Searches for new physics at TeV scale in dilepton final states at ATLAS experiment

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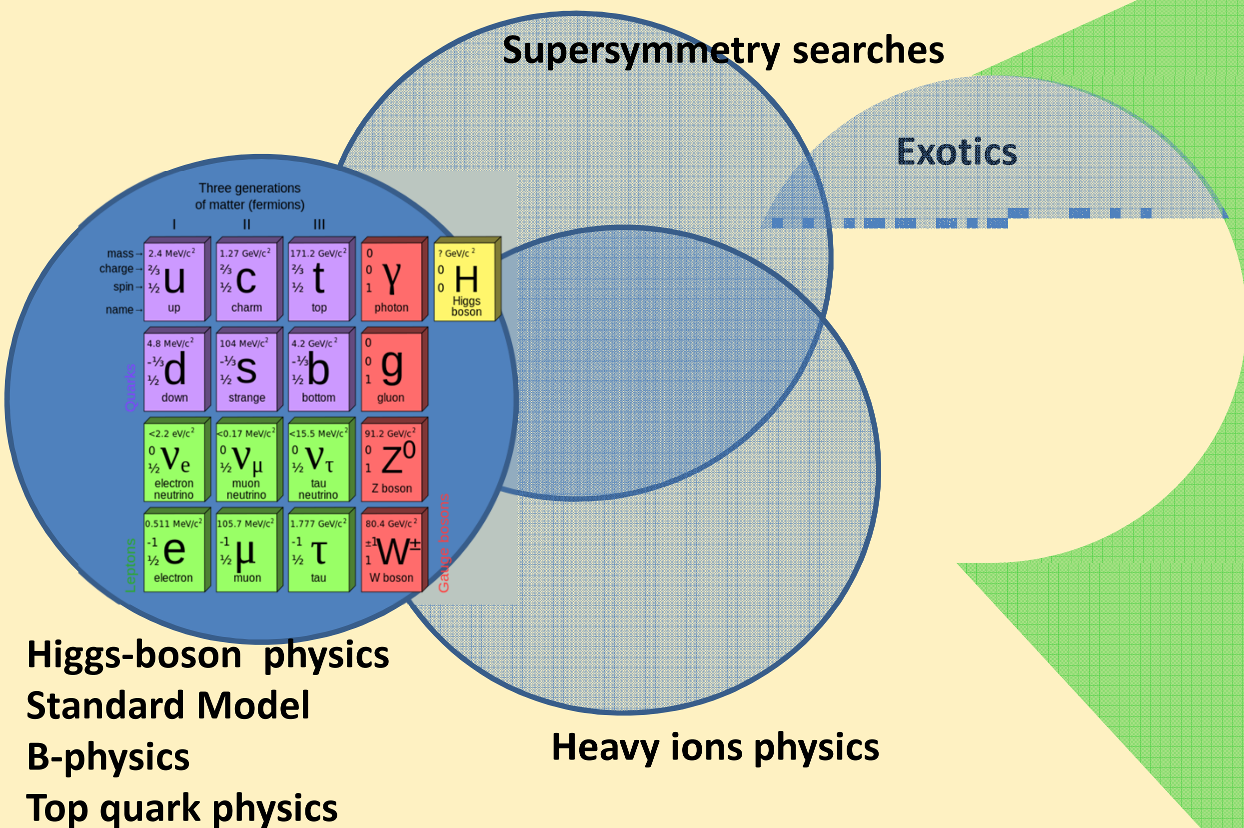
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I
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mass
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up
charm
top
photon
Higgs boson
down
strange
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Z boson
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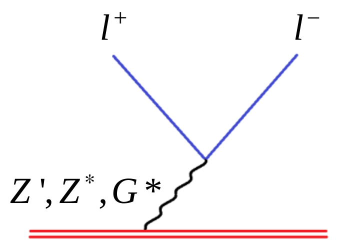
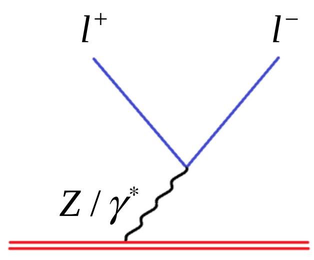
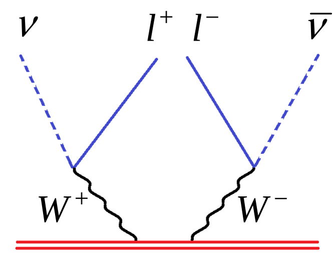
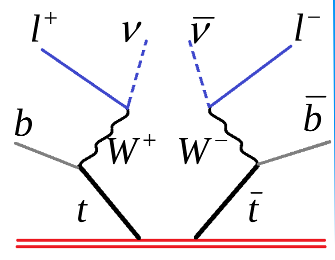
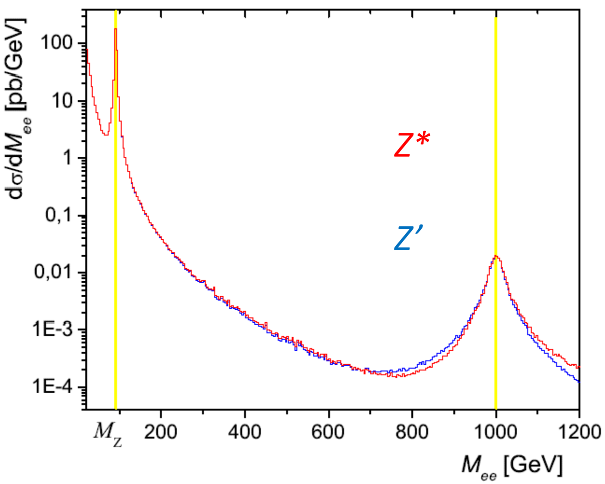
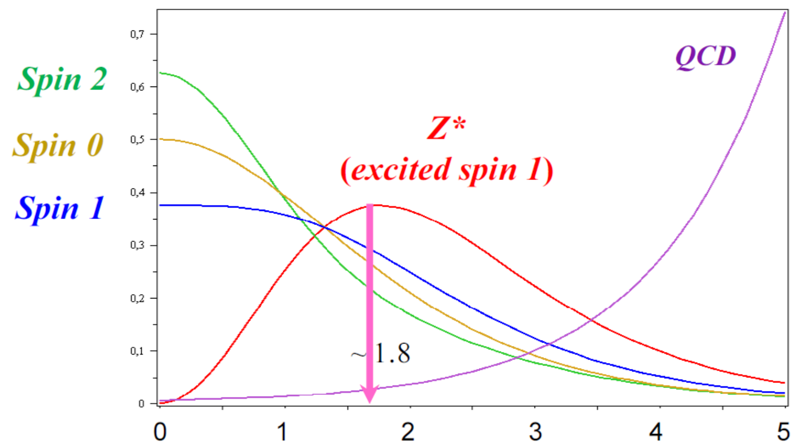
Dilepton channel has a fully reconstructed kinematics. The physical simplicity of the dilepton decays allows precise modeling of signal and background processes together with higher order corrections to them.

Signal	Z/γ^*	ZZ, WZ, WW	$t\bar{t}$	$QCD,\ W + jets$
				Combinations of leptons from jets misidentifications and real leptons in multi-jet and W+jets processes

Main backgrounds are Drell-Yan processes, associate production of several *Z,W* bosons, single top quark and top pairs production, QCD processes.



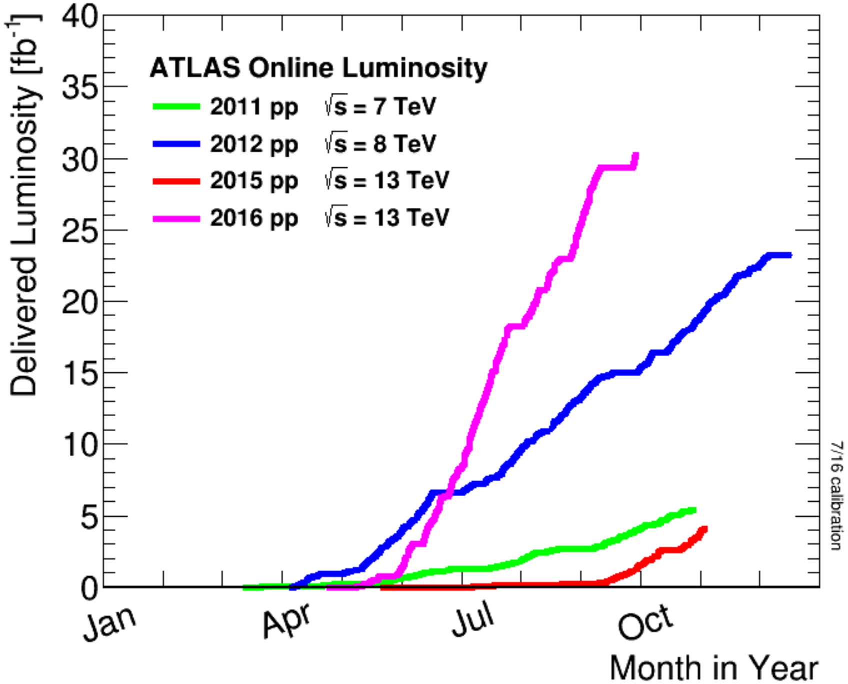
Angular properties of leptons in decay allow distinguishing different types of new resonances.



