Snowmass 2021 mini-workshop
CLFV - Tau Decays and Transitions
July 23 2020

Theory overview: CLFV at the τ scale

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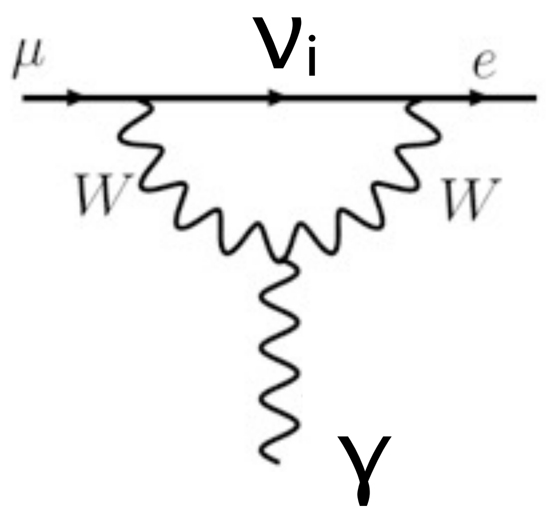
Outline

- Introduction: LFV, BSM physics & the role of tau decays
- EFT description of LFV tau decays:
  - discovery potential & model-diagnosing power
  - LFV couplings of the Higgs
- Conclusion and outlook

Introduction:
LFV and BSM physics

Charged LFV and BSM physics

- ν oscillations ⇒ $L_{e,\mu,\tau}$ not conserved
- In SM + massive ν, effective CLFV vertices are tiny (GIM)



$$Br(\mu \to e\gamma) = \frac{3\alpha}{32\pi} \left| \sum_{i=2,3} U^*_{\mu i} U_{ei} \frac{\Delta m^2_{1i}}{M^2_W} \right|^2 < 10^{-54}$$

Petcov '77, Marciano-Sanda '77 ....

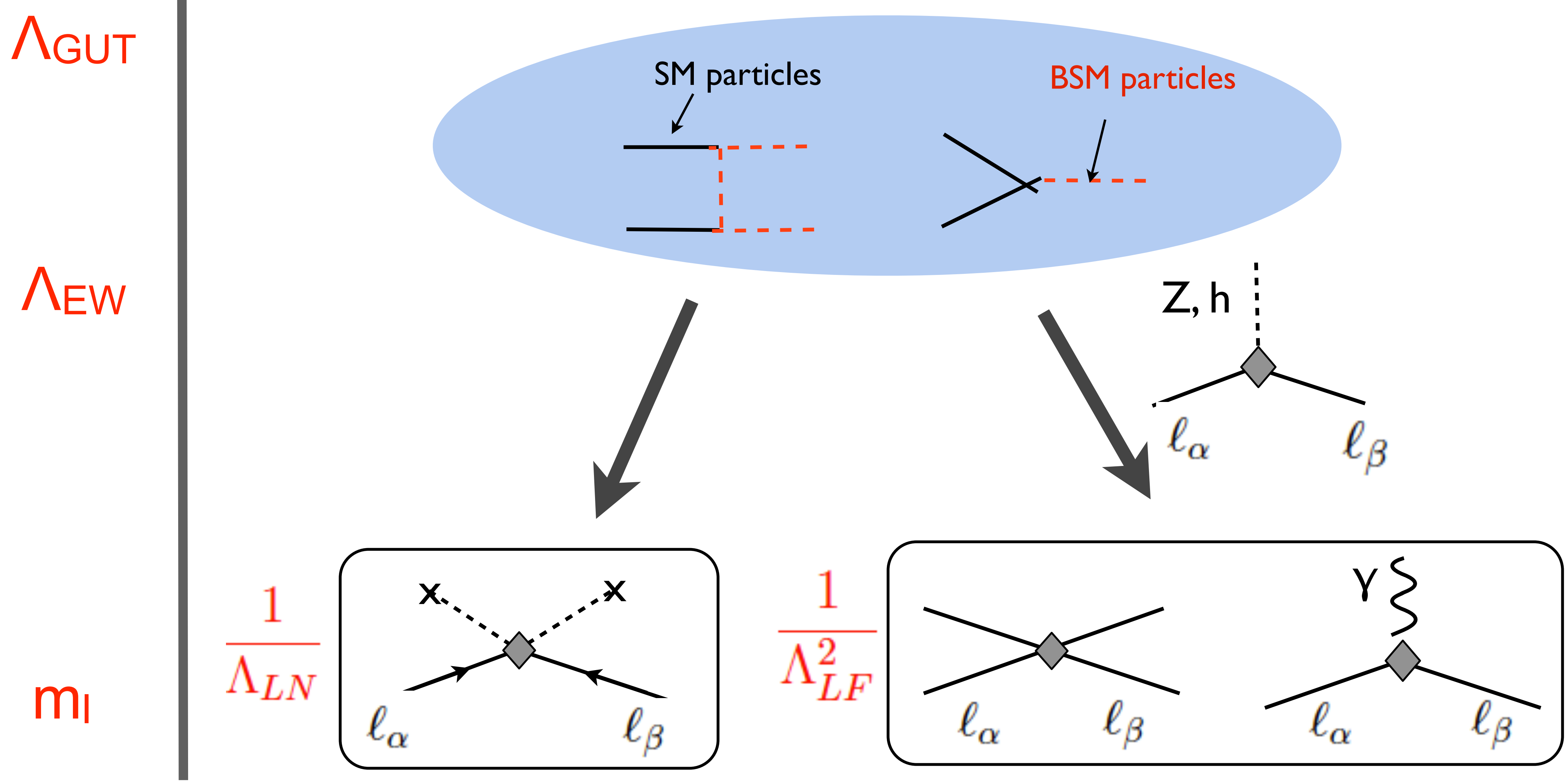
- CLFV processes are an extremely clean probe of "BνSM" physics

$$\mathcal{L}_{\nu \mathrm{SM}} = \mathcal{L}_{\mathrm{SM}} + \mathcal{L}_{\nu-\mathrm{mass}}$$

← dim-4 Dirac or dim5 Majorana

The underlying picture

At some scale between Planck and weak scale,
there exist new LF and possibly LN violating interactions,
involving new particles



Each scenario generates a specific pattern of operators,
controlling ν mass (dim5), LFV processes (dim6), LNV processes (dim7,9)

We can probe the underlying physics through a combination of low-energy and collider searches

CLFV probes

- Low energy: decays of μ, τ, and mesons

$$\mu \to e\gamma, \quad \mu \to e\bar{e}e, \quad \mu\,(A,Z) \to e\,(A,Z)$$

$$\tau \to \ell\gamma, \quad \tau \to \ell_\alpha \bar{\ell}_\beta \ell_\beta, \; \tau \to \ell\, Y \qquad Y = P, S, V, P\bar{P}, \ldots$$

$K \to \pi\mu e$; $B \to K\mu\tau, K\mu e$; $B_s \to \mu\tau, \mu e$, quarkonia , … (not discussed in this talk)

- High Energy:

LHC

$$pp \;\to\; R \to \;\ell_\alpha \bar{\ell}_\beta + X \qquad R = Z', h, \tilde{\nu}, \ldots.$$

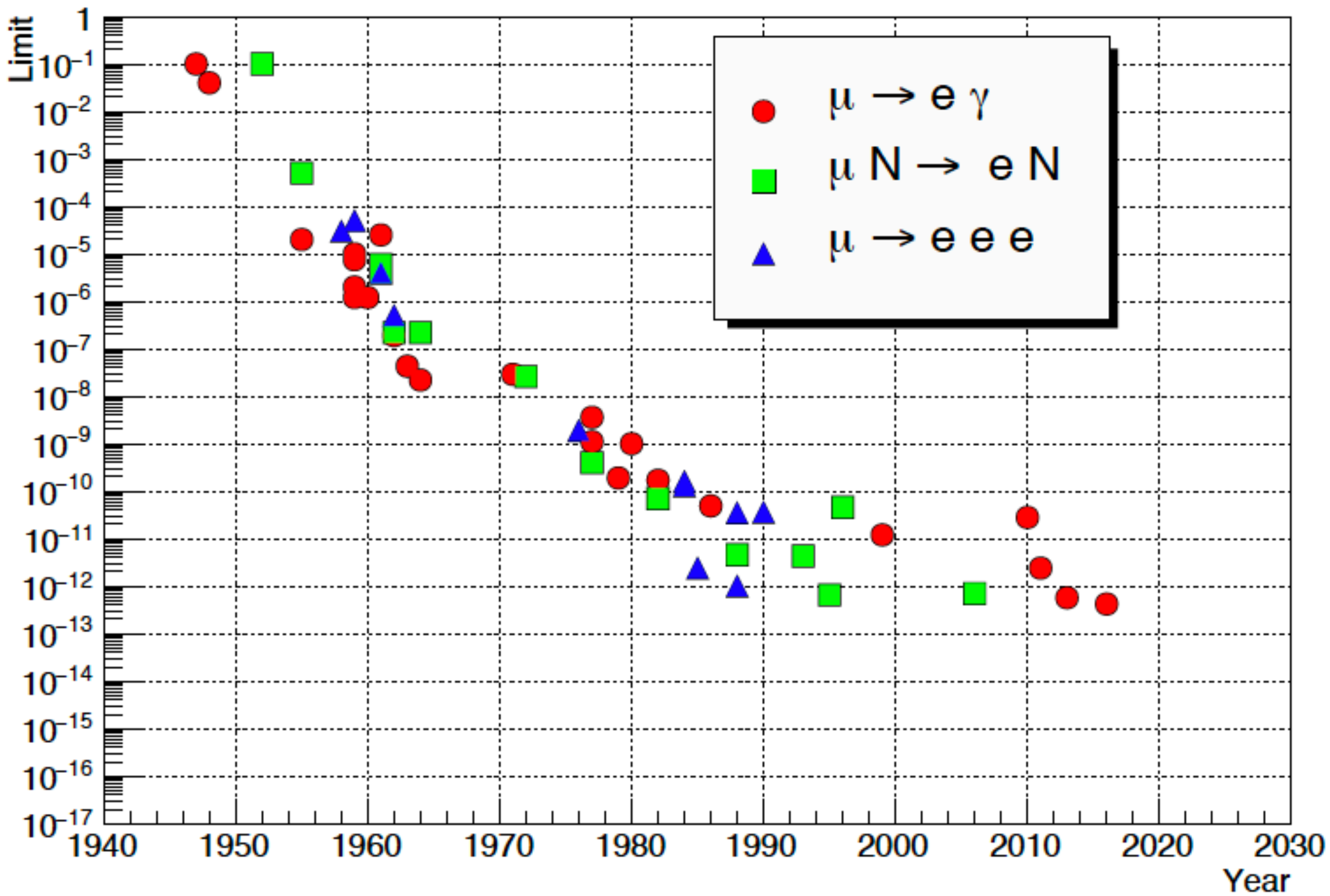
$$pp \;\to\; \ell_\alpha \bar{\ell}_\beta + X$$

HERA, EIC

$$e\,p \;\to\; \ell + X$$

Muon processes

$$\mu \to e\gamma, \quad \mu \to e\bar{e}e, \quad \mu\,(A,Z) \to e\,(A,Z)$$



Calibbi-Signorelli 1709.00294

90% CL

$$B_{\mu\to e\gamma} < 4.2\times10^{-13} \longrightarrow 10^{-/14} \text{ (MEG at PSI)}$$

