FLAVOR BSM

Flavor Portal New Physics at CEPC

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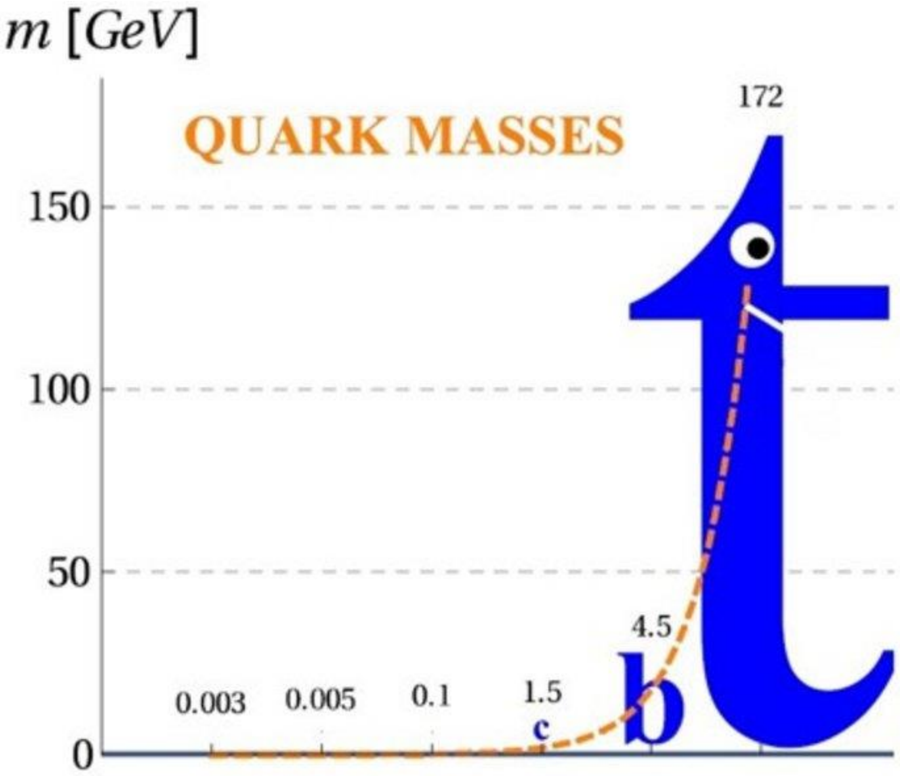
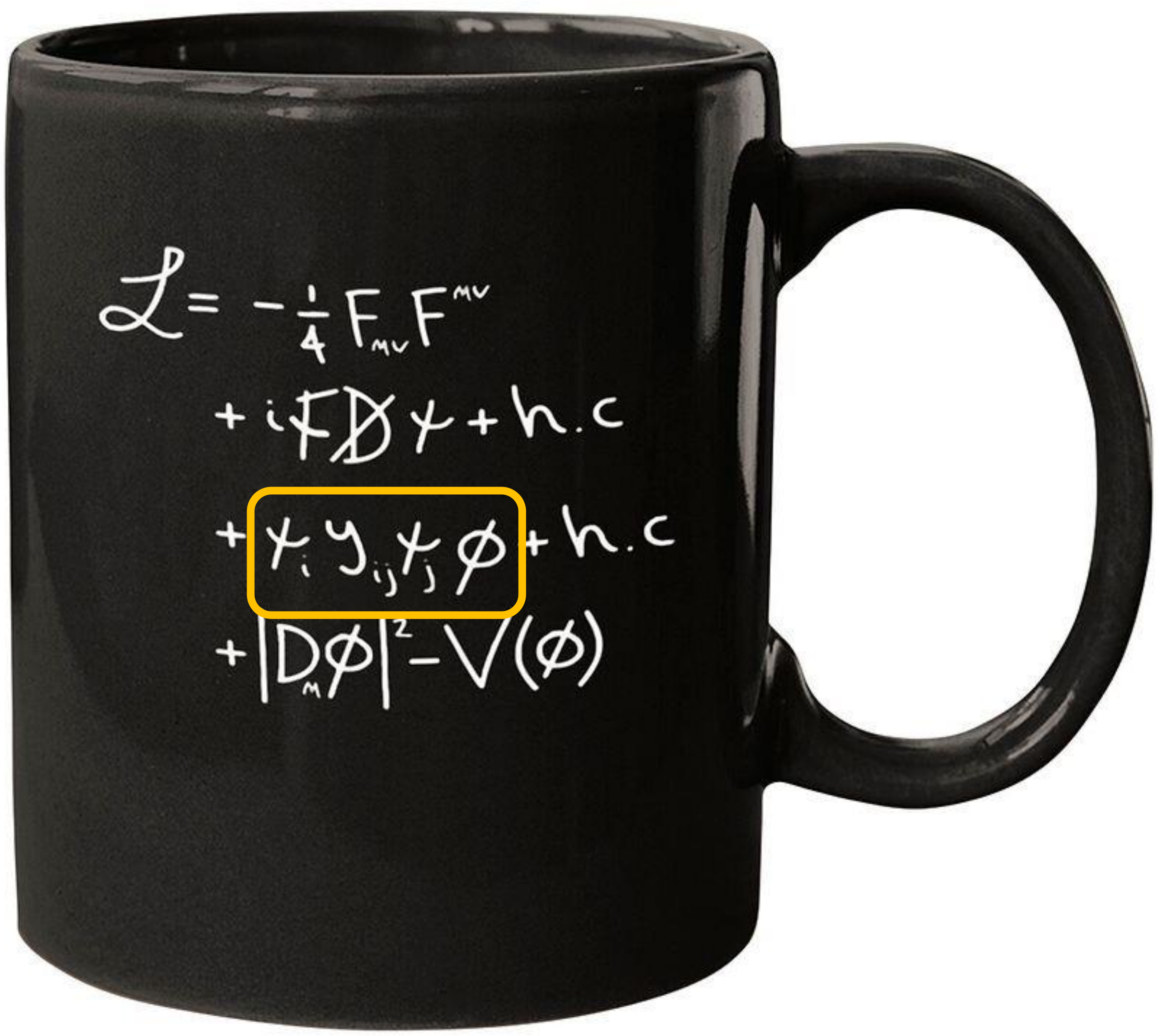
"Don't leave flavor physics just to flavor physicists"

someone awesome, 2019

Flavor Portal?



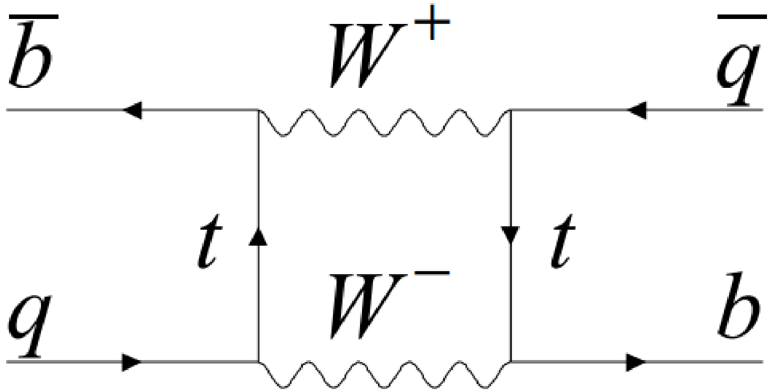
- ❑We don't know why there are 3 generations
- ❑(no CPV with less than 3, hints?)
- ❑The Higgs hierarchy problem greatly sharpens with the heavy top mass, also the "worst" in flavor hierarchy
- ❑Flavor probes tend to be very precise

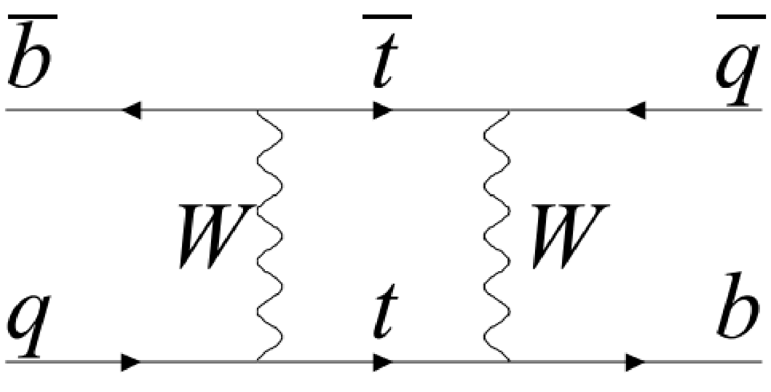


The non-trivial part of flavor physics come from the yij between gauge eigenstates and the Higgs

