Constraining new physics in diboson measurements using EFT

M2 internship project

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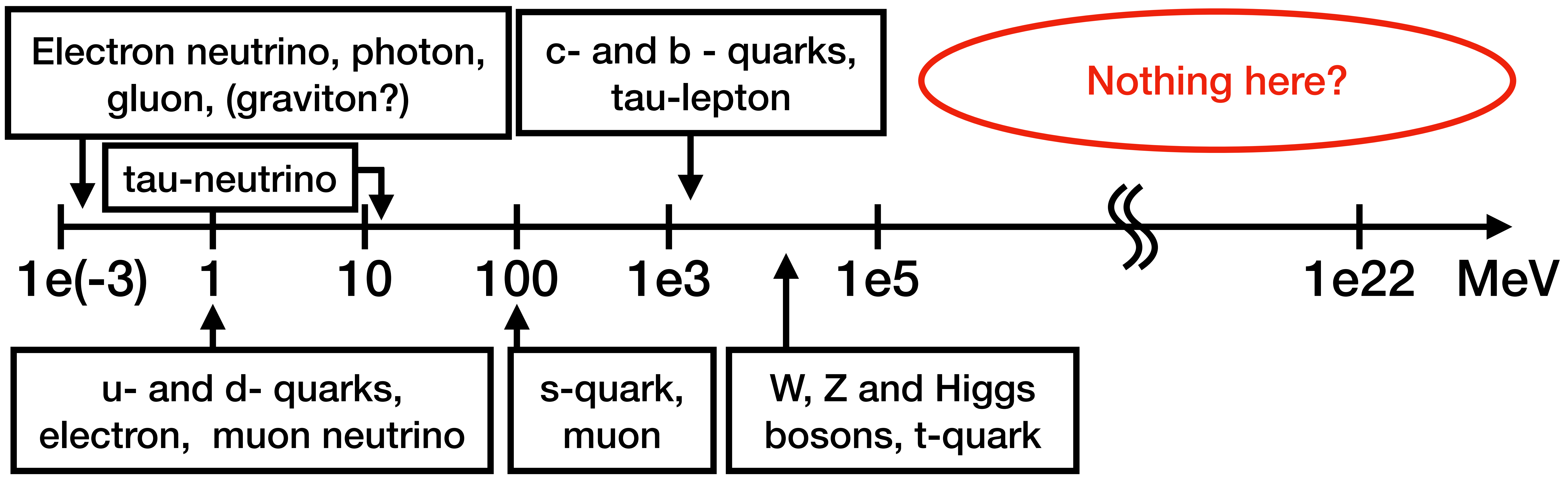
Introduction: The Standard Model

The Standard Model is the most successful theory of the quantum world

$$\mathcal{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + i\bar{\psi}\not{D}\psi + h.c. + \psi_i y_{ij}\psi_j\phi + h.c. + |D_\mu\phi|^2 - V(\phi)$$

