VBS prospects in SMEFT at a future muon collider

Luca Mantani

UCLouvain

Different mode of production at different energies

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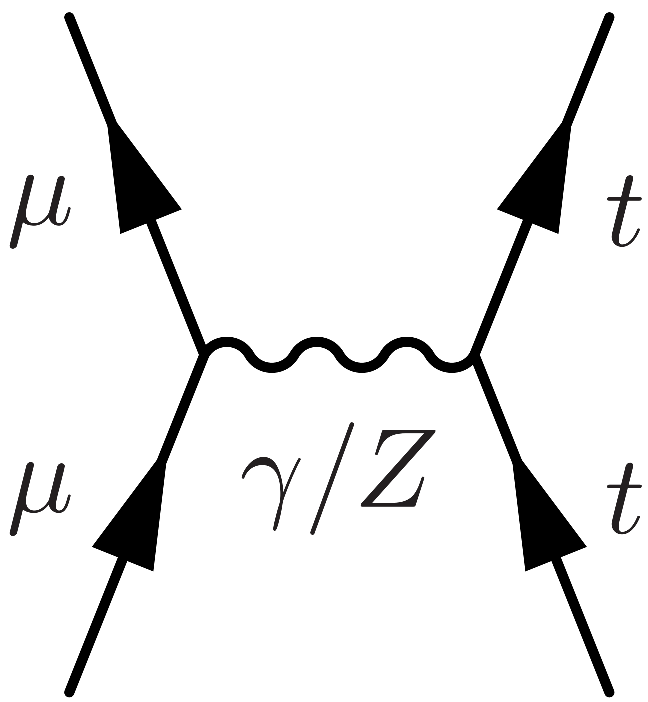
$$\sqrt{s} \lesssim 1\text{-}5\ \text{TeV}$$



s-channel

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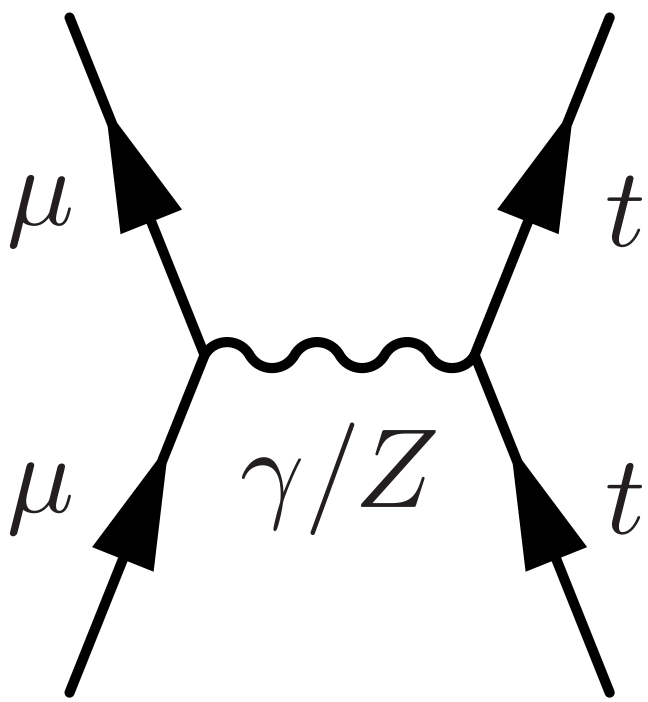

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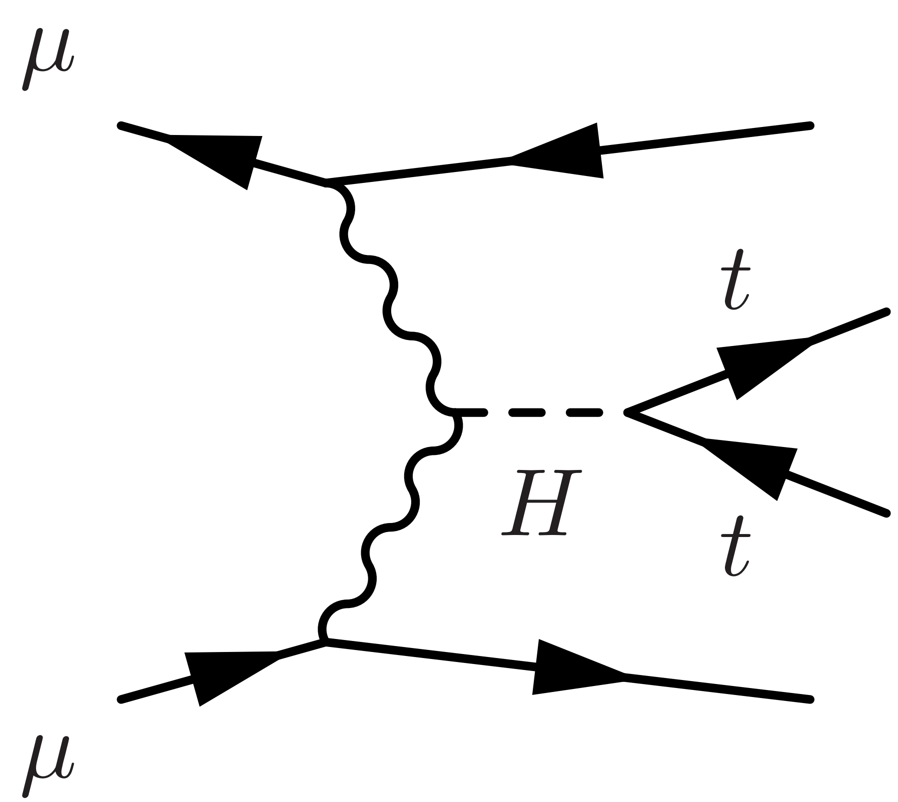
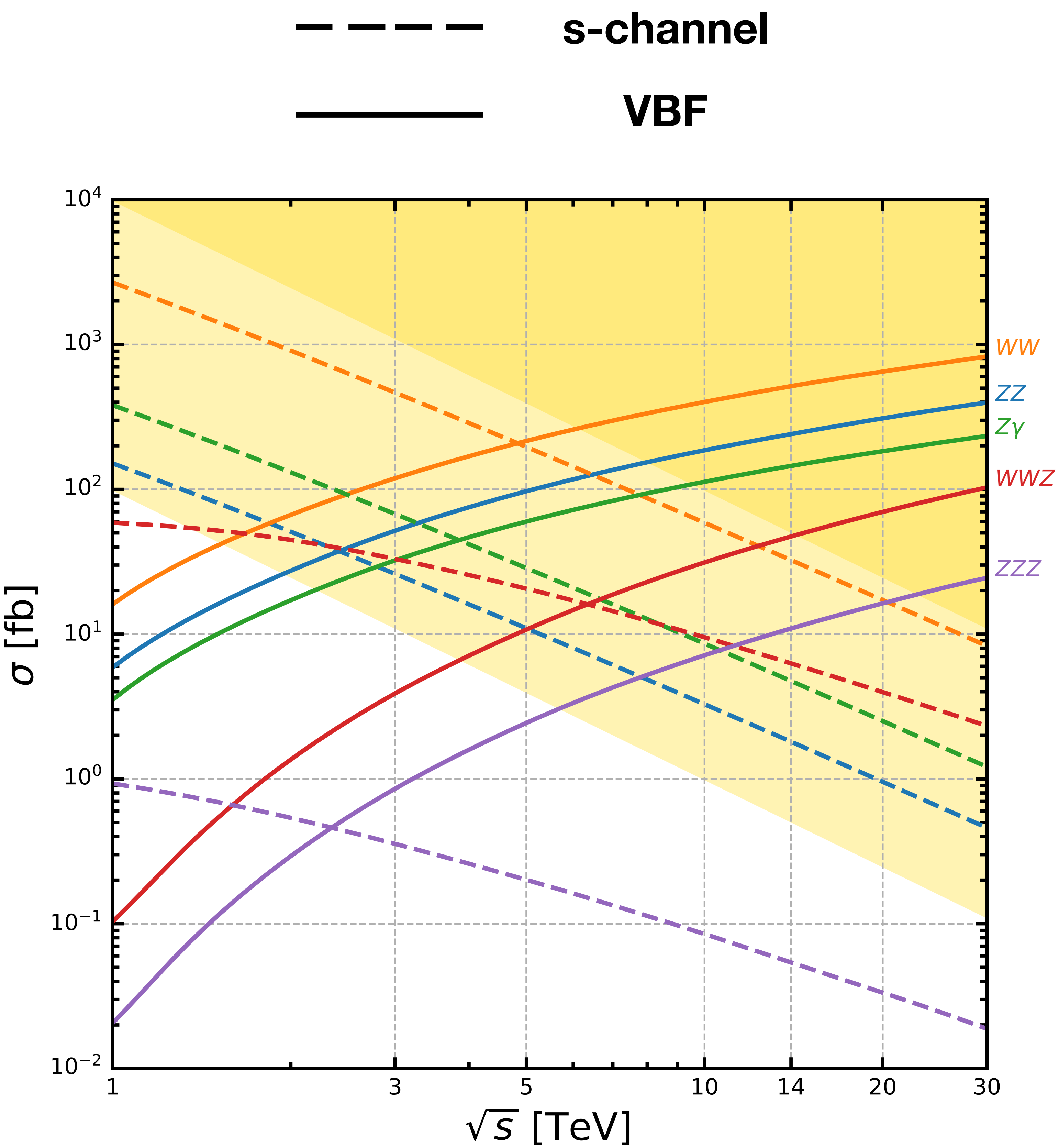
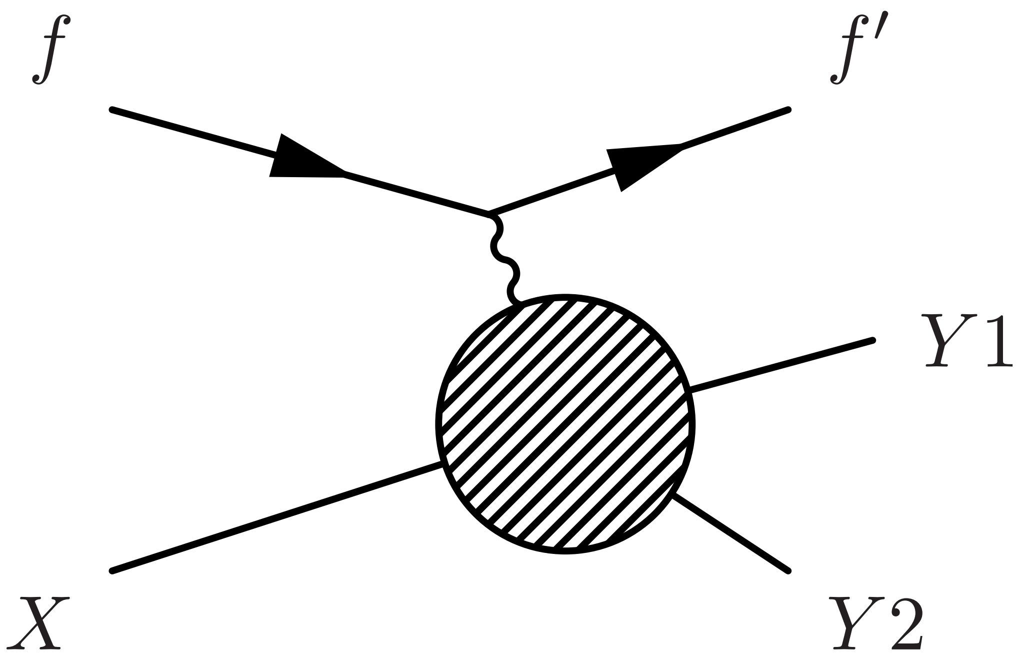


VBF


s-channel
VBF
10^4
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
σ [fb]
1
3
5
10
14
20
30
$\sqrt{s}$ [TeV]
WW
ZZ
Zγ
WWZ
ZZZ

We can have an analytical insight with EWA



$$E \sim xE \sim (1-x)E, \qquad \frac{m}{E} \ll 1, \qquad \frac{p_\perp}{E} \ll 1$$

$$f_+ = \frac{(1-x)^2}{x} \frac{p_\perp^3}{(m^2(1-x)+p_\perp^2)^2},$$

$$f_- = \frac{1}{x} \frac{p_\perp^3}{(m^2(1-x)+p_\perp^2)^2},$$

$$f_0 = \frac{(1-x)^2}{x} \frac{2m^2 p_\perp}{(m^2(1-x)+p_\perp^2)^2}.$$

[P. Borel et al. arXiv:1202.1904]

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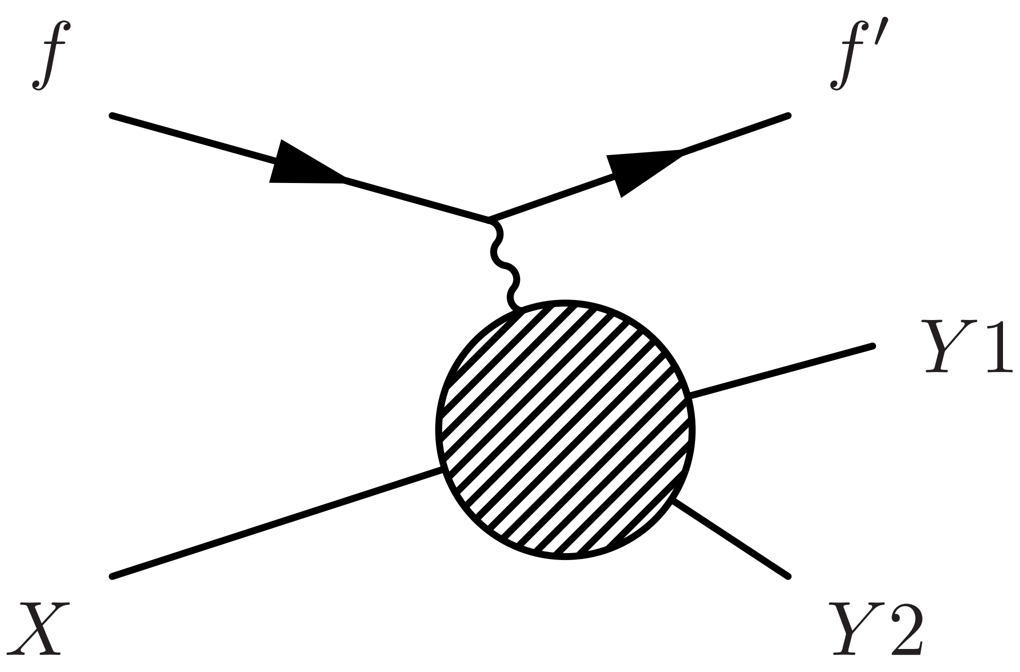

