Higgs-related SM Measurements at ATLAS

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2nd MCTP Spring Symposium on Higgs Boson Physics
April 19, 2012

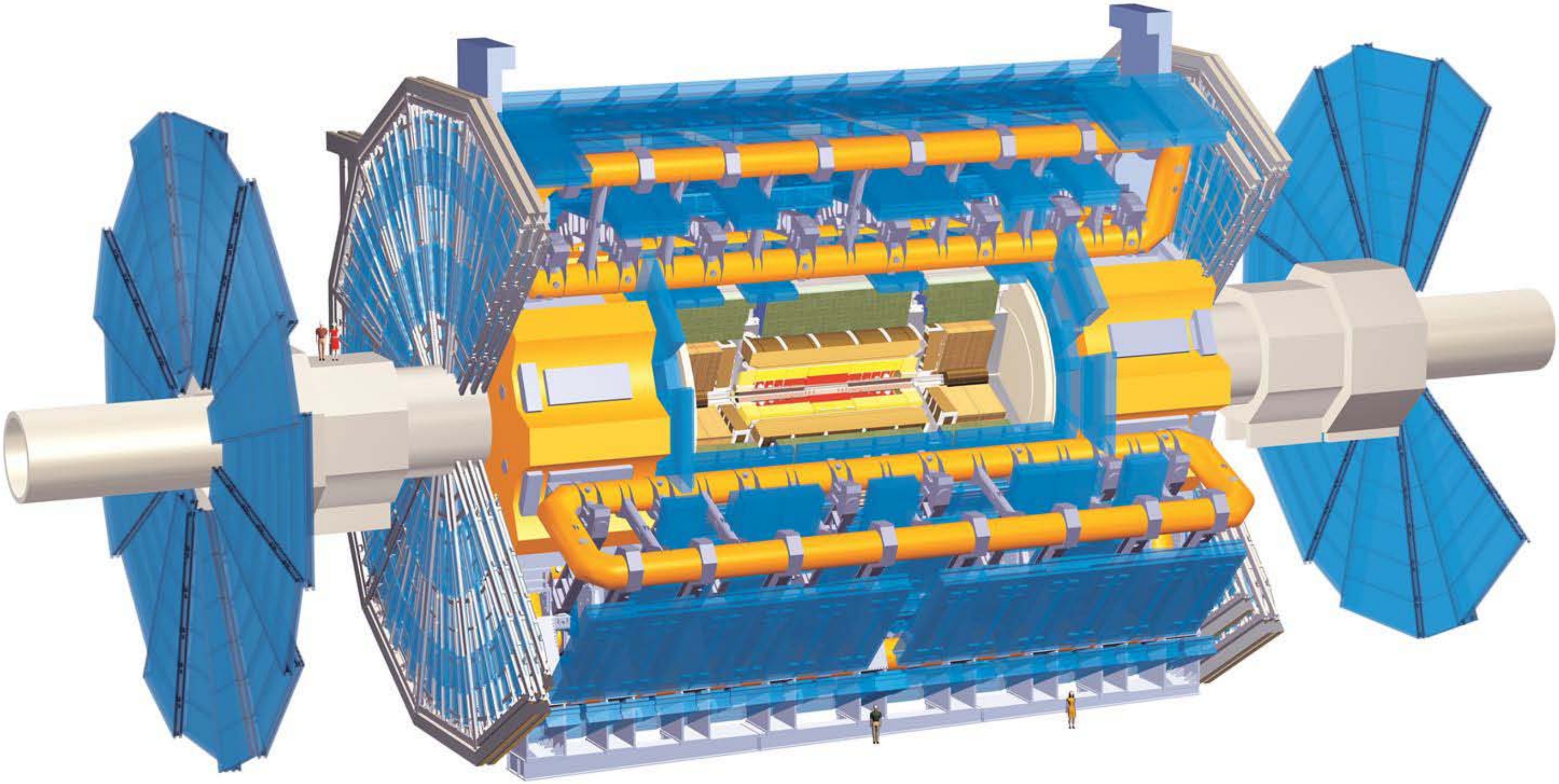
Outline

- Introduction
- Isolated $\gamma\gamma$ cross section (37 pb^{-1}, Phys. Rev. D 85, 012003 (2012))
- $WW \rightarrow l\nu l\nu$ cross section measurement (4.7 fb^{-1}, ATLAS-CONF-2012-025)
- $ZZ \rightarrow llll$ cross section measurement (4.7 fb^{-1}, ATLAS-CONF-2012-026)
- $ZZ \rightarrow ll\nu\nu$ cross section measurement (4.7 fb^{-1}, ATLAS-CONF-2012-027)
- Conclusions

Introduction

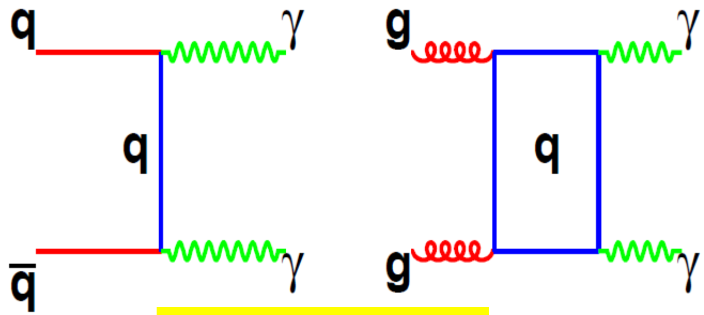
- Importance of Higgs-related SM Measurements:
- Precise measurements of inclusive and differential cross sections
- Validation of SM predictions
- Constraints on anomalous triple gauge couplings
- Major backgrounds for SM Higgs and other new physics searches
- Important for measurements of Higgs properties if it does exist

The ATLAS Detector

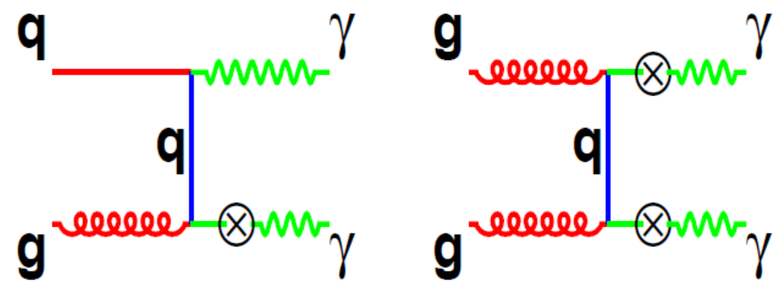


Prompt $\gamma\gamma$ Production at Hadron Colliders

- Prompt $\gamma\gamma$ production at hadron collider via QCD interactions:

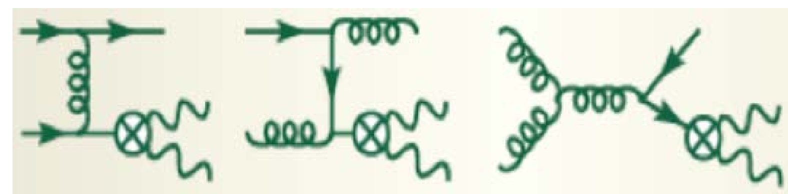


"Direct" photon



Single photon fragmentation

- gg scattering: despite $O(\alpha_S^2)$ suppression relative to qqbar process, the large gluon luminosity can make this contribution sizable in particular kinematic regions
- Several sources of enhancement corrections: ISR, FSR, other possible small-x logs (resummation)
- Fragmentation contributions can be suppressed via experimental photon isolation requirement and $p_T(\gamma\gamma)<M(\gamma\gamma)$



Double photon fragmentation (not included In any theoretical predictions)

Low mass and small angle $\gamma\gamma$ pairs

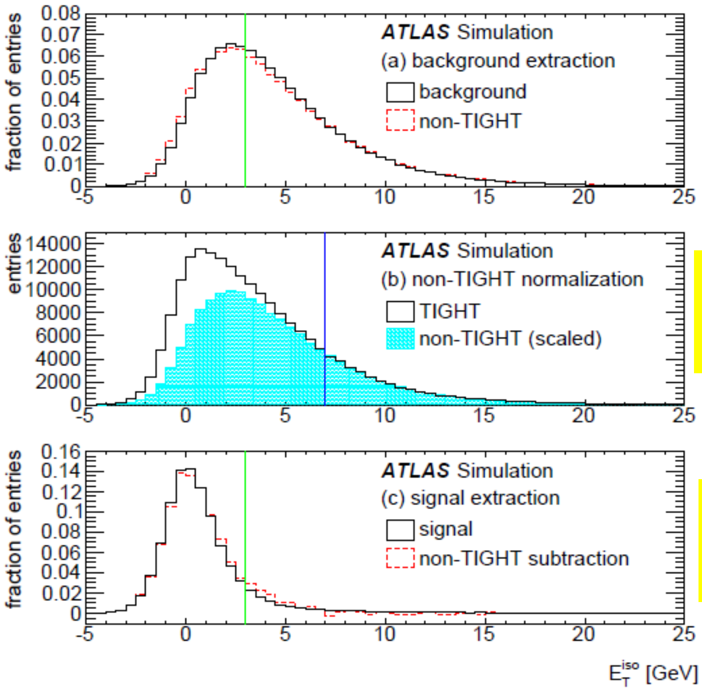
$\gamma\gamma$: Theoretical Predictions

- PYTHIA
  - $qq \to \gamma\gamma$ and $gg \to \gamma\gamma$ matrix elements
  - All orders resummation to LL accuracy via parton shower
  - No fragmentation contributions included
- DIPHOX
  - Fixed-order NLO calculation (except for $gg \to \gamma\gamma$ which is at LO)
  - No resummation: usually avoid divergence by requiring asymmetric cut $p_T(\gamma_1)-p_T(\gamma_2)>0$
  - Single-photon fragmentation (to NLO) included
- RESBOS
  - All-order resummation (to NNLL accuracy) matched to NLO
  - Single photon fragmentation included via parameterization that approximates rate predicted by NLO fragmentation functions
- Partonic isolation applied
- PYTHIA/DIPHOX/RESBOS predictions need to be corrected for non-perturbative effects: underlying event and hadronization