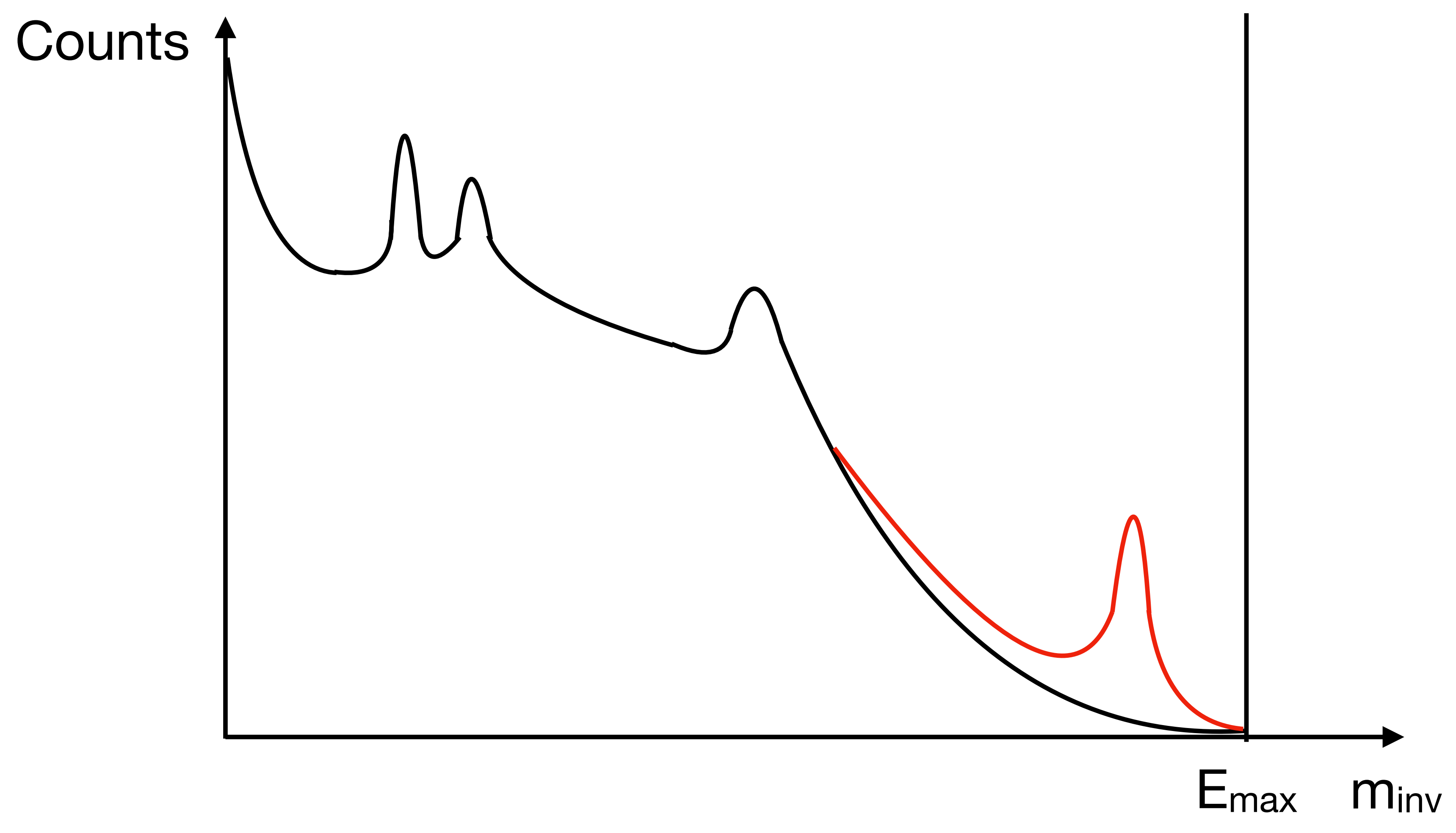


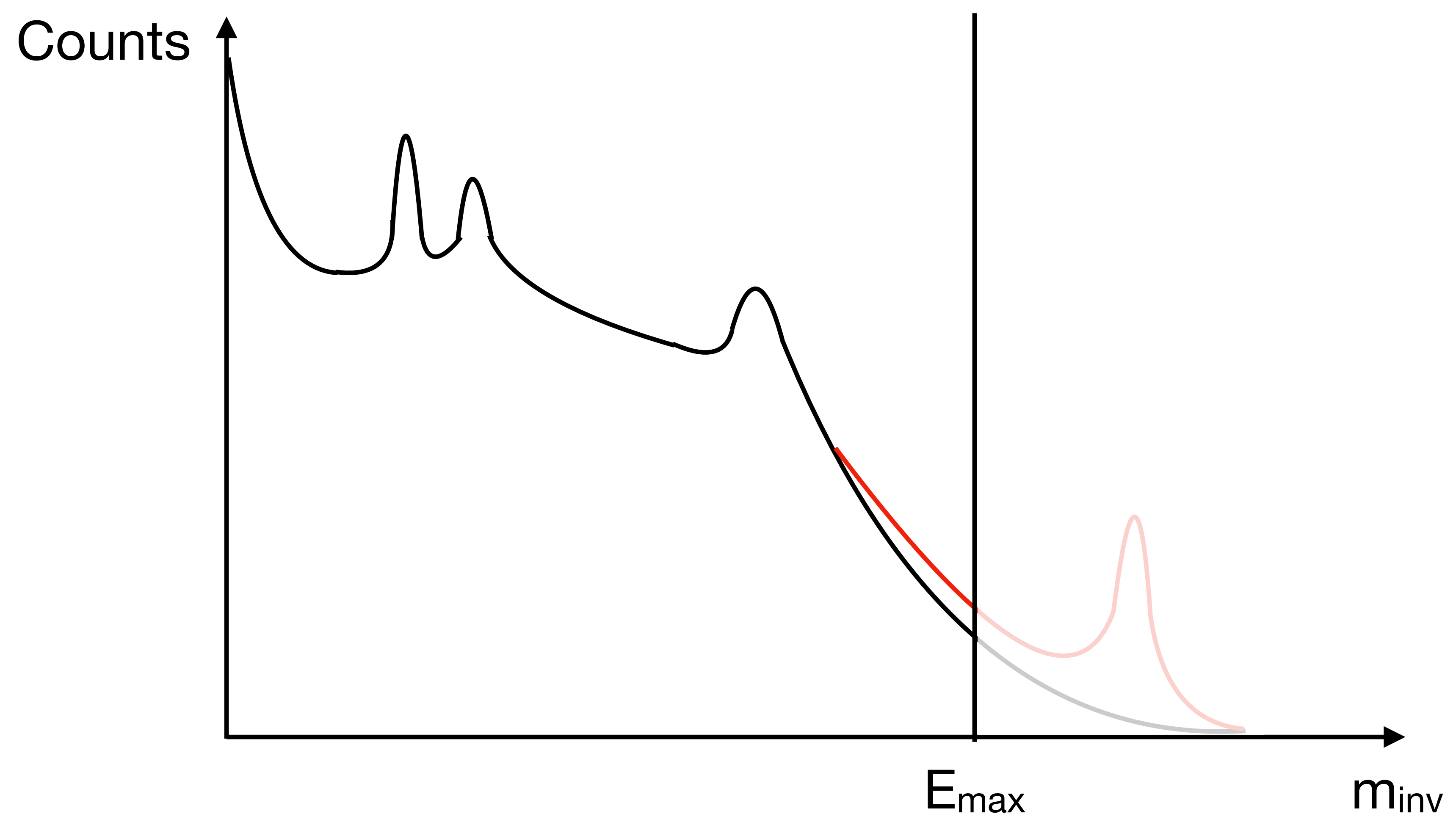
Introduction: How to discover new physics?

Is energy scale accessible at the experimental environment?

yes → Direct search

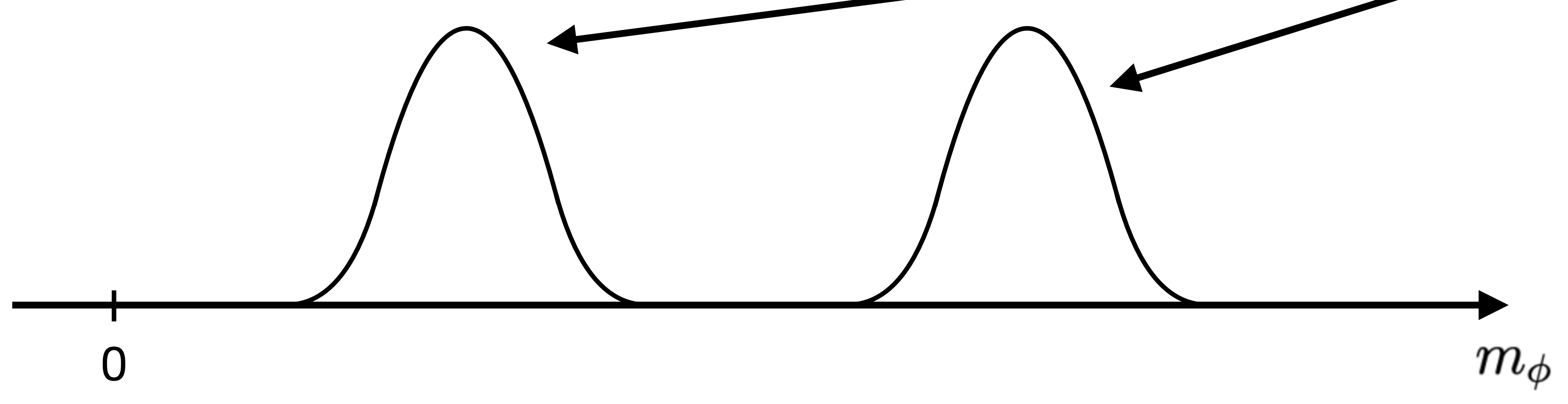
no → Indirect search





Introduction to EFT

Theory with 2 sets of fields: soft and hard



$$Z[j_s, j_h] = \int [D\phi_s D\phi_h] \exp\left\{ iS[\phi_s, \phi_h] + \int_x (j_s\phi_s + j_h\phi_h) \right\}$$

Observables of interest depend only on soft fields

$$\langle \mathcal{O} \rangle = \int [D\phi_s D\phi_h] \exp\{iS[\phi_s, \phi_h]\}\, \mathcal{O}(\phi_s) = \int [D\phi_s] \exp\{iS_\Lambda[\phi_s]\}\, \mathcal{O}(\phi_s)$$

