

Combining Z' and W' searches at the LHC

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based on work with
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Outlook

- Introduction: leptonic signatures
- Singlets
- Triplets
- Mixture
- Combined limits

Z' and W' searches at LHC

Cleanest signatures:

- Dilepton \longrightarrow Neutral resonance
- Lepton + MET \longrightarrow Charged resonance

Effective
Theory

Field content: SM + new resonances

Symmetries: Lorentz, $SU(3) \times SU(2) \times U(1)$

Leading order: Local 4D operators

Vector resonances in leptonic final states:

- Single production
- Renormalizable interactions with SM fields
- Couple to quarks and leptons

Direct couplings

$$\mathcal{B} \in (1, 1)_0$$

$$\mathcal{W} \in (1, 3)_0$$

Couplings via mixing with Z and W

$$\mathcal{B}^1 \in (1, 1)_1$$

$$\mathcal{W}^1 \in (1, 3)_1$$

Vector resonances in leptonic final states:

EWPT with
Higgs at 126 GeV



Small Mixing φ

Direct couplings

$$\mathcal{B} \in (1, 1)_0$$

$$\mathcal{W} \in (1, 3)_0$$

Couplings via mixing with Z and W

~~$$\mathcal{B}^1 \in (1, 1)_1$$~~

$$\varphi < 0.001$$

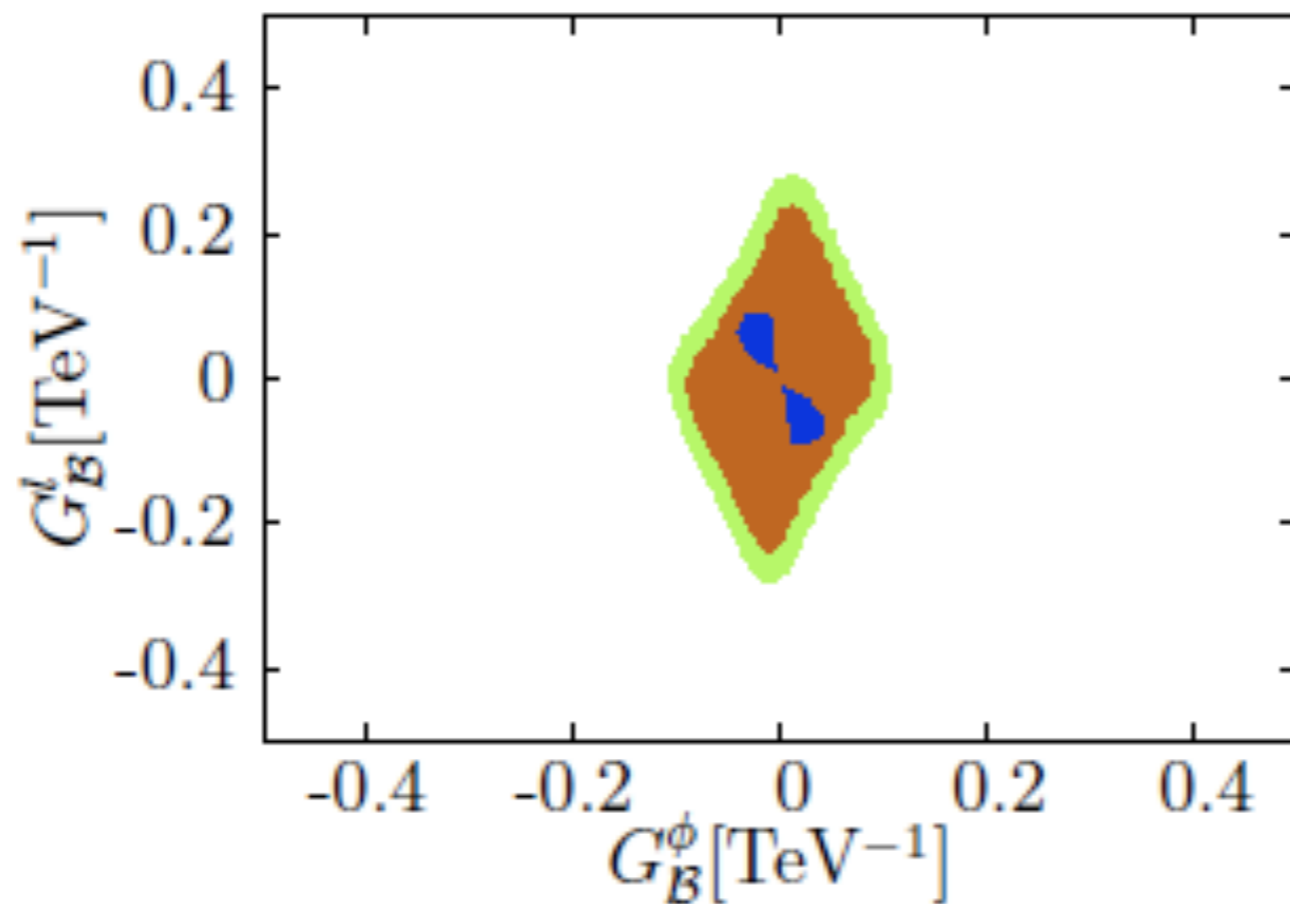
~~$$\mathcal{W}^1 \in (1, 3)_1$$~~

$$\varphi < 0.003$$

Singlets $\mathcal{B} \in (1, 1)_0 \rightarrow Z'$

(Universal) Couplings g_q, g_u, g_d, g_l, g_e

EWPT with Higgs at 126 GeV



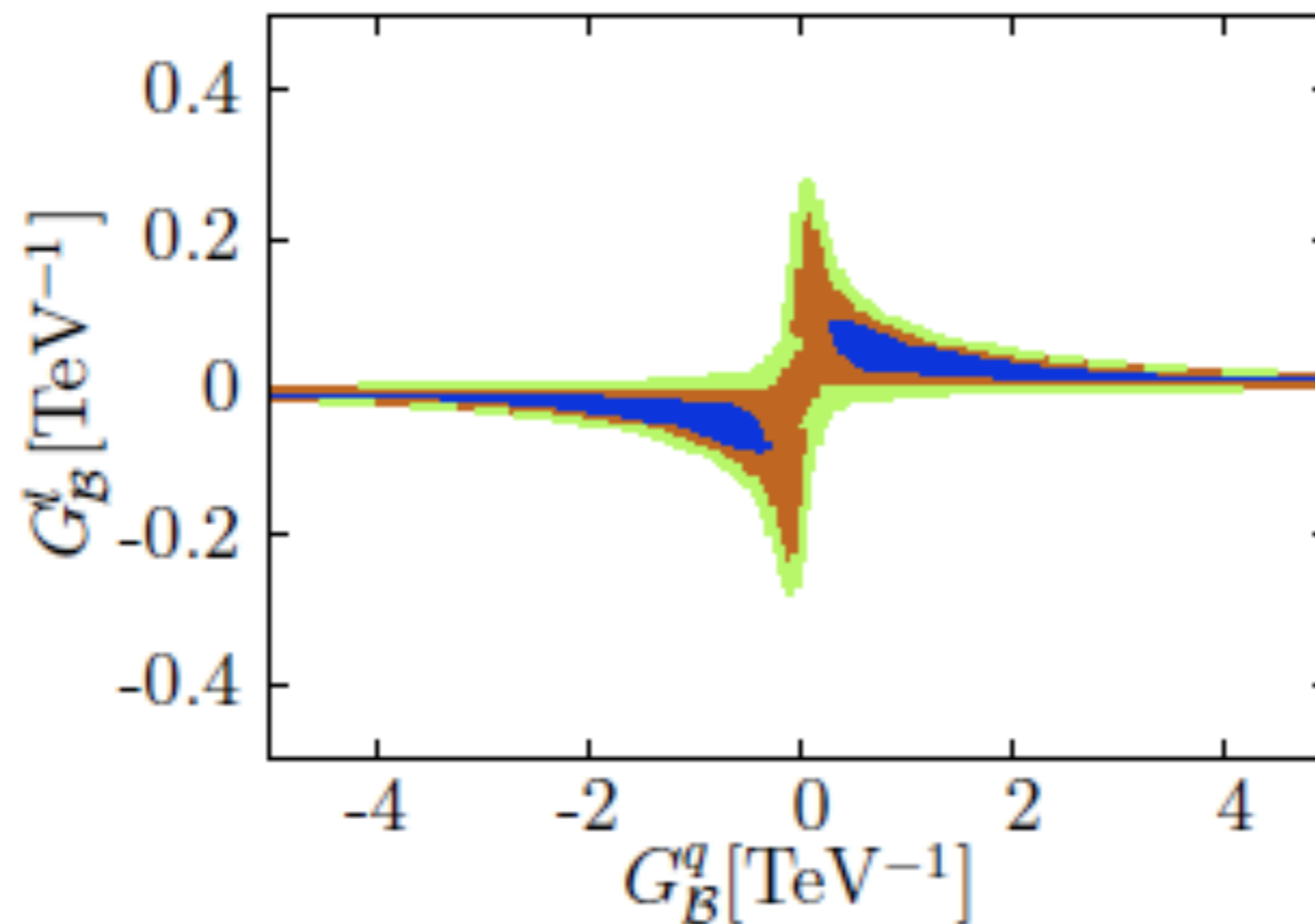
Mixing

$$\varphi \lesssim 0.002$$

Singlets $\mathcal{B} \in (1, 1)_0 \rightarrow Z'$

(Universal) Couplings g_q, g_u, g_d, g_l, g_e

EWPT with Higgs at 126 GeV



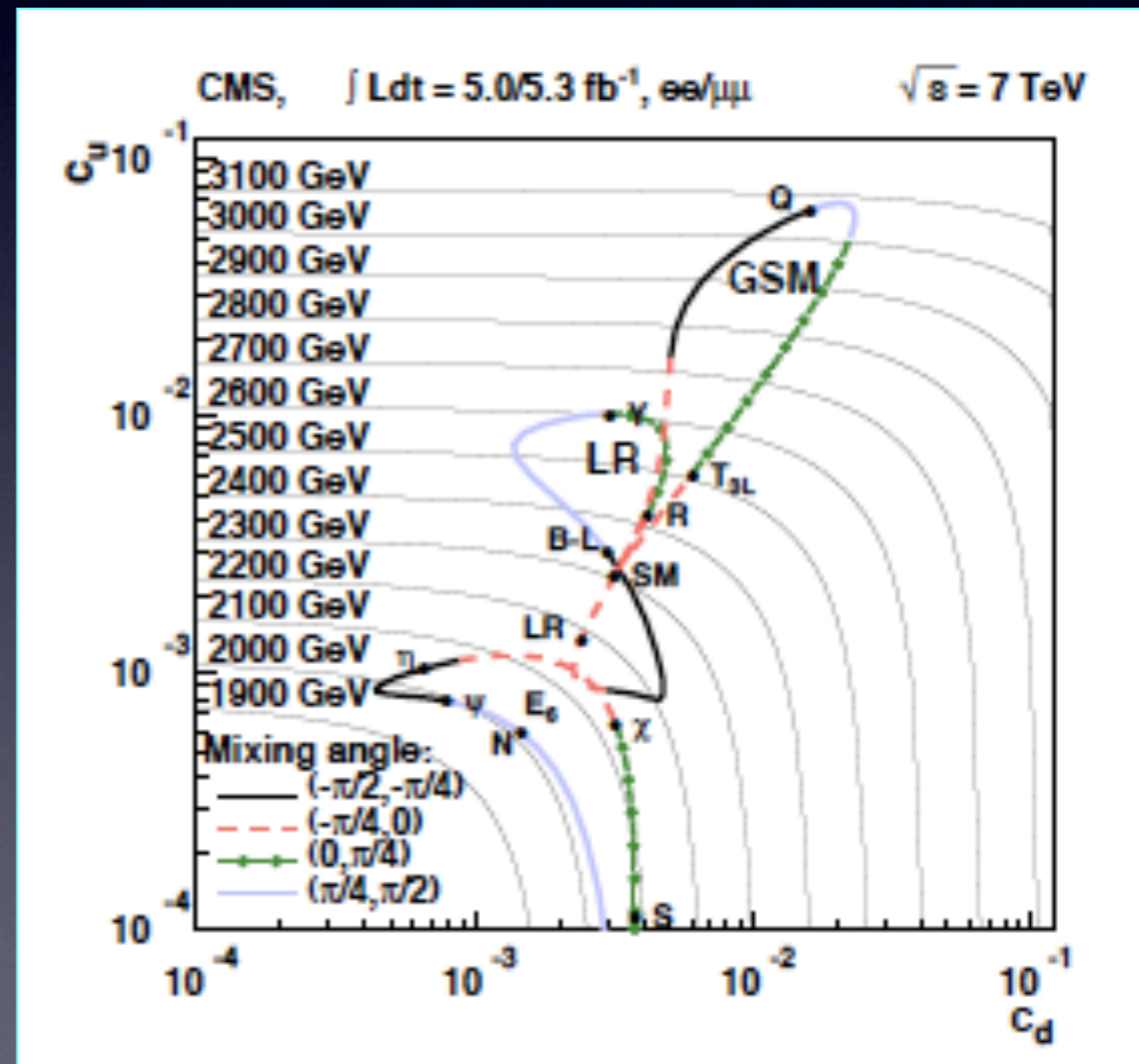
LHC searches

Narrow Width Approximation

$$\sigma(pp \rightarrow l^+l^-) = \frac{\pi}{6s} \left[C_u \omega_u(s, m_{Z'}^2) + C_d \omega_d(s, m_{Z'}^2) \right]$$

[Carena, Daleo, Dobrescu, Tait '04]

