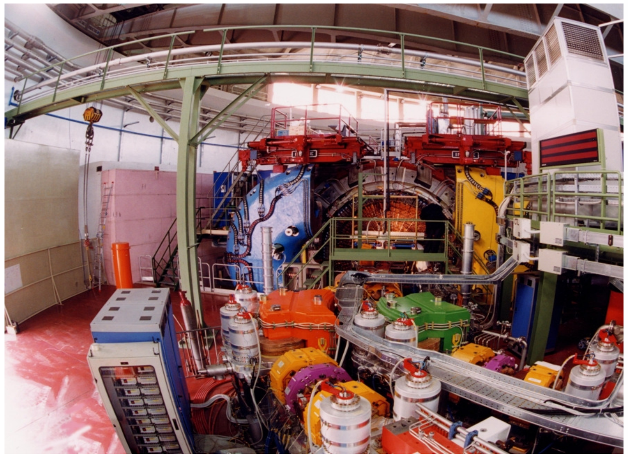
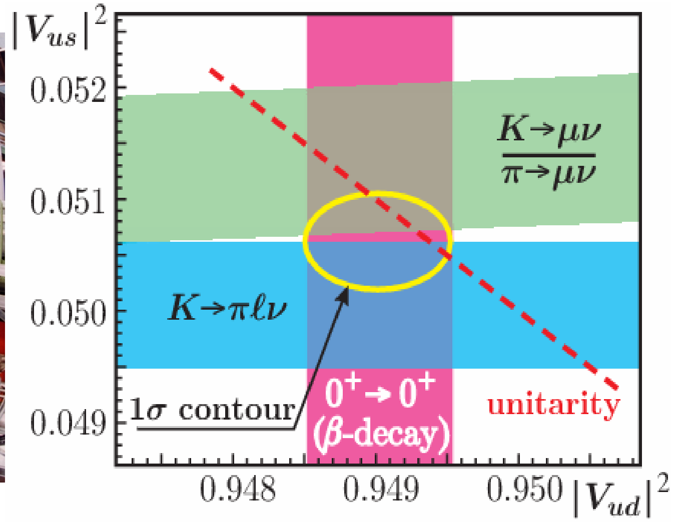
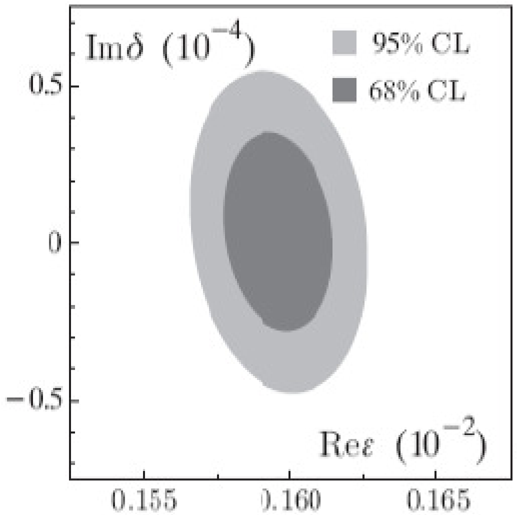
Vus and CP violation from kaon decays with the KLOE detector





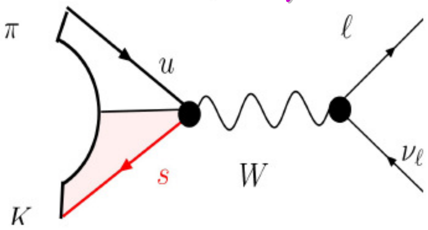


Patrizia de Simone, LNF/INFN
on behalf of the KLOE Collaboration

DISCRETE'08, 11 December 2008, IFIC, Valencia, Spain

Interest for V_{us} meaurement with kaons

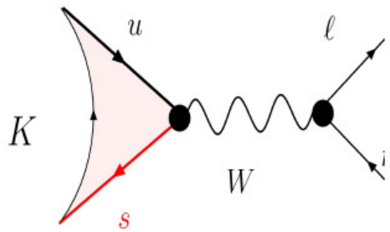
from Kl3 decays



vector transition :
only 2nd order SU(3) breaking
[Ademollo-Gatto]

- precise determination of V_{us}
- most precise test of CKM unitarity
  $(|V_{ud}|^2 + |V_{us}|^2) = 1$ $|V_{ub}| \sim 10^{-5}$
  $\sigma_{rel}|V_{ud}| \sim 0.03\%$
- test of lepton universality Ke3 vs Kμ3
- Gauge universality and Physics beyond SM
  $G_{CKM}^2 = (|V_{ud}|^2 + |V_{us}|^2)G_F^2$

from $\Gamma(K_{\mu 2})/\Gamma(\pi_{\mu 2})$



helicity suppressed :
sensitivity to NP enhanced

- precise determination of V_{us}/V_{ud}
- test of Physics beyond SM
  - right-handed contributions to charged weak currents
  - charged Higgs H^+ exchange

V_{us} from semileptonic kaon decays

$$\Gamma(K \to \pi l \nu(\gamma)) = |V_{us}|^2 \, |f_+^{K\pi}(0)|^2 \, \frac{G_F^2 m_K^5}{192\,\pi^3} \, S_{EW} \, C_K^2 \, I_K^l(\lambda'_+, \lambda''_+, \lambda_0) \, (1 + \delta_K^l)$$

theoretical inputs

✓ $f_+(0)$ form factor at zero momentum transfer ➔ purely theoretical calculation, recent result from UKQCD/RBC 07 $f_+(0) = 0.964(5)$

✓ $\delta^l_K = (\Delta_K^{SU(2)} + \Delta^l_K{}^{em})$ e.m. and I-breaking corr., presently known @ few ‰ level

✓ S_{EW} universal short distance electroweak corr. $S_{EW} = 1.0232$, $C_K^2 = 1$ (2) for K^0 ($K^\pm$) decays

experimental inputs

✓ $I^l_K(\lambda'_+, \lambda''_+, \lambda_0)$ phase space integral, $\lambda'_+, \lambda''_+, \lambda_0$, denote the t-dependence of vector and scalar form factors

✓ $\Gamma K_{l3(\gamma)}$ semileptonic decay widths, evaluated from γ-inclusive BR's and lifetimes

✓ m_K appropriate kaon mass

To extract V_{us}

KLOE has measured all the relevant inputs: BR's, lifetimes, ff's

PLB 632 (2006)

$$BR(K_L e3) = 0.4008(15)$$
$$BR(K_L \mu 3) = 0.2699(14)$$

based on 13×10^6 K_L decays tagged by $K_S \to \pi^+\pi^-$

PLB 626 (2005)

$$\tau_L = 50.92(30)\ \text{ns}$$

fit the time dependence over $0.4\tau_L$ of 8.5×10^6 $K_L \to 3\pi^0$ decays tagged by $K_S \to \pi^+\pi^-$

PLB 636 (2006)

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

based on 2×10^6 $K_L e3$ decays tagged by $K_S \to \pi^+\pi^-$

PLB 636 (2006)

$$BR(K_S \to \pi e \nu) = 7.046(91) \times 10^{-4}$$

based on 1.2×10^8 events tagged by K_L's interacting on the EMC (20% of the full data sample)

PLB 632 (2006)

$$BR(K^+ \to \mu^+ \nu) = 0.6366(17)$$

based on 4.2×10^6 $\phi \to K^+K^-$ tagged by $K^-_{\mu 2}$ decays

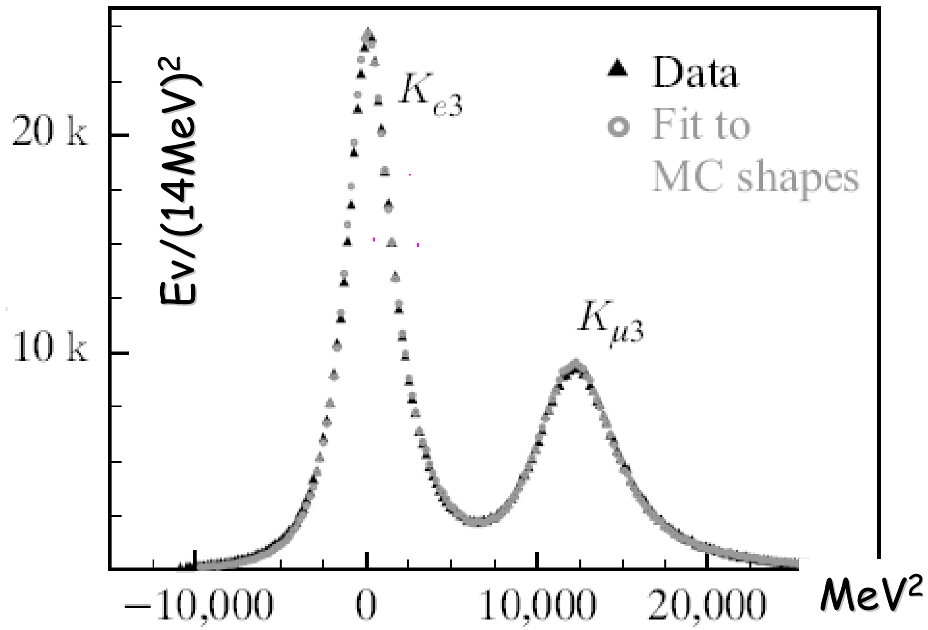
Absolute BR's for $K^{\pm}_{l3}$

- 4 independent-tag samples: *$K^+\mu2$, $K^+\pi2$, $K^-\mu2$, and $K^-\pi2$ (a total of 6×10^7 evts)*
  to keep under control the systematic effects due to the tag selection
- kinematical cuts are used to rejct the background
- selection efficiency from MC and correct for Data/MC differences
- signal count from a constrained likelihood fit to the m_l^2 spectrum (m lepton mass from ToF) using a linear combination of signal and background shapes from MC
- perform the BR measurements on each tag sample, separately normalizing to tag counts in the same data set, and average accounting for correlations

JHEP 02 (2008)

$$\mathbf{BR(K^{\pm} \to \pi^0 e^{\pm}\nu) = 0.04965(53)}$$
$$\mathbf{BR(K^{\pm} \to \pi^0 \mu^{\pm}\nu) = 0.03233(38)}$$

✓fractional accuracy of 1.1% for K_{e3} 1.2% for $K_{\mu3}$
✓ the error is dominated by the error on Data/MC efficiency correction



