Recent Results on Rare And Semileptonic Kaon Decays From NA48

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QCD 05
4th July 2005

On behalf of the NA48 Collaboration

Recent Results to Be Shown

Latest results on rare K_s decays:

- $K_s \rightarrow \pi^+ \pi^- \pi^0$
- $K_s \rightarrow \pi^0 \pi^0 \pi^0$ PLB610
- $K_s \rightarrow e^\pm \pi^\pm \nu$ ($K_s e3$)

Latest results on rare K_L decays:

- $K_L \rightarrow e^+ e^- e^+ e^-$ PLB615

Semileptonic K_L and $K^\pm$ decays:

- $K_L e3$ form factors PLB604
- and BR PLB602
- $K_L \mu 3$ form factors (PREL)
- $K_L e3\gamma$ BR PLB605

- $K^\pm e3$ BR
- $K^\pm \mu 3$/ $K^\pm e3$

Leptonic $K^\pm e2/K^\pm \mu 2$

Some History

NA48: 1997-2001

Direct CP violation

Re(ε′/ ε) = (14.7 ± 2.2) 10^{-4}

NA48/1: 2002

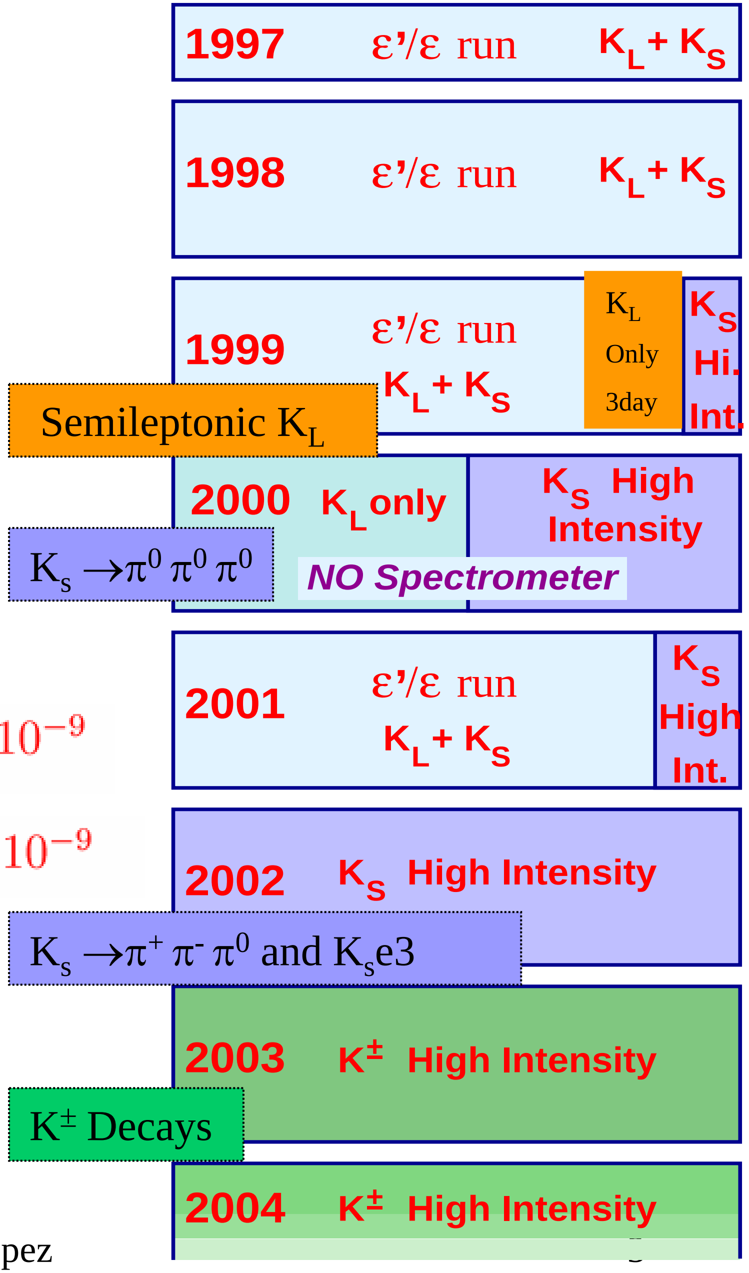
Rare K_s decays

$$BR(K_S \to \pi^0 e^+ e^-) = (5.8^{+2.8}_{-2.3}(stat) \pm 0.8(syst)) \times 10^{-9}$$

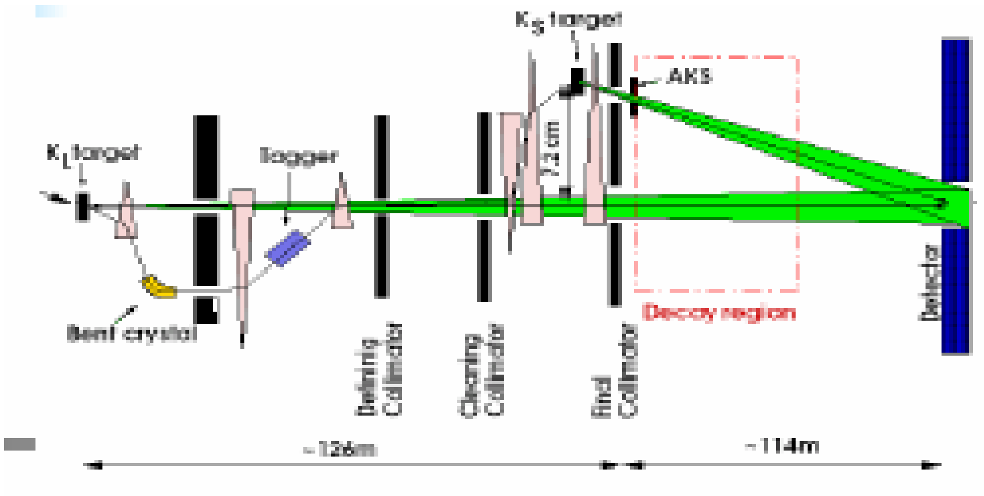
$$BR(K_S \to \pi^0 \mu^+ \mu^-) = (2.8^{+1.5}_{-1.2}(stat) \pm 0.2(syst)) \times 10^{-9}$$

