BSM: Direct and indirect Searches
Flavor

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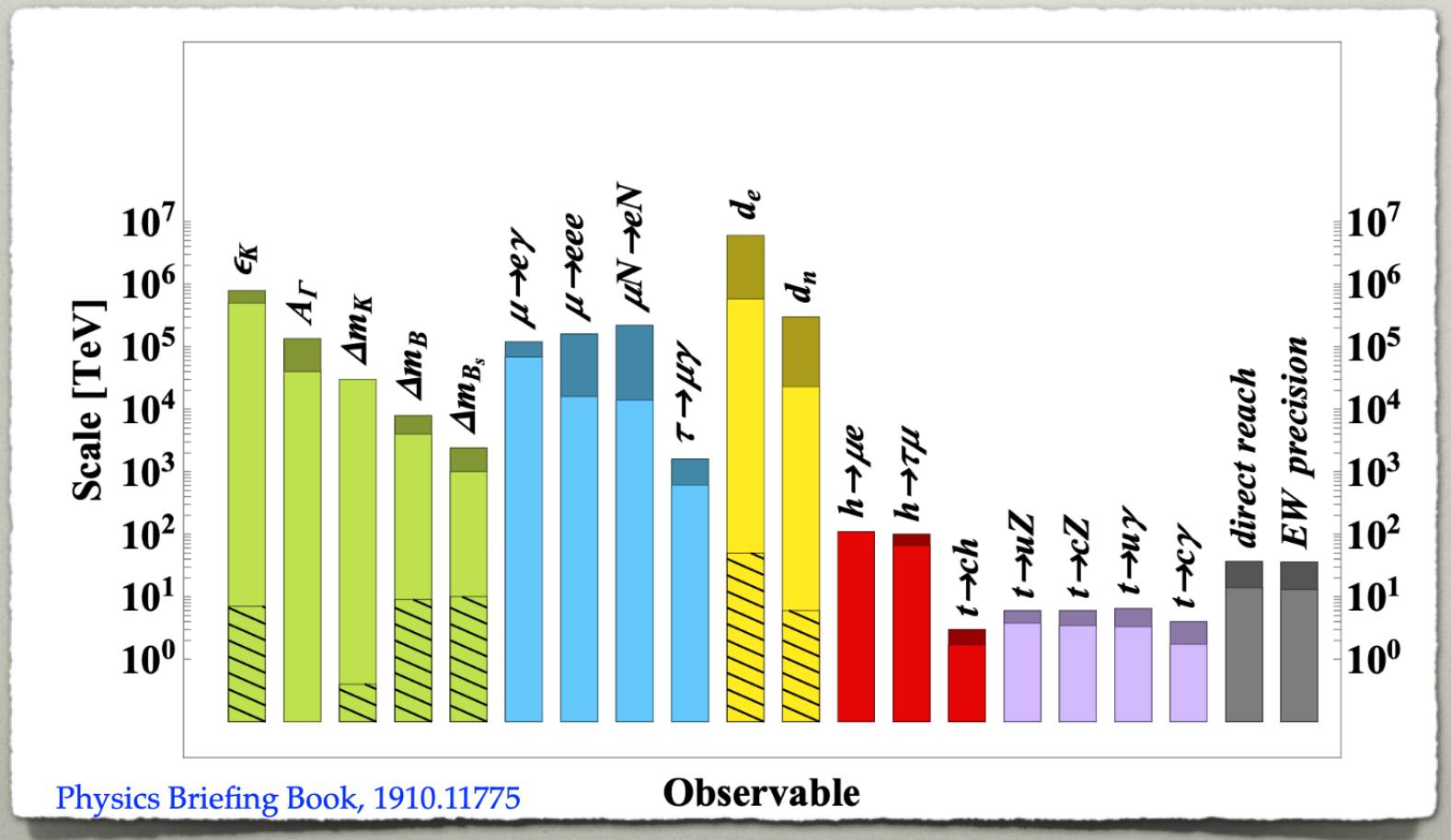
INDIRECT SEARCHES

- through indirect searches probe very high scales
- but depends on the assumed flavor structure



