KAON PHYSICS AT KLOE AND KLOE-2 PROSPECTS

C. Bloise LNF-INFN
On behalf of the KLOE-2 Collaboration

International Europhysics Conference on High Energy Physics
Grenoble, Rhône-Alpes France July 21-27 2011

European Physical Society
HEP 2011

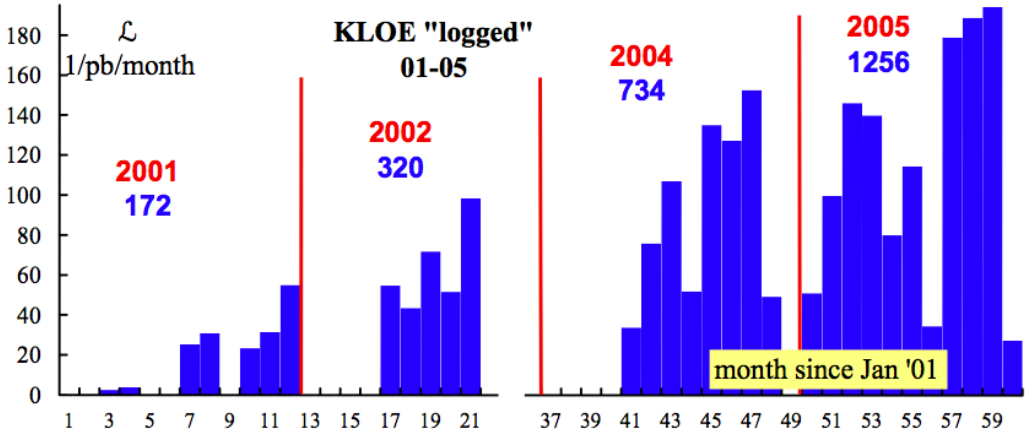
Kaon physics at KLOE

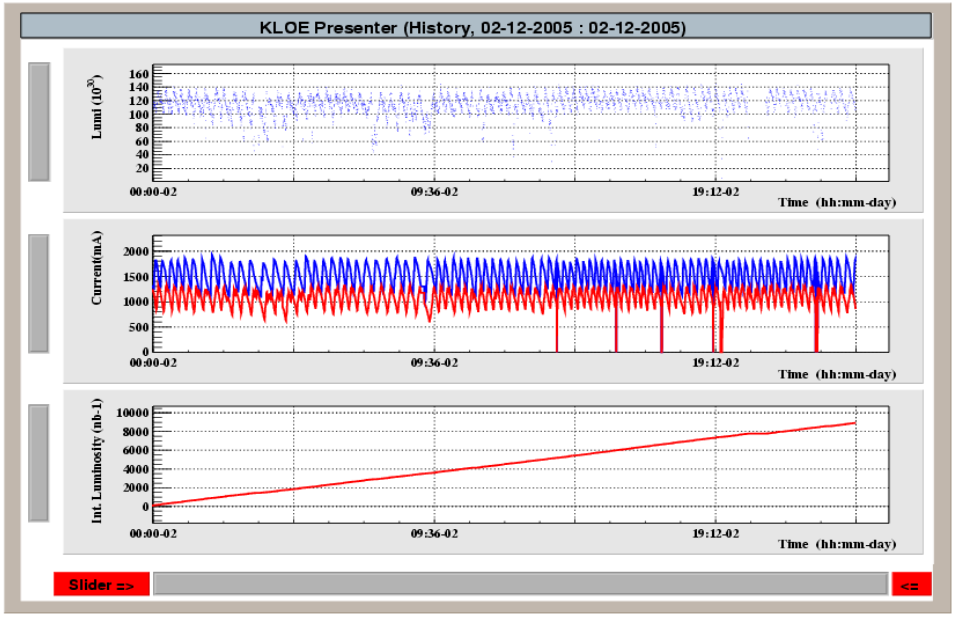
- KLOE has collected 2.5 fb^{-1} at the ϕ peak and 250 pb^{-1} at 1 GeV mostly in year 2004-2006

- Precision measurements in Kaon physics BR, lifetimes, semileptonic form factors

- Study of the QM interference with neutral Kaon pairs sensitive to effects at the Planck scale

- Measurements on pure Ks beams BR of the dominant 2π modes, $\gamma\gamma$, the UL on $3\pi^0$ channel



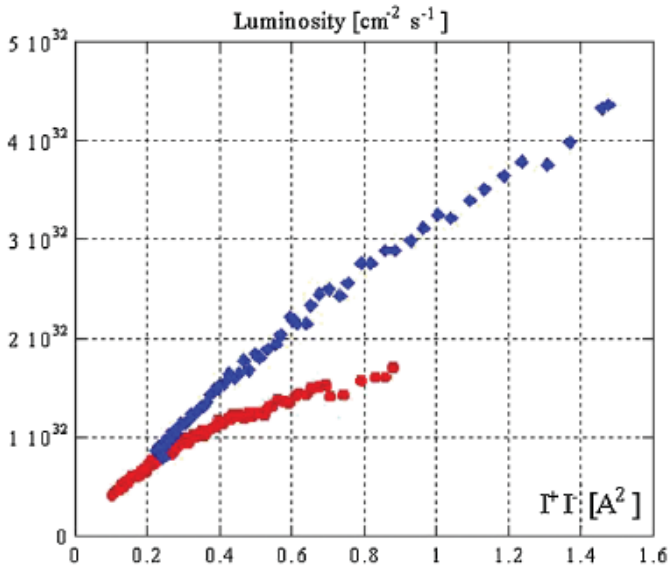


DAϕNE luminosity

DAFNE has been upgraded in luminosity in year 2008

During 2008-2009, a factor of 3 in peak luminosity and a factor of 2 in the integrated luminosity have been achieved

