

Measurement of $BR(K \rightarrow e \nu_e) / BR(K \rightarrow \mu \nu_\mu)$

Roberto Piandani

INFN Perugia & CERN

Work supported by 

for the NA62 collaboration

(Bern ITP, Birmingham, CERN, Dubna, Fairfax, Ferrara, Florence, Frascati, IHEP Protvino, INR Moscow, Louvain, Mainz, Merced, Naples, Perugia, Pisa, Rome I, Rome II, Saclay, San Luis Potosí, SLAC, Sofia, TRIUMF, Turin)

Outline:

- 1) Motivation & experimental status;
- 2) Beam, detector and data taking;
- 3) Backgrounds & systematic effects;
- 4) Preliminary results and prospects.

Pheno 2010

Madison Wisconsin • 10 -12 May 2010

$R_K = K_{e2}/K_{\mu2}$ in the SM

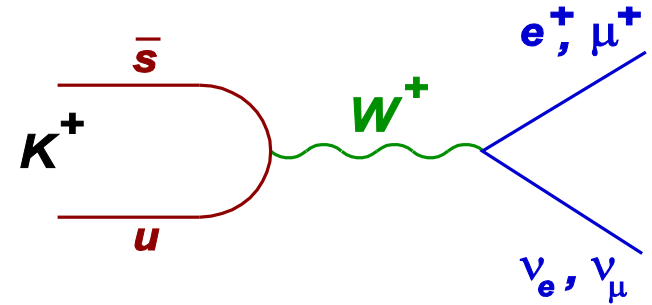
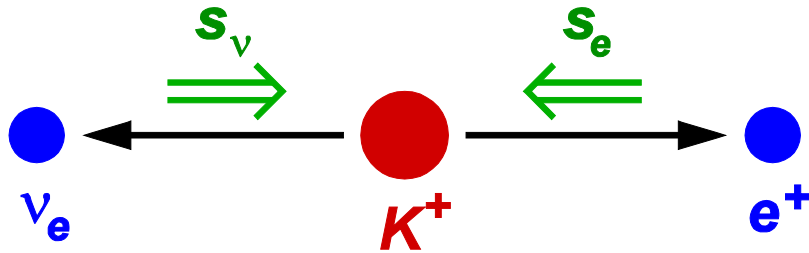
Observable sensitive to lepton flavour violation and its SM expectation:

$$R_K = \frac{\Gamma(K^\pm \rightarrow e^\pm \nu)}{\Gamma(K^\pm \rightarrow \mu^\pm \nu)} = \frac{m_e^2}{m_\mu^2} \cdot \left(\frac{m_K^2 - m_e^2}{m_K^2 - m_\mu^2} \right)^2 \cdot (1 + \delta R_K^{\text{rad. corr.}})$$

(similarly, R_π in the pion sector)

Helicity suppression: $f \sim 10^{-5}$

Radiative correction (few %) due to $K^+ \rightarrow e^+ \nu \gamma$ (IB) process, by definition included into R_K



- × **SM prediction:** excellent sub-permille accuracy due to cancellation of hadronic uncertainties.
- × Measurements of R_K and R_π have long been considered as tests of lepton universality.
- × **Recently understood:** helicity suppression of R_K might enhance sensitivity to non-SM effects to an experimentally accessible level.

$$R_K^{\text{SM}} = (2.477 \pm 0.001) \times 10^{-5}$$

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

Phys. Lett. 99 (2007) 231801

$R_K = K_{e2}/K_{\mu2}$ beyond the SM

2 Higgs Double Models – tree level (including SUSY)

K_{12} can proceed via exchange of charged Higgs H^\pm instead of W^\pm

➤ Does not affect the ratio R_K

2 Higgs Double Models – one-loop level

Dominant contribution to ΔR_K : H^\pm mediated

LFV (rather than LFC) with emission of ν_τ

➤ R_K enhancement can be experimentally accessible

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

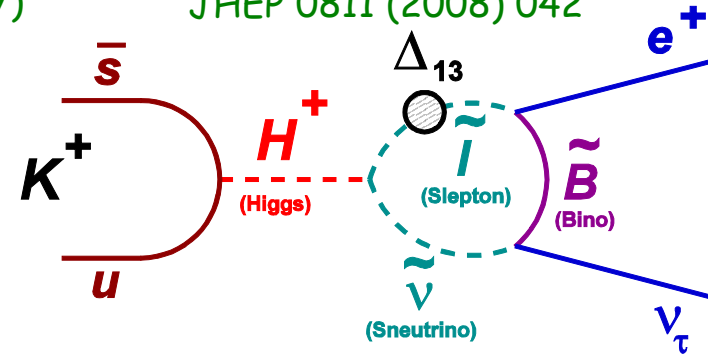
Up to $\sim 1\%$ effect in large (but not extreme) $\tan\beta$ regime with a massive H^\pm

Example:

($\Delta_{13} = 5 \times 10^{-4}$, $\tan\beta = 40$, $M_H = 500 \text{ GeV}/c^2$)

lead to $R_K^{\text{MSSM}} = R_K^{\text{SM}}(1 + 0.013)$.

PRD 74 (2006) 011701,
JHEP 0811 (2008) 042



Analogous SUSY effect in pion decay is suppressed by a factor $(M_\pi/M_K)^4 \approx 6 \times 10^{-3}$

(see also PRD76 (007) 095017)

Large effects in B decays due to $(M_B/M_K)^4 \sim 10^4$:

$B_{\mu\nu}/B_{\tau\nu} \rightarrow \sim 50\%$ enhancement;

$B_{e\nu}/B_{\tau\nu} \rightarrow$ enhanced by \sim one order of magnitude.

Out of reach: $\text{Br}^{\text{SM}}(B_{e\nu}) \approx 10^{-11}$

Experimental status

→ PDG'08 average (1970s measurements):

$$R_K = (2.45 \pm 0.11) \cdot 10^{-5} \quad (\Delta R_K / R_K = 4.5\%)$$

→ Recent improvement: KLOE (Frascati).

Data collected in 2001–2005,
13.8K K_{e2} candidates, 16% background.

$$R_K = (2.493 \pm 0.031) \cdot 10^{-5} \quad (\Delta R_K / R_K = 1.3\%)$$

(EPJ C64 (2009) 627)

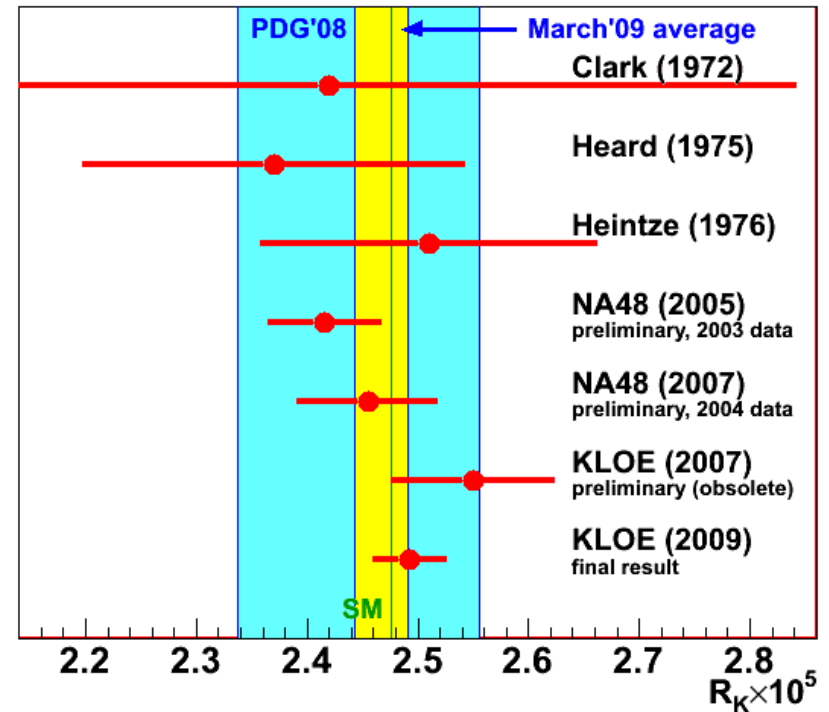
→ **NA62 (phase I)** goal:

dedicated data taking strategy,

~150K K_{e2} candidates, <10% background,

$\delta R_K / R_K < 0.5\%$: a stringent SM test.