$\gamma\gamma$: Photon Identification

- Seeded by a cluster in the EM calorimeter
  - Unconverted γ: no tracks pointing to the cluster
  - Converted γ: one or two tracks associated to the cluster
- Cut on f_{EM}, narrow shower width, no second significant maximum in the 1st ECAL layer (high granularity strips in η), shower shape in the 2nd ECAL layer
- Reconstruction efficiency: 80-85% (barrel) and 70% (endcap)
- Photon isolation: E_T(iso) < 3 GeV within cone R<0.4
- E_T(iso) is used to estimate the contribution from jet background

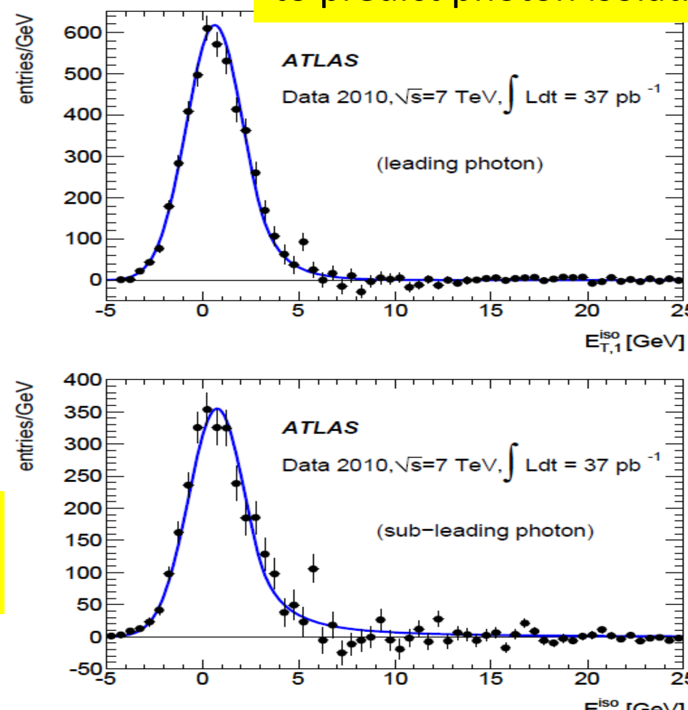
Use electron isolation to predict photon isolation



dijet MC

E_T(iso)>7GeV for normalization

Signal vs jet-like photon subtraction

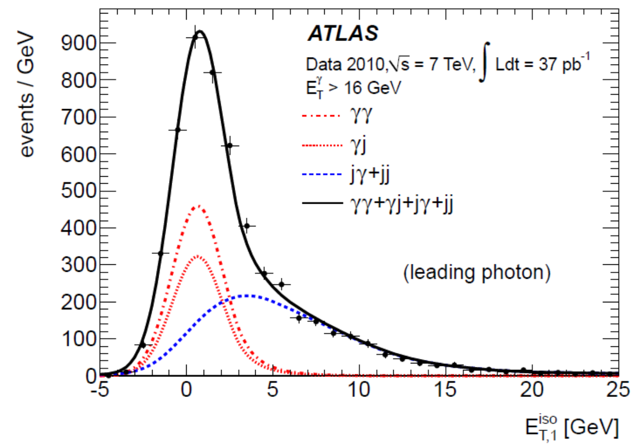


$\gamma\gamma$: Subtracting Backgrounds

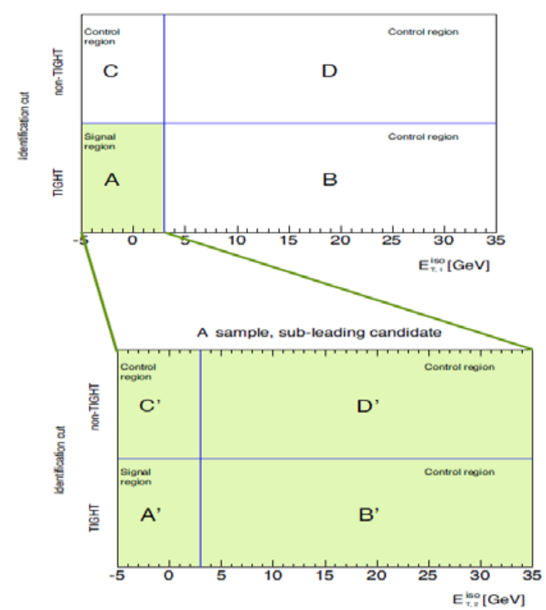
- 4x4 matrix method: classify events into 4 categories (PP/PF/FP/FF) using photon isolation cut (E_T(iso)<3 GeV) and construct an efficiency matrix E (ε: 80-95%, f: 20-40%)

$$\begin{pmatrix} S_{PP} \\ S_{PF} \\ S_{FP} \\ S_{FF} \end{pmatrix} = \mathbf{E} \begin{pmatrix} W_{\gamma\gamma} \\ W_{\gamma j} \\ W_{j\gamma} \\ W_{jj} \end{pmatrix}$$

- 2D isolation template fits [E_T(iso1) vs E_T(iso2)]: isolation templates for γγ, γj and jj events are built from data (using electron extrapolations and non-tight control sample)

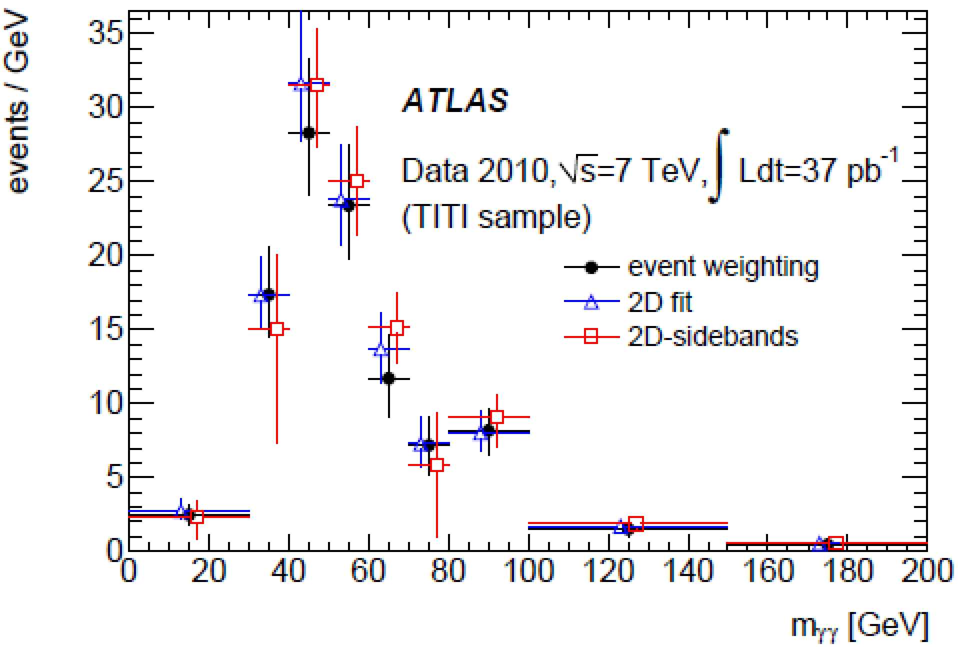


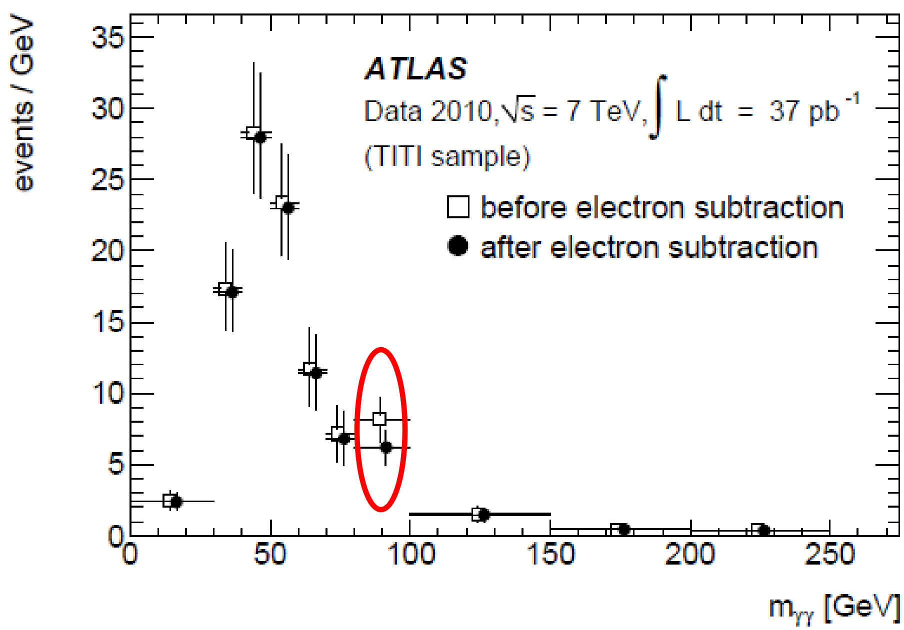
- 2D sideband method for the case of two photon candidates: for events with the leading candidate in A region, a second 2D matrix is used for the second candidate



