DESY 97-260

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b-Quark Physics at DORIS [1]

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Υ -PHYSICS - THE EARLY YEARS 1977 - 1980

The high energy physics program ($E_{cms} \leq 8.6GeV$) at DORIS was initiated by the PLUTO collaboration which sent its proposal to the Forschungskollegium June 30, 1977 [1]. The same day the observation of the $\Upsilon(9.46)$ resonance was announced to the public in a seminar at FNAL [2]. The physics program proposed by PLUTO included the measurement of σ_{tot} and the search for charm and τ. The search for a 3^{rd}–generation quark is not mentioned in the proposal.

The news from FNAL spread fast. The first documented discussion at DESY between machine physicists and members of the PLUTO collaboration took place July 6, 1977 [3]. The energy upgrade of DORIS to $E_{cm} = 10$ GeV at moderate cost within half a year turned out to be possible, if parts of the new PETRA cavities and power supplies were used. Moreover, minor changes of the DORIS lattice were envisaged to avoid strong saturation effects of the magnets. The proposal and its update [4] were discussed by the DESY Forschungskollegium at its meeting on July 15. The interest of measurements in the region of the new resonances was emphasized and the directorate was urged to consider an upgrade of DORIS to $E_{cm} = 10$ GeV [5]. Note in this context that PETRA was under construction at this time and was scheduled to start running late summer 1978.

The possible physics program at a 10 GeV machine was discussed at a DESY workshop in October 1977. [6]. J. Bürger and H. Schröder presented the physics program of the PLUTO and DASP II collaboration, the latter just started to form. The "Physics Priorities at DORIS" from the theorists' point of view were discussed by T. Walsh. Astonishingly enough from todays point of view mainly the physics of the 2^{nd} generation was considered, only the $\Upsilon \to 3$–gluon decay was briefly mentioned. Both experimental groups, on the

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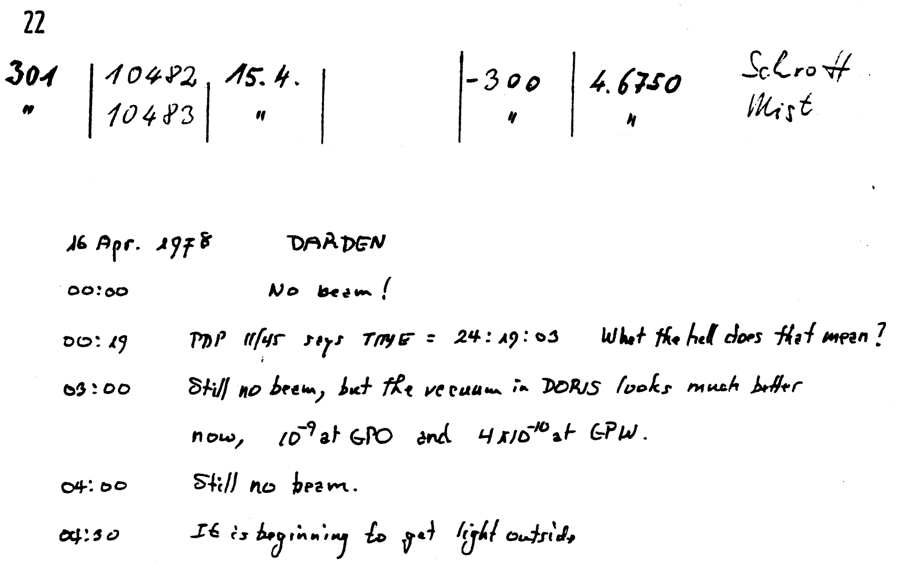
[1] Talk presented at the 20^{th} Anniversary Symposium: Twenty Beautiful Years of Bottom Physics, Chicago, June 29–July 2, 1997



22

301 | 10482 | 15.4. | | -300 | 4.6750 | Schroff
" | 10483 | " | | " | " | Mist

16 Apr. 1978 DARDEN

00:00 No beam!

00:19 PDP 11/45 says TIME = 24:19:03 What the hell does that mean?