R_K world average (March 2009)



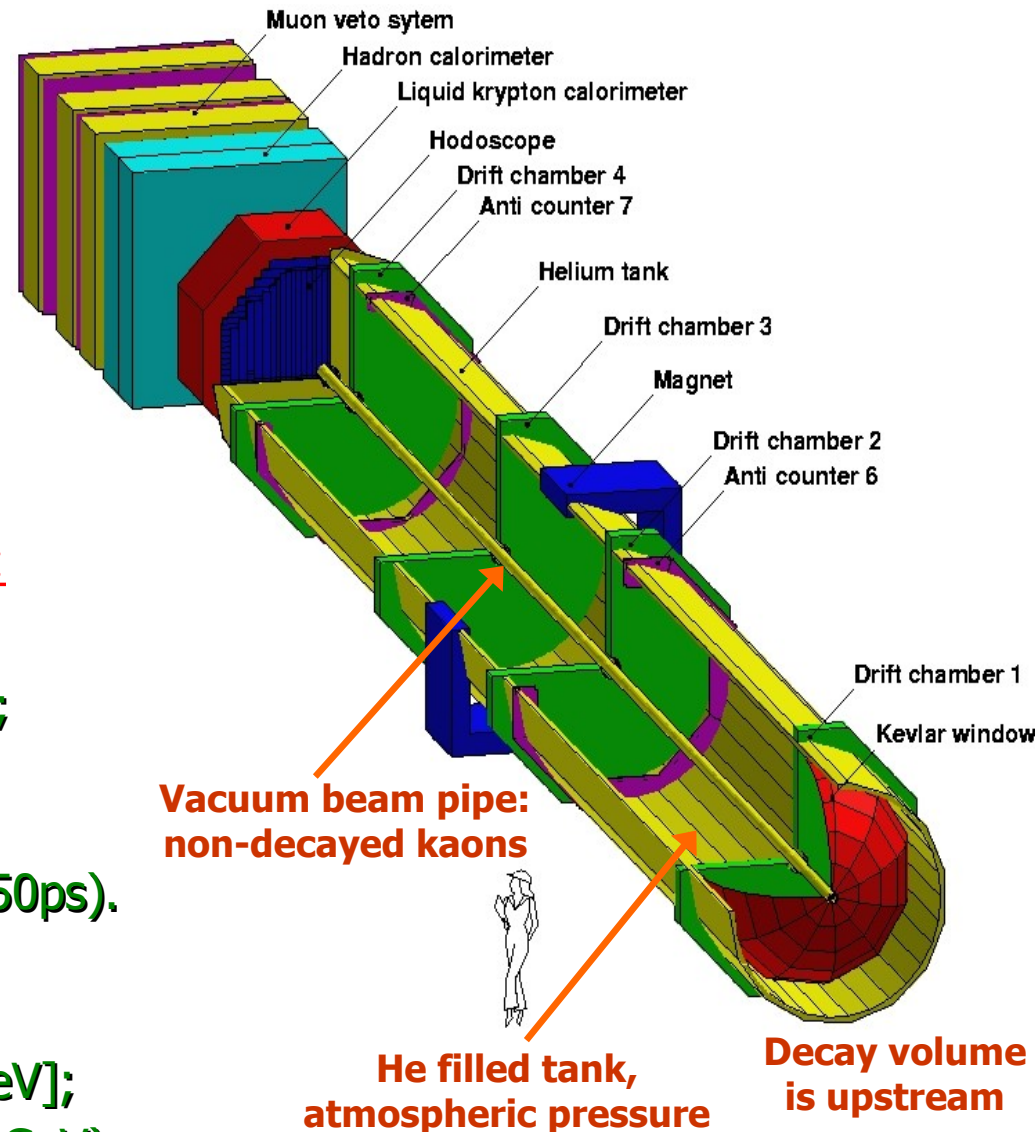
NA62 data taking 2007/08

Data taking:

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

Principal subdetectors for R_K :

- Magnetic spectrometer (4 DCHs):
4 views/DCH: redundancy \Rightarrow efficiency;
 $\Delta p/p = 0.47\% + 0.020\% \cdot p$ [GeV/c]
- Hodoscope
fast trigger, precise t measurement (150ps).
- 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).



Measurement strategy

(1) $K_{e2}/K_{\mu2}$ candidates are collected simultaneously:

- the result does not rely on kaon flux measurement;
- several systematic effects cancel at first order
(e.g. reconstruction/trigger efficiencies, time-dependent effects).

(2) counting experiment, independently in 10 lepton momentum bins
(owing to strong momentum dependence of backgrounds and event topology)

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

$N(K_{e2}), N(K_{\mu2})$: numbers of selected K_{l2} candidates;

$N_B(K_{e2}), N_B(K_{\mu2})$: numbers of background events;

→ $N_B(K_{e2})$: main source of systematic errors

$A(K_{e2}), A(K_{\mu2})$: MC geometric acceptances (no ID);

f_e, f_{μ} : directly measured particle ID efficiencies;

$\varepsilon(K_{e2})/\varepsilon(K_{\mu2}) > 99.9\%$: E_{LKr} trigger condition efficiency;

$f_{LKr} = 0.9980(3)$: global LKr readout efficiency.

(3) MC simulations used to a limited extent only:

- Geometrical part of the acceptance correction (not for particle ID);
- simulation of “catastrophic” bremsstrahlung by muons.

The K_{e2} and $K_{\mu2}$ selection

Large common part (topological similarity)

- one reconstructed track;
- geometrical acceptance cuts;
- K decay vertex: closest approach of track & nominal kaon axis;
- veto extra LKr energy deposition clusters;
- track momentum: $15\text{GeV}/c < p < 65\text{GeV}/c$.