Measurement of the $K^{\pm}$ lifetime

- poor consistency of PDG average with measurements spread

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

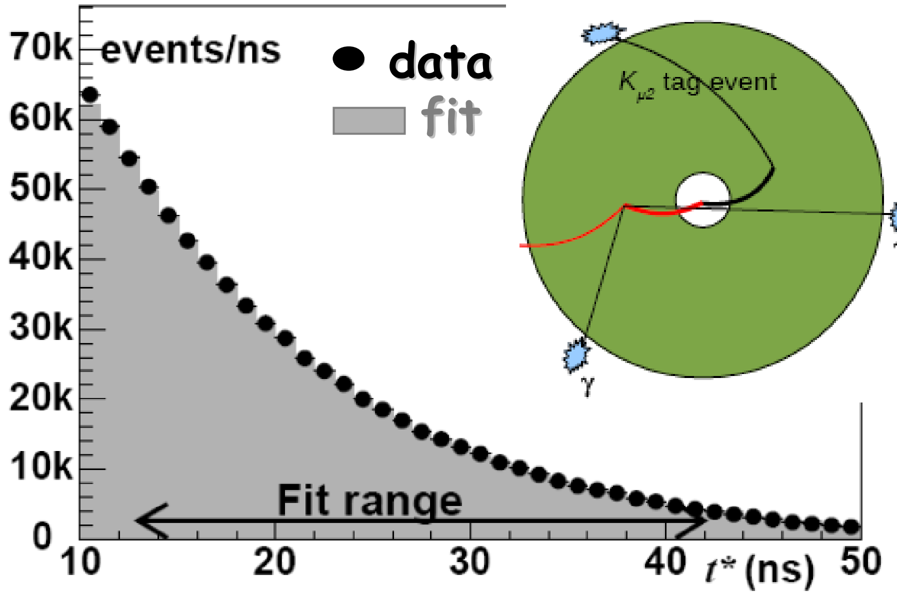
two methods to measure $\tau^{\pm}$ allow cross checks on the systematic error

common to both methods ➔ *events tagged by $K_{\mu 2}$ decay and $K^{\pm}$ vtx in the DC*

a total of 15x10^6 evts.

fit to $\tau^{\pm}$ distribution from the K decay length	*fit to $\tau^{\pm}$ distribution from the K decay time*
coverage: 16-30 ns (1.1 $\tau^{\pm}$)	*coverage: 13-42 ns (2.3 $\tau^{\pm}$)*
evaluation of $\tau^{\pm}$ includes dE/dx	$\tau^{\pm} = 12.337(30)_{stat}(20)_{syst}$
$\tau^{\pm} = 12.364(31)_{sta}\ (31)_{syst}$	

✓ *fit performed folding resolution and efficiency functions*



combined result (ρ = 0.307)

JHEP 01 (2008)

$\tau^{\pm} = 12.347(30)$ ns

PDG06 average $\tau^{\pm}$ =12.385±0.025 ns

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

- available measurement dates back to '72 (no information on radiation cut-off)

CHIANG '72 BR($K^\pm \to \pi^\pm\pi^0$) = (21,18 ± 0.28)% σ_{rel} = 1,3%

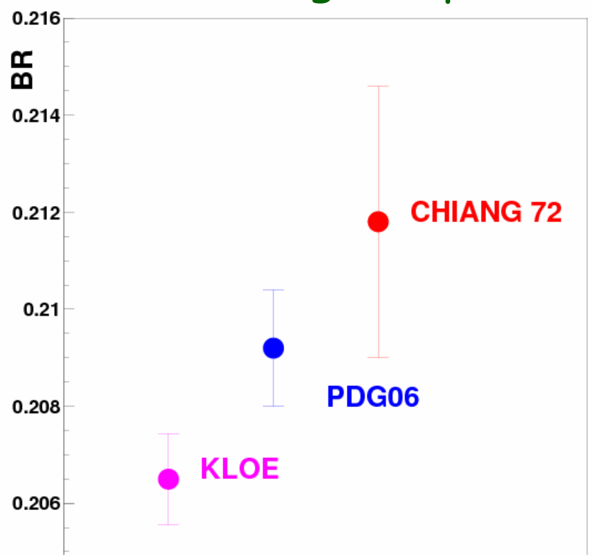
- needed to perform a global fit to $K^\pm$ BR's
- enters in the normalization of

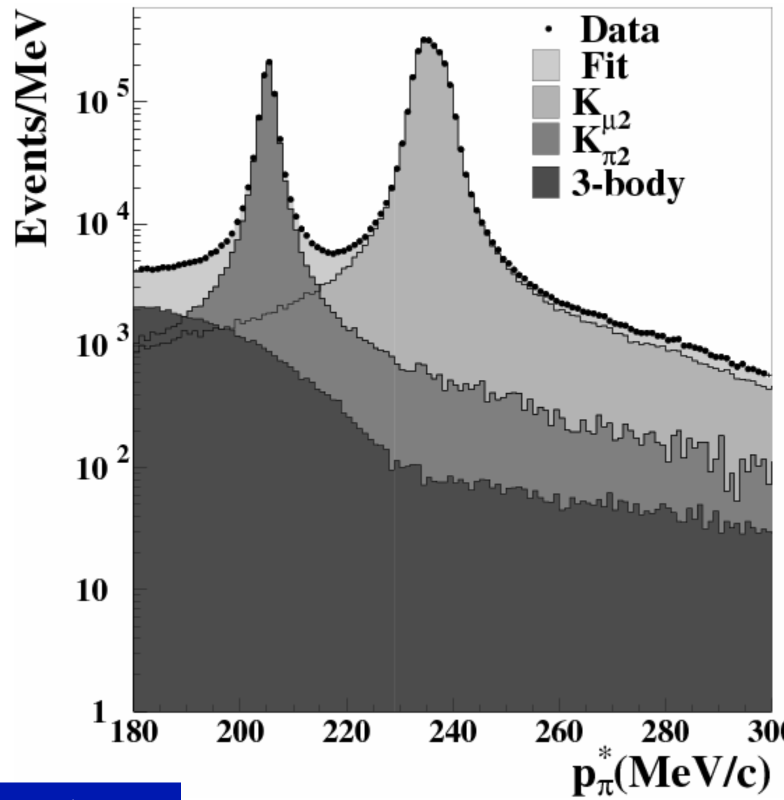
BR($K^\pm l3$) by NA48, ISTRA+, E865

- normalization sample K^+ tagged by $K^-_{\mu 2}$

  a total of 12×10^6 evts.

- fit the distribution of the momentum of the charged decay particle in the kaon rest frame assuming the pion mass (p*)





PLB 666(2008)305

BR($K^+ \to \pi^+ \pi^0 (\gamma)$) = **0.2065(9)** σ_{rel} = 0.5%

KLOE fit to $K^{\pm}$ BRs and lifetime

lifetime and absolute BRs by KLOE
(dBR/d$\tau^{\pm}$ and correlations available)

$K^+ \to \mu\nu$	0.6366(18)	0.3%	*PLB 632(2006)*
$K^+ \to \pi^+\pi^0$	0.2065(9)	0.5%	*PLB 666(2008)*
$K^{\pm} \to \pi^0 e^{\pm}\nu$	0.0497(5)	1.0%	*JHEP 02(2008)*
$K^{\pm} \to \pi^0 \mu^{\pm}\nu$	0.0324(4)	1.2%	*JHEP 02(2008)*
$K^{\pm} \to \pi^{\pm}\pi^0\pi^0$	0.0176(3)	1.7%	*PLB 597(2004)*
$\tau^{\pm}$	12.347(30) ns	0.24%	*JHEP 01 (2008)*

arXiv:0804.4577v1

Fit to $K^{\pm}$ BRs

Parameter	Value	Correlation coefficients					
$BR(K_{\mu2})$	0.6376(12)						
$BR(K_{\pi2})$	0.2071(9)	+0.48					
$BR(\pi^{\pm}\pi^{+}\pi^{-})$	0.0553(9)	−0.48	+0.21				
$BR(K_{e3})$	0.0498(5)	+0.37	−0.13	+0.16			
$BR(K_{\mu3})$	0.0324(4)	+0.34	−0.12	+0.15	+0.58		
$BR(\pi^{\pm}\pi^{0}\pi^{0})$	0.01765(25)	−0.11	+0.05	−0.05	+0.04	+0.04	
τ (ns)	12.344(29)	−0.15	−0.21	−0.07	−0.06	−0.05	−0.015

all KLOE results but
$BR(K^{\pm}\to\pi^{\pm}\pi^{+}\pi^{-})$=0.0550(10) [PDG04 average]

χ^2/ndf=0.51/1 (44%)

arXiv:0804.4577v1

$BR(K^{\pm}\to\pi^{\pm}\pi^{+}\pi^{-})$= 0.0568(22)   measured using $(1 - \Sigma BR_{KLOE})$

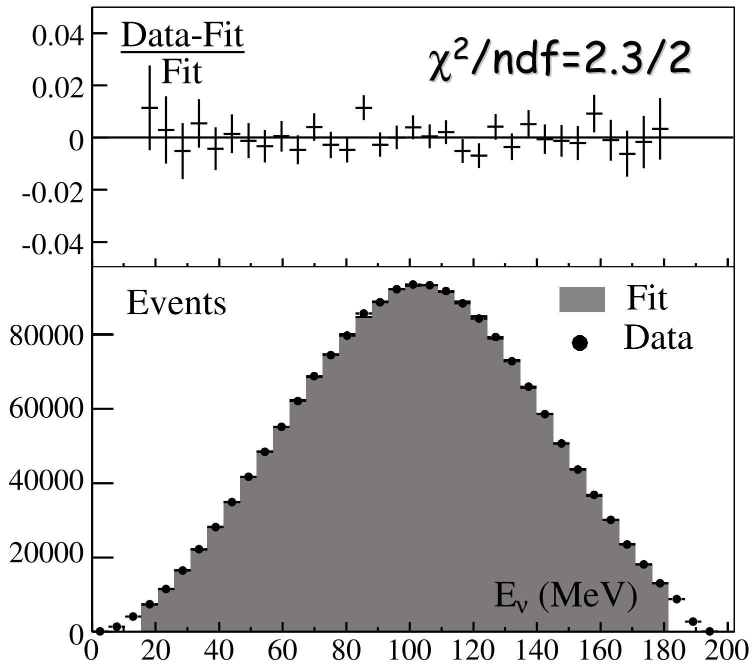
$K_{L\mu3}$ form factor slopes

- standard method ➔ fit t-spectrum $t=(p_K-p_\pi)^2$

Power expansion:

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

- π/μ ID with ToF is difficult al low energies
- slopes by fitting the $E\nu$ distribution
  - loss of sensitivity
  - combined fit with K_Le3 results
- 2×10^6 $K_L\mu3$ and 2×10^6 K_Le3 from ~ 400 pb^{-1}



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$\lambda_+' = (25.6 \pm 1.5_{stat} \pm 0.9_{syst})\times10^{-3}$

$\lambda_+'' = (1.5 \pm 0.7_{stat} \pm 0.4_{syst})\times10^{-3}$

$\lambda_0 = (15.4 \pm 1.8_{stat} \pm 1.3_{syst})\times10^{-3}$

- no simultaneous measurement of λ_0' and $\lambda_0'' \Rightarrow \rho(\lambda_0', \lambda_0'') = -0.9996$
- linear parametrization over estimates λ_0' by ~ 20%
- to clarify this ➔ ff parametrization with t and t^2 terms but one parameter

ff dispersive parametrization

dispersive relation for $f_0(t)$ with 2 subtractions at $t=0$ and at the Callan-Treiman point $t = \Delta_{K\pi}=(m^2_K-m^2_\pi)$ [Stern et al.]

