Measurement of Di-Boson Production at LHC

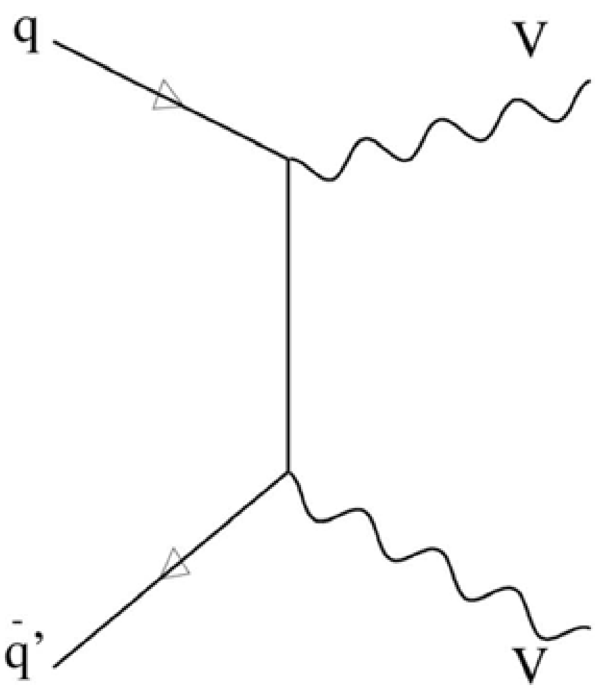
Eyal Brodet

Tel-Aviv University

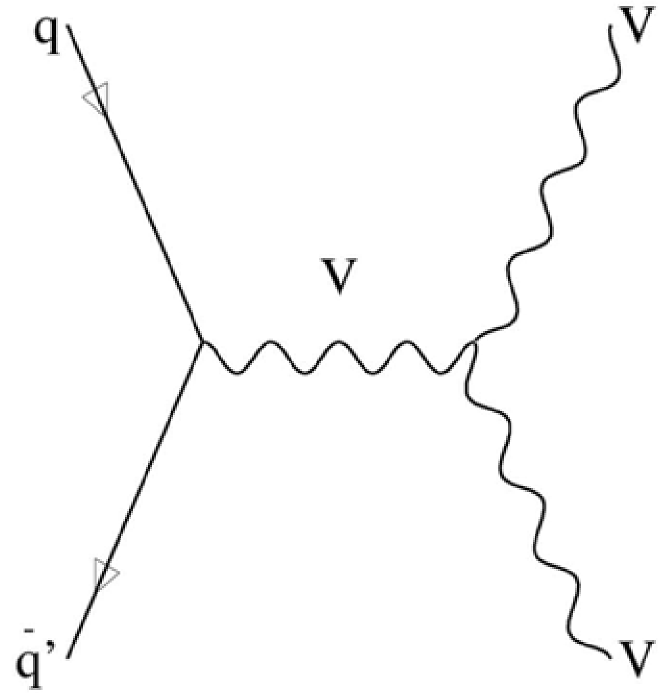
On behalf of the ATLAS and CMS Collaborations

Leading Di-Boson Production

Di-Boson: WW, WZ, ZZ
Where V = Vector Boson



Triple gauge diagram: forbidden for ZZ in SM



Di-Boson Total Cross Sections

- WW = 111.6pb measurable at al low luminosity
- WZ = 47.8pb
- ZZ = 14.8pb measurable at high luminosity

Results: cern-open-2008-020

Note: all studies except where mentioned otherwise use leptonic decays of W and Z at pp at CM energy of 14TeV

Motivation and Di-Boson Studies at LHC

- Test SM at the highest LHC energy
- Background for Higgs search
- Measure cross sections
- Measure triple gauge couplings
- Measure polarization of bosons

Cross Sections Measurements

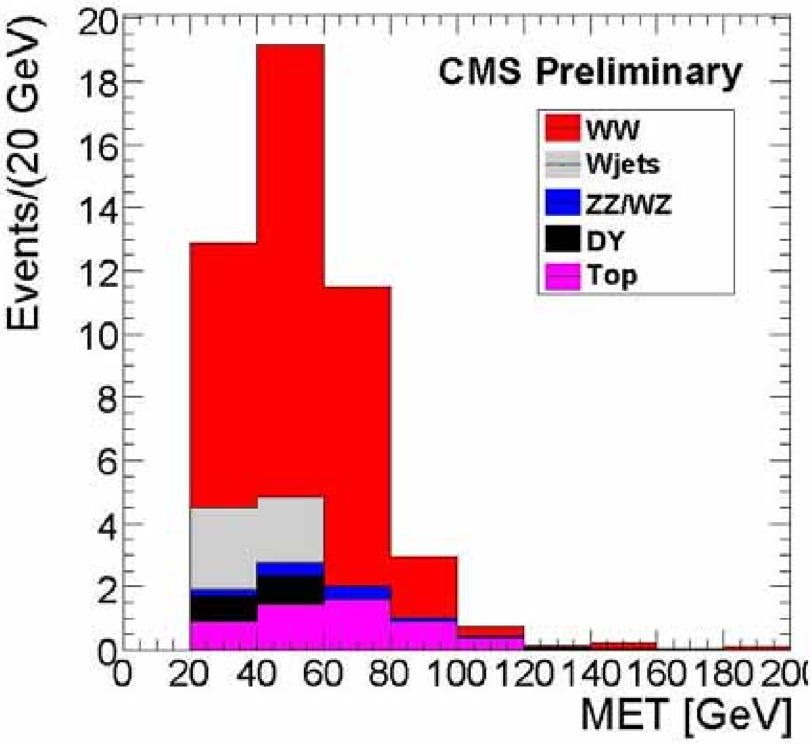
- Possible to measure at early stage (e.g. for WW and WZ)
- Need relatively low luminosity
- Precision will improve with time
- Need to know well luminosity and structure functions

WW Cross Section Measurement with CMS

Main Cuts:

