

Highlights from the ATLAS experiment at the LHC

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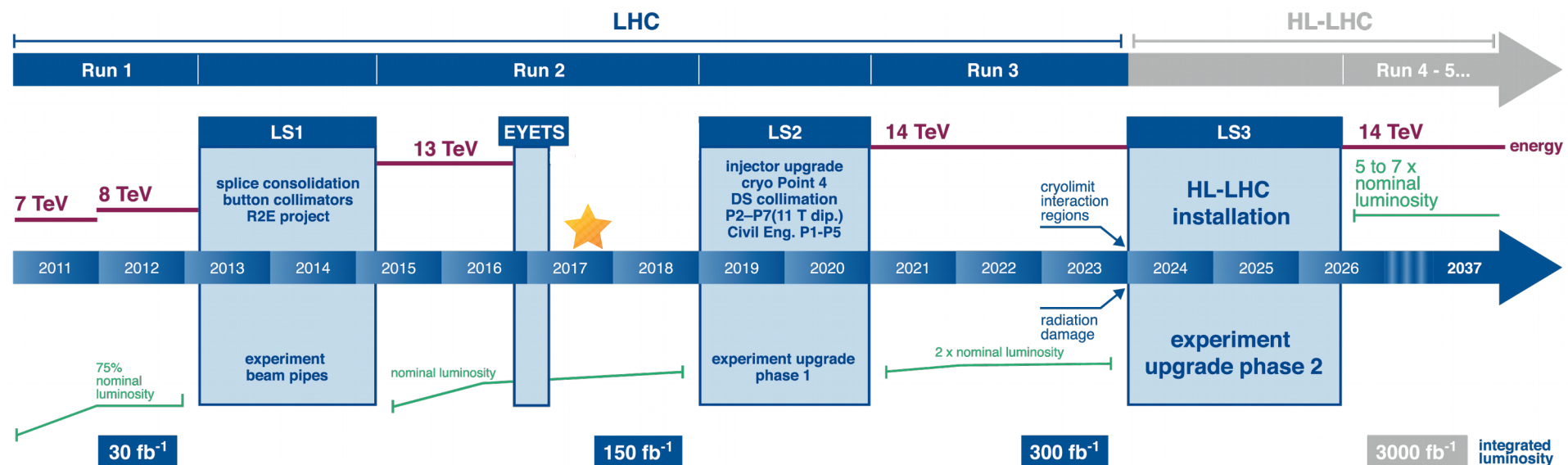
on behalf of the ATLAS Collaboration

Brookhaven Forum 2017

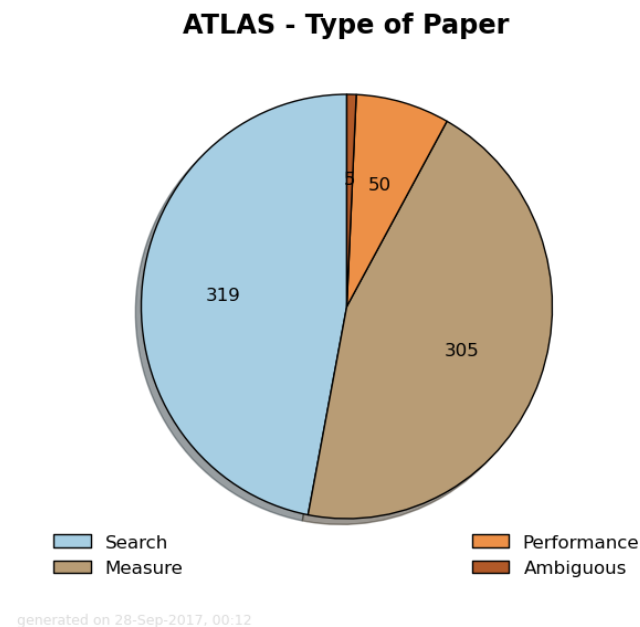
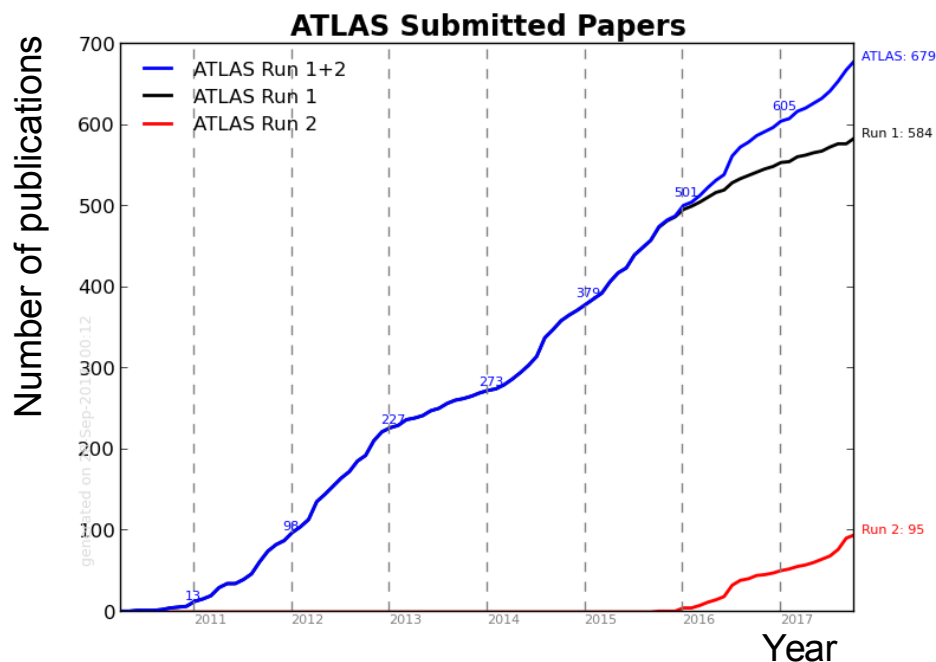
In search of New Paradigms

October 11th, 2017

- The ATLAS experiment: overview
 - Challenges and recent highlights
- Physics results highlights
 - Standard Model and Higgs measurements
 - Search for physics beyond the Standard Model
- A look into the future: High-Luminosity LHC physics reach

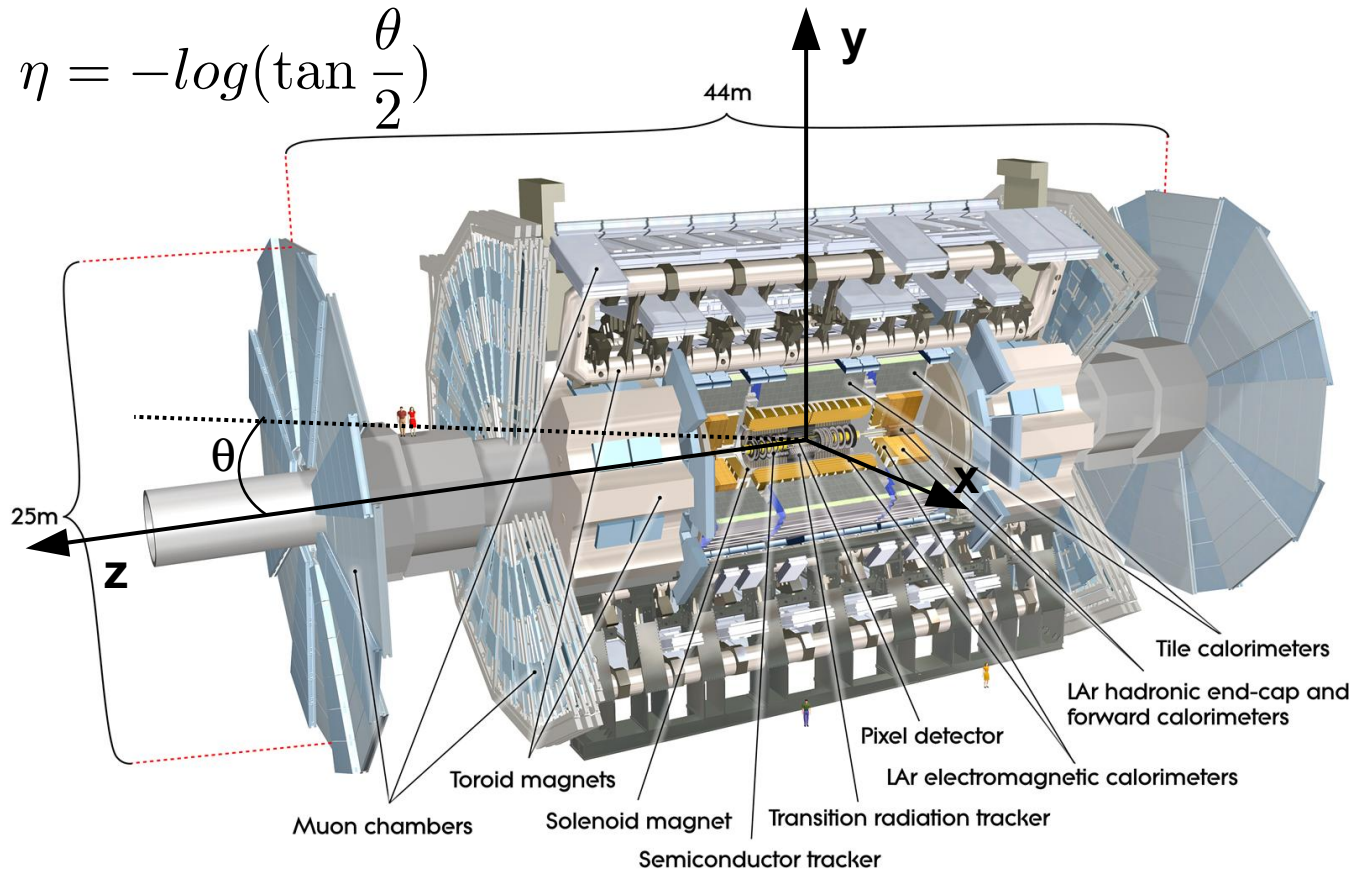


- Large scientific output
 - > 600 papers submitted for publication
 - > 100 papers + preliminary results released only in 2017



- Will present an overview of the physics program highlighting a selection of the most recent results
 - main focus on high- p_T p-p collision data

The ATLAS experiment



Muon system

$|\eta| < 2.7$ (164.2°)
Strong bending power
(air-core toroid)
Trigger chambers

Calorimeters

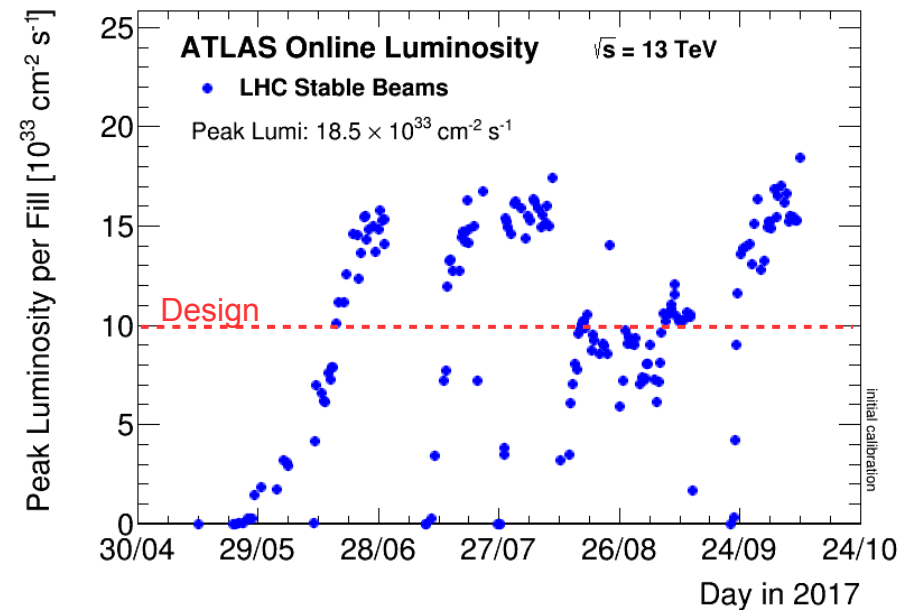
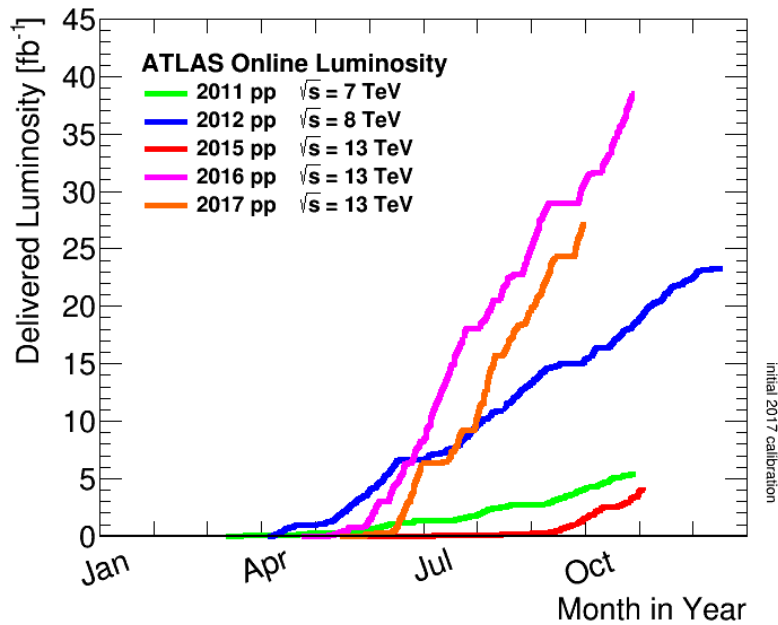
$|\eta| < 4.9$ (178.4°)
Electromagnetic ($>22X_0$)
Hadronic ($>10\lambda_0$)

Tracking system

$|\eta| < 2.5$ (161.2°)
Si Pixels, Strips,
Transition-Radiation
Tracker
2T magnetic field

