Interface between B meson and top physics observables

Gilberto Tetlalmatzi-Xolocotzi

in collaboration with

Matthew Kirk,Christoph Englert
and Oliver Atkinson
(work in progress)

The $\bar{B}^0_{(s)} \to D^{(*)+}_{(s)} \{\pi^-, K^-\}$ puzzle

2007.10338 [hep-ph]   (Huber et al.)

Processes such as $\bar{B}^0 \to D^{(*)+} K^-$ and $\bar{B}^0_s \to D_s^{(*)+} \pi^-$

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(which in general lead to huge uncertainties, QCDF).

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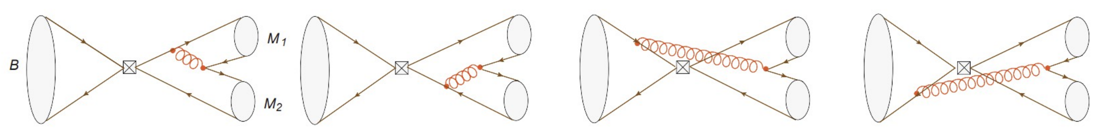

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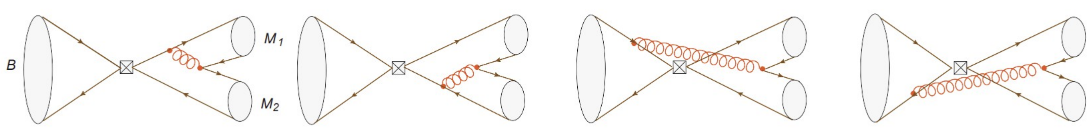

Compare

QCDF predictions

Mode	Theory
$B^- \to \pi^- \bar{K}^0$	$19.3^{+1.9+11.3+1.9+13.2}_{-1.9-7.8-2.1-5.6}$
$B^- \to \pi^0 K^-$	$11.1^{+1.8+5.8+0.9+6.9}_{-1.7-4.0-1.0-3.0}$
$\bar{B}^0 \to \pi^+ K^-$	$16.3^{+2.6+9.6+1.4+11.4}_{-2.3-6.5-1.4-4.8}$
$\bar{B}^0 \to \pi^0 \bar{K}^0$	$7.0^{+0.7+4.7+0.7+5.4}_{-0.7-3.2-0.7-2.3}$
$B^- \to \pi^- \bar{K}^{*0}$	$3.6^{+0.4+1.5+1.2+7.7}_{-0.3-1.4-1.2-2.3}$
$B^- \to \pi^0 K^{*-}$	$3.3^{+1.1+1.0+0.6+4.4}_{-1.0-0.9-0.6-1.4}$
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$\bar{B}^0 \to \pi^0 \bar{K}^{*0}$	$0.7^{+0.1+0.5+0.3+2.6}_{-0.1-0.4-0.3-0.5}$
[illegible]	[illegible]

Arxiv: 0308039 [hep-ph]

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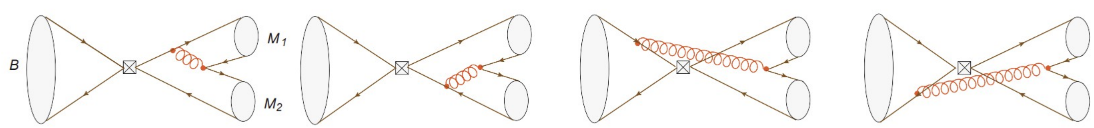

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$\mathcal{B}(\bar{B}^0_s \to D_s^+\pi^-)$	10^{-3}	4.42 ± 0.21
$\mathcal{B}(\bar{B}^0_s \to D_s^{*+}\pi^-)$	10^{-3}	$4.30^{+0.9}_{-0.8}$

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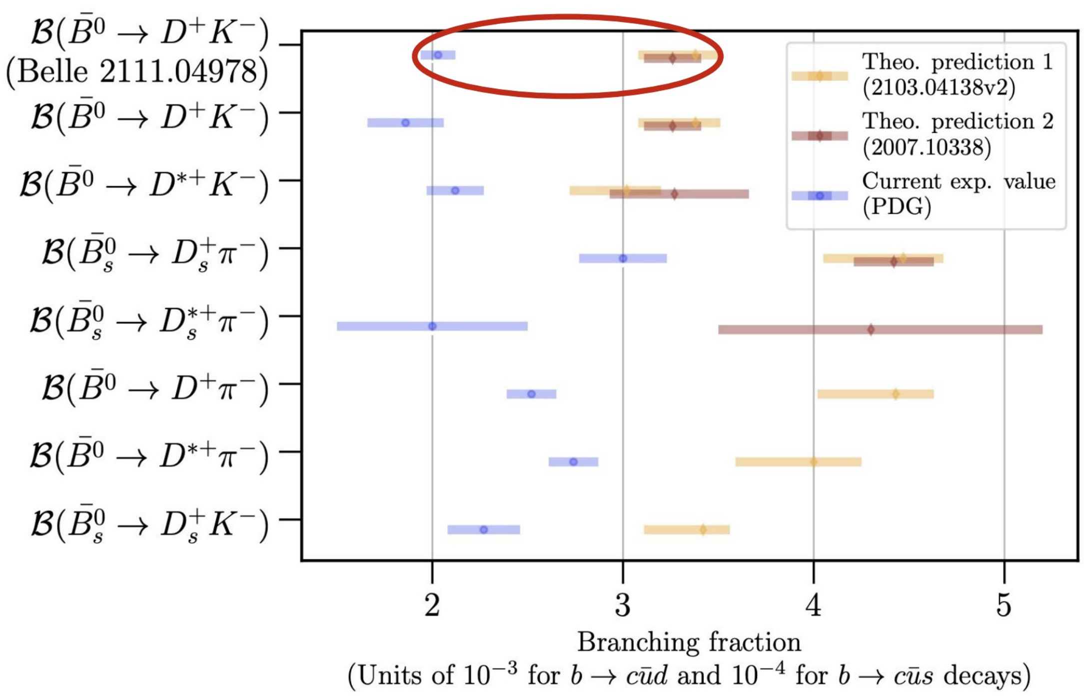