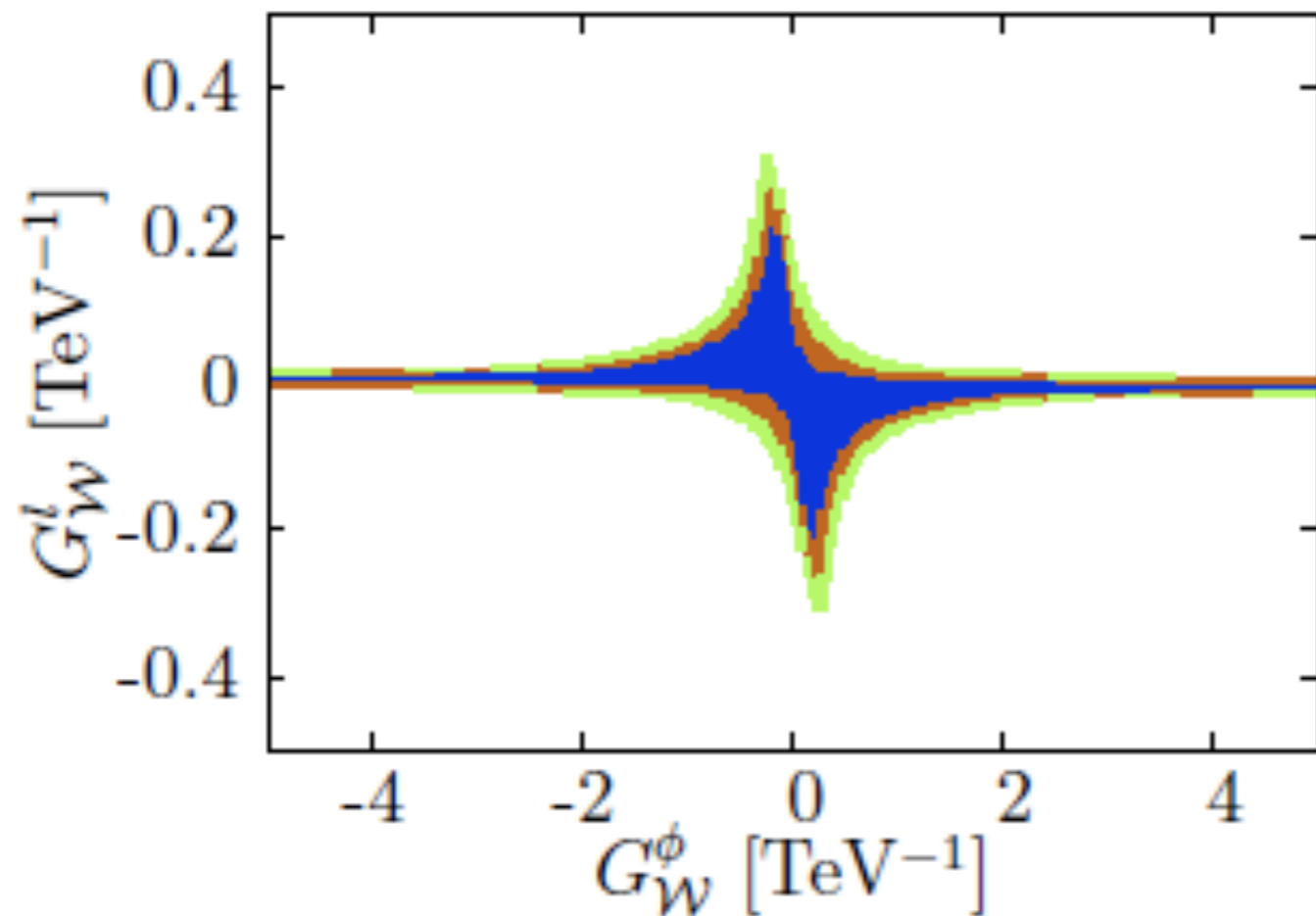
$$C_{u,d} = \frac{(g_q^2 + g_{u,d}^2)(g_l^2 + g_e^2)}{2g_l^2 + g_e^2 + 6g_q^2 + 3g_u^2 + 3g_d^2}$$



Triplets $\mathcal{W} \in (1, 3)_0 \rightarrow Z', W^\pm$

(Universal) Couplings g_q, g_l

EWPT with Higgs at 126 GeV

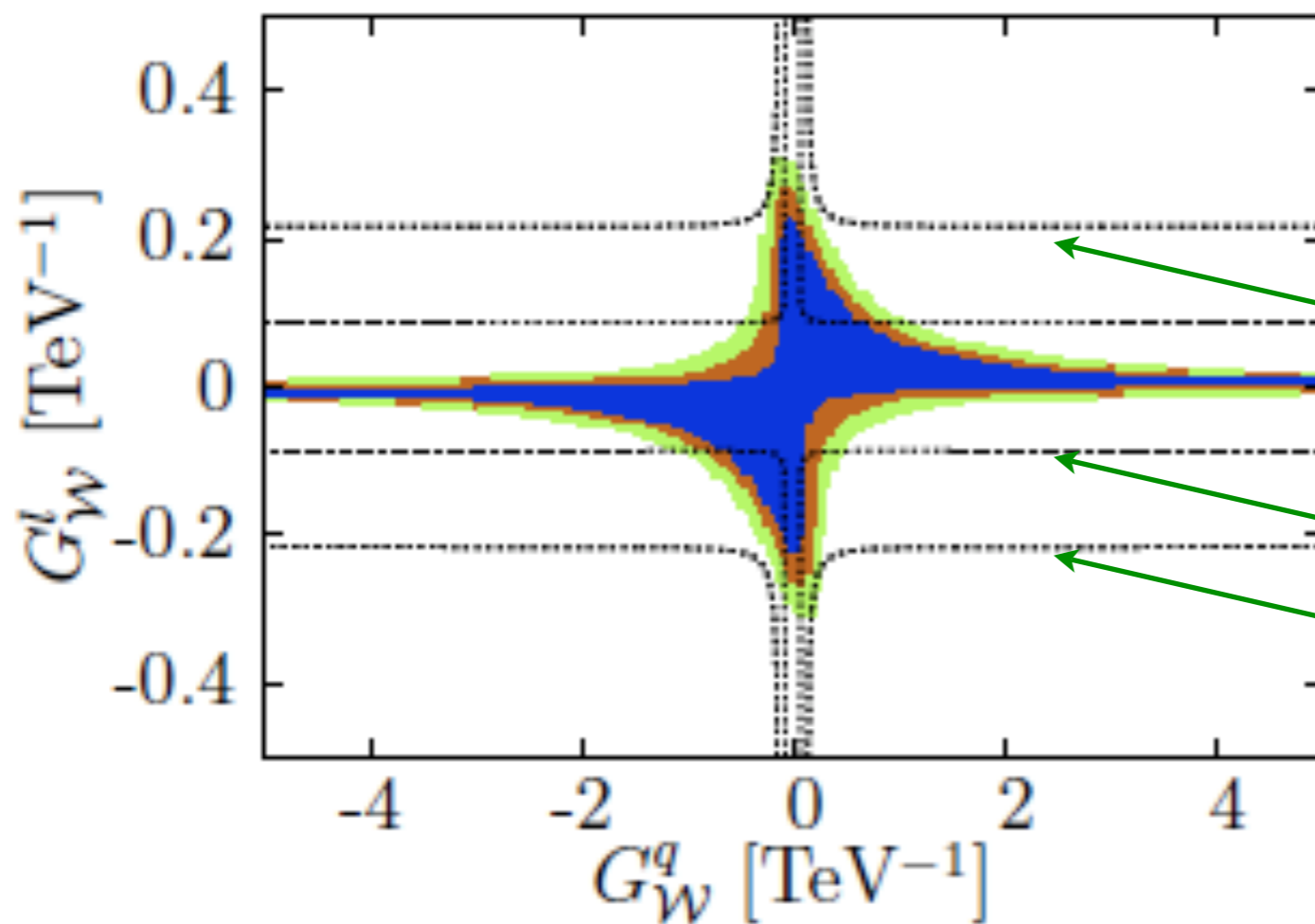


Preserves custodial symmetry ($\rho=1$), but mixings constraint for significant lepton couplings, $\varphi \lesssim 0.01$ and also by perturbativity, $\varphi \lesssim 0.1$