- Two-level triggering system

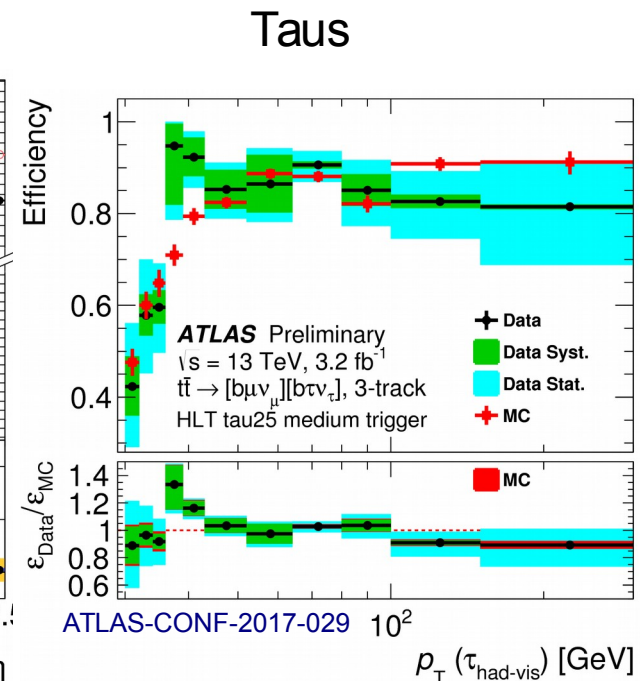
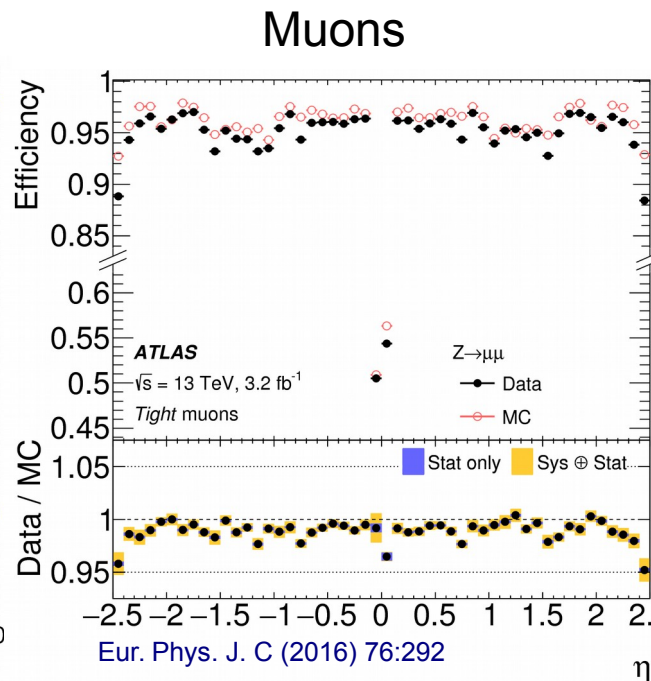
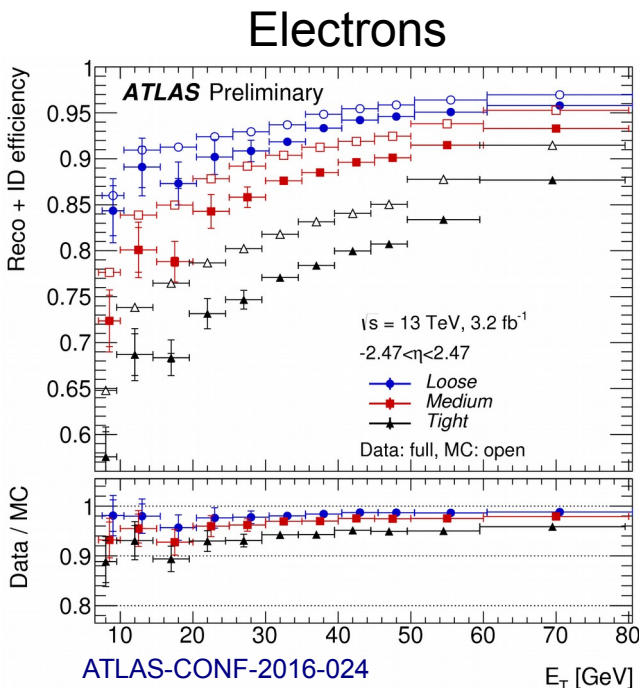
- Reduce 40 MHz event rate down to ~ 1 kHz for disk/tape storage
- Typically ~ 2000 active menu items



- About 70 fb^{-1} ($\sim 5 \cdot 10^{15}$) of 13 TeV pp collisions data delivered by LHC
 - Most of results shown use 2015+2016 dataset: $\sim 36 \text{ fb}^{-1}$ of recorded data
- Instantaneous peak luminosity above design already in 2016; up to $\sim 70!$ inelastic pp interactions per bunch crossing in 2017
- Excellent performance by experiments, with $> 90\%$ data-taking efficiency (good for physics)

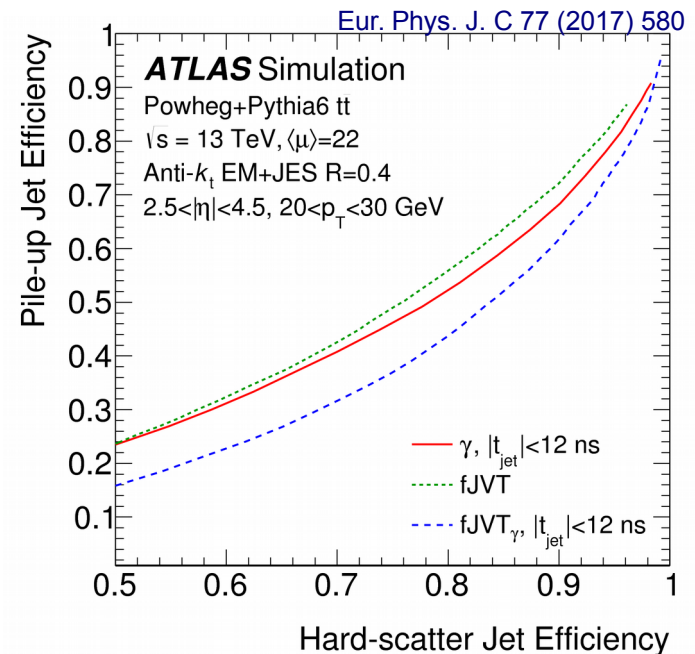
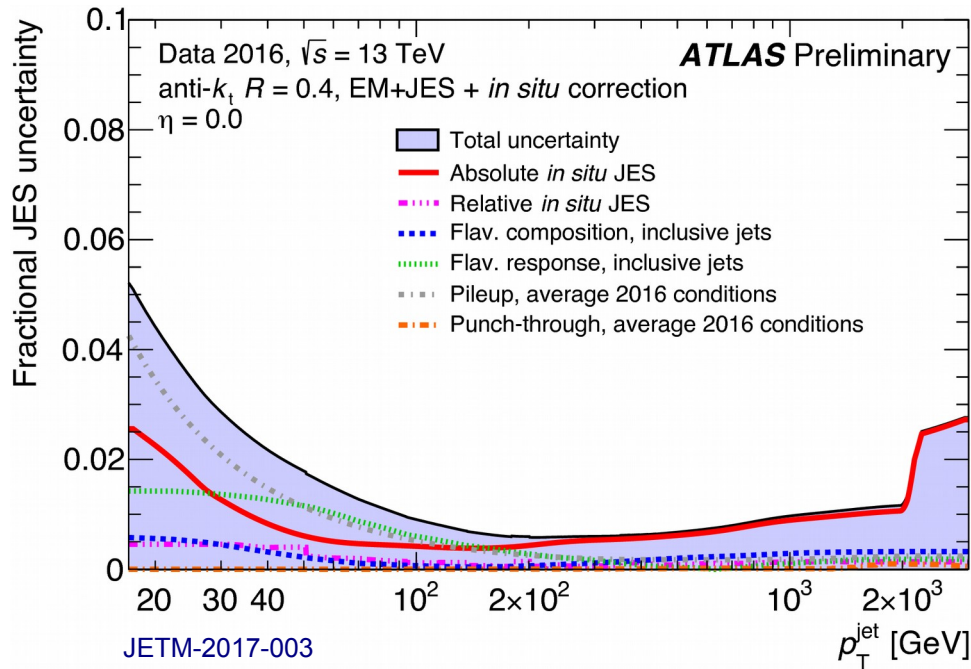
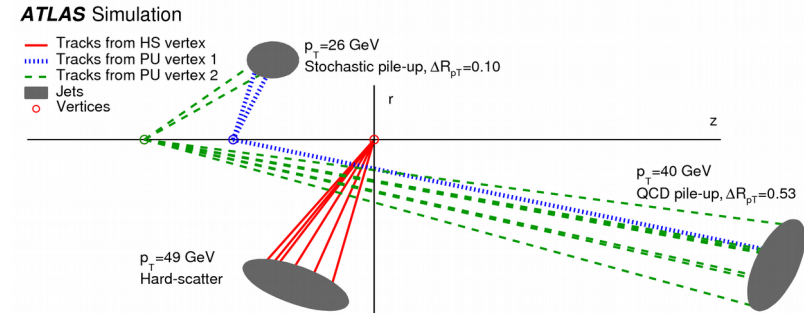
Performance - leptons

- Excellent lepton reconstruction and identification efficiency
 - well modeled by detailed ATLAS detector simulation
- Single e, μ triggers un-prescaled with $p_T > \sim 25$ GeV



Performance - jets

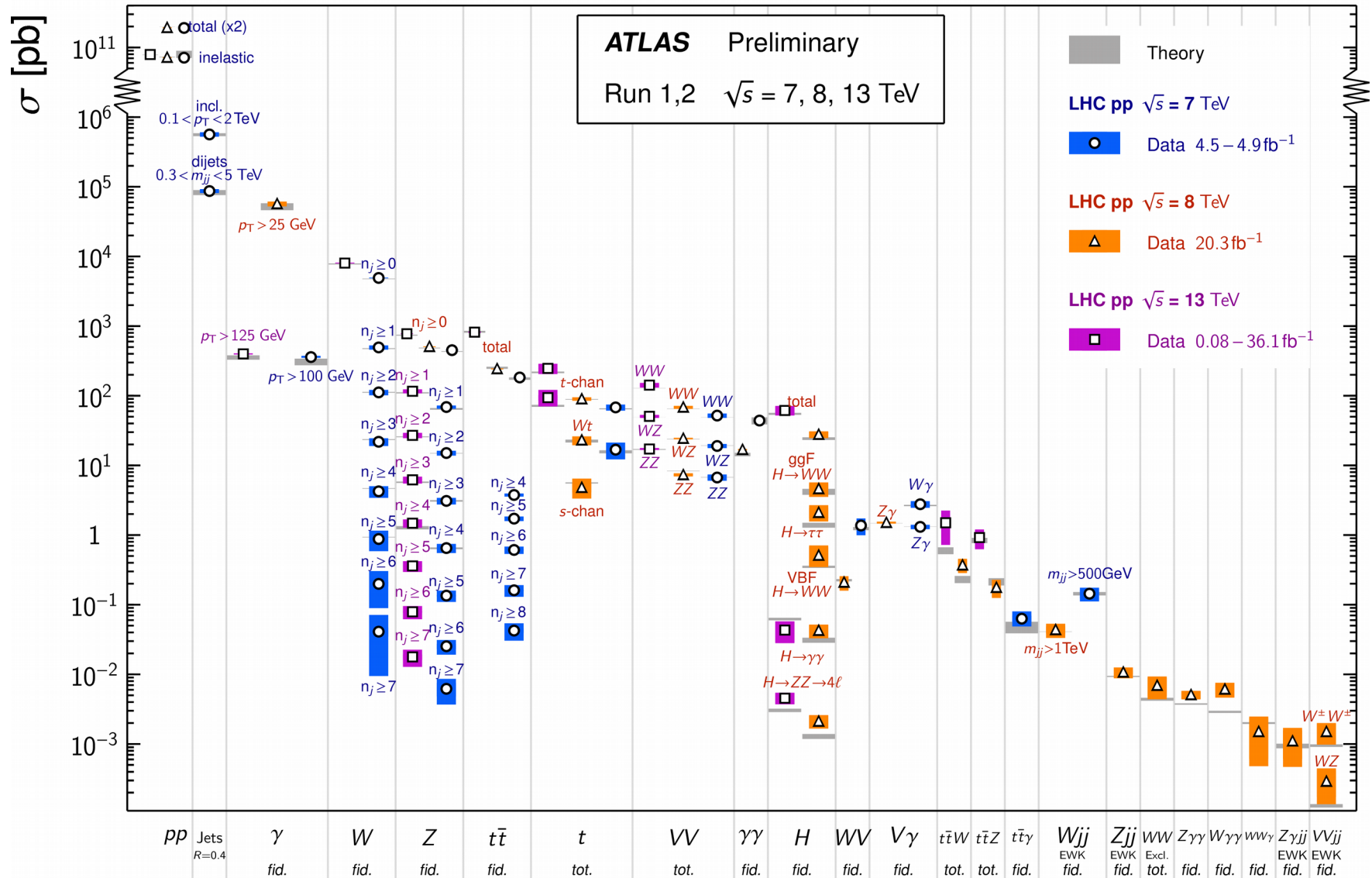
- Excellent jet energy scale calibration to within few %
- Large effort to mitigate effects of pile-up p-p interactions
 - Recently: improved rejection of (forward) pile-up jets



Standard Model measurements

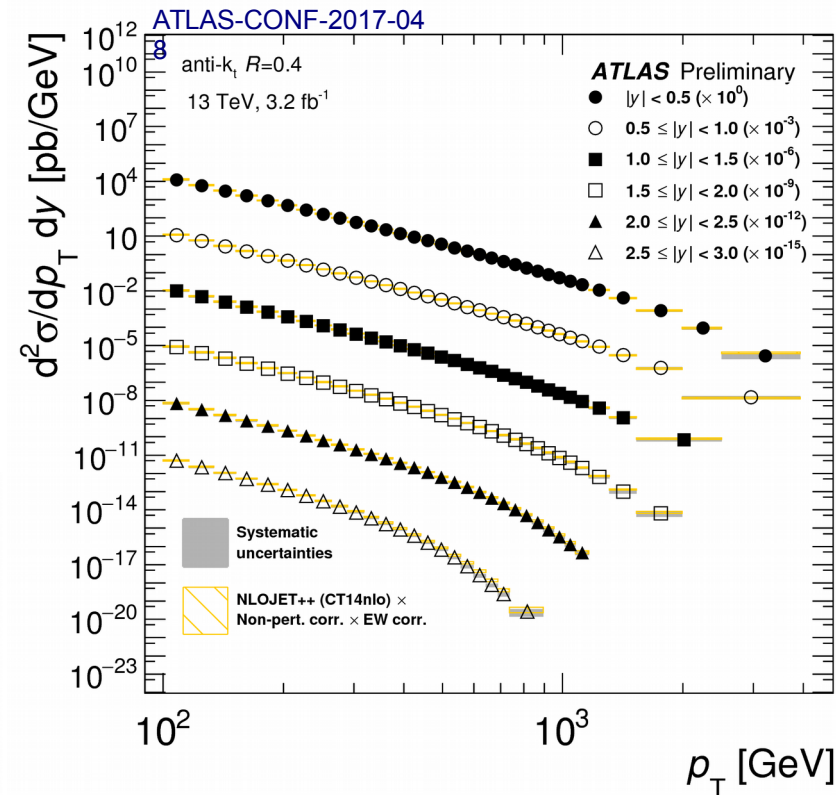
Standard Model Production Cross Section Measurements

Status: May 2017

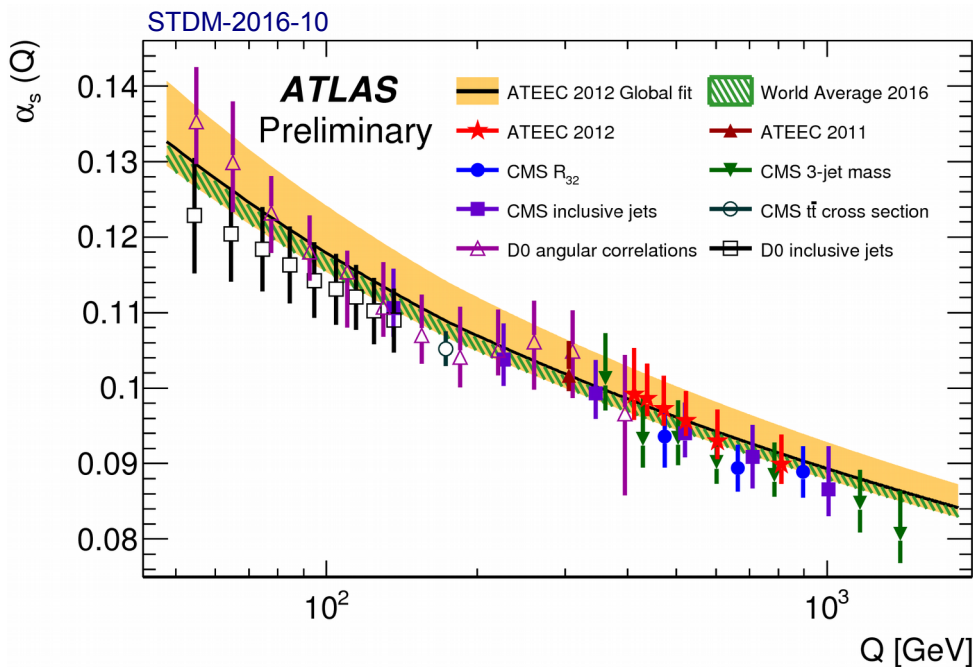


Jet production

- Differential cross section for single and multi-jet production
- Strong coupling constant from energy-energy correlations and asymmetries



