V_{us} determination from KLOE

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(for the KLOE Collaboration)

V_{us} from Kl3 rates

$$\Gamma(K_{l3(\gamma)}) = \frac{C_K^2 G_F^2 M_K^5}{192\pi^3} S_{EW} |V_{us}|^2 |f_+^{K^0\pi^-}(0)|^2 \times I_{Kl}(\{\lambda\}_{Kl}) (1 + 2\Delta_K^{SU(2)} + 2\Delta_{Kl}^{EM})$$

with $K \in \{K^+, K^0\}$; $l \in \{e, \mu\}$, and:

C_K^2 1/2 for K^+, 1 for K^0

Inputs from theory:

S_{EW} Universal short distance EW correction (1.0232)

$f_+^{K^0\pi}(0)$ Hadronic matrix element at zero momentum transfer (t=0)

$\Delta_K^{SU(2)}$ Form factor correction for strong SU(2) breaking

Δ_{Kl}^{EM} Long distance EM effects

Inputs from experiment:

$\Gamma(K_{l3(\gamma)})$ **Branching ratios** with well determined treatment of radiative decays; **lifetimes**

$I_{Kl}(\lambda)$ Phase space integral: λs parameterize form factor dependence on t :

K_{e3} : only λ_+ (or λ_+' λ_+'')

$K_{\mu 3}$: need λ_+ and λ_0

KLOE is measuring all relevant inputs for charged and neutral kaons: BR's, lifetimes, ff's

K_L BRs, lifetime and Ke3 ff slopes

KLOE
PLB 632 (2006)

Absolute BRs: K_L decays tagged by $K_S \to \pi^+\pi^-$
Set $\sum_x$ BR($K_L \to x$, τ_L) = 1 and solve for BRs and τ_L

$BR^{(0)}(Ke3) = 0.4049(21)$
$BR^{(0)}(K\mu3) = 0.2726(16)$ at $\tau_L^{(0)} = 51.54$ ns
$BR^{(0)}(3\pi^0) = 0.2018(24)$
$BR^{(0)}(\pi^+\pi^-\pi^0) = 0.1276(15)$

KLOE
PLB 626 (2005)

Lifetime: fitting the time depence of $K_L \to 3\pi^0$ decays
High, uniform reconstruction efficiency over $0.4\lambda_L$
Independent of BR measurement

$\tau_L = 50.92(30)$ ns cf. Vosburgh '72: $\tau_L = 51.54(44)$ ns

KLOE
PLB 636 (2006)

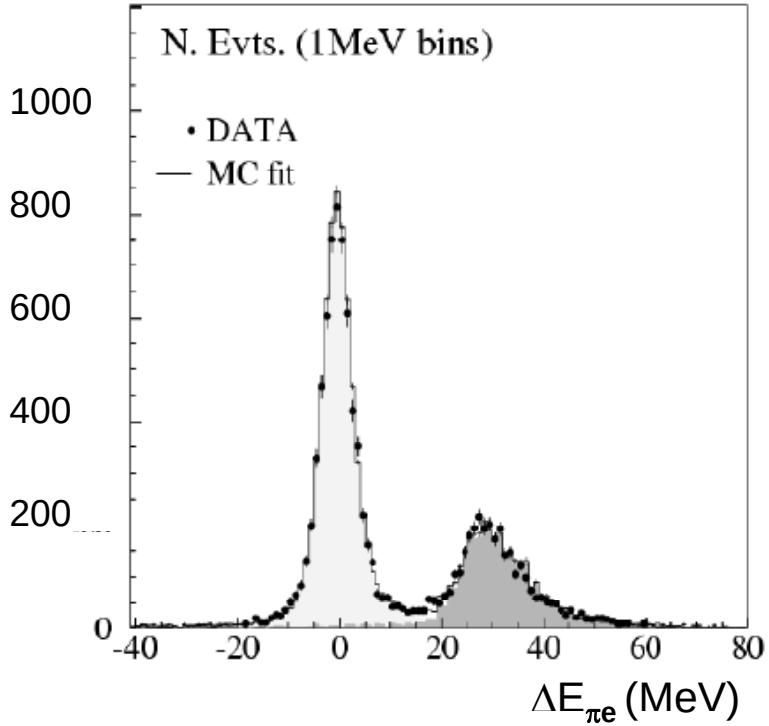
K_Le3 form factor slopes: K_L decays tagged by $K_S \to \pi^+\pi^-$
background rejection and PID using TOF
Agreement between results from quadratic and pole parametrization

