NP implications of B-anomalies & connections with high-pT

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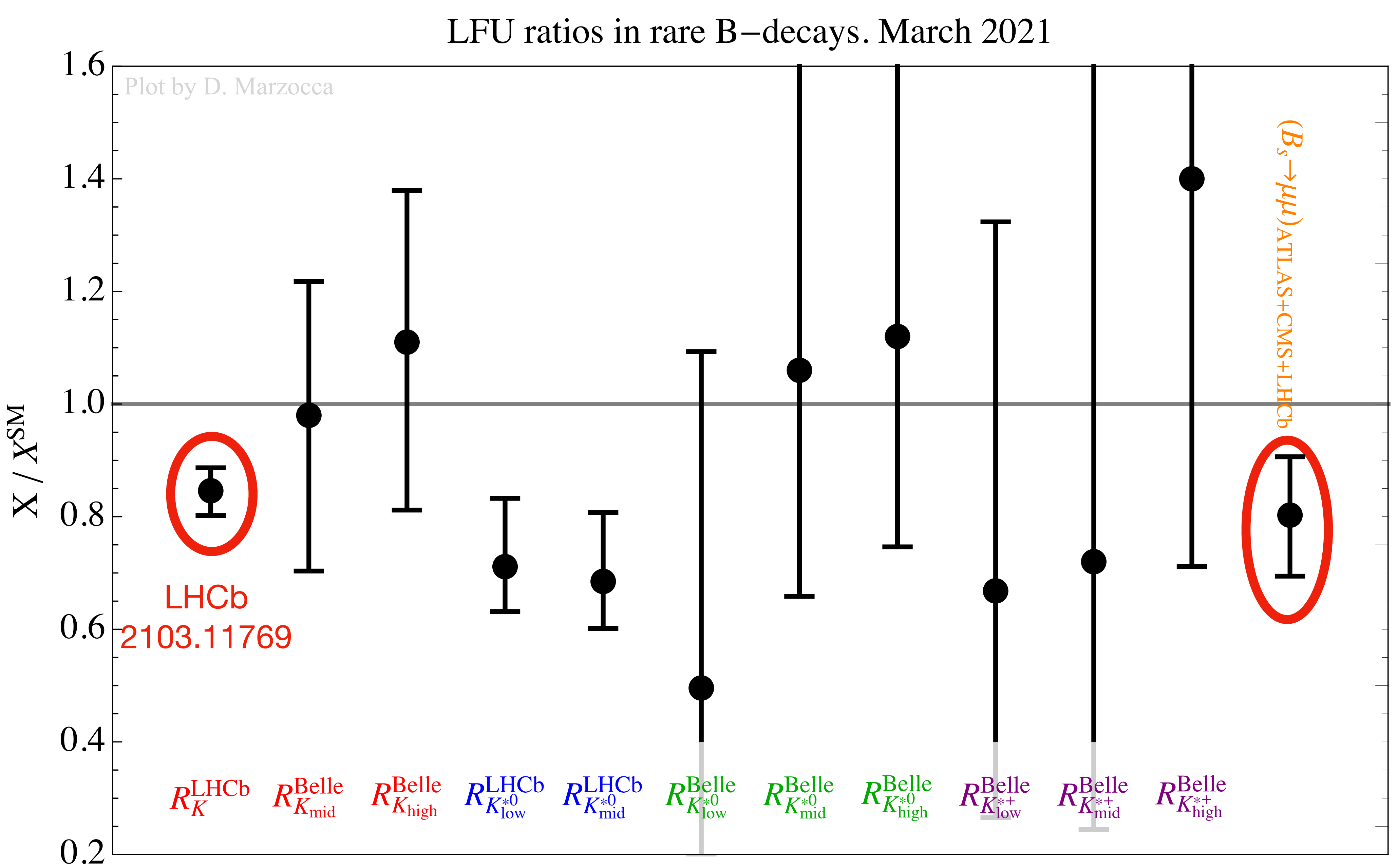
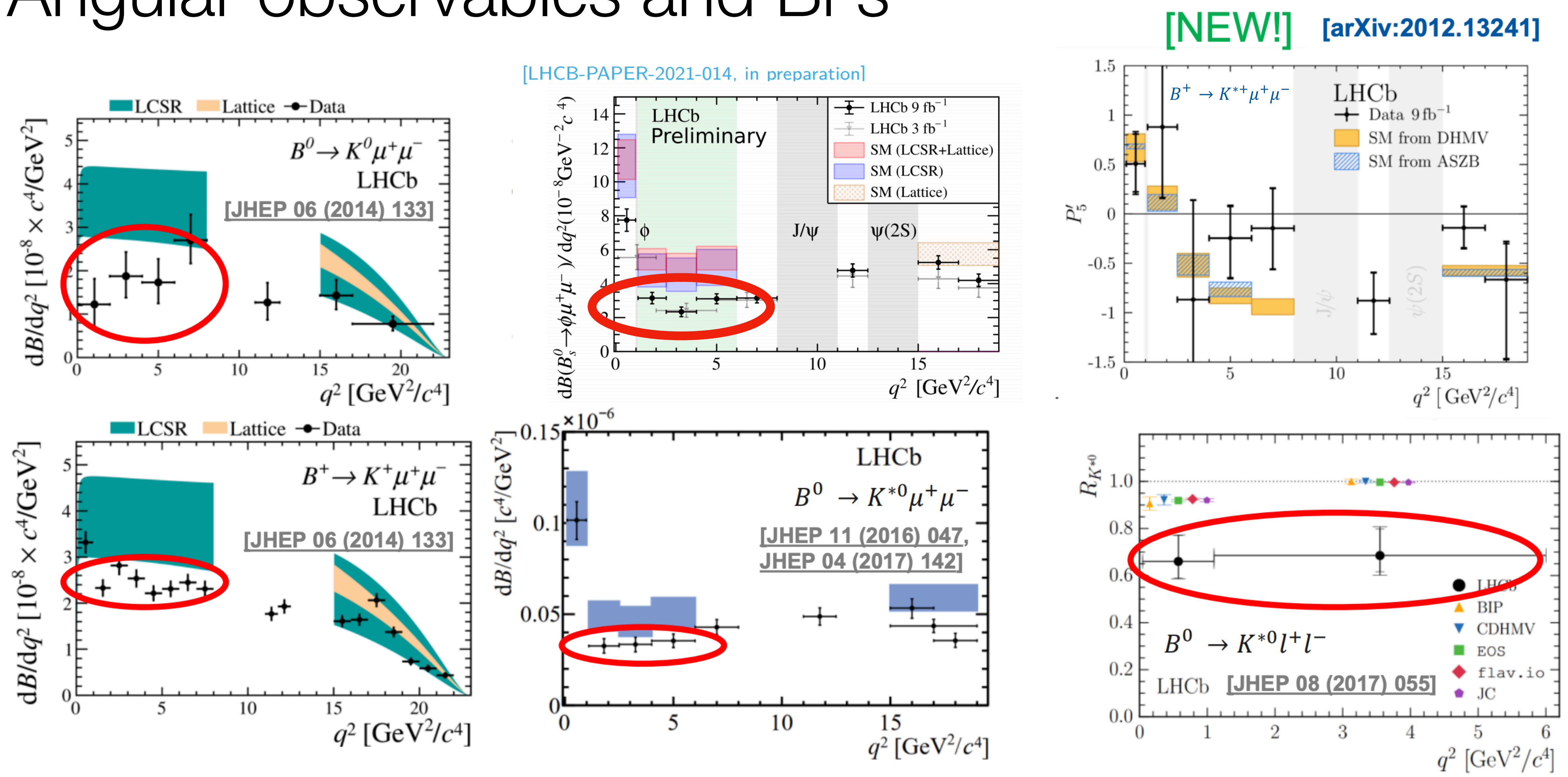
R_K and the other $b \to s\, \mu^+\mu^-$ probes

Compilation of “clean” observables



Angular observables and Br’s



Specific NP hypothesis, with less conservative estimates of SM uncertainties show significances in the 5.9 - 7σ range.

Altmannshofera and Staub [2103.13370], Algueró et al. [2104.08921], Geng et al. [2103.12738]

The global significance of the **New Physics hypothesis** in b → sμ⁺μ⁻ (very conservative SM uncertainties estimate) is:

3.9σ Lancierini, Isidori, Owen, Serra [2104.05631]

Very good solution to all these deviations with:

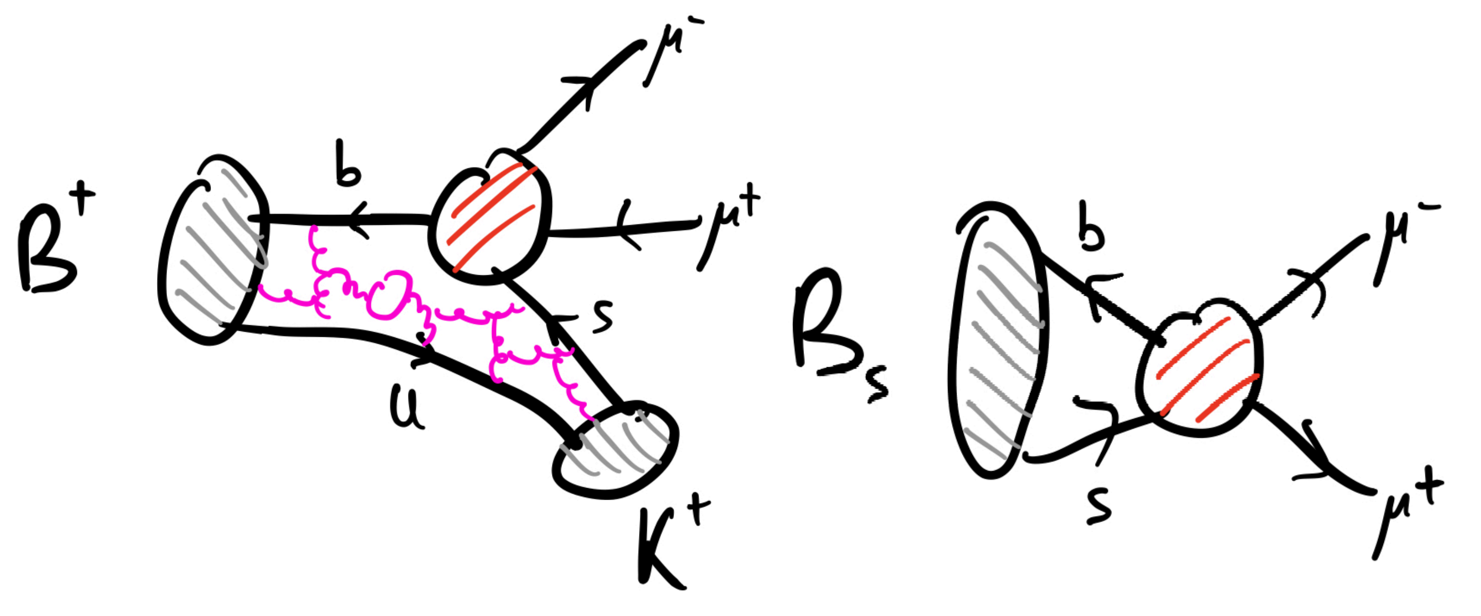
$$\mathcal{L}_{\rm eff} \supset \frac{e^{i\alpha_{bs}}}{\Lambda_{bs}^2} (\bar{s}_L \gamma^\mu b_L)(\bar{\mu}_L \gamma_\mu \mu_L) + h.c.$$

Best-fit for $\alpha_{bs}=0$: $\Lambda_{bs} \approx 37$ TeV

From flavour to High-p_T: EFT

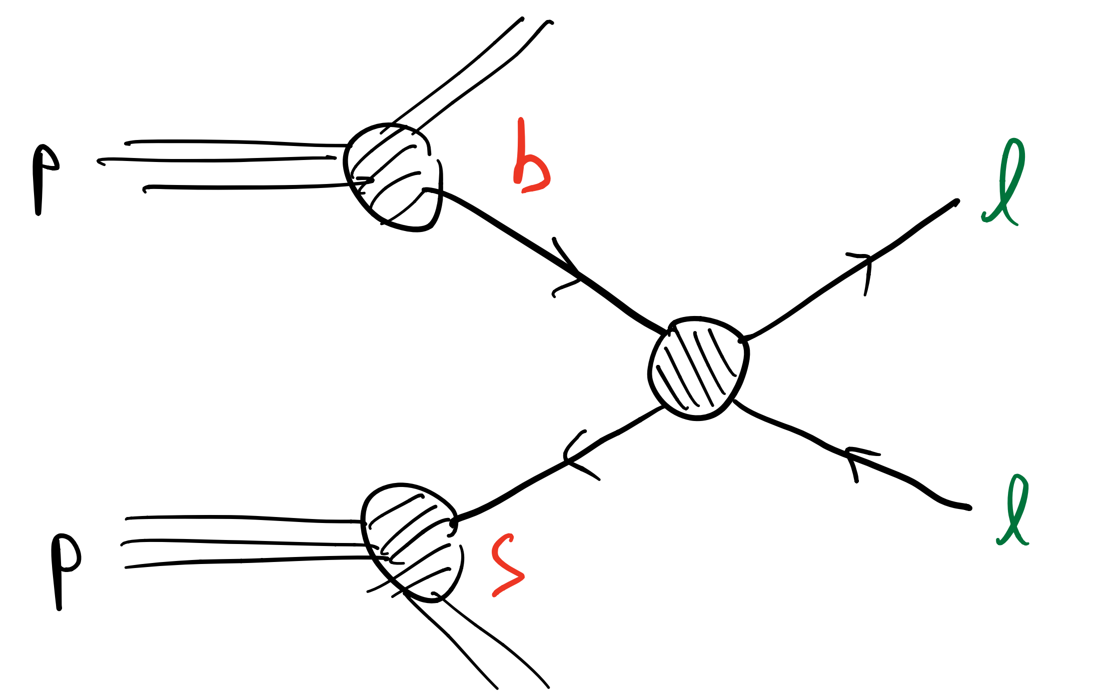
The same contact interactions can be probed at both high and low energies

Meson decays



Crossing symmetry

Drell-Yan tail



From RK anomalies:

$$\frac{1}{\Lambda^2_{bs\mu}}(\bar{s}_L\gamma_\mu b_L)(\bar{\mu}_L\gamma^\mu\mu_L)$$

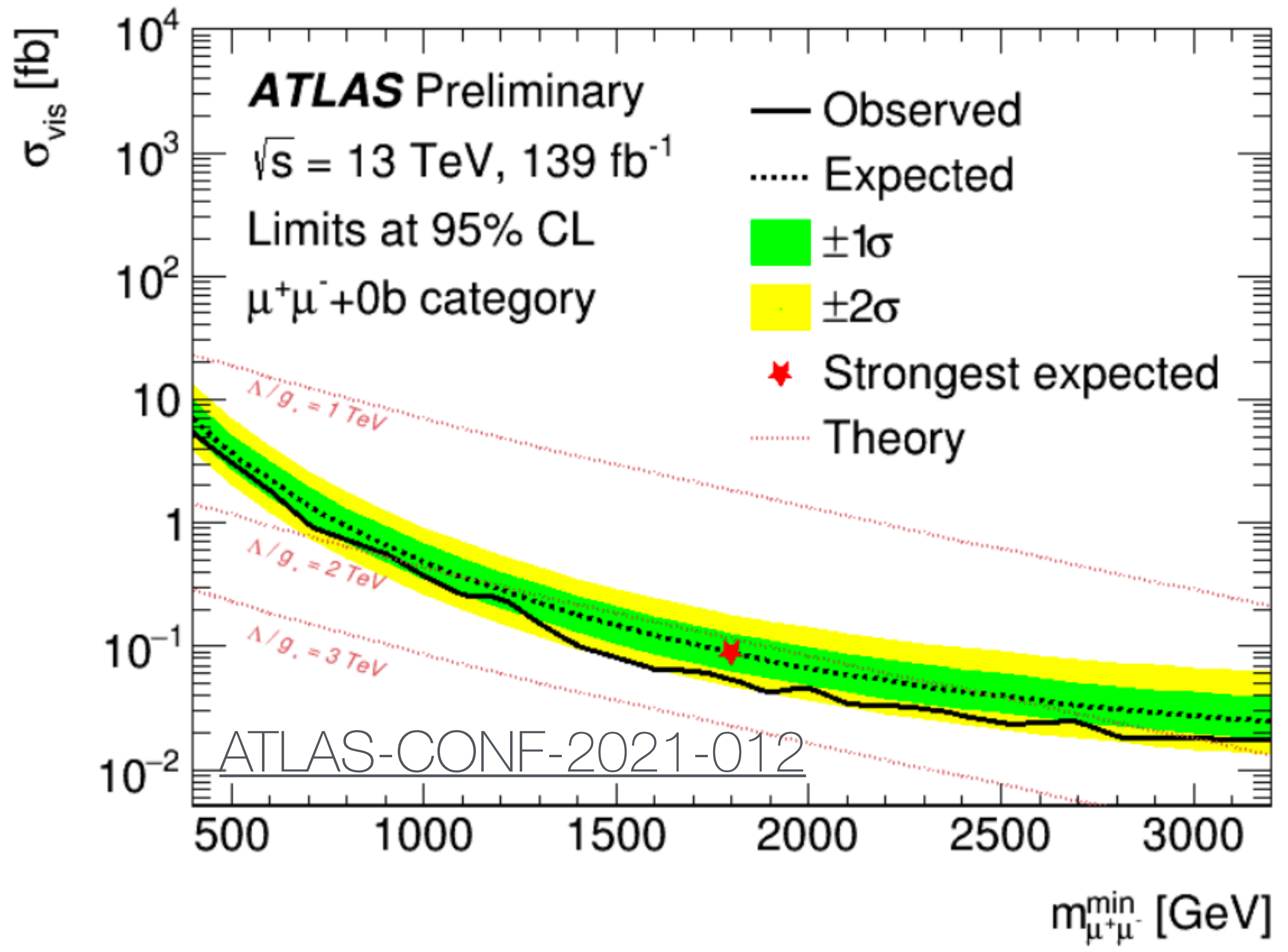
$$\Lambda_{bs\mu} \sim 37 \text{ TeV}$$

If $m_{EW} < E_{\mu\mu} \ll M_{NP}$ we can use an EFT approach:

Present (future 3ab^{-1}) limits from LHC:

$$\Lambda_{bs\mu} > 2.4\ (4.1) \text{ TeV}$$

[Greljo, DM 1704.09015]
[See also Kohda et al. 1803.07492, Afik et al. 1811.07920]
ATLAS search ATLAS-CONF-2021-012



No hope to see this directly…. but…

From flavour to High-p_T: EFT and MFV

In Minimal Flavor Violation the b-s contact interaction is suppressed by Vts compared to flavor-diagonal ones:

D'Ambrosio, Giudice, Isidori, Strumia [hep-ph/0207036]

$$\mathcal{L} = \frac{C_{ij}^{D\mu}}{v^2} \left(\bar{d}_L^i \gamma_\mu d_L^j\right)\left(\bar{\mu}_L \gamma^\mu \mu_L\right)$$

$$\left| C_{bs\mu} \right| \sim \left| C_{D\mu} V_{tb} V_{ts}^* \right|$$

Coeff. of flavor-diagonal (q_i-q_i-μ-μ) operators

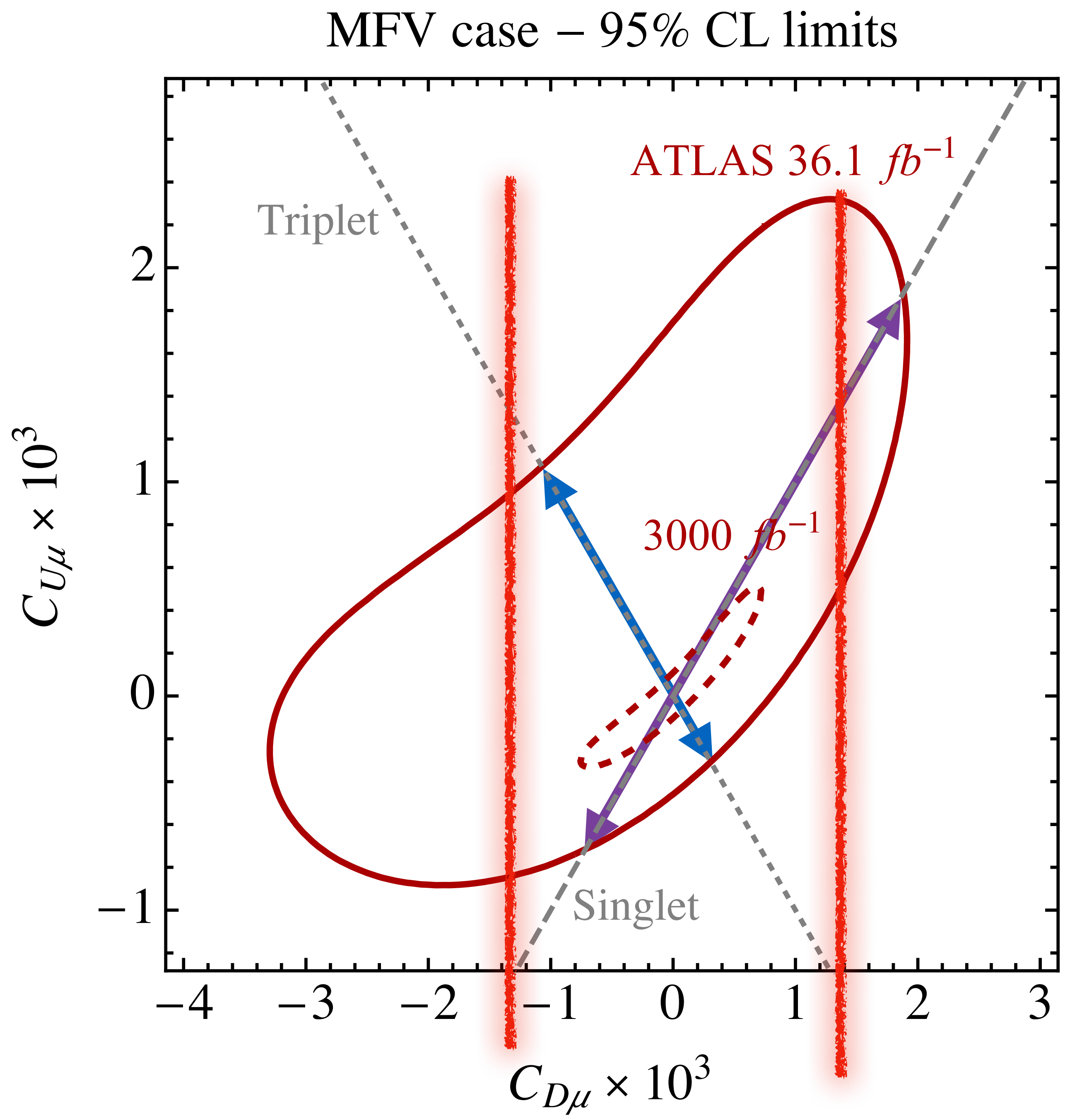
$$C_{bs\mu} = \frac{v^2}{\Lambda_{bs\mu}^2}$$ is fixed by RK fits

We get a prediction for $C_{D\mu}$ (up to O(1) factors)

$$|C_{D\mu}| \sim 1.4 \times 10^{-3}$$

$$\Lambda_{D\mu} \sim 6.4\text{TeV}$$

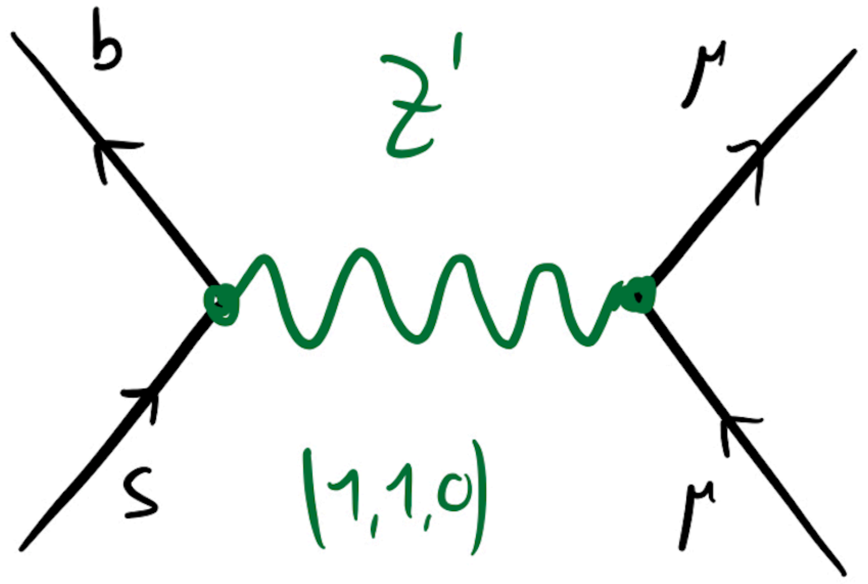
[Greljo, DM 1704.09015]



The MFV solution is in tension with LHC Drell-Yan!

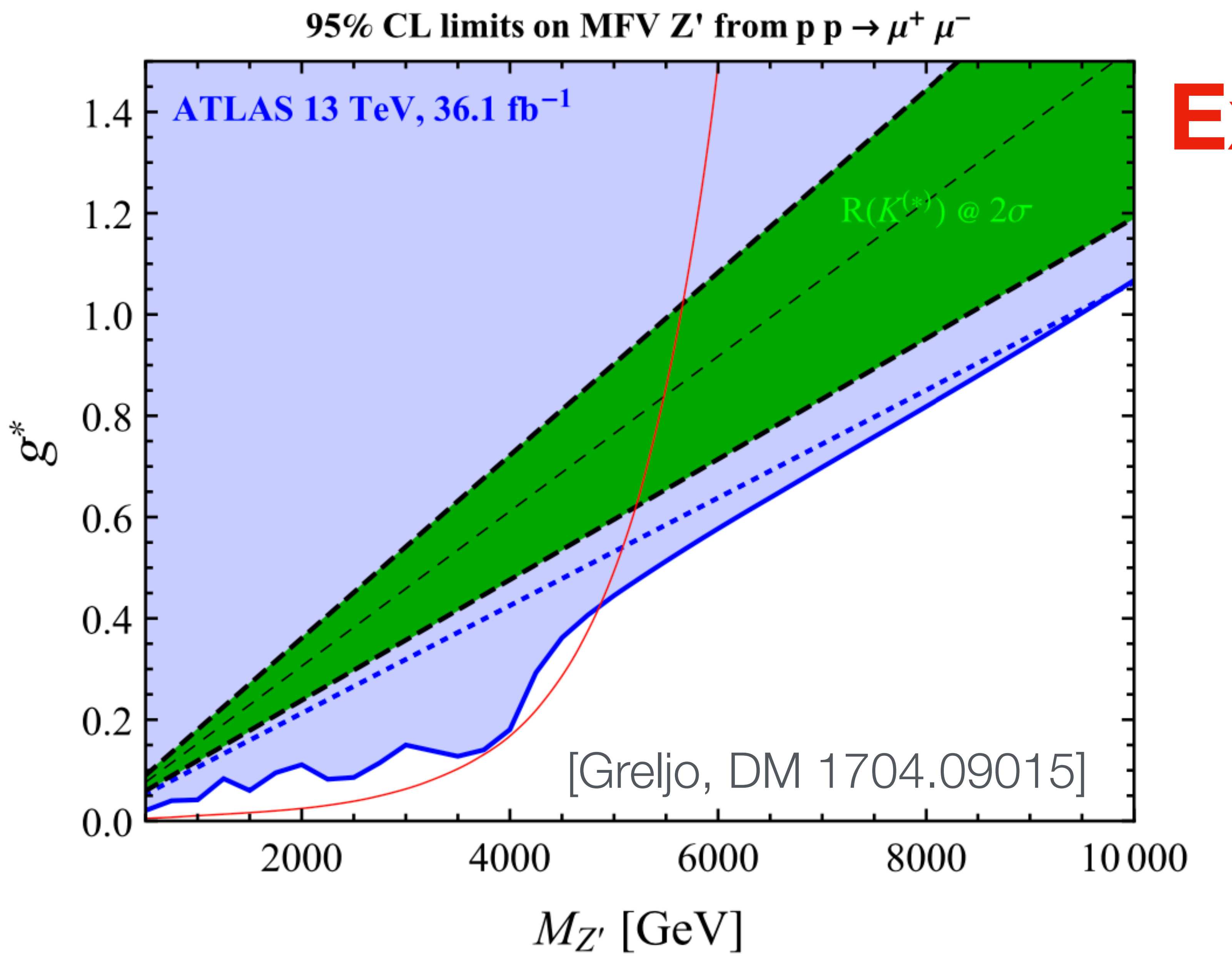
Tree-level Mediators: Z'

Altmannshofer et al 1403.1269, Allanach et al. 1904.10954, 2009.02197, 2103.12056, etc…



$$\frac{g_{bs}\, g_{\mu\mu}}{M_{Z'}^2} \sim \frac{1}{(37\,\text{TeV})^2}$$

This can be searched in **high-p_T Drell-Yan**.
For **MFV**-like flavor structure (e.g. $U(1)_{B-L}$):



Excluded if MFV.

B_s-mixing induced at tree-level:

$$\frac{g_{bs}^2}{M_{Z'}^2} < \frac{1}{(220\,\text{TeV})^2}$$

+ imposing R_K: $g_{bs} \lesssim 0.03\, g_{\mu\mu}$

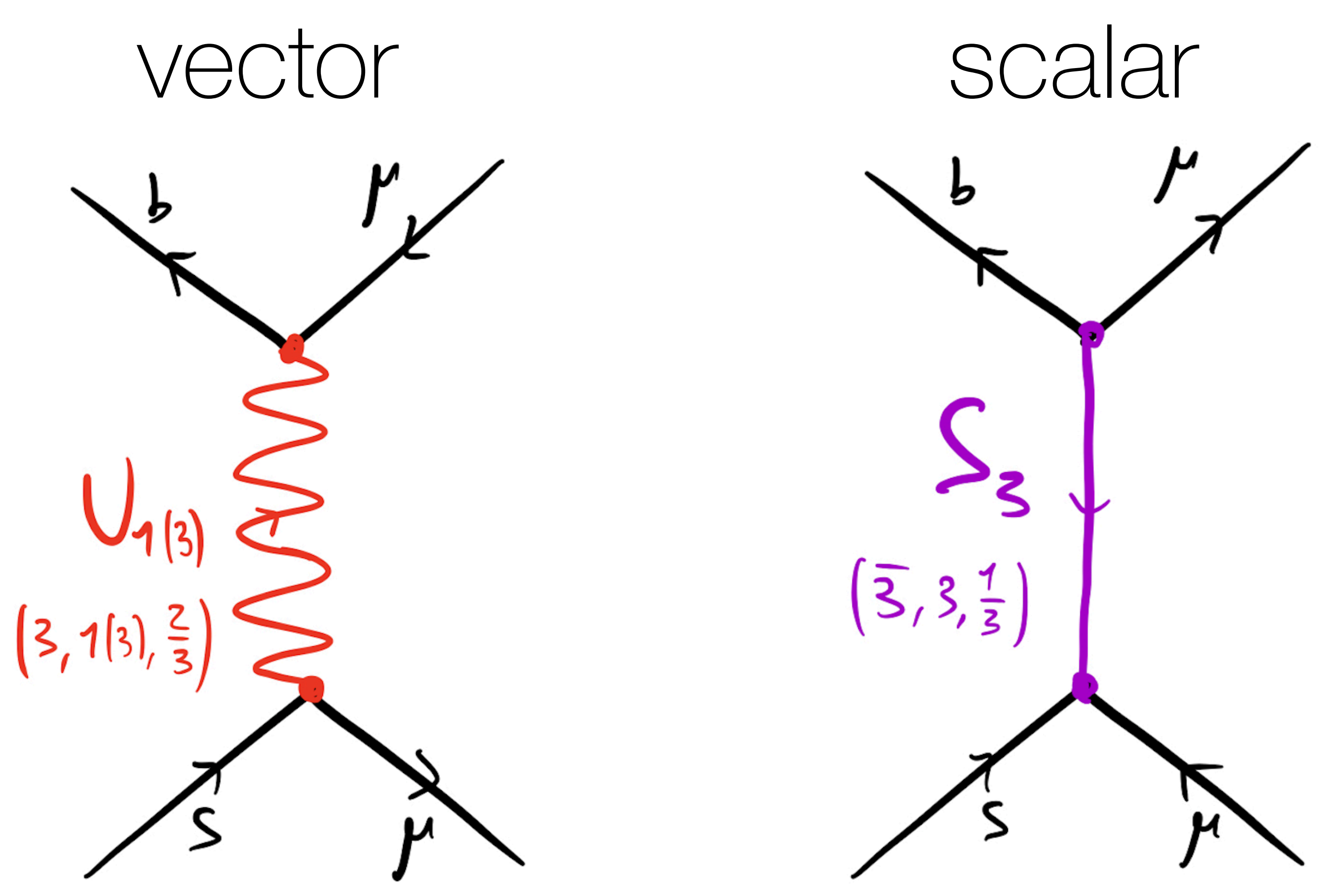
Saturating this and for $g_{\mu\mu} \sim \sqrt{4\pi}$:

Upper bound on $M_{Z'}$ $M_{Z'} \lesssim 22\,\text{TeV}$

This bound is avoided if Z' coupled mainly to 3rd gen: e.g. $U(1)_{B3-L2}$ or via mixing with vector-like quarks.