Triplets $\mathcal{W} \in (1, 3)_0 \rightarrow Z', W^\pm$

(Universal) Couplings g_q, g_l

EWPT with Higgs at 126 GeV



Constant

$$\tilde{g} = \frac{2}{g_q g_l} \sqrt{3g_q^2 + g_l^2}$$

LHC searches

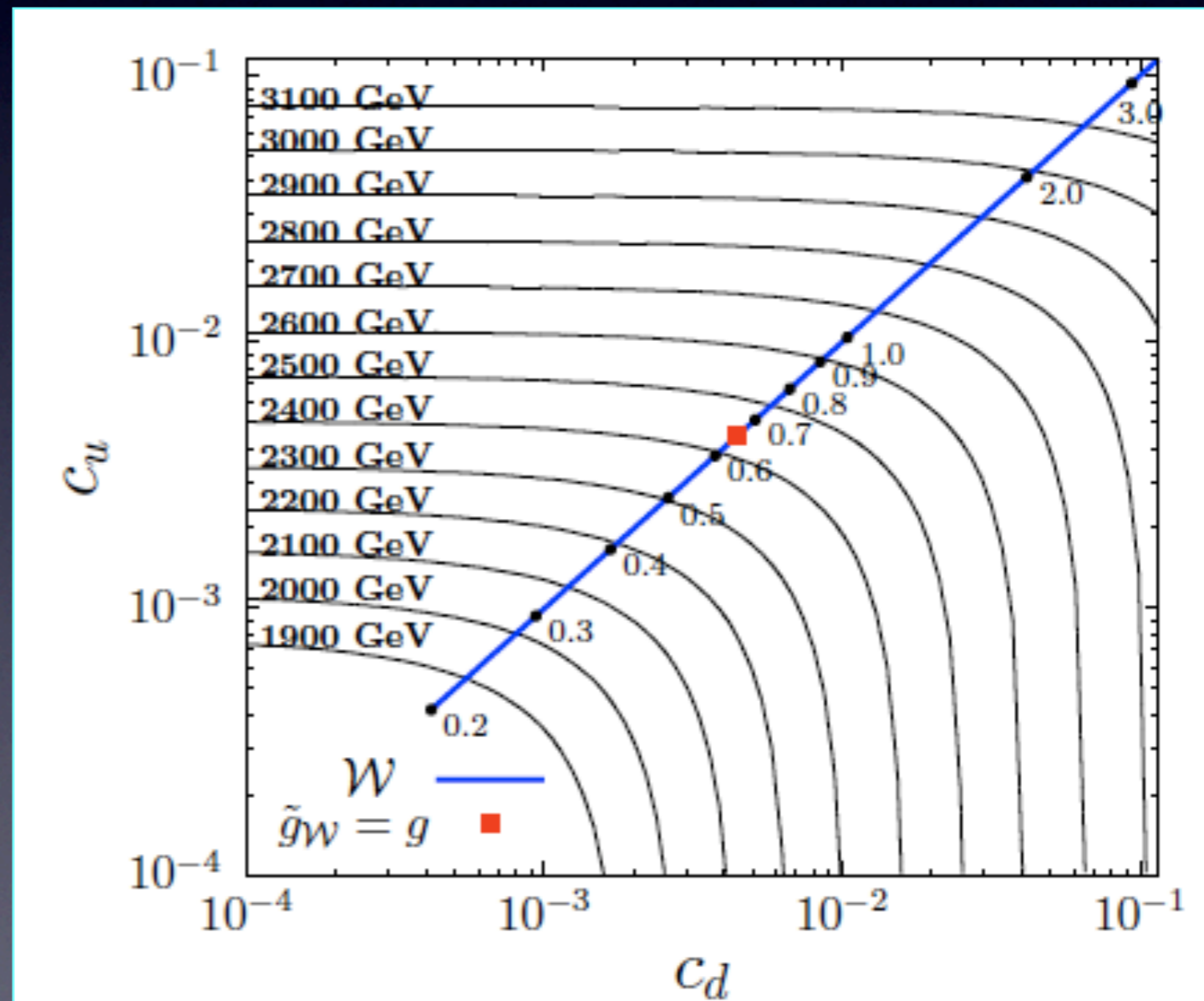
$$\sigma(pp \rightarrow l^+l^-) = \frac{\pi}{6s} [c_u \omega_u(s, m_{Z'}^2) + c_d \omega_d(s, m_{Z'}^2)]$$

$$\sigma(pp \rightarrow l^\pm \nu) = \frac{\pi}{6s} c_c \omega_c(s, m_{W'}^2) \quad \text{NWA}$$

$$c_{u,d} = \frac{\tilde{g}^2}{96}$$

$$c_c = \frac{\tilde{g}^2}{24}$$

$$\tilde{g} = \frac{2}{g_q g_l} \sqrt{3g_q^2 + g_l^2}$$



Singlet + Triplet $\mathcal{W} \in (1, 3)_0$ \rightarrow $W^\pm,$
 $\mathcal{B} \in (1, 1)_0$ Z'_1, Z'_2

$$\mathcal{L} \supset g_{\mathcal{W}\mathcal{B}} \mathcal{W}_\mu^a \mathcal{B}^\mu \phi^\dagger \frac{\sigma_a}{2} \phi$$

Neutral mass-eigenstates:

$$Z'_1 = \cos \theta \mathcal{W}^3 - \sin \theta \mathcal{B}$$

$$Z'_2 = \sin \theta \mathcal{W}^3 + \cos \theta \mathcal{B}$$

Eigenmasses:

$$M_{Z'_1}^2 = M_{\mathcal{W}}^2 - \Delta \sin^2 \theta$$

$$M_{Z'_2}^2 = M_{\mathcal{W}}^2 + \Delta \cos^2 \theta$$

$$\tan 2\theta = \frac{g_{\mathcal{W}\mathcal{B}} v^2}{2(M_{\mathcal{B}}^2 - M_{\mathcal{W}}^2)}$$

$$|\Delta| = \sqrt{(M_{\mathcal{B}}^2 - M_{\mathcal{W}}^2)^2 + g_{\mathcal{W}\mathcal{B}}^2 \frac{v^4}{4}}$$

Singlet + Triplet

$$\mathcal{W} \in (1, 3)_0$$

$$\mathcal{B} \in (1, 1)_0$$



$$W^\pm,$$

$$Z'_1, Z'_2$$

Scenario 1

$$|M_{\mathcal{B}}^2 - M_{\mathcal{W}}^2| \gg v^2$$

$$Z'_2 \simeq Z_{\mathcal{B}}$$

$$W'$$

$$Z'_1 \simeq Z'_{\mathcal{W}}$$

Scenario 2

$$|M_{\mathcal{B}}^2 - M_{\mathcal{W}}^2| \sim v^2$$

$$Z'_2$$

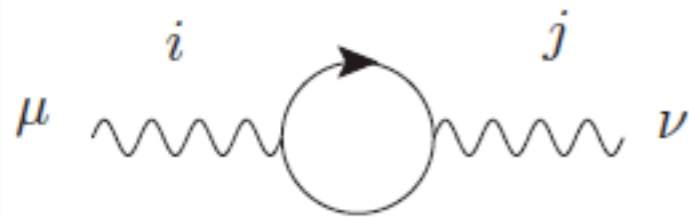
$$W'$$

$$Z'_1$$

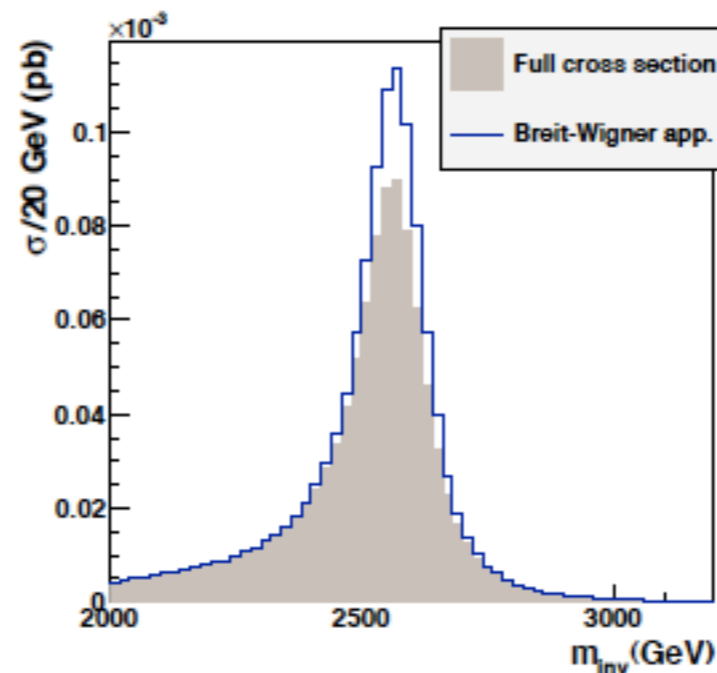
Interference

- Charged sector as in triplet
- Neutral sector \rightarrow Interference

- standard Breit-Wigner not valid [Cacciapaglia, Deandrea, De Curtis, '09]
- non-diagonal imaginary terms



