Measurement of the Standard Model WW→lνlν Production Cross Section at √s=7TeV

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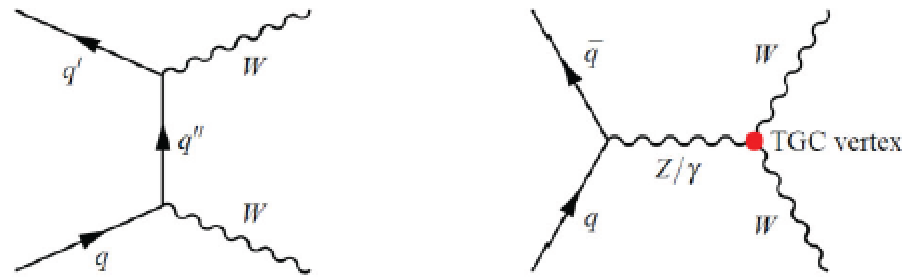
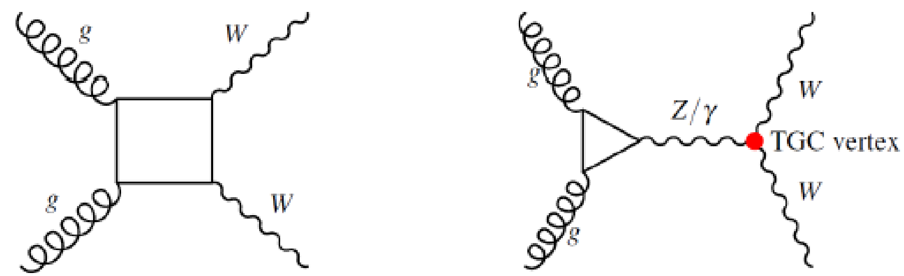
Introduction

- Measurement of the WW production cross-section in the di-lepton (e,μ) final state
- Motivation:
  - Important test of the electroweak sector of the Standard Model
  - Irreducible background for Higgs searches.
  - Sensitive to anomalous triple gauge couplings
    - Updated to 1.02 fb^{-1}
- Latest 4.7 fb^{-1} results for Moriond EW 2012(conf note, conf talk)
  - Update BOTH fiducial and inclusive x-sections for full 2011 dataset
  - Working on optimization and including aTGC for publication

qq->WW production σ_{NLO} = (43.8±2.25)pb at 7TeV

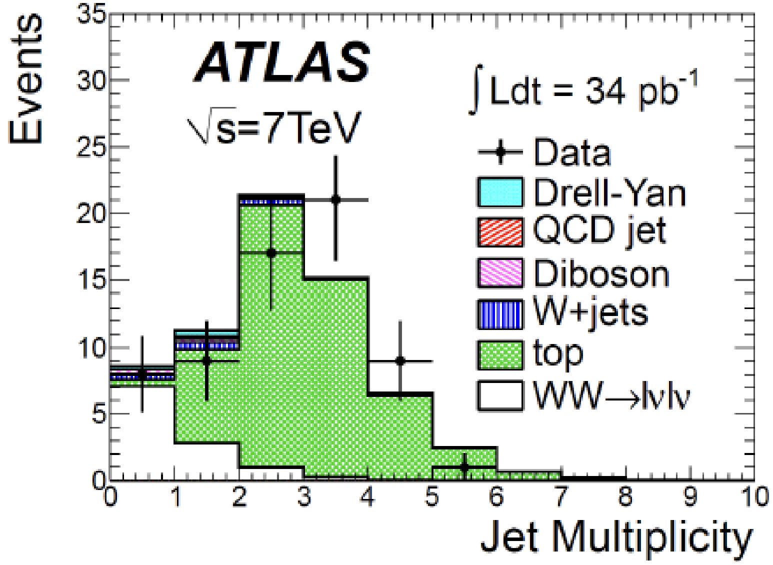


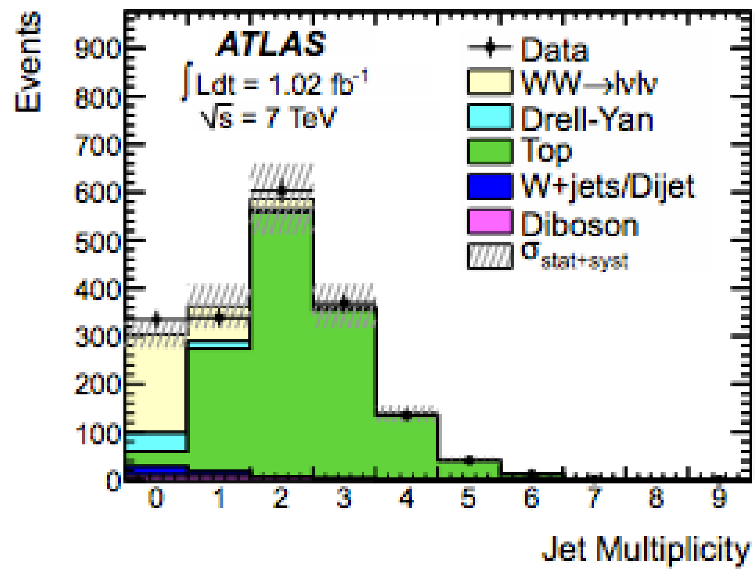
gg->WW contributes additional ~3% of WW event rate: 1.3pb



➢Characteristics:
- ✓ Dileptonic decay channels allow signal extraction from large BG
- ✓ Isolated high pT di-lepton final states are considered: ee, eμ, μμ
- ✓ Cascaded W→τ+X → e/μ+X included
- ✓ Backgrounds: DY, ttbar, single top, W+jets, other dibosons, etc.

2010-2011 results





Njets = 0: 8 candidate evts

WW signal ~ 6.9

Background ~ 1.7

S/B ~ 4

Njets = 0: 414 candidate evts

WW signal ~ 233 (207 scaled from 2010)

Background ~ 147 (51 scaled from 2010)

Background increase due to

$$\sigma_{W^+W^-} = 41^{+20}_{-16}(\text{stat.}) \pm 5(\text{syst.}) \pm 1(\text{lumi.})\ \text{pb}$$

$$54.4 \pm 4.0(stat) \pm 3.8(syst) \pm 2.0(lumi) pb$$

Documents: Conf. Note, INT Note, PRL draft (Accepted)

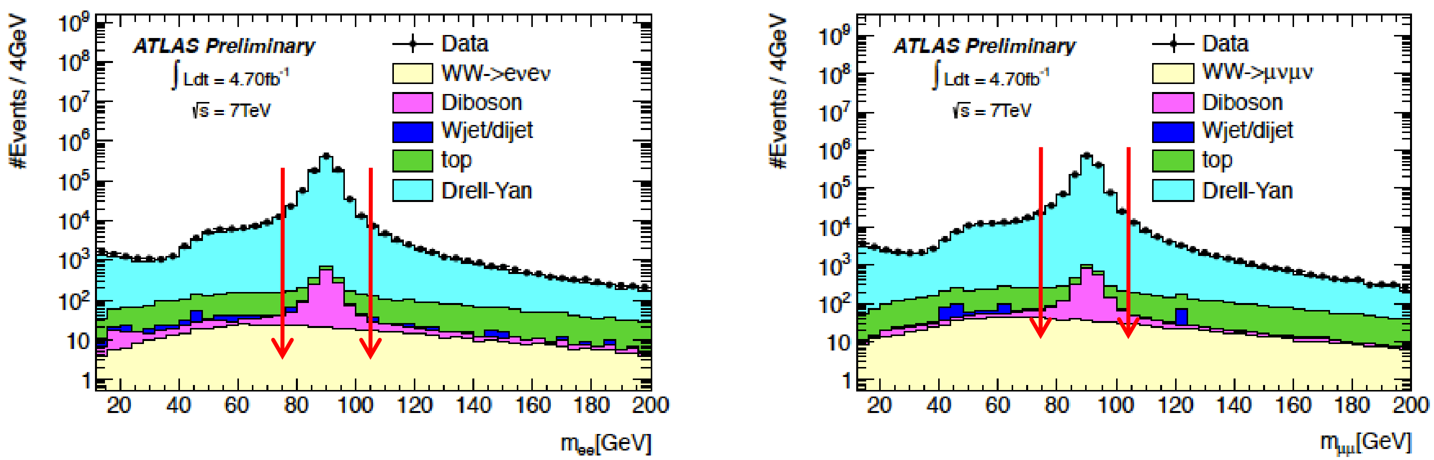
Documents: Conf Note, INT Note, Paper draft(submitted)

What would we expect with 4.7 fb^{-1} data!?

Event Selection

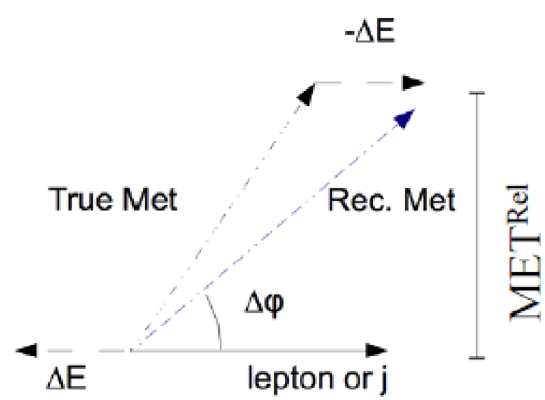
Channel-specific selection:

- **Reduce Drell-Yan contribution:**
  - $|M_{ll}-M_Z|>15$GeV for ee and μμ
  - $M_{ll}>15$GeV for ee and μμ, and $M_{ll}>10$ GeV for eμ



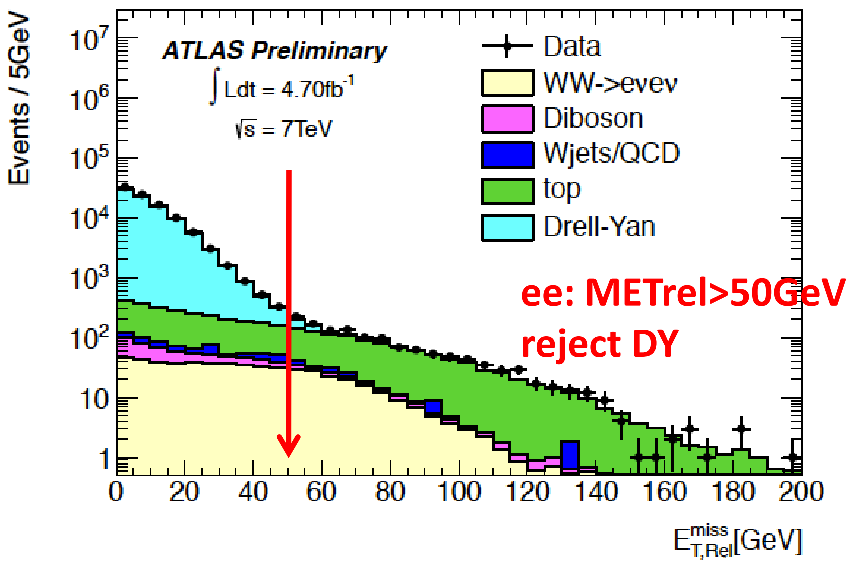
- **Further reduce Drell-Yan and QCD multi-jet contributions:**
  - MET^{Rel} > 55,50 GeV for μμ and ee, 25 GeV for eμ

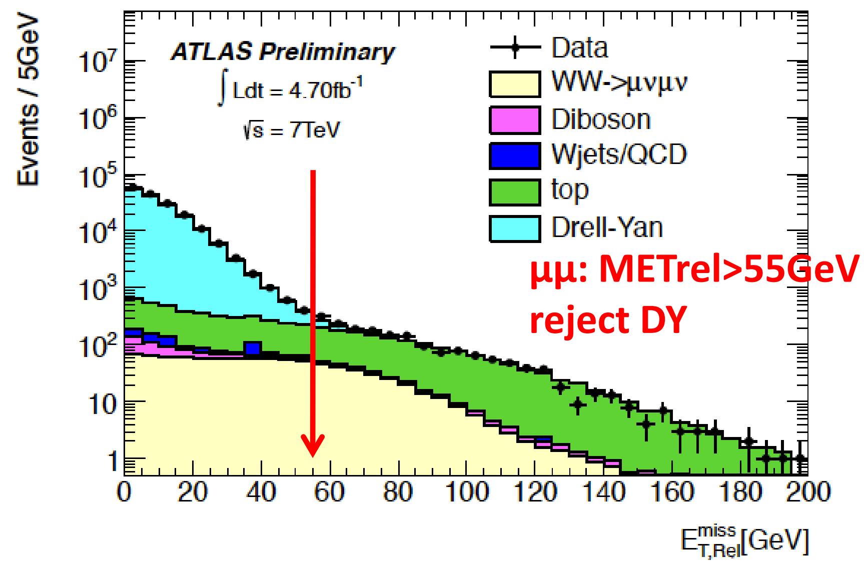
$$
\not{E}_T^{\mathrm{Rel}} = \begin{cases} \not{E}_T \times \sin\left(\Delta\phi_{\ell,j}\right) & \text{if } \Delta\phi < \pi/2 \\ \not{E}_T & \text{if } \Delta\phi \geq \pi/2 \end{cases}
$$

