Prospects for a luminosity upgrade of DAPHNE

- Premessa: Kaon fluxes
  - Flavor physics & rare decays
  - Theory of $K \to \pi\nu\nu$ decays
  - Status & future prospects of $\Gamma(K \to \pi\nu\nu)$ measurements
- Conclusions

Premessa: Kaon fluxes

Kaons produced at existing fixed−targed facilities:

K_L	3×10^{11}	KTeV	[on tape, decays inside fiducial volume]
K_S	3×10^{10}	NA48/1	[on tape]
K^+	6×10^{12}	BNL−E787	[on tape]
$K^\pm$	3×10^{11}	NA48/2	[expected in 2003]

Possible Φ−Factory fluxes:

$$1\ \text{fb}^{-1}\ (= 10^{32}\ \text{cm}^{-2}\text{s}^{-1} \times 10^{7}\ \text{s}) \Rightarrow 10^{9}\ [\,K_L K_S + 1.5\,K^\pm\,]$$

$$10\ \text{fb}^{-1}\ (= 10^{33}\ \text{cm}^{-2}\text{s}^{-1} \times 10^{7}\ \text{s}) \Rightarrow 10^{10}\ [\,K_L K_S + 1.5\,K^\pm\,]$$

$$100\ \text{fb}^{-1}\ (= 10^{34}\ \text{cm}^{-2}\text{s}^{-1} \times 10^{7}\ \text{s}) \Rightarrow 10^{11}\ [\,K_L K_S + 1.5\,K^\pm\,]$$

$\Rightarrow$ $\int \mathscr{L} \geq 100\ \text{fb}^{-1}$ mandatory to start a new competitive program

Possible *main goals* of this program:

Search for $K_L \to \pi^0 \nu\nu$

efficiency substantially higher with respect to proton beams;
SM level out of reach with $O(100\ \text{fb}^{-1})$ but *high theoretical interest* also above the SM level $\Rightarrow$ luminosity & efficiencies are critical

Improved CPT tests with rare K_S decays & K_L/K_S interferometry

moderate th. interest: tests of a fundamental symmetry which is extremely unlikely to be violated at observable levels
$\Rightarrow$ luminosity & efficiencies not so critical

Charge asymmetries in $K^{\pm}$ decays

moderate th. interest: observable effects only in rather exotic models;
difficult to compete with NA48/2

new item with respect to the original KLOE program

parts of the original KLOE program

Flavor physics & rare decays

The SM is likely to be an effective theory valid up to a cut–off scale Λ:

$$\mathscr{L}_{SM} = \mathscr{L}_{gauge}(A_i, \psi_i) + \mathscr{L}_{Higgs}(\phi, \psi_i, v) + \sum_i \frac{c_i}{\Lambda^2} O_i^{(6)} + \ldots$$

?

Only 3 couplings
- simple
- tested with high precision

More than 15 coupl.
- complicated
- not very well known yet

2 +...	Higgs Potential
3 +...	Lepton's Yukawa coupl.
10	Quark's Yukawa coupl.

Quark–flavor mixing is a key ingredient to understand the symmetry–breaking sector of the SM and, possibly, to provide an indirect indication about the value of Λ

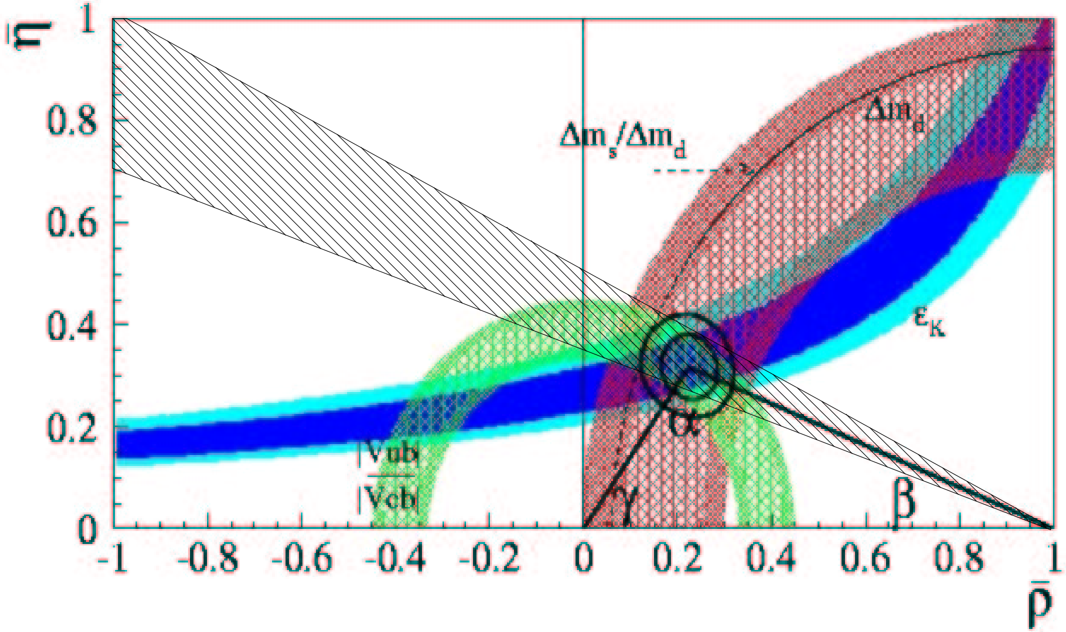
Rare FCNC Processes

$$q_i \rightarrow q_j + \gamma,\ l^+ l^-,\ \bar{\nu}\nu$$

- no SM tree–level contribution
- enhanced sensitivity to Λ

''The Flavor Problem''

Available data on $\Delta F=2$ FCNC amplitudes (meson−antimeson mixing) already provides serious constraints on the scale of New Physics...



