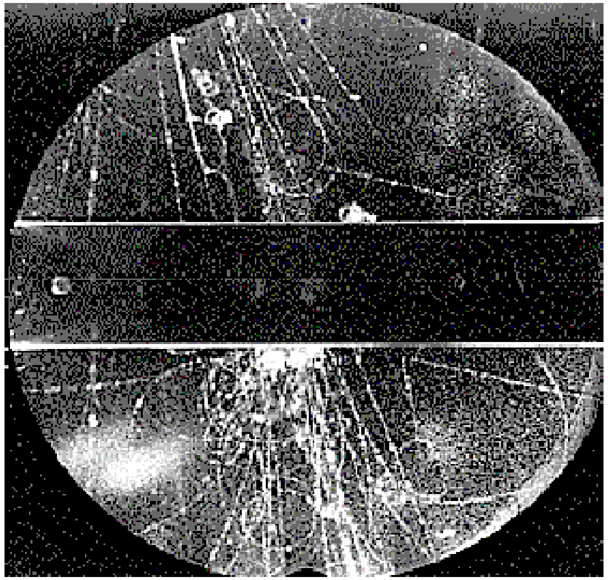
Recent measurements on V_{us}

After a long history the K system continiues to be a laboratory for interesting physics: flavour physics, CP violation, CKM matrix. It can be a sensitive probe for NP. Most of the recent results come from KLOE, KTEV, NA48

Neutral Kaons discovered in ***Cosmic Rays*** in 1947.



- ✓ Unitarity test of the CKM matrix
- ✓ KLOE, KTeV and NA48 experimental results
- ✓ V_{us} & V_{us}/V_{ud} extraction

Unitarity test of CKM

Unitarity (or lack thereof) of CKM matrix tests existence of further quark generations and possible new physics (eg. Supersymmetry)

Most precise test of unitarity possible at present comes from 1st row:

$$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 \sim |V_{ud}|^2 + |V_{us}|^2 \equiv 1 - \Delta$$

Can test if $\Delta = 0$ at 10^{-3} level:

from super-allowed nuclear β-decays: $2|V_{ud}|\delta V_{ud} = 0.0010$
from semileptonic kaon decays: $2|V_{us}|\delta V_{us} = 0.0010$

$V_{ud}^2 = 0.9483 \pm 0.0010$ (nuclear decays)

$V_{us}^2 = 0.0482 \pm 0.0010$ (from e.g. $K^+ \to \pi^0 e^+ \nu_e$)

$V_{ub}^2 = 0.000011 \pm 0.000003$ (B meson decays)

PDG 2004

$$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 0\ 9965 \pm 0.0015$$

(~ 2.3 σ deviation)

V_{us} from Kl3 decays

$|V_{us}|$ can be determined from K_{l3} partial decay widths

$$|V_{us}| \cdot f_+^{K^0\pi^-}(0) = \left[\frac{\Gamma_i}{\mathcal{N}_i\, S_{ew}\, I_i(\lambda_+, \lambda_0, 0)}\right]^{1/2} \frac{1}{1 + \delta^i_{SU(2)} + \delta^i_{e^2p^2} + \frac{1}{2}\Delta I_i(\lambda_+, \lambda_0)}$$

Experimental input

few 10^{-2}

where i runs over the four modes $K^{\pm,0}(e3)$, $K^{\pm,0}(\mu3)$

- $N_i = \dfrac{G^2_\mu M^5_{Ki}}{192\pi^3} C^2_i$ [Ci=1($2^{-½}$) for neutral (charged kaon decays)]
- $f_+^{K0\pi-}(0)$ form factor at zero momentum transfer: pure theory calculation (χPT, lattice)
- $I(\lambda_+, \lambda_0, 0)$ phase space integral, S_{ew} short distance corrections (1.0232)
- $\delta^i_{SU(2)}$, δ_{e2p2} form factor correction due to isospin breaking (strong and electromagnetic)
- $\Delta I_i(\lambda_+,\lambda_0)$) phase space electromagnetic correction
- λ_+,λ_0 slopes (momentum dependence of the vector and scalar form factors)

2003: A new value for BR(K^+_{e3})

BNL E865

***Br*($K^+ \rightarrow \pi^0 e^+ \nu$) =(5.13±0.02stat±0.10sys)%**

PDG(<2004): (4.87±0.06)%

Gives value for V_{us} consistent with unitarity but BR is 2.7σ above previous value.

Using 70,000 K^+_{e3} decays normalized to $K^+ \rightarrow \pi^+\pi^0$, $K^+ \rightarrow \pi^0\mu^+\nu$, $K^+ \rightarrow \pi^+\pi^0\pi^0$,

- Key issue is systematic control of the Branching Ratio.
- Detector not optimized for photons (designed for $\pi^+\mu^- e^+$)
- ***Require:*** $\pi^0 \rightarrow e^+e^-\gamma$ in signal and normalization ($K^+ \rightarrow \pi^+ \pi^0$)

Measurements for V_{us}: 2004-2006

	K^0	$K^{\pm}$
KTeV	✓ K_L dominant BR's	
	✓ K_L semileptonic ff slopes	
NA48	✓ $BR(K_L \to \pi e \nu)$	✓ $BR(K^{\pm} \to \pi^0 e \nu)$
	✓ K_L semileptonic ff slopes	
KLOE	✓ $BR(K_S \to \pi e \nu)$	✓ $K^{\pm}$ semileptonic BR's
	✓ K_L dominant BR's	✓ $BR(K^+ \to \mu^+ \nu (\gamma))$
	✓ K_L lifetime	✓ $K^{\pm}$ lifetime
	✓ $K_L \to \pi e \nu$ ff slopes	
ISTRA		✓ $BR(K^- \to \pi^0 e \nu)$
		✓ K^- semileptonic ff slopes

K_L BRs from KTeV

KTeV measures 5 K_L decay ratios →

(sample sizes 10^5-10^6)

$\Gamma_{e3} / \Gamma_{\mu3}$, $\Gamma_{+-0} / \Gamma_{e3}$, $\Gamma_{000} / \Gamma_{e3}$

$\Gamma_{+-} / \Gamma_{e3}$, $\Gamma_{00} / \Gamma_{000}$

These 6 decay modes account for 99.93% of K_L decays and the ratio can be combined to extract BR,i.e

$$B_{Ke3} = \frac{0.9993}{1 + \frac{\Gamma_{K\mu3}}{\Gamma_{Ke3}} + \frac{\Gamma_{000}}{\Gamma_{Ke3}} + \frac{\Gamma_{+-0}}{\Gamma_{Ke3}} + \frac{\Gamma_{+-}}{\Gamma_{Ke3}} + \frac{\Gamma_{00}}{\Gamma_{Ke3}}}$$

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

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

$BR(K_L \to \pi\pi\pi^0) = 0.1252 \pm 0.0007$ [PRD 70 (2004)]

$BR(K_L \to \pi^0\pi^0\pi^0) = 0.1945 \pm 0.0018$

$BR(K_L \to \pi^+\pi^-) = (1.975 \pm 0.012)\times 10^{-3}$

$BR(K_L \to \pi^0\pi^0) = (0.865 \pm 0.010)\times 10^{-3}$

$BR(K_{L\,e3})$ from NA48

measures ratio of BR: PLB, 602 (2004) **(~6 million reconstructed K_{e3})**

- $$R = \frac{BR(K_L \to \pi e \nu)}{BR(2\ \text{track})} = 0.4978 \pm 0.0035 \approx \frac{BR(K_L \to \pi e \nu)}{1 - BR(K_L \to 3\pi^o)}$$

Using PDG-KTeV average for $BR(K_L \to 3\pi^0) = 0.1992 \pm 0.0070$

↓

$$BR(K_L \to \pi e \nu) = 0.4010 \pm 0.0028_{exp} \pm 0.0035_{norm}$$

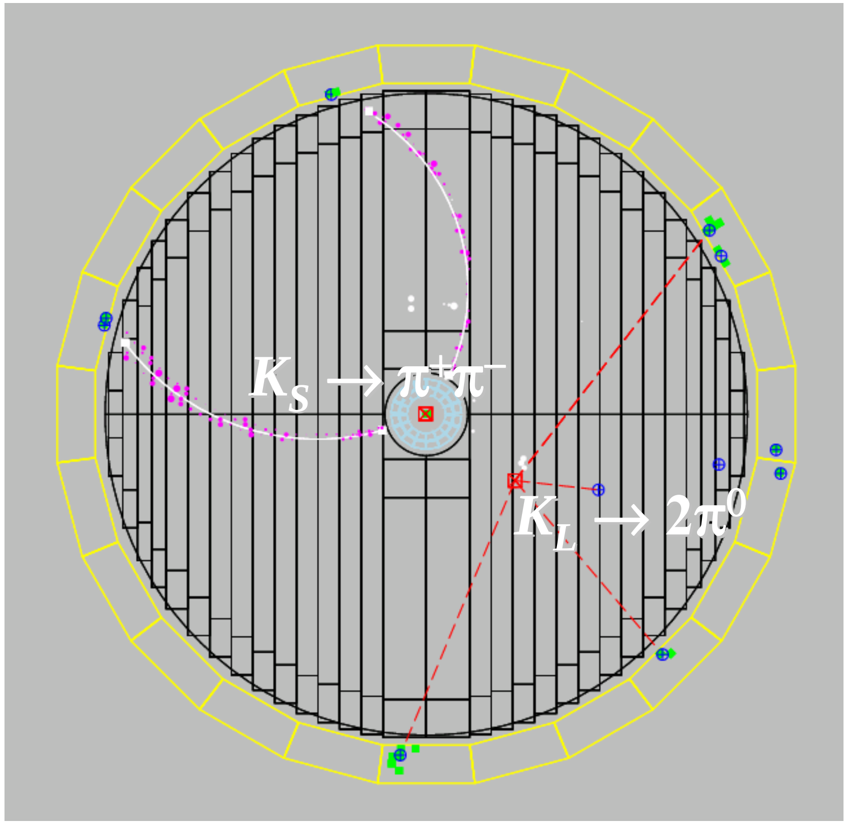
- They also have a **preliminary** measurement of **$BR(K_L \to 3\pi^0)$** extracted from $BR(K_L \to 3\pi^0)/BR(K_S \to 2\pi^0)$