03:00 Still no beam, but the vacuum in DORIS looks much better now, 10^{-9} at GPO and 4×10^{-10} at GPW.

04:00 Still no beam.

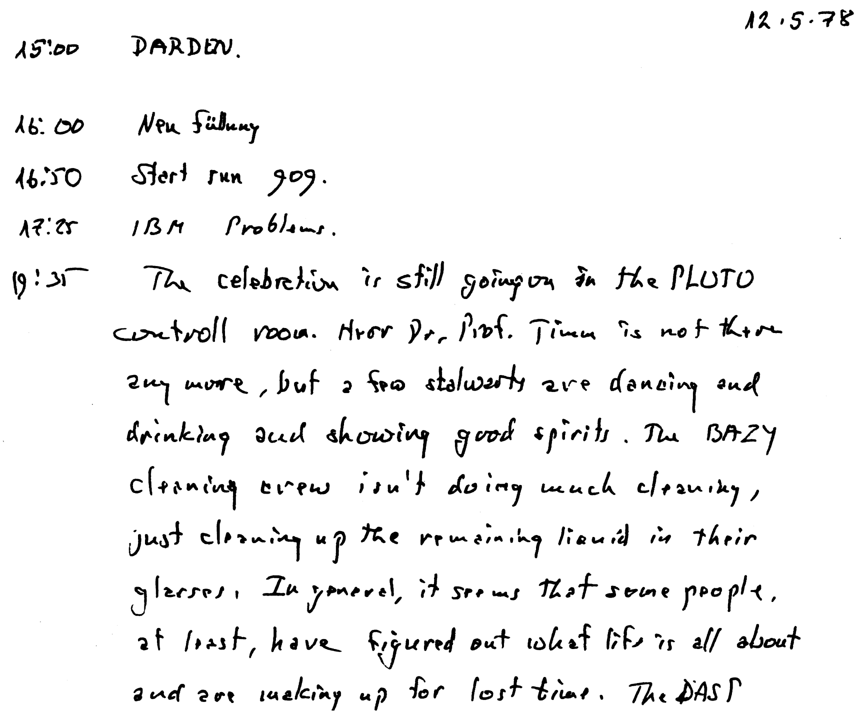
04:50 It is beginning to get light outside

FIGURE 1. Copy from DASP II runbook (15.4.1977)

other hand, discussed in detail the possibility of learning of a 3^{rd}–generation quark's properties in a few days of running.

The steps leading from the 5 GeV double–ring DORIS to the 10 GeV single–ring DORIS I are collected in table 1. The fast energy upgrade of DORIS was unexpected, I remember a seminar given by A. de Rujula at CERN in March 1978, where he discussed Υ physics. According to him the first experimental results were to be expected from CLEO early in 1979. The scan in the $\Upsilon(1S)$ region started at DESY April 15, 1978. Both the machine and the detectors had problems in the beginning (fig.1). A fluctuation observed first by DASP II, and less prominently by the PLUTO collaboration after applying sophisticated cuts was convincing enough to motivate the DESY director to expend the first bottle of champagne. After a few days of running the peak vanished, its trace can still be found in the smaller step size of the scan around 9.38 GeV [9] in the published resonance curve. But finally, on April 30, the resonance signal was established. Why the Booze Up was delayed by 2 weeks (fig.2) cannot be reconstructed any more.

The results proved that the resonance was narrow $\Gamma = (1.3 \pm 0.4)$ keV [9,10] and compatible with a $Q = -\frac{1}{3}$ charged quark. The mass of the resonant state was measured with high precision $M(\Upsilon(1S) = (9.46 \pm 0.01)$ GeV. These results established the $\Upsilon(9.46)$ resonance observed at FNAL [11] as a 3^{rd}–generation quarkonium state. A few months later the DASP II and the LENA collaboration – the latter replacing the PLUTO collaboration – with marginal statistics determined the parameters of the $\Upsilon(2S)$ state [12,13].


12.5.78

15:00 PARDEN.

