$W^{\pm}W^{\pm}jj$ ATLAS report

Zhijun Liang
Alex Oh
Simone Pagan Griso
Jake Searcy
Anja Vest

for the $W^{\pm}W^{\pm}jj$ analysis team and
the ATLAS Collaboration

Brief summary of analysis

Event selections,

Background estimation,

Results

Questions & Answers

Spare slides

Systematics

Fiducial phase space

Thoughts on combination?

Summary of main event selections

$\mu^\pm\mu^\pm jj$, $e^\pm e^\pm jj$, $e^\pm\mu^\pm jj$ final states

Tightly isolated leptons pT > 25 GeV, |h| < 2.5,

Jets p_T > 30 GeV, $|\eta|$ < 4.5 → 30 GeV keeps under control pile-up

Veto events with any additional e (μ) with p_T > 7(6) GeV

- also looser isolation / quality requirements

→ remaining WZ/γ* mainly from out of acceptance (p_T, η)

Missing Transverse Energy > 40 GeV

| m(ee) – mZ | > 10 GeV

reduce charge mis-ID from DY

Veto events containing b-jets → reduce top-related contributions

m(jj) > 500 GeV → Measure strong+EWK

$|\Delta y(jj)|$ > 2.4 → Extract EWK component

Summary of backgrounds

	Inclusive Region			VBS Region		
	$e^\pm e^\pm$	$e^\pm \mu^\pm$	$\mu^\pm \mu^\pm$	$e^\pm e^\pm$	$e^\pm \mu^\pm$	$\mu^\pm \mu^\pm$
Prompt	3.0 ± 0.7	6.1 ± 1.3	2.6 ± 0.6	2.2 ± 0.5	4.2 ± 1.0	1.9 ± 0.5
Conversions	3.2 ± 0.7	2.4 ± 0.8	–	2.1 ± 0.5	1.9 ± 0.7	–
Other non-prompt	0.61 ± 0.30	1.9 ± 0.8	0.41 ± 0.22	0.50 ± 0.26	1.5 ± 0.6	0.34 ± 0.19
$W^\pm W^\pm jj$ Strong	0.89 ± 0.15	2.5 ± 0.4	1.42 ± 0.23	0.25 ± 0.06	0.71 ± 0.14	0.38 ± 0.08
$W^\pm W^\pm jj$ Electroweak	3.07 ± 0.30	9.0 ± 0.8	4.9 ± 0.5	2.55 ± 0.25	7.3 ± 0.6	4.0 ± 0.4
Total background	6.8 ± 1.2	10.3 ± 2.0	3.0 ± 0.6	5.0 ± 0.9	8.3 ± 1.6	2.6 ± 0.5
Total predicted	10.7 ± 1.4	21.7 ± 2.6	9.3 ± 1.0	7.6 ± 1.0	15.6 ± 2.0	6.6 ± 0.8
Data	12	26	12	6	18	10

Prompt:

- Dominated by WZ/γ* (still mostly strong production)
- Sherpa up to 3 jets in the ME
- Reduced by tight 3rd lepton veto. Remaining pass selections mainly from out of acceptance (η, p_T) leptons; especially true for μμ

Summary of backgrounds

	Inclusive Region			VBS Region		
	$e^{\pm}e^{\pm}$	$e^{\pm}\mu^{\pm}$	$\mu^{\pm}\mu^{\pm}$	$e^{\pm}e^{\pm}$	$e^{\pm}\mu^{\pm}$	$\mu^{\pm}\mu^{\pm}$
Prompt	3.0 ± 0.7	6.1 ± 1.3	2.6 ± 0.6	2.2 ± 0.5	4.2 ± 1.0	1.9 ± 0.5
Conversions	3.2 ± 0.7	2.4 ± 0.8	–	2.1 ± 0.5	1.9 ± 0.7	–
Other non-prompt	0.61 ± 0.30	1.9 ± 0.8	0.41 ± 0.22	0.50 ± 0.26	1.5 ± 0.6	0.34 ± 0.19
$W^{\pm}W^{\pm}jj$ Strong	0.89 ± 0.15	2.5 ± 0.4	1.42 ± 0.23	0.25 ± 0.06	0.71 ± 0.14	0.38 ± 0.08
$W^{\pm}W^{\pm}jj$ Electroweak	3.07 ± 0.30	9.0 ± 0.8	4.9 ± 0.5	2.55 ± 0.25	7.3 ± 0.6	4.0 ± 0.4
Total background	6.8 ± 1.2	10.3 ± 2.0	3.0 ± 0.6	5.0 ± 0.9	8.3 ± 1.6	2.6 ± 0.5
Total predicted	10.7 ± 1.4	21.7 ± 2.6	9.3 ± 1.0	7.6 ± 1.0	15.6 ± 2.0	6.6 ± 0.8
Data	12	26	12	6	18	10

