ISTITUTO NAZIONALE DI FISICA NUCLEARE

Sezione di Genova

INFN/AE-97/02
7 Gennaio 1997

C. Caso:

SUMMARY OF THE CONFERENCE

Highlights of the 2nd International Conference on Hyperons, Charm and Beauty Hadrons Montréal, Québec, Canada, 27-30 August 1996

To appear in the Conference Proceedings

SIS-Pubblicazioni
dei Laboratori Nazionali di Frascati

INFN – Istituto Nazionale di Fisica Nucelare
Sezione di Genova

INFN/AE–97/02
7 Gennaio 1997

SUMMARY OF THE CONFERENCE

Highlights of the 2nd International Conference on Hyperons, Charm and Beauty Hadrons
Montréal, Québec, Canada, 27–30 August 1996

Carlo Caso
Department of Physics, University of Genova and INFN
Via Dodecaneso 33, I–16146 Genova, Italy
E–mail: Caso@Genova.Infn.It

Abstract

This is a review of the many experimental results presented at this Conference. Time and space limitations have been serious obstacles to a complete coverage and to a fully comprehensive review.

1 INTRODUCTION

The task of this report is to summarize the many excellent contributions to this Conference. As usual, a summarizer carries this job in accordance with biases based on his personal experience and taste. This case is not exception: for instance I will not report on the many stimulating theoretical presentations (also because some of them are too difficult for me!) and I assume that the various detectors I will mention in the following are all well known. I have tried to put the various arguments in some context: I am not sure I have succeeded in doing this.

2 PHYSICS AT CERN AND SLAC

2.1 R_b and R_c

The measurement of these quantities (especially R_b) is a good test of the Standard Model. In fact R_b has a strong dependence on the top mass and most of the theoretical uncertainties (α_s and m_H) cancel out in the ratio.

At the 1996 Winter Conferences there was a quite intriguing situation; with a SM predictions of $R_b = 0.2155$ and $R_c = 0.1725$ (for $m_{top} = 175$ GeV and $m_H = 300$ GeV) the combination of preliminary LEP and SLD electroweak measurements had given:(1)

$R_b = 0.2215 \pm 0.0017$

$R_c = 0.1596 \pm 0.0070$

with a 3.5 σ and -1.8 σ deviation respectively from their predictions. This was the only corner where the precise LEP/SLD measurements were somehow in disagreement with the SM and this apparent discrepancy had led to some speculation concerning new physics beyond the Standard Model.

Today we are in a more comfortable situation: the Warsaw 1996 preliminary results are:

$R_b = 0.2178 \pm 0.0011$

$R_c = 0.1715 \pm 0.0056$

While R_c is in a very good shape (mostly due to the double tag), R_b is still $\approx 2\ \sigma$ above the SM but it has moved in the right direction (see Figure 1).

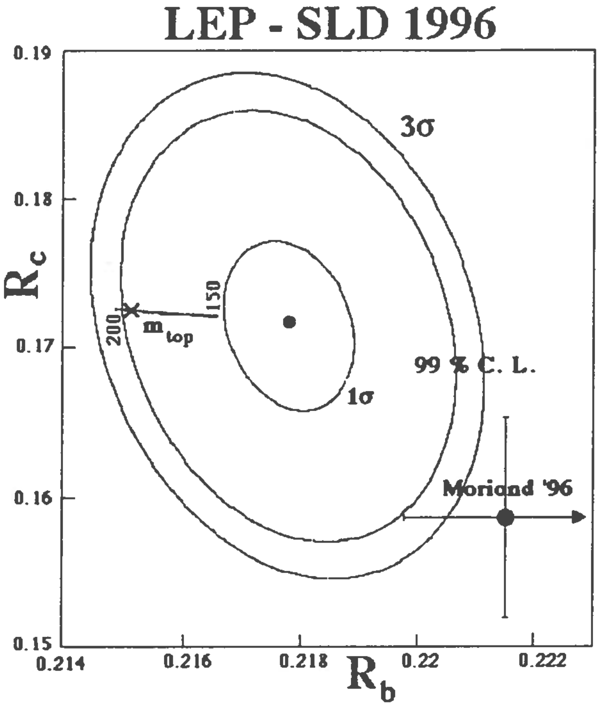

Figure 1: Confidence level contours in the R_b, R_c plane.

