Recent results on Vus from KLOE, KTeV and NA48

Venelin Kozhuharov

University of Sofia "St. Kl. Ohridski" / JINR Dubna

Heavy Quarks and Leptons 2006

19.10.2006

Overview

- CKM matrix
- Extraction of Vus
- Results
- Conclusion

CKM matrix

- Connects the weak interactions eigenstates with the quark flavour eigenstates

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} \boldsymbol{Vud} & \boldsymbol{Vus} & \boldsymbol{Vub} \\ \boldsymbol{Vcd} & \boldsymbol{Vcs} & \boldsymbol{Vcb} \\ \boldsymbol{Vtd} & \boldsymbol{Vts} & \boldsymbol{Vtb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

- The oldest known element: Vus – Cabibbo angle

- In the absence of new physics (fourth generation) the matrix is unitary

CKM matrix: Unitarity

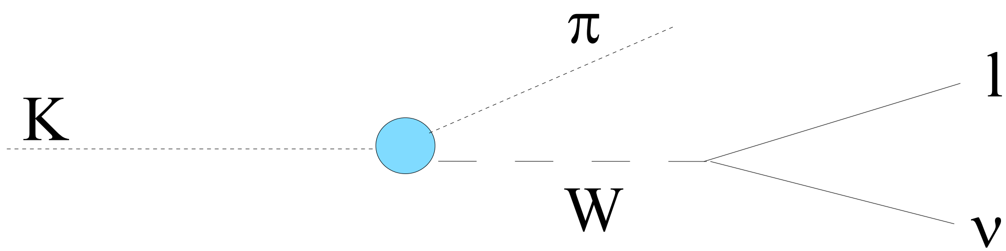
- First raw: $|Vud|^2 + |Vus|^2 + |Vub|^2 = 1 + \delta$
- PDG 2004 data
  - Vud = 0.9738(5)
    from super-allowed 0+ -> 0+ nuclear transitions
  - Vus = 0.2195(25)
    from Kl3 decays
  - Vub = 0.00367(47)
    negligible contribution to the unitarity relatio

$\delta = (3.5 \pm 1.5) * 10^{-3}$

with uncertainty from Vus of 0.0010

- More information desirable

Determination of Vus: Kl3



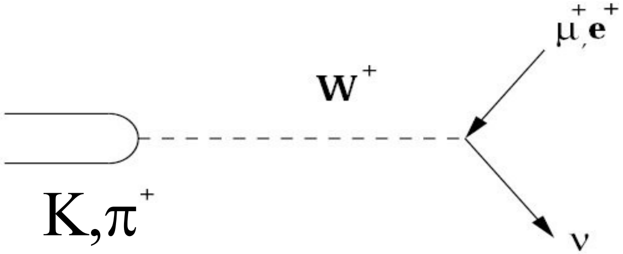
$$|V_{us}| = \sqrt{\frac{128\pi^3 Br(K_{e3(\gamma)})/\tau_K}{C^2 G_F^2 M_K^5 S_{EW} (1+\delta_K^l + \delta_{SU2}) I_K}} * \frac{1}{f_{+(0)}^{K\pi}}$$

where

- $Br(Ke3(\gamma))$ – the experimentally measured branching
- τ_K – kaon lifetime
- $C^2=1$ for K_L and $C^2=1/2$ for $K^\pm$
- I_K – mode and form-factor dependent phase space integrals
- $f_+^{K\pi}(0)$ form factor value at t=0
- S_{EW} , δ_K^l, δ_{SU2} – short- and long- distance radiative corrections and SU2 breaking corrections

Determination of Vus

- Ratio of kaon and pion leptonic decays



$$\frac{\Gamma(K \to \mu\nu)}{\Gamma(\pi \to \mu\nu)} = \frac{|Vus|^2}{|Vud|^2} \frac{M_K \left(1 - \frac{m_\mu^2}{m_K^2}\right)^2}{M_\pi \left(1 - \frac{m_\mu^2}{m_K^2}\right)^2} \frac{f_K^2}{f_\pi^2} * (1 - \delta_{EW})$$

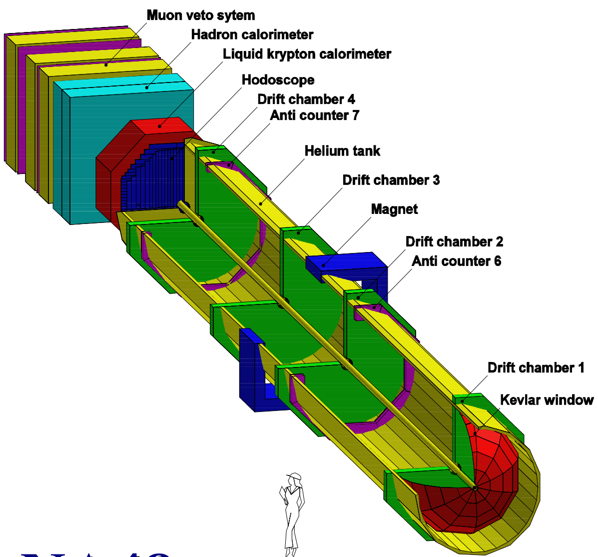
where

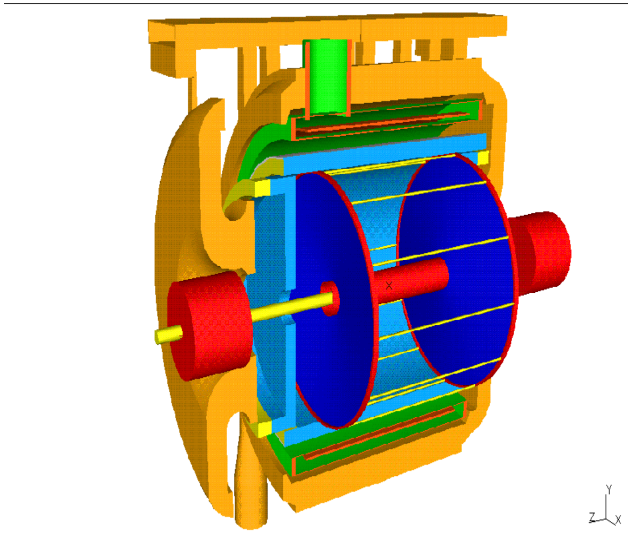
- f_π and f_K are the pion and the kaon decay constants
- δ_{EM} = 0.0070±0.0035 – arrising from the radiative corrections