16:00 Neu Füllung

16:50 Start run 909.

17:25 IBM Problems.

19:35 The celebration is still going on in the PLUTO controll room. Herr Dr. Prof. Timm is not there any more, but a few stalwarts are dancing and drinking and showing good spirits. The BAZY cleaning crew isn't doing much cleaning, just cleaning up the remaining liquid in their glasses. In general, it seems that some people, at least, have figured out what life is all about and are making up for lost time. The DASP

FIGURE 2. Copy from DASP II runbook

After establishment of the quarkonium nature of the new resonances, the detailed study of the hadronic decays was of special interest, since the resonance was predicted to decay mainly via a 3–gluon final state [14]. Already the first study of the event topology by PLUTO revealed "a striking change in mean sphericity and thrust on the $\Upsilon(9.46)$ resonance" [15]. The PLUTO collaboration addressed the problem of the 3–gluon final states in two further papers [16]. In the first paper, received by the publisher in December 1978, the authors concluded:

- The data are inconsistent with Υ decays into 2 light quarks (2–jet structure) and into multipion phase space.
- All quantities related to momentum phase–space configurations are found to be in agreement with the proposed 3–gluon decay mechanism. Vector gluons are consistent with the proposed 3–gluon decays but not proven.

Summarizing, one might say that vector gluons as the field quanta of strong interaction were not *discovered* at DORIS I, but strong evidence for the decay of the $\Upsilon(1S)$ meson into three vector gluons *was* found [17]. This point is missed in some papers describing the discovery of the gluon [18].

The Crystal Ball (CB) [19] and the ARGUS collaboration [20] later contributed further to our understanding of the $\mid b\bar{b}\rangle$ system.

TABLE 1. DORIS storage ring

6.7.1977	First discussion to upgrade DORIS to $2*5$ GeV (DORIS I) Participants : Degele, Bürger, Criegee, Flügge
15.7.1977	Forschungskollegium: strong support for upgrade
16.12.1977	Proposal to upgrade DORIS to $2*5$ GeV accepted
20.2.1978	Upgrade of DORIS starts $\rightarrow$ DORIS I
15.4.1978	Scan in $\Upsilon(1S)$ region starts
30.4.1978	$\Upsilon(1S)$ resonance observed
August 1978	$\Upsilon(2S)$ observed
July 1979	Low–beta insertion to increase luminosity proposed by K. Wille
March 1980	DORIS I stops running for high energy physics
February 1981	DORIS II (11.2 GeV machine) proposed
November 1981	DORIS II upgrade started
May 1982	DORIS II starts running
1991	DORIS II by–pass upgrade for synchrotron radiation
October 1992	ARGUS stops data taking
May 1993	Tests to increase DORIS II luminosity fail high energy physics program at DORIS II ends

DORIS II AND ITS DETECTORS

The major steps leading to the decision to upgrade DORIS I and to increase the machine energy to 11.2 GeV (DORIS II) are collected in table 1. The driving force was the growing interest in B physics and the possibility to upgrade DORIS I at moderate cost and manpower [21]. An essential criterion for the final choice of the DORIS II parameters was the requirement that the layout of the synchrotron–radiation beamlines was undisturbed. The essential changes of DORIS II with respect to DORIS I were the decrease of the gap width and the increase of the number of coil windings of the magnets, thus reducing saturation effects and power consumption. The injection was improved by installing separator plates and a faster kicker magnet. A major increase of the luminosity was achieved by mounting a special strong–focussing quadrupole at a small distance from the interaction point [22].

With these improvements DORIS II achieved a maximal integrated luminosity of 1.8 pb^{-1}/day and an average luminosity of 0.5 pb^{-1}/day.