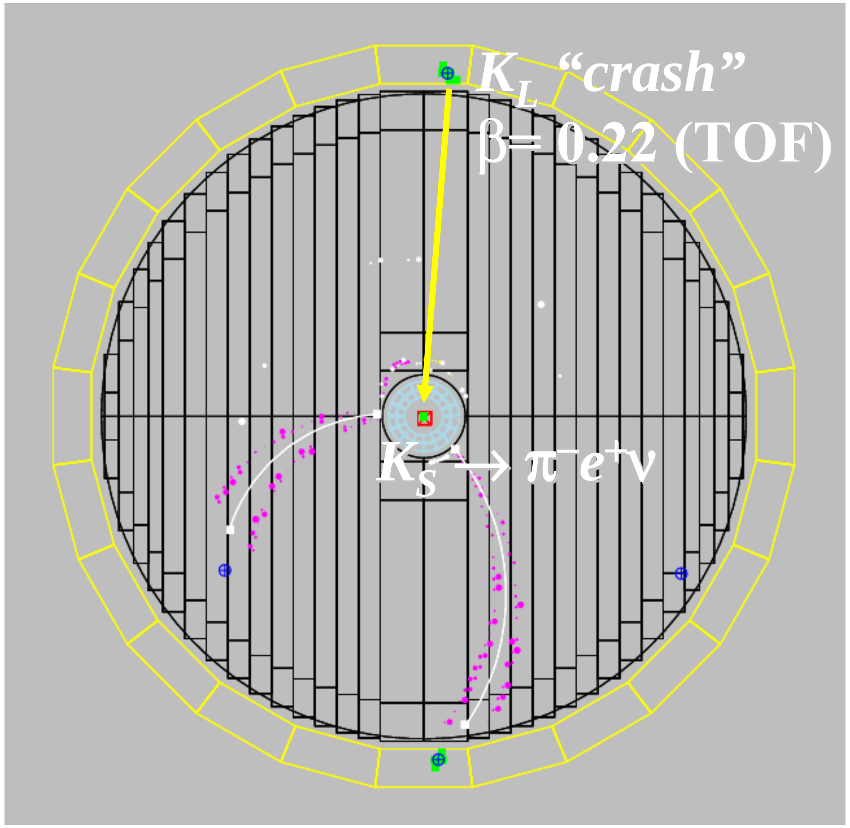
↓

$BR(K_L \to 3\pi^0) = 0.1966 \pm 0.0006 \pm 0.0033$ (PDG value for $BR(K_S \to 2\pi^0)$)

Compare $BR(K_L \to 3\pi^0) = 0.1969 \pm 0.0026$ from KLOE-KTeV average

KLOE:Tagging of neutral kaons





K_L tagged by $K_S \to \pi^+\pi^-$
Efficiency ~ 70%
K_L momentum resolution ~ 1 MeV

K_S tagged by K_L interaction in EmC
Efficiency ~ 30%
K_S momentum resolution ~ 1 MeV

KLOE:Measurement of K_L BR's

Tagging → Precisely measure absolute branching ratios

$$BR(K_L \to i) = \frac{N_i}{N_{tag}} \times \frac{1}{\varepsilon(i)_{rec} \times \varepsilon_{FV}(\tau_L) \times \varepsilon_{tag}(i)/\varepsilon_{tag}(all)}$$

Reconstruction efficiencies:

$K_L \to \pi\mu\nu, \pi e\nu$	ε (rec) ≅ 55%
$K_L \to \pi^+\pi^-\pi^0$	ε (rec) ≅ 40%
$K_L \to 3\pi^0$	ε (rec) ≅ 100%

Integral over the fiducial volume:
ε (FV, τ_L) ≅ 26%, depends on τ_L

Tag bias

Trigger required on the K_S side

Dominant K_L branching ratios

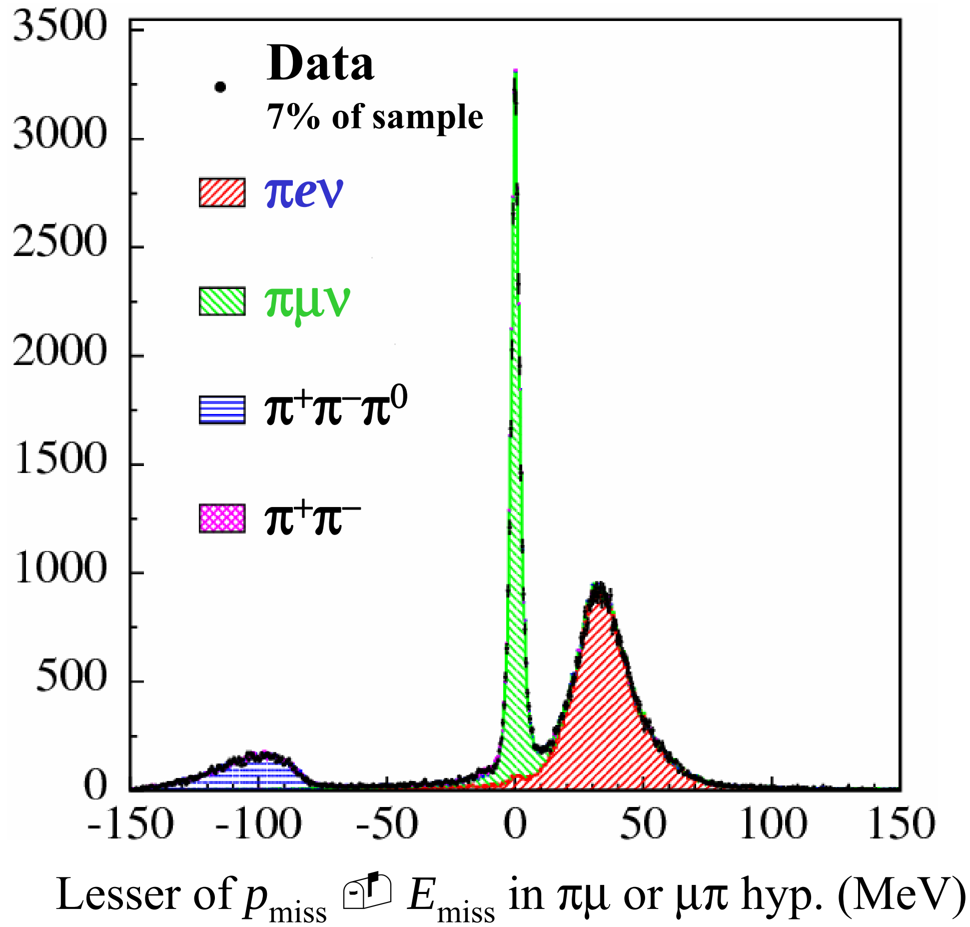
Absolute BR mmts to 0.5-1% using K_L beam tagged by $K_S \rightarrow \pi^+\pi^-$

328 pb^{-1} '01 + '02 data

13 × 10^6 K_L's for counting (25%)
75% used to evaluate efficiencies

BR's to $\pi e\nu$, $\pi\mu\nu$, and $\pi^+\pi^-\pi^0$:

- K_L vertex reconstructed in DC
- PID using decay kinematics
- Fit with MC spectra including radiative processes and optimized EmC response to $\mu/\pi/K_L$



BR to $\pi^0\pi^0\pi^0$:

- Photon vertex reconstructed by TOF using EmC (≥ 3 clusters)
- ε_{rec} = 99%, background < 1%

KLOE: BR results

Errors on absolute BR's dominated by error on ♦$_L$

K_L FV acceptance depends on the lifetime :

