Measurement of the WW Production Cross Section in Proton-Proton Collisions with the ATLAS Detector

Jun Gao[a,b], Shu Li[a,b,c] ,Yanwen Liu[b], Emmanuel Monnier[a] , Ruiqi Zhang[b]

[a]**C**entre de **P**hysique des **P**articules de **M**arseille
[b]**U**niversity of **S**cience and **T**echnology of **C**hina
[c] now at Duke University

7th FCPPL workshop in Clermont-Ferrand in April 2014

OUTLINE

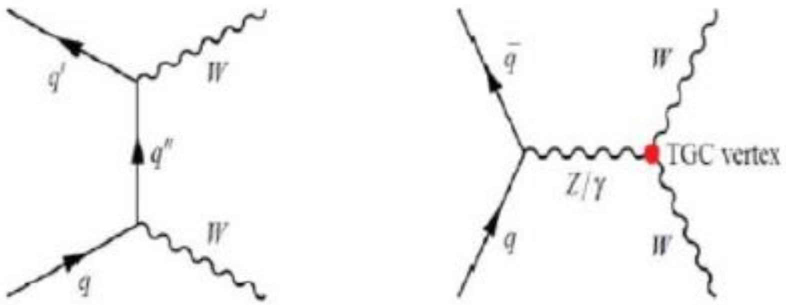
- WW analysis status

  1) 7 TeV results
  2) 8 TeV progress

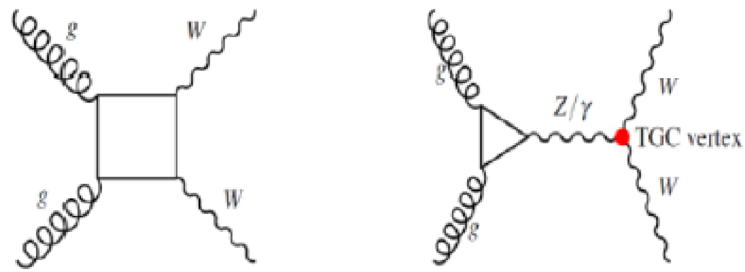
- WWW analysis status

Introduction

qq->WW production



gg->WW contributes additional ~3% of WW event



- Motivation:
  - ✓ Important test of the electroweak sector of the Standard Model
  - ✓ Irreducible background for Higgs searches.
  - ✓ Sensitive to anomalous triple gauge couplings

- Characteristics:

Isolated high pT di-lepton final states are considered: ee, eμ, μμ

High Missing transverse Energy

✓ Main backgrounds:

Z+jets : Missing transverse Energy mismeasurement

Top : ttbar and Wt where no jets are detected

W+jets : jet fakes lepton

Other dibosons : Wγ , WZ, ZZ

Event Selection for 7 TeV

- General Preselection and Object Definition similar to Electroweak-Common Recommendations. In particular:
  - muon Pt>20GeV, |η|<2.4,
  - Tight++ electron Pt>20GeV , |η|<2.47 w/o crack
  - jet, pT>25GeV and |η|<4.5

- Event-Selection

  Opposite sign leptons with pT>20(trailing),25(leading)GeV

  To remove Z+jets contribution

  - $|M_{ll}-M_Z|$>15GeV for ee and μμ
  - M_{ll}>15GeV for ee and μμ, and M_{ll}> 10 GeV for eμ
  - pT(ll) >30GeV for all three channels

  Further reduce Drell-Yan and QCD multi-jet contributions:

  - MET^{Rel} > 45,45 GeV for μμ and ee, 25 GeV for eμ

  Remove top contribution

  - Jet veto: no jets of ET > 25 GeV within |η| < 4.5
  - Bjet veto: reject events if at least one b-jet with pT>20GeV

Channel	Period	Trigger
μ	D-I	mu18_MG
μ	J-M	mu18_MG_medium
e	D-J	e20_medium
e	K	e22_medium
e	L-M	e22vh_medium1

Result for 7 TeV paper

Measurement of the W+W- Production Cross Section in Proton-Proton Collisions at sqrt(s) = 7 TeV with the ATLAS Detector and Limits on the Anomalous Triple-Gauge-Boson Couplings

Support Note: ATL-COM-PHYS-2012-189 (Sec 4 5 6 7 8 9 11 12, Appendix: A B C)

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

Shu Li's PHD these.

