Test of lepton flavour violation and rare decays with the NA48/2-NA62 experiments at CERN

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on behalf of the NA62 Collaboration

Bern ITP, Birmingham, CERN, Dubna, Fairfax, Ferrara, Florence, Frascati, IHEP, INR, Louvain, Mainz, Merced, Naples, Perugia, Pisa, Rome I, Rome II, San Luis Potosi, SLAC, Sofia, Triumf, Turin

23rd Rencontres de Blois

June 1st, 2011

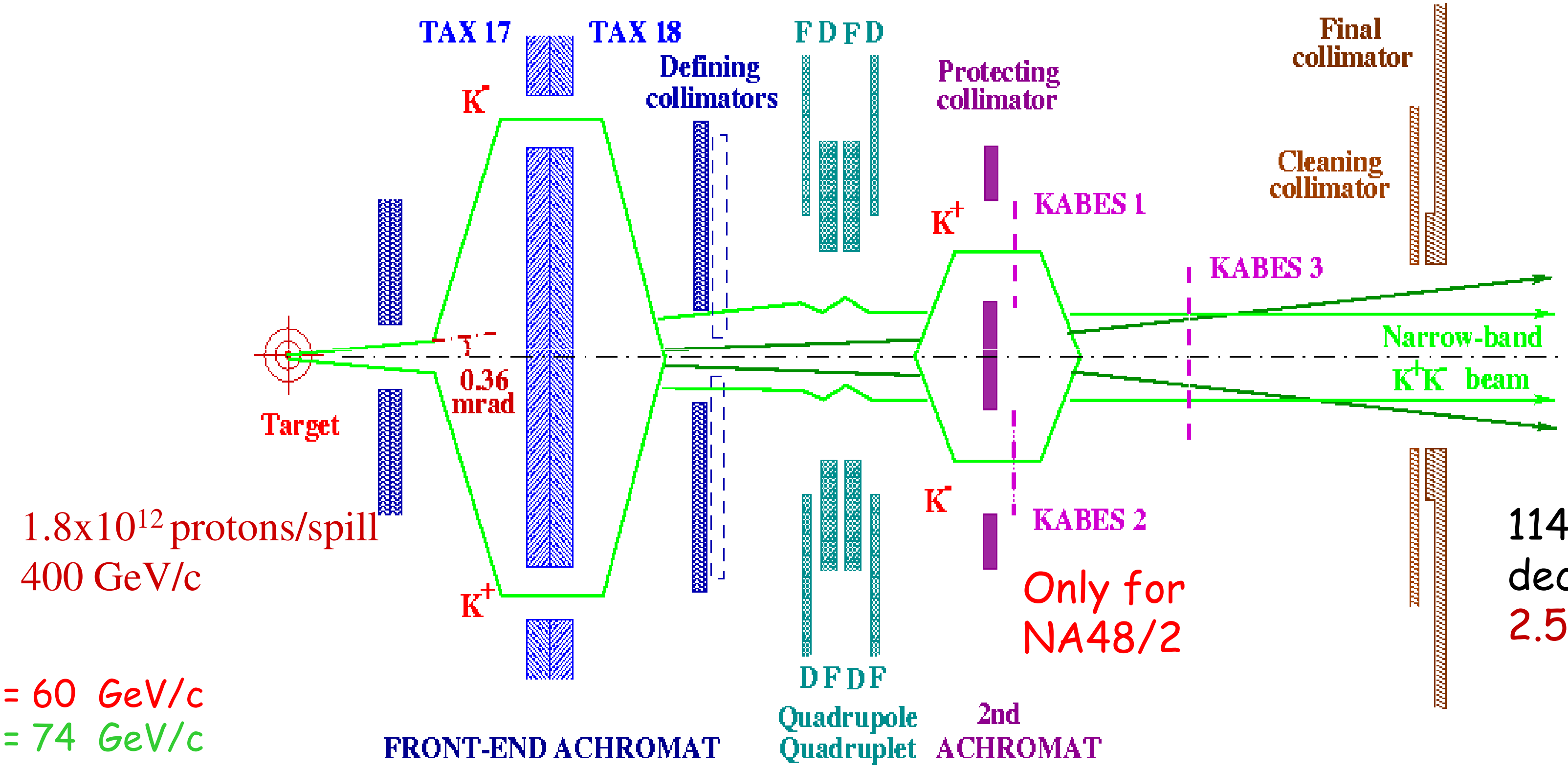
Outline

- The NA48/2-NA62 beam and detector
- NA62 measurement of R_K
- NA48/2 new results on $K^{\pm} \rightarrow \pi^{\pm}\mu^{+}\mu^{-}$