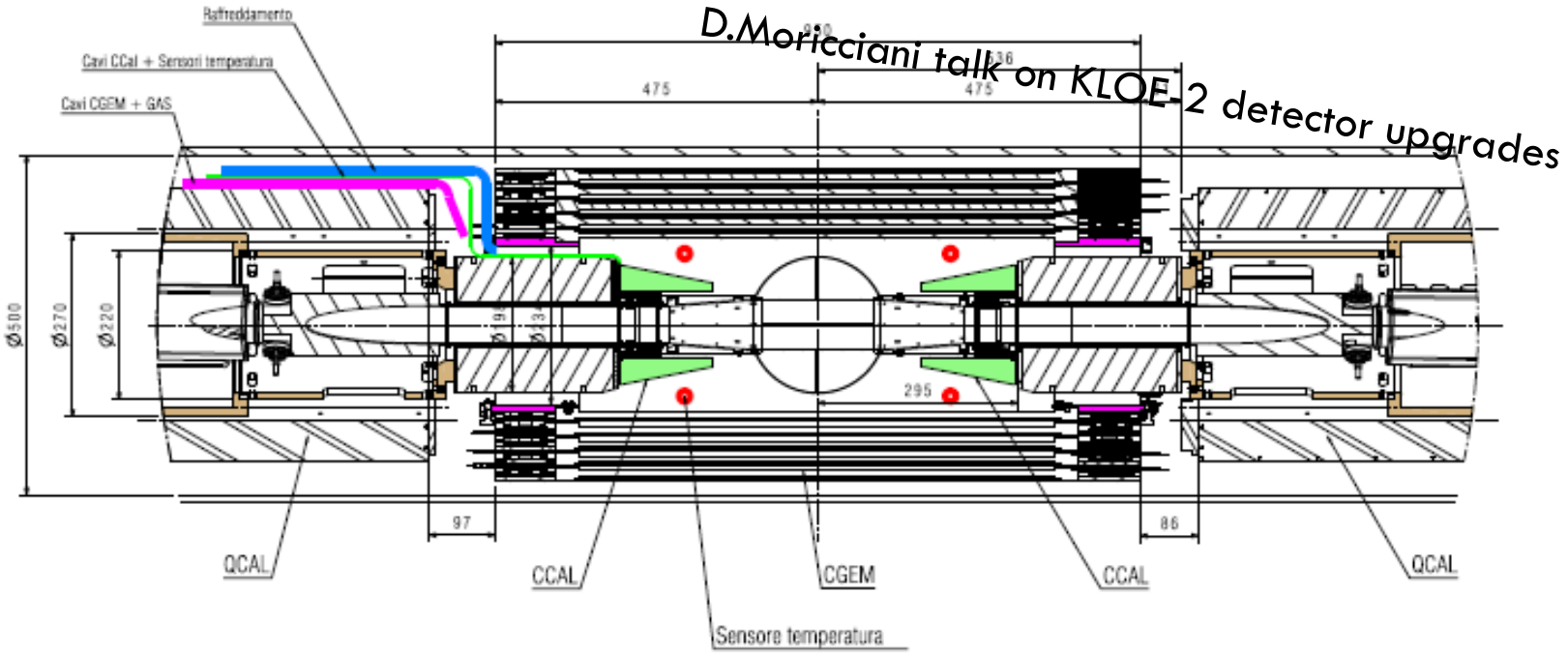
	DAΦNE upgrade SIDDHARTA	DAΦNE KLOE	DAΦNE FINUDA
L_{peak} $[cm^{-2}s^{-1}]$	$4.53 \cdot 10^{32}$	$1.5 \cdot 10^{32}$	$1.6 \cdot 10^{32}$
$L_{\int day}$ $[pb^{-1}]$	14.98	9.8	9.4
$L_{\int 1\ hour}$ $[pb^{-1}]$	1.033	0.44	0.5
I^{-}_{MAX} in collision [A]	1.52	1.4	1.5
I^{+}_{MAX} in collision [A]	1.0	1.2	1.1
$N_{bunches}$	105	111	106



DAFNE commissioning with the final focusing region in the KLOE magnetic field, has started at November 2009 going on slowly for various, uncorrelated failures in the cryogenic system, cooling system, LINAC magnets, LINAC cathode

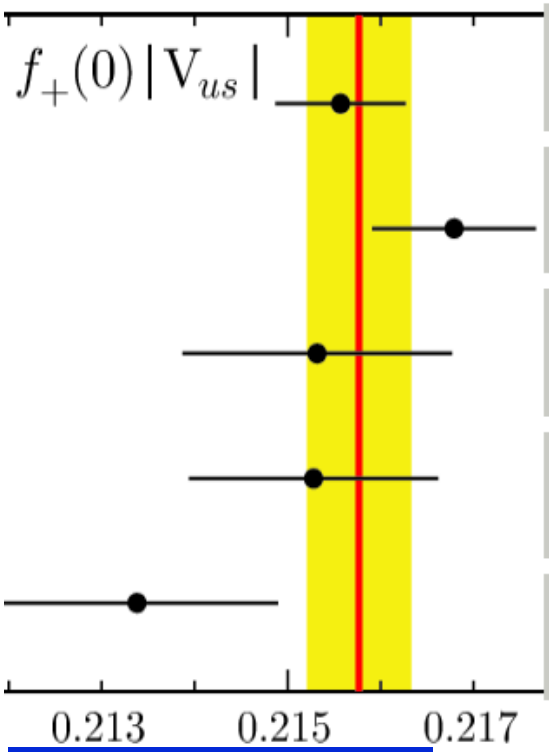
Planning

- DAFNE commissioning will be resumed in October
- The laboratory is committed to provide 4-6 months of physics run in 2012 followed by the shutdown for installing the detector upgrades and DAϕNE maintenance works
- 2013-2015: Physics run to integrate 20 fb^{-1} with the upgraded KLOE apparatus



