Flavor Physics at Future Accelerators

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Workshop on Future Accelerators

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Flavor physics — many puzzles

- Flavor $\equiv$ what distinguishes generations? [break $U(3)_Q \times U(3)_u \times U(3)_d \times U(3)_L \times U(3)_e$]
  Experimentally, rich and sensitive ways to probe SM, and search for NP
- SM flavor: masses? mixing angles? 3 generations? — most of the SM param's
  Flavor in SM is simple: only fermion Yukawa couplings to Higgs break flavor symm.
- BSM flavor: TeV scale (hierarchy problem) $\ll$ "naive" flavor & CP viol. scale
  Any new particle that couples to quarks or leptons $\Rightarrow$ new flavor parameters
- Baryon asymmetry requires CPV beyond the SM
  (Not necessarily in flavor changing processes, nor necessarily in quark sector)
- Neutrino mass: What is the Lagrangian? (Majorana? Dirac?)
- Flavor probes very high scales, relevant even if NP is beyond LHC reach

Disclaimers

- Maybe I took "future accelerators" too literally — will hardly mention Belle II and LHCb
- Will hardly mention flavor anomalies — realized talking to Ben yesterday that this may be my first flavor physics talk in a while without the HFLAV $R(D) - R(D^*)$ plot...
- I am not a fortune teller — do not know where and how NP will show up
  Leave no stone unturned, but won't cover encyclopedia of interesting processes here
  (If I do not talk about your favorite topic, it does not mean that I think it's less important!)
- Many ideas will not work out. I'll show a few. It's OK :)

[Many reports & papers; Grossman, ZL in EPJ+ Focus Point on FCC, 2106.12168]

Physics after 2030s may be very different

- Discover new particles beyond Higgs? (new particle $\Rightarrow$ new flavor sector, recall $H\tau\mu$?)
- Will NP be seen in the quark sector? (Current data: hints of lepton universality violation)
- Will NP be seen in charged lepton sector? $\mu N \to eN$, $\mu \to e\gamma$, $\tau \to \mu\gamma$, $\tau \to 3\mu$?
- Will DM be discovered? Axions? EDMs? Something else?
- Neutrinos: Does 3 flavor paradigm hold? Nature of ν mass?

- No one knows — an exploratory era!

  Michelson 1894: "... it seems probable that most of the grand underlying principles have been firmly established ..."

  (NB: 2 generations $+$ superweak is "more minimal" to accommodate CP violation, than 3 generations...)

- Near future: "anomalies" might first be established
  Long term: large increase in discovery potential in many modes

Factors of a few may be essential

ANNALS OF PHYSICS: **5**, 156–181 (1958)

Long-lived Neutral *K* Mesons*

M. BARDON, K. LANDE, AND L. M. LEDERMAN

Columbia University, New York, New York, and Brookhaven National Laboratories, Upton, New York

AND

WILLIAM CHINOWSKY

Brookhaven National Laboratories, Upton, New York

set an upper limit <0.6% on the reactions

$$K_2^0 \to \begin{cases} \mu^{\pm} + e^{\mp} \\ e^+ + e^- \\ \mu^+ + \mu^- \end{cases}$$

and on $K_2^0 \to \pi^+ + \pi^-$.

VOLUME 6, NUMBER 10 PHYSICAL REVIEW LETTERS MAY 15, 1961

DECAY PROPERTIES OF K_2^0 MESONS*

D. Neagu, E. O. Okonov, N. I. Petrov, A. M. Rosanova, and V. A. Rusakov
Joint Institute of Nuclear Research, Moscow, U.S.S.R.
(Received April 20, 1961)

Combining our data with those obtained in reference 7, we set an upper limit of 0.3% for the relative probability of the decay $K_2^0 \to \pi^- + \pi^+$. Our

"At that stage the search was terminated by administration of the Lab."
[Okun, hep-ph/0112031]

VOLUME 13, NUMBER 4 PHYSICAL REVIEW LETTERS 27 JULY 1964

EVIDENCE FOR THE 2π DECAY OF THE K_2^0 MESON*†

J. H. Christenson, J. W. Cronin,‡ V. L. Fitch,‡ and R. Turlay§
Princeton University, Princeton, New Jersey
(Received 10 July 1964)

We would conclude therefore that K_2^0 decays to two pions with a branching ratio $R = (K_2 \to \pi^+ + \pi^-)/(K_2^0 \to \text{all charged modes}) = (2.0 \pm 0.4) \times 10^{-3}$ where the error is the standard deviation. As empha-

[Not what the goal of the experiment was!]

