From KLOE to KLOE-2

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Workshop on Heavy Flavours Physics

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Effective Summary:

In the last decade the DAΦNE collider at the Frascati National Laboratory of INFN has delivered ~2.5 fb^{-1} of data at or around the $\Phi(1020)$ peak to the KLOE experiment

During 2008-2009 the DAΦNE team has been able to increase the luminosity of the accelerator by a factor ~3 with minor modifications of the machine's hardware

Following this success KLOE has been rolled back on the beam line and is ready to start a new data taking campaign in a few days from now

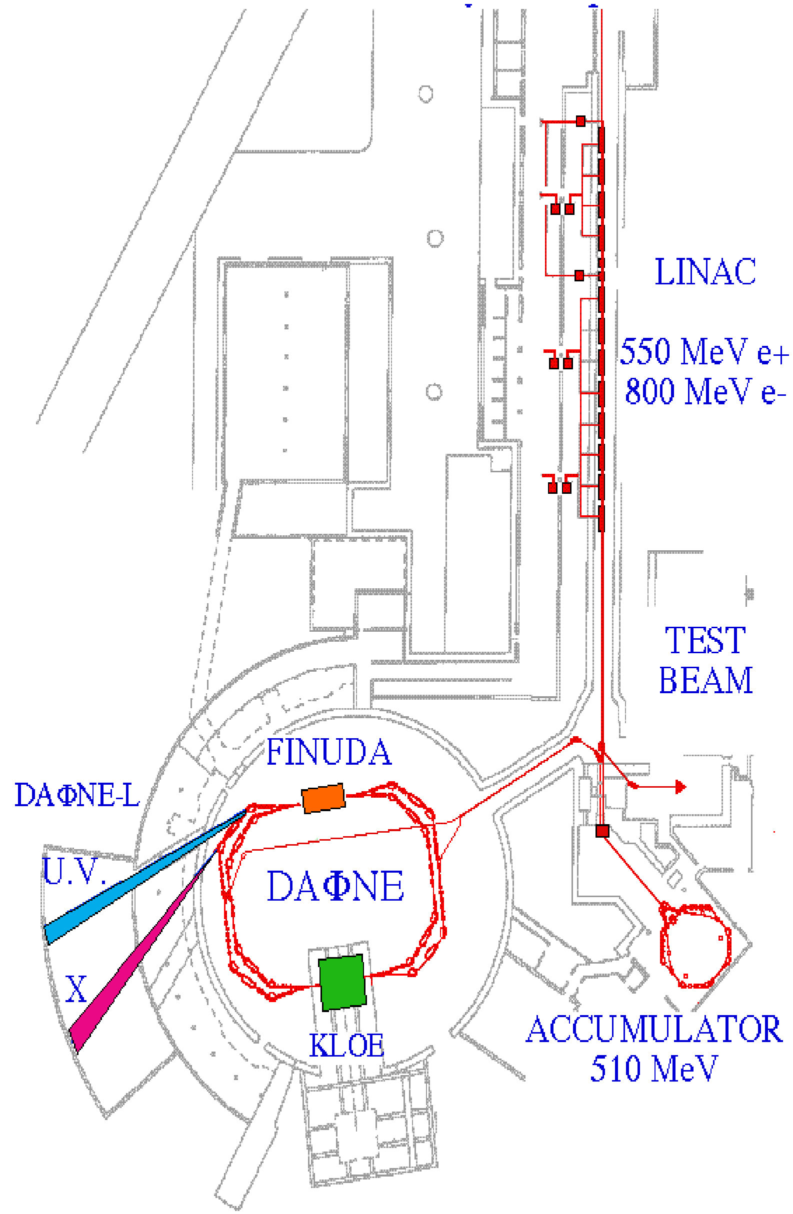
A few detector's upgrades have also been planned and will be installed by the end of 2011

DAΦNE is a ~300 m long symmetric e^+e^- machine operating at $E_{c.m.}$ = 1020 MeV (Φ resonance peak)

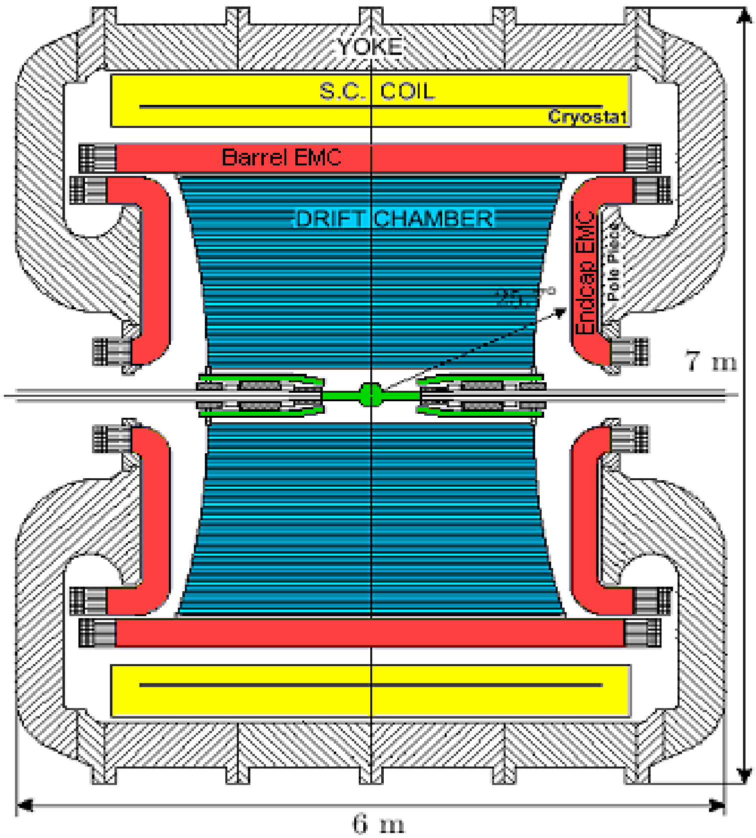
The main event fluxes are:
(in million events/pb^{-1})

- K^+K^- : 1.5
- $\rho\pi$: 0.5
- $K_S K_L$: 1.
- $\eta\gamma$: 0.04

Moreover, one has to consider also $\mu^+\mu^-(\gamma)$, $\pi^+\pi^-(\gamma)$, $e^+e^-(\gamma)$ final states (Bhabha rate ~5 Mevents/pb^{-1}, depending on acceptance cuts)



Built in the late 90's, KLOE is a multi purpose apparatus, optimised to maximise the detection efficiency for K_L decays



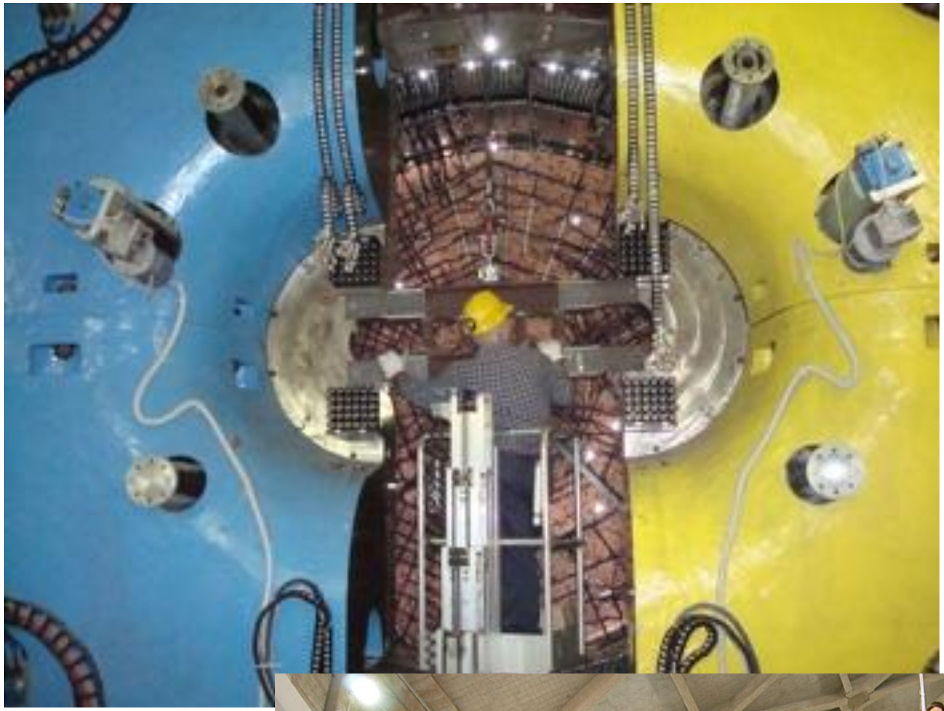
❖ **Superconducting coil** $B = 0.52$ T

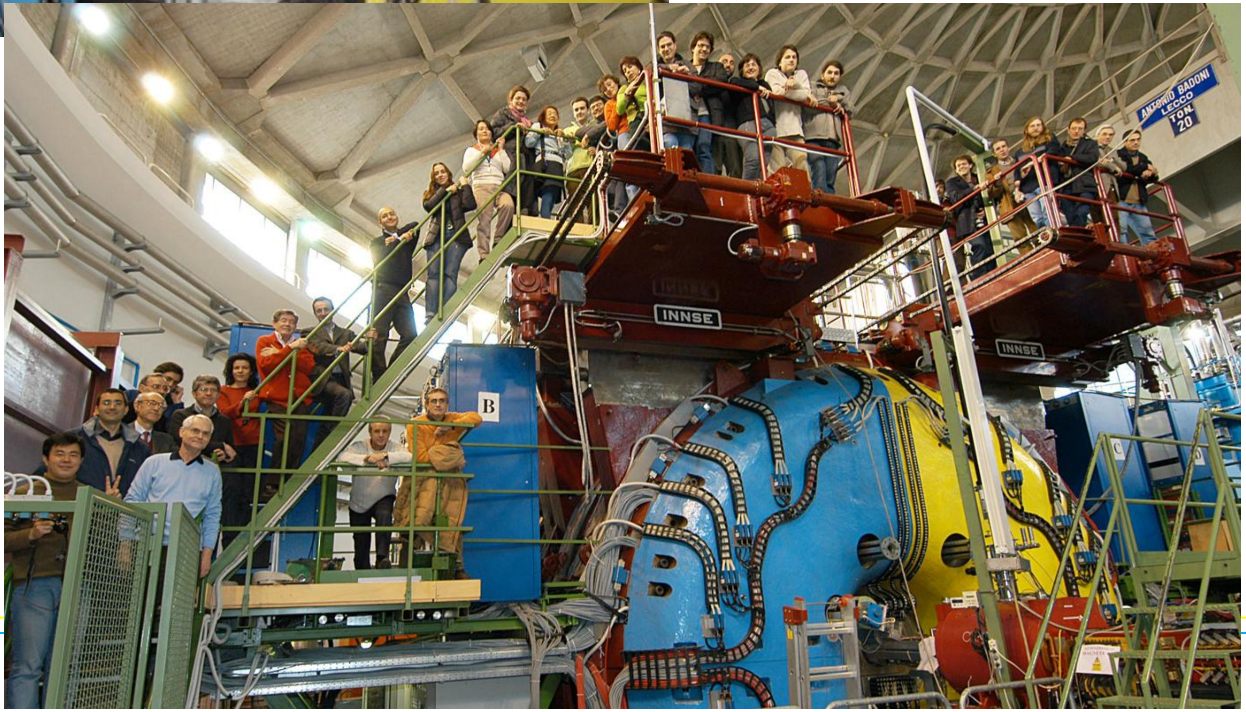
❖**Be beam pipe** (0.5 mm thick), spherical 10 cm radius

