Probing BSM with High-Multiplicity Muon Decays

Work in progress

with Admir Greljo, Mirsad Tunja and Jure Zupan

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Universität Basel

Swiss National Science Foundation

Outline

- **Motivation**
  - From golden modes to high-multiplicity decays
- **EFT approach to high-multiplicity decays**
  - SMEFT
  - Light mediator EFTs and cascades
- **UV completions**
  - Examples of concrete models

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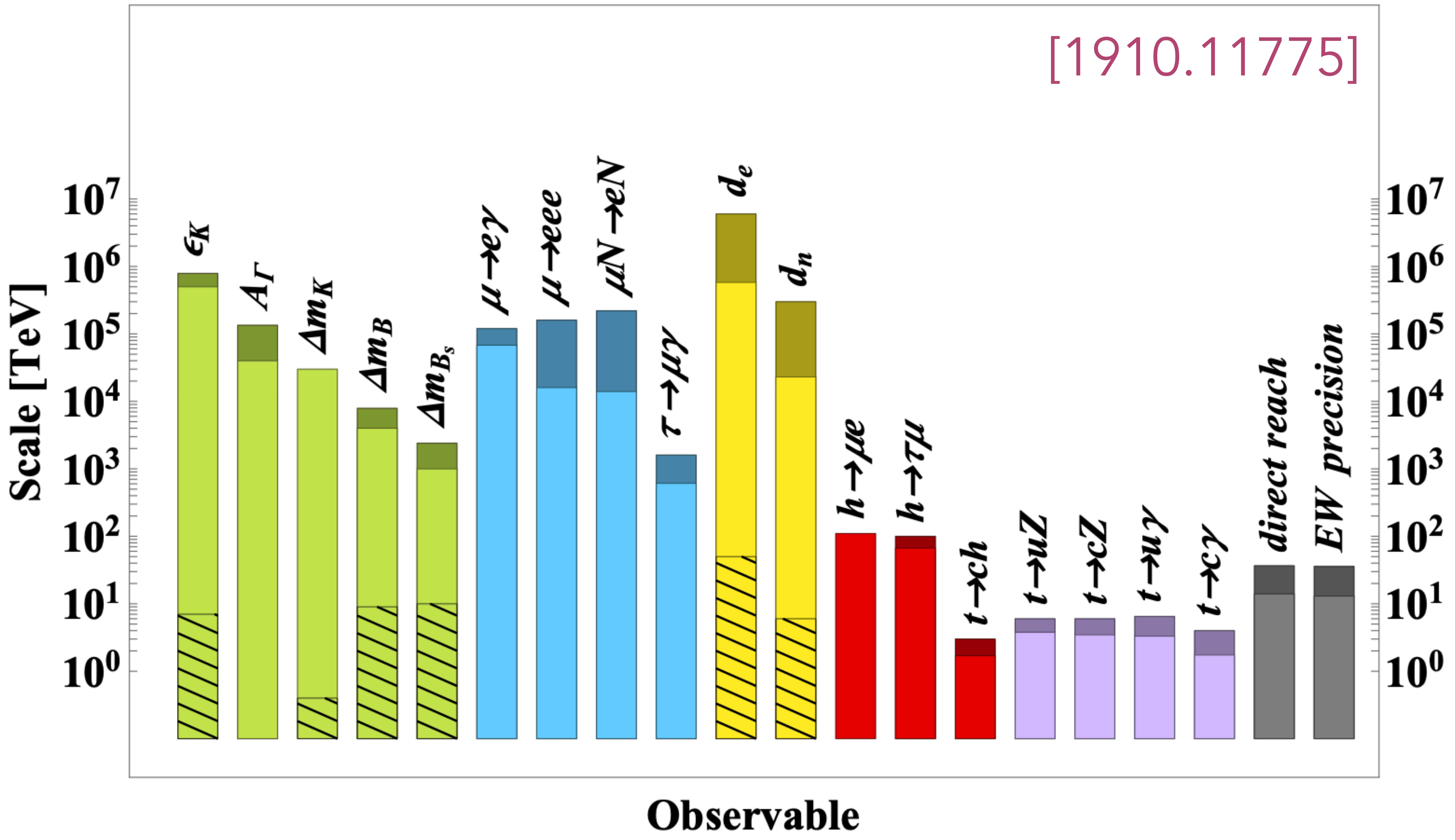