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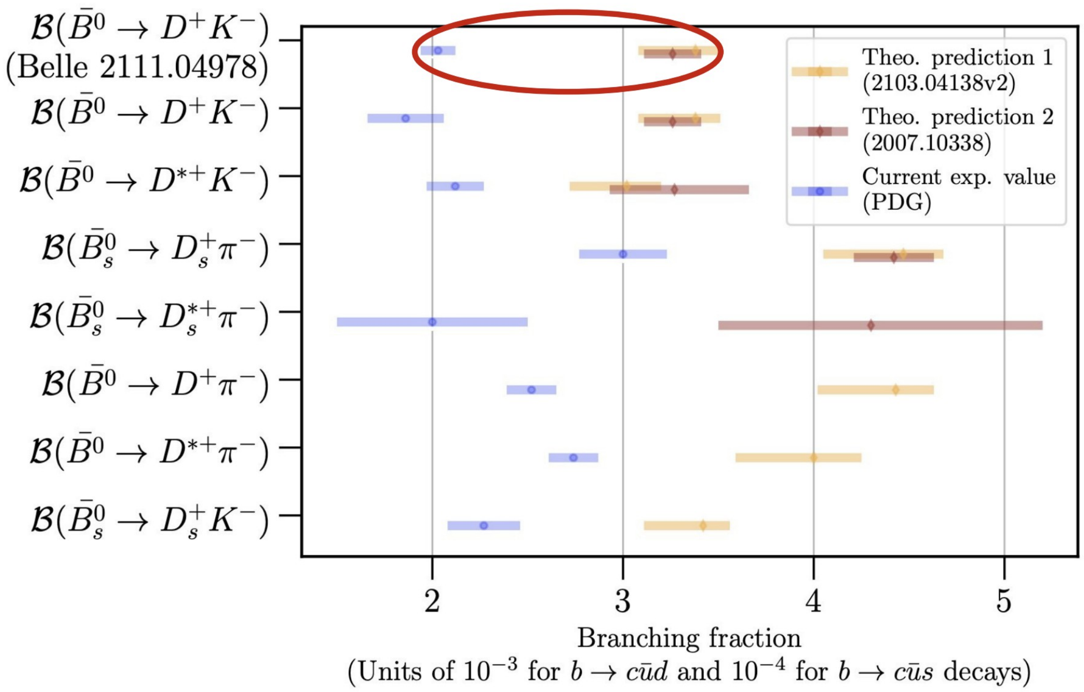

Possible Explanations

- Underestimation of QCD uncertainties

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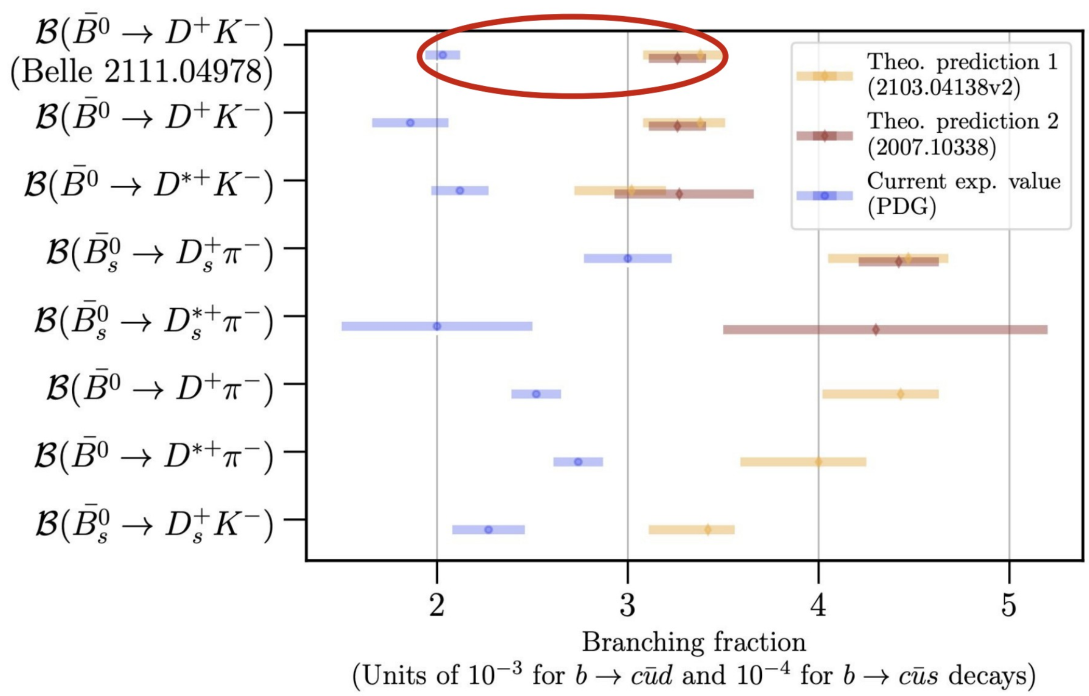


Possible Explanations

- Underestimation of QCD uncertainties
- New Physics?, If so, what would be the interplay with the high energy sector

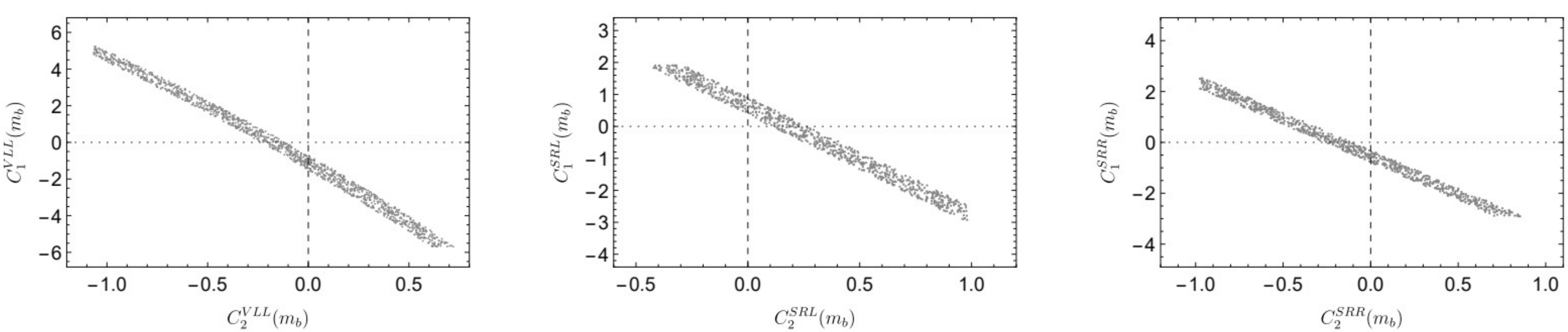
Relevant B physics operators in the context of the puzzle