Anticipated increases in sensitivity

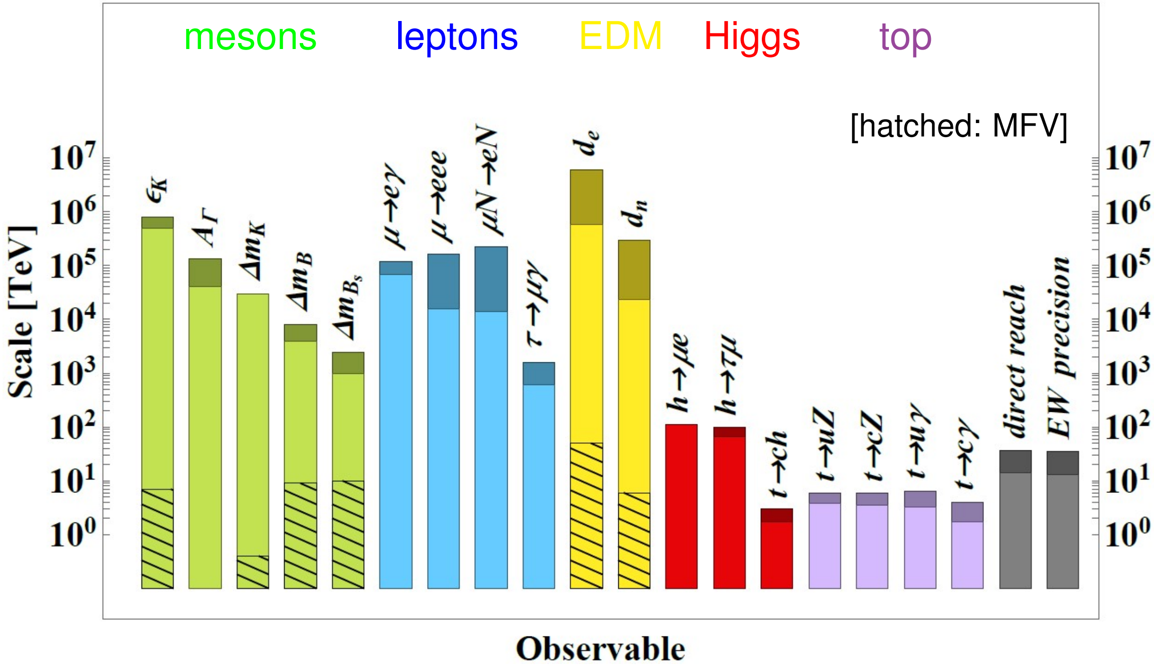
- Scales of dim-6 operators probed $\Longrightarrow$

  Various mechanisms devised so that NP obeys these bounds

  (Patterns matter more than precise values; Note special role of meson mixing)

- If NP is within any collider's reach, must have nontrivial flavor structure

  The idea of (dominantly) 3rd generation NP goes back (at least) to the '90s [hep-ph/9607394]



[European Strategy Update 2020, arXiv:1910.11775]

- Lack of NP in flavor tells us something! Motivates tera-Z, part of comprehensive search

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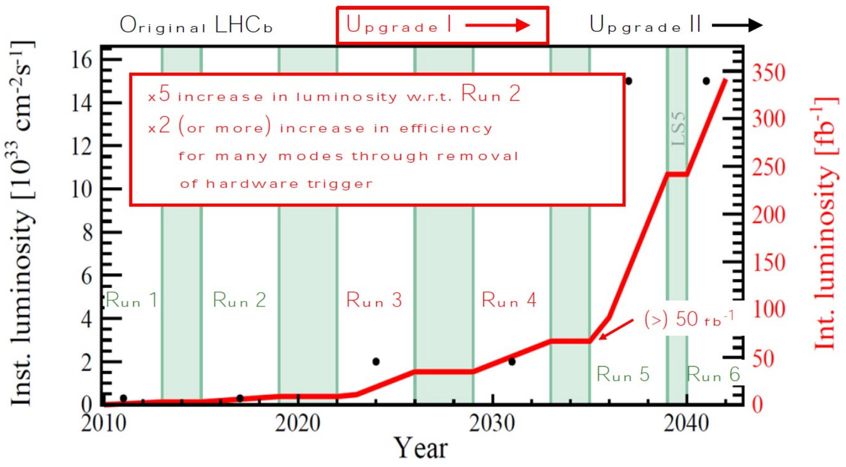
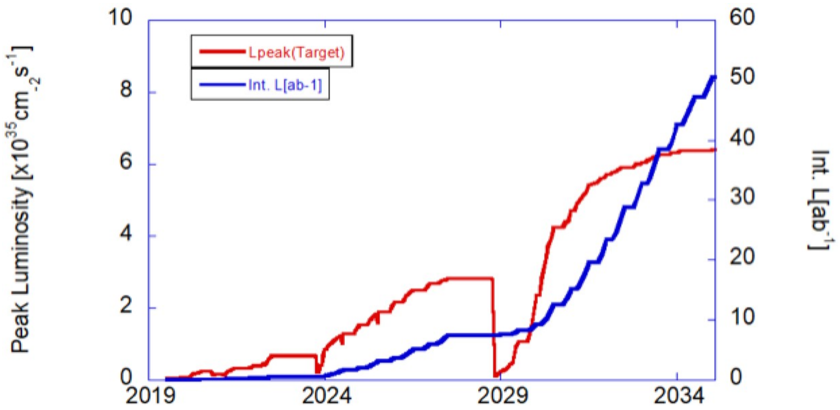
Why is flavor physics interesting?

- Flavor probes scales $\gg 1\,\mathrm{TeV}$, explosion of data in next decade
- In many FCNC (loop) processes, new physics is only constrained at $\sim 20\%$ of the SM
- Few tensions with SM; deviation may be established even beyond ATLAS / CMS reach
  Unambiguous BSM discovery would give upper bound on next scale to explore
- Lattice QCD: no extrapolations of expected (or hoped) uncertainties that far out
- IF BSM discovered: may play a critical role in understanding its structure
- New / improved methods: more progress than simply scaling with statistics
  New theory ideas: data always motivates unforeseen developments

Which future colliders?





