Cross Section Measurements of the Standard Model Multiboson (WW->lvlv && WWW->lllvvv)

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History of Collabration

1. WW->lvlv 7 TeV
   Shu Li's PhD thesis. Defense at 07/2012
   Supervisors: Yanwen Liu, Emmanuel Monnier ,Zhengguo Zhao

   Paper: Phys. Rev. D 87, 112001 (2013)

2. WW->lvlv 8 TeV
   To be Jun Gao's PhD thesis.
   Supervisors: Emmanuel Monnier ,Yanwen Liu

3. WWW->lvlvlv 8 TeV & 14 TeV
   To be Ruiqi Zhang's PhD thesis.
   Supervisors: Cristinel Diaconu, Emmanuel Monnier ,Yanwen Liu

OUTLINE

WW-lvlv 8 TeV analysis status

- CONF note last summer
  https://cds.cern.ch/record/1728248

- Being close to publication. Aim for summer paper.
  Supporting note for paper draft: https://cds.cern.ch/record/1612388

WWW-lvlvlv 8 TeV analysis status

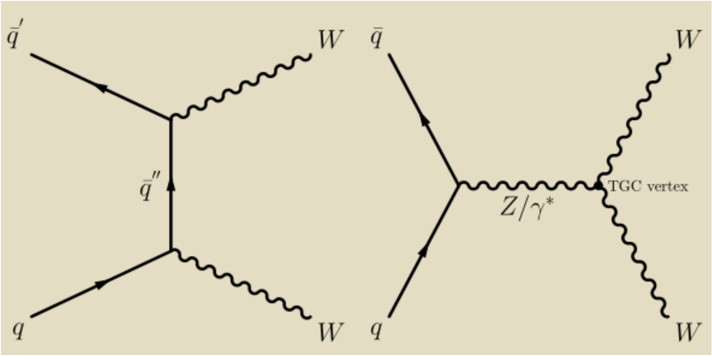
- A analysis newly started

- Will continue for Run 2

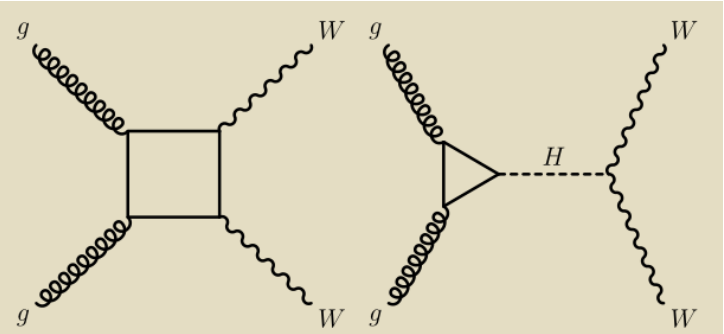
WW->lvlv

Physics Overview

qq->WW production (~90%)



gg->WW(~2%) **gg->H->WW (~6%)**



- Motivation:
  - Important test of the electroweak sector of the Standard Model
  - Irreducible background for Higgs study
  - Sensitive to new physics beyond SM

The predicted total WW cross section (NNLO) $63.2^{+2.0}_{-1.8}\,\mathrm{pb}$

Event Selection

Use full 2012 dataset : total integrated luminosity 20.3 fb^{-1}

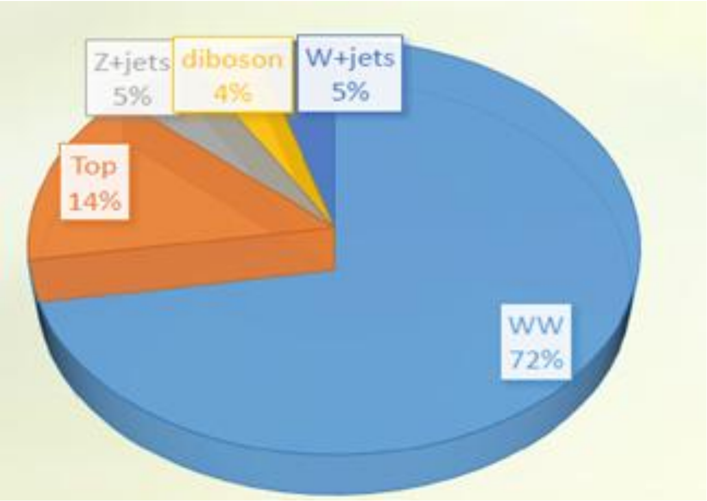
- 2 opposite sign leptons (ee, μμ, eμ channel)
  P_T(leading lepton) >25 GeV P_T(trailing lepton) >20 GeV
- Trigger requirement
- M_{ll} >15GeV (10 GeV) for ee and μμ (eμ) — *suppress QCD, Z+jets*
- $|M_{ll} - M_z|$ >15 GeV for ee and μμ
- E_T^{miss}* > 45 GeV (15 GeV) for ee and μμ (eμ)
- P_T^{miss}* > 45 GeV (20 GeV) for ee and μμ (eμ)
- $\Delta\phi(E_T^{miss}, P_T^{miss})$ < 0.3 (0.6) ee and μμ (eμ)

  suppress Z+jets
- Veto events if containing selected jets — *suppress Top*

* E_T^{miss} : calorimeter-based missing transverse momentum
* P_T^{miss} : track-based missing transverse momentum

