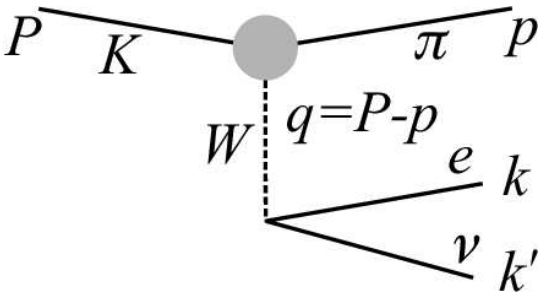
KLOE measurement of form factor slopes for $K_L \rightarrow \pi l \nu$ decays

Form factors: motivations I



$$\langle \pi(p) | j_\mu | K(P) \rangle = C_K [(P+p)_\mu f_+(t) + (P-p)_\mu f_-(t)]$$

$$t = (P-p)^2 = M_K^2 + m_\pi^2 - 2M_K E_\pi$$

$$f_0(t) = f_+(t) + \frac{t}{m_K^2 - m_\pi^2} f_-(t)$$

f_0 and f_+ related to the transition amplitudes 0^+ and 1^-, respectively

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

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

Form factors: motivations II

$\delta V_{us}/V_{us} \propto 0.5\ \delta I / I$

$I_{k0e}(\lambda'_+) - I_{k0e}(\lambda'_+, \lambda''_+) / I_{k0e} = 0.4\%$

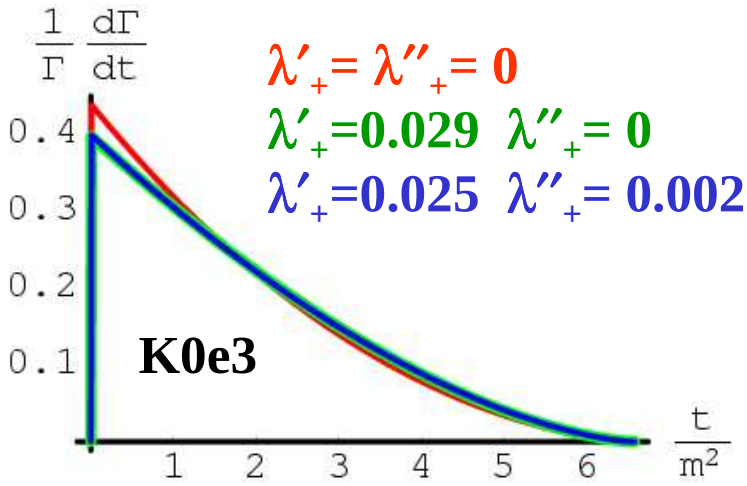
$I_{k0\mu}(\lambda'_+, \lambda''_+) - I_{k0\mu}(\lambda'_+, \lambda''_+, \lambda_0) / I_{k0\mu} = 3\%$

λ'_+ and λ''_+ 95% correlated
λ'_0 and λ''_0 ~100% correlated

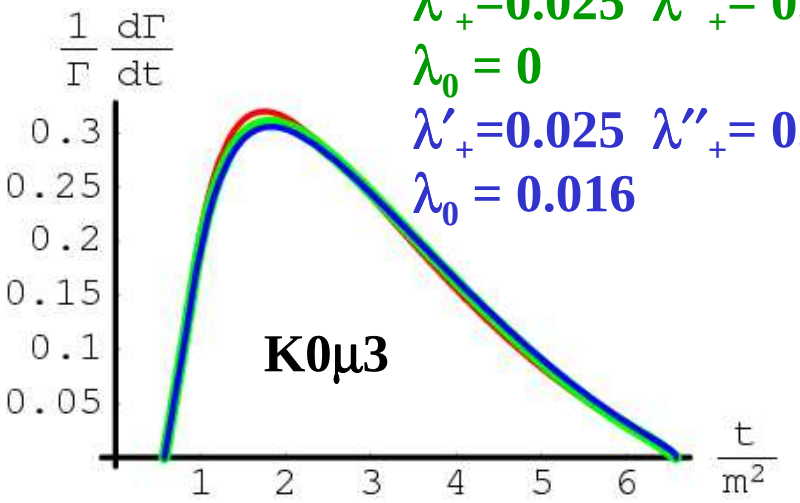
% error on $V_{us} \times f(0)^*$

Mode	%err	BR	τ	Δ	I
KLe3	0.25	0.09	0.19	0.10	0.09
KLμ3	0.31	0.10	0.18	0.15	0.17

* CKM'06



$\lambda'_+ = \lambda''_+ = 0$
$\lambda'_+ = 0.029$ $\lambda''_+ = 0$
$\lambda'_+ = 0.025$ $\lambda''_+ = 0.002$



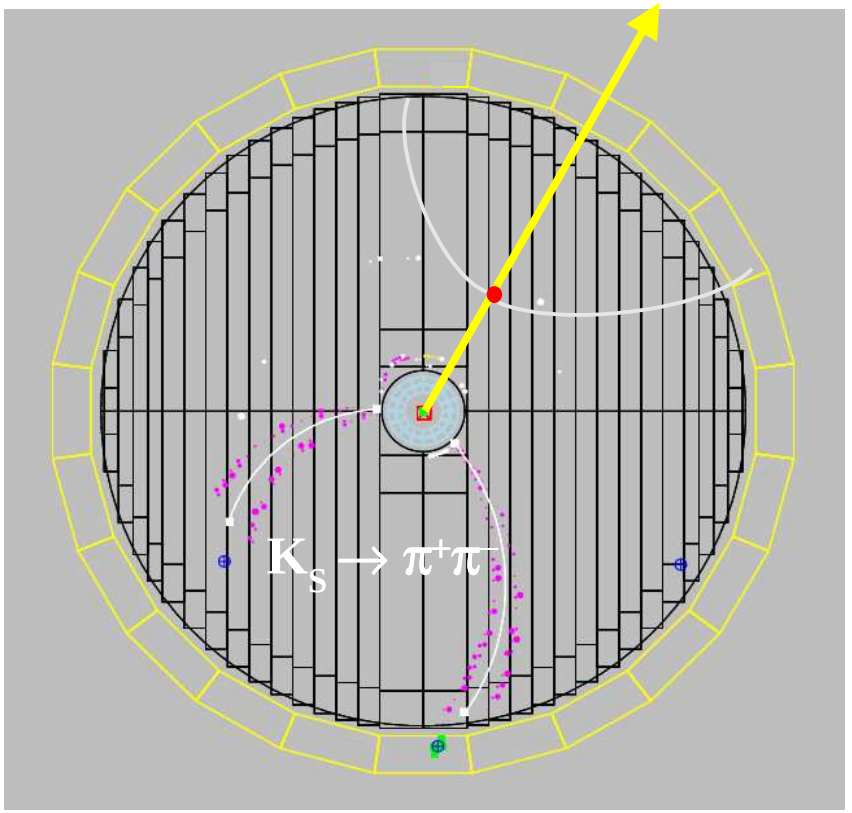
$\lambda'_+ = \lambda''_+ = \lambda_0 = 0$
$\lambda'_+ = 0.025$ $\lambda''_+ = 0.002$
$\lambda_0 = 0$
$\lambda'_+ = 0.025$ $\lambda''_+ = 0.002$
$\lambda_0 = 0.016$