$$P_{\mu\nu} = -i \left[p^2 \delta_{ij} - M_{ij}^2 - i \text{Im} \Pi_{ij}^T(p^2) \right]^{-1} \left[g_{\mu\nu} - \frac{p_\mu p_\nu}{p^2} \right]$$



Generalized NWA taking interference into account

$$c_q = \frac{1}{6\pi \text{Tr}\Sigma} \left\{ \text{Tr} [G_l G_q] + \frac{\text{Tr} [G_l \tilde{\Sigma} G_q \tilde{\Sigma}]}{\det \Sigma} \right\}$$

$$G_{ij}^f = \frac{1}{2} \left[(g_L^f)_i (g_L^f)_j + (g_R^f)_i (g_R^f)_j \right]$$

$$\Sigma_{ij} = \frac{1}{12\pi} \sum_{f=u,d,e,\nu} G_{ij}^f \quad \tilde{\Sigma}_{ij} = \epsilon_{jkm} \epsilon_{in} \Sigma_{mn}$$

Example: Generalized Sequential Model

$$[SU(2) \times U(1)]^2 \rightarrow SU(2) \times U(1)$$

Tuning
(extra dims) $\longrightarrow \mu_{\mathcal{W}} = \mu_{\mathcal{B}}$ (Scenario 2)

- Mass matrix: shifted version of SM
- Couplings of (W', Z'_1, Z'_2) equal to the ones of (W, Z, γ) with the replacements

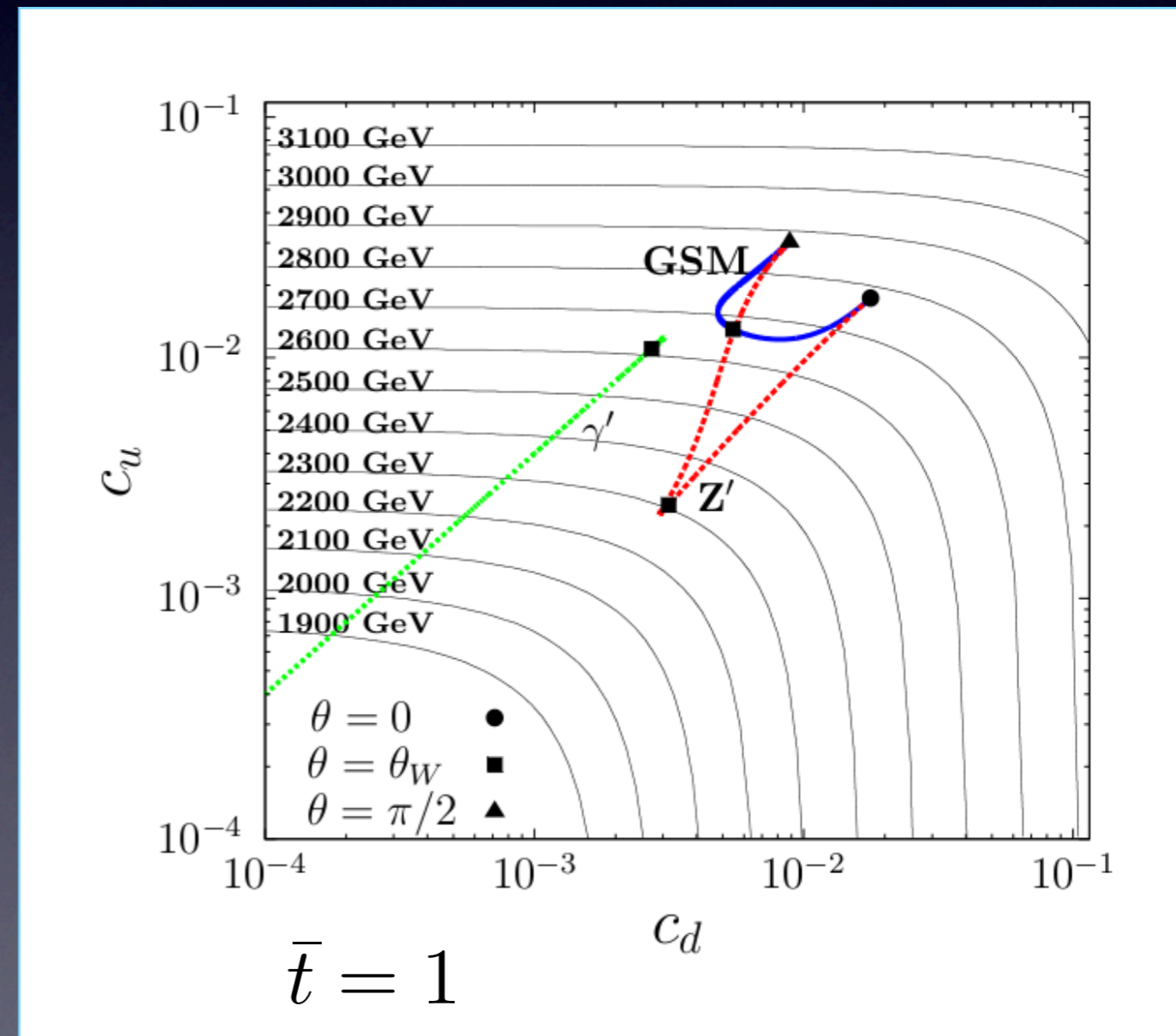
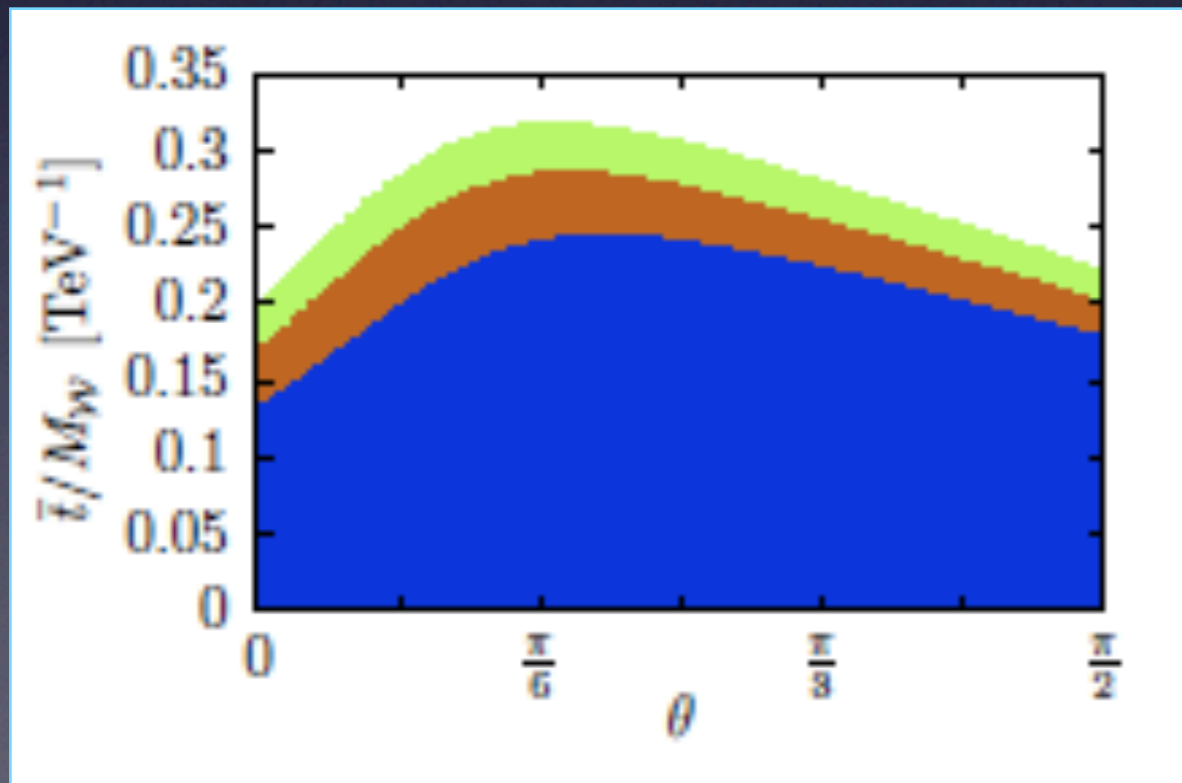
$$g \rightarrow gt, \quad \theta_W \rightarrow \theta \in [0, \pi/2] \quad (g' \rightarrow g't')$$

