Search for New Phenomena Using Dilepton Final States with the ATLAS Detector

Yanlin Liu (刘彦麟)

University of Science and Technology of China
University of Michigan

CLHCP 2017,Nanjing, Dec. 23, 2017

What to Search for?

Resonance: Z'

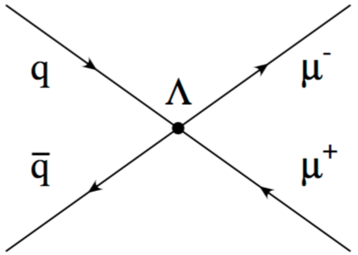
- Sequential Standard Model (SSM): Z' has the same coupling to fermions as Z boson
- E6 model inspired by Grand Unified Theories: breaking into SU(5) and two additional $U(1)_\psi$ and $U(1)_\chi$ groups

$$Z'(\theta_{E_6}) = Z'_\psi \cos\theta_{E_6} + Z'_\chi \sin\theta_{E_6}$$

  - Mixing angle θ_{E_6} specifies Z' coupling to SM fermions and its intrinsic width
  - Z' states given by six different values of θ_{E_6} (Z'_ψ, Z'_N, Z'_η, Z'_I, Z'_S and Z'_χ)

Non-Resonance: Contact Interaction

- Quark and lepton compositeness with energy scale Λ corresponding to the binding energy between fermion constituent

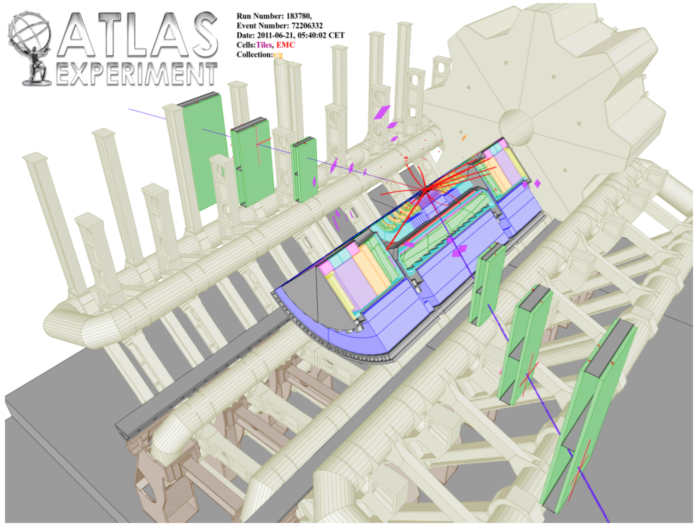


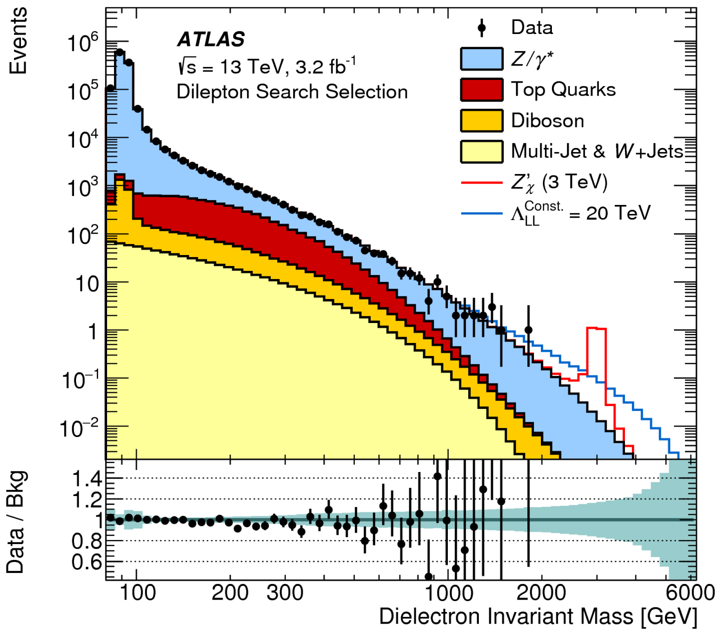
$$\sigma_{\rm tot}(m_{\ell\ell}) = \sigma_{\rm DY}(m_{\ell\ell}) - \eta_{ij}\frac{F_{\rm I}}{\Lambda^2} + \frac{F_{\rm C}}{\Lambda^4}$$

- η defines the corresponding chiral structure
  - η = +(-)1 for destructive (constructive) interference with SM DY process

Methodology

- Signal signature: two isolated, high p_T leptons (ee/μμ)
- Reconstruct the dilepton invariant mass and look for any deviations (peak or broad excess) from the SM prediction
- If no data excess seen, limits on σxBr or energy scale Λ will be set for corresponding benchmark models
  - ➢Search is based on data with an integrated luminosity of 36.1 fb^{-1} recorded in 2015 and 2016





