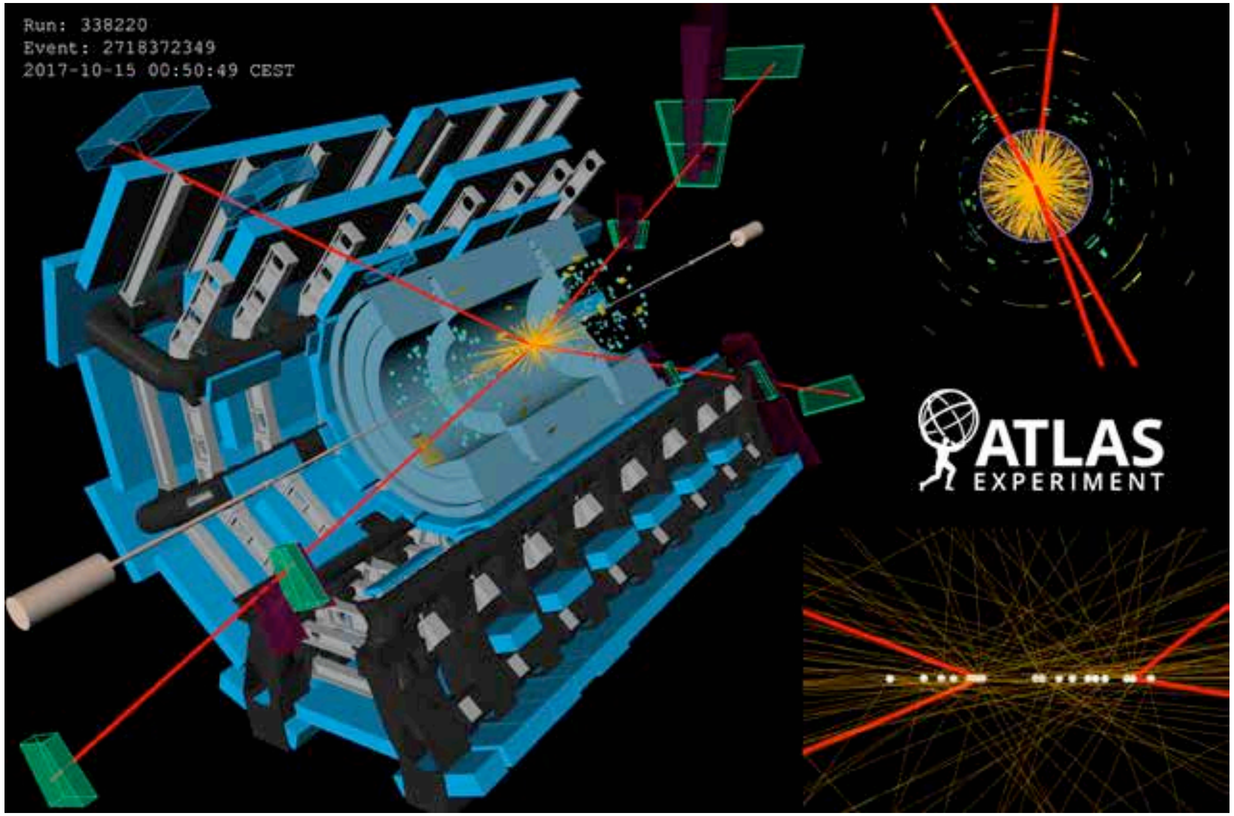
Physics Results from the ATLAS Experiment -present status and perspectives-



Karl Jakobs
University of Freiburg / Germany

JINR Dubna, 16th May 2018

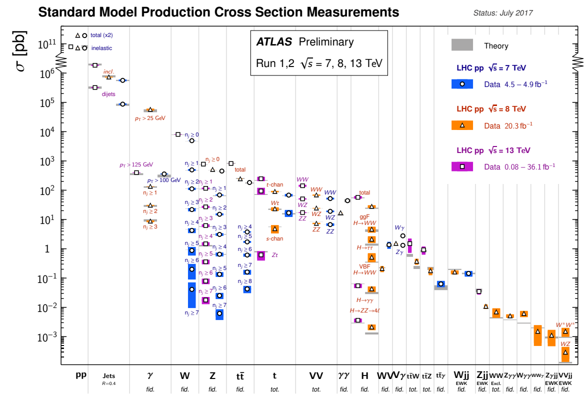
Physics Results from the ATLAS Experiment
-present status and perspectives-

- Physics summary after eight years of LHC
- The ATLAS experiment, present data taking
- Physics Highlights
  * Standard Model measurements
  * Properties of the Higgs boson
  * Searches for Physics Beyond the SM
- Perspectives: detector upgrades and
  physics potential

Karl Jakobs
University of Freiburg / Germany

JINR Dubna, 16th May 2018

The Physics Messages from the LHC
- a summary from the first 8 years-

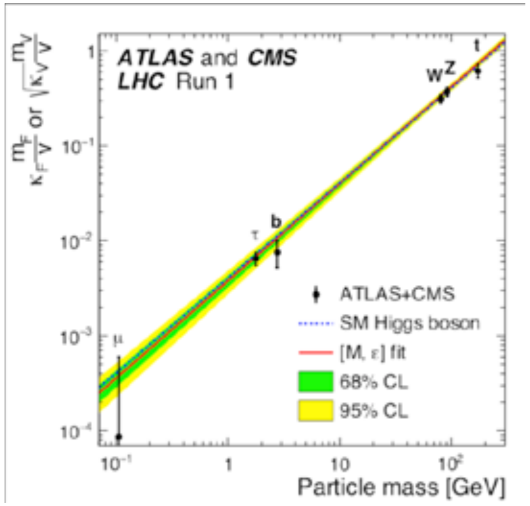


(i) The Standard Model has been tested at the highest energies

High LHC intensities (excellent machine and detectors)
→ rarer and rarer processes are being explored

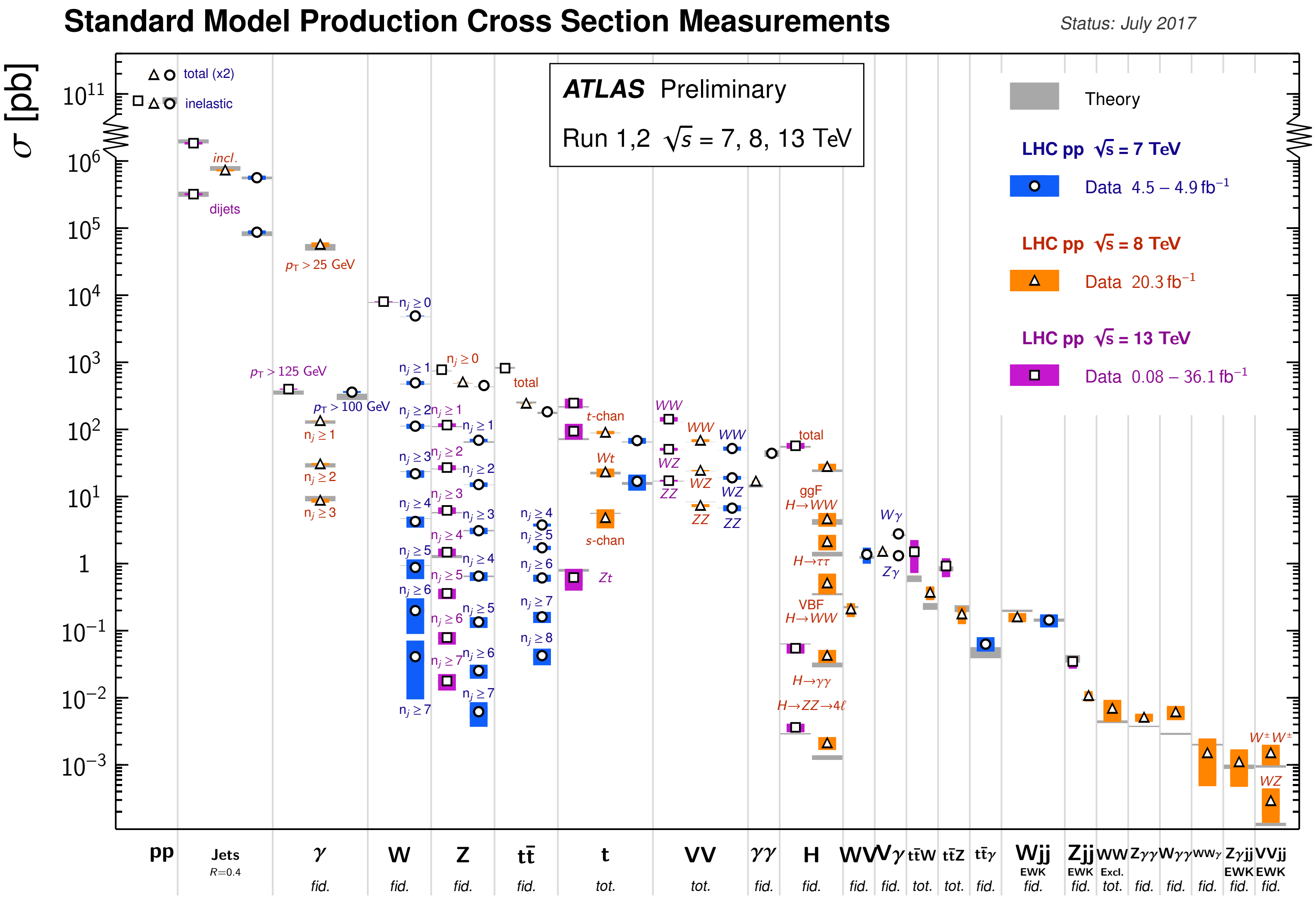
(ii) A Higgs boson has been discovered (2012)

The properties of the discovered Higgs boson are in agreement with the predictions of the Standard Model



(iii) No Physics Beyond the Standard Model has been discovered (yet)

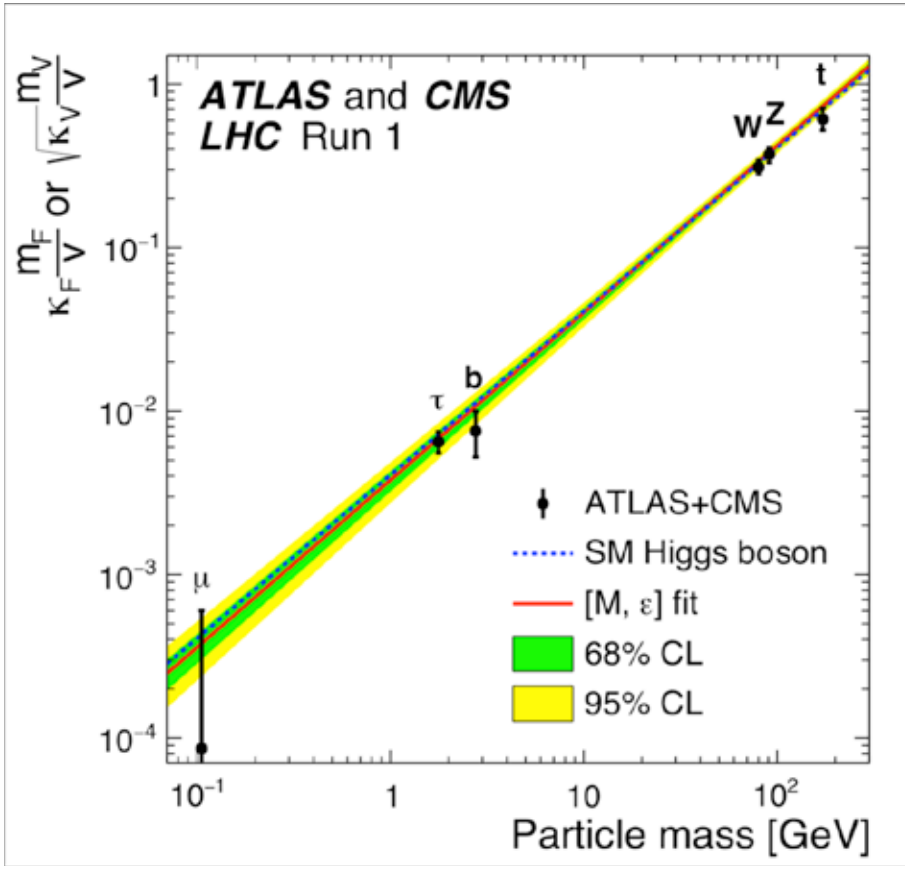
Test of the Standard Model

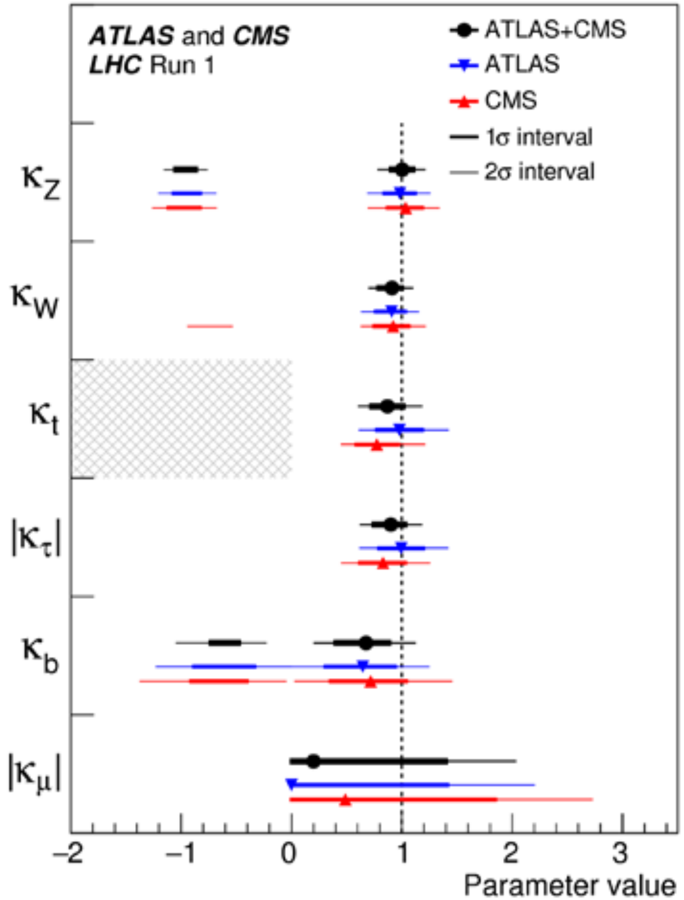


Huge progress also on the theoretical side: (N)NLO QCD / el.weak corrections

→ LHC = Long and Hard Calculations

Higgs boson properties





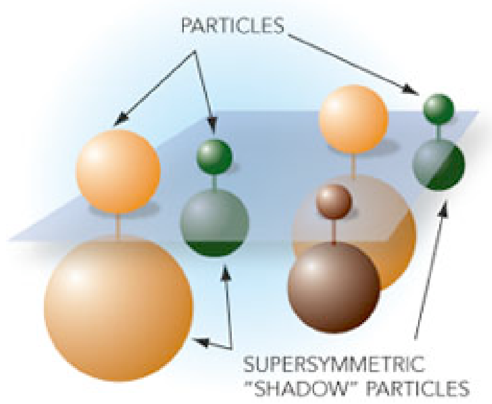
So far, all measured properties are in agreement with the expectations from the Standard Model, however, precision has to be increased

→ access to rare decay modes, higher precision, Higgs boson self-coupling

The mission of the LHC for the next decade (HL-LHC)

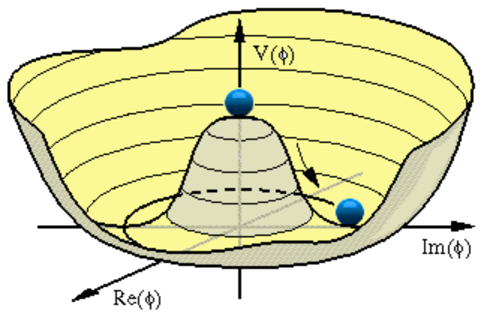
(i) Continue the direct searches for Physics Beyond the Standard Model at the highest energies

→ Address more complex scenarios



(ii) Exploration of the Higgs sector

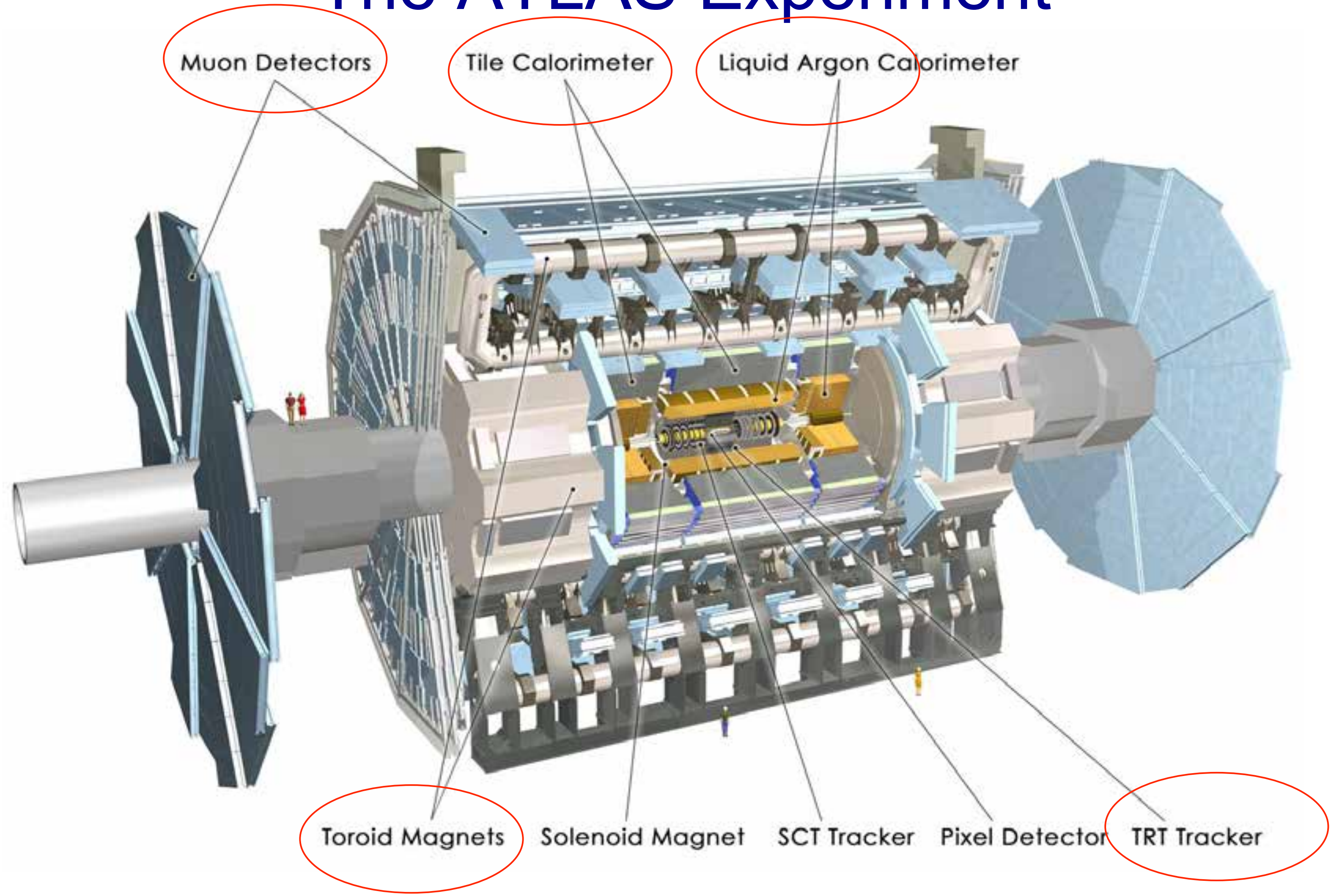
- Does the discovered Higgs particle have the properties as predicted in the Standard Model?
- Investigation of the Higgs boson self-coupling
  → Higgs boson potential



(iii) Precision Measurements

- Precision measurements of Standard Model processes and parameters
- Measurement of rare processes

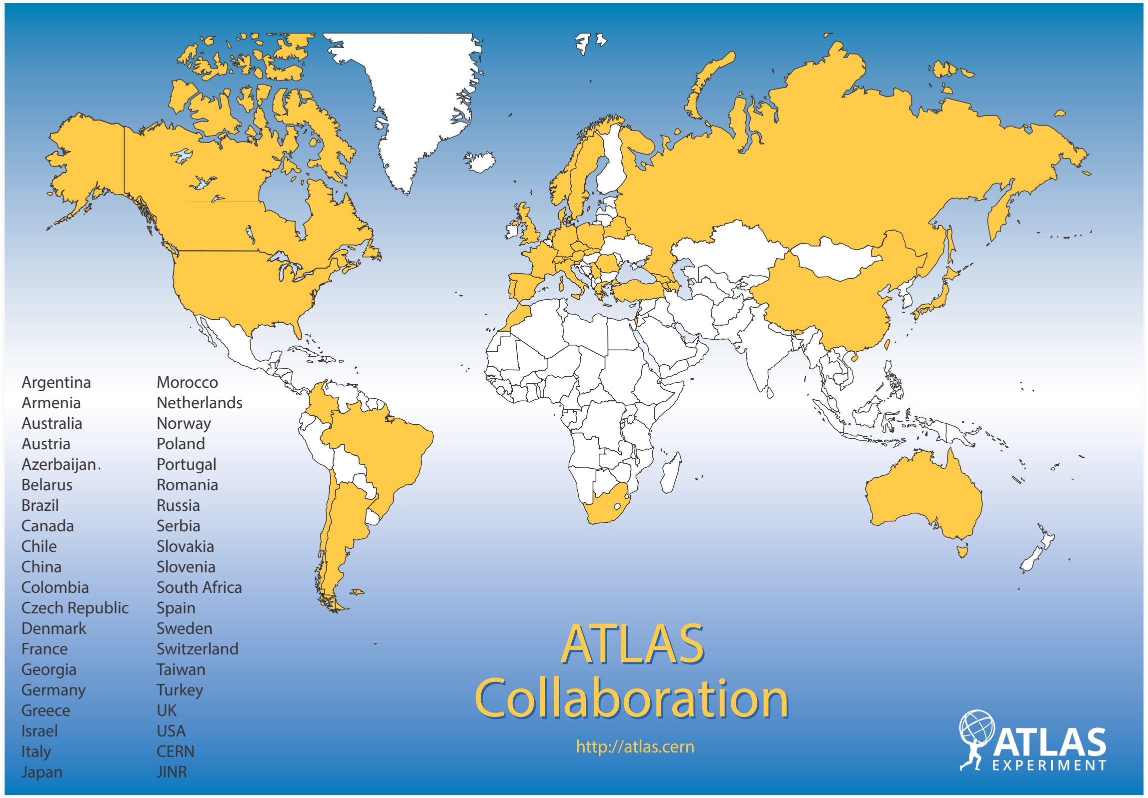
The ATLAS Experiment



JINR Dubna contributed very significantly to ATLAS, throughout all phases!

