V_{us} and lepton universality from K decays at KLOE

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XXVIII Physics In Collision Perugia

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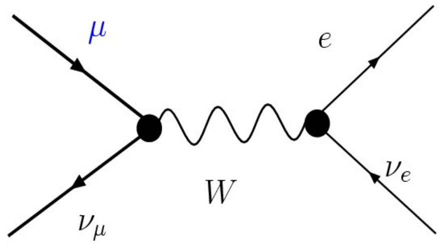
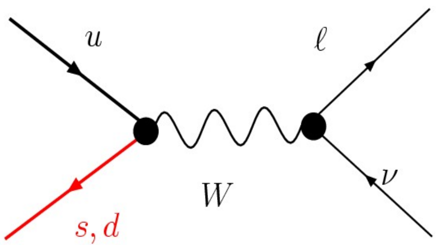
Unitarity test of CKM: G_F universality

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

Universality of Weak coupling- $G_F = (g_W/M_W)^2$

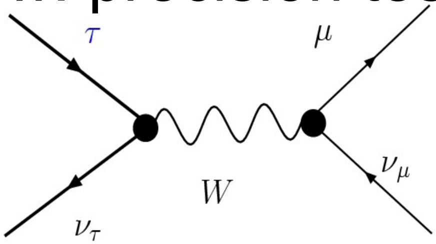
$$G_F^2 \equiv G_{CKM}^2 = (|V_{ud}|^2 + |V_{us}|^2)\, G_F^2$$





$\alpha + M_W + s_W$

[e. w. precision tests]



$G_F = 1.166371(6)\times10^{-5}\ \text{GeV}^{-2}$

V_{us} at 0.5%

$G_{CKM} = 1.16xx(04)\times10^{-5}\ \text{GeV}^{-2}$

$G_{e.w.} = 1.1655(12)\times10^{-5}\ \text{GeV}^{-2}$

$G_\tau = 1.1678(26)\times10^{-5}\ \text{GeV}^{-2}$

Probe for Physics beyond SM

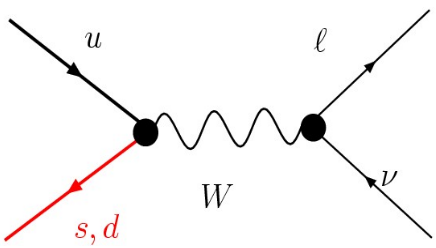
$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 \equiv 1$ (the V_{ub} term is crossed out)

→

Universality of Weak coupling- $G_F=(g_W/M_W)^2$

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

Standard Model



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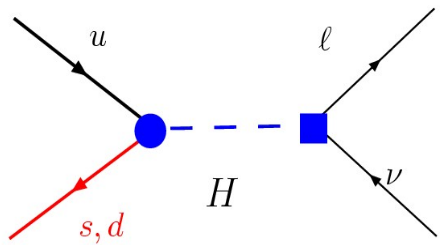
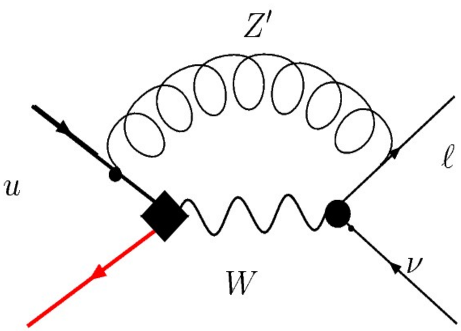
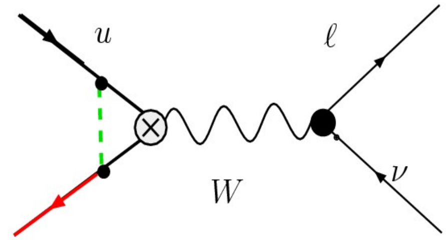






naively:

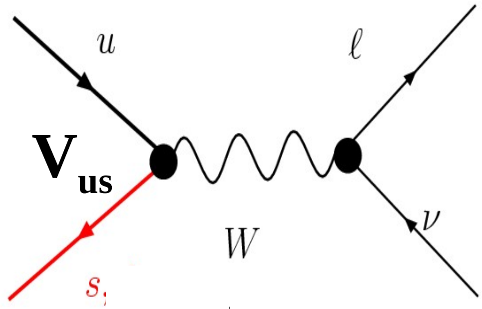
$$G_{CKM}=G_F[1+a(M_W/M_M)^2]$$

Tree level **$a\sim 1$** **$M_M\sim 13$ TeV**

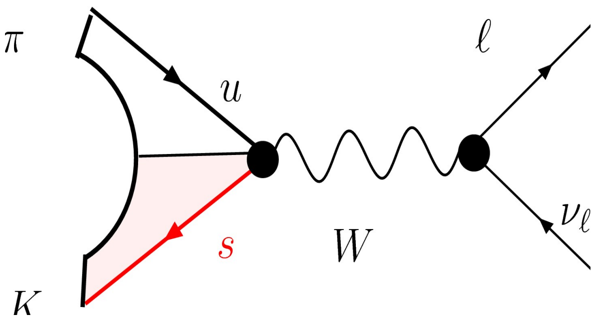
Sensitivity

loops **$a\sim g_W^2(16\pi^2)$** **$M_M\sim 1$ TeV**

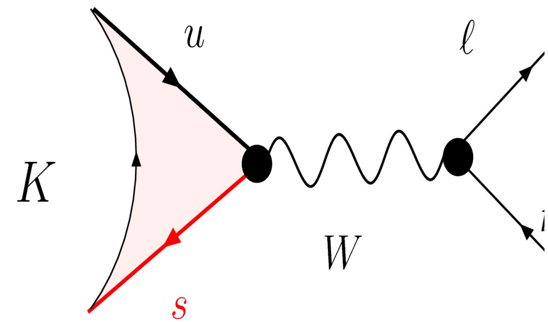
Kaon high precision observables



Short distance physics



Experimental processes



$K_{\ell 3}$: $K \rightarrow \pi \, \ell \, \nu$

Not helicity suppressed

$K_{\ell 2}$: $K \rightarrow \ell \, \nu$

helicity suppressed:
more sensitive to new physics

$K_{\ell 3}$ decays

Vector transition protected against ~~SU~~(3) corrections: [Ademollo Gatto]

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

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

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

S_{EW} Universal SD EW correction (1.0232)

Inputs from theory:

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

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

$\Delta_{K\ell}^{EM}$ Form-factor correction for long-distance EM effects

Inputs from experiment:

$\Gamma(K_{\ell 3(\gamma)})$ Rates with well-determined treatment of radiative decays:

- Branching ratios
- Kaon lifetimes

$I_{K\ell}(\{\lambda\}_{K\ell})$ Integral of dalitz density (includes ff) over phase space:

- K_{e3}: Only λ_+ (or λ_+', λ_+'')
- $K_{\mu 3}$: Need λ_+ and λ_0

$K_{\ell 2}$ decays

[Mariciano]

Small uncertainties in f_K/f_π from lattice → determine V_{us}/V_{ud}

Reduced uncertainty from e.m. Structure Dependence corrections

$$\frac{\Gamma(K_{\mu 2(\gamma)})}{\Gamma(\pi_{\mu 2(\gamma)})} = \frac{|V_{us}|^2}{|V_{ud}|^2} \times \frac{f_K^2}{f_\pi^2} \times \frac{M_K(1-m_\mu^2/M_K^2)^2}{m_\pi(1-m_\mu^2/m_\pi^2)^2} \times 1+\alpha(C_K - C_\pi)$$

Inputs from theory:

f_K/f_π — Ratio of pseudoscalar decay constants

C_K, C_π — Radiative inclusive electroweak corrections

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

Reduced uncertainty from SD virtual corrections

Inputs from experiment:

$\Gamma(K_{\mu 2(\gamma)})$, $\Gamma(\pi_{\mu 2(\gamma)})$ — Rates with well-determined treatment of radiative decays:

- Branching ratios
- lifetimes

the KLOE's role

We have measured all (but τ_S) relevant inputs for 6 channels

PLB 632 (2006)

$\mathbf{BR^{(0)}(K_L \to \pi e \nu) = 0.4049(21)}$

$\mathbf{BR^{(0)}(K_L \to \pi \mu \nu) = 0.2726(16)}$

K_L

PLB 626 (2005)

$\tau_L = 50.92(30)$ ns

PLB 636 (2006)

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

$f_+(t)$

PLB 636 (2006)

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

K_S

PLB 636 (2006)