Background estimation methods

- **Top** $t\bar{t}$ and Wt where no jets are detected
  - Jet Veto Survival Probability method (base-line)
  - Transfer Factor method
  - Simultaneous Fit method



- **W+jets** Jets fake lepton
  - Matrix method (base -line)
  - Fake Factor method

- **Z+jets** Missing Et mismeasurement
  - Silmultaneouls Fit method (base-line)
  - Transfer Factor method
  - ABCD method

- **Other Diboson** Wγ,Wγ*,WZ,ZZ
  - MC estimation

For data-driven estimation
- Take method with smaller systematics as baseline
- Other methods in agreement with the baseline

W+jets :Matrix method

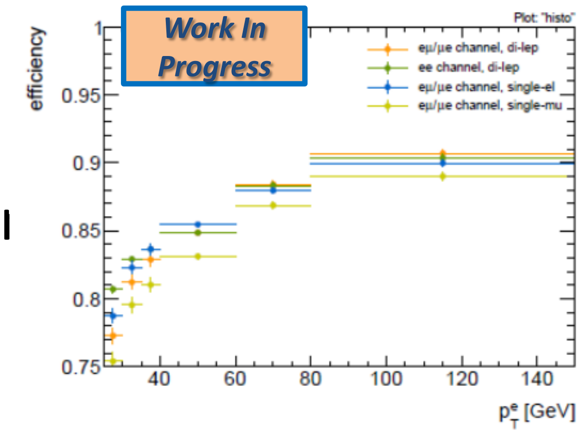
$$\begin{bmatrix} N_{RR} \\ N_{RF} \\ N_{FR} \\ N_{FF} \end{bmatrix} = \begin{bmatrix} r_1 r_2 & r_1 f_2 & f_1 r_2 & f_1 f_2 \\ r_1(1-r_2) & r_1(1-f_2) & f_1(1-r_2) & f_1(1-f_2) \\ (1-r_1)r_2 & (1-r_1)f_2 & (1-f_1)r_2 & (1-f_1)f_2 \\ (1-r_1)(1-r_2) & (1-r_1)(1-f_2) & (1-f_1)(1-r_2) & (1-f_1)(1-f_2) \end{bmatrix}^{-1}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

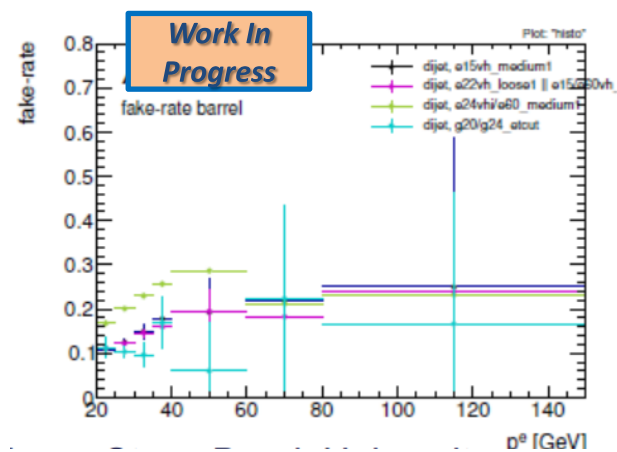
$$N_{W+\text{jets}} = N_{RF} \cdot r_1 f_2 + N_{FR} \cdot f_1 r_2$$
$$N_{\text{QCD}} = N_{FF} \cdot f_1 f_2$$

F: Fake R: real r: signal lepton efficiency f: fake rate T: tight lepton L: loose lepton

At the same time this method provides QCD estimation.

- Loose lepton definition
  No Impact parameter or isolation requiremen
- Fake rate
  Measured from di-jet events.
- Signal lepton efficiency
  Measured using MC simulation
  with data-to-MC correction
- Main Systematics
  From uncertainty on input efficiencies ~10%
  Sample dependence ~50%





Top: Jet Veto Survival Probability Method

B. Mellado, X. Ruan ,Z. Zhang
Phys. Rev. D 84 (2011) 096005.

- Two Control regions:

1st CR:

To compare jet-veto efficiency between DATA and MC

Select pure top events by b-tag requirement

2nd CR:

To derive jet-veto efficiency in top MC

Full selection with Ht*>130GeV instead of jet-veto

Ht : scalar sum of P_T for leptons and jets
To suppress the signal contamination

- Main Systematics:

  - Experimental uncertainties
    Jet Energy Scale(JES) ~4%, Jet Energy Resolution(JER) ~2%, B-tagging ~4%

  - Theoretical uncertainties
    MC generator/Parton Shower ~6%
    Non-top subtraction in the 1^{st} CR ~2%

Z+jets : Simultaneous fit

- This method use the template fit to simultaneously constrain the background and signal normalization

