Triboson production in the SMEFT

Based on a work with Gauthier Durieux, Ken Mimasu, Eleni Vryonidou

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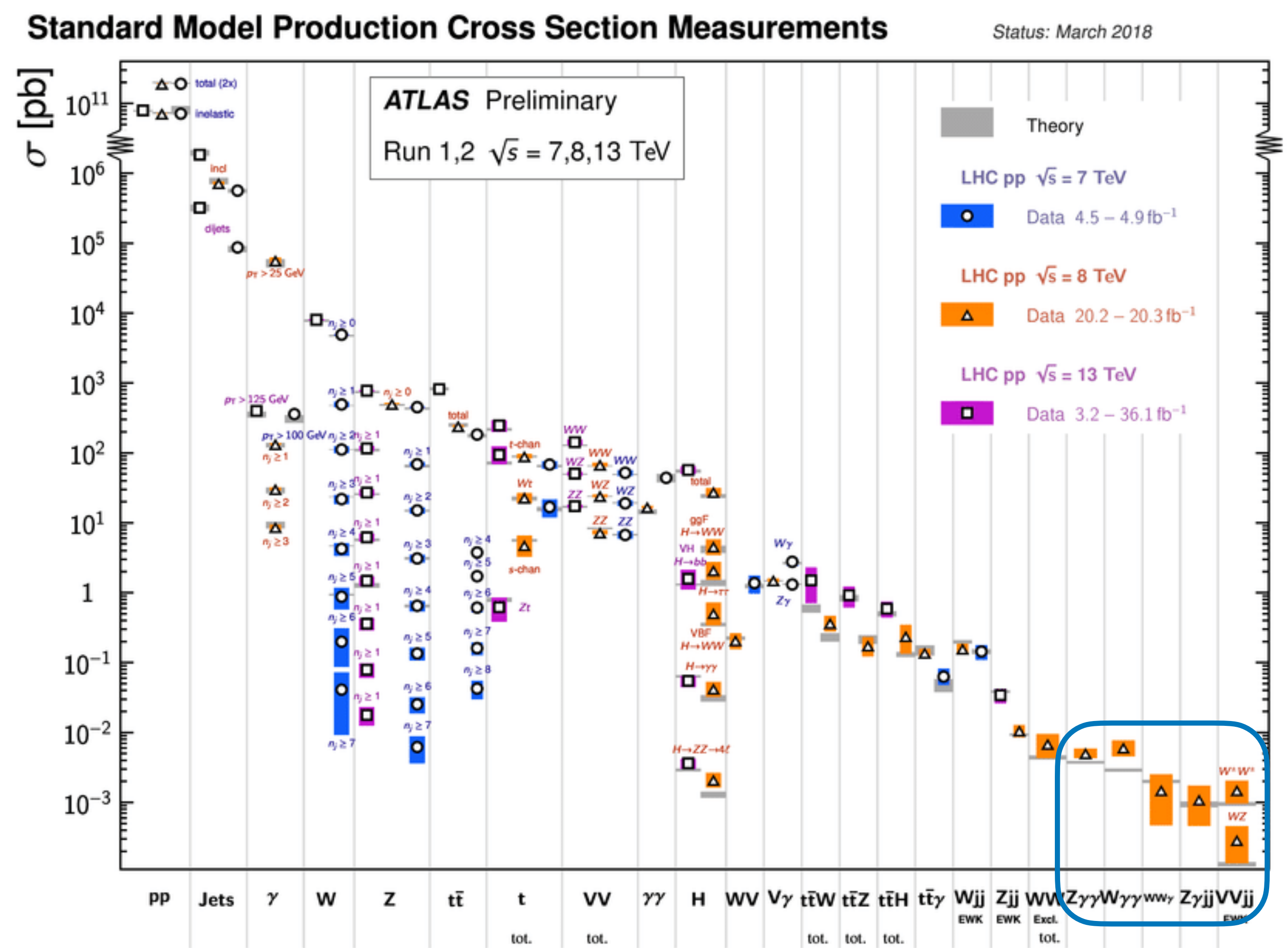
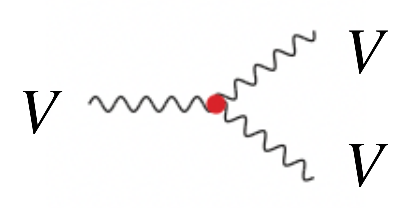
University of Bakirçay,
29/02/24, Izmir, Turkey

