BEACH 2010
IX International Conference on Hyperons, Charm and Beauty Hadrons

Lepton Universality Tests with Leptonic Kaon Decays

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on behalf of the CERN NA62 collaboration

(Birmingham, Bratislava, CERN, Dubna, Fairfax, Ferrara, Firenze, Frascati, Liverpool, Louvain, Mainz, Merced, INR Moscow, Napoli, Perugia, Pisa, IHEP Protvino, Roma I, Roma II, Saclay, San Luis Potosí, SLAC, Sofia, Torino, TRIUMF)

Outline:

1) Purely leptonic meson decays as a SM testing ground
2) New R_K=BR($K\to e\nu$)/BR($K\to\mu\nu$) measurement by CERN NA62
3) The KLOE R_K measurement and the world average
4) Conclusions

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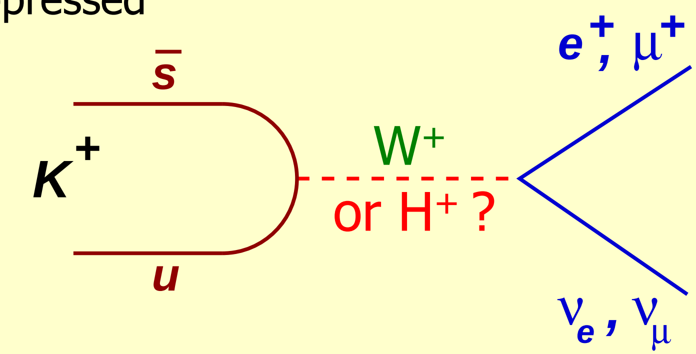
Leptonic meson decays: a SM testing ground

Leptonic meson decays: $P^+ \to l^+ \nu$

Angular momentum conservation → SM contribution is suppressed

$$\Gamma(P^+ \to l^+\nu) = \frac{G_F^2 M_P M_l^2}{8\pi}\left(1 - \frac{M_l^2}{M_P^2}\right)^2 f_P^2 |V_{qq'}|^2$$



Models with 2 Higgs doublets (2HDM-II including SUSY): sizeable charged Higgs ($H^\pm$) exchange contributions

PRD48 (1993) 2342; Prog.Theor.Phys. 111 (2004) 295

(numerical examples for M_H=500GeV/c^2, $\tan\beta$ = 40)

$\pi^+\to l\nu$: $\Delta\Gamma/\Gamma_{SM} \approx -2(m_\pi/m_H)^2\, m_d/(m_u+m_d)\, \tan^2\beta \approx -2\times10^{-4}$

$K^+\to l\nu$: $\Delta\Gamma/\Gamma_{SM} \approx -2(m_K/m_H)^2 \tan^2\beta \approx -0.3\%$

$D^+_s\to l\nu$: $\Delta\Gamma/\Gamma_{SM} \approx -2(m_D/m_H)^2\, (m_s/m_c)\, \tan^2\beta \approx -0.4\%$

$B^+\to l\nu$: $\Delta\Gamma/\Gamma_{SM} \approx -2(m_B/m_H)^2 \tan^2\beta \approx -30\%$

$H^\pm$ exchange in $B^+\to\tau^+\nu$:

BaBar+Belle: $Br_{exp}(B\to\tau\nu)=(1.42\pm0.43)\times10^{-4}$

Standard Model: $Br_{SM}(B\to\tau\nu)=(1.33\pm0.23)\times10^{-4}$

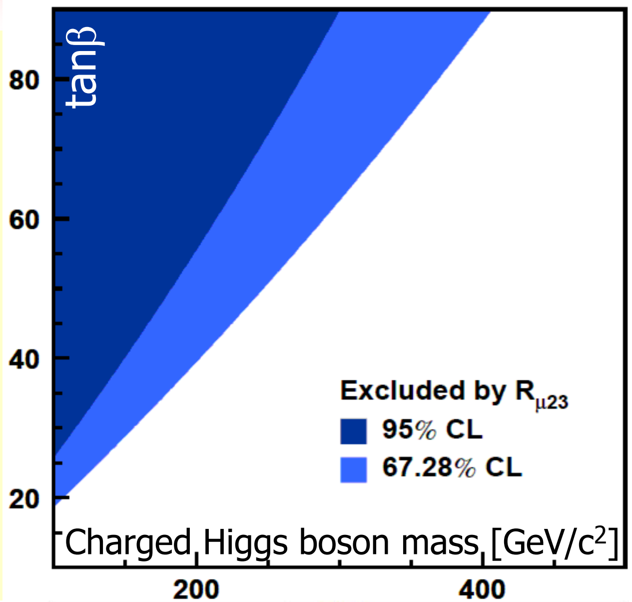
⇒ $\Delta\Gamma/\Gamma_{SM}=1.07\pm0.37$

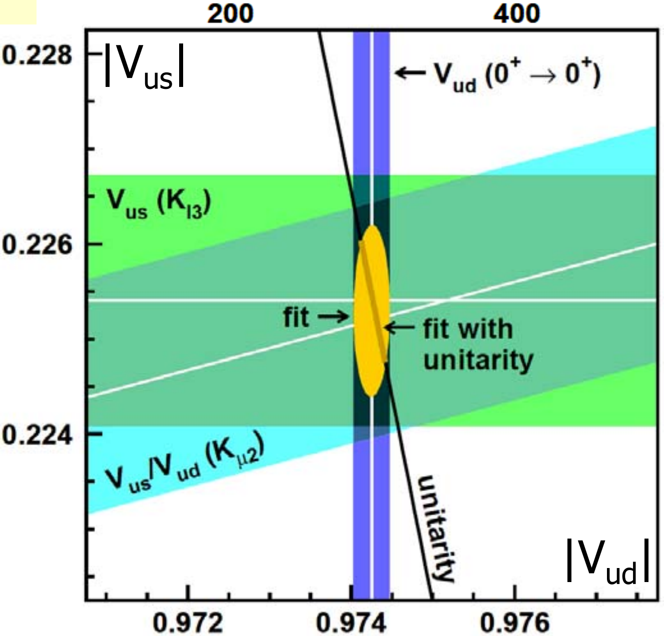
(SM uncertainties: $\delta(f_B^2)/f_B^2$=10%, $\delta|V_{ub}|^2/|V_{ub}|^2$=13%)

(JHEP 0811 (2008) 42)

Search for new physics is obstructed by hadronic uncertainties (f_p)

$H^{\pm}$ exchange in $K^+\to\mu^+\nu$





Comparison of $|V_{us}|$ determined from helicity suppressed $K^+\to\mu^+\nu$ decays vs helicity allowed $K^+\to\pi^0\mu^+\nu$ decays

To reduce the uncertainties of hadronic and EM corrections:

average from nuclear β decays, PRC79 (2009) 055502

$$R_{\mu 23} = \left(\frac{f_K/f_\pi}{f_+(0)}\right)^{-1} \left(\left|\frac{V_{us}}{V_{ud}}\right| \frac{f_K}{f_\pi}\right)_{\mu 2} \frac{|V_{ud}|_{0^+\to 0^+}}{[|V_{us}|f_+(0)]_{\ell 3}}$$

Lattice QCD input — Measured with $K_{\mu 2}/\pi_{\mu 2}$ — Measured with $K\to\pi\mu\nu$

Charged Higgs mediated contribution:

$$R_{\mu 23} \approx \left| 1 - \frac{m_{K^+}^2}{m_{H^+}^2} \frac{\tan^2\beta}{1+\epsilon_0 \tan\beta} \right|$$

Experiment: $R_{\mu 23} = 0.999(7)$,
$|V_{us}|^2+|V_{ud}|^2-1 = -0.0001(6)$.
Precision limited by lattice ICQ input.
(Flavianet Kaon WG, arXiv:1005.2323)

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

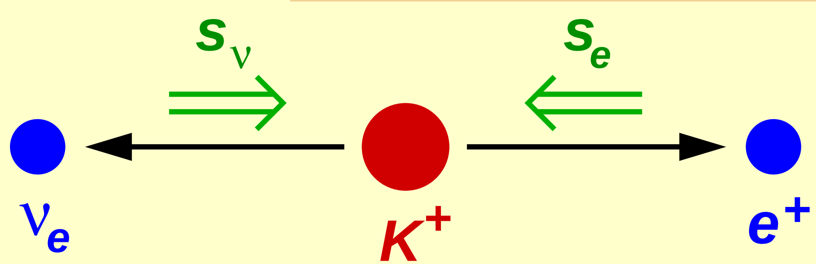
Observable sensitive to lepton flavour violation and its SM expectation:

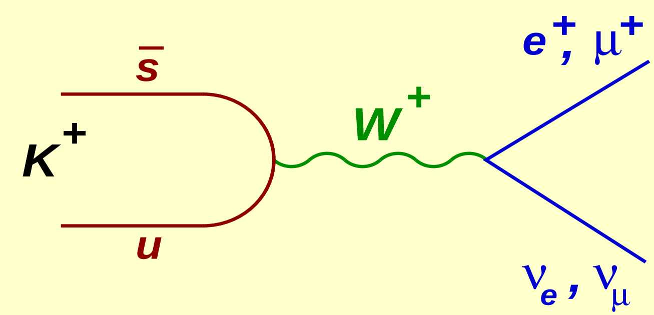
$$R_K = \frac{\Gamma(K^\pm \to e^\pm \nu)}{\Gamma(K^\pm \to \mu^\pm \nu)} = \frac{m_e^2}{m_\mu^2} \cdot \left(\frac{m_K^2 - m_e^2}{m_K^2 - m_\mu^2}\right)^2 \cdot (1 + \delta R_K^{rad.corr.})$$

(similarly, R_π in the pion sector)

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

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





- 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

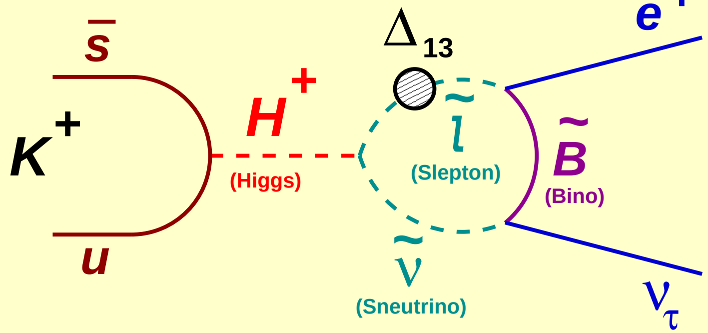
$R_K = K_{e2}/K_{\mu2}$ beyond the SM

2HDM – 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



2HDM – 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 $(M_B/M_K)^4 \sim 10^4$:

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

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

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

R_K & R_π: experimental status

Kaon experiments:

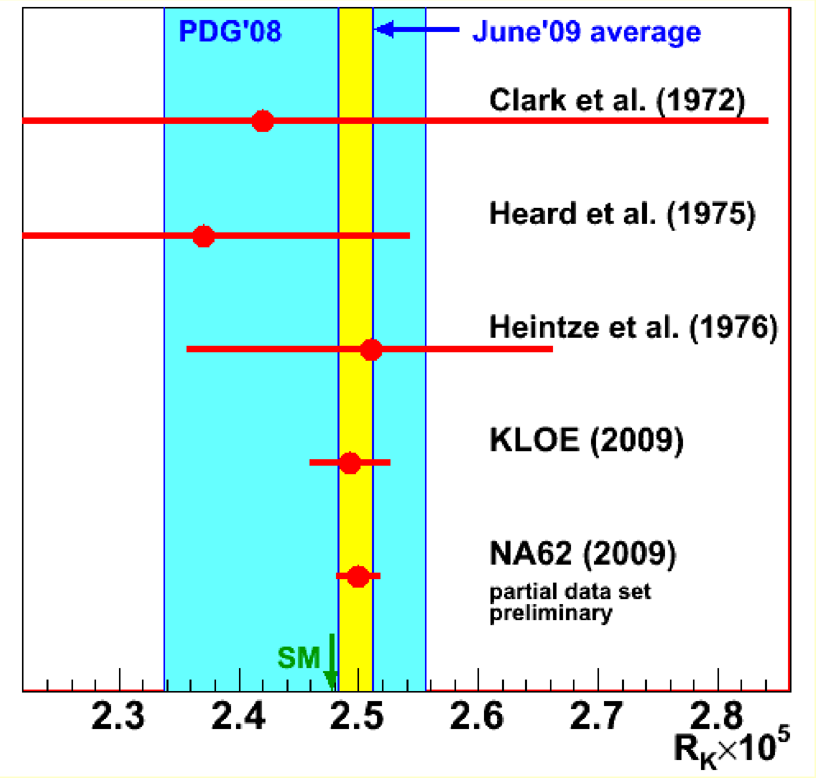
→ PDG'08 average (1970s measurements):
$R_K=(2.45\pm0.11)\times10^{-5}$ ($\delta R_K/R_K=4.5\%$).

→ 2009: KLOE (LNF), 2001–2005 data.
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)

→ 2009: NA62 (CERN), part of 2007 data.
preliminary result presented at Kaon'09:
51.1K K_{e2} candidates, $\delta R_K/R_K=0.7\%$.
(arXiv:0908.3858, 1005.1192)

→ Now: NA62 final result, same data set:
60.0K K_{e2} candidates, $\delta R_K/R_K=0.5\%$. (new!)

R_K world average (June 2009)



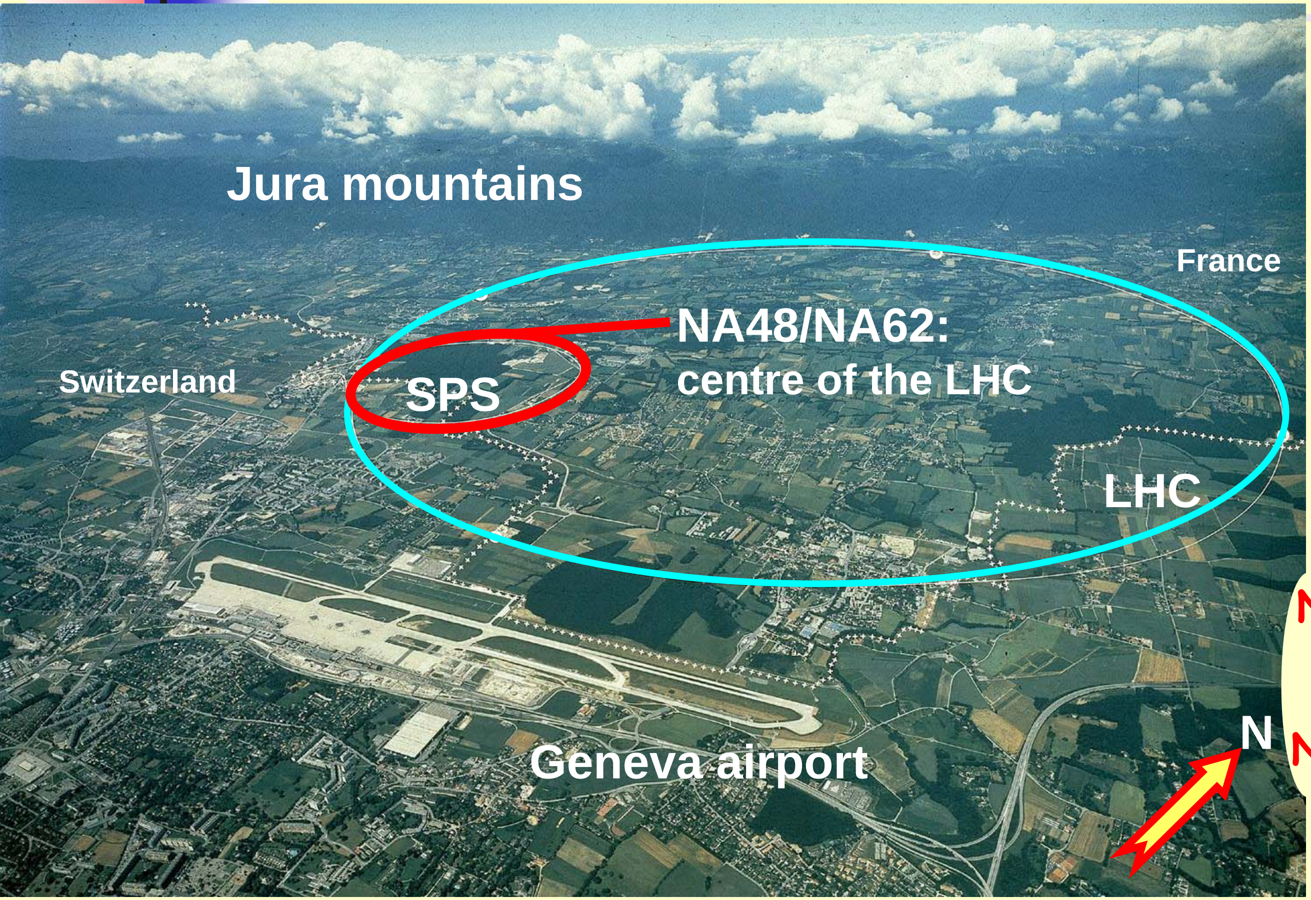
Pion experiments:

→ PDG'08 average (1980s, 90s measurements):
$R_\pi=(12.30\pm0.04)\times10^{-5}$ ($\delta R_\pi/R_\pi=0.3\%$)

→ Current projects: PEN@PSI (stopped π) running (CIPANP 2009; arXiv:0909.4358)
PIENU@TRIUMF (in-flight) proposed (T. Numao, PANIC'08 proceedings, p.874)
$\delta R_\pi/R_\pi\sim0.05\%$ foreseen (similar to SM precision)

The new R_K measurement by CERN NA62

NA48/NA62 at CERN



NA62 phase I: Bern ITP, Birmingham, CERN, Dubna, Fairfax, Ferrara, Firenze, Frascati, Mainz, Merced, Moscow INR, Napoli, Perugia, Pisa, IHEP Protvino Rome I, Rome II, Saclay, San Luis Potosí, SLAC, Sofia, Torino, TRIUMF

NA48 discovery of direct CPV
- 1997: ε'/ε: K_L+K_S
- 1998: K_L+K_S
- 1999: K_L+K_S | K_S HI
- 2000: K_L only | K_S HI
- 2001: K_L+K_S | K_S HI

NA48/1
- 2002: K_S/hyperons

NA48/2
- 2003: K^+/K^-
- 2004: K^+/K^-

NA62 (phase I)
- 2007: $K^{\pm}_{e2}/K^{\pm}_{\mu2}$ | tests
- 2008: $K^{\pm}_{e2}/K^{\pm}_{\mu2}$ | tests

NA62 (phase II) G.Ruggiero's talk
- 2007–2012: design & construction
- 2013–2015: $K^+\to\pi^+\nu\bar{\nu}$ data taking

Data taking 2007

Data taking conditions optimized for a precision $K_{e2}/K_{\mu 2}$ measurement: a low intensity run with a minimum bias trigger

View of the NA48/NA62 beamline (2003-2008)

Primary SPS protons (400 GeV/c): 1.8×10^{12}/SPS spill

Unseparated secondary positive beam: $p=(74.0\pm1.6)$ GeV/c.
Entrance to the 114m long vacuum decay volume:
2.5×10^{7} particles/SPS spill

Composition: $K^{+}(\pi^{+}) = 5\%(63\%)$.
K^{+} decaying in vacuum tank: 18%.

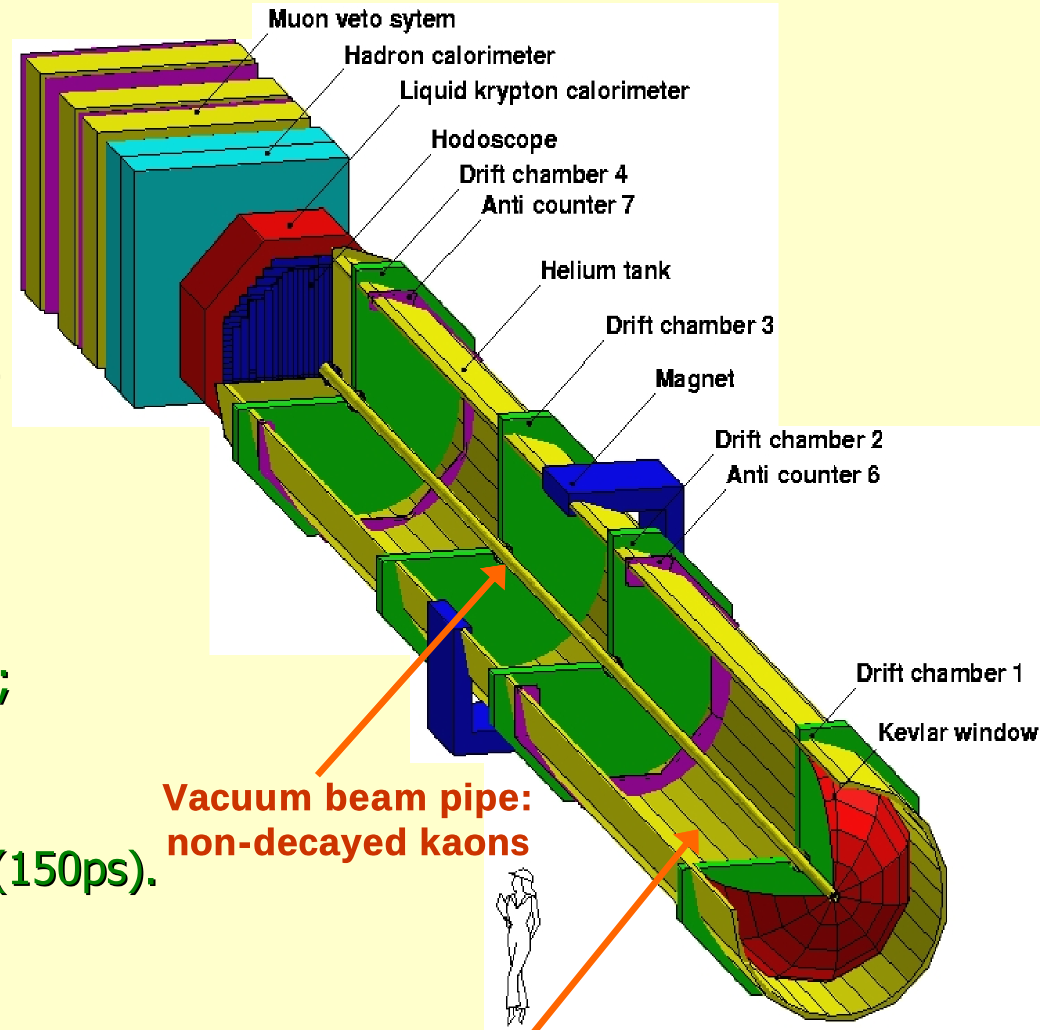
Detector

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 time 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) $K_{e2}/K_{\mu2}$ candidates are collected concurrently:

- analysis 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)

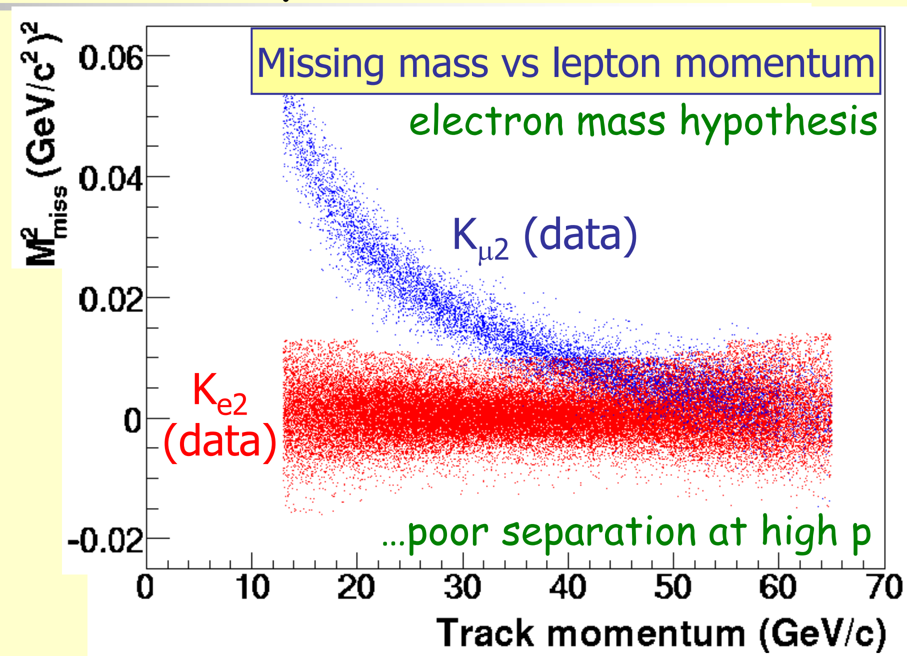
$$R_K = \frac{1}{D} \cdot \frac{N(K_{e2}) - N_B(K_{e2})}{N(K_{\mu2}) - N_B(K_{\mu2})} \cdot \frac{A(K_{\mu2}) \times f_\mu \times \varepsilon(K_{\mu2})}{A(K_{e2}) \times f_e \times \varepsilon(K_{e2})} \cdot \frac{1}{f_{LKr}}$$

$N(K_{e2})$, $N(K_{\mu2})$:	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;
$D=150$:	downscaling factor of the $K_{\mu2}$ trigger.

(3) MC simulations used to a limited extent:

- Geometrical part of the acceptance correction comes from simulation;
- PID, trigger, readout efficiencies are measured directly.

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



Large common part (topological similarity)

- one reconstructed track (lepton candidate);
- geometrical acceptance cuts;
- K decay vertex: closest approach of lepton track & nominal kaon axis;
- veto extra LKr energy deposition clusters;
- track momentum: 13GeV/c<p<65GeV/c.

Kinematic identification

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

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

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

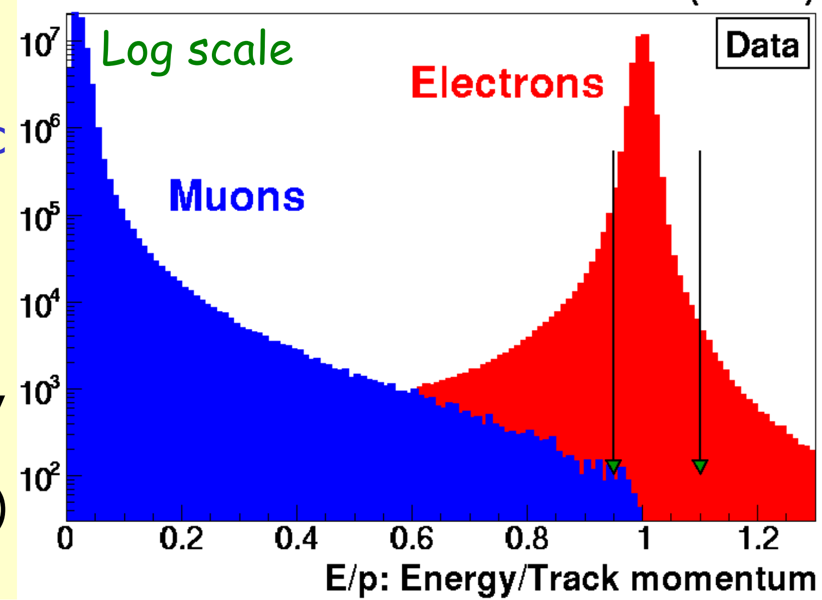
Lepton identification

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

(0.90 to 0.95)<E/p<1.10 for electrons,

E/p<0.85 for muons.

→ Powerful $\mu^{\pm}$ suppression in $e^{\pm}$ sample ($\sim 10^6$)



$K_{\mu 2}$ background in K_{e2} sample

Main background source

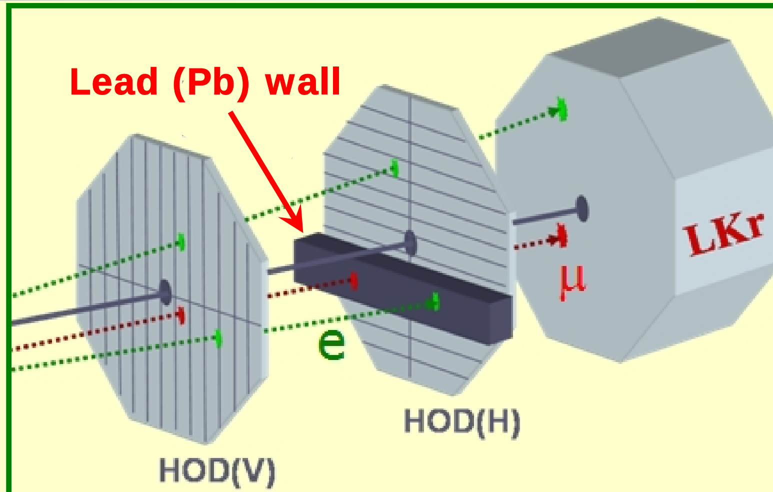
Muon "catastrophic" energy loss in LKr by emission of energetic bremsstrahlung photons. $P_{\mu e} \sim 3\times10^{-6}$ (and momentum-dependent).

$P_{\mu e} / R_K \sim 10\%$:
$K_{\mu 2}$ decays represent a major background

Direct measurement of $P_{\mu e}$

Pb wall ($9.2X_0$) in front of LKr: suppression of $\sim10^{-4}$ positron contamination due to $\mu\to e$ decay.

$K_{\mu 2}$ candidates, track traversing Pb, $p>30$GeV/c, $E/p>0.95$: positron contamination $<10^{-8}$.



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

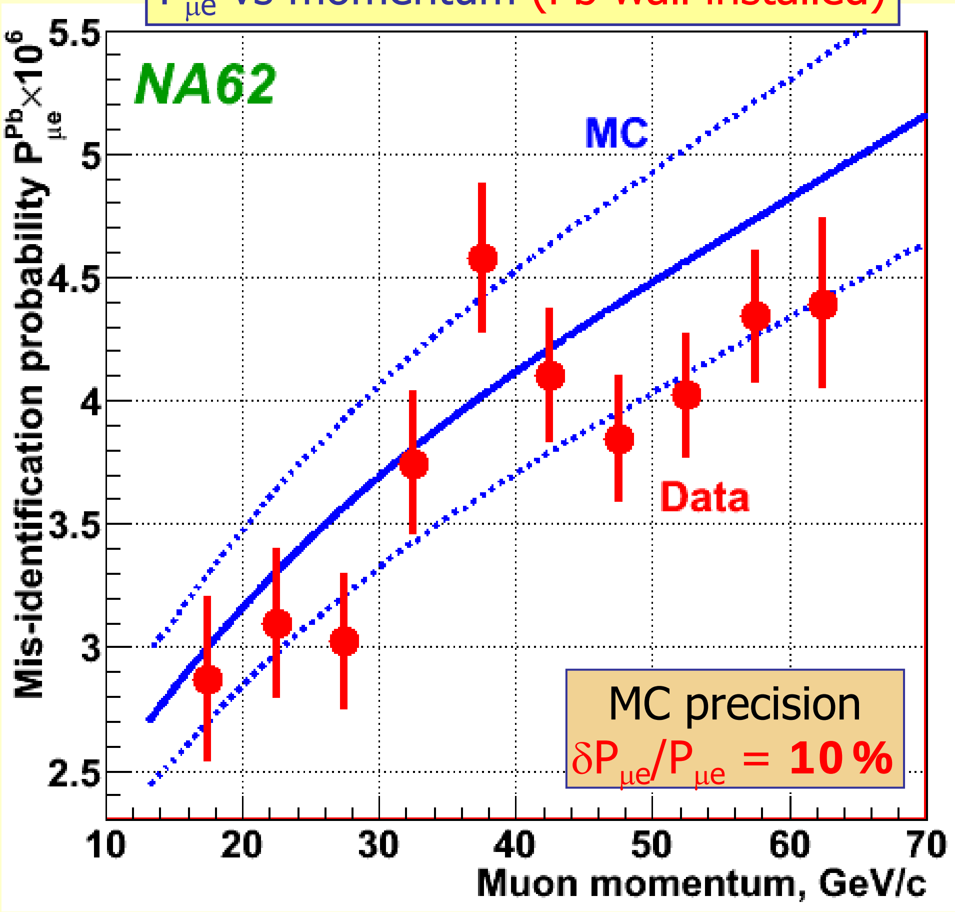
$P_{\mu e}$ is modified by the Pb wall:
→ ionization losses in Pb (low p);
→ bremsstrahlung in Pb (high p).

