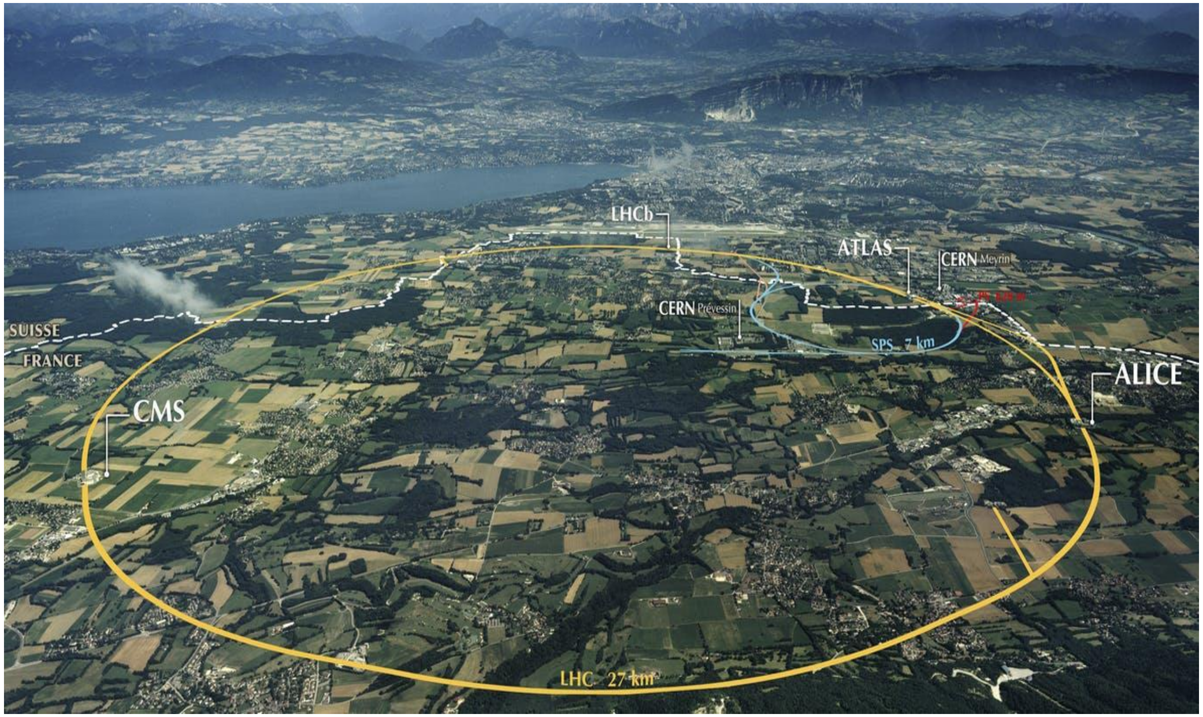


Andreas Crivellin

CERN Theory Division

Leave of absence from Paul Scherrer Institute & University of Zurich

Correlating a_μ to $h\rightarrow\mu\mu$ with Leptoquarks

Higgs 2020, 29.10.2020 (remote)

Work supported by FNSNF

Outline

- Introduction
- Leptoquarks and the Flavour Anomalies
  - $b \to s\mu\mu$
  - $b \to c\tau\nu$
  - a_μ
- Leptoquarks with chiral enhancement
- $h \to \mu\mu$ and a_μ with LQs
- Effects in $Z \to \mu\mu$
- Conclusions

Based on:

Scalar Leptoquarks in Leptonic Processes
arXiv:2010.06593

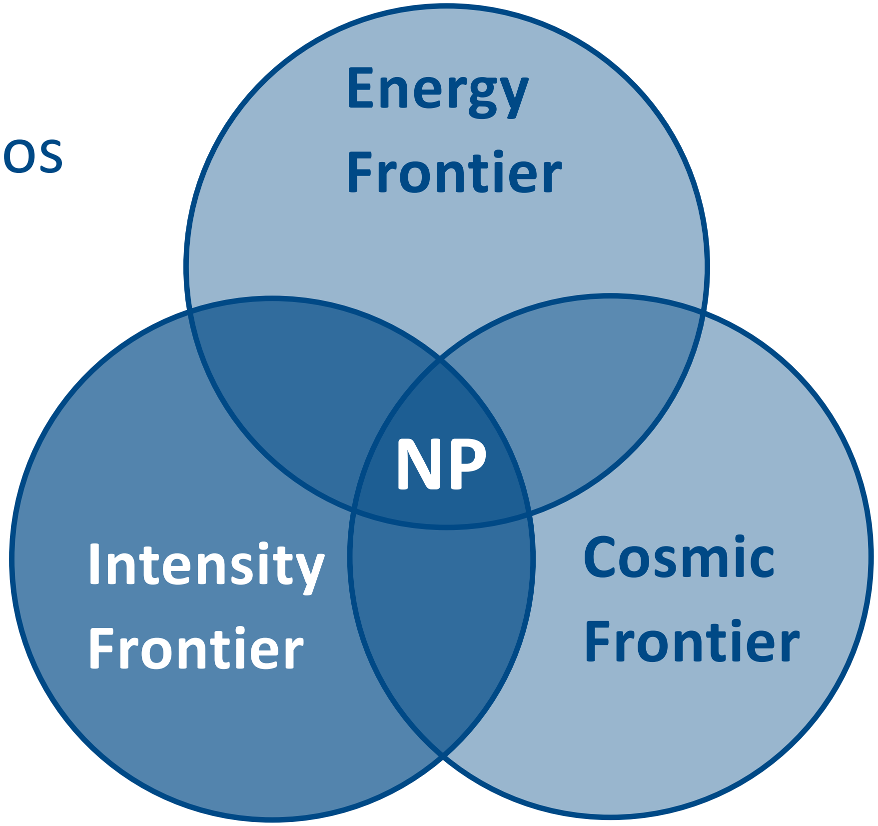
Correlating to the Anomalous Magnetic Moment of the Muon via Leptoquarks,
arXiv:2008.02643