What has really happened? The improvements are certainly due to a combination of many ingredients like:

- better understanding of the correlations;
- improved measurements of various physical quantities (c–lifetimes, c–production rates etc);
- mass tag

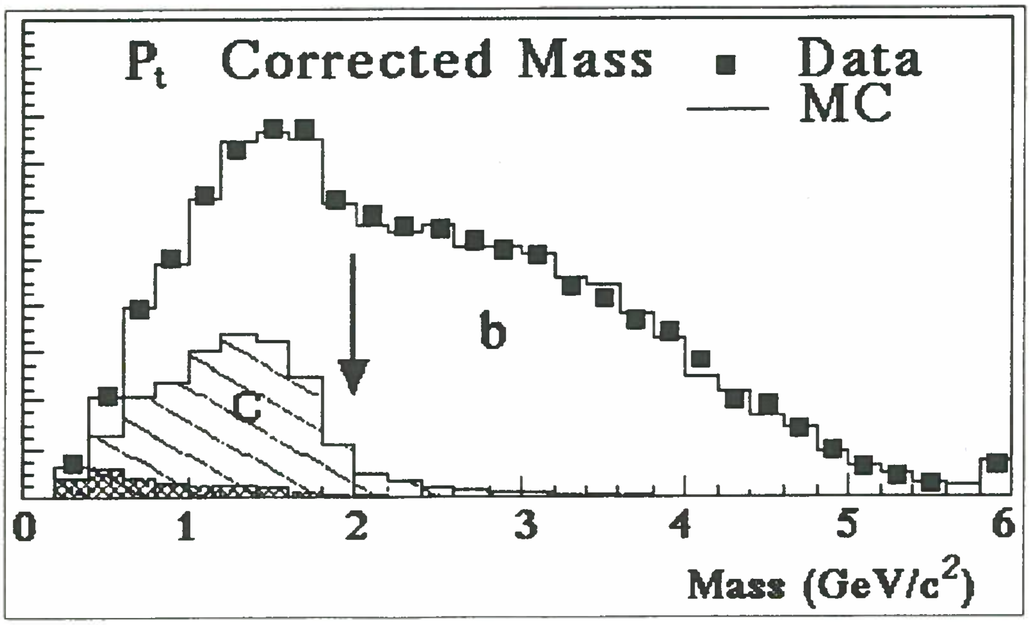

Figure 2: SLD preliminary result on vertex mass.

but my understanding is that the mass tag has been the most effective tool. Its virtue is illustrated in Figure 2 which shows the mass coming from a secondary vertex, corrected with the missing p_T. For $M > 2$ GeV the charm contamination has largely gone and the b–purity becomes higher. It must be stressed that this mass tag results much more efficient for a tiny and stable beam intersection point as SLD has (RMS(xy) < 7 μm).

We have seen three measurements presented to this Conference:

1. an ALEPH measurement (1992–1995 statistics, discussed by Fabrizio Palla) using five mutually exclusive hemisphere tags. Three tags are designed to select the decay of the Z to b–quarks (one tag includes the mass cut mentioned above), while the remaining two select Z decays to c– and light quarks, and are used to measure the background tagging efficiencies. Each tag is given a priority and a hemisphere is tagged at most by one tag. This procedure (together with an improved handling of the correlations obtained using only hemisphere variables) is found to decrease appreciably the statistical and systematic uncertainties. This (preliminary) ALEPH measurement is:
$$R_b = 0.2158 \pm 0.0009 \pm 0.0011$$

2. an SLD measurement (1993–1995 data, presented by Richard Dubois) where the SLD's pixel VXD, the tiny beam spot (both used to have a good topological vertexing), the mass tag and the double tag to get efficiency from the data allow for a rather precise measurement, in spite of the limited statistics if compared to a LEP experiment:
$$R_b = 0.2149 \pm 0.0033 \pm 0.0021$$

3. a "traditional" L3 measurement (1994 data, presented by Maria Chamizo) with a careful study of the hemisphere correlations (the largest source of systematics):
$$R_b = 0.2185 \pm 0.0028 \pm 0.0033$$

All these R_b measurements have a further R_c dependence not included in the values above. The Warsaw 1996 preliminary average (corrected for γ–exchange) $R_b = 0.2178 \pm 0.0011$ is largely dominated by the ALEPH measurement. There are rumors however that the remaining LEP Collaborations are working to produce soon new results on R_b.