WW cross section measurement in dileptonic channel using 4.6 fb^{-1} data

	ee	$\mu\mu$	$e\mu$	Combined
Data	174	330	821	1325
WW	$100 \pm 2 \pm 9$	$186 \pm 2 \pm 15$	$538 \pm 3 \pm 45$	$824 \pm 4 \pm 69$
Top	$22 \pm 12 \pm 3$	$32 \pm 14 \pm 5$	$87 \pm 23 \pm 13$	$141 \pm 30 \pm 22$
W + jets	$21 \pm 1 \pm 11$	$7 \pm 1 \pm 3$	$70 \pm 2 \pm 31$	$98 \pm 2 \pm 43$
Drell-Yan	$12 \pm 3 \pm 3$	$34 \pm 6 \pm 10$	$5 \pm 2 \pm 1$	$51 \pm 7 \pm 12$
Other dibosons	$13 \pm 1 \pm 2$	$21 \pm 1 \pm 2$	$44 \pm 2 \pm 6$	$78 \pm 2 \pm 10$
Total background	$68 \pm 12 \pm 13$	$94 \pm 15 \pm 13$	$206 \pm 24 \pm 35$	$369 \pm 31 \pm 53$

The prediction of the SM WW in the table normalized to the theoretical prediction

The total WW production x-section

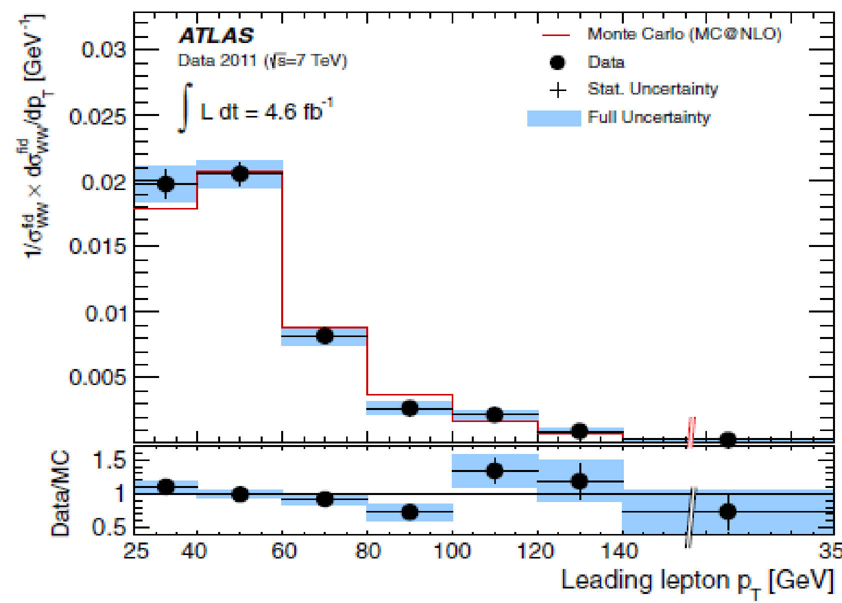
Measured xsection 51.9 ± 2.0(stat) ± 3.9(syst) ± 2.0(Lumi)pb is consistent with the theoretical prediction of 44.7±2.0 pb.

Result for 7 TeV paper

- The reconstructed pT distribution of the leading lepton is used to extract limits on anomalous WWZ and WWγ couplings
- aTGC limits are updated and getting more restrictive than Tevatron results

Scenario	Parameter	Expected ($\Lambda = 6$ TeV)	Observed ($\Lambda = 6$ TeV)	Expected ($\Lambda = \infty$)	Observed ($\Lambda = \infty$)
LEP	$\Delta\kappa_Z$	[−0.043, 0.040]	[−0.045, 0.044]	[−0.039, 0.039]	[−0.043, 0.043]
	$\lambda_Z = \lambda_\gamma$	[−0.060, 0.062]	[−0.062, 0.065]	[−0.060, 0.056]	[−0.062, 0.059]
	Δg_1^Z	[−0.034, 0.062]	[−0.036, 0.066]	[−0.038, 0.047]	[−0.039, 0.052]
HISZ	$\Delta\kappa_Z$	[−0.040, 0.054]	[−0.039, 0.057]	[−0.037, 0.054]	[−0.036, 0.057]
	$\lambda_Z = \lambda_\gamma$	[−0.064, 0.062]	[−0.066, 0.065]	[−0.061, 0.060]	[−0.063, 0.063]
Equal couplings	$\Delta\kappa_Z$	[−0.058, 0.089]	[−0.061, 0.093]	[−0.057, 0.080]	[−0.061, 0.083]
	$\lambda_Z = \lambda_\gamma$	[−0.060, 0.062]	[−0.062, 0.065]	[−0.060, 0.056]	[−0.062, 0.059]

The measured leading lepton pT distribution is unfolded to provide a differential cross-section measurement in the fiducial phase space and allows a comparison with different theoretical models.



8 TeV features

- WW cross section measurement in dileptonic channel using 20.3 fb^{-1} data (2012 full dataset)

- Selection strategy re-optimized from 2012 analysis

Main changes to the Analysis with Respect to the 7 TeV analysis

1) The lepton definition has been altered to be more robust against pile-up effect
2) The pT (ll) cut has been removed . A new cut on track MET has been introduced to further suppress DY contribution
3) Di-lepton trigger introduced

ee, μμ : Dilepton trigger

eμ: OR of dilepton trigger and single lepton trigger

- Triggers
  - ee: EF_2e12Tvh_loose1
  - mm: EF_mu18_tight_mu8_EFFS
  - em: EF_e24vhi_medium1, EF_e60_medium1, EF_mu24i_tight, EF_mu36_tight, EF_e12Tvh_medium1_mu8