(conceptual design, R&D, construction, commissioning, data taking and physics analysis, ..., Phase-I and Phase-II upgrades)

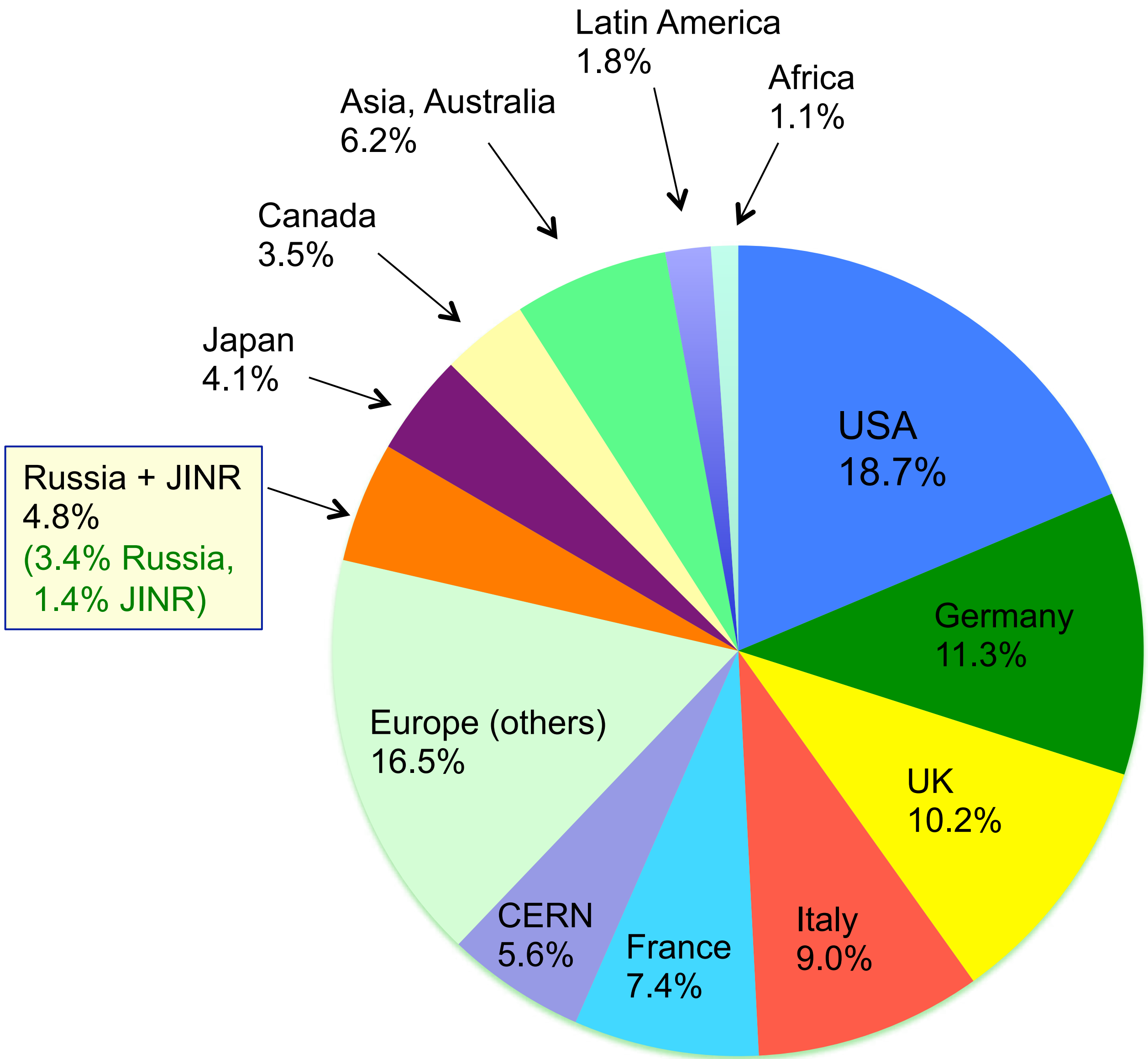
The ATLAS Collaboration



- 182 Institutions (235 institutes) from 38 Countries

- ~ 2'900 Scientific Authors
  ~ 1'900 with PhD, contributing to M&O share
  ~ 1'200 PhD students

  ~ 5'500 Active members
  (physicists, PhD + master students, engineers, technicians, ..)



USA	**18,7%**
Germany	**11,3%**
UK	**10,2%**
Italy	**9,0%**
France	**7,4%**
CERN	**5,6%**
Japan	**4,1%**
Canada	**3,5%**
Russia+ JINR	**4,8%**
Spain	**2,6%**
China	**2,6%**
Czech Republic	**2,1%**
Sweden	**1,6%**
Israel	**1,6%**
Poland	**1,6%**
Switzerland	**1,3%**
Netherlands	**1,3%**
Europe (others)	**6,0%**
Asia (others) + Australia	**2,0%**
Latin America	**1,8%**
Africa	**1,1%**

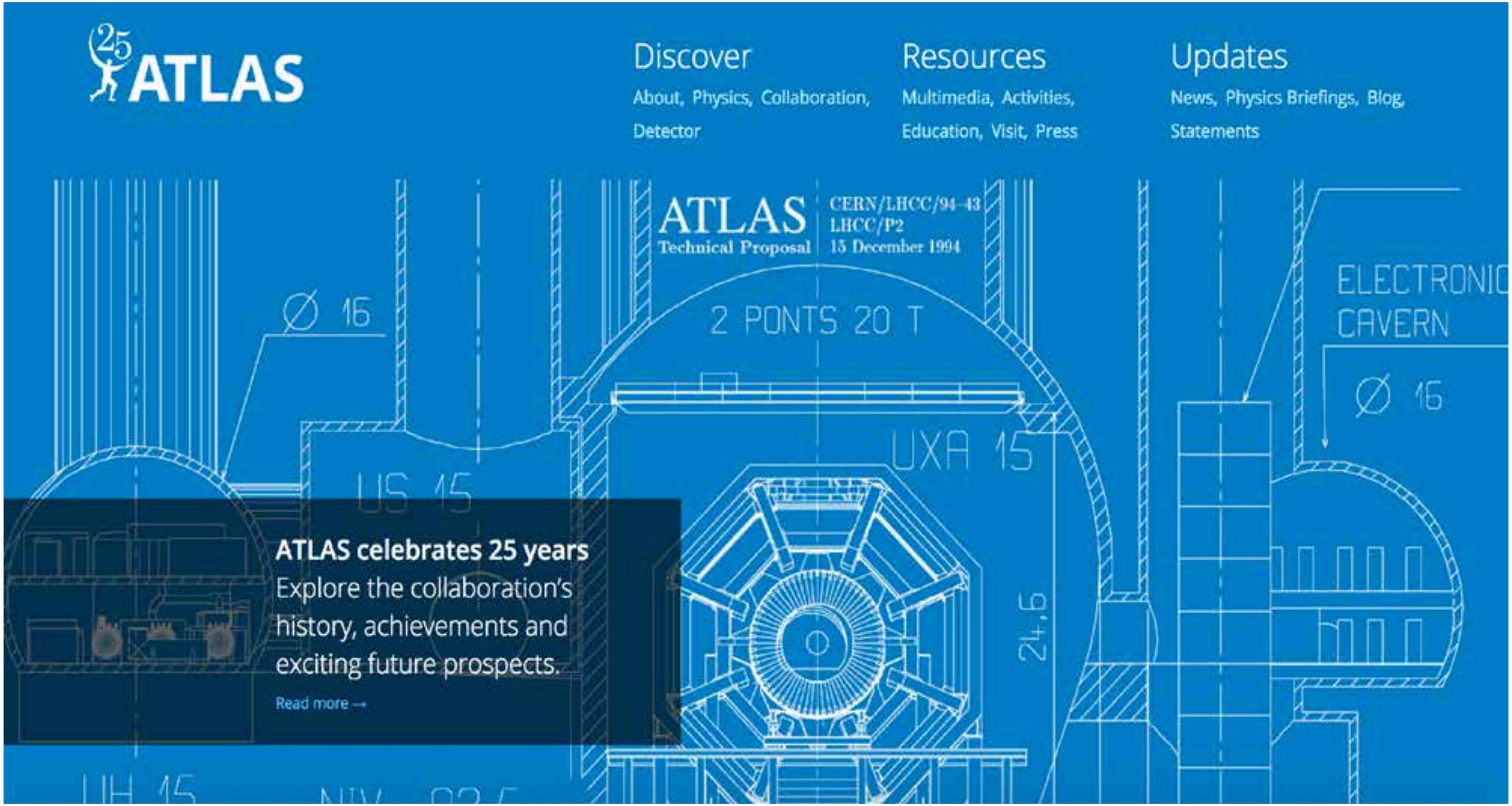
Fractions according to PhD physicists
(M&O share)

ATLAS 25

Members from JINR, signing the ATLAS Letter of Intent (1. October 1992)

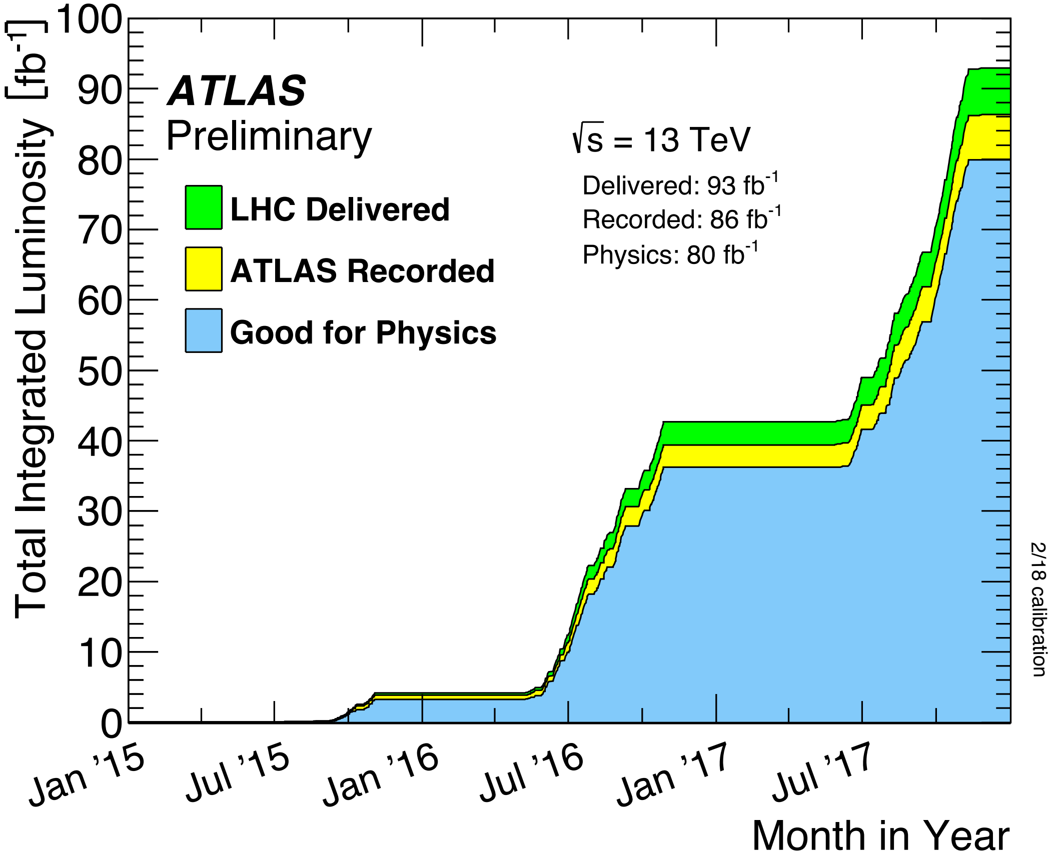
Joint Institute for Nuclear Research, Dubna, Russia

G.Alexandrov, G.Alexeev, A.Bannikov, S.Baranov, D.Bardin, S.Bilenky, I.Boguslavskij, G.Chelkov, A.Cheplakov, A.Efremov, R.Eremeev, O.Gavrishchuk, S.Gerasimov, Yu.Gornushkin, I.Gramenitskij, V.Jamburenko, G.Karpenko, M.Kazarinov, B.Khomenko, N.Khovanski, O.Klimov, V.Kotov, T.Kotova, V.Kravtsov, Z.Krumstein, V.Kukhtin, A.Kutov, O.Kuznetsov, E.Ladygin, V.Malyshev, V.Mel'nikov, L.Merkulov, O.Nozdrin, V.Obudovskij, V.Odintsov, A.Olshevski, R.Pose, V.Romanovsky, T.Rudenko, V.Samsonov, M.Shafranov, A.Shalygin, Yu.Sedykh, A.Sissakian, A.Skachkov, A.Solovjev, L.Tkatchev, V.Tokmenin, L.Vertogradov, A.Volod'ko



Thanks to JINR for the nice present!
... and for the highly valued contributions during the past 25 years

Data taking during Run 2



In 2017:

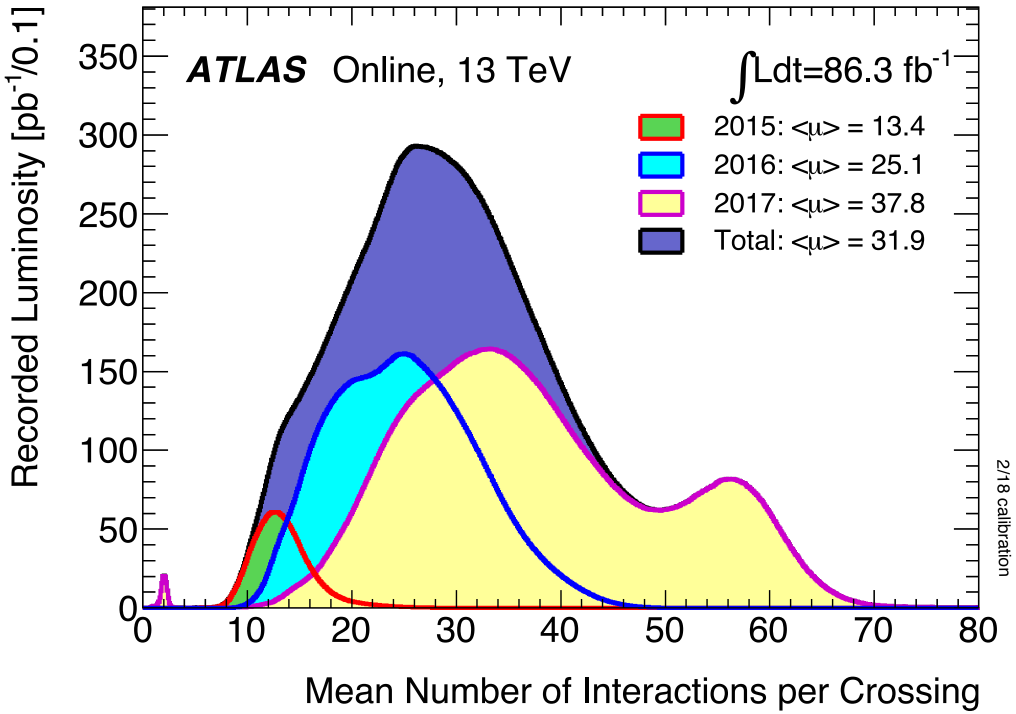
Delivered: 50.2 fb^{-1}

Recorded: 46.9 fb^{-1}
(Data taking efficiency 93.3%)

Good for Physics: 43.6 fb^{-1}
(Efficiency 93.6%, → high data quality)

Excellent performance of the accelerator and of the ATLAS experiment

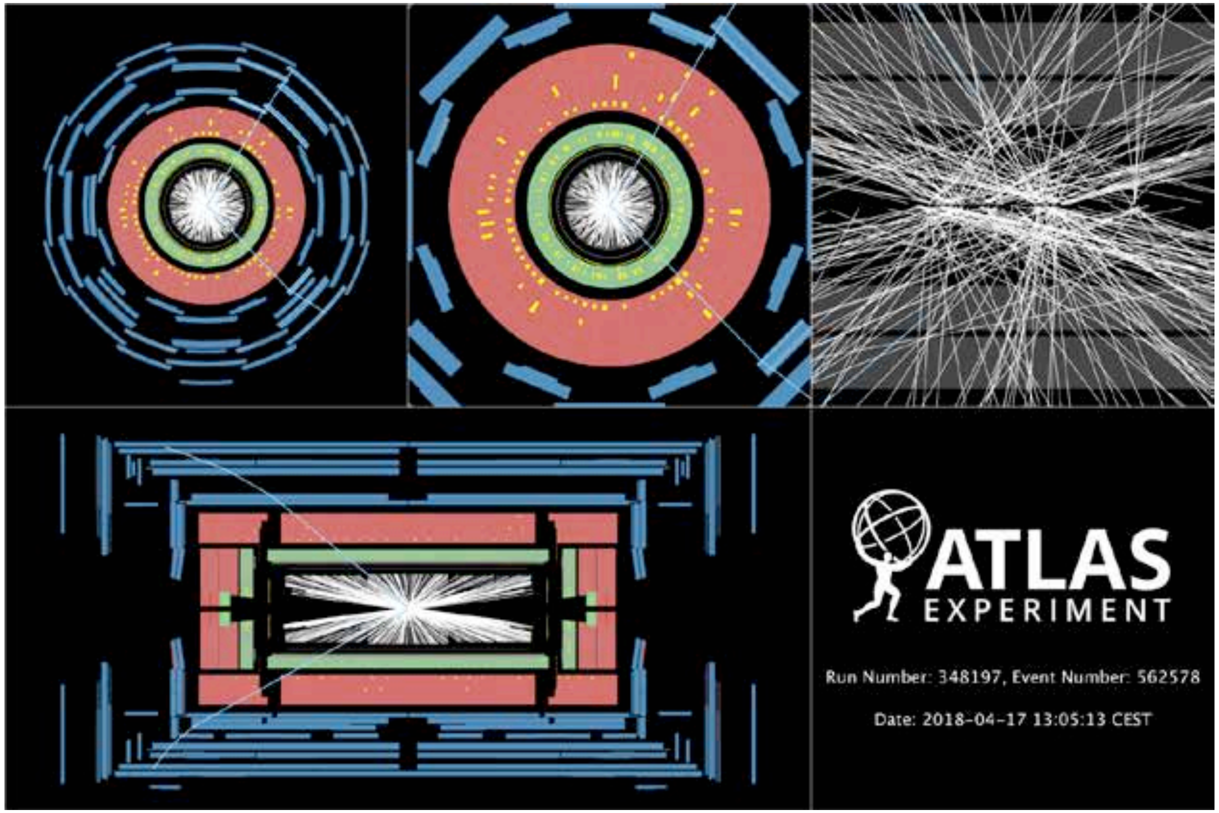
Data taking during Run 2



ATLAS levelling at μ ~ 58 during 2017

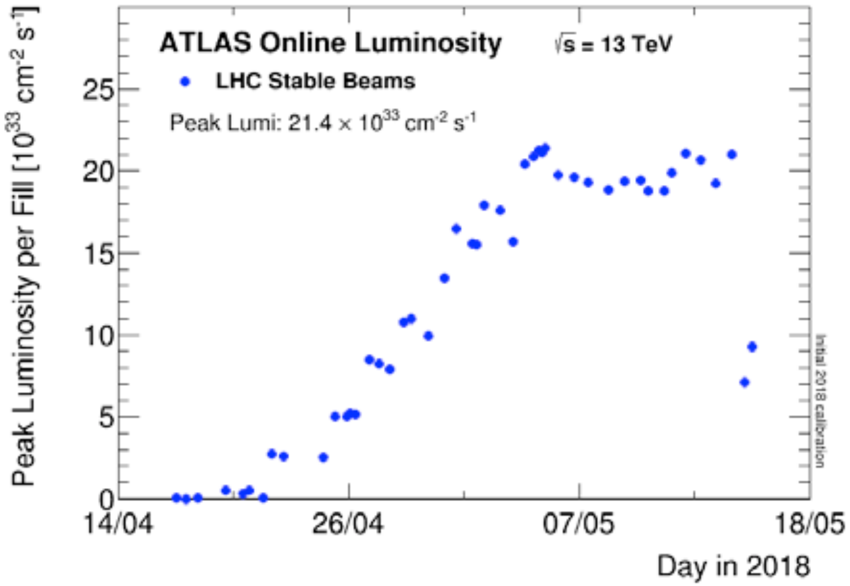
(about 2.5 times the LHC design pileup value)

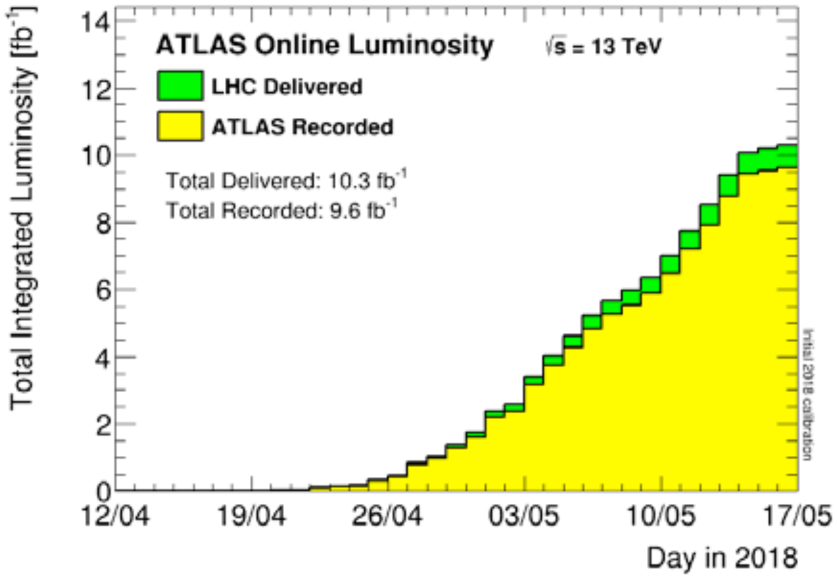
Start-up of Data Taking in 2018



- First collisions with stable beams in 2018 on Tuesday, 17th April around 1 pm
- ATLAS had a very smooth startup, after solid preparation and tests of the various sub-detector systems and of the trigger and data acquisition system during the past months

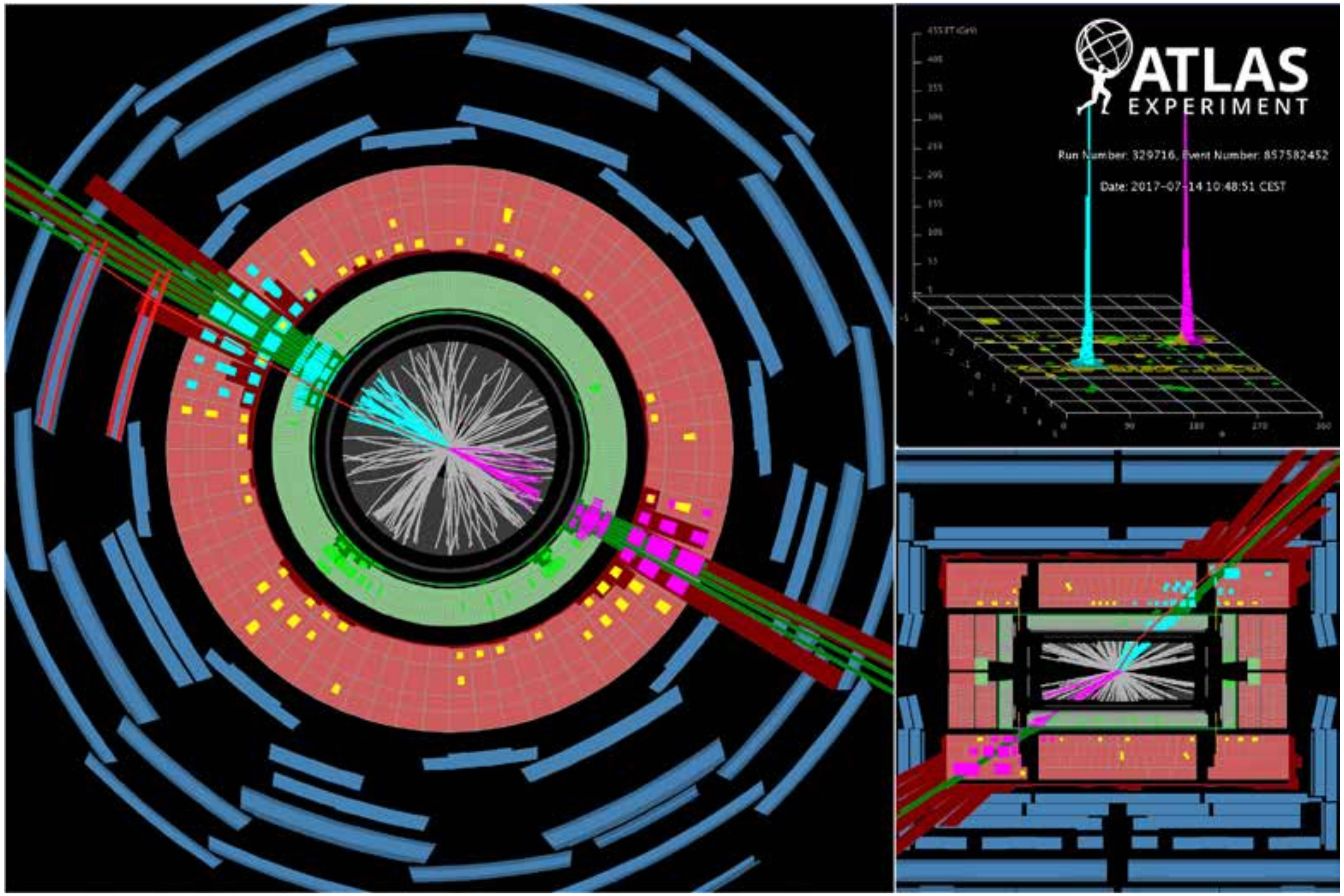
Start-up of Data Taking in 2018 (cont.)