$$\tilde{f}_0(t) = \exp\left[\frac{t}{m_K^2 - m_\pi^2}(\ln C - G(t))\right]$$

G(t) from $K\pi$ scattering data

$C = \tilde{f}_0(\Delta_{K\pi})$

we fit $K_{L\mu 3}$ data with 3rd order expansion of dispersive representation

only one parameter ➔ $\ln C \propto \lambda_0$

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ln C = 0.204 ± 0.023

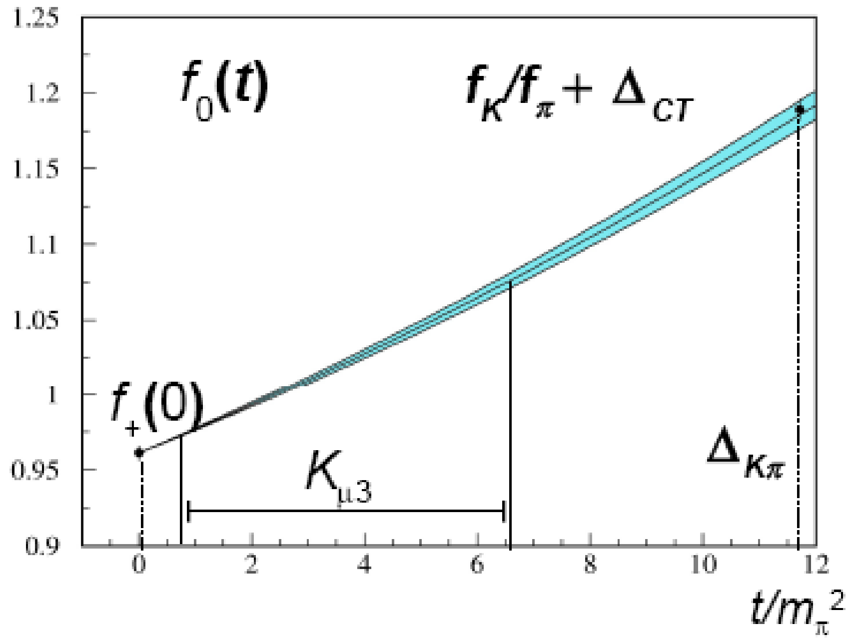
the Callan-Treiman theorem implies

$$\tilde{f}_0(\Delta_{K\pi}) = \frac{f_K}{f_\pi}\frac{1}{f_+(0)} + \Delta_{CT}$$

powerful consistency check of lattice QCD estimates of $f_K/f_\pi/f_+(0)$

$\Delta_{CT}= - 3.5 \times 10^{-3}$ (small theoretical error)

$C = \tilde{f}_0(\Delta_{K\pi})$ from fit to $K_{L\mu 3}$ data

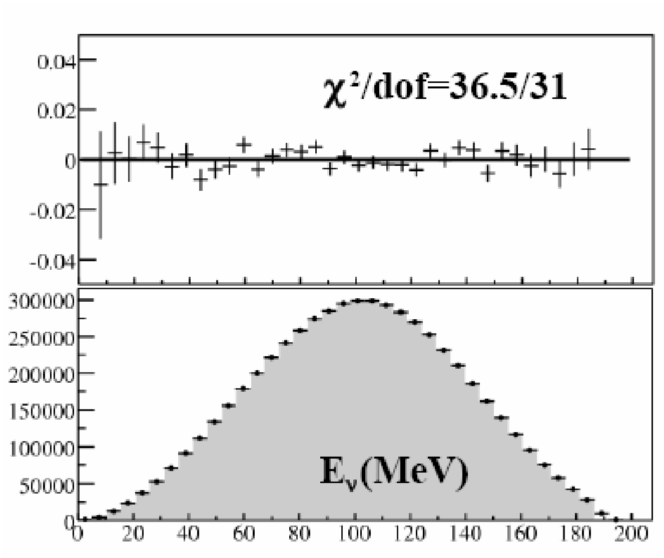


$K_{L\mu3}$ form factor slopes

correlation matrix

λ'_+	λ''_+	λ_0
1	-0.97	0.90
	1	-0.80
		1

- 5.8×10^6 $K_L\mu3$ from ~ 1 fb^{-1}



KLOE Preliminary

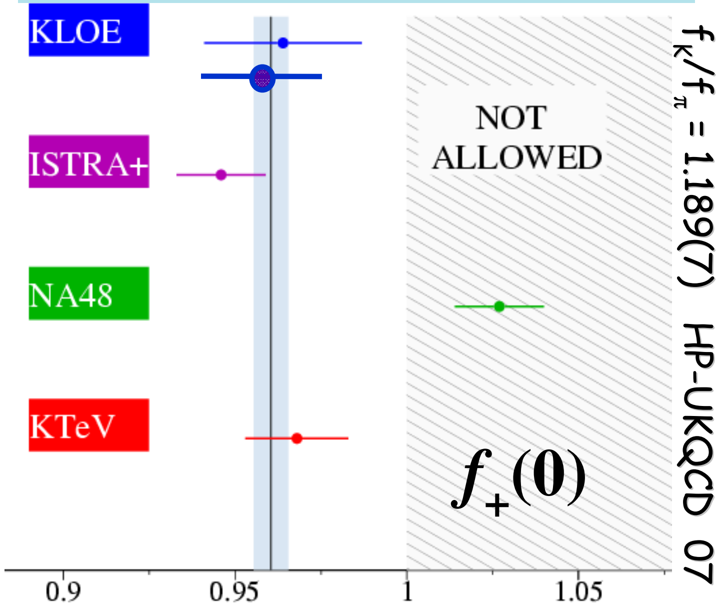
$$\lambda_+' = (25.7 \pm 5.1_{stat} \pm 2.5_{syst})\times10^{-3}$$
$$\lambda_+'' = (2.9 \pm 2.5_{stat} \pm 1.3_{syst})\times10^{-3}$$
$$\lambda_0 = (14.3 \pm 2.9_{stat} \pm 2.4_{syst})\times10^{-3}$$

- results with dispersion relations for $f_{+,0}(t)$ averaged with published results

KLOE Preliminary

$$\lambda_+ = (26.0 \pm 0.5_{stat+syst})\ \text{x}10^{-3}$$
$$\lambda_0 = (15.1 \pm 1.4_{stat+syst})\ \text{x}10^{-3}$$

$f_+(0) = 0.9644(49)$ RBC/UKQCD 07



new KLOE value $f_+(0) = 0.954(16)$ in good agreement with lattice calculations

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

BR(K_{l3})'s, $\tau(K_L)$, $\tau(K^\pm)$, ff's (dispersive relations) from KLOE, $\tau(K_S)$ from PDG

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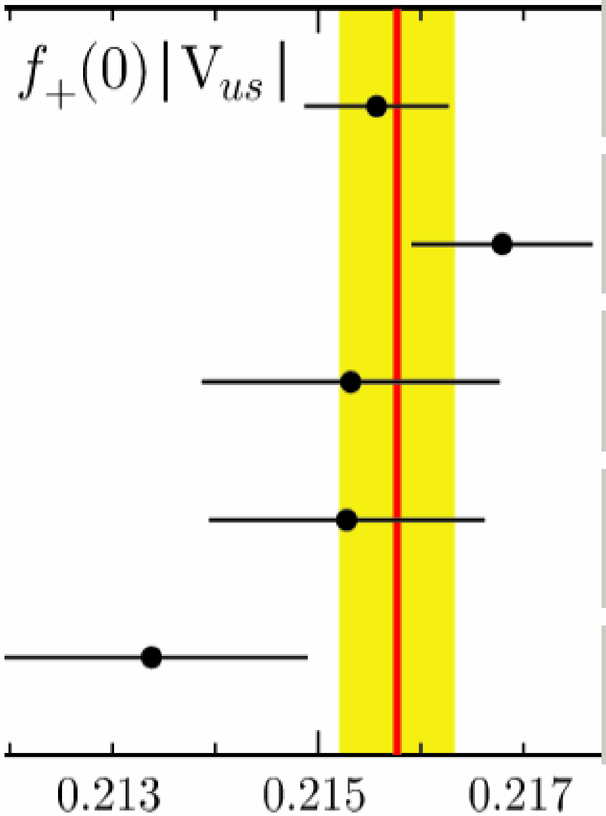
KLOE average $|V_{us}|f_+(0) = 0.2157(6)$ $\chi^2/ndf = 7/4$ (13%)



		err %
K_Le3	0.2155(7)	0.3
$K_L\mu3$	0.2167(9)	0.4
K_Se3	0.2152(14)	0.7
$K^\pm e3$	0.2152(13)	0.6
$K^\pm\mu3$	0.2132(15)	0.7

world average
$|V_{us}|f_+(0) = 0.2167(5)$
$\chi^2/ndf = 2.8/4$ (59%)

$|V_{us}| = 0.2237(13)$

unitarity test
$1 - V_{ud}^2 - V_{us}^2 = 9(8)\times10^{-4}$

$f_+(0) = 0.961(5)$ *RBC/UKQCD,07 arXiv:0710.5136*

$V_{ud} = 0.97418(26)$ *arXiv:0710.3181*

K^0 vs $K^\pm$ within 1.1σ

Lepton universality from K_{l3}

- for each state of kaon charge, we compare Ke3 and Kμ3 modes

$$r_{\mu e} = \frac{(R_{\mu e})_{\rm obs}}{(R_{\mu e})_{\rm SM}} = \frac{\Gamma_{\mu 3}}{\Gamma_{e3}} \cdot \frac{I_{e3}\,(1+\delta_{e3})}{I_{\mu 3}\,(1+\delta_{\mu 3})} = \frac{[|V_{us}|\,f_+(0)]^2_{\mu 3,\ \rm obs}}{[|V_{us}|\,f_+(0)]^2_{e3,\ \rm obs}} = \frac{g_\mu^2}{g_e^2}$$

- in the Standard Model $r_{\mu e} = 1$ $(G^\mu_F = G^e_F)$
- averaging between charged and neutral modes we get

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$r_{\mu e} = 1.000(8)$

compare with

$\pi \to l\nu$	$(r_{\mu e})^\pi = 1.0042 \pm 0.0033$	*Ramsey-Musolf, Su, Turlin 07*
$\tau \to l\nu\nu$	$(r_{\mu e})^\tau = 1.000 \pm 0.004$	*Davier, Hocker, Zhang 06*

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

(Marciano PRL93 231803,2004)

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

inputs from theory

$f_K/f_\pi = 1.189(7)$ HP/UKQCD, 07 arXiv:0706.1726

C_K, C_π radiative inclusive electroweak corrections

$1 \times \alpha(C_K - C_\pi) = 0.9930(35)$

inputs from experiment

$\Gamma(K_{\mu2(\gamma)})$, $\Gamma(K_{\pi2(\gamma)})$ rates with well determined treatment of radiative decays

V_{us} - V_{ud} plane

inputs

PLB 636 (2006)

