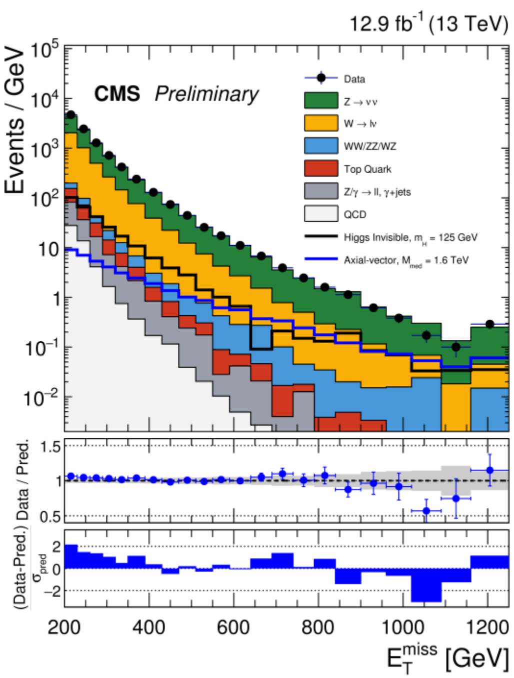
Imbalanced transverse momentum ET miss

Irreducible background: Z(νν)+jets

- jets might be mis-reconstructed as b-jets, γ, W, Z

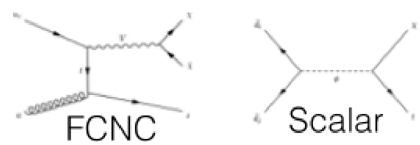
CMS-PAS-EXO--16-037

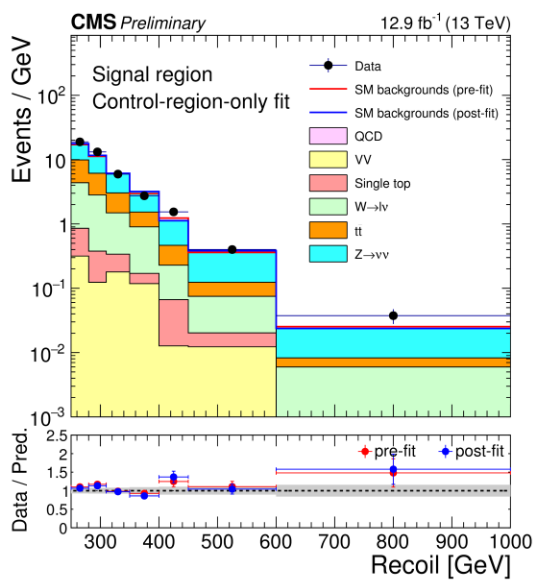
ET miss +jet



CMS-PAS-EXO--16-040

ET miss +t

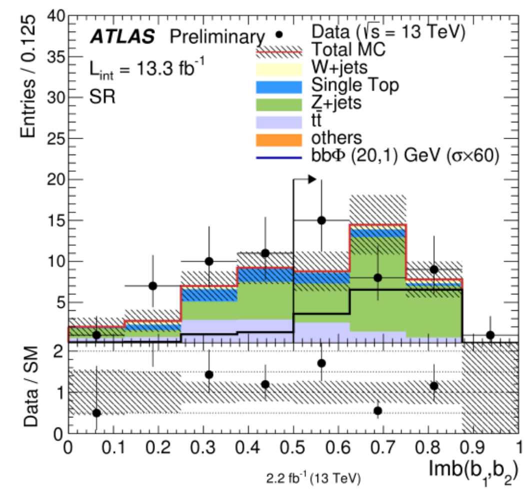


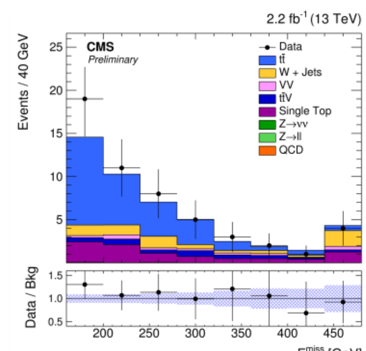


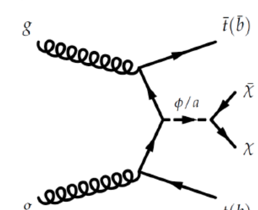
ATLAS-CONF-2016-050,076,077,086

CMS-PAS-EXO-16-005

ET miss +bb̄/tt

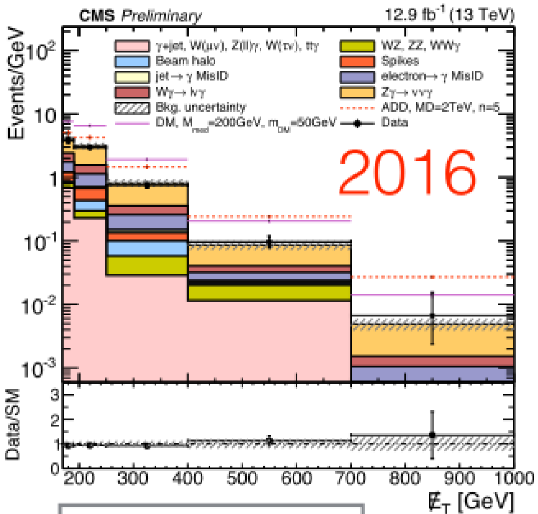






