Status of BR ($K_L \rightarrow \pi^+\pi^-$) analysis and status of the $K_L K_S \rightarrow \pi^+\pi^- \pi^+\pi^-$ interferometry

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$BR(K_L \to \pi^+\pi^-)$ Motivations

- The measurement could be performed at the level of 1% with the present statistics

- The BR enters in the evaluation of $$|\eta_{\pm}| = \frac{|A(K_L \to \pi^+\pi^-)|}{|A(K_S \to \pi^+\pi^-)|} = \sqrt{\frac{\tau_S}{\tau_L} \cdot \frac{BR(K_L \to \pi^+\pi^-)}{BR(K_S \to \pi^+\pi^-)}}$$

  which contributes in the Bell- Steinberger relation with the highest error

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

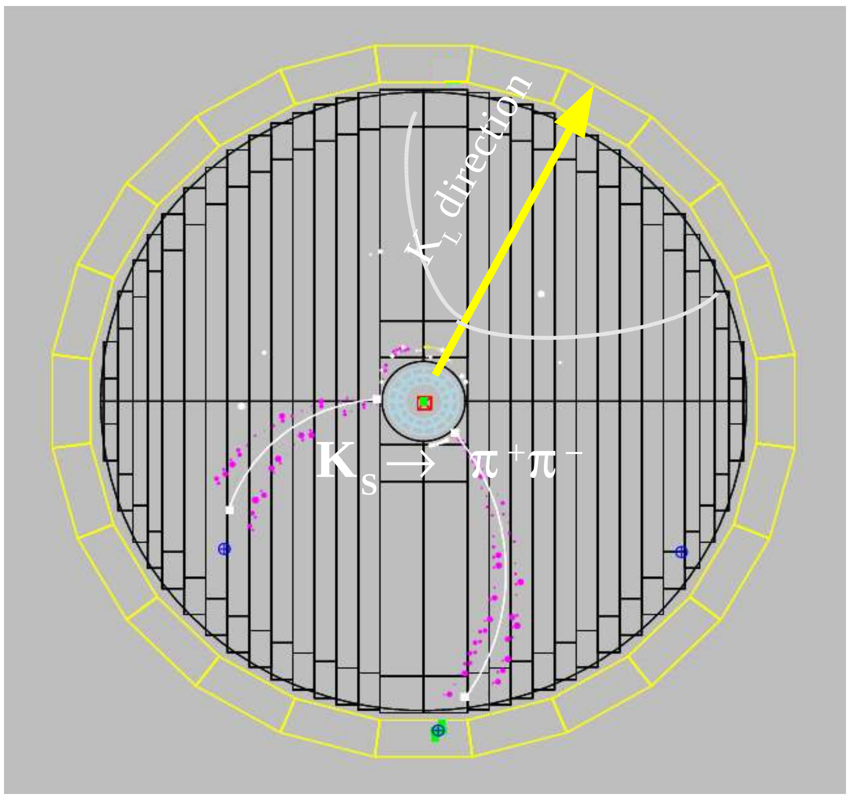
$$\alpha_{\pm} = \eta_{\pm} \cdot BR(K_S \to \pi^+\pi^-)$$

- The measurement of $$\Re\left(\frac{\epsilon'}{\epsilon}\right) = \frac{1}{6}\left(1 - \frac{|\eta_{00}|^2}{|\eta_{\pm}|^2}\right)$$

Status of BR($K_L \to \pi^+\pi^-$)

$$BR = \frac{N_{\pi^+\pi^-}}{N_{tag}} \cdot \frac{1}{\epsilon_{FV}\,\epsilon_{tag\ bias}\,\epsilon_{track}}$$