- LHC has moved very fast up towards the nominal number of bunches (2556); Luminosities around 2 10^{34} cm^{-2} s^{-1} reached; new record: 2.14 10^{34} cm^{-2} s^{-1}
- Still beam losses observed in Q16L2 region, however, a stable mode of operation found; β^* levelling applied towards the end of fills, to increase luminosity
- ATLAS is in data-taking mode; smooth start-up; already ~10 fb^{-1} recorded

A few Physics Highlights

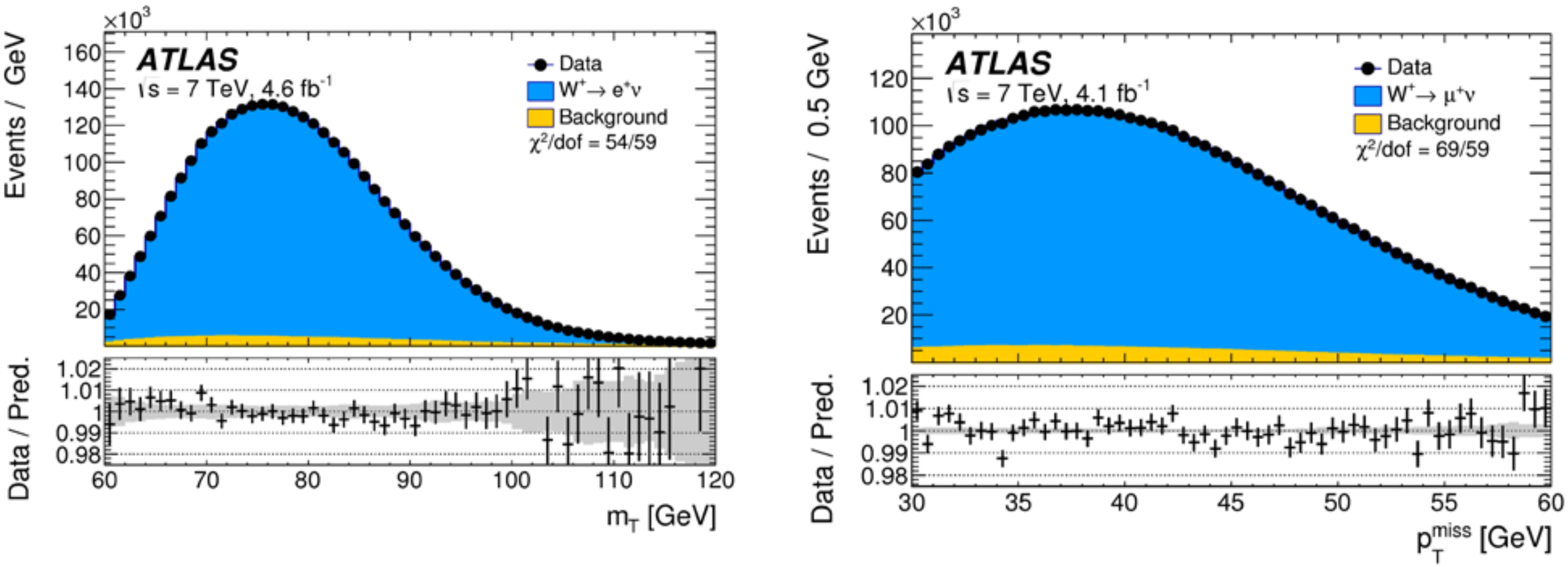


A di-jet event recorded during 2017, with m_{jj} = 9.3 TeV

Measurement of the W-boson mass

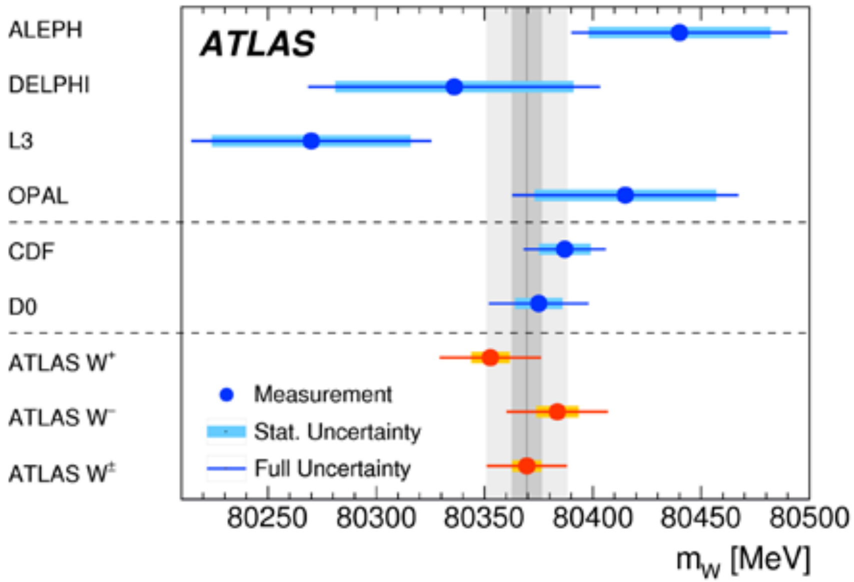
- Based on early data (2011) at $\sqrt{s}$ = 7 TeV (4.6 fb^{-1})
- Huge amount of work to understand detector response and the modelling of kinematic quantities (relies on large Z → ℓℓ sample)
- High quality analysis in W → eν and W → μν channels

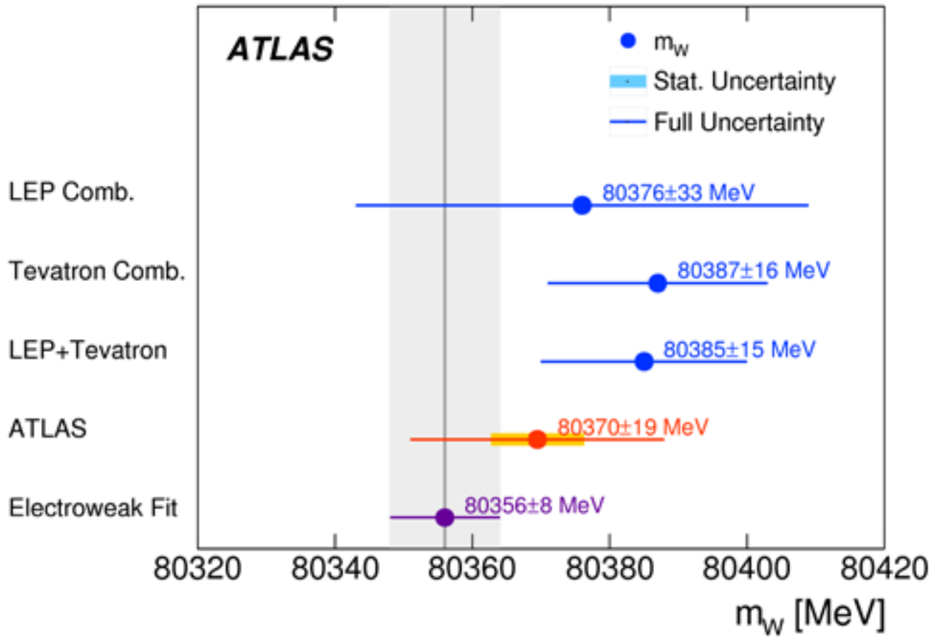
arXiv:1701.07240



Measurement of the W-boson mass (cont.)

arXiv:1701.07240





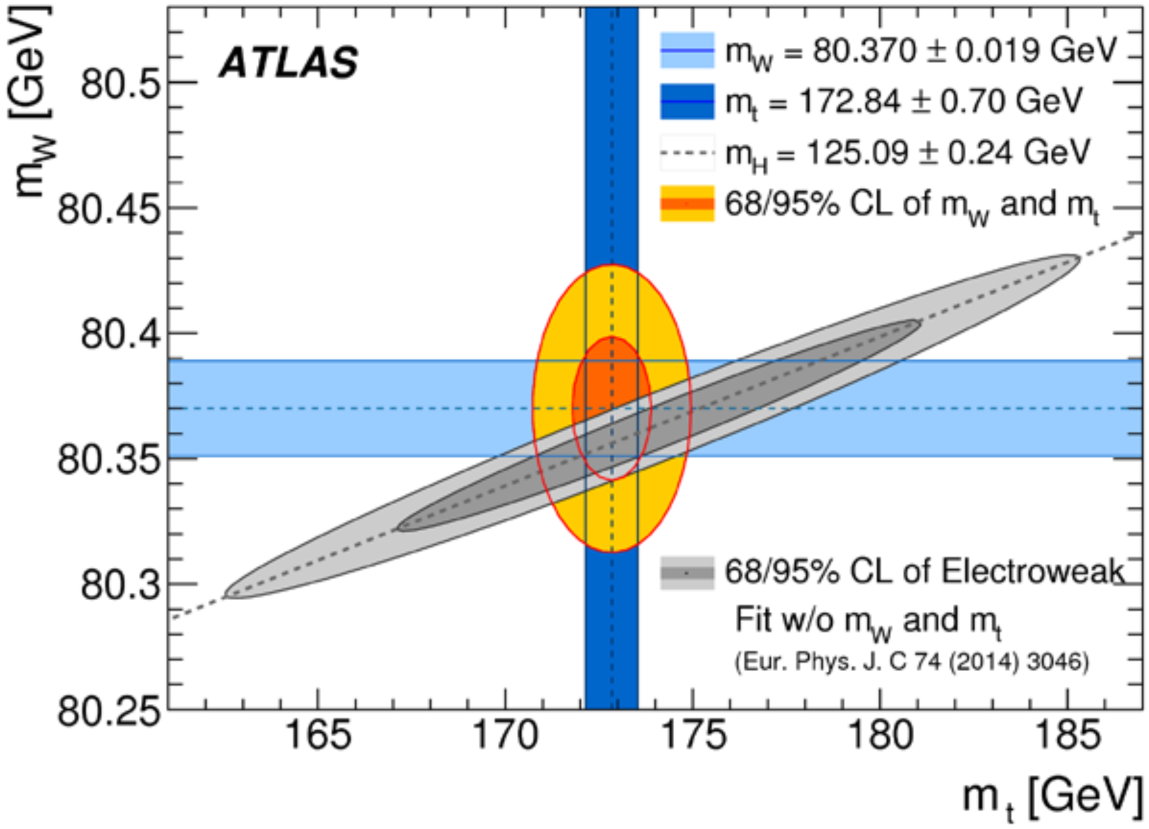
Same precision reached as for current best measurement from the CDF experiment

$m_W = 80.370 \pm 0.019$ GeV

$\pm$ 7 MeV statistical
$\pm$ 11 MeV systematic
$\pm$ 14 MeV modeling

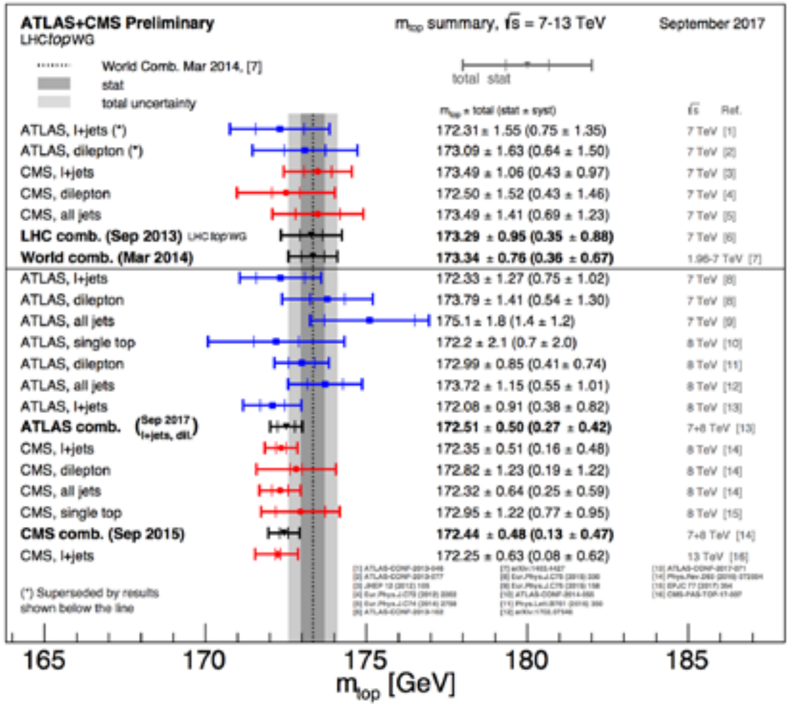
Precision Test of the Standard Model

-test of quantum corrections-



Precision measurement of the Top-quark mass

ATLAS-CONF-2017-071



ATLAS

m_{top} = 172.51 ± 0.50 GeV

(0.3%)

± 270 MeV statistical

± 420 MeV systematic

CMS

m_{top} = 172.44 ± 0.48 GeV

(0.3%)

± 130 MeV statistical

± 470 MeV systematic

Precision reached is significantly higher than expected before LHC data taking!

Other recent highlights on Top-Quark Physics

- Evidence for Zt production [4.2σ (5.4σ expected)]

- Top pole mass measured comparing lepton differential distributions from 8 TeV Run-1 data with NLO QCD fixed-order predictions (MCFM)

- Measurement of tt differential cross-sections of highly boosted top quarks

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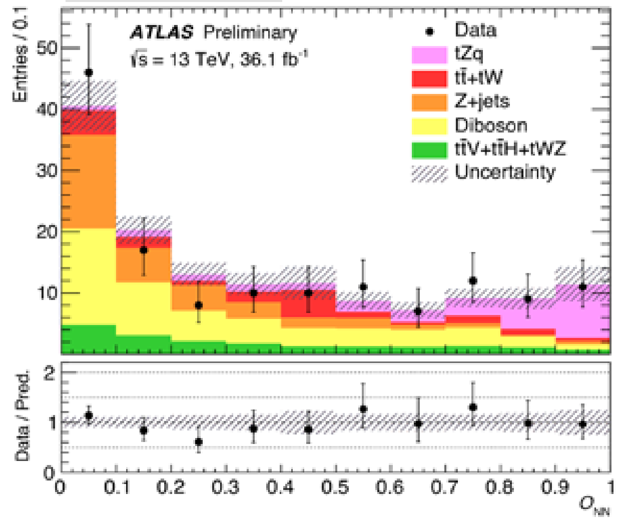
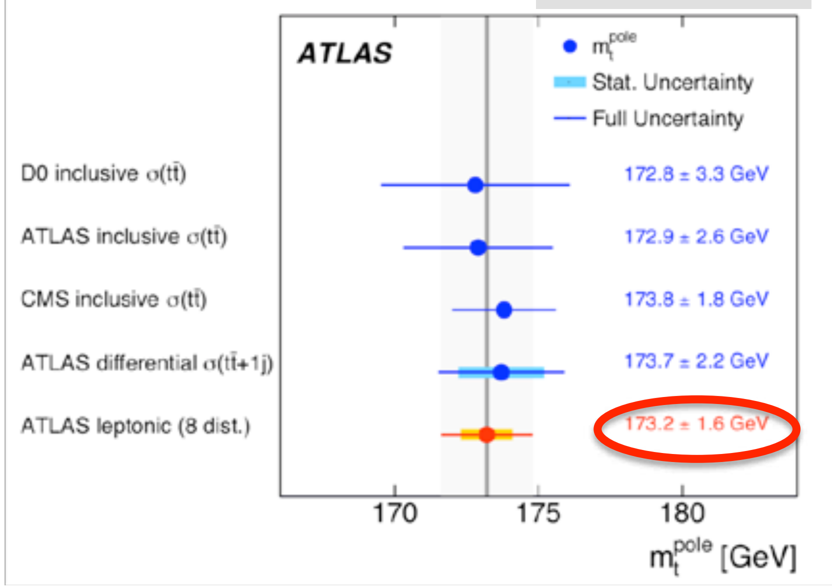
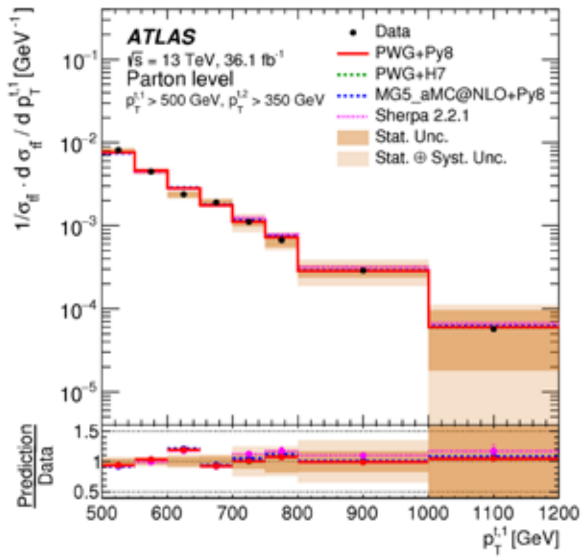


Eur. Phys. C77 (2017) 804



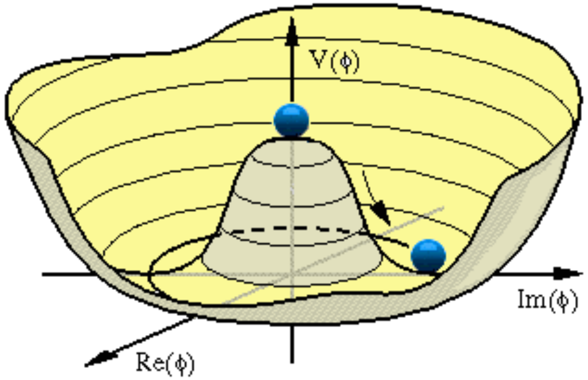
arXiv:1801.02052

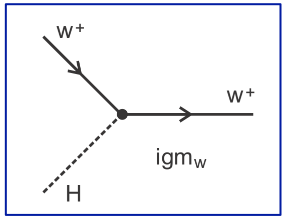


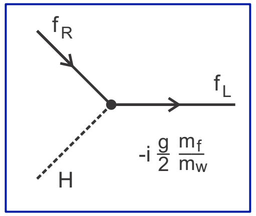
Higgs Boson Physics

-profile of the new particle-

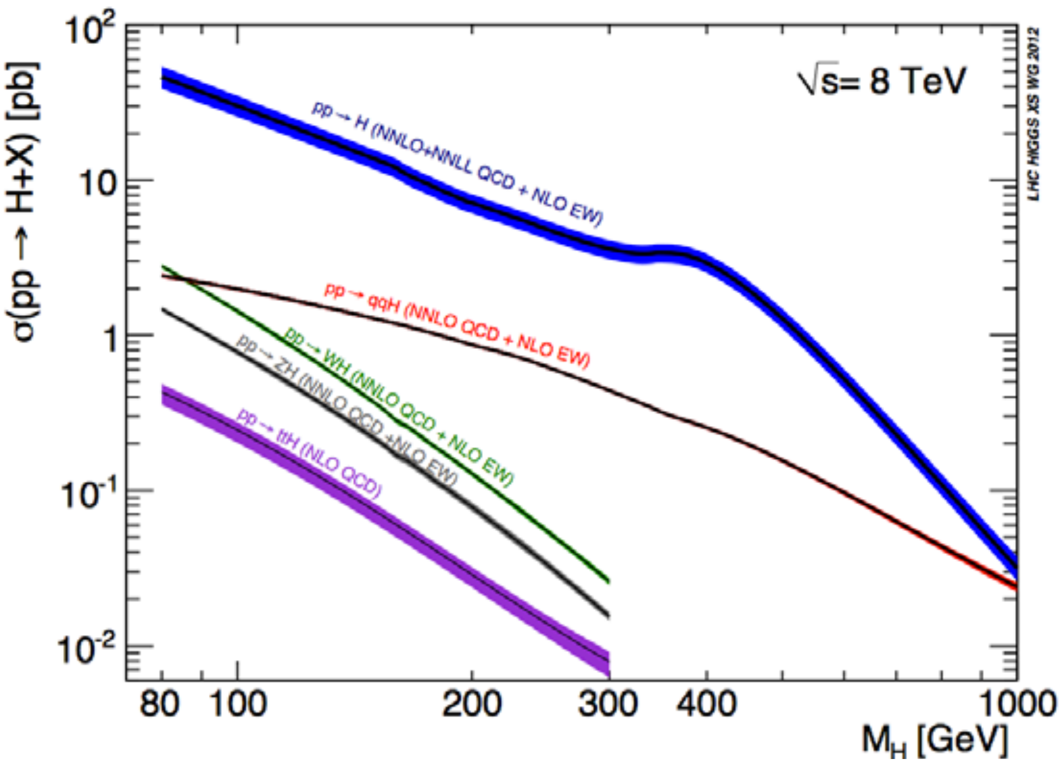
- Status of bosonic decay modes
- Measurements / evidence for couplings to fermions (H → ττ, H → bb, ttH production)
- Mass   (“input parameter”)
- Production rates
- Couplings to bosons and fermions