E.g.: $\bar{K}^0 - K^0$ mixing

$\Downarrow$

$\Lambda \gtrsim 100$ TeV

for $O^{(6)} \sim (\bar{s}d)^2$

...while a natural stabilization of the Higgs potential $\Rightarrow$ $\Lambda \sim 1$ TeV

Two possible solutions:

- *pessimistic* [very unnatural]: $\Lambda > 100$ TeV
  $\Rightarrow$ almost nothing to learn from other FCNC processes

- *natural*: $\Lambda \sim 1$ TeV + flavor–mixing protected by additional symmetries $\Rightarrow$ still a lot to learn from $\Delta F=1$ FCNC

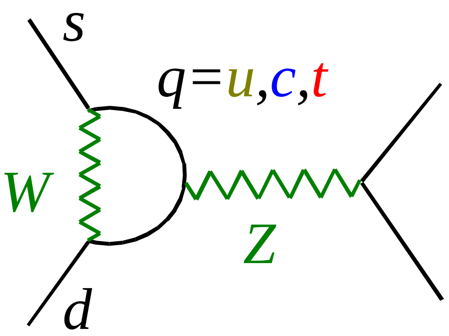
  - no $\Delta F=1$ FCNC appear in the usual CKM fits
    possible to build consistent models with large [~ 100%] new effects in $\Delta F=1$ and small [< 10%] new effects in $\Delta F=2$

  - some observables have irreducible th. errors at the 10% level
    difficult to perform stringent tests of the SM using only $\Delta F=2$

➡ *Theoretically–clean* rare K decays are an essential tool to deeply explore the natural solution

• Theory of $K \to \pi \nu\nu$ decays

Thanks to the *"hard"* GIM mechanism these decays are largely dominated by short−distance dynamics:



$$+ \text{box} \Rightarrow A_q \sim m_q^2 \underbrace{V_{qs}^* V_{qd}}_{\lambda_q} \sim \begin{cases} \Lambda_{QCD}^2 \lambda & (u) \\ m_c^2 \lambda + i\, m_c^2 \lambda^5 & (c) \\ m_t^2 \lambda^5 + i\, m_t^2 \lambda^5 & (t) \end{cases}$$

[$\lambda = \sin \theta_c$]

$$\mathcal{H}_{eff} = \frac{G_F \alpha}{2\sqrt{2}\pi s_W^2} \left[\lambda_c X_c + \lambda_t X_t + \Delta_{\text{new}} \right] (\bar{s} d)_{V-A} (\bar{\nu} \nu)_{V-A}$$

SM contribution
[known with 1−5% error]

non−standard contribution

$\langle \pi | (sd)_{V-A} | K \rangle$
known with ~1% error from K_{l3}

Theoretical predictions for $BR(K \to \pi \nu\bar{\nu})$ within the SM:

K^+ Th. error dominated by the charm contribution

$$BR(K^+)^{(SM)} = C\,|V_{cb}|^4\,[(\bar{\rho}-\rho_c)^2 + (\sigma\bar{\eta})^2] = (7.2 \pm 2.1)\times 10^{-11}$$

$\rho_c = 1.40 \pm 0.06$

Irreducible th. error on the B.R. ~ 8%

present range determined by present uncertainty on CKM parameters

K_L Charm contribution suppressed by the CP structure

$$BR(K_L)^{(SM)} = \underline{4.30\times 10^{-10}}\left(\frac{m_t(m_t)}{170\ GeV}\right)^{2.3}\left[\frac{\Im(V_{ts}^{*}V_{td})}{\lambda^5}\right]^2 = (2.7 \pm 1.0)\times 10^{-11}$$

th. error ~ 2% !

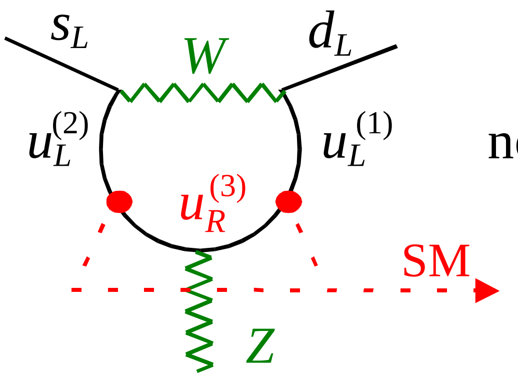
Area of the Unitarity Triangle

$s \to d\, \nu\bar{\nu}$ transitions beyond the SM

Two basic scenarios:

A) Models with new sources of flavor mix. ➡ possible huge effects

[the optimistic perspective] no λ^5 suppression



e.g.: MSSM with non−universal A terms

$(V_{ts}^* m_t) \times (V_{td} m_t)$

Model−independent bound: $\Gamma(K_L \to \pi^0 \nu\nu) < \Gamma(K^+ \to \pi^+ \nu\nu)$

➡ $B(K_L \to \pi^0 \nu\nu) < 1.8 \times 10^{-9}$ [90% C.L.]

