A_{FB} in the SMEFT: precision Z physics at the LHC

Víctor Bresó-Pla

IFIC, CSIC/U. Valencia

In collaboration with

Adam Falkowski and Martín González-Alonso

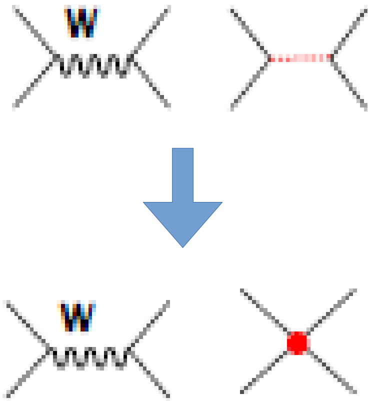
arXiv:[2103.12074]

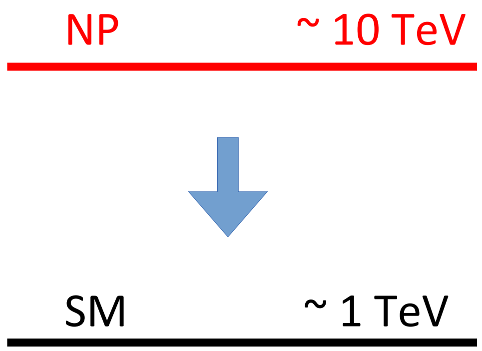
Introduction

Problem: Blind direction in the SMEFT EW global fit at the Z boson sector

Introduction

Problem: Blind direction in the SMEFT EW global fit at the Z boson sector



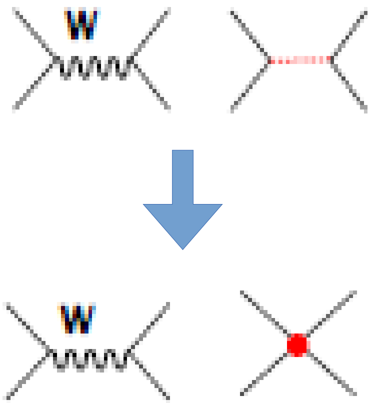


$$\mathcal{L} = \mathcal{L}(\phi, \phi_\Lambda)$$

$$\mathcal{L}_{SMEFT} = \mathcal{L}_{SM} + \frac{1}{\Lambda^2} \sum_i c_i O_i^{d=6}$$

Introduction

Problem: Blind direction in the SMEFT EW global fit at the Z boson sector



NP ~ 10 TeV

SM ~ 1 TeV

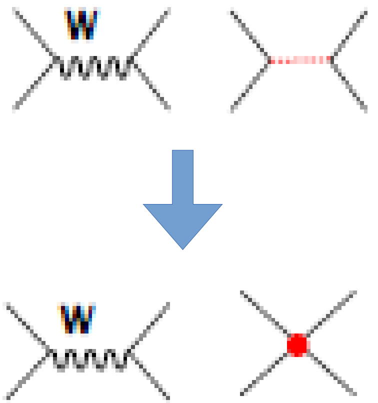
$$\mathcal{L} = \mathcal{L}(\phi, \phi_\Lambda)$$

$$\mathcal{L}_{SMEFT} = \mathcal{L}_{SM} + \frac{1}{\Lambda^2}\sum_i c_i O_i^{d=6}$$

- A **global fit** attempts to set limits for all SMEFT parameters at the same time

Introduction

Problem: Blind direction in the SMEFT EW global fit at the Z boson sector



NP ~ 10 TeV

↓

SM ~ 1 TeV

$$\mathcal{L} = \mathcal{L}(\phi, \phi_\Lambda)$$

↓

$$\mathcal{L}_{SMEFT} = \mathcal{L}_{SM} + \frac{1}{\Lambda^2}\sum_i c_i O_i^{d=6}$$

- A **global fit** attempts to set limits for all SMEFT parameters at the same time
  1. Very precise measurements and theory predictions
  2. Focus on an observable sector → **W and Z pole observables**

Theory framework

Z and W pole observables are mainly sensitive to non-derivative interactions between EW bosons and fermions:

$$\begin{aligned}
\mathcal{L}_{\rm SMEFT} \supset & -\frac{g_L}{\sqrt{2}}\left(W_\mu^+ \bar{u}_L \gamma_\mu (V + \delta g_L^{Wq}) d_L + W_\mu^+ \bar{u}_R \gamma_\mu \delta g_R^{Wq} d_R + \text{h.c.}\right) \\
& -\frac{g_L}{\sqrt{2}}\left(W_\mu^+ \bar{\nu}_L \gamma_\mu (\mathbf{I} + \delta g_L^{We}) e_L + \text{h.c.}\right) \\
& -\sqrt{g_L^2 + g_Y^2}\, Z_\mu \left[\sum_{f \in u,d,e,\nu} \bar{f}_L \gamma_\mu \left((T_f^3 - s_\theta^2 Q_f)\,\mathbf{I} + \delta g_L^{Zf}\right) f_L\right] \\
& -\sqrt{g_L^2 + g_Y^2}\, Z_\mu \left[\sum_{f \in u,d,e} \bar{f}_R \gamma_\mu \left(-s_\theta^2 Q_f\,\mathbf{I} + \delta g_R^{Zf}\right) f_R\right]
\end{aligned}$$

$$\mathcal{L}_{\rm SMEFT} \supset \frac{g_L^2 v^2}{4}(1+\delta m_w)^2 W_\mu^+ W_\mu^- + \frac{(g_L^2 + g_Y^2) v^2}{8} Z_\mu Z_\mu$$

