Recent ATLAS results

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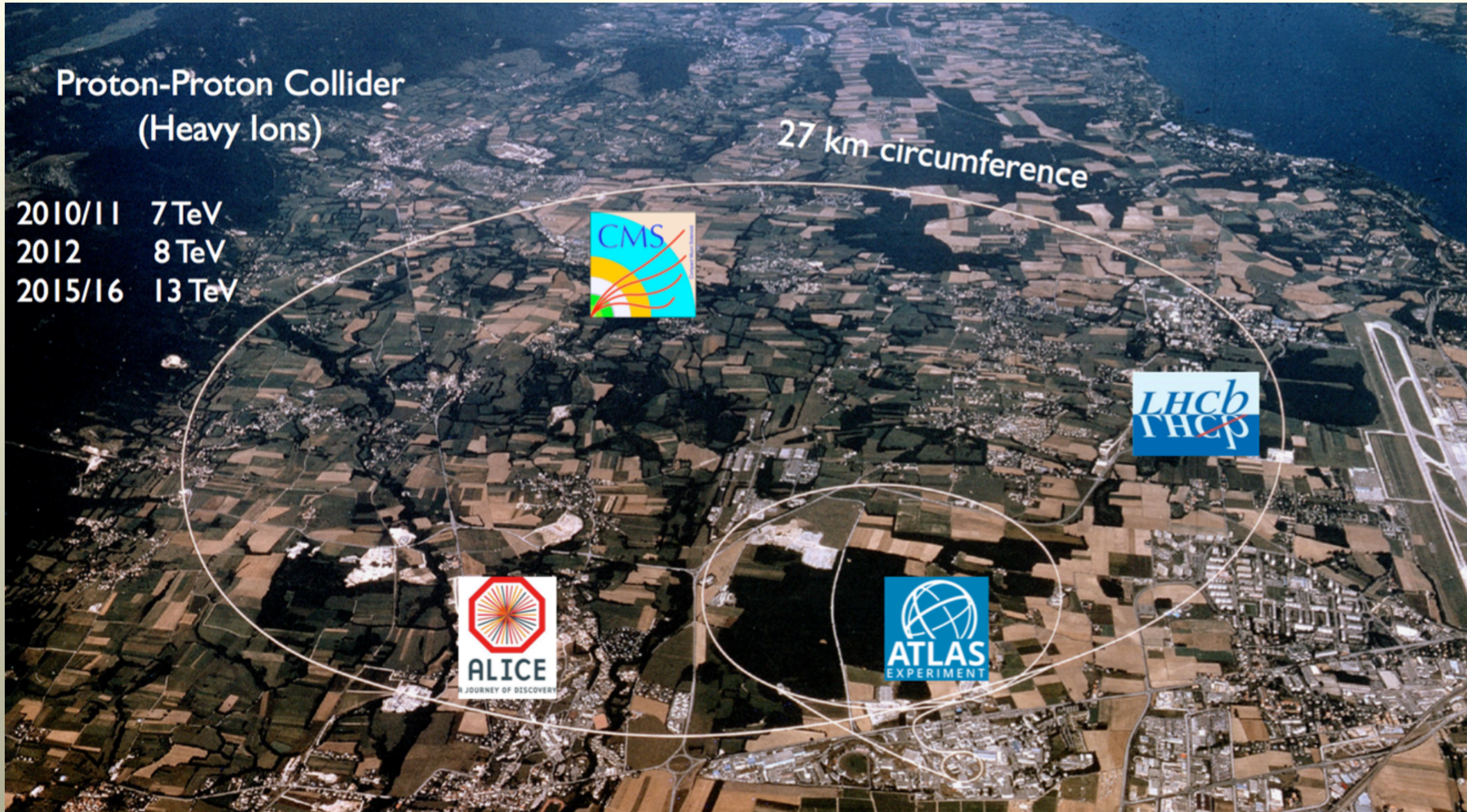
on behalf of ATLAS Collaboration

Outline

- Large Hadron Collider and ATLAS experiment:
  - RUN II luminosity and data sample;
  - Detector performances;
- Standard model results:
  - Total cross section and multiplicity;
  - Bosons and di-bosons production;
  - Top quark;
  - Higgs Boson;
- Beyond Standard Model searches:
  - Search for new Resonances
  - Search for Supersymmetric Particles
  - Search for BSM in Higgs sector
  - Search for Dark Matter

LHC: Large Hadron Collider



ATLAS Detector

Length: 44 m
Height: 25 m
Weight: 7000 t

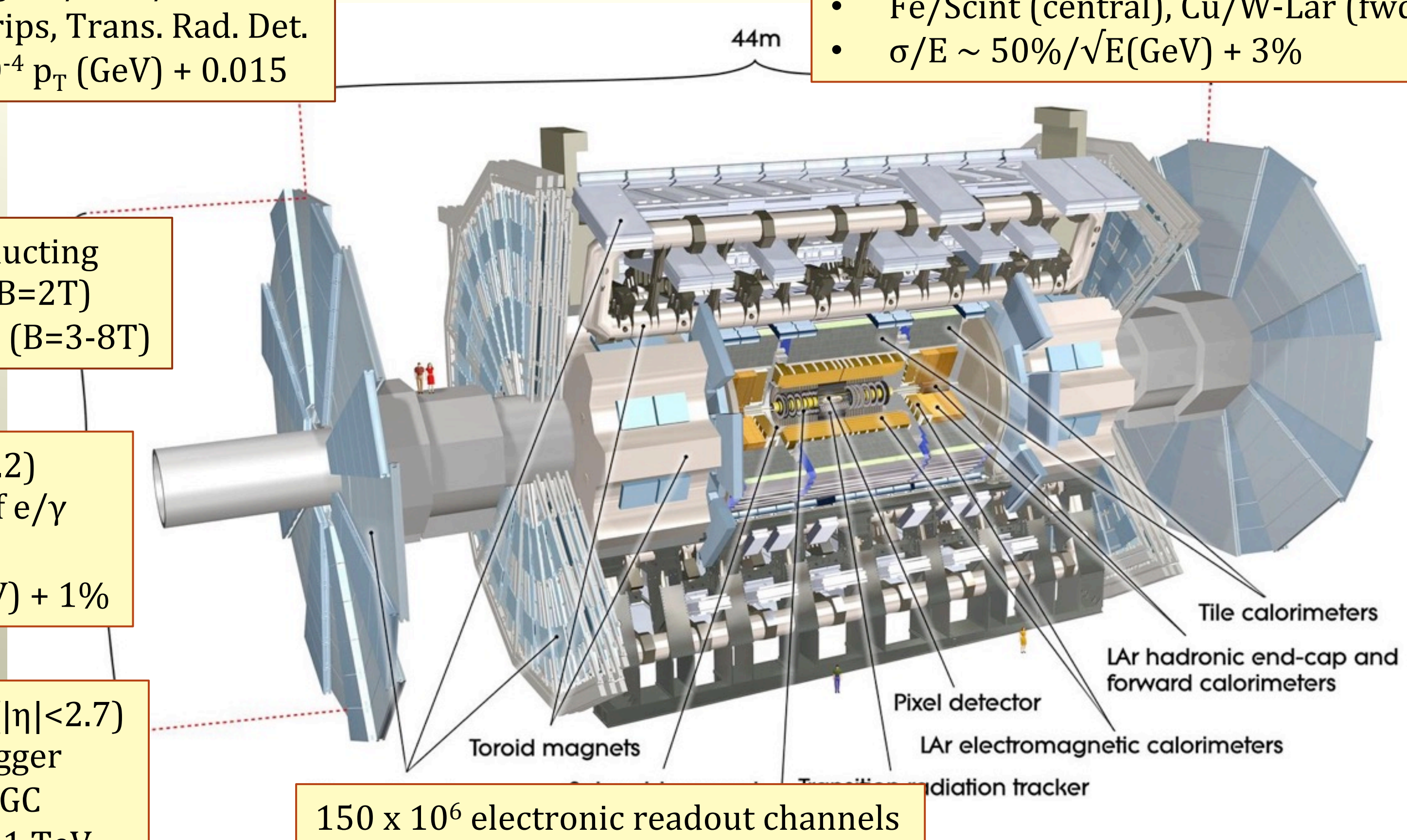
Inner detector: ($|\eta|<2.5$, B=2T)
Traking, vertexing, dE/dx, e/π ID
- Si pixels, Si strips, Trans. Rad. Det.
- $\sigma/p_T \sim 3.8\times10^{-4}\, p_T\,(\text{GeV}) + 0.015$

Hadron Calorimeter: ($|\eta|<5$)
Trigger and meas. of jet/E_{miss}
- Fe/Scint (central), Cu/W-Lar (fwd)
- $\sigma/E \sim 50\%/\sqrt{E(\text{GeV})} + 3\%$

Magnets: 4 superconducting
- Central solenoid (B=2T)
- 3 Air core Toroids (B=3-8T)

EM Calorimeter: ($|\eta|<3.2$)
Trigger, meas. and ID of e/γ
- Pb-Lar accordion
- $\sigma/E \sim 10\%/\sqrt{E(\text{GeV})} + 1\%$

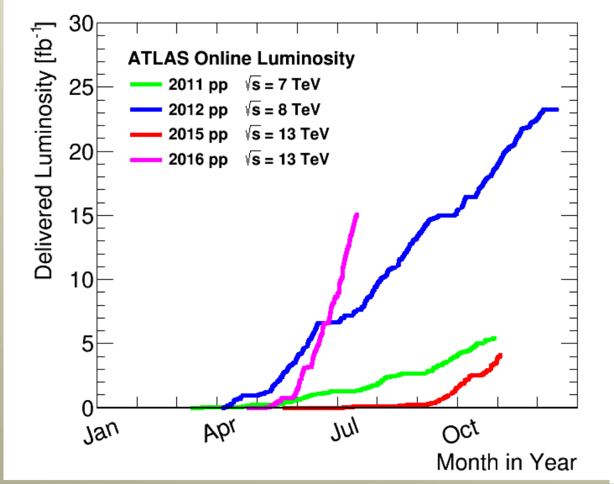
Muon Spectrometer: ($|\eta|<2.7$)
Muon measur. and trigger
- MDT+RPC+CSC+TGC
- $\sigma/p_T \sim 10\%$ up to 1 TeV

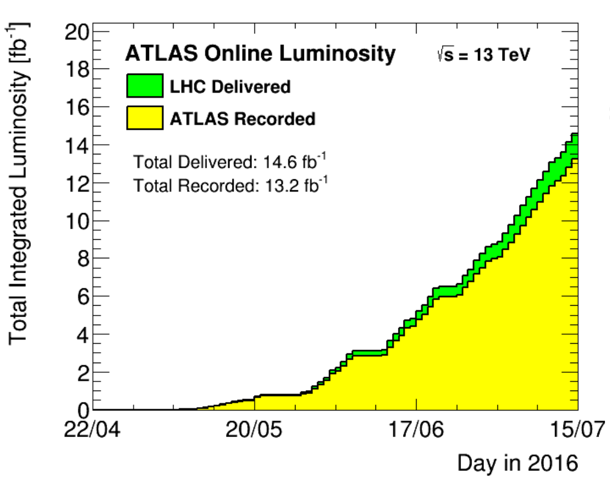


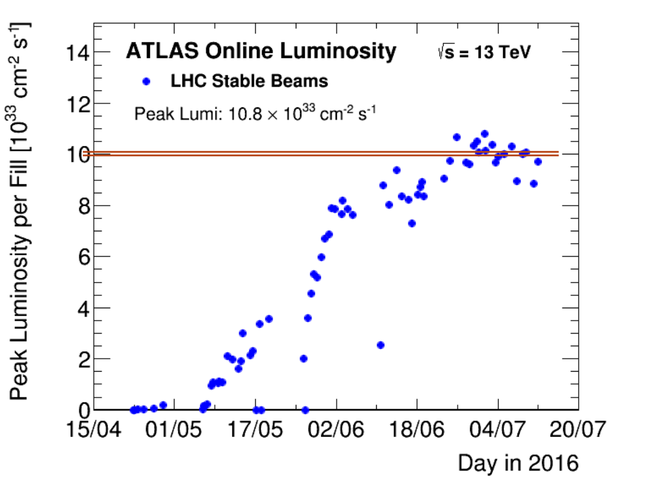
150×10^6 electronic readout channels
40 MHz collision rate
10^{14} B/s raw data flux

ATLAS Run II: Data Acquisition

- 3.9 fb^{-1} pp@13TeV recorded in 2015 (92% DAQ efficiency)
- 13.2 fb^{-1} pp@13TeV recorded in 2016 (up to 15/7) (~ 90.7% DAQ efficiency)
  - 3 times 2015 statistic in about three months
- Peak luminosity delivered by LHC 1.08 x 10^{34} cm^{-2} s^{-1} is greater than design value (1 x 10^{34} cm^{-2} s^{-1})



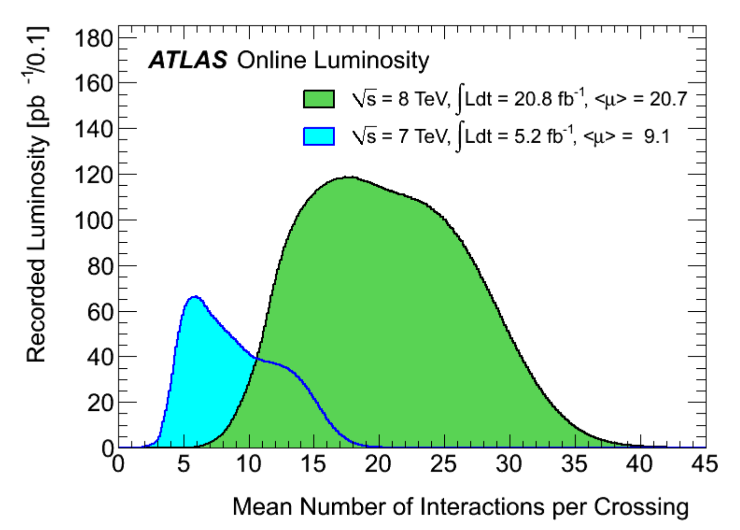


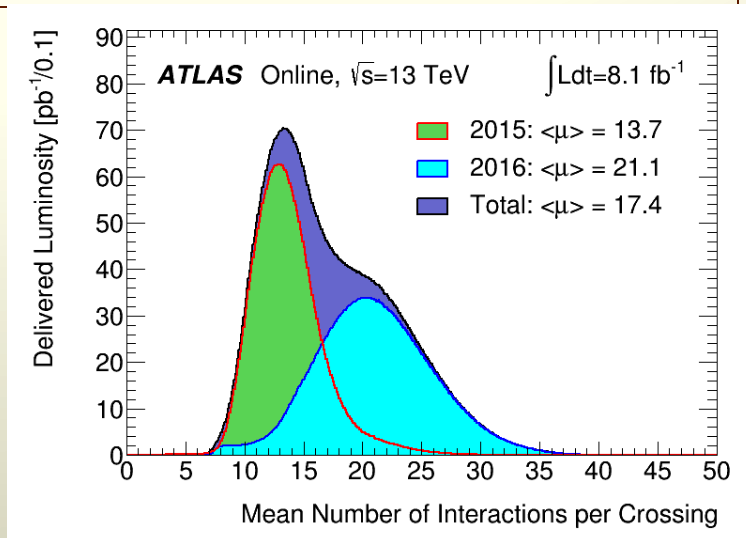


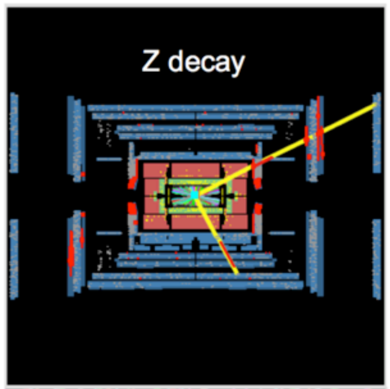
GREAT EFFORT IN DETECTOR OPERATION, DATA QUALITY AND DATA PREPARATION

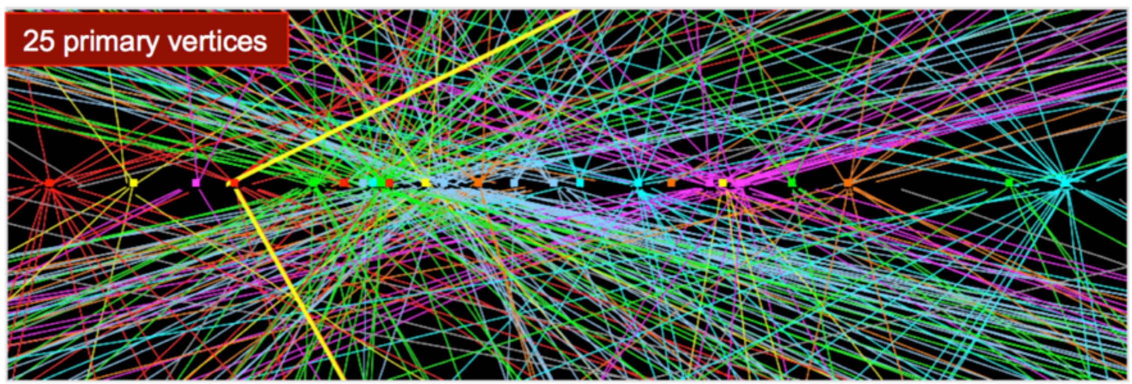
ATLAS Run II: Pile up

- 25 ns bunch spacing during 2015 instead of 50 ns bunch spacing during RUN I
  - less pileup in events.