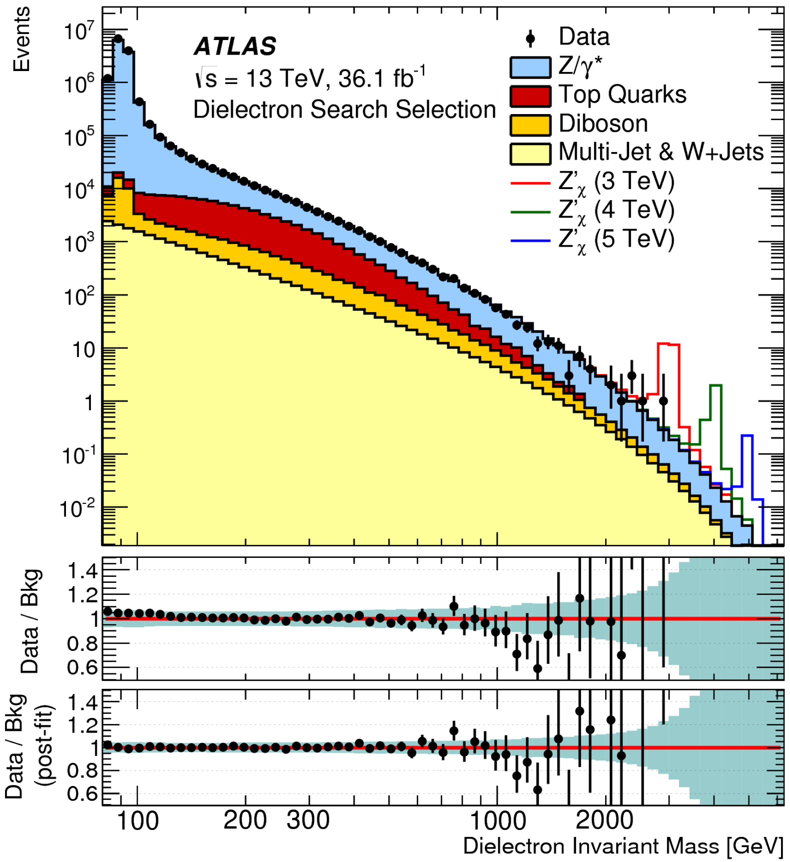
Event Selection Criteria

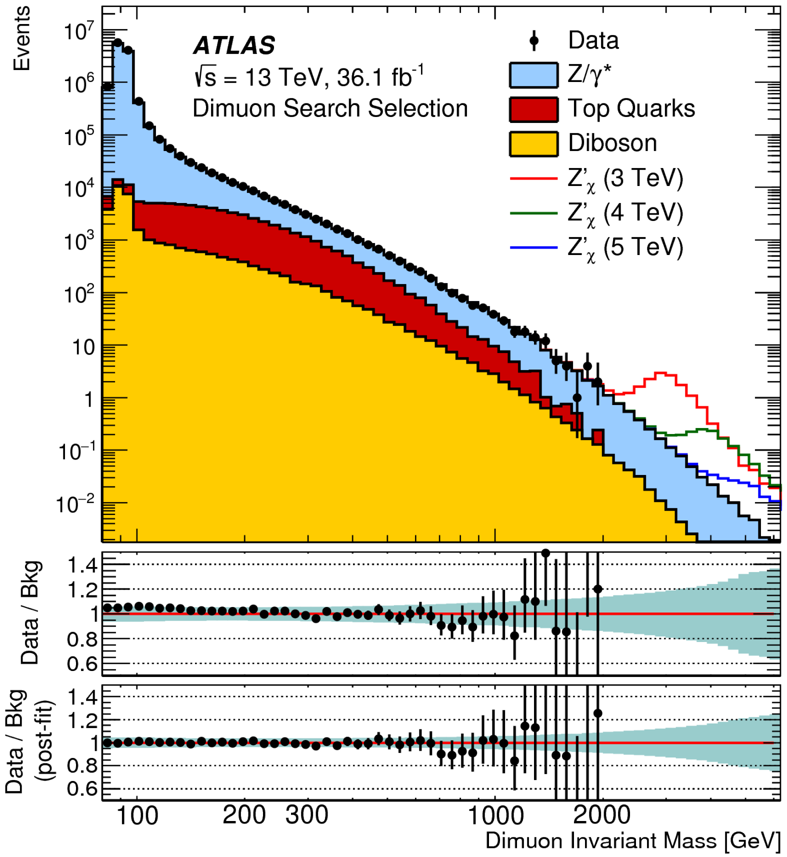
$Z' \rightarrow e^+e^-$	$Z' \rightarrow \mu^+\mu^-$
Trigger and dilepton requirements	
Trigger: di-electron with p_T>17 GeV	Trigger: single μ with p_T>26, 50 GeV
At least two electrons	At least two combined muons
Lepton Selection	
$\|\eta\|$< 2.47 excluding central and forward transition region	$\|\eta\|$< 2.5 & Three Station requirements (High-p_T)
E_T > 30GeV	p_T > 30 GeV
$d0/\sigma_{d0} < 5$; $\|z0 \sin\theta\| < 0.5$ mm	$d0/\sigma_{d0} < 3$; $\|z0 \sin\theta\| < 0.5$ mm
Calo- and track-Isolation requirements	Track-Isolation requirement only
Likelihood identification (Medium)	Opposite charge sign
Select highest E_T/p_T lepton pair	
Invariant Mass > 80GeV	

Background Estimation

- Dominant irreducible background is Drell-Yan simulated from NLO Powheg generator with Pythia8 for event showering
- Other backgrounds: top-quark simulated from Powheg while diboson samples simulated with Sherpa
- Multi-jet and W+jets contributions (jets misidentified as leptons): data-driven approach (matrix method) used for estimation in electron channel; negligible for muon channel
  - First evaluating the probabilities that a jet (*f*) and a real electron (*r*) satisfy the electron identification requirements
  - Then using the derived probabilities *r* and *f* to estimate the level of contamination due to mis-identification