Theory framework

Z and W pole observables are mainly sensitive to non-derivative interactions between EW bosons and fermions:

$$
\begin{aligned}
\mathcal{L}_{\text{SMEFT}} \supset & -\frac{g_L}{\sqrt{2}}\left(W_\mu^+ \bar{u}_L \gamma_\mu (V + \delta g_L^{Wq}) d_L + W_\mu^+ \bar{u}_R \gamma_\mu \delta g_R^{Wq} d_R + \text{h.c.}\right) \\
& -\frac{g_L}{\sqrt{2}}\left(W_\mu^+ \bar{\nu}_L \gamma_\mu (\mathbf{I} + \delta g_L^{We}) e_L + \text{h.c.}\right) \\
& -\sqrt{g_L^2 + g_Y^2} Z_\mu \left[\sum_{f \in u,d,e,\nu} \bar{f}_L \gamma_\mu ((T_f^3 - s_\theta^2 Q_f)\,\mathbf{I} + \delta g_L^{Zf}) f_L\right] \\
& -\sqrt{g_L^2 + g_Y^2} Z_\mu \left[\sum_{f \in u,d,e} \bar{f}_R \gamma_\mu (-s_\theta^2 Q_f\,\mathbf{I} + \delta g_R^{Zf}) f_R\right]
\end{aligned}
$$

Flavor-general corrections!!

$$
\mathcal{L}_{\text{SMEFT}} \supset \frac{g_L^2 v^2}{4}(1 + \delta m_w)^2 W_\mu^+ W_\mu^- + \frac{(g_L^2 + g_Y^2) v^2}{8} Z_\mu Z_\mu
$$

[Efrati, Falkowski & Soreq '15; Falkowski & Mimouni '15; Falkowski, González-Alonso & Mimouni '17; Aebischer et al. '18; …]

Theory framework

Z and W pole observables are mainly sensitive to non-derivative interactions between EW bosons and fermions:

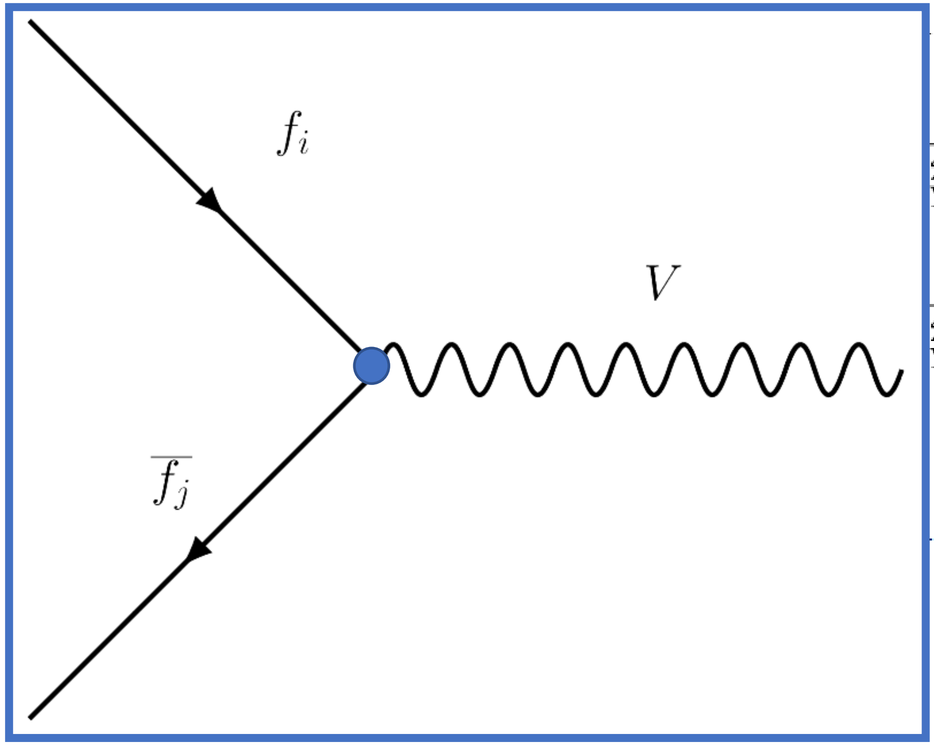
$$\mathcal{L}_{\text{SMEFT}} \supset -\frac{g_L}{\sqrt{2}}\left(W_\mu^+ \bar{u}_L \gamma_\mu (V + \delta g_L^{Wq}) d_L + W_\mu^+ \bar{u}_R \gamma_\mu \delta g_R^{Wq} d_R + \text{h.c.}\right)$$

$$\bar{\nu}_L \gamma_\mu (\mathbf{I} + \delta g_L^{We}) e_L + \text{h.c.})$$

$$\frac{}{}{}^{2}_{Y} Z_\mu \left[\sum_{f \in u,d,e,\nu} \bar{f}_L \gamma_\mu ((T_f^3 - s_\theta^2 Q_f)\,\mathbf{I} + \delta g_L^{Zf}) f_L\right]$$

$$\frac{}{}{}^{2}_{Y} Z_\mu \left[\sum_{f \in u,d,e} \bar{f}_R \gamma_\mu (-s_\theta^2 Q_f\,\mathbf{I} + \delta g_R^{Zf}) f_R\right]$$

$$\delta m_w)^2 W_\mu^+ W_\mu^- + \frac{(g_L^2 + g_Y^2) v^2}{8} Z_\mu Z_\mu$$



Flavor-general corrections!!

