

Theory Review on Rare Kaon Decays: SM and Beyond

Wolfgang Altmannshofer

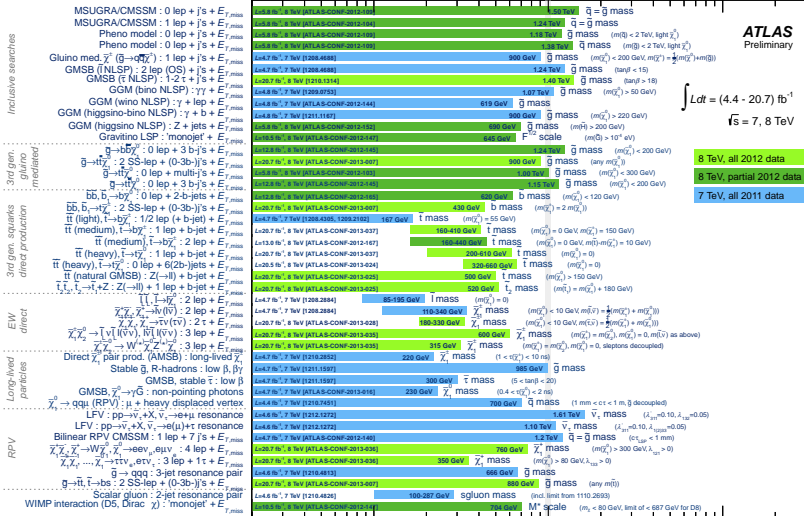


Snowmass Intensity Frontier Workshop
Argonne National Laboratory

April 25 - 27, 2013

Oh New Physics, Where Art Thou?

ATLAS SUSY Searches* - 95% CL Lower Limits (Status: March 26, 2013)



* Only a selection of the available mass limits on new states or phenomena shown.
All limits quoted are observed minus 1 σ theoretical signal cross section uncertainty.

Oh New Physics, Where Art Thou?

ATLAS Exotics Searches* - 95% CL Lower Limits (Status: HCP 2012)

Category	Search Description	Lower Limit [TeV]	Notes
Extra dimensions	Large ED (ADD): monojet + $E_{T,miss}$	4.37 TeV	M_D ($\delta=2$)
	Large ED (ADD): monophoton + $E_{T,miss}$	1.93 TeV	M_D ($\delta=2$)
	Large ED (ADD): diphoton & dilepton, $m_{\tau\tau}/8$	4.18 TeV	M_S (HLZ $\delta=3$, NLO)
	UED: diphoton + $E_{T,miss}$	1.41 TeV	Compact. scale R^4
	S/Z_ν ED: dilepton, $m_{\tau\tau}/8$	4.71 TeV	$M_{KK} - R^4$
	RS1: diphoton & dilepton, $m_{\tau\tau}/8$	2.23 TeV	Graviton mass ($k/M_{Pl} = 0.1$)
	RS1: ZZ resonance, $m_{\tau\tau}/8$	845 GeV	Graviton mass ($k/M_{Pl} = 0.1$)
	RS1: WW resonance, $m_{T,bl}/8$	1.23 TeV	Graviton mass ($k/M_{Pl} = 0.1$)
	RS $g_{\mu\nu} \rightarrow tt$ (BR=0.925): $tt \rightarrow l\bar{l}jets$, $m_{\tau\tau}/8$	1.9 TeV	g_{KK} mass
	ADD BH ($M_{Th}/M_D=3$): SS dimuon, $N_{obs}^{postcut}$	1.25 TeV	M_D ($\delta=6$)
CI	ADD BH ($M_{Th}/M_D=3$): leptons + jets, $2p$	1.5 TeV	M_D ($\delta=6$)
	Quantum black hole: dijet, $F(m_{ij})$	4.11 TeV	M_D ($\delta=6$)
	qqqq contact interaction: $\chi^2(m)$	7.8 TeV	M_D ($\delta=6$)
	qqll CI: ee & $\mu\mu$, m_{ij}	13.9 TeV	Λ (constructive int.)
	uutt CI: SS dilepton + jets + $E_{T,miss}$	1.7 TeV	Λ
	Z' (SSM): $m_{ee\mu\mu}$	2.49 TeV	Z' mass
	Z' (SSM): $m_{\tau\tau}$	1.4 TeV	Z' mass
	W' (SSM): $m_{\tau\tau bl}$	2.55 TeV	W' mass
	W' ($\rightarrow tq, g=1$): m_{tq}	430 GeV	W' mass
	W'_R ($\rightarrow tb$, SSM): m_{tb}	1.13 TeV	W' mass
LQ	W'_R ($\rightarrow tb$, SSM): m_{tb}	2.42 TeV	W' mass
	Scalar LQ pair ($\beta=1$): kin. vars. in eejj, evjj	660 GeV	l^i gen. LQ mass
	Scalar LQ pair ($\beta=1$): kin. vars. in $\mu\mu jj, \mu\nu jj$	685 GeV	$2^{i,j}$ gen. LQ mass
	Scalar LQ pair ($\beta=1$): kin. vars. in $\tau\tau jj, \tau\nu jj$	538 GeV	3^i gen. LQ mass
	4 th generation: $l^i l^i \rightarrow WbWb$	656 GeV	l^i mass
	4 th generation: $b\bar{b}(T_{S2}) \rightarrow WW$	670 GeV	$b'(T_{S2})$ mass
	New quark b' : $b\bar{b}' \rightarrow ZbX, m_{bb'}$	400 GeV	b' mass
	Top partner: $TT \rightarrow tt + A, A_0$ (dilepton), M_{T2}	483 GeV	T mass ($m(A) < 100$ GeV)
	Vector-like quark: CC, m_{T2}	1.12 TeV	VLQ mass (charge -1/3, coupling $\kappa_{qD} = v/m_{LQ}$)
	Vector-like quark: NC, m_{T2}	1.08 TeV	VLQ mass (charge 2/3, coupling $\kappa_{qD} = v/m_{LQ}$)
Excit. ferm.	Excited quarks: γ -jet resonance, m_{jet}	2.46 TeV	q^* mass
	Excited quarks: dijet resonance, m_{ij}	3.84 TeV	q^* mass
	Excited lepton: $l\gamma$ resonance, $m_{l\gamma}$	2.2 TeV	l^* mass ($\Lambda = m(l^*)$)
	Techni-hadrons (LSTC): dilepton, $m_{T,bl}$	850 GeV	ρ_i/ω_i mass ($m(\rho_i/\omega_i) - m(\pi_\pm) = M_{\rho_i}$)
	Techni-hadrons (LSTC): WZ resonance (η), $m_{T,bl}$	483 GeV	ρ_i mass ($m(\rho_i) = m(\tau_\pm) + m_{W_\pm}, m(A) = 2.1 m(\rho_i)$)
	Major. neutr. (LRSM, no mixing): 2-lep + jets	1.5 TeV	N mass ($m(W_\pm) = 2 TeV$)
	W_μ (LRSM, no mixing): 2-lep + jets	2.4 TeV	W_μ mass ($m(N) < 1.4 TeV$)
	$H_c^{H^\pm}$ (DY prod., $BR(H^\pm \rightarrow ll)=1$): SS eu, m_{ll}	409 GeV	$H_c^{H^\pm}$ mass (limit at 398 GeV for $\mu\mu$)
	$H_c^{H^\pm}$ (DY prod., $BR(H^\pm \rightarrow e\mu)=1$): SS eu, m_{ll}	375 GeV	$H_c^{H^\pm}$ mass
	Color octet scalar: dijet resonance, m_{ij}	1.86 TeV	Scalar resonance mass