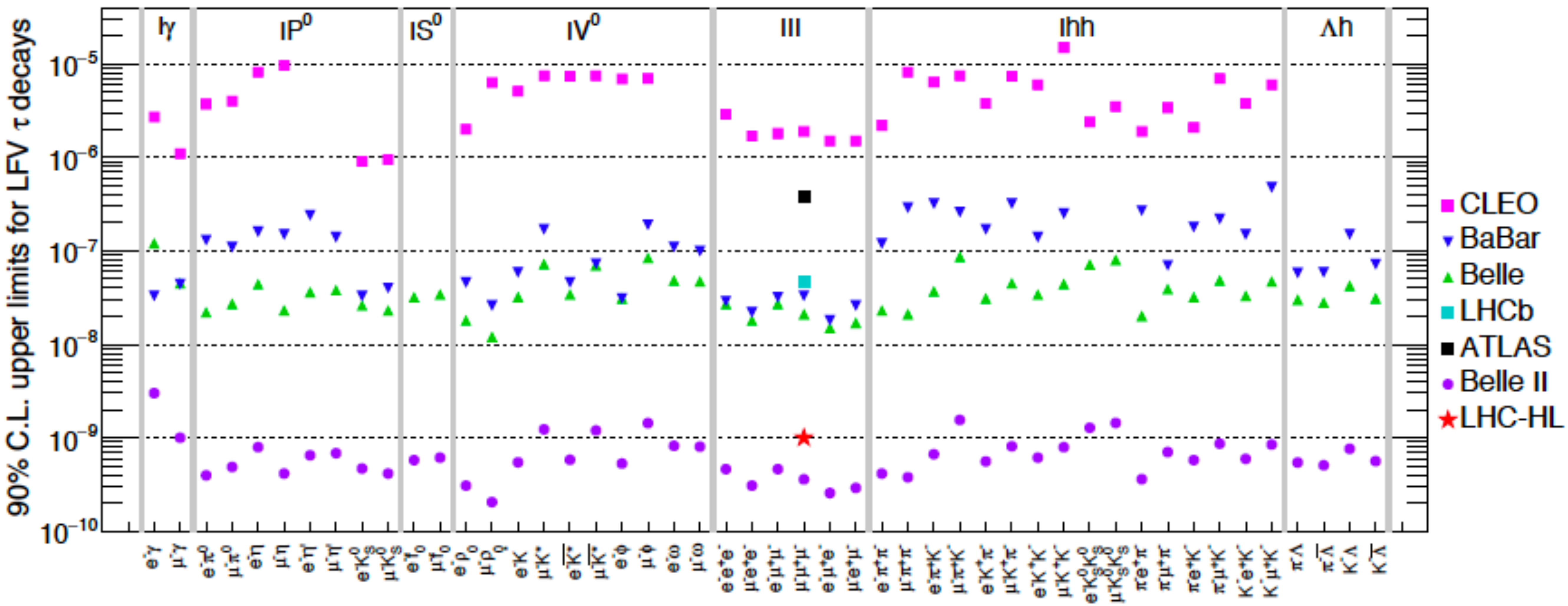
$$B_{\mu\to 3e} < 1.0\times10^{-12} \longrightarrow 10^{-15/16} \text{ (PSI)}$$

$$B^{Ti}_{\mu-e} < 4.3\times10^{-12} \longrightarrow 10^{-16/17\,\to\,-18} \text{ (Mu2e, COMET)}$$

Tau decays

$$\tau \to \ell\gamma, \quad \tau \to \ell_\alpha \bar{\ell}_\beta \ell_\beta, \; \tau \to \ell Y \quad Y = P, S, V, P\bar{P}, \ldots$$

HFLAG-tau → Belle-II Physics Book 1808.10567 ; Flavor @ HL/HE LHC 1912.07638



Rich(er) landscape! Access to hadronic modes.

10^{-9} (or better) sensitivities at Belle-II, LHC-HL, and other future facilities

Discovering & diagnosing

- Redundancy of searches is very important as various probes serve as:
- Discovery tools (observation ⇒ BSM physics)
- Diagnosing tools (correlations ⇒ reconstruct the underlying dynamics)
    - What type of "mediator"? (structure of model)

      $\mu \to 3e$ vs $\mu \to e\gamma$ vs $\mu \to e$ conversion

      $\tau \to 3l$ vs $\tau \to l\gamma$ vs $\tau \to (e,\mu)$ + had. vs $h \to \tau(e,\mu)$
    - What sources of flavor breaking?

      $\mu \to e$ vs $\tau \to \mu$ vs $\tau \to e$

Discovering & diagnosing

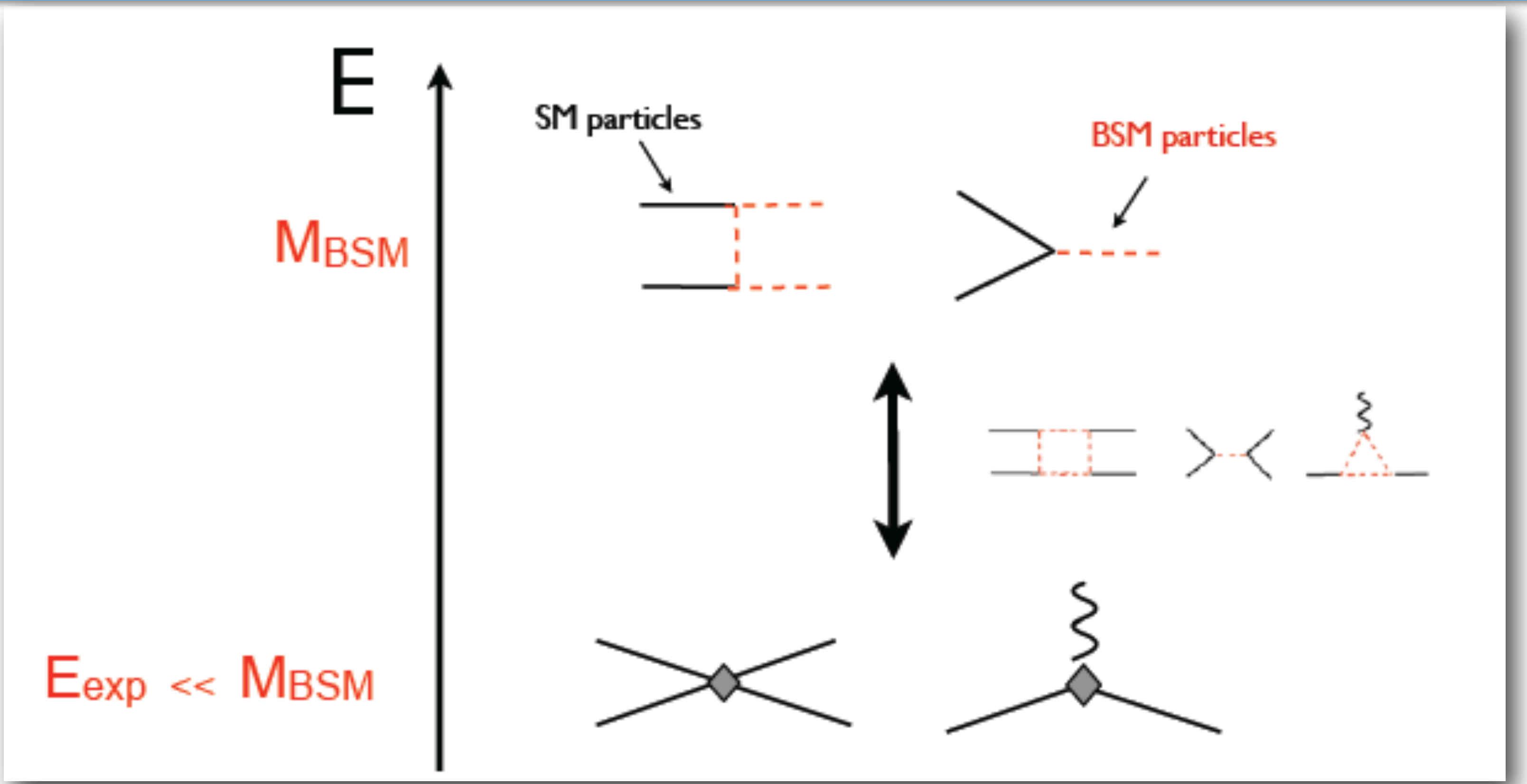
- Redundancy of searches is very important as various probes serve as:
- Discovery tools (observation ⇒ BSM physics)
- Diagnosing tools (correlations ⇒ reconstruct the underlying dynamics)
- Two (not mutually exclusive) approaches:
  1. Concrete models: predict BRs and correlations
  2. EFT: characterize signatures of classes of models (less detailed)

I will discuss τ decays mostly within approach 2.

Vast literature → omissions unavoidable, but not intentional

LFV tau decays in EFT

Low E phenomenology: EFT



- At low energy, LFV dynamics described by local operators

$$\mathcal{L} = \mathcal{L}_{SM} + \frac{C^{(5)}}{\Lambda} O^{(5)} + \sum_i \frac{C_i^{(6)}}{\Lambda^2} O_i^{(6)} + \dots$$

Weinberg '79
...
Buchmuller-Wyler '86
...
Grzadkowski et al
1008.4884
...

$\Lambda \leftrightarrow M_{\rm BSM}$ $\quad C_i \, [g_{\rm BSM}, \; M_a/M_b]$

- Each UV model generates a specific pattern of LFV operators

Rich structure at dimension six

- Effective Lagrangian at the tau scale, induced by dim-6 at high scale

Black-Han-He-Sher
hep-ph/0206056

Dassinger et al,
0707.0988
Matsuzuki-Sanda
0711.0792

Celis-VC-Passemar
1403.5781
...

$$\mathcal{L}_{eff} = \mathcal{L}_{eff}^{(D)} + \mathcal{L}_{eff}^{(4\ell)} + \mathcal{L}_{eff}^{(\ell q)} + \mathcal{L}_{eff}^{(G)}$$

$$\mathcal{L}_{eff}^{(D)} = -\frac{m_\tau}{\Lambda^2} \left\{ (\mathrm{C_{DR}}\, \bar{\mu}\, \sigma^{\rho\nu}\, P_L\, \tau + \mathrm{C_{DL}}\, \bar{\mu}\, \sigma^{\rho\nu}\, P_R\, \tau)\, F_{\rho\nu} + \mathrm{h.c.} \right\}$$

$$\begin{aligned}\mathcal{L}_{eff}^{(4\ell)} = -\frac{1}{\Lambda^2} \Big\{ & \mathrm{C_{SLL}}\, (\bar{\mu}\, P_L\, \tau)\, (\bar{\mu}\, P_L\, \mu) + \mathrm{C_{SRR}}\, (\bar{\mu}\, P_R\, \tau)\, (\bar{\mu}\, P_R\, \mu) \\ & + \mathrm{C_{VLL}}\, (\bar{\mu}\gamma^\mu\, P_L\, \tau)\, (\bar{\mu}\, \gamma_\mu\, P_L\, \mu) + \mathrm{C_{VRR}}\, (\bar{\mu}\, \gamma^\mu\, P_R\, \tau)\, (\bar{\mu}\, \gamma_\mu\, P_R\, \mu) \\ & + \mathrm{C_{VLR}}\, (\bar{\mu}\, \gamma^\mu\, P_L\, \tau)\, (\bar{\mu}\, \gamma_\mu\, P_R\, \mu) + \mathrm{C_{VRL}}\, (\bar{\mu}\, \gamma^\mu P_R\, \tau)\, (\bar{\mu}\, \gamma_\mu\, P_L\, \mu) + \mathrm{h.c.} \Big\}\end{aligned}$$

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$$\mathcal{L}_{eff} = \mathcal{L}_{eff}^{(D)} + \mathcal{L}_{eff}^{(4\ell)} + \mathcal{L}_{eff}^{(\ell q)} + \mathcal{L}_{eff}^{(G)}$$

$$\begin{aligned}\mathcal{L}_{eff}^{(\ell q)} = -\frac{1}{\Lambda^2} \sum_{q=u,d,s} \Big\{ & (\mathrm{C}^{\mathrm{q}}_{\mathrm{VR}}\, \bar{\mu}\, \gamma^\rho P_R \tau + \mathrm{C}^{\mathrm{q}}_{\mathrm{VL}}\, \bar{\mu}\, \gamma^\rho P_L \tau)\, \bar{q}\, \gamma_\rho\, q \\ & + (\mathrm{C}^{\mathrm{q}}_{\mathrm{AR}}\, \bar{\mu}\, \gamma^\rho P_R \tau + \mathrm{C}^{\mathrm{q}}_{\mathrm{AL}}\, \bar{\mu}\, \gamma^\rho P_L \tau)\, \bar{q}\, \gamma_\rho \gamma_5\, q \\ & + m_\tau m_q G_F\, (\mathrm{C}^{\mathrm{q}}_{\mathrm{SR}}\, \bar{\mu}\, P_L \tau + \mathrm{C}^{\mathrm{q}}_{\mathrm{SL}} \bar{\mu}\, P_R \tau)\, \bar{q}\, q \\ & + m_\tau m_q G_F\, (\mathrm{C}^{\mathrm{q}}_{\mathrm{PR}}\, \bar{\mu}\, P_L \tau + \mathrm{C}^{\mathrm{q}}_{\mathrm{PL}}\, \bar{\mu}\, P_R \tau)\, \bar{q}\, \gamma_5\, q \\ & + m_\tau m_q G_F\, (\mathrm{C}^{\mathrm{q}}_{\mathrm{TR}}\, \bar{\mu}\, \sigma^{\rho\nu} P_L \tau + \mathrm{C}^{\mathrm{q}}_{\mathrm{TL}}\, \bar{\mu}\, \sigma^{\rho\nu} P_R \tau)\, \bar{q}\, \sigma_{\rho\nu}\, q + \mathrm{h.c.} \Big\}\end{aligned}$$

$$\begin{aligned}\mathcal{L}_{eff}^{(G)} = -\frac{m_\tau G_F}{\Lambda^2} \frac{\beta_L}{4\alpha_s} \Big\{ & (\mathrm{C}_{\mathrm{GR}}\, \bar{\mu}\, P_L \tau + \mathrm{C}_{\mathrm{GL}}\, \bar{\mu}\, P_R \tau)\, G^a_{\rho\nu} G^{\rho\nu}_a \\ & + (\mathrm{C}_{\tilde{\mathrm{G}}\mathrm{R}}\, \bar{\mu}\, P_L \tau + \mathrm{C}_{\tilde{\mathrm{G}}\mathrm{L}}\, \bar{\mu}\, P_R \tau)\, G^a_{\mu\nu} \widetilde{G}^{\mu\nu}_a + \mathrm{h.c.} \Big\},\end{aligned}$$