$\lambda'_+ \times 10^3$	$\lambda''_+ \times 10^3$
25.5 ± 1.8	1.4 ± 0.8

Correlation -0.95

Unique to KLOE: BR($K_S \to \pi e \nu$)

- Ks tagged by KL interacting in EMC
  - $K_S \to \pi^+ e^- \nu, \pi^- e^+ \nu$:
    extrapolate tracks from IP to EMC
    p/e discrimination from TOF
    signal count from fit of distribution
    of multiple kinetic variables
  - $K_S \to \pi^+ \pi^-$: extrapolate tracks to the IP
    accept events with two tracks
- Normalize $K_S \to \pi^+ e^- \nu, \pi^- e^+ \nu$ to $K_S \to \pi^+ \pi$
- Correct for selection efficiencies by charge



KLOE
PLB 636 (2006)

Using tagged K_S beam

BR($K_S \to \pi e \nu$)/BR($K_S \to \pi^+\pi^-$) = 10.19(13) × 10^{-4}

KLOE
EPJC 48 (2006)

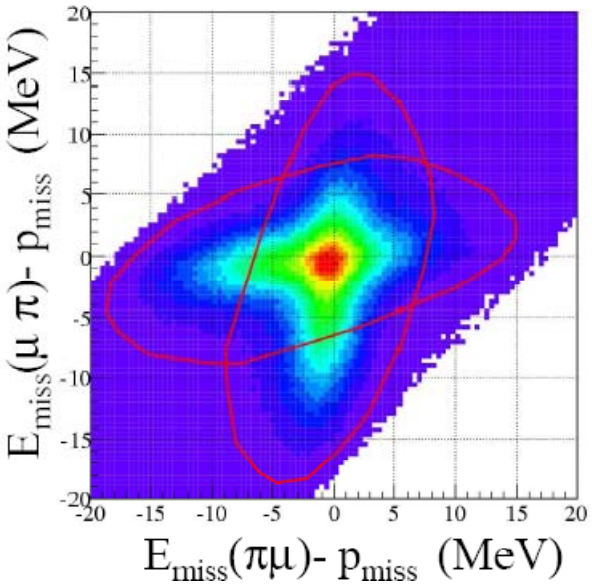
410 pb^{-1}, averaged with KLOE '02 result (17 pb^{-1})

BR($K_S \to \pi^+\pi^-$)/BR($K_S \to \pi^0\pi^0$) = 2.2549(54)

These two measurements completely determine main K_S BRs

BR($K_S \to \pi e \nu$) = 7.046(91) × 10^{-4} (total error dominated by statistics)

$K_L\mu 3$ form factor slopes

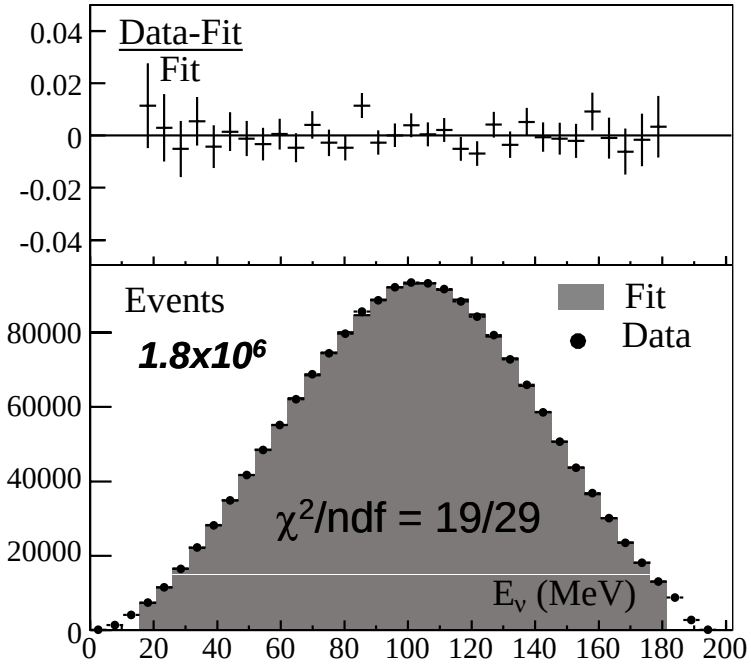


- K_L decays tagged by $K_S \to \pi^+\pi^-$
- preselection cutting on $E_{miss} - p_{miss}$
- background rejection of $\pi\pi$,$\pi\pi\pi$ and $\pi e\nu$ from kinematics
- further reduction of Ke3 background with TOF & NN output (based on E/p and cluster shape)
- *π/μ ID with TOF is difficult at low energies*

