Overview

• Physics motivation for $R_K = \Gamma(K_{e2})/\Gamma(K_{\mu2})$ measurement
• Beams, experimental setup and data taking
• Backgrounds and main systematic uncertainties
• Summary and prospects
K_{12} and \pi_{12} decays in the SM

**Standard Model:** accurate predictions of \( R_p \) due to cancellations of hadronic uncertainties in the ratio

\[
R_p = \frac{\Gamma(P \rightarrow e\nu(\gamma))}{\Gamma(P \rightarrow \mu\nu(\gamma))} = \left( \frac{m_e}{m_\mu} \right)^2 \left( \frac{m_p^2 - m_e^2}{m_p^2 - m_\mu^2} \right)^2 (1 + \delta R_{QED})
\]

- Helicity suppression (V-A couplings): enhances sensitivity to non-SM effects
- Radiative correction (~few %)

**Theory:** uncertainties well below \( 10^{-3} \)

→ latest SM predictions:

\[
R_K^{SM} = (2.477 \pm 0.001) \times 10^{-5} \quad \text{V. Cirigliano, I. Rosell, Phys. Lett. 99 (2007) 231801}
\]

\[
R_{\pi}^{SM} = (12.352 \pm 0.001) \times 10^{-5}
\]

**Experiment:** challenging measurements

→ PDG’08 (world ave. 1990s experiments):

\[
R_{\pi} = (12.30 \pm 0.04) \times 10^{-5} \quad (\delta R_{\pi}/R_{\pi} = 0.33\%)
\]

→ PDG’08 (based on 1970s experiments):

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

→ Significant improvements due to **NA48/2** and **KLOE** preliminary results (2007):

\[
R_K = (2.457 \pm 0.032) \times 10^{-5} \quad (\delta R_K/R_K = 1.3\%)
\]
K_{l2} decay beyond the SM

R_p ratio is a sensitive probe to all SM extensions that induce Pseudo-Scalar currents and non-universal corrections to lepton couplings (eg charged Higgs models, R-Parity violating SUSY, PS and V leptoquarks)

Effects from weak-scale New Physics are expected in the range $\delta R_p/R_p \sim 10^{-4} - 10^{-2}$

A possibility: R-parity violating SUSY (MSSM) LVF contribution with emission of $\tau$ neutrino enhances the decay rate

$$R_{K_{LVF}}^{SM} = R_{K_{SM}}^{SM} \left[ 1 + \left( \frac{m_K}{m_H} \right)^4 \left( \frac{m_\tau}{m_e} \right)^2 |\Delta_{13}|^2 \tan^6 \beta \right]$$

A few percent effect in large $\tan\beta$ regime (not extreme) with massive charged Higgs

Example: $|\Delta_{13}| = 5 \times 10^{-4}$, $\tan\beta = 40$, $M_H = 500$GeV

$R_{K_{LVF}} \approx R_{K_{SM}} (1 + 0.013)$

Note: analogous SUSY effects in pion decay are suppressed by a factor $(m_\pi/m_K)^4 \approx 6 \times 10^{-3}$

$R_{\pi_{LVF}} \ll R_{K_{LVF}}$
The NA62 experiment

A fixed target experiment → modern CERN kaon physics program

NA62 phase I
Dedicated 2007 run to measure:

\[ R_K = \frac{\Gamma(K^\pm \rightarrow e^\pm \nu_e)}{\Gamma(K^\pm \rightarrow \mu^\pm \nu_\mu)} \]

NA62 phase II
measurement of the decay

\[ K^+ \rightarrow \pi^+ \nu \bar{\nu} \]

(2008-2010 R&D & construction 2011 start of data taking)
NA62 goal

Accuracy better than 0.5% to provide a stringent SM test

- Dedicated data taking strategy
- High statistics $K_{e2}$ sample (160K) collected with
- Low background (10%)

Data taking (completed): 2007 and 2008

- Four months in 2007 (23/06–22/10):
  ~400K spills, 300TB of raw data (90TB recorded)
- Two weeks in 2008 (11/09–24/09):
  special data sets allowing reduction of the systematic uncertainties

NA48-2 beams: simultaneous $K^+/K^-$, focused, high momentum, narrow band, designed for the search of direct CPV in $K^{\pm}\rightarrow3\pi$
NA62 beam: $K^+$, high momentum, narrow band

**$K_{l2}$ candidates: kinematic identification**

$$M_{\text{miss}}^2(l) = (P_{K} - P_{l})^2$$

$P_K$ is only measured on average (not on event by event basis)

