LATEST RESULTS FROM DAΦNE*

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The DAΦNE Frascati ϕ factory has continously improved its performances reaching in 2002 an instantaneous luminosity of $8 \times 10^{31}\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$. The DEAR experiment, concluded in 2002, has measured the de-excitation of kaonic atoms. The KLOE experiment, still running, has measured several branching ratios for neutral and charged kaons decays, ρ, η, η', a_0 and f_0 mesons parameters and, via the radiative return, the $e^+e^- \to \pi^+\pi^-$ cross section. Preliminary and final results are presented.

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1. Introduction

The DAΦNE ϕ-*factory* [1] is successfully running in Frascati since 1999. It is particular design, with two different rings intersecting only in the two interaction regions, was intended to reach the extremely high luminosity of $5 \times 10^{32}\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$, allowing 120 bunches per ring with a lifetime of 2 hours and an average luminosity of 5 fb^{-1} per year.

During the year 2002, in the KLOE interaction region, a luminosity of $8\times 10^{31}\ \mathrm{cm}^{-2}\,\mathrm{s}^{-1}$ has been reached using 45 bunches per ring. Beam lifetime has reached the 40 minutes. The total integrated luminosity, optimized by injecting new bunches during the data taking, has been of 0.3 fb^{-1} in 140 days corresponding to $\sim 2\,\mathrm{pb}^{-1}/\mathrm{day}$, more than the double of what had been obtained in 2001.

In the last months of year 2002, in the other interaction region, the DEAR experiment has collected 77 pb^{-1} with a maximum luminosity of $7 \times 10^{31}\ \mathrm{cm}^{-2}\,\mathrm{s}^{-1}$ and 100 bunches circulating in each ring [2].

In the year 2003 major changes have taken place in DAΦNE optics, in particular for the KLOE interaction region the layout of the low beta permanent quadrupoles has been substantially modified for easier tuning of the machine.

The new DAΦNE setup aims to reach a luminosity of $2 \times 10^{32}\ \mathrm{cm}^{-2}\,\mathrm{s}^{-1}$.

The FINUDA experiment has been installed in the interaction region previously occupied by the DEAR experiment.

In the fall of 2003 KLOE will restart taking data with the aim of collecting 2 fb^{-1} before the end of 2004.

The analysis of the data already collected by the DEAR and KLOE experiments has produced the results that will be shown in the following.

2. The DEAR experiment

2.1. Physics program

The DEAR (DAΦNE Exotic Atoms Research) experiment [3] has the goal of measuring the isospin dependent antikaon–nucleon scattering lengths, a_0 and a_1, via the measurement of the K_α line shift (ϵ) and width (Γ) in kaonic hydrogen and deuterium.

From the Deser–Trueman formulas [4] one has for kaonic hydrogen:

$$\epsilon + i\frac{\Gamma}{2} = 412 \cdot a_{K^-p}\ \mathrm{eV\,fm}^{-1} \tag{1}$$

and for kaonic deuterium:

$$\epsilon + i\frac{\Gamma}{2} = 601 \cdot a_{K^-d}\ \mathrm{eV\,fm}^{-1} \tag{2}$$

and, extracting a_{K^-n} from a_{K^-d}, one gets:

$$a_0 = \ 2 \cdot a_{K^-p} - a_{K^-n} \, ; \quad a_1 = \ a_{K^-n} \, . \tag{3}$$

These amplitudes give crucial informations about the meson–nucleon sigma terms and the strangeness content of the proton.

2.2. Experimental technique and results

The experimental setup contains a pressurized cryogenic target cell with a diameter of 11 cm and a thickness of 75 μm of kapton where the kaons, produced in the ϕ decays, are stopped and captured to form kaonic atoms.

The photons produced in the de-excitation of these atoms are detected by 16 CCD-55 (*Charged Coupled Devices*).

In a first period of data taking a nitrogen target has been used to tune up the apparatus: the yield of kaonic nitrogen transitions is indeed 20 times higher than the kaonic hydrogen ones.