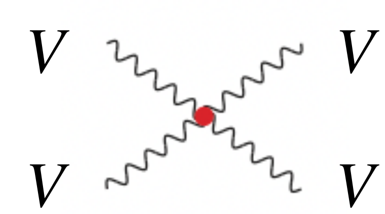
Eugenia Celada
University of Manchester

Triboson production at the LHC

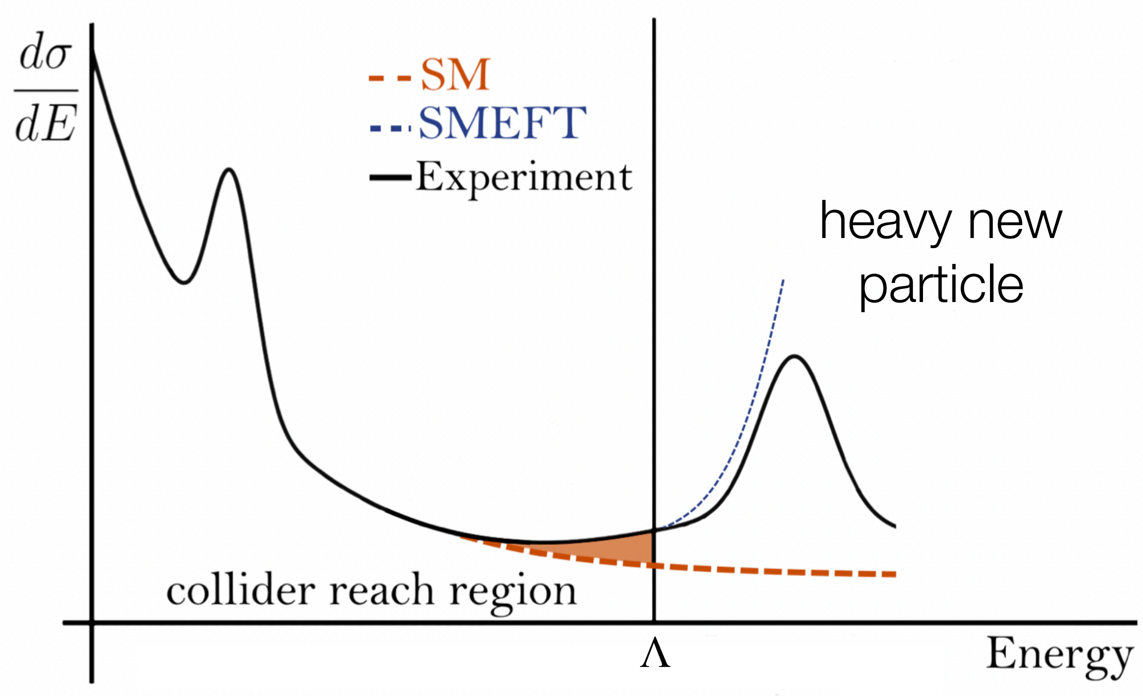


- Triboson have small cross sections, only accessible with LHC run 2
- Tree-level access to TGC and QGC





The SMEFT



Original fig. by C. Severi, M. Thomas, E. Vryonidou

Dimension-6 operators Warsaw basis

$$\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}} + \sum_i \frac{c_i^{(6)}}{\Lambda^2} O_i^{(6)} + \mathcal{O}(\Lambda^{-3})$$

$$\sigma \sim |\mathcal{M}_{\text{SM}}|^2 + \frac{1}{\Lambda^2}\left(\sum c^{(6)}\, 2\text{Re}[\mathcal{M}_{\text{SM}}^* \mathcal{M}_{\text{EFT}}^{(6)}]\right) + \frac{1}{\Lambda^4}\left(\sum c^{(6)} \mathcal{M}_{\text{EFT}}^{(6)}\right)^2$$

EW operators in Warsaw basis

Operator	Definition
bosonic	
$\mathcal{O}_{\phi D}$	$(\phi^\dagger D^\mu \phi)^\dagger (\phi^\dagger D_\mu \phi)$
$\mathcal{O}_{\phi WB}$	$(\phi^\dagger \tau_I \phi) B^{\mu\nu} W^I_{\mu\nu}$
$\mathcal{O}_{WWW}$	$\epsilon_{IJK} W^I_{\mu\nu} W^{J,\nu\rho} W^{K,\mu}_{\rho}$
two-fermion	
$\mathcal{O}^{(1)}_{\phi q}$	$i(\phi^\dagger \overleftrightarrow{D}_\mu \phi)(\bar{q}\gamma^\mu q)$
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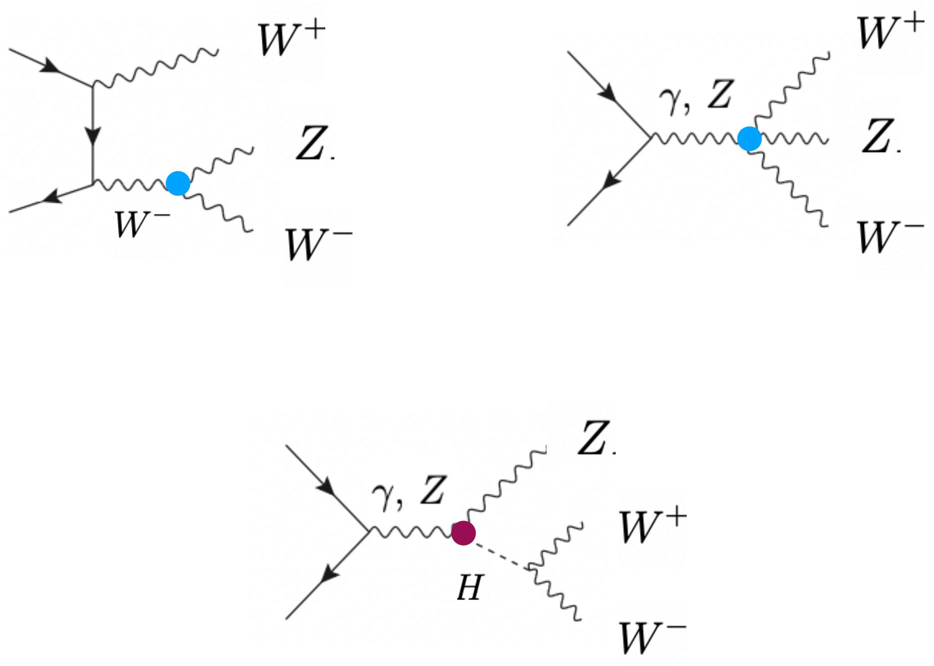
$$pp \to W^+W^-Z$$



