RECENT RESULTS FROM DELCO*

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Abstract: The new data from the DELCO experiment give conclusive evidence for the existence of the heavy lepton. Preliminary results on the τ branching ratio and an analysis of the electron spectrum are presented. A preliminary look at D beta decay in terms of K and $K^*(890)$ is also discussed.

Résumé: Les données récentes accumulées par l'expérience DELCO apportent une preuve convaincante de l'existence du lepton lourd τ. Cet exposé présente des résultats préliminaires sur les modes de desintégration du lepton τ ainsi qu'une analyse du spectre d'impulsion des électrons secondaires. La situation actuelle de notre analyse des desintégrations semileptoniques du méson D est aussi présentée.

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1. Introduction

The DELCO[1)] experiment has been located at SPEAR, in the east pit, since the beginning of 1977. It was designed to study the production and decays of new particles, tagged by direct electrons emitted in weak decays. Two kinds of particles are now known to provide such a signal: the charmed particles[2)] and the heavy lepton τ,[3)] and DELCO is particularly well suited to study their properties. In this talk, I will briefly describe the detector and review older results, as they stood at the end of 1977, before presenting the latest data which are, of course, preliminary.

2. The Detector

The detector[4)] is shown in Fig. 1. The interaction region sits in a 3.5 kG near axial field provided by two coils wrapped on steel pole pieces 85 cm apart. The beam passes through the poles of the magnet and the return yoke is extended far up and down to avoid interfering with the rest of the detector. A set of six cylindrical multiwire proportional chambers extend from the beam pipe to a radius of 30 cm. The inner four cylinders subtend 80% of 4π steradians. Four of the cylindrical high voltage foils are divided into 2 cm strips inclined at 45° to the beam axis, to provide a crude depth measurement. Scintillation counters on the pole tips increase the solid angle for detection of charged particles.

The MWPC are surrounded by a segmented Cerenkov counter filled with ethane at atmospheric pressure. In each of the 12 cells a double bounce optics focuses the Cerenkov light onto a 5 inch phototube coated with PTP wave-shifter yielding, on the average, 10 photoelectrons for a $\beta=1$ particle, and a hadron rejection better than 10^{-3}. Next in the sextants are located two planes of magnetostrictive spark chambers providing two ψ and z measurements per track. Together with the MWPC information they give the following accuracies: $\sigma p/p \simeq 10\ p\ (\mathrm{Gev/c})\%$, $\sigma_{\phi} \simeq \sigma_{\theta} \simeq 5$ mrad. Finally, behind the spark chambers, an array of shower counters consisting of three layers of lead and scintillator covers roughly 60% of 4π steradians, the inner layer strips being timed at both ends. Over the last summer, we added two lead walls followed by spark chambers and scintillation counters to obtain a muon identification over 20% of 4π, for particles with a momentum above 700 MeV/c. We do not have results to report yet involving this new piece of equipment.

The trigger for the experiment relies heavily on the shower counters: the coincidence of at least two out of three layers of a shower module, called an S signal, is satisfied by charged particles, as well as by relatively soft photons. The basic trigger requires a track in the inner two MWPC in coincidence with two S signals from different sextants within 20 ns of the beam