setting Σ BR($K_L \to$ X) =1
independent measurement of τ_{KL}

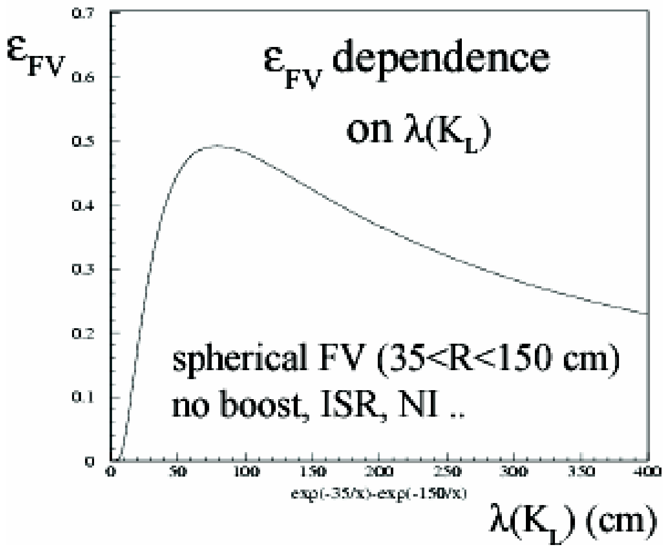
τ_{KL} = 50.72 ± 0.17 ± 0.33 ns

BR($K_L \to \pi e \nu(\gamma)$) = 0.4007 ± 0.0006 ± 0.0014

BR($K_L \to \pi \mu \nu(\gamma)$) = 0.2698 ± 0.0006 ± 0.0014

BR($K_L \to 3\pi^0$) = 0.1997 ± 0.0005 ± 0.0019

BR($K_L \to \pi^+\pi^-\pi^0(\gamma)$) = 0.1263 ± 0.0005 ± 0.0011

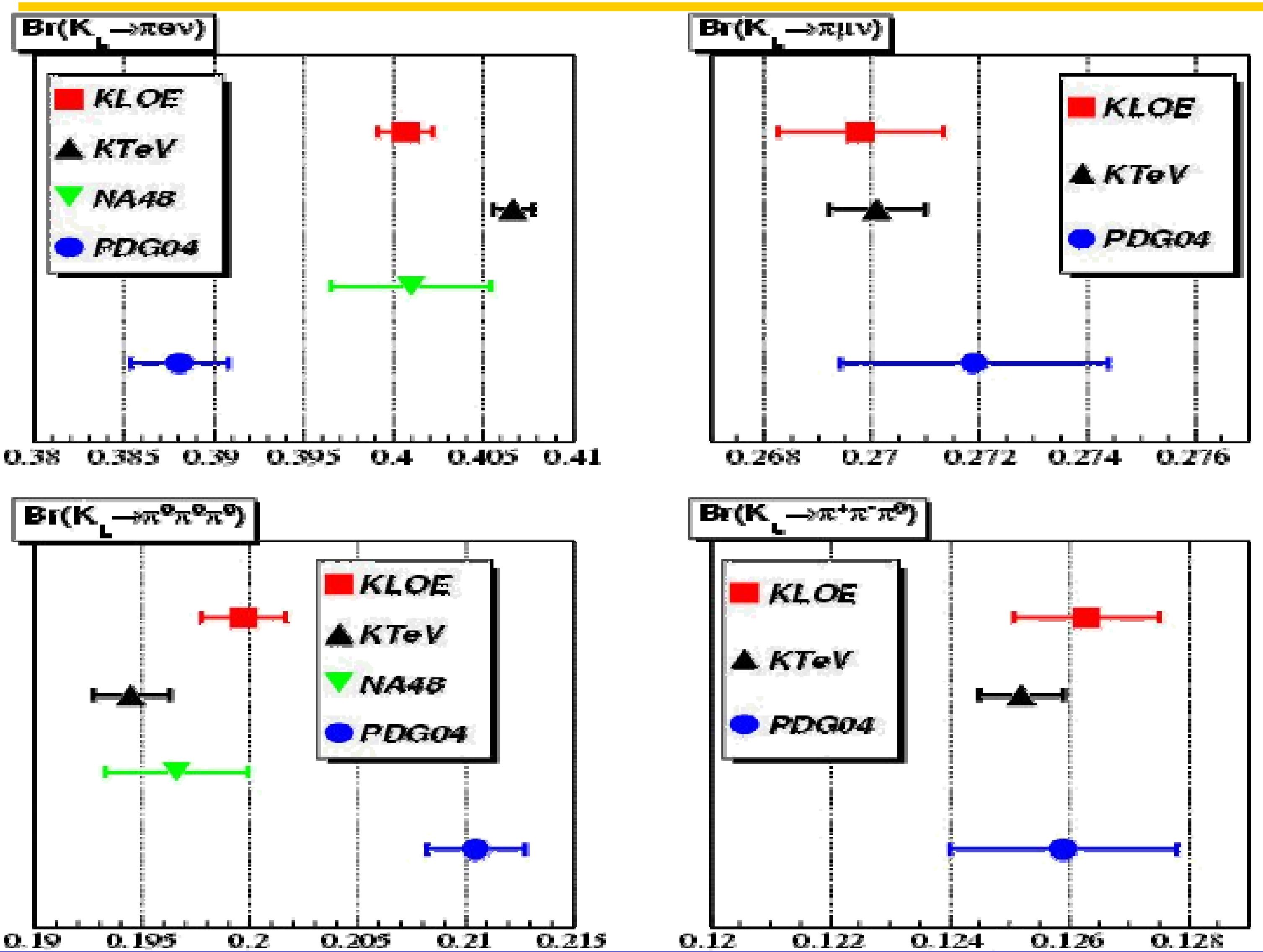


Systematics evaluated including

full error matrix from all sources.

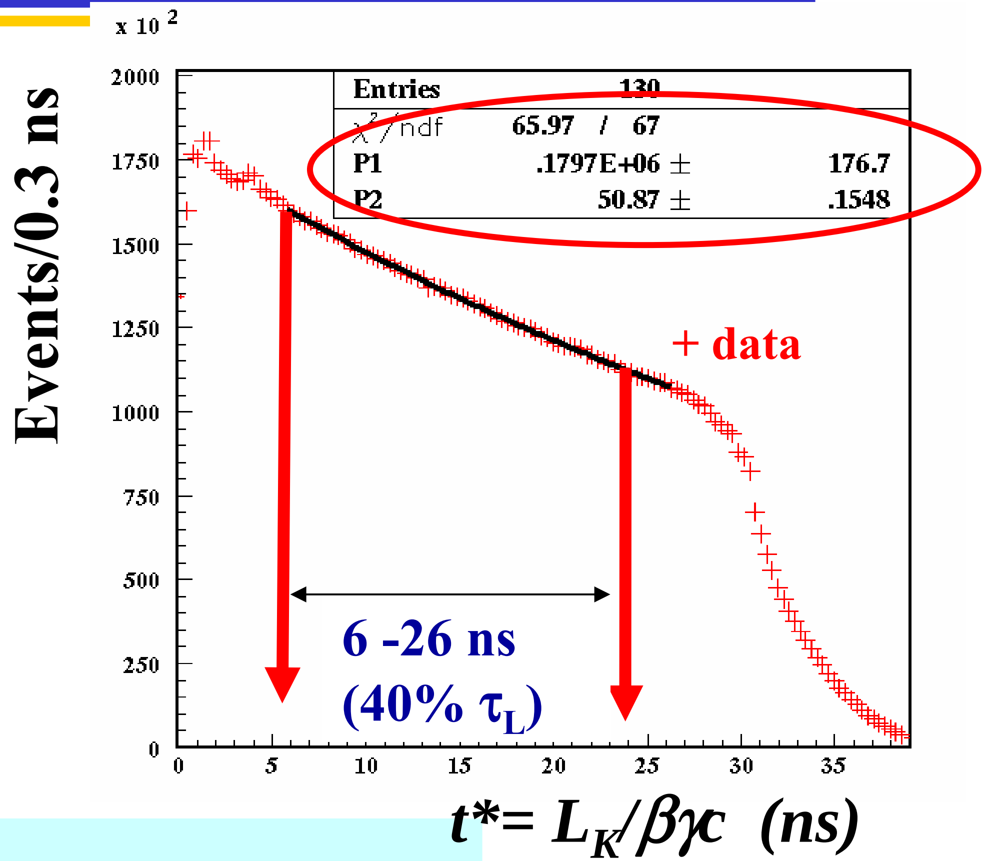
Published PLB608(2005) 199

BR comparison



KLOE: K_L lifetime from $K_L \rightarrow 3\pi^0$

- **Large acceptance for K_L decays ~0.4 $\lambda \Rightarrow$ high statistical accuracy**
- **K_L momentum measured from $K_S \rightarrow \pi^+\pi^-$**
- **$K_L \rightarrow 3\pi^0$ efficiency >99% little variation along the K_L path**
- **$K_L \rightarrow \pi^+\pi^-\pi^0$ as a control sample for the estimate of efficiency, resolution and time scale**



τ (PDG) (fit) = (51.7 ± 0.4) ns
τ (Vosburg, 1972) = (51.54 ± 0.44) ns - 0.4 Mevents
τ_L (KLOE) = (50.92 ± 0.17 ± 0.25) ns - 14.5 Mevents – 440 pb^{-1}

Average with result from K_L BR's: **τ_L = 50.84 ± 0.23 ns**

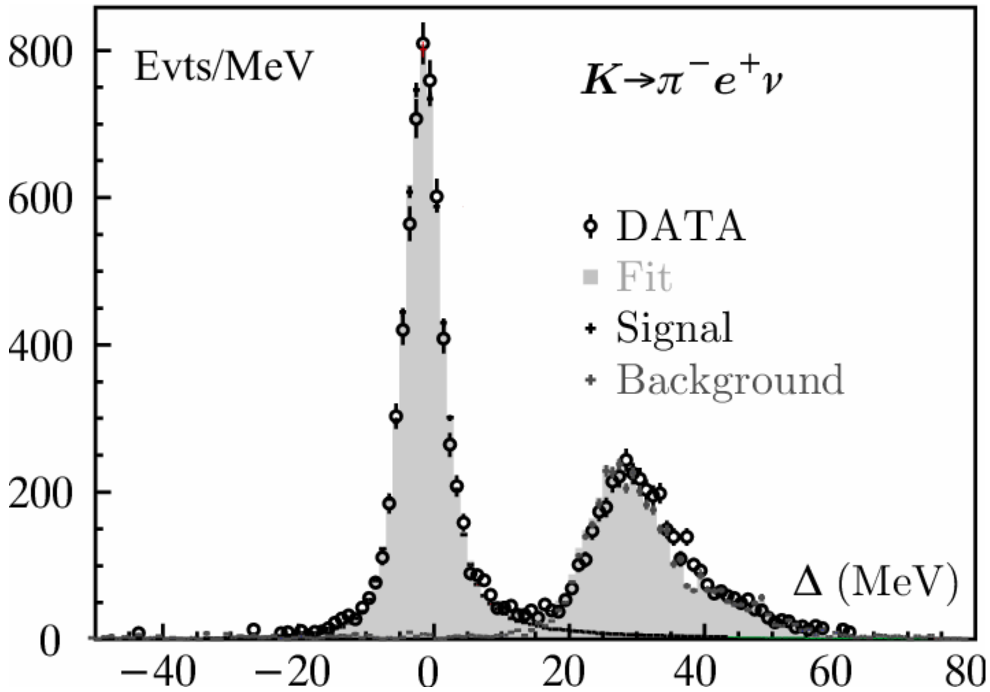
Published PLB626(2005) 15

KLOE $K_S \to \pi e \nu$ decays

- Kinematic closure: use K_L to obtain K_S momentum $\mathbf{P_K}$ and test for presence of neutrino:

$$E_{miss} = \sqrt{M_K^2 + P_K^2} - E_\pi - E_e$$

$$P_{miss} = |\mathbf{P_K} - \mathbf{P_\pi} - \mathbf{P_e}|$$



- Further rejection of $K_S \to \pi\pi$ background from TOF identification
- Obtain number of signal events from a constrained likelihood fit to multiple data distributions
- Use $BR(K_S \to \pi\pi)$ to calculate $BR(K_S \to \pi e \nu)$

