Recent Results on VBS, Exclusive WW and Tri-boson Production from ATLAS

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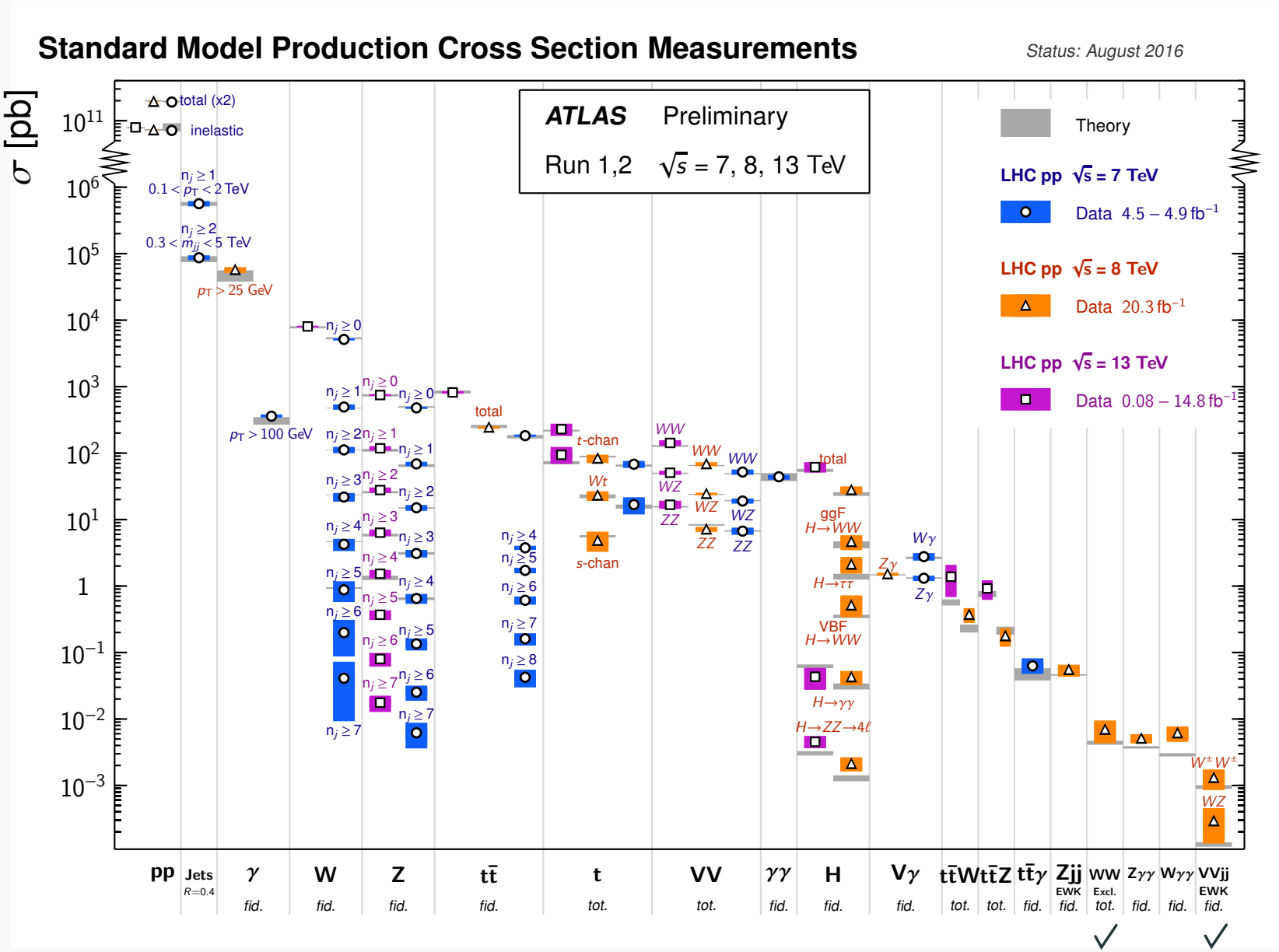
On behalf of the ATLAS Collabration

SM Cross Section Measurement



Anomalous Gauge Couplings

Electroweak theory is non-Abelian.

- Gauge bosons should interact among themselves. .

Effect of new physics at low energy scale can be parametrized by an effective Lagrangian..

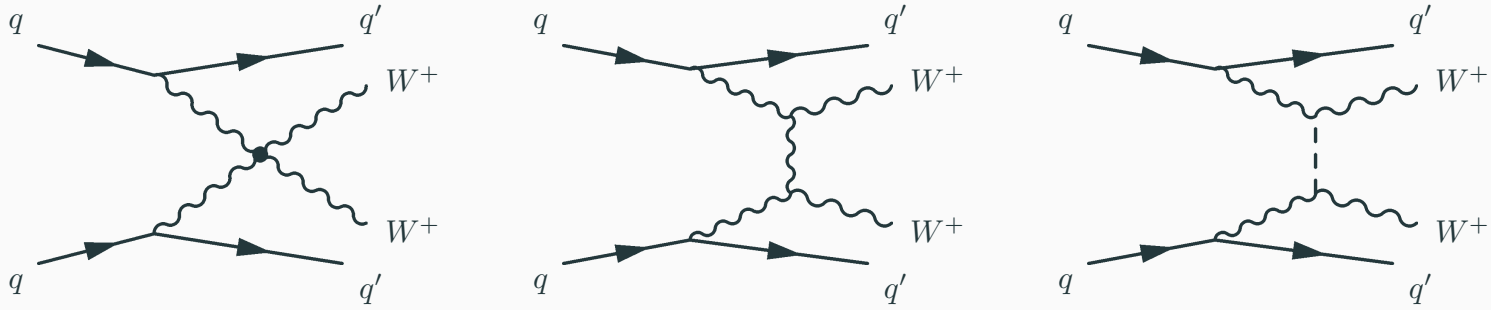
$$\mathcal{L}_{eff} = \mathcal{L}_{SM} + \sum_{dimension\ d} \sum_{i} \frac{c_i^{(d)}}{\Lambda^{d-4}} O_i^{(d)}$$

Dimension 4	Dimension 6	Dimension 8
WWWW, WWZZ	WWZγ, WW$\gamma\gamma$	all VVVV
non-linear representation	non-linear representation	linear representation
α_4, α_5	α_0/λ^2, α_c/λ^2	$f_{S,i}/\lambda^4$, $f_{M,i}/\lambda^4$, $f_{T,i}/\lambda^4$

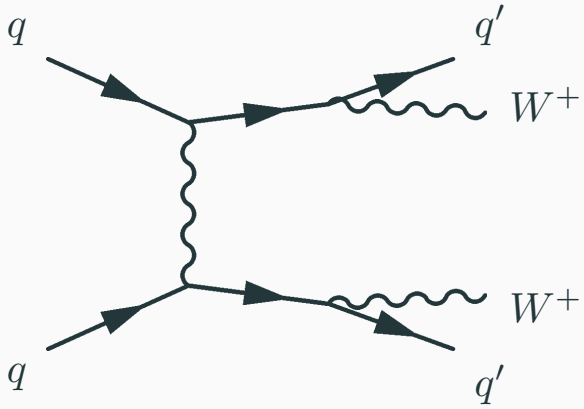
Effective Field Theory description: arXiv:hep-ph/0606118