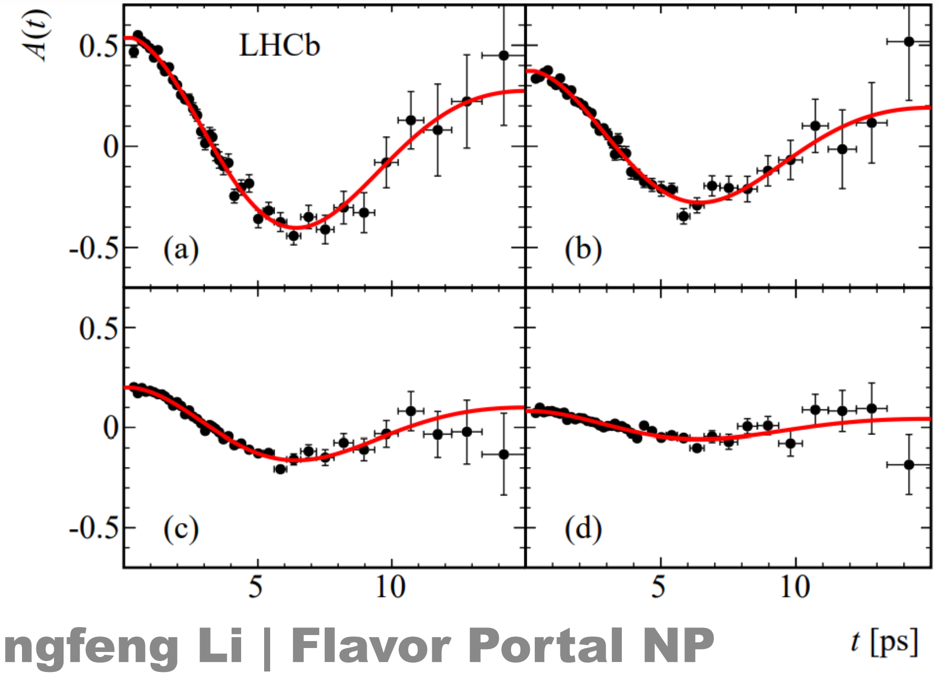
If new particles couple to fermions, in general the coupling shall be different than y_{ij}.

If they also not the same as the SM gauge (or their linear combinations), things can go (very) wrong.





$$M_{12} = -\frac{G_F^2 m_W^2 \eta_B m_{B_q} B_{B_q} f_{B_q}^2}{12\pi^2} S_0(m_t^2/m_W^2)\, \underline{(V_{tq}^* V_{tb})^2}$$



$$\Delta m_q = 2|M_{12}^q| \left[1 + \mathcal{O}\left(|\Gamma_{12}^q/M_{12}^q|^2\right)\right] ,$$

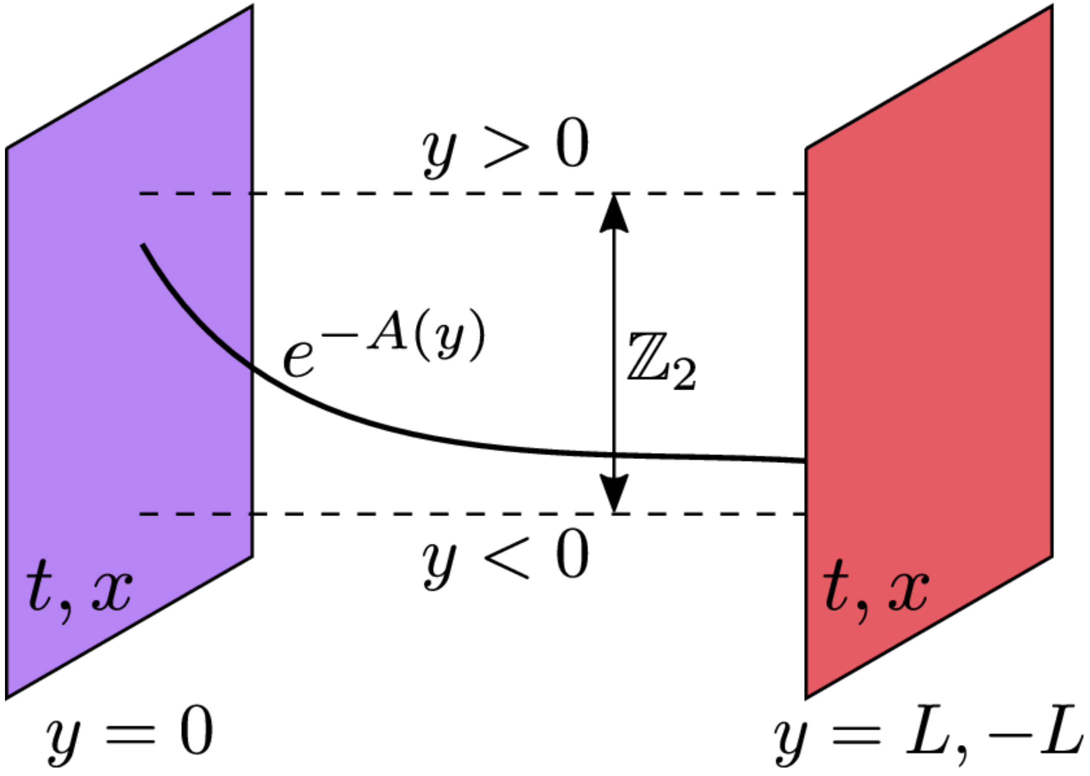
$$\Delta m_{B^0} = m_{B_H^0} - m_{B_L^0}$$

$$(50.65 \pm 0.19) \times 10^{10}\ \hbar\ \mathrm{s}^{-1}$$

Example

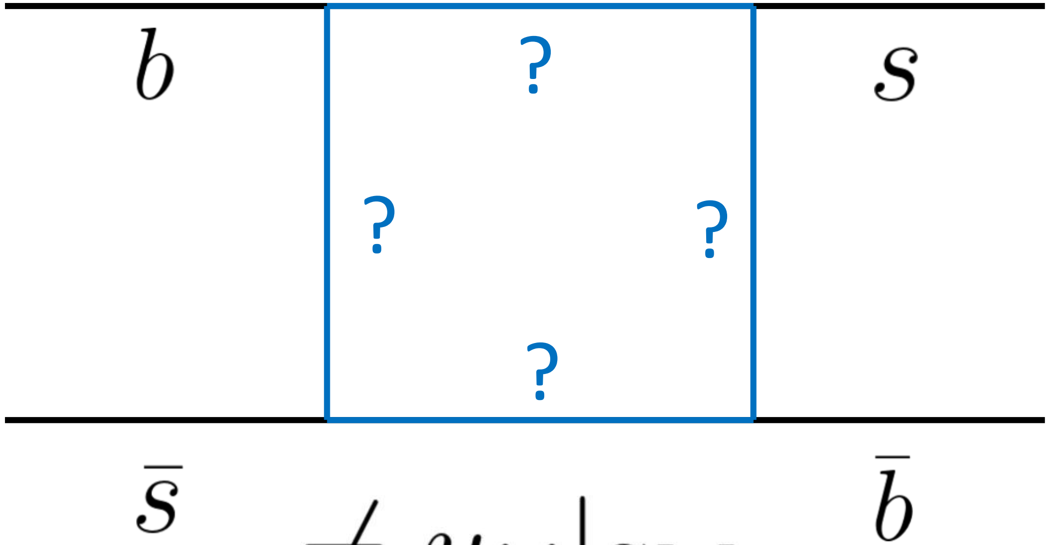
The vanilla Randall-Sundrum (RS) extra dimension model gets huge FCNC rates from strong coupling/mixing between KK modes

→ The new physics scale need to be >> TeV to avoid bounds, fail to aliviate the hierarchy problem



