Unitarization Method Uncertainties in non-resonant VBS at the LHC

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Aim

Quantify uncertainty of experimental constraints on EChL parameters due to choice of unitarization method

New physics in the EWSB sector

We use model independent EFT's to understand the dynamical generation of EWSB

We look at VBS observables, very sensitive to new physics!

In particular, we study WZ scattering

The EChL (HEFT) for VBS

Strongly interacting EWSB sector

- EW Chiral invariant $SU(2)_L \times SU(2)_R \to SU(2)_C$
- EW Gauge invariant $SU(2)_L \times U(1)_Y$

Built as expansion in powers of p

$$\mathcal{L}_{\rm EChL} = \mathcal{L}_2(\mathcal{O}(p^2)) + \mathcal{L}_4(\mathcal{O}(p^4)) + \dots$$

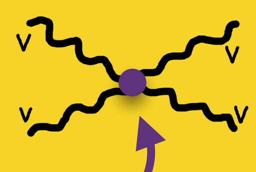
We select the most relevant terms for VBS:

$$\mathcal{L}^{\rm VBS}_{\rm EChL} = \mathcal{L}_{\rm SM} + \mathcal{L}_4(g=g'=0)$$

$$\mathcal{L}_4(g=g'=0) = a_4\left[{\rm Tr}(\mathcal{V}_\mu\mathcal{V}_\nu){\rm Tr}(\mathcal{V}^\mu\mathcal{V}^\nu)\right] + a_5\left[{\rm Tr}(\mathcal{V}_\mu\mathcal{V}^\mu){\rm Tr}(\mathcal{V}_\nu\mathcal{V}^\nu)\right]$$