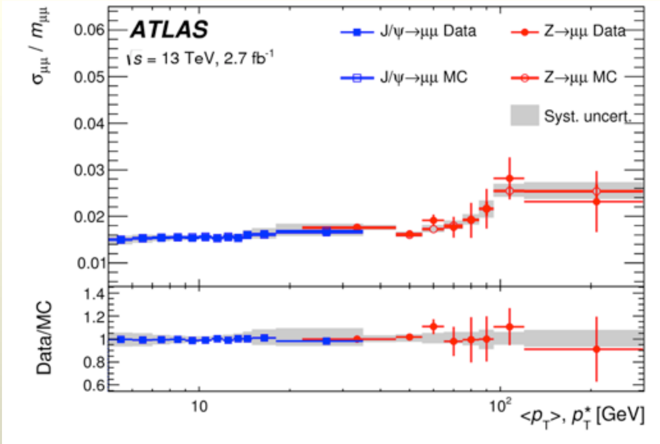


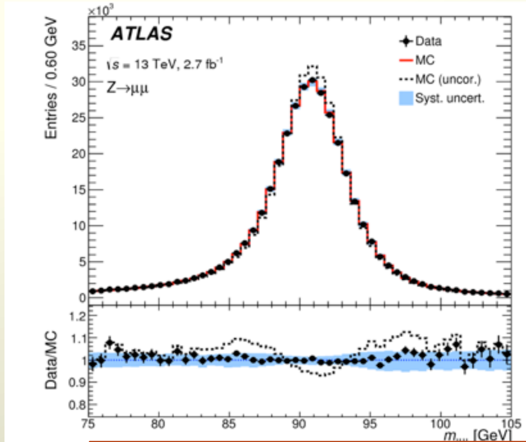


ATLAS RUN II: Detector performances

- RUN II detector performance and calibration very close to RUN I performances

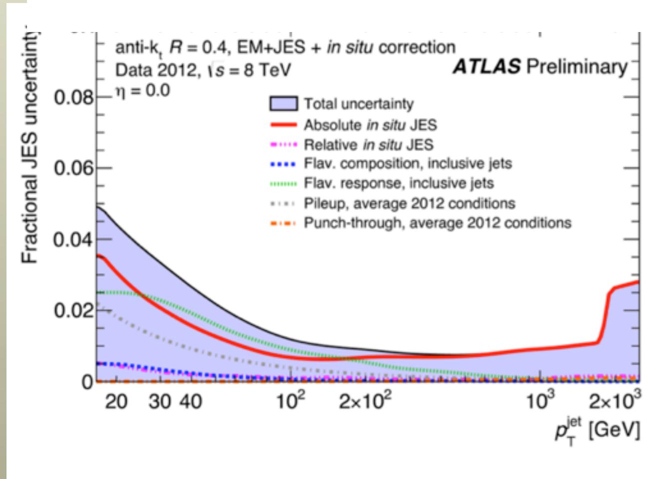
Muon Spectrometer momentum scale and resolution have been studied in detail using $J/\psi \to \mu\mu$ and $Z \to \mu\mu$ decays .

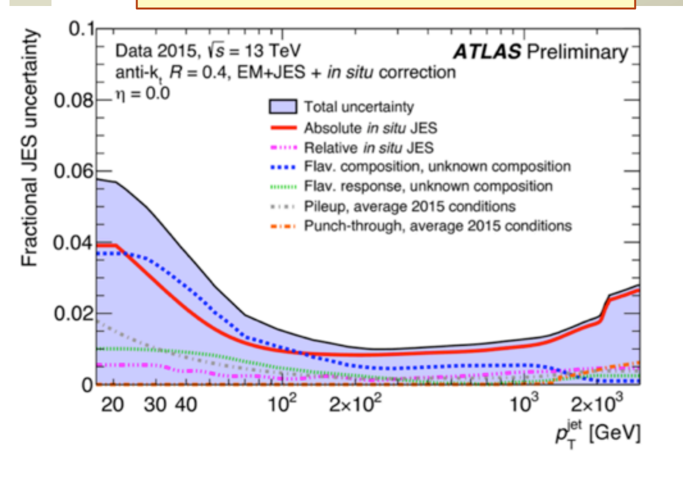




Eur. Phys. J. C (2016) 76:292

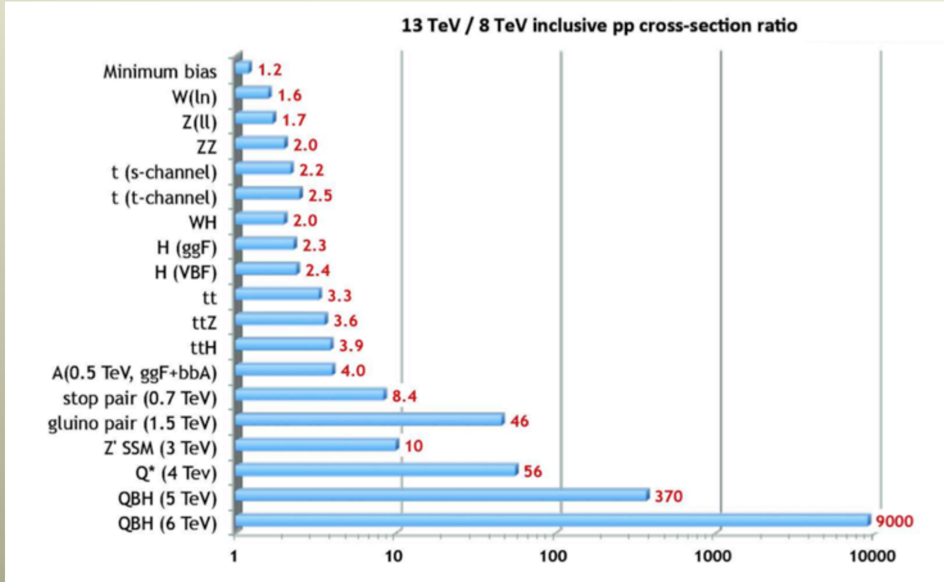
Jet energy scale uncertainty at the level of 2012 data





From 8 TeV to 13 TeV

- Raising the centre of mass energy from 8 to 13 TeV the cross section of processes involving heavy objects is enhanced significantly.
- Increase in measurement precision of known objects (Higgs, Top, W, Z)
- Observation and study of rare process (ttH, 4 top, Boson Couplings)
- Discovery (as we all are hoping to)

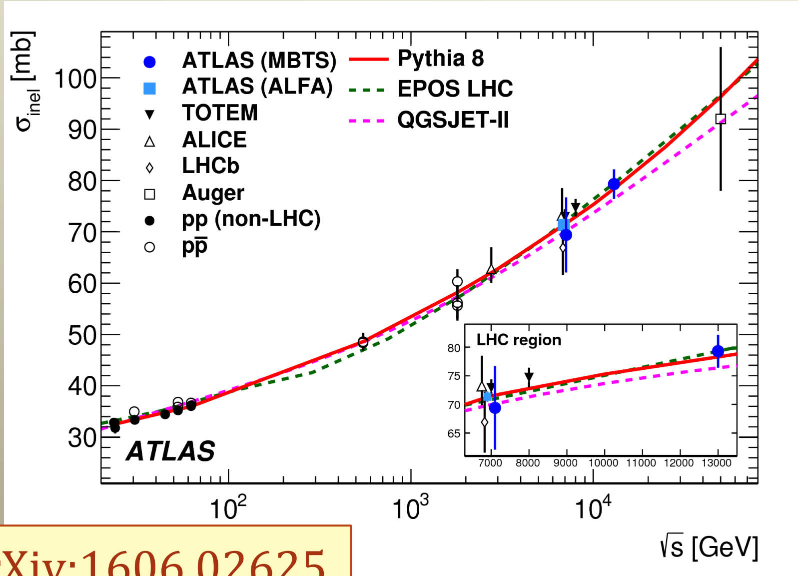


Analysis on 2016 recorded data are ongoing and will be presented to ICHEP at beginning of August

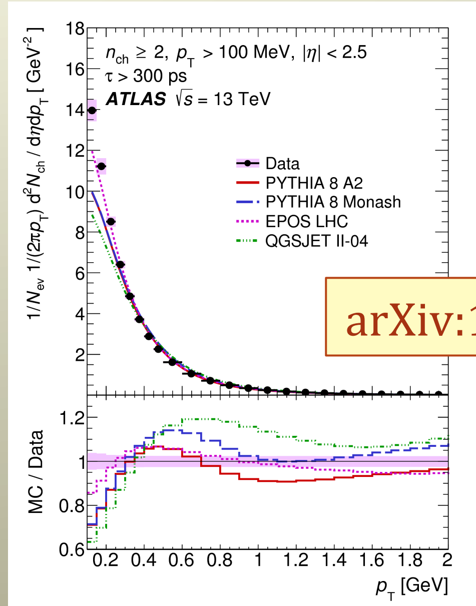
Inelastic pp cross section and Multiplicity

- Measurement done with using Minimum Bias Trigger Scintillators (MBTS)
  - Extrapolation from fiducial region to total depends also on diffractive contributions, which is constrained using single/double sided events
  - Data are compared to PYTHIA 8, EPOS LHC and QGSJet-II MC predictions

- Measurement done with MBTS and Inner detector
  - EPOS describes the data well for *p*T > 300 MeV.
  - For *p*T < 300 MeV, the data are underestimated by up to 15%.
  - Other MC have larger discrepancies



arXiv:1606.02625

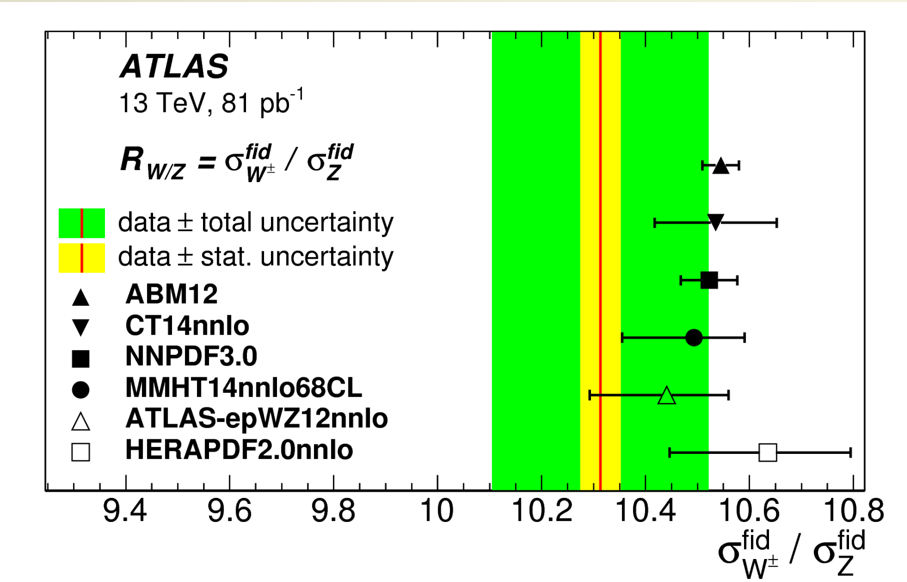


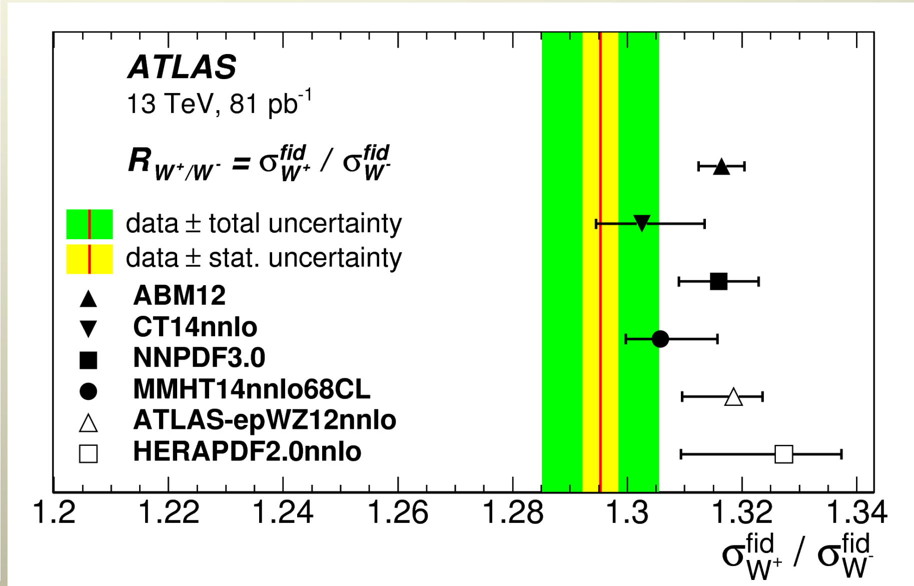
arXiv:1606.01133

W and Z production @ 13 TeV

Phys. Lett. B 759 (2016) 601

- Both absolute cross sections and ratios measured
- Ratio of W+ and W- fiducial cross section @ 13 TeV
  - Sensitive to u & d quark valence distribution, measured to a precision of 0.8%
- Ratio of W+/- and Z fiducial cross section @ 13 TeV
  - Sensitive to strange quark content





1-2σ lower than the various predictions based on different PDFs

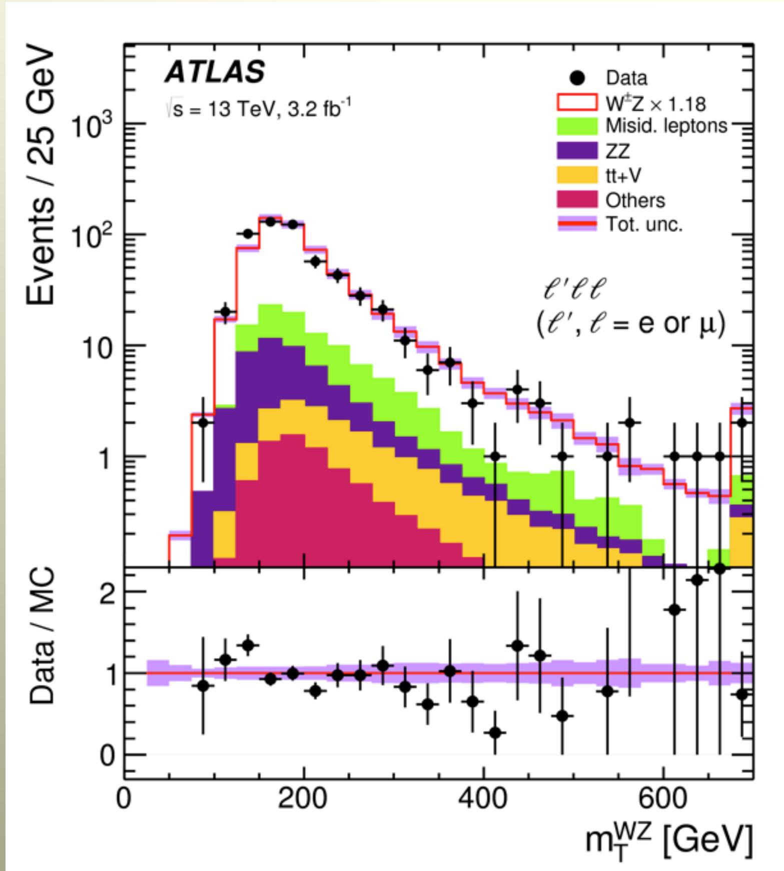
Di-boson production

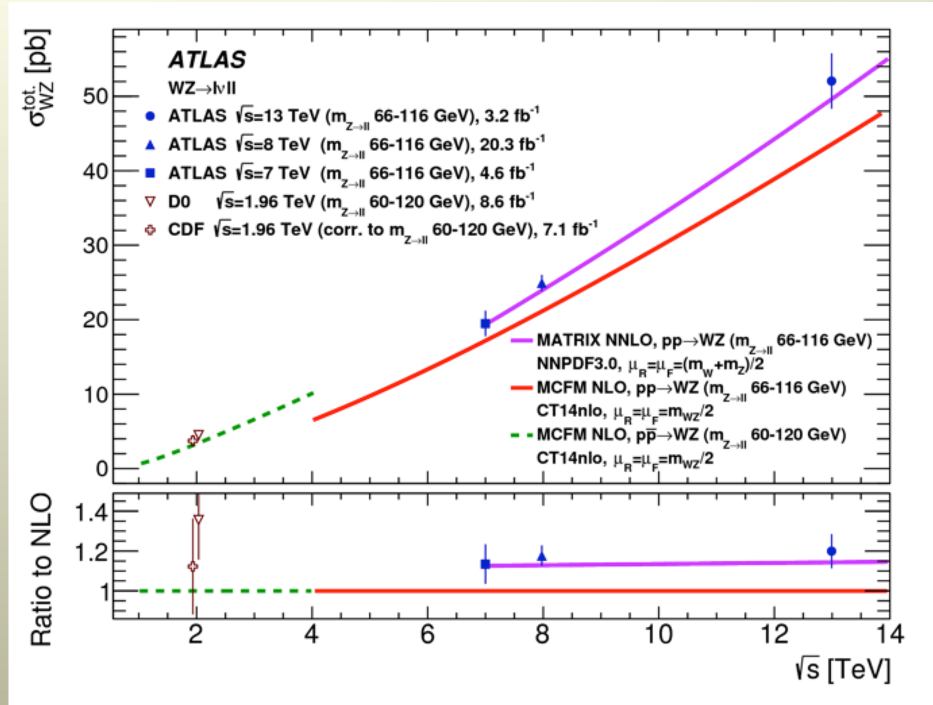
- Precision test of the SM @ TeV scale.
- Understanding these processes is important for back ground estimations needed for many measurements.
- SM production of two or more bosons:
  - boson self-interactions,
  - Higgs to VV decays
- Allows constraints to be set on many exotic models through the study of cross-sections, triple and quartic gauge boson couplings (TGC and QGC) vertices.