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& + (\mathrm{C}^{\mathrm{q}}_{\mathrm{AR}}\, \bar{\mu}\, \gamma^{\rho} P_R \tau + \mathrm{C}^{\mathrm{q}}_{\mathrm{AL}}\, \bar{\mu}\, \gamma^{\rho} P_L \tau)\, \bar{q}\, \gamma_{\rho} \gamma_5\, q \\
& + m_\tau m_q G_F\, (\mathrm{C}^{\mathrm{q}}_{\mathrm{SR}}\, \bar{\mu}\, P_L \tau + \mathrm{C}^{\mathrm{q}}_{\mathrm{SL}} \bar{\mu}\, P_R \tau)\, \bar{q}\, q \\
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& + m_\tau m_q G_F\, (\mathrm{C}^{\mathrm{q}}_{\mathrm{TR}}\, \bar{\mu}\, \sigma^{\rho\nu} P_L \tau + \mathrm{C}^{\mathrm{q}}_{\mathrm{TL}}\, \bar{\mu}\, \sigma^{\rho\nu} P_R \tau)\, \bar{q}\, \sigma_{\rho\nu}\, q + \mathrm{h.c.} \Big\}
\end{aligned}$$

Connection with high scale EFT (SMEFT) known

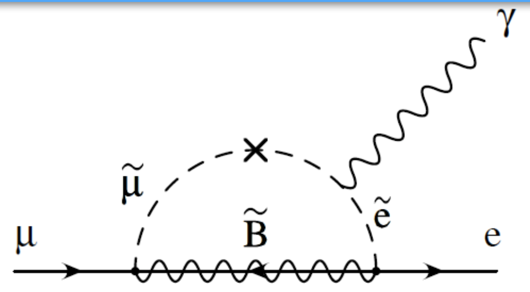
... Crivellin-Davidson-Pruna-Signer 1702.03020 .... Dekens-Stoffer 1908.05295

UV origin of various operators

- Dipole

$$\frac{v_{\rm ew}\,[\alpha_D]^{ij}}{\Lambda^2}\;\bar{e}^i\,\sigma_{\mu\nu}P_{L,R}\,e^j\;F^{\mu\nu}$$

Dominant in SUSY-GUT and
SUSY see-saw scenarios



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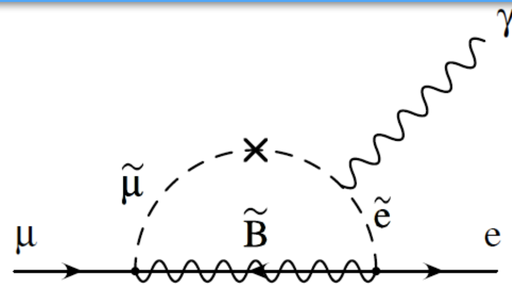
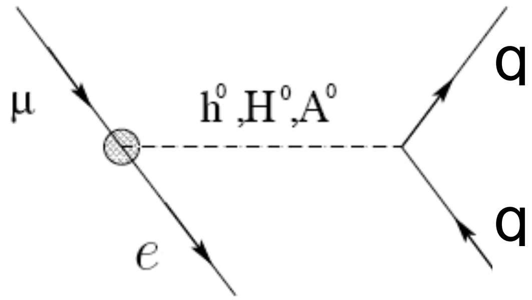


- Scalar (Pseudo-scalar)

$$\frac{[\alpha_S]^{ij}}{\Lambda^2}\;\bar{e}^i\,P_{L,R}\,e^j\;\bar{q}q$$

Relevant in RPV SUSY and RPC SUSY for large tan(β) and low m_A, leptoquarks



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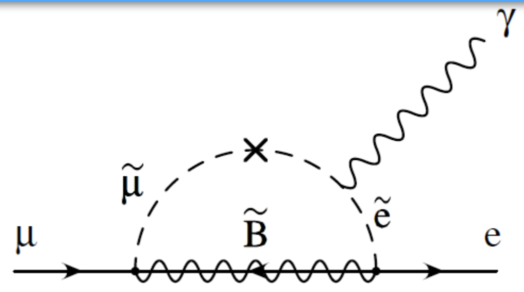

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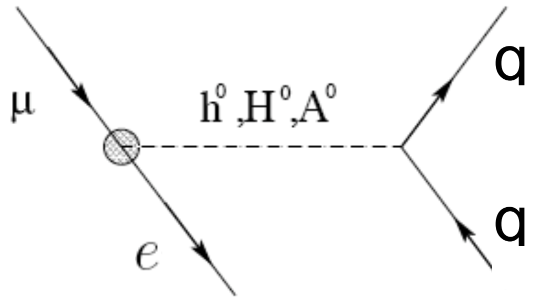
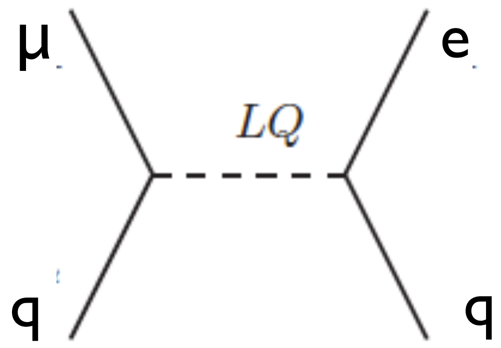


- Vector (Axial-vector)

$$\frac{[\alpha_V]^{ij}}{\Lambda^2}\ \bar{e}^i \gamma_\mu P_{L,R}\, e^j\ \bar{q}\gamma^\mu q$$

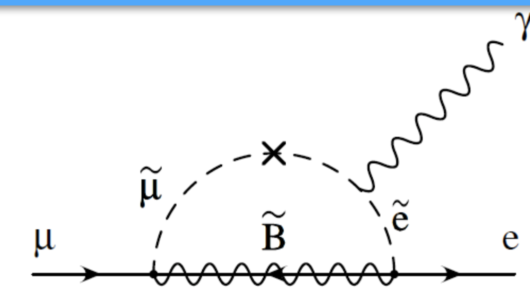
Enhanced in Type III seesaw (Z), Type II seesaw, LRSM, leptoquarks



UV origin of various operators

- Dipole

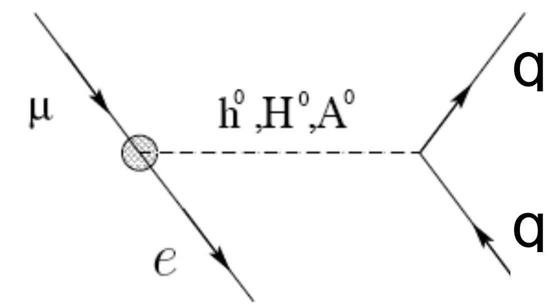
$$\frac{v_{\rm ew}\,[\alpha_D]^{ij}}{\Lambda^2}\;\bar{e}^i\,\sigma_{\mu\nu}P_{L,R}\,e^j\;F^{\mu\nu}$$



Dominant in SUSY-GUT and SUSY see-saw scenarios

- Scalar (Pseudo-scalar)

$$\frac{[\alpha_S]^{ij}}{\Lambda^2}\;\bar{e}^i\,P_{L,R}\,e^j\;\bar{q}q$$



Relevant in RPV SUSY and RPC SUSY for large tan(β) and low m_A, leptoquarks

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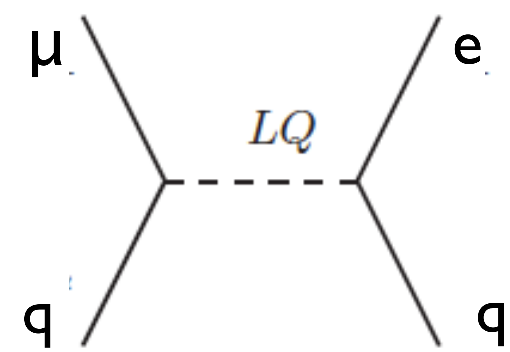
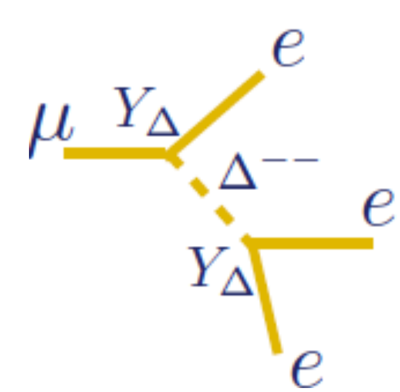


Enhanced in Type III seesaw (Z), Type II seesaw, LRSM, leptoquarks

- 4 Leptons, ...

$\Gamma = 1, \gamma_\mu$

$$\frac{[\alpha_\Gamma^{4L}]^{ij}}{\Lambda^2}\;\bar{e}^i\,\Gamma P_{L,R}\,e^j\;\bar{e}^k\,\Gamma P_{L,R}\,e^k$$



Type II seesaw, RPV SUSY, LRSM

What can we extract from data?

- What effective scale Λ are experiments probing?

- If LFV decays observed, what is the relative strength of various operators (α_D vs α_S ...)? → Mediators, mechanism

- If LFV decays observed, what is the flavor structure of the couplings ($[\alpha_D]^{e\mu}$ vs $[\alpha_D]^{\tau\mu}$...)? → Sources of flavor breaking

↖

(Only briefly discussed in this talk)

Reach in Λ

- LFV BRs scale as

$$BR_{\alpha\to\beta} \sim (v_{EW}/\Lambda)^4 * (\alpha_n)_{\alpha\beta}{}^2$$

- Current limits on $\mu \to e\gamma$ and $\tau\to\mu\gamma$ imply

$$\Lambda/\sqrt{[\alpha_D]^{\mu e}} > 3.4 \times 10^4 \text{ TeV}$$

$$\Lambda/\sqrt{[\alpha_D]^{\tau\mu}} > 5.7 \times 10^2 \text{ TeV}$$

↓

LFV signals in lepton decays are within reach of planned searches, if new physics near TeV scale and reasonable mixing parameters.

Ask what can we learn about the underlying dynamics

Diagnosing power: the τLFV matrix

	$\tau \to 3\mu$	$\tau \to \mu\gamma$	$\tau \to \mu\pi^+\pi^-$	$\tau \to \mu K\bar{K}$	$\tau \to \mu\pi$	$\tau \to \mu\eta^{(\prime)}$
$\mathrm{O}_{\mathrm{S,V}}^{4\ell}$	✓	–	–	–	–	–
O_{D}	✓	✓	✓	✓	–	–
$\mathrm{O}_{\mathrm{V}}^{\mathrm{q}}$	–	–	✓	✓	–	–
$\mathrm{O}_{\mathrm{S}}^{\mathrm{q}}$	–	–	✓	✓	–	–
O_{GG}	–	–	✓	✓	–	–
$\mathrm{O}_{\mathrm{A}}^{\mathrm{q}}$	–	–	–	–	✓	✓
$\mathrm{O}_{\mathrm{P}}^{\mathrm{q}}$	–	–	–	–	✓	✓
$\mathrm{O}_{\mathrm{G\tilde{G}}}$	–	–	–	–	–	✓

•••

•••

Tree-level contributions to τ→μ processes from low-scale operators

Celis-VC-Passemar 1403.5781

↑

Low-scale operators

Diagnosing power: the τLFV matrix

	$\tau \to 3\mu$	$\tau \to \mu\gamma$	$\tau \to \mu\pi^+\pi^-$	$\tau \to \mu K\bar{K}$	$\tau \to \mu\pi$	$\tau \to \mu\eta^{(\prime)}$	...
$O_{S,V}^{4\ell}$	✓	–	–	–	–	–	
O_D	✓	✓	✓	✓	–	–	
O_V^q	–	–	✓	✓	–	–	
O_S^q	–	–	✓	✓	–	–	
O_{GG}	–	–	✓	✓	–	–	
O_A^q	–	–	–	–	✓	✓	
O_P^q	–	–	–	–	✓	✓	
$O_{G\tilde{G}}$	–	–	–	–	–	✓	
...							