Dataset cutflow and Signal-background events

Cuts	ee	$\mu\mu$	$e\mu$	Combined
2 leptons	5973852	10468599	168163	16610614
opposite-sign	5959214	10464315	157773	16581302
$\ell\ p_T$, trigger-match	4891345	8450460	85080	13426885
$M(\ell\ell) > 10/15$ GeV	4880968	8427076	85036	13393080
$\lvert M(\ell\ell) - M_Z\rvert < 15$ GeV	409977	728999	—	1224012
$E_{T,\text{Rel}}^{\text{miss}} > 15/45$ GeV	11649	20249	53468	85366
$p_T^{\text{miss}} > 20/45$ GeV	5850	9402	44929	60181
$\Delta\phi(E_T^{\text{miss}}, p_T^{\text{miss}}) < 0.6/0.3$	2646	4390	28292	35328
Jet veto	585	975	5093	6653

Work In Progress

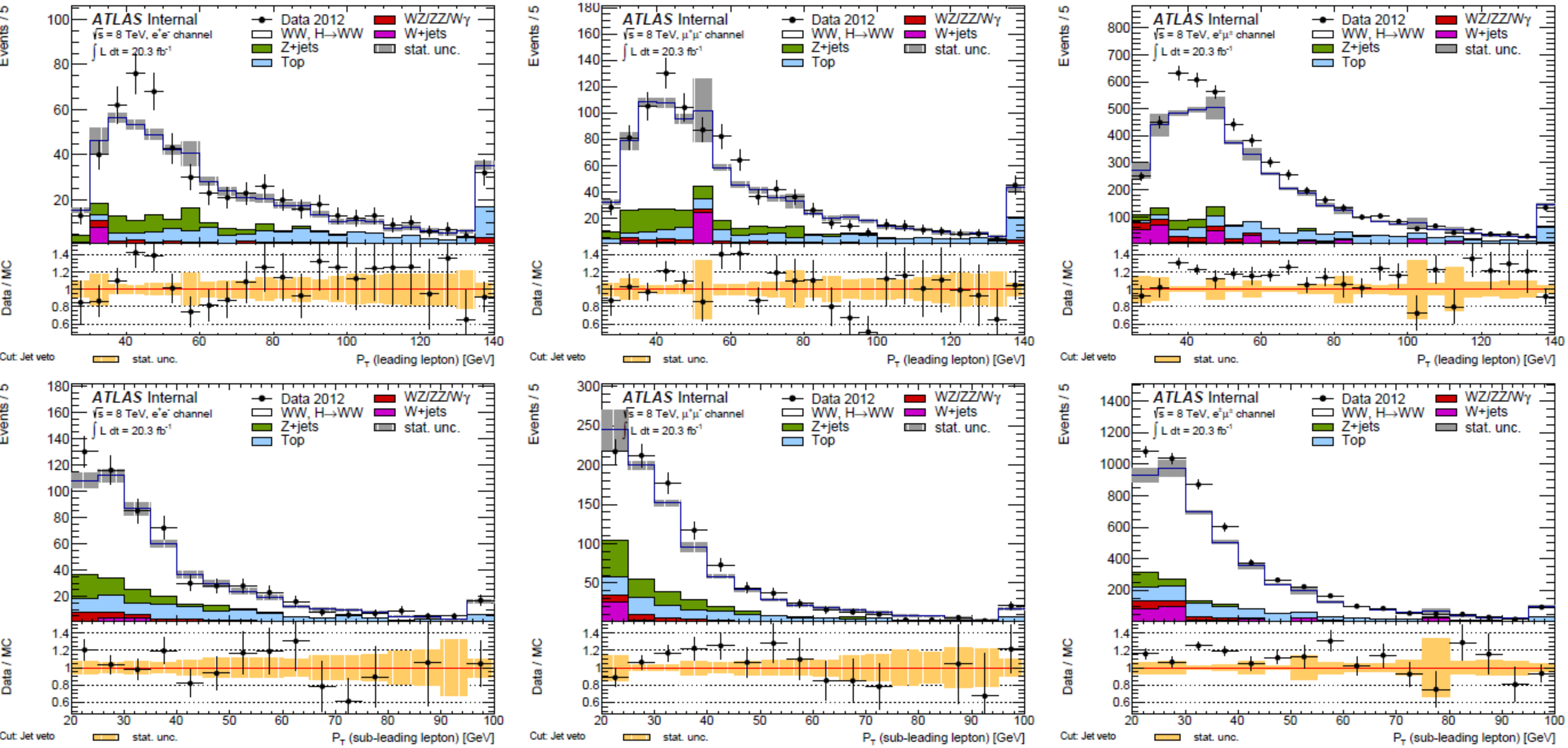
Final State	ee Channel	$\mu\mu$ Channel	$e\mu$ Channel	inclusive
Observed Events	585	975	5093	6653
Total MC prediction (S+B)	547.49	929.55	4503.91	5980.95
MC WW signal	354.81	621.23	3300.04	4276.08
Top	99.17	128.06	619.20	846.43
Z+jets	55.80	113.77	160.85	330.41
W+jets	7.74	28.01	266.77	302.52
Dibosons	29.98	38.48	157.05	225.51
Total Background	192.68	308.52	1203.87	1704.87

Work In Progress

MC yields are normalized to an integrated luminosity of 20.3 fb-1

WW candidate plots

Work In Progress



- Leading lepton Pt and trailing lepton Pt distribution for ee(left), μμ(middle), eμ(right)
- All selection cuts are applied.
- Stacked histograms are from MC predictions for signal and background

Data-driven Wjets Background estimation

Work In Progress

- fake factor method:
  - W+jet Control region : tight lepton + loose lepton
  - W+jet contribution := Control region * “fake factor”.