❖**Electromagnetic calorimeter**
Lead/scintillating fibers (1 mm ∅) 4880 PMT's, 15 X_0

❖**Drift chamber**
(4 m ∅ × 3.3 m) 90% He + 10% IsoB, CF frame, 12582 stereo, single sense wire, "almost squared" cells

❖**Quadrupole calorimeter**

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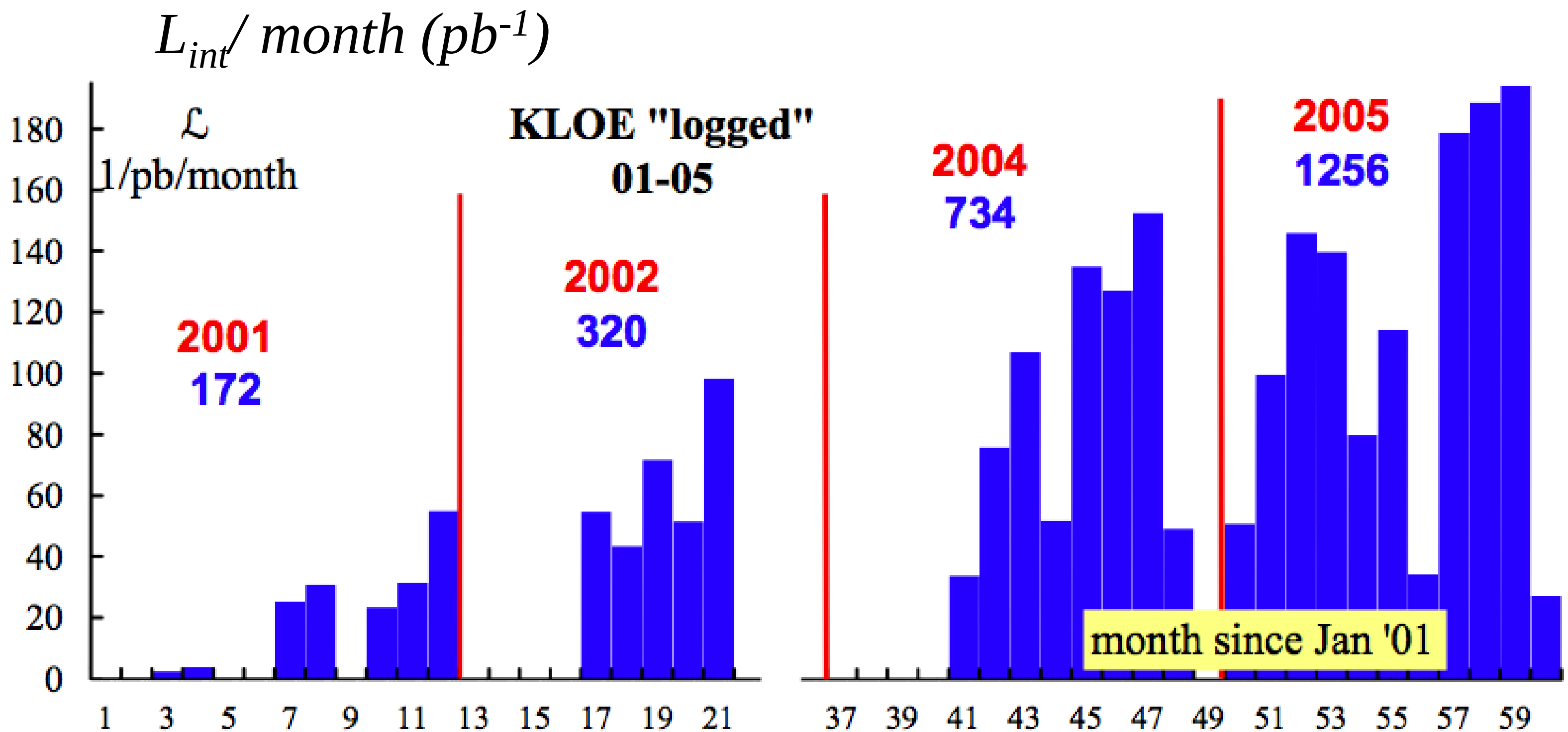
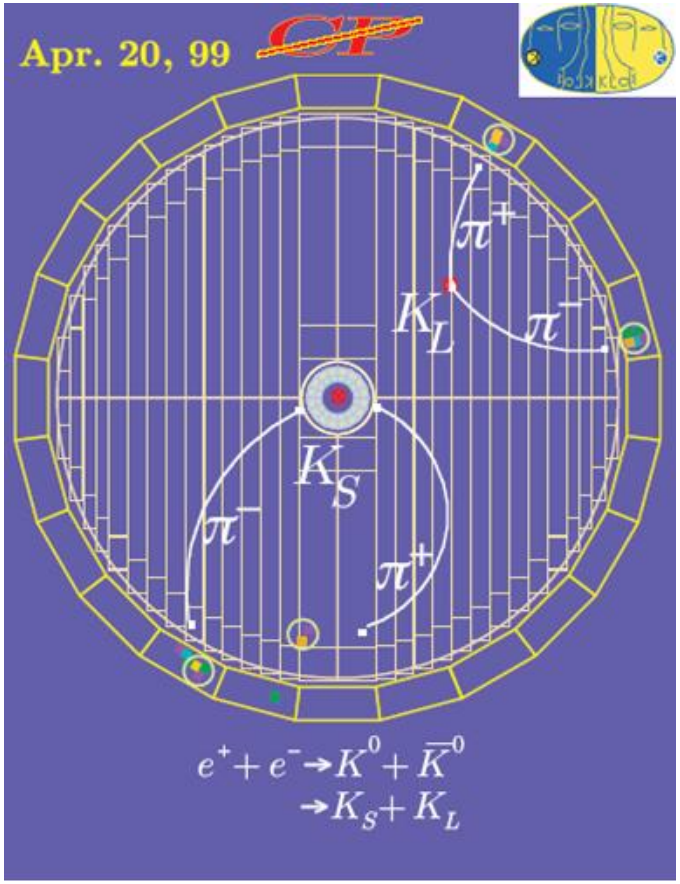
Between years 2000 and 2006 DAΦNE has delivered to KLOE 2.5 fb^{-1} of data at the Φ(1020) peak plus additional 250 pb^{-1} off-peak

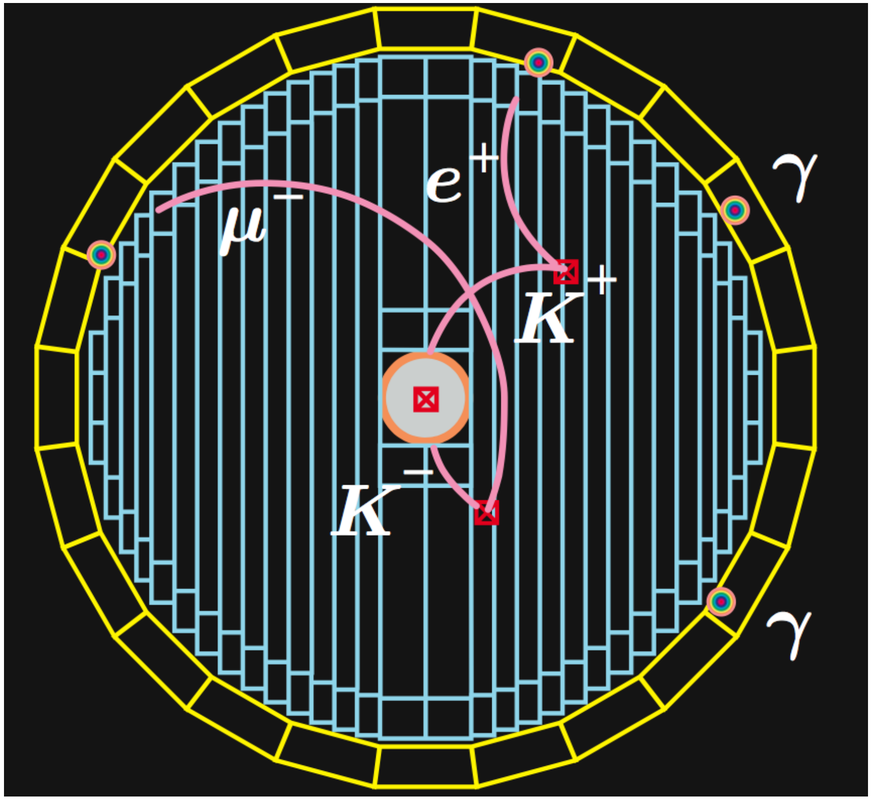


Best day: 10 pb^{-1}

Best month: 194 pb^{-1}

Kaon physics can be performed at KLOE taking advantage of the fact that DAΦNE delivers pure and well tagged K_L, K_S and $K^{\pm}$ beams





All KLOE K_L results

Constrained fit: $\Sigma BRi = 1$, accounting for BR vs τ dependence

$BR(K_{Le3})$	0.4008(15)	*0.4%*
$BR(K_{L\mu3})$	0.2699(14)	*0.5%*
$BR(3\pi^0)$	0.1996(20)	*1.0%*
$BR(\pi^+\pi^-\pi^0)$	0.1261(11)	*0.9%*
$BR(\pi^+\pi^-)$	$1.92(2)\times10^{-3}$	*1.0%*
$BR(\pi^0\pi^0)$	$849(9)\times10^{-4}$	*input PDG '06* (η_{00}/η_{+-})
$BR(\gamma\gamma)$	$5.57(8)\times10^{-4}$	*1.4%*
τ_L	50.84(23) ns	*0.5%*