Exotica: Dark Matter Search, Mono-γ/W/Z/H

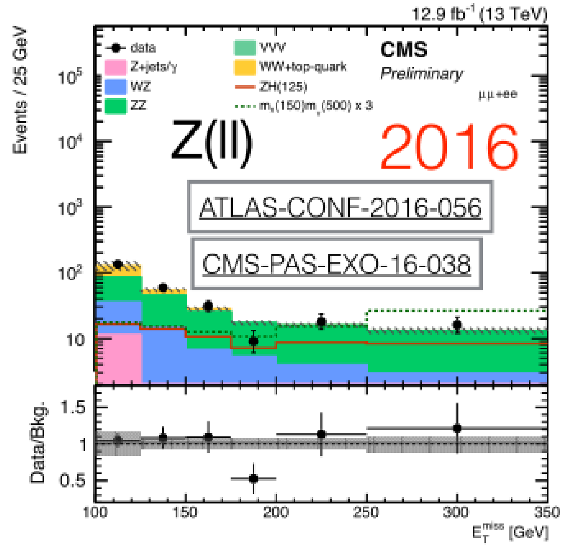
ETmiss+γ



ATLAS-CONF-2015-080

CMS-PAS-EXO-16-039

ETmiss + W/Z



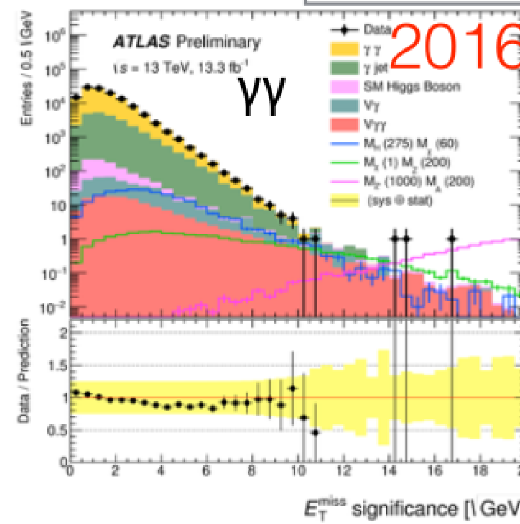
ATLAS-CONF-2016-056

CMS-PAS-EXO-16-038

ETmiss+H

CMS-PAS-EXO-16-011

ATLAS-CONF-2016-087



ATLAS-CONF-2016-019

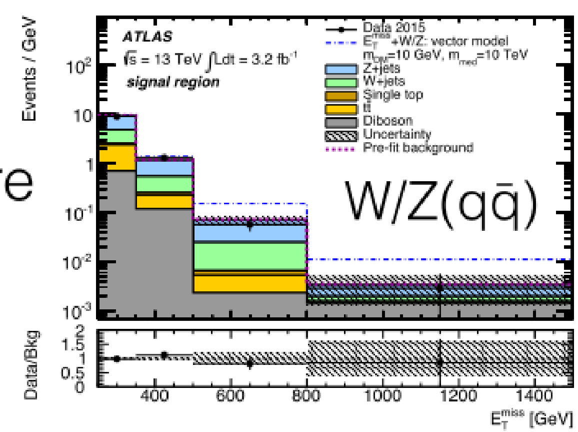
CMS-PAS-EXO-16-012

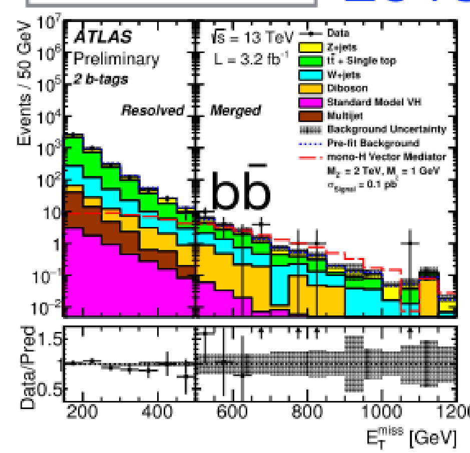
2015

EXOT-2015-08

CMS-PAS-EXO-16-037

2015

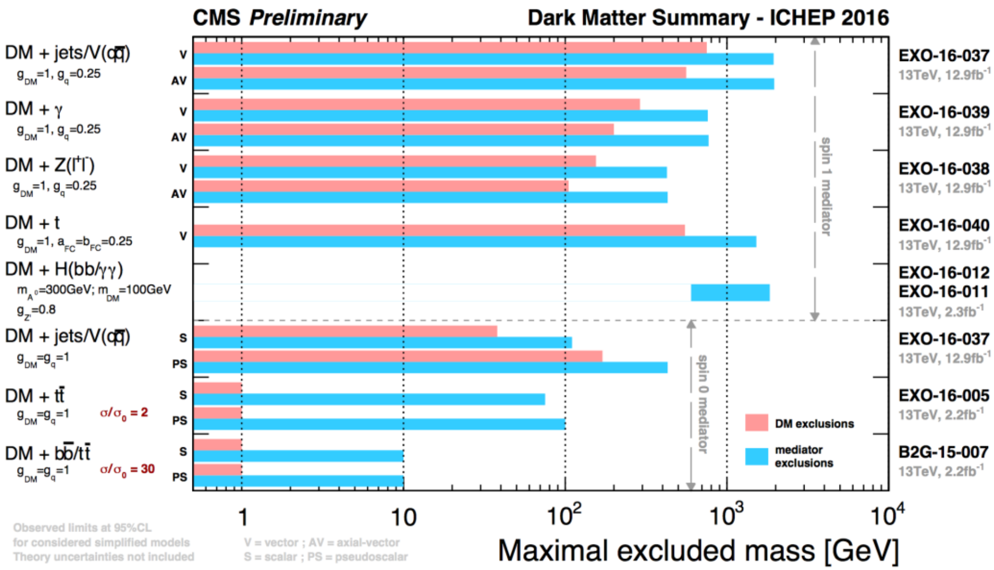


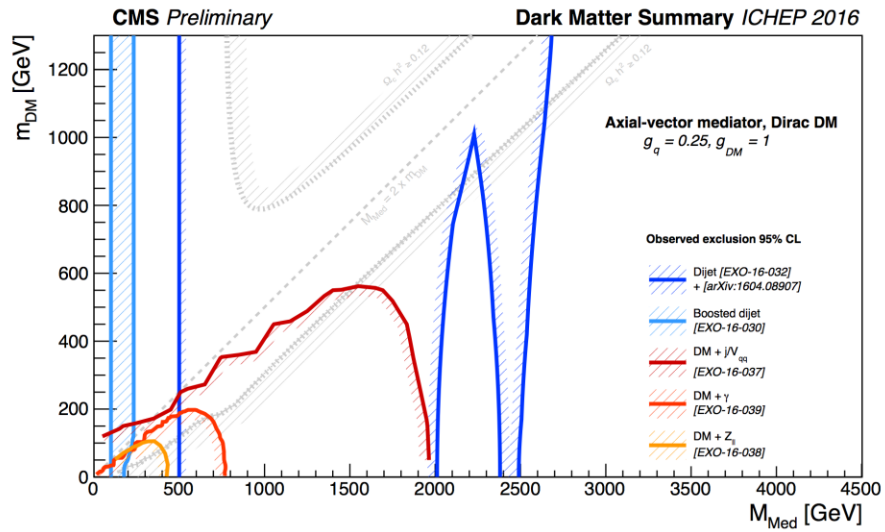