- Fake factor definition : f= Numerator /Denominator

  Numerator : good lepton

  Denominator : bad lepton

  estimated using a di-jet sample.

- Systematic sources

  trigger bias, Pileup-bias, sample dependence (Wjet vs dijet), real lepton contaminations, etc.

- Final estimate

	ee-ch	eμ-ch	$\mu\mu$-ch	Total
W+jet background (e-fakes)	7.54 ± 0.72 ± 6.57	97.08 ± 3.10 ± 64.04	-	104.63 ± 3.18 ± 70.61
W+jet background (μ-fakes)	-	117.38 ± 6.64 ± 76.04	18.47 ± 2.77 ± 11.98	135.85.90 ± 7.19 ± 88.02
Total W+jet background	7.54 ± 0.72 ± 6.57	214.46 ± 7.32 ± 140.08	18.47 ± 2.77 ± 11.98	240.47 ± 7.86 ± 158.63

Data-driven Top Background estimation

✓**Jet-veto Survival Probability Method**

Work In Progress

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

Top Yield without jet-veto

$$N_{Top}^{DATA}(0\,jet) = N_{Top}^{DATA}(all) \times P_2^{DATA} = N^{DATA-NonTop}(all) \times \left((P_{1(Btag)}^{DATA})^2 \times \frac{P_2^{MC}}{(P_{1(Btag)}^{MC})^2} \right)$$

- Two Control regions:

1st CR: b-tagging control sample , purely dominated by ttbar
to compare jet-veto efficiency from DATA and from MC

2ndCR: full selection without jet-veto
to derive jet-veto efficiency in MC

- Agree with MC prediction
- ~8.3% overall uncertainty.
Including experimental uncertainty and theoretical uncertainty.

	ee	Mm	em
DATA-driven estimation	89.6+/-7.2+/-7.7	126.9+/-9.4+/-10.7	611.1+/-17.8+/-50.9
MC prediction	97.9+/4.9(stat)	128.1 +/-5.8(stat)	623.1+/-12.1(stat)

other background estimation

Work In Progress

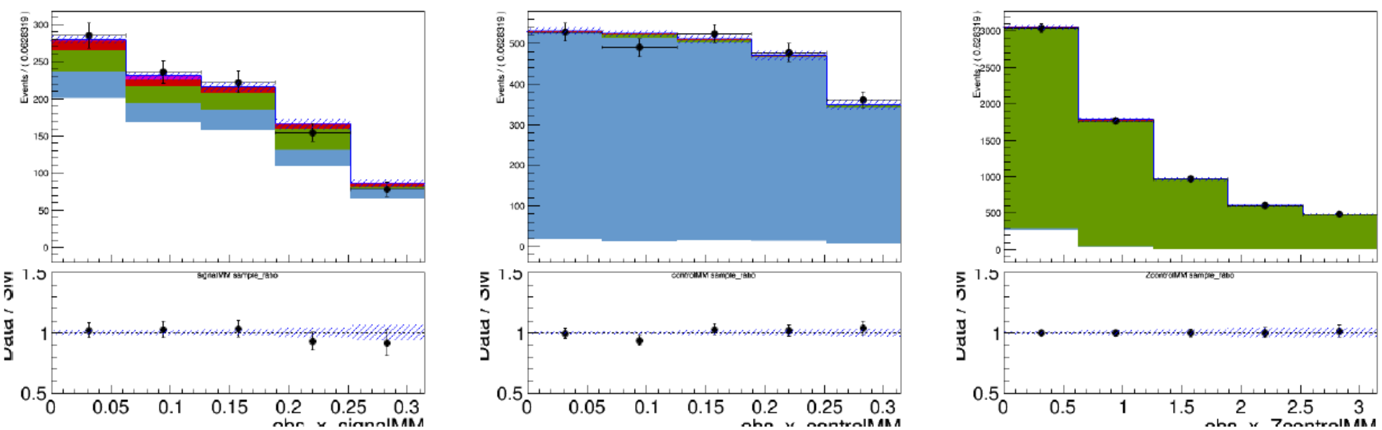
For Top and DY

Simultaneous Fit

- Extract signal cross-section and background (Top & DY) contribution
- Three regions are fitted:

signal region, top control region and DY control region

Adjust the relative contributions of the fitted components



The Δϕ distribution in the signal, top control and Drell-Yan control region for the eμ channel after the fit

For Dibosons (WZ , ZZ , Wγ, Wγ*)

The estimation is based on MC

8 TeV WW analysis status

- Time scale

➢ Jan 7th, 2014 . The end of optimization of the selection criteria

➢ Finalize the background study
Make a cross-section measurement and update supporting note

➢ Inform EB, have another EB meeting and discuss CONF note prob.