$$\mathcal{Q}'_{VLL} = (\bar{u}_L\gamma_\mu T^A d_L)(\bar{d}_L\gamma^\mu T^A u_L) \qquad \mathcal{Q}_{VLL} = (\bar{u}_L\gamma_\mu d_L)(\bar{d}\gamma^\mu u_L)$$
$$\mathcal{Q}'_{VRR} = (\bar{u}_R\gamma_\mu T^A d_R)(\bar{d}_R\gamma^\mu T^A u_R) \qquad \mathcal{Q}_{VRR} = (\bar{u}_R\gamma_\mu d_R)(\bar{d}_R\gamma^\mu u_R)$$
$$\mathcal{Q}'_{VLR} = (\bar{u}_L\gamma_\mu T^A d_L)(\bar{d}_R\gamma_\mu T^A u_R) \qquad \mathcal{Q}_{VLR} = (\bar{u}\gamma_\mu d_L)(\bar{d}_R\gamma^\mu u_R)$$
$$\mathcal{Q}'_{SRL} = (\bar{u}_L T^A d_R)(\bar{d}_R T^A u_L) \qquad \mathcal{Q}_{SRL} = (\bar{u}_L d_R)(\bar{d}_R u_L)$$
$$\mathcal{Q}'_{SLR} = (\bar{u}_R T^A d_L)(\bar{d}_L T^A u_R) \qquad \mathcal{Q}_{SLR} = (\bar{u}_R d_L)(\bar{d}_L u_R)$$
$$\mathcal{Q}'_{SRR} = (\bar{u}_L T^A d_R)(\bar{d}_L T^A u_R) \qquad \mathcal{Q}_{SRR} = (\bar{u}_L d_R)(\bar{d}_L u_R)$$
$$\mathcal{Q}'_{TRR} = (\bar{u}_L\sigma_{\mu\nu} T^A d_R)(\bar{d}_L\sigma^{\mu\nu} T^A u_R) \qquad \mathcal{Q}_{TRR} = (\bar{u}_L\sigma_{\mu\nu} d_R)(\bar{d}_L\sigma^{\mu\nu} u_R)$$

$$\mathcal{Q}'_{VRL} = (\bar{u}_R\gamma_\mu T^A d_R)(\bar{d}_L\gamma_\mu T^A u_L) \qquad \mathcal{Q}_{VRL} = (\bar{u}_R\gamma_\mu d_R)(\bar{d}_L\gamma^\mu u_L)$$
$$\mathcal{Q}'_{SLL} = (\bar{u}_R T^A d_L)(\bar{d}_R T^A u_L) \qquad \mathcal{Q}_{SLL} = (\bar{u}_R d_L)(\bar{d}_R u_L)$$
$$\mathcal{Q}'_{TLL} = (\bar{u}_R\sigma_{\mu\nu} T^A d_L)(\bar{d}_R\sigma^{\mu\nu} T^A u_L) \qquad \mathcal{Q}_{TRR} = (\bar{u}_R\sigma_{\mu\nu} d_L)(\bar{d}_R\sigma^{\mu\nu} u_L)$$

Most suitable structures to explain the tensions in terms of NP

2103.04138 [hep-ph] (Xin-Qiang Li et al)



Relevant LEFT operators

(Obtained through a Fierz transform from the flavour operator basis)

$$[\mathcal{O}_{ud}^{V1,LL}]_{ijkl} = (\bar{u}_L^i\gamma_\mu u_L^j)(\bar{d}_L^k\gamma^\mu d_L^l)\,, \qquad [\mathcal{O}_{ud}^{V8,LL}]_{ijkl} = (\bar{u}_L^i\gamma_\mu T^A u_L^j)(\bar{d}_L^k\gamma^\mu T^A d_L^l)\,,$$

$$[\mathcal{O}_{ud}^{V1,RR}]_{ijkl} = (\bar{u}_R^i\gamma_\mu u_R^j)(\bar{d}_R^k\gamma^\mu d_R^l)\,, \qquad [\mathcal{O}_{ud}^{V8,RR}]_{ijkl} = (\bar{u}_R^i\gamma_\mu T^A u_R^j)(\bar{d}_R^k\gamma^\mu T^A d_R^l)\,,$$

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$$[\mathcal{O}_{du}^{V1,LR}]_{ijkl} = (\bar{d}_L^i\gamma_\mu d_L^j)(\bar{u}_R^k\gamma^\mu u_R^l)\,, \qquad [\mathcal{O}_{du}^{V8,LR}]_{ijkl} = (\bar{d}_L^i\gamma_\mu T^A d_L^j)(\bar{u}_R^k\gamma^\mu T^A u_R^l)\,,$$

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Relevant SMEFT operators

$$[\mathcal{O}_{qq}^{(1)}]_{ijkl} = (\bar{q}_L^i\gamma_\mu q_L^j)(\bar{q}_L^k\gamma_\mu q_L^l), \qquad [\mathcal{O}_{qq}^{(1)}]_{ijkl} = (\bar{q}_L^i\sigma^a\gamma_\mu q_L^j)(\bar{q}_L^k\sigma^a\gamma_\mu q_L^l),$$

$$[\mathcal{O}_{qd}^{(1)}]_{ijkl} = (\bar{q}_L^i\gamma_\mu q_L^j)(\bar{d}_R^k\gamma_\mu d_R^l), \qquad [\mathcal{O}_{qd}^{(8)}]_{ijkl} = (\bar{q}_L^i T^A\gamma_\mu q_L^j)(\bar{d}_R^k T^A\gamma^\mu d_R^l),$$

$$[\mathcal{O}_{quqd}^{(1)}]_{ijkl} = (\bar{q}_L^i u_R^j)i\sigma_2(\bar{q}_R^k d_R^l), \qquad [\mathcal{O}_{quqd}^{(8)}]_{ijkl} = (\bar{q}_L^i T^A u_R^j)i\sigma_2(\bar{q}_R^k T^A d_R^l),$$