Di-boson production: WZ

- Fiducial cross-section in e and mu decay extrapolated to total phase space
- Total cross-section found to be consistent with very recent NNLO prediction

arXiv:1606.04017

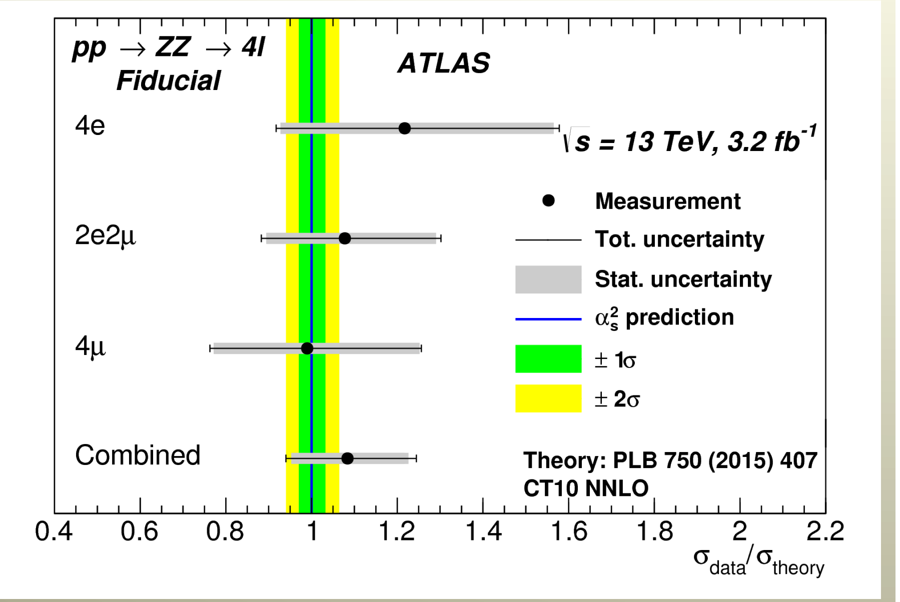


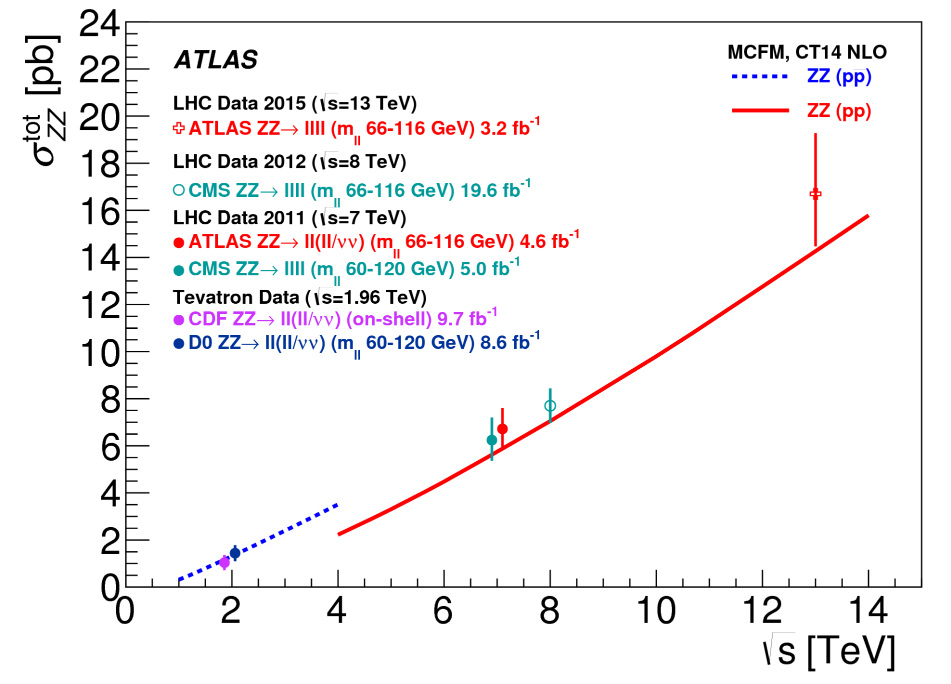


Di-boson production: ZZ

- Cross section measurement of “on shell” ZZ -> 4 leptons production @ 13 TeV
- Agreement with NNLO prediction @ 13 TeV

Phys. Rev. Lett. 116, 101801 (2016)



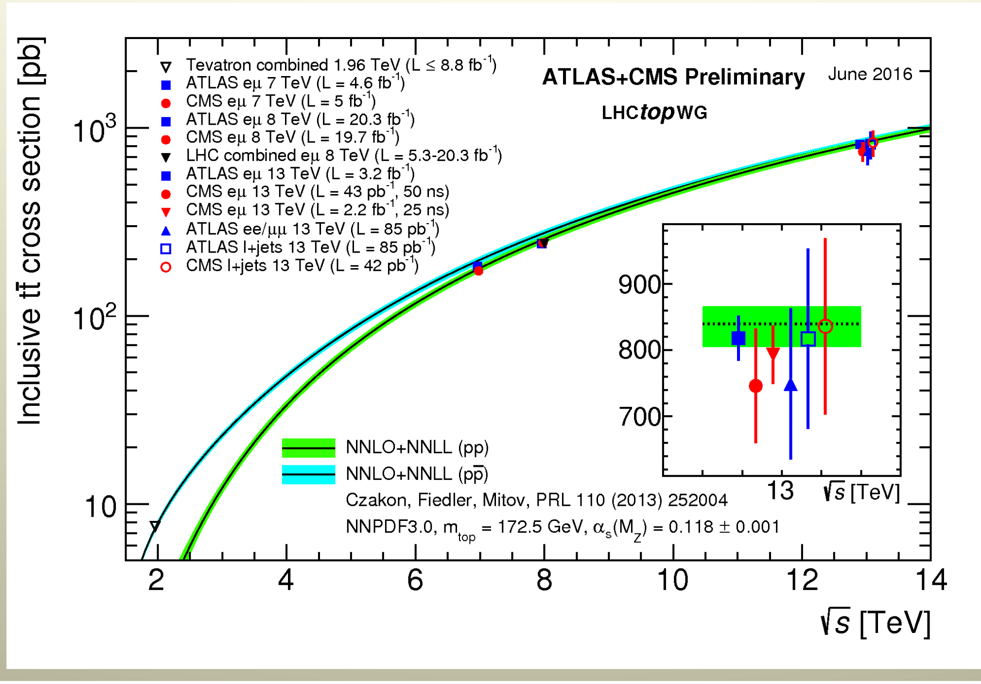


Top quark

- Heaviest of the known fundamental particle
  - its Yukawa coupling ~ 1.
- At LHC ,with luminosity ~10^{34} cm^{-2} s^{-1} top pair production rate is ~ 8 pairs/s
  - Definitely LHC is a "top factory"
- It decays before hadronisation
  - its properties are transferred directly to its decay products (information on "bare quarks")
- Standard model predicts all its properties given the mass
  - Any deviation means "new physics"
  - Top dominates also Higgs production (through gluon fusion)
  - ttH coupling studied also in ttH production

Top pair production cross-section

- Recent measurement using opposite sign eμ events with b-tagged jets @ 13 TeV
- Inclusive top pair production in good agreement with NNLO prediction
- Experimental measurements have reached the theoretical calculation



arXiv:1606.02699

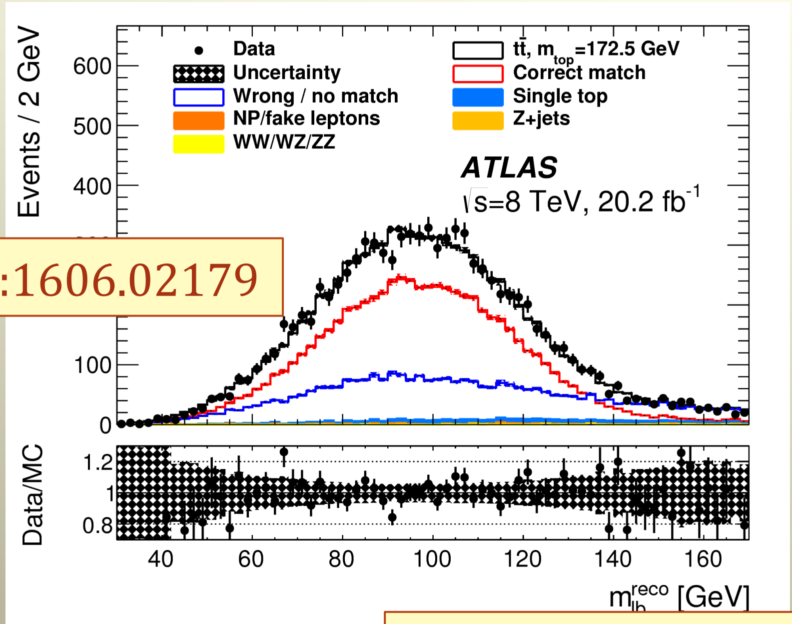
$$\sigma_{t\bar{t}} = 818 \pm 8\,(\mathrm{stat}) \pm 27\,(\mathrm{syst}) \pm 19\,(\mathrm{lumi}) \pm 12\,(\mathrm{beam})\ \mathrm{pb}$$

Top quark mass

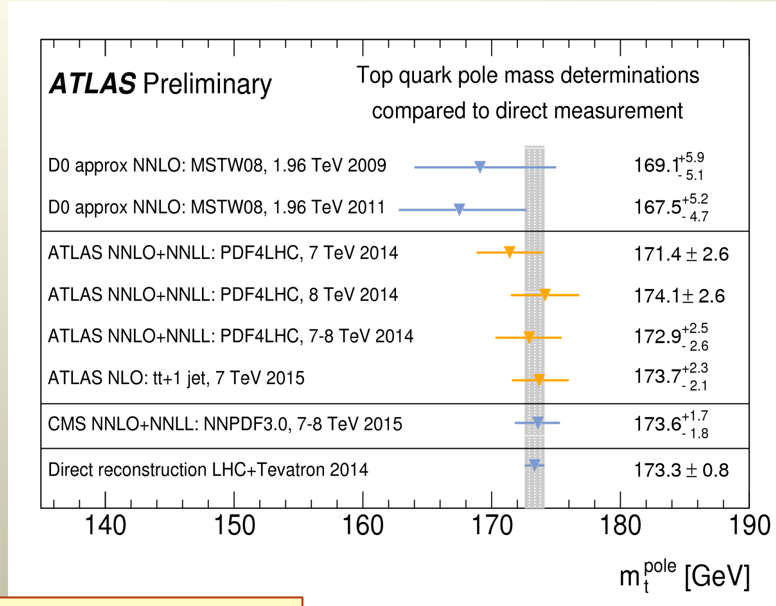
- Measured both directly from invariant mass and derived from cross section (mass pole determination)

Recent meas. from tt->dilepton @ 8 TeV

arXiv:1606.02179



Mass pole detemination

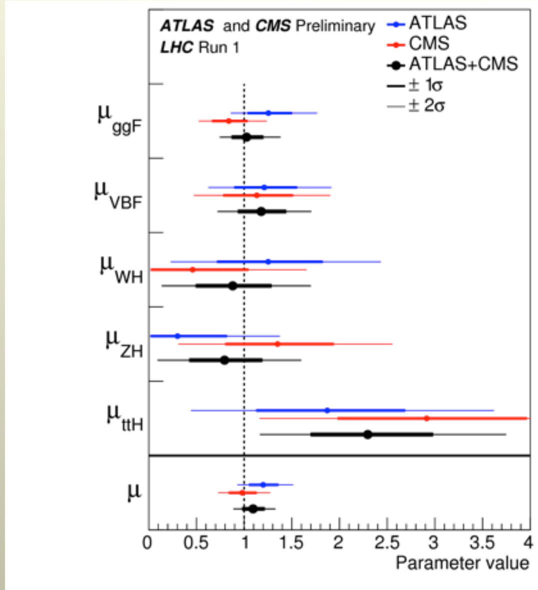


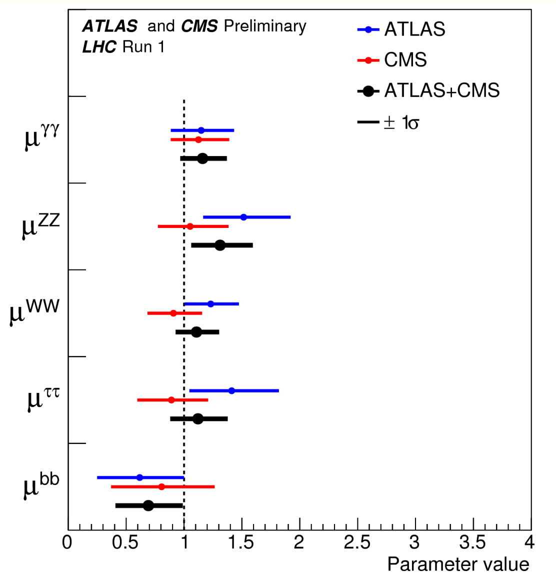
ATLAS combined direct measurement

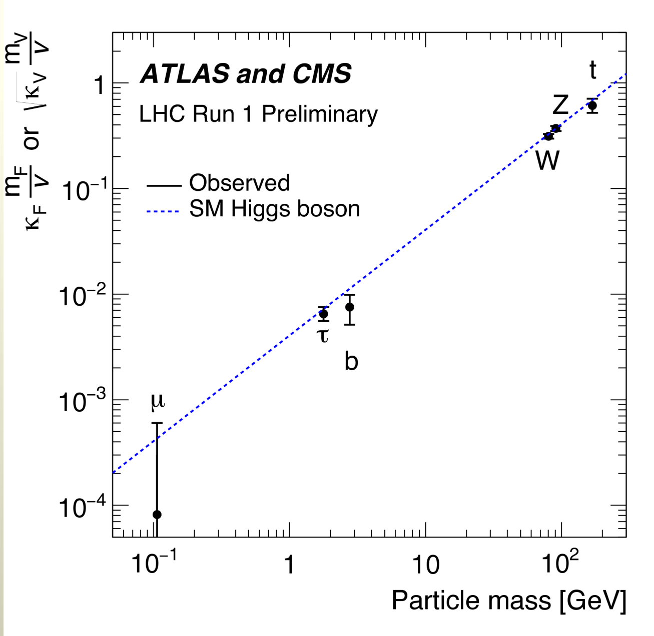
$$m_{top} = 172.84 \pm 0.34(stat.) \pm 0.61(syst.)\ \text{GeV} = 172.84 \pm 0.70\ \text{GeV}$$

Higgs Strength and couplings

- Combined ATLAS and CMS study with RUN I data







Assuming SM decay rates

$$\mu_i = \frac{\sigma_i}{\sigma_{i(SM)}}$$

Assuming SM production rates

$$\mu^f = \frac{BR^f}{BR^f_{(SM)}}$$

ATLAS-CONF-2015-044

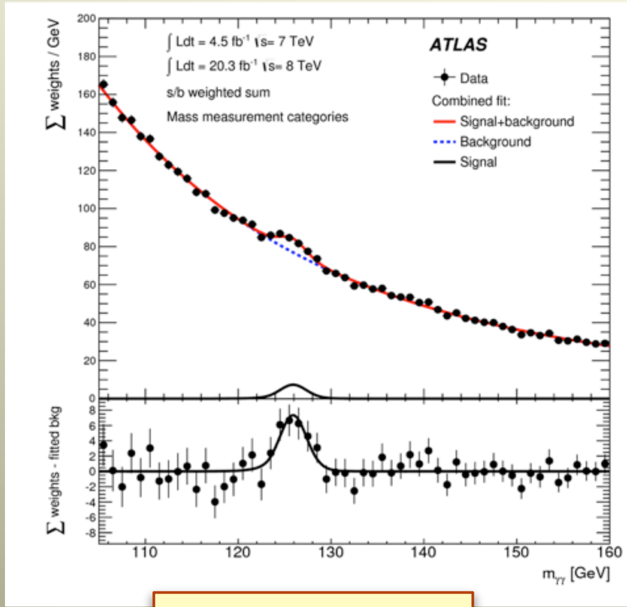
global fit to data

$$\mu = 1.09^{+0.11}_{-0.10} = 1.09^{+0.07}_{-0.07}\ (\text{stat})\ ^{+0.04}_{-0.04}\ (\text{expt})\ ^{+0.03}_{-0.03}\ (\text{thbgd})^{+0.07}_{-0.06}\ (\text{thsig})$$

Higgs Strength (RUN I legacy)

- Signal strength defined as ration between measured cross section and SM cross section.
- Dominant uncertainties:
  - photon energy scale (H->γγ) and statistic (H->ZZ*->4l)

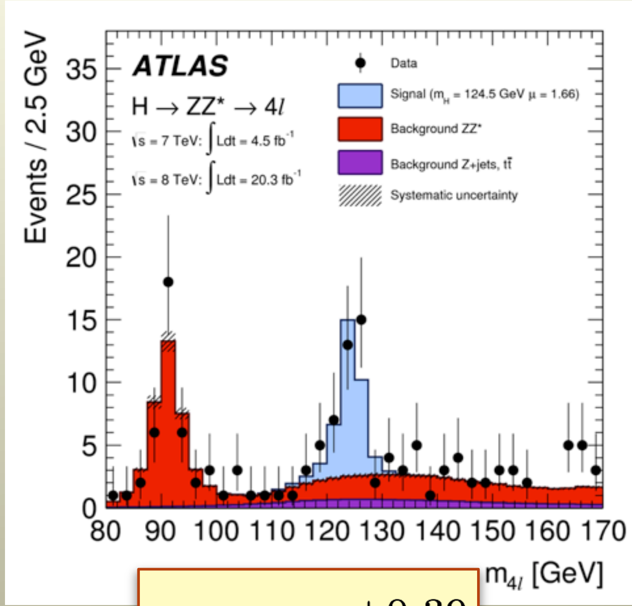
H -> γγ (BR = 0.23%)



$$\mu = 1.17^{+0.27}_{-0.27}$$

$$\mu = \frac{\sigma_{Meas}}{\sigma_{SM}}$$

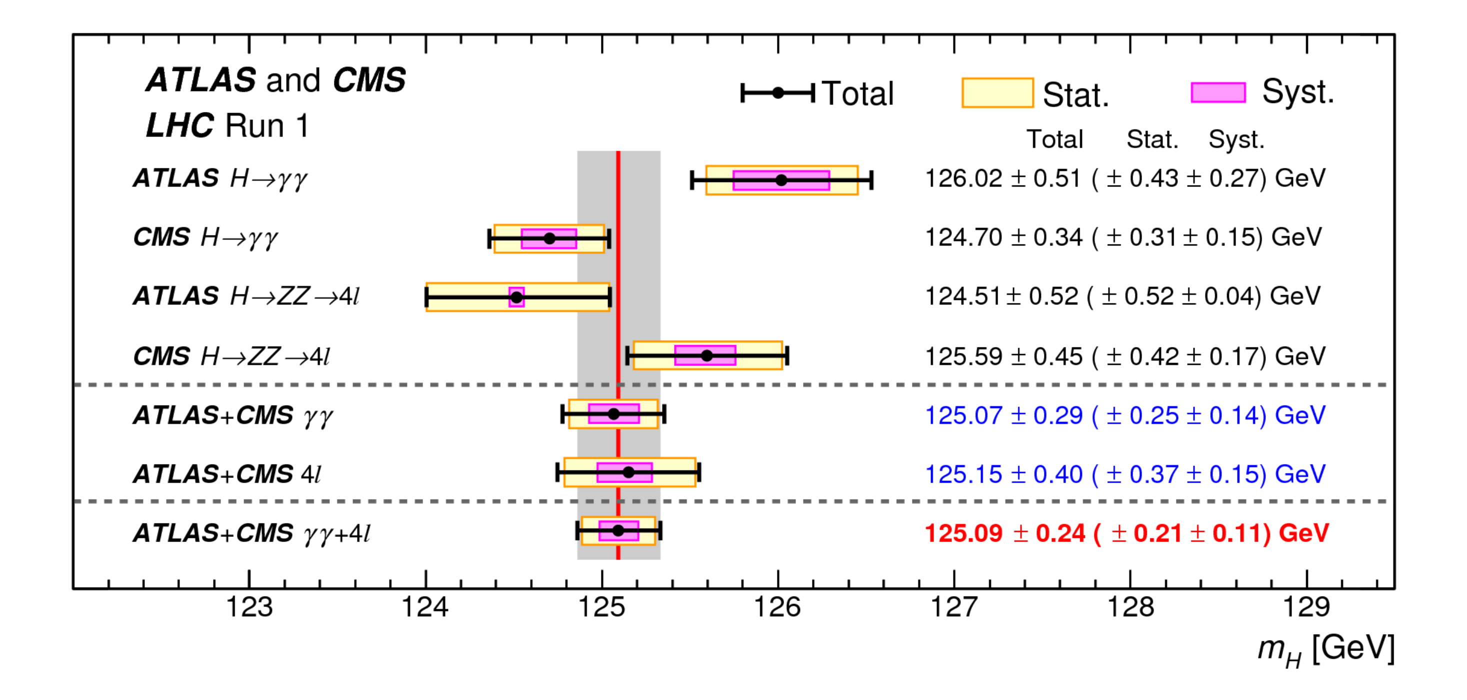
H –> ZZ* -> 4l (e,μ) (BR = 0.013%)



$$\mu = 1.51^{+0.39}_{-0.34}$$

Higgs mass

- Dominated by H->γγ and H->ZZ*->4l channels
- Precision of 240 MeV still dominated by statistic uncertainty