The NA48/2-NA62 Beam

NA48/2 beam (2003-2004): simultaneous K^+/K^-

NA62 beam (2007-2008): only K^+ optimized for R_K measurement

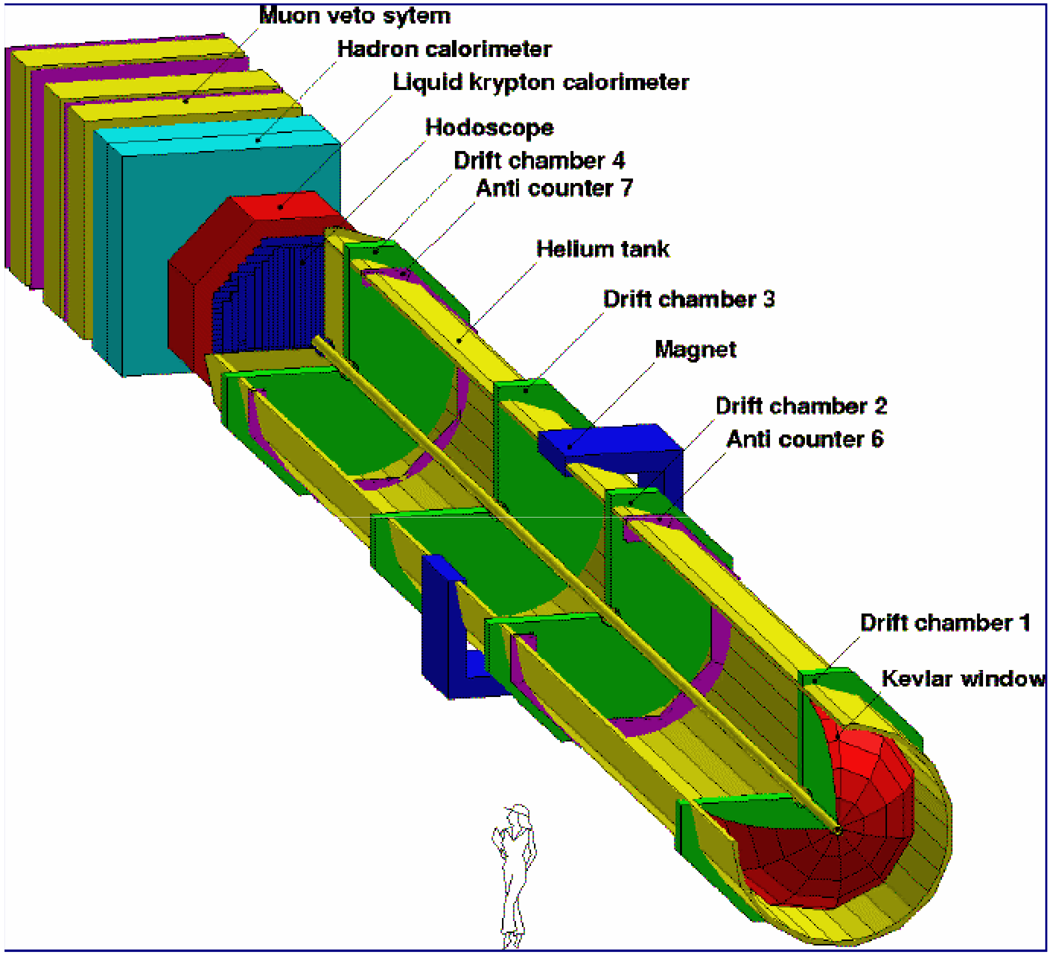


114 m long decay volume
2.5×10^7 K/spill

$P_K = 60$ GeV/c
$P_K = 74$ GeV/c

K+ decays in the vacuum tank: 22% (18%)
Beam size: 4x4 mm^2, 10x10 μr

The NA62 Detector for R_K



Use the NA48 detector

Maximum spectrometer P_T kick to improve missing mass resolution

LKr Calorimeter:

$\sigma(E)/E \cong 3.2\%/\sqrt{E} \oplus 9\%/E \oplus 0.42\%$

$\sigma(E) \sim 1\%$, $\sigma(x)$, $\sigma(y) \sim 1$ mm

Spectrometer:

$\sigma(P)/P \cong 0.48\% \oplus 0.009\ P[GeV/c]\%$

Scintillator hodoscope: fast trigger and good time resolution (150 ps)

R_K measurement

Physics motivations

$$R_K = \frac{\Gamma(K \to e\nu(\gamma))}{\Gamma(K \to \mu\nu(\gamma))} = \frac{m_e^2}{m_\mu^2}\left(\frac{m_K^2 - m_e^2}{m_K^2 - m_\mu^2}\right)^2 (1 + \delta R_K)$$

Test of lepton universality

- Excellent accuracy due to cancellation of hadronic uncertainties in the ratio
- Helicity suppression of electronic mode, enhancement of sensitivity to non-SM effects

$R_K(SM) = (2.477 \pm 0.001) \cdot 10^{-5}$ 0.04% precision!!

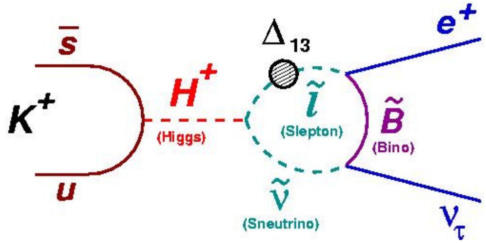
(V. Cirigliano, I. Rosell PRL 99 (2007) 231801)

- δR_K due to IB part of the radiative $K \to e\nu\gamma$ process
- $K \to e\nu\gamma$(IB) included by default in R_K

R_K beyond the Standard Model

- The value of R_K could be different in case of SUSY LFV
  - Masiero, Paradisi, Petronzio, Phys. Rev. D74 (2006) 011701
    - "Charged Higgs mediated SUSY LFV contributions can be strongly enhanced in kaon decays into an electron or a muon and a tau neutrino"

$$R_K^{LFV} \approx R_K^{SM} \left[1 + \left(\frac{m_K^4}{M_{H\pm}^4} \right) \left(\frac{m_\tau^2}{M_e^2} \right) |\Delta_{13}|^2 \tan^6 \beta \right]$$



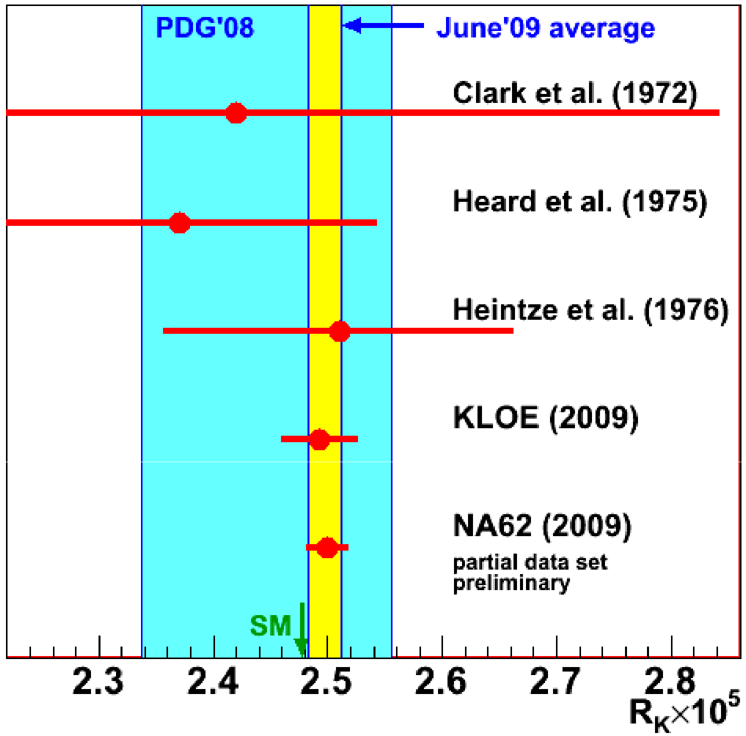
- Δ_{13}= $6 \cdot 10^{-3}$, M_H=500 GeV, $\tan\beta$=40 $\rightarrow$ $R_K^{LFV} \sim R_K^{SM} \cdot (1+0.013)$

  - Analogous SUSY effects in pion decays are suppressed by a factor $(m_\pi/M_K)^4 \sim 6 \cdot 10^{-3}$

B decays: large effects $(M_B/M_K)^4 \sim 10^4$
$B_{e\nu}/B_{e\tau}$ 10 times larger, but $(B_{e\nu})_{SM} \sim 10^{-11}$

The experimental situation

- Three esperiments from the 70's
  - $R_K = (2.45 \pm 0.11) \cdot 10^{-5}$
  - $\delta R_K / R_K = 4.5\%$
- 2009: KLOE (LNF) – 2001-2005 data
  - ~13800 K_{e2} candidates, 16% bckg
  - $R_K = (2.493 \pm 0.025 \pm 0.019) \cdot 10^{-5}$
  - $\delta R_K / R_K = 1.3\%$
- 2009: NA62 (CERN), part of 2007 data, preliminary result, 51100 candidates
  - $R_K = (2.500 \pm 0.016) \times 10^{-5}$
  - $\delta R_K / R_K = 0.7\%$
- NA62 final result, same sample, ~60000 candidates, this talk
  - $\delta R_K / R_K = 0.5\%$