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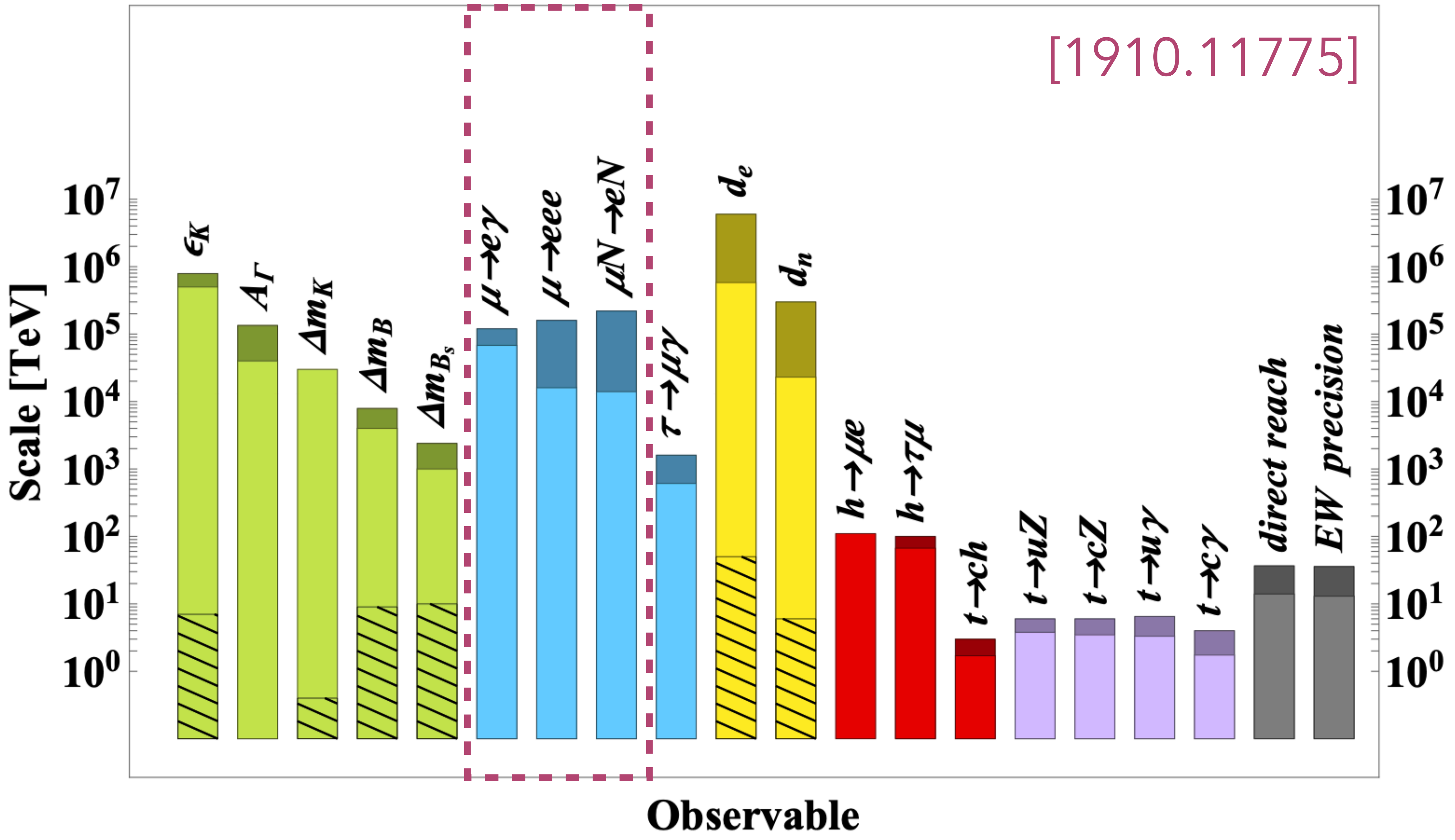