NA48/2: 2003-2004

Search for DCPV in $K^\pm \to 3\pi$



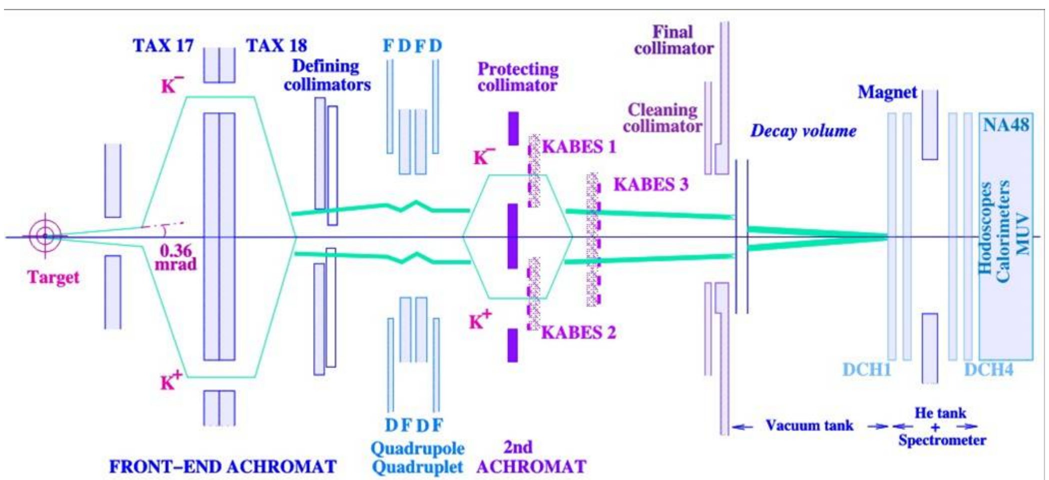
The Beam Lines



NA48

Simultaneous K_L and K_S beams. Periods with only K_L or K_S

NA48/1 K_S line only



NA48/2

Simultaneos K^+ and K^- beams.

$P_K = 60 \pm 3$ GeV

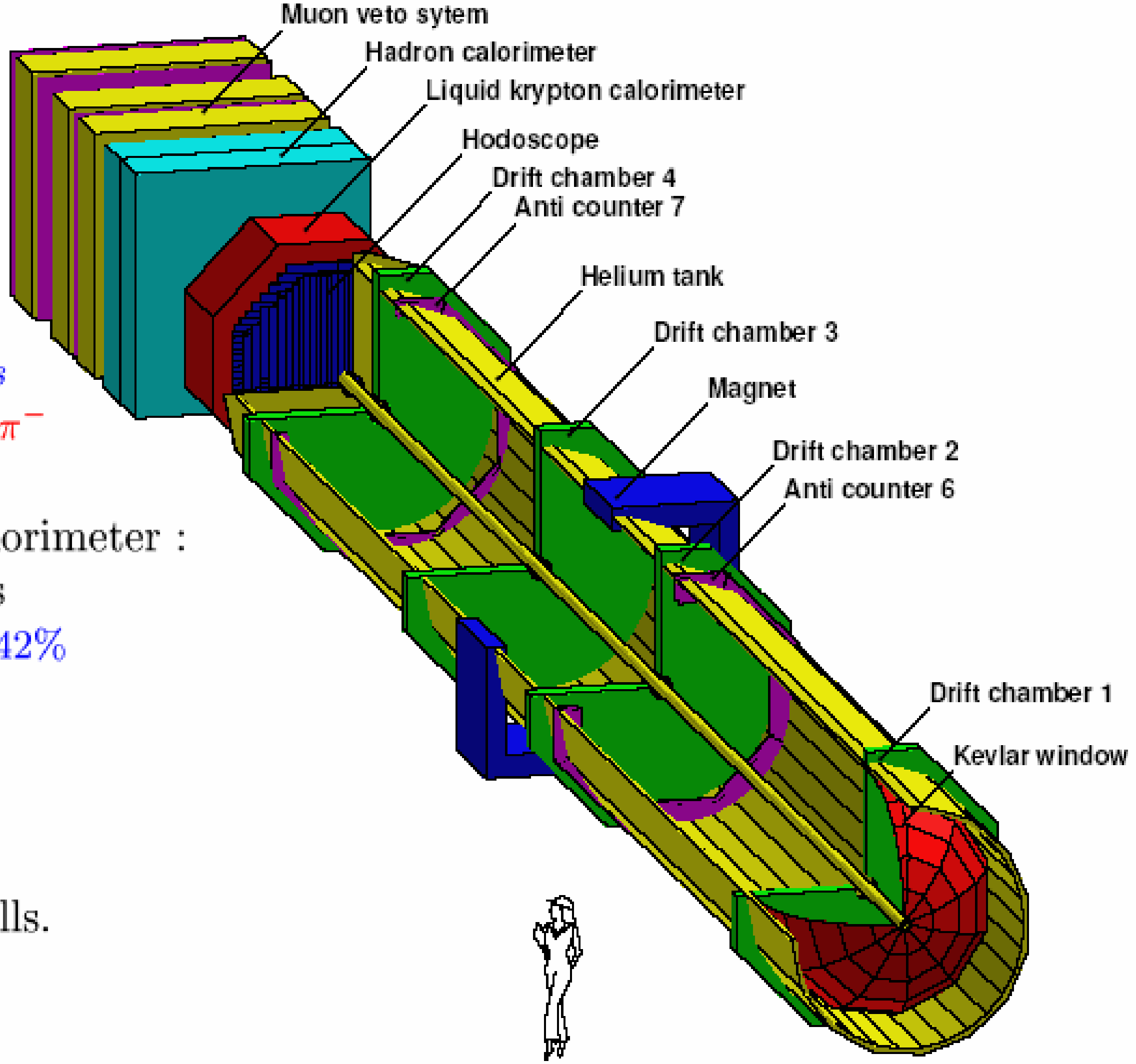
The Detector

NA48 DETECTOR

- Magnetic spectrometer :
  3 DCH, 4 views, 2 planes/view
  $\sigma(p)/p \simeq 0.5\,\% \oplus 0.009\; p[GeV/c]\;\%$
  $(P_{\perp}{}^{kick} \sim 265 MeV/c)$
  $\sigma(t) \simeq 1.4ns.$
  Charged hodoscope: $\sigma(t) \simeq 200ps$
  $\sigma(M_{\pi^+\pi^-}) \simeq 3MeV$ from $K_S \rightarrow \pi^+\pi^-$