$\gamma\gamma$: Extracting the Signal Yield

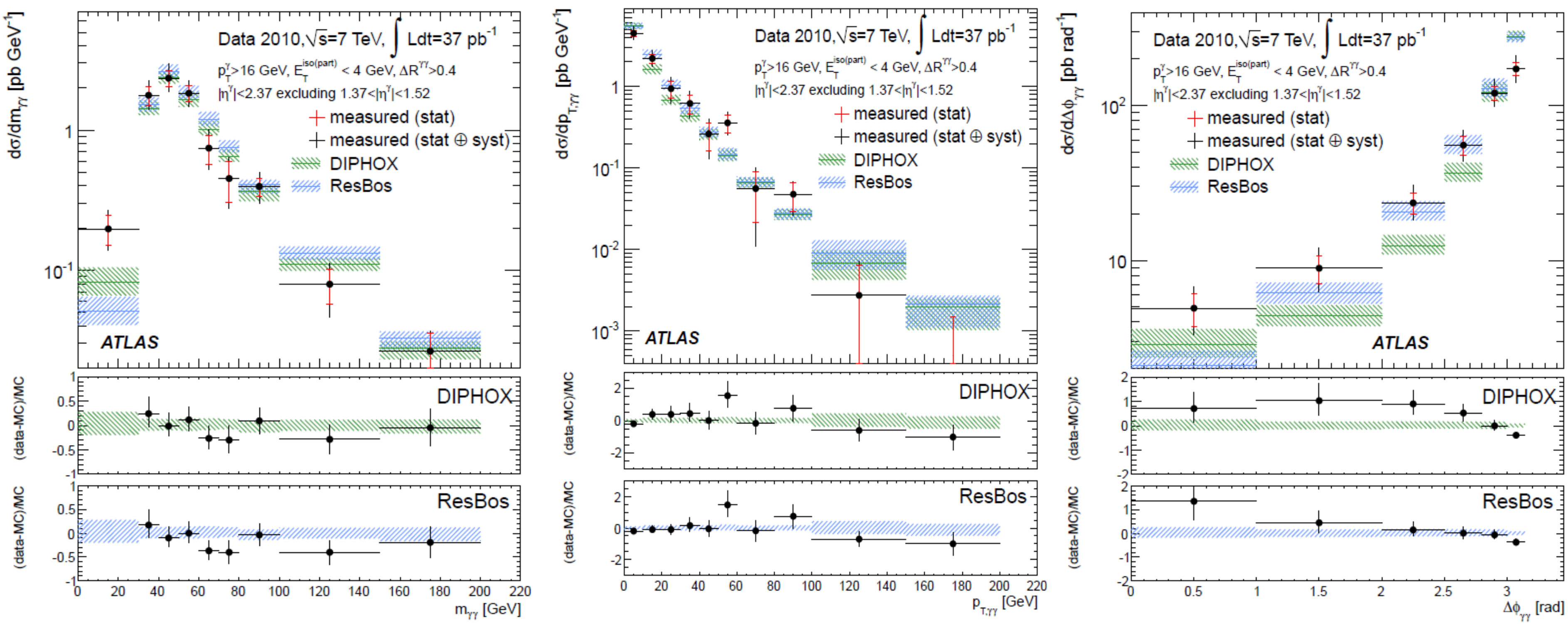
- 2022 diphoton events selected with p_T>16 GeV within fiducial region, tight photon quality and isolated (E_T(iso) < 3 GeV)
- All three background estimation methods agree fairly well with comparable systematic uncertainty (~15%)
- Electron background subtracted using N(Z→ee) × f(e→γ)





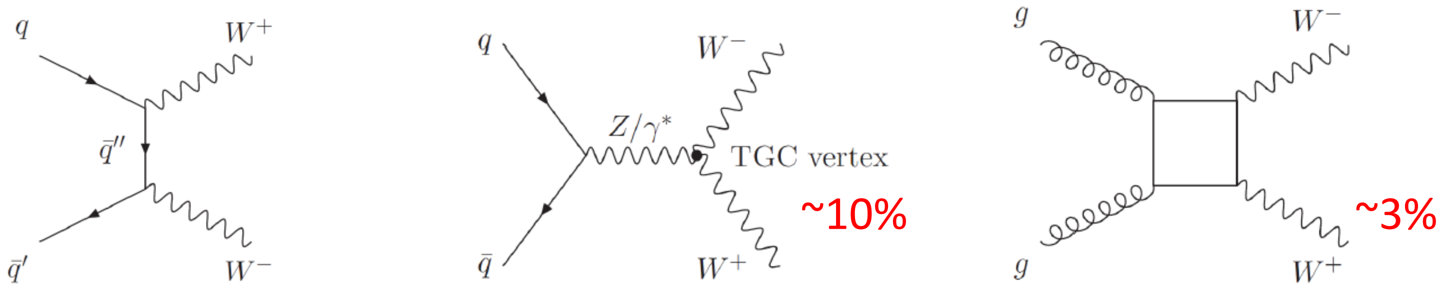
$\gamma\gamma$: Data/Theory Comparison

- Single differential cross section: $$\frac{d\sigma}{dX} = \frac{N - N_{bkg}}{\varepsilon \cdot A \cdot L \cdot \Delta}$$ $$X = M_{\gamma\gamma}, p_T^{\gamma\gamma}, \Delta\phi_{\gamma\gamma}$$
- Some disagreement especially in the low $\Delta\phi$ region and $\Delta\phi \sim \pi$ (missing double photon fragmentation?)
- Qualitatively compatible with measurements from D0, CDF and CMS
- Double differential cross section measurements with larger dataset will be useful



SM WW Cross Section Measurement

- Irreducible background to the Higgs search in H→WW→lνlν



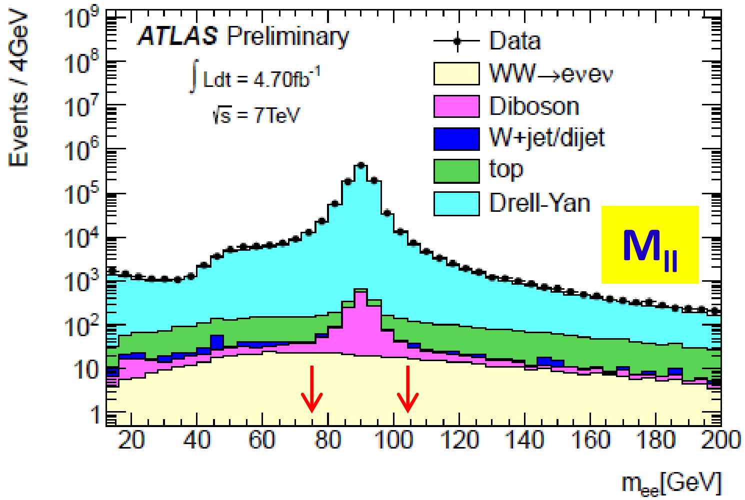
- NLO prediction: σ(pp→WW) = 45.1±2.8 pb
- Two high p_T leptons (e, μ) with large MET
- Sequential decays to electrons or muons via tau leptons are included as signals
- Dominant backgrounds: Z+jets, top and W+jets

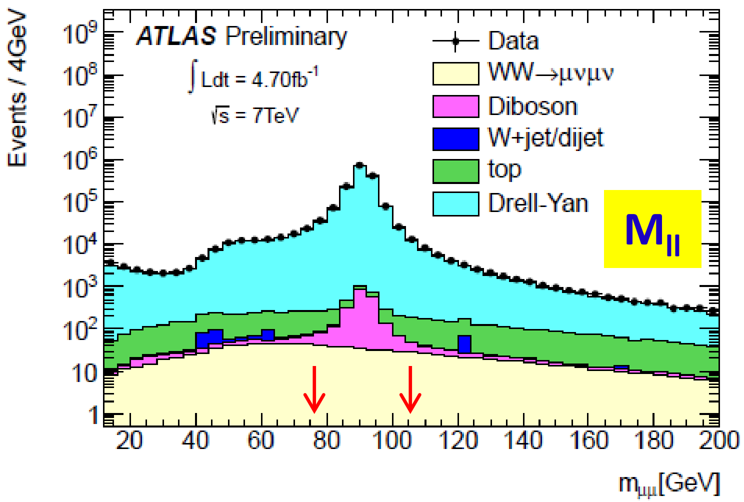
- Cross section is measured as (fiducial vs total cross sections):

$$\sigma(pp \to W^+W^-) = \frac{N_{\rm data} - N_{\rm bg}}{A_{WW} \times C_{WW} \times \mathscr{L} \times BR}$$

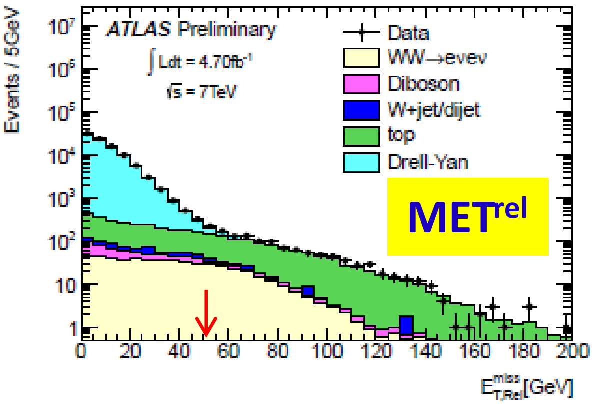
WW→lνlν Event Selection

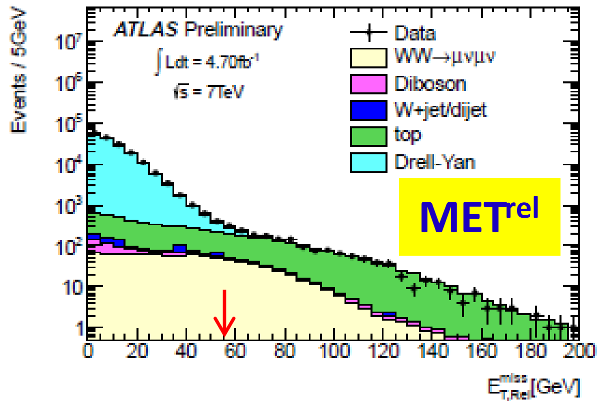
- WW → lνlν: two high p_T leptons and large MET
  - Electrons: isolated, shower shape, inner track matched with p_T>20GeV
  - Muons: isolated, combined muon and inner detector track with p_T>20GeV ($|\eta|<2.4$)
  - Leading lepton with p_T>25 GeV
  - Dilepton invariant mass cut: $|M_{ll}-M_Z|>15$ GeV for ee and μμ
  - MET^{rel} cut
  - No jets with p_T>25 GeV and $|\eta|<4.5$
  - Reject events with at least one b-jet with p_T>20 GeV

