τ Physics with the TPC/2γ Detector at PEP

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Abstract

The TPC/2γ detector and the PEP machine have been upgraded for high-luminosity running. We describe the performance of the new configuration during a test run in fall 1988. Prospects for progress in τ physics, based on a large data sample to be recorded by the TPC/2γ detector, are reviewed.

1 Introduction

The τ lepton was discovered in 1975 at the SPEAR e^+e^- storage ring at SLAC [2]. The initial investigation of its properties at SPEAR and DORIS I established it as a third generation lepton and yielded first measurements of its major decay modes. When the higher energy storage rings PETRA and PEP came into operation the situation improved considerably as large samples of τ's could be obtained which were almost background free. In particular, hadronic events from quark pair production could be clearly distinguished from $\tau^+\tau^-$ events, so that it became possible to study the semihadronic decays of the τ in much more detail. In addition, the known decay channels were remeasured with accuracies of a few percent typically. More recently, even higher statistics (but also higher background) data samples, taken at CESR and DORIS II, became available, adding to our knowledge about the τ lepton and its associated neutrino ν_τ. (See Ref. [3] for a review of the present status.)

All existing measurements so far agree with the τ being a spin-$\frac{1}{2}$ pointlike particle of unit charge with a $V-A$ weak interaction and no strong interaction. Except for phenomena related to its higher mass, no significant differences between the τ and the other charged leptons, electron and muon, have yet been found. However, the picture has become clouded by our failure to solve the problem of missing 1-charged particle decay modes [4], [5] ('1-prong problem').

Compared to the precision reached in the study of other fundamental particles, *e.g.* the muon, research in τ physics still has a long way to go. What is needed to proceed are much larger and cleaner data samples, taken with detectors that can reconstruct virtually all τ decay channels. This goal might ultimately be met only at future facilities like τ/charm [6] and B factories [7]. However, a major step can already be taken in the immediate future at the PEP e^+e^- storage ring at SLAC. The TPC/2γ collaboration aims at collecting $1000\,\mathrm{pb}^{-1}$ of data at $\sqrt{s} = 27\,\mathrm{GeV}$ over the next three years, which would allow us to make important contributions to the fields of τ physics, B physics, hadronization and two-photon physics.

2 Storage Ring and Detector

Since 1986 the TPC/2γ (see Fig. 1) has been the only detector at the PEP storage ring [8]. The central Time Projection Chamber (TPC) is used to track charged particles over 87% of 4π sr, and to identify them by the simultaneous measurement of ionization energy loss (dE/dx) and momentum in a 1.325 T magnetic field. The dE/dx resolution for a track in a hadronic event is 3.4% and the momentum resolution was $(\sigma_p/p)^2 = (0.015)^2 + (0.007\,p)^2$, with p in GeV. The central detector has recently been upgraded by inserting a 14 layer straw vertex chamber (VC) with a beryllium beam pipe, starting at 4 cm radius from the beam [9]. The VC has an impact parameter resolution of 90 μm at 1 GeV and 40 μm at 10 GeV, and we expect it to improve the momentum resolution to $(\sigma_p/p)^2 = (0.011)^2 + (0.003\,p)^2$, Photons are detected in an electromagnetic calorimeter which surrounds the 0.87 radiation length (r.l.) superconducting coil. The calorimeter is highly segmented (8 mrad projective strips) and achieves an energy resolution of $17\%/\sqrt[4]{E/\text{GeV}}$ below 5 GeV and about 14% for Bhabha events. The detector is surrounded by muon chambers which identify muons above 1-2 GeV. Fig. 2 displays a hadronic event obtained in a run in fall 1988, showing that all major detector components performed well.

Also the reconfigured PEP machine performed well despite its 2.5 year shutdown. The instantaneous luminosity of PEP has been increased by a factor of about 2.5 by moving the face of the first quadrupole magnets to 3.5 m from the interaction point, thereby reducing β_y^* from 12 cm to 5.5 cm. During the run in fall 1988 we achieved typical peak luminosities of $\mathcal{L} = 6 \times 10^{31}\,\text{cm}^{-2}\text{s}^{-1}$ with peak total currents of $I = 42\,\text{mA}$. (See Fig. 3 for a plot of $\mathcal{L}$ versus I for a typical fill.) The total current was limited by higher order mode losses which caused unacceptable heating of the VC. A further reduction of β_y^* was prevented by high radiation background originating at a mask 37 m from the interaction point that interfered with the 'beam stay clear'. After removing the mask and watercooling the VC we expect to reduce β_y^* to 4.0 cm and to increase the total current to 52 mA, which will result in an instantaneous luminosity of $10^{32}\,\text{cm}^{-2}\text{s}^{-1}$.