by AC, Dario Mueller, Francesco Saturnino

Introduction

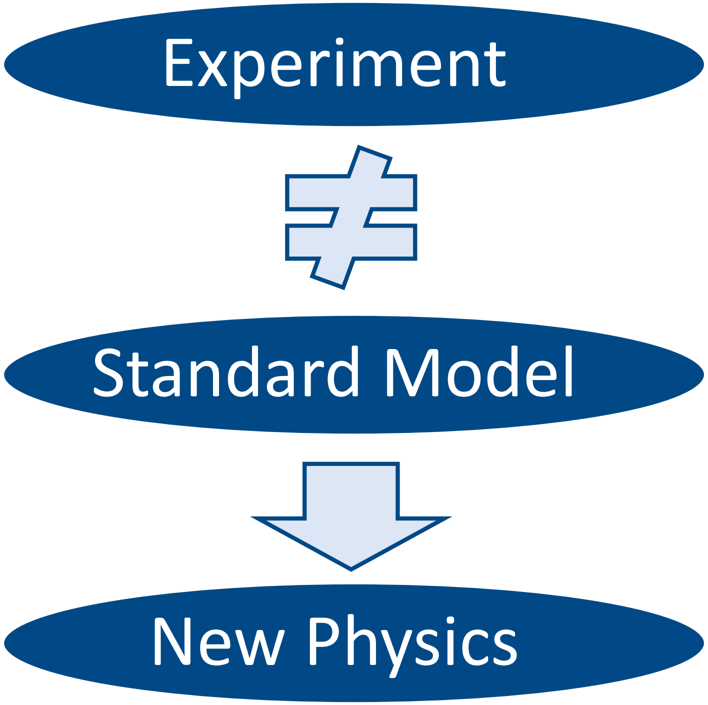
Discovering New Physics

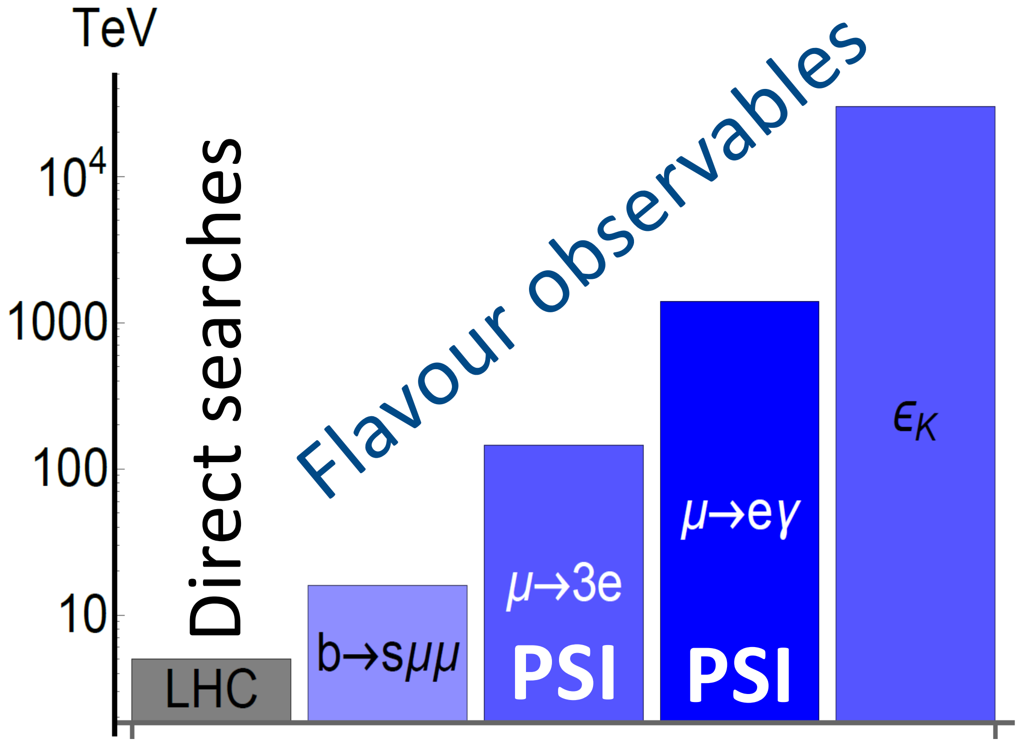
- Cosmic Frontier
  - Cosmic rays and neutrinos
  - Dark Matter
  - Dark Energy
- Energy Frontier
  - LHC
  - Future colliders
- Intensity Frontier
  - Flavour
  - Neutrino-less double-β decay
  - EW precision observables (ILC, CLIC, FCC-ee, CEPC)
  - Proton decay



Finding New Physics with Flavour

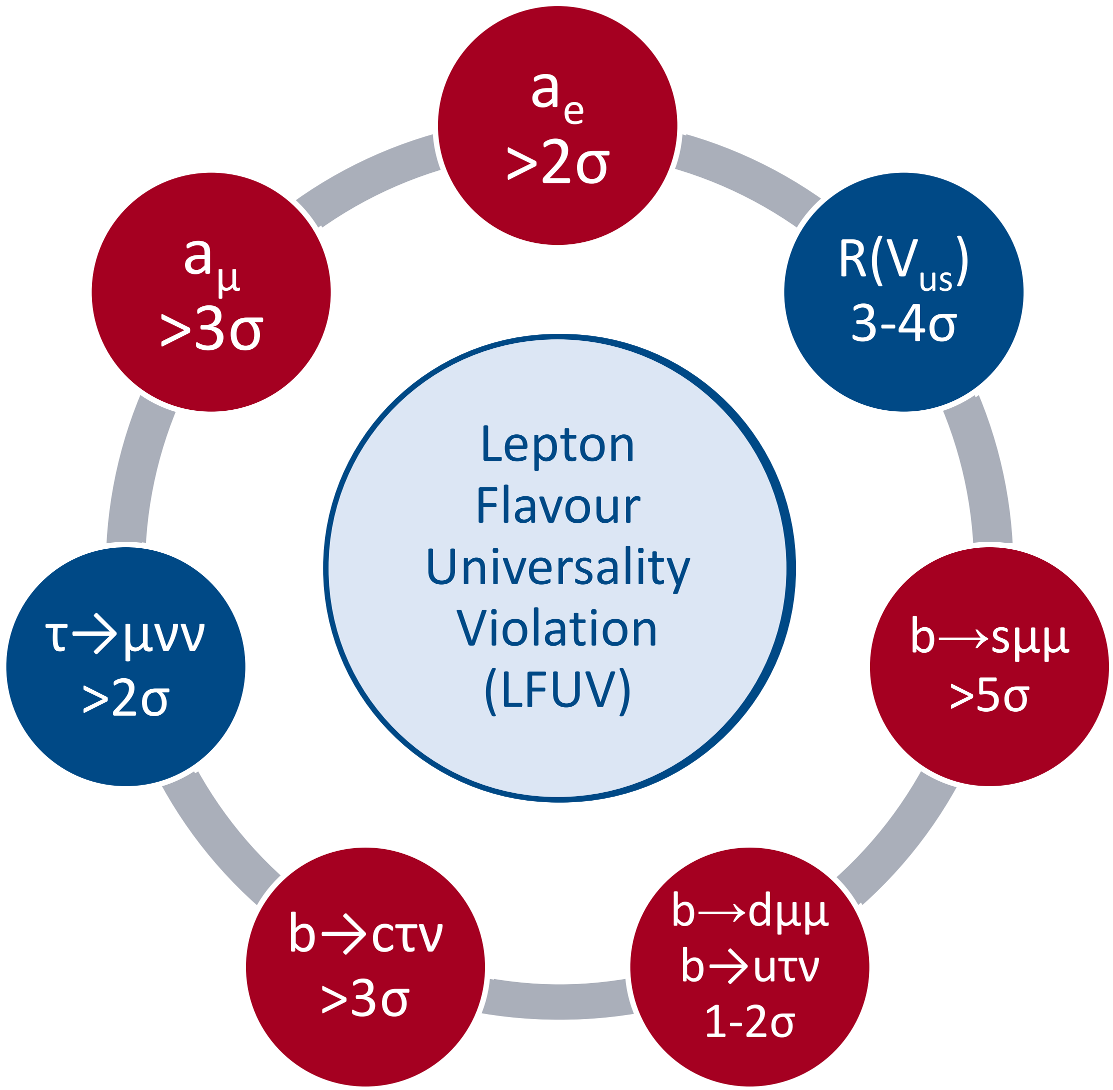
- At colliders one produces many (up to 10^{14}) heavy quarks or leptons and measures their decays into light flavours