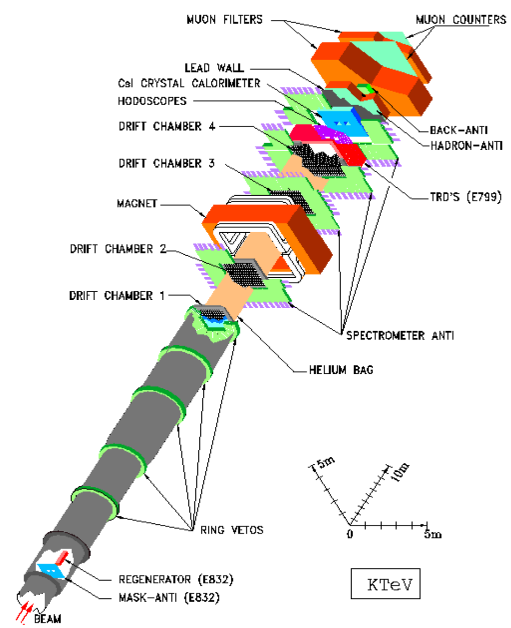
- Hyperon semileptonic decays
  - Analogous to the kaon semileptonic decays
  - Discussed in details in the talk of Rainer Wanke

Exeriments

- The interplay between three experiments in the last years contributed to the measurement of Vus and the understanding of the CKM unitarity







NA48

Kaon decays in fligt

K^0 and $K^{\pm}$

KLOE

Tagged kaons from ϕ decays

K^0 and $K^{\pm}$

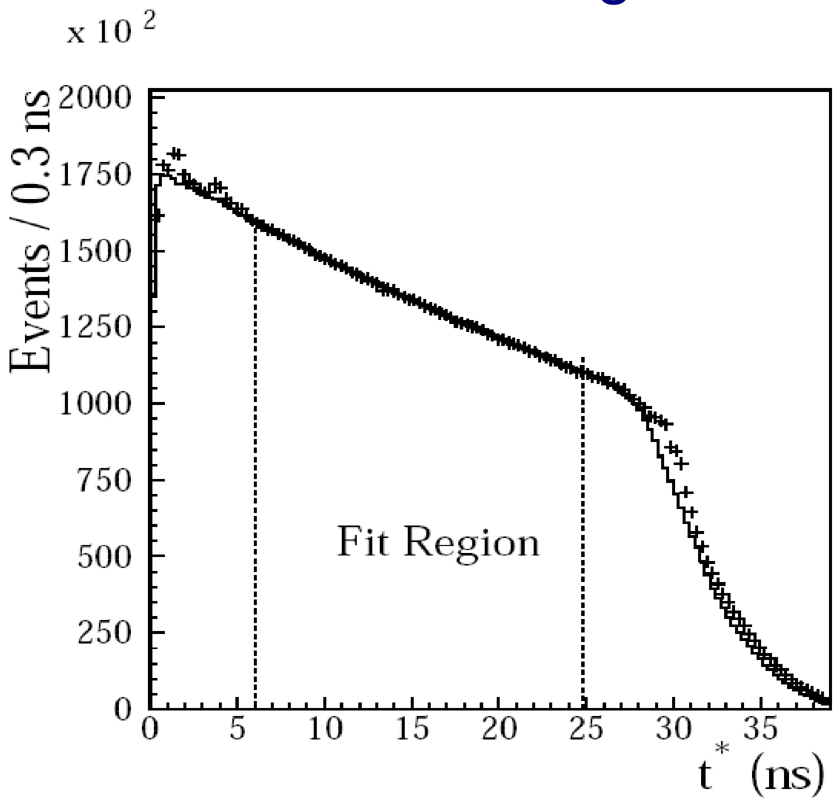
KTEV

Kaon decays in fligt

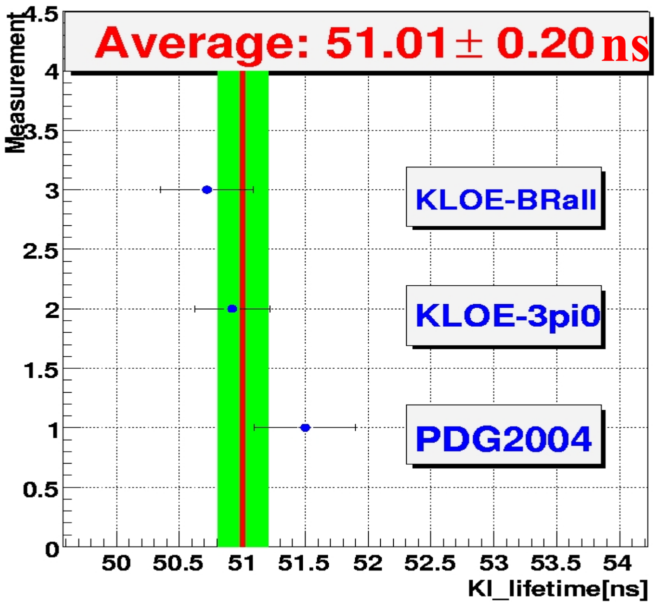
Only K^0

Kaon lifetime

- KL lifetime – *two new measurements by KLOE*
  - Measurement using $K_L \to \pi^0 \pi^0 \pi^0$ decays
  - Measurement using all main decay modes