Low to High Energy

Matching conditions

$$[L_{ud}^{V1,LL}]_{prst} = V_{pi}V_{rj}^{*}\left([C_{qq}^{(1)}]_{ijst} + [C_{qq}^{(1)}]_{stij} - [C_{qq}^{(3)}]_{ijst} - [C_{qq}^{(3)}]_{stij} + \frac{2}{N_c}([C_{qq}^{(3)}]_{itsj} + [C_{qq}^{(3)}]_{sjit})\right)$$

$$[L_{ud}^{V8,LL}]_{prst} = 4V_{pi}V_{rj}^{*}\left([C_{qq}^{(3)}]_{itsj} + [C_{qq}^{(3)}]_{sjit}\right)$$

$$[L_{ud}^{V1,RR}]_{prst} = [C_{ud}^{(1)}]_{prst}$$

$$[L_{ud}^{V8,RR}]_{prst} = [C_{ud}^{(8)}]_{prst}$$

$$[L_{ud}^{V1,LR}]_{prst} = 4V_{pi}V_{rj}^{*}[C_{qd}^{(1)}]_{ijst}$$

$$[L_{ud}^{V8,LR}]_{prst} = 4V_{pi}V_{rj}^{*}[C_{qd}^{(8)}]_{ijst}$$

$$[L_{du}^{V1,LR}]_{prst} = [C_{qu}^{(1)}]_{prst}$$

$$[L_{du}^{V8,LR}]_{prst} = [C_{qu}^{(8)}]_{prst}$$

$$[L_{uddu}^{V1,LR}]_{prst} = 0$$

$$[L_{uddu}^{V8,LR}]_{prst} = 0$$

$$[L_{ud}^{S1,RR}]_{prst} = V_{pi}[C_{quqd}^{(1)}]_{irst}$$

$$[L_{ud}^{S8,RR}]_{prst} = V_{pi}[C_{quqd}^{(8)}]_{irst}$$

$$[L_{uddu}^{S1,RR}]_{prst} = -V_{pi}[C_{quqd}^{(1)}]_{stir}$$

$$[L_{uddu}^{S8,RR}]_{prst} = -V_{pi}[C_{quqd}^{(8)}]_{stir}$$

LEFT-SMEFT

bsuc

$$L_{ud}^{V1LL}[2,1,2,3] = V_{23}V_{11}^{*}\left[2C_{qq}^{(1)*}[1,3,3,2] + \frac{4}{3}C_{qq}^{(3)*}[1,2,3,3] - 2C_{qq}^{(3)*}[1,3,3,2]\right]$$
$$+ V_{23}V_{12}^{*}\left[2C_{qq}^{(1)}[2,3,3,2] + \frac{4}{3}C_{qq}^{(3)}[2,2,3,3] - 2C_{qq}^{(3)}[2,3,3,2]\right]$$
$$+ V_{21}V_{13}^{*}\left[2C_{qq}^{(1)}[1,3,2,3] - \frac{2}{3}C_{qq}^{(3)}[1,3,2,3]\right]$$
$$+ V_{22}V_{13}^{*}\left[2C_{qq}^{(1)}[2,3,2,3] - \frac{2}{3}C_{qq}^{(3)}[2,3,2,3]\right]$$
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$$L_{ud}^{V8LL}[2,1,2,3] = V_{23}V_{11}^{*}\left[8C_{qq}^{(3)*}[1,2,3,3]\right]$$
$$+ V_{23}V_{12}^{*}\left[8C_{qq}^{(3)}[2,2,3,3]\right] + V_{21}V_{13}^{*}\left[8C_{qq}^{(3)}[1,3,2,3]\right]$$
$$+ V_{22}V_{13}^{*}\left[8C_{qq}^{(3)}[2,3,2,3]\right] + V_{23}V_{13}^{*}\left[8C_{qq}^{(3)}[2,3,3,3]\right]$$

bduc

$$L_{ud}^{V1LL}[2,1,1,3] = V_{23}V_{11}^{*}\left[2C_{qq}^{(1)}(1,3,3,1) + \frac{4}{3}C_{qq}^{(3)}(1,1,3,3) - 2C_{qq}^{(3)}(1,3,3,1)\right]$$
$$+ V_{23}V_{12}^{*}\left[2C_{qq}^{(1)}(1,3,3,2) + \frac{4}{3}C_{qq}^{(3)}(1,2,3,3) - 2C_{qq}^{(3)}(1,3,3,2)\right]$$
$$+ V_{21}V_{13}^{*}\left[2C_{qq}^{(1)}(1,3,1,3) - \frac{2}{3}C_{qq}^{(3)}(1,3,1,3)\right]$$
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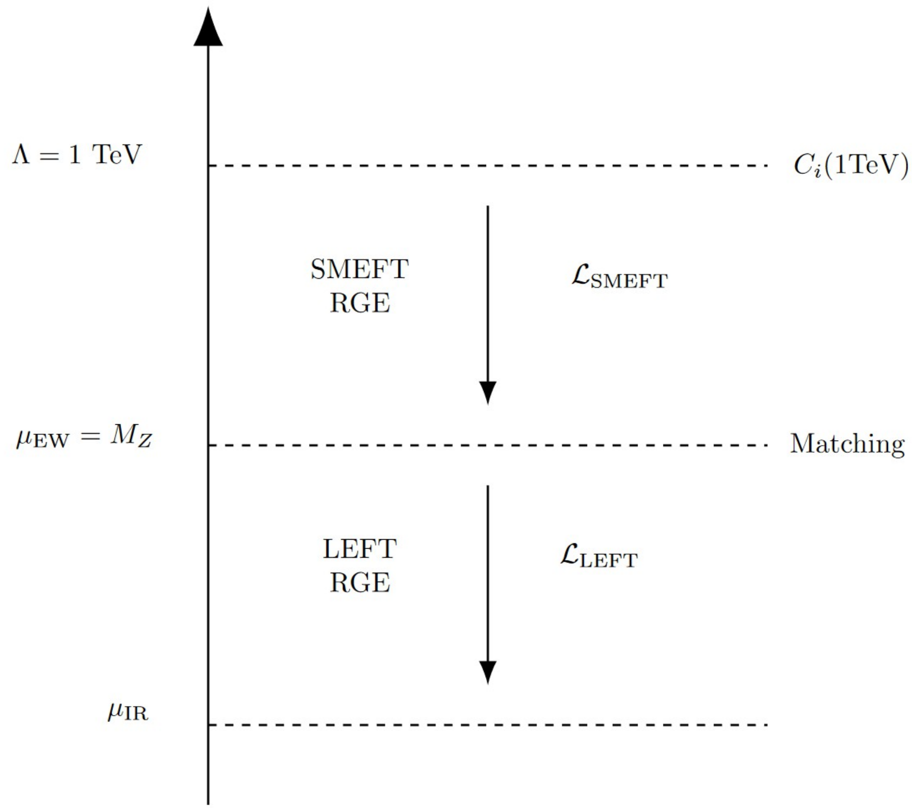
LEFT-SMEFT



Dsix tools

2010.16341 [hep-ph]

Low energy constraints

We want to asses how competitive are the observables from different particle physics sectors in constraining the New physics scale

We used Smelli (1810.07698v2 [hep-ph]) to include low energy constraints from *B* physics

This includes for instance

(and several more)