Allanach 2009.02197, Altmannshofer et al 1403.1269

Tree-level Mediators: Leptoquarks



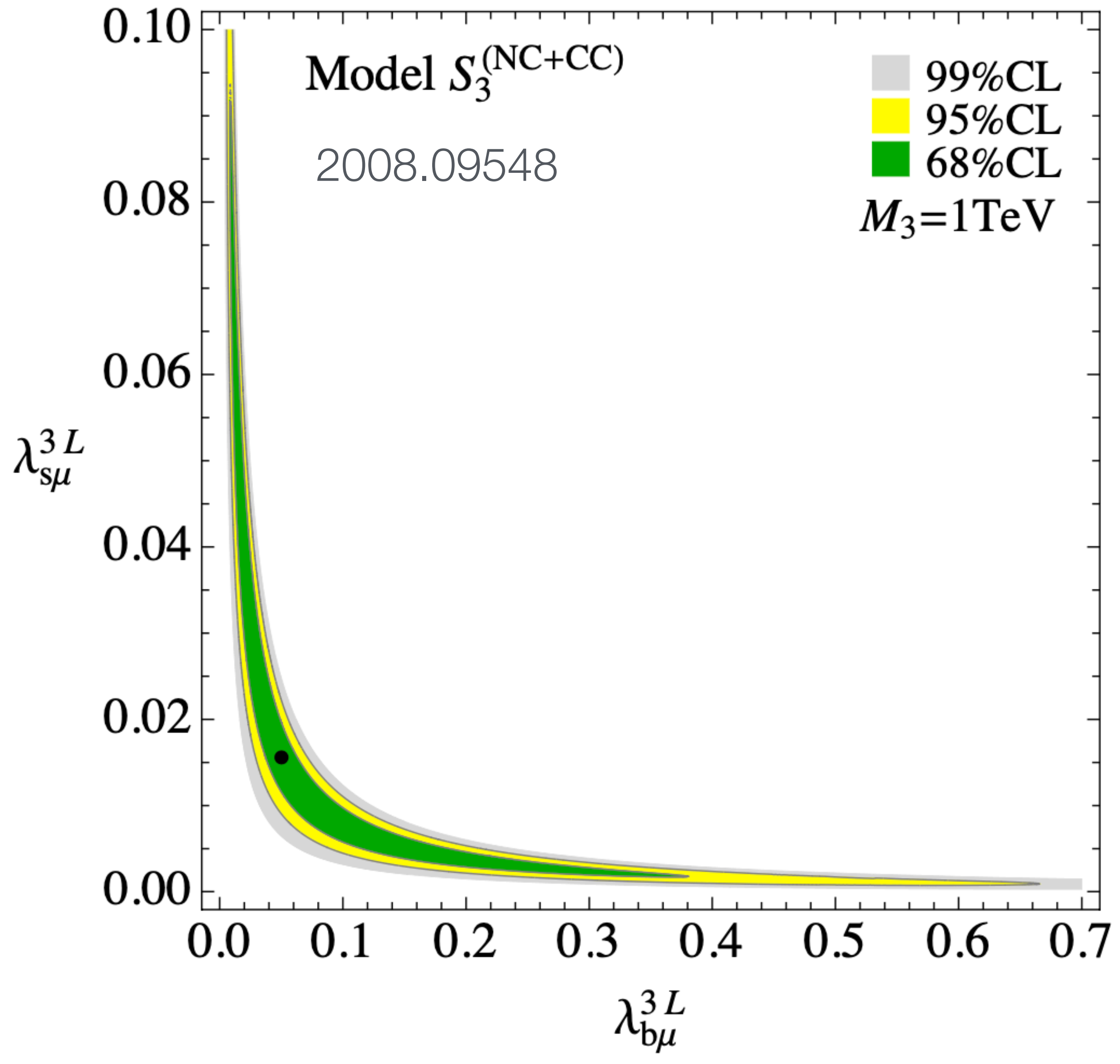
Bs-mixing is only loop-induced.

$$\mathcal{L}_{\text{int}} \supset (\lambda^{3L})_{i\alpha} \bar{q}^c_i \epsilon \sigma^I \ell_\alpha S^I_3 + \text{h.c.}$$

$$\mathcal{L}_{\text{eff}} \supset \frac{\lambda^{3L*}_{s\ell} \lambda^{3L}_{b\ell}}{M_3^2} (\bar{s}_L \gamma^\mu b_L)(\bar{\mu}_L \gamma_\mu \mu_L) + h.c.$$

TeV-scale LQs can fit the anomaly with small couplings.

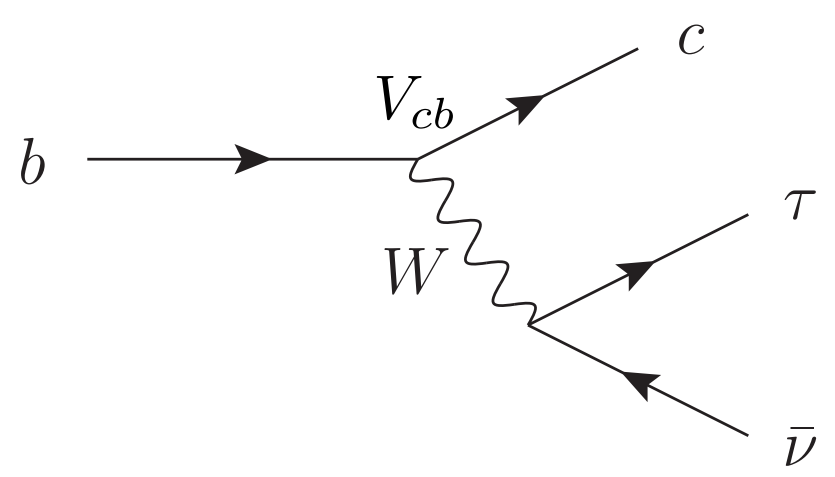
[Gherardi, DM, Venturini 2008.09548]



No show-stoppers to fit the R_K anomalies with LQs at tree-level.

Charged-current B-anomalies

$b \to c\,\tau\,\nu$ vs. $b \to c\,\ell\,\nu$



$$R(D^{(*)}) \equiv \frac{\mathcal{B}(B^0 \to D^{(*)+}\tau\nu)}{\mathcal{B}(B^0 \to D^{(*)+}\ell\nu)}, \quad \ell = \mu, e$$

Tree-level SM process with V_{cb} suppression.

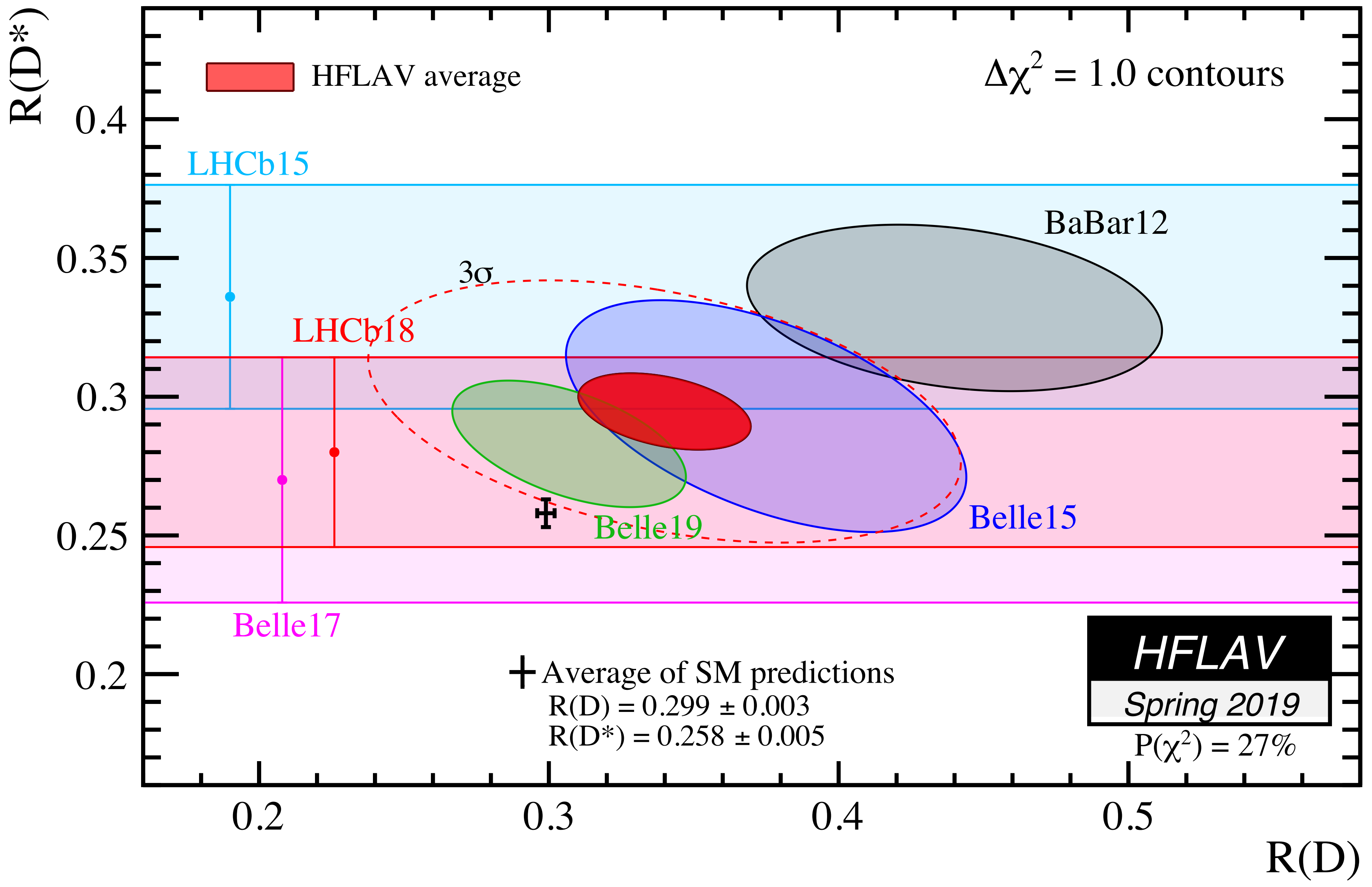
~ 14% enhancement from the SM

~ 3σ from the SM (3.7σ when combined)

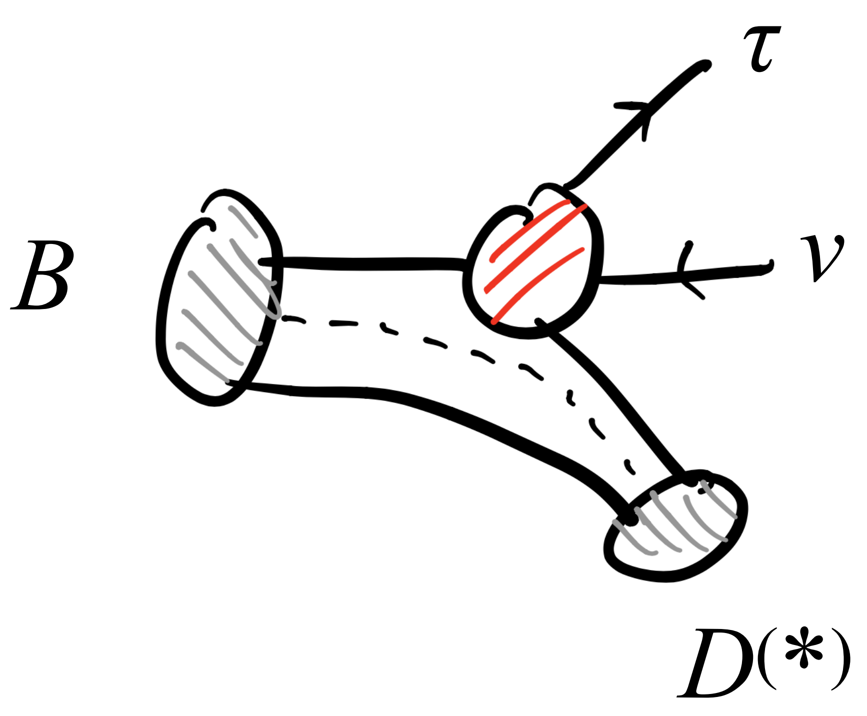
While μ/e universality well tested $R(D)^{\mu/e} = 0.995 \pm 0.045$

Belle - [1510.03657]

All measurements since 2012 consistently above the SM predictions



Low-energy New Physics interpretations:



$$\mathcal{L}_{\rm BSM} = \frac{2c}{\Lambda^2}(\bar{c}_L\gamma_\mu b_L)(\bar{\tau}_L\gamma^\mu\nu_\tau) + h.c.$$

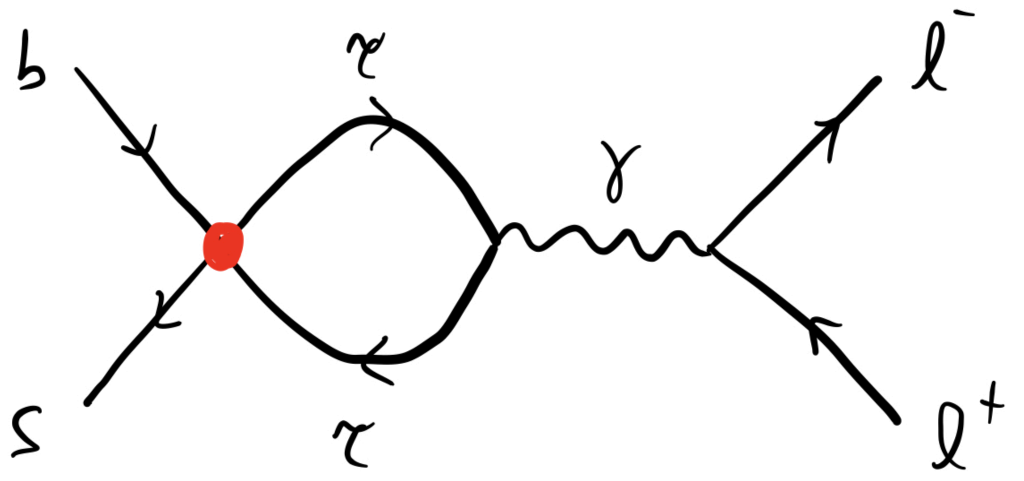
$$\Lambda/\sqrt{c} \sim 4.5\ \text{TeV}$$

Other solutions with tensor and scalar operators also fit well data.

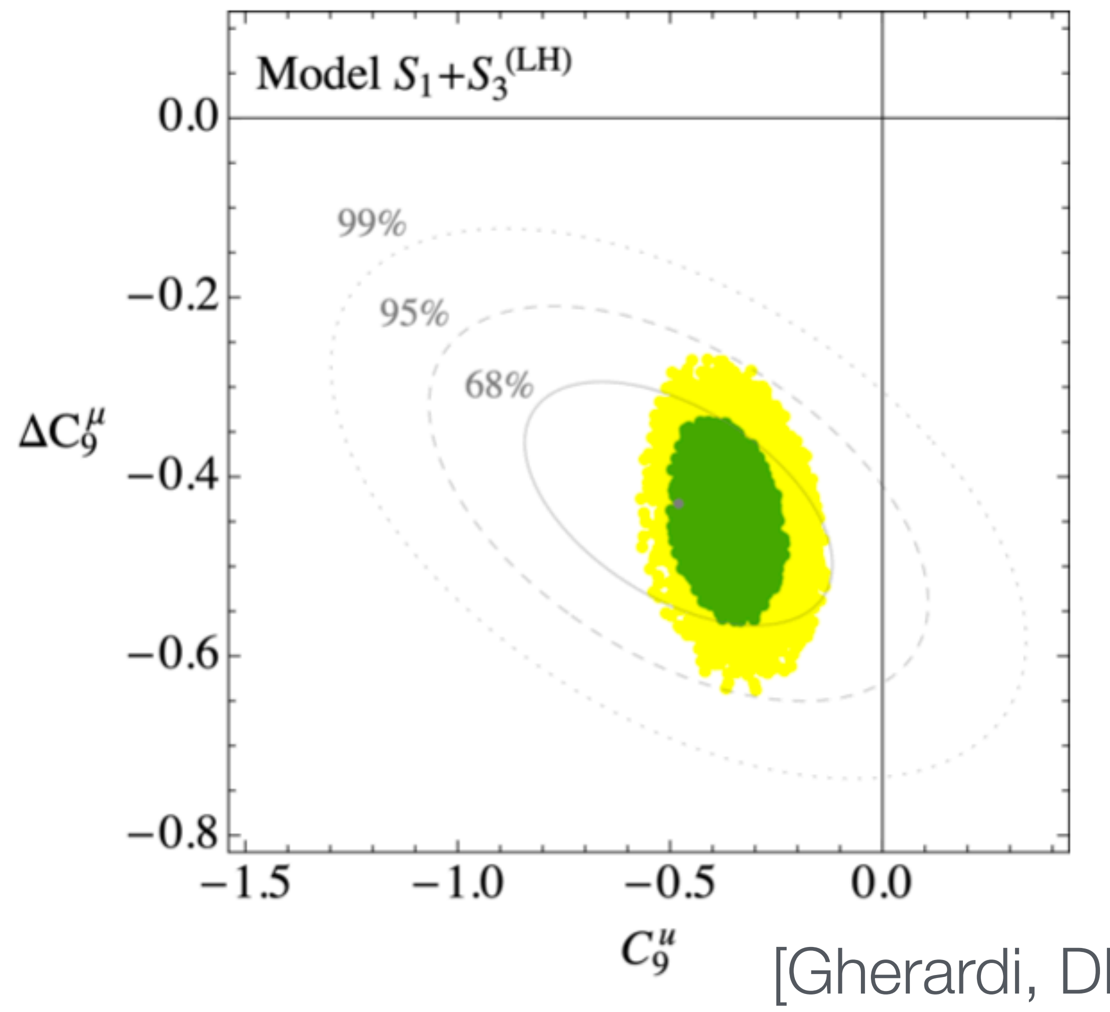
From R_K to $R(D^{(*)})$ anomalies

A large coupling to the τ induces an RG-enhanced **lepton-flavor universal** contribution proportional to C_9^U

Capdevila et al. 1712.01919, Crivellin et al. 1807.02068



$$\mathcal{C}_9^{\rm U} \approx 7.5\left(1-\sqrt{\frac{R_{D^{(*)}}}{R_{D^{(*)}\rm SM}}}\right)\left(1+\frac{\log(\Lambda^2/(1{\rm TeV}^2))}{10.5}\right)$$



Correct size obtained with the preferred value of $R(D^{(*)})$.

[Gherardi, DM, Venturini 2008.09548]

R_K → $\sim \frac{g_\mu V_{ts}}{\Lambda^2}(\bar{b}_L\gamma_\alpha s_L)(\bar{\mu}_L\gamma^\alpha\mu_L)$

$\Lambda/\sqrt{g_\mu} \sim$ **7 TeV**

CKM-like flavor structure

SM gauge invariance $SU(2)_L$

$$C_T\,(\bar{Q}_L^i\gamma_\mu\sigma^a Q_L^j)(\bar{L}_L^\alpha\gamma^\mu\sigma^a L_L^\beta) + C_S\,(\bar{Q}_L^i\gamma_\mu Q_L^j)(\bar{L}_L^\alpha\gamma^\mu L_L^\beta)$$

Usually UV physics generates both.