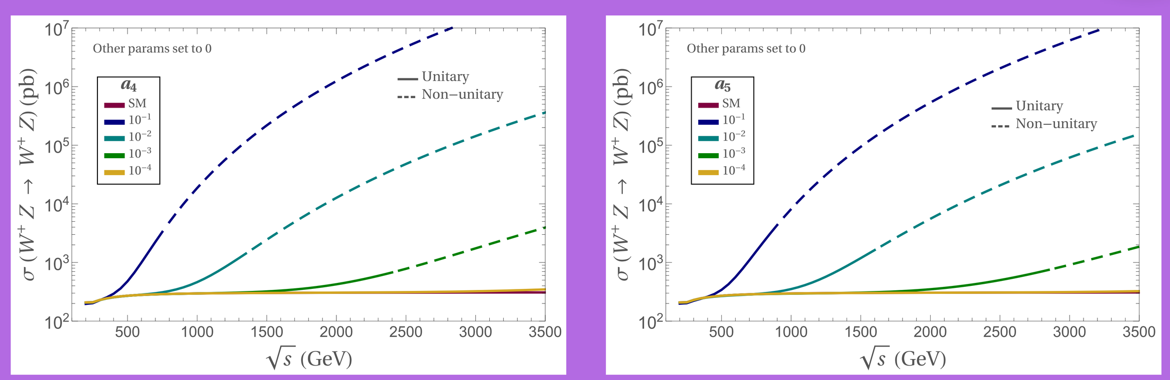
$\boxed{a_4,\ a_5}$

$\mathcal{V}_\mu = (D_\mu U)U^\dagger,\ U = e^{\frac{i w^a \tau^a}{v}}$



Unitarity Violation

EFT expansions lead to unitarity violation

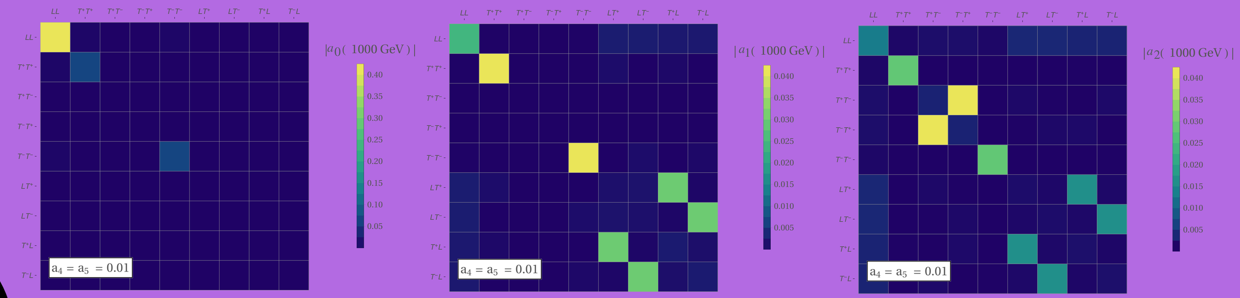


In our case longitudinal modes are most pathological

Reliable predictions have to fulfil unitarity condition

$${\rm Im}(a_{\lambda_1,\lambda_2,\lambda_3,\lambda_4}) = |a_{\lambda_1,\lambda_2,\lambda_3,\lambda_4}|^2 = \sum_{a,b,c,d} a_{\lambda_1,\lambda_2,a,b}\cdot a^*_{c,d,\lambda_3,\lambda_4}$$

and all helicity channels have to be considered consistently



$a_{\lambda_1,\lambda_2,\lambda_3,\lambda_4} =$ Partial wave corresponding to $A(V_{\lambda_1}V_{\lambda_2} \to V_{\lambda_3}V_{\lambda_4})$

Unitarization methods

To ensure unitarity, unitarization methods are addressed

In the non-resonant case different methods lead to very different predictions!!!

We study the 5 most common ways to restore unitarity:

3 suppress the pathological behaviour with energy at the amplitude level:

Form Factor (FF) $\hat{A}(WZ\to WZ) = A(WZ\to WZ)\cdot(1+s/\Lambda^2)^{-2}$

"Kink" $\hat{A}(WZ\to WZ) = A(WZ\to WZ)\cdot\mathcal{F}(s,\Lambda)$ $\quad \mathcal{F}(s,\Lambda) = \begin{cases} 1 & s\le\Lambda^2 \\ (\Lambda^2/s)^2 & s>\Lambda^2\end{cases}$

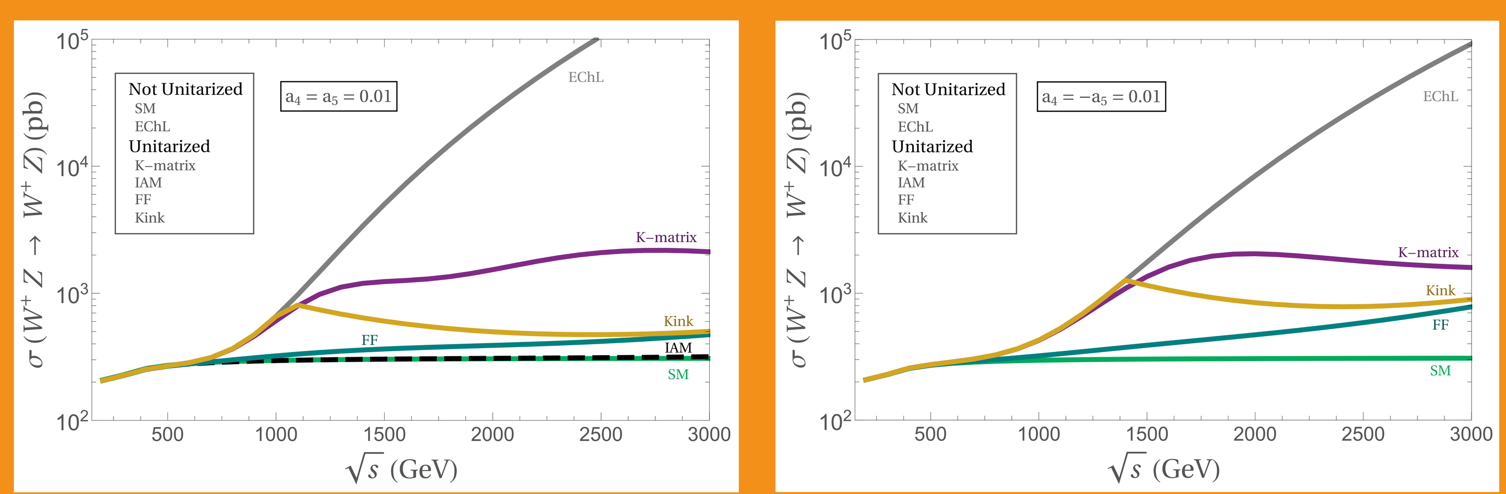
Cut off $\hat{A}(WZ\to WZ) = A(WZ\to WZ)(s\le\Lambda)$