[Efrati, Falkowski & Soreq '15; Falkowski & Mimouni '15; Falkowski, González-Alonso & Mimouni '17; Aebischer et al. '18; …]

Theory framework

Z and W pole observables are mainly sensitive to non-derivative interactions between EW bosons and fermions:

$$
\begin{aligned}
\mathcal{L}_{\text{SMEFT}} \supset & -\frac{g_L}{\sqrt{2}}\left(W_\mu^+ \bar{u}_L \gamma_\mu (V + \delta g_L^{Wq}) d_L + W_\mu^+ \bar{u}_R \gamma_\mu \delta g_R^{Wq} d_R + \text{h.c.}\right) \\
& -\frac{g_L}{\sqrt{2}}\left(W_\mu^+ \bar{\nu}_L \gamma_\mu (\mathbf{I} + \delta g_L^{We}) e_L + \text{h.c.}\right) \\
& -\sqrt{g_L^2 + g_Y^2} Z_\mu \left[\sum_{f \in u,d,e,\nu} \bar{f}_L \gamma_\mu ((T_f^3 - s_\theta^2 Q_f)\mathbf{I} + \delta g_L^{Zf}) f_L\right] \\
& -\sqrt{g_L^2 + g_Y^2} Z_\mu \left[\sum_{f \in u,d,e} \bar{f}_R \gamma_\mu (-s_\theta^2 Q_f \mathbf{I} + \delta g_R^{Zf}) f_R\right]
\end{aligned}
$$

$$
\mathcal{L}_{\text{SMEFT}} \supset \frac{g_L^2 v^2}{4}(1 + \delta m_w)^2 W_\mu^+ W_\mu^- + \frac{(g_L^2 + g_Y^2)v^2}{8} Z_\mu Z_\mu
$$

We end up with only 20 independent parameters

$$
\delta g_L^{We},\ \delta g_L^{W\mu},\ \delta g_L^{W\tau},\ \delta g_{L/R}^{Ze},\ \delta g_{L/R}^{Z\mu},\ \delta g_{L/R}^{Z\tau},\ \delta g_{L/R}^{Zd},\ \delta g_{L/R}^{Zs},\ \delta g_{L/R}^{Zb},\ \delta g_{L/R}^{Zu},\ \delta g_{L/R}^{Zc},\ \delta m_w
$$

Traditional pole observables

Observable	Experimental value	SM prediction	Definition
Γ_Z [GeV]	2.4955 ± 0.0023 [4, 28]	2.4941	$\sum_f \Gamma(Z \to f\bar{f})$
$\sigma_{\rm had}$ [nb]	41.4802 ± 0.0325 [4, 28]	41.4842	$\frac{12\pi}{m_Z^2}\frac{\Gamma(Z\to e^+e^-)\Gamma(Z\to q\bar{q})}{\Gamma_Z^2}$
R_e	20.804 ± 0.050 [4]	20.734	$\frac{\sum_q \Gamma(Z\to q\bar{q})}{\Gamma(Z\to e^+e^-)}$
R_μ	20.785 ± 0.033 [4]	20.734	$\frac{\sum_q \Gamma(Z\to q\bar{q})}{\Gamma(Z\to \mu^+\mu^-)}$
R_τ	20.764 ± 0.045 [4]	20.781	$\frac{\sum_q \Gamma(Z\to q\bar{q})}{\Gamma(Z\to \tau^+\tau^-)}$
$A_{\rm FB}^{0,e}$	0.0145 ± 0.0025 [4]	0.0162	$\frac{3}{4}A_e^2$
$A_{\rm FB}^{0,\mu}$	0.0169 ± 0.0013 [4]	0.0162	$\frac{3}{4}A_e A_\mu$
$A_{\rm FB}^{0,\tau}$	0.0188 ± 0.0017 [4]	0.0162	$\frac{3}{4}A_e A_\tau$
R_b	0.21629 ± 0.00066 [4]	0.21581	$\frac{\Gamma(Z\to b\bar{b})}{\sum_q \Gamma(Z\to q\bar{q})}$
R_c	0.1721 ± 0.0030 [4]	0.17222	$\frac{\Gamma(Z\to c\bar{c})}{\sum_q \Gamma(Z\to q\bar{q})}$
$A_b^{\rm FB}$	0.0996 ± 0.0016 [4, 29]	0.1032	$\frac{3}{4}A_e A_b$
$A_c^{\rm FB}$	0.0707 ± 0.0035 [4]	0.0736	$\frac{3}{4}A_e A_c$
A_e	0.1516 ± 0.0021 [4]	0.1470	$\frac{\Gamma(Z\to e_L^+e_L^-)-\Gamma(Z\to e_R^+e_R^-)}{\Gamma(Z\to e^+e^-)}$
A_μ	0.142 ± 0.015 [4]	0.1470	$\frac{\Gamma(Z\to \mu_L^+\mu_L^-)-\Gamma(Z\to \mu_R^+\mu_R^-)}{\Gamma(Z\to \mu^+\mu^-)}$
A_τ	0.136 ± 0.015 [4]	0.1470	$\frac{\Gamma(Z\to \tau_L^+\tau_L^-)-\Gamma(Z\to \tau_R^+\tau_R^-)}{\Gamma(Z\to \tau^+\tau^-)}$
A_e	0.1498 ± 0.0049 [4]	0.1470	$\frac{\Gamma(Z\to e_L^+e_L^-)-\Gamma(Z\to e_R^+e_R^-)}{\Gamma(Z\to e^+e^-)}$
A_τ	0.1439 ± 0.0043 [4]	0.1470	$\frac{\Gamma(Z\to \tau_L^+\tau_L^-)-\Gamma(Z\to \tau_R^+\tau_R^-)}{\Gamma(Z\to \tau^+\tau^-)}$
A_b	0.923 ± 0.020 [4]	0.935	$\frac{\Gamma(Z\to b_L\bar{b}_L)-\Gamma(Z\to b_R\bar{b}_R)}{\Gamma(Z\to b\bar{b})}$
A_c	0.670 ± 0.027 [4]	0.668	$\frac{\Gamma(Z\to c_L\bar{c}_L)-\Gamma(Z\to c_R\bar{c}_R)}{\Gamma(Z\to c\bar{c})}$
A_s	0.895 ± 0.091 [30]	0.936	$\frac{\Gamma(Z\to s_L\bar{s}_L)-\Gamma(Z\to s_R\bar{s}_R)}{\Gamma(Z\to s\bar{s})}$
R_{uc}	0.166 ± 0.009 [9]	0.1722	$\frac{\Gamma(Z\to u\bar{u})+\Gamma(Z\to c\bar{c})}{2\sum_q \Gamma(Z\to q\bar{q})}$

