Lepton Flavour violation searches with kaons at NA62

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on behalf of NA62 collaboration

Birmingham, CERN, Dubna, Fairfax, Ferrara, Florence, Frascati, Mainz, Merced, Moscow, Naples, Perugia, Pisa, Protvino, Rome I, Rome II, Saclay, San Luis Potosi, Stanford, Sofia, Triumf, Turin
Outline

• Looking for LFV: theory and experiment
• The NA62 experiment
• The measurement strategy
• Conclusions
Looking for Lepton Flavor Violation

In the S.M., Lepton Flavor Violating (LFV) processes are forbidden or strongly suppressed. LFV can arise from extensions of S.M., as in low energy minimal SUSY (MSSM). Kaon and pion leptonic decays are potentially good candidates for NP evidence. The V-A structure of the weak interaction suppresses these decays in the SM, and makes them very sensitive to non-SM effects as pseudoscalar hadronic weak current.

\[
\ell H^\pm \nu_\tau \rightarrow \frac{g_2}{\sqrt{2}} \frac{m_\tau}{M_W} \Delta_R^{3\ell} \tan^2 \beta \beta \quad \ell = e, \mu
\]
\[ R_K = \frac{\Gamma(K^\pm \rightarrow e^\pm \nu_e)}{\Gamma(K^\pm \rightarrow \mu^\pm \nu_\mu)} = \frac{m_e^2}{m_\mu^2} \left( \frac{m_K^2 - m_e^2}{m_K^2 - m_\mu^2} \right)^2 \left( 1 + \delta R_{QED} \right) = (2.477 \pm 0.001) \cdot 10^{-5} \]

\[ \delta R_K / R_K \sim 0.04\% \]

\[ \delta R_{QED} = -3.8\% \]

\[ R_K^{LFV} \approx R_K^{SM} \left[ 1 + \left( \frac{m_K^4}{m_{H^\pm}^4} \right) \left( \frac{m_\tau^2}{m_e^2} \right) |\Delta_{31}|^2 \tan^6 \beta \right] \]

\[ R_K^{LFV} = R_K^{SM} (1 + 0.013) \]

\[ \tan \beta = 40, M_H = 500 \text{ GeV/c}^2, |\Delta_{31}| = 5 \times 10^{-4} \]

Radiative corrections

Only Inner Bresstrahlung (IB) and virtual photon process are included in RK definition. Structure Dependent (SD) are not

While SD contribution is negligible in K\textsubscript{\mu2}, it’s not the case for K\textsubscript{e2}

Experimentally the measure include both IB and SD decays => SD contribution must be subtracted (MC)
Experimental status

Big improvements in the last years in the exp. determination of RK:

World average (2006) (based on 1970s experiments)

\[ R_K^{PDG} (2006) = (2.45 \pm 0.11) \cdot 10^{-5} \]
\[ \delta R_K / R_K = 4.5\% \]

<table>
<thead>
<tr>
<th>NA48/2</th>
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<tbody>
<tr>
<td>• Run 2003</td>
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<tr>
<td>final sample: ((4670 \pm 77_{\text{stat}}) K_e^2) candidates</td>
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<tr>
<td>• Run 2004</td>
</tr>
<tr>
<td>final sample: ((3407 \pm 63_{\text{stat}}) K_e^2) candidates</td>
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\[ R_K = (2.455 \pm 0.045 \pm 0.041) \cdot 10^{-5} \]
\[ \delta R_K / R_K \sim 2\% \]

<table>
<thead>
<tr>
<th>KLOE (preliminary 2007)</th>
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<tr>
<td>(~ 8k K_e^2) candidates</td>
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<tr>
<td>(70% of available statistic)</td>
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\[ R_K = (2.55 \pm 0.05 \pm 0.05) \cdot 10^{-5} \]
\[ \delta R_K / R_K \sim 2.7\% \]
\[ \text{target: 1\%} \]

[arXiv:0707.4623]
Flavianet fit to $R_K$

The Flavianet group combined all these measurements

$$R_K = (2.457 \pm 0.032) \cdot 10^{-5} \quad (\chi^2 / ndf = 2.44 / 3)$$

✓ Big improvement wrt PDG → now $\delta R_K/R_K \sim 1.3\%$
✓ Good agreement with SM prediction
The NA62 experiment

The NA62 collaboration borns from the previous NA48 experience

NA62 phase I:
measure of $R_K$ with 0.5 % error using the NA48/2 exisiting apparatus