Conversions:

- From events with OS leptons (DY, top, di-boson)
  - data-driven using OS events; important in ee channel
  - rate measured in Z peak; control regions and MC to check extrapolations in m(ll),N(jets),physics-process and assign uncertainties
- From Wγ where γ converts in the detector
  - from simulation, checked conversion rate vs η

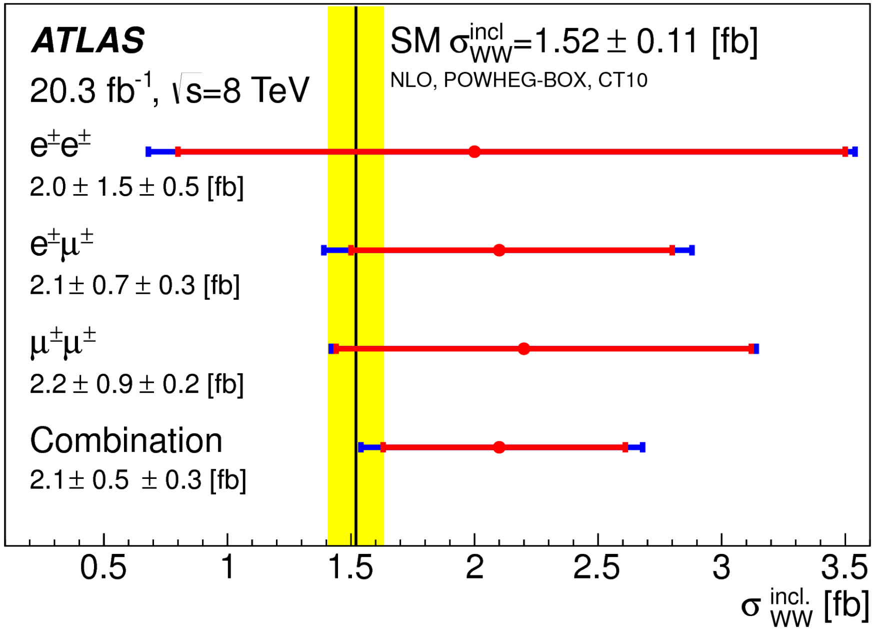
Summary of backgrounds

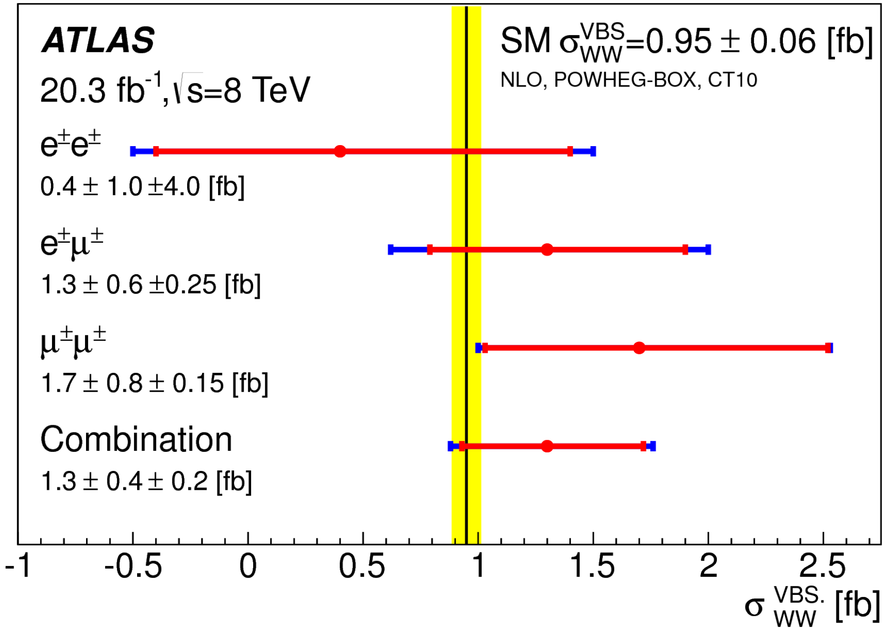
	Inclusive Region			VBS Region		
	$e^{\pm}e^{\pm}$	$e^{\pm}\mu^{\pm}$	$\mu^{\pm}\mu^{\pm}$	$e^{\pm}e^{\pm}$	$e^{\pm}\mu^{\pm}$	$\mu^{\pm}\mu^{\pm}$
Prompt	3.0 ± 0.7	6.1 ± 1.3	2.6 ± 0.6	2.2 ± 0.5	4.2 ± 1.0	1.9 ± 0.5
Conversions	3.2 ± 0.7	2.4 ± 0.8	–	2.1 ± 0.5	1.9 ± 0.7	–
Other non-prompt	0.61 ± 0.30	1.9 ± 0.8	0.41 ± 0.22	0.50 ± 0.26	1.5 ± 0.6	0.34 ± 0.19
$W^{\pm}W^{\pm}jj$ Strong	0.89 ± 0.15	2.5 ± 0.4	1.42 ± 0.23	0.25 ± 0.06	0.71 ± 0.14	0.38 ± 0.08