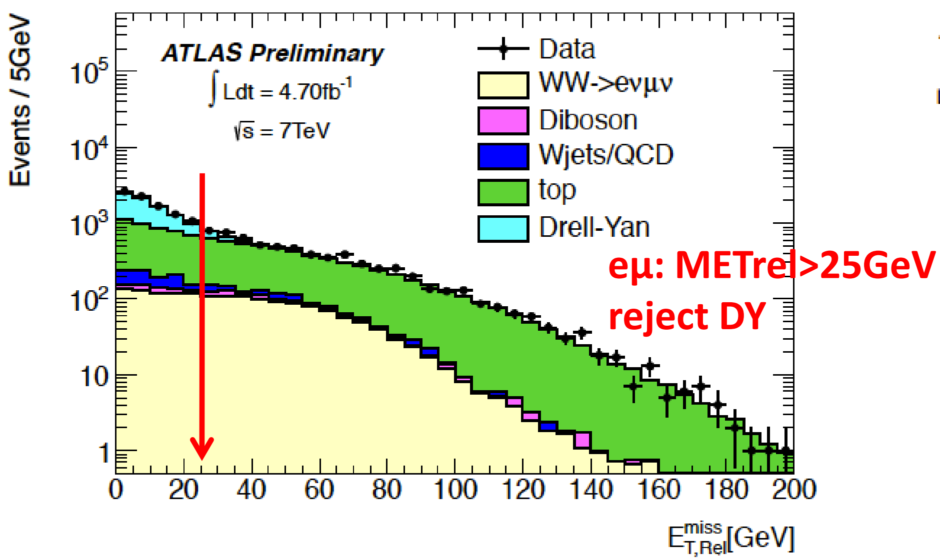


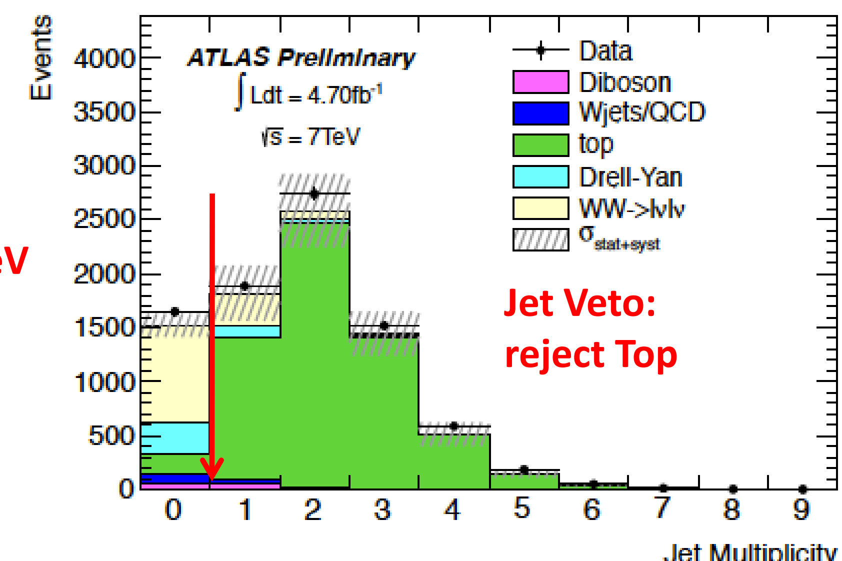
- **Remove top contribution:**
  - Jet veto: no jets w/ p_T > 25 GeV within |η| < 4.5
  - Bjet veto: reject events if at least one b-jet with p_T>20GeV

MET_rel, Jet multiplicity after Z veto









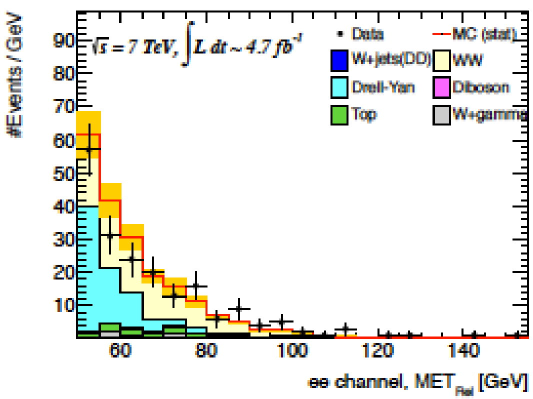
Data-driven Drell-Yan background estimation

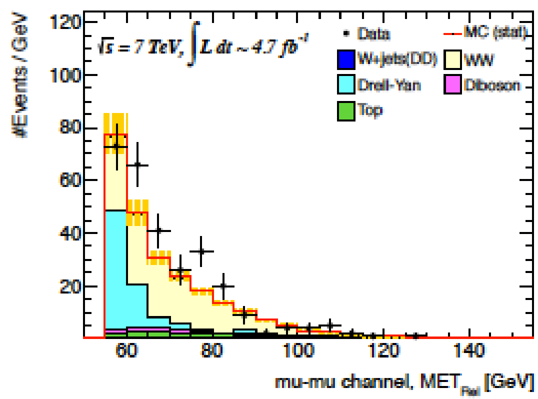
DY bgd: lepton or jet energy not well measured

- The $Et_{miss,Rel}$ not well modeled in DY MC, use a data-driven scale factor to correct for the $Et_{miss,Rel}$ cut efficiency.
- Procedure:
  - ✓ Invert Z window veto, apply other nominal selection cuts
  - ✓ ee, μμ: S Factor

$$S = 1 + \frac{\text{Data} - \text{Sum of MC}}{\text{Drell-Yan MC}}$$

  - ✓ eμ: no Z cut, use MC prediction w/ syst. estimate from ee/μμ using same $Et_{miss,Rel}$ cut value in eμ, corresponding difference quoted.





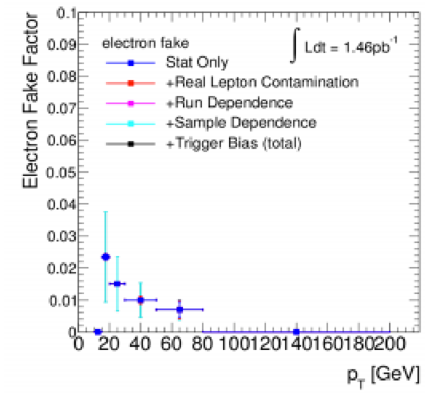
compare $Et_{miss,Rel}$ tail within Z-pole in data and MC

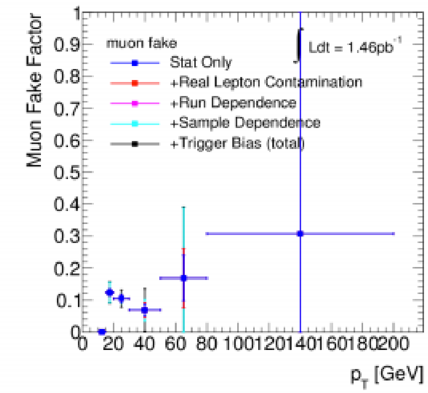
channel	$E_{T,Rel}^{miss}$ cut	N_{data}^{ZCR}	N_{MC}^{ZCR}	$N_{MC,DY}^{ZCR}$	S factor
ee	55 GeV	1066	992 ± 23	903 ± 23	1.082 ± 0.044
$\mu\mu$	50 GeV	953	851 ± 20	736 ± 20	1.139 ± 0.050
ee	25 GeV	779	845 ± 21	834 ± 21	0.921 ± 0.042
$\mu\mu$	25 GeV	1978	1960 ± 33	1940 ± 33	1.009 ± 0.029
$e\mu$	25 GeV	-	-	-	1 ± 0.088(*syst*)

$ee + E_{T,Rel}^{miss}$	$e\mu + E_{T,Rel}^{miss}$	$\mu\mu + E_{T,Rel}^{miss}$
72.0 ± 6.7(*stat*) ± 3.2(*syst*)	142.2 ± 7.1(*stat*) ± 12.5(*syst*)	70.0 ± 6.5(*stat*) ± 3.5(*syst*)

Data-driven W+jet background estimation

- Jets misidentified as leptons not correctly modeled and limited by stat. in MC
- Use W+jets enriched control sample and fake factor measured in data
  - W+jets CR: nominal cuts w/ looser lepton ID for one of the 2 leptons
  - Fake factor: ratio of ID and looser ("jet-rich") leptons.
  - Cross-check of method in SS control region.
  - Syst.: trigger bias, away-side jet pT sub-sample deviation, sample dependence (Wjet vs dijet), real lepton contaminations, etc.





Final estimate:

$$N_{\text{one id + one fake}} = f_l \times N_{\text{one id + one jet-rich}}$$

Fake factor: $$f_l \equiv \frac{N_{\text{identified lepton}}}{N_{\text{jet-rich lepton}}}$$

	ee-ch	eμ-ch	$\mu\mu$-ch	Total
W+jet background (e-fakes)	$19.84 \pm 0.52 \pm 10.50$	$53.51 \pm 0.97 \pm 28.26$	-	$73.4 \pm 1.1 \pm 38.8$
Wjet background (μ-fakes)	-	$0.58 \pm 0.26 \pm 0.17$	$5.09 \pm 0.86 \pm 2.01$	$5.67 \pm 0.90 \pm 2.18$
Total W+jet background	$19.84 \pm 0.52 \pm 10.50$	$54.1 \pm 1.0 \pm 28.3$	$5.09 \pm 0.86 \pm 2.01$	$79.0 \pm 1.4 \pm 38.8$

Consistent with the estimate using Matrix Method

Channel	W+jets	QCD
ee	$11.26 \pm 1.49 \pm 2.70$	$0.37 \pm 0.15 \pm 0.09$
μμ	$3.31 \pm 0.71 \pm 0.99$	0
eμ	$53.90 \pm 3.34 \pm 14.55$	$0.22 \pm 0.06 \pm 0.06$

Data-driven Top Background estimation

- Top DD estimate using b-tagged control sample
  - P1: b-tagging control sample jet Veto survival probability
  - P2: full jet veto survival probability
- Insensitive to the normalization, b-tag eff. , lumi & theo. σ values, JES/JER, ISR/FSR
- Agree w/ MC prediction.
- ~20.4% overall syst. Dominated by theo. Uncertainty~15% and sample dependence~12%

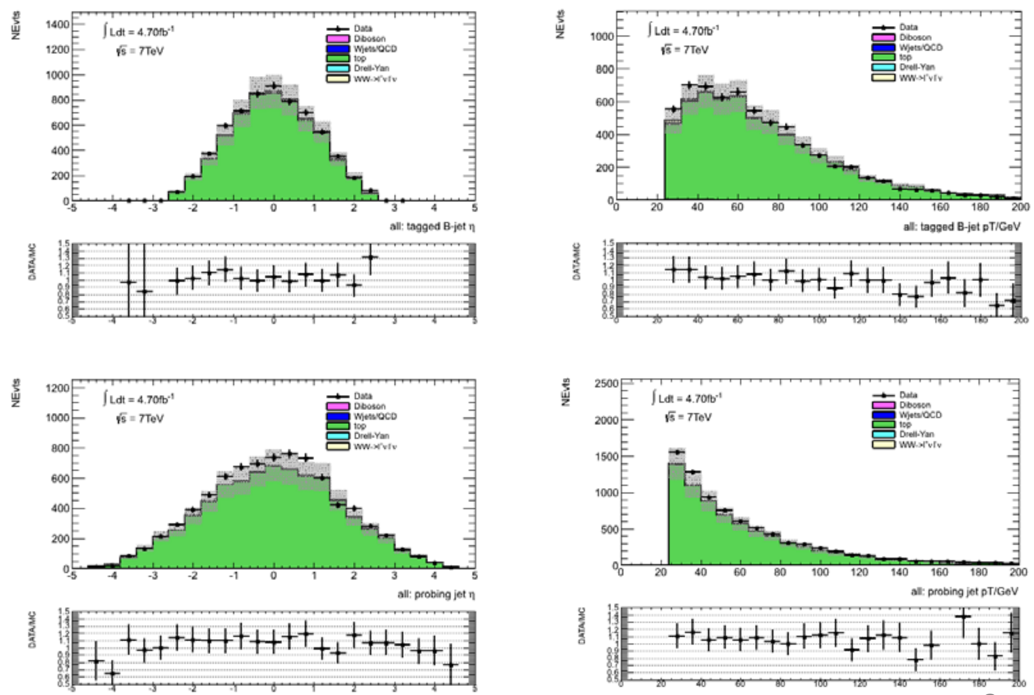
$$N_{\rm top}^{\rm Est.}(\ell\ell + E_T^{\rm miss}, 0j) \simeq N_{\rm top}^{\rm Data}(\ell\ell + E_T^{\rm miss}) \times \overbrace{P_2^{\rm MC} \times \left(\frac{P_1^{\rm Btag,data}}{P_1^{\rm Btag,MC}}\right)^2}^{P_2^{\rm Exp}}$$

$$= (N_{\rm all}^{\rm Data} - N^{\rm non-top}) \times (P_1^{\rm Btag,data})^2 \times \frac{P_2^{\rm MC}}{(P_1^{\rm Btag,MC})^2}$$

$$P_1^{\rm Btag} = N_{0j}^{\rm Btag} / N_{\rm all\text{-}jets}^{\rm Btag}$$

$$P_2^{\rm MC} = N_{0j}^{\rm MC} / N_{\rm all\text{-}jets}^{\rm MC}$$

Channel	Top (MC)	Top (DD)
ee	15.8±1.0	14.0±2.0(stat.)±2.9(syst.)
em	70.4±2.0	70.8±5.2(stat.)±14.4(syst.)
mm	20.0±1.1	25.2±2.9(stat.)±5.1(syst.)
combined	106.3±2.5	110.0±6.2(stat.)±22.4(syst.)