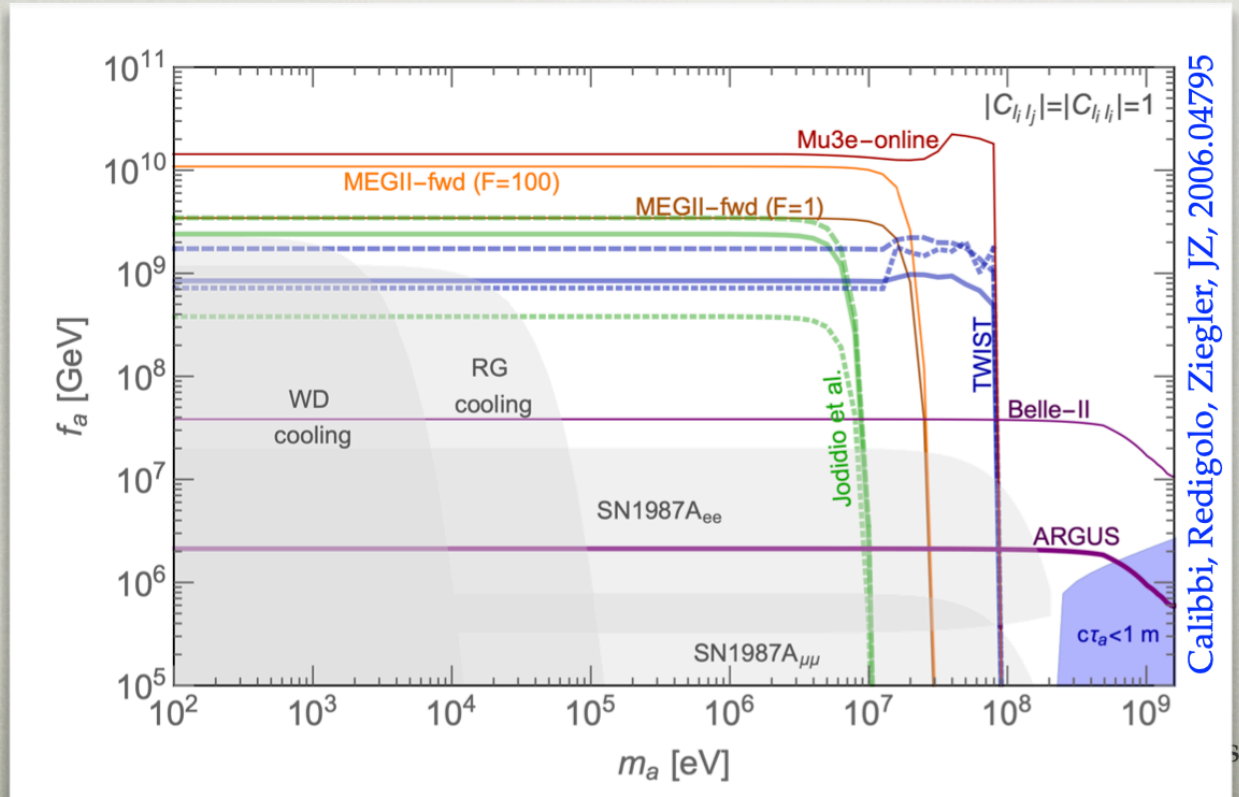
Physics Briefing Book, 1910.11775

LEPTON FLAVOR UNIVERSALITY VIOLATION

- experimental hints in $\frac{b \to c\tau\nu}{b \to c\ell\nu}$ and $\frac{b \to s\mu^+\mu^-}{b \to se^+e^-}$
- theory issues not in these ratios but in:
  - predicting absolute rates and angular observables
    - can one make progress?
  - relating to other observables (either at EFT or UV/simplified model level)
    - other FV transitions, such as $b \to s\tau^+\tau^-$,..., $s \to de^+\mu^-$,
    - to high p_T observables LFVU - using models, how one connects to other phenomena
    - other anomalies (ANITA anomaly, ...)
- is there something we are missing to fully cover all signatures and possible searches in flavor transitions?
  - for example, is there something more we can say in the nonperturbative regime of $b \to c\tau\nu$ models?