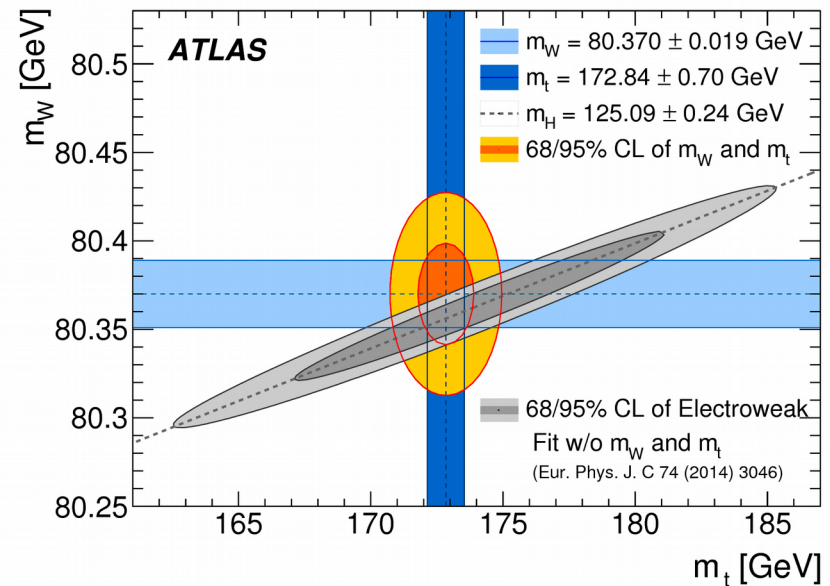
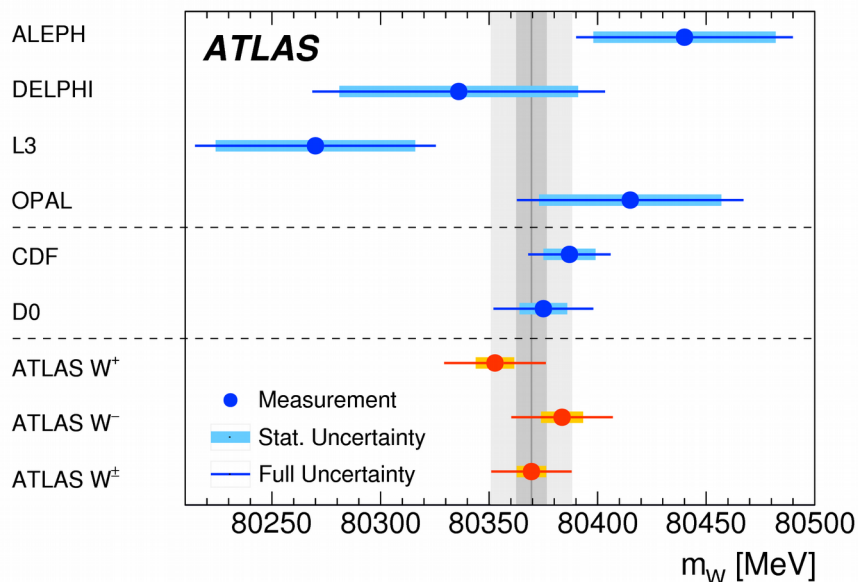
Ref.	$\alpha_s(M_Z)$ measurement
ATLAS	$0.1196 \pm 0.0013(\text{exp.})^{+0.0075}_{-0.0045}(\text{theory})$
W.A.	0.1181 ± 0.0011



- Using low pile-up $\sqrt{s} = 7$ TeV data
 - Huge work in detector understanding
- Uncertainty similar to previous best measurement from CDF
- Expect improvements from theory modeling and larger statistics sample to reduce experimental uncertainties

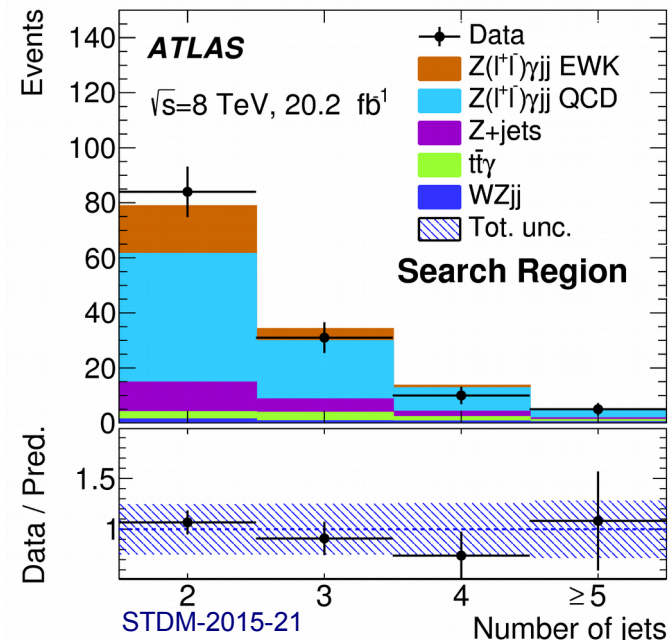
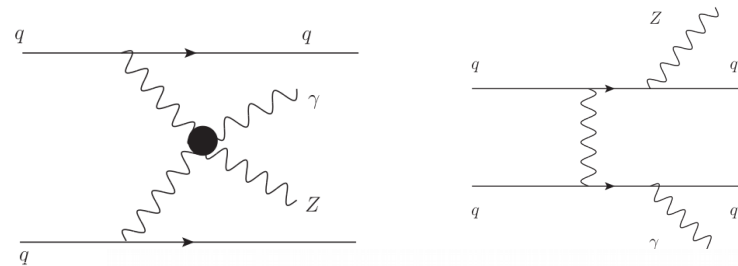
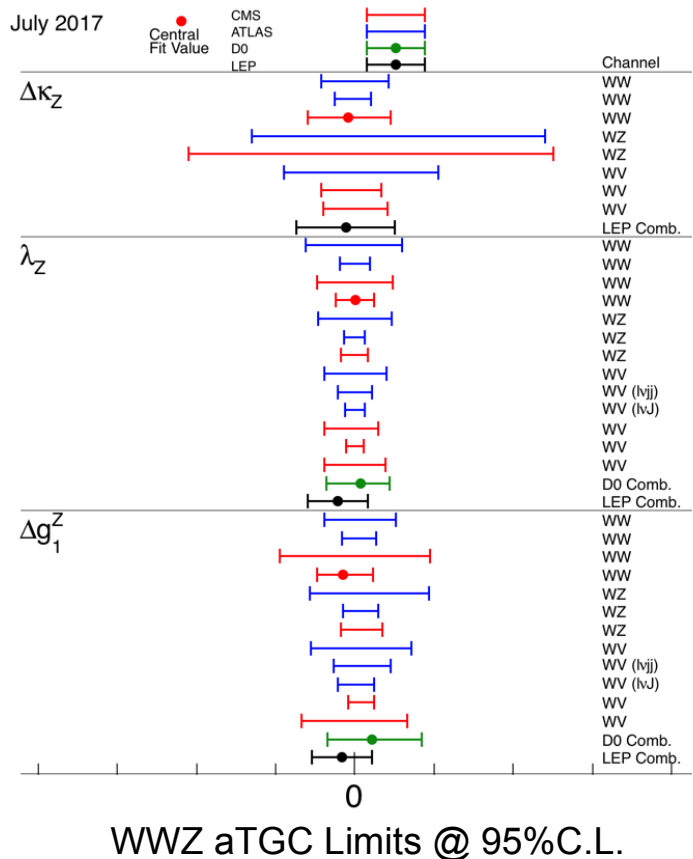
$m(W) = 80370 \pm 19$ MeV
 ± 7 (stat.)
 ± 11 (exp. syst.)
 ± 14 (mod. syst.)

arxiv:1701.07240

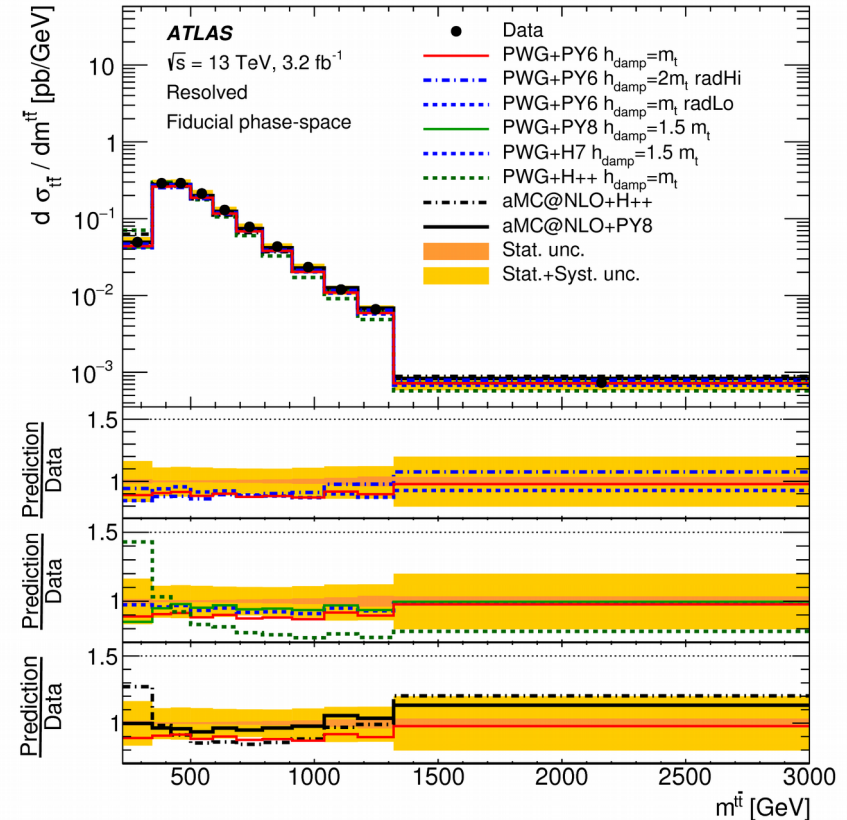


EWK Gauge couplings

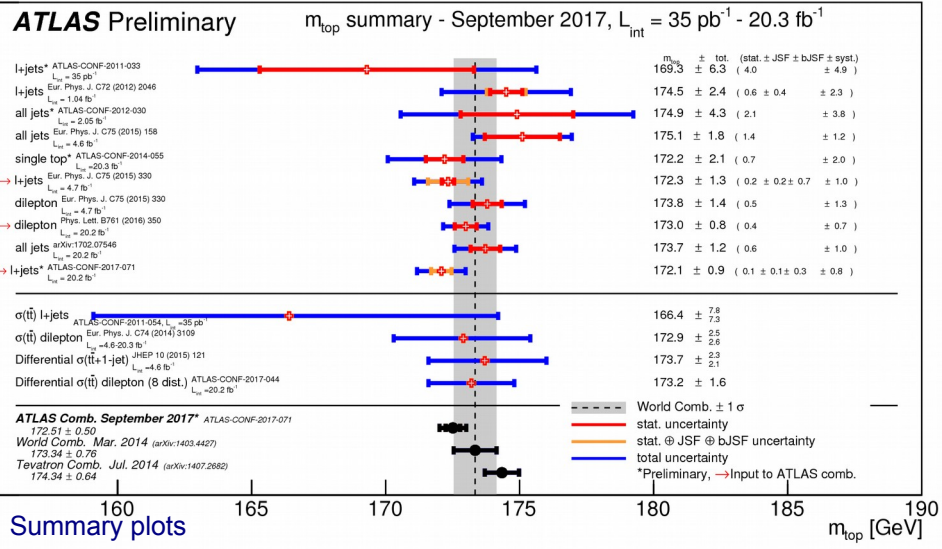
- Extensive studies of diboson and W/Zjj processes
 - constraints on anomalous trilinear gauge couplings beyond LEP limits
- Vector-boson scattering measurements are a milestone in the study of the EWK sector



- Detailed studies of the heaviest fundamental particle known
 - strong indirect probe for New Physics
- Differential cross section meas. to refine theory calculations in extreme phase-space



Recent results extracting top *pole** mass
 $m(\text{top}) = 173.2 \pm 0.9 \pm 0.8 \pm 1.2(\text{th.}) \text{ GeV}$
 * mass definition corresponding to that of a free particle
 and directly measuring top width
 $\Gamma(\text{top}) = 1.76 \pm 0.33 +0.79-0.68 \text{ GeV}$
 using kinematic information of final state
 TOPQ-2015-02, TOPQ-2017-02



top mass (Sep. 2017):
 ATLAS Combination: $172.51 \pm 0.50 \text{ GeV}$
 Tevatron Combination: $174.34 \pm 0.64 \text{ GeV}$