D.Moricciani talk on KLOE-2 detector upgrades

Results on Vus



		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

JHEP04(2008)059

All KLOE exp. inputs but K_S lifetime
2010 result:
$\tau_S = 89.56(03)_{stat}\,(04)_{syst}$ ps

Lepton universality

$$r_{\mu e} \equiv \frac{|f_+(0)\,V_{us}|^2_{\mu 3,\ exp}}{|f_+(0)\,V_{us}|^2_{e3,\ exp}} = \frac{g_\mu^2}{g_e^2}$$

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

τ decays: $(r_{\mu e})_\tau = 1.0005(41)$
π decays: $(r_{\mu e})_\pi = 1.0042(33)$

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

World Average 0.2163(5)

$|V_{us}| = 0.2237(13)$
$1- |V_{ud}|^2 - |V_{us}|^2 = 9(8)\times10^{-4}$

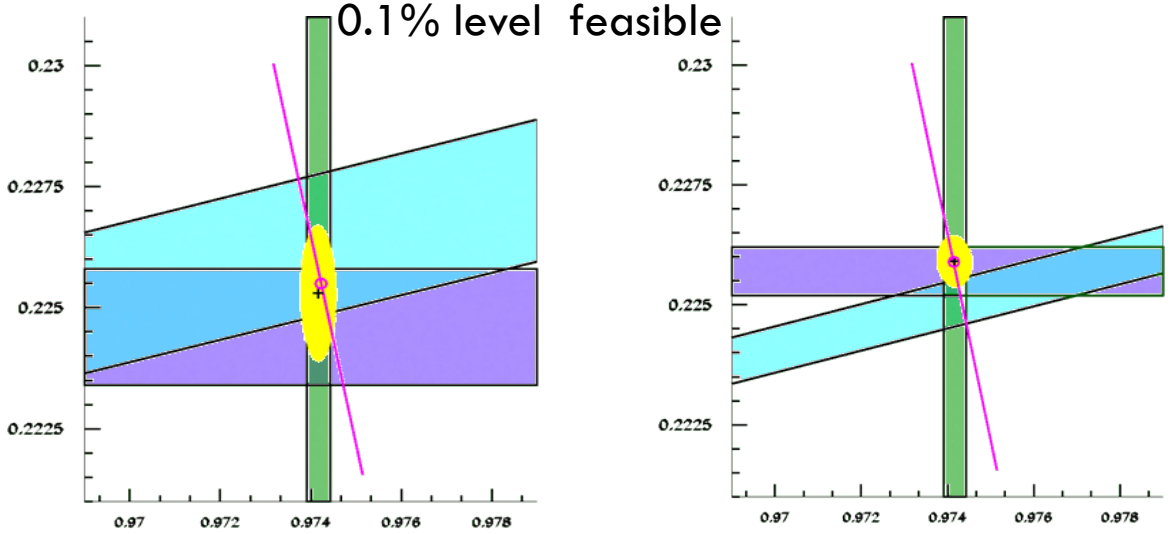
$f_+(0)=0.964(5)$ — **PRL 100 (2008)**

$|V_{ud}| = 0.97418(26)$ — **PRC 77 (2008)**

KLOE-2 prospects on Vus

	%err	BR	τ	δ	I_{Kl}	%err	BR	τ	δ	I_{Kl}
$K_L e3$ 0.2163(6)	**0.28**	0.09	0.19	0.15	0.09	**0.24**	0.09	0.13	0.15	0.09
$K_L \mu 3$ 0.2168(7)	**0.30**	0.10	0.18	0.15	0.15	**0.27**	0.10	0.13	0.15	0.15
$K_S e3$ 0.2154(13)	**0.67**	0.65	0.03	0.15	0.09	**0.35**	0.30	0.03	0.15	0.09
$K^{\pm} e3$ 0.2173(8)	**0.39**	0.26	0.09	0.26	0.09	**0.38**	0.25	0.05	0.26	0.09
$K^{\pm} \mu 3$ 0.2176(11)	**0.51**	0.40	0.09	0.26	0.15	**0.41**	0.27	0.05	0.26	0.15
Aver 0.2166(5)	**0.23**					**0.14**				

Recent big progress on LQCD calculation→
0.1% level feasible



	$f_+(0)V_{us}$
KLOE today *(World Average)*	**0.28%** (0.23%)
KLOE-2	**0.14%**

Ongoing analysis and results

- There are ongoing analysis on Kaon physics, hadron physics (presented this morning by P. Gauzzi) and on precise measurements of the hadronic cross section for the calculation of the muon magnetic moment (G. Venanzoni talk on Saturday morning)

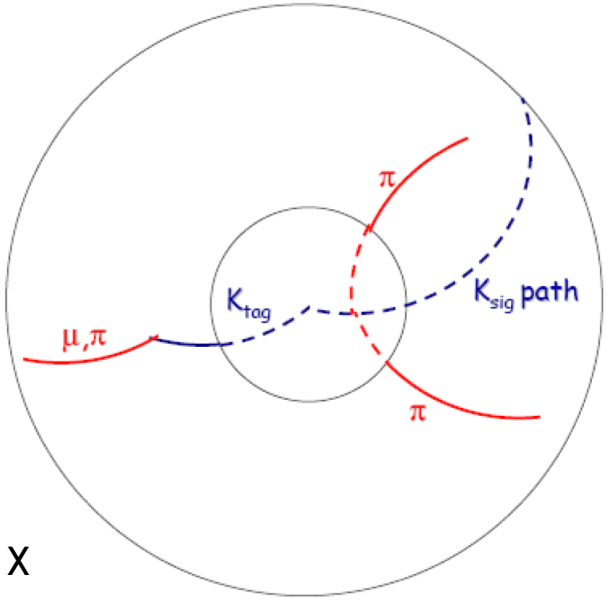
K decays	K_S lifetime	EPJC71(2011)1604
	$K^+ \to \pi^+\pi^+\pi^-$	precision: 0.6% systematics underway
	$K_S \to \pi^0\pi^0\pi^0$	upper limit updated
Interferometry	$K_SK_L \to \pi^+\pi^-\pi^+\pi^-$	QM/CPT tests updated; further studies in progress
	K_S regeneration	in progress
	$K_SK_L \to \pi^+\pi^-\pi^0\pi^0$	in progress
	$K_SK_L \to \pi^+\pi^-\pi\ell\nu$	in progress

