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SEARCH OF GLUEBALLS IN THE $J/\psi \to \gamma\phi\phi$ DECAY

DM2 Collaboration

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In a study of the radiative decay $J/\psi \to \gamma\phi\phi \to \gamma K^+K^-K^+K^-$, from the 8.6 million J/ψ produced in the DM2 experiment at DCI, we found a large production of events with $\phi\phi$ mass below the η_c. The branching ratio, for $m_{\phi\phi} < 2.9$ GeV/c^2, is $BR(J/\psi \to \gamma\phi\phi) = (3.1 \pm 0.3 \pm 0.6) \times 10^{-4}$. The angular analysis of the events with $\phi\phi$ mass below 2.5 GeV/c^2 is consistent with a 2^{++} assignment. An enhancement near 2.2 GeV/c^2 shows a preferred spin–parity $J^P = 0^-$.

Introduction. The radiative decays of the J/ψ are a powerful tool to reach exotic states, as gluonium. Up to now unambiguous glueballs have not been identified. Among the possible candidates are the three states $g_T(2100)$, $g_T(2200)$, $g_T(2360)$, decaying into two ϕ's, seen in the reaction $\pi^- p \to n\phi\phi$ [1]. Such states should be observed in the $J/\psi \to \gamma\phi\phi$ decay too.

In the search of the η_c in this channel, reported in the preceding letter [2], we observed a large production of events at lower ($\phi\phi$) masses. In this paper we report the results of the specific analysis adopted for these events.

The final statistics, 92 events for $m_{\phi\phi} < 2.9$ GeV/c^2, is too low to give a clean interpretation of the overall spectrum. Nevertheless, there is place for a resonant $\phi\phi$ production for $m_{\phi\phi} < 2.5$ GeV/c^2. The angular distribution for the events in this mass interval is consistent with the presence of 2^{++} states. At 2.2 GeV/c^2, where the efficiency is the lowest, a peak of 15 events is observed, with a preferred spin–parity 0^-. Parity conservation forbids such a pseudoscalar state to decay into $K\bar{K}$.

Events selection. The data sample used in this analysis is the 8.6 million of J/ψ, collected by the DM2 experiment. The DM2 detector [3], operated at DCI, the Orsay e^+e^- colliding ring, is a large solid angle spectrometer. Its main features are reported in the preceding letter.

The first selection criteria do not differ from those used in the η_c search. The $J/\psi \to \gamma\phi\phi$ candidates were selected identifying both ϕ's in their K^+K^- decays.

The events were required to have four well-reconstructed tracks, coming from a common vertex inside the fiducial region along the beams, with zero total charge. The kaons are tracked even if they decay inside the drift chamber as soon as the transverse flight is greater than 60 cm.

The missing energy of each event, in the hypothesis that all the tracks are kaons, has to match the missing momentum within 200 MeV/c^2.

A loose time-of-flight condition is then applied. We required, for each event, at least one measured TOF and all the measured TOF's consistent with the kaon assignment within 3σ (1.7 ns). In order to select $\phi\phi$ events, both masses of two independent K^+K^- pairs have to match the ϕ mass within 20 MeV/c^2.

The invariant mass distribution of the four-kaon system for the accepted events shows the presence of a large smooth signal at low mass values (fig. 1), together with the J/ψ peak and the small enhancement at the η_c. The study of this last signal was reported in the preceding letter. In order to get a background estimate, we defined as false ϕ, ϕ_F, each K^+K^- pair with a mass

$$20\ \mathrm{MeV}/c^2 < (m_{KK} - m_\phi) \leqslant 60\ \mathrm{MeV}/c^2 .$$

All the events with two independent false ϕ's, or one true and one false ϕ were selected as control events.

The $\gamma\phi\phi$ signal. In the η_c study, the smallness of the signal at the beginning of the analysis prevented us from using the photon information, in order to get the highest efficiency. The large amount of events at masses below the η_c (fig. 1) permitted a different approach and the detection of the radiative photon was required, in order to perform a more constrained analysis.

All the events with more than one gamma in the photon detector, including the end-caps, were rejected. The products of the interactions of the charged particles into the detector, which mimic real photons, were identified by pattern recognition and TOF's measurements in the octants and discarded.

More stringent requirements on time-of-flight were not adopted due to the large number of kaons decaying in flight into lighter particles.