NP Appears in Flavor

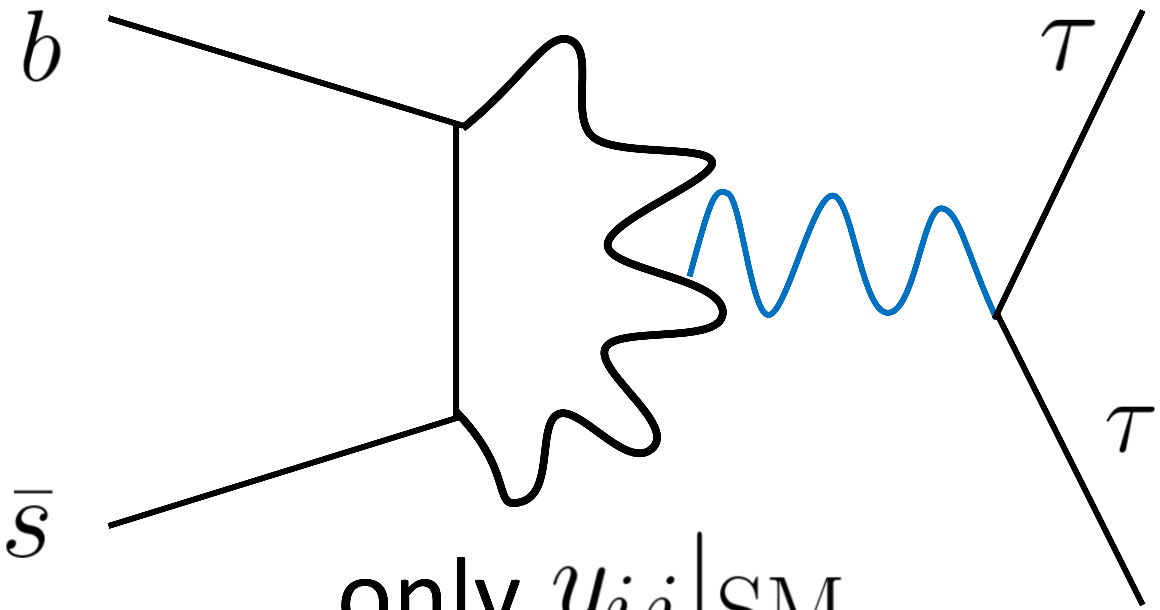
❑“Direct” BSM FCNC



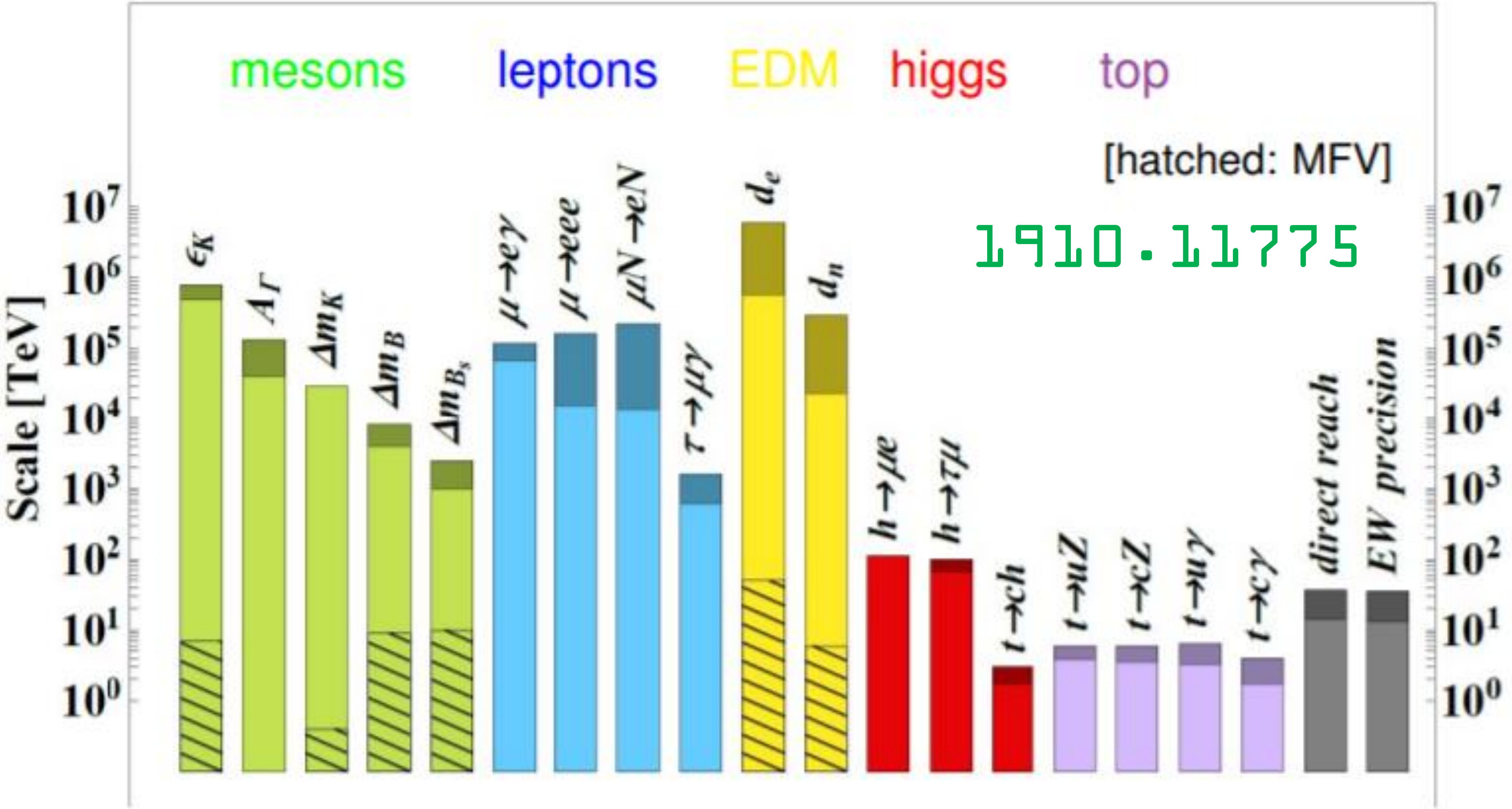
$\neq y_{ij}|_{\rm SM}$

❑“Indirect” BSM FCNC

≈ Minimal Flavor Violation

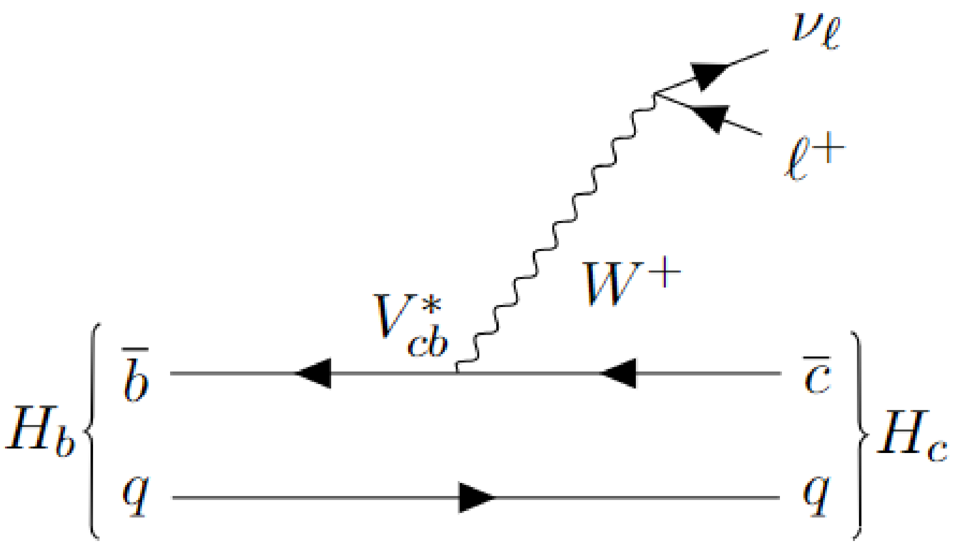


only $y_{ij}|_{\rm SM}$



Already at 10 TeV level with MFV
(model-dependent of course)