Kinematic separation

missing mass

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

P_K : average measured with $K_{3\pi}$ decays

→ Sufficient $K_{e2}/K_{\mu2}$ separation at $p_{track} < 25\text{GeV}/c$

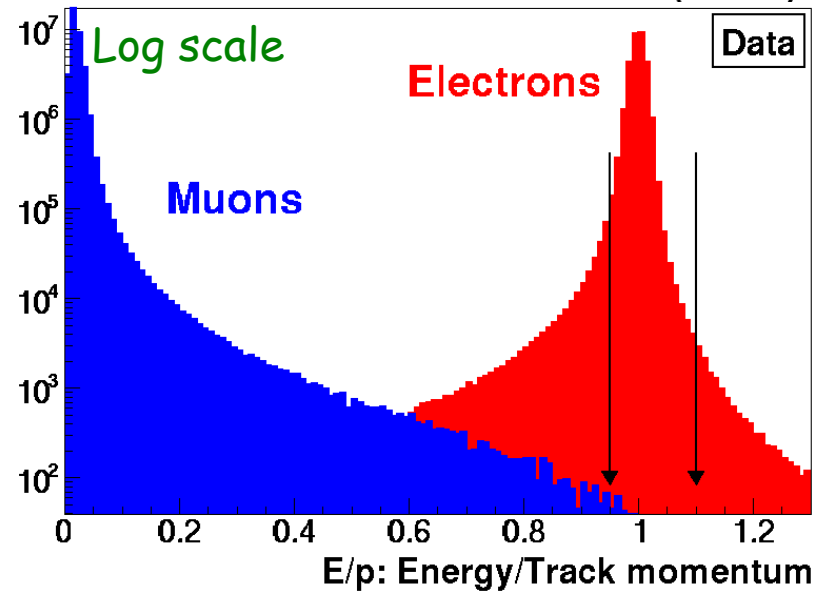
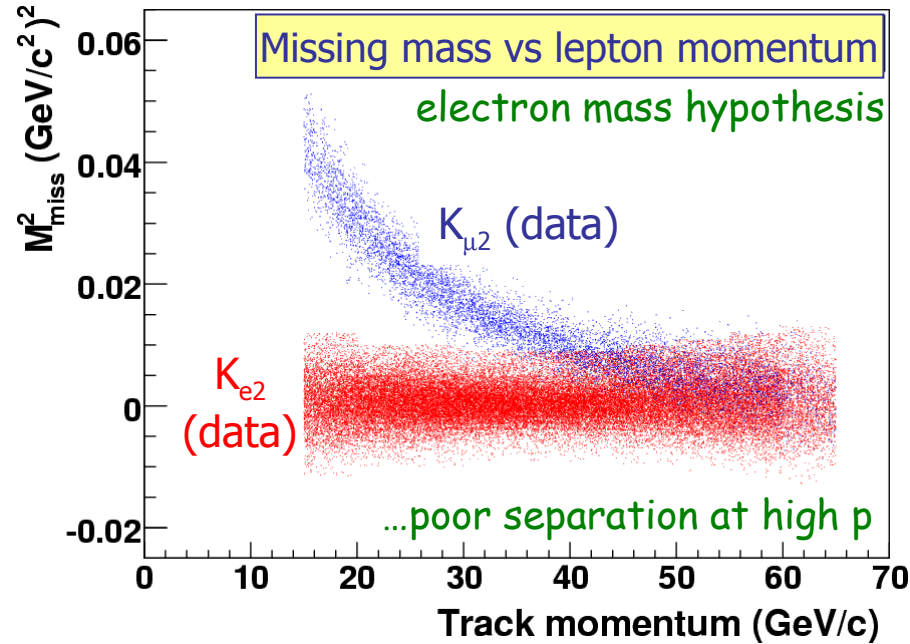
Separation by particle ID

$E/p = (\text{LKr energy deposit}/\text{track momentum})$.

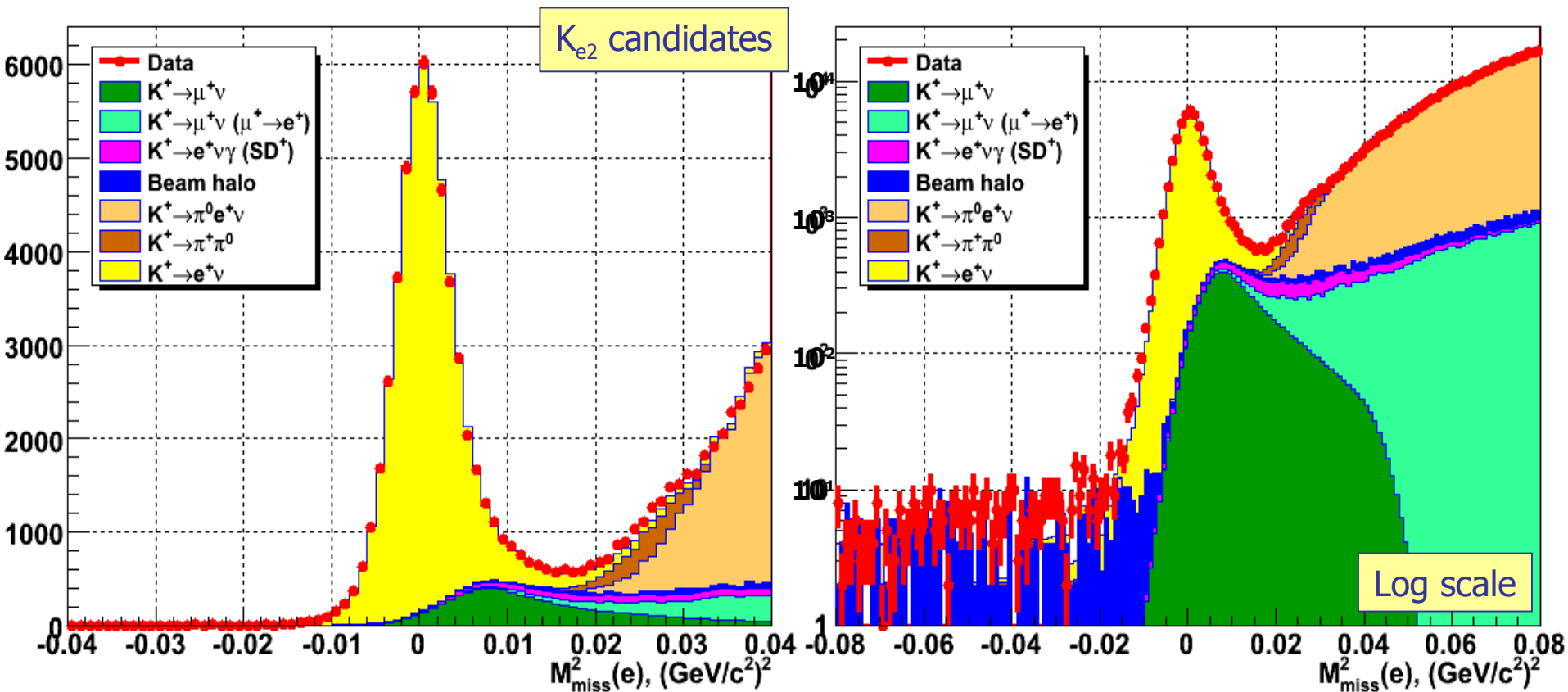
$0.95 < E/p < 1.10$ for electrons,

$E/p < 0.85$ for muons.

Powerful μ^\pm suppression in e^\pm sample: $f \sim 10^6$



K_{e2} : partial (40%) data set



51,089 $K^+ \rightarrow e^+ \nu$ candidates,
 99.2% electron ID efficiency,
 $B/(S+B) = (8.0 \pm 0.2)\%$

cf. KLOE: 13.8K candidates (K^+ and K^-),
 $\sim 90\%$ electron ID efficiency, 16% background

NA62 estimated total K_{e2} sample:
 $\sim 120\text{K } K^+ \text{ \& } \sim 15\text{K } K^- \text{ candidates.}$
 Proposal (CERN-SPSC-2006-033):
150K candidates

$K_{\mu 2}$ background in $K_{e 2}$ sample

Main background source

Muon “catastrophic” energy loss in LKr by emission of energetic bremsstrahlung photons.

