Unitarization Effects in EFT predictions of WZ Scattering at the LHC

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CGG, M.J. Herrero, R. Morales

[IFT-UAM/CSIC-19-81, FTUAM-19-13]

Motivation

Our Aim

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

How?

1. Using model independent EFT's to understand the dynamical generation of EWSB. In particular the EChL (HEFT)

2. Looking at VBS observables: very sensitive to new physics!

3. As a first approach, we study WZ scattering

The EChL (HEFT) for VBS

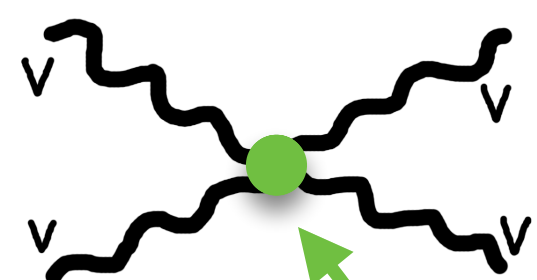
We assume a strongly interacting EWSB sector

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

EW GB's are introduced non-linearly: $U(w^{\pm}, z) = e^{\frac{i w^a \tau^a}{v}}$

Lagrangian is built as an expansion in powers of p

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



We select the most relevant terms for VBS:

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

[A. C. Longhitano, 1980; T. Appelquist et al., 1980]