Other Diboson and final results

- Expected DiBoson Yields(purely MC prediction)

Final State	$e^+e^- E_T^{miss}$	$\mu^+\mu^- E_T^{miss}$	$e^\pm\mu^\mp E_T^{miss}$	Combined
diboson Background				
WZ	2.7±0.3	6.4±0.4	16.1±0.6	25.1±0.8
ZZ	3.0±0.3	4.5±0.3	0.6±0.1	8.1±0.5
$W\gamma$	1.4±1.0	0±0	8.6±2.7	10.0±2.8
$W\gamma*$	1.5±0.4	2.0±0.3	11.0±1.0	14.4±1.1
Total Background	8.6±1.2	12.8±0.6	36.2±2.9	57.6±3.2

Wγ* partially double counted in WZ, therefore scaled down in each channel based on ratio passing WZ gauge boson high mass cut

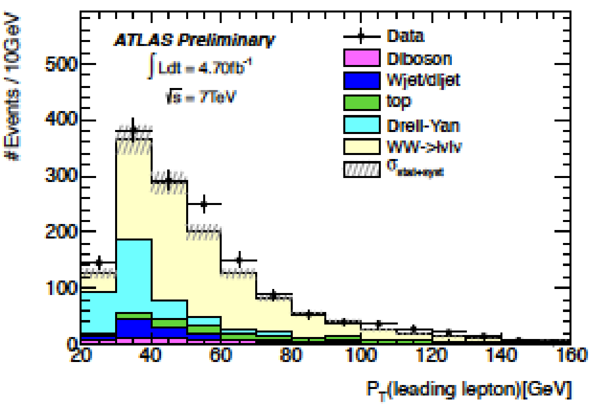
- Systematic uncertainties

			Uncertainties				±ΔN
	Lumi.	Cross-section	Jets	Leptons	MET	Trigger	
ee	3.9%	5.0%	20.8%	2.8%	3.5%	0.5%	1.9
$\mu\mu$	3.9%	5.1*%	13.6%	1.0%	3.6%	0.6%	2.0
$e\mu$	3.9%	5.0%	7.0%	1.6%	0.8%	0.5%	3.5
total	3.9%	5.0%	10.1%	1.4%	1.8%	0.5%	7.0

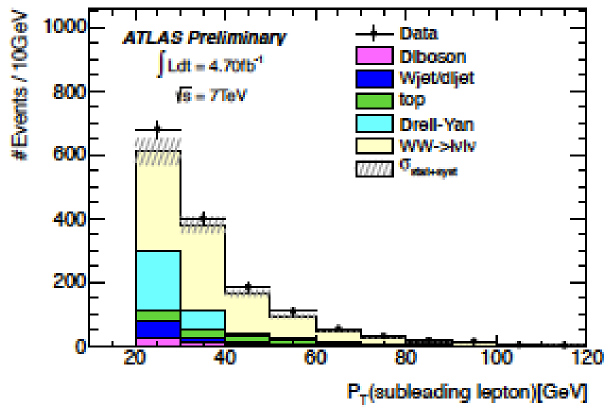
Final DATA Vs predictions

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
Z+jets (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

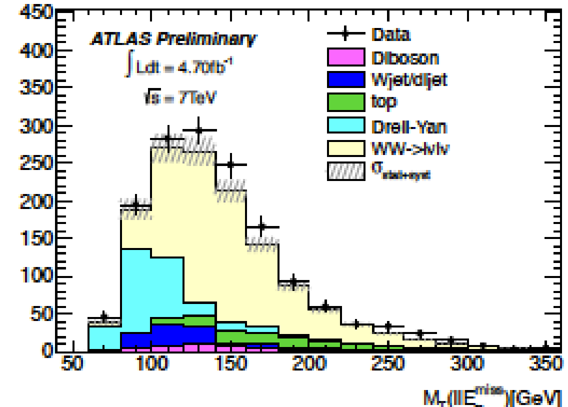
Final WW candidate plots approved for Moriond



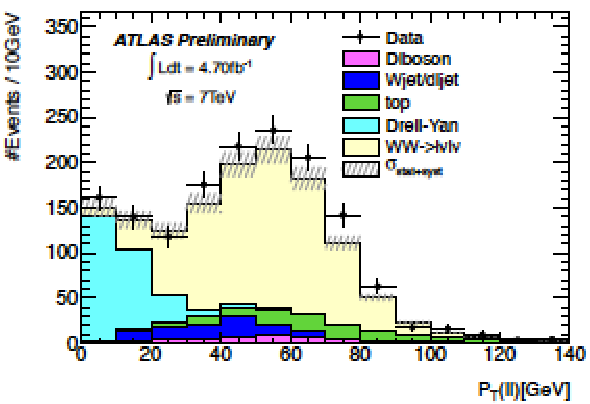
leading pT



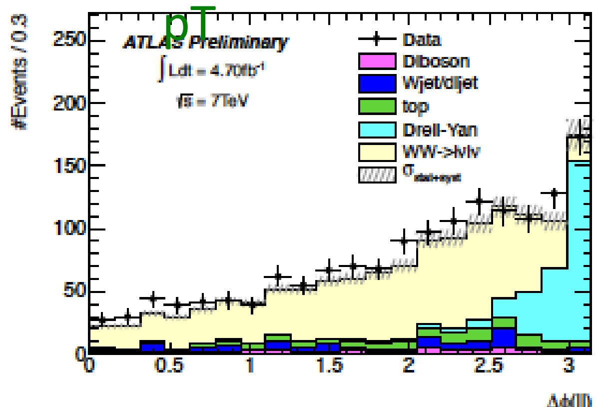
subleading pT



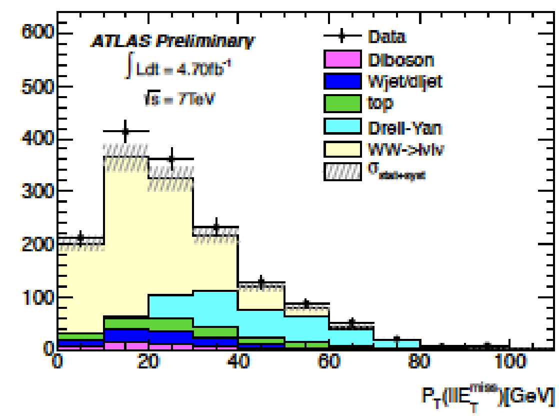
M_T(l+l-, Et_{miss})



$P_T(l^+l^-)$

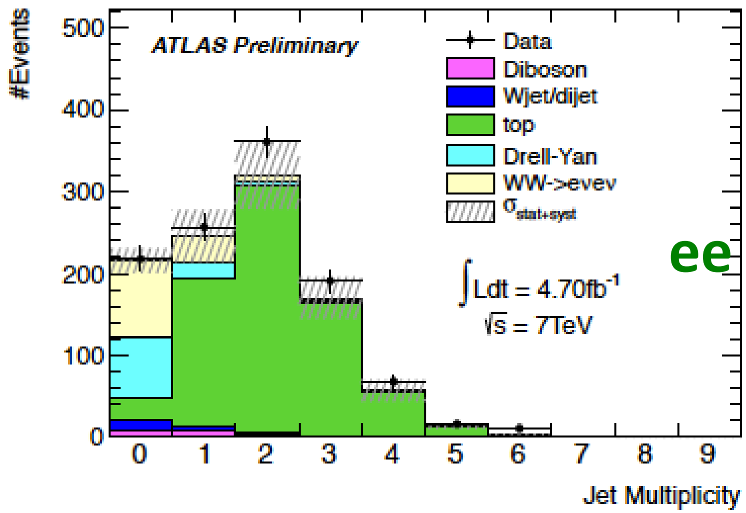


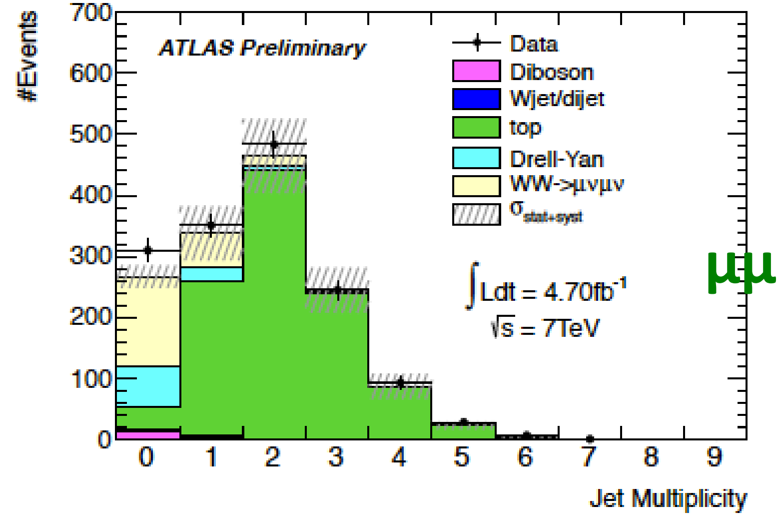
$\Delta\phi(l^+l^-)$

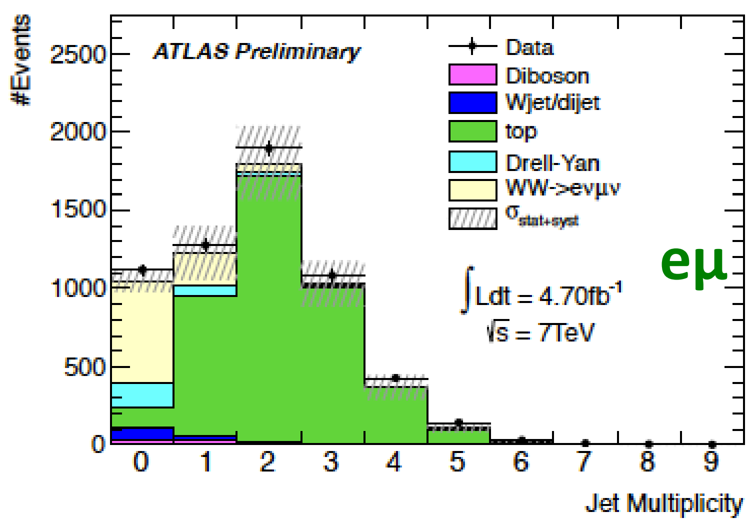


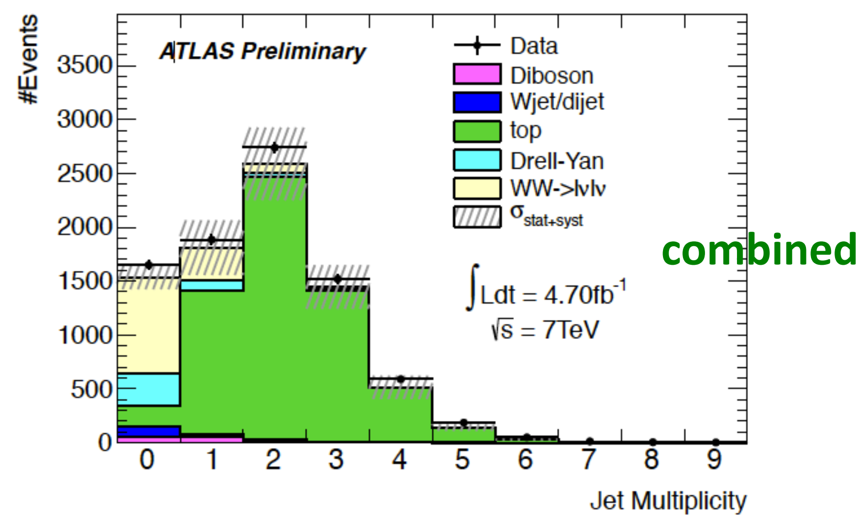
$P_T(l^+l^-, Et_{miss})$

Jet Multiplicity Plots - approved for Moriond









Acceptance and Fiducial xsec

Fiducial cross section measured in the phase space mimic the nominal selection

Overall WW signal acceptance determined by MC

$$\epsilon = A_{WW} \times C_{WW}$$

$$\epsilon = \frac{N_{MC\ WW\to\ell^+\nu\ell^-\nu}(pass\ all\ the\ selection\ cuts)}{N_{MC\ WW\to\ell^+\nu\ell^-\nu}(Total)}, \quad \ell = e,\ \mu, \tau.$$

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

The total WW production x-section is determined from 3 dilepton channels (**ee, μμ and eμ**) by maximizing log-likelihood functions:

$$L(\sigma_{WW}^{total}) = \ln \prod_{i=1}^{3} \frac{e^{-(N_s^i+N_b^i)} \times (N_s^i + N_b^i)^{N_{obs}^i}}{N_{obs}^i!}, \quad N_s^i = \sigma_{WW}^{total} \times Br \times \mathcal{L} \times \epsilon_{WW}^i$$

Deviate from SM prediction	Channels	Total cross-section (pb)	$\Delta\sigma_{stat}$(pb)	$\Delta\sigma_{syst}$(pb)	$\Delta\sigma_{lumi}$(pb)
-0.3σ	$e\nu e\nu$	41.5	± 6.5	± 7.8	± 1.6
+1.4σ	$\mu\nu\mu\nu$	57.3	± 5.5	± 5.4	± 2.2
+1.5σ	$e\nu\mu\nu$	54.3	± 2.4	± 4.4	± 2.1
+1.4σ	Combined	53.4	± 2.1	± 4.5	± 2.1

Conclusion

- WW cross section measurement in dileptonic channel using 4.7fb^{-1} data
- ✓ 1524 candidates observed in 2011 full datasetcompared to 325 in 1.02fb^{-1} analysis
- Data-driven methods used for almost all the backgrounds (Drell-Yan, top and W+jets)

- Detailed studies done on systematic uncertainties for both signal and backgrounds
  - ✓ 3.9% stat. and 8.4% overall syst. Uncertainty. 3.9% for Luminosity accounted separately.

- Measured xsection 53.4 ± 2.1(stat) ± 4.5(syst) ± 2.1(Lumi)pb is consistent(~1.4σ) with the theoretical prediction of 45.1±2.8 pb. Both inclusive and fiducial cross sections measured for three channels

- THANKS A LOT to all of you who are interested in this analysis!