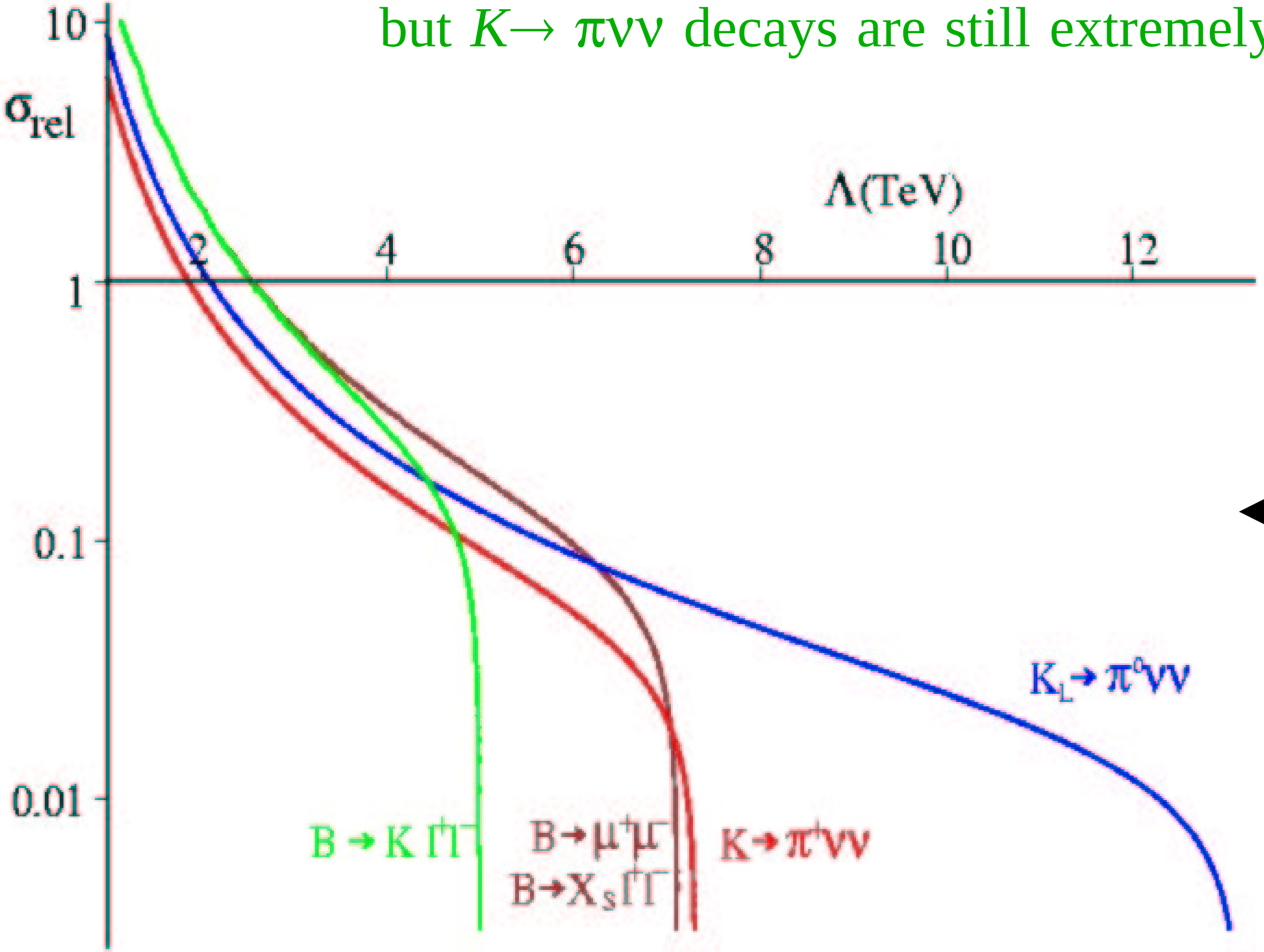
Two orders of magnitudes above the SM:

a wide region for possible interesting (exciting!) phenomena...

A) Models with Minimal Flavor Violation [the most pessimistic perspective...]

