L'esperimento KLOE-2 ai LNF

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Outline

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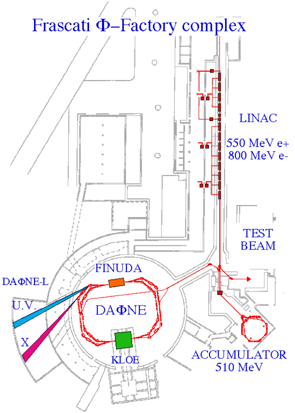
   - KLOE-2
2. Kaon Physics
   - $K_S \to \pi\mu\nu$
3. Hadron Physics
   - $\eta \to \pi^+\pi^-$ decay
   - The $\pi^\circ \to \gamma\gamma$ width
4. Other analyses in progress
5. Conclusions

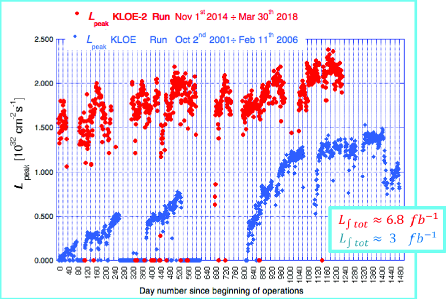
DAΦNE: the ϕ factory



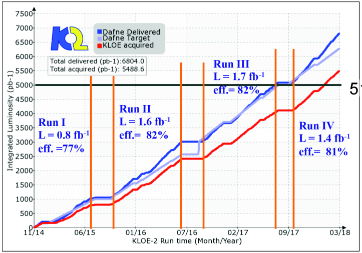
New interaction region:

- Large beam crossing angle: 2×12.5 *mrad*.
- Sextupoles for crabbed waist optics : 59% increase in terms of peak luminosity.

- e^+e^- collider @ $\sqrt{s} = M_\Phi = 1019.4$ *MeV*.
- 2 interaction regions and 2 separate rings.
- 105 + 105 bunches, $T_{RF} = 2.7$ *ns*.
- Best Performance (1999÷2006): $\mathcal{L}_{\text{peak}} = 1.5 \times 10^{32}\ cm^{-2}s^{-1}$.
- Best Performance (2014÷2018): $\mathcal{L}_{\text{peak}} = 2.4 \times 10^{32}\ cm^{-2}s^{-1}$.



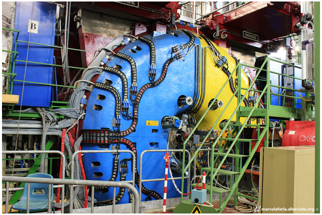
KLOE-2



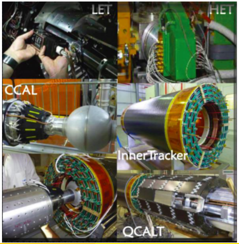
KLOE-2 experiment ended on March 30th 2018:

- $\mathcal{L}_{\text{acquired}} = 5.5\ fb^{-1}$.
- KLOE + KLOE-2 data sample: $\mathcal{L}_{int} = 8\ fb^{-1} \to 2.4 \times 10^{10}$ ϕ mesons produced, the largest sample ever collected at the $\phi(1020)$ peak in collider experiments. In particular we have: 8×10^{9} entangled pair of neutral K, and 3×10^{8} η mesons.

The KLOE detector has been rolled out from the IR after almost 20 years of operation



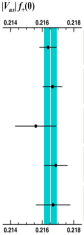
The KLOE-2 new sub-detectors



$K_S \to \pi\mu\nu$, the physics case

- The branching fraction for semi-leptonic decays of charged and neutral kaons together with the lifetime measurements are used to determine the $|V_{us}|$ element of the CKM quark mixing matrix. The relation among the matrix elements of the first row, $|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 1$, provides the most stringent test of the unitarity of the quark mixing matrix.
- the $\mathcal{B}(K_S \to \pi e\nu)$ decay provides the least precise determination of $|V_{us}|$.
- A new measurements of $\mathcal{B}(K_S \to \pi\mu\nu)$ allows an independent determination of $|V_{us}|$ and to extend the test of lepton-flavour universality to K_S semi-leptonic decays by comparison with the expected value of $(4.69 \pm 0.06) \times 10^{-4}$ derived from $\mathcal{B}(K_S \to \pi e\nu)$.