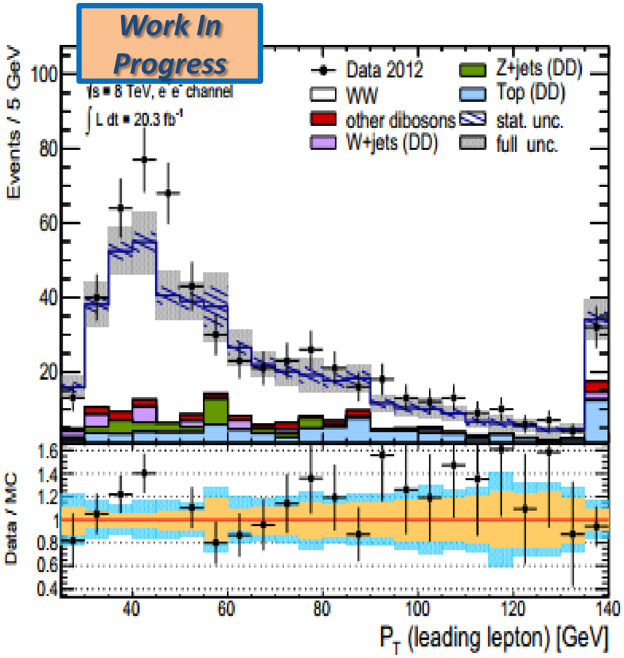
- In our analysis, Top fixed by JVSP and W+jets fixed by Matrix method

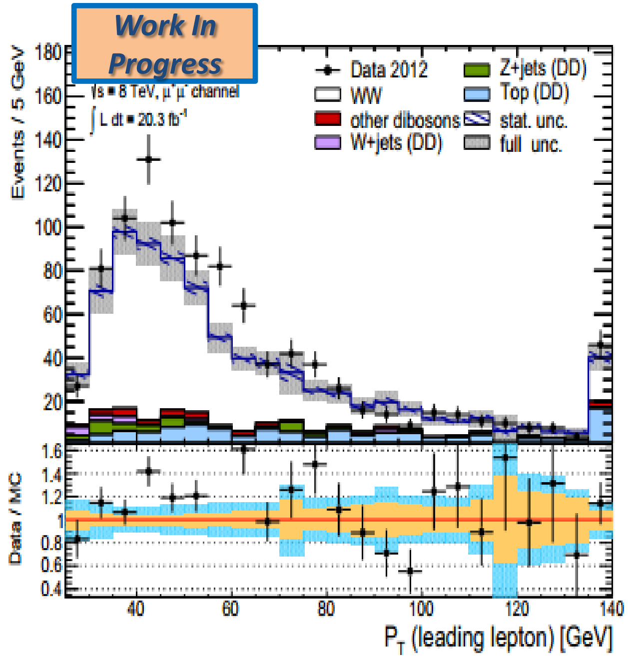
- DY control region: remove $\Delta\phi(E_T^{miss}, P_T^{miss})$ cut , and invert P_t^{miss}

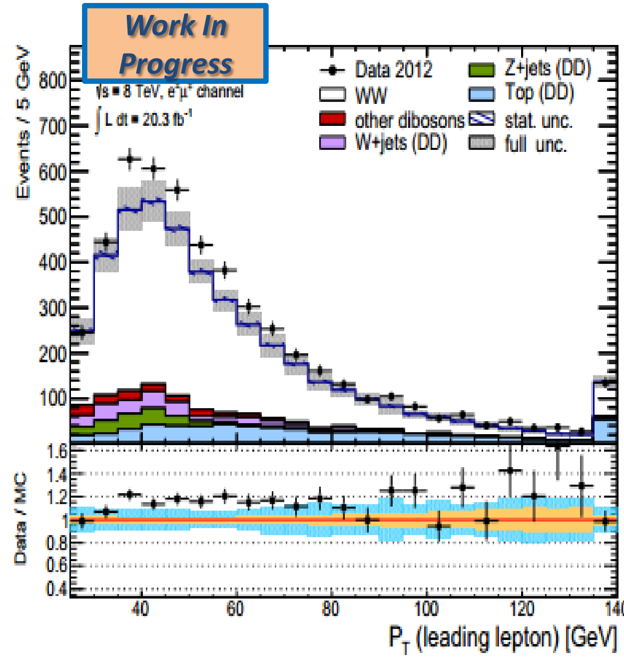
- Drell-Yan normalisation extracted from the fit

- Main systematic sources
  Jet Energy Scale(JES) ~4%, Jet Energy Resolution(JER) ~2%,Missing ET ~4%, MC parton shower ~7%

Distributions for selected events







- Data ~20% off
- Shape in agreement between data and prediction

Aww , Cww , systematics

Reconstruction Efficiency
(Correction factor)

$$C_{WW} = \frac{N^{reco\ in fiducial\ region}_{WW \to l\nu l\nu}}{N^{gen\ in fiducial\ region}_{WW \to l'\nu l'\nu}}$$

Acceptance

$$A_{WW} = \frac{N^{gen\ in fiducial\ region}_{WW \to l'\nu l'\nu}}{N^{all\ gen}_{WW \to l'\nu l'\nu}}$$

Take eμ channel as an example

- Experimental uncertainties
  mainly from pileup (1.3%) , missing ET (~3%), jet energy scale(~4%), jet energy resolution(1.3%)

- Theotical uncertainties
  jet veto (4.3%) , Parton Shower+Generator (4.0%)