Same CKM suppression as in the SM [$A(s \to d\nu\nu) \propto V_{ts} V_{td}$]

Within this framework the effects are certainly small (< 30%) but $K \to \pi\nu\nu$ decays are still extremely interesting if one could reach the SM level

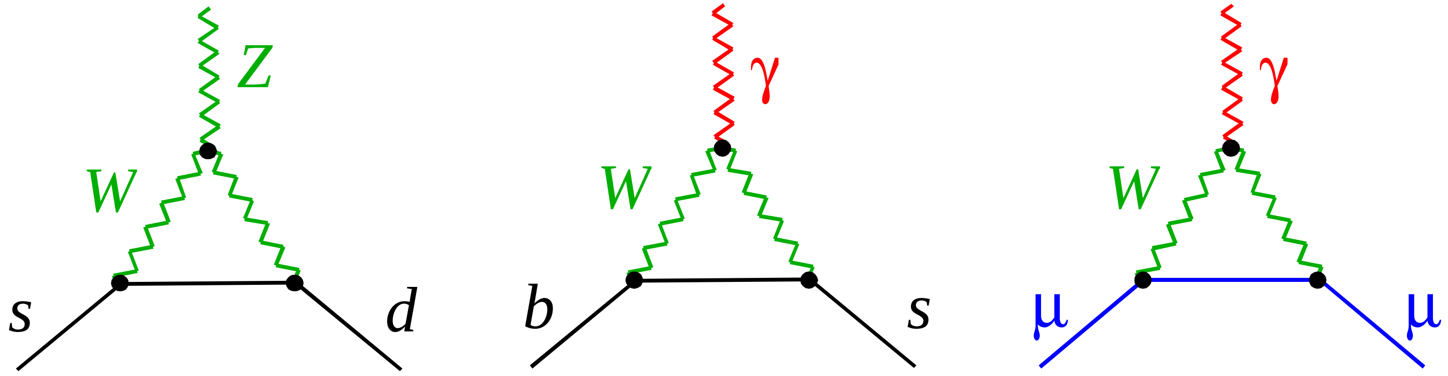


Sensitivity to the scale of new−physics (within MFV models) of future rare−decay experiments

Qualitative comparison between $\Gamma(K_L \to \pi^0 \bar{\nu}\nu)$, $\Gamma(b \to s\gamma)$ & $(g-2)_\mu$

The (one−loop) weak amplitude is somehow similar for the 3 observables

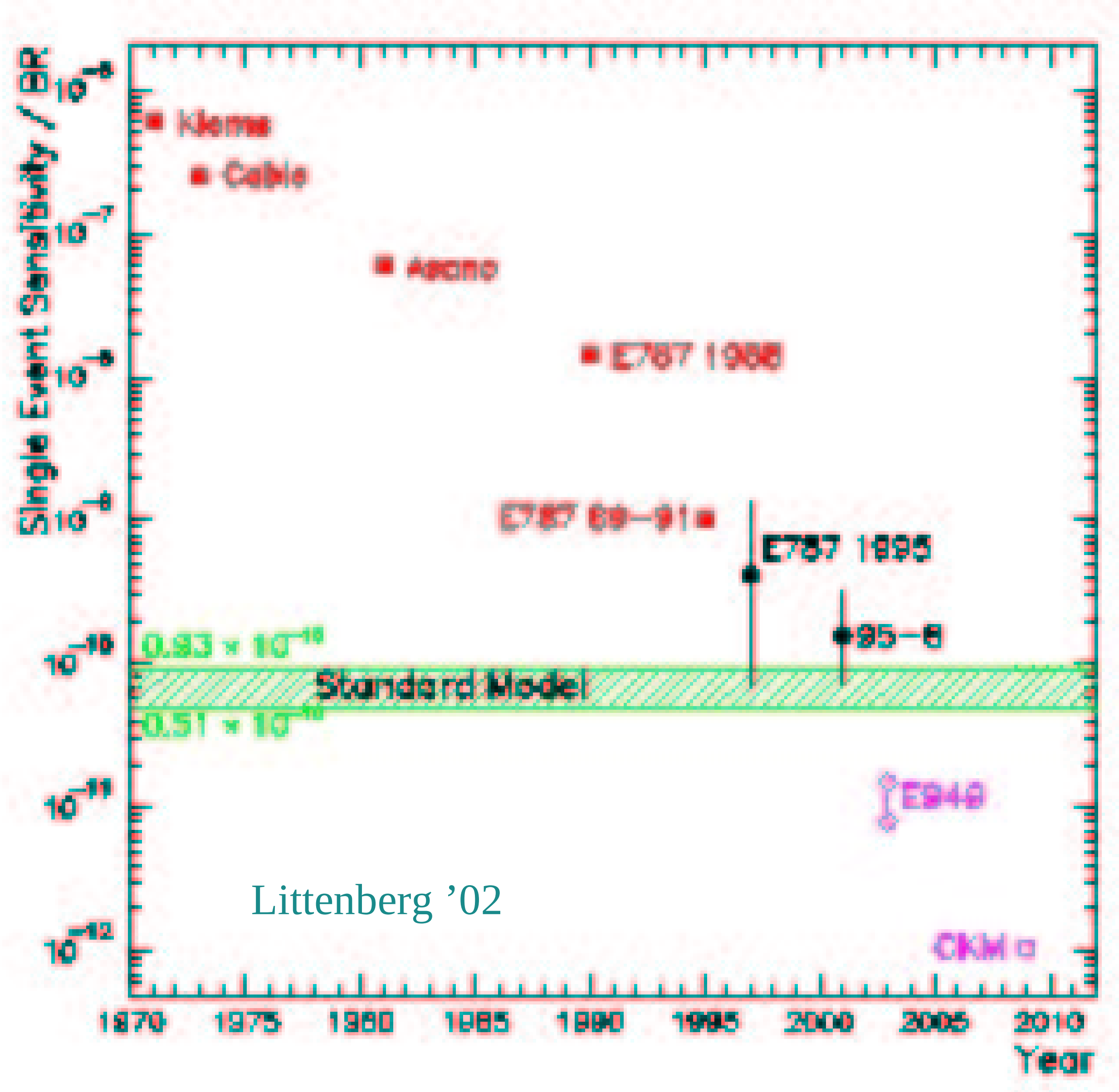
typical Feynman diagrams for the weak amplitudes:



⇒ natural to consider it as a reference scale of possible new−physics effects:

	δA_{weak}	$\delta_{QCD}/\delta A_{weak}$	Th. error$/\delta A_{weak}$
$\Gamma(K_L \to \pi^0 \nu\bar{\nu})$	1	~ 10%	~ 2%
$\Gamma(b \to s\gamma)$	1	~ 300%	~ 10−15%
$(g-2)_\mu$	$\sim 10^{-6}$	~ 4000%	~ 50−100%

Status & future prospects of $\Gamma(K \to \pi \nu\nu)$ measurements



$$B\left(K^+ \to \pi^+ \nu \bar{\nu}\right) = \left(1.57\,^{+1.75}_{-0.82}\right) \times 10^{-10}$$

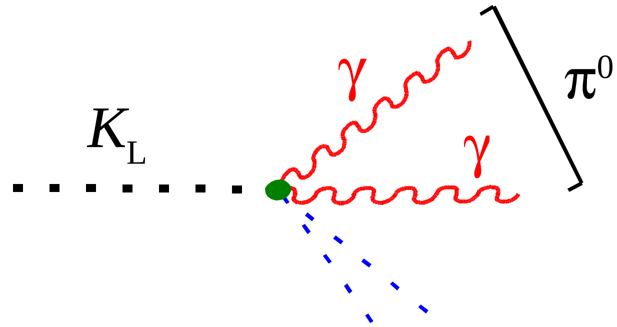
- 2 events observed at BNL–E787 (0.15 bkg)
- central value 2×SM !
- Unfortunately the funding for the upgrade of BNL–E787 (E949) has been suspended....

B) $K_L \to \pi^0 \bar{\nu}\nu$

Extremely difficult measurement

high intensity K_L flux;

excellent photon veto to kill $K_L \to \pi^0\pi^0$



- no dedicated experiment started yet, present best limit:

  $B(K_L \to \pi^0 \nu\bar{\nu}) < 0.59 \times 10^{-6}$ KTeV '99 [using $\pi^0 \to \gamma e^+ e^-$]

- E391 @ KEK [start expected in 2003?]

