Yet another statistically insignificant hint of New Physics

or

ZZ cross section measurement with 4.6 fb^{-1} of 7 TeV ATLAS data

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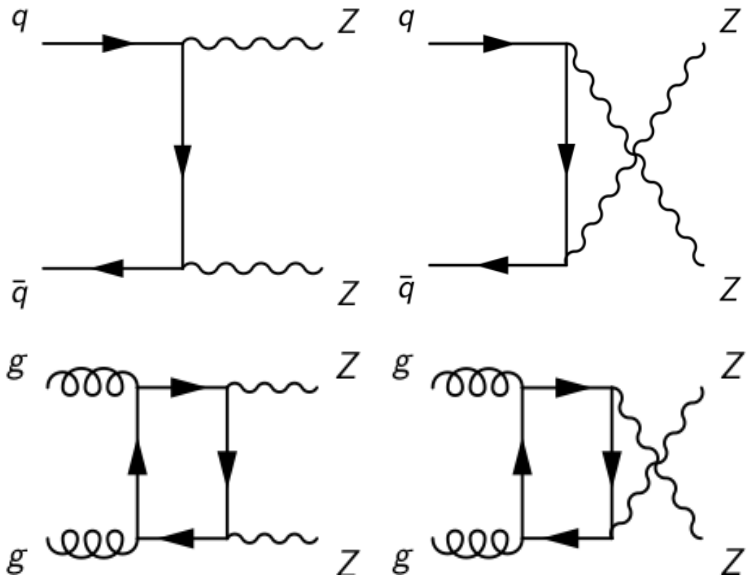
arxiv:1211.6096, submitted to JHEP

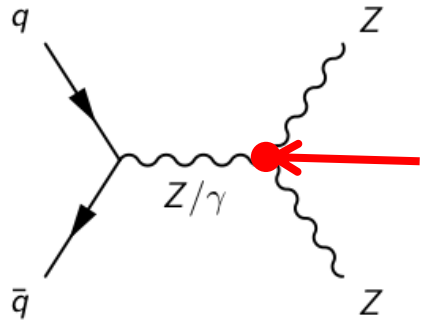
Motivation



Tests electroweak physics

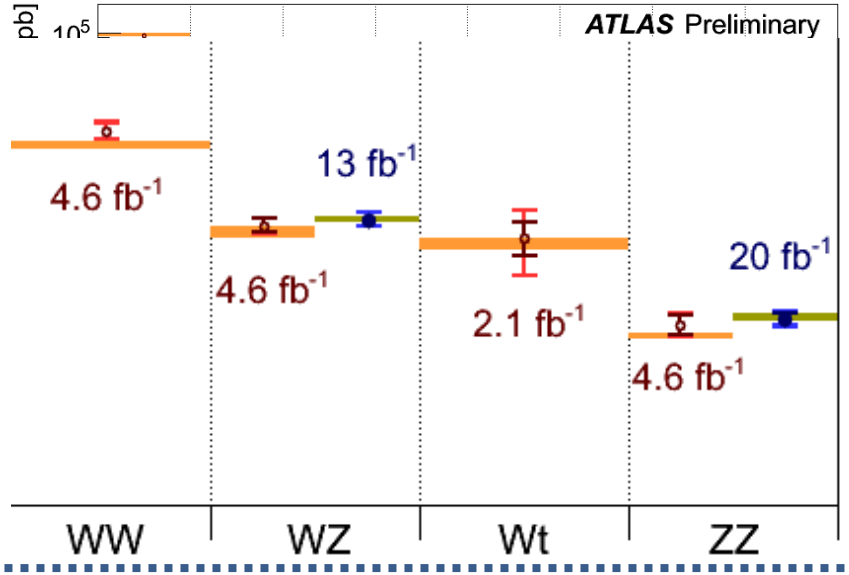
Background to Higgs search

Set limits on anomalous triple gauge couplings (aTGC)

