Rencontres de Moriond, EW, La Thuile, March 2010

NA62 Physics Perspectives

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Introduction

I. *NA62 main targets are the rare K decays* ($Br \lesssim 10^{-11}$)*, e.g.* $K^+ \to \pi^+ \nu\bar{\nu}$

Prime targets because of - their *sensitivity to New Physics*,
- the *cleanness of their SM predictions*.

Very clean since essentially short-distance (perturbative QCD is fine).
But, *some residual long-distance effects are nevertheless present*.

II. *How to deal with these hadronic effects?*

With Chiral Perturbation Theory (ChPT), by relating them to *less rare decays*.

Those should be additional important targets for NA62.

III. *Are there other access(es) to New Physics, once having >10^{13} kaon decays?*

Re-analysis of all K physics observables in progress.
(*NA62 Physics Handbook*)

New Physics searches

A. Kaons and the New Physics flavor puzzle

Most New Physics (NP) models have either *new flavored particles*,
or *new flavor-breaking interactions* between quarks and leptons:

$$\mathcal{L}_{eff} = \frac{c_{bs}}{\Lambda^2}(\bar{b}\Gamma s)(\bar{\nu}\,\Gamma\nu) + \frac{c_{bd}}{\Lambda^2}(\bar{b}\Gamma d)(\bar{\nu}\,\Gamma\nu) + \frac{c_{sd}}{\Lambda^2}(\bar{s}\Gamma d)(\bar{\nu}\,\Gamma\nu) + \ldots$$

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But, there is *no signal of NP in flavor experiments.*

→ Experiments ~ SM predictions

→ $\begin{cases} b \to s: \\ |V_{tb}^* V_{ts}| \sim \lambda^2 \end{cases}$ $\begin{cases} b \to d: \\ |V_{tb}^* V_{td}| \sim \lambda^3 \end{cases}$ $\begin{cases} s \to d: \\ |V_{ts}^* V_{td}| \sim \lambda^5 \end{cases}$ $(\lambda \approx 0.2)$

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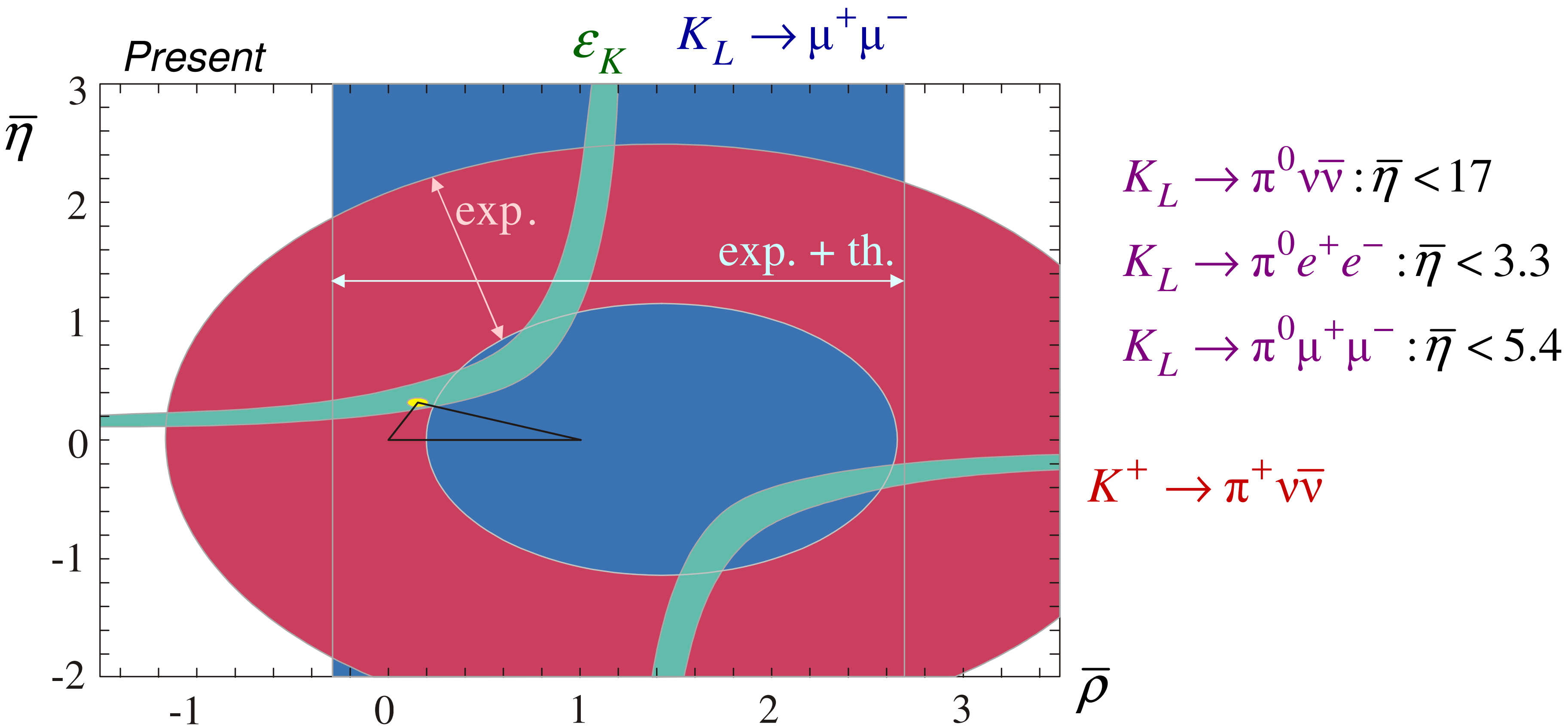
Minimal Flavor Violating $c_{ij} \approx V_{is}^* V_{jd}$:

$\Lambda \lesssim 1\,\text{TeV}$ but $c_{sd} \approx \lambda^5 \ldots$

NP flavor structures highly non-generic.

$s \to d$ *transitions ideal to test MFV*!

B. Where do we stand? How *not* to judge of the interest of K physics…



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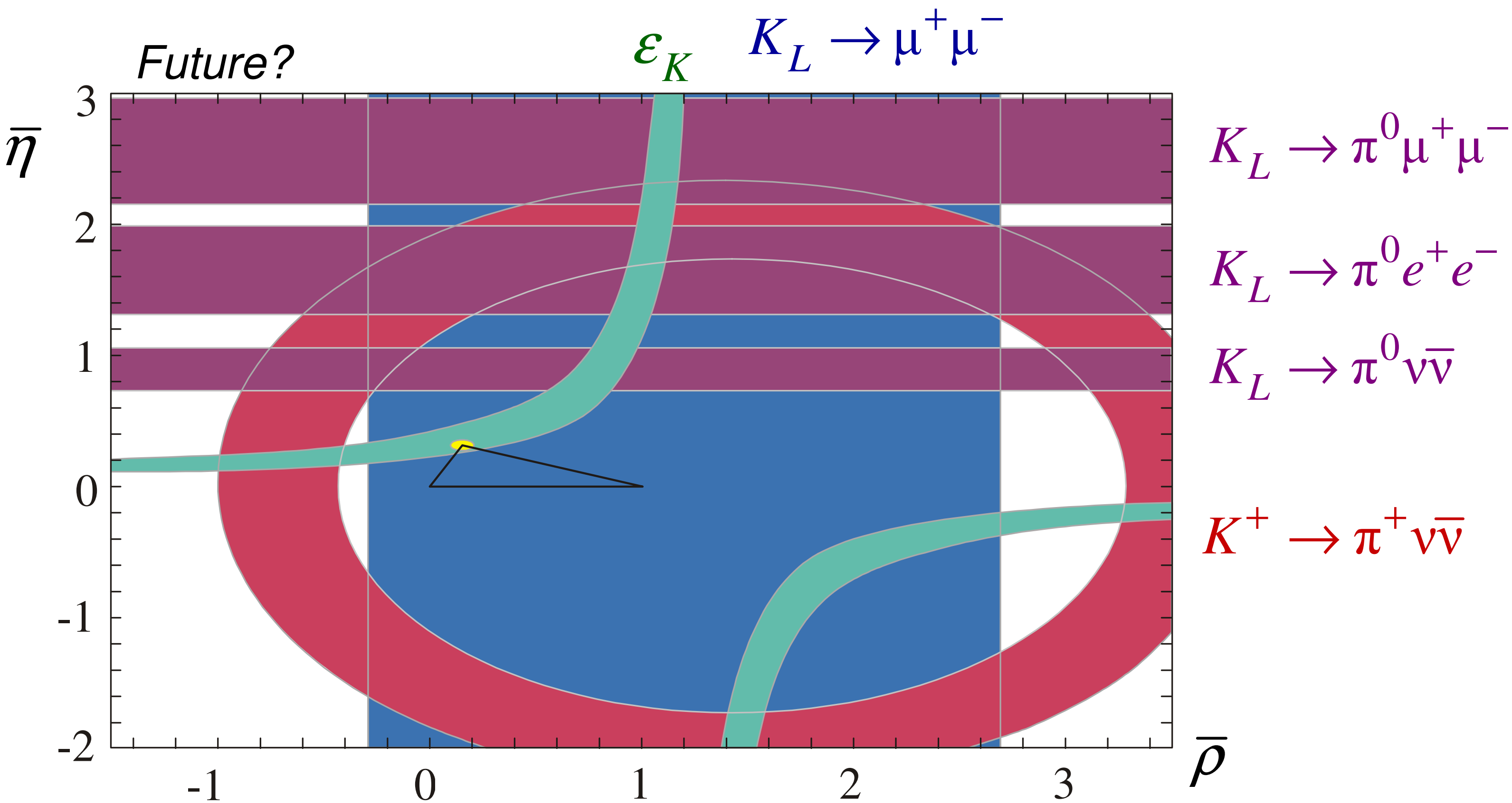