Observable	Prediction	Measurement
$\langle\frac{d\overline{\text{BR}}}{dq^2}\rangle(B_s \to \phi\mu^+\mu^-)^{[15.0,19.0]}$	$(5.57 \pm 0.46) \times 10^{-8}\ \frac{1}{\text{GeV}^2}$	$(4.05 \pm 0.50) \times 10^{-8}\ \frac{1}{\text{GeV}^2}$
$\langle\frac{d\text{BR}}{dq^2}\rangle(\Lambda_b \to \Lambda\mu^+\mu^-)^{[1.1,6]}$	$(1.04 \pm 0.56) \times 10^{-8}\ \frac{1}{\text{GeV}^2}$	$(9.7 \pm 6.0) \times 10^{-9}\ \frac{1}{\text{GeV}^2}$
$\langle\frac{d\text{BR}}{dq^2}\rangle(\Lambda_b \to \Lambda\mu^+\mu^-)^{[15,20]}$	$(7.11 \pm 0.77) \times 10^{-8}\ \frac{1}{\text{GeV}^2}$	$(1.19 \pm 0.27) \times 10^{-7}\ \frac{1}{\text{GeV}^2}$
$A_{\text{CP}}(B \to X_{s+d}\gamma)$	$(-3.7 \pm 2.5) \times 10^{-18}$	$(3.2 \pm 3.4) \times 10^{-2}$
$\text{BR}(B^+ \to K^{*+}\gamma)$	$(4.25 \pm 0.89) \times 10^{-5}$	$(4.21 \pm 0.18) \times 10^{-5}$
$\text{BR}(B^+ \to e^+\nu_e)$	$(9.46 \pm 0.83) \times 10^{-12}$	$(4.7 \pm 3.6) \times 10^{-7}$
$\text{BR}(B^+ \to \mu^+\nu_\mu)$	$(4.04 \pm 0.36) \times 10^{-7}$	$(4.9 \pm 3.7) \times 10^{-7}$
$\text{BR}(B^+ \to \tau^+\nu_\tau)$	$(8.99 \pm 0.79) \times 10^{-5}$	$(1.09 \pm 0.24) \times 10^{-4}$
$\text{BR}(B \to X_s\gamma)$	$(3.29 \pm 0.22) \times 10^{-4}$	$(3.27 \pm 0.14) \times 10^{-4}$
$\text{BR}(B^0 \to K^{*0}\gamma)$	$(4.18 \pm 0.85) \times 10^{-5}$	$(4.34 \pm 0.15) \times 10^{-5}$
$\text{BR}(B^0 \to \mu^+\mu^-)$	$(1.17 \pm 0.13) \times 10^{-10}$	$(1.5 \pm 1.1) \times 10^{-10}$
$\text{BR}(B^0 \to \pi^-\tau^+\nu_\tau)$	$(8.42 \pm 0.92) \times 10^{-5}$	$(1.51 \pm 0.73) \times 10^{-4}$
$\overline{\text{BR}}(B_s \to \mu^+\mu^-)$	$(3.61 \pm 0.19) \times 10^{-9}$	$(2.88 \pm 0.42) \times 10^{-9}$
$\overline{\text{BR}}(B_s \to \phi\gamma)$	$(4.01 \pm 0.52) \times 10^{-5}$	$(3.52 \pm 0.36) \times 10^{-5}$
$\text{BR}(K^+ \to \pi^+\nu\bar{\nu})$	$(9.24 \pm 0.83) \times 10^{-11}$	$(1.8 \pm 1.1) \times 10^{-10}$
$\text{BR}(K_L \to e^+e^-)$	$(1.93 \pm 0.34) \times 10^{-13}$	$(1.06 \pm 0.51) \times 10^{-11}$
$\text{BR}(K_L \to \mu^+\mu^-)$	$(7.5 \pm 1.3) \times 10^{-9}$	$(6.84 \pm 0.11) \times 10^{-9}$
$\text{BR}(K_L \to \pi^0\nu\bar{\nu})$	$(3.32 \pm 0.37) \times 10^{-11}$	$(1.4 \pm 1.1) \times 10^{-9}$
$\text{BR}(K_S \to e^+e^-)$	$(1.625 \pm 0.016) \times 10^{-16}$	$(4.4 \pm 3.3) \times 10^{-9}$
$\text{BR}(K_S \to \mu^+\mu^-)$	$(5.193 \pm 0.053) \times 10^{-12}$	$(3.9 \pm 2.9) \times 10^{-10}$
ΔM_d	$(0.617 \pm 0.083)\ \frac{1}{\text{ps}}$	$(0.5054 \pm 0.0020)\ \frac{1}{\text{ps}}$
ΔM_s	$(18.7 \pm 1.3)\ \frac{1}{\text{ps}}$	$(17.76 \pm 0.02)\ \frac{1}{\text{ps}}$
$S_{K^*\gamma}$	$(-2.3 \pm 1.5) \times 10^{-2}$	-0.16 ± 0.22
$S_{\psi K_S}$	0.706 ± 0.025	0.679 ± 0.020
$S_{\psi\phi}$	$(3.87 \pm 0.23) \times 10^{-2}$	$(3.3 \pm 3.3) \times 10^{-2}$
$\lvert\epsilon_K\rvert$	$(1.81 \pm 0.20) \times 10^{-3}$	$(2.228 \pm 0.011) \times 10^{-3}$
ϵ'/ϵ	$(-0.3 \pm 5.9) \times 10^{-4}$	$(1.66 \pm 0.23) \times 10^{-3}$
$x_{12}^{\text{Im},D}$	$(0.0 \pm 5.9) \times 10^{-6}$	$(0.0 \pm 2.4) \times 10^{-4}$