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

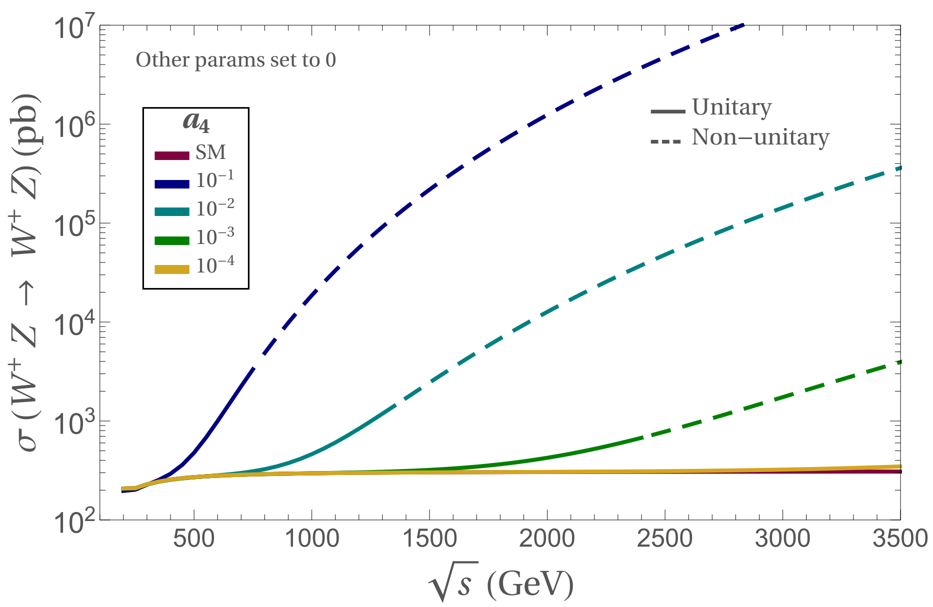
$\mathcal{V}_\mu = (D_\mu U) U^\dagger$

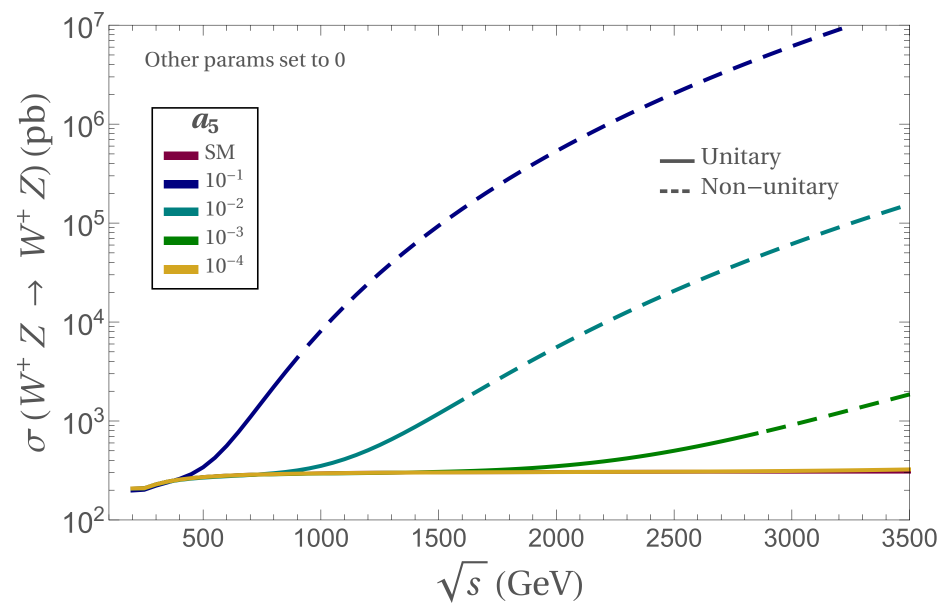
$\boxed{a_4,\ a_5}$

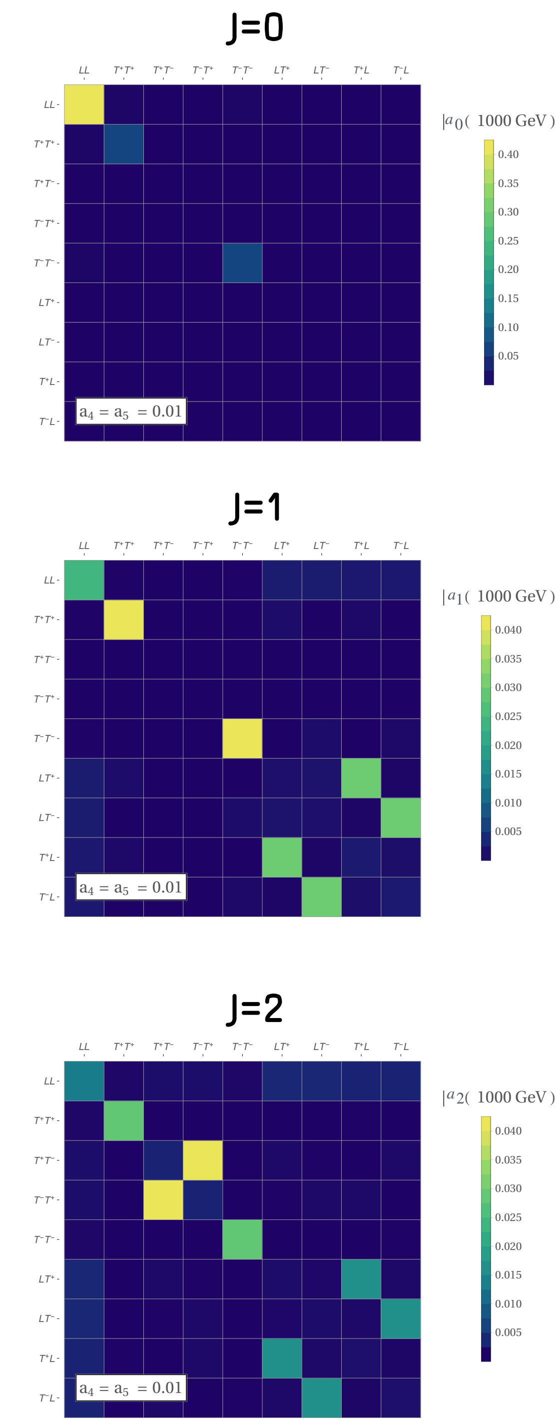
Most relevant parameters for VBS!

Unitarity Violation

EFT expansions lead to unitarity violation







Longitudinal modes are most pathological

Reliable **predictions** have to **fulfil unitarity** condition

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

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

and **all helicity channels** have to be **considered** consistently

Unitarization Methods

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

To ensure unitarity, unitarization methods are addressed

We study the 5 most common ways to restore unitarity:

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

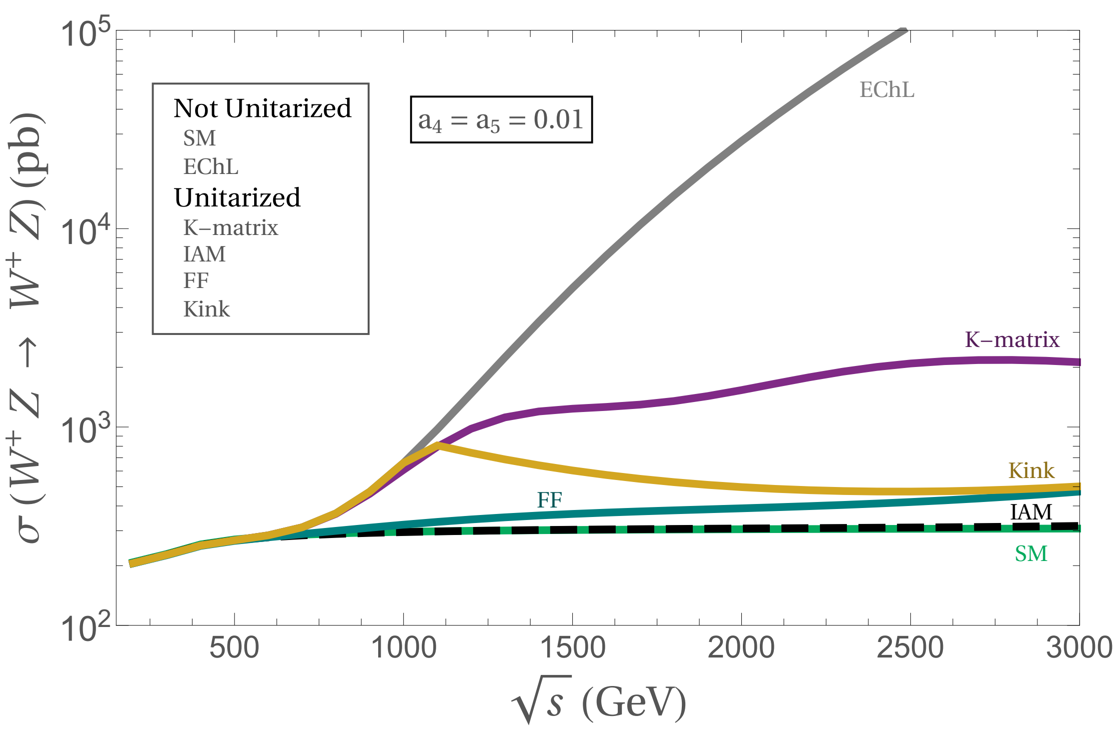
"Kink" $\hat{A}(WZ \to WZ) = A(WZ \to WZ) \cdot \mathcal{F}(s,\Lambda)$ $\quad \mathcal{F}(s,\Lambda) = \begin{cases} 1 & s \le \Lambda^2 \\ (\Lambda^2/s)^2 & s > \Lambda^2 \end{cases}$

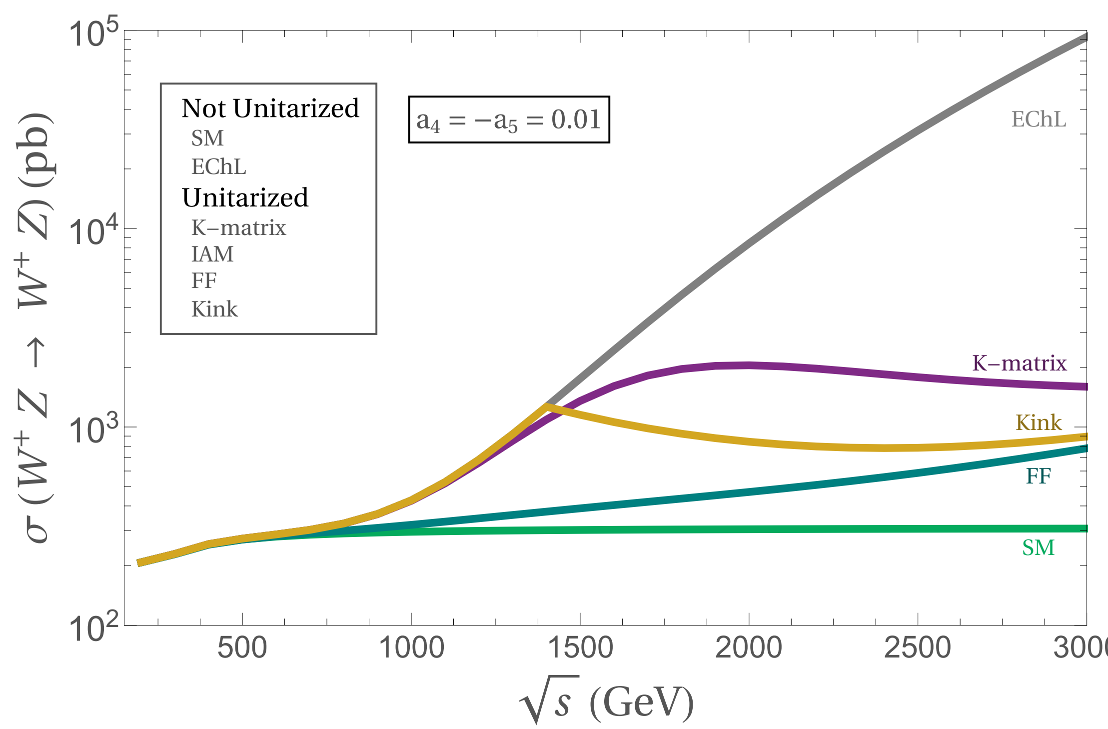
Cut off $\hat{A}(WZ \to WZ) = A(WZ \to WZ)(s \le \Lambda)$