$\mathbf{BR(K^+ \to \mu^+ \nu(\gamma)) = 0.6366(17)}$

$K^\pm$

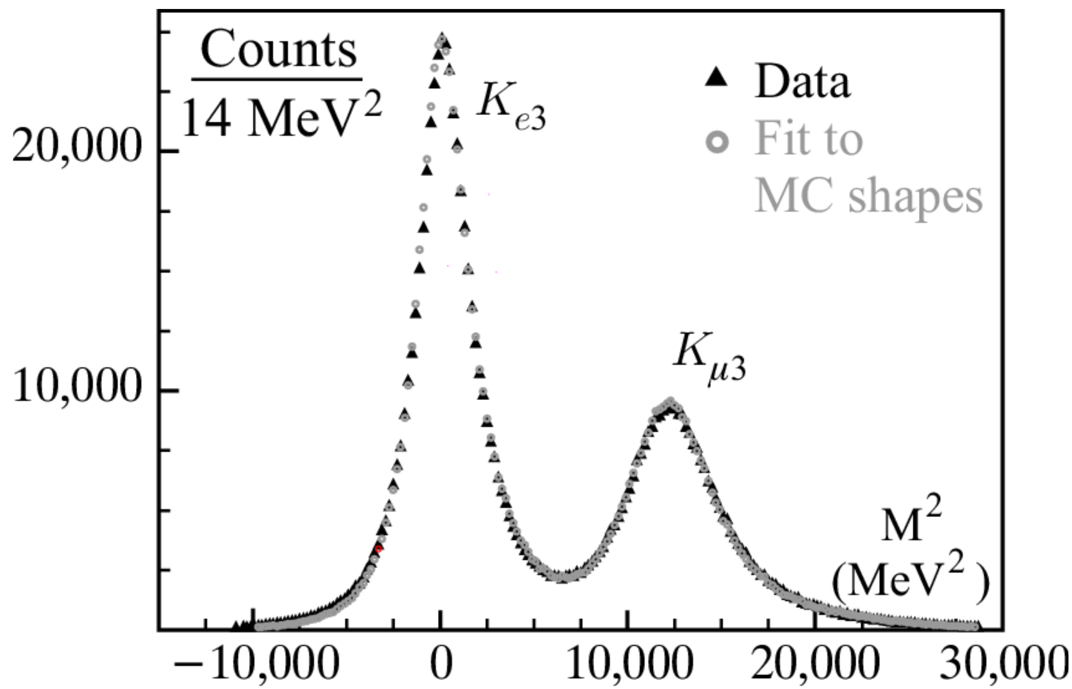
Absolute BR for $K^{\pm}_{l3}$

- 4 independent tag samples: $K^{\pm} \to \mu\nu$, $K^{\pm} \to \pi^{\pm}\pi^{0}$

- Number of signal events from a fit of distribution of lepton mass squared (M^2) known from TOF

- Perform measurement of absolute BR on each tag sample separately, check consistency

JHEP0802:098



$BR(K^{\pm}_{e3})$ = 4.965(52) %

$BR(K^{\pm}_{\mu3})$ = 3.233(39) %

at $\tau_{\pm}$ =12.385 ns, with dBR/BR = -0.5$d\tau_{\pm}/\tau_{\pm}$

σ_{rel}~1%

Absolute BR for $K^+ \to \pi^+\pi^0$

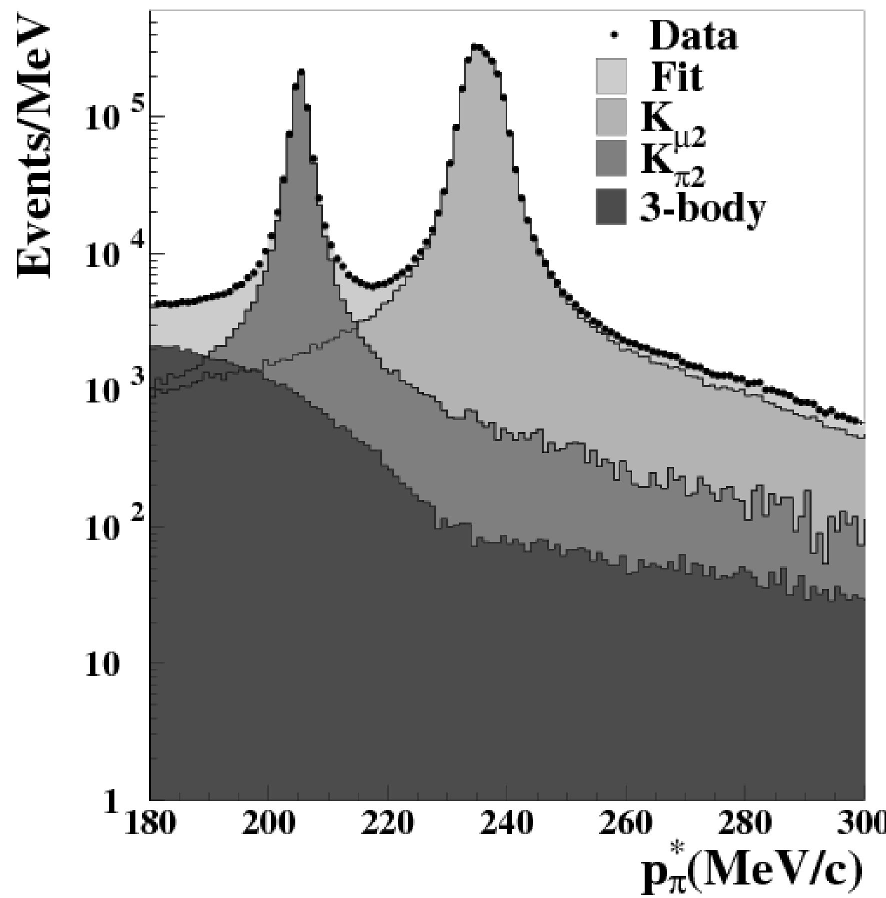
" Needed to perform a global fit to K^+ BRs

" $K_{l3}/K_{\pi 2}$ measured by NA48 and ISTRA

" Available measurement dates back to '72 (no radiative corrections)

" Normalization given by $K^- \to \mu^- \nu$ tag

" Number of $K^+ \to \pi^+\pi^0$ events from a fit of the distribution of the momentum of the secondary particle in K rest frame, p^*



submitted to PLB

BR = (20.65 ± 0.05$_{stat}$ ± 0.08$_{syst}$)%

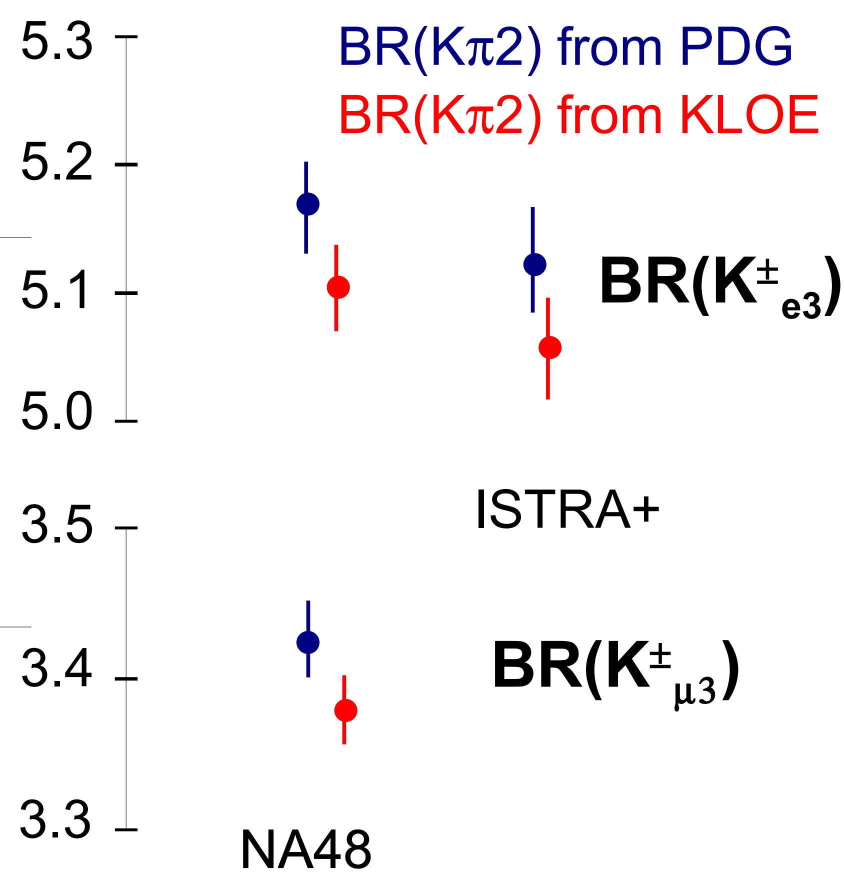
-1.3% respect to PDG'06

σ_{rel}~0.5%

ArXiv: 0707.4631

Absolute BR for $K^+ \to \pi^+\pi^0$

- Needed to perform a global fit to K^+ BRs
- $K_{l3}/K_{\pi 2}$ measured by NA48 and ISTRA
- Available measurement dates back to ‘72 (no radiative corrections)
- Normalization given by $K^- \to \mu^- \nu$ tag
- Number of $K^+ \to \pi^+\pi^0$ events from a fit of the distribution of the momentum of the secondary particle in K rest frame, p^*