ATLAS Preliminary

$$\int L dt = (1.0 - 13.0) \text{ fb}^{-1}$$

$$\sqrt{s} = 7, 8 \text{ TeV}$$



* Only a selection of the available mass limits on new states or phenomena shown

The Rarer the Better

Standard Model

generic New Physics

$$s \rightarrow d \quad \sim \frac{g_2^4}{16\pi^2} \frac{1}{M_W^2} V_{ts} V_{td}^* \simeq \frac{1}{(130 \text{ TeV})^2}$$

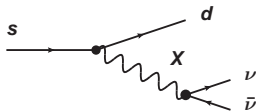
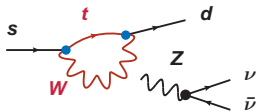
$$\sim \frac{1}{M_X^2}$$

$$b \rightarrow d \quad \sim \frac{g_2^4}{16\pi^2} \frac{1}{M_W^2} V_{tb} V_{td}^* \simeq \frac{1}{(26 \text{ TeV})^2}$$

$$\sim \frac{1}{M_X^2}$$

$$b \rightarrow s \quad \sim \frac{g_2^4}{16\pi^2} \frac{1}{M_W^2} V_{tb} V_{ts}^* \simeq \frac{1}{(12 \text{ TeV})^2}$$

$$\sim \frac{1}{M_X^2}$$



Rare Kaon Decays Discussed in this Talk

$$K^+ \rightarrow \pi^+ \nu \bar{\nu}$$

$$K_L \rightarrow \pi^0 \nu \bar{\nu}$$

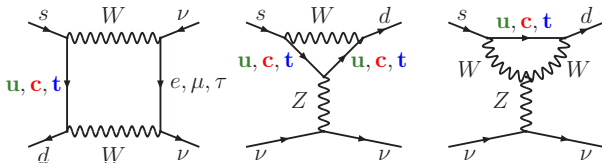
$$K_L \rightarrow \pi^0 e^+ e^-$$

$$K_L \rightarrow \pi^0 \mu^+ \mu^-$$

Rare Kaon Decays in the Standard Model

(many thanks to Joachim Brod for providing many slides)