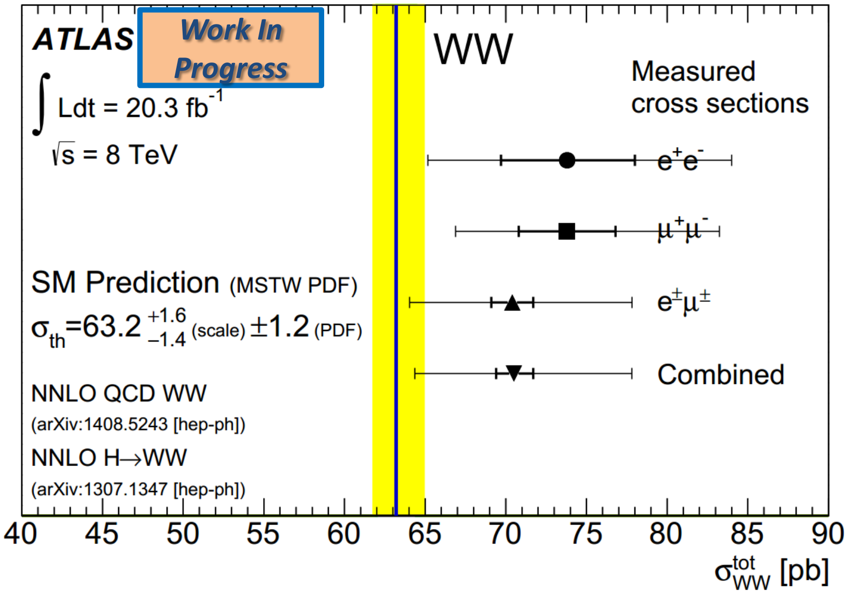
Cross-section

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

- Determined from the three channels observed candidates by minimising the log-likelihood function

Work In Progress

Channel	Cross Section [pb]
ee	$73.9^{+4.2}_{-4.1}$(stat) $^{+9.0}_{-7.3}$(syst) $^{+2.3}_{-2.1}$(lumi)
$\mu\mu$	$73.8^{+3.1}_{-3.0}$(stat) $^{+8.4}_{-6.9}$(syst) $^{+2.2}_{-2.1}$(lumi)
$e\mu$	$70.4^{+1.3}_{-1.3}$(stat) $^{+6.9}_{-5.8}$(syst) $^{+2.1}_{-2.0}$(lumi)
combined	$70.6^{+1.1}_{-1.1}$(stat) $^{+6.7}_{-5.6}$(syst) $^{+2.1}_{-2.0}$(lumi)



Compared to theory 63.2 pb (NNLO)

+1.1σ deviation

WWW->lvlvlv

Introduction

- Motivation :
  - 4-W vertex never directly measured before . Place limits for aQGC
  - Sensitive to HWW coupling .

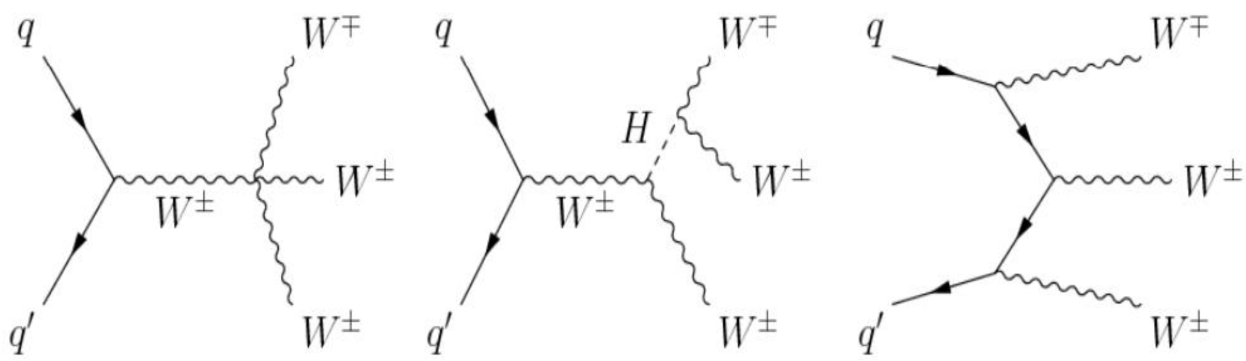
$$\mathcal{L}_{s,0} = [(D_\mu\phi)^\dagger D_\nu\phi] \times [(D^\mu\phi)^\dagger D^\nu\phi]$$

$$\mathcal{L}_{s,1} = [(D_\mu\phi)^\dagger D^\mu\phi] \times [(D_\nu\phi)^\dagger D^\nu\phi]$$