A 3C kinematical fit was applied using the direction of the radiative photon; the events of the control classes, $\phi\phi_F$ and $\phi_F\phi_F$, followed the same chain of

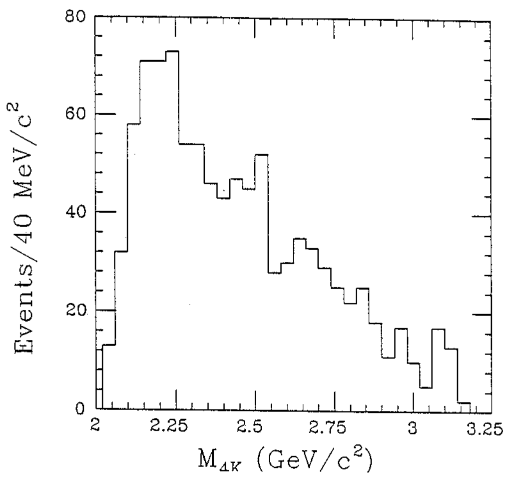

Fig. 1. Four-kaon invariant mass at the first events selection level (GeV/c^2).

analysis. The χ^2 distribution is peaked at low values for the $\gamma\phi\phi$ candidates and is flat for the control events (fig. 2). A $\chi^2 < 25$ was required. A total of 92 good events were accepted: the scatter plot of fig. 3, the first (K^+K^-) mass which in the analysis falls in the ϕ window versus that of the pair opposite to it, shows that we isolated true $\phi\phi$ events with a low background.

The final distribution for the ($\phi\phi$) invariant masses is reported in fig. 4. The efficiency, estimated by a phase-space Monte Carlo, is also shown in fig. 4: the decays in flight of the kaons cause the rapid fall at the lower values of the ($\phi\phi$) mass.

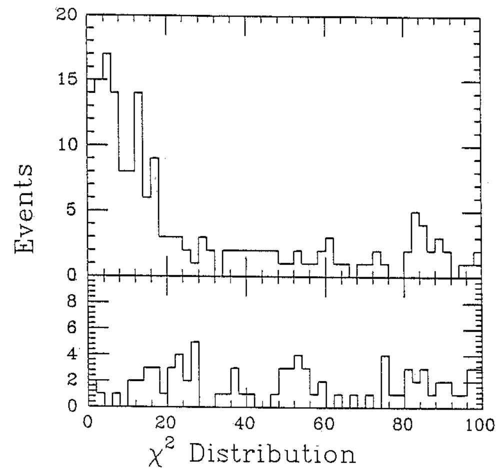

Fig. 2. χ^2 distributions of the 3C kinematical fit for the candidate events (up), and for the control zones events (down).