Flavour observables can be sensitive to higher energy scales than collider searches

Hints for New Physics

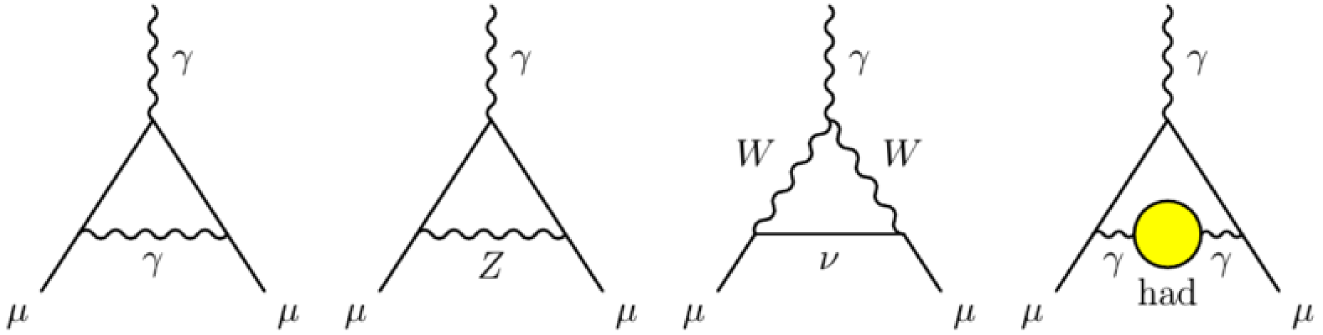


Muon Anomalous Magnetic Moment

- Single measurement from BNL
- Theory prediction sound but challenging because of hadronic effects.

$$\Delta a_\mu = (279 \pm 76) \times 10^{-11}$$

T. Aoyama et al., arXiv:2006.04822



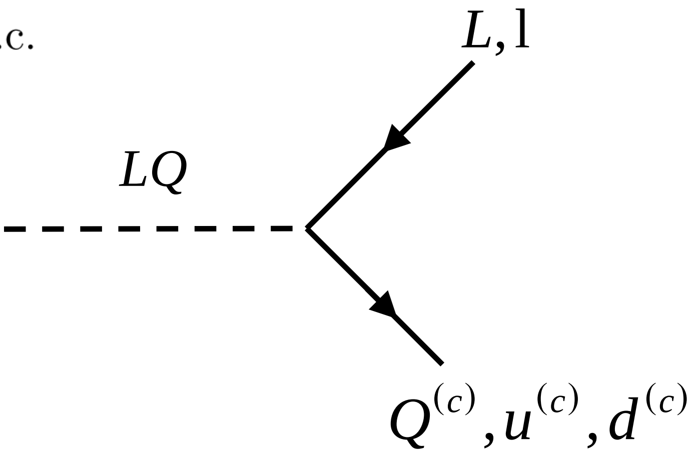
- Soon new experimental results from Fermilab
- Small tension in Δa_e with opposite sign

3.7σ deviation (order of SM-EW contribution)

Leptoquarks for the AMM of the Muon

- Scalar Leptoquarks with top couplings

	$\mathcal{G}_{\rm SM}$	$\mathcal{L}_{q\ell}$
S_1	$\left(3,1,-\frac{2}{3}\right)$	$\left(\lambda^R_{fj}\,\bar{u}^c_f\ell_j+\lambda^L_{fj}\,\bar{Q}^c_f i\tau_2 L_j\right)S_1^\dagger+\text{h.c.}$
S_2	$\left(3,2,\frac{7}{3}\right)$	$\gamma^{RL}_{fj}\,\bar{u}_f\Phi_2^T i\tau_2 L_j+\gamma^{LR}_{fj}\,\bar{Q}_f\ell_j S_2+\text{h.c.}$
S_3	$\left(3,3,-\frac{2}{3}\right)$	$\kappa_{fj}\,\bar{Q}^c_f i\tau_2\left(\tau\cdot S_3\right)^\dagger L_j+\text{h.c.}$

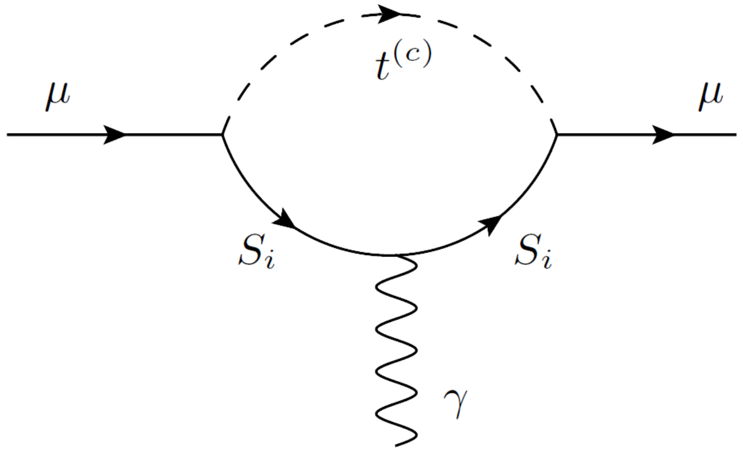


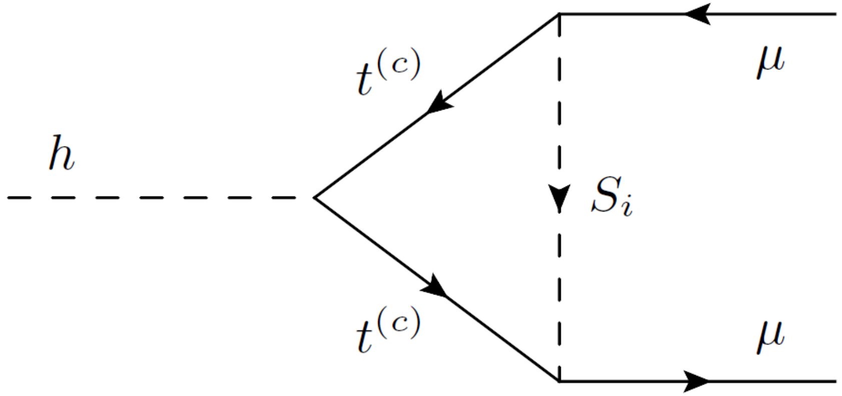
- Couplings to the Higgs

$$\mathcal{L}_H = Y_{13}S_1^\dagger\left(H^\dagger\left(\tau\cdot S_3\right)H\right)+\text{h.c.}$$
$$-Y_{22}(Hi\tau_2 S_2)^\dagger\left(Hi\tau_2 S_2\right)-\sum_{k=1}^{3}(m_k^2+Y_k H^\dagger H)S_k^\dagger S_k$$