Observable	Experimental value	SM prediction
m_W [GeV]	80.379 ± 0.012 [9]	80.356
Γ_W [GeV]	2.085 ± 0.042 [9]	2.088
$\mathrm{Br}(W \to e\nu)$	0.1071 ± 0.0016 [5]	0.1082
$\mathrm{Br}(W \to \mu\nu)$	0.1063 ± 0.0015 [5]	0.1082
$\mathrm{Br}(W \to \tau\nu)$	0.1138 ± 0.0021 [5]	0.1081
$\mathrm{Br}(W \to \mu\nu)/\mathrm{Br}(W \to e\nu)$	0.982 ± 0.024 [32]	1.000
$\mathrm{Br}(W \to \mu\nu)/\mathrm{Br}(W \to e\nu)$	1.020 ± 0.019 [12]	1.000
$\mathrm{Br}(W \to \mu\nu)/\mathrm{Br}(W \to e\nu)$	1.003 ± 0.010 [13]	1.000
$\mathrm{Br}(W \to \tau\nu)/\mathrm{Br}(W \to e\nu)$	0.961 ± 0.061 [9, 31]	0.999
$\mathrm{Br}(W \to \tau\nu)/\mathrm{Br}(W \to \mu\nu)$	0.992 ± 0.013 [14]	0.999
$R_{Wc} \equiv \frac{\Gamma(W\to cs)}{\Gamma(W\to ud)+\Gamma(W\to cs)}$	0.49 ± 0.04 [9]	0.50

Traditional pole observables

- Leptonic couplings:

$$[\delta g_L^{We}]_{ii} = \begin{pmatrix} -1.3 \pm 3.2 \\ -2.8 \pm 2.6 \\ 1.5 \pm 4.0 \end{pmatrix} \times 10^{-3} \qquad [\delta g_R^{Ze}]_{ii} = \begin{pmatrix} -0.43 \pm 0.27 \\ 0.0 \pm 1.4 \\ 0.62 \pm 0.62 \end{pmatrix} \times 10^{-3}$$

$$[\delta g_L^{Ze}]_{ii} = \begin{pmatrix} -0.19 \pm 0.28 \\ 0.1 \pm 1.2 \\ -0.09 \pm 0.59 \end{pmatrix} \times 10^{-3}$$

- W mass correction:

$$\delta m_w = (2.9 \pm 1.6) \times 10^{-4}$$

- s, *c*, *b* couplings:

$$\delta g_L^{Zs} = (1.3 \pm 4.1) \times 10^{-2} \qquad \delta g_R^{Zs} = (2.2 \pm 5.6) \times 10^{-2}$$

$$\delta g_L^{Zc} = (-1.3 \pm 3.7) \times 10^{-3} \qquad \delta g_R^{Zc} = (-3.2 \pm 5.4) \times 10^{-3}$$

$$\delta g_L^{Zb} = (3.1 \pm 1.7) \times 10^{-3} \qquad \delta g_R^{Zb} = (21.8 \pm 8.8) \times 10^{-3}$$

[Update of Efrati, Falkowski & Soreq ‘15]

Traditional pole observables

- Leptonic couplings:

$$[\delta g_L^{We}]_{ii} = \begin{pmatrix} -1.3 \pm 3.2 \\ -2.8 \pm 2.6 \\ 1.5 \pm 4.0 \end{pmatrix} \times 10^{-3} \qquad [\delta g_R^{Ze}]_{ii} = \begin{pmatrix} -0.43 \pm 0.27 \\ 0.0 \pm 1.4 \\ 0.62 \pm 0.62 \end{pmatrix} \times 10^{-3}$$

$$[\delta g_L^{Ze}]_{ii} = \begin{pmatrix} -0.19 \pm 0.28 \\ 0.1 \pm 1.2 \\ -0.09 \pm 0.59 \end{pmatrix} \times 10^{-3}$$

- W mass correction:

$$\delta m_w = (2.9 \pm 1.6) \times 10^{-4}$$

What about Zuu and Zdd corrections?

- s, c, b couplings:

$$\delta g_L^{Zs} = (1.3 \pm 4.1) \times 10^{-2} \qquad \delta g_R^{Zs} = (2.2 \pm 5.6) \times 10^{-2}$$

$$\delta g_L^{Zc} = (-1.3 \pm 3.7) \times 10^{-3} \qquad \delta g_R^{Zc} = (-3.2 \pm 5.4) \times 10^{-3}$$

$$\delta g_L^{Zb} = (3.1 \pm 1.7) \times 10^{-3} \qquad \delta g_R^{Zb} = (21.8 \pm 8.8) \times 10^{-3}$$

[Update of Efrati, Falkowski & Soreq ‘15]

Traditional pole observables

One linear combination of up and down quark vertex corrections is unconstrained:

$$\delta g_L^{Zu} + \delta g_L^{Zd} + \frac{3g_L^2 - g_Y^2}{4g_Y^2}\delta g_R^{Zu} + \frac{3g_L^2 + g_Y^2}{2g_Y^2}\delta g_R^{Zd}$$

