Lepton charge asymmetry measurement for K_S with the KLOE detector

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Outline

- Charge asymmetry in neutral kaons semileptonic decays
- Neutral kaons production at DAΦNE/KLOE
- Main steps to determine the charge asymmetry for short lived kaon

Neutral kaons - short reminder

$$\begin{array}{ll} \bar{K}^0\ (s\bar{d}) & S=-1 \\ K^0\ (d\bar{s}) & S=+1 \end{array}$$

- $\bar{K}^0$ and K^0 are indistinguishable from the point of view of weak interactions ($K^0 \to \pi^+\pi^- \to \bar{K}^0$)
- observed in 1964 $\mathcal{CP}$ symmetry violation is due to mixing of K^0 and its antiparticle
- this effect can be taken into account by introducing parameters $\epsilon_{S\setminus L}$

$$|K_{S\setminus L}\rangle = \frac{1}{\sqrt{2(1+|\epsilon_{S\setminus L}|^2)}}\left((1+\epsilon_{S\setminus L})\,|K^0\rangle \pm (1-\epsilon_{S\setminus L})\,|\bar{K}^0\rangle\right)$$

$$\epsilon_{S\setminus L} = \epsilon_K \pm \delta_K$$

ϵ_K – parameter describing $\mathcal{CP}$ violation

δ_K – parameter describing $\mathcal{CPT}$ violation

Semileptonic decays of neutral kaons

$$|K_{S\backslash L}\rangle = \frac{1}{\sqrt{2(1+|\epsilon_{S\backslash L}|^2)}}\left((1+\epsilon_{S\backslash L})\,|K^0\rangle \pm (1-\epsilon_{S\backslash L})\,|\bar{K^0}\rangle\right)$$

$$\epsilon_{S\backslash L} = \epsilon_K \pm \delta_K$$

ϵ_K: parameter describing $\mathcal{CP}$ violation

δ_K: parameter describing $\mathcal{CPT}$ violation

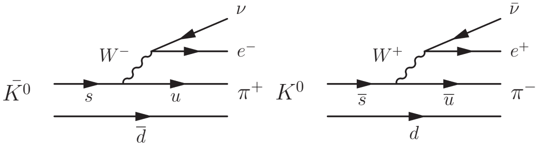
Possible semileptonic decays:

$K^0 \rightarrow \pi^- e^+ \bar{\nu}$

$\bar{K^0} \rightarrow \pi^+ e^- \nu$

$K^0 \rightarrow \pi^+ e^- \nu$

$\bar{K^0} \rightarrow \pi^- e^+ \bar{\nu}$



Two decays are allowed according to the Standard Model ($\Delta S = \Delta Q$ rule)

We can parametrize semileptonic amplitudes in the following way[1]:

$$a + b = \langle \pi^- e^+ \nu | H_{weak} | K^0 \rangle = (\text{if } \mathcal{CP}) = a^* - b^*,$$
$$a^* - b^* = \langle \pi^+ e^- \bar{\nu} | H_{weak} | \bar{K}^0 \rangle = (\text{if } \mathcal{CP}) = a + b,$$
$$c + d = \langle \pi^+ e^- \bar{\nu} | H_{weak} | K^0 \rangle = (\text{if } \mathcal{T}) = c^* - d^*,$$
$$c^* - d^* = \langle \pi^- e^+ \nu | H_{weak} | \bar{K}^0 \rangle = (\text{if } \mathcal{T}) = c + d.$$

and then we obtain following relations between symmetries and semileptonic amplitudes:

	$\mathcal{CP}$	$\mathcal{T}$	$\mathcal{CPT}$	$\Delta S = \Delta Q$
a	$Im = 0$	$Im = 0$		
b	$Re = 0$	$Im = 0$	$= 0$	
c	$Im = 0$	$Im = 0$		$= 0$
d	$Re = 0$	$Im = 0$	$= 0$	$= 0$

Variables that allows to test:

$\mathcal{CPT}$ violation:

$$y = -\frac{b}{a}$$

$\Delta S = \Delta Q$ violation while $\mathcal{CPT}$ is conserved:

$$x_+ = \frac{c^*}{a}$$

$\mathcal{CPT}$ & $\Delta S = \Delta Q$ violation:

$$x_- = -\frac{d^*}{a}$$

[1] L.Maiani, The second DAΦNE physics handbook, 1995

Charge asymmetry

$$A_{S,L} = \frac{\Gamma(K_{S,L} \to \pi^- e^+ \nu) - \Gamma(K_{S,L} \to \pi^+ e^- \bar{\nu})}{\Gamma(K_{S,L} \to \pi^- e^+ \nu) + \Gamma(K_{S,L} \to \pi^+ e^- \bar{\nu})}$$

$$= 2\left[Re\left(\epsilon_K\right) \pm Re\left(\delta_K\right) - Re\left(y\right) \pm Re\left(x_-\right)\right]$$

if $\Delta Q = \Delta S$

$$= 2\left[Re\left(\epsilon_K\right) \pm Re\left(\delta_K\right) - Re\left(y\right)\right]$$

if $\mathcal{CPT}$ and $\Delta Q = \Delta S$

$$= 2\left[Re\left(\epsilon_K\right)\right]$$

$$A_S - A_L \overset{\mathcal{CPT}}{=} 0$$

Determining the value of charge asymmetry for K_L and K_S we can test the fundamental assumptions of Standard Model

Experimental verification

- assuming CPT invariance: $A_S = A_L = 2Re(\epsilon) \approx 3 \cdot 10^{-3}$

$$A_{S/L} = \frac{\Gamma(K_{S/L} \to \pi^- e^+ \nu) - \Gamma(K_{S/L} \to \pi^+ e^- \bar{\nu})}{\Gamma(K_{S/L} \to \pi^- e^+ \nu) + \Gamma(K_{S/L} \to \pi^+ e^- \bar{\nu})}$$

$$A_L = (3.332 \pm 0.058_{stat} \pm 0.047_{syst}) \cdot 10^{-3}$$

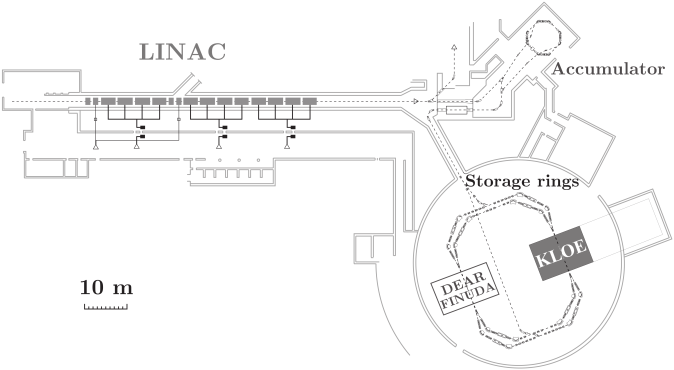
[KTeV Collaboration, Phys. Rev. Lett. 88 (2002) 181601]

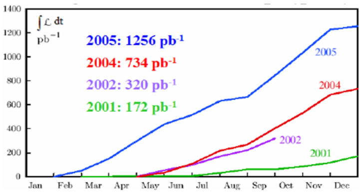
$$A_S = (1.5 \pm 9.6_{\mathrm{stat}} \pm 2.9_{\mathrm{syst}}) \cdot 10^{-3}$$

[KLOE Collaboration, Phys. Lett. B636 (2006) 173]

Sample used in current analysis is approx. 4 times larger in statistics than the one used in a previous KLOE analysis

DAΦNE (Double Annular Φ Factory for Nice Experiments)





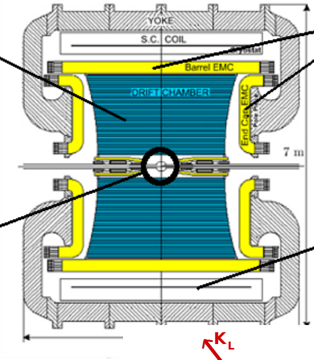
- DAΦNE e^+e^- collider located in Frascati,
- two alternate interaction regions (one for KLOE),
- $\sqrt{s} \approx m_\Phi$,
- $BR(\Phi \to K_L K_S) = 34\%$,
- KLOE has collected $\sim 2.5\text{fb}^{-1}$ of data,

KLOE

- designed to carry out a wide-ranging program in neutral and charged kaon physics, and measurement of the properties of scalar and pseudoscalar mesons

DRIFT CHAMBER

(4 m ⌀ × 3.3 m)
σ_p/p = 0.4 %
$\sigma_{x/y}$ = 150 μm
σ_z = 2 mm
σ_{vtx} = 3 mm



CALORIMETER

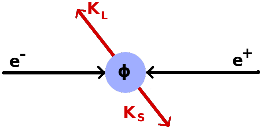
~4π solid angle coverage
barrel-endcap
$\sigma_E/E = 5.7\%/\sqrt{E(GeV)}$
$\sigma_t = 54\ ps/\sqrt{E(GeV)} \oplus 100ps$