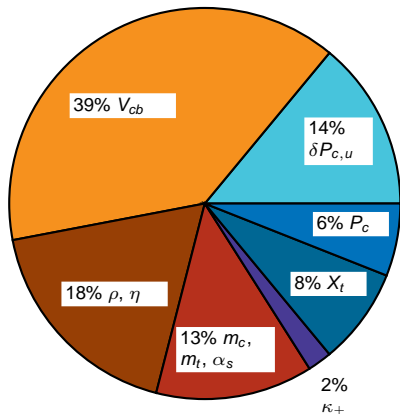
$K^+ \rightarrow \pi^+ \nu \bar{\nu}$ in the SM



$$\text{BR}(K^+ \rightarrow \pi^+ \nu \bar{\nu}) = \kappa_+ (1 + \Delta_{\text{EM}}) \times \left| \frac{1}{\lambda^5} \lambda_t X_t(m_t^2) + \frac{1}{\lambda} \left(\lambda_c P_c(m_c^2) + \lambda_c \delta P_{c,u} \right) \right|^2$$

- ▶ hadronic matrix element κ_+ from well measured $K \rightarrow \pi \ell \nu$ decay, corrected for isospin breaking and QED effects (Mescia, Smith '07)
- ▶ top contrib. $\propto \lambda^5 \frac{m_t^2}{m_W^2}$ NLO QCD and NLO EW (Misiak, Urban '99; Brod et al. '11)
- ▶ charm contrib. $\propto \lambda \frac{m_c^2}{m_W^2} \log \frac{m_c^2}{m_W^2}$ NNLO QCD and NLO EW (Buras et al. '06; Brod et al. '11)
- ▶ long distance $\propto \lambda \frac{\Lambda_{\text{QCD}}^2}{m_W^2}$ estimated in χ PT (Isidori et al. '05)

$K^+ \rightarrow \pi^+ \nu \bar{\nu}$: Error Budget



- ▶ main parametric error from V_{cb}
- ▶ improve on $\delta P_{c,u}$ by lattice calculations

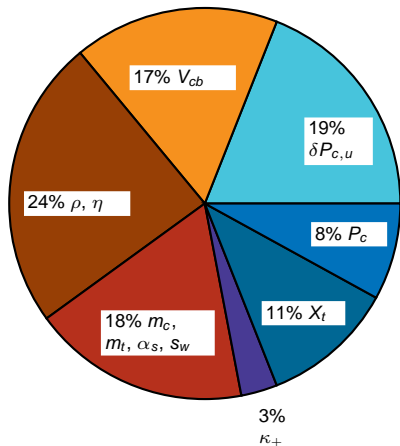
$$\text{Br}^{\text{th}}(K^+) = 7.81(75)(29) \times 10^{-11}$$

Brod, Gorbahn, Stamou '11

$$\text{Br}^{\text{exp}}(K^+) = (17.3^{+11.5}_{-10.5}) \times 10^{-11}$$

E787, E949 '08

$K^+ \rightarrow \pi^+ \nu \bar{\nu}$: Future Error Budget



- ▶ assume reduced uncertainty on V_{cb}

$$\delta V_{cb}/V_{cb} = 1\%$$

$$\text{Br}^{\text{th}}(K^+) = 7.81(37)(29) \times 10^{-11}$$

talk by Brod, Project X Physics Study '12

$$\text{Br}^{\text{exp}}(K^+) = (17.3_{-10.5}^{+11.5}) \times 10^{-11}$$

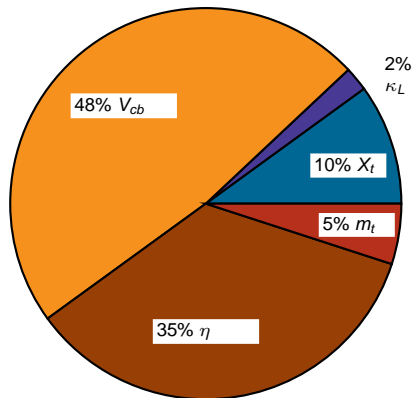
E787, E949 '08

$K_L \rightarrow \pi^0 \nu \bar{\nu}$ is almost purely *CP*-violating

$$\text{BR}(K_L \rightarrow \pi^0 \nu \bar{\nu}) = \kappa_L \times \left[\frac{1}{\lambda^5} \text{Im} \left(\lambda_t X_t(m_t^2) \right) \right]^2$$

- ▶ completely top-quark dominated
- ▶ essentially free of long distance “pollution”

$K_L \rightarrow \pi^0 \nu \bar{\nu}$: Error Budget



- ▶ dominant uncertainty from V_{cb}
- sizable uncertainty also from η

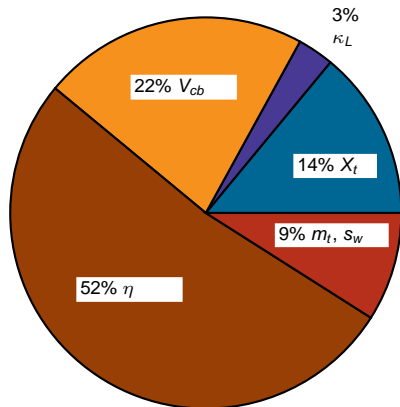
$$\text{Br}^{\text{th}}(K_L) = 2.43(39)(6) \times 10^{-11}$$