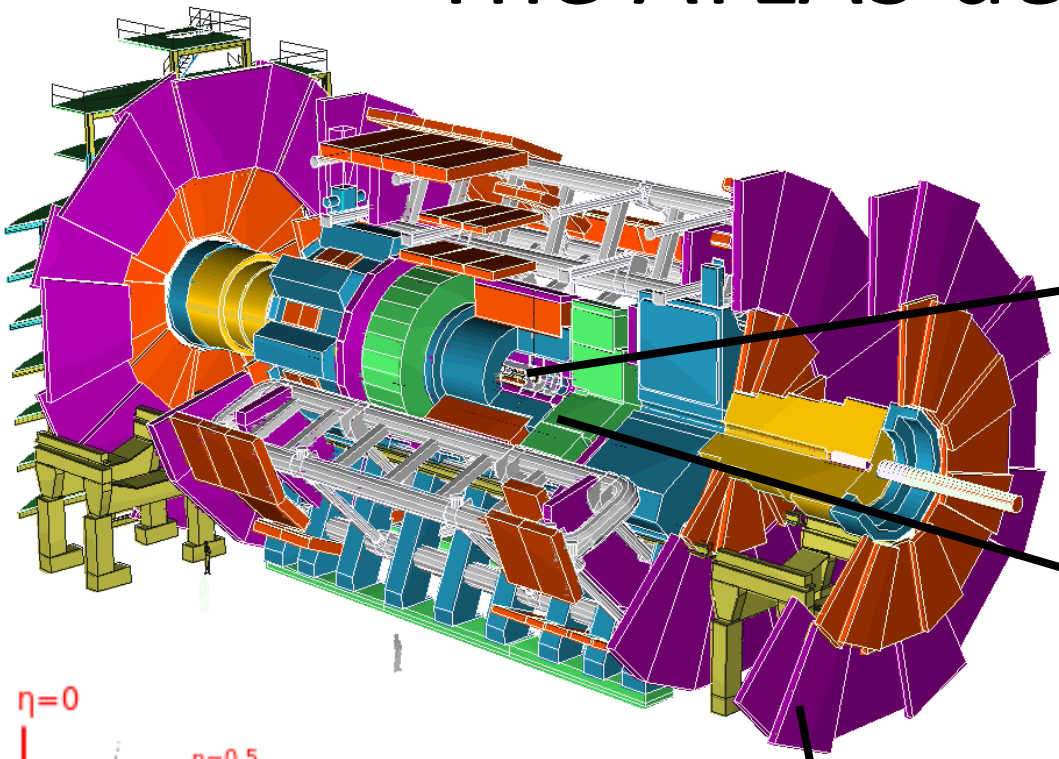


neutral TGCs not in SM

ATLAS diboson x-sections measured high at 7 TeV



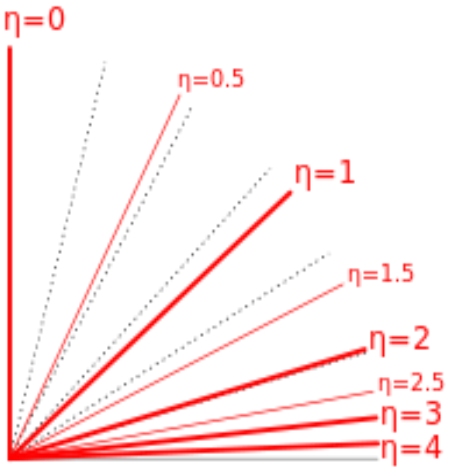
The ATLAS detector



Inner detector
- within solenoid magnet
- pixels for vertex location
- silicon detector tracks

