Riding the seesaw: what Higgsstrahlung may reveal about massive neutrinos

Michael A. Schmidt

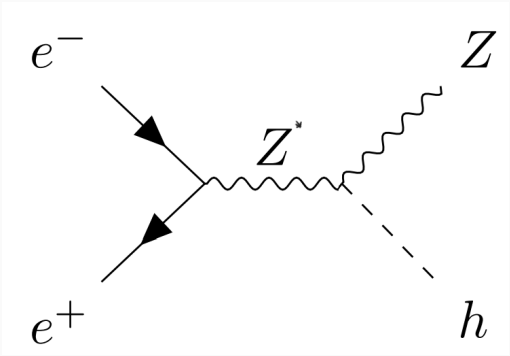
15 Mar 2023 @ CERN Neutrino Platform Pheno Week

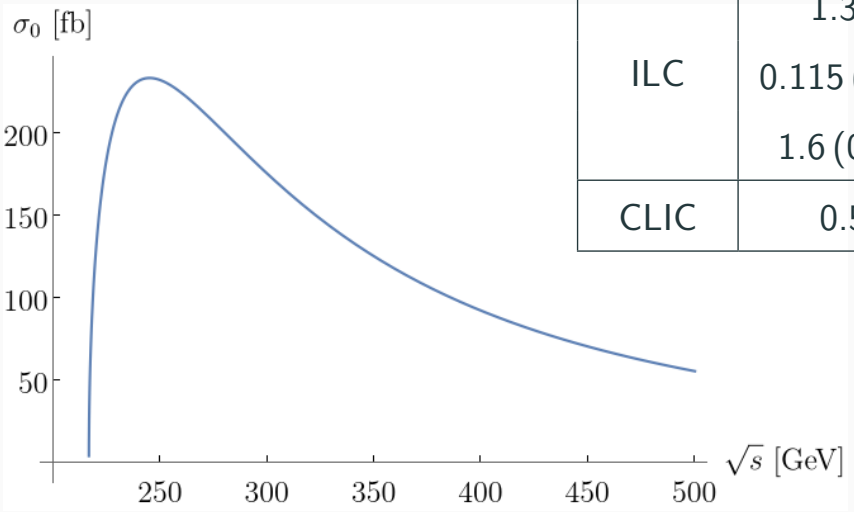
The University of New South Wales Sydney
Sydney-CPPC

UNSW SYDNEY

based on work in collaboration with
Tobias Felkl, Adam Lackner [2211.15954]

Precision measurement of Higgsstrahlung cross section





Collider	L_{int} [ab^{-1}]	Z-decay final states	$\sqrt{s}$ [GeV]	Precision
CEPC	20	$\ell^+\ell^-$, $q\bar{q}$, $\nu\bar{\nu}$	240	0.26%
	1	$\ell^+\ell^-$, $q\bar{q}$, $\nu\bar{\nu}$	360	1.4%
FCC-ee	5	$\ell^+\ell^-$	240	0.5%
	1.5	$\ell^+\ell^-$, $q\bar{q}$, $\nu\bar{\nu}$	365	0.9%
ILC	1.35	$\ell^+\ell^-$	250	1.1%
	0.115 (0.5)	$\ell^+\ell^-$ ($q\bar{q}$)	350	5% (1.63%)
	1.6 (0.5)	$\ell^+\ell^-$ ($q\bar{q}$)	500	2.9% (3.9%)
CLIC	0.5	$\ell^+\ell^-$, $q\bar{q}$	350	1.65%

- Higgs factory reaches sub-percent precision
- Is it possible to learn something about neutrino masses?

→ consider fermionic seesaw in SMEFT

Higgsstrahlung: Kniehl, Pilaftsis hep-ph/9402314; Craig, Farina, McCullough, Perelstein 1411.0676; Lackner (2019); **Sterile neutrinos at lepton colliders:** del Aguila, Aguilar-Saavedra, de la Ossa, Meloni hep-ph/0502189; del Aguila, Aguilar-Saavedra hep-ph/0503026; Antusch, Fischer 1502.05915, +Cazzato 1512.06035, 1604.02420; Zhang, Zhang 1805.09520; Das, Jana, Mandal, Nandi 1811.04291; Barducci, Bertuzzo, Caputo, Hernandez, Mele 2011.04725; Gao, Wang 2102.12826; **triplet fermions:** Das, Mandal 2006.04123; Argüelles *et al* 2203.10811; **triple-Higgs coupling:** Baglio, Weiland 1603.00879, 1612.06403; **Reviews:** Deppisch, Dev, Pilaftsis 1502.06541; Cai, Han, Li, Ruiz 1711.02180; ...

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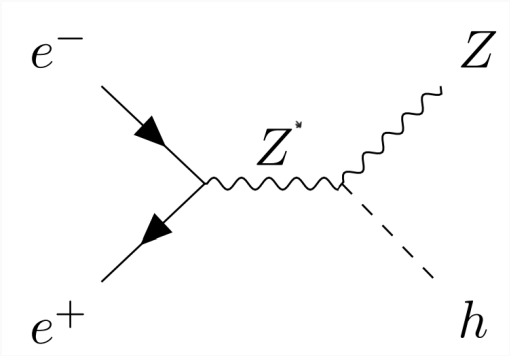

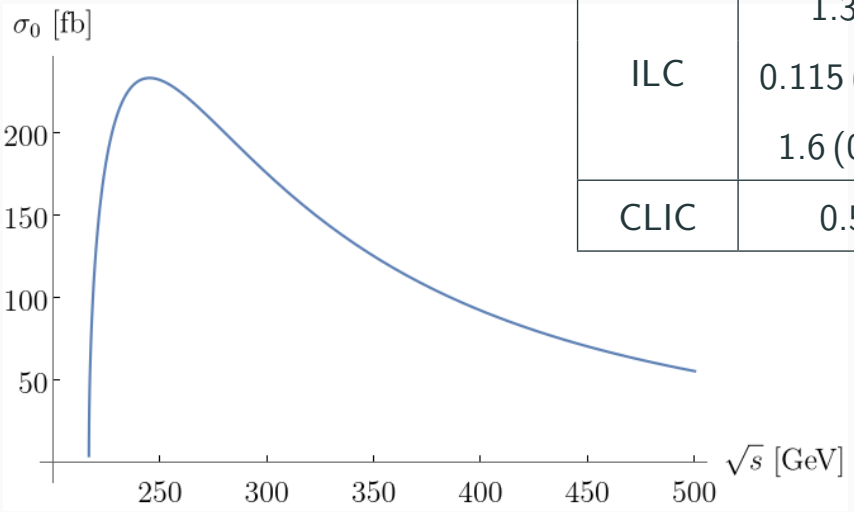

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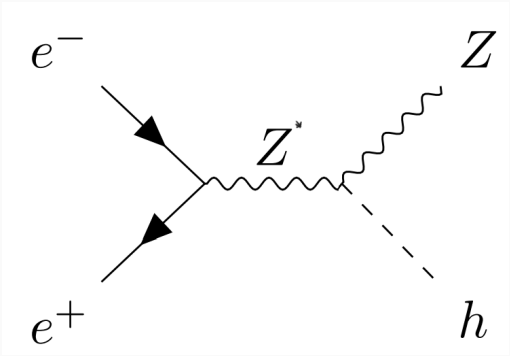