Φ is Higgs doublet

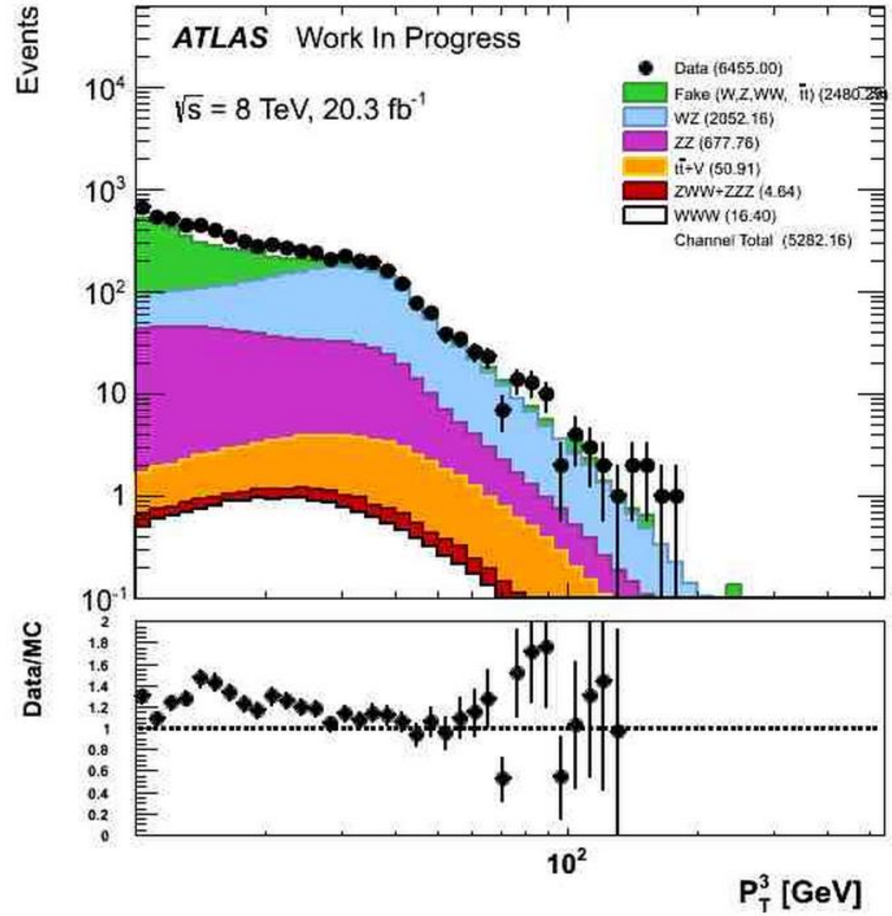
$$\mathcal{L}_{eff} = \mathcal{L}_{SM} + \frac{f_{s0}}{\Lambda^4}\mathcal{L}_{s,0} + \frac{f_{s1}}{\Lambda^4}\mathcal{L}_{s,1}$$

- Signal & Background:
  - Signal: Processes with 3W(lv) in final state .
    In 2012 data 1/3 from electroweak WWW production, 2/3 involving Higgs.
  - Bkg: WW,WZ,ZZ,ttbar,Z+jets,W+jets



Event Pre-selection and backgrounds

- Event PreSelection:
  - Trigger
    - Single lepton trigger
  - Exactly 3 leptons.
    - PT > 15 GeV,
    - Trigger matching.
      At least 1 pT>1GeV above online cut
- Backgrounds
  - Source of real three leptons from MC:
    - WZ, ZZ, ttV.
  - Charge flip leptons:
    - Measure with Likelihood and T&P
  - Fake Leptons (W,Z, WW ,tt)
    - Generalized Matrix method.
- Classification
  - Events are classified depending on the number of Same Flavor Opposite Sign (SFOS) pairs
    e.g. WZ mostly belongs to 1SFOS
  - Veto Z-peak for 1 SFOS and 2 SFOS



0 SFOS: $e^\pm e^\pm \mu^\mp, \mu^\pm \mu^\pm e^\mp$ $(e^\pm e^\pm \mu^\pm, \mu^\pm \mu^\pm e^\pm, e^\pm e^\pm e^\pm, \mu^\pm \mu^\pm \mu^\pm)$

