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

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for the NA62 collaboration

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Outline:

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

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$R_K = K_{e2}/K_{\mu 2}$ in the SM

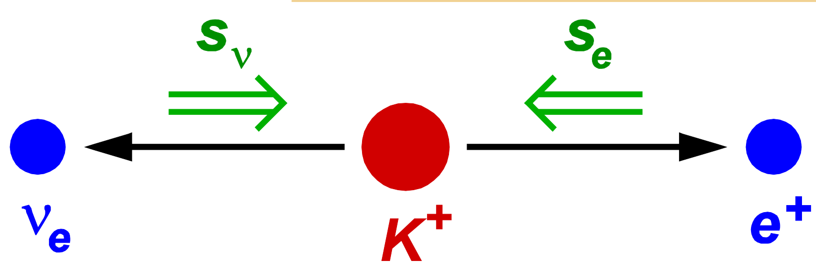
Observable sensitive to lepton flavour violation and its SM expectation:

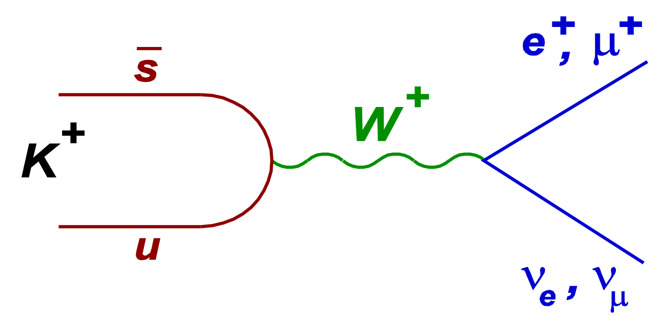
$$R_K = \frac{\Gamma(K^\pm \to e^\pm \nu)}{\Gamma(K^\pm \to \mu^\pm \nu)} = \frac{m_e^2}{m_\mu^2} \cdot \left(\frac{m_K^2 - m_e^2}{m_K^2 - m_\mu^2}\right)^2 \cdot (1 + \delta R_K^{rad.corr.})$$

(similarly, R_π in the pion sector)

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

Radiative correction (few %) due to $K^+ \to e^+ \nu \gamma$ (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.

$R_K^{SM} = (2.477 \pm 0.001) \times 10^{-5}$
$R_\pi^{SM} = (12.352 \pm 0.001) \times 10^{-5}$

Phys. Lett. 99 (2007) 231801

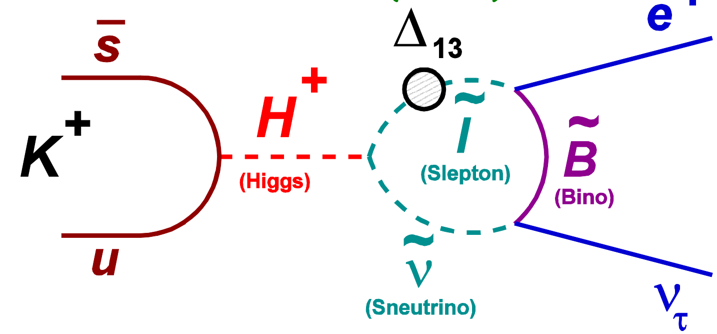
$R_K = K_{e2}/K_{\mu 2}$ beyond the SM

2 Higgs Double Models – tree level (including SUSY)

K_{l2} can proceed via exchange of charged Higgs $H^{\pm}$ instead of $W^{\pm}$

- Does not affect the ratio R_K

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



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

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

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

Example:
($\Delta_{13}=5\times10^{-4}$, $\tan\beta=40$, $M_H=500$ GeV/c^2)
lead to $R_K^{MSSM} = R_K^{SM}(1+0.013)$.

Analogous SUSY effect in pion decay is suppressed by a factor $(M_\pi/M_K)^4 \approx 6\times10^{-3}$

(see also PRD76 (007) 095017)

Large effects in B decays due to $(M_B/M_K)^4\sim10^4$:

$B_{\mu\nu}/B_{\tau\nu}$ → ~50% enhancement;

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

Out of reach: $Br^{SM}(B_{e\nu})\approx10^{-11}$

Experimental status

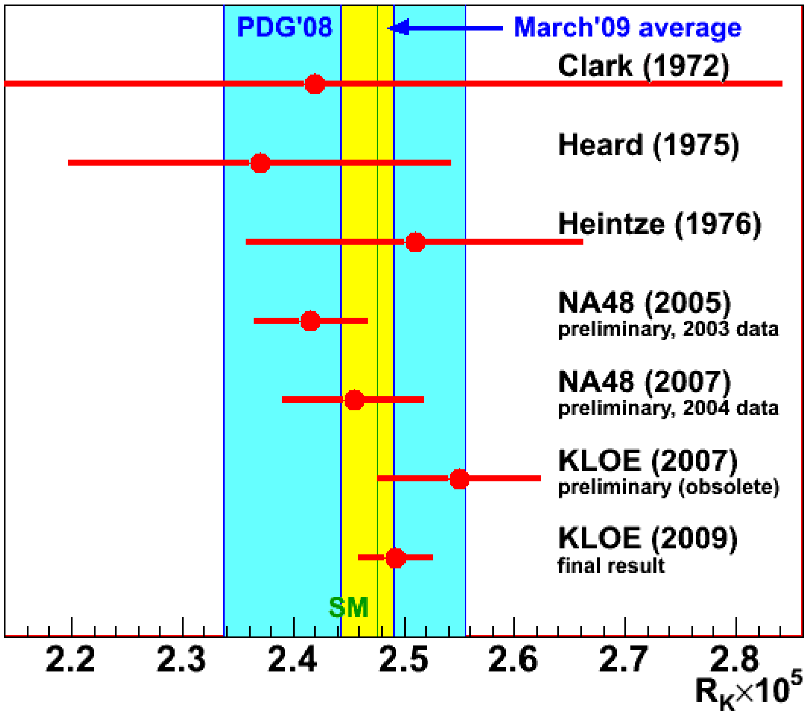
→ PDG'08 average (1970s measurements):
$R_K=(2.45\pm0.11)\cdot10^{-5}$ $(\Delta R_K/R_K=4.5\%)$

→ Recent improvement: KLOE (Frascati).
Data collected in 2001–2005,
13.8K K_{e2} candidates, 16% background.
$R_K=(2.493\pm0.031)\cdot10^{-5}$ $(\Delta R_K/R_K=1.3\%)$

(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)