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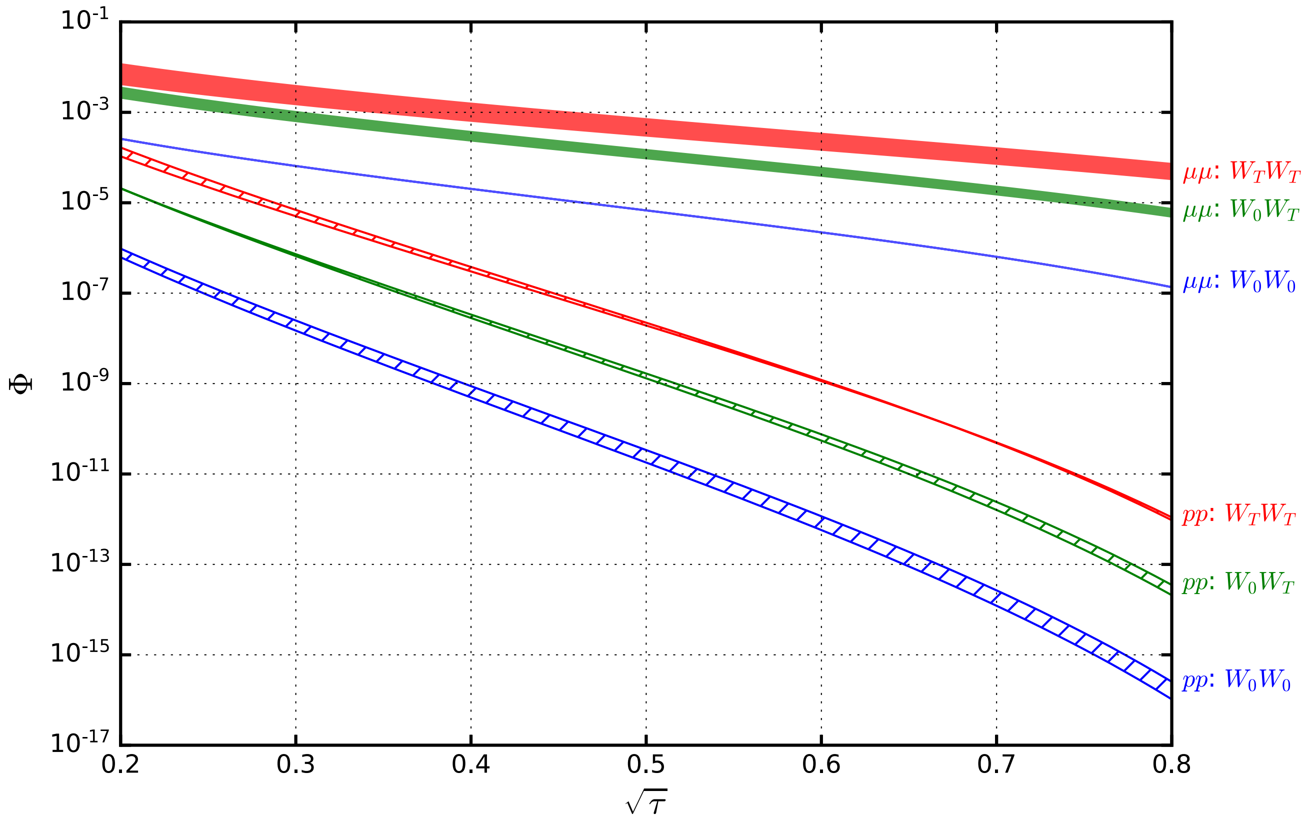
[P. Borel et al. arXiv:1202.1904]

$$\frac{d\sigma_{EWA}}{dx dp_\perp}(fX \to f'Y) = \frac{C^2}{2\pi^2} \sum_{i=+,-,0} f_i \times d\sigma(W_i X \to Y)$$

Weak bosons can be described as partons!

$$\Phi_{W^+_{\lambda_1} W^-_{\lambda_2}}(\tau, \mu_f) = \int_\tau^1 \frac{d\xi}{\xi}\, f_{W_{\lambda_1}/\mu}\left(\xi, \mu_f\right) f_{W_{\lambda_2}/\mu}\left(\frac{\tau}{\xi}, \mu_f\right)$$

Muon vs Proton



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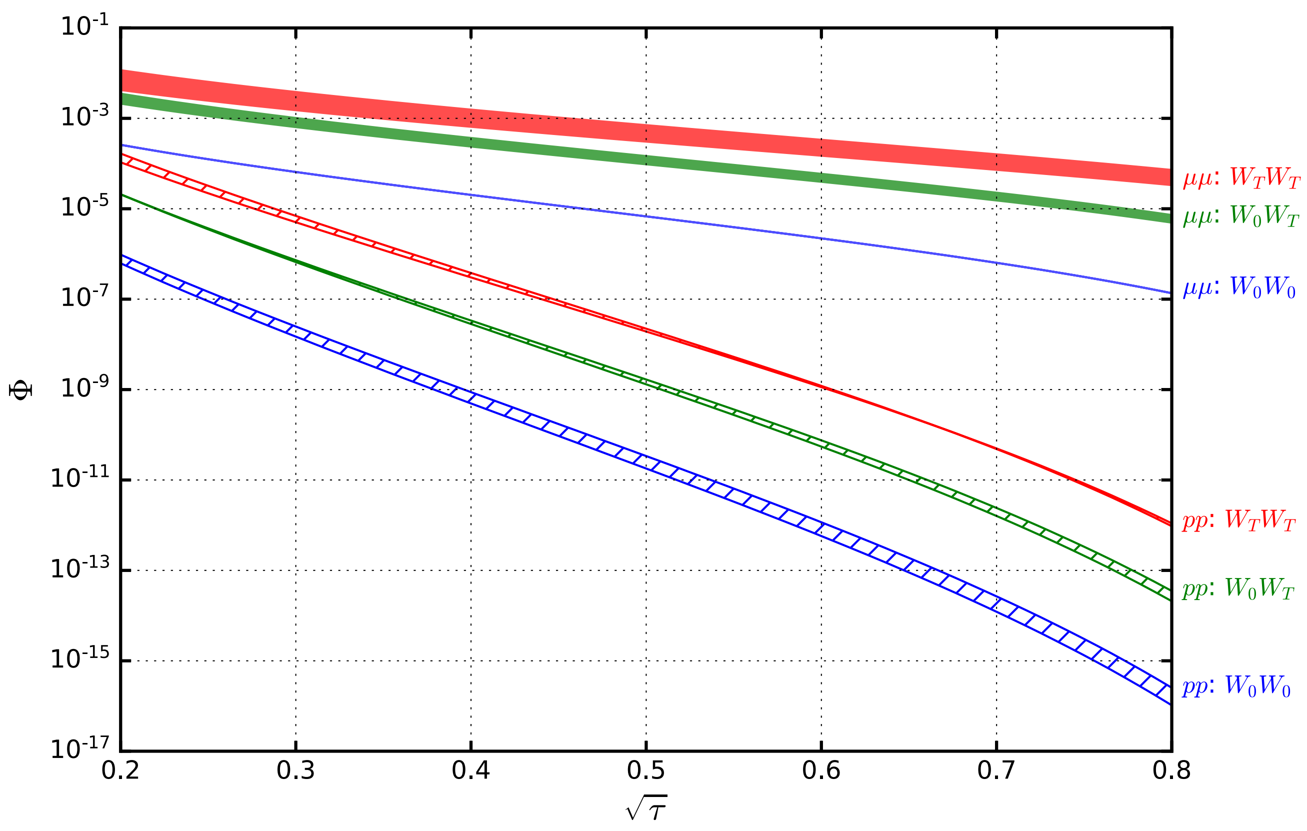
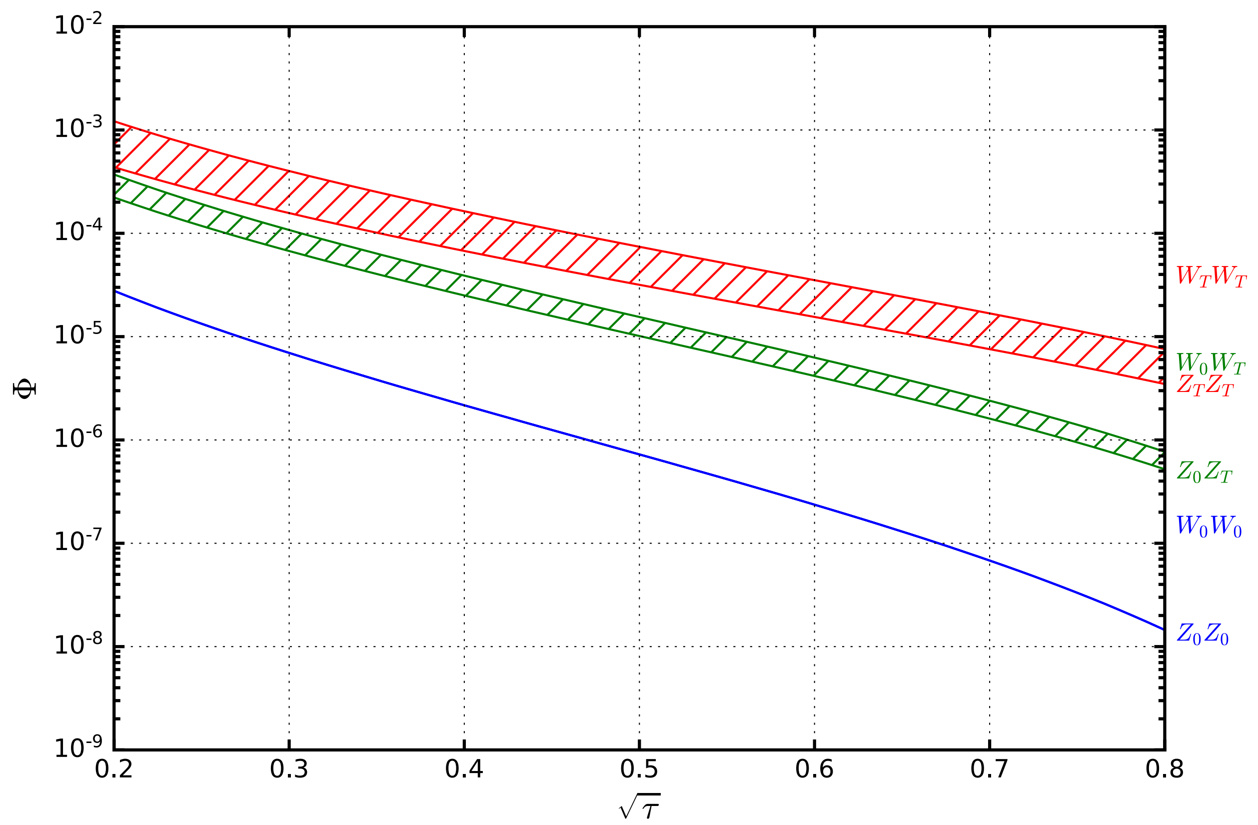
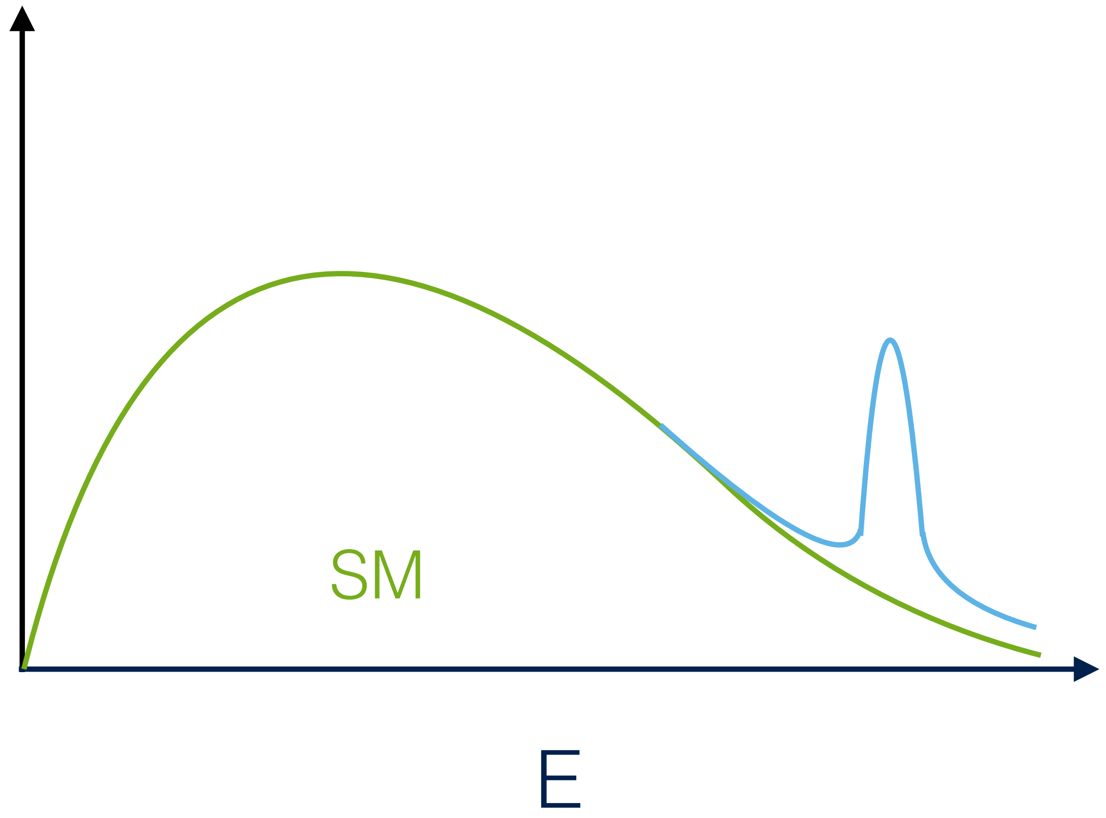


Muon: WW vs ZZ

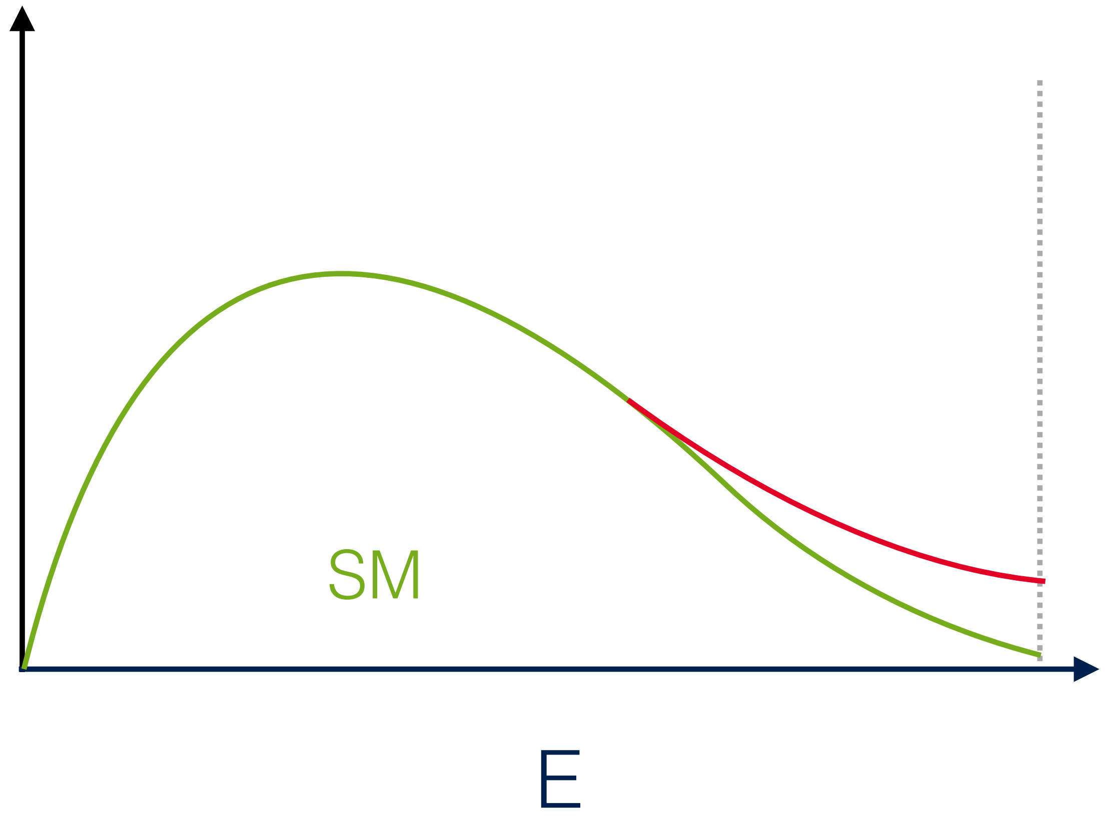


Direct search (Bumps)