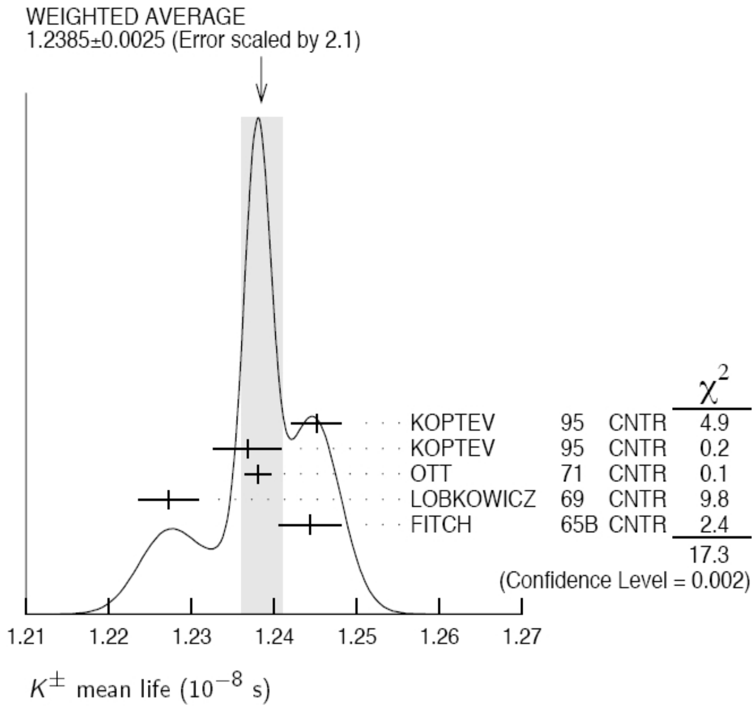


PDG2004	51.5±0.4
KLOE KL branchings	50.72±0.37
KLOE – 3pi0	50.92±0.30



Kaon lifetime

- KS lifetime:
  - Most precise measurements by NA48 and KTeV – already existing in 2004
  - Using the PDG value – $\tau_S = 0.8958(5) * 10^{-10}$s
- K+- lifetime



Discrepancies between the different measurements

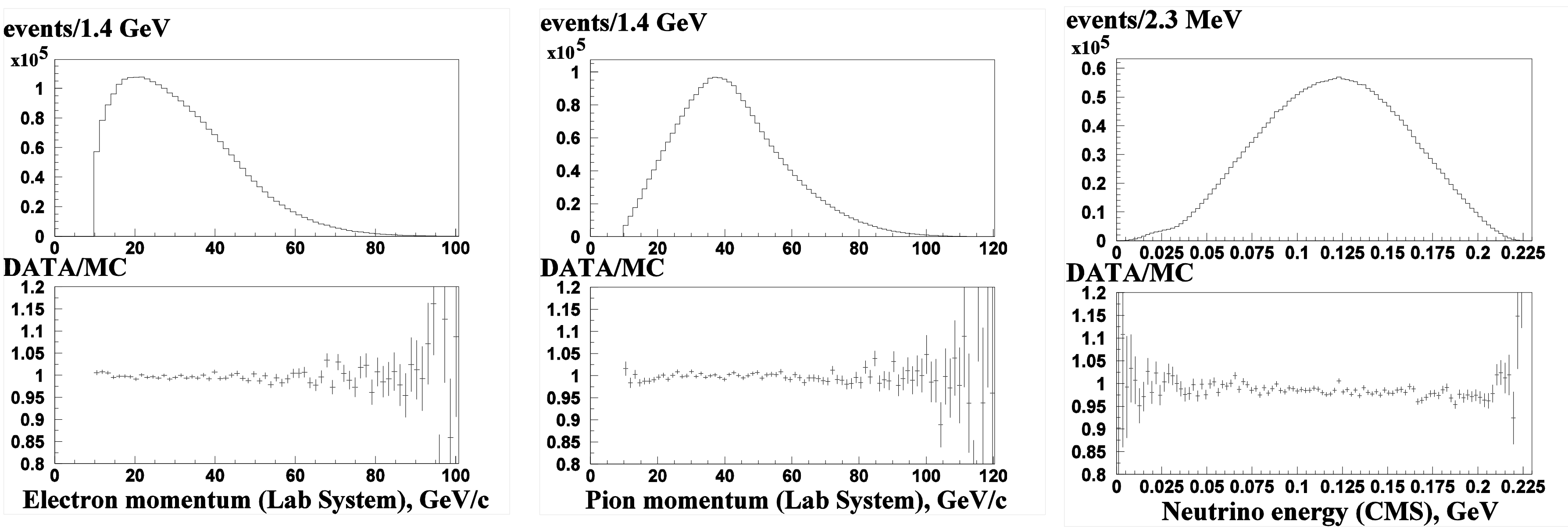
Preliminary result by KLOE presented at Moriond-2006:
$\tau_{K\pm} = (1.2336 \pm 0.0078) * 10^{-8}$s
waiting for a final result

Using the PDG result

Form factor measurements

- Parametrizations: $f_{+(t)} = f_{+(0)}(1+\lambda' \frac{t}{m_\pi^2} + \frac{\lambda''}{2}\frac{t}{m_\pi^2}) = f_{+(0)}(\frac{M_V^2}{M_V^2 - t})$
- Using $5.6*10^6$ events NA48 has performed a measurement of the KLe3 form-factors

Data – MC comparison for λ+=0.0288 and no quadratic term

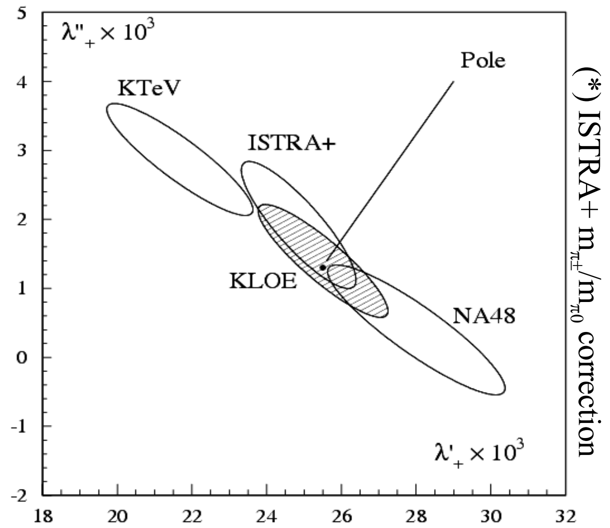


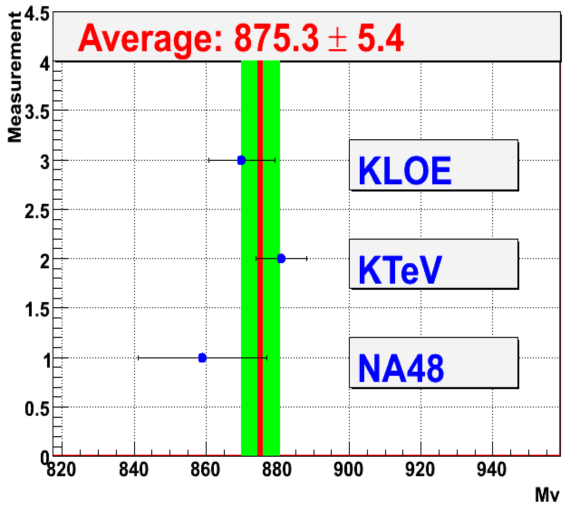
- The analysis doesn't show evidence for the presence of quadratic term
- This result was in contradiction with the measurement of KTeV