$W^{\pm}W^{\pm}jj$ Electroweak	3.07 ± 0.30	9.0 ± 0.8	4.9 ± 0.5	2.55 ± 0.25	7.3 ± 0.6	4.0 ± 0.4
Total background	6.8 ± 1.2	10.3 ± 2.0	3.0 ± 0.6	5.0 ± 0.9	8.3 ± 1.6	2.6 ± 0.5
Total predicted	10.7 ± 1.4	21.7 ± 2.6	9.3 ± 1.0	7.6 ± 1.0	15.6 ± 2.0	6.6 ± 0.8
Data	12	26	12	6	18	10

Other non-prompt:

- Mostly top-related processes
- Fake-factor method using sidebands of isolation and quality
- checked in b-jet enriched and lower jet multiplicities
- Thanks to -especially- tight isolation and b-jet veto, not a dominant background [both selections optimized for best sensivity]

Results





Electrowek+strong $W^{\pm}W^{\pm}jj$

m(jj) > 500 GeV

Electrowek $W^{\pm}W^{\pm}jj$

m(jj) > 500 GeV

|Δy(jj)| < 2.4

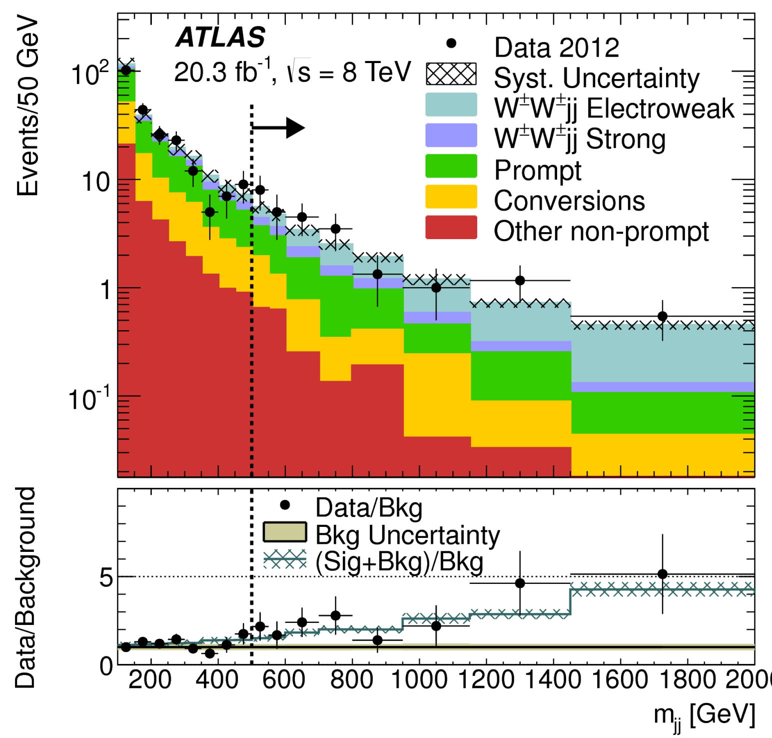
Questions & Answers

Q: What is the fraction of events that pass the reconstruction level selection but not the generator level selection?