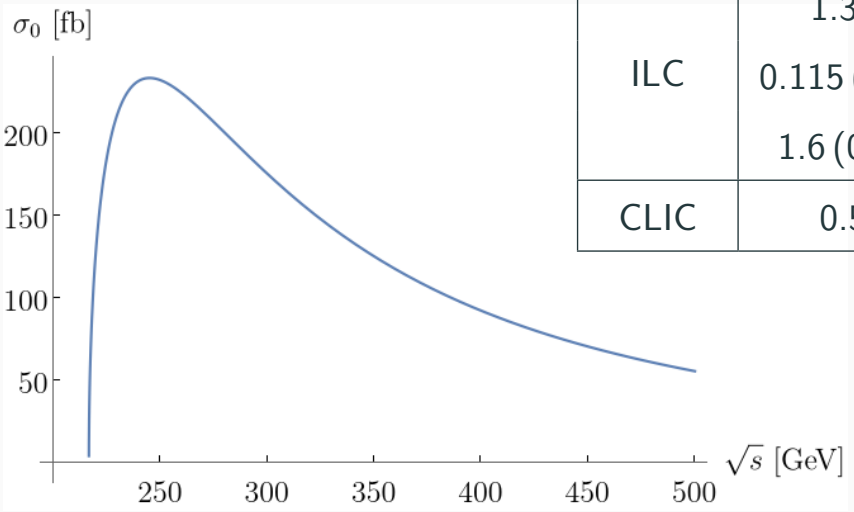

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Fermionic seesaw models

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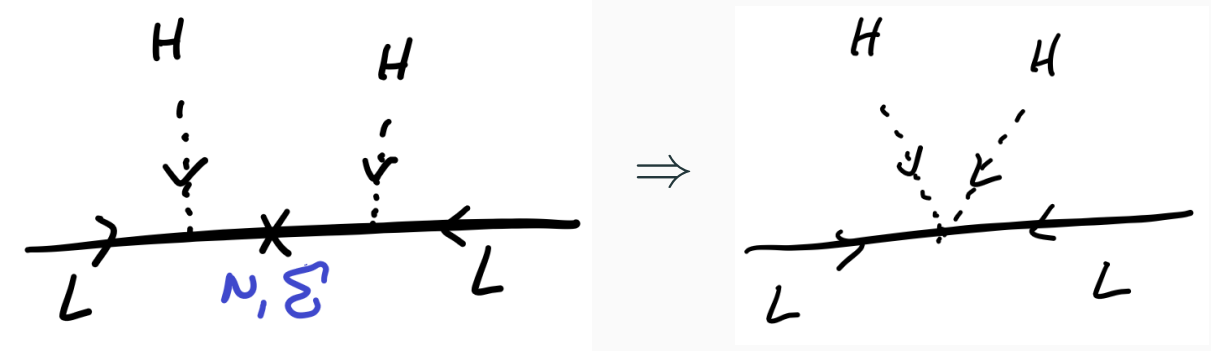

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Leading LNC dimension-6 operators

Type-I seesaw

$$C_{HL}^{(1)} = -C_{HL}^{(3)} = \frac{1}{4}(YM^{-1})(YM^{-1})^\dagger$$

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$$C_{HL}^{(1)} = 3C_{HL}^{(3)} = \frac{3}{4}(YM^{-1})(YM^{-1})^\dagger$$

$$C_{eH} = (YM^{-1})(YM^{-1})^\dagger Y_e$$

see e.g. Du, Li, Yu 2201.04646; Zhang, Zhou 2107.12133; Coy, Frigerio 2110.09126

$$O_{HL}^{(1)} = (H^\dagger i \overleftrightarrow{D}_\mu H)(\bar{L}\gamma^\mu L) \qquad O_{HL}^{(3)} = (H^\dagger i \overleftrightarrow{D}^I_\mu H)(\bar{L}\sigma^I\gamma^\mu L) \qquad O_{eH} = (H^\dagger H)(\bar{L}e_R H)$$

at loop level: $O_{eW} = (\bar{L}\sigma^{\mu\nu}\sigma^a e_R)HW^a_{\mu\nu}$ $O_{eB} = (\bar{L}\sigma^{\mu\nu} e_R)HB_{\mu\nu}$

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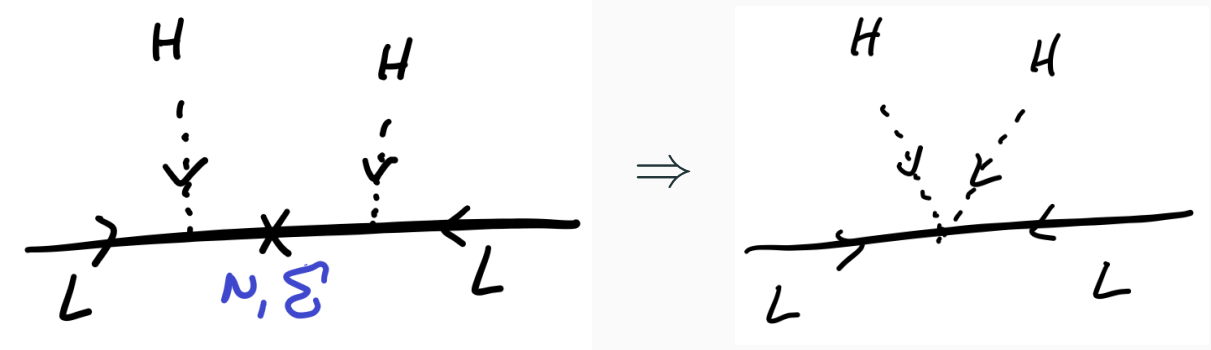

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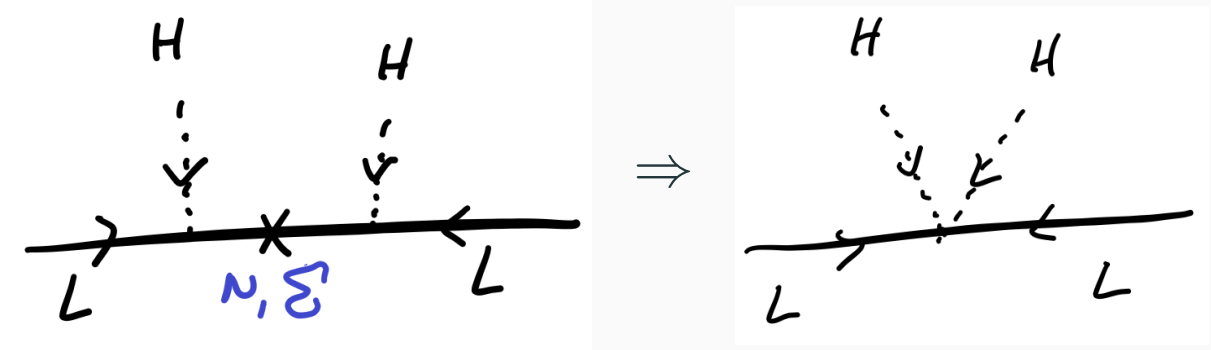