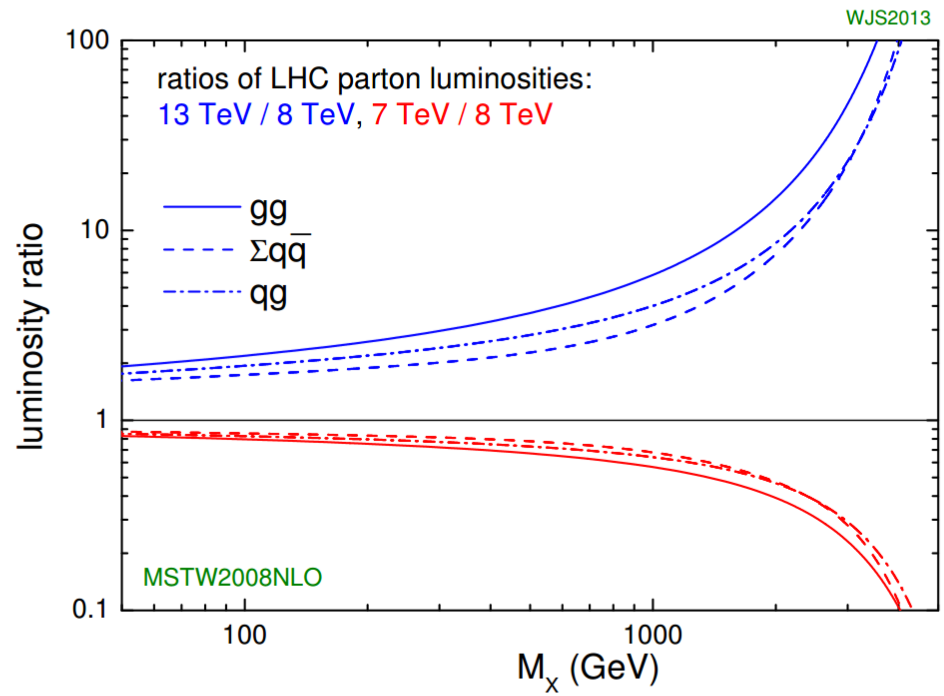
M.V. Chizhov et al., Phys. Atom. Nucl., 2008, 71, pp.2096-2100;

ATLAS *pp* collisions data

Dilepton exotics searches at ATLAS are ongoing since first physics run of LHC.
Our sensitivity to high-mass new physics grew extremely fast with increase of collision energy and collider luminosity.



Integrated luminosity, delivered by LHC in 2011-2016

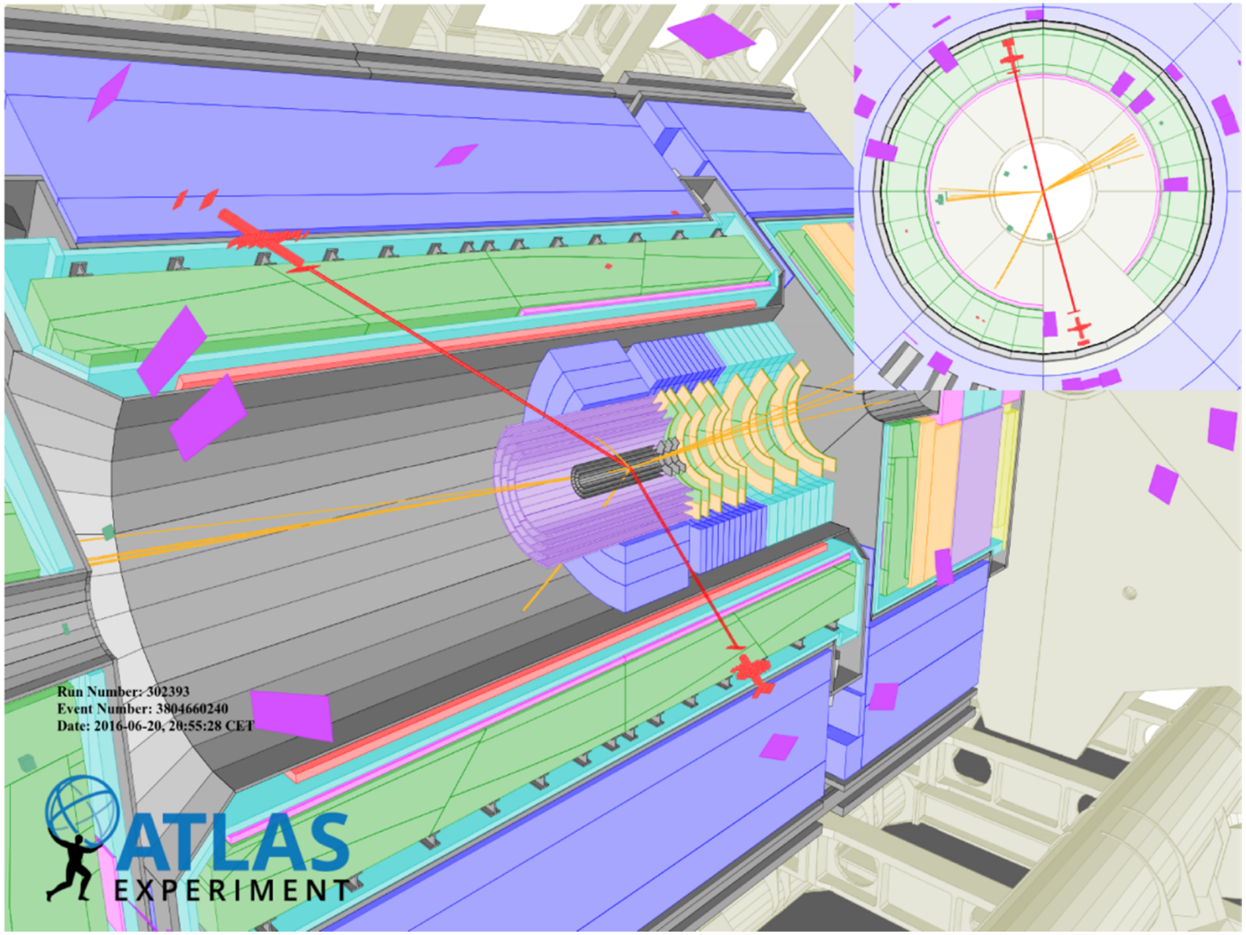


Parton luminosity ratio (right plot) for *pp* collisions of different energies (7, 8, 13 TeV).

Lepton reconstruction and event selection (on example of 13 TeV *pp* data analysis)

Plots from *ATLAS-CONF-2016-045*

ATLAS shows excellent performance w.r.t. high p_T leptons reconstruction.



The highest inv.mass dielectron event (M=2.38TeV), selected in 13TeV *pp* data.

Quality of leptons is ensured by requiring a good reconstruction in different detector subsystems.

Electron candidates are reconstructed via combining the Inner Detector track with the calorimeter information;

E_T > 30 GeV;

$|\eta|$<2.47 (excluding transition region between the barrel and the end-cap calorimeters);

Isolation requirements;

Events are triggered with the dielectron trigger (E_T > 17 GeV).

Two electrons with the highest scalar E_T sum in the event are selected.

Lepton reconstruction and event selection (on example of 13 TeV *pp* data analysis)

Muon candidate tracks are produced as a combined fit of the Muon Spectrometer and the Inner Detector tracks.

p_T > 30 GeV;

ID and MS measurements must be consistent within 7 standard deviations;

