Latest Results from KLOE-2

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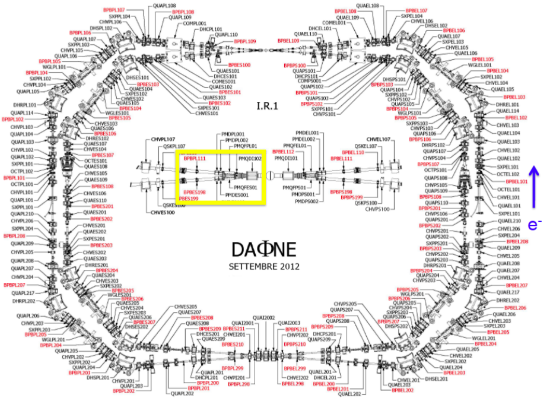
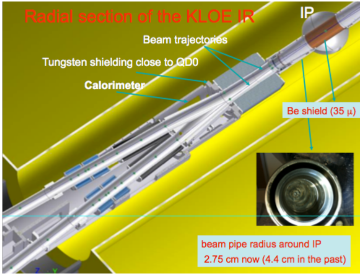
MESON 2014

Workshop on Meson Production, Properties and Interaction
Krakow, May 29 - June 3, 2014

DAΦNE, the Frascati ϕ factory

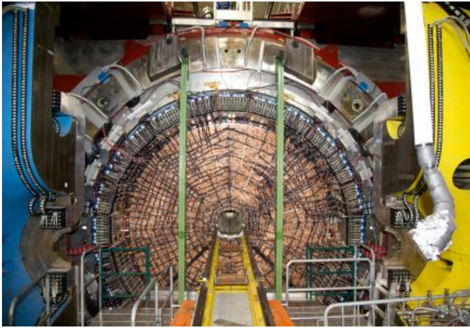




- Most of the infrastructures of the Frascati accelerator complex have been consolidated for a physics run with KLOE-2
- Beam interaction region upgraded
- Commissioning in progress
- The goal is to collect 5 fb^{-1} in 2-3 years

The KLOE detector

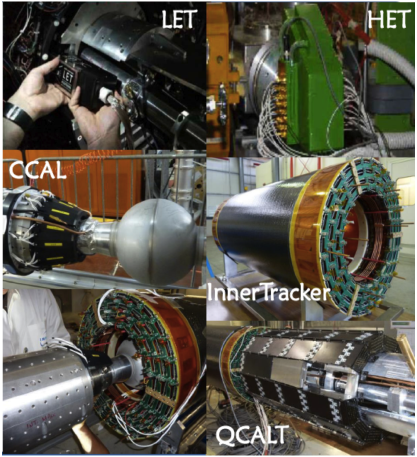
- Big Drift chamber operating with He-rich(90%) mixture, with stereo wires and carbon-fiber structure, $\sigma_{P_T} < 0.4\cdot\%\ P_T\ (\theta > 45^\circ)$
- Hermetic sampling calorimeter with lead, scintillating fibers, C-shaped end-caps for full coverage, $\sigma_t \sim \frac{57}{\sqrt{E(GeV)}} \oplus 100$ ps
- Loose trigger conditions insure maximal acceptance for any event topology for a wide physics program, EPJ C68(2010)619
- Integrated luminosity of 2.5 fb^{-1} with 2002 and 2004-2005 runs



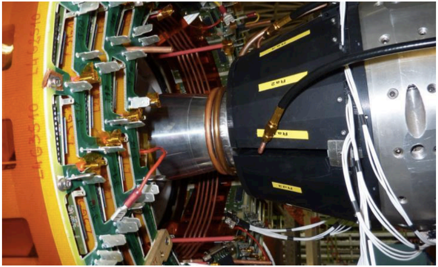
- 250 pb^{-1} collected at 1 GeV for physics in the continuum