2.2 Oscillations

Neglecting the decay width difference of the mass eigenstates, the probability that a generated B^0 meson stays as B^0 at time t is given by:

$$P(B^0 \to B^0) = \frac{e^{-\frac{\Gamma t}{\hbar}}}{2\tau_B}\left[1 + cos\left(\frac{\Delta m\, t}{\hbar}\right)\right] \tag{1}$$

and the probability that it oscillates into $\overline{B}^0$ at time t is:

$$P(B^0 \to \overline{B}^0) = \frac{e^{-\frac{\Gamma t}{\hbar}}}{2\tau_B}\left[1 - \cos\left(\frac{\Delta m\, t}{\hbar}\right)\right] \tag{2}$$

where Γ is the decay width, τ_B is the B lifetime and Δm is the mass difference of the two mass eigenstates.

This is valid both for the B^0_d and B^0_s mesons. Actually, this is valid *mutatis mutandis* for all neutral mesons. However neutral mesons oscillate if they can: for instance the D^0 system decays before oscillating, as we have seen from the E791 results given by Lucien Cremaldi. Using 200,000 fully reconstructed charm decays produced by 20 10^9 500 GeV π^- interactions the time–integrated $D^0 \to \overline{D}^0$ mixing is measured to be consistent with zero [more precisely $r_{mix}(\overline{D}^0 \to D^0) <$ 0.74% (@ 90% CL) and $r_{mix}(D^0 \to \overline{D}^0) <$ 1.45% (@ 90% CL)].

To perform a time–dependent oscillation measurement one has to:

- select a B^0 candidate;
- measure its decay time $t = L\, m_B/p_B$; at LEP energies $L \approx 2.5$ mm with $\approx$ 200–300 μm resolution, $p_B \approx 32$ GeV with $\approx$ 10–20 % resolution;
- tag the flavour at decay (B^0 or $\overline{B}^0$) using the B decay products;
- tag the flavour at the production time. This is achieved in a variety of methods: looking for the lepton charge in the opposite hemisphere, looking for the jet charge in the opposite/same hemisphere, looking for the same hemisphere fragmentation kaon and finally combining all the above in all possible ways.

The LEP measurements on Δm_d have been reviewed by Elisabetta Barberio and we have seen that the precise LEP average ($\approx$ 3.6 % error) is:

$$\Delta m_d = 0.470 \pm 0.017 \text{ ps}^{-1}$$

An SLD measurement (presented by David Jackson) has combined several tagging methods (kaon tag, charge dipole tag, lepton + D–tag, lepton + tracks tag) to produce the preliminary result:

$$\Delta m_d = 0.525 \pm 0.043 \pm 0.037 \text{ ps}^{-1}$$

The measurement of the time–dependent B^0_s oscillations is a much more complex experimental problem. This can be understood as follows: while for a B^0_d meson a complete oscillation period is expected to take $\approx$ 8.5 B^0_d lifetimes, the B^0_s oscillation frequency is predicted to be higher ($\Delta m_s \approx 20\, \Delta m_d$). This measurement would then require high statistics, excellent proper time resolution and high purity.