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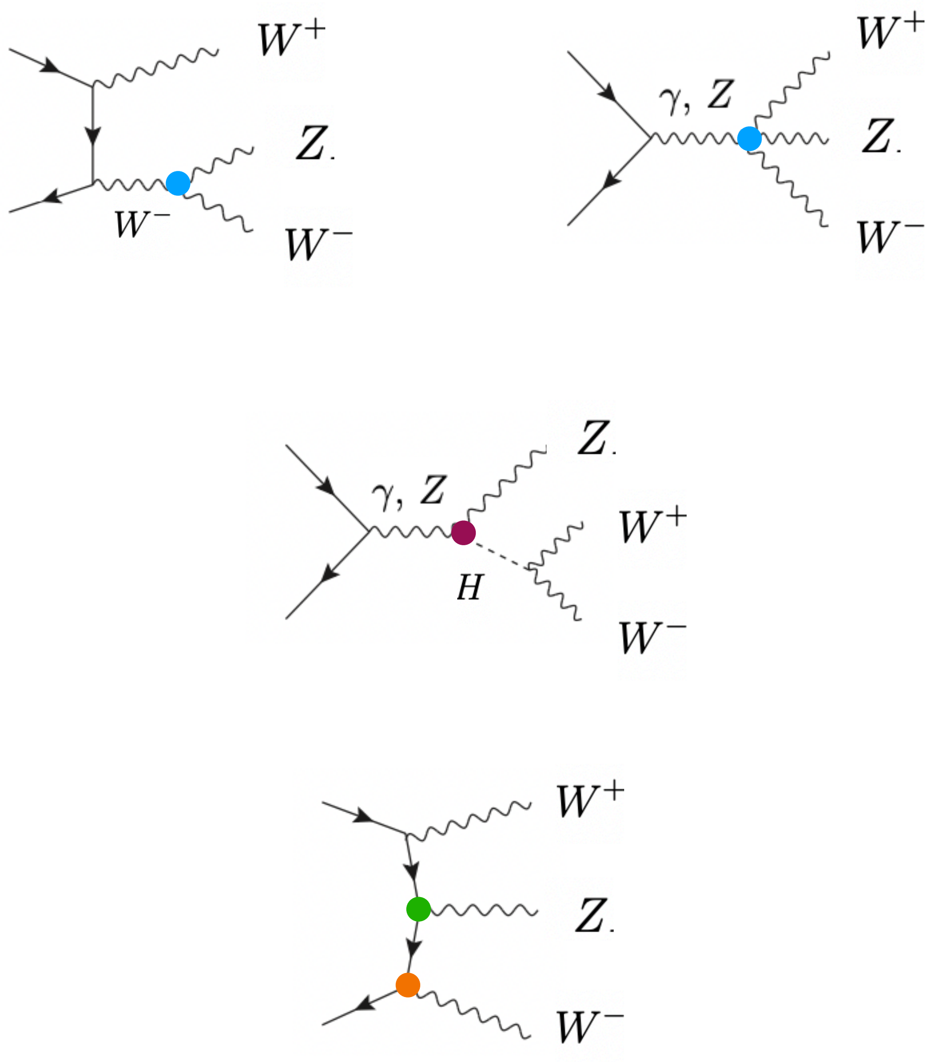

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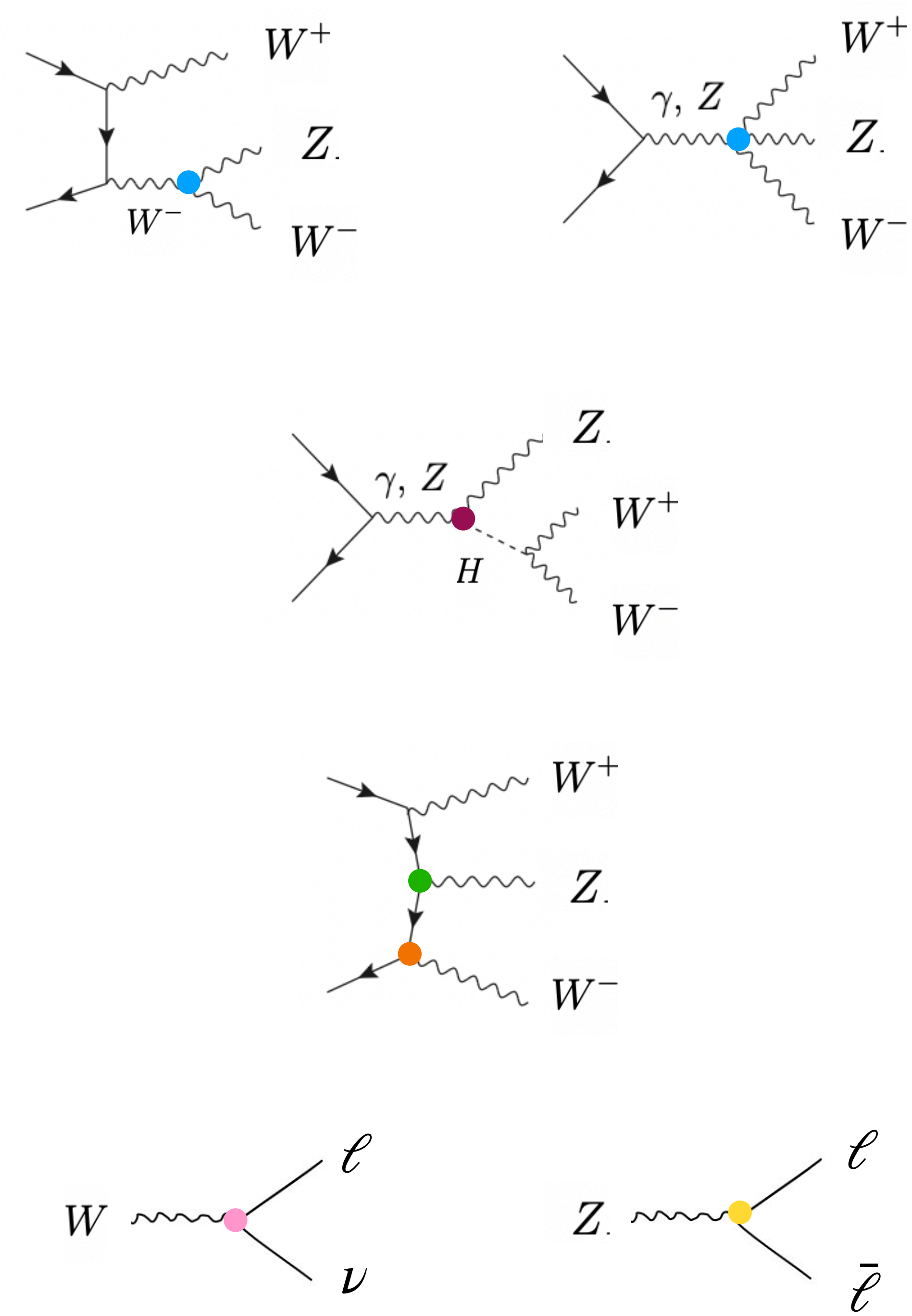