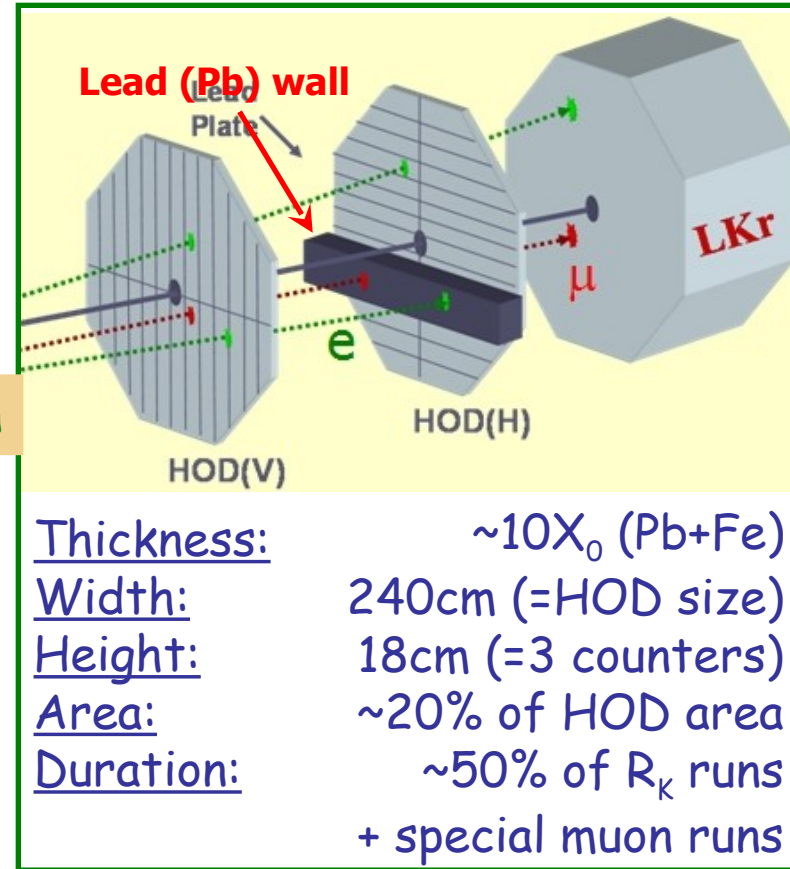
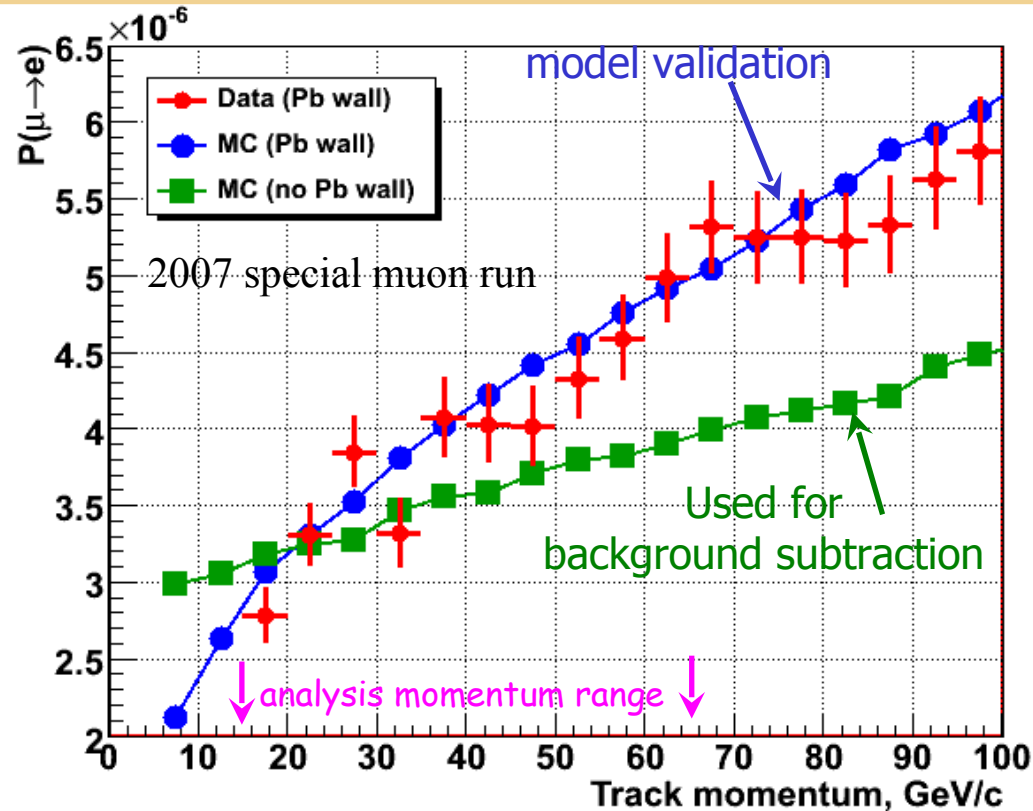
Theoretical bremsstrahlung cross-section

[Phys. Atom. Nucl. 60 (1997) 576]

must be validated in the region $(E_{\gamma}/E_{\mu}) > 0.9$

by a direct measurement of $P(\mu \rightarrow e)$ to $\sim 10^{-2}$ relative precision.

$P(\mu \rightarrow e)$: measurement vs Geant4-based simulation



$P(\mu \rightarrow e)$ is modified by the Pb wall via two competing mechanisms:

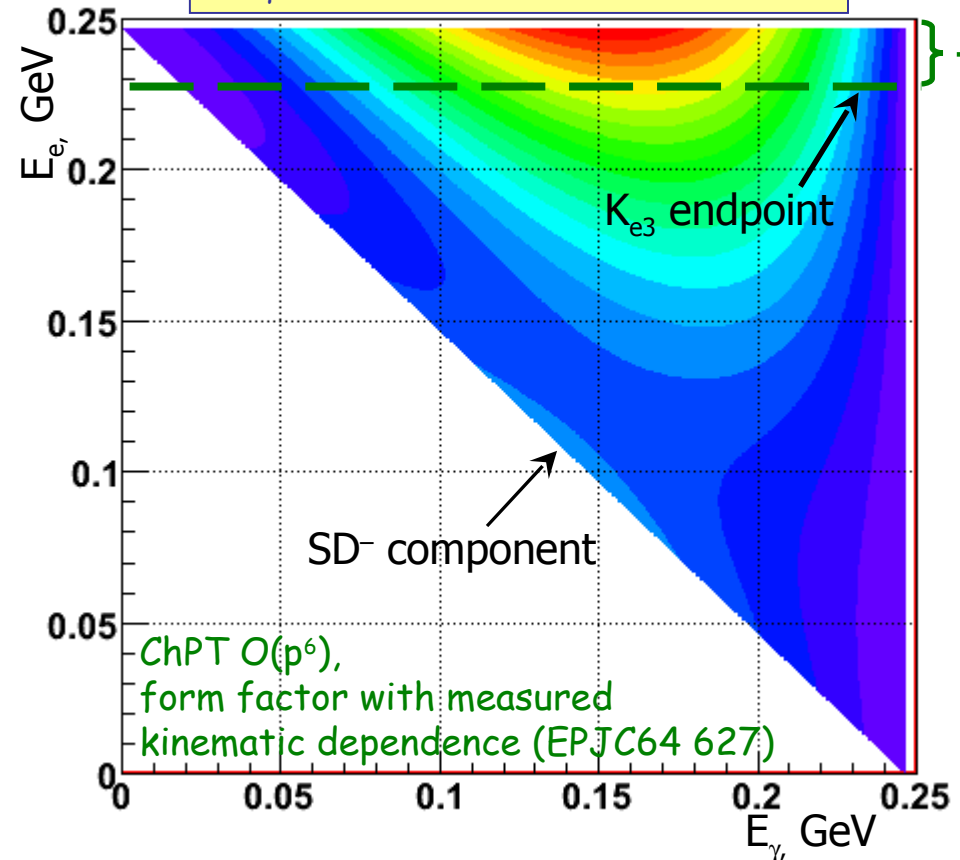
- 1) **ionization** losses in Pb (low p);
- 2) **bremsstrahlung** in Pb (high p).

Result: $B/(S+B) = (6.28 \pm 0.17)\%$

$K^+ \rightarrow e^+ \nu_e \gamma$ (SD) background

- Background by definition of R_K , no helicity suppression.
- Rate similar to that of K_{e2} , limited precision: $BR = (1.52 \pm 0.23) \cdot 10^{-5}$.

$K_{e2\gamma}$ (SD) Dalitz plot distribution



Only energetic electrons ($E_e^* > 230 \text{ MeV}$) are compatible to K_{e2} kinematic ID and contribute to the background



This region of phase space is accessible for direct BR and form-factor measurement (being above the $E_e^* = 227 \text{ MeV}$ endpoint of the K_{e3} spectrum).