Spare

Moriond Support Note & Conf. Note

Draft version 0.3

ATLAS NOTE

ATL-COM-PHYS-2012-145

February 24, 2012

Measurement of the WW Production Cross Section in Proton-Proton Collisions at $\sqrt{s}$ = 7 TeV with the ATLAS Detector

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Abstract

We report a measurement of the W^+W^- production cross section in pp collisions at $\sqrt{s}$ = 7 TeV. The W^+W^- leptonic decay channels are analysed using data corresponding to 4.7 fb^{-1} of integrated luminosity collected by the ATLAS detector in 2011 at the CERN Large Hadron Collider. The measured W^+W^- production cross section $\sigma(pp \to W^+W^-)$ is 54.9 ± 2.1 (stat) ± 4.2 (syst) ± 2.1 (lumi) pb, compatible with the Standard Model NLO prediction of 44.4 ± 2.8 pb.

Draft version 1.0

ATLAS NOTE

ATLAS-COM-CONF-2012-024

February 24, 2012

Measurement of the W^+W^- production cross section in proton-proton collisions at $\sqrt{s} = 7$ TeV with the ATLAS detector

The ATLAS Collaboration

Abstract

This note reports on a measurement of the W^+W^- production cross section in pp collisions at $\sqrt{s} = 7$ TeV. The W^+W^- leptonic decay channels are analyzed using data corresponding to 4.7 fb^{-1} of integrated luminosity collected by the ATLAS detector during 2011 at the CERN Large Hadron Collider. With 1524 observed W^+W^- candidate events and an estimated background of 503 ± 40 events, the measured W^+W^- production cross section is 54.9 ± 2.1(stat) ± 4.2(syst) ± 2.1(lumi) pb, to be compared with the Standard Model NLO prediction of 44.4±2.8 pb.

4.7 fb^{-1} support document and cont. note on CDS.

Support note: ATL-COM-PHYS-2012-145

Conf. note: ATLAS-COM-CONF-2012-024

Jan Kretzschmar's talk for ATLAS and CMS at Moriond EW 2012

Syst.

- **Syst. Sources accounted:**

✓ **Lepton Systematic:**
  - ❖ Lepton reconstruction and identification efficiencies
  - ❖ Lepton isolation efficiency
  - ❖ Lepton energy/momentum scaling and smearing

✓ **Jet Veto**

✓ **MET syst.(pileup uncert., combination with lepton energy res/scale and JES/JER)**

✓ **PDF uncertainty.**

✓ **Dedicated syst. uncertainty from Data-driven background estimation**

✓ **The luminosity uncertainty** (3.9%, listed separately)

- The systematic uncertainty of the total cross section mea $\sqrt{(\Delta A/A)^2+(\Delta C/C)^2}$ 8.4%, which includes the signal acceptance uncertainty ( ) o $\Delta N_{bkg}/(N_{obs}-N_{bkg})$ ainty of the background estimation ( ) 5.1%. The systematic error is calculated using propagation:

$$(\Delta\sigma/\sigma)_{syst} = \sqrt{(\Delta A/A)^2+(\Delta C/C)^2+(\Delta N_{bkg}/(N_{obs}-N_{bkg}))^2}$$

Syst. Summary

Sources	$e^+e^- E_T^{miss}$	$\mu^+\mu^- E_T^{miss}$	$e^\pm\mu^\mp E_T^{miss}$	Combined
Luminosity	3.9%	3.9%	3.9%	3.9%
A_{WW} uncertainties				
PDF	1.42%	1.36%	1.37%	1.23%
Scale (μ_R, μ_F)	2.12%	0.60%	1.65%	1.53%
Jet veto (MC modeling)	5.00%	5.00%	5.00%	5.00%
C_{WW} uncertainties				
Trigger	0.27%	0.63%	0.45%	0.46%
Electron Scale	0.87%	0.0%	0.32%	0.31%
Electron Resolution	0.06%	0.0%	0.02%	0.02%
Muon Scale	0.02%	0.87%	0.20%	0.30%
ID Muon Resolution	0.0%	0.02%	0.01%	0.01%
MS Muon Resolution	0.0%	0.10%	0.01%	0.01%
Electron recon. SF	1.60%	0.0%	0.81%	0.76%
Electron ID SF	2.31%	0.0%	1.01%	0.98%
Muon ID SF	0.0%	0.69%	0.35%	0.37%
Lepton Isolation	4.00%	2.30%	2.28%	2.25%
B tagging SF	0.43%	0.52%	0.45%	0.46%
MET pile-up	2.46%	2.83%	0.65%	1.21%
MET Cluster	1.84%	1.82%	0.47%	0.84%
JES & JER	3.22%	3.17%	1.89%	2.54%
Total Acceptance uncertainty	8.74%	7.48%	6.44%	6.71%
WW signal estimation uncertainty	11.4%	10.5%	9.75%	9.93%

Dominant syst. to be improved

Larger than we expected

Total cross-section measurement

The total WW production cross section is determined from the three dilepton channels (**ee, μμ and eμ**) by maximising log-likelihood functions:

$$L(\sigma_{WW}^{total}) = \ln \prod_{i=1}^{3} \frac{e^{-(N_s^i+N_b^i)} \times (N_s^i + N_b^i)^{N_{obs}^i}}{N_{obs}^i!}, \quad N_s^i = \sigma_{WW}^{total} \times Br \times \mathcal{L} \times \epsilon_{WW}^i$$

SM prediction: 45.1 ± 2.8 pb

Measured: 53.4 ± 2.1(stat) ± 4.5(syst) ± 2.1(Lumi) pb

Channels	$A_{WW} \times C_{WW}$	A_{WW}	C_{WW}
$e\nu e\nu$	$0.026 \pm 0.001 \pm 0.002$	$0.062 \pm 0.001 \pm 0.003$	$0.420 \pm 0.008 \pm 0.029$
$\mu\nu\mu\nu$	$0.040 \pm 0.001 \pm 0.003$	$0.052 \pm 0.001 \pm 0.003$	$0.768 \pm 0.014 \pm 0.042$
$e\nu\mu\nu$	$0.090 \pm 0.001 \pm 0.006$	$0.163 \pm 0.001 \pm 0.009$	$0.551 \pm 0.004 \pm 0.019$

Cross Section Extraction methodology

- Formula used to determine the total cross-section is

$$\sigma_{WW} = \frac{N_{obs} - N_{bkg}}{\epsilon\mathcal{A}\,\mathcal{L}\,Br}$$

- The following relations among εA, C_{WW} and A_{WW} hold

$$\begin{aligned} A_{WW} &= \frac{N(generator-level\ fiducial\ cuts)}{N(generated\ events)}, \\ \epsilon\mathcal{A} &= \frac{N(reco-level\ analysis\ cuts)}{N(generated\ events)}, \\ C_{WW} &= \frac{\epsilon\mathcal{A}}{A_{WW}} = \frac{N(reco-level\ analysis\ cuts)}{N(generator-level\ fiducial\ cuts)}, \end{aligned}$$

  - C_{WW} is the overall correction factor to calculate fiducial xsec(covers det. resolution, efficiency and bg corrections,…)
  - A_{ww} is fiducial acceptance factor to recover the total xsection based on MC
  - Fiducial cuts mimic the nominal analysis cuts with Et_{miss} defined using pT of true ν

Changes w.r.t. $1fb^{-1}$ Paper draft

- The CONF-Note analysis relies mainly on the $1fb^{-1}$ paper draft. In particular
  - Measurement Methodology
  - Background Estimations
  - Systematic Uncertainty Studies

- Significant changes
  - Based on Athena Rel 17 Samples
    - Full Analysis is based on MC11c Monte Carlo Samples
  - Lowering pT-Cut for subleading lepton to 15 GeV at preselection level
    - comparable to Higgs-analysis
    - Last cut rises this threshold back to 20 GeV
  - Raise $E^{T}_{Miss,Rel}$ Cut by 10 GeV in the ee and μμ channel due to new Pile-Up scenario

Channel	$E_{T,\,Rel}^{miss}$-cut [GeV]	Data	Signal	Background	S/B	$S/\sqrt{B}$
ee	40	503	121	350	0.345	6.46
ee	50	192	86	84	1.02	6.59
$\mu\mu$	45	605	195	332	0.588	8.5
$\mu\mu$	55	274	135	82	1.65	9.18

New Baseline selection aiming for Moriond:
https://twiki.cern.ch/twiki/bin/viewauth/AtlasProtected/BaslinecutsforWW5fbMoriond

Object selections, general and technical issues are well documented and shared among all EW DiBoson groups:
https://twiki.cern.ch/twiki/bin/viewauth/AtlasProtected/WZElectroweakCommonTopics2011

Event Selection details

- Selection strategy similar to 2011 analysis: 2011 twiki, Moriond twiki
- General Preselection and Object Definition based on EW-Common Recommendations. In particular:
  - STACO Combined muon >15GeV(leading pT>25GeV for μμ), |η|<2.4, CaloIso(etcone30/pt<0.14), trackIso(ptcone30/pt<0.15)
  - Tight++ electron >15GeV (leading ET>25GeV for ee and eμ), |η|<2.47 w/o crack, CaloIso(Etcone30_corr/ET<0.14), TrackIso(ptcone30/ET<0.13)
  - AntiKt4TopoEM jet, EM+JES pT>25GeV and |η|<4.5, |JVF|>0.75
  - MET_RefFinal with |η|<4.9(out-of-box)

- Event-Selection optimized to accomplish a better S/B and against pileup:
  - ➢ ee, μμ: Exact 2 prompt, isolated, OS leptons with pT>15(trailing),25(leading)GeV
  - ➢ eμ: require electron ET>25GeV
  - ➢ $|M_{ll}-M_Z|$>15GeV for ee and μμ
  - ➢ M_{ll}>15GeV for ee and μμ, and M_{ll}> 10 GeV for eμ
  - ➢ MET^{Rel} > 55,50 GeV for μμ and ee, 25 GeV for eμ
  - ➢ 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
  - ➢ Tailing lepton pT>20GeV to be compatible with 2011 fiducial volume

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

Selected CDS comments I

- **dedicated twiki for CDS discussion**
  - Addressed most comments partially shown below
  - Open for coming / remaining comments
- **Jon**
  - C: “fig.7 - 11 are really very impressive! However, since we are measuring the WW xsec, it would be instructive to (also) see these made with the SM WW cross section allowed to float (but the backgrounds fixed). This would tell us whether the shapes are consistent in the case that the excess we see in data w.r.t. the SM xsec are still modelled on the hypothesis this is entirely due to signal. In general this would be a good approach for plots which we want to use to validate our background models and unfolding (though I realise we aren't doing much unfolding yet, we hopefully will be soon!). It would be interesting to see how the discrepancies in fig.12 & 13 for example, change under such a treatment.”

  - A: **fig.7-10 will not be affected by leaving the WW xsec float as the signal contribution is insignificant here. The largest change is expected when replacing the Alpgen prediction by the Pythia prediction of Drell-Yan. For the shape comparisons in fig.12 and 13 we would propose to compare normalized histograms in addition to a floating signal contribution**.

Selected CDS comments II

❑Eram

- ❖ C: Fig 17: why is there so much contribution to the same sign background from diboson processes in the muon channel compared to ee? The selection is very similar for both, except that the METrel cut is lower for ee. Is this understood?
- ➢ **A: Almost all of the MC is WZ at that stage, the MC predictions being 1.3 events in ee and 5 events in the mm channel. Most of the difference arises in the 0 jet cut, which removes most of the ee contributions. One plausible possibility is that for events at this stage the leptons must be from different bosons due to the Z cut, and most of the a badly measured electron is also identified as a jet whereas a missing muon can sneak out through one of the low-efficiency holes of the detector without a calorimeter deposit. This would explain the jet-veto cut efficiencies of 23%(ee), 43%(em) and 63%(mm).**

- ❖ C: tab.21: this is a nice cross check of the estimation and agrees well with tab.20 although ee channel is much smaller by a factor of 2 (but within errors). In principle you could check the fake e, and the fake mu contributions separately in the e-mu channel to compare also with tab.20. How do these numbers compare?
- ➢ **A: Modified the WW support note to show e or mu fake contribution for e-mu channel separately, e-fake is 21.17+/- 1.33 +/- 5.72, mu-fake is 13.52+/-0.85+/-3.65**

Selected CDS comments III

- **Davide:**
  - C: Line 101, it's not clear to me what you are suppressing? What does the "low mass spectrum" refer to?
  - **A: It is basically the LowM DY backgrounds that lack of M<10GeV modeling currently. We require Mll>15(10) for ee/mumu(emu) channel.**
  - C: Line 106, what is the threshold on the jet used for the etmiss,rel definition? If it's 25GeV, then there is no point in using jets in the definition as events with a jet with pt>25 are thrown away. If it's less than 25, I worry that there may be jets from pileup that affect your variable definition
  - **A: Yes, it is 25GeV jets (after e/jet overlap removal w/o JVF cut) that are used for METrel calculation. Given the fact that we implemented e/jet overlap removal and JVF cut in our analysis, the jets can still survive with quite small probability. In addition the jet-veto cut comes very late on the analysis so we need to correct for this for the MC/Data plots before.**
  - C: The data driven techniques are quite complicated... I'll have to read through them again to properly digest. Can you confirm that the presence of a lepton from a b-quark decay is properly accounted for?
  - **A: Currently the fake lepton method has been borrowed partly from the HWW analysis due to the same objection definition and similar event selection. The b-quark decay was studied and accounted in the estimated fake factor syst.**