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

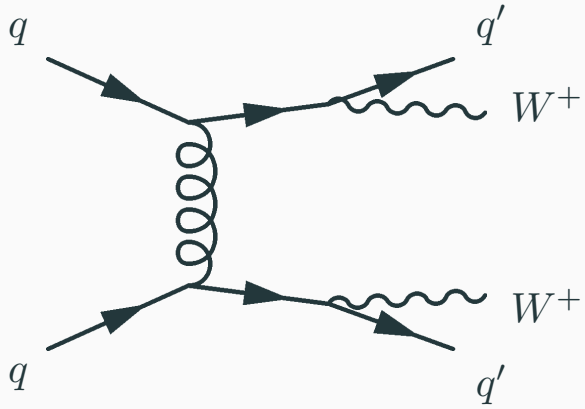
- $\sqrt{s} = 8$ TeV, $\int L = 20.3\ fb^{-1}$, arXiv:1405.6241
- Electroweak(α_{EW}^4 at LO) VBS:



- Electroweak (α_{EW}^4 at LO) non-VBS:



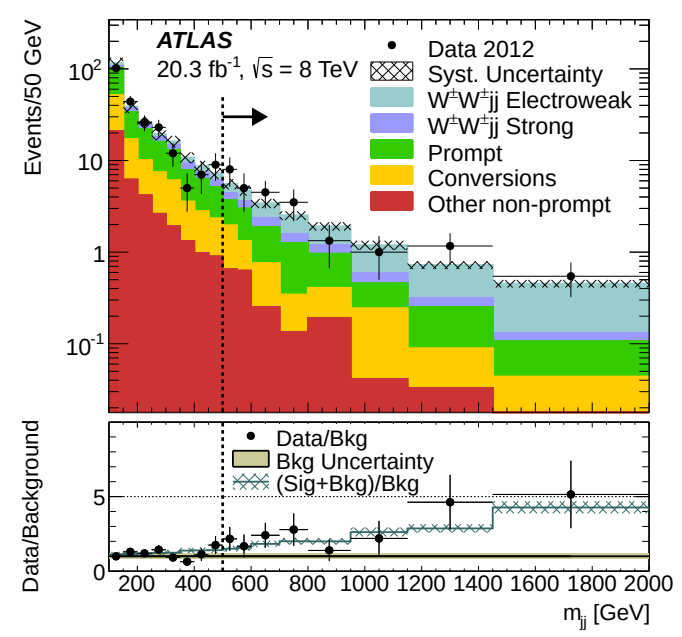
- Strong ($\alpha_S^2\alpha_{EW}^2$ at LO):

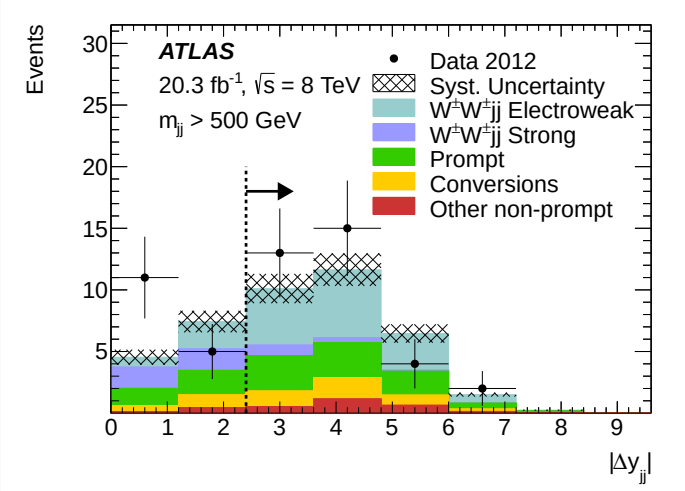


$W^{\pm}W^{\pm}$jj Production

- First search for $W^{\pm}W^{\pm}$jj production.
- Sensitive to new physics via aQGC.
- For EW+Strong measurement(Inclusive region):
  - Two same charge leptons with $p_T > 25$ GeV and $|\eta| < 2.5$.
  - At least 2 jets with $p_T > 30$ GeV and $|\eta| < 4.5$, $\Delta R_{lj} > 0.3$.
  - $m_{ll} > 20\mathrm{GeV}$, $\Delta R_{ll} > 0.3$, $E_T^{miss} > 40\mathrm{GeV}$, $m_{jj} > 500\mathrm{GeV}$.
- For EW only measurement(VBS region)
  - Additional cut $\Delta|y_{jj}| > 2.4$.
- Backgrounds:
  - Prompt background like WZ/γ^*(MC).
  - Conversion background like Wγ(MC).
  - Non-prompt background like W+jets, $t\bar{t}$(Data-driven).