λ_0 slope by fitting the E_ν distribution and combined fit with $K_L e3$ results for λ'_+ and λ''_+

KLOE
preliminary

$\lambda'_+ \times 10^3$	$\lambda''_+ \times 10^3$	$\lambda_0 \times 10^3$
25.6 ± 1.8	1.5 ± 0.8	15.4 ± 2.1



More on slopes

Power expansion:

$$f_{+,0}(t) = f_+(0) \times \left(1 + \lambda'_{+,0} \frac{t}{m_\pi^2} + \frac{1}{2} \lambda''_{+,0} \left(\frac{t}{m_\pi^2}\right)^2 + \ldots\right)$$

Pole expansion:

$$f_{+,0}(t) = f_+(0) \frac{1}{1 - t / m_{V,S}^2}$$

Ke3 – vector form factor

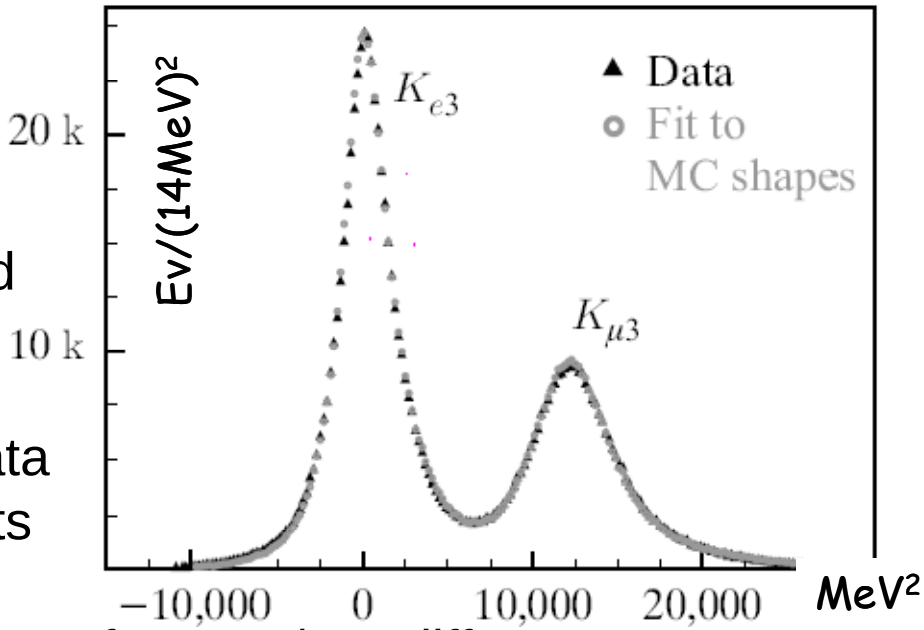
- Experiments are sensitive to both linear and quadratic terms of power exp.
- Results are in agreement with the pole parametrization as expected from dispersion relations

Kμ3 – vector and scalar form factors

- Experiments cannot determine the quadratic coefficient λ_0'' of $\boldsymbol{f_0(t)}$
- Input from theory is needed to write f(t) with one parameter
- Use recent parametrization based on dispersion relations from *Stern & coll.* *PLB 638 (2006)*
  - shift on λ_0' of about -2×10^{-3}
  - impact on phase space integral $\boldsymbol{I_K(\lambda)}$
- Crucial for QCD tests with Callan-Treiman (*see F. Mescia talk*)

Measurement of BR($K^{\pm}l3$)

- **4 independent-tag samples:**
  $K^+\mu 2$, $K^+\pi 2$, $K^-\mu 2$, and $K^-\pi 2$
  keep under control the systematic effects due to the tag selection
- kinematical cuts to reject background
  residual background is about 1.5% of the selected $K^{\pm}_{l3}$ sample
- **constrained likelihood fit of m^2** data distributions from **ToF** measurements
  count the number of signal events
- selection efficiency from MC and correct for Data/MC differences
  (dominating contribution to the final uncertainty)



KLOE final

Absolute BR($K^{\pm}e3$) and BR($K^{\pm}\mu 3$) measurements

Separate measurements for each charge
Tagged by $K \to \mu\nu$ and $K \to \pi\pi^0$: 8 measurements total

$$BR^{(0)}(K^{\pm}e3) = 4.965(53)\%$$
$$BR^{(0)}(K^{\pm}\mu 3) = 3.233(39)\%$$

at $\tau_{\pm}^{(0)} = 12.384$ ns, with d BR/BR $= -0.45\, d\tau_{\pm}/\tau_{\pm}$