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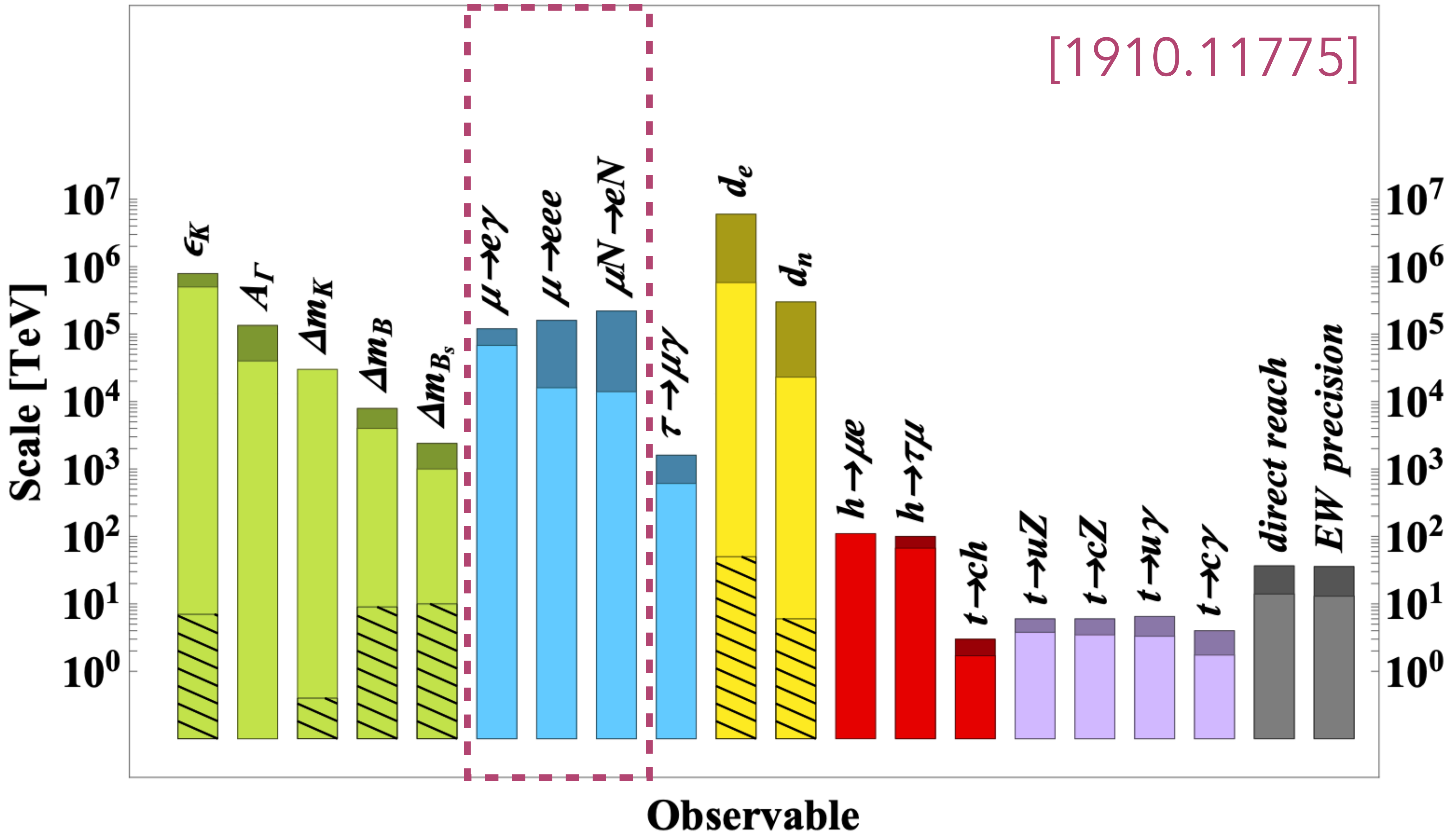