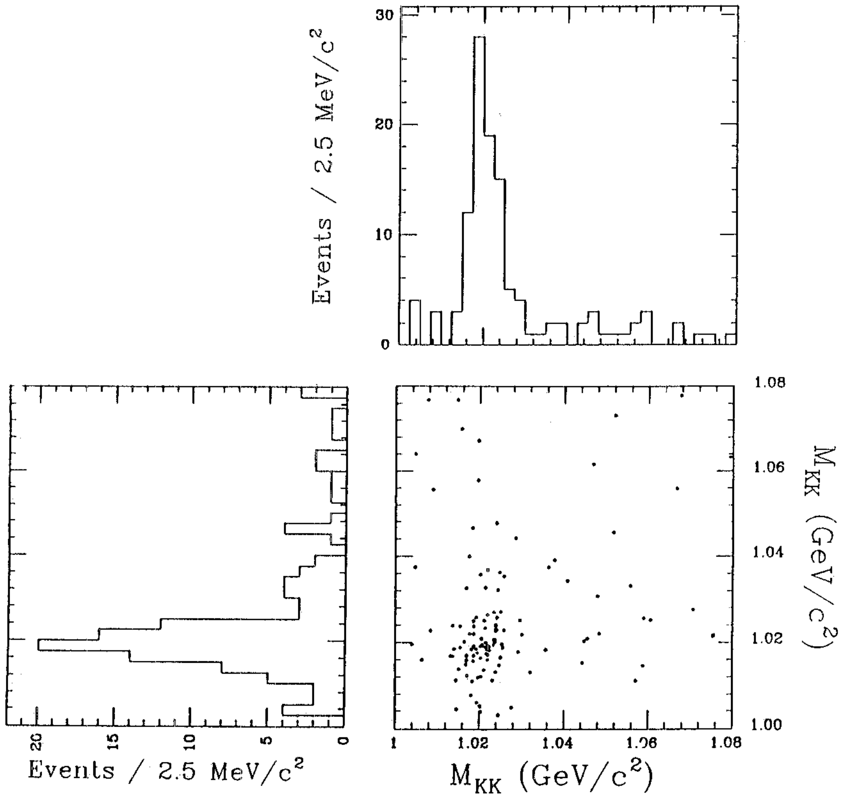

Fig. 3. First K^+K^- mass in the ϕ window (GeV/c^2) versus the opposite one for the sum of the $\gamma\phi\phi$, $\gamma\phi\phi_F$ and $\gamma\phi_F\phi_F$ events.

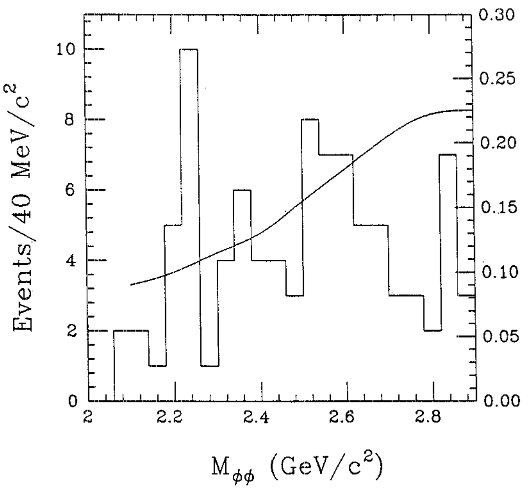

Fig. 4. Final $\phi\phi$ invariant mass distribution (GeV/c^2) with the corresponding efficiency overplotted.

The populations of the $\phi\phi_F$ and $\phi_F\phi_F$ classes, 21 and 6 events, respectively, give the estimate of the background level. No significant presence of true $\gamma\phi\phi$ is expected, from Monte Carlo simulation, in these two classes (< 1 and < 0.1 event, respectively). If only a flat contribution were present, $6 \times 2 = 12$ events would be found in the sum of the two $\phi\phi_F$ zones in front of the 6 events of the $\phi_F\phi_F$ region. The measured difference indicates that we are dealing with two different sources of background: a first one that we assume with a uniform population in the scatter plot of fig. 3, and a second one coming from events with one true ϕ in the final state. The simplest channel we can assume as responsible for this resonant background is $J/\psi \to \phi K^+K^-\pi^0$. A Monte Carlo simulation shows that the rejection level of the analysis is $(99.9 \pm 0.2)\%$ for these events. All the resonant background would come from this channel if its unmeasured branching ratio was of the same order as the $J/\psi \to \phi K^+K^-$ one.

The final contamination in the $\gamma\phi\phi$ sample has been estimated, in this hypothesis, to 6 ± 4 and 9 ± 8 events from the two sources respectively. The branching ratio $J/\psi \to \gamma\phi\phi$, for $(\phi\phi)$ masses up to 2.9 GeV/c^2, calculated after subtraction of the background events, is

$$BR(J/\psi \to \gamma\phi\phi) = (3.1 \pm 0.3 \pm 0.6) \times 10^{-4},$$

where each event was weighted with its appropriate efficiency. The systematic error arises from the normalization (15%) and efficiency (5%) uncertainties. The efficiency error does not include possible dynamical effects.

Mass spectrum analysis. In order to understand the origin of this large production, we looked for the presence of intermediate states decaying into two ϕ's. In fig. 5 the $\phi\phi$ mass spectrum is compared with the phase-space prediction. The latter has been obtained by a high statistics Monte Carlo sample, passed through the reconstruction chain and normalized to the total number of experimental events. The experimental distribution appears overpopulated at the lowest masses region; the enhancement near 2.2 GeV/c^2 has a statistical significance of 2.5 σ.

We have then tried a spin–parity analysis, separately for all the events below 2.5 GeV/c^2, where the g_T's should be found, and for the two bins around 2.2 GeV/c^2. Three angles have been considered: the azimuthal angle χ, between the two ϕ decay planes, and the two polar angles, θ_1 and θ_2, of the K^+ decays in their respective ϕ rest frame relative to the ϕ momenta in the $\phi\phi$ rest frame. The distributions expected by this classical method are given in the preceding letter.