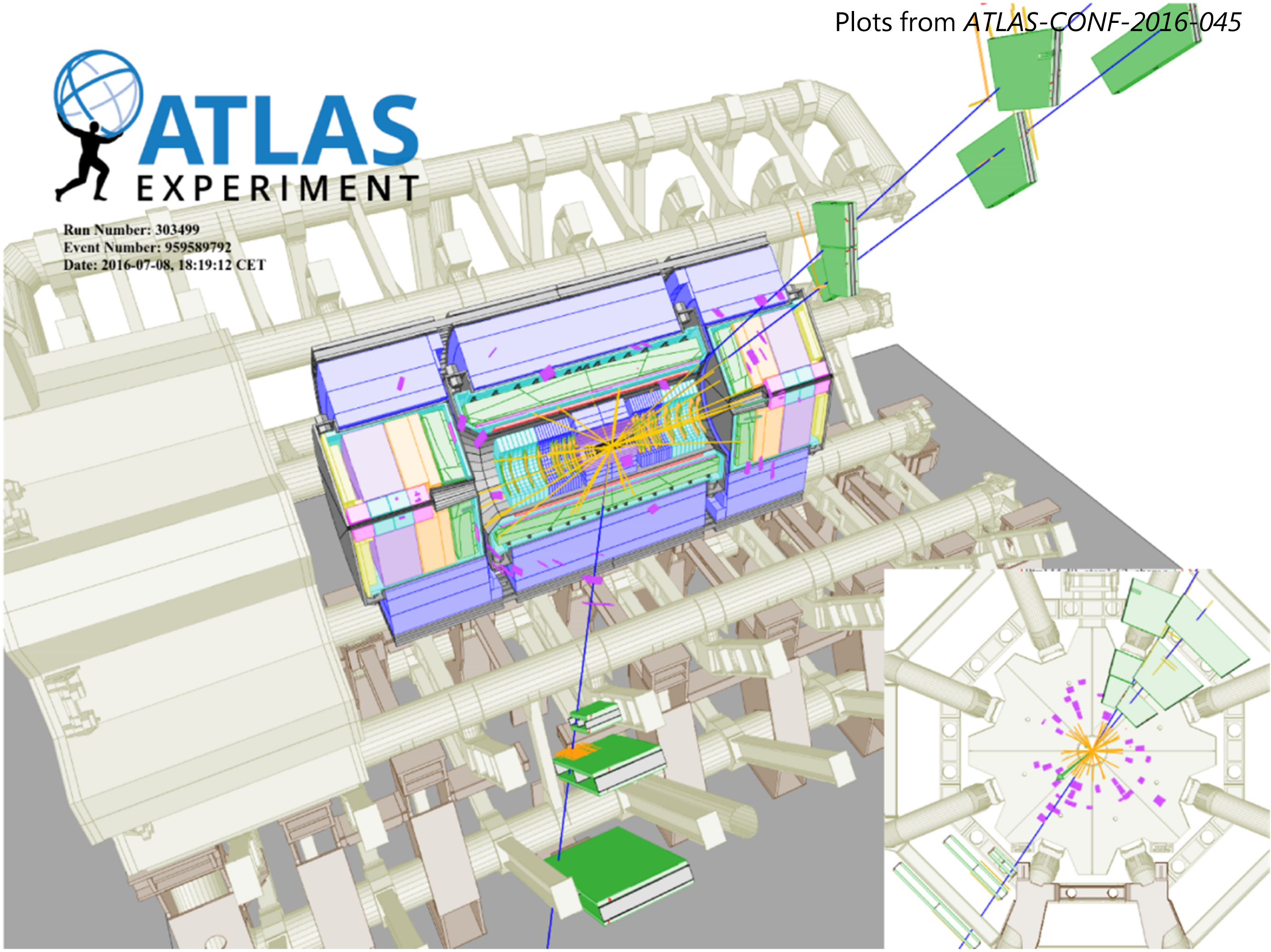
Isolation requirement;

Muons must have hits in all of the 3 precision chambers in MS.

Single muon triggers
(p_T > 26 GeV or p_T > 50 GeV)

Two opposite sign muons with the highest scalar p_T sum in the event are selected.

Plots from *ATLAS-CONF-2016-045*

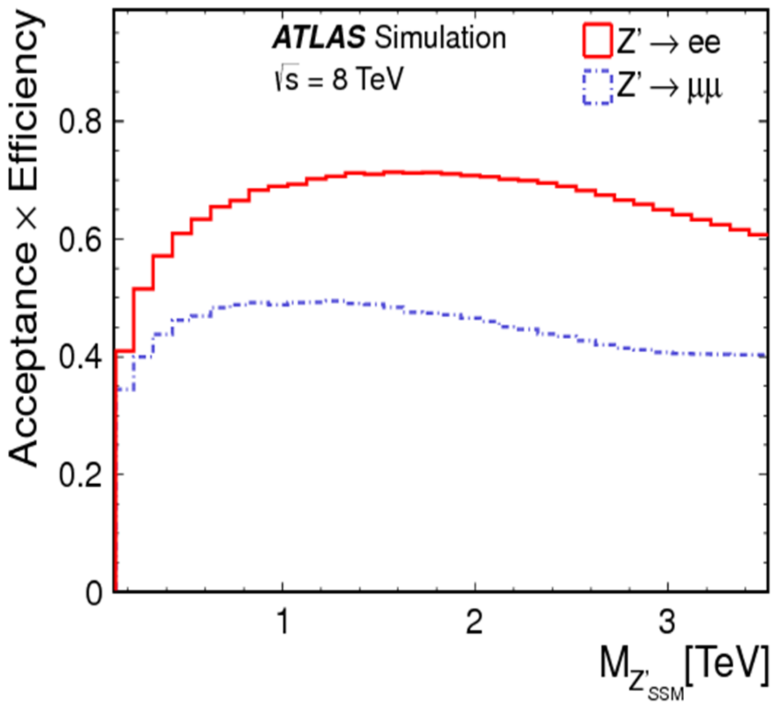


The highest inv.mass dimuon event (M=1.98TeV), selected in 13TeV *pp* data.

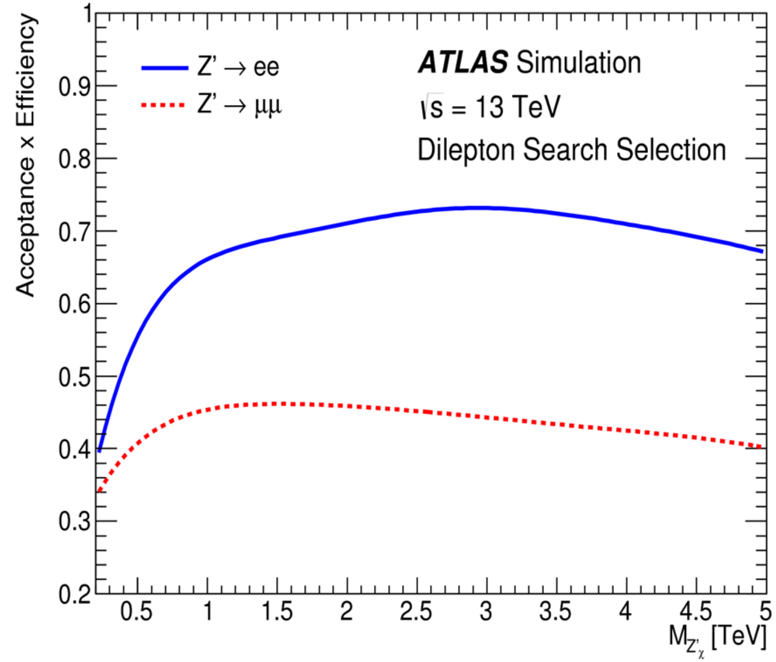
Event selection: efficiencies times acceptance

Acceptance times efficiency for $Z' \to ll$ events selection depending on Z' resonance pole mass.

2012 $Z' \to ll$ selection



2015, 2016 $Z' \to ll$ selection



ATLAS detector upgrade as well as new software allowed rise in efficiency and substantial lepton quality improvements;

Z'→ee events are reconstructed with **~60-75%** efficiency in wide range of masses;
The efficiency for ***Z'→μμ*** events is in **40-45%** range;

Plots and data from *Phys. Rev. D. 90, 052005 (2014)*, *Phys. Lett. B 761 (2016) 372-392*

Estimation of the signal and background distributions (13 TeV data analysis)

For dielectron channel, **multi-jet and W+jets processes** are estimated using a 'fake rate' data-driven method. For dimuon channel it is negligible.
BG-enriched data samples are produced using the 'loose' selection wrt identification and isolation requirements and suppressing real electrons; the jet probability to be misidentified as electron (fake rate) is computed as a E_T, η function;
Contribution to BG from events with one or more fake electrons is obtained from the matrix of the fake rates and probabilities of real electrons to pass selection (ref. backup).

Drell-Yan processes are simulated using Powheg at NLO in QCD and the CT10 PDF. The mass-dependent corrections up to NNLO in QCD are applied;

Diboson processes are simulated in Sherpa generator at NLO and CT10 PDF set;

Double and single top quark production is simulated by Powheg + CT10 PDF set. Top-quark MC samples are normalized to a NNLO cross-section calculated with Top++2.0 program;

Signal *Z'* processes are produced at LO using Pythia8 with NNPDF23LO. Interference effects with background processes are not taken into account. Higher order corrections are applied in the same way as for DY background;

Summary of systematics uncertainties in BG estimation for dielectron channel

Source	7TeV 2011	8TeV 2012	13TeV 2016
Normalization (Luminosity)	5%	4%	2.9%
PDF variation	20% (PDF, α_S, factorization scale)	11%	8.7%
PDF choice		7%	<1.0%
α_S		3%	1.6%
Electroweak corrections	4.5%	2%	2.4%
Photon-induces correction	--	3%	3.4%
W+jets + QCD background	26%	5%	<1.0%
TOTAL	34%	15%	12.4%

Table shows main sources of systematics uncertainties in background estimation for dielectron channel for $\mathbf{M_{ee} = 2TeV}$.