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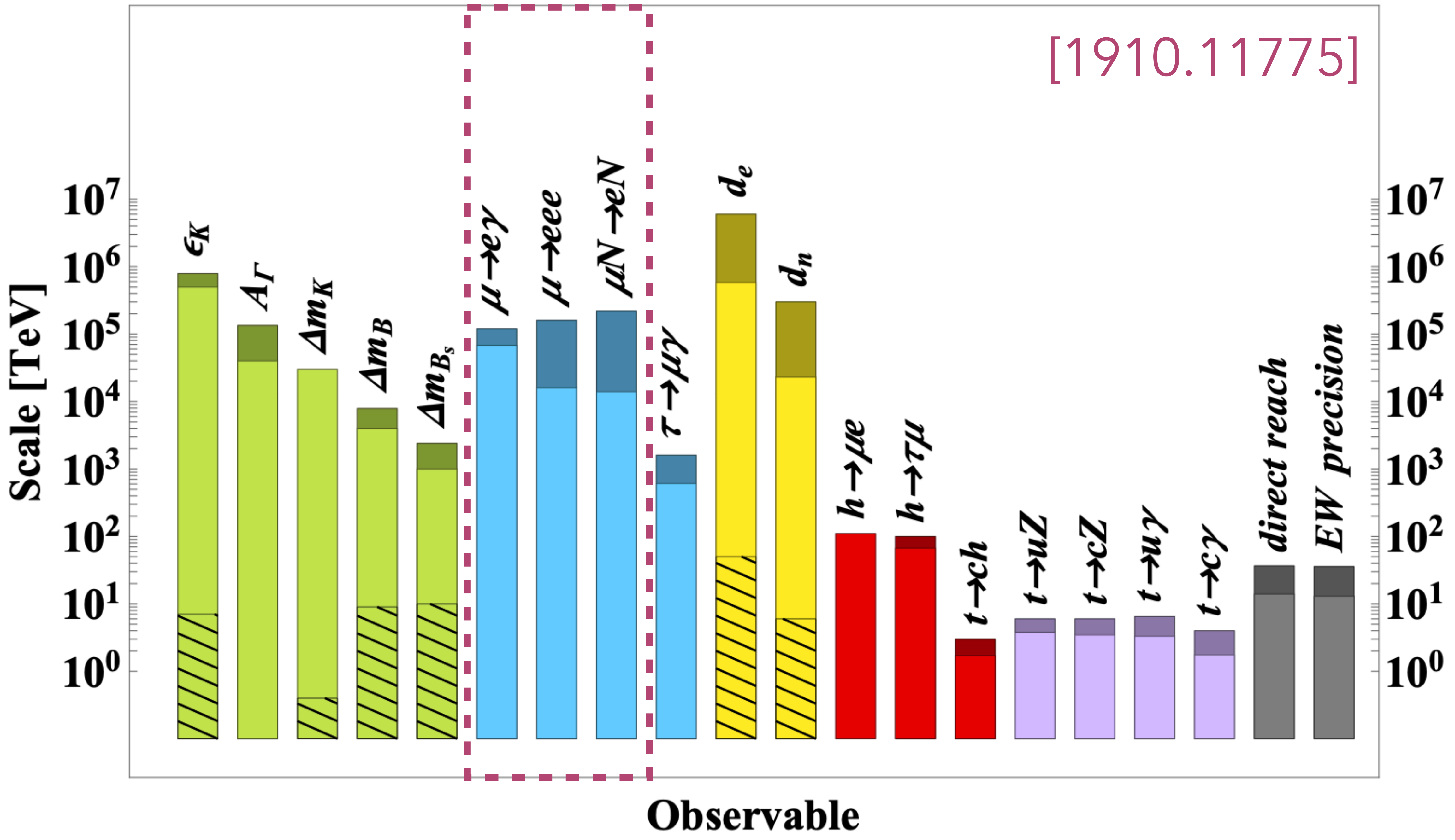
[1910.11775]