charged particles
- $|\eta| < 2.5$

EM & hadronic calorimeters
- measures energy deposited
- $|\eta| < 4.9$



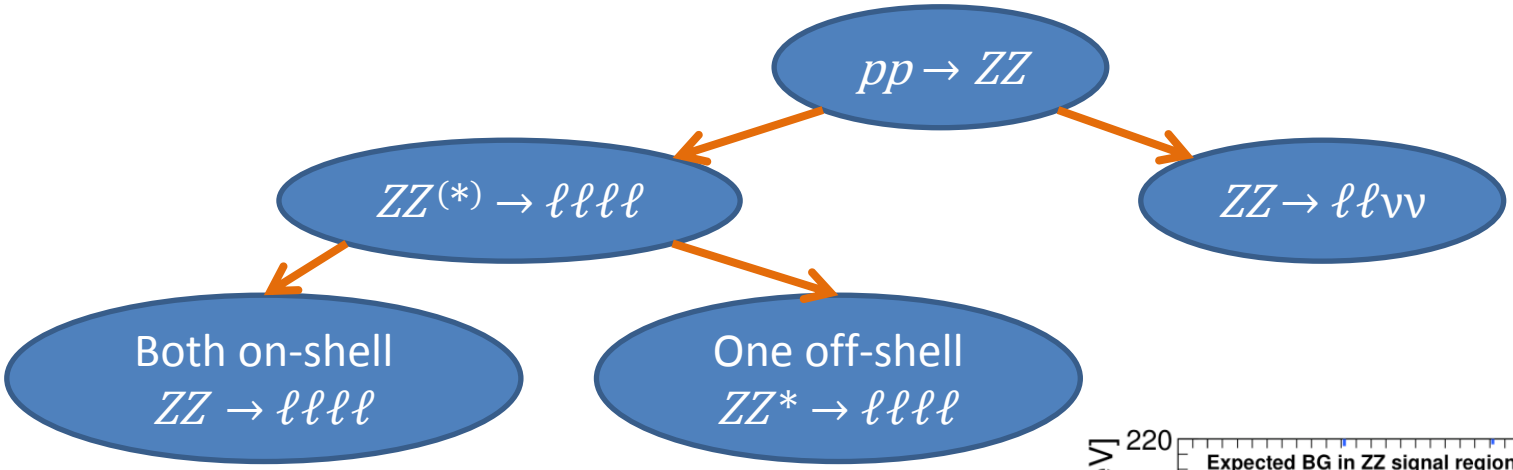
$\eta = - \ln \tan(\theta/2)$

Muon spectrometer
- toroidal magnet
- tracks muons
- $|\eta| < 2.7$

3-level trigger system

Level	Rate
Initial	40 MHz
L1	100 kHz
L2	3 kHz
L3	200 Hz

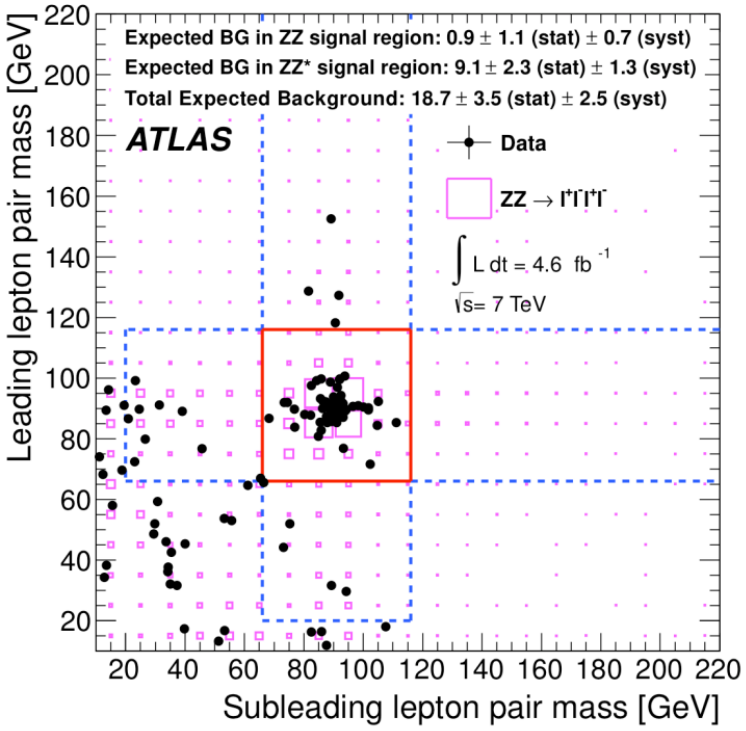
Analysis overview



Identification of *Z* bosons

Channel	Classification	m_{ll}
$ZZ \to \ell\ell\ell\ell$	On-shell	66 – 116 GeV
	Off-shell	> 20 GeV
$ZZ \to \ell\ell\nu\nu$		76 – 106 GeV

Resolve ambiguous cases by selecting the combination that minimises the sum of $|m_{ll} - m_Z|$ for the two pairs

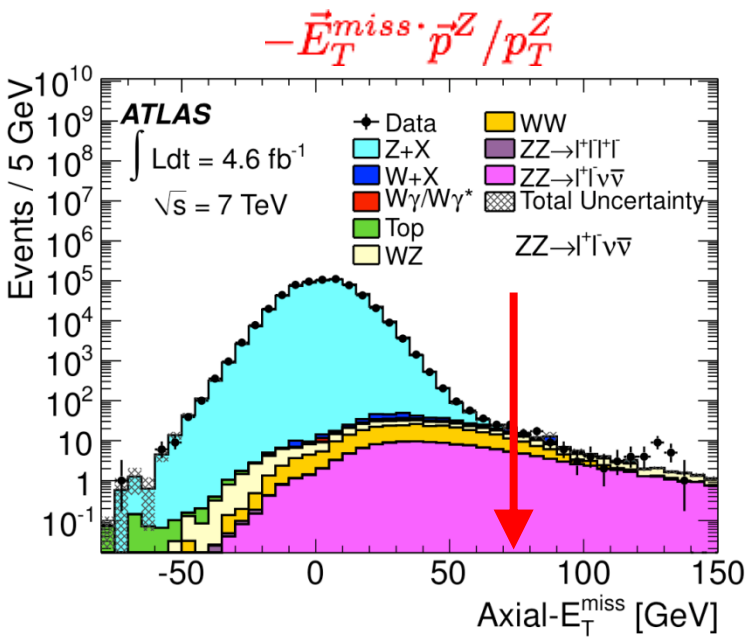


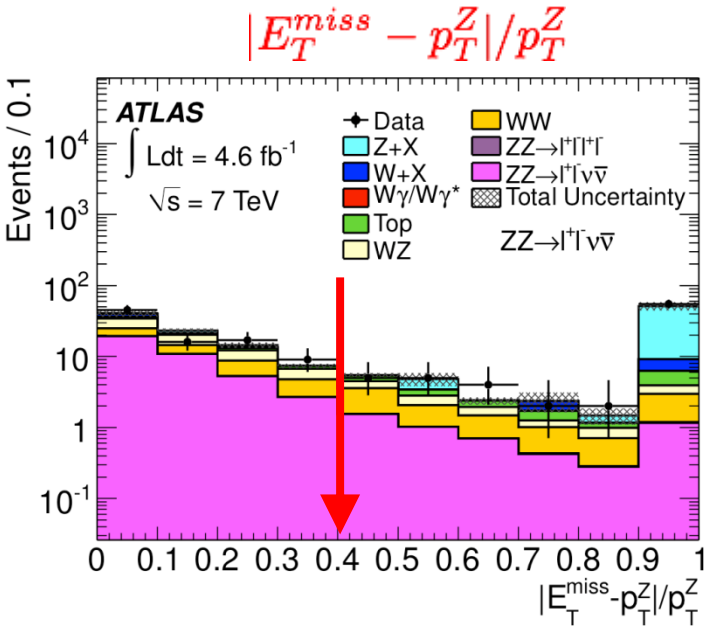
$ZZ^{(*)} \to \ell\ell\ell\ell$ event selection

- pass electron or muon trigger
- exactly 4 isolated leptons with $p_T > 7$ GeV
  - $e^+e^-e^+e^-$, $\mu^+\mu^-\mu^+\mu^-$, $e^+e^-\mu^+\mu^-$
- require at least one muon with $p_T > 20$ GeV **or** electron with $p_T > 25$ GeV
- each same-flavour, opposite-charge dilepton system forms a *Z* candidate
- events sorted into *ZZ* and *ZZ** categories