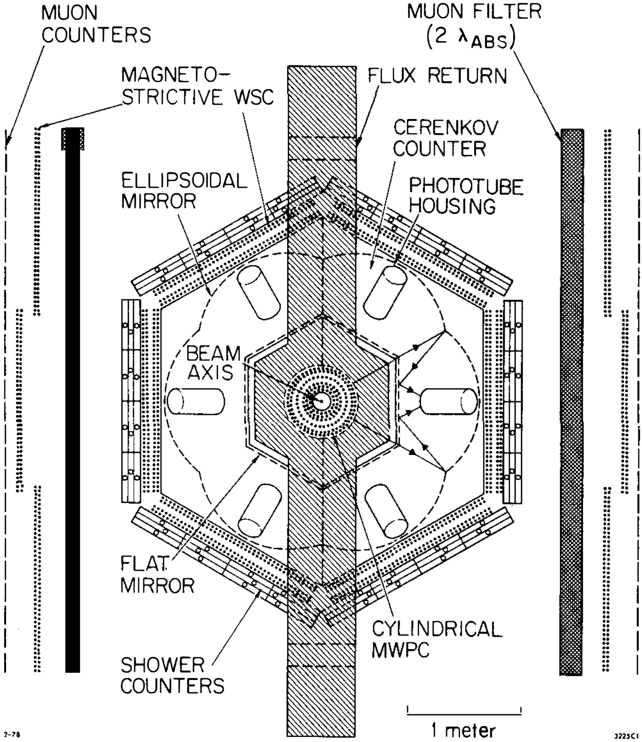

Fig. 1: The DELCO detector.

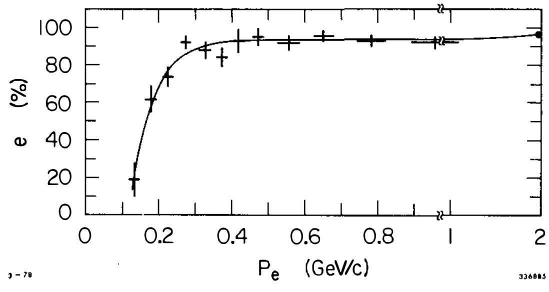

Fig. 2: Cerenkov efficiency as a function of the electron momentum. The curve was obtained by a Monte Carlo simulation of our optics.

crossover time. It is mixed with two other triggers which allow all neutral final states: three S from three different sextants, or two S with a minimum total pulse height rejecting cosmics. The combined trigger rate is 0.7 Hz.

After track finding, cosmic ray events and beam gas interactions are removed on the basis of timing and vertex cuts. The remaining 15% of the triggers are real e^+e^- interactions and are classified into two main categories:

- QED processes including the final states e^+e^-, $\mu^+\mu^-$, $\gamma\gamma$, $e^+e^-\gamma$, etc. These events represent roughly two thirds of the interactions and we use them very extensively for calibration and normalization purposes. In particular, the $ee\gamma$ events gave us a way to measure the efficiency of our Cerenkov as a function of the electron momentum, as shown in Fig. 2.

- hadronic events including multiprong events (with three tracks or more emerging from the interaction region), and two-prong events (if they are acoplanar with the beam by more than 5^o, and one track is not an electron). Particular attention is given to the subset of events having one electron candidate, that is a track giving an in-time pulse in both a Cerenkov cell and a shower module.

The determination of our hadronic detection efficiency somewhat depends on the "true" multiplicity distributions which we tried to unfold from our observed events. Thanks to our neutral triggers, it is well above 90% for events with at least 4 prongs, and around 50% for two-prong events. An averaged detection efficiency at $E_{c.m.}$ of 3.8 GeV is 0.85 ± 0.1.

3. Old Results[4)]

The measured value of $R \equiv \dfrac{\sigma(e^+e^- \to \text{hadrons})}{\sigma(e^+e^- \to \mu^+\mu^-)}$ in the range 3.6 GeV < E_{CM} < 4.8 GeV is displayed on Fig. 3. The errors shown are statistical and the vertical scale may possess an overall systematic error of 20%. The general features of this plot are in reasonable agreement with those already measured at SPEAR[5)] and DORIS.[6)] We very carefully investigated the dip around 4.25 GeV and the new resonance ψ'' whose parameter we determine to be:

$$\begin{aligned} M &= (3770 \pm 6)\ \text{MeV}/c^2 \\ \Gamma &= (24 \pm 5)\ \text{MeV}/c^2 \\ \Gamma_{ee} &= (180 \pm 60)\ \text{eV} \end{aligned}$$

This resonance has been identified as the first $^3D_1$ state of charmonium predicted in 1975 by Eichten et al.[7)] Since it sits above the expected $D\bar{D}$ threshold,[8)] but below any $D\bar{D}^*$ threshold, it decays only into $D\bar{D}$ states, and thus provides a very clean laboratory to study the D meson.[9)]