Example: Generalized Sequential Model

$$[SU(2) \times U(1)]^2 \rightarrow SU(2) \times U(1)$$

$$g \rightarrow gt, \quad \theta_W \rightarrow \theta \in [0, \pi/2] \quad (g' \rightarrow g't')$$

$$\bar{t} \equiv \frac{t + t'}{2}$$



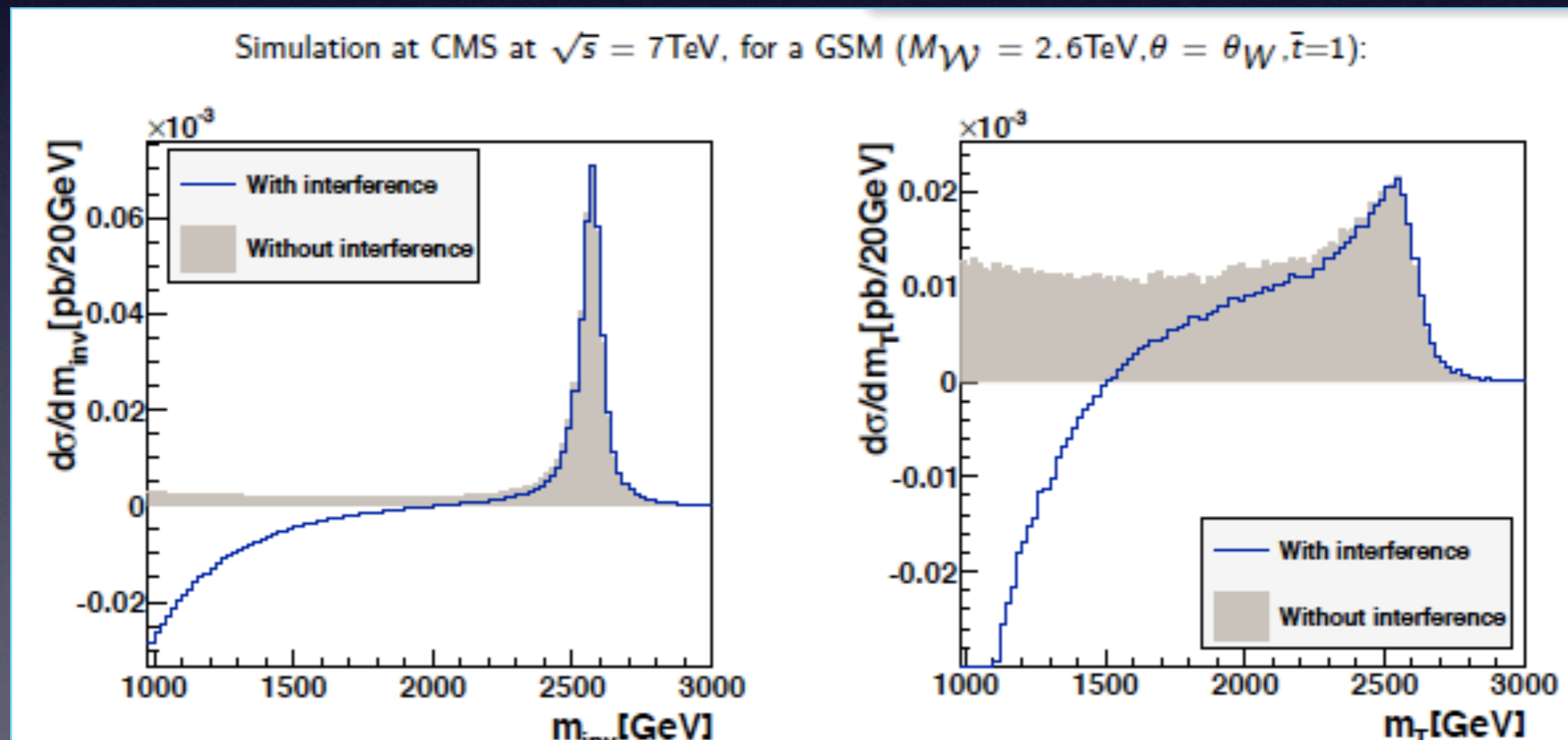
Combined Z' - W' limits

- Vectorial $l+\text{MET}$ resonance comes with vectorial di-lepton resonance(s)
- Nearly-degenerate masses
- Related couplings