- Liquid Krypton electromagnetic calorimeter :
  27 X_0 with 13212 2×2 cm^2 cells
  $\sigma(E)/E = 3.2\%/\sqrt{E} \oplus (9\%)/E \oplus 0.42\%$
  $\sigma(t) \simeq 265ps$
  $\sigma(M_{\gamma\gamma}) \simeq 1MeV$ from $K_S \rightarrow \pi^0\pi^0$

- Muon counters:
  2+1 planes (X,Y) 25cm×25cm cells.
  $\sigma(t) \simeq 350ps$



$K_S \to \pi^+ \pi^- \pi^0$ CPC (KAON05 PRELIMINARY)

Two angular momentum components: L=1 (CPC) and L=0 (CPV)

Dalitz plot variables X and Y

$$X = \frac{s_{\pi^-} - s_{\pi^+}}{m_{\pi^\pm}^2} \qquad Y = \frac{s_{\pi^0} - s_0}{m_{\pi^\pm}^2}$$

L=0 is even in X, L=1 is odd in X

Measurement of CPC component through interference with K_L

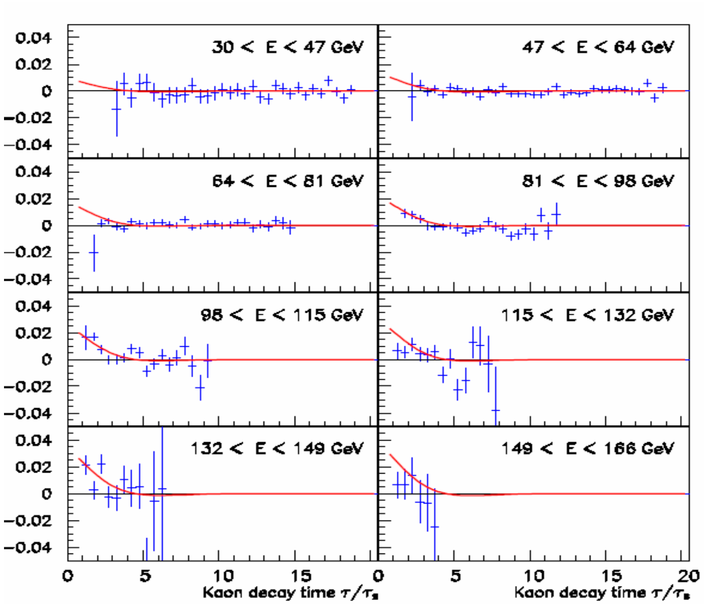
$$\lambda = \frac{\int_{-\infty}^{\infty} dY \int_0^{\infty} dX A_L^{*\,3\pi(l=0)}(X,Y) A_S^{3\pi(l=1)}(X,Y)}{\int_{-\infty}^{\infty} dY \int_0^{\infty} dX \left| A_L^{3\pi(l=0)}(X,Y)\right|^2}$$

Extract small antisymmetric effect from large symmetric background

$$V(t) = \frac{N_{3\pi}^{X>0}(t) - N_{3\pi}^{X<0}(t)}{N_{3\pi}^{X>0}(t) + N_{3\pi}^{X<0}(t)} \approx \frac{2D(E)\left[\mathrm{Re}(\lambda)\cos(\Delta m t) + \mathrm{Im}(\lambda)\sin(\Delta m t)\right] e^{-\frac{t}{2}\left(\frac{1}{\tau_S}+\frac{1}{\tau_L}\right)}}{e^{-\frac{t}{\tau_L}}}$$

$K_s \rightarrow \pi^+ \pi^- \pi^0$

Analysis in energy bins



Data corrected for acceptance and trigger efficiency

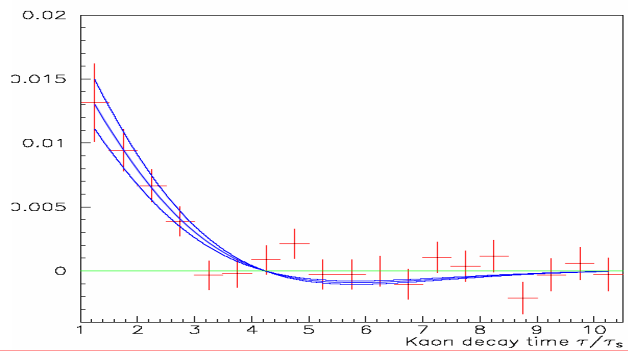
- MC corrections
- Averaging over opposite B

Results from fit:

$\mathrm{Re}\,\lambda = 0.038 \pm 0.008 \pm 0.010$

$\mathrm{Im}\,\lambda = -0.013 \pm 0.005 \pm 0.009$

Function obtained from fitted values for Reλ and Imλ superimposed to all data.