ZZ → $\ell\ell\nu\nu$ event selection

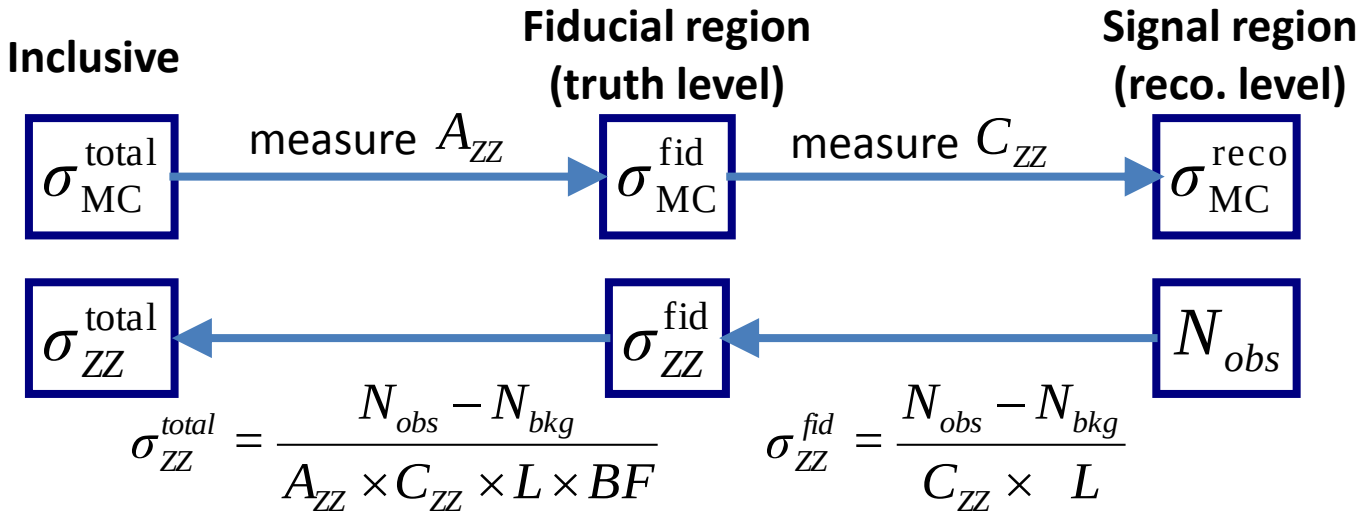
- pass electron or muon trigger
- exactly 2 isolated leptons with p_T > 20 GeV: e^+e^-, $\mu^+\mu^-$
- *Z* candidate in mass window
- veto event if jet p_T > 25 GeV (reduce top background)
- discriminating MET variables to reduce *Z*+jets bkg:





How to get an inclusive σ from data

- σ^{fid} – cross section measured within a restricted (kinematic and geometric) phase space
- σ^{total} – cross section extrapolated to total phase space

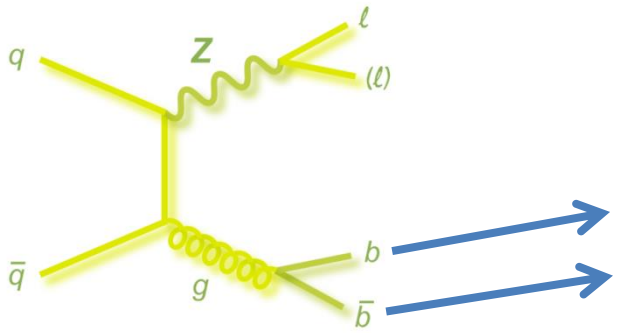


Systematic uncertainties

Source	$ZZ \to \ell^+\ell^-\ell'^+\ell'^-$	$ZZ^* \to \ell^+\ell^-\ell'^+\ell'^-$	$ZZ \to \ell^+\ell^-\nu\bar{\nu}$
	C_{ZZ}		
Lepton efficiency	3.0%	3.1%	1.3%
Lepton energy/momentum	0.2%	0.3%	1.1%
Lepton isolation and impact parameter	1.9%	2.0%	0.6%
Jet+$E_{\mathrm{T}}^{\mathrm{miss}}$ modelling	–	–	0.8%
Jet veto	–	–	0.9%
Trigger efficiency	0.2%	0.2%	0.4%
PDF and scale	1.6%	1.5%	0.4%
	A_{ZZ}		
Jet veto	–	–	2.3%
PDF and scale	0.6%	–	1.9%
Generator modelling and parton shower	1.1%	–	4.6%

But how do we obtain N_{bkg}?