Indirect Discovery with Flavor Physics

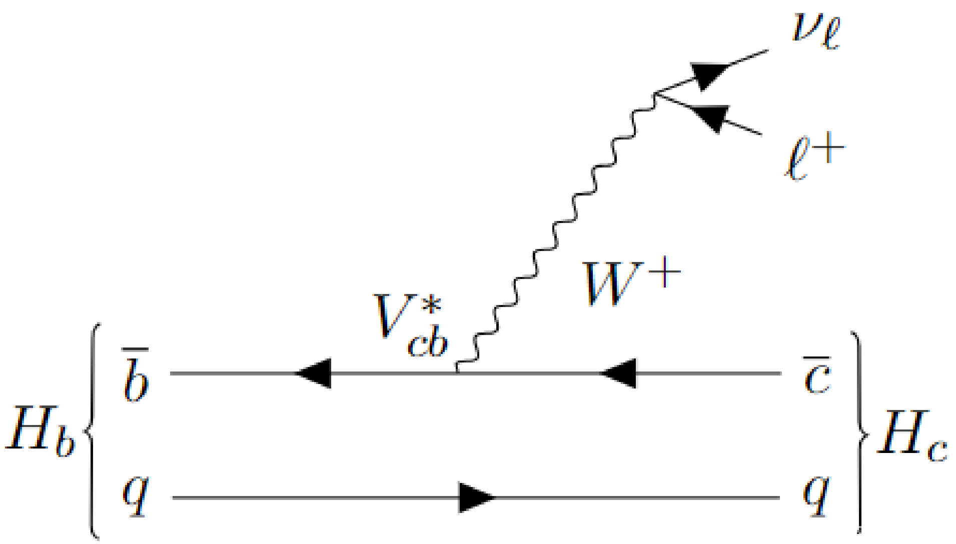


$$\Gamma_{\rm SM} = \frac{G_F^2 m_f^5}{192\pi^3} \times \text{const} \propto \frac{m_f^5}{v^4}$$

The amplitude of flavor physics in the SM is ALREADY suppressed by the EW scale →

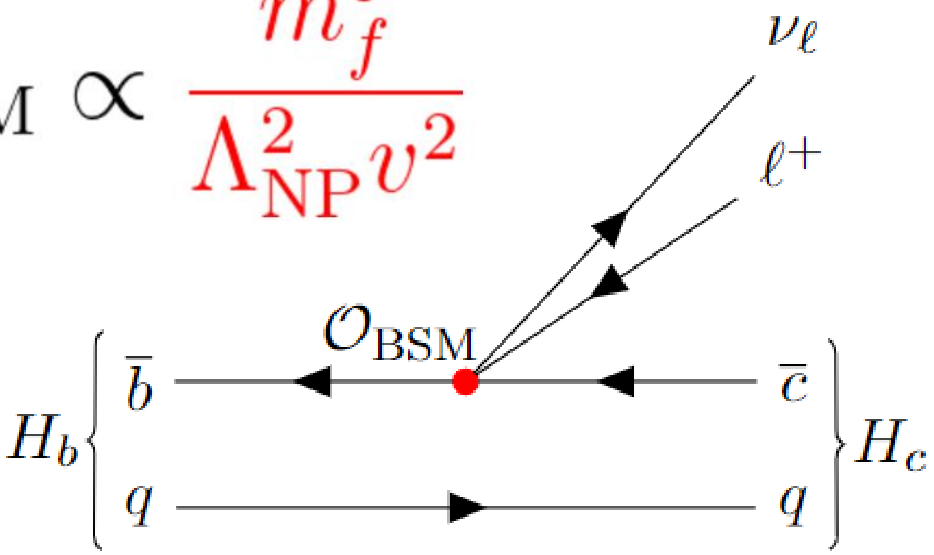
Many flavored states are long-lived ($\Gamma < 10^{-12}$ GeV)

Indirect Discovery with Flavor Physics



$$\Gamma_{\rm BSM} \propto \frac{m_f^5}{\Lambda_{\rm NP}^2 v^2}$$

vs.

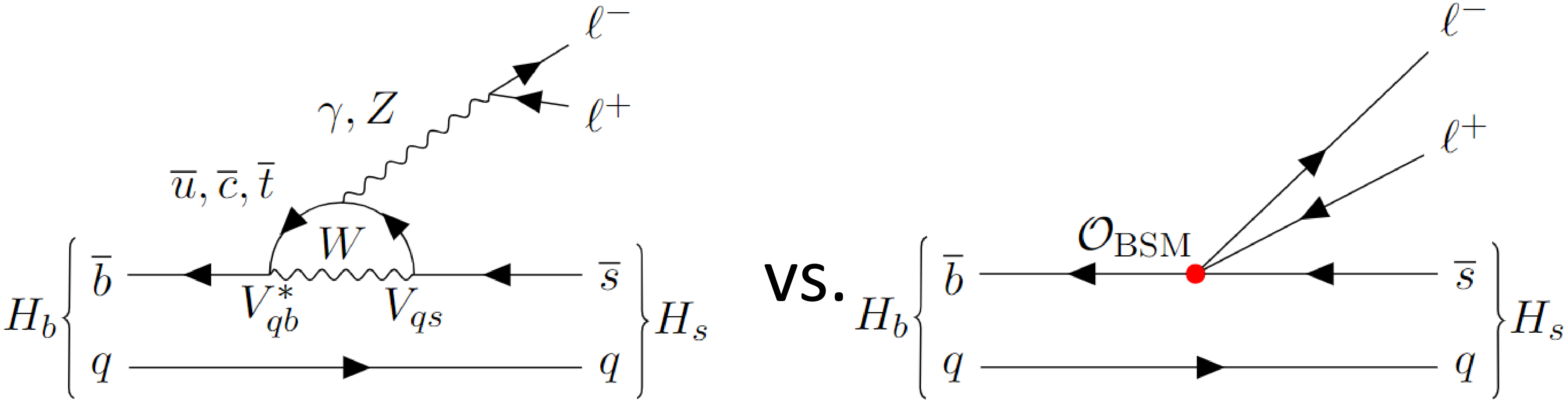


$$\Lambda_{\rm NP}^{\rm SL} \sim (G_F |V_{cb}| \delta_{\rm SL})^{-\frac{1}{2}} \sim (1.5\ {\rm TeV}) \times \delta_{\rm SL}^{-\frac{1}{2}}$$

e.g., a 1% relative precision = probing a scale of 15 TeV*

*: certainly depends on the way of interpretation

Indirect Discovery with Flavor Physics



For SM process suppressed by a loop, the same relative precision means a even higher scale*

$$\Lambda_{\rm NP}^{\rm rare} \sim \left(\frac{\alpha}{4\pi}\frac{m_t^2}{m_W^2} G_F |V_{tb}V_{ts}^*|\delta_{\rm rare}\right)^{-\frac{1}{2}} \sim (30\ \text{TeV}) \times \delta_{\rm rare}^{-\frac{1}{2}}$$

*: still depends on your UV theory in mind

Measurement	Current Limit	CEPC [371]
$\mathrm{BR}(Z \to \tau\mu)$	$< 6.5 \times 10^{-6}$	$\mathcal{O}(10^{-9})$
$\mathrm{BR}(Z \to \tau e)$	$< 5.0 \times 10^{-6}$	$\mathcal{O}(10^{-9})$
$\mathrm{BR}(Z \to \mu e)$	$< 7.5 \times 10^{-7}$	$10^{-8} - 10^{-10}$
$\mathrm{BR}(\tau \to \mu\mu\mu)$	$< 2.1 \times 10^{-8}$	$\mathcal{O}(10^{-10})$
$\mathrm{BR}(\tau \to eee)$	$< 2.7 \times 10^{-8}$	$\mathcal{O}(10^{-10})$
$\mathrm{BR}(\tau \to e\mu\mu)$	$< 2.7 \times 10^{-8}$	$\mathcal{O}(10^{-10})$
$\mathrm{BR}(\tau \to \mu ee)$	$< 1.8 \times 10^{-8}$	$\mathcal{O}(10^{-10})$
$\mathrm{BR}(\tau \to \mu\gamma)$	$< 4.4 \times 10^{-8}$	$\mathcal{O}(10^{-10})$
$\mathrm{BR}(\tau \to e\gamma)$	$< 3.3 \times 10^{-8}$	$\mathcal{O}(10^{-10})$

