#### Measurement of the WW Production Cross Section in Proton-Proton Collisions at 8 TeV with the ATLAS Detector

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#### Introduction

- The WW analysis is an important test of electroweak sector of SM and also a support for Higgs WW analysis
- The WW signal is identified in the llvv final state , requiring both Ws to decay to leptons
- Isolated high pT di-lepton final states : ee/mm/em



#### **Object selection**

Muon: Combined , IDhits

|η|<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( $\theta$ ) <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 : |η|<4.5, pt>25 GeV, JVF >0.5 for jets |η|<2.4, pt<50 GeV !Ugly !LooserBad overlap removal with electron

Impact parameter & Isolation for leptons : Follow HSG3 definition

#### **Event selection**

#### Trigger: ee+mm : Dilepton trigger

em: OR of dilepton trigger and single lepton trig	ger
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ee+mm	em
Leading lepto	n p <sub>T</sub> > 25 GeV
Sub-leading lep	ton p <sub>T</sub> > 20 GeV
M(l,l) > 15 GeV	M(l,l) > 10 GeV
Z Veto: $ M(I,I) - M_Z  > 15 \text{ GeV}$	-
E <sub>T,rel</sub> <sup>miss</sup> (RefFinal) > 45 GeV	E <sub>T,rel</sub> <sup>miss</sup> (RefFinal) > 15 GeV
Jet Veto	Jet Veto
$p_T^{miss} > 45 \text{ GeV}$	p <sub>T</sub> <sup>miss</sup> > 20 GeV
$ \Delta \phi(E_T^{\text{miss}}, p_T^{\text{miss}})  < 0.3$	$ \Delta \phi(E_T^{miss}, p_T^{miss})  < 0.6$

Final State	eµ Channel	µe Channel	ee Channel	$\mu\mu$ Channel	inclusive
Observed Events	2627	2439	589	975	6630
total MC prediction(S+B)	2365.8	2122.7	534.7	907.6	5930.8
MC WWsignal	1721.2	1583.4	355.3	622.3	4282.2
Тор	319.4	282.0	93.7	124.1	819.2
W+jets	172.1	96.2	7.9	28.1	304.3
Drell-Yan	46.0	66.2	44.8	94.0	250.9
Diboson	107.2	94.9	33.0	39.1	274.2
Total Background	644.6	539.3	179.4	285.3	1648.6

MC yields are normalized to an integrated luminosity of 20.3 fb-1.  $_{\mbox{December 16, 2013}}$ 

#### WW group status

Aiming at the paper by early next year

The scope

- cross-section measurement
- aTGCs limits
- ➤ unfolding

Selection optimization studies during the summer -> Finished Ongoing work : background studies

#### Wjets Background Study : fake factor method

## Introduction

- Using fake factor method:
  - W+jet Control Region : tight lepton + loose lepton(non-tight)
  - W+jet contribution := Control region \* "fake factor".
- Fake factor definition : f= Numerator /Denominator
   Numerator : tight lepton
   Denominator :loose lepton (must fail tight selection)
   For electron->softer cuts on isolation&&quality
   For muon -> softer cuts on isolation&&impact parameter
   estimated using a jet-enriched sample(need to veto W,Z).
- The remaining W,Z contamination is subtracted by MC

$$f = \frac{N_{tight}^{DATA} - N_{tight}^{MC}}{N_{loose}^{DATA} - N_{loose}^{MC}}$$



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#### Fake Factor systematic

Systematic source :
 MC subtraction
 Trigger bias
 Pileup bias
 Sample dependence

 (Main contribution, 45% uncertainty for electron 40% for muon)

➤ The differences in jet components and kinematics between di-jet and W+jets samples



#### loose lepton Pt (W+jet CR)



## results

Summary	ee	mm	em (fake e+m & fake m +e)
Data-driven	2.996 +/- 0.082 +/- 1.162	15.79+/-1.90 +/-7.7	169.0 +/- 5.28 +/- 76
W+jet MC prediction	7.1 +/- 2.9	29.3 +- 17.2	265.7 +/- 64.2

#### Top Background Study: JVSP method (Jet Veto Survival Probability)

### Introduction for JVSP



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

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## 1<sup>st</sup> 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<sub>1</sub>)  $P_{1(Btag)} = \frac{N_{Btag}(0ProbJet)}{N_{Btag}(all)}$
- The non-top contribution is small

