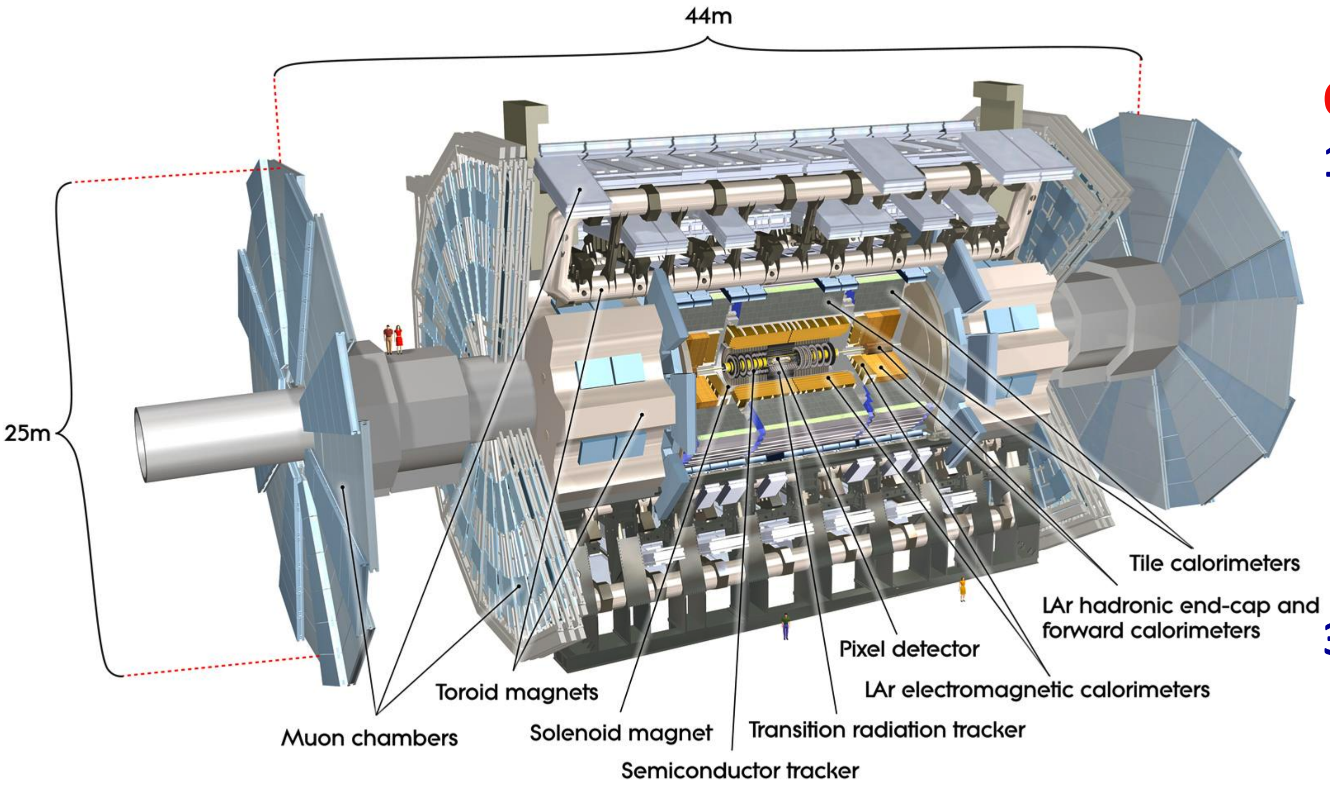
ATLAS

A Toroidal LHC ApparatuS



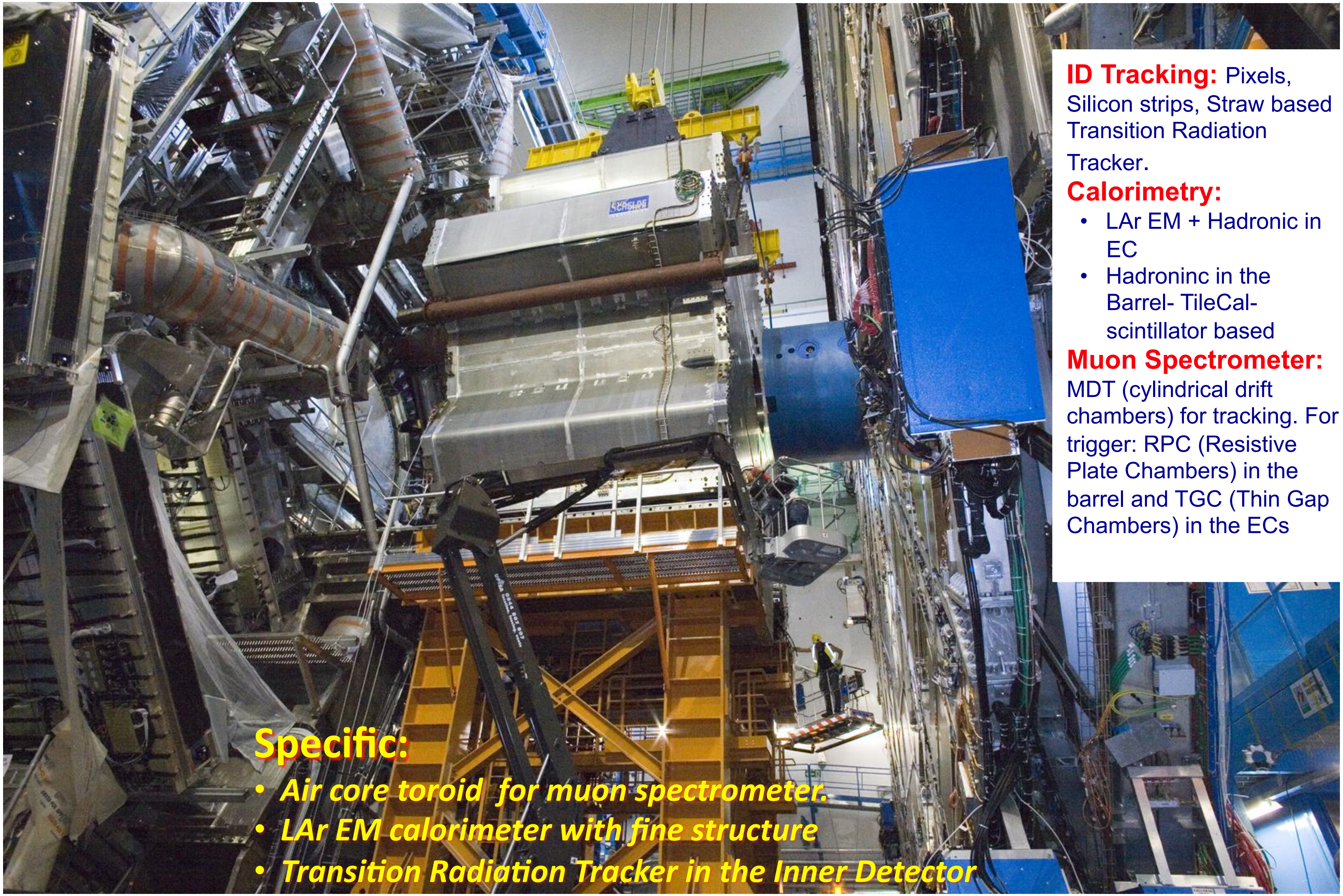
Outline:

1. **ATLAS detector in run 2 and beyond.**
2. **New physics results:**
   - Standard Model
   - BSM
     - SUSY
     - Exotics
     - DM search
3. **Conclusions.**

Run II results

On behalf of the ATLAS Collaboration.

ATLAS detector: The Largest High Energy Physics Experiment 45 meters long, 25 meters high, 7000 tons.



ID Tracking: Pixels, Silicon strips, Straw based Transition Radiation Tracker.

Calorimetry:

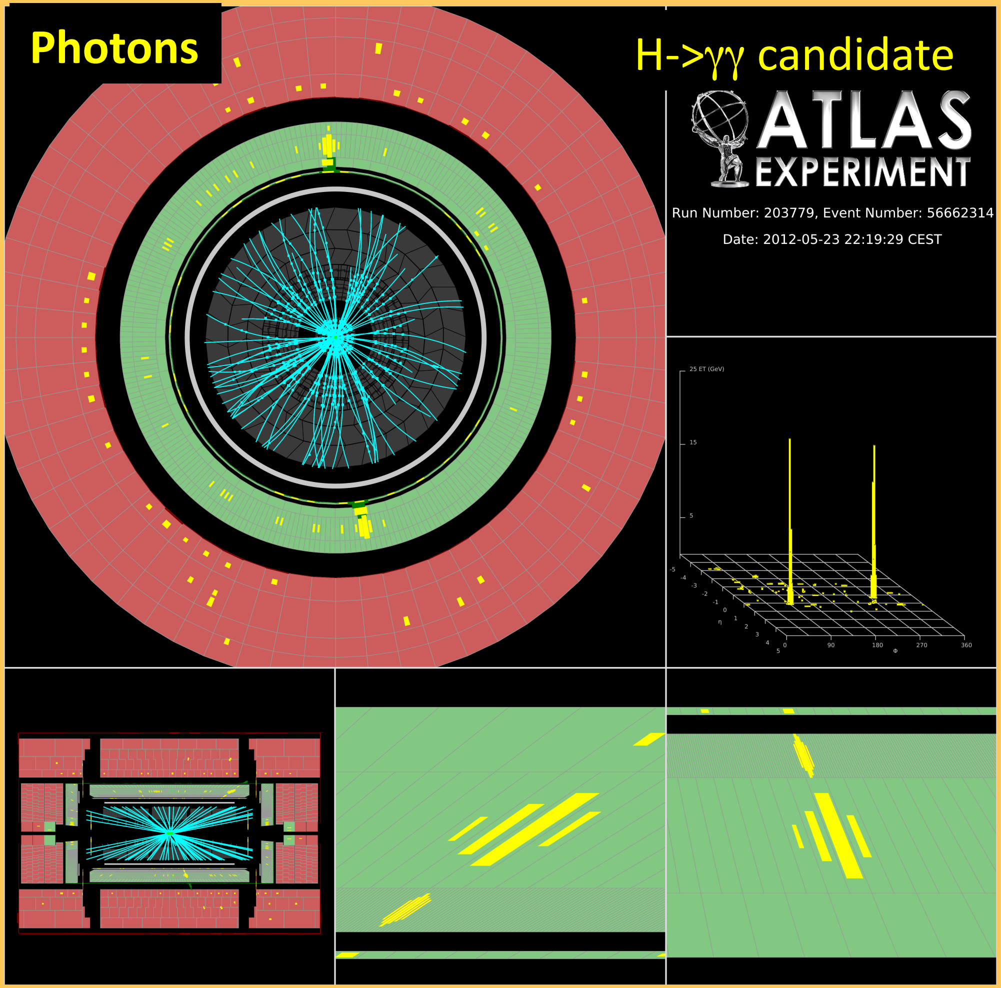
- LAr EM + Hadronic in EC
- Hadroninc in the Barrel- TileCal- scintillator based

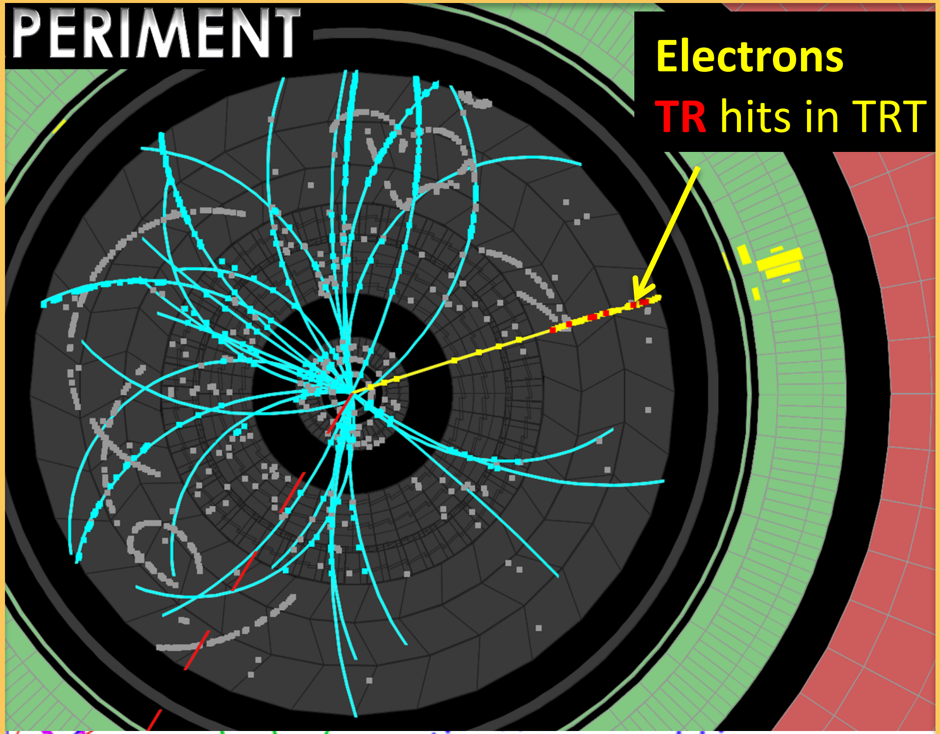
Muon Spectrometer: MDT (cylindrical drift chambers) for tracking. For trigger: RPC (Resistive Plate Chambers) in the barrel and TGC (Thin Gap Chambers) in the ECs

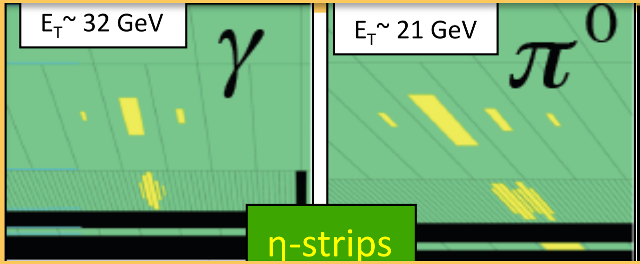
Specific:

- *Air core toroid for muon spectrometer.*
- *LAr EM calorimeter with fine structure*
- *Transition Radiation Tracker in the Inner Detector*

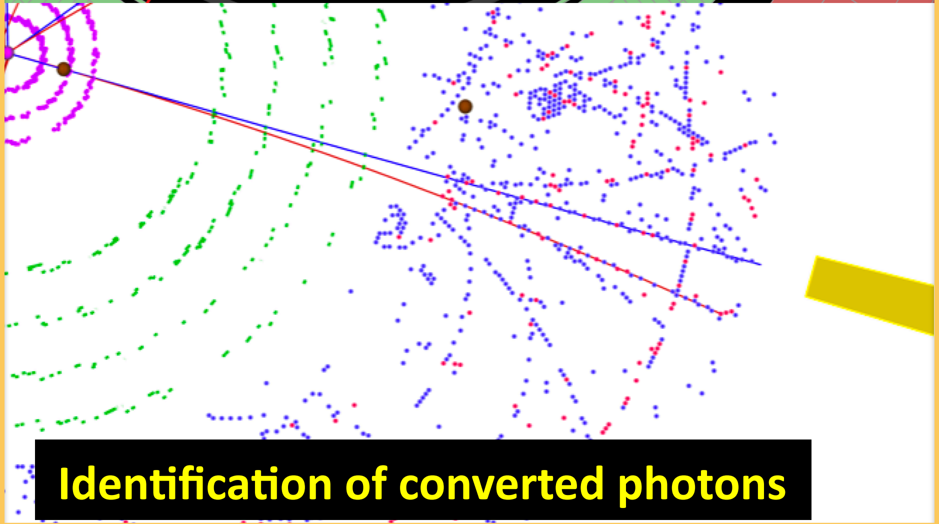
ATLAS: electron AND photon identification





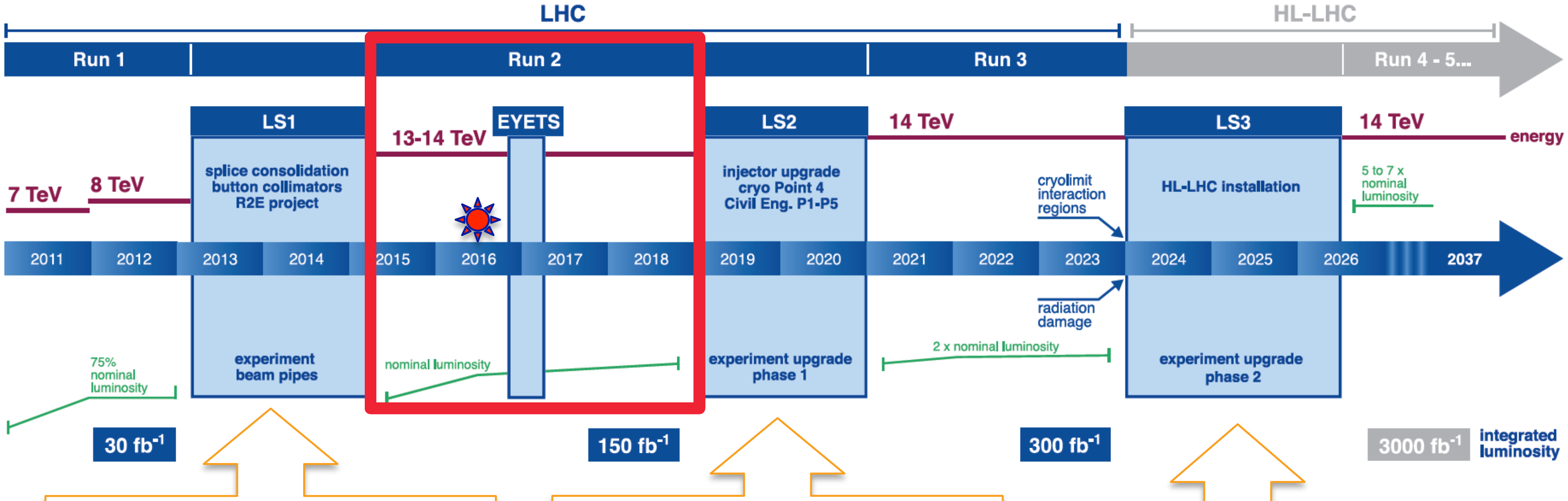


Photon/π^o separation in LAr calorimeter



Identification of converted photons

ATLAS detector: LHC challenges



Phase 0 upgrade

Be ready for:

- $\sqrt{s}$=**13** TeV
- Pile up ~**40**
- L ~ $\mathbf{1.6} * 10^{34}$ cm^{-2}s^{-1}
- Integral L ~ **100-150** fb^{-1}

What to improve:

- One more Pixel layer
- **70->100** kHz L1 trigger rate
- **400->1000** per sec recorded events
- Improve operation reliability of all detectors according to new challenges.

Phase 1 upgrade

Be ready for:

- $\sqrt{s}$=**14** TeV
- Pile up ~**60-80**
- L up to $\mathbf{3} * 10^{34}$ cm^{-2}s^{-1}
- Integral L ~ **300** fb^{-1}

What to improve:

- New Muon Small Wheel (NSW)
- High precision Calorimeter L1 trigger
- Fast Track Trigger based on Si detectors
- Topological L1 trigger processor
- New forward diffractive physics detectors AFP

Phase 2 upgrade

Be ready for:

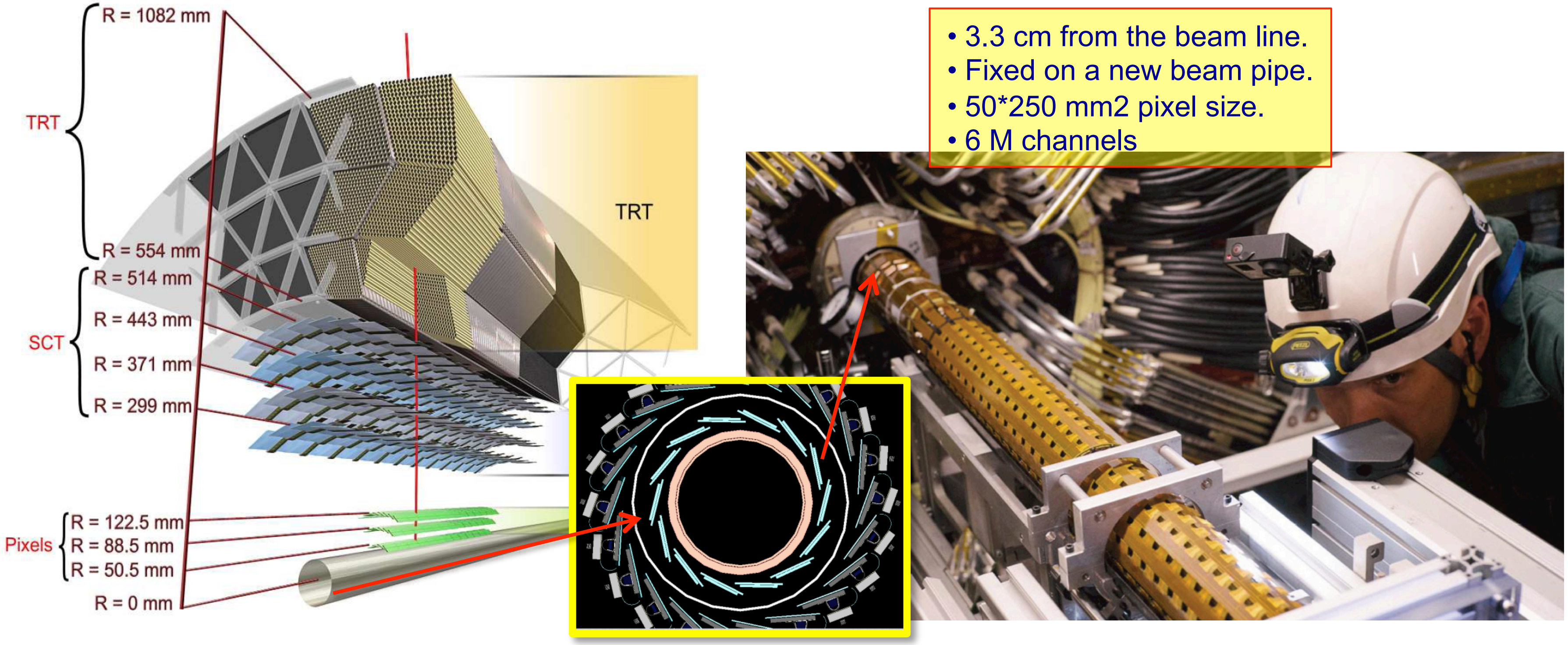
- $\sqrt{s}$=**14** TeV
- Pile up ~**200**
- L ~$\mathbf{7*}$ 10^{34} cm^{-2}s^{-1}
- Integral L ~ **3000** fb^{-}1

What to improve:

- New inner detector (Si)
- Calorimeter electronics upgrade
- Muon system upgrade
- Level-1 track trigger
- New forward calorimeters