Rare top processes

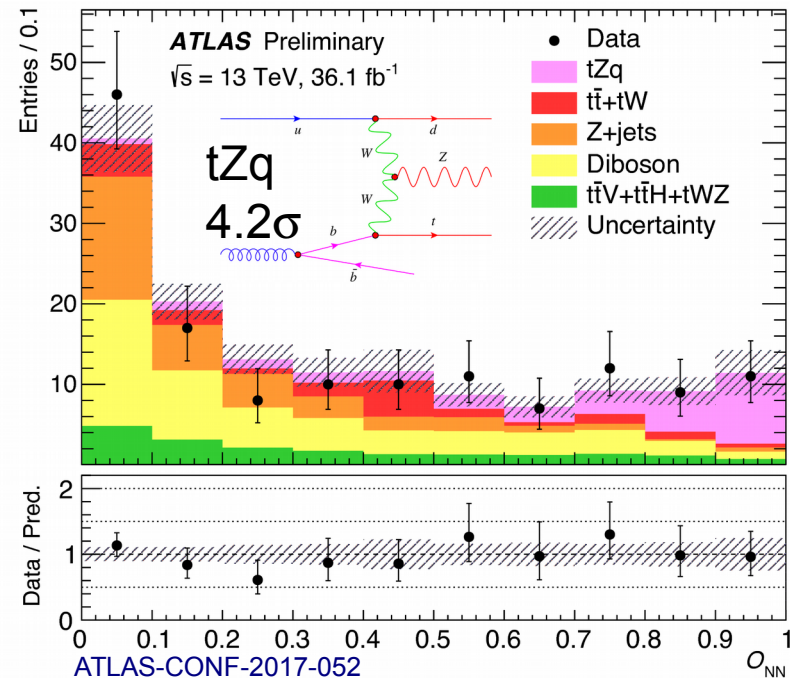
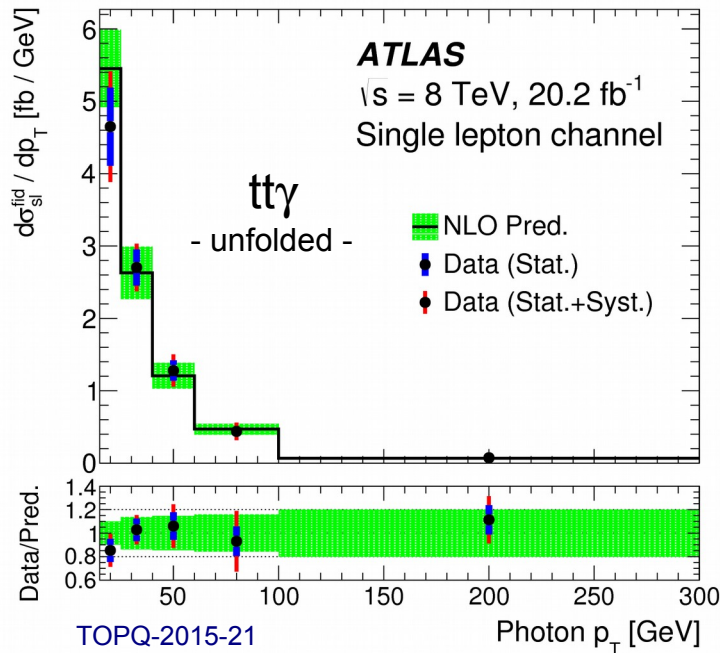
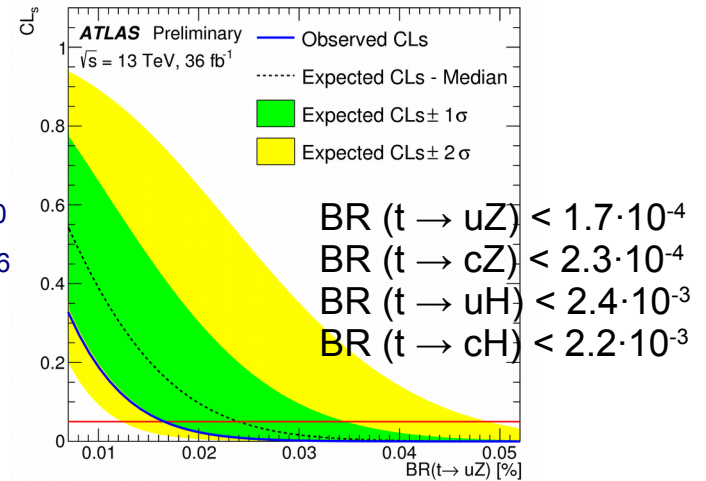
- Rare top decay offer excellent probes for Flavor-Changing-Neutral-Current processes beyond SM

ATLAS-CONF-2017-070

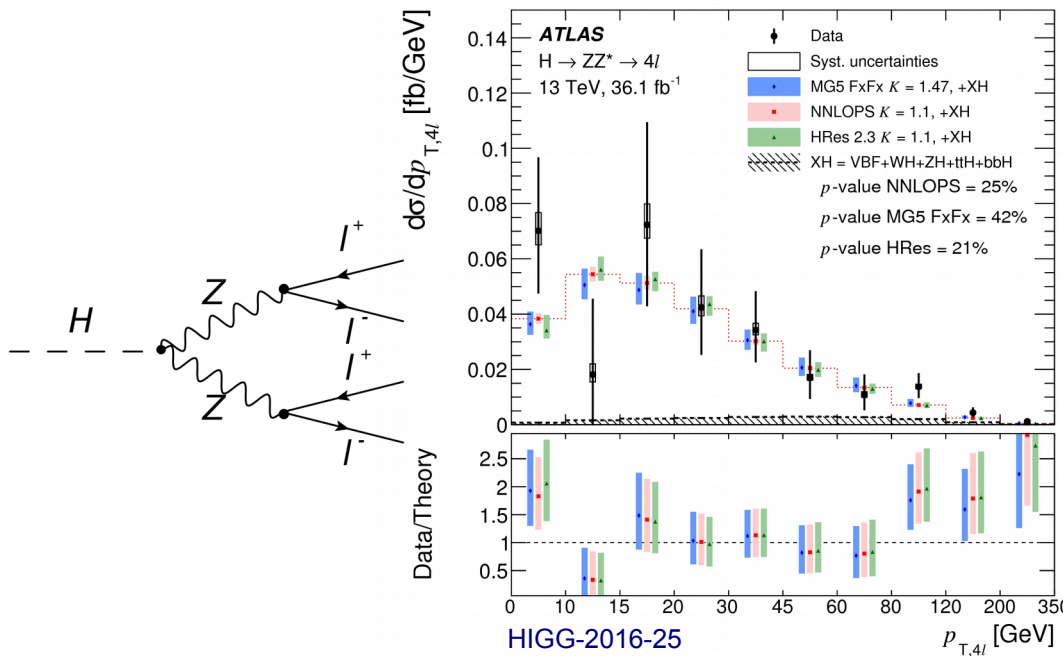
HIGG-2016-26

- $t \rightarrow qZ$, $t \rightarrow qH$ ($q = u, c$)

- Measurement of rare processes in association with top

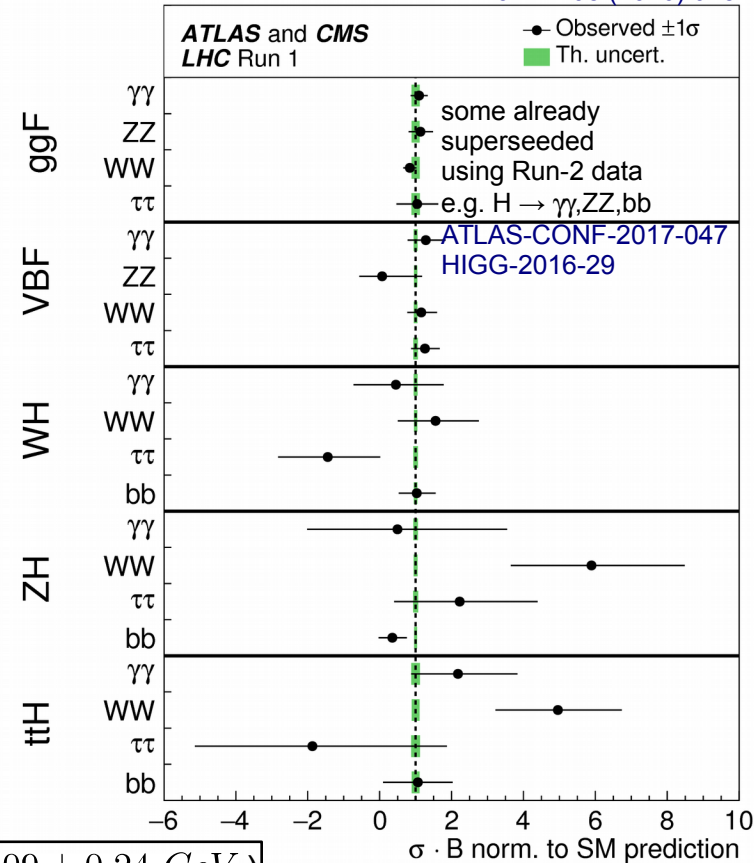


- The only fundamental scalar in the Standard Model
- Test (differential!) cross section prediction in various decay channels



Combined ATLAS+CMS result:

JHEP 08 (2016) 045



- Measure mass, spin/CP and indirect constraints on width

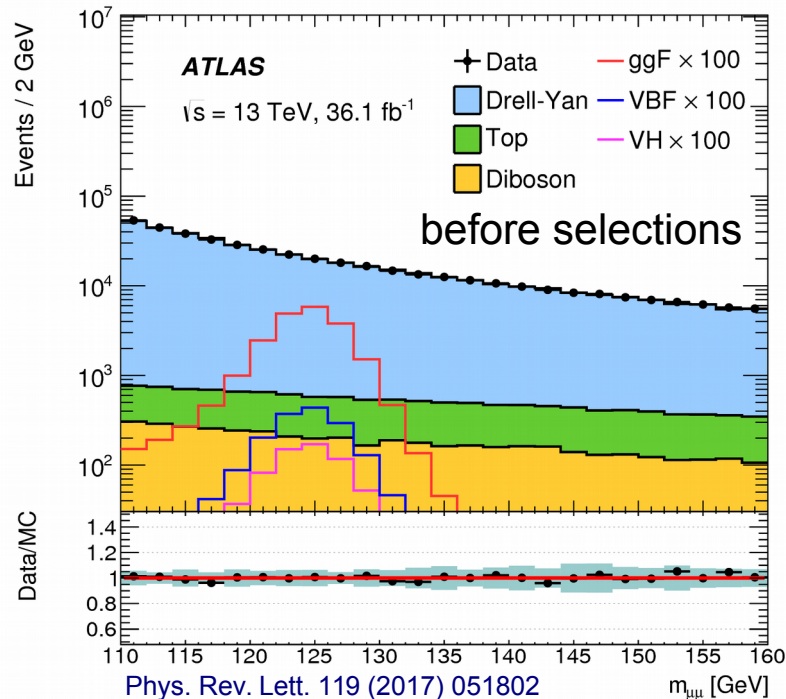
$$m_H = 124.97 \pm 0.28 \text{ GeV} (\text{Run 1: } 125.09 \pm 0.24 \text{ GeV})$$

$$\Gamma_H < 22.7 \text{ MeV} (\text{SM} \sim 4.1 \text{ MeV})$$

ATLAS-CONF-2017-046, Eur. Phys. J. C (2015) 75:335

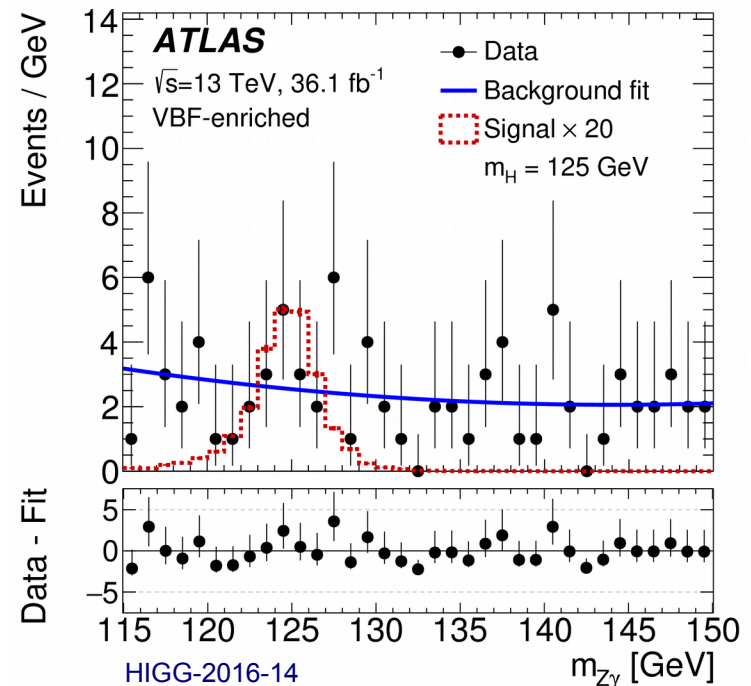
$H \rightarrow \mu\mu$

- Expected BR $\sim 2 \cdot 10^{-4}$
- $(\sigma \cdot \text{BR})^{95\% \text{CL}} / \text{SM} < 2.8$ (2.9 exp.)
combining 7,8,13 TeV data
 - BR $< 0.6\%$ assuming SM $\sigma(\text{pp} \rightarrow H)$



$H \rightarrow Z\gamma$

- Suppressed w.r.t. WW/ZZ or $\gamma\gamma$
- $(\sigma \cdot \text{BR})^{95\% \text{CL}} / \text{SM} < 6.6$ (5.2 exp.)
 - BR $< 1.0\%$ assuming SM $\sigma(\text{pp} \rightarrow H)$
- Additionally search for heavier resonances



Beyond SM searches

ATLAS Exotics Searches* - 95% CL Upper Exclusion Limits

Status: July 2017

ATLAS Preliminary

$$\int \mathcal{L} dt = (3.2 - 37.0) \text{ fb}^{-1}$$

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

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

*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).

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

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

10^{-1}

1

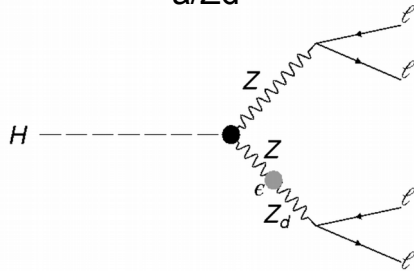
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Mass scale [TeV]

Higgs as portal to new physics

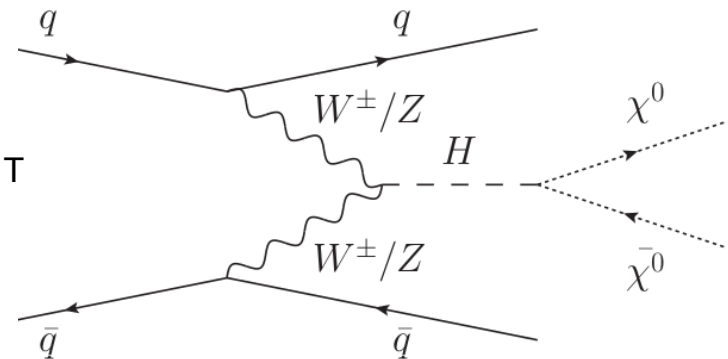
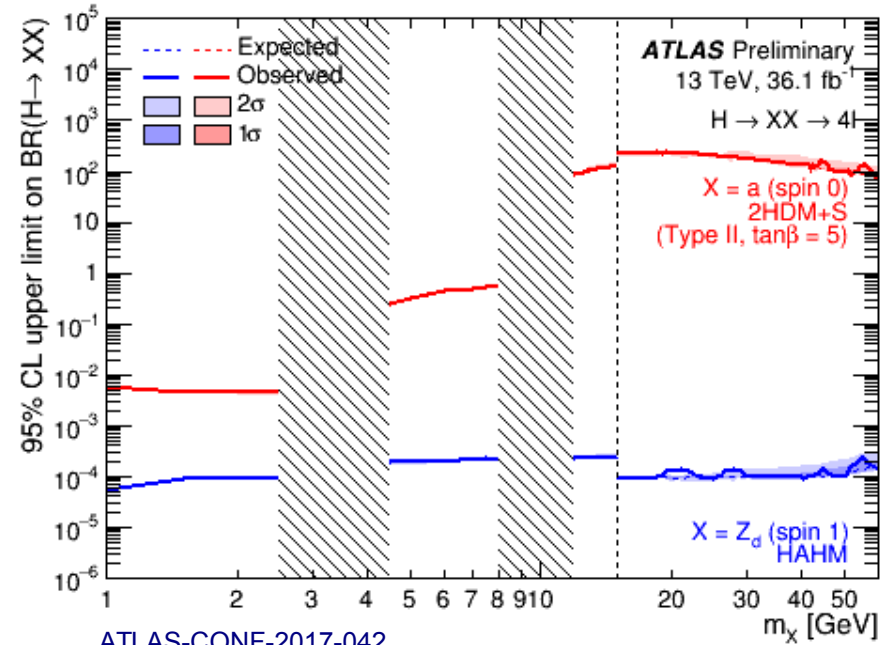
$H \rightarrow aa$ (or ZZ_d) \rightarrow 4 leptons