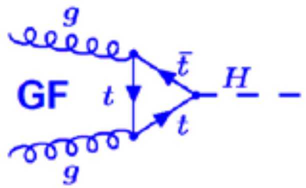




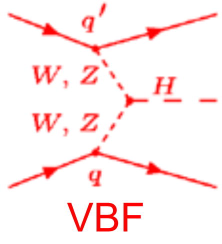


Higgs Boson Production

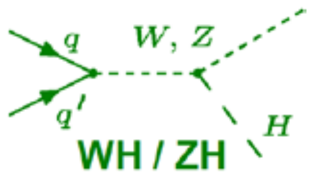




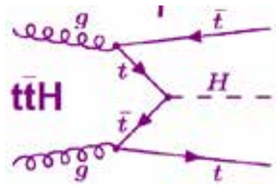
Gluon fusion



Vector boson fusion



WH/ZH associated production



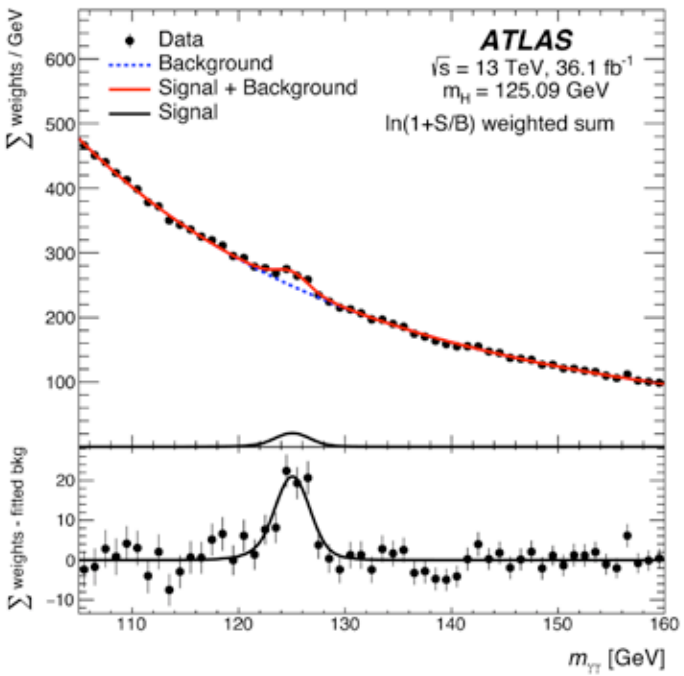
tt associated production

*) LHC Higgs cross-section working group
Large theory effort

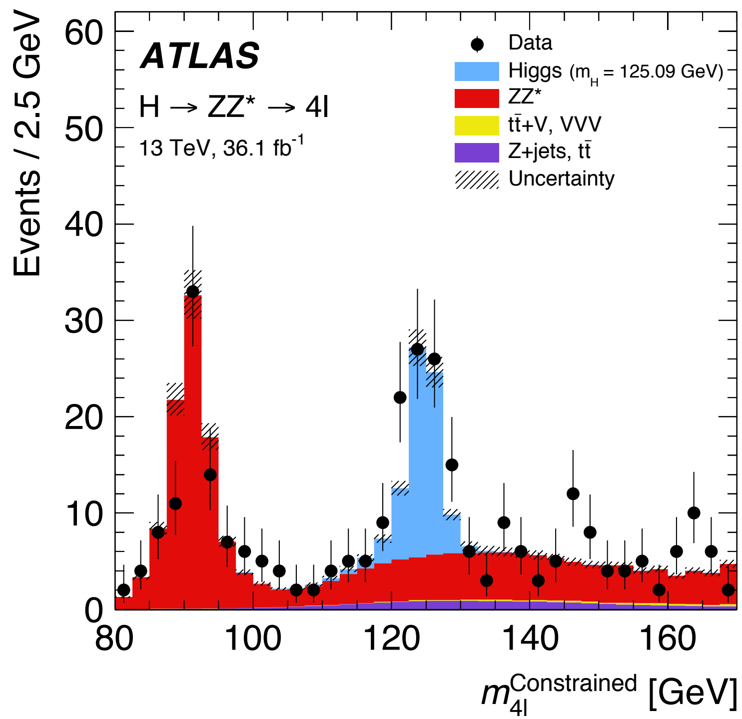
Meanwhile the NNNLO = N^3LO calculation for the gluon-fusion process exists;
B. Anastasiou et al. (2015)

Results of the Searches for H → γγ and H → ZZ* → 4l

arXiv:1802.04146 (2018)

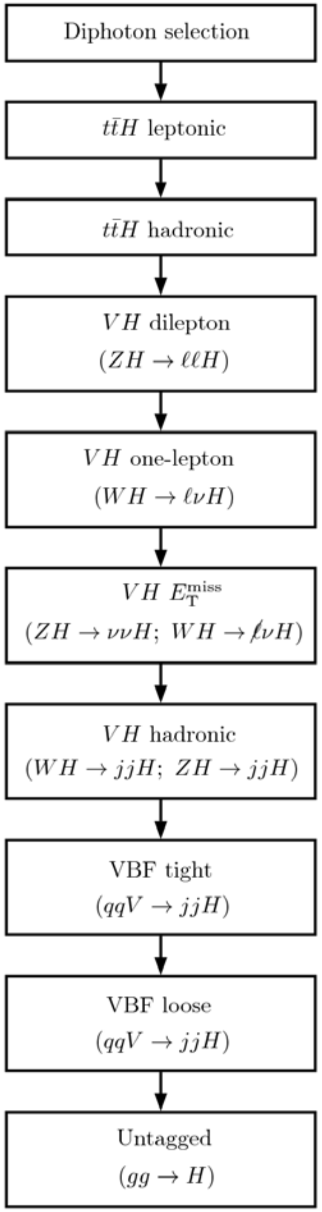


JHEP 03 (2018) 095

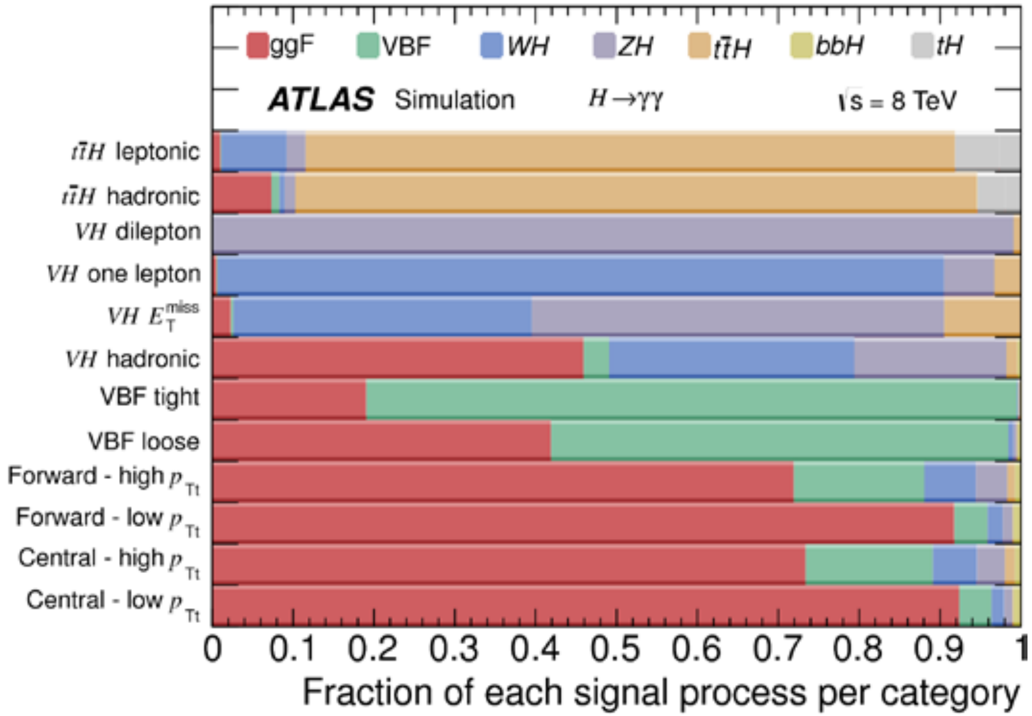


- Impressive signals in these high-resolution bosonic decay channels
  (Data collected during 2015 and 2016 in Run 2 at 13 TeV)
- Observation with a significance of > 5σ in each channel

Categorisation of H → γγ candidate events

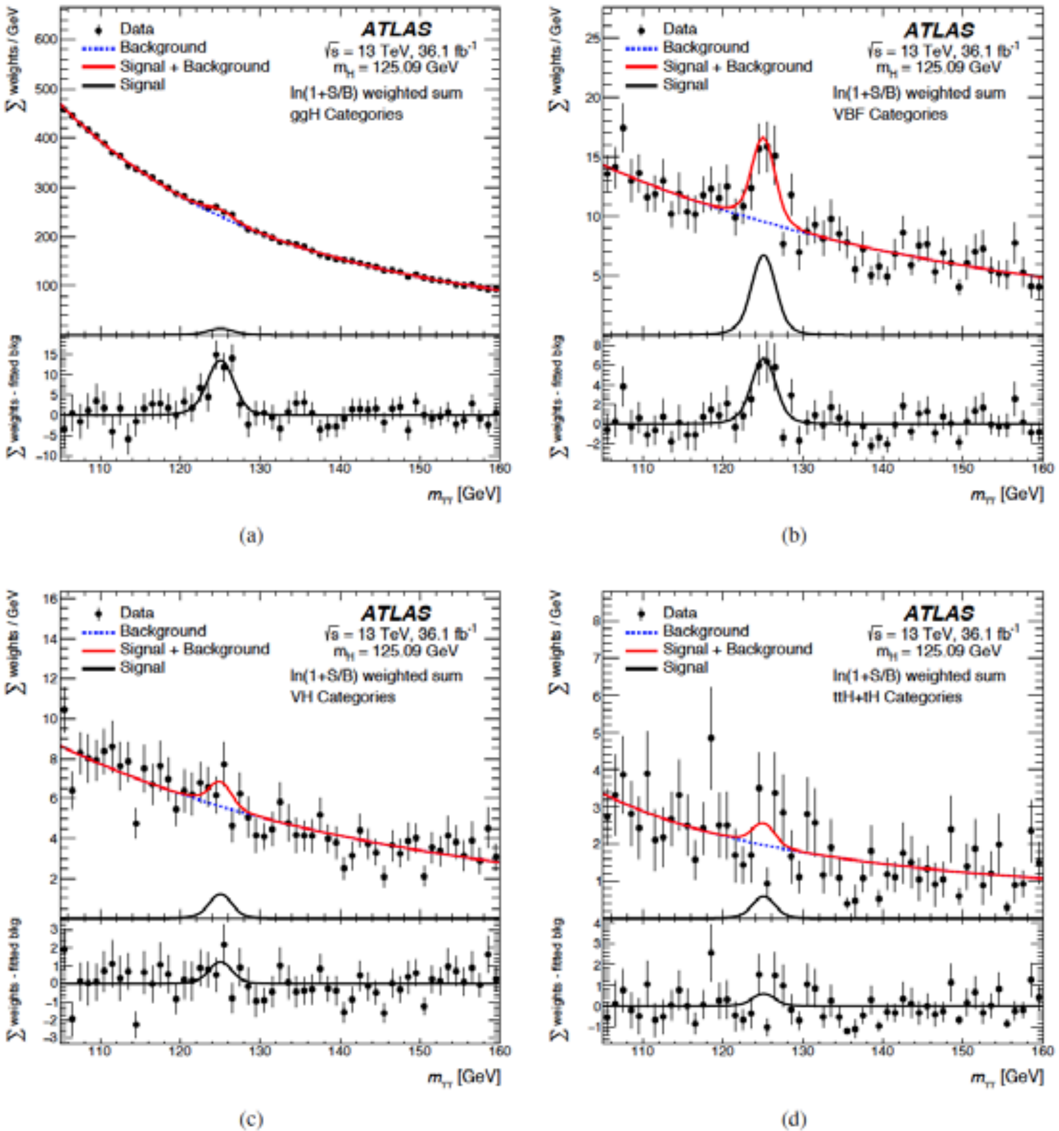


Categorisation: to increase overall sensitivity and sensitivity to different production modes (VBF, VH)



- VH enriched: one-lepton, E_T^{miss}, low-mass di-jets
- VBF enriched (tag-jet configuration, $\Delta\eta$, m_{jj})
- gluon fusion: exploit different mass resolution for for different detector regions, γγ conversion status and p_{Tt}

H → γγ signals for various categories



a) untagged categories
(expected to be dominated by gluon fusion)

b) VBF categories

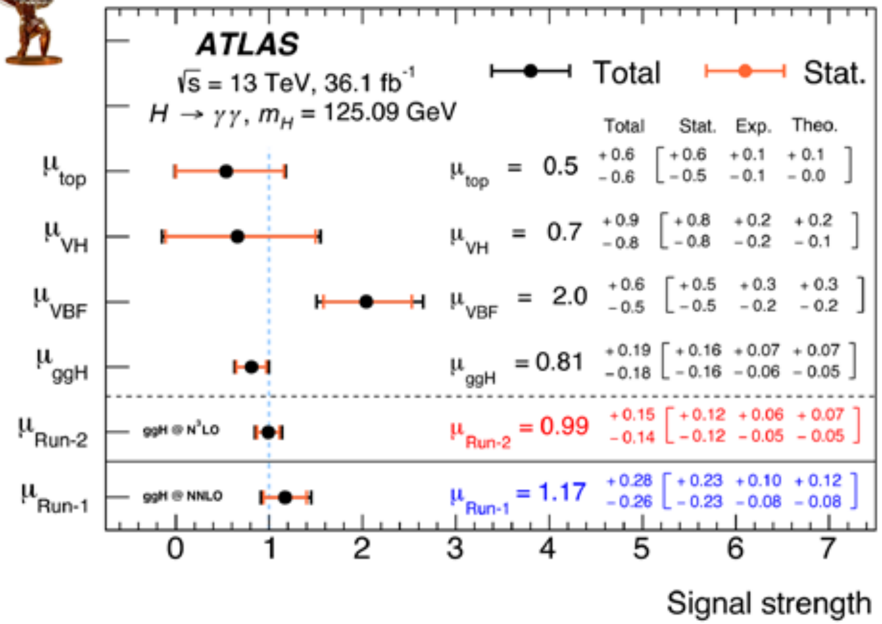
c) VH categories

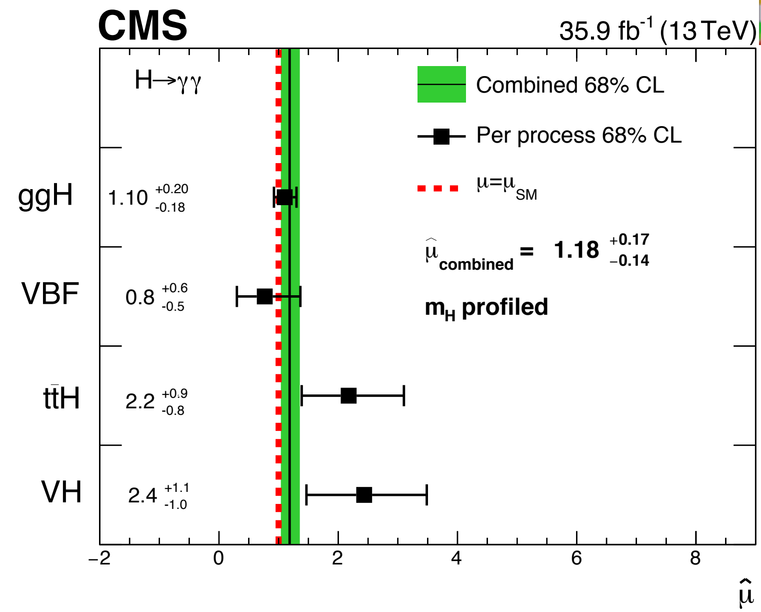
d) ttH categories

arXiv:1802.04146 (2018)

H → γγ signal strengths

arXiv:1802.04146 (2018)





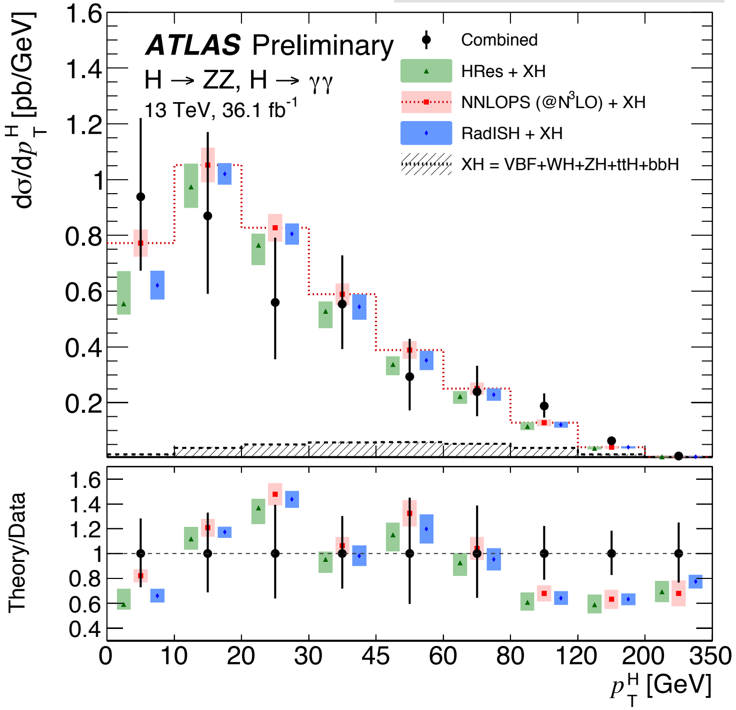
Measured signal strengths: $\mu = \sigma_{obs} / \sigma_{SM}$

ATLAS: $\mu = 0.99 \begin{matrix} +0.15 \\ -0.14 \end{matrix}$

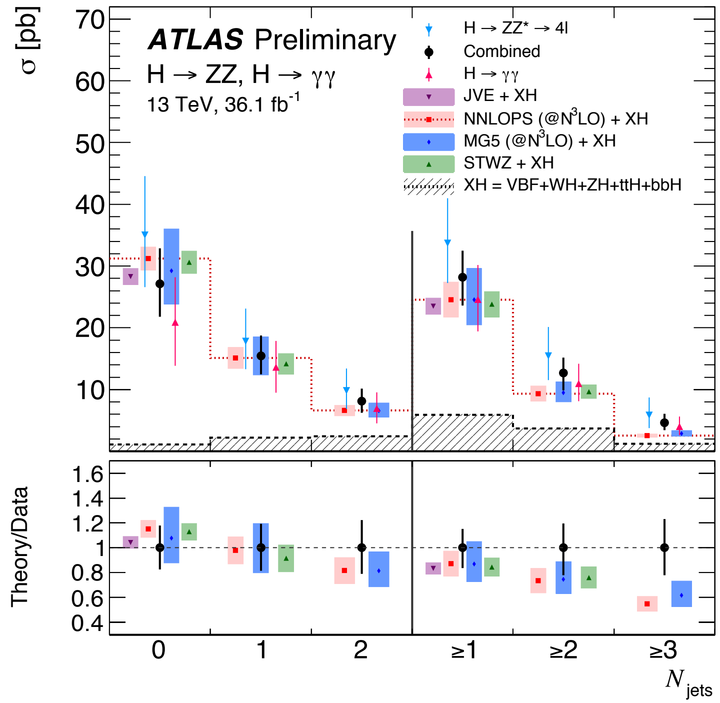
CMS: $\mu = 1.18 \begin{matrix} +0.17 \\ -0.14 \end{matrix}$

Differential cross-section measurements

ATLAS-CONF-2018-002



ATLAS-CONF-2018-002

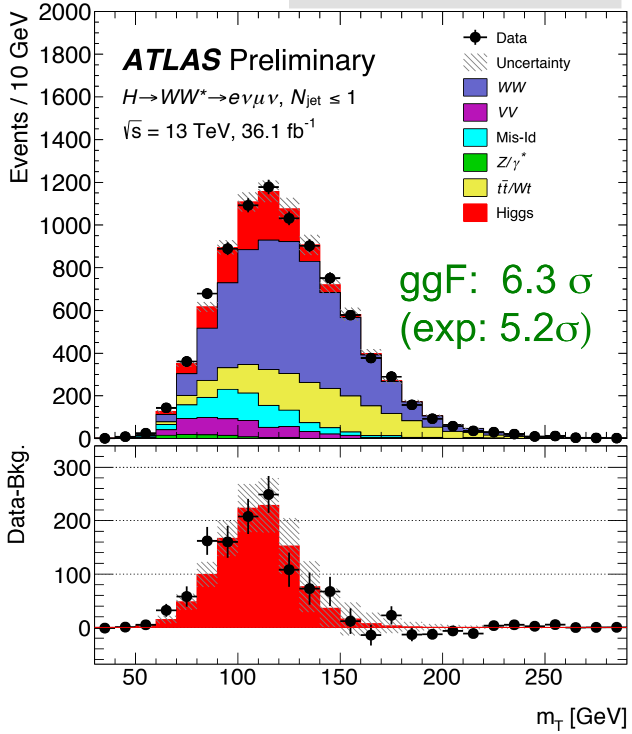


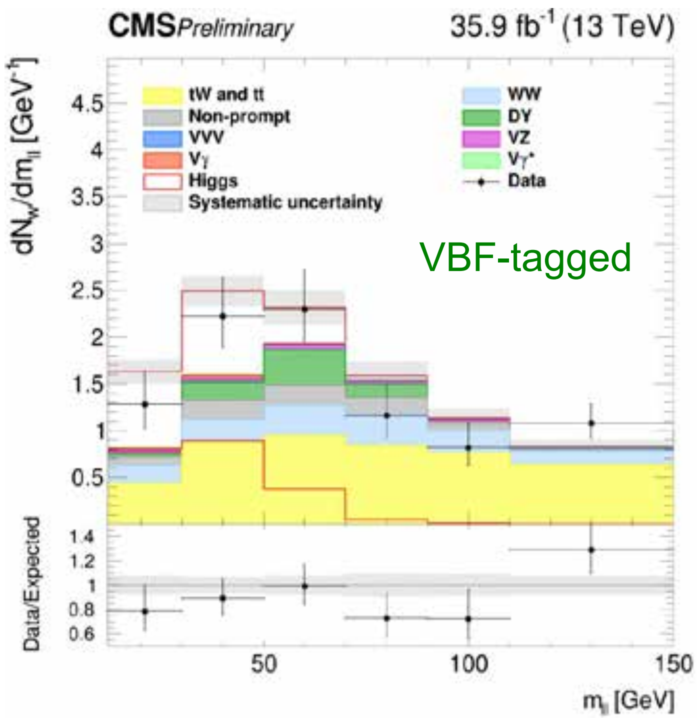
- Data are well described by theoretical calculations (within large uncertainties)
- Such measurements will become important ingredients for future measurements of Higgs boson parameters (Effective Field Theories)

H → WW* → ℓν ℓν signal

- Large branching fraction, however, also severe backgrounds (no mass peak, due to neutrinos)
- → Rely on lepton/jet kinematics (→ transverse mass M_T, di-lepton invariant mass m_{ll}, θ_{ll})

ATLAS-CONF-2018-004



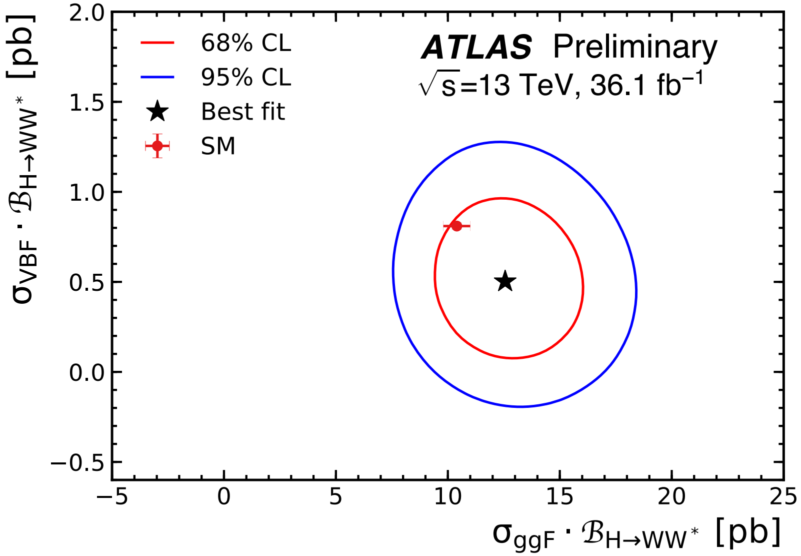


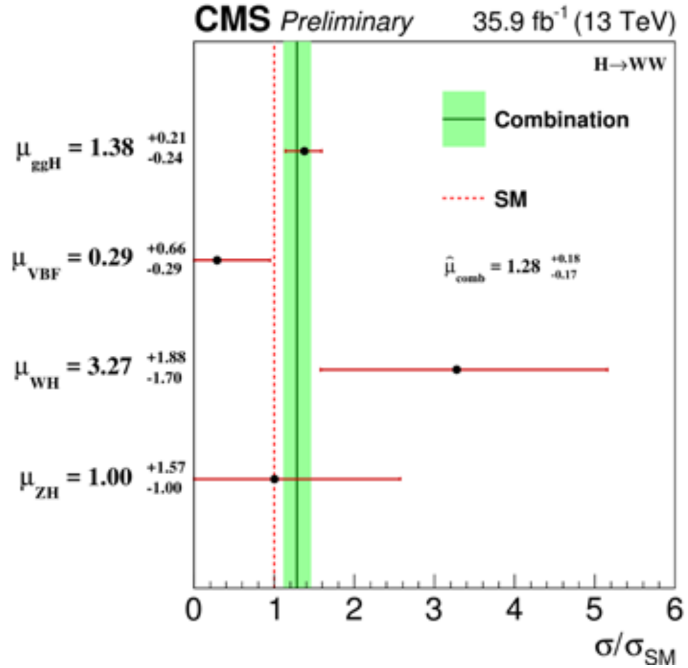
- Very significant excesses visible in the "transverse mass" (ATLAS) and $m_{\ell\ell}$ distributions (CMS)

H → WW* → ℓν ℓν signal

- Due to the large rates, this channel is also well suited to extract precise measurements of the VBF and gluon-fusion components:

ATLAS-CONF-2018-004





ATLAS

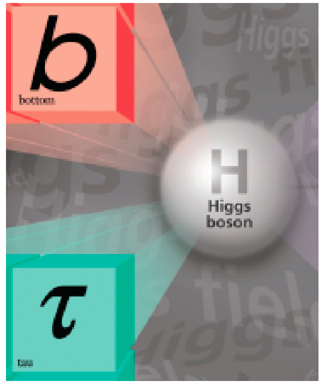
$$\mu_{\mathrm{ggF}} = 1.21^{+0.12}_{-0.11}(\mathrm{stat.})^{+0.18}_{-0.17}(\mathrm{sys.}) = 1.21^{+0.22}_{-0.21}$$

$$\mu_{\mathrm{VBF}} = 0.62^{+0.30}_{-0.28}(\mathrm{stat.}) \pm 0.22(\mathrm{sys.}) = 0.62^{+0.37}_{-0.36}$$

CMS

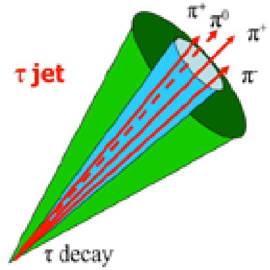
$$\hat{\mu} = 1.28^{+0.18}_{-0.17} = 1.28 \pm 0.10(\mathrm{stat})^{+0.11}_{-0.11}(\mathrm{syst})^{+0.10}_{-0.07}(\mathrm{theo.})$$

Couplings to quarks and leptons ?