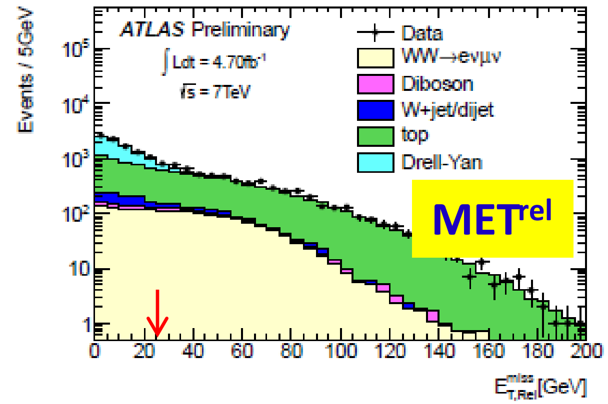




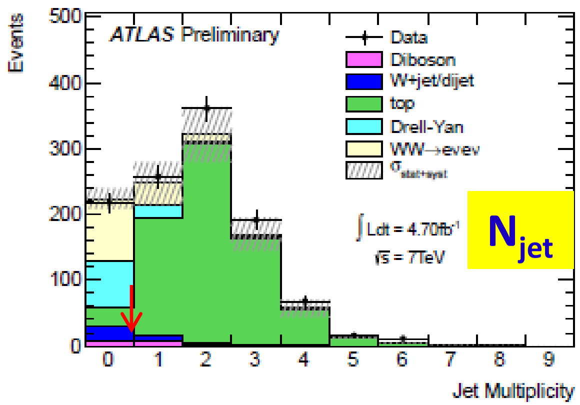
WW→lνlν Event Selection

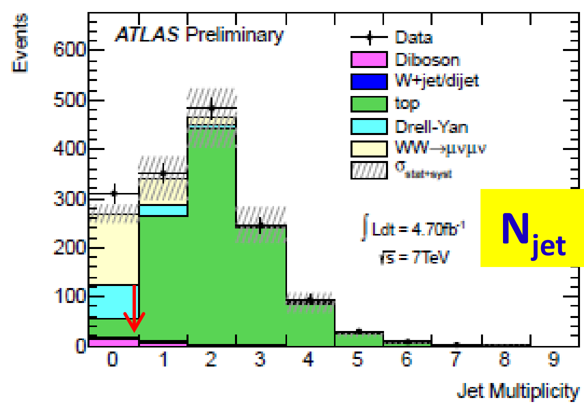


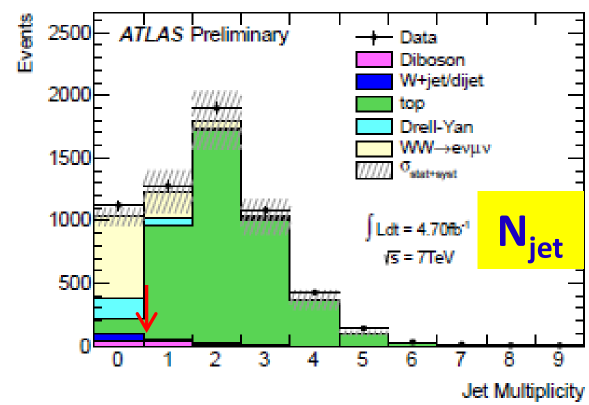




- MET^{rel} is defined as $E_{T,\,Rel}^{miss} = \begin{cases} E_T^{miss} \times \sin(\Delta\phi_{\ell,j}) & \text{if } \Delta\phi < \pi/2 \\ E_T^{miss} & \text{if } \Delta\phi \geq \pi/2 \end{cases}$
- MET^{rel}>50 GeV for ee, 55 GeV for μμ and 25 GeV for eμ







WW→lνlν Cut Flow

Selections	$ee + E_{\mathrm{T}}^{\mathrm{miss}}$	$\mu\mu + E_{\mathrm{T}}^{\mathrm{miss}}$	$e\mu + E_{\mathrm{T}}^{\mathrm{miss}}$
2 leptons (SS+OS)	1049296	1823285	21549
2 leptons (OS)	1043310	1822980	20677
leading lepton $p_{\mathrm{T}} > 25\mathrm{GeV}$	1025363	1773911	15618
trigger matching	1024912	1763886	15579
$m_{\ell\ell(')}$ >15/15/10 GeV	1021200	1753923	15563
Z mass veto	95889	178777	15563
$E_{\mathrm{T,\ Rel}}^{\mathrm{miss}}$ cut	1303	1784	6653
Jet veto (No. of jet=0)	254	357	1265
b-jet veto	229	325	1176
sub-leading lepton $p_T > 20$ GeV	196	287	1041

1524 candidates observed for 4.7 fb^{-1} of data

Electron efficiency: 64-78%

Muon efficiency: 93%

WW→lνlν Signal Estimation

- WW → lνlν generated with MC@NLO (gg2WW) with HERWIG for parton shower and JIMMY for underlying event simulation
- Mean number of interactions per event in MC is reweighted to reproduce that observed in data
- Corrections for lepton identification efficiencies, energy/momentum scale and resolution, MET resolution applied
- Corrections for jet-veto efficiency: $f_Z = \varepsilon_Z^{data}/\varepsilon_Z^{mc}$ =0.953±0.048 determined from Z events

Selections	ee Channel		$\mu\mu$ Channel		$e\mu$ Channel	
	$e\nu e\nu$	$\tau\nu\ell\nu$	$\mu\nu\mu\nu$	$\tau\nu\ell\nu$	$e\nu\mu\nu$	$\tau\nu\ell\nu$
Total Events (4.7 fb^{-1})	2474.4	946.9	2474.4	946.9	4944.8	1893.6
2 leptons (SS+OS)	628.4	90.7	1099.1	150.3	1679.5	229.5
2 leptons (OS)	623.2	90.1	1099.1	150.3	1679.5	229.5
leading lepton $p_T > 25$GeV	616.9	88.2	1081.1	145.4	1496.1	179.7
trigger matching	615.9	87.9	1063.8	141.0	1492.1	179.0
$m_{\ell\ell^{(\prime)}}$ >15/15/10 GeV	612.0	87.6	1054.8	140.0	1491.0	178.9
Z mass veto	478.9	66.6	824.1	108.0	1491.0	178.9
$E_{T,\,Rel}^{miss}$ cut	150.2	13.9	238.3	21.2	940.1	100.7
Jet veto	96.6	7.5	149.9	12.5	623.5	64.1
b-jet veto	93.8	7.4	145.2	11.9	603.1	61.9
sub-leading lepton $p_T > 20$GeV	83.3	5.2	128.1	8.8	562.6	51.0
W^+W^- Acceptance	3.37%	0.55%	5.18%	0.93%	11.38%	2.69%

Sources	$e^+e^-E_T^{miss}$	$\mu^+\mu^-E_T^{miss}$	$e^\pm\mu^\mp E_T^{miss}$	Combined
A_{WW} uncertainties ← Kinematic and geometric acceptance				
PDF	1.4%	1.4%	1.4%	1.2%
Scale (μ_R, μ_F)	2.1%	1.6%	1.7%	1.5%
Jet Veto (MC modeling)	5.0%	5.0%	5.0%	5.0%
C_{WW} uncertainties ← Measured to produced events in fiducial region				
Trigger	0.3%	0.6%	0.5%	0.5%
Electron Scale	0.9%	0.0%	0.3%	0.3%
Electron Resolution	0.0%	0.0%	0.0%	0.0%
Muon Scale	0.0%	0.9%	0.2%	0.3%
ID Muon Resolution	0.0%	0.0%	0.0%	0.0%
MS Muon Resolution	0.0%	0.1%	0.0%	0.0%
Electron Reconstruction	1.6%	0.0%	0.8%	0.8%
Electron ID	2.3%	0.0%	1.0%	1.0%
Muon ID	0.0%	0.7%	0.4%	0.4%
Lepton Isolation	4.0%	2.3%	2.3%	2.3%
B Tagging	0.4%	0.5%	0.5%	0.5%
E_T^{miss} Pile-Up	2.5%	2.8%	0.7%	1.2%
E_T^{miss} Cluster	1.8%	1.8%	0.5%	0.8%
Jet Energy Scale & Resolution	3.2%	3.2%	1.9%	2.5%
Total Acceptance uncertainty	8.7%	7.5%	6.4%	6.7%

WW→lνlν Background Estimation

- W+jets: scale the W+jet control sample (one fully identified lepton + a jet-rich lepton) by a measured fake factor, cross checked with same-sign dilepton events enhanced in W+jets
- Z+jets: shape determined from MC simulation, for ee and μμ channels, the normalization is corrected with a scale factor derived from the MET^{rel} tail distributions in data and MC with $|M_{ll}-M_Z|<15$ GeV
- Top: Using the number of observed top events in the N-jet bins (N≥2):

$$N_{\rm top}^{\rm zero-jet}({\rm estimate}) = N_{\rm MC\ top}^{\rm zero-jet} \times (N_{\rm data}^{\geq 2-{\rm jets}} / N_{\rm MC\ top}^{\geq 2-{\rm jets}})$$

WW→lνlν Cross Section Measurement

Final State	$e^+e^-E_T^{miss}$	$\mu^+\mu^-E_T^{miss}$	$e^\pm\mu^\mp E_T^{miss}$	Combined
Observed Events	196	287	1041	1524
Total expected events (S+B)	202.9±7.2±15.3	250.1±7.4±15.9	916.9±10.0±68.9	1370.1±14.3±96.5
MC WW Signal	88.5±1.3±10.1	137.0±1.6±14.4	613.6±3.6±59.8	839.0±4.2±83.3
Background estimations				
Top(data-driven)	14.0±2.0±2.9	25.2±2.9±5.1	70.8±5.2±14.4	110.0±6.2±22.4
W+jets (data-driven)	19.8±0.5±10.5	5.1±0.9±2.0	54.1±1.0±28.3	79.0±1.4±39.0
Drell-Yan (MC/data-driven)	72.0±6.7±3.2	70.0±6.5±3.5	142.2±7.1±12.5	284.2±11.7±17.2
Other dibosons (MC)	8.6±1.2±1.9	12.8±0.6±2.0	36.2±2.9±3.5	57.6±3.2±7.4
Total background	114.4±7.1±11.5	113.1±7.2±6.8	303.3±9.3±34.3	531.1±13.7±48.7
Significance ($S/\sqrt{B}$)	8.3	12.9	35.2	36.4

