Studies of the neutral kaon regeneration with the KLOE detector

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The KLOE detector at the DAΦNE collider

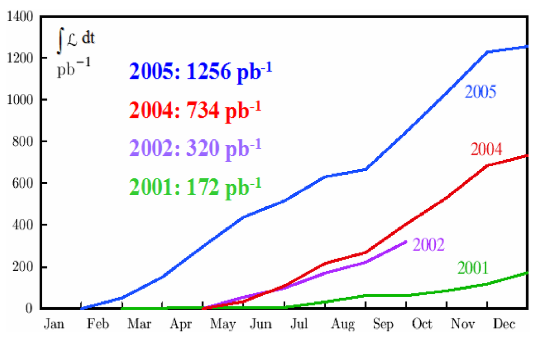


Fig. 1 KLOE integrated luminosity as a function of time

- KLOE (**K LO**ng **E**xperiment) is located at the National Institute of Nuclear Physics (INFN) in Frascati near Rome.
- It is installed at the interaction point of the electron and positron beams of the DAΦNE (**D**ouble **A**nnular **Φ**-factory for **N**ice **E**xperiments) collider.

Total KLOE $\int L\,dt \approx 2.5\ \mathrm{fb}^{-1}$

$\rightarrow$ ~2.6×10^{9} kaon pairs

- $e^{+}e^{-}$ collider
- $L \sim 1.5\cdot10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1}$
- $\sqrt{s} = m_{\phi} = 1.019$ GeV
- $\sigma(e^{+}e^{-}\rightarrow\phi) \approx 3.1$ μb
- $BR(\phi\rightarrow K^{0}\bar{K}^{0}) \approx 34\%$

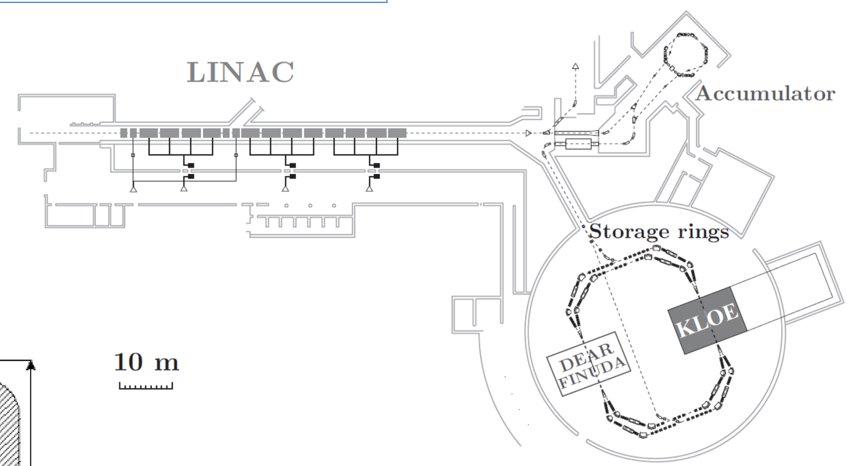


Fig. 2 The DAΦNE facility scheme.

Drift Chamber
4 m diameter × 3.3 m length
helium based gas mixture
momentum: $\frac{\sigma_p}{p} = 0.4\%$
$\sigma_x^{hit} \cong 150$ μm (xy), 2 mm (z)
vertex: $\sigma_x^{vtx} \cong 1$ mm

Interaction point (IP)
10 cm radius Be&Al sphere

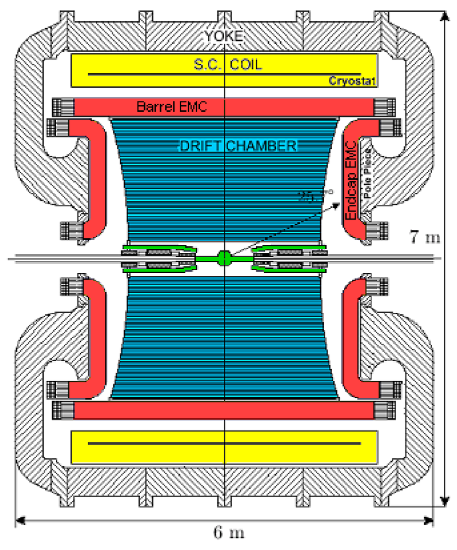


Fig. 3 Scheme of the KLOE detector.