submitted to PLB

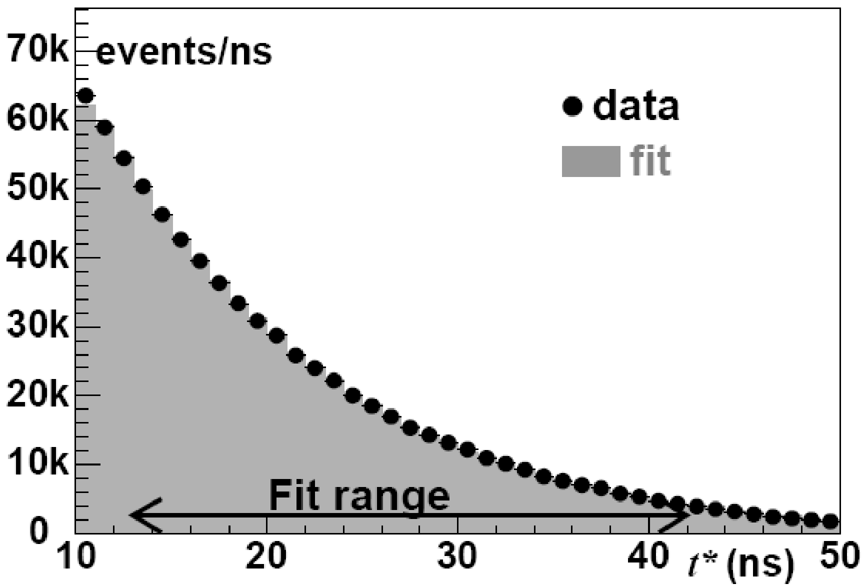
$$\mathbf{BR = (20.65 \pm 0.05_{stat} \pm 0.08_{syst})\%}$$

-1.3% respect to PDG’06

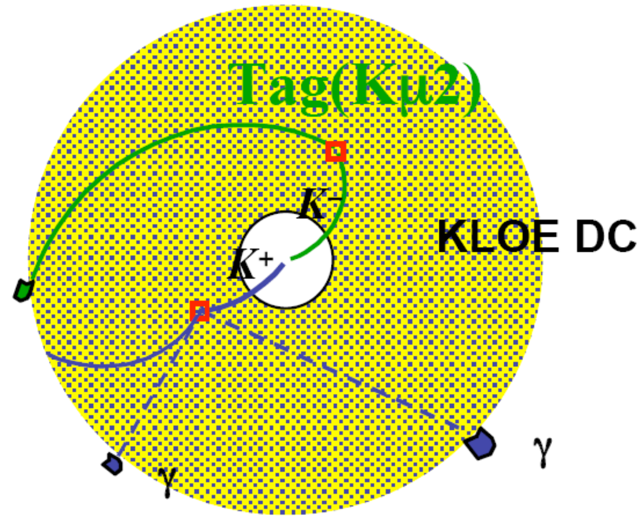
$$\sigma_{rel} \sim 0.5\%$$

ArXiv: 0707.4631

$K^{\pm}$ lifetime



- Tag events with $K^{\pm} \to \mu\nu$ decay
- Identify a kaon decay on the opposite side



2 different methods:

from the K decay length

$\tau_{\pm}$= 12.364(31)(31) ns

JHEP0801:073

ρ = 0.34

from the K decay time

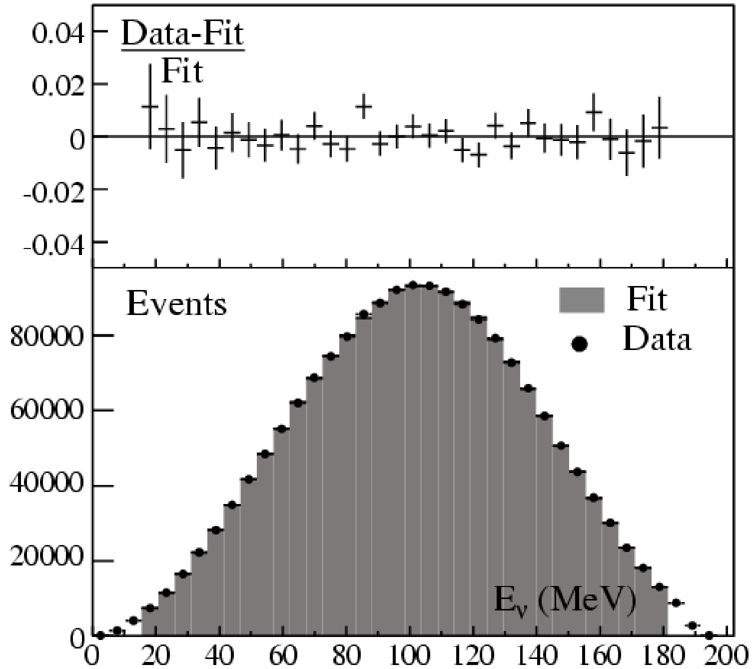
$\tau_{\pm}$= 12.337(30)(20) ns

$\tau_{\pm}$= 12.347(30) ns

σ_{rel}~0.4%

$K_{L\mu3}$ form factor slopes

Standard method: fit t-spectrum, $t = (p_K - p_\pi)^2$



π/μ separation at low energies is difficult

at the end of the spectrum, +1% in signal counts $\rightarrow$ +15% in λ_0

Fit E_ν spectrum, sensitivity loss:

$\times$ 2-3 on $\sigma_{stat}(\lambda_0)$

… $\times$ 1.3 with a combined fit with K_{Le3}

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

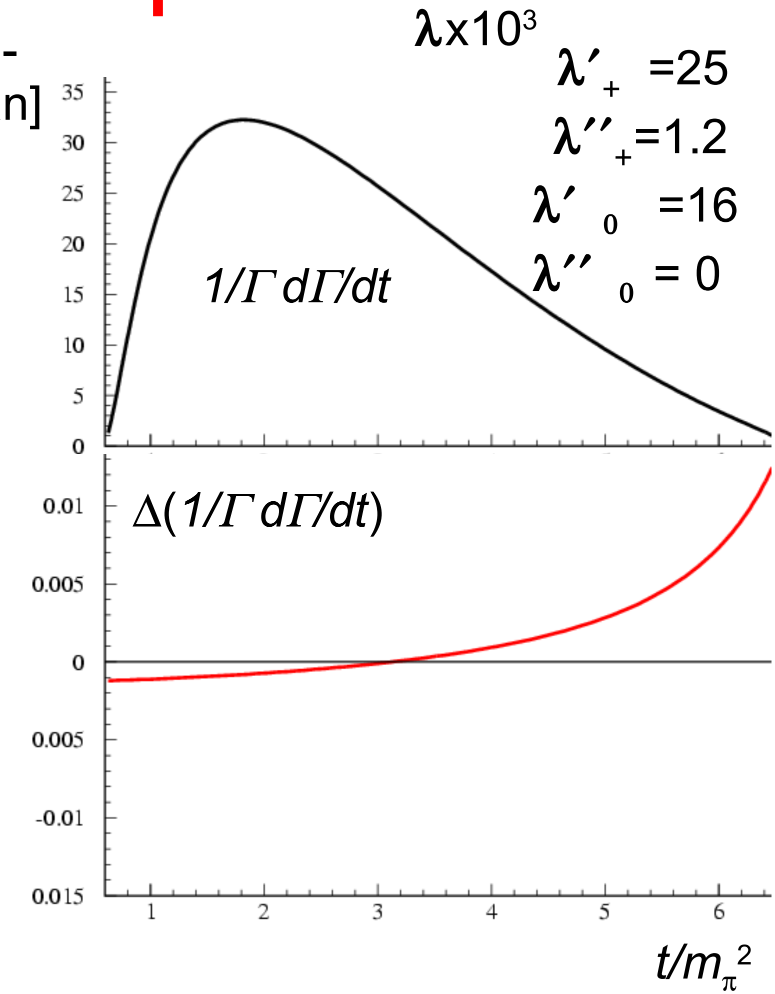
JHEP0712:105

$K_{\mu3}$ form-factor slopes

- Knowledge of $f_0(t)$ important to test [Callan-Treiman]
QCD parameters: $f_0(\Delta_{K\pi}=m_K^2-m_\pi^2) = f_K/f_\pi$
- Linear parametrization not a good physics approximation: hints for λ''_0 ?
- Fractional partial width difference by varying slopes values :