- NA62 goals from the proposal
  - ~150000 K_{e2} events
  - ~0.4% accuracy

NA62 R_K measurement strategy

- K_{e2} and $K_{\mu 2}$ decays collected concurrently
  - Do not rely on the kaon flux measurement
  - Many systematic effects cancel in the ratio
    - » E.g. reconstruction/trigger efficiencies, time dependent effects
- Limited use of MC simulations
  - Geometric acceptance correction
  - PID, trigger, readout efficiencies measured directly
- Perform analysis in 10 lepton momentum bins
  - Background composition and event topology vary strongly with momentum

Selected signal events

PID efficiencies

$$R_K = \frac{N(K_{e2}) - N_B(K_{e2})}{N(K_{\mu 2}) - N_B(K_{\mu 2})} \bullet \frac{A(K_{\mu 2}) \times f_\mu \times \varepsilon(K_{\mu 2})}{A(K_{e2}) \times f_e \times \varepsilon(K_{e2})} \bullet \frac{1}{f_{LKr}} \bullet \frac{1}{D}$$

Bckg events

Main syst source

Acceptances

Trigger efficiencies

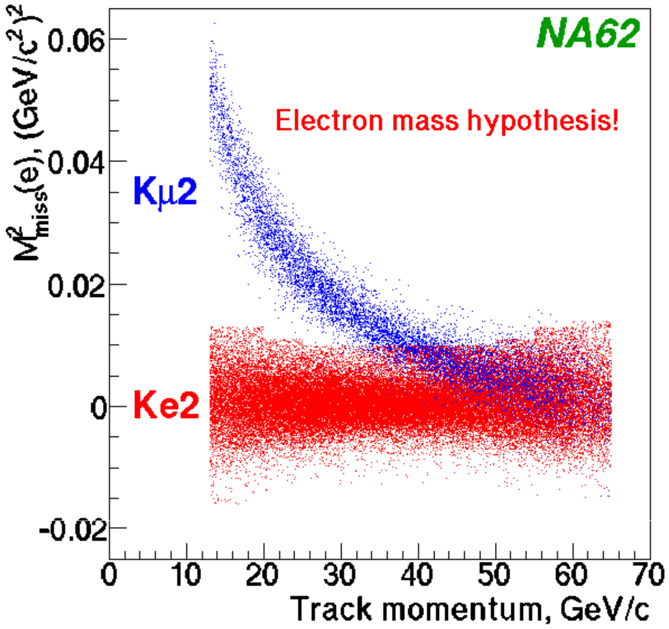
LKR readout efficiency

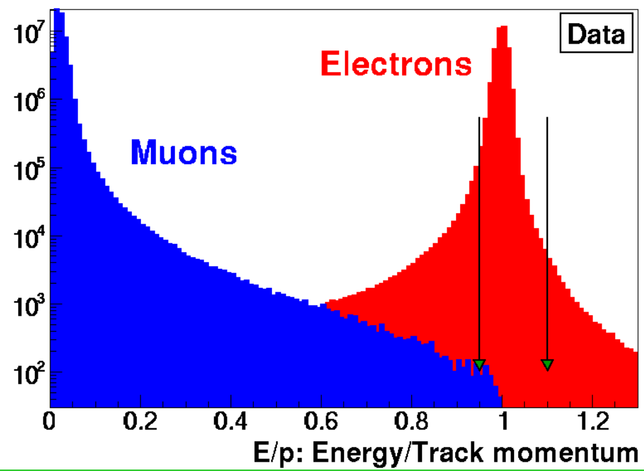
$K_{\mu 2}$ trigger downscaling factor

K_{e2} and $K_{\mu 2}$ selection

- Common selection
  - One reconstructed track, 13 < P < 65 GeV/c
  - Common geometrical cuts
  - Decay vertex defined as closest distance of approach track-nominal K axis
  - Veto extra LKr energy deposition clusters

- Kinematical identification
  - Use missing mass squared $M^2_{miss}=(P_K-P_\ell)^2$
  - P_K (average) is measured from the data with $K \rightarrow 3\pi$
    - Enough $K_{e2}/K_{\mu 2}$ separation for P_{track}< 25 GeV/c
- Lepton identification
  - E_{LKr}/P_{track} < 0.85 for muons, between 0.95 (0.90 below 25 GeV/c) and 1.10 for electrons

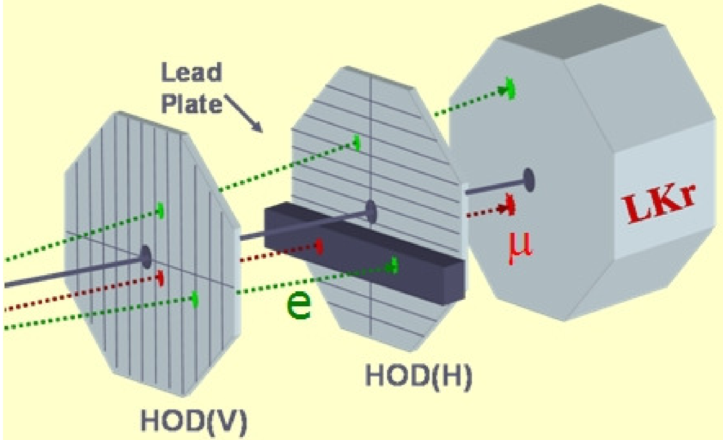




The major background to K_{e2} - 1

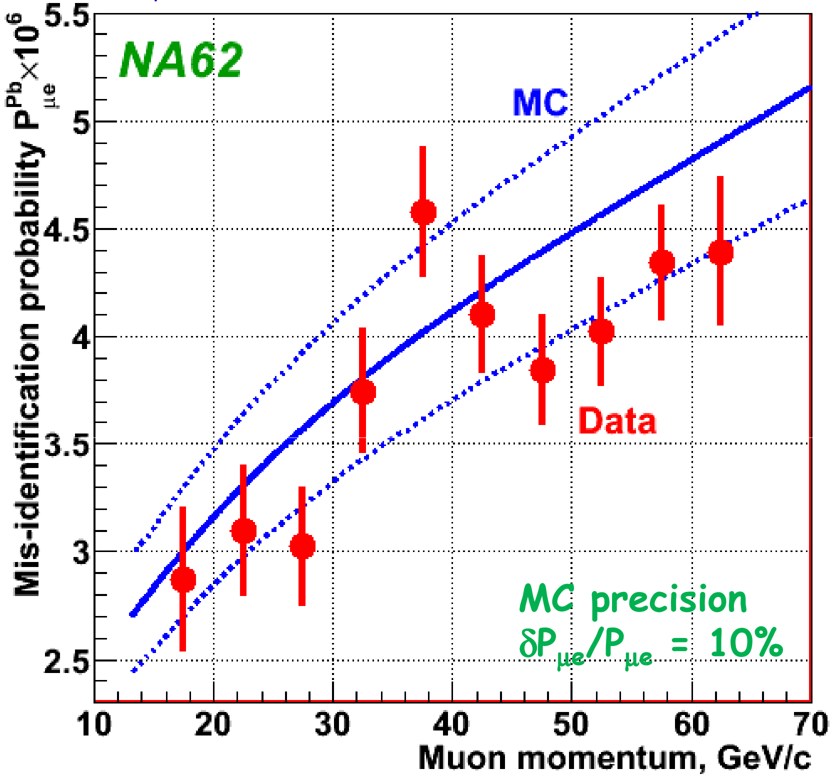
- Catastrophic bremsstrahlung of muons in the LKr
  - Gives $E/p > 0.95 \rightarrow$ tag the event as K_{e2}
  - Probability $P_{\mu e} \sim 3 \cdot 10^{-6}$ (momentum dependent)
    - $K_{\mu 2}/K_{e2} \sim 40000 \rightarrow$ background O(10%)
  - Need a direct measurement to validate the muon bremsstrahlung cross section in this region