2 rely on a partial wave expansion from which the unitary amplitude is reconstructed:

K matrix $a_J^{\rm K\,matrix} = a_J\cdot[\mathbb{1} - i\cdot a_J]^{-1}$

Inverse Amplitude Method $a_J^{\rm IAM} = a_J^{(2)}\cdot[a_J^{(2)} - a_J^{(4)}]^{-1}\cdot a_J^{(2)}$

Reconstructed unitary amplitudes: $\hat{A}_{WZ\to WZ} = A_{WZ\to WZ} + 16\pi\sum_{J=0}^{2}(2J+1)(\hat{a}_J - a_J)\cdot d_J$



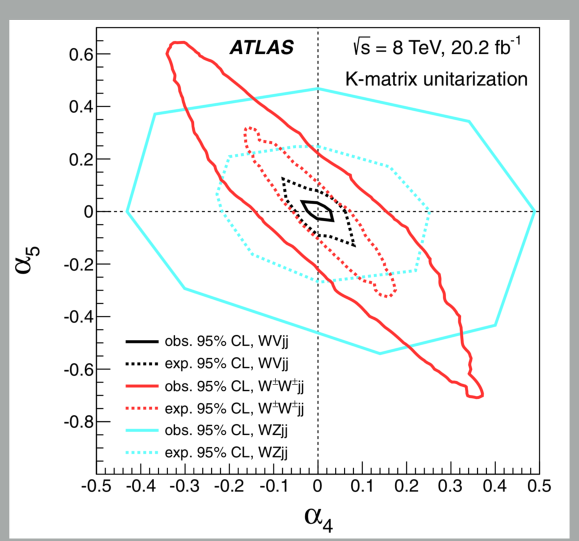
Very different predictions for the WZ→WZ total cross section using different methods!

$\sigma(a_4\cdot a5>0) > \sigma(a_4\cdot a5<0)$ More stringent constraints for same sign a_4 & a_5

$\hat{A}_{WZ\to WZ} =$ Unitary amplitude

Current experimental constraints

Experimental constraints on a_4 & a_5 are given using one method at a time or no method at all



ATLAS[1]: K matrix $[a_4, a_5]$ contours at 95% C.L.

CMS[2]: No unitarization method applied

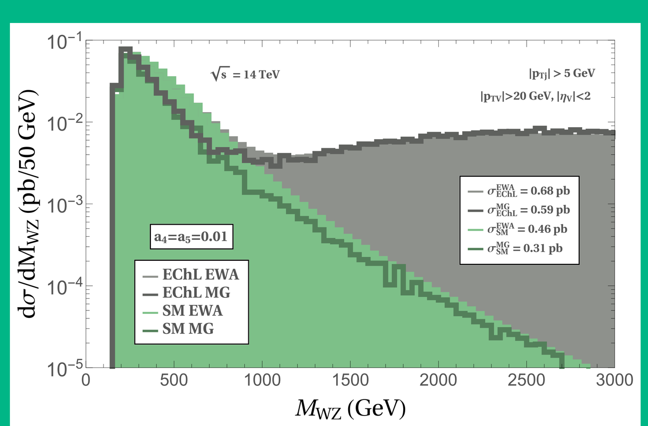
How much can we rely on these constraints?