$\varphi \rightarrow K_S K_L$

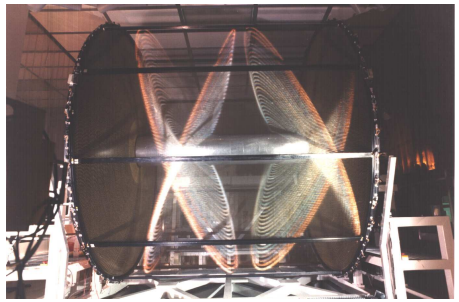
$\varphi \rightarrow K_S K_L$ almost at rest ($p(\varphi) \sim 13$ MeV)
We tag a K_L looking for $K_S \rightarrow \pi^+\pi^-$ decays
K_L momentum computed from 2 body kinematics (~1% resolution)
We measure form factor parameters by measuring kinematical variables in kaon center of mass system

Tag efficiency independent of pion energy (linear in t) within few permil

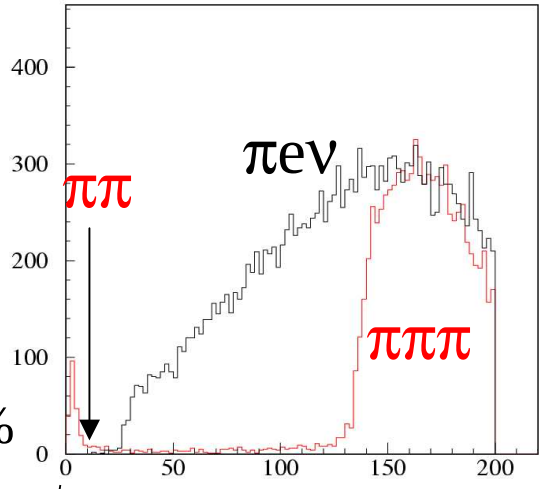
Measurement of the parameters of the form factors with L=330 pb^{-1} collected during 2001 and 2002 corresponding to ~2 million Ke3 and Kμ3 selected



Ke3 Selection: DC

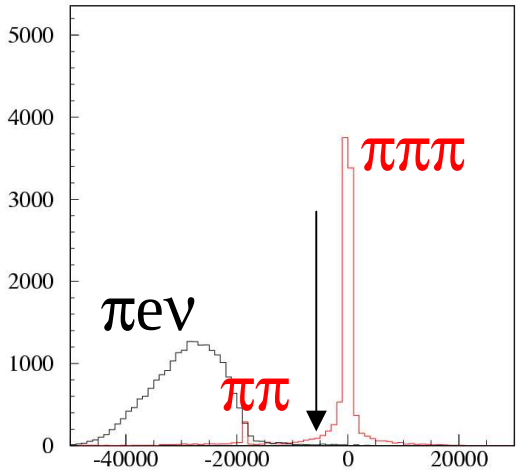


4 m dia., 3.5 m long
12,000 cells
He + 10% iso-C_4H_{10}
B=5.2 kG
$\sigma(p_T)/p_T$ = 0.4 %

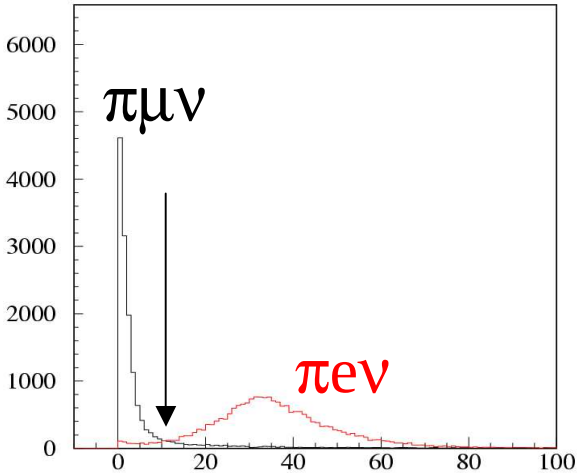


$\sqrt{E_{miss}(\pi\pi)^2 + p_{miss}^2}$ (MeV)

After kinematical cuts: bkg ~ 10 % (Kμ3) and ε ~ 96%
We must distinguish π from e to compute E_π

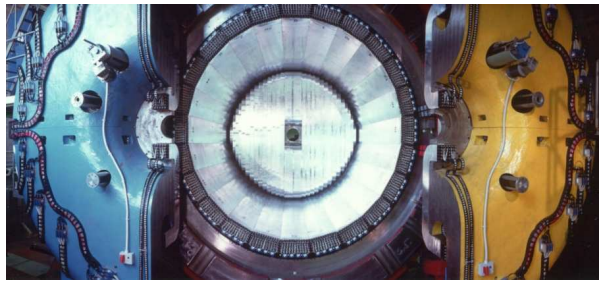


$E_{miss}(\pi\pi)^2 - p_{miss}^2 - M_{\pi 0}^2$ (MeV^2)



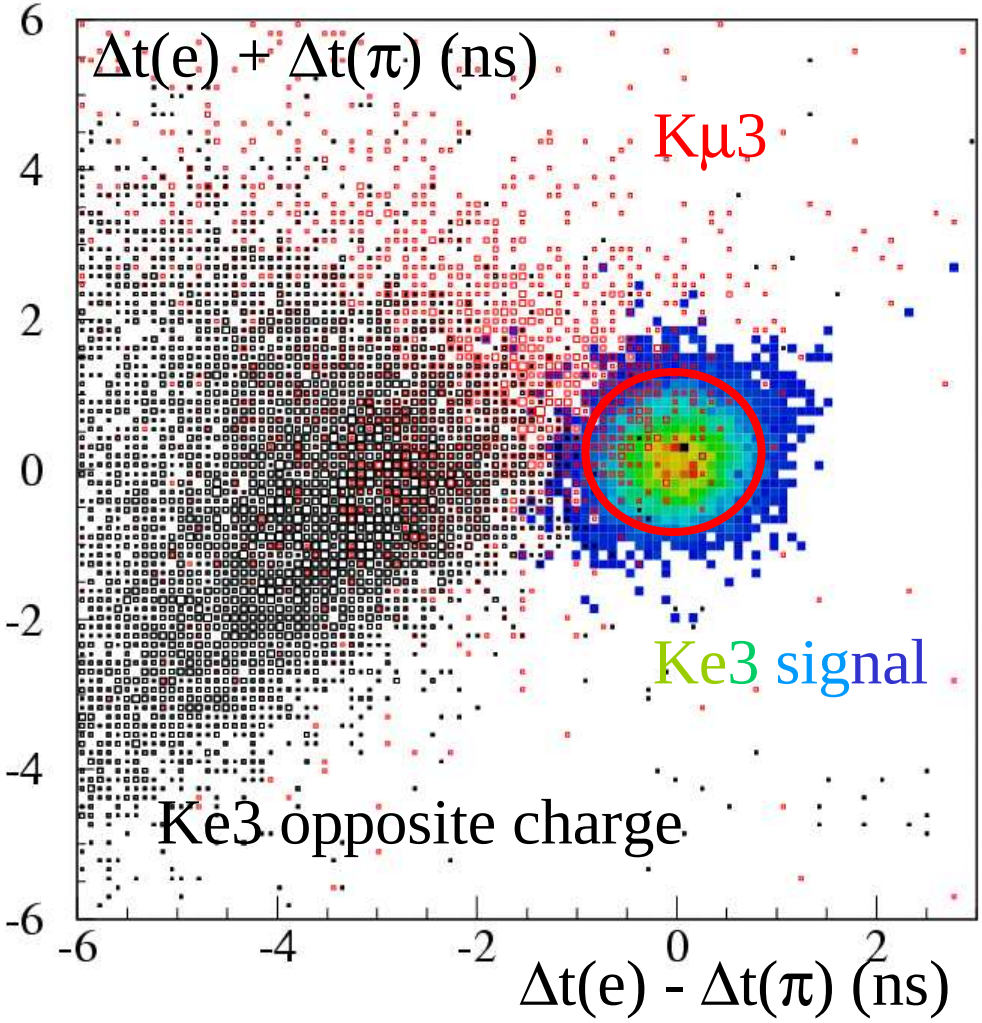
$|E_{miss}(\pi\mu) - p_{miss}|$ (MeV)