- 2 opposite sign leptons with P_t>20GeV
- Missing Energy
- >45GeV
- Di-lepton mass NOT on Z mass
- Jet Veto: E_t >20GeV

For L = 100pb^{-1} with 10TeV



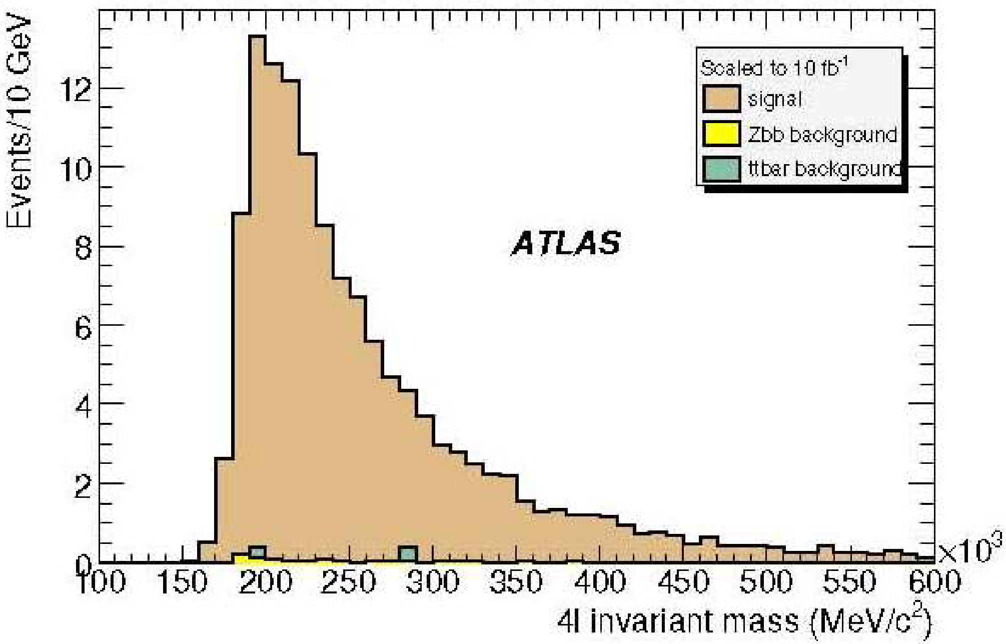
Result from: CMS PAS EWK-09-002

ZZ Cross Section Measurement

Main cuts:

- 4 Leptons with $P_t > 5GeV$
- Rapidity<2.7
- Pair leptons to be on Z mass
- Almost no background

For $L = 10\ fb^{-1}$



Signal and Background for Di-Boson with ATLAS for $1fb^{-1}$

Result from: CERN-OPEN-2008-020

Diboson mode	Signal	Background	Signal eff.	σ_{stat}^{signal}	p-value	Sig.
$W^+W^- \to e^\pm \nu \mu^\mp \nu$	347 ± 3	64 ± 5	12.6% (BDT)	5.4%	3.6×10^{-166}	27.4
$W^+W^- \to \mu^+ \nu \mu^- \nu$	70 ± 1	17 ± 2	5.2% (BDT)	12.0%	8.8×10^{-30}	11.3
$W^+W^- \to e^+ \nu e^- \nu$	52 ± 1	11 ± 2	4.9% (BDT)	13.9%	1.9×10^{-24}	10.1
$W^+W^- \to \ell^+ \nu \ell^- \nu$	103 ± 3	17 ± 2	2.0% (cuts)	9.9%	1.4×10^{-54}	15.5
$W^\pm Z \to \ell^\pm \nu \ell^+ \ell^-$	128 ± 2	16 ± 3	15.2% (BDT)	8.8%	3.0×10^{-76}	18.4
	53 ± 2	8 ± 1	6.3% (cuts)	13.7%	3.1×10^{-30}	11.4
$ZZ \to 4\ell$	17 ± 0.5	2 ± 0.2	7.7% (cuts)	24.6%	6.0×10^{-12}	6.8
$ZZ \to \ell^+\ell^-\nu\bar{\nu}$	10 ± 0.2	5 ± 2	2.6% (cuts)	31.3%	7.7×10^{-4}	3.2

WZ Cross Sections Measurement with CMS

- Split into W^+Z and W^-Z (total 47.8 pb)
- Focus at fully leptonic decay mode
- Main feature: 3 isolated leptons
- For 300 pb^{-1} get about 35 signal events With 40% background

WZ Cross Section Measurement with CMS

Main Cuts:

- 3 leptons $P_t > 20$
- Transverse W mass > 50GeV
- 2 leptons on Z mass: 50-120 GeV

