Searches of new physics in $s \to u\ell\nu$:

Interplay between semileptonic kaon and hyperon decays

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NA-62 Kaon Physics Handbook

H.M. Chang, M. Gonzalez-Alonso and JMC, PRL114(2015)16,161802
M. Gonzalez-Alonso and JMC, arXiv: 1602:XXXXX

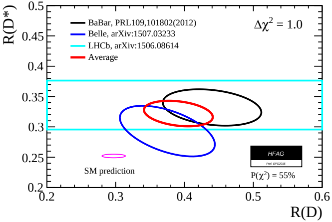
January 21, 2016

Outline

1. $s \to u\ell\nu$ transitions in EFT of NP
2. (Semi)leptonic Kaon decays in the context of NP
   - CKM unitarity and NP in the $\tilde{V}_{us}^{\ell} - \tilde{V}_{ud}^{\ell} -$ plane
   - LUV ratios
   - λ_0 in $K_{\mu 3}$ and bounds on scalar interactions
   - The Dalitz plot and the bounds on tensor contributions
3. Sensitivity to NP of semileptonic hyperon decays (SHD)
   - What are and why hyperons?
   - SHD and $SU(3)_F$-breaking expansion in a nutshell
   - Bounds on scalar and tensor operators from SHD
4. Discussion: Interest of a SHD physics program

(Lepton universality violating) New-Physics in B decays?

- **"$R_{D^{(*)}}$ anomaly"** in $B \to D^{(*)}\ell\nu$!



HFAG @ EPS-HEP 2015

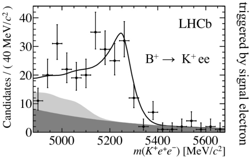
- ***Excesses*** observed at $\sim 4\sigma$
- Other "anomalies" in $b \to (u, c)\ell\nu$
  - Inclusive *vs.* Exclusive V_{ub} and V_{cb}

  S. Descotes-Genon talk

- $\Lambda_{\rm NP} \sim 2$ TeV

- **"R_K anomaly"** in $B \to K\ell\ell$ (**FCNC**)!

LHCb PRL113(2014)151601



$$R_K = 0.745^{+0.090}_{-0.074}(\text{stat}) \pm 0.036(\text{syst})$$

- Tension with **SM** $\sim 2.6\sigma$
- Other anomalies in $b \to s\mu\mu$
  - Branching fractions
  - Angular analysis $B \to K^*\mu\mu$
- Up to 4σ in global fits

  Descotes-Genon *et al.*'13, Altmannshofer and Straub '14,...

- $\Lambda_{\rm NP} \sim 30$ TeV

New-physics in light quark charged-current transitions?

- If $\Lambda_{\rm NP} \sim 1$ TeV it might show up in other flavor observables!

$$\mathcal{L}_{\rm eff}^{s\ell} = -\frac{G_F V_{us}}{\sqrt{2}}[(1+\epsilon_L^{s\ell})\bar{\ell}\gamma_\mu(1-\gamma_5)\nu_\ell\cdot\bar{u}\gamma^\mu(1-\gamma_5)s + \epsilon_R^{s\ell}\ \bar{\ell}\gamma_\mu(1-\gamma_5)\nu_\ell\ \bar{u}\gamma^\mu(1+\gamma_5)s$$

$$+\bar{\ell}(1-\gamma_5)\nu_\ell\cdot\bar{u}[\epsilon_S^{s\ell} - \epsilon_P^{s\ell}\gamma_5]s + \epsilon_T^{s\ell}\ \bar{\ell}\sigma_{\mu\nu}(1-\gamma_5)\nu_\ell\cdot\bar{u}\sigma^{\mu\nu}(1-\gamma_5)s] + \text{h.c.},$$

Wilson coefficients: ϵ_Γ decouple as $\sim v^2/\Lambda_{\rm NP}^2$

1. **Experimental data:** $K_{\ell 2}$ and $K_{\ell 3}$ boast an extremely rich database

   FlaviaNet Kaon Working Group, Antonelli *et al.* EPJC69, 399 (2010), Passemar's talk

2. **Hadronic matrix elements:** Flagship quantities in χPT and LQCD

   FLAG collaboration, Martinelli's talk

3. Radiative and isospin-breaking corrections understood!

   Cirigliano *et al.* Rev.Mod.Phys. 84 (2012) 399, Knecht's talk

Crucial inputs for CKM matrix Descotes-Genon's talk

- Pollutions of NP in determinations of V_{us}
- **Blindspots in kaons** $\Rightarrow$ **Interplay with hyperon decays!**
- *High-energy* EFT: Interplay with colliders

High-Energy EFT guiding principle

Construct the most general effective operators $\mathcal{O}_k$ built with ***all*** the SM fields and subject to the strictures of $SU(3)_c \times SU(2)_L \times U(1)_Y$

Buchmuller& Wyler'86, Grzadkowski *et al.*'10

- Symmetry relations for ϵ_Γ
  - Specially powerful in rare $D \to D'\ell\ell$: No C_T and less C_S Alonso, Grinstein, JMC, PRL113(2014)241802
  - In charged-currents ϵ_R^ℓ: Bernard, Oertel, Passemar & Stern PLB638(2006)480

$$\mathcal{O}_{Hud} = \frac{i}{\Lambda_{\rm NP}^2}\left(\tilde{H}^\dagger D_\mu H\right)\left(\bar{u}_R\gamma^\mu d_R\right)$$

☛ **RHC is lepton universal:** $\epsilon_R^\ell \equiv \epsilon_R + \mathcal{O}(\frac{v^4}{\Lambda_{\rm NP}^4})$

- High-energy $\Longleftrightarrow$ low-energy dictionary
  - Low-energy and collider analyses use the same EFT language
  - Implement flavor symmetries:
    - ★ $U(3)^5$: $\epsilon_R = \epsilon_S^\ell = \epsilon_P^\ell = \epsilon_T^\ell \equiv 0$!
    - ★ MFV: ϵ_R, ϵ_S^ℓ, ϵ_P^ℓ, ϵ_T^ℓ suppressed by small Yukawas!
  - Streamline tests of your favorite UV completion!

$K_{\ell 3}$

- Neglecting contributions $\mathcal{O}(\frac{v^4}{\Lambda^4_{\rm NP}})$ (terms quadratic in ϵ_i^2)

$$\Gamma(K_{\ell 3(\gamma)}) = \frac{\overbrace{G_F^2}^{\text{Measured in } \mu \text{ decay}} m_K^5}{192\pi^3}\, C\, S_{\rm EW}\, \underbrace{|\tilde{V}^\ell_{us}|^2 f_+(0)^2}_{\left(1+\epsilon_L^{s\ell}+\epsilon_R^{s}-\tilde{v}_L\right) V_{us}^{\rm SM}}\, \overbrace{I_K^\ell(\lambda_{+,0},\, \epsilon_S^{s\ell},\, \epsilon_T^{s\ell})}^{\text{Phase-space Int.}}\, \underbrace{\left(1+\delta^c+\delta^{c\ell}_{\rm em}\right)^2}_{\text{Rad. and isosp. corr.}}$$

- $f_+(0)$, δ^c and $\delta^{c\ell}_{\rm em}$ th. inputs (LQCD and χPT)
- $\epsilon^{s\ell}_{S,T}$ accessible through the spectra/angular distribution

Interference with SM is $\propto m_\ell$!

- K_{e3} spectra is SM-like! (sensitivity to $|\epsilon^{se}_{S,T}|^2$)
- $K_{\mu 3}$ sensitive $\Rightarrow$ Simultaneous fit of $\lambda_{+,0}$, $\epsilon_S^{s\mu}$, $\epsilon_T^{s\mu}$

- $|\tilde{V}^\ell_{us}|$ only accessible through CKM unitarity and LUV tests
  - Less NP-polluted for K_{e3}
  - Cross-contamination from NP in μ decays

K_{e3}, β-decay and CKM unitarity test

- **Nuclear β-decay:** $|\tilde{V}^e_{ud}| = \left(1 + \epsilon^{de}_L + \epsilon^d_R - \tilde{v}_L\right)\ V^{\mathrm{SM}}_{ud} = 0.97425(22)$

Hardy&Towner, PRC70,055502 (2009)

- At $\mathcal{O}(\epsilon_i^2)$ NP enters in K_{e3} only through $|\tilde{V}^e_{ud}| = 0.2237(9)$

FlaviaNet Kaon Working Group, Antonelli *et al.* EPJC69, 399 (2010), FLAG'13

- **CKM unitarity test:**

$$\left.\begin{array}{c} |\tilde{V}^e_{ud}|^2+|\tilde{V}^e_{us}|^2+|\tilde{V}^e_{ub}|^2-1\equiv\Delta_{\mathrm{CKM}} \\ |V^{\mathrm{SM}}_{ud}|^2+|V^{\mathrm{SM}}_{us}|^2+|V^{\mathrm{SM}}_{ub}|^2\equiv 1 \end{array}\right\} \Rightarrow |\tilde{V}^e_{ud}|(\epsilon^{d\ell}_L+\epsilon^d_R-\tilde{v}_L)+|\tilde{V}^e_{us}|(\epsilon^{s\ell}_L+\epsilon^s_R-\tilde{v}_L)=\frac{\Delta_{\mathrm{CKM}}}{2},$$

Cirigliano, Gonzalez-Alonso, Jenkins, NPB, 830(2010)95

$$\Delta_{\mathrm{CKM}} = -0.0008(6) \Longrightarrow \Lambda_{\mathrm{NP}} \sim 12\ \mathrm{TeV}$$

Passemar's talk

Interplay of K_{e3} y $\Gamma(K^{\pm}_{e2(\gamma)})/\Gamma(\pi^{\pm}_{e2(\gamma)})$

- $\Gamma(K^{\pm}_{e2(\gamma)})/\Gamma(\pi^{\pm}_{e2(\gamma)})$ and K_{e3} lead to CKM matrix elements with only LQCD input

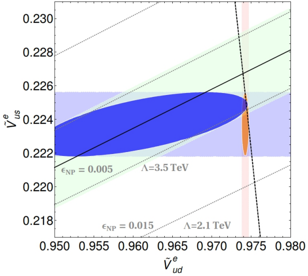
Marciano, PRL93(2004)231803

- **However:** P_{e2} is also sensitive to ϵ_R^D and ϵ_P^{De} !

Cirigliano&Rosell, PRL99(2007)231801

$$\frac{\Gamma(K^{\pm}_{e2(\gamma)})}{\Gamma(\pi^{\pm}_{e2(\gamma)})}=\frac{|\tilde{V}^e_{us}|^2}{|\tilde{V}^e_{ud}|^2}(1-2\epsilon_{\rm NP})\left(\frac{f_{K^\pm}}{f_{\pi^\pm}}\right)^2\frac{m_{K^\pm}}{m_{\pi^\pm}}(1+\delta_{\rm em})+\mathcal{O}((m_e/m_{\pi^\pm,K^\pm})^2,\epsilon^2)$$

$$\epsilon_{\rm NP}=2\epsilon_R^s-2\epsilon_R^d-\frac{m^2_{K^\pm}}{m_e\,(m_s+m_u)}\,\epsilon_P^{se}+\frac{m^2_{\pi^\pm}}{m_e\,(m_d+m_u)}\,\epsilon_P^{de}$$



- NP in the $|\tilde{V}^e_{ud}|-|\tilde{V}^e_{ud}|$ plane

$\epsilon_{\rm NP}=0.0068(26)$ (± 0.0050 at 95% C.L.)

Uncertainties dominated by $f_+(0)$, $f_{K^\pm}/f_{\pi^\pm}$

Connecting to the μ-sector: LUV ratios

- **Consequence of High-Energy EFT:** ϵ_R^s factors out from LUV ratios!
- $K_{\ell 3}$

$$r_{\mu e}=\frac{\tilde{V}_{us}^{\ell}\, f_+(0)\Big|_{\ell=\mu}}{\tilde{V}_{us}^{\ell}\, f_+(0)\Big|_{\ell=e}}\equiv\frac{\tilde{V}_{us}^{\mu}}{\tilde{V}_{us}^{e}}=1+\epsilon_L^{s\mu}-\epsilon_L^{se}+\mathcal{O}(\epsilon^2)$$

$$r_{\mu e}=1.002(5)$$

FlaviaNet Kaon Working Group, Antonelli *et al.* EPJC69, 399 (2010)

- $K_{\ell 2}$

$$R_K=\frac{\Gamma(K^{\pm}_{e2(\gamma)})}{\Gamma(K^{\pm}_{\mu 2(\gamma)})}=\frac{|\tilde{V}_{us}^{e}|^2}{|\tilde{V}_{us}^{\mu}|^2}\left(1+\frac{2m_P^2}{m_u+m_s}\left(\frac{\epsilon_P^{se}}{m_e}-\frac{\epsilon_P^{s\mu}}{m_\mu}\right)\right)\frac{m_e^2}{m_\mu^2}\,\frac{(1-m_e^2/m_P^2)^2}{(1-m_\mu^2/m_K^2)^2}\,(1+\delta_{\rm EM})+\mathcal{O}(\epsilon^2) \qquad (1)$$

  - Very accurately predicted in the **SM**: $R_K^{\rm SM}=2.477(1)\times 10^{-5}$ Cirigliano&Rosell, PRL99(2007)231801
  - Very precise experimental measurement: $R_K^{\rm SM}=2.488(12)\times 10^{-5}$
  - Bound on $\tilde{V}_{us}^{e}/\tilde{V}_{us}^{\mu}$ from $r_{\mu e}\Longrightarrow$ Very strong bounds on $\epsilon_P^{s\ell}$! ($\Lambda_{\rm NP}>100$ TeV!)
  - **Loophole:** Flavor structure $\epsilon_P^{s\ell}\propto m_\ell\,\epsilon_P^{s}$!! (MFV or 2HDMs)

Bounds on $\epsilon_S^{s\mu}$

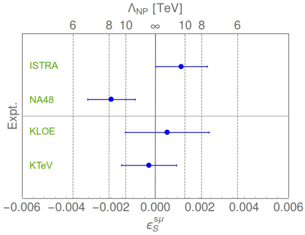
$$\overbrace{m_\mu \frac{f_0(q^2)}{f_+(0)}}^{\text{SM}} \longrightarrow \overbrace{m_\mu \frac{f_0(q^2)}{f_+(0)} \left(1 + \frac{q^2}{m_\mu(m_s - m_u)} \epsilon_S^{s\mu}\right)}^{\text{SM+NP}}$$

$$\lambda_0'^{\,\text{SM}} \longrightarrow \lambda_0' = \lambda_0'^{\,\text{SM}} + \frac{m_\pi^2}{m_\mu(m_s - m_u)} \epsilon_S^{s\mu}$$

- **Callan-Treiman th.:** Very accurate prediction of $\lambda_0'^{\,\text{SM}}$ using $f_+(0)$, f_K/f_π and χPT

$$\lambda_0'^{\,\text{SM}} = 14.3(8) \times 10^{-3}$$

Bernard *et al.*'06'09 (Dispersive), FLAG'13, Gasser&Leutwyler'84, Bijnens and Ghorbani'07



λ_0 has $\mathcal{O}(1)$ sensitivity to $\epsilon_S^{s\mu}$!

Probing $\Lambda_{\text{NP}} \sim 10$ TeV

Bounds on $\epsilon_T^{s\mu}$

- Tensor conts. not simply absorbed into FF parameters
  Direct analysis of the Dalitz plots is needed!
- New parameter in the FF fits, e.g. ISTRA+

O.P. Yushchenko et al. / Physics Letters B 581 (2004) 31–38

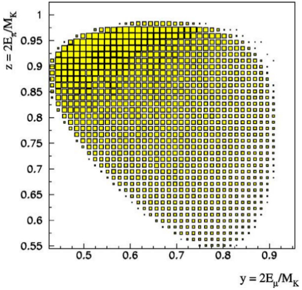


Table 1
The $K_{\mu 3}$ fits

λ_+, λ_0	λ'_+, λ'_0	$f_T/f_+(0), f_S/f_+(0)$
0.0277 ± 0.0013	0.	0.
0.0183 ± 0.0011	0.	0.
0.0215 ± 0.0060	0.0010 ± 0.0010	0.
0.0160 ± 0.0021	0.	0.
0.0216 ± 0.0013	0.001063	0.
0.0163 ± 0.0011	0.	0.
0.0276 ± 0.0014	0.	0.
0.0170 ± 0.0059	0.0002 ± 0.0008	0.
0.0276 ± 0.0014	0.	-0.0007 ± 0.0071
0.0183 ± 0.0011	0.	0.
0.0277 ± 0.0013	0.	0.
0.017	0.	0.0017 ± 0.0014

- In our parametrization $f_T = \epsilon_T^{s\mu} B_T^{\rm QCD}(0) \rightarrow \epsilon_T^{s\mu} = 0.001 \pm 0.011$ ($\Lambda_{\rm NP} \sim 5$ TeV)

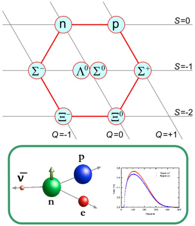
Baum *et al.*, PRD84,074503 (2011) (LQCD)

Question: Is a *full* fit to $\lambda'^{,\prime\prime}_{+,0}$ *and* ϵ_T^{μ} feasible?

Interplay with semileptonic hyperon decays

- **Semileptonic hyperon decays:** Same short-distance physics as $K_{\ell 2}$ and $K_{\ell 3}$
  1. **Alternative determination of** $|\tilde{V}_{us}^{\ell}|$
  2. **Combination of RHCs and pseudoscalar in** $K_{\ell 2}$**:** Disentangle ϵ_R^s and $\epsilon_P^{s\ell}$
  3. **Subtle extraction of tensor from** $K_{\ell 3}$**:** Alternative bounds from SHD ϵ_T^{μ}
  4. **Tensions in** λ_0**:** Independent bounds on ϵ_S^{μ}
- Successfully applied to $d \to u \ell \nu$ transitions: Nuclear and neutron β-decay

Bhattacharya *et al.*, PRD85(2012)054512



- **5** $SU(3)_F$ channels $\times$**2** lepton channels (e and μ)
  $\Lambda \to p \ell \nu$, $\Sigma^- \to n \ell \nu$, $\Xi^- \to \Sigma^0 \ell \nu$,
  $\Xi^- \to \Lambda \ell \nu$, $\Xi^0 \to \Sigma^+ \ell \nu$ (and $\Omega^- \to \Xi^{0(*)} \ell \nu$)
- **Half lifes**: $\tau_Y \sim 10^{-10}$ s
- **Very rich phenomenology:**
  - Polarization observables
  - $SU(3)$-relations to nucleon-structure observables
  - Data is (very) old: Much room for improvement

Semileptonic hyperon decays: Form factors and $SU(3)_F$

- In the **SM** there are **6** FF per channel

$$\langle B_2(p_2)|\bar{u}\gamma_\mu s|B_1(p_1)\rangle = \bar{u}_2(p_2)\left[f_1(q^2)\,\gamma_\mu + \frac{f_2(q^2)}{M_1}\,\sigma_{\mu\nu}q^\nu + \frac{f_3(q^2)}{M_1}\,q_\mu\right]u_1(p_1),$$

$$\langle B_2(p_2)|\bar{u}\gamma_\mu\gamma_5 s|B_1(p_1)\rangle = \bar{u}_2(p_2)\left[g_1(q^2)\gamma_\mu + \frac{g_2(q^2)}{M_1}\sigma_{\mu\nu}q^\nu + \frac{g_3(q^2)}{M_1}q_\mu\right]\gamma_5 u_1(p_1)$$

  - **Exact $SU(3)_F$:** $\langle B_a|J_b|B_c\rangle = f_{bac}F_J(q^2) + d_{bac}D_J(q^2)$
  - **Measure of $SU(3)_F$-breaking:** $\delta \equiv (M_1 - M_2)/M \sim 10 - 20\%$
  - **Kinematic expansion:** $q/M_1 \sim \mathcal{O}(\delta)$
    - ★ $f_1(0)$ ($f_2(0)$) related to the charges (magnetic moments) of p and n up to $\mathcal{O}(\delta^2)$ ($\mathcal{O}(\delta)$)
    - ★ **Second-class currents:** $f_3(q^2)$ and $g_2(q^2)$ are $\mathcal{O}(\delta)$
    - ★ $f_{2,3}(q^2)$ and $g_2(q^2)$ kinematically suppressed $\sim \delta$
    - ★ $g_3(q^2)$ suppressed by $\sim \delta^2$ because of $\langle B_2|\bar{u}\gamma_5 s|B_1\rangle \sim E_1/M_1$

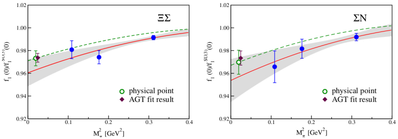
$$\Gamma_e \simeq \frac{G_F^2\,|V_{us}\,f_1(0)|^2\,\Delta^5}{60\,\pi^3}\left[\left(1-\frac{3}{2}\delta\right)+3\left(1-\frac{3}{2}\delta\right)\frac{g_1(0)^2}{f_1(0)^2}\right]+\mathcal{O}(\delta^2)$$

- Including $\mathcal{O}(\delta^2)$ in the rates is standard in analyses of SHD!

Garcia, Kielanowski, Bohm, Lect. Notes Phys. 222, 1 (1985), Cabibbo *et al.* Ann.Rev.Nucl.Part.Sci. 53 (2003) 39-75

$f_1(0)$ and $g_1(0)/f_1(0)$

- $f_1(0)$ essential to extract $\tilde{V}_{us}^{\ell}$ from SHD



- $f_1(0)$ protected by **Ademollo-Gatto th**

  $f_1(0) = f_1^{\mathrm{SU}(3)}(0) + \mathcal{O}(\delta^2)$

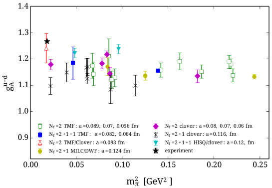
- Corrections in χPT problematic

  Geng, Li & JMC, PRD89(2014)11,113007

- **Efforts in LQCD!**

  Sasaki, PRD86(2012)114502, Shanahan *et al.* PRD92(2015)7,074029

- $g_1(0)/f_1(0)$ measured using angular and polarization information



Alexandrou, arXiv:1512.03924

	$\Lambda \to p$	$\Sigma^- \to n$	$\Xi^0 \to \Sigma^+$	$\Xi^- \to \Lambda$
$g_1(0)/f_1(0)$	0.718(15)	−0.340(17)	1.210(50)	0.250(50)

- Measurement of $g_1(0)$ sensitive to RHCs!

$$g_1(0) = (1 - 2\epsilon_R^s) g_1(0)^{\mathrm{QCD}}$$

- Much effort on $g_A(0)$ in LQCD !

NP contributions in SHD

- **New form factors:** Determine the sensitivity to $\epsilon_S^{s\ell}$, $\epsilon_P^{s\ell}$ and $\epsilon_T^{s\ell}$

$$\langle B_2(p_2)|\bar{u}\, s|B_1(p_1)\rangle = f_S(q^2)\ \bar{u}_2(p_2)\, u_1(p_1)$$

$$\langle B_2(p_2)|\bar{u}\,\gamma_5\, s|B_1(p_1)\rangle = g_P(q^2)\ \bar{u}_2(p_2)\,\gamma_5\, u_1(p_1)$$

$$\langle B_2(p_2)|\bar{u}\,\sigma_{\mu\nu}\, s|B_1(p_1)\rangle = f_T(q^2)\,\bar{u}_2(p_2)\,\sigma_{\mu\nu}\, u_1(p_1) + \mathcal{O}(\delta)$$

- $f_S(0)$ and $g_P(0)$ from **CVC** and **PCAC**

Gonzalez-Alonso&JMC, PRL112(2014)4,042501

$$\frac{f_S(0)}{f_1(0)} = \frac{M_2 - M_1}{m_s - m_u}, \qquad \frac{g_P(0)}{g_1(0)} = \frac{M_2 + M_1}{m_s + m_u}$$

- $f_T(0)$ calculated in **LQCD** for $n \to p$

Bhattacharya *et al.*, PRD85(2012)054512,..., ETMC, PRD92(2015)114513

- **SHD:** Use a model + $SU(3)_F$

$f_T(0)^{\rm LQCD} = 1.027(62)$, $f_T(0)^{\rm model} = 1.22$ for $n \to p$

Ledwig *et al.* PRD82(2010)034022

	$\Lambda \to p$	$\Sigma^- \to n$	$\Xi^0 \to \Sigma^+$	$\Xi^- \to \Lambda$
$f_S(0)/f_1(0)$	1.90(10)	2.80(14)	1.36(7)	2.25(11)
$f_T(0)/f_1(0)$	0.72	-0.28	1.22	0.22

- **Interference with SM $\propto m_\ell$:** μ-modes sensitive to $\epsilon_{S,P}^{s\ell}$ and $\epsilon_T^{s\ell}$
  - Electronic modes appropriate for measuring form factors!
- Sensitivity to $\epsilon_P^{s\ell}$ neutralized by $\sim E_1/M_1$
- **Define LUV ratio:** $R^{\mu e} = \frac{\Gamma(B_1 \to B_2\, \mu^- \, \bar{\nu}_\mu)}{\Gamma(B_1 \to B_2\, e^- \, \bar{\nu}_e)}$

- **SM:** Only phase-space up to $\mathcal{O}(\delta^2)$!

$$R_{\rm SM}^{\mu e} = \sqrt{1 - \frac{m_\mu^2}{\Delta^2}}\left(1 - \frac{9}{2}\frac{m_\mu^2}{\Delta^2} - 4\frac{m_\mu^4}{\Delta^4}\right) + \frac{15}{2}\frac{m_\mu^4}{\Delta^4}\,\text{arctanh}\left(\sqrt{1 - \frac{m_\mu^2}{\Delta^2}}\right)$$

- **NP:**

$$R_{\rm NP}^{\mu e} \simeq \frac{\left(\epsilon_S \frac{f_S(0)}{f_1(0)} + 12\,\epsilon_T \frac{g_1(0)}{f_1(0)}\frac{f_T(0)}{f_1(0)}\right)}{(1 - \frac{3}{2}\delta)\left(1 + 3\frac{g_1(0)^2}{f_1(0)^2}\right)}\Pi(\Delta, m_\mu)$$

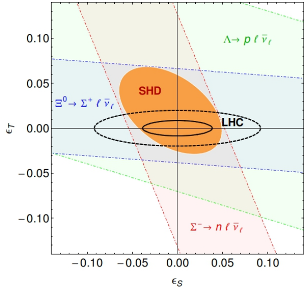
- Most data in the μ-channel is very old (60's and 70's)! $\delta\text{Br}/\text{Br} \sim 10\% - 100\%$

	$\Lambda \to p$	$\Sigma^- \to n$	$\Xi^0 \to \Sigma^+$	$\Xi^- \to \Lambda$
Expt.	0.189(41)	0.442(39)	0.0092(14)	0.6(5)
SM-NLO	0.153(8)	0.444(22)	0.0084(4)	0.275(14)

- Good agreement between SM and data $\Rightarrow$ Bounds on $\epsilon_S^{s\ell}$ and $\epsilon_T^{s\ell}$

Chang, Gonzalez-Alonso and JMC PRL114(2015)16,161802

SHD bounds on $\epsilon_S^{s\ell}$ and $\epsilon_T^{s\ell}$



Chang *et al.* PRL114(2015)16,161802

- **SHD competitive despite poor data!**

$$\epsilon_S^{s\mu} = 0.003(40)$$
$$\epsilon_T^{s\mu} = 0.017(34)$$

  - $\epsilon_S^{s\mu}$ an $\mathcal{O}(10)$ worse than Kaons
  - $\epsilon_T^{s\mu}$ only a $\times 3$ worse!!
  - Bounds better than LHC searches!

- Bounds from HE $s\bar{u} \to \ell\nu$
- **Same EFT language:** Assume that $\Lambda_{\rm NP} \gg \overline{m}_T$

$$N_{pp\to\ell\nu X}(m_T^2 > m_{T,cut}^2) = \varepsilon \times L \times \left(\sigma_W + \sigma_S \epsilon_S^2 + \sigma_T \epsilon_T^2\right)$$

Cirigliano *et al.* JHEP1302(2013)046

- Collider sensitivity is quadratic!

Discussion: Interest of resurrecting SHD physics program

- SHD can be probes of TeV scales complementary to Kaons
  - **Experimental side:** **Vast** room for improvement specially with muonic modes!
  - *e*-modes should be useful for ...
    - ★ Alternative determination of $\tilde{V}_{us}^{e}$
    - ★ Measure of form factors with Dalitz plots and spin observables (e.g. $g_2(0)$)
  - μ-modes useful for $\epsilon_{S,T}^{s\mu}$: $K_{\ell 3}$ bound on $\epsilon_{T}^{s\mu}$ can be easily improved!
- **Theory side:** Developments in LQCD and in χPT to go to $\mathcal{O}(\delta^2)$ accuracy (radiative corrections revisited?)
- **Rare hyperon decays?** Almost uncharted territory ...

- Back in 2009 ...

Hyperon Physics @ NA62

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NA62 Physics Handbook Workshop

NA62 (or NAXX) could do a very good job on the expt. side!