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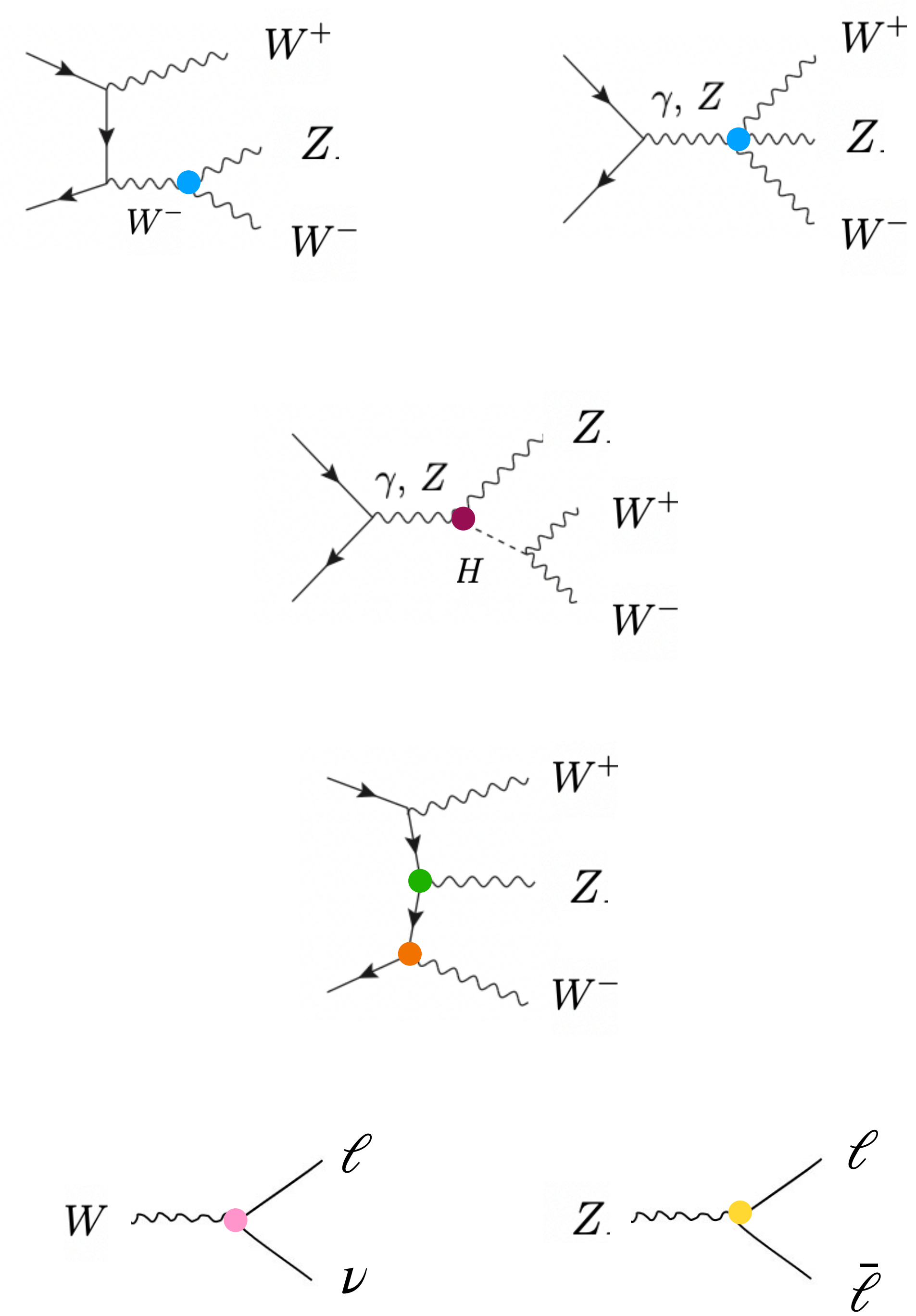