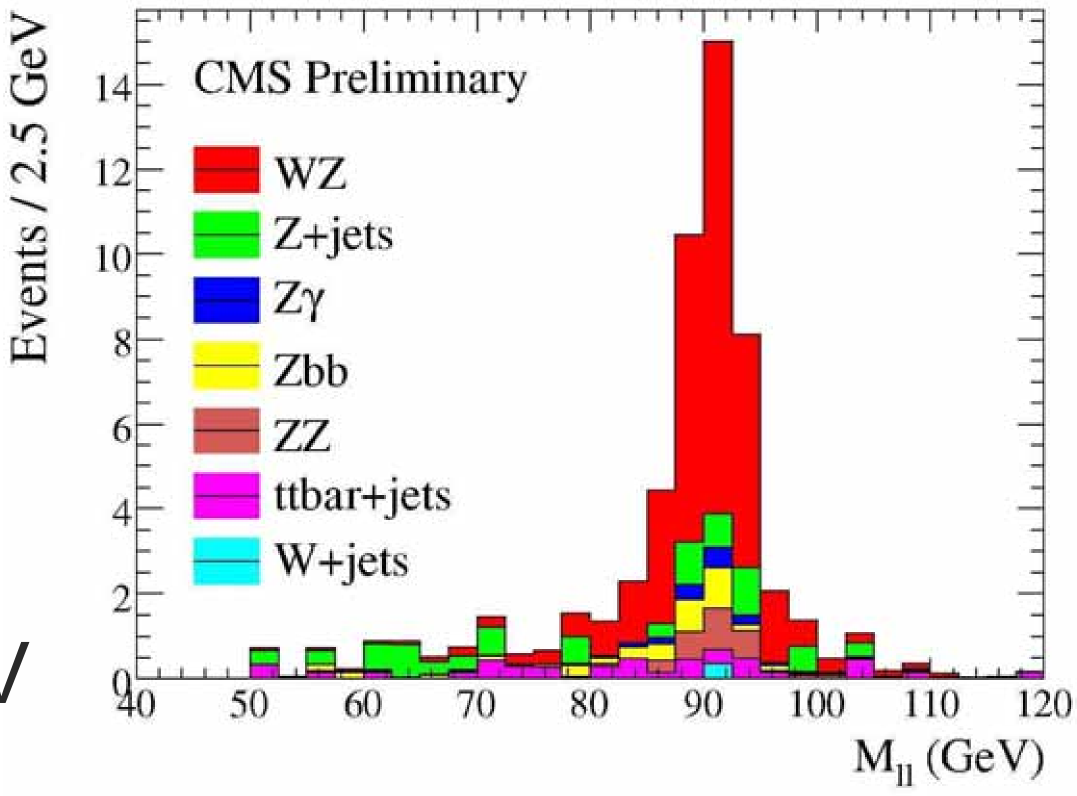
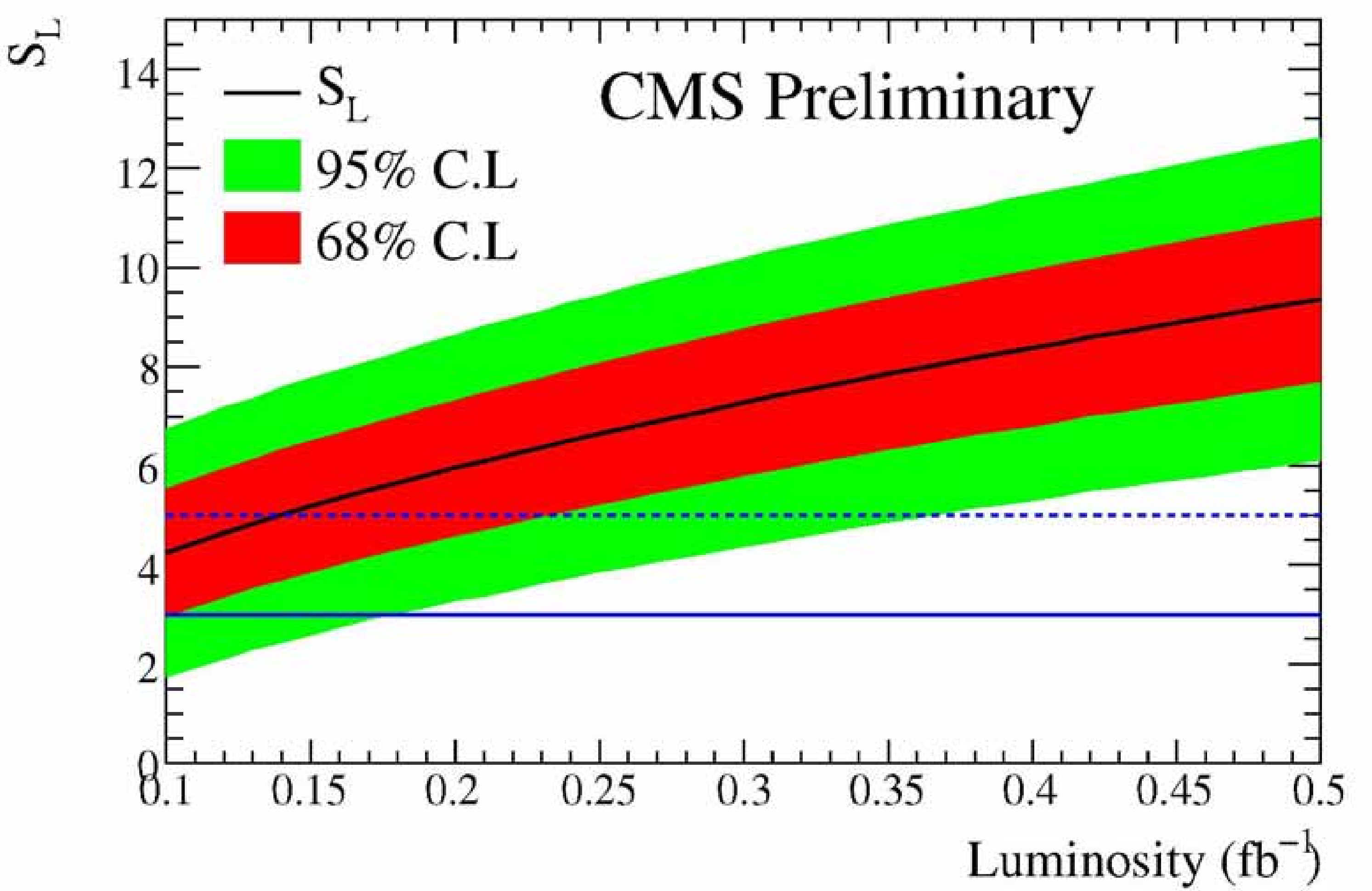


Figure 3: Z^0 candidate invariant mass for all four channels combined, normalized to integrated luminosity of 300 pb^{-1}.