$K^+ \rightarrow \pi^+\pi^-\pi^+$ branching fraction

- Measurement of the absolute BR, to complete the program of precise measurement of the dominant $K^{\pm}$ decay channels
- By the constrained fit of all the BRs has an impact on the semileptonic BR
- The amplitude enters the cusp analysis of $K^{\pm} \rightarrow \pi^{\pm}\pi^0\pi^0$ to extract the $\pi\pi$ phase shift
- Previous measurement :

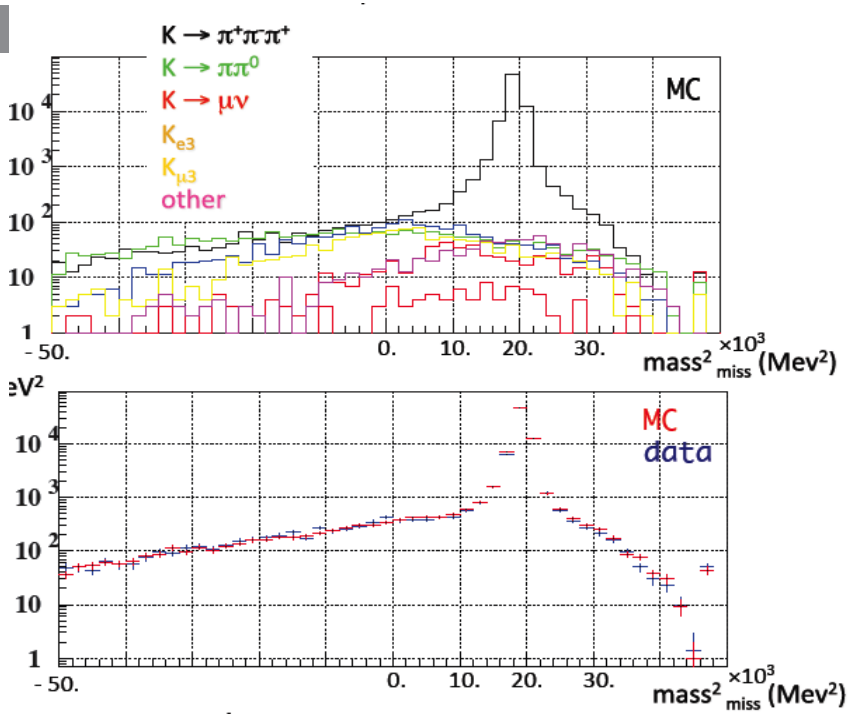
  Chiang ('72) (2330 evts) BR = (5.56 ± 0.20)%

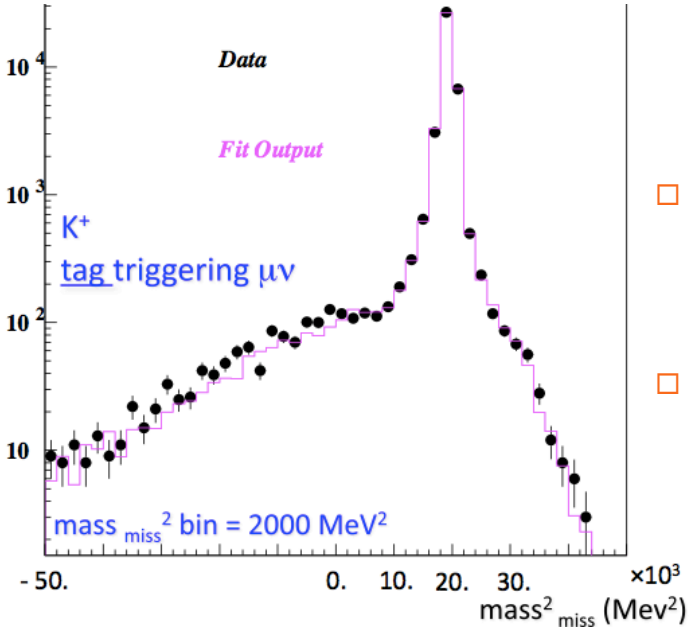
  [PDG fit : BR = (5.59 ± 0.04) %]
- Analysis strategy:
  - tag with $K \rightarrow \mu\nu$
  - tag with $K \rightarrow \pi\pi^0$: evaluation of the systematics
  - 2 tracks with vertex along the K path before the DC wall
  - K path from the extrapolation of the Ktag to I.P.
  - signal peak in the missing mass distribution (3rd pion)
  - control of the selection efficiency by reconstructing $K^+ \rightarrow \pi^-$ X



$K^+ \rightarrow \pi^+\pi^-\pi^+$ analysis

- Analyzed sample: 174 pb^{-1}
- Efficiency evaluated from MC and corrected for data-MC discrepancies measured with $K^+ \rightarrow \pi^-$ X control sample: $\varepsilon_{sel} = (6.85 \pm 0.03)\%$
- Signal obtained from a fit using MC shapes
- BR relative precision: 0.6%