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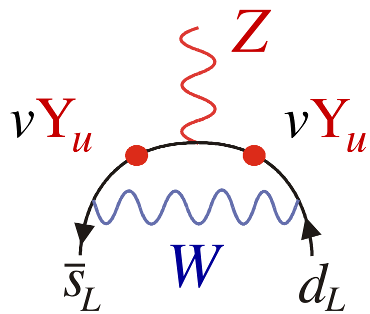
Therefore, it is not competitive to fix the UT, but *it is ideal to get clear NP signals*!

C. $K^+ \to \pi^+ \nu\bar{\nu}$ probes New Physics in the Z penguin



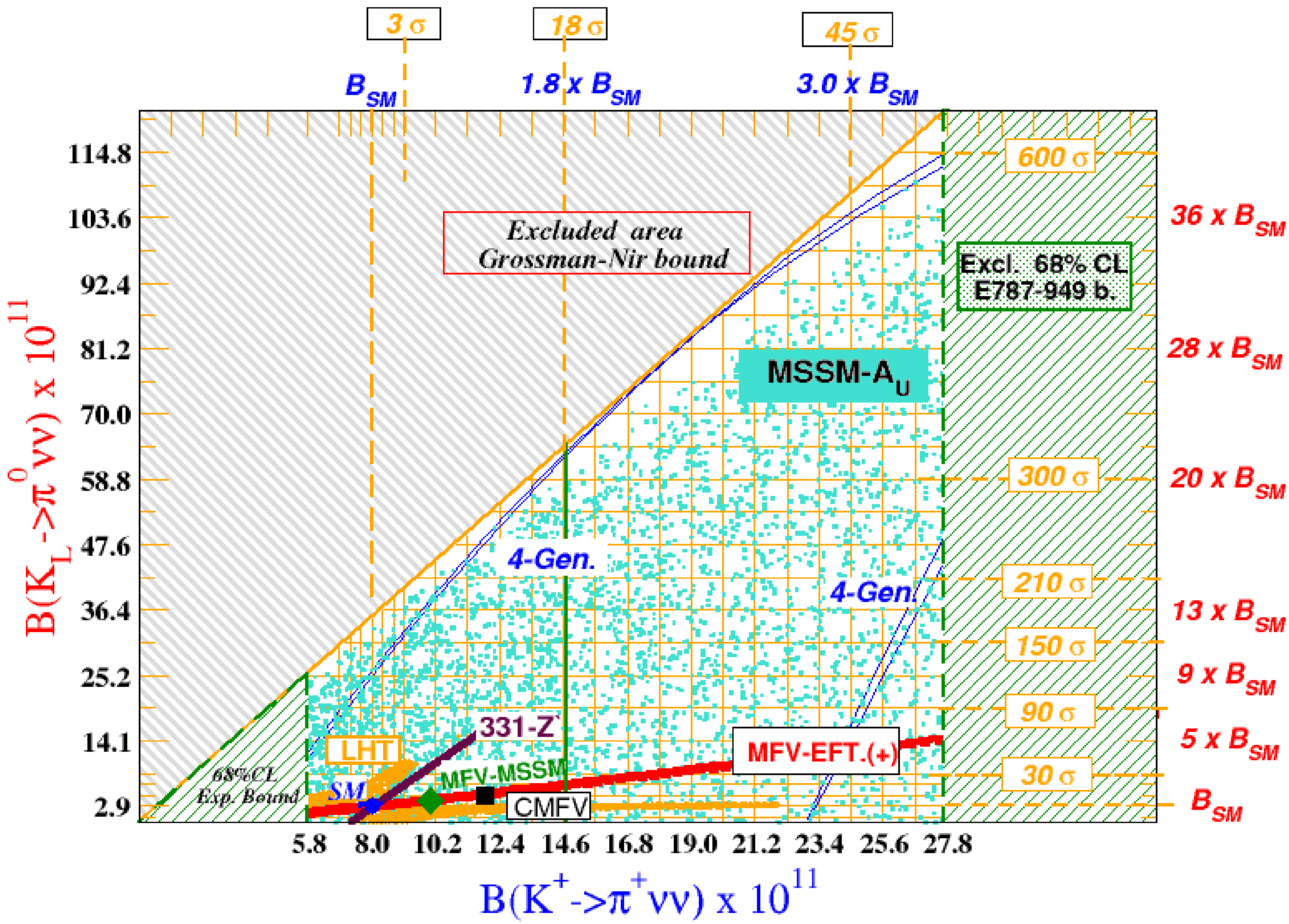
$SU(2)_L$ breaking

→ Very sensitive to the high energy-scale.