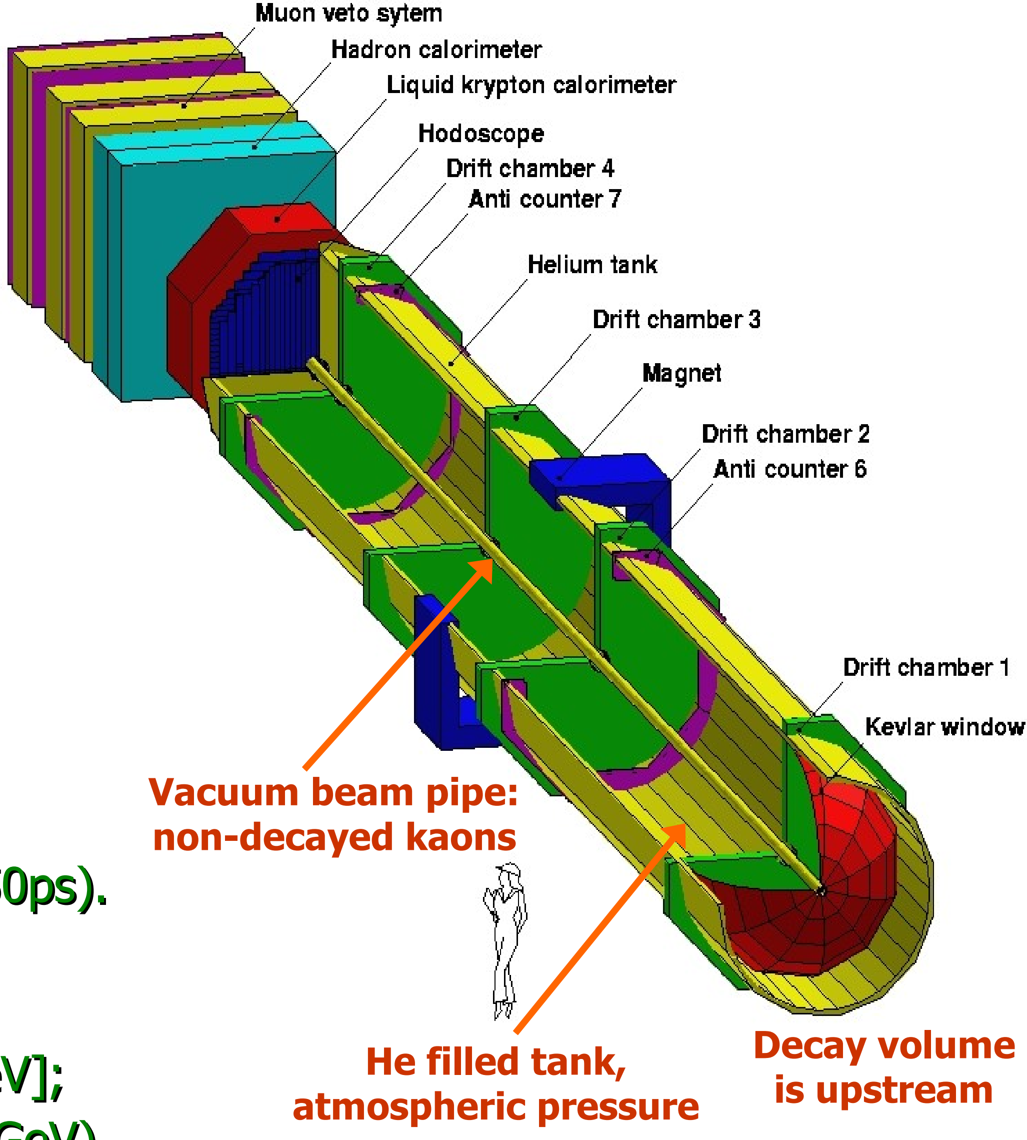
NA62 data taking 2007/08

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 ⇒ efficiency;
  $\Delta p/p = 0.47\% + 0.020\%{*}p$ [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];
  $\sigma_x=\sigma_y=0.42/E^{1/2} + 0.6$mm (1.5mm@10GeV).



Measurement strategy

(1) $K_{e2}/K_{\mu 2}$ 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)

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

$N(K_{e2})$, $N(K\sigma_2)$: numbers of selected K_{l2} candidates;

$N_B(K_{e2})$, $N_B(K_{\mu 2})$: numbers of background events;

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

$A(K_{e2})$, $A(K_{\mu 2})$: MC geometric acceptances (no ID);

f_e, f_μ: directly measured particle ID efficiencies;

$\varepsilon(K_{e2})/\varepsilon(K_{\mu 2})>99.9\%$: 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 $K_{\mu 2}$ selection

<u>Large common part</u> (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: 15GeV/c<p<65GeV/c.