Action of Effective Theory

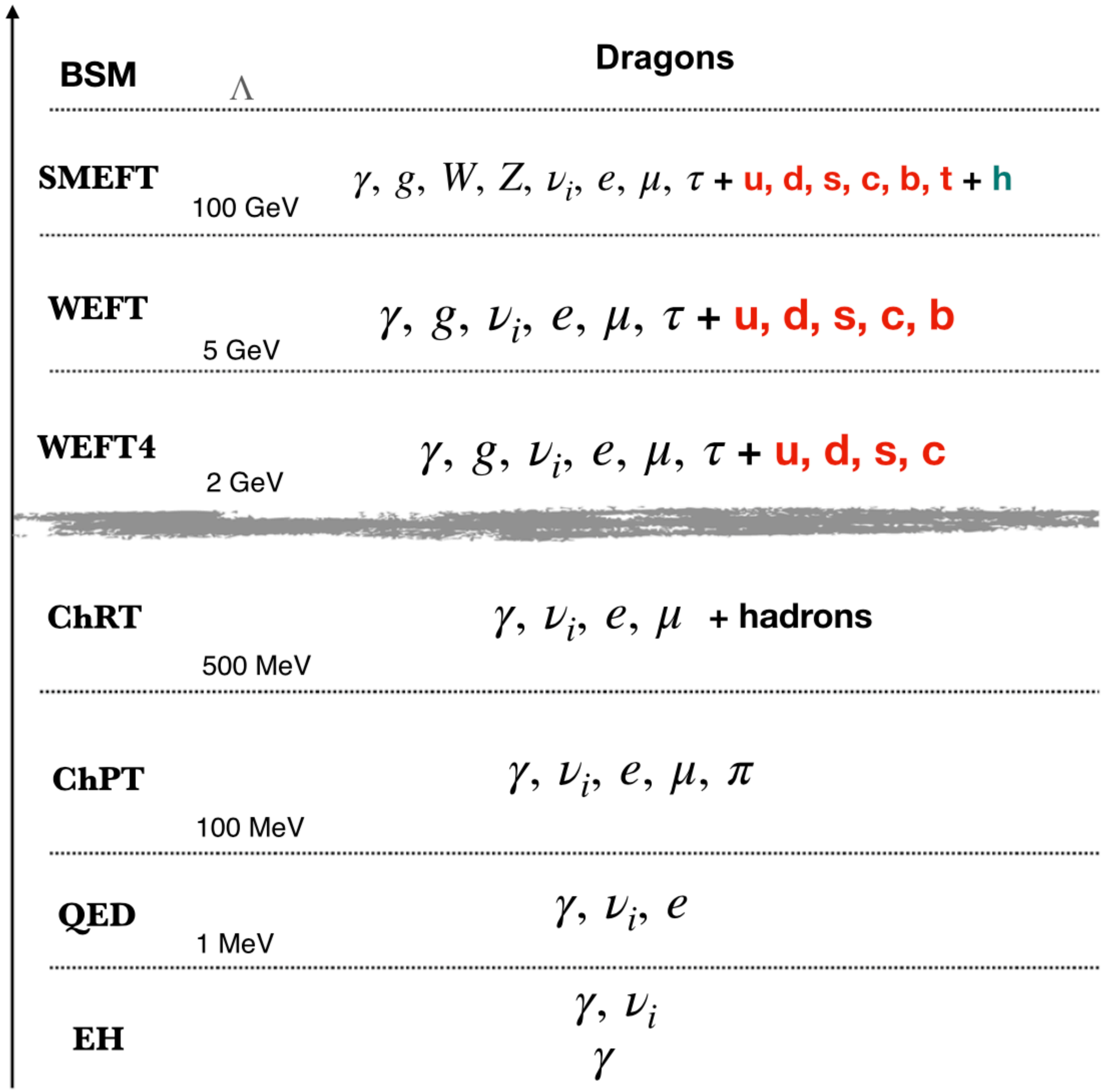
Uncertainty principle allows OPE

$$S_\Lambda[\phi_s] = \int d^D x \sum_n \lambda_n \mathcal{O}_n$$

Local operators

Wilson coefficients

SMEFT



Assumptions behind SMEFT	
Poincaré invariance and locality	Preserve unitarity and causality
Mass Gap	Light BSM particles are not considered
Gauge symmetry	Same as in the SM: SU(3)xSU(2)xU(1)

SMEFT lagrangian

Lagrangian

$$\mathcal{L}_{\mathrm{SMEFT}} = \sum_{D=2}^{\infty} \mathcal{L}_D \qquad \mathcal{L}_D = \sum_i C_{i,D} O_{i,D} \qquad C_{i,D} = \frac{c_{i,D}}{\Lambda^{D-4}}$$

Dimension 2 operator

$$\mathcal{L}_{D=2} = \mu_H^2 H^\dagger H$$

Dimension 4 operators

$$\mathcal{L}_{D=4} = -\frac{1}{4} \sum_{V \in B, W^i, G^a} V_{\mu\nu} V^{\mu\nu} + \sum_{f \in Q, L} i \bar{f} \bar{\sigma}^\mu D_\mu f + \sum_{f \in U, D, E} i f^c \sigma^\mu D_\mu \bar{f}^c$$
$$- \left(\bar{Q} \tilde{H} Y_u \bar{U}^c + \bar{Q} H Y_d \bar{D}^c + \bar{L} H Y_e \bar{E}^c + \mathrm{h.c.} \right) + D_\mu H^\dagger D^\mu H - \lambda (H^\dagger H)^2 + \tilde{\theta} G^a_{\mu\nu} \tilde{G}^a_{\mu\nu}$$

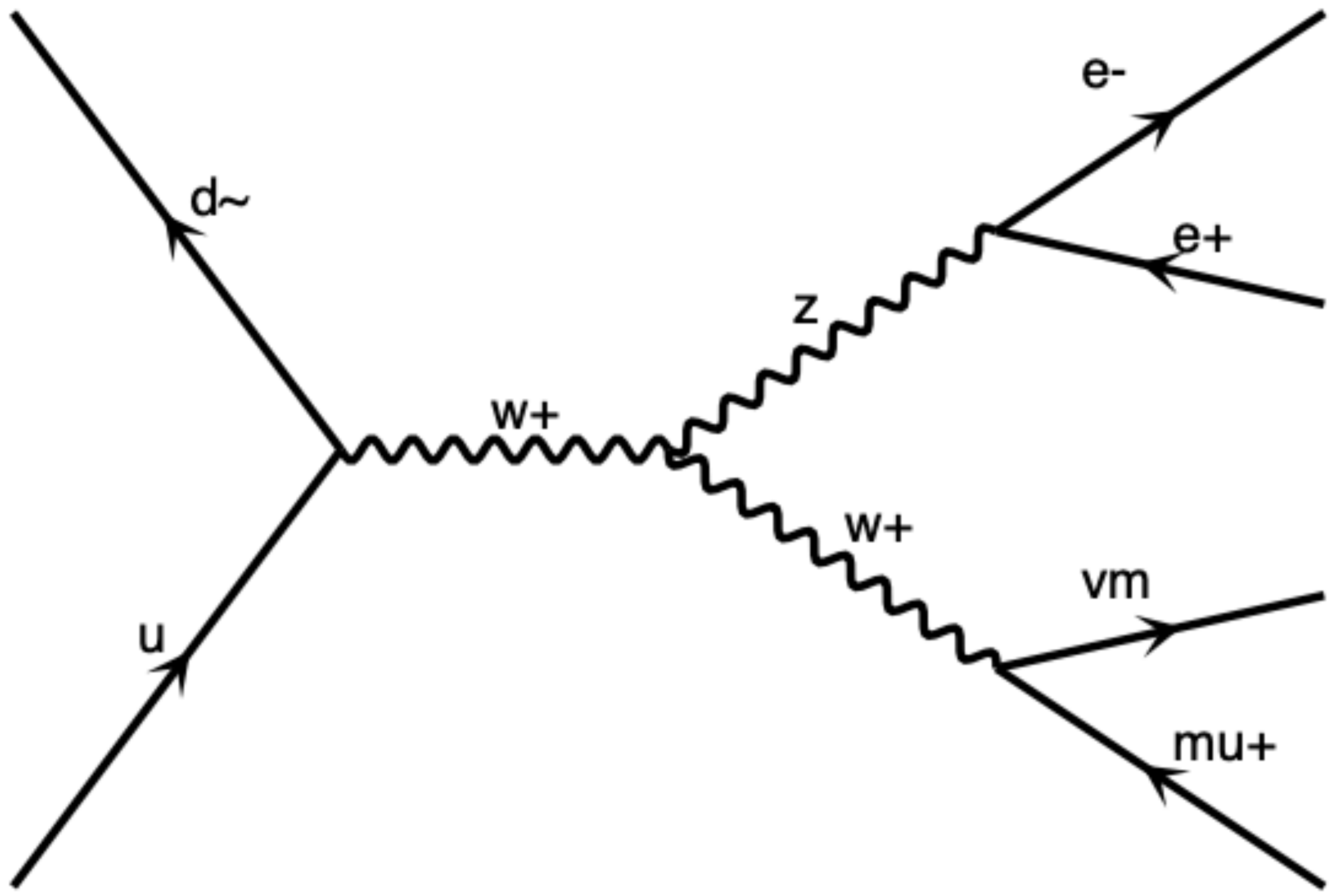
Higher dimensional operators

$$\mathcal{L}_{D=5} = -(\bar{L} H^\dagger) C_5 (\bar{L} H^\dagger) + \mathrm{h.c.}$$

3045 dim-6 operators!!!