Boosted jet substructure technique is used in hadronic W/Z/H

Dark Matter: Limits

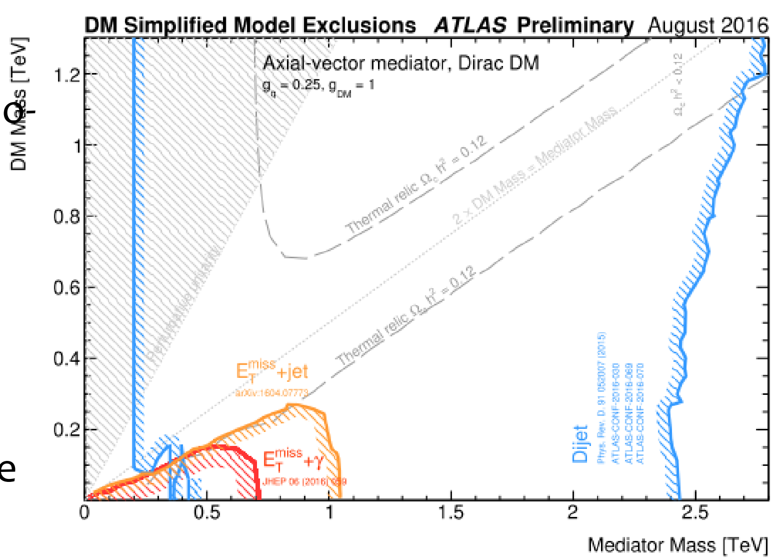
Summary of all Dark Matter Searches in Run 2

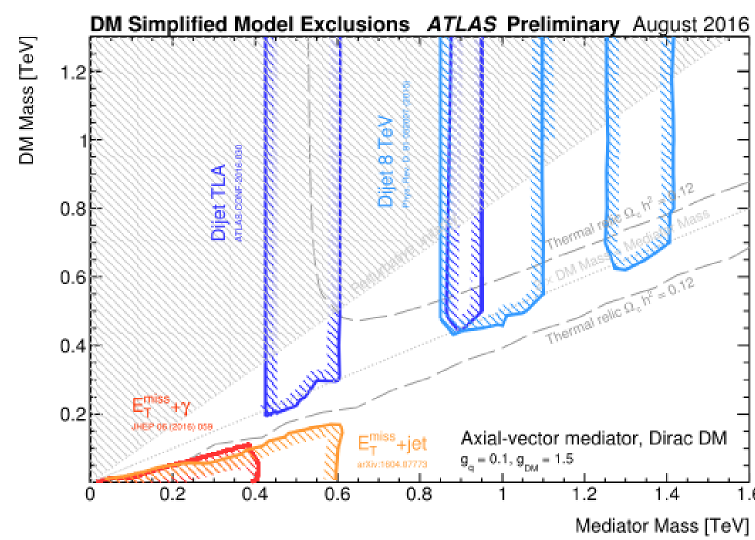




Complementary searches by mono-X and dijet

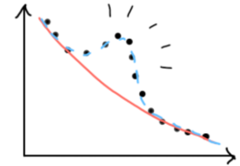
- Dijet searches cover a broad mediator mass range
- Results highly depend on choice of coupling parameters





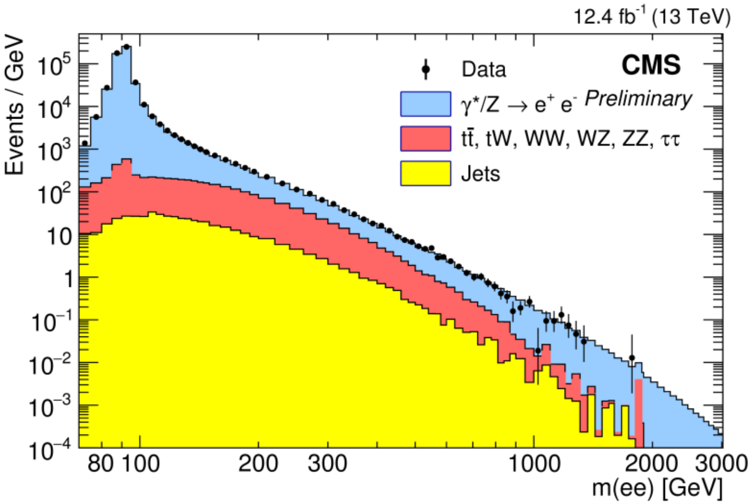
$g_q = 0.25\ g_{DM} = 1$ $\mathcal{L} = g_q \bar{q} \gamma^\mu q Z'_\mu$ $g_q = 0.1\ g_{DM} = 1.5$