Backgrounds to $ZZ^{(*)} \to \ell\ell\ell\ell$



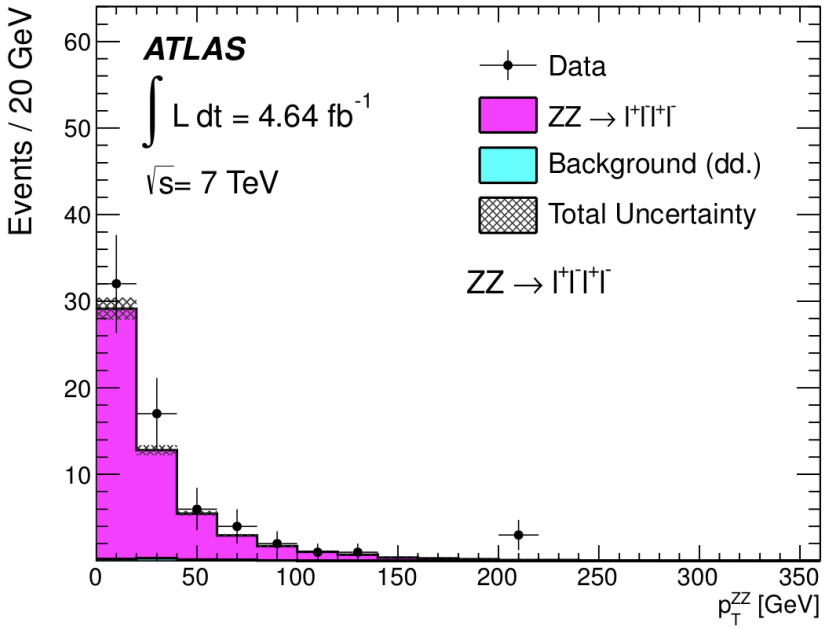
Leptons from HF decay can pass ID cuts

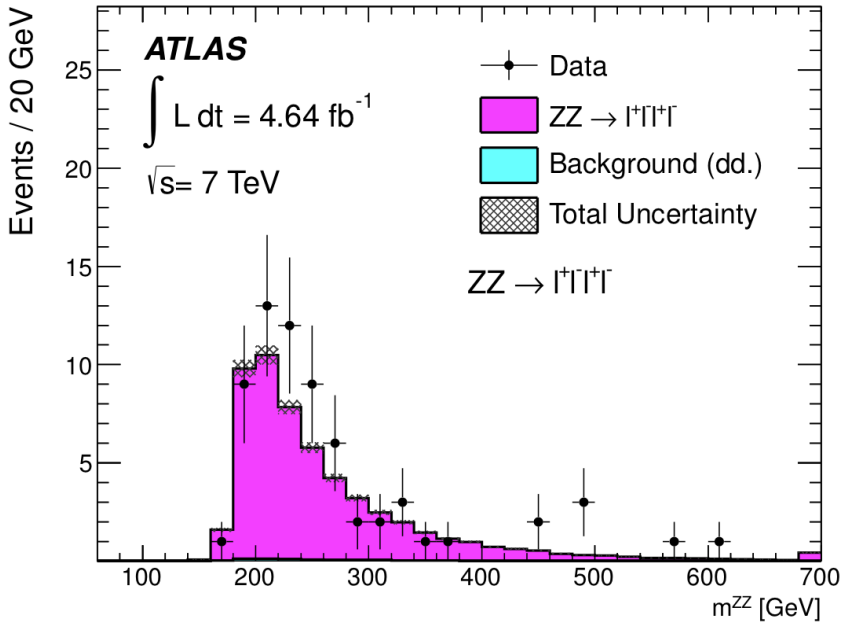
Other mis-ID sources:
- leptons from π^0, K decay
- jets misidentified as leptons

- give rise to "lepton-like jets" (lepton candidates failing isolation criteria)
- background: $\ell\ell\ell j$ and $\ell\ell jj$ with mis-ID jet(s)
- define $f = \frac{P(\text{ID lepton} \mid \text{lepton-like jet})}{P(\text{ID lepton-like jet} \mid \text{lepton-like jet})}$
- measure f based on lepton-like jets in a sample of Z+jets in data/MC in bins of p_T
- total number of expected background events:

$$N(\text{BG}) = [N(\ell\ell\ell j) - N(ZZ)] \times f - N(\ell\ell jj) \times f^2$$

Backgrounds to $ZZ^{(*)} \to \ell\ell\ell\ell$



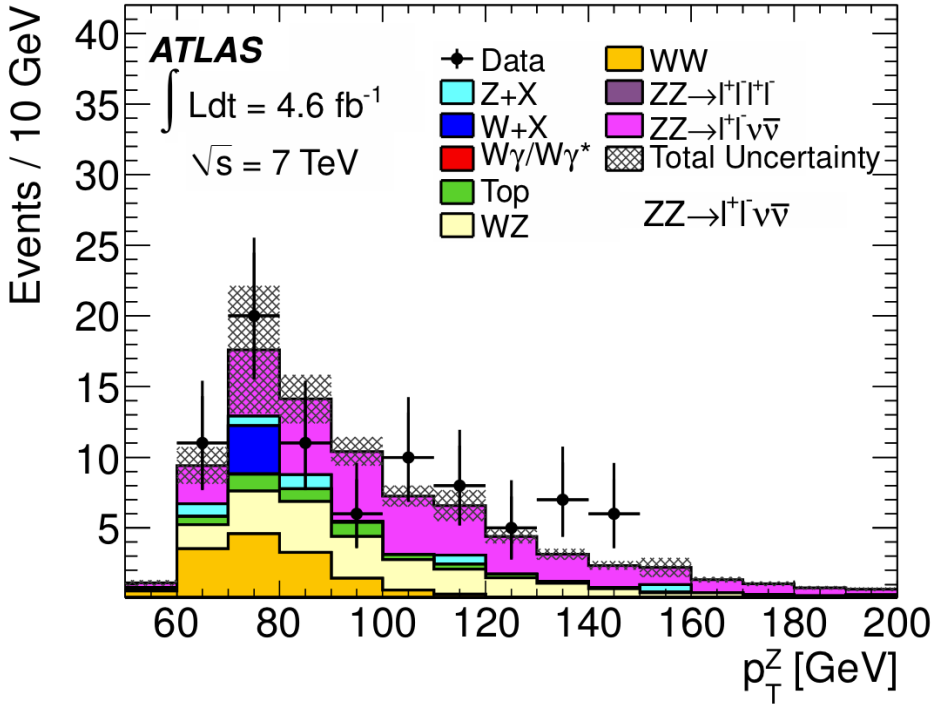


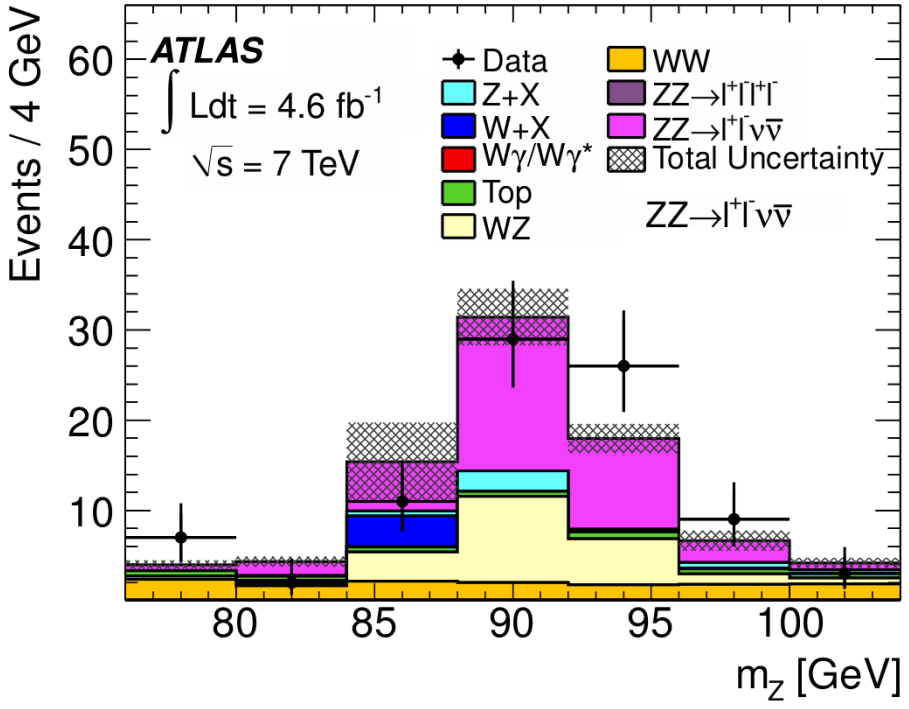
Expected number of background events < 1 for $ZZ \to \ell\ell\ell\ell$