During the course of the run the daily integrated luminosity delivered by PEP increased considerably as we gained experience in operating the machine (see Fig. 4). We reached an average of $\geq 1\,\text{pb}^{-1}$ per day for the last three weeks of the run, the maximum being $2.5\,\text{pb}^{-1}$ per day. The total integrated luminosity delivered was $42\,\text{pb}^{-1}$.

For future running PEP has been promised 20% of the Linac time to fill. Based on our experience with switching between SLC operation and storage ring filling last fall, we project $\geq 250\,\text{pb}^{-1}$ of data per six month of running. This number will improve as we gain operational experience and as the SLC stability improves, and we want to collect a total of $1000\,\text{pb}^{-1}$ over the next three years.

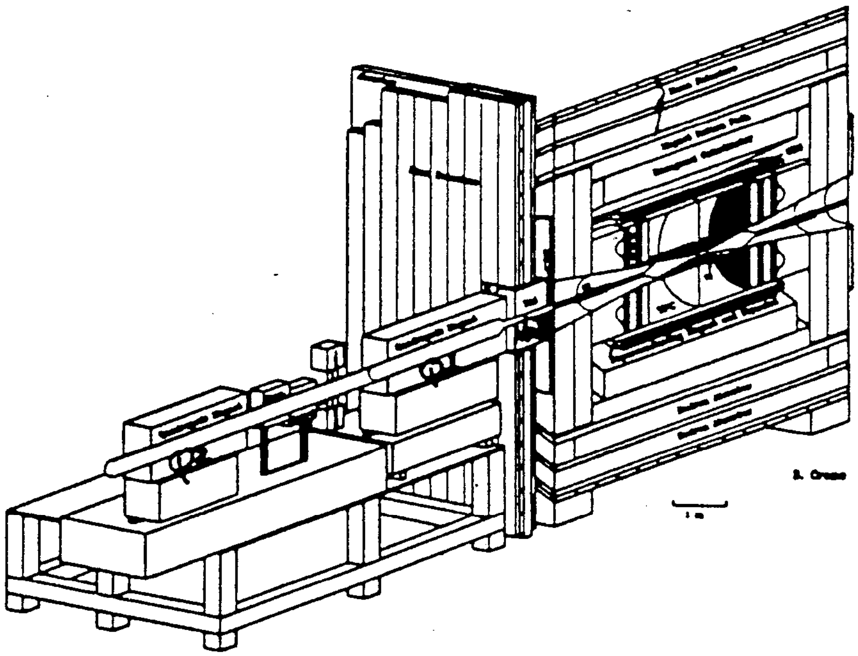

Figure 1: The TPC/2γ detector.

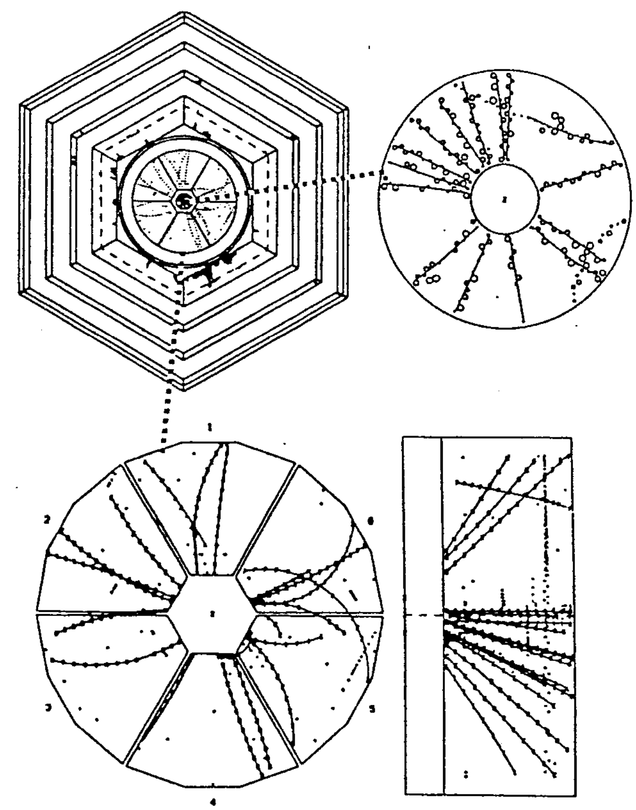

Figure 2: A hadronic event in the TPC/2γ detector.