Chirally enhanced effect in g-2 possible

LQ effects in $(g\text{-}2)_\mu$ and $h\to\mu\mu$



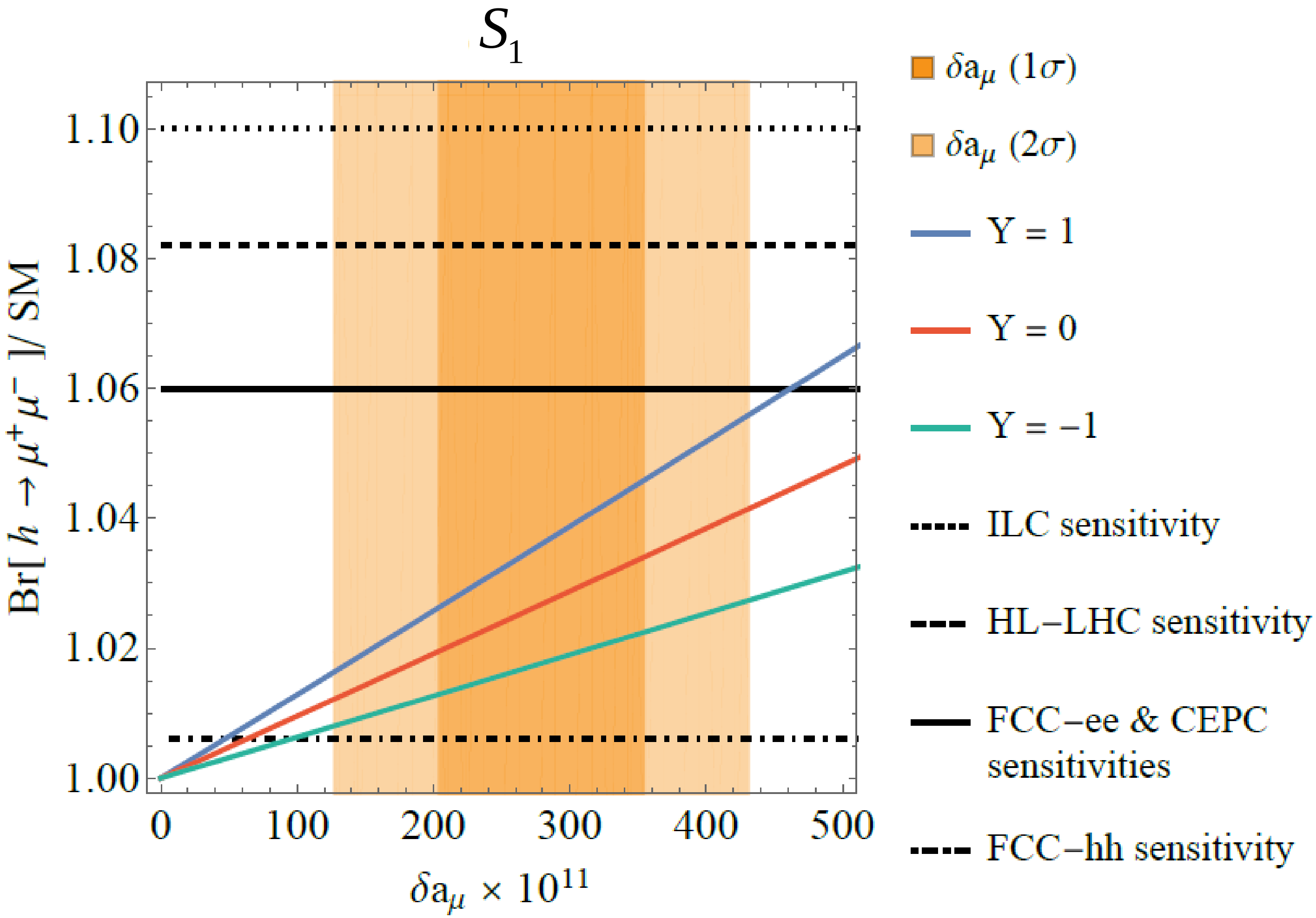


$$\frac{\mathrm{Br}\left[h\to\mu^+\mu^-\right]}{\mathrm{Br}[h\to\mu^+\mu^-]_{\mathrm{SM}}}\approx\left|1+\frac{m_t}{m_\mu}\frac{N_c}{8\pi^2}\left[\frac{\lambda_R^*\lambda_L}{m_1^2}\left(\frac{m_t^2}{8}\mathcal{J}\left(\frac{m_h^2}{m_t^2},\frac{m_t^2}{m_1^2}\right)+v^2Y_1\right)+v^2\lambda_R^*\kappa Y_{13}\frac{\log\left(m_3^2/m_1^2\right)}{m_3^2-m_1^2}\right.\right.$$
$$\left.\left.+\frac{\gamma_{LR}^*\gamma_{RL}}{m_2^2}\left(\frac{m_t^2}{8}\mathcal{J}\left(\frac{m_h^2}{m_t^2},\frac{m_t^2}{m_2^2}\right)+v^2(Y_2+Y_{22})\right)\right]\right|^2,$$

$$a_\mu\approx\frac{m_\mu}{4\pi^2}\frac{N_c m_t}{12}\mathrm{Re}\left[\frac{\gamma_{LR}\gamma_{RL}^*}{m_2^2}\mathcal{E}_1\left(\frac{m_t^2}{m_2^2}\right)-\frac{\lambda_R}{m_1^2}\left(\lambda_L^*\mathcal{E}_2\left(\frac{m_t^2}{m_1^2}\right)+\kappa Y_{13}\frac{v^2}{m_3^2}\mathcal{E}_3\left(\frac{m_1^2}{m_3^2},\frac{m_t^2}{m_3^2}\right)\right)\right],$$