The idea to build the ARGUS detector dates back to a dinner on September 14, 1977 [23]. Already at the DORIS workshop, one month later, the concept of "A New Detector at DORIS" including most of the features of the later ARGUS detector, was presented by W. Schmidt–Parzefall [6]:

- full coverage of the solid angle (96 %)
- good particle identification based on time–of–flight and dE/dx measurements

TABLE 2. ARGUS detector

14.9.1977	First plans to build ARGUS
10.10.1977	Meeting of DORIS Experiments
	Detector design study presented
October 1978	DESY proposal #146 : ARGUS – a new detector for DESY
July 1979	ARGUS proposal accepted by DESY directorate
April 1980	Interest in running ARGUS at 11.2 GeV emphasized
February 1981	B physics program at DORIS II discussed
6.10.1982	ARGUS starts running
September 1987	$B^0\bar{B}^0$ mixing observed
Autumn 1989	Observation of $b \to u$ transitions
8.10.1992	ARGUS stops data taking

- shower counters inside the solenoidal coil to detect photons of low energy $E_\gamma \geq 50$ MeV
- μ chambers to detect muons with a momentum $p \geq 0.9$ GeV/c.

The ARGUS [2] proposal was presented to the Forschungskollegium in October 1978 and accepted in July 1979. The final design followed in many details the original idea, with only the layout of the drift chamber improved to account for the requirements of optimal pattern recognition. The physics benchmarks in the proposal were charm and τ physics. A detailed evaluation of a possible B physics program was presented in April 1980 [24]. An expanded analysis of the possibilities of studying B physics with ARGUS followed in February 1981 [25] when it became clear that DORIS I could be upgraded to an energy of 11.2 GeV. The detector worked in a stable manner from 1982 through 1992.

During the DORIS workshop in February 1981 the idea arose to transfer the Crystal Ball (CB) detector from SLAC to DESY [19]. The proposal was soon presented and accepted in summer 1981. The CB detector was transported to DESY in spring 1982 and started data taking on August 6, 1982, while ARGUS rolled in two months later. The competition between the two experiments delayed the B physics program at DORIS for nearly 3 years because the CB collaboration preferred to run at the energy of the $\Upsilon(1S)$ and $\Upsilon(2S)$ resonance, since its detector was optimized for spectroscopic studies. As shown by Table 3 in the first years of DORIS II running, priority was given to the CB physics program. The following facts may have contributed to the decision:

- CB was a running detector with a respectable record of discoveries.

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[2] The official interpretation is **A**–**R**ussian–**G**erman–**US**–**S**wedish collaboration, indicating the nationalities of the original proponants of the experiment. The unofficial interpretation by one of the spouses knowing the senior members of the group too well reads **A**lle **R**ichtigen **G**enies **U**nter **S**ich

TABLE 3. Integrated luminosity collected 1983/1986 at DORIS II

	1983	1984	1985	1986
$\Upsilon(1S)$	9 pb -1	23 pb -1	-	31 pb -1
$\Upsilon(2S)$	27 pb -1	25 pb -1	-	-
$\Upsilon(4S)$	6 pb -1	14 pb -1	45 pb -1	44 pb -1
Continuum	4 pb -1	7 pb -1	16 pb -1	19 pb -1

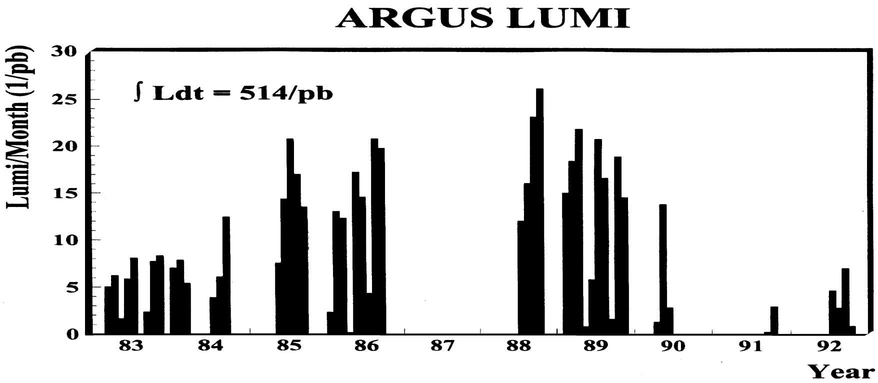

FIGURE 3. Luminosity collected by ARGUS 1982–1992

- It was an established and successful collaboration while the ARGUS senior members at that time were youngsters.
- CB observed an unexpected signal [26] and hopes were running high for a short time that a light Higgs had been discovered [3]. Unfortunately, the result turned out to be irreproducible [28].