χ^2/dof = 0.19/1, CL = 66%

All KLOE $K^{\pm}$ results

Constrained fit: $\Sigma BRi = 1$, accounting for BR vs τ dependence

$BR(K^+ \to \mu^+ \nu)$	0.6376(12)	*0.2%*
$BR(K^+ \to \pi^+ \pi^0)$	0.2071(9)	*0.4%*
$BR(K^{\pm} \to \pi^{\pm} \pi^+ \pi^-)$	0.0553(9)	*input PDG '04*
$BR(K^{\pm} \to \pi^0 e^{\pm} \nu)$	0.0499(5)	*1.0%*
$BR(K^{\pm} \to \pi^0 \mu^{\pm} \nu)$	0.0325(4)	*1.2%*
$BR(K^{\pm} \to \pi^{\pm} \pi^0 \pi^0)$	0.0177(3)	*1.7%*
$\tau(K^{\pm})$	12.344(30) ns	*0.24%*

χ^2/dof = 0.60/1, CL = 44%

All KLOE K_S results

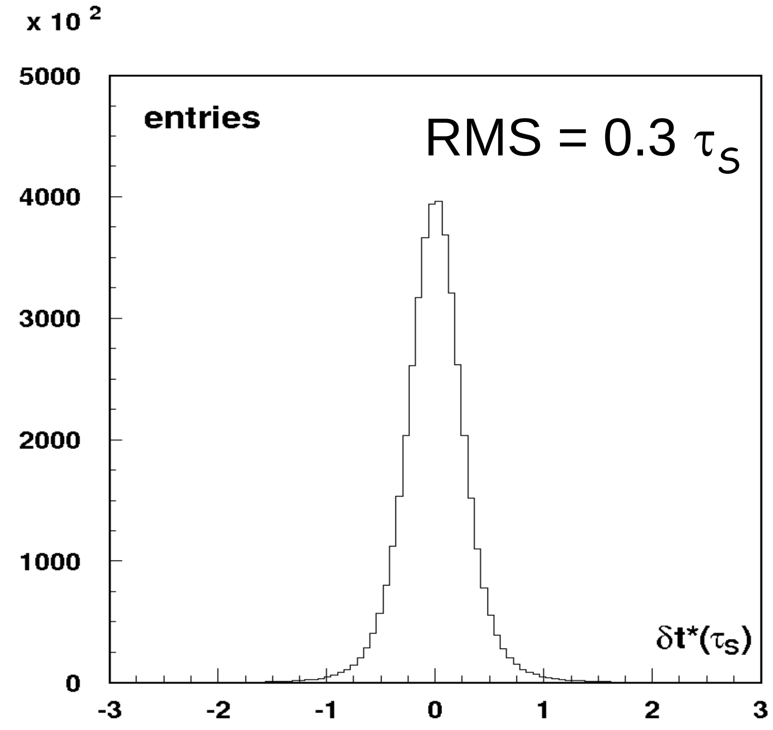
$BR(\pi^+\pi^-)$	$0.69196(51)$	*0.07%*	
$BR(\pi^0\pi^0)$	$0.30687(51)$	*0.1%*	
$BR(K_{Se3})$	$0.3538(6)\times10^{-2}$	*0.16%*	
$BR(\gamma\gamma)$	$0.226(13)\times10^{-5}$	*5.7%*	
$BR(3\pi^0)$	$< 1.2\times10^{-7}$		
$BR(e^+e^-)$	$< 9.0\times10^{-9}$		
τ_S	$89.56(05)\ ps$	*0.04%*	*NEW*

The K_S lifetime is determined by fitting the proper time distribution of $K_S \to \pi^+\pi^-$

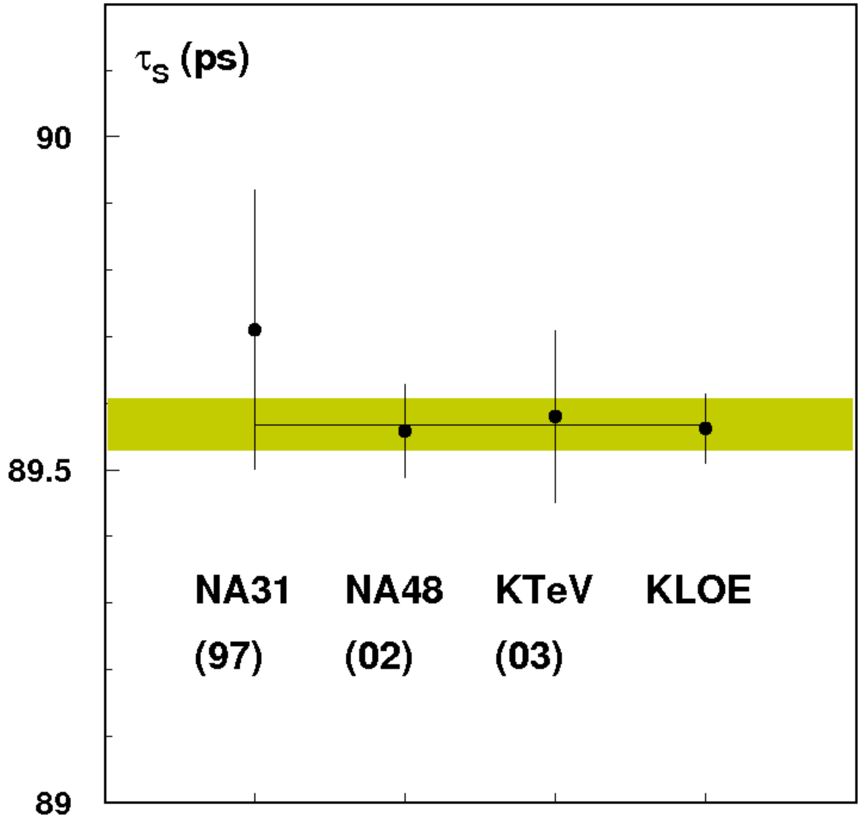
Experimentally this means determining the decay point **d** of the K_S, and its momentum $\mathbf{p_K}$, $t^* = d/\beta\gamma c = \mathbf{d}M_K/c\mathbf{p_K}$

Statistics is not a problem. Choose only events with well reconstructed tracks

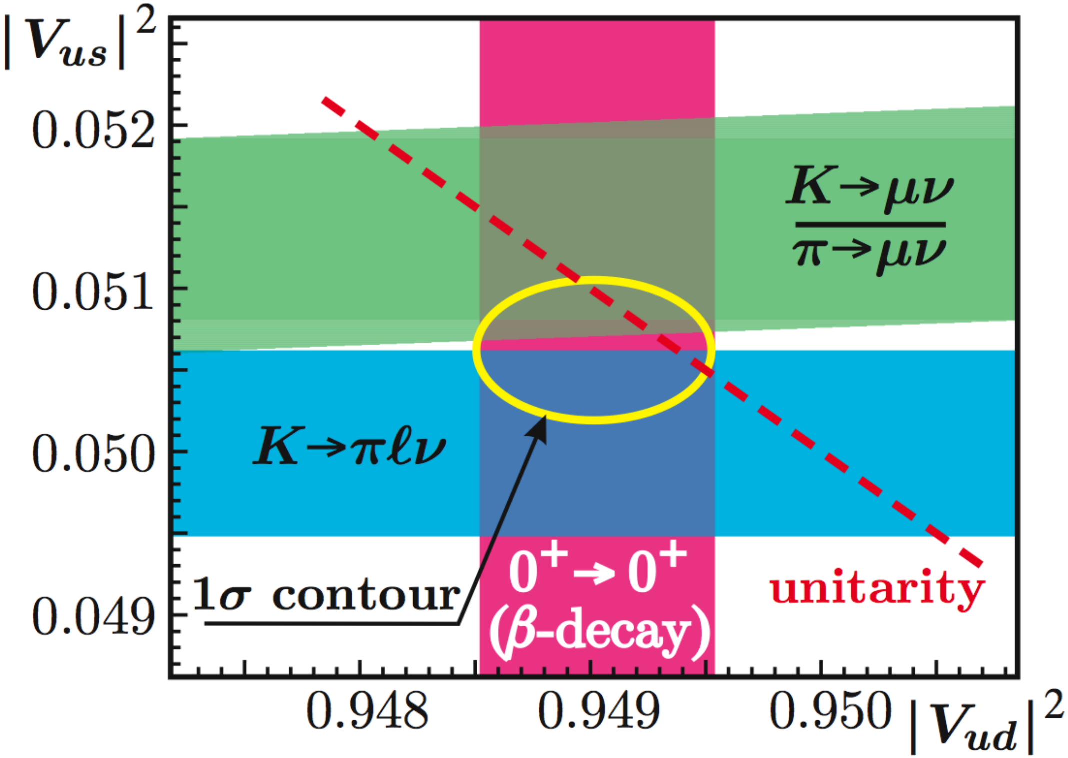
Systematic error dominated by absolute momentum calibration and decay vertex determination