$\mathrm{BR}(B_s \to \phi \nu \bar{\nu})$	$< 5.4 \times 10^{-3}$	$\lesssim 1\%$ (relative)
$\mathrm{BR}(B^0 \to K^{*0} \tau^+ \tau^-)$	-	$\lesssim \mathcal{O}(10^{-6})$
$\mathrm{BR}(B_s \to \phi \tau^+ \tau^-)$	-	$\lesssim \mathcal{O}(10^{-6})$
$\mathrm{BR}(B^+ \to K^+ \tau^+ \tau^-)$	$< 2.25 \times 10^{-3}$	$\lesssim \mathcal{O}(10^{-6})$
$\mathrm{BR}(B_s \to \tau^+ \tau^-)$	$< 6.8 \times 10^{-3}$	$\lesssim \mathcal{O}(10^{-5})$
$\mathrm{BR}(B^0 \to 2\pi^0)$	$\pm 16\%$ (relative)	$\pm 0.25\%$ (relative)
$C_{CP}(B^0 \to 2\pi^0)$	± 0.22 (relative)	± 0.01 (relative)
$\mathrm{BR}(B_c \to \tau \nu)$	$\lesssim 30\%$	$\pm$ 0.5% (relative)
$\mathrm{BR}(B_c \to J/\psi \tau \nu)/\mathrm{BR}(B_c \to J/\psi \mu \nu)$	$\pm$ 0.17 $\pm$ 0.18	$\pm 2.5\%$ (relative)
$\mathrm{BR}(B_s \to D_s^{(*)} \tau \nu)/\mathrm{BR}(B_s \to D_s^{(*)} \mu \nu)$	-	$\pm 0.2\%$ (relative)
$\mathrm{BR}(\Lambda_b \to \Lambda_c \tau \nu)/\mathrm{BR}(B_c \to \Lambda_c \mu \nu)$	$\pm$ 0.076	$\pm 0.05\%$ (relative)

- Sarcastically, many may think that indirect NP searches through flavor are simply flavor physics as there are no fundamental difference in phenomenology.

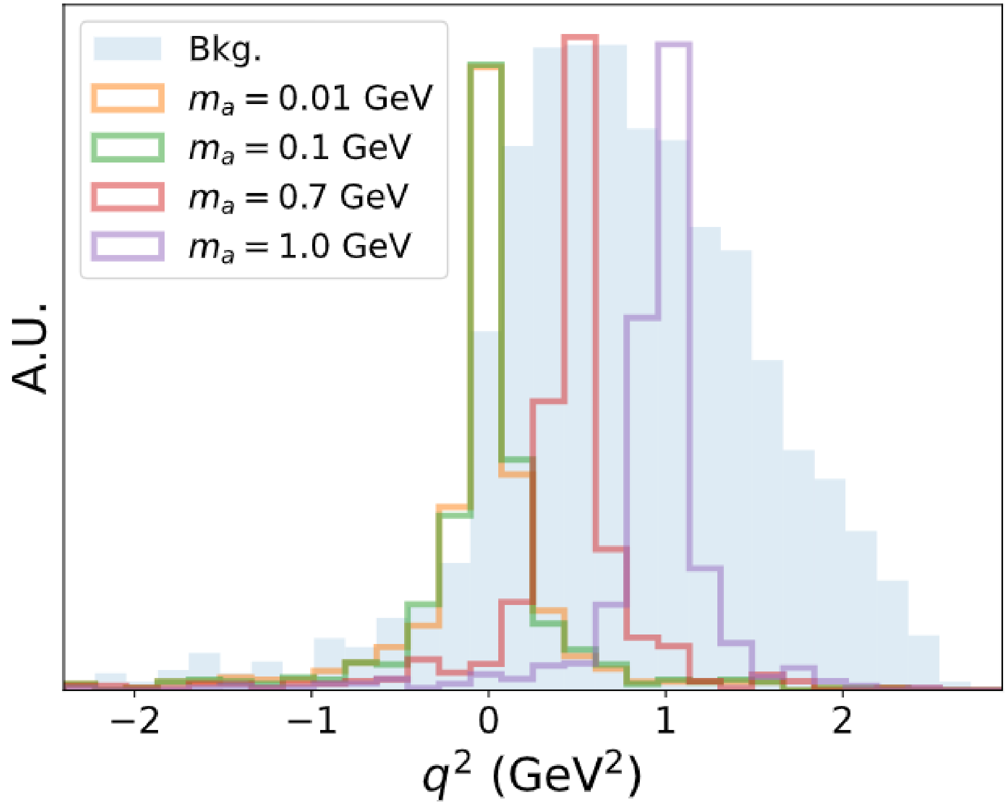
- Limit ourselves to light BSM degrees of freedom with (non)trivial coupling with SM flavors

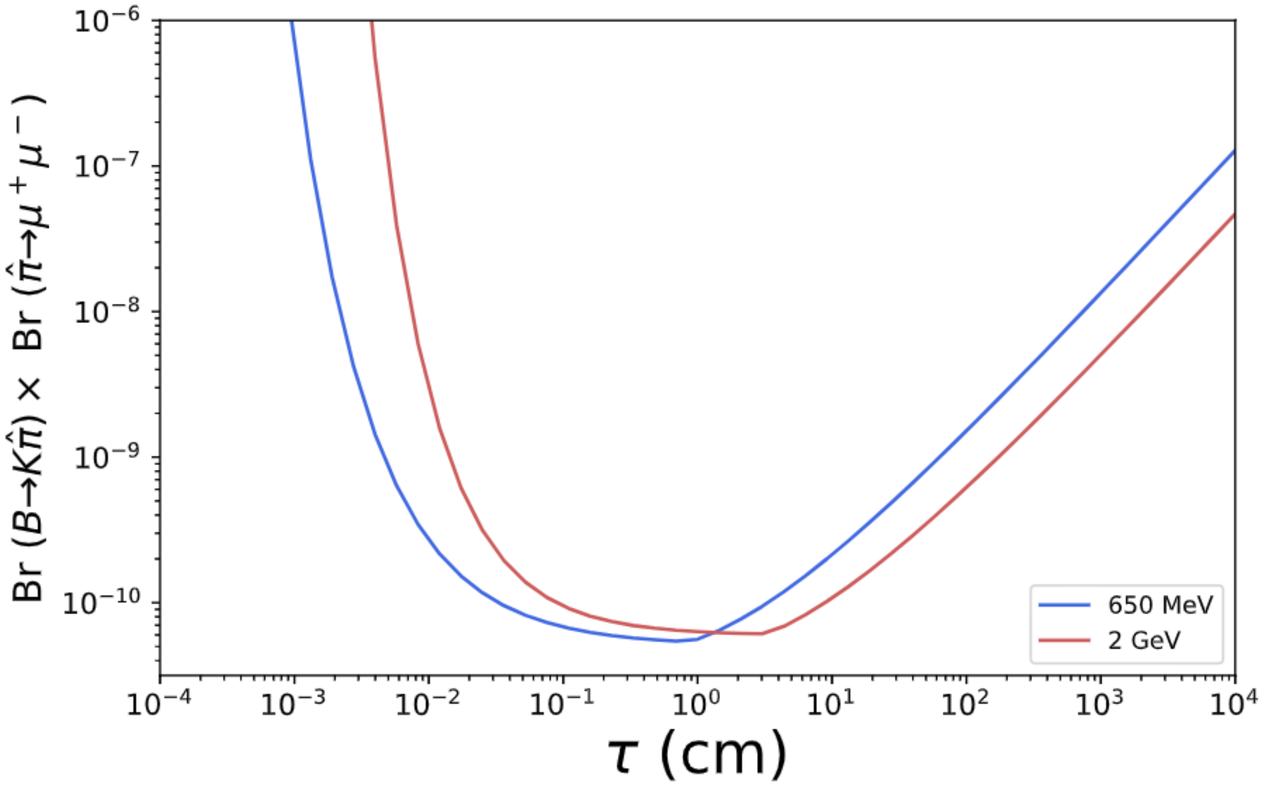
11 Light BSM States from Heavy Flavors

11.1 Lepton Sector

11.2 Quark Sector

← Joint session for both CEPC flavor and BSM white paper





$\mathrm{BR}(\tau \to \mu X_{\mathrm{inv.}})$	7×10^{-4}	$(3\text{-}5) \times 10^{-6}$
$\mathrm{BR}(B \to \mu X_{\mathrm{LLP}}(\to \mu\mu))$	-	$\mathcal{O}(10^{-10})$ (optimal)