Traditional pole observables

One linear combination of up and down quark vertex corrections is unconstrained:

$$\delta g_L^{Zu} + \delta g_L^{Zd} + \frac{3g_L^2 - g_Y^2}{4g_Y^2}\delta g_R^{Zu} + \frac{3g_L^2 + g_Y^2}{2g_Y^2}\delta g_R^{Zd}$$

It is useful to rearrange these 4 couplings so that we can separate the blind direction from the rest of the parameter space:

$$\begin{pmatrix} x \\ y \\ z \\ t \end{pmatrix} = R \begin{pmatrix} \delta g_L^{Zu} \\ \delta g_R^{Zu} \\ \delta g_L^{Zd} \\ \delta g_R^{Zd} \end{pmatrix} = \begin{pmatrix} 0.93 & -0.29 & -0.23 & -0.01 \\ 0.18 & 0.87 & -0.33 & -0.33 \\ 0.27 & 0.18 & 0.90 & -0.29 \\ 0.17 & 0.37 & 0.17 & 0.90 \end{pmatrix} \begin{pmatrix} \delta g_L^{Zu} \\ \delta g_R^{Zu} \\ \delta g_L^{Zd} \\ \delta g_R^{Zd} \end{pmatrix}$$

$$\begin{pmatrix} x \\ y \\ z \end{pmatrix} = \begin{pmatrix} -0.9 \pm 1.8 \\ 0.3 \pm 3.3 \\ -2.4 \pm 4.8 \end{pmatrix} \times 10^{-2}$$

Traditional pole observables

One linear combination of up and down quark vertex corrections is unconstrained:

$$\delta g_L^{Zu} + \delta g_L^{Zd} + \frac{3g_L^2 - g_Y^2}{4g_Y^2}\delta g_R^{Zu} + \frac{3g_L^2 + g_Y^2}{2g_Y^2}\delta g_R^{Zd}$$

It is useful to rearrange these 4 couplings so that we can separate the blind direction from the rest of the parameter space:

$$\begin{pmatrix} x \\ y \\ z \\ t \end{pmatrix} = R \begin{pmatrix} \delta g_L^{Zu} \\ \delta g_R^{Zu} \\ \delta g_L^{Zd} \\ \delta g_R^{Zd} \end{pmatrix} = \begin{pmatrix} 0.93 & -0.29 & -0.23 & -0.01 \\ 0.18 & 0.87 & -0.33 & -0.33 \\ 0.27 & 0.18 & 0.90 & -0.29 \\ 0.17 & 0.37 & 0.17 & 0.90 \end{pmatrix} \begin{pmatrix} \delta g_L^{Zu} \\ \delta g_R^{Zu} \\ \delta g_L^{Zd} \\ \delta g_R^{Zd} \end{pmatrix}$$

$$\begin{pmatrix} x \\ y \\ z \end{pmatrix} = \begin{pmatrix} -0.9 \pm 1.8 \\ 0.3 \pm 3.3 \\ -2.4 \pm 4.8 \end{pmatrix} \times 10^{-2}$$

***t* unconstrained. Can LHC help?**

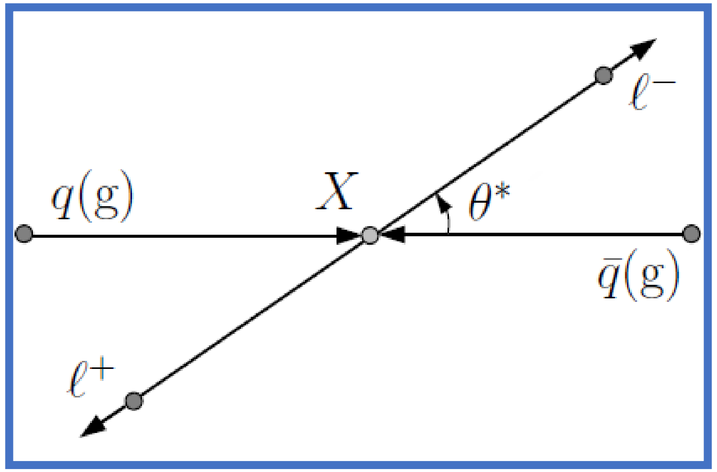
This can be achieved using D0 data [Efrati, Falkowski, Soreq, '15] but with very modest precision: $|t| < 0.2$

Drell-Yan A_{FB} at the LHC

- We find that the cleanest observable for the task at hand is the Drell-Yan forward-backward asymmetry (A_{FB})

$$\frac{d\sigma_{pp}(Y,\hat{s},\cos\theta^*)}{dY\,d\hat{s}\,d\cos\theta^*} \propto \sum_{q=u,d,s,c,b}\left[\hat{\sigma}^{even}_{q\bar{q}}(\hat{s},\cos\theta^*) + D_{q\bar{q}}(Y,\hat{s})\,\hat{\sigma}^{odd}_{q\bar{q}}(\hat{s},\cos\theta^*)\right] F_{q\bar{q}}(Y,\hat{s})$$

$f(Zqq)$



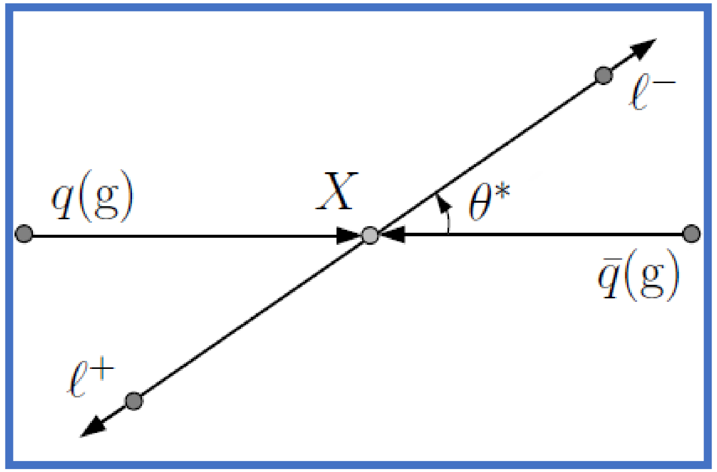
Forward events: $\cos\theta^* > 0$
Backward events: $\cos\theta^* < 0$

