KLOE results on lepton flavor universality tests

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Interest in LU tests with kaons

In SM, electron and muon differs only by mass and coupling to Higgs

New physics extensions of the SM with LFV not ruled out, so:

- **Can search for processes forbidden/ultra-rare in SM, e.g. $K \to \mu e$**

- **Can measure ratio of coupling constants, seeking deviations from 1 in processes well known in SM, like:**

  - $R_{e\mu} = \Gamma(K_{e3})/\Gamma(K_{\mu3}) \to G_F^e/G_F^\mu$
  - $R_K = \Gamma(K \to e\nu)/\Gamma(K \to \mu\nu)$

Don't expect deviations from SM comparing K_{e3} vs $K_{\mu3}$ FF t dependences, but slopes can help in testing H^+ effects in:

  - $R_{K\pi} = \Gamma(K \to \mu\nu)/\Gamma(\pi \to \mu\nu)$

LU from semileptonic kaon decays

Master formula: $\Gamma(K_{l3(\gamma)}) = |V_{us}|^2 \, |f_+^{K^0\pi^-}(0)|^2 \, \frac{G_F^2 \, m_K^5}{128\pi^3} S_{\rm EW} \, C_K^2 \, I_{K\ell} \, (1 + \delta_K^\ell)$

Theoretical inputs:

- **$f_+(0)$**, form factor at zero momentum transfer: purely theoretical calculation
- **δ^ℓ_K**, e.m.- and (for $K^\pm$) I-breaking effects, known @ few per mil level
- [S_{EW}, short distance corrections (1.0232), C_K = 1 ($2^{-1/2}$) for K^0 (K^+) decays]

Experimental inputs:

- **$I^\ell_K = I(\{\lambda_+\},\{\lambda_0\},0)$**, phase space integral, **λ_+, λ_0** denote the t-dependence of vector and scalar form factors;
- **$\Gamma_{K\ell3(\gamma)}$**, semileptonic decay width, evaluated from γ-inclusive BR and lifetime
- **m_K**, appropriate kaon mass

KLOE measurement for all relevant inputs: BR's, τ's, ff's

Can compare short distance couplings $g = |G_F \, V_{us}|$ for e and μ modes

LU from Kl3 decays: results from KLOE

Use ff slopes from KLOE$_{e3}$, KLOE$_{\mu3}$ to evaluate phase space integrals

Mode	$f_+(0) \times \lvert V_{us}\rvert$	**Error,%**	**KLOE input**	**External input**
K_{Le3}	**0.21547(72)**	**0.34**	**ff,** BR, τ_L	
$K_{L\mu3}$	**0.21661(93)**	**0.43**	**ff,** BR, τ_L	
K_{Se3}	**0.21522(145)**	**0.68**	**ff**, BR	τ_S [PDG]
K^+_{e3}	**0.21465(137)**	**0.64**	ff, BR*, τ^{+*}	τ^+ [PDG]
$K^+_{\mu3}$	**0.21302(155)**	**0.73**	BR*, τ^{+*}	τ^+ [PDG]
Avg™	**0.21556(59)**	**0.27**		

e/μ universality satisfied, using only KLOE results get accuracy <0.004:

K_L g(μ)/g(e) = 1.0054(44) cfr with g(μ)/g(e) = 1.0232(68) [PDG04]

K^+ g(μ)/g(e) = 0.9924(54) cfr with g(μ)/g(e) = 1.0020(80) [PDG04]

Average g(μ)/g(e) = 1.0005(38)

Compare with $\tau \to l\nu\nu$ decays: g(μ)/g(e) = 0.9999(20)

™ takes correlations into account (see E. De Lucia talk), P(χ^2/ndf = 6.1/4) = 19%

New-physics potential of R_K

SM prediction has 0.04% precision, benefiting of cancellation of hadronic uncertainties (no f_K)

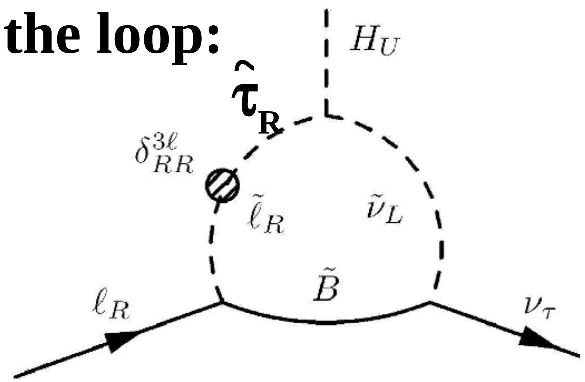
Helicity suppression boosts NP effects in R_K [Masiero-Paradisi-Petronzio]

In R-parity MSSM, LFV can give 1% deviations from SM:

$$R_K^{LFV} \simeq R_K^{SM} \left[1 + \left(\frac{m_K^4}{M_H^4} \right) \left(\frac{m_\tau^2}{m_e^2} \right) |\Delta_R^{31}|^2 \tan^6\beta \right]$$

NP dominated by contribution of $e\nu_\tau$ final state, with effective coupling

$$l H^{\pm} \nu_\tau \rightarrow \frac{g_2}{\sqrt{2}} \frac{m_\tau}{M_W} \Delta_{13}$$ **, from the loop:**