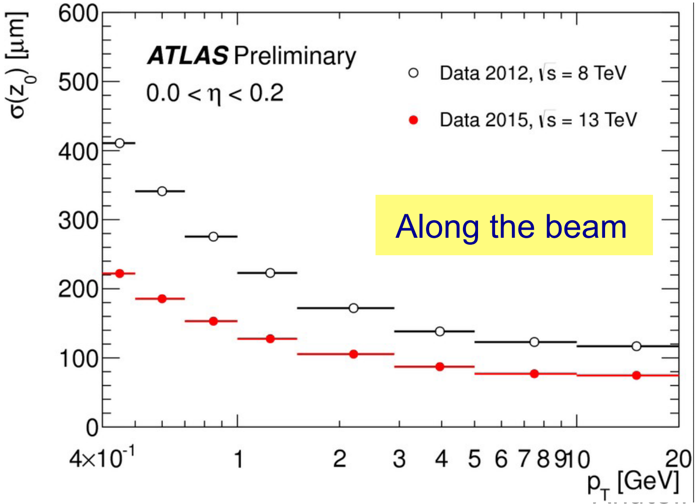
ATLAS detector: New pixel layer added: IBL (Insertable B-Layer)

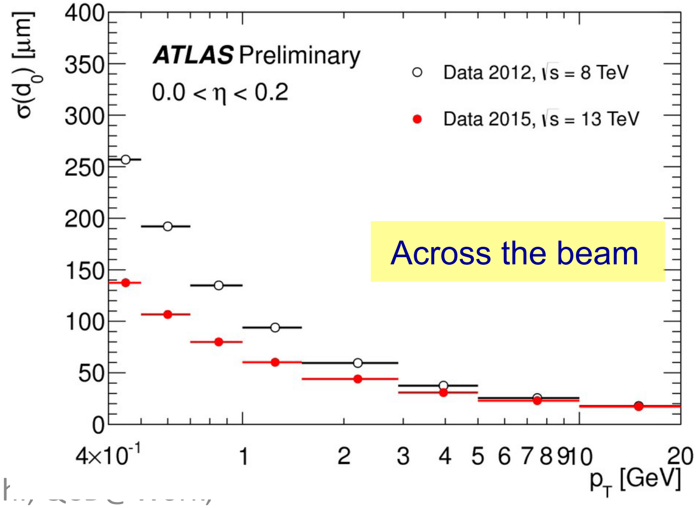
- 3.3 cm from the beam line.
- Fixed on a new beam pipe.
- 50*250 mm2 pixel size.
- 6 M channels



IBL significantly improves impact parameter resolution:

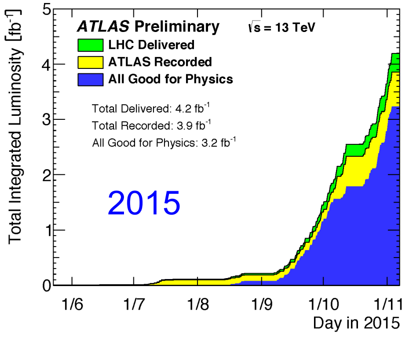
Very important for B tagging (~4 times better rejection of light flavor jets)

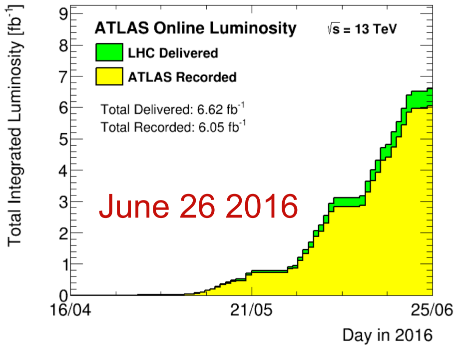




ATLAS detector: Run 2 conditions

Parameter	**Run 1**	**Run 2 2015**	**Run 2 2016**
Peak luminosity , 10^{33} cm^{-2}S^{-1})	7.7	5.1	10
Pile up (<m>)	21	13.5	30
Integrated Luminosity	22.8	4.2	
Data taking efficiency	93	92	93



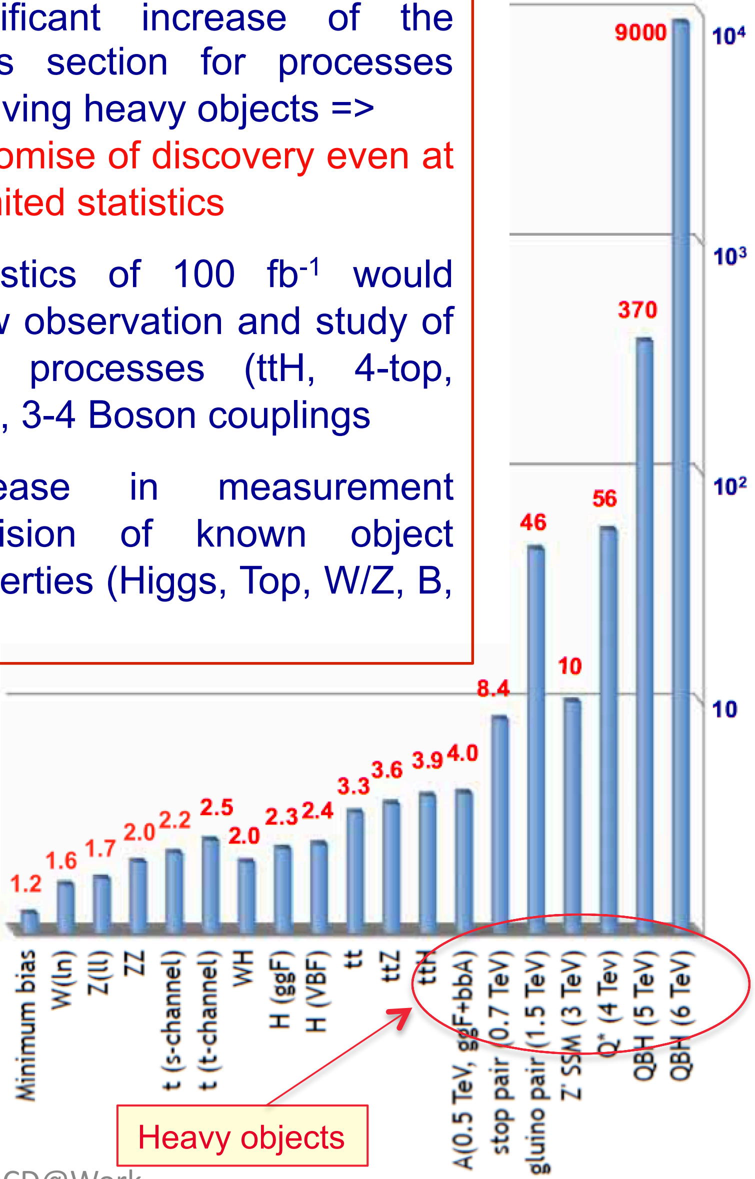


2015: 4.2 fb^{-1} delivered, 3.9 fb^{-1} recorded and **3.2 fb^{-1} used for physics.**

2016: 6.5 fb^{-1} delivered 6.0 fb^{-1} recorded Physics analysis ongoing and will presented on ICHEP.

- Significant increase of the cross section for processes involving heavy objects => a promise of discovery even at a limited statistics
- Statistics of 100 fb^{-1} would allow observation and study of rare processes (ttH, 4-top, VBS, 3-4 Boson couplings
- Increase in measurement precision of known object properties (Higgs, Top, W/Z, B, ….)

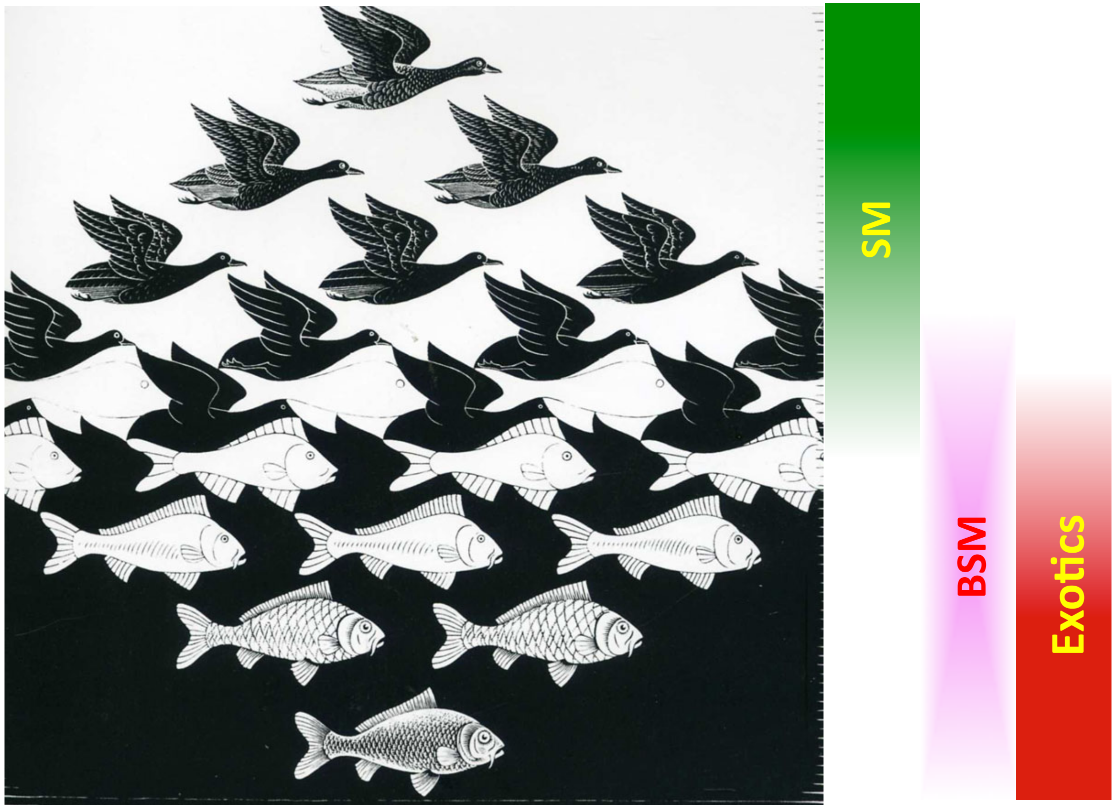
Run1/Run2 cross section

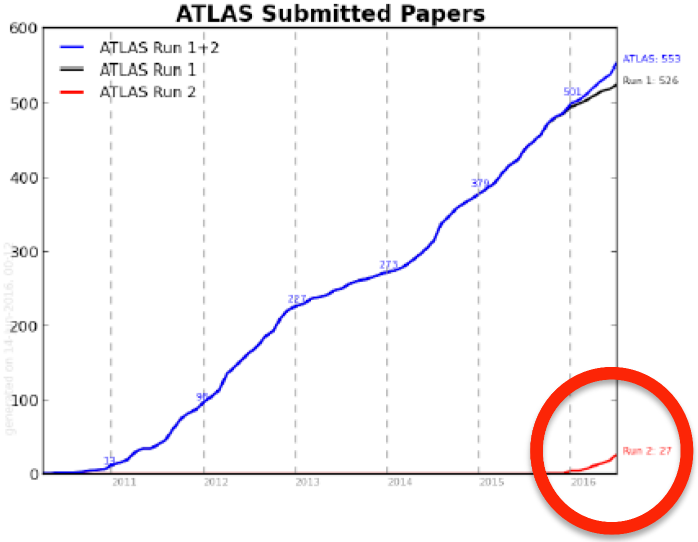


Heavy objects

Run 2 physics results

Disclaimer: *It is not possible to cover all results even they are only a small fraction of what was obtained in Run 2. Will try to cover the most important ones.*





2015 run
30 papers, 15 in pile up,
many conf notes

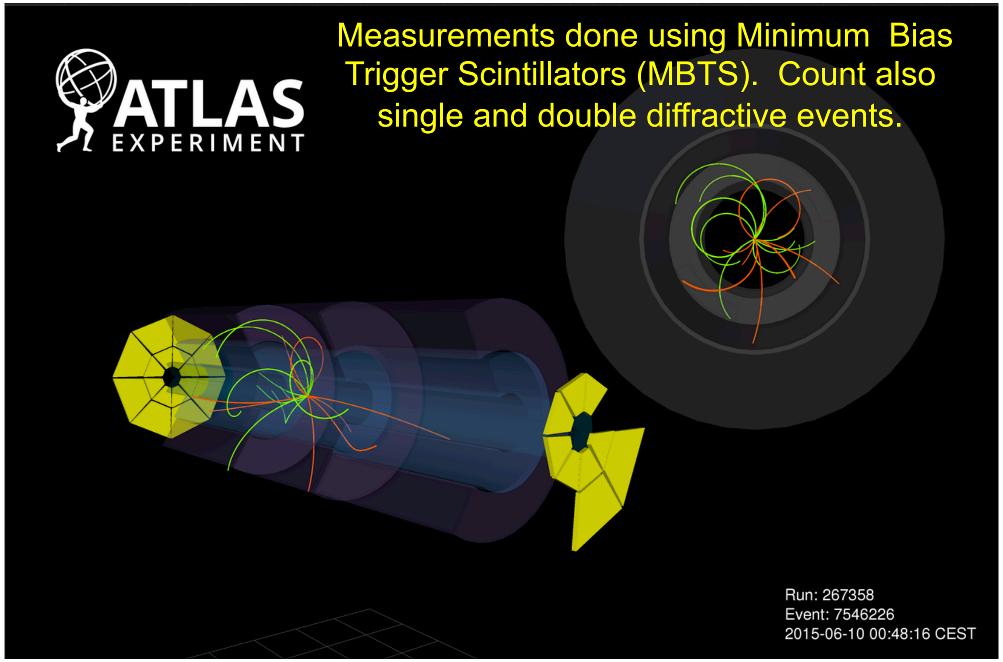
Only selected results can be presented

Significant overlap regions between what is called SM, Beyond SM and Exotics.

Run 2 physics results: SM cross sections

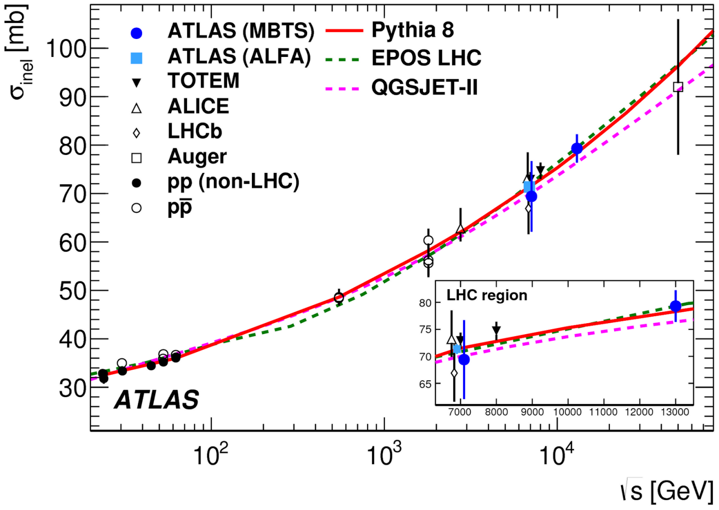
Total inelastic cross section.

arXiv:1606.02625

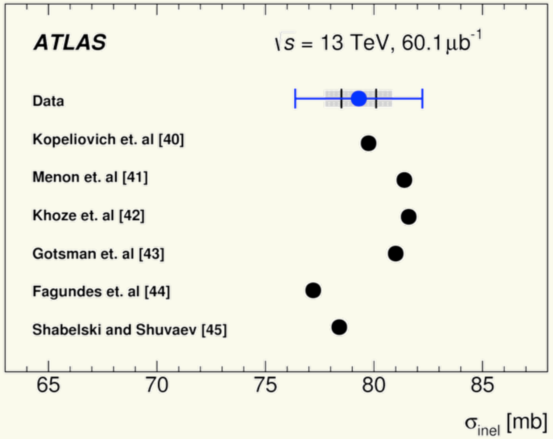


Measurements done using Minimum Bias Trigger Scintillators (MBTS). Count also single and double diffractive events.

Run: 267358
Event: 7546226
2015-06-10 00:48:16 CEST



The inelastic proton-proton cross section versus √s. The data are compared to the **PYTHIA8, Epos LHC** and QGSJet-II MC generator predictions.

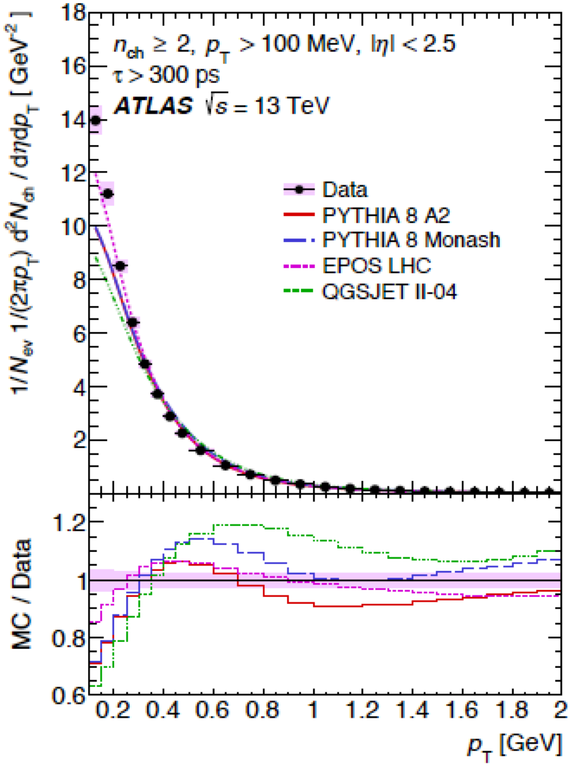


The measured inelastic cross section at 13 TeV compared with various theoretical predictions. The innermost uncertainty markers on the measurement show the experimental uncertainty only, the shaded region shows the experimental and extrapolation uncertainties together, and the outermost markers show the total uncertainty.

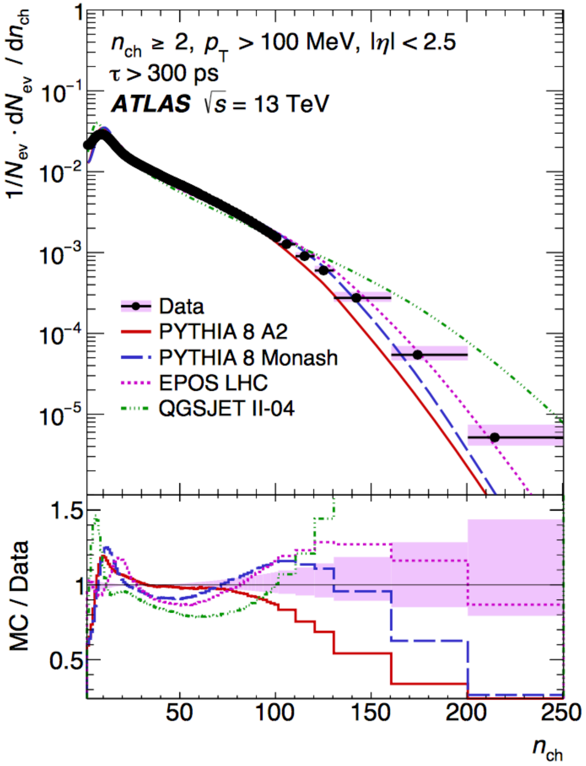
Run 2 physics results: SM

Multiplicity

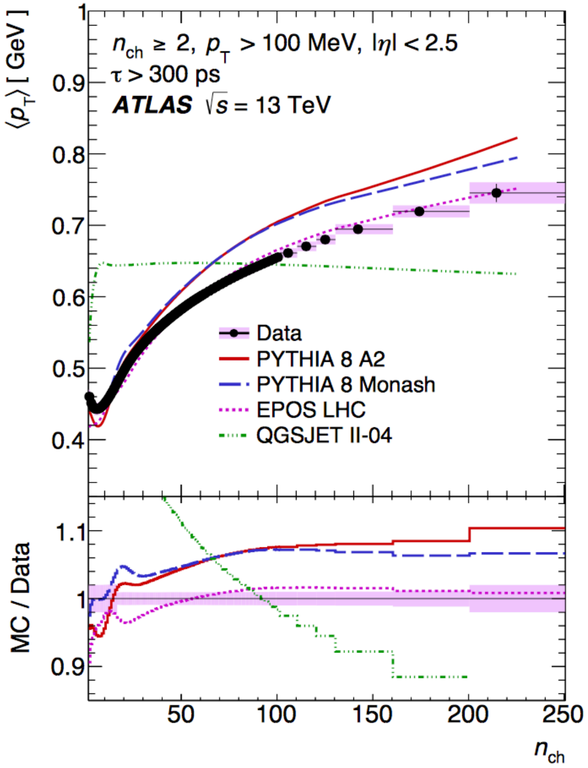
arXiv:1606.01133



Primary charged-particle multiplicities as a function of transverse momentum p_T,



Primary charged-particle multiplicities as a function n_{ch} in event

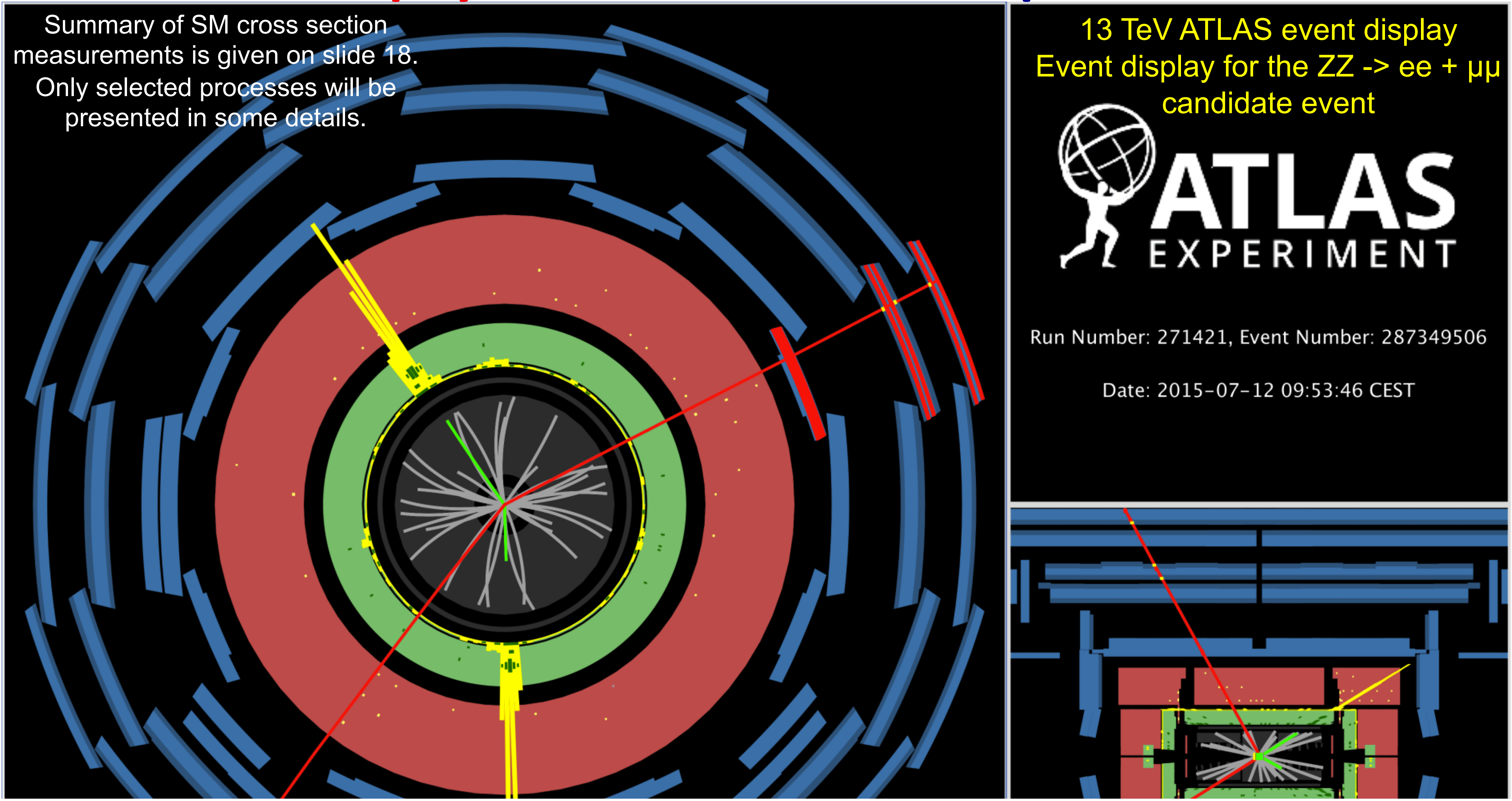


The mean transverse momentum $<p_T>$ versus n_{ch} in event.