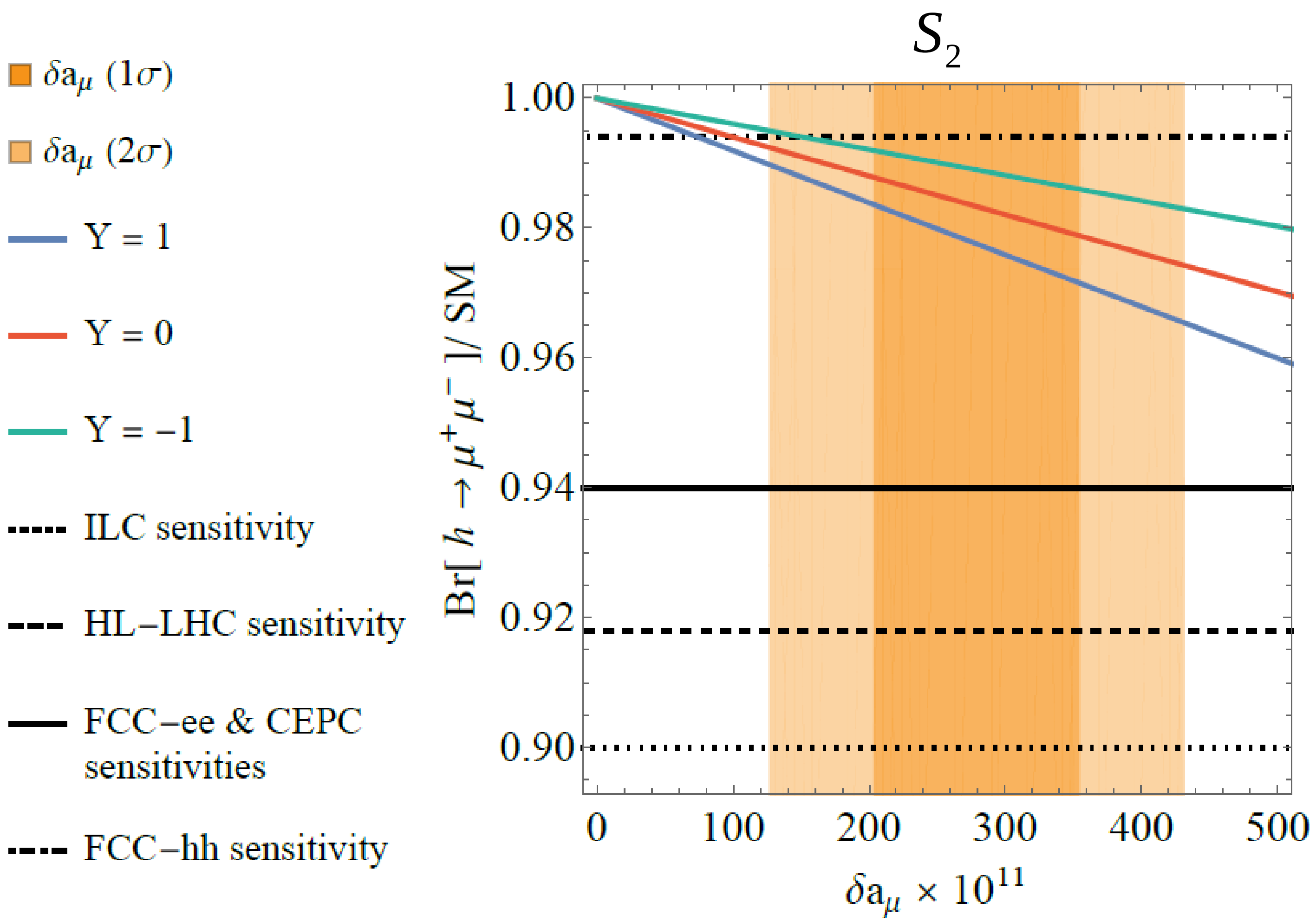
Same couplings → direct correlation

$(g\text{-}2)_\mu$ and $h \rightarrow \mu\mu$: S_1



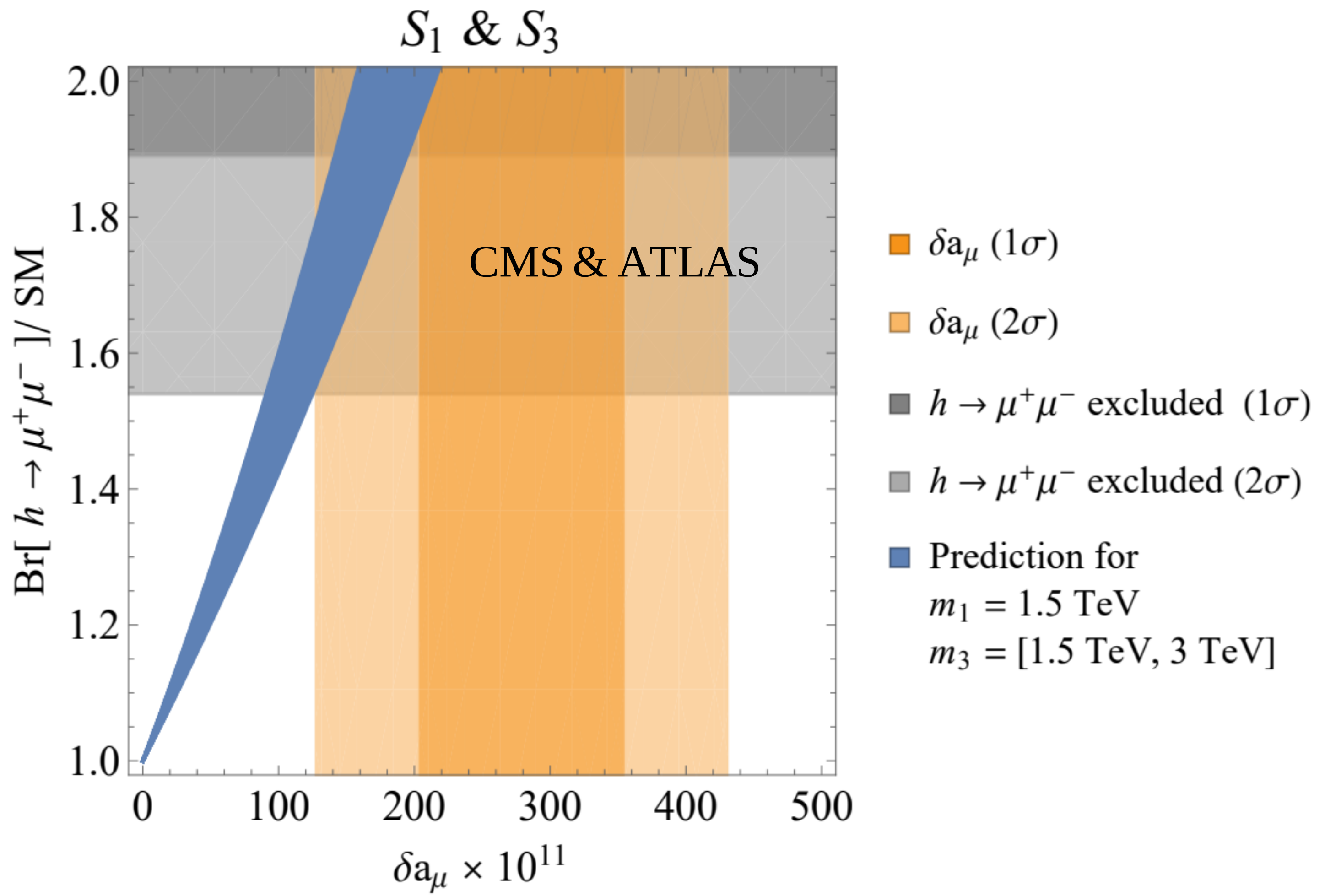
Constructive effect

$(g\text{-}2)_\mu$ and $h\to\mu\mu$: S_2



Destructive effect

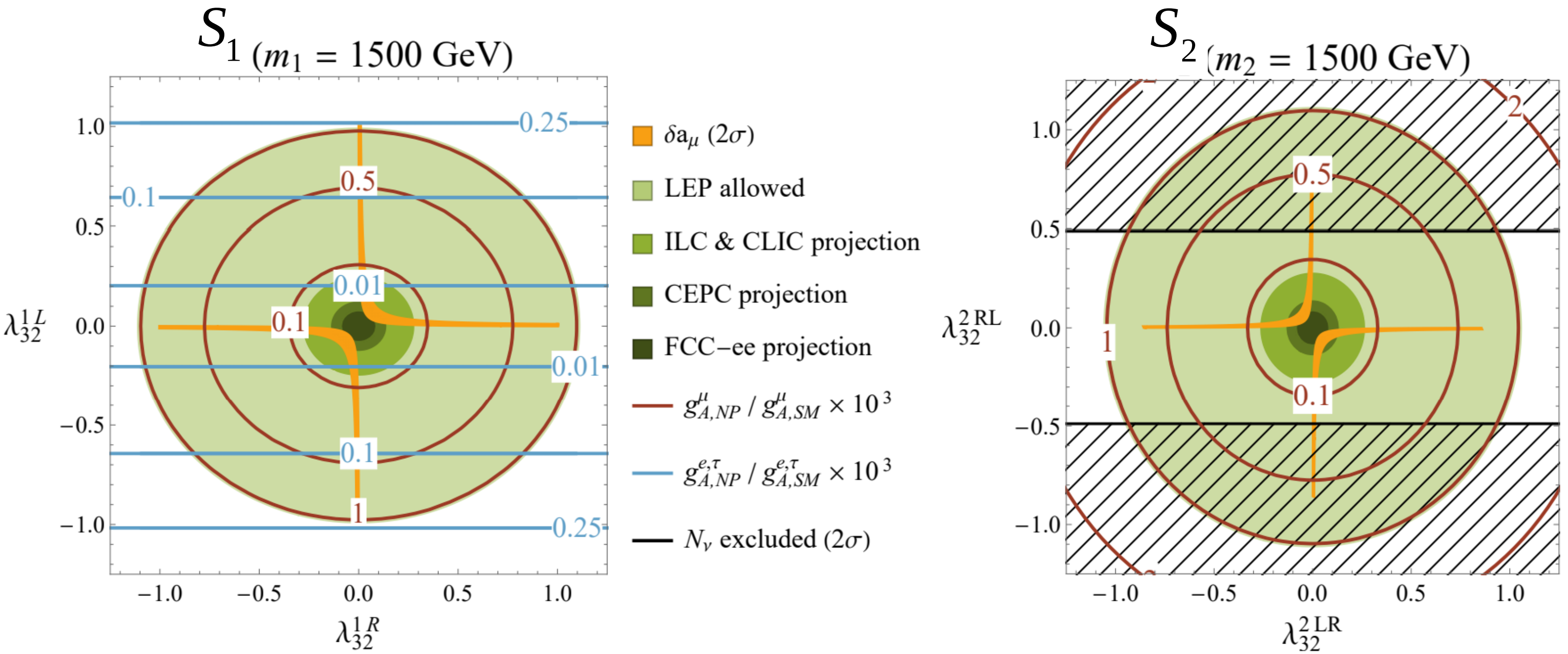
$(g\text{-}2)_\mu$ and $h\to\mu\mu$: S_1 & S_3 with mixing



Scenario already excluded by $h\to\mu\mu$

AMM of the muon and Z->ll

- Wμν modification also leads to an effect in Z→ee