KLOE: $K_S \rightarrow \pi e \nu$ decays: Results

unique to KLOE

$BR(K_S \rightarrow \pi^- e^+ \nu) = (3.528 \pm 0.057_{stat} \pm 0.027_{syst})\ 10^{-4}$

$BR(K_S \rightarrow \pi^+ e^- \nu) = (3.517 \pm 0.051_{stat} \pm 0.029_{syst})\ 10^{-4}$

$BR(K_S \rightarrow \pi e \nu) = (7.046 \pm 0.077_{stat} \pm 0.049_{syst})\ 10^{-4}$

PLB 636(2006)]

KLOE '02, *Phys.Lett.B535*, 17 pb^{-1} : $(6.91 \pm 0.34_{stat} \pm 0.15_{syst})\ 10^{-4}$

$A_S = (1.5 \pm 9.6_{stat} \pm 2.9_{syst}) \times 10^{-3}$
with 2.5 fb^{-1} KLOE can measure A_S to 3×10^{-3}

compare to results for A_L:

KTeV $(3.322 \pm 0.058 \pm 0.047) \times 10^{-3}$

NA48 $(3.317 \pm 0.070 \pm 0.072) \times 10^{-3}$

linear form factor slope $\lambda_+ = (33.9 \pm 4.1) \times 10^{-3}$

compatible with the linear slope obtained from K_L semileptonic decays

KLOE: Charged Kaon

$K^{\pm}$ beam tagged from

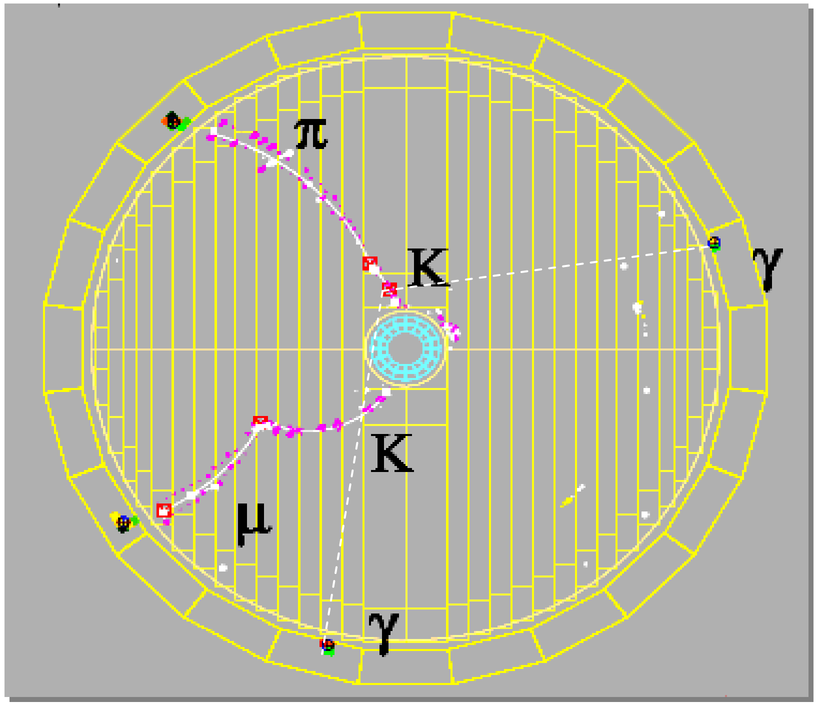
$K^{\pm} \rightarrow \pi^{\pm}\pi^{0}$, $\mu^{\pm}\nu$ (85% of $K^{\pm}$ decays)

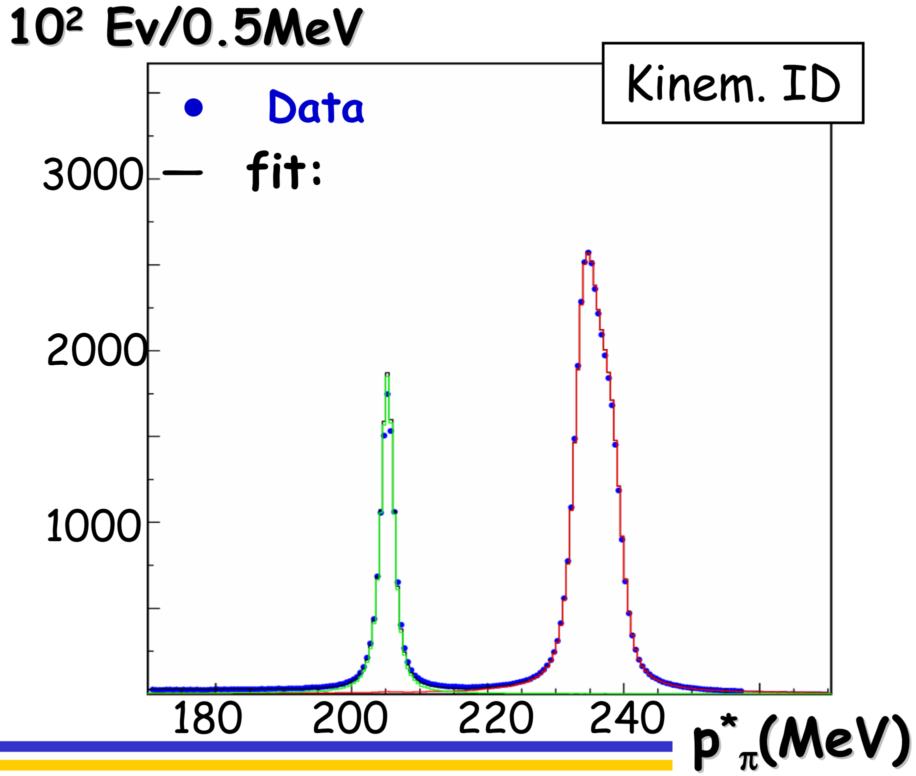
$\cong 1.5 \times 10^{6}\ K^{+}K^{-}$ evts/pb^{-1}

two-body decays identified as peaks in the momentum spectrum of secondary tracks in the kaon rest frame → $P^{*}(m_{\pi})$

$\varepsilon_{tag} \cong 36\ \%\ \Rightarrow \cong 3.4 \times 10^{5}\ \mu\nu$ tags/pb^{-1}

$\cong 1.1 \times 10^{5}\ \pi\pi^{0}$ tags/pb^{-1}





KLOE: $K^{\pm}$ lifetime

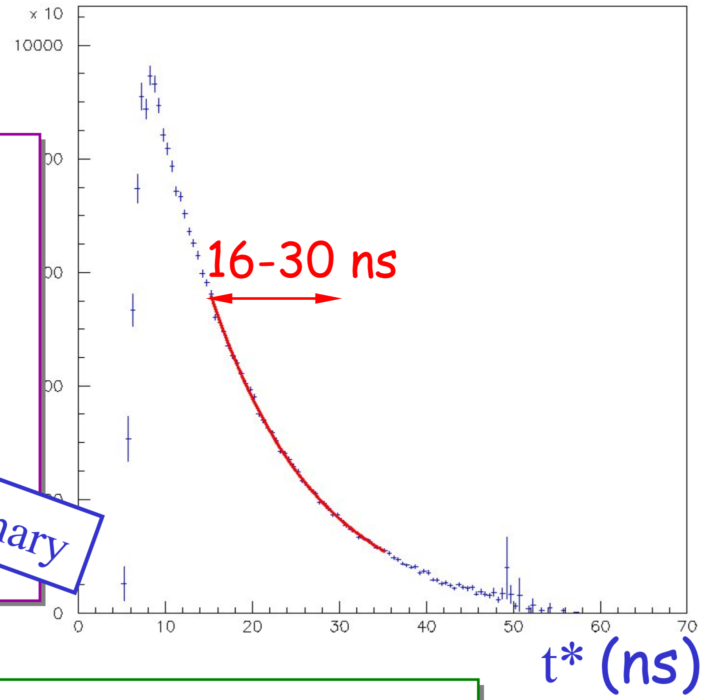
- two methods to measure $\tau_{\pm}$ allow cross checks on the systematic error
- common to both methods
  - tag events with $K_{\mu 2}$ decay
  - kaon decay vertex in the DC

1^{st} method: $\tau_{\pm}$ from the K decay length

Fit the kaon decay length distribution, taking into account the energy loss: $t^* = \sum_i L_i/(\beta_i \gamma_i c)$

$\tau_{\pm} = 12.367 \pm 0.044_{Stat} \pm 0.065_{Syst}$ ns

KLOE preliminary

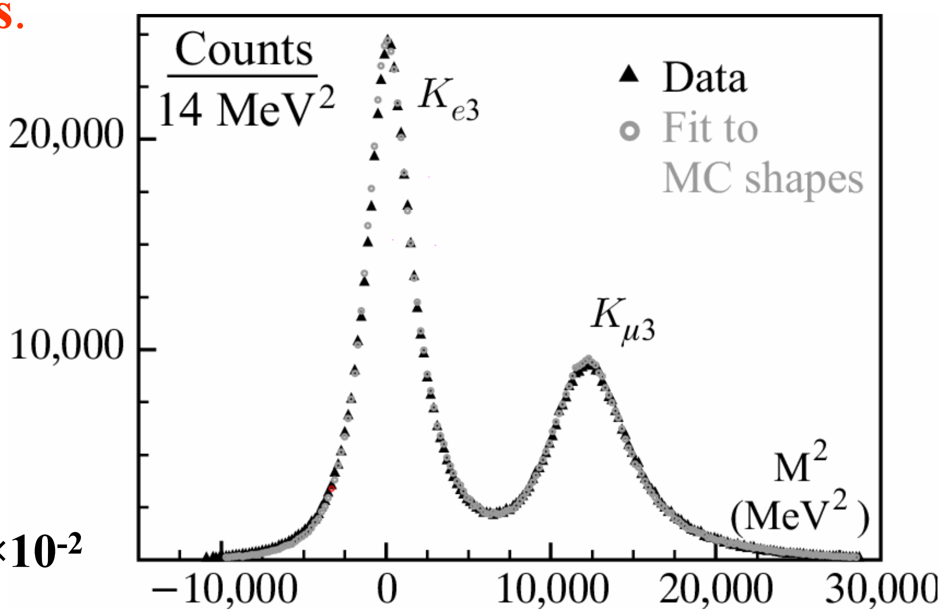


2^{nd} method: $\tau_{\pm}$ from the K decay time

- Use $K \rightarrow \pi^0 X$ decays
- Use tag information to estimate the T_0 i.e. the $\phi \rightarrow K^+K^-$ time
- Measure the kaon proper time: $t^* = (t_\gamma - R_\gamma/c - T_0)\gamma_K$ using the γ clusters

KLOE: $K^{\pm}_{e3,\mu3}$ semileptonic BR

- ✓ **4 independent tag: $K^+\mu2$, $K^+\pi2$, $K^-\mu2$, and $K^-\pi2$**; keep the systematic effects due to the tag selection under control.
- ✓ kinematical cuts to reject non-semileptonic decays, residual background is about 1.5% of the selected $K^{\pm}l3$ sample
- ✓ Obtain number of signal events from a constrained likelihood fit of a **m^2 data distributions from ToF measurements**.