LFV obs.	Present bounds (90% CL)		Expected future limits	
$\mathrm{BR}(\mu\to e\gamma)$	4.2×10^{-13}	MEG (2016)	6×10^{-14}	MEG-II
$\mathrm{BR}(\mu\to eee)$	1.0×10^{-12}	SINDRUM (1988)	10^{-16}	Mu3e
$\mathrm{CR}(\mu\to e,\mathrm{Au})$	7.0×10^{-13}	SINDRUM II (2006)	–	–
$\mathrm{CR}(\mu\to e,\mathrm{Al})$	–	–	6×10^{-17}	COMET/Mu2e

[2107.10273]

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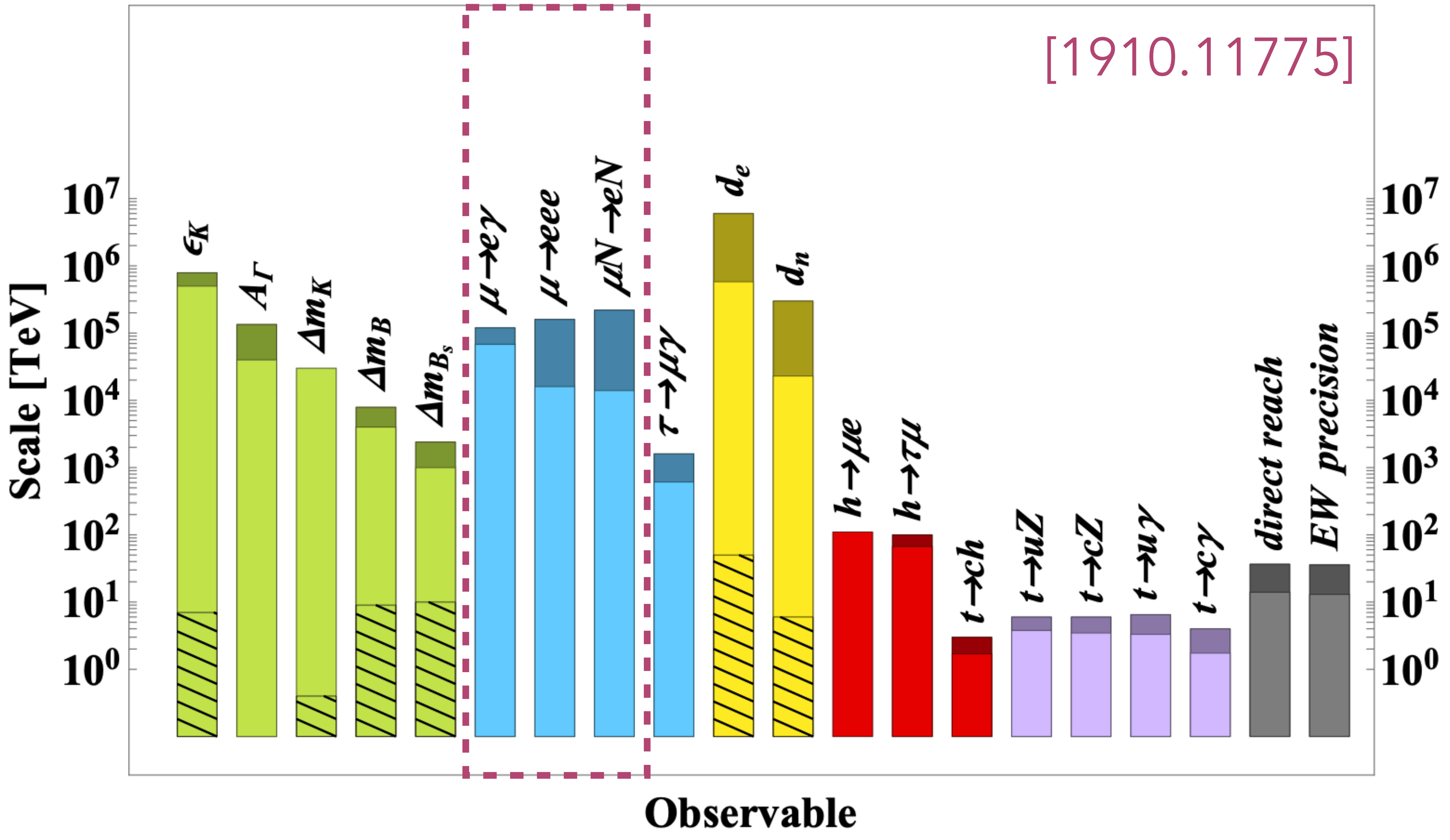
    - Projected improvements by several orders of magnitude