$|V_{us}/V_{ud}|$ = 0.2321(13) from K_{l2}

BR($K^{\pm} \rightarrow \mu^{\pm}\nu$) = 0.6366(17)

f_K/f_π = 1.189(7) from UKQCD '07

$|V_{us}|$ = 0.2237(13) from K_{l3}

$|V_{ud}|$ = 0.97418(26) arXiv:0710.3181

- fit to $|V_{ud}|^2$, $|V_{us}|^2$ and $|V_{us}/V_{ud}|^2$

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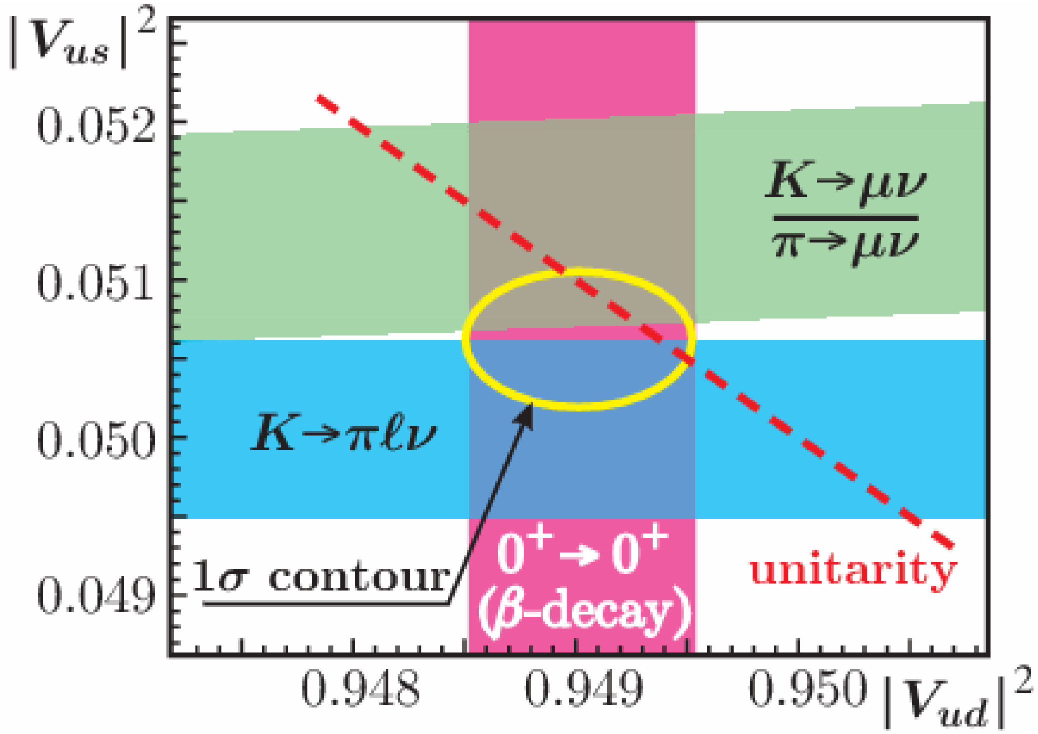
$|V_{ud}|^2 = 0.9490(5)$
$|V_{us}|^2 = 0.0506(4)$
$\chi^2 = 2.3/1\ (13\%)$

- agreement with unitarity @ 0.6σ

$1 - V_{ud}^2 - V_{us}^2 = 4(7)\times 10^{-4}$



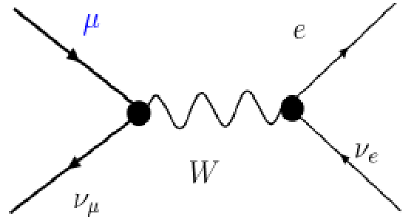
Unitarity test of CKM: G_F universality

comparison between weak couplings from K decays (G_{CKM}) and from τ_μ (G_F)

$$G_F^2 \equiv G_{CKM}^2 = (|V_{ud}|^2 + |V_{us}|^2)\, G_F^2$$

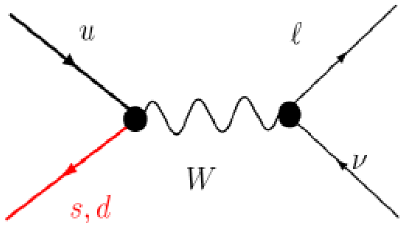
agreement within ~ 0.7σ

$G_F = 1.166371(6) \times 10^{-5}$ GeV^{-2}



V_{us} at 0.4%

$G_{CKM} = 1.1661(04) \times 10^{-5}$ GeV^{-2}



CKM unitarity test with kaons competitive with Electro-Weak precison test

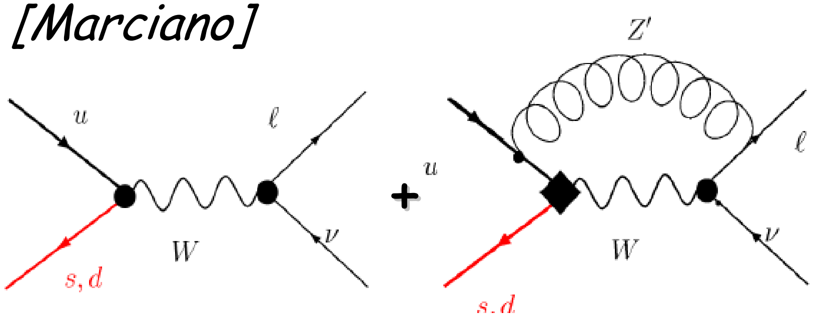
[$G_{e.w.} = 1.1655(12) \times 10^{-5}$ GeV^{-2}]

constraints on NP models, e.g. SO(10) Z ' boson [Marciano]

$G_F = G_{CKM}\,[1 - .007 \times 8/3 \times \ln(M_{Z'}/M_W)/(M_{Z'}^2/M_W^2 - 1)]$

we set the limit $M_{Z'} > 750$ GeV @ 95% CL

($M_{Z'} > 720$ GeV direct search)



$K_{\mu 2}$: sensitivity to charged Higgs

compare $|V_{us}|$ as obtained from helicity-suppressed K_{l2} and helicity-allowed K_{l3} decays

$$R_{l23} = \left| \frac{V_{us}(K_{\ell 2})}{V_{us}(K_{\ell 3})} \times \frac{V_{ud}(0^+ \to 0^+)}{V_{ud}(\pi_{\ell 2})} \right|$$

within the SM, $R_{l23} = 1$

in MSSM a scalar current due to charged Higgs exchange lowers the value of R_{l23}

$$R_{l23} = \left| 1 - \frac{m_{K^+}^2}{M_{H^+}^2} \left(1 - \frac{m_d}{m_s}\right) \frac{\tan^2\beta}{1 + \epsilon_0 \tan\beta} \right|$$

- effects of scalar currents on $0^+ \to 0^+$ nuclear transitions and K_{l3} decays are expected to be insignificant
- the only sizable effects are expected from the K_{l2} decays

from a fit to $K_{\mu 2}$ and $K_{\ell 3}$ data using $f_K/f_\pi = 1.189(7)$ and $f_+(0)=0.964(5)$ we get

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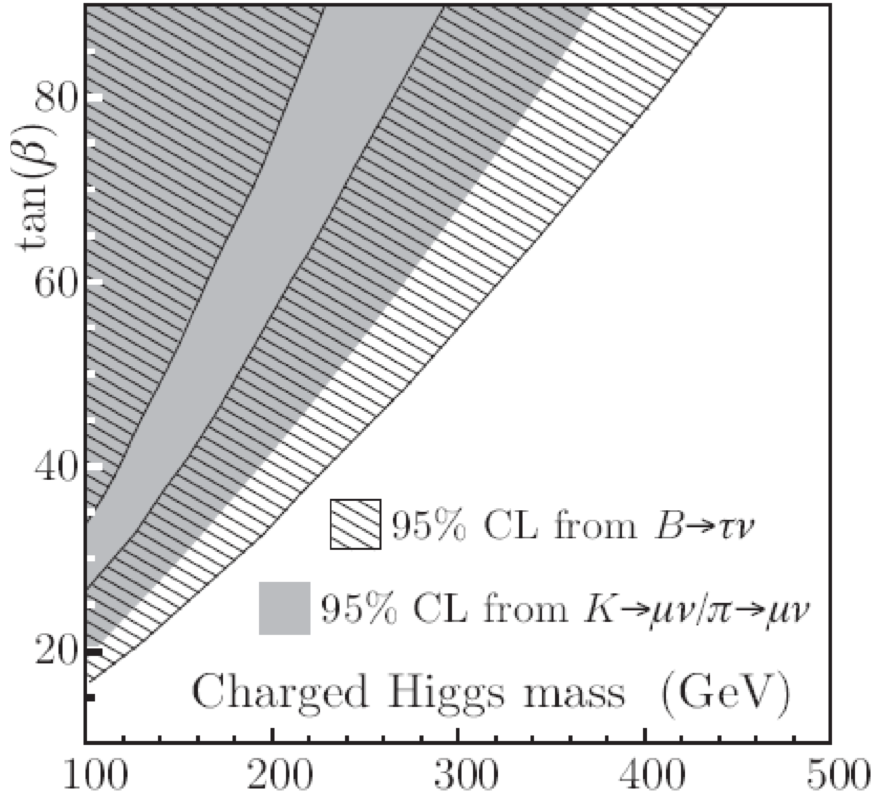
$$R_{l23} = 1.008 \pm 0.008$$



sets bounds on M_{H+} and tan(β) values complementary to B physics

CP and CPT test from unitarity

the Bell Steinberger relation assumes the conservation of unitarity ➔ *link between the CP violating parameter Re(ε), the CPT violating parameter Im(δ), and the physical kaon decay amplitudes*

$$(1 + i \tan \phi_{SW})\,[\mathrm{Re}\,\varepsilon - i\,\mathrm{Im}\,\delta] = \frac{1}{\Gamma_S} \sum_f A^*(K_S \to f)\, A(K_L \to f) = \sum_f \alpha_f$$

where $\phi_{SW} = \tan^{-1}[2(M_L - M_S)/(\Gamma_S - \Gamma_L)]$

the *advantage of the neutral kaon system* is that *only* the ππ(γ), πππ and πlν decay modes *give appreciable contribution > 10^{-7}*

we published values for Re(ε) and Im(δ) using our measurements of $K_{L,S}$ decays, the analysis benefits in particular from

- $BR(K_L \to \pi^+\pi^-)$ relevant for Re(ε) *PLB 638(2006)*
- UP($BR(K_S \to 3\pi^0)$) improves the accuracy on Im(δ) *PLB 619 (2005)*
- the $K_S e3$ charge asimmetry A_S, which allows, *for the first time*, to evaluate the contribution from semileptonic channels *without assuming unitarity* *PLB 636 (2006)*

Parameter	Value	Correlation coefficients						
$BR(K_{e3})$	0.4008(15)							
$BR(K_{\mu 3})$	0.2699(14)	−0.31						
$BR(3\pi^0)$	0.1996(20)	−0.55	−0.41					
$BR(\pi^+\pi^-\pi^0)$	0.1261(11)	−0.01	−0.14	−0.47				
$BR(\pi^+\pi^-)$	$1.964(21) \times 10^{-3}$	−0.15	+0.50	−0.21	−0.07			
$BR(\pi^0\pi^0)$	$8.49(9) \times 10^{-4}$	−0.15	+0.48	−0.20	−0.07	+0.97		
$BR(\gamma\gamma)$	$5.57(8) \times 10^{-4}$	−0.37	−0.28	+0.68	−0.32	−0.14	−0.13	
τ_L	50.84(23) ns	+0.16	+0.22	−0.14	−0.26	+0.11	+0.11	−0.09