Tree-level contributions to τ→μ processes from low-scale operators

Celis-VC-Passemar 1403.5781

- While there may be experimental 'golden modes' (τ→μγ, τ→3μ, ?), the notion of `best probe' (= process with largest rate) is model dependent

Diagnosing power: the τLFV matrix

	$\tau \to 3\mu$	$\tau \to \mu\gamma$	$\tau \to \mu\pi^+\pi^-$	$\tau \to \mu K\bar{K}$	$\tau \to \mu\pi$	$\tau \to \mu\eta^{(\prime)}$
$O_{S,V}^{4\ell}$	✓	–	–	–	–	–
O_D	✓	✓	✓	✓	–	–
O_V^q	–	–	✓	✓	–	–
O_S^q	–	–	✓	✓	–	–
O_{GG}	–	–	✓	✓	–	–
O_A^q	–	–	–	–	✓	✓
O_P^q	–	–	–	–	✓	✓
$O_{G\tilde{G}}$	–	–	–	–	–	✓

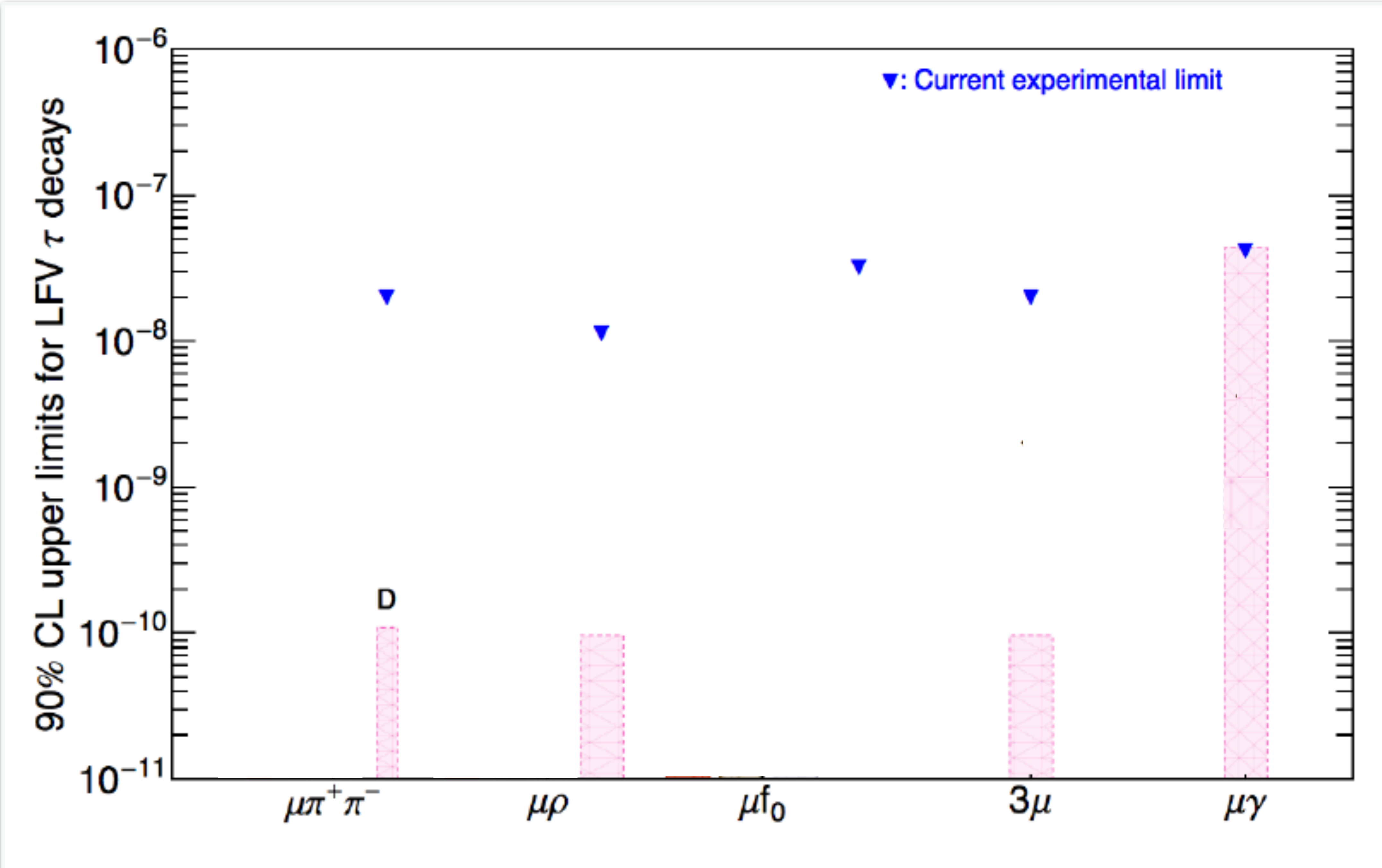
Tree-level contributions to τ→μ processes from low-scale operators

- There is life beyond leptonic and radiative decays!
- Hadronic decays sensitive to large number of operators, but need reliable form factors and decay constants
- Progress in τ →μ(e)ππ using dispersive techniques

Daub et al 1212.4408
Celis-VC-Passemar 1309.3564

Celis-VC-Passemar 1403.5781

- Two basic handles: 1) Pattern of BRs



Dipole only (D)

Celis-VC-Passemar 1403.5781

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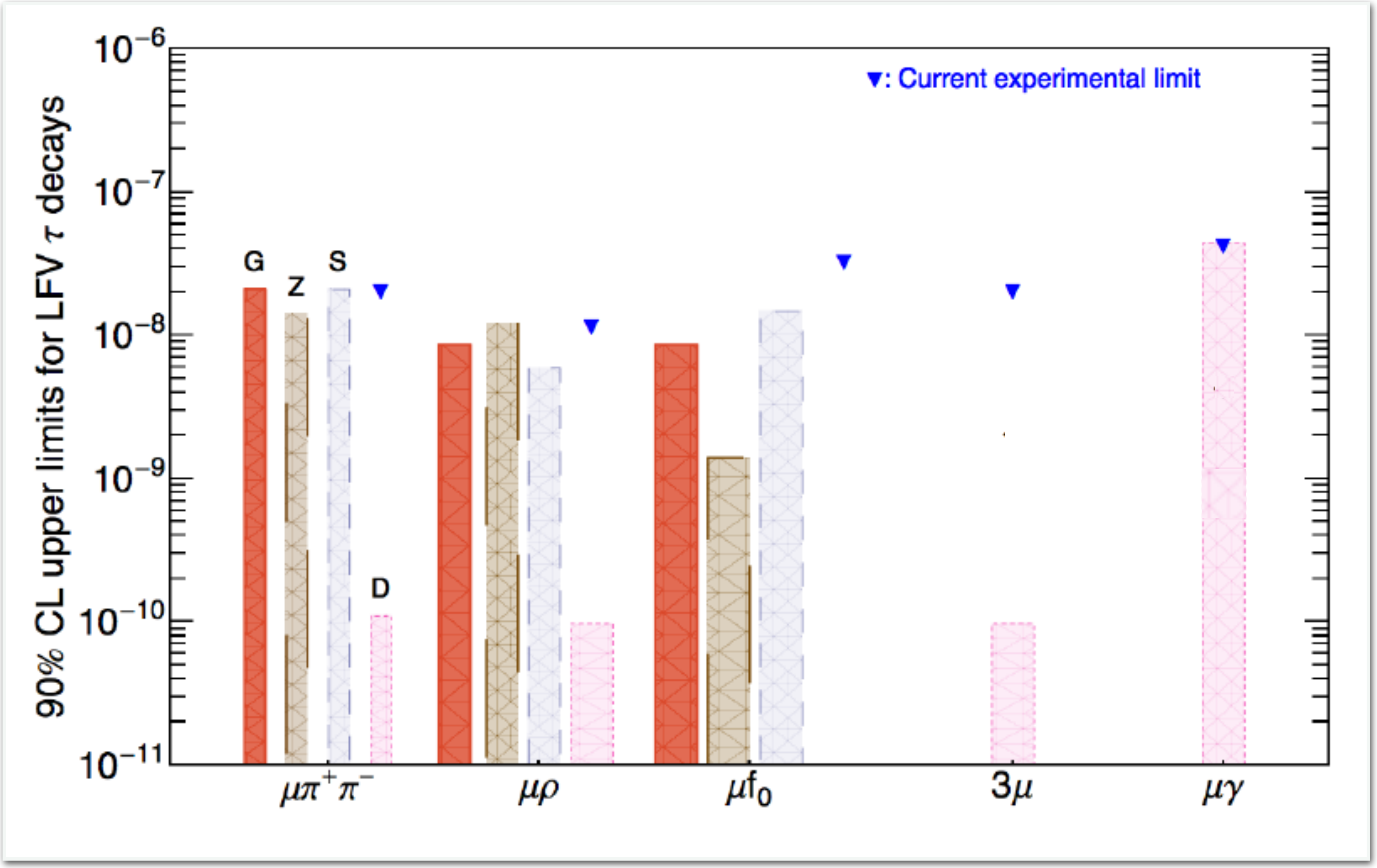
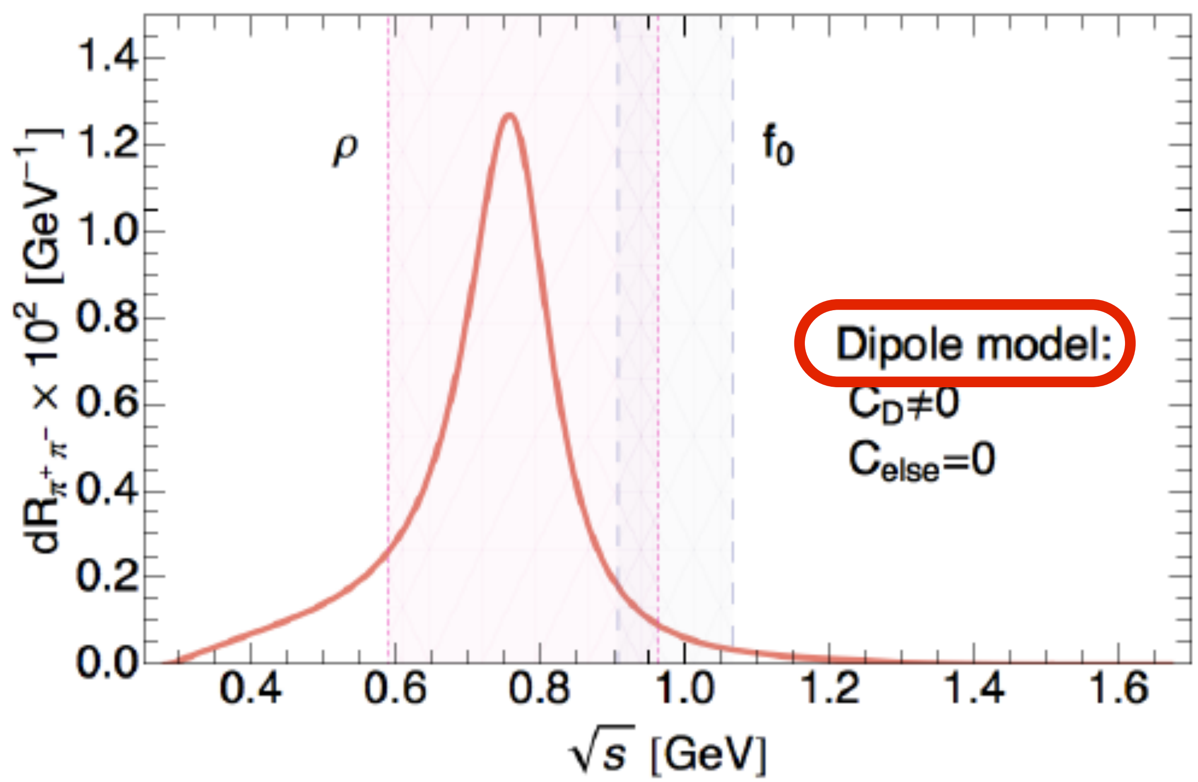