Invariant Mass of Selected e^+e^- or $\mu^+\mu^-$





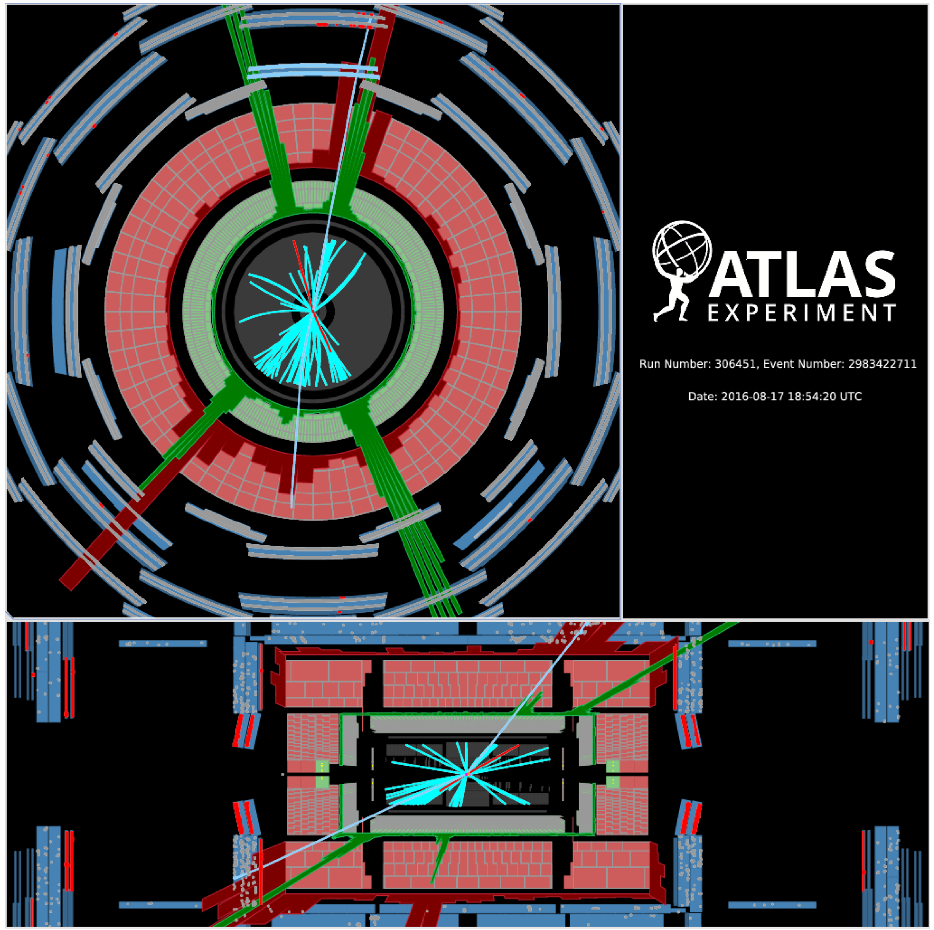
Acc*Eff: 71% for 3 TeV Z'→ee

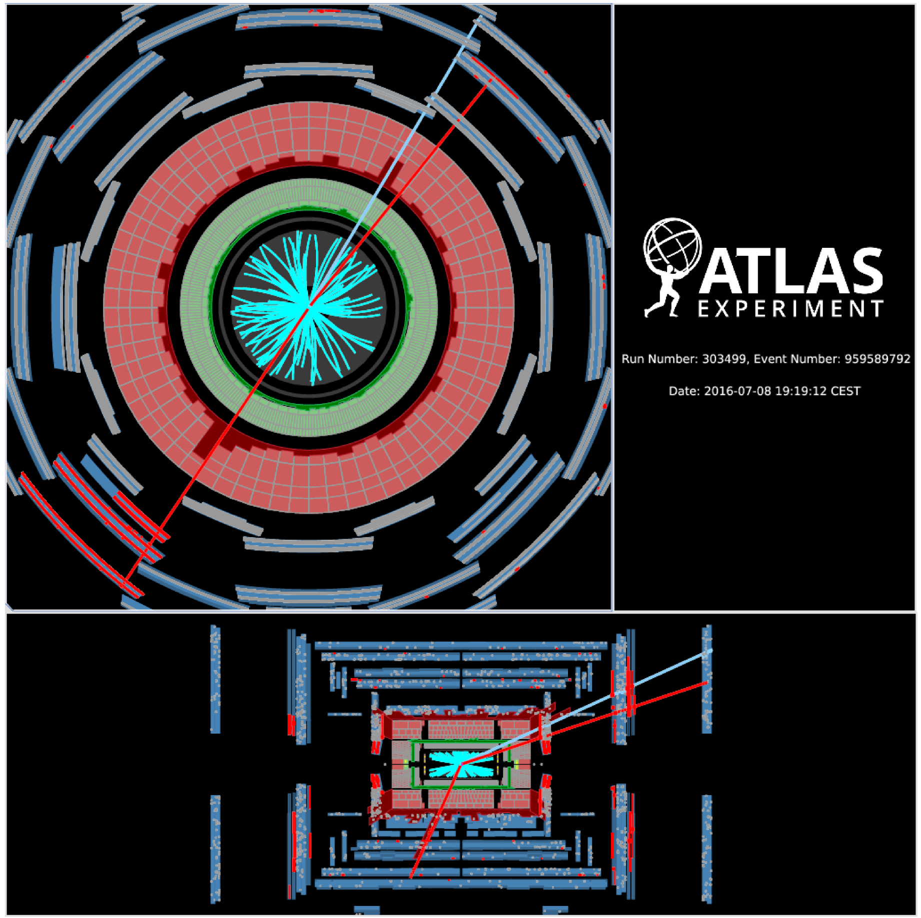
Acc*Eff: 40% for 3 TeV Z'→μμ

- No data excess observed comparing with SM prediction ☹
- Highest mass events in data: 2.90 TeV (e^+e^-) and 1.99 TeV ($\mu^+\mu^-$)

JHEP 10 (2017) 182

Highest m_{ll} Events for Z' Search





- Leading electron: p_T = 889 TeV, η = -0.51
- Subleading electron: p_T = 868 TeV, η = 1.14
- m_{ll} = 2.90 TeV

- Leading muon: p_T = 604 TeV, η = -0.43
- Subleading muon: p_T = 561 TeV, η = 1.81
- m_{ll} = 1.99 TeV; MET = 109 GeV