- Light ($m_{a/Z_d} < m_Z$) boson pair
- Explore $1 < m_{a/Z_d} < 60$ GeV mass



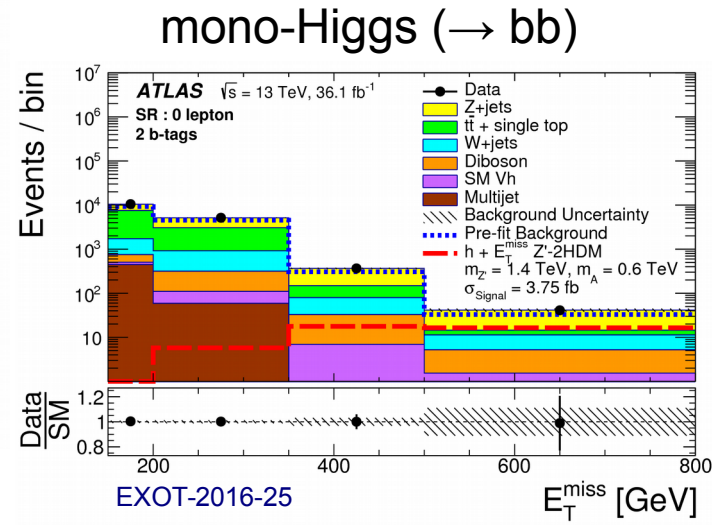
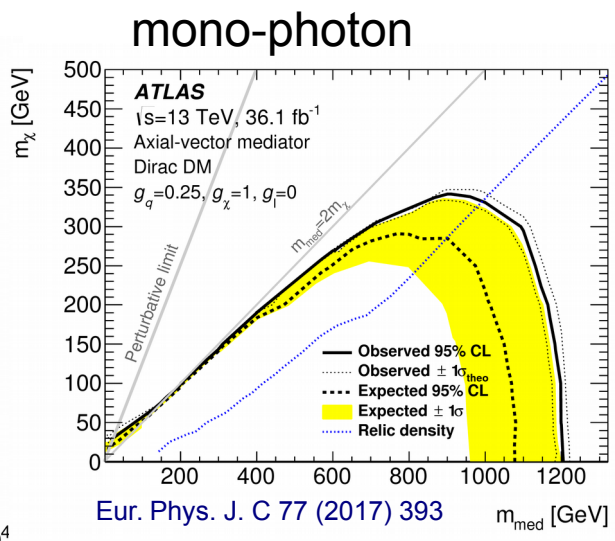
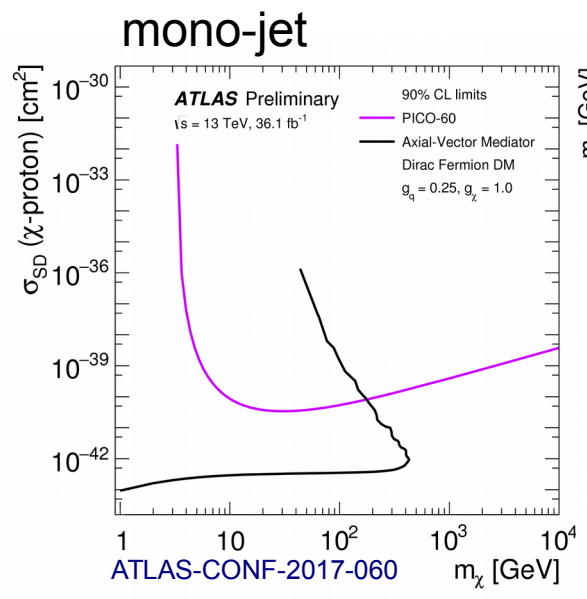
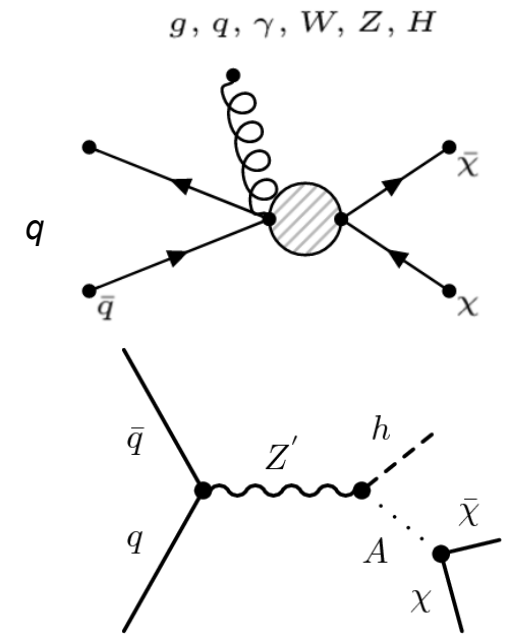
$H \rightarrow$ invisible

- Associated Higgs production and Missing transverse energy (\cancel{E}_T)
- Most recent result: $ZH \rightarrow 2$ leptons + \cancel{E}_T
HIGG-2016-28
- Best constraint when combined with VBF $H \rightarrow 2$ jets + \cancel{E}_T
JHEP 01 (2016) 172
- Run-1 combination: $BR < 23\%$ JHEP11(2015)206



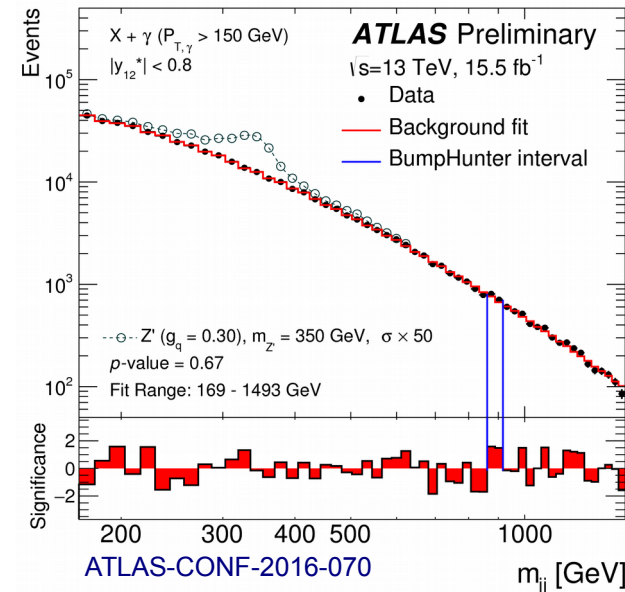
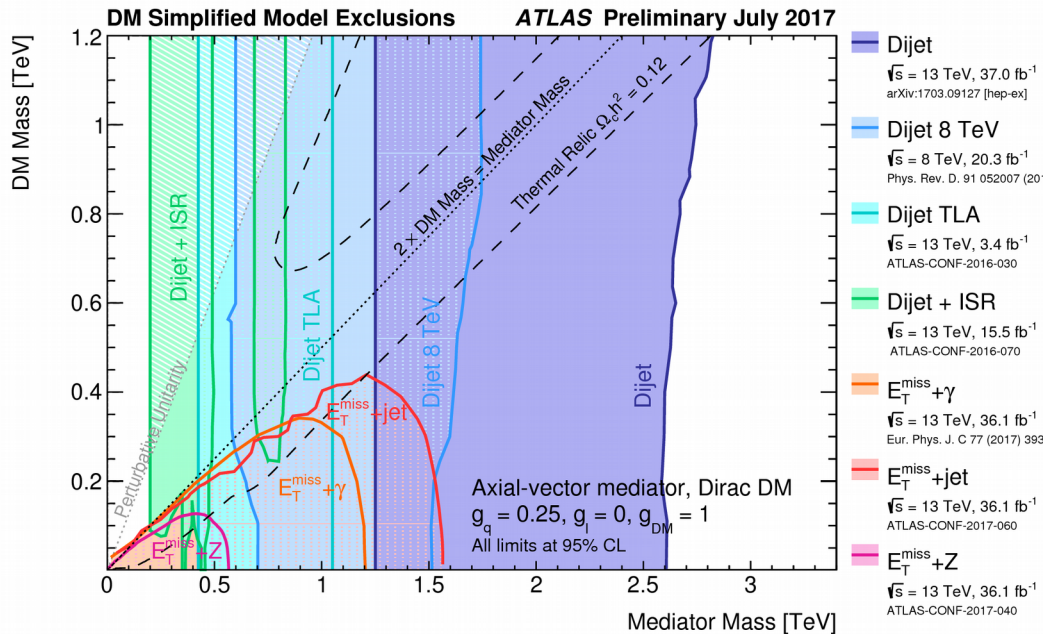
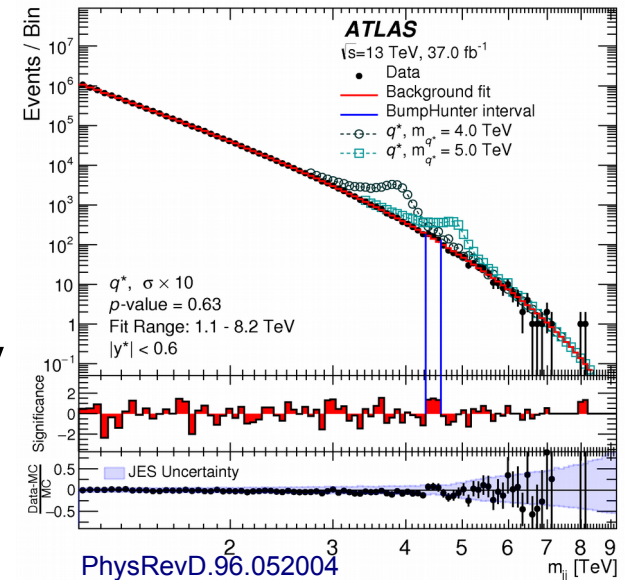
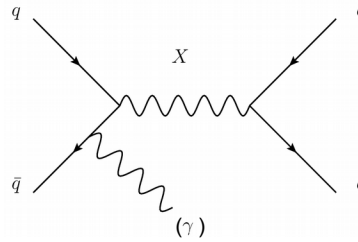
Dark Matter hunt

- LHC in excellent position to test Dark Matter production at EWK scale
- Searches for DM giving Missing Transverse Energy when recoiling against identified object
- Comparison with direct detection only possible in specific models



Di-jet resonances

- Di-jet resonance search also sensitive to DM production
- Synergy between different strategies
 - high-mass di-jet resonance and angular study
 - trigger-level analysis
 - Initial State Radiation + di-jet resonance



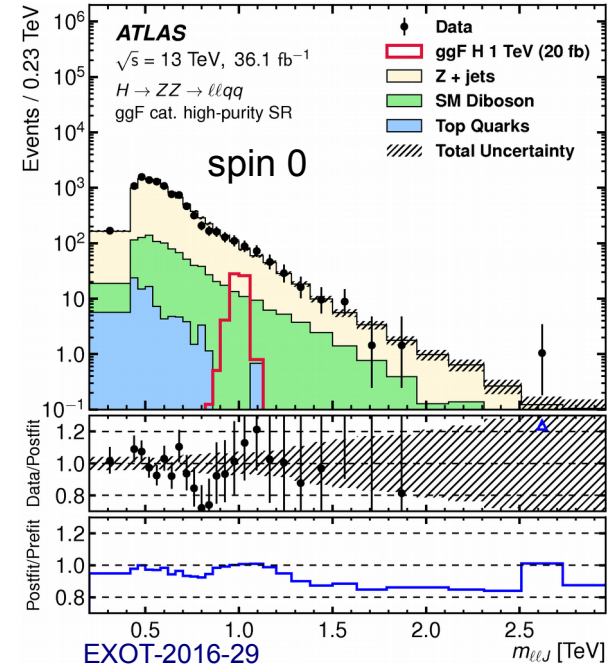
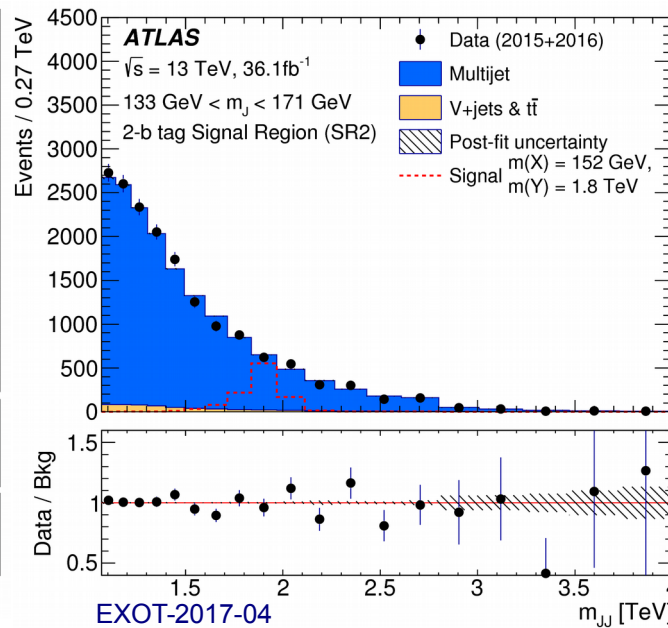
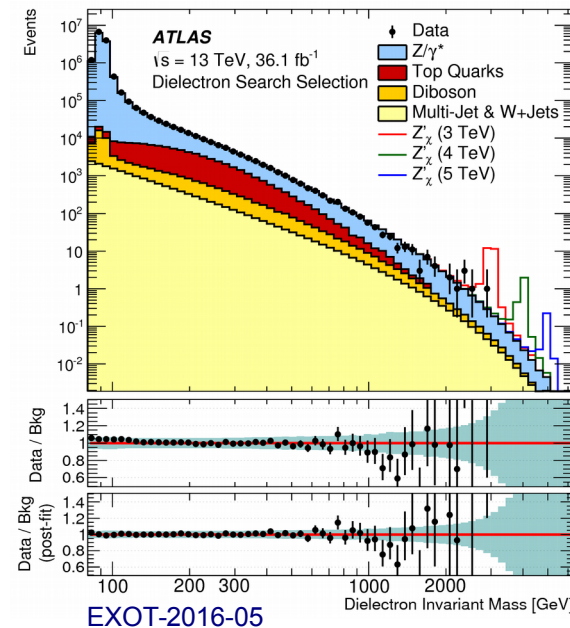
Heavy resonances

- Comprehensive searches for high-mass resonances
- Hadronic final states in boosted regimes for vector-boson final states
- Limits extend to several TeV in mass and $10\text{fb} - 0.1\text{fb}$ in cross section for benchmark models