<u>Kinematic separation</u>

missing mass $M^2_{miss} = (P_K - P_l)^2$

P_K : <u>average</u> measured with $K_{3\pi}$ decays

→ Sufficient $K_{e2}/K_{\mu 2}$ separation at p_{track}<25GeV/c

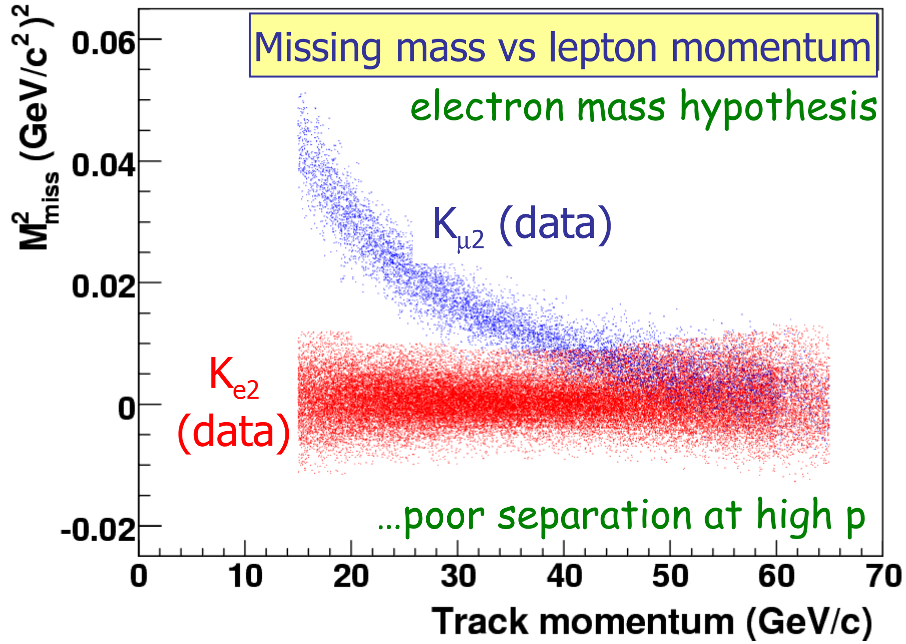
<u>Separation by particle ID</u>

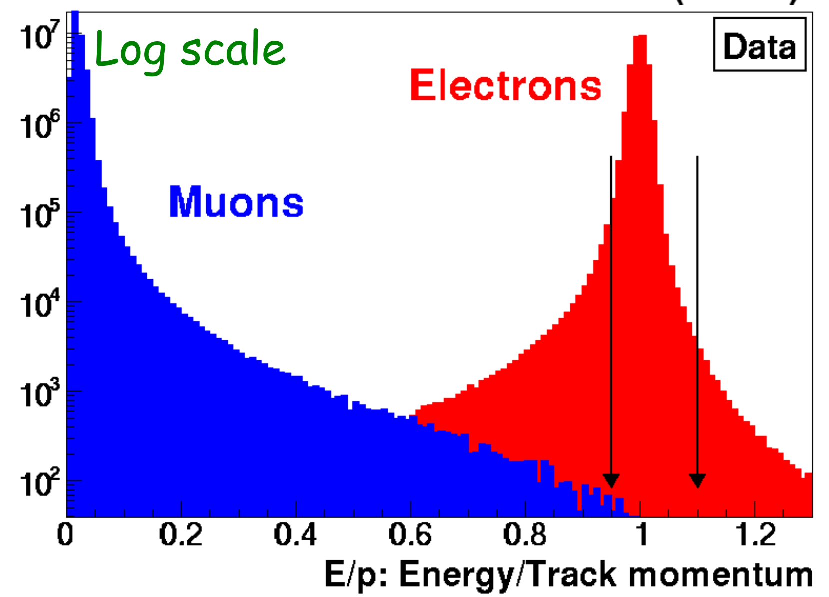
E/p = (LKr energy deposit/track momentum).

0.95<E/p<1.10 for electrons,

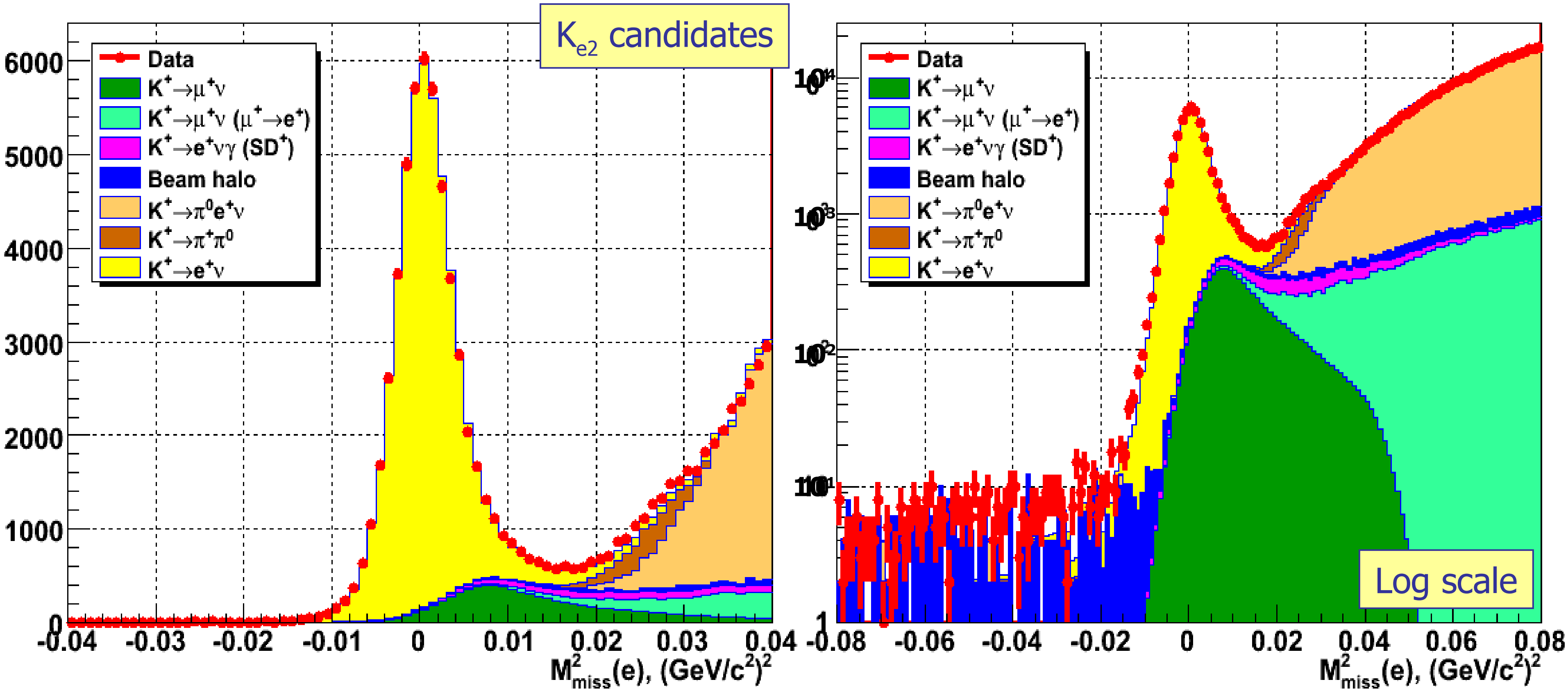
E/p<0.85 for muons.

Powerful $\mu^{\pm}$ suppression in $e^{\pm}$ sample: $f \sim 10^6$





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



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

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

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

$K_{\mu2}$ background in K_{e2} sample

Main background source

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

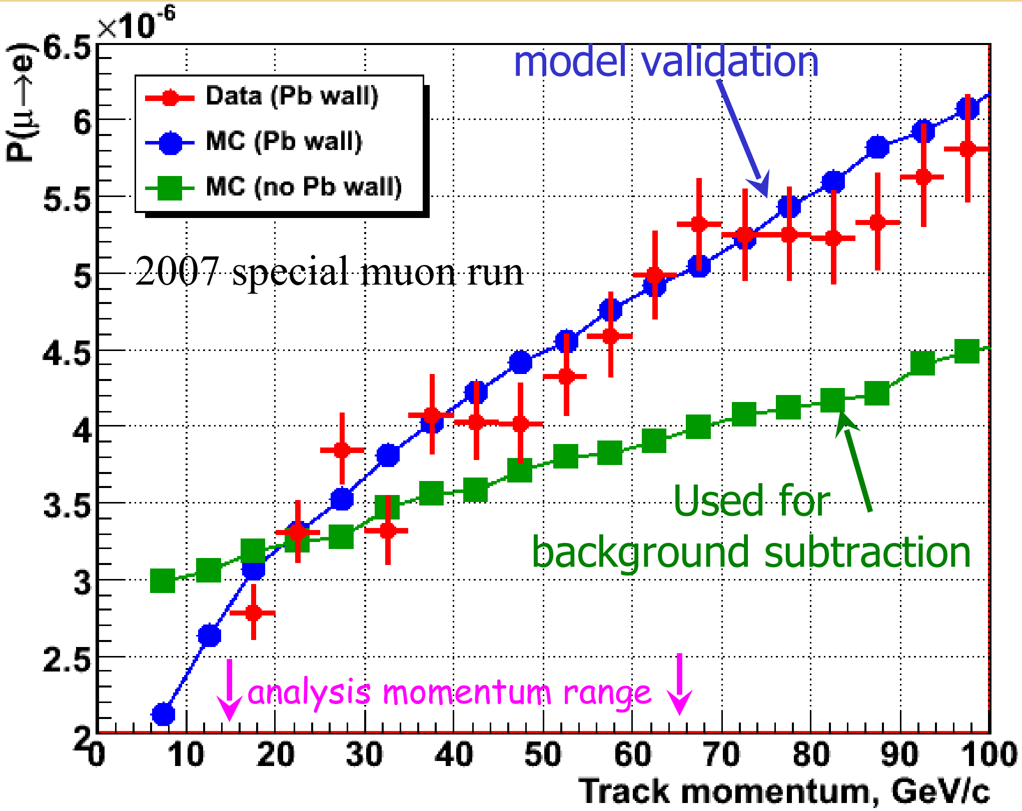
Theoretical bremsstrahlung cross-section