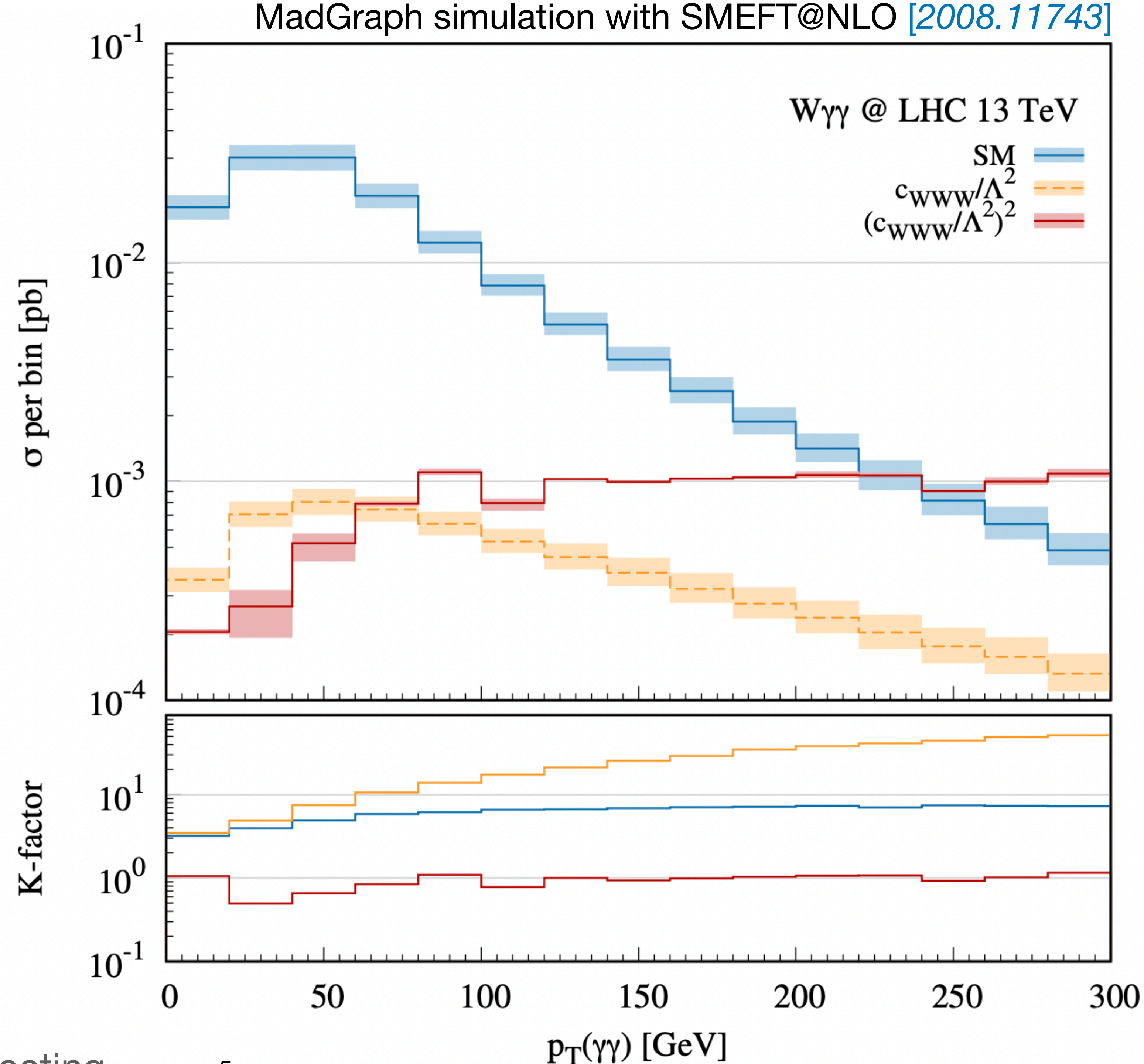
Going NLO

NLO QCD corrections are large in triboson processes

$W\gamma\gamma$	
σ(fb)	K-factor
σ_{SM}	4.84
$\sigma_{\phi D}$	4.86
$\sigma_{\phi D,\phi D}$	4.86
$\sigma_{\phi WB}$	4.70
$\sigma_{\phi WB,\phi WB}$	1.47
σ_{WWW}	12.24
$\sigma_{WWW,WWW}$	0.79
$\sigma_{\phi\ell^{(3)}}$	4.85
$\sigma_{\phi\ell^{(3)},\phi\ell^{(3)}}$	4.85
$\sigma_{\phi q^{(3)}}$	4.80
$\sigma_{\phi q^{(3)},\phi q^{(3)}}$	4.80
$\sigma_{\ell\ell}$	4.82
$\sigma_{\ell\ell,\ell\ell}$	4.82

$$K = \frac{\sigma_{\text{NLO}}}{\sigma_{\text{LO}}}$$

MadGraph simulation with SMEFT@NLO [2008.11743]



Operators and observables

Operator	Definition	EWPOs	LEP WW	LHC VV	$VVV, VV\gamma, V\gamma\gamma$
bosonic					
$\mathcal{O}_{\phi D}$	$(\phi^\dagger D^\mu \phi)^\dagger (\phi^\dagger D_\mu \phi)$	✓	✓	✓	✓
$\mathcal{O}_{\phi WB}$	$(\phi^\dagger \tau_I \phi) B^{\mu\nu} W^I_{\mu\nu}$	✓	✓	✓	✓
$\mathcal{O}_{WWW}$	$\epsilon_{IJK} W^I_{\mu\nu} W^{J,\nu\rho} W^{K,\mu}_{\rho}$		✓	✓	✓
two-fermion					
$\mathcal{O}^{(1)}_{\phi q}$	$i(\phi^\dagger \overleftrightarrow{D}_\mu \phi)(\bar{q}\gamma^\mu q)$	✓		✓	✓
$\mathcal{O}^{(3)}_{\phi q}$	$i(\phi^\dagger \overleftrightarrow{D}_\mu \tau_I \phi)(\bar{q}\gamma^\mu \tau^I q)$	✓	✓	✓	✓
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four-fermion					
$\mathcal{O}_{\ell\ell}$	$(\bar{\ell}\gamma_\mu \ell)(\bar{\ell}\gamma^\mu \ell)$	✓	✓	✓	✓