$W^{\pm}W^{\pm}$jj Cross Section



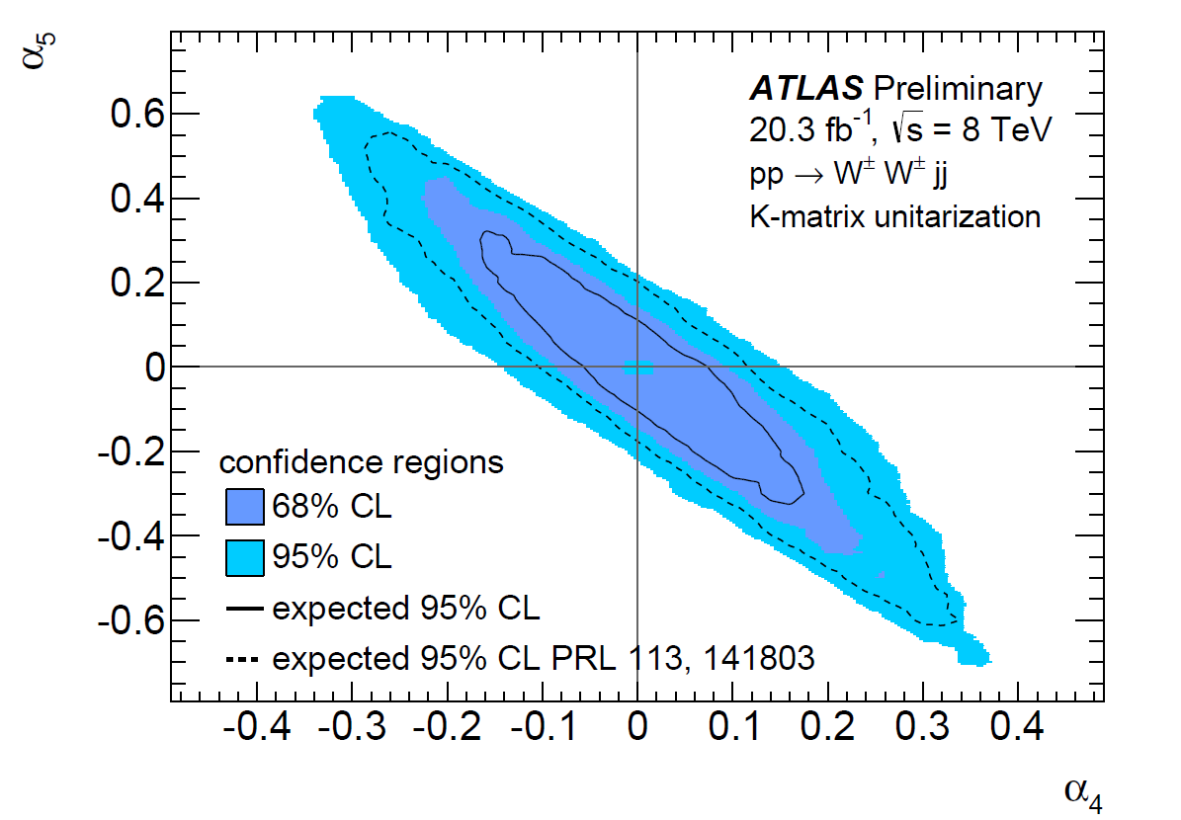


- Measured and predicted cross section of inclusive production: $\sigma^{fid}_{measured} = 2.1 \pm 0.5(\text{stat}) \pm 0.3(\text{syst})$ fb, $\sigma^{fid}_{predicted} = 1.52 \pm 0.11$ fb.

- Measured and predicted cross section of EW production(including interference with strong production): $\sigma^{fid}_{measured} = 1.3 \pm 0.4(\text{stat}) \pm 0.2(\text{syst})$ fb, $\sigma^{fid}_{predicted} = 0.95 \pm 0.06$ fb.

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

- Measurement in VBS region is used to study the aQGCs from WWWW vertex.
- The $M_T > 400$ GeV cut is applied to improve the limits on aQGCs by 35% comparing to old result(the PRL).



$W^{\pm}$Z Production

$\sqrt{s} = 8$ TeV, $\int L = 20.3\ fb^{-1}$, arXiv:1607.03745

VBS phase space

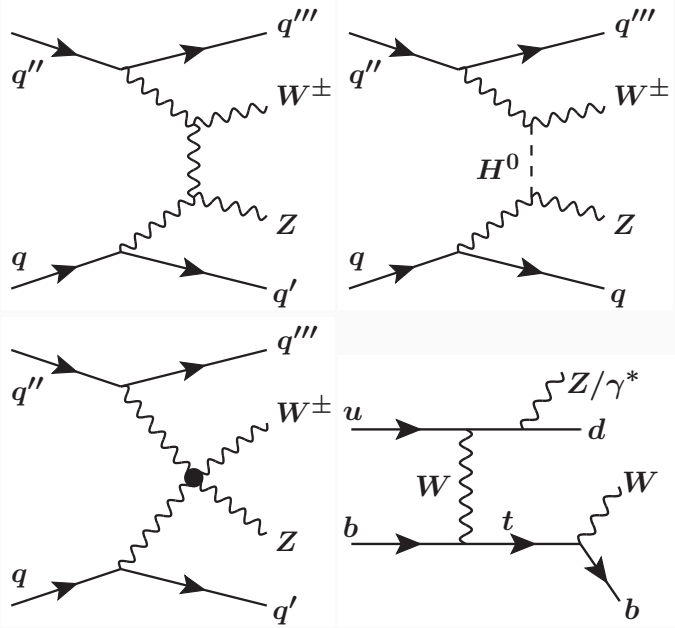
- Lepton $|\eta| < 2.5$, p_T of $l_Z > 15$GeV and p_T of $l_W > 20$, $|m_Z - m_Z^{PDG}| < 10$ GeV, m_T^W >30 GeV, p_T of two leading jets > 30 GeV, $|\eta|$ of two leading jets < 4.5, at least two jets, $m_{jj} > 500$ GeV, $\Delta R(j, l) > 0.3$.

aQGC phase space:

- $|\Delta\Phi(W, Z)| > 2$ and $\sum |p_T^l|$ >250 GeV required in VBS phase space.

Measured electroweak WZjj production is $0.29^{+0.14}_{-0.12}(stat)^{+0.09}_{-0.10}(syst)$ fb.

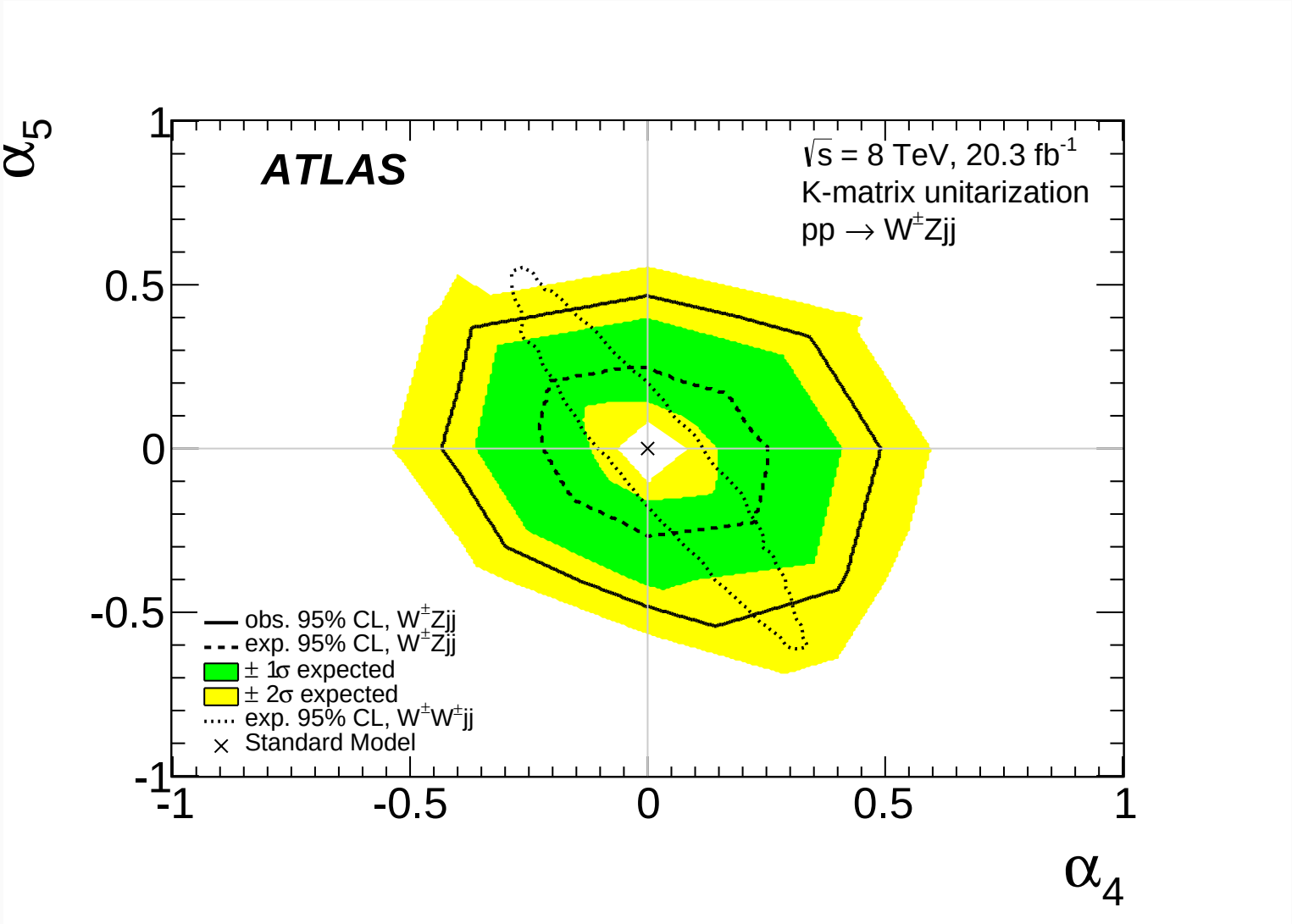
SM prediction is 0.13±0.01 fb at NLO.