Direct search (Bumps)

Indirect (scouting tails)



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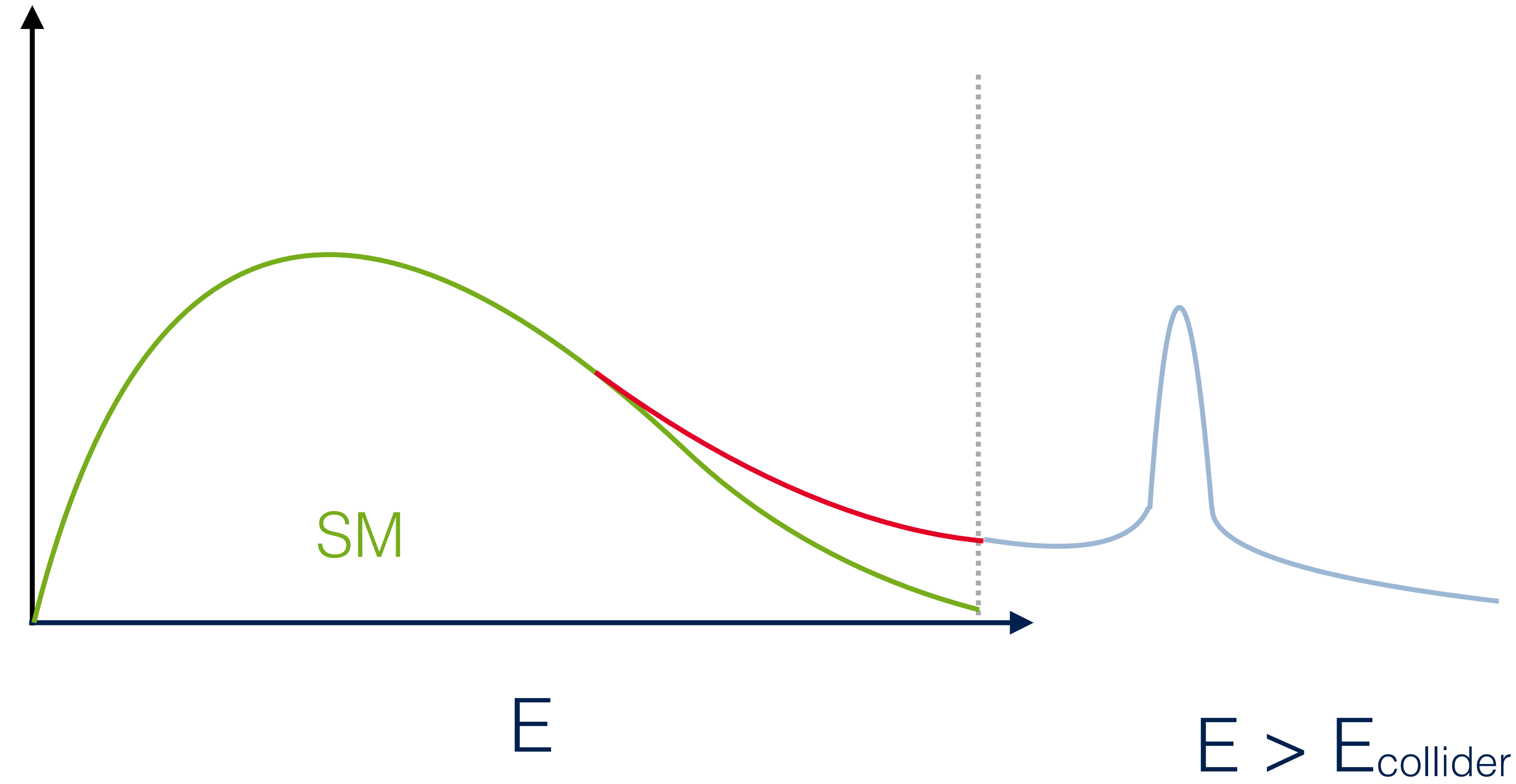
⇒ New physics is heavy



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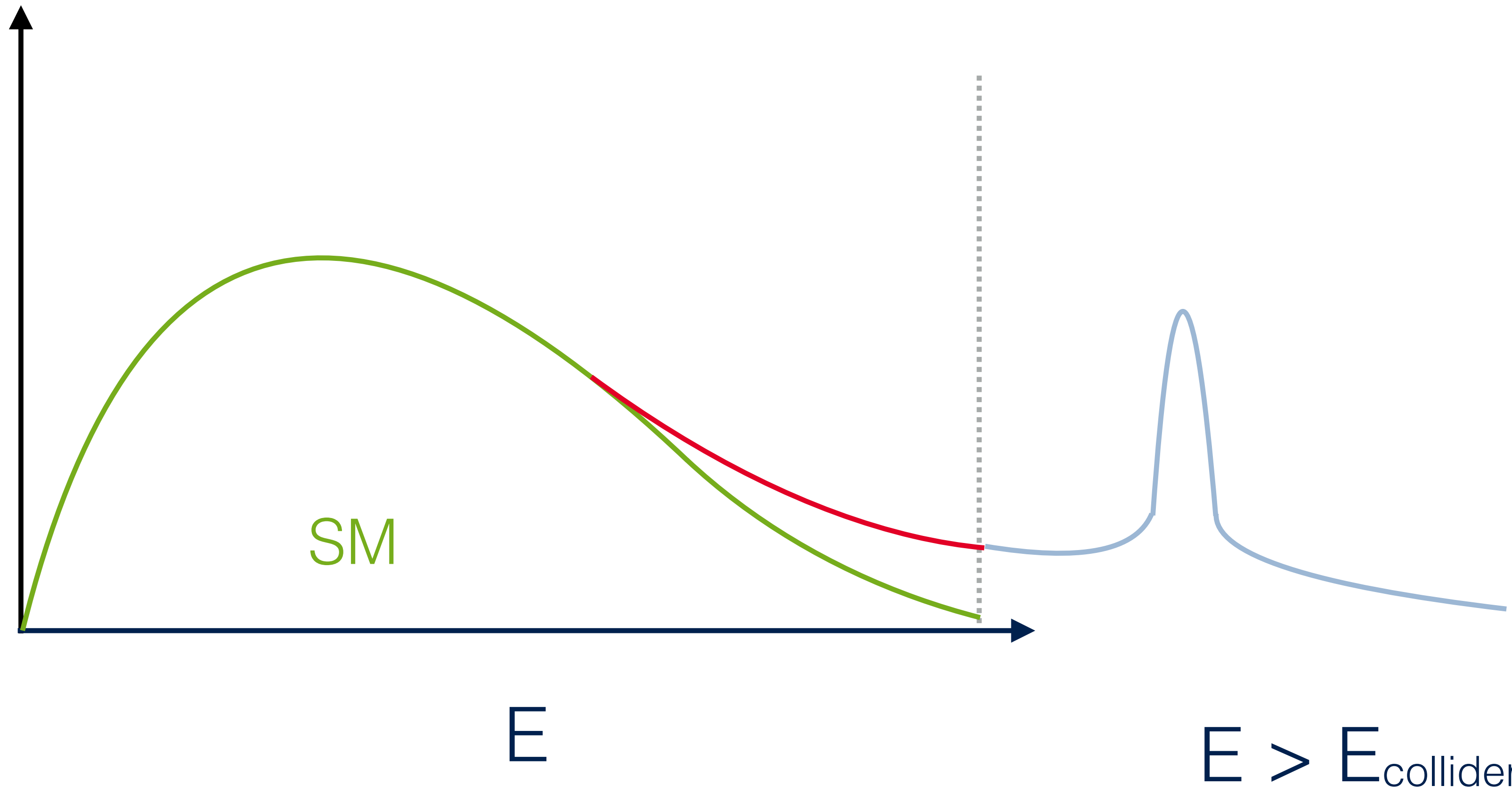

Important to assess the potential of a muon collider in indirect searches

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Indirect (scouting tails)

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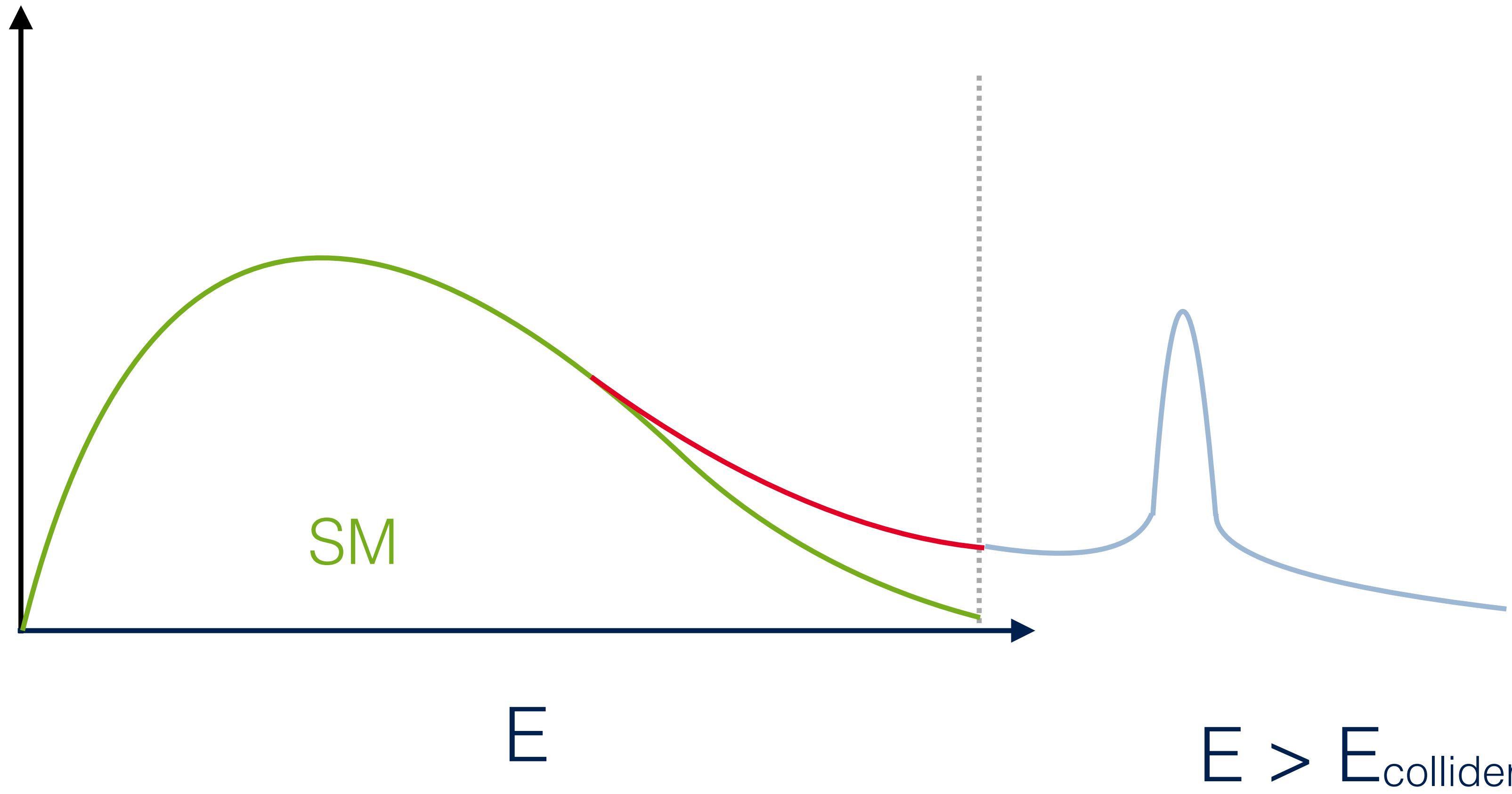

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New physics effects can lead to unitarity violation at high energy

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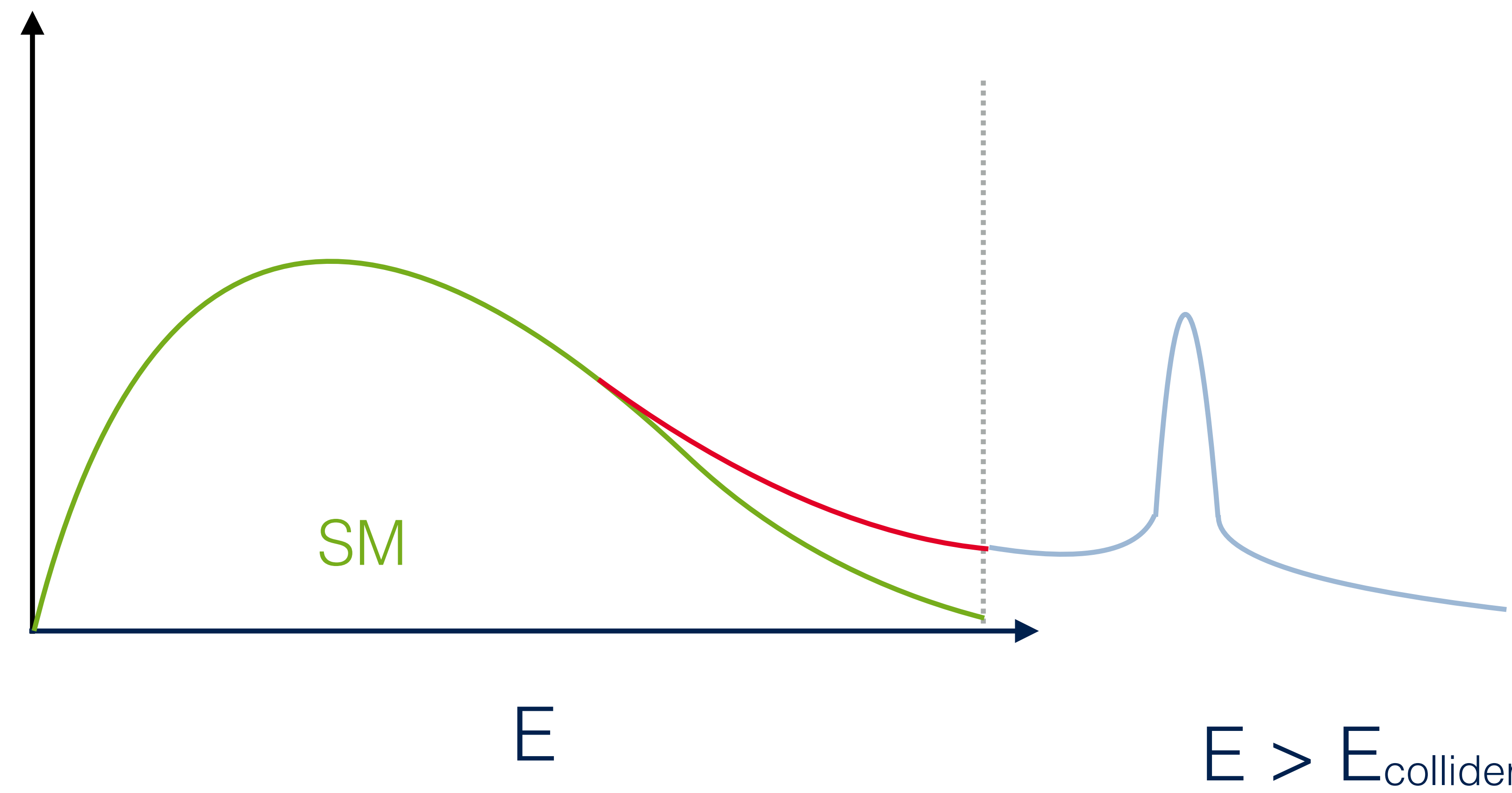