Backgrounds to $ZZ \to \ell\ell\nu\nu$

- ***tt*, *WW*, *Wt* and $Z \to \tau\tau$**
  - two true isolated leptons with missing p_T
    - extrapolate from a control sample of $e\mu$ events
- ***WZ***
  - 3 lepton final state, but one lepton is not identified
    - estimated using MC
    - validated using a control region of 3 high-p_T leptons
- ***Z*+jets**
  - may have missing p_T due to mis-measurement of jet p_T
    - estimated using high-p_T γ+jets events
- ***Z*+jets, *W*+jets, *Zγ*, *Wγ***
  - jet or γ mis-identified as lepton
    - use the "matrix method" to estimate the fraction of events in the signal region containing at least one fake lepton

Backgrounds to $ZZ \to \ell\ell\nu\nu$





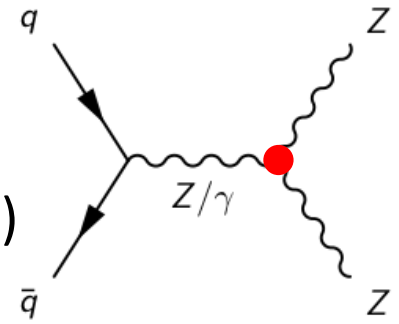
Distributions in signal region using background estimations in previous slide

Cross section results

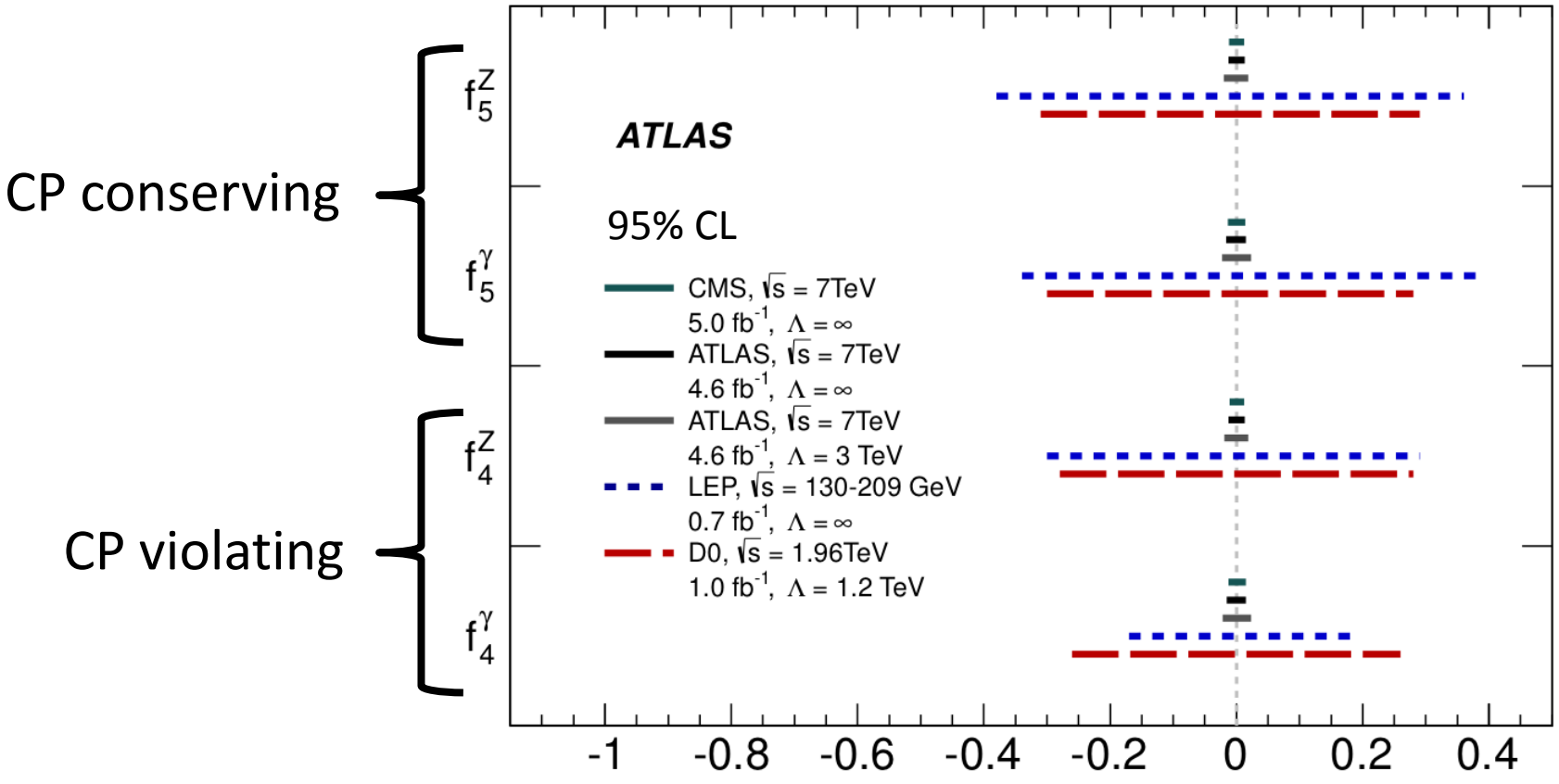
- maximum likelihood fitting method
- treat systematics as nuisance parameters
- single Gaussian across channels for correlated uncertainties