- Fiducial cross section: same cuts as used for event selection except using $p_T^{\nu\nu}$ and jets reconstructed at the generator level

Channels	expected σ^{fid} (fb)	measured σ^{fid} (fb)	$\Delta\sigma_{stat}$ (fb)	$\Delta\sigma_{syst}$ (fb)	$\Delta\sigma_{lumi}$ (fb)
$e\nu e\nu$	44.9±3.7	41.4	± 6.5	± 5.7	± 1.6
$\mu\nu\mu\nu$	38.0±3.1	48.2	± 4.6	± 3.8	± 1.9
$e\nu\mu\nu$	237.4±19.4	284.9	± 12.7	± 14.1	± 11.1

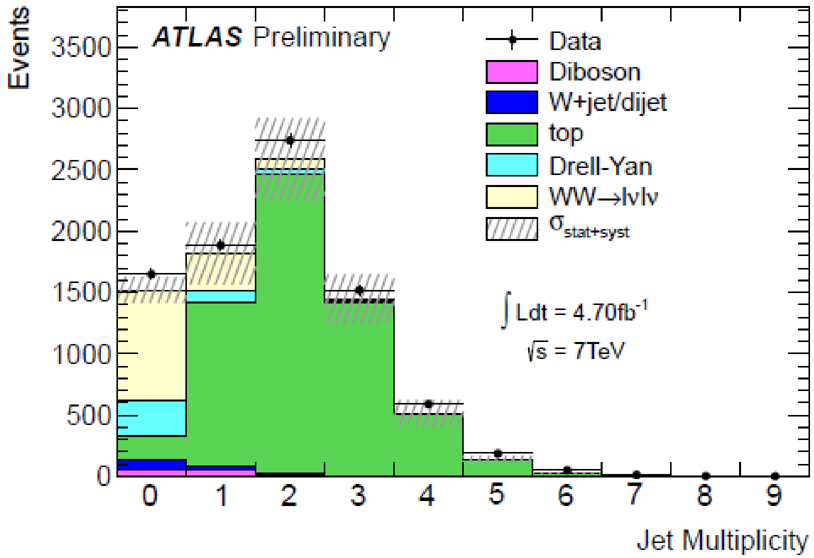
- Total cross section (-0.3σ for ee, +1.4σ for μμ, +1.5σ for eμ): σ(WW) = 45.1±2.8 pb

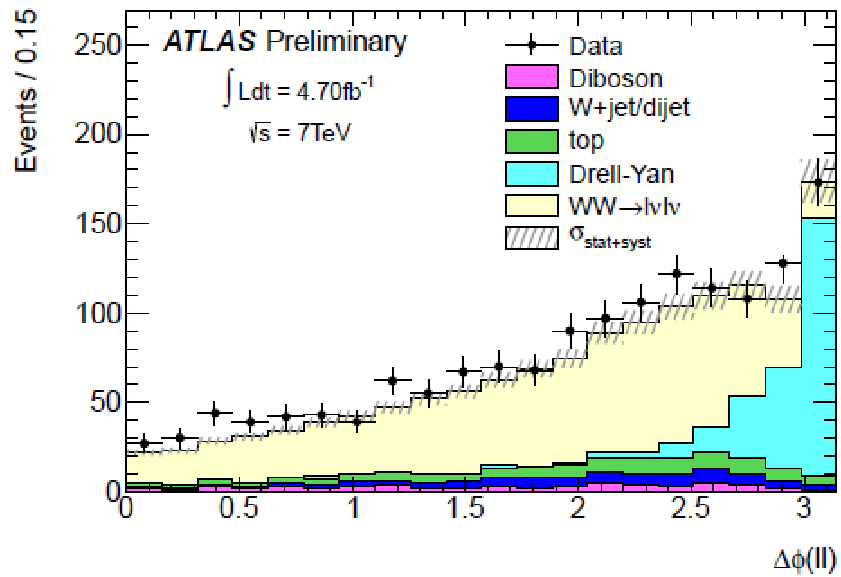
Channels	Total cross-section (pb)	$\Delta\sigma_{stat}$(pb)	$\Delta\sigma_{syst}$(pb)	$\Delta\sigma_{lumi}$(pb)
$e\nu e\nu$	41.5	± 6.5	± 7.8	± 1.6
$\mu\nu\mu\nu$	57.3	± 5.5	± 5.4	± 2.2
$e\nu\mu\nu$	54.3	± 2.4	± 4.4	± 2.1
Combined	53.4	± 2.1	± 4.5	± 2.1

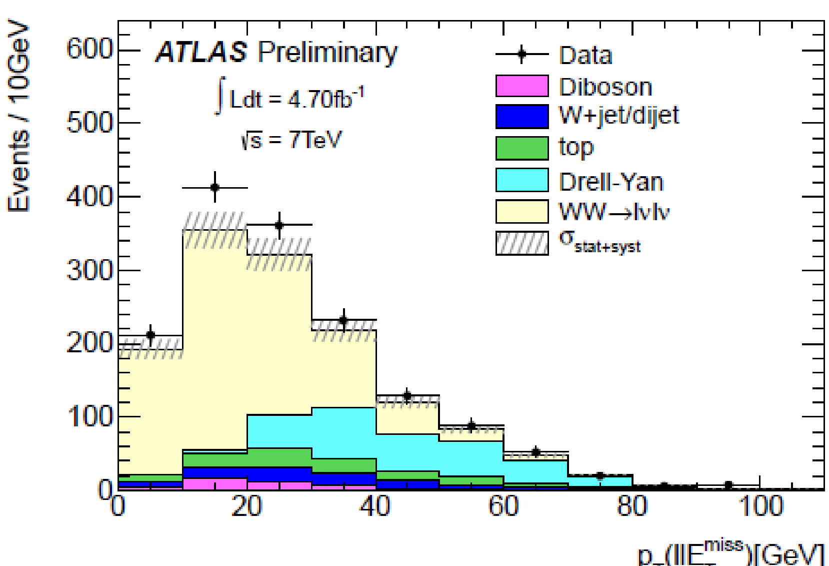
4% stat uncertainty
10% overall uncertainty

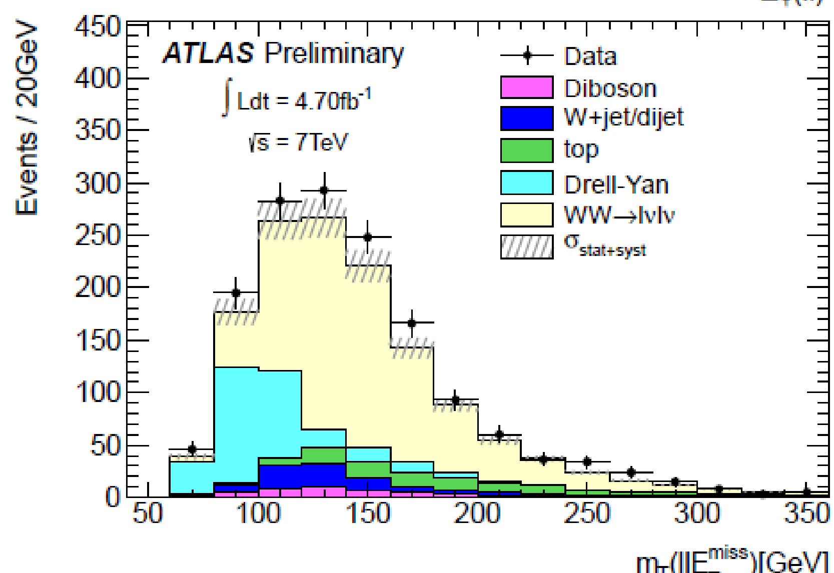
- 2.9, 5.4 and 19.6 Higgs events expected for m_H=125 GeV