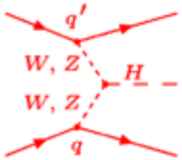


- Search for H → ττ and H → bb decays;

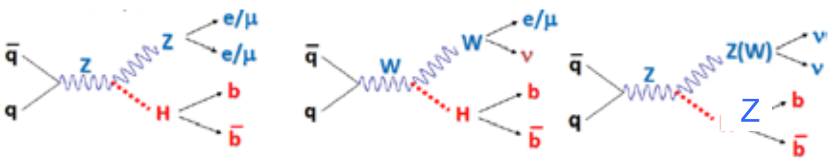
- Challenging signatures due to jets (bb decays) or significant fraction of hadronic tau decays



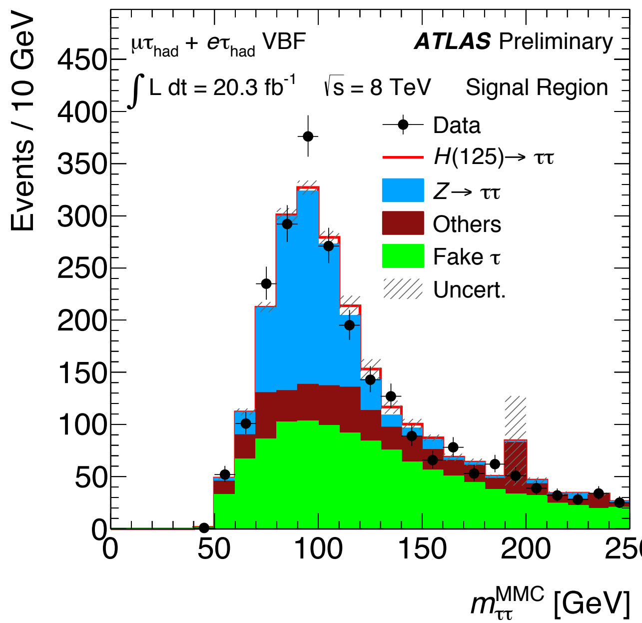
- Vector boson fusion mode essential for H → ττ decays



- Associated production WH, ZH modes have to be used for H → bb decays

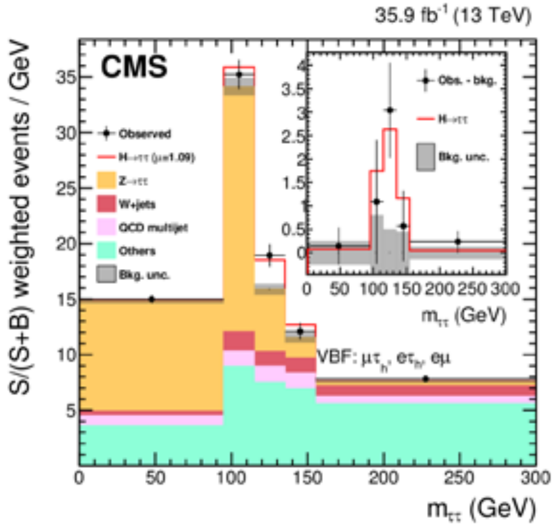


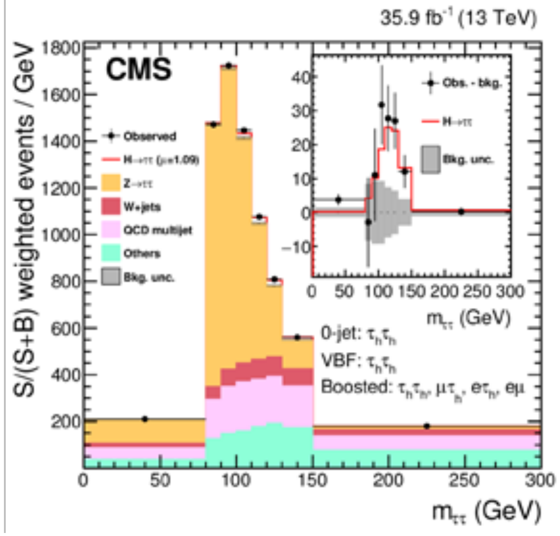
- Exploitation of multivariate analyses



The Higgs Sector: Coupling to Fermions H-> $\tau\tau$

- Search for H → $\tau\tau$ with τ decaying in eμ, μt_h, $e t_h$ and $t_h t_h$
- Largest background from Z→ $\tau\tau$ and hadronic multijet events
- Search in categories aiming at ggH and VBF production

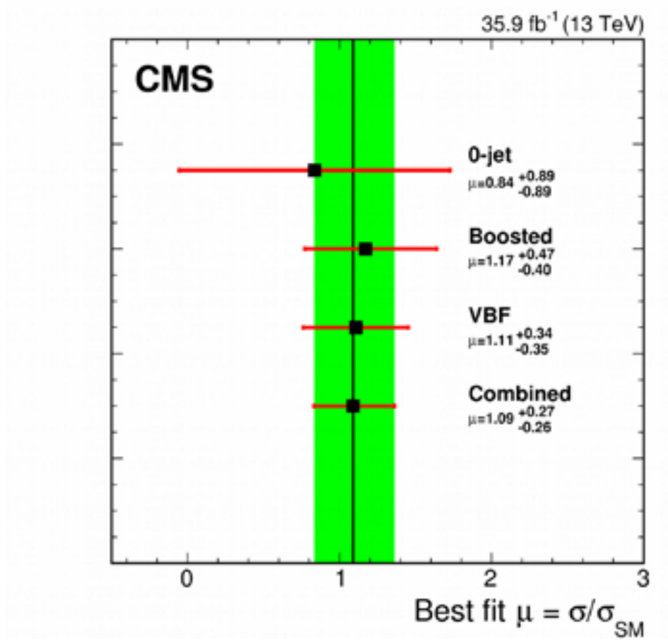


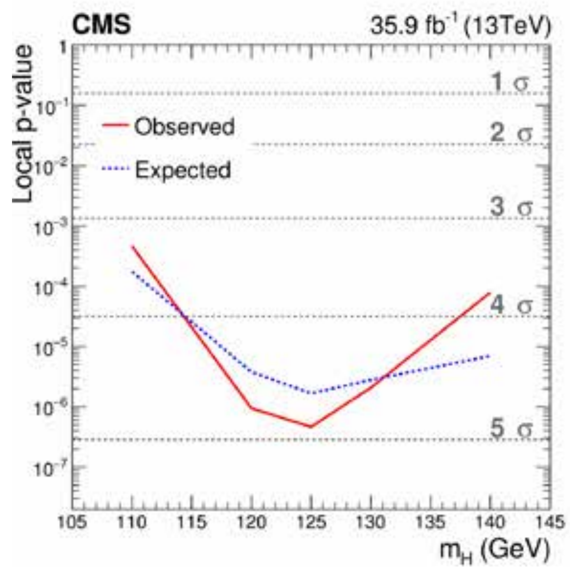


Observation of H → $\tau\tau$
μ= 1.09 ± 0.26

Significance: 4.9σ

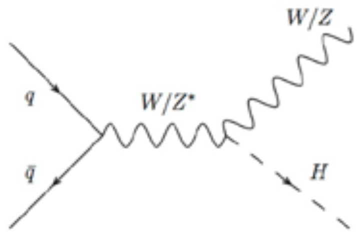
(5.9σ for combination of 13 & 7-8 TeV)



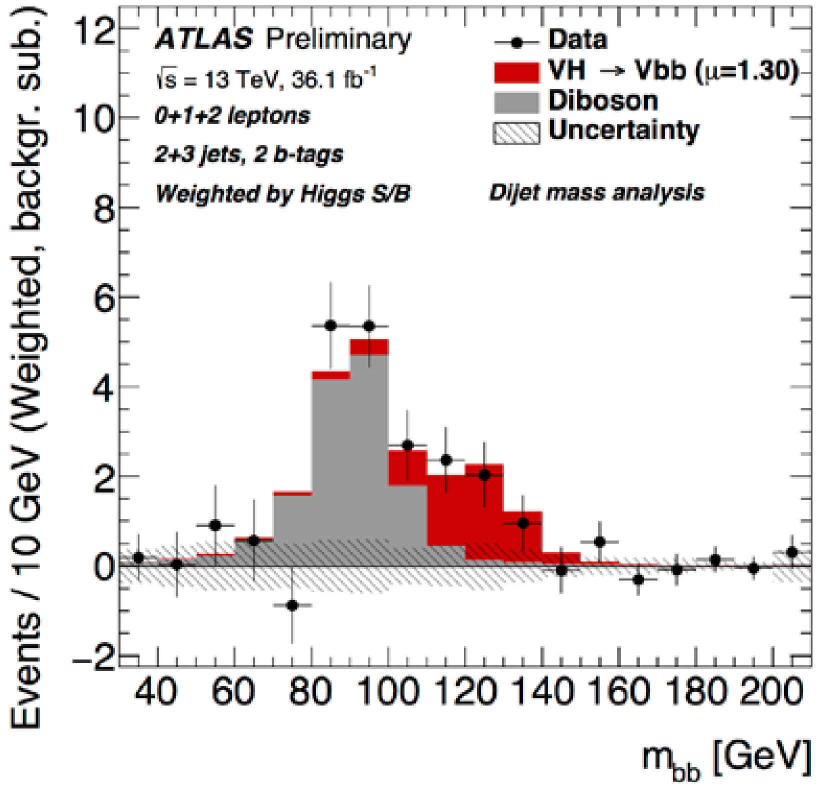


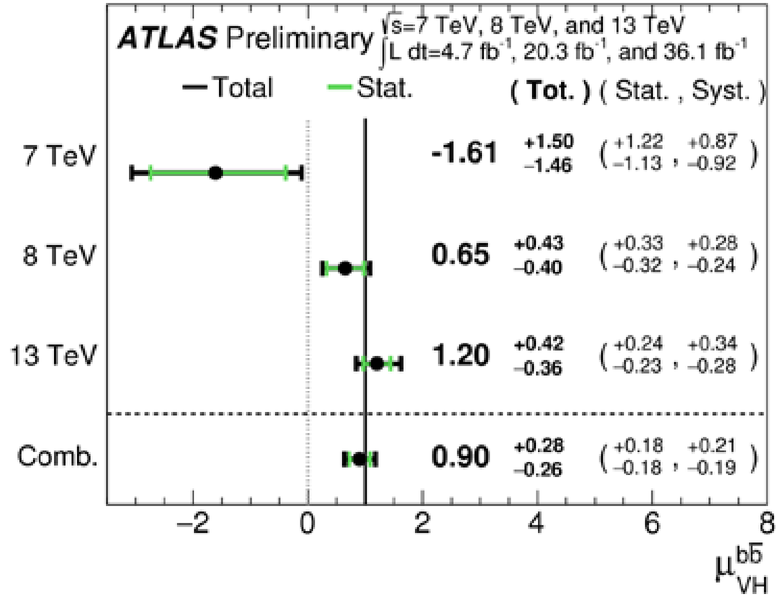
Search for H → bb decays

- H→bb mode dominates Higgs decays (BR~58%)
- Most sensitive channel exploits VH, H→bb (V=W/Z)
- Combined ATLAS+CMS significance 2.6σ (3.7σ expected) from LHC Run-1



- Combination of Z and W final states characterised by lepton multiplicity:
  (2-lepton (Z→ℓℓ), 1-lepton (W→ℓν), and
  0-lepton (Z→νν))

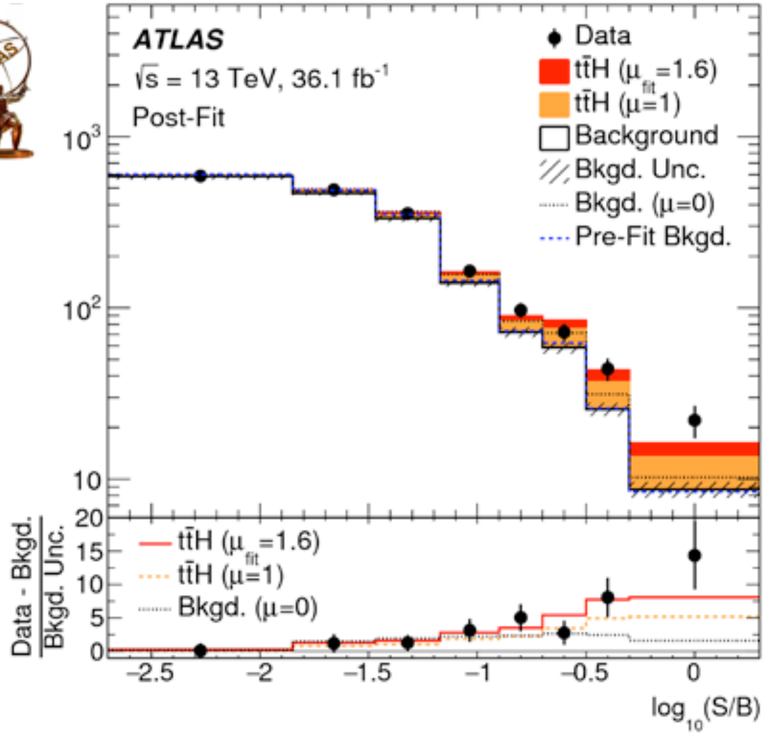


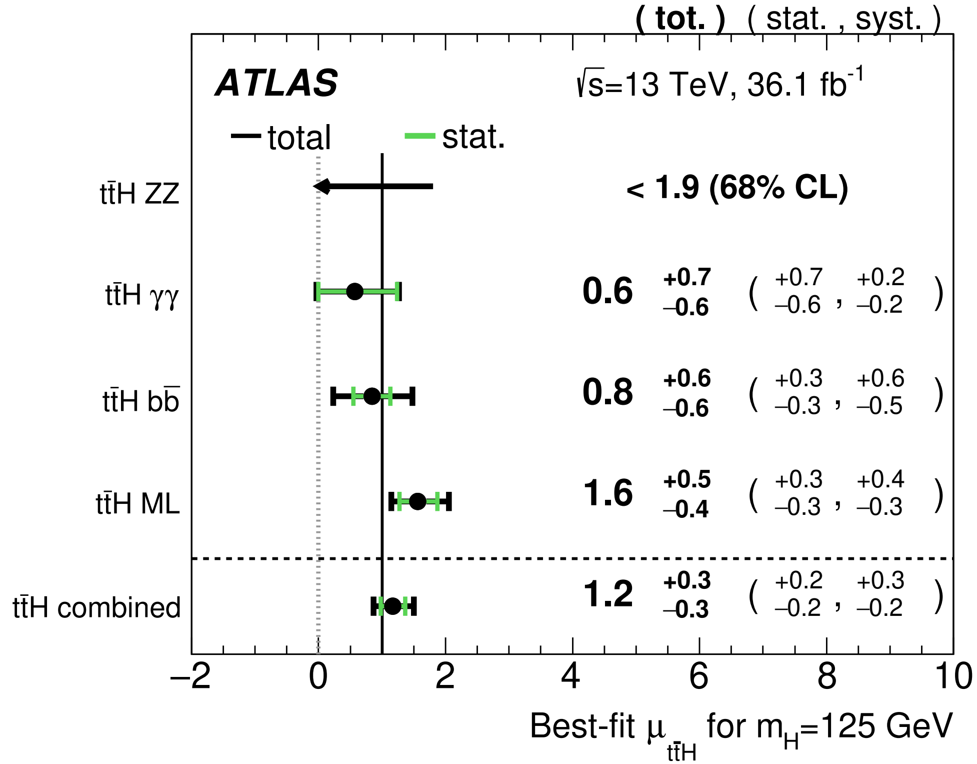


Combination of result with ATLAS Run-1 gives
3.6σ observed (4.0σ expected)

Evidence for ttH production

arXiv:1712.08891, Phys. Rev. D97 (2018) 072003





- Combination of all channels leads to 4.2σ observed (3.8σ expected) (Phys. Rev. D97 (2018) 072003)
  In addition, Run-1 sensitivity of 2.7σ observed (1.8σ expected) (JHEP08 (2016) 045)
- Measured production and decay rates consistent with SM expectation
- Update is planned soon to establish the ttH signal with high sensitivity

Higgs boson mass

The two high resolution channels H → ZZ* → 4ℓ and H → γγ are best suited (reconstructed mass peak, good mass resolution)

Combined results:

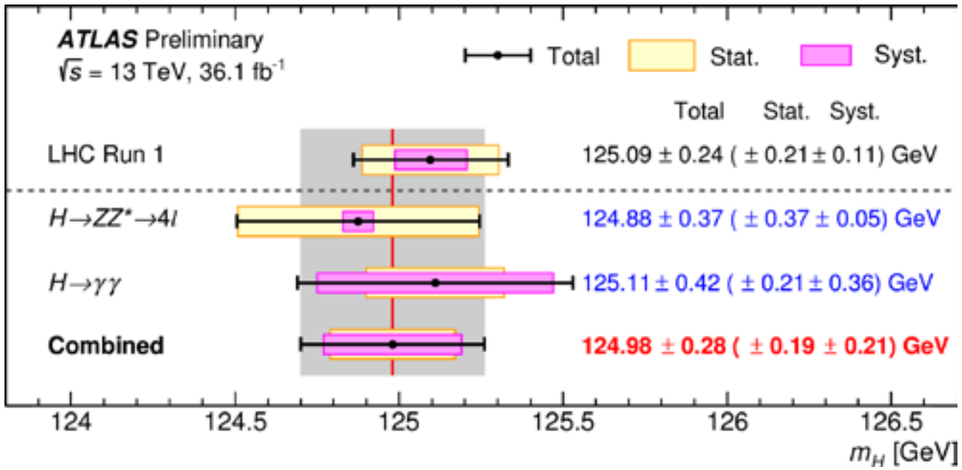
PRL 114 (2015) 191803

ATLAS + CMS: (Run 1)

m_H = 125.09 ± 0.21 (stat) ± 0.11 (syst) GeV

Precision of 0.2%

Updated Run-2 results:



Uncertainties:

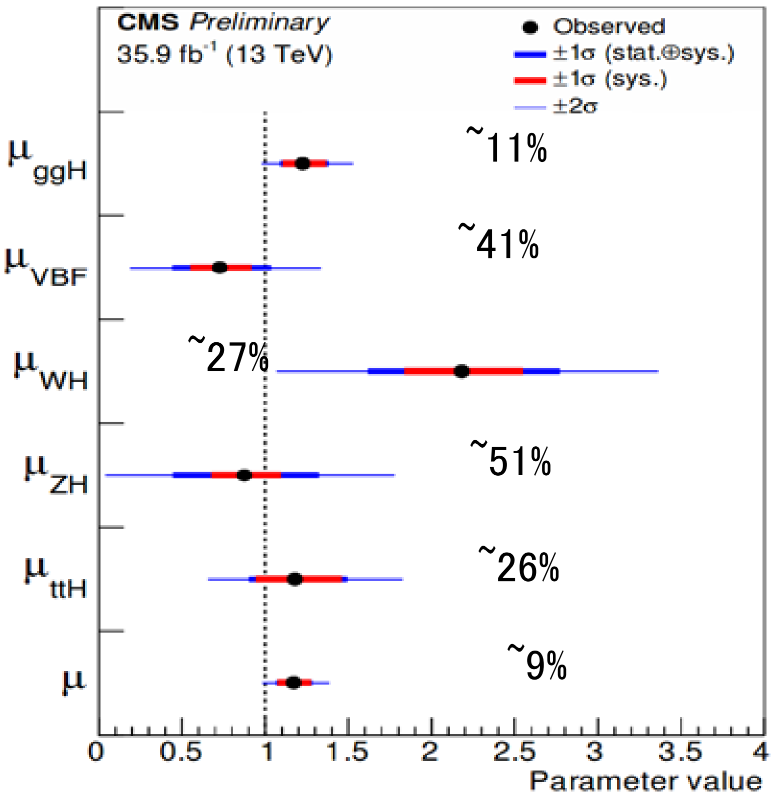
- Statistical uncertainty still dominant
- Major systematic uncertainties: Lepton and photon energy scales and resolutions
- Theoretical uncertainties small (correlated), γγ interference effects neglected