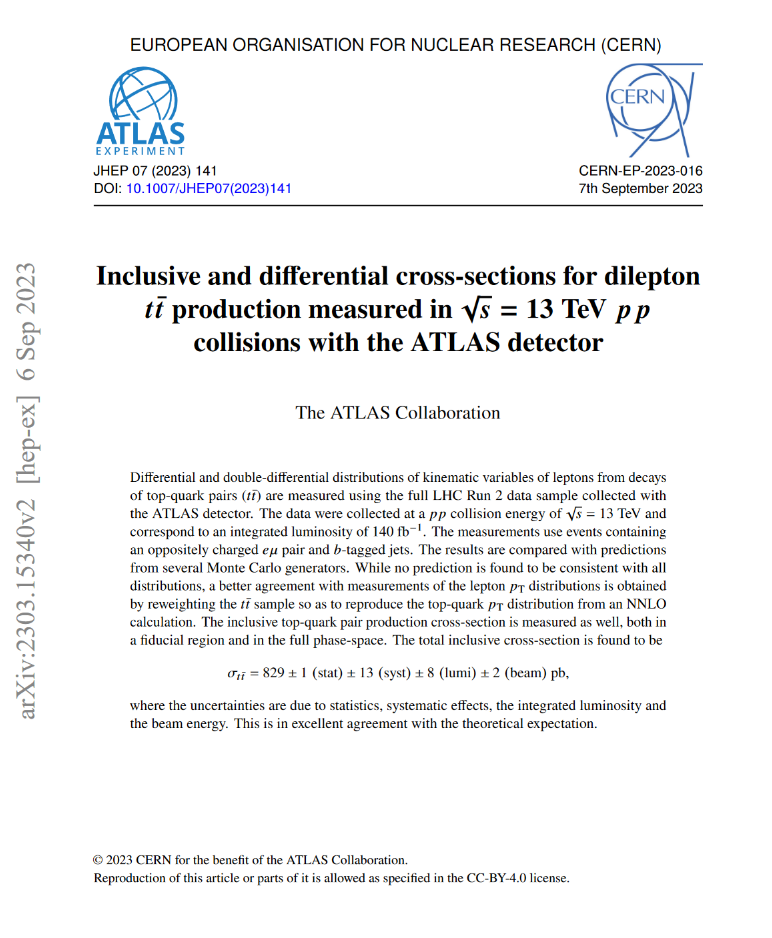
Electroweak constraints

Constraints from flavio

(1810.08132 [hep-ph])

Observable	Description
Γ_Z	Total width of the Z^0 boson
σ^0_{had}	$e^+e^- \to Z^0$ hadronic pole cross-section
R^0_e	Ratio of Z^0 partial widths to hadrons vs. e pairs
R^0_μ	Ratio of Z^0 partial widths to hadrons vs. μ pairs
R^0_τ	Ratio of Z^0 partial widths to hadrons vs. τ pairs
$A^{0,e}_{\mathrm{FB}}$	Forward-backward asymmetry in $Z^0 \to e^+e^-$
$A^{0,\mu}_{\mathrm{FB}}$	Forward-backward asymmetry in $Z^0 \to \mu^+\mu^-$
$A^{0,\tau}_{\mathrm{FB}}$	Forward-backward asymmetry in $Z^0 \to \tau^+\tau^-$
A_e	Asymmetry parameter in $Z^0 \to e^+e^-$
A_μ	Asymmetry parameter in $Z^0 \to \mu^+\mu^-$
A_τ	Asymmetry parameter in $Z^0 \to \tau^+\tau^-$
R^0_b	Ratio of Z^0 partial widths to b pairs vs. all hadrons
R^0_c	Ratio of Z^0 partial widths to c pairs vs. all hadrons
$A^{0,b}_{\mathrm{FB}}$	Forward-backward asymmetry in $Z^0 \to b\bar{b}$
$A^{0,c}_{\mathrm{FB}}$	Forward-backward asymmetry in $Z^0 \to c\bar{c}$
A_b	Asymmetry parameter in $Z^0 \to b\bar{b}$
A_c	Asymmetry parameter in $Z^0 \to c\bar{c}$
m_W	$W^\pm$ boson pole mass
Γ_W	Total width of the $W^\pm$ boson
$\mathrm{BR}(W^\pm \to e^\pm\nu)$	Branching ratio of $W^\pm \to e^\pm\nu$, summed over neutrino flavours
$\mathrm{BR}(W^\pm \to \mu^\pm\nu)$	Branching ratio of $W^\pm \to \mu^\pm\nu$, summed over neutrino flavours
$\mathrm{BR}(W^\pm \to \tau^\pm\nu)$	Branching ratio of $W^\pm \to \tau^\pm\nu$, summed over neutrino flavours
$\mathrm{R}(W^+ \to cX)$	Ratio of partial width of $W^+ \to cX$, $X = \bar{d}, \bar{s}, \bar{b}$ over the hadronic W width
$\mathrm{R}_{\mu e}(W^\pm \to \ell^\pm\nu)$	Ratio of branching ratio of $W^\pm \to \mu^\pm\nu$ and $W^\pm \to e^\pm\nu$, individually summed over neutrino flavours
$\mathrm{R}_{\tau e}(W^\pm \to \ell^\pm\nu)$	Ratio of branching ratio of $W^\pm \to \tau^\pm\nu$ and $W^\pm \to e^\pm\nu$, individually summed over neutrino flavours
A_s	Asymmetry parameter in $Z^0 \to s\bar{s}$
R^0_{uc}	Average ratio of Z^0 partial widths to u or c pairs vs. all hadrons

Top constraints



EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH (CERN)

ATLAS EXPERIMENT

CERN

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7th September 2023

Inclusive and differential cross-sections for dilepton $t\bar{t}$ production measured in $\sqrt{s}$ = 13 TeV pp collisions with the ATLAS detector

The ATLAS Collaboration

Differential and double-differential distributions of kinematic variables of leptons from decays of top-quark pairs ($t\bar{t}$) are measured using the full LHC Run 2 data sample collected with the ATLAS detector. The data were collected at a pp collision energy of $\sqrt{s}$ = 13 TeV and correspond to an integrated luminosity of 140 fb^{-1}. The measurements use events containing an oppositely charged $e\mu$ pair and b-tagged jets. The results are compared with predictions from several Monte Carlo generators. While no prediction is found to be consistent with all distributions, a better agreement with measurements of the lepton p_T distributions is obtained by reweighting the $t\bar{t}$ sample so as to reproduce the top-quark p_T distribution from an NNLO calculation. The inclusive top-quark pair production cross-section is measured as well, both in a fiducial region and in the full phase-space. The total inclusive cross-section is found to be