Using the ~ 10 pb^{-1} collected in the October 2002, the yields of the following 3 transitions have been measured for the first time (Fig. 1), obtaining the following results [5]:

$$\begin{array}{llll} 7 \rightarrow 6 & \text{at } \ 4.6 \text{ keV}: & 2690 \pm 650 \text{ events} & (\, Y = 33.7 \pm \ 8.1 \pm 3.4\% \,) \\ 6 \rightarrow 5 & \text{at } \ 7.6 \text{ keV}: & 5320 \pm 395 \text{ events} & (\, Y = 55.5 \pm \ 4.2 \pm 5.5\% \,) \\ 5 \rightarrow 4 & \text{at } 14.0 \text{ keV}: & 1360 \pm 330 \text{ events} & (\, Y = 66.4 \pm 15.6 \pm 6.4\% \,) \end{array}$$

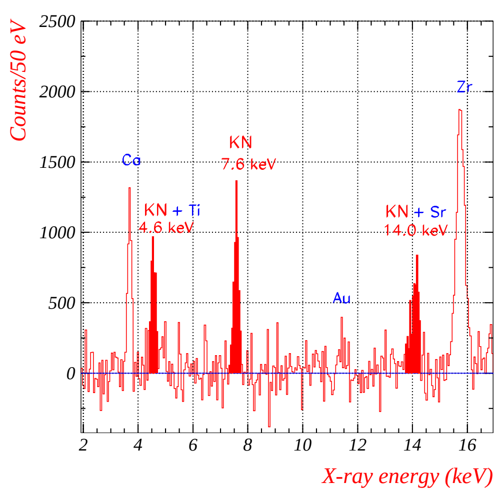

Fig. 1. Background subtracted energy spectrum obtained with KN run of October 2002 [6].

Using the KN data the feasibility of a precision measurement of the charged kaon mass has also been proved [7].

In December 2002, DEAR has collected ~ 60 pb^{-1} with an hydrogen target to measure the K_α line of KH. In addition, background data with no collision, equivalent to ~ 30 pb^{-1} in collision, have been collected for the study of the background.

Two different analyses based on the global fit of the KH spectrum before and after background subtraction have given as preliminary results for the K_α line shift and width [8]:

$$\epsilon = -(162 \pm 40)\text{ eV} \; ; \quad \Gamma = \; 200 \pm 80\text{ eV}\,. \tag{4}$$

2.3. Future plans

An upgrade of the DEAR experiment called SIDDHARTA (SIlicon Drift Detector for Hadronic Atoms Resarch by Timing Application) is under study. The new setup will use fast triggerable devices, namely Silicon Drift Detectors, the trigger being given by the charged kaons entering the cell. A precision at the eV level is aimed on K_α lines of kaonic hydrogen and deuterium. The observation of other exotic atoms will also be possible.

3. The KLOE experiment

3.1. Experimental setup

KLOE (K LOng Experiment) is a general purpose detector [9] whose characteristics have been optimized for the study of the CP violating decays of the neutral kaons.

The main components of the detector are (Fig. 2):

- a *Superconducting Solenoid* giving a magnetic field of 0.52 T.
- the *Drift Chamber* [10]: a cylindrical shape (ø= 4 m, l=3.3 m) filled with a gas mixture, 90% He+10% Isobutane, instrumented with 12582 stereo sense wires. It gives a momentum resolution $\sigma_p/p \leq 0.4\%$ for tracks with $p > 100$ MeV and $\theta > 45°$. The spatial resolution is 150 μm in the radial direction and 2 mm in the longitudinal one.
- the *ElectroMagnetic Calorimeter* [11]: it is a $15X_0$ sampling calorimeter with lead and scintillating fibers read at both sides by photomultipliers. With its cylindrical shape it covers 98% of the solid angle. The energy resolution is $\sigma_E/E = \; 5.7\%/\sqrt{E(\text{GeV})}$. The time resolution is

$\sigma_t = 54\ \mathrm{ps}/\sqrt{E(\mathrm{GeV})} \oplus 50\ \mathrm{ps}$ [1]. The spatial resolution for completely neutral vertices, *e.g.* $K^0_{\mathrm{L}} \to \gamma\gamma$, reconstructed inside the drift chamber is ~ 1.5 cm.

- the *Quadrupole CALorimeter* [12]: two smaller sampling calorimeters with lead and scintillating tiles, surrounding the low β quadrupoles to complete the calorimetric hermeticity.