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Approach

- Consider minimal case with 2 right-handed neutrinos
- Decouple scales of LNV dimension-5 and LNC dimension-6 operators
- Consider LNC limit with

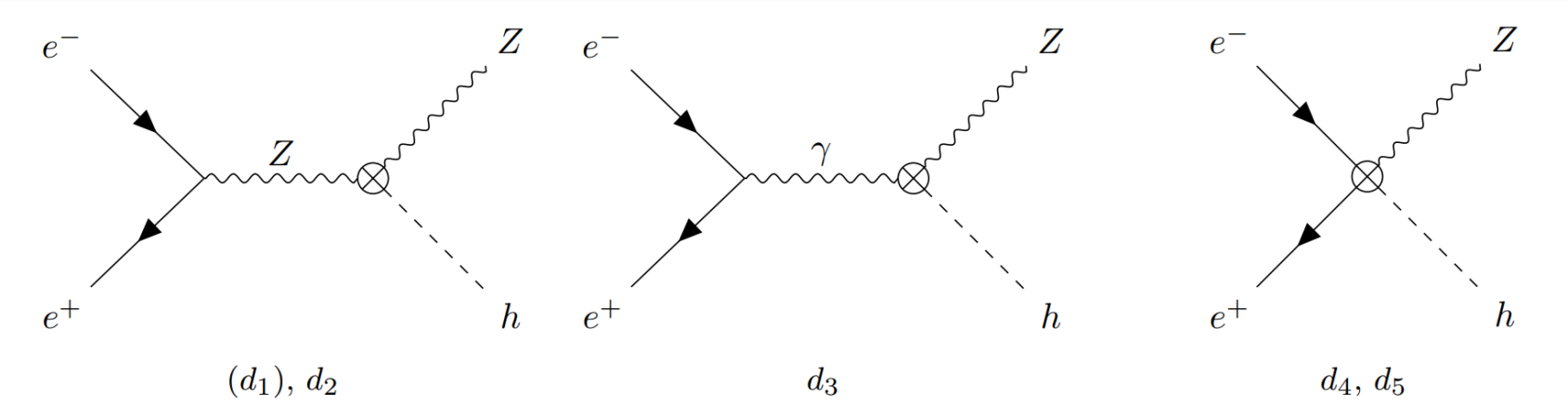
$$Y = \begin{pmatrix} Y^e & 0 \\ Y^\mu & 0 \\ Y^\tau & 0 \end{pmatrix} \qquad M = M_0 \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}$$

- Define operators at scale M_0, include 1-loop RG corrections using DsixTools

Many groups considered decoupling of lepton number violation from lepton number conserving processes:

Wyler, Wolfenstein (1983); Bernabeu, Santamaria, Vidal, Mendez, Valle (1987); Branco, Grimus, Lavoura (1989); Tommasini, Barenboim, Bernabeu, Jarlskog (1995); Kersten,Smirnov 0705.3221; Abada, Biggio, Bonnet, Gavela, Hambye 0707.4058; Gavela, Hambye, Hernandez, Hernandez 0906.1461; Eboli, Gonzalez-Fraile, Gonzalez-Garcia 1108.0661; Fernandez-Martinez, Hernandez-Garcia, Lopez-Pavon, Lucente 1508.03051; Drewes, Karic, Klose 1907.13034; Abada, Escribano, Marcano, Piazza 2208.13882; ...

Higgsstrahlung



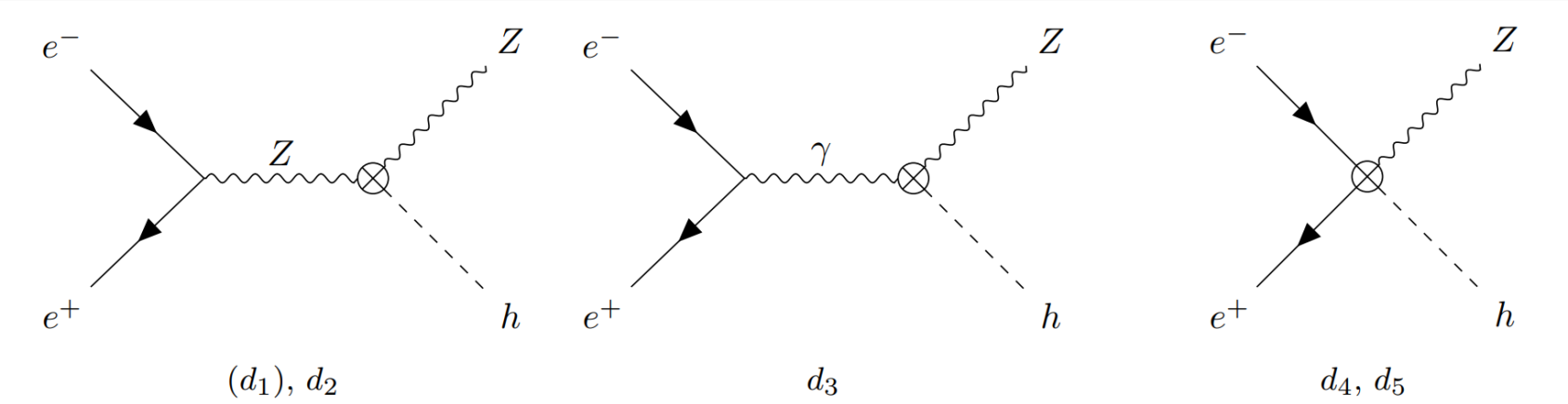
Parameter shifts

- Operators $C_{HL}^{(1,3)}$ modify W, Z boson couplings

$\Rightarrow$ Contributions to other observables like muon decay

$\Rightarrow$ need to carefully treat input parameters G_F, m_Z, α

Higgsstrahlung



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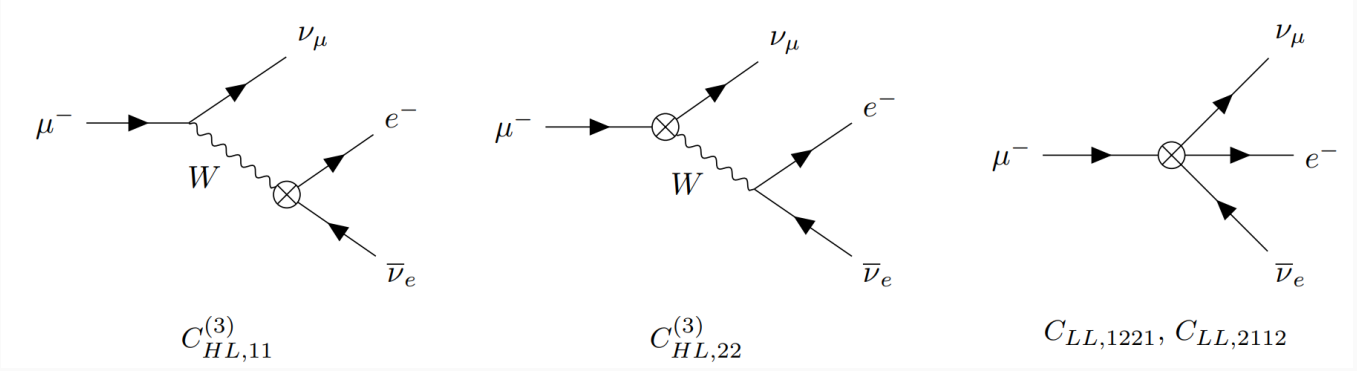