Where we are

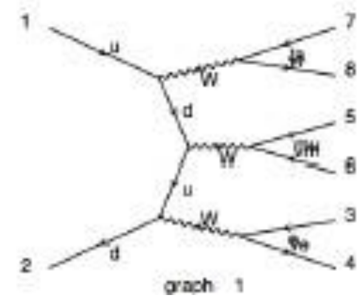
➢ Finish unfolding and aTGCs limit setting

➢ Inform EB and have the completed supporting note reviewed

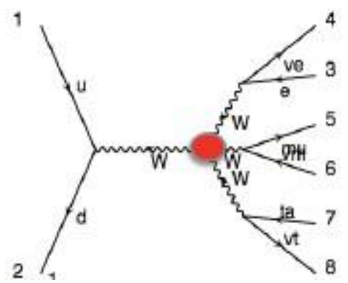
➢ ……

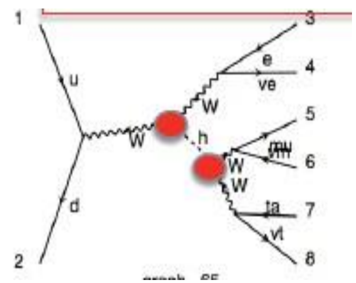
WWW analysis

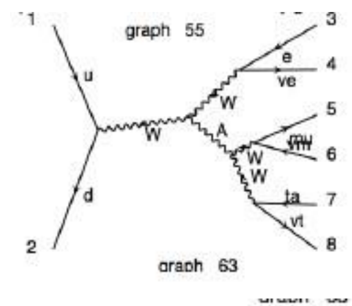
- Motivation :
  - 4-W vertex never directly measured before .
  - Sensitive to HWW coupling .

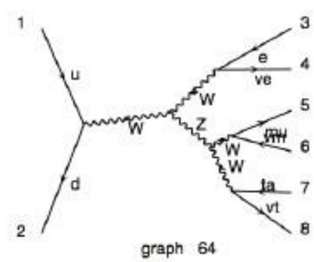


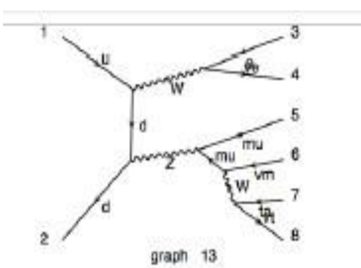
- Signal & Background:
  - Processes with 3W(lv) in final state .
  - WW,WZ,ZZ,ttbar,Z+jets,W+jets

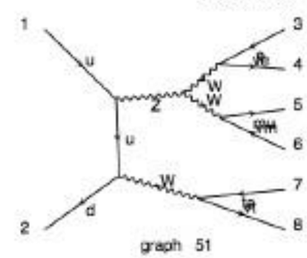












- Analysis status
  - Starting the analysis recently.
  - Skimming samples and singal MC ready
  - Discussion with WH group

To be the PHD thesis of Ruiqi Zhang

Summary

- WW cross section measurement in dileptonic channel .
- We already have nice results for 7 TeV 4.6 fb^{-1} data . Now 8 TeV analysis using 20.3 fb^{-1} data is ongoing.
- Data-driven methods used for almost all the backgrounds (Drell-Yan, top and W+jets).
- WWW analysis is starting.
- THANKS A LOT to all of you!

- backup

Object selection for 8 TEV

Muon: Combined , IDhits

- $|\eta|<2.4$, pt>7 GeV
- Z0*sin(θ) <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(θ) <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

Event selection for 8 TeV

Trigger: ee, μμ : Dilepton trigger

eμ:: OR of dilepton trigger and single lepton trigger

ee+mm	em
Leading lepton $p_T > 25$ GeV	
Sub-leading lepton $p_T > 20$ GeV	
M(l,l) > 15 GeV	M(l,l) > 10 GeV
Z Veto: $\lvert M(l,l) - M_Z \rvert > 15$ GeV	-
$E_{T,rel}^{miss}$ (RefFinal) > 45 GeV	$E_{T,rel}^{miss}$ (RefFinal) > 15 GeV
Jet Veto	Jet Veto
$p_T^{miss} > 45$ GeV	$p_T^{miss} > 20$ GeV
$\lvert\Delta\phi(E_T^{miss}, p_T^{miss})\rvert < 0.3$	$\lvert\Delta\phi(E_T^{miss}, p_T^{miss})\rvert < 0.6$