$K^{\pm}$ lifetime

- Poor consistency of PDG average with measurements spread

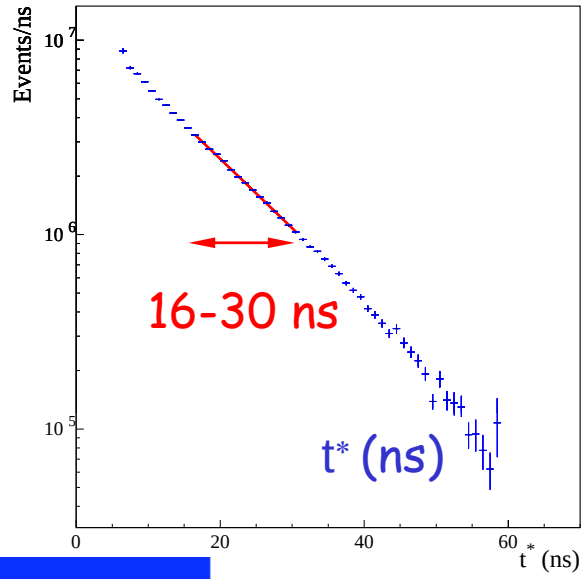
$$\delta\tau/\tau \sim 0.2\% \rightarrow \delta V_{us}/V_{us} \sim 0.1\% \qquad \delta\tau/\tau \sim 0.8\% \rightarrow \delta V_{us}/V_{us} \sim 0.4\%$$

- Use $K_{\mu 2}$ tagged decay vertices in drift chamber and two different methods to evaluate the proper time ***t**** (cross-check systematic effects)

Fit to t^* distribution from decay length

Coverage: 16-30 ns → $1.1\tau_{\pm}$

Evaluation of t^* includes dE/dx (2 mm steps)

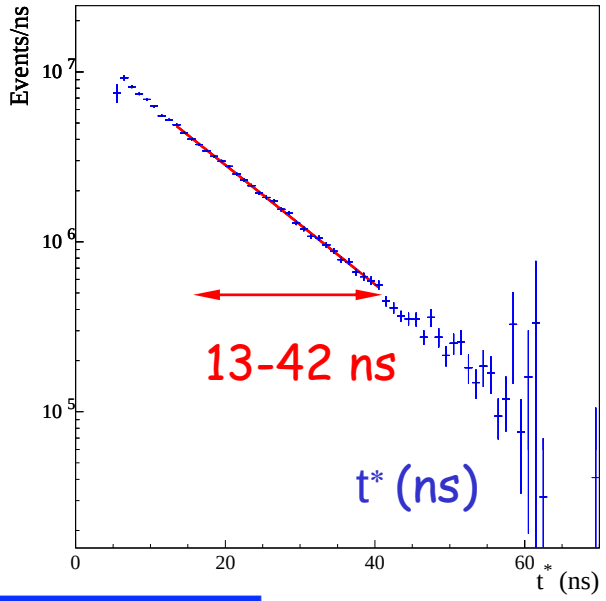


KLOE '06 preliminary

$\tau_{\pm}$ = 12.367(44)(65) ns

Fit to t^* distribution from decay time

Coverage: 13-42 ns → $2.3\tau_{\pm}$

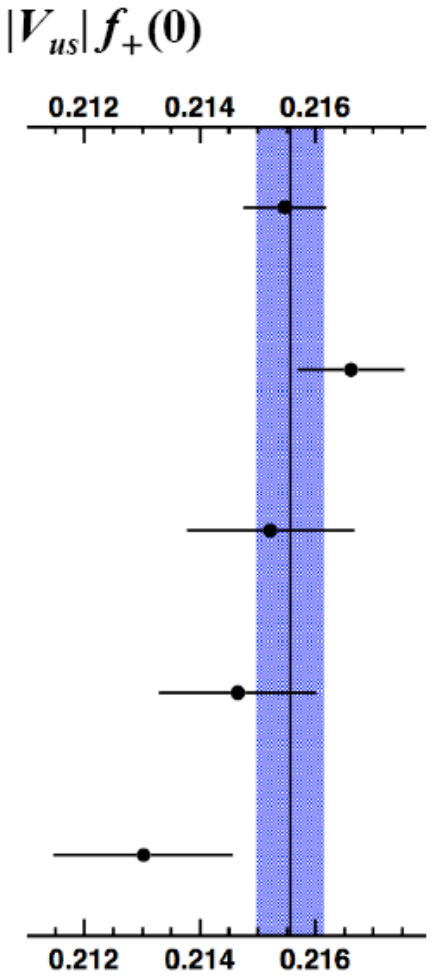


KLOE '07 preliminary

$\tau_{\pm}$ = 12.391(49)(25) ns

ρ = 0.34

$|V_{us}|f_+(0)$ from KLOE data



		% err
$K_L e3$	0.21547(72)	0.34
$K_L \mu 3$	0.21661(93)	0.43
$K_S e3$	0.21522(145)	0.68
$K^\pm e3$	0.21465(137)	0.64
$K^\pm \mu 3$	0.21302(155)	0.73