Drell-Yan A_{FB} at the LHC

- We find that the cleanest observable for the task at hand is the Drell-Yan forward-backward asymmetry (A_{FB})

$$\frac{d\sigma_{pp}(Y,\hat{s},\cos\theta^*)}{dY\,d\hat{s}\,d\cos\theta^*} \propto \sum_{q=u,d,s,c,b}\left[\hat{\sigma}^{even}_{q\bar{q}}(\hat{s},\cos\theta^*) + D_{q\bar{q}}(Y,\hat{s})\,\hat{\sigma}^{odd}_{q\bar{q}}(\hat{s},\cos\theta^*)\right]F_{q\bar{q}}(Y,\hat{s})$$

$f(Zqq)$



Forward events: $\cos\theta^* > 0$
Backward events: $\cos\theta^* < 0$

$$A_{FB}(Y,\hat{s}) = \frac{\sigma_F(Y,\hat{s}) - \sigma_B(Y,\hat{s})}{\sigma_F(Y,\hat{s}) + \sigma_B(Y,\hat{s})} = SM(1 + \#\delta g_i + \cdots)$$

Drell-Yan A_{FB} at the LHC

$\|Y\|$	Experimental value	SM prediction
0.0 - 0.8	0.0195 ± 0.0015	0.0144 ± 0.0007
0.8 - 1.6	0.0448 ± 0.0016	0.0471 ± 0.0017
1.6 - 2.5	0.0923 ± 0.0026	0.0928 ± 0.0021
2.5 - 3.6	0.1445 ± 0.0046	0.1464 ± 0.0021

Exp. value: [ATLAS-CONF-2018-037 (2018)]
NNLO in QCD SM prediction:
[Bozzi et al., 1007.2351;
Catani et al., 0903.2120;
Catani et al., 1507.06937]

$$A_4 = (3/8) A_{FB}$$

Drell-Yan A_{FB} at the LHC

|Y|	Experimental value	SM prediction
0.0 - 0.8	0.0195 ± 0.0015	0.0144 ± 0.0007
0.8 - 1.6	0.0448 ± 0.0016	0.0471 ± 0.0017
1.6 - 2.5	0.0923 ± 0.0026	0.0928 ± 0.0021
2.5 - 3.6	0.1445 ± 0.0046	0.1464 ± 0.0021

Exp. value: [ATLAS-CONF-2018-037 (2018)]
NNLO in QCD SM prediction:
[Bozzi et al., 1007.2351;
Catani et al., 0903.2120;
Catani et al., 1507.06937]

$$A_4 = (3/8) A_{FB}$$

- **Restrictions from each bin:**

$$0.0 < |Y| < 0.8: \quad 0.63\,\delta g_L^{Zu} + 0.71\,\delta g_R^{Zu} - 0.20\,\delta g_L^{Zd} - 0.22\,\delta g_R^{Zd} = 0.088(29)$$
$$0.8 < |Y| < 1.6: \quad 0.60\,\delta g_L^{Zu} + 0.74\,\delta g_R^{Zu} - 0.18\,\delta g_L^{Zd} - 0.22\,\delta g_R^{Zd} = -0.012(12)$$
$$1.6 < |Y| < 2.5: \quad 0.53\,\delta g_L^{Zu} + 0.80\,\delta g_R^{Zu} - 0.16\,\delta g_L^{Zd} - 0.23\,\delta g_R^{Zd} = -0.0014(92)$$
$$2.5 < |Y| < 3.6: \quad 0.43\,\delta g_L^{Zu} + 0.86\,\delta g_R^{Zu} - 0.18\,\delta g_L^{Zd} - 0.21\,\delta g_R^{Zd} = -0.0030(81)$$

Drell-Yan A_{FB} at the LHC

|Y|	Experimental value	SM prediction
0.0 - 0.8	0.0195 ± 0.0015	0.0144 ± 0.0007
0.8 - 1.6	0.0448 ± 0.0016	0.0471 ± 0.0017
1.6 - 2.5	0.0923 ± 0.0026	0.0928 ± 0.0021
2.5 - 3.6	0.1445 ± 0.0046	0.1464 ± 0.0021

Exp. value: [ATLAS-CONF-2018-037 (2018)]
NNLO in QCD SM prediction:
[Bozzi et al., 1007.2351;
Catani et al., 0903.2120;
Catani et al., 1507.06937]

$A_4 = (3/8)A_{FB}$

- **Restrictions from each bin:**

$$0.0 < |Y| < 0.8: \quad 0.63\,\delta g_L^{Zu} + 0.71\,\delta g_R^{Zu} - 0.20\,\delta g_L^{Zd} - 0.22\,\delta g_R^{Zd} = 0.088(29)$$
$$0.8 < |Y| < 1.6: \quad 0.60\,\delta g_L^{Zu} + 0.74\,\delta g_R^{Zu} - 0.18\,\delta g_L^{Zd} - 0.22\,\delta g_R^{Zd} = -0.012(12)$$
$$1.6 < |Y| < 2.5: \quad 0.53\,\delta g_L^{Zu} + 0.80\,\delta g_R^{Zu} - 0.16\,\delta g_L^{Zd} - 0.23\,\delta g_R^{Zd} = -0.0014(92)$$
$$2.5 < |Y| < 3.6: \quad 0.43\,\delta g_L^{Zu} + 0.86\,\delta g_R^{Zu} - 0.18\,\delta g_L^{Zd} - 0.21\,\delta g_R^{Zd} = -0.0030(81)$$