$$\epsilon_{tag\ bias} = \frac{\epsilon_{tag\ \pi\pi}}{\epsilon_{tag\ all}}$$



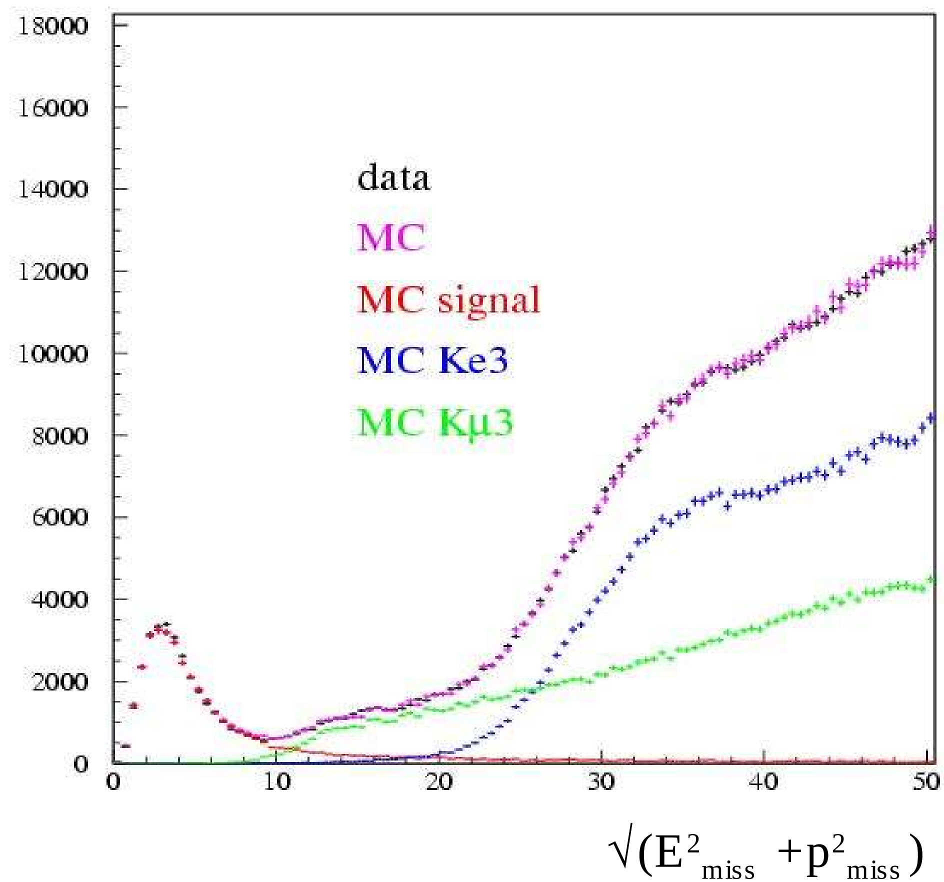
Fiducial volume

$|Z| < 140$ cm, $R_T < 160$ cm, $R > 5$ cm

to avoid regeneration these regions are excluded:

9 cm<R<12 cm, 20 cm <R_T<30 cm

Number of $K_L \to \pi^+\pi^-$ obtained through a fit of the data with a linear combination of MC signal and bkg



Efficiencies

ε_{FV}=0.3493 ± 0.0035

corrected with the preliminary Kloe

result for τ_L (51.35± 0.20) ns ($\tau_{L\,MC}$ =51.7 ns)

(correcting factor ≈1.00507)

0.8% current accuracy on τ_L → 0.6% systematic error for ε_{FV}

first type of tag: $\Delta M<5$ MeV $\Delta P<10$ MeV

$\varepsilon_{TAG\ BIAS} = 1.021970 \pm 0.000063_{stat} \pm 0.01_{syst.}$

$\varepsilon_{TRACK} = 0.6170 \pm 0.0019_{stat}$

$\varepsilon_{TAG} \sim 0.66$

second type of tag: trigger from a K_S's π reduced tag bias

$\varepsilon_{TAG\ BIAS} = 1.00118 \pm 0.00010_{stat} \pm 0.005_{syst}$

$\varepsilon_{TRACK} = 0.6147 \pm 0.0024_{stat}$

$\varepsilon_{TAG} \sim 0.41$

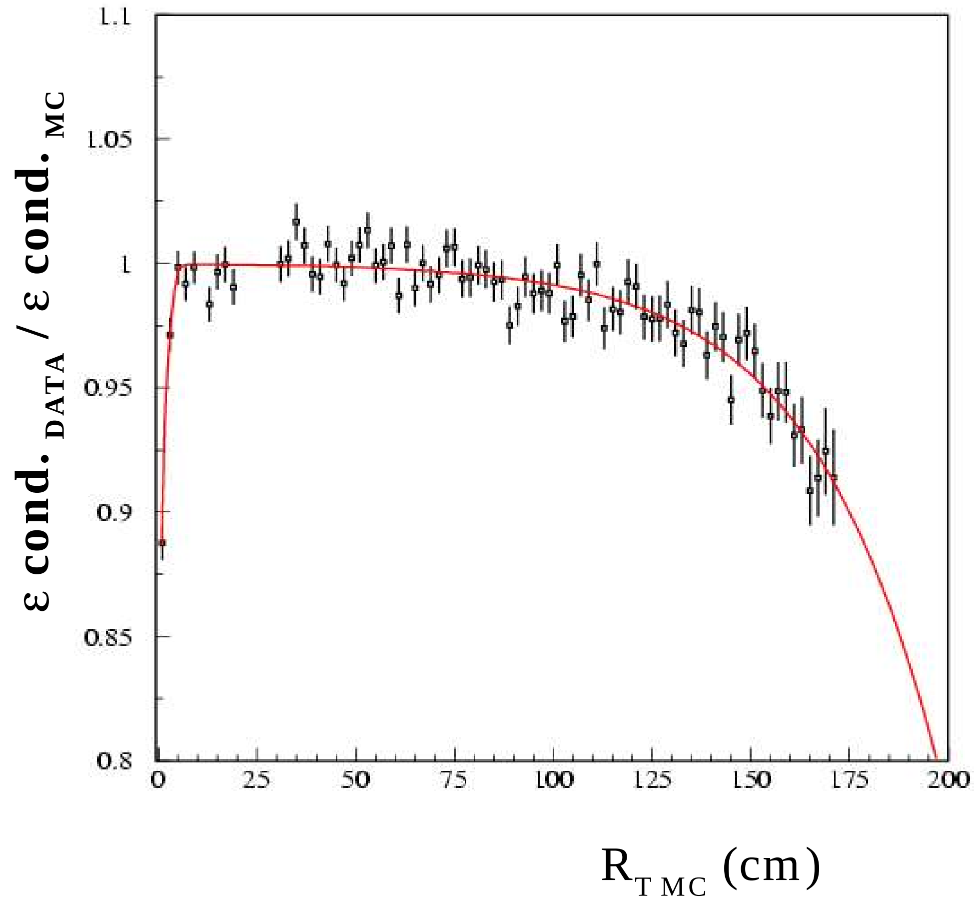
Tracking efficiency from data

The tracking efficiency has been corrected by the data using the conditioned efficiency of having one track given a first track of the opposite charge

$$\epsilon_{cond} = \frac{N_{2\ tracks}}{N_{1\ track}}$$

The correction has been fitted with a NN

systematical error due to the residuals of the correction (~ 0.3%)