- Z→νν constraining for Φ_2



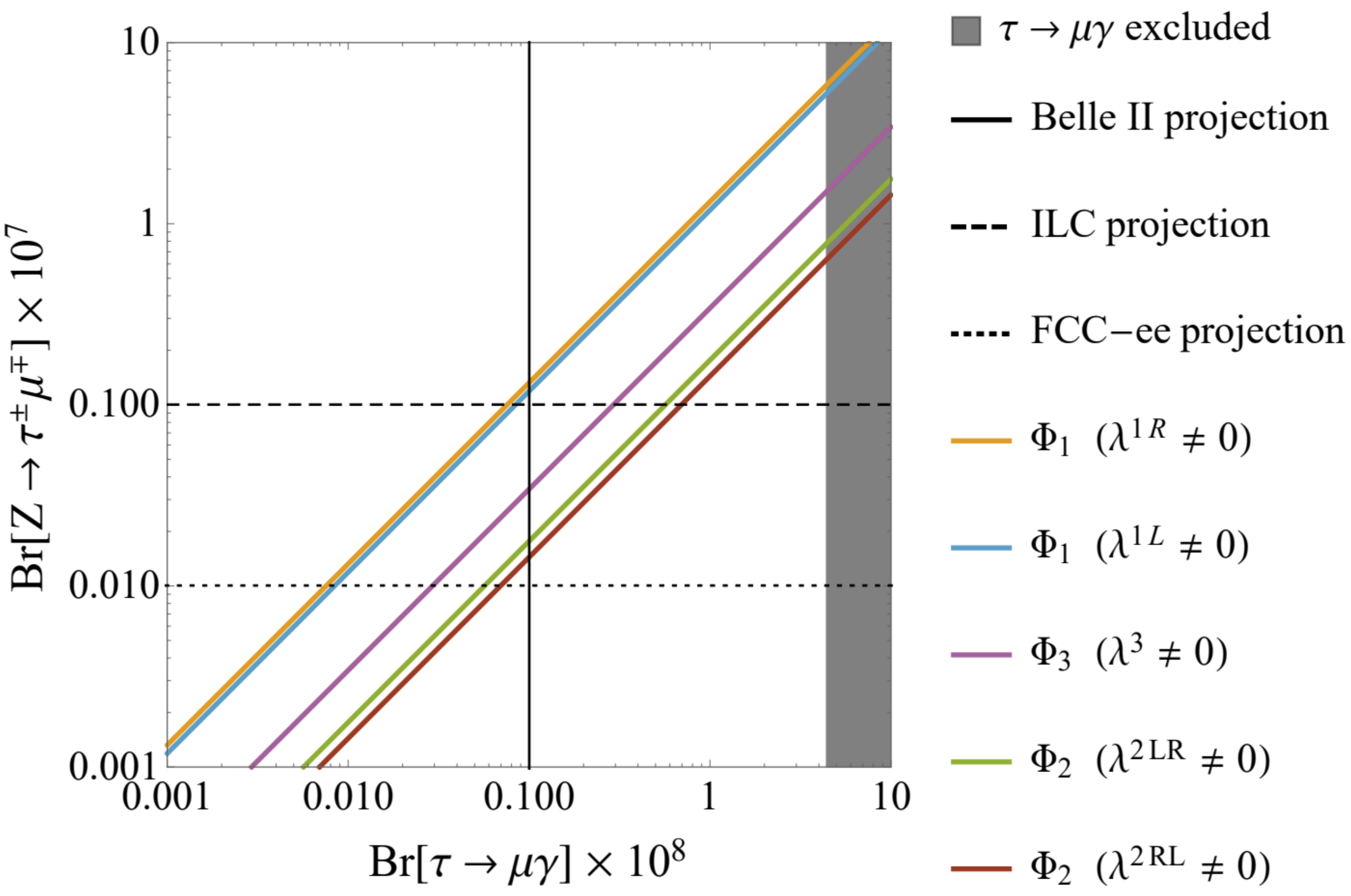
Observable effect in Z→μμ

Conclusions

- Leptoquarks are well motivated by the flavour anomalies
- They can explain $b\to s\mu\mu$, $b \to c\tau\nu$ and $(g-2)_\mu$ via an m_t enhanced effect
- $(g-2)_\mu$ explanation leads to a correlated chirally enhanced effect in $h\to\mu\mu$
- $(g-2)_\mu$ motivates LQ couplings to muon and top quarks ➡ sizable effect in $Z\to\mu\mu$