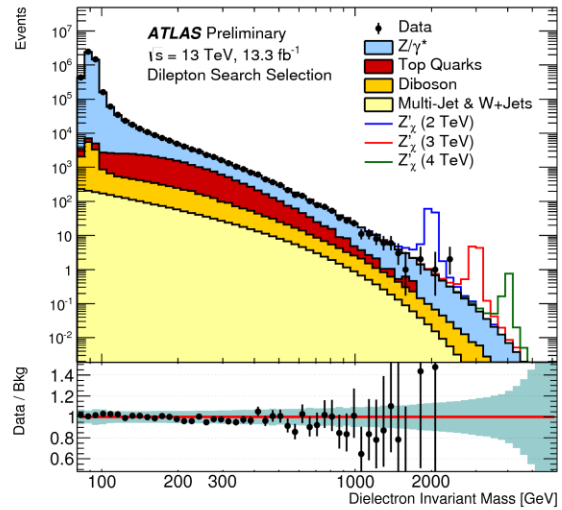
Exotica: Search for resonances (Di-Lepton)



Same Flavor Opposite Sign (ee, μμ, ττ)

CMS-PAS-EXO--16-031, ATLAS-CONF-2016-045



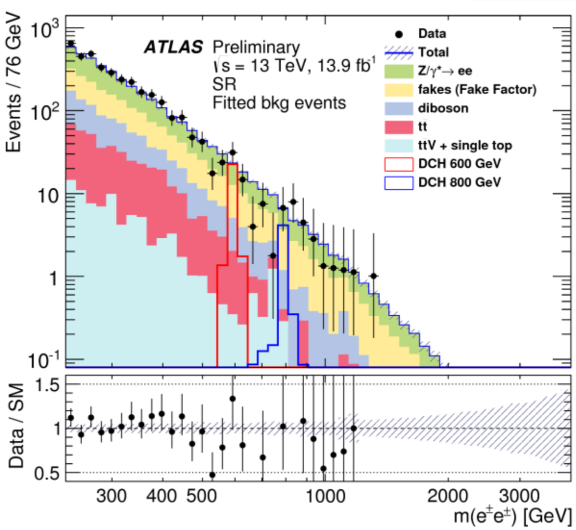


Z'_{SSM} >4.05 TeV
Z'_{SSM} (Run 1) >2.90 TeV

Same Sign (ee, μμ)

ATLAS-CONF-2016-051

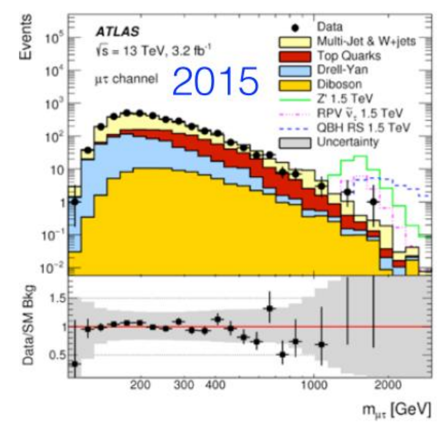
Z'_{SSM} (3% width) >4 TeV
Z'_{Ψ} (0.5% width) >3.36 TeV



$H_R^{\pm\pm}$>420 GeV
$H_L^{\pm\pm}$>570 GeV

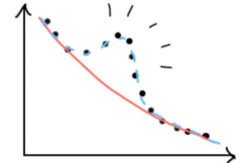
Lepton Flavor Violation (eμ, eτ, μτ)

CMS-PAS-EXO--16-001, ATLAS-CONF-2016-045



RPV ($\lambda'_{311}=\lambda_{132}=\lambda_{231}=0.2$)> 3.3 TeV
QBH (n=6)> 4.5 TeV

Exotica: Search for resonances (Di-jets)



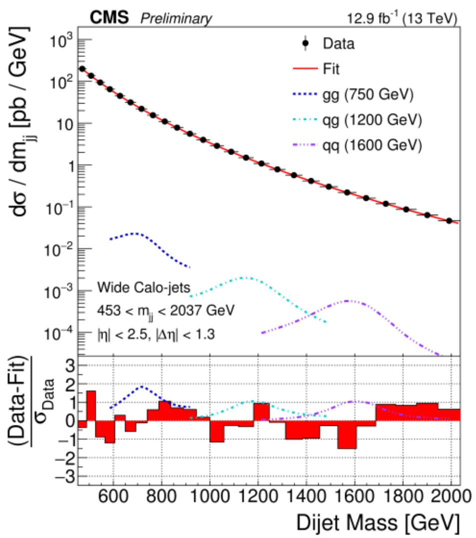
Low mass search, HLT ‘scouting’,

Jet HLT info saved directly (CMS-Run1)

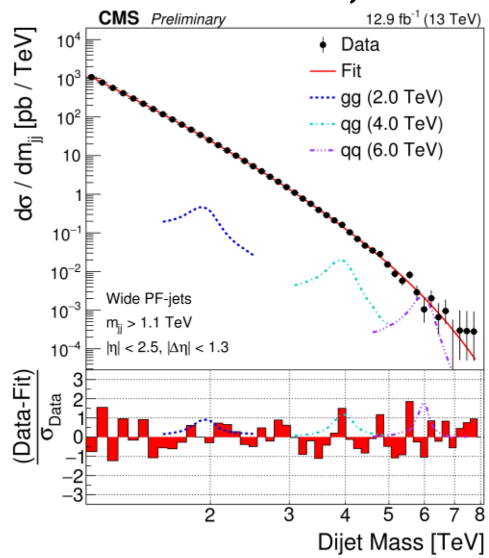
CMS-PAS-EXO--16-032, ATLAS-CONF-2016-069