Top Background Study: JVSP method

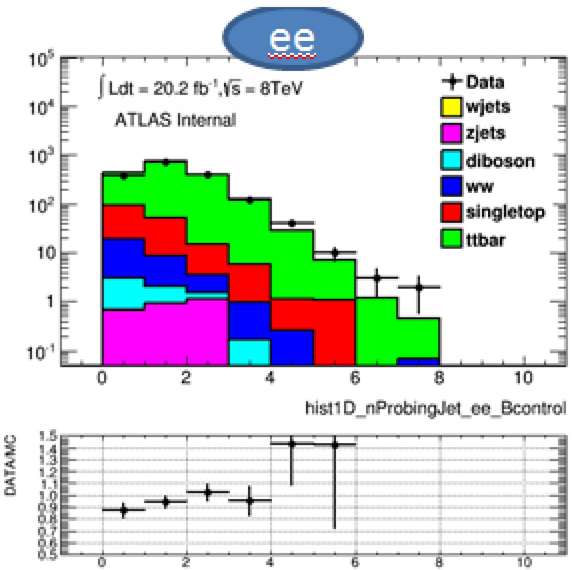
(Jet Veto Survival Probability)

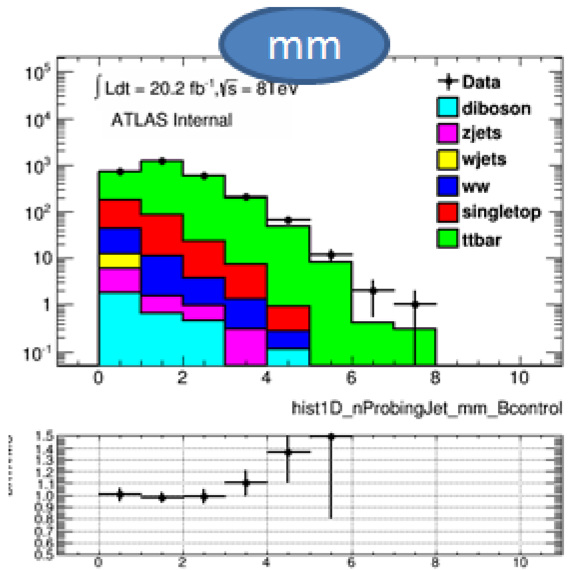
1st control region : Btagging

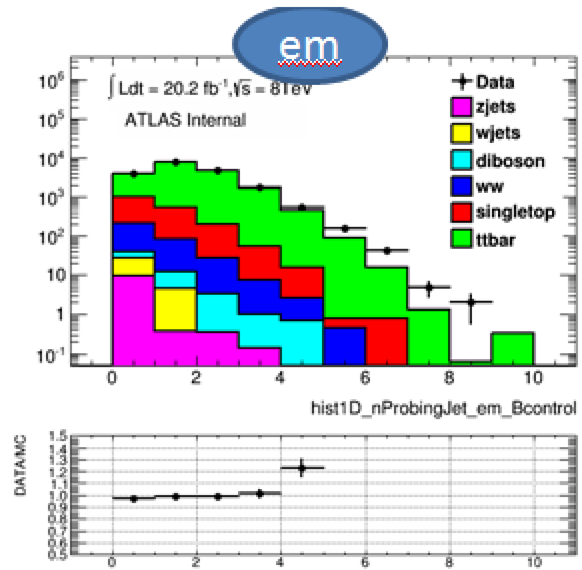
- **All Event selection without jet-veto cut are applied**
- **For all selected jets : at least one b-jet (tag-jet)**
- **For probe jets, derive jet veto efficiency (P_1)**
- **The non-top contribution is small**

$$P_{1(Btag)} = \frac{N_{Btag}(0ProbJet)}{N_{Btag}(all)}$$

nJet(Probe)







$$P^{MC}_{1(Btag)} = \frac{N^{TopMC}_{Btag}(0\,jet)}{N^{TopMC}_{Btag}(all)}$$

$$P^{DATA}_{1(Btag)} = \frac{N^{allDATA}_{Btag}(0\,jet) - N^{NonTopMC}_{Btag}(0\,jet)}{N^{allDATA}_{Btag}(all) - N^{NonTopMC}_{Btag}(all)}$$

2^{nd} control region

- **All Event selection without jet-veto cut are applied**

  CR1(btagging) is a high-purity subset of CR2

- **For good jets, get jet-veto efficiency (P_2) for MC** $P_2^{MC} = \frac{N_{Top}^{MC}(0\,jet)}{N_{Top}^{MC}(all)}$