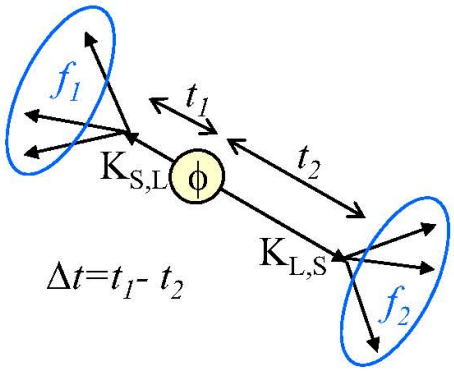


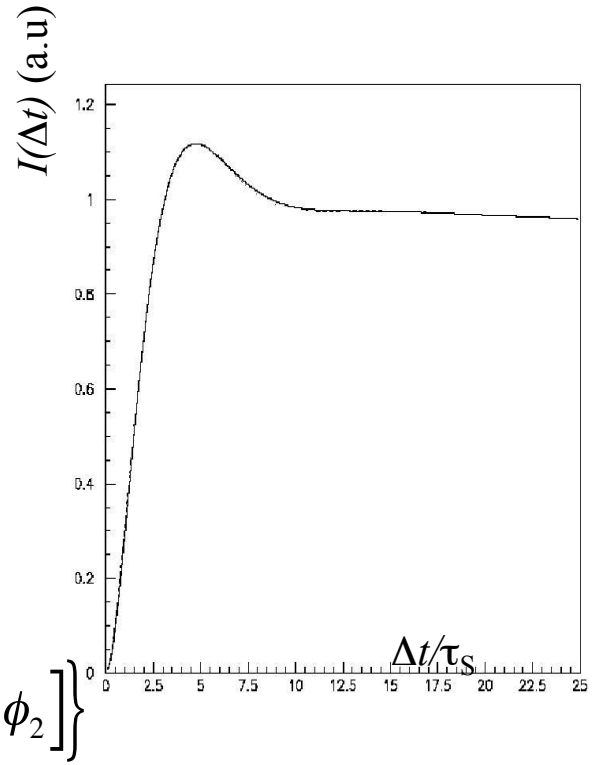


- The sample with $K^- \rightarrow \pi^- \pi^0$ tag confirms the evaluation of the tag-bias, i.e. the coefficient accounting for correlations between tagging and signal selection efficiency
- dE/dx tagging analysis to assess systematics relating with tag-bias in progress

Neutral Kaons

- The analysis of the decay distance between Kaon pairs produced at the ϕ-factory is a test of QM
- The interference pattern can be measured thanks to the fact that $\Delta M \sim \frac{1}{2}\,\Gamma_s$
- Results from the study of the $\pi^+\pi^-\pi^+\pi^-$ final state



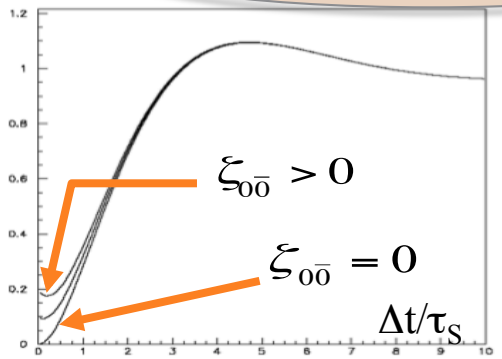


$$I(f_1,t_1;f_2,t_2) = C_{12}\left\{|\eta_1|^2 e^{-\Gamma_L t_1 - \Gamma_S t_2} + |\eta_2|^2 e^{-\Gamma_S t_1 - \Gamma_L t_2}\right.$$

$$\left. -2|\eta_1||\eta_2| e^{-(\Gamma_S+\Gamma_L)(t_1+t_2)/2} \cos\left[\Delta m(t_2 - t_1) + \phi_1 - \phi_2\right]\right\}$$

QM/CPT test with neutral Kaons

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



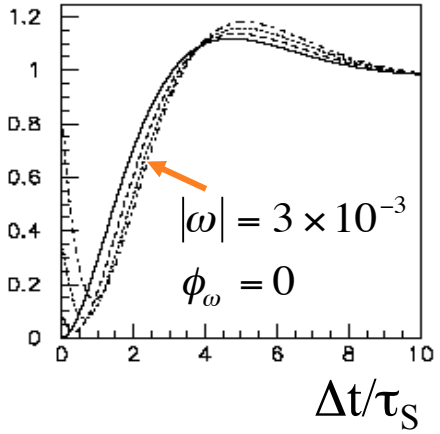
- Loss of coherence can be traced back to modifications in QM relating to CPT/Lorentz-invariance violation at the Planck scale (QG)
- $(1-\zeta_{00})$ factor introduced in the interference term
- Hawking suggested that decoherence is induced by s-t fluctuations in QG which entail CPT violation
- J.Ellis worked out a model of decoherence for neutral kaons, with 3 CPT-violating parameters, at most:

$$\alpha,\beta,\gamma = O\left(\frac{M_K^{\ 2}}{M_{PLANCK}}\right) \approx 2\times 10^{-20}\ \text{GeV}$$

- QG could also imply at Planck scale modified particle/antiparticle states such that

$$|i\rangle \propto \left(K^0\overline{K}^0 - K^0\overline{K}^0\right) + \omega\left(K^0\overline{K}^0 + K^0\overline{K}^0\right)$$
$$\propto \left(K_S K_L - K_L K_S\right) + \omega\left(K_S K_S - K_L K_L\right)$$

$$|\omega|^2 = O\left(\frac{E^2/M_{PLANCK}}{\Delta\Gamma}\right) \approx 10^{-5} \Rightarrow |\omega| \sim 10^{-3}$$