High Mass search

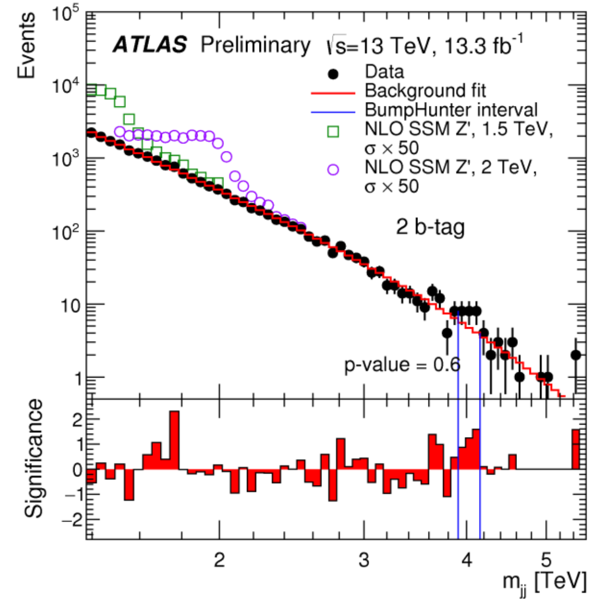
Background modeled by parametrized function for search



>=0 b-jet



>=1 b-jet

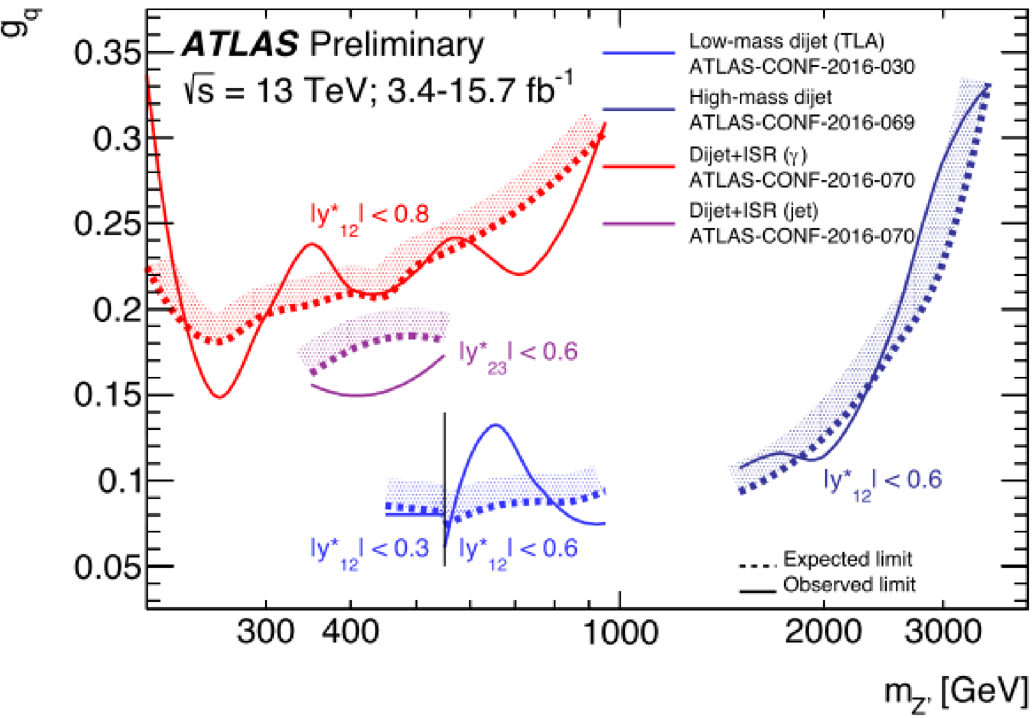


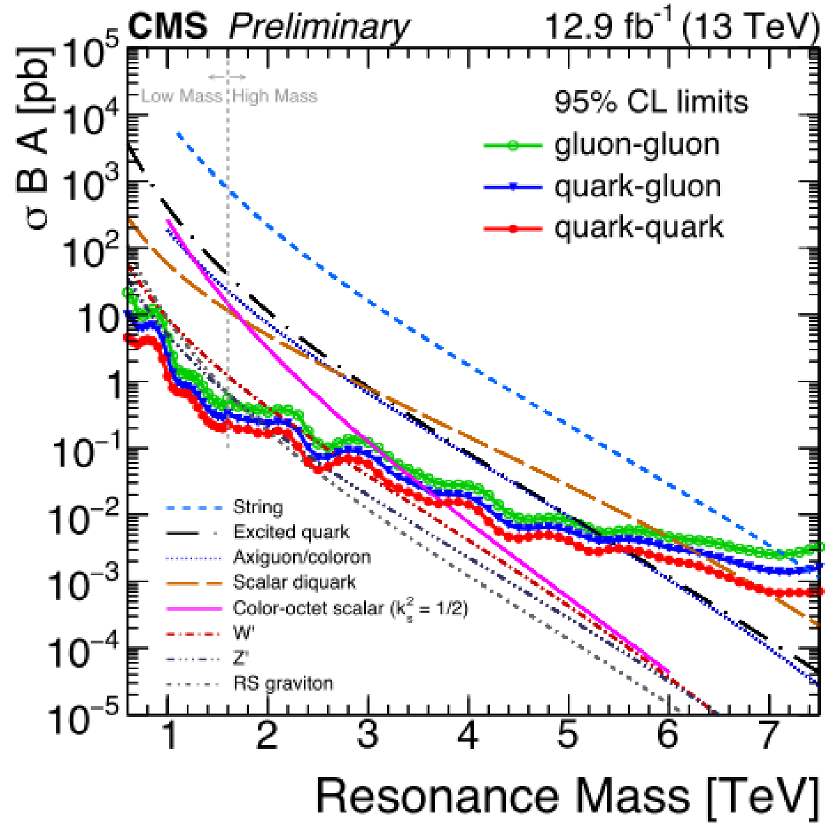
Model	Final State	Observed (expected) mass limit [TeV] 12.9 fb^{-1} 13 TeV	2.4 fb^{-1} 13 TeV	20 fb^{-1} 8 TeV
String	qg	7.4 (7.4)	7.0 (6.9)	5.0 (4.9)
Scalar diquark	qq	6.9 (6.8)	6.0 (6.1)	4.7 (4.4)
Axigluon/coloron	$q\bar{q}$	5.5 (5.6)	5.1 (5.1)	3.7 (3.9)
Excited quark	qg	5.4 (5.4)	5.0 (4.8)	3.5 (3.7)
Color-octet scalar ($k_s^2 = 1/2$)	gg	3.0 (3.3)	—	—
W′	$q\bar{q}$	2.7 (3.1)	2.6 (2.3)	2.2 (2.2)
Z′	$q\bar{q}$	2.1 (2.3)	—	1.7 (1.8)
RS Graviton	$q\bar{q}$, gg	1.9 (1.8)	—	1.6 (1.3)