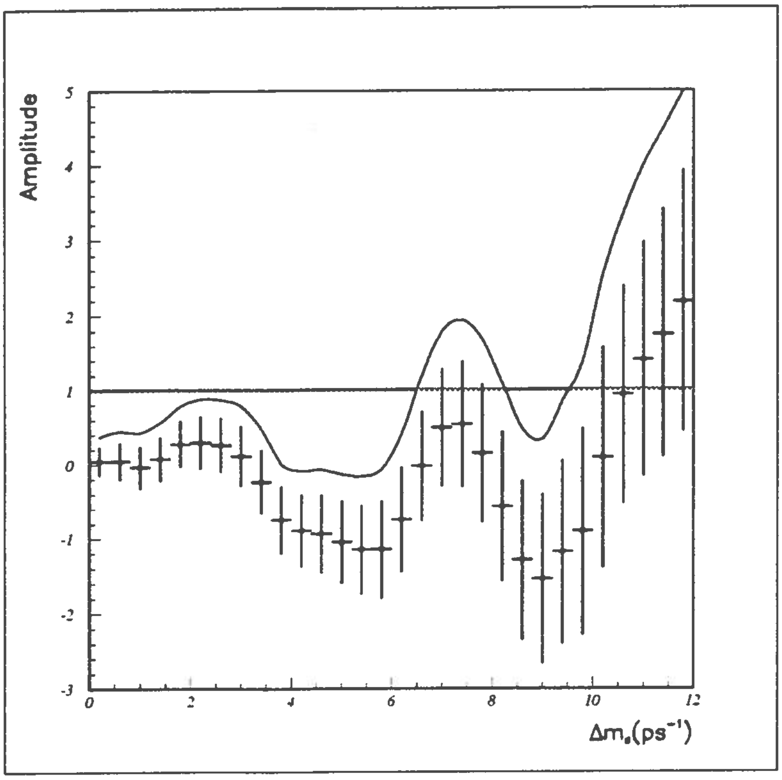

Figure 3: DELPHI combination of dilepton + lepton jet–charge + D$_s$–lepton amplitude analysis.

For this reason there are not yet measurements but only LEP limits on Δm_s. To set a lower limit on this quantity there are tricky procedures (toy Montecarlo and amplitude method); I will illustrate the amplitude method using Figure 3. One first multiply the function describing the oscillation by a factor A [$1 \pm cos\left(\frac{\Delta m_s t}{\hbar}\right) \Rightarrow 1 \pm A\ cos\left(\frac{\Delta m_s t}{\hbar}\right)$ with A = 0 no oscillation, A = 1 oscillation at frequency Δm_s]. For any fixed value of Δm_s fit the data with A as free parameter, calculate its statistical and systematic uncertainty σ_A and exclude oscillations at frequency Δm_s if A < 1 at 95% CL (draw the contour line A + 1.65σ_A and intercept with A = 1). Applying this procedure to Figure 3 one obtains $\Delta m_s > 6.5$ ps^{-1} at 95% CL. The further excluded interval $\Delta m_s \in [8.2, 9.6]$ ps^{-1} of Figure 3 has low exclusion probability.

The amplitude method allows to combine different limits; this has been used by DELPHI ($\Delta m_s > 6.5$ ps^{-1}) and ALEPH ($\Delta m_s > 7.8$ ps^{-1}). A preliminary combination of these two limits has been presented to the 1996 Warsaw Conference:

$$\Delta m_s > 9.2 \text{ ps}^{-1} \text{ at } 95\% \text{ CL}$$

2.3 Lifetimes

On the basis of our present knowledge of the various possible decay diagrams one has the following qualitative prediction for the c–sector:

$$\tau(D^+) > \tau(D^0) \approx \tau(D_s^+) > \tau(\Lambda_c^+)$$

which is well satisfied experimentally.

For the b–sector, since the spectator model is expected to be a much better approximation, one has a similar predicted hierarchy:

$$\tau(B^+) > \tau(B^0) \approx \tau(B_s^0) > \tau(\Lambda_b^0)$$

but, since the magnitude of the differences scales as $\approx \frac{1}{m_Q^2}$, the various b lifetimes will differ by $\leq O(10\%)$.