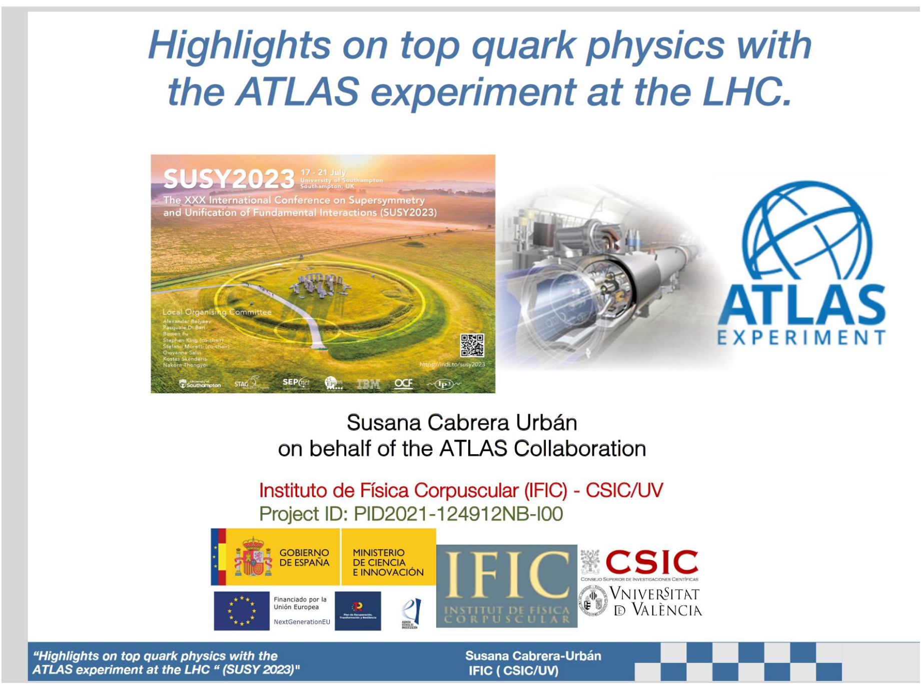
$$\sigma_{t\bar{t}} = 829 \pm 1 \text{ (stat)} \pm 13 \text{ (syst)} \pm 8 \text{ (lumi)} \pm 2 \text{ (beam) pb},$$

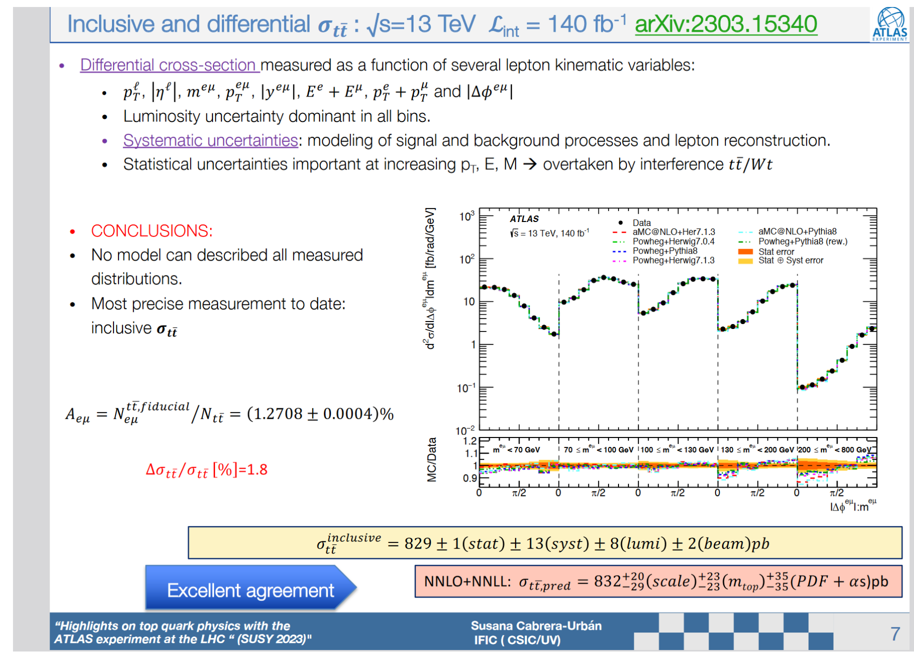
where the uncertainties are due to statistics, systematic effects, the integrated luminosity and the beam energy. This is in excellent agreement with the theoretical expectation.

Look at the inclusive cross section for $t\bar{t} \longrightarrow W^+W^-b\bar{b}$

with the W bosons decaying leptonically

Top constraints

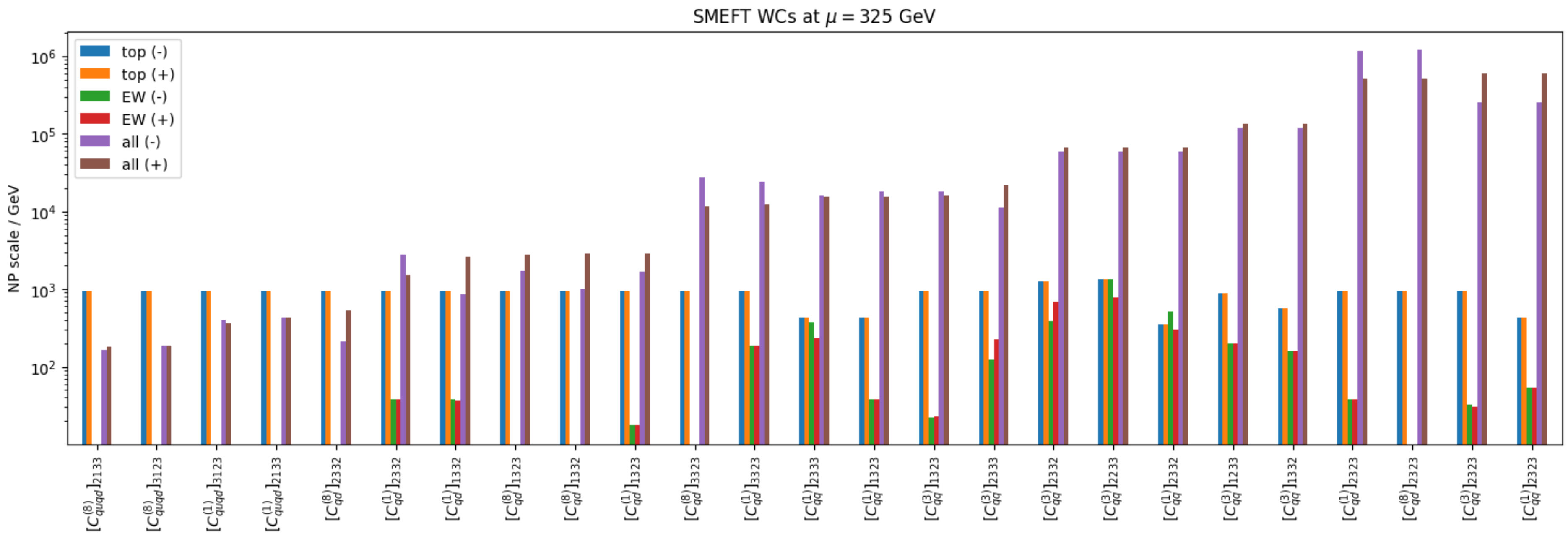




$$\sigma_{t\bar{t}} = 829 \pm 1\ (\text{stat}) \pm 13\ (\text{syst}) \pm 8\ (\text{lumi}) \pm 2\ (\text{beam})\ \text{pb},$$