2.5 $|V_{us}| f_+(0)$ from world data: Update



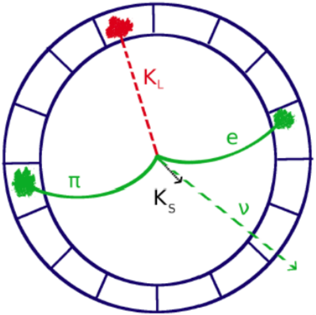
Approx. contrib. to % err from:

		% err	BR	τ	Δ	Int
K_Le3	0.2164(6)	0.26	0.09	0.20	0.11	0.05
$K_L\mu3$	0.2167(6)	0.29	0.15	0.18	0.11	0.07
K_Se3	0.2156(13)	0.61	0.60	0.02	0.11	0.05
$K^\pm e3$	0.2169(8)	0.35	0.27	0.06	0.21	0.05
$K^\pm\mu3$	0.2167(11)	0.50	0.45	0.06	0.21	0.07

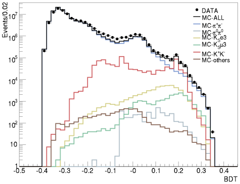
Average: $|V_{us}| f_+(0) = 0.21652(41)$ $\chi^2/\mathrm{ndf} = 0.98/4$ (91%)

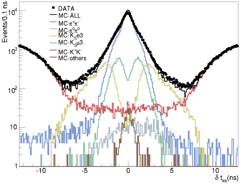
$K_S \to \pi\mu\nu$, the experimental measure procedure

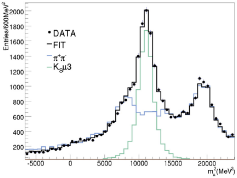
- The $K_S(K_L)$ mesons are identified (tagged) by the observation of a $K_L(K_S)$ meson in the opposite hemisphere.
- This tagging procedure allows the selection efficiency for $K_S \to \pi\mu\nu$ to be evaluated with good accuracy using a control sample of the abundant decay $K_L \to \pi\mu\nu$ tagged close to IP by the detection of $K_S \to \pi^+\pi^-$ decays.
- The branching fraction is extracted normalizing the number of $K_S \to \pi\mu\nu$ events to the number of $K_S \to \pi^+\pi^-$ events recorded in the same dataset.
- KLOE statistics 1.63 fb^{-1}.



$K_S \to \pi\mu\nu$, results: [PLB804(2020)135378]







Summary of systematic uncertainties of $\epsilon_{\pi\pi}$, $\epsilon_{\pi\mu\nu}$ and R_ϵ.

Source	$\epsilon_{\pi\pi}$ [%]	$\epsilon_{\pi\mu\nu}$ [%]	R_ϵ [%]
$K_S \to \pi^+\pi^-$ selection	0.1		
BDT selection		0.3	
TOF selection		3.0	
Fit m_μ^2 distribution		0.3	
MC and data CS statistics		0.8	
Trigger			0.1
T_0 determination			<0.1
K_L-crash and β^*			0.1
K_S identification			1.7
Total	0.1	3.1	1.7

$BDT > 0.18$ with kinematic variables in order to reject main background, PID with Time of Flight, Signal count give: $N_{ev} = (7223 \pm 180)\ K_{S\mu3}$ from the fit of $M_\mu^2 = (E_{K_S,tag} - E_\pi - p_{\rm mis})^2 - p_\mu^2$.

$$\mathcal{B}(K_S \to \pi\mu\nu) = (4.56 \pm 0.11_{\rm stat} \pm 0.17_{\rm syst}) \times 10^{-4}$$

$\eta \to \pi^+\pi^-$ decay, the physics case

- In the Standard Model the P and CP violating decay $\eta \to \pi^+\pi^-$ with an expected branching fraction less than 2×10^{-27}.
- Introducing CP violation in strong interactions through a possible $\theta-$term in the QCD Lagrangian would enhance this limit at the level of $\sim 3 \times 10^{-17}$.
- Allowing additional CP violation phases in the extended Higgs sector of the electroweak theory could generate the decay with a branching fraction up to 1.2×10^{-15}.
- Detection at any accessible level would be signal of CP violation beyond the SM.
- Best limit $\mathcal{B} < 1.3 \times 10^{-5}$ at 90% C.L. ($\mathcal{L}_{int} = 350\ pb^{-1}$) [KLOE, PLB606(2005)276].
- LHCb recent measurement: $\mathcal{B} < 1.6 \times 10^{-5}$ at 90% C.L. [PLB764(2017)233].