Most NP models affects this FCNC (or also lead to a $V \otimes V$-A operator):

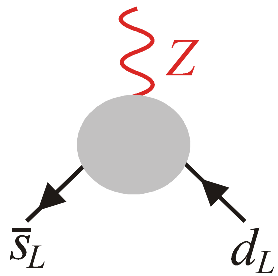
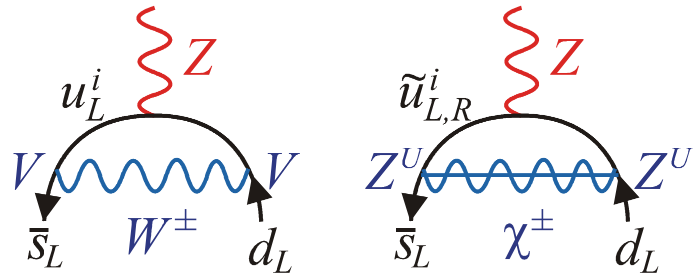
MSSM moderate $\tan\beta$ (chargino),	*Nir,Worah '98, Buras,Romanino,Silvestrini '98* *Colangelo,Isidori '98* *Isidori,Mescia,Paradisi,Trine,CS '06*
MSSM large $\tan\beta$ (charged Higgs),	*Isidori,Paradisi '06*
R-parity violation (non MFV),	*Grossman,Isidori,Murayama '03* *Deshpande,Ghosh,He '04,Deandrea,Welzel,Oertel '04*
EEWP,	*Buras,Fleischer,Recksiegel,Schwab '04*
Little Higgs,	*Rai Choudhury,Gaur,Joshi,McKellar '04* *Blanke et al. '06,'07,'09; Goto,Okada,Yamamoto '09*
Universal extra dimensions,	*Buras,Spranger,Weiler '02*
Fourth generation,	*Hou,Nagashima,Soddu '05* *Buras et al. '10*
...	

D. Beyond $K^+ \to \pi^+ \nu\bar{\nu}$ *:* Use $K_L \to \pi^0 \nu\bar{\nu}$ to discriminate among NP models



Mescia '09, see **http://www.lnf.infn.it/wg/vus/**

D. Beyond $K^+ \to \pi^+ \nu\bar{\nu}$ *:* Use *all the rare K decays* for a better identification

<table>
<tr><th>EW Penguin</th><th>SM and/or example of SUSY effect</th><th>Contributes to</th></tr>
<tr><td>
</td><td>
</td><td>$K \to \pi\nu\bar{\nu}$
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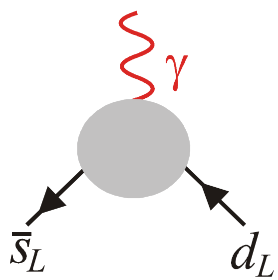
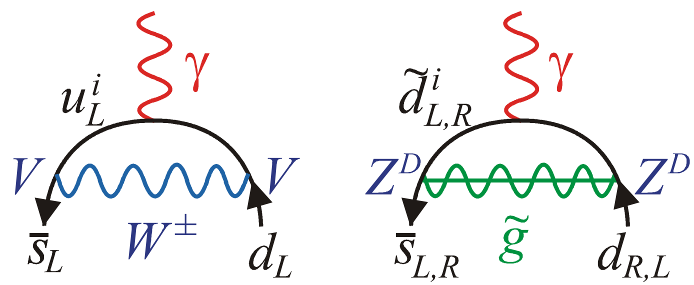
<tr><td>
</td><td>
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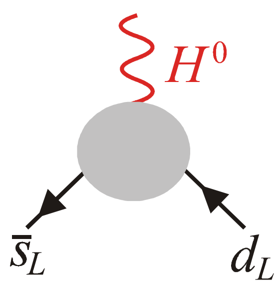
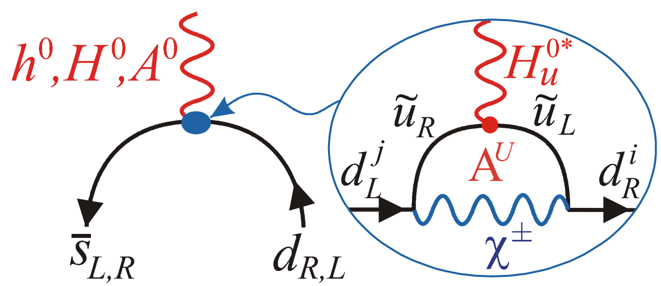
<tr><td>
</td><td>
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(helicity-suppressed)</td></tr>
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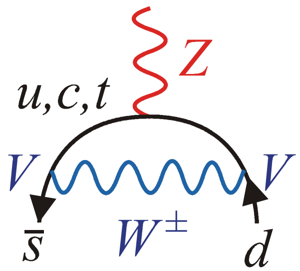
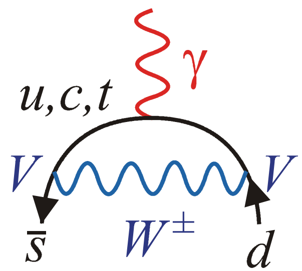
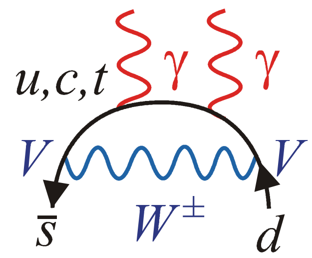
NP to be identified by looking at *patterns of deviations*!