$K^+ - K^0$ diff.: -1.3σ

$\Delta^{SU(2)}_{exp}$ = 1.52(63)%

$r_{\mu e}(K^0)$ =1.0109(89)

$r_{\mu e}(K^+)$ = 0.9848(108)

$r_{\mu e}$ = 1.0011(76)

Prob(χ^2) = 3.43%

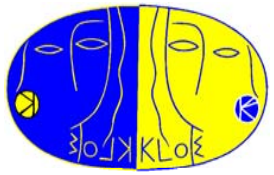
see T. Spadaro talk

$|V_{us}|$ = 0.22433(134)

Unitarity test: -2.0σ

Average: $|V_{us}|f_+(0)$ = 0.21556(59) χ^2/ndf = 6.1/4 (19%)

$BR(K^{\pm} \to \mu\nu(\gamma))$ and V_{us}/V_{ud}



Marciano '04

$$\frac{\Gamma(K^{\pm} \to \mu^{\pm}\nu(\gamma))}{\Gamma(\pi^{\pm} \to \mu^{\pm}\nu(\gamma))} = \frac{|V_{us}|^2 f_K^2 m_K (1 - m_\mu^2/m_K^2)^2}{|V_{ud}|^2 f_\pi^2 m_\pi (1 - m_\mu^2/m_\pi^2)^2} \times 0.9930(35)$$

Uncertainty from SD virtual corrections

HP/UKQCD '07
arXiv:0706.1726

f_K/f_π = 1.189(7)
N_f = (2+1)$_{stag}$
Cancellation of lattice-scale uncertainties

KLOE
PLB 636 (2006)

BR($K^+ \to \mu^+\nu(\gamma)$) = 0.6366(17)
Uses $K^- \to \mu^-\nu$ to tag 2-body K decays
Counts $K^+ \to \mu^+\nu$ from decay-momentum spectrum

Use KLOE BR($K^+ \to \mu^+\nu(\gamma)$) instead of value from BR/lifetime fit:
Error slightly larger, but radiative contribution under better control

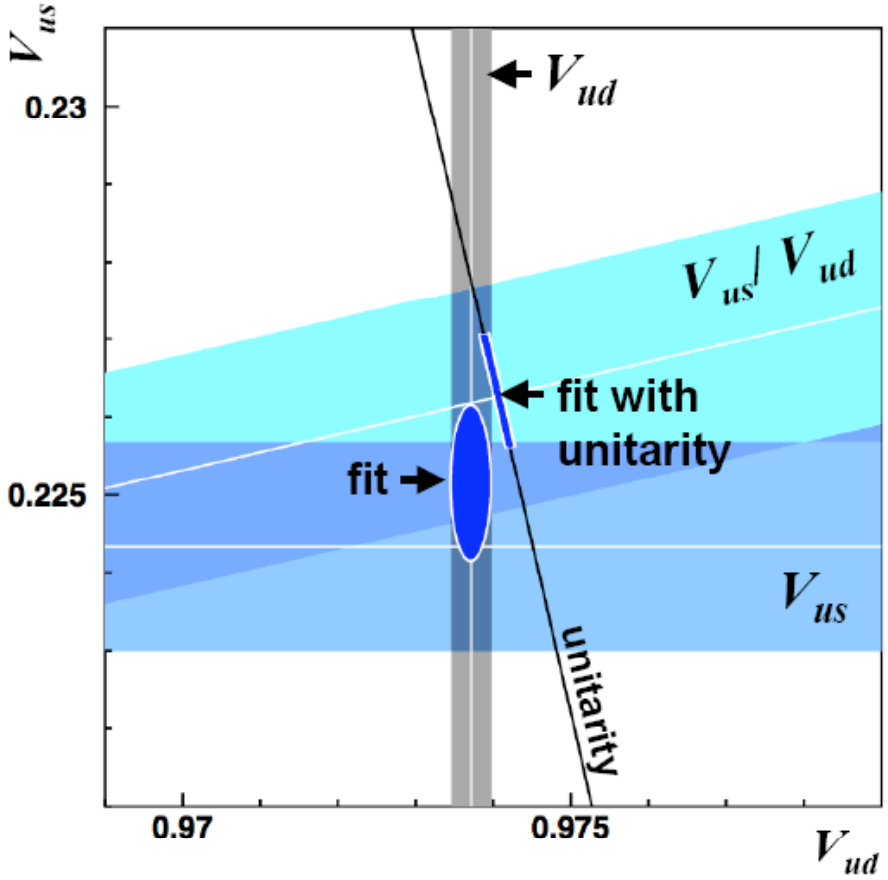
V_{us}/V_{ud} = 0.2323(15)