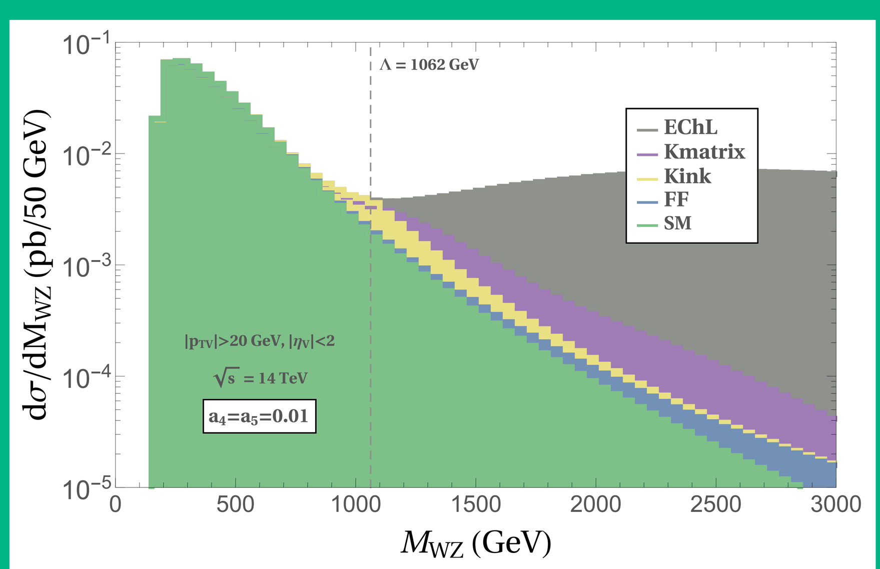
Parameter determination uncertainty due to unitarization scheme choice

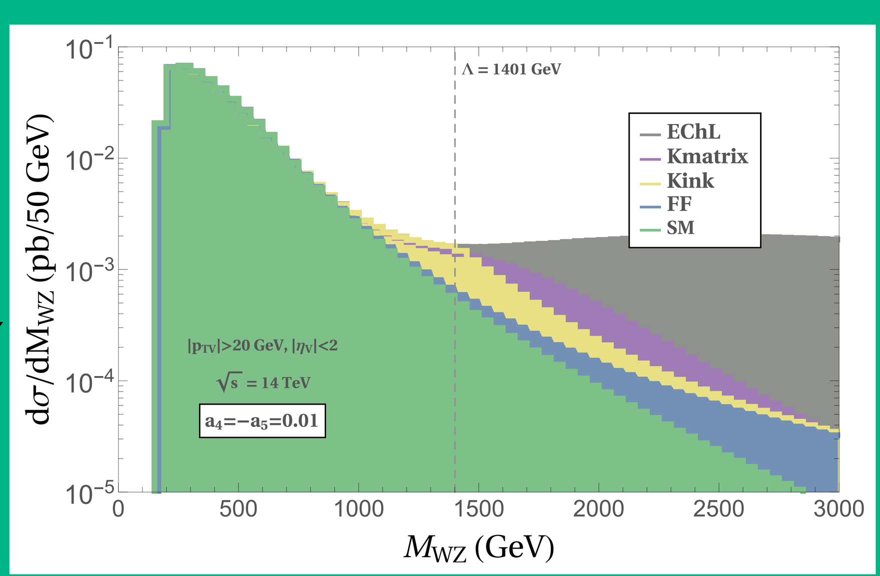
We use the EWA[3] to give predictions of pp > (WZ, Wγ) > WZ+X events at the LHC for different unitarization methods

The Effective W Approximation (EWA) treats the EW gauge bosons as partons inside the proton establishing a "PDF" for them

We have tested the SM and EChL EWA predictions with MadGraph 5







Very different results depending on unitarization method!!