WZ diboson production

- Precision measurements of WZ channel are available
- LO in QCD and EFT
- 21 EFT operators affect scattering amplitude



$$\mathcal{A} = \mathcal{A}_{SM} + \mathcal{A}_{BSM}$$

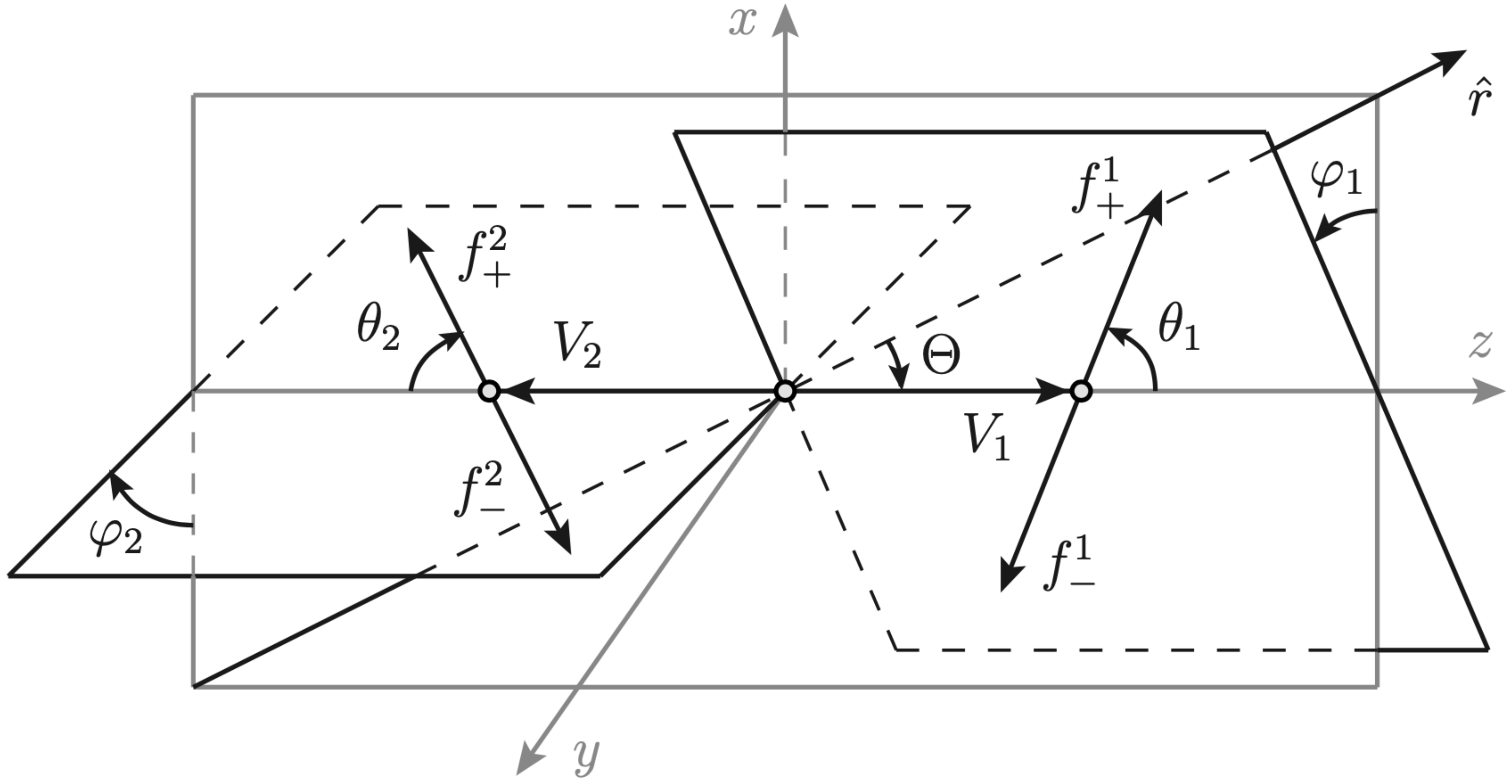
$$\sigma = \sigma_{SM} + \sigma_{int} + \sigma_{BSM}$$

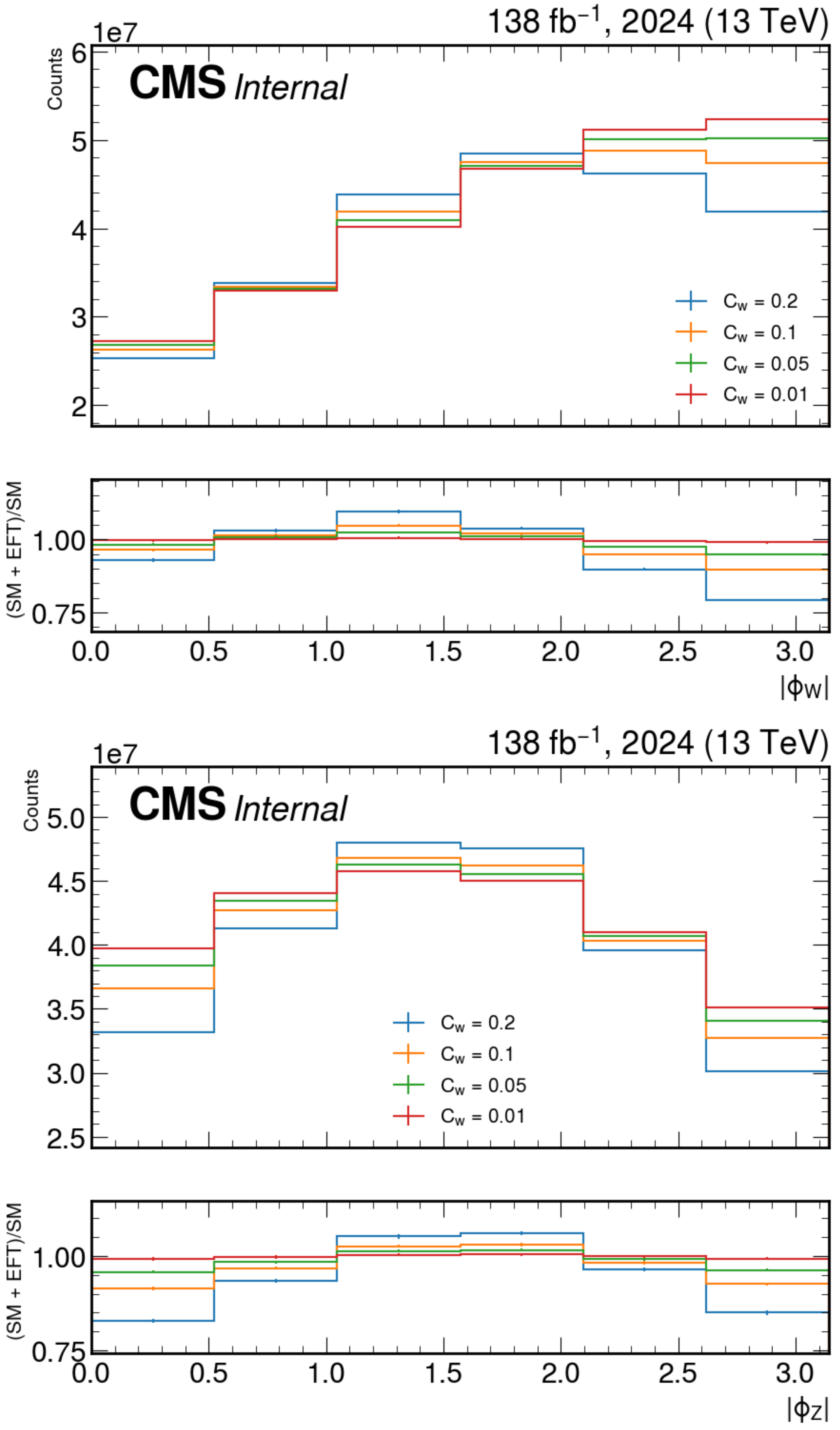
$$\sigma_{int} \propto \Lambda^{-2} \qquad \sigma_{BSM} \propto \Lambda^{-4}$$

⟶ BSM is visible at high energies

- Non-interference theorem: In the high-energy limit amplitudes are well characterized by the helicities of the external bosons