b^* (BR($b^* \to bg$)=0.85) >2.3 TeV

Z’ >1.5TeV

Exotica: Search for resonances (Di-jets, summary)



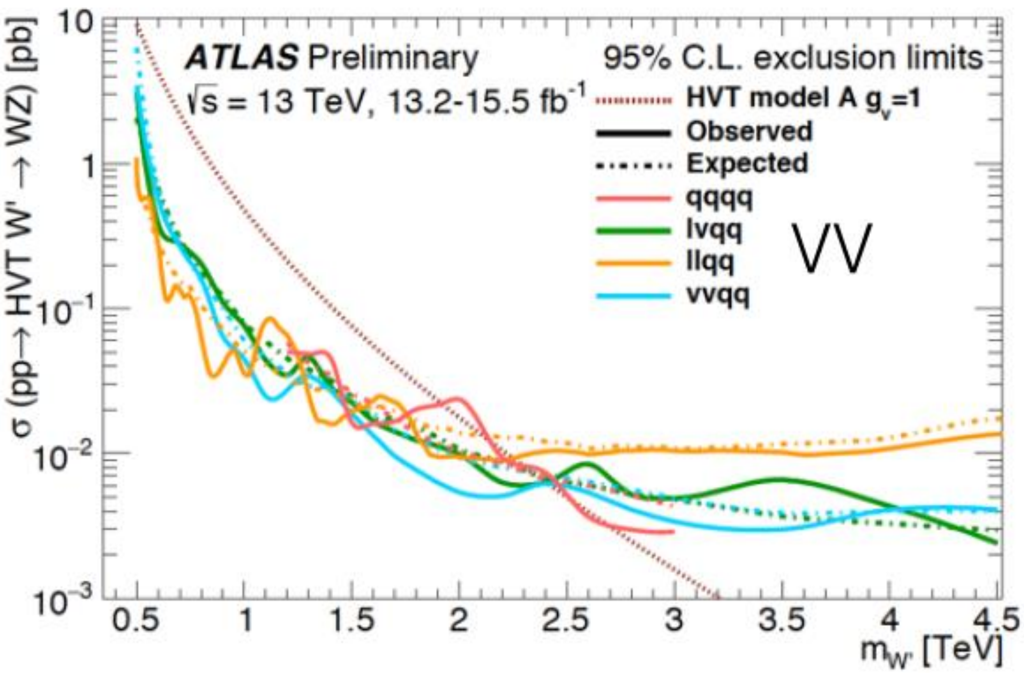


A broad mass - leptophobic Z' coupling parameter space constrained by combining various dijet channels.

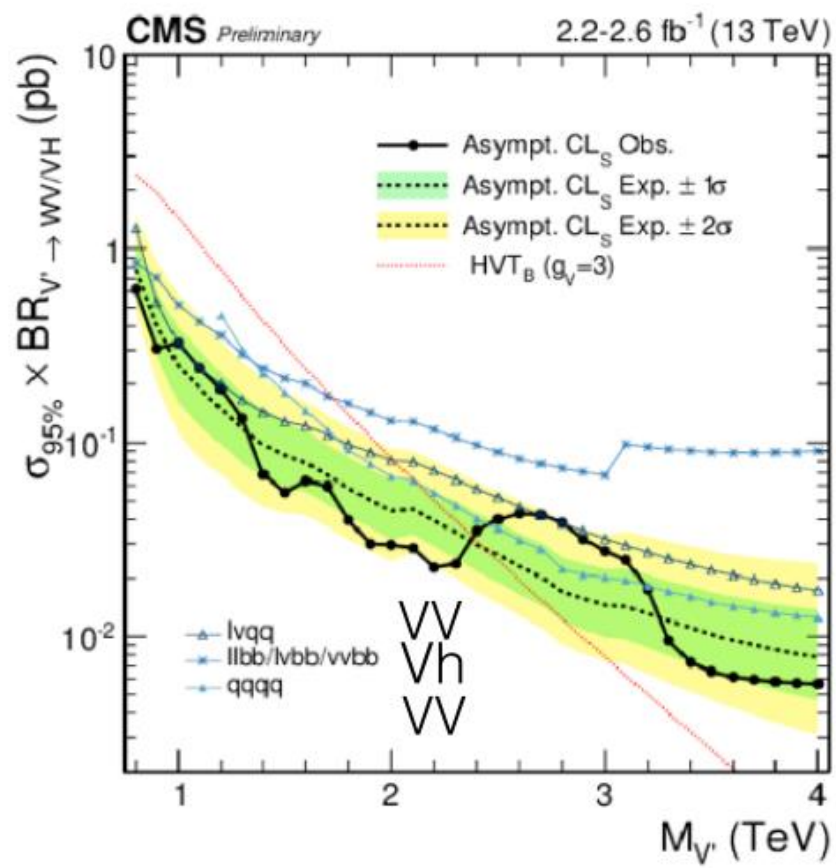
Diboson Resonance

Excesses in Run1 not confirmed in Run2

- RS Graviton mass limit up to 2 TeV
- HVT W’ mass limit up to 2.4 TeV
- a joint interpretation of VV/Vh channel