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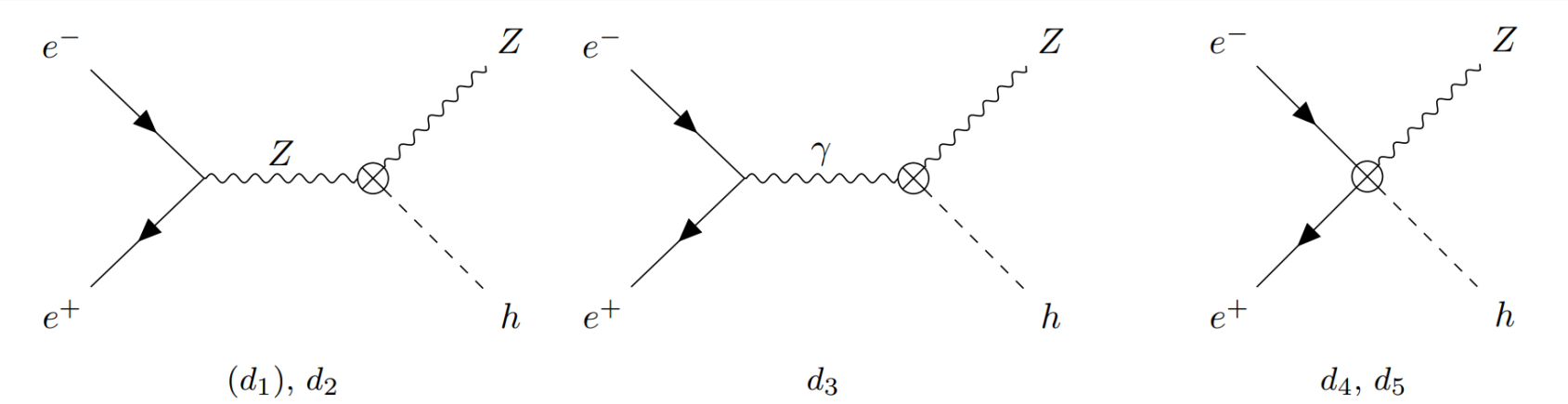

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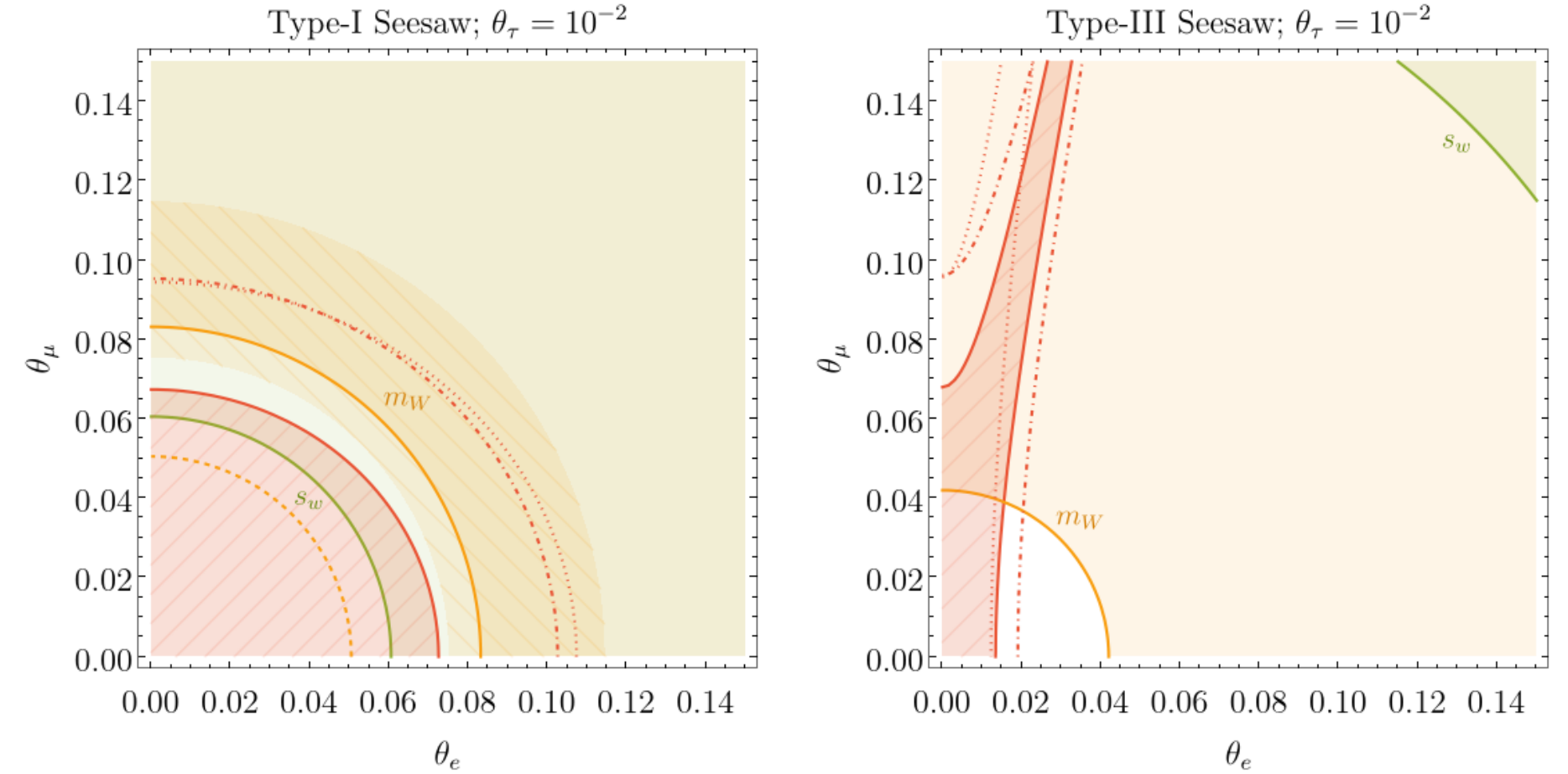
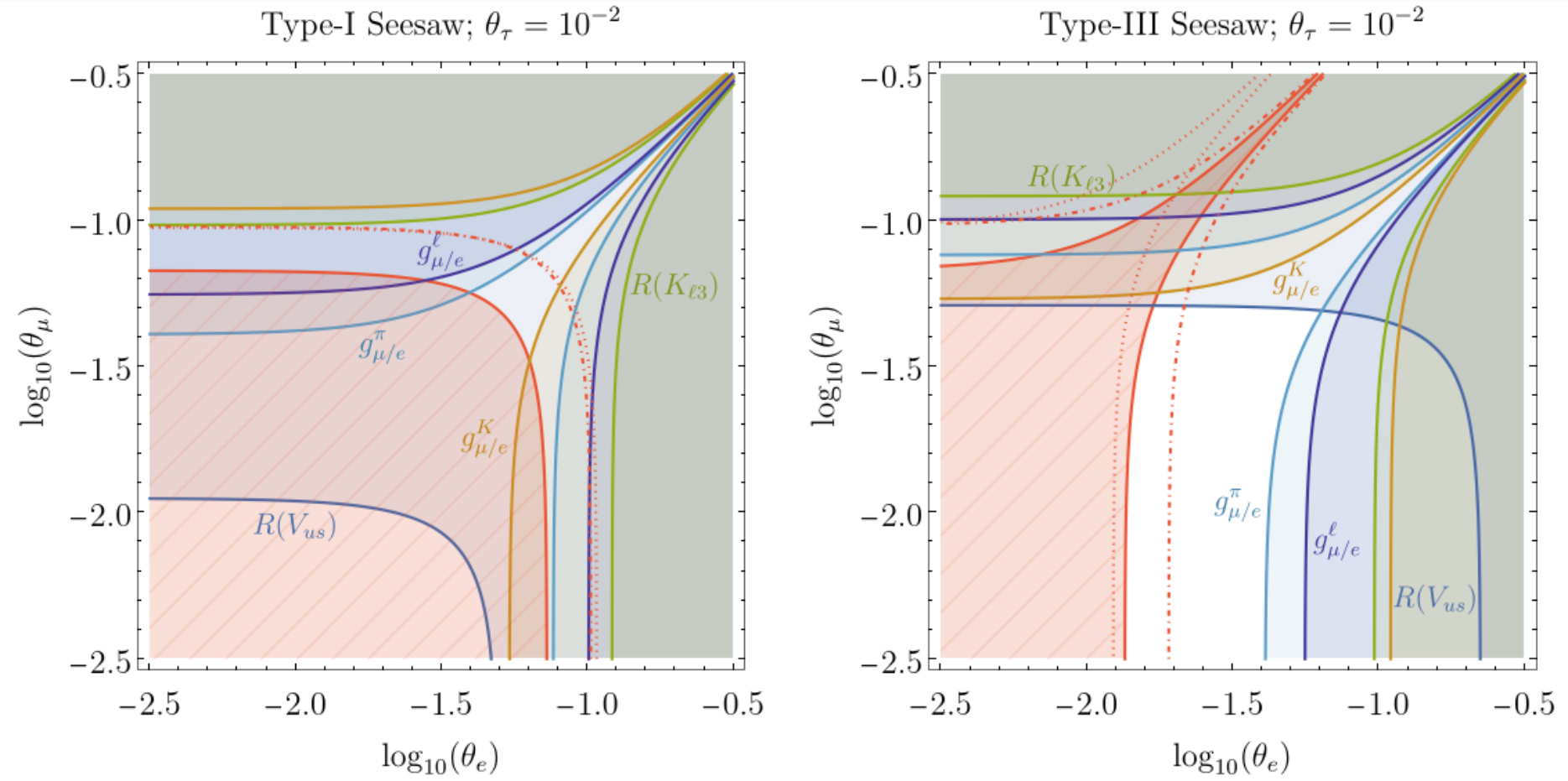
$$\frac{\Delta\sigma}{\sigma_0} \approx \begin{cases} 0.90\hat{C}_{HL,11}^{(1)} + 0.77\hat{C}_{HL,11}^{(3)} - 0.13\hat{C}_{HL,22}^{(3)} & \sqrt{s} = 240\text{GeV} \\ 2.09\hat{C}_{HL,11}^{(1)} + 1.96\hat{C}_{HL,11}^{(3)} - 0.13\hat{C}_{HL,22}^{(3)} & \sqrt{s} = 365\text{GeV} \end{cases}$$