⇒ The correction $f_{Pb}=P_{\mu e}/P_{\mu e}^{Pb}$ is evaluated with a dedicated Geant4-based simulation

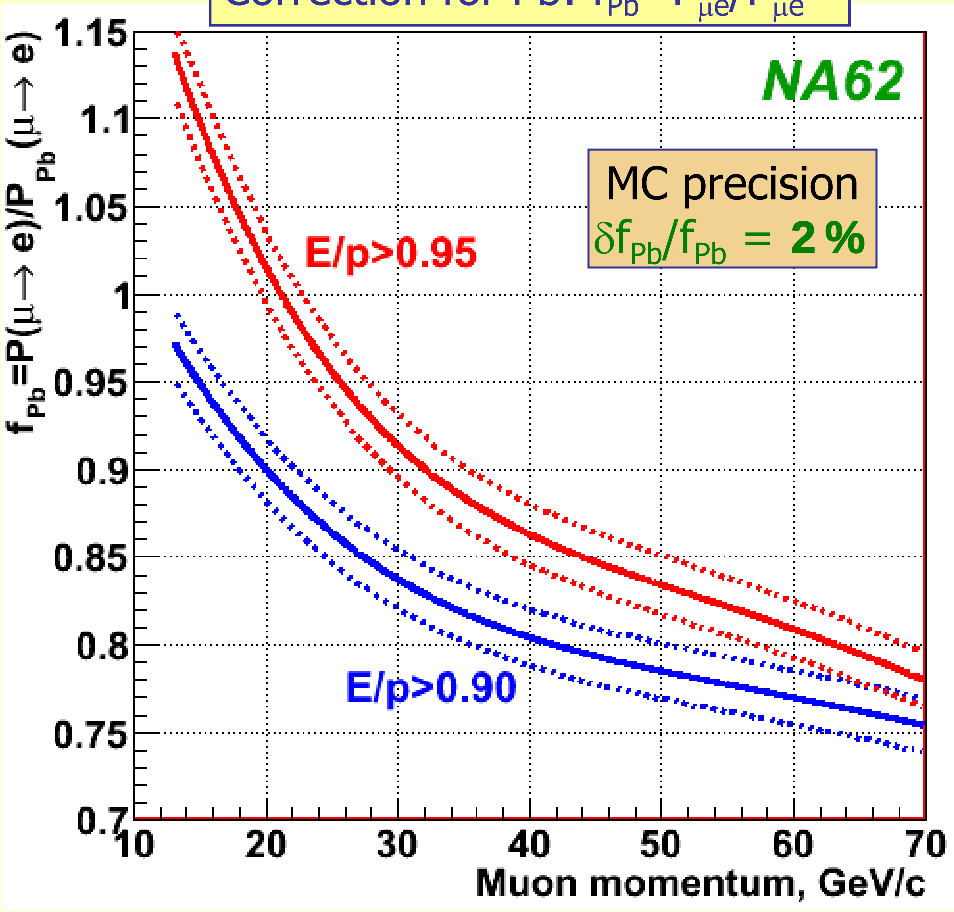
[Muon bremsttranlung: Phys. Atom. Nucl. 60 (1997) 576]

Muon mis-identification

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



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



Result: B/(S+B) = (6.10±0.22)%

Uncertainty is ~3 times smaller than the one obtained solely from simulation

Uncertainties

Limited data sample (0.16%);
MC correction (0.12%);
M^2_{miss} vs P_{track} correlation (0.08%).

$K_{\mu 2}$ 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

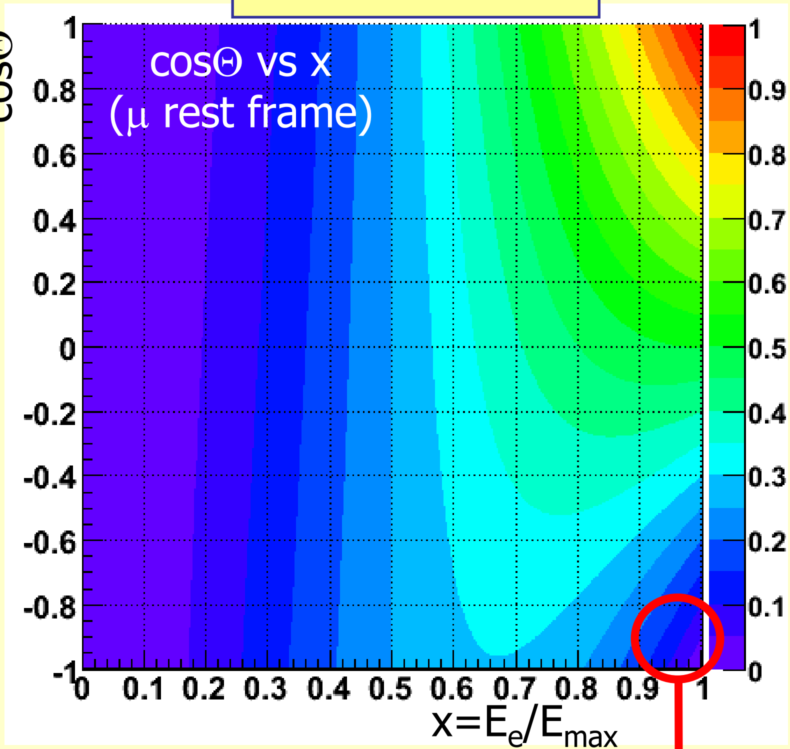
$$d^2\Gamma/dxd(\cos\Theta) \sim x^2[(3-2x) - \cos\Theta(1-2x)]$$

$x = E_e/E_{max} \approx 2E_e/M_\mu$,
Θ is the angle between p_e and the muon spin
(all quantities are defined in muon rest frame).

Result: $B/(S+B) = (0.27\pm0.04)\%$

Important but not dominant background

Michel distribution



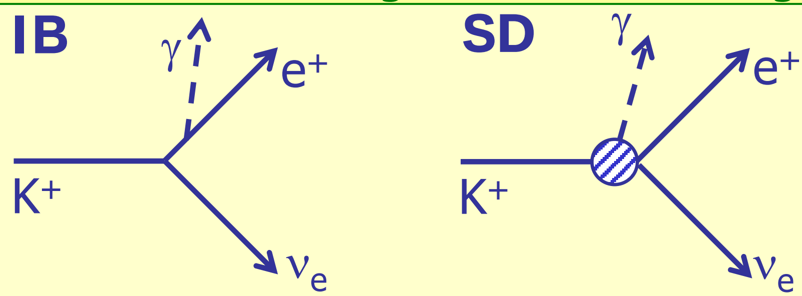
Only energetic forward positrons are selected as K_{e2} candidates

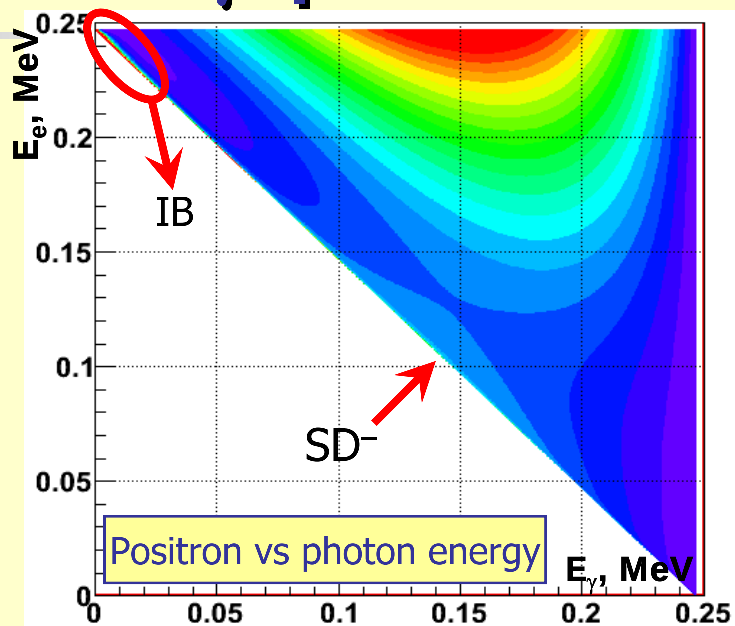
They are naturally suppressed by the muon polarisation

(radiative corrections provide another ~10% suppression)

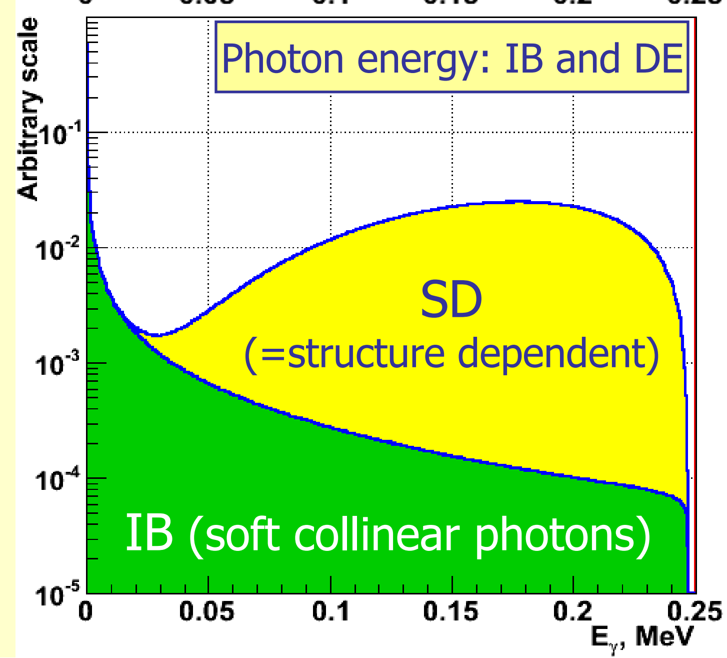
Radiative $K^+ \to e^+\nu\gamma$ process

R_K is inclusive of IB radiation by definition. SD radiation is a background. INT is negligible.





SD radiation is not helicity suppressed.
KLOE measurement of the form factor leads to
$BR(SD^+, \text{full phase space}) = (1.37\pm0.06)\times10^{-5}$.
(EPJC64 (2009) 627)



SD background contamination

$B/(S+B) = (1.15\pm0.17)\%$

Conservative uncertainty ($3\times\delta BR_{KLOE}$) to accommodate the observed R_K variation w.r.t the LKr veto selection condition.

A new $K_{e2\gamma}$ (SD^+) measurement is being performed by NA62.