Before discussing the most important ARGUS discovery a further obstacle met by ARGUS should be mentioned. As shown in fig.3 two major gaps in the data taking are manifest. They follow the most important ARGUS discoveries: 1987 $B^0\bar{B}^0$ mixing was observed, 1989 $b \to u$ transitions were detected. One might wonder if the DESY directorate suspected ARGUS was not putting enough emphasis on analysis, and therefore wanted to give the collaboration a chance to improve in this respect. Note, however, that the official explanation is different: 1987 HERA got priority and 1990/1991 the DORIS bypass was built. From the latter "improvement" the machine never recovered for high energy running.

[3] At this place it is appropriate to remind the reader of the guidelines for searches formulated 200 years ago: "one may notice that a shrewd intellect brings more artifice to bear the fewer data are available; indeed, to demonstrate his mastery he will select from all available data only those few favorable to his views; the remainder he will arrange so as not to obviously contradict his conclusions; and finally hostile data will be isolated, surrounded and disarmed" [27].

DISCOVERIES

The ARGUS collaboration for more than one decade substantially contributed to different fields of high energy physics. The results are summarized in [20]. In B physics the highlights are the following "firsts":

- Observation of $B^0\bar{B}^0$ mixing [29]
- Observation of charmless B decays [30]
- Reconstruction of exclusive semileptonic B decays to D^* and D mesons respectively [31]
- Reconstruction of exclusive hadronic B decays [32]
- Model–independent measurement of semileptonic B decays [33]
- Observation of charmed baryons in B decays [34]

Due to a lack of time only the most important discovery is discussed in some detail.

$B^0\bar{B}^0$ Mixing

Present universal interest in B physics is largely due to the discovery of $B^0\bar{B}^0$ mixing by the ARGUS collaboration. As is well known [35] the process is mediated by box diagrams. The mixing parameter r_d derived from time integrated measurements is given by the expression

$$r_d = \frac{N(B^0 \to \bar{B}^0)}{N(B^0 \to B^0)} = \frac{(\Delta M \tau_B)^2}{(2 + \Delta M \tau_B)^2} \sim m_{top}^4 \tag{1}$$

$$\Delta M = \frac{G_F^2}{6\pi^2}\ B_B f_B^2 m_B \mid V_{tb}^* V_{td} \mid^2 m_{top}^2 F\ \left(\frac{m_{top}^2}{m_W^2}\right)\ \eta_{QCD} \tag{2}$$

i.e. mixing is dominated by virtual t–quark exchange. The experimental situation in 1986 was as follows: PETRA experiments did not observe a signal, i.e. $m_{top} \leq 23.3$ GeV, while UA1 claimed [36] a signal at $m_{top} \approx 40$ GeV. As a consequence a small mixing parameter $r_d \approx 0.01$ was expected. A scan of the literature by the author in September 1985, while preparing a memo to the DESY PRC, showed that under optimistic assumptions on f_B a mixing of $r_d \leq 0.05$ was predicted [37]. Mixing searches using b–quark jets by MARK II, MAC and UA1 were not conclusive.

In summer 1986, for the first time ARGUS and CLEO had enough statistics to exploit the particularly clean conditions at the $\Upsilon(4S)$ to search for

$B^0\bar{B}^0$ mixing. The semileptonic decay $B^0(\bar{b}d) \to l^+X$ served as tag of the heavy flavor, i.e. $l^\pm l^\pm$ and l^+l^- events were used to measure the mixed and unmixed events respectively. At the Berkeley conference the groups presented their limits (90 % CL): $r_d \leq 0.12$ (ARGUS [38]) and $r_d \leq 0.20$ (CLEO [39]). Immediately after the conference ARGUS prepared a publication which even got a DESY number (DESY 86–121). However, the distribution of the paper was stopped at the last moment by H. Schröder. He collected all preprints at the moment they left the printer's office. All copies were burnt!