1 SFOS: $e^\pm e^\mp \mu^\pm, e^\pm e^\mp \mu^\mp, \mu^\pm \mu^\mp e^\pm, \mu^\pm \mu^\mp e^\mp$

2 SFOS: $e^\pm e^\pm e^\mp, \mu^\pm \mu^\pm \mu^\mp$

Charge Mis-ID Measurement

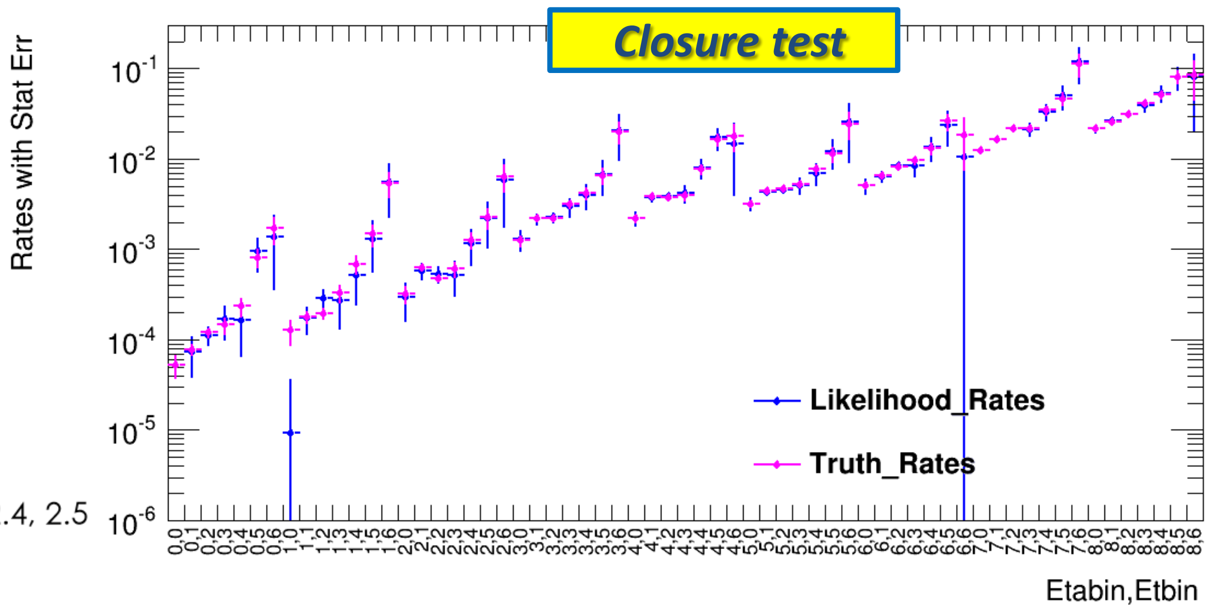
Work In Progress

- To estimate the background with electron charge mis-identification
  - Muon case neglected
  - Mostly from bremsstrahlung e->eγ->eee

- 2 Methods. Both parameterized as the function of pT and η
  - Use Z->ee events from data (base-line)
  - Truth method (Cross-check)

    Use Z->ee MC and compare reconstructed charge with truth charge.

- 2 methods agree well



Bins:

- E_T: 15, 30, 40, 50, 60, 80, 120, 1000,
- η :0., 0.8, 1.15, 1.60, 1.80, 2.0, 2.2, 2.3, 2.4, 2.5

Anomalous Quartic Gauge Couplings

$$\mathcal{L}_{eff} = \mathcal{L}_{SM} + \frac{f_{s0}}{\Lambda^4}\mathcal{L}_{s,0} + \frac{f_{s1}}{\Lambda^4}\mathcal{L}_{s,1}$$

$$\mathcal{L}_{s,0} = [(D_\mu\phi)^\dagger D_\nu\phi] \times [(D^\mu\phi)^\dagger D^\nu\phi]$$

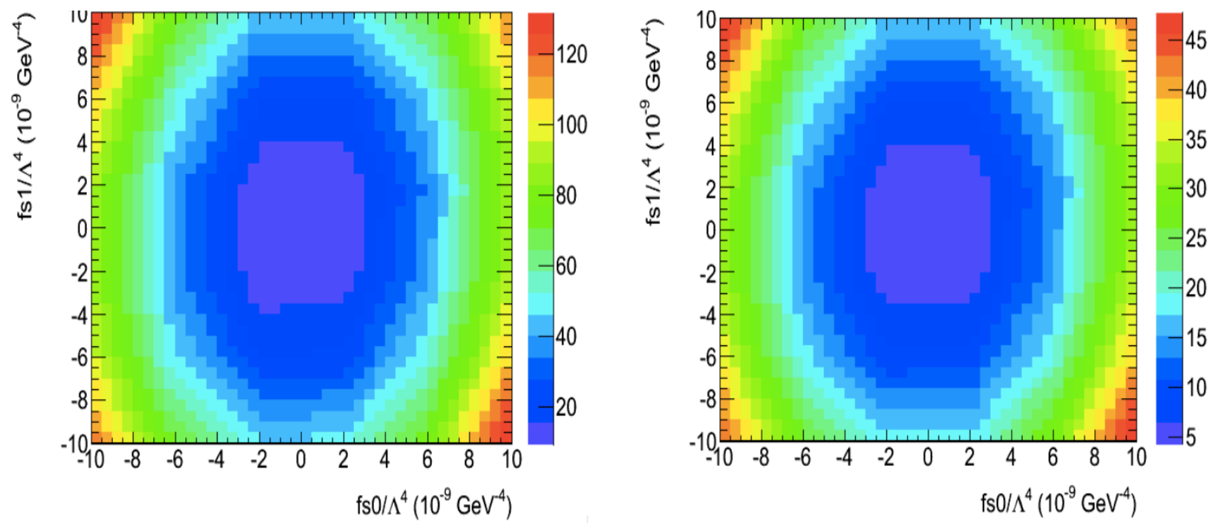
$$\mathcal{L}_{s,1} = [(D_\mu\phi)^\dagger D^\mu\phi] \times [(D_\nu\phi)^\dagger D^\nu\phi]$$

- Effective Lagrangian. The cross-section sensitive to $\frac{f_{s0}}{\Lambda^4}$. and $\frac{f_{s1}}{\Lambda^4}$.
- Samples generated and simulated
- Ongoing study

  Might optimize the selection for better aQGC study

  Calculate the limits with official tool

  Theoretical uncertainties evaluation



Work In Progress

Summary

WW analysis

- in 0-jet bin for purely leptonic channel. Classical measurement for electro-weak analysis and also important for Higgs studies or new physics.
- Cross-section measurement as well as unfolding/atgc study already performed
- CONF note released. Towards the paper publication