$\chi^2/ndf = 0.19/1$
CL =66%

TABLE II. – *Final KLOE measurements of main K_L BRs and τ_L.*

Mode	$BR(\text{mode})/BR(\pi^+\pi^-)$	BR(mode)
$\pi^+\pi^-$	—	$(69.196 \pm 0.024 \pm 0.045)\%$
$\pi^0\pi^0$	$1/(2.2549 \pm 0.0054)$	$(30.687 \pm 0.024 \pm 0.045)\%$
$\pi^-e^+\nu$	$(5.099 \pm 0.082 \pm 0.039) \times 10^{-4}$	$(3.528 \pm 0.057 \pm 0.027) \times 10^{-4}$
$\pi^+e^-\bar{\nu}$	$(5.083 \pm 0.073 \pm 0.042) \times 10^{-4}$	$(3.517 \pm 0.050 \pm 0.029) \times 10^{-4}$
$\pi e\nu$	$(10.19 \pm 0.11 \pm 0.07) \times 10^{-4}$	$(7.046 \pm 0.076 \pm 0.051) \times 10^{-4}$

TABLE III. – *KLOE measurements of K_S branching ratios.*

Results for Re(ε) and Im(δ)

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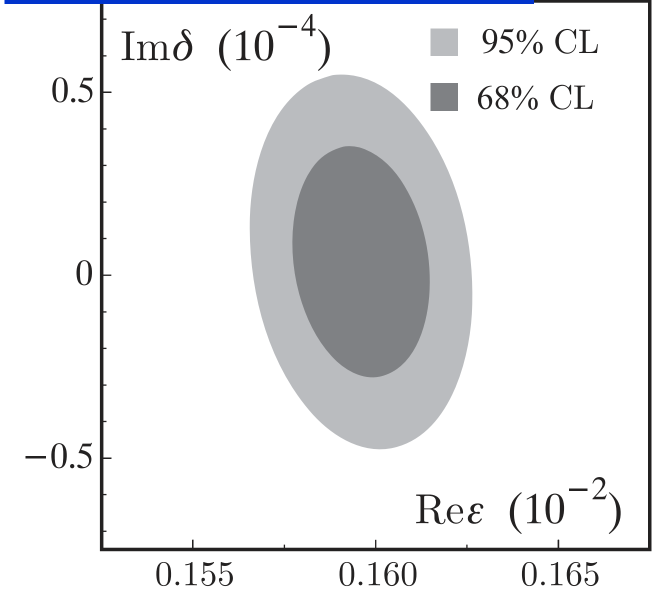


$$Re(\varepsilon) \propto \cos\phi_{SW}\Sigma_f\, Re(\alpha_f) + \sin\phi_{SW}\Sigma_f\, Im(\alpha_f)$$

$$Im(\delta) \propto \cos\phi_{SW}\Sigma_f\, Re(\alpha_f) - \sin\phi_{SW}\Sigma_f\, Im(\alpha_f)$$

$Re\,\varepsilon = (159.6 \pm 1.3) \times 10^{-5}$.
$Im\,\delta = (0.4 \pm 2.1) \times 10^{-5}$

the main contribution to the uncertainty of Im(δ) comes from $\phi_{\pi\pi}$ → $\sigma(Im(\delta)) = \underset{\pi\pi}{1.8} \oplus \underset{\pi l\nu}{1.2}$

CPLEAR

$Re\,\varepsilon = (164.9 \pm 2.5) \times 10^{-5}$.
$Im\,\delta = (2.4 \pm 5.0) \times 10^{-5}$

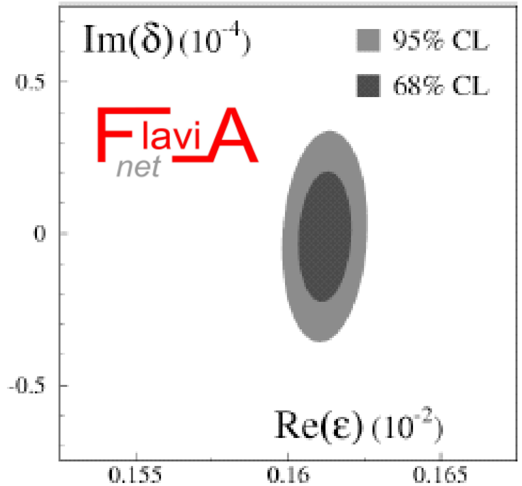
PDG 08

$Re\,\varepsilon = (161.2 \pm 0.6) \times 10^{-5}$.
$Im\,\delta = (-0.6 \pm 1.9) \times 10^{-5}$

FlaviA net

$Re\,\varepsilon = (161.2 \pm 0.6) \times 10^{-5}$.
$Im\,\delta = (-0.1 \pm 1.4) \times 10^{-5}$

benefits of the preliminary KTeV results on $\phi_{\pi\pi}$
M.Palutan FlaviAnet, Capri Workshop, June 2008



CPT test: $m(K^0)-m(\overline{K}^0)$

$$\delta = \frac{1}{2}\frac{\Delta M - \frac{i}{2}\Delta\Gamma}{(M_L - M_S) + \frac{i}{2}(\Gamma_S - \Gamma_L)}$$

$\Delta M \propto -\sin\phi_{SW}\,\mathrm{Re}(\delta) + \cos\phi_{SW}\,\mathrm{Im}(\delta)$

$\Delta\Gamma \propto \cos\phi_{SW}\,\mathrm{Re}(\delta) + \sin\phi_{SW}\,\mathrm{Im}(\delta)$

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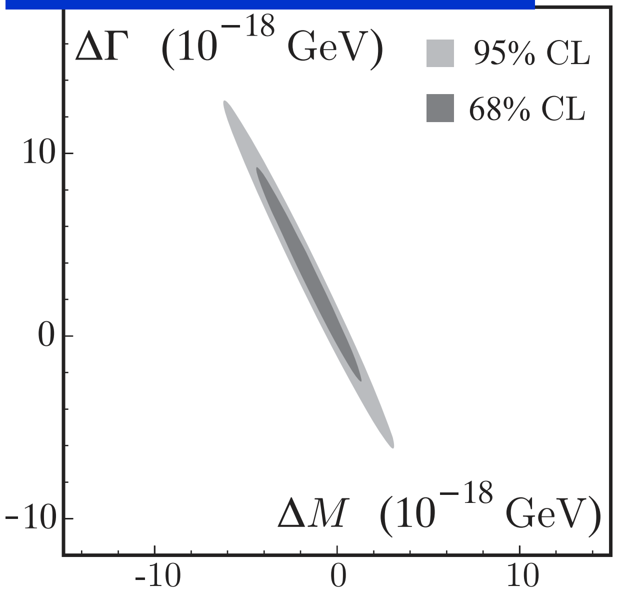


$\mathrm{Im}\,\delta = (0.4 \pm 2.1)\times10^{-5}$ from BSR

$\mathrm{Re}\,\delta = (2.5 \pm 2.3)\times10^{-4}$ from CPLEAR

assuming CPT violation only in the mass matrix ($\Delta\Gamma$=0)

$\Delta M = (0.5 \pm 3.0) \times 10^{-19}$ GeV

CPLEAR

$\Delta M = (3.3 \pm 7.0) \times 10^{-19}$ GeV

PDG 08

$\Delta M = (-0.9 \pm 2.6) \times 10^{-19}$ GeV

FlaviA net

$\Delta M = (-0.1 \pm 2.0) \times 10^{-19}$ GeV

Conclusions

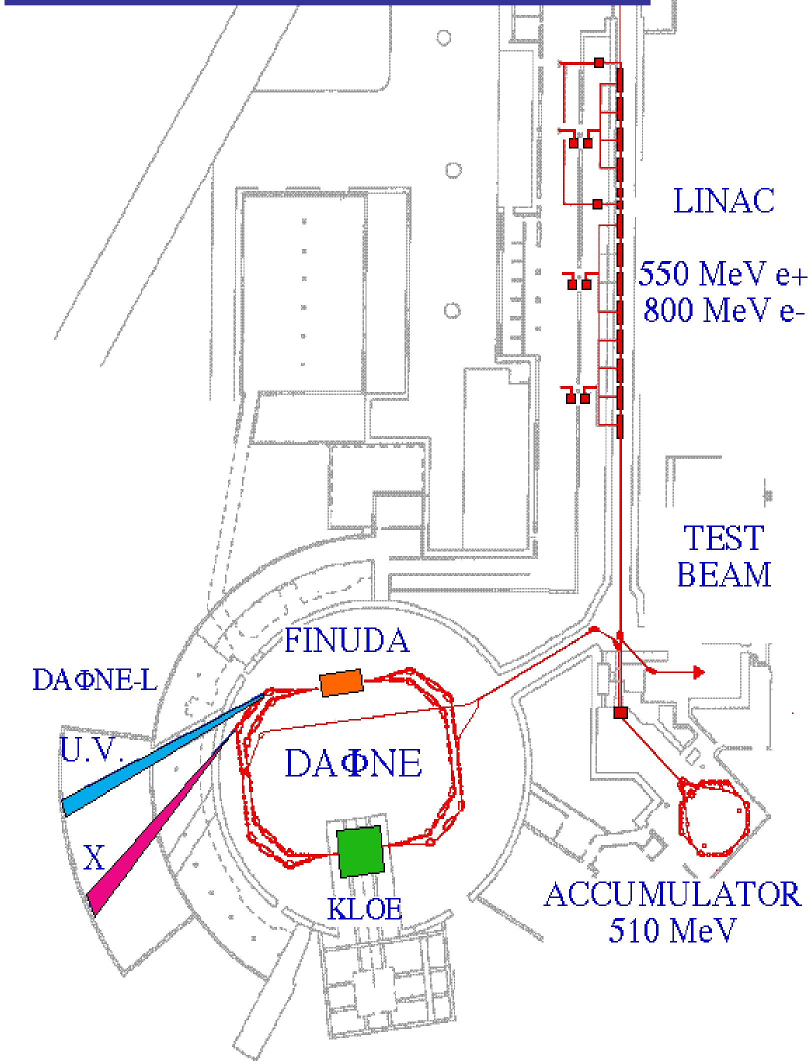
- *comprehensive set of observables from K decays: BR's, τ's, λ's*
- *present accuracy on $|V_{US}|f_+(0)$ is 0.3 % using only KLOE results*
  0.2 % from World Average FlaviA net
- *unitarity of the first row of the CKM matrix at 0.1 %*
- *lepton universality test from K_{l3} decays satisfied at 0.8%*
- *competitive test of universality of lepton and quark weak coupling from unitarity* $G_F^2 \equiv G_{CKM}^2 = (|V_{ud}|^2 + |V_{us}|^2)\, G_F^2$
- *sensitivity to NP effects from $K_{\mu 2}/\pi_{\mu 2}$*