SC MAGNET

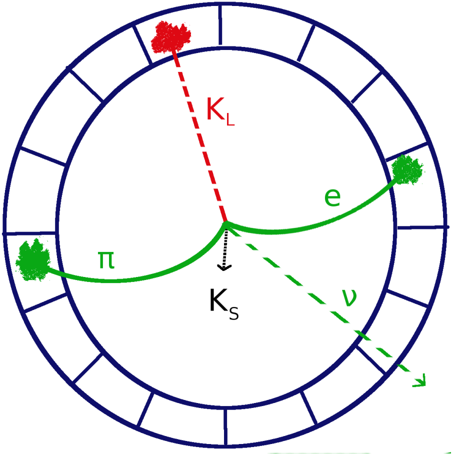
B = 0.52 T

INTERACTION POINT

berylium beam pipe
(⌀ 10 cm)



Analysis stages: $\phi \to K_L K_S \to K_L(crash)\pi e \nu$



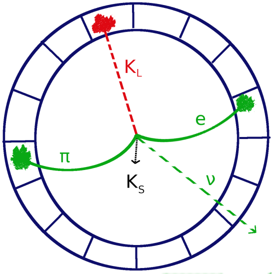
1. K_L crash selection,
   - about 60% of produced K_L mesons reach the calorimeter and deposit up to 497 MeV,
2. $K_S \to \pi e \nu$ events preselection,
   - reject two body decays.
3. Time of Flight analysis,
   - aims at particle identification,
   - improves signal over background ratio.
4. Normalization procedure.

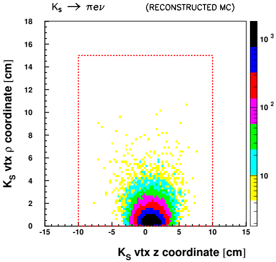
Details will be presented on further slides

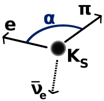
$K_S \to \pi e \nu$ events preselection

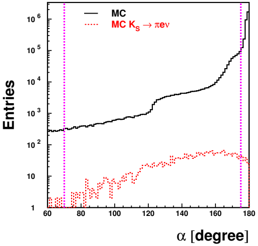
- 100% - number of events when K_L crash was identified

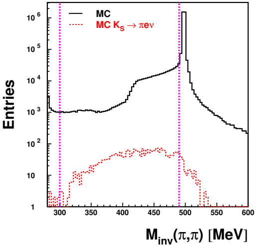
Remaining (%) signal	background
Find two tracks forming a vertex	
87	67
Cut on $\lvert z_{vtx}\rvert < 10$ cm and $\rho_{vtx} < 15$ cm	
79	56
Cut on $70^\circ < \alpha < 175^\circ$	
74	12
Cut on $300 < M_{inv} < 490$ MeV	
71	8
Successfully reconstructed tracks and assigned clusters	
36	3











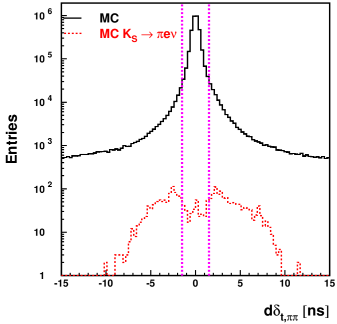
Time of Flight analysis scheme

$$\delta t(m_X) = t_{cl} - \frac{L}{c\beta(m_X)}$$

$$d\delta_{t,ab} = \delta t(m_a) - \delta t(m_b)$$

- cut on $d\delta_{t,\pi\pi}$ to reject $K_S \to \pi^+\pi^-$
- particle identification
  - electron is the first track, $|d\delta_{t,e\pi}| < 1.3 \wedge d\delta_{t,\pi e} < -3.4$
  - pion is the first track, $d\delta_{t,e\pi} > 3.4 \wedge |d\delta_{t,\pi e}| < 1.3$

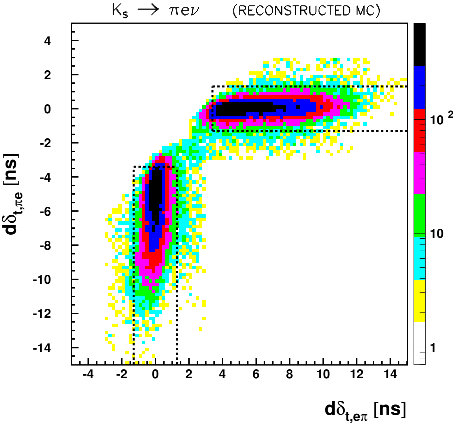
Graphical representation is presented on next slides