$\Delta(1/\Gamma\, d\Gamma/dt)$ **[λ''_0=0.4, 0]**

λx10^3



$K_{\mu 3}$ form-factor slopes

- Knowledge of $\tilde{f}_0(t)$ important to test [Callan-Treiman] QCD parameters: $f_0(\Delta_{K\pi}=m_K^2-m_\pi^2) = f_K/f_\pi$
- Linear parametrization not a good physics approximation: hints for λ''_0 ?
- Fractional partial width difference by varying slopes values :

$\Delta(1/\Gamma\, d\Gamma/dt)$ [λ''_0=0.4, 0]

$\Delta(1/\Gamma\, d\Gamma/dt)$ [λ'_0=14.7, 16]

λx10^3

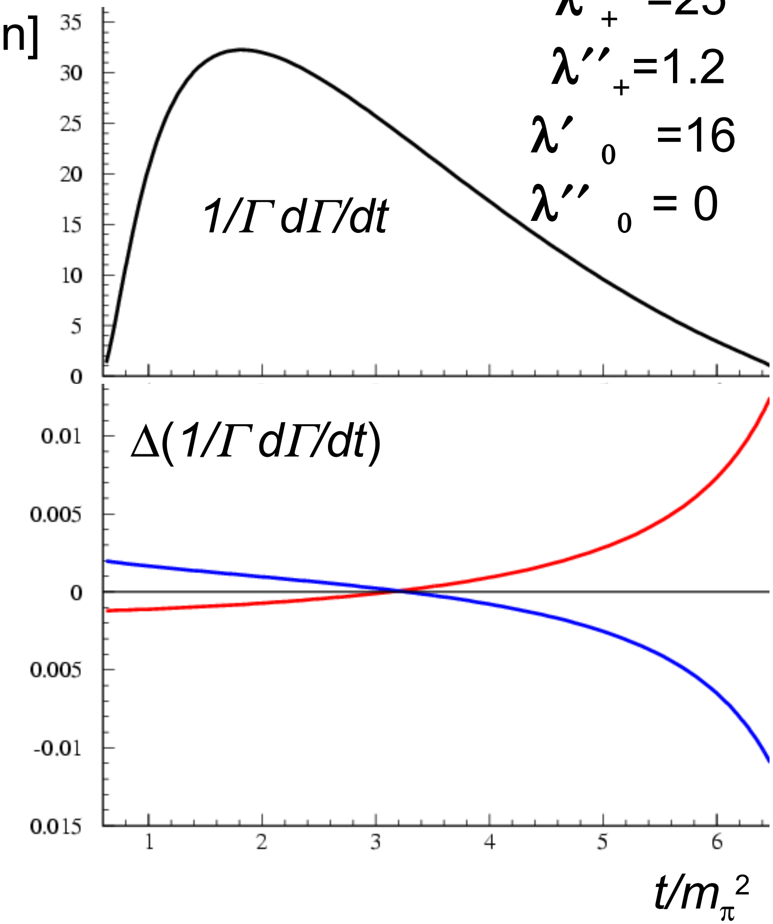
λx10^3

λ'_+ =25

λ''_+=1.2

λ'_0 =16

λ''_0 = 0



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- Fractional partial width difference by varying slopes values :

$\Delta(1/\Gamma\, d\Gamma/dt)$ **[λ''_0=0.4, 0]**

$\Delta(1/\Gamma\, d\Gamma/dt)$ **[λ'_0=14.7, 16]**

$\lambda \mathrm{x} 10^3$

- Almost exact cancellation

$\Delta(1/\Gamma\, d\Gamma/dt)$ **[λ'_0=14.7, 16: λ''_0=0.4, 0]**

- Correlation matrix from Ideal t-spectrum experiment:

λ'_0	1	-0.9996	-0.97	0.91	[Franzini]
λ''_0		1	0.98	-0.92	
λ'_+			1	-0.98	
λ''_+				1	

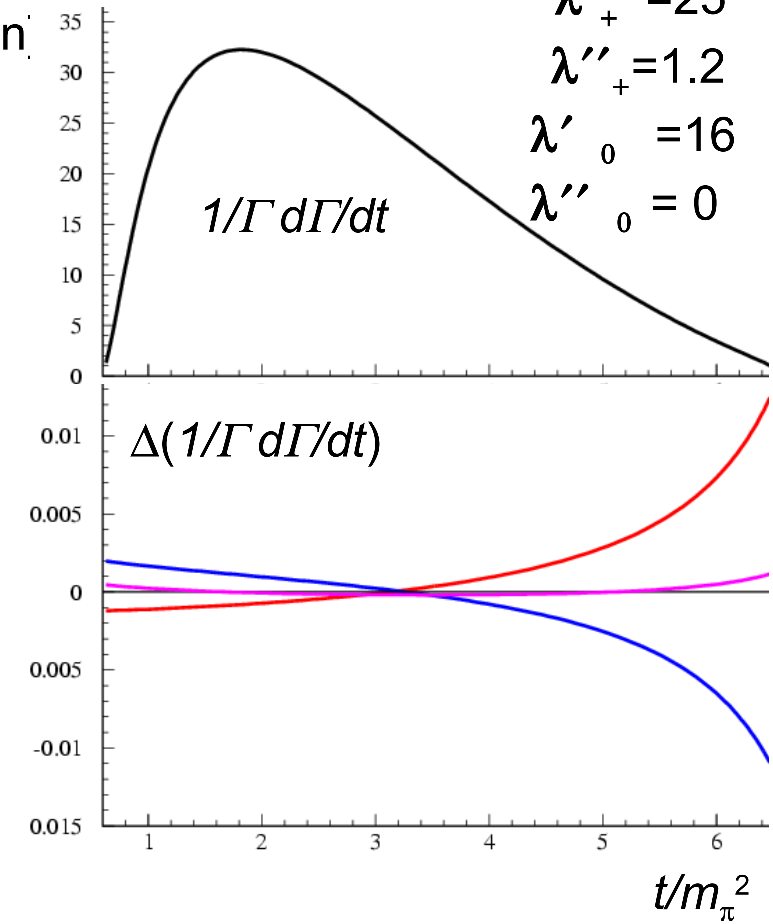
$\lambda \mathrm{x} 10^3$

λ'_+ =25

λ''_+=1.2

λ'_0 =16

λ''_0 = 0



Simultaneous $\lambda'_0\lambda''_0$ measurement not possible

Beyond quadratic parametrization

[Stern et al]

Dispersion relation for ln $f_0(t)$ subtracted at $t = 0$ and $t = m_K^2 - m_\pi^2$, giving:

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

$G(t)$ evaluated using $K\pi$ scattering data

1 fit parameter: log C

log C = 0.204 ± 0.023

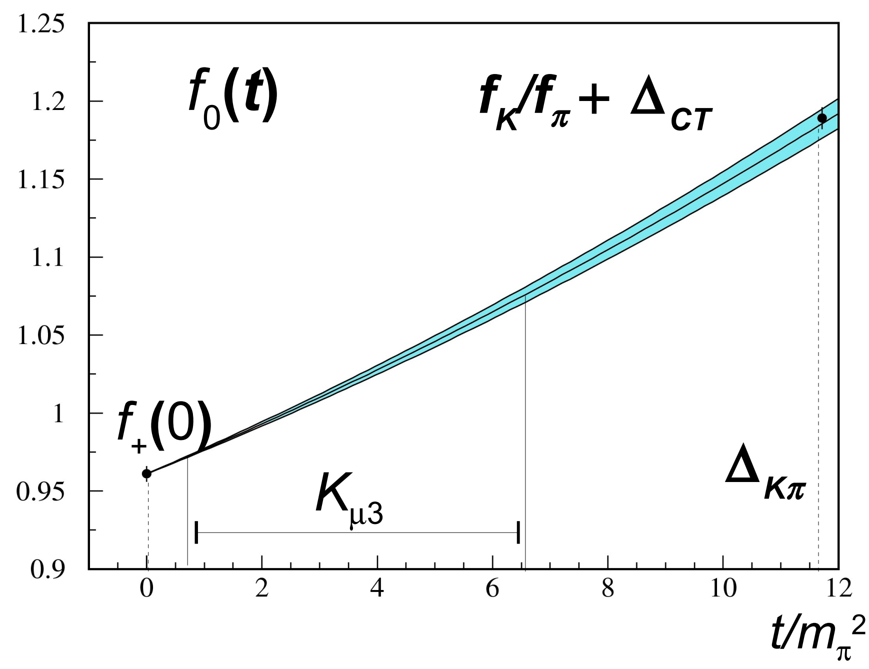
JHEP0712:105

Very precise relation between $f_0(0)^*$ and f_K/f_π :

$$f_0(\Delta_{K\pi}) = f_K/f_\pi + \Delta_{CT}$$

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

$\Delta_{K\pi} = m_K^2 - m_\pi^2$; $\Delta_{CT} = 3.5 \times 10^{-3}$ SU(2) (struck through)