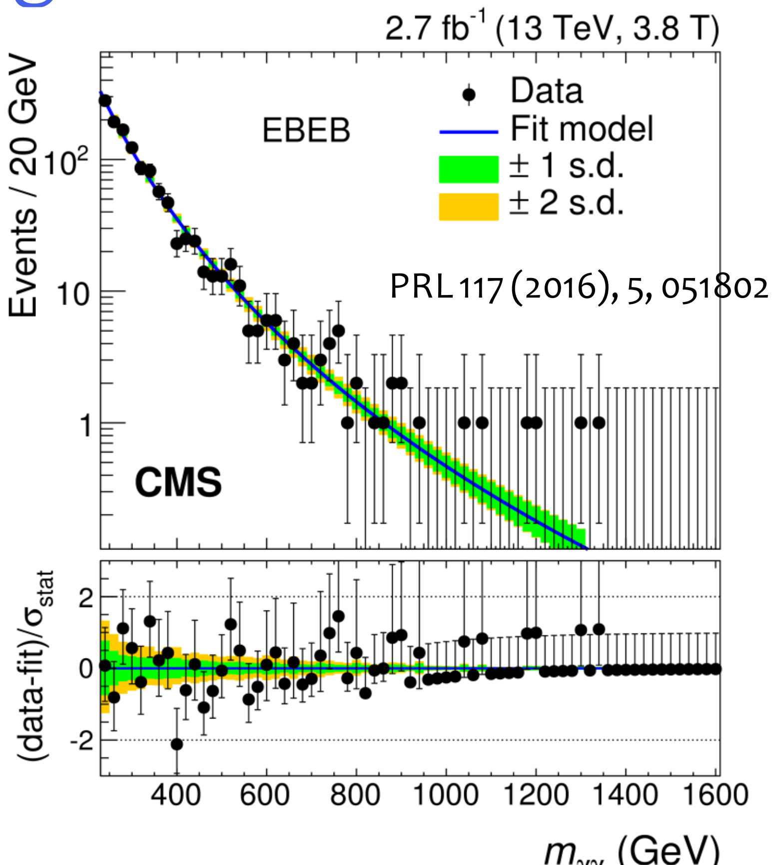


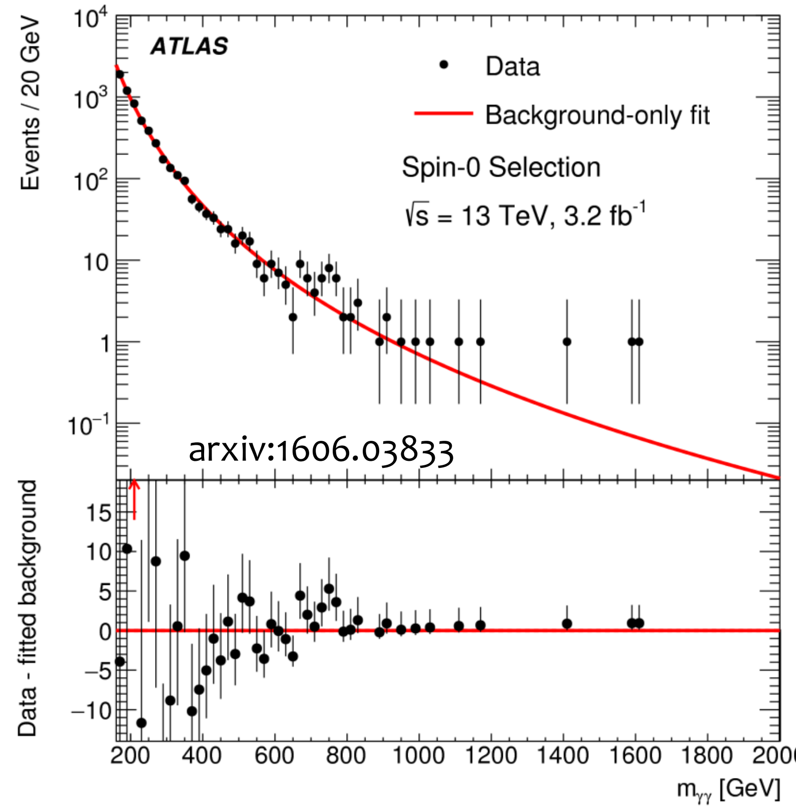
Overlaying limits from all WZ searches – no persistent excesses



Exotica: Search for resonances (Di-photons)