Indeed this is not stated and is not public unfortunately (yet).

Having chosen a fiducial cut on m(jj) (and p_T^{jet}, □y^{jj}) which is the same as reconstruction-level, the correction won’t be small, and will be absorbed in the efficiency correction.

As usual a choice with lower m(jj) would reduce this but increase the model dependence due to the extrapolation; often the same value at generator-level and reco-level is a good and well acepted compromise.



Q: How pure is the electroweak-only fiducial region?

From Table 2 of the paper, strong WW production is 10% of the electroweak production. This is at reco level of course.

	Inclusive Region			VBS Region		
	$e^\pm e^\pm$	$e^\pm \mu^\pm$	$\mu^\pm \mu^\pm$	$e^\pm e^\pm$	$e^\pm \mu^\pm$	$\mu^\pm \mu^\pm$
Prompt	3.0 ± 0.7	6.1 ± 1.3	2.6 ± 0.6	2.2 ± 0.5	4.2 ± 1.0	1.9 ± 0.5
Conversions	3.2 ± 0.7	2.4 ± 0.8	–	2.1 ± 0.5	1.9 ± 0.7	–
Other non-prompt	0.61 ± 0.30	1.9 ± 0.8	0.41 ± 0.22	0.50 ± 0.26	1.5 ± 0.6	0.34 ± 0.19
$W^\pm W^\pm jj$ Strong	0.89 ± 0.15	2.5 ± 0.4	1.42 ± 0.23	0.25 ± 0.06	0.71 ± 0.14	0.38 ± 0.08
$W^\pm W^\pm jj$ Electroweak	3.07 ± 0.30	9.0 ± 0.8	4.9 ± 0.5	2.55 ± 0.25	7.3 ± 0.6	4.0 ± 0.4
Total background	6.8 ± 1.2	10.3 ± 2.0	3.0 ± 0.6	5.0 ± 0.9	8.3 ± 1.6	2.6 ± 0.5
Total predicted	10.7 ± 1.4	21.7 ± 2.6	9.3 ± 1.0	7.6 ± 1.0	15.6 ± 2.0	6.6 ± 0.8
Data	12	26	12	6	18	10

Q: interference effects between QCD and EWK WW are strongly scale dependent for Madgraph and the sign of the interference term can change depending on the scale. Can you confirm that you see a positive contribution for the interference term? Have you checked how stable/solid it is?

This is really interesting. We saw a significant difference of interference effects from one phase space to another.

Generally, a wider phase space having larger interference effects (but never observed a negative interference). Sherpa LO was used and madgraph in early studies.

We did not check scale dependence but assigned a 50% error on the theory prediction for interference.

@CMS: how big these effects were observed to be in your analysis phase space?

Note that we explicitly mentioned the contribution of interference to the predicted x-section in the paper, to allow the measurement to be compared with any improved determination available.

Q:Are the W->taunu events considered at all? It seems they are not part of the signal, but we assume they are considered as a background process, correct?

They are not part of the fiducial phase space definition (they are indeed vetoed).

They are of course considered and this means the efficiency correction takes care of this correction.

The expected fraction of signal contribution from W decays to taus and subsequent leptonic decay is 10%, as stated in the paper:

"10% of signal candidates are expected to originate from leptonic tau decays."

Q: What are the systematic uncertainties associated to the conversions and the non-prompt background? Table II seems to indicate relatively small values.

The uncertainty on the background determination itself is at the level of 30-40%, depending on the process/channel. We can discuss more individual contributions but did not do so in the paper since the effect on the measurement is quite small anyway.

See auxiliary table in the next slide: the table reports the systematic contribution to the *total* background, which gives a measurement of how much important such uncertainty is for the measurement.