$K_{L\mu3}$ form factor slopes

<u>Preliminary</u> results with ~1fb^{-1}

5.8 x 10^6 Kμ3 decays selected

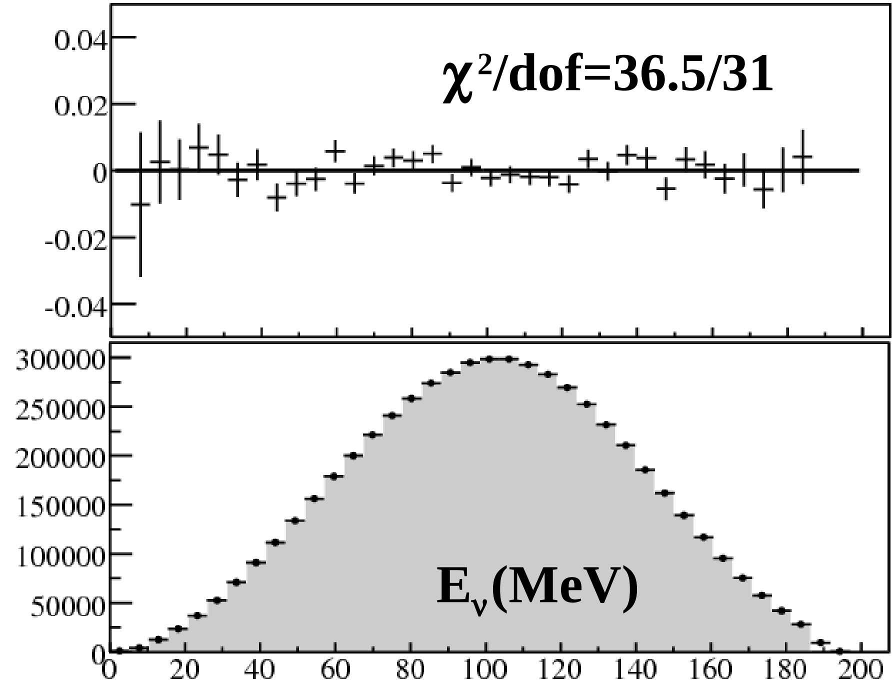
Sensitivity to all FF's parameters

$\lambda_+ = (25.7 \pm 5.1 \pm 2.5)\times 10^{-3}$

$\lambda_+ = (2.9 \pm 2.5 \pm 1.3)\times 10^{-3}$

$\lambda_0 = (14.3 \pm 2.9 \pm 2.4)\times 10^{-3}$

$$\begin{pmatrix} -0.97 & 0.90 \\ & -0.80 \end{pmatrix}$$



Results obtained with dispersive relations for $f_{+,0}(t)$ averaged with published results

$\lambda_+ = (26.0 \pm 0.5_{\text{STAT+SYST}})\times 10^{-3}$

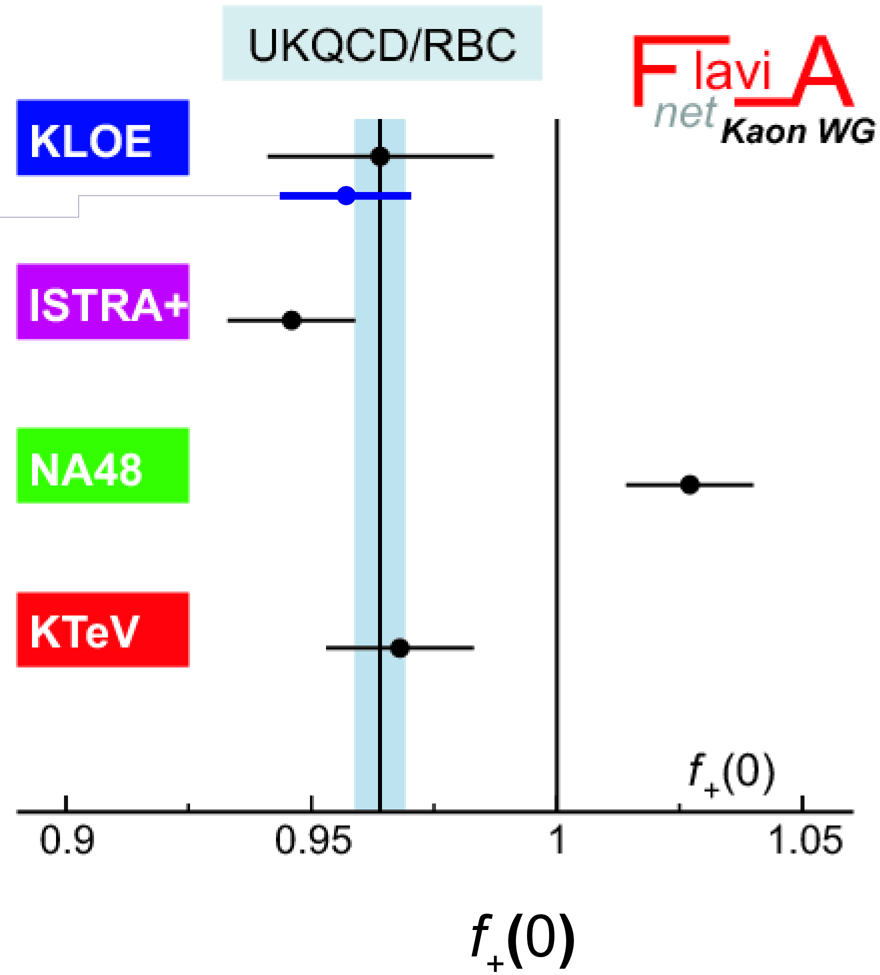
$\lambda_0 = (15.1 \pm 1.4_{\text{STAT+SYST}})\times 10^{-3}$

log C = 0.217 ± 0.016

$K_{\mu 3}$ form factor slopes

<u>*Preliminary*</u>

$f_+(0) = 0.954 \pm 0.016$



using:

$f_+(0) = (f_K/f_\pi + \Delta_{CT})/C$

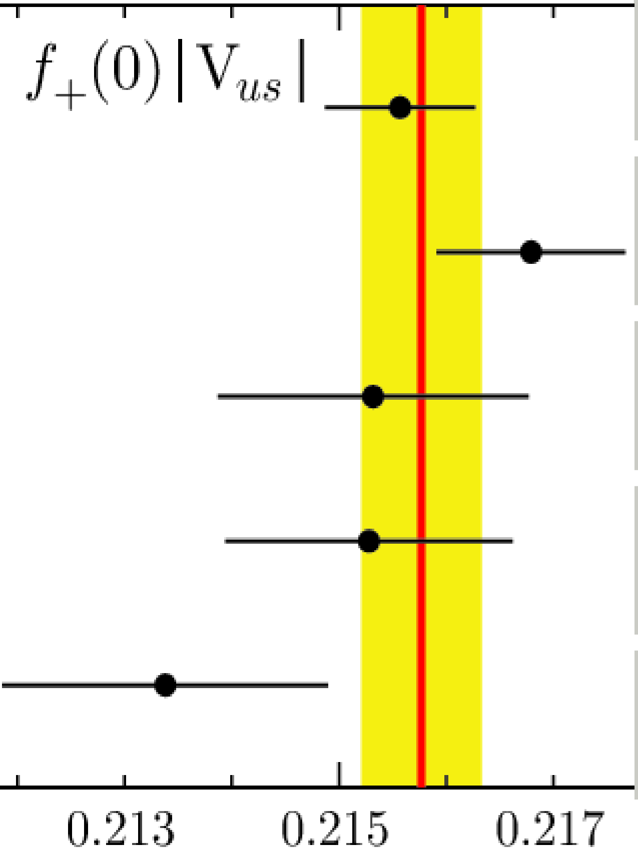
and

$f_K/f_\pi = 1.189(7)$

from HPQCD-UKQCD(MILC)

V_{us} from KLOE K_{l3} data

JHEP 0804:059



		% err
$K_L e3$	0.2155(7)	0.3
$K_L \mu 3$	0.2167(9)	0.4
$K_S e3$	0.2152(14)	0.7
$K^{\pm} e3$	0.2152(13)	0.6
$K^{\pm} \mu 3$	0.2132(15)	0.7

$|V_{us}|\, f_+(0)$

KLOE Avg:
0.2157(6)
$\chi^2/\text{ndf} = 7/4$ (13%)

World Avg:
0.2166(5)

$f_+(0)=0.964(5)$ **RBC/UKQCD, 07 prel.**

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

$\Rightarrow$ V_{us} = 0.2237(13)

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

V_{us}/V_{ud} from $K_{\mu 2}$

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
preliminary
arXiv:0706.1726

$f_K/f_\pi = 1.189(7)$

$N_f = (2+1)_{\mathrm{stag}}$

Cancellation of lattice-scale uncertainties

PLB 636 (2006)