Electroweak observables



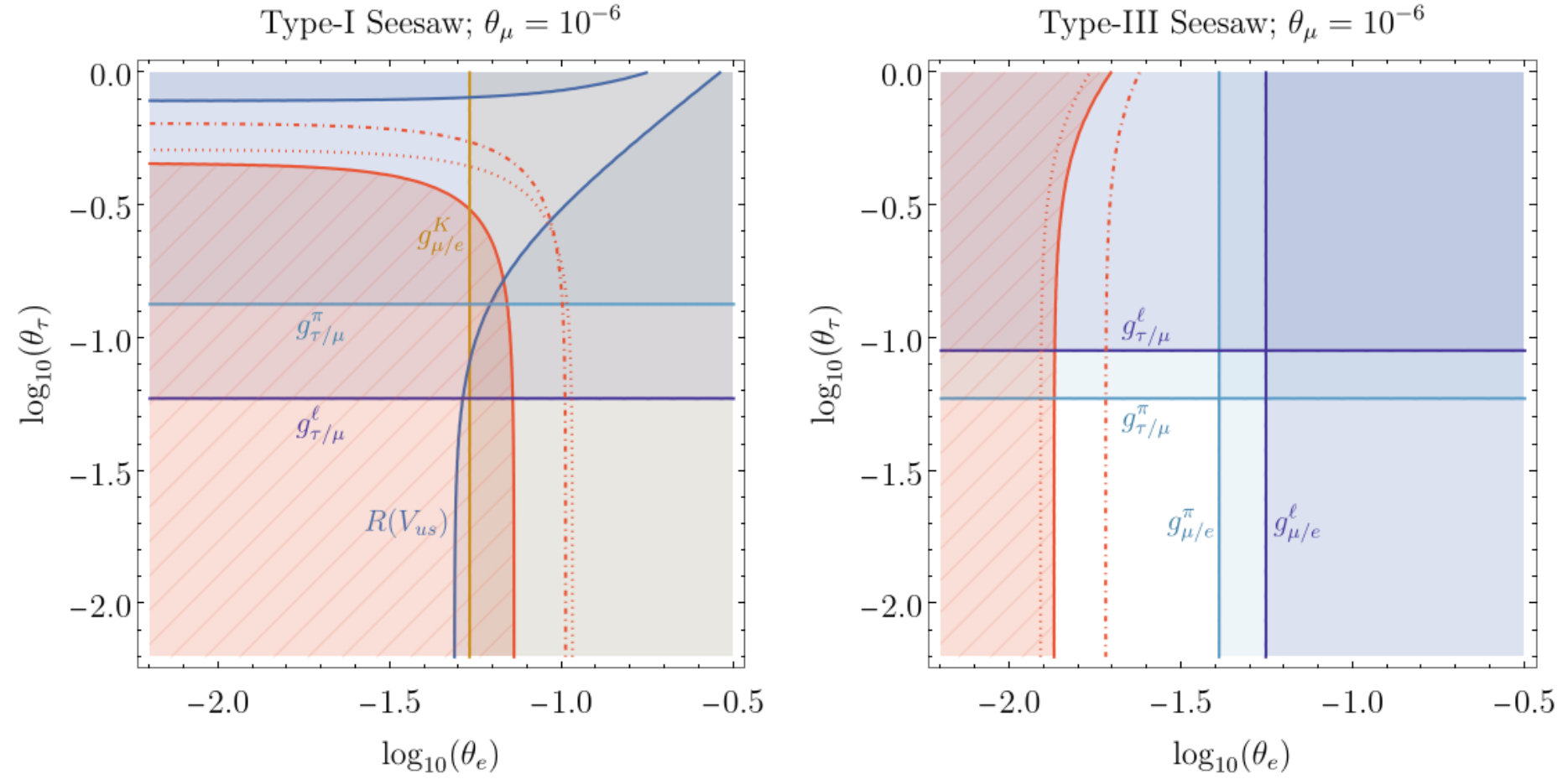
- Higgsstrahlung: solid 0.5% at 240 GeV; dot-dashed (dashed) 1% at 240(365) GeV
- Shift in weak mixing angle $\delta s_w^2 \approx 0.02(\hat{C}^{(3)}_{HL,11} + \hat{C}^{(3)}_{HL,22}) - 0.005 \sum_i (\hat{C}^{(1)}_{HL,ii} + \hat{C}^{(3)}_{HL,ii})$
- W boson mass $\delta m_W \approx -1.05(\hat{C}^{(3)}_{HL,11} + \hat{C}^{(3)}_{HL,22})$ GeV
  in orange: world-average (dashed), CDF @2σ (ruled-region)
- Third mixing angle θ_τ as large as possible