SC Magnet
B = 0.52 T

Electromagnetic calorimeter
4π solid angle coverage
lead layers & scintillating fibers
energy: $\sigma_E \cong 5.7\%/\sqrt{E(\mathrm{GeV})}$
time: $\sigma_t \cong \frac{54\ \mathrm{ps}}{\sqrt{E(\mathrm{GeV})}} \oplus 100$ ps

Search for decoherence and CPT violation in the process $\phi\rightarrow K_S K_L \rightarrow \pi^+\pi^-\pi^+\pi^-$

- If one considers that both K_S and K_L decay into any identical final states $f_1 = f_2$, for example $K_S\rightarrow\pi^+\pi^-$ and $K_L\rightarrow\pi^+\pi^-$ which is *CP*-violating channel, one obtains that intensity of these decays reads [3]:

$$I(f_1=f_2,\Delta t)=\frac{C_{12}|\eta|^2}{\Gamma_S+\Gamma_L}[e^{-\Gamma_L|\Delta t|}+e^{-\Gamma_S|\Delta t|}-2\cdot e^{-\frac{\Gamma_S+\Gamma_L}{2}|\Delta t|}\cos(\Delta m|\Delta t|)]$$

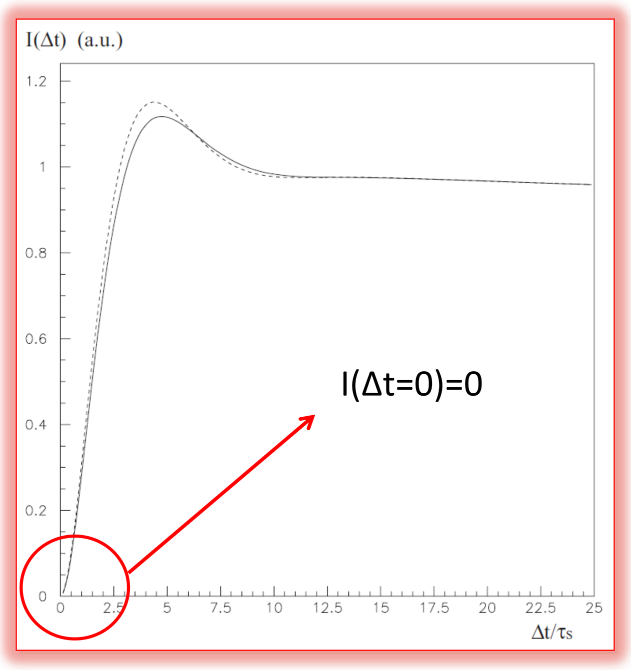
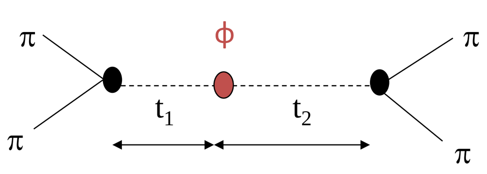


Fig. 4 Double decay rate as a function of Δt for $\zeta = 0$ (solid line) and $\zeta = 0.05$ (dashed line).

EPR correlation:

no simultaneous decays (Δt=0) in the same final state due to the destructive quantum interference

$\Delta t = |t_1 - t_2|$



- Entanglement can be lost by decoherence that denotes the transition of a pure state into an incoherent mixture of states.

$$I(f_1=f_2,\Delta t)=\frac{C_{12}|\eta|^2}{\Gamma_S+\Gamma_L}[e^{-\Gamma_L|\Delta t|}+e^{-\Gamma_S|\Delta t|}-2(1-\xi)e^{-\frac{\Gamma_S+\Gamma_L}{2}|\Delta t|}\cos(\Delta m|\Delta t|)]$$

Decoherence parameter:

$\zeta = 0 \rightarrow$ QM

$\zeta = 1 \rightarrow$ total decoherence

- In CPT violation induced by quantum gravity the definition of the particle-antiparticle states could be modified. This in turn could induce a breakdown of the *EPR* correlations to the kaon state:

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

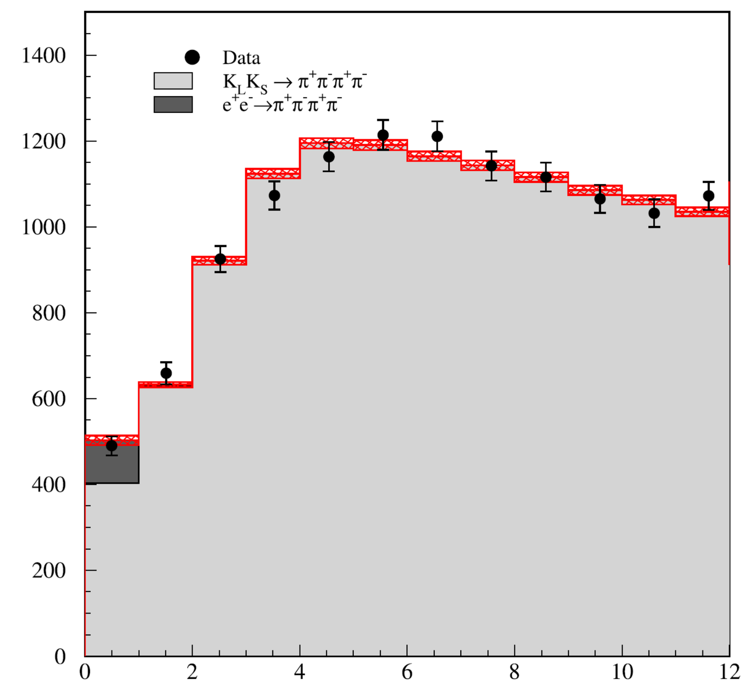


Fig. 5 Fit to Δt distributions of the events $\phi\rightarrow K_S K_L\rightarrow\pi^+\pi^-\pi^+\pi^-$. The figure is adapted from [2].

- Hawking suggested that at a microscopic level, in a quantum gravity picture, nontrivial space-time fluctuations could give rise to decoherence effects, which would necessarily entail a violation of CPT [2]. In the model of decoherence for neutral kaons one has 3 new CPTV paramameters α,β,γ:

$$\dot{\rho}(t) = -iH\rho + i\rho H^{+} + L(\rho)$$

$$L(\rho) = L(\rho;\alpha,\beta,\gamma)$$

- Current KLOE measurements in $\phi\rightarrow K_S K_L\rightarrow\pi^+\pi^-\pi^+\pi^-$ reaction chain show that there are no deviations from quantum mechanics [1, 2]:

$$\varsigma_{SL} = 0.018 \pm 0.040_{stat} \pm 0.007_{syst}$$
$$\varsigma_{0\bar{0}} = \left(1.0 \pm 2.1_{stat} \pm 0.4_{syst}\right)\cdot 10^{-6}$$

$$\alpha = \gamma, \quad \beta = 0$$
$$\gamma = \left(0.7 \pm 1.2_{stat} \pm 0.3_{syst}\right)\cdot 10^{-21}\ GeV$$

$$\mathrm{Re}(\omega) = \left(-1.6^{+3.0}_{-2.1\,stat} \pm 0.4_{syst}\right)\cdot 10^{-4}$$
$$\mathrm{Im}(\omega) = \left(-1.7^{+3.3}_{-3.0\,stat} \pm 1.2_{syst}\right)\cdot 10^{-4}$$
$$|\omega| < 1.0\cdot10^{-3}\ at\ 95\%\ C.L.$$

$K_L \rightarrow K_S \rightarrow \pi^+\pi^-$ regeneration

Regeneration is the main source of systematic errors in measurement of decoherence and *CPT*-violation parameters at KLOE.

- Final state after scattering on nuclei reads [4]: $|f\rangle = \frac{1}{2}[f(\theta)+\bar{f}(\theta)]|K_L\rangle + \frac{1}{2}[f(\theta)-\bar{f}(\theta)]|K_S\rangle$, where θ denotes the scattering angle and $f(\theta)$ the scattering amplitude for K^0 and $\bar{f}(\theta)$ for $\bar{K}^0$.