The exception are Z' models, which generate only the singlet

$$\sim \frac{g_\mu V_{cb}}{\Lambda^2}(\bar{b}_L\gamma_\alpha c_L)(\bar{\nu}_L^\mu\gamma^\alpha\mu_L)$$

Charged-current in muons

Generalising lepton flavour

$$\sim \frac{g_\tau V_{cb}}{\Lambda^2}(\bar{b}_L\gamma_\alpha c_L)(\bar{\nu}_L^\tau\gamma^\alpha\tau_L)$$

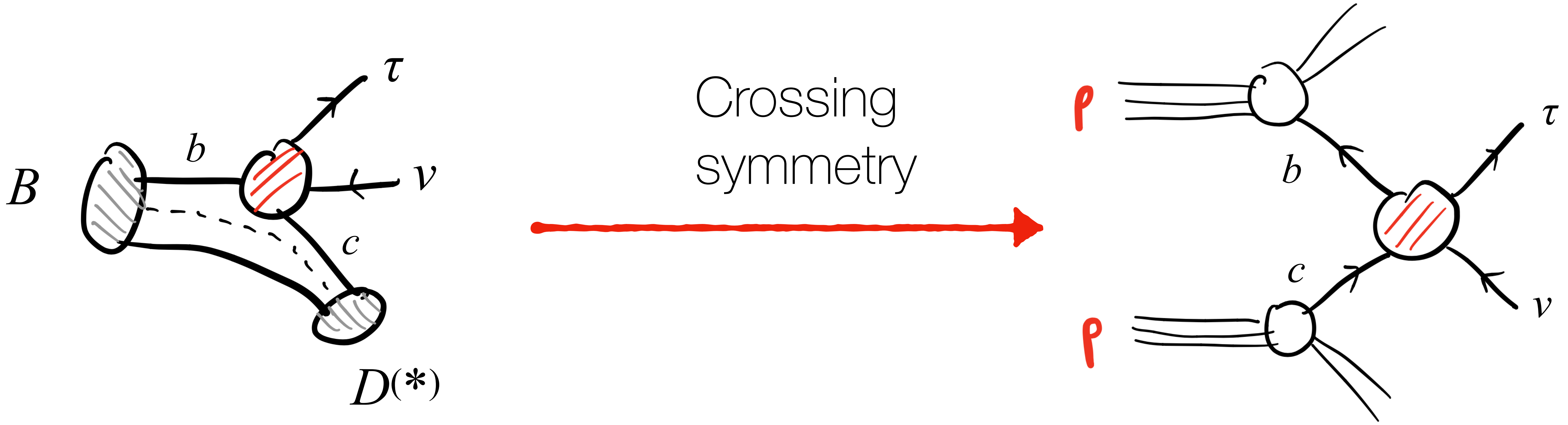
$R(D^{(*)})$ ←

$\Lambda/\sqrt{g_\tau} \sim$ **1 TeV**

If $g_e \ll g_\mu \ll g_\tau$ same hierarchy as $m_e \ll m_\mu \ll m_\tau$

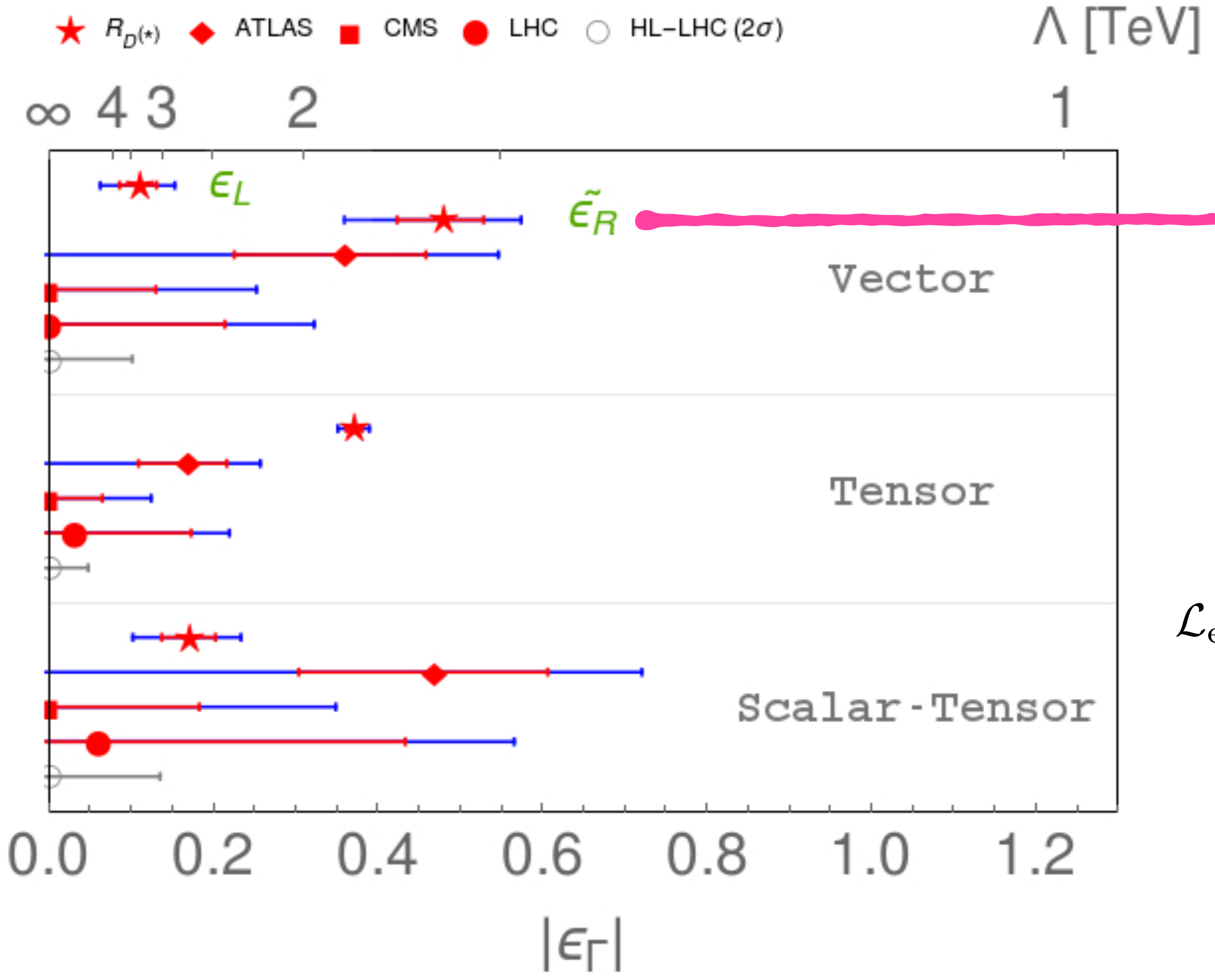
Required for R_K

From R(D(*)) to mono-τ tails

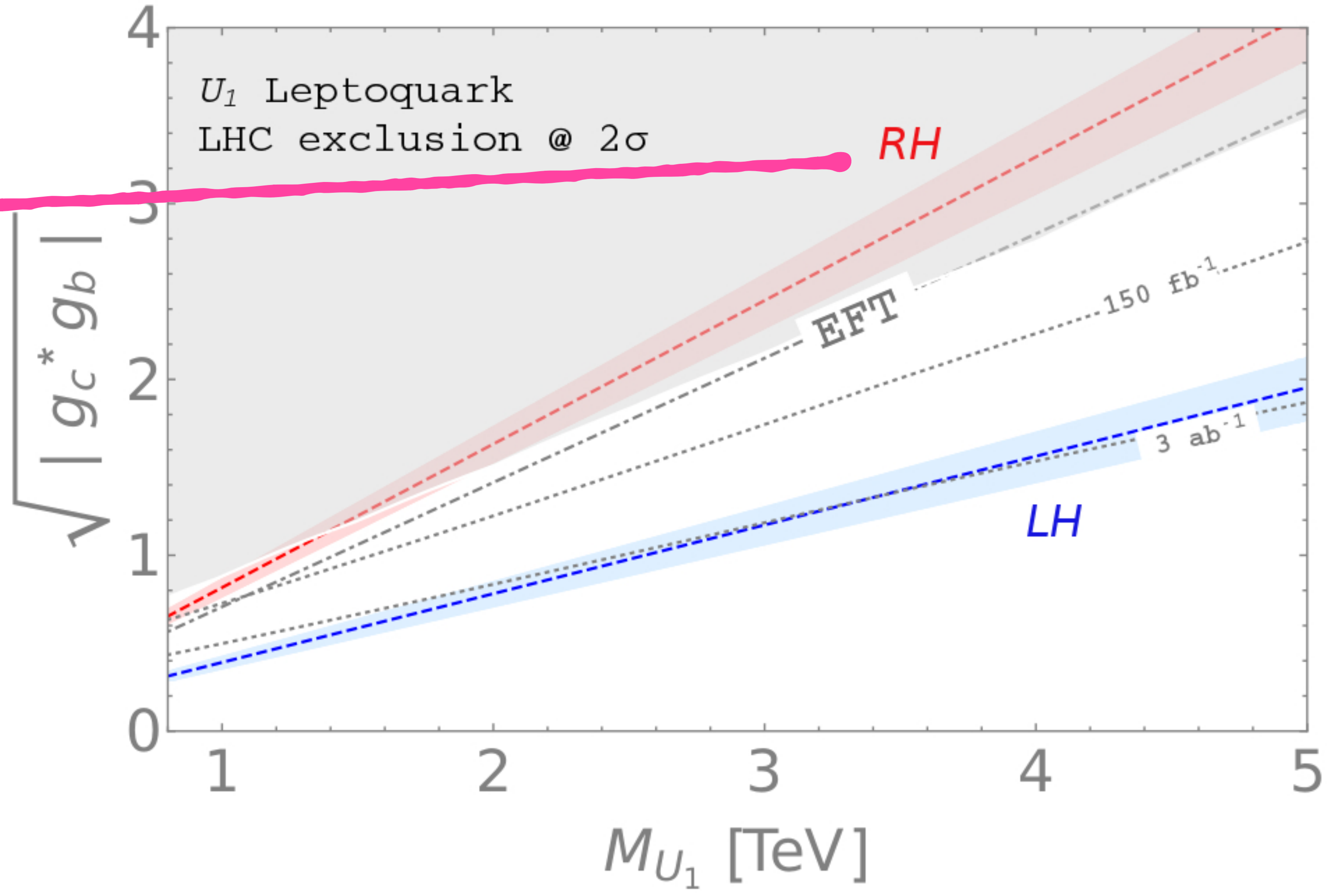


The mono-tau tail is directly sensitive to the same operator (or mediator) contributing to R(D(*))

Greljo, Camalich, Ruiz-Alvarez [1811.07920]



Possible solutions with RH neutrinos are already excluded by mono-τ data.

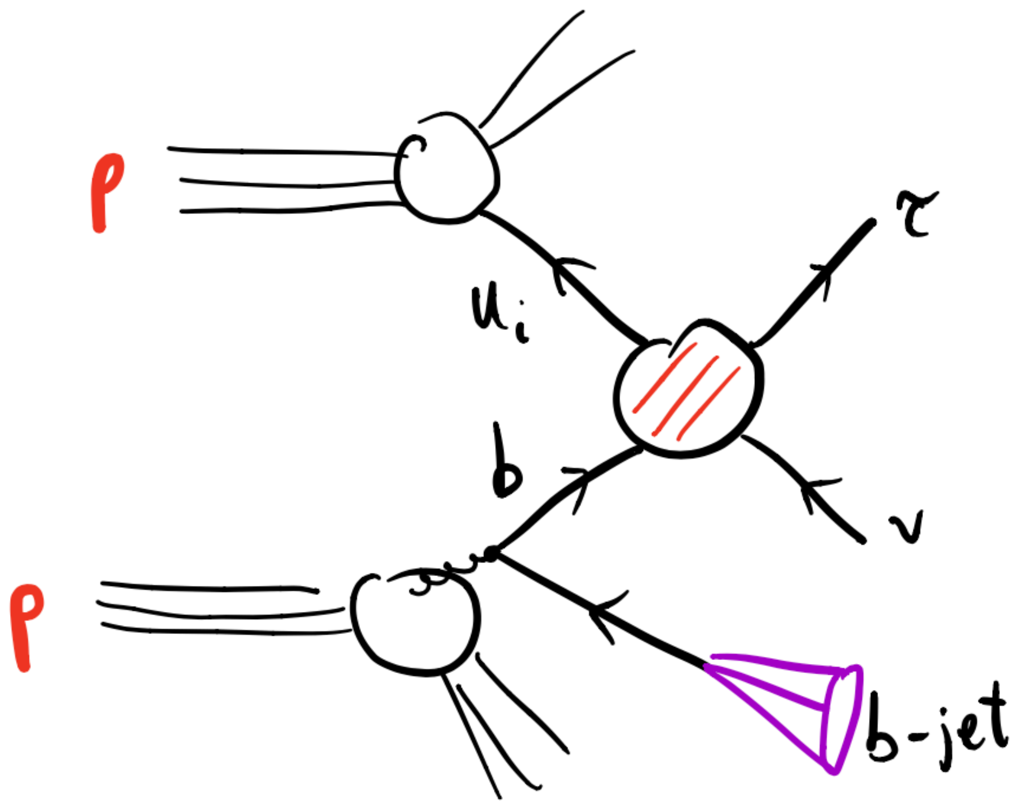


$$\mathcal{L}_{\rm eff} \supset -\frac{2V_{ib}}{v^2}\Big[\left(1+\epsilon_L^{ib}\right)\bar\tau\gamma_\mu P_L\nu_\tau \cdot \bar u_i \gamma^\mu P_L b + \epsilon_R^{ib}\bar\tau\gamma_\mu P_L \nu_\tau\cdot\bar u_i\gamma^\mu P_R b + \epsilon_T^{ib}\,\bar\tau\sigma_{\mu\nu}P_L\nu_\tau\cdot\bar u_i\sigma^{\mu\nu}P_L b + \epsilon_{S_L}^{ib}\,\bar\tau P_L\nu_\tau\cdot\bar u_i P_L b + \epsilon_{S_R}^{ib}\,\bar\tau P_L\nu_\tau\cdot \bar u_i P_R b\Big] + \text{h.c.} \quad (1)$$

Mono-tau tails at LHC

[DM, Min, Son, 2008.07541]

Optimise the sensitivity to $b \to c\,\tau\,\nu$ operators requiring **b-jet tagging**:



- Improves the Signal/Background ratio
- Selects only operators with b-quark

By comparing 3rd and 4th columns:

b-tagging improves the limits by at least ~30%

95%CL limits

EFT coeff.	CMS ($\mathcal{L}$=35.9 fb^{-1})	$\tau\nu$ - $\mathcal{L}$=300 fb^{-1}	$\tau\nu b$ - $\mathcal{L}$=300 fb^{-1}
$\lvert C_{SL}^{11}\rvert$	1.5×10^{-3}	1.1×10^{-3}	–
$\lvert C_{SL}^{12}\rvert$	9.8×10^{-3}	7.5×10^{-3}	–
$\lvert C_{SL}^{13}\rvert$	2.2	1.7	1.1
$\lvert C_{SL}^{21}\rvert$	1.6×10^{-2}	1.2×10^{-2}	–
$\lvert C_{SL}^{22}\rvert$	9.8×10^{-3}	7.5×10^{-3}	–
$\lvert C_{SL}^{23}\rvert$	0.33	0.26	0.18
$\lvert C_{SL}^{23}\rvert = 4\lvert C_{T}^{23}\rvert$	0.31	0.24	0.17
$\lvert C_{SR}^{11}\rvert$	1.5×10^{-3}	1.1×10^{-3}	–
$\lvert C_{SR}^{12}\rvert$	9.9×10^{-3}	7.5×10^{-3}	–
$\lvert C_{SR}^{13}\rvert$	2.2	1.7	1.1
$\lvert C_{SR}^{21}\rvert$	1.6×10^{-2}	1.2×10^{-2}	–
$\lvert C_{SR}^{22}\rvert$	9.7×10^{-3}	7.5×10^{-3}	–
$\lvert C_{SR}^{23}\rvert$	0.33	0.26	0.19
$\lvert C_{T}^{11}\rvert$	8.5×10^{-4}	6.5×10^{-4}	–
$\lvert C_{T}^{12}\rvert$	5.5×10^{-3}	4.2×10^{-3}	–
$\lvert C_{T}^{13}\rvert$	1.3	0.97	0.57
$\lvert C_{T}^{21}\rvert$	9.4×10^{-3}	7.2×10^{-3}	–
$\lvert C_{T}^{22}\rvert$	5.8×10^{-3}	4.5×10^{-3}	–
$\lvert C_{T}^{23}\rvert$	0.20	0.16	0.099
C_{VLL}^{11}	$[-0.40, 3.2] \times 10^{-3}$	3.1×10^{-4}	–
C_{VLL}^{12}	$[-0.78, 1.1] \times 10^{-2}$	9.0×10^{-3}	–
C_{VLL}^{13}	$[-2.1, 2.1]$	1.6	0.93
C_{VLL}^{21}	$[-1.4, 1.8] \times 10^{-2}$	1.4×10^{-2}	–
C_{VLL}^{22}	$[-0.73, 1.2] \times 10^{-2}$	1.5×10^{-3}	–
C_{VLL}^{23}	$[-0.33, 0.34]$	$[-0.25, 0.26]$	$[-0.14, 0.15]$
$\lvert C_{VRL}^{11}\rvert$	1.5×10^{-3}	1.1×10^{-3}	–
$\lvert C_{VRL}^{12}\rvert$	9.6×10^{-3}	7.3×10^{-3}	–
$\lvert C_{VRL}^{13}\rvert$	2.1	1.6	0.94
$\lvert C_{VRL}^{21}\rvert$	1.6×10^{-2}	1.2×10^{-2}	–
$\lvert C_{VRL}^{22}\rvert$	9.6×10^{-3}	7.4×10^{-3}	–
$\lvert C_{VRL}^{23}\rvert$	0.33	0.26	0.15