It is very interesting to compare the behavior of R with the variation of $R_e = \dfrac{\sigma(e^+e^- \to e^\pm + XX)}{\sigma(e^+e^- \to \mu^+\mu^-)}$ in the same energy range, shown in Fig. 4. All the

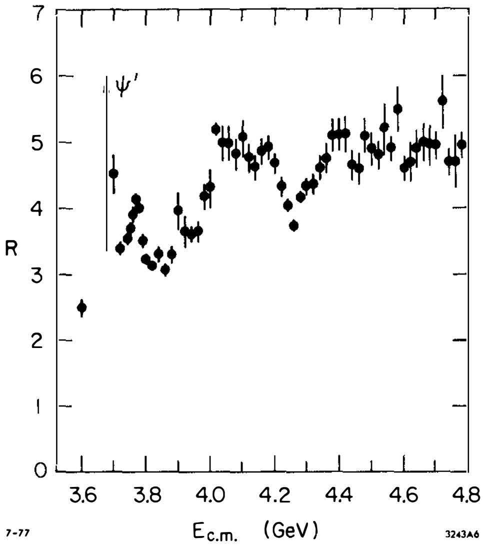

Fig. 3: The hadronic cross-section R as a function of the center of mass energy.

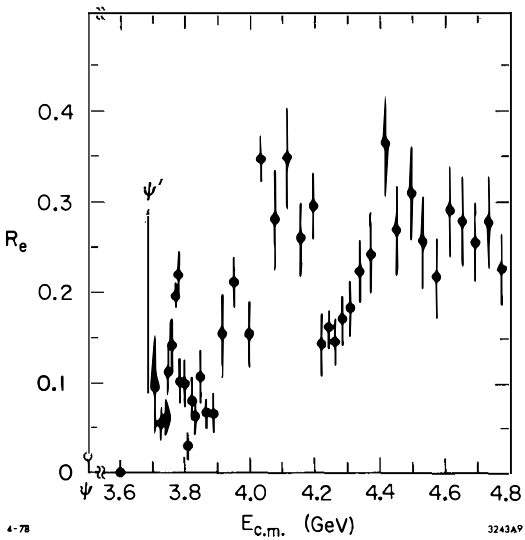

Fig. 4: Variation of R_e as a function of $E_{c.m.}$

structures observable in R are also visible in R_e, but with a much smaller background. In particular, the ψ'' resonance is clearly visible, and this provides unambiguous evidence for the semileptonic decay of D mesons. The comparison of the relative size of the ψ'' peaks in both plots, after correction for losses into two and fewer observed prongs gives a measurement of the semileptonic branching ratio:

$$\frac{BR\ (D \to e\nu X)}{BR\ (D \to all)} = 11 \pm 2\%$$

This is consistent with other measurements at SPEAR and DESY.[10)]

Finally, the smooth excitation curve we obtained for the two-prong electron events contrasted sharply with the R_e curve and gave support to the hypothesis of a heavy lepton as a possible origin for those events.

4. New Results

Since last summer, in order to investigate further the heavy lepton hypothesis, we first took a lot of new data at energies below charm threshold (3.5 GeV, 3.625 GeV, 3.684 GeV, 3.72 GeV) and we performed a new analysis of our older data, in order to gain some statistics. The steps in our new procedure invole selecting events with only 2 charged prongs and any number of photons. One of the tracks, the electron cadidate, must have a momentum greater than 200 MeV/c and trigger the Cerenkov cell it traverses. The other track must have a momentum greater than 300 MeV/c and not trigger its Cerenkov cell. The relative azimuthal angle between the two tracks has to be less than 160°. Events with a topology compatible with $ee\gamma$ (15) are then rejected, leaving a sample of 660 events. The shower pulse height for both tracks in these events is shown in Fig. 5, together with the distribution expected for a non-electron track. To further eliminate electrons which have not been tagged by the Cerenkov, the X prong is required to have a shower counter pulse less than 3.3 times a minimum ionizing pulse. This leaves 540 events with an estimated background of 15 events, consistant with the rate of events seen at the $\psi(3095)$ and at 3.5 GeV. The contribution from two photon processes ($e^+e^- \to e^+e^-\mu^+\mu^-$) where only two particles are detected is estimated to be less than 2% by comparing the number of events witn like sign and opposite sign particles.