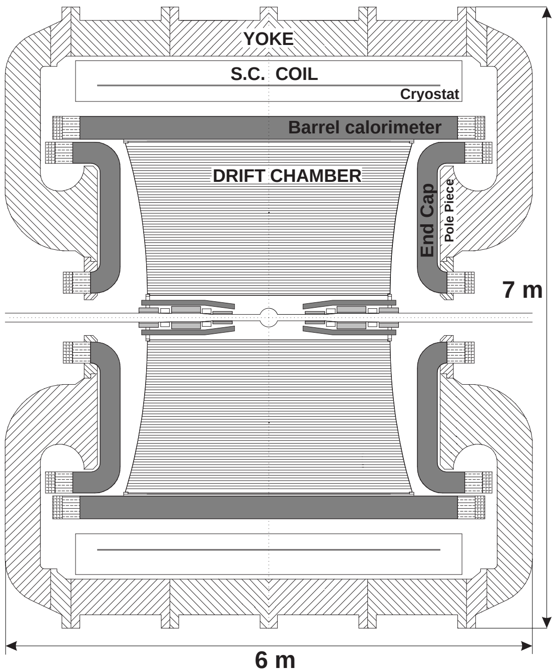

Fig. 2. Schematic view of KLOE detector.

3.2. KLOE physics

Most of the ϕ mesons decay in charged kaons (49%) or neutral kaons (34%), so that kaon physics is the largest part of KLOE program.

Other particles, produced in ϕ decays with enough abundance to improve the existing experimental measurements, are ρ ($\sim$15%), η ($\sim$1.3%), η' ($O(10^{-4})$), a_0 ($O(10^{-4})$) and f_0 ($O(10^{-4})$).

Furthermore, thanks to the *radiative return* that reduces the center of mass energy of the colliding beams, KLOE can measure the hadronic cross section, $e^+e^- \to \pi^+\pi^-$, in the crucial region from the $\pi\pi$ threshold to the ϕ resonance.

[1] Interaction time spread due to the bunch length is not included.

Results presented in the following are obtained from the analysis of 2000 data (25 pb^{-1}) and, in some cases, from the preliminary analysis of 2001 (170 pb^{-1}) and 2002 (280 pb^{-1}) data.

3.2.1. Kaon physics

Kaons are produced at a ϕ-factory in a pure antisymmetric initial state with quantum numbers $J^{\mathrm{PC}} = 1^{--}$. At DAΦNE the ϕ mesons are produced practically at rest, with only a small momentum (~ 13 MeV$/c$) in the plane of the orbit, so that the kaons are produced practically back to back.

In the case of neutral kaons one has:

$$|i\rangle \simeq \frac{1}{\sqrt{2}}(|K_{\mathrm{L}},\vec{p}\rangle|K_{\mathrm{S}},-\vec{p}\rangle - |K_{\mathrm{L}},-\vec{p}\rangle|K_{\mathrm{S}},\vec{p}\rangle)\,. \tag{5}$$

This simultaneous production allows for a clean tagging of $K_{\mathrm{S}}(K_{\mathrm{L}})$ looking at the $K_{\mathrm{L}}(K_{\mathrm{S}})$ on the other side, having also a precise information on the tagged kaon momentum.

The two main tagging algorithms in KLOE are:

- $\boldsymbol{K_{\mathrm{S}}}$ **tagged** by K_{L} interaction in the calorimeter (K_{L}-*crash*): K_{L} interactions are identified using the time of flight and some additional request on the energy deposit [13]. The tagging efficiency, mostly geometrical, is $\sim 30\%$. The K_{S} momentum is obtained with a resolution of ~ 2 MeV and an angular resolution of $\sim 1^\circ$ (0.3° in Φ).

- $\boldsymbol{K_{\mathrm{L}}}$ **tagged** by $K_{\mathrm{S}} \to \pi^+\pi^-$ vertex close to the interaction point: K_{S} decays are identified asking for the K_{S} invariant mass and momentum. Tagging efficiency, mainly geometrical, is $\sim 70\%$. The resolution on K_{L} momentum is ~ 2 MeV and the angular resolution is $\sim 1^\circ$.

Using just the $\sim 2\times 10^6$ K_{L}-*crash* tagged K_{S} from 17 pb^{-1} collected in 2000, KLOE has measured the ratio of the partial widths of the main K_{S} decay modes [13]:

$$\frac{\Gamma(K_{\mathrm{S}} \to \pi^+\pi^-(\gamma))}{\Gamma(K_{\mathrm{S}} \to \pi^0\pi^0)} = 2.236 \pm 0.003 \pm 0.015\,. \tag{6}$$

The measurement is fully inclusive with respect to the radiated photon energy. The ratio in (6) is important not only because it enters in the *double ratio* used to measure $\mathrm{Re}(\frac{\epsilon'}{\epsilon})$, but also because it can be used to derive the strong phases in the amplitudes $A(K_{\mathrm{S}} \to \pi\pi)$, investigating the presence of *isospin-breaking* electromagnetic phase shifts.