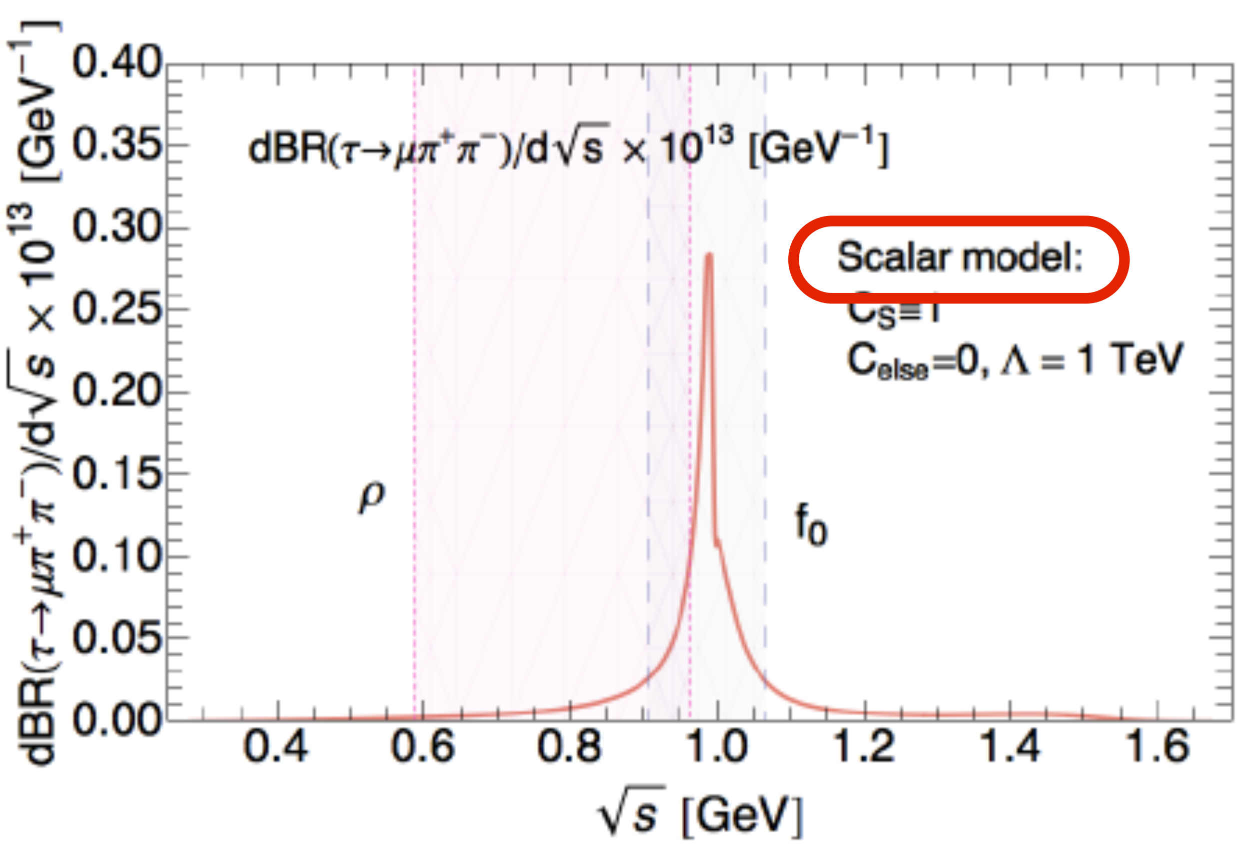
Gluon, Vector, Scalar (G,Z, S)

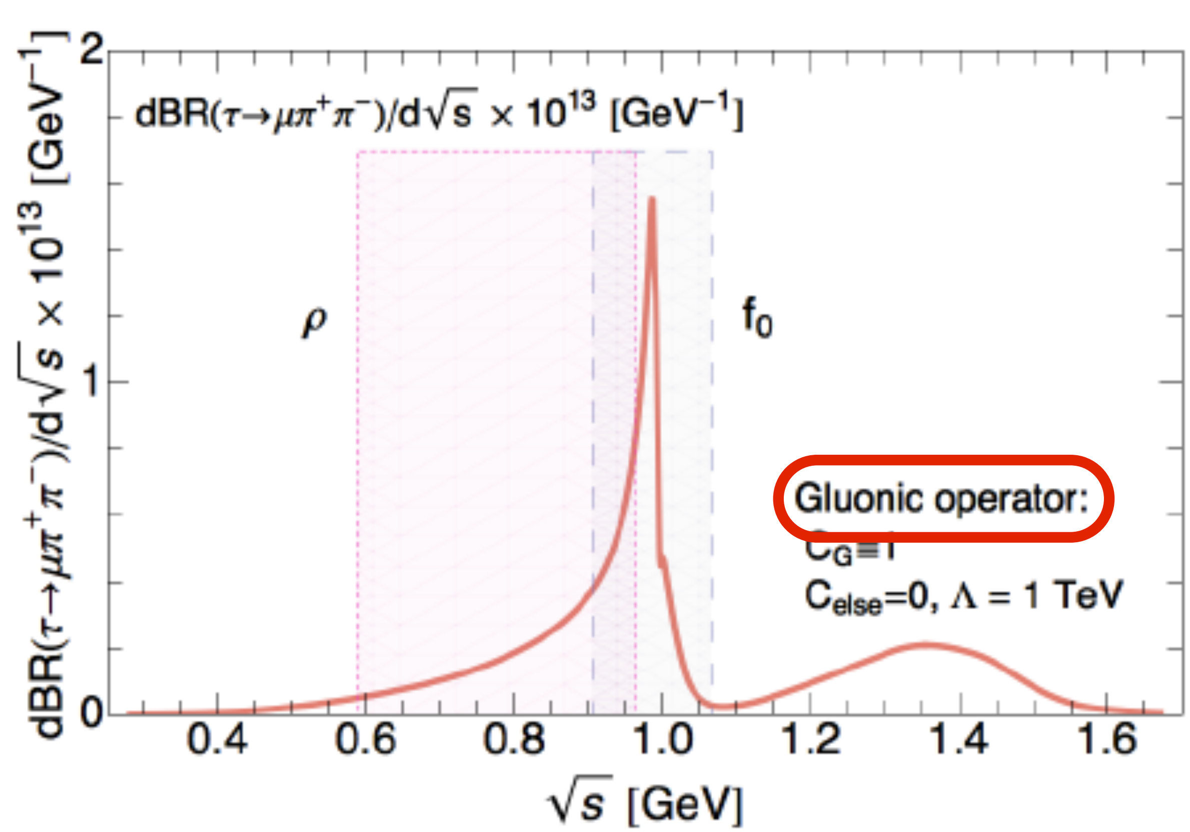
- Two basic handles: 2) differential distributions



Spectra in $\tau \to \mu(e)\pi\pi$

Spin and isospin of the hadronic operator determine the spectrum

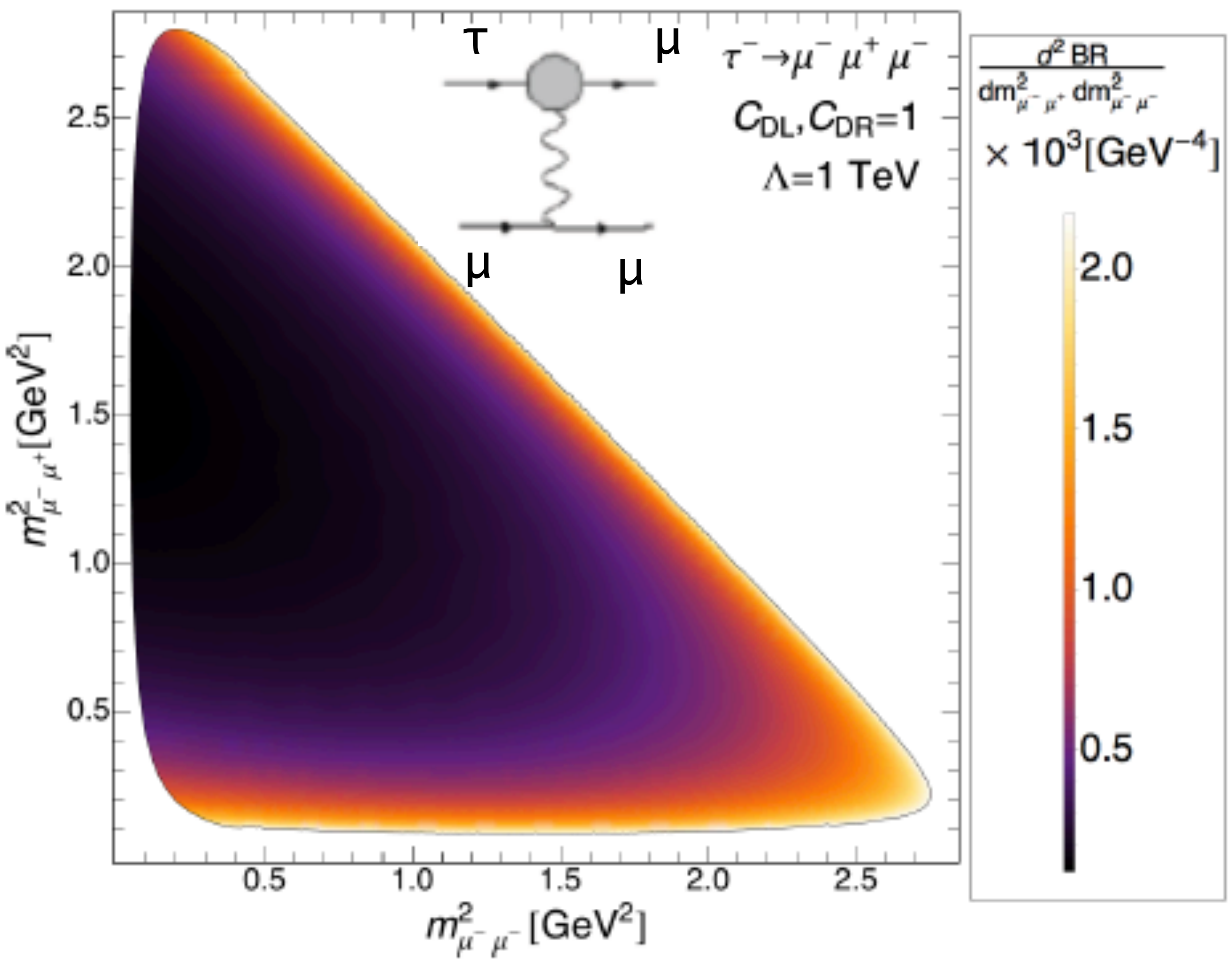




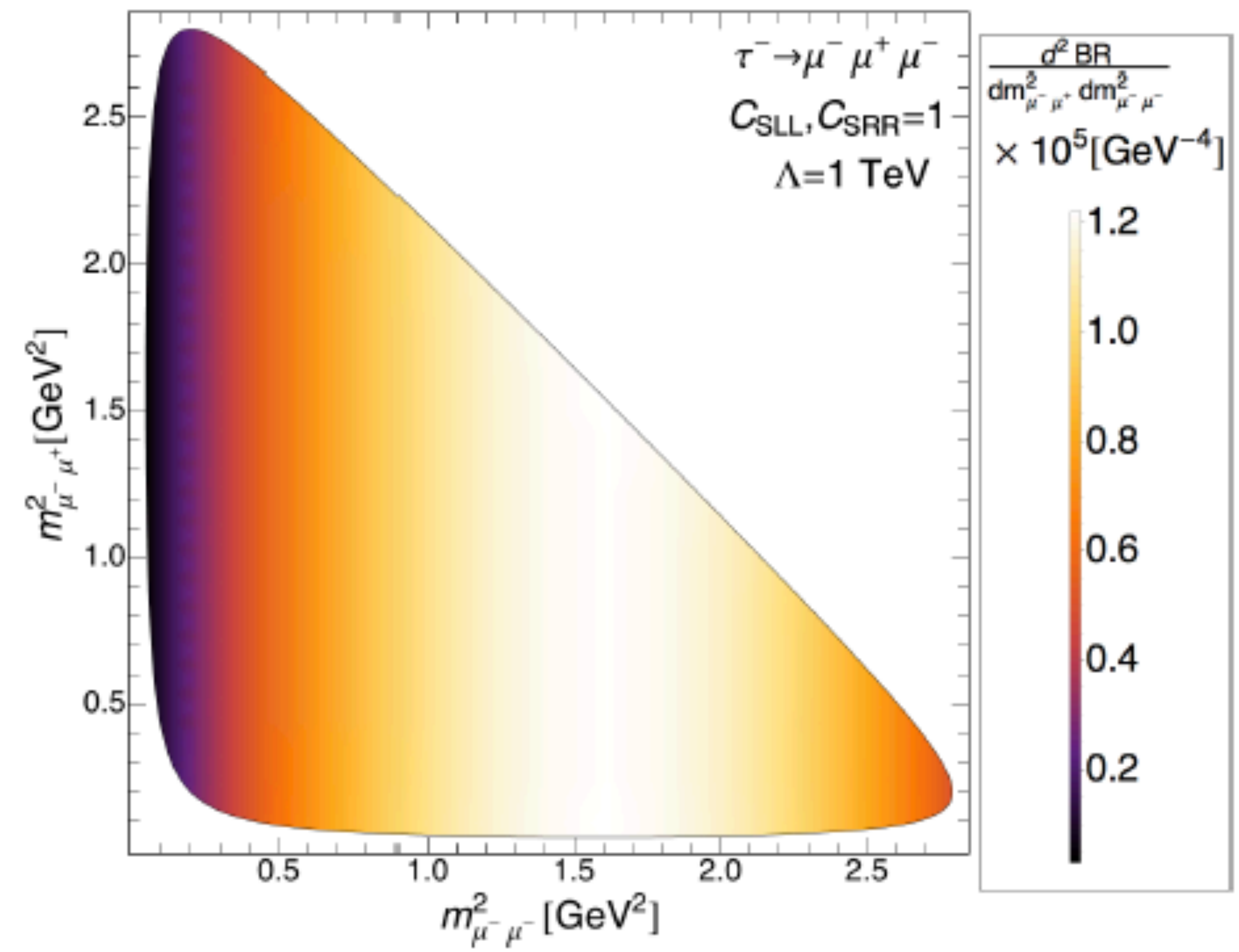
- Two basic handles: 2) differential distributions