Summary of systematics uncertainties in BG estimation for dimuon channel

Source	7TeV 2011	8TeV 2012	13TeV 2016
Normalization (Luminosity)	5%	4%	2.9%
PDF variation	20% (PDF, α_S, factorization scale)	12%	7.6%
PDF choice		6%	<1.0%
α_S		3%	1.4%
Electroweak corrections	4.5%	3%	2.0%
Photon-induces correction	--	3%	3.0%
Reconstruction efficiency	--	--	10.4%
TOTAL	21%	15%	14.6%

Table shows main sources of systematics uncertainties in background estimation for dimuon channel for $\mathbf{M_{\mu\mu}}$ **= 2TeV**.

Historical retreat. 2010 results: first probe of real data

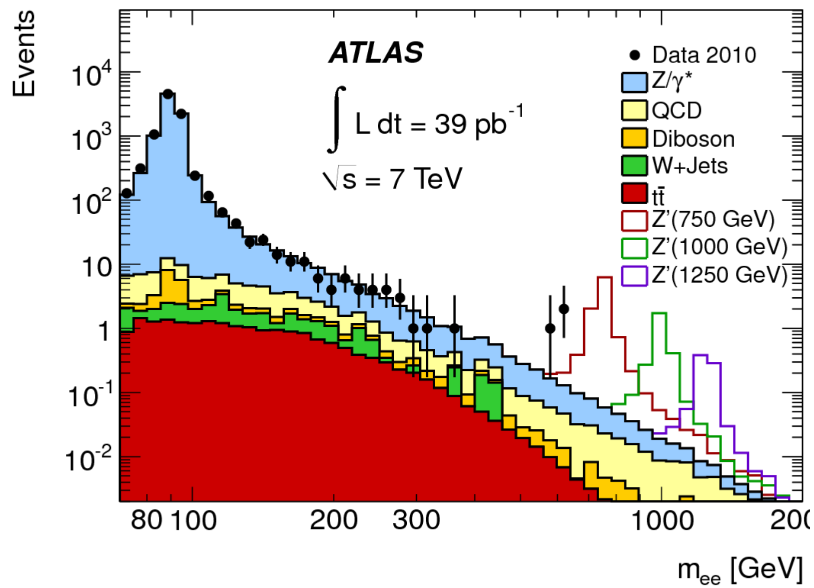
Invariant mass distributions for selected dielectron (left) and dimuon (right) events in data and SM simulation (top), cross section times branching ratio and mass limits for several BSM models (bottom).

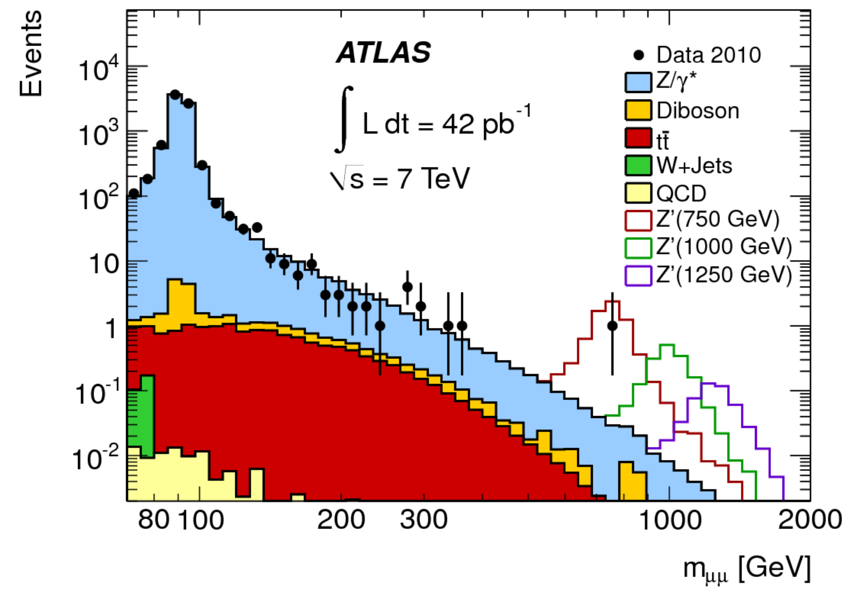
The first *pp* collisions at $\sqrt{s}$=7TeV have been delivered by LHC in summer 2010, with the instant luminosity up to 2.1x10^{32} cm^{-2}s^{-1}.

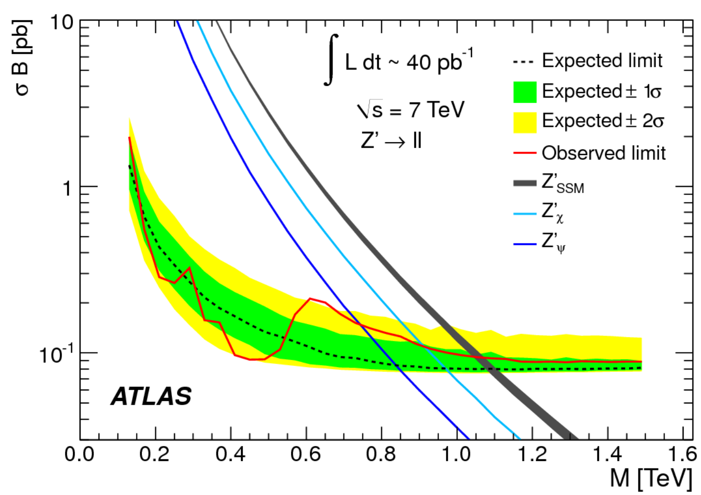
2010 analysis involved ~40pb^{-1} of data.

The good agreement was observed between data and SM.

The limits on the cross section times branching were set on several *Z′* models and *Z** model.







	Observed combined mass limit, TeV
Z'_{SSM}	0.957
Z'_{χ}	0.900
Z'_{ψ}	0.738
Z^*	1.152

Historical retreat. 2011 results: start looking beyond 1 TeV

Invariant mass distributions for selected dielectron (left) and dimuon (right) events in data and SM simulation (top), cross section times branching ratio and mass limits for several BSM models (bottom).

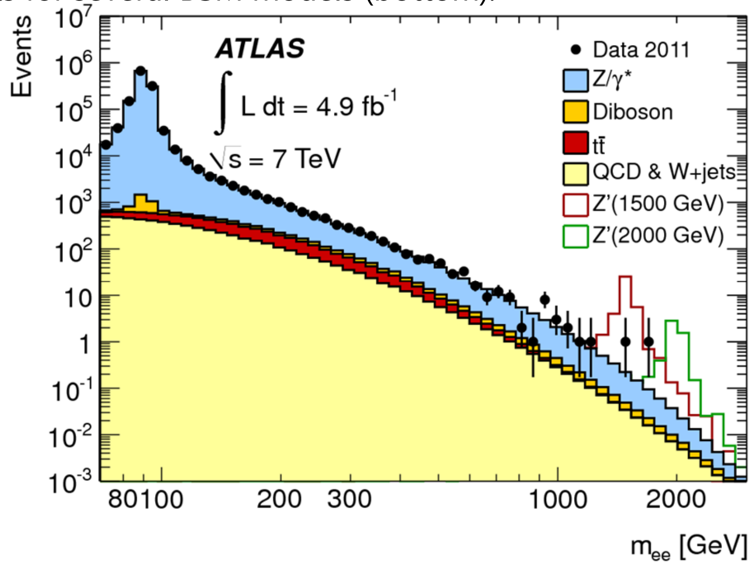
In 2011 LHC *pp* run, the instantaneous luminosity reached 3×10^{33} $cm^{-2}s^{-1}$.

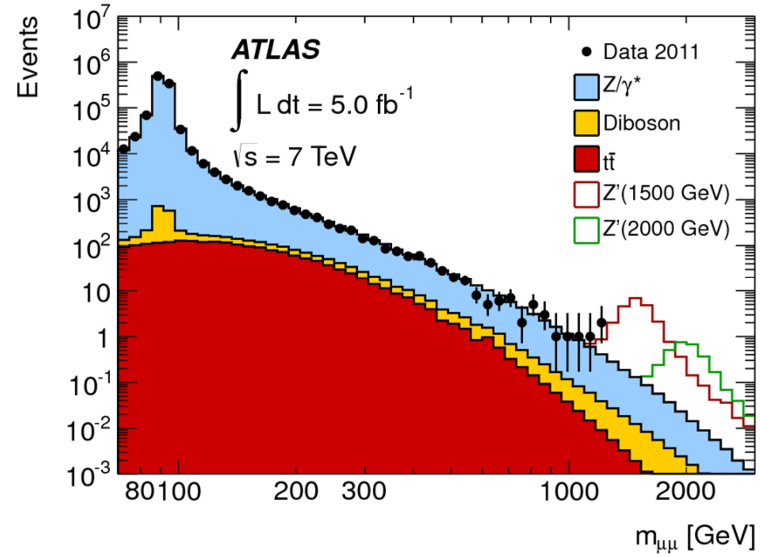
ATLAS recorded ~$5fb^{-1}$ of $\sqrt{s}$=7TeV data by the end of 2011.