The number of events for different values of the center of mass energy is given in Table I, and the corresponding rate normalized to muon pairs, r_e, is shown in Fig. 6. It is already clear from the table that there is a threshold between 3.5 and 3.6 GeV for the production of eX events, and that this threshold is definitively different from the charm threshold, since we observe 35 events without photons at energies between 3.6 and 3.72, with an expected background of at most 2 events.[11)] The data at the ψ'' are estimated to contain a 20% background from charm and will be eliminated from all the subsequent analysis.

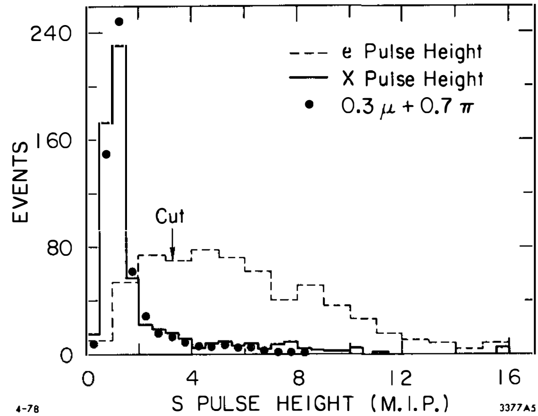

Fig. 5: Shower counter pulse height for both tracks in eX events, normalized to minimum ionizing particles.

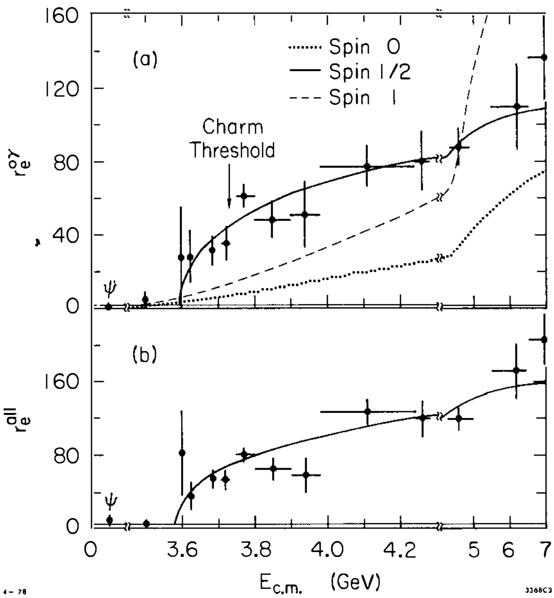

Fig. 6: Rate of eX production, normalized to muon pairs for a) events without photons, b) all events.

Table I: Measurement of the eX production rate as a function of energy.

$E_{c.m.}$	$N^{4\pi}_{\mu\mu}$	eX(noγ)	$r_e^{o\gamma}$(x10^{-3})	eX(all)	r_e(x10^{-3})
ψ	2456	0	0 + 2.3	4	9±5
3.5	1253	1	4.5±4.5	1	4.5±4.5
3.6	207	1	27.5±27.5	3	82.6±47.7
3.625	817	4	27.9±14	5	34.9±15.6
'ψ'(3.689)	2724	15	31.4±8.1	26	54.4±10.7
3.725	2434	15	35.1±9	23	54±11
ψ''(3770)	8329	89	60.9±6	118	81±7
3.80-3.90	2615	22	48±10	30	65±12
3.90-3.98	889	8	51.3±18	9	68±19
3.98-4.24	3841	52	77.1±11	86	128±14
4.24-4.28	1856	26	79.8±16	39	120±19
4.28-4.99	4899	76	88.4±10	104	121±12
4.99-6.5	1187	23	110.4±23	36	173±29
6.5-7.4	1535	37	137.4±23	56	208±28

Charm background at higher energies is expected to be less than our statistical errors and has therefore been neglected. Also shown on Fig. 6 are the fitted excitation curves for a pointlike spin 1/2 particle, letting the mass and the branching ratios vary. The results of the fits are summarized in Table II.[12] It is not possible to get a good fit to the data, either with a spin 0 pointlike particle because of the high yield of eX events, or with a spin 1 particle because of the very slow rise with the center-of-mass energy.