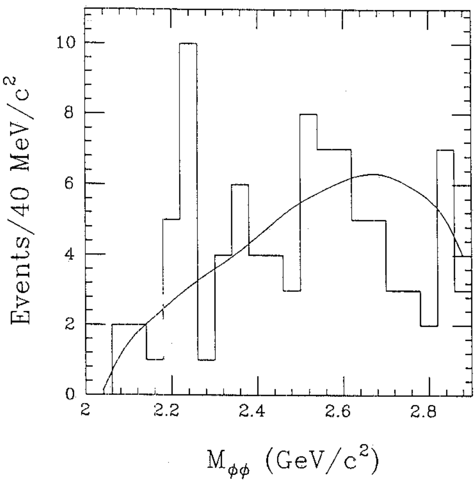

Fig. 5. Experimental $\phi\phi$ invariant mass (GeV/c^2), compared to the distribution expected from phase space (continuous line).

A likelihood function

$$L = \sum_{\#\text{events}} \ln R(\chi, \theta_1, \theta_2) \tag{1}$$

has been evaluated for each partial wave hypothesis, where $R(\chi, \theta_1, \theta_2)$ is the expected angular distribution for the wave. Only the states up to $L = 2$ have been taken into account and possible mixing between different waves has not been considered.

Each R distribution [4] has been normalized to

$$\int R \, d\chi \, d\cos\theta_1 \, d\cos\theta_2 . \tag{2}$$

The likelihood function has been computed also for a flat distribution:

$$R(1) = \frac{1}{\int d\chi \, d\cos\theta_1 \, d\cos\theta_2}, \tag{3}$$

where χ, θ_1 and θ_2 are assumed completely uncorrelated. Integrations (2) and (3) are over the solid angle covered by the set-up.

The parameter ΔL_{wave}, defined as

$$\Delta L_{\text{wave}} = L_{R(1)} - L_{\text{wave}} \tag{4}$$

has been used to compare the likelihoods of the different partial waves.

The values of ΔL_{wave} for the mass spectrum below 2.5 GeV/c^2 are reported in table 1, row 1, and in fig. 6. In the same figure, and in table 1, row 2, we also report the Monte Carlo predictions for each wave with errors that take into account the experimental number of events [‡1].

The assumptions $0^\pm$, $1^\pm$ and 2^+ ($L = 2, S = 0$) can be discarded by comparison. The 2^+ ($L = 0$) hypothesis agrees well with the data, since the experimental likelihood ratio is that expected for the hypothesis. The probability that the observed distributions belong to another wave is, however, significant: 15% for the 2^- ($L = 1$) wave. Nevertheless the analysis of how sets

[‡1] We generated ten Monte Carlo simulations, one for each considered wave. The experimental $\phi\phi$ mass spectrum was taken into account. A large number of random samples of 42 events were taken from each Monte Carlo. The ΔL_{wave} parameters were computed for each wave.

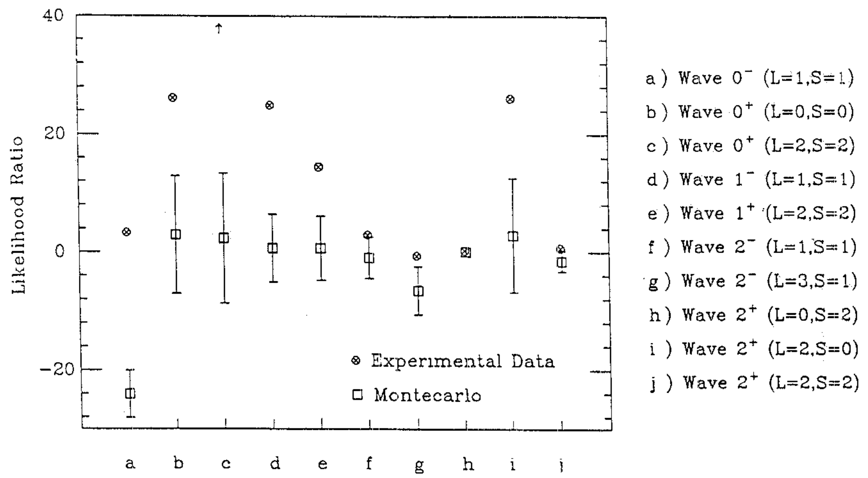

Fig. 6. Likelihood ratios of the events below 2.5 GeV/c^2 for the waves from 0^- to 2^+, compared to the expected values. The lines are ±1 RMS around the mean value of the Monte Carlo distributions.