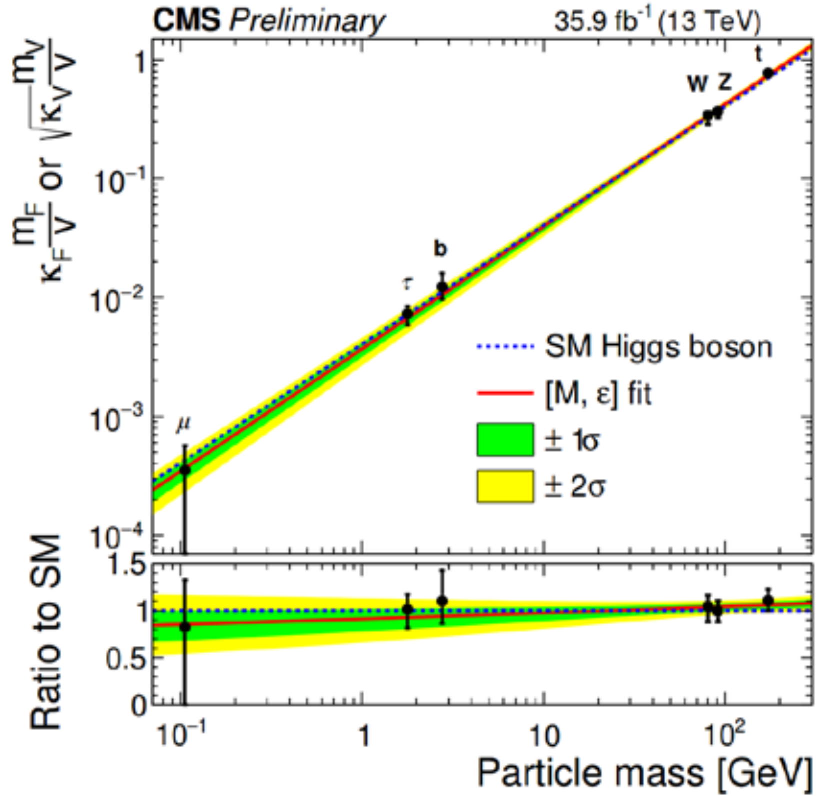
Updated CMS mass measurement is 12% more precise than Run-1 ATLAS+ CMS combination, using only H → ZZ* → 4l

$$m_{\mathrm{H}} = 125.26 \pm 0.21\ (\pm 0.20\ \mathrm{stat.} \pm 0.08\ \mathrm{sys.})\ \mathrm{GeV}$$

CMS Combination of Run-2 results

Higgs boson production

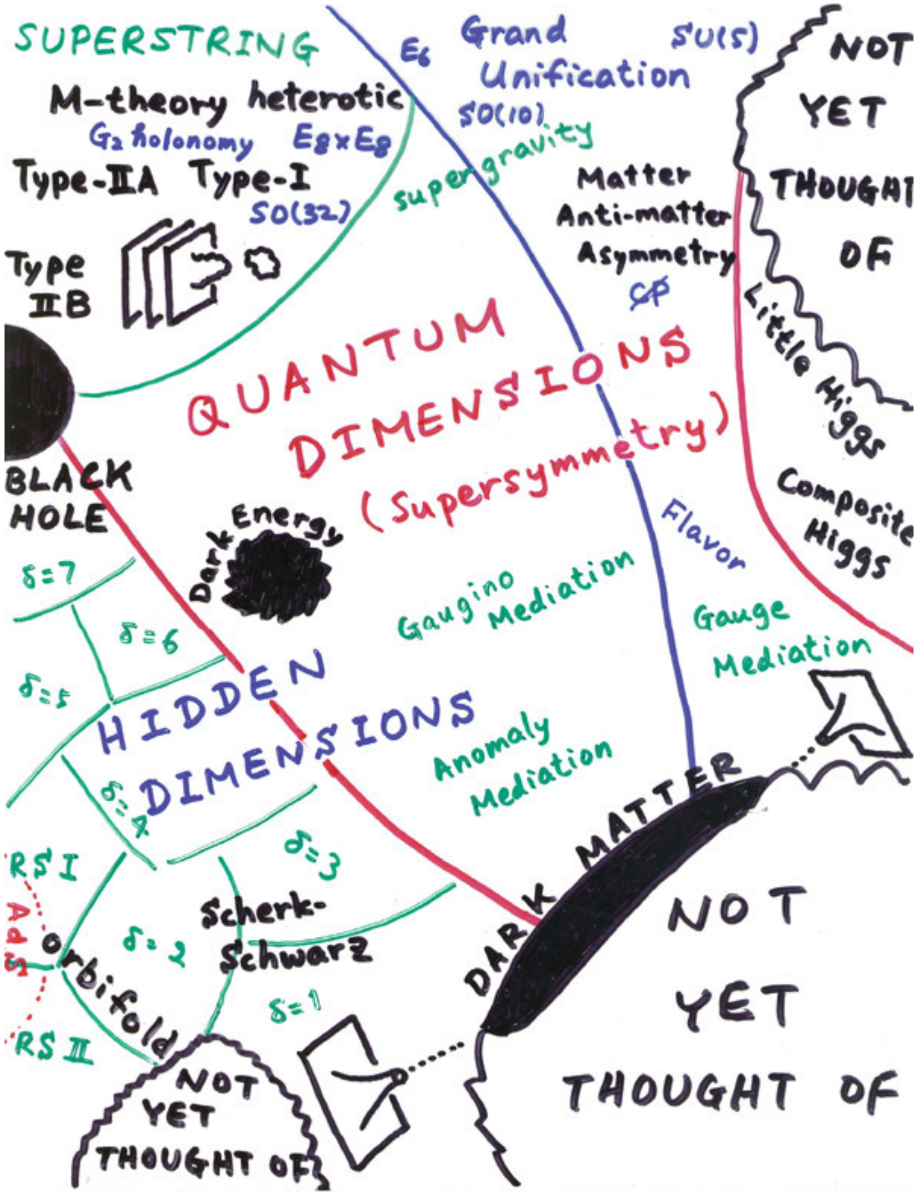




$$\mu = 1.17^{+0.10}_{-0.10}$$

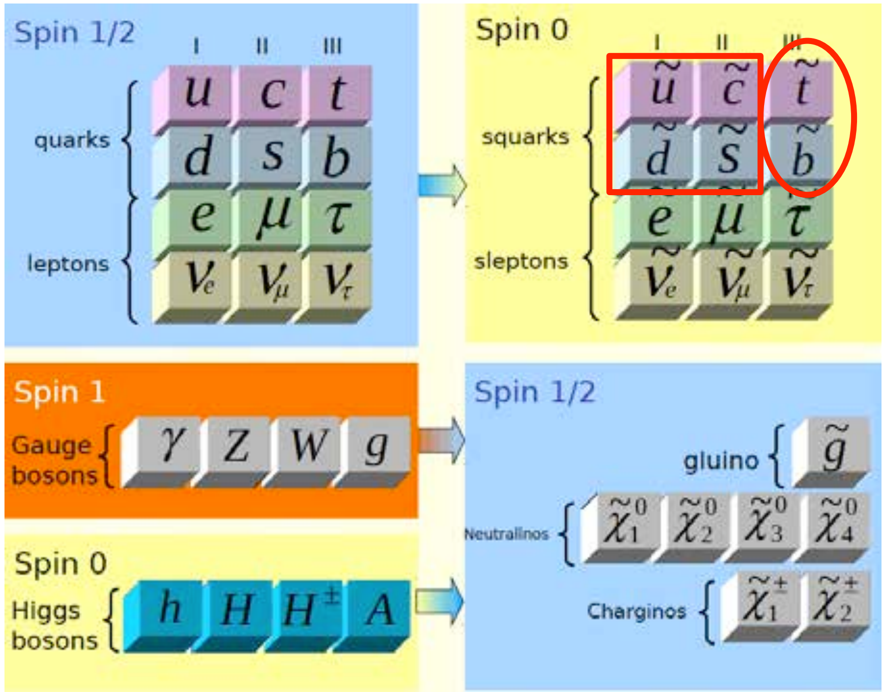
Updated combined results are expected for complete Run-2 dataset

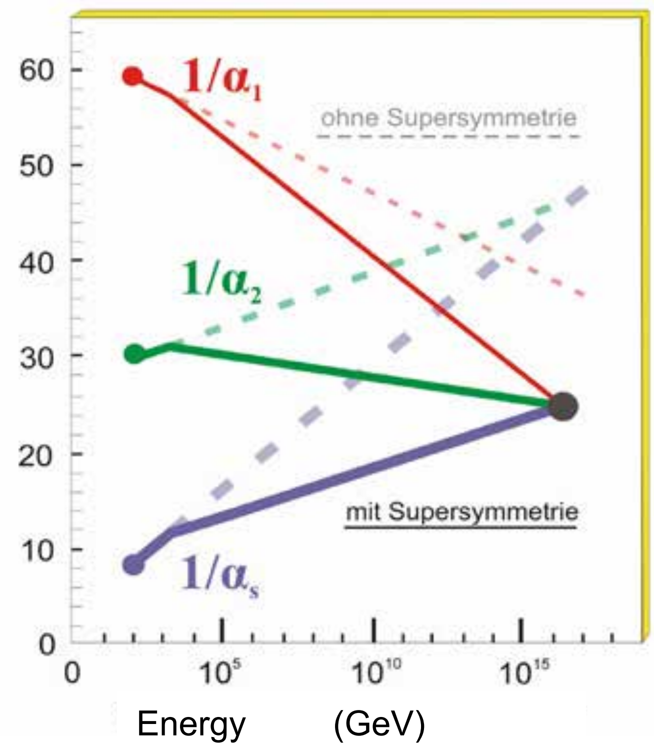
Physics Beyond the Standard Model



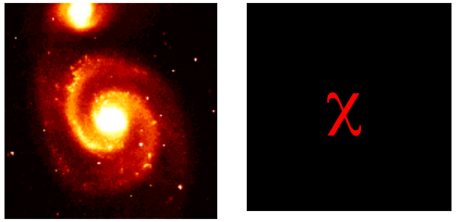
Hitoshi Murayama, IPMU Tokyo & Berkeley

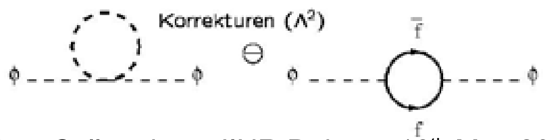
Supersymmetry





Important motivation:
- Supersymmetry provides a candidate for dark matter
- Unification of couplings of the three interactions seems possible
- Quadratically divergent quantum corrections are cancelled

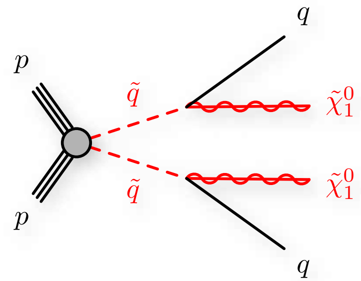


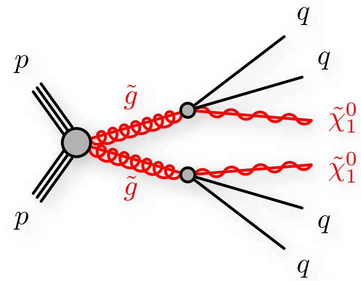


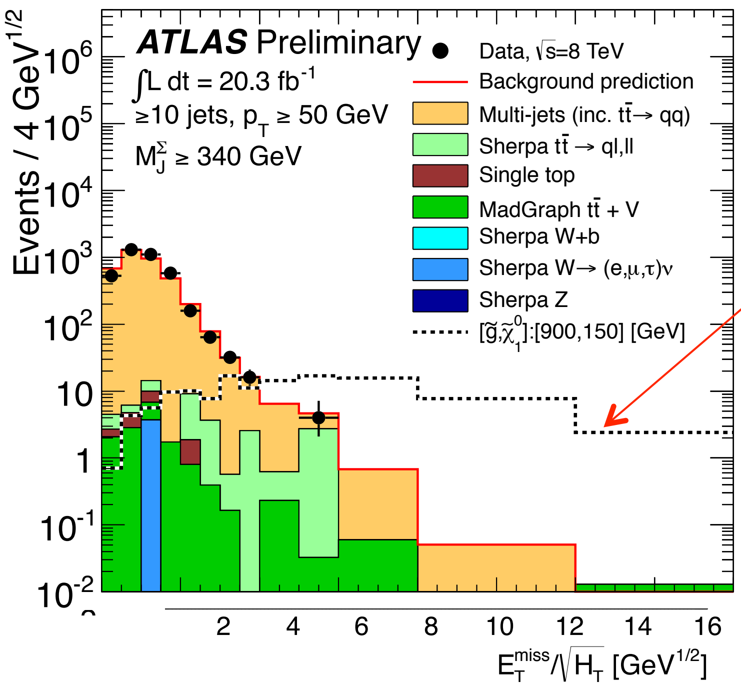
Results on the Search for Supersymmetry

- Example: search for squark and gluino production

- Data are in agreement with predictions from background from Standard Model processes





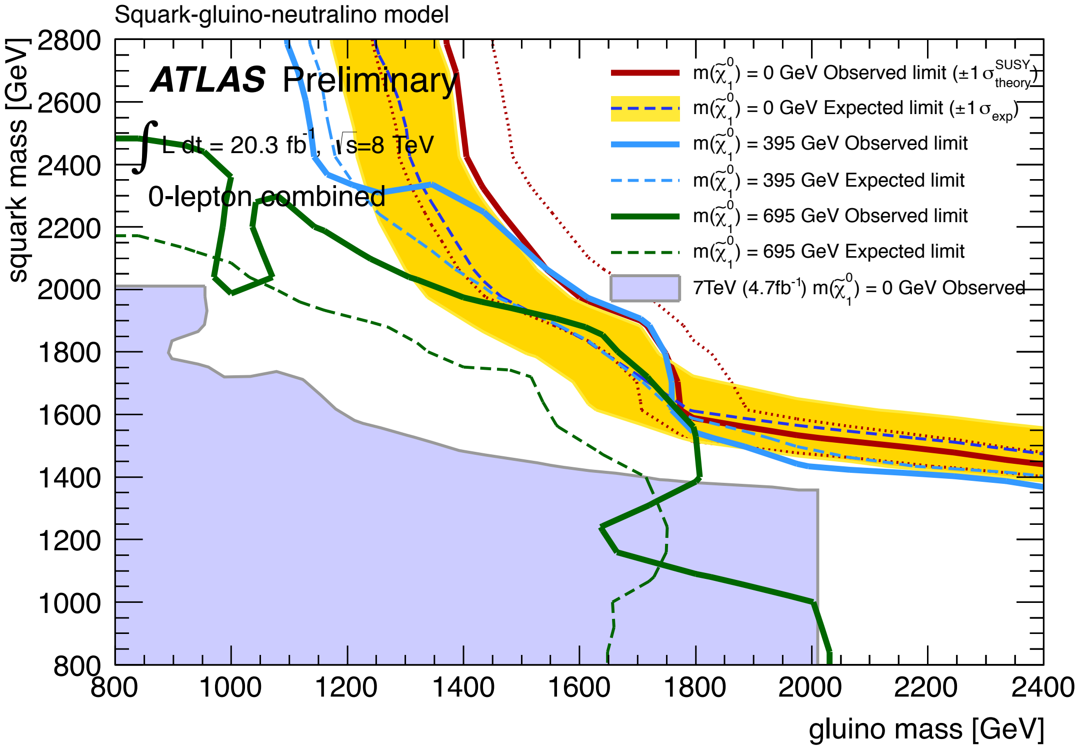


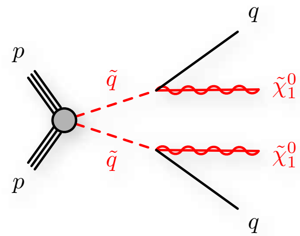
SUSY contribution would show up here

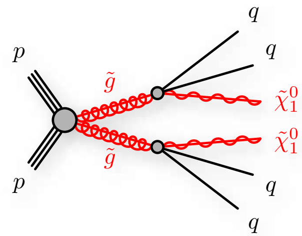
$E_T^{miss} / \sqrt{H_T}$ = missing transverse energy normalized to the square root of the total transverse energy (H_T) seen in the event

Results on the Search for Supersymmetry (Run 1)

→ Exclusion limits are set on masses of these particles







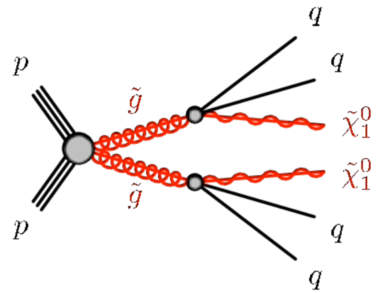
m(squark), m(gluino) > 1.4 TeV (95% CL) for the partners of the first two generations and light LSPs

however:

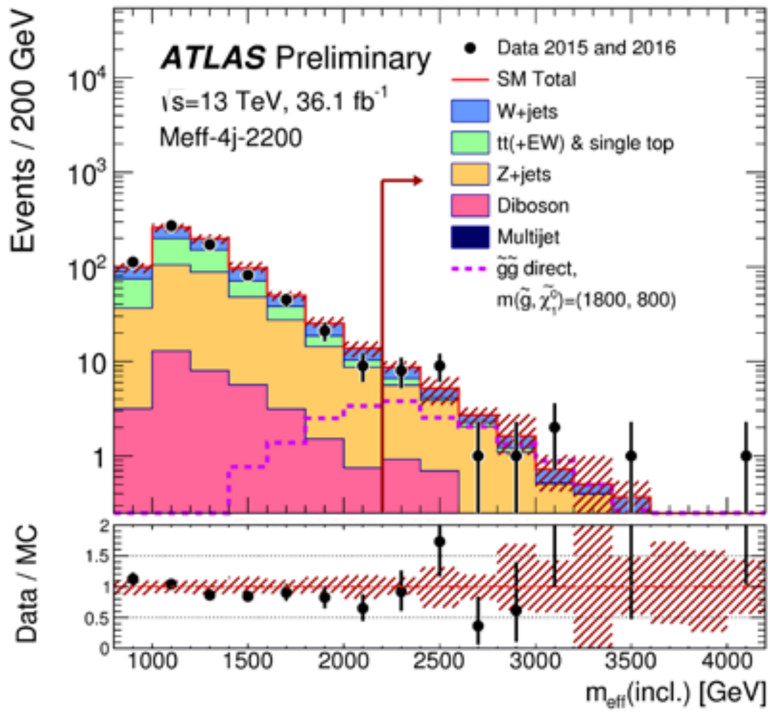
- Mass limits depend on assumptions on m_χ (LSP)
- So far, simple decay scenarios investigated (not most general search)
- Mass limits for third generation squarks are weaker

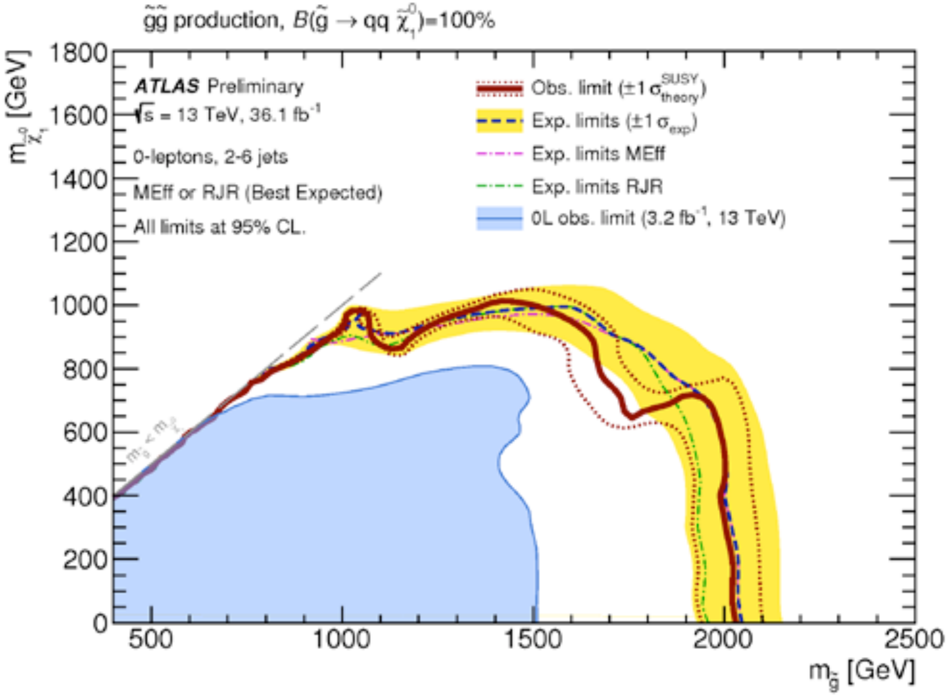
Search for Supersymmetry

-Important new results with complete Run-2 dataset-



ATLAS-CONF-2017-022





Data well described by expectations from SM processes

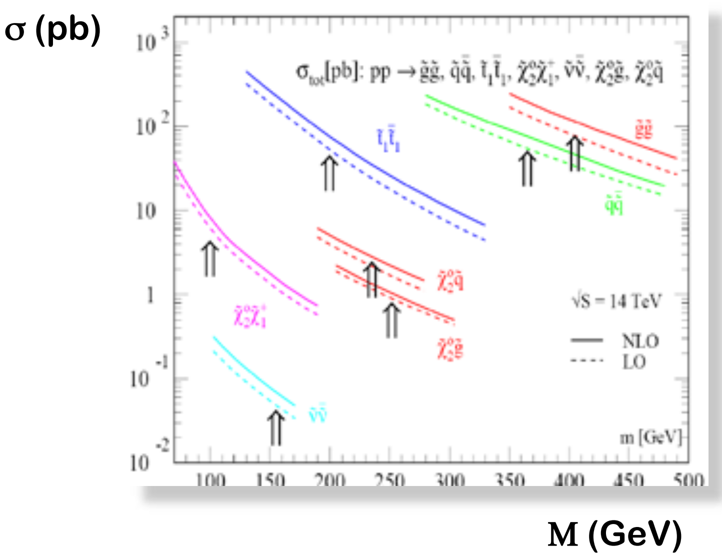
Gluino mass limit beyond 2 TeV, $m(\chi^0) = 0$

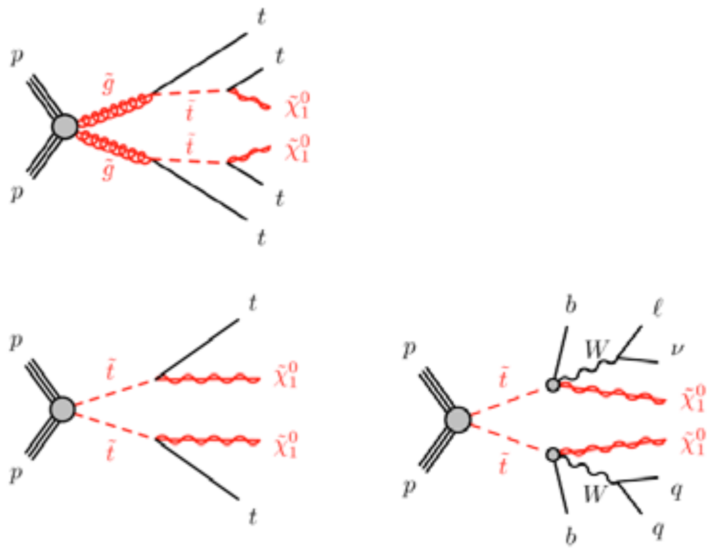
The special role of top squarks (stops)

- The partners of the top (bottom) quarks might be the lightest squarks, whereas all other squarks might be too heavy to be produced at the LHC;

- Light stops could solve the so-called “hierarchy” problem (cancellation of large quantum corrections to the Higgs boson mass) “Natural SUSY”