95% CL upper limit on $\sigma^{\text{fid.}}_{W^{\pm}Zjj\text{-EW}\to\ell'\nu\ell\ell}$ [fb]			
		VBS only	VBS + tZj
VBS phase space			
	Observed	0.63	0.67
	Expected	0.45	0.49
$\pm1\sigma$	Expected	[0.28 ; 0.62]	[0.33 ; 0.67]
$\pm2\sigma$	Expected	[0.08 ; 0.80]	[0.19 ; 0.84]
aQGC phase space			
	Observed	0.25	0.25
	Expected	0.13	0.13
$\pm1\sigma$	Expected	[0.08 ; 0.20]	[0.08 ; 0.20]
$\pm2\sigma$	Expected	[0.04 ; 0.28]	[0.06 ; 0.28]

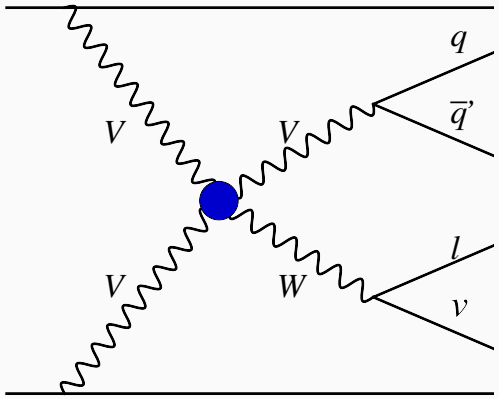
$W^{\pm}$Z aQGCs

- Constrains are derived on the aQGCs from the WWZZ vertex.



WVjj Production

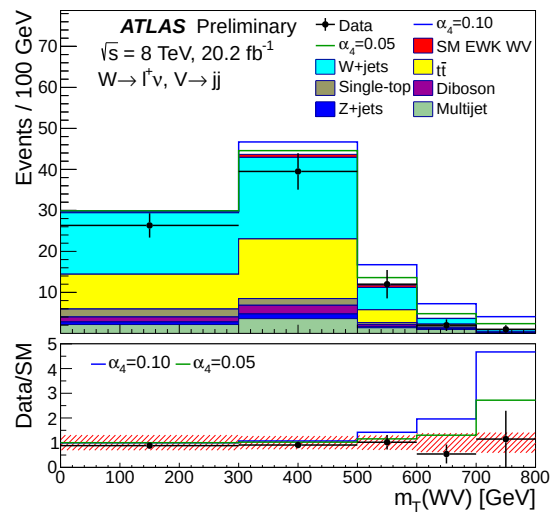
- Preliminary results in July 2016.
- Better sensitivity to aQGCs due to large branch ratio.
- Less sensitivity to SM signal due to large background.



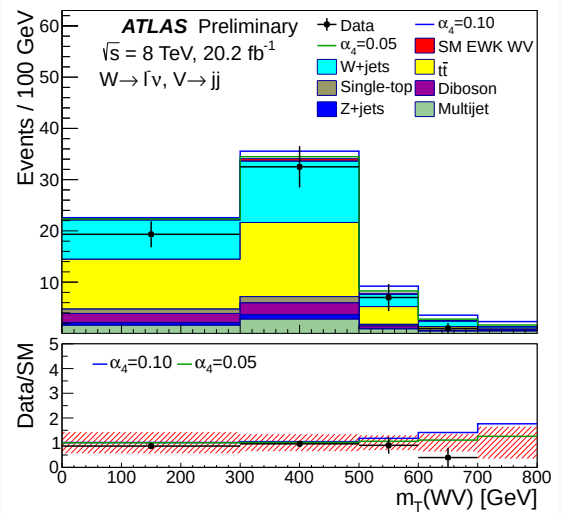
- V→ *jj* reconstructed as either two jets or one merged jet.
  - Resolved selection:
    - Four small radius (0.4) jets.
  - Merged selection:
    - Two small radius (0.4) jets.
    - One large radius(1.2) jet, jet substructure consistent with the two-body decay.
- The resolved region is further categorized by W→ $l^+\nu$ and W→ $l^-\nu$.

WVjj Production

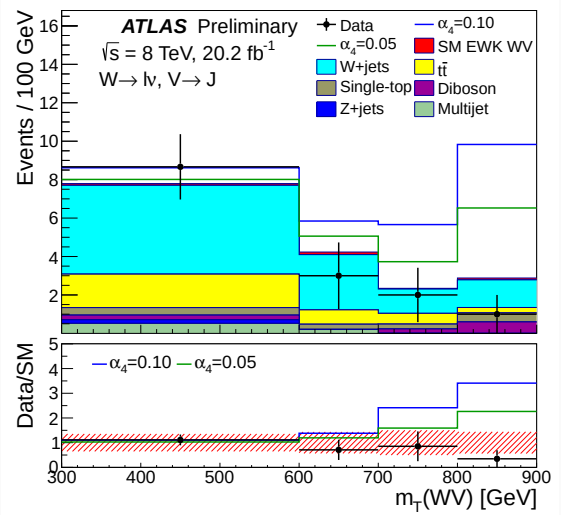
- The transverse mass of WV is used to search for aQGCs.
- Merged region significantly improves the aQGCs sensitivity.