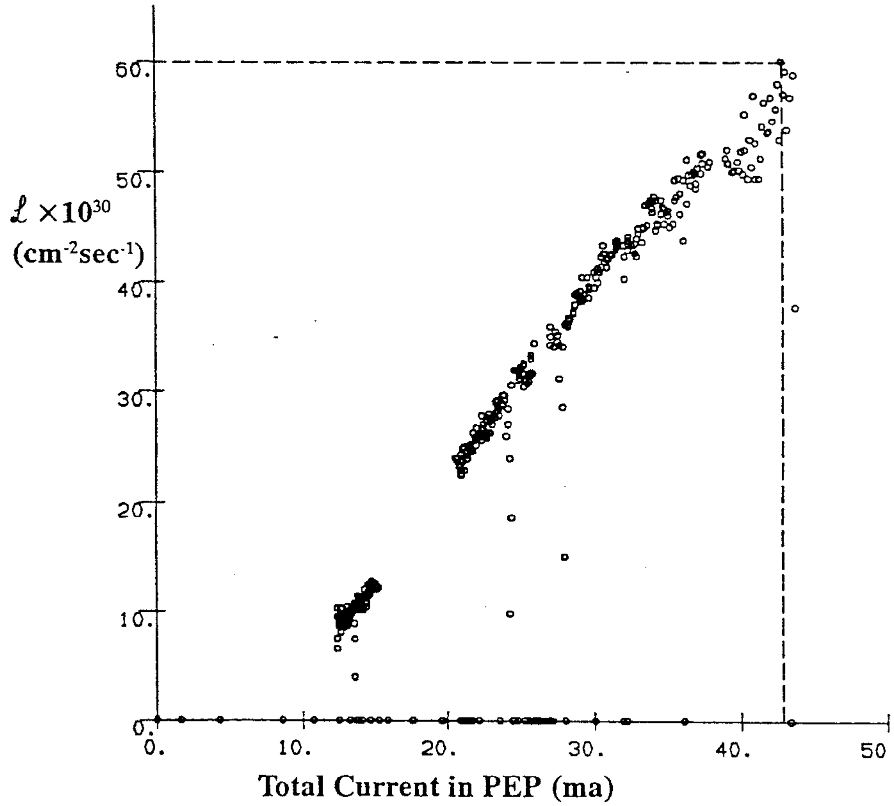

Figure 3: Instantaneous luminosity versus total current in PEP.

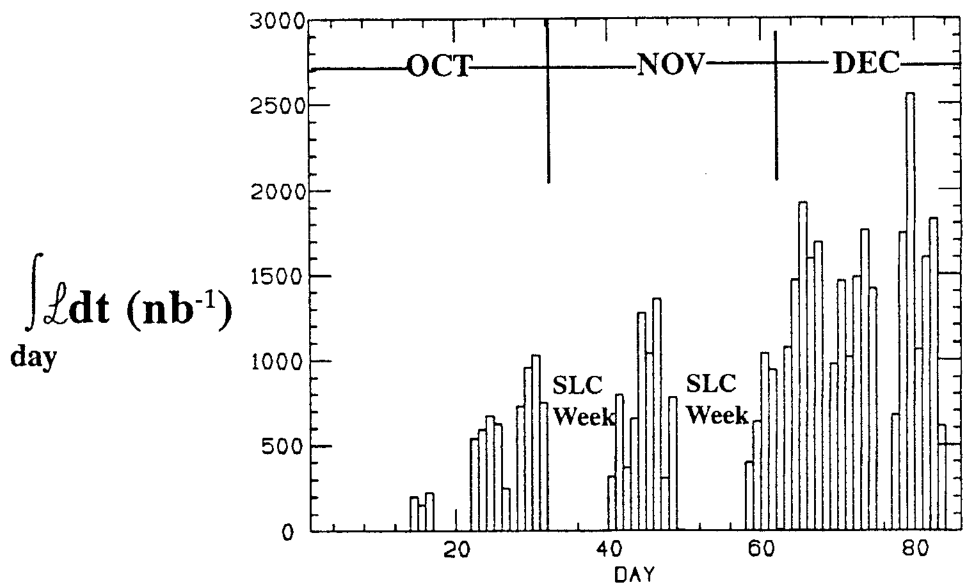

Figure 4: Daily integrated luminosity delivered by PEP.

3 The TPC/2γ Physics Program

Given a large data sample the TPC/2γ collaboration has a rich physics program in various fields:

- two-photon physics
  - quark/gluon structure of $C = +1$ states
  - QCD tests in exclusive and inclusive measurements
  - missing mass search for new states
- hadronization
  - flavor dependent cross sections and correlations
  - gluon fragmentation
- B physics
  - mixing for B_d and B_s
  - charge and flavor tagged lifetimes
- τ physics
  - τ decay branching ratios
  - τ lifetime
  - ν_τ mass
  - structure of the τ-W-ν_τ vertex