Data and MC Comparison



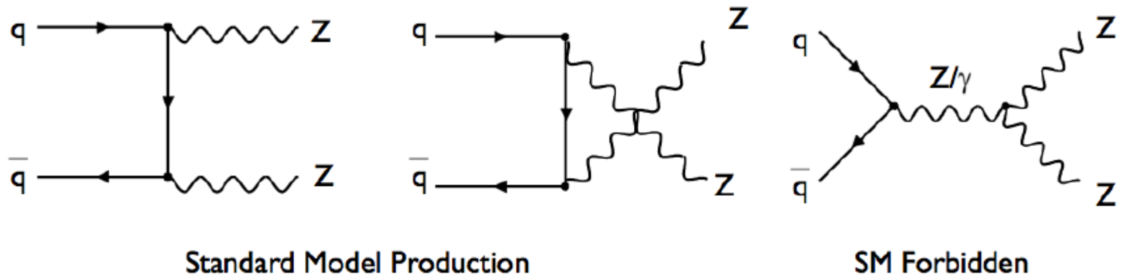






SM ZZ Cross Section Measurements

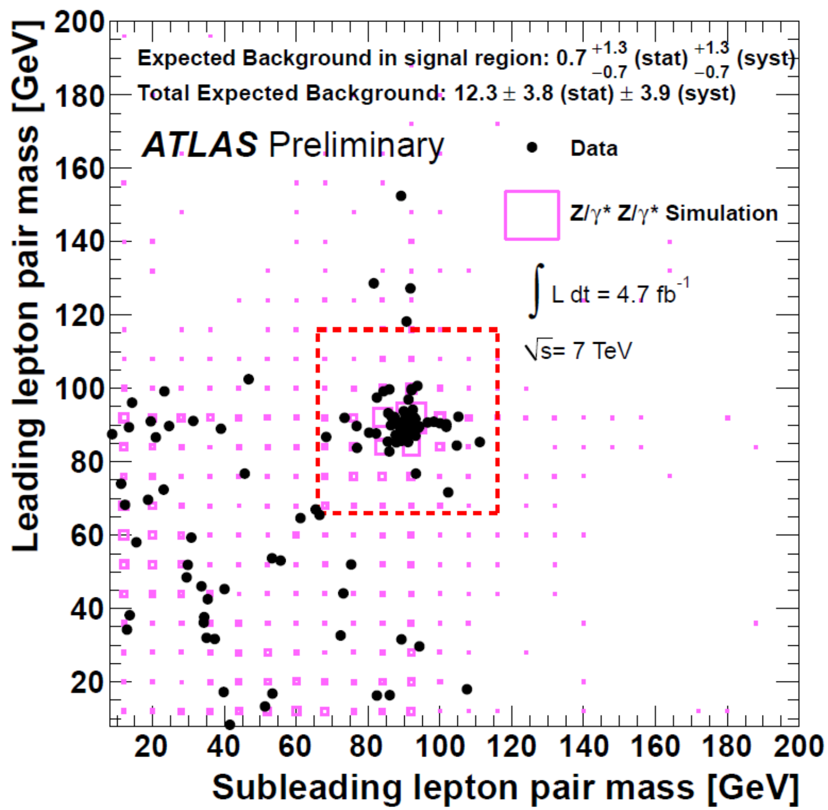
- Irreducible backgrounds to the H→ZZ*→4l and H→ZZ→llνν searches
- Mainly produced through $q\bar{q}$ annihilation, ~6% contribution from gluon fusion
- Study ZZZ and ZZγ neutral TGCs



- $\sigma_{NLO}(pp\rightarrow ZZ)=6.5^{+0.3}_{-0.2}$ pb (MCFM with MSTW2008 NLO PDF)
- Production cross section ~5 timers larger than at the Tevatron
- Results from two decay channels presented here: 4l and llνν
  - llll: 0.5% of the total ZZ cross section, clean detector signature
  - llνν: has six times higher cross section but larger backgrounds

ZZ→4l Event Selection

- ZZ → 4l: two pairs of opposite-sign dilepton ($e^+e^-e^+e^-$, $\mu^+\mu^-\mu^+\mu^-$, $e^+e^-\mu+\mu-$)
  - Electrons: isolated, shower shape, inner track matched with p_T>7GeV and $|\eta|<2.47$
  - Muons: isolated, combined muon and inner detector track with p_T>7GeV ($|\eta|<2.5$) or muon track with p_T>10 GeV ($2.5<|\eta|<2.7$)
  - At least one lepton with p_T>20 (25) GeV for a muon (electron)
  - Two Z candidates with $66<m_{ll}<116$ GeV (for $e^+e^-e^+e^-$ and $\mu^+\mu^-\mu^+\mu^-$, use the pairs which results in the smaller value of the sum of the two $|m_{ll}-m_Z|$ values)

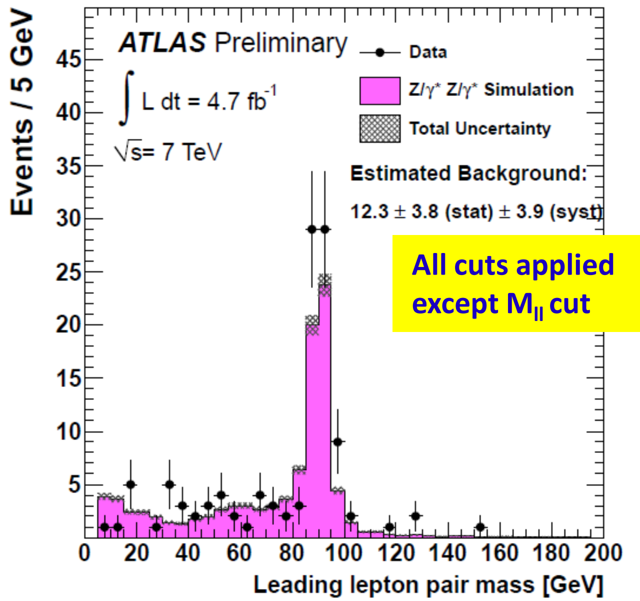


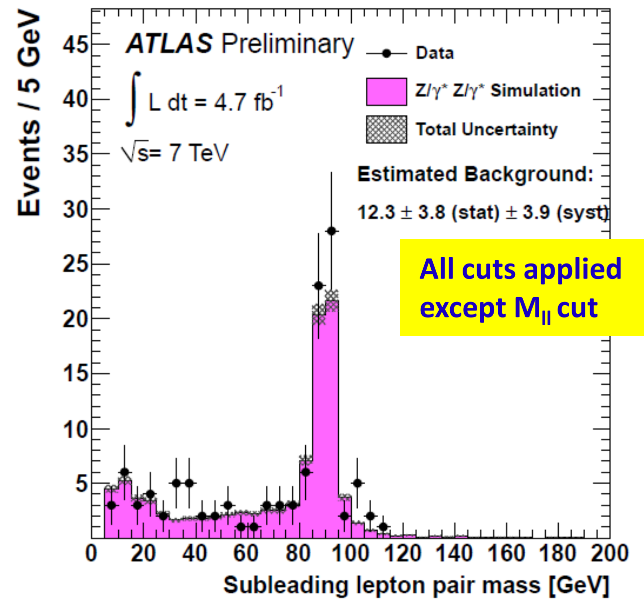
ZZ→4l Signal and Backgrounds

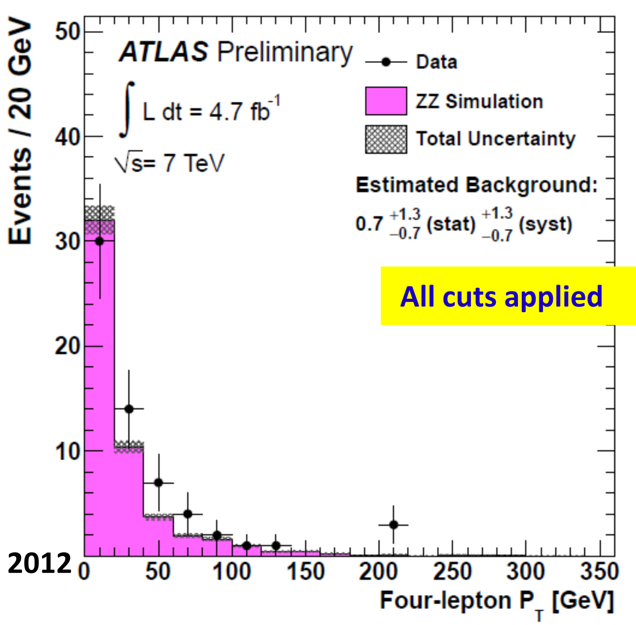
- Signal: LO SHERPA generator used with CTEQ66 PDF
  - Interference terms between the Z and γ^* also included (m_{Z/γ^*}>7GeV)
  - Normalized to the NLO calculation using MCFM with MSTW2008 NLO PDF
- Reconstruction correction factor from data to the ZZ fiducial phase space: 0.46±0.02 ±0.04 (4e), 0.81±0.02±0.02(eμ), 0.60±0.01±0.02 (2e2μ)
- Dominant systematics arise from ε_e (5.8% for 4e and 2.8% for 2e2μ) and ε_μ(1.3% for 4μ and 0.6% for 2e2μ)
- Background: W/Z+jets, WW and WZ: one or two jets misidentified as isolated leptons
- Define lepton-like jets: fail isolation or d_0 significance requirement (muon), fail isolation or identification requirement (electron)
- Fake factor for jets: $f = \varepsilon_{lepton}/\varepsilon_{lepton\text{-}like\ jet}$

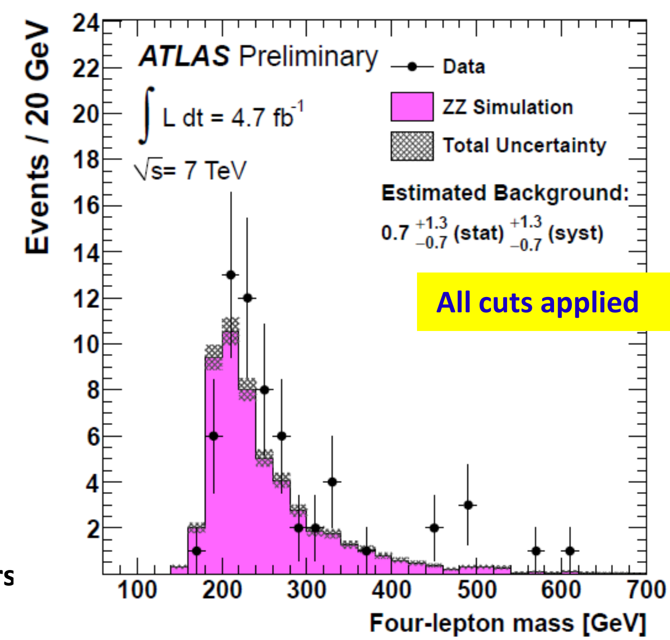
$$N(\text{background}) = N(\ell\ell\ell j) \times f - N(\ell\ell jj) \times f^2 - N(ZZ \text{ in control sample})$$

ZZ→4l: Data/MC Comparison









ZZ→4l Cross Section Measurement

- Number of observed and expected ZZ candidates:

Final state	$eeee$	$\mu\mu\mu\mu$	$ee\mu\mu$	combined ($\ell\ell\ell\ell$)
Observed	15	21	26	62
Signal(MC)	$9.9 \pm 0.5 \pm 0.8$	$16.6 \pm 0.6 \pm 0.3$	$26.8 \pm 0.8 \pm 1.0$	$53.2 \pm 1.1 \pm 1.9$
Bkg(d.d.)	$0.6^{+0.7+0.8}_{-0.6-0.6}$	$< 0.3^{+0.5}_{-0.2}$	$0.3^{+0.9+0.8}_{-0.3-0.3}$	$0.7^{+1.3+1.3}_{-0.7-0.7}$
Bkg(MC)	0.3 ± 0.3	< 0.8	0.6 ± 0.6	1.0 ± 0.6