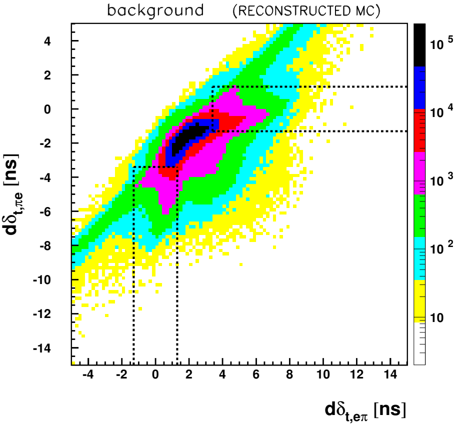


Remaining (%)	
signal	background
preselection (previous slide)	
36	3
$\lvert d\delta_{t,\pi\pi}\rvert < 1.5ns$	
33	0.7
particle identification	
30	0.2

TOF analysis - particle identification

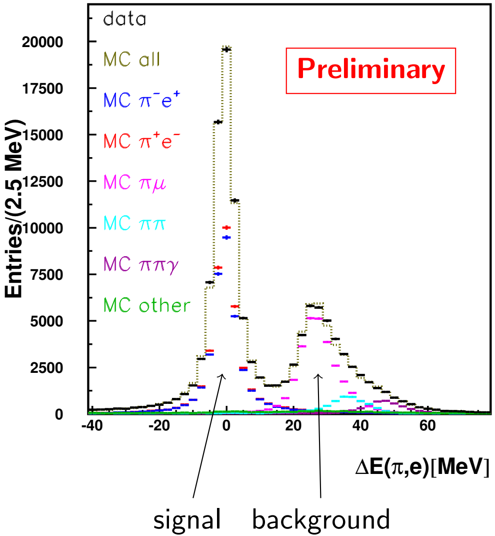
$$\delta t(m_X) = t_{cl} - \frac{L}{c\beta(m_X)} \qquad d\delta_{t,ab} = \delta t(m_a) - \delta t(m_b)$$

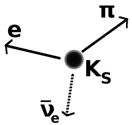




Plots made with $0.8 fb^{-1}$

Determining number of semileptonic decays





$$\Delta E(\pi, e) = E_{miss} - p_{miss}$$

- the analysis is still in progress and preliminary results will be available soon,
- further improvements of both statistical and systematical uncertainty are expected thanks to upgrade of DAΦNE and KLOE

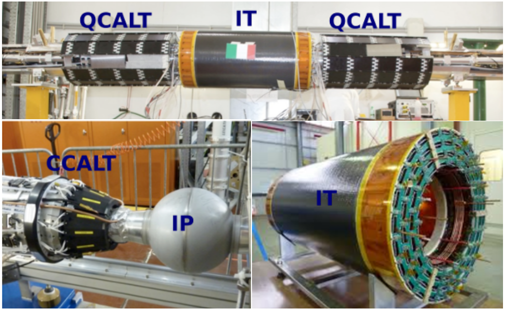
Upgrade to KLOE-2

DAΦNE upgrade in luminosity:

- reduced beam size at the crossing point,
- sextupoles pairs for crab-waist configuration of beam interaction.

Detector upgrades:

- Quadrupole Calorimeter with Tiles (NIMA 617 (2010),105),
- Crystal Calorimeter with Timing (NPB 197 (2009), 215),
- C-Gem Inner Tracker (NIMA 628 (2011),194),
- Low and High Energy Taggers (NIMA 617 (2010), 81 NIMA 617 (2010), 266).



KLOE-2 started data taking on November 2014 with the goal to collect an integrated luminosity of $\mathcal{O}(10\text{fb}^{-1})$ - extending the KLOE Physics program on discrete symmetry tests, hadron physics etc. (EPJC 68 (2010), 619)

Conclusions

- Determining the value of charge asymmetry for K_L and K_S we can test the fundamental assumptions of Standard Model.
- Value of A_S determined by KLOE Collaboration is best published result.
- Uncertainty of A_S is dominated by the statistical uncertainty which is about three times larger than the systematic contribution.
- Sample used in current analysis is approximately 4 times larger in statistics than the one used in previous analysis.
- Further improvements are expected due to upgrade of KLOE-2 detector and DAΦNE collider.

Thank you for your attention