- LHCb upgrade in LS2 (inst. lumi.: 2×10^{33})
- LHCb Upgrade II in LS4 (inst. lumi.: 1.5×10^{34})

  ATLAS & CMS competitive in some modes

  Extensive sensitivity projections: 1812.07638, LHCB-TDR-023

- Goal: over $50\times$ the Belle data set
- Discussions about physics case and feasibility of an upgrade, aiming 50/ab $\to$ 250/ab (parallel LHCb Upgrade II)

  Extensive sensitivity projections: 1808.10567

- Only Tera-Z would go well beyond current program — clear case if BSM seen

The tera-Z data sets

- Large and clean data sets ($10^5 \times$ LEP); production yields compared to Belle II [2106.01259]

Particle production (10^9)	$B^0 + \overline{B}^0$	$B^\pm$	$B^0_s + \overline{B}^0_s$	$\Lambda_b + \bar{\Lambda}_b$	$B^\pm_c$	$c\bar{c}$	$\tau^+\tau^-$
Belle II (50 ab^{-1})	27	27	tbd	—	—	65	45
tera-Z (5×10^{12} Z)	600	600	150	130	3	600	170

(This is often the sole focus of talks on flavor @ tera-Z)

Comparison with LHCb complex: roles of trigger, LHCb has advantage for fully reconstructed final states, if there are neutrals, tera-Z likely wins (counterexample: $B \to \mu^+\mu^-$)

- WW threshold: $W \to b\bar{c}$ can give a qualitatively new determination of $|V_{cb}|$
Estimate 0.2% uncertainty, using 10^8 WW, independent of B measurements

[Monteil @ 7th FCC Physics Workshop, Jan 2024]; also: [2405.08880]

Important, as $|V_{cb}|$ may limit improving BSM sensitivity in $B_{d,s}$ mixing [Charles *et al.*, 2006.04824]

Can one appreciate / anticipate a 10^5 improvement?

- What might $10^5 \times$ LEP mean? Can we predict it...? (Recall : Belle II / ARGUS $\sim 10^5$!)

  Theory and experimental techniques both changed a lot! (e.g., full hadronic reconstruction)

  Asymmetric B factories at $\Upsilon(4S)$ great for CP violation, less ideal for (semi)leptonic decays (~~hermetic~~)

- What was not even tried at LEP? (due to lack of statistics or lack of physics interest)

  E.g., $\tau\tau$ spin correlations with 3-prong decays? (0.03×0.1^2)

  Some rare decay sensitivity linear with statistics; e.g., $Z \to \mu\tau, \mu e$, etc.

- Some of what's called precision electroweak (interim report, talks), also concerns flavor (τ lifetime & mass, R_ℓ for each ℓ flavor, etc.)

New physics in $B_{d,s}$ mixing

New physics in B mixing

- In many BSM scenarios, dominant deviations from SM may be in neutral meson mixing

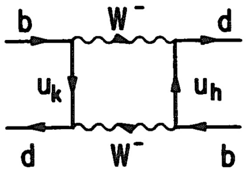
  Importance known since 1970s: $\dfrac{\Delta m_K}{m_K} \sim \dfrac{g_2^4}{16\pi^2}\,|V_{cs}V_{cd}|^2\,\dfrac{m_c^2}{m_W^4}\,f_K^2 \sim 7\times 10^{-15}$

- Assume: (i) 3×3 CKM matrix is unitary; (ii) tree-level decays dominated by SM

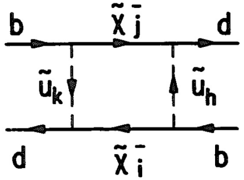
  General parametrization of many models
  by two real parameters (in addition to SM):

  $$h\,e^{2i\sigma} = A_{\rm NP}(B^0\to\overline{B}{}^0)/A_{\rm SM}(B^0\to\overline{B}{}^0)$$

  NP parameters



SM: $\dfrac{C_{\rm SM}}{m_W^2}$



NP: $\dfrac{C_{\rm NP}}{\Lambda^2}$

  What is the scale Λ? How different is the $C_{\rm NP}$ coupling from $C_{\rm SM}$?

- Relies on many measurements and theory inputs ($\Rightarrow$ conservative view of future progress)

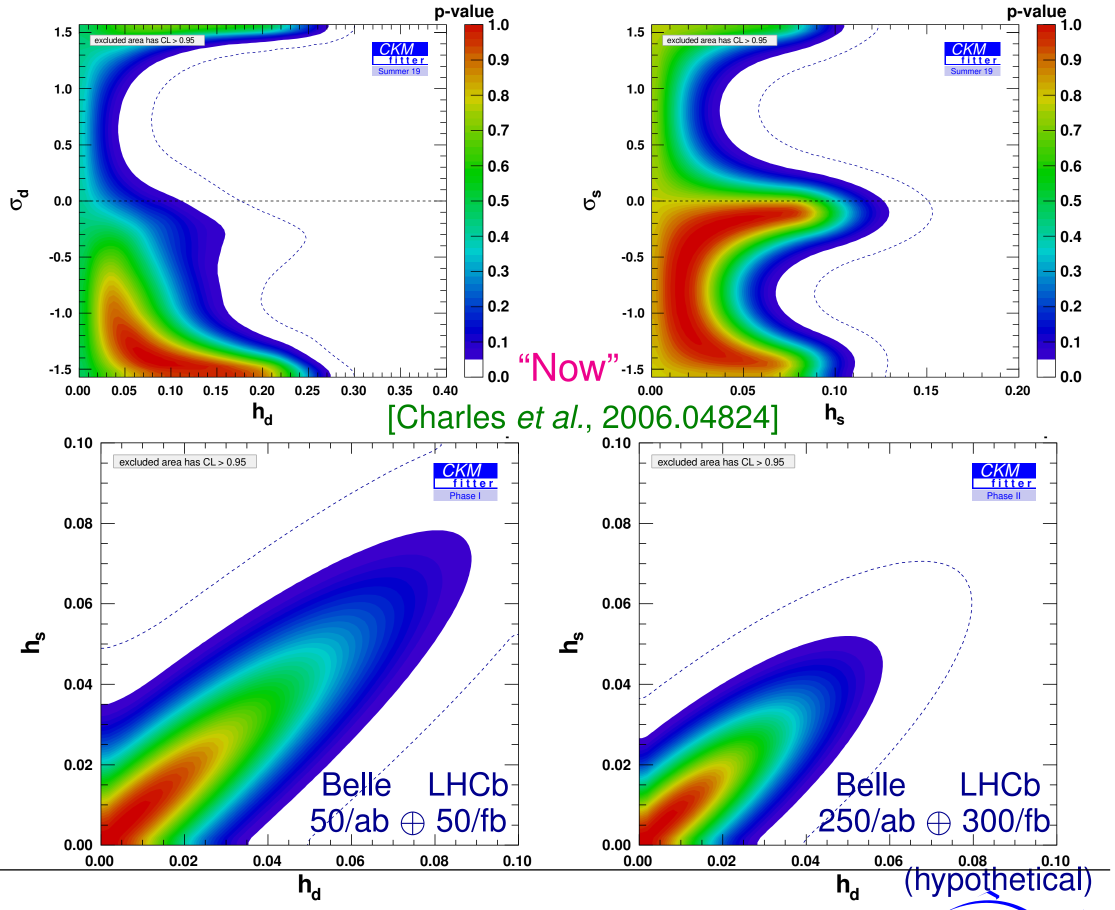
Sensitivity to new physics in B mixing and limitations