Hadronic uncertainties and ChPT

A. Electroweak anatomy of rare & radiative K decays

	SD: c and t (QCD pert.) LD: only u (ChPT)			
Rare	$K \to \pi\nu\bar{\nu}$	SD	—	—
	$K_L \to \pi^0 \ell^+ \ell^-$	SD	SD + ε_K LD	α_{QED} LD
	$K_{L,S} \to \ell^+ \ell^-$	SD	—	α_{QED} LD
Radiative	$K_S, K^+ \to \pi^{0,+} \ell^+ \ell^-$	*Negligible, except for CP-asymmetries.*	LD (+ ε_K SD)	(α_{QED}-suppr.)
	$K \to (n\pi)\gamma\gamma$		—	LD
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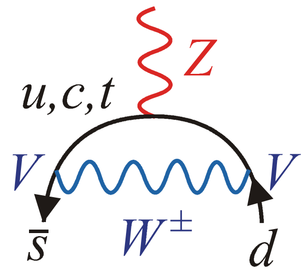
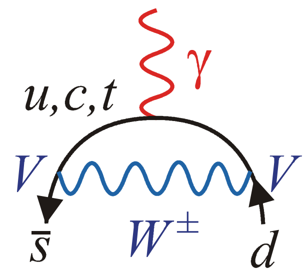
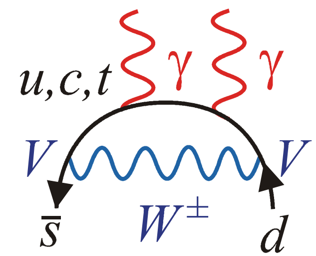
	SD: c and t (QCD pert.) LD: only u (ChPT)			
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Radiative decays allow to fix LD contributions to rare decays

D'Ambrosio et al.'98;Buchalla,D'Ambrosio,Isidori'03;Gerard,CS,Trine'05;Isidori,Unterdorfer,CS'04;Mescia,Trine,CS'06;…

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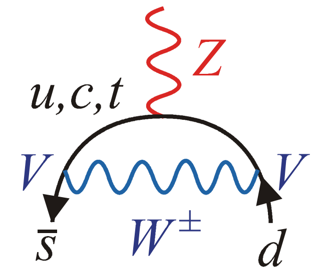
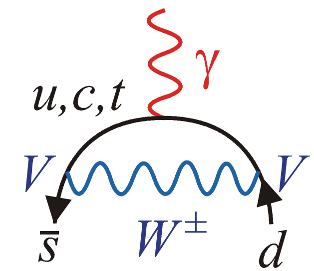
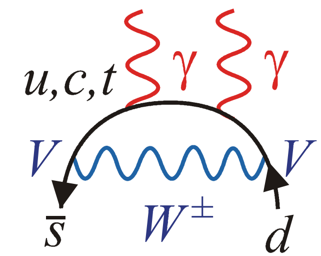
SD: c and t (QCD pert.) LD: only u (ChPT)		 	 	
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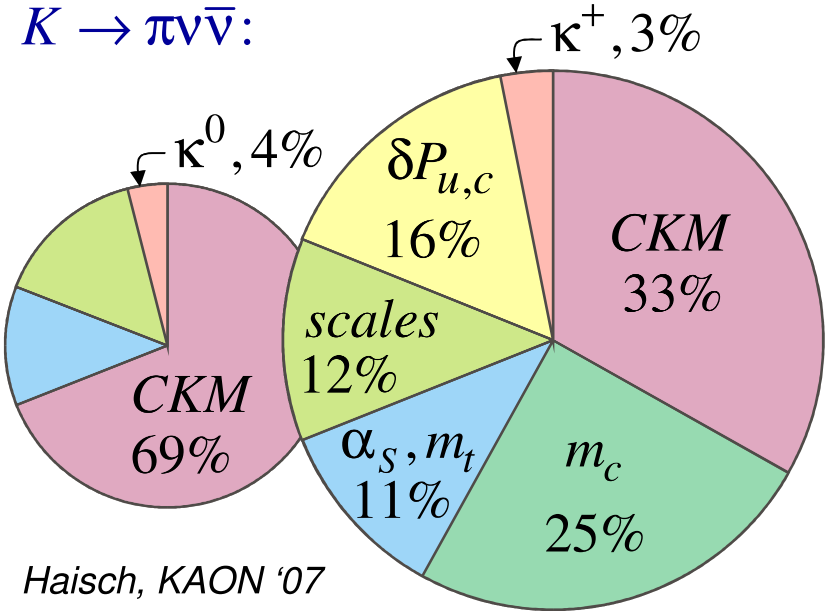
$K_{\ell 3} = K \to \pi \ell \nu$ for the precise extraction of the matrix elements.