- **True jet veto efficiency for data**

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

This CR also dominated by top , with 20% WW contribution

summary for the main systematic sources

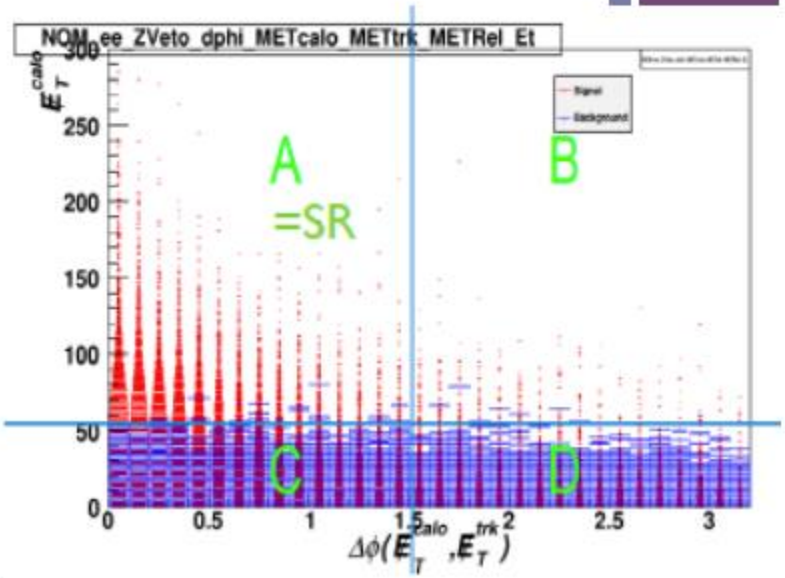
	Source	Result (overall)	HSG result for comparison
1	JES	3.1% (bjet) 2.0%(base) 1.5% (NP modeling)	3.0% (bjet) 1.6%(base) 1.5%(NP modeling)
2	JER	1.8%	<1%
3	B-tagging(bjet)	3.5%	2.9%
4	Non-top bkg substruction	2.1%	2.7%
5	Single-top Xsec variation	1.8%	<1%
6	MC generator/paton shower+had	6.3%	3.4 %
7	Single top- ttbar interference	**1.1%**	0.8%
8	Theory(scale unc.)	1.9%	1.5%
10	PDF (perform pdf reweighting to get the relative variation)	1.7%	1.3%
11	Exponent /Yield Scale	<1% / ~1%	Not considered
	Total uncertainty	8.3% (all combined)	7.6%

DY – ABCD

- Define ABCD regions using METrel and $\Delta\phi$
  - Remove ptmiss to gain statistics. Later use the efficiency of this cut to extrapolate to SR

$$Z^{A} = (Data^{C} - MC^{C}_{Non-Z}) \cdot \frac{(Data^{B} - MC^{B}_{Non-Z})}{(Data^{D} - MC^{D}_{Non-Z})} \cdot SF$$

SF obtained from MC as A/B = SF * C/D



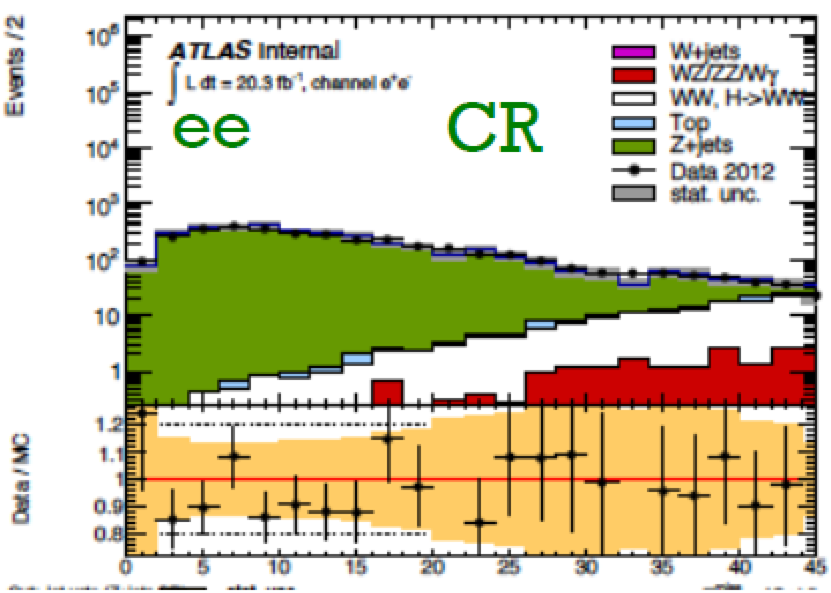
- Systematic evaluation on ptmiss efficiency
  - Main systematic: JER, Etmiss

	DD estimation
ee	59.2 ± 3.9 ± 23.4
mm	118.1 ± 5.6 ± 37.5
em	166 ± 11 ± 28

DY – Transfer Factor

- CR
  - SF: invert METtrk, no $\Delta\phi$
  - OF: invert $\Delta\phi$, no METtrk
- Obtain bkg yield in SR using

$$\text{Data-Driven } Z + \text{jets} = \text{TF} \cdot \left(N^{\text{data}}_{\text{CR}} - N^{\text{MC}}_{non-\text{Z,CR}}\right) \qquad \text{TF} = \frac{N^{\text{MC}}_{\text{Z,SR}}}{N^{\text{MC}}_{\text{Z,CR}}}$$