	Measured (fb)	NLO prediction (fb)
$\sigma^{\text{fid}}_{ZZ\to l^+l^-l'^+l'^-}$	$25.4^{+3.3}_{-3.0}(\text{stat})^{+1.2}_{-1.0}(\text{syst})\pm 1.0(\text{lumi})$	$20.9\pm 0.1(\text{stat})^{+1.1}_{-0.9}(\text{theory})$
$\sigma^{\text{fid}}_{ZZ^*\to l^+l^-l'^+l'^-}$	$29.8^{+3.8}_{-3.5}(\text{stat})^{+1.7}_{-1.5}(\text{syst})\pm 1.2(\text{lumi})$	$25.6\pm 0.1(\text{stat})^{+1.3}_{-1.1}(\text{theory})$
$\sigma^{\text{fid}}_{ZZ\to l^+l^-\nu\bar{\nu}}$	$12.7^{+3.1}_{-2.9}(\text{stat})^{+1.7}_{-1.7}(\text{syst})\pm 0.5(\text{lumi})$	$12.5\pm 0.1(\text{stat})^{+1.0}_{-1.1}(\text{theory})$
$\sigma^{\text{total}}_{ZZ}$	$6.7\pm 0.7(\text{stat})^{+0.4}_{-0.3}(\text{syst})\pm 0.3(\text{lumi})$ pb	$5.89^{+0.22}_{-0.18}(\text{theory})$ pb