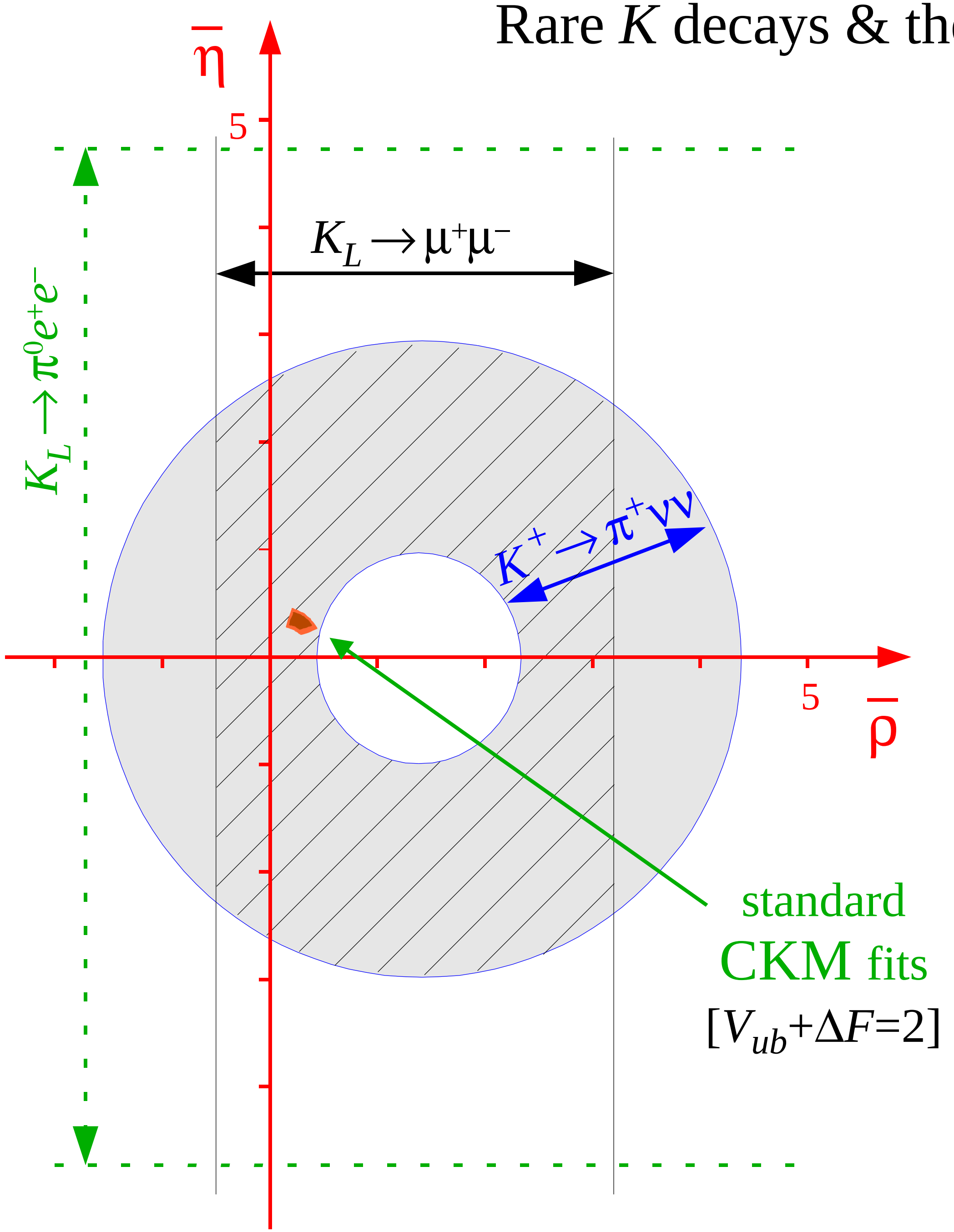
  $\Rightarrow$ SES $\sim 3\times10^{-10}$ [first step below the model−independent bound?]

- KOPIO @ BNL [proposal approved by NSF, awaiting funding...]

  micro−bounced, low−energy K_L beam $\Rightarrow$ TOF determination of p_K

  $\Rightarrow$ ~ 50 SM events (S/B ~ 2) [construction not yet started...]