$$\tau_S = (89.562 \pm 0.029_{stat} \pm 0.043_{syst})\ \text{ps}$$



V_{us} determination and CKM unitarity



Fit on

V_{us} *from* K_{l3}

V_{us}/V_{ud} *from* $K_{\mu 2}/\pi_{\mu 2}$

V_{ud} *from* $0^+ \to 0^+$ β **decays**

$$|V_{us}| = 0.2249 \pm 0.0010$$

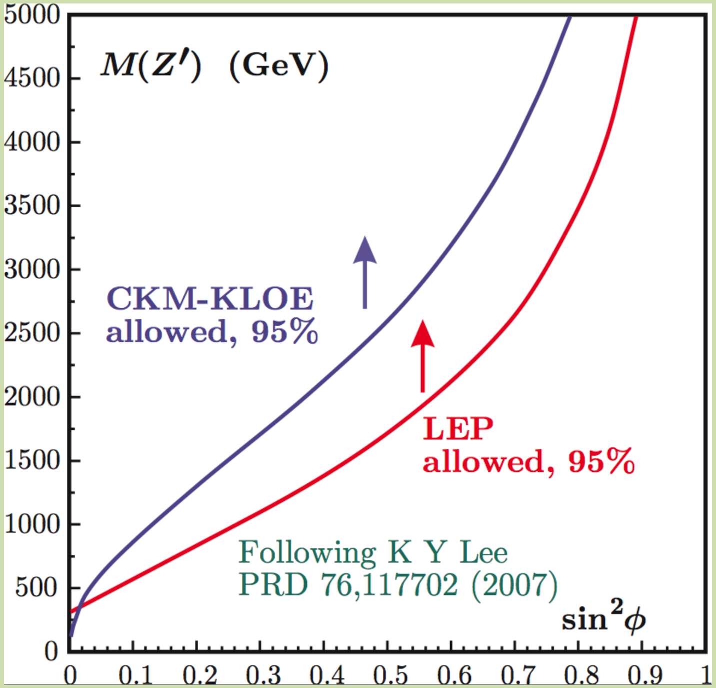
$$|V_{ud}| = 0.97418 \pm 0.00026$$

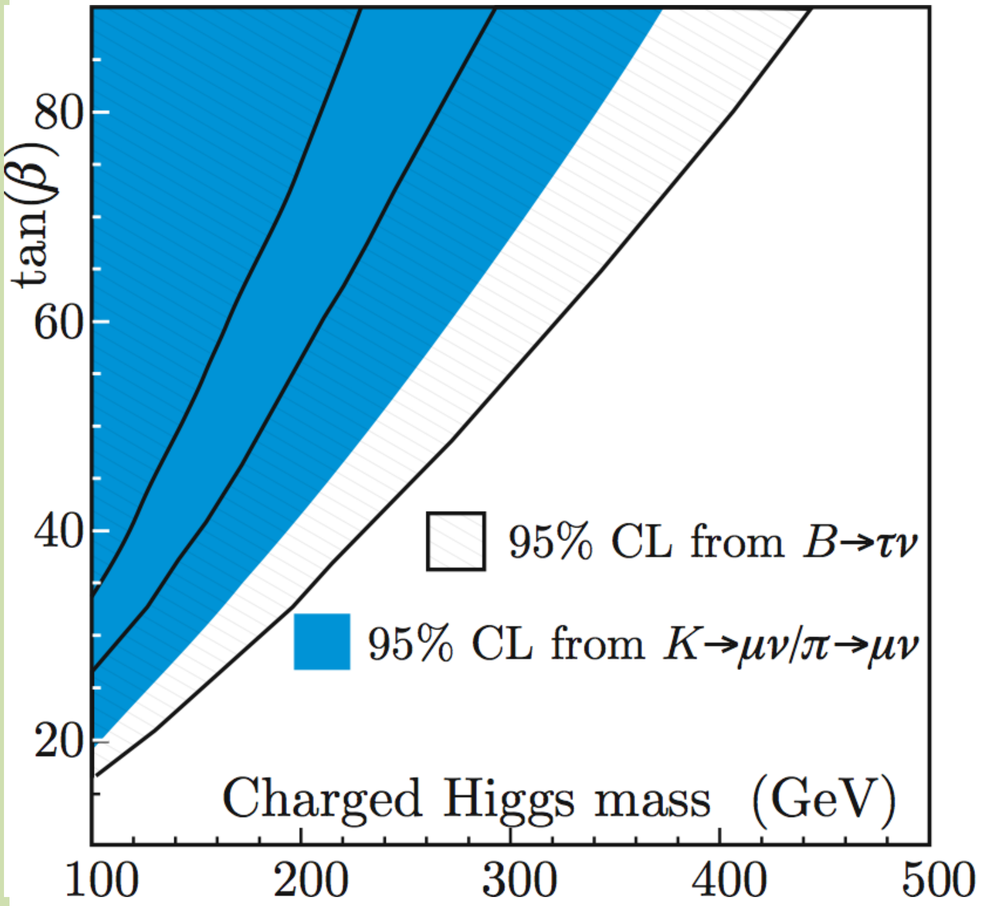
$$1 - |V_{us}|^2 - |V_{ud}|^2 = 0.0004 \pm 0.0007$$

was 0.0031 ± 0.0015 in PDG04

Constraints on New Physics

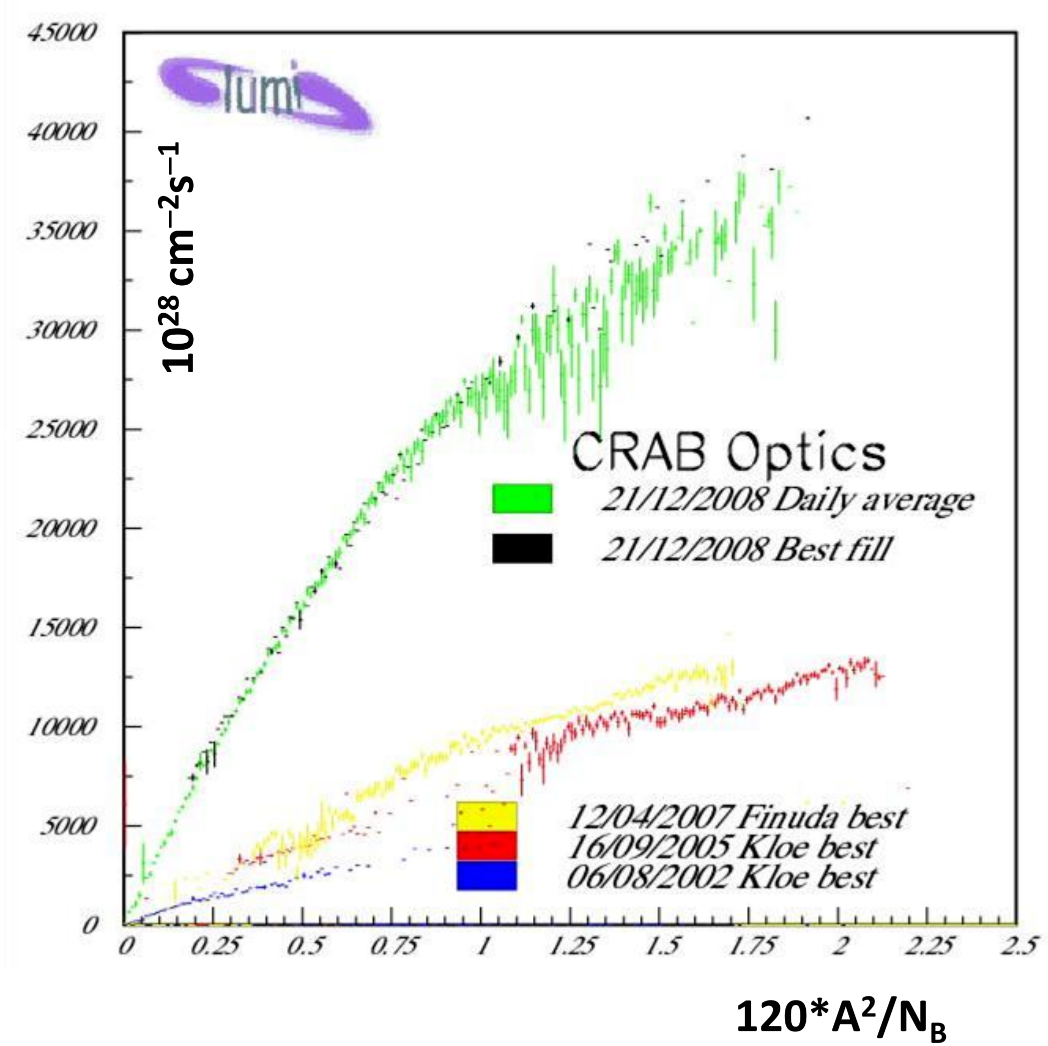
Tree level breaking of unitarity in models with non-universal gauge interaction



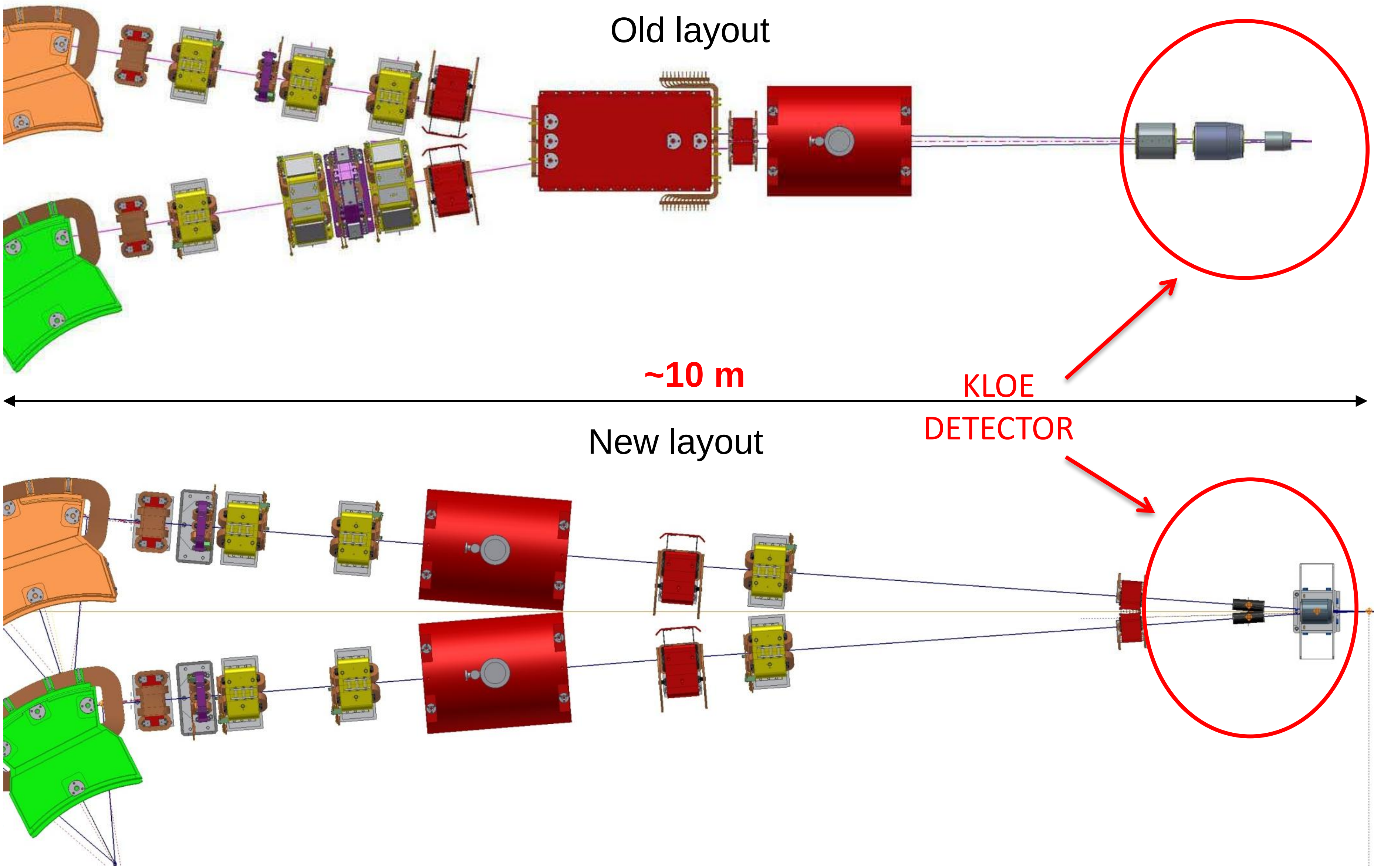


Since the beginning of 2008, DAΦNE has implemented a new interaction scheme based on the use of a large Piwinski angle in combination with a crabbed waist induced by properly designed sextupoles