NA62 phase II:
construction of a new detector to measure the BR

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

B.R $\sim 10^{-10}$; $\sim$ 80 events in two years of D.T. S:B = 10:1

2008-2010 R&D & construction
2011 start of data taking
NA62 experiment

Located at the Nord Area of the CERN laboratory

Fixed Target: 400 GeV/c protons on Be target
high intensity $K^+$ 75 GeV/c momentum
Not separated beam ( $K/\pi = 8\%$)

$K^+$ and $K^-$ can be provided simultaneously or individually
The NA62 detector (phase I)

Sub set of NA48/2

Magnet spectrometer (4 DCHs):
4 view: redundancy ⇒ efficiency
\( \sigma(p)/p = 0.47\% + 0.020\% \ p \ [\text{GeV}/c] \)

Charged Hodoscope:
two planes x-y, strip shaped counters
Fast trigger and good time resolution
(~200ps on single track)

E.m. calorimeter with Liquid Krypton (LKr):
10 m\(^3\) (~22 t), 1.25 m (27 \(X_0\)), 13212 cells
granularity: 2x2 \(\text{cm}^2\), quasi-homogeneous
\( \sigma(E)/E = 3.2\%/\sqrt{E} + 9\%/E + 0.42\% \ [\text{GeV}] \)

~100 m long decay volume
The goal: to measure $R_K$ with an error better than 0.5%

This requires:

• A large data sample has to be collected (order $10^5$)

• Control over the systematic effects, in particular background subtraction

We performed:

• Improvements of the run conditions respect to NA48/2 experience

• A 4 months data taking run, collecting $\sim 110 \times 10^3 K_{e2}$ decays (summer 2007)

• special runs for the study of the background subtraction
Analysis strategy

\[ R_K = \frac{N(K_{e2}) - N_B(K_{e2})}{N(K_{\mu2}) - N_B(K_{\mu2})} \cdot \frac{1}{D} \frac{A(K_{\mu2}) \times f_\mu \times \varepsilon(K_{\mu2})}{A(K_{e2}) \times f_e \times \varepsilon(K_{e2})} \]

- \( N(K_{e2}), N(K_{\mu2}) \): numbers of selected \( K_{l2} \) candidates;
- \( N_B(K_{e2}), N_B(K_{\mu2}) \): numbers of background events;
- \( A(K_{e2}), A(K_{\mu2}) \): MC geometric acceptances (no ID);
- \( f_e, f_\mu \): measured particle ID efficiencies;
- \( \varepsilon(K_{e2})/\varepsilon(K_{\mu2}) \): \( E_{LKr} \) trigger condition efficiency
- \( D \): trigger downscaling

- \( K_{e2} \) and \( K_{\mu2} \) collected simultaneously
- fluxes cancel in the ratio
- Many time-dependent systematic effects also cancel
- The main contribution to systematic error comes from background subtraction (stat. dependent)
- \( R_K \) measured in bins of track momentum
Many improvements during data taking to increase the number of $K_{e2}$ collected:

1) Drift chambers multiplicity (1TRK)
2) Optimization of trigger downscaling
3) Beam steering
4) Removal of the lead wall

<table>
<thead>
<tr>
<th>Trigger</th>
<th>Condition</th>
<th>Rates/SPS spill</th>
<th>Purity</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Start-up</td>
<td>End-of-run</td>
<td></td>
</tr>
<tr>
<td>$K_{e2}$</td>
<td>$Q_1 \times E_{LKr}$</td>
<td>$Q_1 \times E_{LKr} \times 1TRK$</td>
<td>0.23 0.54</td>
</tr>
<tr>
<td>$K_{\mu2}$</td>
<td>$Q_1/50$</td>
<td>$Q_1 \times 1TRK/150$</td>
<td>290 160</td>
</tr>
</tbody>
</table>

- The $K_{\mu2}$ trigger also used as control trigger for $K_{e2}$ trigger
- Other minimum bias control triggers included
- Small trigger inefficiencies (~0.1%) directly measured from data
Signals selection

$K_{e2}$ and $K_{\mu2}$ decays similar → set of common cuts

- 1 track events
- $15 < p < 50 \text{ GeV/c}$
- reconstructed decay vertex inside the fiducial decay region
- Geometrical acceptance

**Kinematics:**
- $M_{\text{miss}}^2 = (p_K-p_l)^2$, $-0.015 < M_{\text{miss}}^2 < 0.015$

**Particle ID (E/p):**
- e ($0.95 < E/p < 1.05$)
- $\mu$ ($E/p < 0.2$)

Express analysis:
~3% of the 2007 $K^+$ sample
Na48/2 beam line: capable of delivering simultaneous $K^+ / K^-$ beams (75 GeV/c in 2007). $K^+$ only beam used for most of the run: lower beam halo background (1% vs 20%).