$h\to\mu\mu$ important channel for the LHC and future colliders

Lepton Flavour Violating

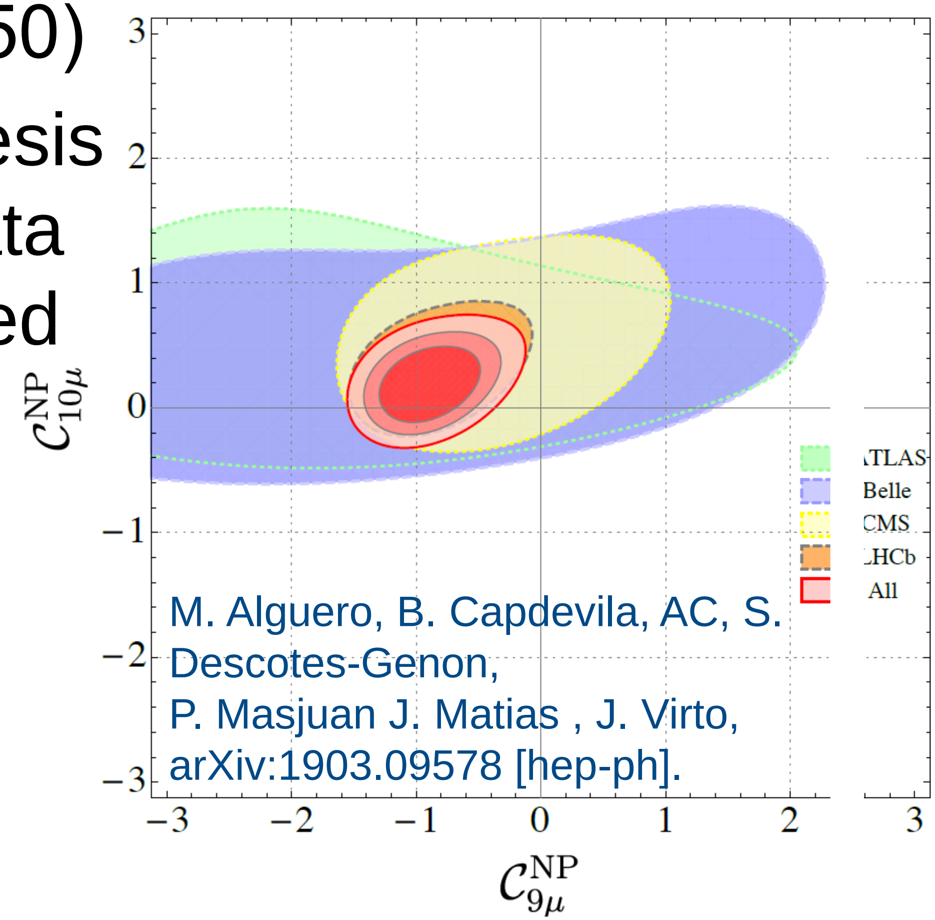


Z→τμ promising channel

Backup

Global Fit to $b \to s\mu^+\mu^-$ Data

- Perform global model independent fit to include all observables (≈150)
- Several NP hypothesis give a good fit to data significantly preferred over the SM hypothesis



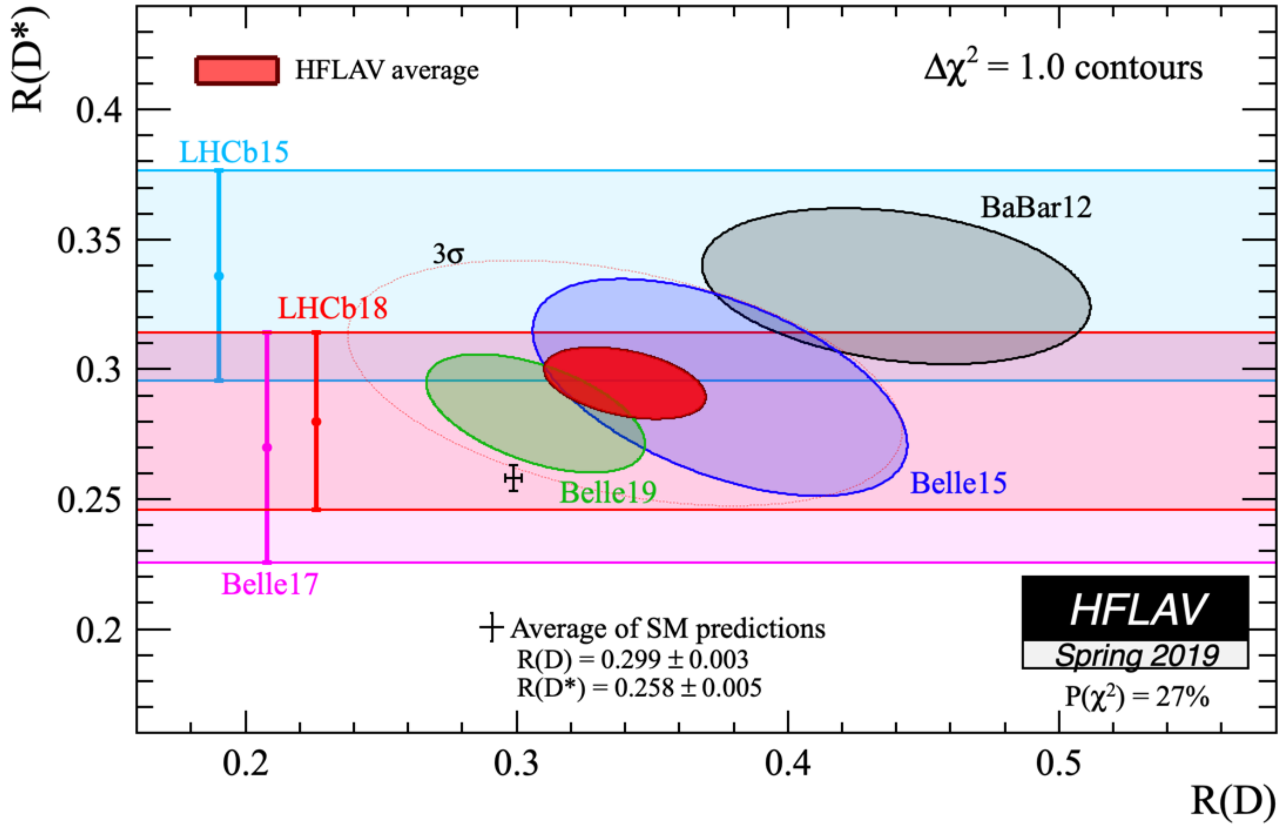
$$O_9 = \bar{s}\gamma^\mu P_L b\,\bar{l}\gamma_\mu l$$