Present accuracy on R_K @ 6%

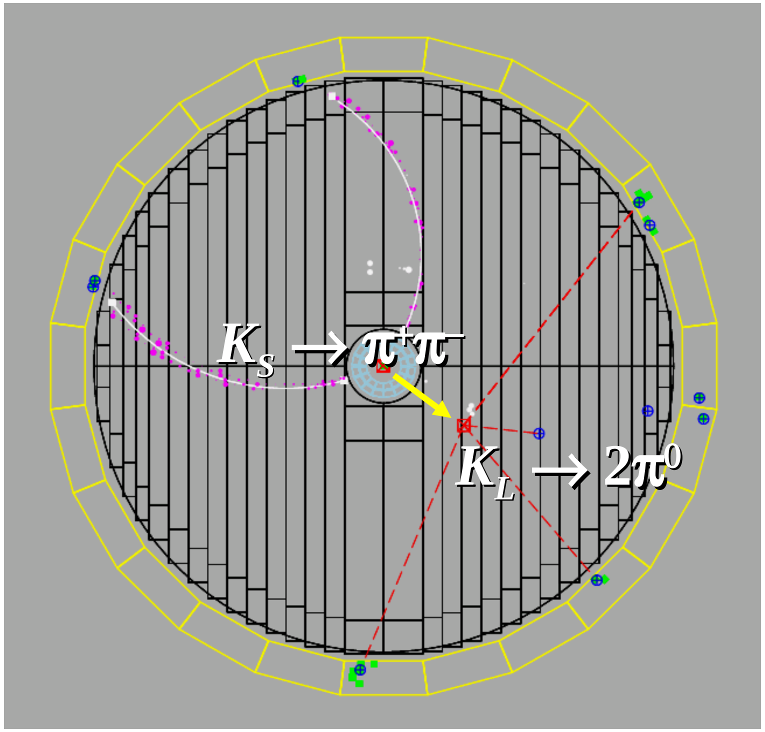
New measurement of R_K can be very interesting, if error is pushed @1% or better

Kaon physics at KLOE

$K_{S,L}$ $K^{+,-}$ pairs from ϕ decays, emitted ~back to back, p ~ 110 MeV

Identification of $K_{S,L}$($K^{+,-}$) decay (interaction) tags presence of $K_{L,S}$($K^{-,+}$)

Almost pure $K_{L,S}$ and $K^{+,-}$ beams of known momentum + PID (kinematics & TOF):

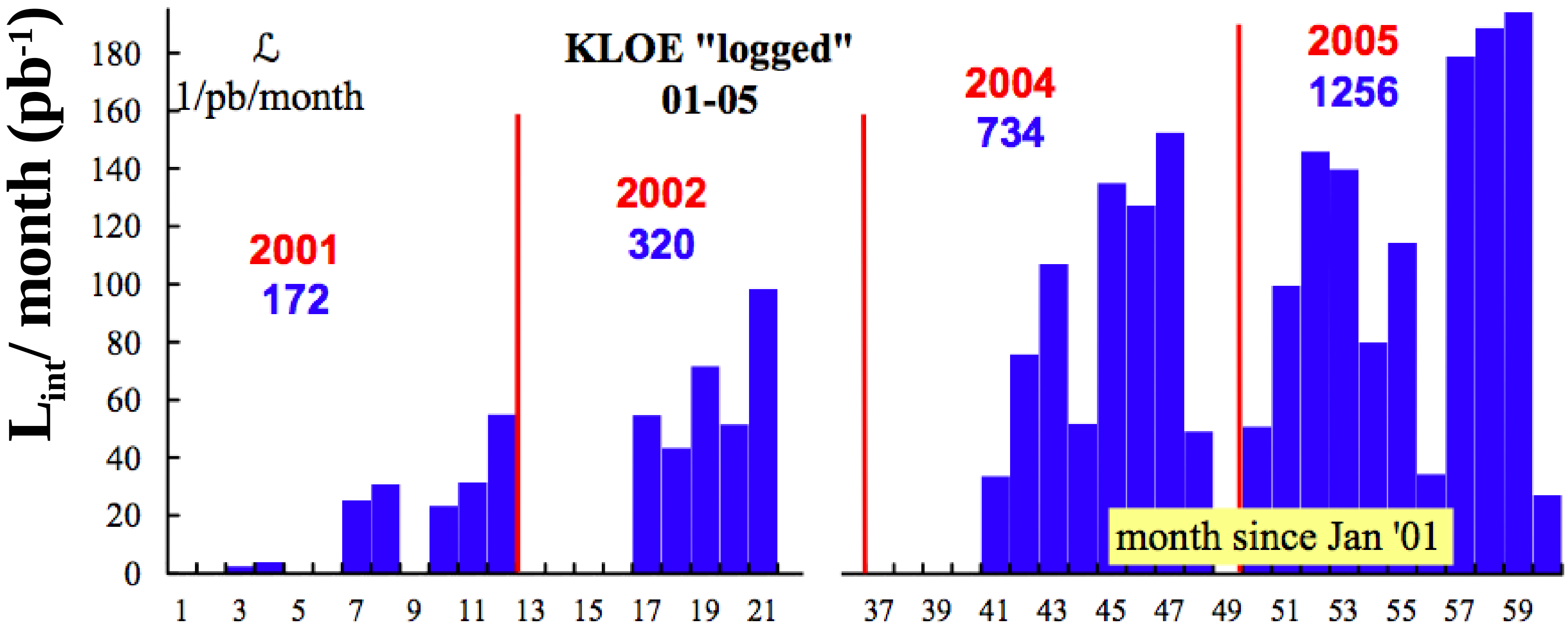


- Access to absolute BR's
- Precise measurements of K_{Le3} from factors and K_L, K^+ lifetimes (acceptance ~0.5 τ_L, τ_+)

Above points crucial for Vus determination from Ke3 decays

Overview of KLOE data

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



~2.5 fb^{-1} integrated @ $\sqrt{s}$=M(ϕ), corresponding to 2.5 10^9 K_SK_L pairs