Selected CDS comments IV

- **Hans Peter**
  - C: #98 I am not sure I quite follow the event selection in case of the em channel. Apparently, the electron pT needs to be above 25 GeV regardless of the muon pT. With this, a nice event with pT e = 22 GeV and pt m = 40 GeV is discarded. Is this really what you want? (Note, this is not a problem with the analysis if treated consistently; it just raises my eye-brow.)
  - **A: Added in the text: The lowering of the pT cut of the electron in the emu channel leads only to a small gain in the acceptance but to a significant increase of the W+jets background.**
  - C: Table 5: Should ZtautaubbNp0,1,2,3 be added to this list? If not, why? For W's, associated c and cc jets are considered, but these are apparently ignored for Z's. Is there a good reason for ignoring c's in Z+X?
  - **A: heavy flavour samples are important for the estimation of background where the second signal lepton comes from a heavy flavor decay. Hence this is only dominating for the W+jets background. The dominating contribution from Z->tautau comes instead from the full leptonic decay mode**
  - C: Figure 24: The systematic uncertainties get big at high jet multiplicities and for large Etmissrel. I could not quite follow whether this uncertainties are considered bin by bin, or whether an overall average uncertainty was used.
  - **A: The uncertainty is just taken at the cut-value itself. The plot just illustrates the dependence on the cut-value.**

HSG3 Vs SMWW xchecks

- **Compared with HSG3 baselines:**
  - No b-Veto in HSG3 0-jet bin analysis (different tagger in use)
  - NO separate jet transition region treatment and NO jet smearing in SMWW
  - Higher M(ll) cut for ee/mm (SM:15GeV, Higgs:12GeV)
  - Higher METrel cut (SM: ee/mm/em->50/55/25GeV, Higgs: 45/45/20GeV)
  - No p_T(ll) cut and other topological cut
  - Same e/μ definition except H→WW includes low p_T leptons (10-15GeV)

- **Quick xchecks documented in Evelyn's summary slides:**
  - Good agreement well in WW Control region
  - Addapting the SMWW selection to the HWW ntuples gives comparable results
  - Fixed a bug implementing HSG3 fake factors in SMWW, W+jets d-d numbers are still a bit different(~10evts less in SMWW) in emu channel but well covered by syst. Uncertainty ~50%
  - Z+jets MC slightly different due to different Alpgen samples in use(larger stat. in HSG3)

SM WW numbers in Higgs WW control region

Albert-Ludwigs-Universität Freiburg

My exercise (from SM WW side) on "Higgs WW control region".

Note: WW cross section is using Higgs' (0.520)

WW	Diboson (MC)	Top (MC)	Drell-yan (MC)	Wjets (DD)	Bkg	Data	(Data-Bkg)/WW
42.2628	4.0159	18.3935	0.5620	1.2434	24.2148	85	1.4383
72.0583	7.5597	22.5145	2.2364	0.4620	32.7725	91	0.8081
351.2966	18.0102	85.9477	2.4722	20.4582	126.8882	514	1.1020
465.6177	29.5862	126.8575	5.2706	22.1636	183.8779	690	1.0870

Sum: 649.5 Ratio: 1.06

	WW	WZ/ZZ/ Wgam	Top	DY	Wjets d-d	Wjets	Bkg	Data	Ratio
ee	41.90	3.17	18.12	2.03	4.32	4.93	69.53	85	1.22
mm	71.67	4.21	22.47	3.98	1.00	0.00	103.34	91	0.88
em	351.86	17.38	85.39	2.88	42.96	34.29	500.47	522	1.04
ll	465.43	24.76	125.98	8.89	48.28	39.21	673.34	698	1.04

Conf note:

Control Regions	Signal	WW	$WZ/ZZ/W\gamma$	$t\bar{t}$	$tW/tb/tqb$	$Z/\gamma^* + \text{jets}$	$W + \text{jets}$	Total Bkg.	Obs.
WW 0-jet	0.1 ± 0.1	465 ± 3	25 ± 2	85 ± 2	41 ± 2	9 ± 2	48 ± 27	673 ± 5	698

Higgs WW numbers with SM WW selection

SM WW numbers provided by Shu :
b-jet veto is dropped because WW group uses MV1 85 and HWW group CombNN80

	WW	WZ/ZZ Wgam	Top	DY	Wjets d.d	Wjets	Bkg	Data	Ratio
ee	98.33	8.78	30.64	73.60	13.73	12.55	225.08	218	0.97
mm	152.64	13.17	39.62	70.79	2.22	3.71	278.44	310	1.11
em	740.24	43.41	154.46	197.97	36.15	92.15	1172.13	1262	1.07
all	991.21	65.36	224.72	342.36	52.10	108.41	1675.75	1790	1.07

HWW numbers:

	WW	WZ/ZZ Wgam	Top	DY	Wjets d.d	Wjets	Bkg	Data	Ratio
ee	96.72	5.98	27.89	85.42	20.33	16.03	236.34	225	0.95
mm	150.57	9.79	36.99	79.69	4.29	1.70	281.33	320	1.14
em	733.83	42.78	143.99	222.46	97.55	98.67	1240.61	1282	1.03
all	981.12	58.54	208.88	387.56	122.17	116.40	1758.28	1827	1.04

Jet veto scale factor

- Reduce uncertainty on WW jet veto acceptance
- Calculate a scale factor using Drell-Yan process $Z \to \ell\ell$
- $\epsilon_{WW}^{data} = \epsilon_{WW}^{MC} \times \frac{\epsilon_Z^{data}}{\epsilon_Z^{MC}}$ where $\epsilon = \frac{N_{0\ \mathrm{jet}}}{N_{\geq 0\ \mathrm{jet}}}$
- Select Z events from dielectron and dimuon data by requiring $|m_{\ell\ell} - m_Z| < 15\ \mathrm{GeV}$
- Study uncertainties due to JES uncertainty and JER
- Dominated by theory uncertainty due to scale choice
- (Measure this from a MCFM truth-level study)

$$0.953 \pm 0.001\ (stat)\ \pm 0.048\ (MC)\ \pm 0.007\ (JER \oplus JES).$$

Sources	$e^+e^- E_T^{miss}$	$\mu^+\mu^- E_T^{miss}$	$e^\pm\mu^\mp E_T^{miss}$	Combined
Jet-veto (Monte Carlo)	7.82%	6.04%	6.9%	7.37%
Jet-veto (Data-Driven)	4.8%	4.8%	4.8%	4.8%

DATA & MC Samples

- Signal
  - qq $\rightarrow$ WW: MC@NLO
  - gg $\rightarrow$ WW: gg2ww
- V+X
  - W+X Np0-5: Alpgen
  - Z+X Np0-5: Alpgen
    - 10<M<40 GeV; M>40 GeV
  - Zbb Np0-3: Alpgen
  - Wc/cc/bb Np0-4: Alpgen
- Dibosons
  - WZ, ZZ: Herwig
  - Wγ Np0-5: Alpgen
  - Wγ*: MadGraph
- Top
  - tt: MC@NLO
  - Wt: AcerMC
  - Single top: AcerMC
- QCD bb/cc: PythiaB

- Periods D1-M10
  - 4.7 fb-1
  - 3.7% uncertainty
- Good Run List:

data11_7TeV.periodAllYear_DetStatus-v36-pro10_CoolRunQuery-00-04-08_WZjets_allchannels.xml

- Egamma stream
  - EF_e20_medium
  - EF_e22_medium
  - EF_e22vh_medium1
- Muon stream
  - EF_mu18_MG OR EF_mu40_MSonly_barrel
  - EF_mu18_MG_medium OR EF_mu40_MSonly_barrel_medium
- D3PD p833
  - Release v17.0.5.6.1
- Dilepton filter
  - 2 leptons Pt>10 GeV
  - Medium electrons or looser muons

CutFlow Tables for 4.7fb^{-1} data

Cuts	$ee + E_T^{miss}$	$\mu\mu + E_T^{miss}$	$e\mu + E_T^{miss}$
>= 2 leptons (SS+OS)	1049296	1823285	21549
2 leptons (OS)	1043310	1822980	20677
ℓ $p_T > 25$GeV	1025363	1773911	15618
trigger matching	1024912	1763886	15579
$M_{\ell\ell'}$ >15/10 GeV	1021200	1753923	15563
Z mass veto	95889	178777	15563
$E_{T,Rel}^{miss}$ cut	1303	1784	6653
Njet(0,1,2,3,>=4)	(254,306,416,221,106)	(357,427,558,282,160)	(1265,1423,2112,1177,676)
Jet veto	254	357	1265
b-jet veto	229	325	1176
trailing ℓ $p_T > 20$GeV	196	287	1041

- **CutFlow converged between all different groups**
- **1524 candidates observed compared with 325 candidates in r16 1fb^{-1} analysis last year**

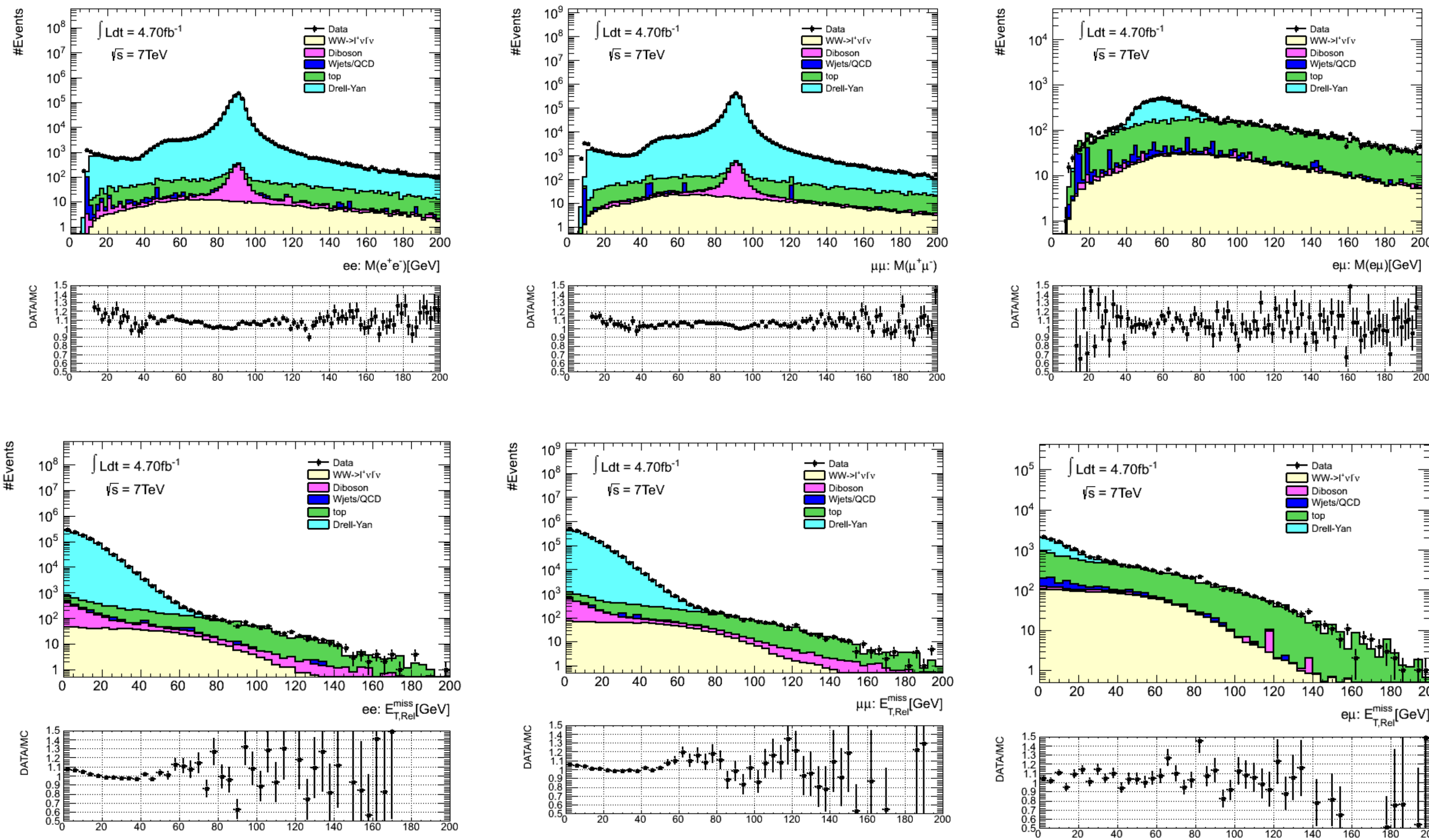
MC signal acc./bgd expectation($4.7fb^{-1}$)

Cuts	*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
$\ell\ p_T > 25$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
$M_{\ell\ell^{(\prime)}} > 15/10$ 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
trailing $\ell\ p_T > 20$GeV	83.3	5.2	128.1	8.8	562.6	51.0
WW Acceptance	3.37%	0.55%	5.18%	0.93%	11.38%	2.69%

Final State	*ee* Channel	$\mu\mu$ Channel	$e\mu$ Channel	combined
Observed Events	196	287	1041	1524
MC WW signal	88.5	137.0	613.6	839.0
Top	15.8	20.0	70.4	106.3
W+jets+QCD	12.5	3.7	65.8	81.9
Drell-Yan	66.5	62.2	142.0	270.7
Diboson	8.6	12.8	36.2	57.6
Total Background	102.9	98.3	314.8	516.0
S+B	191.4	235.3	928.4	1355.0

All backgrounds are estimated using MC simulation in this table

M(ll) and $E_T^{miss,rel}$ at preselection



Syst. Uncertainty details

- Scale factors and object properties varied within their uncertainty ranges
  - Correlated with MET: electron/muon/jet - scale and resolution
- MET central value → uncert. from selected el/mu/jets propagated by hand
- MET uncertainty → using METUtility
  - Other uncertainties added in quadrature
- Jet Energy Resolution – smaller in MC than in Data
  - no smearing applied for jet on MC (yet?)
  - Resolution varied symmetrically:

$$\Delta\sigma_{Res} = \left[(\sigma_{Res,Data} + \Delta\sigma_{Res,Data})^2 - \sigma^2_{Res,Mc}\right]^{1/2}$$