Beam halo background

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

Background measurement:

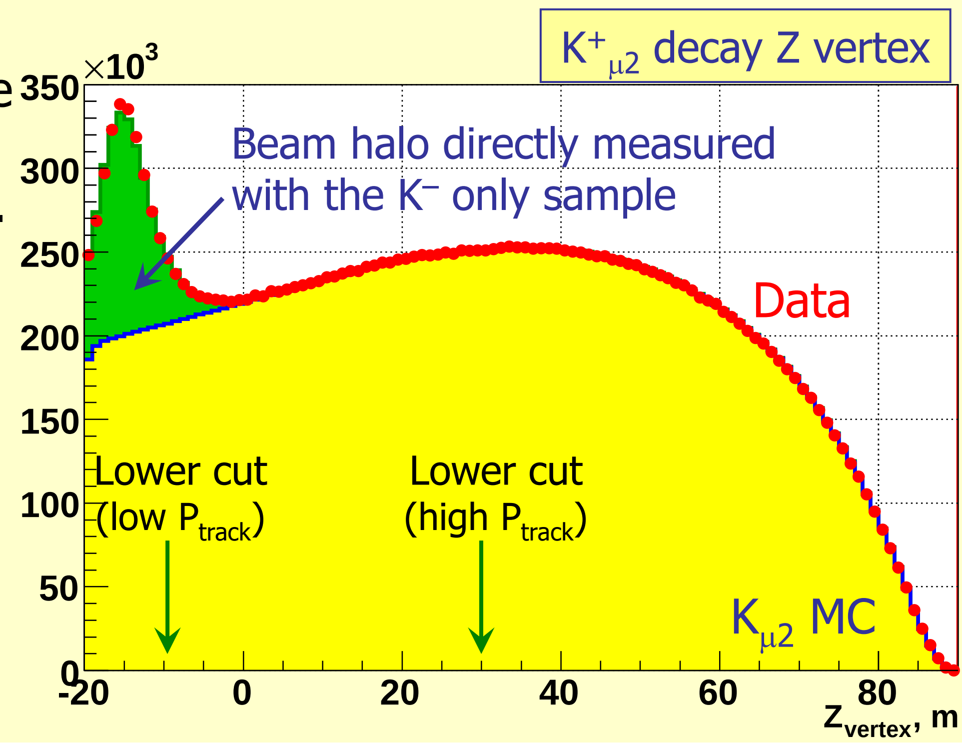
- Halo background much higher for K_{e2}^- (~20%) than for K_{e2}^+ (~1%).
- Halo background in the $K_{\mu 2}$ sample is considerably lower.
- ~90% of the data sample is K^+ only, ~10% is K^- only.
- K^+ halo component is measured directly with the K^- sample and vice versa.

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

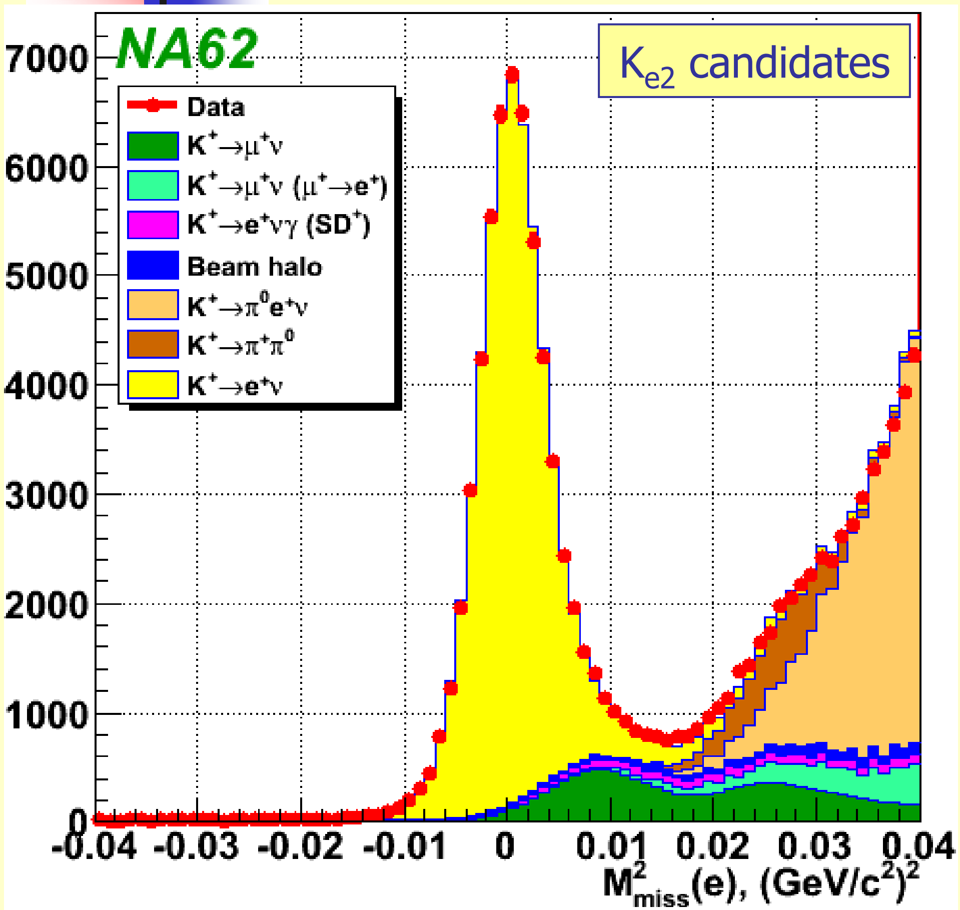
The selection criteria (esp. Z_{vertex}) are optimized to minimize the halo background.

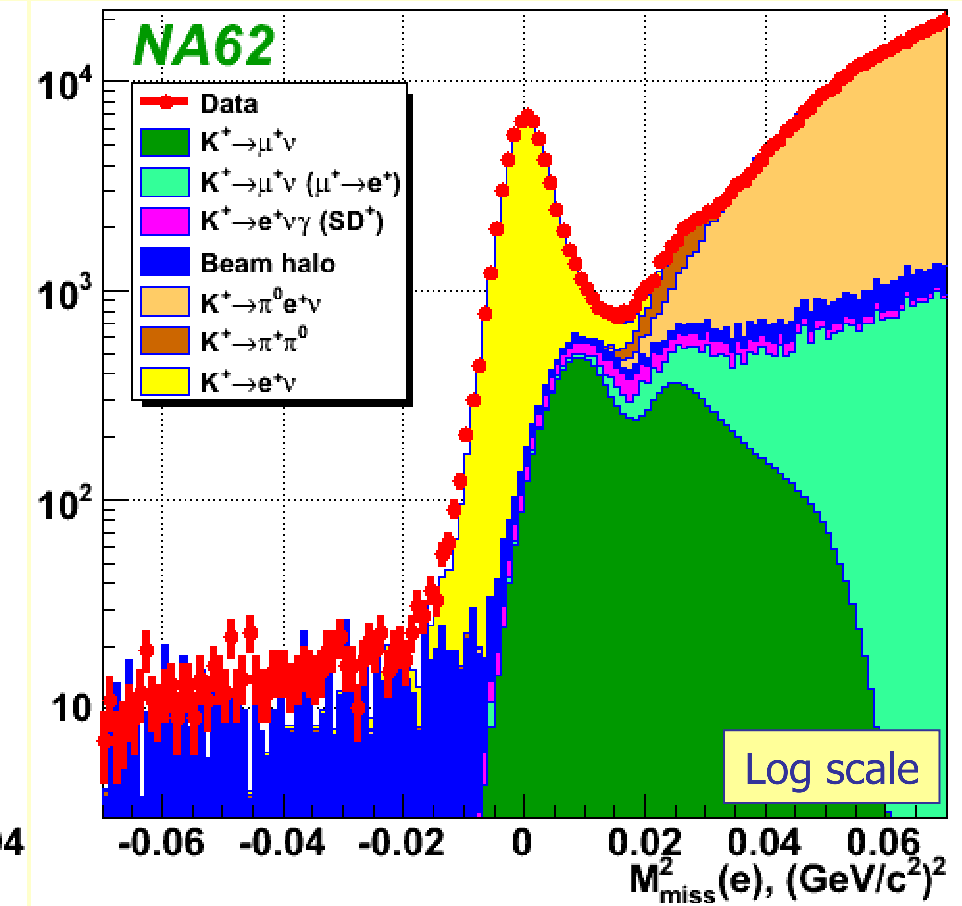
$$B/(S+B) = (1.14 \pm 0.06)\%$$

Uncertainty:
1) limited size of control sample;
2) π, K decays upstream vacuum tank.



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





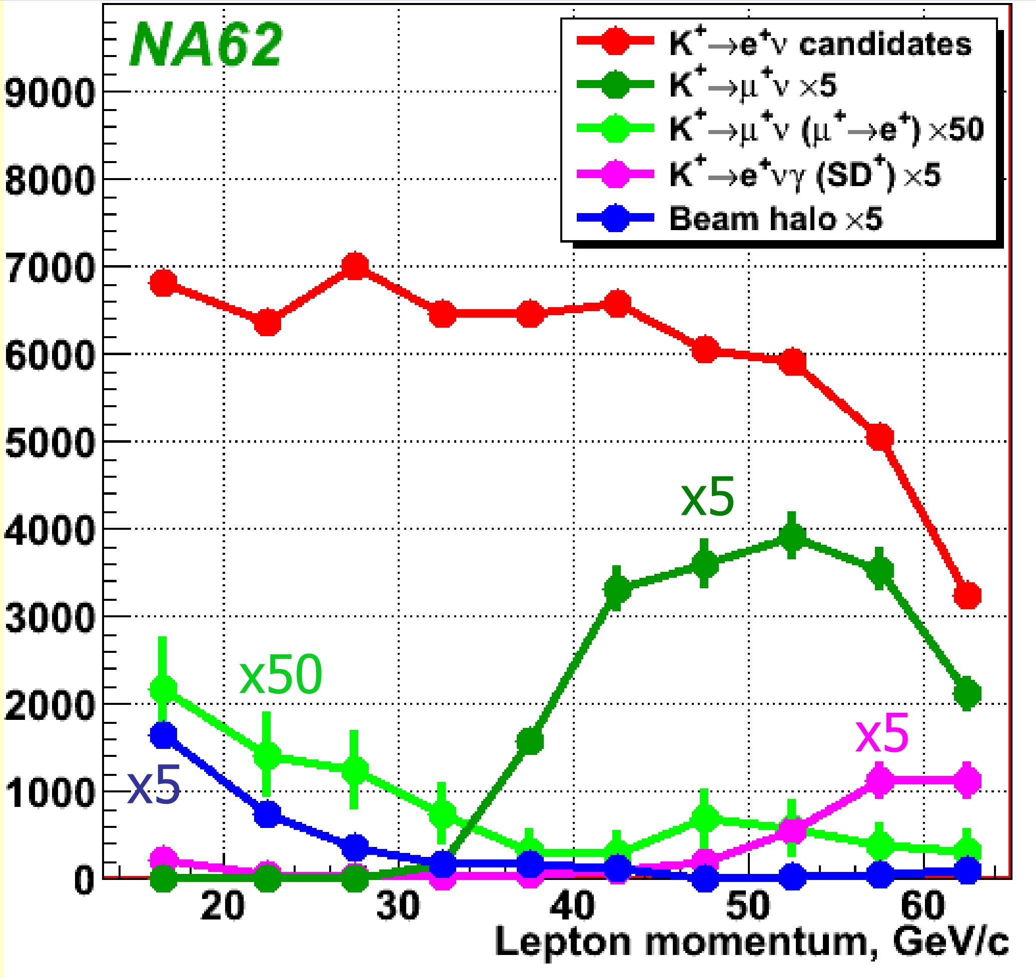
59,963 $K^+\to e^+\nu$ candidates.
Positron ID efficiency: (99.27±0.05)%.
B/(S+B) = (8.8±0.3)%.