Interference resurrection technique



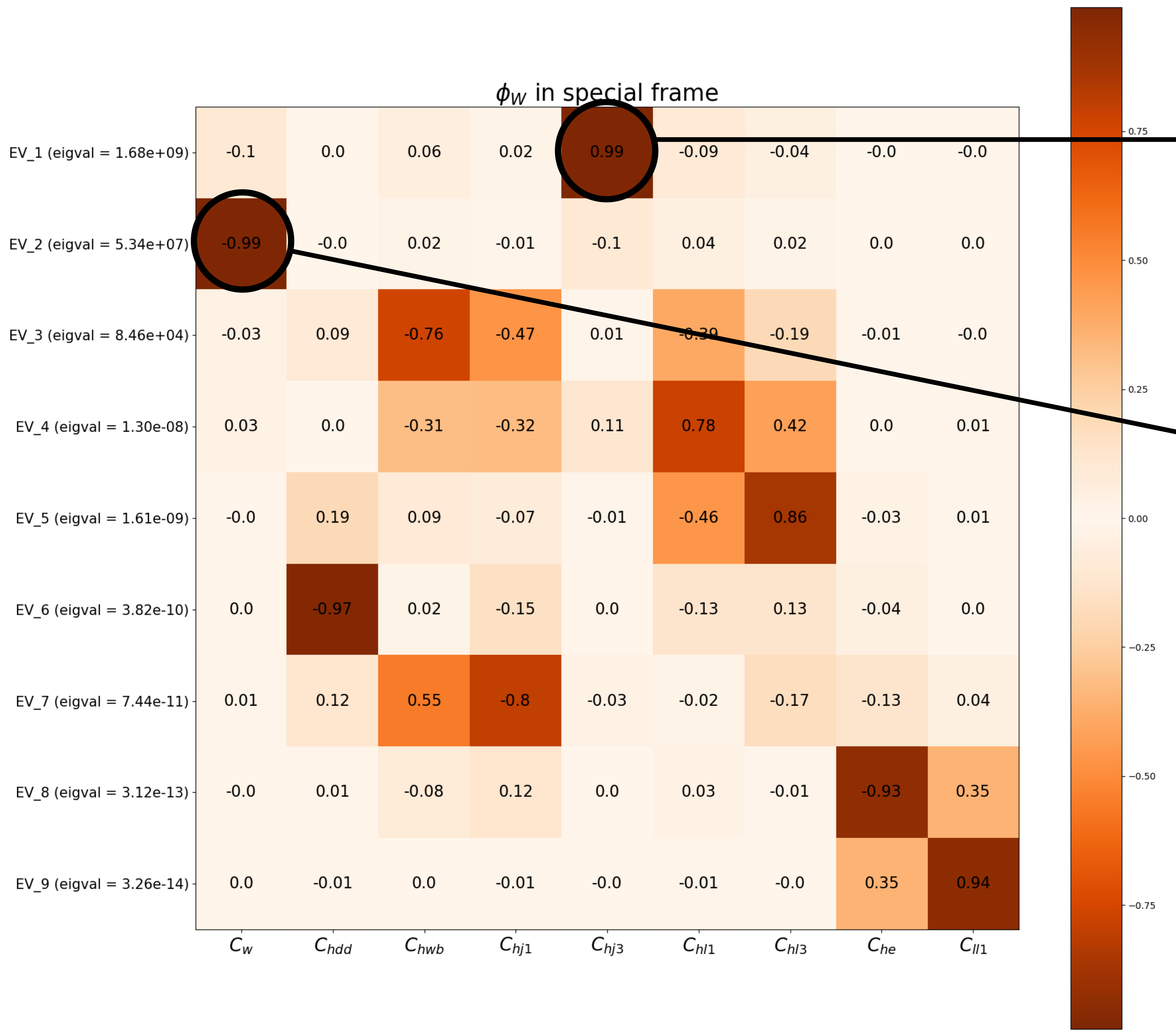


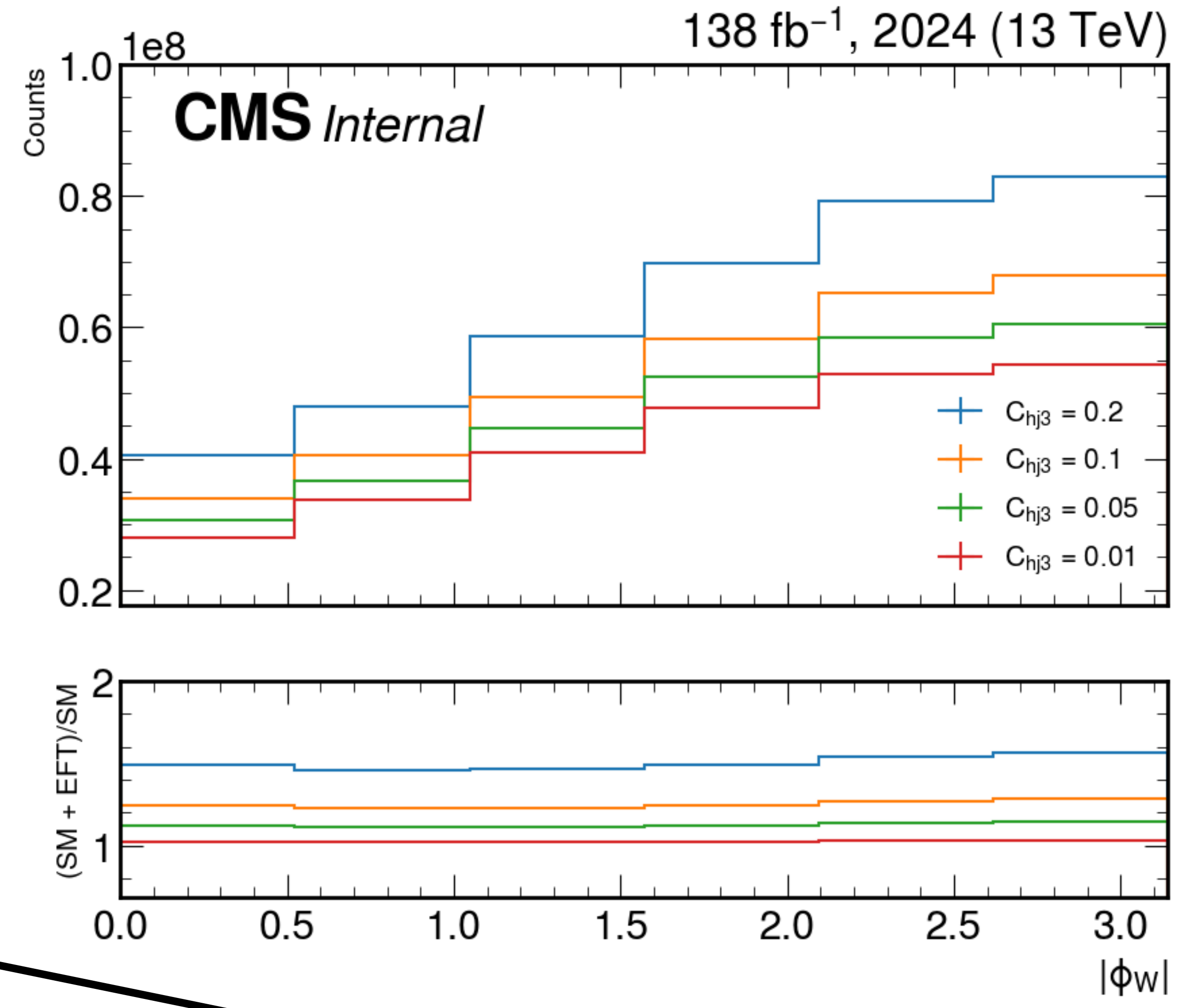
- r — direction of the boost vector to CoM frame
- ϕ_1 and ϕ_2 are sensitive to the interference term