$m(Z' \rightarrow ee, \mu\mu) > 4.1 \text{ TeV}$

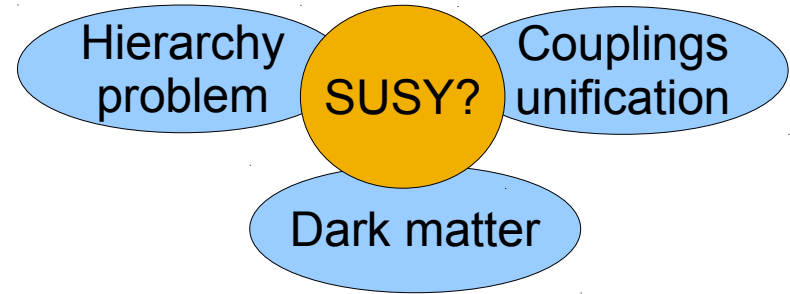
$Y \rightarrow XH \rightarrow qq'bb$

ZZ/ZW resonances



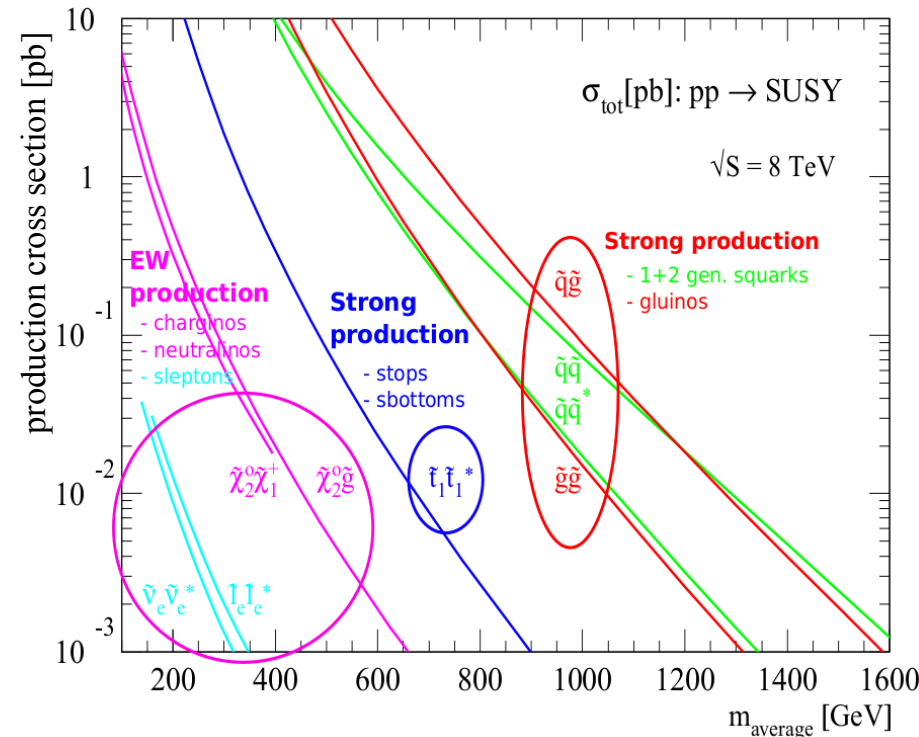
Supersymmetry

- SUSY represents an attractive solution to three main present questions
- Rich phenomenology depending on details of SUSY breaking
- Large improvements compared to Run-1:
 - energy jump (8 → 13 TeV)
 - increased luminosity
 - targeted search techniques



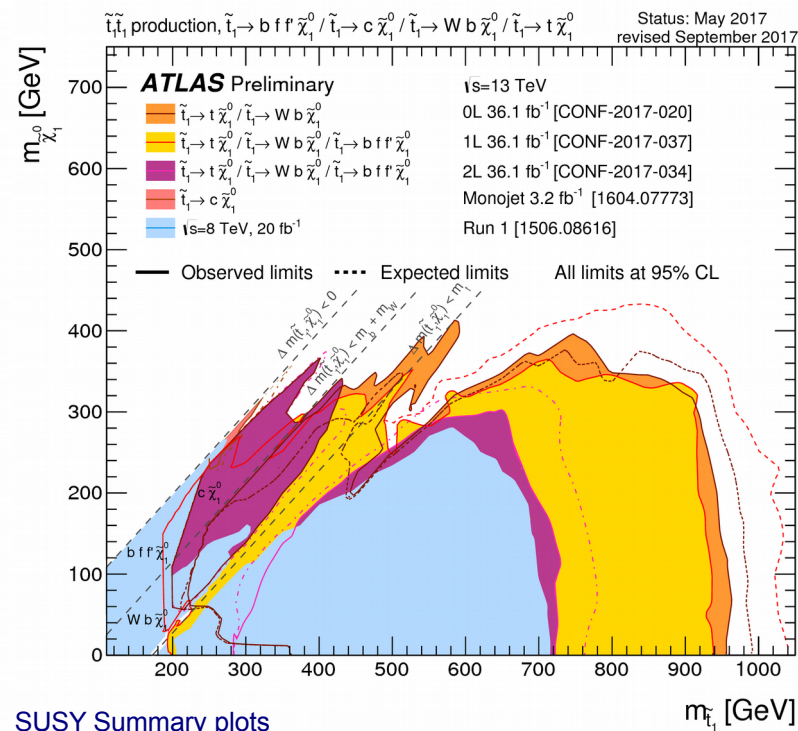
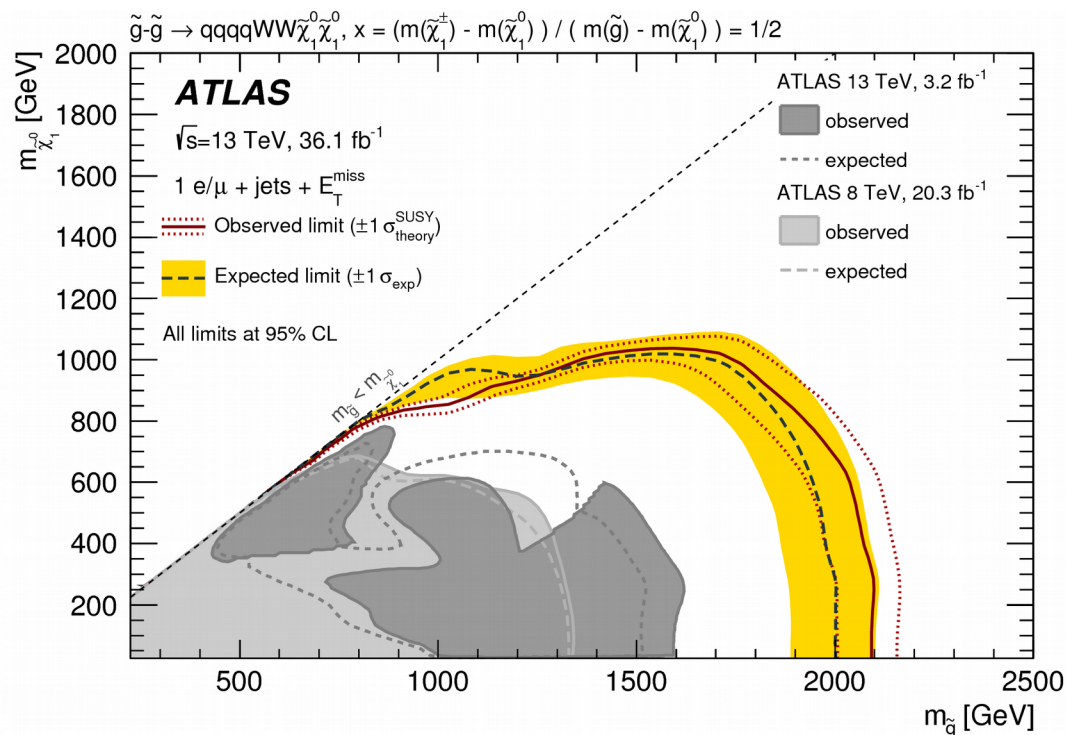
Process	$\frac{\sigma(13 \text{ TeV})}{\sigma(8 \text{ TeV})}$
$\tilde{g}\tilde{g}$ ($m_{\tilde{g}} \approx 1.5 \text{ TeV}$)	30
$\tilde{t}\tilde{t}$ ($m_{\tilde{t}} \approx 0.7 \text{ TeV}$)	8
$\tilde{\chi}^{\pm}\tilde{\chi}^{\pm}$ ($m_{\tilde{\chi}^{\pm}} \approx 0.5 \text{ TeV}$)	4

- Almost 40 null results using Run-2 data, and counting



SUSY Strong production

- In simplified models with light χ^0_1
 - stop excluded up to ~ 1 TeV
 - gluino excluded up to ~ 2 TeV
- In particular scenarios even e.g. a light stop is still allowed!
 - although current searches are constraining it more and more



SUSY Summary plots

Electroweak SUSY partners

Low expected cross section \rightarrow need luminosity

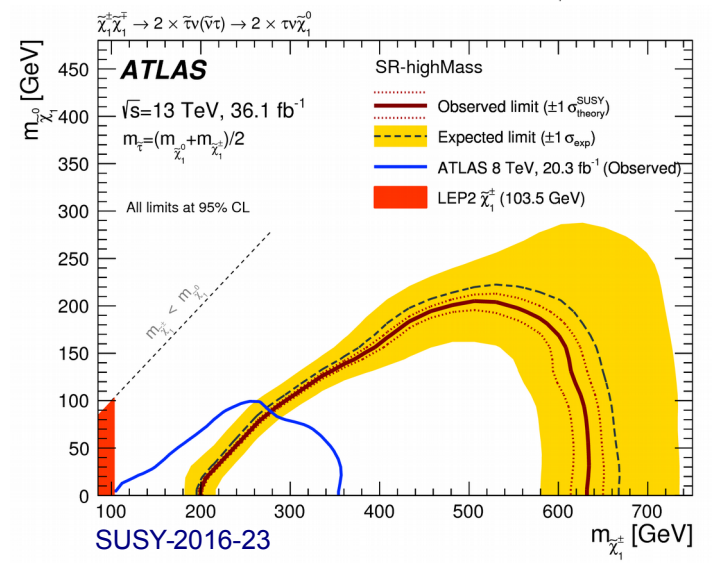
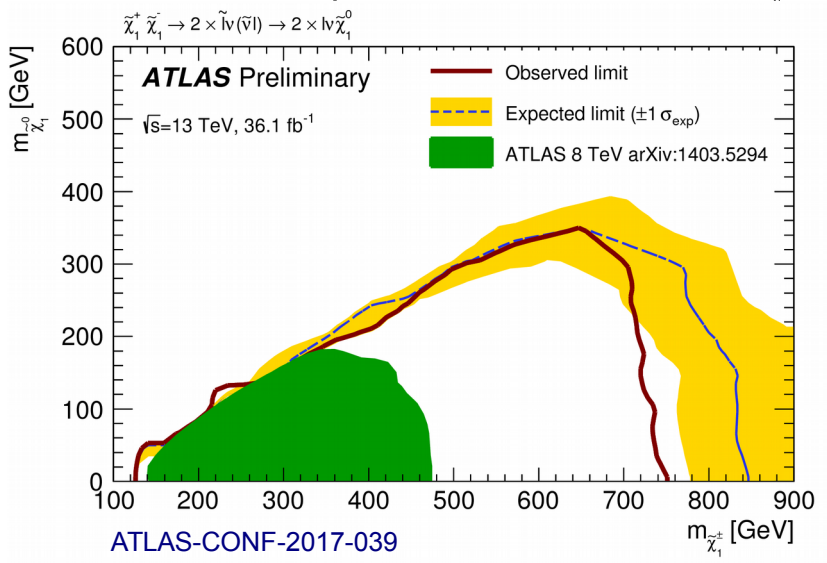
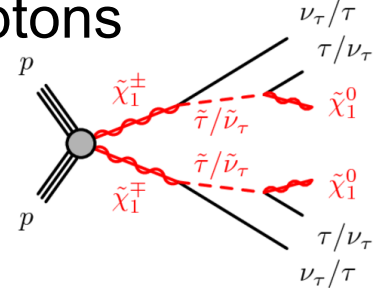
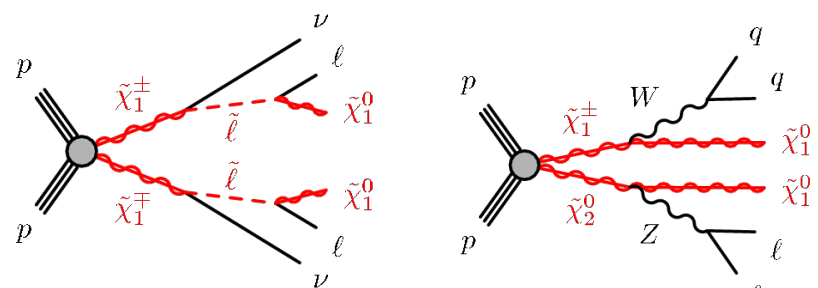
Light staus and Higgsinos are a primary target

2/3 leptons + \cancel{E}_T (+jets)

$\tau\tau + \cancel{E}_T$

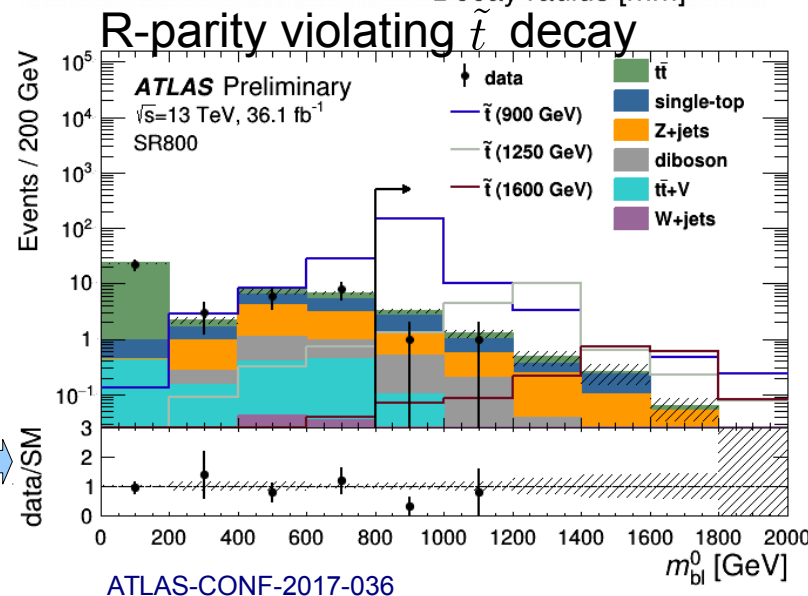
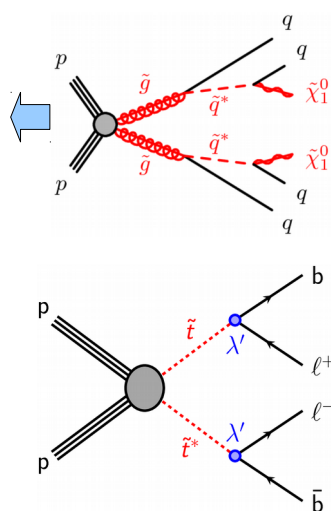
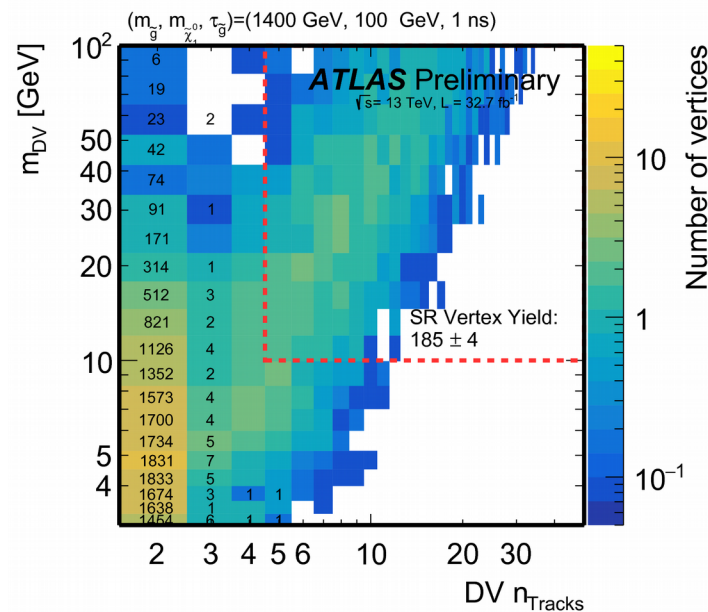
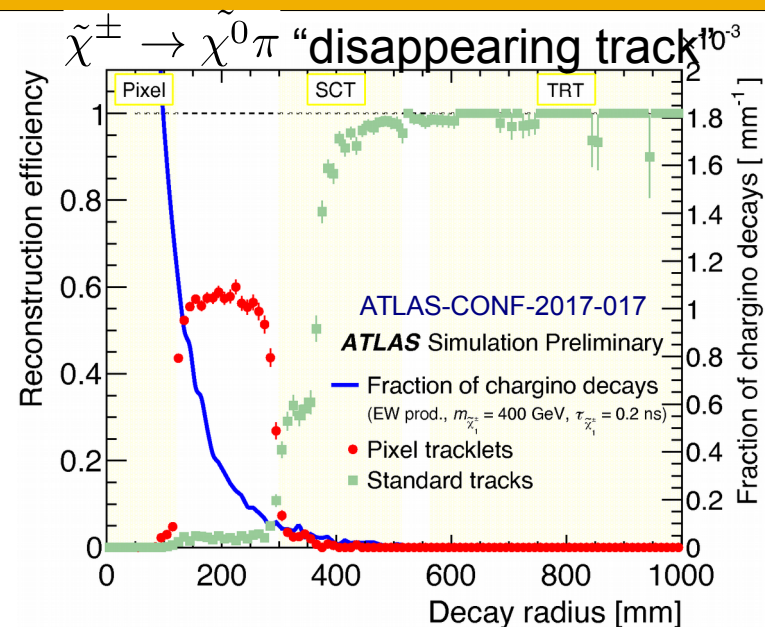
- search for $\tilde{\chi}_1^\pm \tilde{\chi}_1^0, \tilde{\chi}_1^+ \tilde{\chi}_1^-, \tilde{l}\tilde{l}$