Lepton flavour universality and CKM ratios: $e - \mu$



- Higgsstrahlung: solid 0.5% at 240 GeV; dot-dashed (dashed) 1% at 240(365) GeV
- Leptonic gauge couplings $\delta g_{\mu/e} = \delta(g_\mu/g_e) \approx 0.06(\hat{C}^{(3)}_{HL,22} - \hat{C}^{(3)}_{HL,11})$
- semi-leptonic kaon decay $R(K_{\ell 3}) = V_{us}^{K_{\mu 3}}/V_{us}^{K_{e3}}$
- Crivellin, Hoferichter 2002.07184 $R(V_{us}) = V_{us}^{K_{\mu 2}}/V_{us}^{\beta} \approx 1 - v_T^2\left[\left(\frac{V_{ud}}{V_{us}}\right)^2 C^{(3)}_{HL,22} + C^{(3)}_{HL,11}\right]$

Lepton flavour universality and CKM ratios: $e - \tau$



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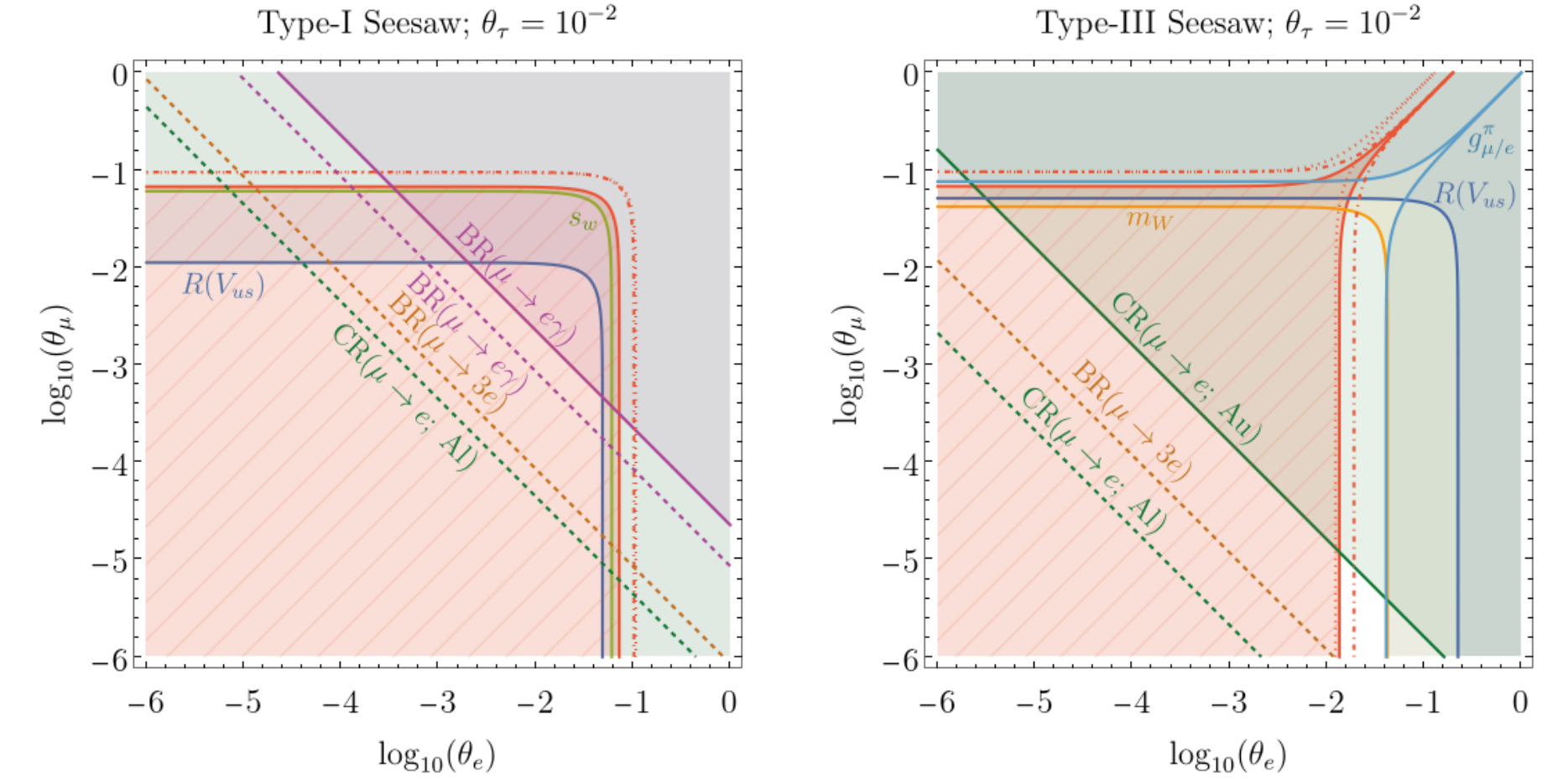
Final results: $e - \mu$