- Perform the **BR measurement on each tag sample** separately normalizing to tag counts in the same data set.

KLOE 2005 **preliminary**:

$$\mathbf{BR(K^{\pm}_{e3}) = (5.047 \pm 0.019_{Stat} \pm 0.039_{Syst})\times 10^{-2}}$$

$$\mathbf{BR(K^{\pm}_{\mu3}) = (3.310 \pm 0.016_{Stat} \pm 0.045_{Syst})\times 10^{-2}}$$

$K^{\pm}_{e3}$ from NA48 and ISTRA

NA48 preliminary:

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

Using PDG04 value for $BR(K^{\pm} \to \pi^{\pm}\pi^0)$

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

Measurement of $R_{\mu e} = BR(K^{\pm} \to \pi^0 \mu\nu)/BR(K^{\pm} \to \pi^0 e\nu)$

$R_{\mu e} = 0.6749 \pm 0.0035$

ISTRA+ preliminary:

Measurement of $BR(K^- \to \pi^0 e\nu)/BR(K^- \to \pi^- \pi^0)$

$BR(K^- \to \pi^0 e\nu) = (5.22 \pm 0.11)\%$

Note: Both values depend on $BR(K^{\pm} \to \pi^{\pm}\pi^0)$

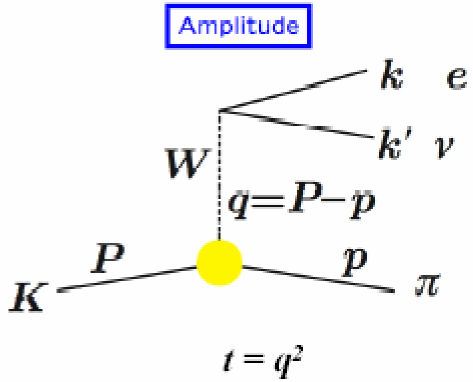
Post-PDG'04 results for Ke3 (E865) and Kμ2 (KLOE) decrease $BR(K^{\pm} \to \pi^{\pm}\pi^0)$ by ~1% from global fit to $K^{\pm}$ BRs

Form Factor

$$\langle \pi | J^{\alpha}_{H,V} | K \rangle = f(0)\left((P+p)^{\alpha}\tilde{f}_{+}(t) + (P-p)^{\alpha}\tilde{f}_{-}(t)\right)$$

$$\tilde{f}_0(t) = \tilde{f}_+(t) + t/(m^2_{\pi+} + m^2_K)\,\tilde{f}_-(t)$$

$$\tilde{f}_{+,0}(t) = 1 + \lambda'_{+,0}\, t/m_{\pi+} + 1/2\, \lambda''_{+,0}\,(t/m_{\pi+})^2$$



$I(\lambda_+, \lambda_0, 0)$ phase space integral needed for extracting Vus is a function of FF slopes

e.g. for Ke3, $I_{e3} = 0.56340158 + 1.9470583\lambda' + 2.6907652(\lambda'^2 + \lambda'') + 9.2753527\lambda'\lambda'' + 9.1097871\lambda''^2$

Fit of ***t*-spectrum** with different hypotheses on form factor $f_+(t)/f_+(0)$:

Quadratic

$$\tilde{f}(t) = 1 + \lambda' \frac{t}{m^2} + \frac{\lambda''}{2}\frac{t^2}{m^4}\cdots$$

or

Polar

$$\frac{M_V^2}{M_V^2 - t}$$, implying $\lambda' = \left(\frac{m}{M_V}\right)2,\ \lambda'' = 2\lambda'^2$

KLOE: Form Factor

- **328 pb^{-1}, 2 × 10^6 K_{Le3} decays**
- Kinematic cuts + TOF PID to reduce background (~ 0.7% final contamination)
- Momentum transfer **t** measured from π and K_L momenta: σ_t/m_π^2 ~0.3
- separate measurement for each charge state ($e^+\pi^-$, π^+e^-) to check systematics

Linear: $1 + \lambda_+ t$

P(χ²) =89%

$\lambda_+ = (28.6 \pm 0.5 \pm 0.4) \times 10^{-3}$

Quadratic: $1 + \lambda'_+ t/m_{\pi+} + 1/2\, \lambda''_+ (t/m_{\pi+})^2$

$\lambda'_+ = (25.5 \pm 1.5 \pm 1.0) \times 10^{-3}$

$\lambda''_+ = (1.4 \pm 0.7 \pm 0.4) \times 10^{-3}$

$\rho(\lambda'_+, \lambda''_+) = -0.95$

P(χ²) =92%

Pole model: $M_V^2/(M_V^2 - t)$,

Taylor exp.⇒ $\lambda'_+ = (m_\pi/M_V)^2$, $\lambda''_+ = 2\, \lambda'^2_+$

$m_V = (870 \pm 7)$ MeV

P(χ²) =92.4%

[PLB 636(2006)]

Form Factor comparison

KTeV [PRD 70(2004)]

K^0_{e3} quadratic fit: $\lambda''_+ \neq 0$ @ 4σ level

$K^0_{\mu3}$ quadraqtic fit: $\lambda_0 = (13.72 \pm 1.31)\ 10^{-3}$

Slopes consistent for K^0_{e3} and $K^0_{\mu3}$

ISTRA+ [PLB 581(2004), PLB589(2004)]

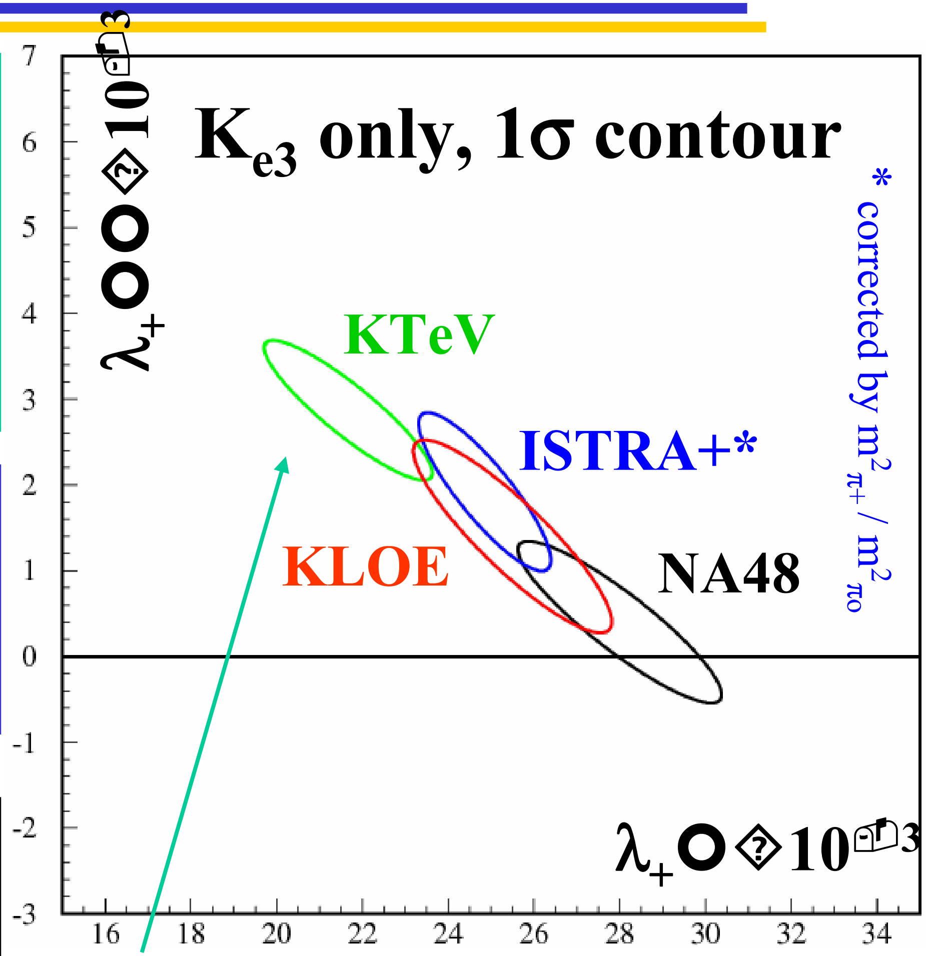
K^-_{e3} quadratic fit: $\lambda''_+ \neq 0$ @ 2σ level

$K^-_{\mu3}$ quadratic fit: $\lambda_0 = (17.11 \pm 2.31)\ 10^{-3}$

NA48 [PLB 604(2004),HEP2005 289)

K^0_{e3}: No evidence for quadratic term

$K^0_{\mu3}$ linear fit: $\lambda_0 = (12.0\ \pm 1.7)\ 10^{-3}$
compatible with KTeV



$\lambda''_+ \rightarrow -1\%$ phase space integral
$\rightarrow +0.5\%$ for V_{us}