R_K analysis presented here based on first 1700 pb^{-1} collected

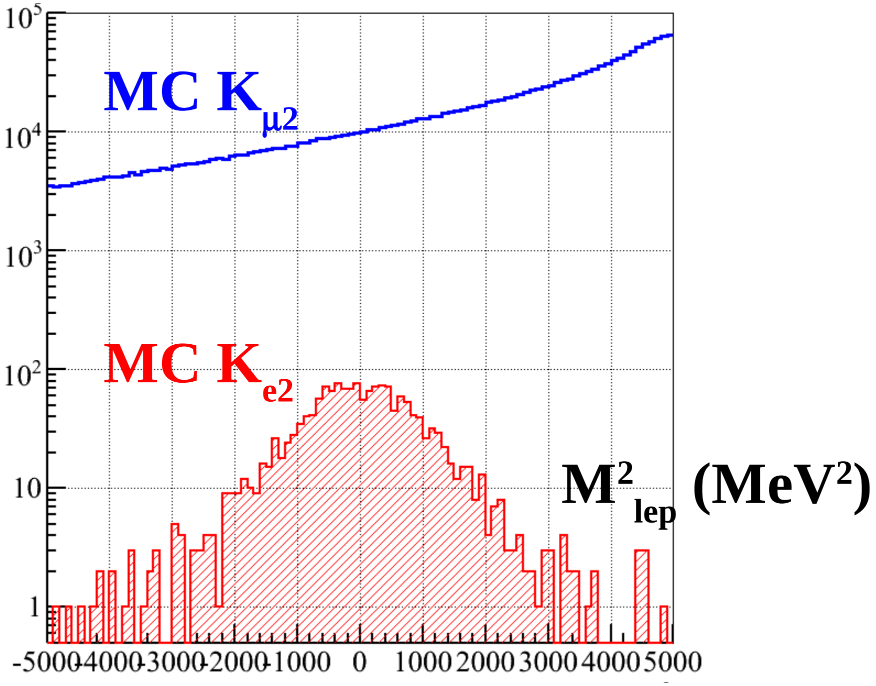
Analysis of Ke2/Km2

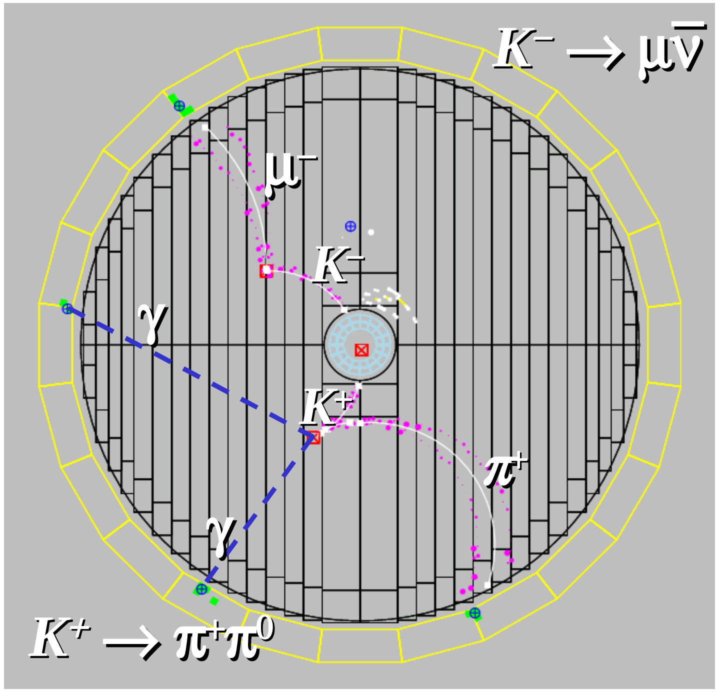
BR(K_{e2})~10^{-5}, expect at most 4×10^4 events

Perform direct search for K_{e2}, $K_{\mu2}$, no tag: gain ×4 of statistics

Select 1-prong decays in DC, K track from IP, secondary 180<P<270 MeV

Exploit tracking of K and secondary: assuming m_ν=0 get M^2_{lep}





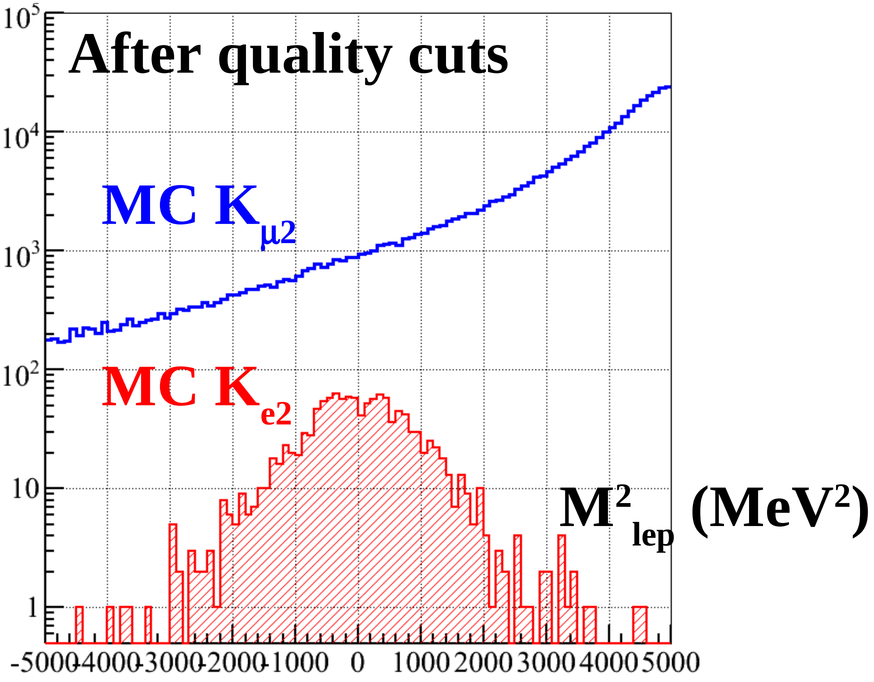
Analysis of R_K = Ke2/Km2

Apply quality cuts, OK to count $K_{\mu2}$, not for K_{e2} (still B ~ 10×S)