From Re λ the BR can be extracted :

$BR(K_s \rightarrow \pi^+ \pi^- \pi^0) = (4.7 \pm 3.2)\ 10^{-7}$

PDG04: $BR(K_s \rightarrow \pi^+ \pi^- \pi^0) = (3.2_{-1.0}^{+1.2})\ 10^{-7}$

$K_s \to \pi^{\pm} e^{\pm} \nu$ ΔS=ΔQ (KAON05 PRELIMINARY)

Time evolution w/o distinguishing the two charged states:

$$N(\pi\ e\ \upsilon)(t) = e^{-\frac{t\tau_S}{\tau_L}} + |\eta|^2 e^{-t}$$

Assuming CPT $\eta = |\eta| e^{i\phi} = \frac{1+x}{1-x} \qquad x = \frac{A_w(\Delta S = -\Delta Q)}{A_w(\Delta S = \Delta Q)}$

BR extraction: $BR(K_s \to \pi\ e\ \upsilon) = |\eta|^2 \frac{\tau_S}{\tau_L} BR(K_L \to \pi\ e\ \upsilon)$

Experimental approach: Measure $|\eta|^2$ by fitting the z distribution

$$N(z) = \alpha_S F_S^{MC}\left(E, \frac{z}{c\tau_s}\right) + \alpha_L F_L^{MC}\left(E, \frac{z}{c\tau_L}\right) \qquad |\eta|^2 = \frac{\tau_S \alpha_L}{\tau_L \alpha_S}$$

$K_s \rightarrow \pi^{\pm} e^{\pm} \nu$

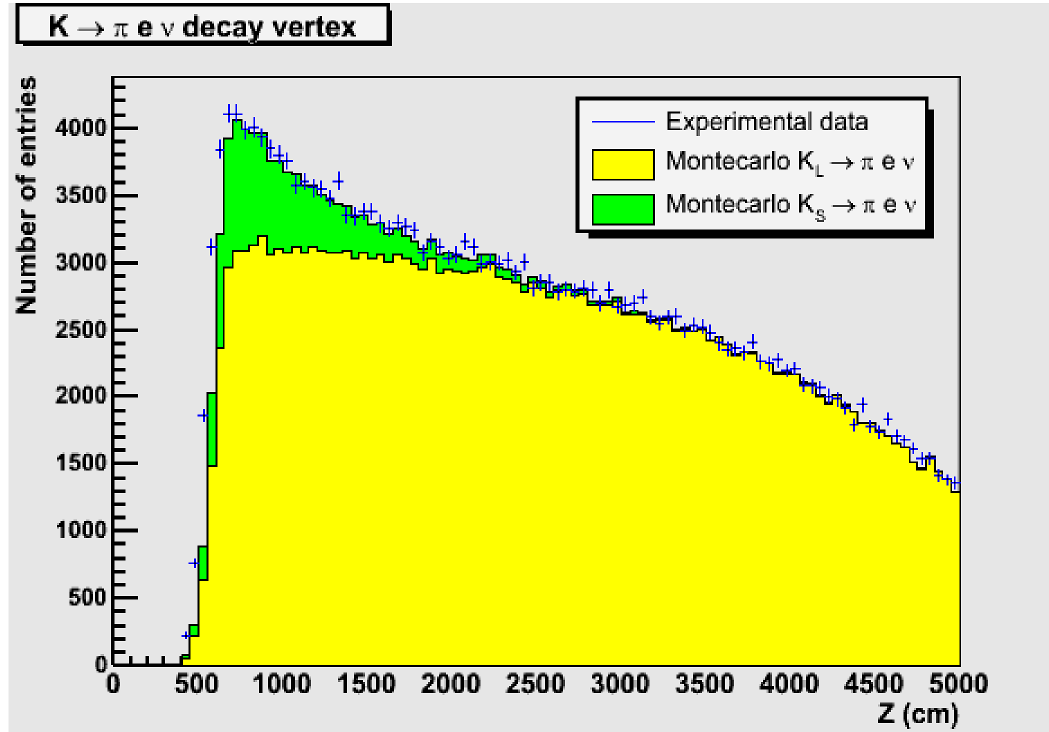
Measurement relies on

MC simulation:

- Target position
- Beam shape
- Kaon spectrum
- Form factors input
- Radiative corrections

DATA:

234 10^3 events from minimum bias trigger



Inputs for BR(K_Se3) from PDG04 and NA48

- $\tau_L = (0.8953 \pm 0.0006)\ 10^{-10}$ s
- $\tau_S = (5.18 \pm 0.04)\ 10^{-8}$ s
- BR(K_Le3) = 0.4010 ± 0.0045

$BR(K_s \rightarrow e^{\pm} \pi^{\pm} \nu) = (6.8 \pm 0.2 \pm 0.2)\ 10^{-4}$

PDG04: $BR(K_s \rightarrow e^{\pm} \pi^{\pm} \nu) = (6.9 \pm 0.4)\ 10^{-4}$

$\Delta S = \Delta Q$ OK

$K^{\pm} \to \pi^0 e^{\pm} \nu$ V_{us} (ICHEP04 PRELIMINARY)

DATA: Low intensity run (8h) with minimum bias trigger 2003

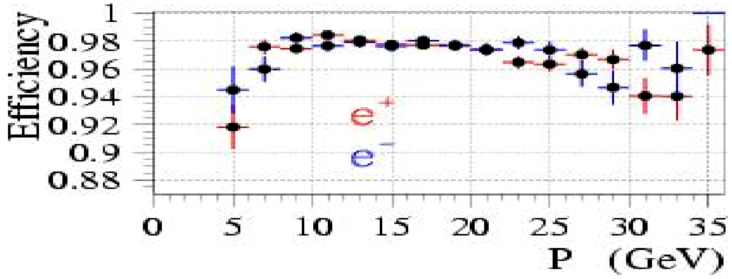
METHOD: Normalize to $K^{\pm} \to \pi^{\pm} \pi^0$

SELECTION: Signal, ID efficiency for e (E/p>0.95) and mass cut . Norm, ID efficiency for π (E/p)<0.95

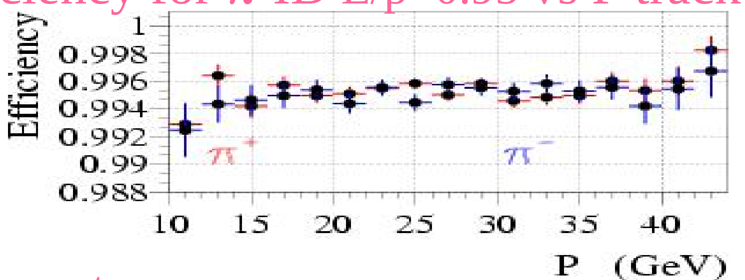
SELECTED EVENTS:

$K^+ \to \pi^0 e^+ \nu$	$59\ 10^3$
$K^- \to \pi^0 e^- \nu$	$33\ 10^3$
$K^+ \to \pi^0 \pi^+$	$468\ 10^3$
$K^- \to \pi^0 \pi^-$	$260\ 10^3$