Form Factor comparison

Pole model $\lambda' = (m/M_V)^2,\ \lambda'' = 2\lambda'^2$

KLOE

$M_V = (870 \pm 7)$ MeV $/c^2$

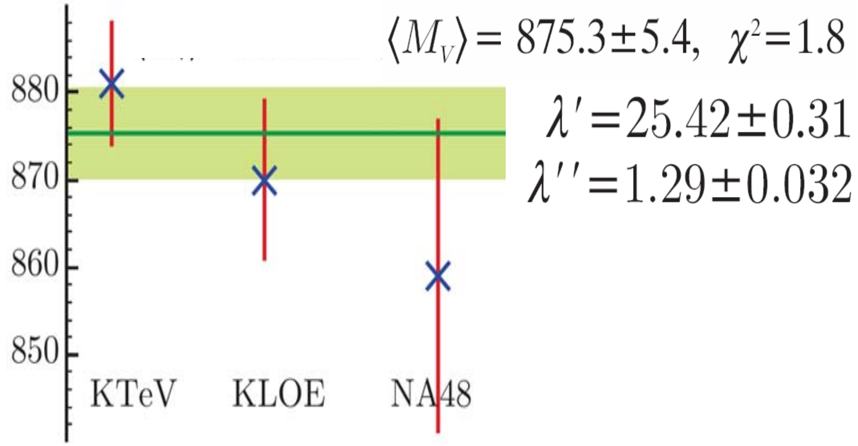
KTeV

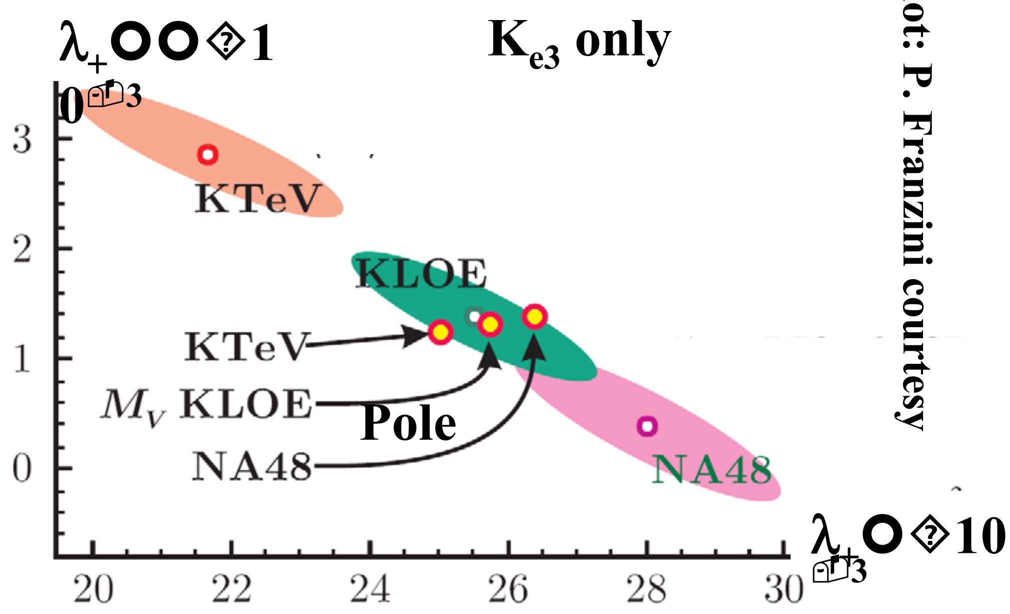
$M_V = (882.32 \pm 6.54)$ MeV $/c^2$

$M_s = (1173.80 \pm 39.47)$ MeV$/c^2$

NA48

$M_V = (859 \pm 18)$ MeV $/c^2$





plot: P. Franzini courtesy

Phase space integral, **Pole model** versus **Quadratic parameterization**:

- KLOE: 0.5 per mil difference
- KTeV: 6 per mil difference.

V_{us} from KLOE BR

	$K_L\,e3$	$K_L\,\mu3$	$K_S\,e3$	$K^{\pm}e3$	$K^{\pm}\mu3$
BR	0.4007(15)	0.2698(15)	$7.046(91)\times10^{-4}$	0.05047(46)	0.03310(40)
τ	50.84(23) ns		89.58(6) ps	12.384(24) ns	

Slopes

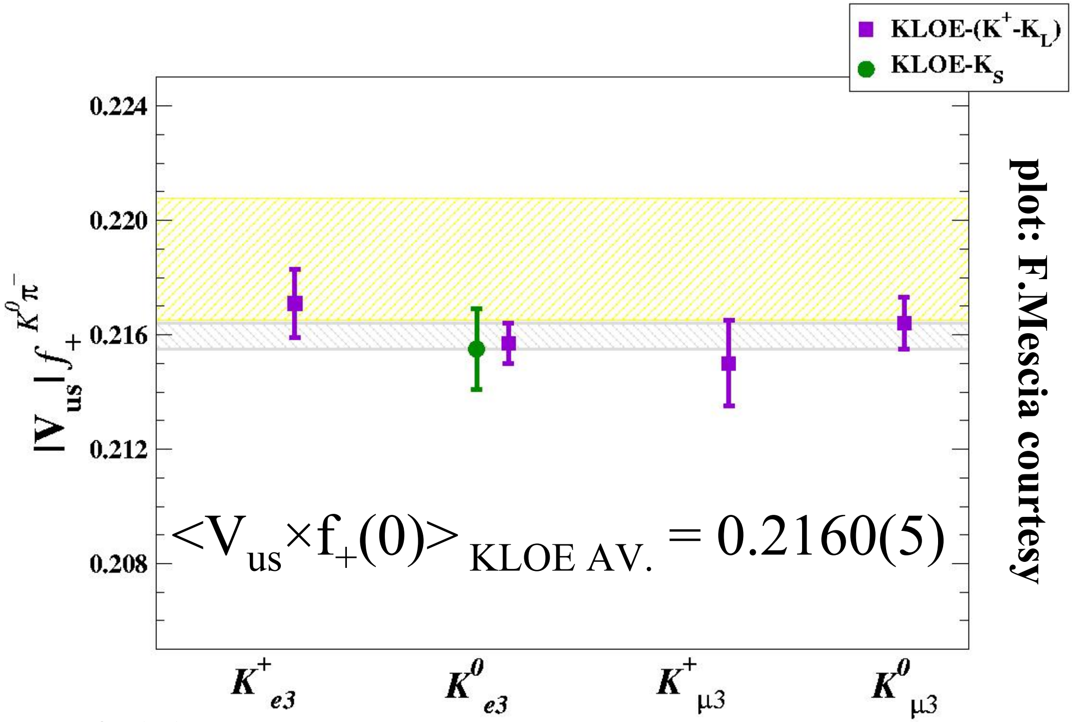
$\lambda'_+ = 0.02542(31)$

$\lambda''_+ = 0.00129(3)$

(Pole model: KLOE, KTeV, and NA48 ave.)

$\lambda_0 = 0.01587(95)$

(KTeV and Istra+ ave.)



plot: F.Mescia courtesy

From unitarity

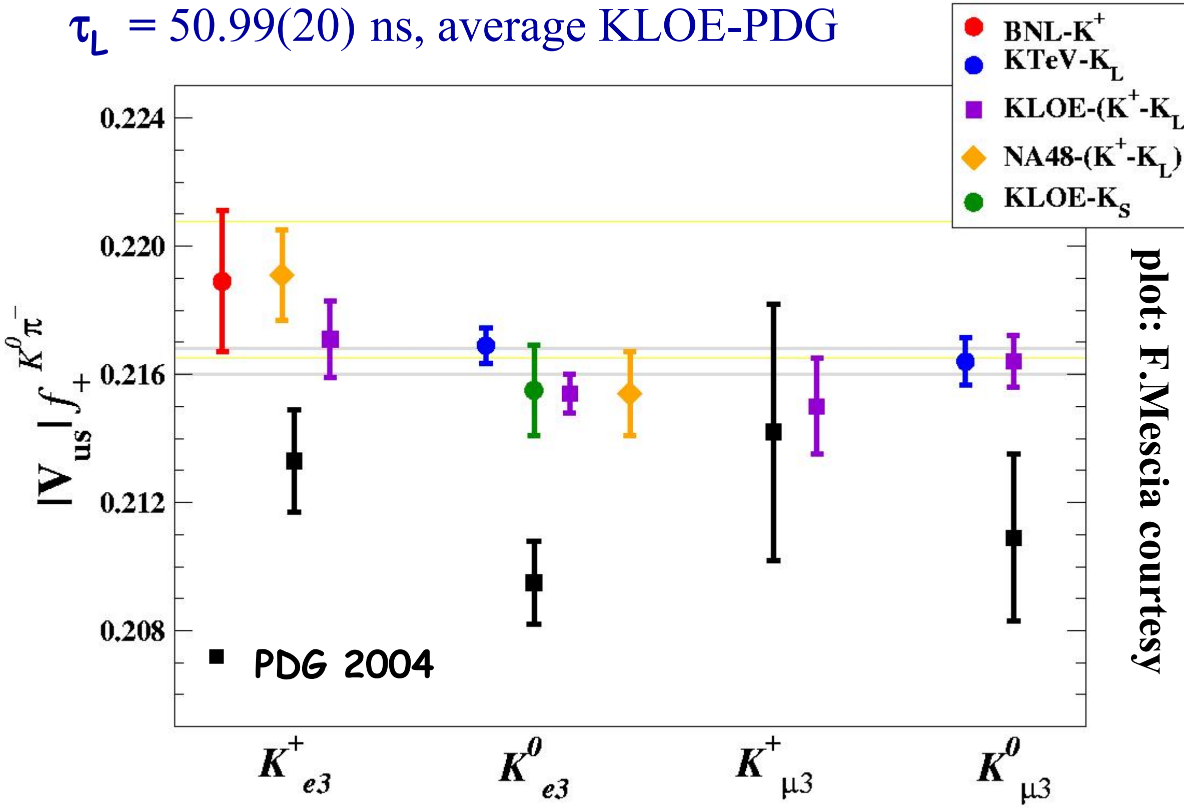
- $f_+(0)=0.961(8)$
  Leutwyler and Roos Z. [Phys. **C25**, 91, 1984]
- $V_{ud}=0.97377(27)$
  Marciano and Sirlin [Phys.Rev.Lett.96 032002,2006]

$$V_{us}\times f_+(0) = 0.2187(22)$$

$$\frac{\delta|V_{us}f_+(0)|}{|V_{us}f_+(0)|} \approx 0.14\%\,(\Gamma) \oplus 0.05\%\,(I) \oplus 0.13\,\%(\Delta_{em})$$

V_{us} from all experiments

τ_L = 50.99(20) ns, average KLOE-PDG



$$\langle V_{us} \times f_+(0) \rangle_{\text{WORD AV.}} = 0.2164(4)$$

CKM unitarity within $\sim 1\sigma$

Slopes

$\lambda'_+ = 0.02542(31)$

$\lambda''_+ = 0.00129(3)$

(Pole model: KLOE, KTeV, and NA48 ave.)