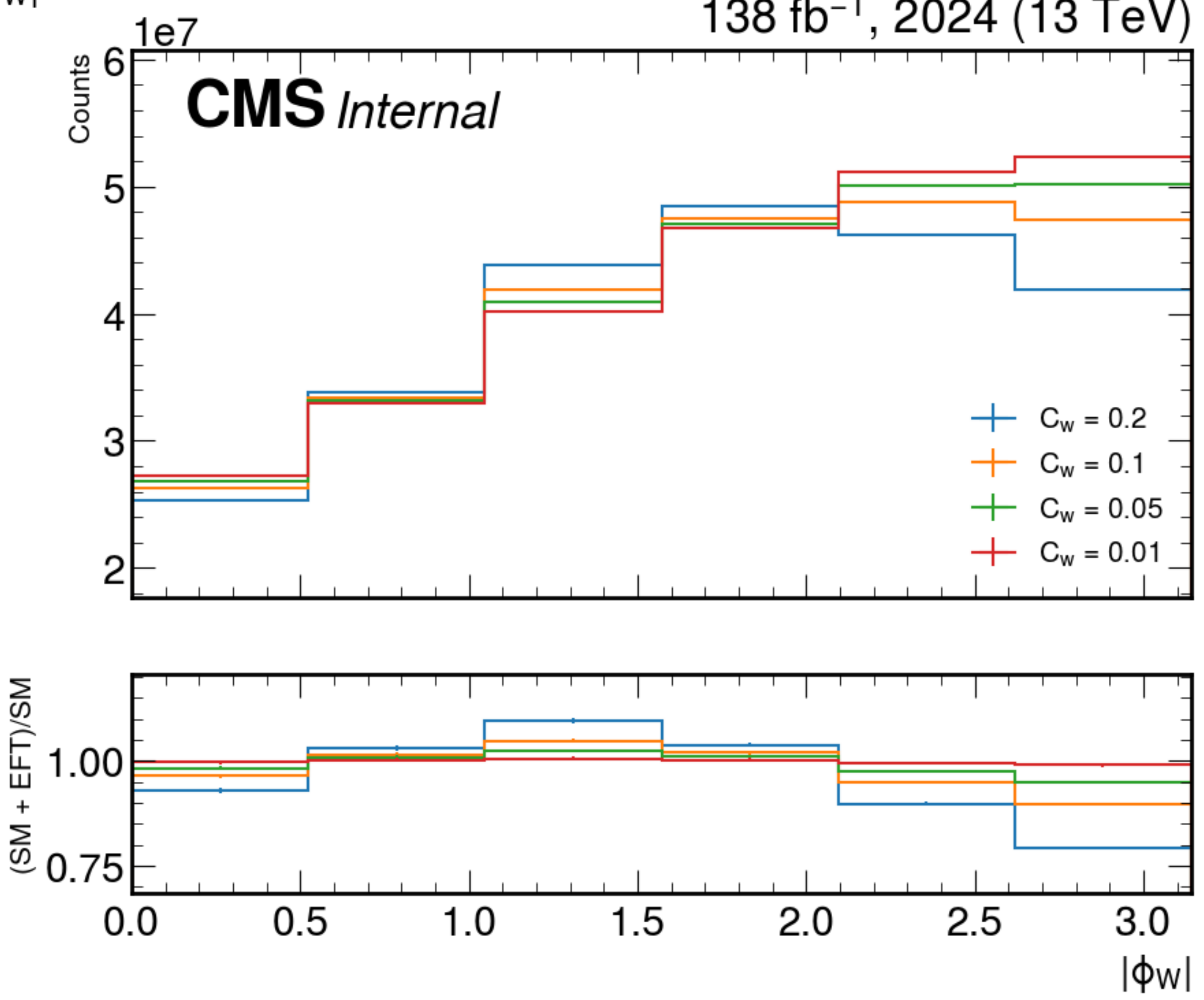
$$|\mathcal{M}_{int}|^2 \propto \mathcal{A}_h^{\mathrm{SM}} \mathcal{A}_{h'}^{BSM} \cos(\Delta h \cdot \varphi)$$

Deviations from the SM and sensitivity of ϕ_W

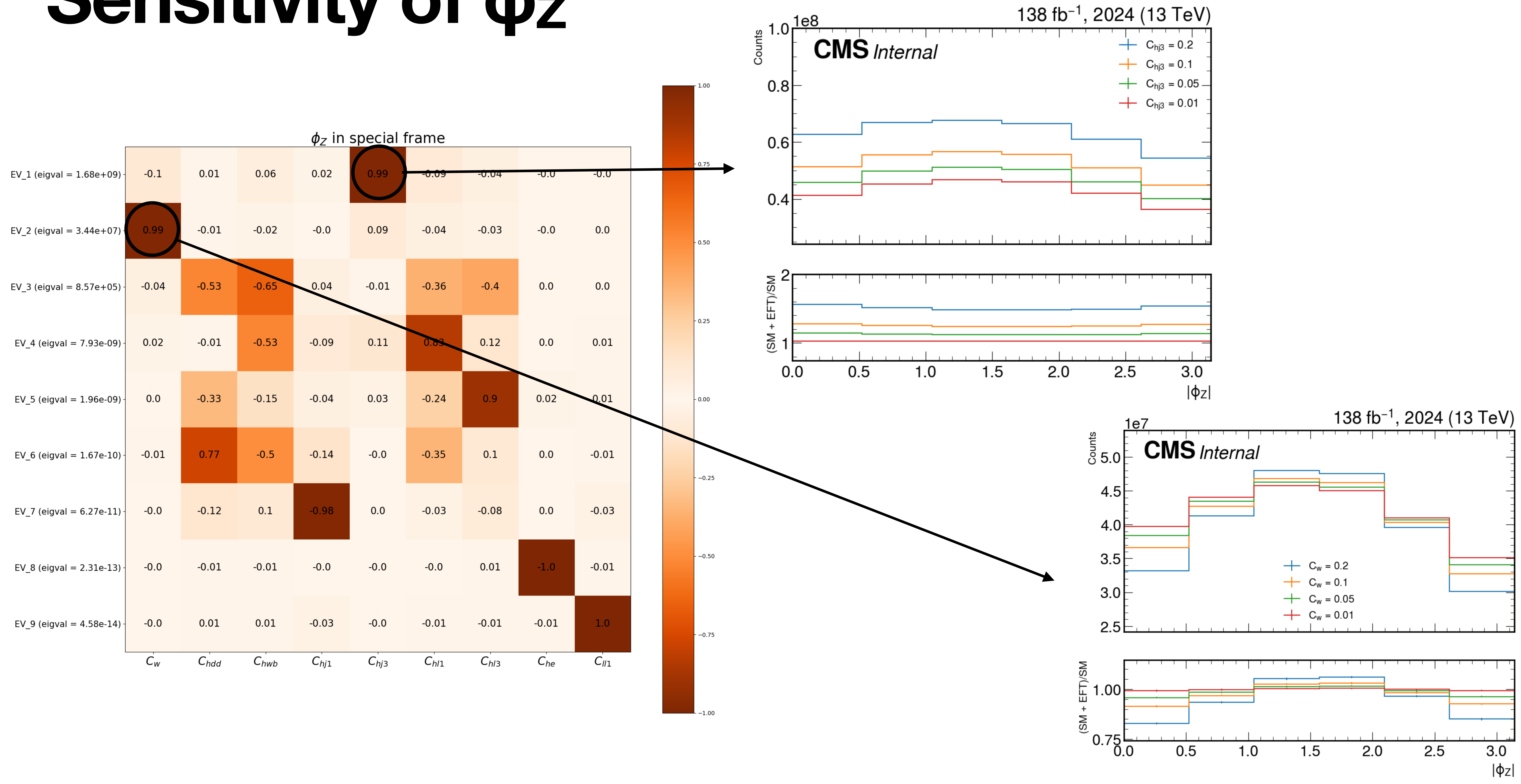
- Kinematic variables: 5 angular (ϕ_W, ϕ_Z, Θ_{Boost}, θ_W, θ_Z) and 1 energetic (M_{4l})
- After operator selection, 9/21 operators left