Check of MC shapes

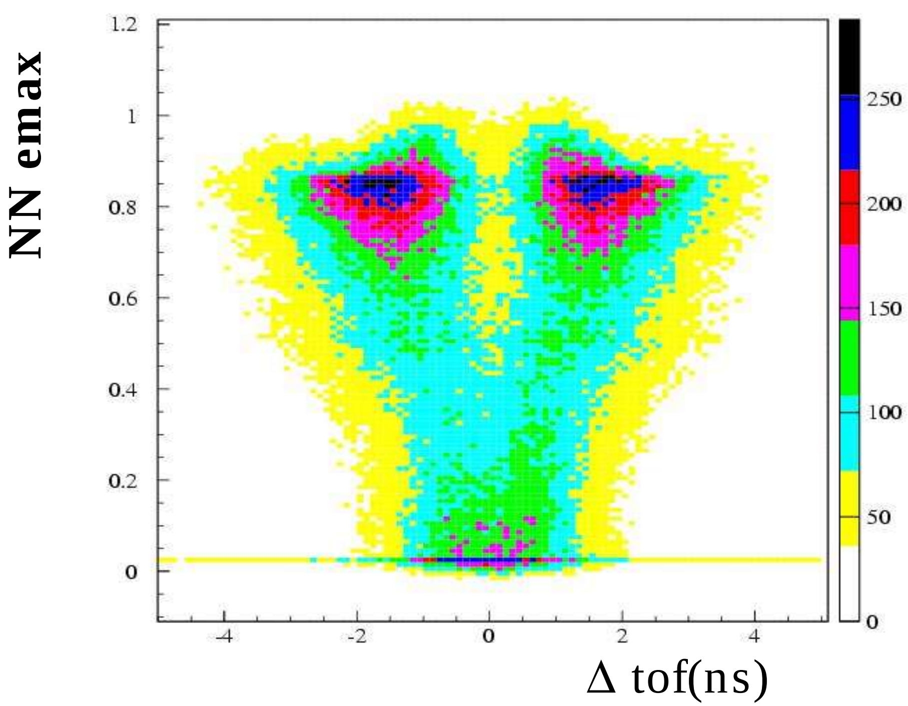
Use of EMC variables to select a pure sample of signal and background in order to check the reliability of the MC shapes: $\pi/\mu/e$ separation required

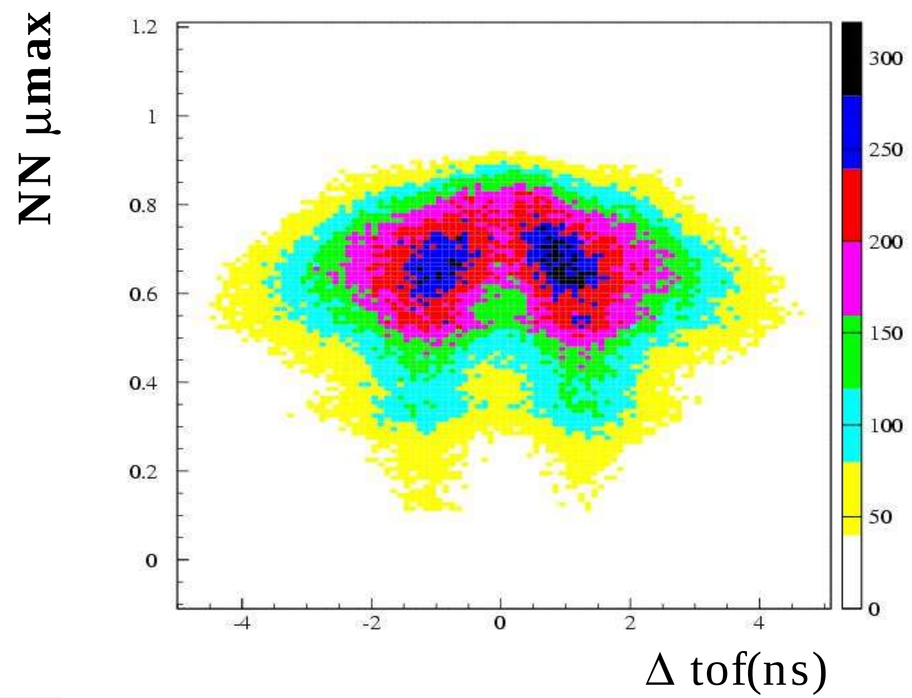
Use of :

Δ tof $(\pi,\pi)=[t_1^{CLU} - t_2^{CLU}] + [L_1/c\,\beta(\pi) - L_2/c\,\beta(\pi)]$

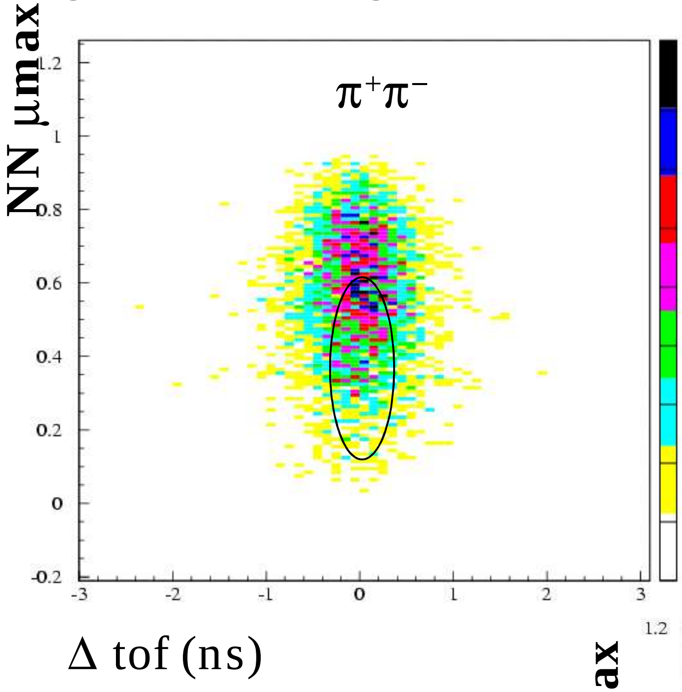
Maximum between NN output (function of position and energy of clusters) in $\mu^+\pi^-$ hypothesis and NN output in $\mu^-\pi^+$ hypothesis (NN emax)