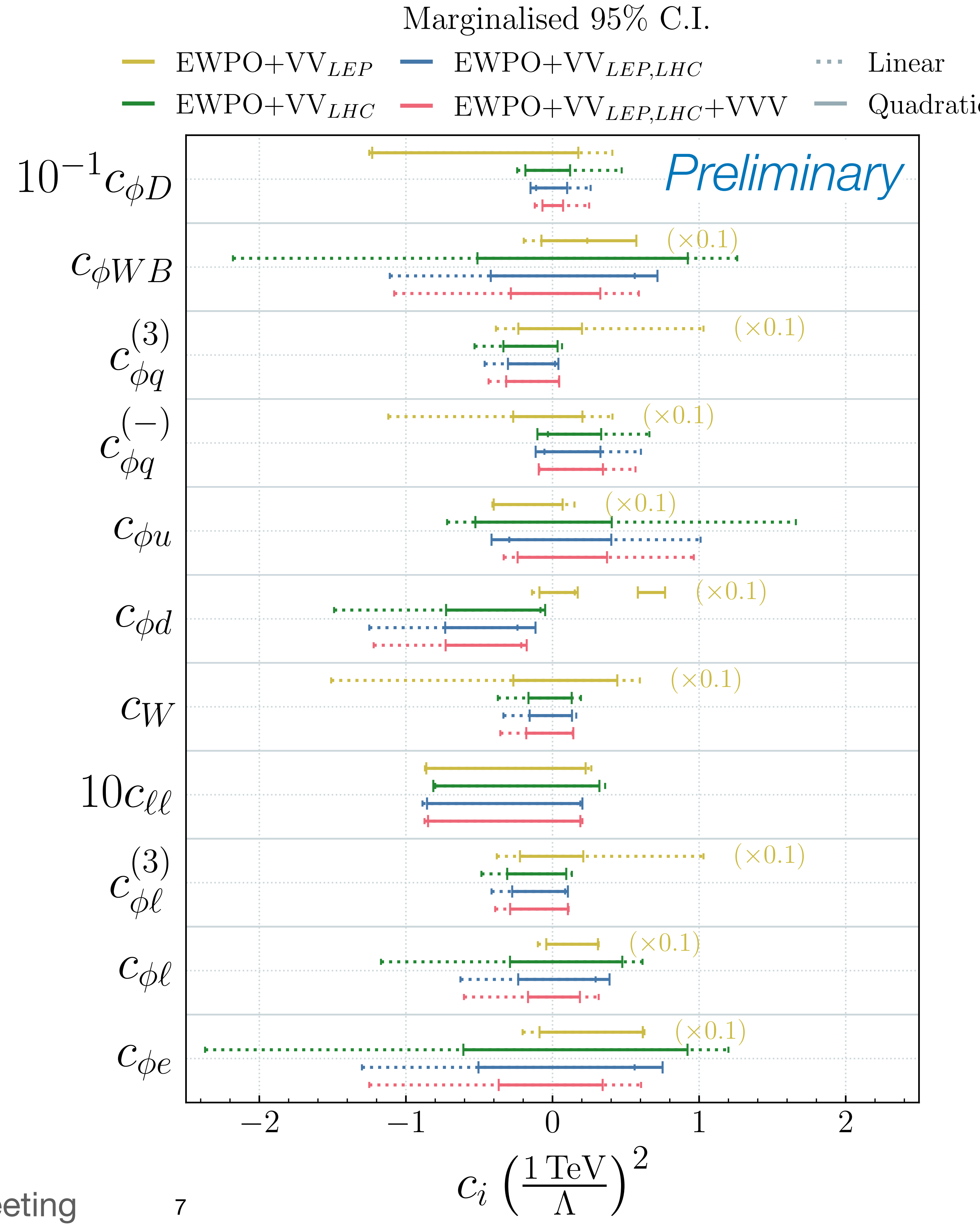
Fit results

- LHC VV & VVV appear to improve significantly the bounds from EWPOs & LEP VV

- 50% improvement from VVV on $O_{\phi D}, O_{\phi WB}, O_{\phi \ell}, O_{\phi e}$

- Linear bounds are weaker than quadratic

Done with Fitmaker [2012.02779]