- Measure it putting 9.2 X_0 of lead in front of the calorimeter
  - For about 50% of the run time, 18% acceptance reduction
  - Suppress 10^{-4} contamination of $\mu \rightarrow e$ decays
  - Tracks traversing the lead are pure muons
  - $P_{\mu e}$ is modified by the Pb wall
    - Ionization losses in the Pb (at low p)
    - Bremsstrahlung in Pb (at high p)
  - The correction is evaluated with a dedicated Geant4 simulation



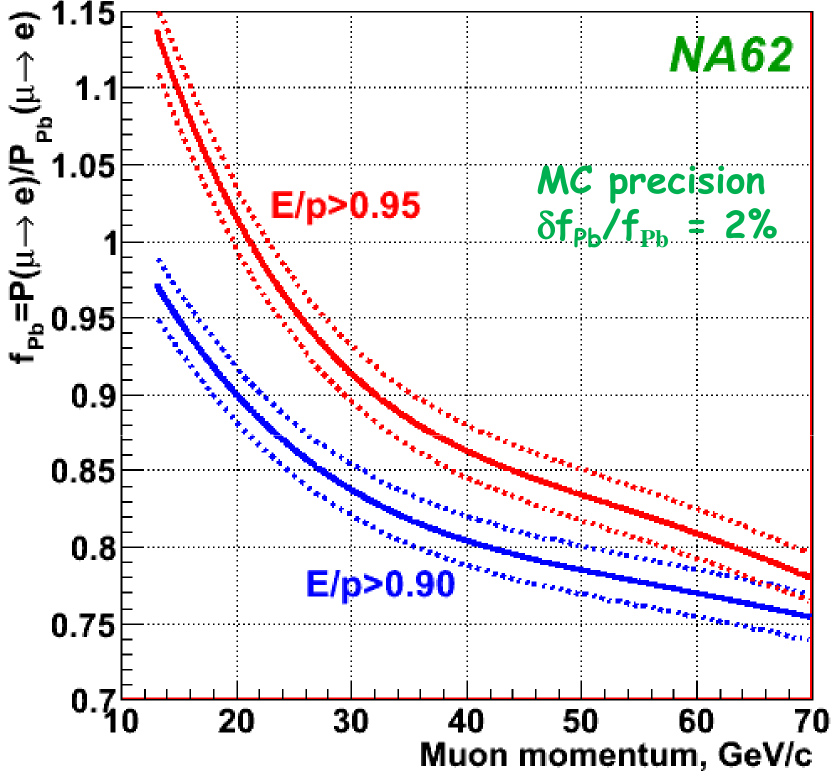
The major background to K_{e2} - 2

$P_{\mu e}$ vs momentum (Pb wall installed)



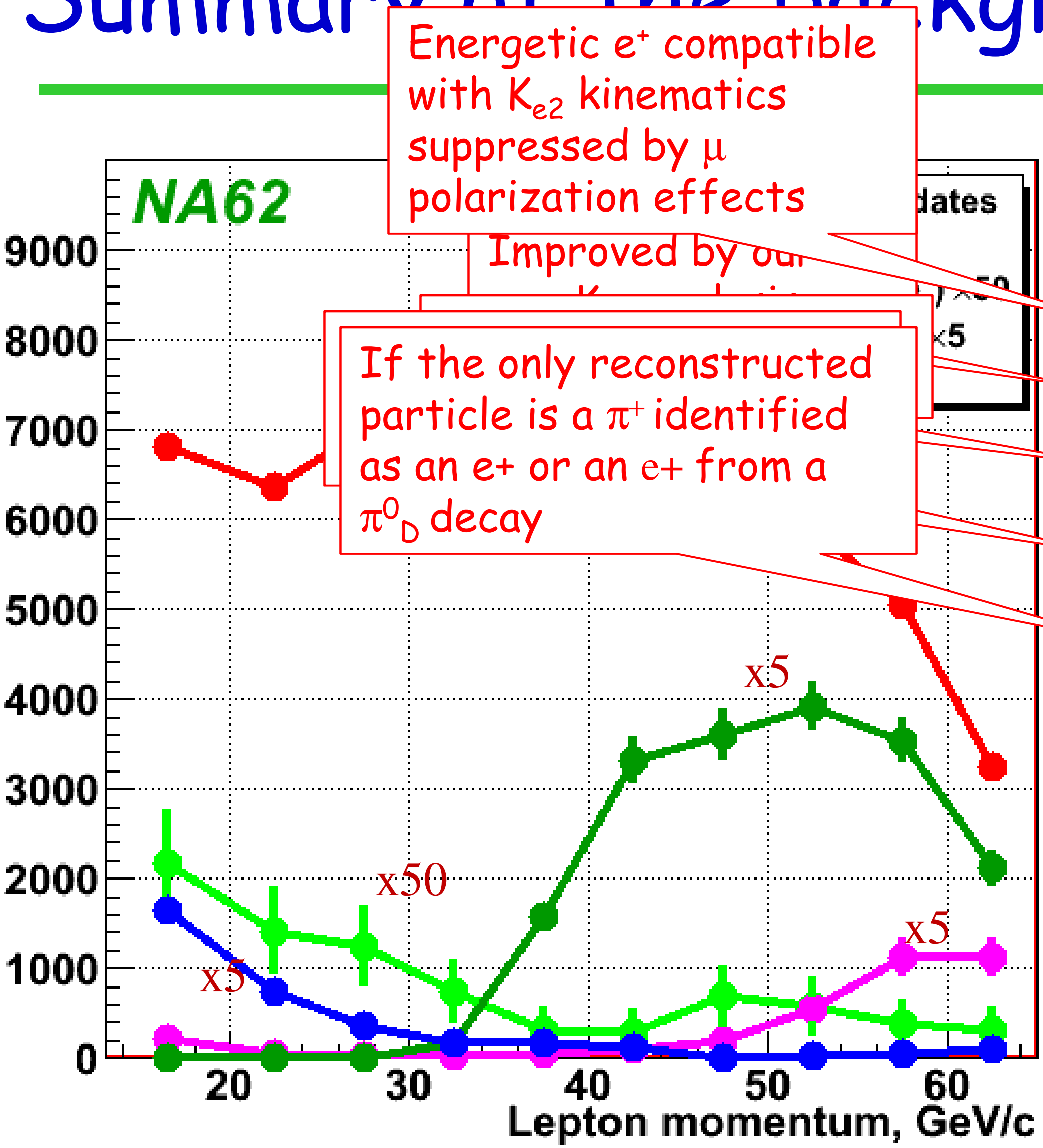
Contribution to background:
B(S+B) = (6.11±0.22)%
Uncertainty ~3 times smaller than simulation alone