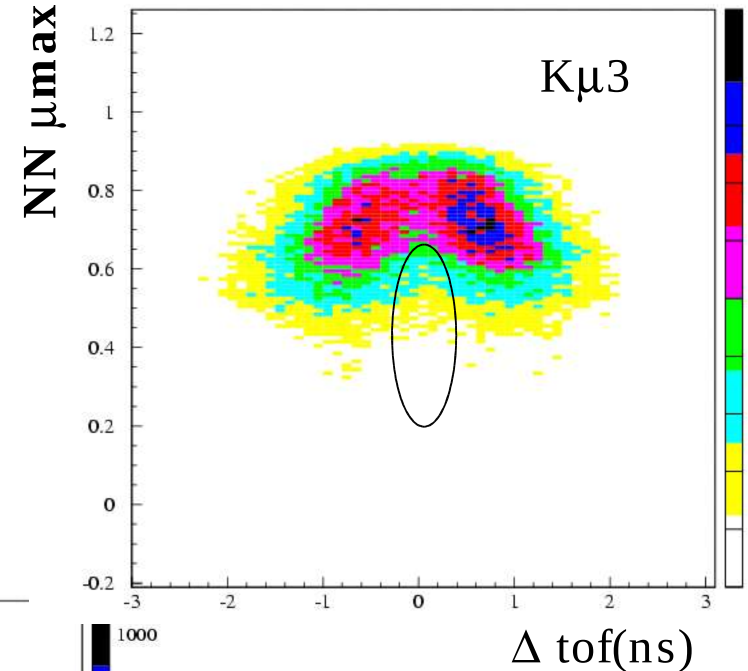
Maximum between NN output (function of position and energy of clusters) in $e^+\pi^-$ hypothesis and NN output in $e^-\pi^+$ hypothesis(NN μmax)

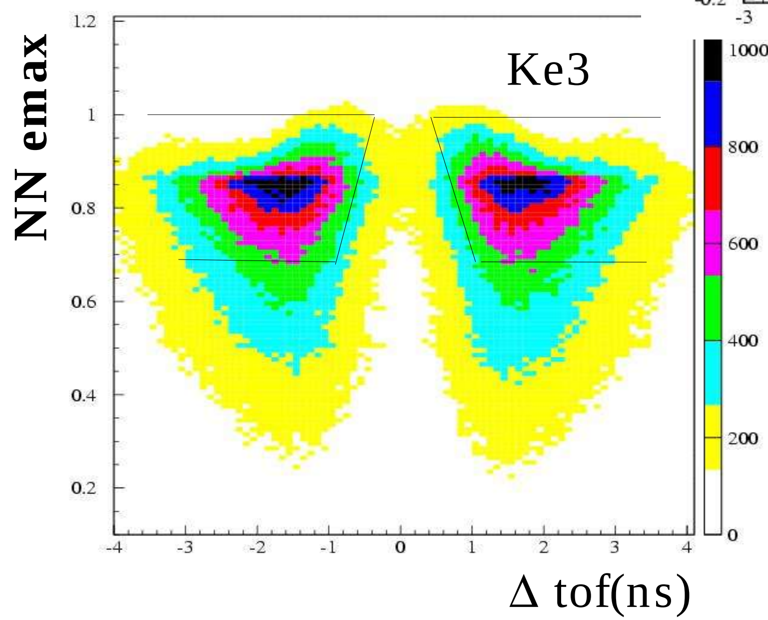




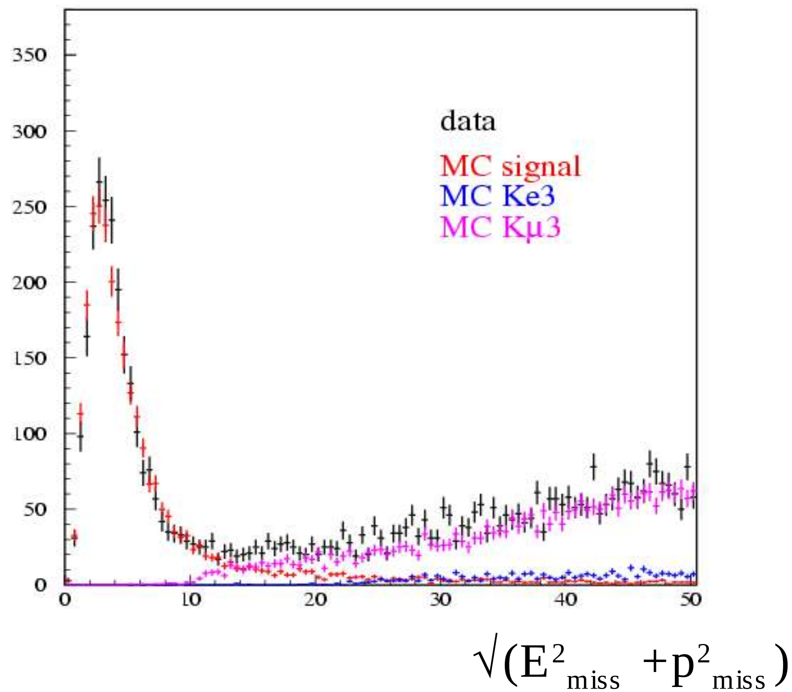
In order to choose the cuts on the distribution NN output vs Δtof, a sample of signal and background has been obtained appliyng tight cuts on DC variables