SD background contamination

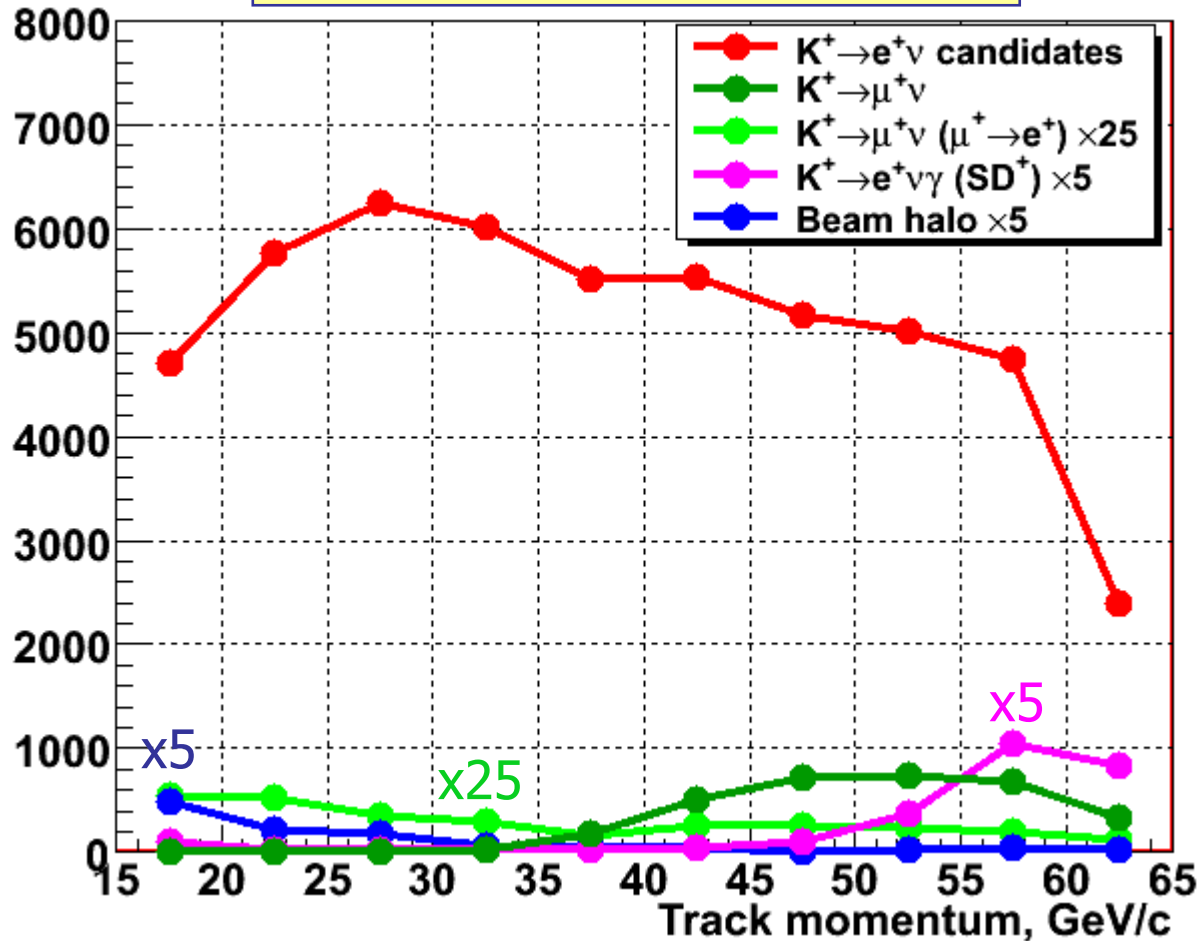
$$B/(S+B) = (1.02 \pm 0.15)\%$$

(uncertainty due to PDG BR, will be improved using a recent KLOE measurement, EPJC64 627)

$K_{e2\gamma}$ (SD⁻) background is negligible, peaking at $E_e = E_{\text{max}}/2 \approx 123 \text{ MeV}$

Backgrounds: summary

Statistics in lepton momentum bins



(selection criteria, e.g. Z_{vertex} and M_{miss}^2 , are optimised individually in each P_{track} bin)

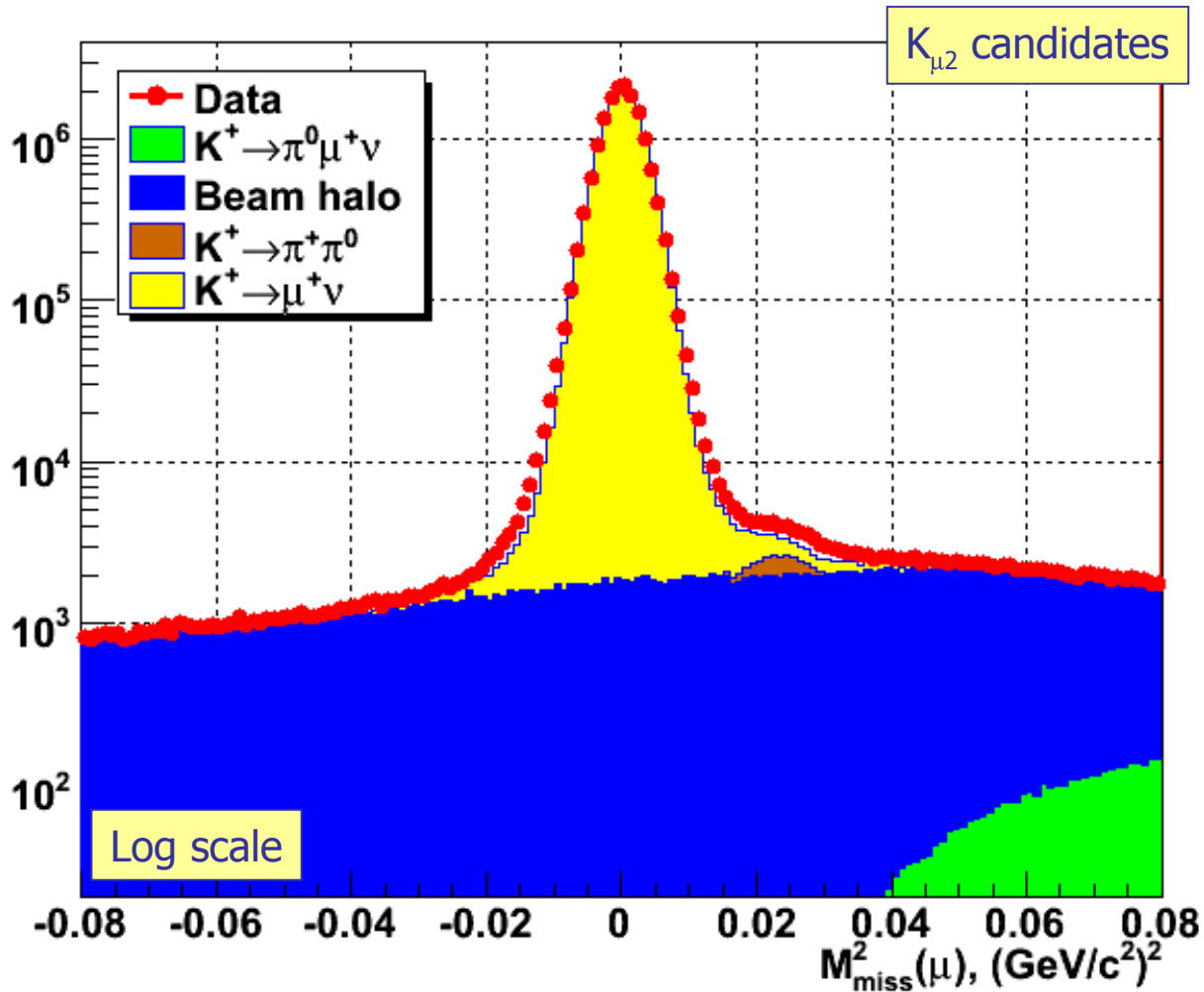
Backgrounds

Source	B/(S+B)
$K_{\mu 2}$	$(6.28 \pm 0.17)\%$
$K_{\mu 2} (\mu \rightarrow e)$	$(0.23 \pm 0.01)\%$
$K_{e 2 \gamma} (SD^+)$	$(1.02 \pm 0.15)\%$
Beam halo	$(0.45 \pm 0.04)\%$
$K_{e 3}$	0.03%
$K_{2\pi}$	0.03%
Total	$(8.03 \pm 0.23)\%$

Record $K_{e 2}$ sample:
51,089 candidates
with low background
 $B/(S+B) = (8.0 \pm 0.2)\%$

Lepton momentum bins are differently affected by backgrounds and thus the systematic uncertainties.