#### nJet(Probe)



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## 2<sup>nd</sup> 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<sub>2</sub>) for MC
- $P_2^{MC} = \frac{N_{Top}^{MC}(0\,jet)}{N_{Top}^{MC}(all)}$

• True jet veto efficiency for data

$$P_2^{DATA} pprox P_2^{MC} imes \left( rac{P_{1(Btag)}^{DATA}}{P_{1(Btag)}^{MC}} 
ight)^2$$

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

## Systematic sources

Define :  $MC \_ SF = \left(\frac{P_2^{MC}}{(P_{1(Btag)}^{MC})^2}\right) \checkmark$  An important term for theoretical systematic uncertainty  $\checkmark$  Systematic cancelation for numerator and denominator

- Experimental: JES, JER, B-jet weight...
- Theoretical

(in most cases , compare MC SF under different situation)

- ✓ Single top X-section variation
- ✓ Single top ttbar interference NLO Wt shares the same final states with as LO ttbar
- ✓ Renormalization/factorisation Scale Uncertainty

Generator samples with different Renormalization Factor (RF) or Factorization Factor(FF)

✓ PDF

perform pdf reweighting to get the relative variation

- ✓ MC generator and parton shower
- ✓ Non-Top MC subtraction in 2<sup>nd</sup> CR

# Systematic table

	Source	systematic	HSG result
1	JES	2.7% (bjet) 1.8% (base) 1.1% (NP modeling)	3.0% (bjet) 1.6%(base) 1.5%(NP modeling)
2	JER	1.68%	<1%
3	B-tagging(bjet)	2.5%	2.9%
4	Non-top bkg substruction	6.2% (plant ww uncertainty 15%)	2.7% (plant ww uncertainty 6%)
5	Single-top Xsec variation	<1.25%	<1%
6	MC generator/paton shower+had	9.4	3.4 %
7	Single top- ttbar interference	1.1%	0.8%
8	Renormalization/factoris ation Scale Uncertainty	1.76%	1.5%
10	PDF	1.2%	1.3%
	Total uncertainty	11.6%	7.6% (new)

## Non-Top MC subtraction uncertainty

2nd control s Channel	ample summary:	ee	mumu	emu	all
DATA	N(before jet-veto):	2379+/-48.775	4503+/-67.1044	27198+/-164.918	34080+/-184.608
TTbar	N(before jet-veto):	1818.33+/-16.3745	2881.6+/-20.8627	19080+/-53.3934 23779	9.2+/-59.6174
Single Top	N(before jet-veto):	193.852+/-9.31854	357.054+/-13.2276	2044.13+/-31.1305	2595.03+/-35.0844
ALL Top	N(before jet-veto):	2012.18+/-18.8403	3238.66+/-24.7027	21124.2+/-61.8059	26374.2+/-69.1747
WW	N(before jet-veto):	474.071+/-5.17595	1078+/-7.69371 5480.	59+/-16.6786 7032.	.67+/-19.0829
Wjets/QCD	N(before jet-veto):	3.02714+/-2.69668	45.1561+/-19.2983	377.662+/-65.47 425.8	845+/-68.3082
Drell-Yan	N(before jet-veto):	39.3896+/-2.86442	140.588+/-10.8198	301.375+/-37.7193	481.353+/-39.3449
DiBoson	N(before jet-veto):	27.591+/-1.50509	36.2367+/-1.29261	222.11+/-4.76128	285.938+/-5.15809
nonTop	N(before jet-veto):	544.078+/-6.67328	1299.98+/-23.4597	6381.74+/-77.5236	8225.8+/-81.2699

The uncertainty assigned

WW 15% (a conservative number got from the difference between measured WW x-section and theoretical prediction)

- Zjets/wjets 40% diboson 15%
- Ralatvie error =  $\delta$ (Nnontop) /(Ndata-Nnontop) = 6.2%

WW is the main contribution of nonTop Events. (20% signal contamination) One idea is to do an iteration of Top && WW .