Other interesting $K_{\rm S}$ branching ratios measured by KLOE are:

$$\begin{aligned}\mathrm{BR}(K_{\rm S}\to\pi^-e^+\nu) &= (3.46\pm0.09\pm0.06)\times10^{-4}\,,\\ \mathrm{BR}(K_{\rm S}\to\pi^+e^-\bar{\nu}) &= (3.33\pm0.08\pm0.05)\times10^{-4}\,,\end{aligned}\tag{7}$$

the results are obtained from a still preliminary analysis of 170 pb^{-1} collected in 2001 and are consistent with the ones published using the 2000 data sample [14].

Combining the results in (7) one gets the first preliminary measurement of $K_{\rm S}$ semileptonic asymmetry:

$$A_{\rm S}=\frac{\mathrm{BR}(K_{\rm S}\to\pi^-e^+\nu)-\mathrm{BR}(K_{\rm S}\to\pi^+e^-\bar{\nu})}{\mathrm{BR}(K_{\rm S}\to\pi^-e^+\nu)+\mathrm{BR}(K_{\rm S}\to\pi^+e^-\bar{\nu})}=(19\pm17\pm6)\times10^{-3}\,.\tag{8}$$

This asymmetry can be compared with the value of the $K_{\rm L}$ semileptonic asymmetry [15] to perform a nice test of CPT conservation.

$K_{\rm S}$ semileptonic decays can also be used to test the $\Delta S=\Delta Q$ rule which forbids decays like $K^0\to\pi^+e^-\bar{\nu}$. The $\Delta S=\Delta Q$ violation is commonly expressed via:

$$\mathrm{Re}\,x_+=\frac{1}{2}\frac{\mathrm{BR_S}(\pi e\nu)/\tau_{\rm S}-\mathrm{BR_L}(\pi e\nu)/\tau_{\rm L}}{\mathrm{BR_S}(\pi e\nu)/\tau_{\rm S}+\mathrm{BR_L}(\pi e\nu)/\tau_{\rm L}}\,.\tag{9}$$

If CPT holds, $\Delta S=\Delta Q$ implies $x_+=0$. The standard model allows $\Delta S=\Delta Q$ violation only at next to leading order predicting $\mathrm{Re}\,x_+\sim10^{-7}$. KLOE preliminary result (2001 data sample) is:

$$\mathrm{Re}\,x_+=(2.2\pm5.3\pm3.5)\times10^{-3}\tag{10}$$

in agreement with the comparable result obtained by CPLEAR [16].

Using an energy scan around the ϕ peak, KLOE has also measured the $K_{\rm S}$ mass [17]:

$$m(K_{\rm S})=497.583\pm0.005\pm0.020\ \mathrm{MeV}\tag{11}$$

by normalizing the energy scale to the precise determination of the ϕ mass obtained by resonant beam depolarization at Novosibirsk [18].

$K_{\rm L}$ neutral decays are reconstructed using the momentum information obtained from the $K_{\rm S}\to\pi^+\pi^-$ vertex and the time and position of the energy deposited in the calorimeter by the photons produced in the decays. These informations are sufficient to completely reconstruct neutral vertices like $K_{\rm L}\to\pi^0\pi^0$ or $K_{\rm L}\to\gamma\gamma$ with a spatial resolution of ~1.5 cm.

Exploiting the simple dynamics of the $\gamma\gamma$ decay it is possible to obtain a precise measurement of the corresponding branching ratio [19] (362 pb^{-1} analyzed):

$$\mathrm{BR}(K_{\mathrm{L}} \to \gamma\gamma) = (2.793 \pm 0.022 \pm 0.024) \times 10^{-3} \tag{12}$$

in agreement with the recent NA48 result [20].

Preliminary results on K_{L} charged decays are also in good agreement with the PDG values [21]. In particular, a final error much better than 1% is expected on K_{l3} decays, improving the error on the kaon form factors (λ_+, λ_0), the K_{L} lifetime (τ_{L}) and, finally, on the CKM matrix element V_{us}.