CHARGE LEPTON FLAVOR VIOLATION

- $\mu \to e\gamma, \mu \to 3e, \mu \to e$ conv., from dim-6 ops, will reach NP scales of $\sim 10^7 - 10^8$GeV
- $\mu \to ea$ from dim-5 ops., can reach NP scales $\sim 10^{10}$ GeV
  - higher than astrophysics constraints



Calibbi, Redigolo, Ziegler, JZ, 2006.04795

see also SNOWMASS21-RF5_RF0_C_Wu-120
SNOWMASS21-RF5_RF6-006

CHARGE LEPTON FLAVOR VIOLATION

- are we making full use of CLFV facilities?
- in principle many more NP scenarios one could search for

SNOWMASS21-RF5_RF0-080

signature	$\mu \to e X_{\rm NP}$	$\mu \to e\gamma X_{\rm NP}$	$\mu \to e\nu X_{\rm NP}$	$\mu \to e\nu\bar{\nu} X_{\rm NP}$
$\mu \to e + \text{inv}$	$a\|_{\rm inv}, \gamma_d\|_{\rm inv}$	–	$N\|_{\rm inv}$	$a\|_{\rm inv}, \gamma_d\|_{\rm inv}$
$\mu \to 3e$	$a, \gamma_d \to e^+e^-$	–	–	–
$\mu \to e\,2\gamma$	$a \to \gamma\gamma$	–	–	–
$\mu \to e\gamma + \text{inv}$	$a, \gamma_d \to \gamma + \text{inv}$	$a\|_{\rm inv}, \gamma_d\|_{\rm inv}$	$N \to \gamma + \text{inv}$	$a, \gamma_d \to \gamma + \text{inv}$
$\mu \to 3e\,\gamma$	$a \to e^+e^-\gamma$	$a, \gamma_d \to e^+e^-$	–	–
$\mu \to e + 3\gamma$	$\gamma_d \to 3\gamma$	$a \to \gamma\gamma$	–	–
$\mu \to e2\gamma + \text{inv}$	$a, \gamma_d \to \gamma\gamma + \text{inv}$	$N \to \gamma + \text{inv}$	–	$a \to 2\gamma$
$\mu \to 3e + \text{inv}$	$a, \gamma_d \to e^+e^- + \text{inv}$	–	$N \to e^+e^-\nu$	$a, \gamma_d \to e^+e^-$

CHARGE LEPLON FLAVOR VIOLATION

- any theoretical issues?
  - $\mu \to e$ conversion
    - bakground from $\mu \to e\nu_\mu\bar{\nu}_e$ decay in orbit (DIO)
    - BSM intepretation of $\mu \to e$ conversion :issues of nuclear matrix elements for general interactions
    - searching for $\mu \to ea$ at Mu2e requires knowledge of DIO
  - anything else?