- Improvement of $K_{e2} / K_{\mu2}$ separation by
  1) high momentum beam ($p=75$ GeV/c)
  2) narrow momentum band beam ($\Delta P_{K}^{\text{RMS}}/P_K=2\%$)
  (optimization of $M_{\text{miss}}^2$ resolution)

**K beam charge:**

beam halo background much higher for $K^-_{e2}$ ($\sim 20\%$) than for $K^+_{e2}$ ($\sim 1\%$):

- $\sim 90\%$ of data sample: $K^+$ only beam
- $\sim 10\%$ of data sample: $K^-$ only beam

Collection of "$K^+$ only" and "$K^-$ only" data allows precision "cross-measurements" of beam halo background


**NA62 Main sub-detectors**

**K_{l2} candidates:**
- e/μ particle identification from E/p

- **Magnetic spectrometer (4 DCHs):**
  4 views/DCH: redundancy → efficiency; $\sigma_p/p = 0.47\% + 0.02\%p$ [GeV/c]

- **Liquid Krypton EM calorimeter (LKr):**
  High granularity, quasi-homogeneous; $\sigma_E/E = 3.2\%/E^{1/2} + 9\%/E + 0.42\%$ [GeV]; $\sigma_x=\sigma_y=0.42/E^{1/2} + 0.6\text{mm (1.5mm@10GeV)}$

- **Hodoscope**
  fast trigger and track time ($\sigma_t \sim 200\text{ps}$)
Minimum bias (high efficiency, but low purity) trigger configuration used

\[ K_{e2} \text{ condition: } Q_1 \times E_{LKr} \times 1TRK \]
Purity \( \sim 10^{-5} \)

\[ K_{\mu2} \text{ condition: } Q_1 \times 1TRK/D \]
Downscaling (D) = 50 to 150
Purity \( \sim 2\% \)

- \( K_{\mu2} \) & control triggers to monitor the efficiency of \( K_{e2} \) trigger
- \( E_{LKr} \) inefficiency is \(< 0.1\%\) for \( p>15\text{GeV/c} \)
Measurement strategy

(1) $K_{e2}$ and $K_{\mu2}$ collected simultaneously:
   • result does not rely on K flux measurement
   • cancellation of many systematic effects at first order
     (eg. reconstruction/trigger efficiencies, time dependent systematics)

(2) Counting events in track momentum bins:

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

   • $N(K_{e2}), N(K_{\mu2})$: numbers of selected $K_{l2}$ candidates
   • $N_B(K_{e2}), N_B(K_{\mu2})$: numbers of background events (Data, MC)
   • $A(K_{e2}), A(K_{\mu2})$: geometric acceptances (MC)
   • $f_e, f_\mu$: measured particle ID efficiencies (Data)
   • $\varepsilon(K_{e2})/\varepsilon(K_{\mu2}) > 0.999$: $E_{LKr}$ trigger condition efficiency (Data)
   • $f_{LKR} \approx 0.998$: global LKr readout efficiency (Data)

(3) Minimal use of MC simulations:
   • Acceptance correction (geometry)
   • Correction for background from energetic bremsstrahlung by muons

Main contribution to systematic errors from background evaluation
Ke2 and Kµ2 selection

Common criteria for Ke2 and Kµ2
- One reconstructed charged track;
- Track in geometrical acceptance of the main sub-detectors;
- Upper limit on LKr energy deposition not associated to the track;
- Decay vertex: closest dist. approach (CDA) of track & kaon beam axis: CDA<2cm and (Z_{vertex} - Z_{collimator})>18m;
- Track momentum: 15GeV/c<p<65GeV/c

Selections to discriminate Ke2 from Kµ2
- Kinematic identification by invariant missing mass
  \[ M_{\text{miss}}^2(l) = (p_K - p_l)^2 - m_K^2 (1 - p_l/p_K) - p_t^2 (p_K/p_l) \]
  (electron mass hypothesis):
  \[ |M_{\text{miss}}^2(l)| < 0.01 \text{ (GeV/c}^2)^2 \]
- Particle identification by energy deposition in Calorimeter (E_{LKr})
  - 0.95<E/p<1.10 for electron
  - E/p<0.2 for muon
**K_{e2}:** present analysis with 40% of full data sample

Estimated NA62 full K_{e2} sample:
140K K^+ & 20K K^- candidates.
Proposal (CERN-SPSC-2006-033): 150K candidates