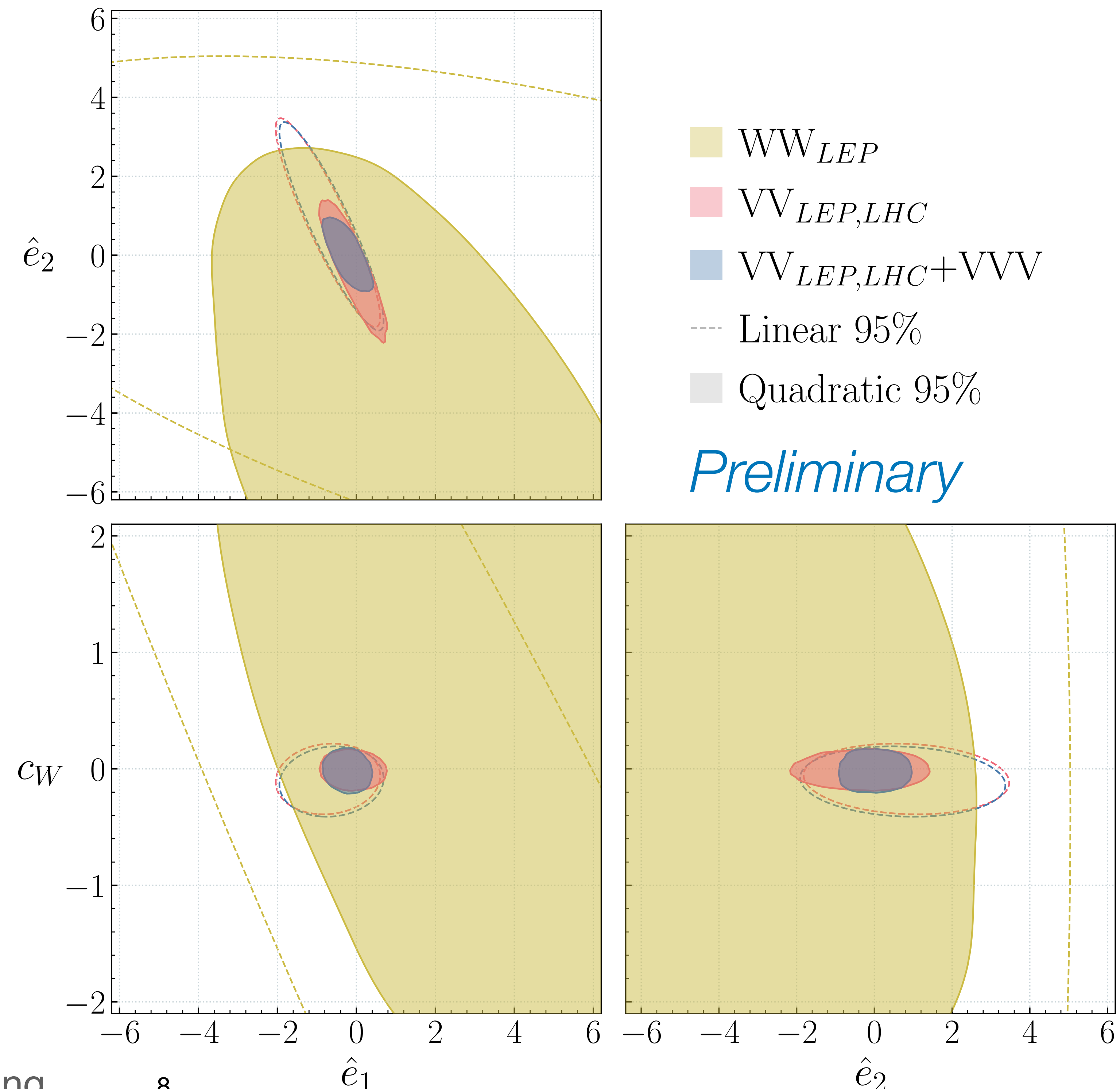
Where do VV & VVV help?

Three EWPOs unconstrained parameters: $\hat{e}_1, \hat{e}_2, O_{WWW}$ [1701.06424]

- At order $\mathcal{O}(\Lambda^{-2})$ triboson doesn't help
- VVV constrains the $\hat{e}_1, \hat{e}_2$ space

↓

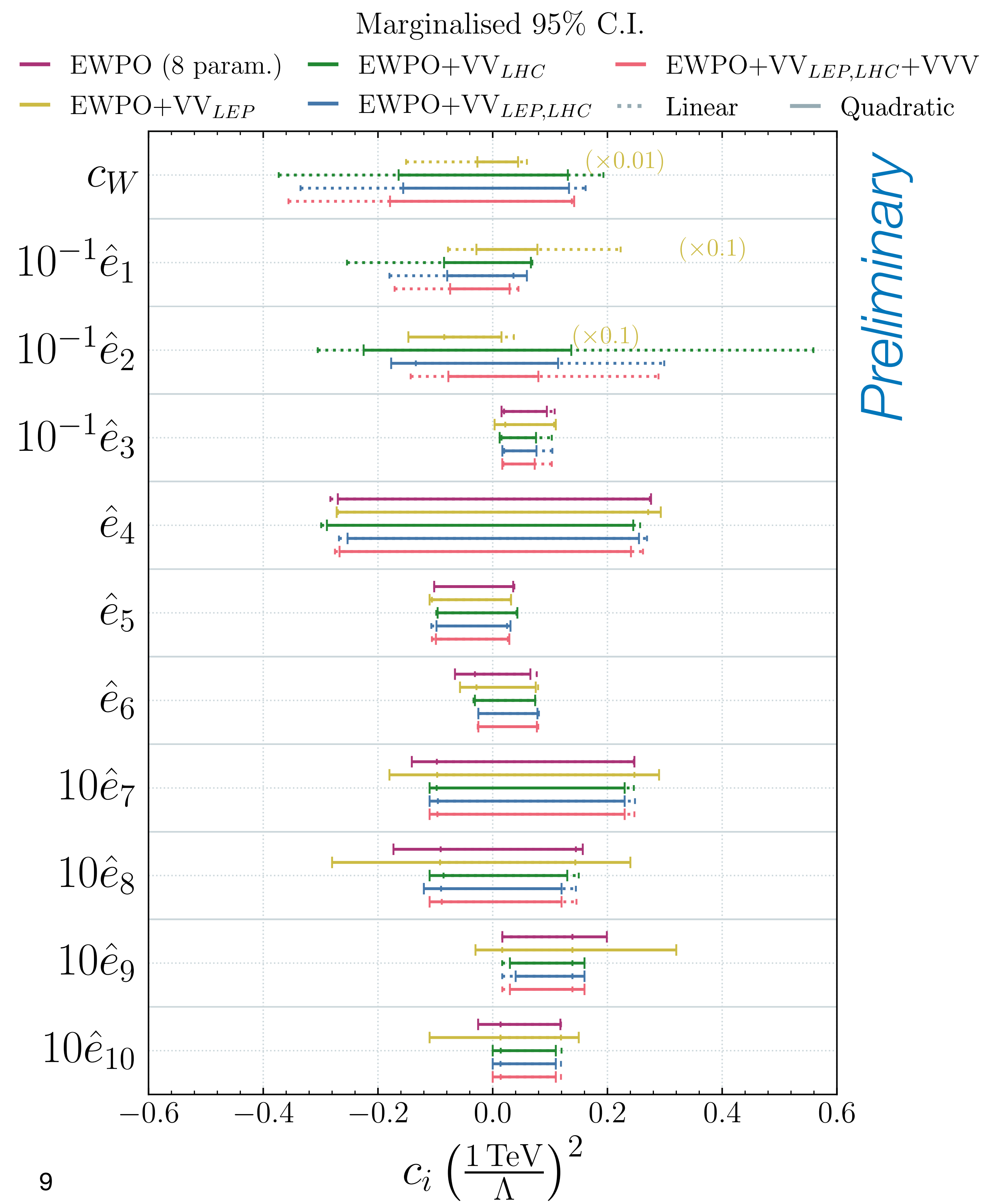
- Quadratic corrections are important (also for LEP WW!)
- VVV improves in EWPOs flat directions