- Well motivated in presence of light sleptons



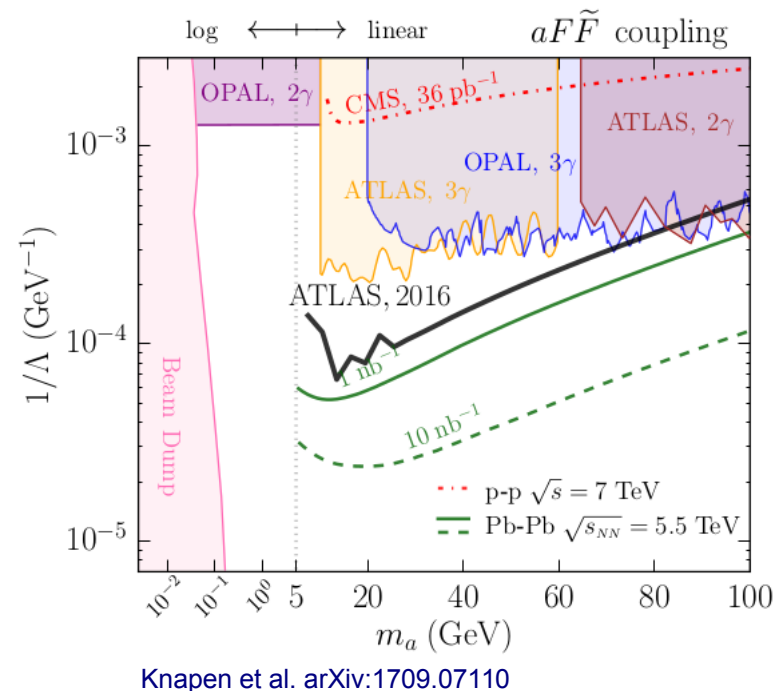
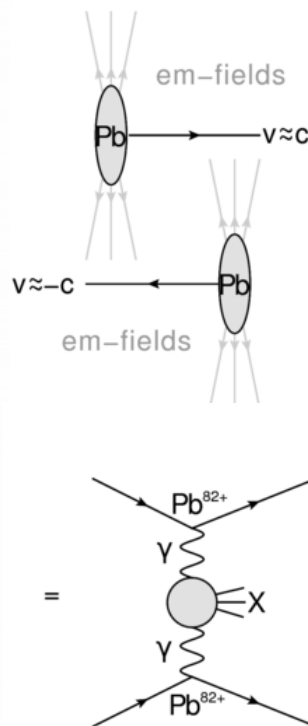
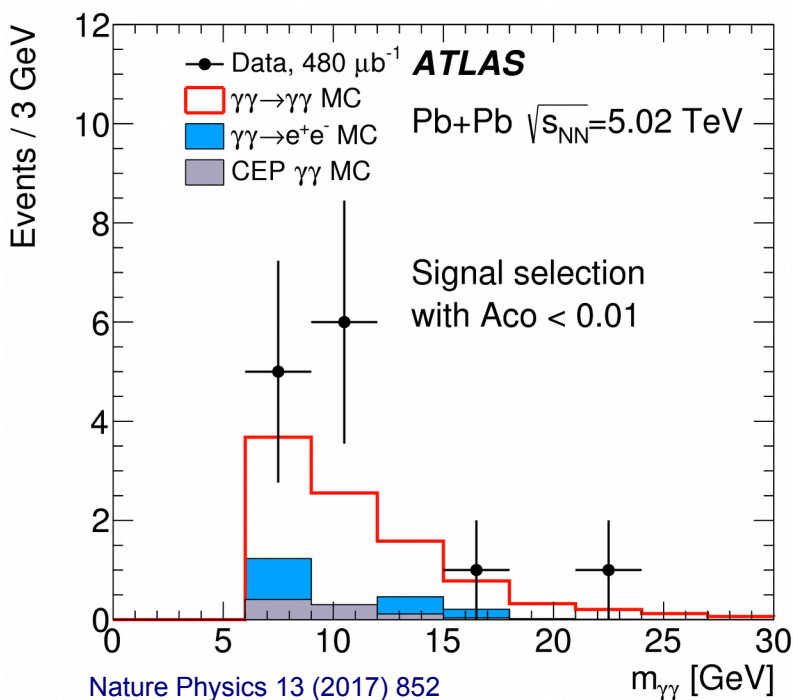
RPV SUSY and Long-lived particles

- Relax common assumptions
 - SUSY partners can easily acquire significant lifetime
 - R-parity violation can lead to unexpected signatures
- Often require dedicated event reconstruction strategies

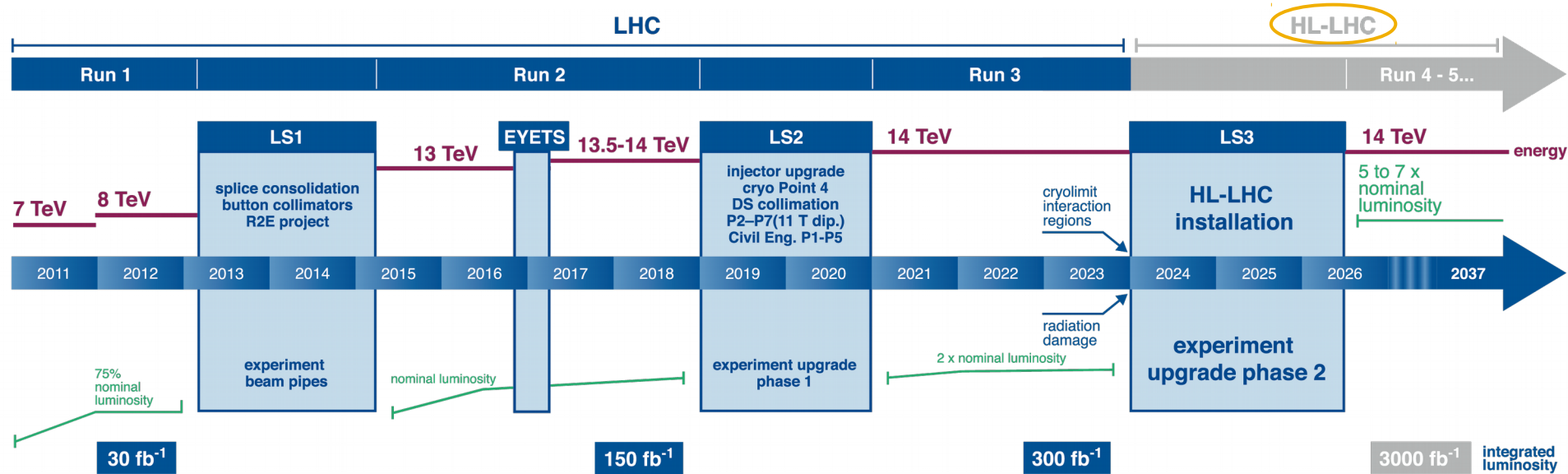


Heavy-Ion program

- Vibrant Heavy-Ion (Pb) collision program, Pb-Pb, p-Pb, Pb-p
- Recent highlight: observation of light-light scattering
 - can also constrain axion models (thanks to large ion electric charge)

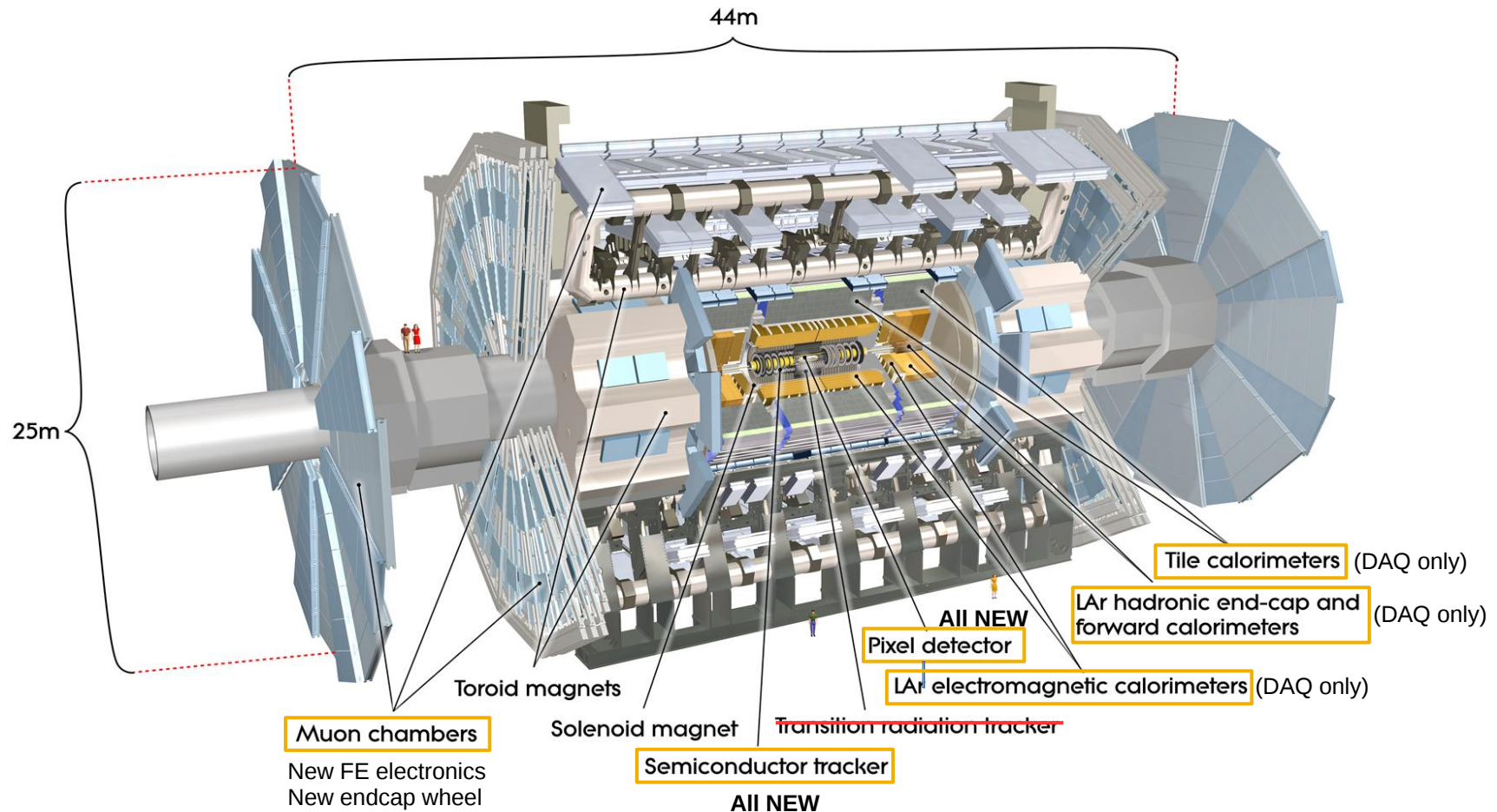


High Luminosity LHC



- To maximize physics output in the long-term, a major upgrade to the accelerator is planned, aiming to increase the instantaneous luminosity and deliver a total of 3000/fb by the end of the HL-LHC
- The ATLAS detector will also be upgraded to cope with the higher instantaneous luminosity expected (up to 200 interactions / bunch crossing)

Systems planning upgrade



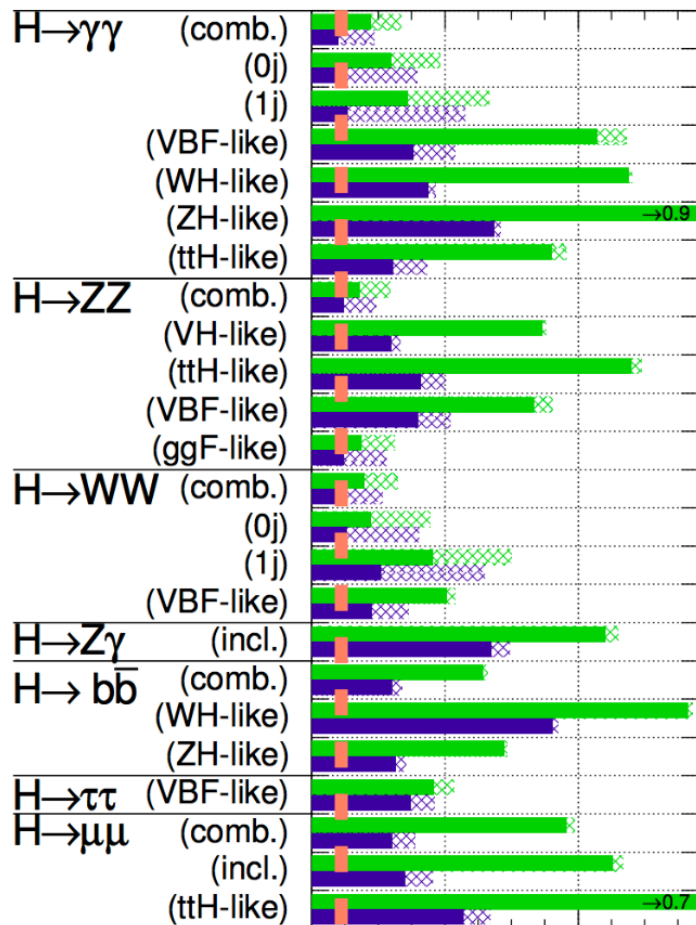
Completely new inner tracking system, extending up to $|\eta| \sim 4$

+ Trigger system, Computing, possibly new forward timing detectors

- Precision measurement of main couplings: WW , $\gamma\gamma$, bb
- Strengthen evidence of couplings with fermions / leptons (τ , b , t)
- Test couplings to 2nd generation (μ , c)
- Indirect measurement of Higgs width
 - For $\Gamma_H = \Gamma_H^{\text{SM}}$
 $\Gamma_H = 4.2_{-2.1}^{+1.5} \text{ MeV}$ with 3000 fb⁻¹
 Run-1 limit: $\Gamma_H < 22.7 \text{ MeV}$ @ 95% C.L.