Systematics Uncertainties

Source	Dielectron channel [%] Signal	Dielectron channel [%] Background	Dimuon channel [%] Signal	Dimuon channel [%] Background
Luminosity	3.2 (3.2)	3.2 (3.2)	3.2 (3.2)	3.2 (3.2)
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 (3.1)	1.9 (3.1)
Pile-up effects	<1.0 (<1.0)	<1.0 (<1.0)	<1.0 (<1.0)	<1.0 (<1.0)
DY PDF choice	N/A	<1.0 (8.4)	N/A	<1.0 (1.9)
DY PDF variation	N/A	8.7 (19)	N/A	7.7 (13)
DY PDF scales	N/A	1.0 (2.0)	N/A	<1.0 (1.5)
DY α_S	N/A	1.6 (2.7)	N/A	1.4 (2.2)
DY EW corrections	N/A	2.4 (5.5)	N/A	2.1 (3.9)
DY γ-induced corrections	N/A	3.4 (7.6)	N/A	3.0 (5.4)
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 (17)	10 (17)
Isolation efficiency	9.1 (9.7)	9.1 (9.7)	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	2.6 (2.4)	2.6 (2.4)	N/A	N/A
Lepton energy scale	<1.0 (<1.0)	4.1 (6.1)	<1.0 (<1.0)	<1.0 (<1.0)
Lepton energy resolution	<1.0 (<1.0)	<1.0 (<1.0)	2.7 (2.7)	<1.0 (6.7)
Multi-jet & W+jets	N/A	10 (129)	N/A	N/A
Total	10 (11)	18 (132)	11 (18)	14 (24)

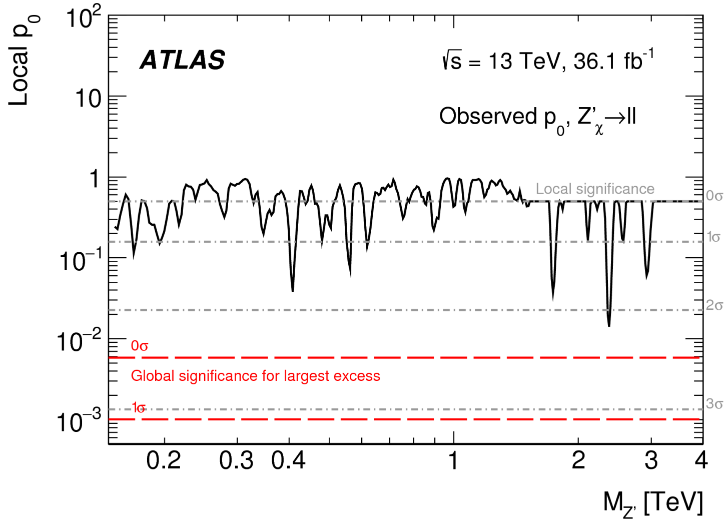
- Summary of relative systematic uncertainties in the expected number of events at dilepton masses of 2 TeV (4 TeV)
- Dominated systematic resources coming from PDF and lepton reconstruction (muon) and isolation efficiency (electron)

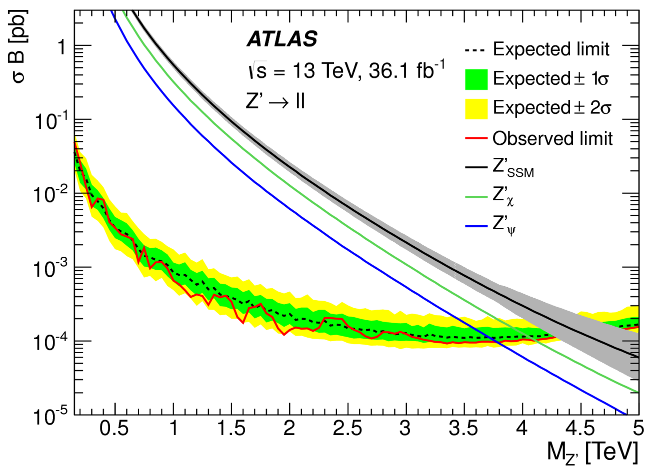
Results for Dilepton Search

- Statistical analysis:
  - ➢Log-likelihood ratio (LLR) test used for Z' signal search
  - ➢Upper limits on σB for different Z' model and lower limit on CI scale Λ are set using the Bayesian approach

JHEP 10 (2017) 182

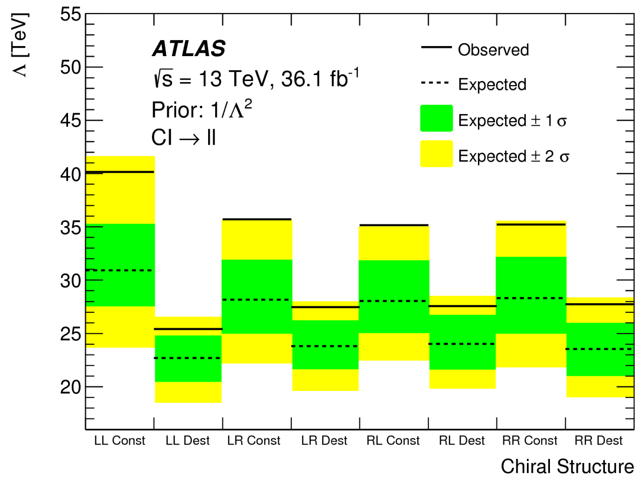
➢ P value scan using LLR test: largest deviation is observed ~2.4 TeV (global significance -0.2σ)