Form factor measurements

- The phase space integrals depend on the parametrization of the form-factors

KLe3 form factors	λ'_+	λ''_+	Mass the pole [MeV]
NA48 – 2004	0.0280±0.0024	0.0004 ± 0.0009	859 ± 18
KTeV – 2004	0.02167±0.0020	0.0029 ± 0.0008	881±7.1
KLOE – 2006	0.0255±0.0018	0.0014 ± 0.0008	870 ± 9.2





- The recent measurements from KLOE are closer to the NA48 results

Phase space integrals

- The phase space integrals depend on the parametrization of the form-factors. Different values for the form factors give different values for the phase space integrals for K^0e3
  - Using new calculations by KTeV collaboration diminish the model dependency:

    $$\mathbf{I_{K0e3} = 0.10262(32)}$$

  - Between the pole parametrization from KLOE ($\mathbf{I_{K0e3} = 0.1032(2)}$) and linear from NA48 ($\mathbf{I_{K0e3} = 0.1034(6)}$) and quadratic from KTeV ($\mathbf{I_{K0e3} = 0.1023(7)}$)
- $K^0\mu3$: using the KTeV quadratic form-factor parametrization

  $$I_{K0\mu3} = 0.06777(53)$$

- $K^{\pm}e3$: using ISTRA form factor measurements $I_{K\pm e3} = 0.1061(8)$

Theoretical inputs

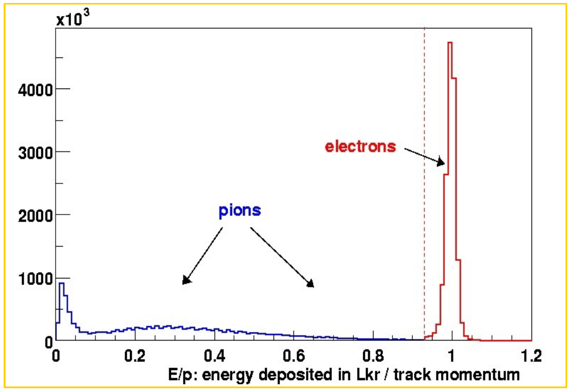
- First estimate of f+(0) done by Leutwyler and Roos in 84
  χPT calculation
  $f_+^{K0\pi-}(0) = (0.961 \pm 0.008)$ $f_+^{K+\pi0}(0) = 1.022 * f_+^{K0\pi-}(0)$
- New estimation within χPT at the order of p^6 give higher values (J. Bijnens, P. Talavera and V.Cirigliano)
  $f_+^{K0\pi-}(0) = (0.974 \pm 0.012)$
- Latice QCD result is consistent with the "classical" estimation
  $f_+^{K0\pi+}(0) = (0.960 \pm 0.009)$
- More information on that topic is definitely desirable
- S_{EW}=1.023 – Short distance EW corrections calculated by Marciano&Sirlin
- δ_{SU2}= 0.046±0.004 – by Cirigliano et.al and Leutwyler and Roos

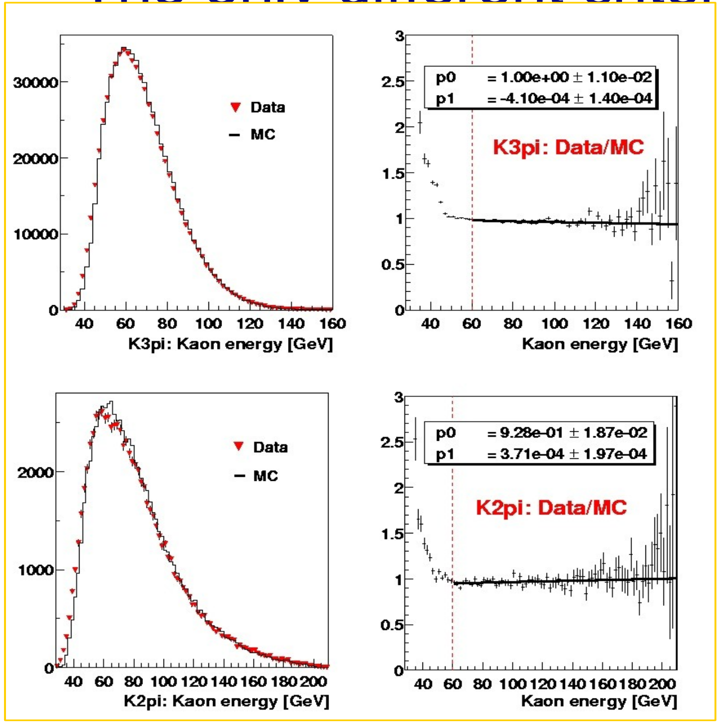
NA48: KLe3 branching fraction

- Method: normalizing to all two track events

$$R_e = \frac{Br(K_{e3})}{Br(K \rightarrow 2-tracks)}, \quad Br(K_{e3}) = R_e[1.0048 - Br(K_{3\pi^0})]$$

- External input: Br(K3π0) = **0.1969±0.0026**
- The only different criteria for selecting Ke3 evens: e-PID