Results from interference studies

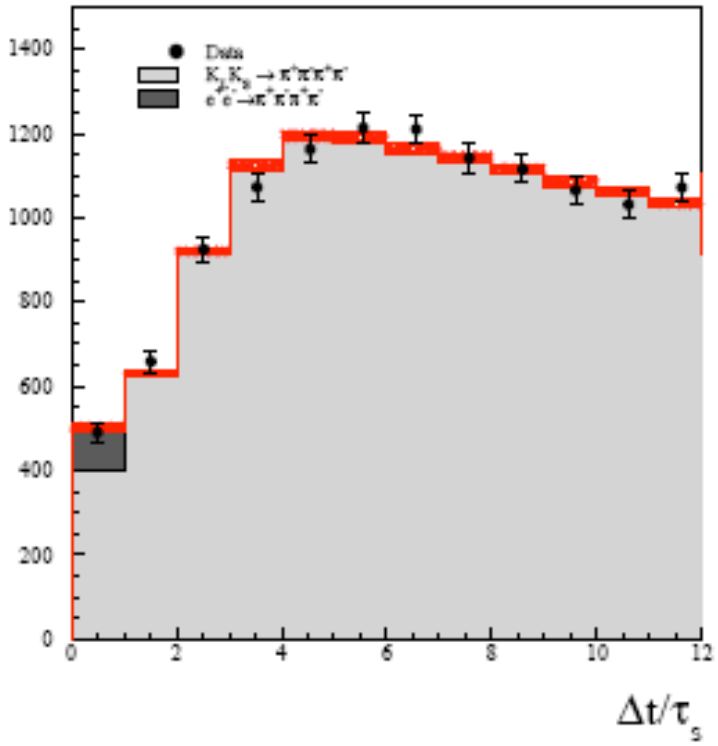
1.5 fb^{-1} analysed data sample:

Fit including time resolution and efficiency effects + regeneration

KLOE best results :

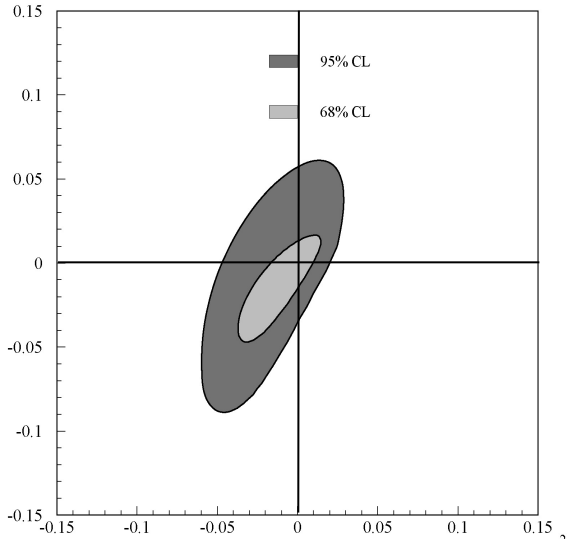
$$\zeta_{00} = \left(1.4 \pm 9.5_{\mathrm{STAT}} \pm 3.8_{\mathrm{SYST}}\right) \times 10^{-7}$$

$$\gamma = \left(0.7 \pm 1.2_{STAT} \pm 0.3_{SYST}\right) \times 10^{-21}\ \mathrm{GeV}$$



CPT invariance test

Im ω x10^{-2}



Re ω x10^{-2}

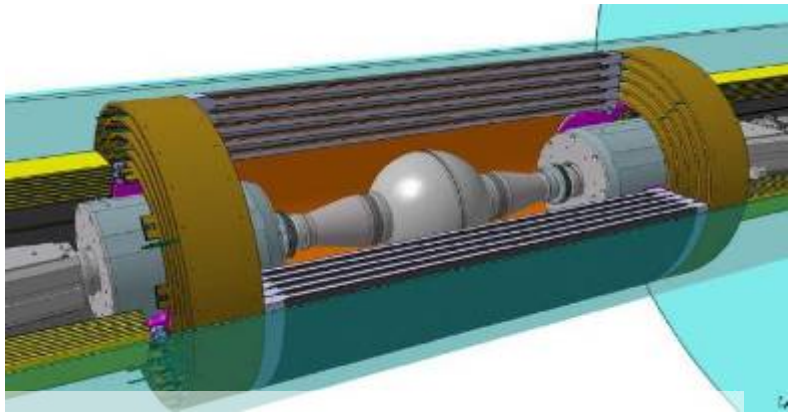
KLOE with 1.5 fb^{-1}

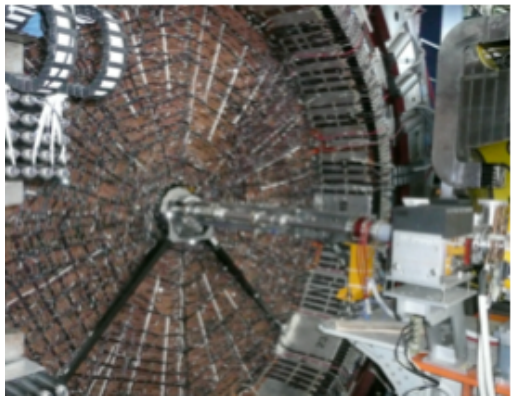
$$\Re\omega = \left(-1.6^{+3.0}_{-2.1\,STAT} \pm 0.4_{SYST}\right) \times 10^{-4}$$

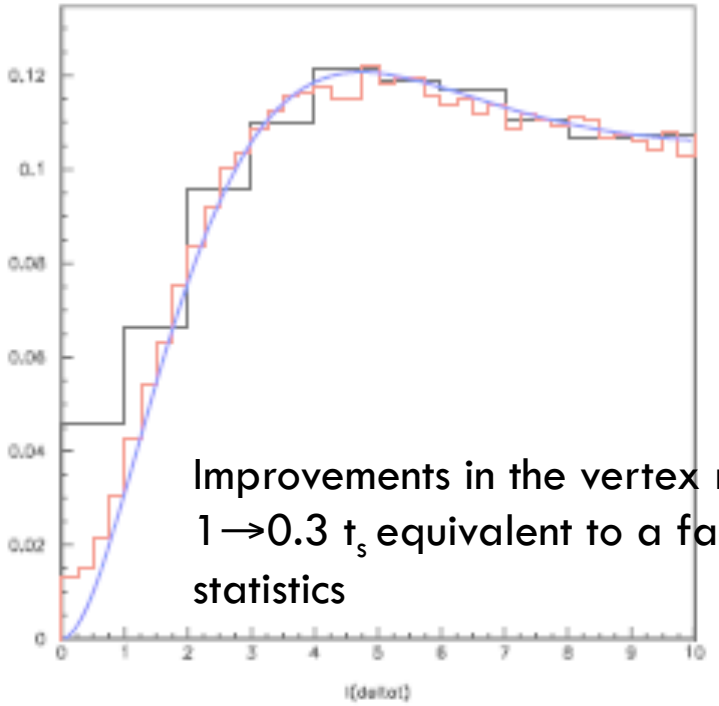
$$\Im\omega = \left(-1.7^{+3.3}_{-3.0\,STAT} \pm 1.2_{SYST}\right) \times 10^{-4}$$

