Search for the $K_S \to 3\pi^0$ decay with the KLOE detector

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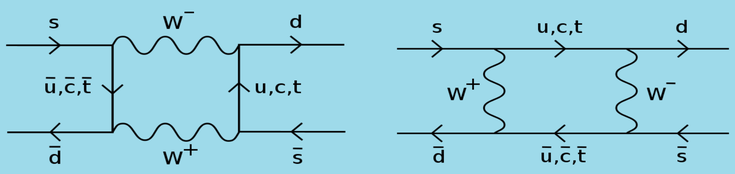
Introduction

Weak interactions do not conserve strangeness and allow for $K^0 \leftrightarrow \overline{K^0}$ oscillations



Neutral kaon in the basis of the CP operator (assuming CPT invariance):

$$|K_S> = \frac{1}{\sqrt{1+|\varepsilon|^2}}(|K_1> + \varepsilon|K_2>) \qquad (\tau = 0.9\cdot10^{-10}\,\text{s};\ c\tau = 2.68\ \text{cm})$$

$$|K_L> = \frac{1}{\sqrt{1+|\varepsilon|^2}}(|K_2> + \varepsilon|K_1>) \qquad (\tau = 5.1\cdot10^{-8}\,\text{s};\ c\tau = 15.5\ \text{m})$$

where $\mathbf{CP}|K_1> = |K_1>$ and $\mathbf{CP}|K_2> = -|K_2>$.

The $K_S \to 3\pi^0$ decay is purely CP violating:

$$\eta_{000} = \frac{A(K_S \to 3\pi^0)}{A(K_L \to 3\pi^0)} = \varepsilon + \varepsilon'_{000} = \varepsilon + i\frac{Im(A_1)}{Re(A_1)}$$

mixing — direct violation — Weak decay amplitude for K^0 into I=1 final state

Measurement of η_{000} allows us to study direct CP violation

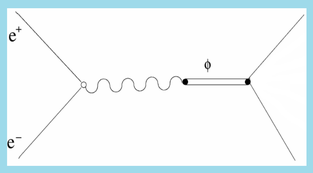
$Re(\eta_{000}) = Re(\varepsilon) = 0.001728 \pm 0.000009$

$|\eta_{000}| < 0.018 \longleftrightarrow BR(K_S \to 3\pi^0) < 1.2\cdot10^{-7}$

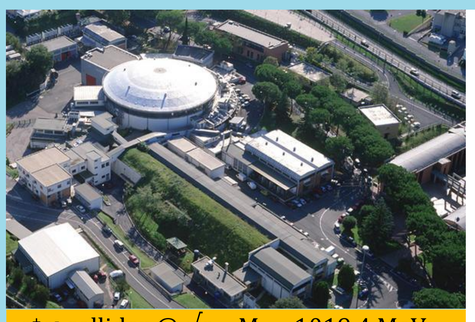
The Standard Model prediction: $BR(K_S \to 3\pi^0) = 1.9\cdot10^{-9}$

The DAΦNE Φ–factory

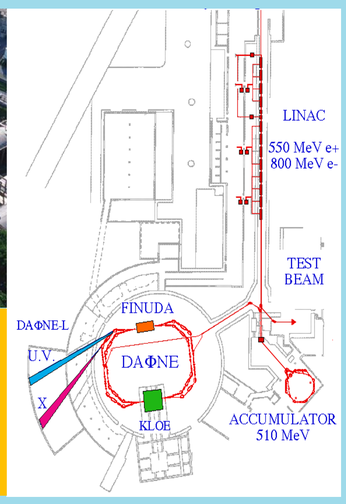
A Φ-factory offers the possibility to select pure kaon beams: neutral kaons from $\Phi \to K_S K_L$ are in fact produced in pairs and the detection of a K_S (K_L) tags the presence of a K_L (K_S), the same holds for charged kaons.



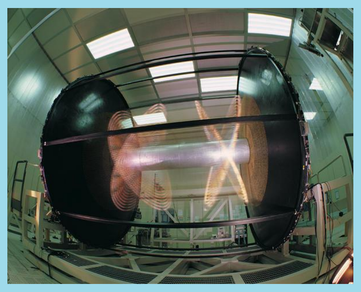
BR's for selected Φ decays	
K^+K^-	49.1%
K_SK_L	**34.1%**
$\rho\pi + \pi^+\pi^-\pi^0$	15.5%