Table II: Results of the fits to the excitation curve (see ref.12)

		eX,noγ	eX,all
M_τ (GeV/c^2)	:	$1.795 {}^{+.005}_{-.011}$	$1.792 {}^{+.006}_{-.011}$
$2b_e b_x$	:	0.118 ± .008	0.170 ± 0.10
χ^2/NDF	:	7.6/11	17.0/11

In order to extract some branching ratio information from the asymptotic values of r_e, we use the results of the theoretical computation by Gilman and Miller[13] and assume that the relative decay rates for τ giving one charged prong are well known. This yields a branching ratio to electrons of (16±1)% and a branching ratio to multiprongs of (32±3)%, where the errors are statistical only.

We can now use our two-prong electron events to study the electron momentum distribution which, in complete analogy to muon decay, yields information about the helicity of the τ neutrino and thus about the V-A or V+A coupling responsible for the decay. In the same spirit, it is very convenient to parametrize this momentum spectrum in terms of the Michel parameter ρ whose values are 0 for V+A, and 0.75 for V-A. We first compare in Fig. 7 the mean value of the electron energy divided by the beam energy, for different energy bins, with the predicted values:[14] 0.35 for V-A and 0.30 for V+A. Next, we fit the electron spectrum integrated over all energies (Fig. 8) with spectra obtained by Monte Carlo, for different values of ρ. The results of the fits are summarized in Table III. We conclude from those two tests that the agreement with V-A is excellent, and that if V+A is not completely ruled out, it is at least very unlikely (<1% probability). We also investigated the effect of a finite neutrino mass[15] on the electron spectrum and found an upper limit of 250 MeV/c^2 at the 90% confidence level.

Table III: Results of fits to the electron spectrum

Hypothesis	ρ	χ^2/NDF
V+A	0	38/18
V-A	0.75	17.6/18
	0.73±0.15	17.5/17

We also tried to extract some information on the τ from our multiprong electron events. The problem there is to take care of the very important contribution of the charmed particles to those events. We used two different methods. First we selected the multiprong electron events in the charm depleted regions at $E_{c.m.}$ of 3.72, 3.85 and 4.25 GeV, and we rejected the remaining charm contribution by requiring the electron momentum to be greater than one third of the beam momentum. This gives us 78 multiprong events to be compared with 29 eX events with the same cuts. After correction for the relative detection efficiencies and assuming our measured value for the branching ratio into electrons, we obtain a multiprong branching ratio of (34±6)%. The other method relies on the assumption that charm events do not contribute to the highest part of the electron momentum spectrum: as we cut progressively higher on the electron momentum, the ratio of multiprong to two-prong electron events should become constant, when the charm limit has been reached. This is shown on Fig.9. The ratio of 1.8±.3 gives, after correction for detection efficiencies, a multiprong branching ratio of (35±6)%.

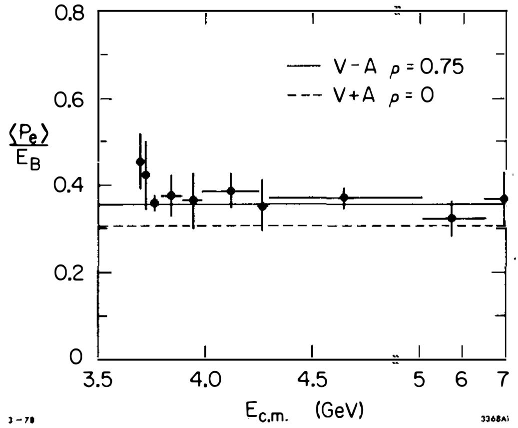

Fig. 7: Averaged electron momentum divided by the beam energy, for eX events.