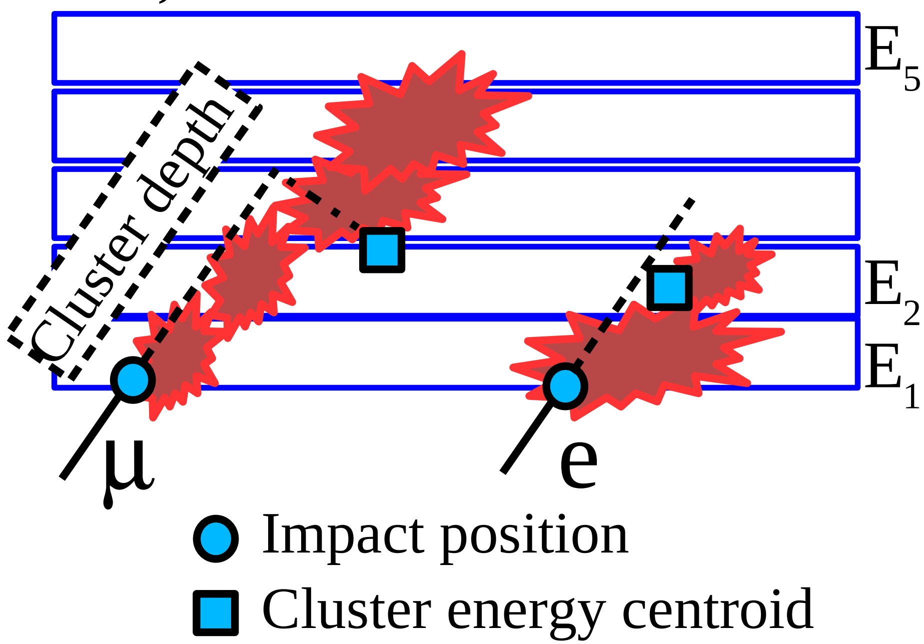
1-prong efficiency ratio correction only 2%, use data CS of $K_{\mu2}$ to check

Further rejection for K_{e2}: extrapolate track to EmC, select closest cluster

PID exploits EmC granularity: energy deposits E_k into 5 layers in depth



EmC, fiber direction view



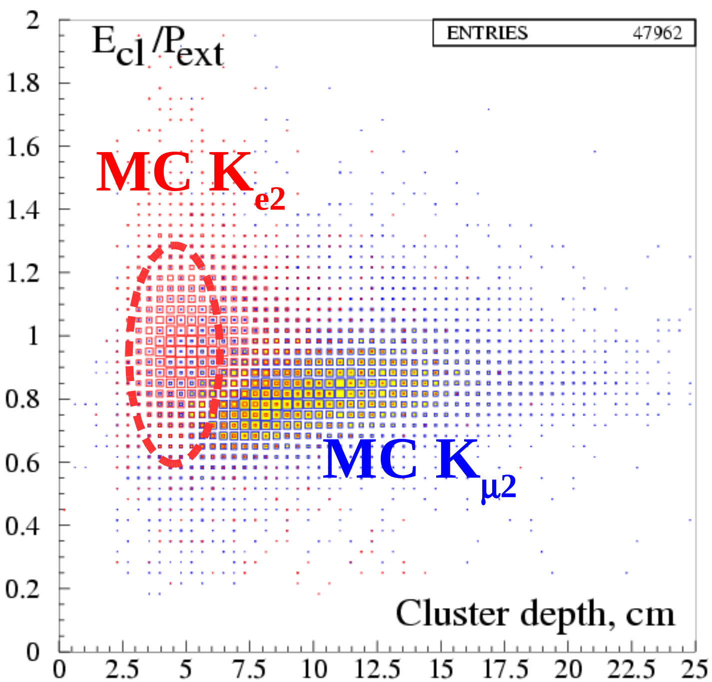
Analysis of R_K – PID using EmC

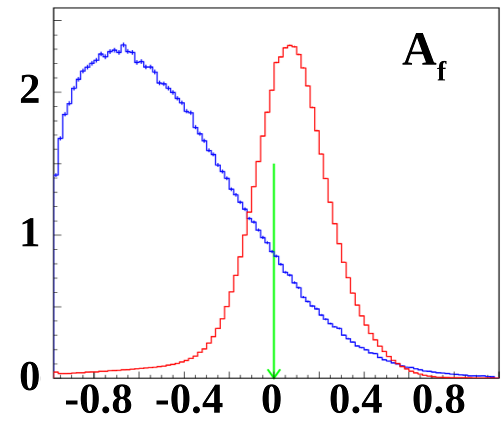
Electrons: initiate shower soon at EmC entrance, total energy $E_{cl}/P \sim 1$

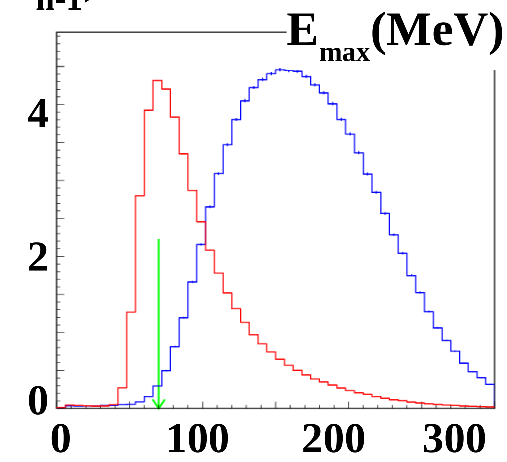
Muons: mip-like in first two layers, Bragg's peak at the end

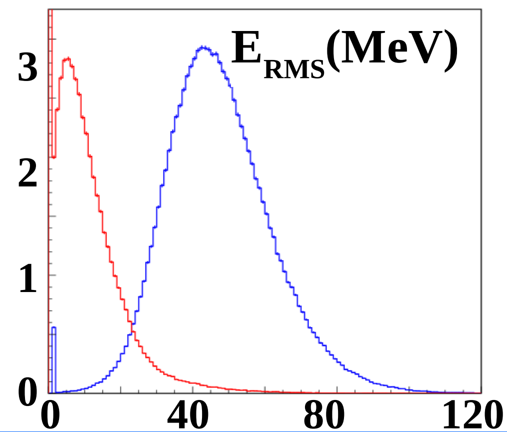
Cut on $A_f = E_2\text{-}E_1/(E_2+E_1)$, $\max\{E_k\}$, $A_l = (E_n\text{-}E_{n-1})/(E_n+E_{n-1})$