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

NA62 estimated total K_{e2} sample:
~130K K^+ & ~20K K^- candidates.
Proposal (CERN-SPSC-2006-033):
150K candidates

Backgrounds: summary

K_{e2} candidates and backgrounds in momentum bins



(selection criteria optimized individually in each P_{track} bin)

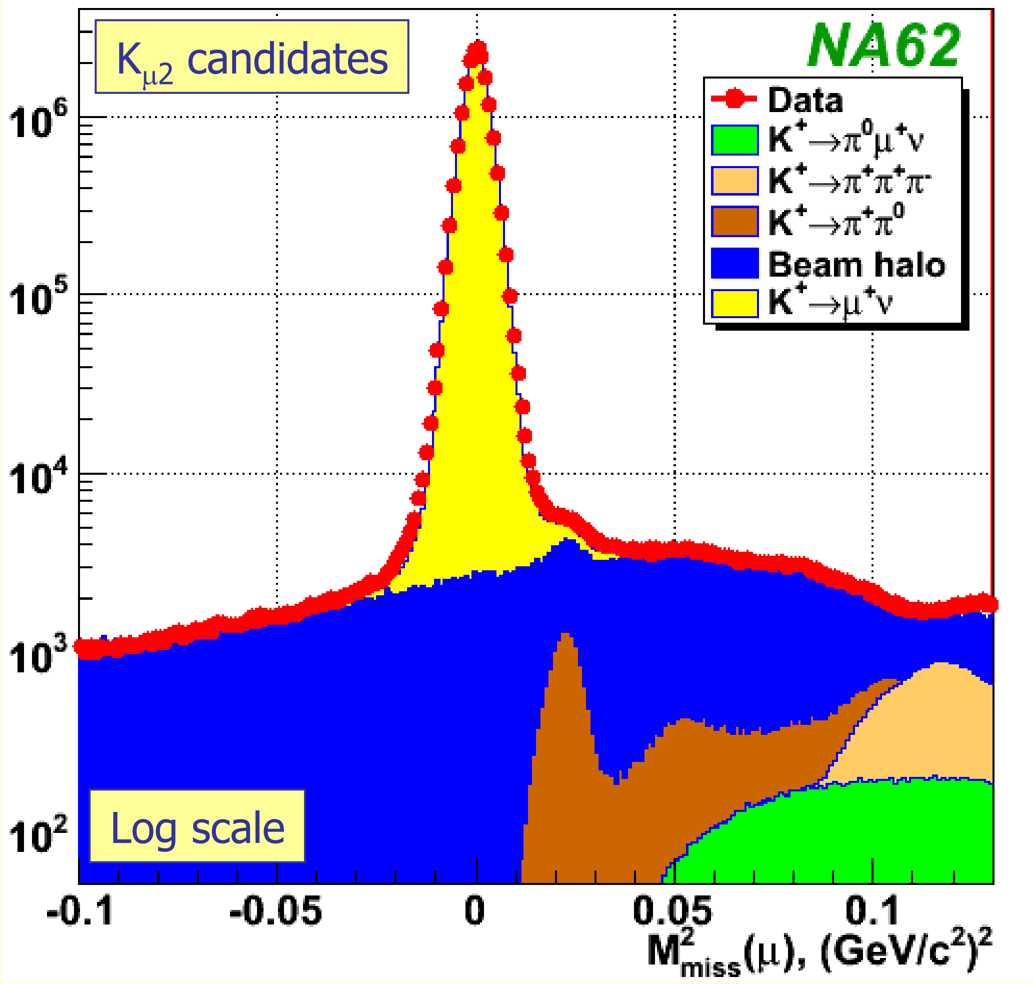
Backgrounds

Source	B/(S+B)
$K_{\mu2}$	$(6.10\pm0.22)\%$
$K_{\mu2}$ $(\mu\to e)$	$(0.27\pm0.04)\%$
$K_{e2\gamma}$ (SD^+)	$(1.15\pm0.17)\%$
Beam halo	$(1.14\pm0.06)\%$
$K_{e3(D)}$	$(0.06\pm0.01)\%$
$K_{2\pi(D)}$	$(0.06\pm0.01)\%$
Total	$(8.78\pm0.29)\%$

Record K_{e2} sample:
59,963 candidates
with low background
$B/(S+B) = (8.8\pm0.3)\%$

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

$K_{\mu 2}$: partial (40%) data set



Backgrounds

Source	B/(S+B)
Beam halo	$(0.38\pm0.01)\%$
Total	$(0.38\pm0.01)\%$

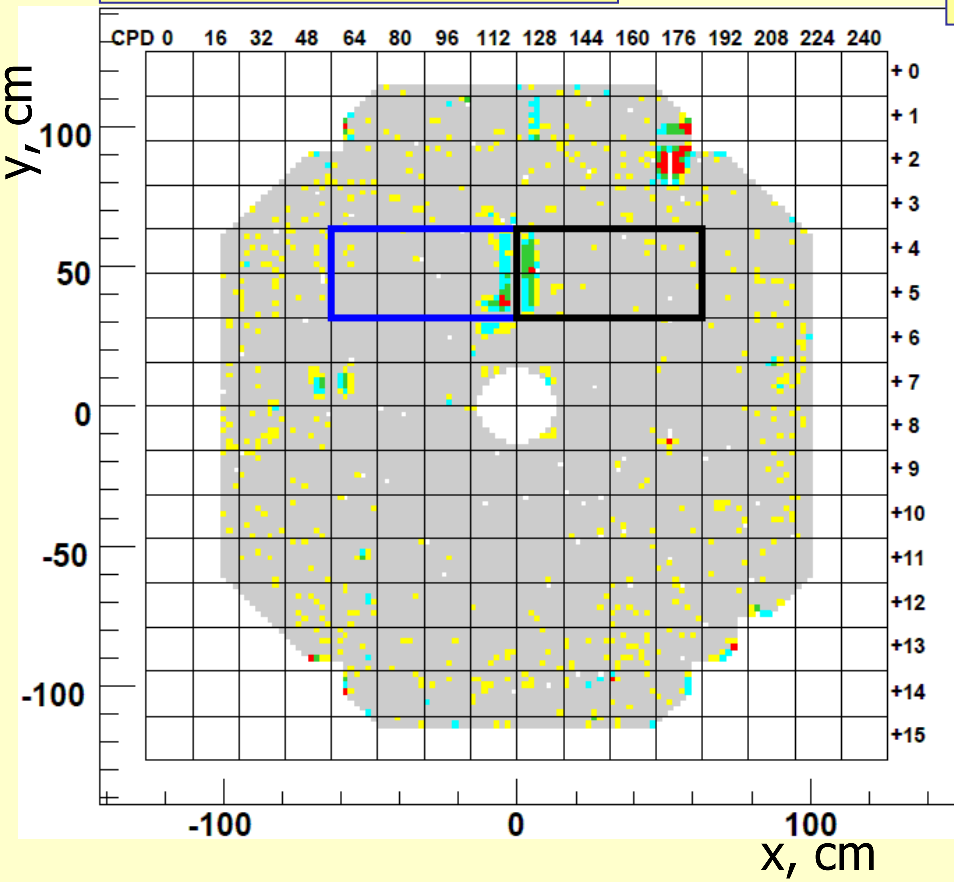
18.030 M candidates with low background B/(S+B) = 0.38%

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

Systematic effect: positron ID

A typical inefficiency map

LKr energy response is calibrated
for every 2×2cm² cell within acceptance

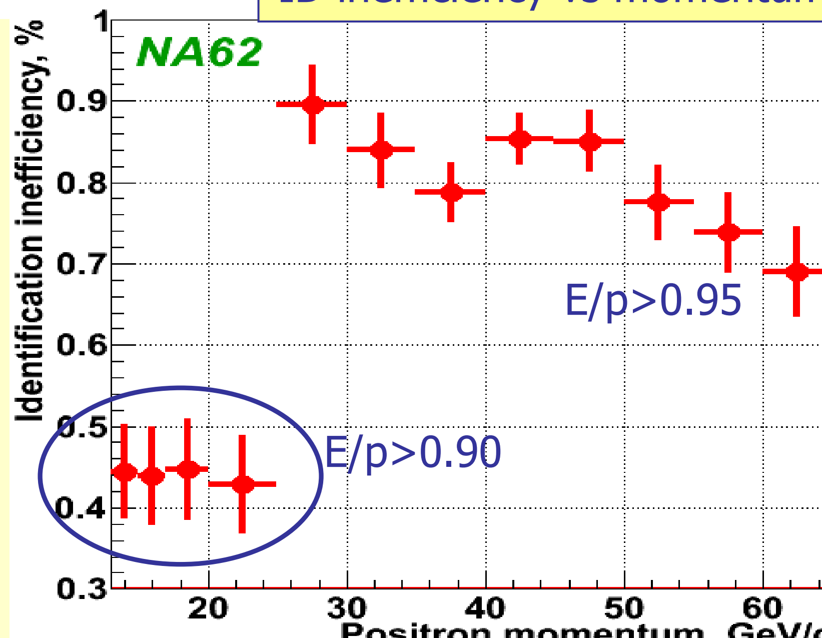


Colour code

- Ineff < 1.2%
- Ineff = (1.2 - 2)%
- Ineff = (2.0-4.0)%
- Ineff = (4.0-10)%
- Ineff > 10%

(an effect of a loose cable is visible in this map)