Events with at least two primary charged particles with $p_T > 100$ MeV and $\eta < 2:5$, each with a lifetime > 300 ps are considered

*Amongst the models presented **EPOS** has the best overall description of the data.*
This is used now to model Pile Up events in the ATLAS detector up to <mu>=40.

Run 2 physics results: Di-boson production



Summary of SM cross section measurements is given on slide 18. Only selected processes will be presented in some details.

13 TeV ATLAS event display
Event display for the ZZ -> ee + μμ candidate event

Run Number: 271421, Event Number: 287349506

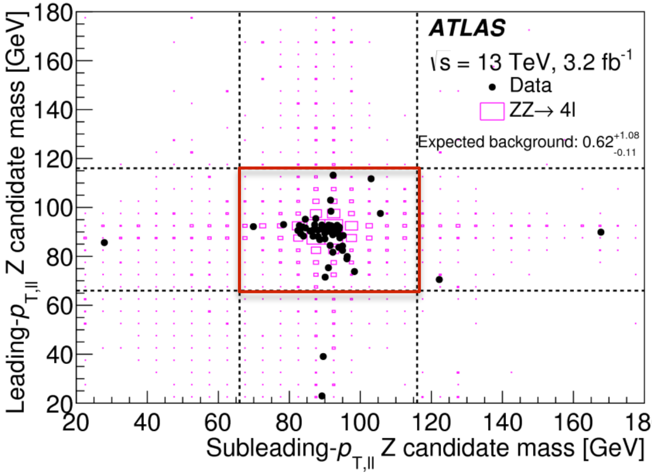
Date: 2015-07-12 09:53:46 CEST

Multi boson production in general:

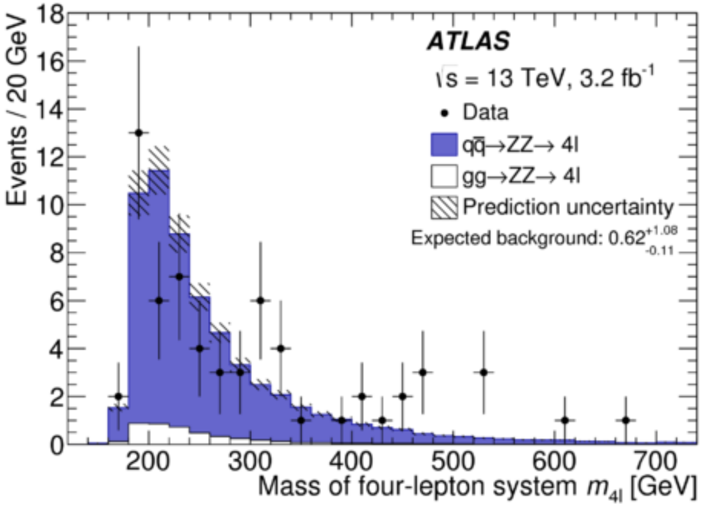
- Precision test of the standard model (SM) at the TeV scale.
- Understanding these processes is important for background estimations needed for many measurements.
- SM production of >=2 bosons (contains boson self-interactions, Higgs to VV decays)
- Allows constraints to be set on many exotic models through the study of cross-sections, triple and quartic gauge boson couplings (TGC and QGC) vertices.

Run 2 physics results: Di-boson production – ZZ

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

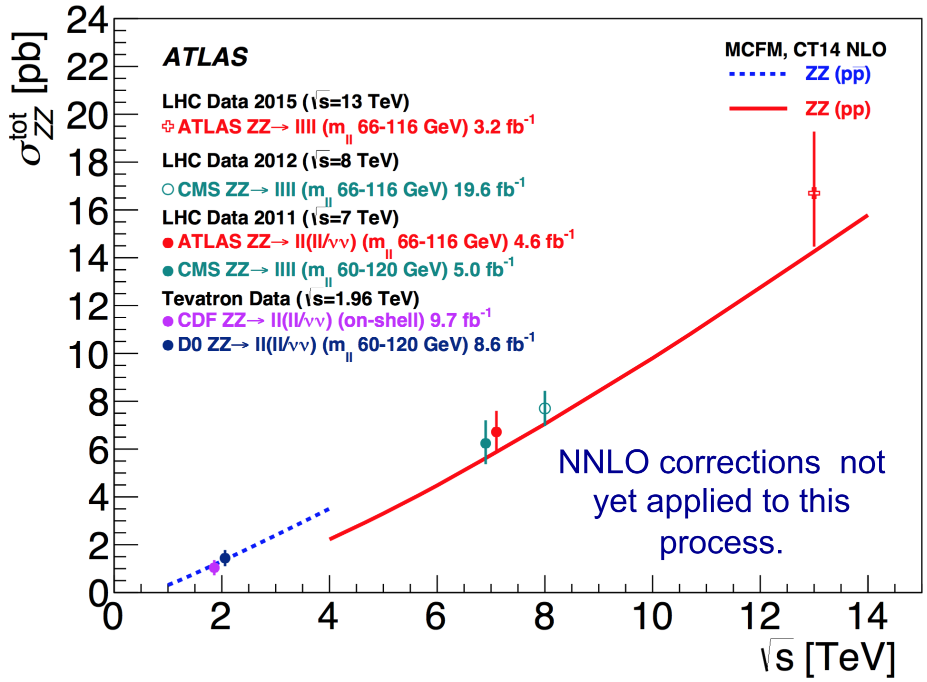


Event selection: each lepton pT>20 GeV, each Z pairs with 66 < mass < 116 GeV



4 lepton mass spectrum

Main goal is to examine the validity of EWK interaction and test NNLO QCD prediction at highest energy

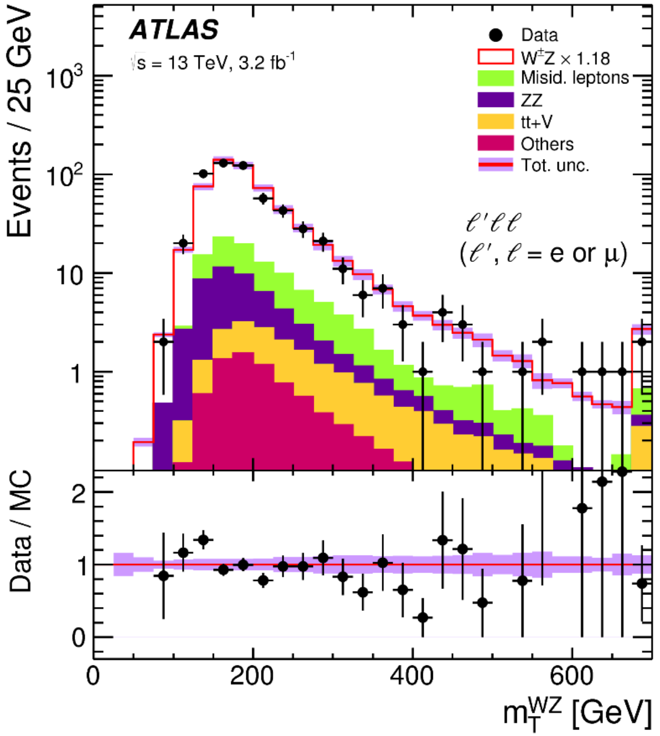


NNLO corrections not yet applied to this process.

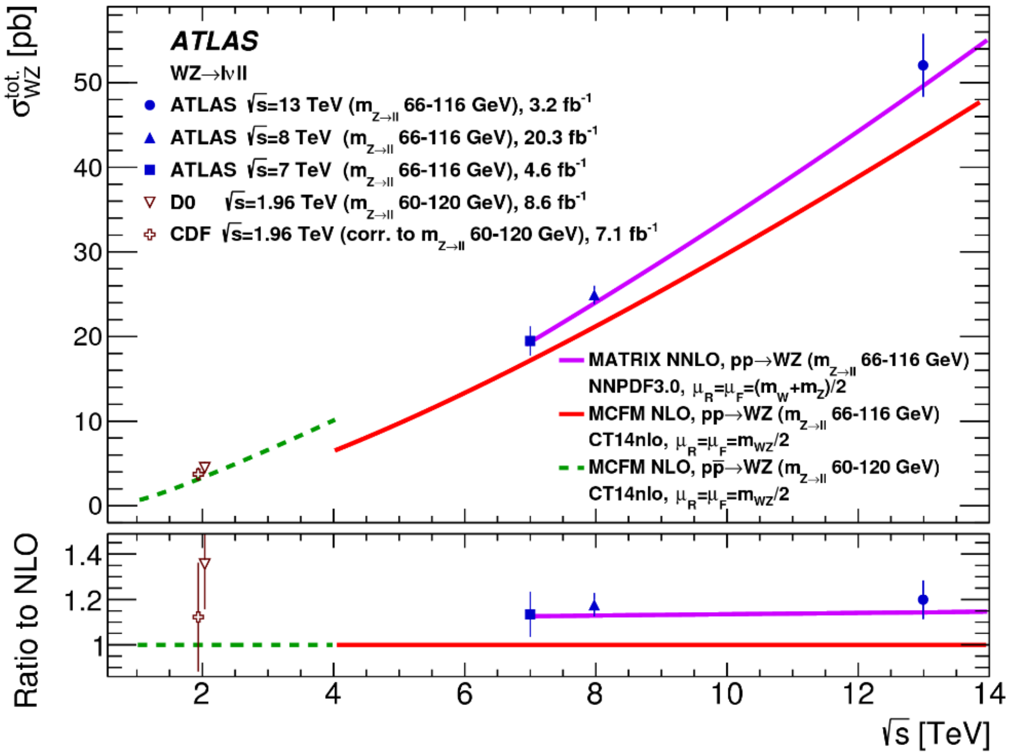
Cross-section measurement of on-shell ZZ ->4l production at 13TeV

Run 2 physics results: Di-boson production - WZ

arXiv:1606.04017



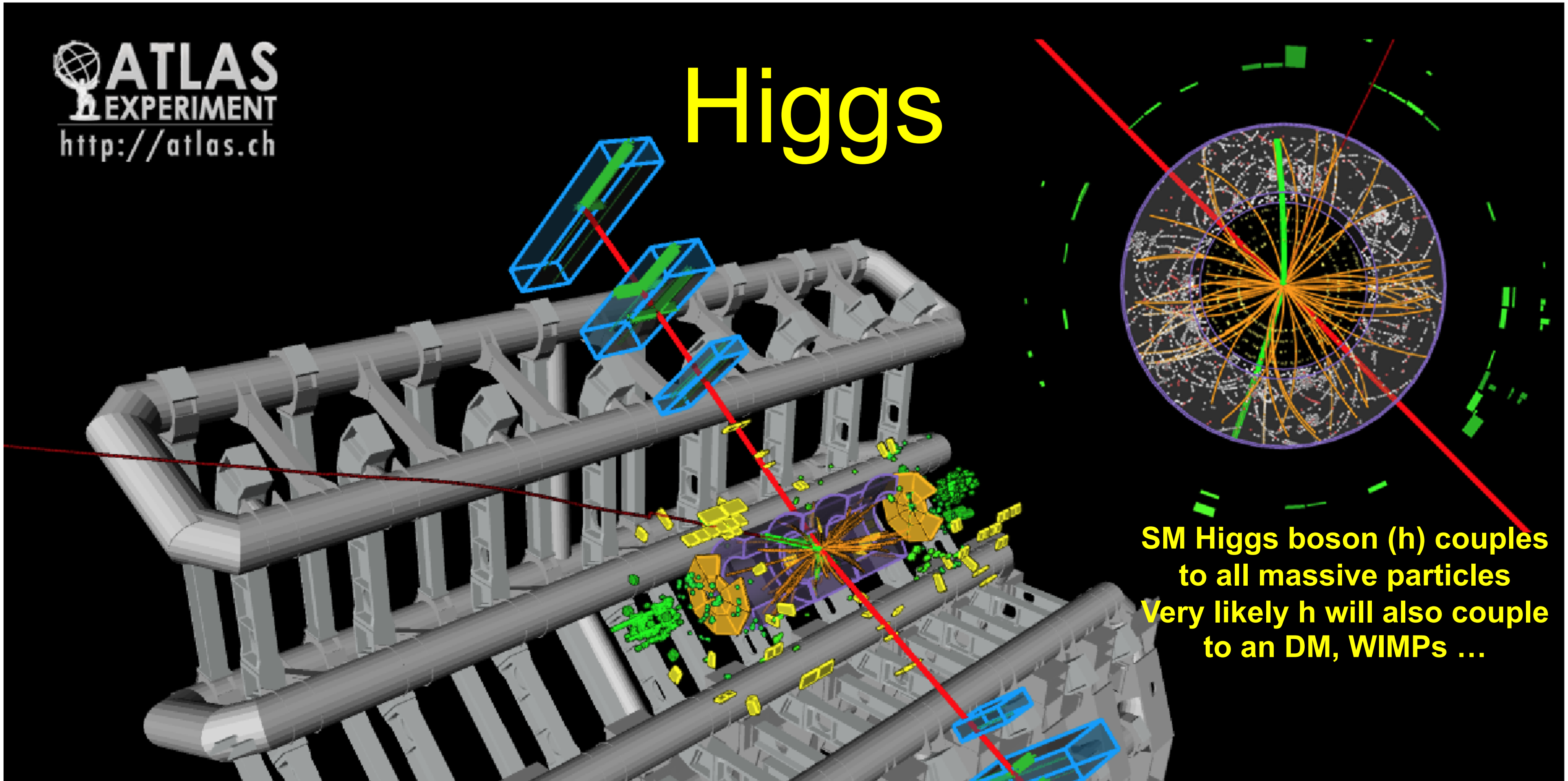
The distributions for the sum of all channels of the transverse mass variable mTWZ for the WZ system



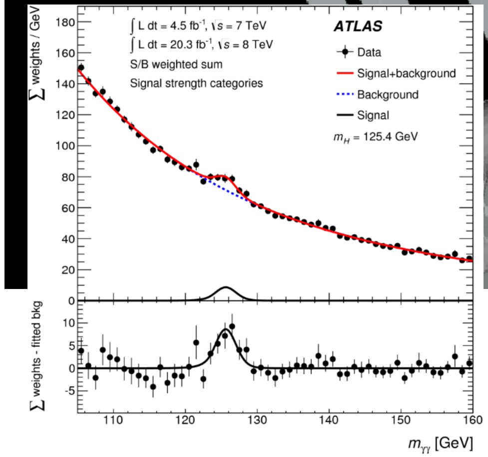
Comparison of W±Z cross section measurements at various centre-of-mass energies with Standard Model expectations.

Measured total σ found consistent to NNLO prediction

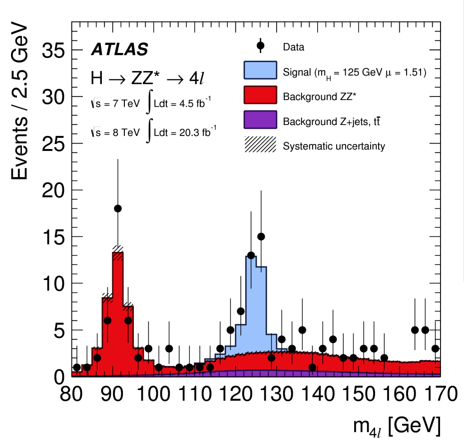
Higgs



SM Higgs boson (h) couples to all massive particles
Very likely h will also couple to an DM, WIMPs …



Results of Run 1

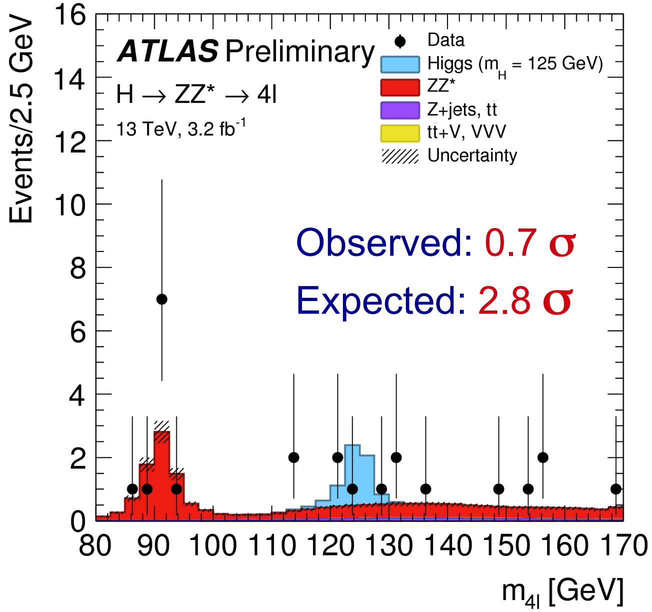


Run 2 physics results: HIGGS

Lots of results either approaching or exceeding Run-I sensitivity!

Only few will be shown.

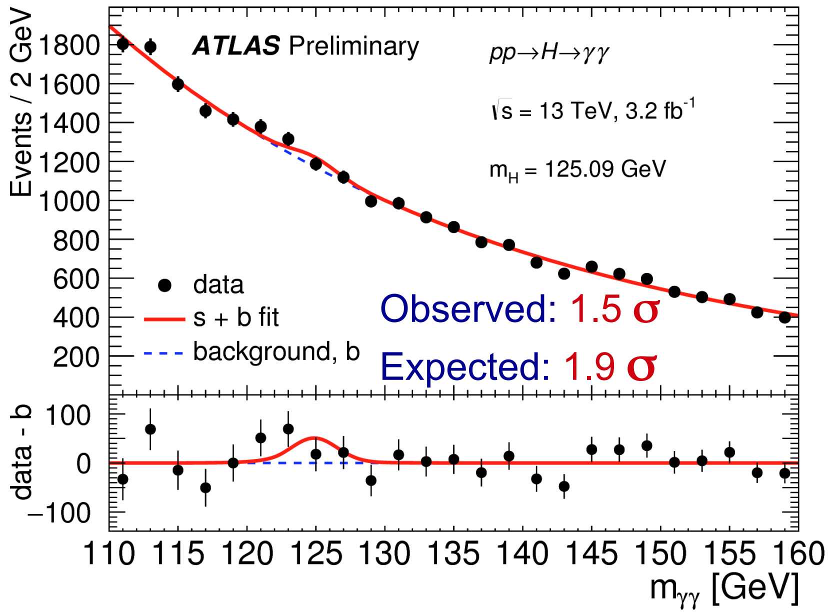
ATLAS-CONF-2015-059



Observed: 0.7 σ

Expected: 2.8 σ

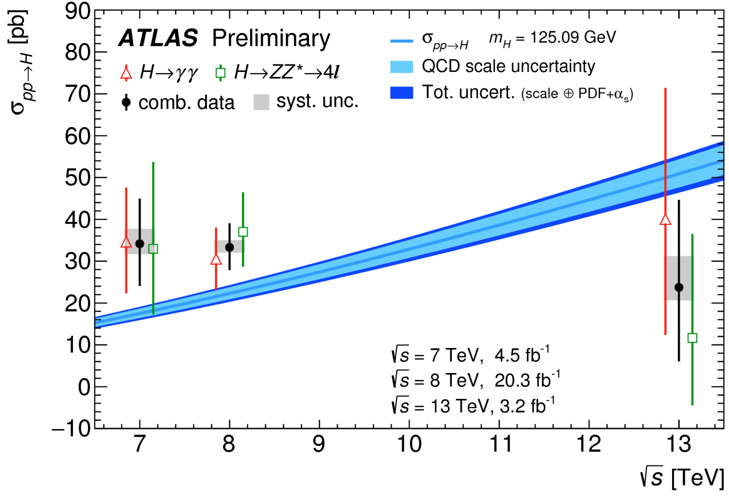
[ATLAS-CONF-2015-060]



Observed: 1.5 σ

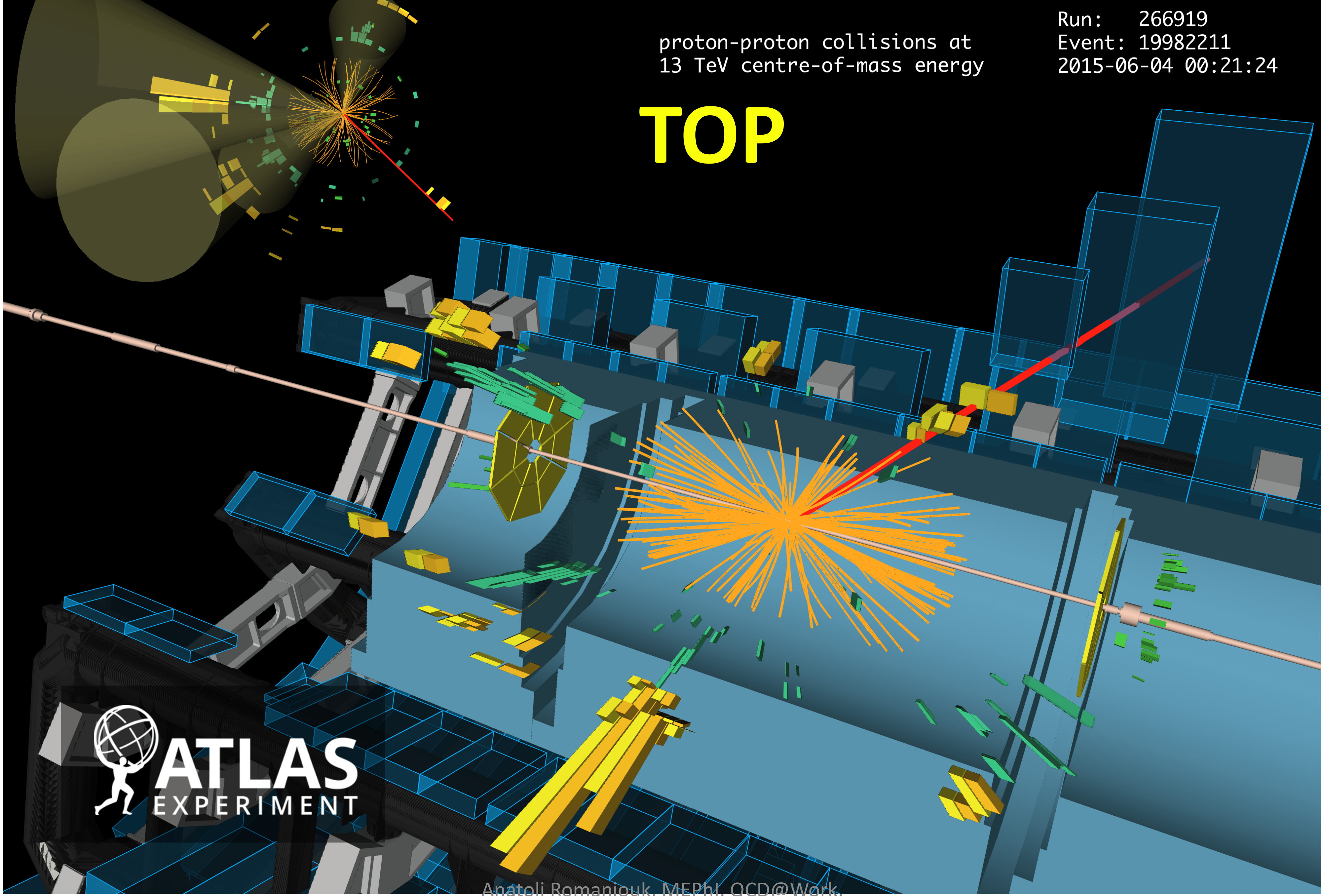
Expected: 1.9 σ

ATLAS-CONF-2015-069



Higgs production cross section (γγ, 4 leptons and combined)

ttbar production at 13 TeV

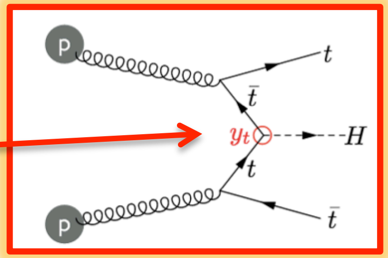


Run 2 physics results: Top

- Heaviest know particle.
- Only fermions with mass close to EW breaking scale.
- Only quark with Yukawa coupling y~1:

  M_{top}=173 ± 0.27± 0.73 **or** $M_{top} \approx v^*y_t/\sqrt{2}$=174 GeV

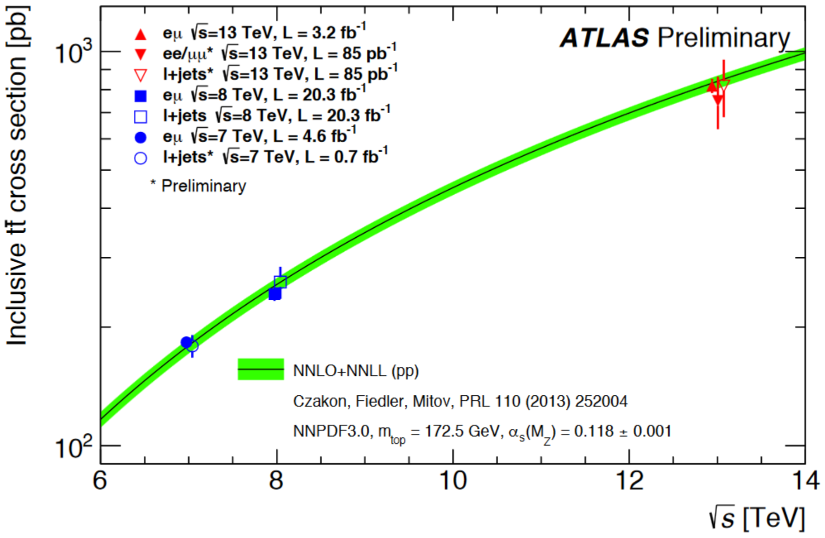
  $v= 1/sqrt(\sqrt{2}^*G_{F})\approx 246$ GeV
- Decays before hadronization =>> directs studies of particle properties using decay products.
- Perfect candidate to precision tests of SM and search BSM particles.
- Dominates Higgs productions (through gluon fusion).
- ttbar resonance is one of the most powerful tools to search for new heavy particles in the LHC pp



Very intriguing process! Some deviation from SM seen in Run 1 but not yet statistically significant. At full Run 2 statics precise measurements of this channel together with t-tbar + V will be available.

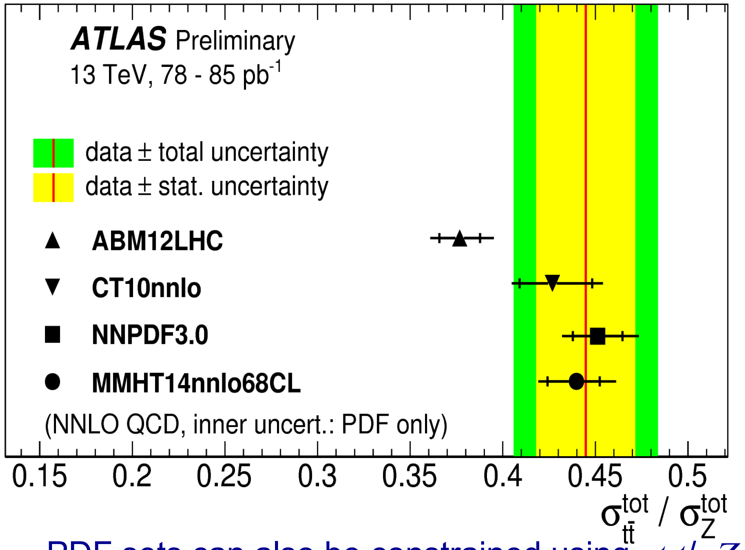
t-tbar production

arXiv:1606.02699



Inclusive t-tbar cross section in good agreement with NNLO prediction

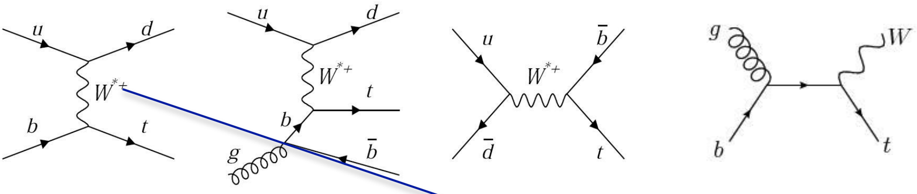
ATLAS-CONF-2015-049



PDF sets can also be constrained using $\sigma t\ t/\sigma Z$
Some models already show tension with data

Run 2 physics results: Single Top

Electro week single top production



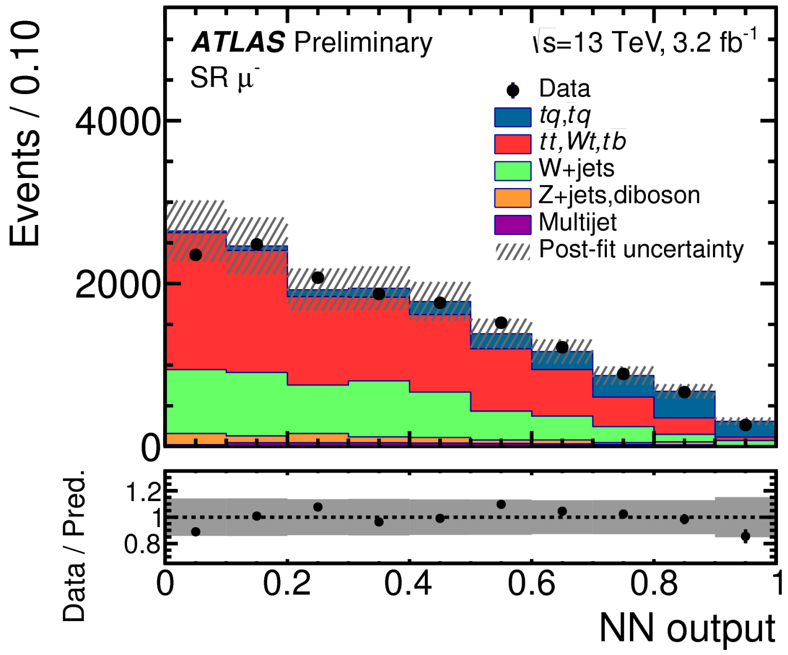
t-channel

s-channel

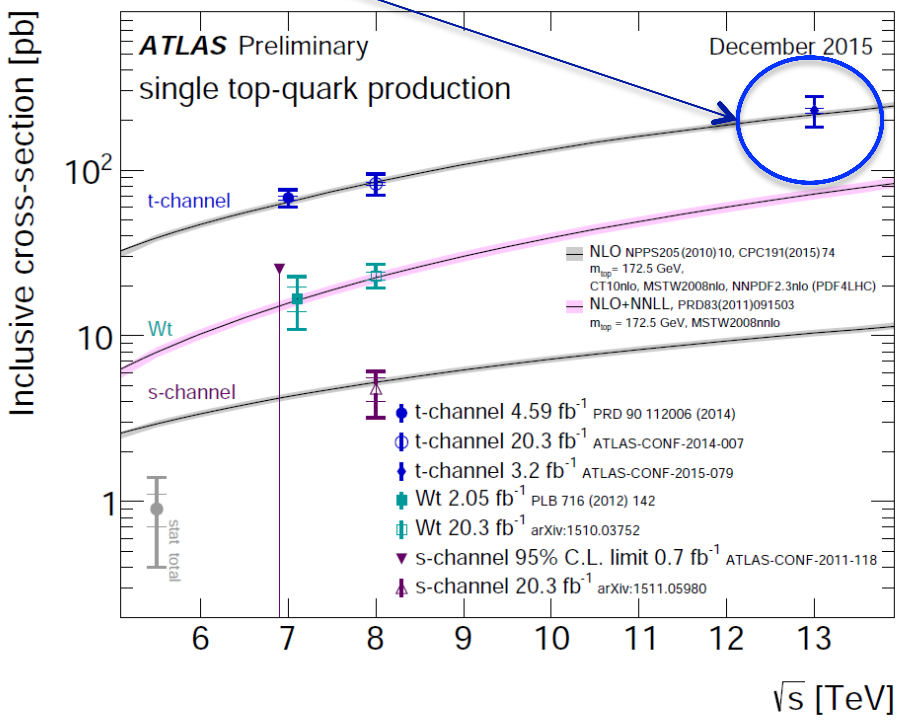
Wt

- Single top-quarks are produced via the weak interaction
- t-channel production is the dominant mode, the associated Wt and s-channel contribute about 1/3 of the combined cross-section

ATLAS-CONF-2015-079



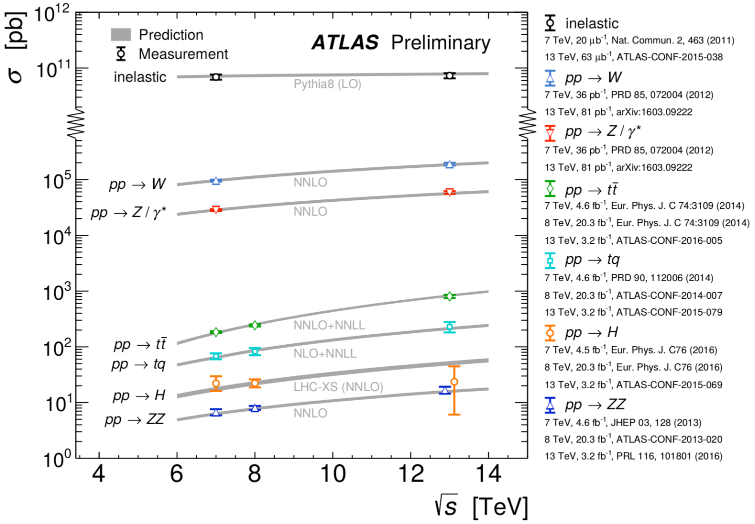
Neural Network based analysis. Binned maximum likelihood fit on the NN output.



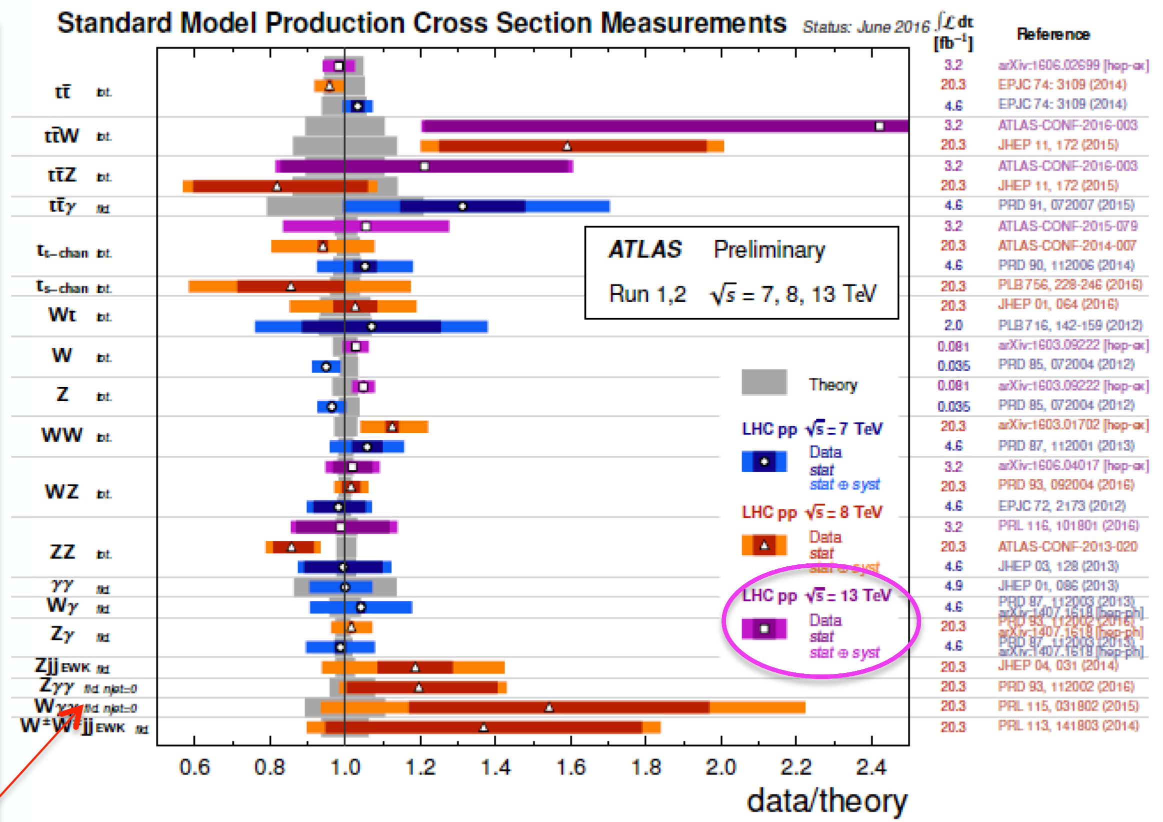
Inclusive single top quark production cross section

Run 2 physics results:

SM Production cross sections



Summary of cross section measurements by ATLAS presented as a function of centre-of-mass energy for a few selected processes.



No enough yet statistic to probe 3 and 4 gauge coupling at new conditions

The data/theory ratio for several Standard Model. **The lighter-color error bar** represents the full uncertainty, including systematic and luminosity uncertainties.

Theory uncertainties shown in grey color.

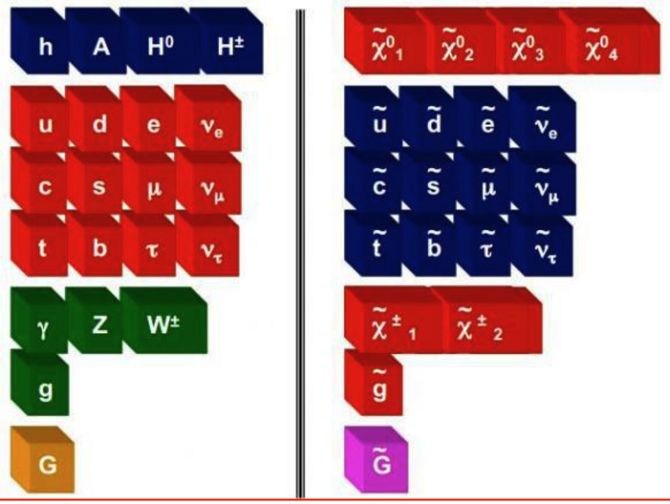
Run 2 physics results

Searches Beyond Standard Model

Run 2 physics results: SUSY

Many physicists like very much SUSY because it offers solutions to most important physics problems:

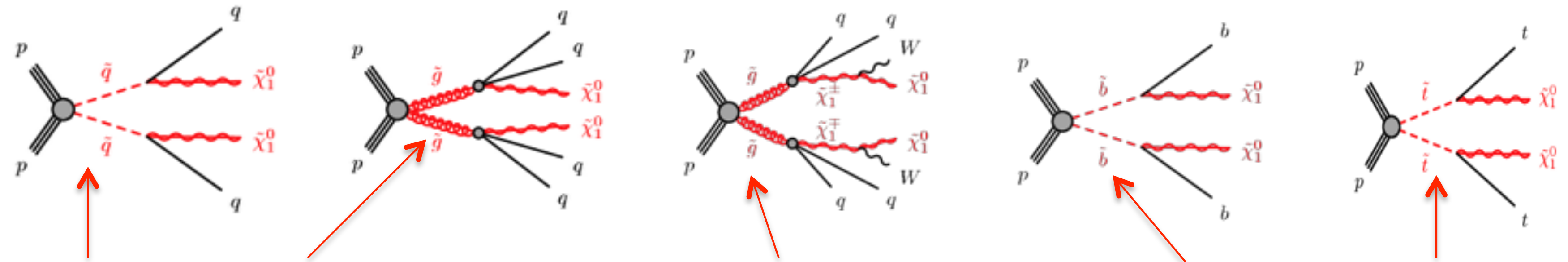
- *The problem of naturalness of Higgs mass.*
- *Dark matter (lowest mass stable particle).*
- *Grand unification theory.*



Typical cascade decays:

- *Multiple jets*
- ***Missing transfer energy***
- *Leptons (W/Z bosons)*
- *Top quarks*

With early Run2 data, strong production channels are more appropriate to search for SUSY **as σ_{strong} ~ 10000 σ_{EW}.**



SQuark→**LSP** or Gluino→**LSP**

Gluino→**LSP**
via slepton/chargino/neutralino

3rd generation:
sbottom and stop

0ℓ:

Multi-jet events
Without charged leptons

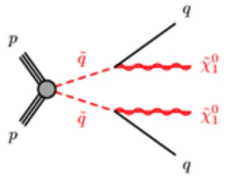
$1/2/3\ell$:

Multi-jet events
With charged leptons

b-jets

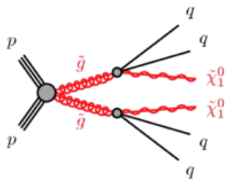
B-jet events
With and without charged leptons

Run 2 physics results: SUSY

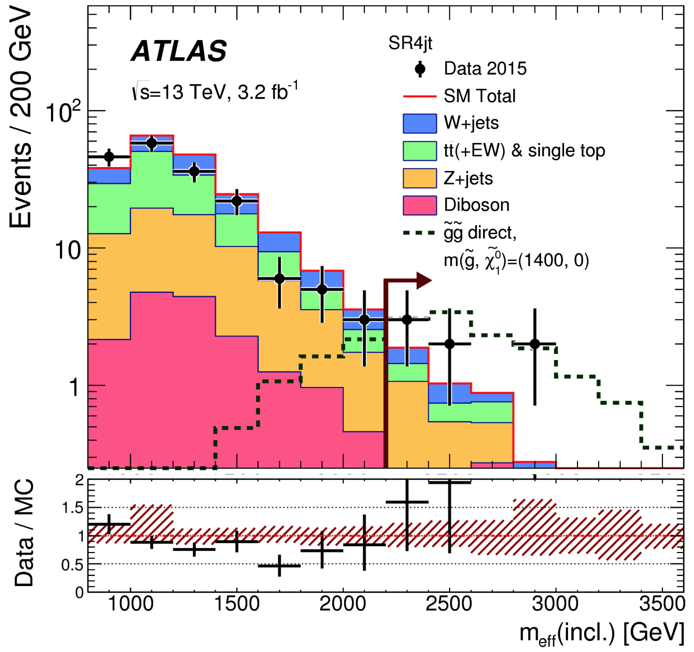


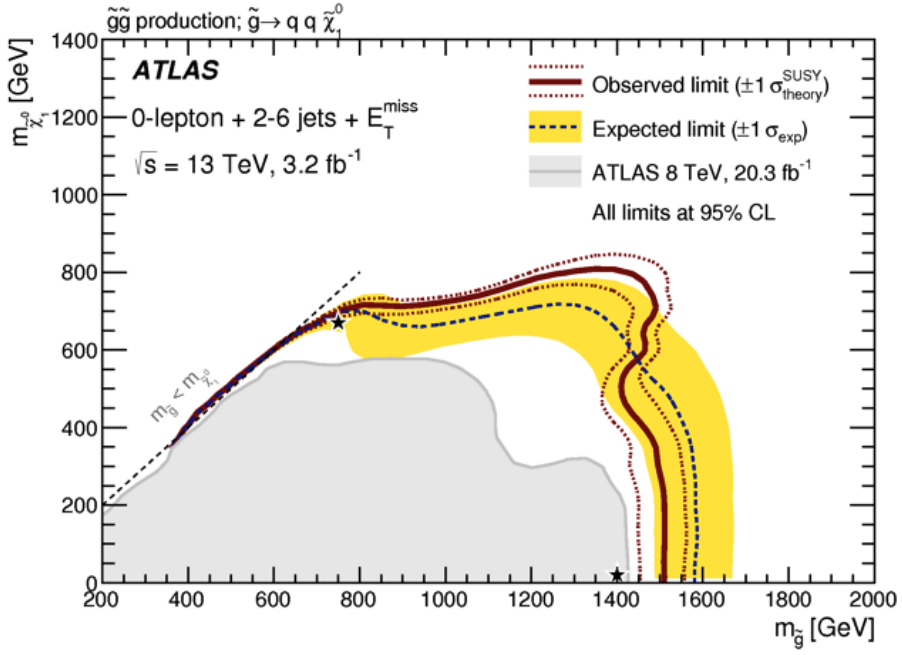
0ℓ with 2-6 jets

arXiv:1605.03814



Target: gluino/squark search → Lowest mass SUSY Particle (LSP)





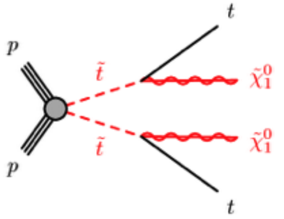
Observed yields are consistent with SM prediction.
Gluino mass limit is set up to 1.5 TeV for gluino → LSP decay.