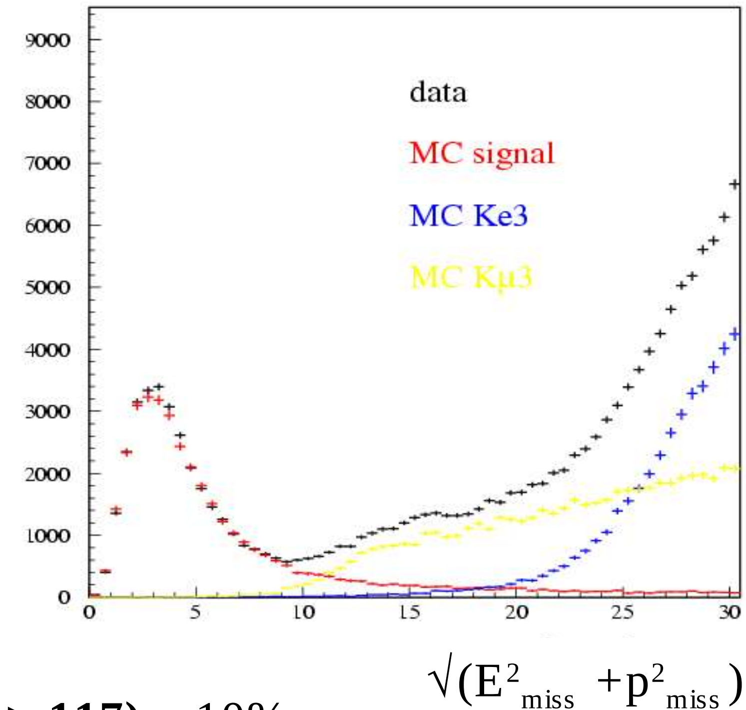


Anti- correlation for Kμ3: the capabilty of separing π/μ with NN increases with momentum, while it decreases using Δtof

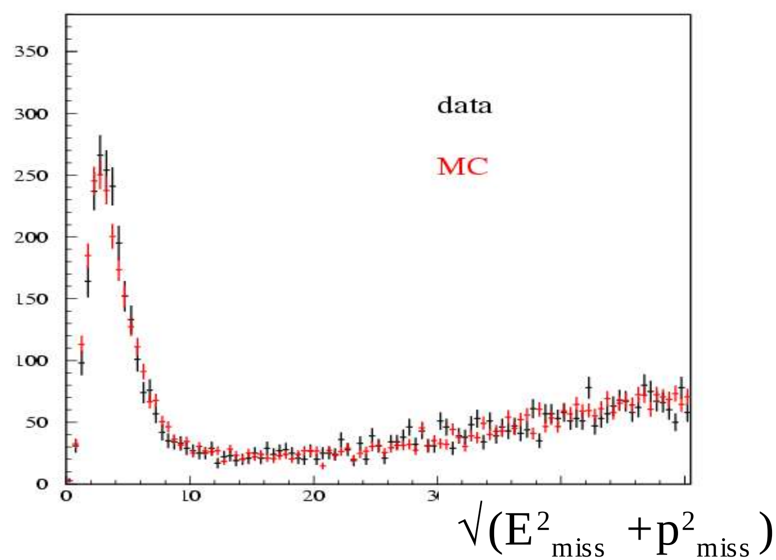


$\mathbf{Prob(\chi^2_{100} > 121)} \cong 7.2\%$

~ factor 10
increase in S/B



$\mathbf{Prob(\chi^2_{99} > 117)} \cong 10\%$



Using the cut on NN output and Δtof,
the ratio Kμ3/signal is significantly reduced

The agreement data- MC is still good,
proving that the MC shapes are reliable

$BR(K_L \rightarrow \pi^+\pi^-)$: Preliminary results

Fit up to 50 MeV, number of signal corrected for the cut efficiency
The number of 'remaining' bkg (i.e. not ke3 nor kμ3 most regeneration) has to be fixed in the fit

first type of tag

\# signal events = 71688 ± 464

$BR = (1.970 \pm 0.013_{stat} \pm 0.024_{syst}) * 10^{-3}$

second type of tag

\# signal events = 41060 ± 383

$BR = (1.970 \pm 0.018_{stat} \pm 0.017_{syst}) * 10^{-3}$

Statistical error dominated by MC statistics:
At present number of MC signal < number of data signal