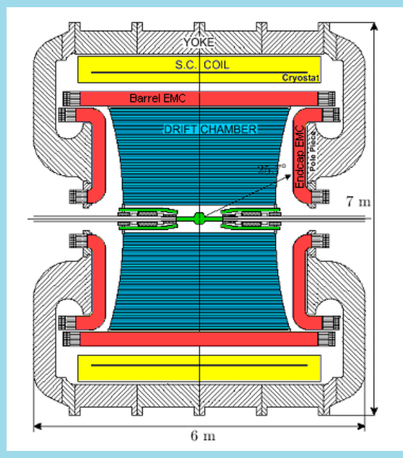
- e^+e^- collider @ $\sqrt{s} = M_\phi = 1019.4$ MeV
- $\sigma_{peak} \sim 3000$ nb
- Separate e^+e^- rings to reduce beam-beam interaction
- Beams crossing angle: 25 mrad
- Peak luminosity 1.5×10^{32} cm^{-2}s^{-1}

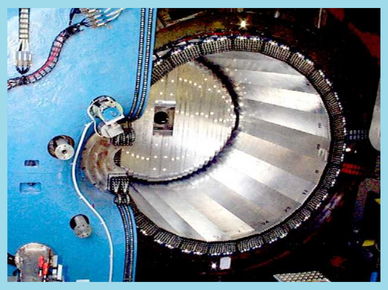


The KLOE detector



Superconducting coil: B = 0.52 T





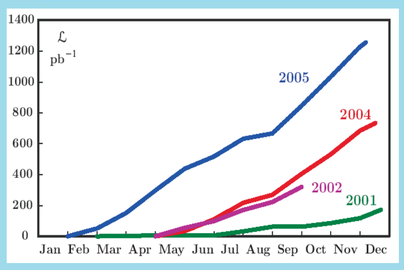
Large cylindrical drift chamber:
- Uniform tracking and vertexing in all volume
- Helium based gas mixture (90% He – 10% $IsoC_{4H10}$)
- Stereo wire structure

$\sigma_p/p = 0.4$ %
$\sigma_{xy} = 150$ mm; $\sigma_z = 2$ mm
$\sigma_{vtx} \sim 3$ mm
$\sigma(M_{\gamma\gamma}) \sim 1$ MeV

Lead/scintillating-fiber calorimeter:
- Hermetical coverage
- High efficiency for low energy photons

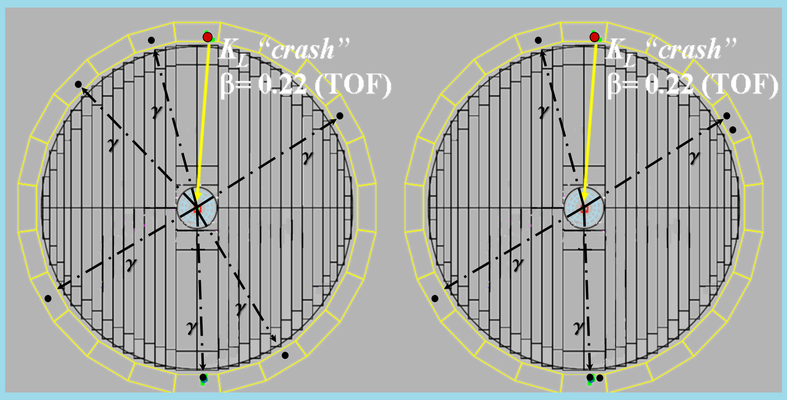
$\sigma_E/E = 5.7\% / \sqrt{E(\text{GeV})}$
$\sigma_t = 57\ \text{ps} / \sqrt{E(\text{GeV})} \oplus 140$ ps
$\sigma_{vtx}(\gamma\gamma) \sim 1.5$ cm

Integrated luminosity
~ 2.5 fb^{-1} @ φ-peak (**$2.7\cdot10^9$ K_SK_L pairs**)
~ 250 pb^{-1} @ $\sqrt{s}$ = 1000MeV (~ 10^8 η mesons)



Analysis strategy

$E_{cr} > 129$ MeV
$0.196 \le \beta_{cr} \le 0.25$
$40^0 \le \theta_{cr} \le 140^0$
} $\varepsilon_{Cr} \approx 28\%$



$K_S \to 3\pi^0 \to 6\gamma$ — $K_S \to 2\pi^0$ + accidental/splitted clusters, $K_L \to 3\pi$, $K_S \to \pi^+\pi^-$

- K_s tagging using K_L interaction in the calorimeter („ K_L-crash")
  - Angular resolution: ~ 1°
  - K_s momentum resolution: ~ 1 MeV/c
- Search for six photons coming from $3\pi^0$:
  - EMC clusters not associated to charged track
  - Consistency between time of the cluster and TOF for photon

$E_{cl} > 7$ MeV
$\cos\theta_{cl} | \le 0.915$
$|\Delta T_{cl}| \le \text{Min}(3.5\cdot\sigma_T(E_{cl}), 2\ \text{ns})$
} $\varepsilon \approx 47\%$

- Counting the number of $K_S \to 2\pi^0$ decays in the same tagged sample (normalization of the branching ratio)
- Main source of background: $K_S \to 2\pi^0$ + accidental/splitted clusters, $K_L \to 3\pi$, $K_S \to \pi^+\pi^-$ („fake K_L-crash")