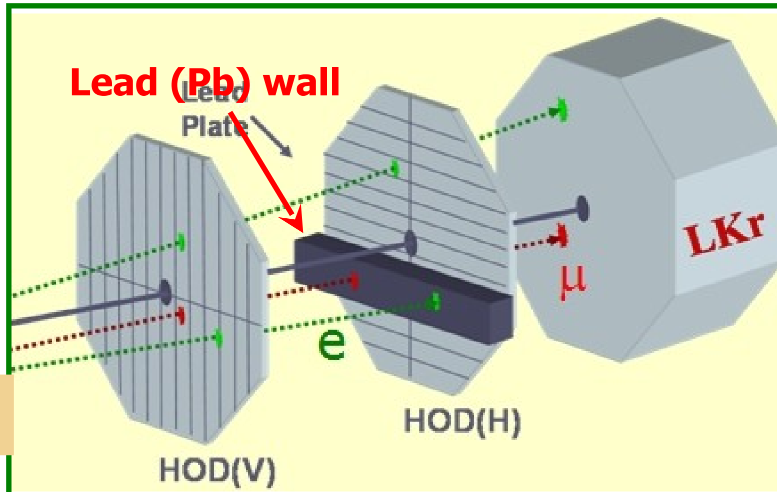
[Phys. Atom. Nucl. 60 (1997) 576]

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

by a direct measurement of $P(\mu\to e)$ to $\sim10^{-2}$ relative precision.

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





Thickness:	$\sim10X_0$ (Pb+Fe)
Width:	240cm (=HOD size)
Height:	18cm (=3 counters)
Area:	~20% of HOD area
Duration:	~50% of R_K runs
	+ special muon runs

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

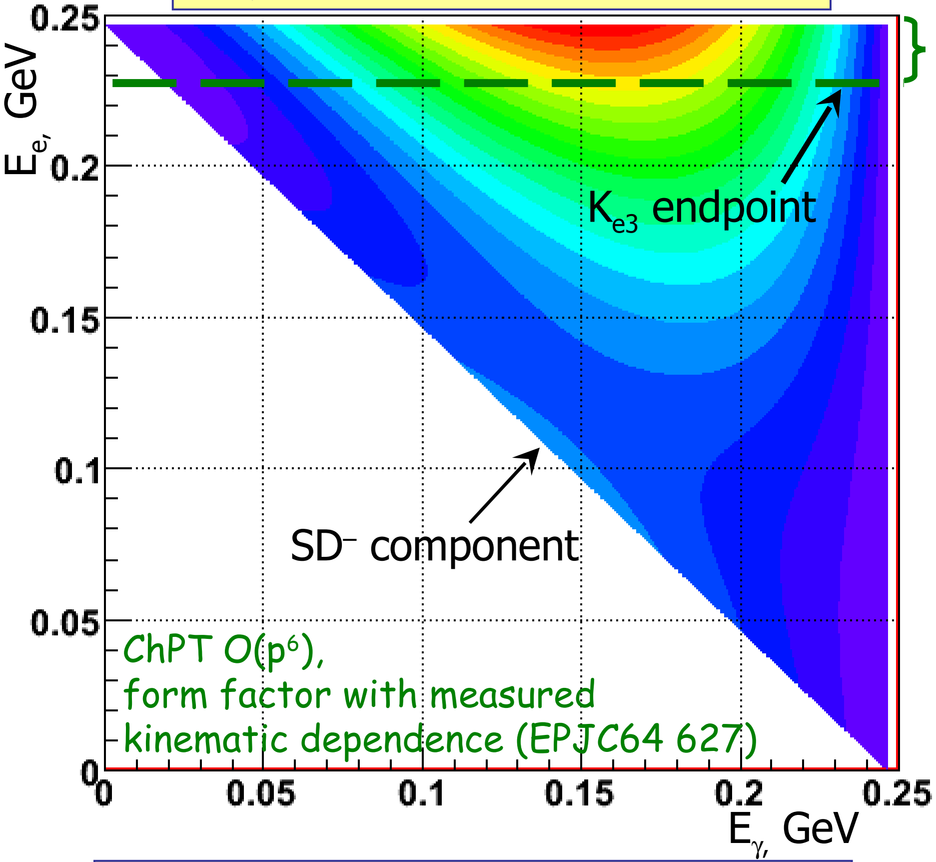
1) ionization losses in Pb (low p);
2) bremsstrahlung in Pb (high p).

Result: $B/(S+B) = (6.28\pm0.17)\%$

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

- Background by definition of R_K, no helicity suppression.
- Rate similar to that of K_{e2}, limited precision: $BR=(1.52\pm0.23)\cdot10^{-5}$.

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



Only energetic electrons (E_e^*>230MeV) 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 MeV endpoint of the K_{e3} spectrum).