Axion-Like Particle (ALP): A Handy Example

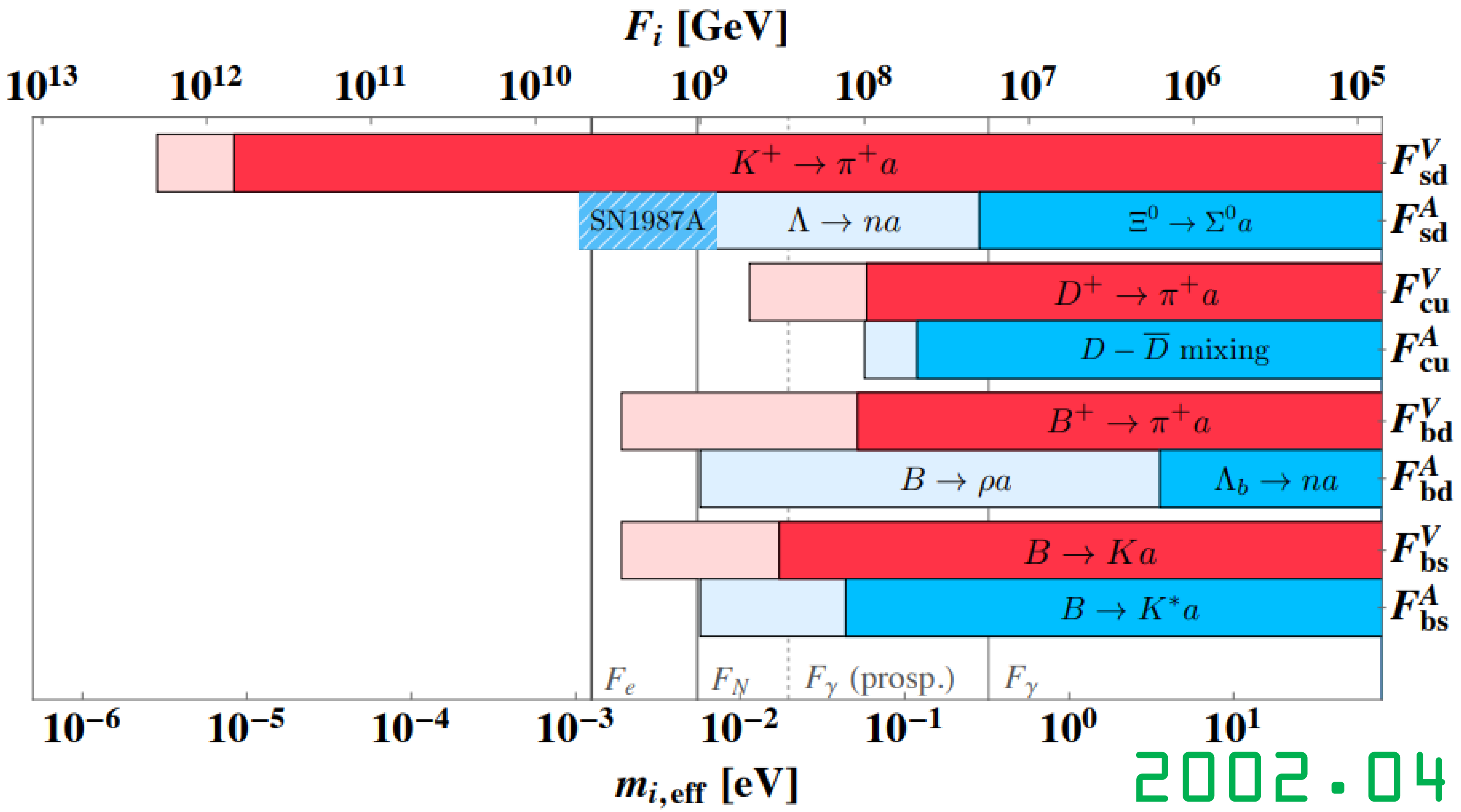
The pNGB of a softly broken U(1) global symmetry at f_a

- Strong CP problem: axion is also an ALP!
- Welcomed by many UV complete theories
- Interesting cosmology, e.g., dark matter candidate
- Represent other states, such as dark QCD pions

$$\mathcal{L}_{aff} = \frac{\partial_\mu a}{2f_a} \bar{f}_i \gamma^\mu \left(c^V_{f_i f_j} + c^A_{f_i f_j} \gamma_5\right) f_j \,,$$

Leads to exotic FCNC processes, e.g., $B \to K a$ decays

QCD Axion with Off-Diagonal Couplings



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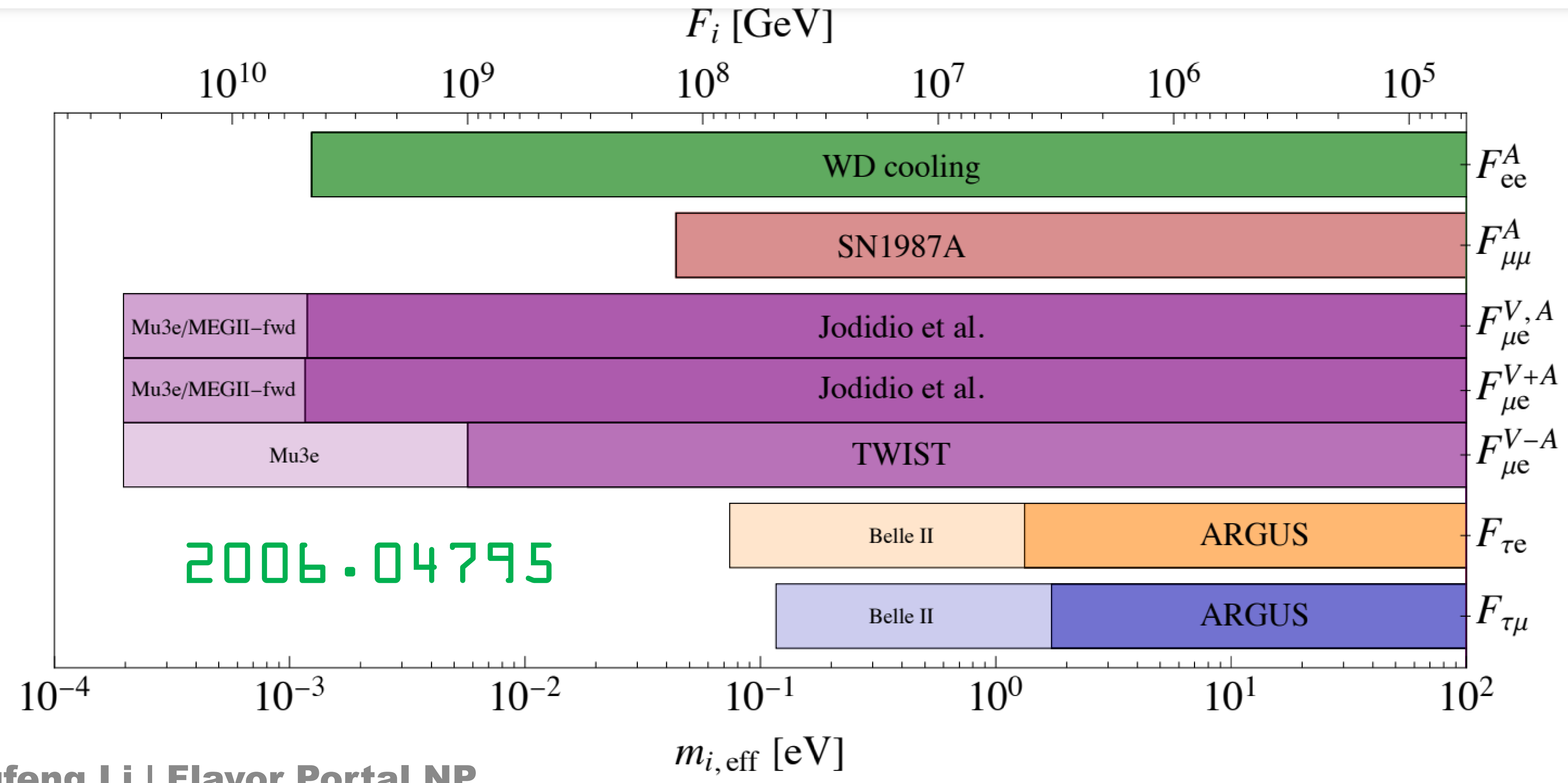
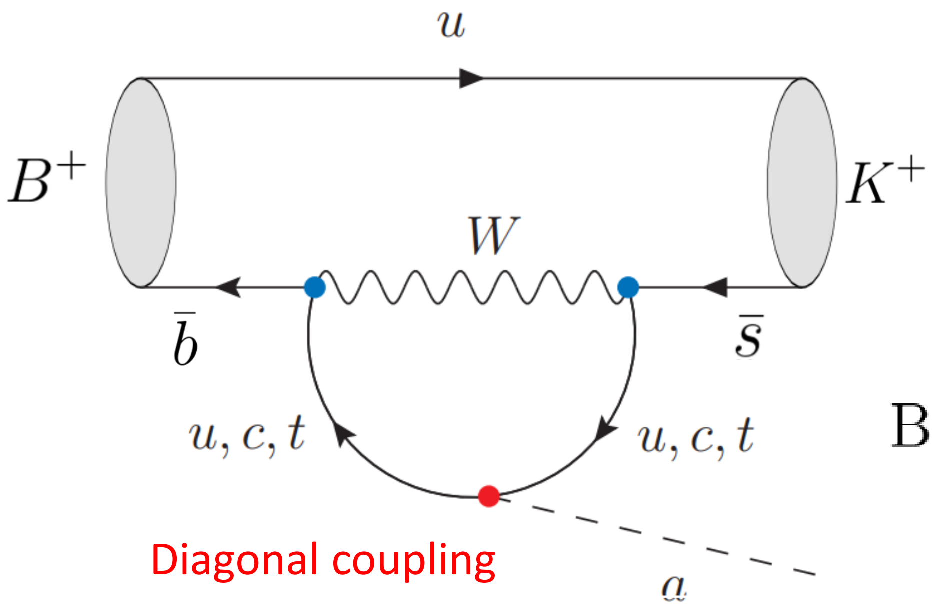
Coupling to Leptons