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

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

Unitary amplitude is reconstructed from partial waves





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

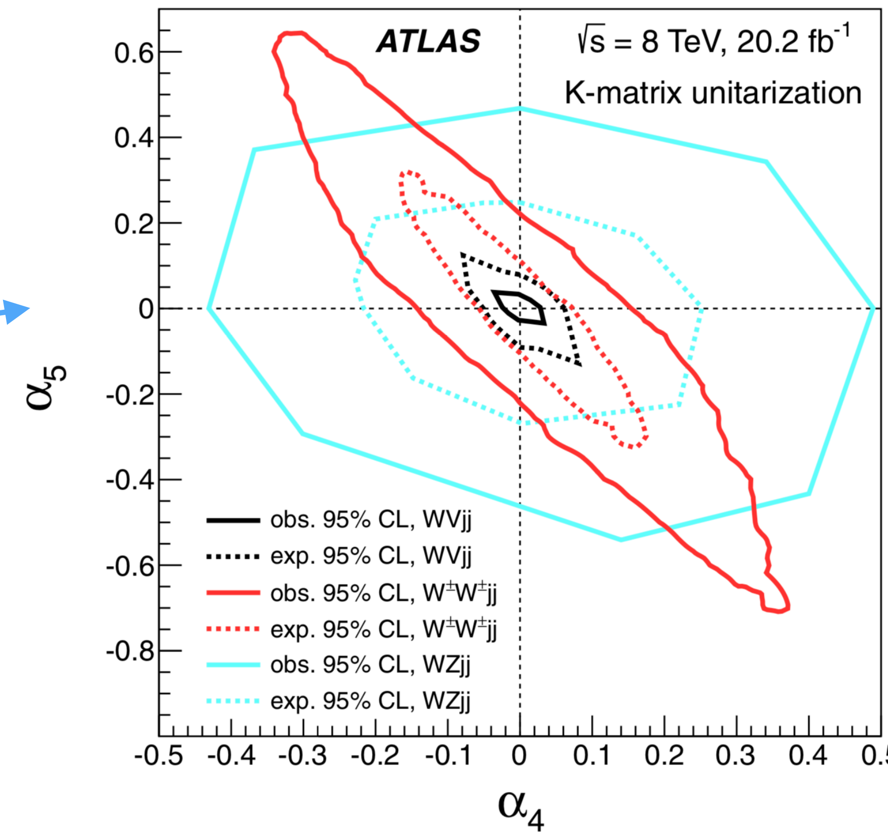
$\sigma(a_4 \cdot a5 > 0) > \sigma(a_4 \cdot a5 < 0)$ More stringent constraints for same sign a_4 & a_5

Current exp. Constraints

Experimental constraints on a4 & a5 are given using one method at a time or no method at all

Some ATLAS analyses:
K matrix a_4 a_5
contours at 95% C.L.