R_e=0.4978±0.0035

⇓

$Br(K_L \rightarrow \pi^{\pm} e \nu)$ = 0.4022 ± 0.0031

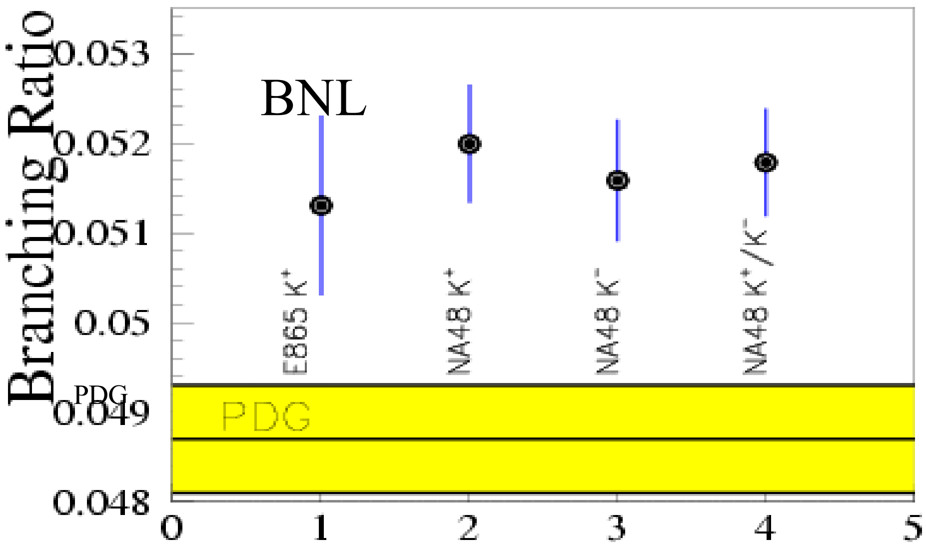
normalization error - 0.0013

NA48/2: $K^{\pm}$e3 branching fraction

- Measuring $Br(K^{\pm}\rightarrow\pi^{0}e\nu)/Br(K^{\pm}\rightarrow\pi^{\pm}\pi^{0})$
- Preliminary result:

$$Br(K^{\pm}\rightarrow\pi^{0}e\nu) = (5.14 \pm 0.02_{stat} \pm 0.06_{syst})\%$$

  – Confirms the deviation from PDG observed by BNL



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

$$Br(K^{\pm}\rightarrow\pi^{0}\mu\nu) = (3.462\pm0.071)\%$$

Final results on the $Br(K^{\pm}\rightarrow\pi^{0}e\nu)$ and $Br(K^{\pm}\rightarrow\pi^{0}\mu\nu)$ expected soon

K_L l3 Branching Fractions: KTeV

- Measure all six largest decay modes in terms of five branching fractions:

$$\Gamma_{K\mu3}/\Gamma_{Ke3} \equiv \Gamma\,(K_L \to \pi\mu\nu) / \Gamma\,(K_L \to \pi e\nu)$$

$$\Gamma_{+-0}/\Gamma_{Ke3} \equiv \Gamma\,(K_L \to \pi^+\pi^-\pi^0) / \Gamma\,(K_L \to \pi e\nu)$$

$$\Gamma_{000}/\Gamma_{Ke3} \equiv \Gamma\,(K_L \to \pi^0\pi^0\pi^0) / \Gamma\,(K_L \to \pi e\nu)$$

$$\Gamma_{+-}/\Gamma_{Ke3} \equiv \Gamma\,(K_L \to \pi^+\pi^-) / \Gamma\,(K_L \to \pi e\nu)$$

$$\Gamma_{00}/\Gamma_{000} \equiv \Gamma\,(K_L \to \pi^0\pi^0) / \Gamma\,(K_L \to \pi^0\pi^0\pi^0)$$

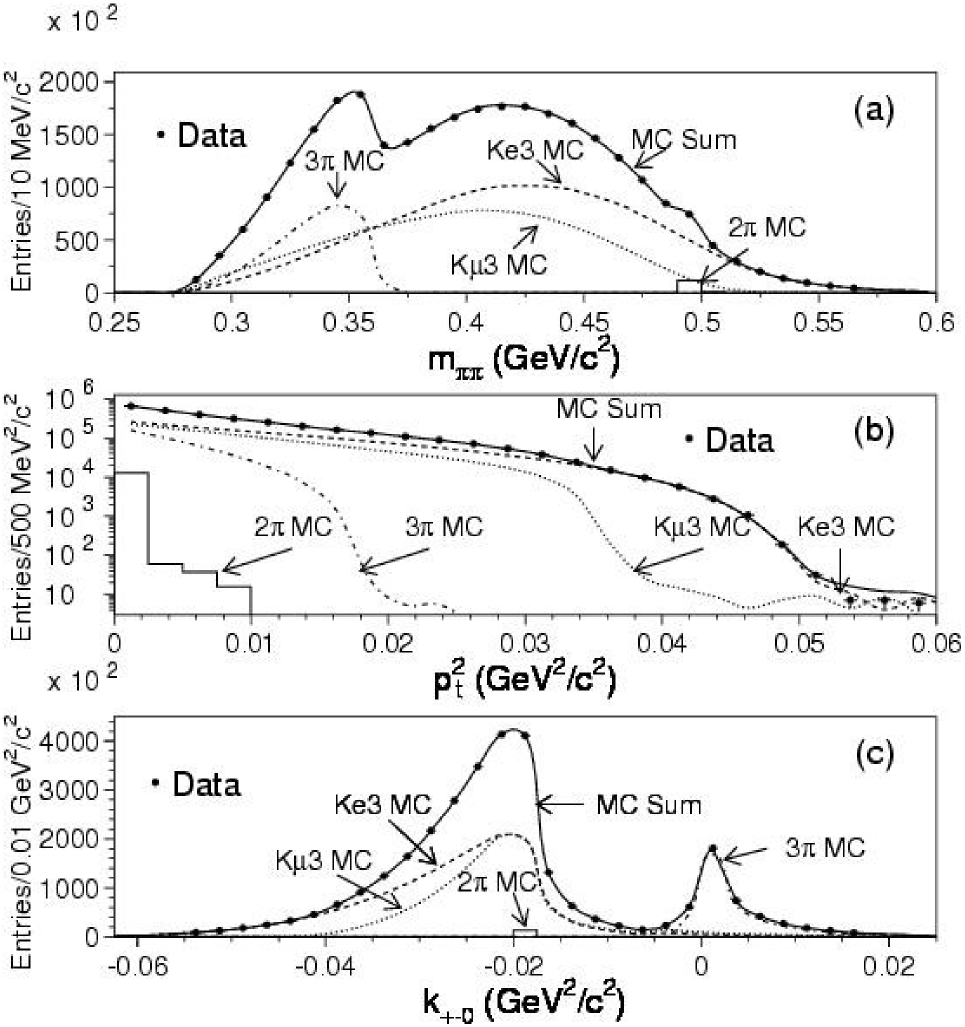
- Using the constraint that the remaining width is only 0.03% to convert into branchings