- Note: Analysis uses AntiKt4TopopEM, whereas AntiKt4LCTopo used to smear MET
- Note that: the dominant uncertainty from MC simulation is JES/JER, we used data-driven method to estimate the jet-veo uncertainty for signal acceptance, the preliminary uncertainty is 5%

Systematic Uncertainties from Theory

- Central values for A_{WW}, C_{WW} are calculated via MC@NLO Samples
- Theoretical uncertainties on A_{WW} and C_{WW}
  - PDF-Uncertainties
    - Standard CTEQ 6.6 PDF Set variation with 44 eigenstates
    - CTEQ 6.6 to the central MSTW 2008 NLO 68% CL PDF
  - MC modelling renormalisation (μ_R) and factorisation (μ_F) scale factor uncertainties
    - vary the two scales "up" and "down" by a factor of 2

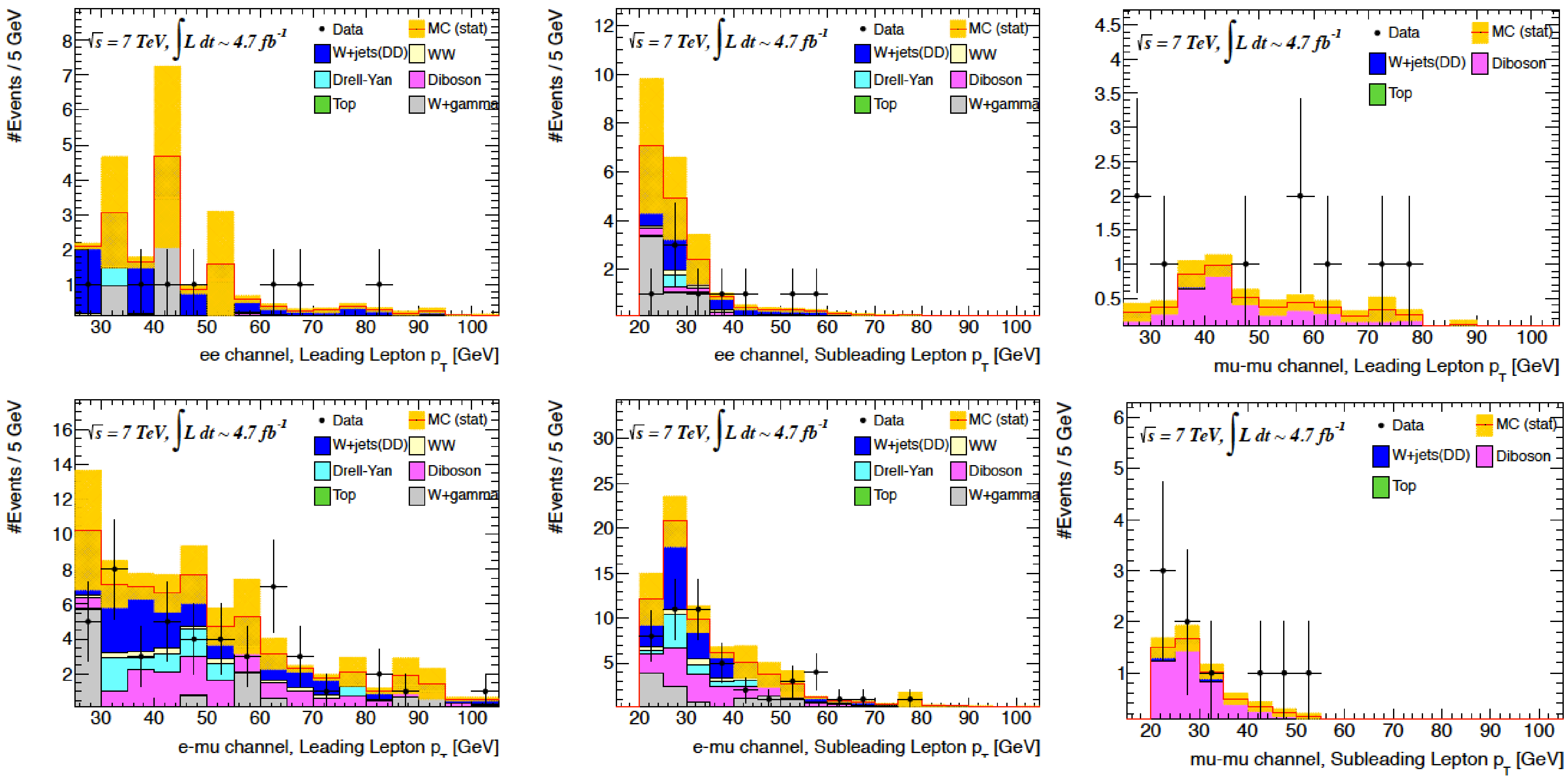
Channel	PDF	Scale	Jet-Veto	Combined
$e\nu e\nu$	1.3%	1.9%	4.8%	5.3%
$mu\nu e\nu$	1.4%	1.6%	4.8%	5.2%
$e\nu\mu\nu$	1.2%	1.6%	4.8%	5.2%

Theoretical uncertainties on A_{WW}

Channel	PDF	Scale	Combined
$e\nu e\nu$	0.3%	1.1%	1.1%
$\mu\nu e\nu$	0.1%	1.0%	1.0%
$e\nu\mu\nu$	0.2%	0.3%	0.4%

Theoretical uncertainties on C_{WW}

Wjets same-sign region control plots



Matrix Method for QCD Estimation

- This method has been used in Tevatron experiments. It was also used in the ATLAS SUSY / SM groups since 2010.

  (ATL-COM-PHYS-2010-1045, ATL-COM-PHYS-2011-1522)

- **The idea:**

  use a 4x4 matrix to map the observed lepton types (Tight-T or Loose-L) to the true nature of the lepton (Real-R or Fake-F)

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

▸Reconstruction efficiency (r) is measured in a Z-rich control sample
  r = N_TT / N_TL, r1 / r2 are eff for leading and 2nd leading leptons

▸ Fake rate (f) is measured in a jet-rich control sample
  f = N_T / N_L, f1 / f2 are fake rates from jet to the 1st and 2nd leptons

QCD Estimation using Matrix Method

- Select events passing two "Loose" leptons cut and all other WW selection cuts, then each event
  - We know that exactly one of (N_TT, N_TL, N_LT, N_LL) is 1
  - Invert the 4x4 Matrix
  - Obtain weights for each event (N_RR, N_RF, N_FR, N_FF)
  - Sum weights over all selected events to estimate bkgd

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

$$N_{TT}^{\mathrm{est,fake}} = \sum_{i}^{N_{\mathrm{events}}} \boxed{r_{1,i} f_{2,i} N_{RF,i} + f_{1,i} r_{2,i} N_{FR,i}} + \boxed{f_{1,i} f_{2,i} N_{FF,i}}$$

Estimated background from W+jets, ttbar, single top with 1 real lepton and 1 fake lepton

Estimated QCD bkgd with 2 fake leptons

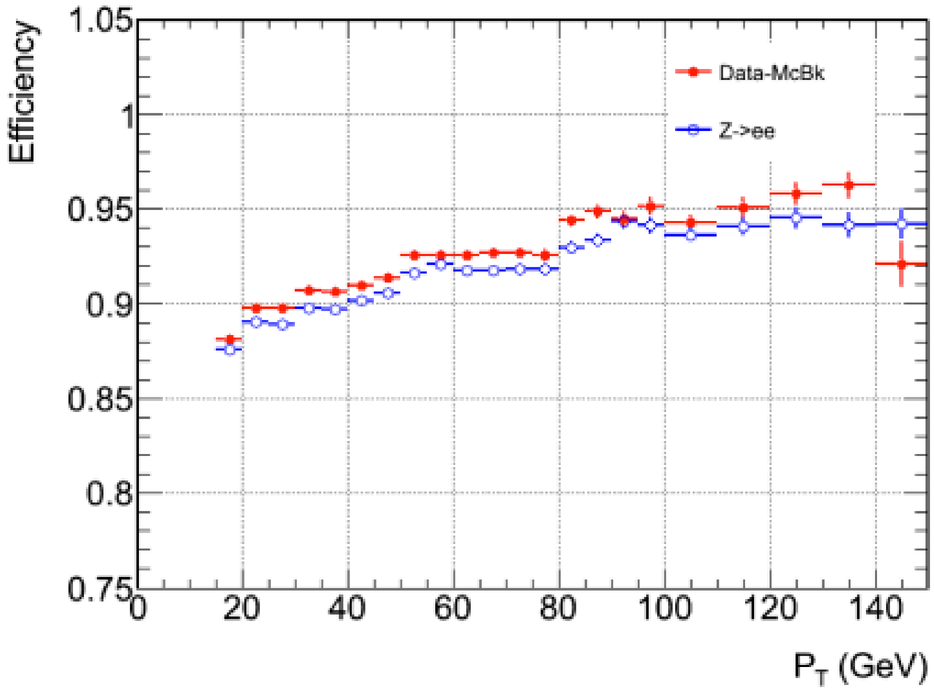
Real Lepton Efficiency and Fake Rate

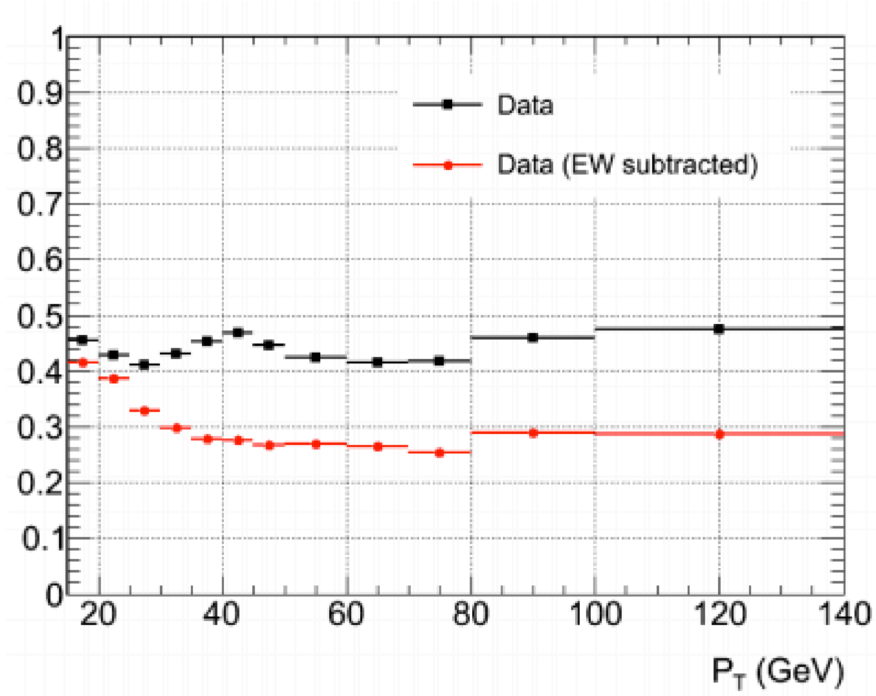
- The lepton efficiency (R) is measured Z control samples: R = N_T / N_L (ratio of num of lepton pass tight cuts vs. num. of lepton pass loose cut):
  - Only require one Tight lepton in Z sample (pT > 20 GeV).
  - $|M_{ll} - M_Z| < 5$ GeV

    Tight electron (el_tightPP==1); ***Loose*** electron (el_mediumPP==1)

    Tight muon (with isolation cut, ptcone30/pt<0.15 && CorrectEtCone30Rel < 0.14), ***Loose*** muon (no isolation cut)
- Fake rate (f) is measured in a jet-rich control data sample: f = N_T / N_L
  - One and only one ***Loose*** lepton with Pt > 20 GeV
  - MET < 20 GeV
  - $M_T < 60$ GeV (if lepton Pt > 30 GeV)
  - Remove the Electroweak contamination using MC