RMS$\{E_k\}$ left for signal counting









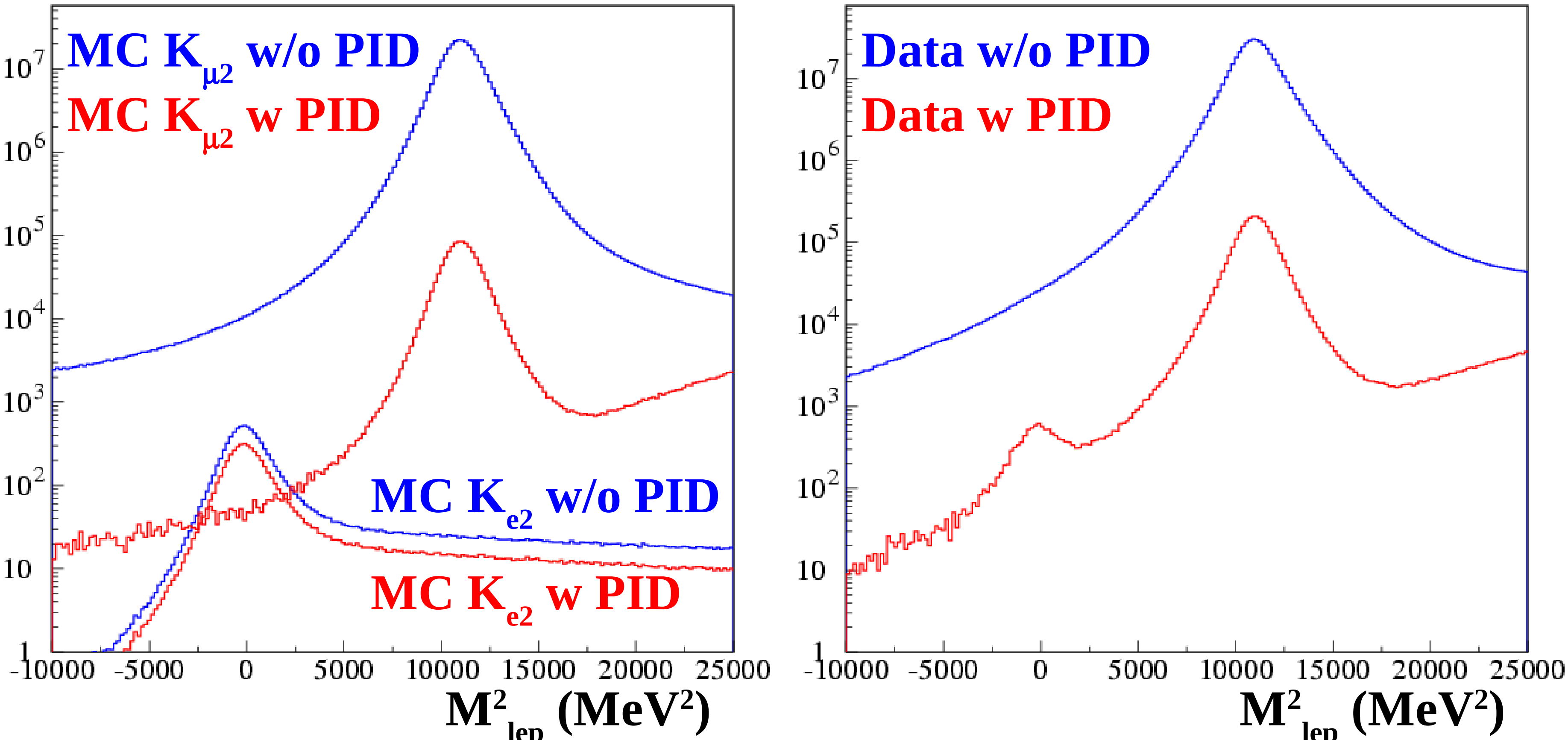
MC K_{e2}
MC $K_{\mu2}$

Analysis of Ke2/Km2 – PID via EmC

Impact of PID: retain 60% of signal, reject all but 0.2% of background

Check with K_{Le3} data/MC control sample (w incomplete coverage)