# Result table

$N_{\scriptscriptstyle Top}^{\scriptscriptstyle DATA}$	$(0 jet) = N_{Top}^{DATA}(all) \times H$	$P_2^{DATA} = N^{DATA-NonTop}(al)$	$(l) \times \left( (P_{1(Btag)}^{DATA})^2 \times \frac{P_2^{MC}}{(P_{1(Btag)}^{MC})} \right)$	$\overline{\left( \right)^{2}}$
	ee	Mm	em	combined
P1(btag, MC)	0.239+/-0.004	0.200+/-0.001	0.251+/-0.004	0.209+/-0.001
P1(btag,DATA)	0.218+/-0.010	0.195+/-0.003	0.250+/-0.009	0.203+/-0.002
P2(MC)	0.035+/-0.002	0.039+/-0.002	0.027+/-0.001	0.029+/-0.001
Final result				
MC prediction	95.8+/-4.8	127.7+/-6.1	621.8+/-12.6	845.4+/-14.9
DATA-driven estimation	82.6+/-5.1+/-9.7	125.9+/-9.3+/-14.7	597.1+/-17.6+/-69.9	805.7+/-20.4+/-94.3

## Conclusion

- Measurement of WW cross-section at 8 TeV with ATLAS detector
- Some background studies are shown
- aTGC and unfolding studies in the new year

• Back up

#### HWW selection

	HWW
Mll	10 <mll<50 gev<="" td=""></mll<50>
METrel	>25 GeV (might drop?)
$\Delta \phi$ (ll,MET)	1.57
ptll	>30 Gev
$\Delta \phi$ (l,l)	<1.8

	HWW
Mll	>12 GeV
Z veto	Yes
METrel	>45 GeV
METtrk	>45 GeV
ptll	>30 Gev
frecoil	<0.05

DF channels (left) SF channels (right)

Different MII cuts well motivated by event topology  $\Delta \phi(I,I)$  used to reject SMWW fRecoil used in Z+jets estimate, SMWW study showed poor WW/Z discrimination • Wjets bkg backup

## Lepton Definition : Electron

Electron	Numerator	Denominator	
Pt, eta, Nhits	20 GeV,  eta <2.47 , exclude [1.37,1.52],Nhits>=4		
Author, object quality	author = 1 or 3 , (el_	OQ & 1446) == 0	
z0sin $ heta$	<0.4 r	nm	
$d0/\sigma(d0)$	<3	<3	
Etcone30/Et	<0.16 <0.28	<0.3	
Ptcone30/Et	<0.12 (20 <pt<25) &lt;0.16 (pt&gt;25) &lt;0.1</pt<25) 	<0.16	
IsEM	tightPP (likelihoodID)	fail MediumPP (likelihoodID)	
		Fail Numerator selection	

#### •• • **Text** in red are old selection

#### Lepton Definition : Muon

Muon	Numerator = tight lepton	Denominator		
Pt, eta, ID track combined muon	20 GeV,  eta <2.4			
Author, object quality	author	- = 6		
z0sin $ heta$	<1 m	m		
$ d0/\sigma(d0) $	<3	Cut removed		
Etcone30/Et	<0.20 && <0.014*pt-0.15 <0.18 if 20 <pt<25 &lt;0.30 if pt&gt;25</pt<25 	<0.3 <0.25 if 20 <pt<25 &lt; 0.3 if pt&gt;25</pt<25 		
Ptcone30/Et	<0.15 && <0.01pt-0.105 <0.12	removed		
		Fail Numerator selection		

• Text in red are old selection

Top bkg backup

## 1<sup>st</sup> control sample : Btagging

use CalibrationDataInterface-00-03-04 to correct event weight

- All Event selection without jet-veto cut are applied
- good jets definition:

#### Jet definition (AntiKt4LCTopo)

eta	abs(emscale eta)<4.5
pt	calibrated pt > 25GeV
JVF	for jets with abs(emscale eta) < 2.4 && calibrated pt < 50GeV, require JVF>0.5
Quality	isBadLooseMinus==0 && isUgly==0
Overlap	Remove jets that are within DR<0.3 to any selected electron (For DR use el_cl_eta, el_cl_phi and jet_X_emscale_eta, jet_X_emscale_phi variables)

Remove selected muon that is within DR<0.3 to a selected jet (For DR use mu staco eta, mu staco phi and jet X emscale eta, jet X emscale phi variables)

# • For all selected jets : at least one b-jet b-jet definition:

good jet + MV1 tagged at 85% operating point +  $|\eta|$ <2.5 if events has more than 1 b-jet, choose the b-jet with largest MV1 to be the tag-jet one tag-jet per event