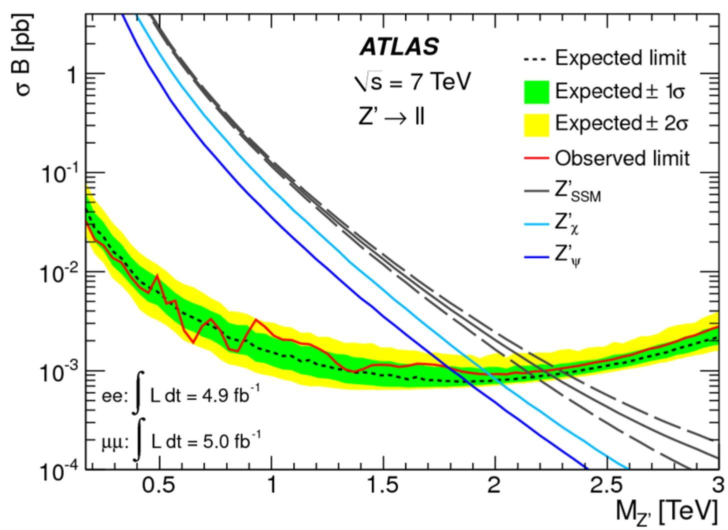
In 2011, the events with one 2-MS-stations muon were added to the analysis.

2011 data showed good agreement with the SM predictions.

The new limits on Z′, Z*, G*, Torsion and Technicolor models have been set.





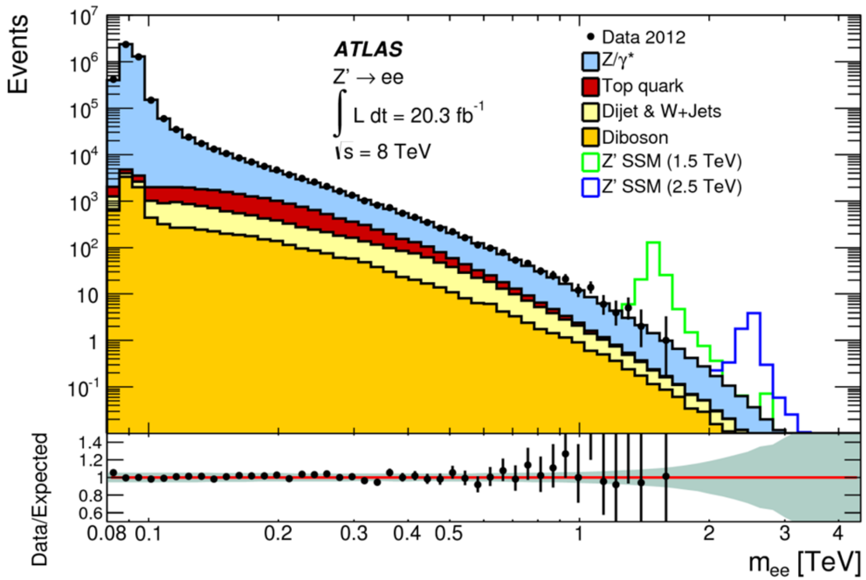


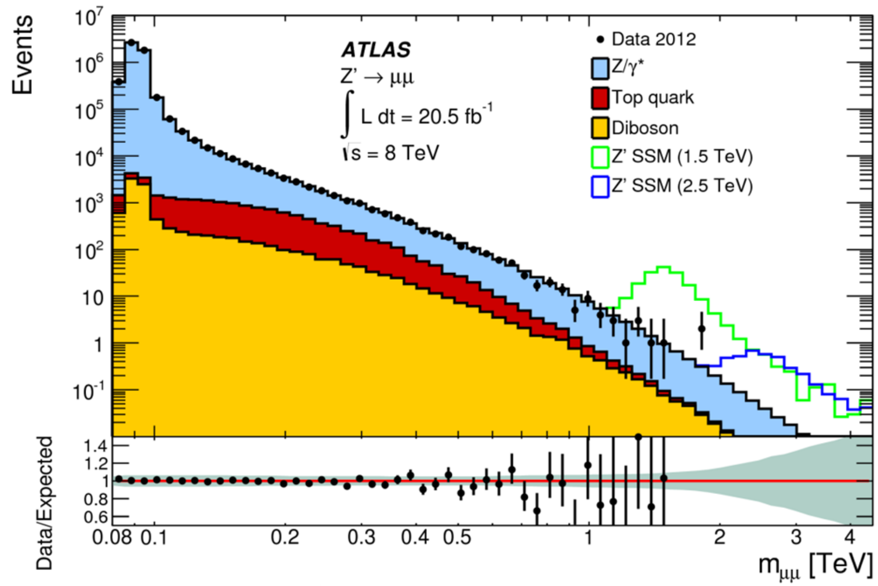
	Observed combined mass limit, TeV
Z'_{SSM}	2.22
Z'_{χ}	1.97
Z'_{ψ}	1.79
Z^*	2.20
$G^*(k=0.1)$	2.16

Plots and data from *JHEP 1211 (2012) 138*

Historical retreat. 2012 results: transition to 8 TeV collisions

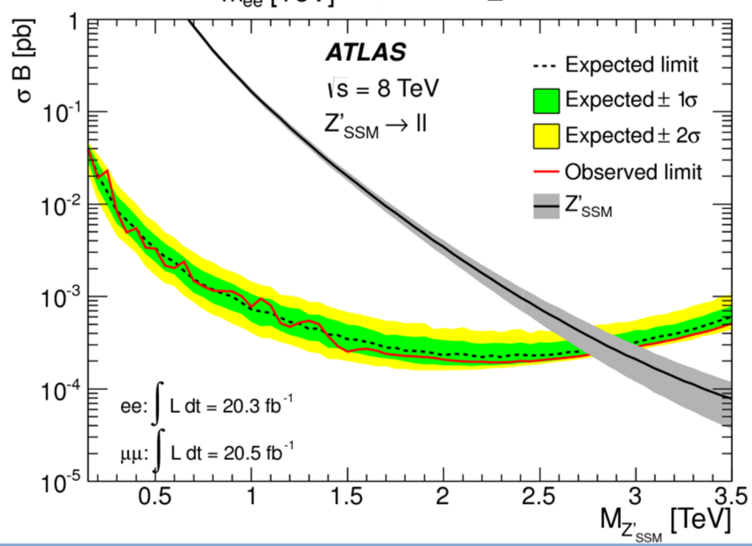
Invariant mass distributions for selected dielectron (left) and dimuon (right) events in data and SM simulation (top), cross section times branching ratio and mass limits for several BSM models (bottom).





LHC produced 8 TeV *pp* collisions in 2012 with high instantaneous luminosity (up to 8x10^{33} cm^{-2}s^{-1}), which substantially increased sensitivity to heavy resonance production.

Again, a very good data/BG agreement was observed, and new limits were set on Z′, Z*, G*, QBH and Technicolor.



	Observed combined mass limit, TeV
Z'_{SSM}	2.90
Z'_{χ}	2.69
Z'_{ψ}	2.51
*Z**	2.85
G(k=0.1)*	2.68

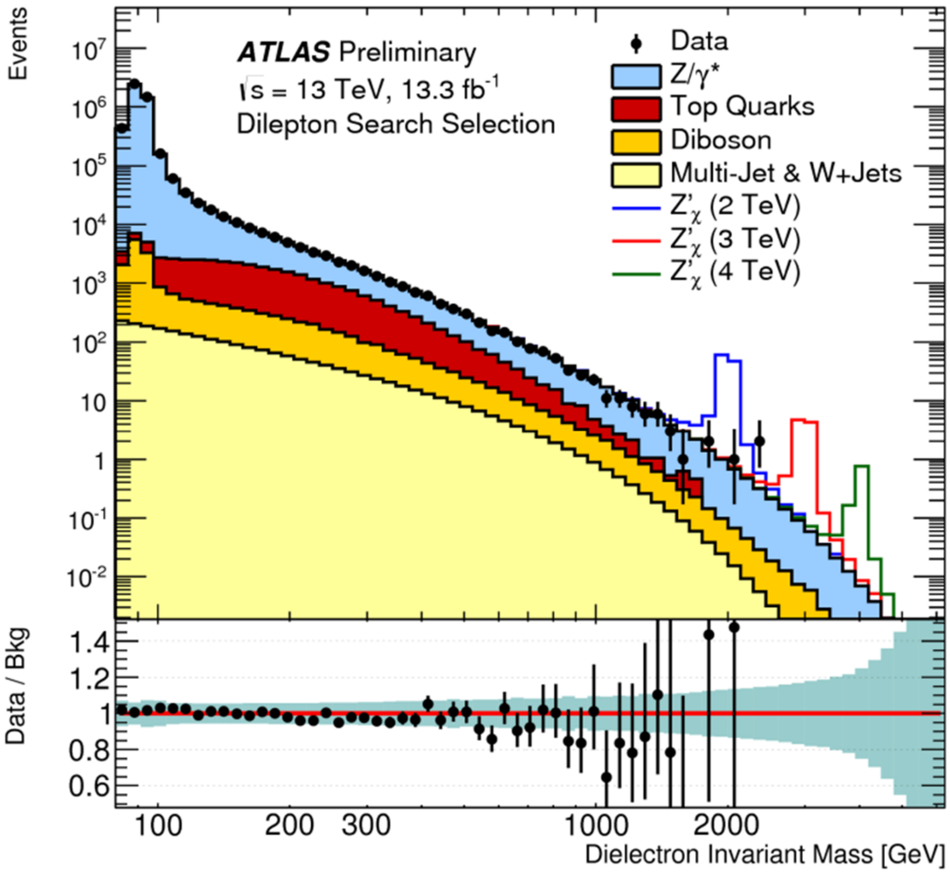
Plots and data from *Phys. Rev. D. 90, 052005 (2014)*