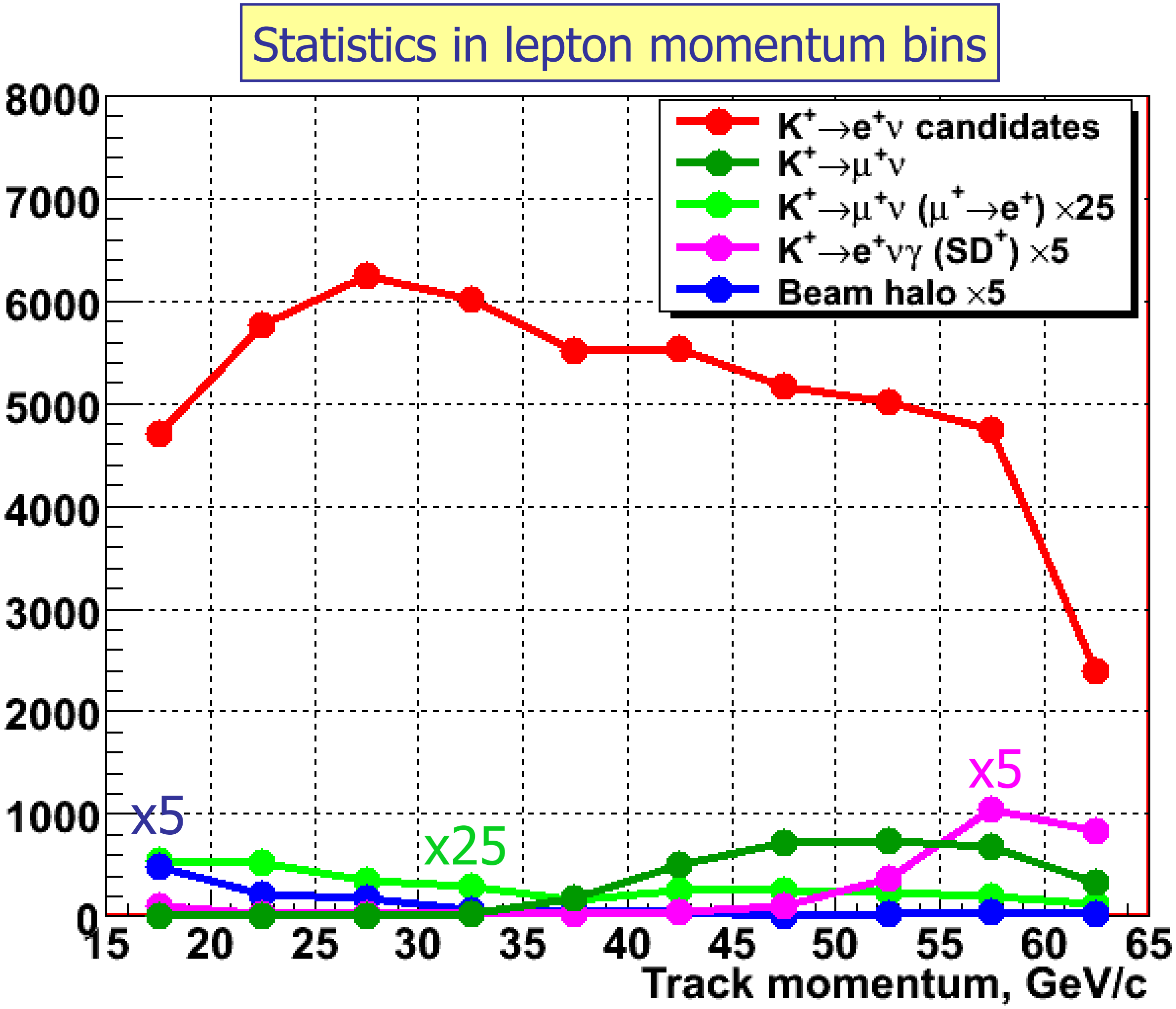
$K_{e2\gamma}$ (SD^-) background is negligible, peaking at $E_e = E_{max}/2 \approx 123$ MeV

SD background contamination

$B/(S+B) = (1.02\pm0.15)\%$

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

Backgrounds: summary



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

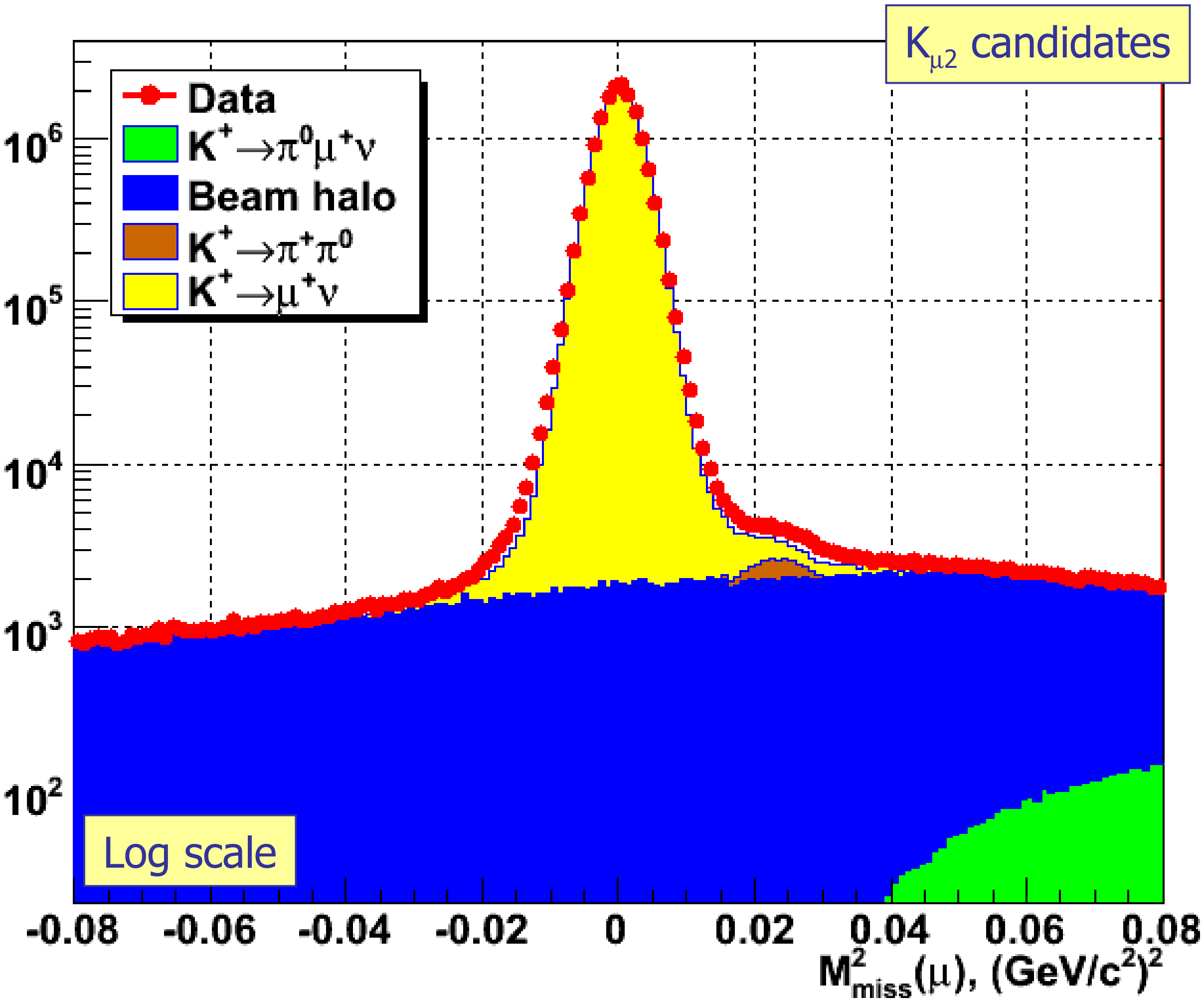
Backgrounds

Source	B/(S+B)
$K_{\mu 2}$	(6.28±0.17)%
$K_{\mu 2}$ ($\mu\rightarrow e$)	(0.23±0.01)%
$K_{e2\gamma}$ (SD^+)	(1.02±0.15)%
Beam halo	(0.45±0.04)%
K_{e3}	0.03%
$K_{2\pi}$	0.03%
Total	(8.03±0.23)%