Ke3 Selection:TOF



Pb scintillating-fibers
L~4 m
~5000 pm tubes
σ(E)/E=5.7%/√E(GeV)
σ(t)=57 ps/ √E(GeV) ⊕100 ps

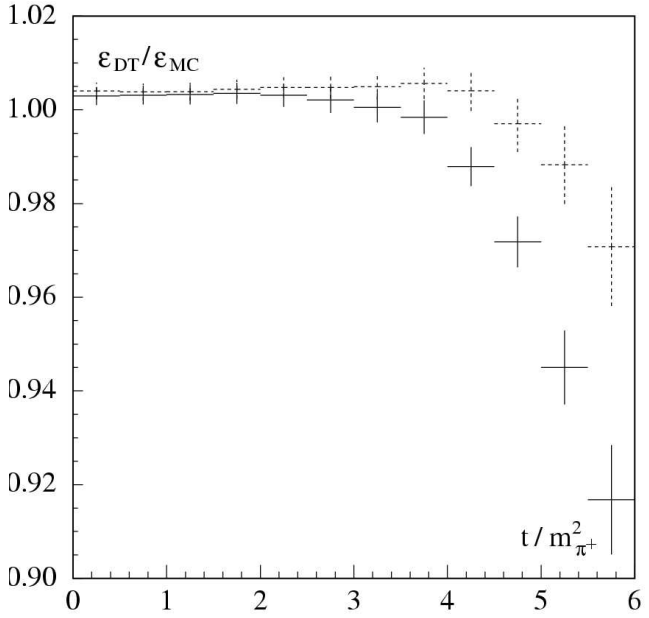
Tracks are associated to clusters in EmC (TCA)
We reject the background and perform Particle ID using TOF
ε~40% bkg ~ 1% (Kμ3)

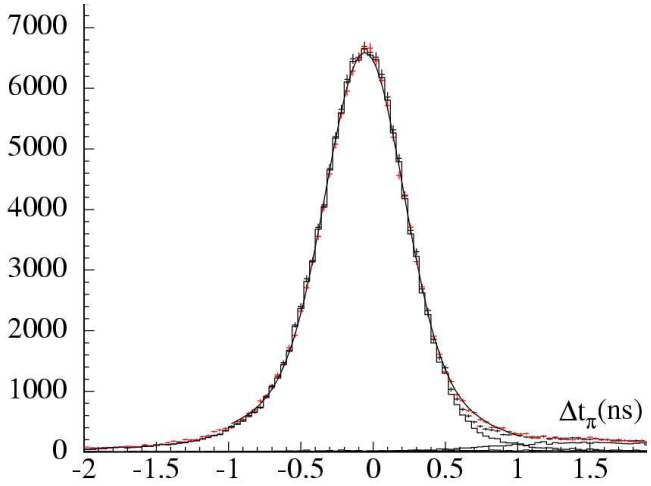


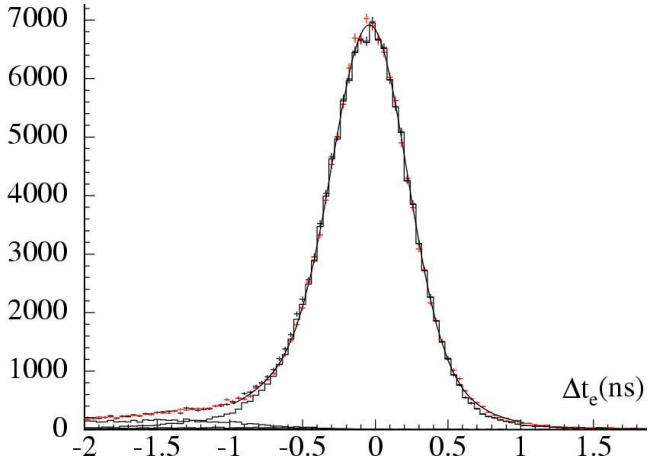
Ke3 Selection:TOF

TCA efficiency different for the two charge modes (different behavior of low-p π^+ and π^- in EmC).
If not corrected $\Rightarrow$ different results for λ'_+ (15%) for each charge.