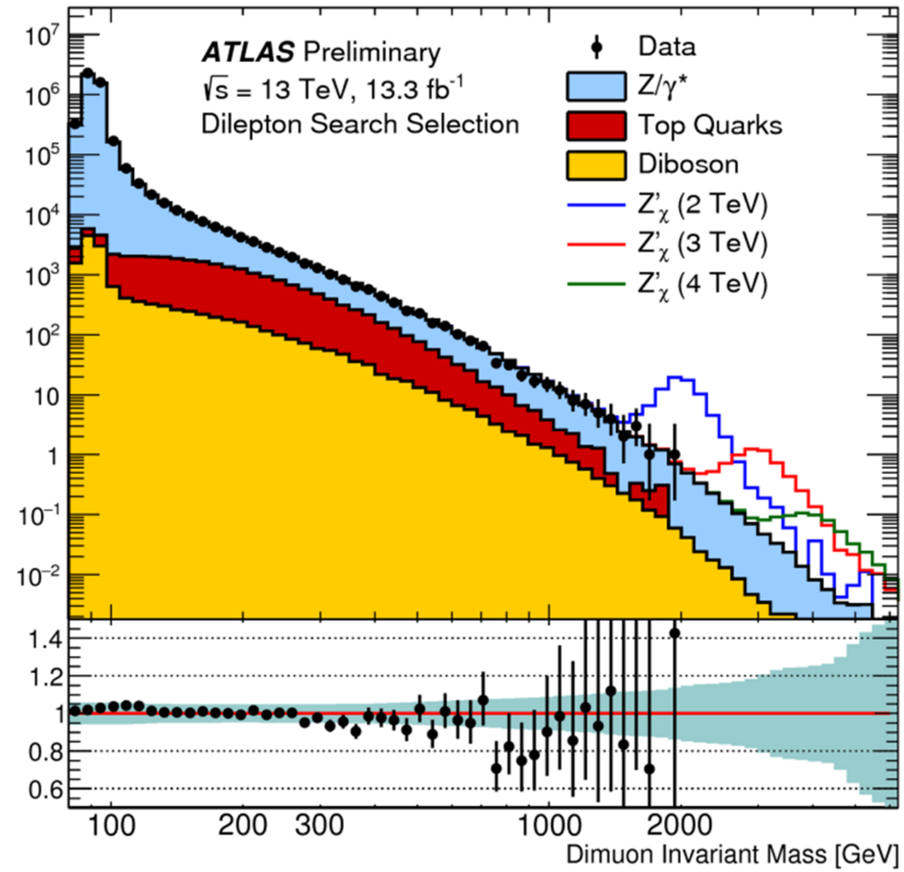
Results for 13TeV 2015, 2016 *pp*-collisions

Plots from *ATLAS-CONF-2016-045*

Transition towards 13TeV collisions in 2015 allowed further increase of our search potential.
By mid-2016 ATLAS recorded 13.3fb^{-1} of data.
Since ATLAS upgrade, no more 2-station muons are involved.

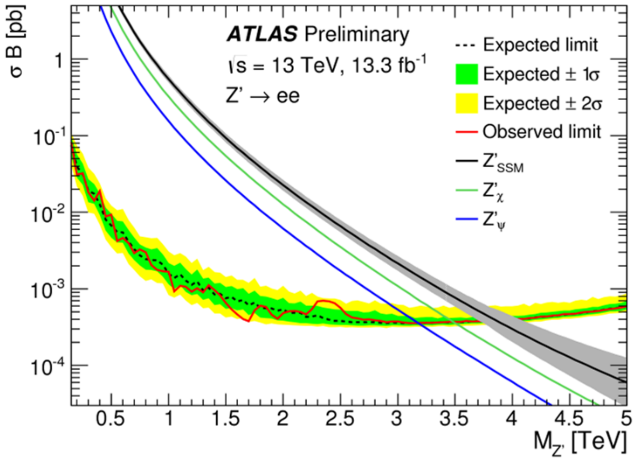
Invariant mass distributions for selected dielectron (left) and dimuon (right) events in data and SM simulation (top), cross section times branching ratio and mass limits for several Z′ models (bottom).

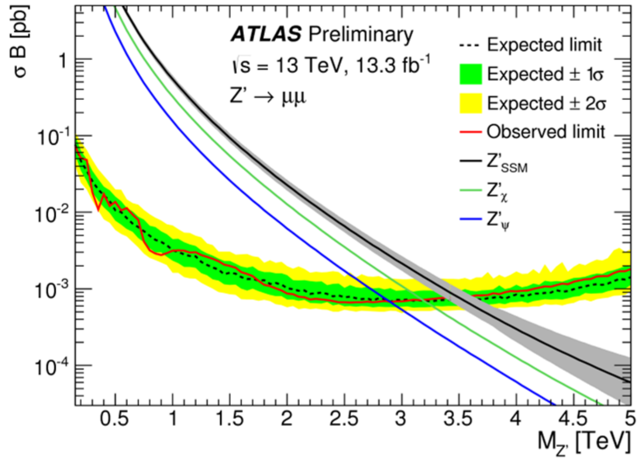




The deficit of the events in 500-800GeV region in dimuon channel has total significance of 1.4σ.

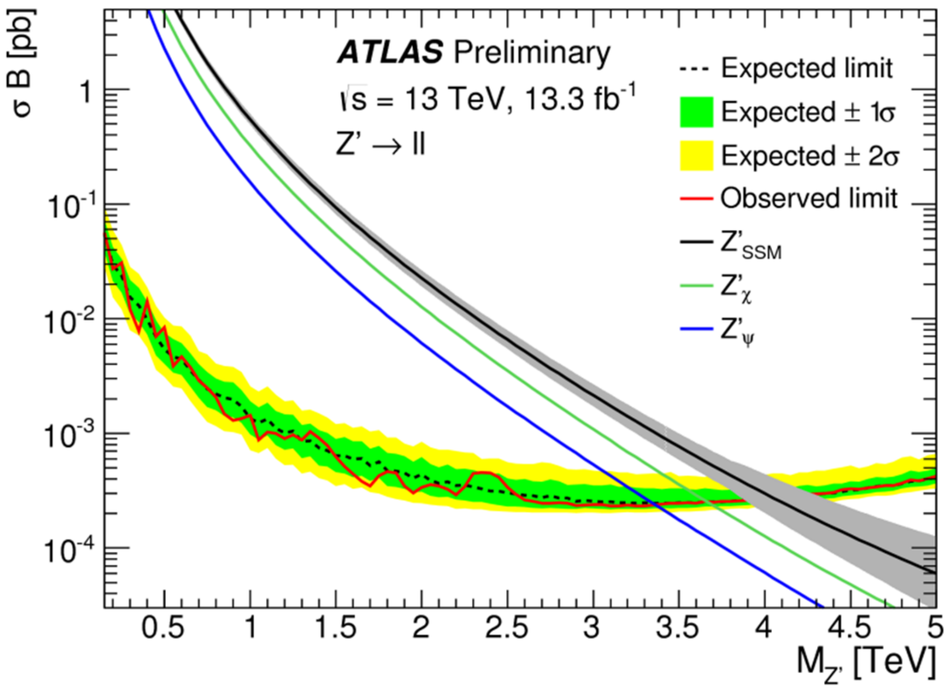
Results for 13TeV *pp*-collisions (2015, 2016)





Cross-section times branching ratio exclusion limits for Z' resonances of different masses.

Limits in dielectron (top left) and dimuon (top right) channels are shown together with combined limit (bottom).