What observation led to this reaction? In August 1986 H. Schröder started an analysis of the $\bar{B}^0 \to D^{*+}l^-\bar{\nu}_l$ decay, which was of special interest, since a large branching ratio of $\sim$ 8 % was predicted but no measurements existed. Since the D^{*+} reconstruction capabilities of ARGUS were excellent and e and μ were identified with high efficiency, a high– statistics $\bar{B}^0 \to D^{*+}l^-\bar{\nu}_l$ sample out of $\sim$ 25000 $B^0\bar{B}^0$ events was expected. However, a new method had to be developed to reconstruct these events with an undetected ν_l, whose mass can be derived from the measurements:

$$m_\nu^2 = (E_B - E_{D^{*+}} - E_{l^-})^2 - (\vec{p_B} - (\vec{P}_{D^{*+}} + \vec{P}_{l^-}))^2 \qquad (3)$$

From the first successful reconstruction of exclusive hadronic B decays [32] it was known that

$$2E_B = m(\Upsilon(4S)) \approx 2m_B\,. \qquad (4)$$

Since $E_B = E_{beam}$, $\mid \vec{p_B} \mid = 0.33$ GeV/c and hence can be neglected in (3). Therefore,

$$m_\nu^2 \approx M_{rec}^2 = (E_{beam} - E_{D^{*+}} - E_{l^-})^2 - (\vec{p_{D^{*+}}} + \vec{p_{l^-}})^2 \qquad (5)$$

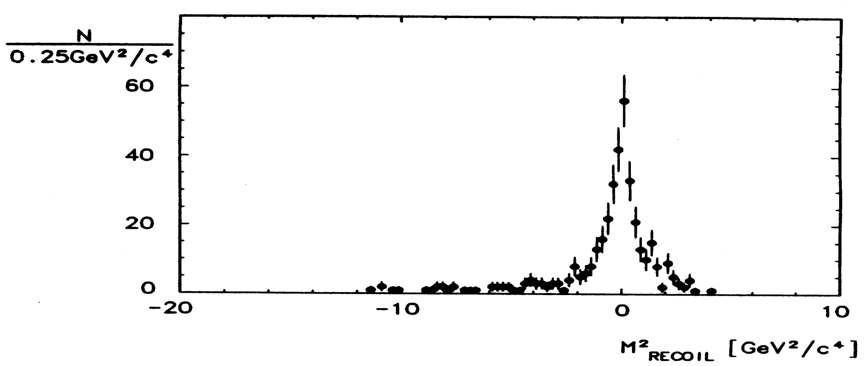

FIGURE 4. Measured recoil mass distribution

As expected, a peak at $M_{rec}^2 \approx 0$ is observed with small, wel–known background (fig.4). Though the application of this method was controversial [40], in the following years it was applied in many analyses by the CLEO and the ARGUS collaboration. In September 1986, 50 events with a reconstructed $B^0(\bar{B}^0)$ were available to tag the heavy flavor of the B^0. H. Schröder presented the first results of his analysis at the ARGUS group meeting on September 25, 1986 (fig.5). He studied in detail the events with a full reconstructed $B^0(\bar{B}^0)$ meson. The observed multiplicity, number of kaons and leptons followed the expectation, but he stumbled over a few events with wrong charged kaons and leptons respectively. In the data sample five candidates for mixed events were observed: $2B^0e^+$, $2\bar{B}^0e^-$, $1\bar{B}^0\mu^-$ besides 23 candidates for unmixed events. After background subtraction a mixing ratio of $r_d = 0.20 \pm 0.12$ was obtained.