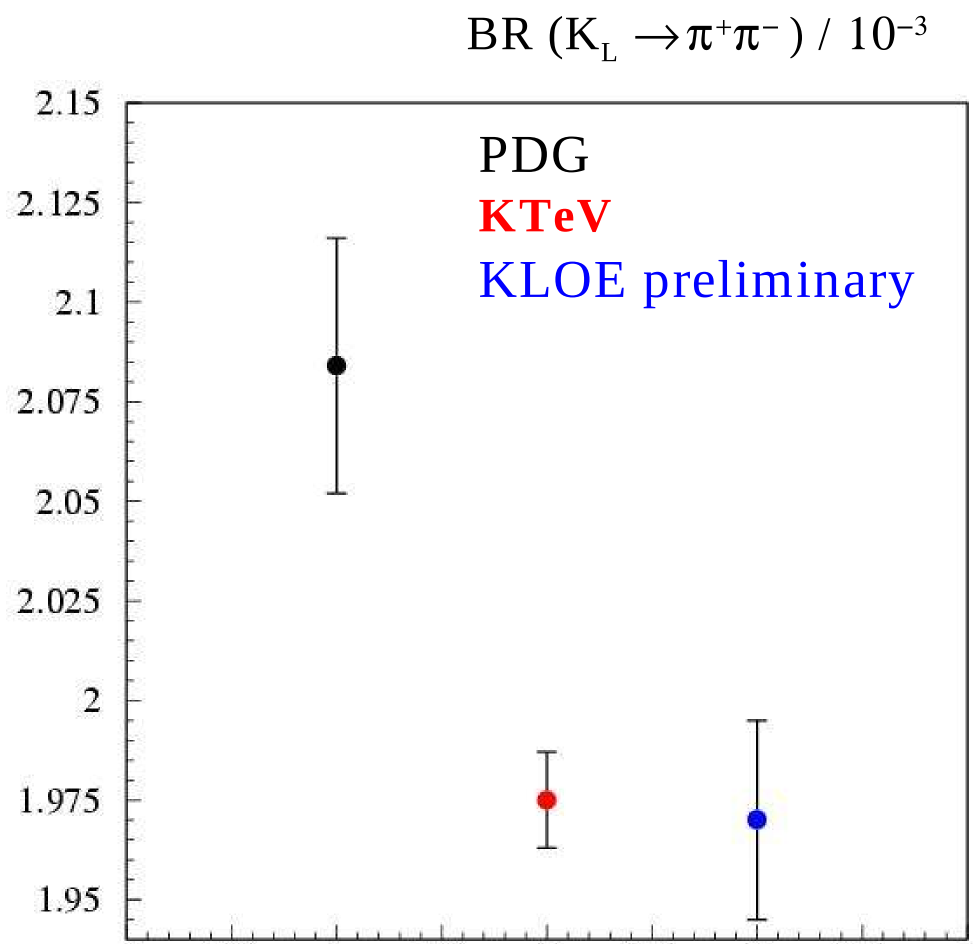
$BR(K_L \to \pi^+\pi^-)$: Preliminary results

Good agreement with recent KTeV result:

$BR_{KTeV} = (1.975 \pm 0.012) \cdot 10^{-3}$

~5% lower than the value given by PDG :

$BR = (2.084 \pm 0.032)\ 10^{-3}$



First evaluation of *Re* (ε'/ε)

$$|\eta_{\pm}|^2 = \frac{\Gamma(K_L \to \pi^+\pi^-)}{\Gamma(K_S \to \pi^+\pi^-)} = \epsilon + \epsilon'$$

$$\Re\left(\frac{\epsilon'}{\epsilon}\right) = \frac{1}{6}\left(1 - \frac{|\eta_{00}|^2}{|\eta_{\pm}|^2}\right)$$

$$|\eta_{00}|^2 = \frac{\Gamma(K_L \to \pi^0\pi^0)}{\Gamma(K_S \to \pi^0\pi^0)} = \epsilon - 2\epsilon'$$

Using the BR ($K_S \to \pi^+\pi^-$)/BR($K_S \to \pi^0\pi^0$) (R_s^{π}) measured by KLOE, the BR($K_L \to \pi^0\pi^0$) measured by KTeV and the BR($K_L \to \pi^+\pi^-$) preliminarly obtained :

Relative error of R_s^{π} = 0.0068

Relative statistical error of BR($K_L \to \pi^0\pi^0$) = 0.012

Relative statistical error of BR($K_L \to \pi^+\pi^-$) = 0.0093

$$\Re\left(\frac{\epsilon'}{\epsilon}\right) = 0.0030 \pm 0.0028$$

If also the systematic error is taken into account

$$\Re\left(\frac{\epsilon'}{\epsilon}\right) = 0.0030 \pm 0.0030$$

the systematic error can be reduced by measuring the ratio
BR($K_L \to \pi^+\pi^-$)/ BR($K_L \to \pi^0\pi^0$)
and by a new R_s measurement

Interferometry in the $\phi \to K_S K_L \to \pi^+\pi^- \pi^+\pi^-$ channel

From quantum mechanics calculations the time difference distribution for decay into final state $\pi^+\pi^-$ ($\Delta t = t_{KS} - t_{KL}$) is :

$$I\left(\pi^+\pi^-,\pi^+\pi^-;|\Delta t|\right) \propto e^{-\Gamma_L|\Delta t|} + e^{-\Gamma_S|\Delta t|} - 2e^{-(\Gamma_S+\Gamma_L)|\Delta t|/2}\cos\left(\Delta m|\Delta t|\right)$$

Interference term could be modified by the introduction of a decoherence parameter ζ:

$\zeta = 0 \quad \to$ "Orthodox" Quantum Mechanics

$\zeta = 1 \quad \to$ Furry's hypothesis (spontaneous factorization) [W.Furry, P.R.49 (1936) 393]

$$I\left(\pi^+\pi^-,\pi^+\pi^-;|\Delta t|\right) \propto e^{-\Gamma_L|\Delta t|} + e^{-\Gamma_S|\Delta t|} - 2\cdot(1-\zeta)\cdot e^{-(\Gamma_S+\Gamma_L)|\Delta t|/2}\cos\left(\Delta m|\Delta t|\right)$$