W→ $l^{+}\nu$, V→ jj
Resolved region

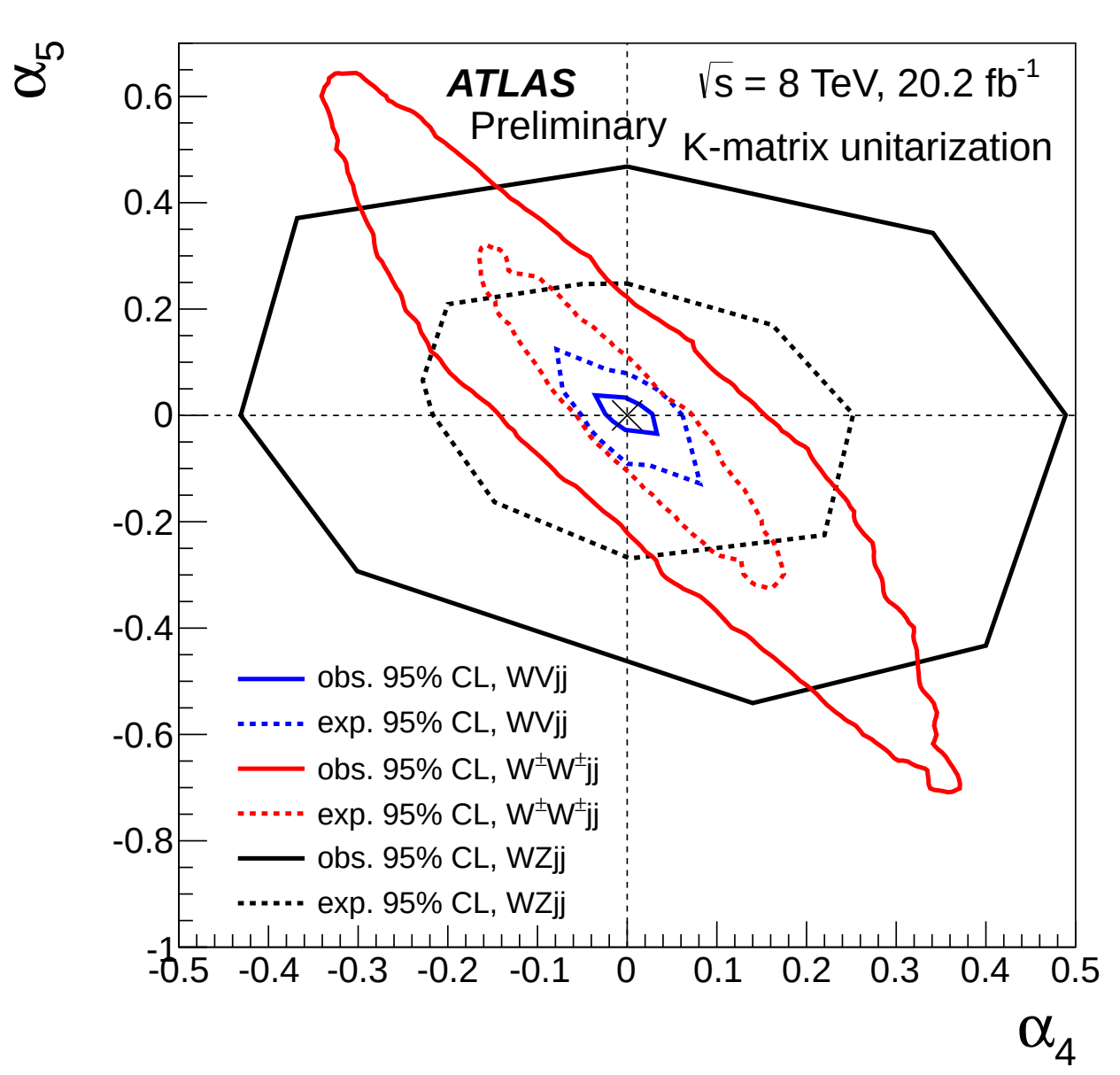


W→ $l^{-}\nu$, V→ jj
Resolved region



W→ $l\nu$, V→ jj
Merged region

WVjj aQGCs


ATLAS
Preliminary
√s = 8 TeV, 20.2 fb-1
K-matrix unitarization
obs. 95% CL, WVjj
exp. 95% CL, WVjj
obs. 95% CL, W±W±jj
exp. 95% CL, W±W±jj
obs. 95% CL, WZjj
exp. 95% CL, WZjj
α5
α4
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-0.5
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
0.5

Exclusive $\gamma\gamma \to W^+W^-$

$\sqrt{s} = 8$ TeV, $\int L = 20.2\ fb^{-1}$, arXiv:1607.03745

Goals:

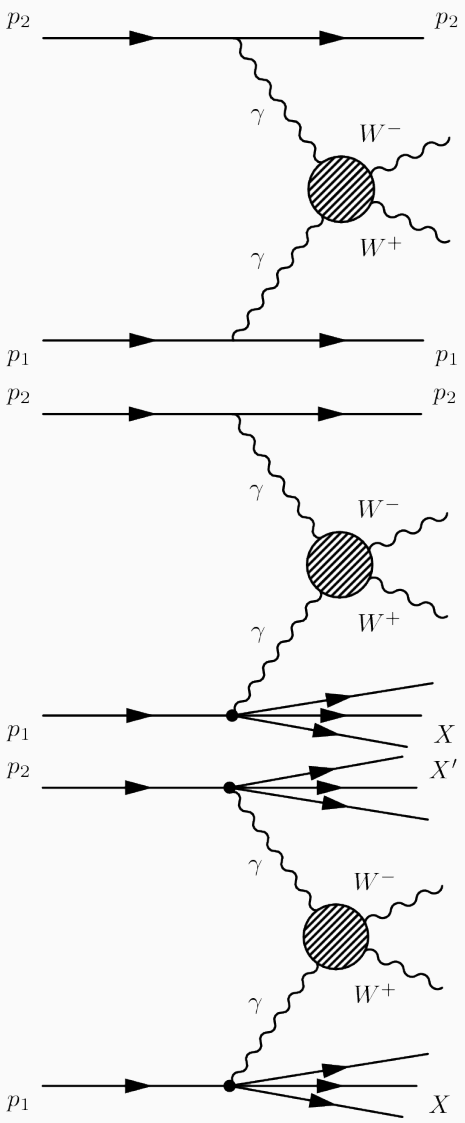
- Search for exclusively produced W boson pairs in the process pp$(\gamma\gamma) \to pW^+W^-p$.
- Sensitive to new physics via aQGC.

Signal:

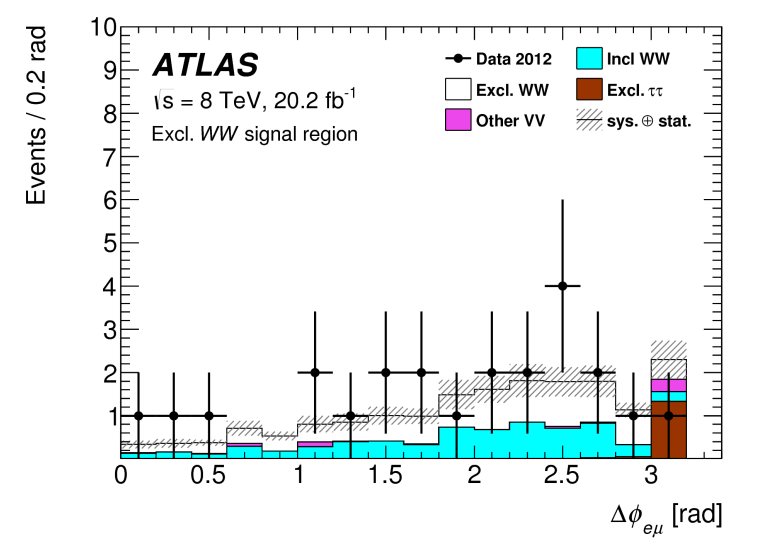
- Opposite charged $e^{\pm}\mu^{\mp}$ leptons with $p_T^1 > 25$ GeV and $p_T^2 > 20$ GeV, $m_{ll} > 20 GeV$, $p_T^{e\mu} > 30 GeV$, exclusivity selection requires no extra tracks within 1 mm of primary vertex.
- Additional $p_T^{e\mu} > 120 GeV$ requirement for aQGCs study.