- A maximum likelihood method is applied to extract the ZZ cross section from these three channels (l=e, μ)

$$\sigma^{\mathrm{fid}}_{ZZ\to\ell^+\ell^-\ell^+\ell^-} = 21.2^{+3.2}_{-2.7}\,(\mathrm{stat})\,^{+1.0}_{-0.9}\,(\mathrm{syst})\,\pm 0.8\,(\mathrm{lumi})\,\mathrm{fb}$$

17% overall uncertainty

- Consistent with the SM prediction of 19±1 fb
- Numbers from three individual channels:

4e $6.6^{+2.0}_{-1.6}\,(\mathrm{stat})\,^{+0.8}_{-0.5}\,(\mathrm{syst})\,^{+0.3}_{-0.2}\,(\mathrm{lumi})\,\mathrm{fb}$

4μ $5.5^{+1.3}_{-1.1}\,(\mathrm{stat})\,^{+0.2}_{-0.1}\,(\mathrm{syst})\,^{+0.3}_{-0.2}\,(\mathrm{lumi})\,\mathrm{fb}$

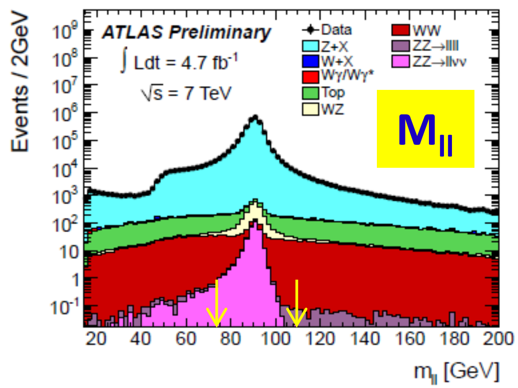
2e2μ $9.1^{+2.1}_{-1.7}\,(\mathrm{stat})\,^{+0.5}_{-0.4}\,(\mathrm{syst})\,^{+0.4}_{-0.3}\,(\mathrm{lumi})\,\mathrm{fb}$

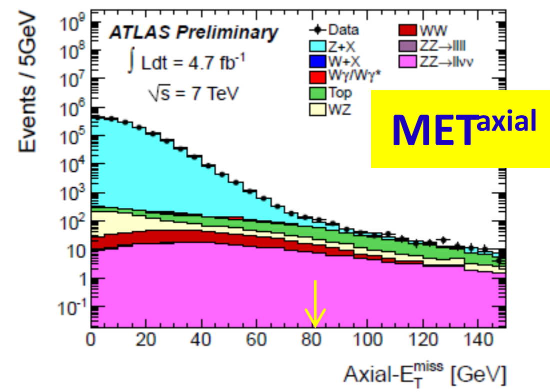
- Total on-shell ZZ cross section:

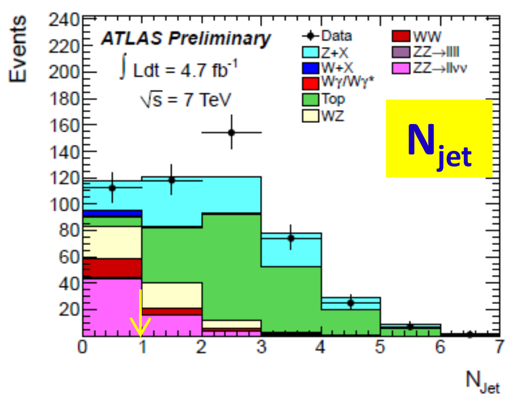
$$\sigma^{\mathrm{tot}}_{ZZ} = 7.2^{+1.1}_{-0.9}\,(\mathrm{stat})\,^{+0.4}_{-0.3}\,(\mathrm{syst})\,\pm 0.3\,(\mathrm{lumi})\,\mathrm{pb}$$

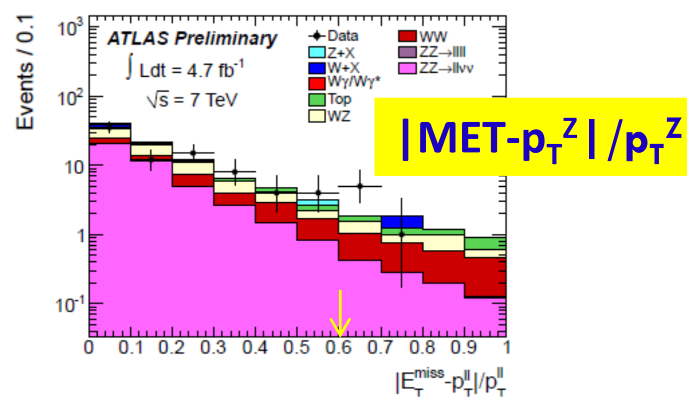
ZZ→llνν Event Selection

- ZZ → llνν: two oppositely-charged high p_T electrons or muons
- Isolated in both calorimeter and tracker: reduce QCD multijet
- Dilepton invariant mass $|m_{ll}-m_Z|<15$ GeV: reduce W+jets, top and WW
- MET^{axial} > 80 GeV (MET projected to the Z p_T direction): reduce Z+jets
- Zero jets with p_T>25 GeV reconstructed: reduce top and Z+jets
- Fractional p_T difference $|MET-p_T^Z|/p_T^Z<0.6$: reduce WW









ZZ→llνν Signal Estimation

- NLO generator MC@NLO with CT10 PDF used
- ZZ bosons are treated as on-shell with zero width
- Production due to gg initial states is not included (MC@NLO predictions scaled up by 6.3%)
- Cut flow table for both channels:

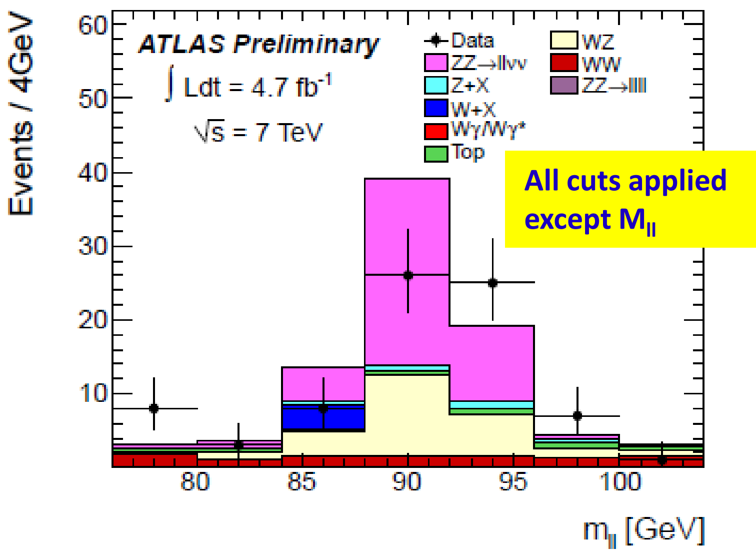
Channels	$ee\nu\nu$	$\mu\mu\nu\nu$	$\ell\ell\nu\nu$
Two leptons	140.5 ± 1.5	179.6 ± 1.6	320.1 ± 2.2
Z mass	138.4 ± 1.5	167.3 ± 1.6	305.7 ± 2.2
Axial $E_{\mathrm{T}}^{\mathrm{miss}}$	29.4 ± 0.6	35.4 ± 0.7	64.8 ± 0.9
Jet veto	19.8 ± 0.5	24.0 ± 0.6	43.8 ± 0.8
Frac. p_{T} diff.	$19.3 \pm 0.5 \pm 1.2$	$23.0 \pm 0.6 \pm 0.9$	$42.3 \pm 0.8 \pm 1.8$

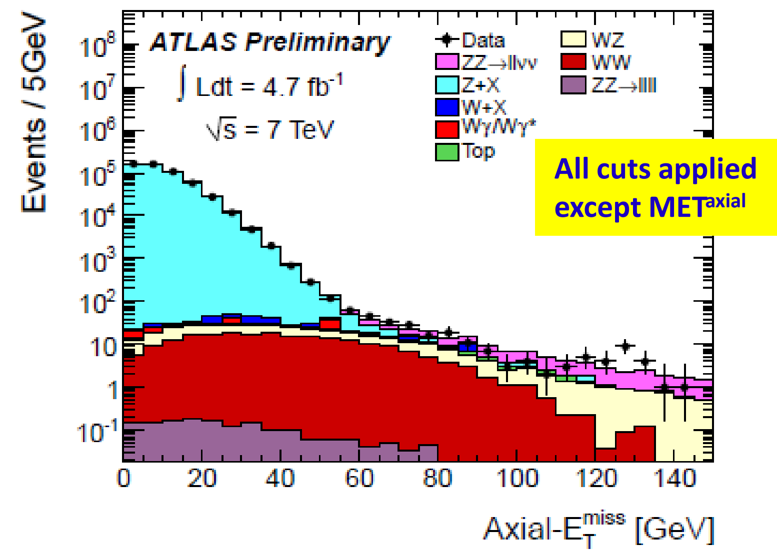
ZZ→llνν Background Estimation

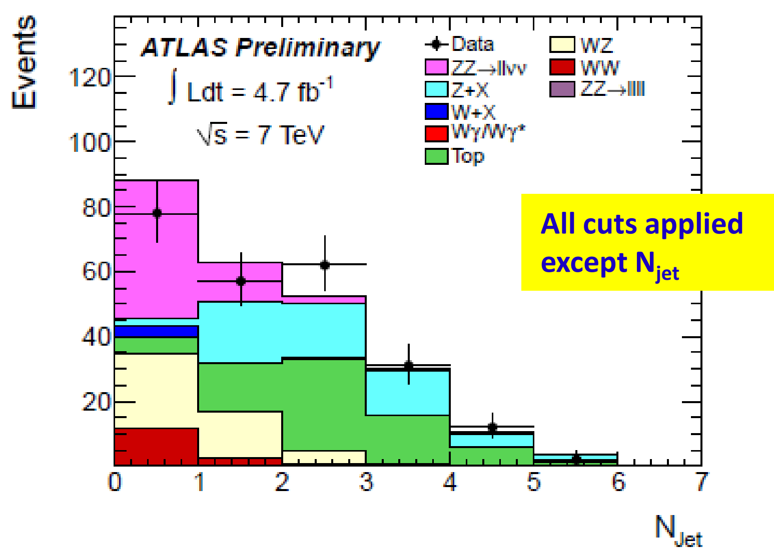
- MC-based estimation: WZ (two real leptons and large MET) and Wγ
- Data-driven estimation: top, WW, Z→ττ, W+jets and Z+jets
  - Top, WW, Z→ττ: using opposite-sign eμ events with $|m_{e\mu} - m_Z| < 15$ GeV with corrections for electron and muon acceptance and identification applied
  - Z+jets: estimated from γ+jets events with γ p_T reweighted to Z p_T
  - W+jets: 4×4 matrix method using tight and loose leptons