We will focus here on the prospects in τ physics. At 27 GeV center-of-mass energy the cross section for $e^+e^- \to \tau^+\tau^-(\gamma)$ is 156 pb, resulting in a sample of 156k $\tau^+\tau^-(\gamma)$ events in the anticipated $1000\,\mathrm{pb}^{-1}$ of data. Although the $\tau^+\tau^-(\gamma)$ cross section is nearly six times lower compared to running on the $\Upsilon(4S)$ ($\sqrt{s} = 10.6\,\mathrm{GeV}$), the PEP energy regime is a good place to do competitive τ physics for the following reasons:

- The decay products of τ^+ and τ^- are well separated into two hemispheres due to the rather large boost of the τ's ($\gamma \approx 7.5$).
- The τ direction is known to within a few degrees, *e.g.* from the thrust axis.
- There is typically $\leq$5% low-multiplicity hadronic background. This background is especially troublesome for experiments at lower energies.
- The τ's have a rather long mean decay length ($< l > \approx 700\,\mu\mathrm{m}$).
- There is a high correlation between the τ spins.

The high boost of the τ's causes the decay products from a single τ to stay fairly close together, causing some difficulties in reconstructing τ decays with many charged or neutral particles. At PEP/PETRA energies this problem can be overcome by detectors with good charged particle tracking and highly segmented electromagnetic calorimeters - like the TPC/2γ detector. (Such a solution is much harder to achieve at LEP/SLC energies.)

Due to the advantages described above, PEP/PETRA experiments have often lead the efforts in τ physics despite the enormous rate advantage that the CESR/DORIS experiments gained meanwhile. In fact, there are several important measurements that have only been done at PEP/PETRA: topological 1-prong, 3-prong and 5-prong branching ratios (B_1, B_3 and B_5), leptonic branching ratios (B_e and B_μ), forward-backward asymmetry, etc.

3.1 τ Decay Branching Ratios

Measuring topological and exclusive branching ratios will be one of the major points in the TPC/2γ τ physics program. We aim at measuring branching ratios to a high precision and down to fractions of a percent. The motivation for doing so is twofold: First of all, many τ decay modes can be calculated assuming the Standard Model with a $V-A$ interaction of universal strength between the τ and ν_τ, and using experimental data from outside the τ decay, *e.g.* $e^+e^-\rightarrow hadrons$ in the 1-2 GeV region. It is interesting to check that the individual decay modes appear at the predicted rate. So far no significant deviations have been observed. Secondly, the exclusive decay modes which yield one charged prong, three charged prongs, etc., must sum up to give the inclusive charged-prong multiplicities, leaving no τ decays unaccounted for. If only experimental results are used (see Tab. 1) there appears to be no problem in accounting for every decay, mainly because only relatively poor upper limits exist for 1-prong decays with multiple π°'s or η's. The 1-prong problem shows up however, when other experimental data and conventional theoretical concepts (conserved vector current and isospin invariance) are used to tighten these upper limits. Then 5.6% of the 1-prong decays are left unaccounted for. We do not know if this is caused by experimental errors, by misuse of the theory, or by unknown phenomena in τ decay.

Recently, a set of measurements of most τ decay channels performed by the CELLO collaboration has been published [11], [10] that points to a conventional solution of the problem. They measure $B_1 = (84.9 \pm 0.5)\%$, which is nearly three standard deviations (s.d.) lower than the previous world average of $(86.6 \pm 0.3)\%$. They also measure B_e, $B_{\pi 2\pi^\circ}$, $B_{\pi 3\pi^\circ}$, B_3 and $B_{3\pi}$ somewhat higher than the world averages, thus being able to account for all 1-prong decays [1].

Existing TPC/2γ measurements [12], [13] agree very well with the CELLO values for B_1,B_e, ($B_{\pi 2\pi^\circ}$+ $B_{\pi 3\pi^\circ}$) and B_3, however, they have larger statistical errors. ($B_{3\pi}$ has not yet been measured by TPC/2γ.) Given 1000 pb^{-1} of data and the capabilities of the TPC/2γ detector we will also be able to measure most of the τ decay channels (due to the TPC's superior particle identification we will also be able to measure channels with kaons), and thus do a conclusive test of CELLO's proposed solution of the 1-prong

[1]Note that B_1 and B_3 are anti-correlated since they are constrained to add up to $1 - B_5 = 99.85\%$.

problem.