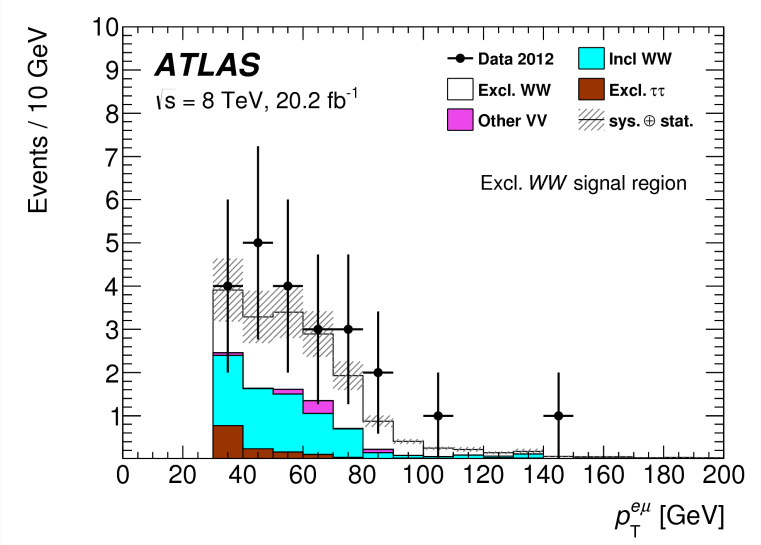
Main Backgrounds:

- Inclusive W^+W^-(~70%).
- $\gamma\gamma \to \tau^+\tau^-$(~15%).



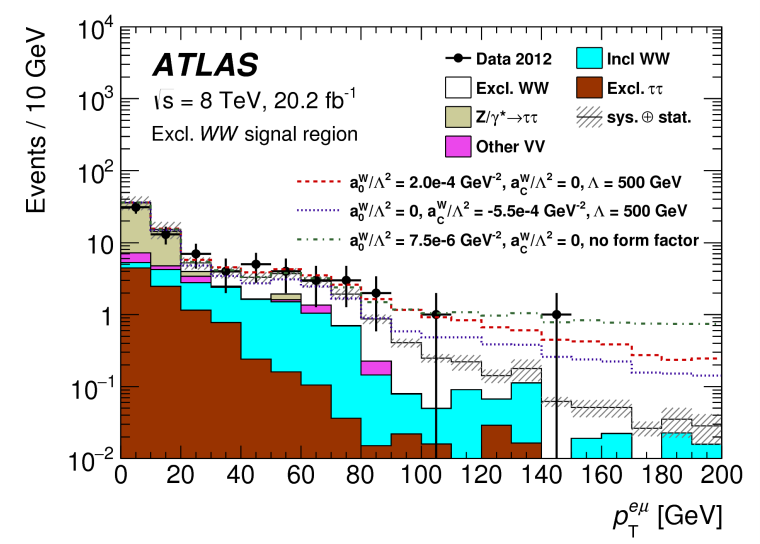
Exclusive $\gamma\gamma \to W^+W^-$ Cross Section

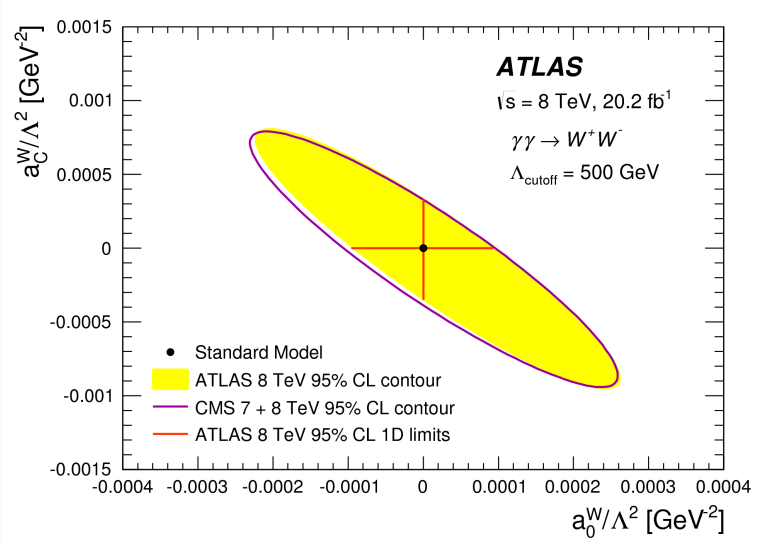




- Observed signal significance is 3.0σ.
- $\sigma^{Measued}_{\gamma\gamma\to W^+W^-\to e^\pm\mu^\mp} = 6.9\pm2.2(\text{stat})\pm1.4(\text{syst})$ fb.
- $\sigma^{Predicted}_{\gamma\gamma\to W^+W^-\to e^\pm\mu^\mp} = 4.4\pm0.3$ fb.

Exclusive $\gamma\gamma \to W^+W^-$ aQGCs





- The 95% CL limits on the couplings α_0^W/Λ^2 and α_C^W/Λ^2.

WWW

$\sqrt{s} = 8$ TeV, $\int$L $= 20.3\ fb^{-1}$

Goals:

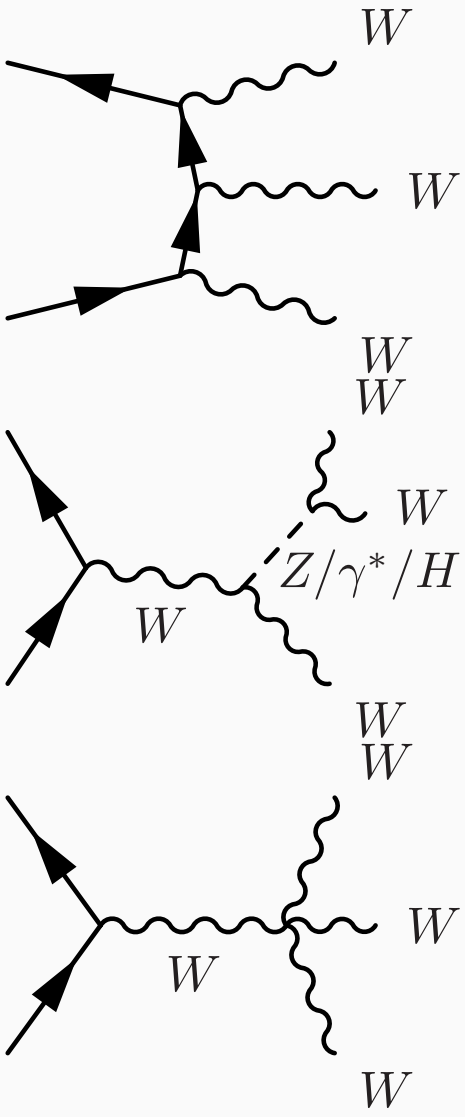
- Search for triboson $W^{\pm}W^{\pm}W^{\mp}$ production.
- Sensitive to new physics via aQGC.