Significance as a function of luminosity in the WZ case

Result from:
CMS PAS
EWK-08-003



Triple Gauge Couplings

- The most general WWγ, WWZ effective Lagrangian has 14 couplings
- Using only C and P conserving terms and assume QED gauge invariance we are left with 5 couplings:

TGC values according to SM:

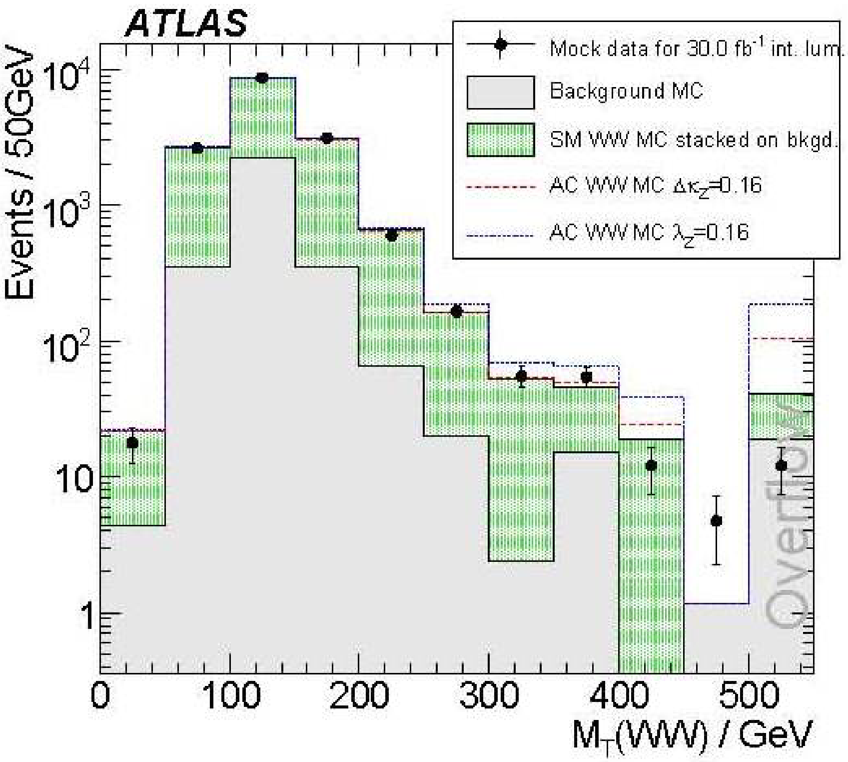
$$g_1^Z = 1,\ k_{\gamma,Z} = 1$$

$$\lambda_{\gamma,Z} = 0$$

Triple Gauge Couplings

- Look at WW process
- Transverse mass distribution
- Result from ATLAS csc book:

CERN-OPEN-2008-020



Comparison Between TGC Limits of LHC, Tevatron and LEP2: 95%CL

ATLAS for 30 fb^{-1}

$$\Delta g_1^Z = [-0.14, 0.25]$$

$$\Delta k_\gamma = [-0.056, 0.51]$$

$$\lambda_\gamma = [-0.052, 0.100]$$

D0 for 0.16 fb^{-1}

$$\Delta k_\gamma = [-0.88, 0.96]$$

$$\lambda_\gamma = [-0.2, 0.2]$$

LEP2:

$$\Delta g_1^Z = [-0.051, 0.034]$$

$$\Delta k_\gamma = [-0.105, 0.069]$$

$$\lambda_\gamma = [-0.059, 0.026]$$

With constraints:

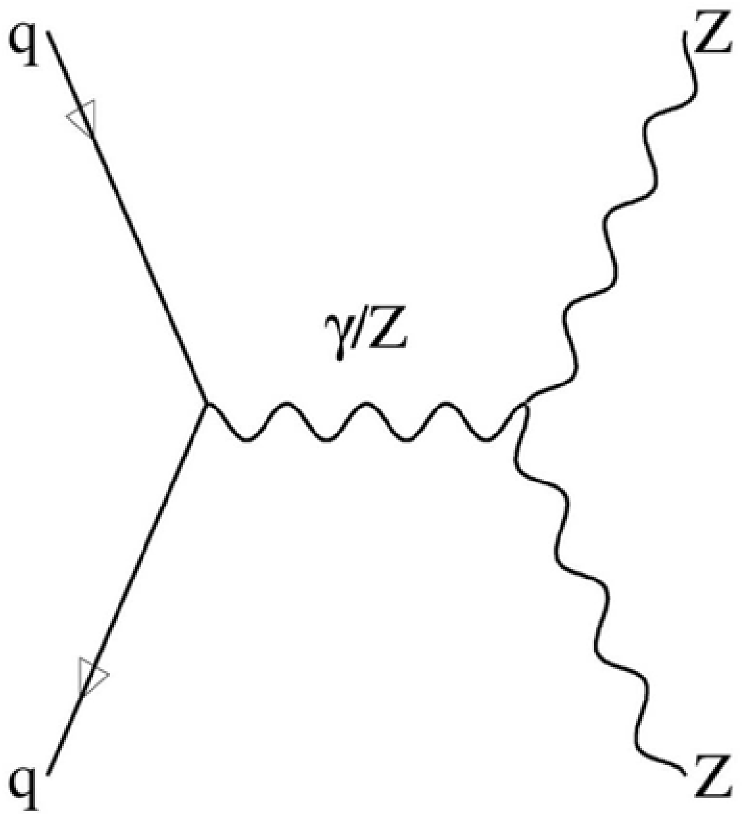
$$\Delta k_Z = \Delta g_1^Z - \Delta k_\gamma \tan^2\theta_W$$

$$\lambda_Z = \lambda_\gamma$$

Neutral Triple Gauge Couplings

In ZZ Case:

Forbidden in SM at Tree level

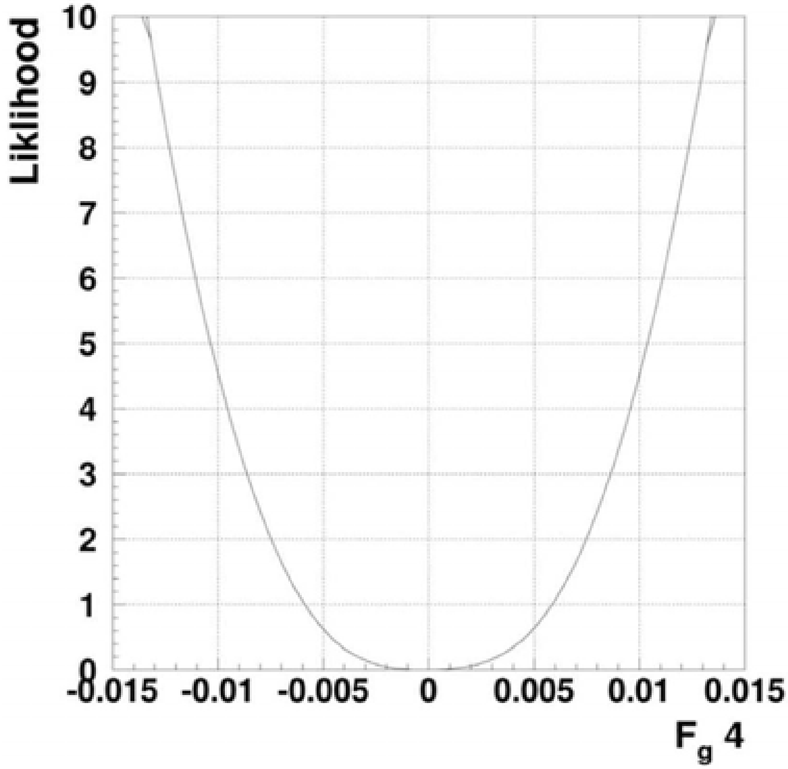


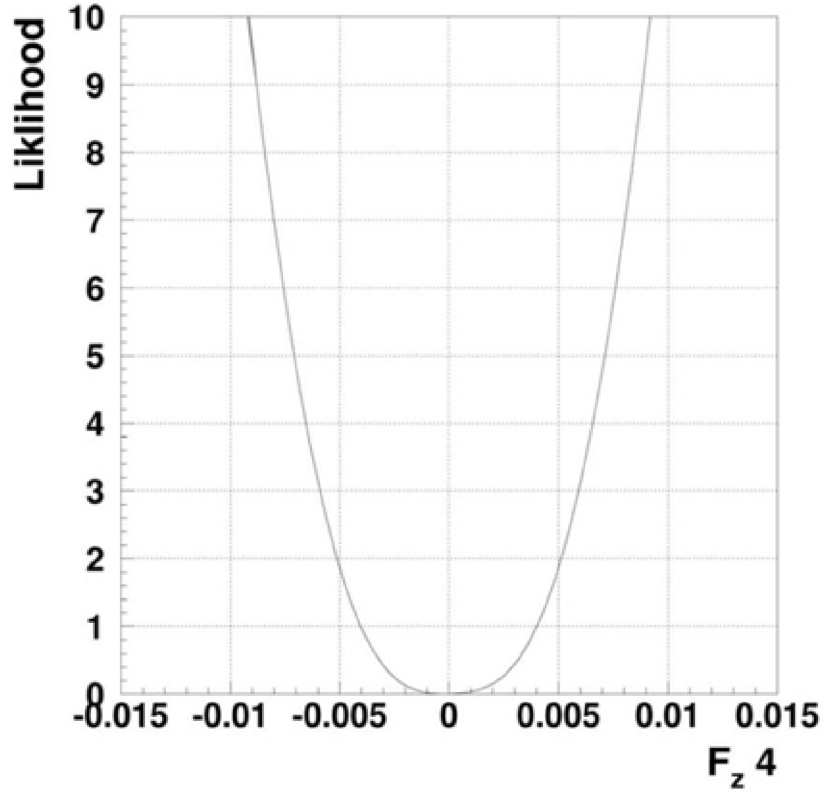
ATLAS Study Results Likelihoods and 95% C.L

Results from: ATL-PHYS-PUB-2007-015

$$-0.0051 < f_4^Z < 0.0051 \qquad -0.0053 < f_5^Z < 0.0055$$

$$-0.0075 < f_4^\gamma < 0.0075 \qquad -0.0078 < f_5^\gamma < 0.0078$$





Comparison to LEP2

- ZZ: Great improvement from LEP2
- The improvement in ZZ is due to strong energy dependence of anomalous TGC contribution to ZZ production
- E.g. F_4^Z limit 0.005 at LHC, c.f. 0.3 at LEP2