One of the key channels in this context is [2] $\tau^- \to \nu_\tau \pi^- \pi^\circ \pi^\circ$, which unfortunately is very difficult to measure because of the high photon multiplicity. This is the only substantial 1-prong decay channel for which no firm theoretical prediction exists. However, it is bound by isospin invariance to the corresponding all-charged branching ratio: $B_{\pi 2\pi^\circ} \leq B_{3\pi}$ [5]. The existing measurements of both channels show some peculiarities. Tab. 2 gives the measured branching ratios for multiple neutrals channels. Using the theoretical expectations for $B_{\pi 3\pi^\circ}$ and $B_{\pi\pi^\circ\eta}$, $B_{\pi 2\pi^\circ}$ can be extracted for those experiments that measure a sum of branching ratios [15] Calculating a formal average yields $B_{\pi 2\pi^\circ}$=(8-9±0.8)%, depending on which of the statistically correlated Mark II measurements is used. Tab. 3 shows the measured branching ratios into three charged pions plus $n\pi^\circ$, $n \geq 0$. The formal average for $B_{3\pi}$ is $B_{3\pi} = (6.8 \pm 0.4)\%$, even somewhat *lower* than $B_{\pi 2\pi^\circ}$:

$$(8 - 9 \pm 0.8)\% = B_{\pi 2\pi^\circ} \overset{\text{isospin}}{\leq} B_{3\pi} = (6.8 \pm 0.4)\% . \tag{1}$$

Note however, that there is considerable disagreement among the $B_{3\pi}$ measurements, which seem to cluster into two groups. (In the contrary, the $B_{3\pi\pi^\circ}$ measurements all agree nicely with a theoretical prediction [5] of 4.8%.) It is also worth noting, that for ARGUS, which has the most precise $B_{3\pi}$ measurement, the sum $B_{3\pi} + B_{3\pi\pi^\circ}$ is unexpectedly far from saturating $B_3 \approx B_{3\pi} + B_{3\pi\pi^\circ} + B_{K+X}$, the last contribution being limited by a TPC/2γ measurement [16] to $< 0.6\%$ at 90% confidence level (C.L.). And finally, all experiments contributing to the average of $B_{3\pi}$ measure a B_3 that falls on the low side of the world average, the only exception being CELLO, which correspondingly finds the highest $B_{3\pi}$ value. These should be enough reasons to treat the formal average for $B_{3\pi}$ with some caution. TPC/2γ, which has already proven its ability to measure the difficult channel $\tau^- \to \nu_\tau \pi^- \pi^\circ \pi^\circ$ and which can easily handle the all-charged channel, will redo all these measurements to clarify the subject [3].

Because of the greatly improved statistics of the anticipated data sample, a major objective will be to bring down systematic errors. Regarding the detector improvements and having more data available for careful checks, it will be feasible to reach accuracies where the TPC/2γ branching ratio measurements will dominate the world averages. A very important check of the systematics will come from a different approach for measuring branching ratios: a 'single-tag' technique, so far explored only by the Mark II collaboration [24]. There, a $\tau^+\tau^-$ event is selected by identifying only one of the τ's (not by imposing cuts on the whole event), allowing for a more unbiased measurement of the decays of the opposite τ. Scaling from the Mark II we can expect nearly 20000 singly-tagged $\tau^+\tau^-$ candidate events with $< 5\%$ background.

To conclude this section, given large enough a data sample and given the capabilities of the TPC/2γ detector, we can expect to have a major impact on all τ branching ratio measurements and potentially solve the long-standing 1-prong problem.

[2] Throughout the text τ^- is used for both charge states of the τ.

[3] Note that due to various detector upgrades the amount of material in front of the electromagnetic calorimeter has been cut in half since its previous $B_{\pi 2\pi^\circ}$ measurement.

Table 1: Measurements of branching ratios of one charged particle decay modes and comparison with theoretical predictions. Rows 7 and 13 contain the sum of rows 1-7 and 8-12, respectively. Comparing the total sum in row 14, which contains the theoretical upper limits, with the measured B_1 in row 15 exhibits the 1-prong problem.

Row	Decay channel	Measured branching ratio or 95% C.L. upper limit (%)	95% C.L. upper limit(%) from CVC or Isospin
1	$\nu_\tau e^- \bar{\nu}_e$	17.6 ± 0.4	
2	$\nu_\tau \mu^- \bar{\nu}_\mu$	17.7 ± 0.4	
3	$\nu_\tau \pi^-$	10.8 ± 0.6	
4	$\nu_\tau K^- n X^0$, $n \geq 0$	1.7 ± 0.3	
5	$\nu_\tau \pi^- \pi^\circ$	22.3 ± 0.8	
6	$\nu_\tau \pi^- 2\pi^\circ$	8.5 ± 0.8	
7		78.6 ± 1.4	
8	$\nu_\tau \pi^- 3\pi^\circ$	< 2.5	< 1.25
9	$\nu_\tau \pi^- 4\pi^\circ + \nu_\tau \pi^- 5\pi^\circ$	< 4.0	< 0.17
10	$\nu_\tau \pi^- \eta$	} < 2.1 (rows 10–12)	< 0.0
11	$\nu_\tau \pi^- \eta n \pi^\circ$, $n \geq 0$		< 0.61 $n = 1, 2$
12	$\nu_\tau \pi^- \eta \eta n \pi^\circ$, $n \geq 0$		< 0.31
13		< 8.6	< 2.4
14		<87.2 ± 1.4	<81.0 ± 1.4
15		86.6 ± 0.3	