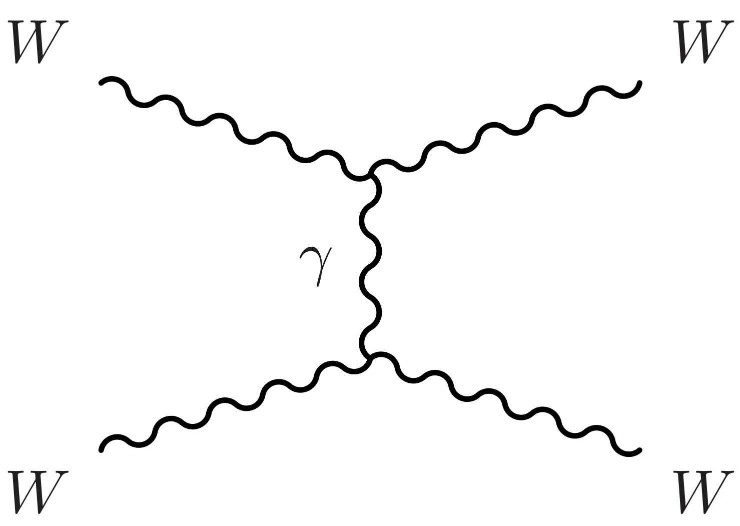
Important to assess the potential of a muon collider in indirect searches

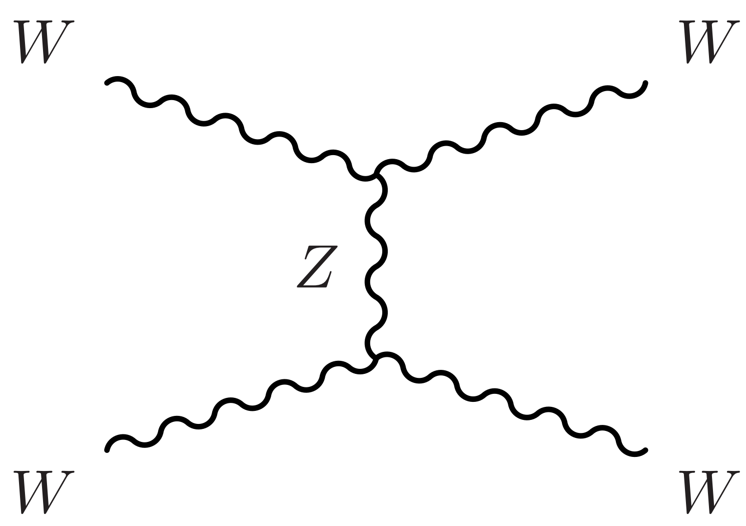
New physics effects can lead to unitarity violation at high energy

High energy tails → **Less statistics, more sensitivity**

The most well-known example is longitudinal W-boson scattering

$$W_L W_L \to W_L W_L$$





$$\propto E^4$$

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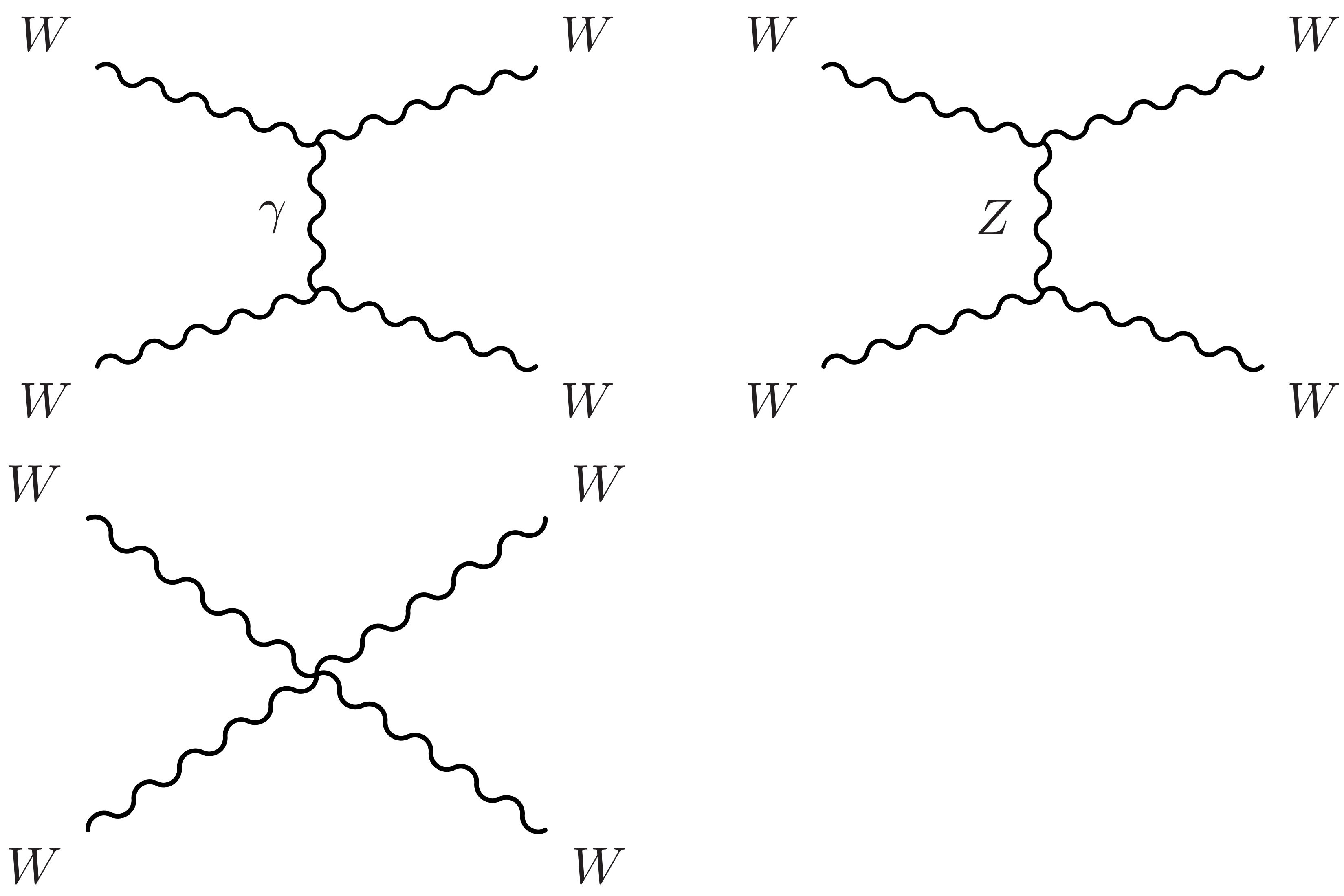

$$\propto E^2$$

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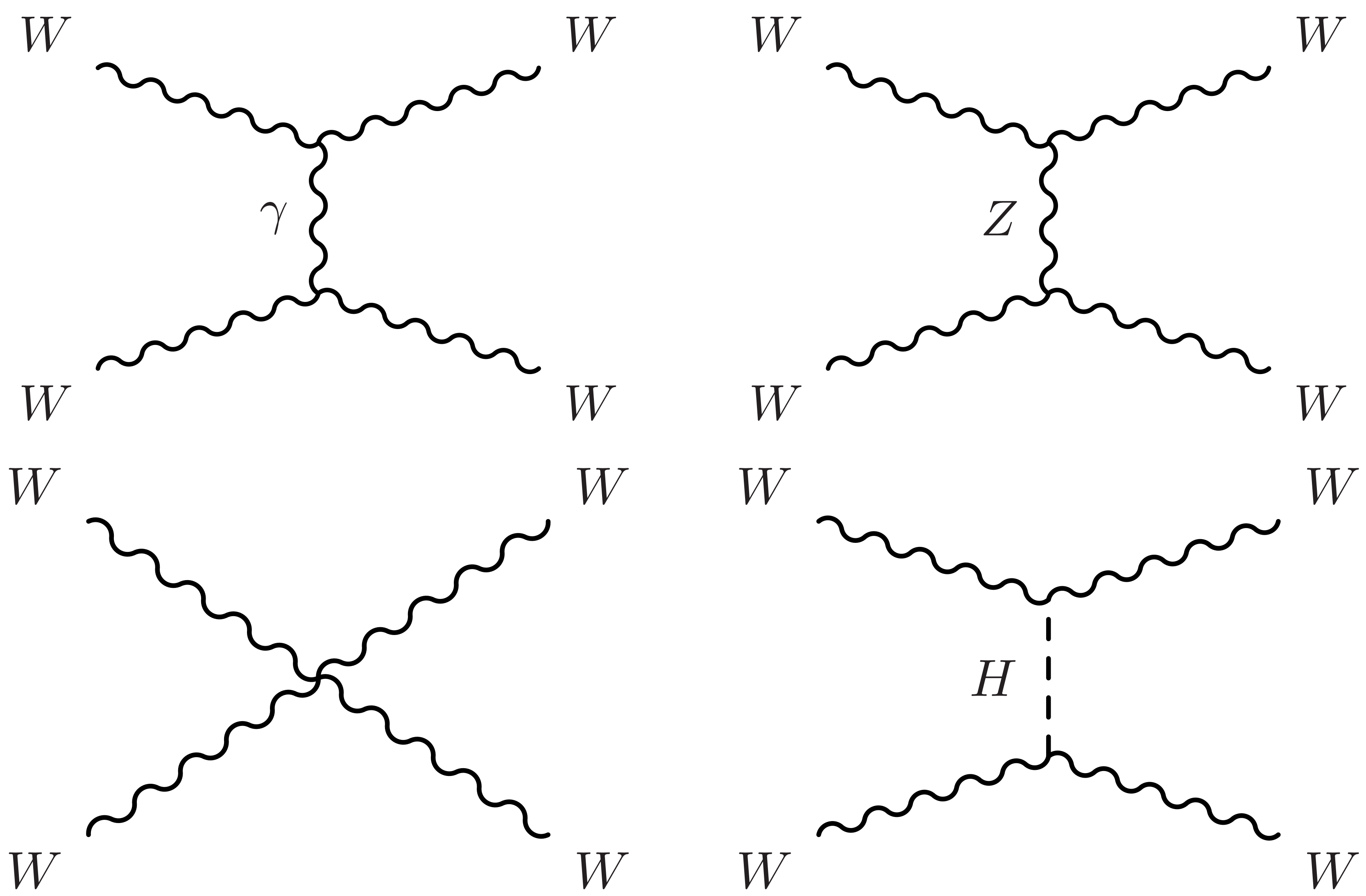

$$\propto E^0$$

$$\mathcal{L} = \mathcal{L}_{SM} + \sum_i \frac{1}{\Lambda}\mathcal{O}_i^5 + \sum_i \frac{1}{\Lambda^2}\mathcal{O}_i^6 + \ldots$$

- **Higher dimensional operators preserve SM symmetries.**
- **Mappable to a large class of BSM models.**
- **Lambda is scale of NP, allows us to truncated the series.**

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Dim 6 operators introduce energy growing effects

$$\mathcal{M} \sim \mathcal{M}_{SM}\left(1 + C_i\frac{v^2}{\Lambda^2} + C_j\frac{vE}{\Lambda^2} + C_k\frac{E^2}{\Lambda^2}\right) \qquad E < \Lambda$$

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Sensitivity linear

Sensitivity quadratic

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Significant challenges: signal to background ratio not good.
Diboson production dominates.

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Caveat: SMEFT should be treated globally.
Currently no global analysis including VBS exists.