WWW analysis

- Represent the first inclusive measurement for the WWW production . Sensitive to aQGC and HWW couplings.
- A new analysis in Run1 . Will continue in Run2

- Thanks for your attention

- backup

Object selection for WW 8 TEV

Muon: Combined , IDhits
- $|\eta|<2.4$, pt>7 GeV
- $Z0*\sin(\theta)$ <1 mm sig (d0)<3
- Calo Isolation
  - 7<pt≤15GeV, Etcone30/Pt<0.06
  - 15<pt≤20GeV, Etcone30/Pt<0.12
  - 20<pt≤25GeV, Etcone30/Pt<0.18
  - pt>25GeV, Etcone30/Pt<0.30
- Track Isolation
  - 7<pt≤15GeV, Ptcone40/Pt<0.06
  - 15<pt≤20GeV, Ptcone30/Pt<0.08
  - pt>20GeV, Ptcone30/Pt<0.12
- overlap removal with jet

Electron: author , good OQ , pt>7 GeV
- $|\eta|<2.4$ exclude crack region
- VeryTight likelihood eID
- $Z0*\sin(\theta)$ <0.4 mm sig (d0)<3
- Calo Isolation
  - 7<pt≤15GeV,TopoEtcone30/Pt<0.20
  - 15<pt≤20GeV, TopoEtcone30/Pt<0.24
  - pt>20GeV, TopoEtcone30/Pt<0.28
- Track Isolation
  - 7<pt≤15GeV, Ptcone40/Pt<0.06
  - 15<pt≤20GeV, Ptcone30/Pt<0.08
  - pt>20GeV, Ptcone30/Pt<0.10
- overlap removal with jet

Jet : ANtiKt4TopoLCjets
- $|\eta|<4.5$, pt>25 GeV , JVF >0.5 for jets $|\eta|<2.4$, pt<50 GeV
- !Ugly !LooserBad
- overlap removal with electron

Impact parameter & Isolation for leptons : Basically Follow HSG3 definition

Object selection for WWW

- Electrons:
  - (author is 1 or 3) and Tight++
  - PT > 15 GeV § |η|< 1.37 or 1.52 < |η| < 2.47
  - I ETcone20/ET < 0.10 for pT > 20GeV
  - I ETcone20/ET < 0.07 for pT < 20GeV
  - I pTcone20/pT < 0.04
  - |d0/sigma d0| < 3.0
  - z0/sigma z0| < 0.5mm
  - No duplicate μ or e within ΔR < 0.1
- Jets:
  - Anti-kT 4 LC Topo Jets
  - PT > 25 GeV
  - |η|< 4.5
  - JVF > 0.5 for jets with |η| < 2.4 and PT < 50GeV
  - No duplicate μ or e within ΔR < 0.2
- Muons:
  - Tight STACO Combined
  - PT > 15 GeV
  - |η| < 2.5
  - MCP ID Hits selection
  - I ETcone20/ET < 0.10 for pT > 20GeV
  - I ETcone20/ET < 0.07 for pT < 20GeV
  - I pTcone20/pT < 0.04
  - |d0/sigma d0| < 3.0
  - z0/sigma z0| < 0.5mm
  - No duplicate e within ΔR < 0.1
- MET:
  - Use STVF

Signal region

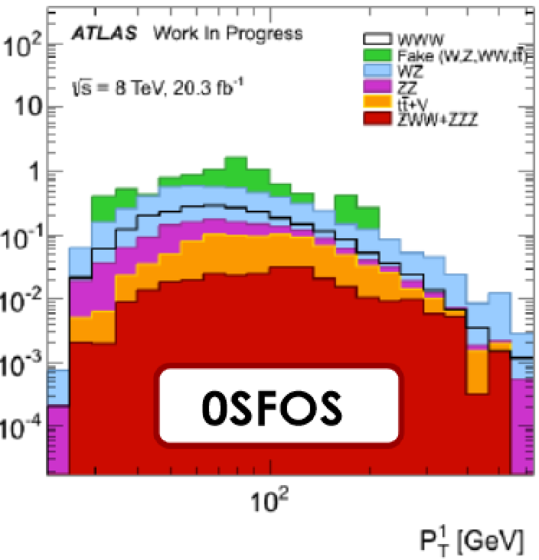
Work In Progress

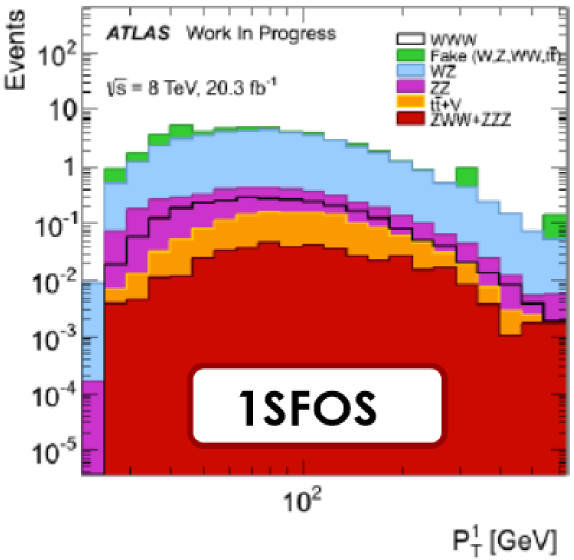
SR	0SFOS	1SFOS	2SFOS
Lepton p_T	p_T>20 GeV		
E_T^{miss}	-	E_T^{miss}>40 GeV	E_T^{miss}>35GeV
Z Veto	-	$\|m_{SFOS}-m_Z\|$>15 GeV	
b-tag jet veto	70% b-tag working point		