Lower limits on Z' mass at 95% CL

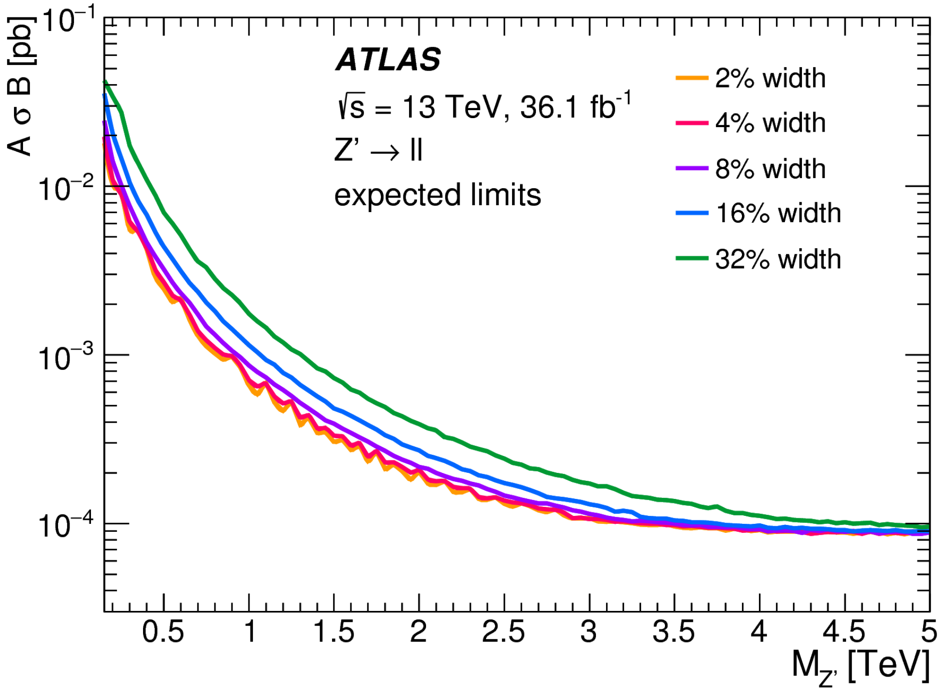
- ➢ SSM Z': 4.5 TeV
- ➢ Z'_{χ}: 4.1 TeV

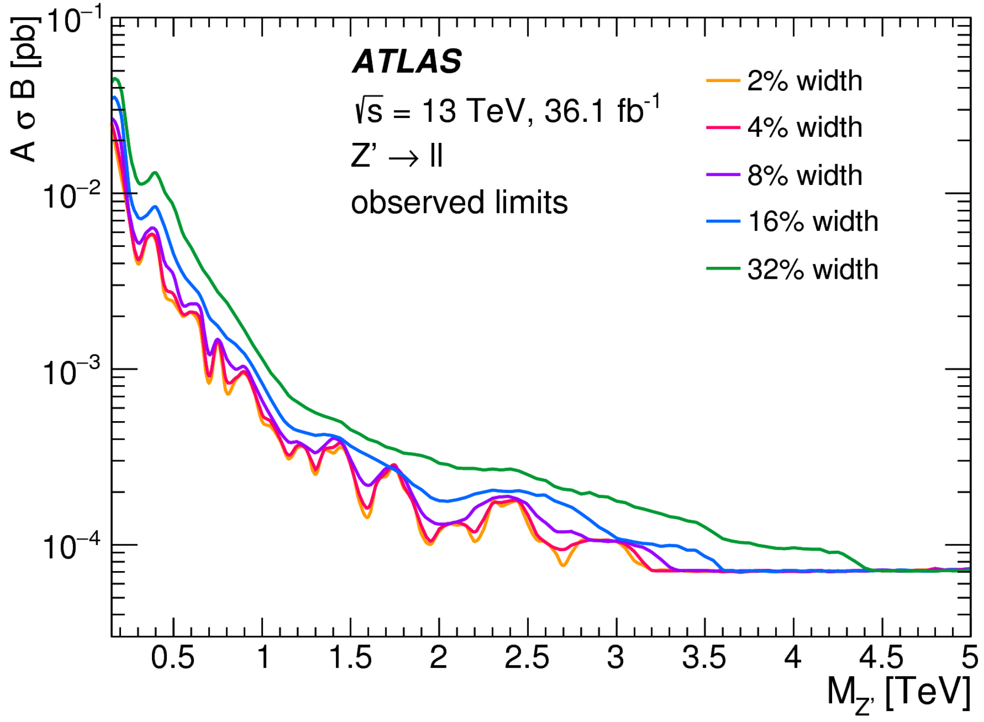


For contact interaction, limits on Λ ranging between 23.5 TeV and 40.1 TeV depending on models @ 95% CL

Generic Z' Limits

- Applying fiducial cuts to signal templates (p_T > 30 GeV, $|\eta|$ < 2.5) and a mass window of two times the signal width around signal polemass
  - ➢Parton luminosity tail and interference effect removed
  - ➢More model independent limits