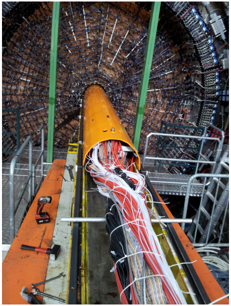
The detector upgrades

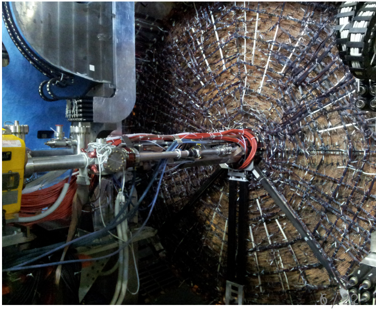
- Two different stations of γ–γ taggers, for the detection of e^+ and e^- in the high-energy (HET) and low-energy (LET) windows, : $E_e > 400 MeV$ and $130 < E_e < 300$ MeV.
- The Inner Tracker is the first cylindrical 3-GEM chamber ever built
- CCALT is a LYSO-crystal calorimeter to detect low-angle photons
- QCALT is a sampling calorimeter to instrument the final focusing region



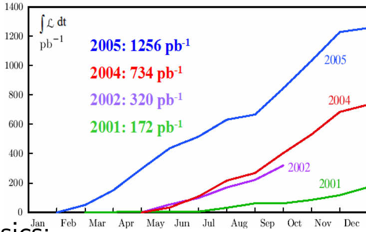
The installation, July 2013







Physics



- Data collected in 2002 and 2004-2006 are being used for precision measurements in various fields.
- Recently-finalized physics analyses include:
  - CPT tests with entangled kaons;
  - The $K^+ \to \pi^+\pi^-\pi^0$ decays; Kaon physics;
  - Dark–photon searches;
  - Transition form factors $F_{\phi\eta}$ and $F_{\phi\pi^0}$ presented by I. Sarra at this conference;
  - The η radiative width JHEP 1301(2013)119, $\Gamma(\eta \to \gamma\gamma) = (520 \pm 20_{st} \pm 13_{syst})$ eV;
  - Isospin violating decays: $\eta \to \pi^+\pi^-\pi^0$ to improve on light quark masses;
  - The hadronic cross section to improve on the theoretical calculation of $(g-2)_\mu$ PLB 720(2013)336

Method

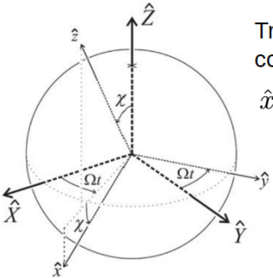
- Entangled kaon pairs are produced at the ϕ–factory in a pure QM state, 1^{--}
- $\phi \to \pi^+\pi^-\pi^+\pi^-$ final state considered for the precision measurement of the interference pattern
- Any deviation from the expected distribution of the decay distance of the two kaons is a signal of effects at the Planck scale, M_P
- The SME is a model-independent framework created to select observables pointing to physics at M_P
- In this framework Δa_μ parametrization of CPT violation is used

$$\delta_k \sim i \sin\phi_{\mathrm{SW}} e^{i\phi_{\mathrm{SW}}} \gamma_{\mathrm{K}} (\Delta a_0 - \vec{\beta_{\mathrm{K}}} \cdot \Delta\vec{a})/\Delta m$$

appearing in the flavor mixture of the mass eigenstates :

$|\mathrm{K}_{\mathrm{S,L}}\rangle \propto (1 + \epsilon_{S,L})|\mathrm{K}^0\rangle \pm (1 - \epsilon_{S,L})|\bar{\mathrm{K}}^0\rangle$ with $\epsilon_{\mathrm{S,L}} = \epsilon_{\mathrm{K}} \pm \delta_{\mathrm{K}}$