- *the Bell-Steinberger relation is a very powerful tool to probe some of the basic principles of fundamental interactions CPT and unitarity*
- *KLOE have obtained precision results on CP and CPT violation parameters ➔ data are consistent with CPT symmetry and unitarity*
  - *present uncertainty on Im(δ) is dominated by 2π channels*

Spare slides

DaΦne: the frascati ϕ factory

$\mathcal{L}_{design}$ = 5×10^{32} cm^{-2} s^{-1}



- e+e- collider @ $\sqrt{s}$ = 1019.4 MeV
- separate e+, e- rings to minimize beam-beam interactions
- crossing angle: 12.5 mrad (2001/02) 15 mrad (2004/05)
- time between collision 2.7 ns
- injection during data-taking

Daϕne performances in 2004/05

$\cong$ 105 $e^+ + e^-$ bunches

$I^-_{peak}\sim 2.4$ A, $I^+_{peak}\sim 1.5$ A

$\mathcal{L}_{peak} = 1.4\times10^{32}$ cm^{-2} s^{-1}

$\mathcal{L}_{avg}$ month $\cong$ 200 pb^{-1}

Kaon production

the ϕ decay at rest provides monochromatic and pure kaon beams

the KK pairs in the final state have the same quantum numbers as the ϕ, *i.e.*, they are produced in a pure $J^{PC} = 1^{--}$ state

$\sigma(e^+e^- \to \phi) \approx 3\ \mu b$ $\quad K_S, K^+ \longleftarrow \phi \longrightarrow K_L, K^-$

detection of a K_S (K_L) guarantees the presence of a K_L (K_S) with known momentum and direction (the same for K^+K^-) $\Rightarrow$ **tagging**

pure kaon beam obtained $\Rightarrow$ normalization (N_{tag}) sample

$\Rightarrow$ allows precision measurements of absolute BRs

K^+K^-

BR $\cong$ 49%

p_{lab} = 127 MeV/c

$\lambda_\pm$ = 95 cm

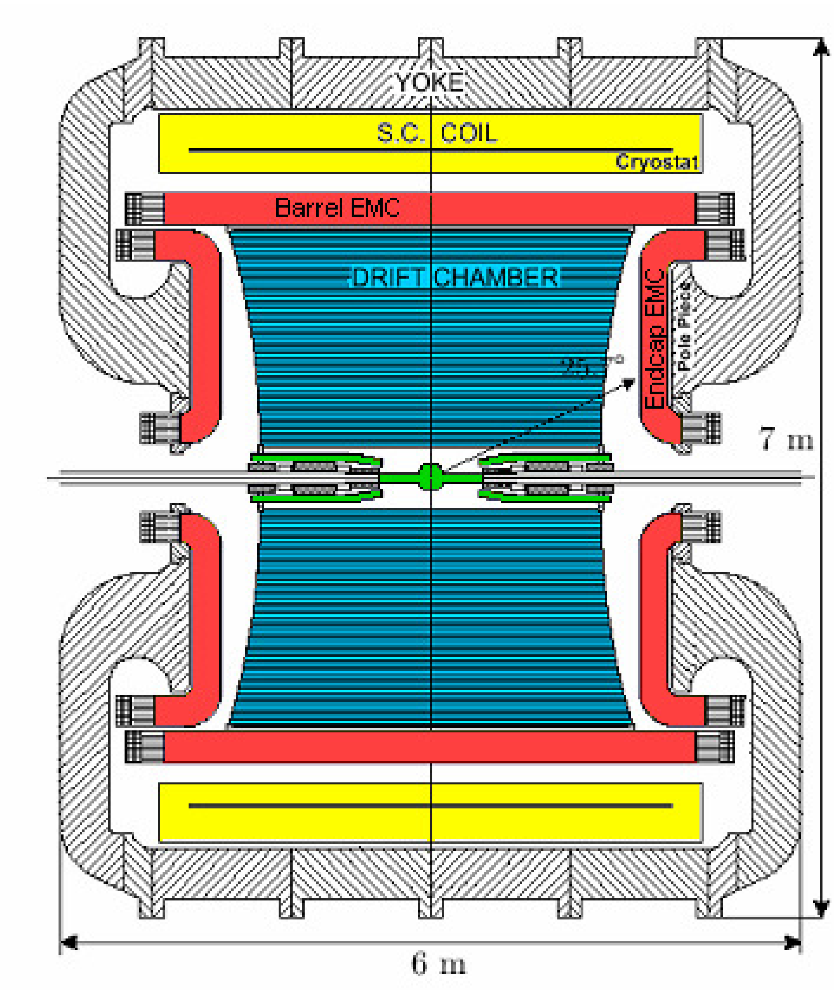
K_LK_S

BR $\cong$ 34% ; p_{lab} = 110 MeV/c

λ_S = 0.6 cm K_S decays near interaction point

λ_L = 340 cm Large detector to keep reasonable acceptance for K_L decays (~0.5 λ_L)

The KLOE experiment



Be beam pipe (0.5 mm thick),
r =10 cm (K_S fiducial volume)
Instrumented permanent magnet quadrupoles (32 PMT's)

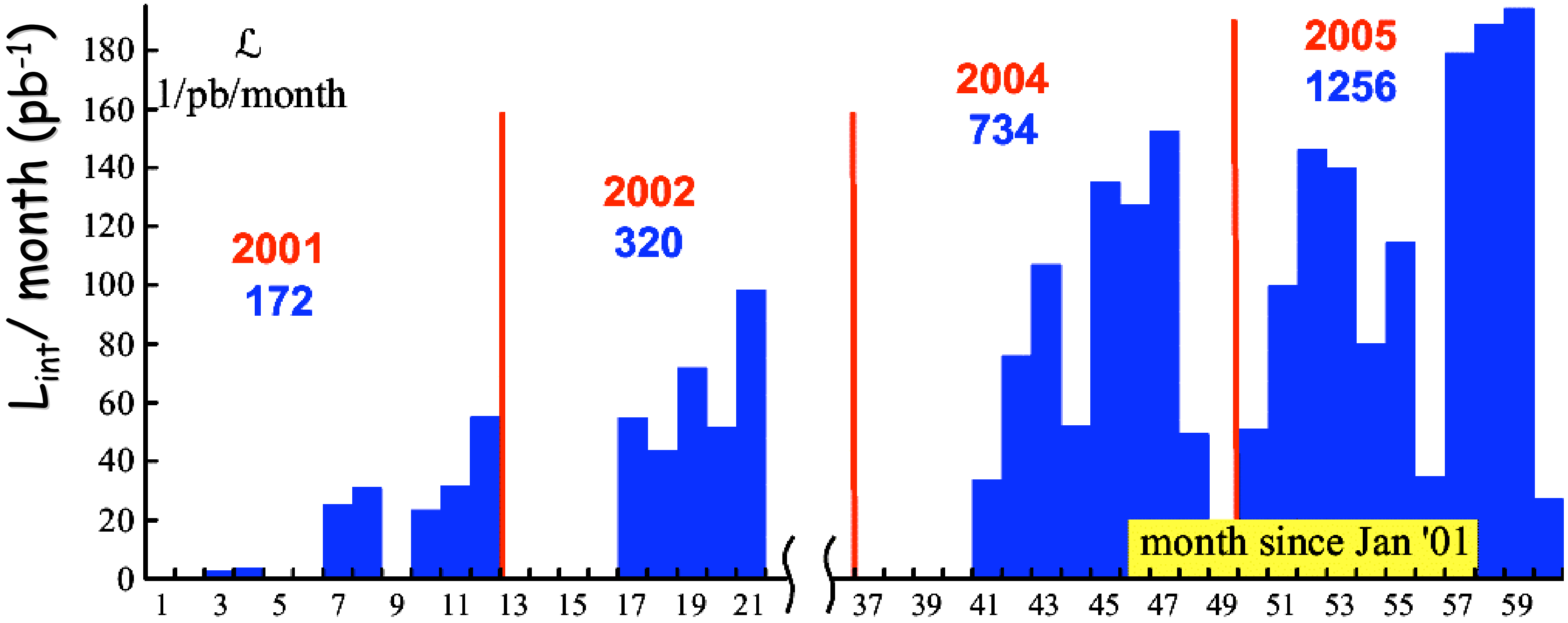
Drift chamber (4 m Ø × 3.3 m)
90% He + 10% IsoB, CF frame
12582 stereo sense wires

Electromagnetic calorimeter
Lead/scintillating fibers
4880 PMT's, cover 98% of the solid angle

Superconducting coil
B = 0.52 T ($\int Bdl$ = 2 T·m)

The KLOE data sample

data taking for KLOE experiment, years 2001-2005, now run completed

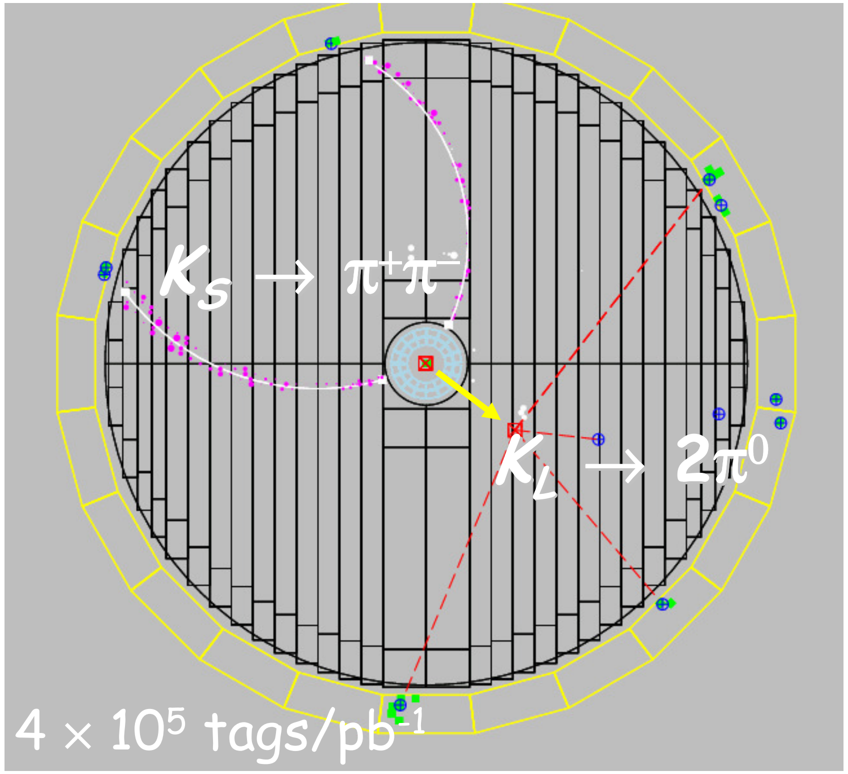


2001-5 ~2.5 fb^{-1} integrated @ $\sqrt{s}=M(\phi)$, yielding ~2.5 x 10^9 $K_S K_L$ and ~ 3.6 x 10^9 K^+K^- pairs