Mescia,CS '06

B. Current status: SM predictions for the very rare decays

	SD	ε_K	$\gamma\gamma_{J=2}$	$\gamma\gamma_{J=0}$	SM $(\times 10^{-11})$	Experiment	
$K_L \to \pi^0 \nu\bar{\nu}$	100%	(≈ 1%)	–	–	2.8(4)	$< 6.7 \cdot 10^{-8}$	E391a
$K_L \to \pi^0 e^+ e^-$	40%	60%	(<3%)	–	3.5(1)	$< 2.8 \cdot 10^{-10}$	KTeV
$K_L \to \pi^0 \mu^+ \mu^-$	30%	35%	–	35%	1.4(3)	$< 3.8 \cdot 10^{-10}$	KTeV
$K^+ \to \pi^+ \nu\bar{\nu}$	100%	–	–	–	8.5(7)	$17.3^{+11.5}_{-10.5} \cdot 10^{-11}$	E787 E949

Theory errors for $K \to \pi\nu\bar{\nu}$:



Haisch, KAON '07

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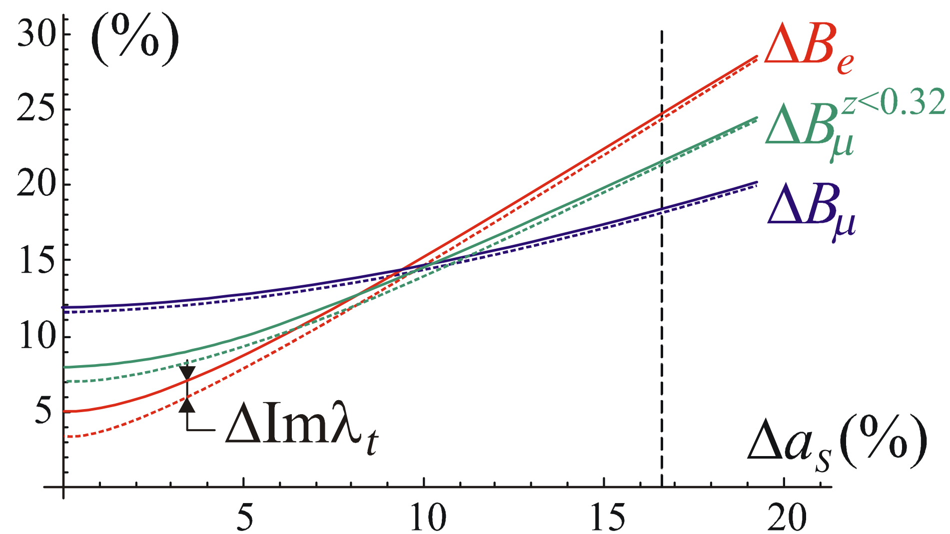

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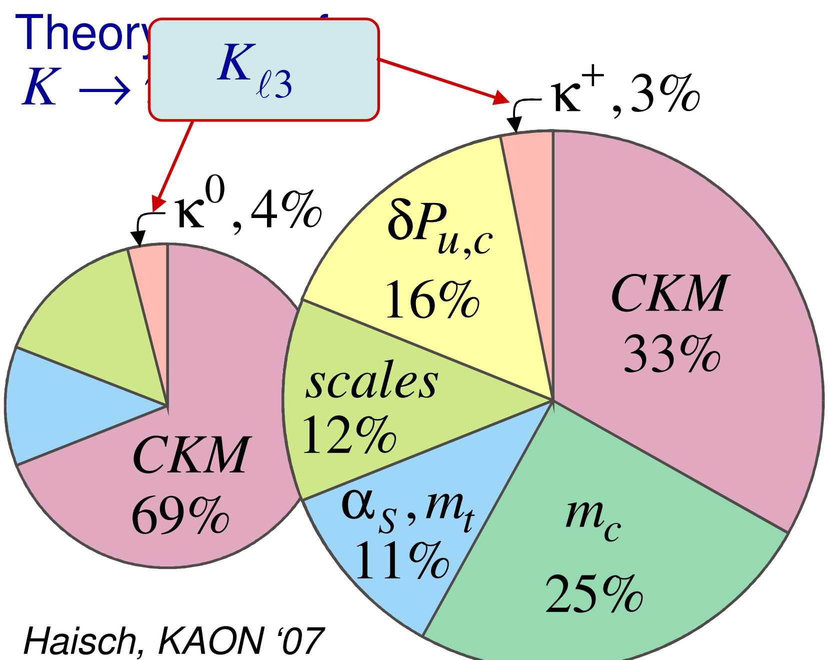