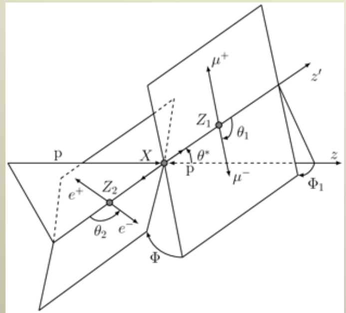


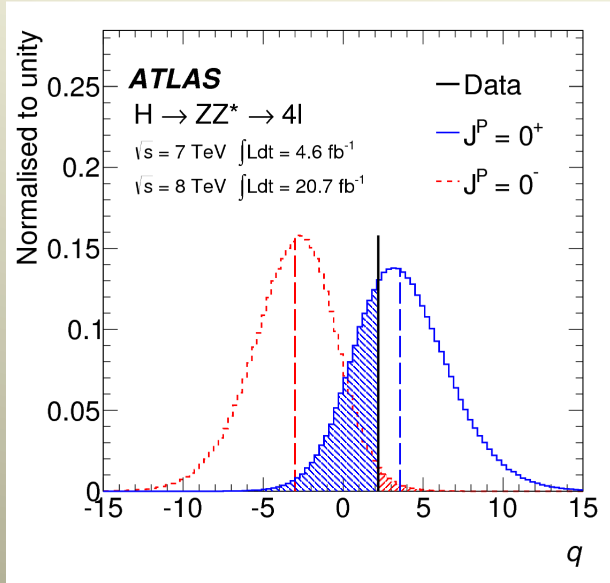
PhysRevLett114(2015)191803

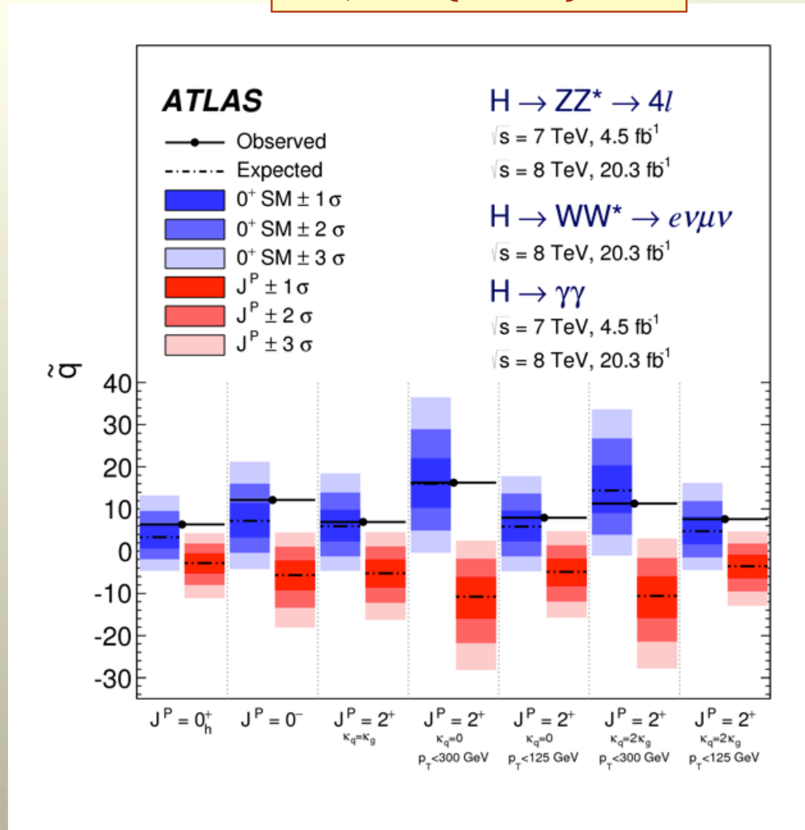
Higgs Spin & Parity

- Studying angular variable distributions in Higgs decay products in bosonic decays several hypothesis on H(125) spin and parity can be tested
- Consistency with SM J=0+ hypothesis
- All others excluded at 99% CL

EPJC75(2015)476

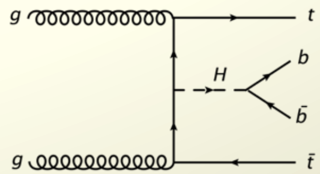


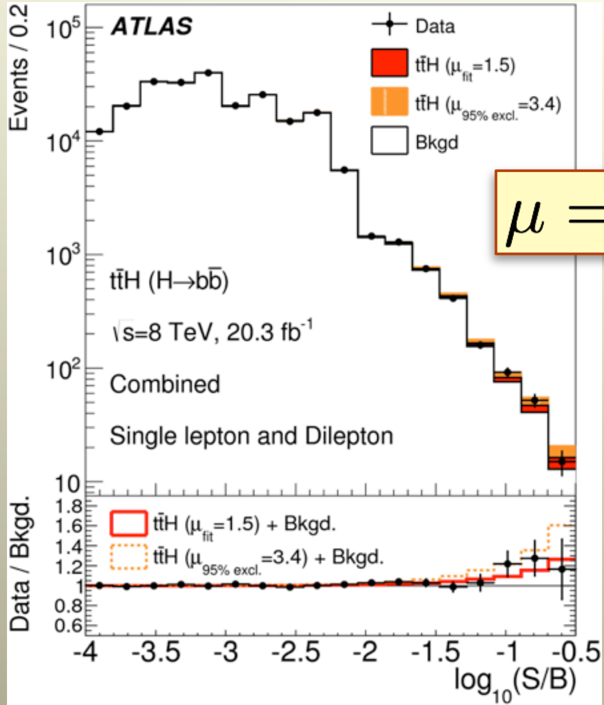




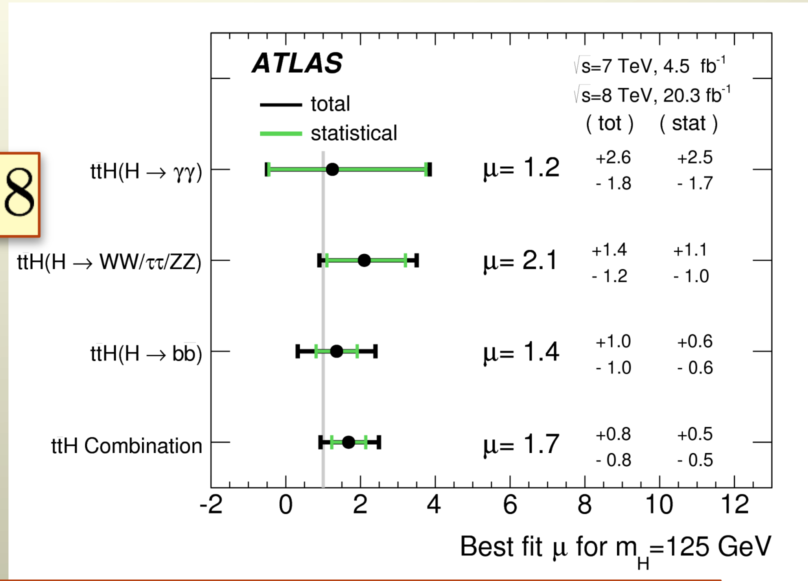
Higgs ttH production: ttH coupling

- H coupling to top quarks "seen" in gluon fusion process, and loop in $\gamma\gamma$ decays
- important to probe directly for model independent determination of coupling





$$\mu = 1.6 \pm 0.8$$



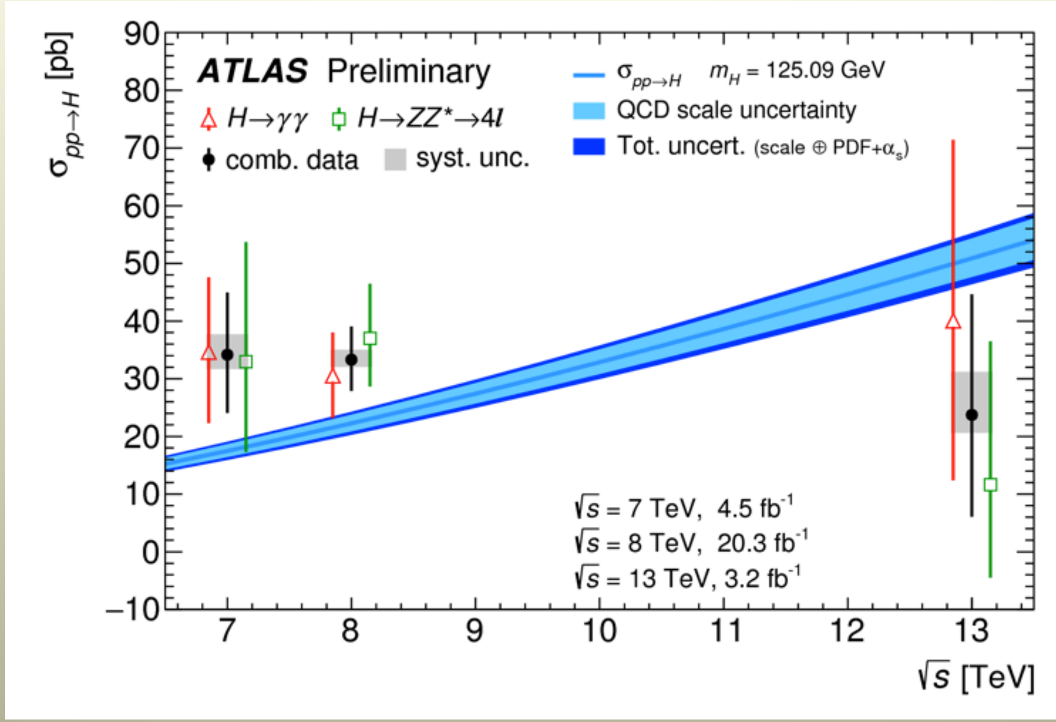
upper limit 95% CL 3.1 (1.4 exp)

EPJC75(2015)349

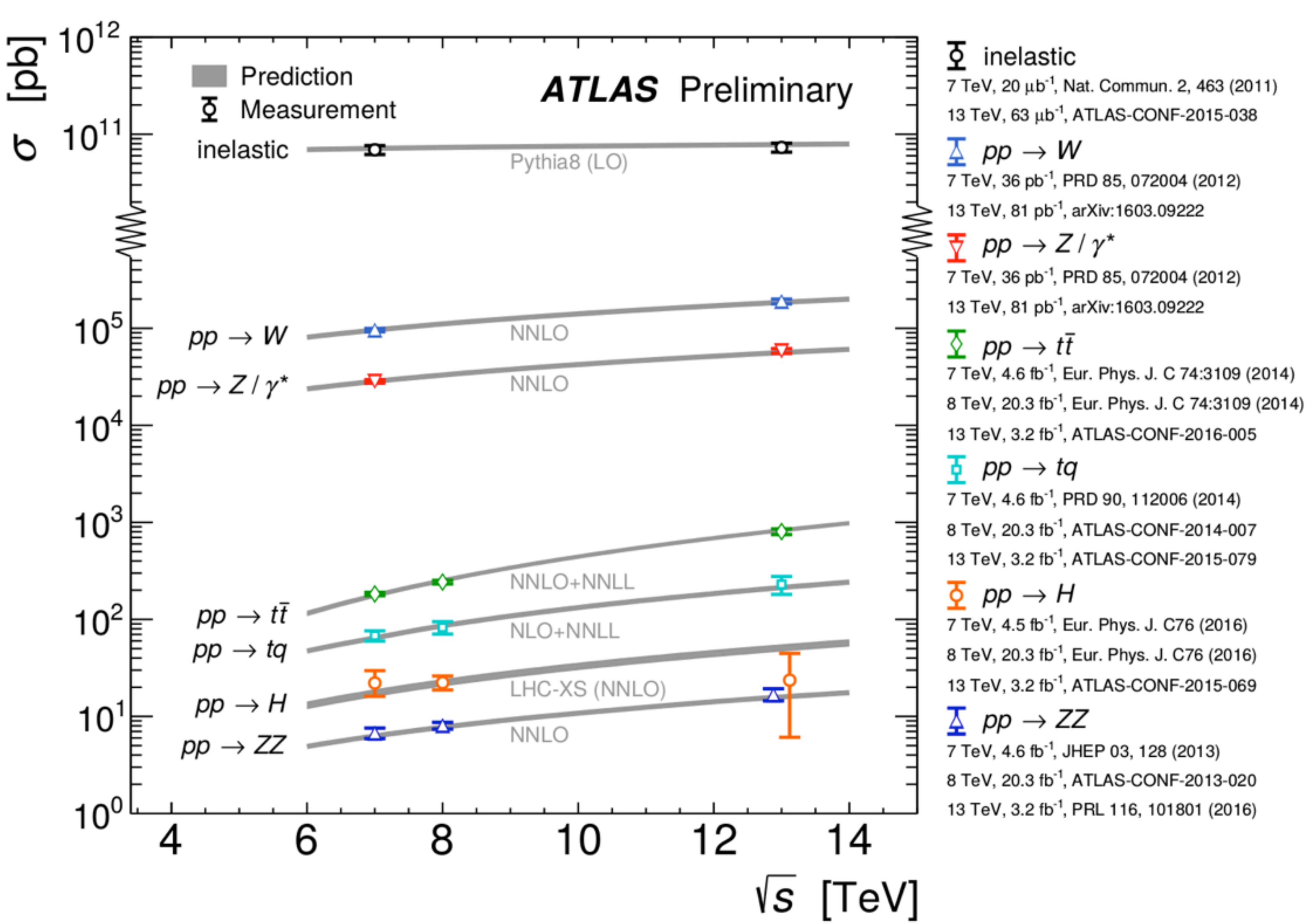
JHEP 05 (2016) 160

First look at Higgs @ 13 TeV

- 2015 13 TeV data (3.2 fb^{-1}) 13 TeV are not enough to reach run 1 sensitivity for H(125)
- Cross section @ 13 TeV is almost doubled w.r.t. 8 TeV



Summary of SM Measurements



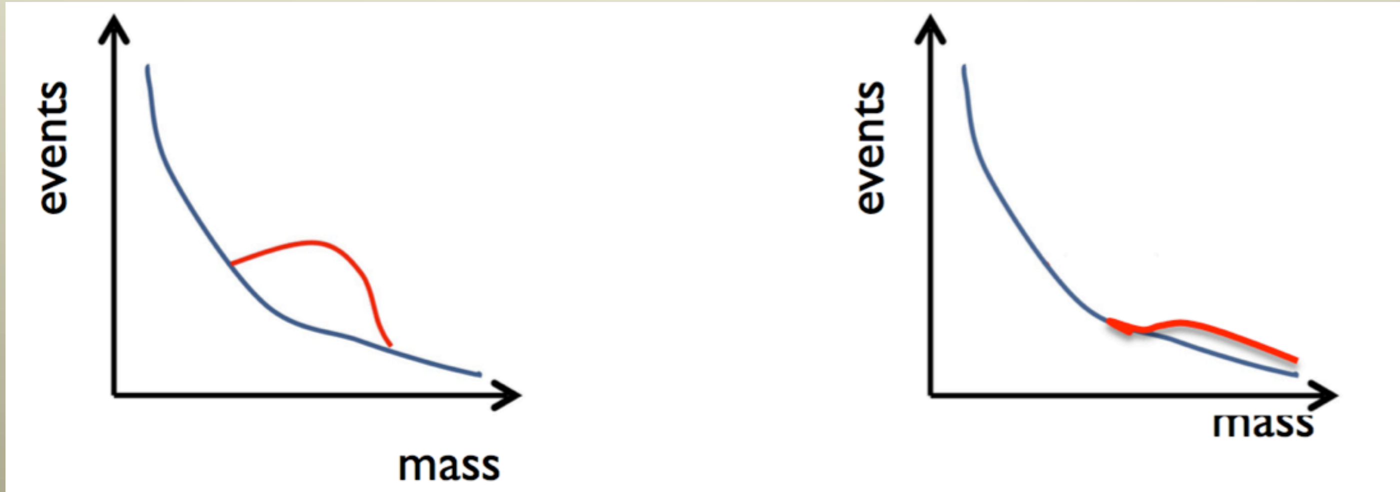
ATLAS BSM Searches

- ATLAS has a very large portfolio of results about beyond Standard Model Searches
  - SUSY Searches
  - Higgs BSM
  - Exotics
- In the next slides some highlights with emphasis on 13 TeV results or recently published Run1 results
  - Search for new Resonances
  - Search for Supersymmetric Particles
  - Search for BSM in Higgs sector
  - Search for Dark Matter

Search for new resonances

- Could manifest themselves
  as "peak" (resonance) or as broad "shoulders"
  in invariant mass spectra of dijets, dilepton, diphotons.