Combine $l+\text{MET}$ and di-lepton data in a single likelihood

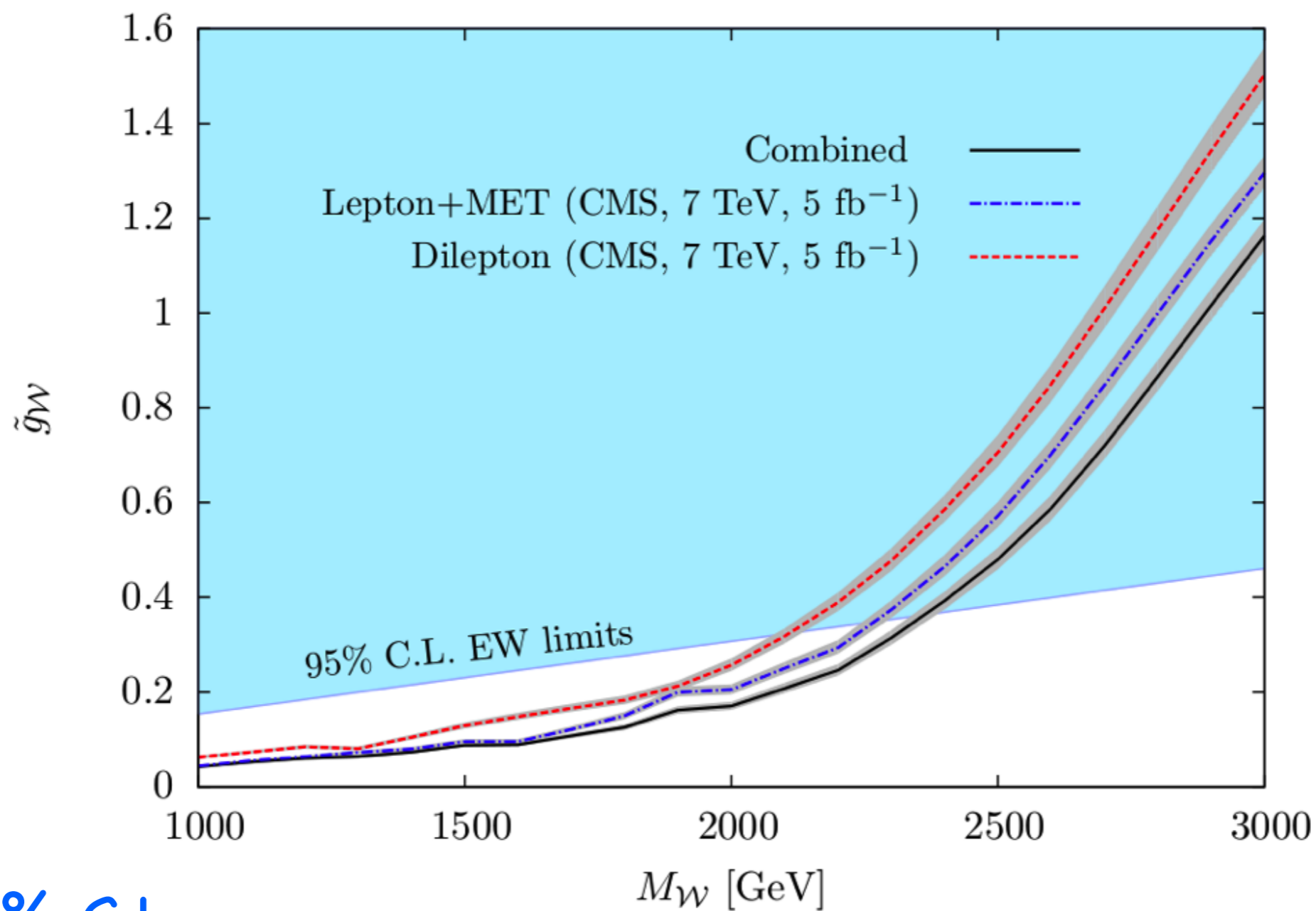
Combined Z' - W' limits

- Data from CMS, 5 fb^{-1} , 7 TeV
- Montecarlo based on Madgraph-Pythia-PGS
- Interference of nearby heavy resonances
- Interference with SM amplitudes



Combined Z' - W' limits

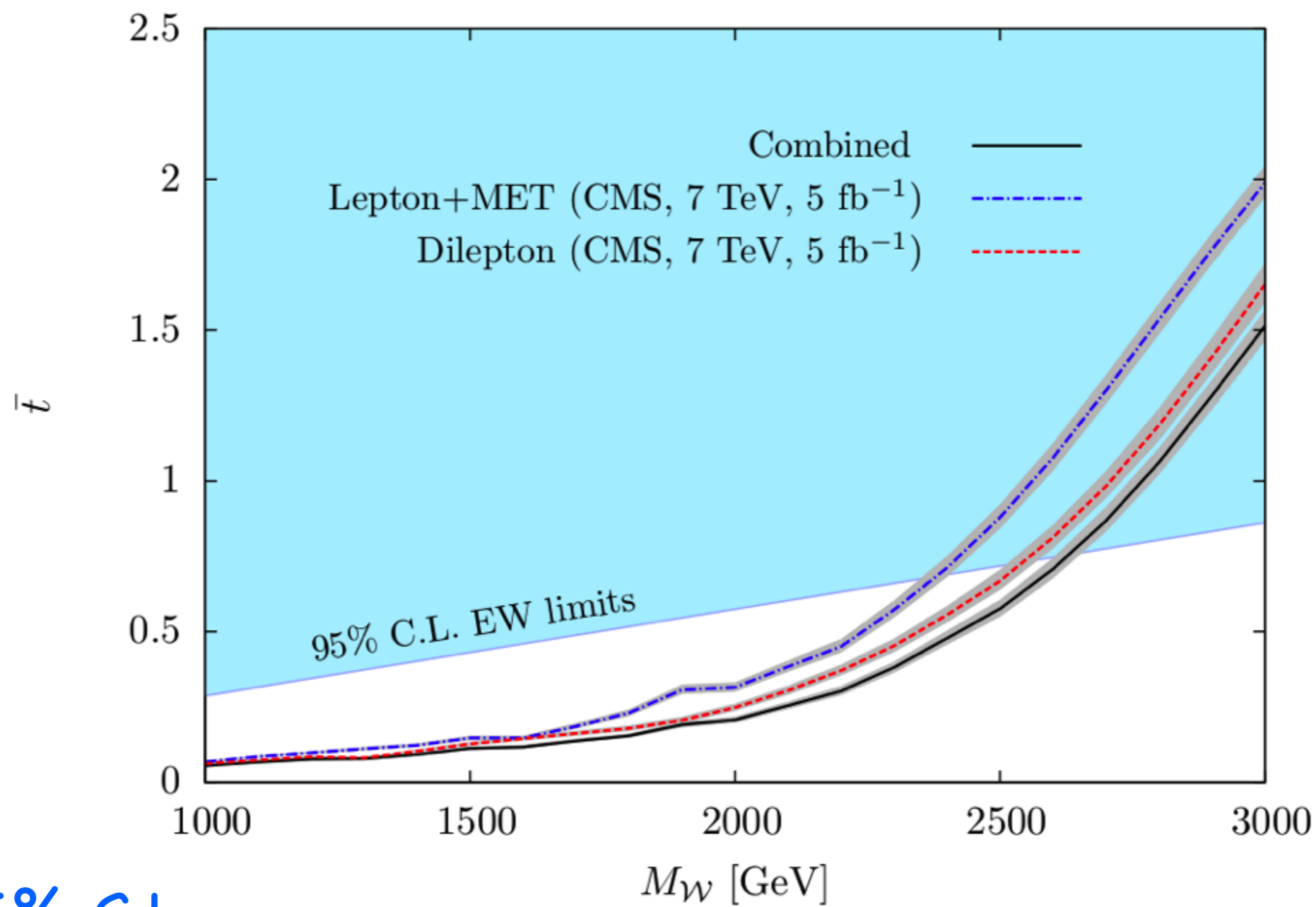
Triplet with $g_q = g_l$



95% C.L.