EmC time-response in MC simulation tuned with data control samples



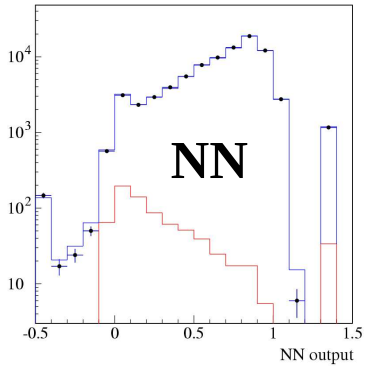




Ke3 Selection: Purity

Residual background ~1%

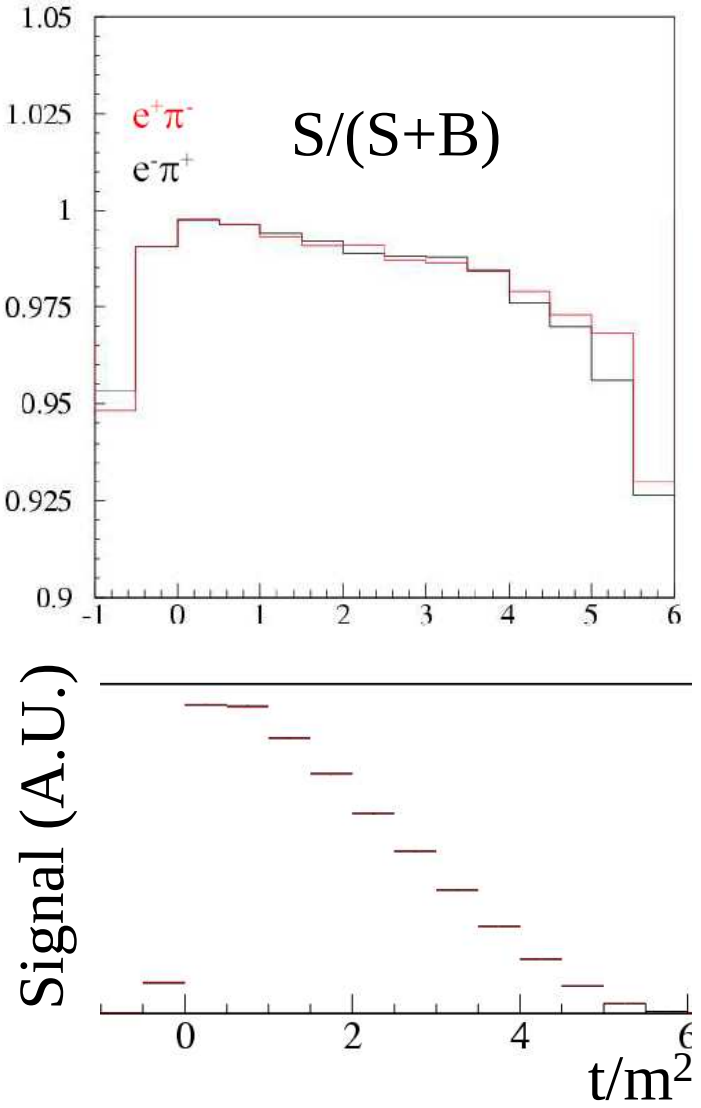
$\delta\lambda'_+ / \lambda'_+ \sim 10\%$ if not corrected

E/p, cluster shape $\rightarrow$ 

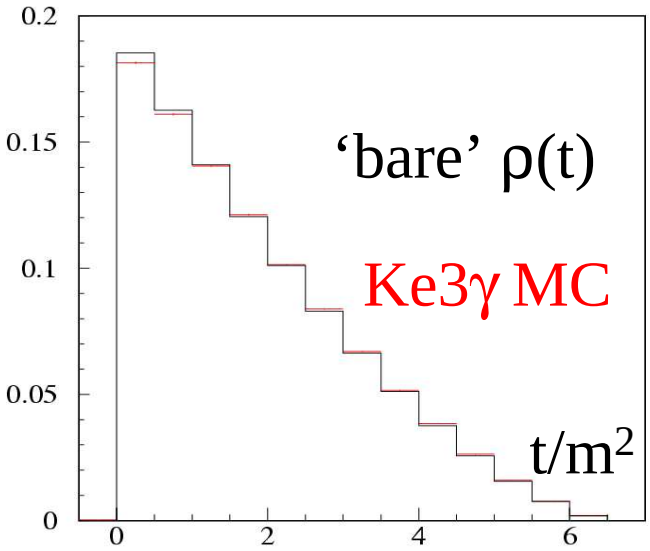
$\rightarrow$**e** π μ

We cut on a variable calculated using a neural network (NN)

Reducing the background by a factor 2, the variations of the measured slopes are well within statistical errors