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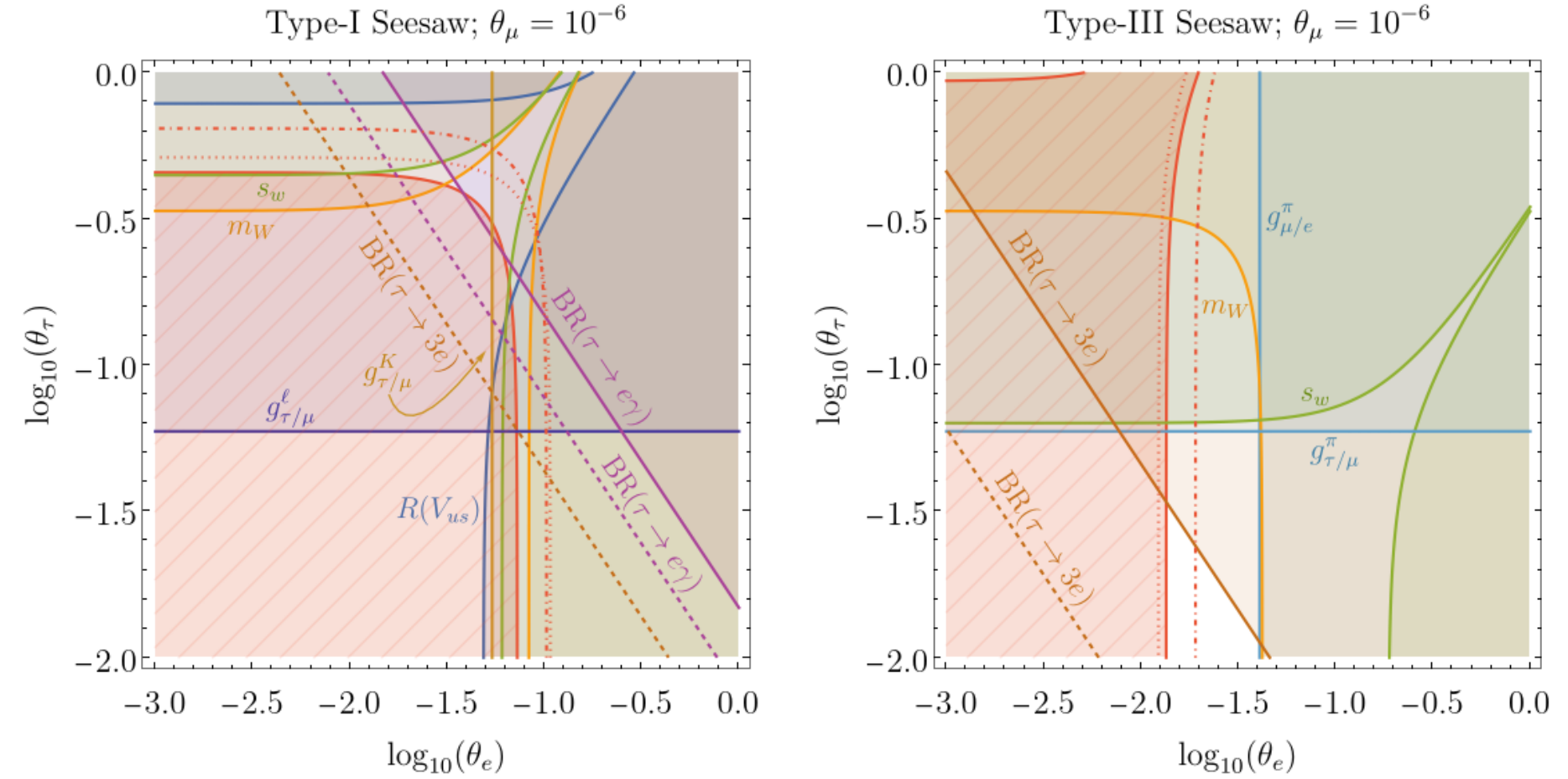

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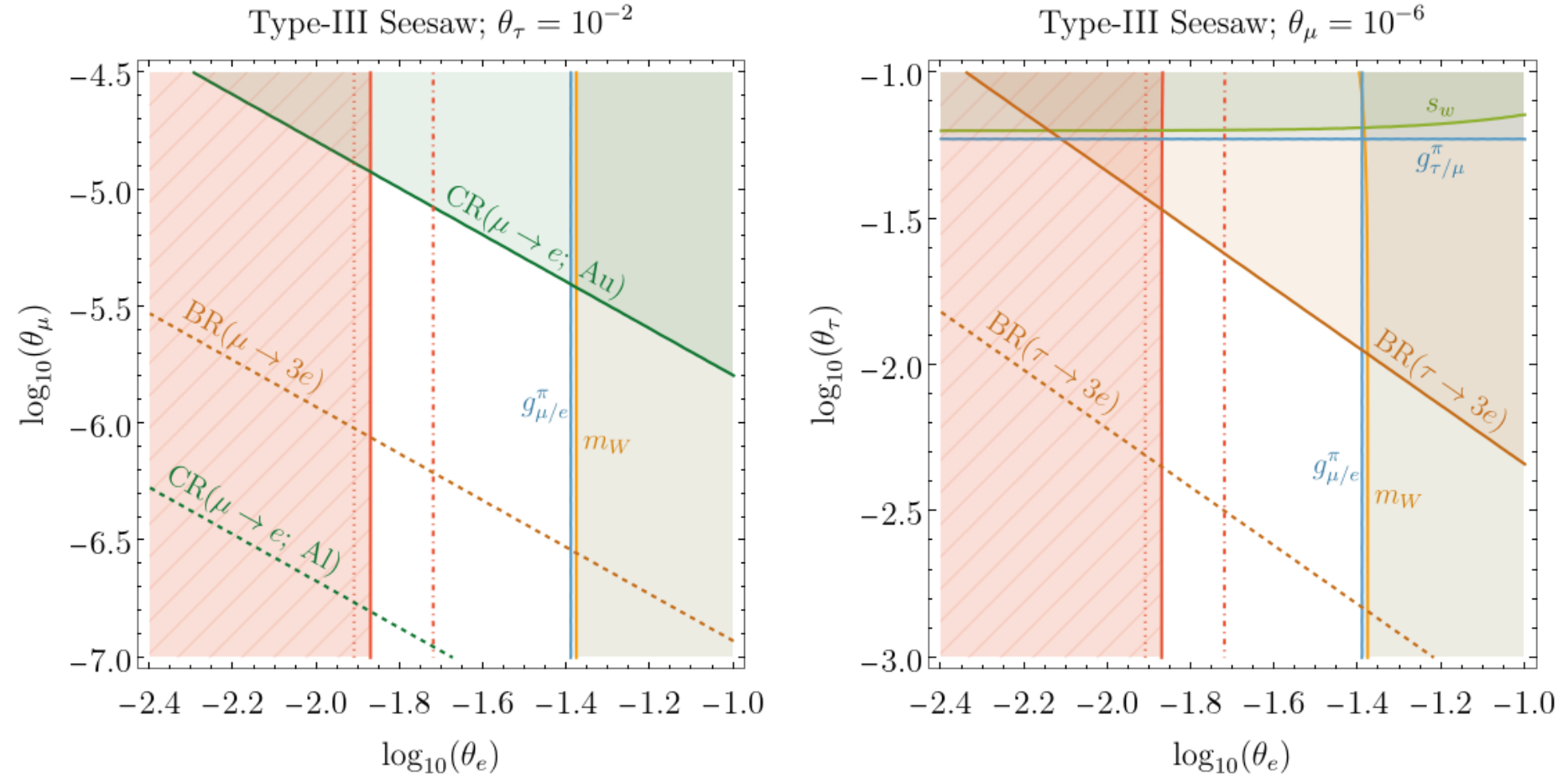
Final results: Type-III seesaw