Record K_{e2} sample:
51,089 candidates
with low background
B/(S+B) = (8.0±0.2)%

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

$K_{\mu2}$: 40% of data set



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

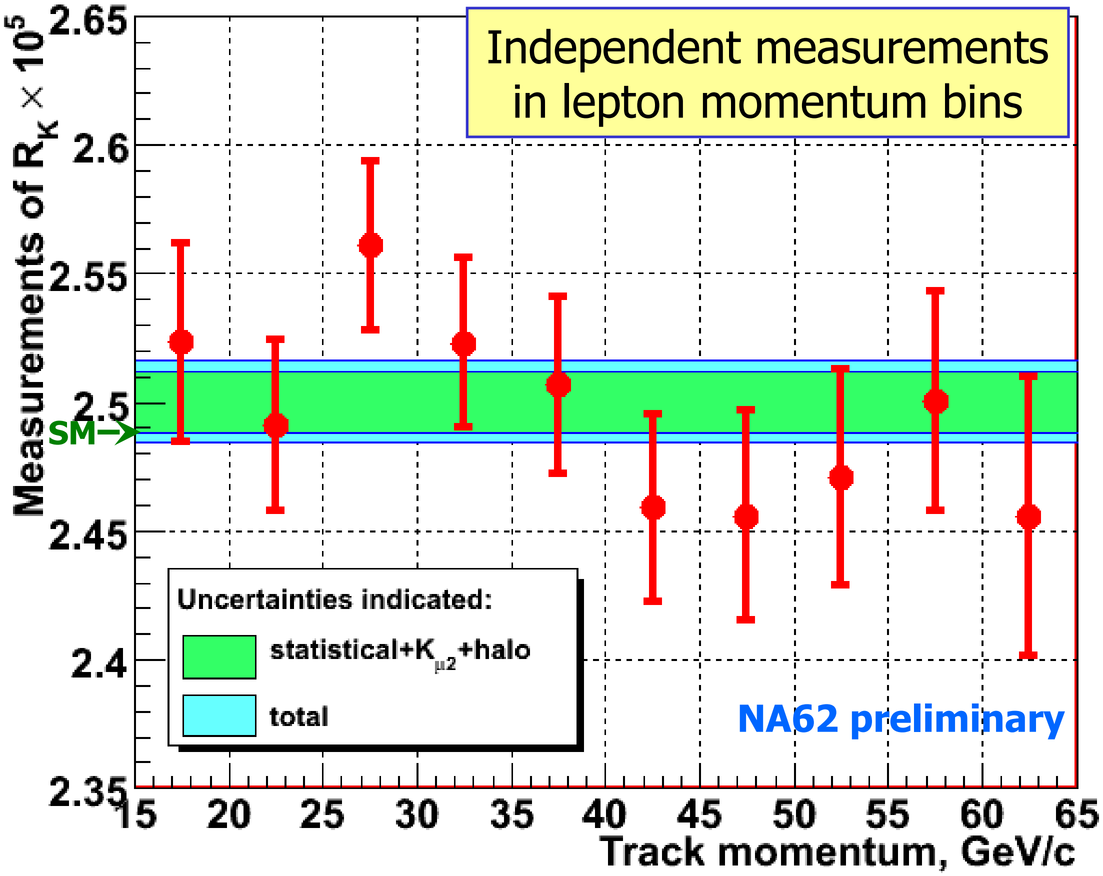
($K_{\mu2}$ trigger was pre-scaled by D=150)

The only significant background source is the beam halo.

Preliminary result (40% data set)

$$R_K = (2.500 \pm 0.012_{stat} \pm 0.011_{syst}) \times 10^{-5}$$
$$= (2.500 \pm 0.016) \times 10^{-5}$$

(arXiv:0908.3858)



Uncertainties

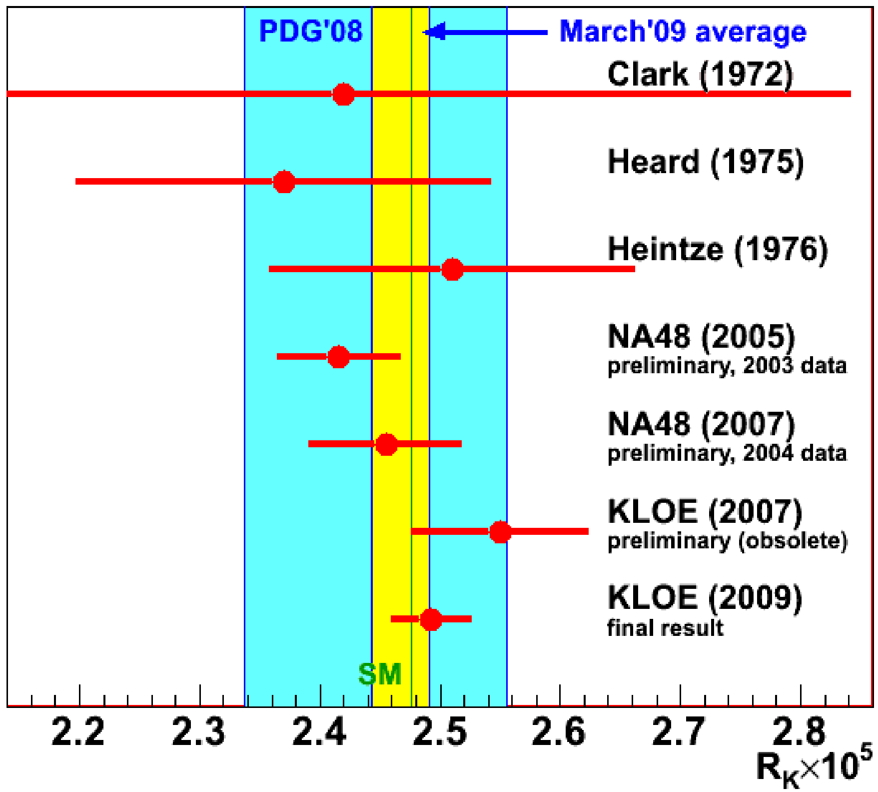
Source	$\delta R_K \times 10^5$
Statistical	0.012
$K_{\mu2}$	0.004
Beam halo	0.001
$K_{e2\gamma}$ (SD^+)	0.004
Electron ID	0.001
IB simulation	0.007
Acceptance	0.002
Trigger timing	0.007
Total	0.016