$K_{\mu 2}$: 40% of data set



15.56M candidates
with low background
 $B/(S+B) = 0.25\%$

($K_{\mu 2}$ trigger was
pre-scaled by $D=150$)

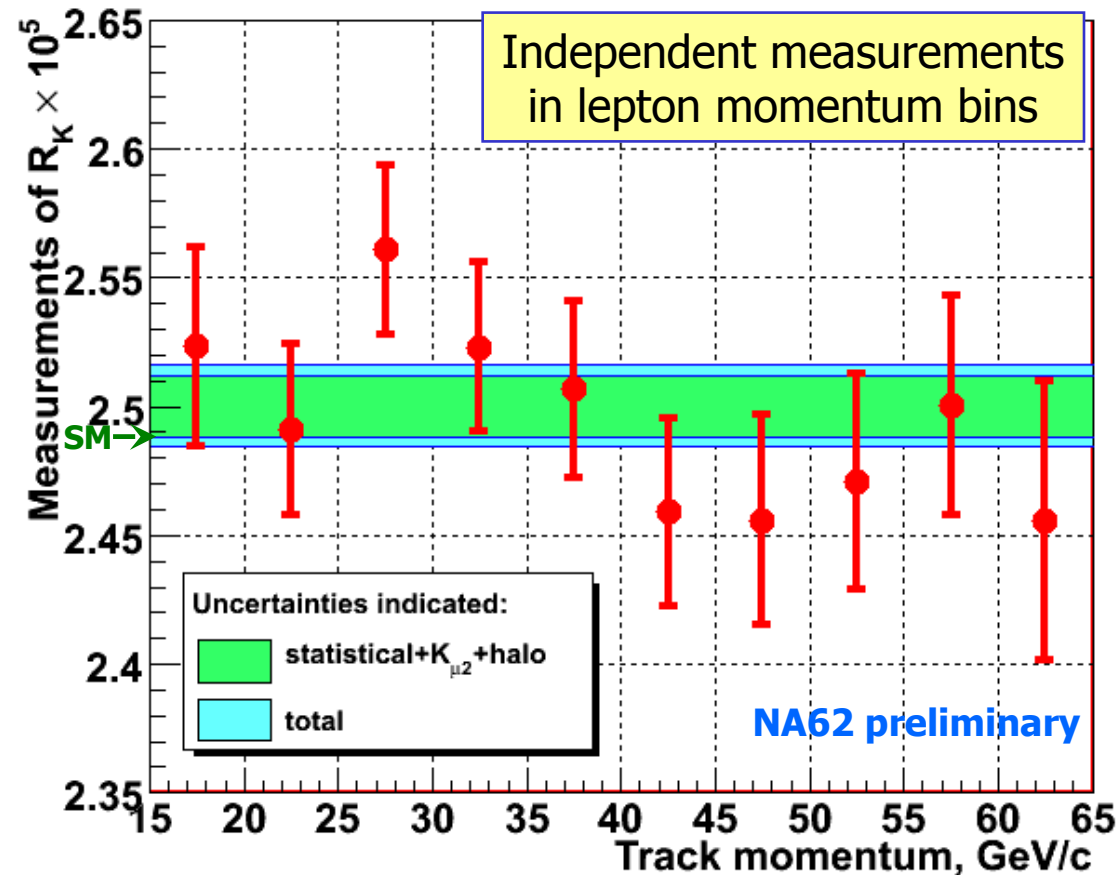
The only significant
background source
is the beam halo.

Preliminary result (40% data set)

$$R_K = (2.500 \pm 0.012_{\text{stat}} \pm 0.011_{\text{syst}}) \times 10^{-5}$$

$$= (2.500 \pm 0.016) \times 10^{-5}$$

(arXiv:0908.3858)



Uncertainties

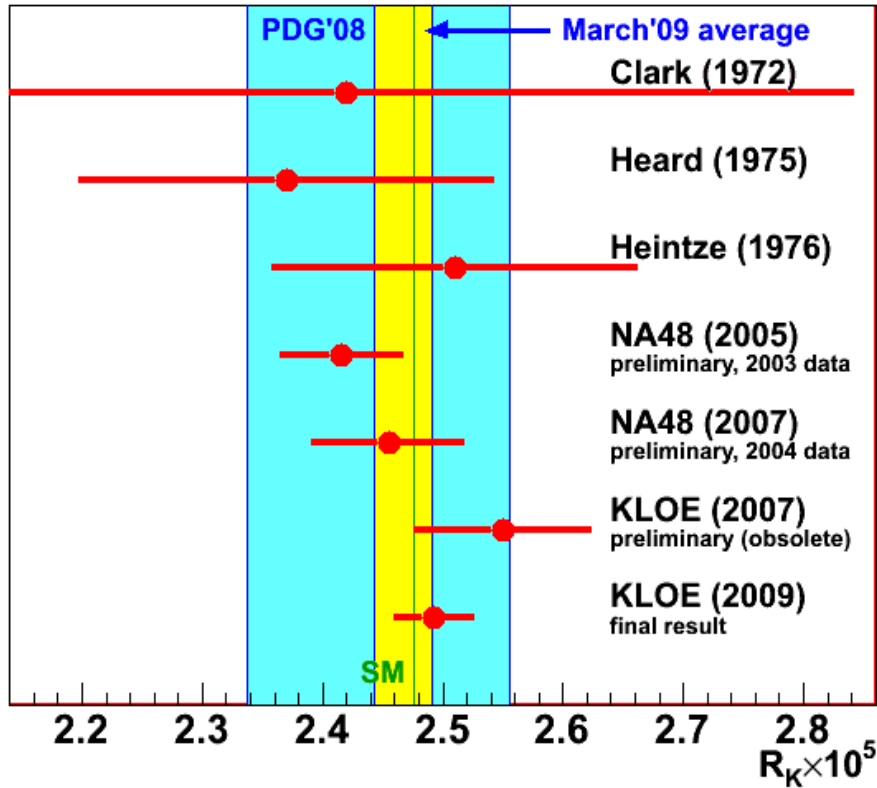
Source	$\delta R_K \times 10^5$
Statistical	0.012
$K_{\mu 2}$	0.004
Beam halo	0.001
$K_{e 2\gamma}$ (SD ⁺)	0.004
Electron ID	0.001
IB simulation	0.007
Acceptance	0.002
Trigger timing	0.007
Total	0.016

(0.64% precision)