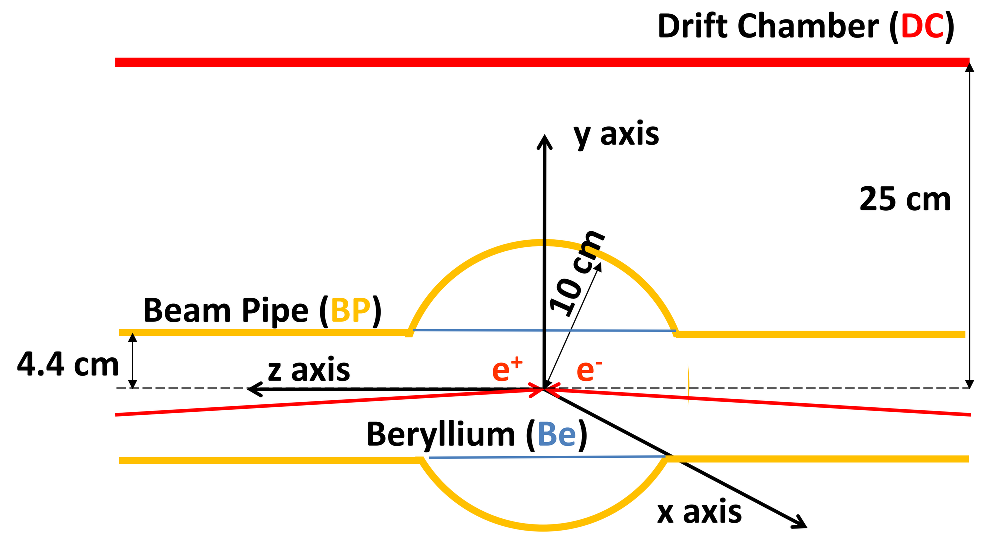


Fig. 6 Scheme of the regenerators' location at KLOE.

- **DC cylinder**-shape, 25 cm radius
  - 675 μm of C
  - 200 μm of Al
- **BP sphere**-shape, 10 cm radius
  - 62% Be
  - 38% Al

  thickness: 500 μm
- **Be cylinder**-shape

	OLD	NEW
thickness:	60 μm	30 μm
radius:	4.4 cm	3.7 cm

- The data sample comprising of $\sim 7\cdot10^{8}$ reconstructed neutral kaon pairs was used.
- The K_L mesons were identified based on primary identification of the K_S meson decays into $\pi^+\pi^-$ close to the interaction point and φ momentum:

$$\vec{p}_{K_L^{tag}} = \vec{p}_{\phi} - \vec{p}_{K_S}$$

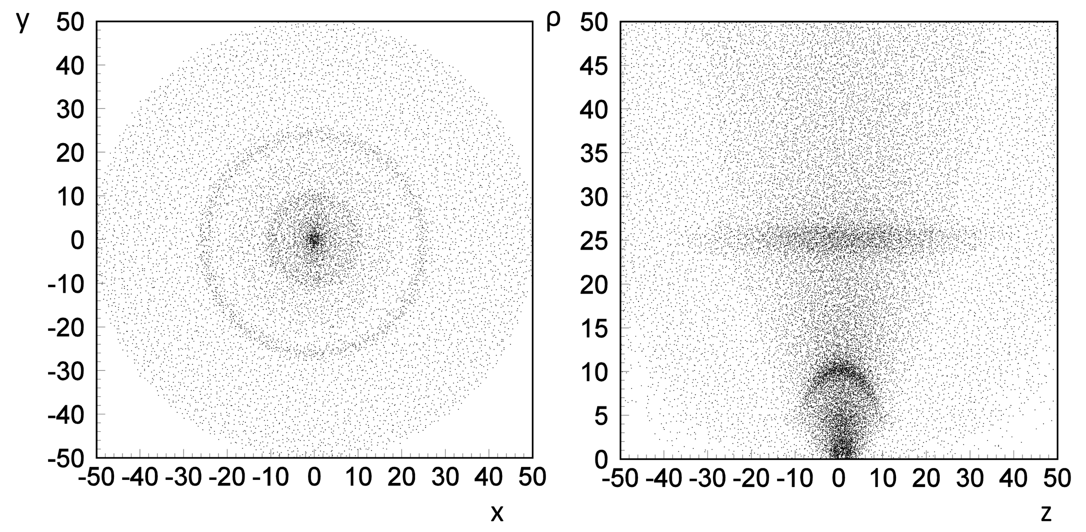


Fig. 7 Experimental spatial distributions of reconstructed K_L vertex in planes y-x and ρ-z, where ρ denotes cylindrical coordinate. The structure induced by the decay points of regenerated events is clearly visible.