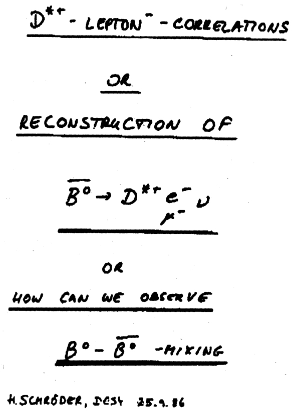

FIGURE 5. First page of H. Schröder's talk announcing the observation of $B^0\bar{B}^0$ mixing

The claim that $B^0\bar{B}^0$ mixing had indeed been observed was supported by the observation of one full reconstructed event with 2 $\bar{B}^0$ mesons in the final state decaying via $\bar{B}^0 \to D^*\mu^+\bar{\nu}_\mu$ (fig.6). Both μ^+ and the K^+ meson were uniquely identified. The observation of this event is a convincing example of the advantages of the ARGUS detector: precise momentum measurement, good particle identification and hermiticity. The observation of D^*–lepton correlation therefore provided an extremely useful tool. This proved the existence of $B^0\bar{B}^0$ mixing with a large mixing parameter, totally unexpected at that time.

This result stimulated further activity. Y. Zaitsev and A. Golutvin repeated the same–sign lepton pair analysis. A signal was observed in this sample as well. The major improvement compared to the previous analysis presented at Berkeley [38] was the increase in the collected luminosity of more than a factor of 2. Furthermore, the better understanding of the detector allowed improving the cuts applied in the analysis. The mixing parameter derived in this analysis was in good agreement with the result of the exclusive analysis. Combining the results ARGUS got

$$r_d = (0.21 \pm 0.08) \tag{6}$$

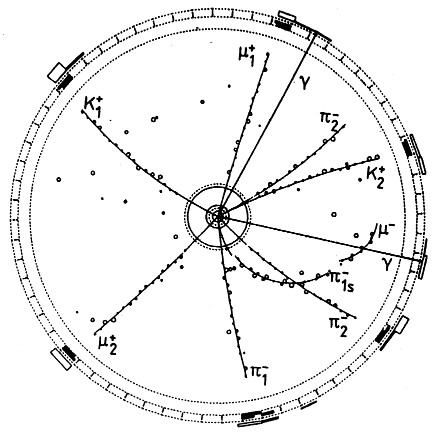

FIGURE 6. First full reconstructed $B^0\bar{B}^0$ mixing event

in good agreement with the present world average [41].

To explain the large mixing parameter, ARGUS had to assume the top mass to be large, $m_{top} > 50$ GeV, 10 years ago an unconventional assumption in view of the UA1 claim [36]. The paper was published on June 25, 1987, just 10 years after the discovery of the $\Upsilon(1S)$ resonance by Lederman and coworkers at FNAL. The large mixing in the B system raised hopes of observing CP violation in this system, a prospect attracting many scientists to the field. The experiments presently under construction [42] underline the importance of the seminal ARGUS result obtained 10 years ago.

SUMMARY

I will abstain from discussing in detail the other important contributions of ARGUS to B physics, I only want to address the question why the collaboration was so successful for nearly 10 years. The answer was given by David Cassel in his talk "The Impact of ARGUS on Experimental Heavy Flavor Physics" [43], where he discussed the lessons to be learned from ARGUS:

- Have a better detector that can see "all".
- Learn to use the hermiticity of the detector.
- Have excellent physics ideas and follow them.
- Have excellent physics analysis software.
- Have a little bit of luck.
- Do not underestimate the competition.

There are a bit too many *excellent's* in this list but otherwise I have nothing to add. Hopefully the new generation of experiments will be as prolific as the 2^{nd} generation, and the participants will have as much fun as the CLEO and ARGUS collaborations had.

Acknowledgement

I thank the organizers for their generous hospitality and for a stimulating conference, where I learned many secrets of those experiments which established the field of B physics. Thanks for discussions, unpublished material, etc. to J. Bürger, H. Meyer, W. Schmidt–Parzefall, K. Wacker and K. Wille. Most helpful in reconstructing the steps leading to the discovery of $B^0\bar{B}^0$ mixing was the information I got from H. Schröder. This work was supported by the BMBF under contract number 6DO57I.

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