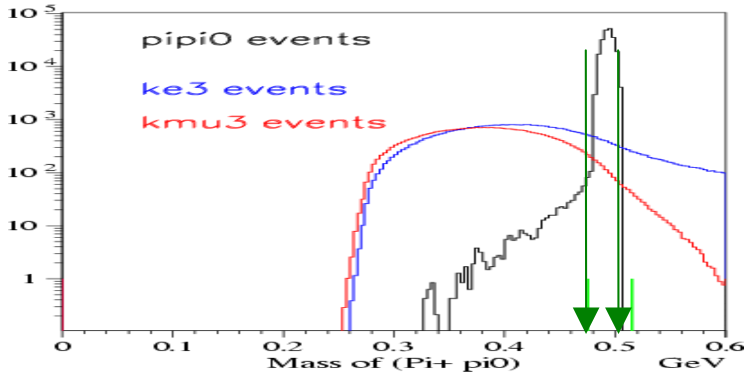
Efficiency for e-ID E/p>0.95 vs P track



Efficiency for π-ID E/p<0.95 vs P track

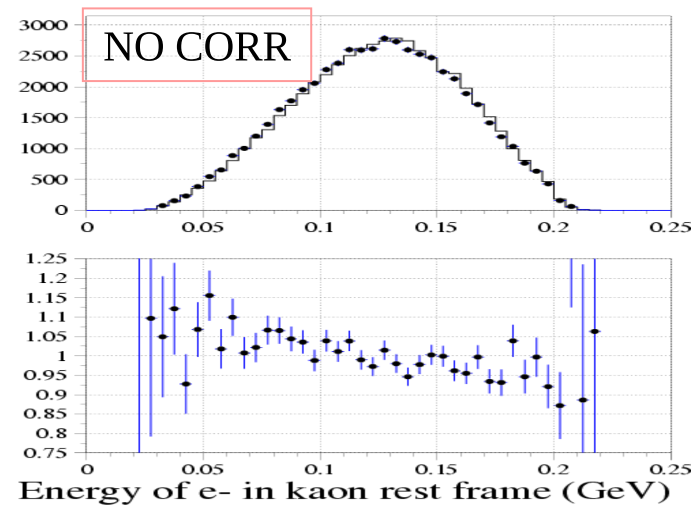


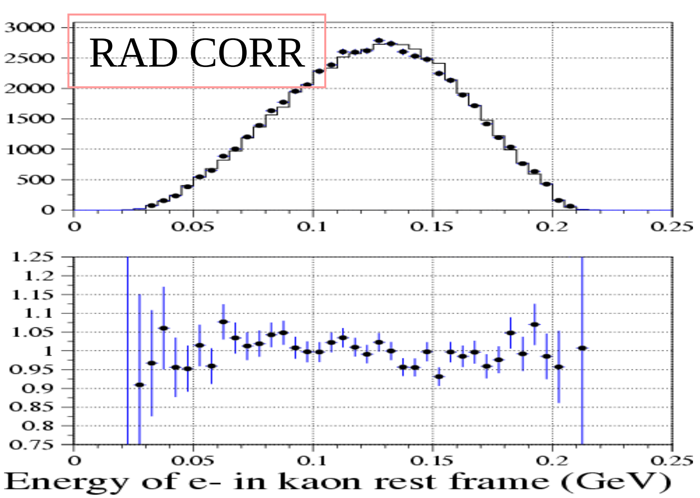
Mass cut



GINSBERG, RADIATIVE CORRECTIONS:

$K^{\pm} \rightarrow \pi^0 e^{\pm} \nu$



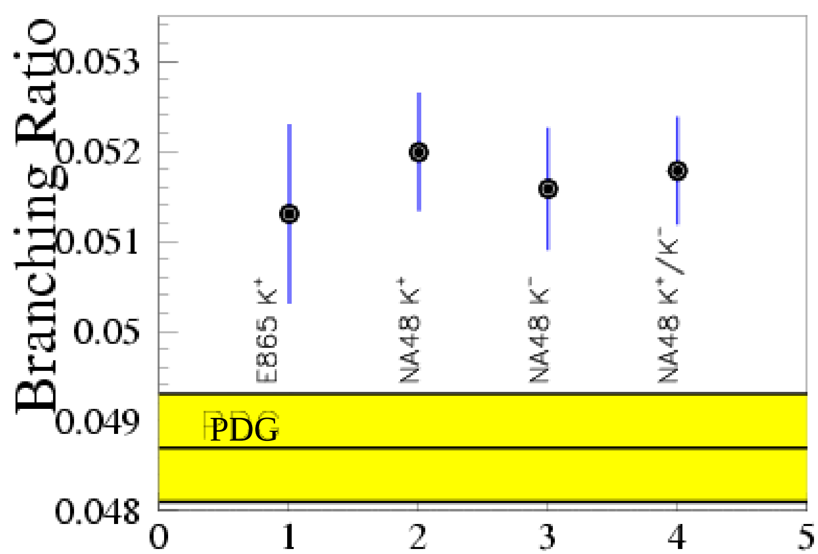


RESULT:

$BR(K^{\pm} \rightarrow \pi^0 e^{\pm} \nu) = (5.14 \pm 0.02 \pm 0.06)\ \%$

PDG04: $BR(K^{\pm} \rightarrow \pi^0 e^{\pm} \nu) = (4.87 \pm 0.06)\ \%$

Input for $BR(K^{\pm} \rightarrow \pi^{\pm} \pi^0)$ from PDG04



$K^{\pm}\mu 3 / K^{\pm}e3$ V_{us} (KAON05 PRELIMINARY)

DATA: $K^{\pm} \rightarrow \pi^0 \mu^{\pm} \nu$ from same period as e-mode and comparable statistics

METHOD: Normalize to $K^{\pm} \rightarrow \pi^0 e^{\pm} \nu$

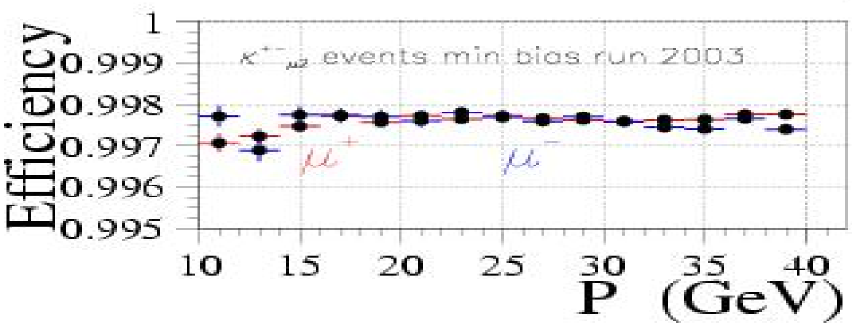
SELECTION: ID efficiency for μ-ID
Two methods, MU detector and calorimeters signals.