Table of systematics for VBS region

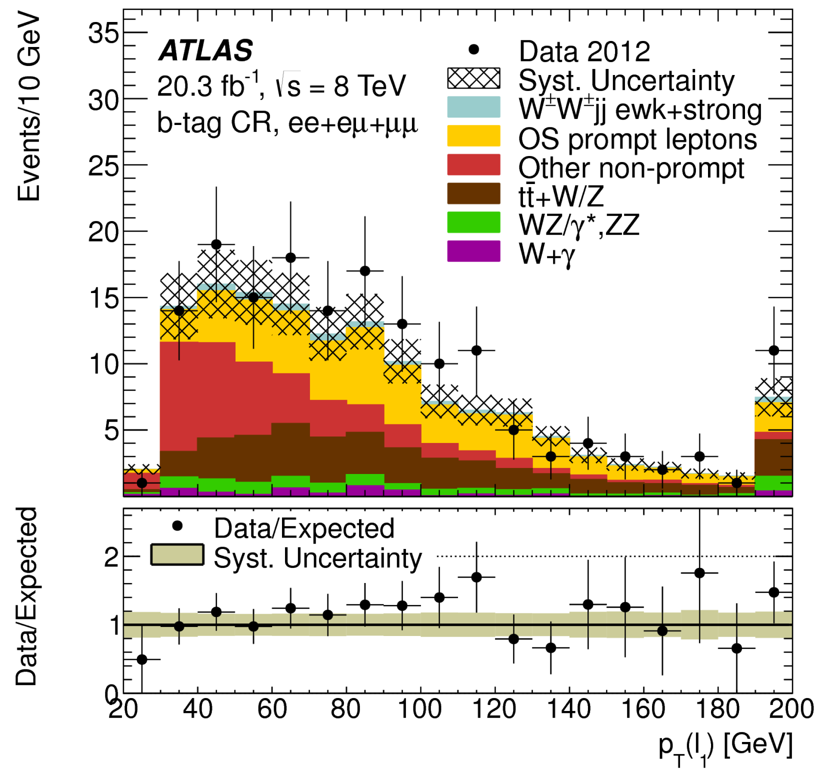
Systematic Uncertainties $ee/e\mu/\mu\mu$ (%) - VBS SR			
Background		Signal	
Jet uncertainties	13/15/15	Theory $W^{\pm}W^{\pm}jj$-ewk	6.0
Theory WZ/γ^*	4.5/5.4/7.8	Jet uncertainties	5.1
MC statistics	8.9/6.4/8.4	Luminosity	2.8
Fake rate	4.0/7.2/6.8	MC statistics	4.5/2.7/3.7
OS lepton bkg/ Conversion rate	5.5/4.4/–	E_T^{miss} reconstruction	1.1
E_T^{miss} reconstruction	2.9/3.2/1.4	Lepton reconstruction	1.9/1.0/0.7
Theory $W+\gamma$	3.1/2.6/–	b-tagging efficiency	0.6
Luminosity	1.7/2.1/2.4	trigger efficiency	0.1/0.3/0.5
Theory $W^{\pm}W^{\pm}jj$-strong	0.9/1.5/2.6		
Lepton reconstruction	1.7/1.1/1.1		
b-tagging efficiency	0.8/0.9/0.7		
Trigger efficiency	0.1/0.2/0.4		

Q: Do you apply anti b-tagging on jets for the Inclusive/VBS selection?. There is a mention about b-tagging in the paper, but it's not clear if it's used or not.

Yes, we do:

"Events are also required to have E^miss_T > 40 GeV, and [...] events must not contain a b-jet."

Inverting this selection helps defining a good control region for non-prompt leptons



Q: What ATLAS is doing for DPS same-sign WW background. Can you give a bit more details?

We used two approaches. The main one uses Pythia to simulate DPS processes, normalized with the usual factorization approximation and sigma_eff ~15mb. We also compared Herwig and finally looked for some control regions enriched for DPS (although details are not public). In the end all of these indicated a completely negligible contribution (below 1% the signal).

It's interesting to note that we found the biggest DPS contribution (although still negligible) to come from (WZ)+(JJ) production!

This is heavily suppressed by the m(jj) cut, but was still much higher than WW DPS contribution.

Q: Do you plan to produce limits without unitarity constraints?

For aQGC/dim-8 operator limits the K-matrix unitarisation should be used where such an implementation is available (e.g. for VBS processes WW and WZ in Whizard, http://arxiv.org/abs/0806.4145).

Since un-unitarized aQGC limits are physically not meaningful, we suggest a comparison between ATLAS and CMS on the basis of fiducial cross sections in the same fiducial phase space, which is much easier, meaningful and model independent.

This is especially true since the measurement is optimized on the SM process and not on BSM scenarios.

Q: How to compare the ATLAS limits on the alpha_4 and alpha_5 parameters to the CMS limits on dimension 8 operator parameters?

In the below figure, the aQGC limits on $\alpha_{4,5}$ presented in the paper are directly re-interpreted as limits on the 8-dimensional operators $f_{S,0,1} / \Lambda^4$ described in PhysRevD.74.073005 [hep-ph/0606118].