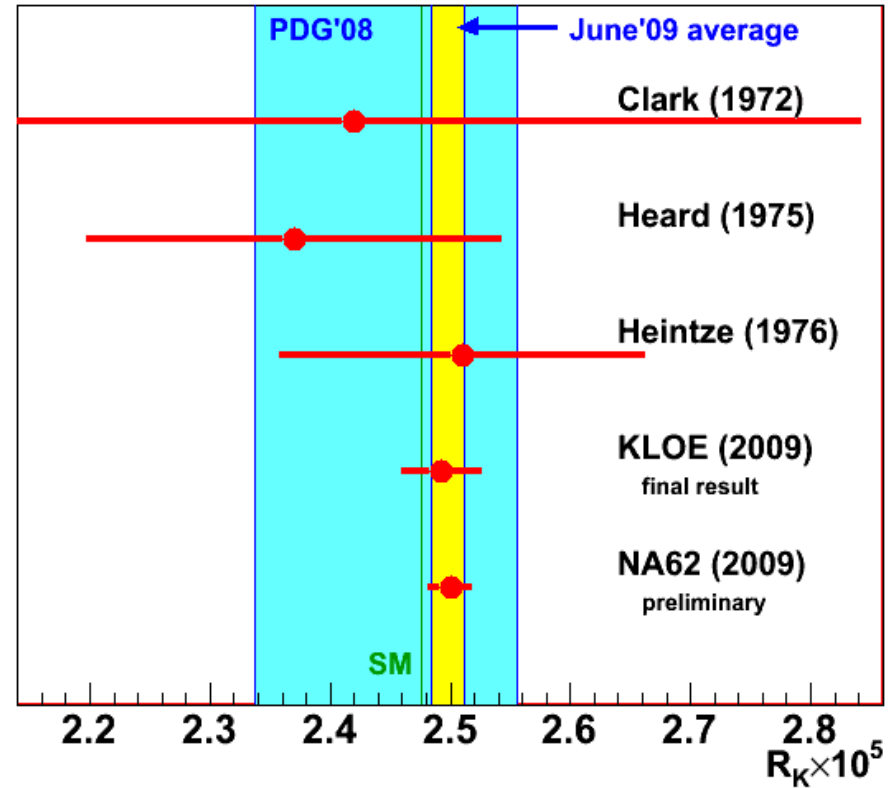
The whole 2007 sample will allow statistical uncertainty $\sim 0.3\%$, total uncertainty of 0.4–0.5%.

Comparison to world data

March 2009



Now



World average	$\delta R_K \times 10^5$	Precision
March 2009	2.467 ± 0.024	0.97%
June 2009	2.498 ± 0.014	0.56%

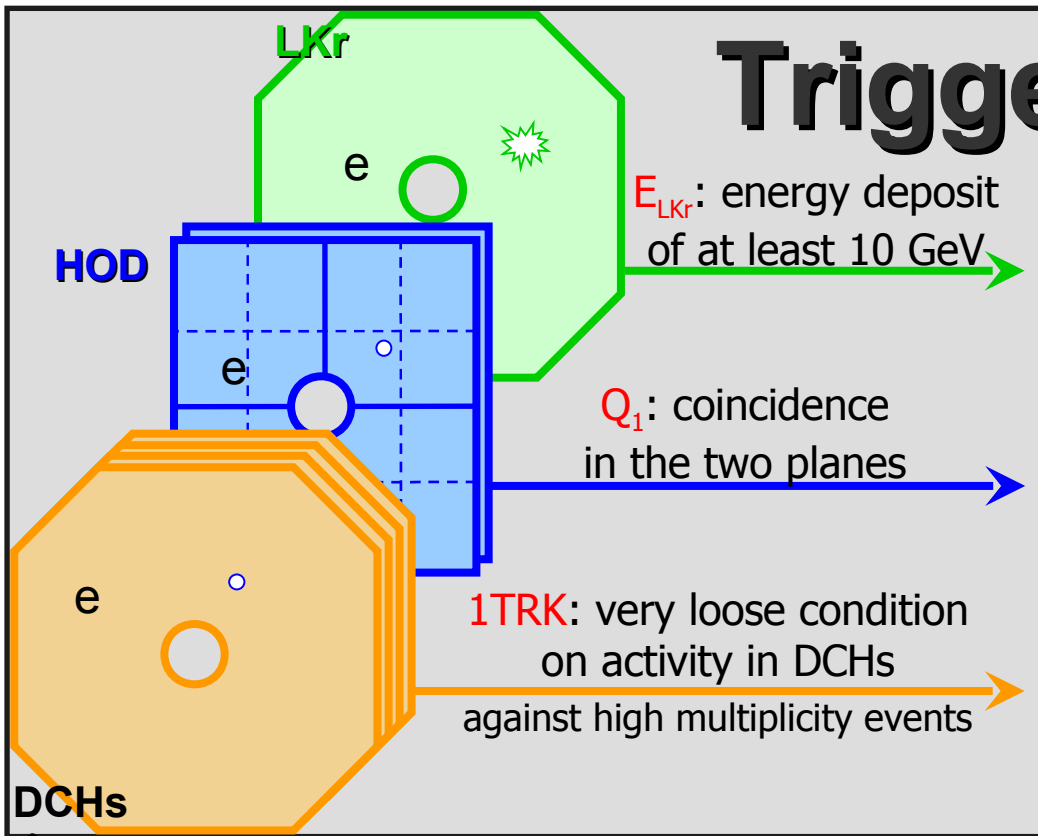
(NA48/2 preliminary results excluded from the new average: they are superseded by NA62)

Conclusions & prospects

- ✗ Due to the helicity suppression of the K_{e2} decay, the measurement of R_K is well-suited for a **stringent test of the Standard Model**.
- ✗ NA62 data taking in 2007/08 was **optimised for R_K measurement**.
The NA62 K_{e2} sample is ~ 10 times the world sample.
Powerful $K_{e2}/K_{\mu2}$ separation ($>99\%$ electron ID efficiency and $\sim 10^6$ muon suppression) leads to a low 8% background.
- ✗ Preliminary result based on $\sim 40\%$ of the NA62 K_{e2} sample:
 $R_K = (2.500 \pm 0.016) \cdot 10^{-5}$, reaching **0.7% accuracy**.
- ✗ The R_K value is compatible to the **SM prediction within 1.5σ** .
- ✗ With the full NA62 data sample of 2007/08, the precision is **expected to be improved** to better than $\delta R_K/R_K = 0.5\%$.
- ✗ R_K measurement with $\sim 0.1\%$ precision has been proposed in the framework of the NA62 (phase II) experiment.

Spare

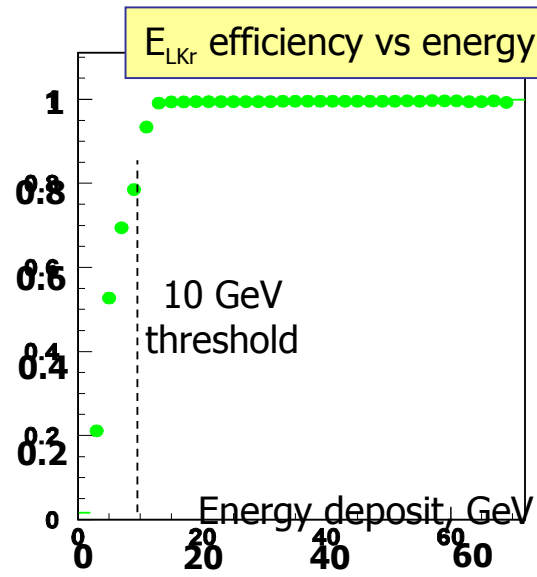
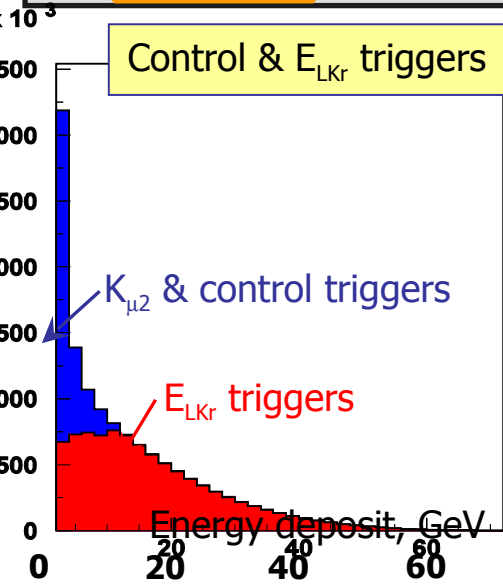
Trigger logic



Minimum bias
(high efficiency, but low purity)
trigger configuration used

K_{e2} condition: $Q_1 \times E_{LKr} \times 1TRK$.
Purity $\sim 10^{-5}$.