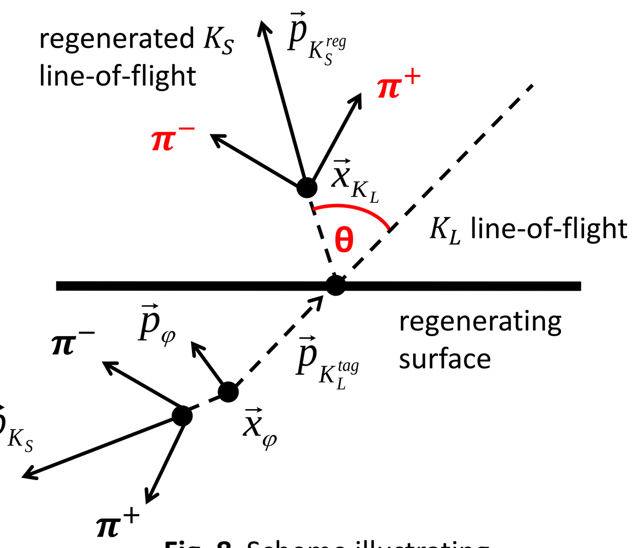


Fig. 8 Scheme illustrating identification method and definition of the regeneration angle.

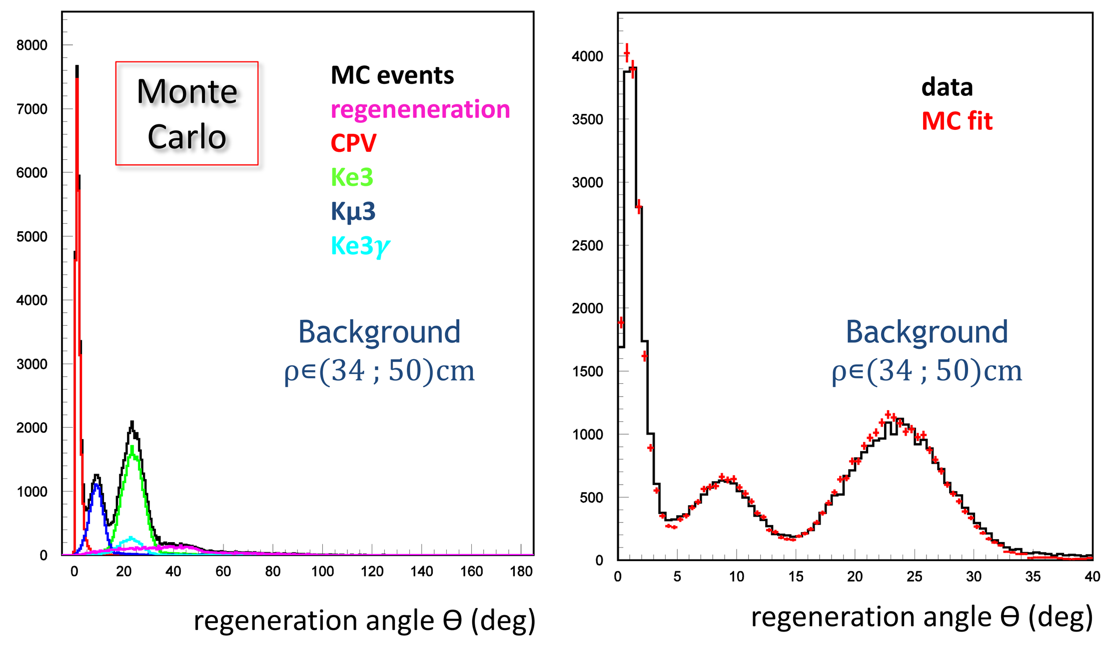


Fig. 9 Distributions of the regeneration angle after analysis cuts. Result of the MonteCarlo simulations is shown in the left panel and in the right panel the fit used for the background normalization is presented.