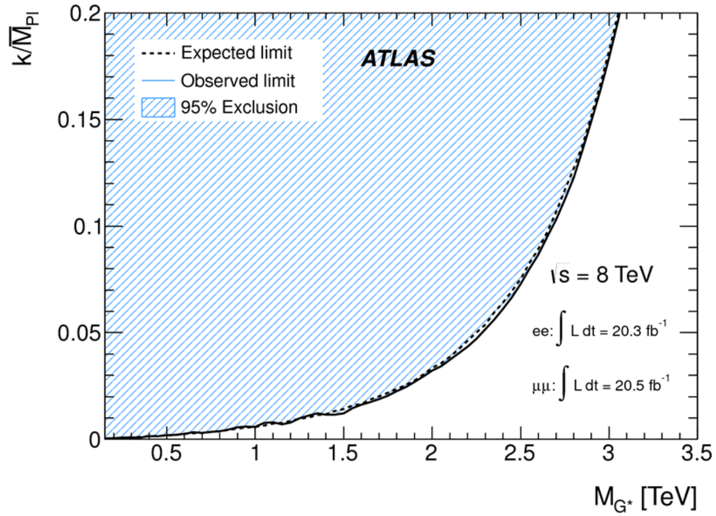
Summary of the mass exclusion limits

	Observed combined mass limit, TeV
Z'_{SSM}	4.05
Z'_{χ}	3.66
Z'_{ψ}	3.36

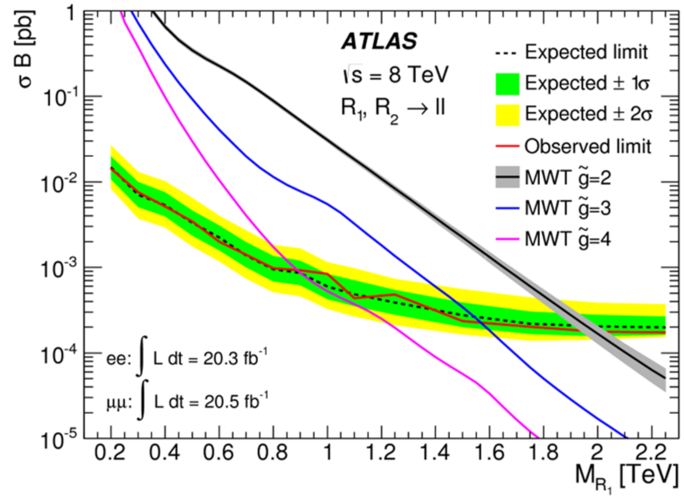
Plots and data from *ATLAS-CONF-2016-045*

Results for other BSM models

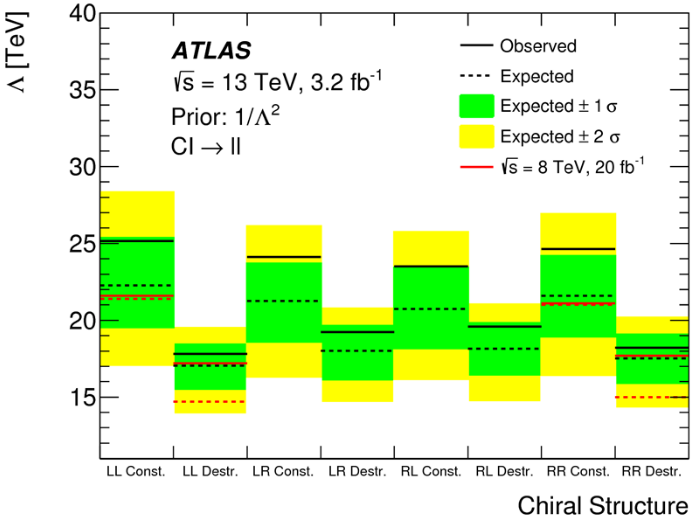
RS Graviton limits



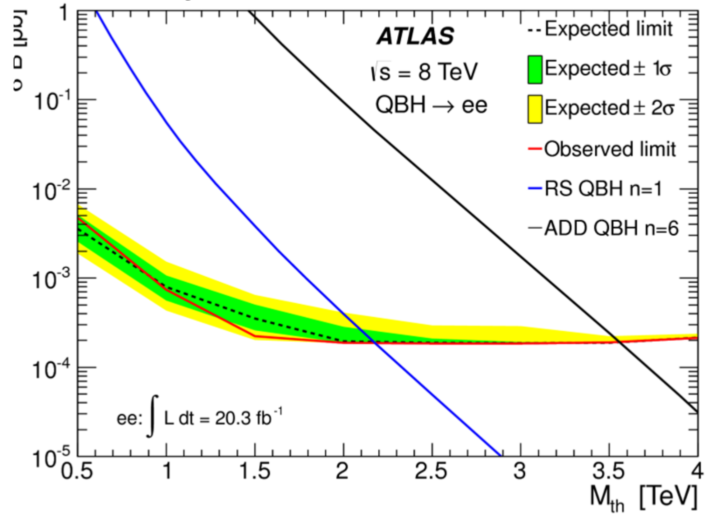
MW technicolor limits



Contact Interactions limits



Quantum Black Holes limits



Conclusions

1. LHC and ATLAS showed excellent performance since first data takings and up to latest runs in 2016;

2. Good agreement between data and SM predictions have been observed in 7, 8, 13 TeV *pp*-collisions.

3. Several BSM models (*Z'*, *Z**, *G**, QBH, CI, MWT, etc…) have been extensively studied experimentally. As a results, the new experimental limits has been set on the models' parameters, e.g., up to over 4TeV for Z'_{SSM} mass.

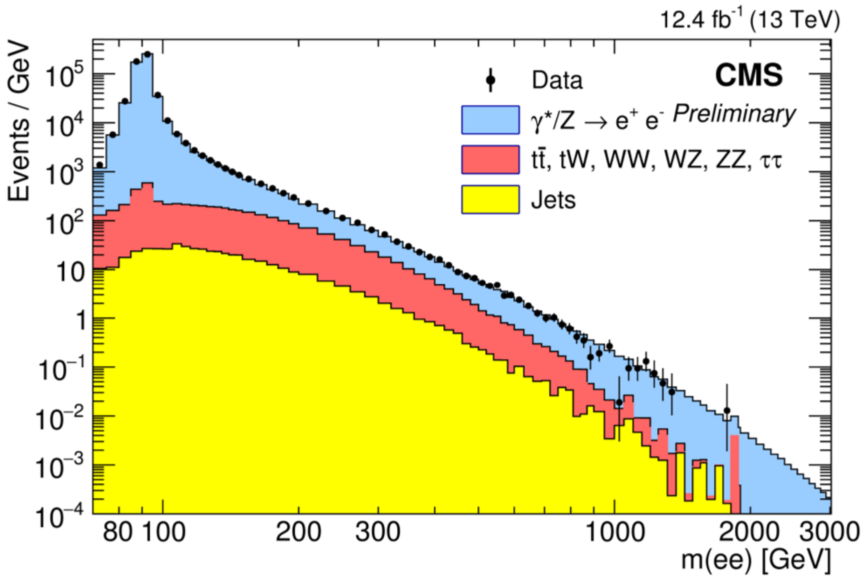
4. Not only new limits is the result: several data analysis methods, modeling techniques and search strategies have been improved or developed .

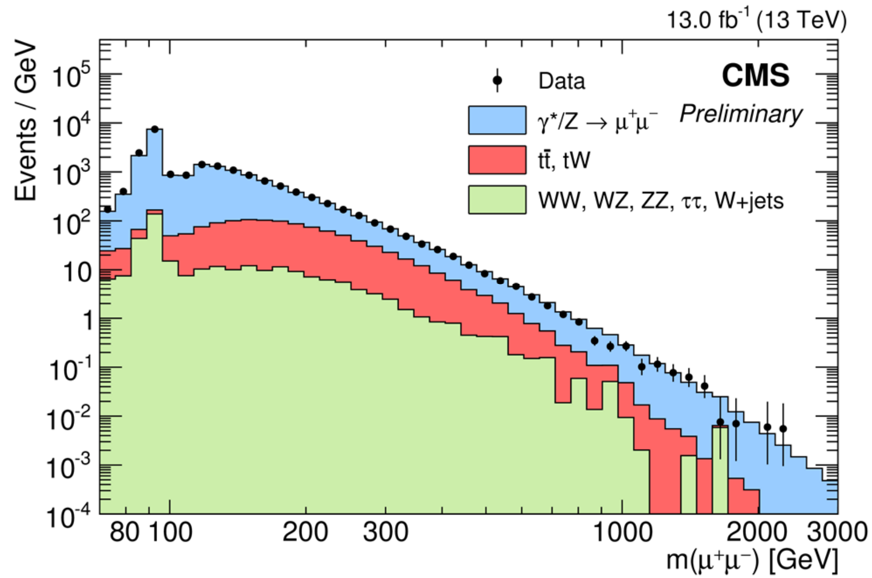
5. Besides limits on BSM models, these results also provided a rigid test of the Standard Model in 'few TeV' region.

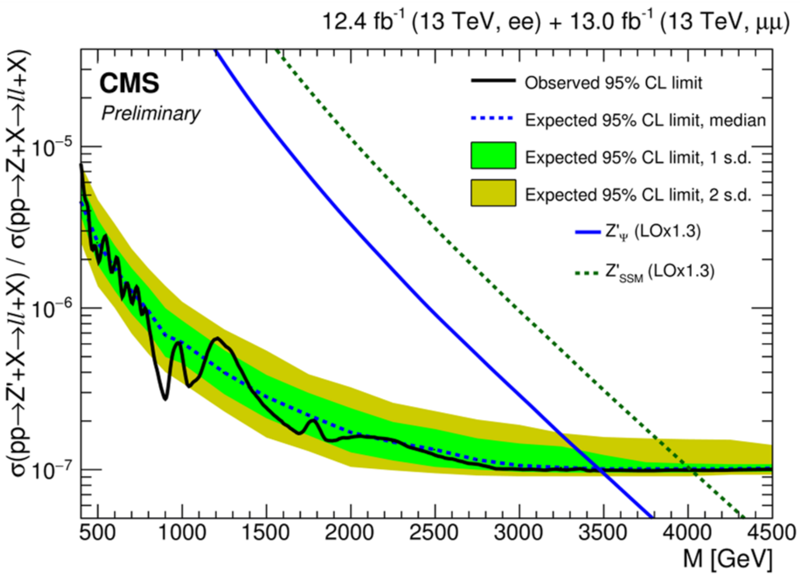
Thanks for attention!