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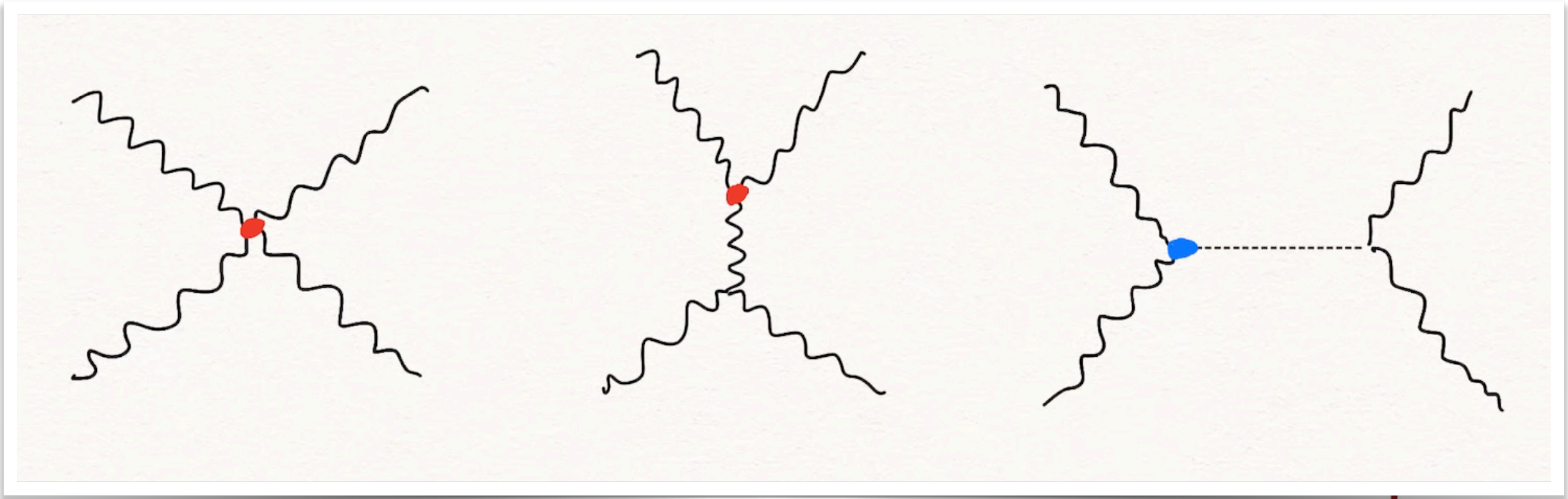
@Muon **Reversed situation: diboson production is negligible at HE**

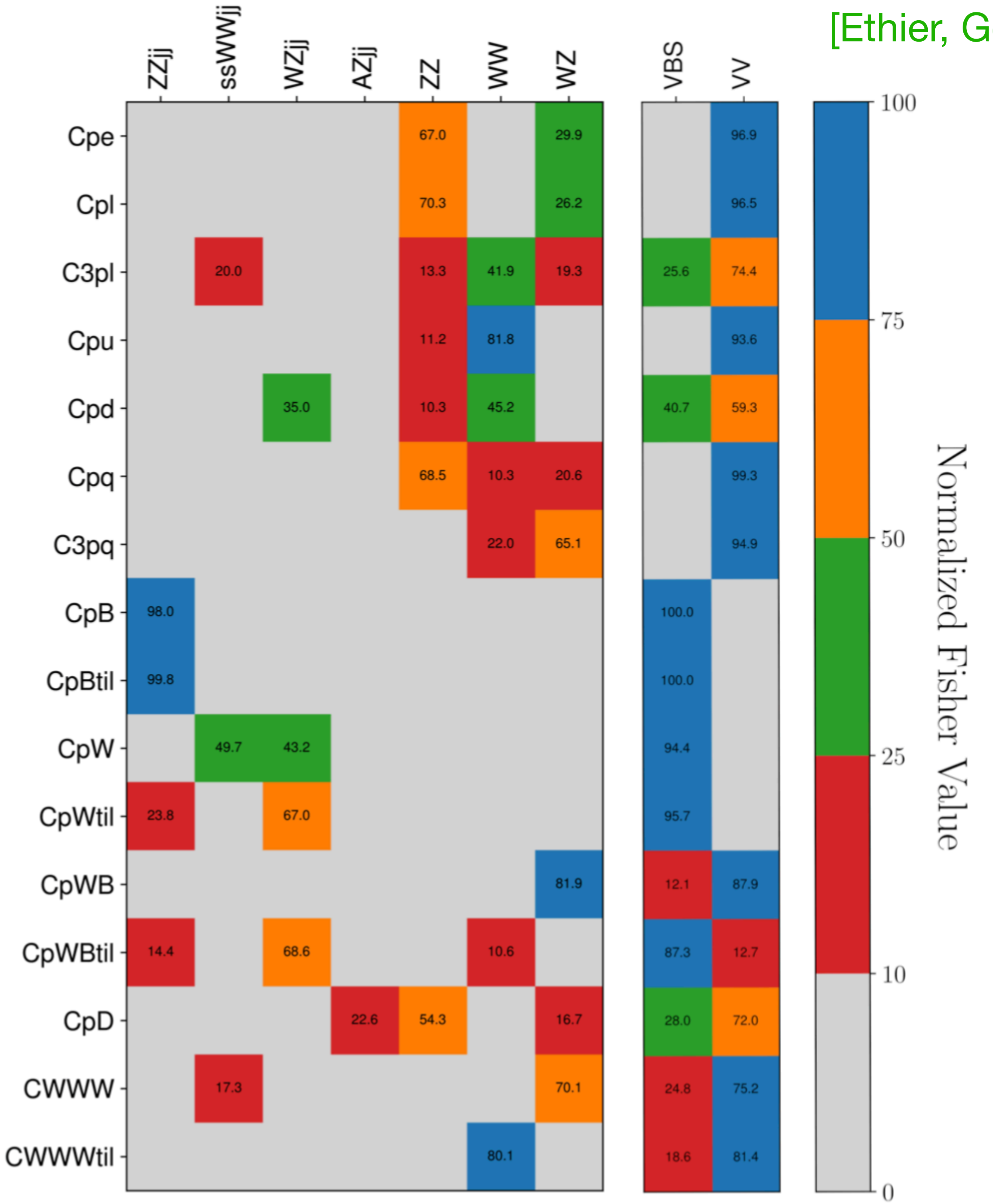
Caveat: SMEFT should be treated globally.
Currently no global analysis including VBS exists.

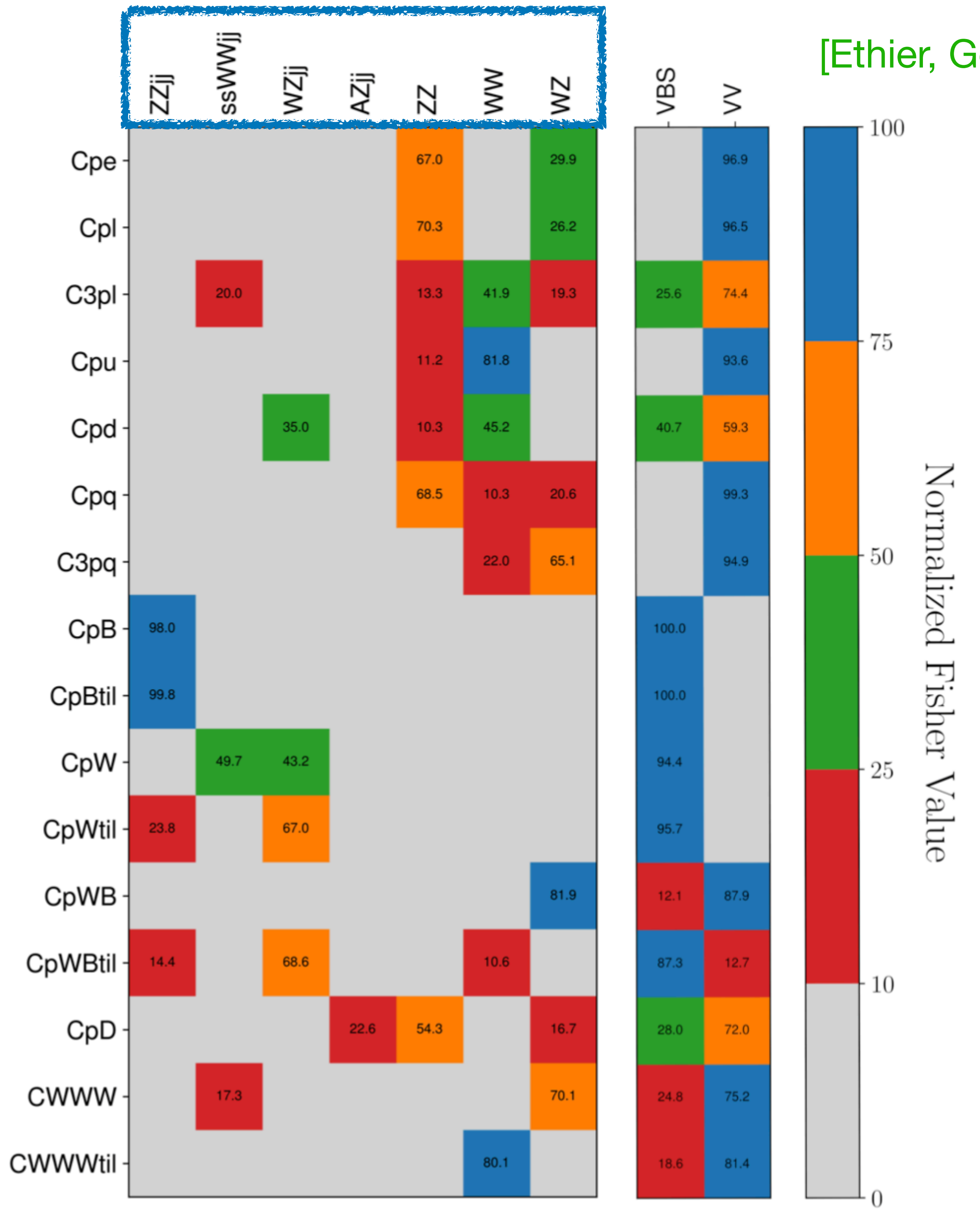
Simplified analysis can nonetheless bring useful information and help in understanding the underlying phenomenology.

Operator	Coefficient	Definition
$\mathcal{O}_W$	c_W	$\epsilon^{IJK} W_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}$
$\mathcal{O}_{\varphi W}$	$c_{\varphi W}$	$(\varphi^\dagger \varphi - \frac{v^2}{2}) W_{\mu\nu}^I W^{I\mu\nu}$
$\mathcal{O}_{\varphi B}$	$c_{\varphi B}$	$(\varphi^\dagger \varphi - \frac{v^2}{2}) B_{\mu\nu} B^{\mu\nu}$
$\mathcal{O}_{\varphi WB}$	$c_{\varphi WB}$	$\left(\varphi^\dagger \sigma_I \varphi\right) W_{\mu\nu}^I B^{\mu\nu}$
$\mathcal{O}_{\varphi D}$	$c_{\varphi D}$	$(\varphi^\dagger D^\mu \varphi)^* (\varphi^\dagger D_\mu \varphi)$



[Ethier, Gomez-Ambrosio, Magni, Rojo arXiv:2101.03180]





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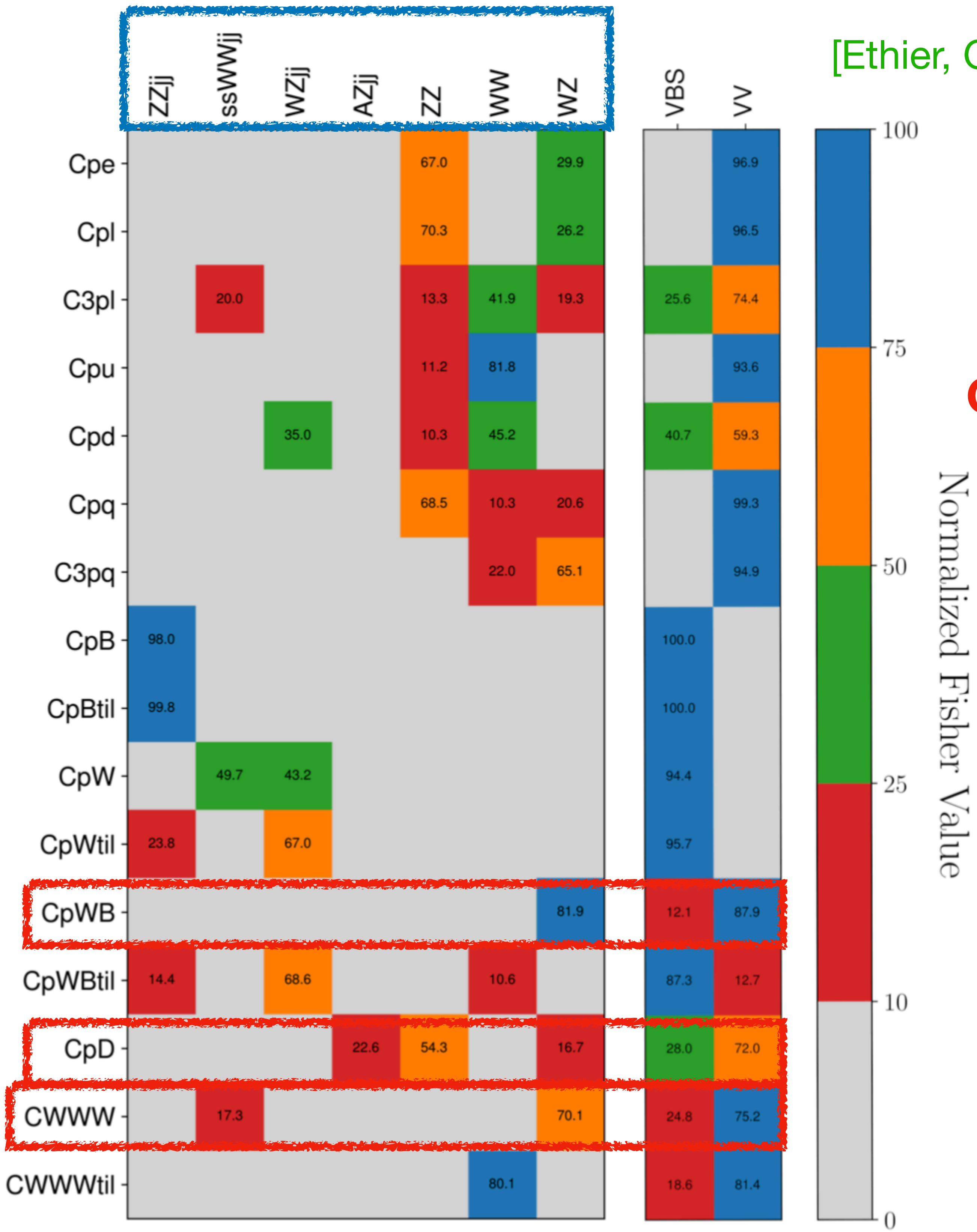
Processes included in the fit