[ATLAS col. Phys. Rev. D 95 (2017) no.3, 032001][arXiv: 1609.05122]



Other ATLAS analyses and CMS ones: No unitarization method applied

[ATLAS col. arXiv:1905.07714]

[CMS col. arXiv:1905.07445]

	Expected (WV) (TeV^{-4})	Observed (ZV) (TeV^{-4})	Expected (ZV) (TeV^{-4})
f_{S0}/Λ^4	$[-4.2, 4.2]$	$[-40, 40]$	$[-31, 31]$
f_{S1}/Λ^4	$[-5.2, 5.2]$	$[-32, 32]$	$[-24, 24]$

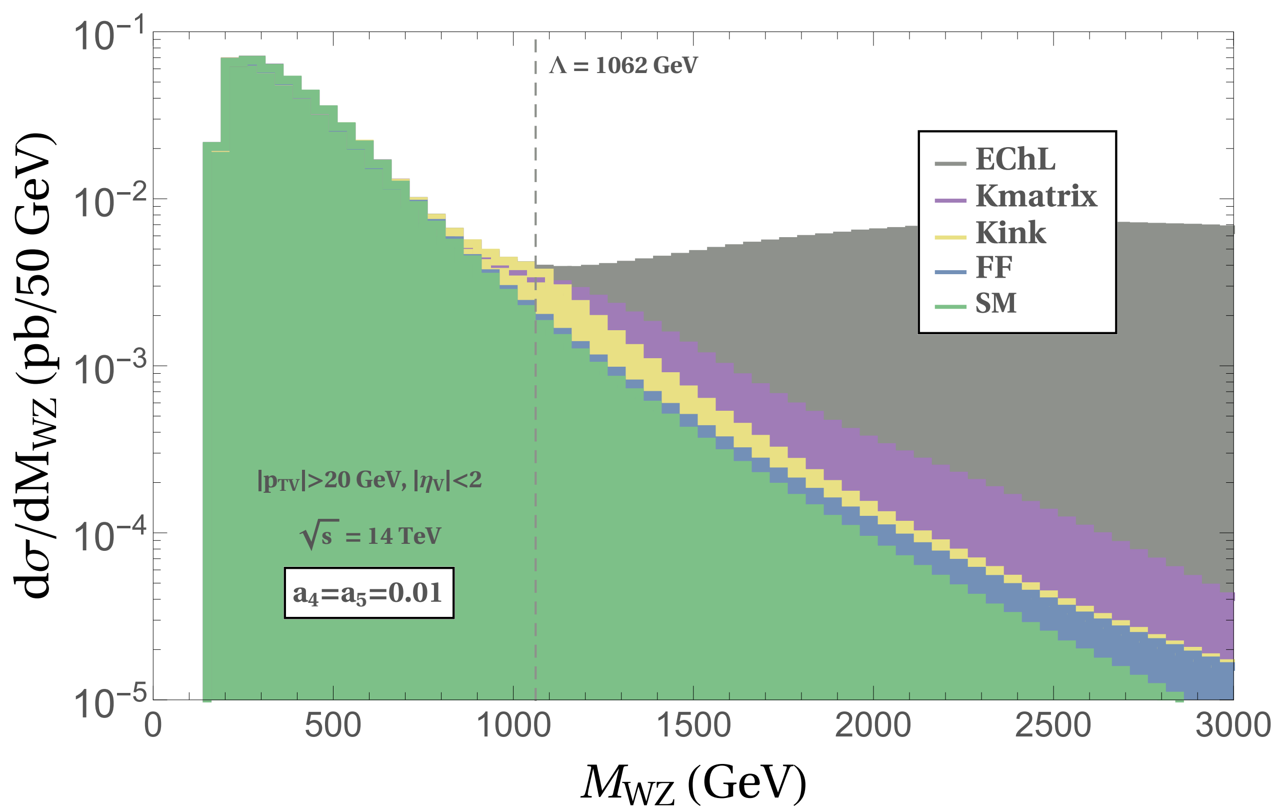
Related to a_4,a_5

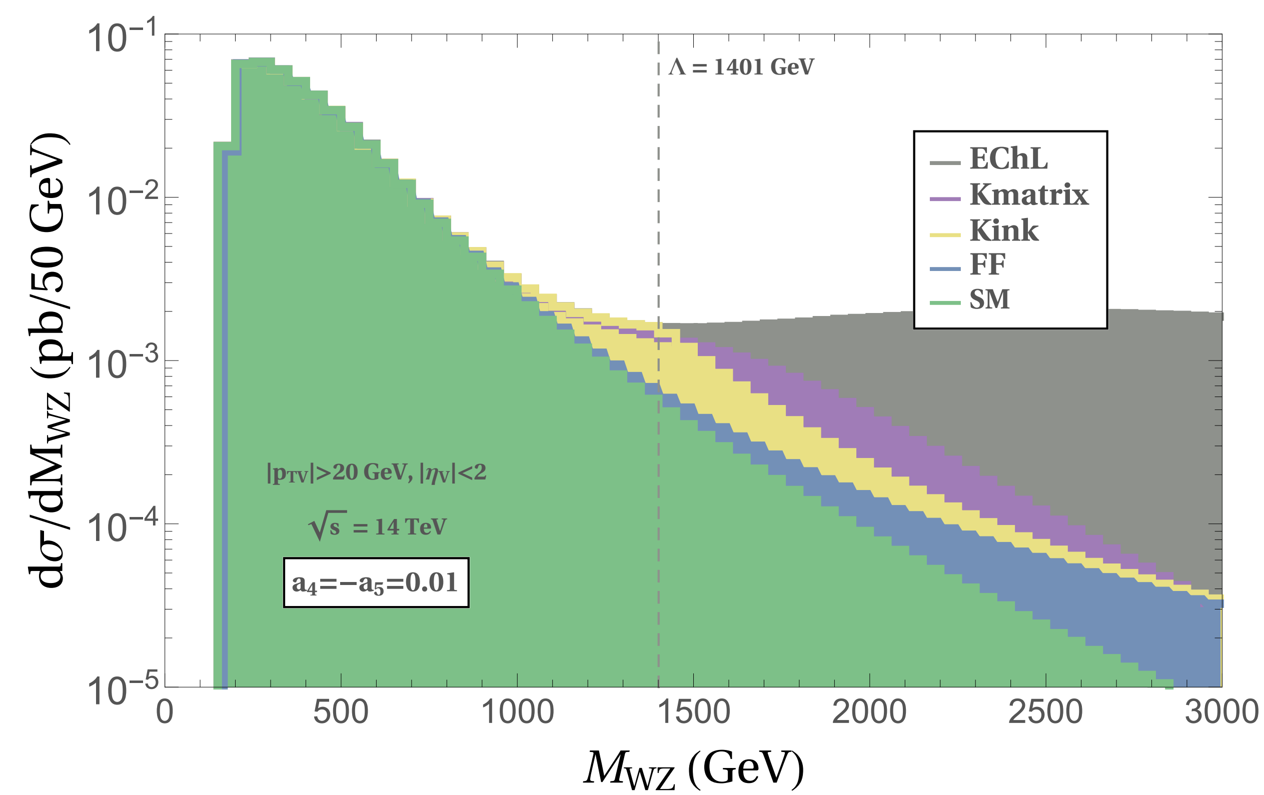
Other searches: Cut off used

How much can we rely on these constraints?

Different Unitarizations at LHC

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



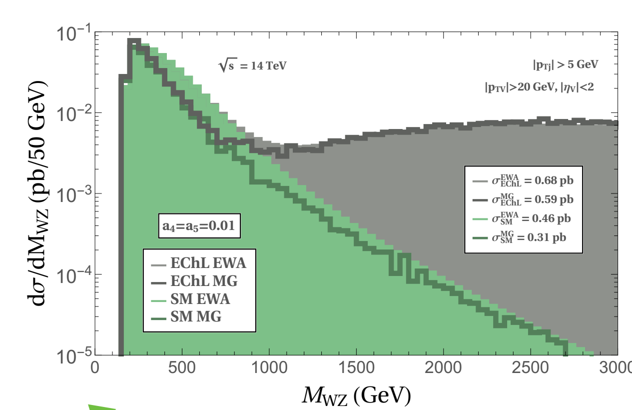


Very **different results** depending on unitarization method at the **LHC**!!