$$|\omega| < 1.0 \times 10^{-3} \quad \text{at } 95\%\ \text{C.L.}$$

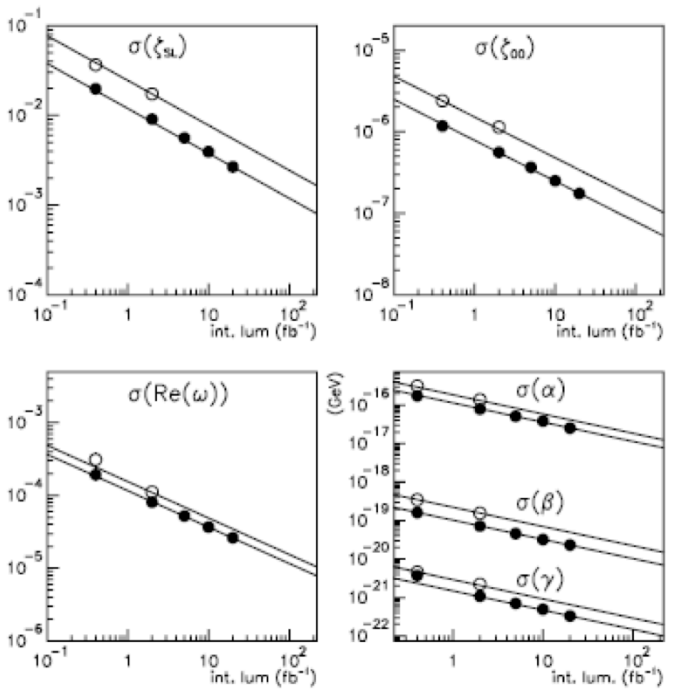
Improving on vertex resolution







Improvements in the vertex resolution from 1→0.3 t_s equivalent to a factor of 3-4 in statistics



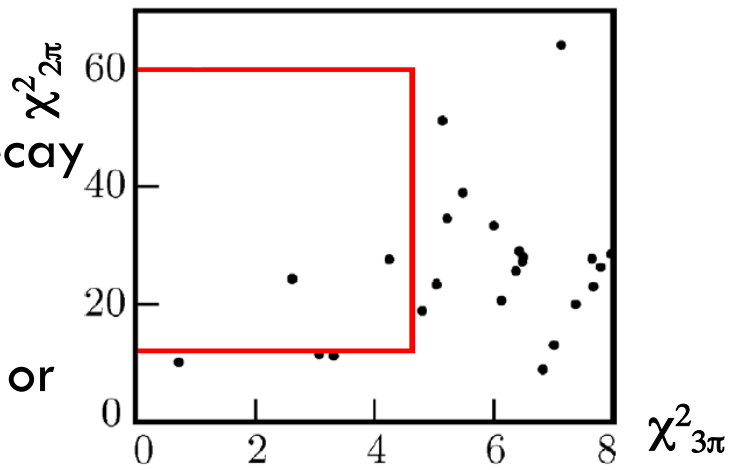
Sensitivity at KLOE-2

Mode	Test of	Param.	Present	KLOE-2
$\pi^+\pi^-$ $\pi^+\pi^-$	QM	ζ_{00}	$(0.1 \pm 1.0) \times 10^{-6}$	$\pm 0.1 \times 10^{-6}$
$\pi^+\pi^-$ $\pi^+\pi^-$	QM	ζ_{SL}	$(0.3 \pm 1.9) \times 10^{-2}$	$\pm 0.2 \times 10^{-2}$
$\pi^+\pi^-$ $\pi^+\pi^-$	CPT & QM	α	$(-0.5 \pm 2.8) \times 10^{-17}$ GeV	$\pm 2 \times 10^{-17}$ GeV
$\pi^+\pi^-$ $\pi^+\pi^-$	CPT & QM	β	$(2.5 \pm 2.3) \times 10^{-19}$ GeV	$\pm 0.2 \times 10^{-19}$ GeV
$\pi^+\pi^-$ $\pi^+\pi^-$	CPT & QM	γ	$(1.1 \pm 2.5) \times 10^{-21}$ GeV compl. pos. hyp. $(0.7 \pm 1.2) \times 10^{-21}$ GeV	$\pm 0.3 \times 10^{-21}$ GeV compl. pos. hyp. $\pm 0.2 \times 10^{-21}$ GeV
$\pi^+\pi^-$ $\pi^+\pi^-$	CPT & EPR corr.	Re(ω)	$(-1.6 \pm 2.6) \times 10^{-4}$	$\pm 3 \times 10^{-5}$
$\pi^+\pi^-$ $\pi^+\pi^-$	CPT & EPR corr.	Im(ω)	$(-1.7 \pm 3.4) \times 10^{-4}$	$\pm 4 \times 10^{-5}$
$K_{S,L} \rightarrow \pi e \nu$	CPT & Lorentz	Δa_0	$[(0.4 \pm 1.8) \times 10^{-17}$ GeV]	$\pm 2 \times 10^{-18}$ GeV
$\pi^+\pi^-$ $\pi^+\pi^-$	CPT & Lorentz	Δa_Z	$[(2.4 \pm 9.7) \times 10^{-18}$ GeV]	$\pm 1 \times 10^{-18}$ GeV
$\pi^+\pi^-$ $\pi e \nu$	CPT & Lorentz	$\Delta a_{X,Y}$	$[<10^{-21}$ GeV]	$\pm 6 \times 10^{-19}$ GeV