$K_{\mu2}$ condition: $Q_1 \times 1TRK / D$,
downscaling (D) 50 to 150.
Purity $\sim 2\%$.



- Efficiency of K_{e2} trigger: monitored with $K_{\mu2}$ & other control triggers.
- E_{LKr} inefficiency for electrons measured to be $(0.05 \pm 0.01)\%$ for $p_{track} > 15$ GeV/c.
- Different trigger conditions for signal and normalization!

$K_{\mu 2}$ with $\mu \rightarrow e$ decay in flight

For NA62 conditions

(74 GeV/c beam, ~ 100 m decay volume),

$$N(K_{\mu 2}, \mu \rightarrow e \text{ decay})/N(K_{e 2}) \sim 10$$

$K_{\mu 2} (\mu \rightarrow e)$ naively seems a huge background

Muons from $K_{\mu 2}$ decay are fully polarized:
Michel electron distribution

$$d^2\Gamma/dx d(\cos\Theta) \sim x^2[(3-2x) - \cos\Theta(1-2x)]$$

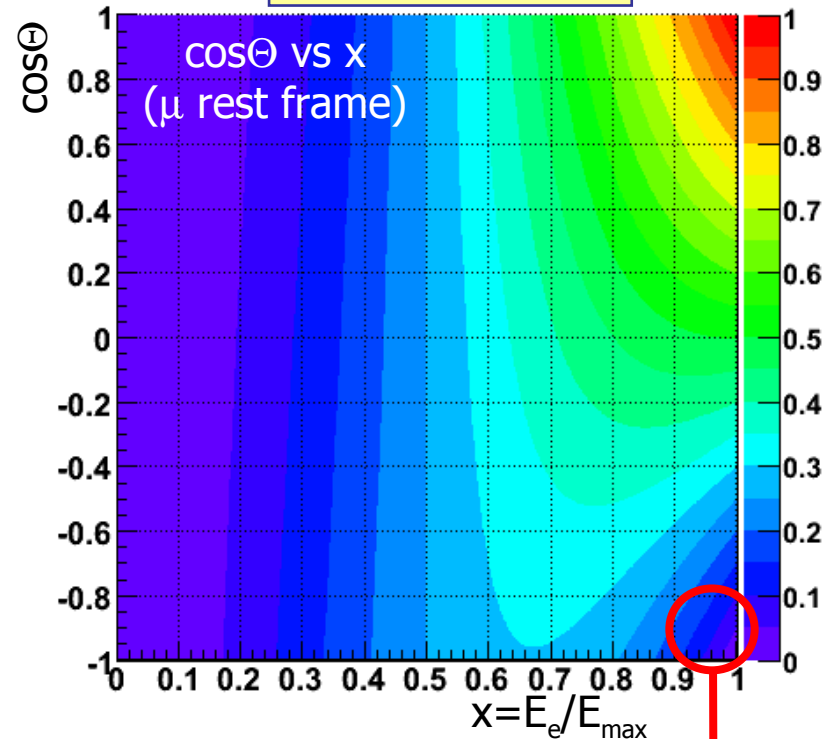
$$x = E_e/E_{\max} \approx 2E_e/M_\mu,$$

Θ is the angle between p_e and the muon spin
(all quantities are defined in muon rest frame).

$$\text{Result: } B/(S+B) = (0.23 \pm 0.01)\%$$

Important but not dominant background

Michel distribution



Only energetic forward electrons
(passing M_{miss} , E/p , vertex CDA cuts)
are selected as $K_{e 2}$ candidates:
(high x , low $\cos\Theta$).

They are naturally suppressed
by the muon polarisation

Beam halo background

Electrons produced by beam halo muons via $\mu \rightarrow e$ decay can be kinematically and geometrically compatible to genuine K_{e2} decays

Background measurement:

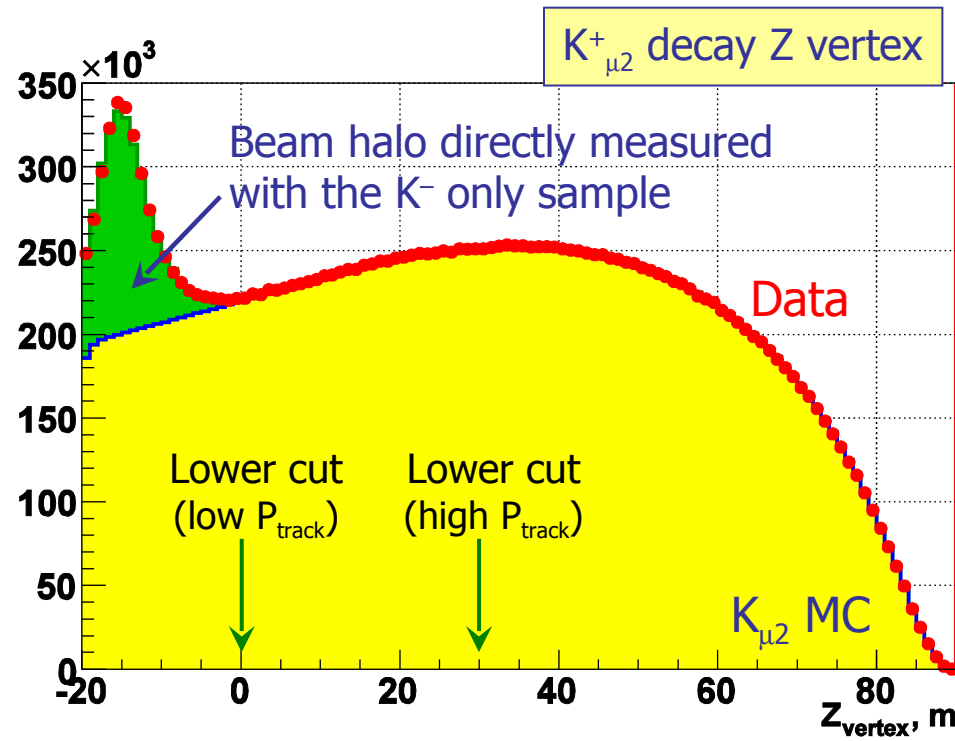
- Halo background much higher for K_{e2}^- ($\sim 20\%$) than for K_{e2}^+ ($\sim 1\%$).
- $\sim 90\%$ of the data sample is K^+ only, $\sim 10\%$ is K^- only.
- K^+ halo component is measured directly with the K^- sample and vice versa.

The background is measured to sub-permille precision, and strongly depends on decay vertex position and track momentum.

The selection criteria (esp. Z_{vertex}) are optimized to minimize the halo background.

$$B/(S+B) = (0.45 \pm 0.04)\%$$

Uncertainty is due to the limited size of the control sample.



R_K : sensitivity to new physics

R_K measurements are currently in agreement with the SM expectation at $\sim 1.5\sigma$. Any significant enhancement with respect to the SM value would be an evidence of new physics.

For non-tiny values of the LFV slepton mixing D_{13} , sensitivity to H^\pm in $R_K = K_{e2}/K_{\mu2}$ is better than in $B \rightarrow \tau \nu$