Table 2: Branching ratios for multiple neutrals channels (%)

Experiment	$\nu_\tau \pi^- 2\pi^\circ$	$\nu_\tau \pi^- 3\pi^\circ$	$\nu_\tau \pi^- \pi^\circ \eta$	Reference
TPC/2γ		$13.9 \pm 2.0\ ^{+1.9}_{-2.2}$		[13]
	>8.3 @ 95% CL			[13]
Mark II	$12.0 \pm 1.4 \pm 2.5$			[24]
	$7.9 \pm 1.0 \pm 1.2$	$4.6 \pm 1.0 \pm 1.1$		[17]
	$6.2 \pm 0.6 \pm 1.2$	$0.0\ ^{+1.4}_{-0.0}\ ^{+1.1}_{-0.0}$	$4.2\ ^{+0.7}_{-1.2} \pm 1.6$	[17]
MAC	$8.7 \pm 0.4 \pm 1.1$			[21]
Crystal Ball	$7.2 \pm 0.6 \pm 1.4$	<2.5 @ 95% CL	<0.9 @ 95% CL	[18]
CELLO	10.0 ± 1.9	3.2 ± 1.4		[10]
Theory	5-10	1.0 ± 0.15	<0.24 @ 95% CL	[5], [14]

Table 3: τ decay branching ratios into three charged pions. The average for B_3 has been taken from Ref. [25].

Experiment	$B_{3\pi}$ (%)	$B_{3\pi n\pi^\circ}$, $n \geq 1$ (%)	Sum (%)	B_3 (%)	Reference
PLUTO	5.4 ± 1.7			12.2 ± 4.1	[19]
DELCO	5.0 ± 1.0	6.0 ± 1.2	11.0 ± 1.6	12.1 ± 1.3	[20]
MAC	7.0 ± 0.8	5.2 ± 0.8	12.2 ± 1.1	13.3 ± 0.7	[21], [26]
Mark II	7.8 ± 0.9	4.7 ± 0.9	12.5 ± 1.3	12.8 ± 0.9	[22]
ARGUS	5.6 ± 0.7	4.2 ± 1.0	9.8 ± 1.2		[23]
CELLO	8.7 ± 0.8	5.6 ± 0.8	14.3 ± 1.1	15.0 ± 0.5	[10], [11]
Average	6.8 ± 0.4	5.1 ± 0.4		13.3 ± 0.3	

3.2 τ Lifetime

The decay width for the leptonic decay $l_i \to \nu_i l_j \nu_j$ mediated by a general 4-fermion interaction is [7]

$$\Gamma_{ij} = \frac{G_i G_j}{192\pi^3} m_i^5 f_{ija} r_{ija} , \tag{2}$$

$$\text{with} \quad f_{ija} = 1 + 4\eta \frac{m_j}{m_i} - 8 \left(\frac{m_j}{m_i}\right)^2 - \frac{3}{5}\left(\frac{m_i}{m_W}\right)^2 .$$

G_i denotes the coupling constant at the l_i-W-ν_i vertex, $a = S, V, T$ indicates the type of interaction, η is the low energy shape parameter, and r_{ija} holds the radiative corrections. For a pure $V - A$ interaction we have $\eta = 0$ and thus $f_{ijV} \approx 1$, and $r_{ijV} = 0.996$ independent of m_i or m_j. For the electronic decay one finds for the τ lifetime

$$\tau_\tau = \frac{G_\mu}{G_\tau} \left(\frac{m_\mu}{m_\tau}\right)^5 B(\tau \to \nu e \nu) . \tag{3}$$

This relation offers a sensitive test of lepton universality since it involves well-measurable quantities. Assuming e-μ universality gives [25] $B(\tau \to \nu e \nu) = (18.0 \pm 0.3)\%$ and the world average of the τ lifetime measurements (see Tab. 4) is $\tau_\tau = (3.03 \pm 0.08)\, 10^{-13}\,\mathrm{s}$. This yields

$$\frac{G_\mu}{G_\tau} = 1.052 \pm 0.035 , \tag{4}$$

which is consistent with 1.0 within 1.5 s.d. It is highly desirable to have better measurements of τ_τ and B_e to be able to check μ-τ universality to a higher precision.

Table 4: τ lifetime measurements. The errors are statistical and systematic, respectively. Some experiments give only the combined error.