Search for $K_S \to \pi^0\pi^0\pi^0$

- $\Gamma(K_S \to 3\pi^0) = \Gamma(K_L \to 3\pi^0)\ |\eta_{000}|^2$
  $\Rightarrow$ BR~ 2×10^{-9}
- K_L interactions in the calorimeter to tag Ks decay
- 6 prompt γ's required
- Dominant background from $K_S \to 2\pi^0$ + 2 split or 2 accidental clusters
- Best sensitivity from KLOE [PLB619(2005)61]:
  450 pb^{-1} $\Rightarrow$ BR($K_S \to 3\pi^0$)< 1.2×10^{-7} @ 90%
- The analysis has been updated
  - improving clustering procedure to reduce split clusters
  - hardening the $\beta^*(K_L)$ cut for tagging the Ks decays
  - processing the entire data set

2005 analysis



Results on $K_S \rightarrow \pi^0\pi^0\pi^0$

E_C >129 MeV

$0.196 \leq \beta_{cr} \leq 0.25$

$\chi^2_{fit} < 35$

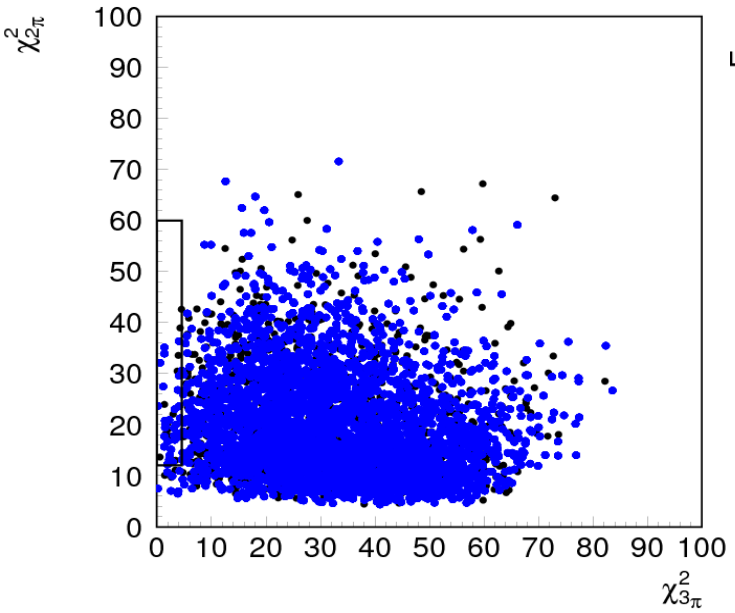
$\Delta E/\sigma_E \geq 1.7$

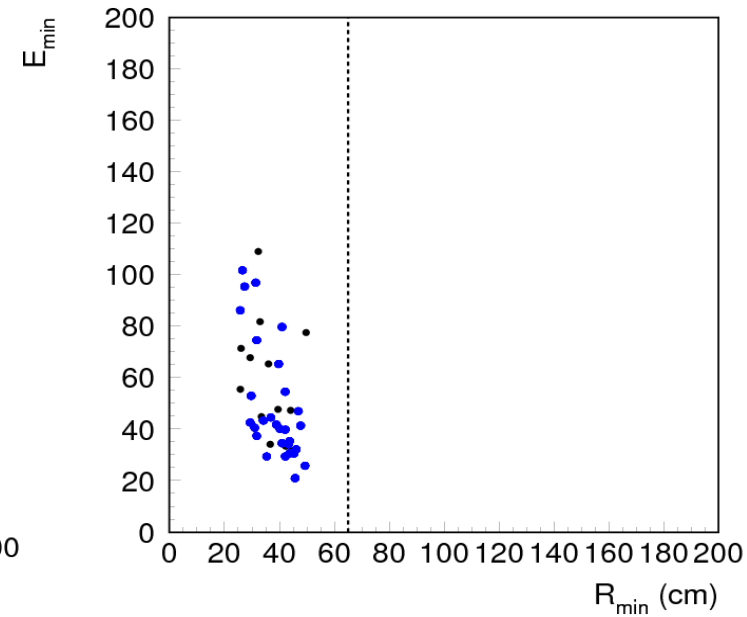
$12.1 \leq \chi^2_{2\pi} \leq 60$

$\chi^2_{3\pi} \leq 4.6$

$R_{min} > 65$ cm

$\varepsilon_{3\pi} = 0.053 \pm 0.003$





- $N_{3\pi^0} \leq 2.44/\varepsilon_{3\pi^0} = 12.84$ at 90% C.L.
- Normalized to $N_{2\pi^0} = 90062000/\varepsilon_{3\pi^0} = 136457576$
- $BR(K_S \rightarrow 3\pi^0) < 2.9\ 10^{-8}$ at 90% C.L.

Conclusions

- Precision measurements in Kaon physics

  $\rightarrow$ CKM unitarity tested at 6 10^{-4} level

- From ongoing analysis on Kaons we have obtained
  - the best upper limit on Ks$\rightarrow$ $3\pi^0$, BR()$\leq$2.9 10^{-8} , pointing to the feasibility of the first observation at KLOE-2
  - the measurement at 0.6% precision of the BR($K^+ \rightarrow \pi^+\pi^-\pi^+$)
  - from the analysis of the neutral kaon pairs, stringent constraints, at the Planck scale, on decoherence/CPT violation have been achieved
- Planning: to improve tracking and photon acceptance with the inner tracker and the calorimeters in the final focusing region, installed by the end of 2012; collect, during 2013-15, 20 fb^{-1} for the physics program [EPJ C68(2010)619]