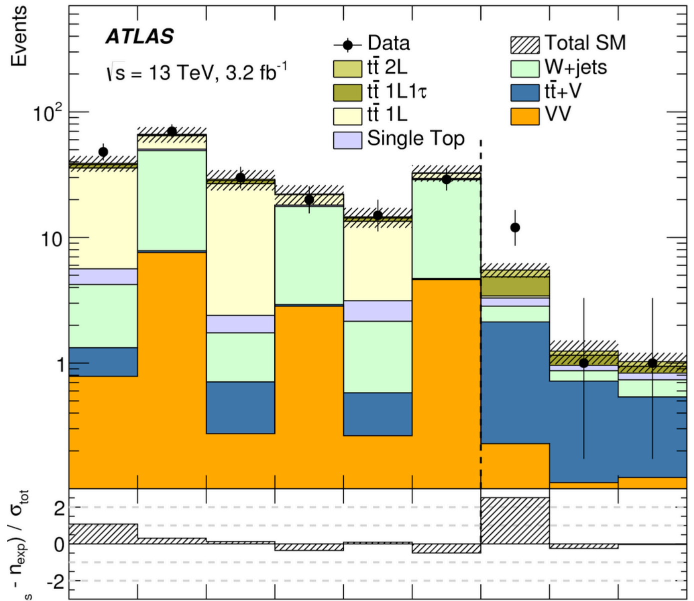
Run 2 physics results: SUSY

1ℓ + jets with b jet Requirement

arXiv:1606.03903

Target: stop search → LSP + top decays

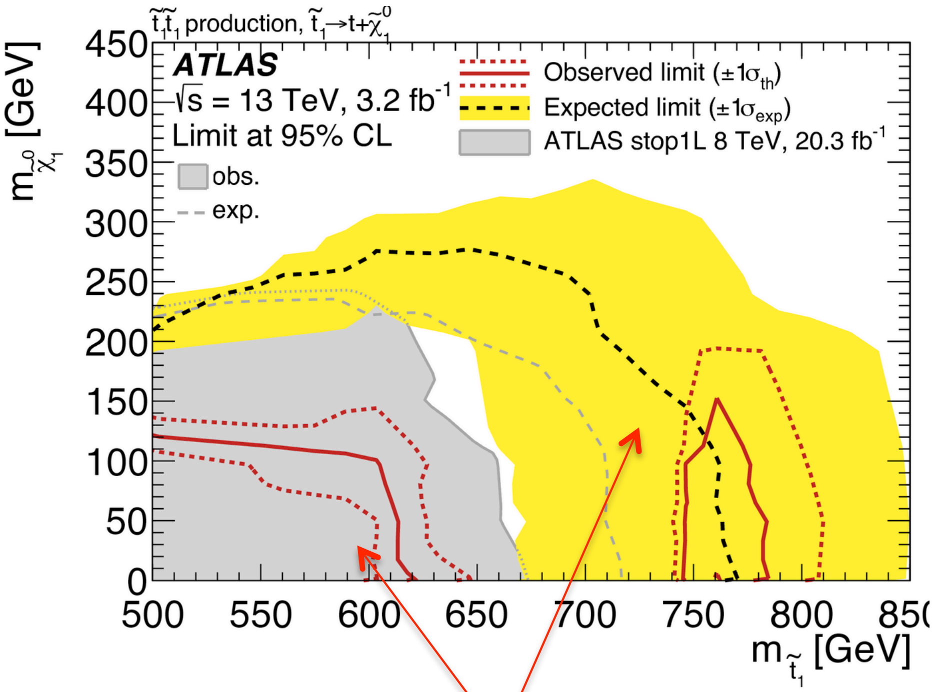




Validation regions

Signal regions

2.3σ local excess observed in Signal region 1 (SR1)



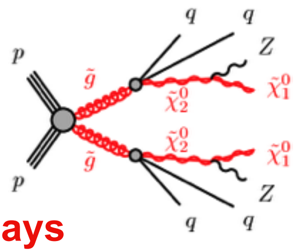
Gap in 600-750 GeV sTop mass due to SR1 excess

SR1 has a production cross-section and kinematic properties similar to those of a direct stop model with $\tilde{t}$ and $\tilde{\chi}^0$ masses of about (600 GeV and 260 GeV. SR2 and SR3 have other hypothesis and less sensitive to direct stop models.

Run 2 physics results: SUSY

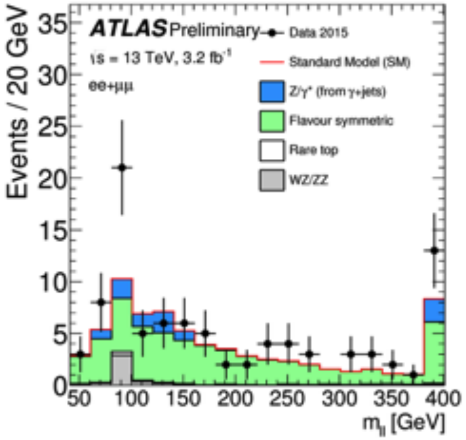
2ℓ +≥ 2 jets with Z Requirement

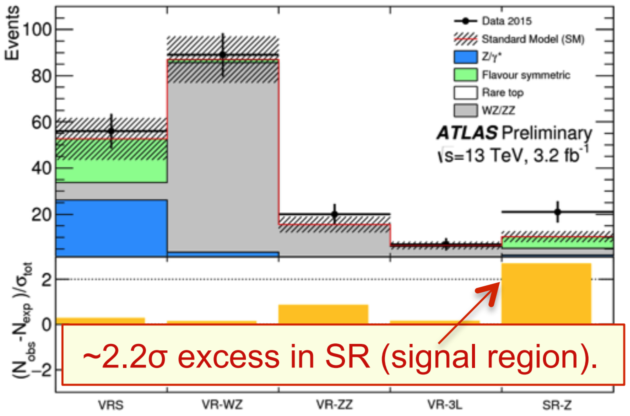
ATLAS-CONF-2015-082



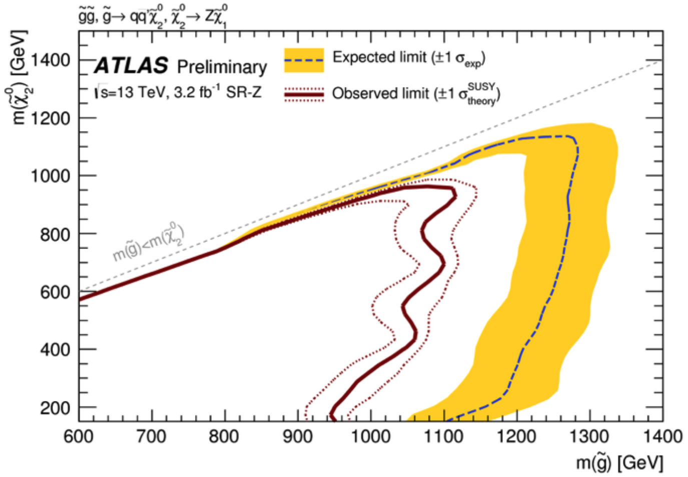
Target: gluino search→ LSP via intermediate neutralino and on-shell Z decays

CERN-PH-2016-108





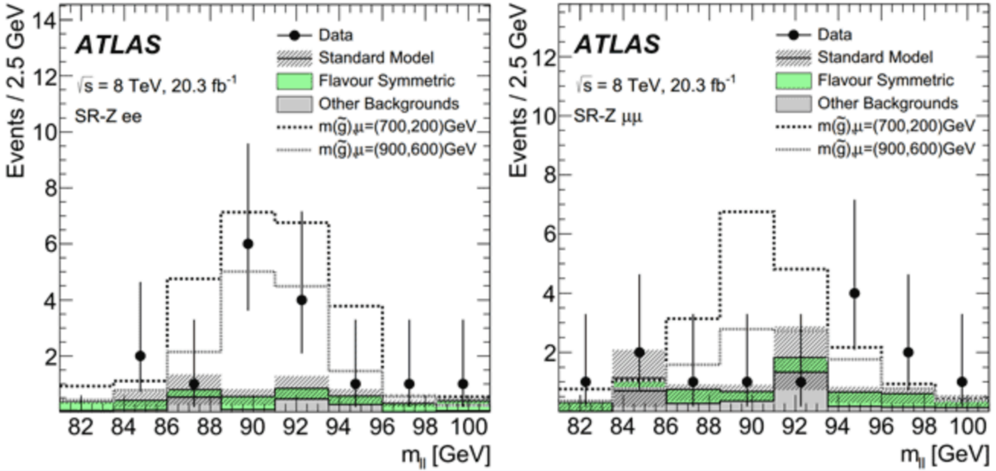
~2.2σ excess in SR (signal region).



Gluino mass limit can be still set

~3σ excess from Run1

CERN-PH-EP-2015-038



Challenge:
correctly estimate **Z + jets with mis-measured jet pT,** which is difficult to model in MC.

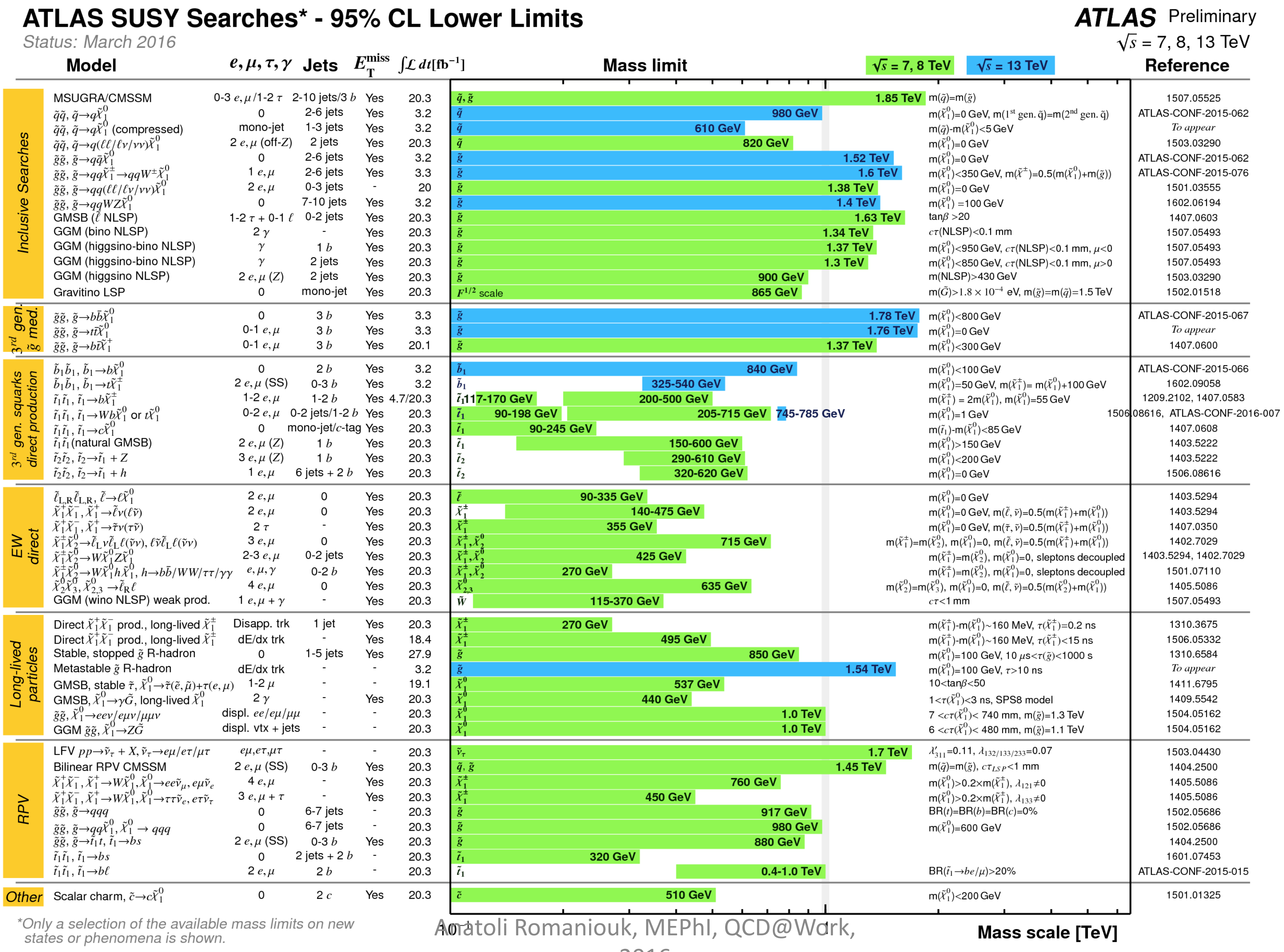
Data driven estimate based on a gamma-jet control sample

Nothing in CMS.

Run 2 physics results: SUSY

Summary table

🟦 13 TeV Data



ATLAS SUSY Searches* - 95% CL Lower Limits

Status: March 2016

ATLAS Preliminary

$\sqrt{s}$ = 7, 8, 13 TeV

🟩 $\sqrt{s}$ = 7, 8 TeV 🟦 $\sqrt{s}$ = 13 TeV

	Model	e,μ,τ,γ	Jets	$E_T^{\rm miss}$	$\int\mathcal{L}\,dt[\mathrm{fb}^{-1}]$	Mass limit		Reference
Inclusive Searches	MSUGRA/CMSSM	0-3 e,μ/1-2 τ	2-10 jets/3 b	Yes	20.3	$\tilde{q},\tilde{g}$ 1.85 TeV	m($\tilde{q}$)=m($\tilde{g}$)	1507.05525
	$\tilde{q}\tilde{q}$, $\tilde{q}\to q\tilde{\chi}_1^0$	0	2-6 jets	Yes	3.2	$\tilde{q}$ 980 GeV	m($\tilde{\chi}_1^0$)=0 GeV, m($1^{\rm st}$ gen. $\tilde{q}$)=m($2^{\rm nd}$ gen. $\tilde{q}$)	ATLAS-CONF-2015-062
	$\tilde{q}\tilde{q}$, $\tilde{q}\to q\tilde{\chi}_1^0$ (compressed)	mono-jet	1-3 jets	Yes	3.2	$\tilde{q}$ 610 GeV	m($\tilde{q}$)-m($\tilde{\chi}_1^0$)<5 GeV	*To appear*
	$\tilde{q}\tilde{q}$, $\tilde{q}\to q(\ell\ell/\ell\nu/\nu\nu)\tilde{\chi}_1^0$	2 e,μ (off-Z)	2 jets	Yes	20.3	$\tilde{q}$ 820 GeV	m($\tilde{\chi}_1^0$)=0 GeV	1503.03290
	$\tilde{g}\tilde{g}$, $\tilde{g}\to q\bar{q}\tilde{\chi}_1^0$	0	2-6 jets	Yes	3.2	$\tilde{g}$ 1.52 TeV	m($\tilde{\chi}_1^0$)=0 GeV	ATLAS-CONF-2015-062
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qq\tilde{\chi}_1^\pm\to qqW^\pm\tilde{\chi}_1^0$	1 e,μ	2-6 jets	Yes	3.3	$\tilde{g}$ 1.6 TeV	m($\tilde{\chi}_1^0$)<350 GeV, m($\tilde{\chi}^\pm$)=0.5(m($\tilde{\chi}_1^0$)+m($\tilde{g}$))	ATLAS-CONF-2015-076
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qq(\ell\ell/\ell\nu/\nu\nu)\tilde{\chi}_1^0$	2 e,μ	0-3 jets	-	20	$\tilde{g}$ 1.38 TeV	m($\tilde{\chi}_1^0$)=0 GeV	1501.03555
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qqWZ\tilde{\chi}_1^0$	0	7-10 jets	Yes	3.2	$\tilde{g}$ 1.4 TeV	m($\tilde{\chi}_1^0$) =100 GeV	1602.06194
	GMSB ($\tilde{\ell}$ NLSP)	1-2 τ + 0-1 ℓ	0-2 jets	Yes	20.3	$\tilde{g}$ 1.63 TeV	tanβ >20	1407.0603
	GGM (bino NLSP)	2 γ	-	Yes	20.3	$\tilde{g}$ 1.34 TeV	$c\tau$(NLSP)<0.1 mm	1507.05493
	GGM (higgsino-bino NLSP)	γ	1 b	Yes	20.3	$\tilde{g}$ 1.37 TeV	m($\tilde{\chi}_1^0$)<950 GeV, $c\tau$(NLSP)<0.1 mm, μ<0	1507.05493
	GGM (higgsino-bino NLSP)	γ	2 jets	Yes	20.3	$\tilde{g}$ 1.3 TeV	m($\tilde{\chi}_1^0$)<850 GeV, $c\tau$(NLSP)<0.1 mm, μ>0	1507.05493
	GGM (higgsino NLSP)	2 e,μ (Z)	2 jets	Yes	20.3	$\tilde{g}$ 900 GeV	m(NLSP)>430 GeV	1503.03290
	Gravitino LSP	0	mono-jet	Yes	20.3	$F^{1/2}$ scale 865 GeV	m($\tilde{G}$)>1.8×10^{-4} eV, m($\tilde{g}$)=m($\tilde{q}$)=1.5 TeV	1502.01518
3^{rd} gen. $\tilde{g}$ med.	$\tilde{g}\tilde{g}$, $\tilde{g}\to b\bar{b}\tilde{\chi}_1^0$	0	3 b	Yes	3.3	$\tilde{g}$ 1.78 TeV	m($\tilde{\chi}_1^0$)<800 GeV	ATLAS-CONF-2015-067
	$\tilde{g}\tilde{g}$, $\tilde{g}\to t\bar{t}\tilde{\chi}_1^0$	0-1 e,μ	3 b	Yes	3.3	$\tilde{g}$ 1.76 TeV	m($\tilde{\chi}_1^0$)=0 GeV	*To appear*
	$\tilde{g}\tilde{g}$, $\tilde{g}\to b\bar{t}\tilde{\chi}_1^+$	0-1 e,μ	3 b	Yes	20.1	$\tilde{g}$ 1.37 TeV	m($\tilde{\chi}_1^0$)<300 GeV	1407.0600
3^{rd} gen. squarks direct production	$\tilde{b}_1\tilde{b}_1$, $\tilde{b}_1\to b\tilde{\chi}_1^0$	0	2 b	Yes	3.2	$\tilde{b}_1$ 840 GeV	m($\tilde{\chi}_1^0$)<100 GeV	ATLAS-CONF-2015-066
	$\tilde{b}_1\tilde{b}_1$, $\tilde{b}_1\to t\tilde{\chi}_1^\pm$	2 e,μ (SS)	0-3 b	Yes	3.2	$\tilde{b}_1$ 325-540 GeV	m($\tilde{\chi}_1^0$)=50 GeV, m($\tilde{\chi}_1^\pm$)= m($\tilde{\chi}_1^0$)+100 GeV	1602.09058
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to b\tilde{\chi}_1^\pm$	1-2 e,μ	1-2 b	Yes	4.7/20.3	$\tilde{t}_1$ 117-170 GeV 200-500 GeV	m($\tilde{\chi}_1^\pm$) = 2m($\tilde{\chi}_1^0$), m($\tilde{\chi}_1^0$)=55 GeV	1209.2102, 1407.0583
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to Wb\tilde{\chi}_1^0$ or $t\tilde{\chi}_1^0$	0-2 e,μ	0-2 jets/1-2 b	Yes	20.3	$\tilde{t}_1$ 90-198 GeV 205-715 GeV 745-785 GeV	m($\tilde{\chi}_1^0$)=1 GeV	1506.08616, ATLAS-CONF-2016-007
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to c\tilde{\chi}_1^0$	0	mono-jet/c-tag	Yes	20.3	$\tilde{t}_1$ 90-245 GeV	m($\tilde{t}_1$)-m($\tilde{\chi}_1^0$)<85 GeV	1407.0608
	$\tilde{t}_1\tilde{t}_1$(natural GMSB)	2 e,μ (Z)	1 b	Yes	20.3	$\tilde{t}_1$ 150-600 GeV	m($\tilde{\chi}_1^0$)>150 GeV	1403.5222
	$\tilde{t}_2\tilde{t}_2$, $\tilde{t}_2\to\tilde{t}_1+Z$	3 e,μ (Z)	1 b	Yes	20.3	$\tilde{t}_2$ 290-610 GeV	m($\tilde{\chi}_1^0$)<200 GeV	1403.5222
	$\tilde{t}_2\tilde{t}_2$, $\tilde{t}_2\to\tilde{t}_1+h$	1 e,μ	6 jets + 2 b	Yes	20.3	$\tilde{t}_2$ 320-620 GeV	m($\tilde{\chi}_1^0$)=0 GeV	1506.08616
EW direct	$\tilde{\ell}_{\rm L,R}\tilde{\ell}_{\rm L,R}$, $\tilde{\ell}\to\ell\tilde{\chi}_1^0$	2 e,μ	0	Yes	20.3	$\tilde{\ell}$ 90-335 GeV	m($\tilde{\chi}_1^0$)=0 GeV	1403.5294
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\to\tilde{\ell}\nu(\ell\tilde{\nu})$	2 e,μ	0	Yes	20.3	$\tilde{\chi}_1^\pm$ 140-475 GeV	m($\tilde{\chi}_1^0$)=0 GeV, m($\tilde{\ell},\tilde{\nu}$)=0.5(m($\tilde{\chi}_1^\pm$)+m($\tilde{\chi}_1^0$))	1403.5294
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\to\tilde{\tau}\nu(\tau\tilde{\nu})$	2 τ	-	Yes	20.3	$\tilde{\chi}_1^\pm$ 355 GeV	m($\tilde{\chi}_1^0$)=0 GeV, m($\tilde{\tau},\tilde{\nu}$)=0.5(m($\tilde{\chi}_1^\pm$)+m($\tilde{\chi}_1^0$))	1407.0350
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0\to\tilde{\ell}_{\rm L}\nu\tilde{\ell}_{\rm L}\ell(\tilde{\nu}\nu)$, $\ell\tilde{\nu}\tilde{\ell}_{\rm L}\ell(\tilde{\nu}\nu)$	3 e,μ	0	Yes	20.3	$\tilde{\chi}_1^\pm,\tilde{\chi}_2^0$ 715 GeV	m($\tilde{\chi}_1^\pm$)=m($\tilde{\chi}_2^0$), m($\tilde{\chi}_1^0$)=0, m($\tilde{\ell},\tilde{\nu}$)=0.5(m($\tilde{\chi}_1^\pm$)+m($\tilde{\chi}_1^0$))	1402.7029
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0\to W\tilde{\chi}_1^0Z\tilde{\chi}_1^0$	2-3 e,μ	0-2 jets	Yes	20.3	$\tilde{\chi}_1^\pm,\tilde{\chi}_2^0$ 425 GeV	m($\tilde{\chi}_1^\pm$)=m($\tilde{\chi}_2^0$), m($\tilde{\chi}_1^0$)=0, sleptons decoupled	1403.5294, 1402.7029
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0\to W\tilde{\chi}_1^0h\tilde{\chi}_1^0$, $h\to b\bar{b}/WW/\tau\tau/\gamma\gamma$	e,μ,γ	0-2 b	Yes	20.3	$\tilde{\chi}_1^\pm,\tilde{\chi}_2^0$ 270 GeV	m($\tilde{\chi}_1^\pm$)=m($\tilde{\chi}_2^0$), m($\tilde{\chi}_1^0$)=0, sleptons decoupled	1501.07110
	$\tilde{\chi}_2^0\tilde{\chi}_3^0$, $\tilde{\chi}_{2,3}^0\to\tilde{\ell}_{\rm R}\ell$	4 e,μ	0	Yes	20.3	$\tilde{\chi}_{2,3}^0$ 635 GeV	m($\tilde{\chi}_2^0$)=m($\tilde{\chi}_3^0$), m($\tilde{\chi}_1^0$)=0, m($\tilde{\ell},\tilde{\nu}$)=0.5(m($\tilde{\chi}_2^0$)+m($\tilde{\chi}_1^0$))	1405.5086
	GGM (wino NLSP) weak prod.	1 $e,\mu+\gamma$	-	Yes	20.3	$\tilde{W}$ 115-370 GeV	$c\tau$<1 mm	1507.05493
Long-lived particles	Direct $\tilde{\chi}_1^+\tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^\pm$	Disapp. trk	1 jet	Yes	20.3	$\tilde{\chi}_1^\pm$ 270 GeV	m($\tilde{\chi}_1^\pm$)-m($\tilde{\chi}_1^0$)~160 MeV, τ($\tilde{\chi}_1^\pm$)=0.2 ns	1310.3675
	Direct $\tilde{\chi}_1^+\tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^\pm$	dE/dx trk	-	Yes	18.4	$\tilde{\chi}_1^\pm$ 495 GeV	m($\tilde{\chi}_1^\pm$)-m($\tilde{\chi}_1^0$)~160 MeV, τ($\tilde{\chi}_1^\pm$)<15 ns	1506.05332
	Stable, stopped $\tilde{g}$ R-hadron	0	1-5 jets	Yes	27.9	$\tilde{g}$ 850 GeV	m($\tilde{\chi}_1^0$)=100 GeV, 10 μs<τ($\tilde{g}$)<1000 s	1310.6584
	Metastable $\tilde{g}$ R-hadron	dE/dx trk	-	-	3.2	$\tilde{g}$ 1.54 TeV	m($\tilde{\chi}_1^0$)=100 GeV, τ>10 ns	*To appear*
	GMSB, stable $\tilde{\tau}$, $\tilde{\chi}_1^0\to\tilde{\tau}(\tilde{e},\tilde{\mu})+\tau(e,\mu)$	1-2 μ	-	-	19.1	$\tilde{\chi}_1^0$ 537 GeV	10<tanβ<50	1411.6795
	GMSB, $\tilde{\chi}_1^0\to\gamma\tilde{G}$, long-lived $\tilde{\chi}_1^0$	2 γ	-	Yes	20.3	$\tilde{\chi}_1^0$ 440 GeV	1<τ($\tilde{\chi}_1^0$)<3 ns, SPS8 model	1409.5542
	$\tilde{g}\tilde{g}$, $\tilde{\chi}_1^0\to ee\nu/e\mu\nu/\mu\mu\nu$	displ. $ee/e\mu/\mu\mu$	-	-	20.3	$\tilde{\chi}_1^0$ 1.0 TeV	7 <$c\tau$($\tilde{\chi}_1^0$)< 740 mm, m($\tilde{g}$)=1.3 TeV	1504.05162
	GGM $\tilde{g}\tilde{g}$, $\tilde{\chi}_1^0\to Z\tilde{G}$	displ. vtx + jets	-	-	20.3	$\tilde{\chi}_1^0$ 1.0 TeV	6 <$c\tau$($\tilde{\chi}_1^0$)< 480 mm, m($\tilde{g}$)=1.1 TeV	1504.05162
RPV	LFV $pp\to\tilde{\nu}_\tau+X,\tilde{\nu}_\tau\to e\mu/e\tau/\mu\tau$	$e\mu$,$e\tau$,$\mu\tau$	-	-	20.3	$\tilde{\nu}_\tau$ 1.7 TeV	λ'_{311}=0.11, $\lambda_{132/133/233}$=0.07	1503.04430
	Bilinear RPV CMSSM	2 e,μ (SS)	0-3 b	Yes	20.3	$\tilde{q},\tilde{g}$ 1.45 TeV	m($\tilde{q}$)=m($\tilde{g}$), $c\tau_{LSP}$<1 mm	1404.2500
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\to W\tilde{\chi}_1^0$, $\tilde{\chi}_1^0\to ee\tilde{\nu}_\mu, e\mu\tilde{\nu}_e$	4 e,μ	-	Yes	20.3	$\tilde{\chi}_1^\pm$ 760 GeV	m($\tilde{\chi}_1^0$)>0.2×m($\tilde{\chi}_1^\pm$), $\lambda_{121}\neq0$	1405.5086
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\to W\tilde{\chi}_1^0$, $\tilde{\chi}_1^0\to\tau\tau\tilde{\nu}_e, e\tau\tilde{\nu}_\tau$	3 $e,\mu+\tau$	-	Yes	20.3	$\tilde{\chi}_1^\pm$ 450 GeV	m($\tilde{\chi}_1^0$)>0.2×m($\tilde{\chi}_1^\pm$), $\lambda_{133}\neq0$	1405.5086
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qqq$	0	6-7 jets	-	20.3	$\tilde{g}$ 917 GeV	BR(t)=BR(b)=BR(c)=0%	1502.05686
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qq\tilde{\chi}_1^0$, $\tilde{\chi}_1^0\to qqq$	0	6-7 jets	-	20.3	$\tilde{g}$ 980 GeV	m($\tilde{\chi}_1^0$)=600 GeV	1502.05686
	$\tilde{g}\tilde{g}$, $\tilde{g}\to\tilde{t}_1t$, $\tilde{t}_1\to bs$	2 e,μ (SS)	0-3 b	Yes	20.3	$\tilde{g}$ 880 GeV		1404.2500
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to bs$	0	2 jets + 2 b	-	20.3	$\tilde{t}_1$ 320 GeV		1601.07453
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to b\ell$	2 e,μ	2 b	-	20.3	$\tilde{t}_1$ 0.4-1.0 TeV	BR($\tilde{t}_1\to be/\mu$)>20%	ATLAS-CONF-2015-015
Other	Scalar charm, $\tilde{c}\to c\tilde{\chi}_1^0$	0	2 c	Yes	20.3	$\tilde{c}$ 510 GeV	m($\tilde{\chi}_1^0$)<200 GeV	1501.01325