Earth rotation: from lab to celestial coordinates

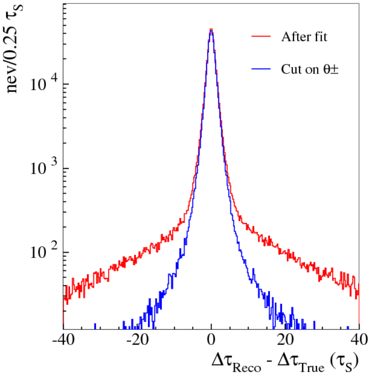


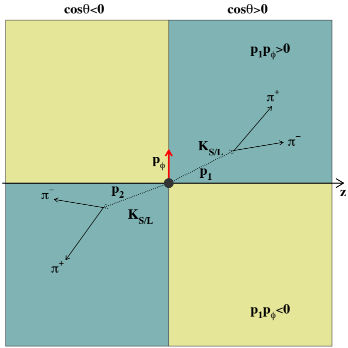
Transformation of δ parameter in a terrestrial coordinate system where:

$$\hat{x} \in \Pi : \alpha\hat{z} + \beta\hat{Z}; \alpha, \beta \in \mathcal{R}$$

$$\begin{aligned}\delta_K(\vec{P}_K, T_{sid}) \;=\; & \frac{i \sin\phi_{SW} e^{i\phi_{SW}}}{\Delta m}\gamma_K \Big[\Delta a_0 + \beta_K \Delta a_Z (\cos\vartheta \cos\chi - \sin\vartheta\cos\varphi\sin\chi) \\ & -\beta_K \Delta a_X \sin\vartheta \sin\varphi \sin\omega_E T_{sid} \\ & +\beta_K \Delta a_X (\cos\vartheta\sin\chi + \sin\vartheta\cos\varphi\cos\chi)\cos\omega_E T_{sid} \\ & +\beta_K \Delta a_Y (\cos\vartheta\sin\chi + \sin\vartheta\cos\varphi\cos\chi)\sin\omega_E T_{sid} \\ & +\beta_K \Delta a_Y \sin\vartheta\sin\varphi\cos\omega_E T_{sid}\Big]\end{aligned}$$

Resolution



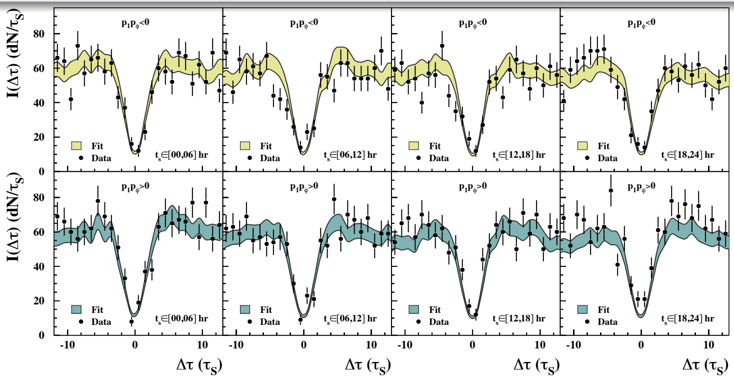


- Sensitivity strongly dependent on the vertex resolution
- Dedicated work to improve on vertex reconstruction near the IP
- Cut on kaon acollinearity improves tails
- Data analyzed in different bins of i) sidereal time (4) and ii) kaon momentum (2)

Results

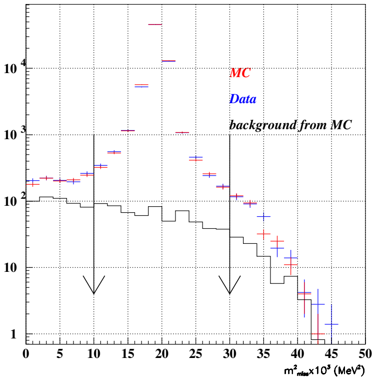
The best sensitivity ever reached in the quark sector [PLB 730(2014)89]:

$$\Delta a_o = (-6.0 \pm 7.7_{stat} \pm 3.1_{syst}) \times 10^{-18}\ \text{GeV}$$
$$\Delta a_x = (\ 0.9 \pm 1.5_{stat} \pm 0.6_{syst}) \times 10^{-18}\ \text{GeV}$$
$$\Delta a_y = (-2.0 \pm 1.5_{stat} \pm 0.5_{syst}) \times 10^{-18}\ \text{GeV}$$
$$\Delta a_z = (\ 3.1 \pm 1.7_{stat} \pm 0.5_{syst}) \times 10^{-18}\ \text{GeV}$$