For New Physics search related to this channel refer to T. Spadaro talk

V_{us} – V_{ud} plane

$f_+(0)$ from UKQCD/RBC '06

$|V_{us}|$ = 0.2243(13) from KLOE *Kl3*



Fit results, no constraint:

V_{ud} = 0.97371(26)
V_{us} = 0.2252(10)
χ^2/ndf = 0.85/1 (36%)

Fit results, unitarity constraint:

V_{ud} = 0.97405(17)
V_{us} = 0.2263(7)
χ^2/ndf = 3.8/2 (14.6%)

Agreement with unitarity 1.5σ

$BR(K^+ \to \pi^+ \pi^0 (\gamma))$

This new measurement is crucial in order to perform the fit to $K^\pm$ BR's:

- ✧ only Kl3 and Kl3/Kπ2 measured recently
- ✧ Kl3 and Kπ2 are strongly correlated
- ✧ the available measurement dates back to Chiang '72

  $BR(K^\pm \to \pi^\pm \pi^0) = (21{,}18 \pm 0.28)\%$ $\quad \Delta BR/BR = 1{,}3 \times 10^{-2}$
- ✧ but no radiative corrections & no correlations available

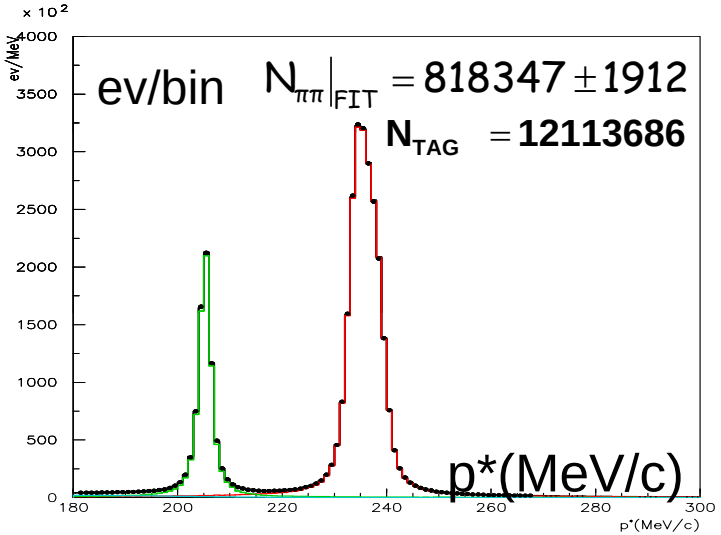
This decay enters in the normalization of BR($K^\pm$l3) by NA48, ISTRA+, E865 used for Vus

The absolute $BR(K_{\pi 2})$ measurement

- ❖ Normalization sample is given by $K^- \to \mu^- \nu$ tag
- ❖ Number of $K^\pm \to \pi^\pm \pi^0$ decays from the fit of the distribution of the momentum of the charged decay particle in the kaon rest frame assuming the pion mass (p*)
- ❖ Selection efficiency related to Drift Chamber information only and measured directly on DATA using the $K^\pm \to X^\pm \pi^0$ control sample identified from $\pi^0 \to \gamma\gamma$ decay vertex