(0.64% precision)

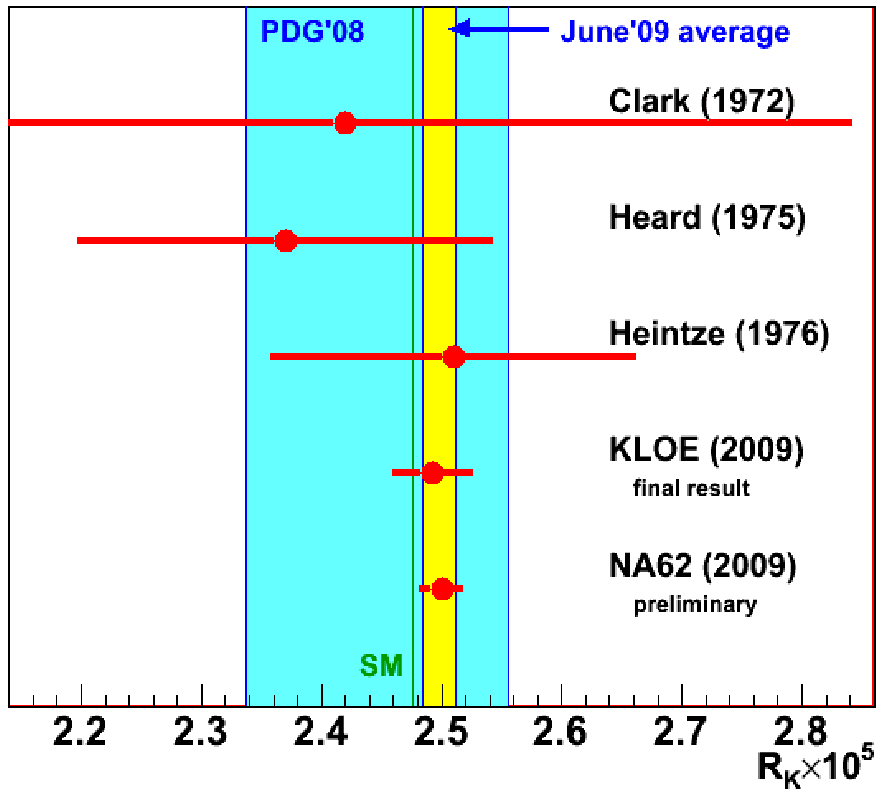
The whole 2007 sample will allow statistical uncertainty ~0.3%, total uncertainty of 0.4–0.5%.

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 $K_{e2}/K_{\mu 2}$ separation (>99% electron ID efficiency and ~10^6 muon suppression) leads to a low 8% background.

- ✗ Preliminary result based on ~40% of the NA62 K_{e2} sample:
  $R_K = (2.500 \pm 0.016) \cdot 10^{-5}$, reaching 0.7% accuracy.

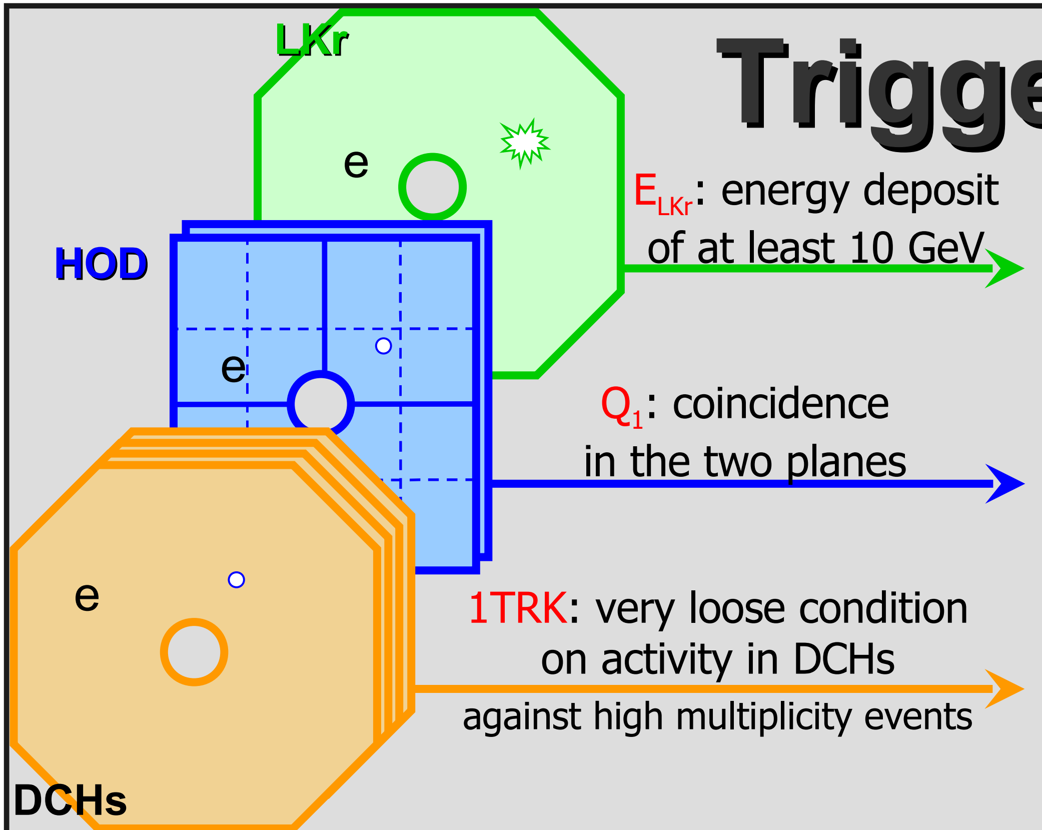
- ✗ The R_K value is compatible to the SM prediction within 1.5σ.

- ✗ 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 ~0.1% precision has been proposed in the framework of the NA62 (phase II) experiment.