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

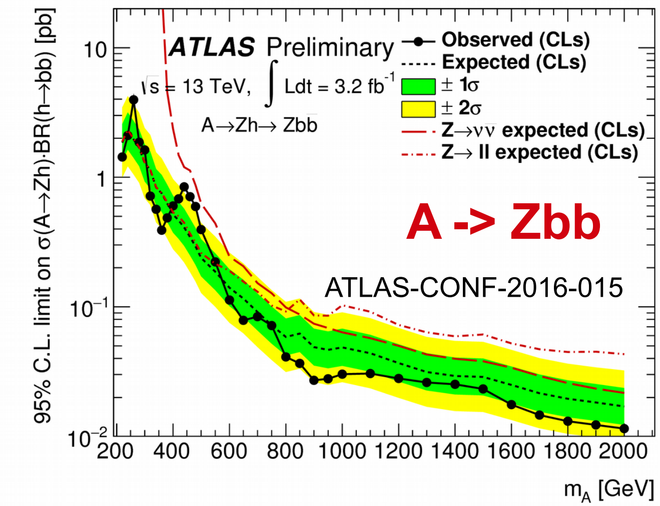
BSM/Exotic hunting.

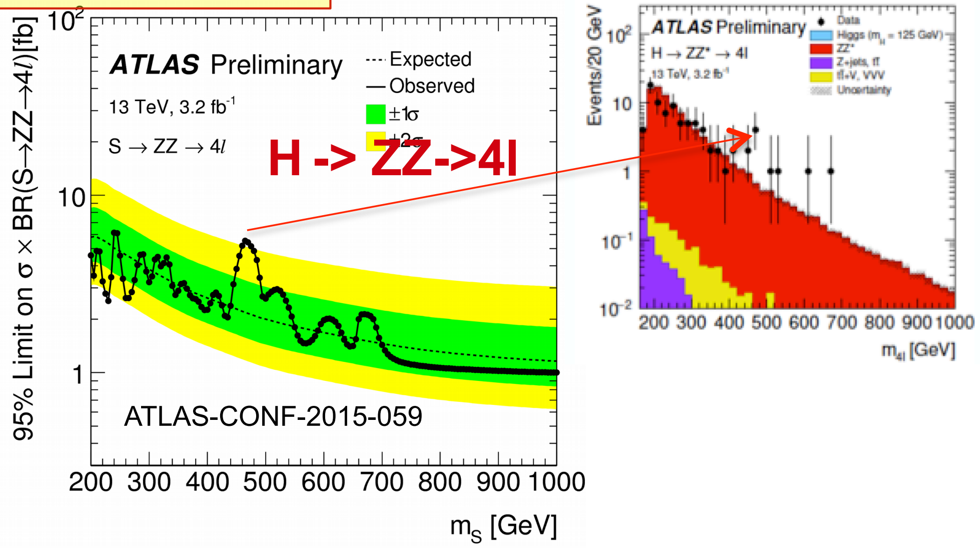
“Exotics” means direct searches for particles/phenomena: - Beyond the Standard Model
- Not SUSY (nor BSM Higgs)

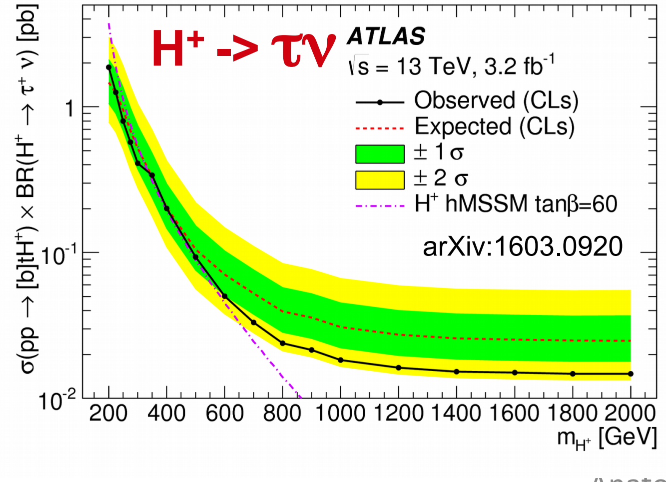
Run 2 physics results: high mass HIGGS

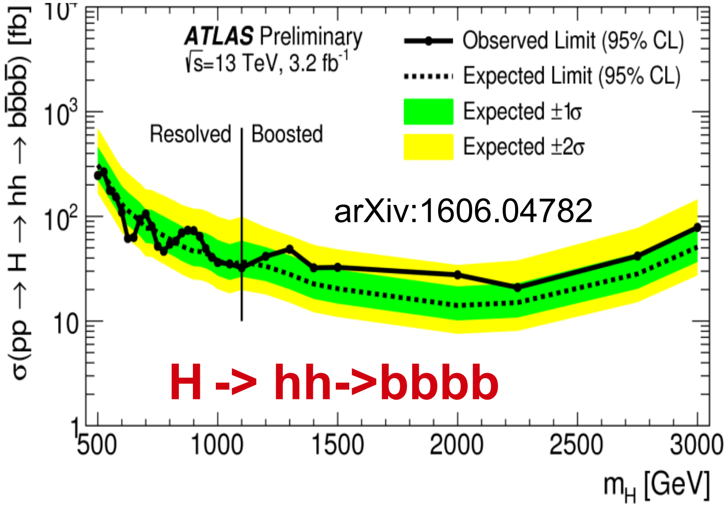
One of the simplest SM extension - MSSM suggests existence of 5 Higgs bosons:

- CP even neutral: **h** and **H**
- CP odd neutral: **A**
- Charged: **H^+** and **H^-**





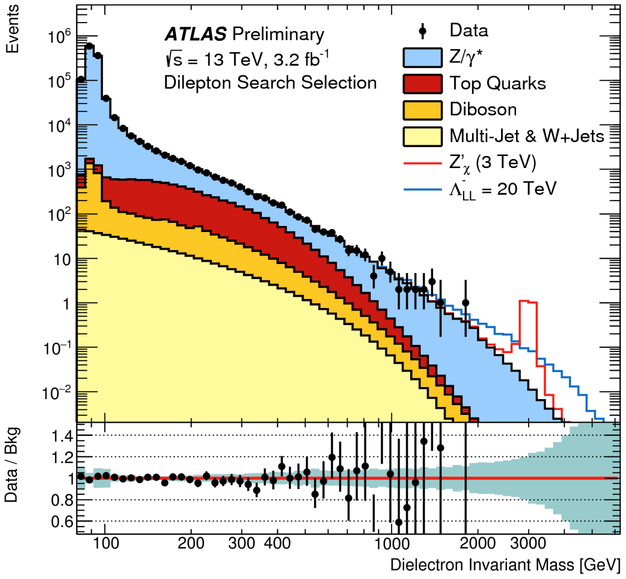


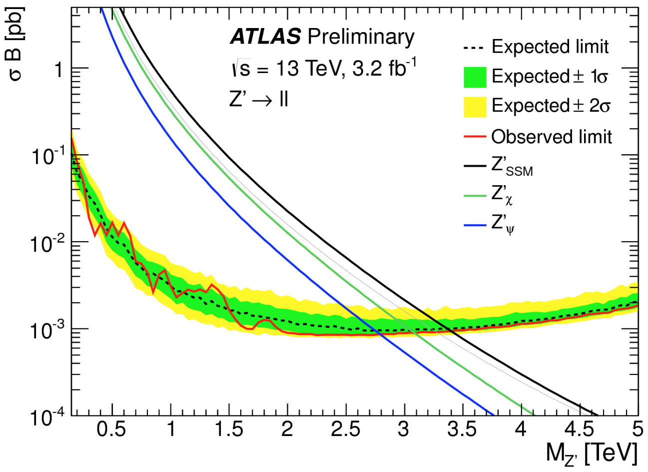


Run 2 physics results: Di-lepton resonances

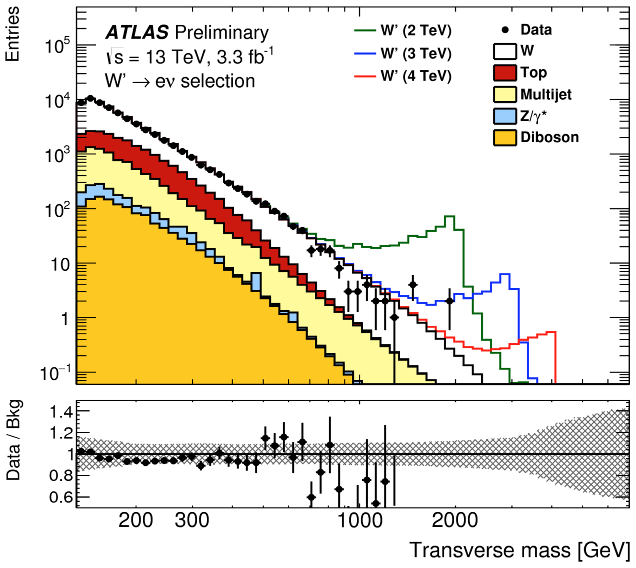
Heavy gauge bosons: **Z', W'**

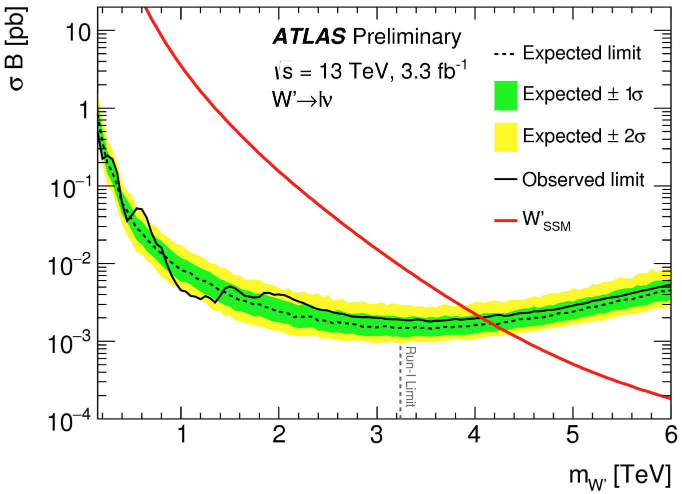
ATLAS-CONF-2015-070





ATLAS-CONF-2015-063



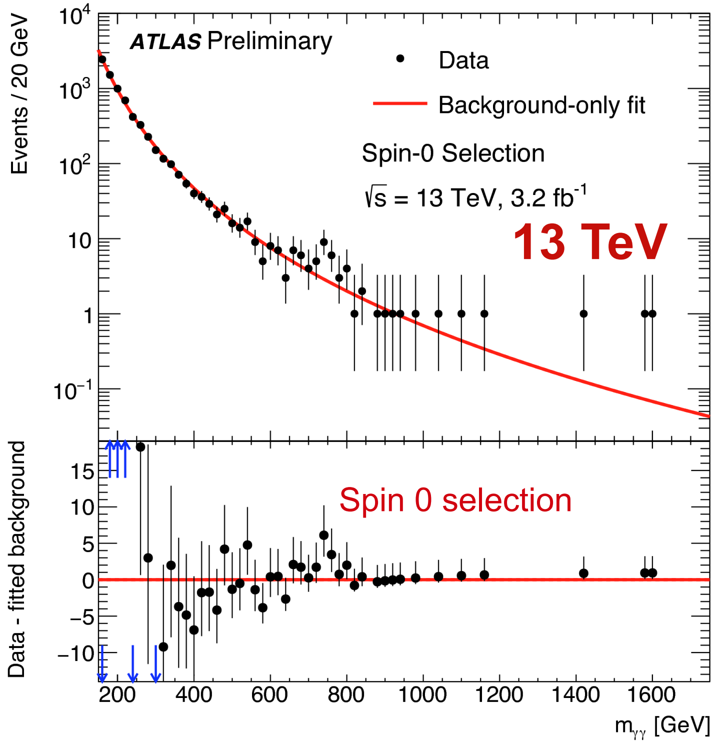


Exclusion limits moved by almost 1 TeV with respect to Run 1!

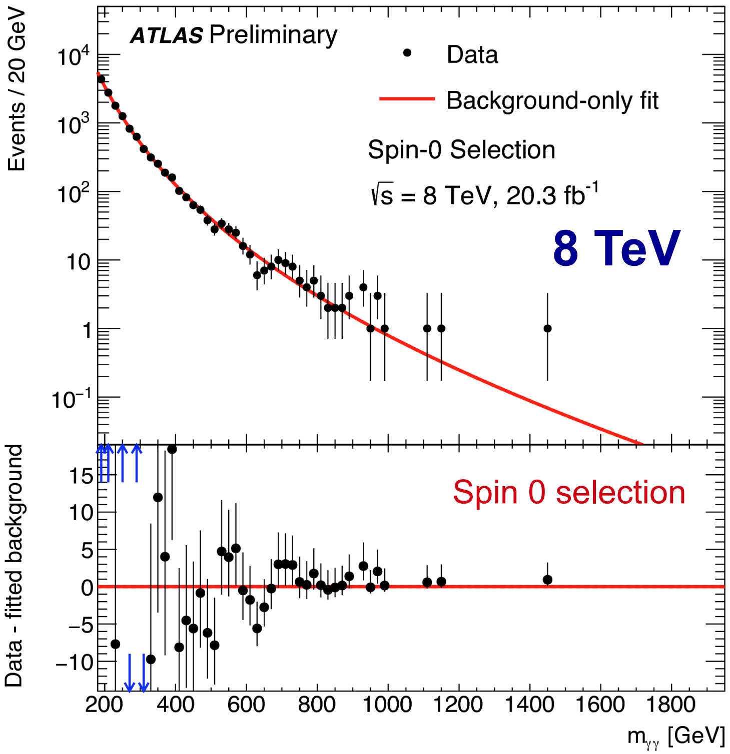
Run 2 physics results: Di-bosone resonances - γγ

ATLAS-CONF-2016-018

New high-mass states decaying into two photons are predicted in many extensions of the SM. Spin 0 and spin 2 hypothesis considered in data analysis



Peak at 750 GeV (?)



Two photon mass distributions

13 TeV

Spin 2: 48 GeV width **3.6** sigma (local) **1.8** sigma (global

Spin 0: 6% width => **3.9** sigma (local) **2.0** sigma (global)

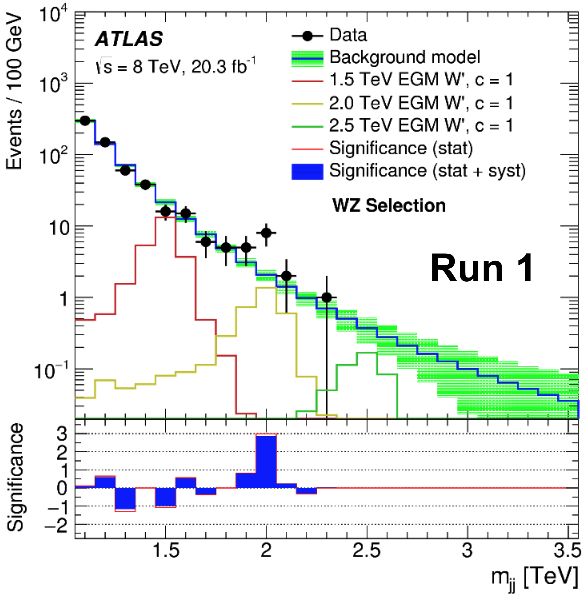
8 TeV

Spin 0: slight excess (1.9 local)

Spin 2: no exces

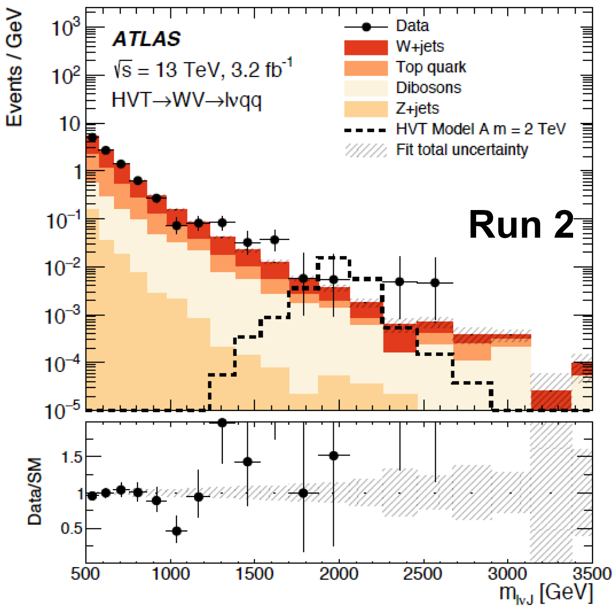
Run 2 physics results: Di-V resonances (WW, WZ, ZZ)

Diboson resonances are predicted in several extensions to the Standard Model (SM), such as composite Higgs models, technicolour, warped extra dimensions.