Brod, Gorbahn, Stamou '11

$$\text{Br}^{\text{exp}}(K_L) < 2.6 \times 10^{-8}$$

E391a '08

$K_L \rightarrow \pi^0 \nu \bar{\nu}$: Future Error Budget



- ▶ assume reduced uncertainty on V_{cb}

$$\delta V_{cb}/V_{cb} = 1\%$$

$$\text{Br}^{\text{th}}(K_L) = 2.43(25)(6) \times 10^{-11}$$

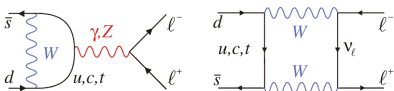
talk by Brod, Project X Physics Study '12

$$\text{Br}^{\text{exp}}(K_L) < 2.6 \times 10^{-8}$$

E391a '08

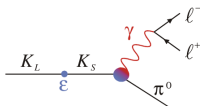
$K_L \rightarrow \pi^0 \ell^+ \ell^-$: Three Types of Contributions

▶ short distance Direct CP Violating



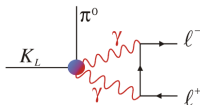
- ▶ described by local 4 fermion operators
- ▶ known at NLO in QCD (Buchalla et al. '95)

▶ long distance Indirect CP Violating



- ▶ estimate from ϵ_K and $K_S \rightarrow \pi \ell^+ \ell^-$ (D'Ambrosio et al. '98; Mescia et al. '06)
- ▶ sign of interference with DCPV?

▶ long distance CP Conserving



- ▶ estimate from $K_L \rightarrow \pi^0 \gamma \gamma$ (Isidori et al. '04)

SM Predictions for the Branching Ratios

$$B^{\text{SM}}(K_L \rightarrow \pi^0 e^+ e^-) = 3.23^{+0.91}_{-0.79} [1.37^{+0.55}_{-0.43}] \times 10^{-11}$$

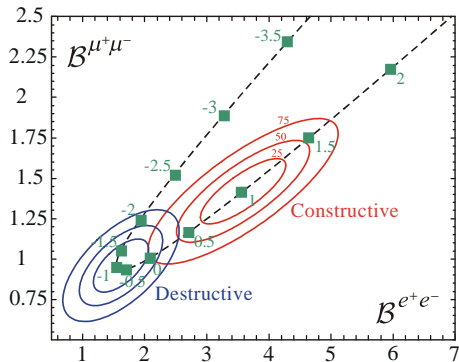
$$B^{\text{SM}}(K_L \rightarrow \pi^0 \mu^+ \mu^-) = 1.29^{+0.24}_{-0.23} [0.86^{+0.18}_{-0.17}] \times 10^{-11}$$

Mertens, Smith '11

$$B^{\text{exp}}(K_L \rightarrow \pi^0 e^+ e^-) < 28 \times 10^{-11}$$

$$B^{\text{exp}}(K_L \rightarrow \pi^0 \mu^+ \mu^-) < 38 \times 10^{-11}$$

KTEV '00; '03



Mescia, Smith, Trine '06

Uncertainty in SM prediction dominated by $K_S \rightarrow \pi^0 \ell^+ \ell^-$ measurements!

Rare Kaon Decays as Probes of New Physics

Model Independent Approach

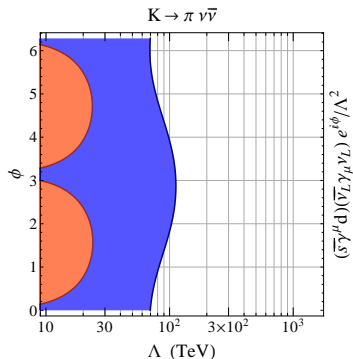
$$\mathcal{H}_{\text{eff}} = \mathcal{H}_{\text{eff}}^{\text{SM}} + \sum_i \mathcal{O}_i \times (c_i/\Lambda_{\text{NP}}^2)$$