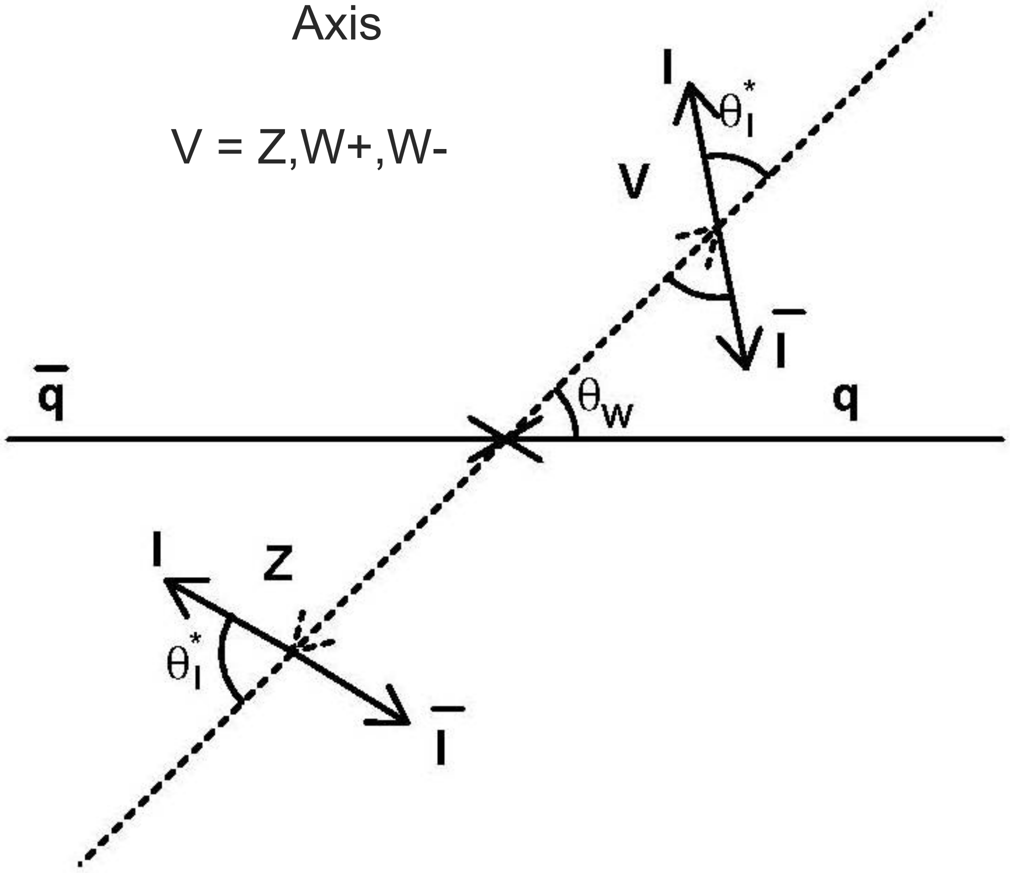
ZZ and WZ Polarization

- Z,W polarization: longitudinal and transverse
- At LHC unique opportunity to observe and study longitudinal Z,W
- Do this by studying the angular distribution of the Z,W decay products, $\cos\theta_l^*$

Angular variables

ll Production
Axis

V = Z,W+,W-



Looking at $\cos\theta_l$ for e.g. WZ:

- Angular distribution in the W rest frame:

$$\frac{1}{\sigma}\frac{d\sigma}{d\cos\theta_l} = \rho_{--}\frac{3}{8}(1+\cos\theta_l^*)^2 + \rho_{++}\frac{3}{8}(1-\cos_l^*)^2 + \rho_{00}\frac{3}{4}\sin^2\theta_l^*$$

- Angular distribution in the Z rest frame:

$$\frac{1}{\sigma}\frac{d\sigma}{d\cos\theta_l} = \rho_{--}\frac{3}{8}(1+\cos\theta_l^{*2} + 2A\cos_l^*) + \rho_{++}\frac{3}{8}(1+\cos_l^{*2} - 2A\cos_l^*) + \rho_{00}\frac{3}{4}\sin^2\theta_l^*$$

where $\rho_{--}, \rho_{++}, \rho_{00}$ are the diagonal elements of the spin density matrix(SDM)

- ρ_{00} corresponds to longitudinal polarization
- Extract $\rho_{--}, \rho_{++}, \rho_{00}$ from the data

Reconstruction $\cos\theta_l$

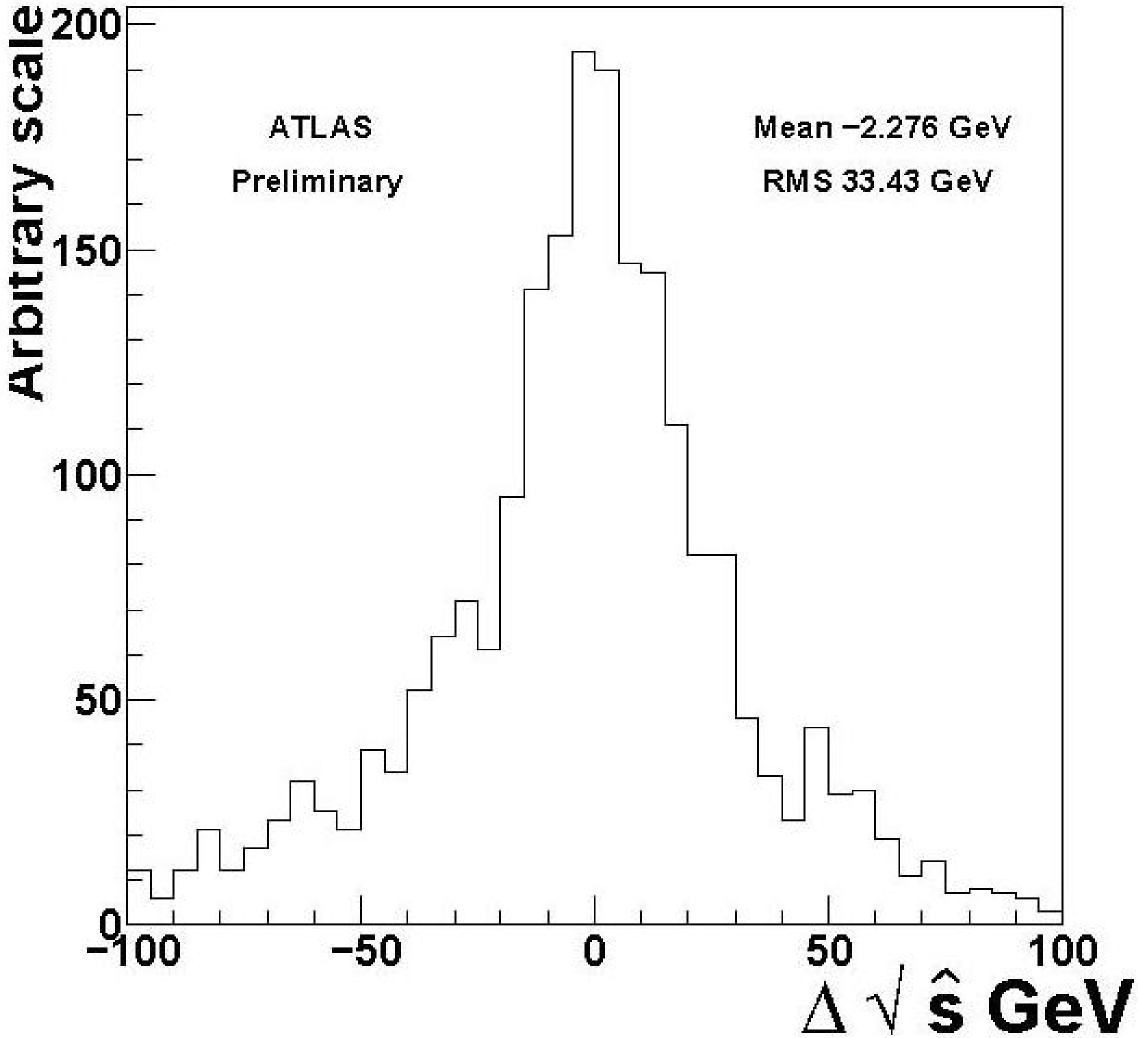
- In ZZ :trivial
- Problem in WZ: $\sqrt{\hat{s}}$ is unknown, missing P_L (neutrino)
- Therefore can not know the boost to reconstruct $\cos\theta_l$
- Solution: require lepton mom. and missing P_t to be on W mass