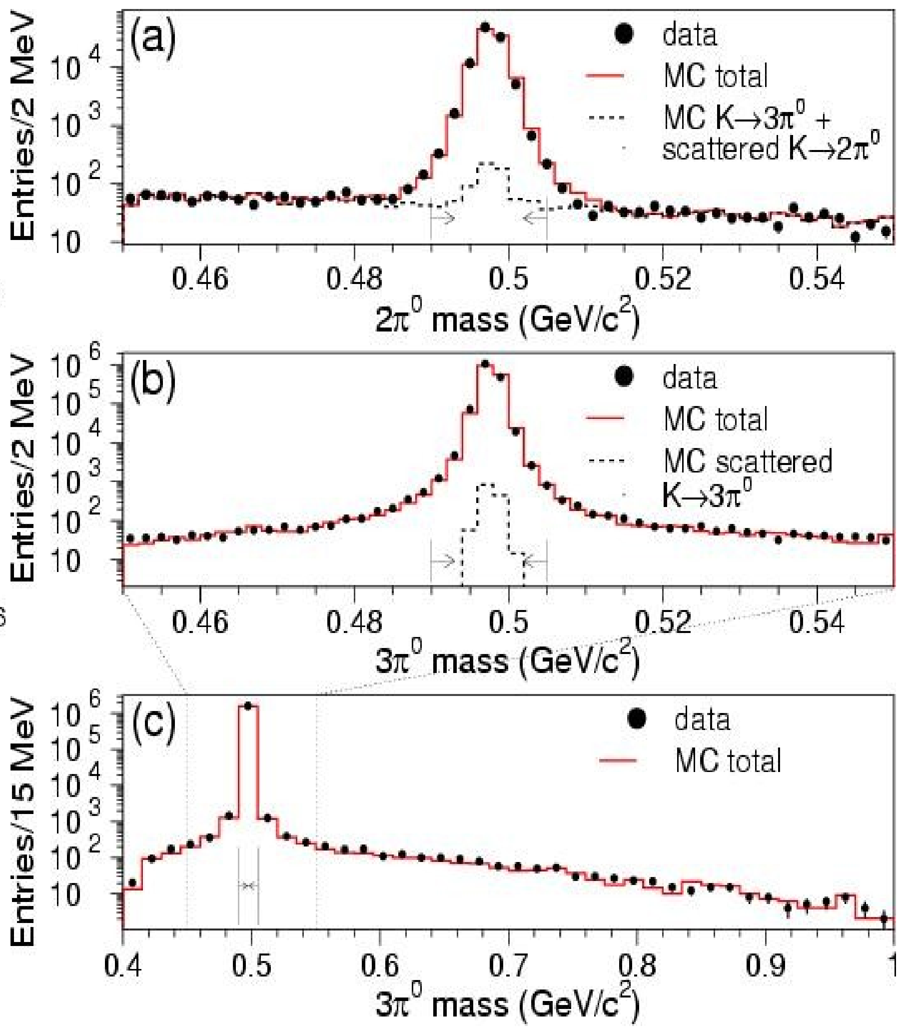
$BR(K_L \to \pi e\nu) = 0.4067 \pm 0.0011$

$BR(K_L \to \pi\mu\nu) = 0.2701 \pm 0.0009$

K_L l3 Branching Fractions: KTeV

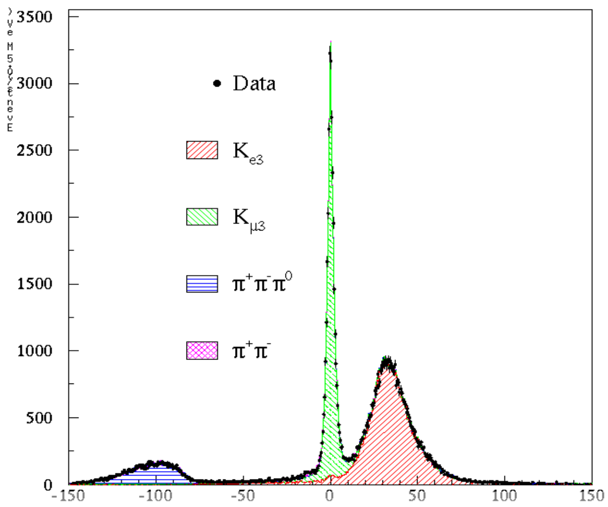
Data – MC comparisons





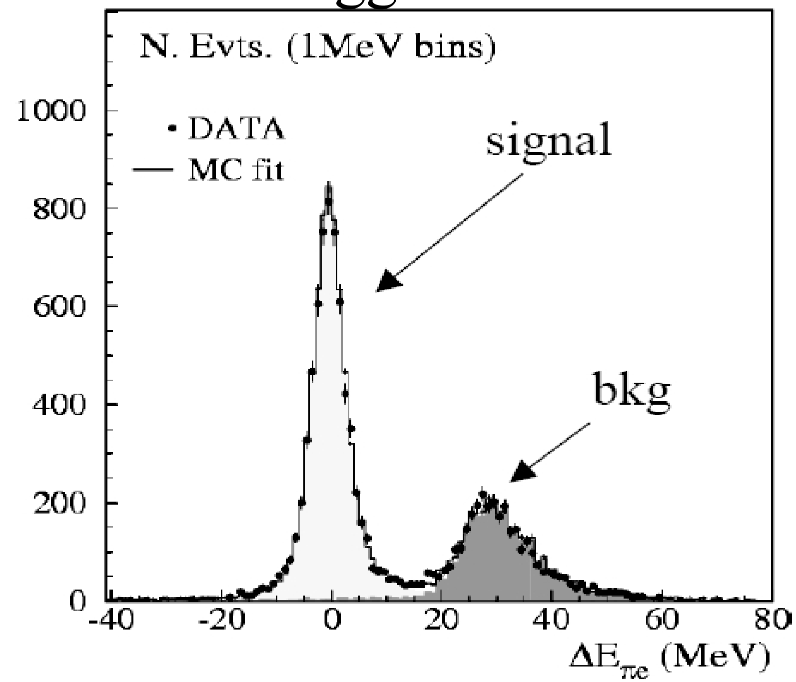
Kl3 Branching Fractions: KLOE

Measured all major KL decay modes



p_{miss}–E_{miss} in πμ or μπ hyp. (MeV)