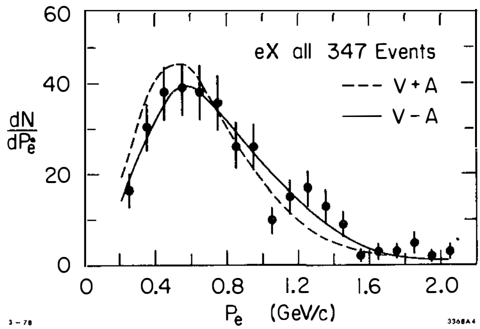

Fig. 8: Electron momentum spectrum for eX events, Ψ'' excluded. The curves are Monte Carlo generated simulations.

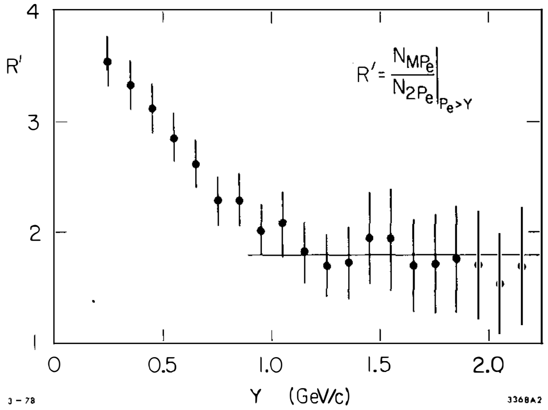

Fig. 9: Ratio of the number of multi-prong electron events to the number of two-prong electron events, as a function of the lower cut on the electron momentum.

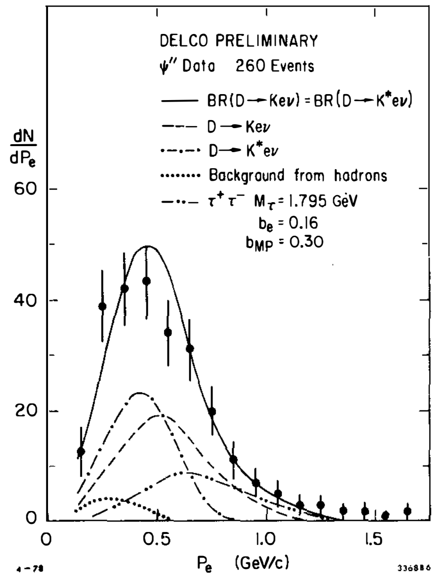

Fig. 10: Electron momentum spectrum for multiprong events at the Ψ''(3370). The full line represents the sum of all the other contributions.

It is worth pointing out that our three independant determinations of the multiprong branching ratio are in very good agreement with each other and with earlier estimates by the PLUTO and DASP collaborations at DESY.[16)] Such a high multiprong branching ratio implies a very important contribution of the τ in the multiprong events all over the charm region, and in particular a 20% background at the $\psi''(3770)$!!

Let us finally turn to the D meson semileptonic decays and assume we understand reasonably well the τ background under the ψ''. The multiprong electron spectrum at this resonance is shown on Fig. 10 together with our best estimates for the background from misidentified hadrons and heavy lepton events. The remaining part has been fitted with $D \to Ke\nu$ and $D \to K^*(890)e\nu$ in variable amounts. The best agreement has been obtained for equal amounts of those two decay modes and the resulting curve is also drawn on Fig. 10. It should be noted that this result is still very preliminary, and that it is very sensitive to the τ background subtraction which we are still investigating.

5. Conclusion

In the present status of our experiment, I have tried to convince you that the heavy lepton τ exists and in particular that the charm is completely ruled as a single source for the two-prong electron events. All the properties we could investigate so far are perfectly compatible with a spin 1/2 pointlike particle decaying through V-A into a massless neutrino and other particles, with branching ratios accurately predicted by different models.

The second conclusion is that the complete study of the 4 GeV energy region will be very delicate, with a sizeable contribution from charm into the two-prong class (at least at the ψ''), and a contribution of the same order of magnitude from the heavy lepton in the multiprong class.

We are now trying to pursue our analysis using our new muon detector, and we are still taking data which will, maybe, bring still other unexpected developments.

Acknowledgments

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