Measurement of $BR(K \rightarrow e\nu)/BR(K \rightarrow \mu\nu)$ with NA62

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Outline

- Physics Motivations;
- Previous experimental status;
- NA62 experiment 2007-8 data taking;
- K_{e2} and $K_{\mu 2}$ data samples;
- Background studies & systematic effects;
- NA62 R_K preliminary result;
- Conclusion and prospects;

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

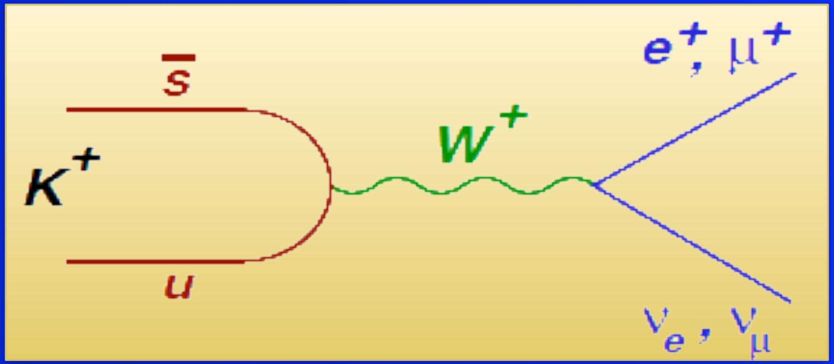
Sensitive to lepton flavor violation and its SM expectation:

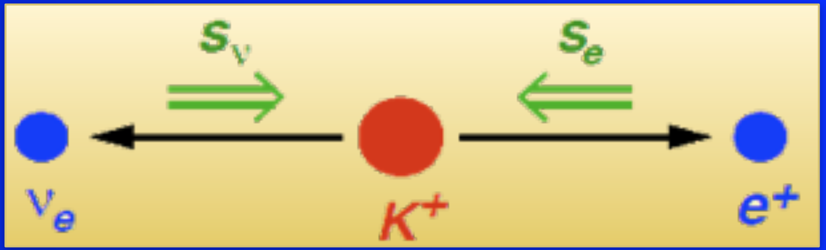
$$R_K = \frac{\Gamma(K^\pm \to e^\pm \nu)}{\Gamma(K^\pm \to \mu^\pm \nu)} = \boxed{\frac{m_e^2}{m_\mu^2}} \left(\frac{m_K^2 - m_e^2}{m_K^2 - m_\mu^2}\right)^2 \cdot (1 + \boxed{\delta R_K^{rad.corr.}})$$

Helicty suppression factor ~10^{-5}

Few % due to: K->eν(γ) IB process

- ☑ 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



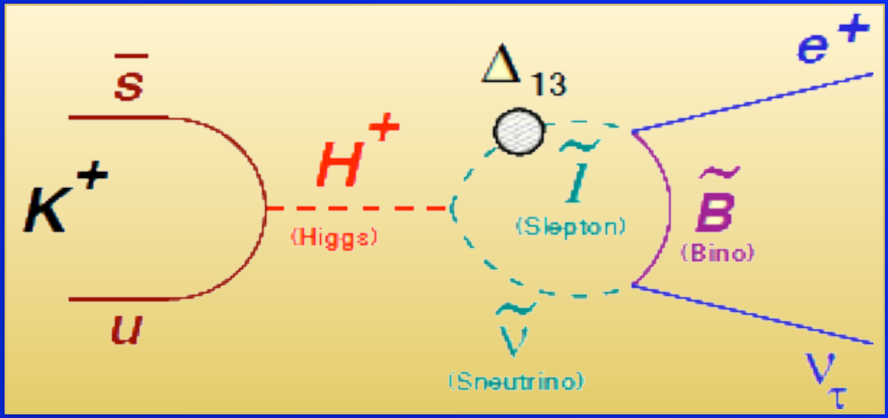


Theoretical expect. (Phys. Lett. 99 (2007) 231801):

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

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

R_K beyond the SM



2 Higgs Doublet Models – tree level

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

→ Does not affect the ratio R_K

2 Higgs Doublet 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

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

3 unknown parameters: $M_{H\pm}$, Δ_{13}, $\tan\beta$

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

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

$B_{e\nu}/B_{\tau\nu}$ → enhancement factor 10!

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

Effect in large $\tan\beta$ regime with a massive $H^\pm$ (PRD 74 (2006) 01170)

($\Delta_{13}=5\times10^{-4}$, $\tan\beta=40$, $M_H=500$ GeV/c^2)

lead to $R_K^{MSSM} = R_K^{SM}(1+0.013)$ 1.3% measurable!

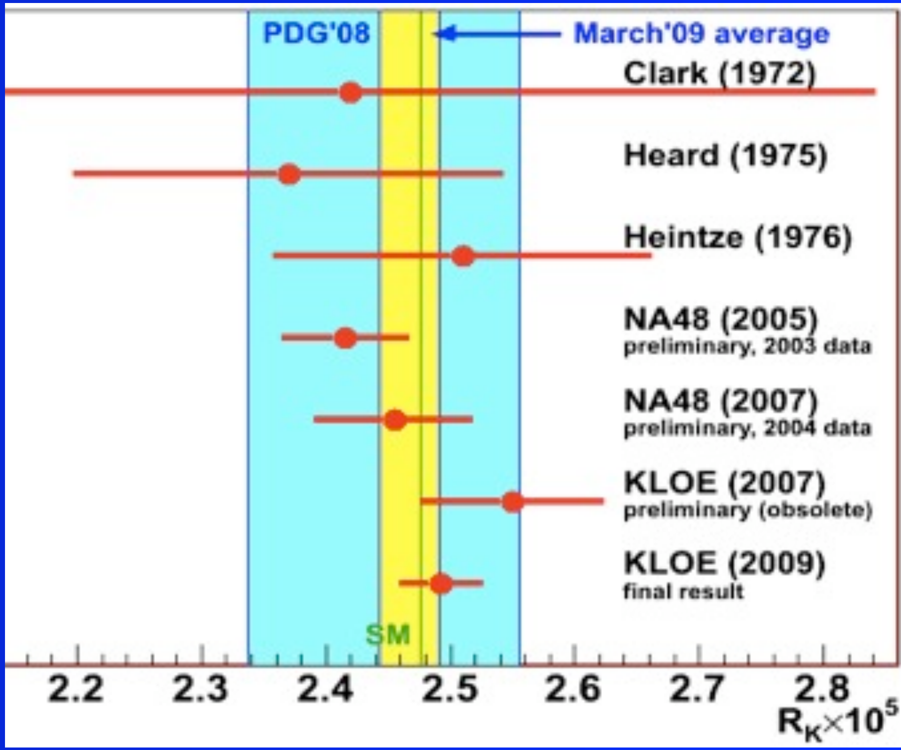
Experimental status of R_K

After first searches in the early Seventies new interest rose by PRD 74 (2006) 01170

New studies both in the NA48/2 (@ CERN) and KLOE (@ LNF) collaborations lead to preliminary results

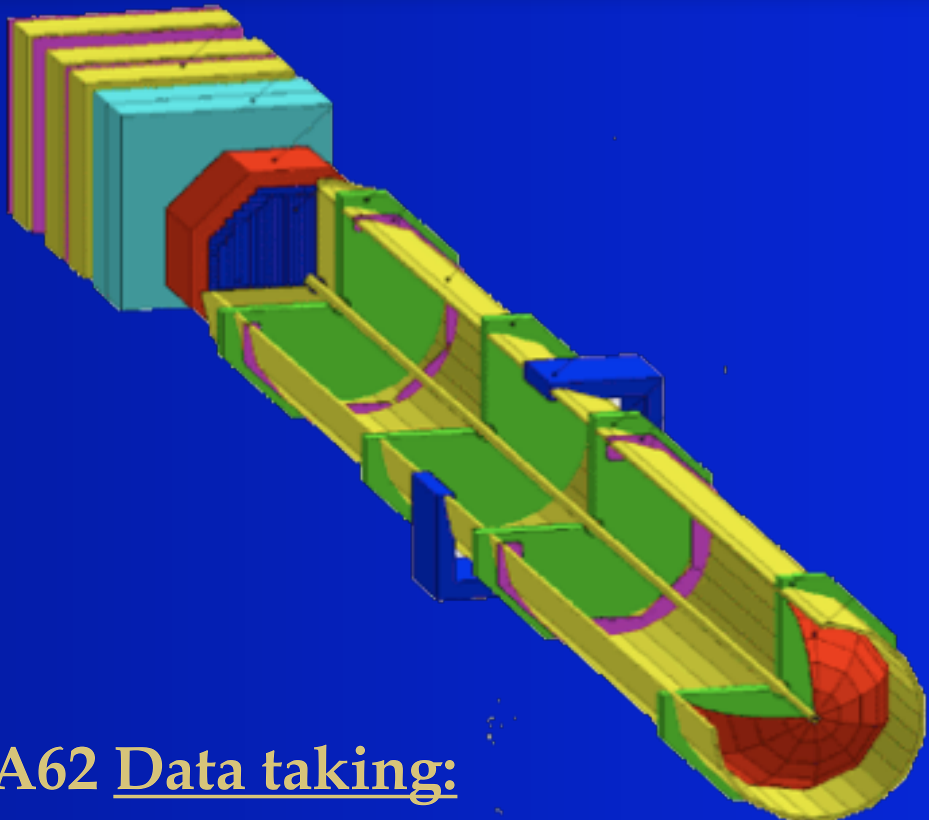
Recent improvement: KLOE (LNF).
Data collected in 2001–2005,
13.8K K_{e2} candidates, 16% background.
$R_K=(2.493\pm0.031)\times10^{-5}$ ($\delta R_K/R_K=1.3\%$)
(EPJ C64 (2009) 627)

R_K world average (March 2009)



NA62 (phase I) dedicated data taking goal:
~150K K_{e2} candidates, <10% background, $\delta R_K/R_K<0.5\%$:
sub % measurement able to spot for deviation from SM.

NA62 detector



LKr EM calorimeter

$$\frac{\sigma(E)}{E} = \frac{3.2\%}{\sqrt{E}} \oplus \frac{9\%}{E} \oplus 0.4\%$$

$$\sigma_{x,y} < 1.3mm$$

Spectrometer

- **4 Drift Chambers**
- **Magnet**

$$\frac{\sigma(p)}{p} = 0.47\% \oplus 0.02 \times p(GeV)$$

$$\sigma_{VTX}^{x,y} \sim 2mm$$

Trigger Hodoscope

$$\sigma_t \approx 150\,ps$$

NA62 Data taking:

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

R_K Measurement strategy

- ☑ $K_{e2}/K_{\mu 2}$ candidates are collected simultaneously:
  - the result does not need any kaon flux measurement;
  - several systematic effects cancel at first order (e.g. reconstruction/trigger efficiencies, time-dependent effects).
- ☑ Counting experiment, independently in 10 lepton momentum bins
  - owing to strong momentum dependence of backgrounds
- ☑ MC simulations used to a limited extent only:
  - Geometrical part of the acceptance correction (not for particle ID);
  - simulation of "catastrophic" bremsstrahlung by muons.

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

$N(K_{e2})$, $N(K_{\mu 2})$	:	numbers of selected K_{l2} candidates;
$N_B(K_{e2})$, $N_B(K_{\mu 2})$	:	numbers of background events;
$A(K_{e2})$, $A(K_{\mu 2})$	:	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.

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

Common selection criteria

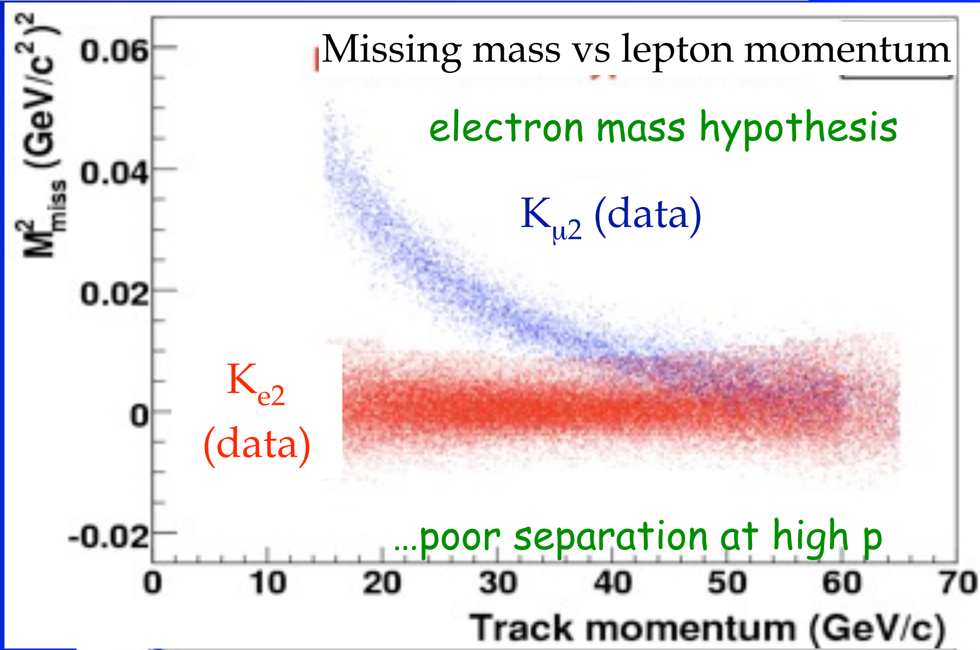
☑ One reconstructed track;
☑ Geometrical acceptance cuts;
☑ K decay vertex: closest approach of track & nominal kaon axis;
☑ Veto extra LKr energy deposition clusters;
☑ Track momentum: 15GeV/c<p<65GeV/c

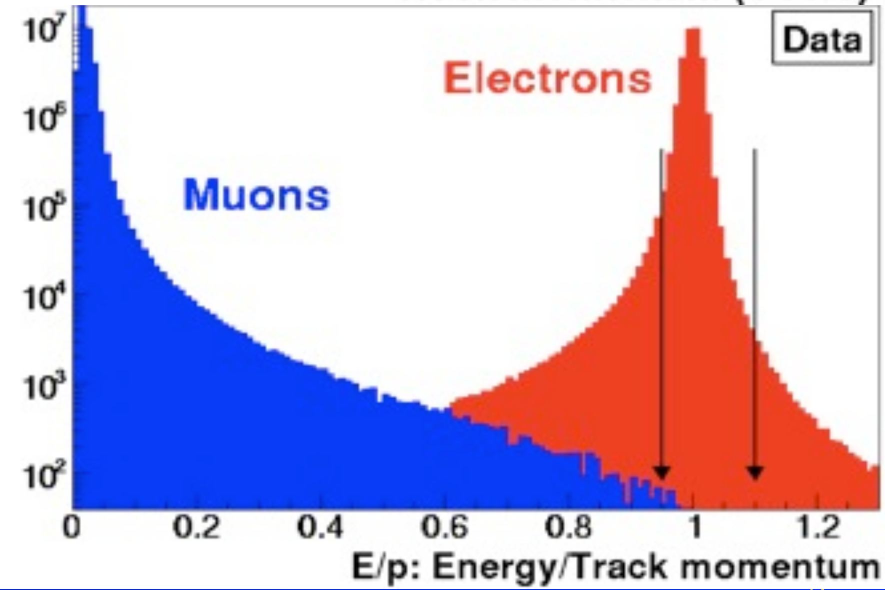
Kinematic separation

- Missing mass $M^2_{miss} = (P_K - P_l)^2$
- Good $K_{e2}/K_{\mu 2}$ separation at p_{track}<25GeV/c

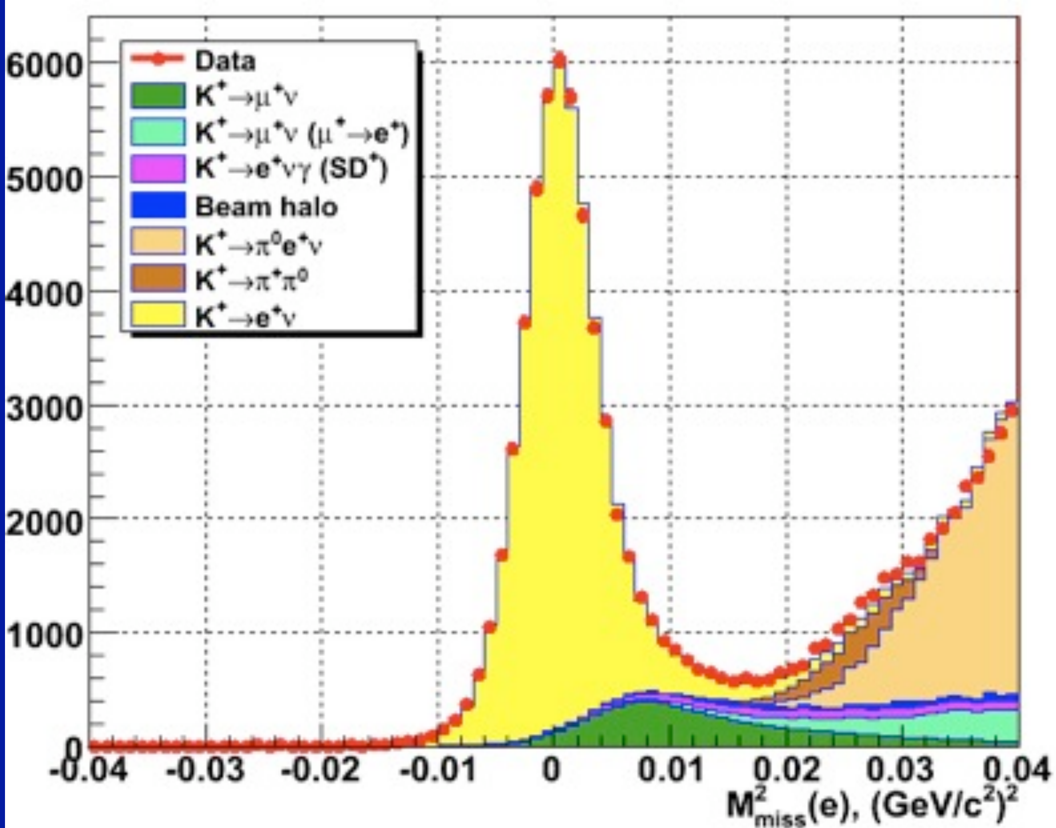
Separation by particle ID

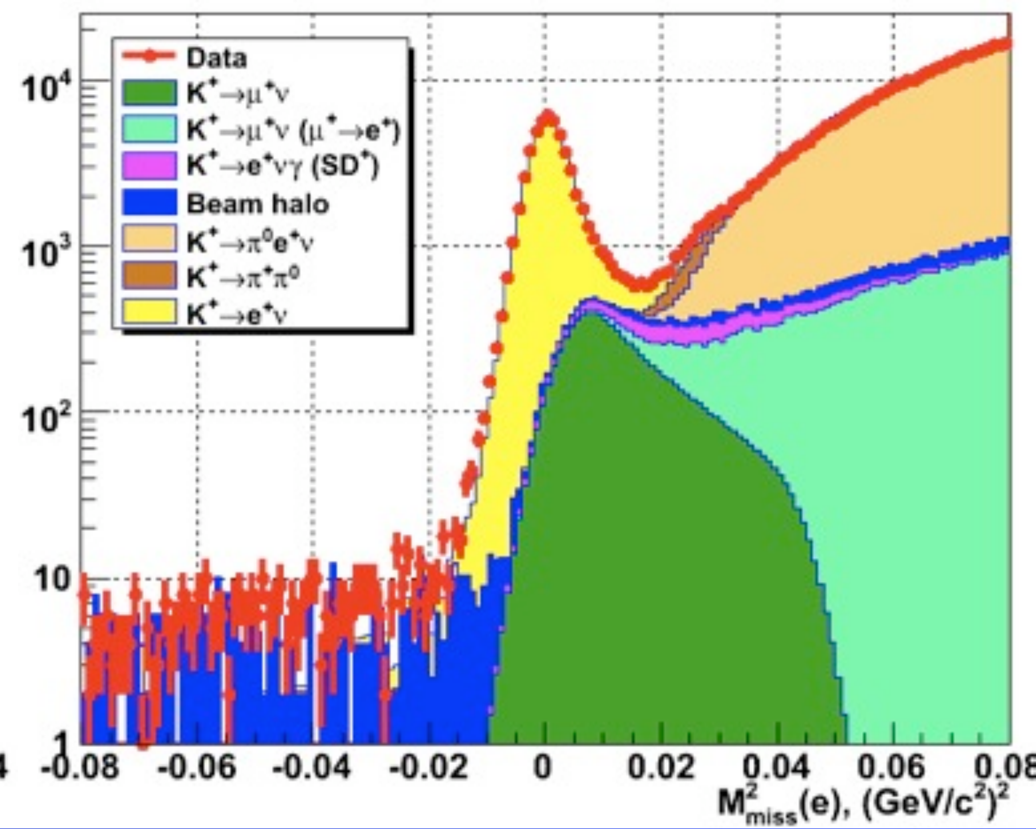
- E/p = (LKr energy deposit/track momentum)
  - 0.95<E/p<1.10 for electrons,
  - E/p<0.85 for muons.
- Powerful $\mu^{\pm}$ suppression in $e^{\pm}$ sample: $f \sim 10^6$





NA62 K_{e2} sample (40% data set)





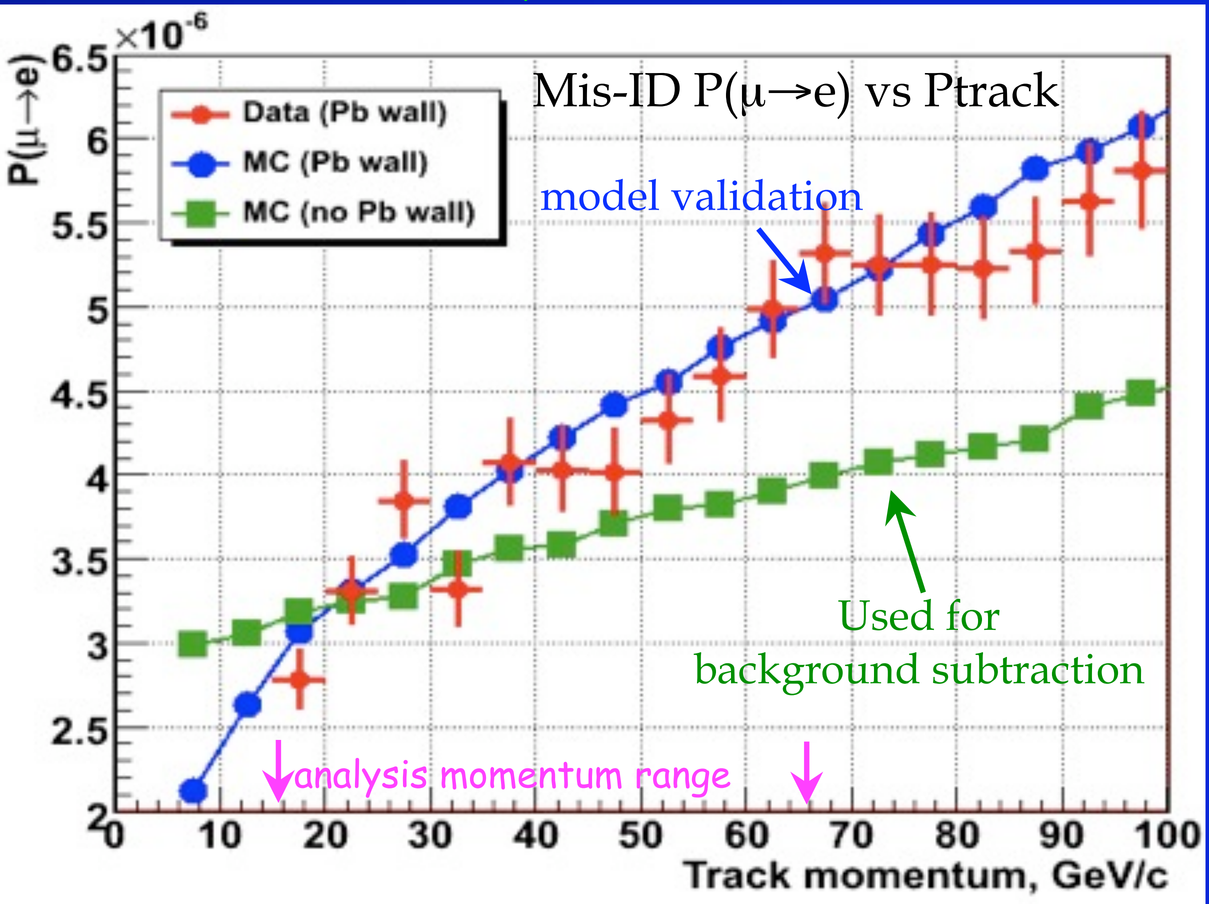
NA62 preliminary result sample:
51,089 $K^+ \rightarrow e^+\nu$ candidates,
99.2% electron ID efficiency,
B/(S+B) = (8.0±0.2)%

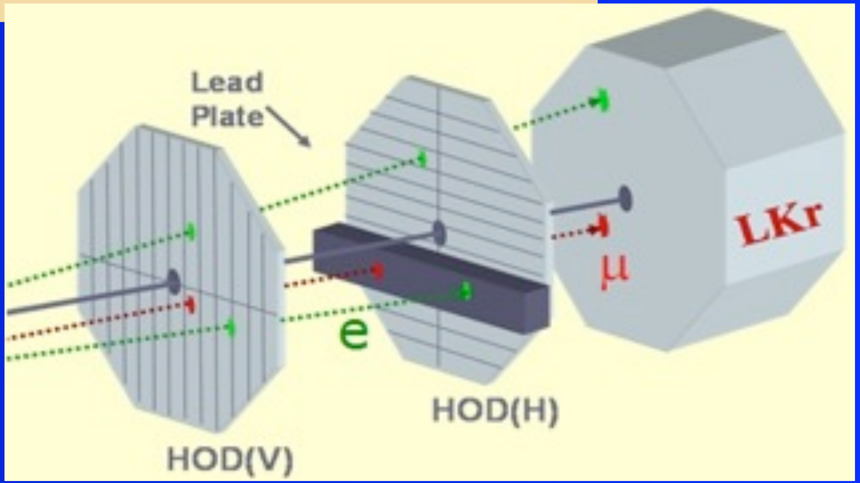
NA62 estimated total K_{e2} sample:
~120K K^+ & ~15K K^- candidates.

$K_{\mu 2}$ background measurement

P(μ→e): measurement (2007 special muon run) vs Geant4-based simulation

[Cross-section model: Phys. Atom. Nucl. 60 (1997) 576]





Thickness: ~10X_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(μ→e) is modified by the Pb wall

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

Result: B/(S+B) = (6.28±0.17)%

Beam halo background

Electrons produced by beam halo muons via $\mu \rightarrow e$ decay can mimic K_{e2} decays

Halo 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^- sample is used to directly measure K^+ halo component and vice versa

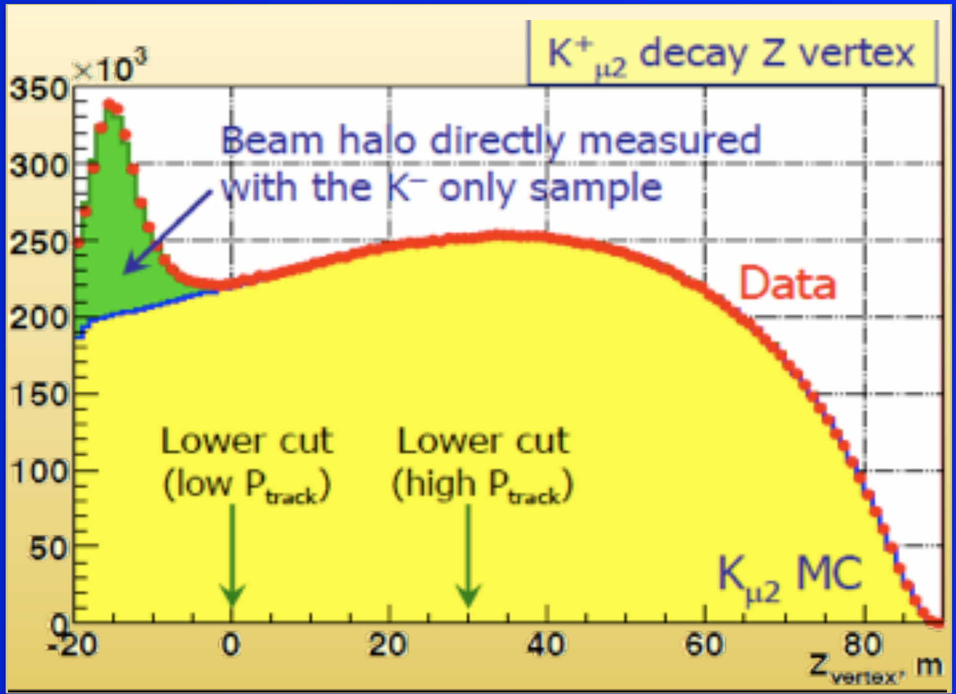
- K^+ selection applied to K^- run to calculate halo BG probability

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

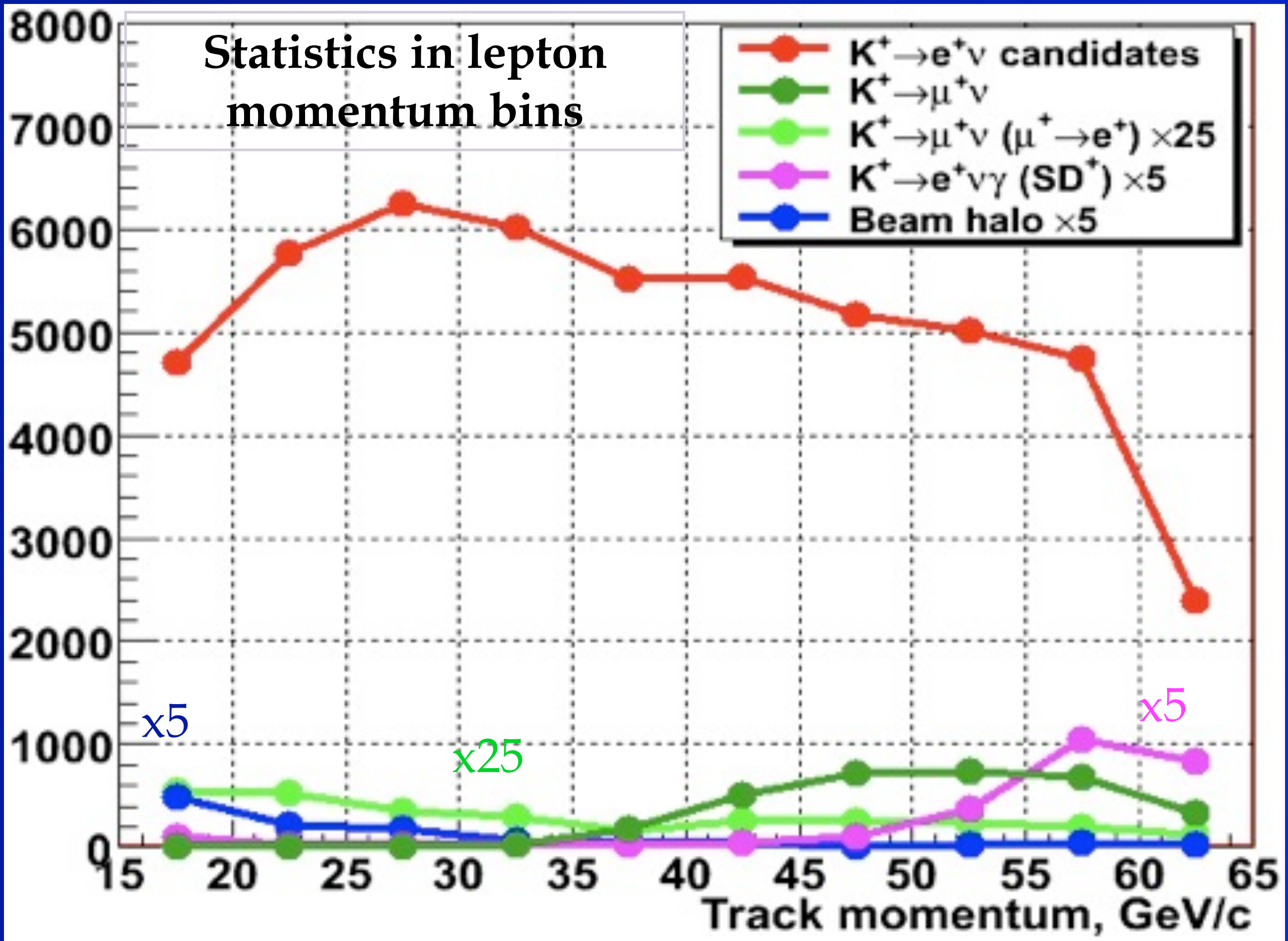
The selection criteria (esp. Z_{vertex}) are optimized to minimize the halo background.

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

Uncertainty is due to the limited size of the K^- control sample.



Backgrounds: summary



Backgrounds

Source	B/(S+B)
$K_{\mu2}$	(6.28±0.17)%
$K_{\mu2}$ ($\mu \to e$)	(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)%

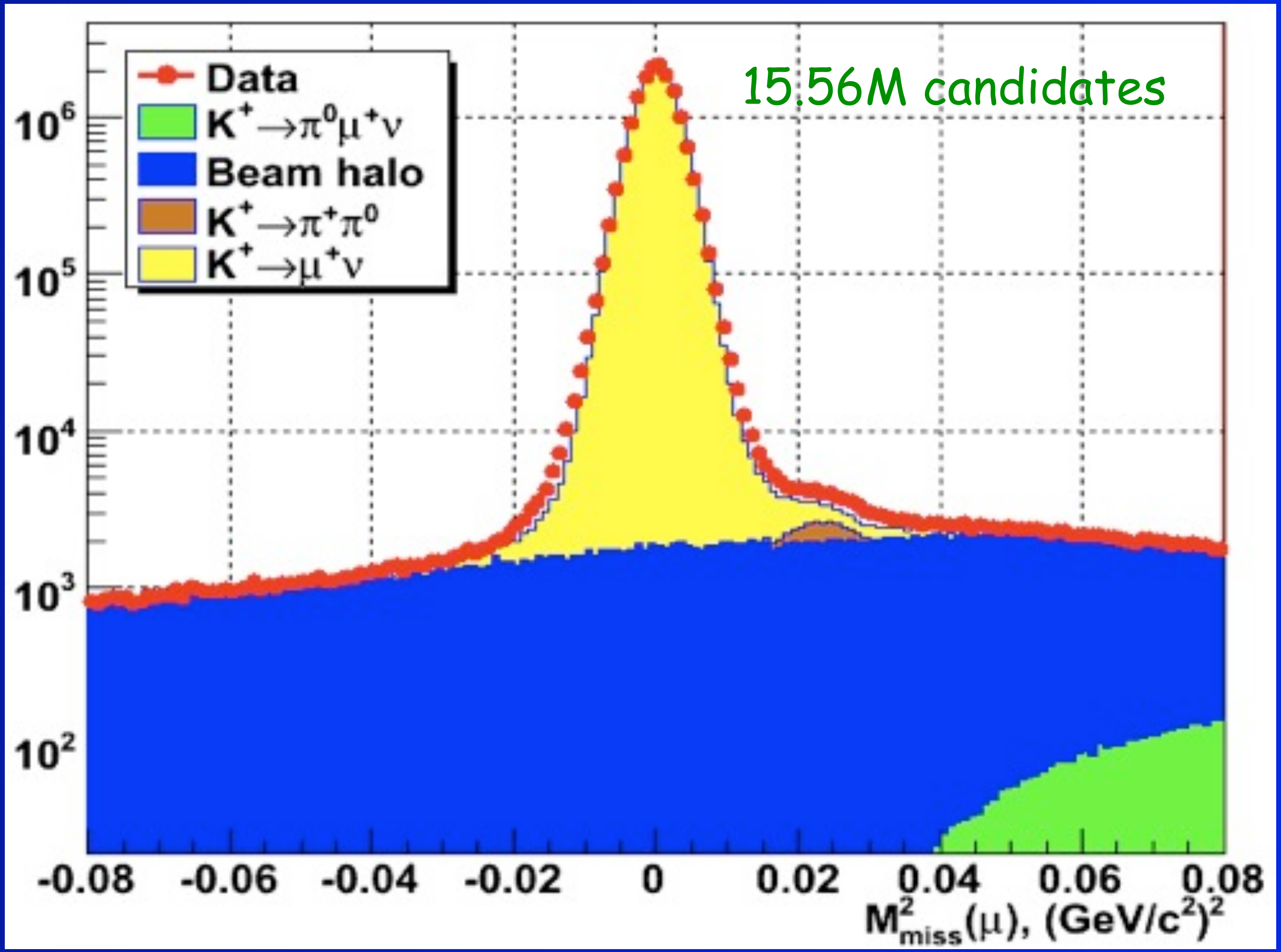
Record K_{e2} sample:
51,089 candidates
with low background
B/(S+B) = (8.0±0.2)%

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

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

NA62 $K_{\mu 2}$ sample (40% data set)

$K_{\mu 2}$ candidates



Acquired using a trigger pre-scaled by D=150

The only significant background source comes form the beam halo muons.

15.56M candidates

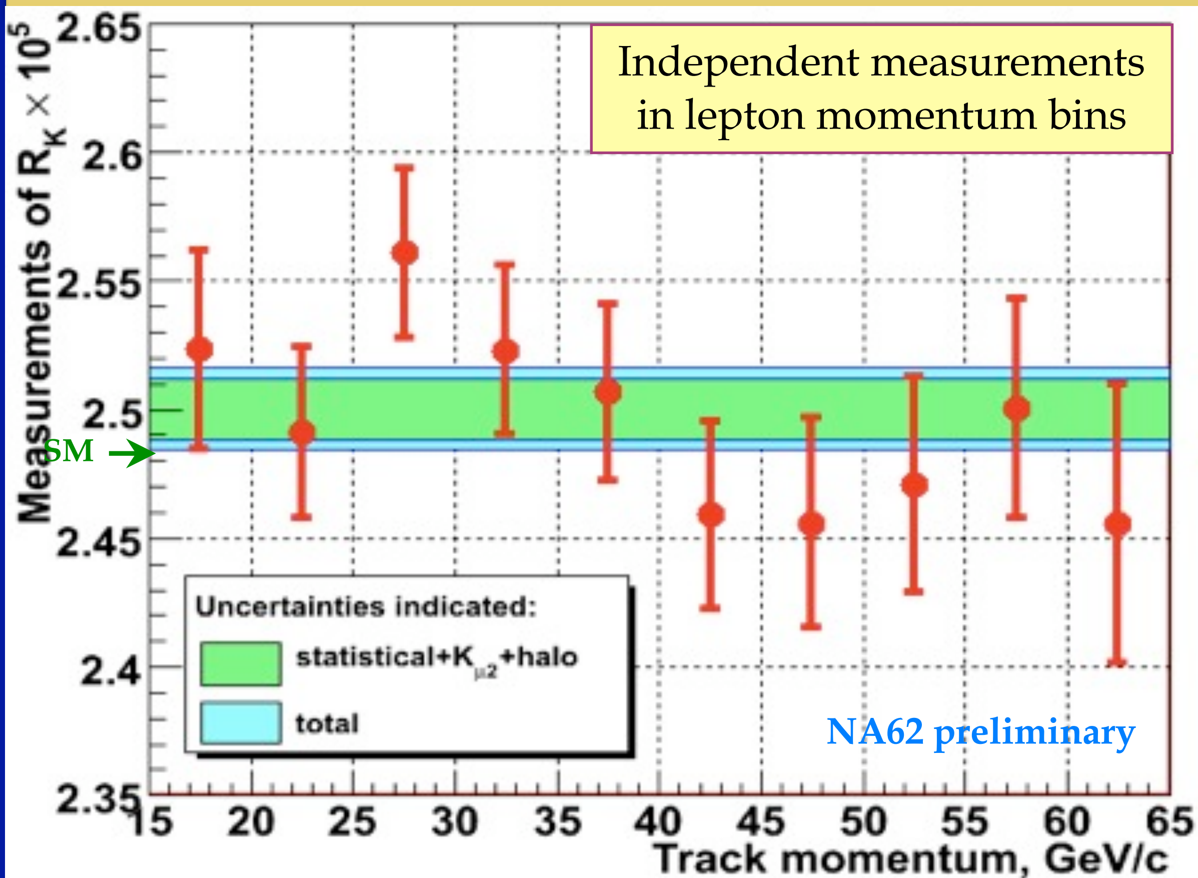
very low background

B/(S+B) = 0.25%

R_K preliminary result (40% data set)

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

$$R_K = (2.500 \pm 0.016) \times 10^{-5}$$ (arXiv:0908.3858)



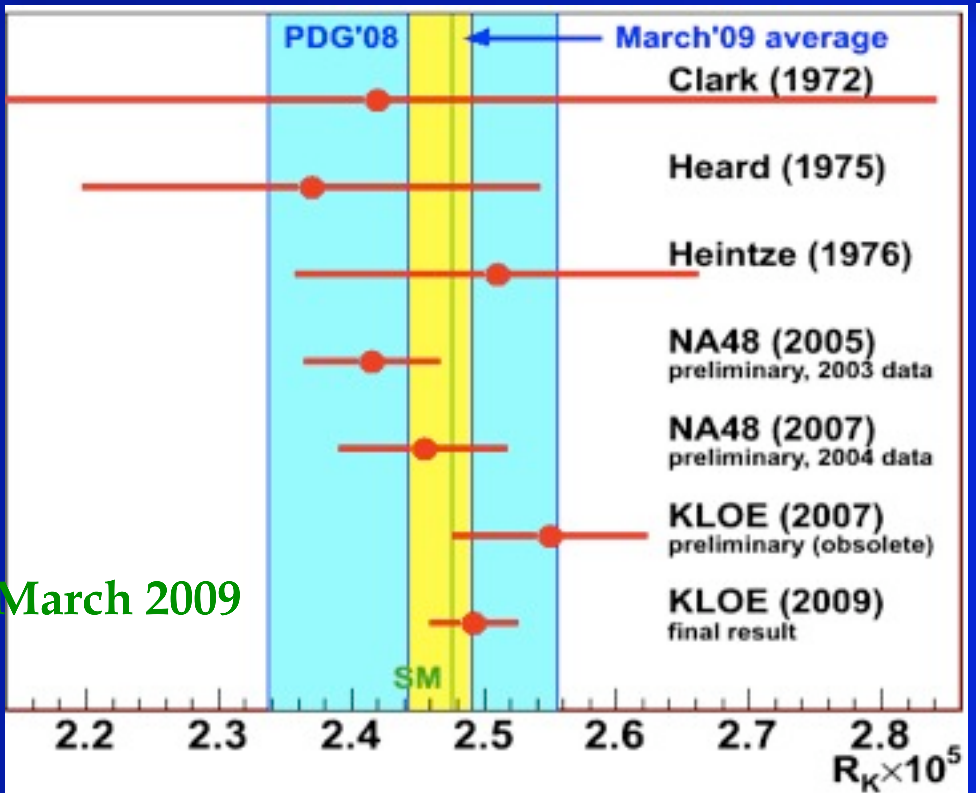
Uncertainties

Source	$\delta R_K \times 10^5$
Statistical	0.012
$K_{\mu 2}$(BG)	0.004
Beam halo (BG)	0.001
$K_{e2\gamma}$ (SD^+) (BG)	0.004
Electron ID	0.001
IB sim. (MC)	0.007
Acceptance (MC)	0.002
Trigger timing	0.007
Total (0.64% prec)	0.016

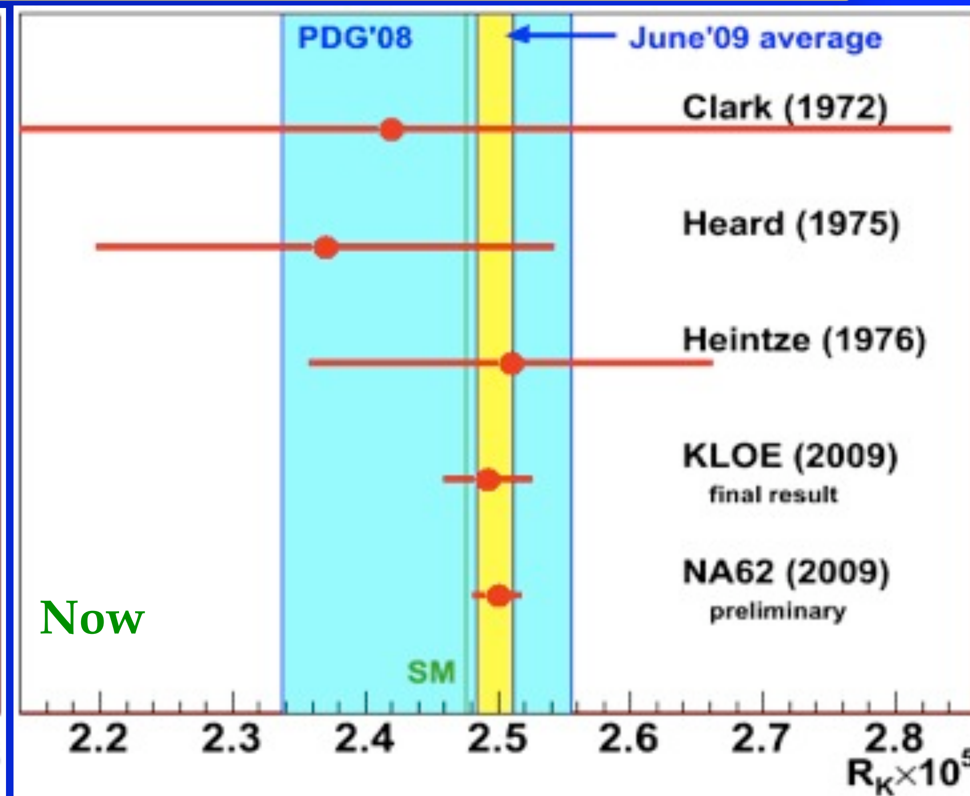
The whole 2007 sample will allow statistical uncertainty ~0.3%, total uncertainty of 0.4–0.5%.

Effect on world average

March 2009



Now



NA48/2 preliminary results excluded they are superseded by NA62 one. KLOE preliminary result excluded superseded by KLOE final.

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%
Theory	2.477±0.001	0.04%

R_K: sensitivity to new physics

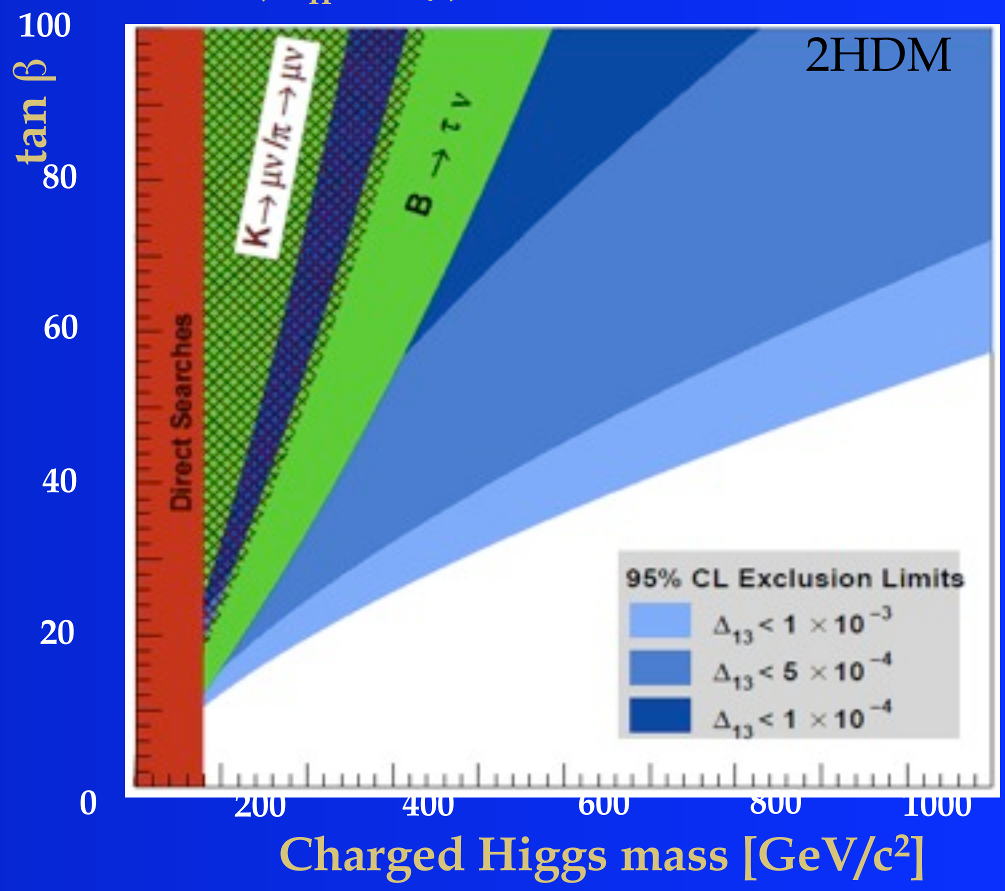
R_K world average is currently in agreement with the SM expectation at ~1.5σ.

Any significant enhancement with respect to the SM value would be an evidence of new physics.

~ 1% effects are still not excluded!

For non-tiny values of the LFV slepton mixing Δ_{13}, sensitivity to $H^{\pm}$ in $R_K = K_{e2}/K_{\mu 2}$ is better than in $B \rightarrow \tau\nu$

(M_H, tan β) 95% exclusion limits



Conclusion

☑ Due to the helicity suppression factor (~10^5) of the K_{e2} decay, the ratio R_K is stringent test of the Standard Model.

☑ NA62 during data taking in 2007/08 has collected K_{e2} sample ~10 times the world sample with a low 8% background.

☑ Preliminary result based on ~40% of the NA62 K_{e2} candidates leads to: $R_K = (2.500 \pm 0.016) \times 10^{-5}$, reaching 0.7% accuracy

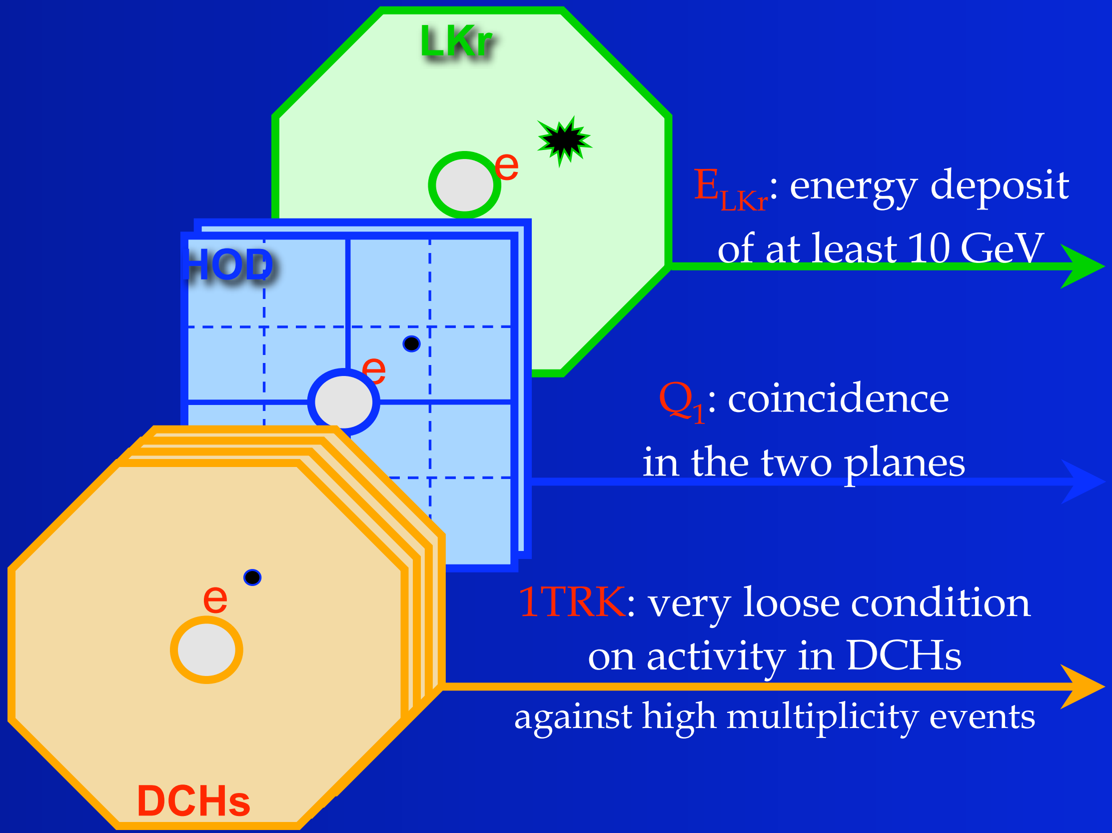
☑ The R_K value is compatible to the SM prediction in within 1.5σ

☑ The precision is expected to be improved to better than $\delta R_K R_K = 0.5\%$ using the full NA62 (Phase I) data sample.

☑ R_K measurement with ~0.1% precision is expected to be performed in the framework of the NA62 (phase II) experiment.

Backup slides

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}.

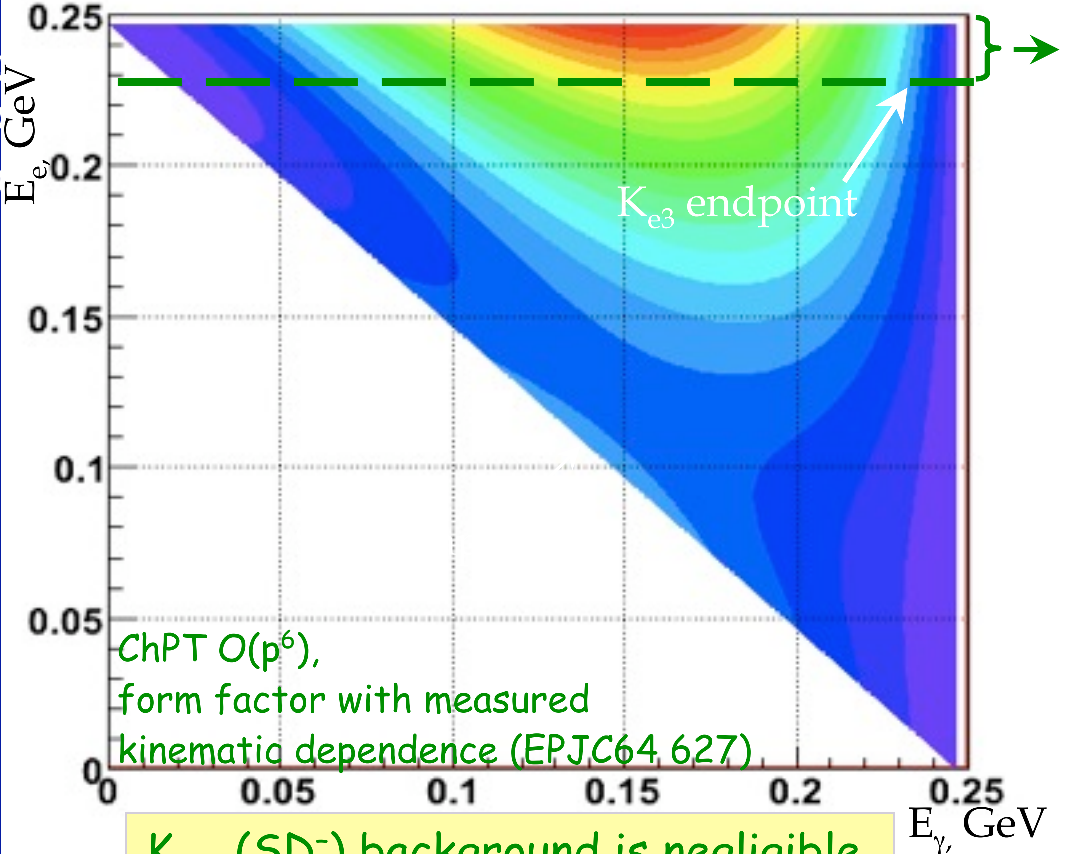
$K_{\mu 2}$ condition: $Q_1 \times 1TRK/D$,
downscaling (D) 50 to 150.
Purity ~2%.

- Efficiency of K_{e2} trigger: monitored with $K_{\mu 2}$ & other control triggers.
- E_{LKr} inefficiency for electrons measured to be (0.05±0.01)% for p_{track}>15 GeV/c.
- Different trigger conditions for signal and normalization!

$K^+ \to e^+\nu\gamma$ (SD) background

- Background by definition of R_K, no helicity suppression.
- Rate similar to that of K_{e2}, limited precision: $BR=(1.52\pm0.23)\times10^{-5}$.

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



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

Only energetic electrons ($E_e^*>230$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 $E_e^*=227$ MeV endpoint of the K_{e3} spectrum).

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)