What about the other directions?

Does multiboson help EWPOs in the directions orthogonal to $\hat{e}_1, \hat{e}_2, O_{WWW}$?

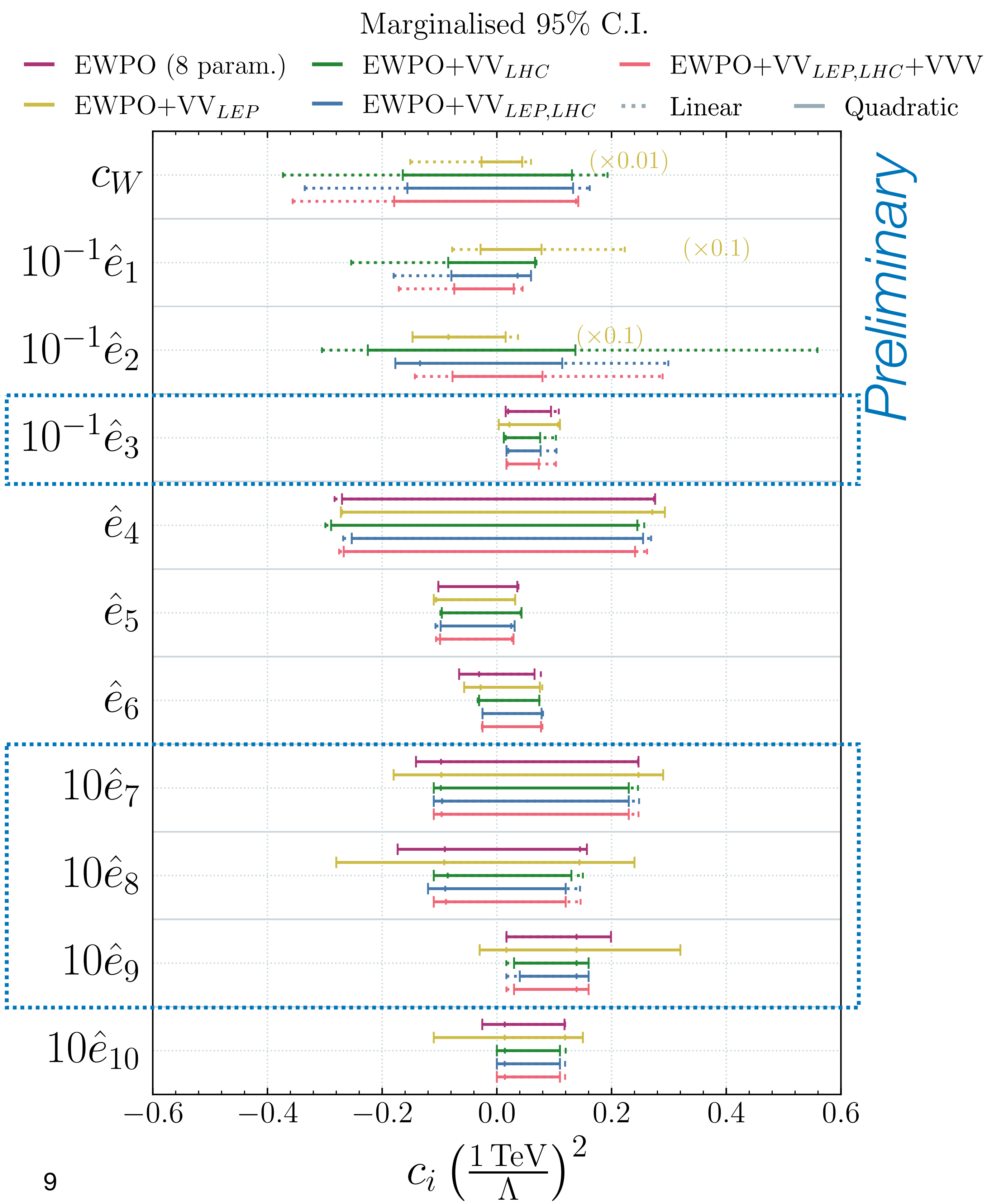
- in general, EWPOs constraints are dominant



What about the other directions?

Does multiboson help EWPOs in the directions orthogonal to $\hat{e}_1, \hat{e}_2, O_{WWW}$?

- in general, EWPOs constraints are dominant
- mild improvement from quadratics (even EWPOs) on some directions
- secondary minima in EWPOs+LEP lifted by LHC



Conclusions

- Triboson improves the bounds of up to a factor 2 compared to diboson in directions unconstrained by EWPOs

- Quadratic EFT contributions are sizeable for all the processes, from EWPO leading to secondary minima, to LEP diboson, and the LHC VV&VVV

Backup

Constraints from multiboson in EWPOs flat directions space and in the orthogonal directions