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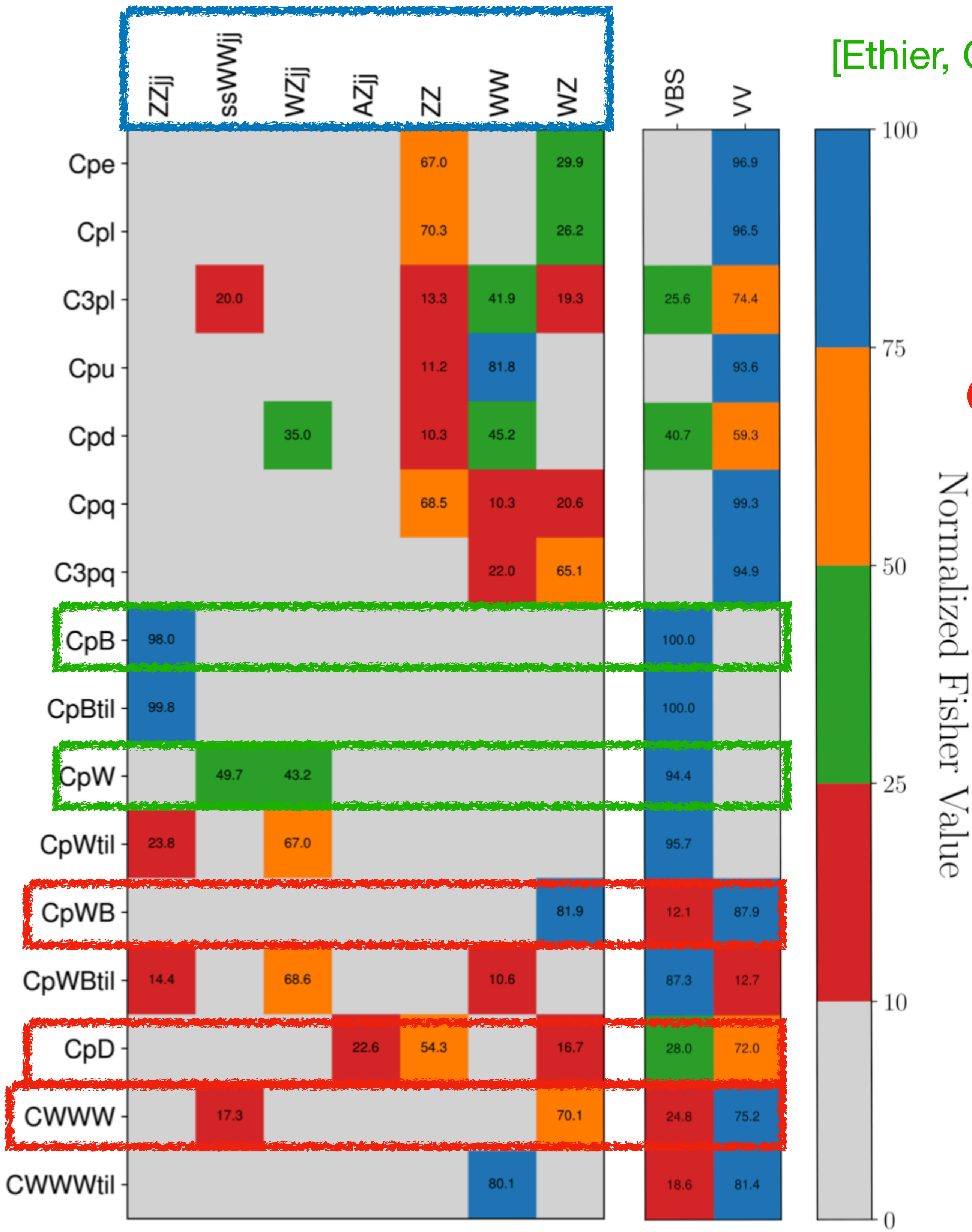
More information in diboson.
CpD and CpWB also constrained by EWPO



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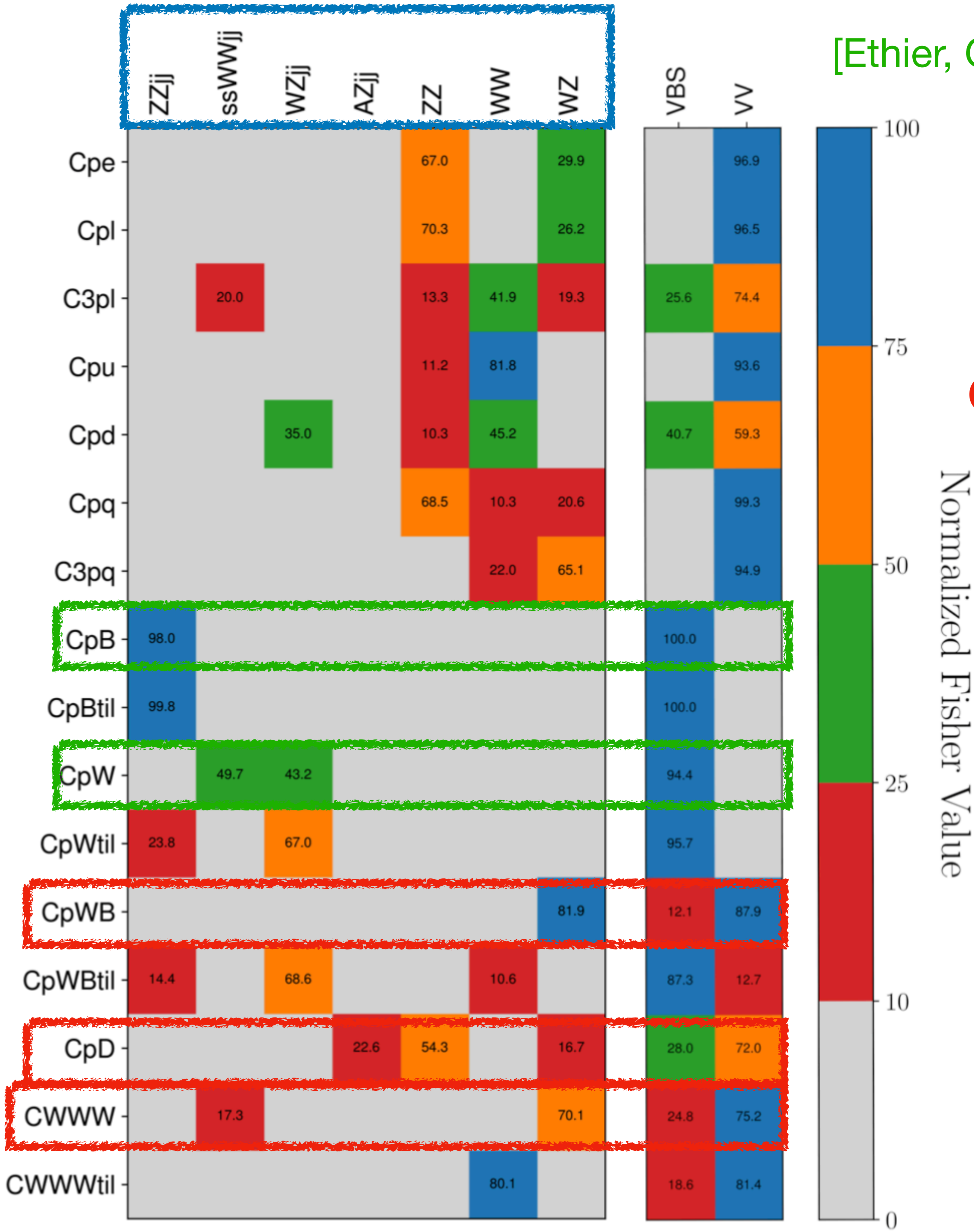

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Processes included in the fit

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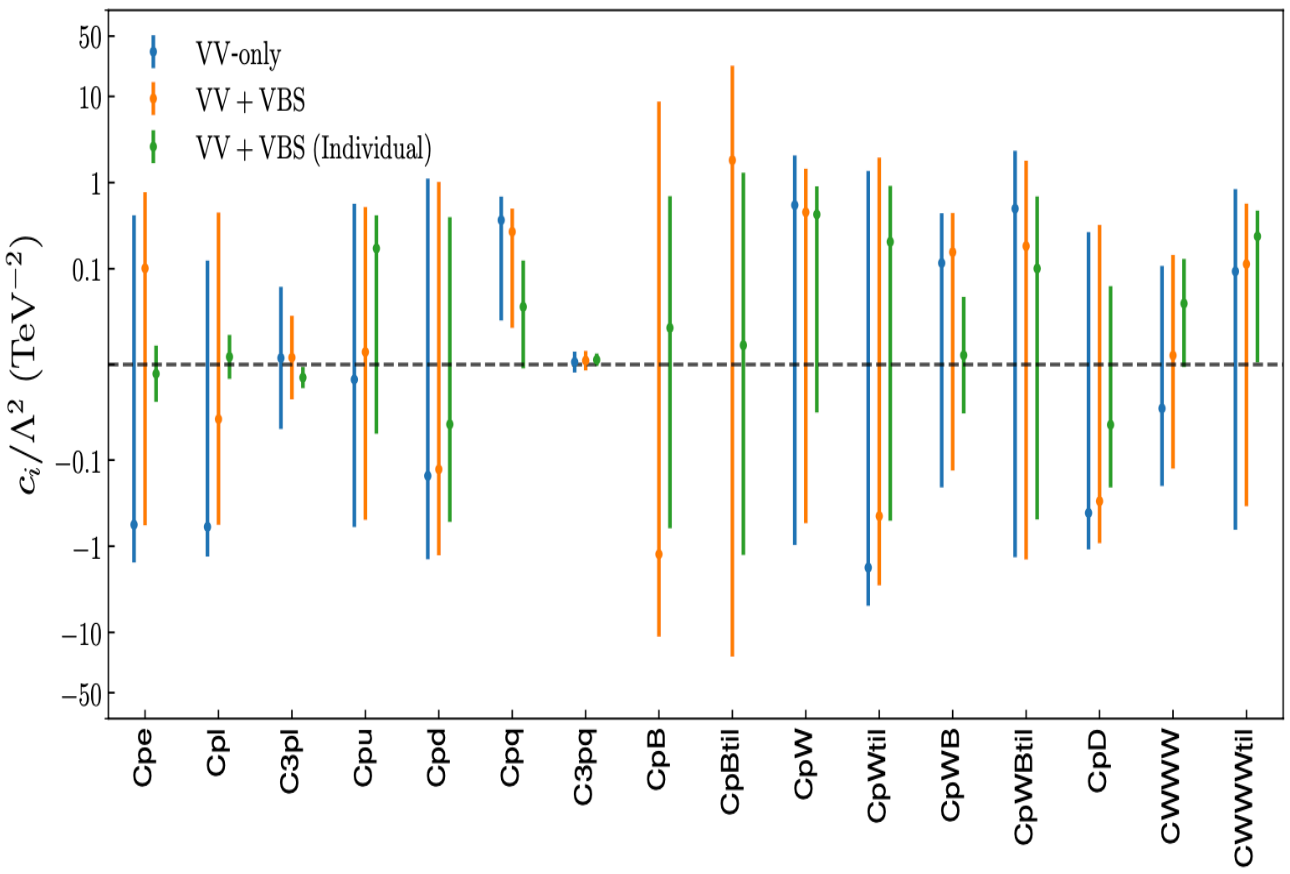
Basically unconstrained by diboson.
This is where VBS brings useful info.

All the 2F operators included in this broad analysis are better constrained by other processes.

[Ethier, Gomez-Ambrosio, Magni, Rojo arXiv:2101.03180] **Talk by Raquel for more details**

Linear fit



$$C_{\varphi W} \sim [-0.55, 1.4]$$

$$C_{\varphi B} \sim [-11, 8.8]$$

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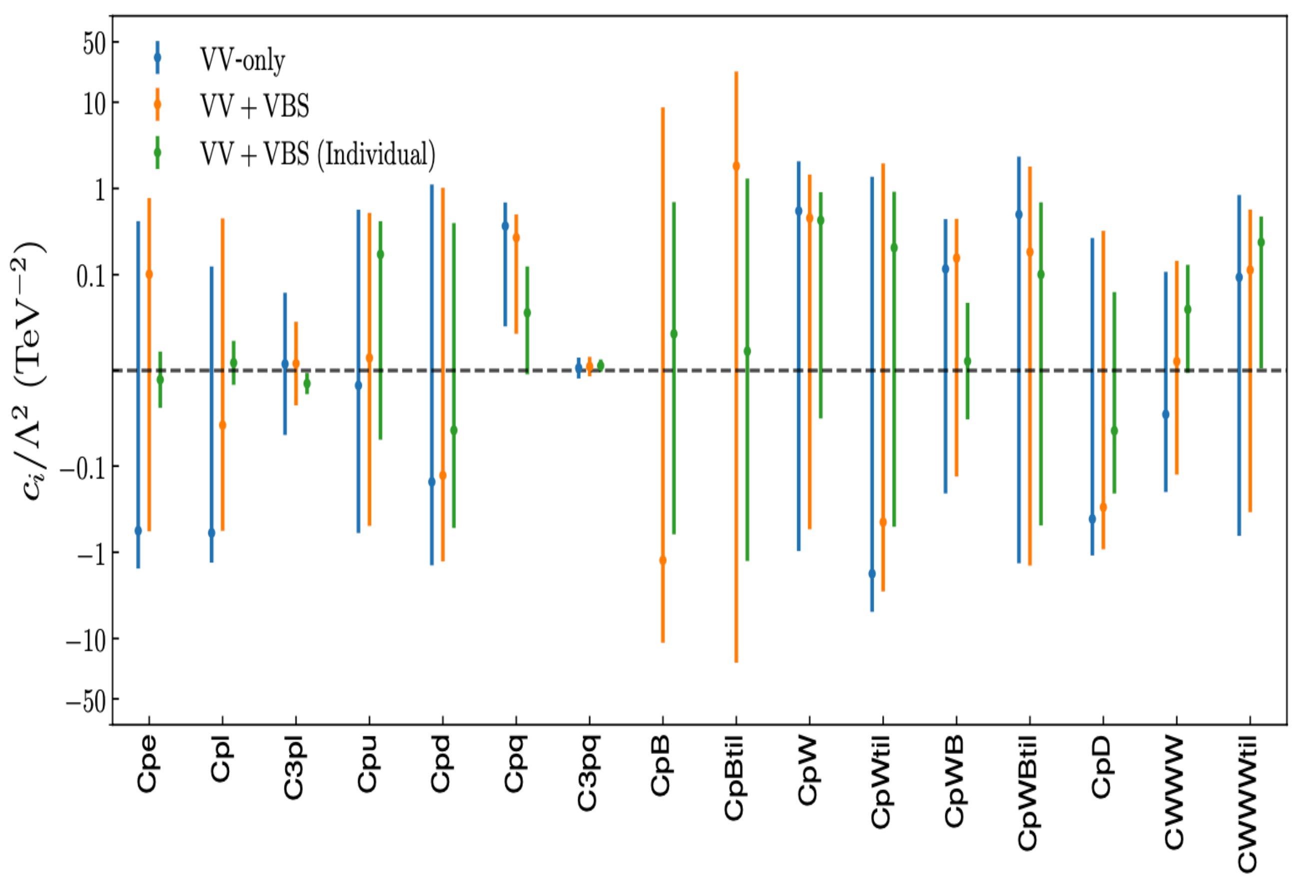