Reconstruction $\cos\theta_l$

- Gives quadratic equation with 2 solutions for the P_L (neutrino)
- For each P_L (neutrino) solution find the events contribution to the cross section
- Average 2 solutions for P_L (neutrino) according to the cross section weight
- Find estimated $\sqrt{\hat{s}}$ and find $\cos\theta_l^*$

Difference Between True and Reconstructed $\sqrt{\hat{s}}$

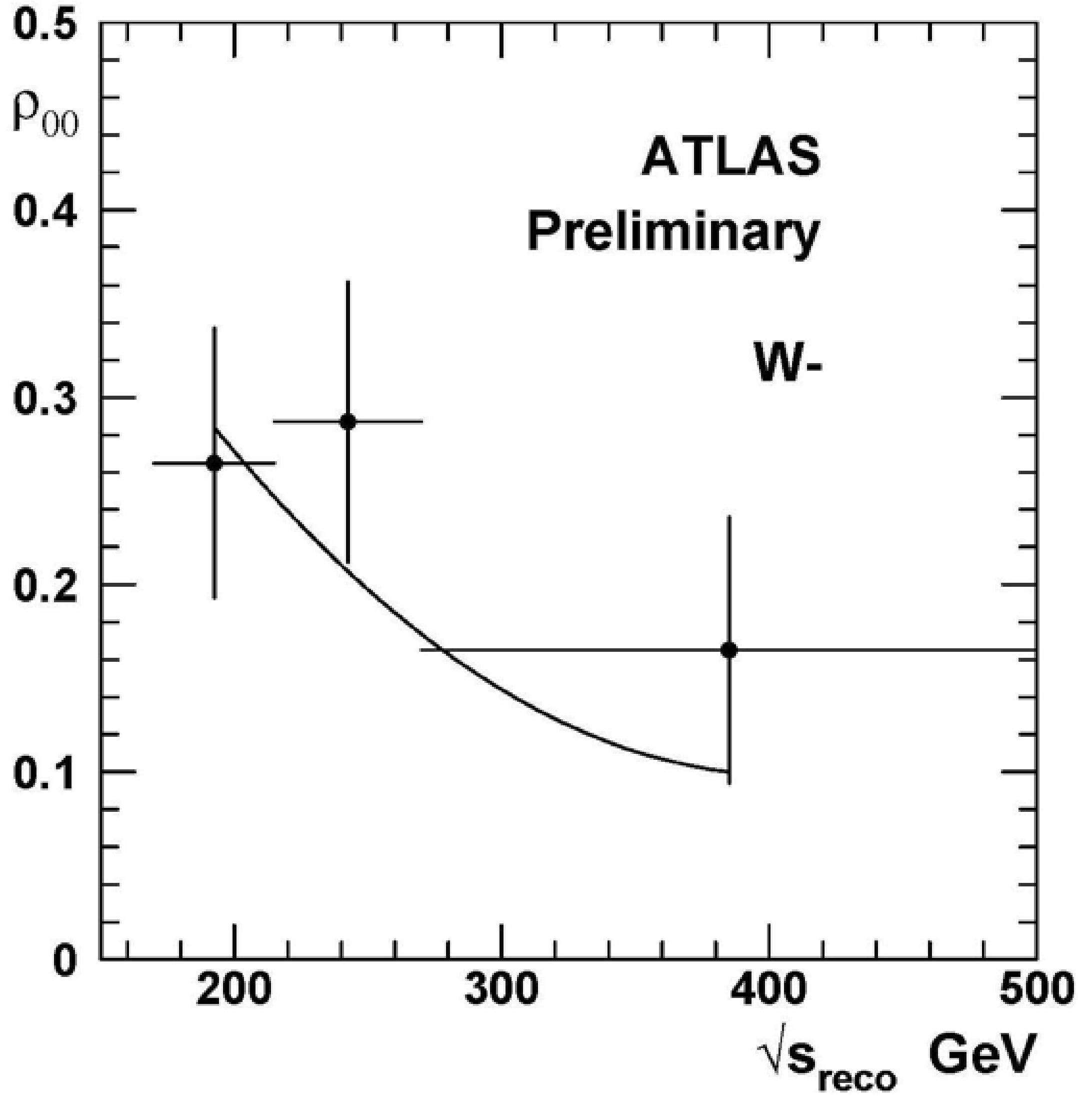
Result from: ATL-PHYS-PUB-2009-078



ρ_{00} As a Function of $\sqrt{\hat{s}}$ For WZ

Result from:
ATL-PHYS-PUB
-2009-078

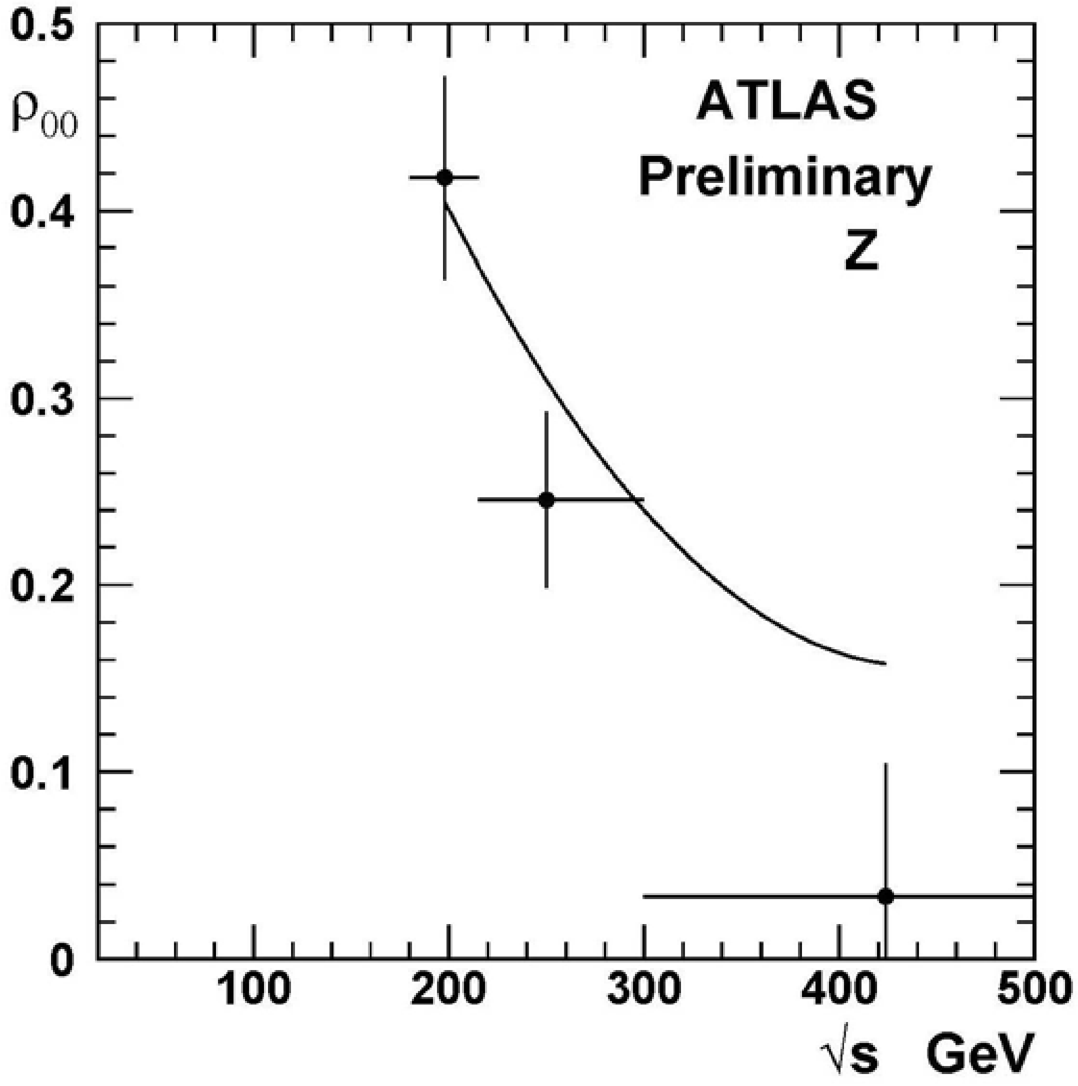
For L = 100fb $^{-1}$



ρ_{00} As a Function of $\sqrt{\hat{s}}$ For ZZ

Result from:
ATL-PHYS-PUB-2008-002

For L = 100fb^{-1}



Summary

- Di-Boson cross section can be measured with low luminosity
- TGC expected limits for WWZ, WWγ, ZZZ and ZZγ were presented
- Expected limits on NTGC improved in LHC from LEP2
- With high luminosity, polarization measurements in ZZ and WZ events are feasible

Backup slides

TGC limits

ATLAS Limits:

Table 21: One-dimensional 95% C.L. interval of the WWZ and $WW\gamma$ anomalous coupling sensitivities from the WW final state analysis for 0.1, 1, 10 and 30 fb^{-1} integrated luminosities, with $\Lambda = 2$ TeV.

Int. Lumi (fb^{-1})	$\Delta\kappa_Z$	λ_Z	Δg_1^Z	$\Delta\kappa_\gamma$	λ_γ
0.1	[-0.242, 0.356]	[-0.206, 0.225]	[-0.741, 1.177]	[-0.476, 0.512]	[-0.564, 0.775]
1.0	[-0.117, 0.187]	[-0.108, 0.111]	[-0.355, 0.616]	[-0.240, 0.251]	[-0.259, 0.421]
10.0	[-0.035, 0.072]	[-0.040, 0.038]	[-0.149, 0.309]	[-0.088, 0.089]	[-0.074, 0.165]
30.0	[-0.026, 0.048]	[-0.028, 0.027]	[-0.149, 0.251]	[-0.056, 0.054]	[-0.052, 0.100]

Tevatron Limits

Table 3: Anomalous gauge coupling limits (95% C.L.) for $WW\gamma$ and WWZ from the Tevatron experiments, with $\Lambda = 2$ TeV.

Coupling	Source	L (fb^{-1})	λ_Z	$\Delta\kappa_Z$	$\Delta\kappa_\gamma$	λ_γ
$WW\gamma$ from $W^\pm\gamma$	D0 [27]	0.16			[-0.88, 0.96]	[-0.2, 0.2]
WWZ from $W^\pm Z$	D0 [24]	1.0	[-0.17, 0.21]	[-0.12, 0.29]		
WWZ from $W^\pm Z$	CDF	1.9	[-0.13, 0.14]	[-0.82, 1.27]		
$WWZ = WW\gamma$ from W^+W^-	D0 [30]	0.25	[-0.31, 0.33]	[-0.36, 0.33]		
from W^+W^-, $W^\pm Z$	CDF [31]	0.35	[-0.18, 0.17]	[-0.46, 0.39]		

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