Analysis chain

Track Veto → χ^2_{fit} → $\Delta E/\sigma_E$ → Sbox → R_{min} → counting

- **Track Veto**

  events with at least one track from the Interaction Point ($\rho_{PCA} < 4$ cm & $|z_{PCA}| < 10$ cm)

- **Kinematical fit**

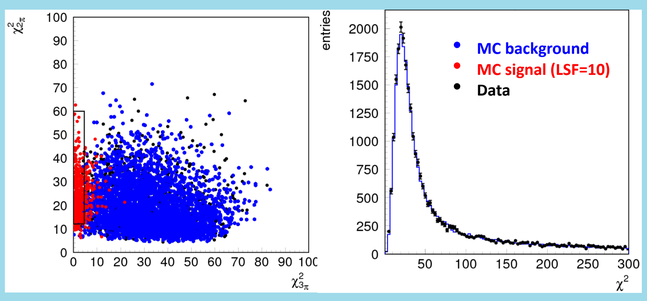
  K_S mas, total 4-momentum conservation, consistency between the measured time and position of each cluster

- **$\Delta E/\sigma_E$**

  $\Delta E = E_{Ks} - \Sigma E_\gamma$

- **Signal Box**

  $\chi^2_{2\pi}$: pairing of 4 out of 6 photons
  (π^0 masses, E_{Ks}, P_{Ks}, angle between π^0's)
  $\chi^2_{3\pi}$: pairing of 6 clusters with best π^0 mass estimates



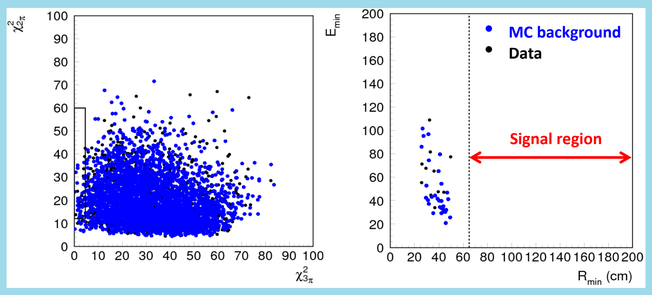
$$\chi^2_{2\pi} = \frac{(M_{\pi_1} - M_{pdg})^2}{\sigma^2_{\pi_1}} + \frac{(M_{\pi_2} - M_{pdg})^2}{\sigma^2_{\pi_2}} + \frac{(E_{K_S} - \sum E_{\gamma_i})^2}{\sigma^2_E} + \frac{(P^x_{K_S} - \sum P^x_{\gamma_i})^2}{\sigma^2_{P^x}} + \frac{(P^y_{K_S} - \sum P^y_{\gamma_i})^2}{\sigma^2_{P^y}} + \frac{(P^z_{K_S} - \sum P^z_{\gamma_i})^2}{\sigma^2_{P^z}} + \frac{(\pi - \vartheta_{\pi\pi})^2}{\sigma^2_{\vartheta_{\pi\pi}}}$$

$$\chi^2_{3\pi} = \sum_{i=1}^{3}\frac{(M_{\pi_i} - M_{pdg})^2}{\sigma^2_{\pi_i}}$$

- **R_{min}** the minimum distance between clusters

Preliminary result

$\chi^2_{fit} < 35$
$\Delta E/\sigma_E \ge 1.7$
$12.1 \le \chi^2_{2\pi} \le 60$
$\chi^2_{3\pi} \le 4.6$
$R_{min} > 65$ cm
} $\varepsilon_{3\pi} = 0.19 \pm 0.012$



We count **N_{obs} =0 event selected as a signal and N_{bck}=0 background events expected from MC**

- The upper limit on the number of expected signal events **$N_{3\pi}$: 2.44 at 90% C.L.**
- The number of tagged $K_S \to 2\pi^0$ decays: **$N_{2\pi}$ = 90062000**
- The selection efficiency for $K_S \to 2\pi^0$: **$\varepsilon_{2\pi} = 0.660 \pm 0.005$**

$$BR(K_S \to 3\pi^0) = \frac{N_{3\pi}/\varepsilon_{3\pi}}{N_{2\pi}/\varepsilon_{2\pi}} \times BR(K_S \to 2\pi^0) < 2.9\times10^{-8}\ (90\%\ C.L.)$$

Summary

- Using the whole KLOE data sample we will be able to improve by a factor of four the upper limit on the $K_S \to 3\pi^0$ branching ratio
- **Using KLOE-2 apparatus equipped with the inner tracker, new scintillation calorimeters and the γγ taggers we will have a chance to register the $K_S \to 3\pi^0$ decay for the first time in the world**

References

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