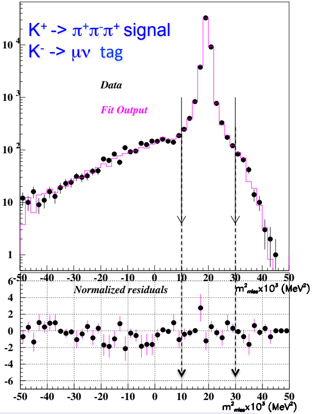
$K^+ \to \pi^+\pi^+\pi^-$: Data analysis

- The absolute BR($K^+ \to \pi^+\pi^+\pi^-$) is the last of the precision measurement in the kaon sector, the other dominant decays and the lifetime being obtained at sub–percent precision level
- It is based on $\sim$ 174 pb^{-1}
- The decays are tagged reconstructing the two–body decays of K$^-$
- Two pions are required to be reconstructed on the signal side
- The missing mass distribution from kaon (obtained from tagging side) and two pions, is used for event counting



Results

- From tagged samples of $\sim$ 12 M $K^- \to \mu^-\nu$ and $\sim$5 M $K^- \to \pi^-\pi^0$ we obtain 48,032 and 20,063$K^+ \to \pi^+\pi^-\pi^+$
- Systematics relating to tagging, efficiency, analysis cuts have been carefully evaluated and are at 0.5% level



$$BR(K^+ \to \pi^+\pi^-\pi^+(\gamma))|_{TagK_{\mu 2}} = (0.05552 \pm 0.00034_{stat} \pm 0.00034_{syst})$$
$$BR(K^+ \to \pi^+\pi^-\pi^+(\gamma))|_{TagK_{\pi 2}} = (0.05587 \pm 0.00053_{stat} \pm 0.00033_{syst})$$

and combining

$$BR(K^+ \to \pi^+\pi^-\pi^+(\gamma)) = (0.0557 \pm 0.0003_{stat} \pm 0.0003_{syst})$$

Constrained fit of $K^\pm$ BR's and lifetime

- KLOE provided consistent precision measurements of the $K^\pm$ lifetime and the six largest branching fractions
- The fit with the unitary constraint on the sum of the BR's, taking into account of the BR dependence on the lifetime and the covariance matrix gives $\chi^2/\text{ndf} = 0.24/1$ (P=0.68)

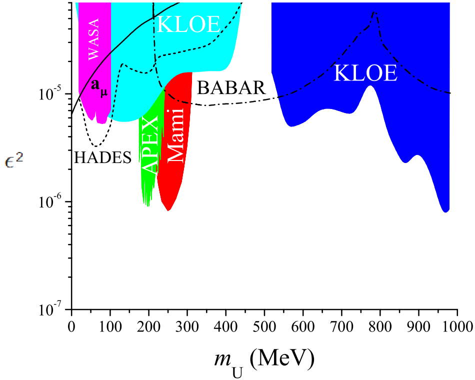
Parameter	Value						
$BR(K^+_{\mu 2})$	0.6372(11)						
$BR(K^+_{\pi 2})$	0.2070(9)	0.55					
$BR(\pi^+\pi^-\pi^+)$	0.0558(4)	-0.23	-0.05				
$BR(K^\pm_{e3})$	0.0498(5)	0.42	-0.15	0.06			
$BR(K^\pm_{\mu 3})$	0.0324(4)	-0.39	0.14	-0.05	-0.58		
$BR(\pi^\pm\pi^0\pi^0)$	0.01764(25)	-0.13	0.05	-0.02	0.04	-0.04	
$\tau^\pm_K$ (ns)	12.344(29)	0.20	0.19	-0.14	0.05	-0.04	0.02