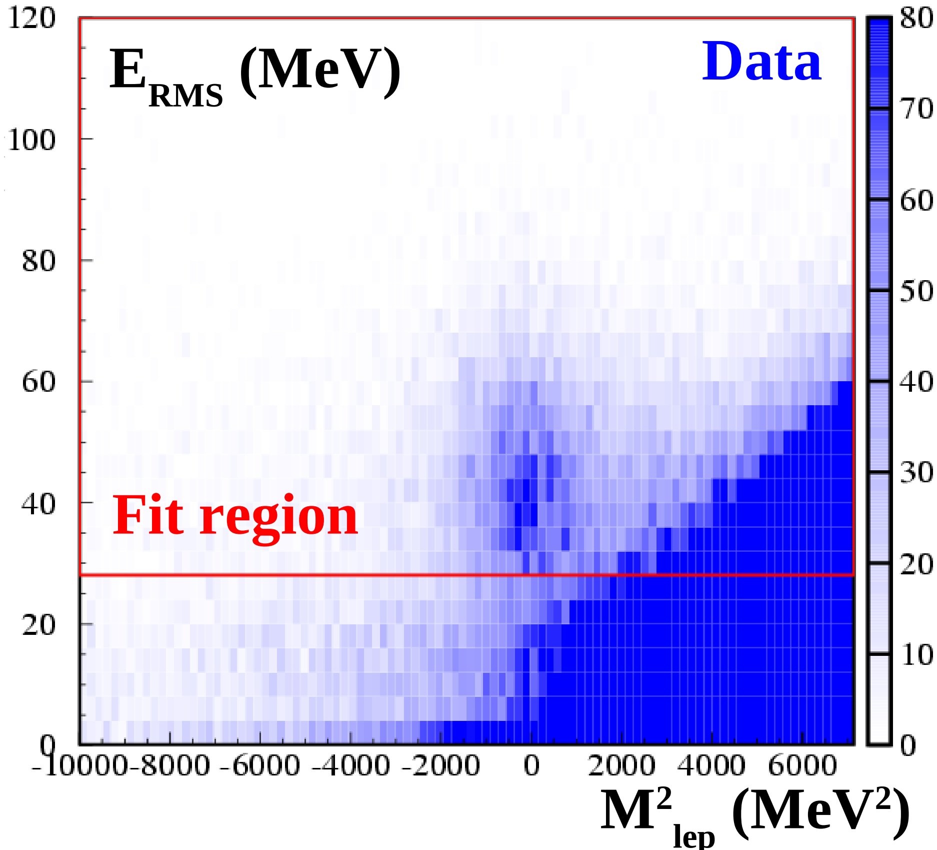
After PID count Ke2 events

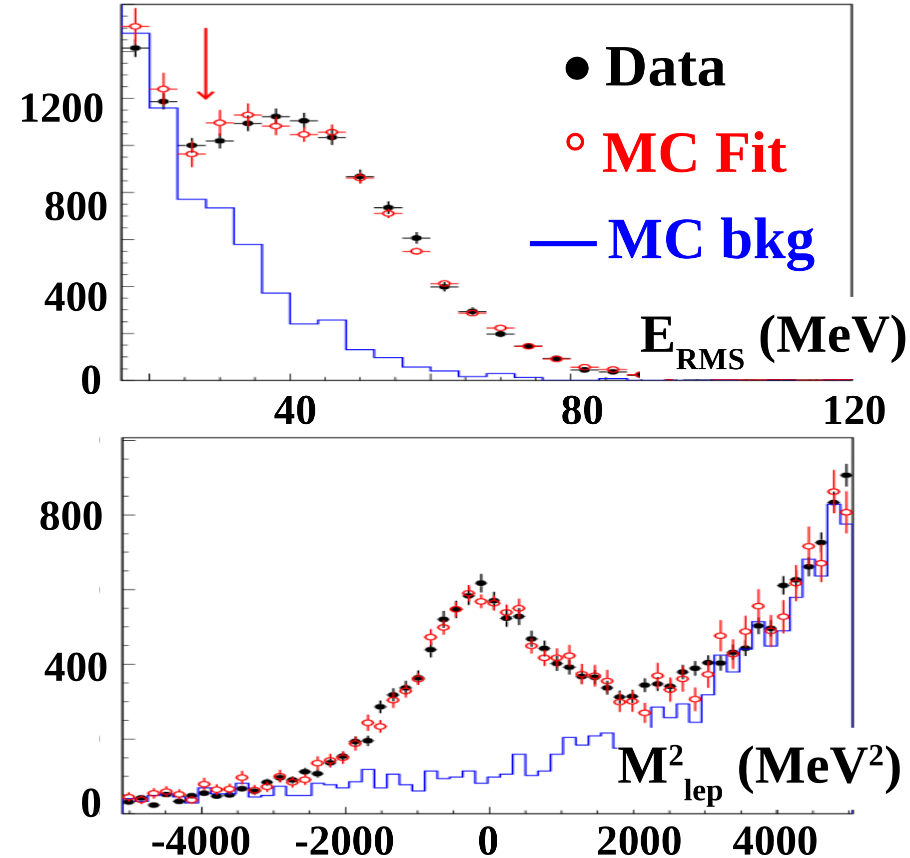


Analysis of R_K – Count Ke2 events

K_{e2} event counts: likelihood fit of M_{lep} vs E_{RMS}

- **Input: MC shapes for $K_{e2(\gamma)}$ and background**
- **Fit parameters: # of K_{e2} and background, get 8090±160 observed evts**



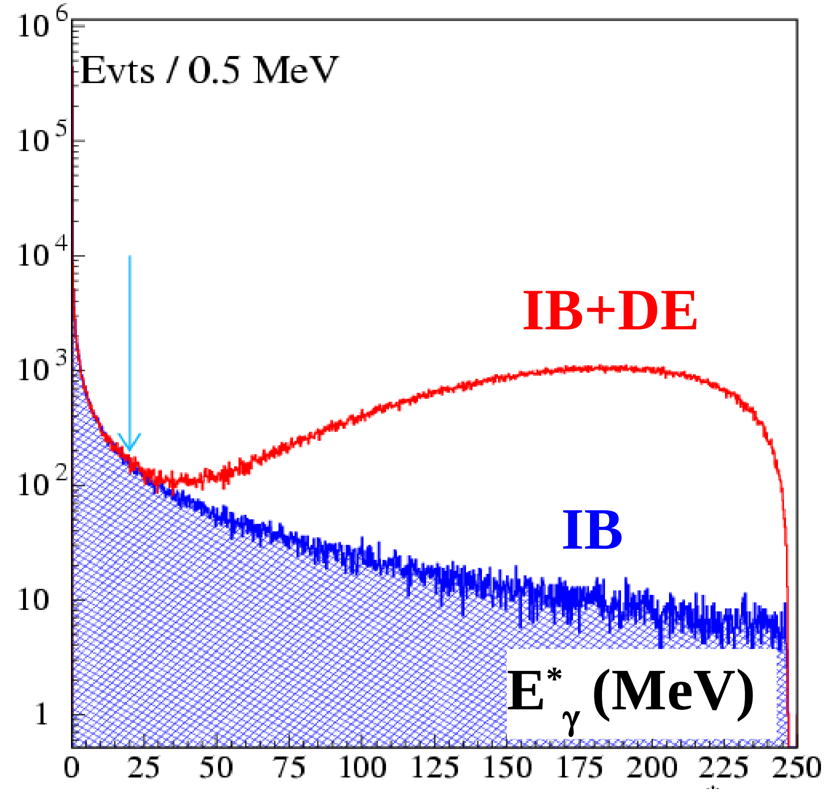


Analysis of R_K – Radiative corrections

To match theory, has to count IB only:

- **Fit using IB+DE, count IB by considering as "signal" E^*_γ<20 MeV**
- **Correct for IB tail, $\varepsilon^{IB} = 95.28(5)$**
- **Repeat fit varying DE by its 15% uncertainty, get 0.45% error**

Correct for ratio of Ke2 and Km2 trigger and one-prong efficiencies, and for PID Ke2 efficiency, get:



$$R_K = \frac{N_{Ke2}}{N_{K\mu2}} \left[\frac{\varepsilon^{TRG}_{K\mu2}}{\varepsilon^{TRG}_{Ke2}}\right] \left[C^{TRK}\frac{\varepsilon^{TRK}_{K\mu2}}{\varepsilon^{TRK}_{Ke2}}\right] \left[\frac{1}{C^{PID}\varepsilon^{PID}_{Ke2}}\right] \frac{1}{\varepsilon^{IB}} = (2.55 \pm 0.05 \pm 0.05)\times 10^{-5}$$