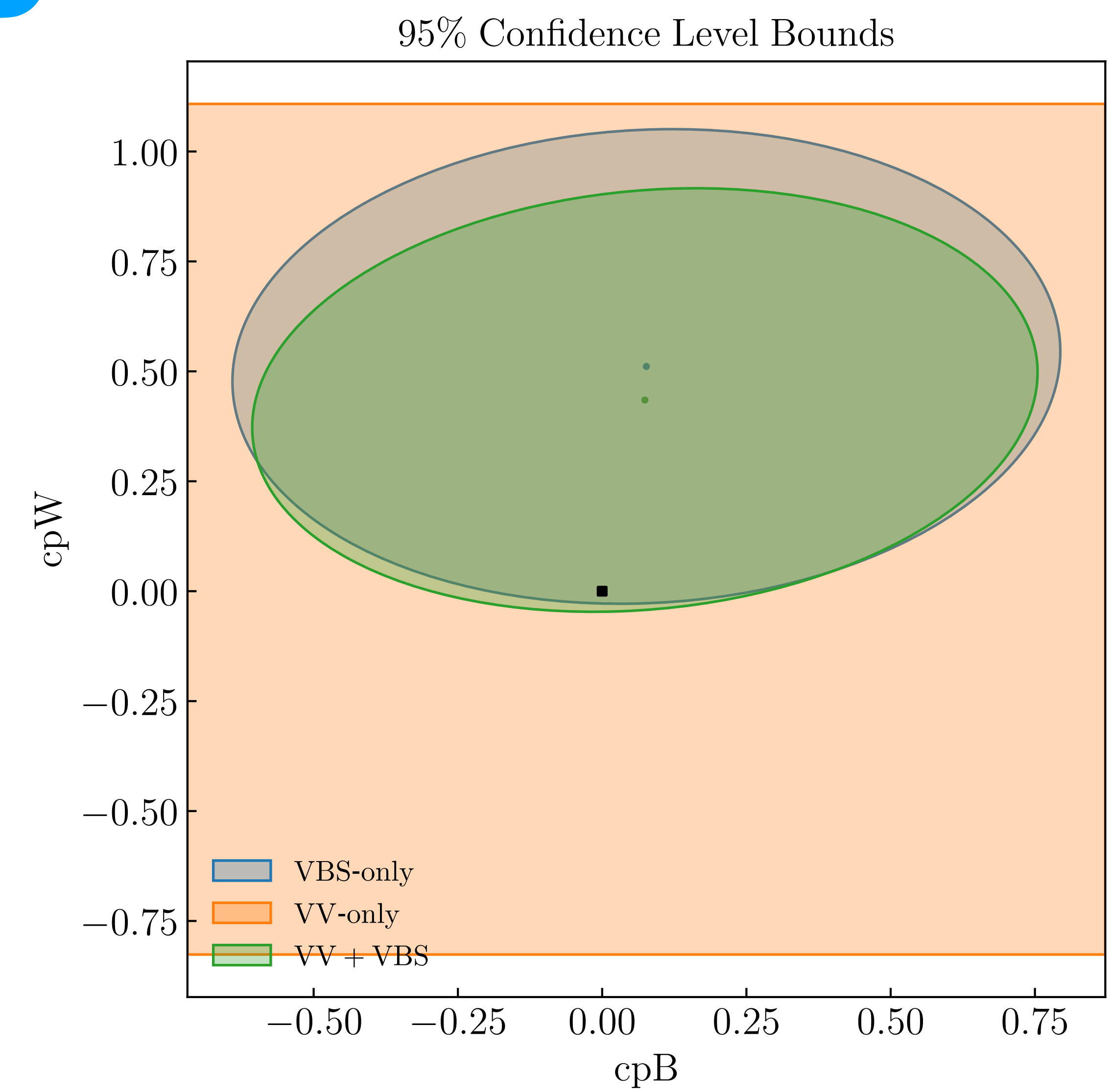

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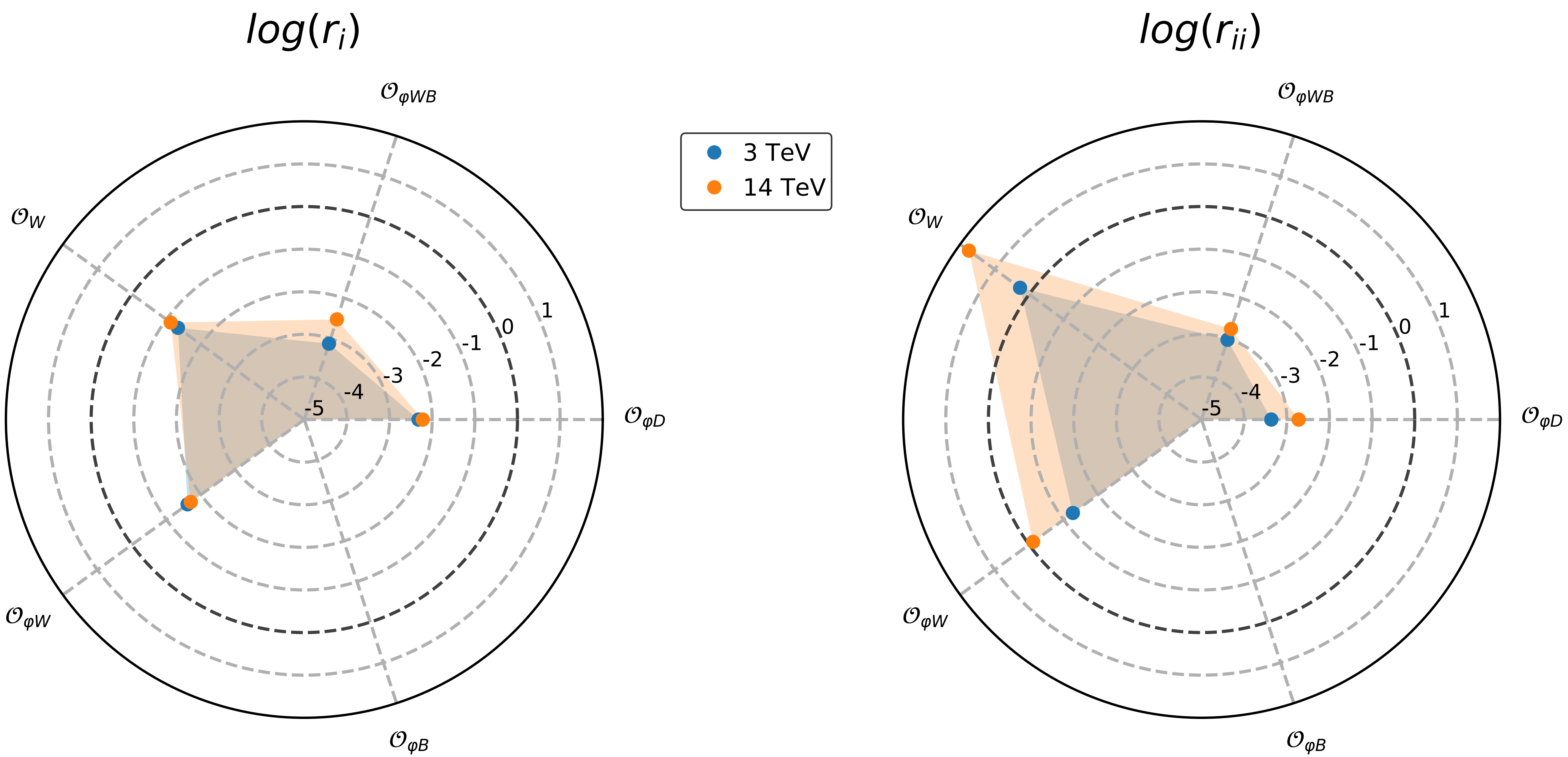
$$C_{\varphi W} \sim [-0.05, 0.92]$$

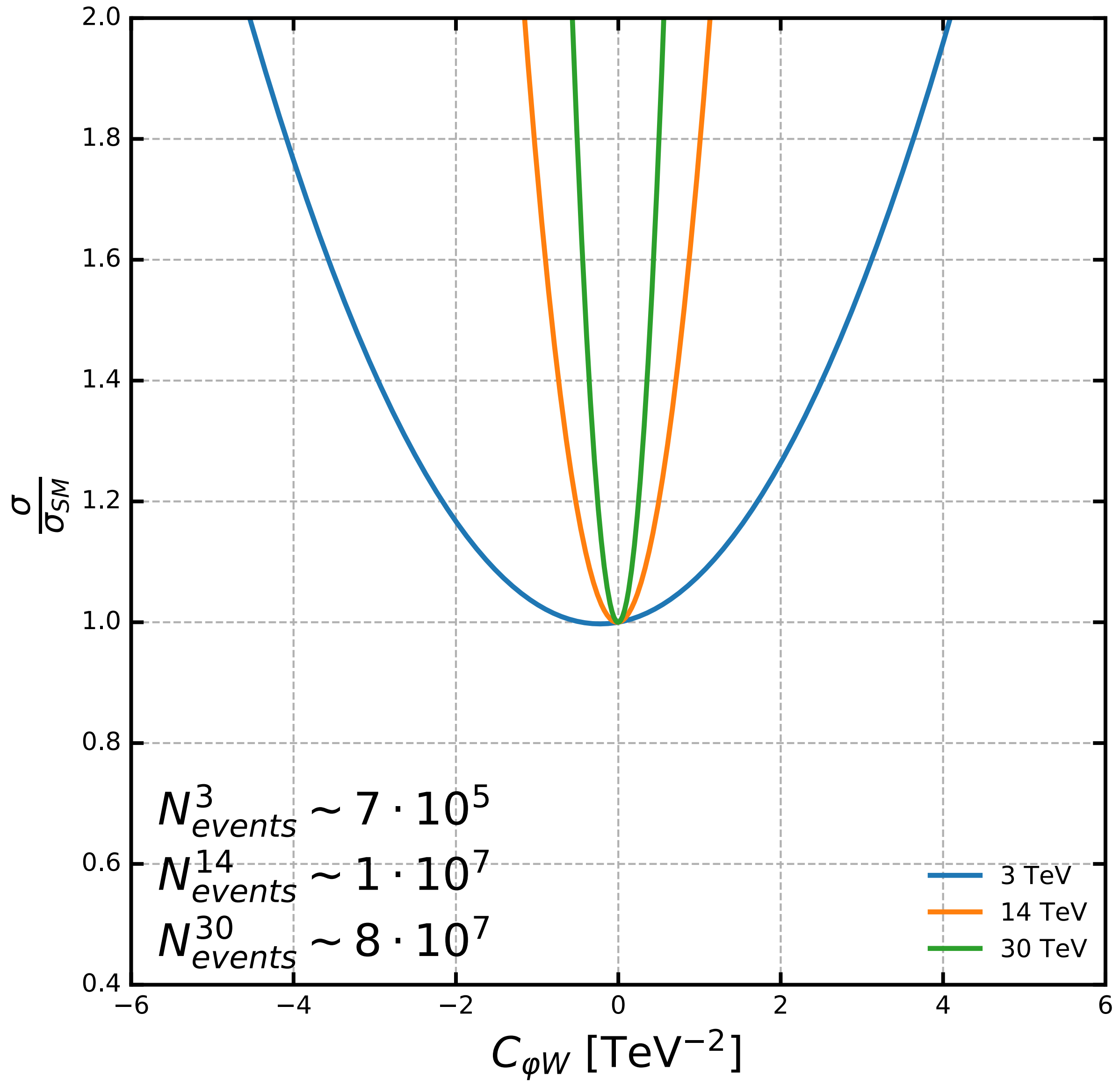
$$C_{\varphi B} \sim [-0.60, 0.75]$$

$$R(c_i) \equiv \frac{\sigma}{\sigma_{SM}} = 1 + c_i \frac{\sigma^{i}_{Int}}{\sigma_{SM}} + c_i^2 \frac{\sigma^{i,i}_{Sq}}{\sigma_{SM}} = 1 + c_i\, r_i + c_i^2\, r_{i,i}.$$

$WW \to W^+W^-$



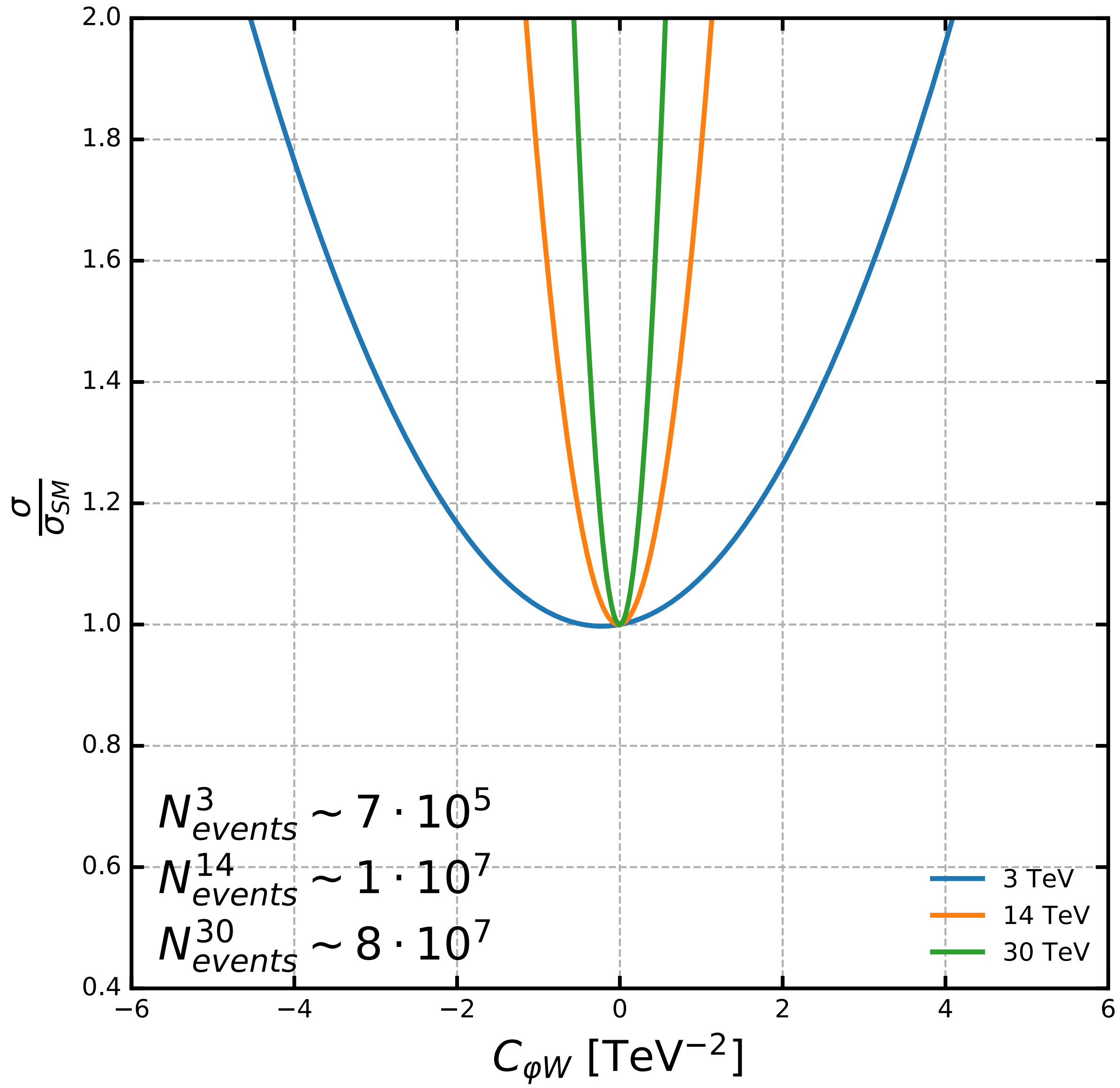
WW


$\frac{\sigma}{\sigma_{SM}}$
$C_{\varphi W}$ [TeV^{-2}]
$N^{3}_{events} \sim 7 \cdot 10^{5}$
$N^{14}_{events} \sim 1 \cdot 10^{7}$
$N^{30}_{events} \sim 8 \cdot 10^{7}$
3 TeV
14 TeV
30 TeV