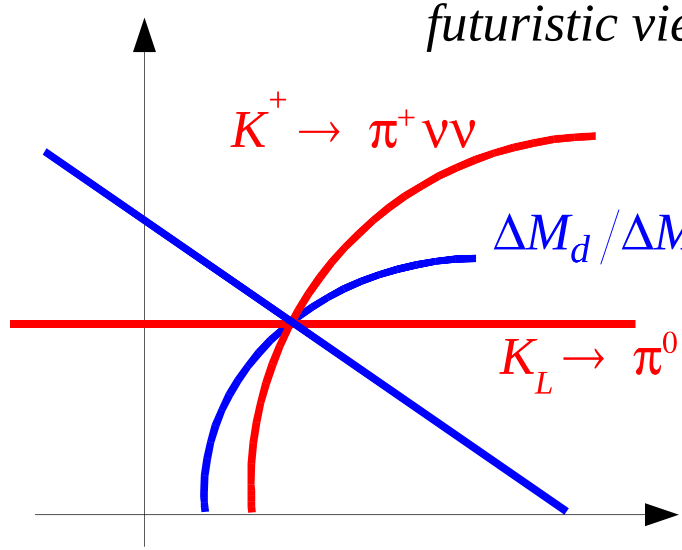
Rare K decays & the Unitarity Triangle



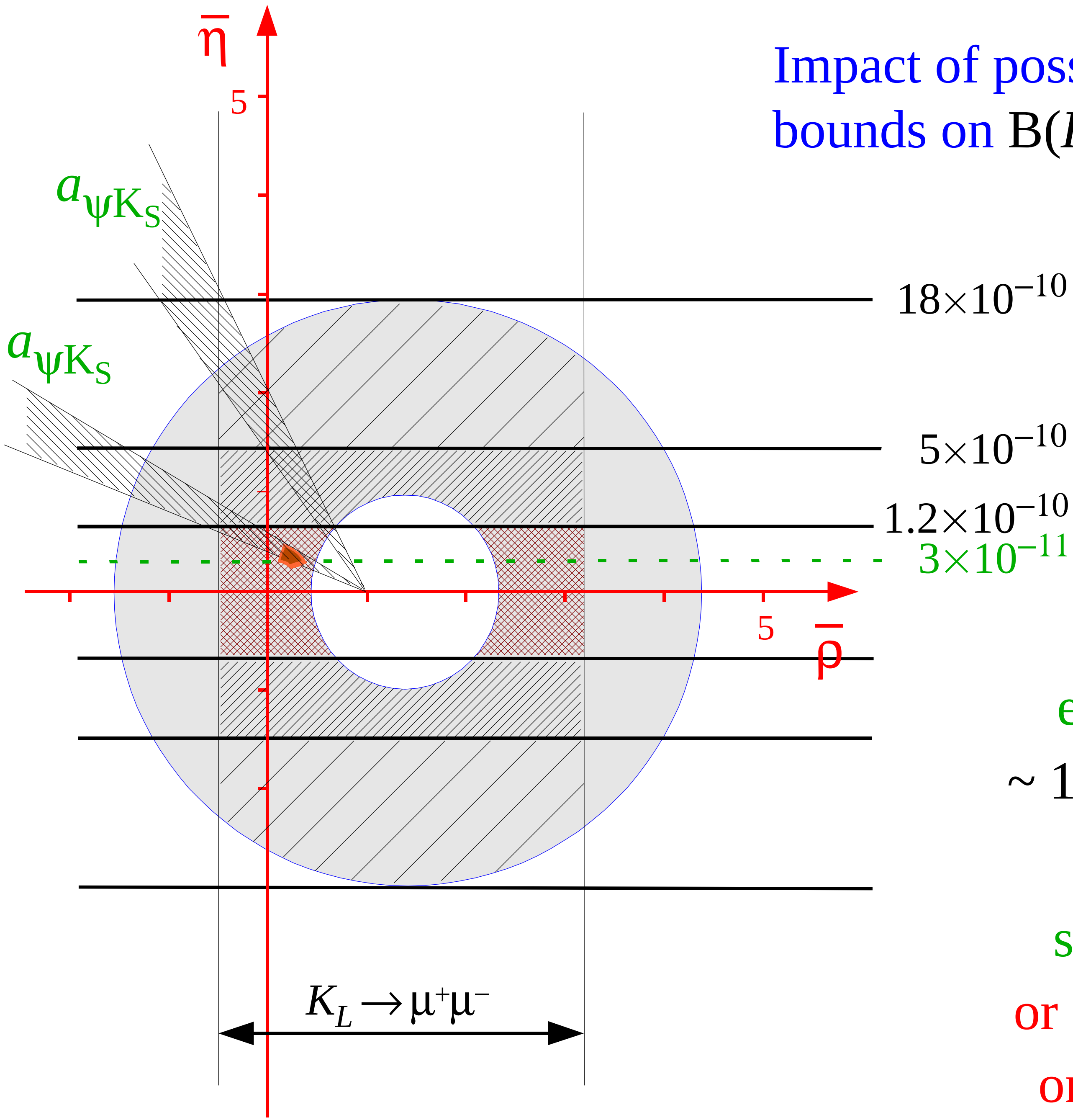
negligible impact –at present–
on precision SM tests

- still at lot of room for possible large $\Delta F=1$ non−standard effects...
- N.B: adding the info from ε'/ε does not help to reduce the allowed region

futuristic view:



Impact of possible future bounds on $B(K_L \to \pi^0 \nu\nu)$:



even bounds in the range

$\sim 10\times B(K_L)^{SM} \sim \text{few}\times10^{-10}$

would provide a very significant test of the SM or clear stringent constraints on new−physics scenarios

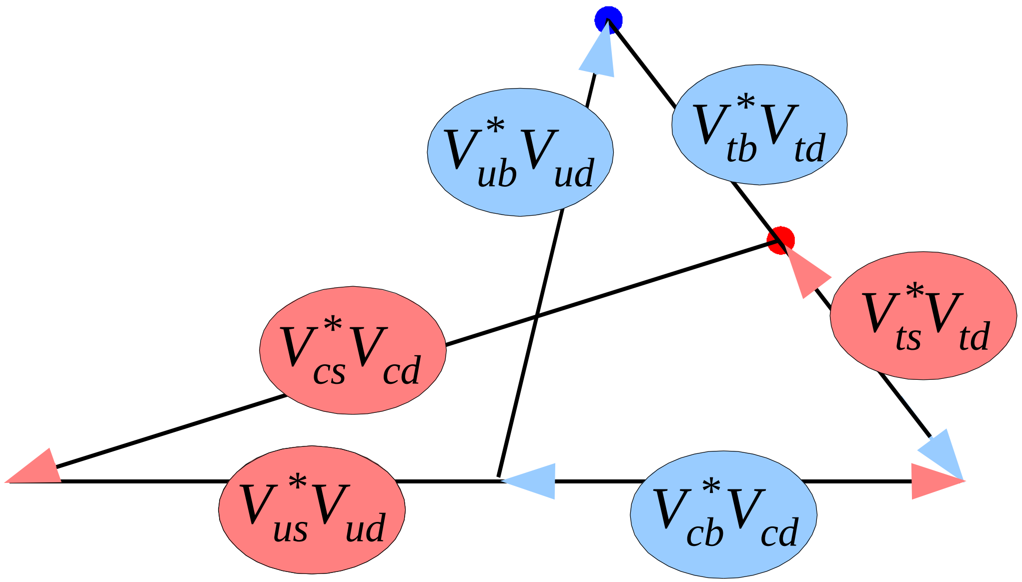
The significance of rare–kaon–decay measurements becomes even more clear if we look at CKM unitarity triangles from a different perspective:

The (usual) $b \to d$ triangle:

$$V_{ub}^{*} V_{ud} + V_{cb}^{*} V_{cd} + V_{tb}^{*} V_{td} = 0$$

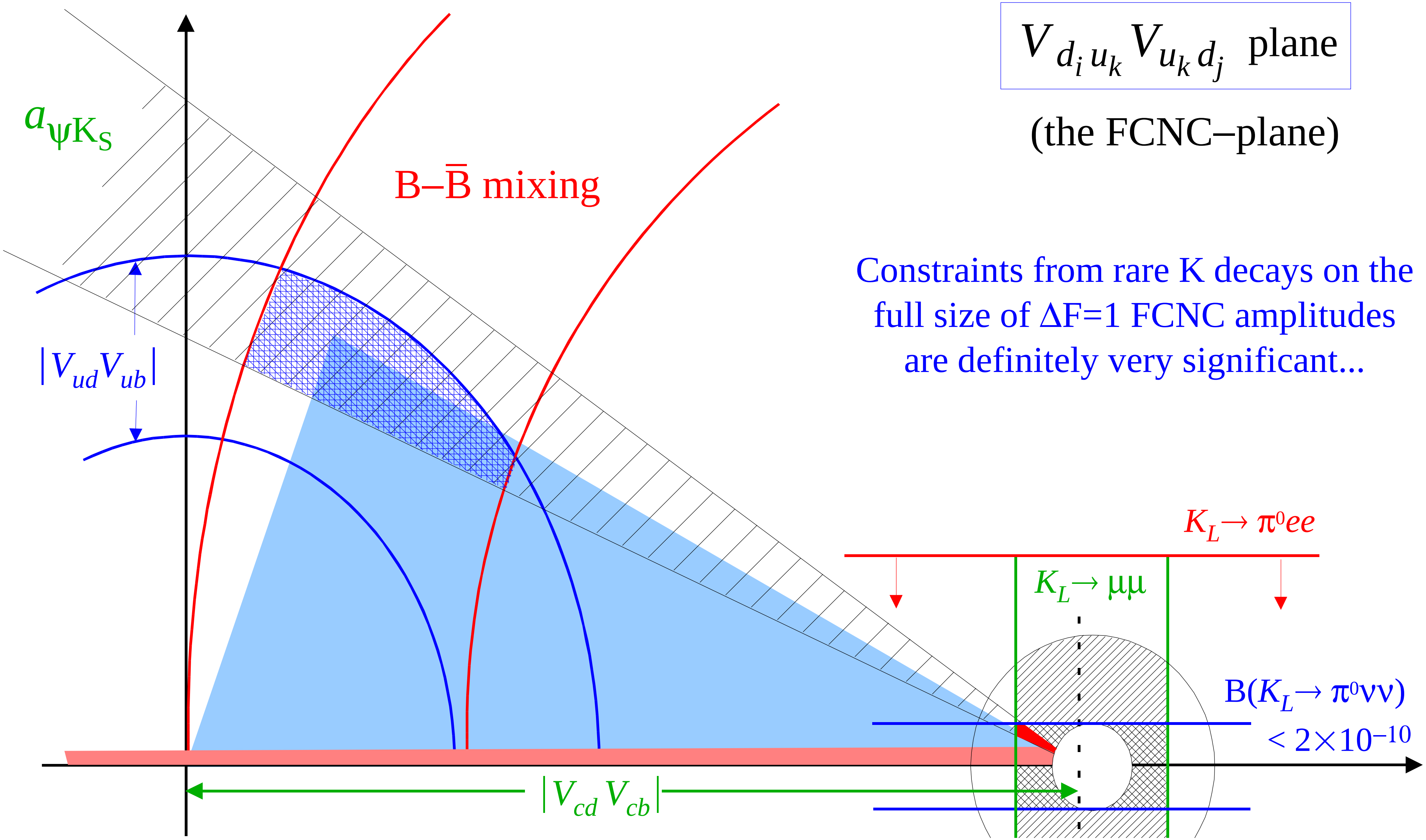
The (kaon) $s \to d$ triangle:

$$V_{us}^{*} V_{ud} + V_{cs}^{*} V_{cd} + V_{ts}^{*} V_{td} = 0$$



Same area (not in scale !)

$b \to d$ & $s \to d$ unitarity triangles on the same scale



Conclusions

If the luminosity will remain in the few$\times 10^{33}$ range, the original Kaon program of DAΦNE will not be substantially modified: the present frontier of flavor physics [$K \to \pi\nu\nu$ decays] will not be accessible.

If possible, the search for $B(K_L \to \pi^0\nu\nu)$ in the 10^{-10} region [between the model−independent upper bound and above the SM level] would already justify a substantial upgrade both of DAΦNE and KLOE. This effort would become even more justified if this search could be considered as a first step toward a measurement of $B(K_L \to \pi^0\nu\nu)$ in the SM range, i.e. if the possibility of further upgrades [in a long−term perspective] is not completely excluded.

$\Rightarrow$ The measurement of $B(K_L \to \pi^0\nu\nu)$ will remain a fundamental issue also in the LHC era