$$O_{10} = \bar{s}\gamma^\mu P_L b\,\bar{l}\gamma_\mu \gamma^5 l$$

Fit is 5-6 σ better than the SM

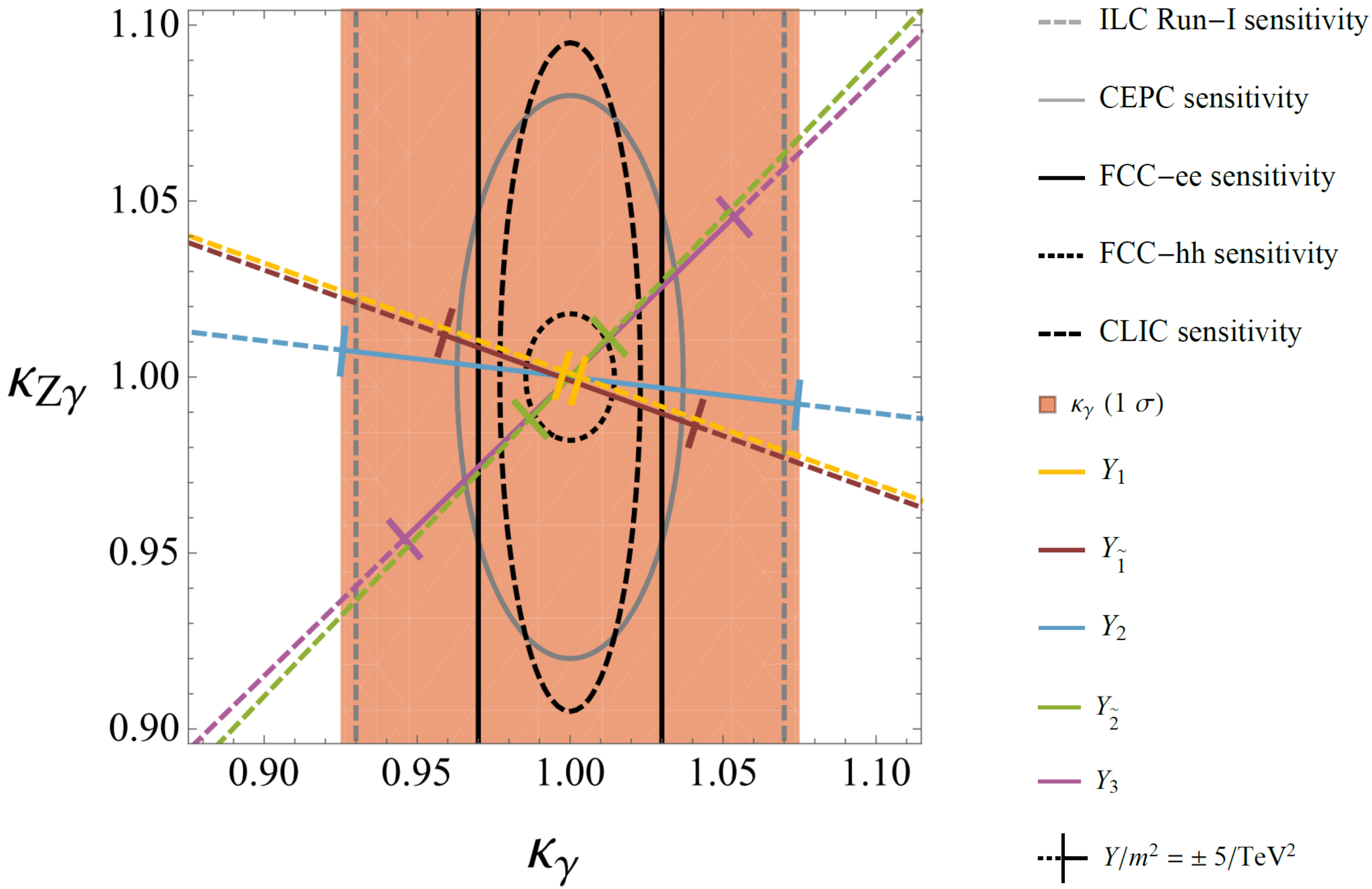
b→cτν Measurements

$$R\left(D^{(*)}\right) = B \to D^{(*)}\tau\nu / B \to D^{(*)}l\,\nu$$



All measurements above the SM prediction
O(10%) constructive effect at 3σ preferred

Higgs signal strength (γZ)

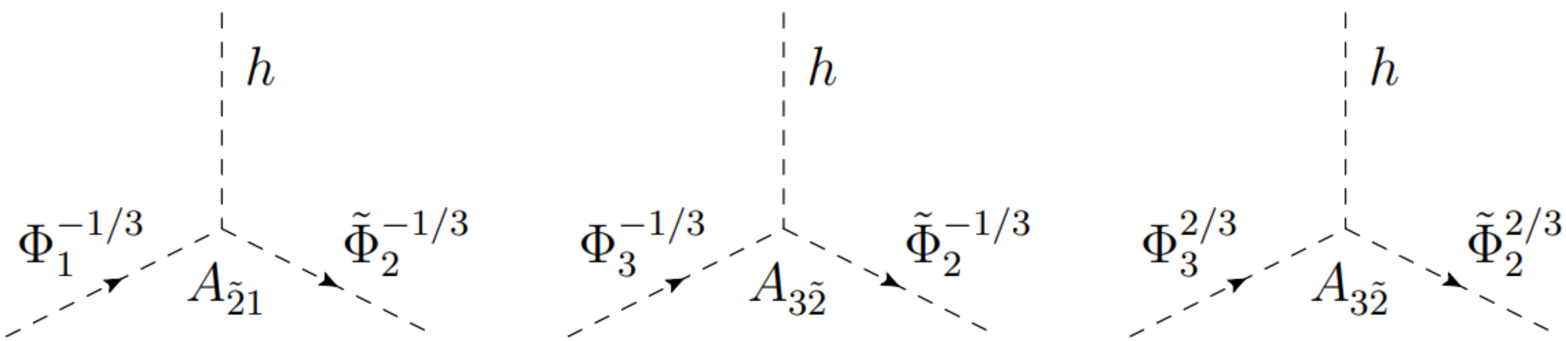


γZ provides complementary information

Leptoquark-Higgs Interactions

- LQs can (must) couple to the SM Higgs

$$
\begin{aligned}
\mathcal{L}_{H\Phi} = & -A_{\tilde{2}1}\big(\tilde{\Phi}_2^\dagger H\big)\Phi_1 + A_{3\tilde{2}}\big(\tilde{\Phi}_2^\dagger\big(\tau\cdot\Phi_3\big)H\big) + Y_{\tilde{2}2}\big(\Phi_2^\dagger H\big)\big(H i\tau_2\tilde{\Phi}_2\big) \\
& + Y_{3\tilde{1}}\big(H i\tau_2\left(\tau\cdot\Phi_3\right)^\dagger H\big)\tilde{\Phi}_1 + Y_{31}\big(H^\dagger\left(\tau\cdot\Phi_3\right)H\big)\Phi_1^\dagger + \text{h.c.} \\
& - Y_{22}\big(H i\tau_2\Phi_2\big)\big(H i\tau_2\Phi_2\big)^\dagger - Y_{\tilde{2}\tilde{2}}\big(H i\tau_2\tilde{\Phi}_2\big)\big(H i\tau_2\tilde{\Phi}_2\big)^\dagger \\
& - iY_{33}\varepsilon_{IJK}H^\dagger\tau_I H\Phi_{3,K}^\dagger\Phi_{3,J} \\
& - \sum_{k=1}^{3}\big(m_k^2 + Y_k H^\dagger H\big)\Phi_k^\dagger\Phi_k - \sum_{k=1}^{2}\big(\tilde{m}_k^2 + Y_{\tilde{k}}H^\dagger H\big)\tilde{\Phi}_k^\dagger\tilde{\Phi}_k\,.
\end{aligned}
$$



Additional sources of EW Symmetry Breaking