- Assume: (i) 3×3 CKM matrix is unitary; (ii) tree-level decays dominated by SM
- $h\, e^{2i\sigma} = A_{\rm NP}(B^0 \to \overline{B}^0)/A_{\rm SM}(B^0 \to \overline{B}^0)$

  Redo CKM fit w/ 4 BSM param's added:

  Relies on many measurements & theory inputs
- Big improvements: Sensitive to TeV scale, even if NP is MFV-like (loop & CKM suppressed)

  Complementary to high-p_T searches
- $|V_{cb}|$ becomes a bottleneck $\Rightarrow$ improve



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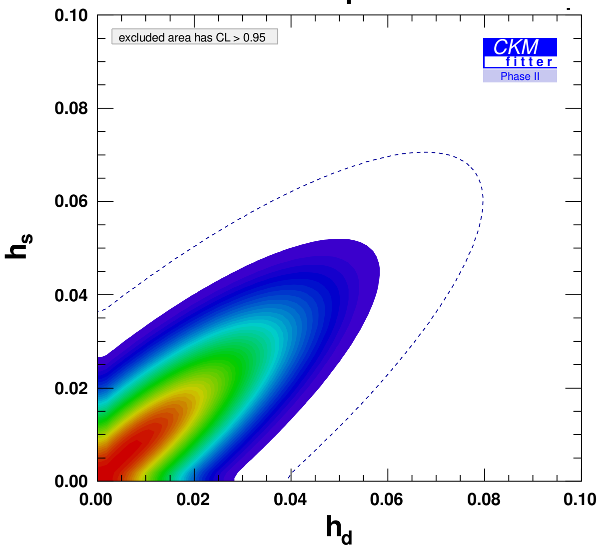
Bottlenecks

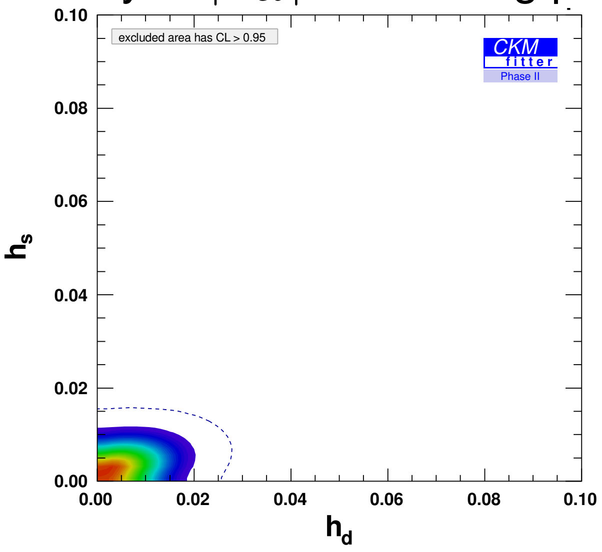
- Sensitivity does not improve as expected from Phase I to Phase II and Phase III

  Main bottlenecks: (i) $|V_{cb}|$ precision, (ii) mixing parameters from LQCD and η_B
- The Phase II sensitivity [LHCb 300/fb, Belle II 250/ab; late 2030s], as an example:

Nominal prediction



Set uncertainty of $|V_{cb}|$ and mixing param's $\to 0$



[2006.04824]

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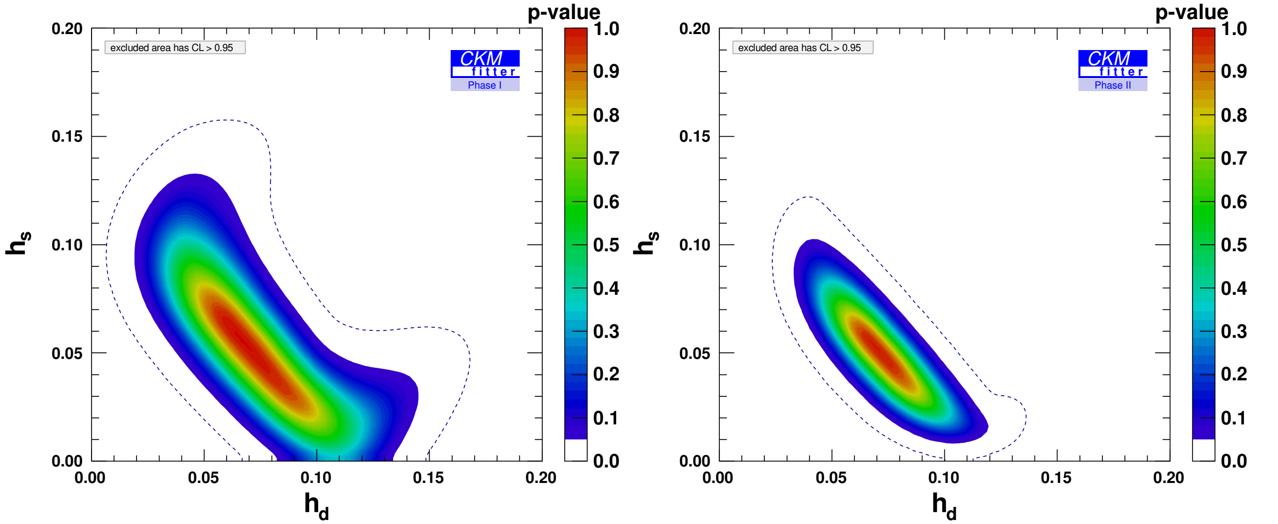
Example of discovery potential

- Discovery significance at Phase I (left) and Phase II (right), if central values (CKM param's, $h_{d,s}$, $\sigma_{d,s}$) remain as in the current fit

  (Assume future measurements have the same central values, with reduced uncertainties)



- If new physics contributes to semileptonic decays, as hinted at by the $R(D^{(*)})$ anomaly, then things get more complicated, may still isolate sources (see paper)

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CP violation in mixing: $A_{\rm SL}^{d,s}$

- CPV in mixing, BSM may not contain an m_c^2/m_b^2 suppressions, specific to the SM

[hep-ph/0202010]

$$A_{\rm SL} = {\rm Im}\frac{\Gamma_{12}}{M_{12}} = \frac{\Gamma[\overline{B}^0(t) \to \ell^+ X] - \Gamma[B^0(t) \to \ell^- X]}{\Gamma[\overline{B}^0(t) \to \ell^+ X] + \Gamma[B^0(t) \to \ell^- X]}$$

In large classes of BSM models, the dominant deviations from the SM may be in neutral meson mixing amplitudes, with smaller impacts on decay rates

- Current status: Data: $A_{\rm SL}^d = -(2.1 \pm 1.7) \times 10^{-3}$ $\quad A_{\rm SL}^s = -(0.6 \pm 2.8) \times 10^{-3}$

  SM: $A_{\rm SL}^d = -(4.7 \pm 0.6) \times 10^{-4}$ $\quad A_{\rm SL}^s = (2.22 \pm 0.27) \times 10^{-5}$ [1603.07770]

  Plenty of room between current sensitivity and the SM predictions

  (Hard to extrapolate whether LHCb becomes systematics limited)

- Tera-Z expectation: uncertainty $\sim 2.5 \times 10^{-5}$ for both $A_{\rm SL}^d$ and $A_{\rm SL}^s$

Lots of rare processes

Rare Z and h decays

- Intrinsic motivation: possible to probe Yukawa couplings in exclusive final states?

  E.g., $Z \to J/\psi\,\gamma$, expect $\mathcal{B} \sim 10^{-7}$ — calibration for $H \to J/\psi\,\gamma$ $(\mathcal{B} \sim 3 \times 10^{-6})$

  Focus of a number of papers, recently h, Z, W, t few-body decays [Study ~ 200 channels, 2312.11211]

- FCNC Z and h decays in SM probably beyond reach, jet tagging, small rates

  $\mathcal{B}(Z \to bs) \sim 4 \times 10^{-8}$ in SM, exp bound 3×10^{-3} [Tammaro @ Annecy]
  $\mathcal{B}(h \to bs) \sim 9 \times 10^{-8}$ in SM, exp bound 0.16, indirect bounds much better for both

- How about exclusive modes? Might $Z \to BK^*$ $(bK^*?)$ be measurable? [talking with D. d'Enterria]

(Very) rare (semi)leptonic decays

- Unique capabilities for decays with large missing energy, i.e., ν or τ in final state
  (And better than LHCb for $e^\pm$)

  Many decays mediated by $b \to s\nu\bar\nu$ or $b \to s\tau^+\tau^-$, and their $b \to d$ counterparts

- Tera-Z could be the first to measure

  $B \to K^{(*0)}\tau^+\tau^-$, $\Lambda_b \to \Lambda\tau^+\tau^-$, $B \to K^{(*)}\nu\bar\nu$, $B_s \to \phi\nu\bar\nu$, $\Lambda_b \to \Lambda\nu\bar\nu$, $B \to \pi(\rho)\nu\bar\nu$, etc.

- Two-body $B \to \ell^+\ell^-$ decays sensitive to very high scales (comparable to $K \to \pi\nu\bar\nu$)

  $B_{s,d} \to \mu^+\mu^-$: tera-Z expected to be comparable to HL-LHC
  $B_{s,d} \to \tau^+\tau^-$: tera-Z is much more sensitive: measure it, if $\geq$ SM level [$\sim 8 \times 10^{-7}$]

- Another important 2-body decay: $B_c \to \tau\bar\nu$

- $R_{K^{(*)}}$ and $R(D^{(*)})$: in many models, correlated effects in many of these processes

Inclusive $B \to X\ell^+\ell^-$ and $X\nu\bar\nu$

- Theoretically, inclusive $B \to X\nu\bar\nu$ is “easy”; questions will arise from experimental aspects — phase space cuts, sum over exclusive?

- $B \to X\ell^+\ell^-$: I think the role of J/ψ, ψ' is less understood than claims in literature

  Theoretical arguments (both for these and for nonleptonic decays) that $c\bar c$ loop should be perturbatively tractable, and arguments that they might not be so

- How to construct a sequence of tests to build a case?

  Nonleptonic decays no less puzzling than early 2000s, differences between QCD factorization and data more pronounced, even for $B \to$ heavy-light decay [2007.10338]

  (Charm loops an issue for $B \to$ light-light)

Inclusive semileptonic decay rates

- $\Gamma(B \to X_s\gamma)$ motivated multi-loop developments since '90s; important to constrain SM
- $\Gamma(B \to X_c\ell\bar{\nu})/|V_{cb}|^2$ has been calculated in the OPE with $\sim 2\%$ uncertainty

  Impressive recent 3-loop results (semileptonic rate, $m_b^{\rm kin}$) [2011.13654, 2011.11655, 2107.00604]
  And also α_s corrections to $\mathcal{O}(1/m^3)$ [2112.03875]

  My tentative conclusion: may be hitting a wall around 1% (may be too strong?)
  (Not accounting for any experimental cuts on phase space)

- Uncertainty of $|V_{cb}|$ will limit improving BSM sensitivity in B_d and B_s mixing
- If $\Gamma(B \to X_u\ell\bar{\nu})$ could be measured without cuts on phase space (to remove X_c background based on kinematics), uncertainty of $|V_{ub}|$ would be similar to $|V_{cb}|$

Since 2HDM came up: SIMBA analysis of $B \to X_s\gamma$

- Extract from global fit short-distance and hadronic parameters (shape functions) fully consistently

  [Bernlochner, Lacker, ZL, Stewart, Tackmann, Tackmann, 2007.04320]

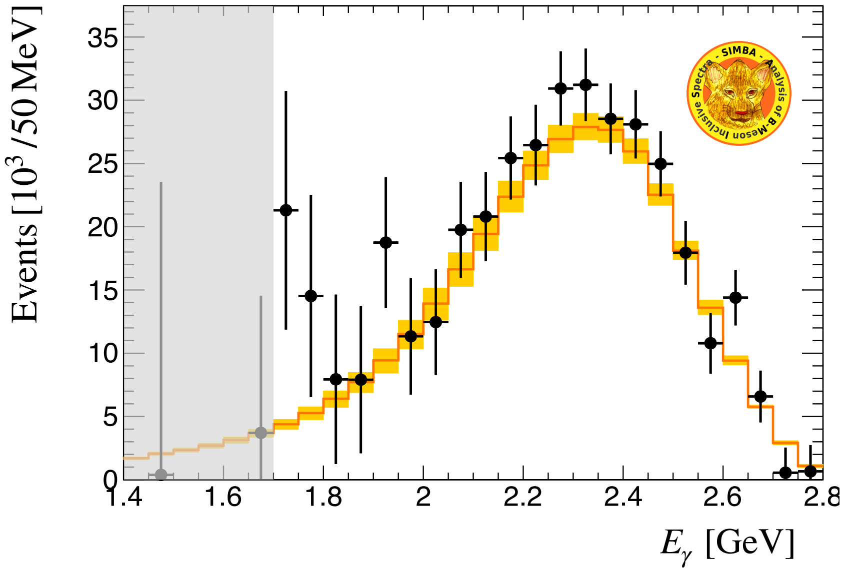
  Exp. & theor. uncertainty small in different regions

- SIMBA: Consistent theory across E_γ spectrum

  Model-independent treatment of shape fn.

  (issues: mass schemes, resummations, model dep.)

Belle inclusive Phys. Rev. Lett. 103, 241801 (2009)



$$|C_7^{\rm incl} V_{tb} V_{ts}| = (14.77 \pm 0.51_{\rm fit} \pm 0.59_{\rm theory} \pm 0.08_{\rm param}) \times 10^{-3}$$

Larger uncertainty than HFLAV

$$m_b^{1S} = (4.750 \pm 0.027_{\rm fit} \pm 0.033_{\rm theory} \pm 0.003_{\rm param})\ \mathrm{GeV}$$

$$\widehat{\lambda}_1 = (-0.210 \pm 0.046_{\rm fit} \pm 0.040_{\rm theory} \pm 0.056_{\rm param})\ \mathrm{GeV}^2$$

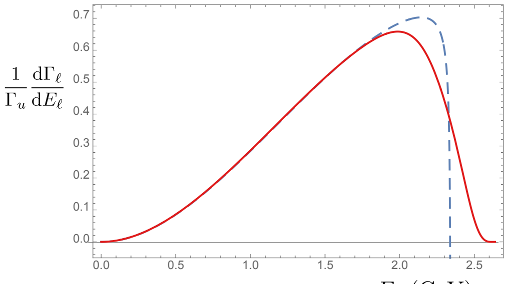
Inclusive $B \to X_u \tau \bar{\nu}$ — curiosity or doable?

- Calculated lepton energy spectrum, τ polarization, etc. [ZL, Luke, Tackmann, 2112.07685]

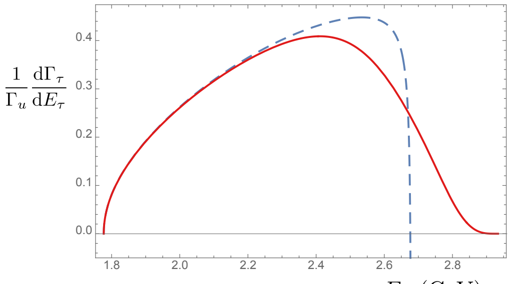
  Managed to write $\mathrm{d}\Gamma/\mathrm{d}E_\ell$ at $\mathcal{O}(\alpha_s)$ in closed form (1st time for massive $\to$ massive?)
  (As far as I know, $\mathrm{d}\Gamma/\mathrm{d}E_\ell$ at $\mathcal{O}(\alpha_s)$ is not known analytically in $B \to X_c e \bar{\nu}$)

- The b-quark pdf is much more important in $B \to X_u \tau \bar{\nu}$ than in $B \to X_u e \bar{\nu}$ decay!

  Sizable in half of the phase space

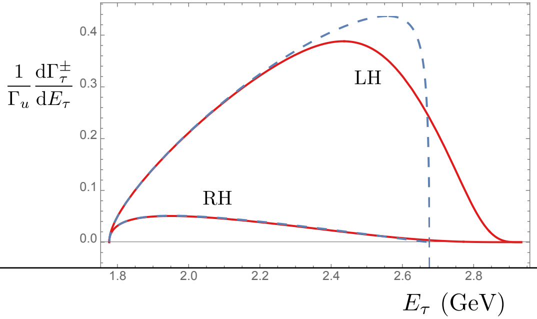


(a)



(b)

- Recent claim of a large correction from a dim-6 ("Darwin") term in HQET [Moreno, 2402.13805]



CP violation in D decay and mixing

- CP violation in D decay:

  LHCb, Nov. 2011: $\Delta A_{CP} \equiv A_{K^+K^-} - A_{\pi^+\pi^-} = -(8.2 \pm 2.4) \times 10^{-3}$ (I think a stretch in the SM)

  LHCb, Mar. 2019: $\Delta A_{CP} = -(1.82 \pm 0.33) \times 10^{-3}$ (only in 2021 was $\Delta m \neq 0$ established at $> 3\sigma$)

- Maximal effect that could be due to SM? CKM factors: $|V_{cb}V_{ub}/(V_{cd}V_{ud})| \simeq 7 \times 10^{-4}$

  Before measurements, most papers stated (assumed) that strong interaction suppresses CPV further

- Semileptonic and FCNC D decays are also of great interest

- Same questions about CPV in $D^0 - \overline{D}^0$ mixing: high scales probed, large improvements

  Complementary to B and K: down quarks in loops (or in SUSY up squarks)

- Can CP violation in decay, or in mixing (more "inclusive") still be a clear BSM probe?

Tidbits of τ physics

- Recent anomalies increased interest in probing lepton flavor universality

  PIONEER will soon improve $\pi \to e\nu$ vs. $\mu\nu$ by factor ~ 15 ($+$ searches for new particles)

- In τ decay, best precision from $\tau \to e\nu\bar{\nu}$ vs. $\mu\nu\bar{\nu}$ — and lifetime (n.b. $e_e \to \mu_\mu \to \tau_\tau$)

  Beyond statistics improvement, many analyses benefit from τ boost

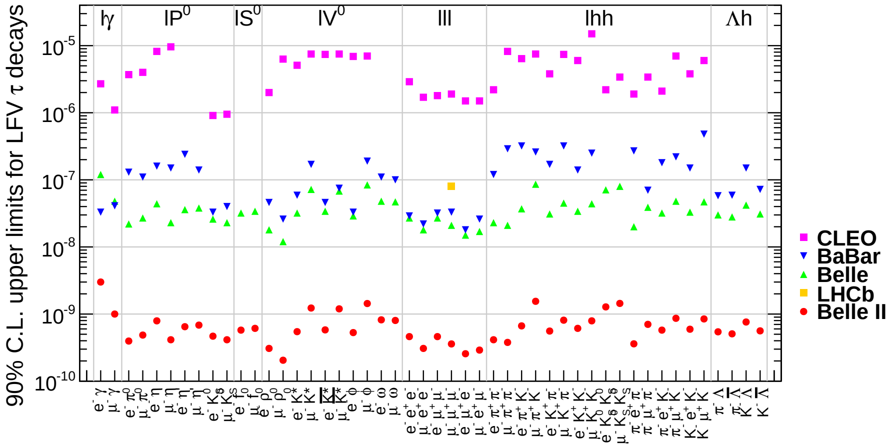
- Large improvements in CLFV τ searches

- Belle II: 2 orders of magnitude; e.g., $\tau \to \mu\gamma, \mu\mu\mu$

  Big model dependence in $\mathcal{B}(\tau \to \mu\gamma)/\mathcal{B}(\mu \to e\gamma)$

- FCC would yield further improvement

- Any discovery $\Rightarrow$ broad program to map structure



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Polarized baryons: unique, but how useful?

- Baryons can probe short-distance physics in some ways that mesons cannot

  b and c quarks in Z decays are highly polarized, largely retained by baryons

- Baryon polarization tells us about Dirac structure of operators that create them
  (Washed out by hadronization for mesons)

  Need to know how well the quark polarization is retained by the baryons
  (More work needed, connections with top decays [1505.02771])

- With highly polarized Λ_b from Z decay, semileptonic $\Lambda_b \to \Lambda_c \ell \nu$ can test the chirality of weak interaction in similar ways to the Michel parameters in μ decay

  Similar studies in rare FCNC decays, e.g., $\Lambda_b \to \Lambda \ell^+ \ell^-$ (+ analogous Λ_c decays)

Many "exotic" searches

- Better tests of (exact or approximate) conservation laws
- Exhaustive list of dark / hidden sector searches
- LFV meson decays, e.g., $M^0 \to \mu^- e^+$, $B^+ \to h^+ \mu^- e^+$, etc.
- Invisible modes, "mesogenesis", $B \to N + \text{invis.}\ [+\text{mesons}]$ [1708.01259, 1810.00880, 2101.02706]
- Hidden valley inspired scenarios, e.g., multiple displaced vertices, even with $\ell^+\ell^-$
- Exotic Higgs decays, e.g., high multiplicity, displaced vertices ($H \to XX \to abab$)
- Search for "quirks" (non-straight "tracks"); e.g., at LHCb using many velo layers
- Hot topics in 2040s are probably not what we have thought about so far
  (Whether or not NP is discovered by then)

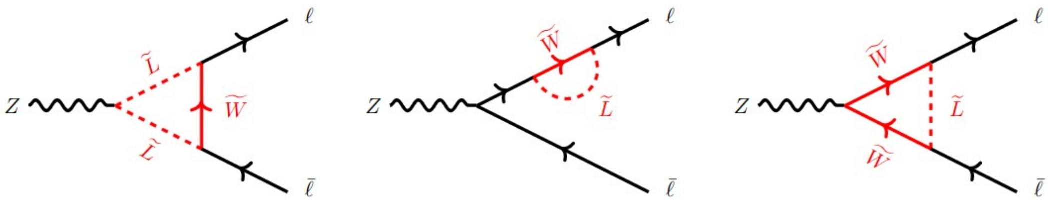
Tera-Z and SUSY

A particular sensitivity to SUSY

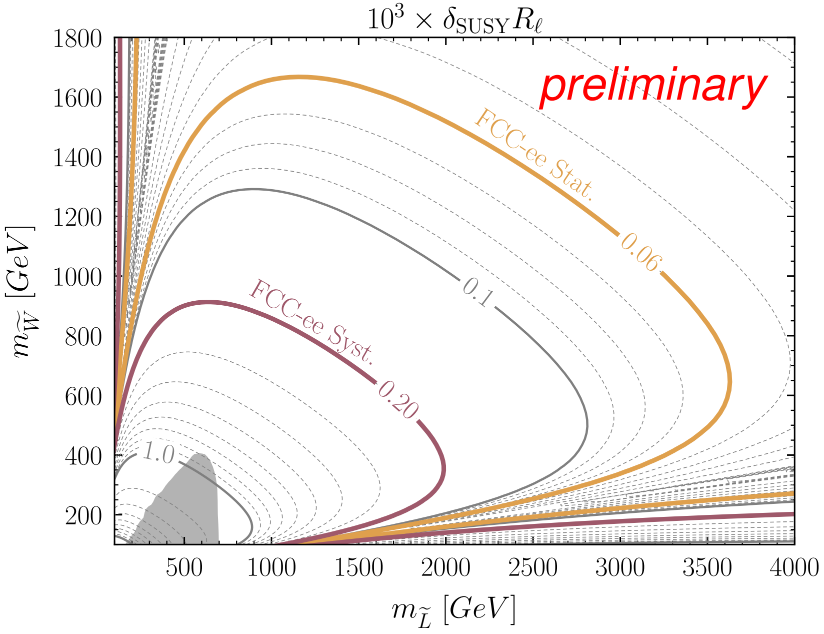
- Precisely measured: $R_\ell = \dfrac{\Gamma_{\ell^+\ell^-}}{\Gamma_{\text{hadrons}}}$

R^Z_ℓ ($\times 10^3$)	20767	±	25	**0.06**	0.2-1	Ratio of hadrons to leptons Acceptance for leptons

- Consider a SUSY simplified model, with $\tilde{q}, \tilde{g}$ heavy, only gauginos & sleptons light



[Knapen, Langhoff, ZL, soon]



- Ultimate sensitivity: stay tuned (α_s, $\sin^2\theta_W$, etc.)

  Significant sensitivity to flavor non-universal contribution

- Complementary to SMEFT based studies, any model may have important correlations

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Final remarks

Planning, similarities, 40 years ago

- "Lederman's Shoulder, Weinberg's Nose, and Other Lessons from the Past" [Politzer, 1982]

  Complementarity: "Planning for discovery is both absolutely necessary and fundamentally silly. We can't know what will be. However, we can look back. The unexpected has come sometimes at the highest energy frontier ... and sometimes in a careful look over old ground, such as CP violation ... Whatever the current theoretical beliefs, our future plans should not stifle the possibility of discovery."

- "Problems, Puzzles & Prospects: A Personal Perspective on Present Particle Physics" [Politzer, 1982]

  "A few years ago, we solved everything." "Is the smallness of the ... cosmological constant relative to the Planck scale ... the most importat problem facing basic physics or is it simply a non-problem?"

  "When is the soonest that something dramatic might happen? The answer here is clearly tomorrow. The answer might even be yesterday"

  "... the experimental prospects are wide open. All we have to do is try."

What are the largest useful data sets?

- No one has seriously explored it! (Recall, Sanda, 2003: the question is not 10^{35} or 10^{36}...)
- Which measurements will remain far from being limited by theory uncertainties?
  - For $\gamma \equiv \phi_3$, theory uncertainty only from higher order EW
  - $B_{s,d} \to \mu\mu$, $B \to \mu\nu$ and other leptonic decays (lattice QCD, [double] ratios)
  - $A_{\text{SL}}^{d,s}$ — can it keep scaling with statistics?
  - Lepton flavor violation & lepton universality violation searches
  - Possibly CP violation in D mixing (firm up theory)
- Very broad program
- In some decays, even in 2030s we'll have (exp. bound)/SM $\gtrsim 10^3$ (E.g., $B_{d,s} \to e^+e^-$, $\tau^+\tau^-$)
- Sensitivity to NP could improve with data $\gg$ LHCb, Belle II, tera-Z

Conclusions

- Flavor physics probes scales $\gg 1\,\text{TeV}$, sensitivity limited by statistics
  New physics in FCNCs may still be $\gtrsim 20\%$ of SM, could show up any time measurements improve
- Several tensions with SM; some of these (or others) could soon become decisive
- Discovering NP would give a target and upper bound on the next scale to explore
- Tera-Z would shed light on many open questions after LHC & Belle II
- Explosion of data always triggered unforeseen developments (both theory $+$ exp.)
- Complementarity between high p_T and precision probes of BSM (and understanding it)
- Ample reasons to aim for the largest possible data sets that technology allows