The re-interpretation is done through a linear transformation, which is described in arXiv:1309.7890 (equations 60 and 61).

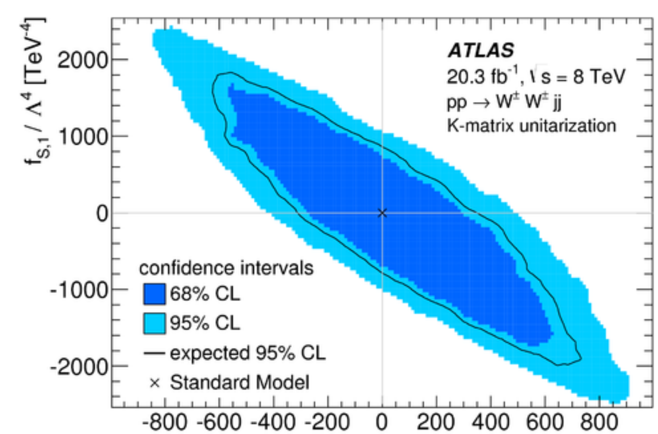
The transformation is done on the already K-matrix unitarized cross sections and are therefore only an approximate conversion.

Points outside of the solid light blue ellipse are excluded by the data at 95% confidence level. Points outside the inner dark blue ellipse are excluded at the 68% confidence level. The expected exclusion is given by the solid line.

The one-dimensional limits at $f_{S,0/1} / \Lambda^4 = 0$ are:

-420 TeV^{-4} < $f_{S,0} / \Lambda^4$ < 490 TeV^{-4} and

-1010 TeV^{-4} < $f_{S,1} / \Lambda^4$ < 1060 TeV^{-4}.



https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/STDM-2013-06/

Spare slides

Link to ATLAS public page with more plots / tables:

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/STDM-2013-06/

Systematic uncertainties

Systematic Uncertainties $ee/e\mu/\mu\mu$ (%) - VBS SR			
Background		Signal	
Jet uncertainties	13/15/15	Theory $W^{\pm}W^{\pm}jj$-ewk	6.0
Theory WZ/γ^{*}	4.5/5.4/7.8	Jet uncertainties	5.1
MC statistics	8.9/6.4/8.4	Luminosity	2.8
Fake rate	4.0/7.2/6.8	MC statistics	4.5/2.7/3.7
OS lepton bkg/ Conversion rate	5.5/4.4/–	E_T^{miss} reconstruction	1.1
E_T^{miss} reconstruction	2.9/3.2/1.4	Lepton reconstruction	1.9/1.0/0.7
Theory $W+\gamma$	3.1/2.6/–	b-tagging efficiency	0.6
Luminosity	1.7/2.1/2.4	trigger efficiency	0.1/0.3/0.5
Theory $W^{\pm}W^{\pm}jj$-strong	0.9/1.5/2.6		
Lepton reconstruction	1.7/1.1/1.1		
b-tagging efficiency	0.8/0.9/0.7		
Trigger efficiency	0.1/0.2/0.4		

Fiducial phase space

Two same-charge leptons (eμ; veto tau decays), $p_T > 25$ GeV, $|\eta| < 2.5$
- dress with photons in a cone of radius $\Delta R=0.1$ around the leptons

At least two jets $p_T > 30$ GeV, $|\eta| < 4.5$
- anti-k_T, $R=0.4$

$\Delta R(ll) = (\Delta\varphi(ll)^2 + \Delta\eta(ll)^2)^{1/2} > 0.3$

$\Delta R(l, \text{jet}) > 0.3$

$m(ll) > 20$ GeV

|Missing Transverse momentum| > 40 GeV

[jj system defined as two leading jets]

$m(jj) > 500$ GeV → Inclusive fiducial region

$|\Delta y(jj)| > 2.4$ → VBS fiducial region

Thoughts on combination

Dominated by stat error -> combination gains

Need to converge on the same fiducial regions definition

→ Use Rivet to help avoiding mistakes in common definition

At a first rought look, correlating uncertainties seem not too difficult

→ CMS relies less on theory errors on WZ, so this uncorrelates

→ lumi is easy to treat and has ~negligible contribution on backgrounds

→ a lot of other experimental syst are uncorrelated

Then use the combined fiducial x-sec to set limits on aQGC?