- **Restrictions on the four uncorrelated and orthonormal linear combinations:**

$$\begin{pmatrix} x' = 0.21\delta g_L^{Zu} + 0.19\delta g_R^{Zu} + 0.46\delta g_L^{Zd} + 0.84\delta g_R^{Zd} \\ y' = 0.03\delta g_L^{Zu} - 0.07\delta g_R^{Zu} - 0.87\delta g_L^{Zd} + 0.49\delta g_R^{Zd} \\ z' = 0.83\delta g_L^{Zu} - 0.54\delta g_R^{Zu} + 0.02\delta g_L^{Zd} - 0.10\delta g_R^{Zd} \\ t' = 0.51\delta g_L^{Zu} + 0.82\delta g_R^{Zu} - 0.17\delta g_L^{Zd} - 0.22\delta g_R^{Zd} \end{pmatrix} = \begin{pmatrix} -10 \pm 4 \\ 0.5 \pm 0.4 \\ 0.04 \pm 0.06 \\ -0.001 \pm 0.005 \end{pmatrix}$$

Drell-Yan A_{FB} at the LHC

|Y|	Experimental value	SM prediction
0.0 - 0.8	0.0195 ± 0.0015	0.0144 ± 0.0007
0.8 - 1.6	0.0448 ± 0.0016	0.0471 ± 0.0017
1.6 - 2.5	0.0923 ± 0.0026	0.0928 ± 0.0021
2.5 - 3.6	0.1445 ± 0.0046	0.1464 ± 0.0021

Exp. value: [ATLAS-CONF-2018-037 (2018)]
NNLO in QCD SM prediction:
[Bozzi et al., 1007.2351;
Catani et al., 0903.2120;
Catani et al., 1507.06937]

$$A_4 = (3/8)A_{FB}$$

- **Restrictions from each bin:**

$$0.0 < |Y| < 0.8: \quad 0.63\,\delta g_L^{Zu} + 0.71\,\delta g_R^{Zu} - 0.20\,\delta g_L^{Zd} - 0.22\,\delta g_R^{Zd} = 0.088(29)$$
$$0.8 < |Y| < 1.6: \quad 0.60\,\delta g_L^{Zu} + 0.74\,\delta g_R^{Zu} - 0.18\,\delta g_L^{Zd} - 0.22\,\delta g_R^{Zd} = -0.012(12)$$
$$1.6 < |Y| < 2.5: \quad 0.53\,\delta g_L^{Zu} + 0.80\,\delta g_R^{Zu} - 0.16\,\delta g_L^{Zd} - 0.23\,\delta g_R^{Zd} = -0.0014(92)$$
$$2.5 < |Y| < 3.6: \quad 0.43\,\delta g_L^{Zu} + 0.86\,\delta g_R^{Zu} - 0.18\,\delta g_L^{Zd} - 0.21\,\delta g_R^{Zd} = -0.0030(81)$$

- **Restrictions on the four uncorrelated and orthonormal linear combinations:**

$$\begin{pmatrix} x' = 0.21\delta g_L^{Zu} + 0.19\delta g_R^{Zu} + 0.46\delta g_L^{Zd} + 0.84\delta g_R^{Zd} \\ y' = 0.03\delta g_L^{Zu} - 0.07\delta g_R^{Zu} - 0.87\delta g_L^{Zd} + 0.49\delta g_R^{Zd} \\ z' = 0.83\delta g_L^{Zu} - 0.54\delta g_R^{Zu} + 0.02\delta g_L^{Zd} - 0.10\delta g_R^{Zd} \\ t' = 0.51\delta g_L^{Zu} + 0.82\delta g_R^{Zu} - 0.17\delta g_L^{Zd} - 0.22\delta g_R^{Zd} \end{pmatrix} = \begin{pmatrix} -10 \pm 4 \\ 0.5 \pm 0.4 \\ 0.04 \pm 0.06 \\ -0.001 \pm 0.005 \end{pmatrix}$$

We are capable of obtaining per mille level constraints

Drell-Yan A_{FB} at the LHC

- **Impact on the global fit:**

$$\begin{pmatrix} x \\ y \\ z \\ t \end{pmatrix} = \begin{pmatrix} 0.004 \pm 0.017 \\ 0.010 \pm 0.032 \\ 0.021 \pm 0.046 \\ -0.03 \pm 0.19 \end{pmatrix}, \quad \rho = \begin{pmatrix} 1. & -0.09 & -0.08 & -0.04 \\ -0.09 & 1. & -0.09 & -0.93 \\ -0.08 & -0.09 & 1. & -0.19 \\ -0.04 & -0.93 & -0.19 & 1. \end{pmatrix}$$

The combination of LEP+LHC is good enough to lift the blind direction, but we are not as restrictive as in t', since $t \cdot t' = 0.16$

Drell-Yan A_{FB} at the LHC

- **Impact on the global fit:**

$$\begin{pmatrix} x \\ y \\ z \\ t \end{pmatrix} = \begin{pmatrix} 0.004 \pm 0.017 \\ 0.010 \pm 0.032 \\ 0.021 \pm 0.046 \\ -0.03 \pm 0.19 \end{pmatrix}, \quad \rho = \begin{pmatrix} 1. & -0.09 & -0.08 & -0.04 \\ -0.09 & 1. & -0.09 & -0.93 \\ -0.08 & -0.09 & 1. & -0.19 \\ -0.04 & -0.93 & -0.19 & 1. \end{pmatrix}$$