Combined Z' - W' limits

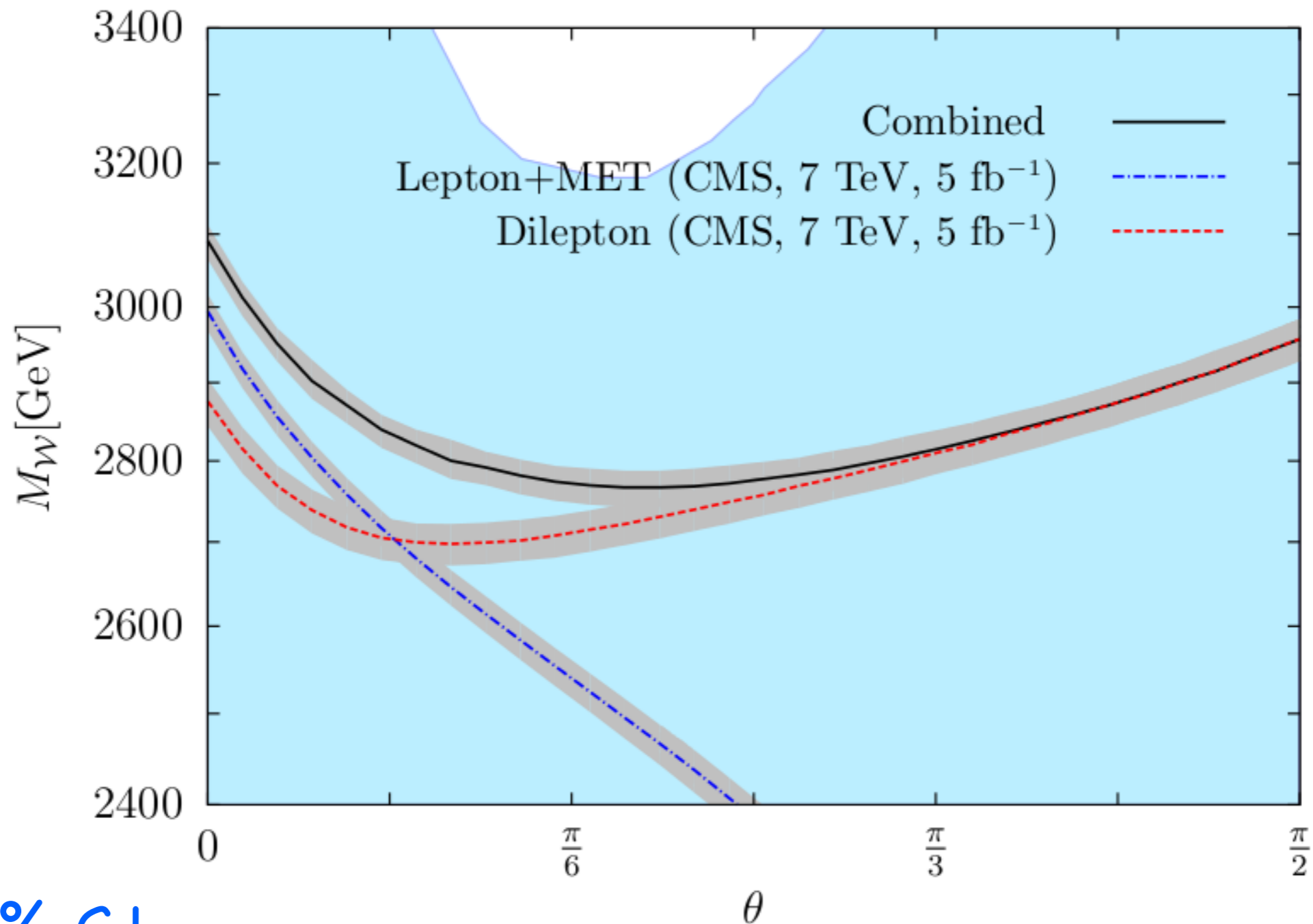
GSM with $\theta = \theta_W$



95% C.L.

Combined Z' - W' limits

GSM with $\bar{t} = 1$



95% C.L.

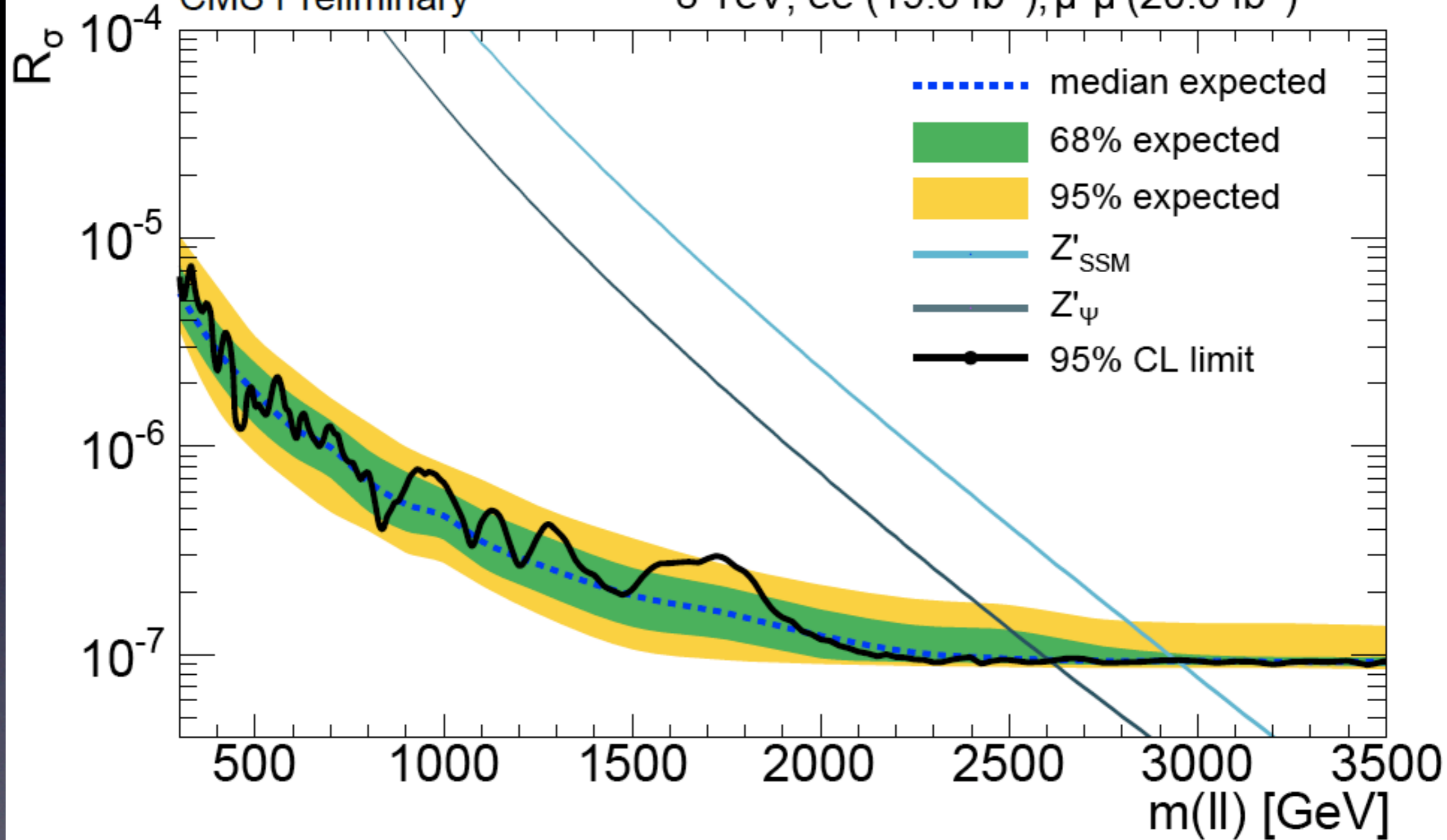
Conclusions

- W' decaying into charged lepton-neutrino is accompanied by Z' of similar mass decaying into two charged leptons
- Combination of neutral and charged channels improves individual limits
- EWPT competitive with LHC for large couplings /masses

K C A B

CMS Preliminary

8 TeV, ee (19.6 fb⁻¹), μ⁺μ⁻ (20.6 fb⁻¹)



CMS preliminary, 20 fb⁻¹, 2012, $\sqrt{s} = 8$ TeV