[S. Dawson, Nucl. Phys. B 249 (1985) 42]

* The Effective W Approximation (EWA) treats the EW gauge bosons as partons inside the proton

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



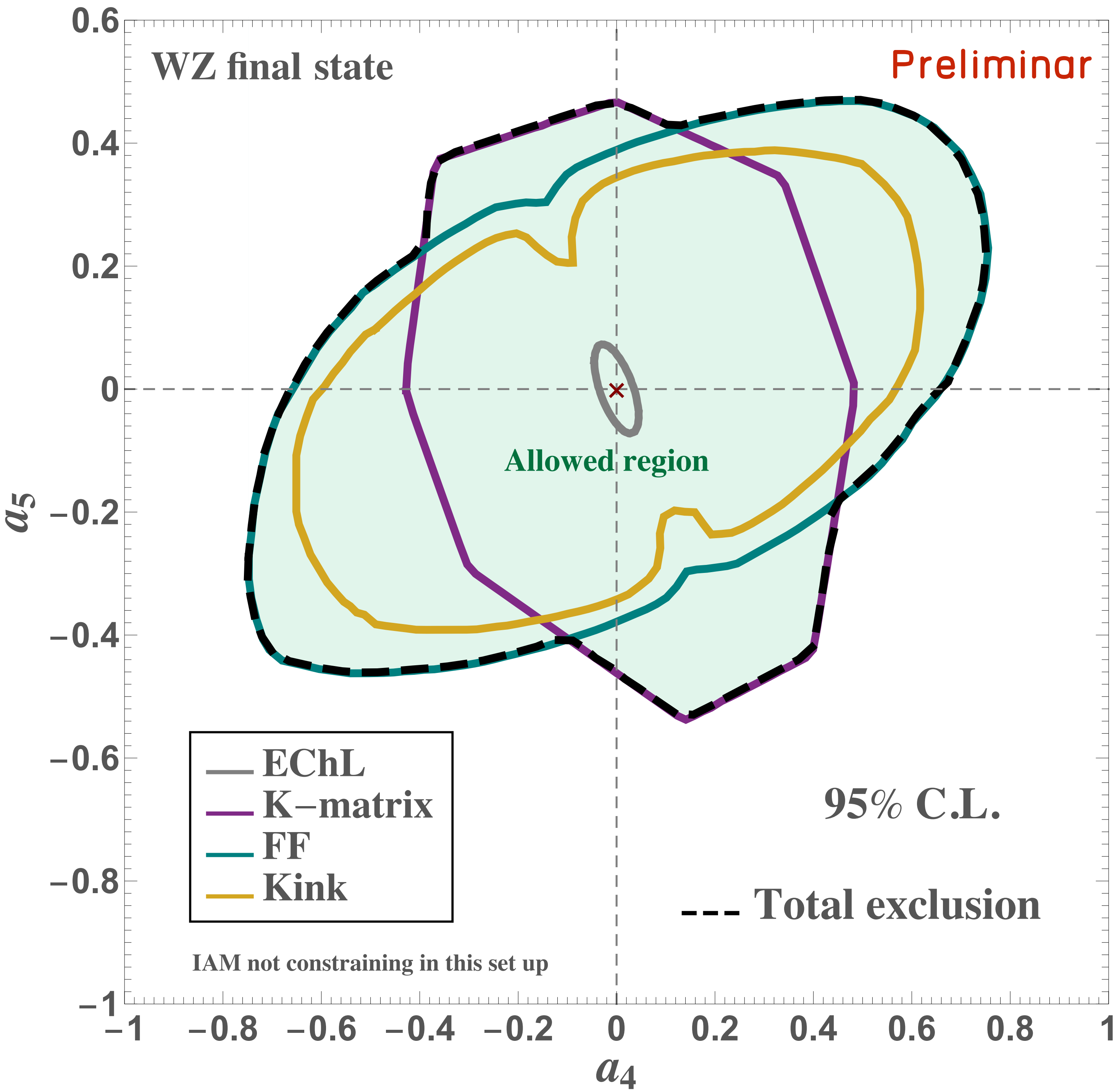
Parameter uncertainty

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

From that we construct the 95 % C.L. exclusion [a_4,a_5] regions for the studied unitarization methods

Overlap corresponds to the uncertainty in a_4 and a_5 determination due to unitarizacion scheme choice!!!