SELECTED EVENTS:

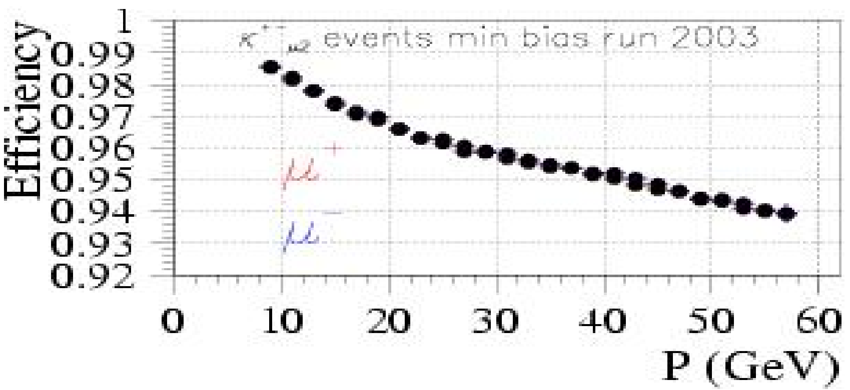
$K^+ \rightarrow \pi^0 e^+ \nu$	$59\ 10^3$
$K^- \rightarrow \pi^0 e^- \nu$	$33\ 10^3$
$K^+ \rightarrow \pi^0 \mu^+ \nu$	$50\ 10^3$
$K^- \rightarrow \pi^0 \mu^- \nu$	$27\ 10^3$

Efficiency for μ-ID vs P track

Muon detector.



Signals in calorimeters



$K^{\pm} \rightarrow \pi^0 \mu^{\pm} \nu$

RESULTS:

$\Gamma(K^{\pm} \rightarrow \pi^0 \mu^{\pm} \nu)/\Gamma(K^{\pm} \rightarrow \pi^0 e^{\pm} \nu) =$

$(67.49 \pm 0.35 \pm 0.11 \pm 0.21_{(\lambda+,\lambda 0)})$ %

PDG04: = (67.2 ± 0.7) %

In agreement with theory:

$$\frac{\Gamma(K^{\pm}_{\mu 3})}{\Gamma(K^{\pm}_{e3})} = 0.6457 - 0.1546\lambda_+ + 1.5646\lambda_0 + O(\lambda_+^2 + \lambda_+\lambda_0 + \lambda_0^2)$$

Fearing, Fischbach, Smith (1970)

Inputs of λ_+, λ_0 from PDG04:

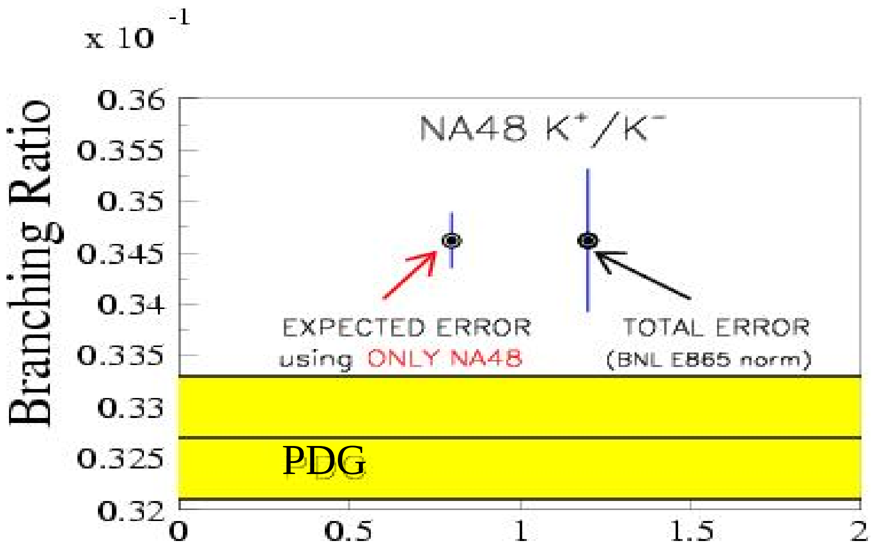
- $\lambda_+ = (2.78 \pm 0.07)\ 10^{-2}$
- $\lambda_0 = (1.77 \pm 0.16)\ 10^{-2}$

$BR(K^{\pm} \rightarrow \pi^0 \mu^{\pm} \nu) = (3.462 \pm 0.018 \pm 0.006 \pm 0.011_{(\lambda+,\lambda 0)} \pm 0.068_{\text{(norm BNL)}})$ %

PDG04: $BR(K^{\pm} \rightarrow \pi^0 \mu^{\pm} \nu) = (3.27 \pm 0.06)$ %

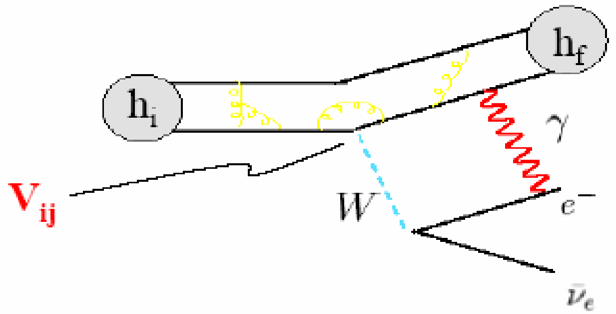
Inputs BR($K^{\pm}$e3) BNL E865:

- BR ($K^{\pm}$e3)= $(5.13 \pm 0.10)\ 10^{-2}$



Vus from semileptonic decays

$$\Gamma(K_{l3(\gamma)}) \propto G_F^2 \left|V_{us}\right|^2 \cdot \left|f_+^{K\pi}(0)\right|^2 I_K^l(\lambda_{+,0})\left(1+\delta_{SU(2)}^K+\delta_{em}^{Kl}\right)^2$$



V. Cirigliano

KAON 05

$$A \sim \frac{g^2}{M_W^2} V_{ij} \langle h_f | \overline{u}_i \, \gamma_\mu (1-\gamma_5) \, d_j | h_i \rangle \times J_{\rm lept} \times (1+\Delta_{\rm EM})$$

Inputs:

- λ_+, λ_0 from PDG04 (phase-space integrals $I_K(\lambda)$)
- $\delta_{SU(2)}$ and δ_{EM} from F. Mescia (hep-ph/0411097)

RESULTS:

From $K^\pm e3$:

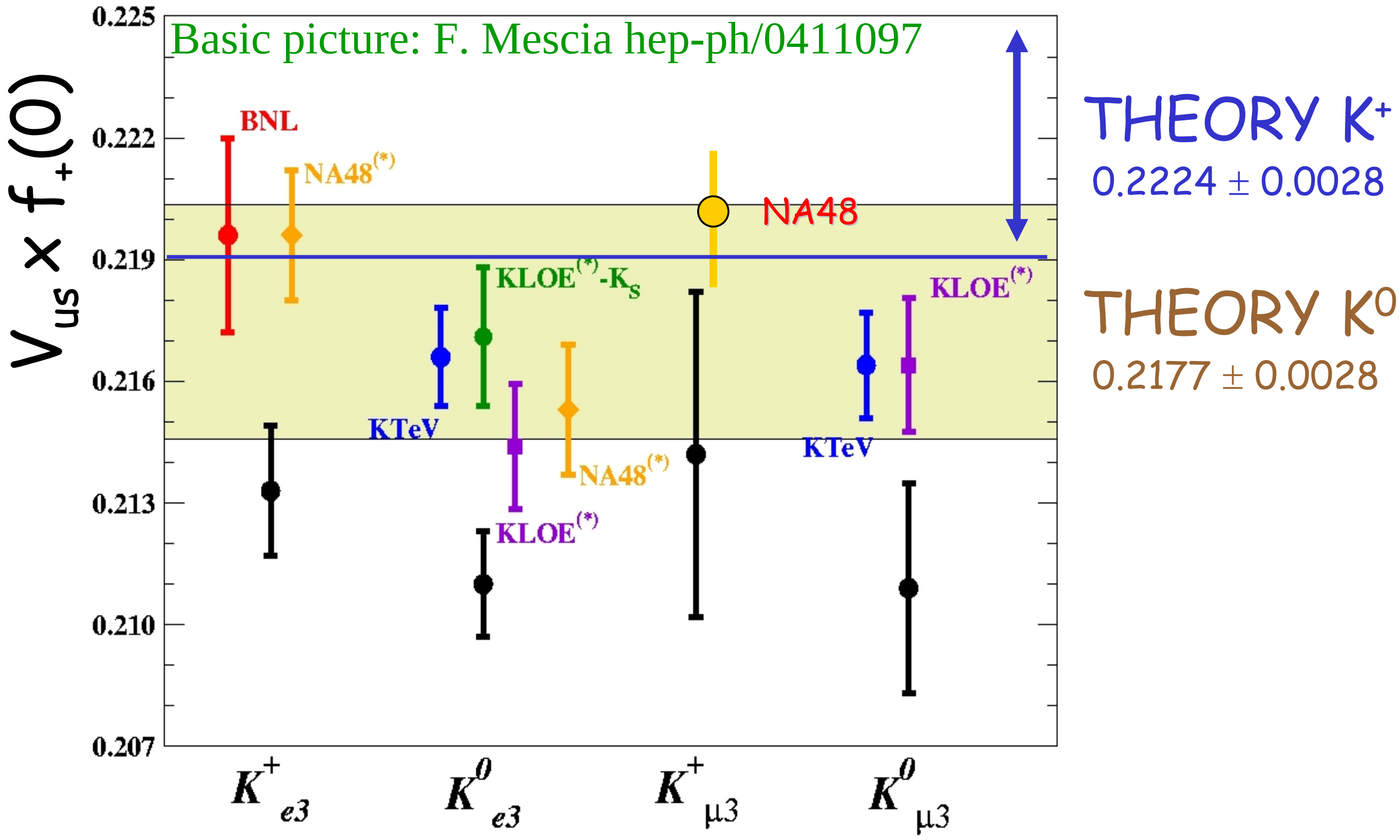
Vus $|f_+(0)|$= (0.2192 ± 0.0015)

From $K^\pm \mu3$:

Vus $|f_+(0)|$= (0.2204 ± 0.0015)

NA48 results on Vus compatible for e and μ channels

Vus from semileptonic decays



SM: Vus = 0.2265 ± 0.0022 Assuming unitarity (@ICHEP)

Leutwyler-Roos: $f^+(0)_{KL}$=0.961 ± 0.008 ⇒ $f^+(0)_{K+}$ = 0.982 ± 0.008

$K^{\pm}e2/K^{\pm}\mu 2$ Lepton Universality (KAON05 PREL)

DATA: $K^{\pm} \to e^{\pm}\nu$ and $K^{\pm} \to \mu^{\pm}\nu$ from ~1 month during 2003 run.