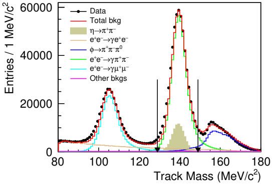
$\eta \to \pi^+\pi^-$ decay, the experimental measure procedure

Selection of signal candidate events $\phi \to \eta\gamma$ with $\eta \to \pi^+\pi^-$:

- A neutral cluster in the EMC compatible with the photon recoiling against the η meson from the IP.
- Two opposite charged trackswith a vertex near the e^+e^- interaction point (IP) are required.
- The remaining background originates from the processes $e^+e^- \to e^+e^-\gamma$, $\mu^+\mu^-\gamma$, $\phi \to \rho^\pm\pi^\mp$ with $\rho^\pm \to \pi^\pm\gamma$, and $\phi \to \pi^+\pi^-\pi^\circ$ with an undetected photon.
- To separate $\pi^+\pi^-\gamma$ and $e^+e^-\gamma$ events, particle identification with a time of flight technique is used.
- KLOE statistics 1.63 fb^{-1}.

$\eta \to \pi^+\pi^-$ decay, results

Accepted for the pubblication on JHEP



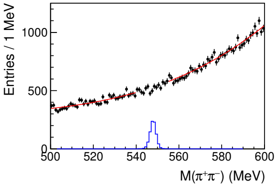


Table 1. Summary of the systematic uncertainties.

Source	Relative uncertainty(%)
Background Estimate	0.5
ψ cut	2.0
M_{trk} cut	3.0
Time of flight cuts	1.0
Integrated luminosity	0.6
$\sigma(e^+e^- \to \phi \to \eta\gamma)$	1.4
Total	4.1

Fit η sidebands in the regions (500,540) and (555,600) permit to estimate the background in signal region. Evaluation of the UL using the CLs method:

$$\mathcal{B}(\eta \to \pi^+\pi^-) < 4.4 \times 10^{-6} \text{ at 90\% confidence level}.$$

The $\pi^\circ \to \gamma\gamma$ width, physics case

- The QCD Green's function $\langle VVA \rangle$ exhibits the axial anomaly of Adler, Bell and Jackiw (non-conservation of the axial vector current), which is responsible for the decay $\pi^0 \to \gamma\gamma$.
- The anomaly is a pure one-loop effect (triangle diagram).
- Link between the strong dynamics of infrared physics at low energies (pions) with the perturbative description in terms of quarks and gluons at high energies.
- Due to the recent theoretical advances, the decay width $\Gamma_{\pi^0 \to \gamma\gamma}$ is now predicted with a 1.4% accuracy:

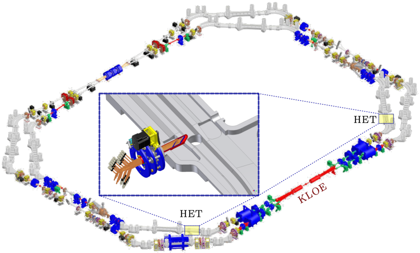
$$\Gamma^{\rm theor}_{\pi^0 \to \gamma\gamma} = 8.09 \pm 0.11 \; eV. \quad (1)$$

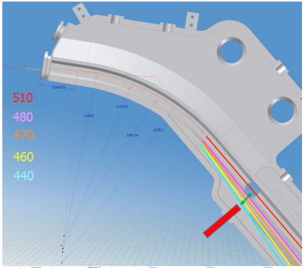
- The most precise experimental measurement on this decay comes from the photo-production of pions on a nuclear target via the Primakoff effect.