$\lambda_0 = 0.01587(95)$

(KTeV and Istra+ ave.)

From unitarity

- $f_+(0)=0.961(8)$
  Leutwyler and Roos Z. [Phys. **C25**, 91, 1984]
- $V_{ud}=0.97377(27)$
  Marciano and Sirlin [Phys.Rev.Lett.96 032002,2006]

$V_{us} \times f_+(0) = 0.2187(22)$

KLOE: BR($K^+ \to \mu^+ \nu(\gamma)$)

Combining the experimental value of $\Gamma(K\to\mu\nu(\gamma))/\Gamma(\pi\to\mu\nu(\gamma))$ with the ratio f_K/f_π obtained from lattice calculations we can extract $|V_{us}|/|V_{ud}|$ (Marciano hep-ph/0406324) $\Gamma(K\to\mu\nu(\gamma))/\Gamma(\pi\to\mu\nu(\gamma)) \propto |V_{us}|^2/|V_{ud}|^2 f_K^2/f_\pi^2$

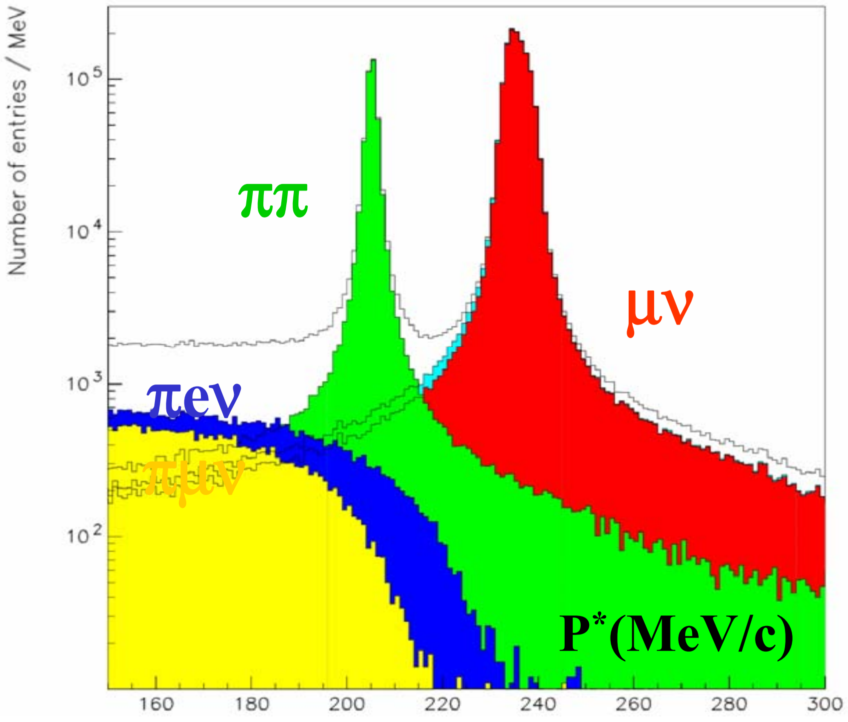
Selection

- **Tag from $K^-\to\mu^-\nu$**
- **2002 data ~175 pb^{-1} (2/3 used for efficiency**
- **Event counting performed by fitting the P^* distribution with signal and background shapes**

[PLB 632 (2006)]

BR($K^+ \to \mu^+\nu(\gamma)$) =

$0.6366 \pm 0.0009_{stat.} \pm 0.0015_{syst.}$



PDG fit = 0.6343 ± 0.0017

$V_{us} - V_{ud}$ plane

- Using $f_K/f_\pi = 1.198(3)(^{+16}_{-5})$ from MILC Coll. (2005) and **KLOE BR($K^+ \to \mu^+\nu$)** we get $\mathbf{V_{us}/V_{ud} = 0.2294 \pm 0.0026}$

- $V_{us} = 0.2248 \pm 0.0020$

  K_{l3} KLOE, using $f_+(0)$=0.961(8)

- $V_{ud} = 0.97377 \pm 0.00027$

  Marciano and Sirlin
  Phys.Rev.Lett.96 032002,2006

Fit of the above results:

$\mathbf{V_{us} = 0.2242 \pm 0.0016}$

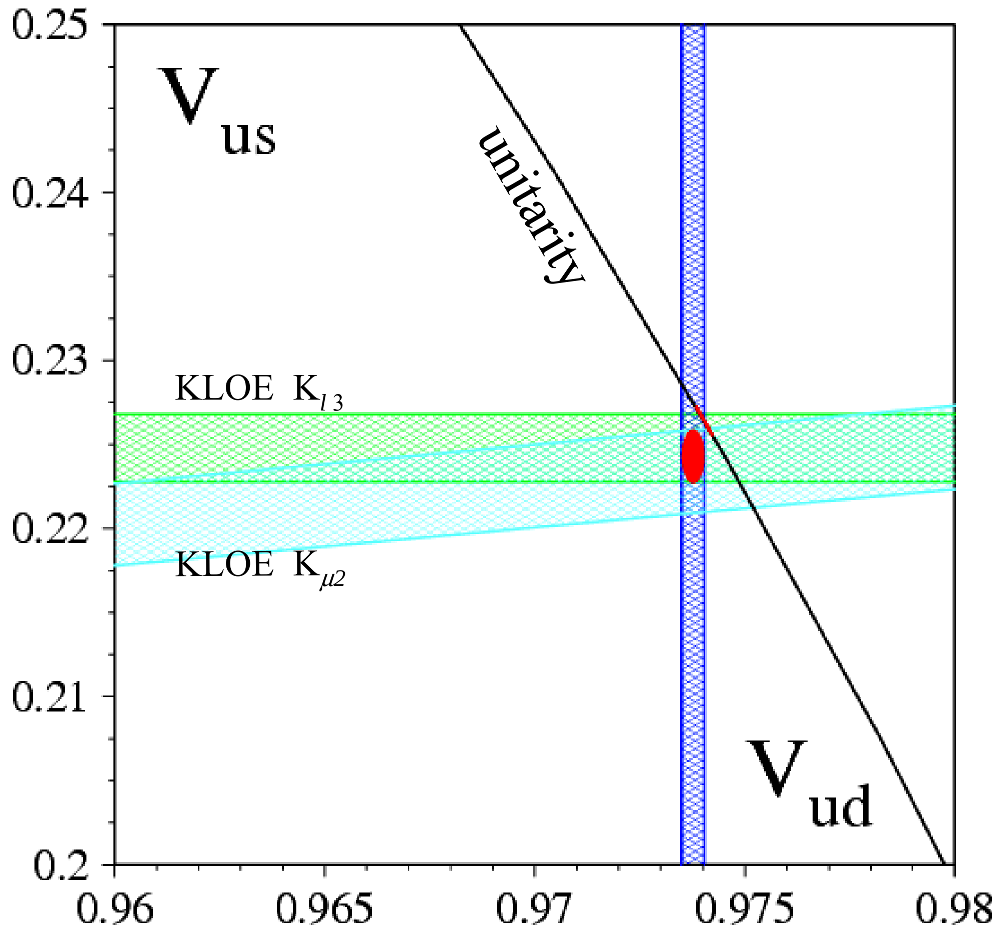
$\mathbf{V_{ud} = 0.97377 \pm 0.00027}$

$P(\chi^2) = 0.8$

Fit assuming unitarity:

$\mathbf{V_{us} = 0.2264 \pm 0.0009}$

$P(\chi^2) = 0.1$



Conclusions and Perspectives

- the CKM matrix appears to be unitary within $\sim 1\sigma$
- V_{us} still only known to about 1%

➢ KLOE and NA48 will have soon final results on charged kaon Branching Ratios and slopes

➢ KLOE will have soon preliminary results on λ_0 fitting the $K_{L\mu3}$ spectrum

➢ Using the full data sample (2.4 fb^{-1}) KLOE will update the BR measurement and will refine the slopes measurements improving by a factor 2 the statistical accuracy

➢ improvement for $f_+(0)$ expected from lattice calculations

NA48, KTEV,ISTRA: Form Factor

KTeV [PRD 70 (2004)]

$f_+(t)$ is consistent for the two decay modes ➔ $\lambda' = (20.64 \pm 1.75) \times 10^{-3}$

$\lambda''_+ = (3.20 \pm 0.69) \times 10^{-3}$ 4σ

λ_0 ~ 5 times more precise than PDG ➔ $\lambda_0 = (13.72 \pm 1.31) \times 10^{-3}$

Pole model

$M_V = (882.32 \pm 6.54)$ MeV $/c^2$

$M_s = (1173.80 \pm 39.47)$ MeV$/c^2$

λ''_+ ➔results in a 1% reduction of the phase space integral corresponding to an increase of 0.5% for V_{us}

NA48 (HEP2005) 289

K^0_{e3} $\lambda'_+ = (28.8 \pm 1.2) \times 10^{-3}$ no evidence for quadratic term