2006 4-pt energy scan around ϕ peak + 225 pb^{-1} off peak data, $\sqrt{s}$=1GeV

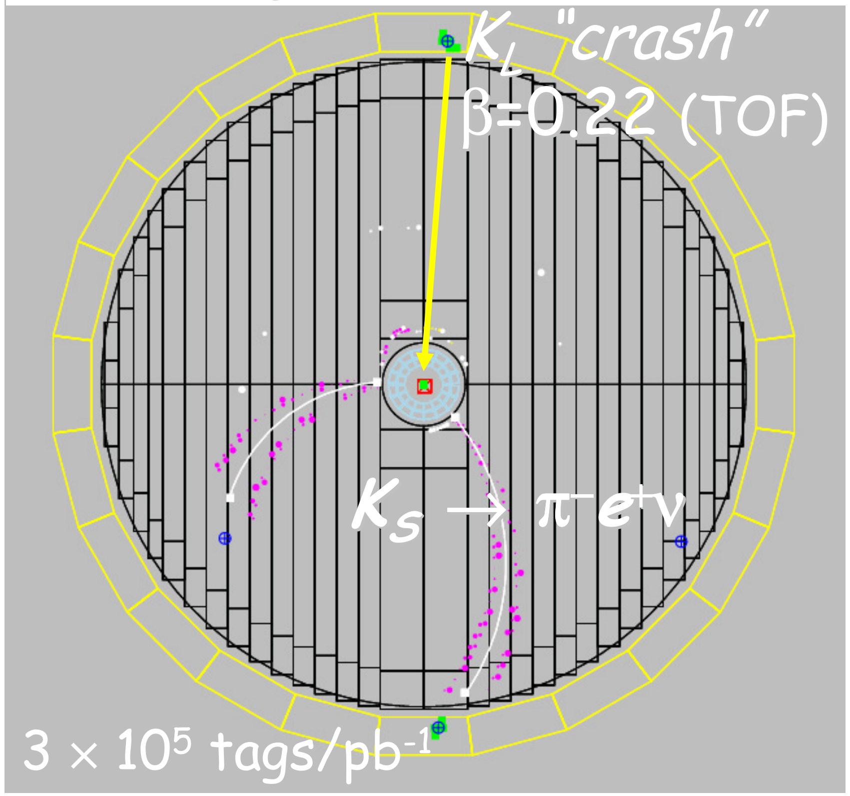
Tagging of K_L K_S beams

K_L tagged
by $K_S \to \pi^+\pi^-$ vertex at IP



ε ~ **70%** (mainly geometrical)
K_L angular resolution: ~ 1°
K_L momentum resolution: ~ 1 MeV

K_S tagged
by K_L interaction in EmC



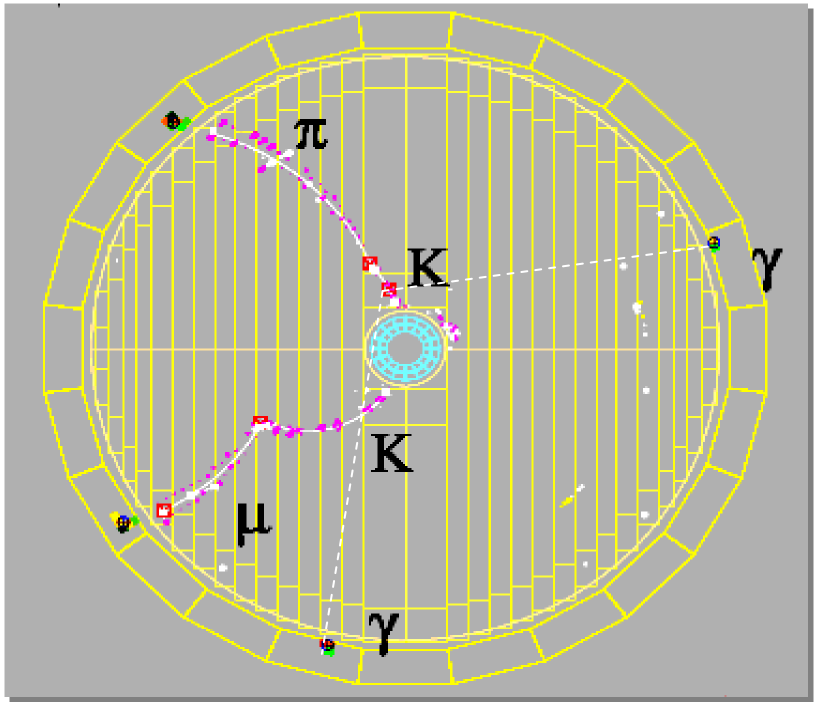
ε ~ **30%** (mainly geometrical)
K_S angular resolution: ~ 1° (0.3° in ϕ)
K_S momentum resolution: ~ 1 MeV

Tagging of K^+K^- beams

$K^\pm$ beam tagged from

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

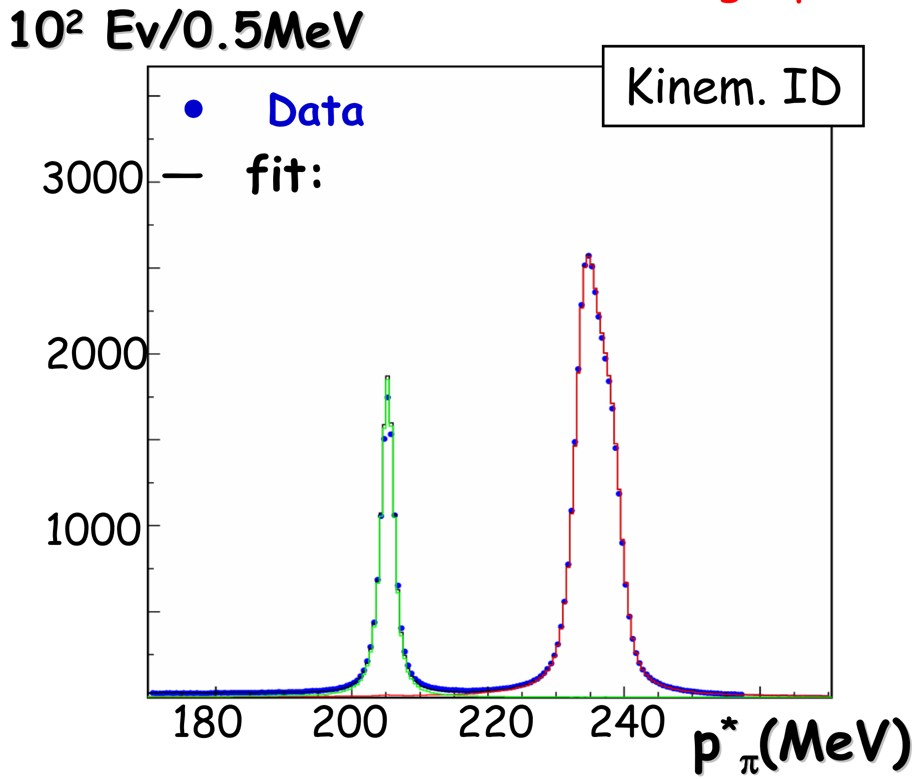
$\cong 1.5 \times 10^6$ K^+K^- evts/pb^{-1}



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

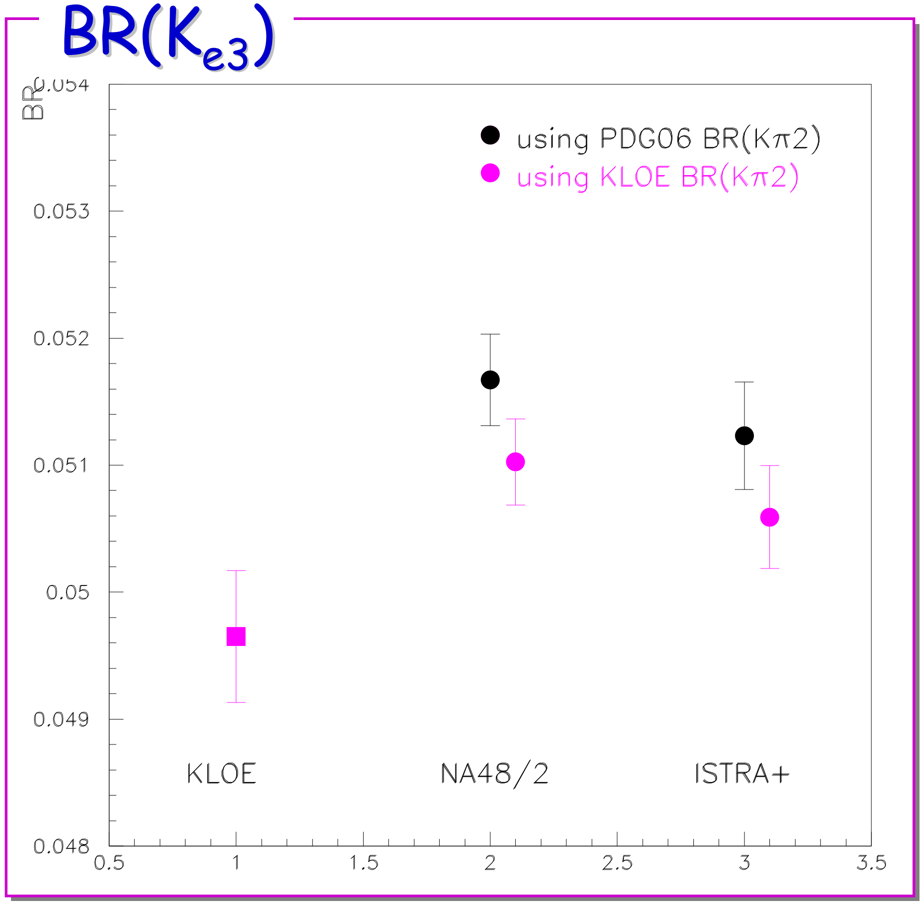
$\varepsilon_{tag} \cong 36$ % $\Rightarrow \cong 3.4 \times 10^5$ $\mu\nu$ tags/pb^{-1}