Backup

CMS results for dilepton searches in 13 TeV *pp* collisions







	Observed combined mass limit, TeV
Z'_{SSM}	4.0
Z'_{ψ}	3.5

Plots and data from *Phys. Rev. D. 90, 052005 (2014)*

Estimation of the W+jets and multi-jets backgrounds in dielectron channel

The special BG-enriched data samples are produced using the 'loose' electron selection wrt identification and isolation requirements and suppressing real electrons;

The jet probability to be misidentified as electron (fake rate) is computed as a E_T, η function;
Contribution to BG from events with one or more fake electrons is obtained from the matrix of the fake rates (f_1, f_2 for leading and subleading electron) and probabilities of real electrons to pass selection (r_1, r_2 for leading, subleading electron).

$$\begin{pmatrix} N_{TT} \\ N_{TL} \\ N_{LT} \\ N_{LL} \end{pmatrix} = \begin{pmatrix} r_1 r_2 & r_1 f_2 & f_1 r_2 & f_1 f_2 \\ r_1(1-r_2) & r_1(1-f_2) & f_1(1-r_2) & f_1(1-f_2) \\ (1-r_1)r_2 & (1-r_1)f_2 & (1-f_1)r_2 & (1-f_1)f_2 \\ (1-r_1)(1-r_2) & (1-r_1)(1-f_2) & (1-f_1)(1-r_2) & (1-f_1)(1-f_2) \end{pmatrix} \begin{pmatrix} N_{RR} \\ N_{RF} \\ N_{FR} \\ N_{FF} \end{pmatrix}$$

where N_{TT}, N_{TL}, N_{LT}, N_{LL} – numbers of electron pairs each passing the tight and/or the loose selection;
N_{RR}, N_{RF}, N_{FR}, N_{FF} – numbers of electron pairs with each of them either real or fake;

From this matrix, one gets the system of equations to determine the desired backround level:

$$N_{TT}^{\text{Dijet\&}W\text{+jets}} = r_1 f_2 N_{RF} + f_1 r_2 N_{FR} + f_1 f_2 N_{FF}.$$

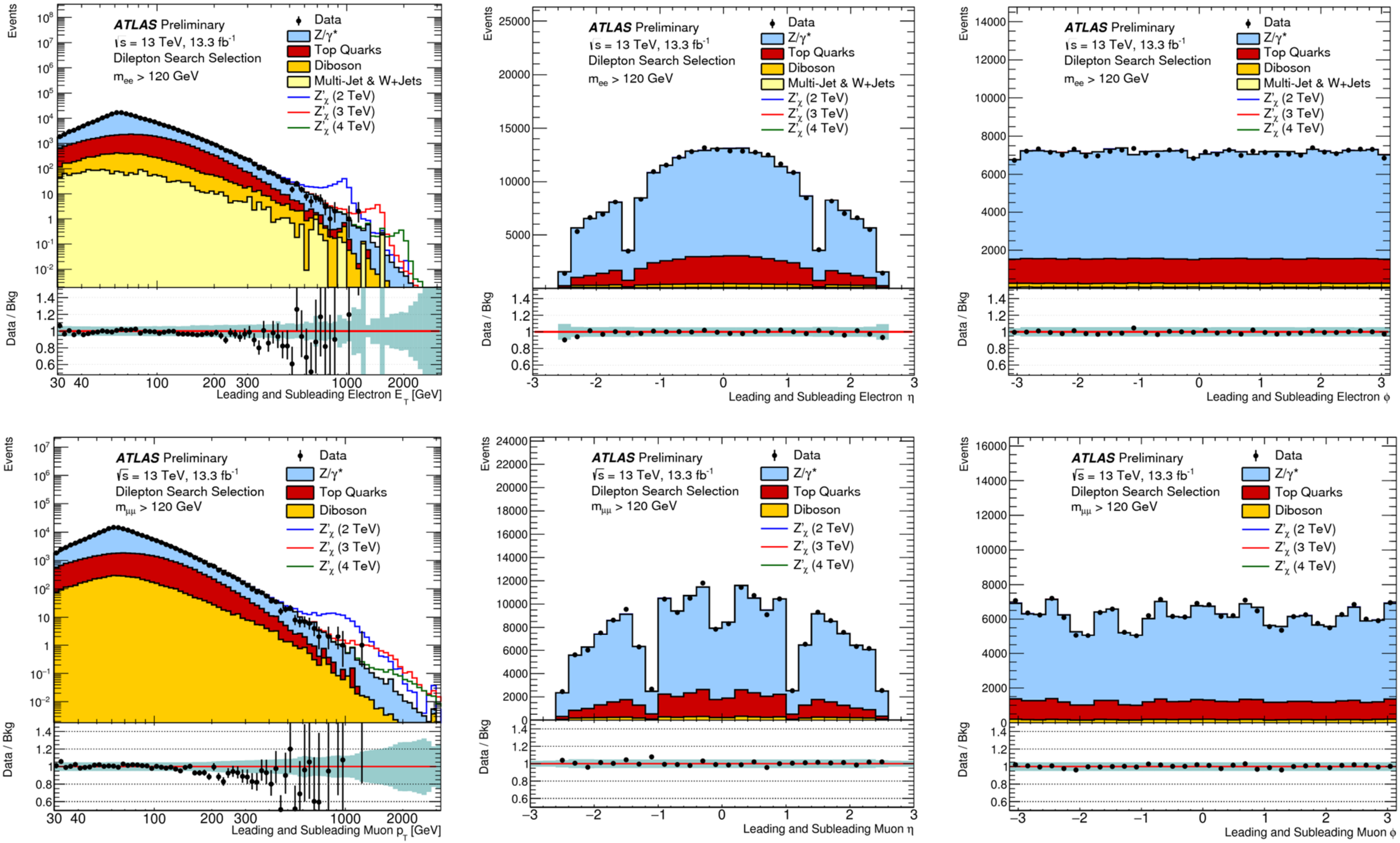
Summary of systematics uncertainties (13 TeV 2015, 2016 data analysis)

Source	Dielectron		Dimuon	
	Signal	Background	Signal	Background
Luminosity	2.9% (2.9%)	2.9% (2.9%)	2.9% (2.9%)	2.9% (2.9%)
MC Statistical	<1.0% (<1.0%)	<1.0% (<1.0%)	<1.0% (<1.0%)	<1.0% (<1.0%)
Beam Energy	2.0% (4.1%)	2.0% (4.1%)	1.9% (3.3%)	1.9% (3.3%)
DY PDF Choice	N/A	<1.0% (8.4%)	N/A	<1.0% (2.0%)
DY PDF Variation	N/A	8.7% (18.5%)	N/A	7.6% (13.2%)
DY PDF Scale	N/A	1.0% (2.0%)	N/A	0.9% (1.5%)
DY α_S	N/A	1.6% (2.7%)	N/A	1.4% (2.3%)
DY EW Corrections	N/A	2.4% (5.5%)	N/A	2.0% (4.0%)
DY Photon-induced Corrections	N/A	3.4% (7.6%)	N/A	3.0% (5.5%)
Top Quarks Theoretical	N/A	<1.0% (<1.0%)	N/A	<1.0% (<1.0%)
Dibosons Theoretical	N/A	<1.0% (<1.0%)	N/A	<1.0% (<1.0%)
Reconstruction Efficiency	<1.0% (<1.0%)	<1.0% (<1.0%)	10.4% (16.7%)	10.4% (16.7%)
Isolation Efficiency	4.0% (4.0%)	4.0% (4.0%)	1.8% (2.0%)	1.8% (2.0%)
Trigger Efficiency	<1.0% (<1.0%)	<1.0% (<1.0%)	<1.0% (<1.0%)	<1.0% (<1.0%)
Identification Efficiency	3.0% (2.9%)	3.0% (2.9%)	N/A	N/A
Lepton Energy Scale	<1.0% (<1.0%)	4.2% (7.3%)	<1.0% (<1.0%)	<1.0% (<1.0%)
Lepton Energy Resolution	<1.0% (<1.0%)	<1.0% (<1.0%)	2.3% (2.1%)	3.6% (9.9%)
Multi-jet & W+jets	N/A	<1.0% (<1.0%)	N/A	N/A
Total	6.2% (7.1%)	12.4% (24.8%)	11.4% (17.5%)	14.6% (25.2%)

Summary of the relative systematic uncertainties in the expected number of events at a dilepton mass of 2 TeV (4 TeV)

Data from *ATLAS-CONF-2016-045*

Kinematic plots for selected dilepton events (13 TeV 2015, 2016 data analysis)



Data from *ATLAS-CONF-2016-045*