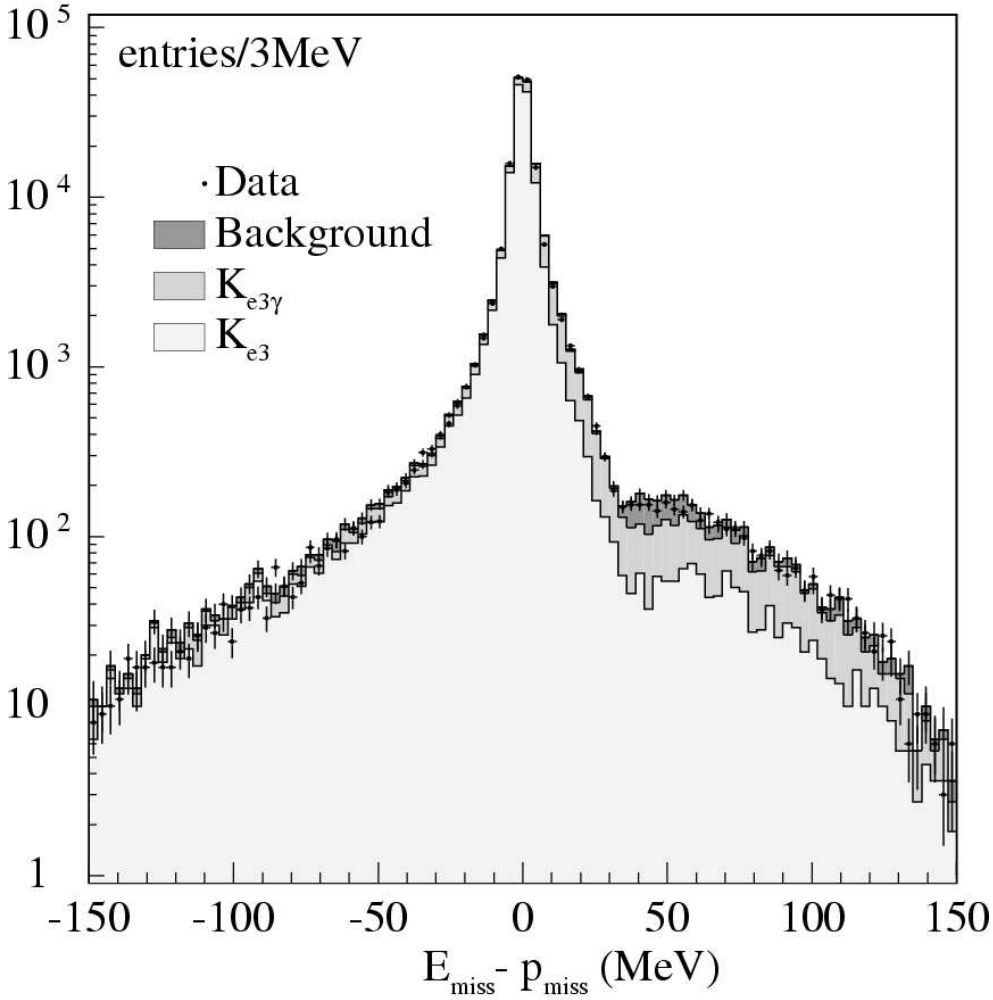


Radiative corrections



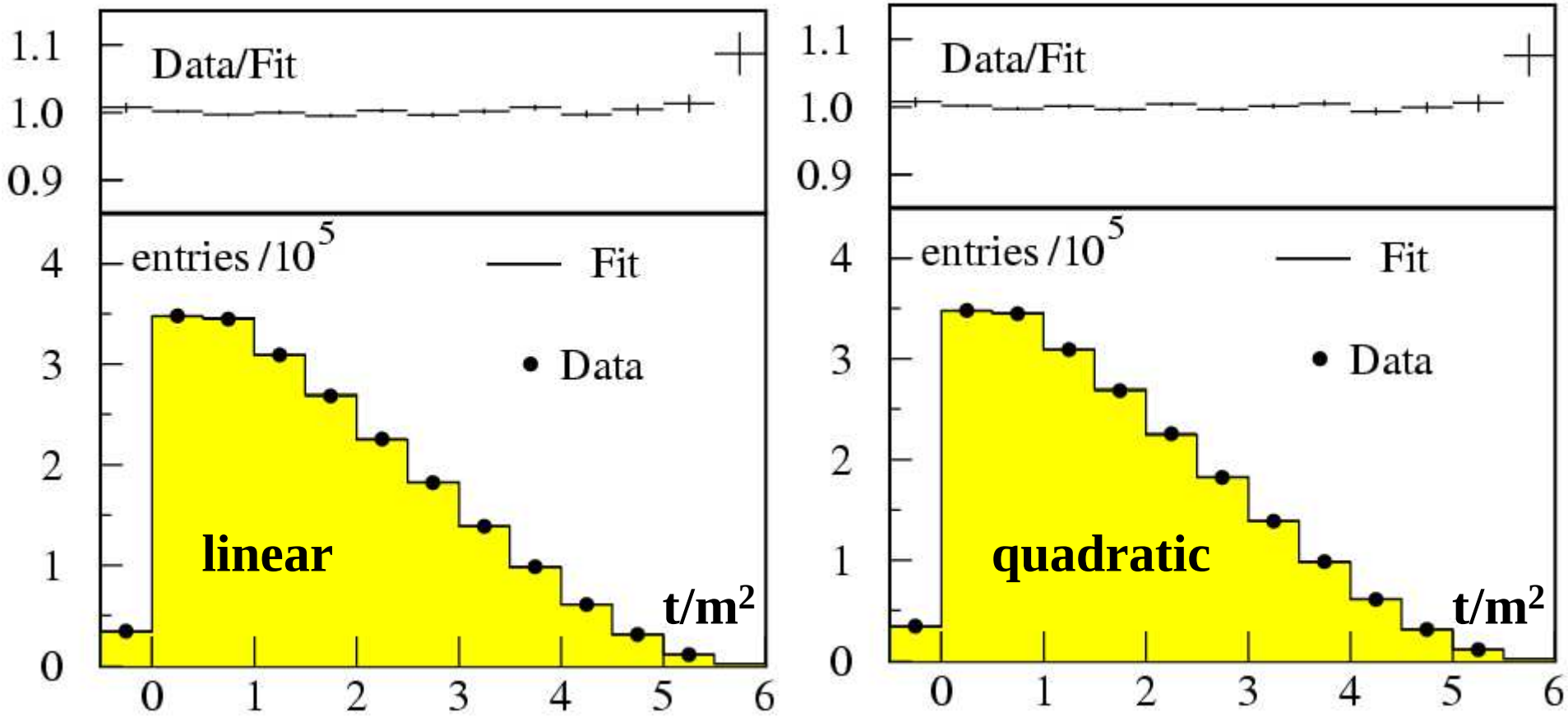
Inner bremsstrahlung affects mainly the low t region (3-5% effect)

Final state radiation included in the simulation of kaon decays



Fit

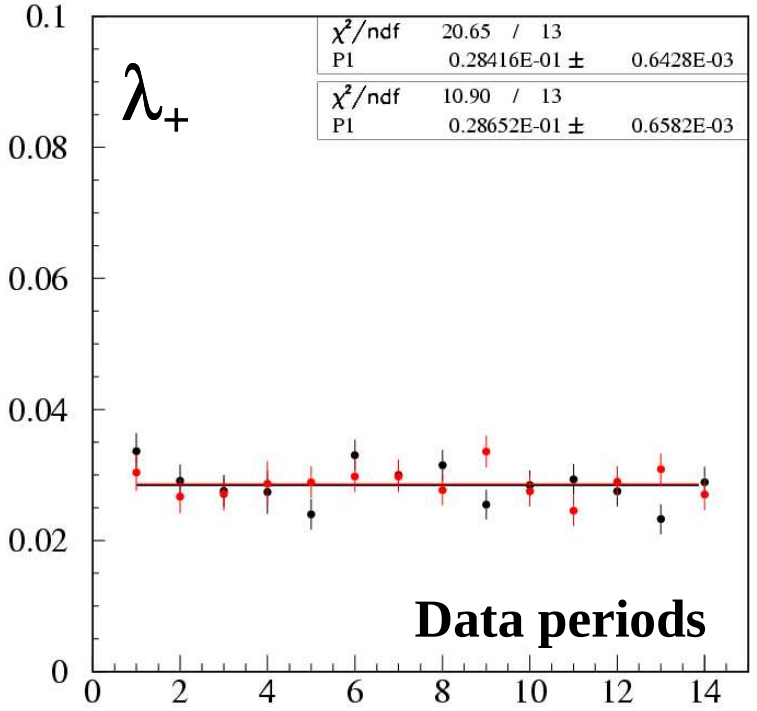
$$dN/dt(i) = N_0 \sum_{j=1}^{20} A(i,j) \times \rho(j;\lambda'_+,\lambda''_+) \times \varepsilon(j) \times F_{FSR}(j)$$



λ'_+, λ''_+: Results

From 2 million Ke3 events selected

Linear fit	$\lambda_+ \times 10^3$	χ^2/ndf
$\pi^- e^+ \nu$	28.7±0.7	156/181
$\pi^+ e^- \nu$	28.5±0.6	174/181
Comb.	28.6±0.5	330/363



Quadratic fit	$\lambda'_+ \times 10^3$	$\lambda''_+ \times 10^3$	χ^2/ndf
$\pi^- e^+ \nu$	24.6±2.1	1.9±1.0	152/180
$\pi^+ e^- \nu$	26.4±2.1	1.0±1.0	173/180
Comb.	25.5±1.5	1.4±0.7	325/362