Spares

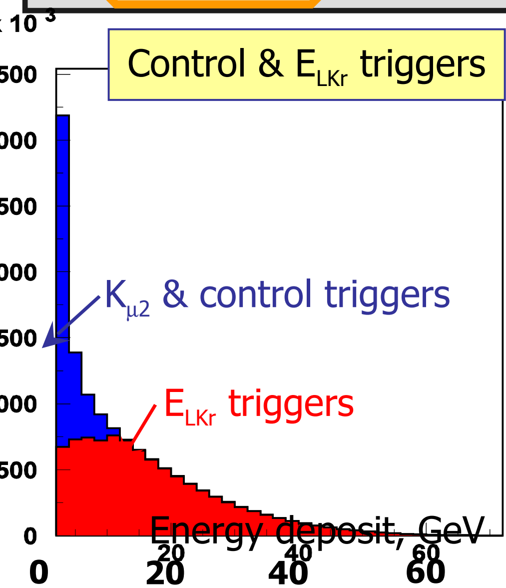
Trigger logic

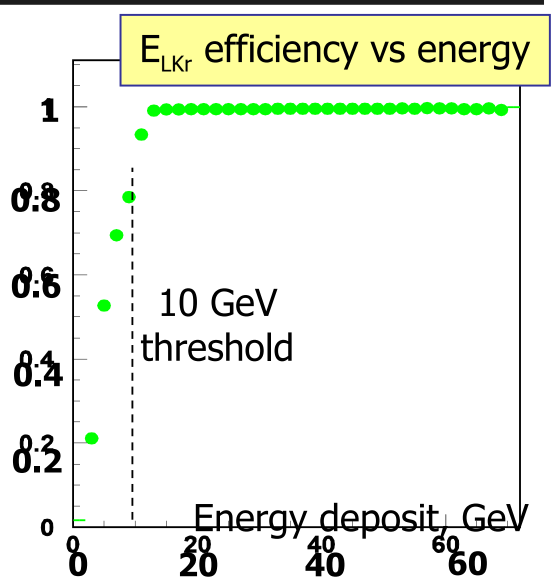


Minimum bias (high efficiency, but low purity) trigger configuration used

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

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





- Efficiency of K_{e2} trigger: monitored with $K_{\mu 2}$ & other control triggers.
- E_{LKr} inefficiency for electrons measured to be $(0.05\pm0.01)\%$ for $p_{track}>15$ GeV/c.
- Different trigger conditions for signal and normalization!

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

For NA62 conditions
(74 GeV/c beam, ~100 m decay volume),

$N(K_{\mu 2}, \mu \to e \text{ decay})/N(K_{e2}) \sim 10$

$K_{\mu 2}$ ($\mu \to e$) naïvely seems a huge background

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

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

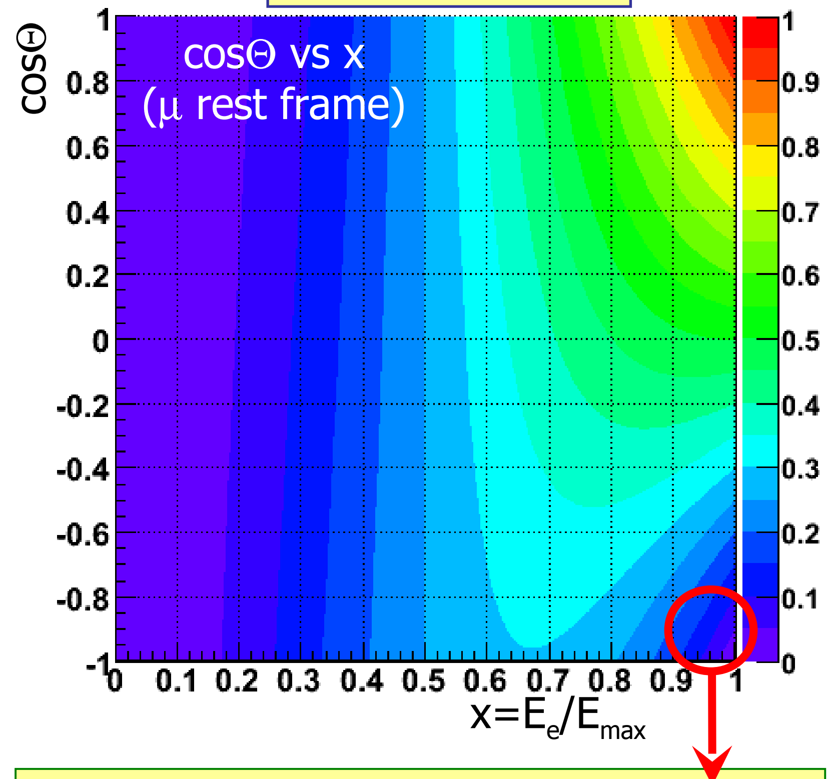
$x = E_e/E_{max} \approx 2E_e/M_\mu$,

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

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_{e2} 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:

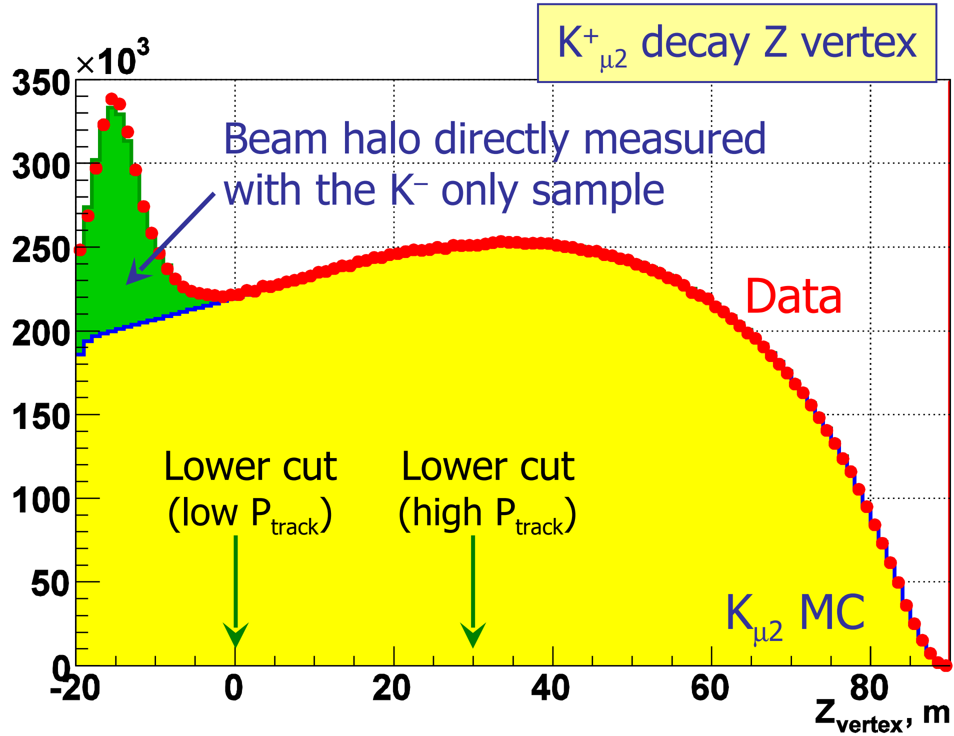
- ➔ Halo background much higher for K_{e2}^- (~20%) than for K_{e2}^+ (~1%).
- ➔ ~90% of the data sample is K^+ only, ~10% is K^- only.
- ➔ K^+ halo component is measured directly with the K^- sample and vice versa.

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 ~1.5σ.
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 $R_K=K_{e2}/K_{\mu 2}$ is better than in $B\rightarrow\tau\nu$

(MH, tanβ) 95% exclusion limits