Signal:

- $W^{\pm}W^{\pm}W^{\mp} \rightarrow l^{\pm}\nu l^{\pm}\nu l^{\mp}\nu$.
- $W^{\pm}W^{\pm}W^{\mp} \rightarrow l^{\pm}\nu l^{\pm}\nu$jj (l = e,$\mu$).

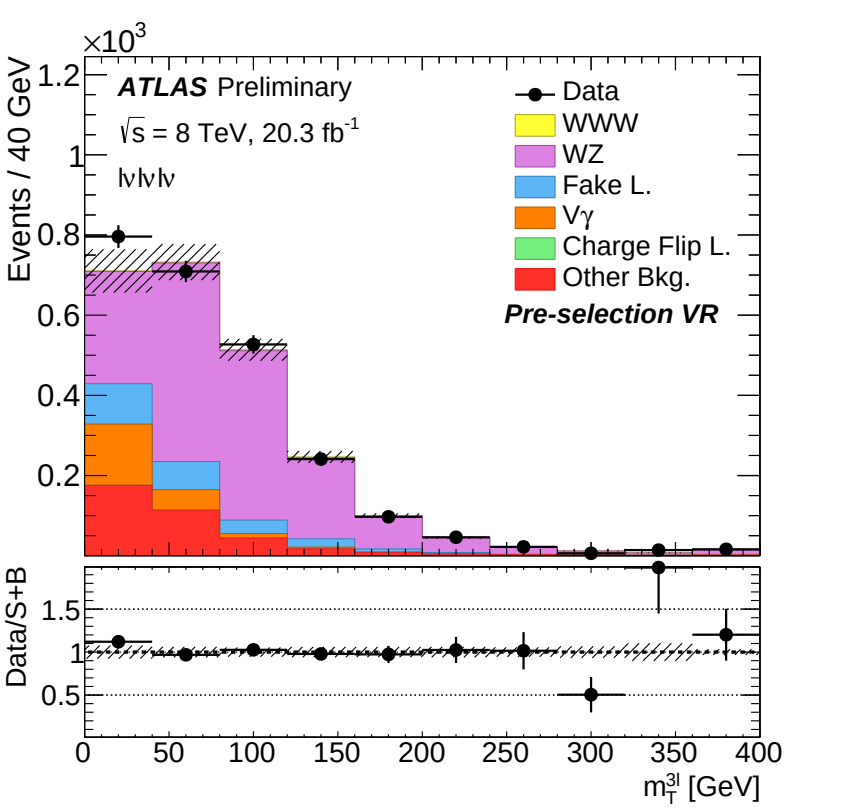
Backgrounds:

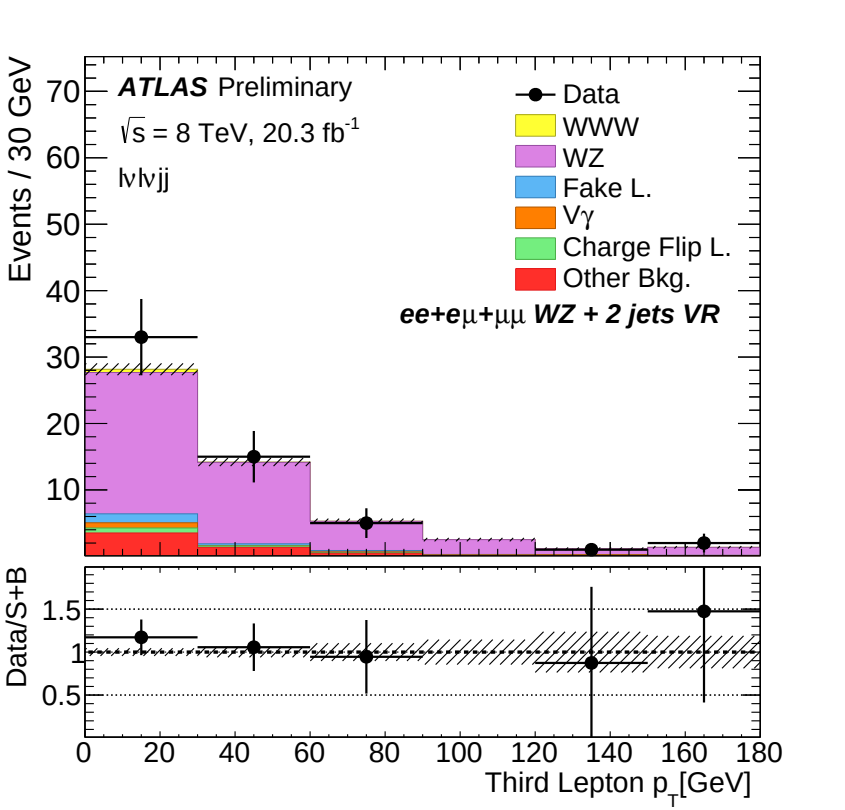
- WZ/γ^*, Wγ+jets or Zγ+jets (MC).
- Lepton's charge mis-ID (Data-driven).
- Fake leptons originated from jets or hadronic decays(Data driven).