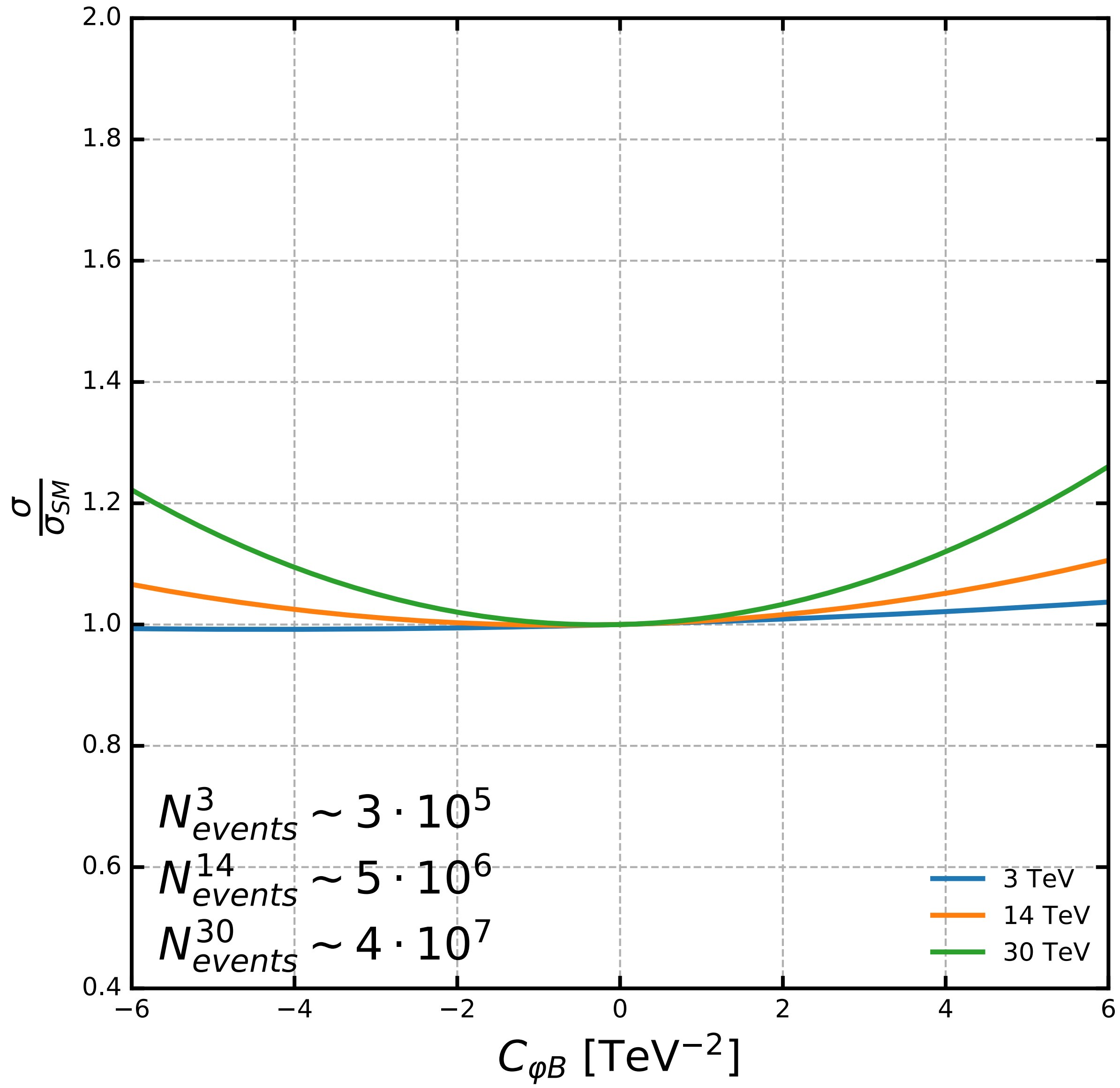
Energy sensitivity

Luca Mantani

WW



ZZ



$$\frac{S}{\sqrt{B}} = \frac{|\mathcal{L} \cdot (\sigma - \sigma_{SM})|}{\sqrt{\mathcal{L} \cdot \sigma_{SM}}} \leq 2$$

3 TeV

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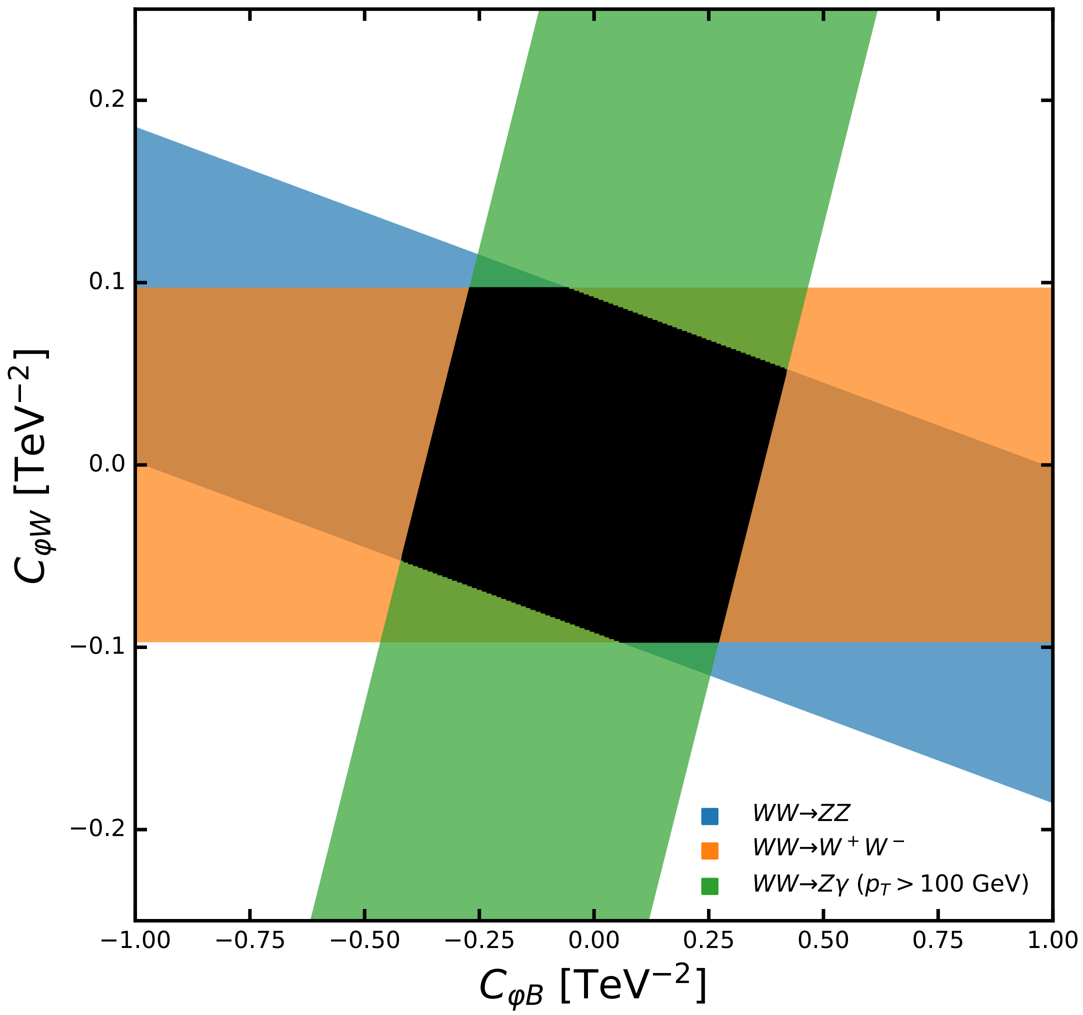

$$C_{\varphi B} \sim [-0.42, 0.42]$$

$$C_{\varphi W} \sim [-0.097, 0.097]$$

3 TeV

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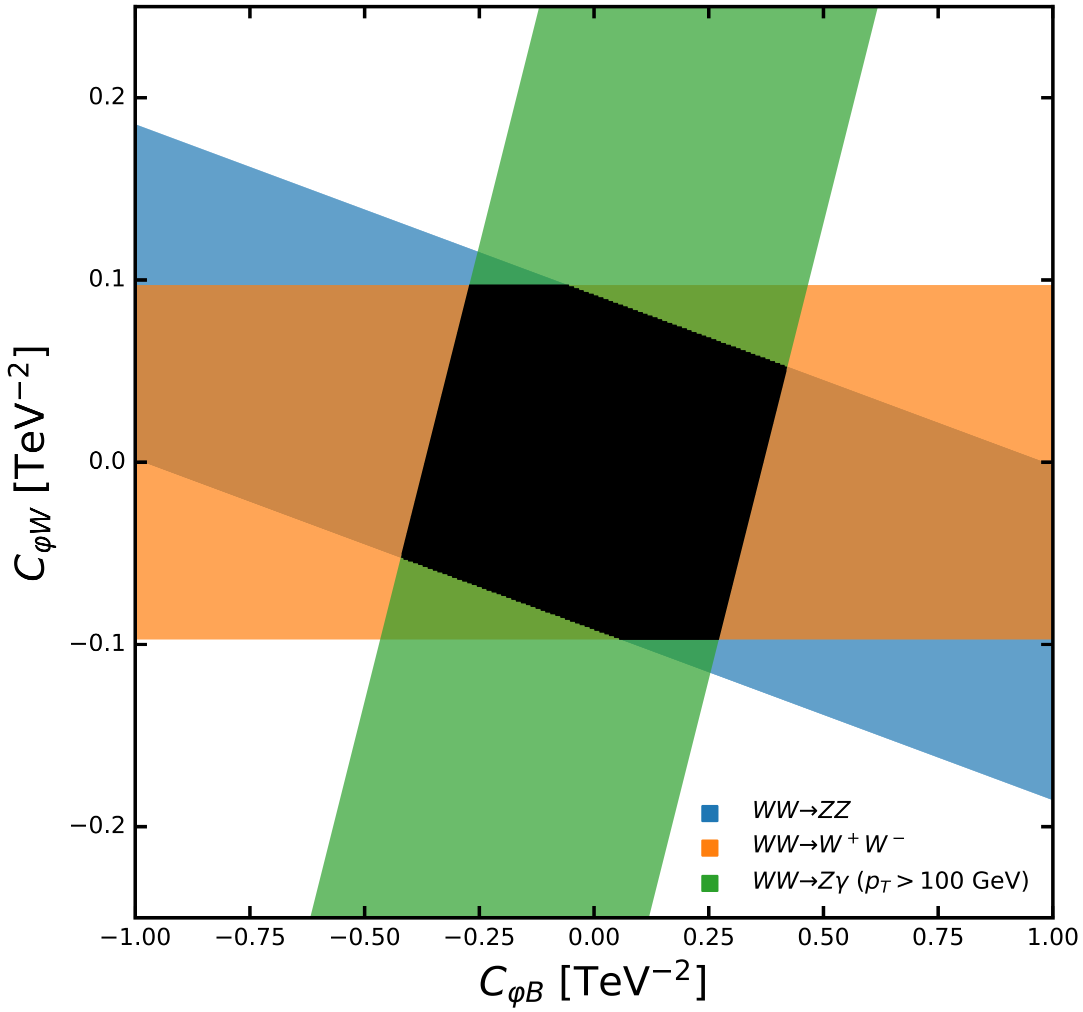
14 TeV



$$C_{\varphi B} \sim [-0.42, 0.42]$$
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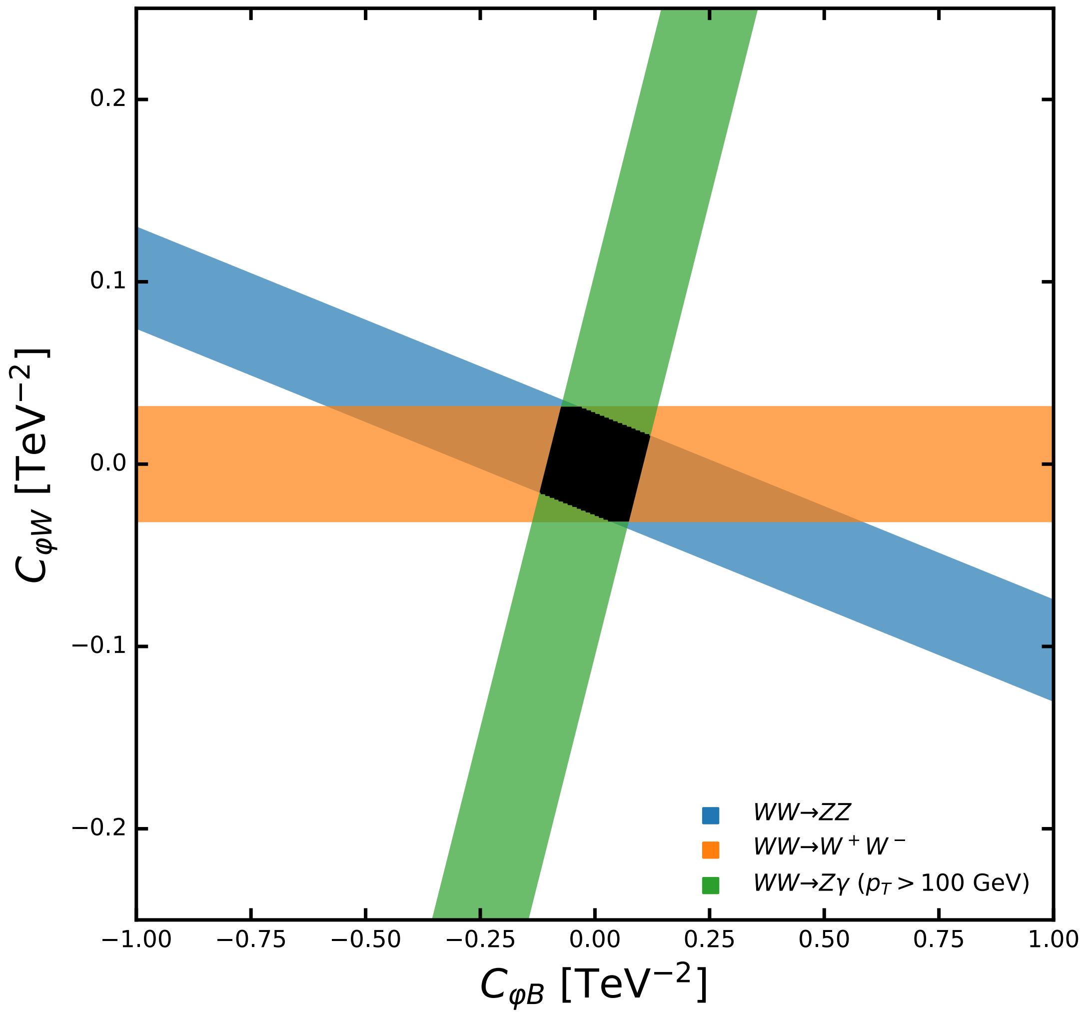

$$C_{\varphi W} \sim [-0.03, 0.03]$$
$$C_{\varphi B} \sim [-0.12, 0.12]$$

- Muon collider is a dream machine to explore EW sector
- Both precision and discovery potential are top notch
- A multi-TeV machine would be effectively a EW boson
- A naive projection was performed, considering only inclusive cross sections. No observable optimisation was performed, likely a very conservative projection.
- Muon collider would give us access to new set of processes (multiboson), increasing our sensitivity to NP effects.

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Thanks!