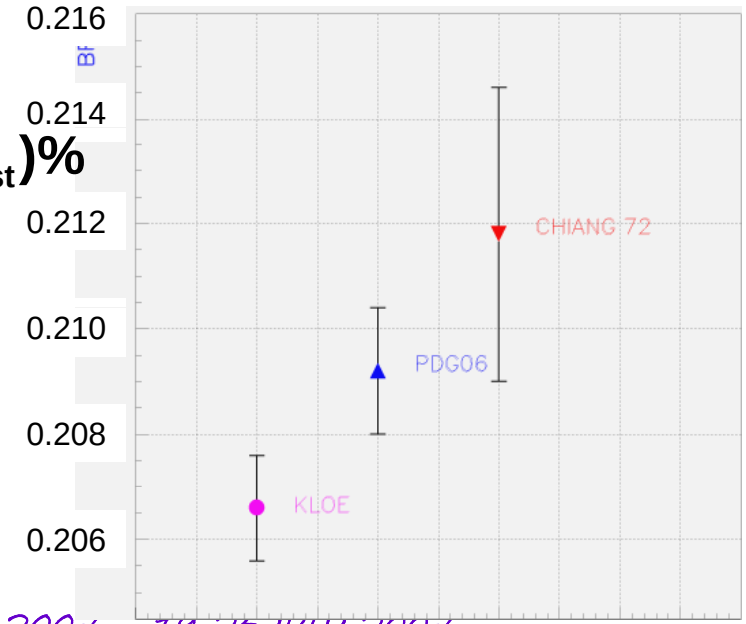
$BR(K^+ \to \pi^+ \pi^0 (\gamma))$: Preliminary result

- Signal count from the fit the p* distribution with three contributions:
  - $\mu\nu$ peak from DATA control sample selected using calorimetric information only
  - $\pi\pi^0$ peak from DATA control sample selected using calorimetric information only
  - 3-body decays from MC
- Normalize to the number of tags
- Correct for the selection efficiency



KLOE preliminary

$$BR(K^+ \to \pi^+ \pi^0(\gamma)) = (20.658 \pm 0.065_{stat} \pm 0.090_{syst})\%$$



PDG fit '06

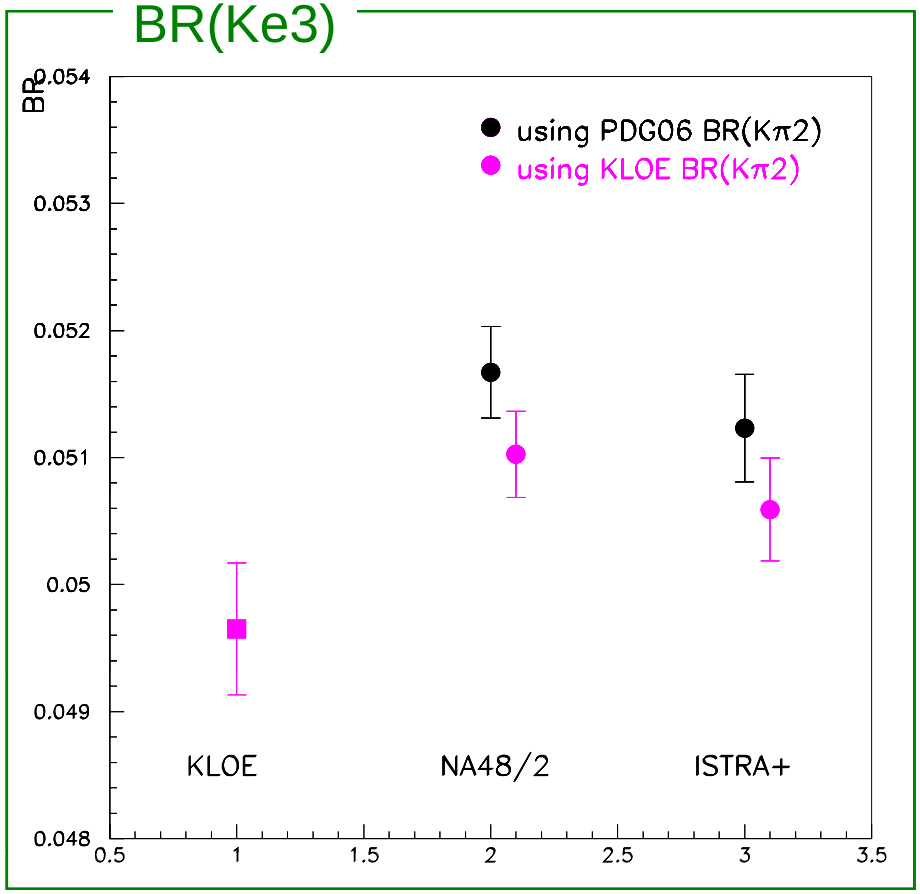
$BR(K^\pm \to \pi^\pm \pi^0) = (20{,}92 \pm 0.12)\%$ $\Delta BR/BR = 5{,}7 \times 10^{-3}$