ATLAS Simulation Preliminary

$\sqrt{s} = 14 \text{ TeV}$: $\int \mathcal{L} dt = 300 \text{ fb}^{-1}$; $\int \mathcal{L} dt = 3000 \text{ fb}^{-1}$

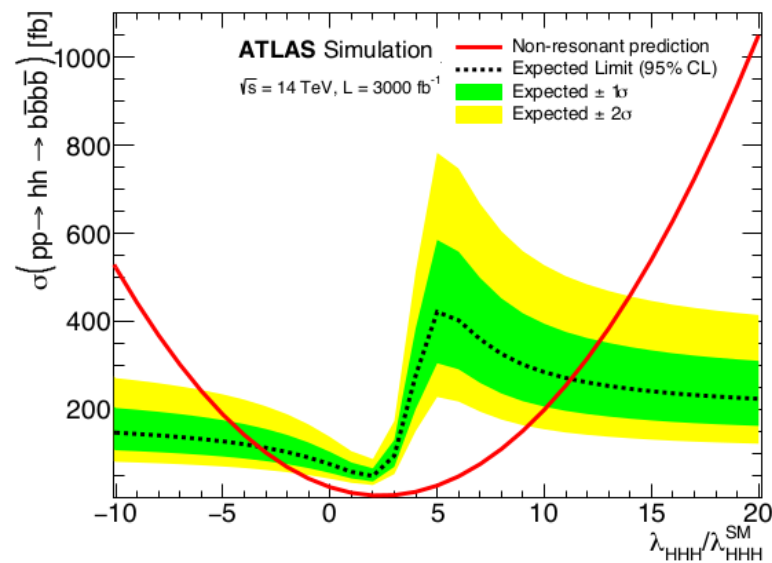
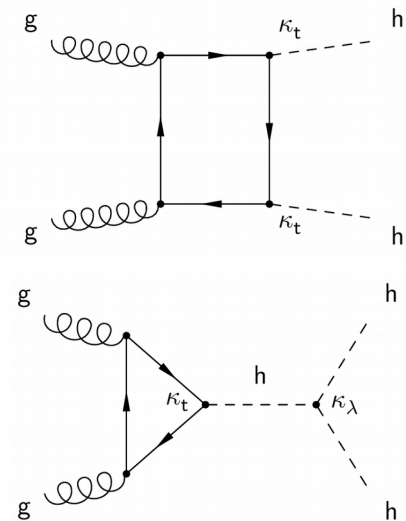


ATL-PHYS-PUB-2014-016

0 0.2 0.4
 $\mu = \sigma / \sigma_{\text{SM}} \quad \Delta\mu / \mu$

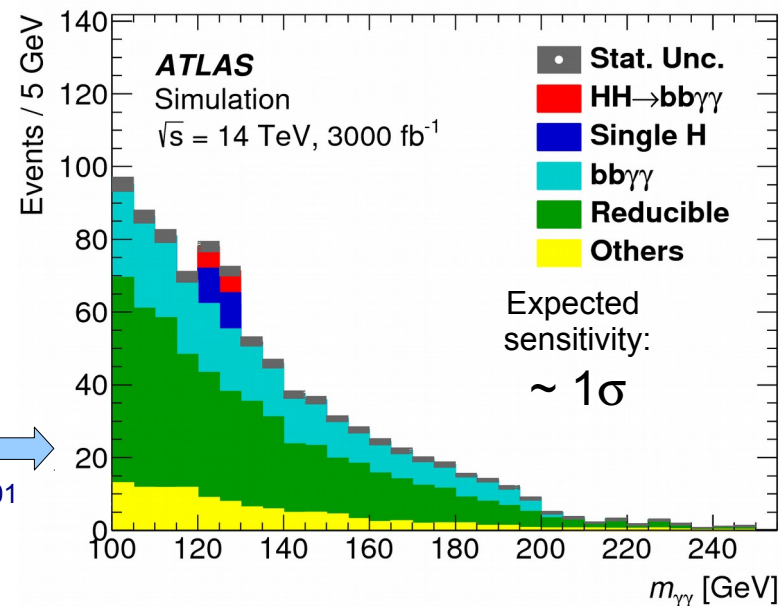
Higgs self-coupling

- Critical to test Higgs self-coupling in the SM
- Very low cross-section
 - small couplings + destructive interference: ~ 40 fb
- Full HL-LHC dataset and combination of channels needed for SM sensitivity
 - upgraded detector critical to maintain e.g. low jet p_T trigger thresholds and b-tagging capabilities



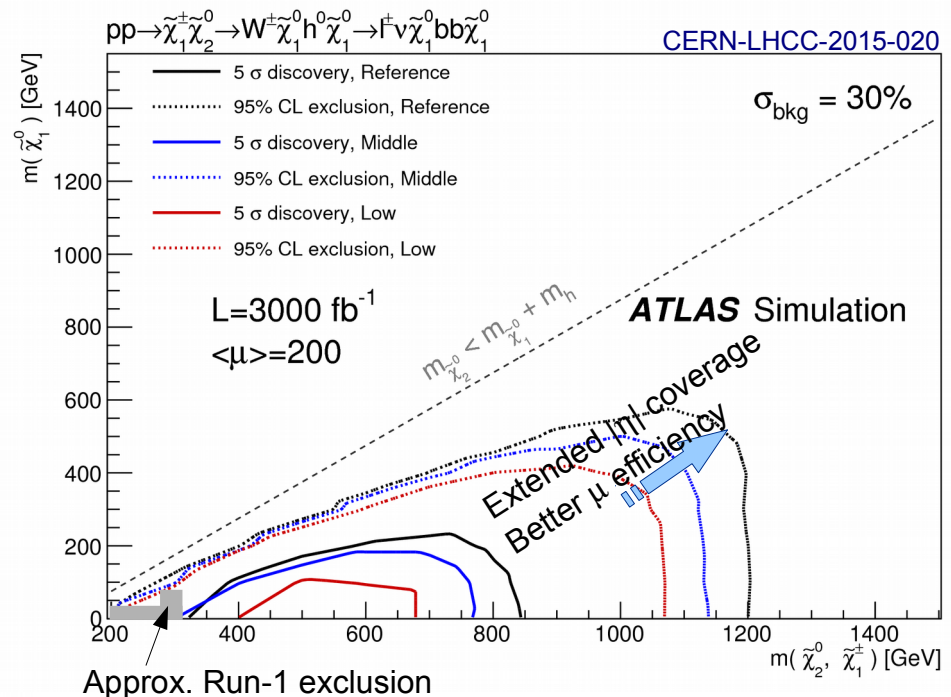
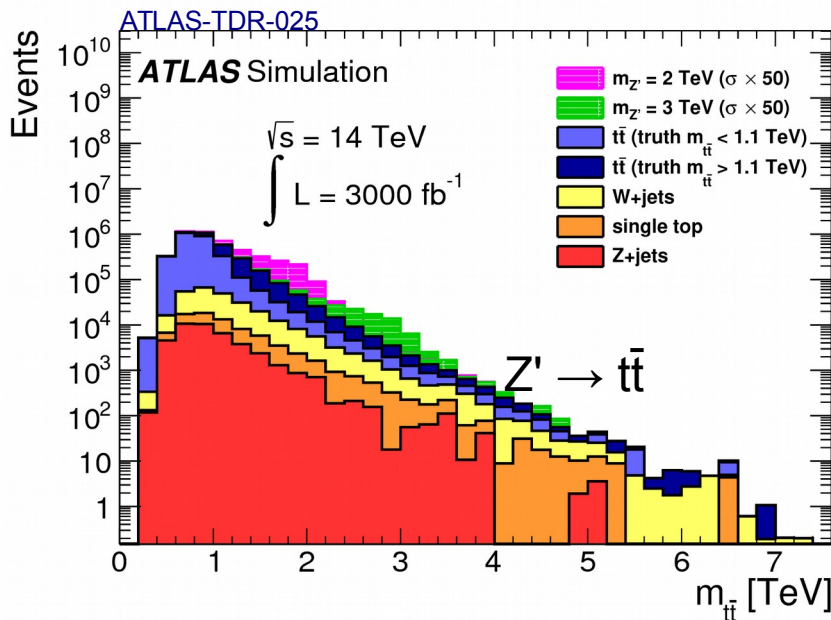
← $HH \rightarrow b\bar{b}b\bar{b}$
 ATLAS-TDR-025

$HH \rightarrow b\bar{b}\gamma\gamma$ →
 ATLAS-PHYS-PUB-2017-001



Beyond the Standard Model

- Increase mass reach for resonant states
 - e.g. $Z' \rightarrow t\bar{t}$ reach increases from $\sim 2\text{TeV}$ (2015) to $\sim 4\text{TeV}$ (HL-LHC)
- Large dataset increase sensitivity to rare processes
 - EWK SUSY partners reach extends from few hundreds of GeV to above 1 TeV in standard simplified models

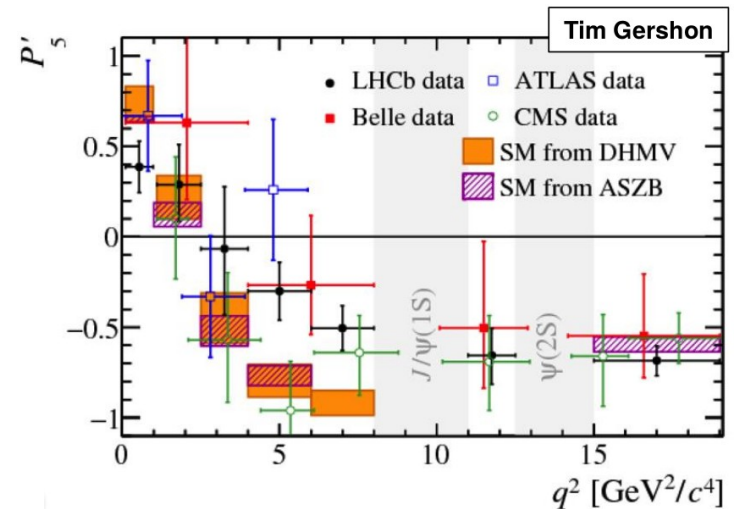
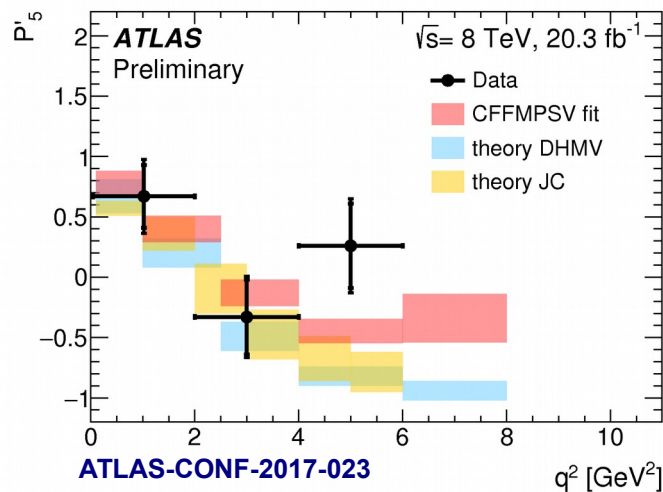


- LHC has been performing remarkably well
 - e.g. instantaneous luminosity beyond design value
- ATLAS is collecting and analyzing data efficiently
 - continuous improvements to detector and analysis technique to cope with increasingly challenging conditions
- Vast physics program to test the Standard Model
 - accurate measurement of known processes
 - direct search of beyond-SM physics in a variety of final states
- The Standard Model remarkably reproduces observations
- The current dataset is $\sim 2\%$ of what expected by end of HL-LHC
 - More luminosity will allow us to explore new ways to test theory

- Heavy flavor physics is a robust probe of new physics through loop contributions

Angular analysis of $B_d \rightarrow K^* \mu\mu$

- P_5' amplitude parameter measured to exceed SM expectation at moderate $q^2 = m(\mu\mu) \sim 5 \text{ GeV}^2$ by LHCb and Belle
- ATLAS analysis with 8 TeV Run-1 data consistent with SM but also with LHCb and Belle measurements



Vector Boson Scattering

- Golden channel: $pp \rightarrow W^\pm W^\pm jj$
- First evidence from Run-1 data

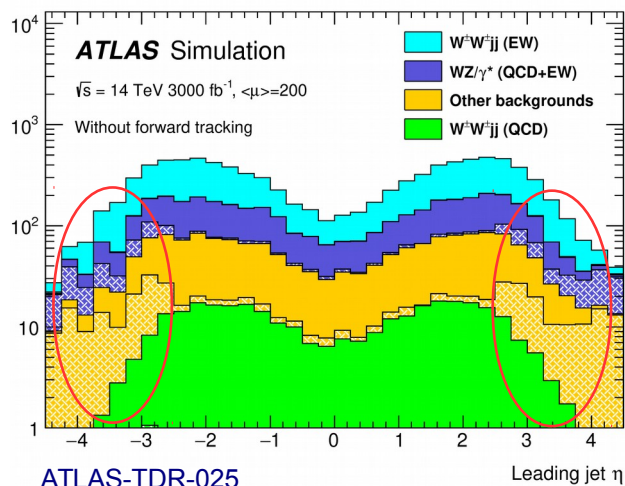
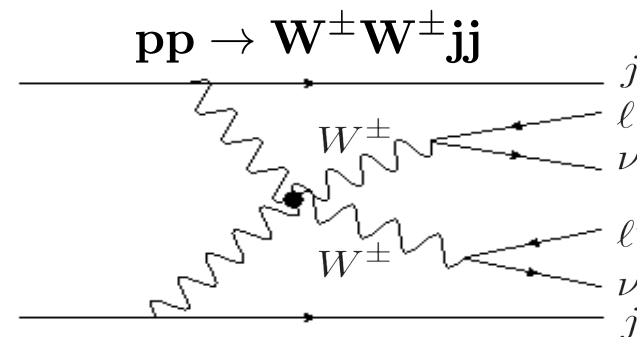
– $\sigma \sim 1 \text{ fb @ } 8 \text{ TeV}, \Delta\sigma / \sigma \sim 30\%$

- Greatly profit from large dataset and extended tracker coverage

- Expect $\Delta\sigma / \sigma \sim 4\%$ by end of HL-LHC

→ differential cross section measurements become possible

→ Sensitivity to higher mass resonances 2-3 TeV → 4-6 TeV



$|\eta|$ tracking coverage
 2.5 → 4.0