Experiment	τ_τ (10^{-13} s)	Reference
MAC	$3.15 \pm 0.36 \pm 0.40$	[26]
MAC	3.09 ± 0.19	[27]
CLEO	$3.25 \pm 0.14 \pm 0.18$	[28]
HRS	$2.99 \pm 0.15 \pm 0.10$	[29]
ARGUS	$2.95 \pm 0.14 \pm 0.11$	[30]
Mark II	$2.88 \pm 0.00 \pm 0.00$	[31]
TASSO	$3.06 \pm 0.20 \pm 0.14$	[32]
JADE	3.01 ± 0.29	[33]
Average	3.03 ± 0.08	

The two most precise τ lifetime measurements to date, both using a decay length method, come from HRS at PEP and from ARGUS at DORIS. Although the mean τ

decay length at DORIS is almost a factor of three smaller than at PEP (see Tab. 5), ARGUS reaches the same precision as HRS due to a much larger data sample and a superior VC. Note that both measurement errors are still dominated by the statistical error.

Table 5: Comparison of quantities relevant for a lifetime measurement. E_b denotes the beam energy, $< l >$ the mean decay length, δ the impact parameter resolution and $(\Delta\tau_\tau)_{stat}$ the statistical error on the τ lifetime.

Experiment	E_b (GeV)	$< l >$ (μm)	δ (μm)	1-3 events	$(\Delta\tau_\tau)_{stat}/\tau_\tau$ (%)
HRS	14.5	725	140	1311	5
ARGUS	5	250	95	5696	5
TPC/2γ	13.5	675	40	9000	1

Given the large expected 1-3 event sample and the excellent properties of the TPC/2γ VC, and scaling from the HRS and ARGUS results, we expect to measure τ_τ with better precision than today's world average.

3.3 ν_τ Mass

The question of non-zero neutrino masses has become of considerable interest in view of certain theoretical ideas, *e.g.* GUT's, neutrino oscillations, dark matter, etc. Whereas fairly stringent limits exist for the electron and muon neutrinos [34] ($m_{\nu_e} < 18\,\mathrm{eV}$ at 95% C.L. and $m_{\nu_\mu} < 250\,\mathrm{keV}$ at 90% C.L.), the τ neutrino mass is limited only to $< 35\,\mathrm{MeV}$ at 95% C.L. [35].

The most sensitive technique to obtain a limit on m_{ν_τ} is based on the study of the hadronic invariant mass distribution in high multiplicity τ decays. The endpoint of this distribution is related to m_{ν_τ} by $m_{\nu_\tau} = m_\tau - m^{max}_{hadron}$. Since the τ mass is known to $^{+2.7}_{-3.6}$ MeV, the m_{ν_τ} limit is governed by the resolution on m_{hadron} (typically around 15 MeV) and by the number of events observed close to the τ mass. The latter fact is why the limit is essentially independent of the full shape of the hadronic mass spectrum, which is a priori unknown.

The limit of $< 35\,\mathrm{MeV}$ has been obtained by the ARGUS collaboration using 11 events from the decay channel $\tau^- \rightarrow \nu_\tau \pi^- \pi^+ \pi^- \pi^+ \pi^-$, for which they measure a branching ratio [35] of $B_{5\pi} = (0.064 \pm 0.025)\%$. Another hadronic final state, well suited for such a study because of the high rest masses of the particles involved is $KK\pi$. Its branching ratio has been measured [36] to be even higher: $B(\tau^- \rightarrow \nu_\tau K^+ K^- \pi^-) = (0.22^{+0.17}_{-0.11})\%$, in good agreement with the theoretical expectation of 0.24%. Due to the unique particle identification of the TPC this channel can be selected (in the 1-3 topology) with an efficiency of about 8% and negligible background. From $1000\,\mathrm{pb}^{-1}$ of data we thus expect about 50 1-3 events with $K^+K^-\pi^-$ which will enable us to derive a ν_τ mass limit of

$$m_{\nu_\tau} < 15\,\mathrm{MeV} \quad \text{at } 95\% \text{ C.L.} \tag{5}$$

3.4 Structure of the τ-W-ν_τ Vertex

The exact form of the τ coupling to the charged current is far from being sufficiently constrained by existing data. The general 4-fermion interaction hamiltonian contains ten complex coupling constants, with one phase, leading to 19 real parameters to be determined experimentally [7]. (Among them is the Fermi constant in τ decays which can be derived from a τ lifetime measurement.)