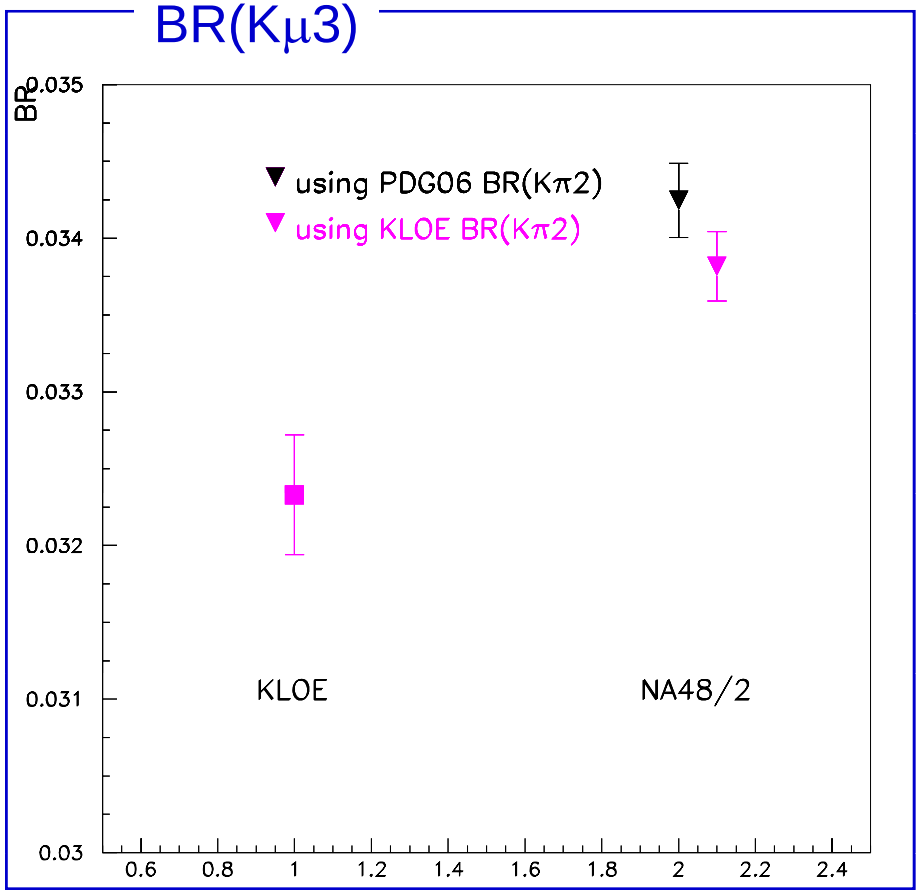
CHIANG '72

$BR(K^\pm \to \pi^\pm \pi^0) = (21{,}18 \pm 0.28)\%$ $\Delta BR/BR = 1{,}3 \times 10^{-2}$

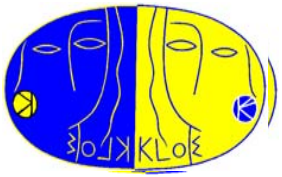
$BR(K^+ \to \pi^+ \pi^0 (\gamma))$: Preliminary result

Impact of the new measurement wrt PDG06 fit value on the BR(Kl3) measurements normalized to Kπ2 decays and comparison with absolute BR(Kl3) measurements from KLOE





Summary & conclusions



- KLOE is playing a fundamental role in the determination of V_{us} being the only experiment able to measure all the parameters needed for its determination and using both $K^{\pm}$ and $K_{L,S}$

Kaon decay analyses published in 2006

- ✓ absolute BR's for 4 main K_L channels and τ_L
- ✓ form factor slopes for $K_L e3$ decays
- ✓ BR's and charge asymmetry for $K_S e3$
- ✓ precise measurement of $\Gamma(\pi^+\pi^-(\gamma))/\Gamma(\pi^0\pi^0)$
- ✓ absolute BR for $K^+ \to \mu\nu(\gamma)$ decay

Results announced at previous conferences

- ✓ preliminary result on form factor slopes for $K_L\mu 3$ decays
- ✓ final results on absolute BR's of $K^{\pm}_{l3}$ decays
- ✓ $K^{\pm}$ lifetime from both decay length and timing measurements

Preliminary measurement announced at this conference

- ✓ absolute BR's of $K^+ \to \pi^+\pi^0(\gamma)$

… and more to come: $K_S\mu 3$ decays, ff slopes for $K^{\pm}$ (l3) decays and analyze the whole data set

- Present accuracy on $|V_{us}|f_+(0)$ is <0.3% using KLOE results only