Charged kaons are tagged using the two body decays into $\mu^\pm\nu$ and $\pi^\pm\pi^0$. Again one kaon is tagged looking at the other kaon on the opposite side.

Using the momentum and time of flight informations obtained by the drift chamber and the calorimeter it's possible to isolate the different decay channels [22].

In particular for the $\pi^\pm\pi^0\pi^0$ channel one gets:

$$\mathrm{BR}(K^\pm \to \pi^\pm\pi^0\pi^0) = \ 1.807 \pm 0.008 \pm 0.018\% \quad (112\ \mathrm{pb}^{-1})\,. \tag{13}$$

Looking at the charge asymmetries of the slopes of the Dalitz plot for this channel it's possible to have an evidence of direct CP violation in charged kaon decays. A preliminary fit of the Dalitz plot with just 6.3 pb^{-1} has obtained[2]:

$$g = 0.607 \pm 0.026\,, \quad h = 0.026 \pm 0.027\,, \quad k = 0.0080 \pm 0.0037\,. \tag{14}$$

3.2.2. Non-kaon physics at ϕ resonance

From the fit of the Dalitz plot for the $\phi \to \pi^+\pi^-\pi^0$ decays, it's possible to obtain the ρ-meson parameters for its three charge states and the cross section for $\mathrm{e}^+e^- \to \omega\pi^0$ with $\omega \to \pi^+\pi^-$. The result obtained with 17 pb^{-1} from 2000 data sample is [23]:

$$\begin{aligned} m_\rho &= \ 775 \pm 0.5 \pm 0.3\ \mathrm{MeV}\,, & \Gamma_\rho &= \ 143.9 \pm 1.3 \pm 1.1\ \mathrm{MeV}\,, \\ m_0 - m_\pm &= \ 0.4 \pm 0.7 \pm 0.6\ \mathrm{MeV}\,, & m_+ - m_- &= \ 1.5 \pm 0.8 \pm 0.7\ \mathrm{MeV}\,, \end{aligned}$$
$$\sigma(e^+e^- \to \omega\pi^0 \to \pi^+\pi^-\pi^0) = 92 \pm 15\ \mathrm{pb}\,.$$

Using 2000 data KLOE has also measured the relative branching ratio for ϕ decays in $\eta'\gamma$ and $\eta\gamma$ [24]:

$$\frac{\mathrm{BR}(\phi \to \eta'\gamma)}{\mathrm{BR}(\phi \to \eta\gamma)} = (4.70 \pm 0.47 \pm 0.31) \times 10^{-3} \tag{15}$$

[2] Errors are statistical only.

from where one can extract the pseudoscalar mixing angle ($\theta_{\rm P}$) and the gluon content in η' (Z'):

$$\theta_{\rm P} = \ (12.9^{+1.9}_{-1.6}\ )^\circ \ ; \quad (Z')^2 = \ 0.06^{+0.09}_{-0.06} \, . \tag{16}$$

Scalar mesons are detected at KLOE through their decay channels: $a_0 \to \eta\pi^0\gamma$ [25] and $f_0 \to \pi^0\pi^0\gamma$ [26]. From the integration of the $\eta\pi^0$ and $\pi^0\pi^0$ mass spectra of 2001 and 2002, these preliminary updated branching ratios are found:

$$\begin{aligned} {\rm BR}(\phi \to \eta\pi^0\gamma) \ &= \ (0.85 \pm 0.05 \pm 0.06) \times 10^{-4} \, , \\ {\rm BR}(\phi \to \pi^0\pi^0\gamma) \ &= \ (1.09 \pm 0.03 \pm 0.05) \times 10^{-4} \, . \end{aligned}$$

A fit of the Dalitz plots to extract the a_0 and f_0 contributions is in progress.

3.2.3. Measurement of hadronic cross section

The determination of hadronic cross section $\sigma(e^+e^- \to \pi^+\pi^-)$ in the energy region from $\pi\pi$ threshold to the ϕ resonance is still one of the main source of error for the theoretical estimate of the muon anomaly (a_μ) [27].

Furthermore, recent results obtained in this region from e^+e^- and τ data show an inconsistency of some percent [28].

Despite of the fact that DAΦNE runs at fixed energy, $\sqrt{s} = m_\phi$, KLOE can measure the hadronic cross section via the *radiative return* [29]: Initial State Radiation (ISR) from the beams can lower the value of $\sqrt{s}$ down to the $\pi^+\pi^-$ threshold.