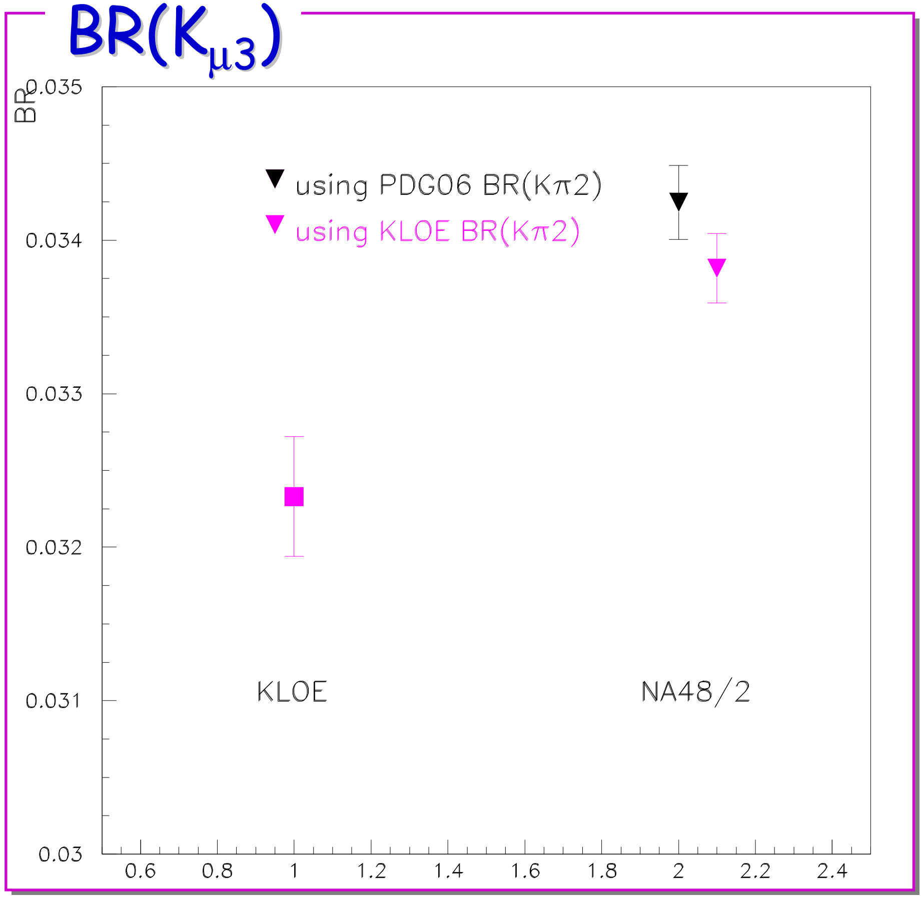
$\cong 1.1 \times 10^5$ $\pi\pi^0$ tags/pb^{-1}



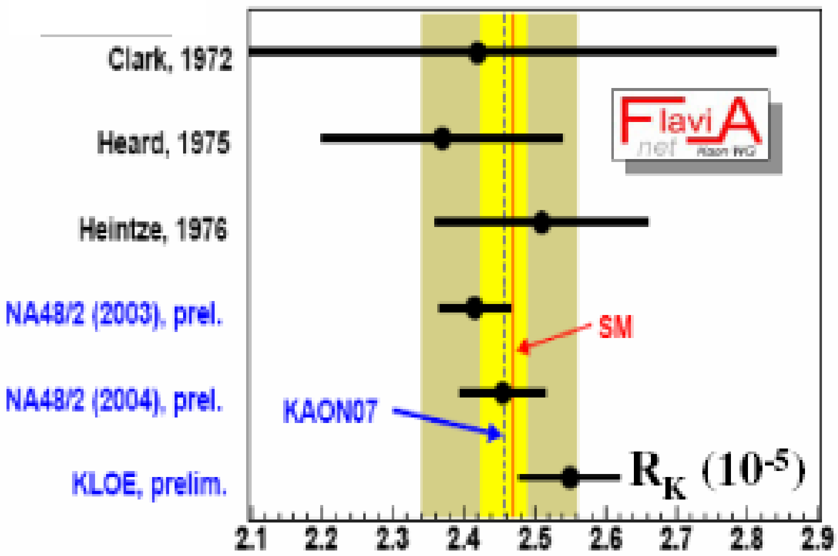
Measurement of the $BR(K^+ \to \pi^+\pi^0)$

impact of the new measurement wrt PDG 06 fit value on the $BR(K^{\pm}_{l3})$ measurements normalized to $K_{\pi 2}$ decays and comparison with absolute $BR(K^{\pm}_{l3})$ measurements from KLOE





$R_K = K_{e2}/K_{\mu 2}$



- In the SM $R_K=\Gamma(Ke2)/\Gamma(K\mu 2)$ precisely calculated:
  $R_K^{SM}=2.477(1)\times 10^{-5}$
- Lepton Flavor Violation in the MSSM would enhance R_K up to a few % (LFV appears at 1-loop level via an effective $H^+ \ell \nu_\tau$ Yukawa interaction)
- World average agrees with SM
  $R_K= 2.457(32)\times 10^{-5}$

With the full data set

$R_K= 2.55(7)\times 10^{-5}$ KLOE preliminary 2.7% accuracy using 8000 Ke2 decays

95%-CL excluded regions in the $\tan\beta - M_{H+}$ plane

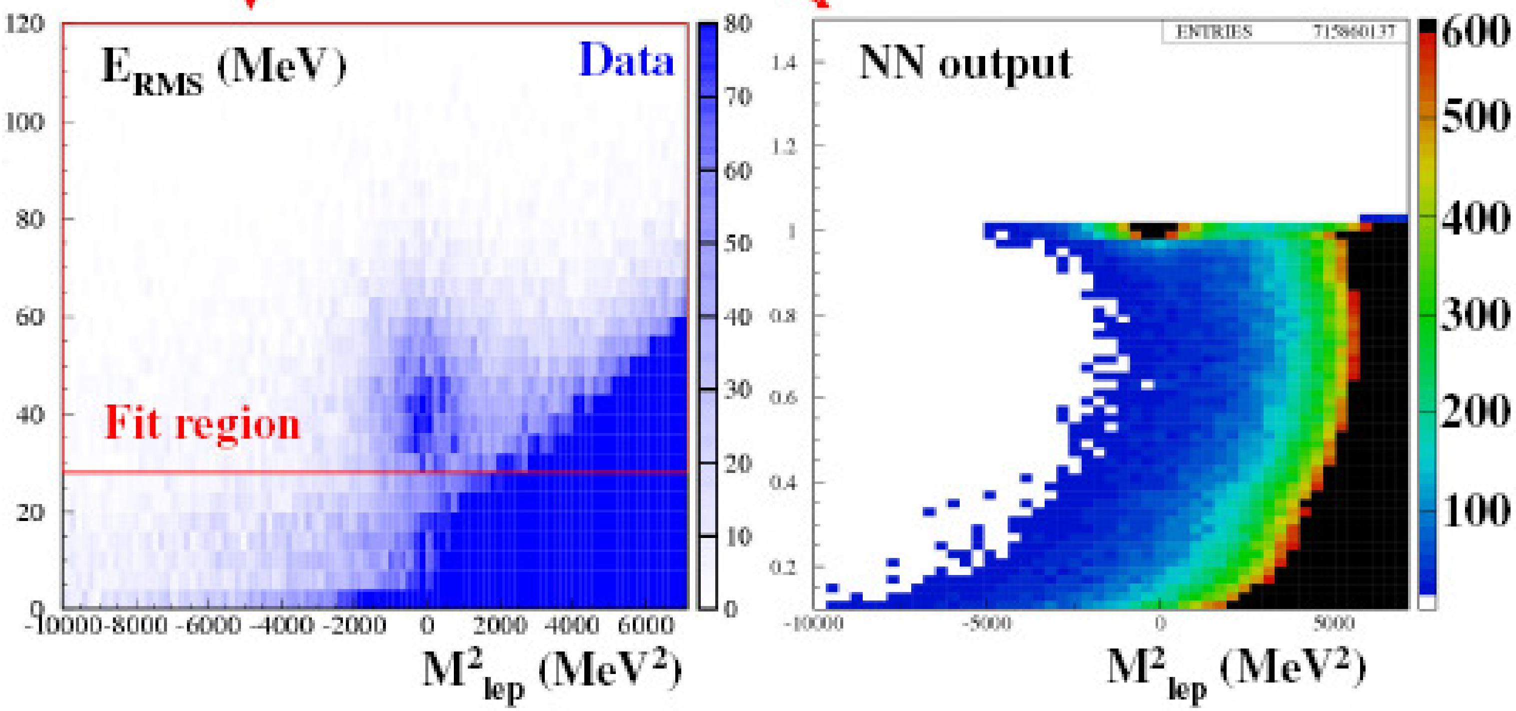
arXiv: 0707.4623

work in progress for final result at <1.3% accuracy

$R_K = K_{e2}/K_{\mu2}$: toward the final result

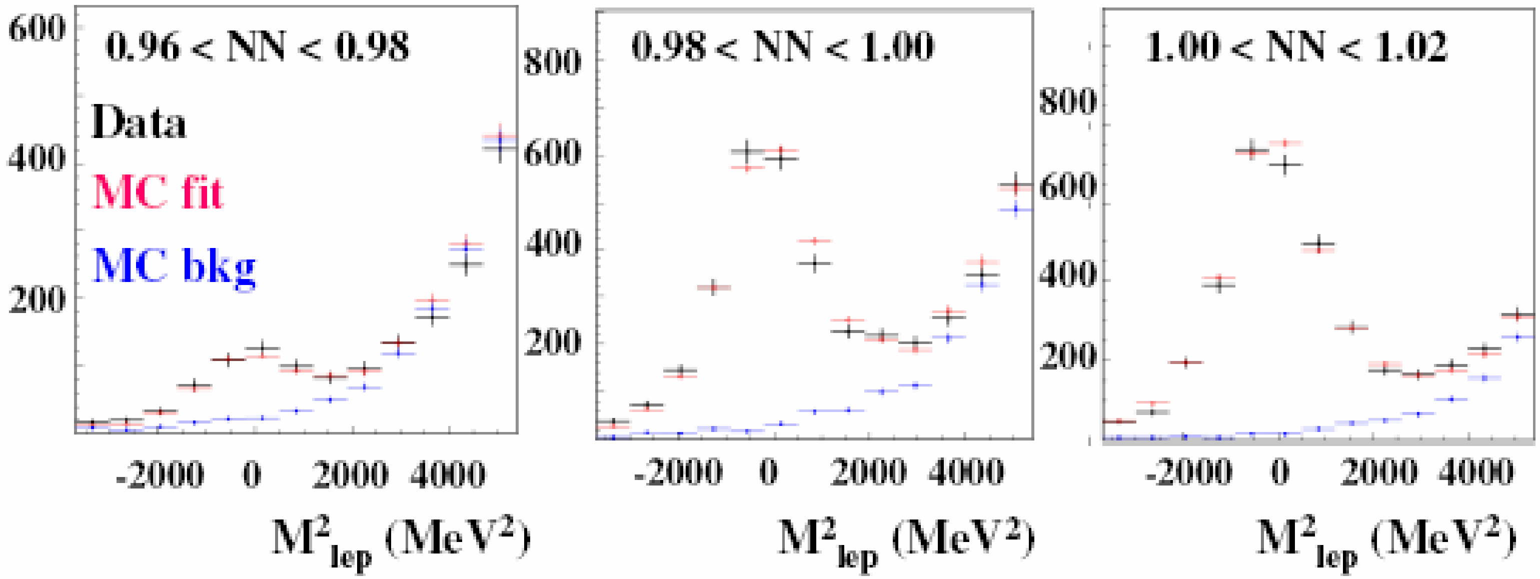
Rejection from PID now > 1000 → loosen kinematic criteria

Compare OLD selection with NEW selection



$R_K = K_{e2}/K_{\mu2}$: toward the final result

Two-dimensional binned likelihood fit in the NN- M^2_{lep} plane



Using the whole statistics: NKe2(e^+) = 6901(98), NKe2(e^-) = 6514(97)

Yield +30% wrt old analysis, reach 1.1% statistical error