Correction for Pb wall: $f_{Pb} = P_{\mu e}/P_{\mu e}^{Pb}$



Contributions to uncertainty:
Limited data sample 0.16%
MC correction 0.12%
Missing mass vs P correlation 0.08%

Summary of the backgrounds

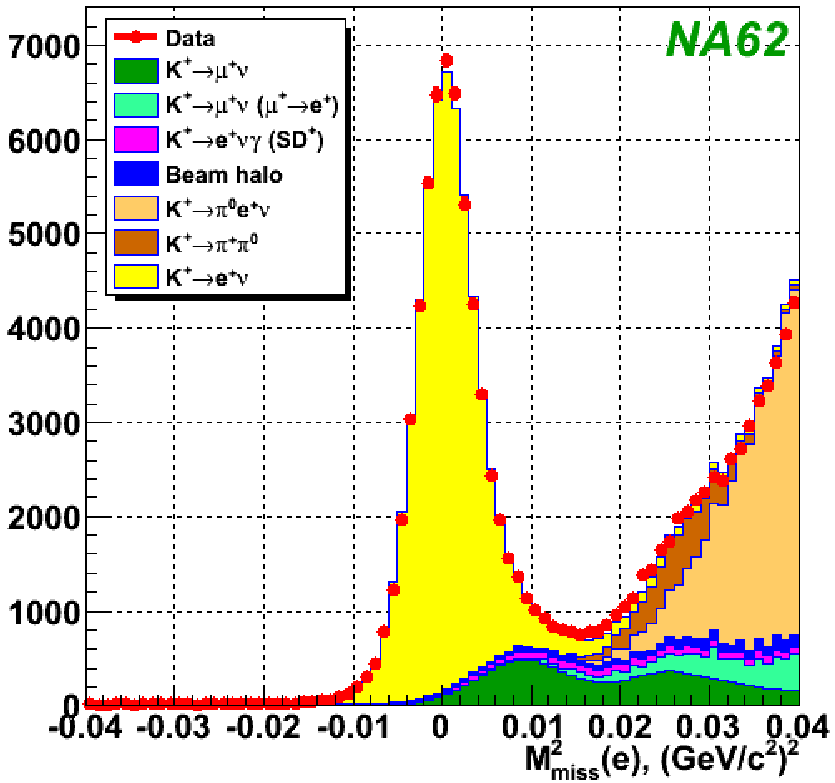


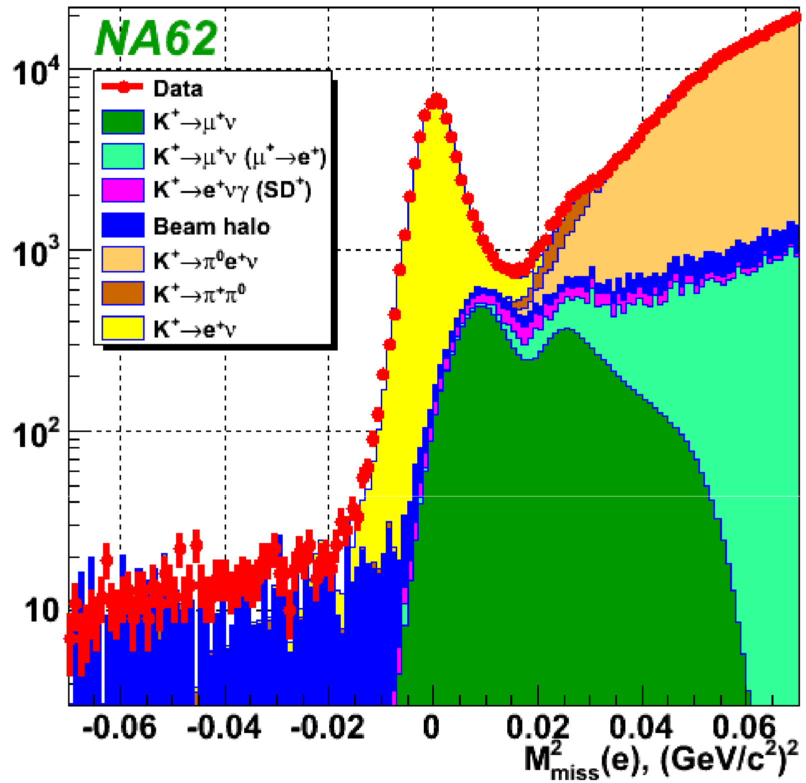
Source	B/(S+B)
$K_{\mu 2}$	(6.11±0.22)%
$K_{\mu 2}$ ($\mu \rightarrow e$)	(0.27±0.04)%
$K_{e2\gamma}$ (SD+)	(1.07±0.05)%
Beam halo	(1.16±0.06)%
$K_{e3(D)}$	(0.05±0.03)%
$K_{2\pi\ (D)}$	(0.05±0.03)%
Total	(8.71±0.24)%

Record K_{e2} sample:
59813 candidates

Different effects in lepton momentum bins

K_{e2} candidates





59813 K_{e2} candidates
B/(S+B) = (8.71 ±0.24)%
Positron ID efficiency (99.27 ± 0.05)%

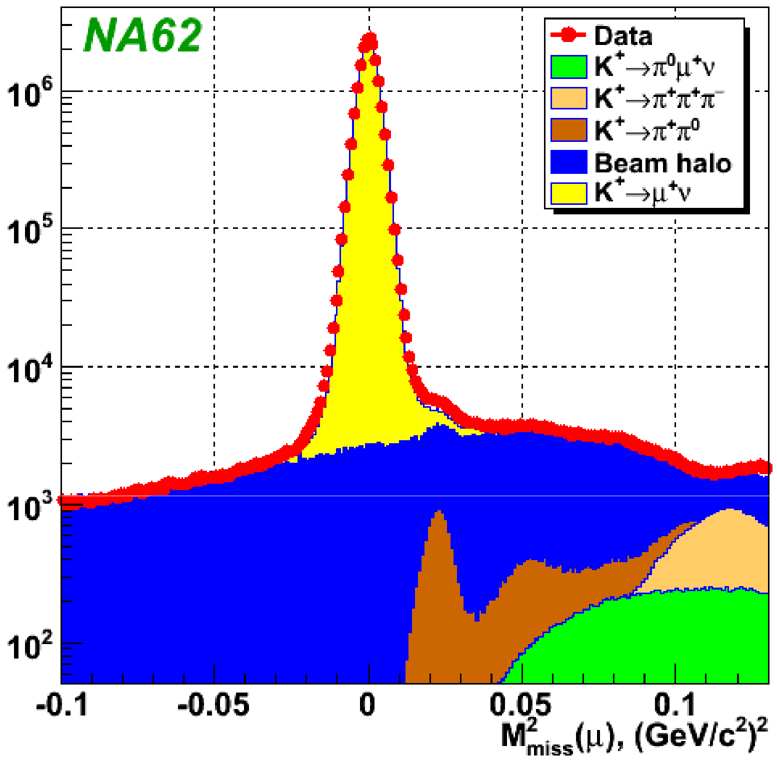
Cfr. KLOE: 13.8Kevents, ~90% electron id efficiency, 16% background

