IMPLICATIONS OF CKM UNITARITY

$(|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 1)$

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KAON 07

- Superallowed Nuclear Beta Decays
- $|V_{ud}| = 0.97372(10)_{exp}(15)_{Nuc}(19)_{RC}$
- (Preliminary Update)
- Was 0.97377(11)(15)(19) in 2006

Neutron Decay: $|V_{ud}|^2 = \frac{4908.7(1.9)\text{sec}}{\tau_n(1+3g_A^2)}$

τ_n and g_A exp. discrepancies

Future Best Bet

Many New Experiments Planned

- Superallowed $0^+ \rightarrow 0^+$ Nuclear Beta Decays

Nucleus	$V_{ud}(15)_{Nuc}(19)_{RC}$	
^{10}C	0.97381(77)	
^{14}O	0.97368(39)	
^{26}Al	0.97390(21)*	
^{34}Cl	0.97412(26)	
^{38}K	0.97404(26)	
^{42}Sc	0.97317(28)*	
^{46}V	0.97284(34)*	
^{50}Mn	0.97372(53)*	
^{54}Co	0.97373(46)	*small changes
World Ave.	0.97372(10)(15)(19)	

K_{l3} Decays $K \to \pi l \nu_l$ ($l=e,\mu$):

$|V_{us}|=0.21673(46)/f_+(0)$ M. Moulson 2007

Lattice: $f_+(0)=0.9609(51)$

- $|V_{us}|=0.2255(5)_{exp}(12)_{f+(0)}$

*ChPT, $K_{\mu 2}$, tau decays -> smaller $V_{us} \approx 0.222(3)$

Future in the hands of lattice: $f_+(0)$, f_K/f_π, m_s

$|V_{ub}|^2=1\times10^{-5}$ Negligible: Becomes Cabibbo Universality

$V_{ud} \approx \cos\theta_C$ $V_{us}=\sin\theta_C=\lambda$ (Wolfenstein)

$|V_{ud}|^2+|V_{us}|^2+|V_{ub}|^2=0.9990(5)_{Vud}(2)_{Kl3}(5)_{f+}$

$=0.9990(7)$

Good Agreement With Unitarity

Confirms SM Radiative Corrections:

$2\alpha\ln(m_Z/m)/\pi+\ldots \approx +3.6\%$ at 50 sigma level!

Naively Fits $m_Z=74(11)$GeV

New Physics Constraints-Implications:

Exotic Muon Decays, W*bosons, SUSY,

Z' Bosons, Heavy Quark/Lepton Mixing…

- All CC and NC Amplitudes Normalized Relative To The Muon Lifetime

$\tau_\mu = 2.197019(21) \times 10^{-6}$ sec (update)

$G_F = G_\mu = 1.166371(6) \times 10^{-5}\,\mathrm{GeV}^{-2}$

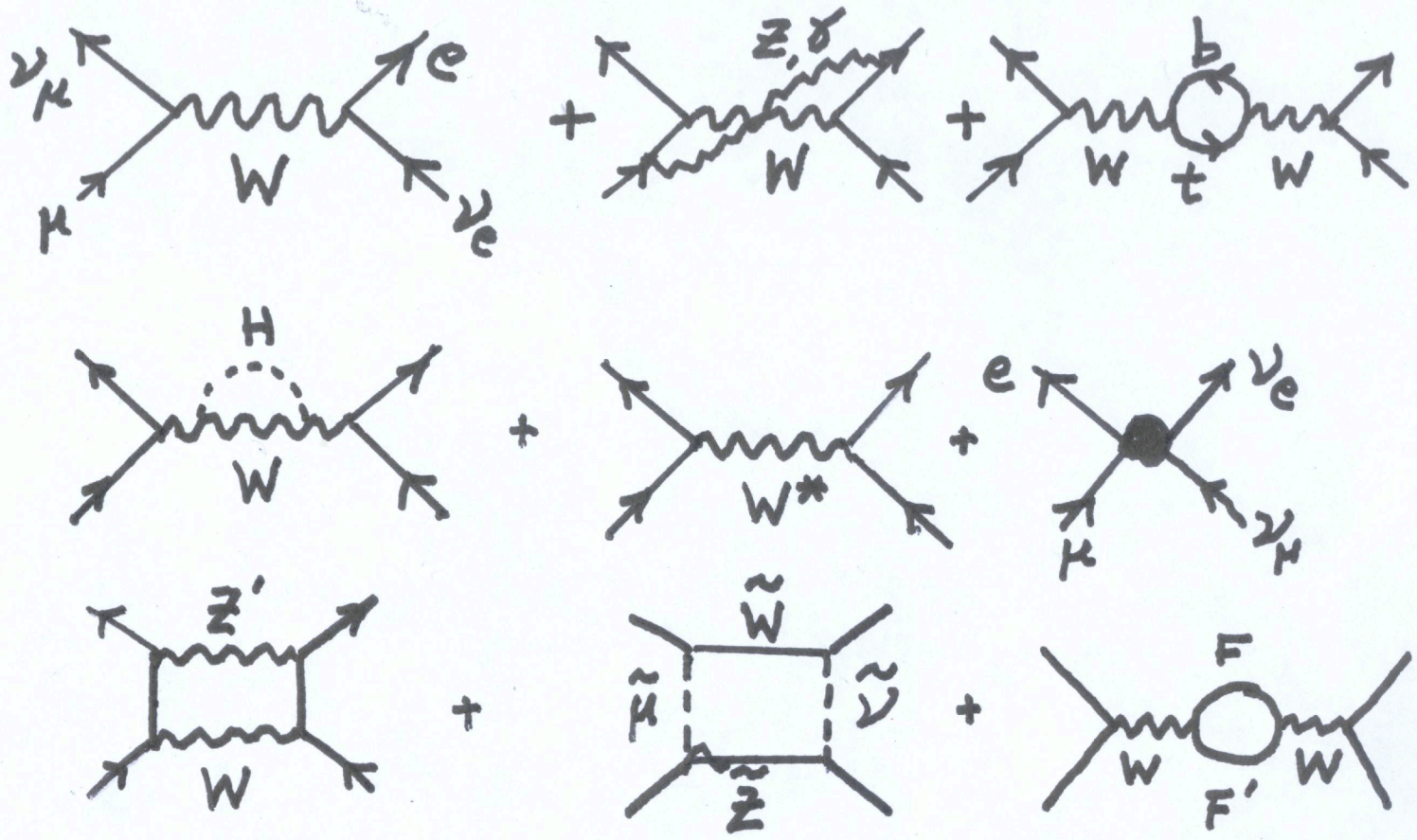
New Physics Effects Absorbed In G_μ:

Top-bottom loop, Higgs loop, W*, WZ' box,

SUSY loops, Technicolor, Exotic μ Decays…

Comparison of G_μ with other measurements unveils "New Physics"

Loop and Tree Level Corrections to Muon Decay



Z' Boson SUSY Technicolor

+ . . .

- Comparisons can be viewed as differences among Fermi Constants

$\mu \rightarrow e$ Decay $G_\mu = 1.166371(6) \times 10^{-5} GeV^{-2}$

$\tau \rightarrow \mu$ Decay $G_F = 1.1678(26) \times 10^{-5} GeV^{-2}$

$\tau \rightarrow e$ Decay $G_F = 1.1675(26) \times 10^{-5} GeV^{-2}$

Agreement Constrains Heavy Lepton Mixing

Other Precision Measurements:

$\alpha^{-1} = 137.036$, $m_W = 80.398(25) GeV$ (High),

$\sin^2\theta_W(m_Z)_{MS} = 0.23122(17)$

$\rightarrow G_F = 1.1655(12) \times 10^{-5} GeV^{-2}$

$= G_\mu(1-0.0085S+other)$

- S=0.09(12): No Sign of Technicolor,
  Mirror Fermions, 4th Gen…

CKM Unitarity: $G_F^{CKM}=1.1658(4)\times10^{-5}GeV^{-2}$

Best After τ_μ! $G_\mu=1.166371(6)\times10^{-5}GeV^{-2}$

Agreement Constrains: Exotic Muon Decays, Heavy Quark Mixing, W* (extra dim.),SUSY Loops (Squarks vs Sleptons), Z', …

- Exotic Muon Decays:
- $\mu \rightarrow e \nu_e \nu_\mu$ wrong neutrinos!
- BR=0.0010(7) allowed $\leq$0.002 (90%CL)
- Potential Background Uncertainty For Neutrino Oscillations At Neutrino Factory
- (LSND Effect? Babu and Pakvasa)
- Unlikely-But Needs Testing

- Heavy Quark Mixing (e.g. E6 D_L singlets)

  V_{uD}≈0.03? Possible

  Seems unlikely, since V_{ub}=0.003

- W* Excited KK Bosons (Extra Dim.)

  $4(m_W/m_{W^*})^2$=0.0010(7), m_{W^*}≈5TeV?
- Cancellation? Compare G_μ with m_W
- Suggests m_{W^*}≈3.8TeV (still high)
- (1TeV extra dim. Unlikely?)

- SUSY Loops: squarks in beta decay vs sleptons in muon decay loops
- Barbieri et al (1985)
- Ramsey-Musolf & Su (2006)
- Many Possibilities!
- More Natural $\rightarrow |V_{ud}|^2+|V_{us}|^2+|V_{ub}|^2 \geq 1$

  But large mixing can cause ≤ 1

  No real sign of supersymmetry in CKM!

  (g_μ-2, $b \rightarrow s\gamma$, $\mu \rightarrow e\gamma$ do better)

- Z' Bosons→WZ' Box Diagrams

Different For Muon and Beta Decay

$G_\mu = G_F^{CKM}[1-0.007Q_{eL}(Q_{\mu L}-Q_{dL})\ln x_i/(x_i-1)]$

$x_i=(m_{Zi}/m_W)^2$

SO(10) $Z\chi$ Boson: $Q_{eL}=Q_{\mu L}=-3Q_{dL}=1$

$m_{Z\chi} \geq 1$TeV (95%CL-One Sided)

Similar Bounds From APV & $A_{LR}(e^-e^-)$

No Sign of Z' Bosons!

- Summary and Conclusion

  CKM Unitarity Tested At The Quantum Loop Level: $|V_{ud}|^2+|V_{us}|^2+|V_{ub}|^2=0.9990(7)$!

  Constrains "New Physics" in Muon Decay and Beta Decay

- Future Improvements: V_{ud} neutron decay, V_{us} Lattice, ChPT, tau decays

  Goal: ±0.07%→±0.04%

  If $V_{us}\approx 0.222(3)$: $|V_{ud}|^2+|V_{us}|^2+|V_{ub}|^2=0.9974(14)$

  More Interesting-Potential 4-5 sigma!

  Confront LHC Discoveries!