Kinematic ID of the $K_{l2}$ candidates:

$$M_{miss}^2(l) = (P_K - P_l)^2$$

Poor $K_{e2} / K_{\mu2}$ separation at $p_{track} > 40$GeV/c

Optimization of $M_{miss}^2$ resolution:

- $P_K$: [$M_{miss}$ evaluated with measured beam average]: narrow band beams ($\Delta P_K / P_K$ = 2% vs 3% in 2003-4);
- $P_l$: analyzing magnet momentum kick increased: 263MeV/c vs 120MeV/c in 2003-4, resolution $\delta p / p = 0.47\% + 0.020\% p$ [p in GeV/c].

Expected $K_{\mu2}$ background in analysis region: 7%.
Background:
The $M^2_{\text{miss}}$ fails to separate muons from electron for $P > 40\text{GeV}/c$

Particle identification needed: $E(\text{calorimeter})/P(\text{spectrometer})$

Electron identification relays on $E/p$:
$0.95 < E_{\text{LKr}}/p_{\text{tr}} < 1.05$

But:
A non-negligible fraction of muons has a catastrophic bremsstrahlung in the LKr

$\mu$ misidentified as electrons

$P(\mu \rightarrow e) \sim 4 \times 10^{-6}$, depending from $p$
(according to bremsstrahlung cross section)
Main source of background!!
Background subtraction

$P(\mu \rightarrow e)$ can be measured directly from data:

- pure muon samples available:
  1) electron stopped by a lead wall
  2) special muon runs
  3) $K\mu\nu$ from standard data taking

Lead wall between the two hodoscopes planes just before the LKr cal. to stop electrons and measure muon E/p response

$P(\mu \rightarrow e)$ from the $\mu$ run

- Thickness: Pb(4.5cm)+Fe(2.0cm)
- Width: 240cm (=HOD diameter)
- Height: 18cm (=3 counters)
- 18% of geom. acceptance
- Installed: ~50% of running time
**Background summary**

**K_{e2} sample**

1) $K_{\mu 2}$: Evaluated with the direct measurement of $P(\mu \rightarrow e)$
2) Beam halo: $(1.3 \pm 0.1)\%$ estimated with $K$-less runs
3) $K_{e2\gamma}$ (SD): Evaluated from MC: $(0.7 \pm 0.1)\%$
4) $K_{e3}$: Evaluated with MC: < 1\%
5) $K^+ \rightarrow \pi^+\pi^0$: Evaluated with MC: < 1\%

**K_{\mu 2} sample**

1) Beam halo: $\sim 0.1\%$
2) $K^+ \rightarrow \pi^+\pi^0$: $< 0.5\%$
**Identification efficiencies**

**Electron ID efficiency** $f_e$ can be measured from the data:

- clean sample of electrons by kinematic selection of $K^±\rightarrow\pi^0e^±\nu$ decays: collected simultaneously with main data taking, but $p<50\text{GeV/c}$.
- special 15h $K_L$ run: kinematic selection of $K_L\rightarrow\pi^±e^±\nu$ decays in the whole analysis track momentum range $15\text{GeV/c}<p<65\text{GeV/c}$.

Expected precision of $f_e$ measurement: better than 0.1%.

**Muon ID efficiency** $f_\mu$:

- ID by LKr energy deposit: $E/p<0.2$
- Measurement with clean muon samples
- $f_\mu$ preliminarily measured to be in the range 0.996–0.999 in analysis $p$ region;
- Expected uncertainty: $\delta f_\mu<0.1%$. 

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**Preliminary result from the 2007 $K_L$ run**

Electron ID inefficiency vs electron momentum

$1-f_e$, %

electron track momentum [GeV/c]
Data collected

Data taking period: from June, 23th to October, 22th in 2007

$112 \times 10^3$ candidates selected, background < 10%

Statistical error on $R_K \sim 0.3\%$, total error < 0.5 %
CONCLUSIONS

• The ratio $R_K$ is an exceptional probe for LVF beyond SM
• New measurements in the last few years have improved $\delta R_K$ (1.3% FlaviaNet fit)
• A sub-% measurement is a tight SM test
• NA62 successfully completed a 4 month long run, >100k $K_{e2}$ collected (largest sample)
• Main systematic effects under control and directly measured from data
• < 0.5% $\delta R_K/R_K$ achievable

analysis work is in progress
results coming soon...