$\mathrm{BR}(K^+ \to \mu^+\nu(\gamma)) = 0.6366(17)$

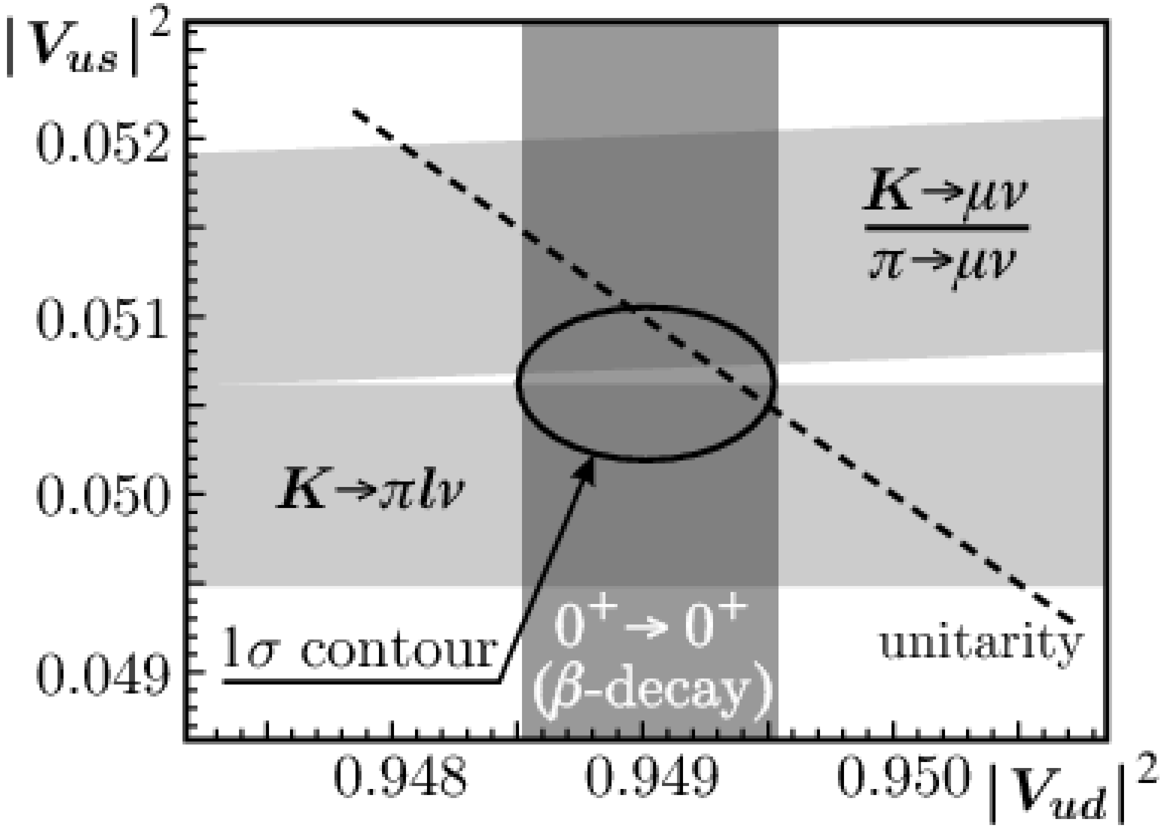
Uses $K^- \to \mu^-\nu$ to tag 2-body K decays

Counts $K^+ \to \mu^+\nu$ from decay-momentum spectrum

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

V_{ud}, V_{us} and V_{us}/V_{ud}

JHEP 0804:059



no constraint:

$V_{ud}^2 = 0.9490(5)$

$V_{us}^2 = 0.0506(4)$

$\chi^2/\mathrm{ndf} = 2.3/1\ (13\%)$

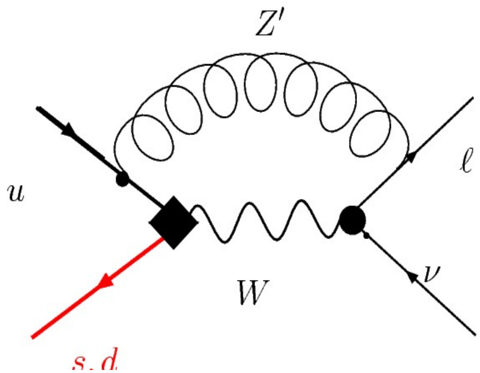
agreement with unitarity:

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

@ 0.6 σ

sensitivity to NP: Z'oology

1)



$\mathbf{G_F}=\mathbf{G_{CKM}}[1-0.007Q_{eL}(Q_{\mu L}-Q_{dL})\,\frac{2\ln(m_{Z'}/m_W)}{(m_{Z'}^2/m_W^2-1)}]$

[Marciano]

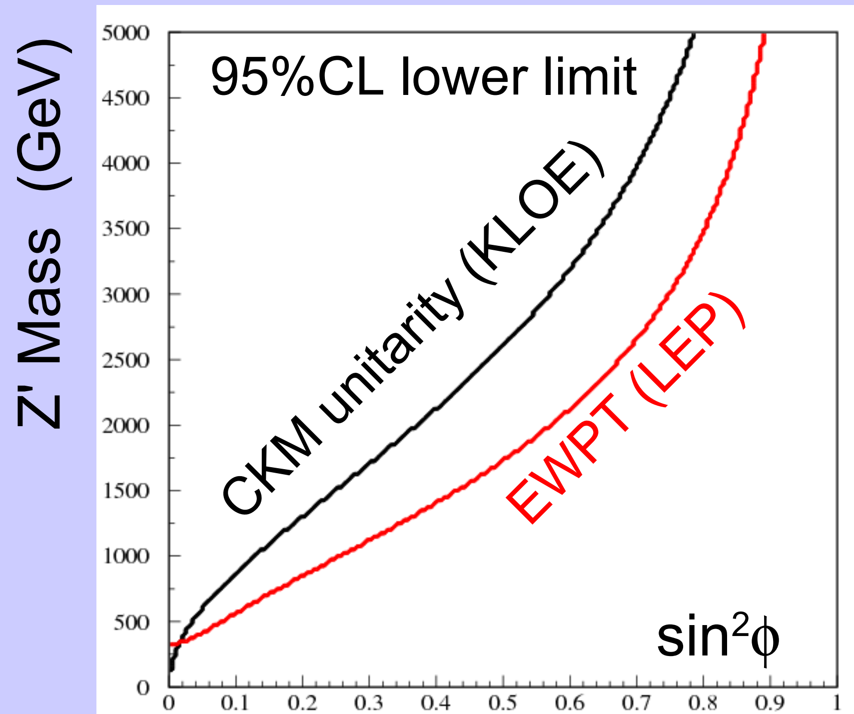
SO(10) Zχ Boson: $Q_{eL}=Q_{\mu L}=-3Q_{dL}=1$

$m_{Z\chi}$> 750 GeV 95%CL

2)

[K.Y. Lee]

Tree level breaking of unitarity in models with non-universal gauge interaction



sensitivity to NP: charged Higgs

JHEP 0804:059

Pseudoscalar currents, e.g. due to H±, affect the K width:

$$\frac{\Gamma(M\to\ell\nu)}{\Gamma_{SM}(M\to\ell\nu)} = \left[1-\tan^2\beta\left(\frac{m_{s,d}}{m_u+m_{s,d}}\right)\frac{m_M^2}{m_H^2}\right]^2$$

for M = K, π

Hou, Isidori-Paradisi

The observable

$$R_{\ell 23} = \left|\frac{V_{us}(K_{\mu 2})}{V_{us}(K_{\ell 3})}\times\frac{V_{ud}(0^+\to 0^+)}{V_{ud}(\pi_{\mu 2})}\right|$$

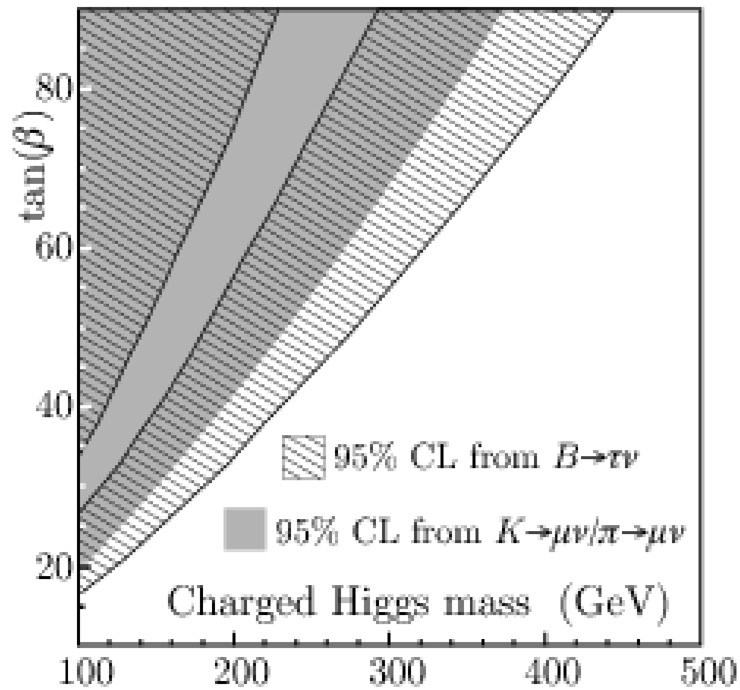
we get:

- **R_{l23} = 1.008(8)**

(unitarity for K_{l3} and β -decays is used)

R_{l23} sensitivity to H± exchange

$$R_{\ell 23} = \left|1-\frac{m_{K^+}^2}{m_{H^+}^2}\left(1-\frac{m_{\pi^+}^2}{m_{K^+}^2}\right)\frac{\tan^2\beta}{1+\epsilon_0\tan\beta}\right|$$



K_{l3} wa data and lepton universality

For each state of kaon charge, we evaluate:

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

FlaviA net Kaon WG

$r_{\mu e}$ = 1.004(4) from Kl3

$\tau \to l\nu\nu$ decays:

$(r_{\mu e})_\tau$ = 1.001(4) [PDG07]

$\pi \to l\nu$ decays:

$(r_{\mu e})_{\pi l2}$ = 1.003(3) see Erler, Ramsey-Musolf '06

0.1% on gauge couplings

$r_{\mu e}$ = 1.003(2) K, τ, π average

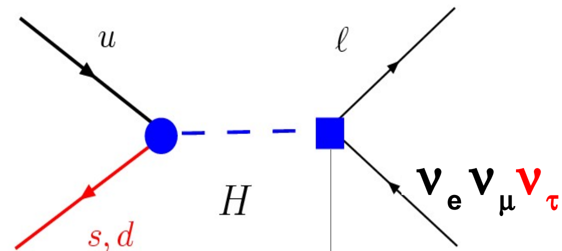
The special role of $\Gamma(K_{e2})/\Gamma(K_{\mu 2})$

SM: very well known no hadronic uncertainties (no $\boldsymbol{f_K}$)

In MSSM, LFV can give up to % deviations: [Masiero, Paradisi, Petronzio]

NP dominated by contribution of $e\nu_\tau$ final state:

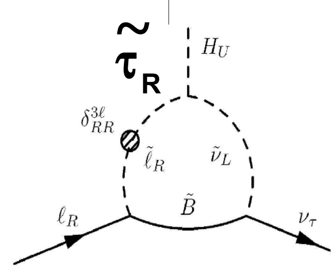
$$R_K \approx \frac{\Gamma(K\to e\nu_e)}{\Gamma(K\to \mu\nu_\mu)+\Gamma(K\to e\nu_\tau)}$$



$$R_K \approx R_K^{SM}\left[\,1+\frac{m_K^4}{m_H^4}\,\frac{m_\tau^2}{m_e^2}\,|\Delta^R_{31}|^2\tan^6\beta\right]$$

$$eH^\pm\nu_\tau \to \frac{g_2}{\sqrt{2}}\frac{m_\tau}{M_W}\Delta_R^{31}\tan^2\beta$$

1% effect (Δ^R_{31} ~5×10^{-4}, tanβ~40, m_H~500GeV) not unnatural



Present accuracy on R_K @ 6% Need for precise measurements

$K_{e2}/K_{\mu 2}$:New measurements

KLOE
arXiv:0707.4623

Preliminary result with 1.7 fb^{-1} (~ 8000 events)

$$BR(K^{\pm}e2)/BR(K^{\pm}\mu 2) = 2.55(5)(5) \times 10^{-5}$$

X 2 more data(1.7/2.5fb^{-1}) + 30%more from an independent sample σR_K ~ 1%

NA48/2 (2005)
Preliminary

Preliminary result with 2003 data (~ 4500 events)

$$BR(K^{\pm}e2)/BR(K^{\pm}\mu 2) = 2.416(43)(24) \times 10^{-5}$$

NA48/2 (2007)
Preliminary

Preliminary result with 2004 data (~ 3500 events)

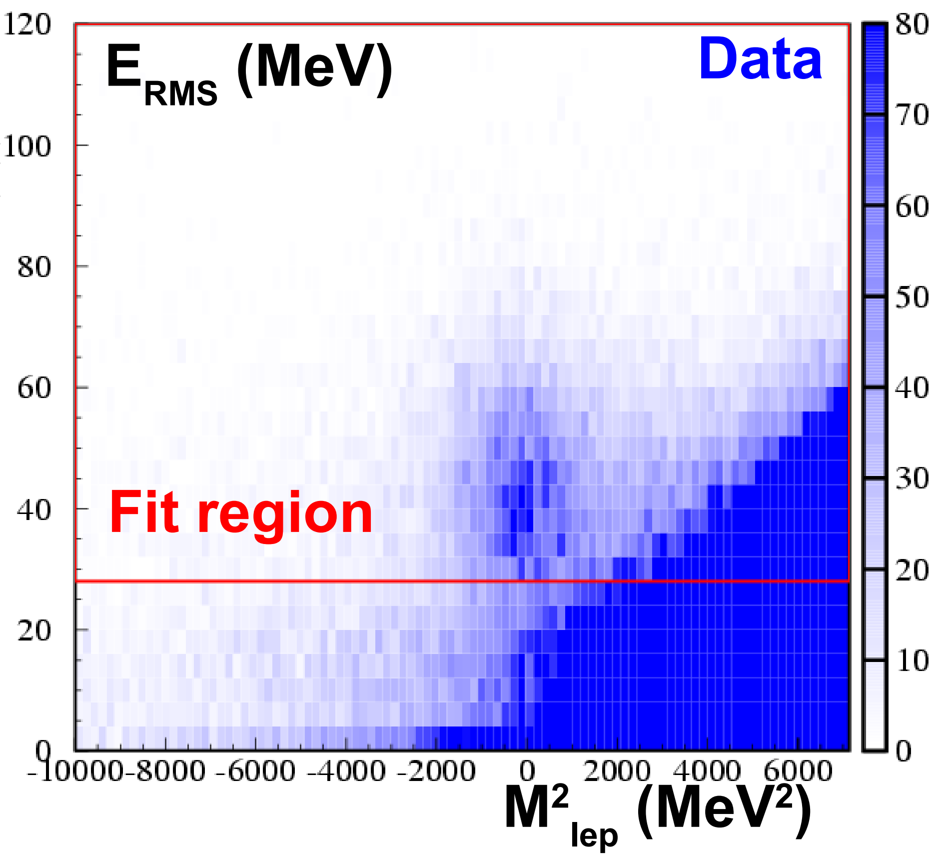
$$BR(K^{\pm}e2)/BR(K^{\pm}\mu 2) = 2.455(45)(41) \times 10^{-5}$$

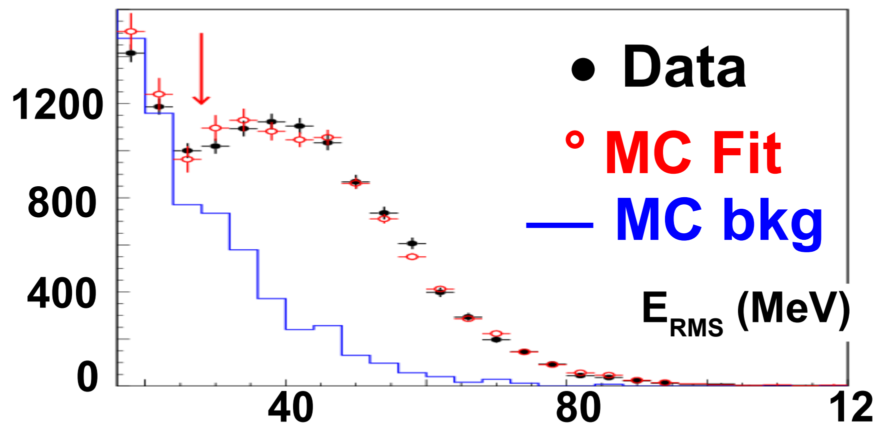
X 10 more data from new run (end in October) σR_K ~ 0.3%