$P(\chi^2) \sim 90\%$

λ'_+, λ''_+: Results

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

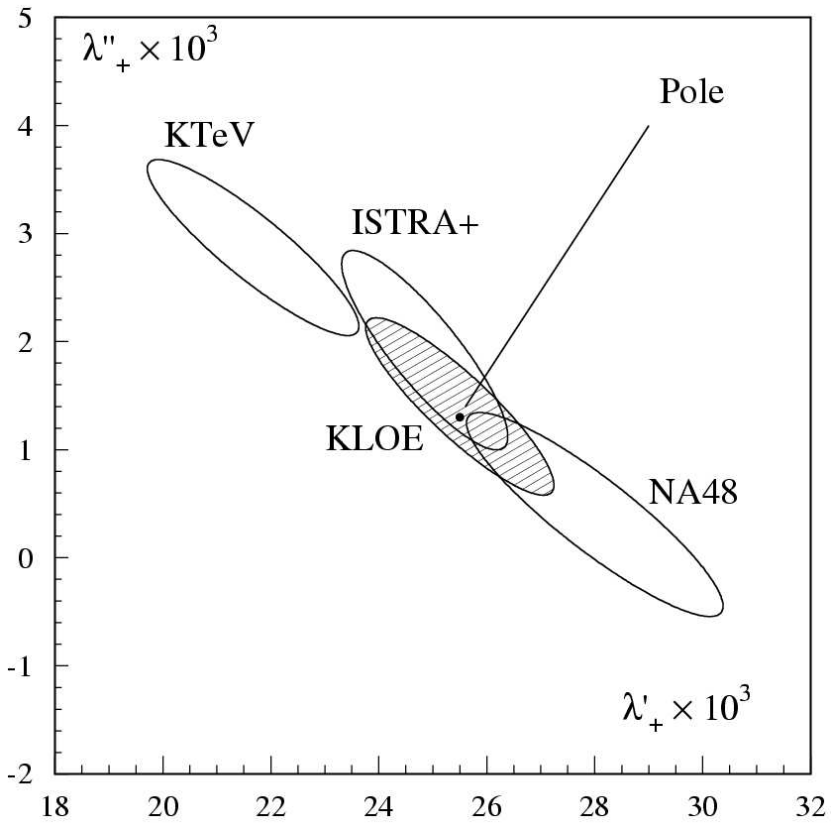
$\lambda''_+ = (1.4 \pm 0.7_{stat} \pm 0.4_{syst}) \times 10^{-3}$

Correlation -0.95

Pole parametrization:

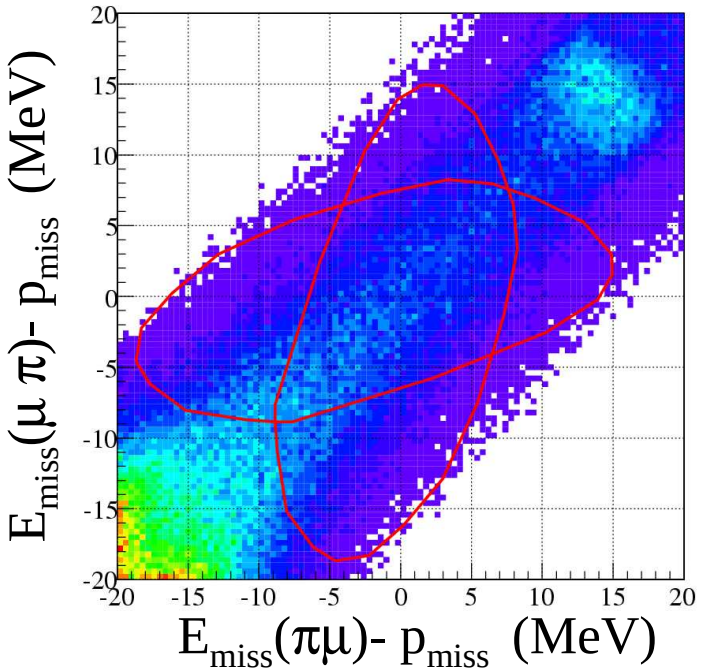
$M_V = (870 \pm 6_{stat} \pm 7_{syst})$ MeV

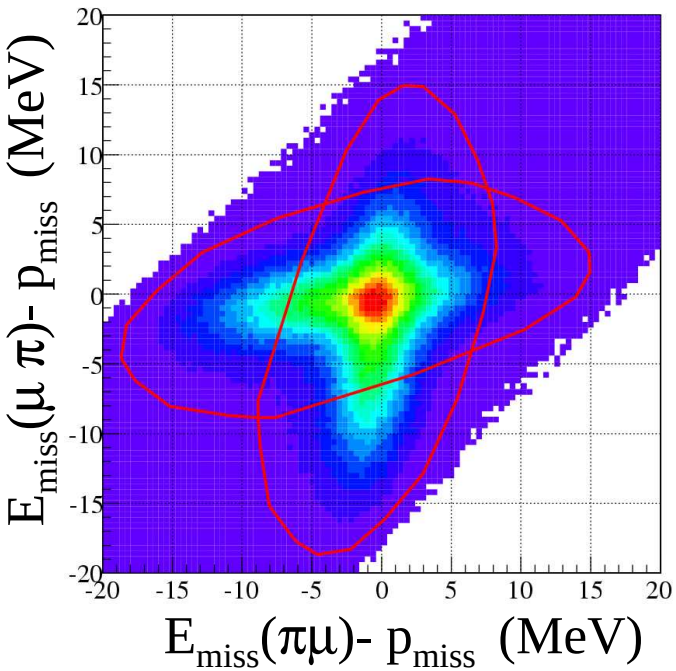
$P(\chi^2) \sim 92\%$



Values only from Ke3

Kμ3 Selection





Kinematic preselection cutting on E_{miss}- p_{miss}

Rejection of ππ, πππ, and πeν: similar cuts used for the Ke3 selection

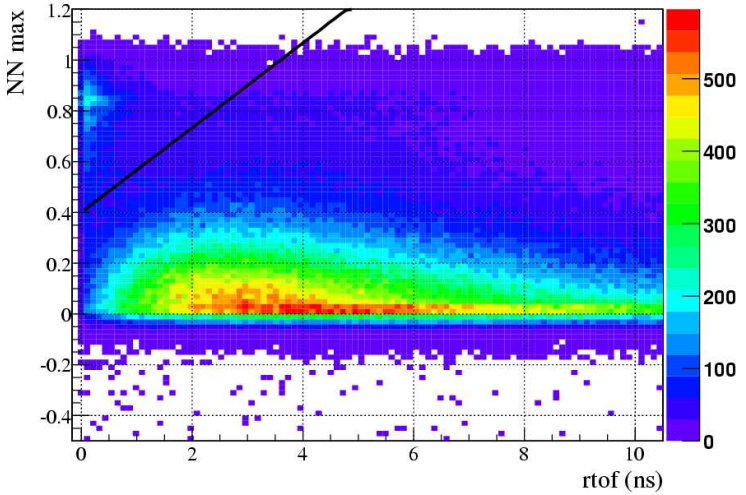
4% contamination (Ke3)

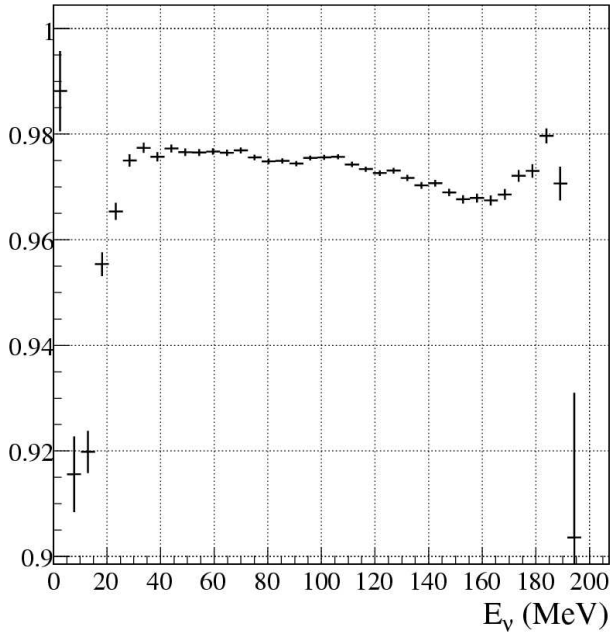
We don't distinguish π from μ

Kμ3 Selection

Ke3 background reduced by a combined cut on NN output and on TOF variable
Final background ~2%