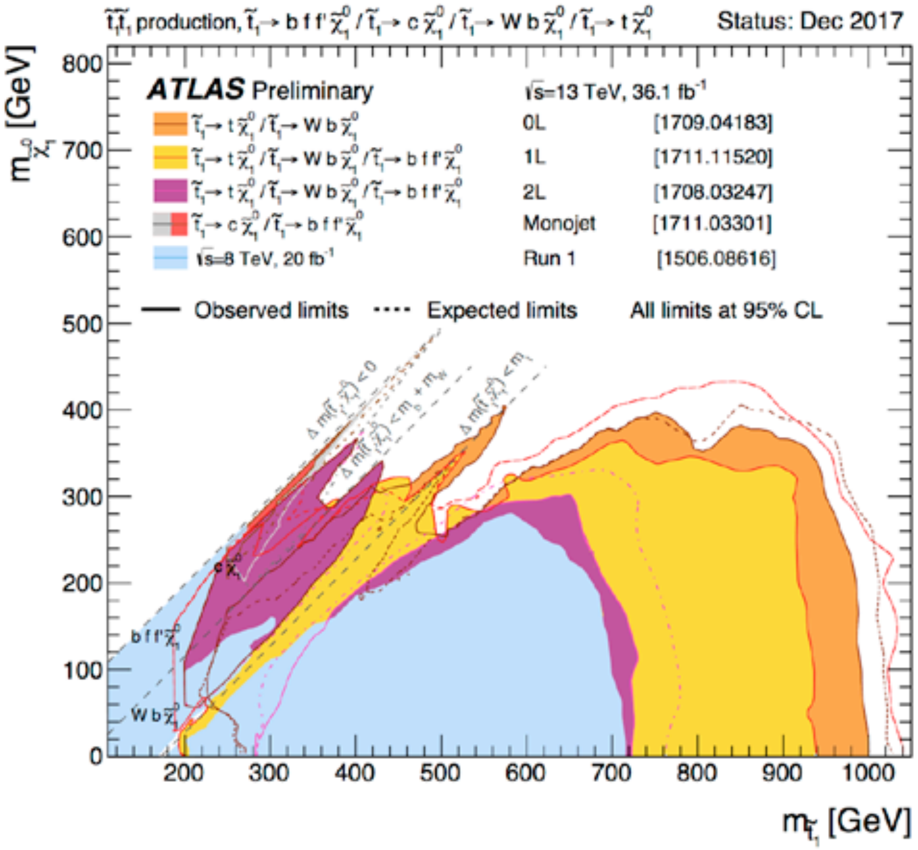
- Production of stops and sbottoms is significantly weaker at the LHC





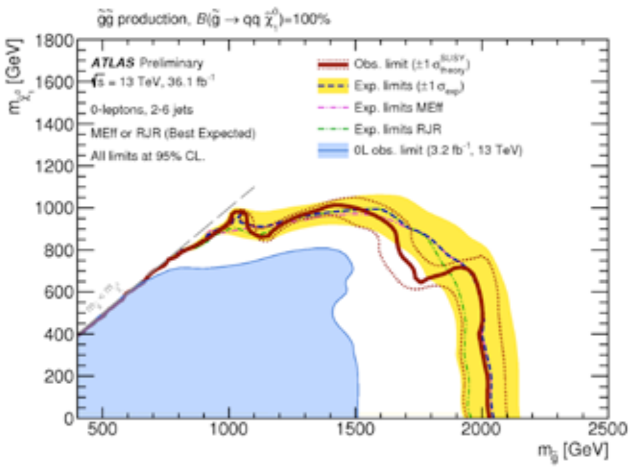
- They might appear in gluino decays or via direct production (smaller rates)

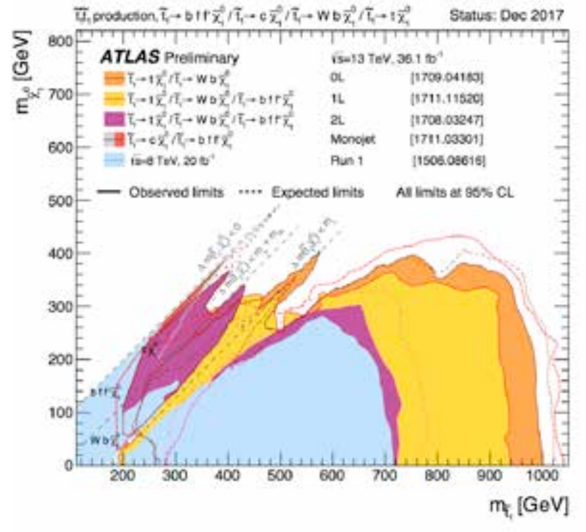
Results on dedicated searches for stop quarks



- Weaker mass limits for partners of the top quark (lower production rate, tt background)

- However, significant progress, with mass limits ~1 TeV (light neutralinos), including coverage for complex decay scenarios

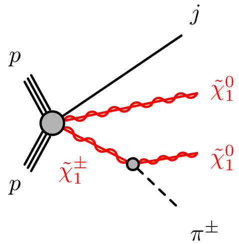


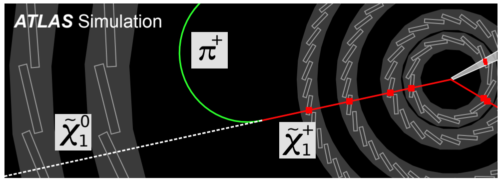


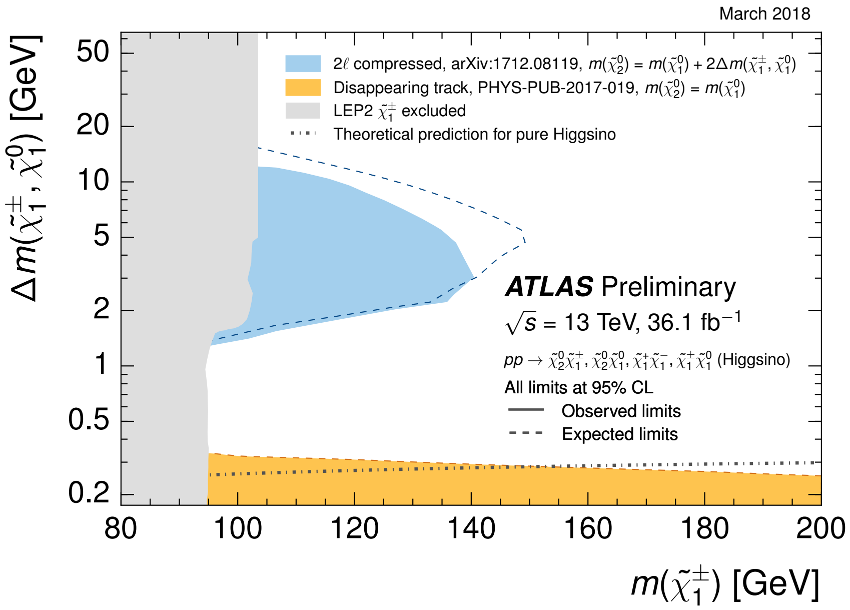
Is SUSY dead ?

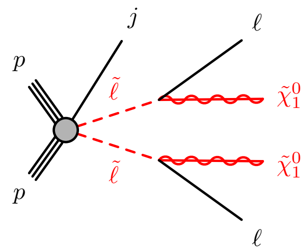
- *"Under attack from all sides, but not dead yet."*
- Some of the simplest models are ruled out, however, interpretations rely on many simplifying assumptions.
- Plausible "natural" scenarios still not ruled out;
  - RPV scenarios have fewer constraints.
  - Search for electroweak SUSY production → higher luminosity required
  - Addressing more difficult corners of phase space

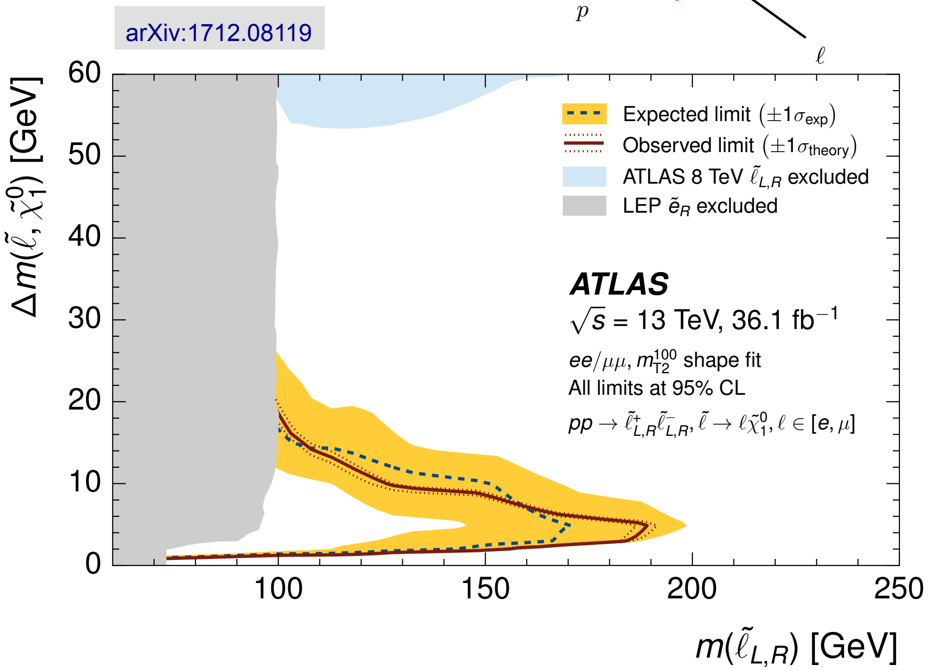
Electroweak SUSY sensitivity beyond LEP limits











Interesting limits for electroweak SUSY production with compressed mass states
(left): First direct Higgsino constraints from ATLAS (combination of several analyses)

(right): Exclusion of slepton masses up to 190 GeV

ATLAS Exotics Searches* - 95% CL Upper Exclusion Limits

Status: July 2017

ATLAS Preliminary

$\int \mathcal{L}\, dt = (3.2 - 37.0)\ \mathrm{fb}^{-1}$ $\sqrt{s} = 8, 13$ TeV

	Model	ℓ, γ	Jets†	E_T^{miss}	$\int \mathcal{L}\, dt [\mathrm{fb}^{-1}]$	Limit		Reference
Extra dimensions	ADD $G_{KK} + g/q$	$0\ e, \mu$	1 – 4 j	Yes	36.1	M_D 7.75 TeV	$n = 2$	ATLAS-CONF-2017-060
	ADD non-resonant $\gamma\gamma$	$2\ \gamma$	–	–	36.7	M_S 8.6 TeV	$n = 3$ HLZ NLO	CERN-EP-2017-132
	ADD QBH	–	2 j	–	37.0	M_{th} 8.9 TeV	$n = 6$	1703.09217
	ADD BH high $\sum p_T$	$\geq 1\ e, \mu$	≥ 2 j	–	3.2	M_{th} 8.2 TeV	$n = 6$, $M_D = 3$ TeV, rot BH	1606.02265
	ADD BH multijet	–	≥ 3 j	–	3.6	M_{th} 9.55 TeV	$n = 6$, $M_D = 3$ TeV, rot BH	1512.02586
	RS1 $G_{KK} \to \gamma\gamma$	$2\ \gamma$	–	–	36.7	G_{KK} mass 4.1 TeV	$k/\overline{M}_{Pl} = 0.1$	CERN-EP-2017-132
	Bulk RS $G_{KK} \to WW \to qq\ell\nu$	$1\ e, \mu$	1 J	Yes	36.1	G_{KK} mass 1.75 TeV	$k/\overline{M}_{Pl} = 1.0$	ATLAS-CONF-2017-051
	2UED / RPP	$1\ e, \mu$	≥ 2 b, ≥ 3 j	Yes	13.2	KK mass 1.6 TeV	Tier (1,1), $\mathcal{B}(A^{(1,1)} \to tt) = 1$	ATLAS-CONF-2016-104
Gauge bosons	SSM $Z' \to \ell\ell$	$2\ e, \mu$	–	–	36.1	Z' mass 4.5 TeV		ATLAS-CONF-2017-027
	SSM $Z' \to \tau\tau$	$2\ \tau$	–	–	36.1	Z' mass 2.4 TeV		ATLAS-CONF-2017-050
	Leptophobic $Z' \to bb$	–	2 b	–	3.2	Z' mass 1.5 TeV		1603.08791
	Leptophobic $Z' \to tt$	$1\ e, \mu$	≥ 1 b, ≥ 1J/2j	Yes	3.2	Z' mass 2.0 TeV	$\Gamma/m = 3\%$	ATLAS-CONF-2016-014
	SSM $W' \to \ell\nu$	$1\ e, \mu$	–	Yes	36.1	W' mass 5.1 TeV		1706.04786
	HVT $V' \to WV \to qqqq$ model B	$0\ e, \mu$	2 J	–	36.7	V' mass 3.5 TeV	$g_V = 3$	CERN-EP-2017-147
	HVT $V' \to WH/ZH$ model B	multi-channel			36.1	V' mass 2.93 TeV	$g_V = 3$	ATLAS-CONF-2017-055
	LRSM $W'_R \to tb$	$1\ e, \mu$	2 b, 0-1 j	Yes	20.3	W' mass 1.92 TeV		1410.4103
	LRSM $W'_R \to tb$	$0\ e, \mu$	≥ 1 b, 1 J	–	20.3	W' mass 1.76 TeV		1408.0886
CI	CI $qqqq$	–	2 j	–	37.0	Λ 21.8 TeV η_{LL}^-		1703.09217
	CI $\ell\ell qq$	$2\ e, \mu$	–	–	36.1	Λ 40.1 TeV η_{LL}^-		ATLAS-CONF-2017-027
	CI $uutt$	2(SS)/≥3 e,μ	≥1 b, ≥1 j	Yes	20.3	Λ 4.9 TeV	$\lvert C_{RR}\rvert = 1$	1504.04605
DM	Axial-vector mediator (Dirac DM)	$0\ e, \mu$	1 – 4 j	Yes	36.1	m_{med} 1.5 TeV	g_q=0.25, g_χ=1.0, $m(\chi) < 400$ GeV	ATLAS-CONF-2017-060
	Vector mediator (Dirac DM)	$0\ e, \mu, 1\ \gamma$	≤ 1 j	Yes	36.1	m_{med} 1.2 TeV	g_q=0.25, g_χ=1.0, $m(\chi) < 480$ GeV	1704.03848
	$VV\chi\chi$ EFT (Dirac DM)	$0\ e, \mu$	1 J, ≤ 1 j	Yes	3.2	M_* 700 GeV	$m(\chi) < 150$ GeV	1608.02372
LQ	Scalar LQ 1st gen	$2\ e$	≥ 2 j	–	3.2	LQ mass 1.1 TeV	$\beta = 1$	1605.06035
	Scalar LQ 2nd gen	$2\ \mu$	≥ 2 j	–	3.2	LQ mass 1.05 TeV	$\beta = 1$	1605.06035
	Scalar LQ 3rd gen	$1\ e, \mu$	≥1 b, ≥3 j	Yes	20.3	LQ mass 640 GeV	$\beta = 0$	1508.04735
Heavy quarks	VLQ $TT \to Ht + X$	0 or 1 e, μ	≥ 2 b, ≥ 3 j	Yes	13.2	T mass 1.2 TeV	$\mathcal{B}(T \to Ht) = 1$	ATLAS-CONF-2016-104
	VLQ $TT \to Zt + X$	$1\ e, \mu$	≥ 1 b, ≥ 3 j	Yes	36.1	T mass 1.16 TeV	$\mathcal{B}(T \to Zt) = 1$	1705.10751
	VLQ $TT \to Wb + X$	$1\ e, \mu$	≥ 1 b, ≥ 1J/2j	Yes	36.1	T mass 1.35 TeV	$\mathcal{B}(T \to Wb) = 1$	CERN-EP-2017-094
	VLQ $BB \to Hb + X$	$1\ e, \mu$	≥ 2 b, ≥ 3 j	Yes	20.3	B mass 700 GeV	$\mathcal{B}(B \to Hb) = 1$	1505.04306
	VLQ $BB \to Zb + X$	2/≥3 e, μ	≥2/≥1 b	–	20.3	B mass 790 GeV	$\mathcal{B}(B \to Zb) = 1$	1409.5500
	VLQ $BB \to Wt + X$	$1\ e, \mu$	≥ 1 b, ≥ 1J/2j	Yes	36.1	B mass 1.25 TeV	$\mathcal{B}(B \to Wt) = 1$	CERN-EP-2017-094
	VLQ $QQ \to WqWq$	$1\ e, \mu$	≥ 4 j	Yes	20.3	Q mass 690 GeV		1509.04261
Excited fermions	Excited quark $q^* \to qg$	–	2 j	–	37.0	q^* mass 6.0 TeV	only u^* and d^*, $\Lambda = m(q^*)$	1703.09127
	Excited quark $q^* \to q\gamma$	$1\ \gamma$	1 j	–	36.7	q^* mass 5.3 TeV	only u^* and d^*, $\Lambda = m(q^*)$	CERN-EP-2017-148
	Excited quark $b^* \to bg$	–	1 b, 1 j	–	13.3	b^* mass 2.3 TeV		ATLAS-CONF-2016-060
	Excited quark $b^* \to Wt$	1 or 2 e, μ	1 b, 2-0 j	Yes	20.3	b^* mass 1.5 TeV	$f_g = f_L = f_R = 1$	1510.02664
	Excited lepton ℓ^*	$3\ e, \mu$	–	–	20.3	ℓ^* mass 3.0 TeV	$\Lambda = 3.0$ TeV	1411.2921
	Excited lepton ν^*	$3\ e, \mu, \tau$	–	–	20.3	ν^* mass 1.6 TeV	$\Lambda = 1.6$ TeV	1411.2921
Other	LRSM Majorana ν	$2\ e, \mu$	2 j	–	20.3	N^0 mass 2.0 TeV	$m(W_R) = 2.4$ TeV, no mixing	1506.06020
	Higgs triplet $H^{\pm\pm} \to \ell\ell$	2,3,4 e, μ (SS)	–	–	36.1	$H^{\pm\pm}$ mass 870 GeV	DY production	ATLAS-CONF-2017-053
	Higgs triplet $H^{\pm\pm} \to \ell\tau$	$3\ e, \mu, \tau$	–	–	20.3	$H^{\pm\pm}$ mass 400 GeV	DY production, $\mathcal{B}(H_L^{\pm\pm} \to \ell\tau) = 1$	1411.2921
	Monotop (non-res prod)	$1\ e, \mu$	1 b	Yes	20.3	spin-1 invisible particle mass 657 GeV	$a_{\text{non-res}} = 0.2$	1410.5404
	Multi-charged particles	–	–	–	20.3	multi-charged particle mass 785 GeV	DY production, $\lvert q\rvert = 5e$	1504.04188
	Magnetic monopoles	–	–	–	7.0	monopole mass 1.34 TeV	DY production, $\lvert g\rvert = 1g_D$, spin 1/2	1509.08059

$\sqrt{s} = 8$ TeV $\sqrt{s} = 13$ TeV

Mass scale [TeV] (10^{-1}, 1, 10)

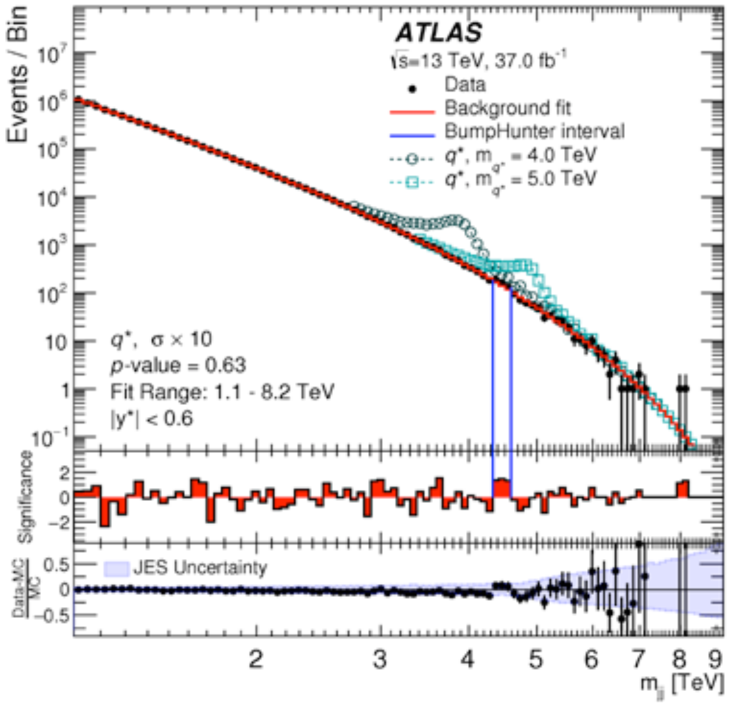
*Only a selection of the available mass limits on new states or phenomena is shown.

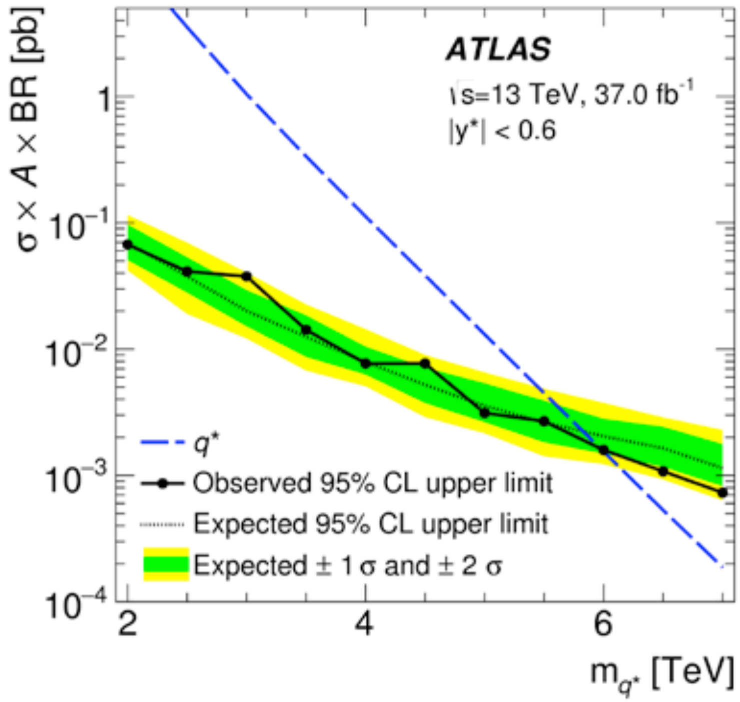
†Small-radius (large-radius) jets are denoted by the letter j (J).