Dalitz plot in τ →3 leptons

Dassinger et al, 0707.0988
Matsuzuki-Sanda 0711.0792
Celis-VC-Passemar 1403.5781



Dipole operator dominance

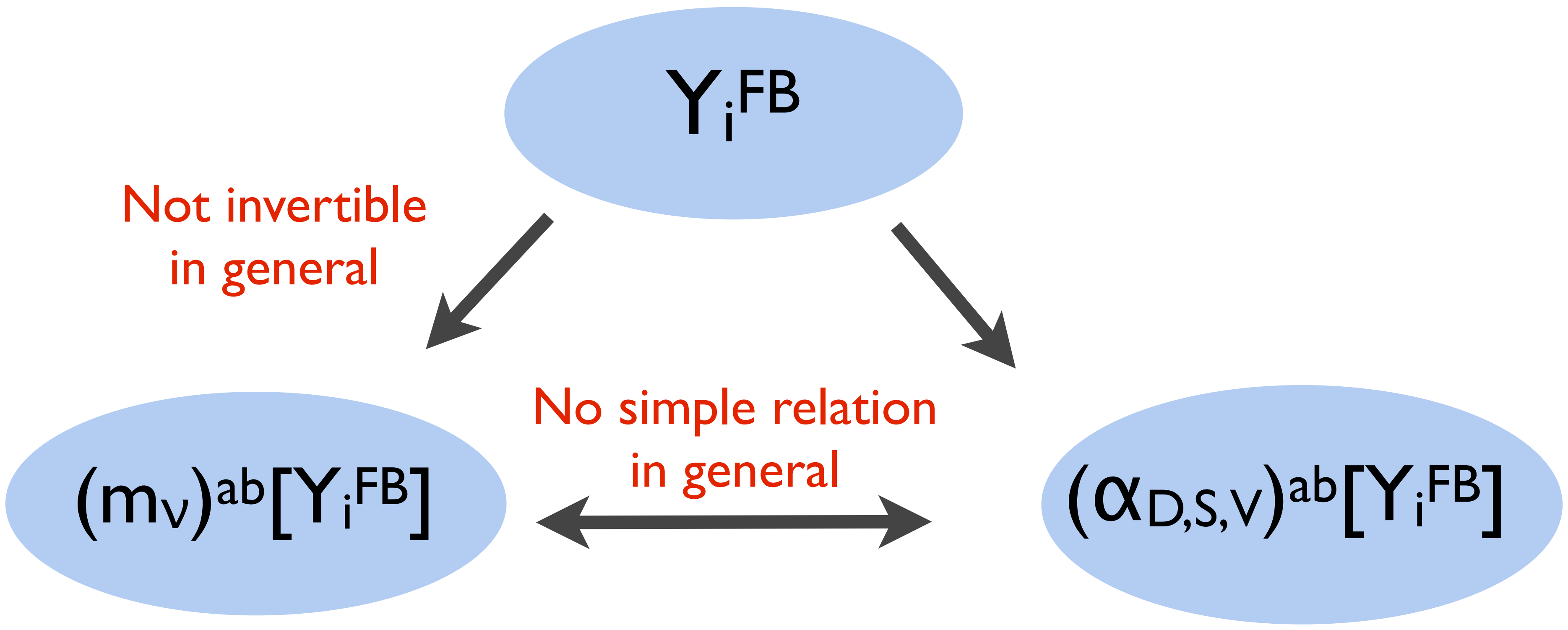


Scalar 4-lepton operator dominance

Diagnosing power: flavor structure

- Each model has its sources of flavor breaking Y_i^{FB} (Yukawa-type, mass matrices of heavy states, ...)

- Y_i^{FB} leave imprint in m_ν and CLFV effective couplings $\alpha_{D,V,S,...}$



Diagnosing power: flavor structure

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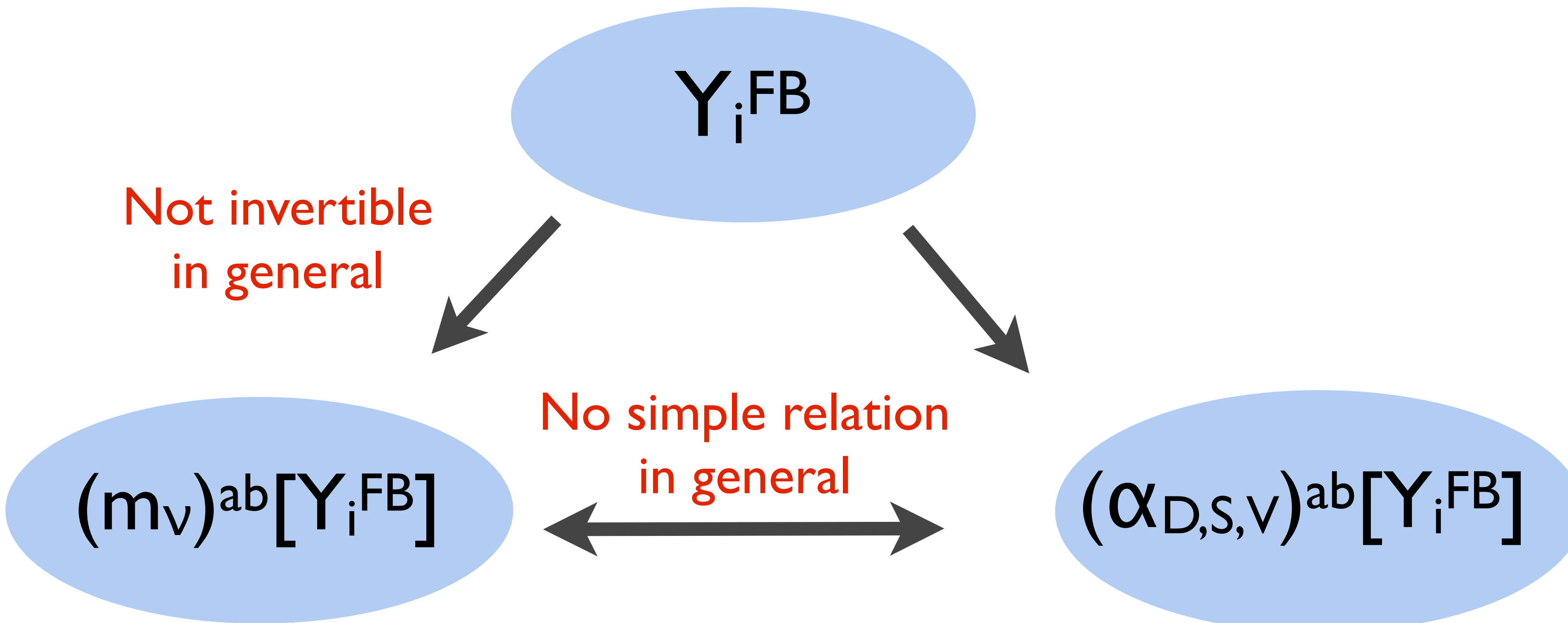

Aside: Minimal Lepton Flavor Violation tries to remedy this issue. No unique realization

VC-Grinstein-Isidori-Wise '05
Davidson-Palorini '06
Gavela-Hambye-Hernandez-Hernandez '09
Alonso-Isidore-Merlo-Munoz-Nardi '11
..

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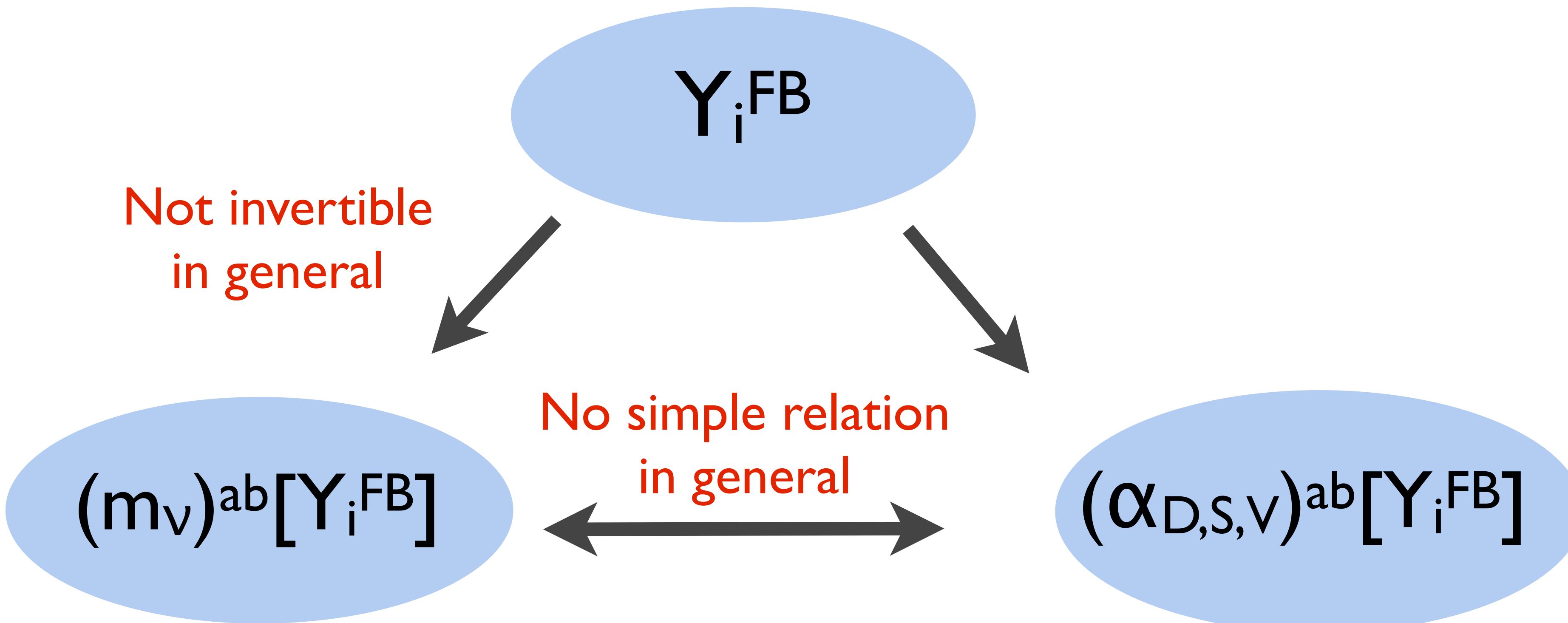

- CLFV processes probe the structure of Y_i^{FB}

  Cleanest test-ground: $\mu \to e\gamma$ vs $\tau \to \mu\gamma$ vs $\tau \to e\gamma$

Diagnosing power: flavor structure

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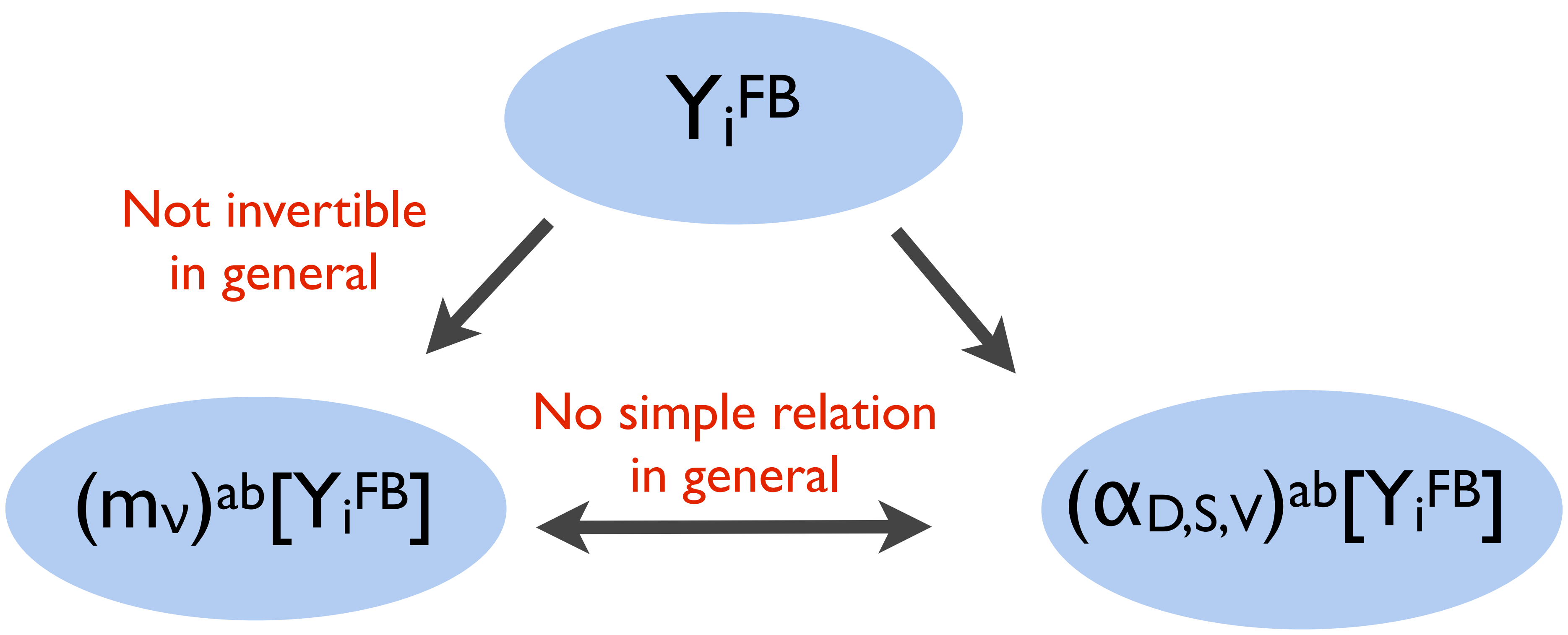