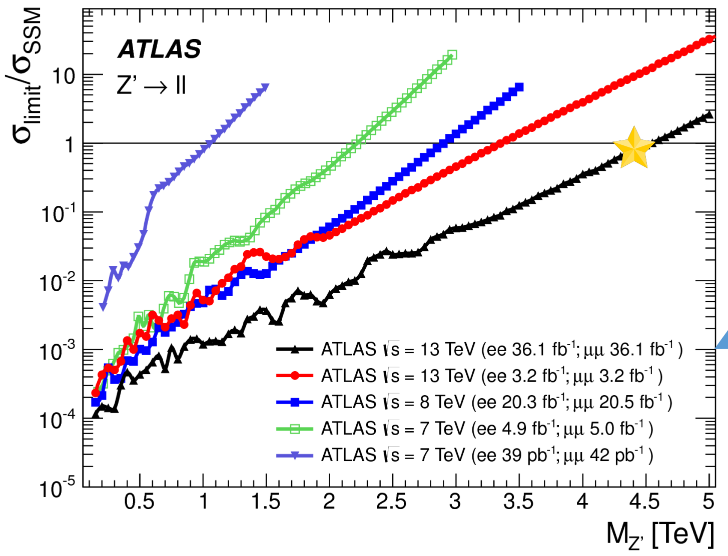




JHEP 10 (2017) 182

Summary

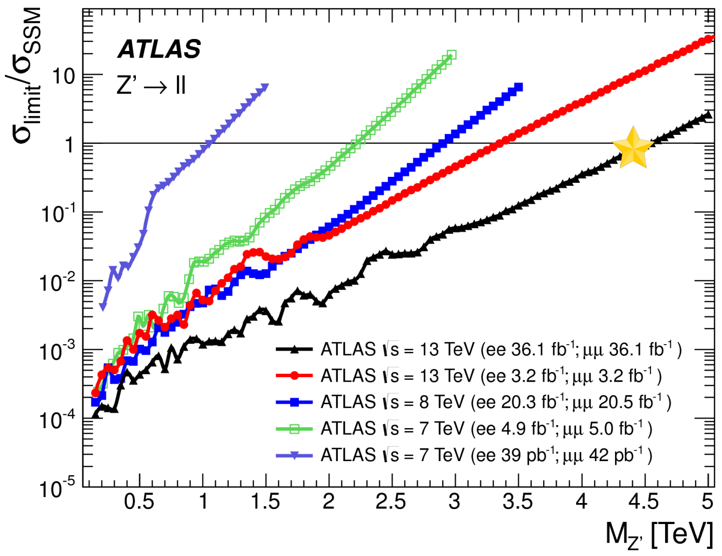
- Have presented results for new phenomena search with dilepton final state at the ATLAS experiment: the most stringent limit results up to date
  - ➢Significant improvement comparing with previous results

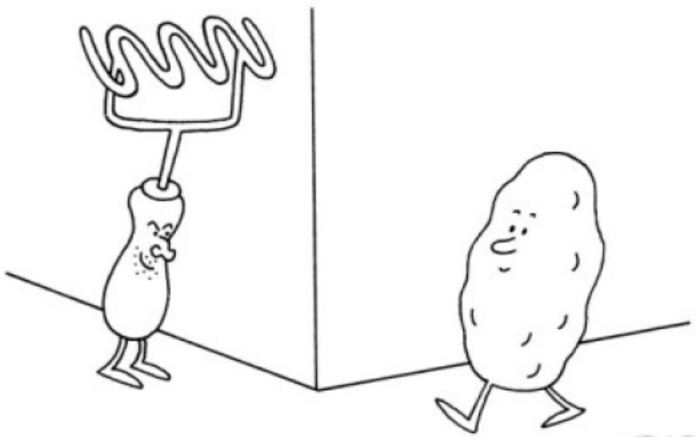


Comparisons for upper limit on signal strength (Z'_{SSM}) at 7, 8, and 13 TeV

Summary

- Have presented results for new phenomena search with dilepton final state at the ATLAS experiment: the most stringent limit results up to date
  - ➢Significant improvement comparing with previous results

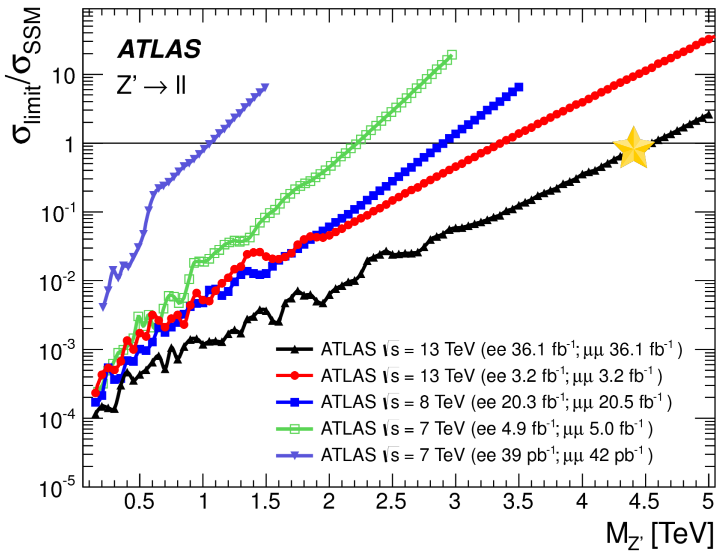


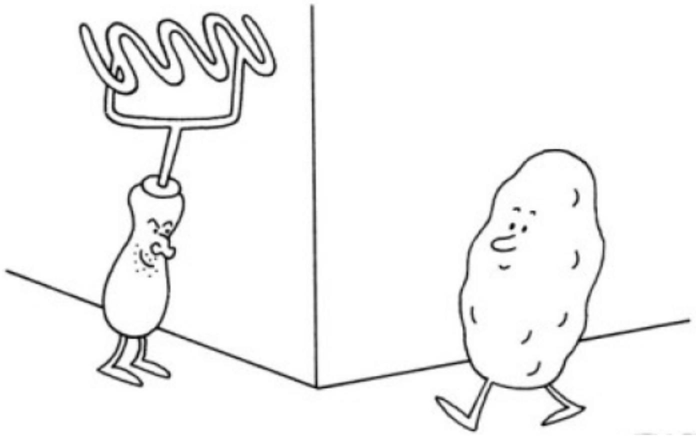


New phenomena may be just around the corner

Summary

- Have presented results for new phenomena search with dilepton final state at the ATLAS experiment: the most stringent limit results up to date
  - ➢Significant improvement comparing with previous results
- More and more data are coming and ~120 fb^{-1} will be expected by the end of 2018 (Run 2): plenty of opportunities for gaining more sensitivity and discoveries!