The $\pi^\circ \to \gamma\gamma$ width, HET detector idea

In order to fully reconstruct the reaction $e^+e^- \to e^+e^-\gamma\gamma$ at the ϕ peak, new detectors along the (DAΦNE) beam line have been installed in order to detect the e^+e^- in the final state.
General scheme:

- $e^+_{in}e^-_{in} \to e^+_{fin}e^-_{fin}\gamma\gamma \to e^+_{fin}e^-_{fin}X$
- $e^+_{fin}e^-_{fin}$ detected by HETs
- $X = (\pi^\circ,\ \pi\pi$ or $\eta)$ detected by KLOE

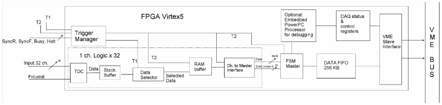


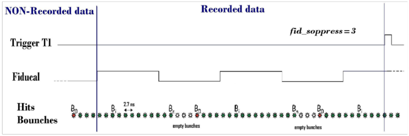


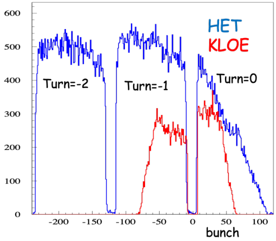
The $\pi^\circ \to \gamma\gamma$ width, HET detector DAQ

HET detectors could store data corresponding to 3 DAΦNE turns and transfer them to KLOE DAQ when KLOE trigger is asserted:

- A^+ is in coincidence with KLOE
- A_0 and A_2 are pure accidentals

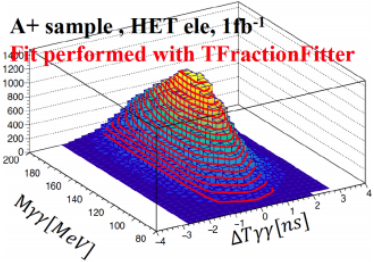


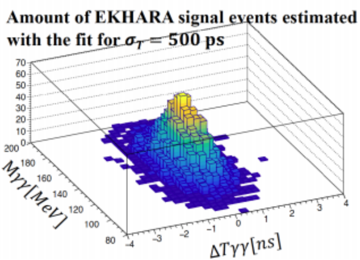




The $\pi^\circ \to \gamma\gamma$ width, results *Work in progress*

Comparison of A^+ and $A_{1,2}$ samples performed with $1 fb^{-1}$ shows 3500 ± 700 tagged events in the $M_{\gamma\gamma}$ vs $\Delta T_{\gamma\gamma}$ region where $\gamma\gamma \to \pi^\circ$ are expected.





Other analyses in progress

1. $K_S \to 3\pi^\circ$ (CP viol.)
2. T/CPT tests with $\phi \to K_S K_L \to 3\pi^\circ \pi e\nu, \pi\pi\pi e\nu$
3. $K_S \to \pi^+\pi^-$ and $K_L \to \pi^+\pi^-$
4. $K_S \to \pi e\nu$
5. $\phi \to \eta\pi^+\pi^-$ and $\phi \to \eta\mu^+\mu^-$
6. $\eta \to \pi^\circ\gamma\gamma$
7. $\eta \to \pi^+\pi^-\pi^\circ$
8. ...

Conclusions

1. KLOE and KLOE-2 collected 8 fb^{-1} which correspond to 2.4×10^{10} ϕ mesons produced, the largest sample ever collected at the $\phi(1020)$ peak in e^+e^- collider experiments.
2. $\mathcal{B}(K_S \to \pi\mu\nu) = (4.56 \pm 0.11_{\text{stat}} \pm 0.17_{\text{syst}}) \times 10^{-4}$ to be compared with the expected value of $(4.69 \pm 0.06) \times 10^{-4}$ assuming lepton-flavour universality.
3. The upper limit at 90% CL of $\mathcal{B}(\eta \to \pi^+\pi^-) < 4.4 \times 10^{-6}$ which is almost a factor of three smaller than the previous limit.
4. $\gamma - \gamma$ physics program at KLOE thanks to new detectors.
5. Other analyses are in progress using KLOE + KLOE-2 data.