Operator	Observable	in MSSM?										
		$K^+ \rightarrow \pi^+ \nu \bar{\nu}$	$K_L \rightarrow \pi^0 \nu \bar{\nu}$	$K_L \rightarrow \pi^0 l^+ l^-$	$K_L \rightarrow l^+ l^-$	$K^+ \rightarrow l^+ \nu$	$P_T(K^+ \rightarrow \pi^0 \mu^+ \nu)$	Δ_{CKM}	ϵ'/ϵ	ϵ_K		
$Q_{lq}^{(1)}$	$(\bar{D}_L \gamma_\mu S_L)(\bar{L}_L \gamma^\mu L_L)$	✓	✓	✓	hs	—	—	—	—	—	—	✓
$Q_{lq}^{(3)}$	$(\bar{D}_L \gamma_\mu \sigma^i S_L)(\bar{L}_L \gamma^\mu \sigma^i L_L)$	✓	✓	✓	hs	hs	✓	✓	—	—	—	✓
Q_{qe}	$(\bar{D}_L \gamma_\mu S_L)(\bar{l}_R \gamma^\mu l_R)$	—	—	✓	hs	hs	✓	✓	—	—	—	small
Q_{ld}	$(\bar{d}_R \gamma_\mu s_R)(\bar{L}_L \gamma^\mu L_L)$	✓	✓	✓	hs	—	—	—	—	—	—	small
Q_{ed}	$(\bar{d}_R \gamma_\mu s_R)(\bar{l}_R \gamma^\mu l_R)$	—	—	✓	hs	—	—	—	—	—	—	small
Q_{lq}^\dagger	$(\bar{u}_R S_L)(\bar{l}_R L_L)$	—	—	—	—	✓	✓	✓	—	—	—	tiny
$(Q_{lq}^\dagger)^\dagger$	$(\bar{u}_R \sigma_{\mu\nu} S_L)(\bar{l}_R \sigma^{\mu\nu} L_L)$	—	—	—	—	—	?	?	—	—	—	tiny
Q_{qde}	$(\bar{d}_R S_L)(\bar{L}_L l_R)$	—	—	✓	✓	—	—	—	—	—	—	tiny
Q_{qde}^\dagger	$(\bar{D}_L s_R)(\bar{l}_R L_L)$	—	—	✓	✓	✓	✓	✓	—	—	—	large $\tan \beta$
$Q_{\phi q}^{(1)}$	$(\bar{D}_L \gamma_\mu S_L)(\phi^\dagger D^\mu \phi)$	✓	✓	✓	hs	—	—	—	✓	(✓)	—	✓
$Q_{\phi q}^{(3)}$	$(\bar{D}_L \gamma_\mu \sigma^i S_L)(\phi^\dagger D^\mu \sigma^i \phi)$	✓	✓	✓	hs	hs	✓	✓	✓	(✓)	—	✓
$Q_{\phi d}$	$(\bar{d}_R \gamma_\mu s_R)(\phi^\dagger D^\mu \phi)$	✓	✓	✓	hs	—	—	—	✓	(✓)	—	large $\tan \beta$ (non-MFV)

[see S. Jäger, talk at NA62 Physics Handbook Workshop]

Probing High Scales with $K \rightarrow \pi \nu \bar{\nu}$

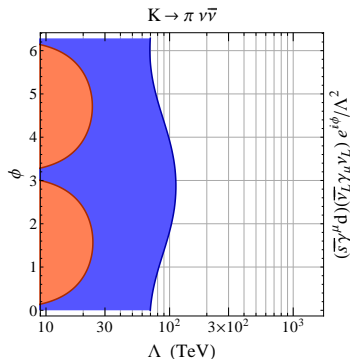
current situation



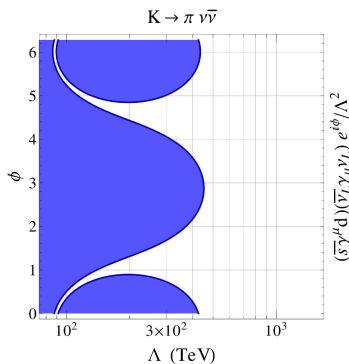
- ▶ $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ already constrains scales of ~ 100 TeV
- ▶ $K_L \rightarrow \pi^0 \nu \bar{\nu}$ bound still above the Grossman-Nir bound
→ no additional constraint

Probing High Scales with $K \rightarrow \pi \nu \bar{\nu}$

current situation



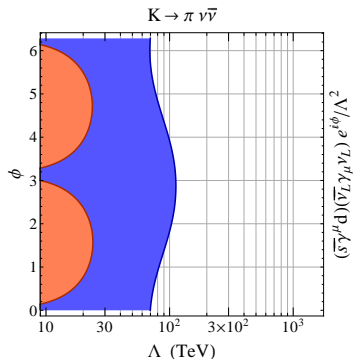
assuming 5% measurements of both modes



- ▶ $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ already constrains scales of ~ 100 TeV
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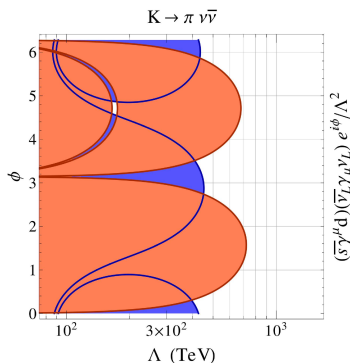
Probing High Scales with $K \rightarrow \pi \nu \bar{\nu}$

current situation



- ▶ $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ already constrains scales of ~ 100 TeV
- ▶ $K_L \rightarrow \pi^0 \nu \bar{\nu}$ bound still above the Grossman-Nir bound
→ no additional constraint

assuming 5% measurements of both modes



- ▶ $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ and $K_L \rightarrow \pi^0 \nu \bar{\nu}$ give complementary information
- ▶ scales of order 700 TeV are probed

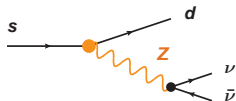
Modified Z Penguins

- ▶ in many NP models, largest effects in the Kaon decays come from Z penguins
- ▶ model independent parametrization of **modified Z couplings**

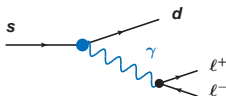
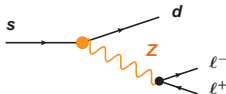
$$(V_{ts}V_{td}^*C_{\text{SM}} + C_{\text{NP}})(\bar{d}_L\gamma_\mu s_L)Z^\mu + \tilde{C}_{\text{NP}}(\bar{d}_R\gamma_\mu s_R)Z^\mu$$