- MLFV: $BR(\mu \to e\gamma) / BR(\tau \to \mu\gamma) \sim 10^{-2}$
- GUT models: $BR(\mu \to e\gamma) / BR(\tau \to \mu\gamma) \sim |V_{us}|^6 \sim 10^{-4}$

Barbieri-Hall-Strumia '95, VC-Grinstein-Isidori-Wise '06

Probing LFV Higgs couplings

- Simplest framework: LFV Yukawa couplings of the Higgs

$$\Delta\mathcal{L}_Y = -\frac{\lambda_{ij}}{\Lambda^2}\,(\bar{L}_L^i e_R^j H)\, H^\dagger H \quad \to \quad -Y_{ij}\; \bar{e}_L^i e_R^j\, h$$

Goudelis-Lebedev-Park '11
Davidson-Grenier '10
...
Harnik-Kopp-Zupan '12
Blankenburg-Ellis-Isidori 12
McKeen-Pospelov-Ritz '12
...

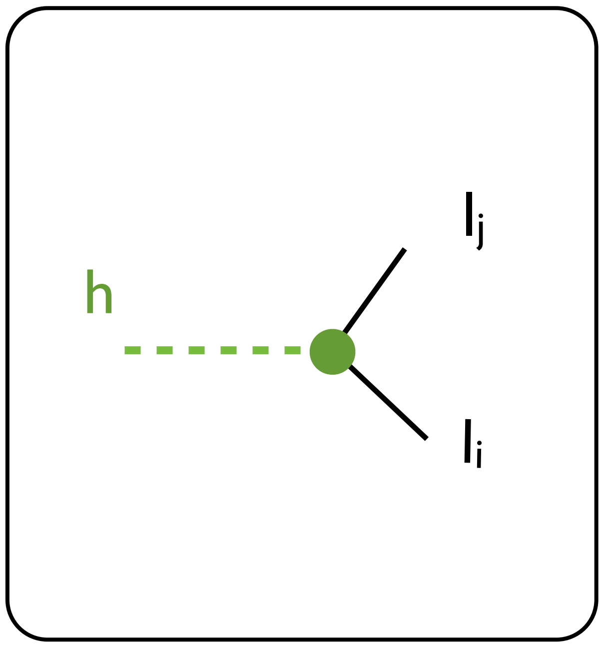
- Achieved in the SM-EFT through a single dim-6 operator that decouples lepton mass matrix from O(h) couplings

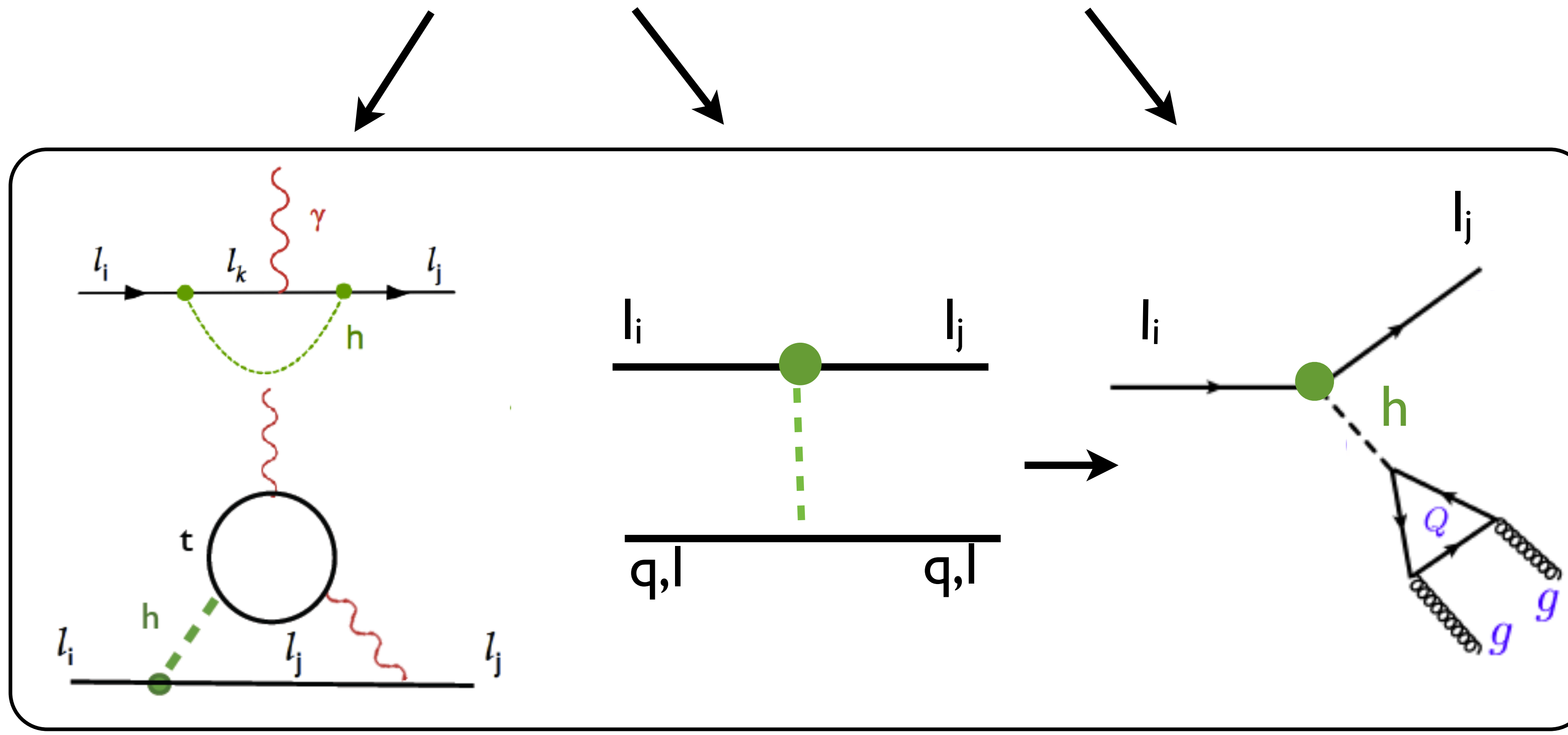
- Good starting point if new physics is heavy