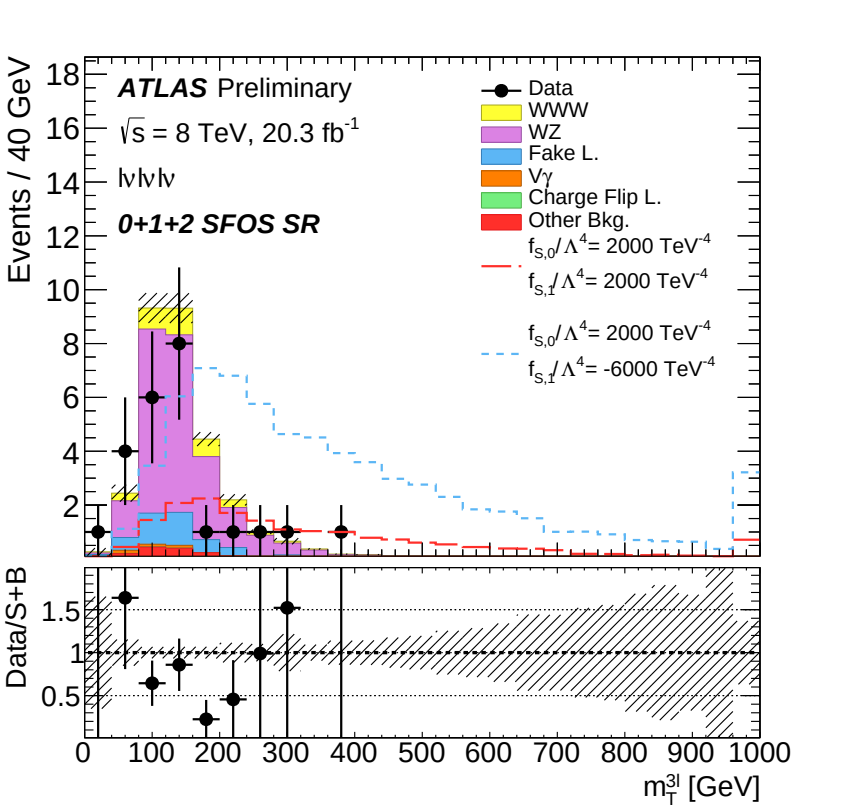
WWW

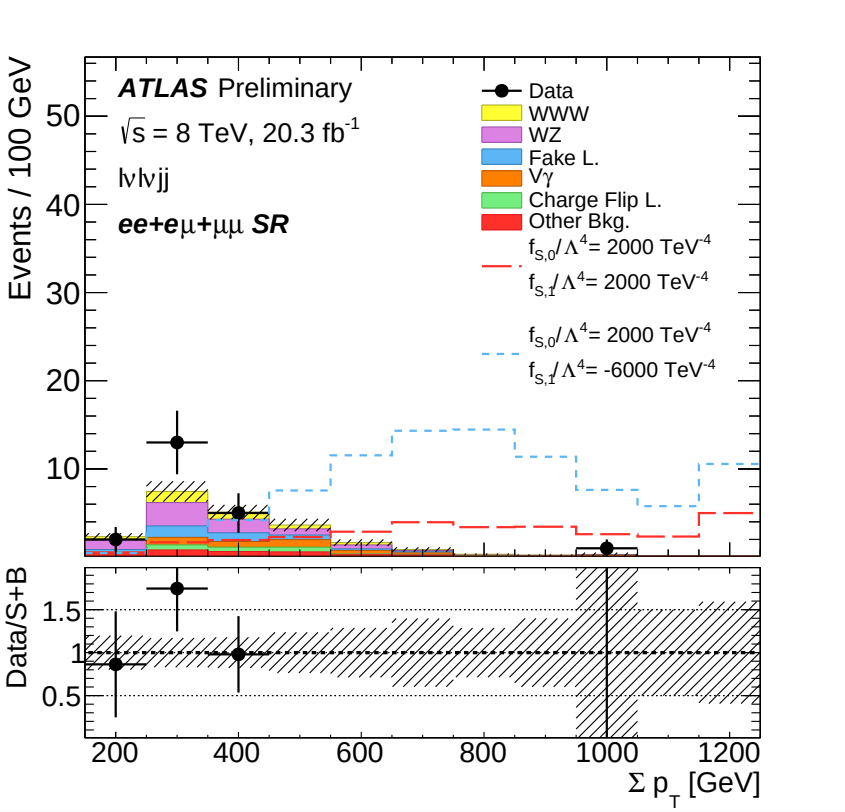
- Distributions in validation region for $l\nu l\nu l\nu$ and $l\nu l\nu jj$ channels.
- m_T^{3l} for $l\nu l\nu l\nu$ channel(Left).
- Third lepton pT for $l\nu l\nu jj$ channel(Right).





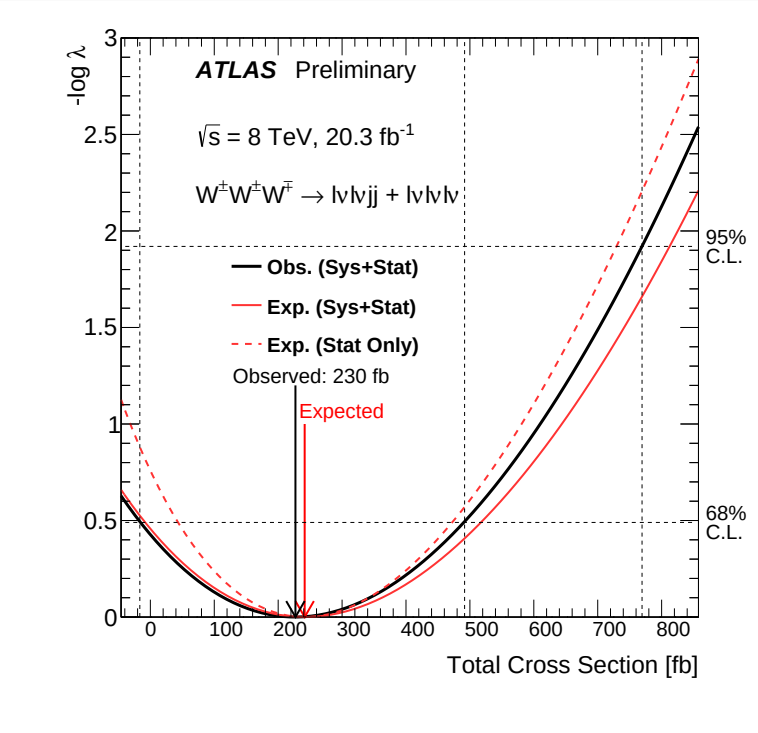
WWW

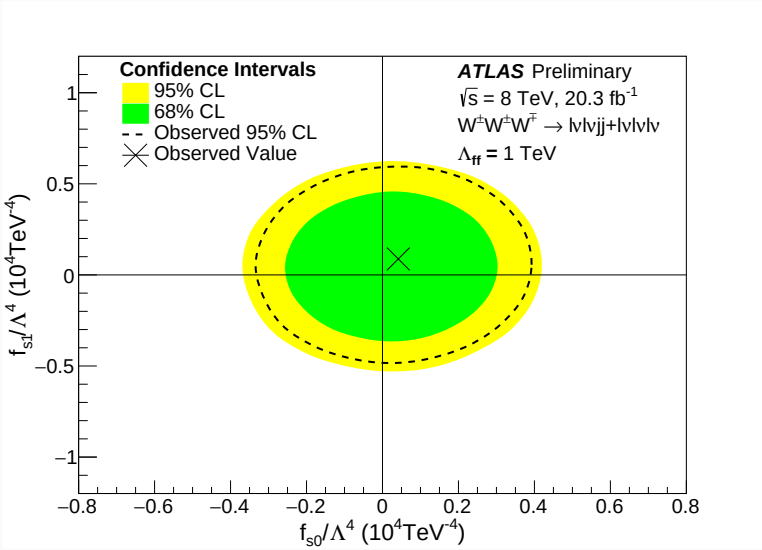

ATLAS Preliminary
√s = 8 TeV, 20.3 fb-1
lνlνlν
0+1+2 SFOS SR
Data
WWW
WZ
Fake L.
Vγ
Charge Flip L.
Other Bkg.
fS,0/Λ4= 2000 TeV-4
fS,1/Λ4= 2000 TeV-4
fS,0/Λ4= 2000 TeV-4
fS,1/Λ4= -6000 TeV-4
Events / 40 GeV
Data/S+B
m3lT [GeV]


ATLAS Preliminary
√s = 8 TeV, 20.3 fb-1
lνlνjj
ee+eμ+μμ SR
Data
WWW
WZ
Fake L.
Vγ
Charge Flip L.
Other Bkg.
fS,0/Λ4= 2000 TeV-4
fS,1/Λ4= 2000 TeV-4
fS,0/Λ4= 2000 TeV-4
fS,1/Λ4= -6000 TeV-4
Events / 100 GeV
Data/S+B
Σ pT [GeV]

WWW Cross Section and aQGCs

- No significant deviation from SM observed.
  - Total and fiducial cross-sections extracted, only ∼1 sigma significance.
- aQGCs limits with 95%CL set.





Summary

- Results of VBS, Exclusive WW and Tri-boson analysis presented.
- Overall good agreement with SM expectations!