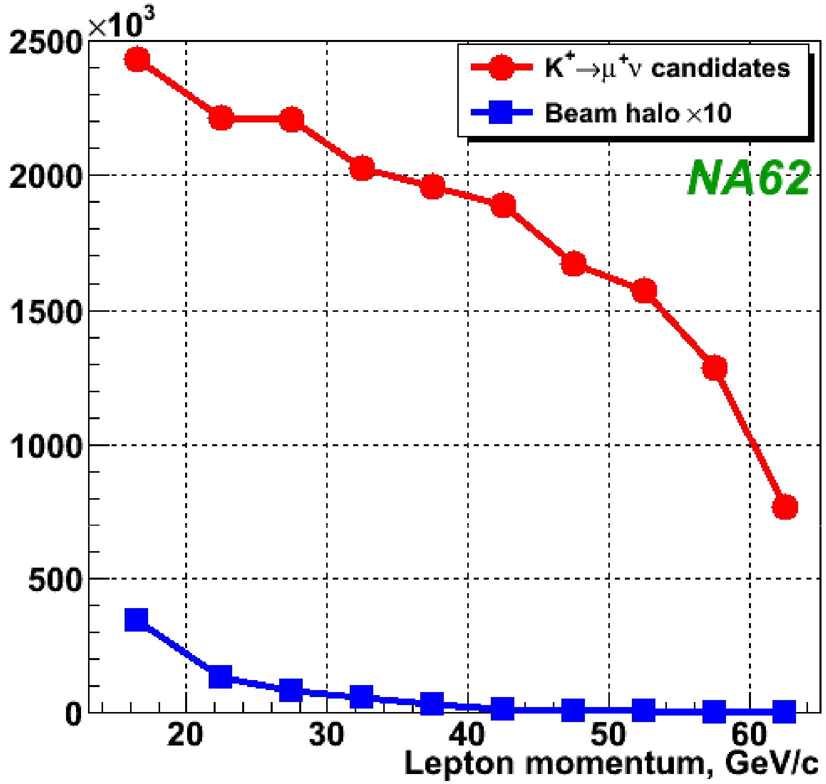
Only 40% of data used

Total estimated sample: ~130k K^+ and ~20k K^- candidates

Proposal: 150k candidates

$K_{\mu 2}$ candidates





Source	B/(S+B)
Beam halo	(0.38±0.01)%
Total	(0.38±0.01)%

18 M candidates with low background

B/(S+B) = 0.38%

$K_{\mu 2}$ trigger prescaled by a factor 150

NA62 final result (40% data set)

$R_K = (2.487 \pm 0.011_{stat} \pm 0.007_{syst}) \times 10^{-5} = (2.487 \pm 0.013) \times 10^{-5}$ (January 2011)

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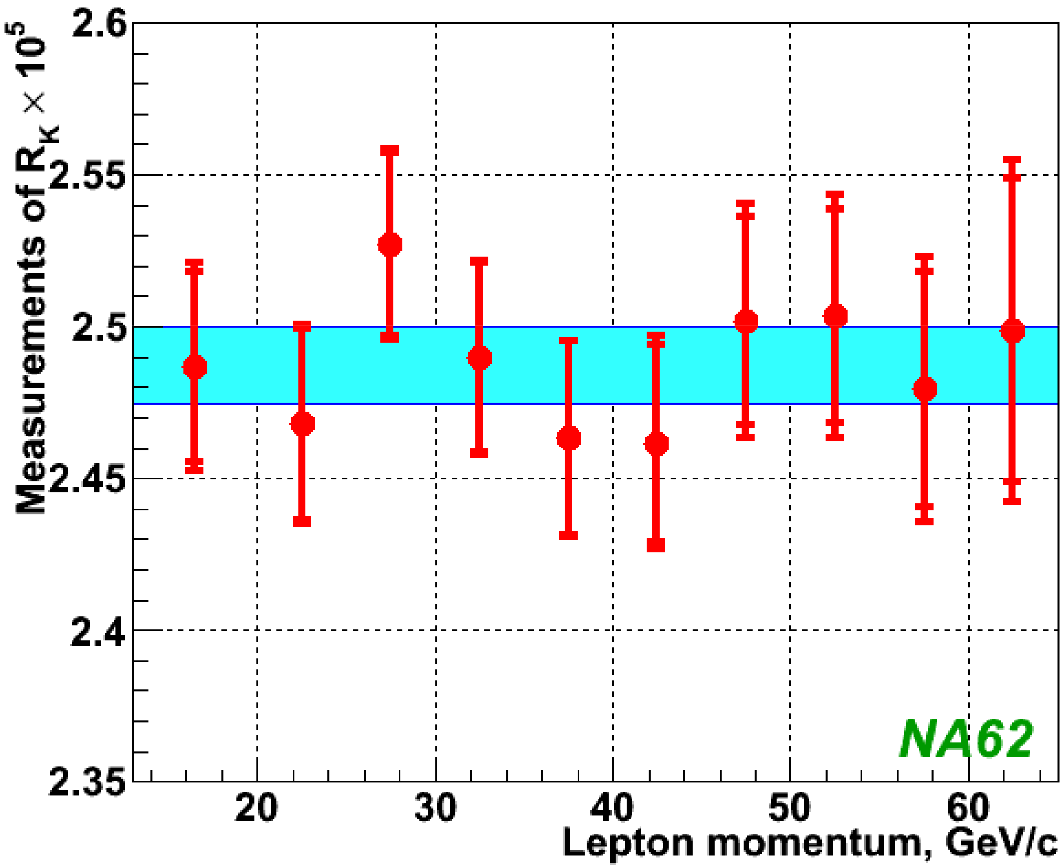
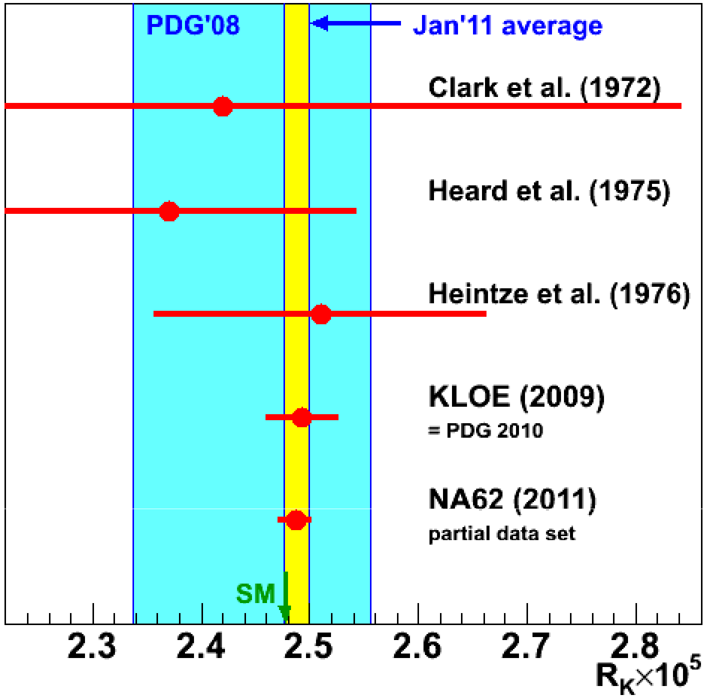
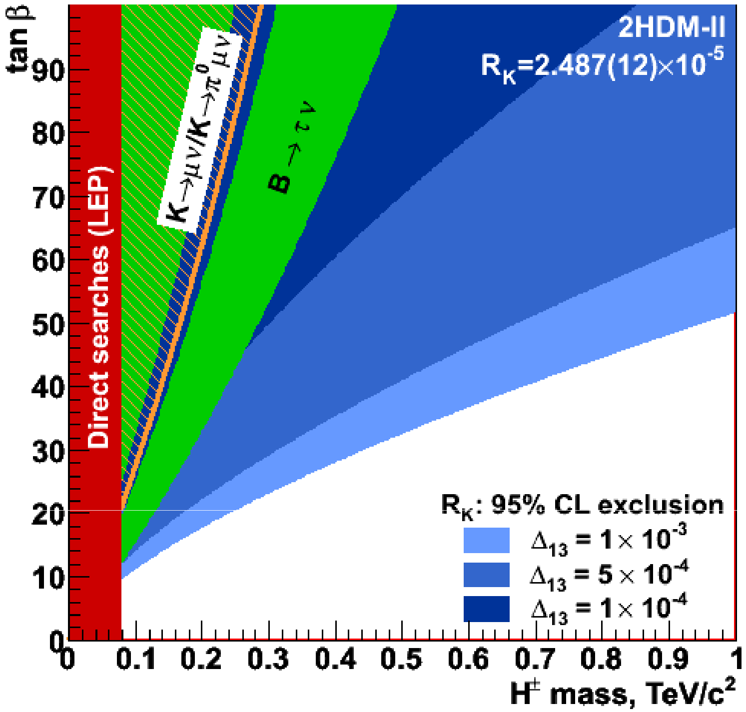