- Two approaches to estimate of SM background:
  - detailed simulations of shape of mass spectrum
  - smooth functional form fitted to data



Di-photons final state

- Several SM extensions predict high-mass states decaying to two photons

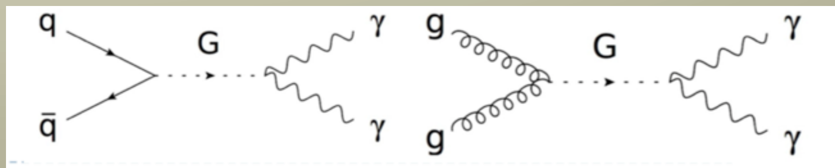
SPIN 0
Extended Higgs Sector

- Example: 2HDM
  - 5 phys. states $h^0, H^0, A^0, H^\pm$
  - under certain conditions, scalar and/or pseudo-scalar states can have sizeable BR→di-photons

ATLAS-CONF-2016-018

SPIN 2
Randall-Sundrum graviton

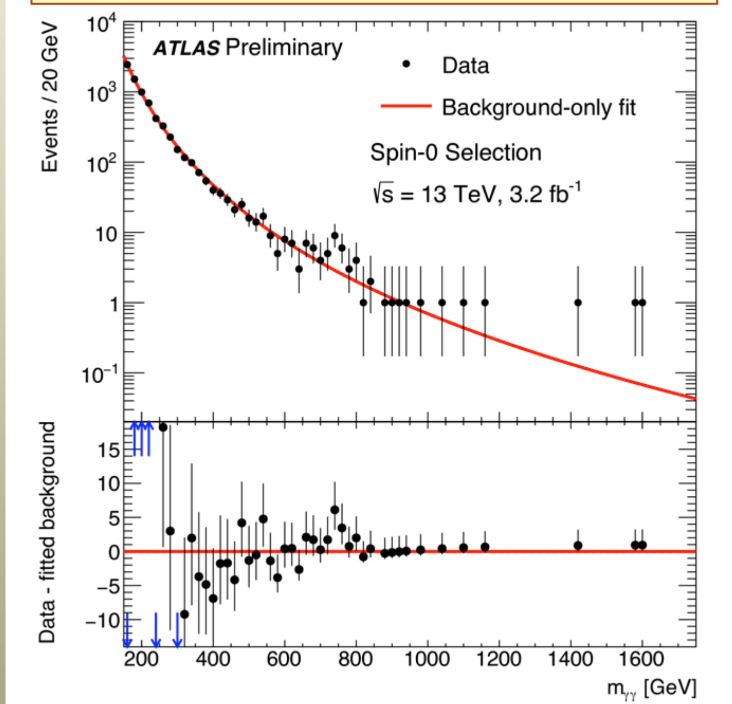
- Tower of Kaluza-Klein (KK) graviton excitations;
  - first state at TeV mass scale
- Phenomenology:
  - MG* = mass of lightest KK excitation
  - κ/M_{Pl} = dimensionless coupling to SM fields



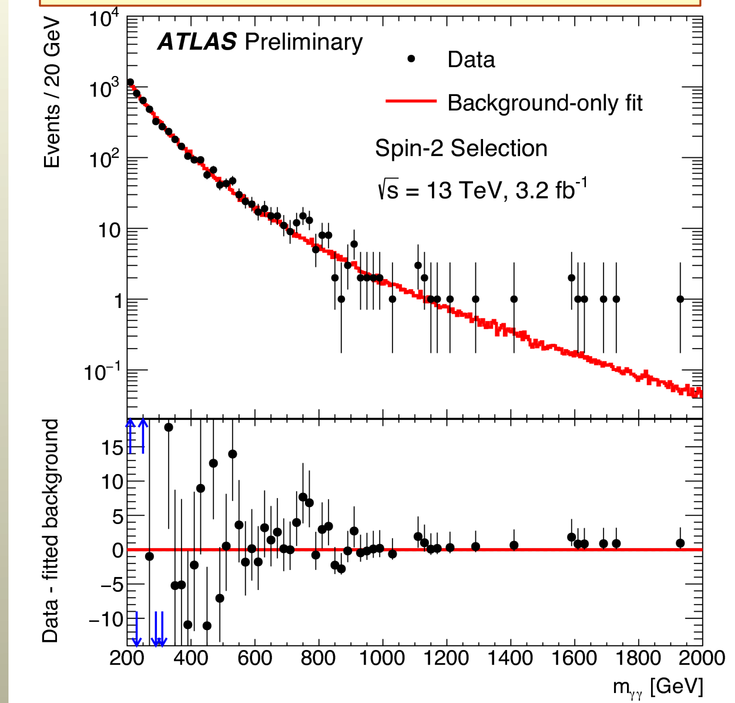
Diphoton: Search for resonance

- Selection optimised for Higgs- like signal:
  - two Photons (tight identification and isolated)
  - Different cut on photons for different analysis
- Background model: detailed shape prediction from NLO SM di-photons;

SPIN 0

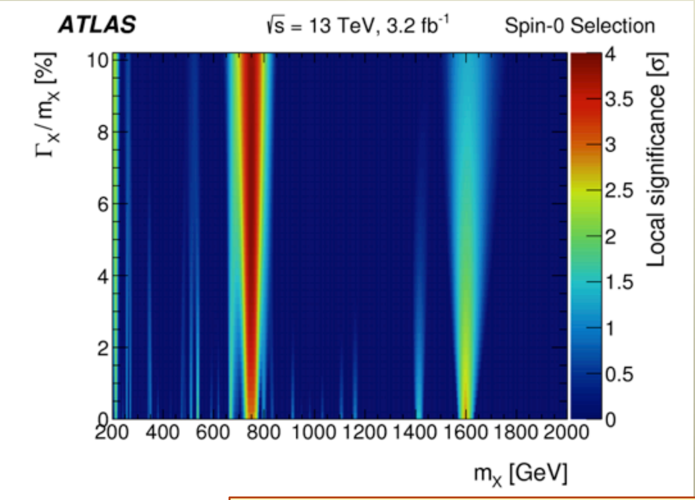


SPIN 2

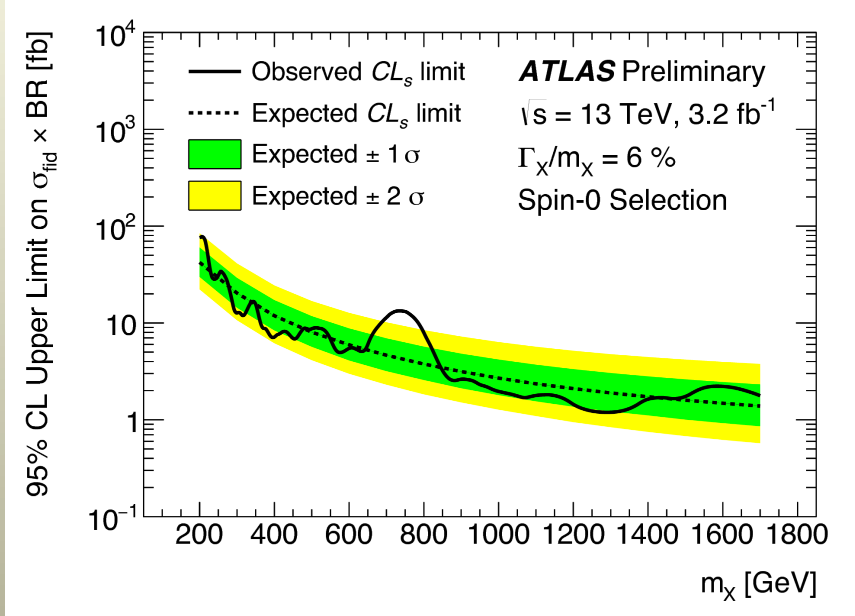


Diphoton: Results for spin-0 resonance

- Perform 2D p_0 scan (as function of mass and width of the hypothetical resonance).
- Largest deviation from background-only hypothesis:
  near:
  - 750 GeV
  - width ≈ 45 GeV (i.e. 6%)
- Local significance: 3.9 σ (Global : 2.0 σ)



- Limits on fiducial cross section as a function of mass hypothesis, for several width hypotheses.
- Example shown here: width of 6%



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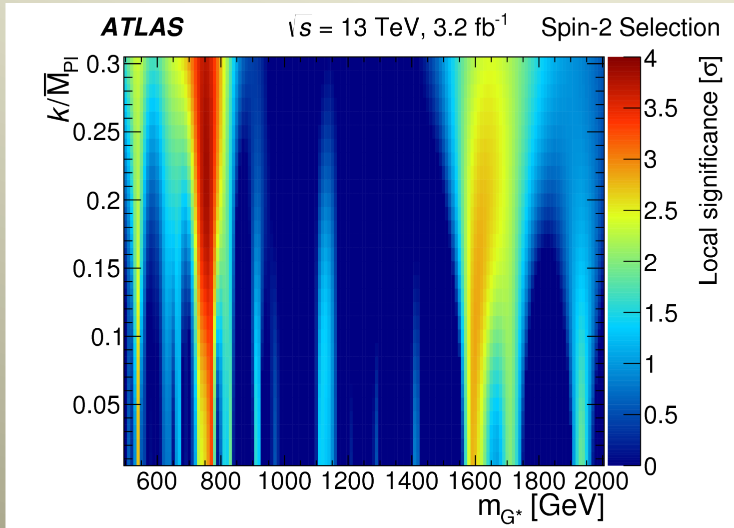
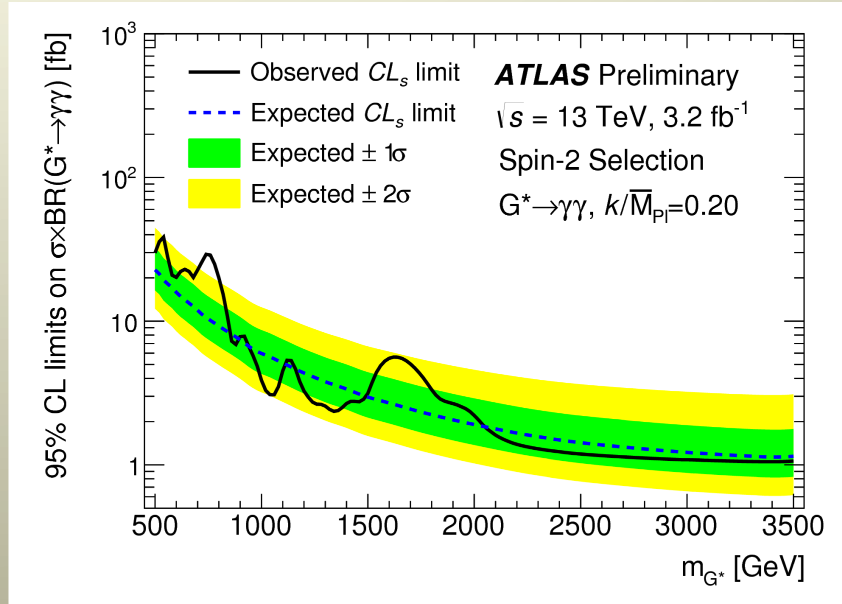
Diphoton: results for spin-2 resonance

- Perform 2D p0 scan (as function of mass and width [i.e. coupling] of the hypothetical resonance).
- Largest deviation from background-only hypothesis:
  near:
  - κ/MPl ≈ 0.21 (i.e. 6% width)
- Local significance: 3.6 σ (Global : 1.8 σ)



- Limits on fiducial cross section as a function of mass hypothesis, for several width hypotheses.
- Example shown here: $\kappa/M_{Pl} \approx 0.20$



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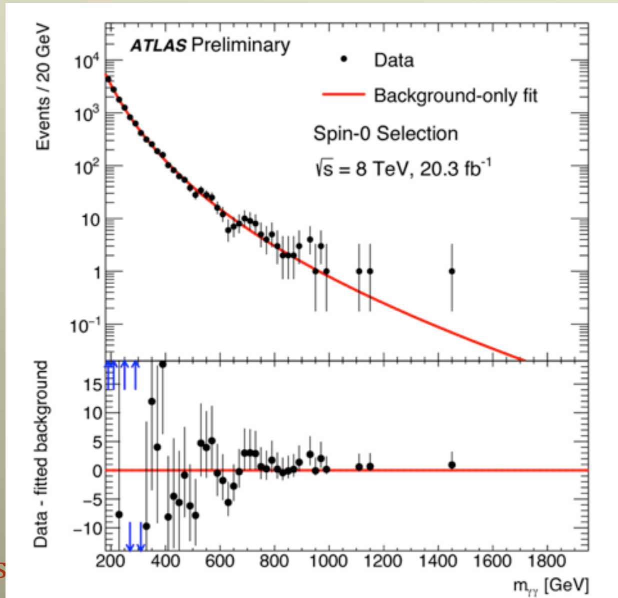
Diphoton compatibility to 8 TeV data

SPIN 0	SPIN 2

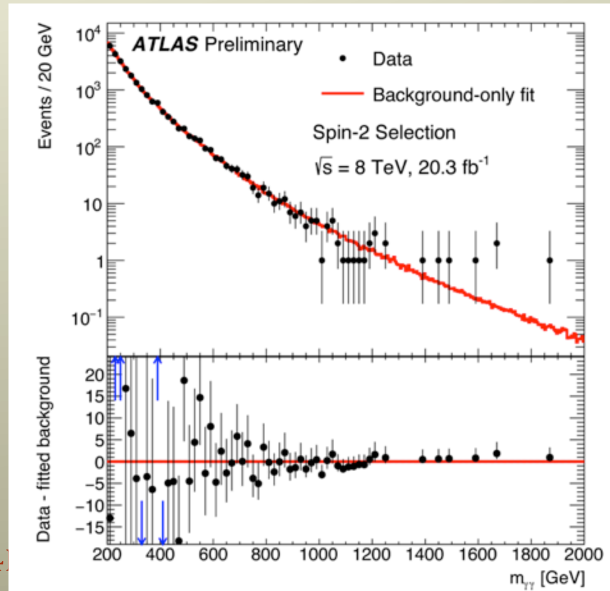
SPIN 0

- 8 TeV data: 1.9 σ deviation from bkg-only hypothesis at m_X = 750 GeV, Γ_X/m_X = 6%
- Compatibility 8 TeV ↔ 13 TeV (gg hypothesis): 1.2 σ
- Compatibility 8 TeV ↔ 13 TeV (qq hypothesis): 2.1 σ



SPIN 2

- 8 TeV data: no excess in the region of interest
- Compatibility 8 TeV ↔ 13 TeV (gg hypothesis): 2.7σ
- Compatibility 8 TeV ↔ 13 TeV (qq hypothesis): 3.6σ



Supersymmetry "for dummies"

- **SuSy is a generalization of the SM: symmetry between fermions and bosons**
  - Introduces sfermions and gauginos
    doubles particles content with respect to SM
  - Extended Higgs sector: h, H, A, H+, H-

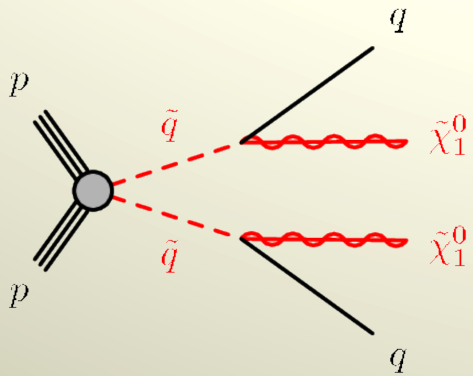
- PRO:
  - alleviates hierarchy problem ($m_h << m_P$)
  - has a good Dark Matter candidate(neutralino)
  - allows for gauge coupling unification

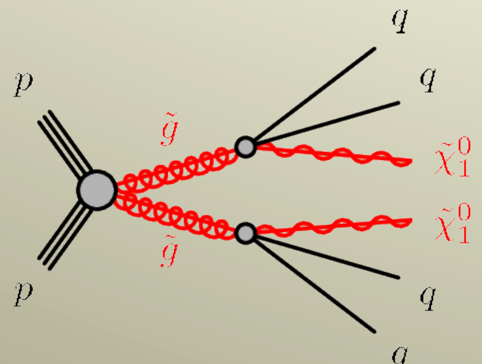
- CONS:
  - in MSSM over 100 free parameters (although with some both theoretical and experimental arguments we can reduce the number of parameters)
  - wide range of possible experimental signatures

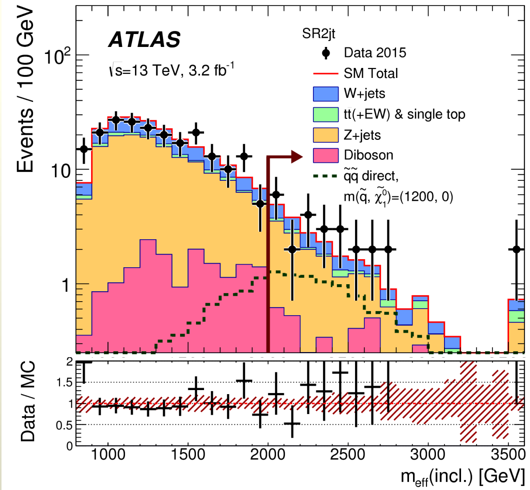
Something expected at TeV Scale

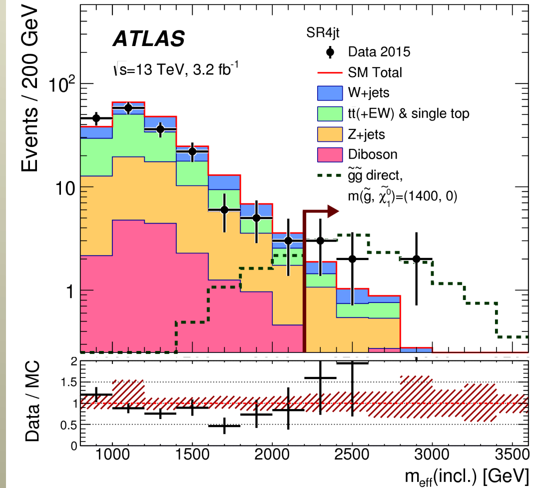
SUSY: gluino and squarks

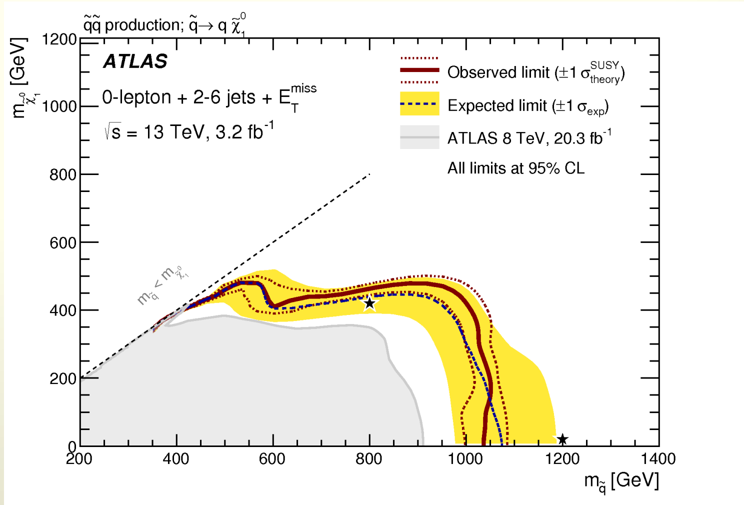
- Signature: 0 lepton + jets + E_T^{MISS}