ID inefficiency vs momentum

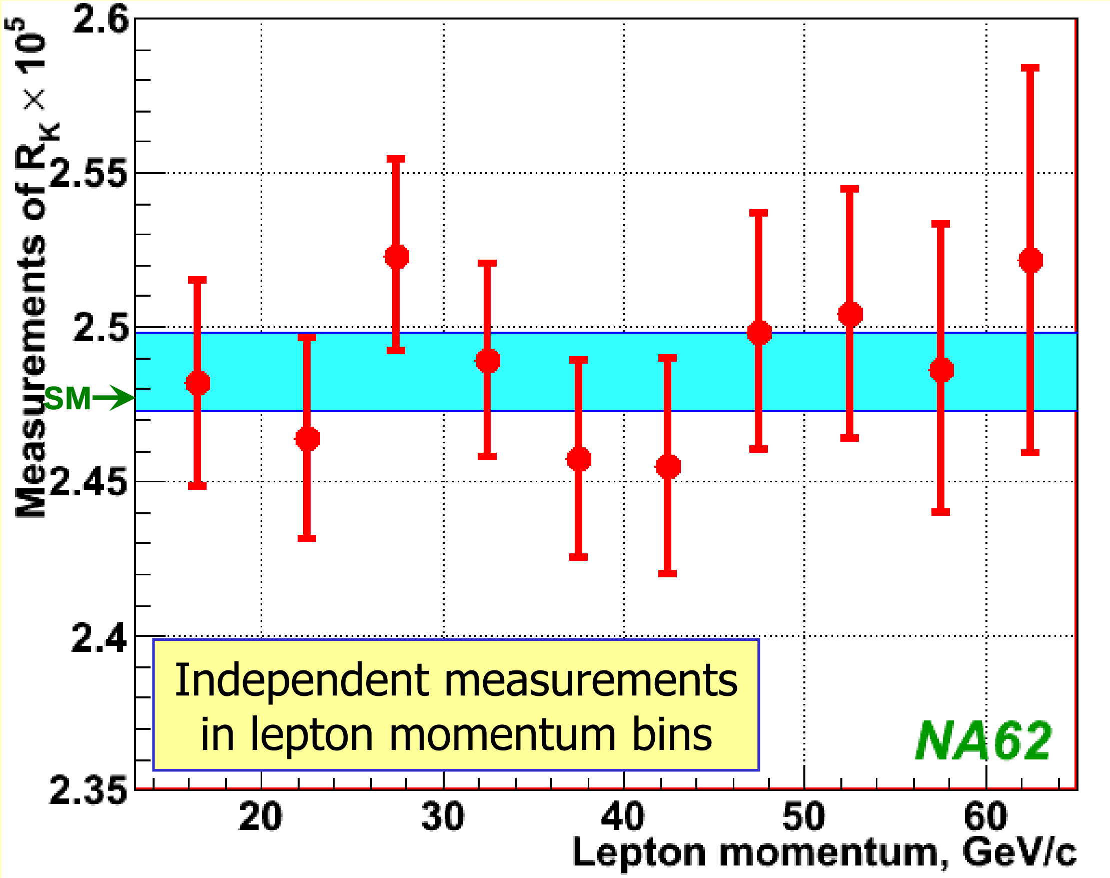


Positron ID efficiency is measured
with $K^+ \to \pi e \nu$ and special $K_L \to \pi e \nu$ samples:
integral $\varepsilon = (99.27 \pm 0.05)\%$

NA62 final result (40% data set)

$R_K = (2.486 \pm 0.011_{stat} \pm 0.007_{syst}) \times 10^{-5}$
$= (2.486 \pm 0.013) \times 10^{-5}$

(new: June 2010)



(systematic errors included, partially correlated)

Uncertainties

Source	$\delta R_K \times 10^5$
Statistical	0.011
$K_{\mu 2}$	0.005
$BR(K_{e2\gamma}\ SD^+)$	0.004
Beam halo	0.001
Acceptance corr.	0.002
DCH alignment	0.001
Positron ID	0.001
1-track trigger	0.002
Total	0.013

(0.52% precision)

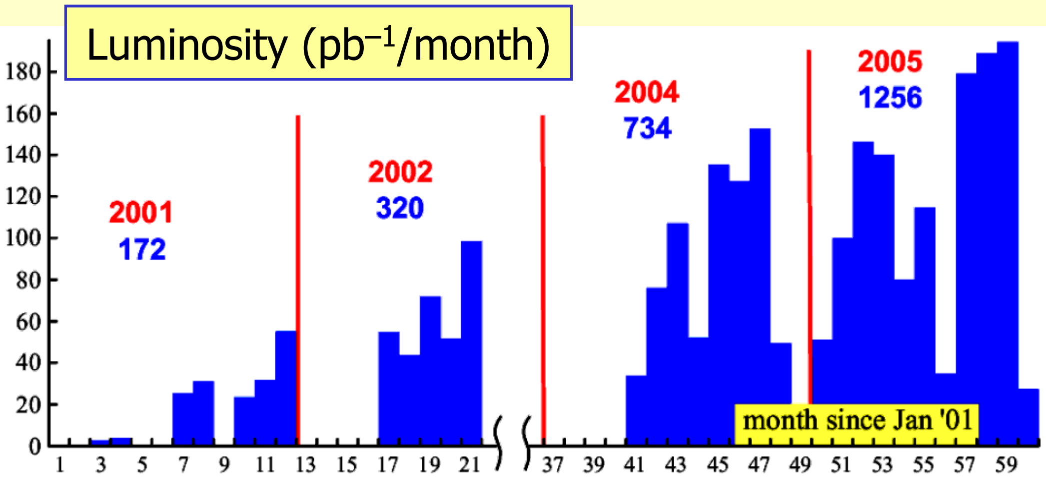
Preliminary result: $R_K = 2.500(16) \times 10^{-5}$. Shift due to multi-photon corrections to the $K_{e2\gamma}$ (IB) decay.

The KLOE R_K measurement and the world average

KLOE: ~100 MeV kaons

DAΦNE: e^+e^- collider at LNF Frascati

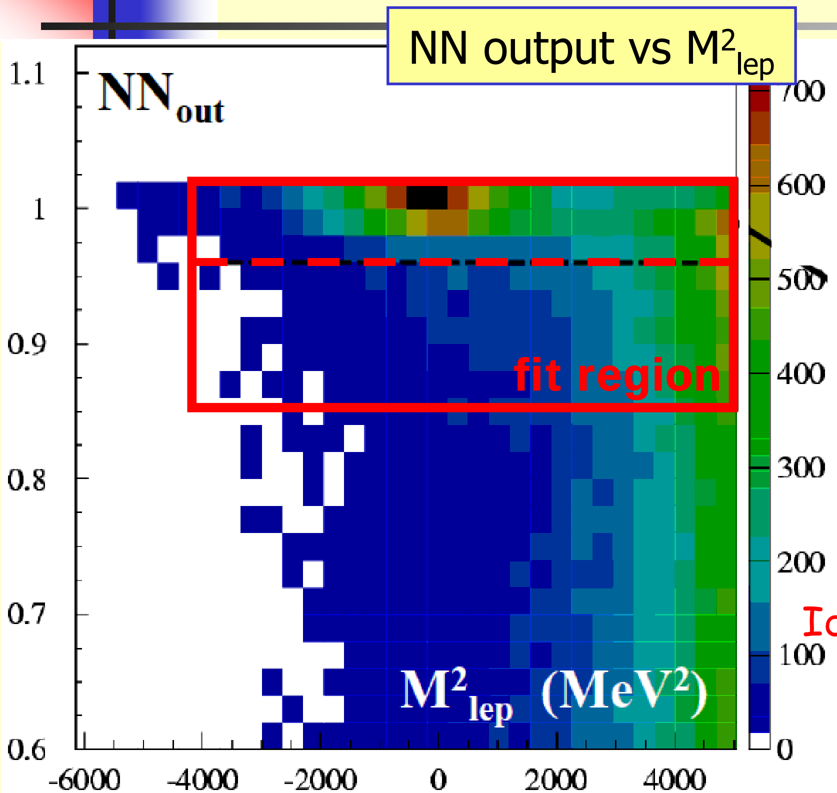
- CM energy ~ m_ϕ = 1.02 GeV;
- $BR(\phi \to K^+K^-)$ = 49.2%;
- ϕ production cross-section σ_ϕ=1.3μb;
- Data sample (2001–05): 2.5 fb^{-1}.



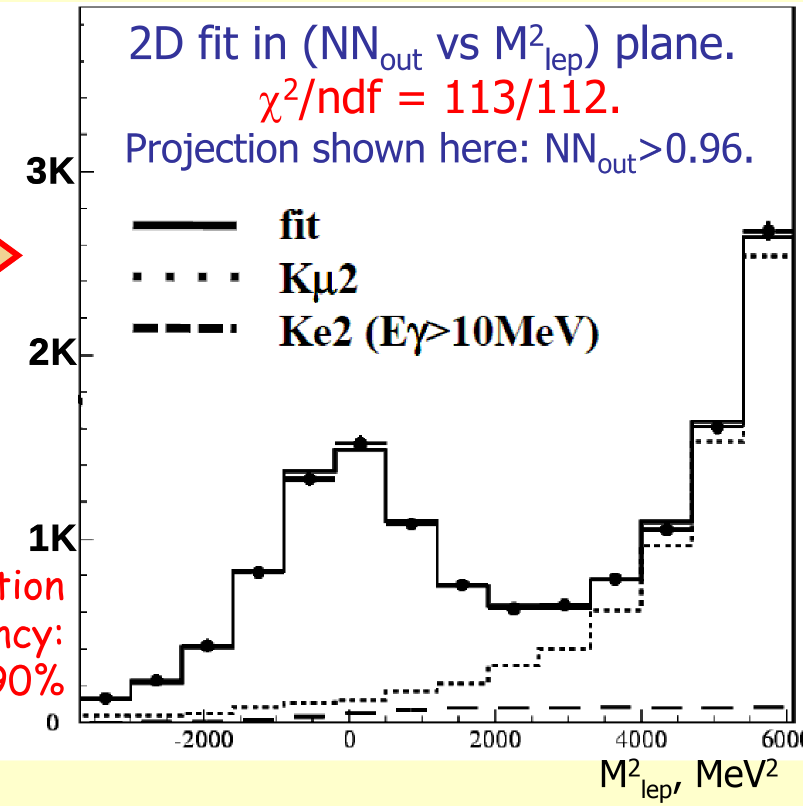
$K_{e2}/K_{\mu2}$ selection technique (vs NA62):

- Kinematics: by M^2_{lep} (equivalent to M_{miss}^2);
- PID: neural network with 12 input parameters (vs E/p for NA62).