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e.g. PNGB of a broken global symmetry

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  - Flavor-violating interactions

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- **Estimates on the scale f**

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- **Idea: systematic analysis of these *exotic* muon decay signatures**

EFT approach to high-multiplicity muon decays

Signature-Driven EFT Approach

- Focus on final-state multiplicity and composition

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$e\backslash\gamma$	**0**	**1**	**2**	**3**	**4**
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- **EFT analysis of the signatures**
  - SMEFT
  - EFT with single light mediator

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- **Example: SMEFT analysis of $\mu \to 5e$**

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Signature-Driven EFT Approach

- Overview of other representative SMEFT operators

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$$\mathcal{L}^{\mu\to 3e2\gamma}_{\rm SMEFT} \supset \frac{\mathcal{C}_8^{(4)}}{\Lambda^4}(\bar{\ell}\gamma^\mu \overleftrightarrow{D}^\nu\ell)(\bar{\ell}\gamma_\mu \overleftrightarrow{D}_\nu\ell)\,, \quad \Lambda \sim 100\,\mathrm{GeV}$$

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EFT with single light mediator

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$$\mathcal{L}_{\rm eff} \supset \frac{\mathcal{C}_{\mathcal{S}}^{(n)}}{\Lambda^{4+n}}(\bar{\ell}_2 H e_1)\mathcal{S}^n + \text{h.c.}$$

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Light vector EFT	$\mathcal{L}_{\rm eff} \supset \frac{\mathcal{C}_{V}^{(1)}}{\Lambda^{4}}(D_\mu \Phi)^\dagger (D^\mu \Phi)(\bar{\ell}_2 H e_1) + \text{h.c.}$

EFT with single light mediator

- Estimates on the EFT scales

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- **Estimates on the EFT scales**

$\mathcal{L}_{\text{eff}} \supset$	$\mathbf{\Lambda}$ [TeV]
$\frac{\mathcal{C}_{\mathcal{S}}^{(1)}}{\Lambda}(\bar{\ell}_2 H e_1)\,\mathcal{S}$	$\mathcal{O}(10^{14})$
$\frac{\mathcal{C}_{\mathcal{S}}^{(2)}}{\Lambda^2}(\bar{\ell}_2 H e_1)\,\mathcal{S}^2$	$\mathcal{O}(10^{4})$
$\frac{\mathcal{C}_{\mathcal{S}}^{(3)}}{\Lambda^3}(\bar{\ell}_2 H e_1)\,\mathcal{S}^3$	$\mathcal{O}(10)$
$\frac{\mathcal{C}_{\mathcal{S}}^{(4)}}{\Lambda^4}(\bar{\ell}_2 H e_1)\,\mathcal{S}^4$	$\mathcal{O}(1)$
$\frac{\mathcal{C}_{N}^{(1)}}{\Lambda^2}(\bar{\ell}_2 \gamma^\mu \ell_1)(\bar{N}\gamma_\mu N)$	$\mathcal{O}(10^{3})$
$\frac{\mathcal{C}_{N}^{(2)}}{\Lambda^6}(\bar{\ell}_2 H e_1)(\bar{N}\gamma_\mu N)(\bar{N}\gamma^\mu N)$	$\mathcal{O}(1)$
$\frac{\mathcal{C}_{V}^{(1)}}{\Lambda^4}(D_\mu \Phi)^\dagger (D^\mu \Phi)(\bar{\ell}_2 H e_1)$	$\mathcal{O}(10^{4})$

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EFT with single light mediator