Agrees w SM: $(2.472 \pm 0.001)\times 10^{-5}$ &2 NA48 preliminary: $(2.43\pm 0.04)\times 10^{-5}$

R_K – Perspectives toward 1% error

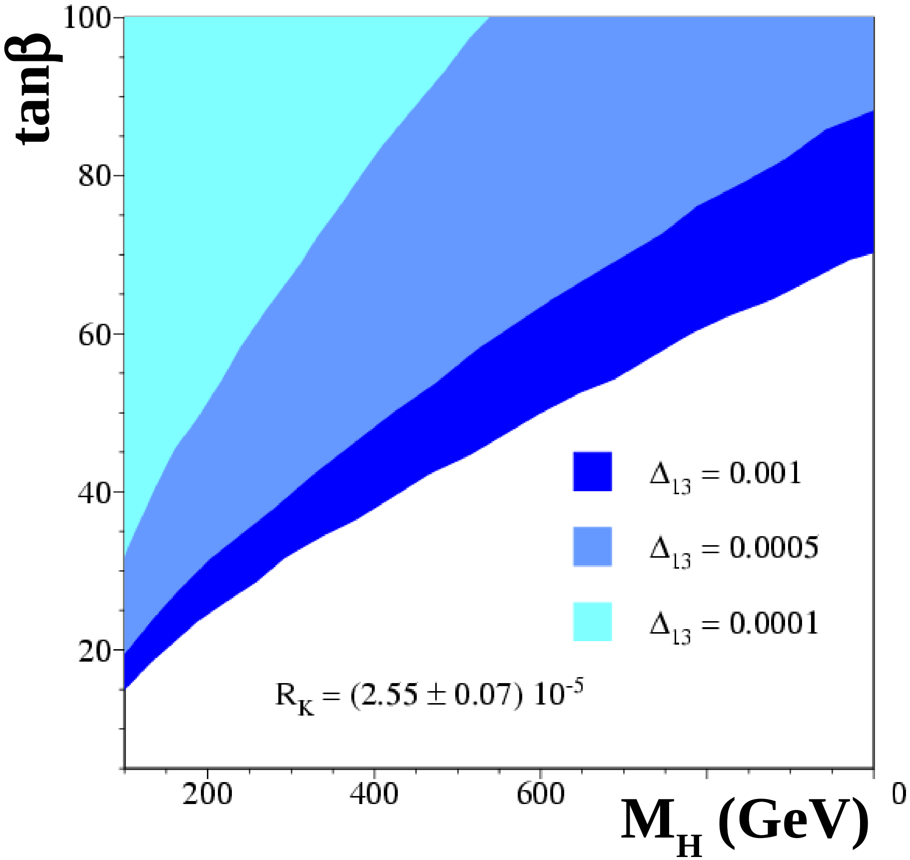
Present status	To complete analysis
1.1% Signal counts/1.7fb^{-1}	+30% of data under processing
	+40% w recover of prompt K decays
0.7% Bkg subtraction	×2 rejection from kinematics
1.4% MC Bkg statistics	×2 MC stat under processing
1.9% stat error	
1.5% incomplete PID CS coverage	× 4--8 CS stat available, loosen PID cut
0.9% one-prong CS stat	< 0.3% using all data
0.9% TRG minimum-bias stat	Better control of trigger variables
2.0% syst error	

Will push error @ 1%: final mmt will be compared with forecoming mmt with 0.3% accuracy from P326/NA62, see R. Fantechi talk in BSM session

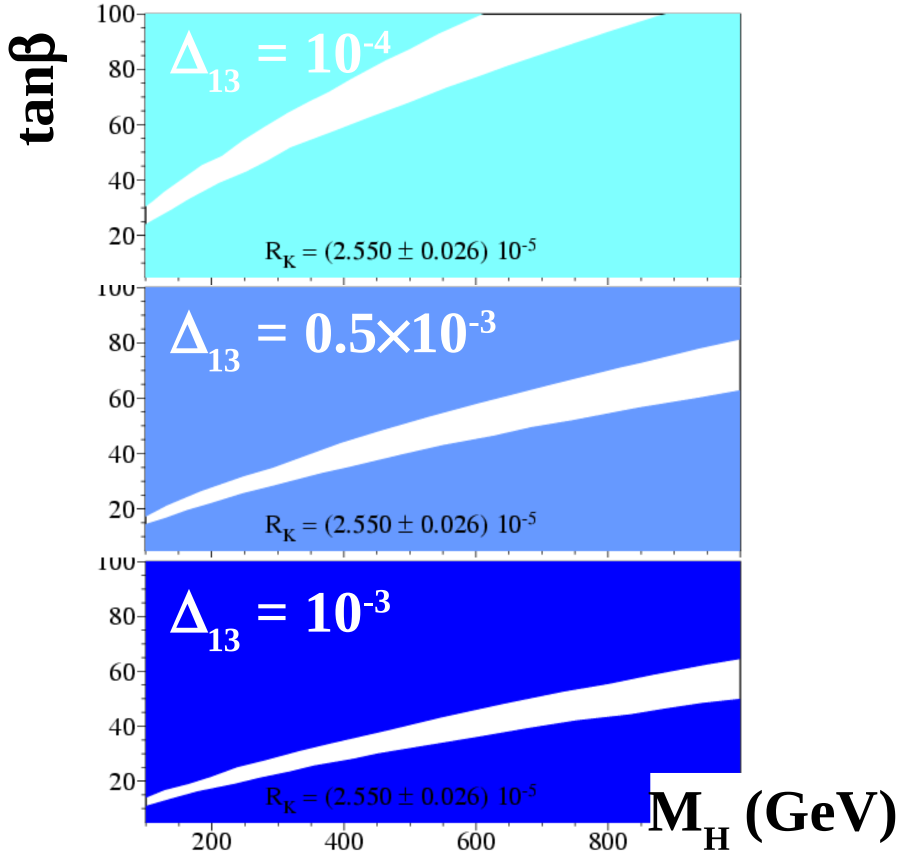
R_K – Sensitivity to NP

Sensitivity shown as 95%-CL excluded regions in the tanβ - M_H plane, for fixed values of the 1-3 slepton-mass matrix element, $\Delta_{13} = 10^{-3}, 0.5\times10^{-3}, 10^{-4}$