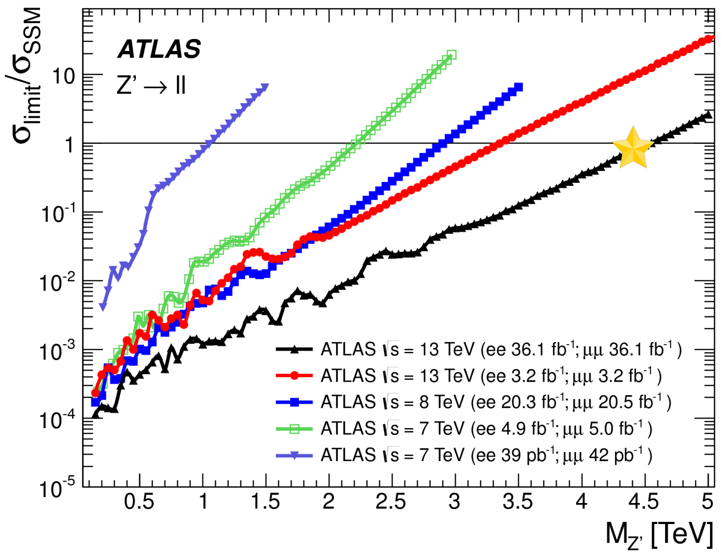


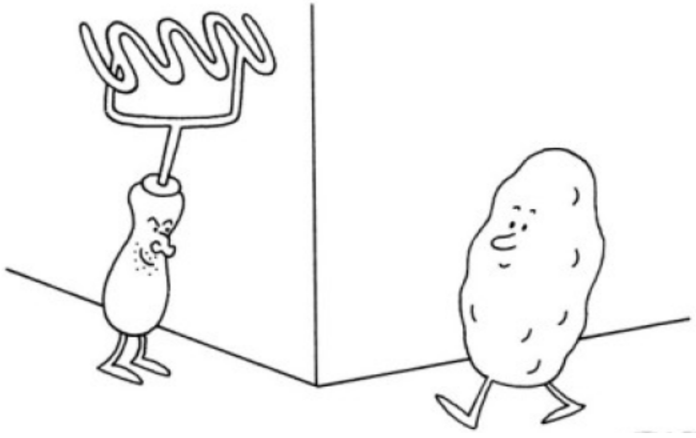


New phenomena may be just around the corner

Summary

- Have presented results for new phenomena search with dilepton final state at the ATLAS experiment: the most stringent limit results up to date
  - ➢Significant improvement comparing with previous results
- More and more data are coming and ~120 fb^{-1} will be expected by the end of 2018 (Run 2): plenty of opportunities for gaining more sensitivity and discoveries!





New phenomena may be just around the corner

Thanks!

Merry Christmas & Happy New Year!

Backup

Matrix Method

$$\begin{pmatrix} N_{\rm TT} \\ N_{\rm TL} \\ N_{\rm LT} \\ N_{\rm LL} \end{pmatrix} = \begin{pmatrix} r^2 & rf & fr & f^2 \\ r(1-r) & r(1-f) & f(1-r) & f(1-f) \\ (1-r)r & (1-r)f & (1-f)r & (1-f)f \\ (1-r)^2 & (1-r)(1-f) & (1-f)(1-r) & (1-f)^2 \end{pmatrix} \begin{pmatrix} N_{\rm RR} \\ N_{\rm RF} \\ N_{\rm FR} \\ N_{\rm FF} \end{pmatrix} \qquad (1)$$

Here the subscripts R and F refer to real electrons and fakes (jets), respectively. The subscript T refers to electrons that satisfy the nominal selection criteria. The subscript L corresponds to electrons that pass the loosened requirements described above but fail the nominal requirements.

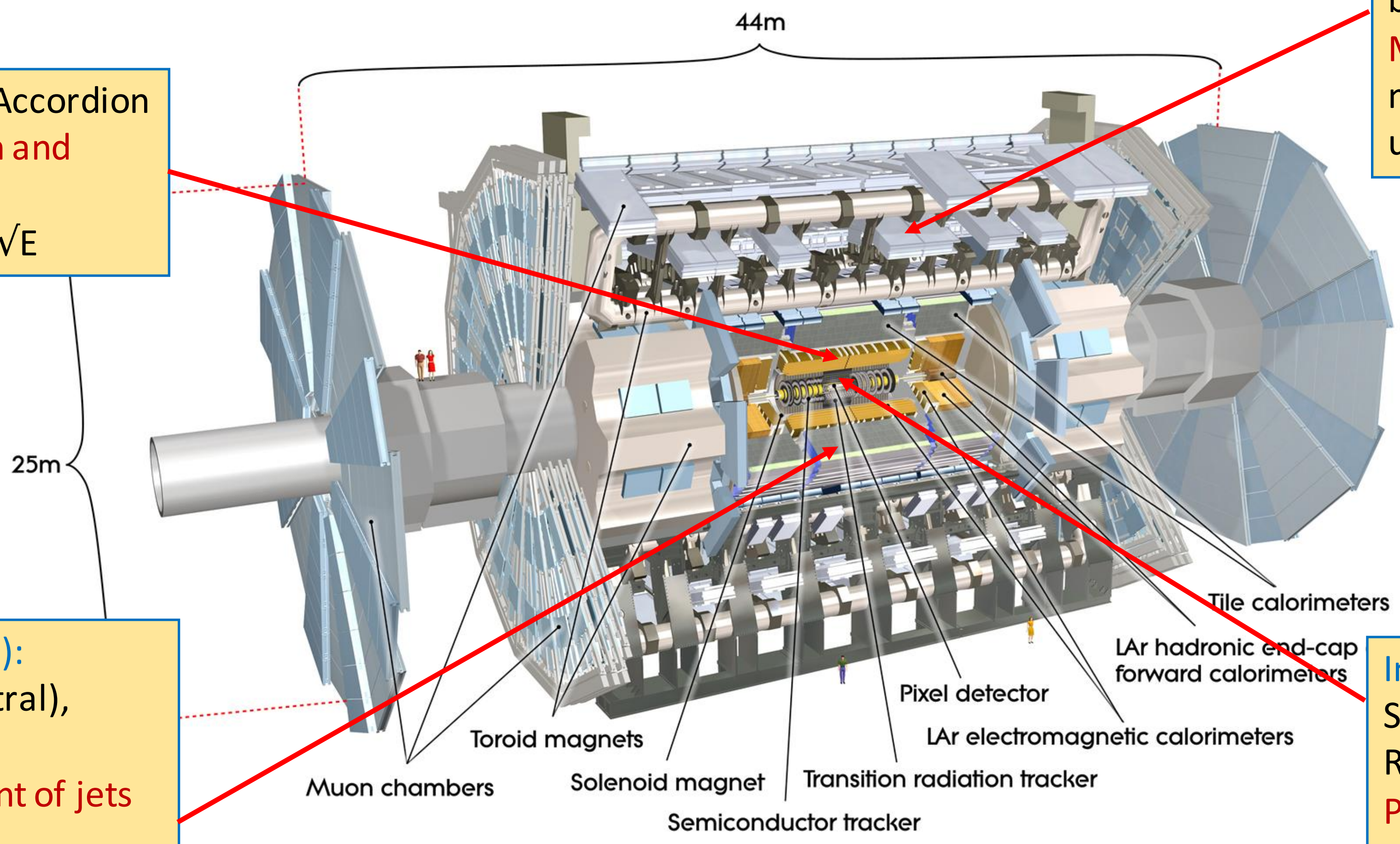
The background is given as the part of $N_{\rm TT}$ that originates from a pair of objects with at least one fake electron:

$$N^{\text{Multi-jet \& W+jets}} = rf(N_{\rm RF} + N_{\rm FR}) + f^2 N_{\rm FF} \qquad (2)$$

The true paired objects on the right-hand side of Eq. (2) can be expressed in terms of measureable quantities ($N_{\rm TT}, N_{\rm TL}, N_{\rm LT}, N_{\rm LL}$) by inverting the matrix in Eq. (1).

The ATLAS Detector

EM calorimeter: Pb-LAr Accordion
e/γ trigger, identification and measurement
E-resolution: $\sigma/E \sim 10\%/\sqrt{E}$

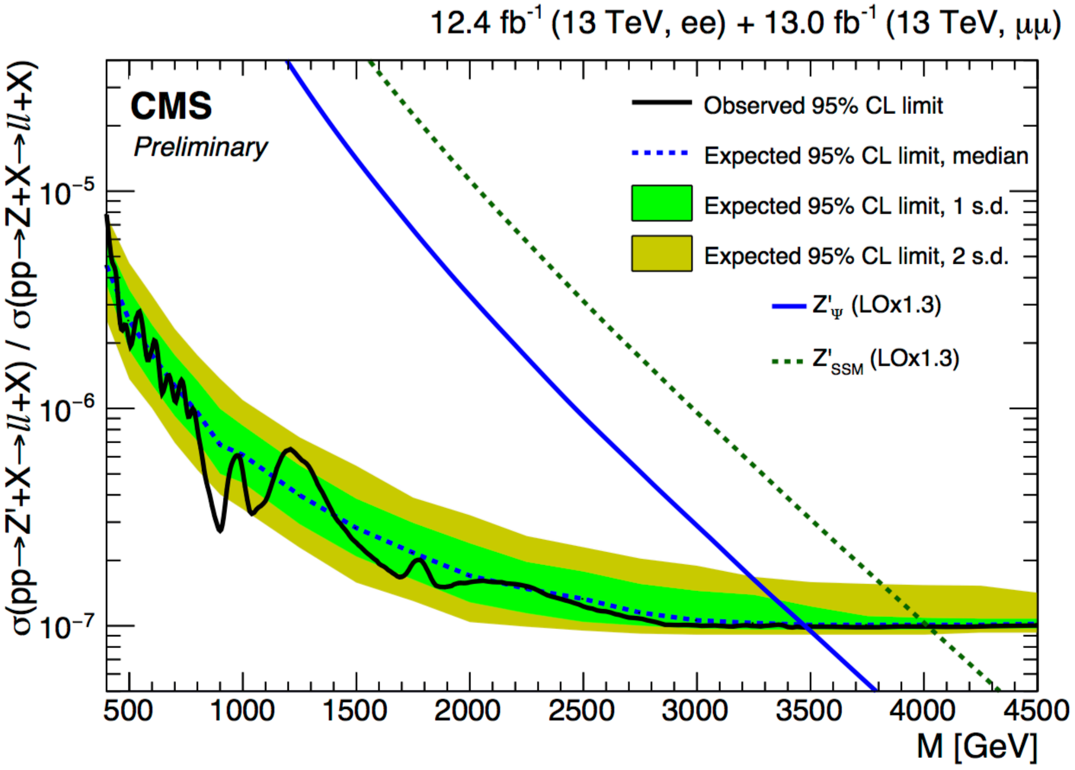


Muon Spectrometer ($|\eta|<2.7$) :
air-core toroids (B ~ 0.5 / 1T in barrel/ end-cap)
Muon trigger and tracking with momentum resolution < 10% up to 1 TeV

HAD calorimeter ($|\eta|<5$):
Fe/scintillator Tiles (central), Cu/W-LAr (fwd)
Trigger and measurement of jets and missing E_T
E-resolution: $\sigma/E \sim 50\%/\sqrt{E} \oplus 0.03$

Inner Detector ($|\eta|<2.5$, B=2T):
Si Pixels, Si strips, Transition Radiation detector (straws)
Precise tracking and vertexing, e/π separation
Momentum resolution:
$\sigma/p_T \sim 3.8\text{x}10^{-4}\ p_T\,(\text{GeV}) \oplus 0.015$

CMS Results



- $L = 13.0\ fb^{-1}$
- SSM Z': 4.0 TeV
- Z'_{ψ}: 3.5 TeV