Di-tau high-p_T tail

If $R(D^{(*)})$ is addressed by this operator

$$(\bar{b}_L \gamma_\alpha c_L)(\bar{\nu}_\tau \gamma^\alpha \tau_L)$$

$SU(2)_L$ ↓

A sizeable effect is also induced in at least one of these:

$$(\bar{b}_L \gamma_\alpha s_L)(\bar{\tau}_L \gamma^\alpha \tau_L)$$

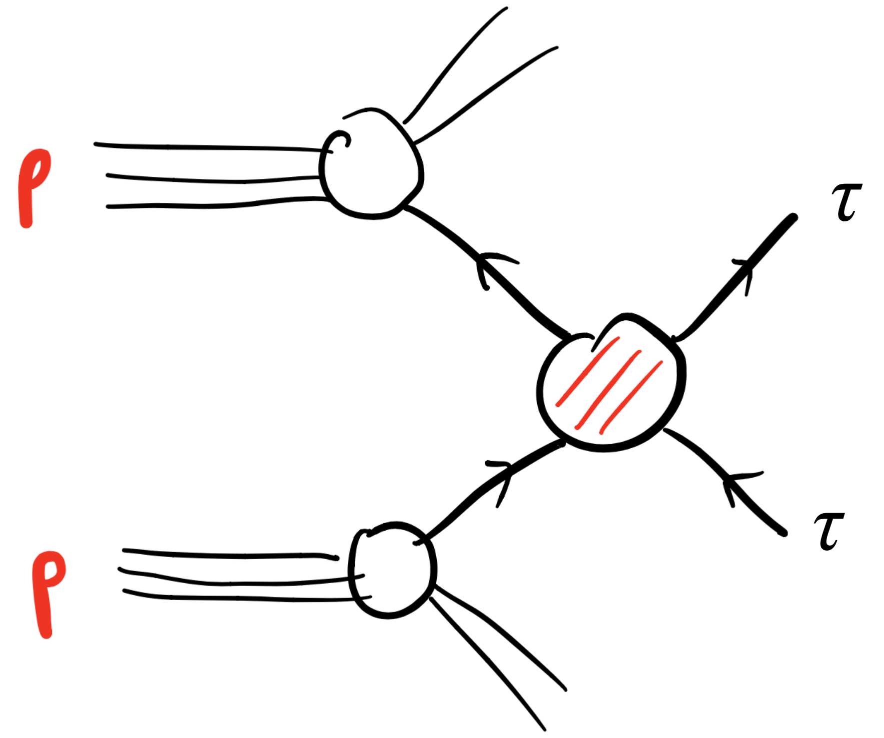
$$(\bar{b}_L \gamma_\alpha b_L)(\bar{\tau}_L \gamma^\alpha \tau_L)$$

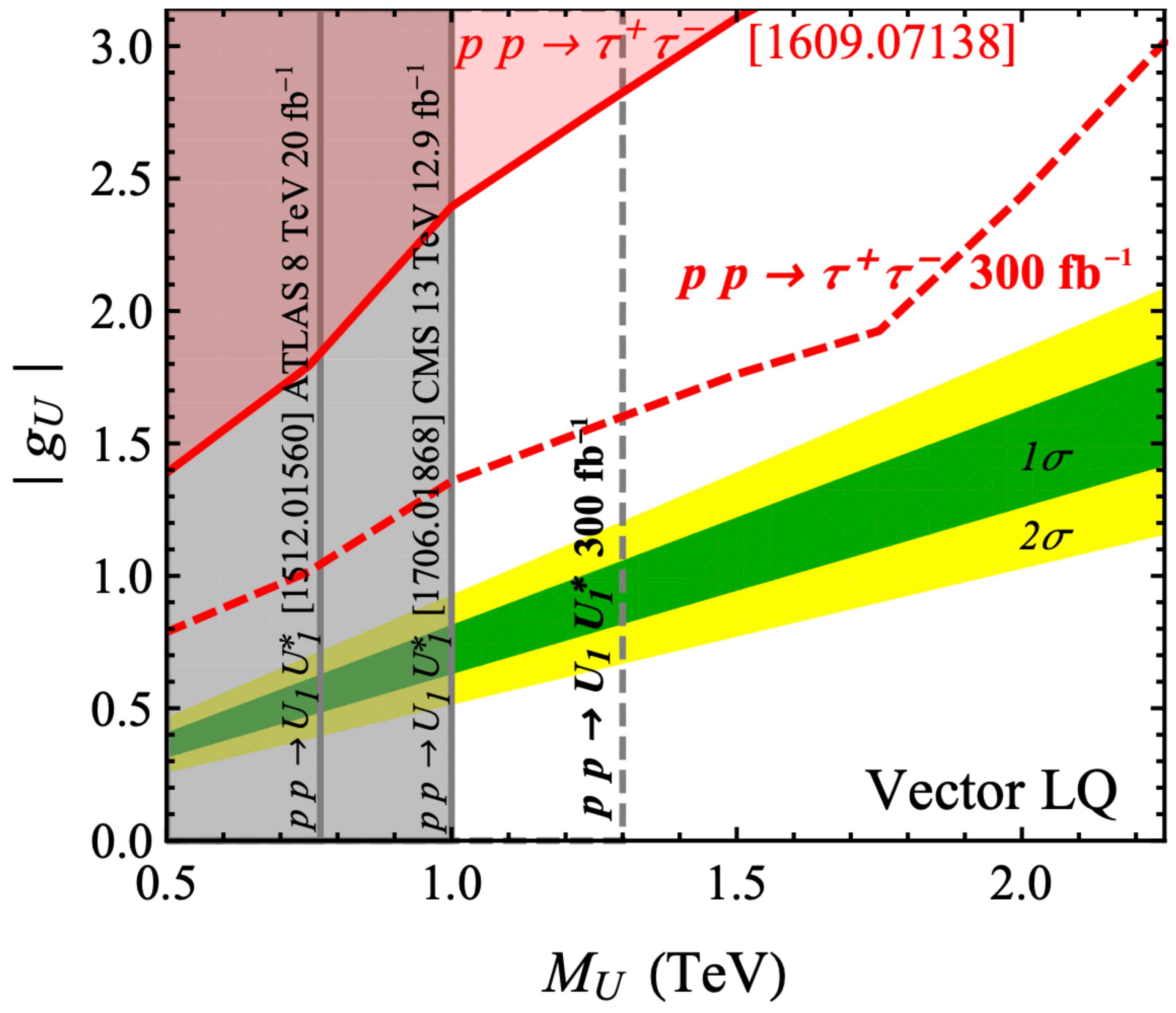
$$(\bar{c}_L \gamma_\alpha c_L)(\bar{\tau}_L \gamma^\alpha \tau_L)$$

[Faroughy, Greljo, Kamenik 1609.07138]

These can be looked for in

ττ high-p_T searches





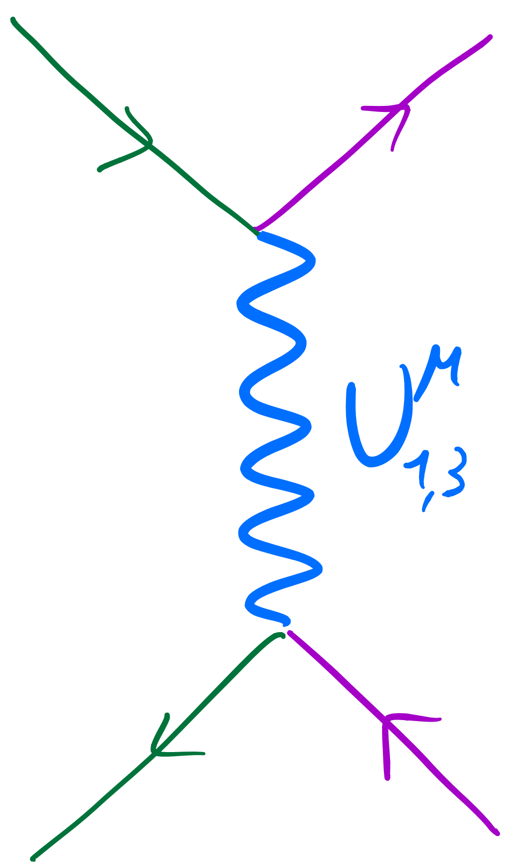
[Buttazzo, Greljo, Isidori, DM 1706.07808, see also 1808.08179, 1810.10017 for more general scenarios]

Tree-level Mediators: Leptoquarks

These two setups offer the best explanations to both anomalies:

Vector Leptoquark

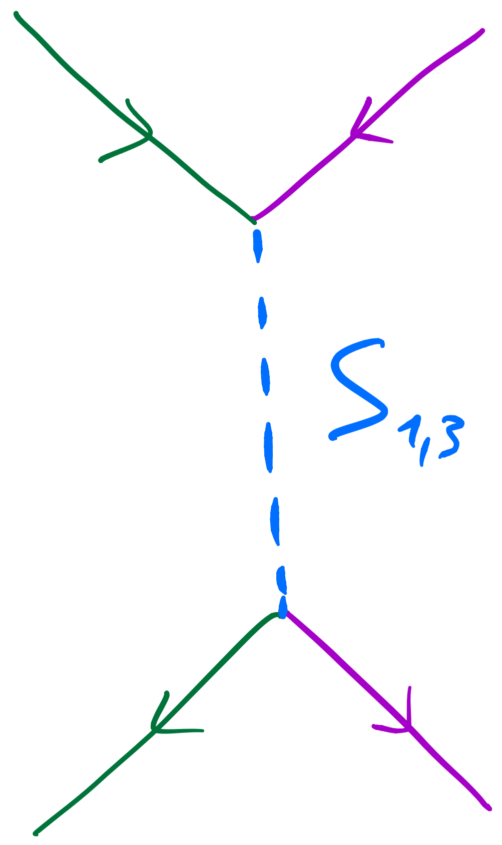
$U_1 = (\mathbf{3}, \mathbf{1}, 2/3)$,



Barbieri et al 1512.01560; Buttazzo, Greljo, Isidori, DM 1706.07808; Di Luzio et al 1708.08450; Bordone et al. 1712.01368; Calibbi et al. '17; Blanke, Crivellin '18; Cornella et al 2103.16558; Angelescu et al 1808.08179

Scalar Leptoquarks

$S_1 = (\bar{\mathbf{3}}, \mathbf{1}, 1/3)$,
$S_3 = (\bar{\mathbf{3}}, \mathbf{3}, 1/3)$,



Crivellin et al. 1703.09226; Buttazzo, Greljo, Isidori, DM 1706.07808; D.M. 1803.10972; Arnan et al 1901.06315; Bigaran et al. 1906.01870; Crivellin et al. 1912.04224; Saad 2005.04352; V. Gherardi, E. Venturini, D.M. 2003.12525, 2008.09548; Bordone et al. 2010.03297; Crivellin et al. 2010.06593, 2101.07811; ETC…

Scalar Leptoquarks S_1 and S_3:

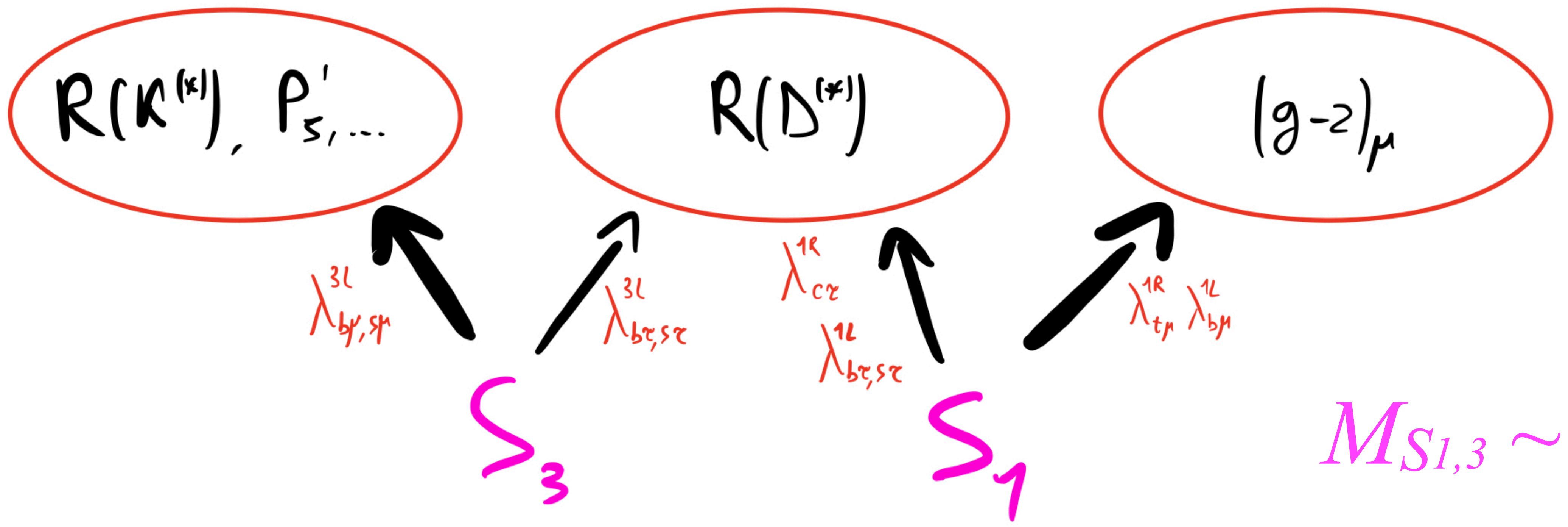
$$\mathcal{L}_{int} \sim \left(\lambda^{1L}_{ij}\, q^i_L \epsilon\, \ell^j_L + \lambda^{1R}_{ij}\, u^i_R e^j_R\right) S_1 + \lambda^{3L}_{ij}\, q^i_L \epsilon \sigma^A \ell^j_L\, S^A_3 + h.c.$$

Several important **observables** constraining this model are induced at one-loop.

We approach this problem systematically, performing a full one-loop analysis by:

- deriving the **complete one-loop SMEFT matching** for these two leptoquarks,
  V. Gherardi, E. Venturini, D.M. [2003.12525]
- including an **exhaustive list of observables**, computed at one-loop.
  V. Gherardi, E. Venturini, D.M. [2008.09548]

The combination of the two scalars can address both anomalies.
If the S_1 coupling to RH fermions is allowed, also a solution to $(g-2)_\mu$ is possible.



$M_{S_{1,3}} \sim 1$ TeV

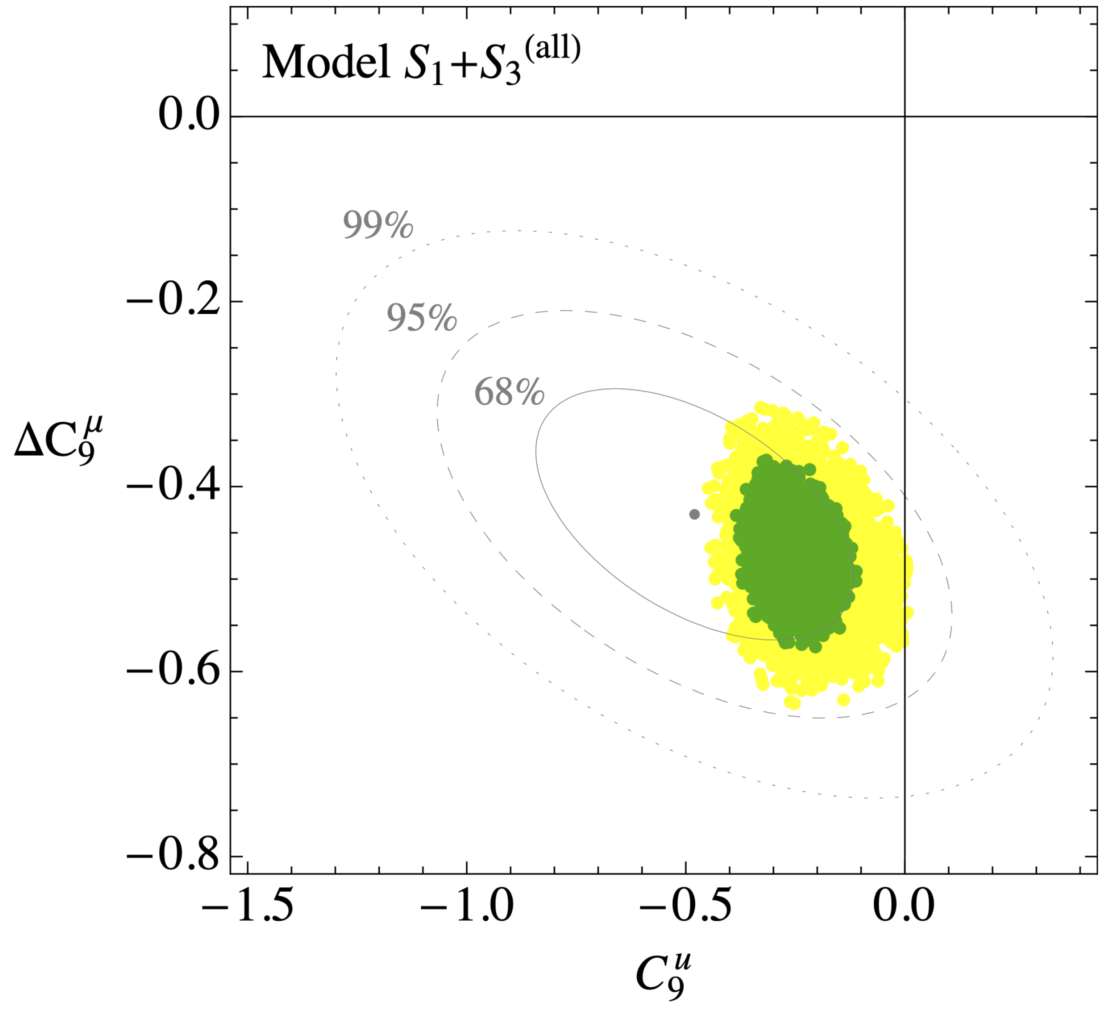
S_1+S_3: R(K$^{(*)}$) + R(D$^{(*)}$) + (g-2)$_\mu$