• For probe jets, derive jet veto efficiency (P<sub>1</sub>)  $P_{1(Btag)} = \frac{N_{Btag}(0ProbJet)}{N_{Btag}(all)}$ Probe jet definition:

good jet + not tag jet + DeltaR( tag jet, probe jet ) > 1

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## Renormalization/factorisation Scale Uncertainty

- ✓ Desciption for samples
- MC@NLO interfaced to Herwig++ samples produced by HWW
- Different Renormalization Factor (RF) or Factorization Factor (FF) *(for details see yichen & zhiqing talk*

https://indico.cern.ch/getFile.py/access?contribId=0&resId=0&materialId=slides&confId=246247 )

- Only em channel .
- How b-jet is located?

Searching for all partons around the jet, and with cone size 0.4. Check the flavor(ID) to see if the parton is a b-quark.

- Probe jet selection strategy remains the same
- ✓ Result table : Maximun variation : -1.76% for RF=2,FF=1

	FF= 0.5	FF =1	FF =2
RF =0.5	+ 0.8%	+0.06%	+1.13%
RF =1	+1.21%	(Nominal)	+1.22%
RF = 2	+ 1.17%	- 1.76%	+0.3%

#### Single top/ttbar interfernce

The NLO Wt process shares the same final states as LO ttbar precess → Interference between Wt and ttbar



FIG. 1. Feynman diagrams contributing to  $gg \rightarrow b\bar{b}e^-\bar{\nu}_e\mu^+\nu_\mu g$  in the narrow-width approximation: (a) on-shell  $t\bar{t}$  production and (b) Wt single top production. The double bars indicate heavy quark propagators which may be treated as on-shell particles in various approximations.

## Single top/ttbar interfernce

Using dedicated MC@NLO samples produced by HWW

DR(Diagram Removal): one simply removes all diagrams in the NLO Wt amplitudes that are doubly resonant DS(Diagram Subtraction): one modifies the NLO Wt Cross-section by implementing a subtraction term designed to cancel locally the ttbar contribution

 ✓ Check MC\_SF variation for ttbar+Wt(DS): 0.5112+/- 0.0043 for ttbar+Wt(DR): 0.5056 +/- 0.0046 Relative difference 1.1%

#### Single top related issue: Different Exponents

✓ In the formula there is a squire term (P1\_data/P1\_MC)<sup>2</sup>

True jet veto efficiency for data

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

When these probabilities are much smaller than one for low  $p_T$  thresholds, one can assume  $P_2^{\text{Exp}} \approx \epsilon_0^2 P_2$  and  $P_1^{\text{Btag},\text{Exp}} \approx \epsilon_0 P_1^{\text{Btag}}$  where  $\epsilon_0$  is an experimental efficiency of observing a low  $p_T$  jet in the region of interest. These relations may be rewritten as

$$\frac{P_2^{\text{Exp}}}{\left(P_1^{\text{Btag,Exp}}\right)^2} \approx \frac{P_2}{\left(P_1^{\text{Btag}}\right)^2} \,. \tag{7}$$

- ✓ Why there is nominal exponent 2 ?
   We think 2(b) jets will exist in ttbar and Wt single top events
- ✓ We vary the exponets for the term  $(P1_data/P1_MC)^n$  n = 1.5, 2.5
- ✓ The relative difference +0.539% / -0.536%
   P1\_data/P1\_MC is close to 1 . So this exponet effect is small.

# MC generator/parton shower

#### ✓ Samples studied:

mc12\_8TeV.105860.PowhegJimmy\_AUET2CT10\_ttbar\_LeptonFilter.merge.NTUP\_COMMON.e1576\_a159\_a171\_r3549\_p1575/mc12\_8TeV.105861.PowhegPythia\_AUET2BCT10\_ttbar\_LeptonFilter.merge.NTUP\_COMMON.e1317\_a159\_a165\_r3549\_p1575/

	P2	P1	MC_SF
a) McAtNloJimmy (nominal)	0.021	0.181	0.641
b) PowHegJimmy	0.023	0.182	0.694
c) PowHegPythia	0.030	0.202	0.735

✓ Relative Variation
 Different generators:

 use sample a) and b)
 7.6%

 Different parton shower/hadronization
 use sample b) and c)
 5.6%