- Estimates on the EFT scales

- Example: analysis of $\mu \to 7e$

$\mathcal{L}_{\text{eff}} \supset$	Λ [TeV]
$\frac{\mathcal{C}_{\mathcal{S}}^{(1)}}{\Lambda}(\bar{\ell}_2 H e_1)\,\mathcal{S}$	$\mathcal{O}(10^{14})$
$\frac{\mathcal{C}_{\mathcal{S}}^{(2)}}{\Lambda^2}(\bar{\ell}_2 H e_1)\,\mathcal{S}^2$	$\mathcal{O}(10^{4})$
$\frac{\mathcal{C}_{\mathcal{S}}^{(3)}}{\Lambda^3}(\bar{\ell}_2 H e_1)\,\mathcal{S}^3$	$\mathcal{O}(10)$
$\frac{\mathcal{C}_{\mathcal{S}}^{(4)}}{\Lambda^4}(\bar{\ell}_2 H e_1)\,\mathcal{S}^4$	$\mathcal{O}(1)$
$\frac{\mathcal{C}_{N}^{(1)}}{\Lambda^2}(\bar{\ell}_2 \gamma^\mu \ell_1)(\bar{N}\gamma_\mu N)$	$\mathcal{O}(10^{3})$
$\frac{\mathcal{C}_{N}^{(2)}}{\Lambda^6}(\bar{\ell}_2 H e_1)(\bar{N}\gamma_\mu N)(\bar{N}\gamma^\mu N)$	$\mathcal{O}(1)$
$\frac{\mathcal{C}_{V}^{(1)}}{\Lambda^4}(D_\mu \Phi)^\dagger (D^\mu \Phi)(\bar{\ell}_2 H e_1)$	$\mathcal{O}(10^{4})$

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EFT with single light mediator

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  - Taking $\text{BR} \times \text{Acceptance} \sim 10^{-15}$ we analyze the $p_T > 10\,\text{MeV}$ and $p_T > 6\,\text{MeV}$ cuts

$\mathcal{L}_\text{eff} \supset$	Λ [TeV]
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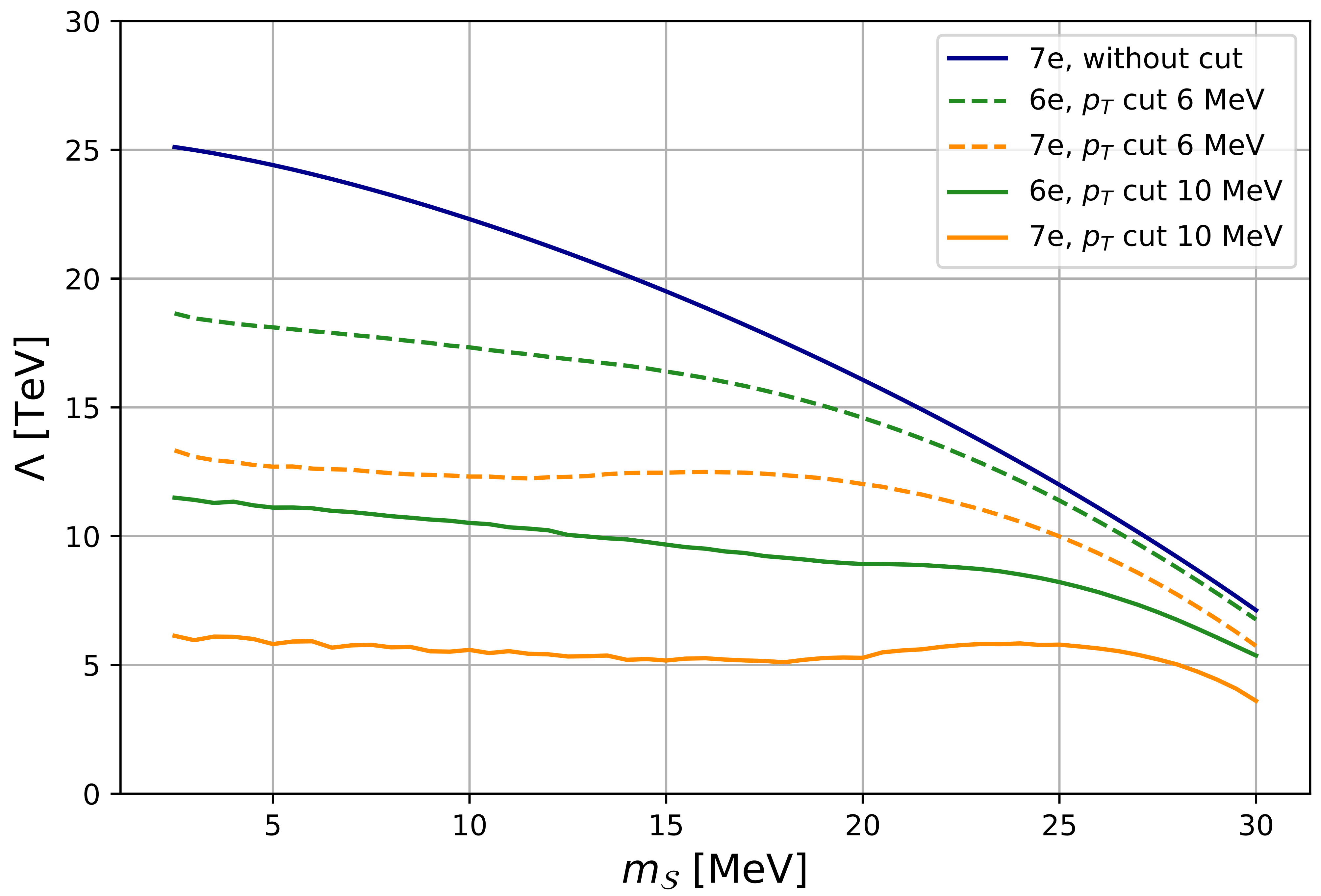