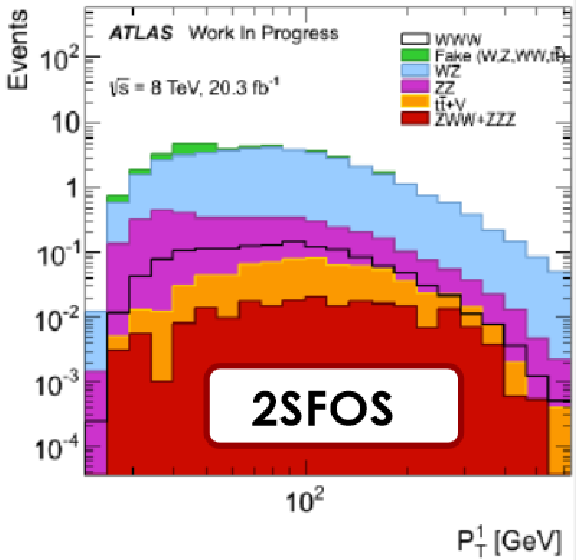
- Include the MC samples and charge mis-ID study
- No systeamtics included
- To be updated once new data-driven study ready

0 SFOS yield

	Contribution to Total BG [%]
WZ	40
ttbar	40
ttbar + V	7
ZZ	7
VVV	3
WW	3
Other	< 1
Total [%]	100
Total Events @ 20.3 fb-1	13







Top: Jet Veto Survival Probability Method

(Phys. Rev. D 84 (2011) 096005.)

Work In Progress

- Two Control regions:

1st CR: Subset of 2^{nd} CR. Require a b-jet as tag jet.
Study the jet-veto efficiency for probing jet.
To compare jet-veto efficiency from DATA and from MC

* Ht : scalar sum of P_T for leptons and jets

2nd CR: Full selection with Ht*>130GeV instead of jet-veto
Ht cut is to suppress the signal contamination
To derive jet-veto efficiency in MC

$$P_2^{\mathrm{Data}} = \left(P_{1(\mathrm{Btag})}^{\mathrm{DATA}}\right)^2 \times \frac{P_2^{\mathrm{MC}}}{\left(P_{1(\mathrm{Btag})}^{\mathrm{MC}}\right)^2}$$

$$N_{Top}^{DATA}(0\,jet) = N_{Top}^{DATA}(all) \times P_2^{DATA}$$

- Main Systematics:

  - Experimental uncertainties
    Jet Energy Scale(JES) ~4%, Jet Energy Resolution(JER) ~2%, B-tagging ~4%

  - Theoretical uncertainties
    MC generator/Parton Shower ~6%
    Non-top subtraction in the 1^{st} CR ~2%

Fiducial cross-section

$$\sigma_{WW}^{fiducial} = \frac{N_{obs} - N_{bkg}}{C_{WW}\,\mathcal{L}}$$

Channel	Cross Section [fb]
ee	$73.7^{+4.2}_{-4.1}$(stat) $^{+7.2}_{-6.2}$(syst) $^{+2.3}_{-2.1}$(lumi)
$\mu\mu$	$80.1^{+3.3}_{-3.2}$(stat) $^{+7.2}_{-6.1}$(syst) $^{+2.4}_{-2.3}$(lumi)
$e\mu$	$373.5^{+6.9}_{-6.8}$(stat) $^{+26.6}_{-23.6}$(syst) $^{+11.2}_{-10.5}$(lumi)

Process	σ [pb]	Δ_σ^{Total} [pb]	Δ_σ^{Scale}	Δ_σ^{PDF}	$\Delta_\sigma^{Br.}$	Calculation
1) $q\bar{q} \rightarrow WW$	53.2	$^{+2.5}_{-2.2}$	$^{+2.3}_{-1.9}$	$^{+1.0}_{-1.1}$	-	NLO MCFM
2) $gg \rightarrow WW$	1.4	$^{+0.3}_{-0.2}$	$^{+0.3}_{-0.2}$	$^{+0.1}_{-0.1}$	-	LO MCFM
3) $q\bar{q} \rightarrow WW$	59.1	$^{+1.6}_{-1.7}$	$^{+1.2}_{-1.0}$	$^{+0.9}_{-0.9}$	-	NNLO [7]
4) $gg \rightarrow H \rightarrow WW$	4.1	±0.5	$\pm$ 0.3	±0.3	±0.2	NNLO [8]
W^+W^- production (pNNLO)	58.7	$^{+3.0}_{-2.7}$	$^{+2.7}_{-2.3}$	$^{+1.3}_{-1.4}$		1)+2)+4)
W^+W^- production (NNLO)	63.2	$^{+2.0}_{-1.8}$	$^{+1.6}_{-1.4}$	$^{+1.2}_{-1.2}$		3)+4)