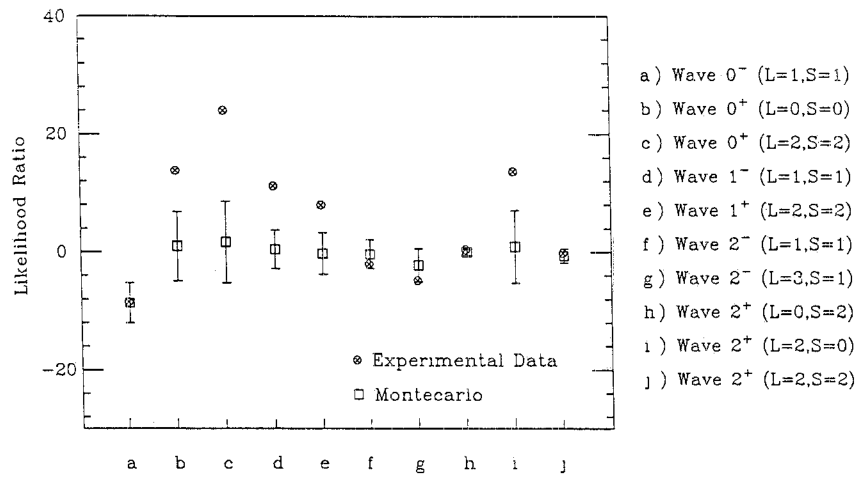

Fig. 7. Likelihood ratios of the events below 2.2 GeV/c^2 for the waves from 0^- to 2^+, compared to the expected values. The lines are ±1 RMS around the mean value of the Monte Carlo distributions.

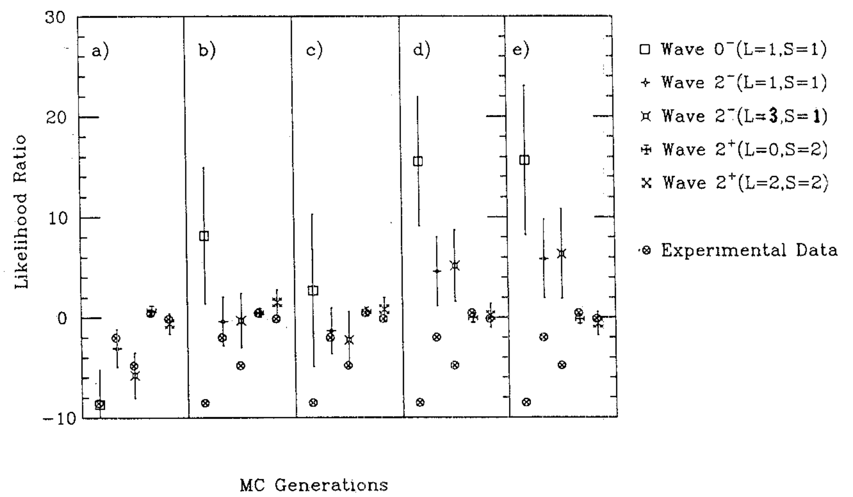

Fig. 8. Experimental likelihood ratios, at 2.2 GeV/c^2, calculated in the hypothesis 0^-, 2^- (L = 1), 2^- (L = 3), 2^+ (L = 0) and 2^+ (L = 2, S = 2). The ratios are compared, (a)–(e), with the values expected for the considered angular assumptions.

Table 1
Experimental and expected likelihood ratios for the ten angular hypotheses in the three $\phi\phi$ mass regions:
– below 2.5 GeV/c^2, rows 1 and 2, hypothesis in the $\phi\phi$ mass regions,
– around 2.2 GeV/c^2, rows 3 and 4,
– below 2.5 GeV/c^2, after subtraction of the 2.2 GeV/c^2 sample, rows 5 and 6.
Errors indicate the RMS of the Monte Carlo distributions.