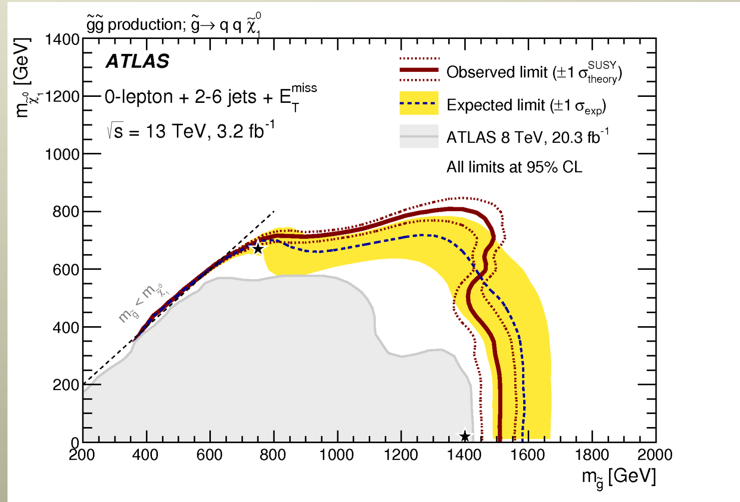








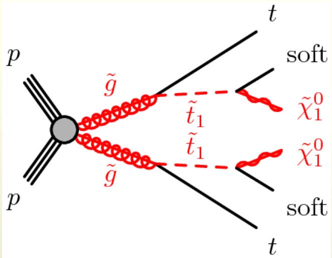
limits assuming simplified model

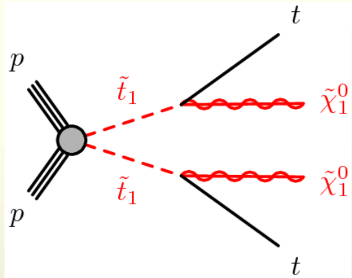


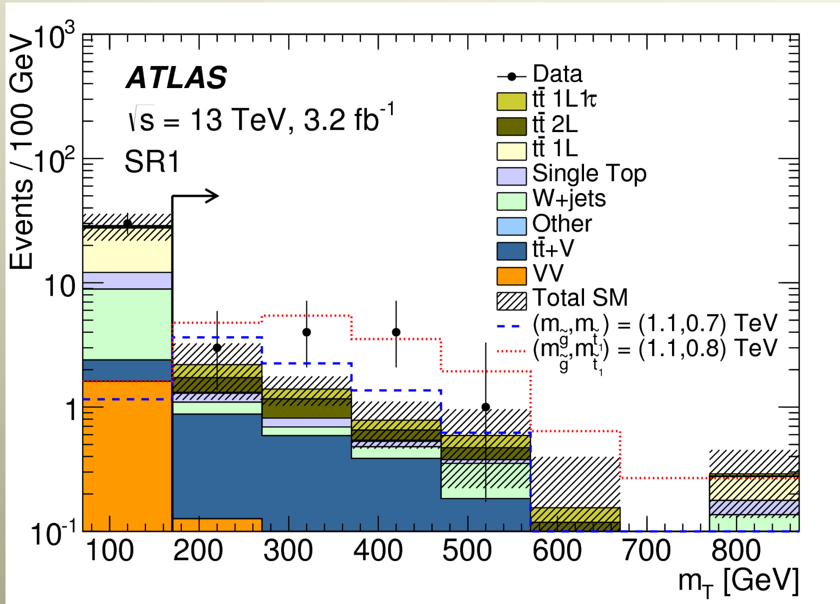
arXiv:1605.03814

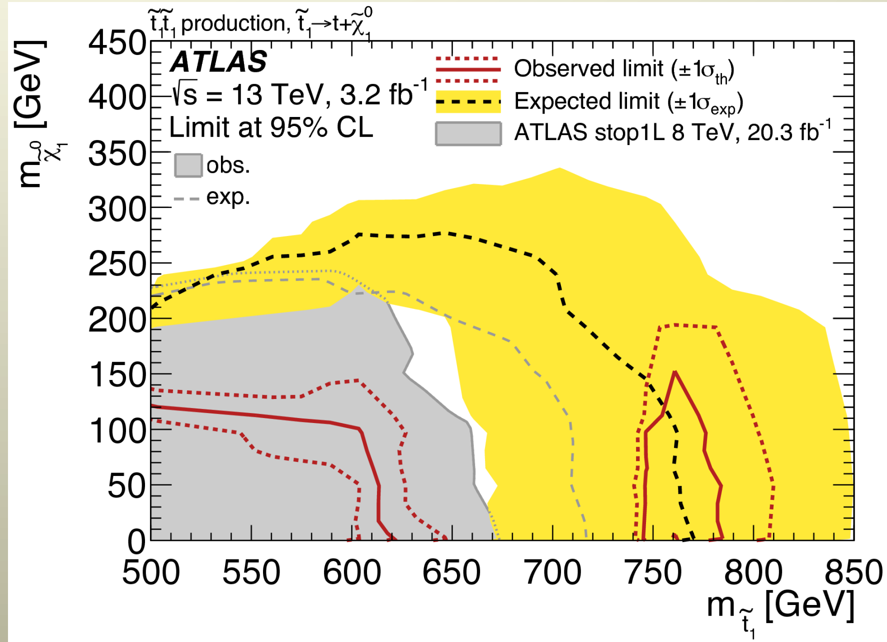
SUSY stop

- Signature: 1lepton + jets + E_T^{MISS}



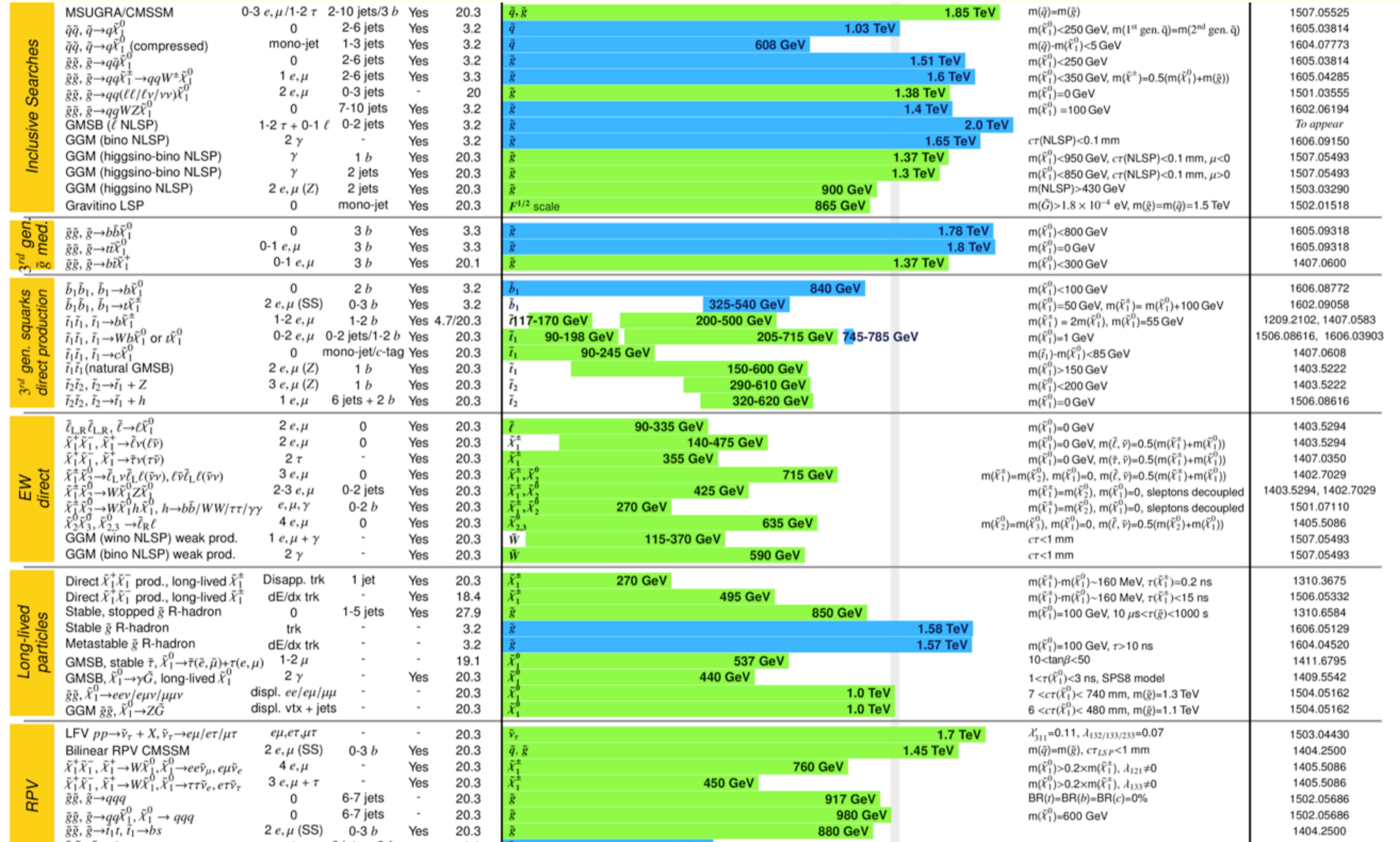






arXiv:1606.03903

SUSY current summary



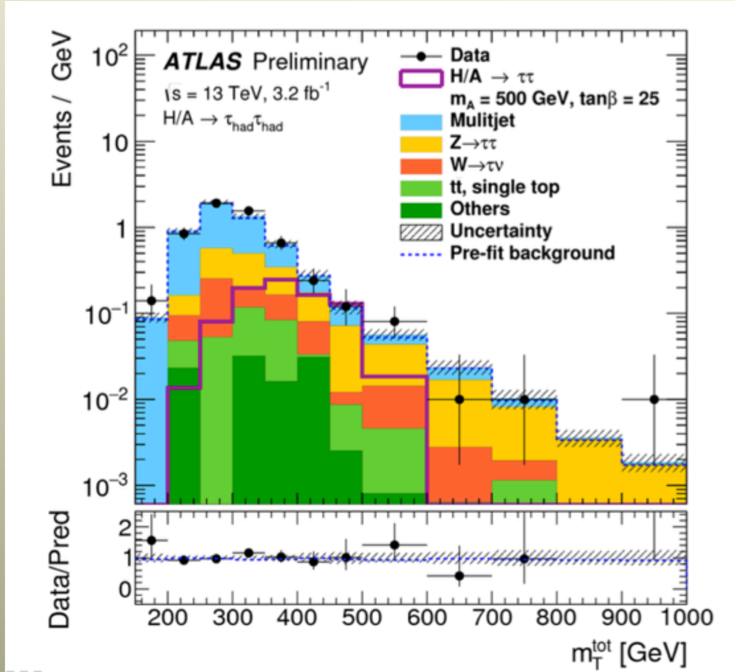
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults

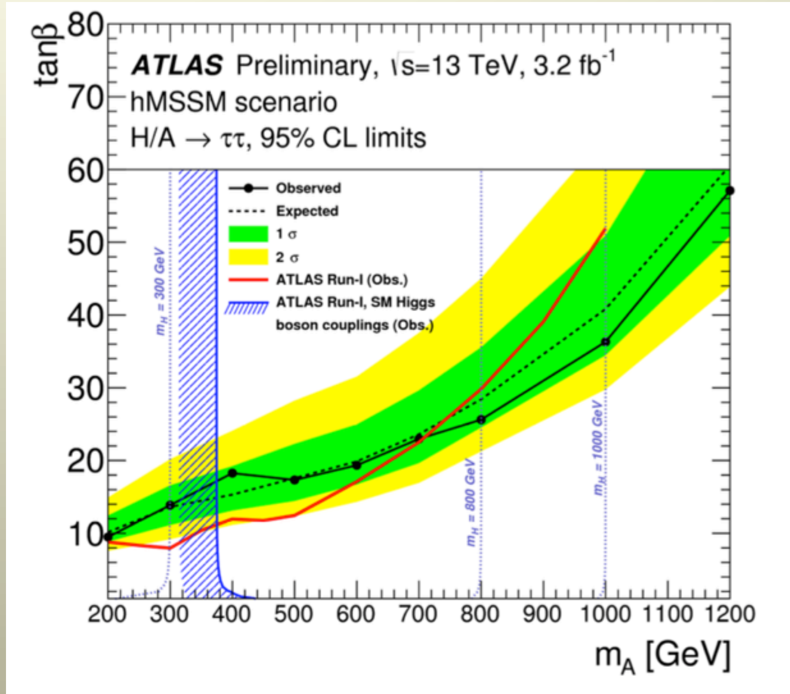
BSM Higgs: example H/A→ττ

ATLAS-CONF-2015-061

- Two channels: $\tau_{had}\tau_{had}$ and $\tau_{lep}\tau_{had}$
- Mainly backgrounds: Zττ (MC – datadriven) and multijets (datadriven)

$$m_T^{tot} = \sqrt{m_T^2(E_T^{miss},\tau_1) + m_T^2(E_T^{miss},\tau_2) + m_T^2(\tau_1,\tau_2)}$$

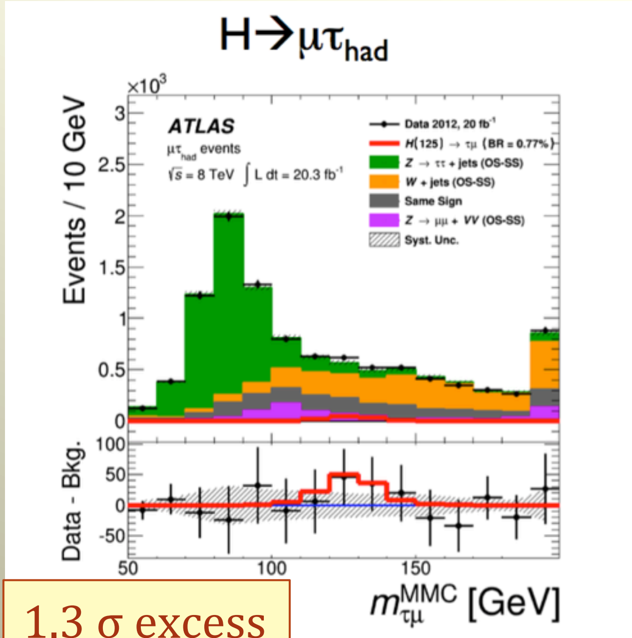




Lepton Flavour Violating Higgs decays

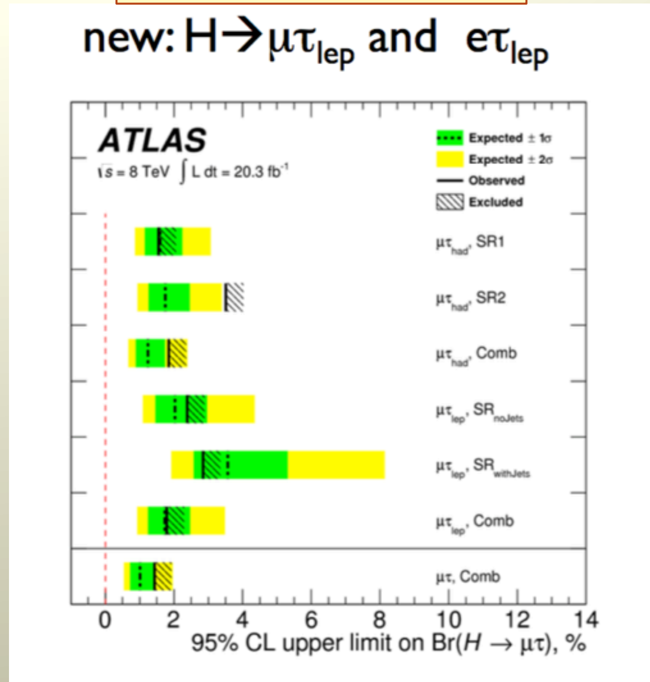
- Not allowed in SM but can occur in 2HDM and other models

JHEP11(2015)211



1.3 σ excess

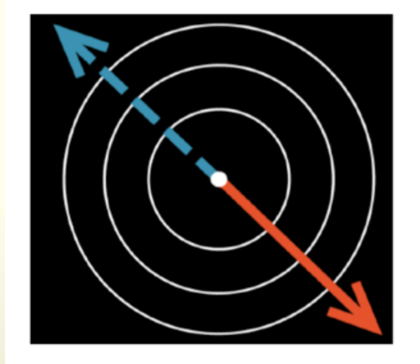
arXiv 1604.07730



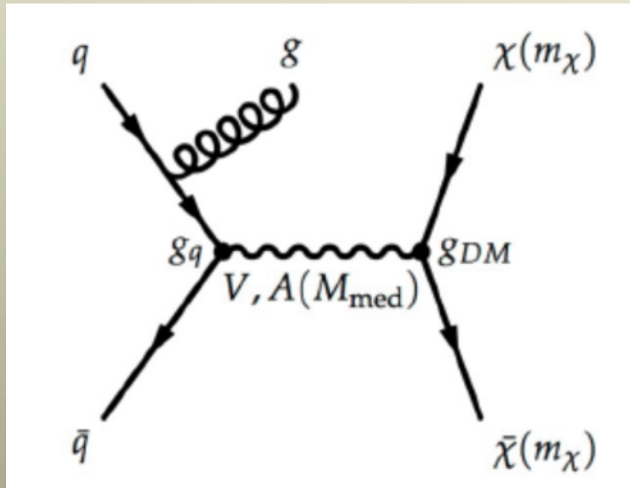
Combining both searches:

BR(H→τμ) < 1.43% BR(H→τe) < 1.04%

Dark Matter: Mono-X searches



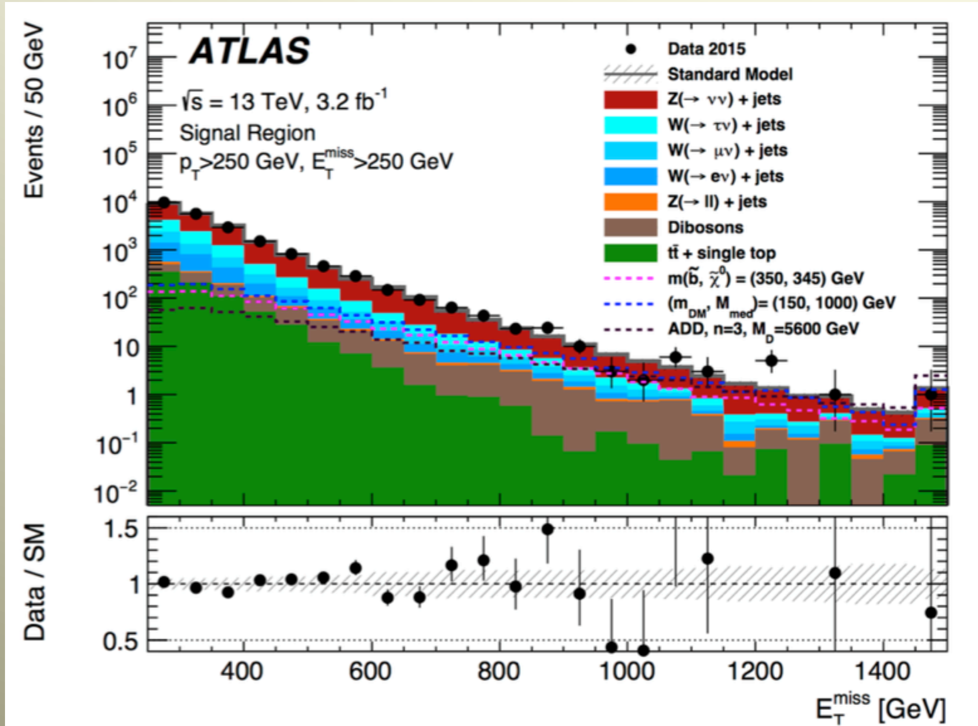
- **General analysis strategy**
  - Require MET
  - Select for X
  - Veto other objects
  - Additional cuts to suppress background
- Data-driven techniques to estimate background
  - invert vetoes