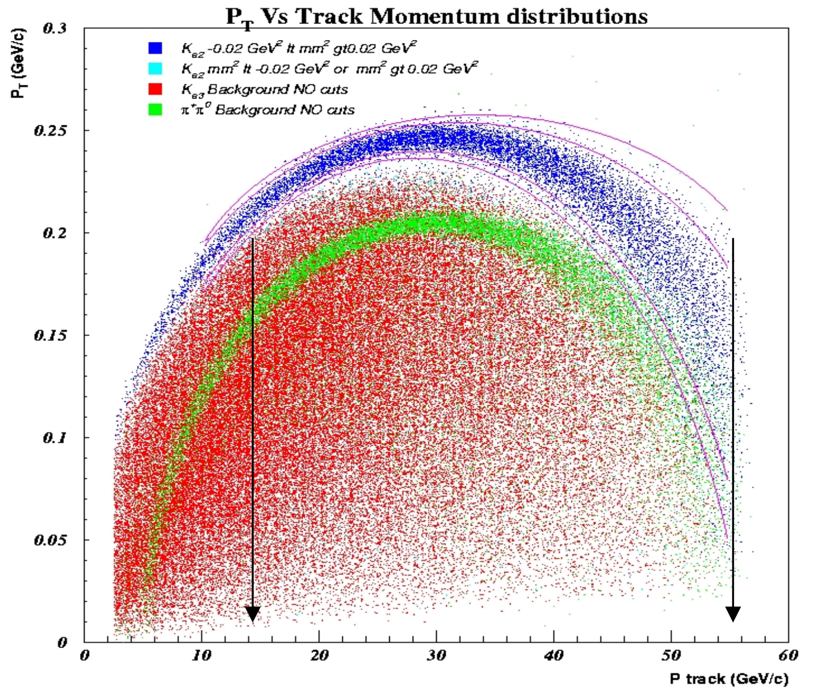
METHOD: Find ratio $K^{\pm}e2/K^{\pm}\mu 2$

SELECTION: Based on P_T.vs.P shape
Cut on M_{ν}^2 and number extra clusters.
E/p for e-ID

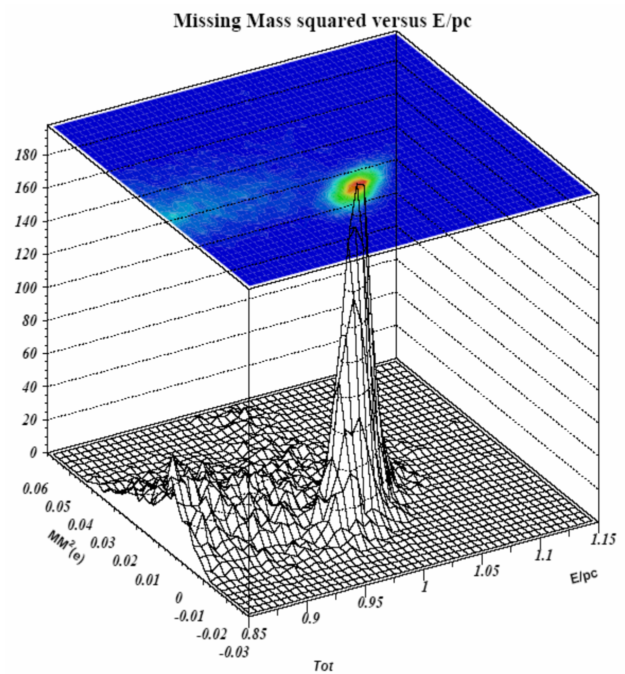
SELECTED EVENTS: Statistics four times bigger all previous added!

$K^{\pm} \to e^{+}\nu$	$4670 \pm 77\ ^{+29}_{-8}$
$K^{\pm} \to \mu^{+}\nu$	$619\ 10^3$

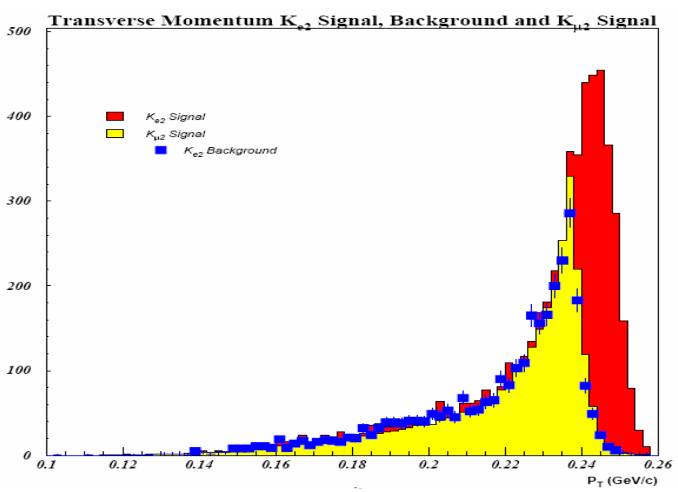
Background to $K^{\pm}e2$ in sig region	659 ± 26



$K^{\pm} \to e^{\pm} \nu$



Background from Kμ2 high E/p



RESULTS:

$BR(K^{\pm} \to e^{\pm} \nu) / BR(K^{\pm} \to \mu^{\pm} \nu) =$

$(2.416 \pm 0.043 \pm 0.024)\ 10^{-5}$

PDG04 $= (2.45 \pm 0.11)\ 10^{-5}$

In agreement with theory:

$$\frac{\Gamma(K \to e\nu(\gamma))}{\Gamma(K \to \mu\nu(\gamma))} = \quad 2.472 \pm 0.001$$

$$= \frac{m_e^2}{m_\mu^2} \left(\frac{m_K^2 - m_e^2}{m_K^2 - m_\mu^2} \right) (1 + \delta R_K)$$

Where $\delta R_K = -(3.729 \pm 0.023 \pm 0.025)\% + O(\alpha^2)$

M. Finkemeier, hep-ph/94112267

And More to Come…

Rare $K^{\pm}$ decays:

- $K^{\pm} \to e^{\pm} \pi^{\pm} \pi^{0} \nu$ ($K^{\pm}e4$)
- $K^{\pm} \to \pi^{\pm} \pi^{0} \gamma$
- $K^{\pm} \to \pi^{\pm} \gamma \gamma$
- $K^{\pm} \to \pi^{\pm} e^{+} e^{-}$
- $K^{\pm} \to \pi^{\pm} \mu^{+} \mu^{-}$

Semileptonic $K^{\pm}$ decays:

- Form factors
- Radiative decays

AND 2004 DATA…