- ▶ correlated effects in various processes

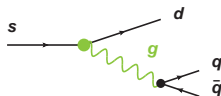
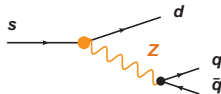
$K \rightarrow \pi\nu\bar{\nu}$



$K_L \rightarrow \pi^0\ell^+\ell^-$

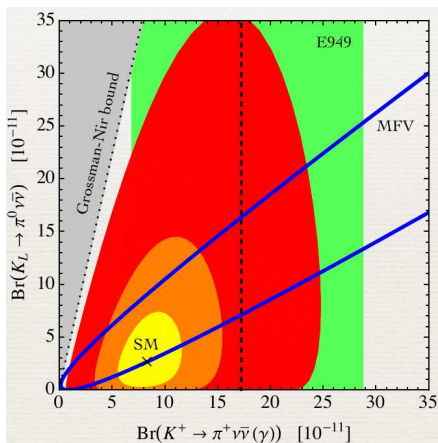


$\epsilon'/\epsilon \quad (K \rightarrow \pi\pi)$



Z Penguins in $K \rightarrow \pi \nu \bar{\nu}$

- ▶ $|C_{NP}| \leq 0.5 |V_{ts} V_{td}^* C_{SM}|$
- ▶ $|C_{NP}| \leq |V_{ts} V_{td}^* C_{SM}|$
- ▶ $|C_{NP}| \leq 2 |V_{ts} V_{td}^* C_{SM}|$
- ▶ The assumption of **Minimal Flavor CP Violation** leads to a strict correlation between the two neutrino modes



talk by Haisch, Project X Physics Study '12

Z Penguins in $K \rightarrow \pi \nu \bar{\nu}$

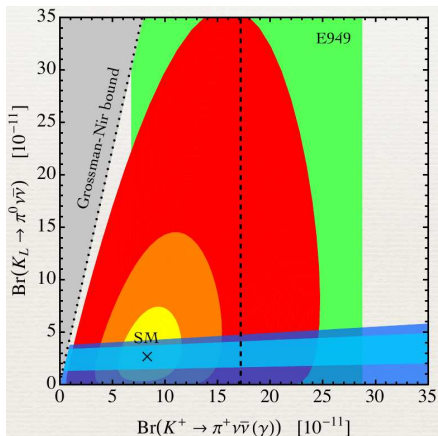
- ▶ $|\mathbf{C}_{\text{NP}}| \leq 0.5 |V_{ts} V_{td}^* \mathbf{C}_{\text{SM}}|$
- ▶ $|\mathbf{C}_{\text{NP}}| \leq |V_{ts} V_{td}^* \mathbf{C}_{\text{SM}}|$
- ▶ $|\mathbf{C}_{\text{NP}}| \leq 2 |V_{ts} V_{td}^* \mathbf{C}_{\text{SM}}|$
- ▶ The assumption of **Minimal Flavor CP Violation** leads to a strict correlation between the two neutrino modes
- ▶ constraint from ϵ'/ϵ

$$0.2(\epsilon'/\epsilon)_{\text{SM}} < \epsilon'/\epsilon < 5(\epsilon'/\epsilon)_{\text{SM}}$$

$$0.5(\epsilon'/\epsilon)_{\text{SM}} < \epsilon'/\epsilon < 2(\epsilon'/\epsilon)_{\text{SM}}$$

excludes huge enhancements of $K_L \rightarrow \pi^0 \nu \bar{\nu}$

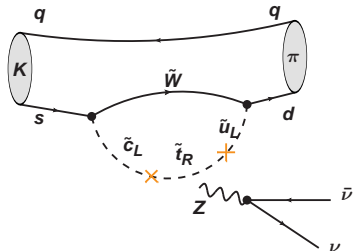
(barring cancellations with contrib. other than Z penguins)



talk by Haisch, Project X Physics Study '12

$K \rightarrow \pi \nu \bar{\nu}$ in the MSSM

Colangelo, Isidori '98



$$\sim \frac{g^4}{16\pi^2} \frac{1}{M_Z^2} (\delta_u^{LR})_{23} (\delta_u^{LR})_{13}^*$$

- ▶ dominant contribution comes from a Wino-loop induced Z penguin
- ▶ effective $(2 \rightarrow 1)$ transition through the third generation $(2 \rightarrow 3) \times (3 \rightarrow 1)$
- ▶ $K \rightarrow \pi \nu \bar{\nu}$ decays probe flavor violation in the up-squark sector!
- ▶ several motivated frameworks exist that lead to $O(1)$ effects in the BRs

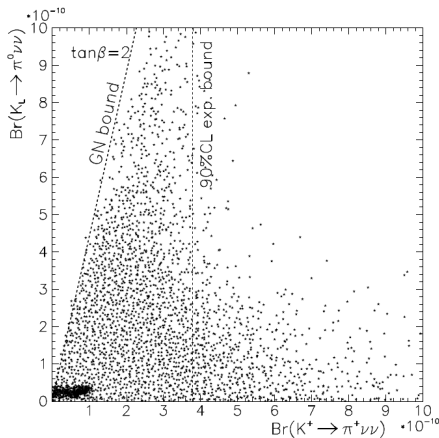
models with “Radiative Flavor Violation” Crivellin, Hofer, Nierste, Scherer '11