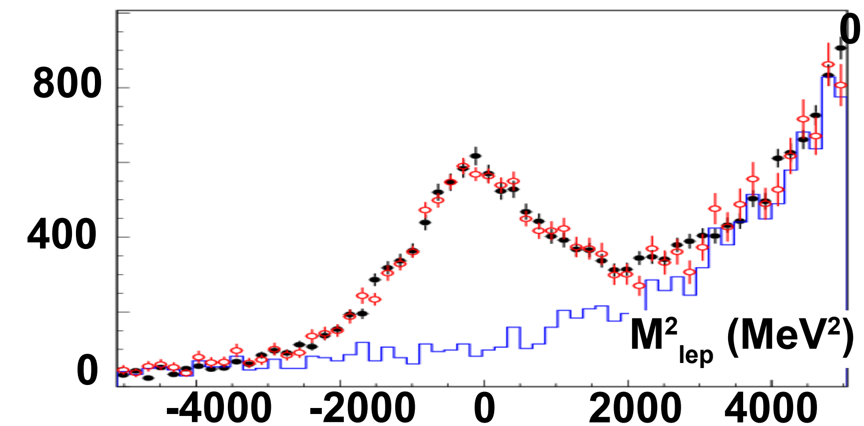
Counting K_{e2} events

Perform direct search for K_{e2} without tag: gain × 4 of statistics

8090±160 observed events on 1.7 fb^{-1}





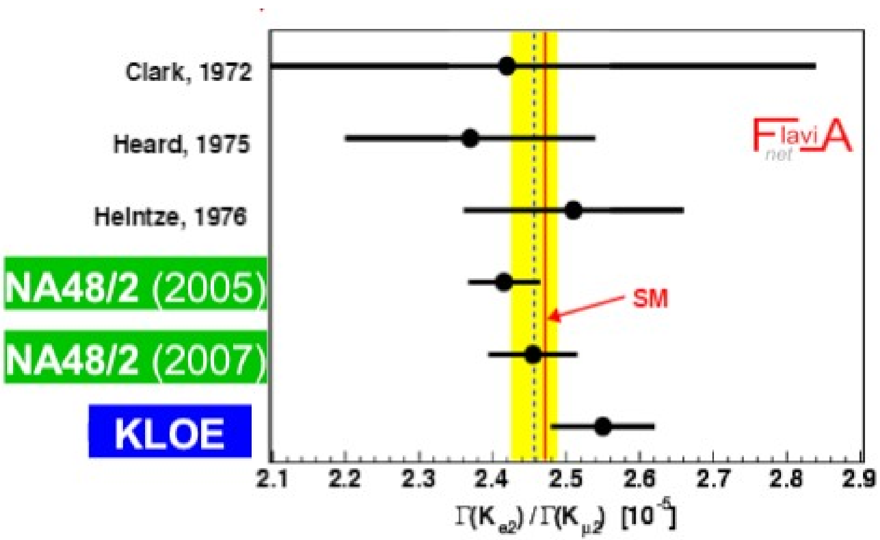


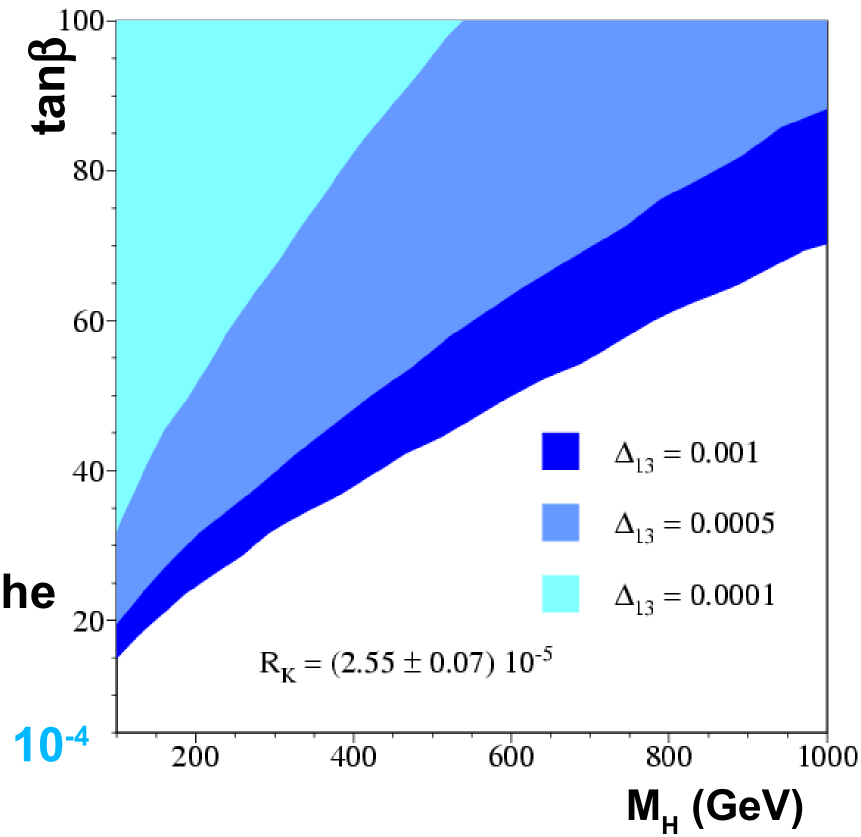
K_{e2} result at KAON07

We presented a preliminary result with 2.7% uncertainty:

$$R_K = 2.55(7)\times10^{-5}$$

ArXiv: 0707.4623





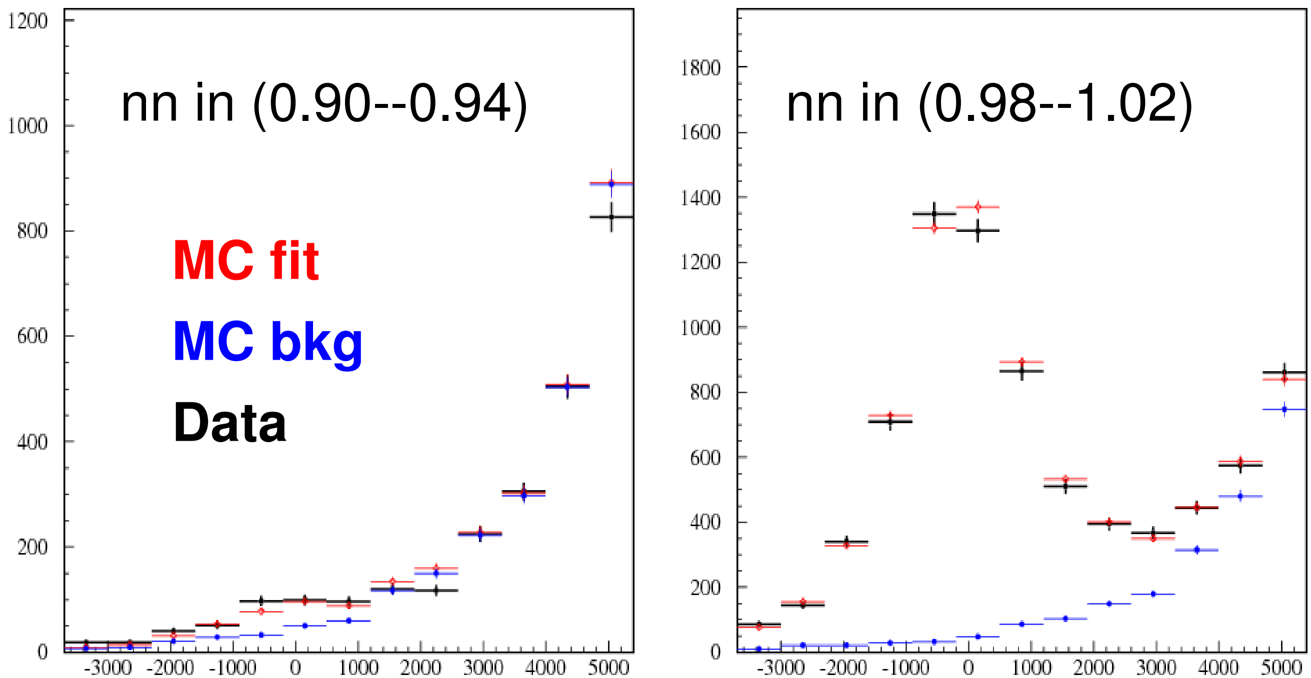
95%-CL excluded regions in the tanβ - M_H plane, for

$\Delta_{13} = 10^{-3}, \ 0.5\times10^{-3}, \ 10^{-4}$

K_{e2} perspectives

Improved PID + better understanding of P_{lepton} measurement tails

~ 13K events selected with full statistics (2.2 fb^{-1})



M_{lep}^2 (MeV^2) M_{lep}^2 (MeV^2)

$N(e^+) = 6901 \pm 98$

$N(e^-) = 6514 \pm 97$

frac. error 1.1%

Expect fractional accuracy stat.$\oplus$syst. <1.5%

CONCLUSIONS

- 8 publications + 2 final since last meeting
- Most important results

  best measurements of V_{us}

  best measurement of $a_\mu^{\pi\pi}(0.35\text{-}0.95\ \mathrm{GeV}^2)$
- Many preliminary results + ongoing analyses

  $K_{e2}/K_{\mu 2}$, K_{l3} slopes, $\sigma_{had}(\pi\pi\gamma\ /\mu\mu\gamma$, low $q^2)$,

  $f_0 \rightarrow KK\gamma$ $\eta \rightarrow \pi\pi\, ee$ . . . .