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



Conclusions

- **New physics** in the EWSB sector will **show** dominantly in **VBS** and can be parametrized using **EFT's**

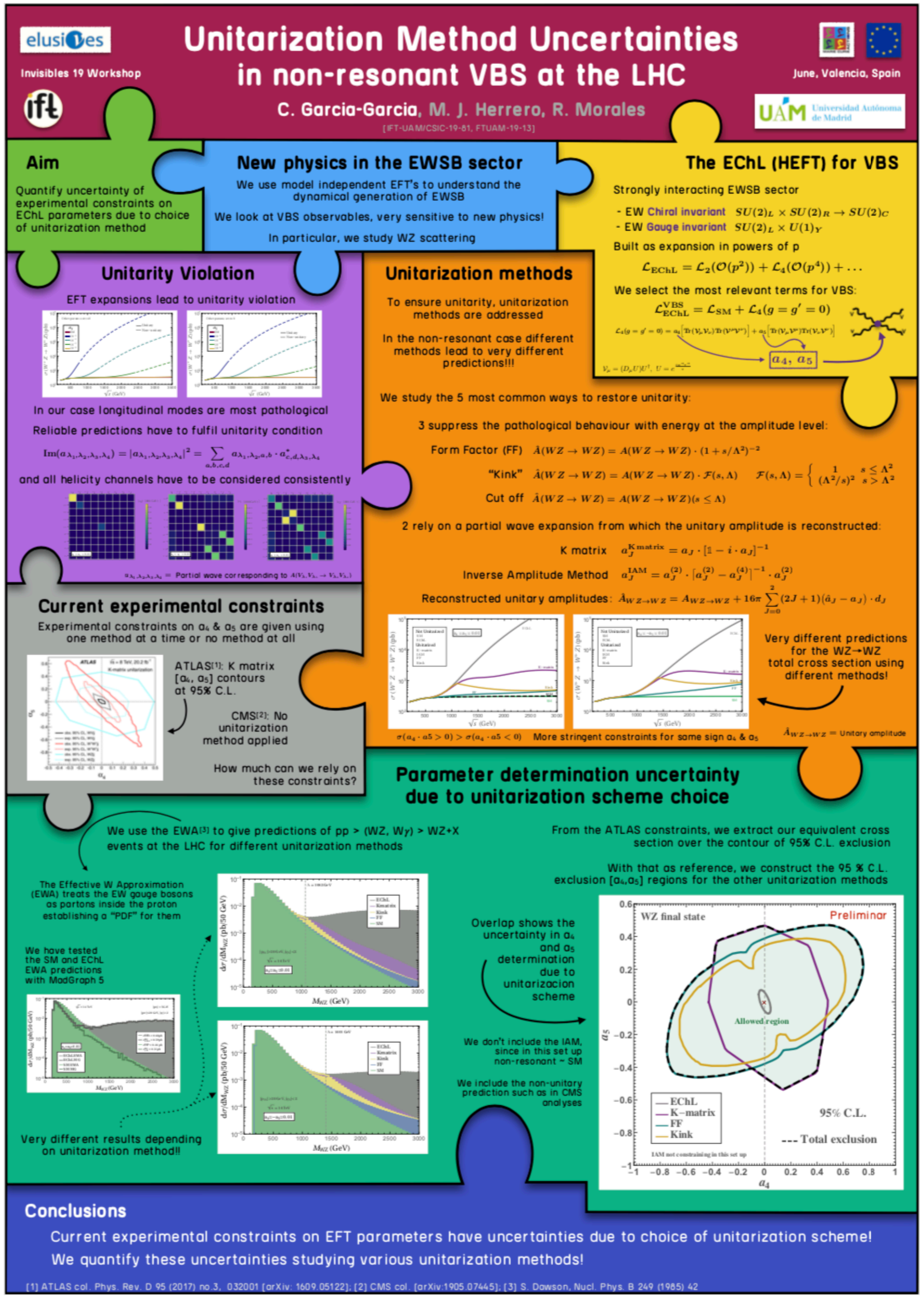
- **EFT expansion** lead to **unitarity violation** problems

- To give **reliable predictions unitarization** methods are addressed

- **Different methods** lead to very **different predictions** in **VBS** observables at the **LHC**

- We **quantify** the **uncertainty** in the **experimental determination** of the most relevant **EFT parameters** for VBS **due to** the **unitarization** scheme **choice**!

Poster!!!



If you want to know more…

We can discuss with a coffee/beer in the **poster session!!!!!**

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THANK YOU!