	DD estimation
ee	58.5 ± 7.0 ± 30.9
mm	121.6 ± 10.2 ± 52.3
em	161.5 ± 16.6 ± 26.6

- Main systematics: JER, METrel, ptmiss

+ W+jets – Matrix Method

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

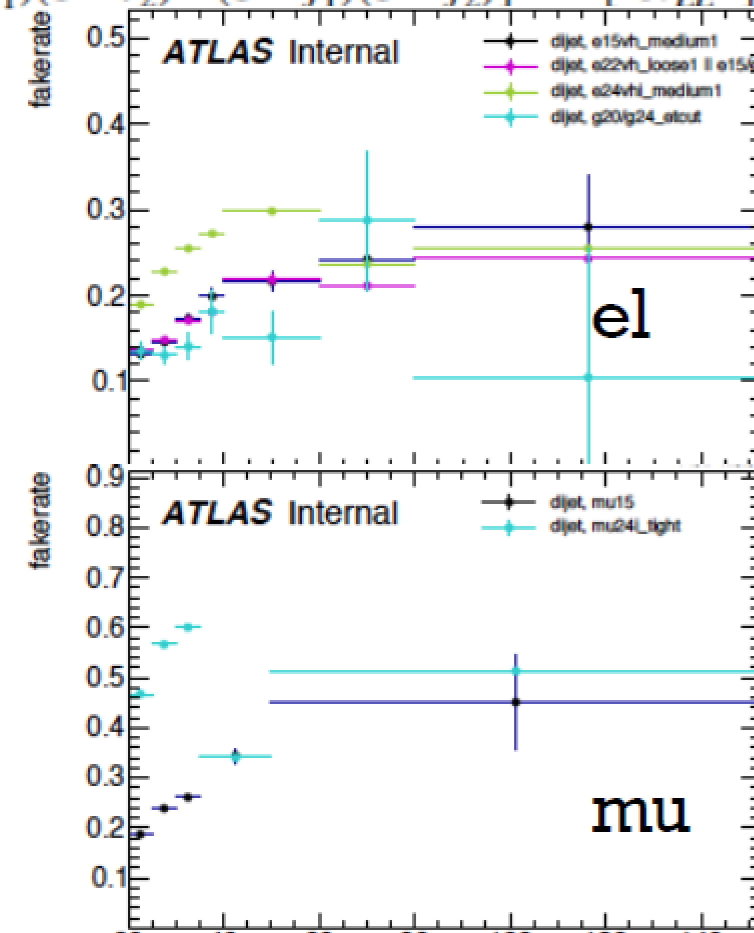
W+jets (N_{RF}, N_{FR})

QCD (N_{FF})

- Tight leptons: VTLL & isolation – ID hits & isolation
- Loose leptons: MediumLL & relax isolation +IP – isCombined & relax isolation+IP
- Fake rates are measured on di-jet events using supported triggers

Channel	DD esrtimate
ee	$16.6 \pm 4.7^{stat} \pm 5.3^{syst}$
mm	$6.3 \pm 4.6^{stat} \pm 5.3^{syst}$
em	$252.7 \pm 15.1^{stat} \pm 78.2^{syst}$

- Main systematics: Sample dependence



Dibosons

- Estimation of WZ, ZZ, W γ and W γ * is based on MC
  - Wg k-factor = 1.37 (from 2011 ATLAS W γ measurement)

Final State	$e^+e^- E_{\mathrm{T}}^{\mathrm{miss}}$	$\mu^+\mu^- E_{\mathrm{T}}^{\mathrm{miss}}$	$e^\pm\mu^\mp E_{\mathrm{T}}^{\mathrm{miss}}$	Combined
Diboson Background				
WZ	7.96±0.72	19.57±1.02	66.05±1.78	93.58±2.17
ZZ	10.76±0.43	16.19±0.54	3.55±0.19	30.50±0.72
$W\gamma$	5.91±1.02	0.00±0.00	44.82±2.81	50.72±2.99
$W\gamma*$	5.41±0.84	2.74±0.58	43.09±2.31	51.24±2.53
Total Background	30.03±1.57	38.51±1.29	157.51±4.06	226.05±4.53

+ Yield & Background Summary

		ee	mm	em
Data		589	975	5067
WW (signal - MC)		355	621	3300
Dibosons		30.03 ± 1.57^{stat}	38.51 ±1.29^{stat}	157.51 ± 4.06^{stat}
Wjets	MC	7.7	28	267
	MM	16.6 ± 4.7 ± 5.3	6.3 ± 4.6 ± 5.3	252.7 ± 15.1 ± 78.2
	FFM	7.54 ± 0.72 ± 6.57	18.5 ± 2.8 ± 12.0	214.5 ± 7.3 ± 140.1
Top	MC	97	129	624
	TF	97.3 ± 5.1 ± 22.8	131.2 ± 6.4 ± 38.6	641.4 ± 13.6± 145.9
	JVSP	89.6 ± 7.2 ± 7.7	126.9 ± 9.4 ± 10.7	611 ± 17.8 ± 50.9
	SimFit	92 ± 24	132± 25	662 ± 103
DY	MC	55	114	158
	TF	58.5 ± 7.0 ± 30.9	121.6 ± 10.2 ± 52.3	161.5 ± 16.6 ± 26.6
	ABCD	59.2 ± 3.9 ± 23.4	118.1 ± 5.6 ± 37.5	166 ± 11 ± 28
	SimFit	54 ± 18	97 ± 19	146 ± 25