Results obtained during the run of the SIDDHARTA experiment have been extremely positive: an increase of the peak luminosity by a factor of ~3 and of the integrated luminosity by a factor ~2 has been achieved

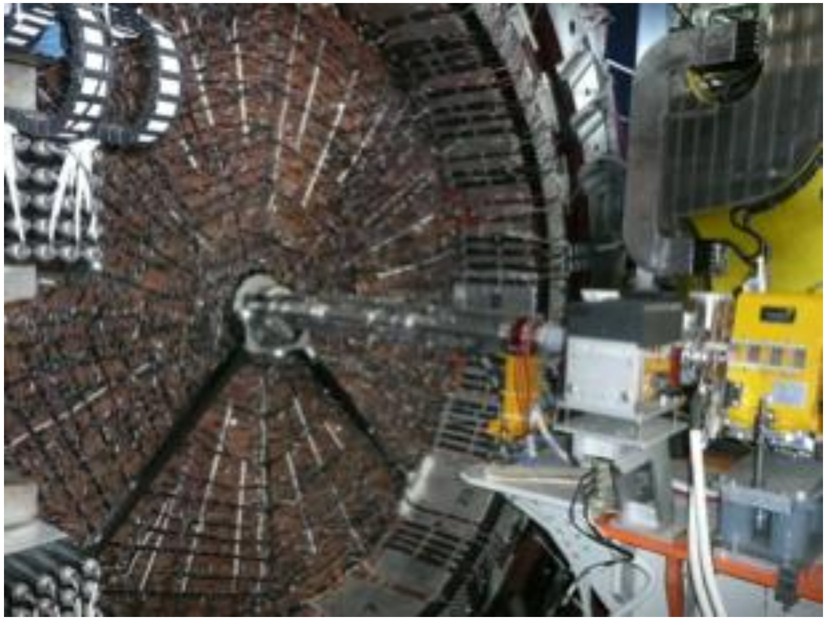


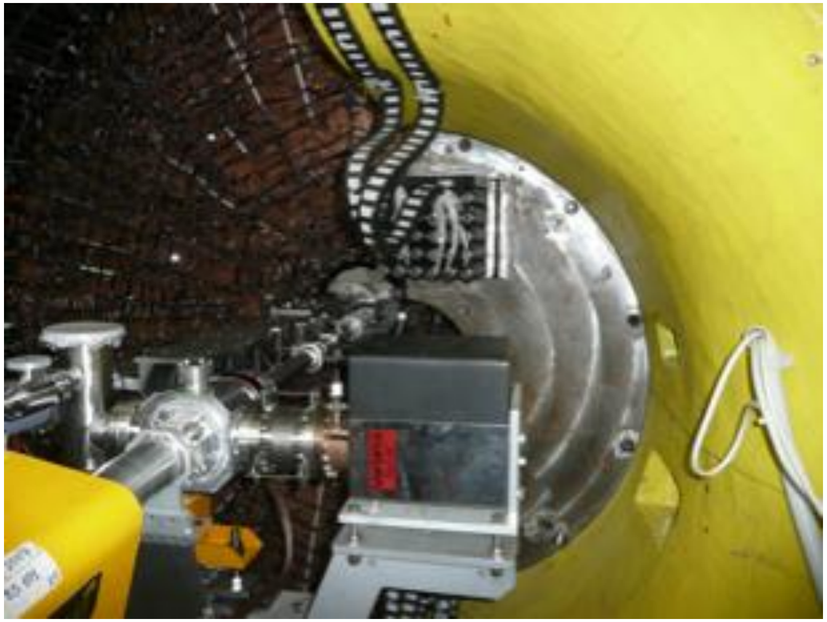
Magnetic layout: old and new

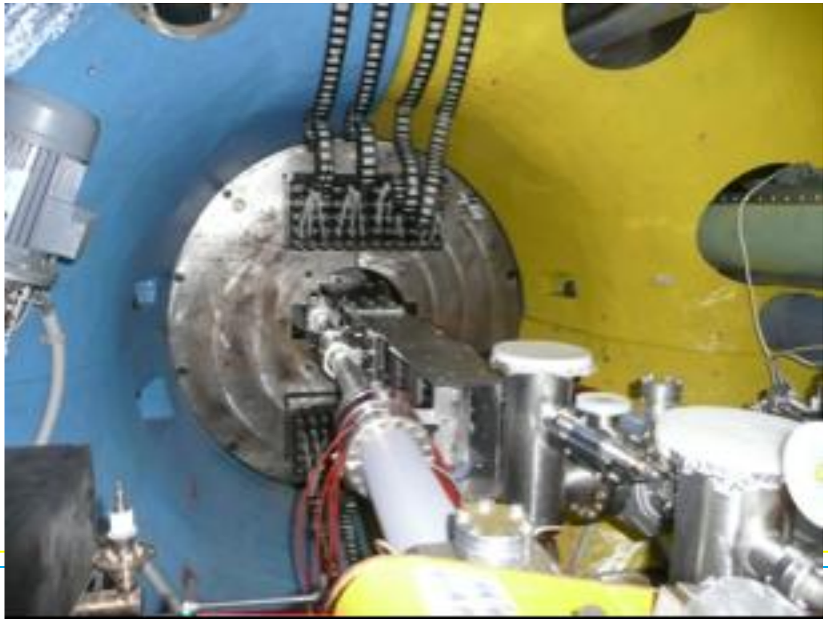


Insertion of the new IR, a very delicate business, succesfully completed on June 1st, 2010

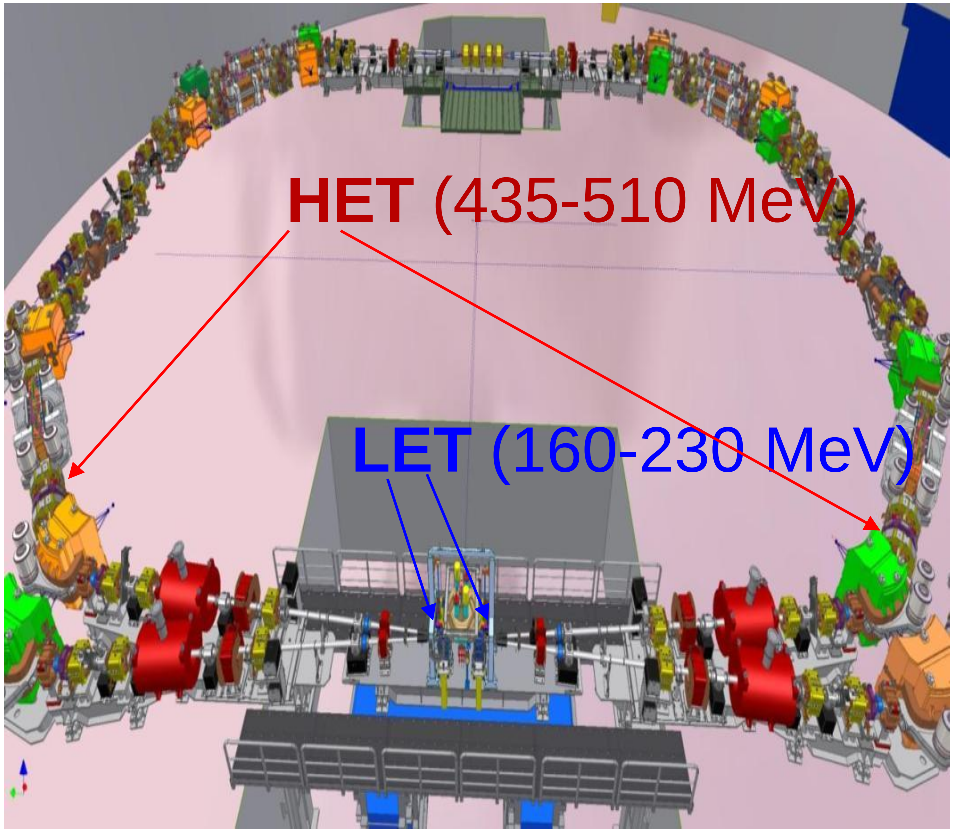
End caps closing June 17th, 2010







Two new pairs of different subdetectors have been installed to tag scattered leptons from 2γ interactions



There is quite a number of physics channels which can profit of the increased statistics expected from the forecoming run

Since, however, most of them involve decay processes at or very close the interaction point, we have also proposed a program for upgrading the detector aimed at *improving its charged vertex efficiency near the IP and its acceptance for photons emitted at low polar angles*