CLFV: muons

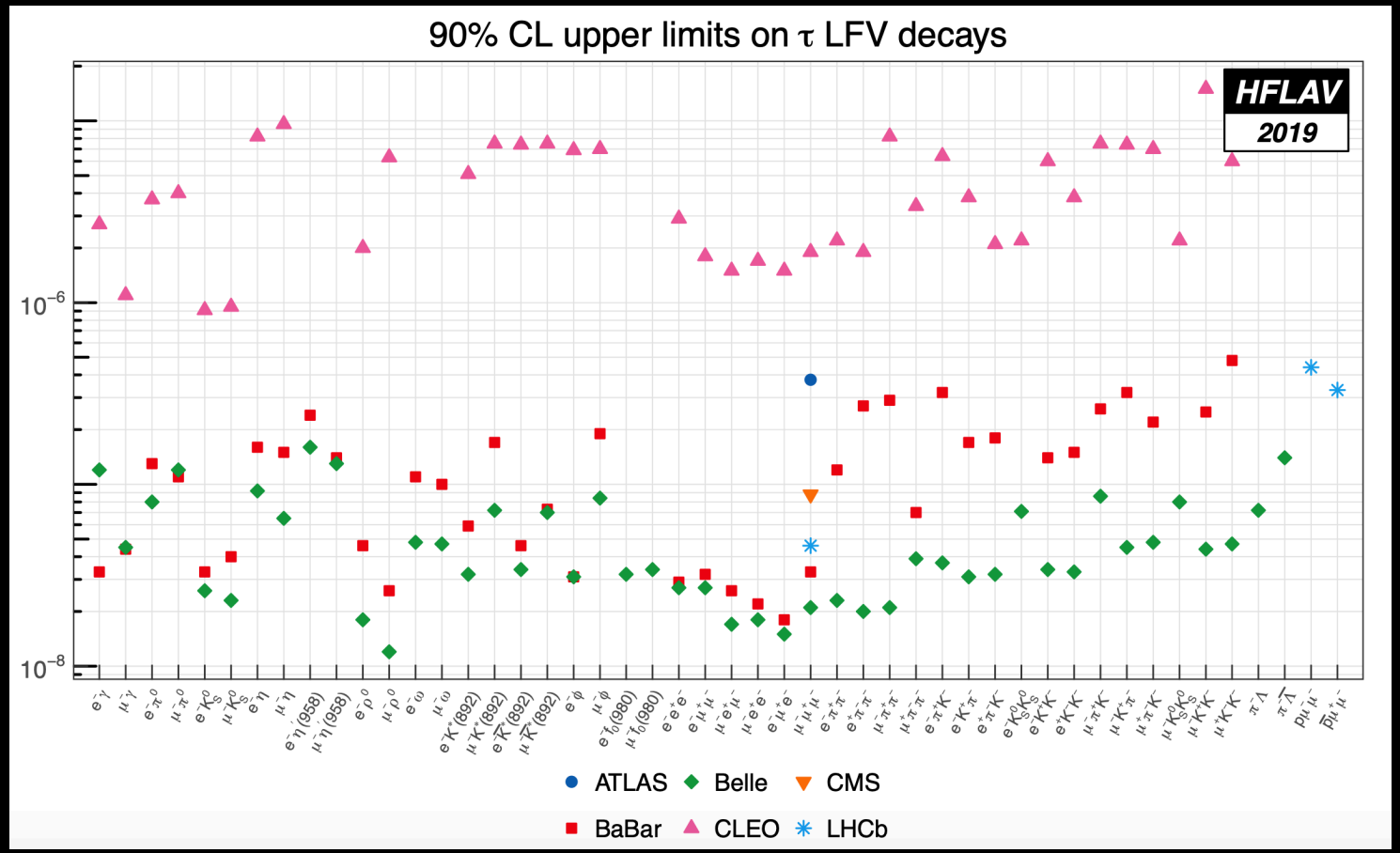
- Questions
  - What facilities are needed?
    - Further advances require high statistics
    - Intense Continuous or Pulsed Beams of Muons
  - What are the limiting Technologies?
    - Fixed Field Alternating Gradient Ring?
    - Production Target: geometries, cooling
    - Transparent Tracking
    - Energy/Momenta/Angular Resolution
    - Precision Timing (MEG II 70 ps -> 35 ps)
    - Calibration and Background Control
    - …

Interesting Session on Oct 2!

Search for Muonium to Antimuonium Conversion	Jian Tang	
Zoom	12:50 - 13:02	
Physics of muonium and anti-muonium oscillations	Alexey Petrov	
Zoom	13:02 - 13:14	
Searching for muon-to-positron Conversion at Upcoming Experiments and the Process of Radiative Muon Capture	Michael Mackenzie	
The MEG II experiment and its future developments	Angela Papa	
Zoom	13:26 - 13:38	
A new experiment for the mu -> e gamma search	Giovanni Francesco Tassielli	
Zoom	13:38 - 13:50	
A New Charged Lepton Flavor Violation Program at Fermilab	Robert Bernstein	
Zoom	13:50 - 14:02	
The Mu2e, COMET and DeeMe experiments	Sophie Middleton	
Zoom	14:02 - 14:14	
Mu2e-II	Rebecca Chislett	
Zoom	14:14 - 14:31	
Beam Delivery for Mu2e-II in the PIP-II Era	Eric Prebys	
Zoom	14:31 - 14:43	
Break		
Zoom	14:43 - 15:04	
Theory challenges and opportunities of Mu2e-II	Leo Borrel	
Zoom	15:04 - 15:16	
Upgraded Low-Energy Muon Facility at Fermilab	Carol Johnstone	
Zoom	15:16 - 15:28	
A Phase Rotated Intense Source of Muons (PRISM) for a mu-e Conversion Experiment	Jaroslaw Pasternak	
Zoom	15:28 - 15:40	
CLFV in tau decays	Swagato Banerjee	
Zoom	15:40 - 15:52	
Charged Lepton Flavour Violation at the FCC-ee	Mogens Dam	
Zoom	15:52 - 16:04	
CLFV in heavy state decays	Simone Pagan Griso	
Zoom	16:04 - 16:16	
Rare muon decays and light new physics	Diego Redigolo	
Zoom	16:16 - 16:28	
Discussion		
Zoom	16:28 - 16:50	