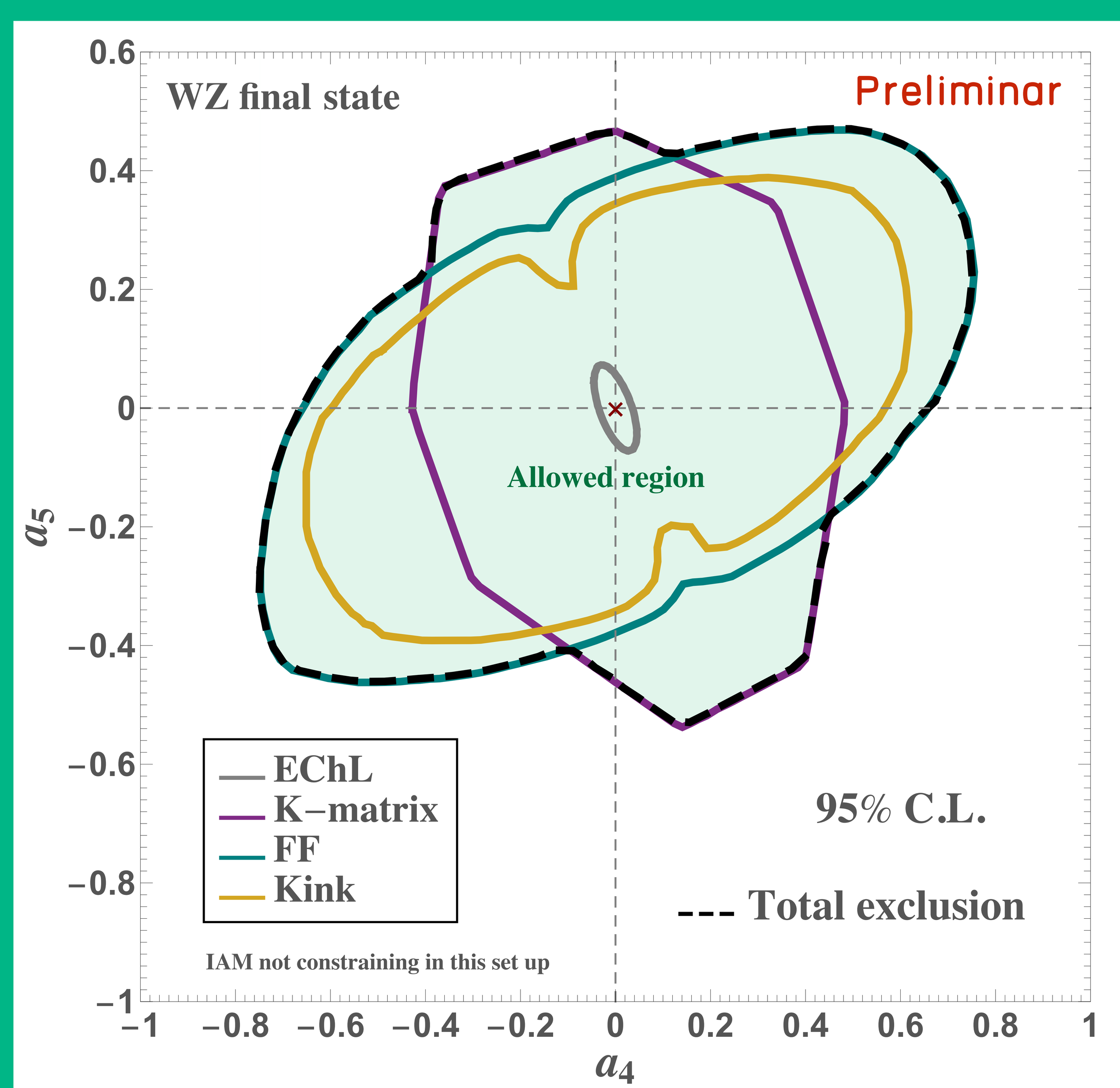
From the ATLAS constraints, we extract our equivalent cross section over the contour of 95% C.L. exclusion

With that as reference, we construct the 95 % C.L. exclusion $[a_4,a_5]$ regions for the other unitarization methods

Overlap shows the uncertainty in a_4 and a_5 determination due to unitarizacion scheme

We don't include the IAM, since in this set up non-resonant ~ SM

We include the non-unitary prediction such as in CMS analyses



Conclusions

Current experimental constraints on EFT parameters have uncertainties due to choice of unitarization scheme!

We quantify these uncertainties studying various unitarization methods!

[1] ATLAS col. Phys. Rev. D 95 (2017) no.3, 032001 [arXiv: 1609.05122]; [2] CMS col. [arXiv:1905.07445]; [3] S. Dawson, Nucl. Phys. B 249 (1985) 42