Electron Eff. and Jet Fake Rate

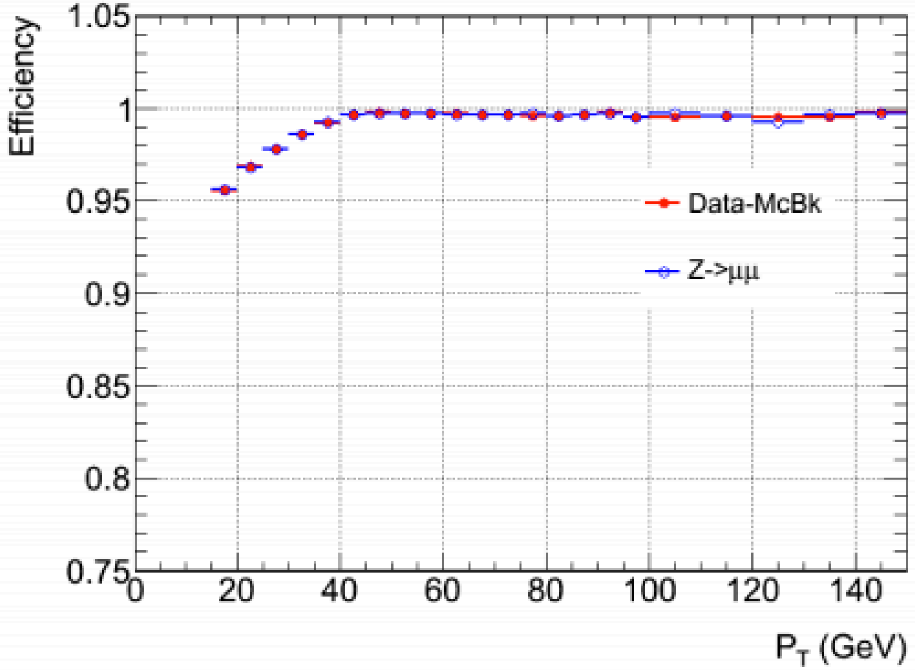


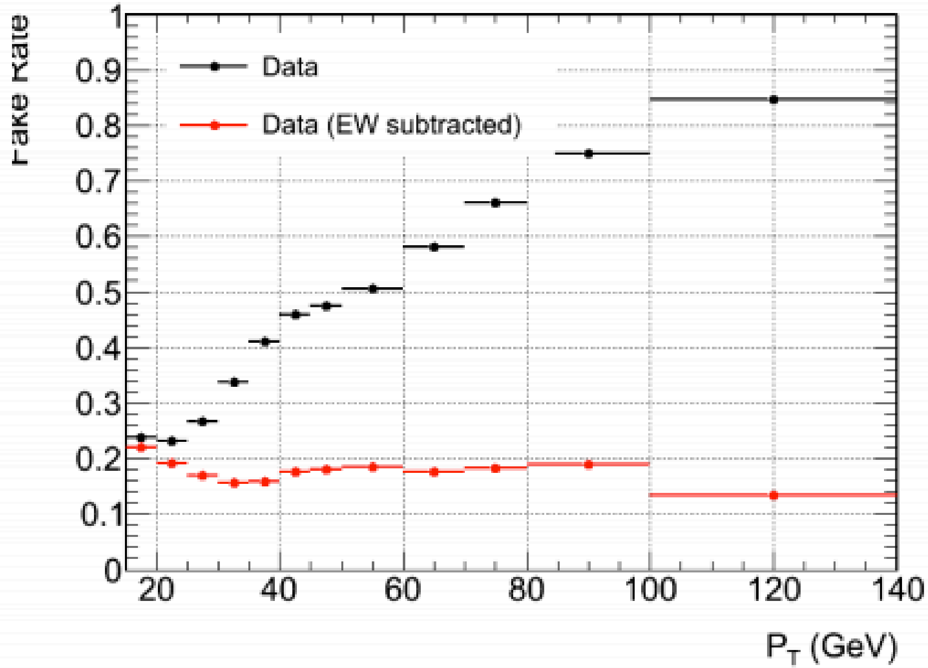


e Efficiency

Jet → e Fake rate

Muon Eff. and Jet Fake Rate

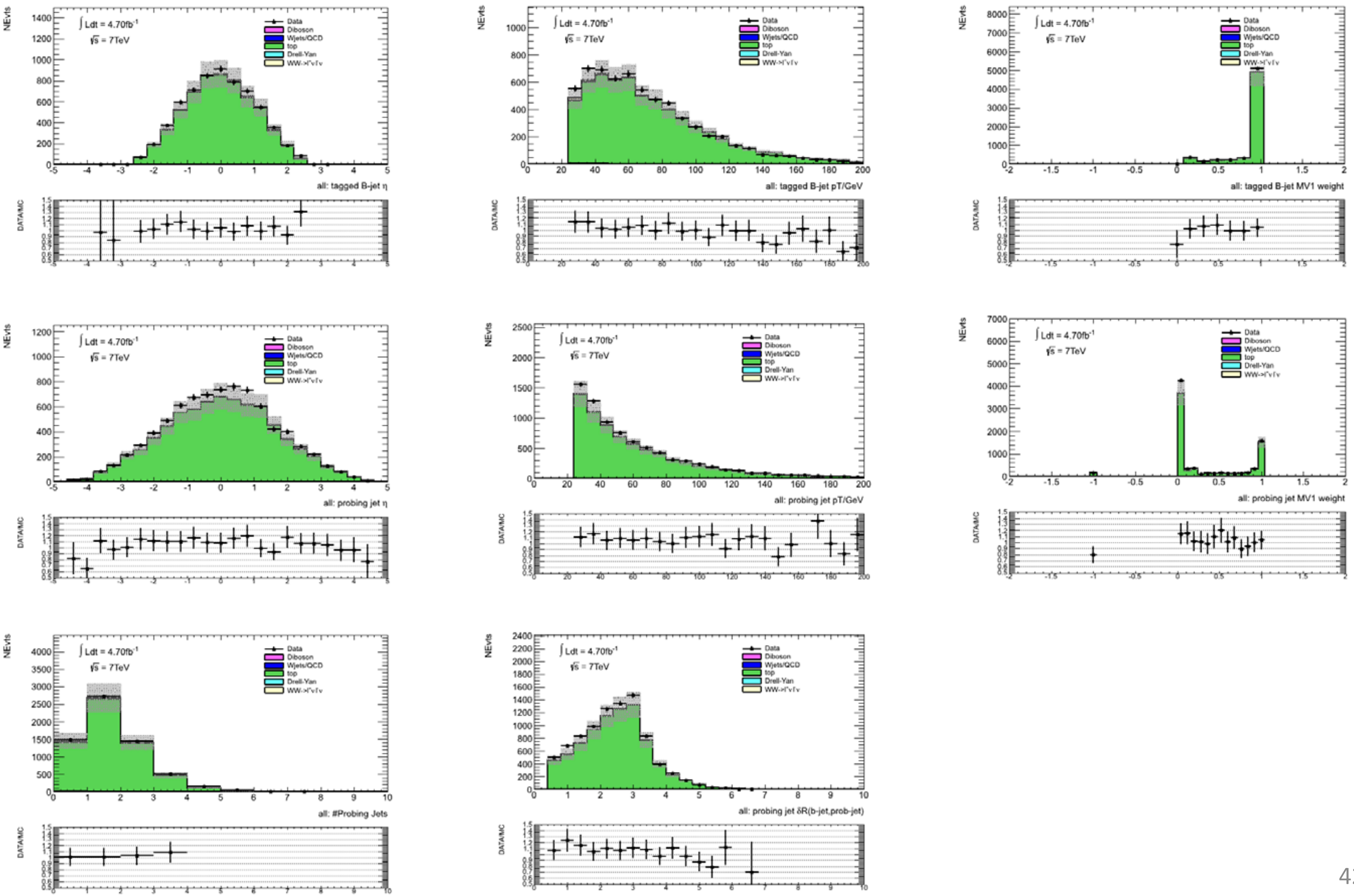




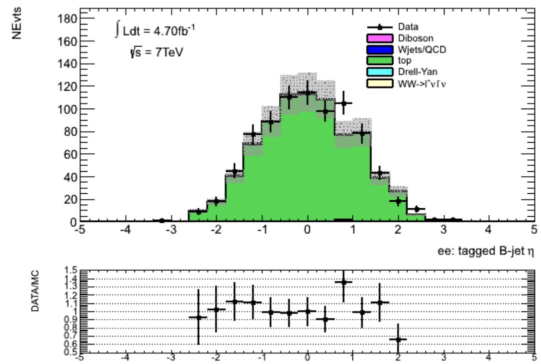
μ Efficiency

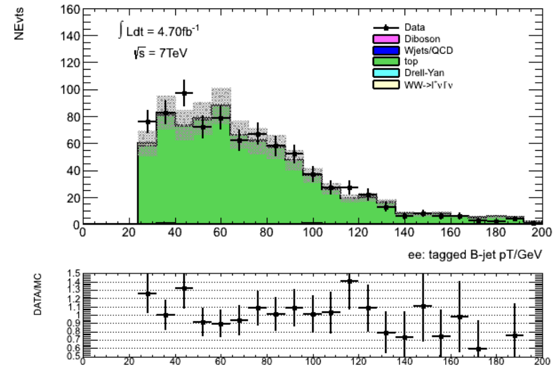
Jet → μ Fake rate

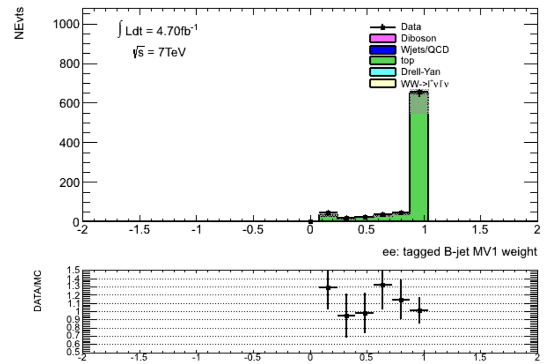
Top DD estimation Btagging control sample plots: combined

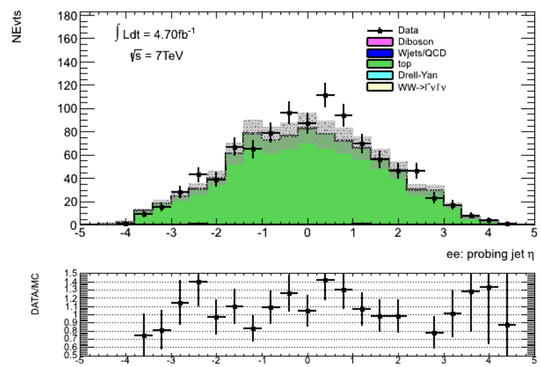


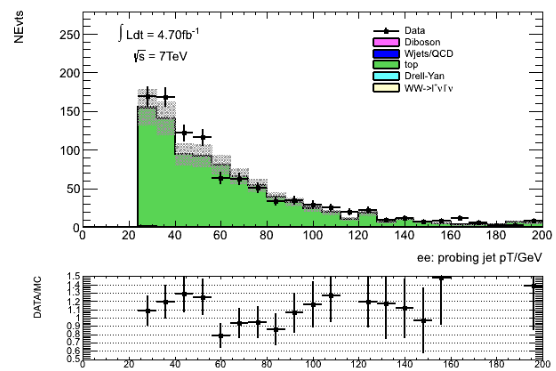
Top DD estimation Btagging control sample plots: ee

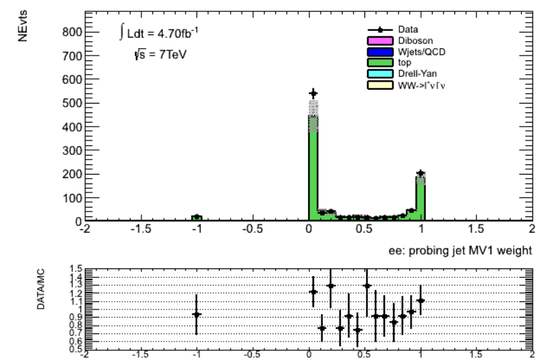


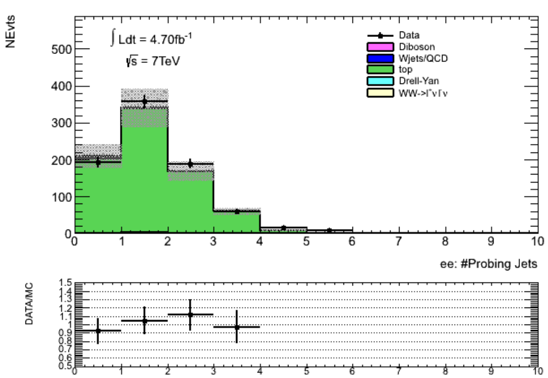


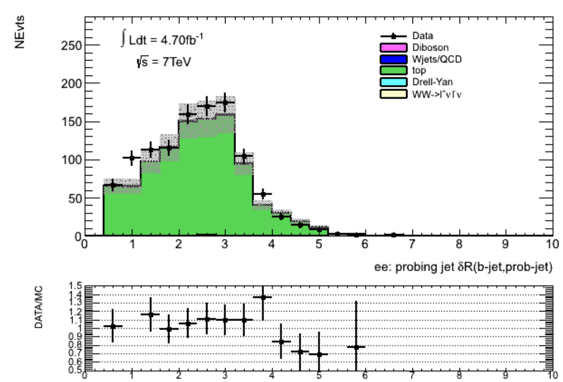




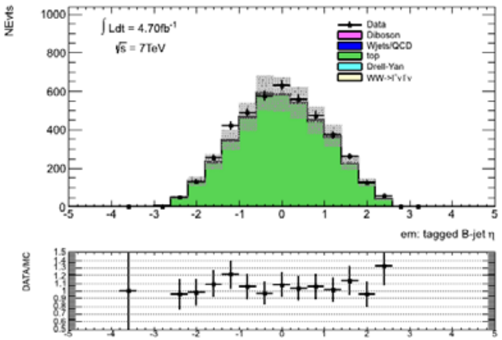


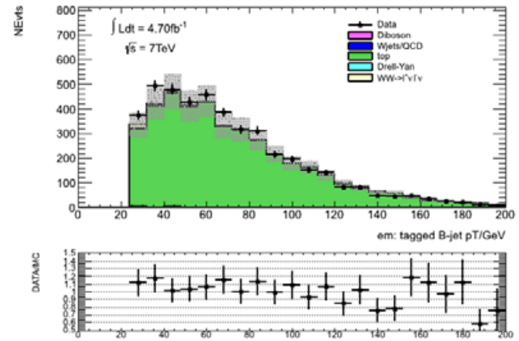


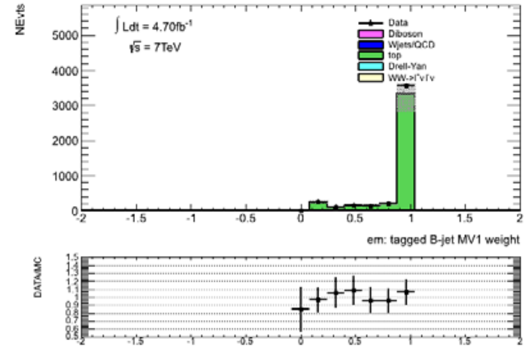


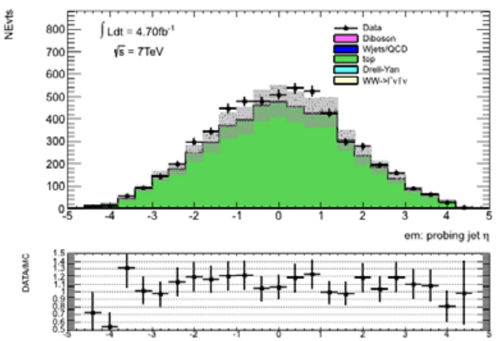


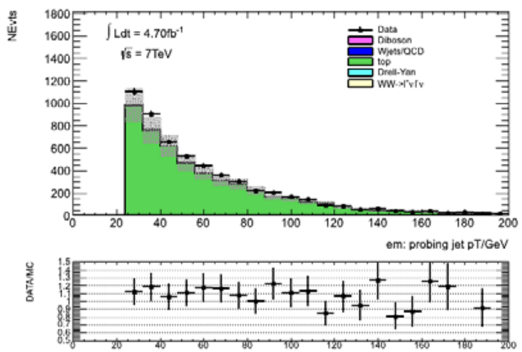
Top DD estimation Btagging control sample plots: eμ