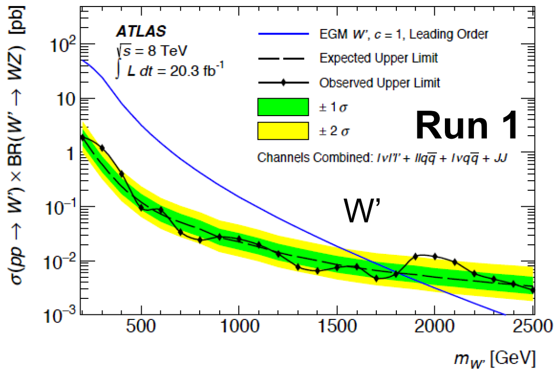
Wide (due to resolution) excess around 2 TeV seen in 8 TeV data in some di-boson channels: 3.4 (local) 2.5 (global) significance

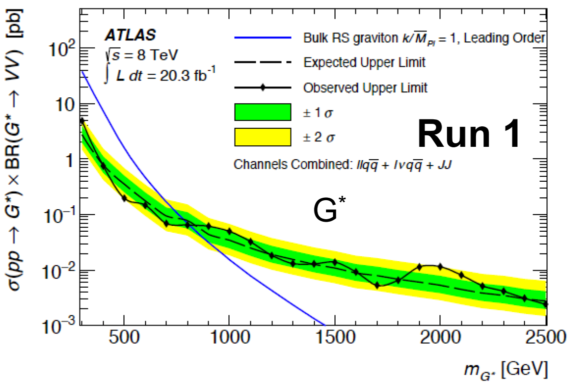
Seems not seen in Run 2! Though more statistics is needed.

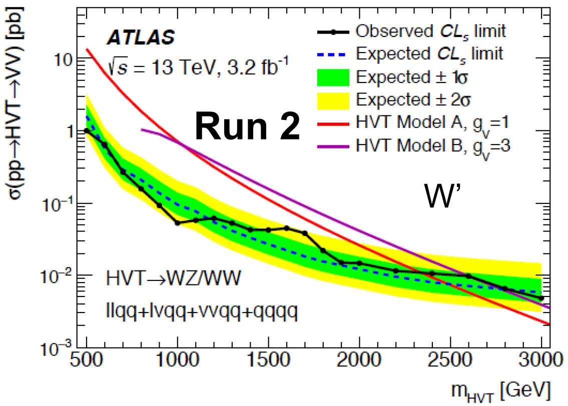


arXiv:1512.05099

arXiv:1606.04833



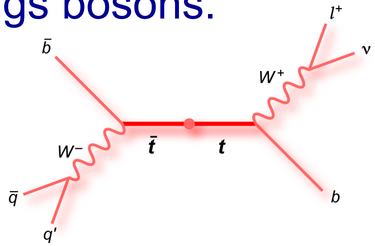




Run 2 physics results: t-tbar resonances

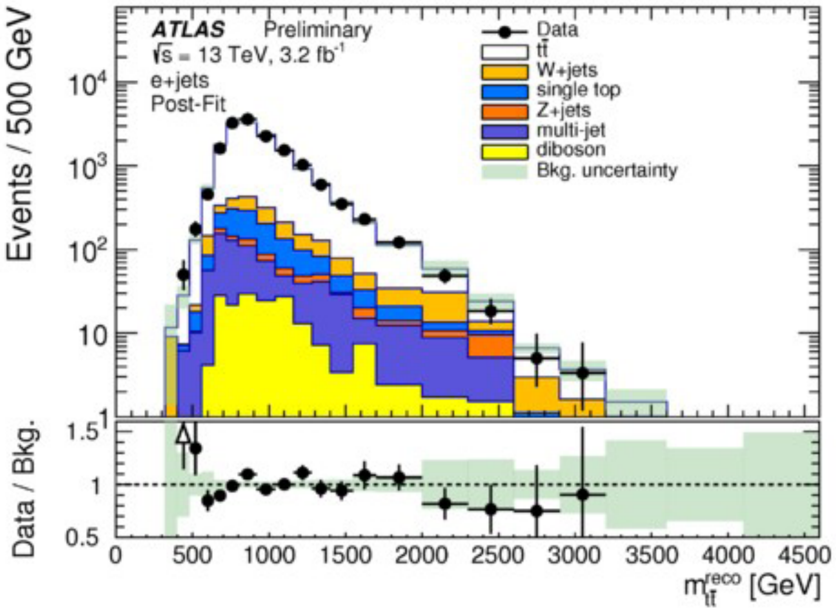
one of the most powerful tools to search for new heavy particles at LHC.

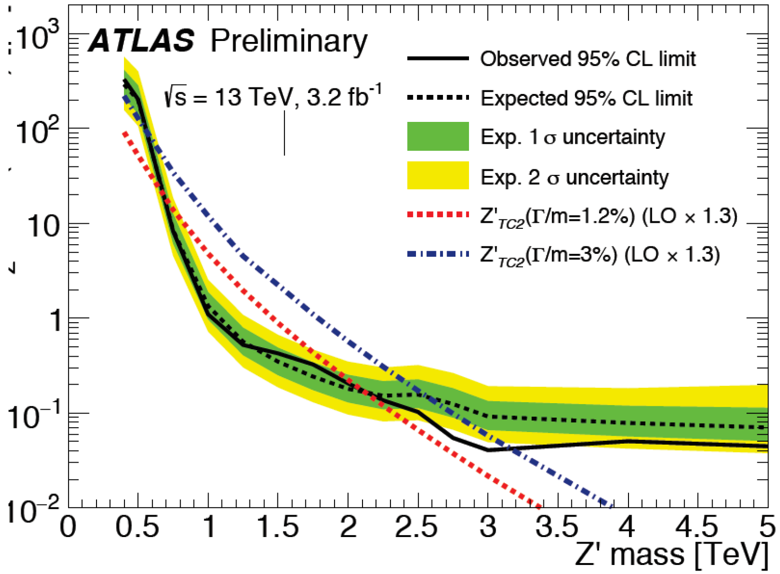
Some new physics theories suggest new gauge interactions with enhanced couplings to quarks of 3rd generation: W', Z' , Pseudo scalar, Higgs bosons.



Resonances in t-tbar or t-b invariant masses.

ATLAS-CONF-2016-017

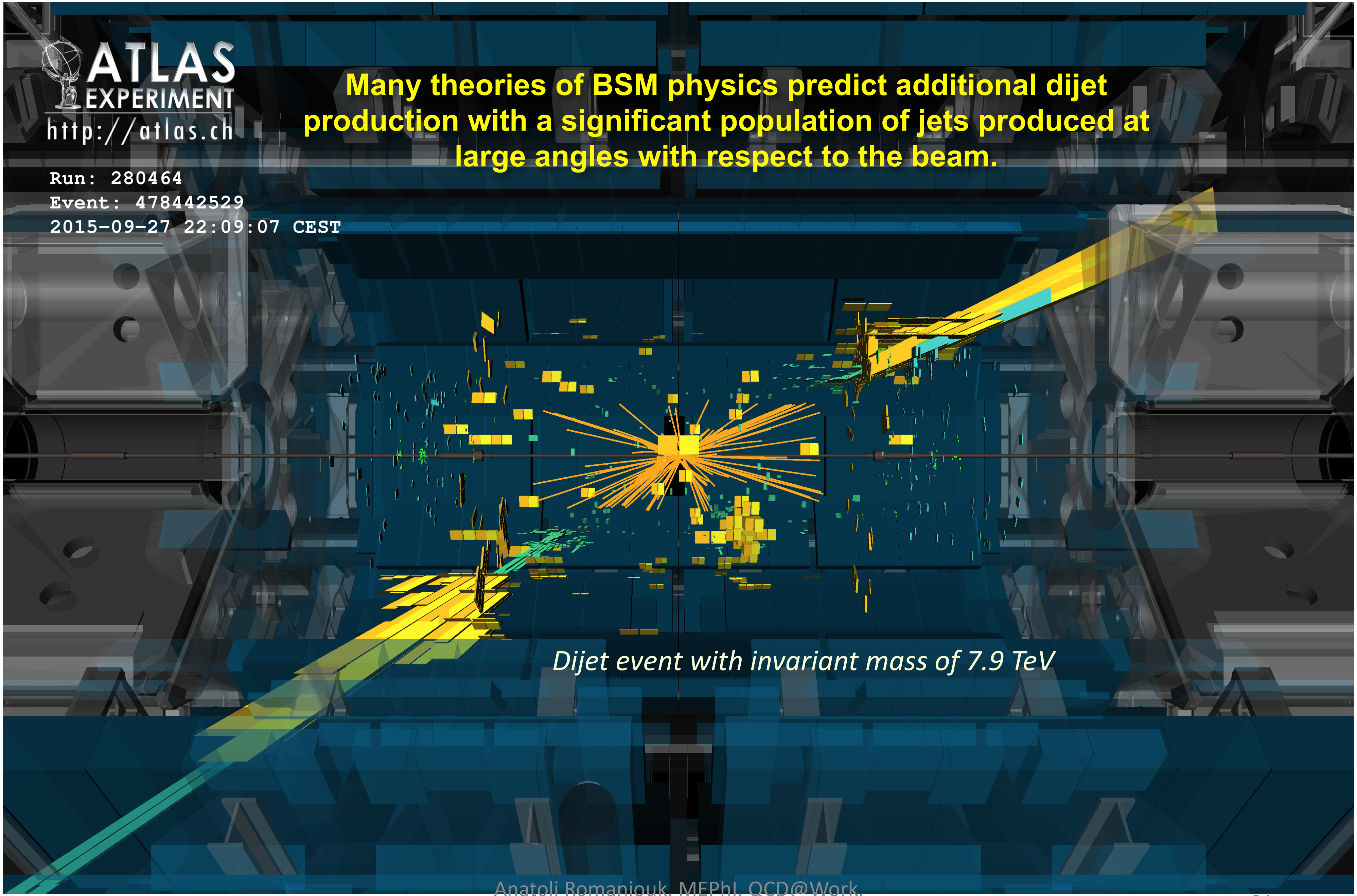




No excess beyond SM expectation was observed. Z'TC excluded

0.7 TeV < mZ' < 2.0 TeV (95%)

Run 2 physics results: Di-jet resonances



Many theories of BSM physics predict additional dijet production with a significant population of jets produced at large angles with respect to the beam.

Dijet event with invariant mass of 7.9 TeV

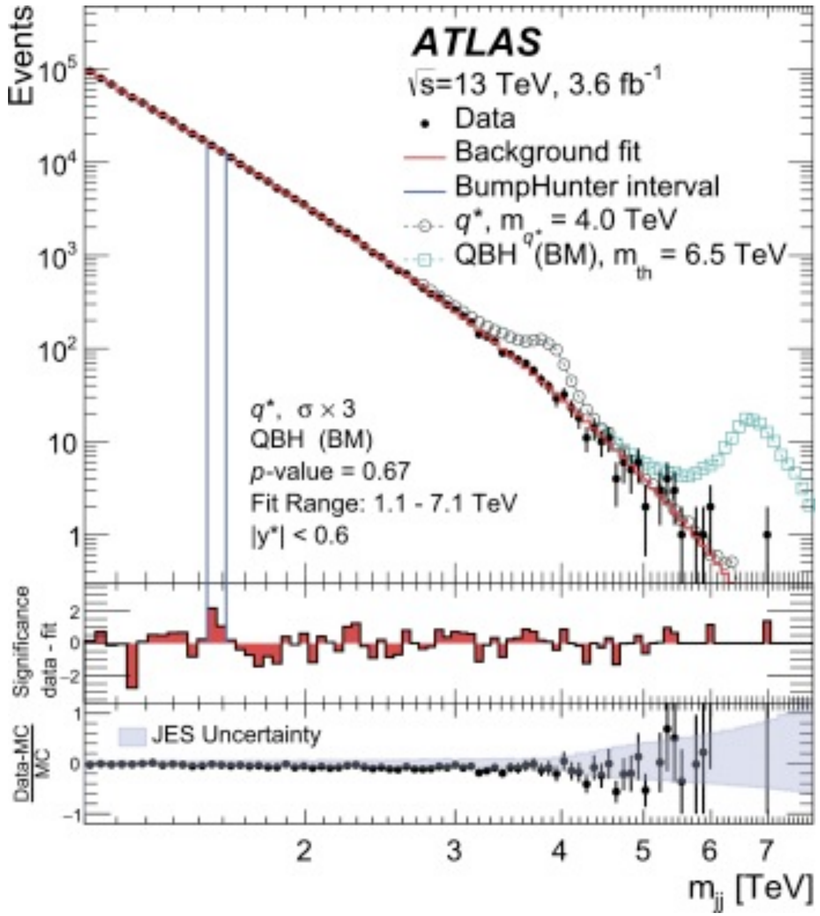
Run 2 physics results: Di-jet resonances

Physics Letters B 754 (2016) 302-322

QCD predicts a smoothly falling dijet invariant mass distribution m_{jj}.

New states decaying to two jets may introduce localized excesses in this distribution.

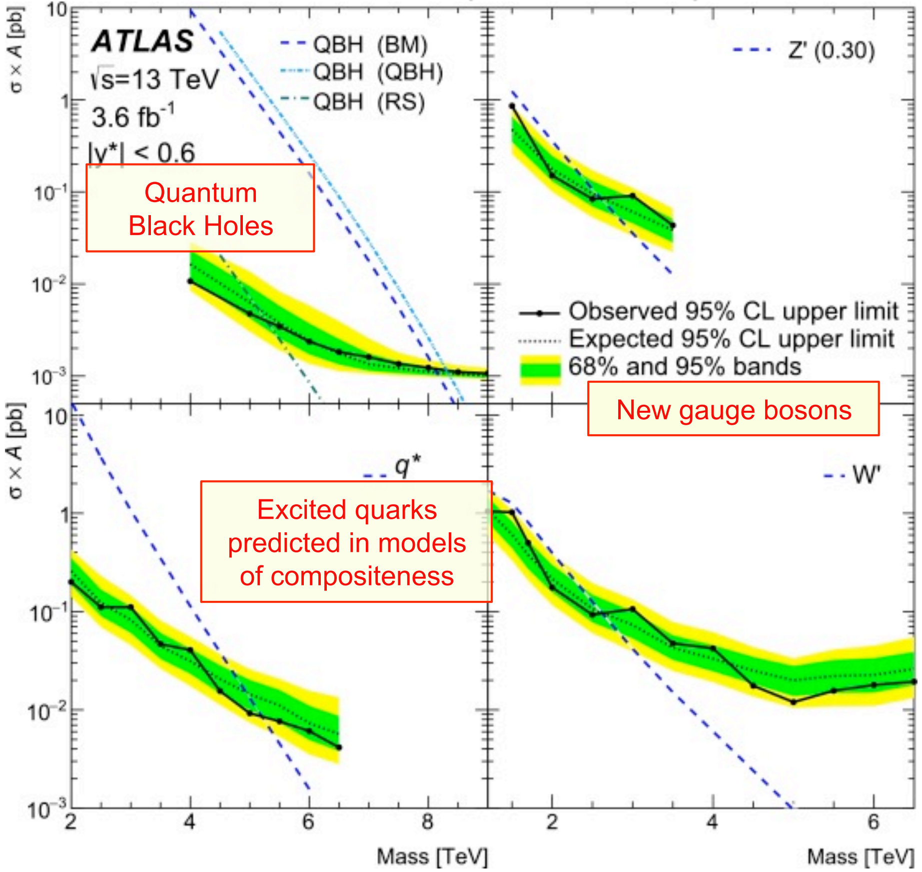
The reconstructed dijet mass distribution.



Predictions for an excited quarks and a quantum black holes are shown above the fit.

Exclusion limits for several types of signals.

DM mass constrains can also be extracted from these measurements (see next slides)



Quantum Black Holes

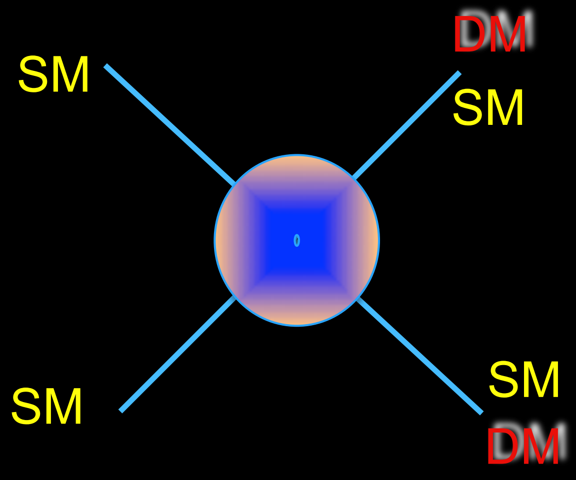
New gauge bosons

Excited quarks predicted in models of compositeness

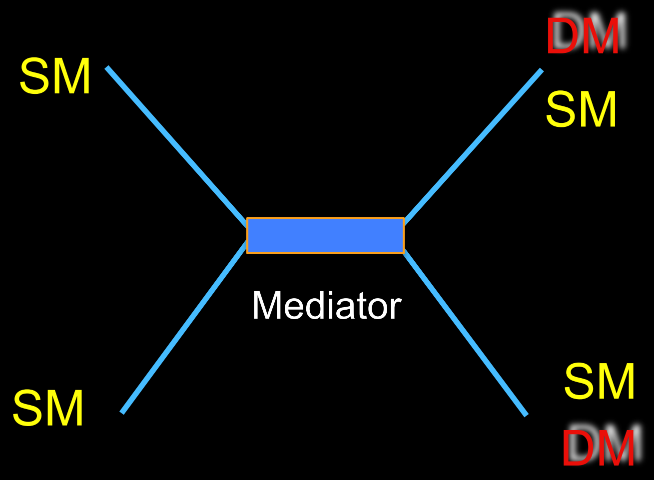
Cross sections taken as predicted by models of quantum black holes, excited quarks, W′ and Z′ bosons.

Detecting Dark Matter at LHC

Mono-search: Mono Jet, photon, higgs, V, gravitino….



Contact interactions



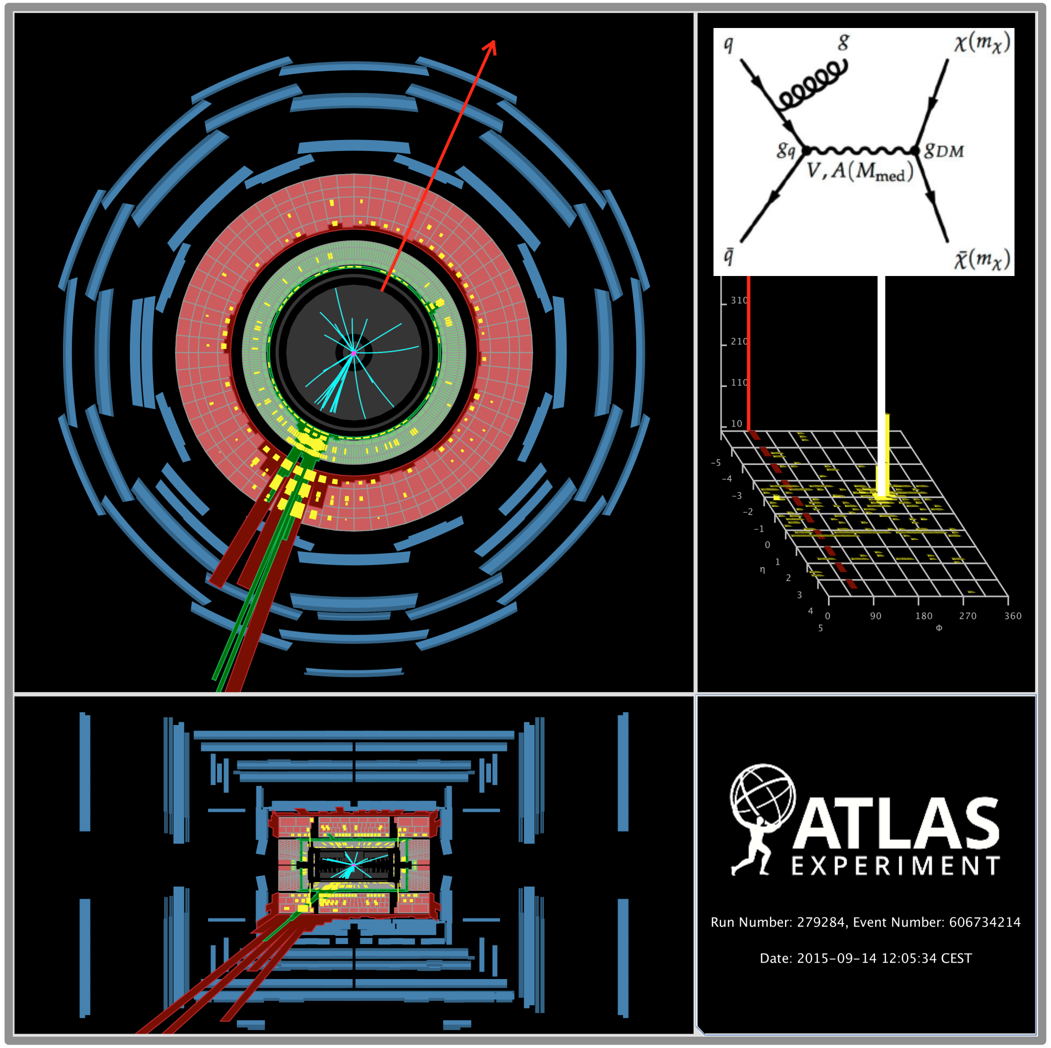
Simplified model

Contact interaction (EFT) “works” if the scale Λ >> Q2 (like Fermi theory).

Otherwise we need a Simplified Model with (at least) a Mediator.

Extensive searches at ATLAS

Run 2 physics results: Example - Monojects

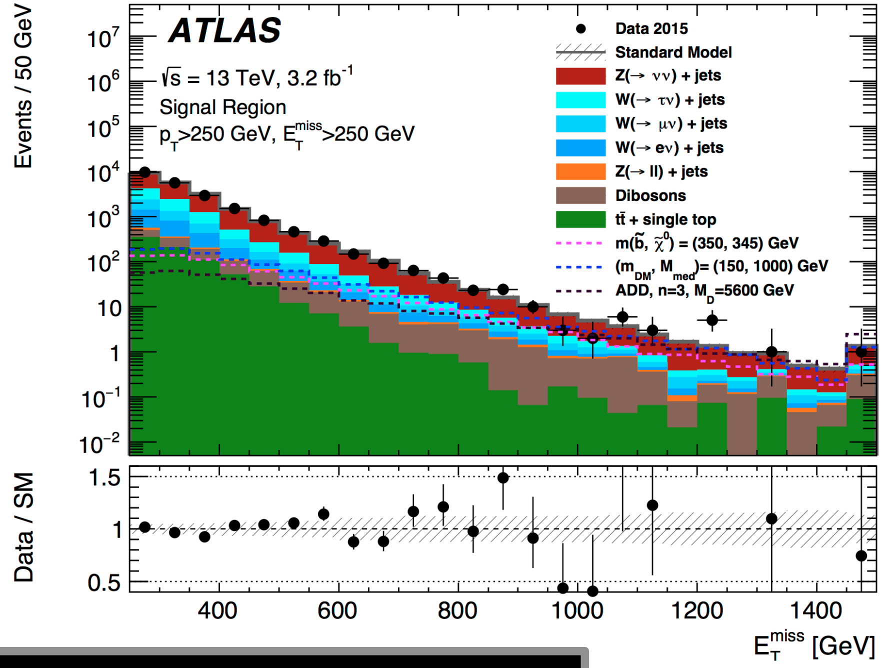


Main backgrounds are EW processes with E_T^{miss} accompanied by Jets (Z->νν +jets, W->lν +jest (with misses l).

Both estimated from leptionic Z and W control region.