Pole model $M_V = (859 \pm 18)$ MeV $/c^2$

$K^0_{\mu3}$ $\lambda'_+ = (26.0 \pm 1.2\ ) \times 10^{-3}$

$\lambda_0 = (12.0 \pm 1.7\ ) \times 10^{-3}$

ISTRA +[PLB 581 (2004), PLB 589 (2004)]

K^0_{e3} $\lambda'_+ = (24.85 \pm 1.66) \times 10^{-3}$

$\lambda''_+ = (1.92 \pm 0.94) \times 10^{-3}$

$K^0_{\mu3}$ $\lambda'_+ = (22.99 \pm 6.46) \times 10^{-3}$

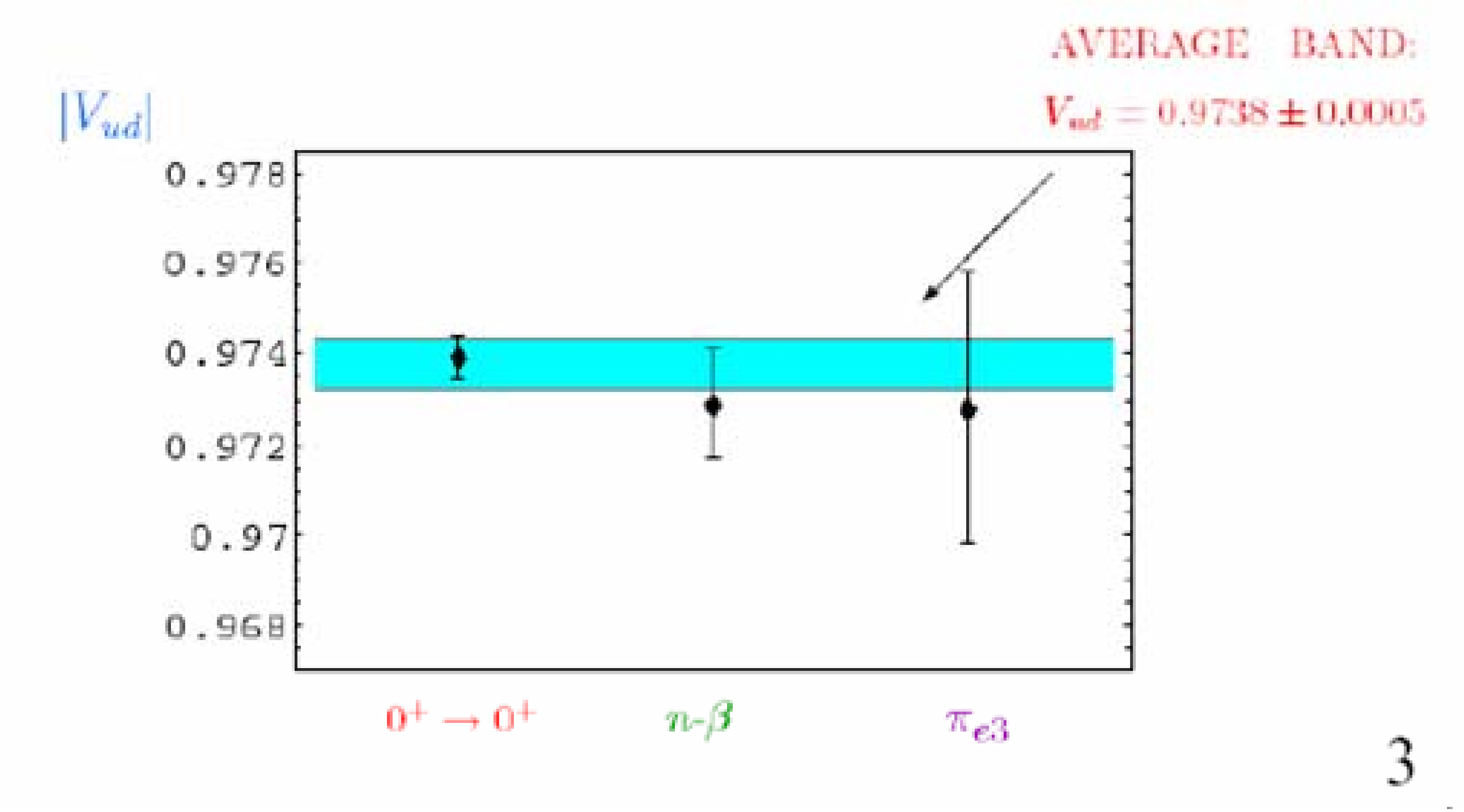
$\lambda''_+ = (2.99 \pm 2.29) \times 10^{-3}$

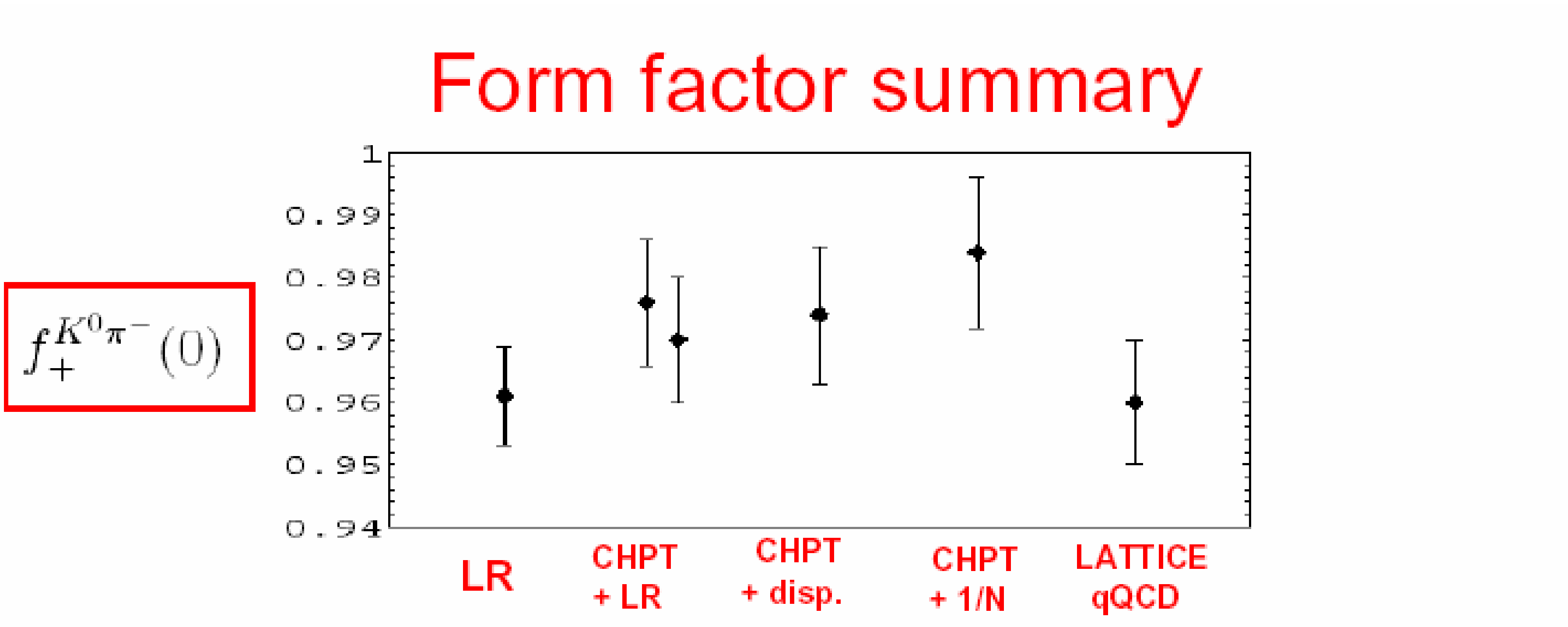
$\lambda_0 = (17.11 \pm 2.31) \times 10^{-3}$

$fi(t) = fi(0)(1 + \lambda'_I\, t/m^2_{\pi+} + \lambda''_i\, t^2/2m^4_{\pi+})$ * Istra values are corrected by $m^2_{\pi+} / m^2_{\pi o}$

SU(2) and em corrections

	$\delta^{K}_{SU(2)}(\%)$	$\delta^{K\ell}_{em}(\%)$	
		3-body	full
K^{+}_{e3}	2.31 ± 0.22	-0.35 ± 0.16	-0.10 ± 0.16
K^{0}_{e3}	0	$+0.30 \pm 0.10$	$+0.55 \pm 0.10$
$K^{+}_{\mu3}$	2.31 ± 0.22	-0.05 ± 0.20	$+0.20 \pm 0.20$
$K^{0}_{\mu3}$	0	$+0.55 \pm 0.20$	$+0.80 \pm 0.20$


AVERAGE BAND:
$V_{ud} = 0.9738 \pm 0.0005$
$|V_{ud}|$
0.978
0.976
0.974
0.972
0.97
0.968
$0^+ \to 0^+$
n-β
π_{e3}
3


Form factor summary
$f_+^{K^0\pi^-}(0)$
1
0.99
0.98
0.97
0.96
0.95
0.94
LR
CHPT + LR
CHPT + disp.
CHPT + 1/N
LATTICE qQCD

KLOE: Absolute BR's results

- **Absolute BR results with (τ_{KL}= 51.54 ± 0.44 ns):**

330 pb^{-1}

2001-2002

¾ of 2001-2002 data has been used for efficiency evaluation and ¼ for BR measurement corresponding to 13×10^6 tagged K_L.

BR($K_L \rightarrow \pi e \nu(\gamma)$) = 0.4049 ± 0.0010 ± 0.0031	**~8×10^5 events**
BR($K_L \rightarrow \pi \mu \nu(\gamma)$) = 0.2726 ± 0.0008 ± 0.0022	**~ 5×10^5 events**
BR($K_L \rightarrow 3\pi^0$) = 0.2018 ± 0.0004 ± 0.0026	**~ 7×10^5 events**
BR($K_L \rightarrow \pi^+\pi^-\pi^0(\gamma)$) = 0.1276 ± 0.0006 ± 0.0016	**~ 2×10^5 events**