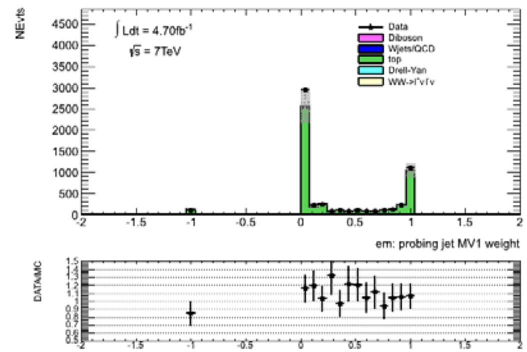


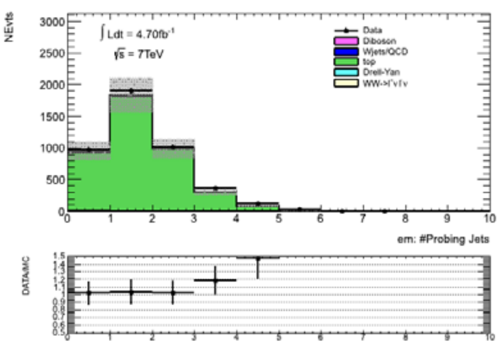


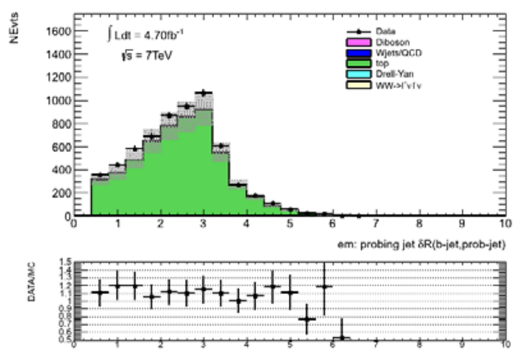




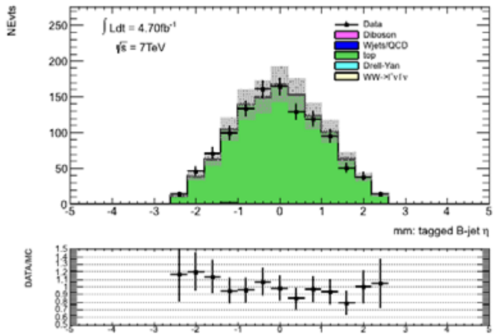


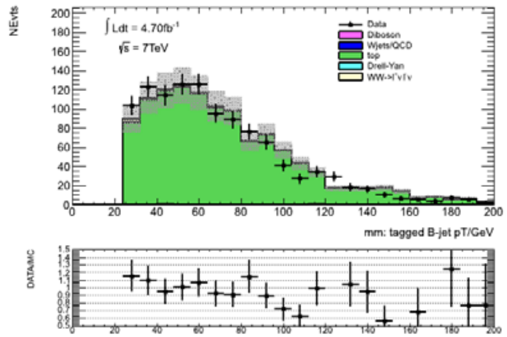


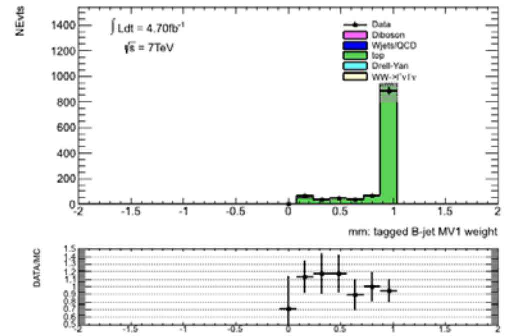


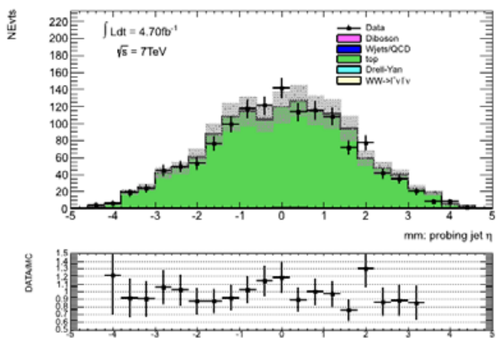


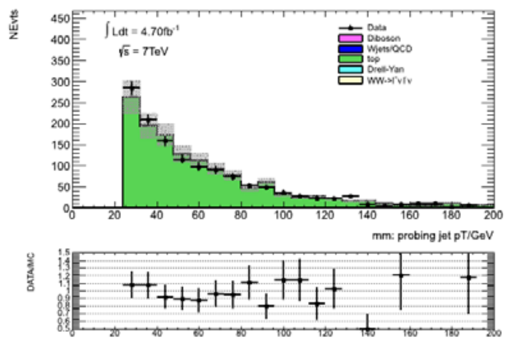
Top DD estimation Btagging control sample plots: μμ

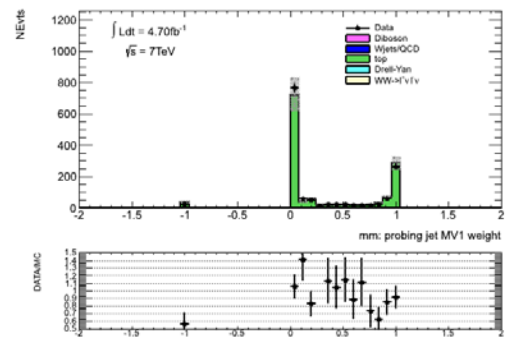


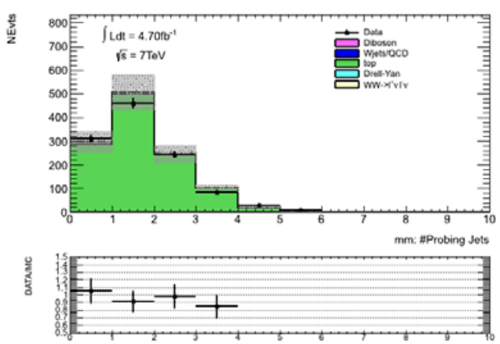


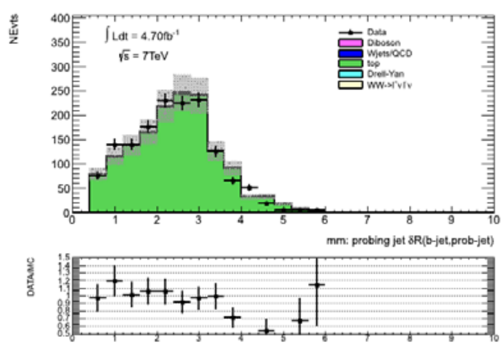




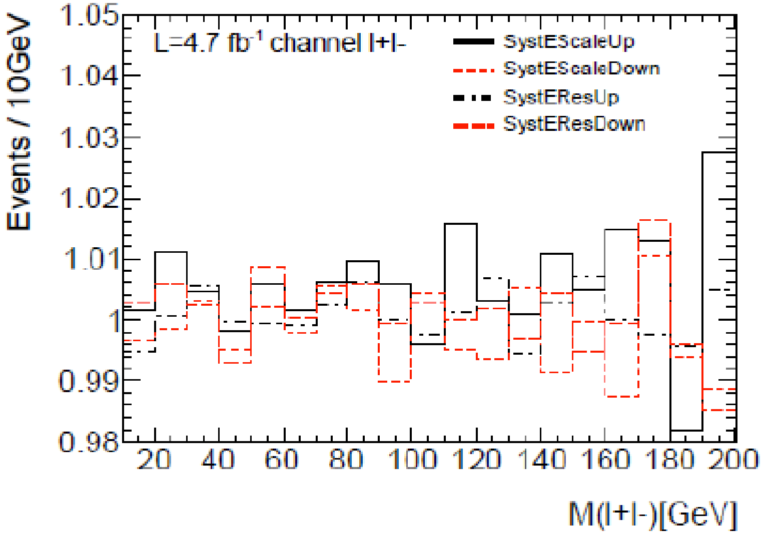




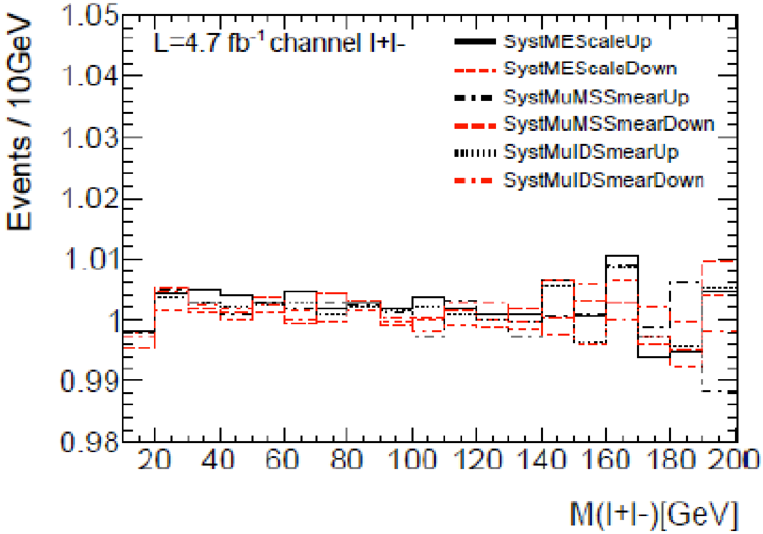




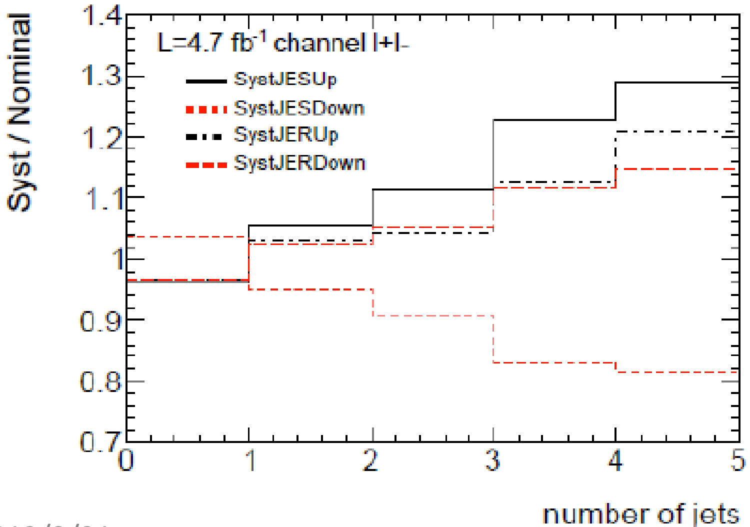
Syst. Plots



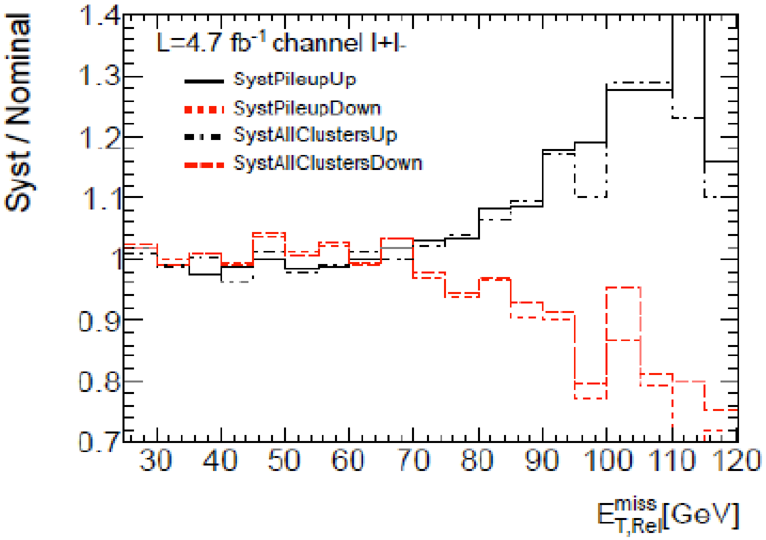
L=4.7 fb-1 channel l+l-
SystEScaleUp
SystEScaleDown
SystEResUp
SystEResDown
Events / 10GeV
M(l+l-)[GeV]



L=4.7 fb-1 channel l+l-
SystMEScaleUp
SystMEScaleDown
SystMuMSSmearUp
SystMuMSSmearDown
SystMuIDSmearUp
SystMuIDSmearDown
Events / 10GeV
M(l+l-)[GeV]



L=4.7 fb-1 channel l+l-
SystJESUp
SystJESDown
SystJERUp
SystJERDown
Syst / Nominal
number of jets



L=4.7 fb-1 channel l+l-
SystPileupUp
SystPileupDown
SystAllClustersUp
SystAllClustersDown
Syst / Nominal
E miss T,Rel [GeV]