Uncertainties

Source	δR_K*10^5
Statistical	0.011
Systematic	0.007
$K_{\mu 2}$	0.005
BR($K_{e2\gamma}$ SD+)	0.001
$K^+ \to \pi^0 e^+ \nu$, $K^+ \to \pi^+ \pi^0$ bkg	0.001
Beam halo	0.001
Helium purity	0.003
Acceptance	0.002
DCH alignment	0.001
Positron ID eff.	0.001
1-track trigger eff.	0.002
LKr readout ineff.	0.001
Total	0.013

Result summary





Exclusion limits at 95% confidence level from the new R_K average

World average	R_K*10^5	Precision
PDG 2008	2.447±0.109	4.5%
Today	2.487±0.012	0.48%

Still in agreement within 1σ with the SM

Any significant enhancement wrt the SM value would be an evidence of New Physics

New results on $K^{\pm} \rightarrow \pi^{\pm}\mu^{+}\mu^{-}$

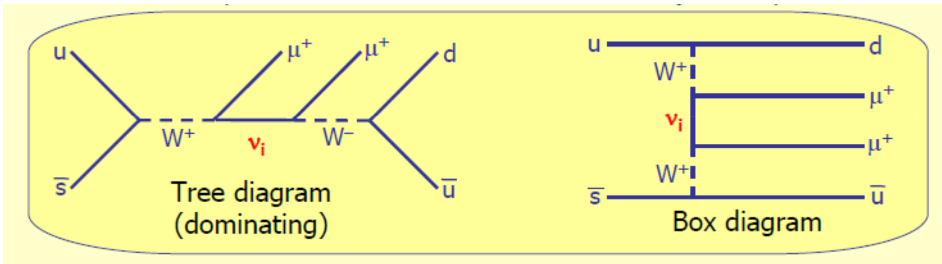
Motivation

- $K^\pm \to \pi^\pm\mu^+\mu^-$: FCNC decay induced at 1 loop in SM
  - Rate dominated by long-distance contribution with one photon exchange

$$\frac{d\Gamma}{dz} = \lambda^{\frac{3}{2}}\left(1, z, r_\pi^2\right)\sqrt{1-4\frac{r_\mu^2}{z}}\left(1+\frac{2r_\mu^2}{z}\right)\left|W(z)\right|^2 \qquad z=\left(\frac{M_{\mu\mu}}{M_K}\right)^2$$

Experimental situation before NA48:

- Decay observed by E787 in 1997
- E865 (2000): vector nature, upper limit on LNV
- HyperCP (2002) limit on CP-violating rate asymmetry
- Total world sample: 700 events



- NA48/2 aims:
  - BR, form factors, charge asymmetry, FB asymmetry
  - 4.5 times the world statistics
- $K^\pm \to \pi^\mp\mu^\pm\mu^\pm$: Lepton number violation
  - Possible if the neutrino is a Majorana particle
  - BR ~ $(\langle m_{\mu\mu}\rangle/\mathrm{TeV})^2 \cdot 10^{-8}$
  - Strongest limit by E865: BR$<3\cdot10^{-9}$ $\to \langle m_{\mu\mu}\rangle$ < 500 GeV