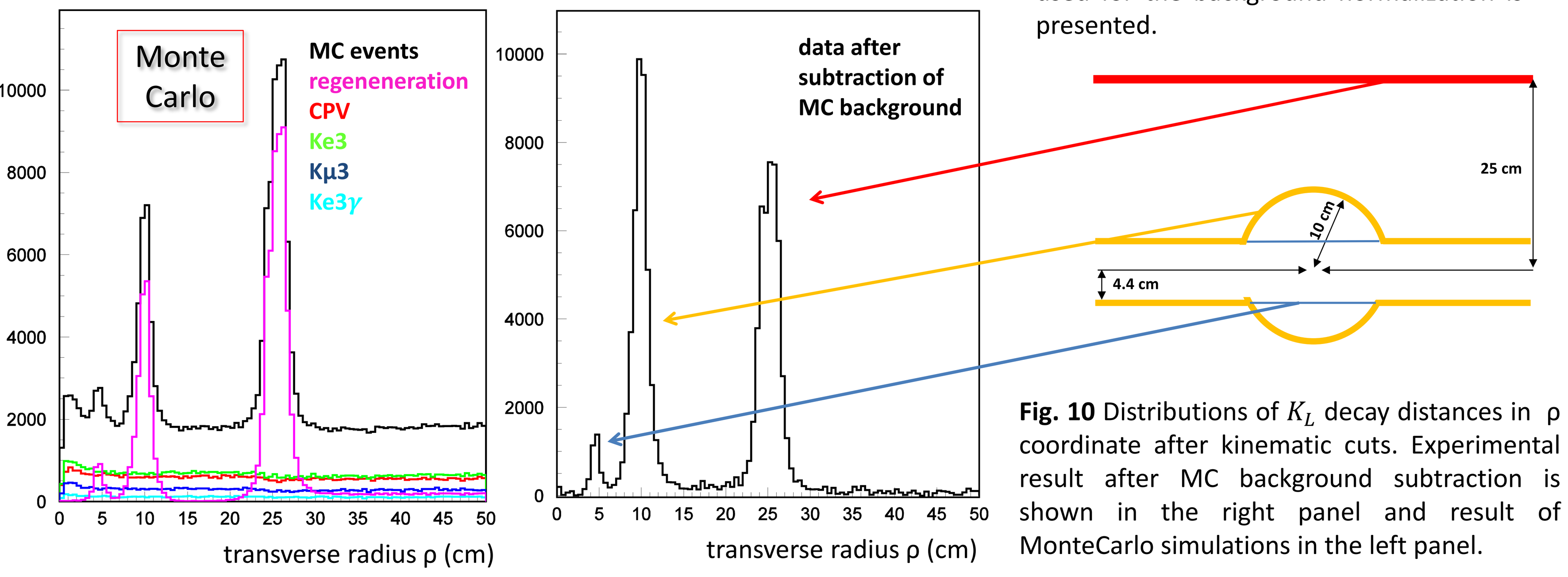


Fig. 10 Distributions of K_L decay distances in ρ coordinate after kinematic cuts. Experimental result after MC background subtraction is shown in the right panel and result of MonteCarlo simulations in the left panel.

KLOE-2 project

- extend the KLOE physics program at DAΦNE upgraded in luminosity
- collect $\sim 10 fb^{-1}$ of integrated luminosity in the next 3-4 years

Physics program [5]:

- Neutral kaon interferometry, CPT symmetry & QM tests
- Kaon physics, CKM, LFV, rare K_S decays
- η,η′ physics
- Light scalars, γγ physics
- Dark forces
- Hadronic cross section at low energy, muon anomaly

Detector upgrade:

- γγ tagging system
- inner tracker
- small angle and quad calorimeters
- FEE maintenance and upgrade
- Computing and networking update
- etc.. (Trigger, software, …)

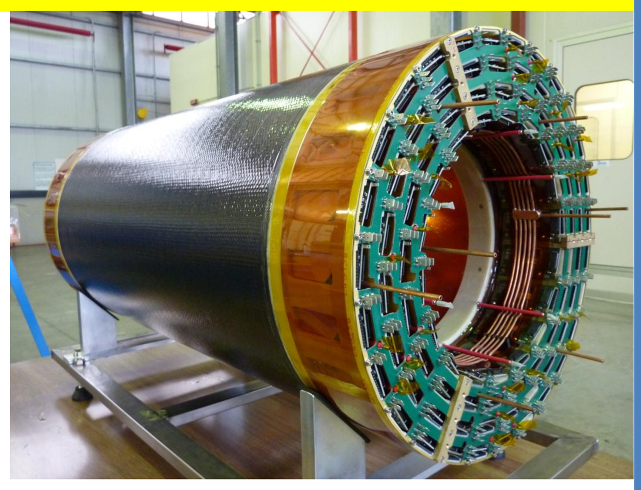


Fig. 11 Assebled KLOE-2 Inner Tracker

References

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