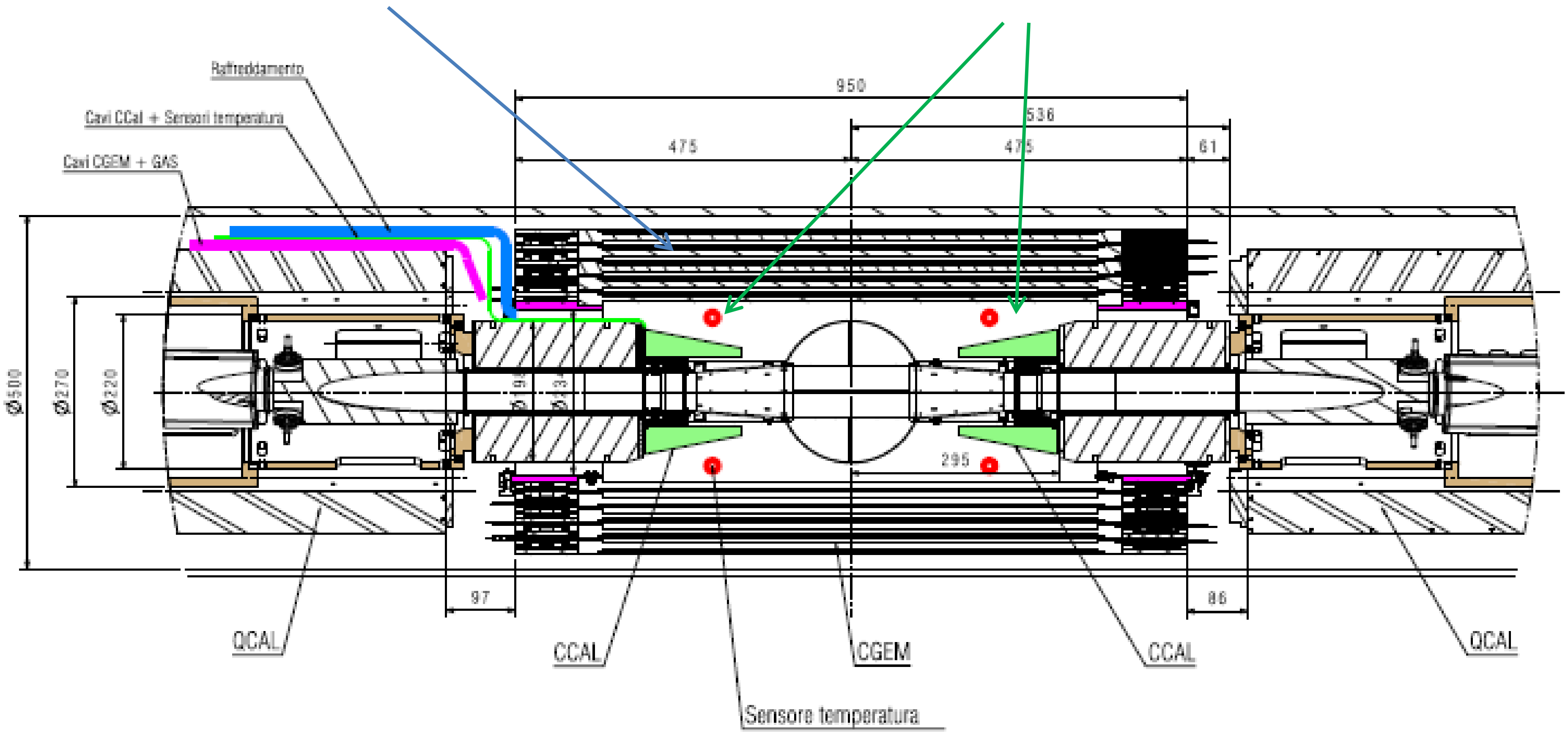
The new subdetectors are being presently built and will be ready for installation by the fall of 2011 (*step-1* phase, in the KLOE-2 jargoon). The run starting these days (*step-0* phase) has the multiple purpose of improving our understanding of the machine conditions, of increasing at best the statistical sample for some rare or forbidden decays analysis, and of exploiting the performance of the newly installed $\gamma\gamma$ detectors

The upgraded interaction region

New sub-detectors will be installed around the interaction region

An inner tracker to improve on tracking resolution and acceptance

Forward calorimeters to increase acceptance for photons



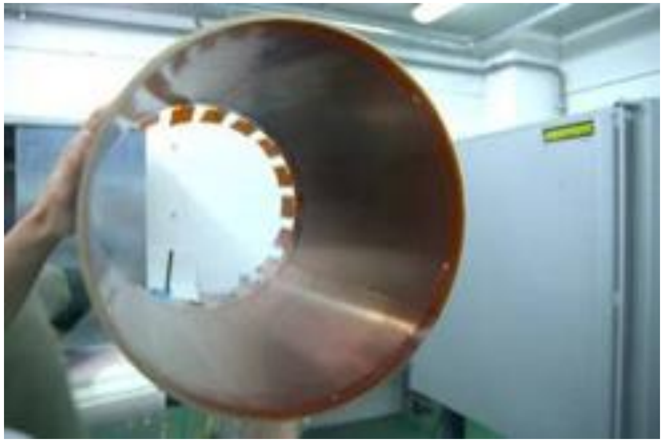
The “core” project of the step-1 phase is the construction and insertion of a new Inner Tracker (IT) detector

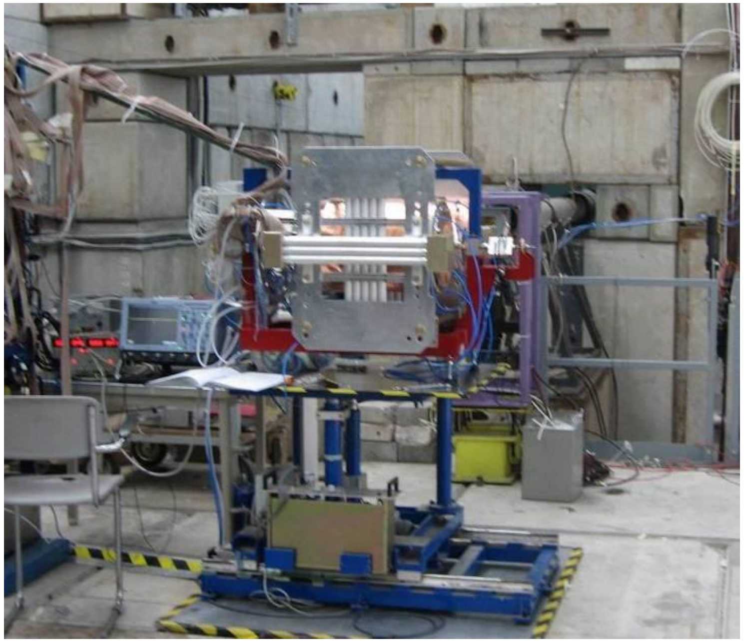
It is based on a well established technology, shaped in a totally innovative geometry, i.e. the *cylindrical GEM* (C-GEM)

This new subdetector allows us to improve our vertex efficiency for charged tracks, while keeping the increase in the material budget at the level of 2% of X_0

# lyers	dx@vtx (mm)	dz@vtx (mm)	dx@pca (mm)	dz@pca (mm)
5	**1.6**	**1.1**	**0.5**	**0.85**
4	**1.7**	**1.18**	**0.5**	**0.85**
NO IT	**4.2**	**3.1**	**1.6**	**2.2**

A small size prototype of the C-GEM has been built and succesfully tested in 2008-2009. After some further R&D work, we are now starting the construction of the final “large size” detector

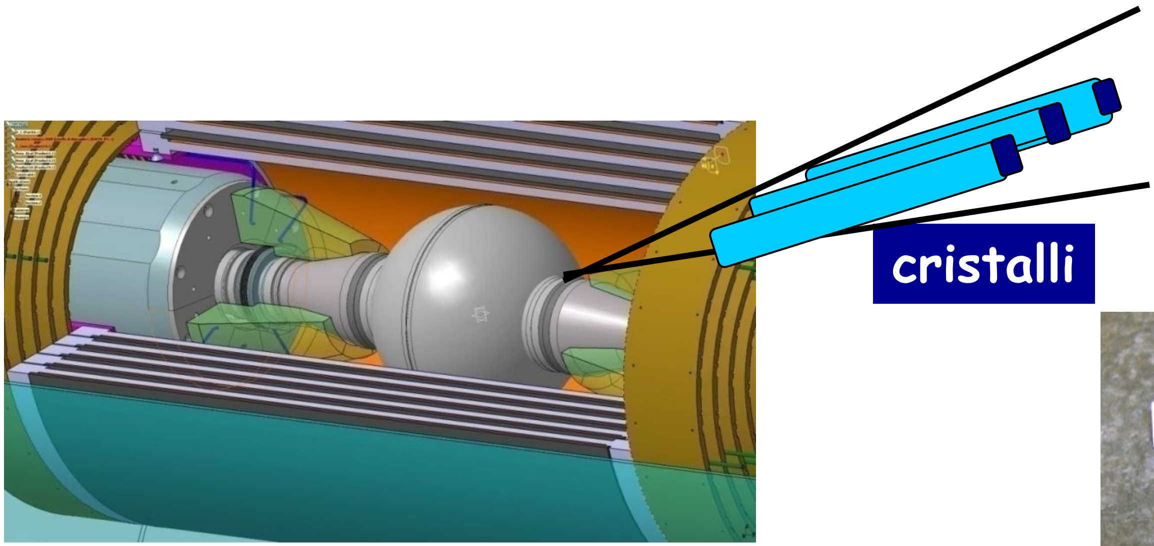


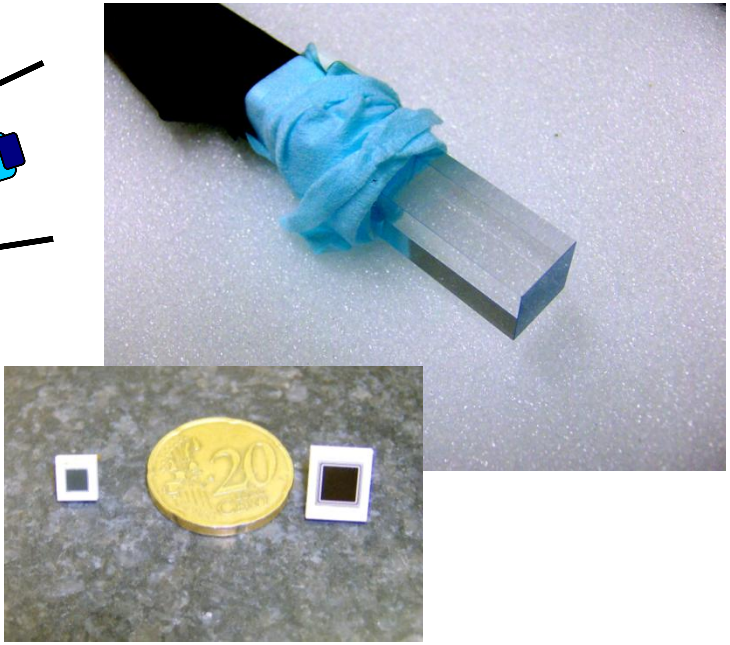


The forward calorimeters (CCAL) consist of two rings of 24 crystals of length of 10-13 cm and area from 1.5x1.5 to 2x2 cm^2