*cfr.* KLOE preliminary: 8,090 candidates after background subtraction

Record sample: 59,3K candidates
Total B/S ≈ 10.7%

Data

Missing invariant mass, K_{e2} candidates

Same plot, log scale

**K_{e2} background sources**
- \( K_{\mu2} \): (8.07±0.21)%
- \( K_{e2\gamma} (SD^+) \): (1.29±0.32)%
- Beam halo: (1.23±0.07)%
- \( K_{2\pi} \): 0.11%
- \( K_{e3} \): 0.03%

Detailed studies with data and MC

So far, fast simulation only
Muonic background in $K_{e2}$ sample

Electron ID is based on LKr energy deposition: $0.95 < E/p < 1.10$

**Muon mis-identification as electron**
due to “catastrophic” bremsstrahlung:
$P(\mu \rightarrow e) \sim 3 \times 10^{-6}$ (and $p$-dependent)
$\rightarrow P(\mu \rightarrow e)/R_K \sim 10\%$:

$K_{\mu 2}$ decays represent a major background

- Direct measurement of $P(\mu \rightarrow e)$ is necessary
to validate theoretical brems. description
  in the critical high $E_\gamma$ region

- Problem: $\mu \rightarrow e$ decay: electron
  contamination $\sim 10^{-4}$

- Solution: Pb wall between the HOD planes
Tracks traversing the wall & with $E/p > 0.95$
are pure $\mu$ samples (contamination $< 10^{-7}$)

**Pure muon samples collected:**
- From $K_{\mu 2}$ decays during main data taking with kaon beams;
- Special $\mu$ runs with hadron beam absorbed (2007+2008).
2007 special sample analysed: $\sim 1,500$ muons with $E/p > 0.95$, $35 < p < 65$(GeV/c)
Muonic background in $K_{e2}$ sample (2)

Mis-identification probability $P(\mu \rightarrow e)$: measurement (2007 muon sample) vs MC simulation (Geant4-improved)

The simulation was improved in collaboration with G4 developers

$\rightarrow$ Data with Pb wall used for MC validation

$P(\mu \rightarrow e)$ is appreciably modified by the Pb wall, due to:
1) muon ionization losses (low $p$);
2) bremsstrahlung in Pb (high $p$)

$\rightarrow$ MC used to estimate the background in $K_{e2}$
Result: $B/S = (8.07 \pm 0.21)\%$

Uncertainty is due to the limited size of the data sample used to validate the simulation

Prospects:
• The 2008 muon sample is twice as large as the 2007 one;
• Another tool: muons from $K_{\mu2}$ decays in $K_{e2}/K_{\mu2}$ separation region ($p<25\text{GeV}/c$)
**K^±→e^±νγ** background

**K_{e2γ} structure dependent (SD^+):**

- Background (by definition of R_K)
- Rate similar to K_{e2}
- Known with very poor precision (~20%):

  - Theory: \( \text{BR} = (1.12 - 1.34) \times 10^{-5} \) [model-dependent form-factor]
  - Experiment: \( \text{BR} = (1.52 \pm 0.23) \times 10^{-5} \) [measurements in the 1970s]

**Prospects:**

- Improve B/S estimate uncertainty by direct measurement with NA62 2007 data

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**K_{e2γ} (SD^+) Dalitz plot distribution**

- Only energetic electron events \( (E_e^* > 230 \text{MeV}) \) are compatible with K_{e2} kinematic ID
- This part of phase space is accessible for a direct BR measurement, (being outside the area populated by the K_{e3} background \( (E_e^* < 227 \text{ MeV}) \)

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**Estimate:** \( \text{B/S} = (1.29 \pm 0.32)\% \)

Uncertainty is due to poor precision of theoretical and experimental knowledge
Beam halo background

Background source in $K_{e2}$ sample:
electrons produced by muons in beam halo via $\mu \rightarrow e$ decay,
kinematically and geometrically compatible to a genuine $K_{e2}$ decay

Directly measured with $K^-$ only sample:
Result: $B/S=(1.23\pm0.07)$% 

Background rate and distribution are well reproduced with beam halo simulation

Uncertainty due to the limited size of control data sample

Prospects:
• 2008 $K^-$ sample will improve precision;
• Smallness of uncertainty allows expanding the analysis fiducial volume further upstream and increase the data sample