10 active couplings

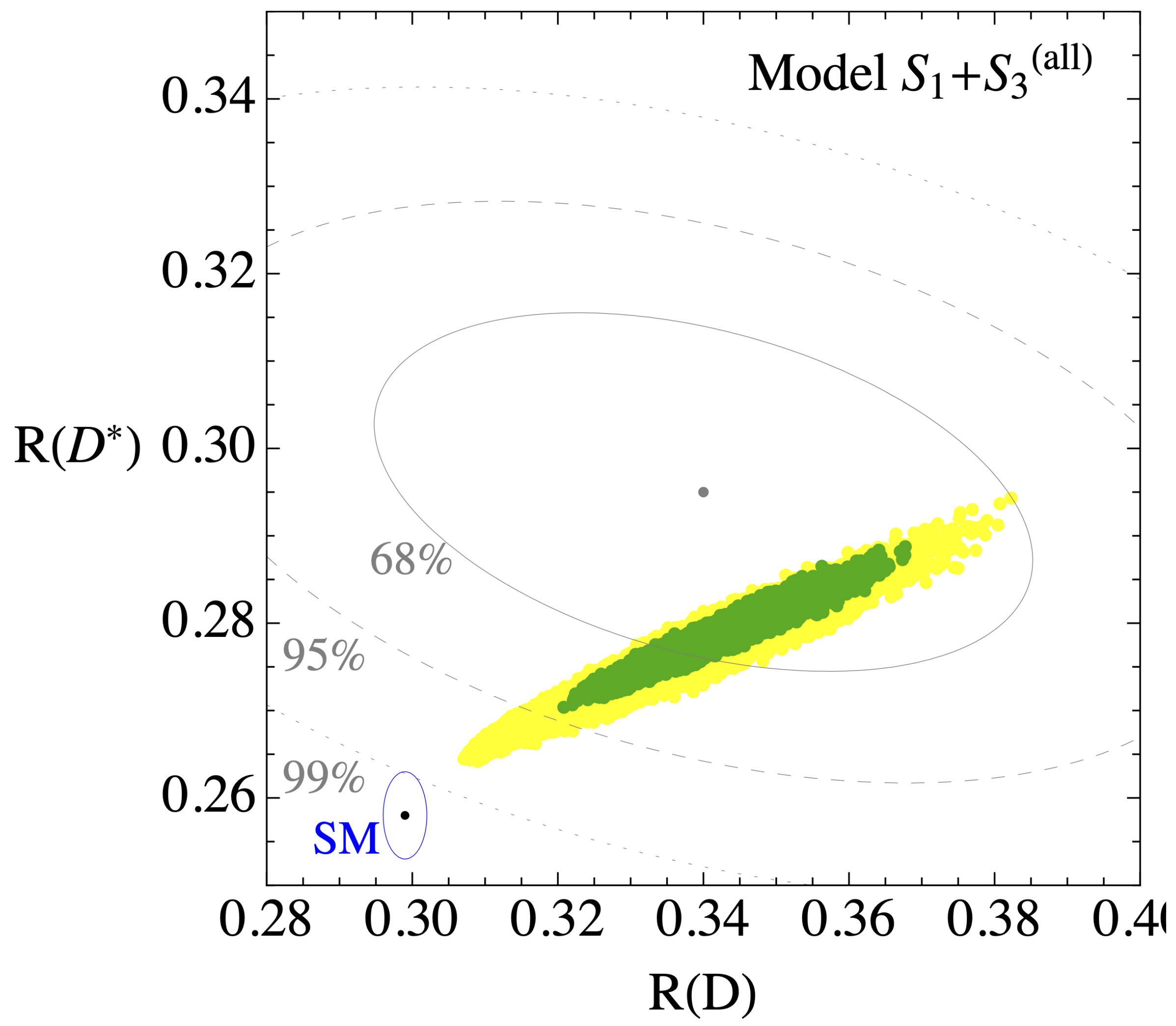
$$\lambda^{1L} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & s\tau \\ 0 & b\mu & b\tau \end{pmatrix} \quad \lambda^{3L} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & s\mu & s\tau \\ 0 & b\mu & b\tau \end{pmatrix}$$

$$\lambda^{1R} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & c\tau \\ 0 & t\mu & t\tau \end{pmatrix}$$

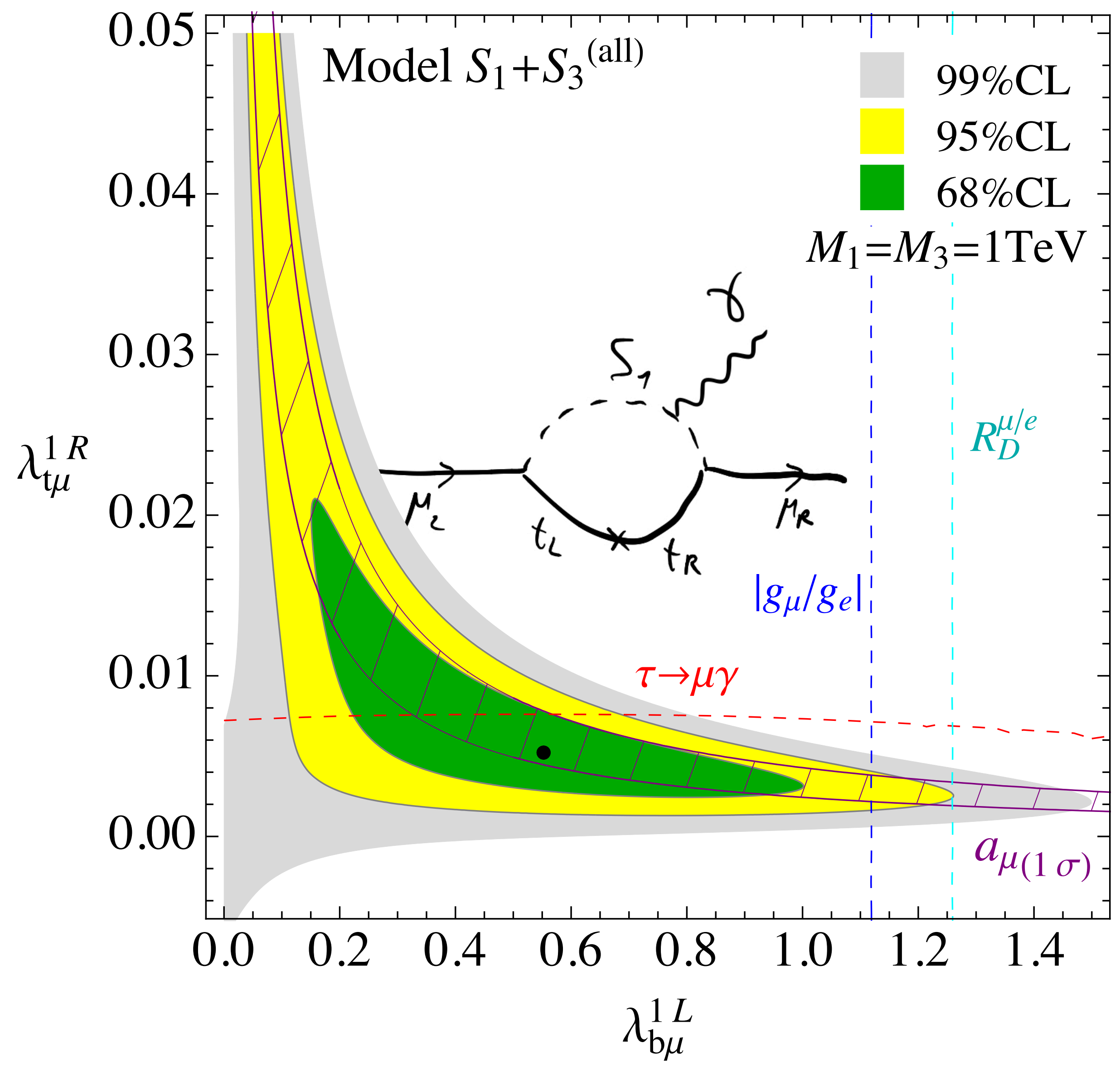
R(K$^{(*)}$)

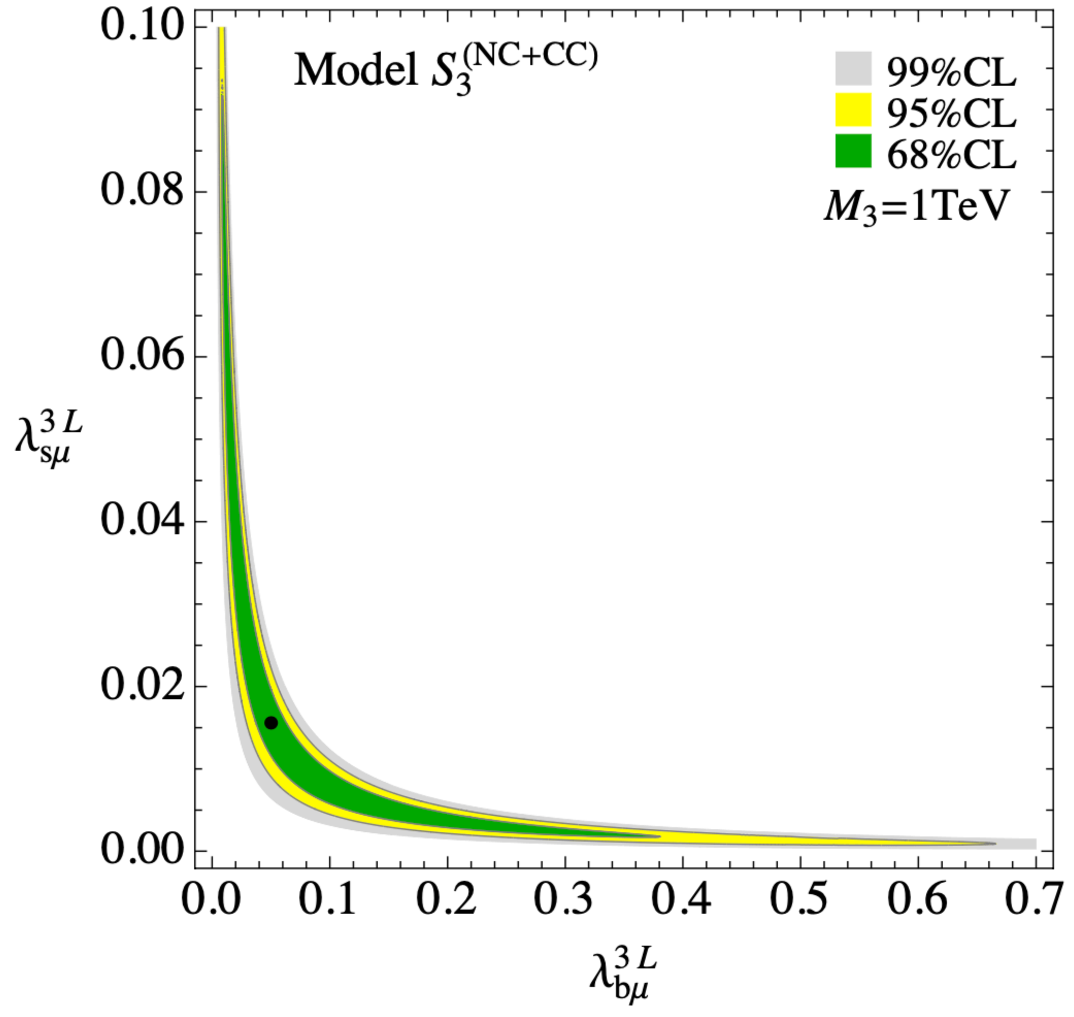


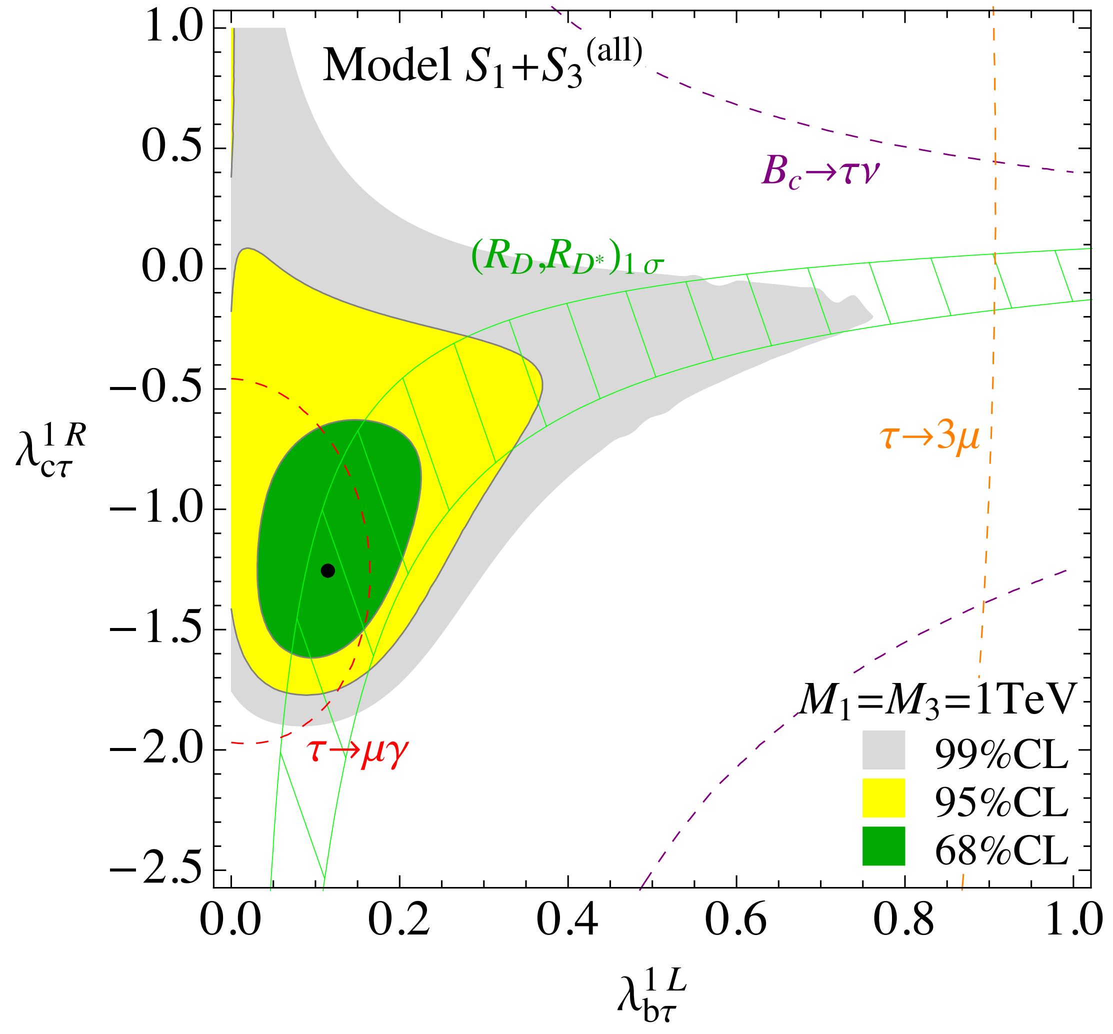
R(D$^{(*)}$)



(g-2)$_\mu$



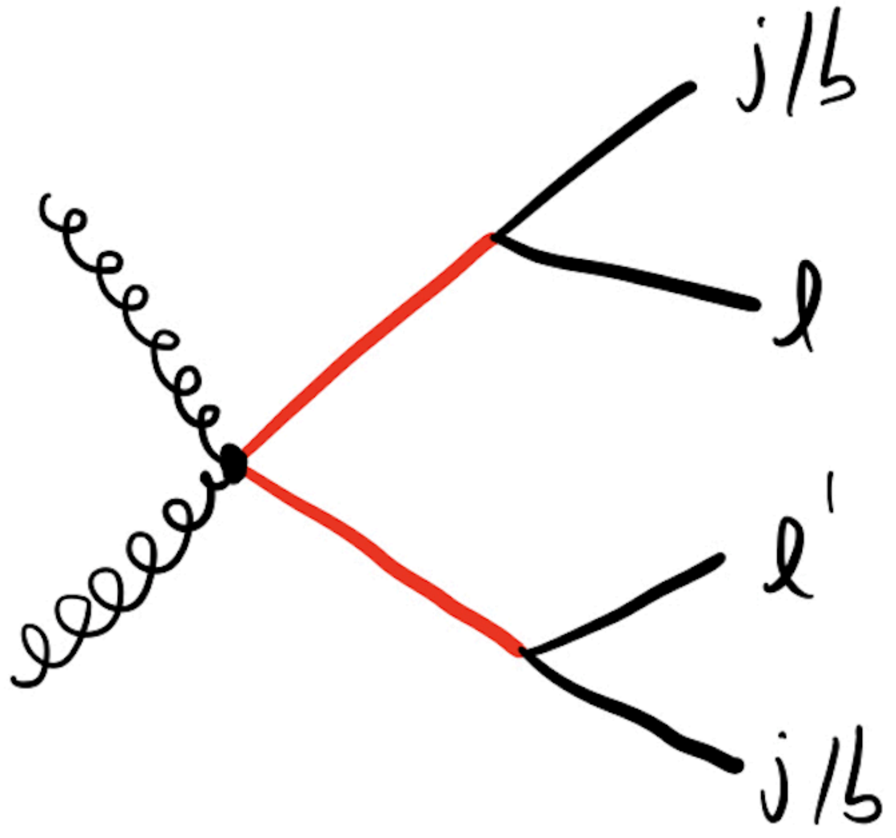




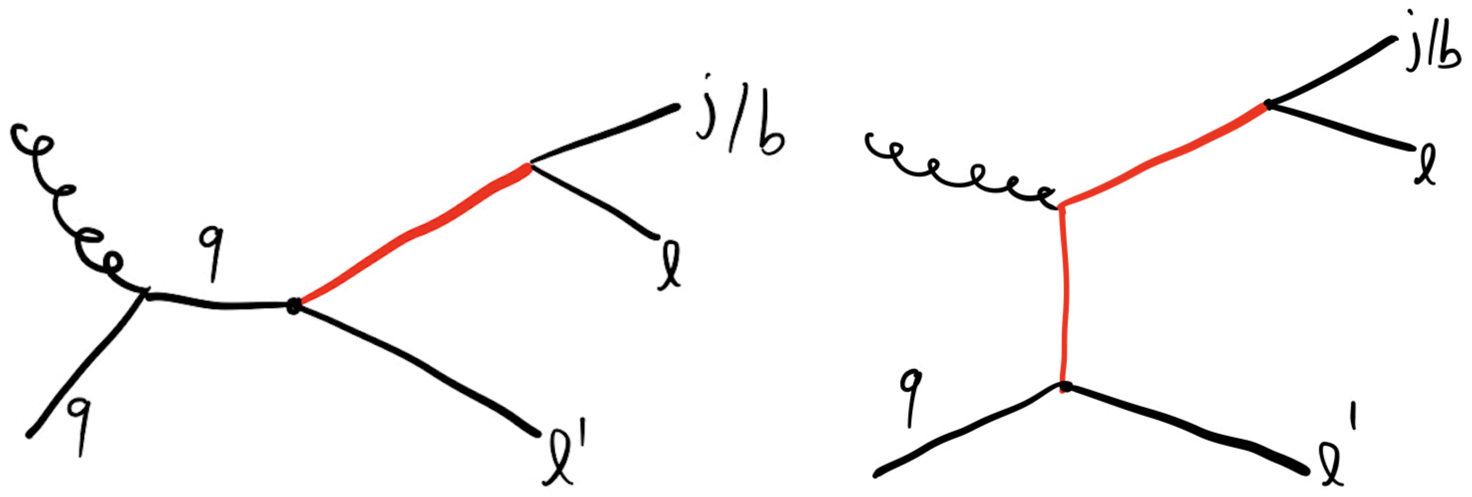
A **very good fit** of all three classes of anomalies can be achieved,
while being consistent with all phenomenological bounds.