- Significant excesses observed in 2015 data

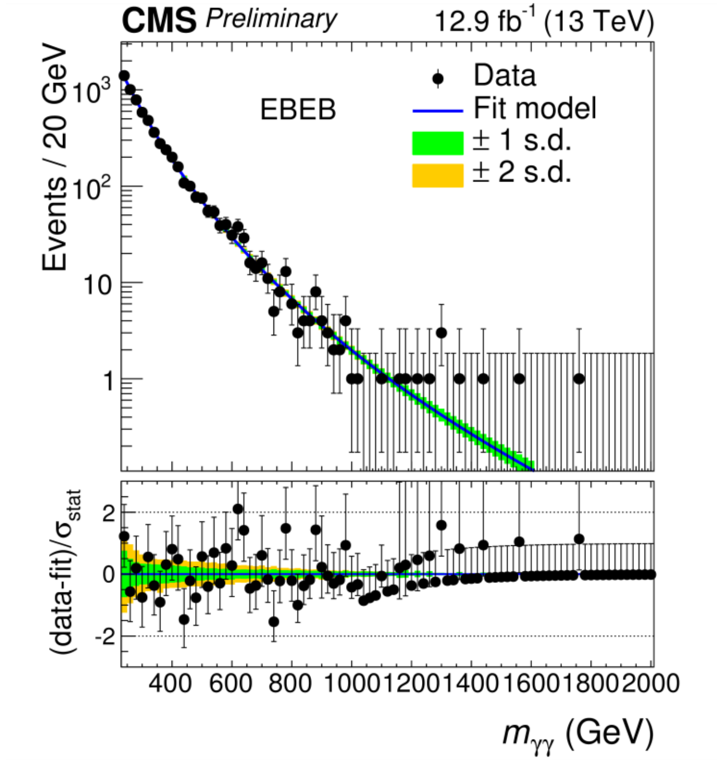




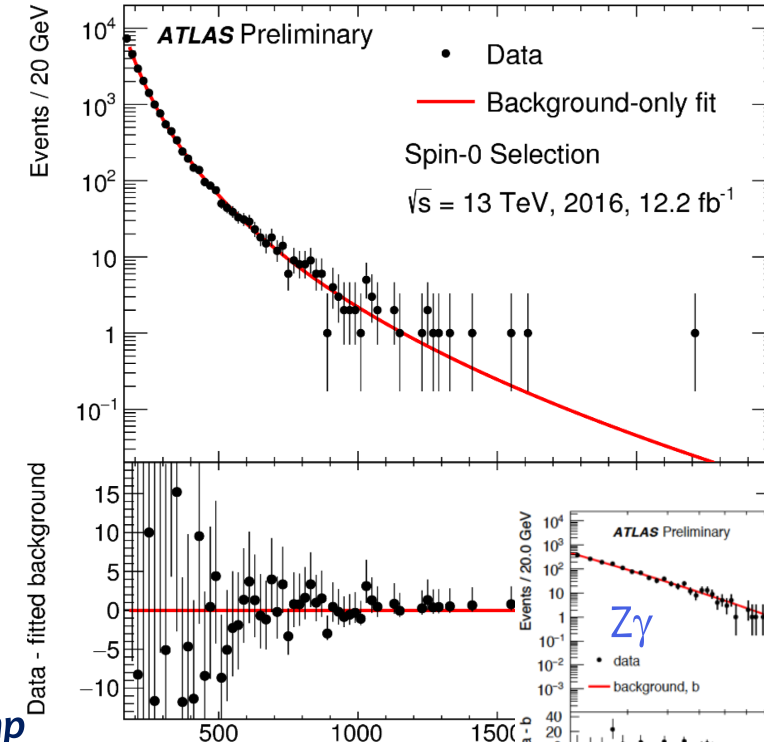
CMS: the small excess at 750 GeV remained there after reprocessing and final calibration (CMS choice to reprocess prior to publishing). Global significance of CMS 13 TeV(2015)+8 TeV was 1.6 σ

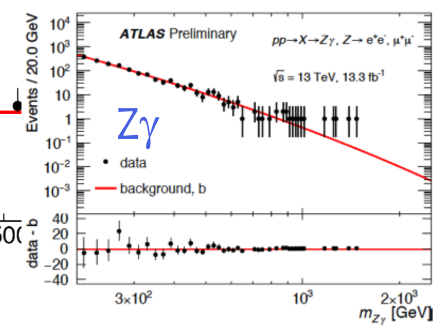
Localised excess seen in 2015 ATLAS data
- 2.1σ global (3.9σ local) significance at 750 GeV (spin-0 search), width ~50 GeV
- After reprocessing, new 2016 reconstruction 3.4 → σ local, at ~730 GeV

Exotica: Search for resonances (2016 data) (Di-photons)

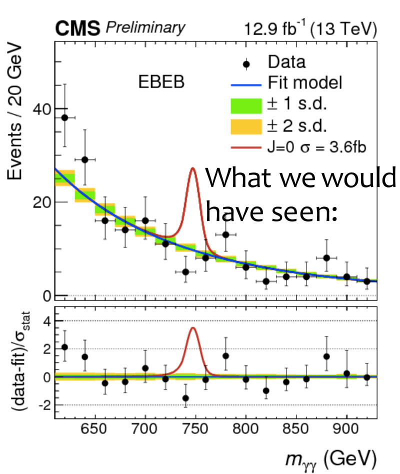


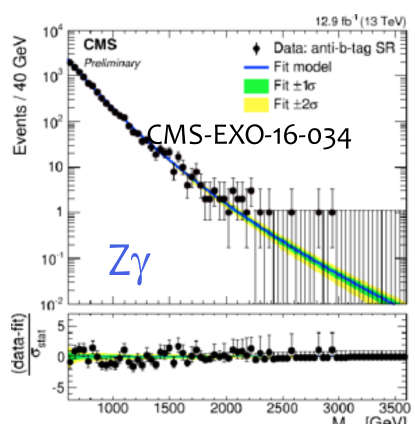
ATLAS-CONF-2016-059





CMS: no evidence of strengthening of 2015 *bump*





ATLAS 2016 data: no clustering around 730-750 GeV, and 3.8x more data

- **2016 data consistent with 2015 at the 2.7σ level**
- **Appears that the 2015 excess was a statistical fluctuation**

Summary

- **Very successful operation of the LHC and the experiments (enhanced detectors and trigger systems) in 2016.**
- **Exploration of the new energy regime of 13 TeV has started** (detectors able to cope with PU levels close to twice the design)
- A broad scan of several different scenarios for physics beyond the standard model have been performed, e.g. in **SUSY**: mass limits up to about 1.9 TeV (gluinos) and 900 GeV (top squarks) , and limits on EW production even for small mass differences
- Several **measurements of Standard Model** processes done, including various with low cross-sections. New 13TeV results confirm 8TeV results with already impressive precision
- New era in **Higgs precision physics**, Higgs re-discovered, **ttH**, H->bb
- New probes of **CP violation** from **LHCb**
- From this first look **no significant deviation from the Standard model has been observed**. Data in general compatible with SM predictions at higher orders in pQCD.
- The performance of the Accelerator complex at CERN makes us confident that **it will be possible to exploit the full physics reach of the LHC.**