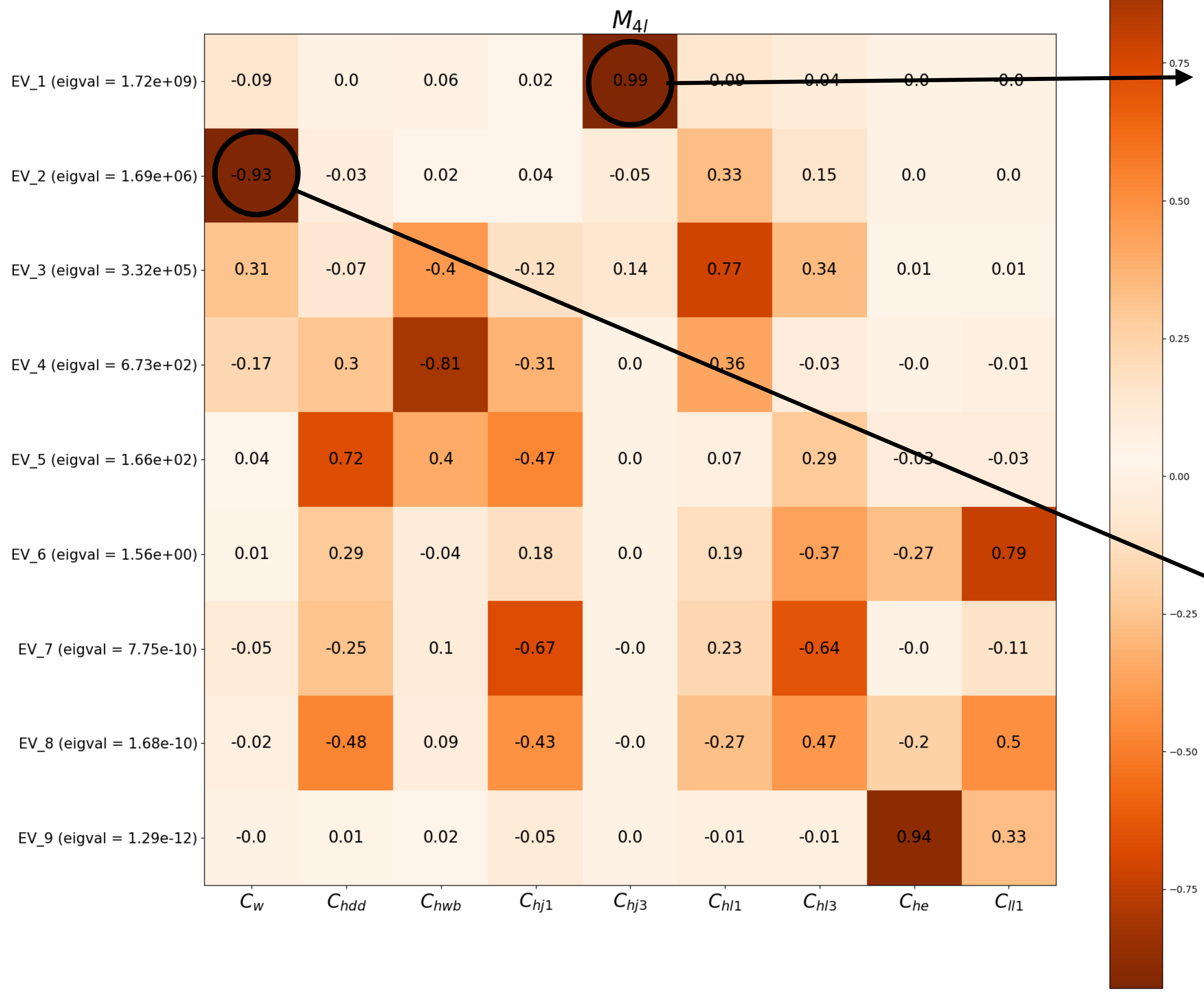


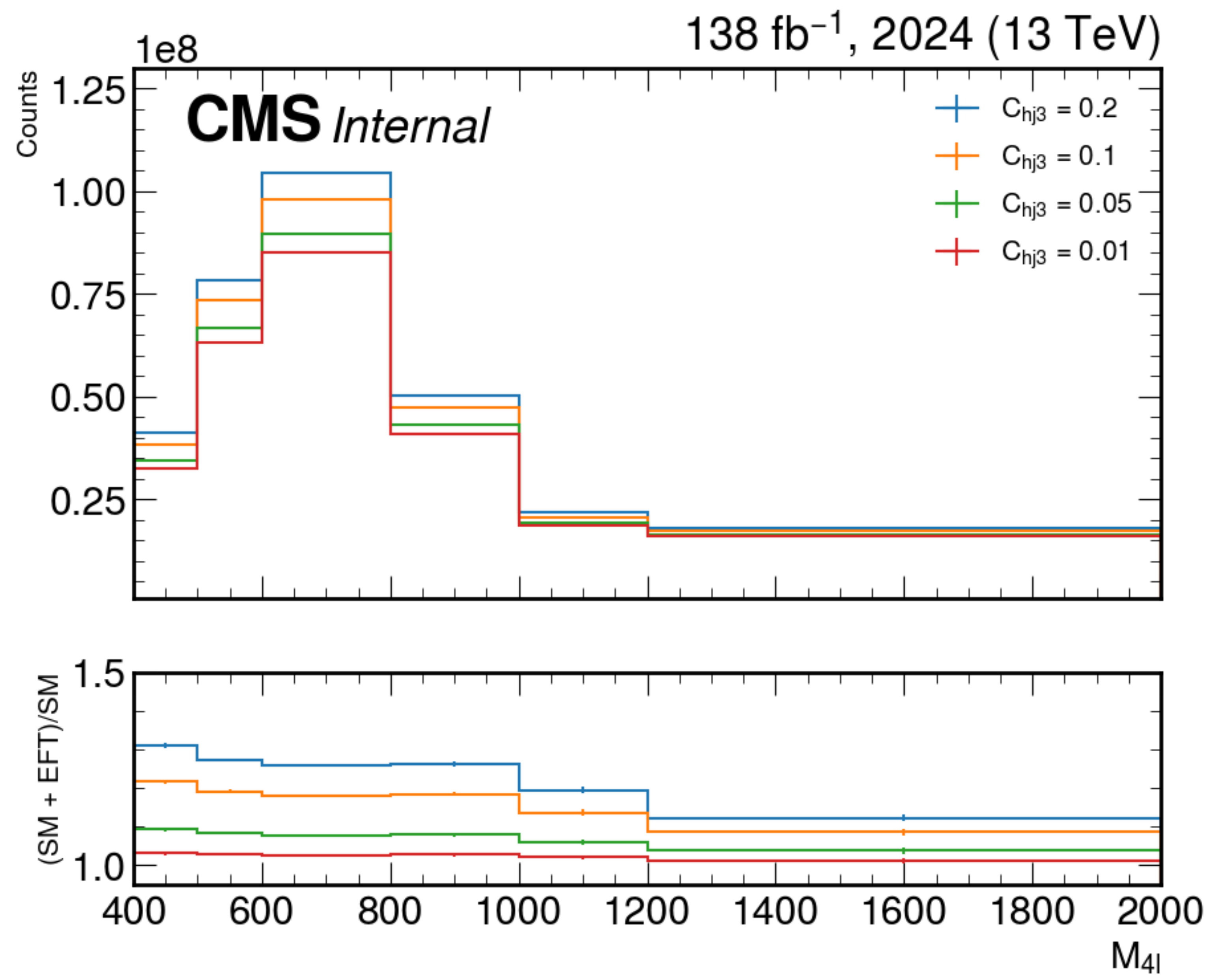


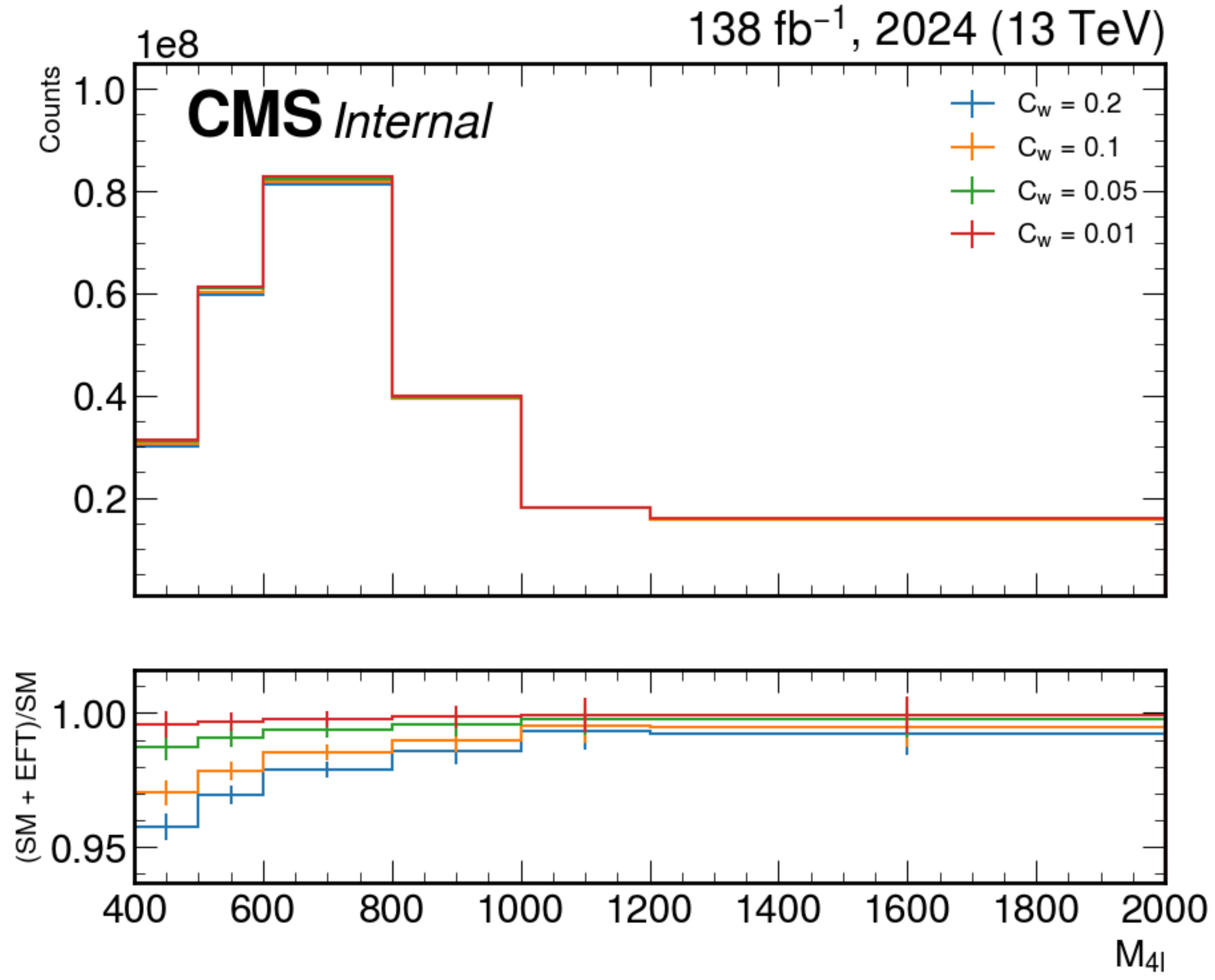
Sensitivity of ϕz



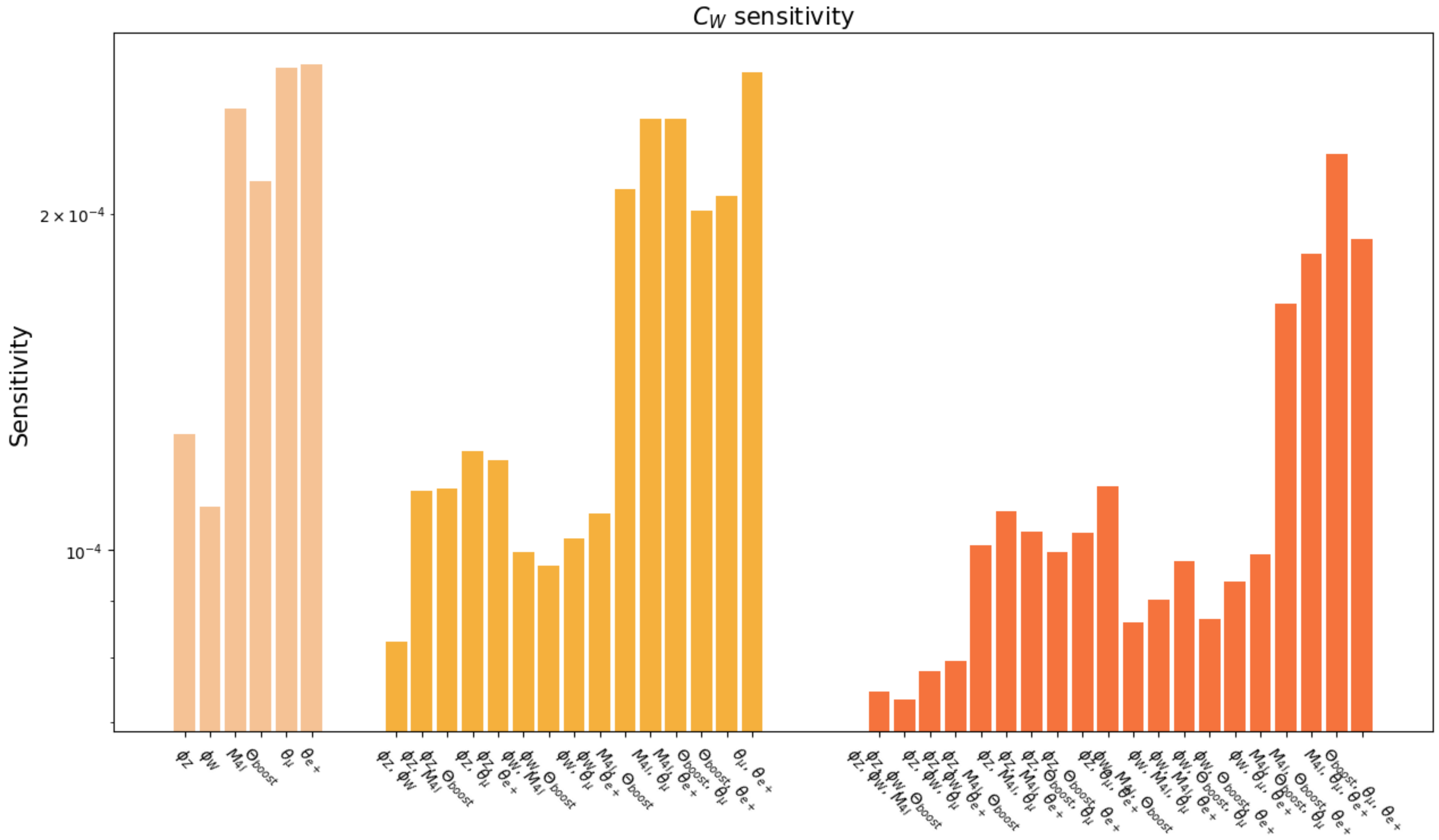
Sensitivity of M_{4l}







Sensitivity to c_W



Conclusion

- Interference terms are accessible via interference resurrection technique
- WZ-channel is sensitive to 9 EFT operators
- Sensitivity to operators increases with the dimension of an observable
- M_{4l} is sensitive to interference term at low energies
- The most sensitive observable to cW is the combination of ϕ_W, ϕ_Z and Θ_{Boost}

Future work

- Implement algorithms of machine learning to define the most optimal observable
- Analyse sensitivity to all operators involved in WZ channel