The Threefold Way of LQ Searches at LHC

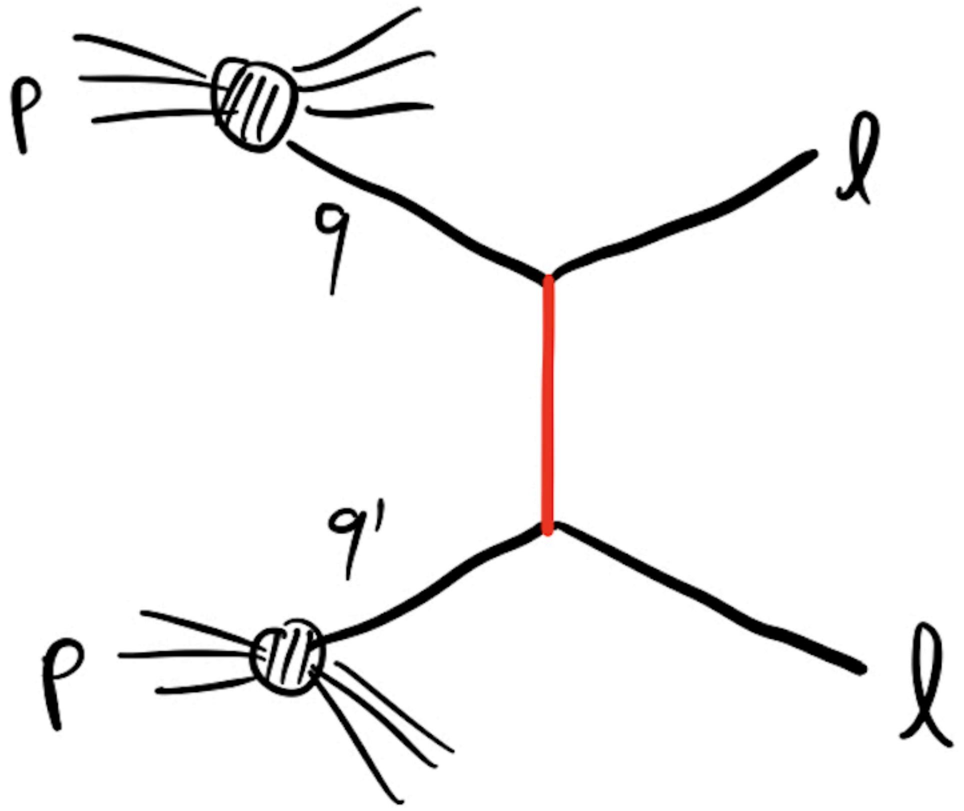
QCD
pair-production

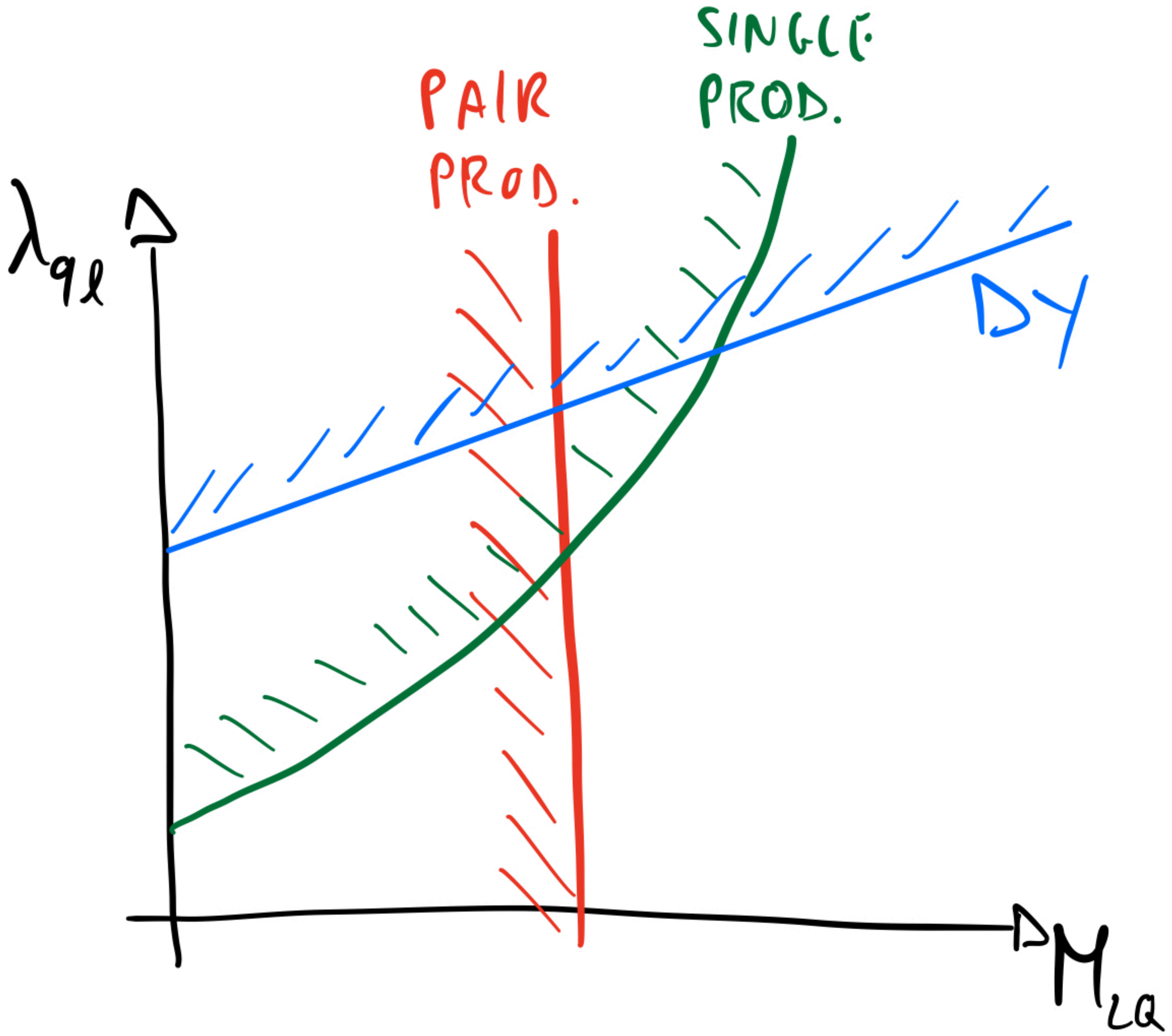


single-production



High-p_T Drell-Yan



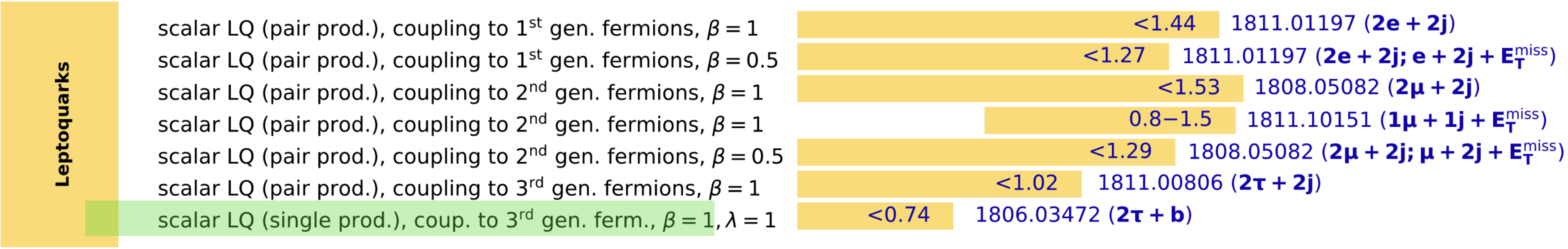


[Diaz, Schmaltz, Zhong 1706.05033, 1810.10017; Dorsner, Greljo 1801.07641]

In order to cover all couplings it is important to consider all combinations of different lepton & quark combinations in final state!

Leptoquark searches at CMS and ATLAS

CMS



CMS ττbb 1703.03995, 1811.00806
CMS ττtt 1803.02864
CMS μμjj & μνjj CMS PAS EXO-17-003
CMS μμtt 1809.05558
CMS νν+(jj,bb,tt) 1805.10228

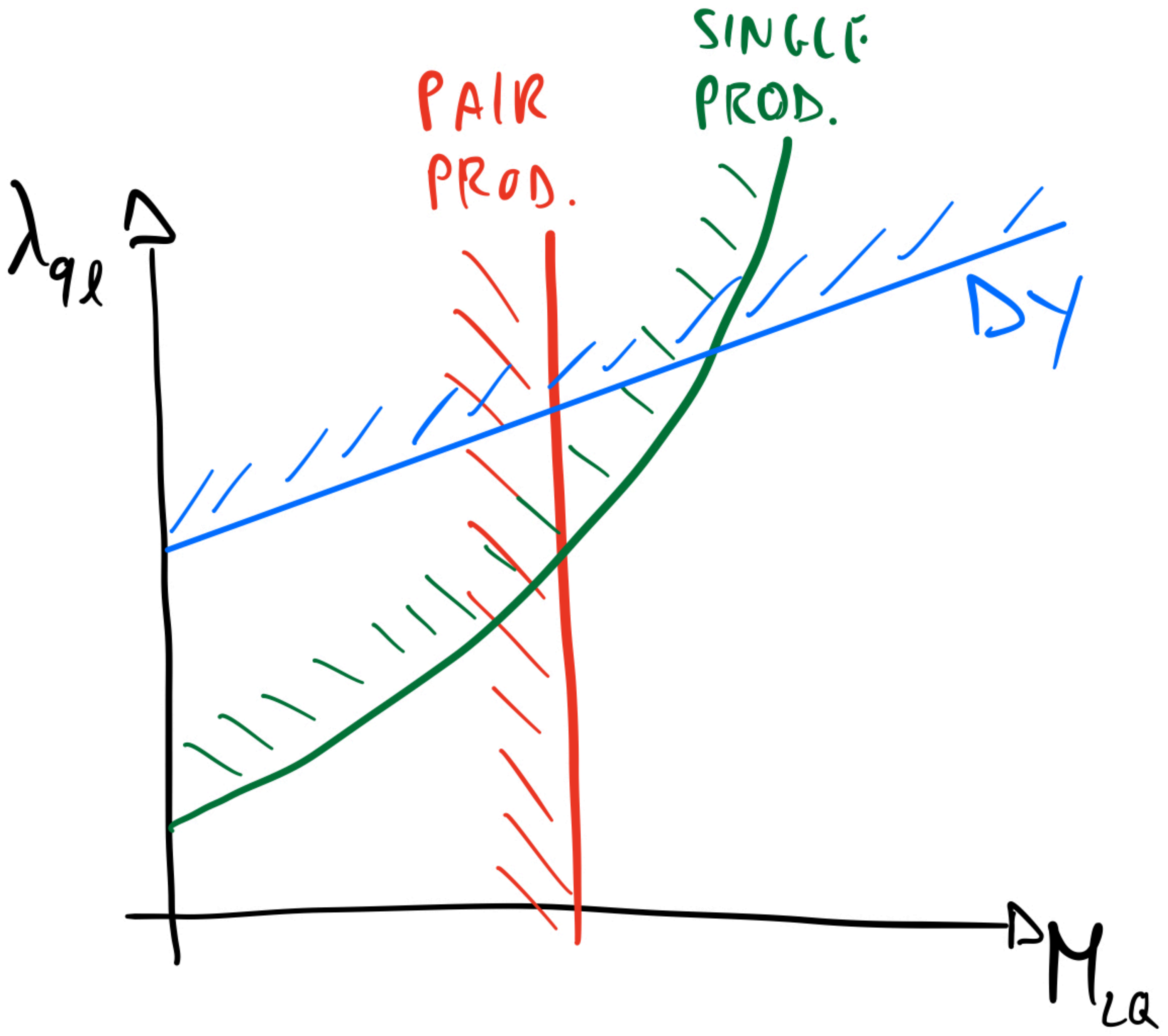
ATLAS lljj, lνjj 1902.00377
ATLAS lljj 2006.05872
ATLAS tt(ee,μμ) 2010.02098
ATLAS LQ→(tν,bτ) 1902.08103
ATLAS LQ→(bν,tτ) 2101.12527
ATLAS ttττ 2101.11582

Conclusions

- R_K anomalies are now rather robust deviations from the SM
- While **signatures at LHC cannot be guaranteed**,
  in several motivated scenarios LHC searches are already constraining:
  in particular **di-muon high-p_T tails**.
- $R(D^{(*)})$ anomalies still need more experimental confirmation,
  they would strongly hint to **leptoquark** solutions.
- The model-independent signature is **mono-τ at high-p_T**, potentially
  improved by requiring **b-tagging**.
- A sizeable effect is also expected in **di-tau high-p_T tails**.

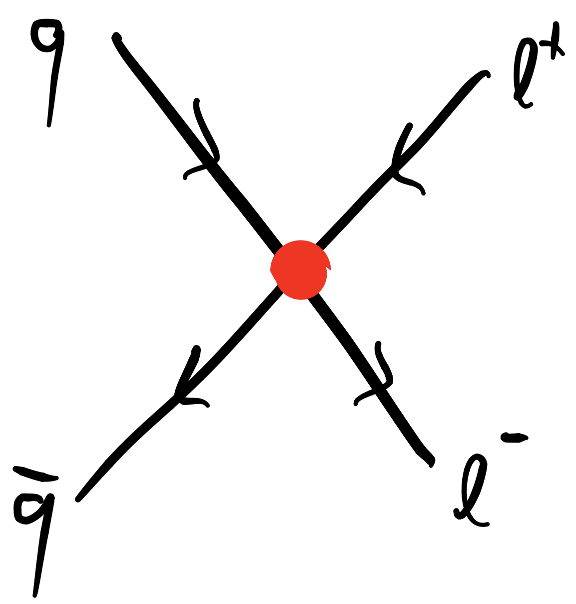
- In general, following the **threefold way of leptoquark searches**
  in all possible channels is crucial.