→ The combination of LEP+LHC is good enough to lift the blind direction, but we are not as restrictive as in t', since $t \cdot t' = 0.16$

- LHC constrains a specific direction much strongly than D0. Both hadron measurements are important for the global fit, although for simple scenarios LHC has a larger effect. All in all, **traditional pole observables + ATLAS + D0** give:

$$\begin{pmatrix} \delta g_L^{Zu} \\ \delta g_R^{Zu} \\ \delta g_L^{Zd} \\ \delta g_R^{Zd} \end{pmatrix} = \begin{pmatrix} -0.012 \pm 0.024 \\ -0.005 \pm 0.032 \\ -0.020 \pm 0.037 \\ -0.03 \pm 0.13 \end{pmatrix}, \quad \rho = \begin{pmatrix} 1 & 0.51 & 0.68 & 0.69 \\ 0.51 & 1 & 0.56 & 0.94 \\ 0.68 & 0.56 & 1 & 0.54 \\ 0.69 & 0.94 & 0.54 & 1 \end{pmatrix}$$

The other 16 parameters are also being fitted here, to almost no changes in their limits

Summary

- LHC A_{FB} provides ~0.5% bounds on Zqq corrections

$$0.51\delta g_L^{Zu} + 0.82\delta g_R^{Zu} - 0.17\delta g_L^{Zd} - 0.22\delta g_R^{Zd} = -0.001 \pm 0.005$$

- **The t variable is lifted with the inclusion of the A_{FB} ATLAS input**
- We find that the ATLAS A_{FB} information provides a significant improvement on LEP-only bounds on the Zqq vertex corrections

---

- **Outlook 1:** Current and future measurements of Drell-Yan dilepton production by LHC could be analyzed following our procedure to extend the impact of hadron colliders on the electroweak precision program
- **Outlook 2:** Information from Drell-Yan cross sections could be added, and off-pole data could be analyzed too ($\longrightarrow$ LLQQ operators enter)

Moving forward

- We use DYTurbo to produce multiloop calculations of the observable with kinematic cuts
- We expand the experimental input by considering off-pole data (maybe other measurements from CMS, LHCb, etc.)
- **Preliminary results** (A_{FB} from [1710.05167], whole dilepton mass spectrum, 4-fermion couplings included):

$$\begin{pmatrix} -0.004 & -0.011 & -0.006 & -0.037 & -0.007 & -0.766 & -0.204 & 0.217 & -0.519 & -0.232 \\ 0.010 & 0.051 & 0.012 & 0.180 & -0.008 & -0.249 & -0.202 & 0.548 & 0.732 & -0.158 \\ -0.006 & 0.034 & 0.013 & 0.086 & 0.009 & -0.582 & 0.239 & -0.526 & 0.336 & 0.454 \\ -0.058 & -0.259 & -0.110 & -0.930 & -0.004 & -0.079 & 0.065 & 0.053 & 0.196 & -0.022 \\ -0.023 & 0.059 & 0.014 & 0.070 & 0.062 & -0.075 & 0.889 & 0.149 & 0.000 & -0.411 \\ -0.163 & 0.227 & 0.345 & -0.108 & 0.252 & 0.021 & 0.178 & 0.508 & -0.176 & 0.638 \\ -0.308 & 0.248 & 0.769 & -0.137 & 0.073 & -0.005 & -0.145 & -0.278 & 0.100 & -0.346 \\ 0.848 & 0.019 & 0.223 & -0.085 & 0.466 & -0.010 & -0.028 & -0.047 & 0.021 & -0.057 \\ 0.315 & 0.698 & -0.048 & -0.206 & -0.605 & 0.003 & 0.031 & 0.026 & -0.012 & 0.030 \\ -0.239 & 0.570 & -0.474 & -0.095 & 0.586 & 0.006 & -0.107 & -0.117 & 0.034 & -0.124 \end{pmatrix} \begin{pmatrix} \delta g_L^{Zu} \\ \delta g_R^{Zu} \\ \delta g_L^{Zd} \\ \delta g_R^{Zd} \\ [C_{lq}]_{11} \\ [C_{lu}]_{11} \\ [C_{ld}]_{11} \\ [C_{eq}]_{11} \\ [C_{eu}]_{11} \\ [C_{ed}]_{11} \end{pmatrix} = \begin{pmatrix} 8 \pm 27 \\ 2.8 \pm 3.6 \\ 4.1 \pm 2.2 \\ -1.1 \pm 1.7 \\ 0.21 \pm 0.52 \\ 0.090 \pm 0.059 \\ 0.033 \pm 0.029 \\ -0.057 \pm 0.020 \\ 0.011 \pm 0.013 \\ 0.0224 \pm 0.0089 \end{pmatrix}$$

$$\begin{pmatrix} \delta g_L^{Zu} \\ \delta g_R^{Zu} \\ \delta g_L^{Zd} \\ \delta g_R^{Zd} \\ [C_{lq}]_{11} \\ [C_{lu}]_{11} \\ [C_{ld}]_{11} \\ [C_{eq}]_{11} \\ [C_{eu}]_{11} \\ [C_{ed}]_{11} \end{pmatrix} = \begin{pmatrix} -0.056 \pm 0.018 \\ 0.031 \pm 0.012 \\ -0.035 \pm 0.016 \\ -0.086 \pm 0.048 \\ 0.009 \pm 0.012 \\ 3.1 \pm 1.0 \\ -0.129 \pm 0.073 \\ -0.065 \pm 0.053 \\ 0.15 \pm 0.16 \\ -0.047 \pm 0.046 \end{pmatrix}$$

Extra: Drell-Yan A_{FB} at the LHC

- A_{FB}^{LHC} provides crucial information in simple NP scenarios: