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Lepton Flavour violation searches with kaons at NA62

Giulio Saracino

Università degli studi di Napoli Federico II and
Istituto Nazionale di Fisica Nucleare

on behalf of NA62 collaboration

Birmingham, CERN, Dubna, Fairfax, Ferrara, Florence,Frascati, Mainz, Merced, Moscow, Naples, Perugia, Pisa, Protvino, Rome I, Rome II, Saclay, San Luis Potosi, Stanford, Sofia,Triumf, Turin

Outline

- Looking for LFV : theory and experiment
- The NA62 experiment
- The measurement strategy
- Conclusions

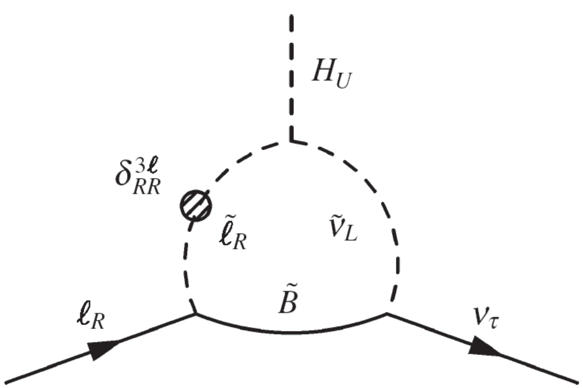
Looking for Lepton Flavor Violation

In the S.M. Lepton Flavor Violating (LFV) processes are forbitten or hardly suppressed

LFV can arise from extensions of S.M., as in low energy minimal SUSY (MSSM)

Kaon and pion leptonic decays are potenzially good candidates for NP evidence

The V-A structure of the weak interaction suppress these decays in the SM, and makes them very sensitive to non-SM effect as pseudoscalar hadronic weak current



$$\Gamma(K^+ \to \ell \upsilon)\Big|_{\exp} = \Gamma(K^+ \to \ell \upsilon_\ell) + \Gamma(K^+ \to \ell \upsilon_\tau)$$

SM

effective pseudoscalar LFV amplitude

$$\ell H^\pm \nu_\tau \to \frac{g_2}{\sqrt{2}} \frac{m_\tau}{M_W} \Delta_R^{3\ell} \tan^2 \beta \qquad \ell = e, \mu$$

R_K: a sensitive probe of New Physics

One way to look for such effects is in ratio R_K, where the non perturbative form factors f_K cancels out allowing a very precise (SM) theoretical estimations (*)

$$R_K = \frac{\Gamma\left(K^\pm \to e^\pm \nu_e\right)}{\Gamma\left(K^\pm \to \mu^\pm \nu_\mu\right)} = \frac{m_e^2}{m_\mu^2}\left(\frac{m_K^2 - m_e^2}{m_K^2 - m_\mu^2}\right)^2 \left(1 + \delta R_{QED}\right) = \left(2.477 \pm 0.001\right)\cdot 10^{-5}$$

$\delta R_{QED} = -3.8\%$

$\delta R_K / R_K \sim 0.04\%$

Radiative corrections

as pointed out by a recent work (**) it's possible to find in MSSM value of tanβ and M_H such that the R_K value can shift at the percent level the SM prediction.

$$R_K^{LFV} \approx R_K^{SM}\left[1 + \left(\frac{m_K^4}{m_{H^\pm}^4}\right)\left(\frac{m_\tau^2}{m_e^2}\right)\left|\Delta_{31}\right|^2 \tan^6\beta\right]$$

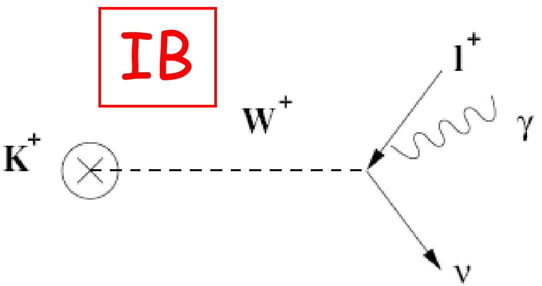
$$R_K^{LFV} = R_K^{SM}\,(1 + 0.013)$$

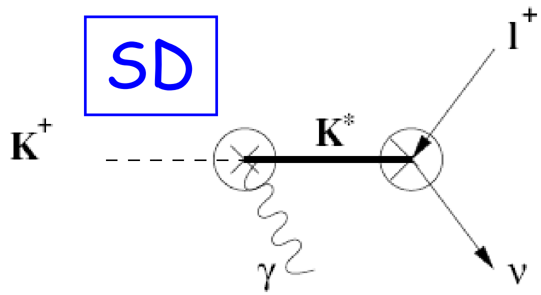
$\tan\beta = 40$ $M_H = 500\ \mathrm{GeV}/c^2$ $\Delta_{31} = 5\times10^{-4}$

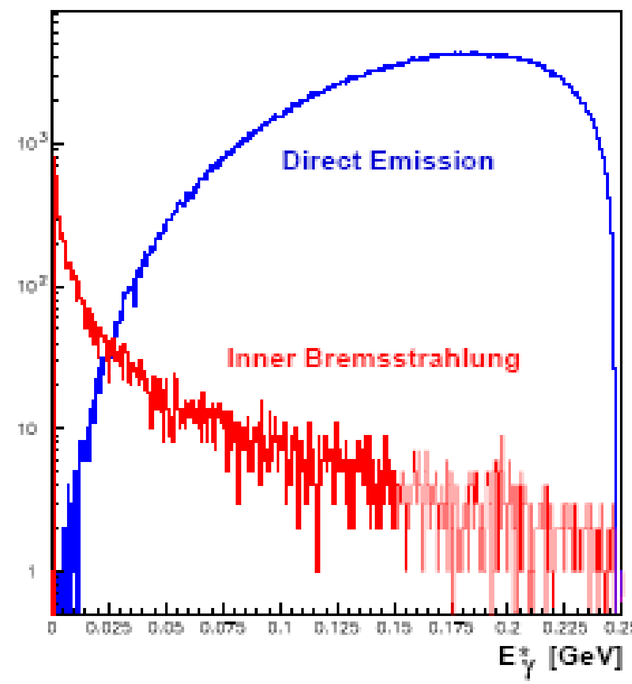
(*) V. Cirigliano and I Rosell, JHEP 0710:005 (2007) (**) Masiero, P. Paradisi, R. Petronzio hep-ph/0511289 PRD74 (2006))

Radiative corrections

Only Inner Bresstrahlung (IB) and virtual photon process are included in RK definition. Structure Dependent (SD) are not







While SD contribution is negligible in $K_{\mu 2}$, it's not the case for K_{e2}

Experimetally the measure include both IB and SD decays => SD contribution must be subtracted (MC)

Experimental status

Big improvements in the last years in the exp. determination of RK:

World average (2006) (based on 1970s experiments)

$$R_K^{PDG}(2006) = (2.45 \pm 0.11) \cdot 10^{-5} \qquad \delta R_K / R_K = 4.5\%$$

NA48/2

- Run 2003

  final sample: $(4670 \pm 77_{stat})$ K_{e2} candidates
- Run 2004

  final sample: $(3407 \pm 63_{stat})$ K_{e2} candidates

$$R_K = (2.455 \pm 0.045 \pm 0.041) \cdot 10^{-5}$$

$\delta R_K/R_K \sim 2\%$

KLOE (preliminary 2007)

~ 8k K_{e2} candidates

(70% of available statistic)

[arXiv:0707.4623]

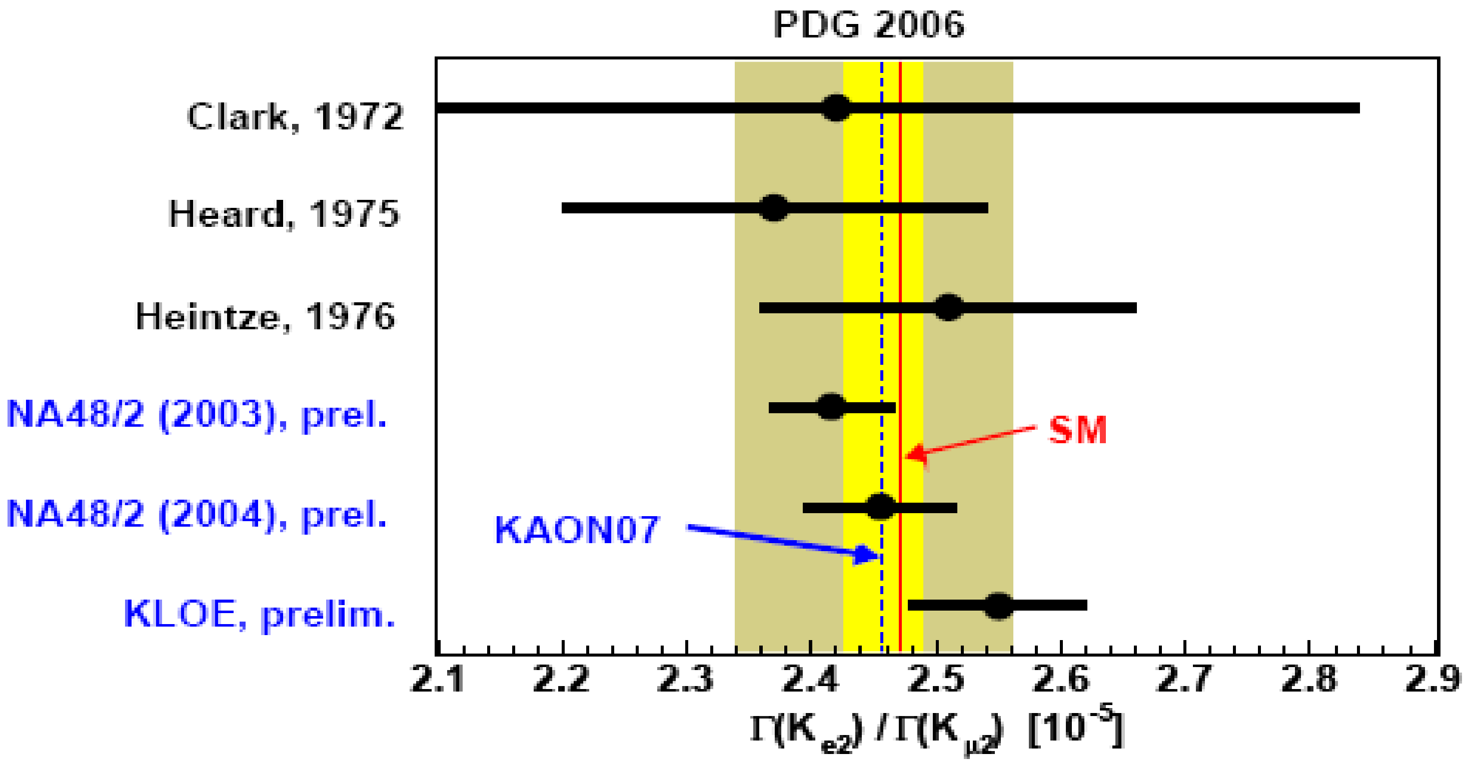
$$R_K = (2.55 \pm 0.05 \pm 0.05) \cdot 10^{-5}$$

$\delta R_K/R_K \sim 2.7\%$

target: 1%

Flavianet fit to R_K

The Flavianet group combined all these measurements



$$R_K = (2.457 \pm 0.032) \cdot 10^{-5} \qquad (\chi^2 / ndf = 2.44/3)$$

- ✓ Big improvement wrt PDG → now $\delta R_K / R_K \sim 1.3\ \%$
- ✓ Good agreement with SM prediction

The NA62 experiment

The NA62 collaboration borns from the previous NA48 experience

NA62 phase I :

measure of R_K with 0.5 % error using the NA48/2 exisiting apparatus

NA62 phase II:

construction of a new detector to measure the BR

$$K^+ \rightarrow \pi^+ \nu \bar{\nu}$$

B.R ~ 10^{-10} ; ~ 80 events in two years of D.T. S:B = 10:1

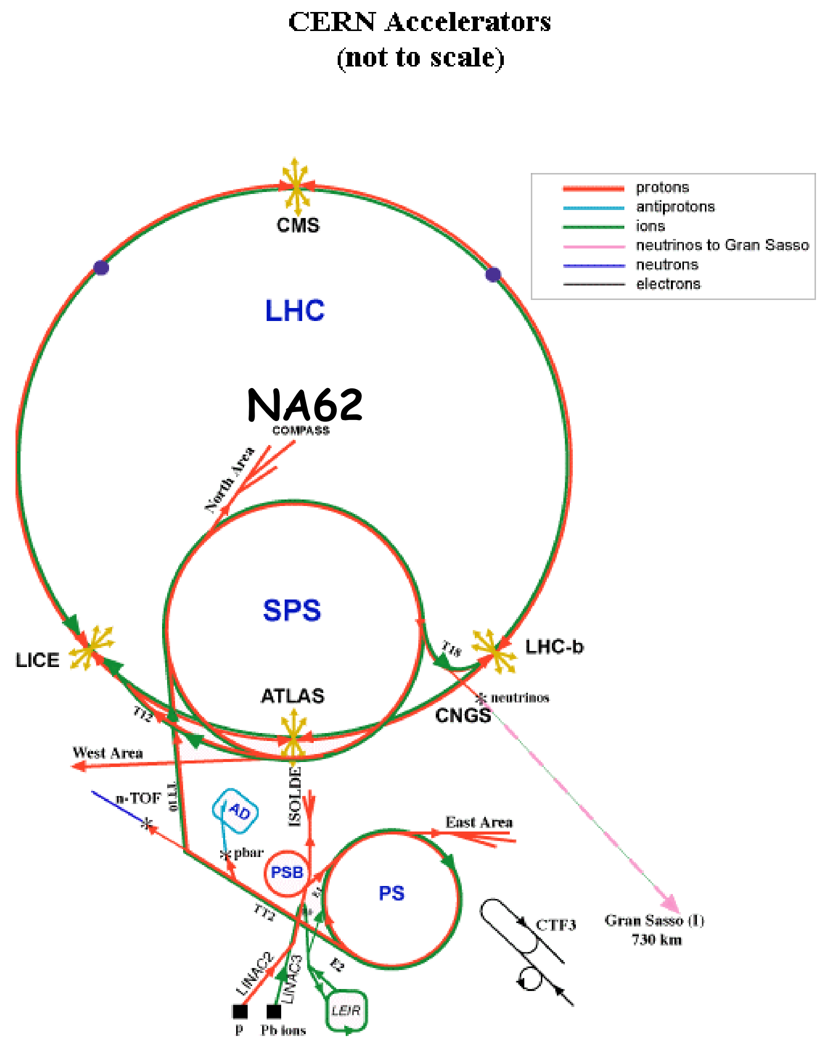
2008-2010 R&D & construction
2011 start of data taking

NA62 experiment

Located at the Nord Area of the CERN laboratory

Fixed Target: 400 MeV/c protons on Be target
high intensity K^{+-} 75 MeV/c momentum
Not separeted beam (K/π =8%)

K^+ and K^- can be provided simultaneously or individually



The NA62 detector (phase I)

sub set of NA48/2

Magnet spectrometer (4 DCHs):

4 view: redundancy ⇒ efficiency

$\sigma(p)/p = 0.47\% + 0.020\%\ p$ [GeV/c]

Charged Hodoscope:

two planes x-y, strip shaped counters

Fast trigger and good time resolution

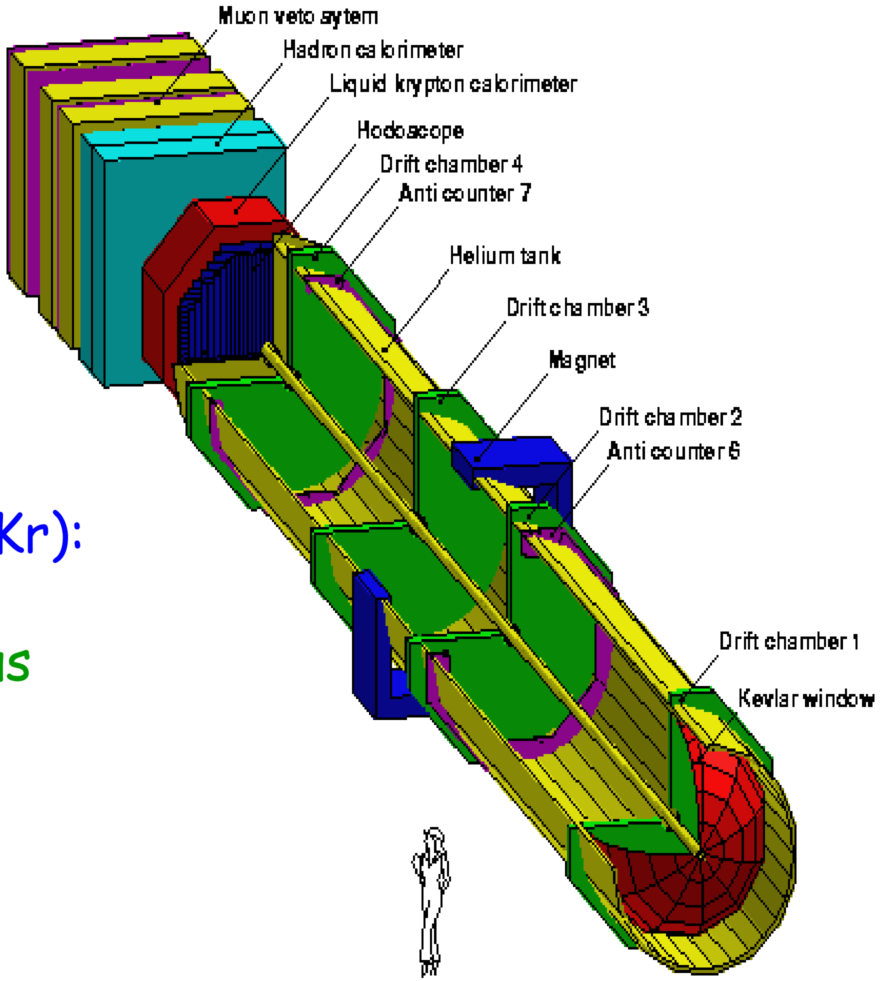
(~200ps on single track)

E.m. calorimeter with Liquid Krypton (LKr):

10 m^3 (~22 t), 1.25 m (27 X_0), 13212 cells

granularity:2x2 cm^2, quasi-homogeneous

$\sigma(E)/E = 3.2\%/\sqrt{E} + 9\%/E + 0.42\%$ [GeV]



~100 m long decay volume

The goal:
to measure R_K with an error better than 0.5%

This requires:

- A large data sample has to be collected (order 10^5)
- Control over the systematic effects, in particular background subtraction

We performed:

- Improvements of the run conditions respect to NA48/2 experience
- A 4 months data taking run, collecting $\sim 110 \times 10^3$ K_{e2} decays (summer 2007)
- special runs for the study of the background subtraction

Analysis strategy

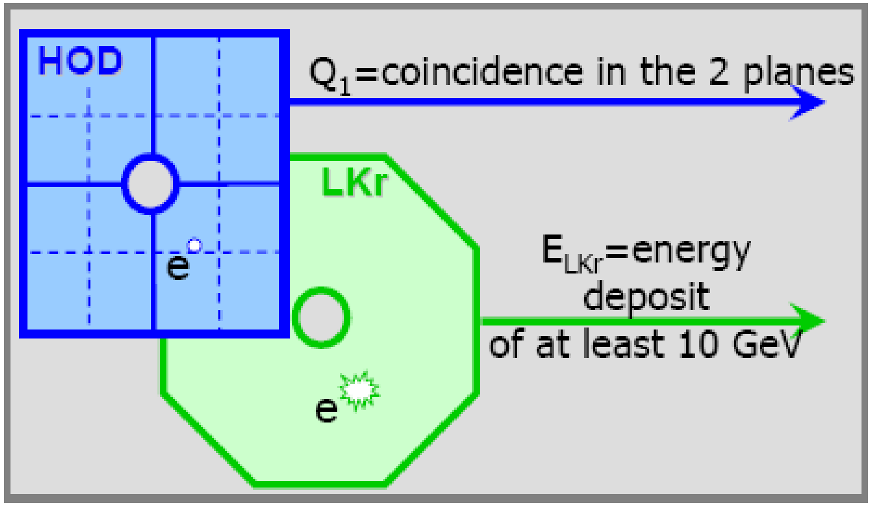
$$R_K = \frac{N(K_{e2}) - N_B(K_{e2})}{N(K_{\mu 2}) - N_B(K_{\mu 2})} \cdot \frac{1}{D} \frac{A(K_{\mu 2}) \times f_\mu \times \varepsilon(K_{\mu 2})}{A(K_{e2}) \times f_e \times \varepsilon(K_{e2})}$$

- $N(K_{e2})$, $N(K_{\mu 2})$: 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: measured particle ID efficiencies;
- $\varepsilon(K_{e2})/\varepsilon(K_{\mu 2})$: E_{LKr} trigger condition efficiency
- D: trigger downscaling

- K_{e2} and $K_{\mu 2}$ collected simultaneously

  ➡ fluxes cancel in the ratio
- Many time-dependent systematic effects also cancel
- The main contribution to systematic error comes from background subtraction (stat. dependent)
- RK measured in bins of track momentum

Trigger



Many improvements during data taking to increase the number of K_{e2} collected:

1) Drift chambers multiplicity (1TRK)
2) Optimization of trigger downscaling
3) Beam steering
4) Removal of the lead wall

Trigger	Condition		Rates/SPS spill		Purity	
	Start-up	End-of-run	Start-up	End-of-run	Start-up	End-of-run
K_{e2}	$Q_1 \times E_{LKr}$	$Q_1 \times E_{LKr} \times 1TRK$	0.23	0.54	0.6×10^{-5}	1.3×10^{-5}
$K_{\mu 2}$	$Q_1/50$	$Q_1 \times 1TRK/150$	290	160	1.8%	1.8%

- The $K_{\mu 2}$ trigger also used as control trigger for K_{e2} trigger
- Other minimum bias control triggers included
- Small trigger inefficiencies (~0.1%) directly measured from data

Signals selection

K_{e2} and $K_{\mu 2}$ decays similar→ set of common cuts

- 1 track events
- 15 < p < 50 GeV/c
- reconstructed decay vertex inside the fiducial decay region
- Geometrical acceptance

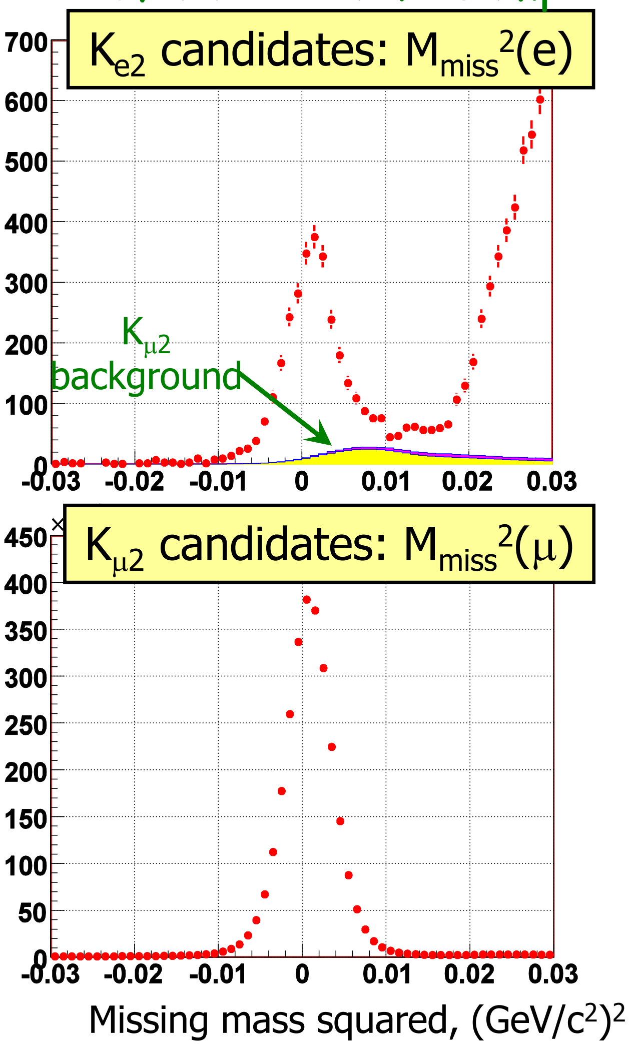
Kinematics:

- $M_{miss}^2 = (p_K - p_l)^2$, $-0.015 < M_{miss}^2 < 0.015$

Particle ID (E/p):

- e (0.95<E/p <1.05)
- μ (E/p < 0.2)

Express analysis:
~3% of the 2007 K^+ sample



Kaon beams

NA48/2 beam line: capable of delivering simultaneous K^+/K^- beams (75 GeV/c in 2007). K^+ only beam used for most of the run: lower beam halo background (1% vs 20%).

Kinematic ID of the K_{l2} candidates:

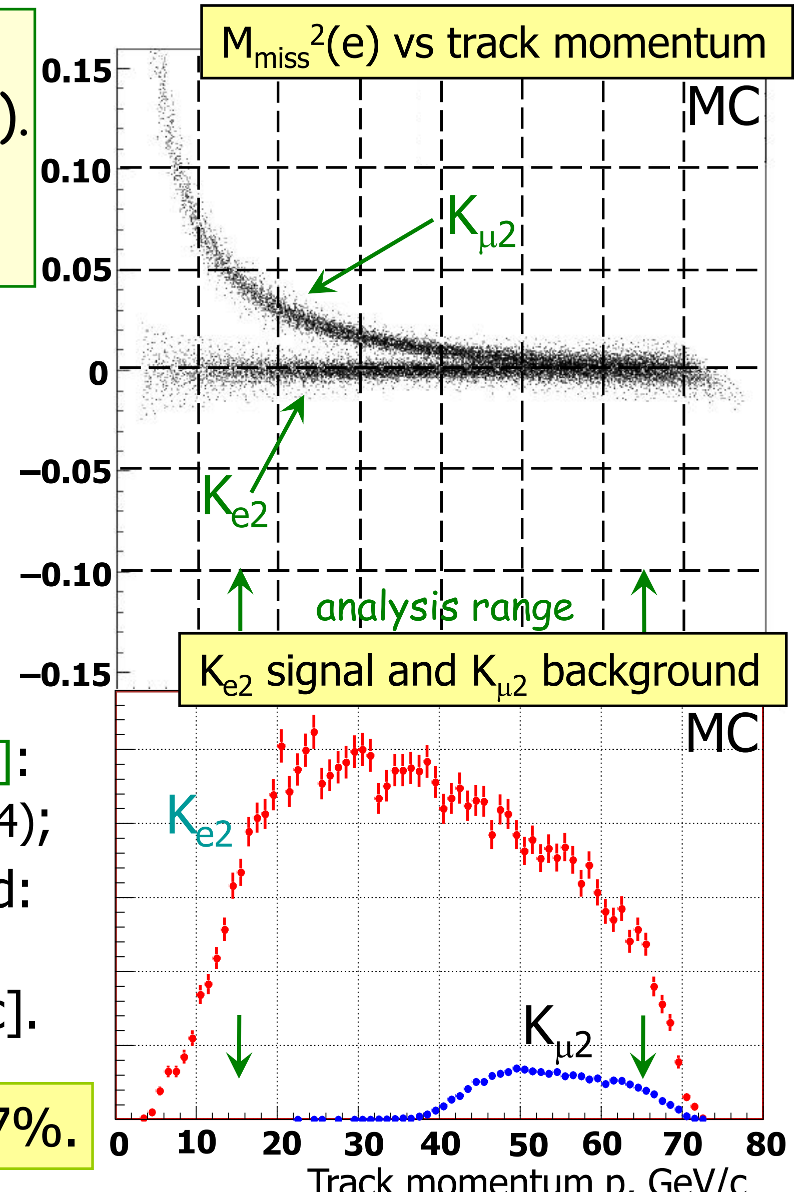
$$M_{miss}^2(l)=(P_K-P_l)^2$$

Poor $K_{e2}/K_{\mu2}$ separation at p_{track}>40GeV/c

Optimization of M_{miss}^2 resolution:

- P_K [M_{miss} evaluated with measured beam average]: narrow band beams ($\Delta P_K/P_K$=2% vs 3% in 2003-4);
- P_l: analyzing magnet momentum kick increased: 263MeV/c vs 120MeV/c in 2003-4, resolution $\delta p/p$ = 0.47%+0.020%p [p in GeV/c].

Expected $K_{\mu2}$ background in analysis region: 7%.



Background:

The M^2_{miss} fails to separate muons from electron for P > 40GeV/c

Particle identification needed: E(calorimeter)/P (spectrometer)

Electron identification relays on E/p:

$0.95 < E_{LKr}/p_{tr} < 1.05$

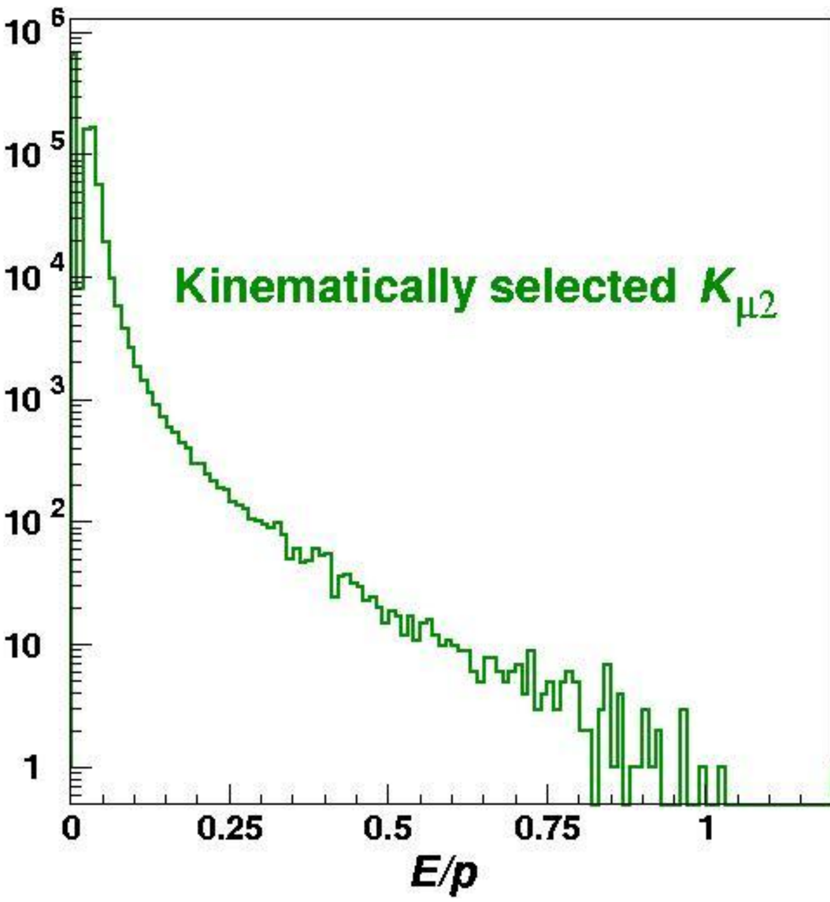
But:

A non-negligible fraction of muons has a catastrophic bremsstrahlung in the LKr

→ μ misidentified as electrons

$P(\mu \rightarrow e) \sim 4 \times 10^{-6}$, depending from p (according to bremsstrahlung cross section)

Main source of background !!



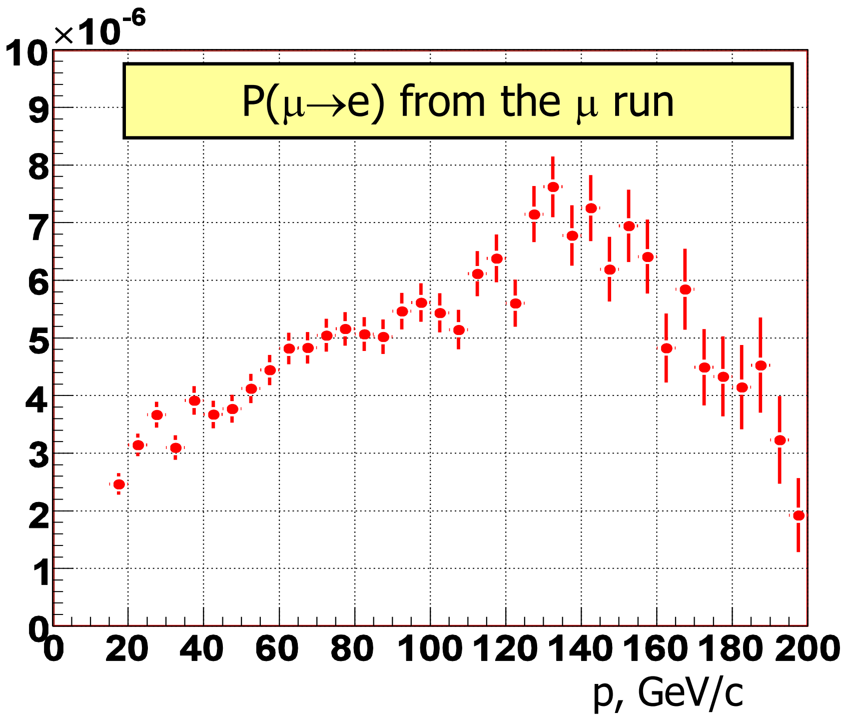
Background subtraction

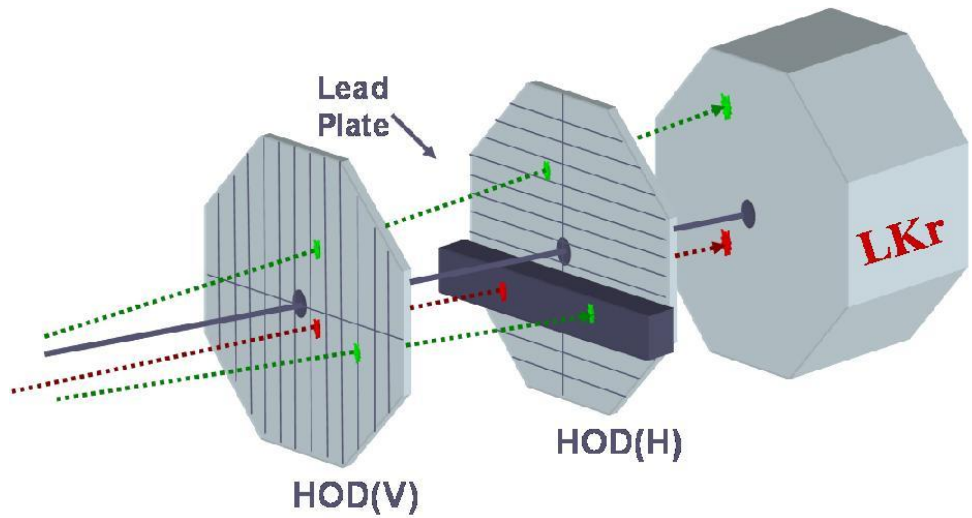
P(μ→e) can be measured directly from data:

pure muon samples available:

1) electron stopped by a lead wall
2) special muon runs
3) Kμν from standard data taking

Lead wall between the two hodoscopes planes just befor the LKr cal. to stop electrons and measure muon E/p response





Thickness: Pb(4.5cm)+Fe(2.0cm)
Width: 240cm (=HOD diameter)
Height: 18cm (=3 counters)
18% of geom. acceptance
Installed: ~50% of running time

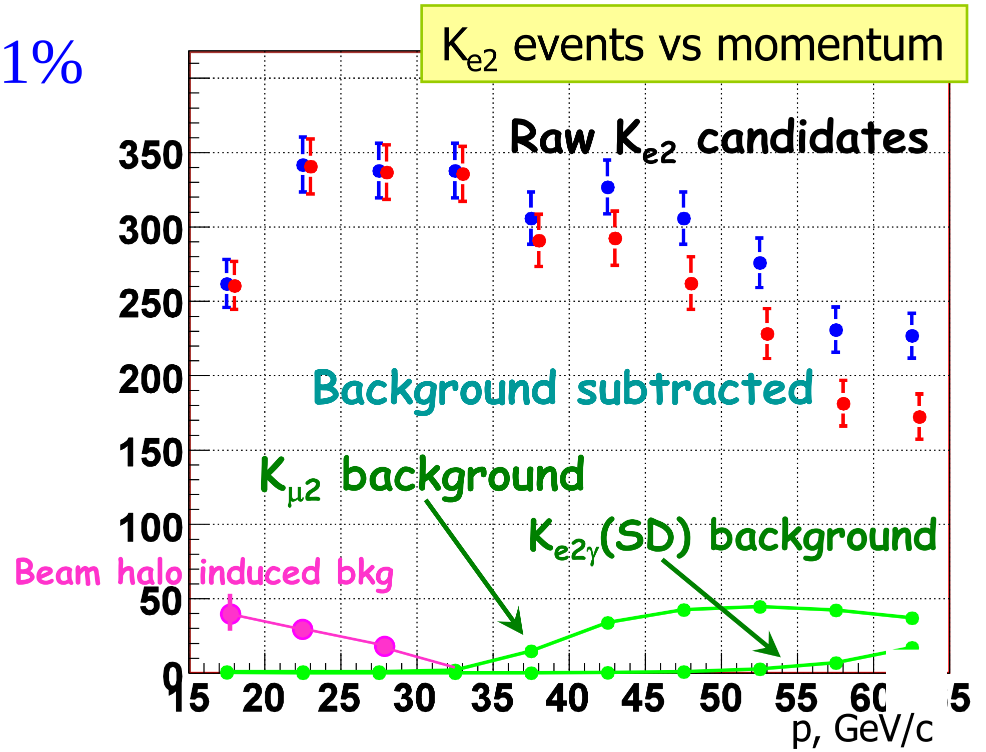
Background summary

K_{e2} sample

1) $K_{\mu2}$: Evaluated with the direct measurement of P(μ→e)
2) Beam halo: (1.3 ±0.1)% estimated with K-less runs
3) $K_{e2\gamma}$ (SD): Evaluated from MC: (0.7 ±0.1)%
4) K_{e3}: Evaluated with MC: < 1%
5) $K^+ \rightarrow \pi^+\pi^0$:Evaluat. with MC: <1%

$K_{\mu2}$ sample

1) Beam halo ~ 0.1%
2) $K^+ \rightarrow \pi^+\pi^0$ < 0.5%



Identification efficiencies

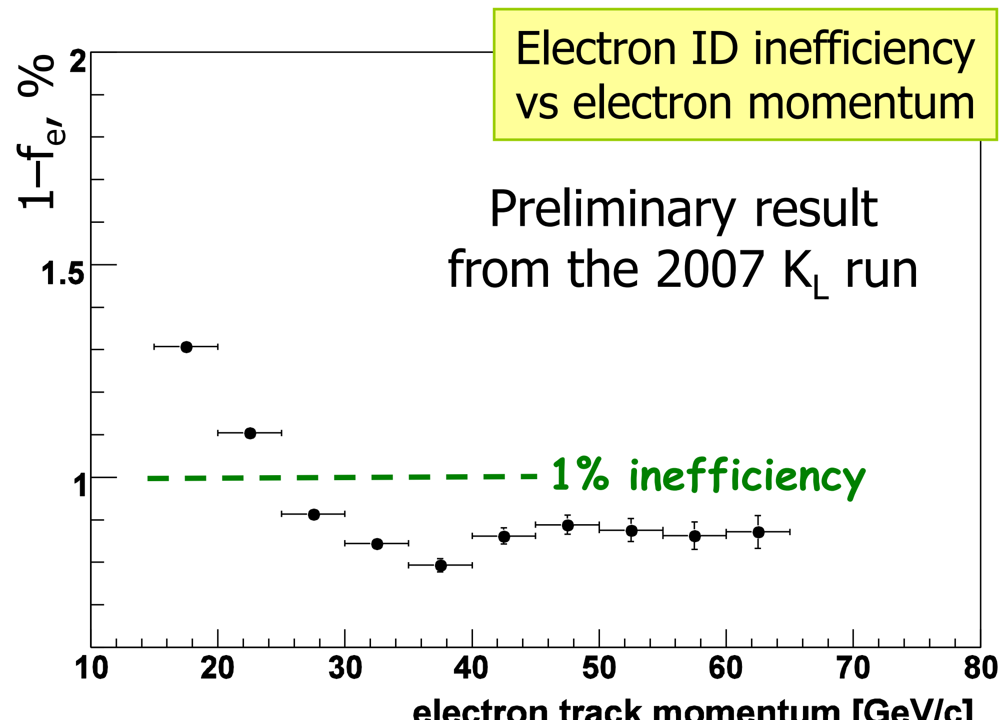
Electron ID efficiency f_e can be measured from the data:

- clean sample of electrons by kinematic selection of $K^{\pm}\to\pi^0 e^{\pm}\nu$ decays: collected simultaneously with main data taking, but p<50GeV/c.
- special 15h K_L run: kinematic selection of $K_L\to\pi^{\pm}e^{\pm}\nu$ decays in the whole analysis track momentum range 15GeV/c<p<65GeV/c.

Expected precision of f_e measurement: better than 0.1%.

Muon ID efficiency f_μ:

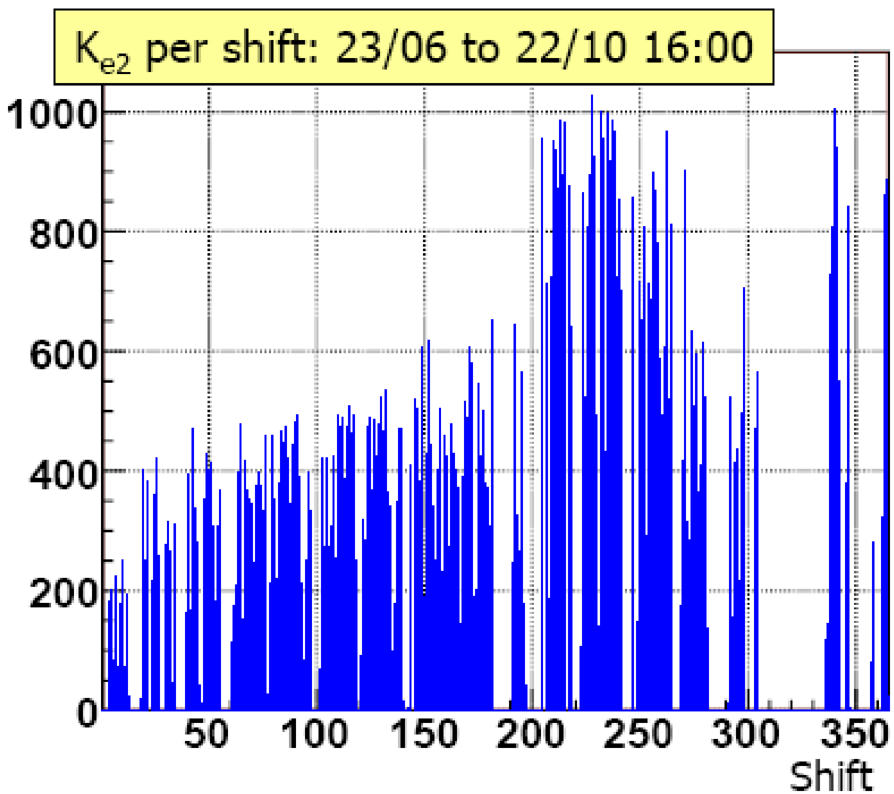
- ID by LKr energy deposit: E/p<0.2
- Measurement with clean muon samples
- f_μ preliminarily measured to be in the range 0.996–0.999 in analysis p region;
- Expected uncertainty: δf_μ<0.1%.

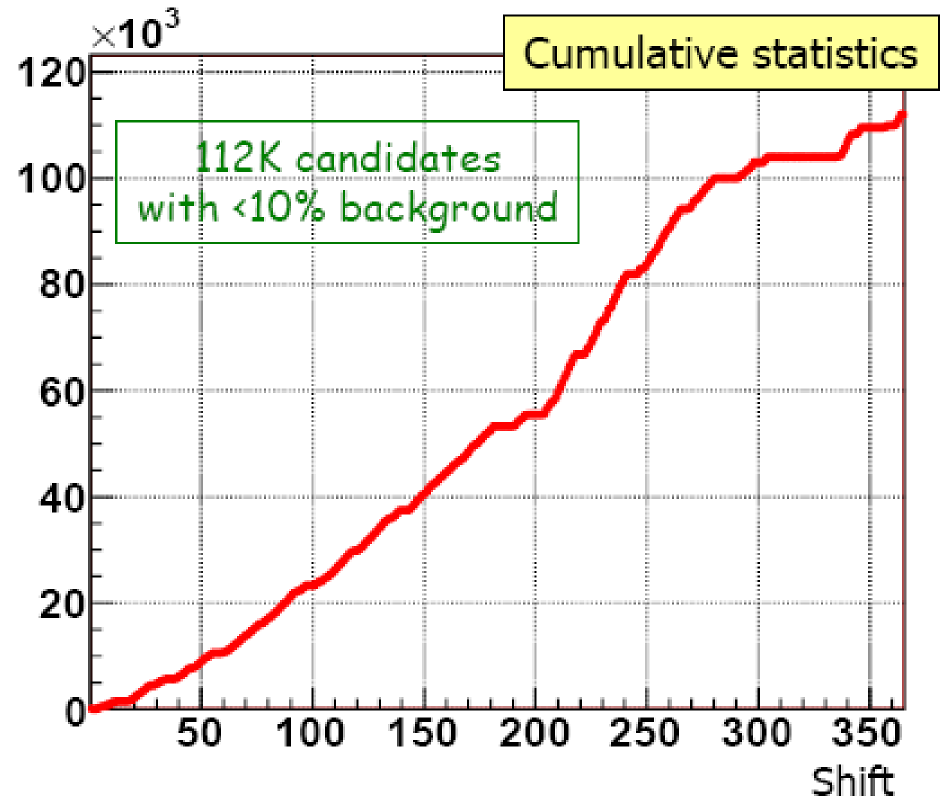


Data collected

Data taking period: from June, 23th to October,22th in 2007

112×10^3 candidates selected, background < 10%





Statistical error on R_K ~ 0.3%, total error < 0.5 %

CONCLUSIONS

- The ratio R_K is an exceptional probe for LVF beyond SM
- New measurements in the last few years have improved δR_K (1.3% FlaviaNet fit)
- *A* sub-% measurement is a tight SM test
- NA62 successfully completed a 4 month long run , >100k K_{e2} collected (largest sample)
- main sytematic effects under control and directly measured from data
- < 0.5% $\delta R_K/R_K$ achievable

analysis work is in progress

results coming soon...