π-μ separation by TOF difficult due to the small Δm and at low energy (100 MeV) calorimetry doesn't help much
⇒ we fit the Eν spectrum (no need to distinguish π from μ)





Kμ3: t vs E_ν

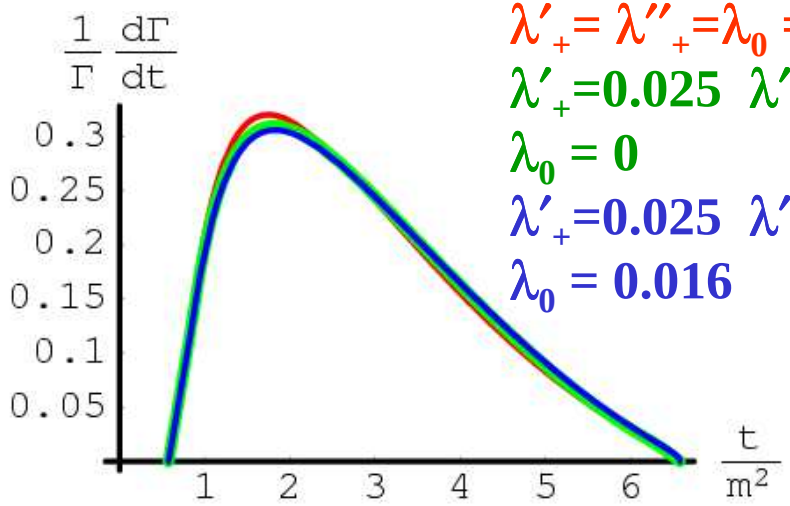
$\lambda'_+ = \lambda''_+ = \lambda_0 = 0$

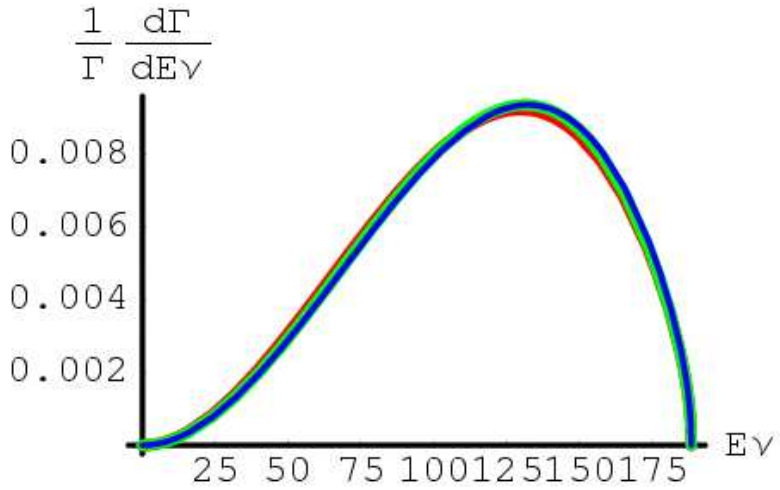
$\lambda'_+ = 0.025 \quad \lambda''_+ = 0.002$

$\lambda_0 = 0$

$\lambda'_+ = 0.025 \quad \lambda''_+ = 0.002$

$\lambda_0 = 0.016$





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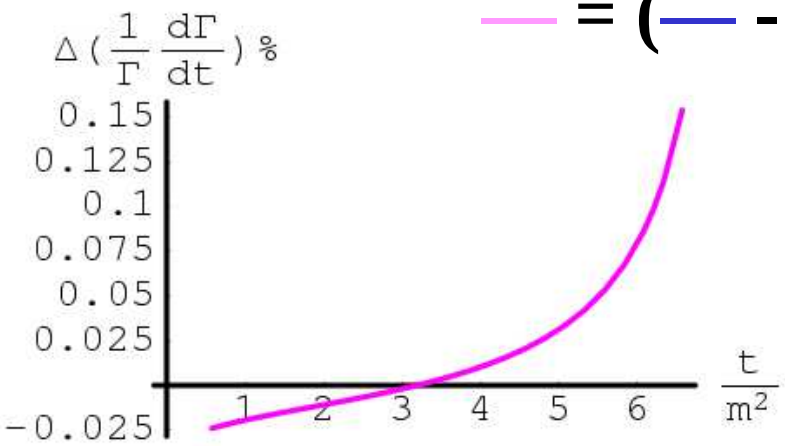
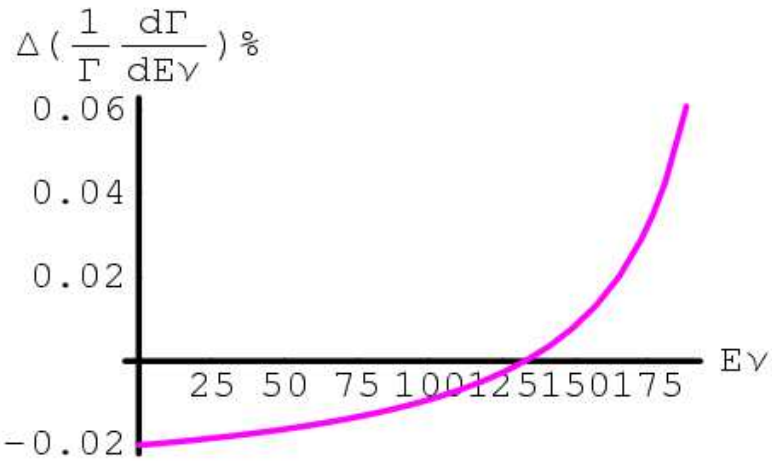




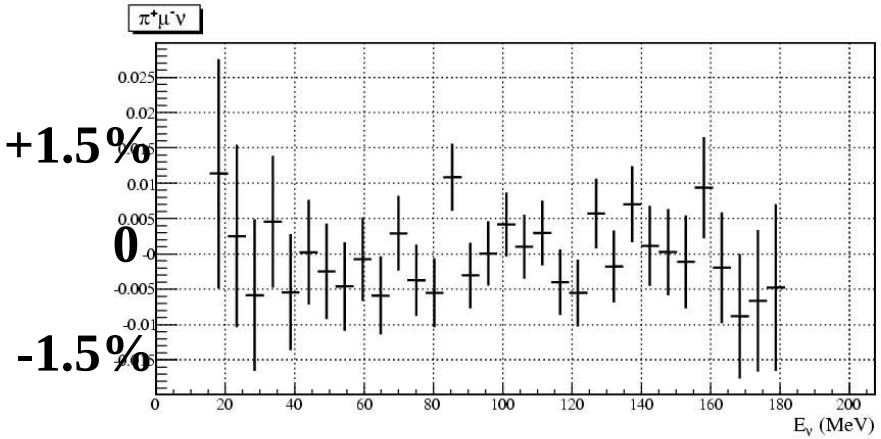
Statistical errors on slopes are 2-3 times bigger using E_ν and higher correlations