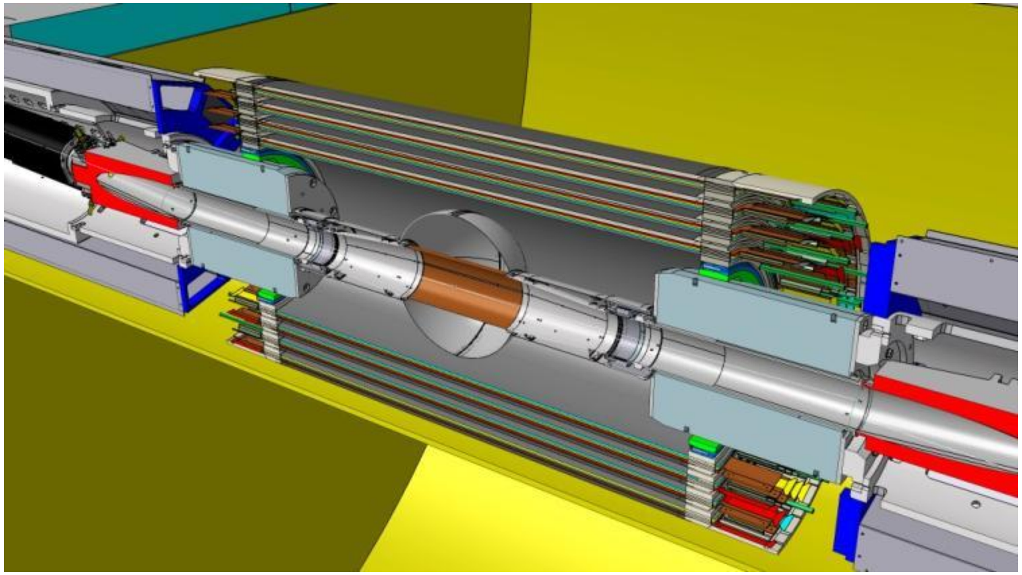
They will extend angular coverage down to 8°. Very useful for rare K_S decays

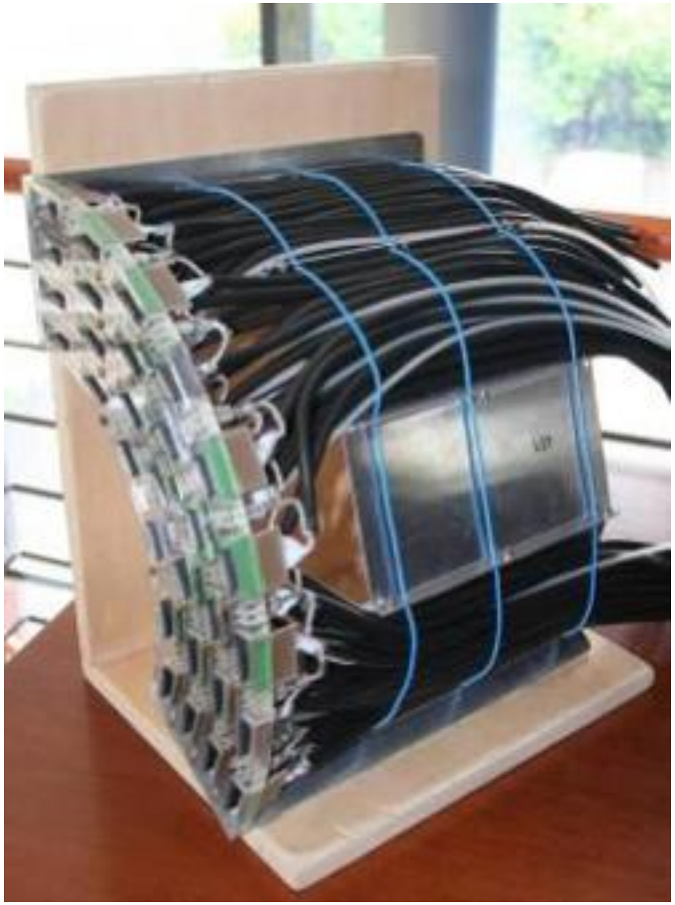
Components choice, basically finalised. Now working on mechanics and costing optimisation





The installation of these very delicate new detectors inside the relatively limited space available in KLOE will not be trivial and is being studied with great care. Cable routing and heat dissipation are also an issue





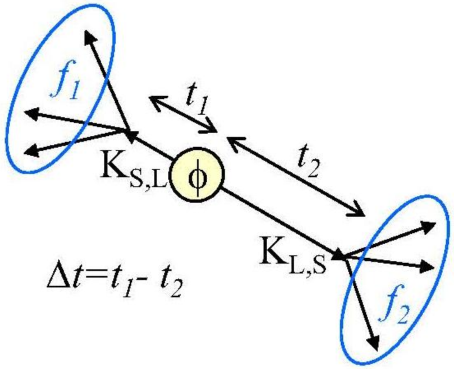
A thorough discussion of the KLOE-2 physics program can be found in *arXiv:1003.3868* which has been accepted for publication on EPJC

- Studies on CPT and QM violation with neutral kaons interferometry
- Tests of Lepton Flavor Violation with K_{e2} decays
- Studies on C, P, CP violation using rare η and K_S decays
- Tests of Chiral Perturbation Theory with η, η', and K_S decays
- Searches for signals of a Secluded Gauge Symmetry

It can be seen as a "natural" extension of the KLOE program in the field of flavour and hadronic physics, with some additions, such as $\gamma\gamma$ interactions, or searches for new light gauge bosons

The most specific (and intriguing) feature of the neutral kaon system produced in Φ decays is that it is subject to quantum entanglement

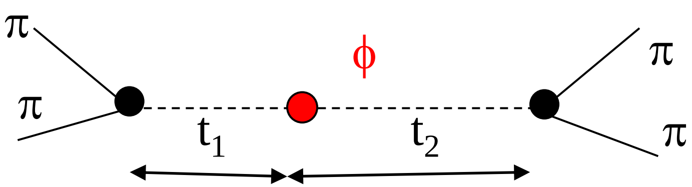
This means that the decay probability of each one of the kaons depends also on what the other particles does, giving rise to a well defined interference term in the decay intensity



$$I(f_1,t_1;f_2,t_2) = C_{12}\left\{|\eta_1|^2 e^{-\Gamma_L t_1 - \Gamma_S t_2} + |\eta_2|^2 e^{-\Gamma_S t_1 - \Gamma_L t_2} - 2|\eta_1||\eta_2| e^{-(\Gamma_S + \Gamma_L)(t_1 + t_2)/2} \cos\left[\Delta m (t_2 - t_1) + \phi_1 - \phi_2\right]\right\}$$

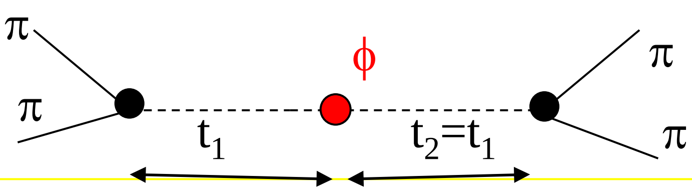
The specific form of the decay intensity depends on the final decay channel. In the case of $4\pi^{\pm}$ it has the form shown in the plot below