aTGC limits

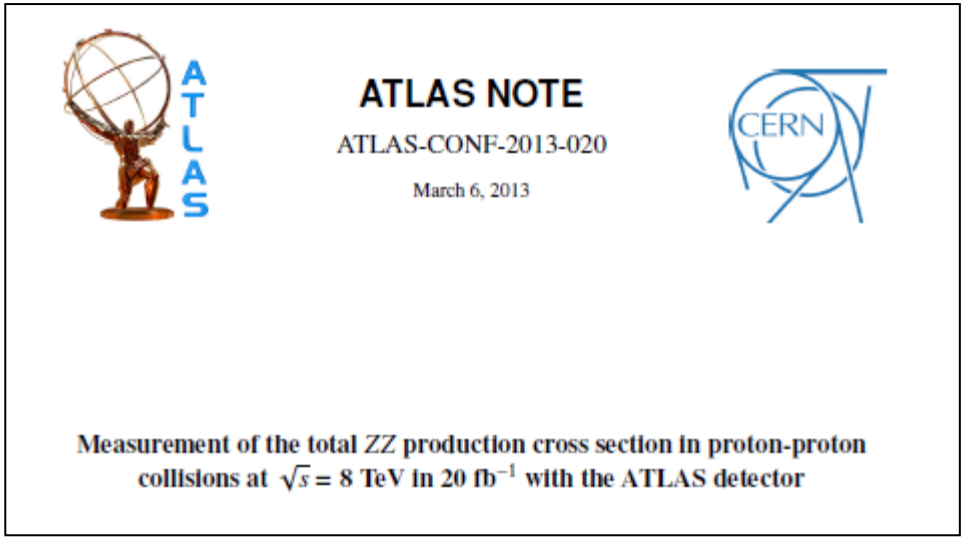


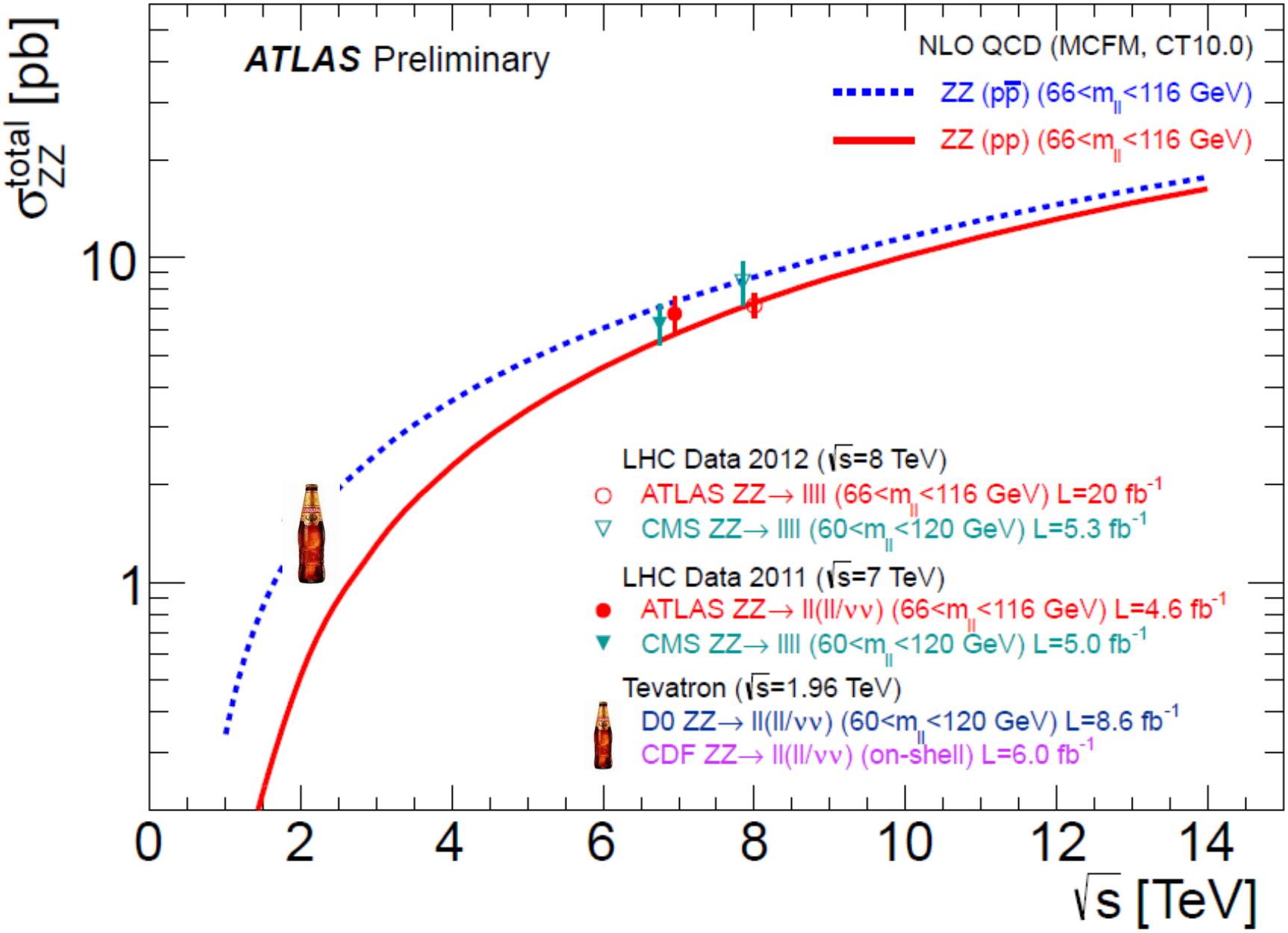
- aTGCs described by 4 parameters f^V_i (with f^V_i = 0 in SM)
- aTGCs produce longer tail in p_T^Z spectrum
- fit p_T^Z distribution
- limits set using maximum profile likelihood ratio



Conclusions

- total and fiducial *ZZ* cross sections measured with full 2011 dataset
- used $ZZ^{(*)} \rightarrow \ell\ell\ell\ell$ and $ZZ \rightarrow \ell\ell\nu\nu$ decay channels
- statistically consistent with SM NLO prediction, although measured value is slightly higher
  - analysis recently performed in 4ℓ channel with 20 fb^{-1} of 8TeV data: ATLAS-CONF-2013-020




ATLAS Preliminary
NLO QCD (MCFM, CT10.0)
ZZ (pp̄) (66<m_ll<116 GeV)
ZZ (pp) (66<m_ll<116 GeV)
LHC Data 2012 (√s=8 TeV)
ATLAS ZZ→ llll (66<m_ll<116 GeV) L=20 fb^-1
CMS ZZ→ llll (60<m_ll<120 GeV) L=5.3 fb^-1
LHC Data 2011 (√s=7 TeV)
ATLAS ZZ→ ll(ll/νν) (66<m_ll<116 GeV) L=4.6 fb^-1
CMS ZZ→ llll (60<m_ll<120 GeV) L=5.0 fb^-1
Tevatron (√s=1.96 TeV)
D0 ZZ→ ll(ll/νν) (60<m_ll<120 GeV) L=8.6 fb^-1
CDF ZZ→ ll(ll/νν) (on-shell) L=6.0 fb^-1
σ^total_ZZ [pb]
10
1
0
2
4
6
8
10
12
14
√s [TeV]

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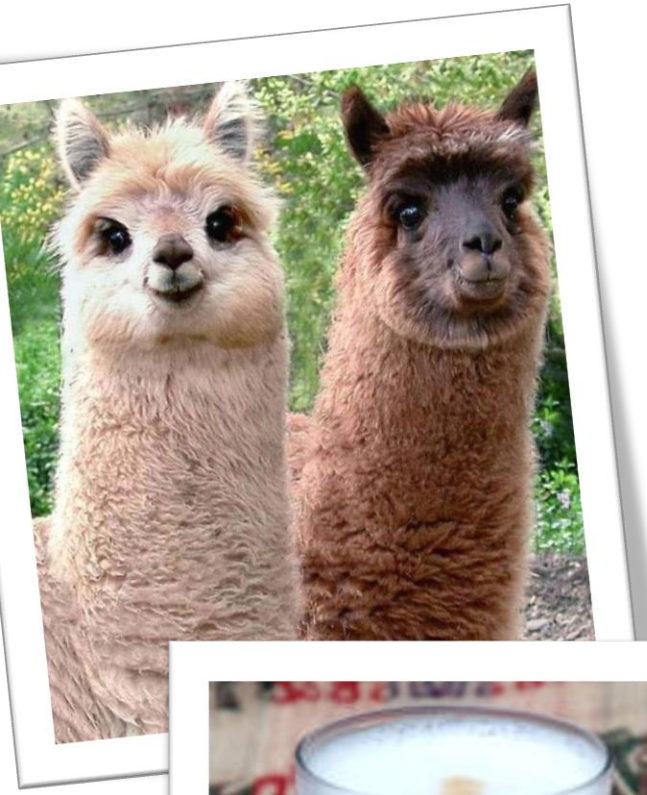

Backup slides