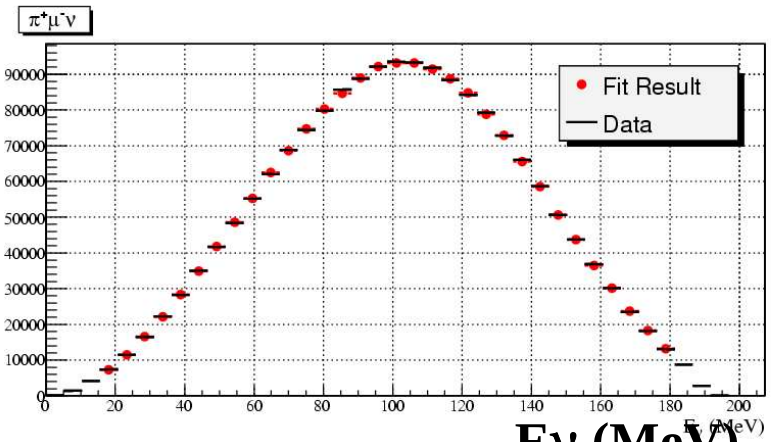
The error on λ_0 is only 30% bigger if the fit is performed combining Ke3 and Kμ3

λ_0: Fit result

1.8 million selected events
Combined fit Ke3 and Kμ3

λ_0	λ'_+	λ''_+
1	-0.95	0.31
	1	-0.41
		1





Preliminary result

$\lambda_0=(15.6\pm1.8_{stat}\pm1.9_{syst})\times10^{-3}$

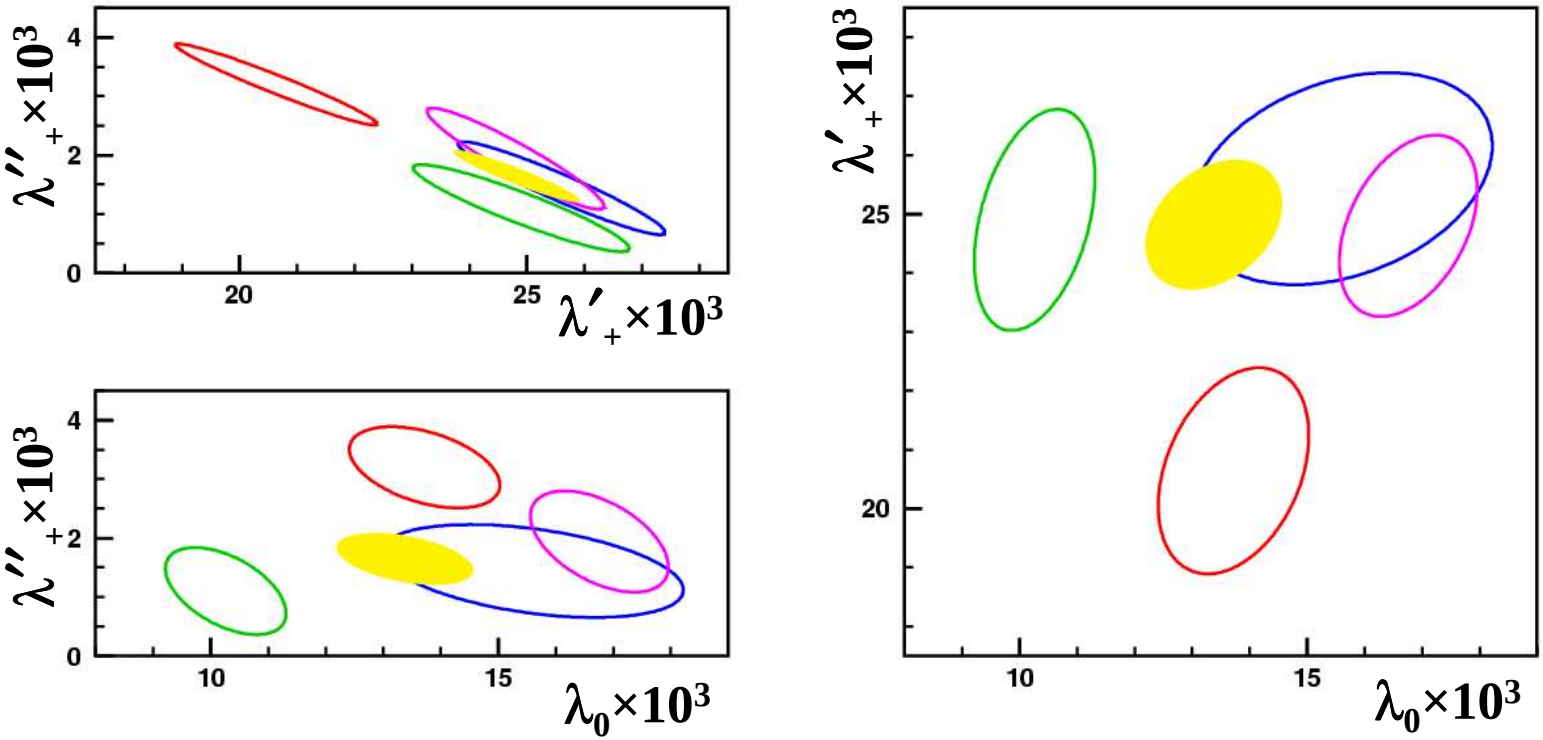
χ^2/ndf =21/31

Comparison of experimental results (Ke3 and Kμ3)

KTeV KLOE NA48 ISTRA+

FlaviA net

Each ellipse is from the average of Ke3 and Kμ3



$\lambda'_+ = (24.8 \pm 1.1) \times 10^{-3}$ $\lambda''_+ = (1.64 \pm 0.44) \times 10^{-3}$ $\lambda_0 = (13.4 \pm 1.2) \times 10^{-3}$

$P(\chi^2) \sim 10^{-6}$ S=1.4, 1.3, 1.9

Conclusion

With ~0.3 fb^{-1} KLOE has measured the form factor parameters with K0e3 and K0μ3 decays, with relative errors of 7%, 58%, and 17% for λ'_+ λ''_+ and λ_0 respectively.

Experimental situation for λ_0 comparing different experiments is not very clear.

The overall fit has very low χ^2 probability, the systematics must be kept under control.

The first row of the CKM matrix offers the most precise test of unitarity.

The ratio $r_{\mu e}$, test of lepton universality, with kaons is now reaching the precision obtained with πl2 decays (0.5% vs 0.3%).

KLOE still has to analyze 2 fb^{-1} of data.

For instance, the relative error on λ_0 can be reduced to 5-10%.

Measurements on charged kaons form factors are underway.