Dark forces

- New gauge symmetries advocated for explaining dark matter
- Light vector bosons, with M_U in the GeV range are not completely ruled out if the dark sector is weakly coupled to the SM
- The KLOE program in this field includes several analyses
- Search for the U–boson resonance in the ηe^+e^- final state
- Search for the U–boson resonance in the $\mu^+\mu^-\gamma$ final state
- Search for the U–boson resonance in the $e^+e^-\gamma$ final state
- Search for associated U-h' production in the $\mu^+\mu^- +$ missing energy final state (invisible h' expected for $M_h' < M_U$)
- The U–boson portal should also be different from the SM photon (vector portal)
- Further analyses are feasible to search for U-bosons in case of fermion (quark) portal looking at $\eta\pi^0\gamma$ and $\eta\gamma \to (\pi^0\gamma\gamma)\gamma$ final states

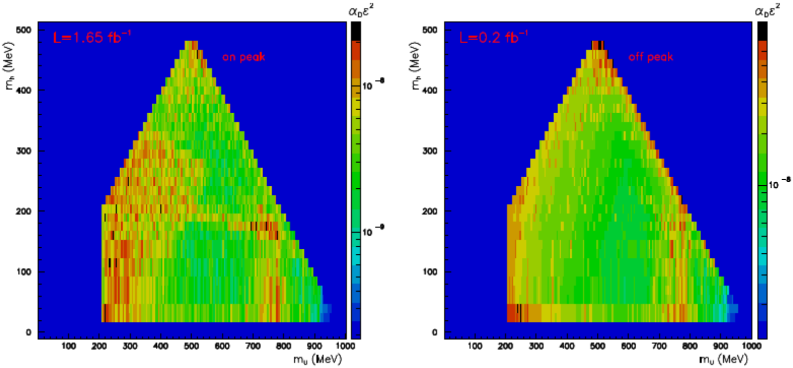
The exclusion plot

From the analysis of $\phi \to \eta e^+e^-$ and $e^+e^- \to \mu^+\mu^-\gamma$
No evidence for the signal $\to$ we obtaian an excluded region at 90% C.L. of couplings vs the U–boson mass



Limits on $e^+e^- \to Uh' \to \mu^+\mu^- +$ missing energy

From the analysis of final states with 2 μ + missing energy
On 1.65 fb^{-1} of on–peak data and ~200 pb^{-1} at 1 GeV (off–peak) no evidence for $e^+e^- \to Uh' \to \mu^+\mu^-$ + invisible h'



Transition form factors

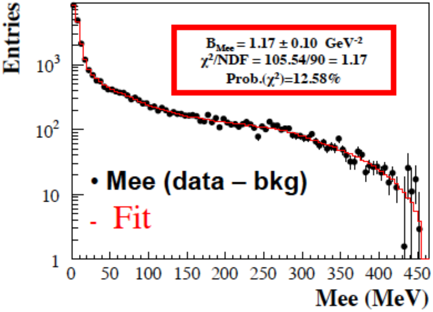
- Meson to photon couplings (TFF) are fundamental observables in hadron physics
- They are provided by radiative (and Dalitz–pair) meson decays, $V \to P\gamma^{(*)}$, e.g. $\phi \to \eta e^+ e^-$

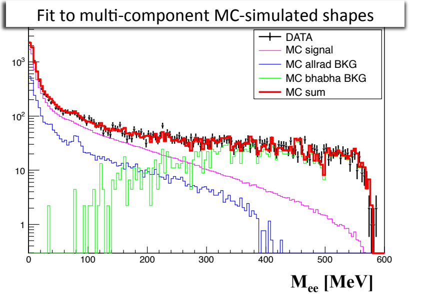
$$\frac{d}{dq^2}\Gamma\left(\phi \to \eta e^+ e^-\right) = \frac{\alpha}{3\pi}\Gamma\left(\phi \to \eta\gamma\right)\frac{\left|F_{\phi\eta}\left(q^2\right)\right|^2}{q^2}\sqrt{1-\frac{4m^2}{q^2}}\left(1+\frac{2m^2}{q^2}\right)\left[\left(1+\frac{q^2}{m_\phi^2-m_\eta^2}\right)^2-\frac{4m_\phi^2 q^2}{\left(m_\phi^2-m_\eta^2\right)^2}\right]^{3/2}$$