- Higgsstrahlung: solid 0.5% at 240 GeV; dot-dashed (dashed) 1% at 240(365) GeV
- LFV and $g^\pi_{\mu/e}/m_W$ constrain available parameter space
- left: need hierarchy $\theta_\mu \ll \theta_e$; right: $\theta_e \simeq \theta_\tau$
- large improvement for LFV processes expected

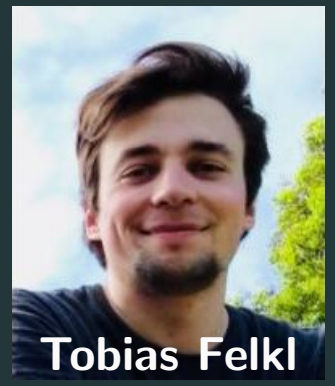
Summary: Take-home messages

Higgsstrahlung is complementary probe

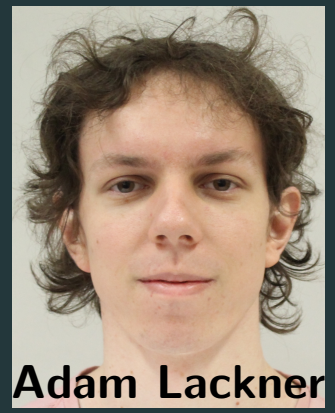
Type-III seesaw allows a sizable O(10%) deviation

Higgsstrahlung in Type-I seesaw too constrained from other obserables

Collaborators



Tobias Felkl



Adam Lackner

[2211.15954]

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Thank you!

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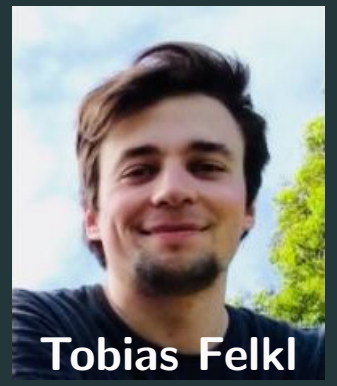
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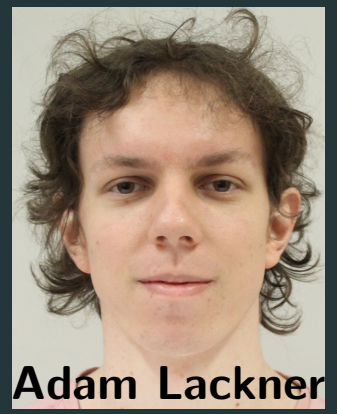
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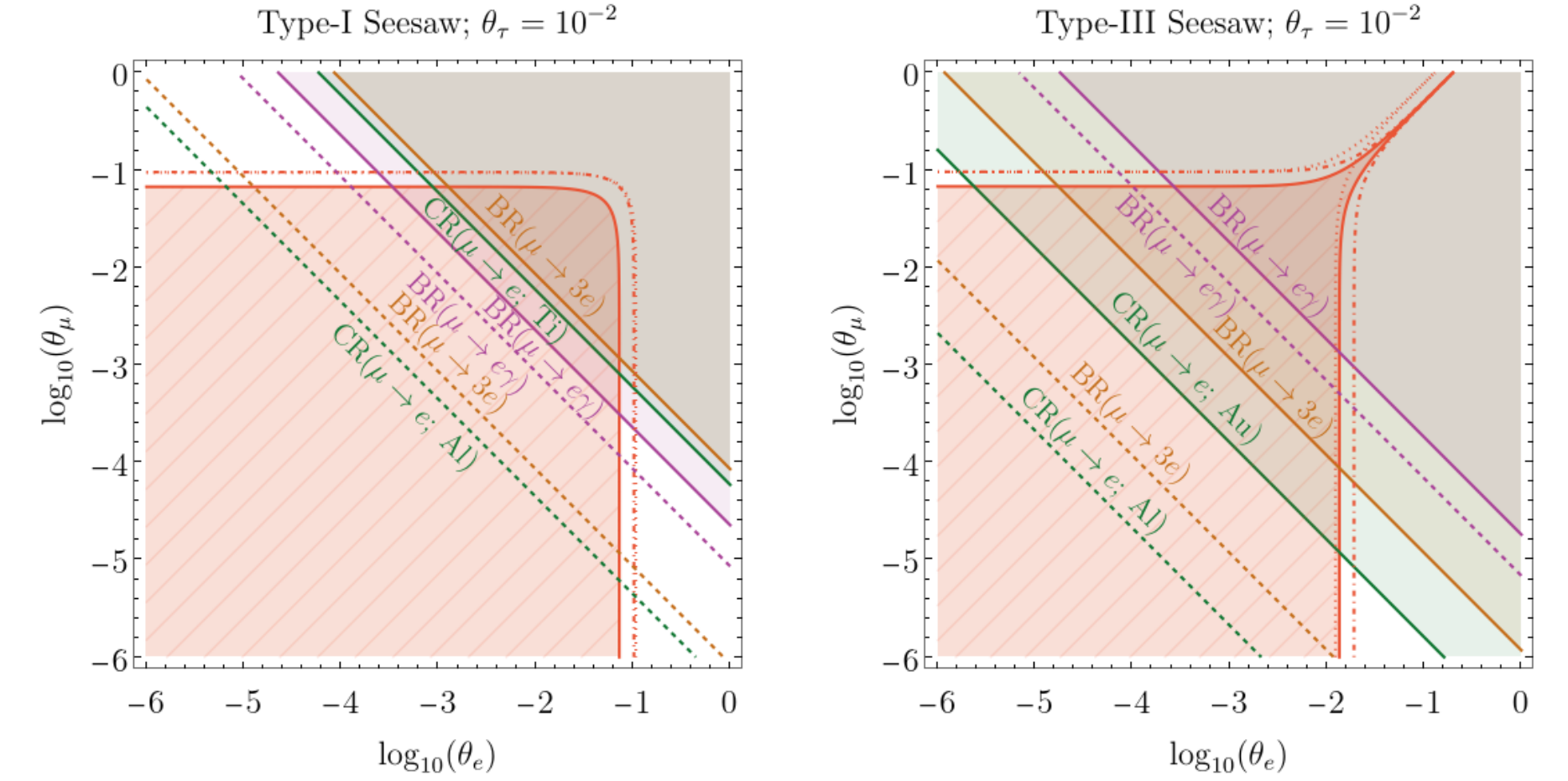
Backup slides

Lepton flavour violation: $e - \mu$



- Higgsstrahlung: solid 0.5% at 240 GeV; dot-dashed (dashed) 1% at 240(365) GeV
- Type-I seesaw: cancellation in $\mu \to e$ processes, particularly for *Au*

Lepton flavour violation: $e - \tau$