Used tagged Ks events



$BR(K_L \to \pi e \nu) = 0.4007 \pm 0.0015$

$BR(K_L \to \pi \mu \nu) = 0.2698 \pm 0.0015$

$BR(K_S \to \pi e \nu) = (7.046 \pm 0.091) * 10^{-2}$

Preliminary results for the charged semileptonic decays

$BR(K^{\pm} \to \pi^0 e \nu) = (5.047 \pm 0.043) * 10^{-2}$

$BR(K^{\pm} \to \pi^0 \mu \nu) = (3.310 \pm 0.048) * 10^{-2}$

Kaon semileptonic decays: Summary

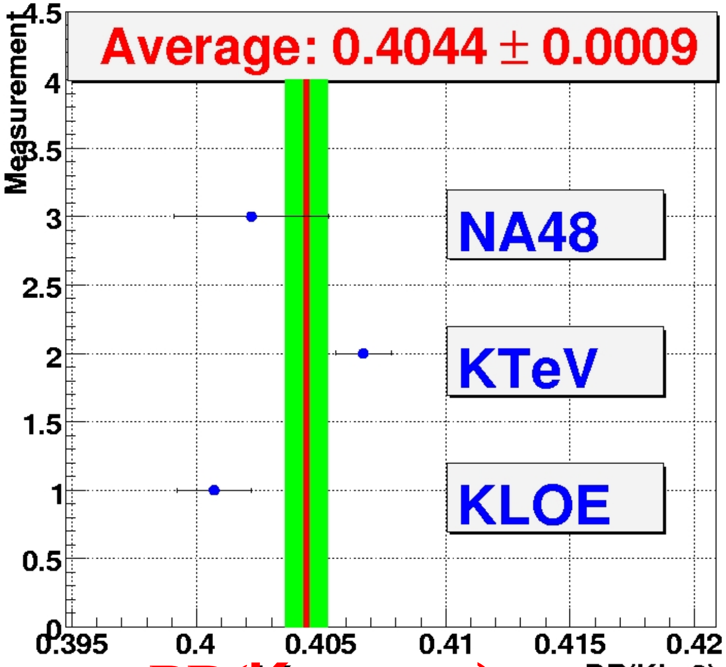
Experiment	Decay	Result
KLOE	$K_L e3$	0.4007 ± 0.0015
	$K_L \mu 3$	0.2698 ± 0.0015
	$K_S e3$	$(7.046 \pm 0.091)*10^{-2}$
	$K^{\pm} e3$	$(5.047 \pm 0.043)*10^{-2}$
	$K^{\pm} \mu 3$	$(3.310 \pm 0.048)*10^{-2}$
KTeV	$K_L e3$	0.4067 ± 0.0011
	$K_L \mu 3$	0.2701 ± 0.0009
NA48	$K_L e3$	0.4022 ± 0.0031
	$K^{\pm} e3$	$(5.14 \pm 0.06)*10^{-2}$
	$K^{\pm} \mu 3$	$(3.462 \pm 0.071)*10^{-2}$

K_L lifetime
$(5.10 \pm 0.02) * 10^{-8}$s

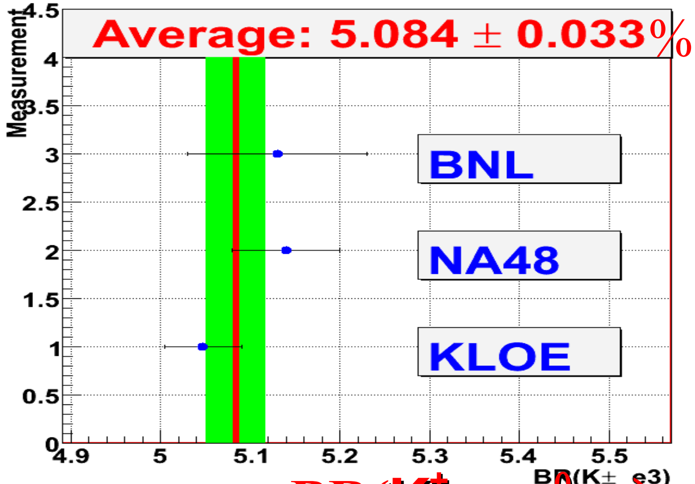
K_S lifetime
$(0.8958 \pm 0.0005) * 10^{-10}$s