$\Delta\sigma_{t\bar{t}}/\sigma_{t\bar{t}}$ [%]=1.8

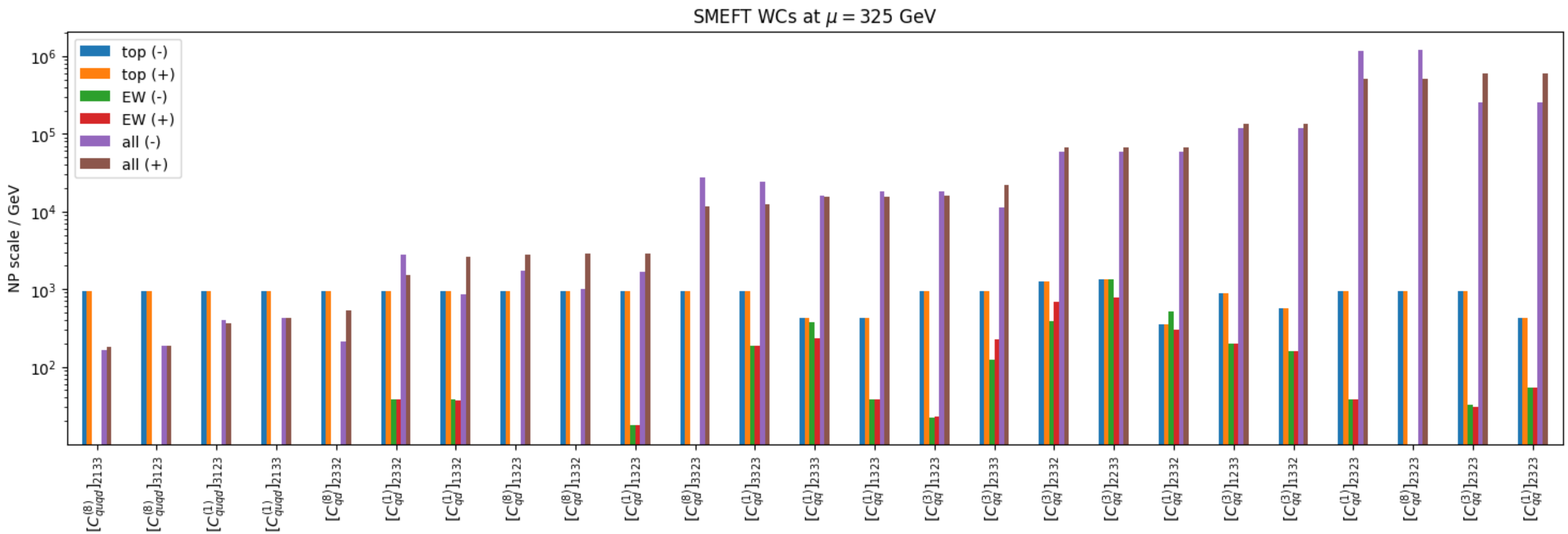
Combined constraints



"all" refers to the application of all the flavour physics constrains from Smelli

$$C^{\rm SMEFT} \sim \frac{1}{\Lambda^2_{\rm NP}}$$

Combined constraints

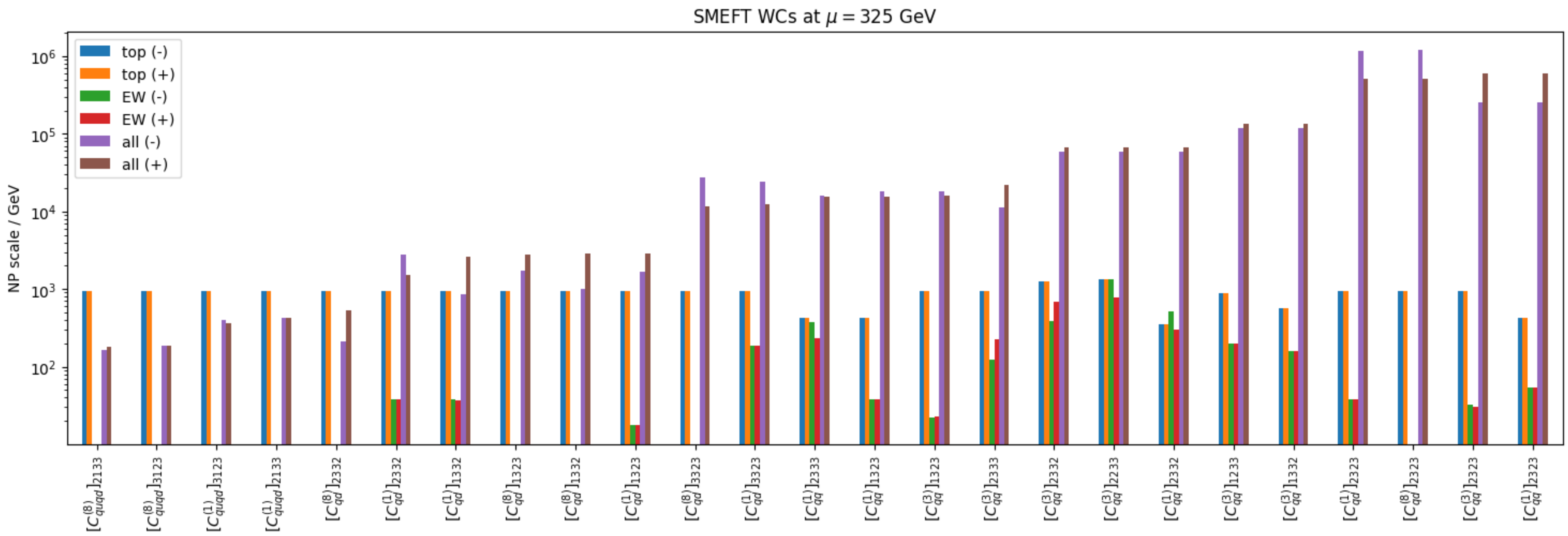


"all" refers to the application of all the flavour physics constrains from Smelli

$$C^{\mathrm{SMEFT}} \sim \frac{1}{\Lambda_{\mathrm{NP}}^2}$$

Flavour structure.

Combined constraints



"all" refers to the application of all the flavour physics constrains from Smelli

$$C^{\rm SMEFT} \sim \frac{1}{\Lambda_{\rm NP}^2}$$

Flavour structure.

More top observables.

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