“Disoriented A terms” Giudice, Isidori, Paradisi '12

$K \rightarrow \pi \nu \bar{\nu}$ in the MSSM

- ▶ large effects in $K \rightarrow \pi \nu \bar{\nu}$ cannot be excluded by Kaon and charm mixing constraints (mainly sensitive to other, independent sources of flavor violation)
- ▶ result of a **general scan of the MSSM parameter space**, taking into account all relevant constraints (apart from ϵ'/ϵ !):

both branching ratios can in principle be enhanced by **more than an order of magnitude** (ϵ'/ϵ constraint has to be “fine-tuned away”)



Buras, Ewerth, Jager, Rosiek '05

$K \rightarrow \pi \nu \bar{\nu}$ and Partial Compositeness

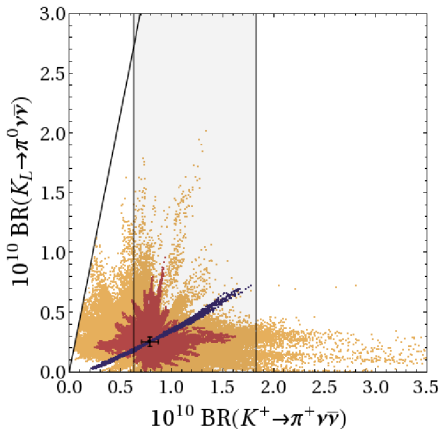
- ▶ mixing of elementary SM quarks with heavy composite fermions leads to **flavor changing Z couplings already at tree level**
- ▶ various representations of the heavy fermions, and various flavor structures are possible

anarchic triplets

anarchic bidoublets

bidoublets with $U(2)^3$ LH compositeness

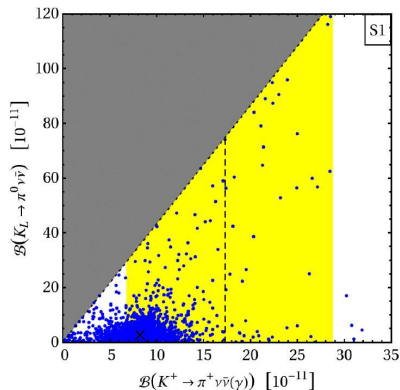
- ▶ strong constraints from ϵ_K do not exclude large effects in the rare decays
what about ϵ'/ϵ ?



Straub '13

$K \rightarrow \pi \nu \bar{\nu}$ in Warped Extra Dimensions

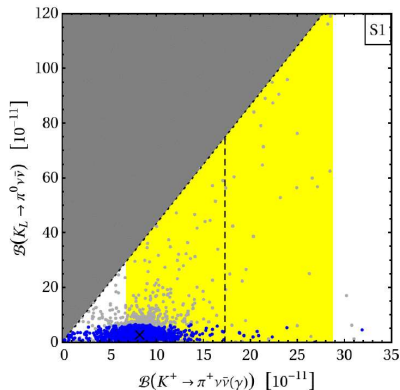
- ▶ **dual description of the partial composite models:**
composite fermions
 \leftrightarrow KK modes of SM fermions
- ▶ model has tree level flavor changing Z couplings
- ▶ assuming anarchic flavor structure:
no correlation between the charged and neutral mode



Bauer, Casagrande, Haisch, Neubert '09
(see also Blanke, Buras, Duling, Gemmler, Gori '08)

$K \rightarrow \pi \nu \bar{\nu}$ in Warped Extra Dimensions

- ▶ dual description of the partial composite models:
composite fermions
 \leftrightarrow KK modes of SM fermions
- ▶ model has tree level flavor changing Z couplings
- ▶ assuming anarchic flavor structure:
no correlation between the charged and neutral mode
- ▶ ϵ'/ϵ disfavors very large enhancements of $K_L \rightarrow \pi^0 \nu \bar{\nu}$
- ▶ $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ not constrained by ϵ'/ϵ

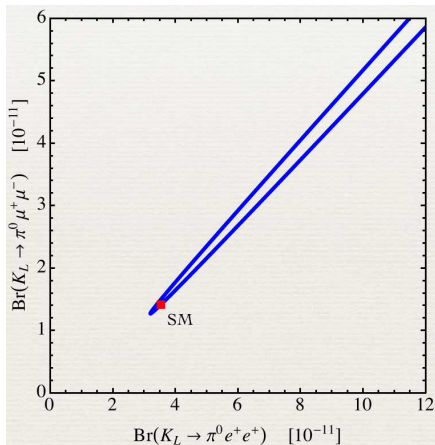


Bauer, Casagrande, Haisch, Neubert '09
(see also Blanke, Buras, Duling, Gemmler, Gori '08)

$K \rightarrow \pi \ell^+ \ell^-$: Z Penguins and Beyond

- ▶ leptonic modes receive contributions from Vector, Axialvector, Scalar, and Pseudoscalar operators