ALP within MFV

$$\frac{\partial_\mu a}{f_a}\bar{f}\gamma^\mu\gamma^5 f \quad \Rightarrow \quad \frac{\partial_\mu a}{f_a}\frac{g^2\mathcal{K}V_{ti}^*V_{jt}}{64\pi^2}\bar{f}_i\gamma^\mu\gamma^5 f_j$$

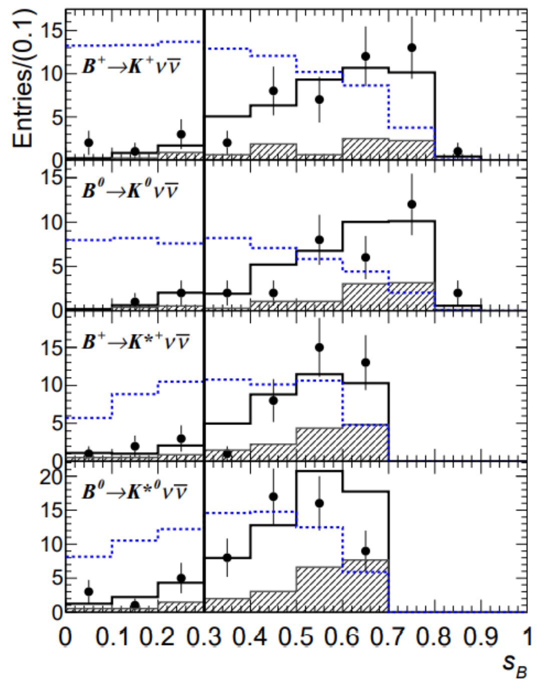


$$\mathrm{BR}(B^{+,0}\to\{K^+a, K^{*0}a\})\approx 1\times 10^{-8}\left(\frac{1\ \mathrm{PeV}}{f_a}\right)^2\left(\frac{\mathcal{K}_t}{10}\right)^2$$

Signal: Invisible vs. Long-Lived

ALP, as a feebly interacting particle, is not charged under SM and elusive

- If mass << GeV, invisible as only decay to photons (or electrons)