Signatures at high and low energy

Dipole (D), Scalar 4-fermion (S), Gluon (G) operators

Higgs decay





τ→μγ

τ→3μ

τ→μππ

τ→μππ

τ→3μ

Dependence on light fermion Yukawa couplings $Y_{u.d,s,\,\mu}$

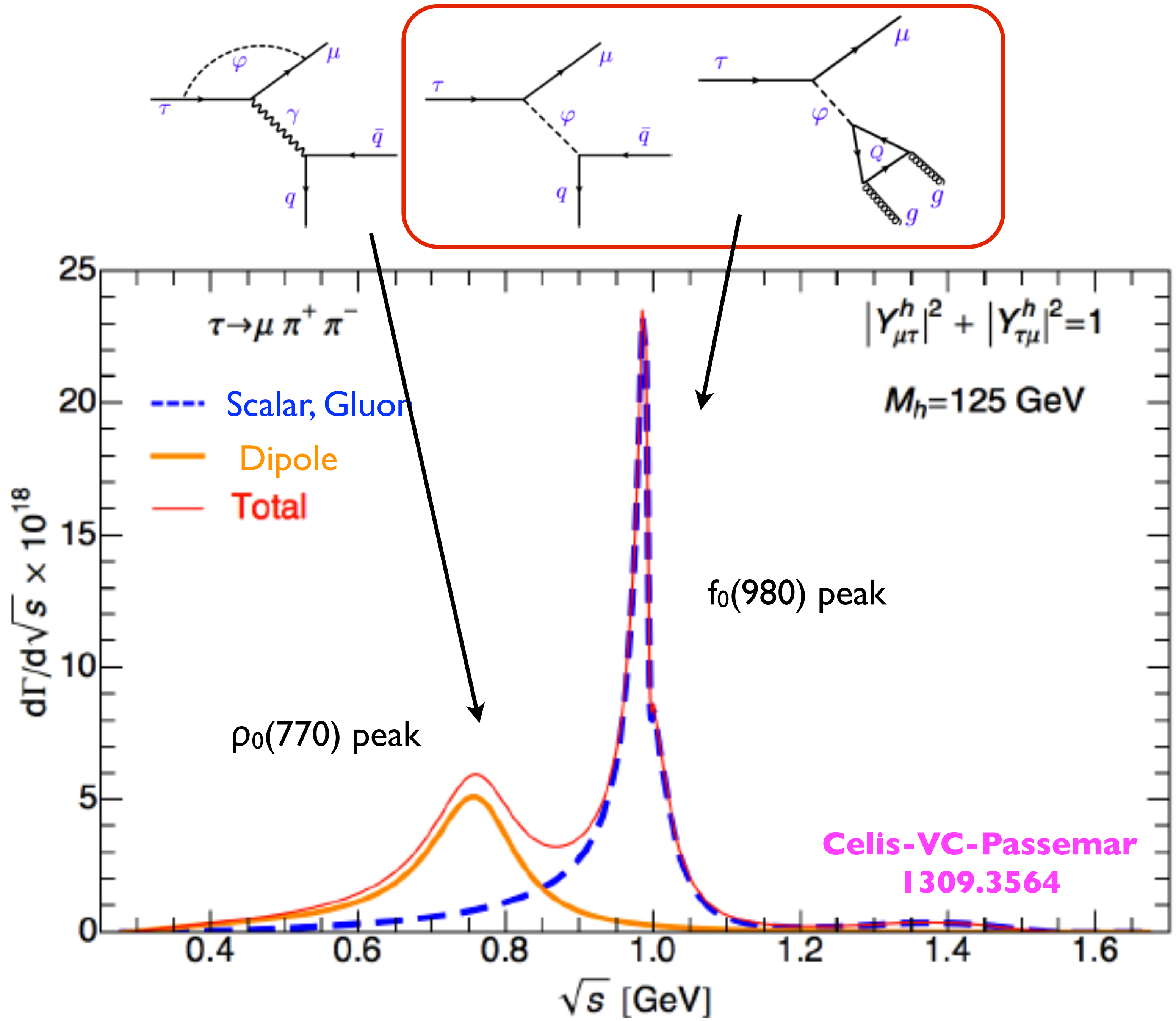
τ→μππ

Pattern of LFV τ decays

- Radiative mode dominates, followed by ππ and 3 lepton

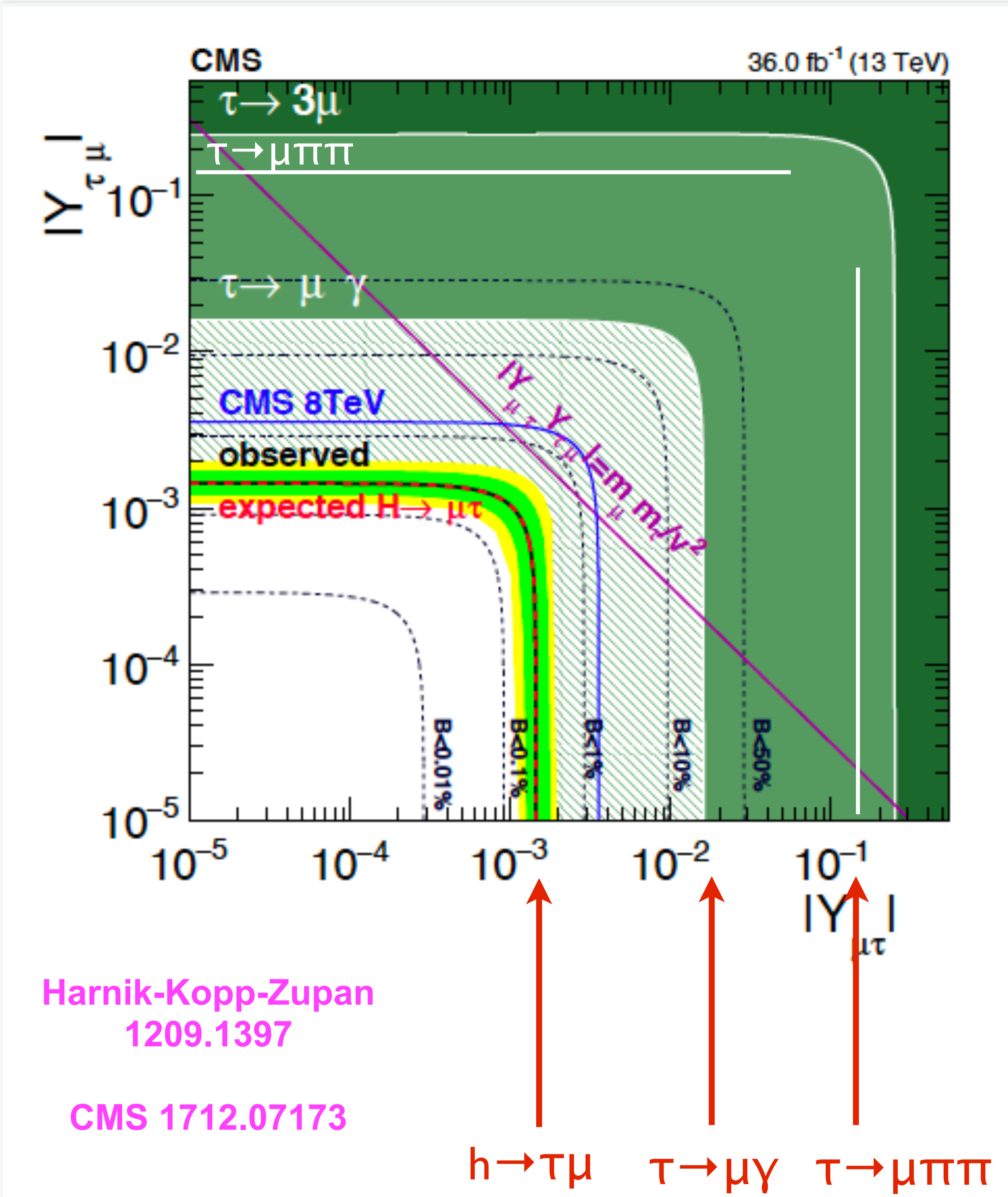
$B(\tau \to \mu \pi^+ \pi^-) / B(\tau \to \mu \gamma) = 0.7(1) \times 10^{-2}$

- $\tau \to \mu\pi\pi$ controlled by Higgs-specific combination of D, S, G → unique signature in ππ spectrum



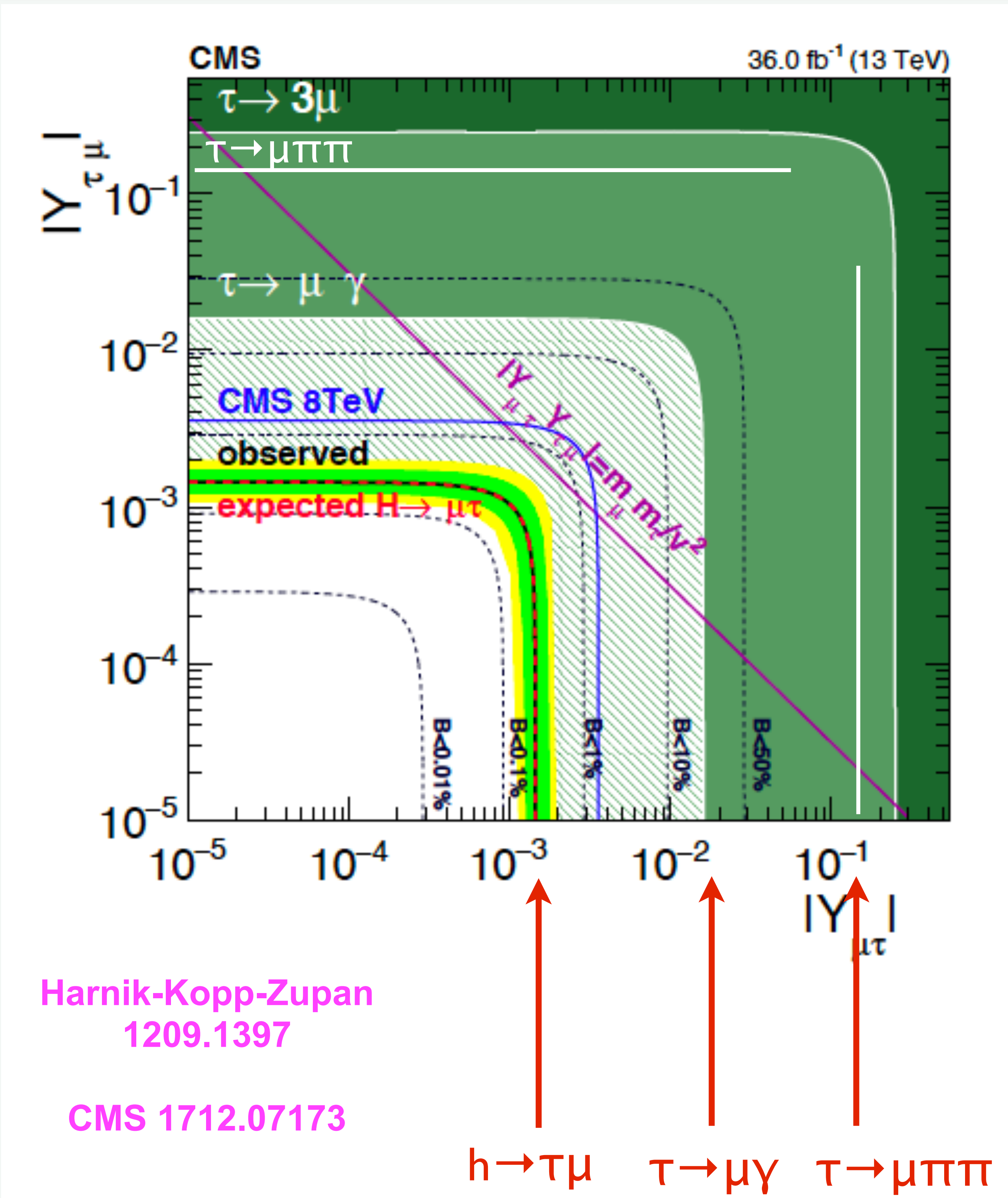
Plot assumes SM values for $Y_{u,d,s}$, but strength of the $f_0(980)$ peak depends on light quark Yukawas

τ-μ sector: h vs τ decays



- Assuming SM values for $Y_{u,d,s}$, current tau BRs ($\sim 10^{-(7-8)}$) imply $Y_{\tau\mu,\tau e} < 0.01\text{-}0.1$, which translates into BR(h→μτ) < 0.1
- LHC (CMS) limit BR(h→μτ) <0.25% (95%CL) is stronger: $|Y_{\tau\mu,\mu\tau}| < 0.00143$

τ-μ sector: h vs τ decays



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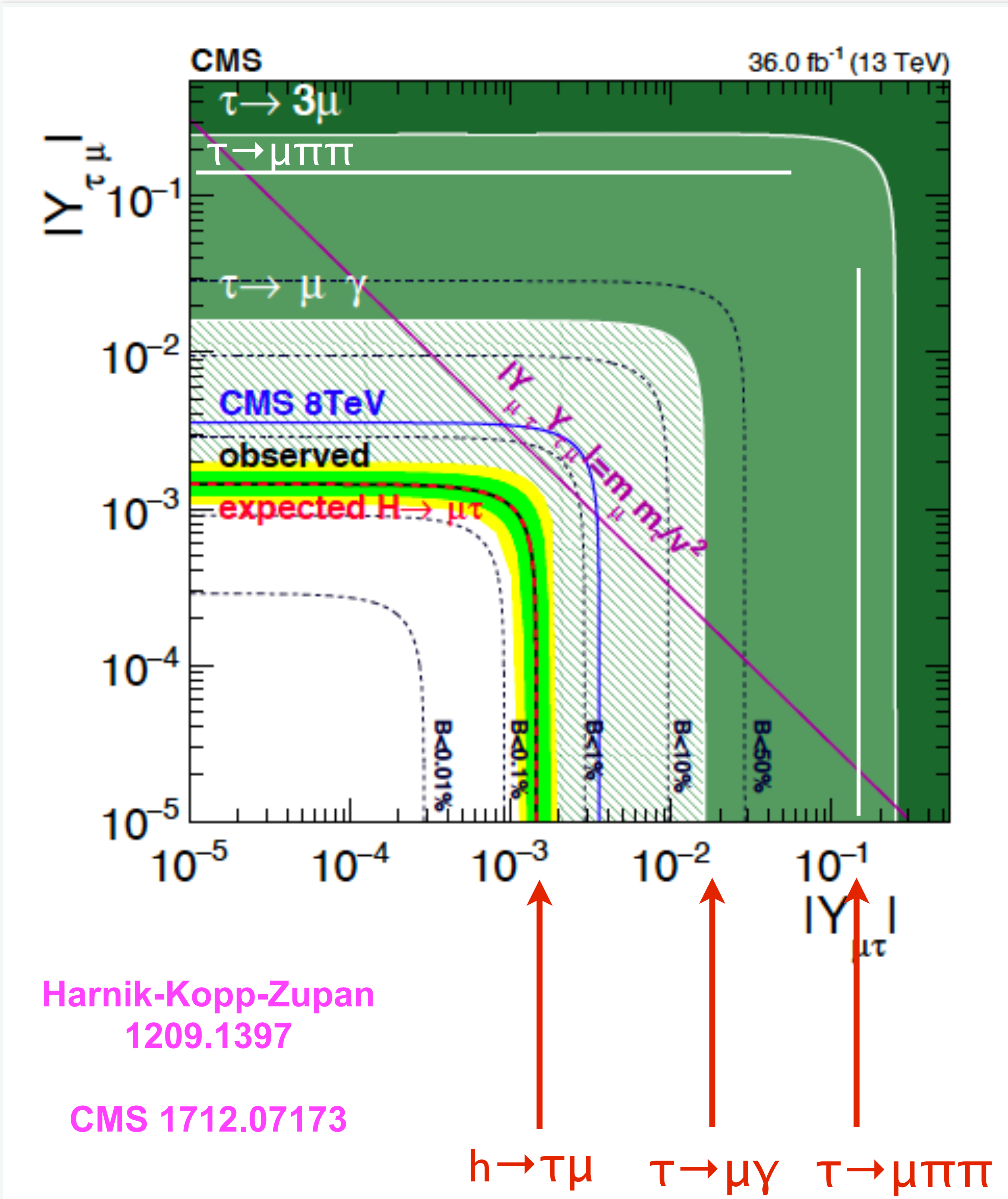
- If use SM values for $Y_{u,d,s}$, CMS bound implies

$B(\tau\to\mu\gamma) < 6.7\times 10^{-10}$
$B(\tau\to\mu\pi^+\pi^-) < 4.5\times 10^{-12}$
$B(\tau\to\mu\pi^0\pi^0) < 1.4\times 10^{-12}$

Challenging target for next generation

τ-μ sector: h vs τ decays



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- LHC (CMS) limit BR($h \to \mu\tau$) <0.25% (95%CL) is stronger: $|Y_{\tau\mu,\mu\tau}| < 0.00143$
- If use $Y_{u.d,s} \sim Y_b$, CMS bound implies

$B(\tau \to \mu\gamma) < 6.7 \times 10^{-10}$
$B(\tau \to \mu\pi^+\pi^-) < 9.1 \times 10^{-9}$
$B(\tau \to \mu\pi^0\pi^0) < 4.5 \times 10^{-9}$

Within reach of next generation

Conclusions & Outlook

- Charged LFV processes are great probes of new physics
  - *Discovery* tools: clean, high scale reach
  - *Model-diagnosing* tools: mediators, sources of flavor breaking
- Tau decays offer a rich arena to discover and diagnose CLFV
  - In general, no theoretical 'golden mode'
  - Besides $\tau \to \mu\gamma$, $\tau \to 3\mu$, hadronic modes such as $\tau \to \mu(e)\pi\pi$ can be quite interesting (e.g. imprint of Higgs couplings) and are relatively clean theoretically

Looking forward to the next decade:

★ 1-2 (3-4) orders of magnitude improvement in τ (μ) processes

★ Colliders (LHC, EIC) can play a significant role ($h \to \tau\mu$, $e \to \tau$)