In muon decay all parameters have been measured, leading to a lower limit for $V-A$ and upper limits for all other interactions. Such a precision test of the structure of the τ-W-ν_τ vertex has hardly begun, mainly because of lack of large data samples. Besides the lifetime, only the decay parameter ρ has been determined using the lepton energy spectrum in $\tau\to\nu l\nu$. Its value, $\rho_\tau = 0.70 \pm 0.05$ [37], is in agreement with the $V-A$ expectation of 0.75. A comparison with the muon decay measurement $\rho_\mu = 0.7517 \pm 0.026$ [34] demonstrates however the lack of precision in ρ_τ. The lepton energy spectrum can also be used to determine the low energy shape parameter η.

Whereas ρ and η are best measured near $\tau^+\tau^-$ threshold (due to the smaller Lorentz boost distortion of the energy spectrum), the decay asymmetry parameters ξ and δ will most likely be determined at higher energies. ξ and δ describe the decay asymmetry with respect to the spin of the mother lepton and their determination thus requires knowledge of the τ polarization. This is possible (without polarized beams) because the spins of two τ's produced in e^+e^- annihilation are strongly correlated if their β is close to one. (At high energies the τ helicities prefer to be opposite to each other [38].) The correlation is best observable in the two-body decay $\tau^\pm\to\nu_\tau\pi^\pm$. For pure $V-A$ the $\pi^-(\pi^+)$ is emitted (anti)parallel to the τ spin, resulting in an angular correlation [39]

$$\frac{1}{\sigma}\frac{\mathrm{d}\sigma}{\mathrm{d}z} = \frac{1}{2}\left(1-\frac{z}{3}\right), \tag{6}$$

where $m_{\nu_\tau} = 0$ was assumed, $z = \cos\theta_-\cos\theta_+ + \sin\theta_-\sin\theta_+\cos(\phi_+ - \phi_-)$ and $\theta_\pm, \phi_\pm$ are polar and azimuthal angles of the $\pi^\pm$ momenta in the $\tau^\pm$ rest frames. The correlation peaks at $z=-1$ with the ratio

$$\frac{\frac{1}{\sigma}\frac{\mathrm{d}\sigma}{\mathrm{d}z}(z=-1)}{\frac{1}{\sigma}\frac{\mathrm{d}\sigma}{\mathrm{d}z}(z=+1)} = \frac{2}{1}, \tag{7}$$

which yet has to be observed experimentally. Using a whole set of measurements (see Tab. 6) yields ξ_e^2, ξ_μ^2 and $h_{\nu_\tau}^2$, the ν_τ helicity, and their relative signs. However, with the anticipated data sample it will not be possible to determine the sign of h_{ν_τ}. Without longitudinally polarized beams this measurement needs $\geq 10^7$ produced τ pairs and thus might be performed at a future B factory.

4 Conclusions

The PEP storage ring and the TPC/2γ detector have been successfully upgraded for high-luminosity running.

Table 6: Minimal set of measurements to determine ξ_μ, ξ_e and h_{ν_τ}.

$\tau^+ \to$	$\tau^- \to$	Quantity measured
$\bar{\nu}_\tau \mu^+ \nu_\mu$	$\nu_\tau e^- \bar{\nu}_e$	$\xi_\mu \xi_e$
$\bar{\nu}_\tau \mu^+ \nu_\mu$	$\nu_\tau \pi^-$	$\xi_\mu h_{\nu_\tau}$
$\bar{\nu}_\tau e^+ \nu_e$	$\nu_\tau \pi^-$	$\xi_e h_{\nu_\tau}$

During a test run in fall 1988, PEP reached instantaneous luminosities of $\mathcal{L} = 6 \times 10^{-31}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ and average integrated luminosities in excess of 1 pb^{-1} per day. With minor modifications we expect to reach $\mathcal{L} = 10^{-32}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ in the near future.

The TPC/2γ detector has been greatly improved by insertion of a high precision straw vertex chamber. The chamber performed well during the fall 1988 run.

Given a large data sample, to be collected over the next three years, TPC/2γ has an interesting and competitive physics program in the fields of two-photon physics, hadronization, B physics and τ physics. Particularly in τ physics, we want to measure τ decay branching ratios and the τ lifetime to a higher precision, improve the limit on m_{ν_τ} and further explore the structure of the τ-W-ν_τ vertex.

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TPC/2γ [13]: $B_{\pi 2\pi^\circ} + 1.6 B_{\pi 3\pi^\circ} + 1.1 B_{\pi\pi^\circ\eta} = (13.9 \pm 2.0^{+1.9}_{-2.2})\%$,
Mark II [24]: $B_{\pi 2\pi^\circ} + B_{\pi 3\pi^\circ} = (12.0 \pm 1.4 \pm 2.5)\%$, and
Mark II [17]: $B_{\pi 2\pi^\circ} = (9.0 \pm 1.0 \pm 1.2 - 0.95 B_{\pi 3\pi^\circ} - 0.43 B_{\pi\pi^\circ\eta})\%$.

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