The parameter ζ depends on the basis in which the initial state is written

For a generic basis $\{K_\alpha, K_\beta\}$:

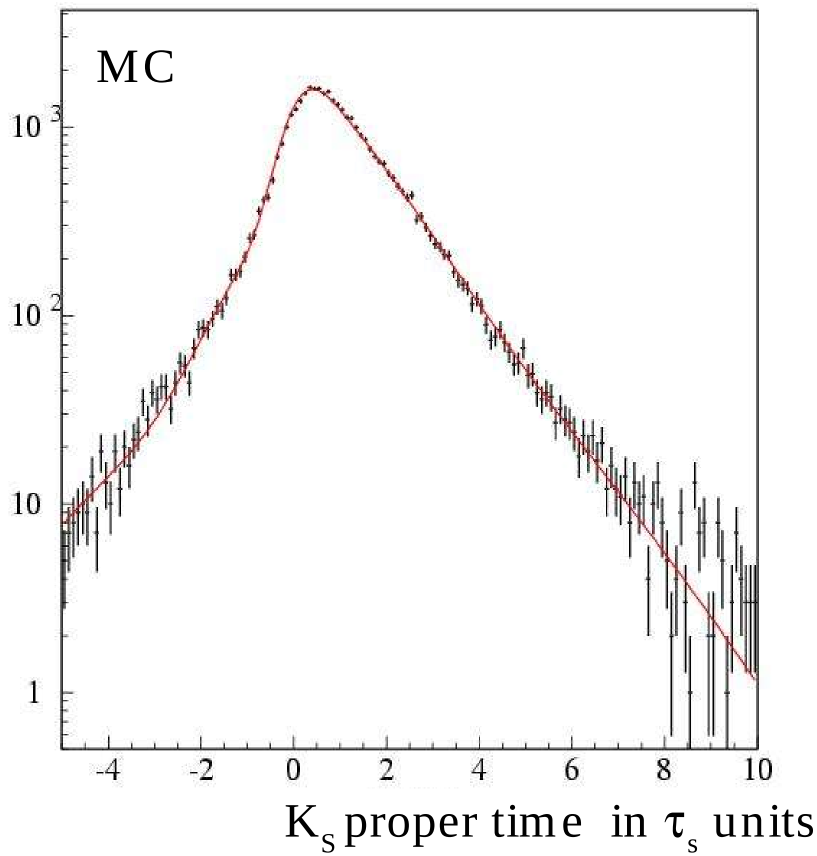
$$I(f_1,t_1;f_2,t_2) = \tfrac{1}{2}\Big[\left|\langle f_1|K_\alpha(t_1)\rangle\langle f_2|K_\beta(t_2)\rangle\right|^2 + \left|\langle f_1|K_\beta(t_1)\rangle\langle f_2|K_\alpha(t_2)\rangle\right|^2 - 2\cdot\left(1-\zeta_{K_\alpha,K_\beta}\right)\cdot\Re\left(\langle f_1|K_\beta(t_1)\rangle\langle f_2|K_\alpha(t_2)\rangle\langle f_1|K_\alpha(t_1)\rangle^*\langle f_2|K_\beta(t_2)\rangle^*\right)\Big]$$