KLOE K_{e2} analysis



Identification efficiency: ~90%



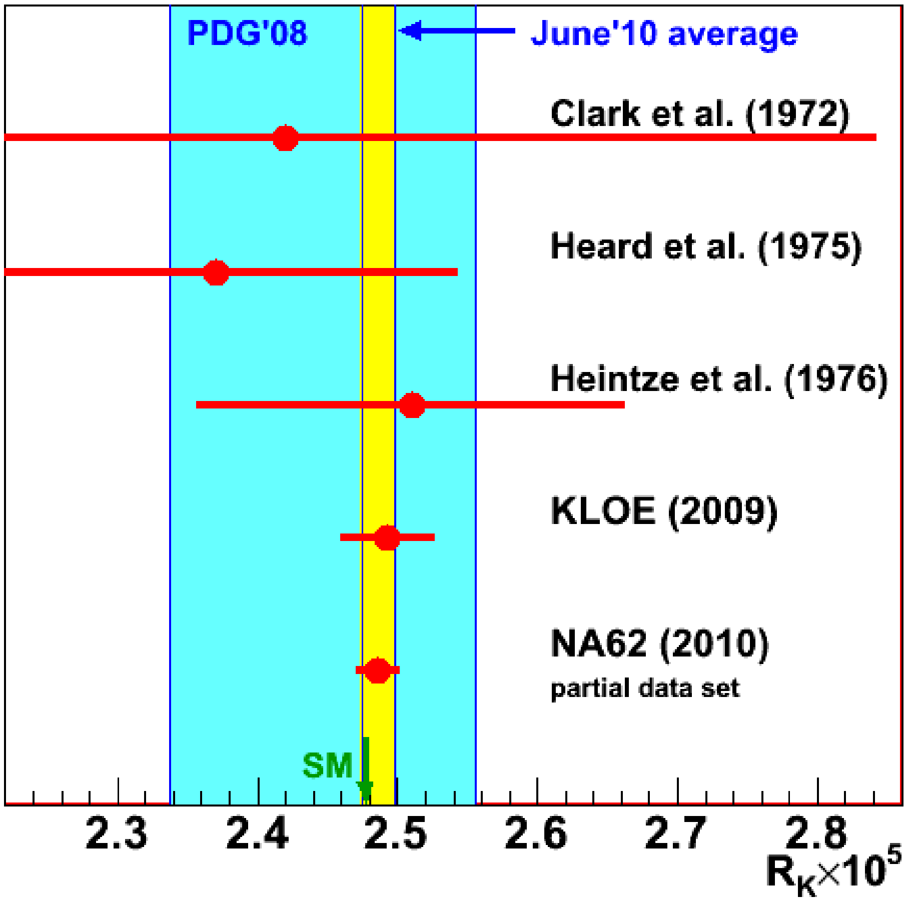
Uncertainties	$\delta R_K/R_K$ (%)
Statistical	1.0
$K_{\mu2}$ subtraction	0.3
$K_{e2\gamma}$ (SD$^+$)	0.2
Reconstruction efficiency	0.6
Trigger efficiency	0.4
Total	1.3

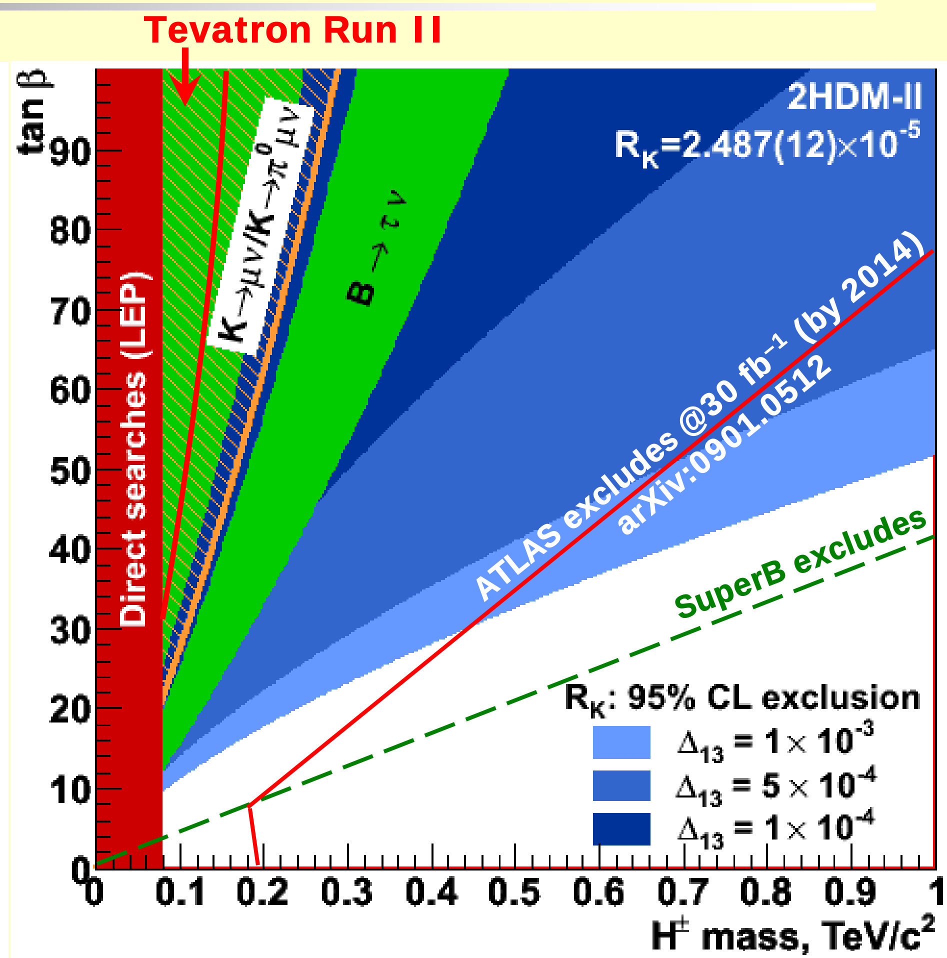
Full data sample analyzed
[EPJ C64 (2009) 627]

13.8K K_{e2} candidates, 16% background

KLOE-2: starting in 2010, expect $\delta R_K/R_K$=0.4%.
[arXiv:1003.3862]

R_K: world average





World average	$\delta R_K \times 10^5$	Precision
March 2009	2.467±0.024	0.97%
June 2010	2.487±0.012	0.48%

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

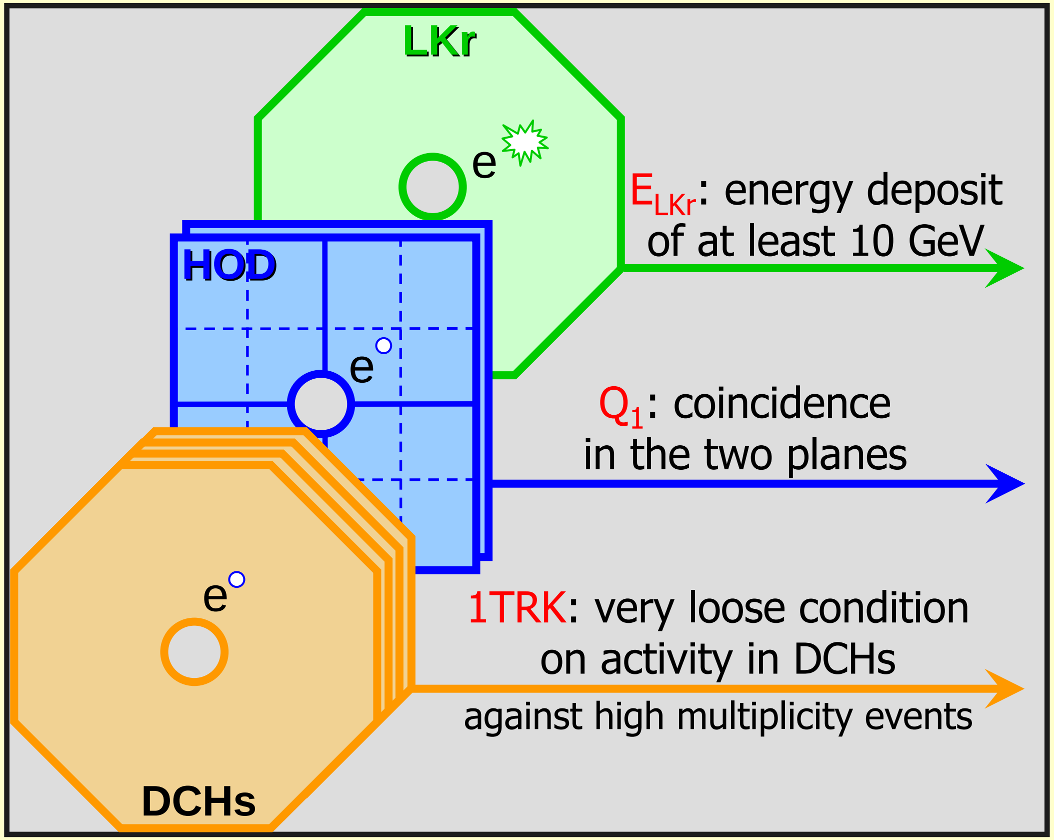
Conclusions & prospects

- Leptonic meson decays and their ratios are well-suited for stringent tests of the Standard Model. In particular, $R_K=K_{e2}/K_{\mu2}$ is sensitive to lepton flavour violation in multi-Higgs models.
- NA62 data taking in 2007/08 was optimised for R_K measurement. NA62 K_{e2} sample is ~10 times the world sample, with excellent $K_{e2}/K_{\mu2}$ separation (99.3% electron ID efficiency, 6% $K_{\mu2}$ background).
- Final result based on ~40% of the NA62 K_{e2} sample $R_K = (2.486\pm0.013)\times10^{-5}$ reached a record 0.5% accuracy. A timely result, as searches for New Physics at the LHC are starting.
- Future experimental improvements on R_K:
  1) the full NA62 data sample of 2007/08: $\delta R_K/R_K<0.4\%$;
  2) NA62 phase II (2012–2015) and KLOE-2 (2010–) aim at ~0.2% and ~0.4% precision.

Spare slides

Trigger logic

NA62 trigger in 2007/08



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

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

$K_{\mu 2}$ 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.
- Different trigger conditions for signal and normalization!

K_{l3}: lepton universality test

Comparison of $|V_{us}|$ determined from K_{e3} vs $K_{\mu 3}$ decays

SM

$$r_{\mu e} = \frac{[|V_{us}| f_+(0)]^2_{\mu 3,\,\text{exp}}}{[|V_{us}| f_+(0)]^2_{e3,\,\text{exp}}} = \frac{\Gamma_{K\mu 3}}{\Gamma_{Ke3}} \frac{I_{e3}\,(1 + 2\delta^{Ke}_{\text{EM}})}{I_{\mu 3}\,(1 + 2\delta^{K\mu}_{\text{EM}})} = (g_\mu/g_e)^2 = 1$$

lepton coupling at the $W \to l\nu$ vertex

Experimental results

$K^\pm$: $r_{\mu e} = 0.998(9)$

K^0: $r_{\mu e} = 1.003(5)$

→ $r_{\mu e} = 1.002(4)$

Non-kaon measurements:

$\pi \to l\nu$: $r_{\mu e} = 1.0042(33)$ (PRD 76 (2007) 095017)

$\tau \to l\nu\nu$: $r_{\mu e} = 1.000(4)$ (Rev.Mod.Phys. 78 (2006) 1043)

The sensitivity in kaon sector approaches those obtained in the other fields.