$K^{\pm}$ lifetime
$(1.2385 \pm 0.0024) * 10^{-8}$s

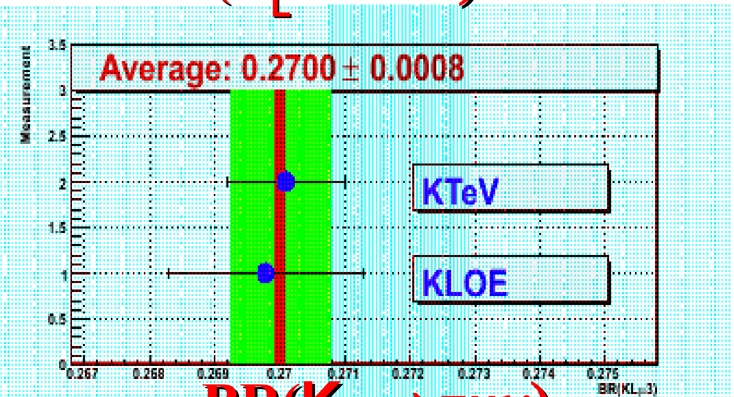
Putting the things together



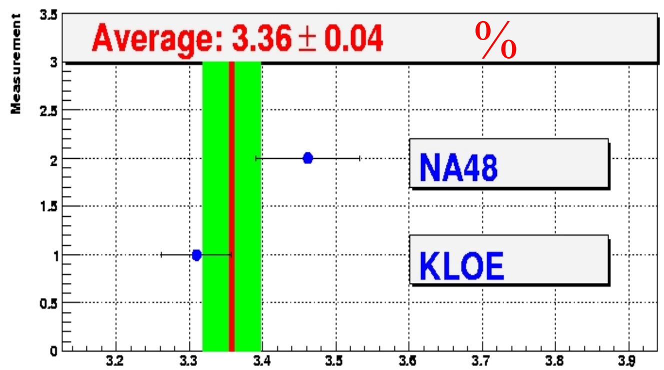
$BR(K_L \to \pi e \nu)$



$BR(K^{\pm} \to \pi^0 e \nu)$



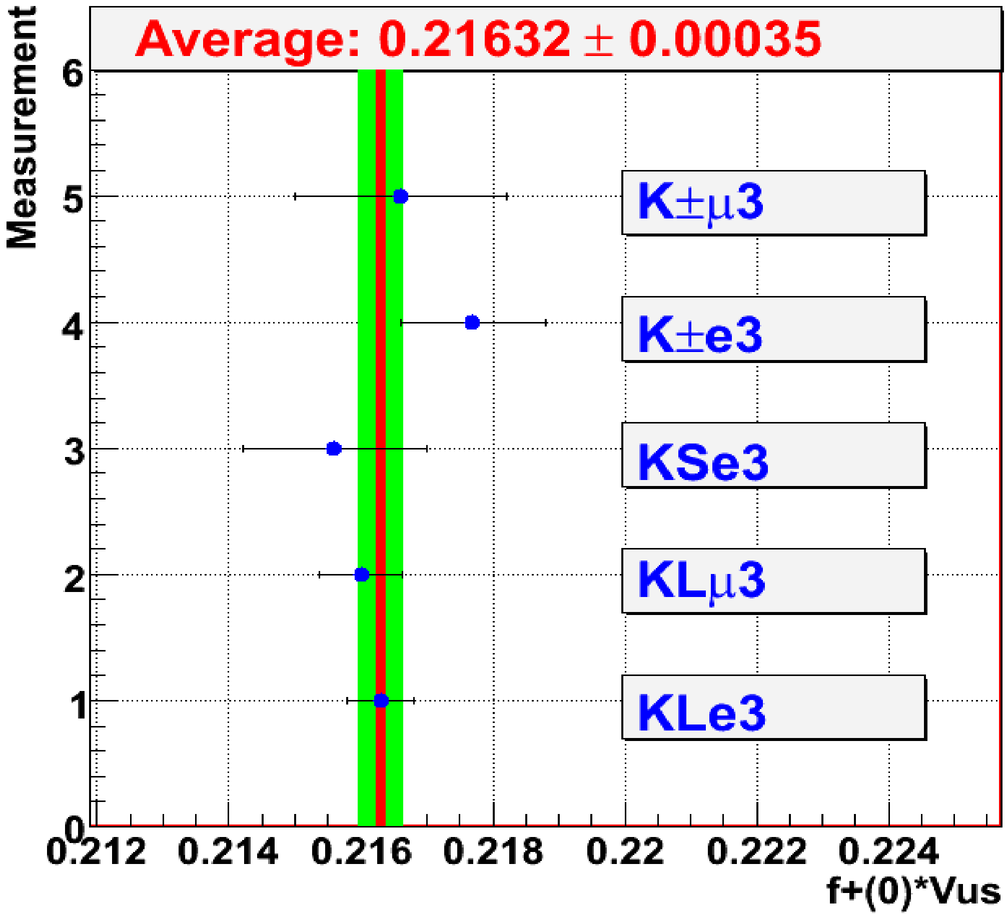
$BR(K_L \to \pi \mu \nu)$



$BR(K^{\pm} \to \pi^0 \mu \nu)$

$$BR(K_S e3) = (7.046 \pm 0.091) * 10^{-2}$$

Vus from kaon semileptonic decays



- Using the f+(0) by Leutwyler and Roos

  Vus = 0.2251±0.0019

  error coming from f+(0)

- Using Vud=0.97377(27)

  Marciano&Sirlin 2006 PRL96 032002

$|Vus|^2 + |Vud|^2 = 0.9989 \pm 0.0010$

Vus from Kμ2 decay

- New result from KLOE for the Br(Kμ2)

$$Br(K\mu2(\gamma)) = 0.6366 \pm 0.0009_{stat} \pm 0.0015_{syst}$$

- Latice calculations give

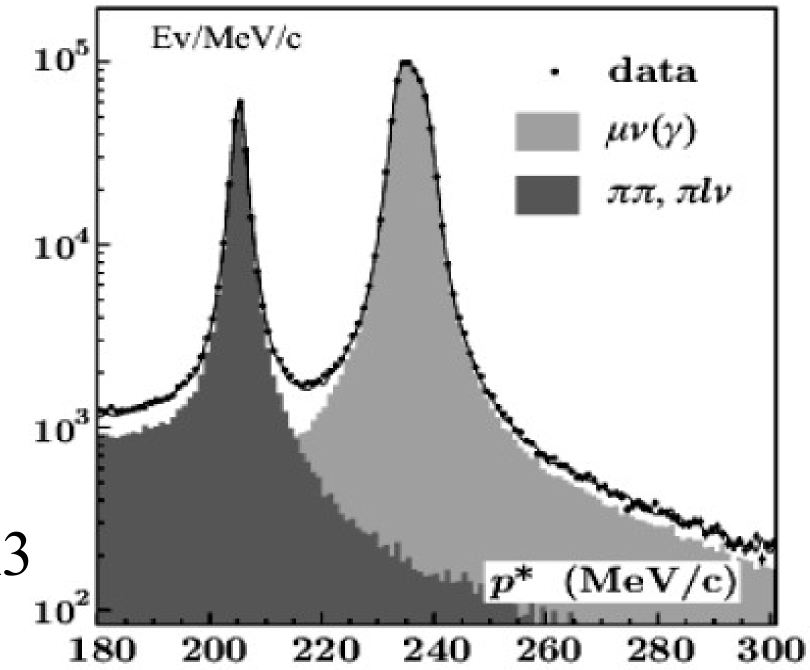
$f_K / f_\pi = 1.198(3)(^{+16}_{-5})$

(MILC Coll. PoS (LAT 2005) 025,2005)

|Vus| / |Vud| = 0.2294 ± 0.0026

|Vus| = 0.2234 ± 0.0026

consistent with the results from Kl3



Conclusion

- NA48, KTeV and KLOE experiments continue to provide a valuable data
- Vus has been obtained using two different methods giving consistent values

$$|V_{us}| = 0.2245 \pm 0.0015$$

- The value of Vus is consistent with unitarity of CKM matrix
- However more clarification on the Kl3 form factors desirable
- Further improvement on the Vus measurement depends on the theory