$K^\pm \to \pi^\pm\mu^+\mu^-$ analysis

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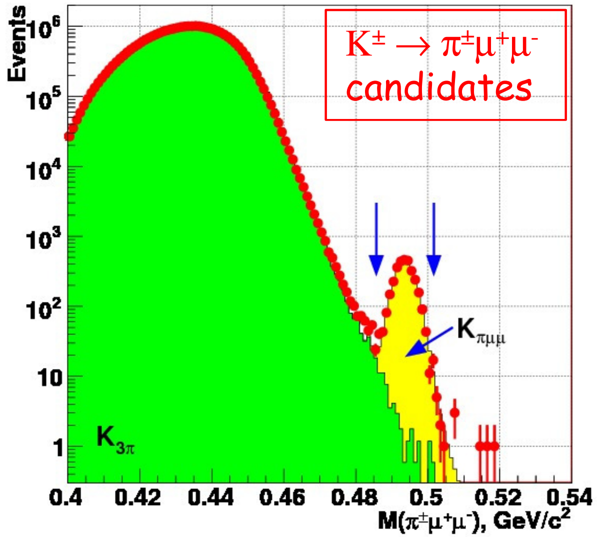
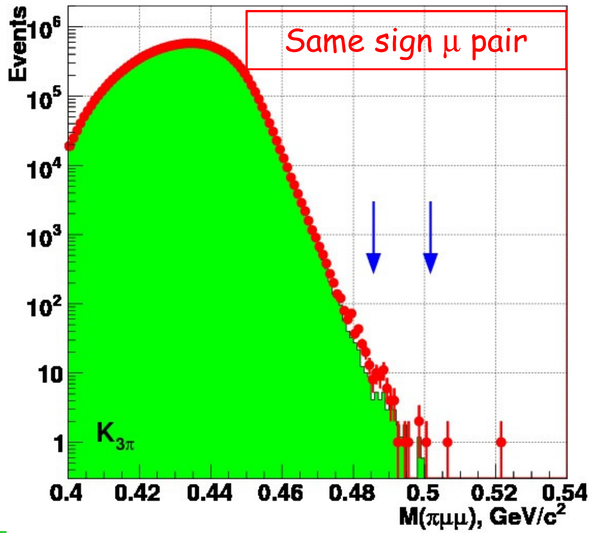
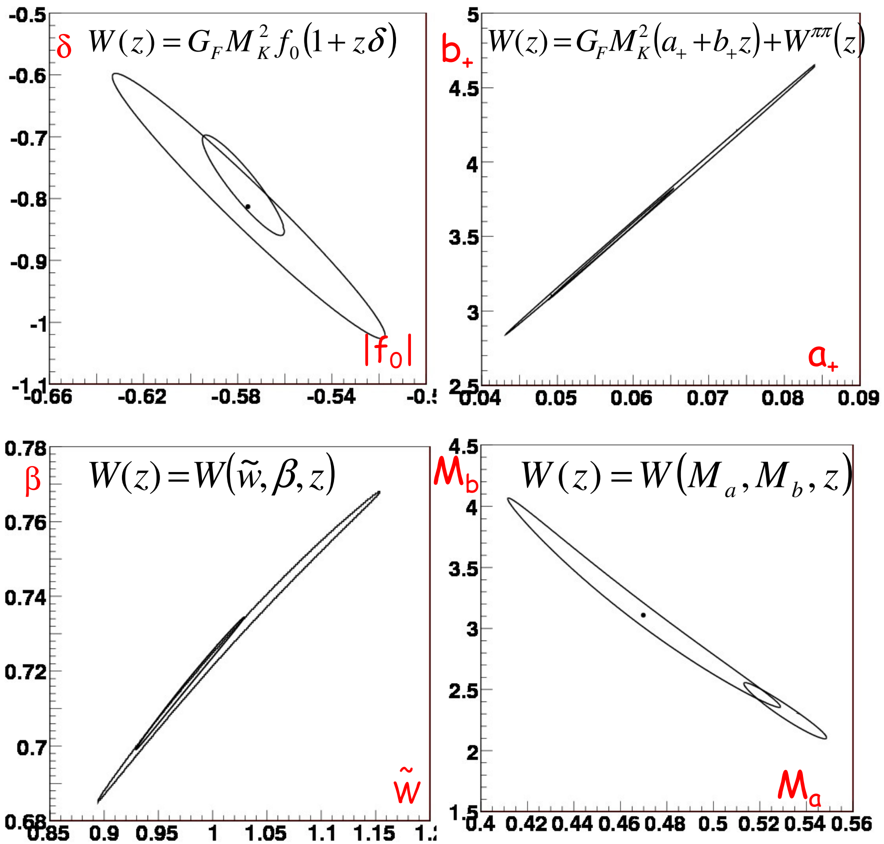
- Common selection criteria
  - 3 tracks in time with a vertex in the decay volume
  - Track momentum > 10 GeV/c
  - Reconstructed K momentum between 54 and 66 GeV/c
  - $p^2_T < 0.5\times10^{-3}$ $(GeV/c)^2$
- Selection for signal $K^\pm \to \pi^\pm\mu^+\mu^-$
  - One $\pi^\pm$ candidate with E/p < 0.95
  - $\mu^+\mu^-$ pair with E/p<0.2 and associated hits in the MUV
  - $|M_{3tracks}-M_K^{PDG}| < 8$ MeV/c^2
- Selection for normalization $K^\pm \to \pi^\pm\pi^+\pi^-$
  - One $\pi^\pm$ candidate with E/p < 0.95
  - $|M_{3tracks}-M_K^{PDG}| < 8$ MeV/c^2
- Total signal sample: 3120 events (2003 K+, 1117 K-)
  - 4 times the world sample
- Background (3.3 ±0.7)%
- From the wrong-sign plot derive LNV limits
  - N_{data} = 52
  - N_{bkg} (MC) = $52.6 \pm 19.8_{syst}$
  - A 3x improvement

→ BR < 1.1x10-9 (90% CL)





$K^{\pm} \to \pi^{\pm}\mu^{+}\mu^{-}$ results



Smaller contours from NA48 $K^{\pm} \to \pi^{\pm}e^{+}e^{-}$ analysis
Not enough statistics to distinguish btw models

- Model independent branching ratio

$BR(K^{\pm} \to \pi^{\pm}\mu^{+}\mu^{-}) = (9.62 \pm 0.21_{stat} \pm 0.11_{syst} \pm 0.07_{ext}) \times 10^{-8}$
E865: $(9.22 \pm 0.77) \times 10^{-8}$
HyperCP: $(9.8 \pm 1.1) \times 10^{-8}$

- Charge asymmetry

$|\Delta(K^{\pm}{}_{\pi\mu\mu})| < 2.9 \times 10^{-2}$ at 90% CL
Improvement by a factor 5
Expected $O(10^{-4})$ in SM, $O(10^{-3})$ in SUSY

- Forward-backward asymmetry

$|A_{FB}| < 2.3 \times 10^{-2}$ at 90% CL
Limit from di-photon intermediate state and MSSM contribution: 10^{-3}

- Upper limit on LNV: $BR(K^{\pm} \to \pi^{\mp}\mu^{\pm}\mu^{\pm})$

$BR < 1.1 \times 10^{-9}$ at 90% CL
Improvement by a factor 3
Bound on effective Majorana neutrino mass:
$\langle m_{\mu\mu} \rangle < 300$ GeV

Conclusions

- NA62 has taken data in 2007 to reach 0.4% precision on R_K
- The analysis of a partial data set (40% of the data) has been completed
- The measured value is $R_K = (2.487 \pm 0.013) * 10^{-5}$
- The precision achieved is 0.52%

- The analysis of the complete data set (~150K K_{e2} events) will bring the statistical error below 0.3% and the total at the 0.4% level
- For the summer conferences, it is expected to present our final result

- NA48/2 has published results and limits on the parameters of the FCNC decay $K^\pm \to \pi^\pm \mu^+ \mu^-$
  - Model independent $BR = (9.62 \pm 0.21_{stat} \pm 0.11_{syst} \pm 0.07_{ext}) \times 10^{-8}$
  - Limit on CP asymmetry: $|\Delta(K^\pm_{\pi\mu\mu})| < 2.9 \times 10^{-2}$ at 90% CL
  - Limit on FB asymmetry: $|A_{FB}| < 2.3 \times 10^{-2}$ at 90% CL
- And a limit on the LNV decay $K^\pm \to \pi^\mp \mu^\pm \mu^\pm$
  - $BR < 1.1 \times 10^{-9}$ at 90% CL $\langle m_{\mu\mu} \rangle < 300$ GeV