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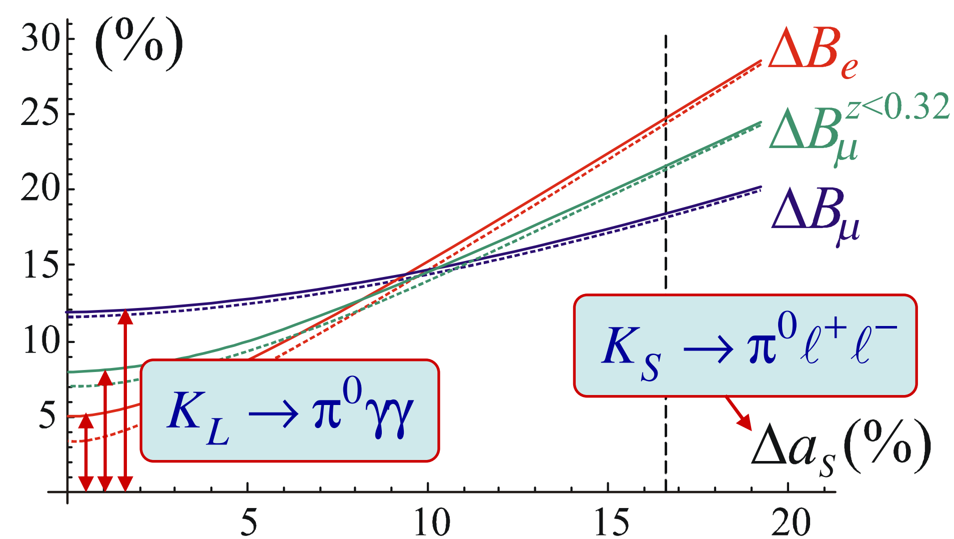

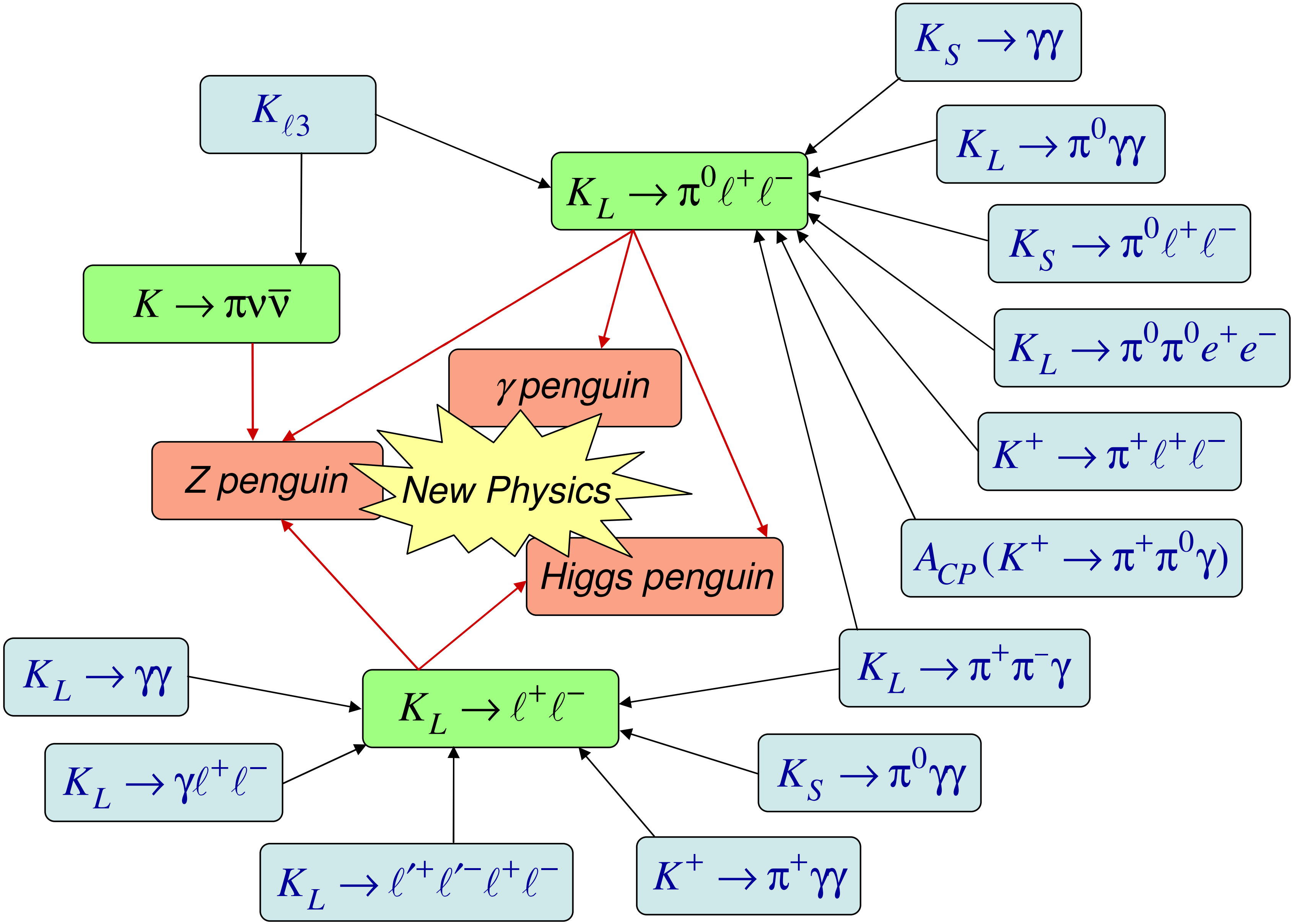
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γ penguin
$K^+ \to \pi^+\ell^+\ell^-$
Z penguin
New Physics
$A_{CP}(K^+ \to \pi^+\pi^0\gamma)$
Higgs penguin
$K_L \to \pi^+\pi^-\gamma$
$K_L \to \gamma\gamma$
$K_L \to \ell^+\ell^-$
$K_L \to \gamma\ell^+\ell^-$
$K_S \to \pi^0\gamma\gamma$
$K_L \to \ell'^+\ell'^-\ell^+\ell^-$
$K^+ \to \pi^+\gamma\gamma$