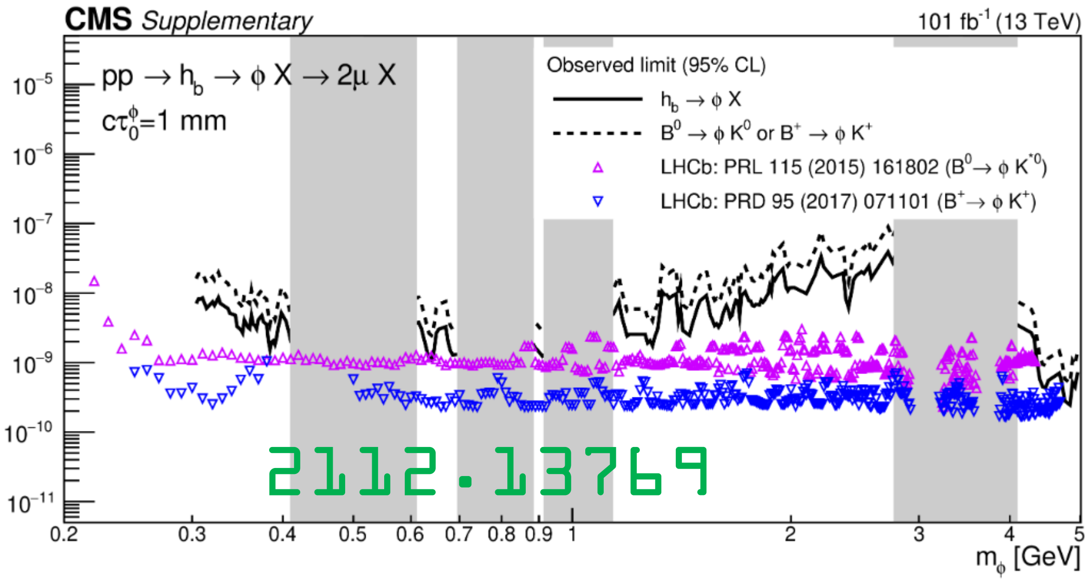


Current limit: O (10^{-5}) from flavor factories

1303.7465

- If mass~ O(GeV), long-lived but depending on many parameters

Current Limit: up to O (10^{-9}) but lifetime dependent



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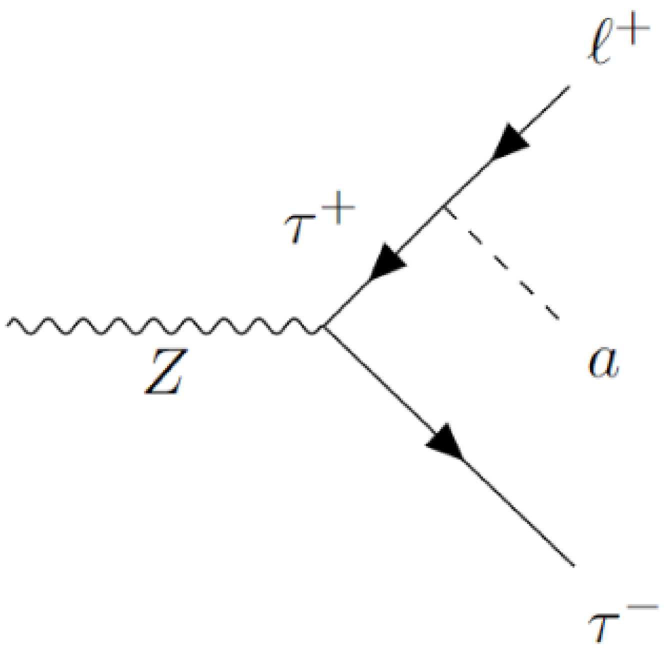
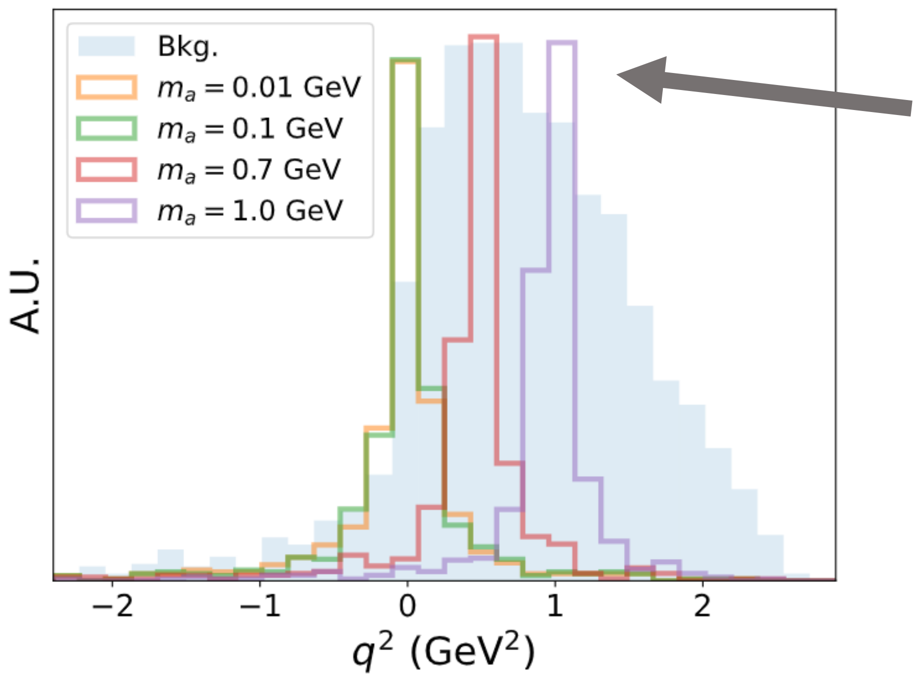
Benchmark 1: Leptonic



Targeting invisible ALPs, challenging for vertex and track reconstruction

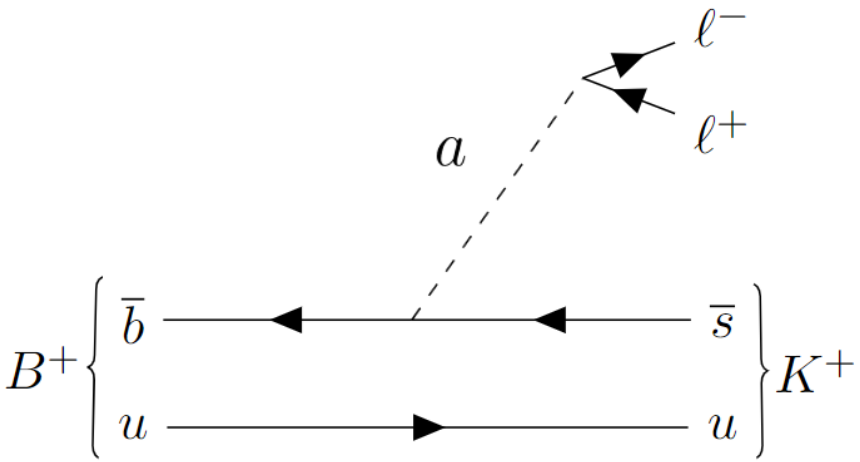


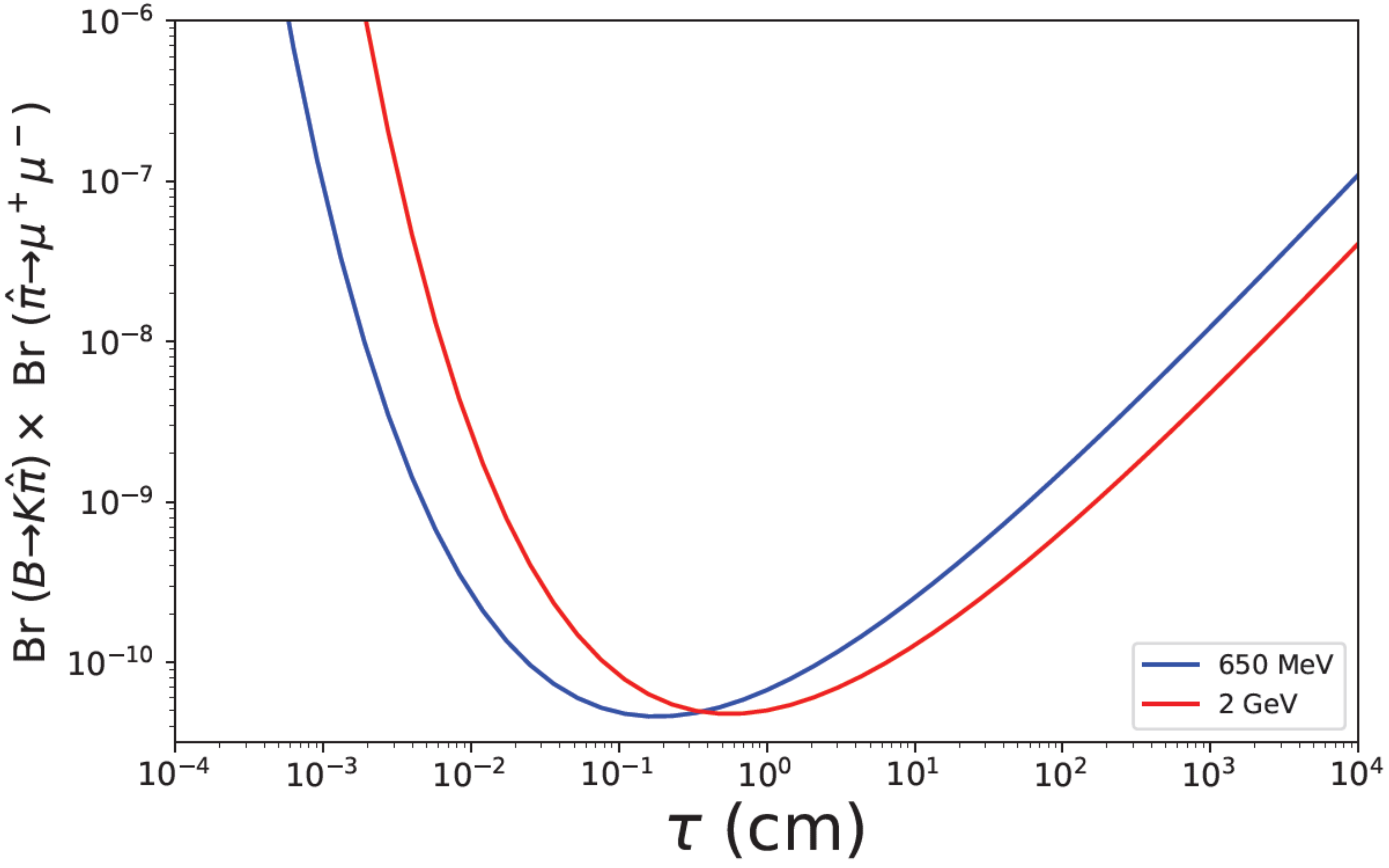
But we get the invisible inv. mass peak here!

Potential to probe exotic BR down to O (10^{-6}) level, corresponding an $f_a \approx 10^8$ GeV

Benchmark 2: Hadronic

Dominant dileptonic (muons actually) decays with macroscopic lifetime, greatly help the search





Able to probe $f_a > 10^7$ GeV in the MFV scenario

Summary

- Flavor physics is closely related to many big problems in HEP (naturalness, baryogenesis, neutrino…)
- Most flavor studies are also indirect probes of BSM
- If you don’t like the above statement, light resonances can still have enhanced production via flavor portal
- CEPC has good phenomenology potential