KLOE $\pi\pi\gamma$ events are selected asking for two charged tracks coming from the interaction region with an angle respect to the beam pipe $50^\circ < \theta < 130^\circ$. Additional cuts on the momentum, $p_{\rm T} > 160$ MeV or $|p_Z| > 90$ MeV, are used to reject tracks spiraling along the beam line.

In order to suppress the events in which the $\pi\pi$ invariant mass is reduced by the presence of a Final State Radiated (FSR) photon, a cut on the missing momentum angle, $\theta_{\rm miss} < 15^\circ$ *or* $\theta_{\rm miss} > 165^\circ$, is imposed.

Background from Bhabha scattering, $\phi \to \pi^+\pi^-\pi^0$ decays and $e^+e^- \to \mu^+\mu^-\gamma$ events is suppressed using a particle identification method based on the time of flight, the energy deposit in the calorimeter and the kinematic closure of the event in the hypothesis of only one photon in the final state [30].

Residual background is evaluated from the fit of the mass distribution of the charged particles and subtracted.

The yield of the selection is ~ 11000 events/pb^{-1}.

The cross section is obtained by dividing for the luminosity measured with large angle Bhabha events using the BABAYAGA generator [31].

The $e^+e^- \to \pi^+\pi^-$ cross section is obtained from the $e^+e^- \to \pi^+\pi^-(\gamma)$ cross section by dividing for the *radiation function* (Fig. 3(left)) given by the PHOKHARA event generator [32] used with $F_\pi = 1$ and vacuum polarization off[3] and multiplying by the appropriate kinematic factor.

After correcting for the vacuum polarization the bare $e^+e^- \to \pi^+\pi^-$ cross section shown in Fig. 3(right) is obtained.

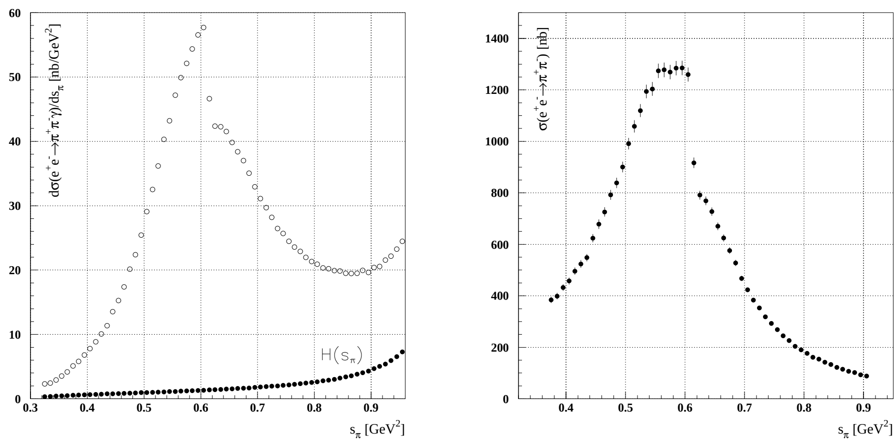

Fig. 3. Left: Cross section for $e^+e^- \to \pi^+\pi^-\gamma$. The radiator function H is also shown. Right: Bare cross section for $e^+e^- \to \pi^+\pi^-$.

The corresponding preliminary value for the $\pi\pi$ contribution to a_μ in the interval $0.37 < s < 0.93$ GeV^2 is:

$$a_\mu^{\pi\pi} = 378.4 \pm 0.8_{\rm stat} \pm 4.5_{\rm syst} \pm 3.0_{\rm theo} \pm 3.8_{\rm FSR}\,, \tag{17}$$

where the theoretical error comes from the knowledge of the radiation function, of the vacuum polarization and of the Bhabha cross section used to determine the luminosity.

The result (17) is in good agreement with the one obtained by CMD2 with the energy scan method [33] and confirms a discrepancy with τ data.

It is a pleasure to thank C. Curceanu (Petrascu) for the help she gave in presenting the DEAR results and all the DAΦNE team for the nice successful work they did to improve the accelerator performances.

[3] The method is exact only if the contribution of FSR is negligible. This holds only at leading order (see [32]) and the effect of residual FSR will be quoted as a 1% in the final systematical error.

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