J^P									
0^-	0^+		1^-	1^+	2^-		2^+		
$L=1$ $S=1$	$L=0$ $S=0$	$L=2$ $S=2$	$L=1$ $S=1$	$L=2$ $S=2$	$L=1$ $S=1$	$L=3$ $S=1$	$L=0$ $S=2$	$L=2$ $S=0$	$L=2$ $S=2$
3.3	26.1	52.1	24.9	14.4	2.9	−0.6	0.3	26.1	0.7
−24.1 ± 4.0	2.9 ± 10.0	2.3 ± 11.0	0.6 ± 5.8	0.6 ± 5.4	−1.0 ± 3.5	−6.5 ± 4.0	0.0 ± 0.7	2.8 ± 10.0	−1.5 ± 1.8
−8.5	13.8	24.0	11.2	8.0	−2.0	−4.8	0.4	13.7	−0.1
−8.7 ± 3.4	1.0 ± 5.9	1.7 ± 6.9	0.4 ± 3.3	−0.2 ± 3.6	−0.4 ± 2.4	−2.2 ± 2.8	0.0 ± 0.5	0.9 ± 6.2	−0.6 ± 1.2
11.8	12.3	27.9	13.7	4.6	4.9	4.2	−0.2	12.3	0.8
−15.6 ± 3.2	2.5 ± 8.2	0.8 ± 7.9	0.2 ± 4.4	0.4 ± 4.4	−0.5 ± 3.1	−3.8 ± 3.6	0.0 ± 0.6	2.0 ± 6.9	−0.8 ± 1.5

of 42 events, generated as 2^- (L = 1), 2^- (L = 3), 2^+ (L = 2, S = 2), respectively, can mimic the angular distributions of another wave, shows that this is the limit we can obtain in order to separate the $2^\pm$ waves among themselves.

Then we calculated a branching ratio for the production of 2^{++} states with a mass below 2.5 GeV/c^2 decaying into $\phi\phi$, in the hypothesis that all the above events belong to the class 2^+ (L = 0). The value is

$$\mathrm{BR}(\mathrm{J}/\psi \to \gamma[\phi\phi]_{2^{++}}) = (1.8 \pm 0.3 \pm 0.6) \times 10^{-4},$$

where in the systematic error we included the uncertainties on the helicity amplitudes of production. The presence of an enhancement in the data near 2.2 GeV/c^2 suggested to isolate these events. The same analysis as above was performed for the 15 events in the enhancement and for their Monte Carlo simulations: the results are summarized in table 1, rows 3 and 4, and in figs. 7, 8. Fig. 7 shows that there is consistency between the experimental data and the 0^-, $2^\pm$ hypothesis, the first one being preferred: the remaining assignments can be ruled out. Fig. 8 shows that 0^- Monte Carlo generation is the only one in full agreement with experimental data.

If the events in the peak at 2.2 GeV/c^2 belong to a resonant state at this mass, the pseudoscalar assignment forbids the decay of this state into $\mathrm{K\bar{K}}$. The identification of the overall enhancement with the particle candidate ξ, observed in $\mathrm{K\bar{K}}$ by the MARK III [5] experiment, is therefore not possible. The events up to 2.5 GeV/c^2, after subtraction of the 15 events at 2.2 GeV/c^2, remain compatible with a 2^{++} assignment; the obtained likelihood ratios are reported, with the Monte Carlo predictions, in table 1, rows 5 and 6, respectively.

Conclusions. We measured an important production of ($\phi\phi$) states in the radiative decays of the J/ψ, with a branching ratio, up to $m_{\phi\phi} < 2.9$ GeV/c^2, $\mathrm{BR}(\mathrm{J}/\psi \to \gamma\phi\phi) = (3.1 \pm 0.3 \pm 0.6) \times 10^{-4}$. The production, below 2.5 GeV/c^2 is consistent with the presence of a 2^{++} dynamics, but other assignments cannot be definitely ruled out. For the enhancement near 2.2 GeV/c^2 the preferred spin–parity is 0^-, and an even-parity assignment is strongly disfavoured.

We are particularly appreciative of the efforts of the technicians of the DM2 group for the construction and maintenance of the apparatus. We are indebted to the technical staff of the LAL for its constant support and especially to the DCI storage ring group directed by P. Marin for the continual improvements in machine performance.

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