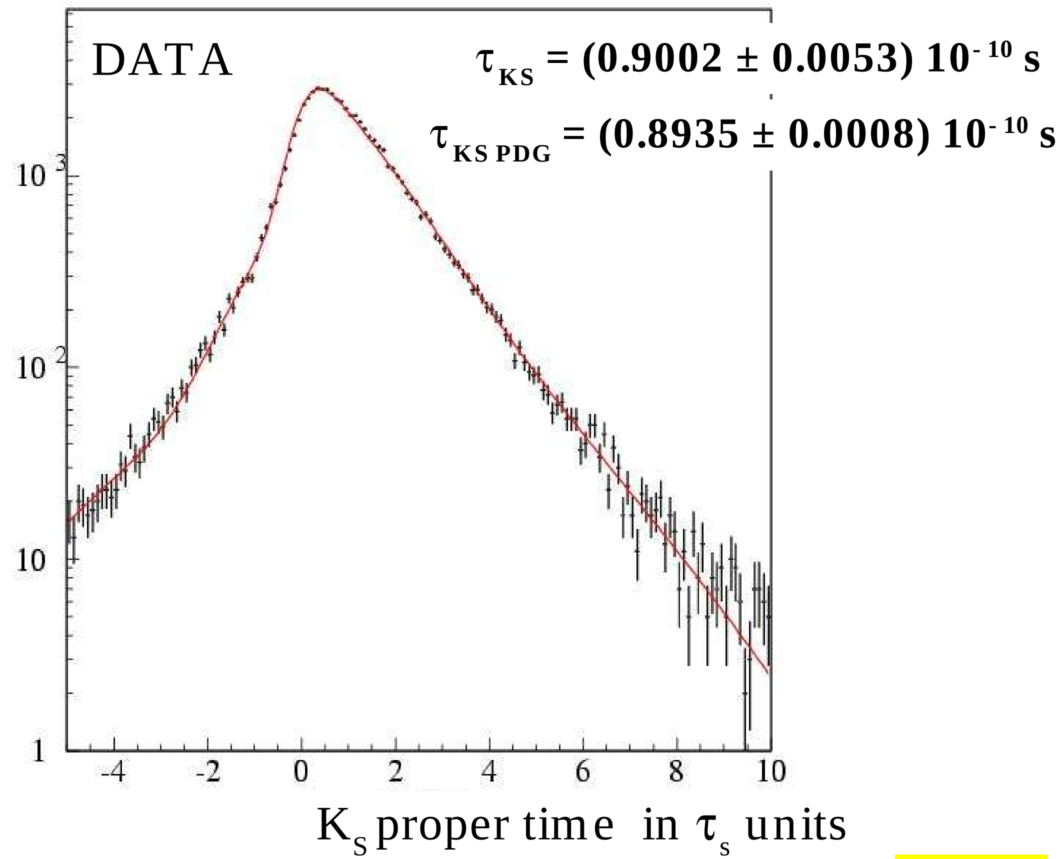
Resolution : check of negative tails

Distribution of the K_S proper time with an exponential smeared with 3 gaussians

$$f(t)=N\int e^{\frac{-t'}{\tau}}\left(\frac{a_1}{\sigma_1}\,e^{\frac{-(t'-t)^2}{2\cdot\sigma_1^2}}+\frac{a_2}{\sigma_2}\,e^{\frac{-(t'-t)^2}{2\cdot\sigma_2^2}}+\frac{a_3}{\sigma_3}\,e^{\frac{-(t'-t)^2}{2\cdot\sigma_3^2}}\right)dt'$$

The parameters of the resolutions for data and MC are in good agreement





Measure of the decoherence parameter

The fit includes reconstruction efficiency, resolution and regeneration (both coherent and incoherent) on the beam pipe

KLOE preliminary results
430 pb^{-1} (2001 + 2002 data)

- Not introducing ζ in the fit:

$$\Delta m = (5.01 \pm 0.34)\ 10^9\ \hbar s^{-1}$$

$$PDG02: (5.301 \pm 0.016)\ 10^9\ \hbar s^{-1}$$

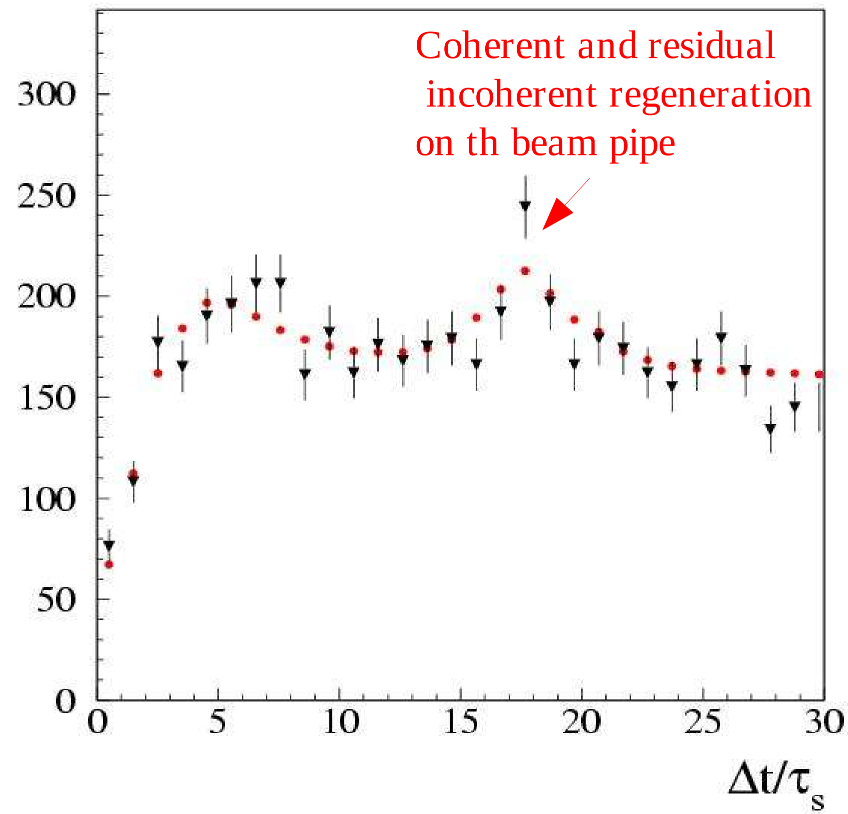
- Fixing Δm to the PDG value in the fit:

$$\zeta_{K_S,K_L} = -0.019\ {}^{+0.030_{stat}}_{-0.027_{stat}}$$

Prob(χ^2_{24}> 23) ≅ 53%

$$\zeta_{K_0,\bar{K}_0} = \left(-0.13\ {}^{+0.15_{stat}}_{-0.14_{stat}}\right) 10^{-5}$$

Prob(χ^2_{24}> 30) ≅ 21%



Using CPLEAR data R.R. Bertlmann et al., Phys. Rev. D60 (1999) 114032 measure:

$$\zeta_{K_S,K_L} = 0.13\ {}^{+0.16}_{-0.15}$$

$$\zeta_{K_0,\bar{K}_0} = 0.4 \pm 0.7$$

Conclusions

- A preliminary ~1% measurement of the BR ($K_L \to \pi^+\pi^-$)

- Tracking efficiency from data

- Independent check of MC shapes with PID

- Present statistical error dominated by MC statistics

- Interference study: measurement of the decoherence parameter ζ
  K_S- K_L basis ~10^{-2} accuracy
  K_0- $\overline{K}_0$ basis ~10^{-6} accuracy
  sizeble improvement with respect to the present measurements
  (respectively a factor ~10 and ~10^5)