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Example of UV completion

UV completion

- **Gauged $U(1)_{\mu-e}$ model**

Field	$SU(2)_L$	$U(1)_Y$	$U(1)_{\mu-e}$
ℓ_1	**2**	-1/2	-1
ℓ_2	**2**	-1/2	1
ℓ_3	**2**	-1/2	0
e_1	**1**	-1	-1
e_2	**1**	-1	1
e_3	**1**	-1	0
H	**2**	1/2	0
Φ	**1**	0	2

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UV completion

- **Gauged $U(1)_{\mu-e}$ model**
  - Yukawa interactions

$$-\mathcal{L}_Y = \hat{y}_{ii}\left(\bar{\ell}_i H e_i\right) + \frac{y_5^{e\mu}}{\Lambda}\Phi^\dagger\left(\bar{\ell}_1 H e_2\right) + \frac{y_5^{\mu e}}{\Lambda}\Phi\left(\bar{\ell}_2 H e_1\right) + \text{h.c.}$$

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  - After SSB the gauge sector reads

$$\mathcal{L}_{\text{gauge}} \supset |D_\mu \Phi|^2 \supset 2g_d^2\varphi^2 B_{d\,\mu}^2 + 4g_d^2 v_\Phi B_{d\,\mu}^2\varphi + 2g_d^2 v_\varphi^2 B_{d\,\mu}^2$$

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  - Cascade decay of the form

$$\mu \to e\varphi \to e(\gamma_d\gamma_d) \to e(e\bar{e})(e\bar{e})$$

Field	$SU(2)_L$	$U(1)_Y$	$U(1)_{\mu-e}$
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e_3	**1**	-1	0
H	**2**	1/2	0
Φ	**1**	0	2

$e\backslash\gamma$	**0**	**1**	**2**	**3**	**4**
1	e	$e\gamma$	$e2\gamma$	$e3\gamma$	$e4\gamma$
3	$3e$	$3e\gamma$	$3e2\gamma$	$\dots$	
5	$5e$	$5e\gamma$	$\dots$		
7	$7e$	$\dots$			
$\dots$					

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Conclusions

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- Overview of *golden* cLFV muon transitions
- Motivation for the analysis of high-multiplicity muon decays
- Unified EFT framework: SMEFT and single-particle EFTs
- Benchmark example: $\mu \to 7e$
  - Correlation of the scalar mass and the scales probed
  - Analysis of the p_T cuts
- Example of a UV completion leading to $\mu \to 5e$ through cascade