Halo background in $K_{\mu2}$ sample measured with similar technique:
$B/S=0.14$
negligible uncertainty
Backgrounds: summary

Other identified backgrounds (minor):

- $K^\pm \rightarrow \pi^0 e^\pm \nu$, $K^\pm \rightarrow \pi^\pm \pi^0$ (below 0.1%)
- $K_{\mu 2}$ + accidental LKr cluster (~0.1%)

Scales differ by a factor of 5

- $K_{e2}$ candidates in track momentum bins
- Background in track momentum bins
- Raw candidates

- B/S $\approx 10.7\%$, mainly at high momentum
- Systematic effect due to BKG: $\delta R_K / R_K = 0.4\%$
- Improvement in precision for each background source is foreseen
**Particle ID efficiencies**

**Electron ID efficiency** $f_e$
directly measured by kinematic selection of electrons:
- from $K^\pm \rightarrow \pi^0 e^\pm \nu$ decays collected during main $K$ data taking (limited momentum range $p<50\text{GeV}/c$);
- from $K_L \rightarrow \pi^\pm e^\pm \nu$ decays collected in a special $15h K_L$ run (whole track momentum range, due to broad $K_L$ momentum spectrum).

$\rightarrow f_e$ is measured (range: 0.988-0.992) with uncertainty below $\delta f_e < 0.1\%$

**Muon ID efficiency** $f_\mu$
measurement is simple: electro-contamination is outside the muon ID region, and is negligible wrt $1-f_\mu$

$\rightarrow f_\mu$ is measured directly (range: 0.996-0.999) with an uncertainty below $\delta f_\mu < 0.1\%$
Other effects

Acceptance correction:
- Momentum dependent: \( A(K_{\mu^2})/A(K_{e^2}) \approx 1.3 \)
- \( K_{e^2} \) radiative (IB) corrections strongly affect the acceptance
- Preliminary conclusion: the correction can be evaluated with a 0.1% precision

Trigger efficiency correction:
- Efficiencies are monitored with control trigger samples;
- \( Q_1 \) efficiency mostly cancels in \( R_K \), while \( E_{LKr} \) efficiency directly affects \( R_K \)
- \( E_{LKr} \) inefficiency measurement: \( 1-\varepsilon(E_{LKr}) \approx 1-\varepsilon(K_{e^2})/\varepsilon(K_{\mu^2}) < 0.1\% \)

Other known sources of uncertainties (can be corrected for):
- Trigger after-pulses biasing the \( Q_1 \) downscaling factor;
- Global inefficiency of LKr calorimeter readout (measured: \( 1-f_{LKr} \approx 0.002 \))
Analysis summary & prospects

- **Main uncertainties** (40% of the data sample)
  - Statistical: 0.43%
  - $K_{\mu^2}$: 0.25%
  - $K_{e^2y}$ (SD): 0.32%
  - Beam halo: 0.10%
  - **Total**: 0.60%

  (there is room for improvement of the systematic errors)

- **Expected total uncertainty** with the partial 40% sample: **0.6-0.7%**
  (below 1% level for the first time)

- **Preliminary result in winter** (in agreement with the proposal goal)

The whole sample of $\sim$160K candidates: statistical uncertainty pushed below **0.3%**, total uncertainty of **0.4-0.5%** is within reach.

**Independent measurements in lepton momentum bins**

**Overall offset applied!**

**$\chi^2 / \text{ndf}$**: 8.799 / 9

**p0**: $2.477 \pm 0.01275$
Conclusions

• NA62 data taking in Y2007 was optimized for $K_{e2}$ decays. It increased the World $K_{e2}$ sample by more than an order of magnitude.

• Additional data were collected in Y2008 to reduce systematic uncertainties.

• The analysis of a partial data sample (~40%) is well advanced and aims at a preliminary $R_K$ result with ~0.7% accuracy by the winter conferences.

• The analysis demonstrates that the overall uncertainty of 0.4%, as declared in the proposal, is within reach.

• Precision measurement of $R_K$ is going to be a timely result, as direct searches for New Physics at the LHC are approaching.
Spares
Radiative corrections in the SM computation of $R_K$:

- Inner bremsstrahlung (IB) contribution is included
- Structure dependent direct emission (SD) contribution is not included

Experiments measure inclusive $K\mu 2(\gamma)$ and $K\ell 2(\gamma)$ candidates and then SD contribution is subtracted (properly accounting for acceptance)

Note: SD contribution is negligible in $K\mu 2$, not in $K\ell 2$