There are other backgrounds (multijets, top ….)

arXiv:1604.07773



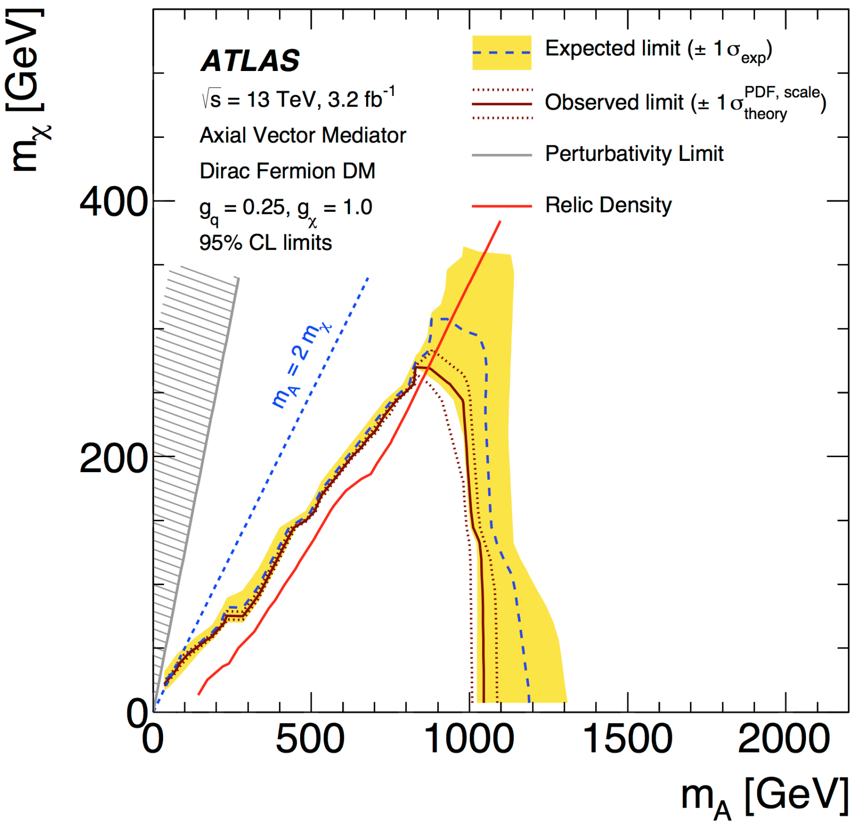
Dominant uncertainties: statistics (3-10%), Boson+jet modeling

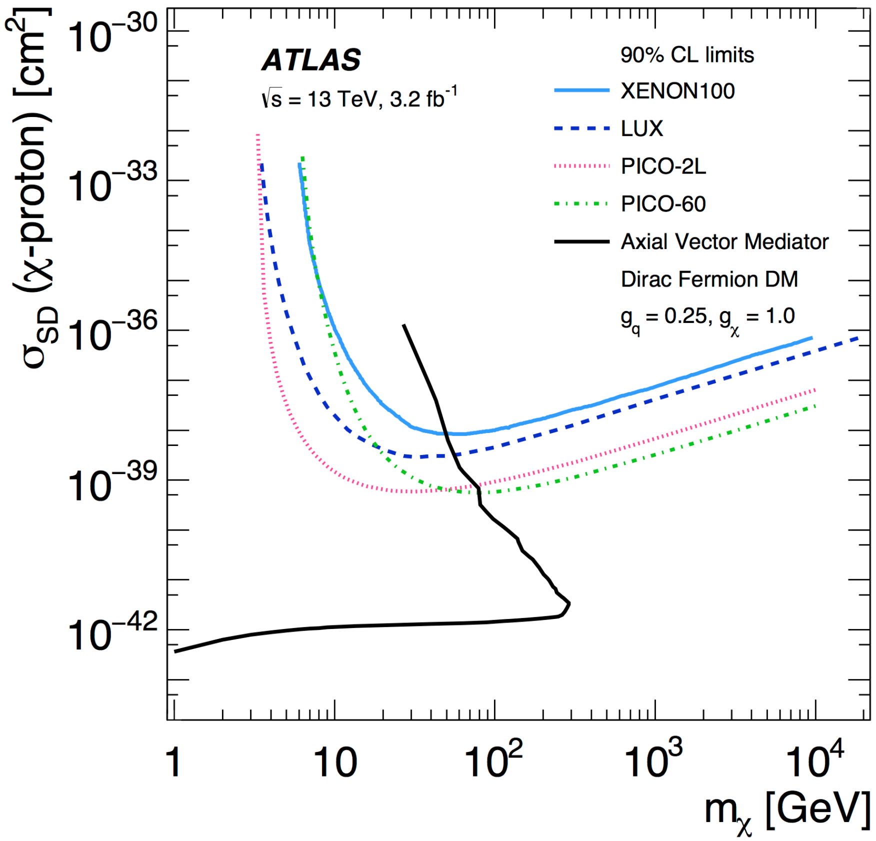
No excess observed!

Run 2 physics results: Monojects DM limits

arXiv:1604.07773

DM mass limits





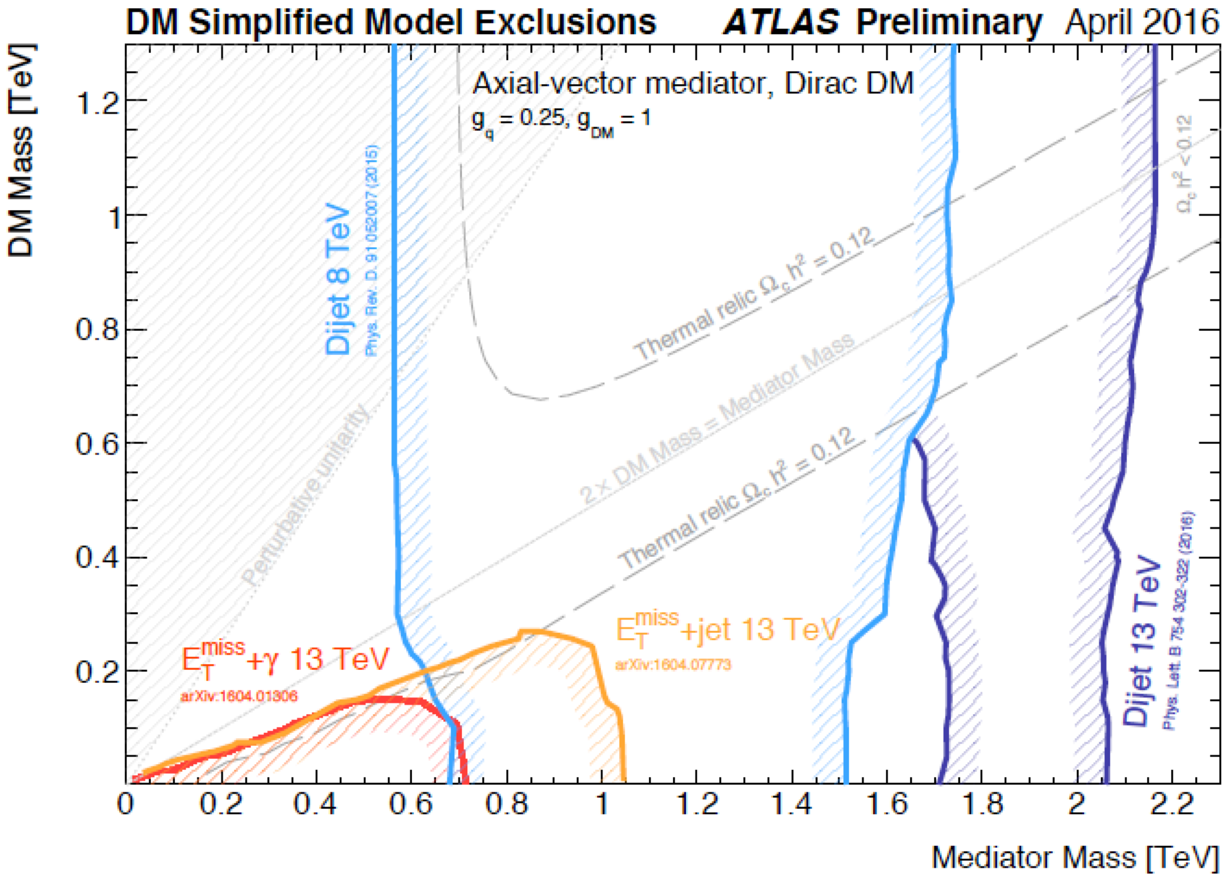
Limits as a function of DM & mediator mass
DM excluded up to 265 GeV for 1 TeV mediator

Limits reinterpreted as limit on DM-proton scattering cross section (complimentary at low m_{DM} searches).

Run 2 physics results: DM search summary

arXiv:1507.00966

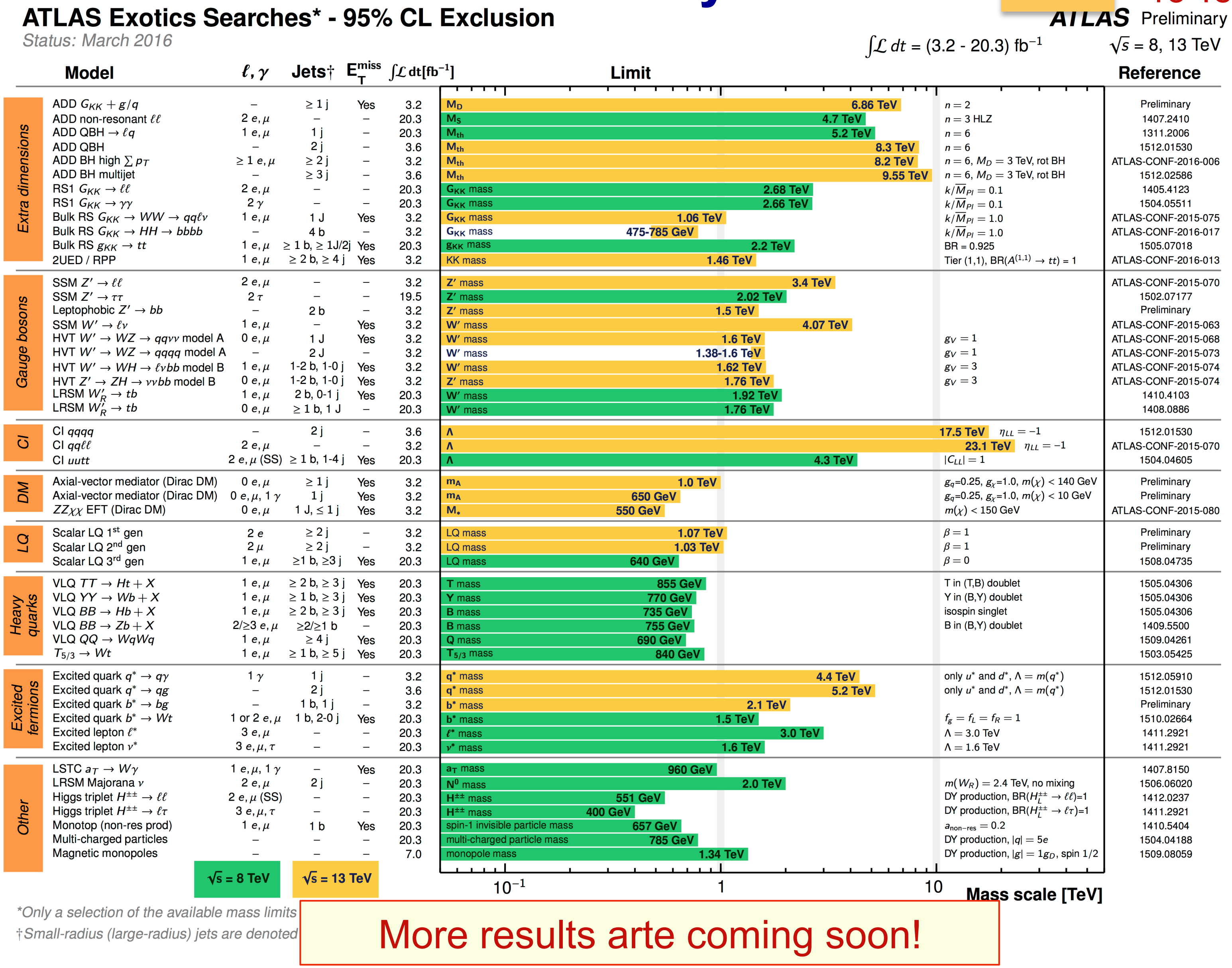
Regions in a dark matter mass–mediator mass plane excluded at 95% CL by a selection of ATLAS dark matter searches, for one possible interaction between the Standard Model and dark matter, the lepto-phobic axial-vector.



The bounds shown in the figure are obtained from the model-agnostic limits on Gaussian-shaped resonances that are provided all three dijet results, following the instructions provided in Appendix A of our 8 TeV dijet search paper, Phys. Rev. D91, 052007 (2015)

Run 2 physics results: Exotic searches
Summary table

🟨 13 TeV Data



ATLAS Exotics Searches* - 95% CL Exclusion

Status: March 2016

ATLAS Preliminary

$\int \mathcal{L}\, dt = (3.2 - 20.3)\ \text{fb}^{-1}$

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

	Model	ℓ, γ	Jets†	E_T^{miss}	$\int \mathcal{L} dt[\text{fb}^{-1}]$	Limit			Reference
Extra dimensions	ADD $G_{KK} + g/q$	–	≥ 1 j	Yes	3.2	🟨 M_D	6.86 TeV	$n = 2$	Preliminary
	ADD non-resonant $\ell\ell$	2 e, μ	–	–	20.3	🟩 M_S	4.7 TeV	$n = 3$ HLZ	1407.2410
	ADD QBH $\rightarrow \ell q$	1 e, μ	1 j	–	20.3	🟩 M_{th}	5.2 TeV	$n = 6$	1311.2006
	ADD QBH	–	2 j	–	3.6	🟨 M_{th}	8.3 TeV	$n = 6$	1512.01530
	ADD BH high $\sum p_T$	≥ 1 e, μ	≥ 2 j	–	3.2	🟨 M_{th}	8.2 TeV	$n = 6$, $M_D = 3$ TeV, rot BH	ATLAS-CONF-2016-006
	ADD BH multijet	–	≥ 3 j	–	3.6	🟨 M_{th}	9.55 TeV	$n = 6$, $M_D = 3$ TeV, rot BH	1512.02586
	RS1 $G_{KK} \rightarrow \ell\ell$	2 e, μ	–	–	20.3	🟩 G_{KK} mass	2.68 TeV	$k/\overline{M}_{Pl} = 0.1$	1405.4123
	RS1 $G_{KK} \rightarrow \gamma\gamma$	2 γ	–	–	20.3	🟩 G_{KK} mass	2.66 TeV	$k/\overline{M}_{Pl} = 0.1$	1504.05511
	Bulk RS $G_{KK} \rightarrow WW \rightarrow qq\ell\nu$	1 e, μ	1 J	Yes	3.2	🟨 G_{KK} mass	1.06 TeV	$k/\overline{M}_{Pl} = 1.0$	ATLAS-CONF-2015-075
	Bulk RS $G_{KK} \rightarrow HH \rightarrow bbbb$	–	4 b	–	3.2	🟨 G_{KK} mass	475-785 GeV	$k/\overline{M}_{Pl} = 1.0$	ATLAS-CONF-2016-017
	Bulk RS $g_{KK} \rightarrow tt$	1 e, μ	≥ 1 b, ≥ 1J/2j	Yes	20.3	🟩 g_{KK} mass	2.2 TeV	BR = 0.925	1505.07018
	2UED / RPP	1 e, μ	≥ 2 b, ≥ 4 j	Yes	3.2	🟨 KK mass	1.46 TeV	Tier (1,1), BR($A^{(1,1)} \rightarrow tt$) = 1	ATLAS-CONF-2016-013
Gauge bosons	SSM $Z' \rightarrow \ell\ell$	2 e, μ	–	–	3.2	🟨 Z' mass	3.4 TeV		ATLAS-CONF-2015-070
	SSM $Z' \rightarrow \tau\tau$	2 τ	–	–	19.5	🟩 Z' mass	2.02 TeV		1502.07177
	Leptophobic $Z' \rightarrow bb$	–	2 b	–	3.2	🟨 Z' mass	1.5 TeV		Preliminary
	SSM $W' \rightarrow \ell\nu$	1 e, μ	–	Yes	3.2	🟨 W' mass	4.07 TeV		ATLAS-CONF-2015-063
	HVT $W' \rightarrow WZ \rightarrow qq\nu\nu$ model A	0 e, μ	1 J	Yes	3.2	🟨 W' mass	1.6 TeV	$g_V = 1$	ATLAS-CONF-2015-068
	HVT $W' \rightarrow WZ \rightarrow qqqq$ model A	–	2 J	–	3.2	🟨 W' mass	1.38-1.6 TeV	$g_V = 1$	ATLAS-CONF-2015-073
	HVT $W' \rightarrow WH \rightarrow \ell\nu bb$ model B	1 e, μ	1-2 b, 1-0 j	Yes	3.2	🟨 W' mass	1.62 TeV	$g_V = 3$	ATLAS-CONF-2015-074
	HVT $Z' \rightarrow ZH \rightarrow \nu\nu bb$ model B	0 e, μ	1-2 b, 1-0 j	Yes	3.2	🟨 Z' mass	1.76 TeV	$g_V = 3$	ATLAS-CONF-2015-074
	LRSM $W'_R \rightarrow tb$	1 e, μ	2 b, 0-1 j	Yes	20.3	🟩 W' mass	1.92 TeV		1410.4103
	LRSM $W'_R \rightarrow tb$	0 e, μ	≥ 1 b, 1 J	–	20.3	🟩 W' mass	1.76 TeV		1408.0886
CI	CI $qqqq$	–	2 j	–	3.6	🟨 Λ	17.5 TeV	$\eta_{LL} = -1$	1512.01530
	CI $qq\ell\ell$	2 e, μ	–	–	3.2	🟨 Λ	23.1 TeV	$\eta_{LL} = -1$	ATLAS-CONF-2015-070
	CI $uutt$	2 e, μ (SS)	≥ 1 b, 1-4 j	Yes	20.3	🟩 Λ	4.3 TeV	$\lvert C_{LL}\rvert = 1$	1504.04605
DM	Axial-vector mediator (Dirac DM)	0 e, μ	≥ 1 j	Yes	3.2	🟨 m_A	1.0 TeV	g_q=0.25, g_χ=1.0, $m(\chi) < 140$ GeV	Preliminary
	Axial-vector mediator (Dirac DM)	0 e, μ, 1 γ	1 j	Yes	3.2	🟨 m_A	650 GeV	g_q=0.25, g_χ=1.0, $m(\chi) < 10$ GeV	Preliminary
	$ZZ\chi\chi$ EFT (Dirac DM)	0 e, μ	1 J, ≤ 1 j	Yes	3.2	🟨 M_*	550 GeV	$m(\chi) < 150$ GeV	ATLAS-CONF-2015-080
LQ	Scalar LQ 1st gen	2 e	≥ 2 j	–	3.2	🟨 LQ mass	1.07 TeV	$\beta = 1$	Preliminary
	Scalar LQ 2nd gen	2 μ	≥ 2 j	–	3.2	🟨 LQ mass	1.03 TeV	$\beta = 1$	Preliminary
	Scalar LQ 3rd gen	1 e, μ	≥1 b, ≥3 j	Yes	20.3	🟩 LQ mass	640 GeV	$\beta = 0$	1508.04735
Heavy quarks	VLQ $TT \rightarrow Ht + X$	1 e, μ	≥ 2 b, ≥ 3 j	Yes	20.3	🟩 T mass	855 GeV	T in (T,B) doublet	1505.04306
	VLQ $YY \rightarrow Wb + X$	1 e, μ	≥ 1 b, ≥ 3 j	Yes	20.3	🟩 Y mass	770 GeV	Y in (B,Y) doublet	1505.04306
	VLQ $BB \rightarrow Hb + X$	1 e, μ	≥ 2 b, ≥ 3 j	Yes	20.3	🟩 B mass	735 GeV	isospin singlet	1505.04306
	VLQ $BB \rightarrow Zb + X$	2/≥3 e, μ	≥2/≥1 b	–	20.3	🟩 B mass	755 GeV	B in (B,Y) doublet	1409.5500
	VLQ $QQ \rightarrow WqWq$	1 e, μ	≥ 4 j	Yes	20.3	🟩 Q mass	690 GeV		1509.04261
	$T_{5/3} \rightarrow Wt$	1 e, μ	≥ 1 b, ≥ 5 j	Yes	20.3	🟩 $T_{5/3}$ mass	840 GeV		1503.05425
Excited fermions	Excited quark $q^* \rightarrow q\gamma$	1 γ	1 j	–	3.2	🟨 q^* mass	4.4 TeV	only u^* and d^*, $\Lambda = m(q^*)$	1512.05910
	Excited quark $q^* \rightarrow qg$	–	2 j	–	3.6	🟨 q^* mass	5.2 TeV	only u^* and d^*, $\Lambda = m(q^*)$	1512.01530
	Excited quark $b^* \rightarrow bg$	–	1 b, 1 j	–	3.2	🟨 b^* mass	2.1 TeV		Preliminary
	Excited quark $b^* \rightarrow Wt$	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, μ	–	–	20.3	🟩 ℓ^* mass	3.0 TeV	$\Lambda = 3.0$ TeV	1411.2921
	Excited lepton ν^*	3 e, μ, τ	–	–	20.3	🟩 ν^* mass	1.6 TeV	$\Lambda = 1.6$ TeV	1411.2921
Other	LSTC $a_T \rightarrow W\gamma$	1 e, μ, 1 γ	–	Yes	20.3	🟩 a_T mass	960 GeV		1407.8150
	LRSM Majorana ν	2 e, μ	2 j	–	20.3	🟩 N^0 mass	2.0 TeV	$m(W_R) = 2.4$ TeV, no mixing	1506.06020
	Higgs triplet $H^{\pm\pm} \rightarrow \ell\ell$	2 e, μ (SS)	–	–	20.3	🟩 $H^{\pm\pm}$ mass	551 GeV	DY production, BR($H_L^{\pm\pm} \rightarrow \ell\ell$)=1	1412.0237
	Higgs triplet $H^{\pm\pm} \rightarrow \ell\tau$	3 e, μ, τ	–	–	20.3	🟩 $H^{\pm\pm}$ mass	400 GeV	DY production, BR($H_L^{\pm\pm} \rightarrow \ell\tau$)=1	1411.2921
	Monotop (non-res prod)	1 e, μ	1 b	Yes	20.3	🟩 spin-1 invisible particle mass	657 GeV	$a_{non-res} = 0.2$	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

**Only a selection of the available mass limits*

†Small-radius (large-radius) jets are denoted

More results arte coming soon!

Conclusions:

Playing the game with Nature we are never sure what next is coming!

- Many measurements and searches performed with ~ 3.2 fb-1 of data taken in 2015 at 13 TeV.
- Sensitivity in many of them already exceed Run-1 results and new results obtained.
- Most BSM searches do not see significant excesses and end up with larger exclusion limits.
- Some of them show intriguing excesses. The largest one is γγ a resonance around mX = 750 GeV. However it is early to consider it statistically significant.
- More definite answers are expected by the end of the year when ~25 fb-1 will be accumulated (may be even earlier).
- Run 2 may bring many surprises: years 2016-2018 are critical for high energy physics!