- and by meson production in γ–γ processes
- KLOE measured $F_{\phi\eta}$, $F_{\phi\pi^0}$
- With the new run and the γ–γ tagger system we can measure TFF $\gamma\gamma^{(*)} \to \pi^0$ at low q^2 with 5-6% per-bin precision and $\Gamma(\pi^0 \to \gamma\gamma)$ at 1% pecision level (5 fb^{-1} of integrated luminosity)

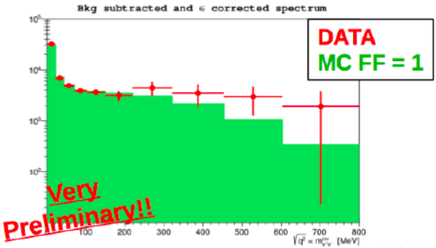
Transition form factors: $F_{\phi\eta}$, $F_{\phi\pi^0}$

From I. Sarra talk





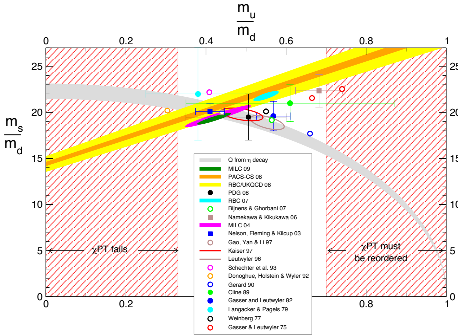
	SND/CMD-2 (2001)	KLOE
$b_{\phi\eta}$ [GeV^{-2}]	3.8 ± 1.8/ --	$1.17 \pm 0.10^{+0.07}_{-0.11}$
BR (x10^4)	1.19 ± 0.31 / 1.14 ± 0.16	$1.075 \pm 0.038 \pm 0.007^{+0.006}_{-0.002}$



Light quark masses from $\eta \to 3\pi$

H.Leutwyler 0911.1416 [hep-ph]

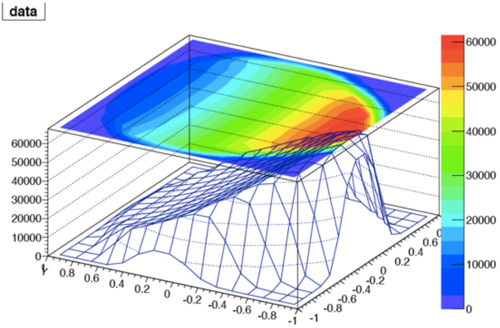
- Isospin violating decays are sensistive to quark mass differences
- $\eta \to 3\pi$ provides the experimental input to ChPT
- Branching fraction proportional to Q^{-4}; $Q^2 = \frac{m_s^2 - m_{ud}^2}{m_d^2 - m_u^2}$



- Dispersion relations have been applied to improve on the one–loop results in ChPT
- Theoretical and experimental work in progress to derive more powerful constraints on the light quark masses

The $\eta \to \pi^+\pi^-\pi^0$ Dalitz plot

- The analysis provides the coefficients of a polynomial expansion around the centre of the Dalitz plot, $\rho(X, Y) \propto 1+aY+bY^2+dX^2+fY^3$
- On respect previous KLOE results, JHEP0805(2008)006, the statistical improvement is of 4.48 10^6 events vs 1.34 10^6



The dominant systematic effect relating to pre–selection efficiency in old data overcome by the minimum–bias sample collected in 2004-2005

	a	b	d	f
JHEP0805,006	$-1.090(5)(^{+8}_{-19})$	0.124(6)(10)	$0.057(6)(^{+7}_{-16})$	0.140(20)
preliminary,2013	-1.104(3)	0.144(3)	0.073(3)	0.155(6)

Conclusions and Outlook

- The KLOE experiment has recently obtained several results on kaon and hadron physics
- The innermost part of the detector has been upgraded to improve vertex resolution near the IP, to increase the acceptance at low polar angle and to instrument the DAΦNE final focusing region
- A tagging system for γ–γ physics is installed
- DAΦNE commissioning is in progress
- The goal is to collect $\sim$ 5 fb^{-1} in 2-3 years