The Threefold Way of LQ Searches at LHC



Backup

Di-lepton tails at LHC

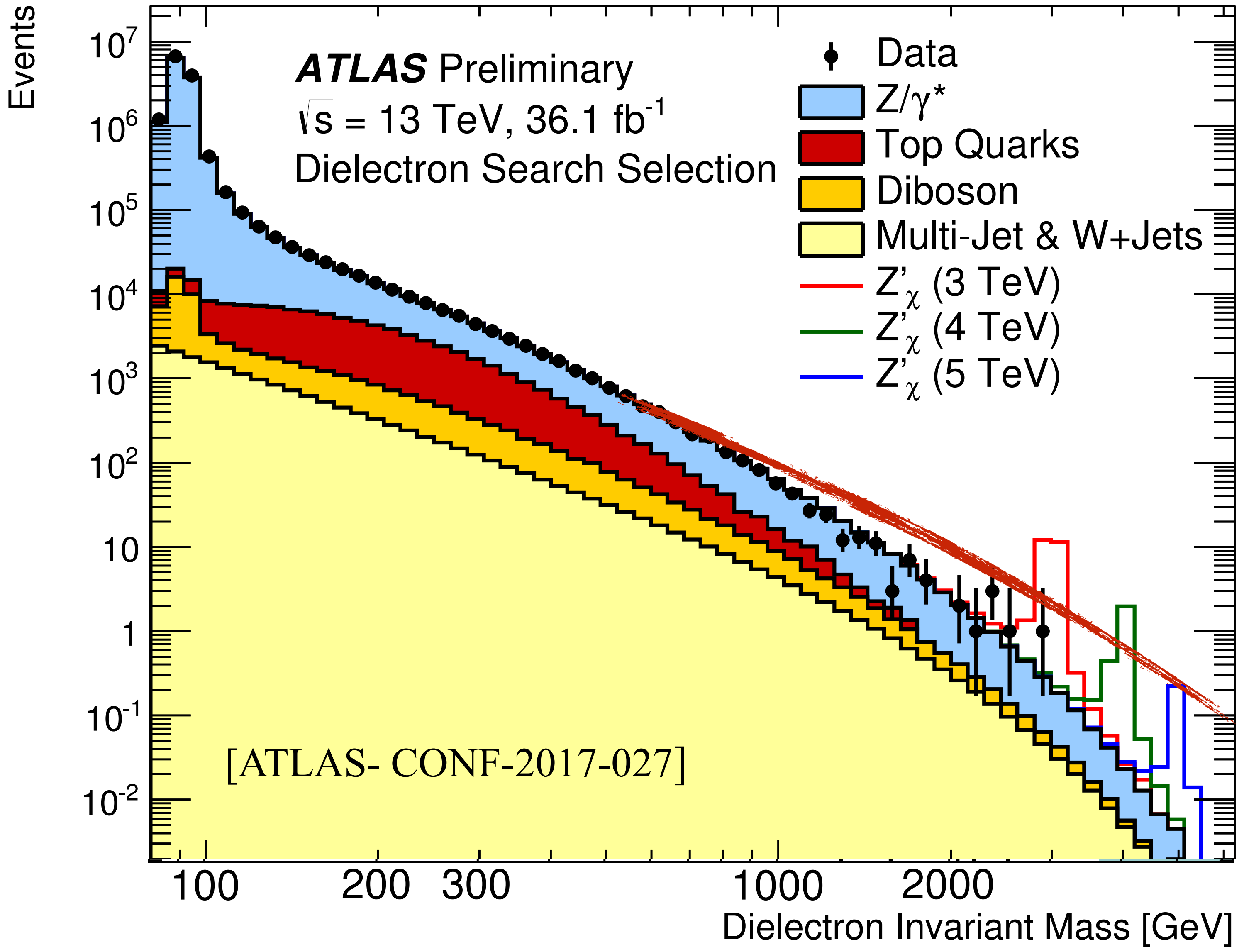


$$\mathcal{L}_{\rm SMEFT} = \sum_i \frac{C_i}{v^2} \mathcal{O}_i$$

$$C_x \equiv \frac{v^2}{\Lambda^2} c_x$$

Operators interfering with SM:

$(\mathcal{O}^{(1)}_{lq})_{\alpha i} = (\bar{l}_\alpha \gamma_\mu l_\alpha)(\bar{q}_i \gamma^\mu q_i)$	$(\mathcal{O}^{(3)}_{lq})_{\alpha i} = (\bar{l}_\alpha \gamma_\mu \sigma^a l_\alpha)(\bar{q}_i \gamma^\mu \sigma^a q_i)$
$(\mathcal{O}_{qe})_{i\alpha} = (\bar{q}_i \gamma^\mu q_i)(\bar{e}_\alpha \gamma^\mu e_\alpha)$	
$(\mathcal{O}_{lu})_{\alpha i} = (\bar{l}_\alpha \gamma_\mu l_\alpha)(\bar{u}_i \gamma^\mu u_i)$	$(\mathcal{O}_{ld})_{\alpha i} = (\bar{l}_\alpha \gamma_\mu l_\alpha)(\bar{d}_i \gamma^\mu d_i)$
$(\mathcal{O}_{eu})_{\alpha i} = (\bar{e}_\alpha \gamma_\mu e_\alpha)(\bar{u}_i \gamma^\mu u_i)$	$(\mathcal{O}_{ed})_{\alpha i} = (\bar{e}_\alpha \gamma_\mu e_\alpha)(\bar{d}_i \gamma^\mu d_i)$



- Limits on flavor-conserving operators, recasting ATLAS 13TeV analysis: [Greljo, D.M. 1704.09015]

- Limits recasting ATLAS Drell-Yan 8TeV analysis: [Les Houches 2002.12220 (Sec.2)]

C_i	ATLAS 36.1 fb^{-1}	3000 fb^{-1}
$C^{(1)}_{Q^1L^1}$	[-0.0, 1.75] $\times 10^{-3}$	[-1.01, 1.13] $\times 10^{-4}$
$C^{(3)}_{Q^1L^1}$	[-8.92, -0.54] $\times 10^{-4}$	[-3.99, 3.93] $\times 10^{-5}$
$C_{u_R L^1}$	[-0.19, 1.92] $\times 10^{-3}$	[-1.56, 1.92] $\times 10^{-4}$
$C_{u_R e_R}$	[0.15, 2.06] $\times 10^{-3}$	[-7.89, 8.23] $\times 10^{-5}$
$C_{Q^1 e_R}$	[-0.40, 1.37] $\times 10^{-3}$	[-1.8, 2.85] $\times 10^{-4}$
$C_{d_R L^1}$	[-2.1, 1.04] $\times 10^{-3}$	[-7.59, 4.23] $\times 10^{-4}$
$C_{d_R e_R}$	[-2.55, 0.46] $\times 10^{-3}$	[-3.37, 2.59] $\times 10^{-4}$
$C^{(1)}_{Q^2L^1}$	[-6.62, 4.36] $\times 10^{-3}$	[-3.31, 1.92] $\times 10^{-3}$
$C^{(3)}_{Q^2L^1}$	[-8.24, 2.05] $\times 10^{-3}$	[-8.87, 7.90] $\times 10^{-4}$
$C_{Q^2 e_R}$	[-4.67, 6.34] $\times 10^{-3}$	[-2.11, 3.30] $\times 10^{-3}$
$C_{s_R L^1}$	[-7.4 , 5.9] $\times 10^{-3}$	[-3.96, 2.8] $\times 10^{-3}$
$C_{s_R e_R}$	[-8.17, 5.06] $\times 10^{-3}$	[-3.82, 2.13] $\times 10^{-3}$
$C_{c_R L^1}$	[-0.83, 1.13] $\times 10^{-2}$	[-3.74, 5.77] $\times 10^{-3}$
$C_{c_R e_R}$	[-0.67, 1.27] $\times 10^{-2}$	[-2.59, 4.17] $\times 10^{-3}$
$C_{b_L L^1}$	[-1.93, 1.19] $\times 10^{-2}$	[-8.62, 4.82] $\times 10^{-3}$
$C_{b_L e_R}$	[-1.47, 1.67] $\times 10^{-2}$	[-7.29, 8.99] $\times 10^{-3}$
$C_{b_R L^1}$	[-1.65, 1.49] $\times 10^{-2}$	[-8.86, 7.48] $\times 10^{-3}$
$C_{b_R e_R}$	[-1.73, 1.40] $\times 10^{-2}$	[-9.38, 6.63] $\times 10^{-3}$

C_i	ATLAS 36.1 fb^{-1}	3000 fb^{-1}
$C^{(1)}_{Q^1L^2}$	[-5.73, 14.2] $\times 10^{-4}$	[-1.30, 1.51] $\times 10^{-4}$
$C^{(3)}_{Q^1L^2}$	[-7.11, 2.84] $\times 10^{-4}$	[-5.25, 5.25] $\times 10^{-5}$
$C_{u_R L^2}$	[-0.84, 1.61] $\times 10^{-3}$	[-2.00, 2.66] $\times 10^{-4}$
$C_{u_R \mu_R}$	[-0.52, 1.36] $\times 10^{-3}$	[-1.04, 1.08] $\times 10^{-4}$
$C_{Q^1 \mu_R}$	[-0.82, 1.27] $\times 10^{-3}$	[-2.25, 4.10] $\times 10^{-4}$
$C_{d_R L^2}$	[-2.13, 1.61] $\times 10^{-3}$	[-8.98, 5.11] $\times 10^{-4}$
$C_{d_R \mu_R}$	[-2.31, 1.34] $\times 10^{-3}$	[-4.89, 3.33] $\times 10^{-4}$
$C^{(1)}_{Q^2L^2}$	[-8.84, 7.35] $\times 10^{-3}$	[-3.83, 2.39] $\times 10^{-3}$
$C^{(3)}_{Q^2L^2}$	[-9.75, 5.56] $\times 10^{-3}$	[-1.43, 1.15] $\times 10^{-3}$
$C_{Q^2 \mu_R}$	[-7.53, 8.67] $\times 10^{-3}$	[-2.58, 3.73] $\times 10^{-3}$
$C_{s_R L^2}$	[-1.04 , 0.93] $\times 10^{-2}$	[-4.42, 3.33] $\times 10^{-3}$
$C_{s_R \mu_R}$	[-1.09 , 0.87] $\times 10^{-2}$	[-4.67, 2.73] $\times 10^{-3}$
$C_{c_R L^2}$	[-1.33, 1.52] $\times 10^{-2}$	[-4.58, 6.54] $\times 10^{-3}$
$C_{c_R \mu_R}$	[-1.21, 1.62] $\times 10^{-2}$	[-3.48, 6.32] $\times 10^{-3}$
$C_{b_L L^2}$	[-2.61, 2.07] $\times 10^{-2}$	[-11.1, 6.33] $\times 10^{-3}$
$C_{b_L \mu_R}$	[-2.28, 2.42] $\times 10^{-2}$	[-8.53, 10.0] $\times 10^{-3}$
$C_{b_R L^2}$	[-2.41, 2.29] $\times 10^{-2}$	[-9.90, 8.68] $\times 10^{-3}$
$C_{b_R \mu_R}$	[-2.47, 2.23] $\times 10^{-2}$	[-10.5, 7.97] $\times 10^{-3}$

Mono-tau tails at LHC

[D.M., Min, Son, 2008.07541]

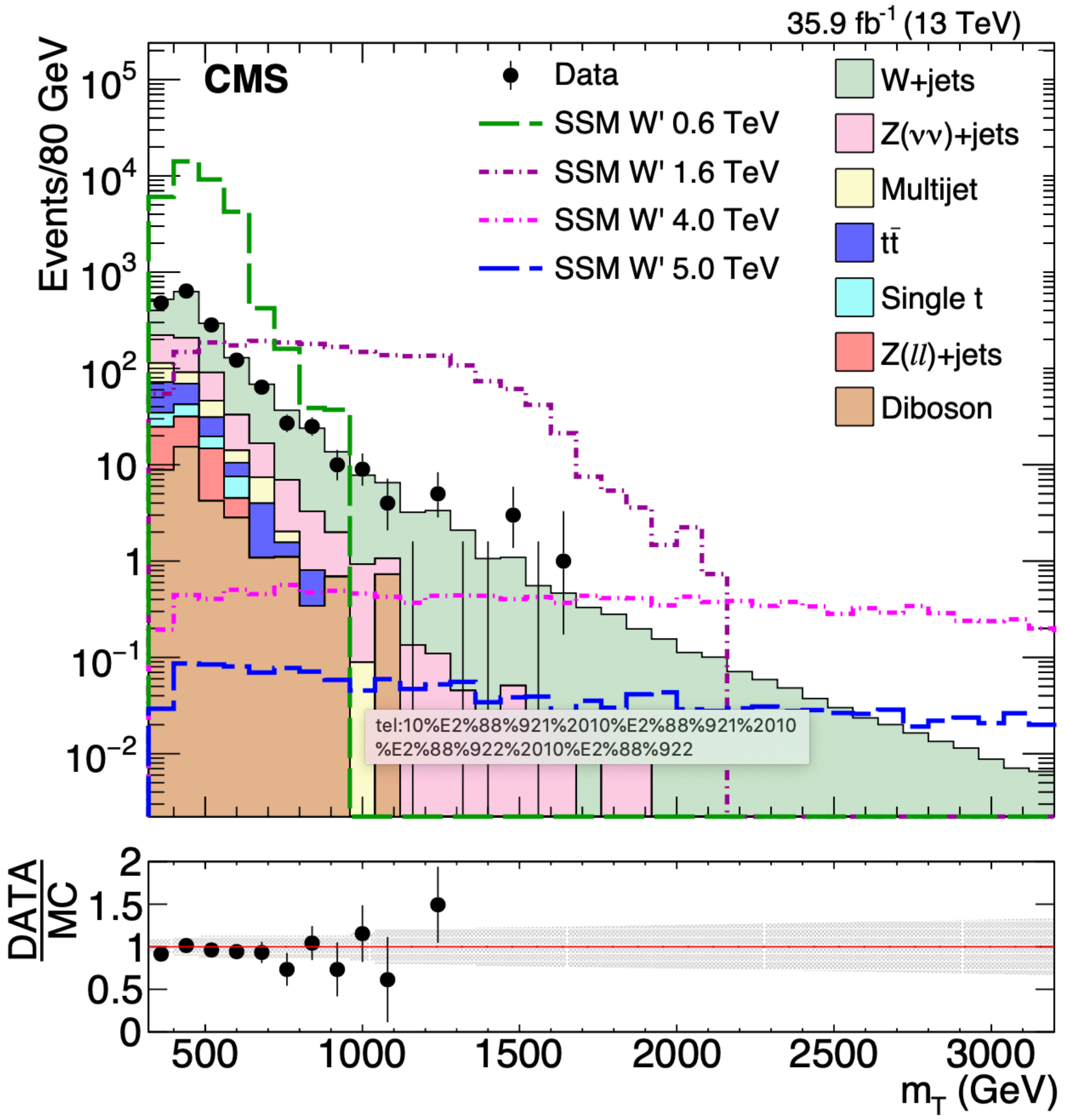
We recast CMS $\tau\nu$ analysis at 13 TeV and 35.9fb^{-1} [1807.11421]

$$p_T(\tau) > 80\text{ GeV}\,, \quad |\eta(\tau)| < 2.1\,, \quad p_T^{miss} > 200\text{ GeV}$$

$$0.7 < p_T^\tau / p_T^{miss} < 1.3\,, \quad \Delta\phi(\vec{p}_T^{\,\tau}, \vec{p}_T^{\,miss}) > 2.4$$

Bins in **transverse mass**

$$m_T = \sqrt{2 p_T^\tau p_T^{miss}[1 - \cos\Delta\phi(\vec{p}_T^{\,\tau}, \vec{p}_T^{\,miss})]}$$



For each bin we get the xsection:

$$\sigma = \sigma_{SM} + C_X^{ij}\,\sigma_{SM-EFT}^{ij,X} + (C_X^{ij})^2\,\sigma_{EFT^2}^{ij,X}$$

… which we use to build the likelihood

and get limits on all $u_i\, d_j\, \tau\, \nu$ operators.

After validating with CMS $\tau\nu$ analysis, we devise **our own $\tau\nu$+b analysis**

$$p_T(\tau) > 70\text{ GeV}\,, \quad |\eta(\tau)| < 2.1\,, \quad p_T^{miss} > 150\text{ GeV}$$

$$p_T(b) > 20\text{ GeV}\,, \quad |\eta(b)| < 2.5\,, \quad N_j \leq 4$$

$$0.7 < p_T^\tau / p_T^{miss} < 1.3\,, \quad \Delta\phi(\vec{p}_T^{\,\tau}, \vec{p}_T^{\,miss}) > 2.4$$

Flavor at High vs. Low Energy

[D.M., Min, Son, 2008.07541]

$$\mathcal{L}_{\rm eff}^{\rm CC} = -\mathcal{H}_{\rm eff}^{\rm CC} = -\frac{4G_f V_{ij}}{\sqrt{2}}\Big[C_{VLL}^{ij}(\bar{u}_i\gamma_\mu P_L d_j)(\bar{\tau}\gamma^\mu P_L\nu_\tau) + C_{VRL}^{ij}(\bar{u}_i\gamma_\mu P_R d_j)(\bar{\tau}\gamma^\mu P_L\nu_\tau) + C_{SL}^{ij}(\bar{u}_i P_L d_j)(\bar{\tau}P_L\nu_\tau) + C_{SR}^{ij}(\bar{u}_i P_R d_j)(\bar{\tau}P_L\nu_\tau) + C_T^{ij}(\bar{u}_i\sigma_{\mu\nu}P_L d_j)(\bar{\tau}\sigma^{\mu\nu}P_L\nu_\tau)\Big] + h.c.\ .$$

How do these LHC limits compare with bounds from low energy?

Let us focus for simplicity on LL operators.

EFT coeff.	CMS ($\mathcal{L}$=35.9 fb^{-1})	$\tau\nu$ - $\mathcal{L}$=300 fb^{-1}	$\tau\nu b$ - $\mathcal{L}$=300 fb^{-1}
C_{VLL}^{11}	$[-0.40, 3.2]\times 10^{-3}$	3.1×10^{-4}	–
C_{VLL}^{12}	$[-0.78, 1.1]\times 10^{-2}$	9.0×10^{-3}	–
C_{VLL}^{13}	$[-2.1, 2.1]$	1.6	0.93
C_{VLL}^{21}	$[-1.4, 1.8]\times 10^{-2}$	1.4×10^{-2}	–
C_{VLL}^{22}	$[-0.73, 1.2]\times 10^{-2}$	1.5×10^{-3}	–
C_{VLL}^{23}	$[-0.33, 0.34]$	$[-0.25, 0.26]$	$[-0.14, 0.15]$

τ→νπ $C_{VLL}^{ud} \in [-9.2, 1.6]\times 10^{-3}$

τ→νK $C_{VLL}^{us} \in [-2.8, -0.02]\times 10^{-2}$

B→τν $C_{VLL}^{ub}(m_b) \in [-0.13, 0.41]$

charm $C_{VLL}^{cd} \in [-0.21, 0.27]$

$C_{VLL}^{cs} \in [-1.4, 7.0]\times 10^{-2}$.

R(D(*)) $C_{VLL}^{cb}(\mathrm{TeV}) = 0.068\pm 0.017$

Mono-tau tails are (or will be in the future) competitive with low-energy limits from

semileptonic τ decays [A. Pich 1310.7922]

and **charm physics** [Fuentes-Martin, Greljo, Camalich, Ruiz-Alvarez, 2003.12421]