Precision physics

A. CP-violation

Indirect CP-violation: ε_K

$\Delta S = 2 \; K^0 - \overline{K}^0$ boxes

Well measured.
Theory → Lattice (B_K)
(see Mescia's talk)

Direct CP-violation: ε'_K

$\Delta S = 1$ penguins

Well measured, but theory?

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Could NA62 be of any help?

- By measuring *rare K decays*, since they are (model-dependently) correlated.

- By measuring *direct CP-asymmetries*, i.e.

$$A_{CP} = \frac{\Gamma(K^+ \to X) - \Gamma(K^- \to X)}{\Gamma(K^+ \to X) + \Gamma(K^- \to X)}\,, \quad X = \pi\pi\pi,\ \pi\pi\ell\nu, \pi\pi\gamma, \pi\gamma\gamma, \pi\ell\ell, \ldots$$

Usually small, but with specific sensitivities to scalar, EW, QCD penguins,...

Could/should NA62 run also with K^-?

- *Phase-space asymmetries* (angles, FB, polarization,...) could also help.

- *Neutral modes*: CP-aymmetries in general essentially give back ε_K.

B. Other subjects under investigation

- $K_{\ell 2}$, $K_{\ell 3}$ *decays*

  CKM unitarity and New Physics constraints → Gonzalez Alonso's talk

  Universality tests and LFV effects → Goudzovski's talk

  Form-factor studies, extraction of light quark masses,…

- *LFV modes* $K^+ \to \pi^+ \mu^\pm e^\mp,\ K^0 \to (\pi^0)\mu^\pm e^\mp, \ldots$

  May be correlated with LFV processes, e.g. $\mu \to e\gamma$ → Baracchini's talk.

- $\pi\pi$ *scattering phases:* From $K_{\ell 4}$ or hadronic decays.

- *Pion & hyperon decays*

- *Anything else?* $K_{\ell 5}$, $K \to \pi\pi\pi\gamma,\ K \to \ell\nu\gamma,\ K \to \ell\nu\ell\nu,\ \ldots$

Conclusion

The NA62 (and K0TO) physics perspectives are very promising!

The rare K decays are unique windows into the $s \to d$ sector.

- *Essential to identify the NP*, once combined with $b \to s$ and $b \to d$.
- Allow detailed analysis of the $s \to d$ transitions through their correlations (e.g. Z, photon, and Higgs penguins)

The less rare radiative decays permit to control their hadronic uncertainties.

Detailed study of the *electroweak – strong interaction interplays* at low energy.

The dominant decays can be measured with unprecedented precision.

Opens the door to *new or improved tests of the SM*.

(CP-asymmetries, universality, CKM unitarity,...)

Anything else? All suggestions are welcome!

See the *NA62 handbook* project page at **`http://na62pb.ph.tum.de/`**