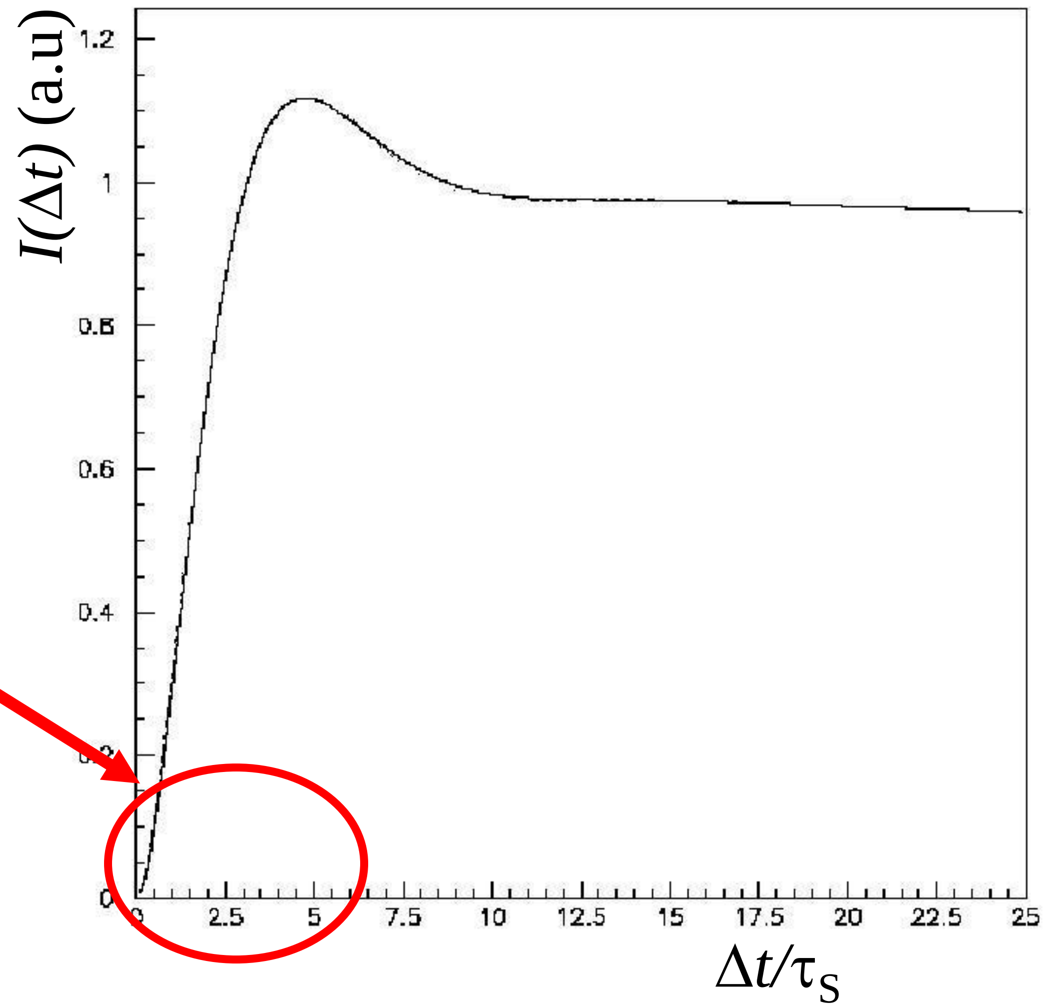
$$\Delta t = |t_1 - t_2|$$



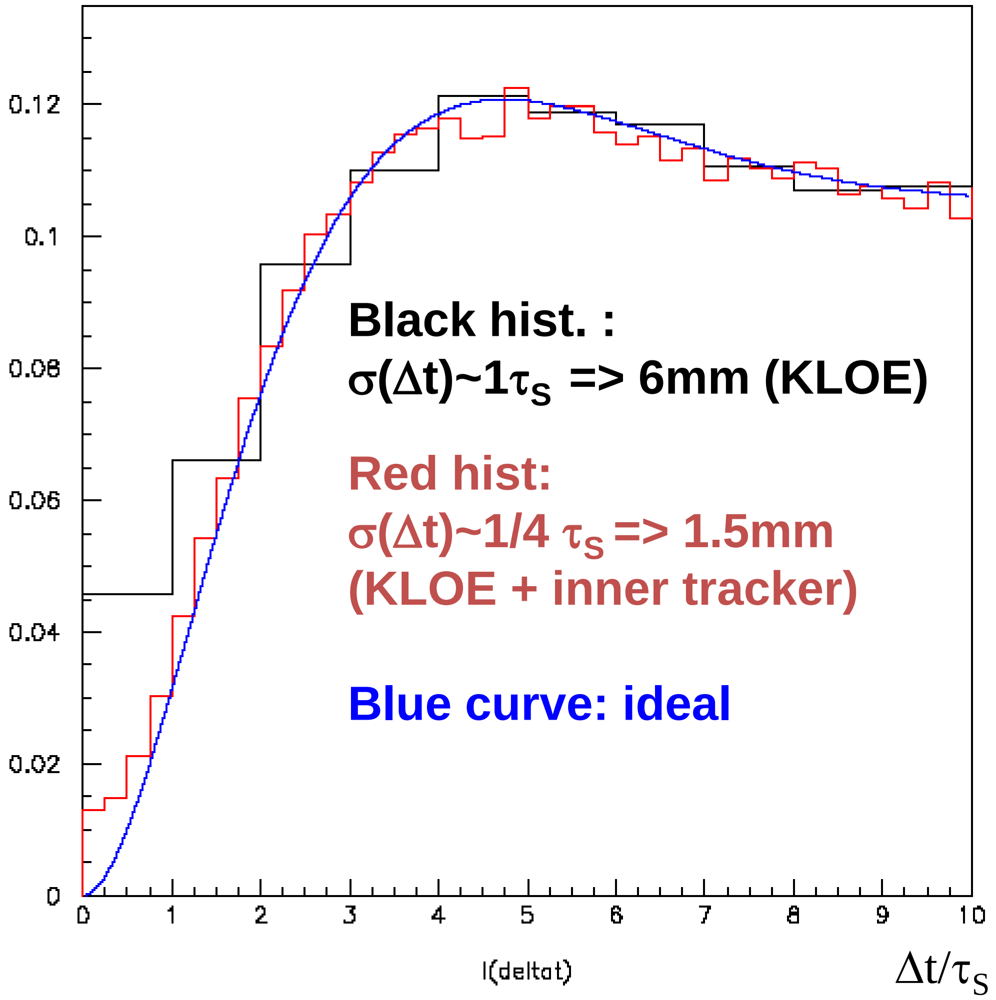
EPR correlation:

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





The use of the Inner Tracker greatly improves the accuracy achievable for this kind of measurements

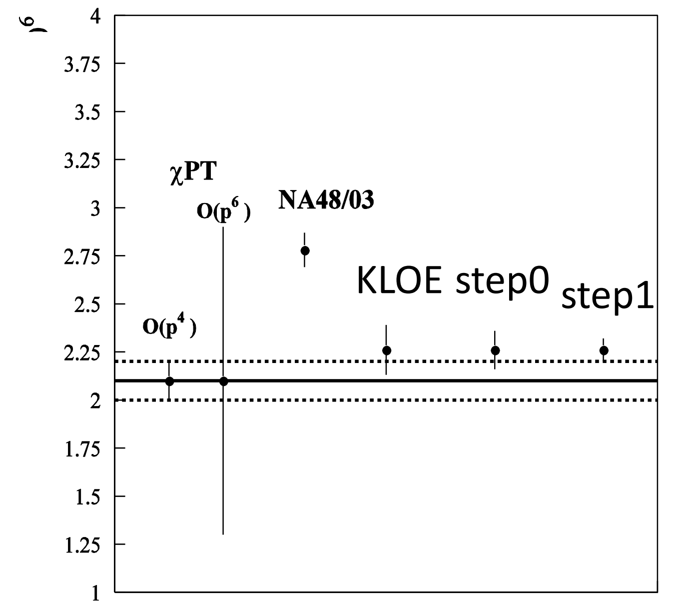


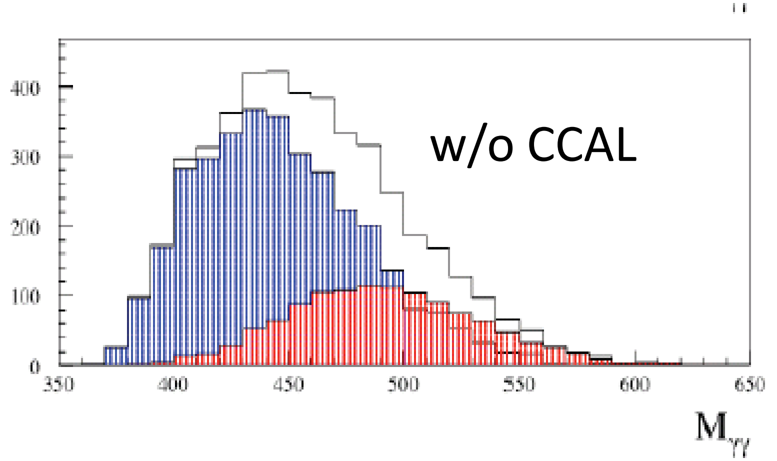
Mode	Test of	Param.	Present best published measurement	KLOE-2 (with IT) L=50 fb^{-1}
$\pi^+\pi^- \quad \pi^+\pi^-$	QM	ζ_{00}	$(1.0 \pm 2.1) \times 10^{-6}$	$\pm\, 0.1 \times 10^{-6}$
$\pi^+\pi^- \quad \pi^+\pi^-$	QM	ζ_{SL}	$(1.8 \pm 4.1) \times 10^{-2}$	$\pm\, 0.2 \times 10^{-2}$
$\pi^+\pi^- \quad \pi^+\pi^-$	CPT & QM	α	$(-0.5 \pm 2.8) \times 10^{-17}$ GeV	$\pm\, 2 \times 10^{-17}$ GeV
$\pi^+\pi^- \quad \pi^+\pi^-$	CPT & QM	β	$(2.5 \pm 2.3) \times 10^{-19}$ GeV	$\pm\, 0.1 \times 10^{-19}$ GeV
$\pi^+\pi^- \quad \pi^+\pi^-$	CPT & QM	γ	$(1.1 \pm 2.5) \times 10^{-21}$ GeV	$\pm\, 0.2 \times 10^{-21}$ GeV compl. pos. hyp. $\pm\, 0.1 \times 10^{-21}$ GeV
$\pi^+\pi^- \quad \pi^+\pi^-$	CPT & EPR corr.	$\mathrm{Re}(\omega)$	$(1.1 \pm 7.0) \times 10^{-4}$	$\pm\, 2 \times 10^{-5}$
$\pi^+\pi^- \quad \pi^+\pi^-$	CPT & EPR corr.	$\mathrm{Im}(\omega)$	$(3.4 \pm 4.9) \times 10^{-4}$	$\pm\, 2 \times 10^{-5}$
$K_{S,L} \rightarrow \pi e \nu$	CPT & Lorentz	Δa_0	$[(0.4 \pm 1.8) \times 10^{-17}$ GeV]	$\pm\, 2 \times 10^{-18}$ GeV
$\pi^+\pi^- \quad \pi^+\pi^-$	CPT & Lorentz	Δa_Z	$[(2.4 \pm 9.7) \times 10^{-18}$ GeV]	$\pm\, 7 \times 10^{-19}$ GeV
$\pi^+\pi^- \quad \pi e \nu$	CPT & Lorentz	$\Delta a_{X,Y}$	$[<10^{-21}$ GeV]	$\pm\, 4 \times 10^{-19}$ GeV

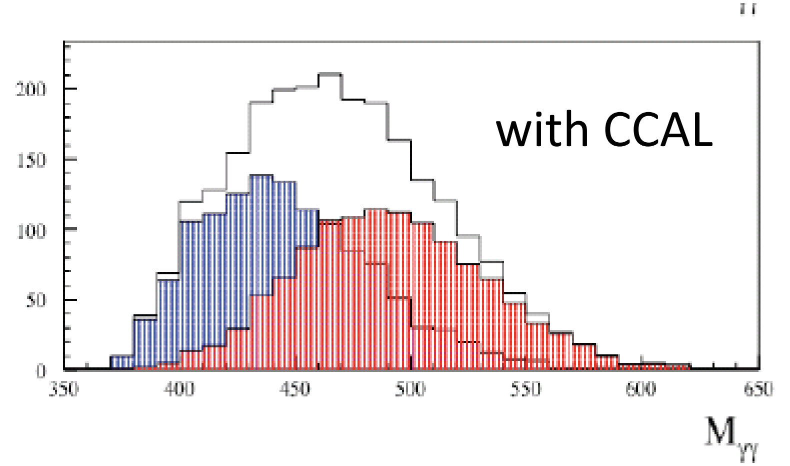
There are at least three analyses that can benefit of an extension at low angle of the KLOE calorimetry:

$K_S \to \gamma\gamma \quad K_S \to 3\pi^0 \quad \eta \to \pi^0\gamma\gamma$

both for bckg reduction and for increasing acceptance







$K_S \to \gamma\gamma$: red = signal blue= background

Conclusions:

After about 2 years of preparatory work, KLOE-2 is ready to start a new bright period of data taking at the renewed DAΦNE

The approved plan is to keep the detector running at least up to end 2012. What will happen next is still under debate and will depend on many not only technical issues

Still, I personally hope to have the excuse to come to Capri for many years to come…