Search for new phenomena in di-jet events

- First publication on complete Run-2 (2015+2016) dataset: 37.0 fb^{-1} at $\sqrt{s}$ = 13 TeV

arXiv:1703.09127





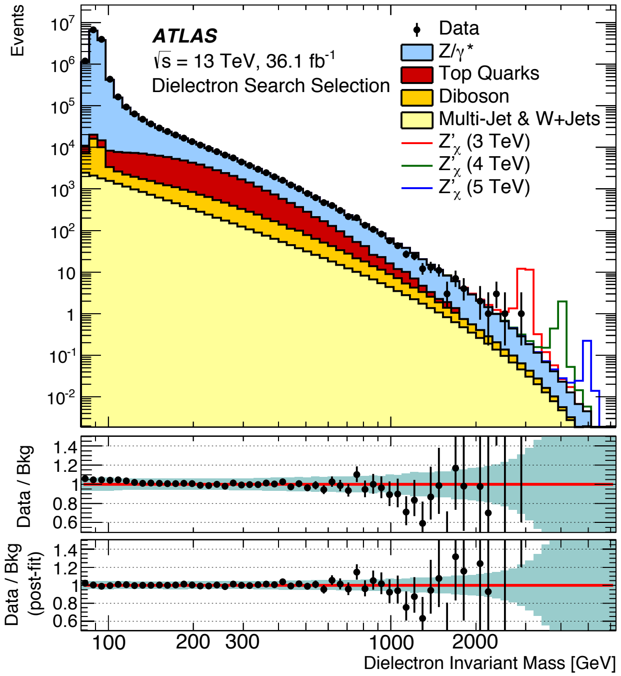
- 95% CL exclusion limits:

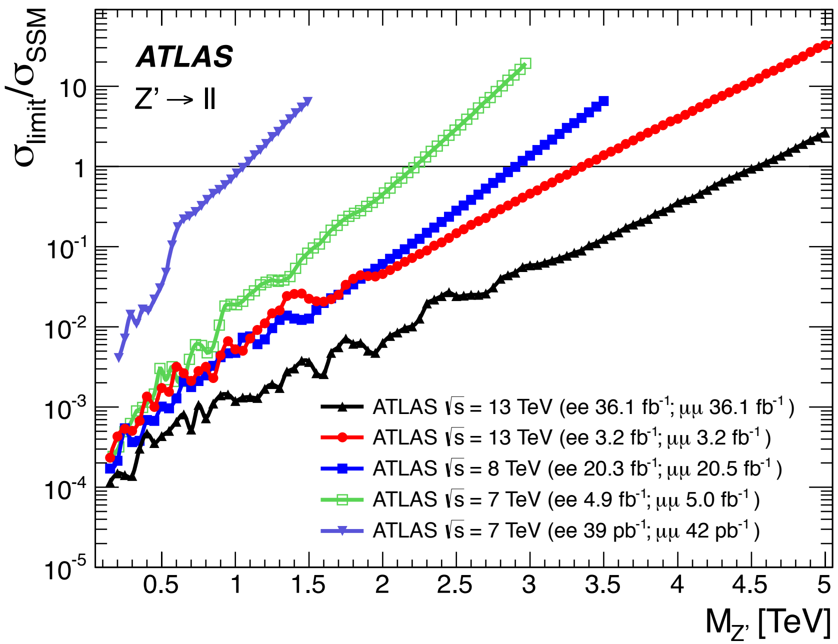
Excited quarks	m_{q*} > 6.0 TeV	(5.8 TeV exp.)
Add. gauge bosons:	$m_{W'}$ > 3.6 TeV	(3.7 TeV exp.)
Quantum Black Holes:	m_{BH} > 8.9 TeV	(8.9 TeV exp.)
Contact Interactions:	Λ > 13.1 TeV (η_{LL} = +1)	
	Λ > 21.8 TeV (η_{LL} = -1)	

Search for di-lepton resonances

- Search is based on complete Run-2 (2015+2016) dataset: 36.1 fb^{-1} at $\sqrt{s}$ = 13 TeV

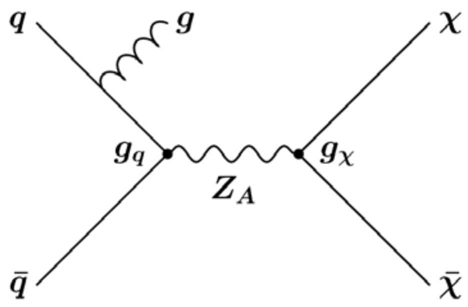
arXiv:1707.02424





- No significant deviations from the Standard Model expectations observed
  → resulting lower mass limits, e.g. m(Z'_{SSM}) > 4.5 TeV (95% C.L.)
  significant improvement w.r.t. Run 1 (due to higher energy)
- In addition: no indication of contact interactions, energy scale $\Lambda_{\ell\ell qq}$ > 23.5 - 40.1 TeV

Searches for Dark Matter particles (using signatures with large E_T^{miss})



- Mono-jet
- Mono-photon
- Mono-W or mono-Z
- Mono Higgs (H → bb)
- Mono-top

Example: mono-jet search, E_T^{miss} spectrum

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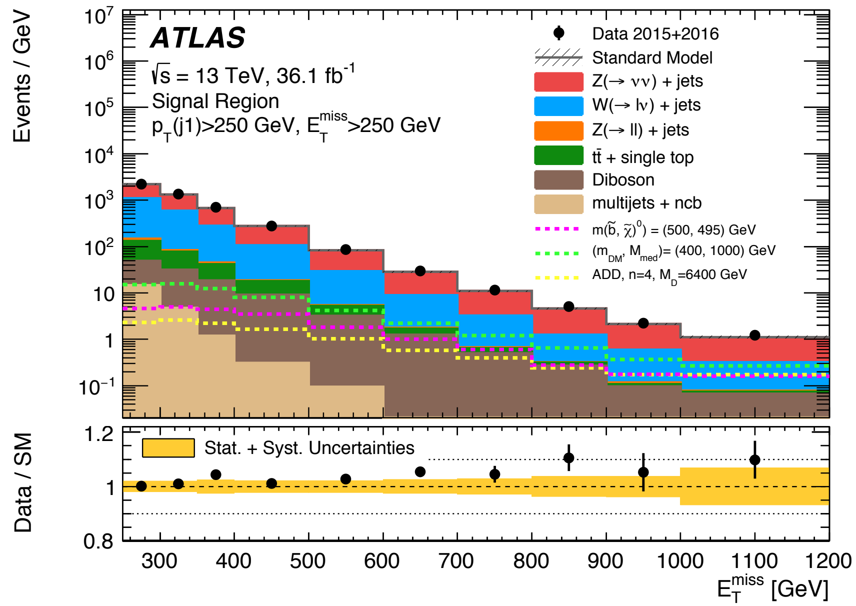
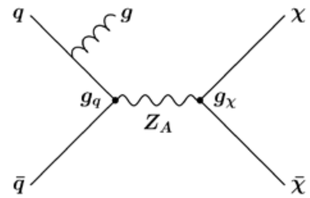


Data are in good agreement with the expectations from Standard Model processes

(applies to all mono-X searches)

Interpretation on searches for Dark Matter:



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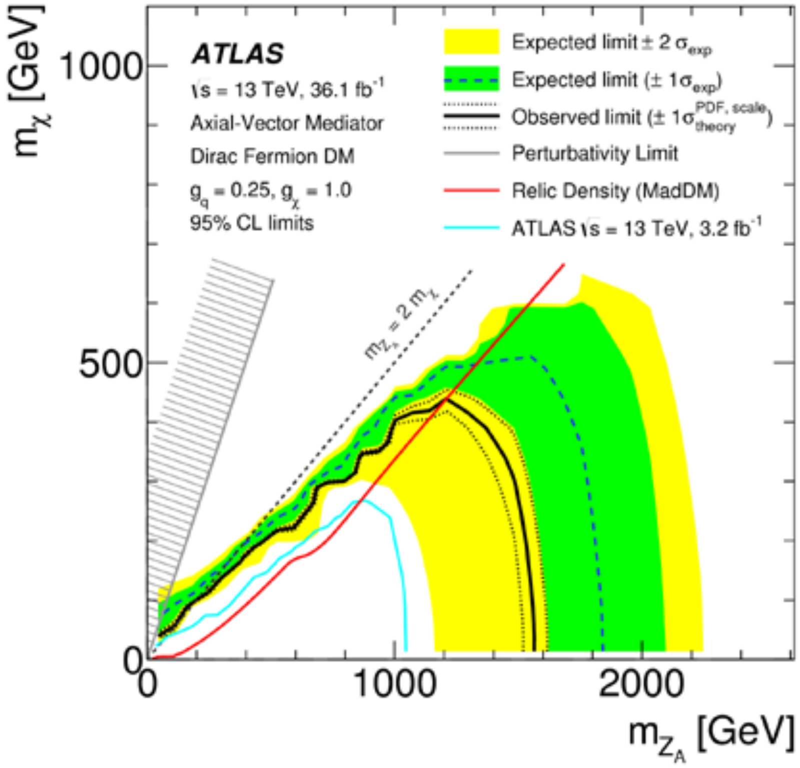

95% CL exclusion contours in the $(m(Z_{A)} - m(\chi))$-plane (axial vector)

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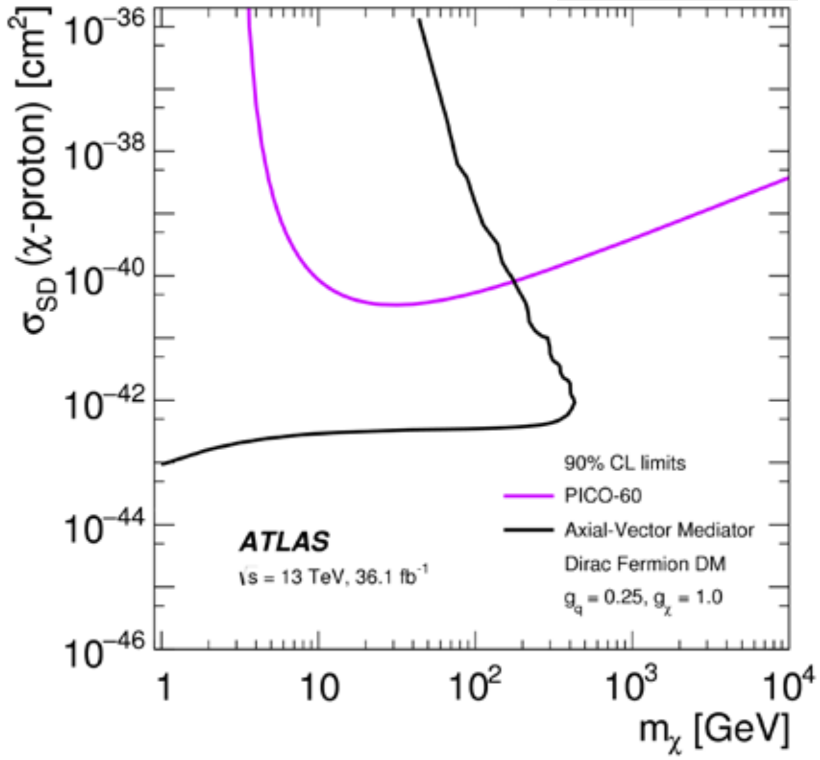
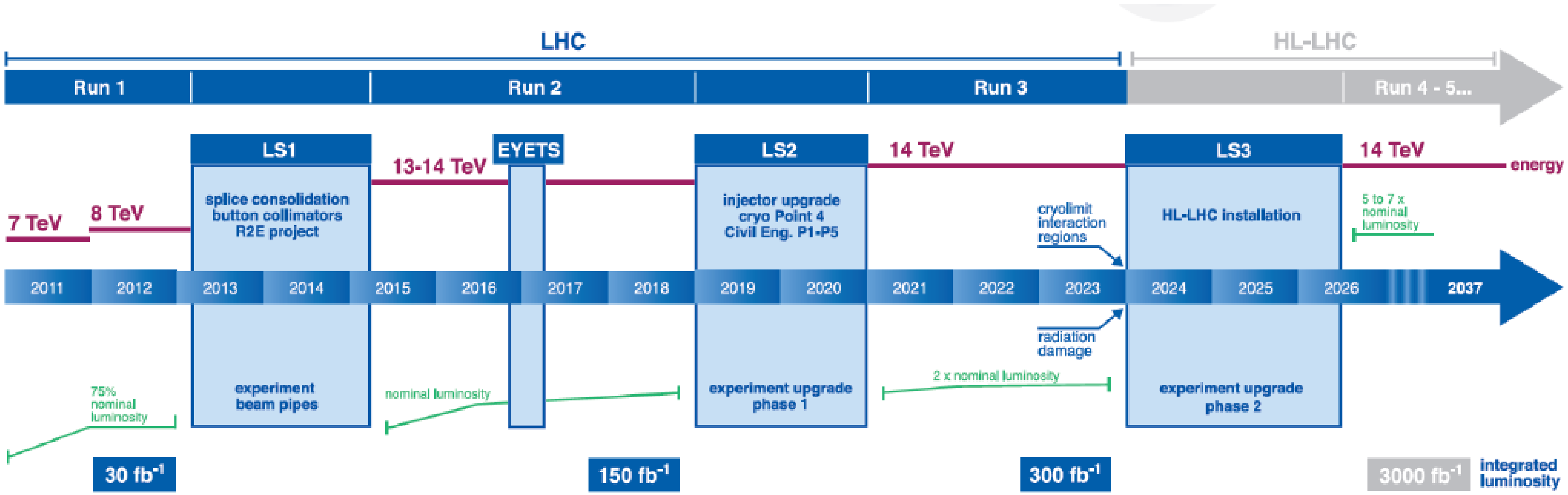


Comparison of the inferred limits (black line) to the constraints from direct detection experiments (purple line) on the spin-dependent WIMP–proton scattering cross section in the context of the simplified model with axial-vector couplings

The Phase-I and Phase-II Detector Upgrades

LHC Schedule



Phase-I upgrades to be installed by end of LS2, i.e. end of 2020

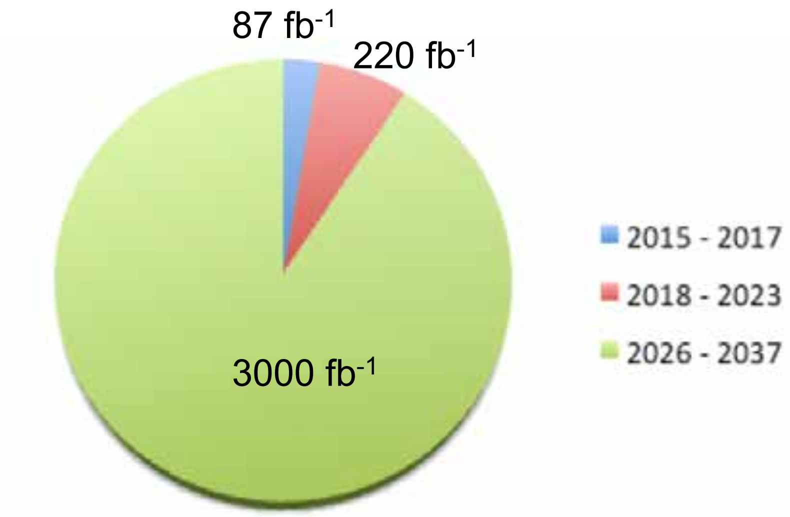
- Parts already installed (LS1) or coming during Run 2 (FTK)
- Larger parts to come in LS2 (NSW, LAr electronics, L1 Calo, L1 Muon, and FELIX)
- 14 TeV running after LS2 (in Run 3)

Phase-II upgrades for installation in LS3 in 2024-2026

- Technical Design Reports written for all upgrade projects and approved !
- Next steps: define Memoranda of Understanding for construction, finalize R&D

LHC Challenges and Luminosities

Increase of the integrated luminosity is required to reach rare processes, e.g. Higgs boson self-coupling, and to explore higher mass ranges



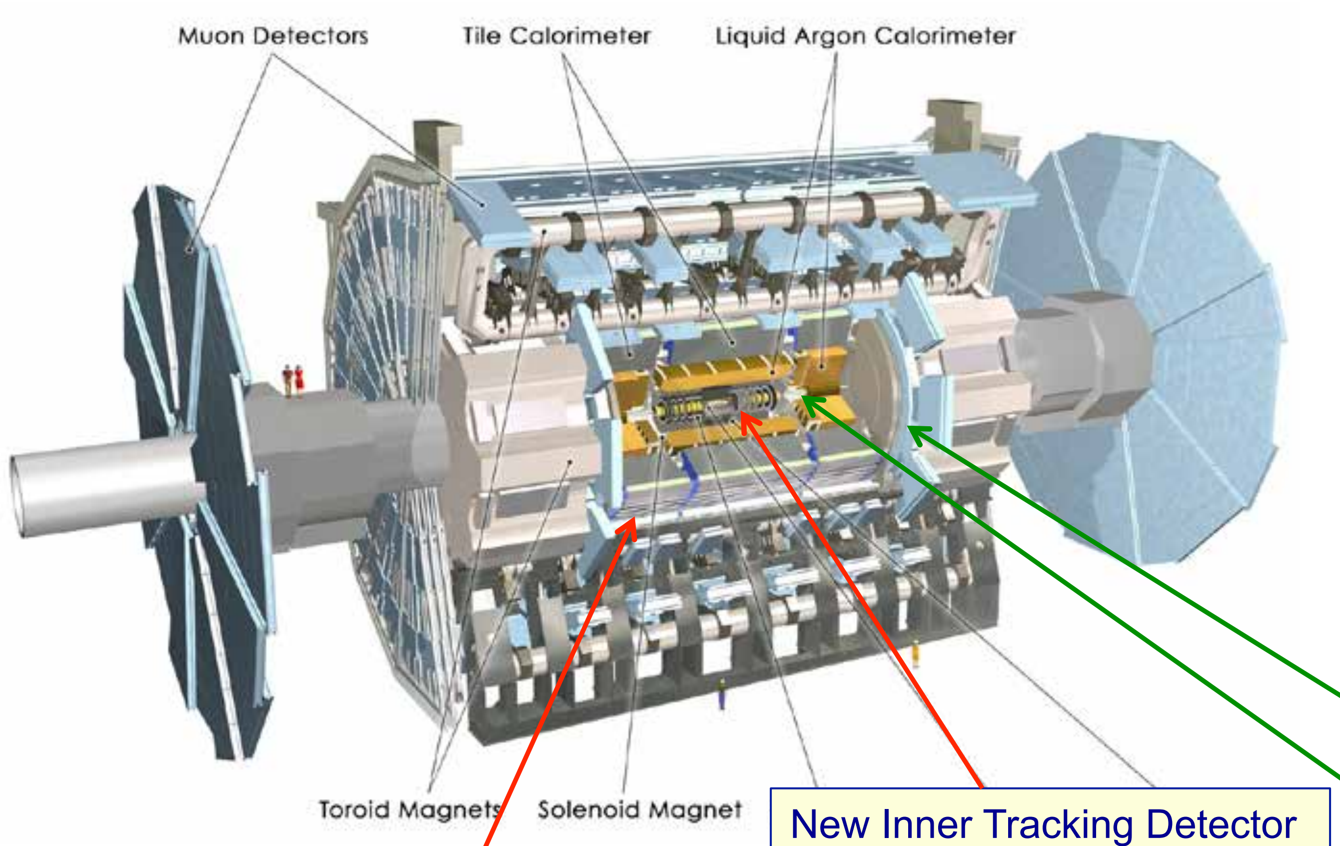
Instantaneous luminosity:
$2 \cdot 10^{34}$ cm^{-2} s^{-1} → $7.5 \cdot 10^{34}$ cm^{-2} s^{-1}

Number of pile-up events per bunch crossing: ~60 → ~200

→ Detector Upgrades needed

Major components:
- (i) Inner Tracking Detectors
- (ii) Trigger System (and Data Acquisition)
- (iii) Electronics on all sub-detector systems

ATLAS Phase-II Upgrade



Upgraded Trigger and Data Acquisition System:

- L0: 1 MHz
- Improved High-Level Trigger

Electronics Upgrade :

- LAr Calorimeter
- Tile Calorimeter
- Muon system

New Inner Tracking Detector (all silicon tracker, up to $|\eta|$ =4)

New muon chambers in the inner barrel region

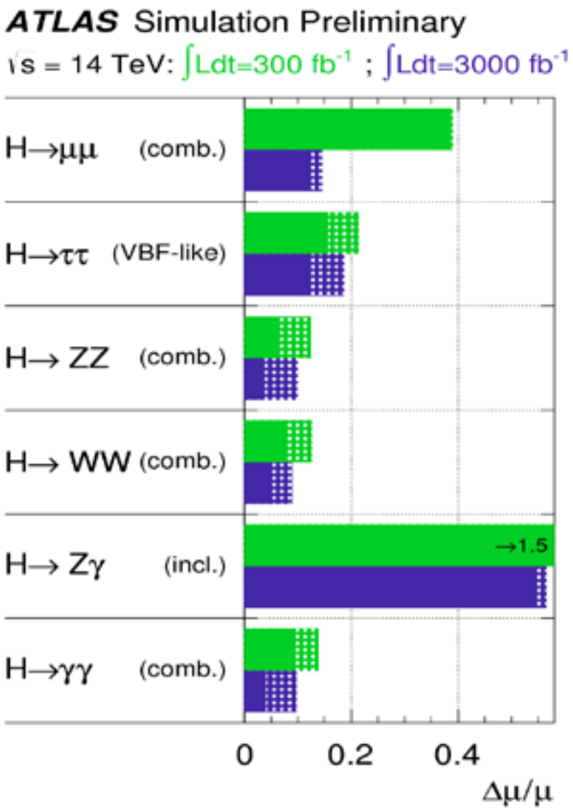
Options:

- High granularity timing detector (forward region)
- High-η muon tagger
- Forward detectors, incl. luminosity

Major Physics Prospects

- Precise measurements of Higgs boson profile
  (rare, interesting decay modes, test of more exotic models, e.g. composite Higgs, Higgs self coupling, …)

- Extend the searches for New Physics in all possible directions, cover more complex scenarios, … + … look for the unexpected !



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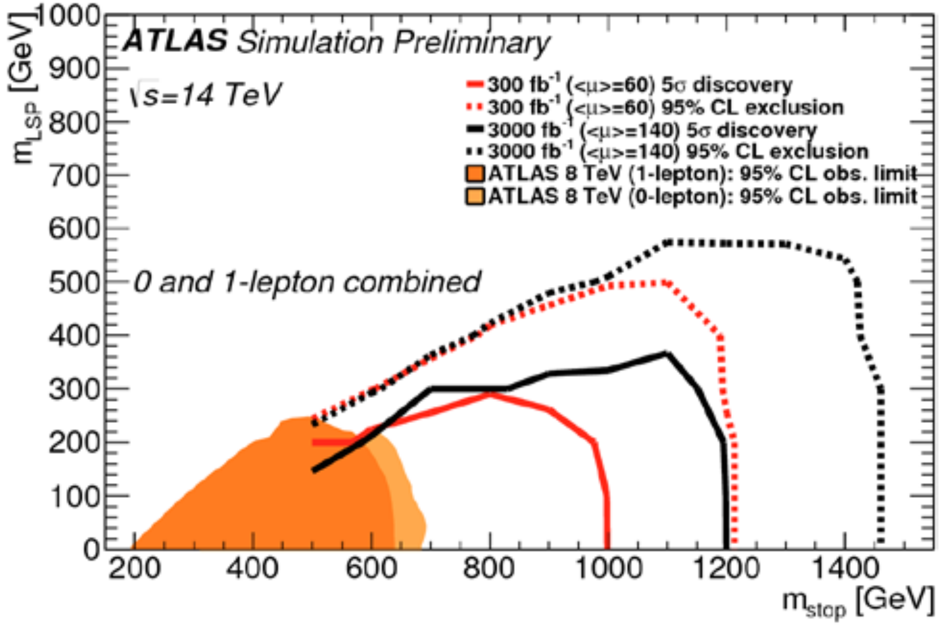

ATL-PUB-2013-011

Conclusions

- The LHC and the experiments (ATLAS, CMS, LHCb, and ALICE) challenge the validity of the Standard Model at the high-energy frontier with ever increasing precision

  - Performance of the LHC and the experiments is superb

  - So far the Standard Model has survived all attacks
    * No evidence for Physics Beyond the Standard Model (yet)
    * Within measurement uncertainties the Higgs boson seem to have the properties as expected in the Standard Model
    * LHC has entered the precision era (m_W, m_t, ...) and will address rarer and rarer processes

- In order to exploit the full potential of the LHC, massive upgrades are needed for the accelerators and the experiments

  .. . to reach new territory and hopefully ground-breaking discoveries