Z penguins



talk by Haisch, Project X Physics Study '12
see also Mescia, Smith, Trine '06

$K \rightarrow \pi \ell^+ \ell^-$: Z Penguins and Beyond

- ▶ leptonic modes receive contributions from Vector, Axialvector, Scalar, and Pseudoscalar operators

Z penguins

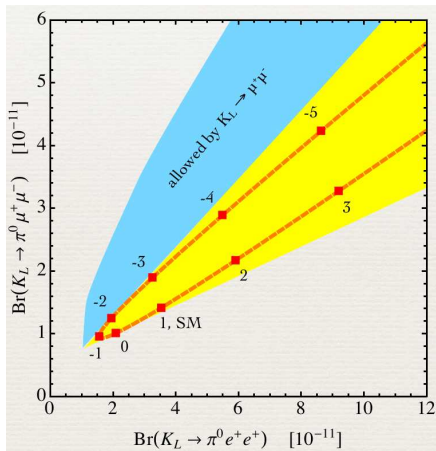
SM rescaled

generic V and A

(\sim Z penguins + γ penguins)

also S and P

- ▶ $K \rightarrow \pi \ell^+ \ell^-$ decays allow to disentangle the various contributions



talk by Haisch, Project X Physics Study '12

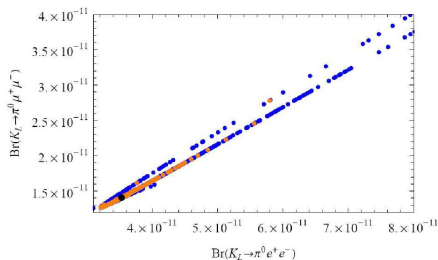
see also Mescia, Smith, Trine '06

$K \rightarrow \pi l^+ l^-$ in Warped Extra Dimensions

- contributions to the decays dominated by Z boson exchange

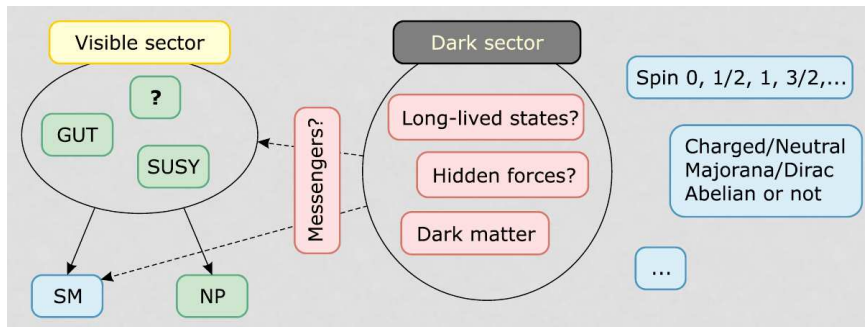
→ clear correlation between the two $K_L \rightarrow \pi^0 l^+ l^-$ branching ratios

can be easily falsified



Blanke, Buras, Duling, Gemmler, Gori '08
(see also Bauer, Casagrande, Haisch, Neubert '09)

$K \rightarrow \pi + \cancel{E}$ as Portal to Hidden Sectors

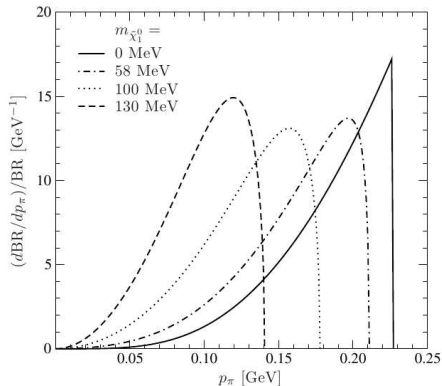


talk by Philippe Mertens, Project X Physics Study '12;

Kamenik, Smith '11

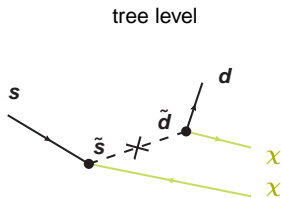
- ▶ there might be new, light, and very weakly coupled states (dark matter, axions, ...)
- ▶ rare Kaon decays can provide a portal to hidden sector
experimental signature: $K \rightarrow \pi + \cancel{E}$
- ▶ model dependent distortion the pion momentum spectrum compared to $K \rightarrow \pi \nu \bar{\nu}$

Concrete Example: Very Light Neutralinos



Dreiner et al. '09

- ▶ the mass of the lightest neutralino is largely unconstrained by direct searches
- ▶ if M_χ is sufficiently small the $K \rightarrow \pi\chi\chi$ decay is possible



- ▶ the p_π spectrum for $K \rightarrow \pi\chi\chi$ depends on the mass of the neutralinos

- ▶ the $K_L \rightarrow \pi^0 \ell^+ \ell^-$ and in particular the $K \rightarrow \pi \nu \bar{\nu}$ decays are theoretically clean and highly sensitive to NP
- ▶ 5% measurements of the neutrino modes have discovery potential for New Physics up to scales of almost 1000 TeV
- ▶ model discriminating power once information from several decay modes is combined
- ▶ $K \rightarrow \pi \nu \bar{\nu}$ decays also probe dark sectors