CLFV: taus

- Experimental Programs at Belle II and LHC(b)
- Some Proposals:
  - Polarized Beams at Belle II
  - FCC-ee at CERN
  - Future tau-charm facilities in China and Russia



- Experimental Challenges: statistics, particle ID (timing detectors?), high detector granularity with energy/momentum resolution and excellent tracking/vertexing, polarized beams

QUARK TRANSITIONS

- same goes for quark transitions, are we covering all possibly interesting signatures?
  - Belle II: bump hunting for new light dark sectors in all possible ways?
  - what can be done with kaons?

SNOWMASS21-RF6_RF0-034

Signature	$s \to dX_{\rm NP}$	$s \to dX_{\rm NP}X_{\rm NP}$	$\pi^0 \to \gamma X_{\rm NP}$
$K \to \pi + \text{inv}$	$s \to d(a/\gamma')$ [a,e]	$s \to d(aa/\gamma'\gamma'/\bar{N}N)$ [h]	–
$K \to 2\pi + \text{inv}$	$K \to 2\pi(a/\gamma')$ [a,e]	–	–
$K \to \pi\gamma + \text{inv}$	$s \to d(a \to \gamma\gamma')$ [i]	–	$K \to \pi(\pi^0 \to \gamma\gamma')$ [e]
$K \to 2\pi\gamma + \text{inv}$	$s \to d(a \to \gamma\gamma')$ [i]	–	$K \to 2\pi(\pi^0 \to \gamma\gamma')$ [e]
$K \to \pi\gamma\gamma$	$s \to d(a \to \gamma\gamma)$ [a,f]	–	–
$K \to \pi\ell_\alpha^+\ell_\alpha^-$	$s \to d(a/\gamma' \to \ell_\alpha^+\ell_\alpha^-)$ [a,e]	–	–
$K_L \to \gamma\gamma + \text{inv}$	$K_L \to \pi^0 a, \gamma\gamma a$ [f]	$K_L \to \pi^0(aa/\bar{N}N)$ [f]	–
		$K_L \to \gamma\gamma(aa/\bar{N}N)$ [f]	–
$K_L \to \ell^+\ell^- + \text{inv}$	$K_L \to \ell^+\ell^-(a/\gamma')$ [g]	–	–
$K_L \to \ell^+\ell^-\gamma\gamma$	$K_L \to \ell^+\ell^-(a \to \gamma\gamma)$ [g]	–	–
$K^+ \to \ell_\alpha^+ + \text{inv}$	$K^+ \to \ell_\alpha^+ N, \ell_\alpha^+\nu(a/\gamma')$ [b,c]	–	–
$K^+ \to \ell_\alpha^+\ell_\beta^-\ell_\beta^+ + \text{inv}$	$K^+ \to \ell_\alpha^+\nu(a/\gamma' \to \ell_\beta^+\ell_\beta^-)$ [b,e] $K^+ \to \ell_\alpha^+(N \to \ell_\beta^+\ell_\beta^-\nu)$ [d]	–	–
$K^+ \to \ell_\alpha^+\gamma\gamma + \text{inv}$	$K^+ \to \ell_\alpha^+\nu(a \to \gamma\gamma)$ [b] $K^+ \to \pi^0\ell_\alpha^+ N$ [c]	–	–
$K^+ \to \pi^-\ell_\alpha^+\ell_\beta^+$	$u\bar{s} \to \ell_\alpha^+(N^* \to d\bar{u}\ell_\beta^+)$ [i]	–	–

OTHER TOPICS

- many classic standard flavor physics observables: $B - \bar{B}$ mixing, $B \to \pi \ell \nu$, ...
- is there a way to think of legacy measurements even if lattice QCD/theory is lagging behind and will catch in ~20years
- similar for charm physics: can we guide which measurements are interesting/to be made, even though theory is not there yet?