Present KLOE result: $R_K = 2.55(7)\times10^{-5}$



Perspective: $R_K = 2.55(3)10^{-5}$



$K_{\mu 2}$ – Sensitivity to NP

Other NP searches in helicity-suppressed decays: Γ(K → μν)/Γ(π→ μν)

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]

Expect 0.4% effect on K/π ratio wrt SM, $\frac{\Gamma(K\to\mu\nu(\gamma))}{\Gamma(\pi\to\mu\nu(\gamma))} = \frac{m_K\left(1-\frac{m_\mu^2}{m_K^2}\right)^2}{m_\pi\left(1-\frac{m_\mu^2}{m_\pi^2}\right)^2}\frac{|V_{us}|^2}{|V_{ud}|^2}\frac{f_K^2}{f_\pi^2}\frac{1+\frac{\alpha}{\pi}C_K}{1+\frac{\alpha}{\pi}C_\pi}$

Theoretical inputs:

- $\mathbf{f_K / f_\pi}$***=1.189(7),*** from HPQCD-UKQCD [arXiv:0706.1726]
- Radiative corrections $C_{K,\pi}$ for K and π decays [Marciano PRL93 231803,2004]

Experimental inputs:

- $m_{K,\pi,\mu}$, $\Gamma(\pi_{\mu 2})$ from PDG
- τ^+ from average of PDG and recent KLOE measurement
- **BR($K^+ \to \mu^+\nu(\gamma)$) = 63.66(9)(15)%, from analysis of ~ 175 pb^{-1} of 2002 data**

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

$K_{\mu 2}$ – Sensitivity to NP

How to compare this with the CKM elements extracted from K_{l3}?

- **Use KLOE-average V_{us} = 0.22433(134), with $f^+(0)$= 0.9609(51) [UKQCD-RBC]**
- **Use world-average V_{ud} = 0.97372(26)**
- **Assume CKM unitarity for K_{l3} decays**

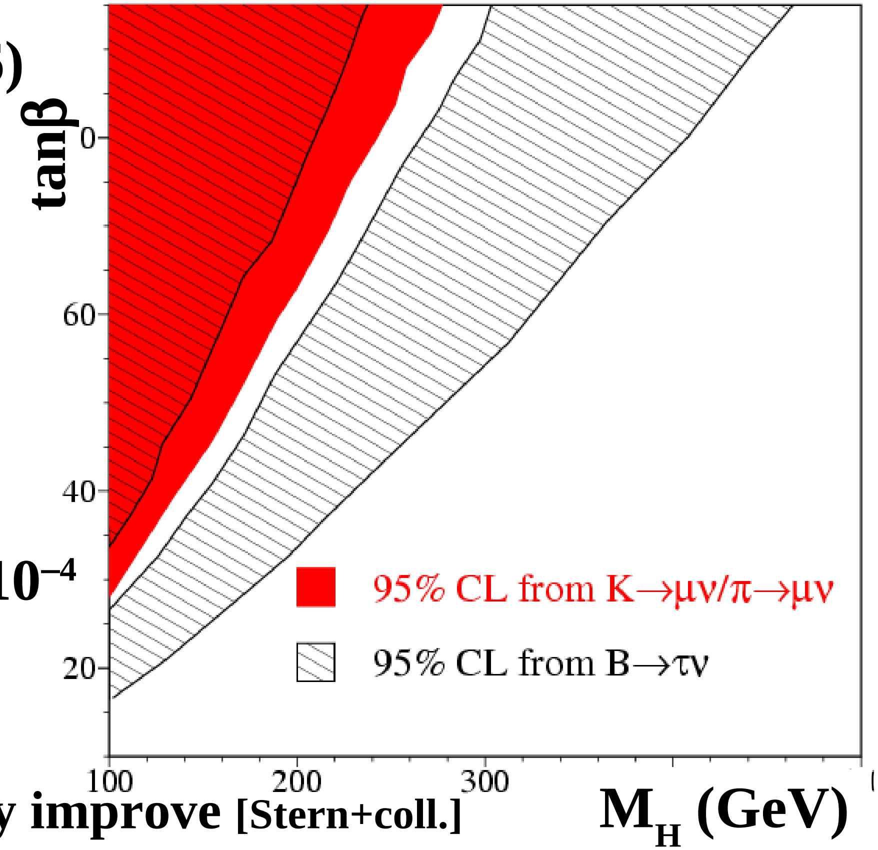
Fit V_{us} from $K_{\mu 2}$ and V_{us} from K_{l3}, get:

- **$V_{us}(K_{l3})$ = 0.22635(86)**
- **$V_{us}(K_{\mu 2})$ = 0.22626(146)**
- **$\rho = -3\%$**

NP sensitivity of $B(B \to \tau\nu) = 1.42(44)\times 10^{-4}$

[Babar-Belle average] can be compared:

- **Complementary**
- **Promising: Callan-Treiman + FF's may improve [Stern+coll.]**



V+A terms may also affect $V_{us}(K_{l3})/V_{us}(K_{\mu 2})$ [see Oertel and Mescia talks]

Conclusions

KLOE measurements greatly improve knowledge of gauge coupling:

- **Comprehensive set of observables for K decays: BR's, τ's, FF's**
- **Lepton universality test from K_{l3} decays satisfied at < 0.5%**

New and interesting tests of NP effects from two-body decay studies:

- **Golden observable: R_K, measured @ 3%, already interesting to limit**
- **Solid roadmap to push both statistical and systematic errors down @ 1%**
- **Sensitivity to NP effects from $K_{\mu2}/\pi_{\mu2}$:**
  - **Complementary with Babar-Belle average of $B \rightarrow \tau\nu$**
  - **Expect both theoretical and experimental improvements, see F. Mescia's talk**

Future developments:

- **Focus put on FF slopes from analysis of $K^{\pm}_{l3}$ decays, still missing**
- **Don't forget, analyses of whole data set for $K_S \rightarrow \pi\mu\nu$, FF's for $K_L \rightarrow \pi\mu\nu$**