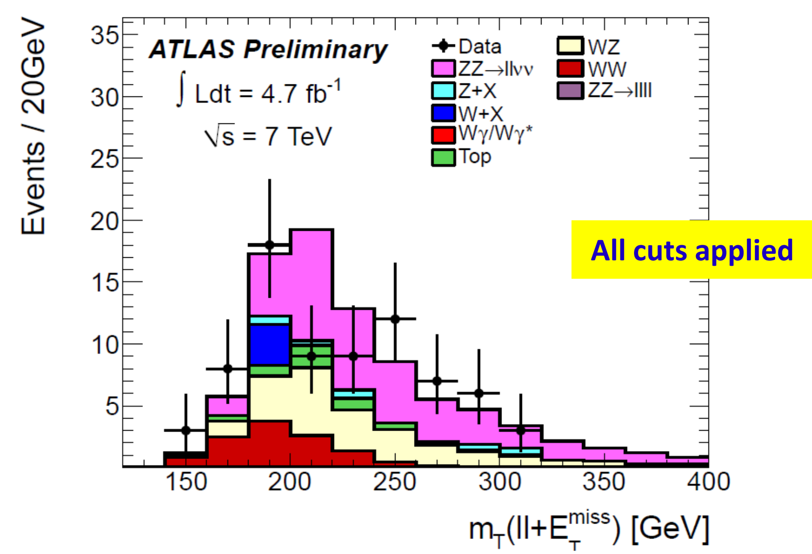
Final State	$e^+e^-\nu\bar{\nu}$	$\mu^+\mu^-\nu\bar{\nu}$	$\ell^+\ell^-\nu\bar{\nu}$
Observed	33	45	78
Expected ZZ	19.3 ± 0.5 ± 1.2	23.0 ± 0.6 ± 0.9	42.3 ± 0.8 ± 1.8
Background estimations:			
$W^{\pm}Z$ (MC)	9.4 ± 0.5 ± 1.5	13.3 ± 0.6 ± 2.1	22.7 ± 0.8 ± 3.5
$W^{\pm}+\gamma$ (MC)	0.20 ± 0.10 ± 0.01	0.09 ± 0.06 ± 0.01	0.29 ± 0.12 ± 0.01
$t\bar{t}$, $W^{\pm}t$, W^+W^- and $Z \to \tau\tau$ (data-driven)	6.5 ± 1.8 ± 0.3	8.2 ± 2.3 ± 0.3	14.7 ± 4.1 ± 0.6
Z+jets (data-driven)	0.8 ± 0.4 ± 0.4	0.9 ± 0.3 ± 0.4	1.7 ± 0.5 ± 0.8
$W^{\pm}$+jets (data-driven)	1.1 ± 0.4 ± 0.3	0.2 ± 0.1 ± 0.1	1.3 ± 0.4 ± 0.3
Total Background	18.0 ± 2.0 ± 1.6	22.7 ± 2.4 ± 2.1	40.7 ± 4.3 ± 3.7

Data and MC Comparison









Cross Section Measurement

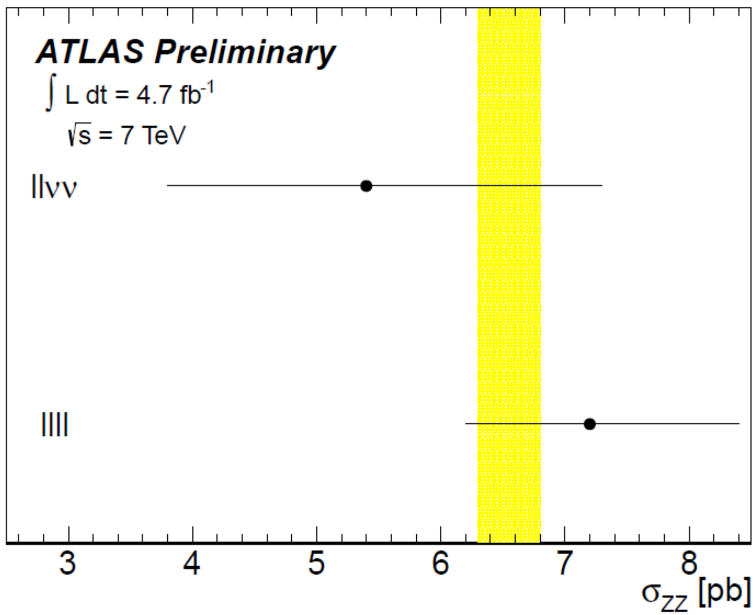
- Fiducial region: same cuts as used for event selection except using $p_T^{\nu\nu}$ and jets reconstructed at the generator level

$$\sigma^{\text{fid}}_{ZZ\to\ell^+\ell^-\nu\bar{\nu}} = 12.2^{+3.0}_{-2.8}(\text{stat.}) \pm 1.9(\text{syst.}) \pm 0.5(\text{lumi.})\ \text{fb}$$

- Fiducial acceptance: 0.084 ± 0.013 (uncertainties include PDF, QCD scale, acceptance difference between gg→ZZ[gg2zz] and qqbar→ZZ[MC@NLO])

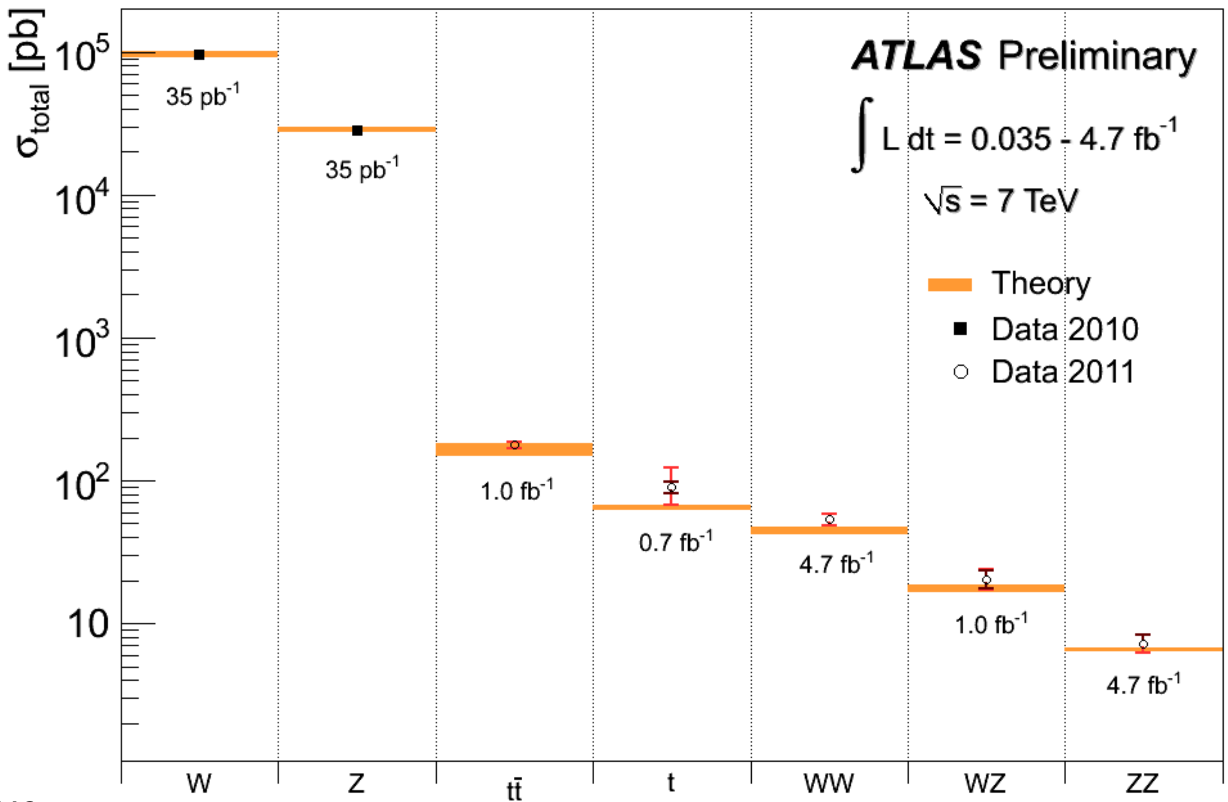
$$\sigma^{\text{tot}}_{ZZ} = 5.4^{+1.3}_{-1.2}(\text{stat.})^{+1.4}_{-1.0}(\text{syst.}) \pm 0.2(\text{lumi.})\ \text{pb}$$

- Consistent with the SM NLO prediction using MC@NLO



Conclusions

- Good agreement between data and SM expectation for $\gamma\gamma$, WW and ZZ cross section measurements
- Experimental precision will start to challenge theory calculations soon
- After a Higgs-like particle is discovered, it is important to understand these irreducible SM backgrounds in order to measure the Higgs boson properties



~σ(H→ WW) with m_H=130 GeV