- **Results are interpreted in the Simplified Model framework to allow comparison with Direct Detection**
  - Mediator particle connects the SM quarks to DM particles: Axial Vector, Pseudoscalar, etc...
- Model depends on four parameters:
  - DM mass,
  - Mediator mass,
  - SM-mediator coupling,
  - DM-mediator coupling

Dark Matter: Monojets

- Main backgrounds:
  - EW processes with intrinsic E_{T}^{miss} + jets:
  - Z(νν)+jets: irreducible background
  - W(lν)+jets: with unrecostructed or misidentified lepton



- Both estimated from data using leptonic Z or W control regions
- **Other backgrounds:**
  - Non-collision background (data)
  - Multijet background (data)
  - Z->ee, top, diboson (MC)

NO EXCESS OBSERVED

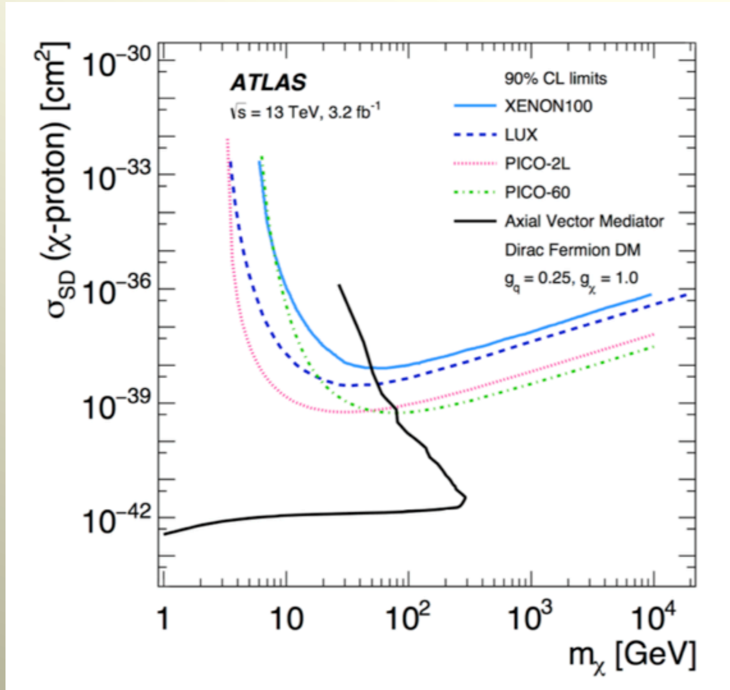
Dominant uncertainties:
Statistical (3-10%),
top (~3%),
boson+jet modeling (2-4%)

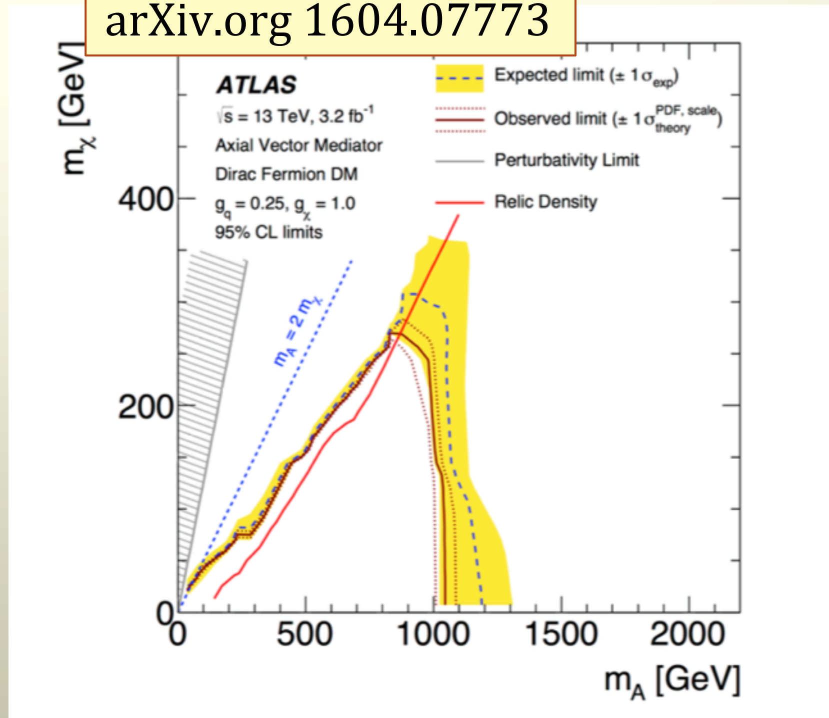
arXiv.org 1604.07773

Dark Matter: Monojets

- Area under the limit is excluded: for m_{med} < 1TeV,mχ < 250 GeV

arXiv.org 1604.07773

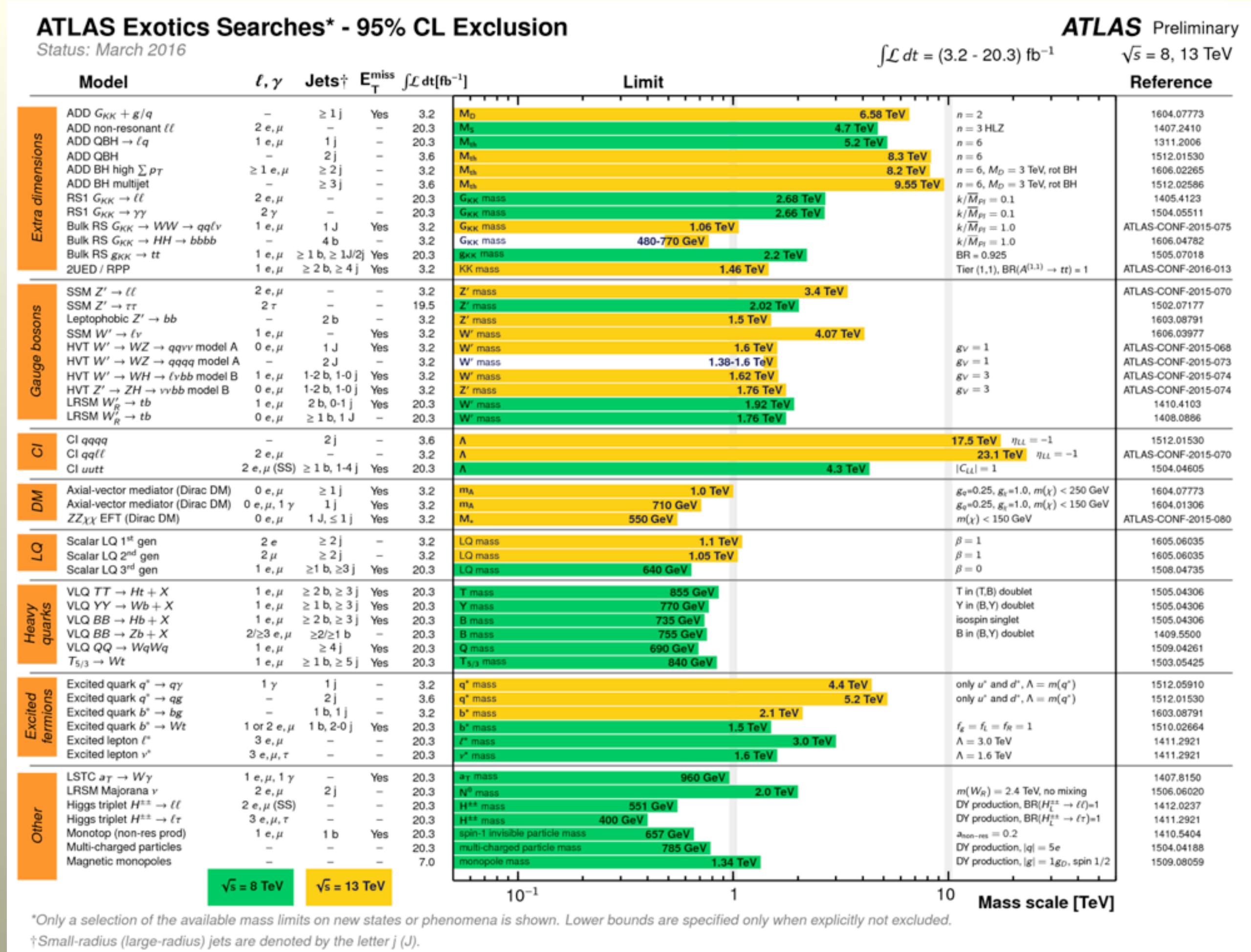




- Translate to 90% CL exclusion limit on the spin-dependent χ-p scattering σSD
- Complementary to direct searches: excluded σSD (χ-p) > 10^{-42}cm², low mχ

Summary of exotic searches

- https: //twiki. cern. ch/twiki/bin/view/ AtlasPublic/ WebHome



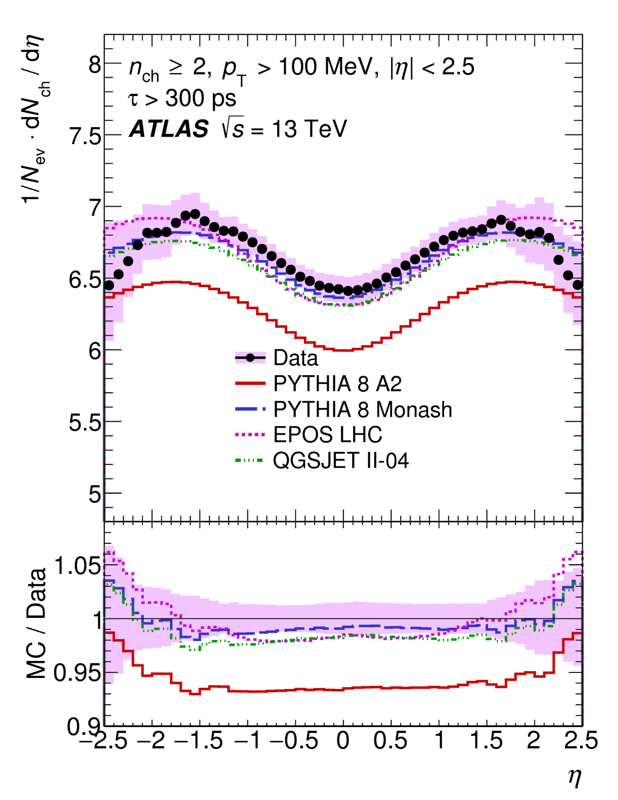
Conclusions

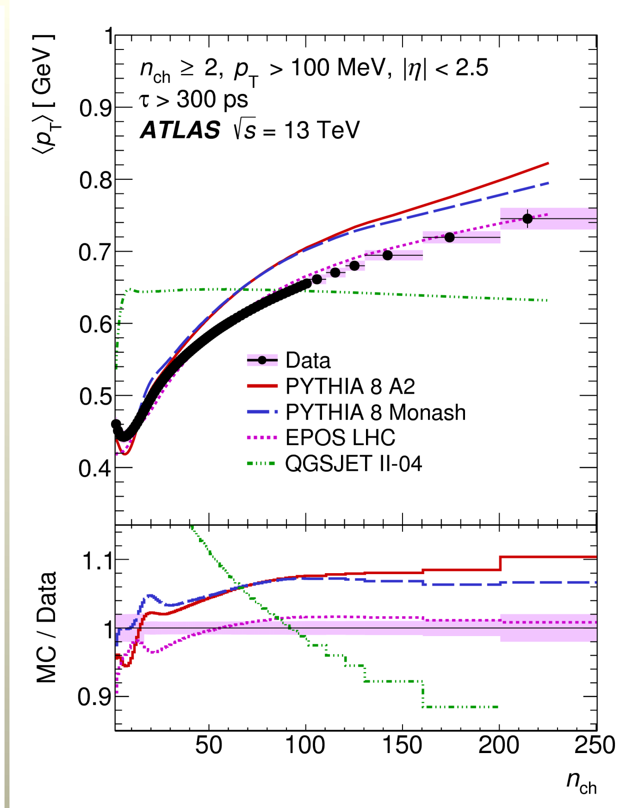
- ATLAS has published to date more than 500 physics papers; here I presented just a tiny fraction of our results
  - (see ATLAS Public Results)
- Run 1 legacy data are (still become) available.
- Many results from 2015 13 TeV run are provided.
  - The detector performed well
  - Increased sensitivity for high mass BSM searches
- High expectation from 2016 Run (25 fb-1 expected)
  - i.e. Confirm or deny Diphoton excess
- LHC plan is to take data in 2016, 2017 and 2018 at full steam before another long shutdown period to collect 100 fb-1

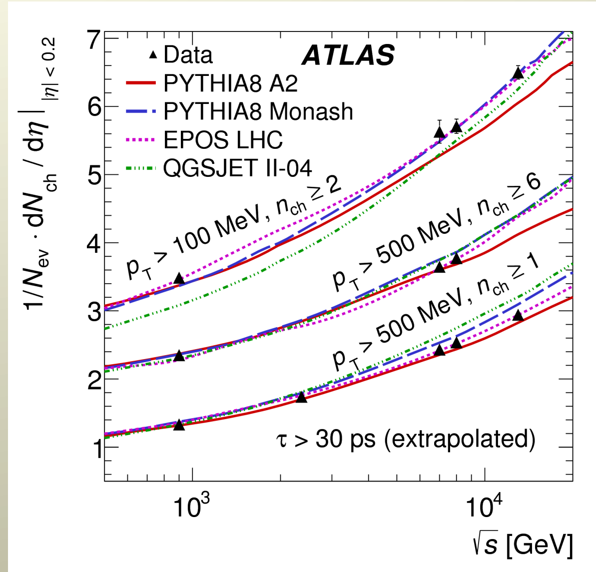
Backup slides

Multiplicity

- Events with al least two charged particle with pT > 100 MeV and eta<2.5, each with a lifetime >300 ps are considered





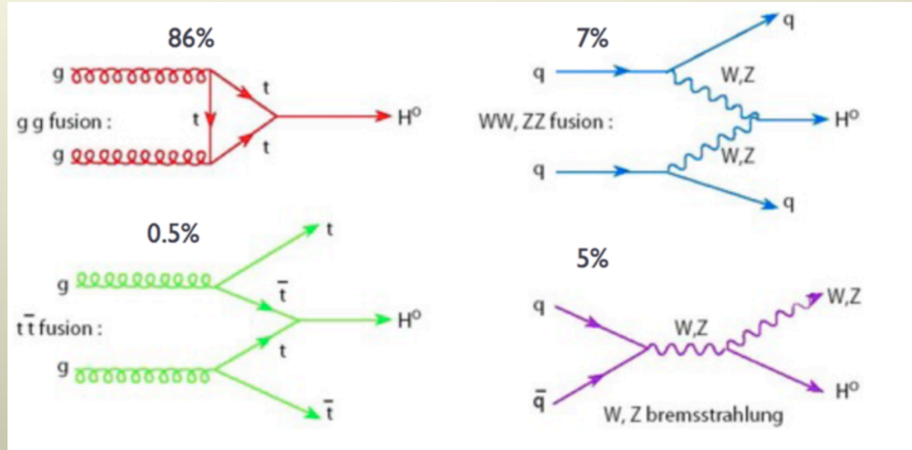


arXiv:1606.01133

Higgs boson & decay modes

- Total cross section @ 13 TeV is doubled with respect to RUN I data.

Production process	Cross section [pb] $\sqrt{s} = 7$ TeV	Cross section [pb] $\sqrt{s} = 8$ TeV
ggF	15.0 ± 1.6	19.2 ± 2.0
VBF	1.22 ± 0.03	1.57 ± 0.04
WH	0.573 ± 0.016	0.698 ± 0.018
ZH	0.332 ± 0.013	0.412 ± 0.013
bbH	0.155 ± 0.021	0.202 ± 0.028
ttH	0.086 ± 0.009	0.128 ± 0.014
tH	0.012 ± 0.001	0.018 ± 0.001
Total	17.4 ± 1.6	22.3 ± 2.0

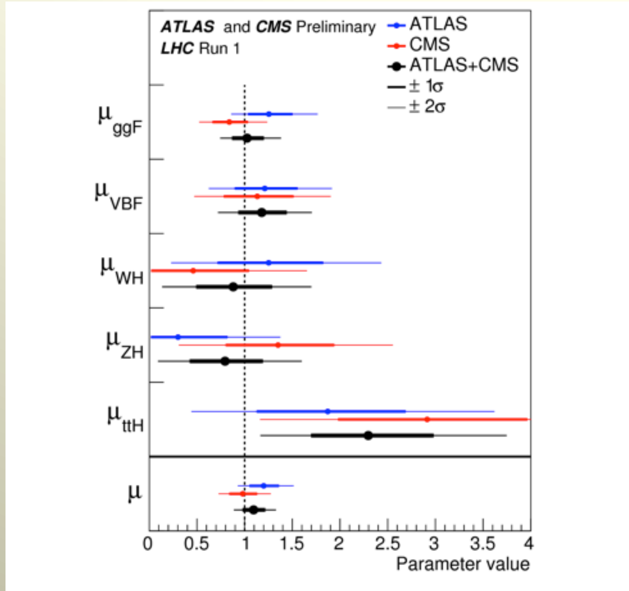


$$\sigma_{tot}(13\ \text{TeV}) = \sim 2\sigma_{tot}(8\ \text{TeV})$$

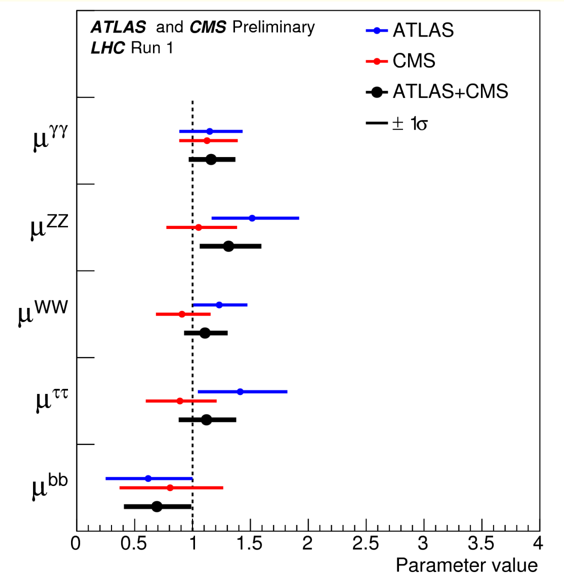
Higgs Strength

- Combined ATLAS and CMS study with RUN I data

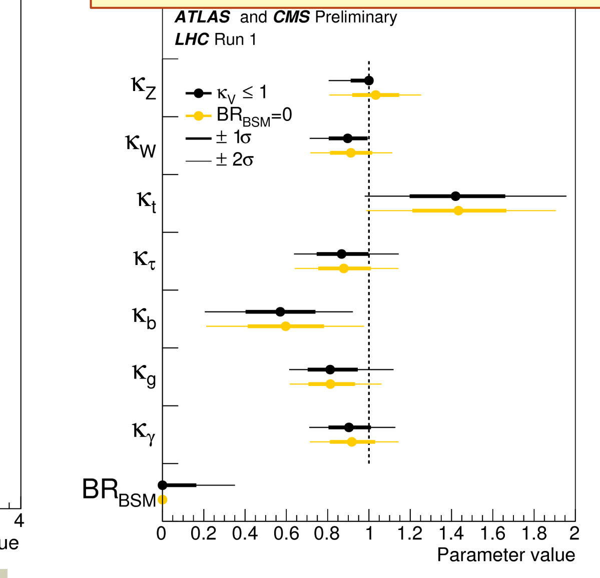
ATLAS-CONF-2015-044



Assuming SM decay rates



Assuming SM production rates



Test BSM loops and decay
Two models:
k_V <1 or BR(H->BSM)=0

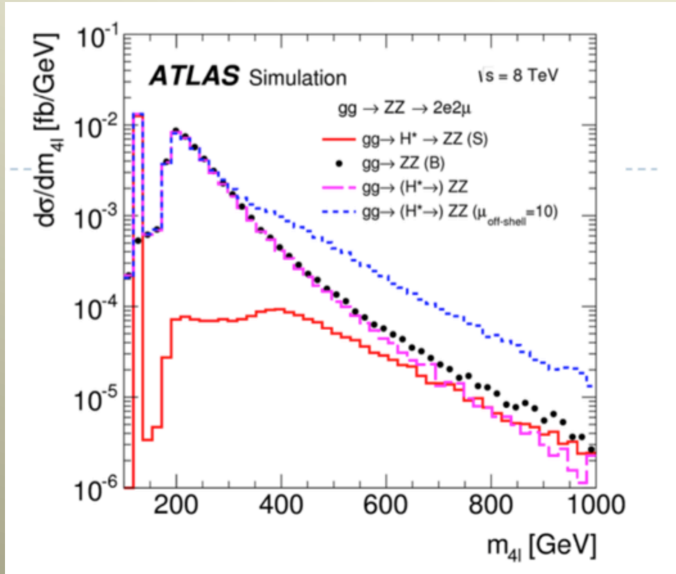
Global fitting to data:

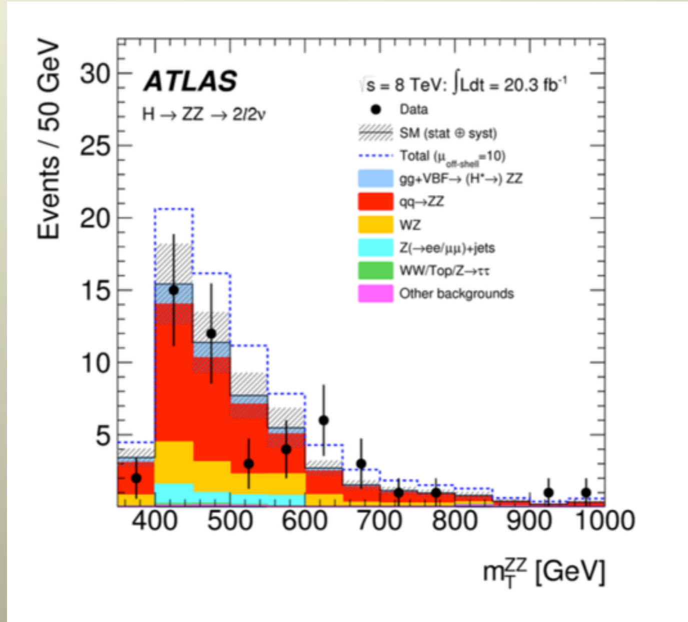
$$\mu = 1.09^{+0.11}_{-0.10} = 1.09^{+0.07}_{-0.07}\ (\text{stat})\ ^{+0.04}_{-0.04}\ (\text{expt})\ ^{+0.03}_{-0.03}\ (\text{thbgd})^{+0.07}_{-0.06}\ (\text{thsig})$$

$BR_{BSM} \leq 34\%$	SM p-value
95%CL	11%

Higgs width

- SM expectation $\Gamma_H \sim 4$ MeV
- Direct measurements of width of mass distributions (channels γγ and ZZ→4l) $\sigma_m \sim$ 1-2 GeV
- Indirect constraint through the on-shell/off-shell ratio of gg→H→VV : $\Gamma_H <$ 23 MeV (31 exp)
  - (Assuming no change of couplings, no new physics at high masses, no anomalous couplings)

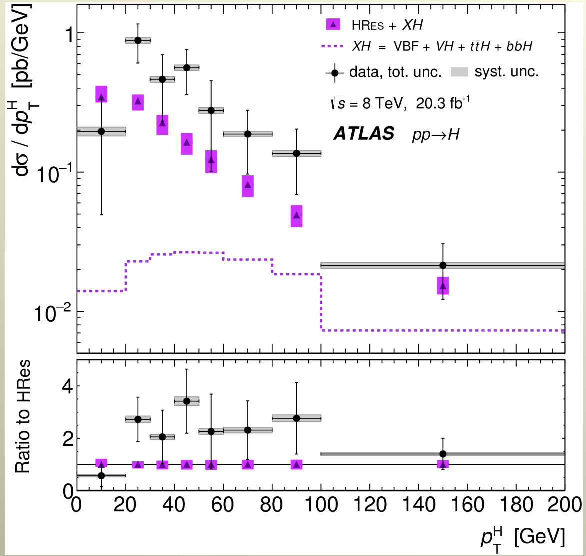


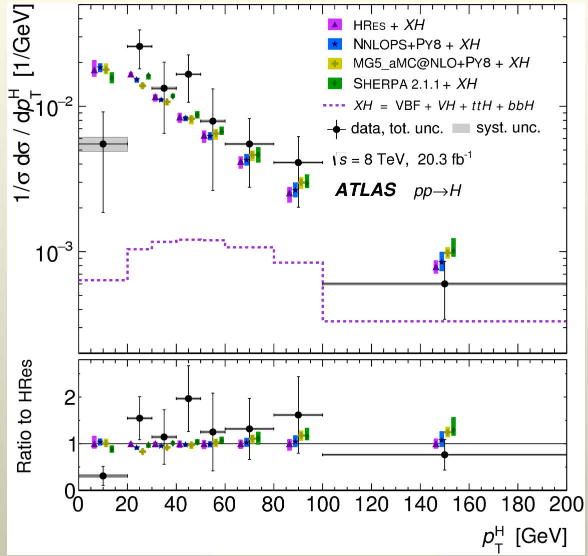


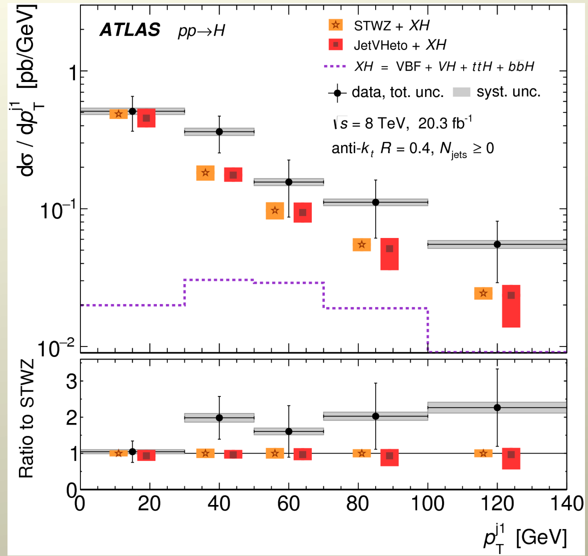
EPJC75(2015)335

Higgs differential cross section

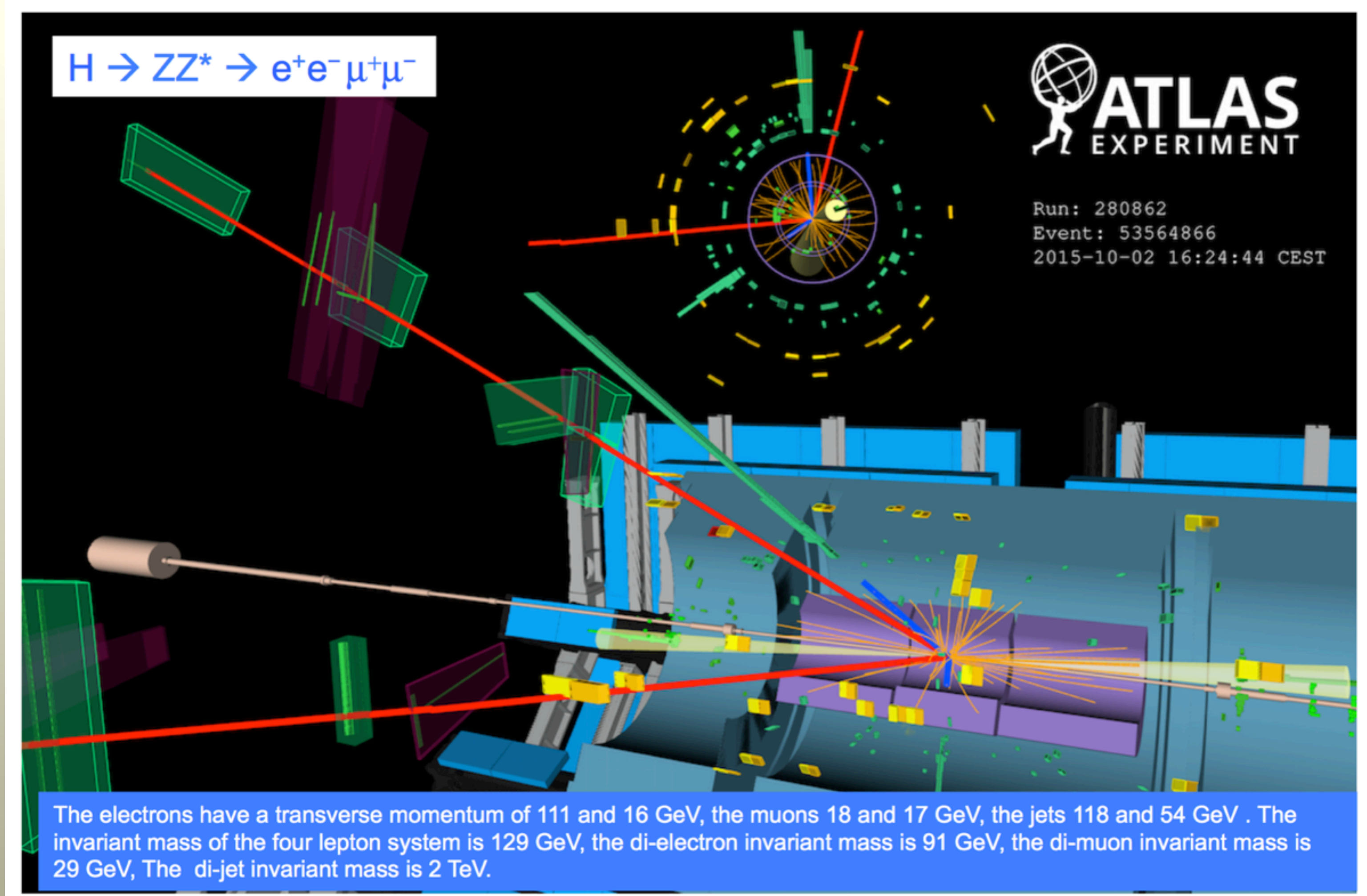
- Differential cross section measured with $\gamma\gamma$ and ZZ→4l channels:





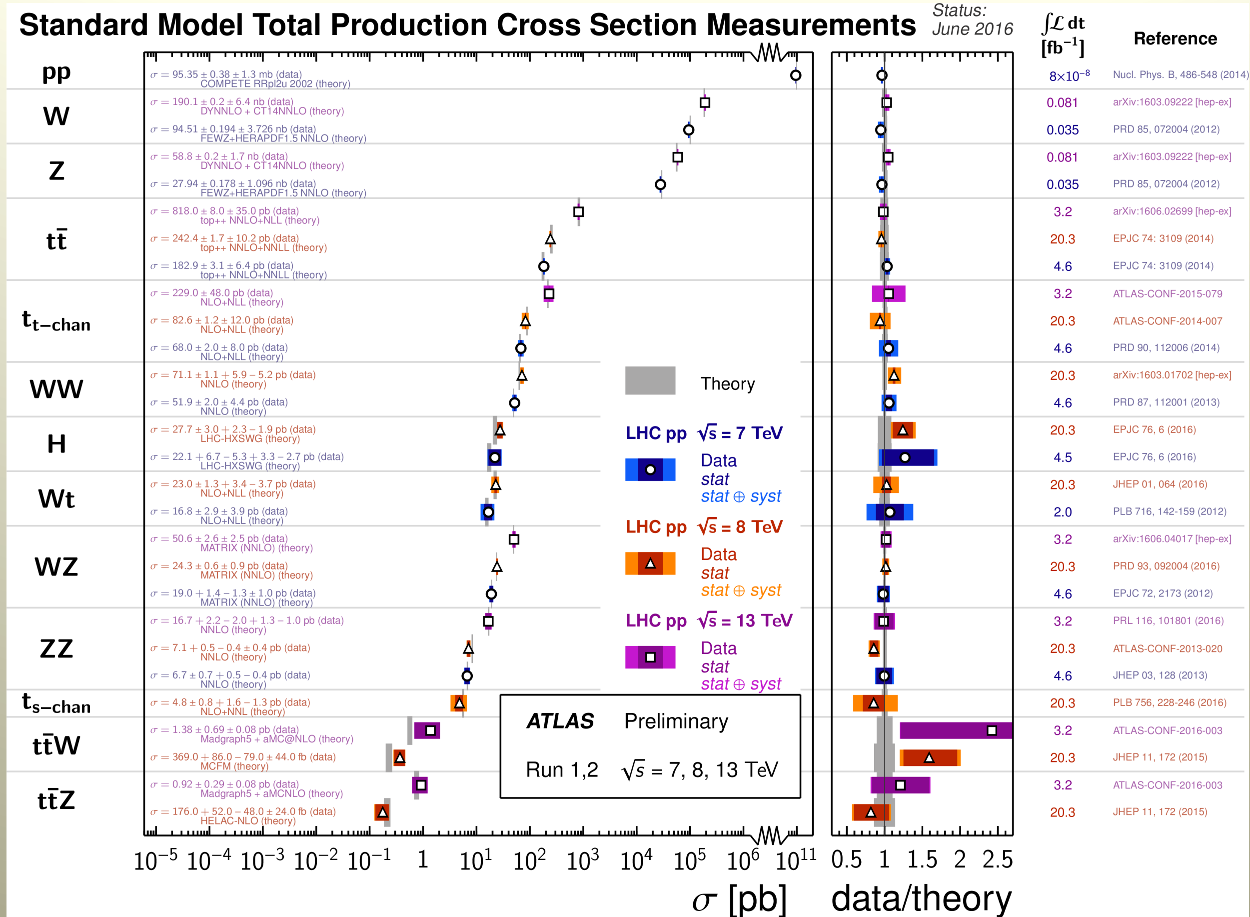


First look at H(125) @ 13 TeV



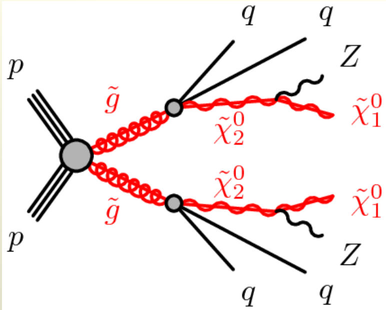
ATLAS SM Measurements

- Summary of several total cross section measurements
- Comparison with best available theoretical prediction (NLO or higher)



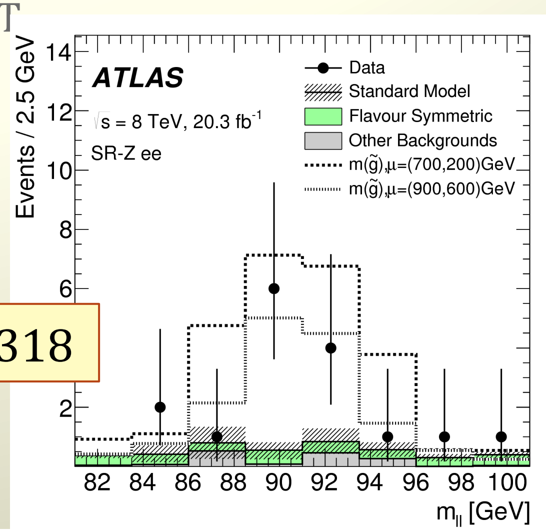
SUSY gluino

- Signature: 2 opposite-sign leptons + Z + E_T^{MISS}

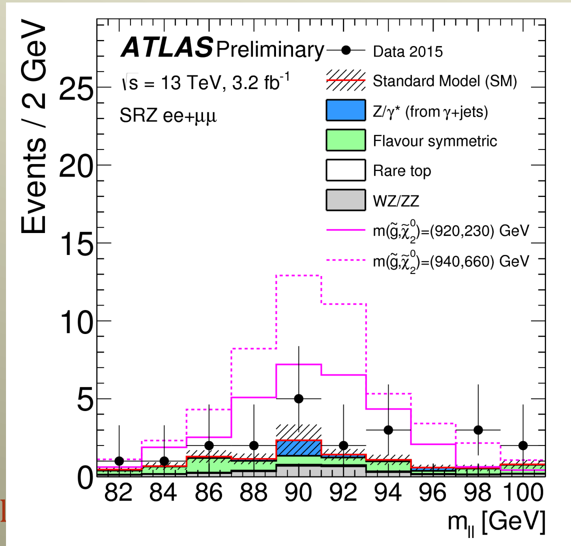


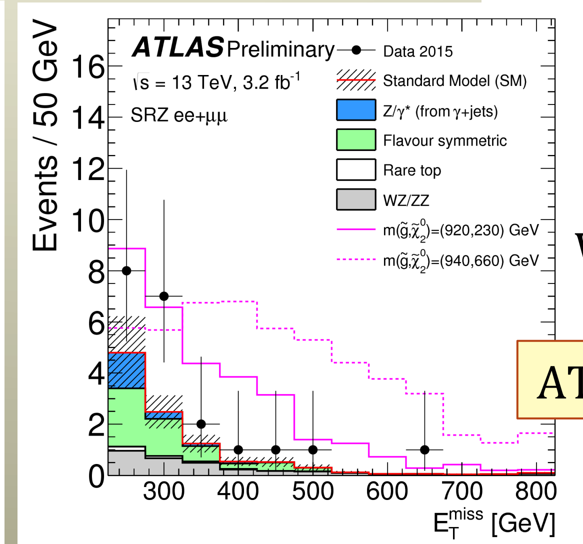
Run 1 search:
3 (1.7) σ
excess in ee (μμ) channel

Eur. Phys. J. C75 (2015) 318



Run2 search: 21 observed versus 10.3 +- 2.3 expected (2.2 σ) symmetric in ee and μμ





Waiting for more data

ATLAS-CONF-2015-082