We have had three contributions on lifetimes:

- an inclusive B–lifetime measurement (presented by Hannelies Nowak) with the decay length method which exploits the L3 silicon microstrip detector to reconstruct secondary vertices. A likelihood fit in the region 2 mm $\leq$ L $\leq$ 30 mm gives:
$$\tau(\mathrm{B}) = 1.552 \pm 0.023 \pm 0.043 \text{ ps}$$
- SLD measurements of the B^+ and B^0 lifetimes (presented by Richard Dubois). There is first a secondary vertex finding; then the vertex is identified as originating from b's using the vertex mass discussed in (2.1) and finally the vertex charge is reconstructed. The lifetimes turn out to be:
$$\tau(\mathrm{B}^+) = 1.69 \pm 0.08 \pm 0.06 \text{ ps}$$
$$\tau(\mathrm{B}^0) = 1.63 \pm 0.07 \pm 0.08 \text{ ps}$$
- the first CDF measurement of the Λ_b lifetime (discussed by Jeff Tseng). This measurement is à la LEP, searching for Λ_b production in the decay $\Lambda_b \to \Lambda_c e^- \overline{\nu}_e + X$ (with $\Lambda_c \to pK^-\pi^+$). Evidence for Λ_b production is given by an excess of "right–sign" pairs $e^-\Lambda_c$ (or C. C.) in the same hemisphere while "wrong–sign" pairs $e^+\bar{\Lambda}_c$ are used to estimate the background. A likelihood fit to the pseudo–proper time distribution gives:
$$\tau(\Lambda_b) = 1.32 \pm 0.15 \pm 0.07 \text{ ps}$$

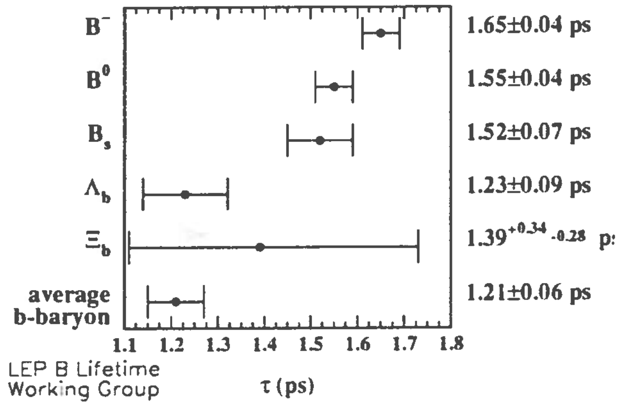

Figure 4: Summary of B–hadron lifetimes.

Figure 4 shows the latest summary of the B–hadron lifetimes as obtained by the LEP B Lifetime Working Group. Taking into account the dominating systematic effects, $\Delta\tau = 0.02$ ps could be the present limit of the accuracy.

One observes that the hierarchy expected from the spectator model appears rather well satisfied; however Λ_b is shorter than expected ($\tau_{\Lambda_b}/\tau_{\mathrm{B}^0} = 0.79 \pm 0.06$), $\approx$ 1.8 s.d. away from its QCD prediction of $\tau_{\Lambda_b}/\tau_{\mathrm{B}^0} \approx 0.9$. Since this ratio is too small to be explained by corrections of order $\frac{1}{m_Q^2}$ or $\frac{1}{m_Q^3}$, it has been argued$^{(2)}$ that there might be a violation of the local duality property which is assumed for non–leptonic widths.

2.4 Branching Fractions

This is an almost infinite field and I do have to do my own selection of results.

First of all there are good news since the LEP inclusive semileptonic branching fraction $BR(\mathrm{b} \to \ell\nu X)$ = (10.91 $\pm$ 0.18 $\pm$ 0.25)% has now decreased and it is approaching its $\Upsilon(4S)$ value$^{(3)}$ (10.19 $\pm$ 0.37 %, as given by the dilepton method which reduces the model dependence of the result: however at $\Upsilon(4S)$ there is neither B_s^0 nor Λ_b production).

The branching fraction $BR(\mathrm{b} \to \tau\nu X)$ has been improved by ALEPH (and presented by Anna Pascual). Since there are two ν's in the final state they look for large missing energy in the same hemisphere for lifetime tagged events; b $\rightarrow \ell\nu X$ decays are reduced by applying an e/μ veto to this hemisphere. Fitting the missing energy spectrum of the 91–95 data they obtain $BR(\mathrm{b} \rightarrow \tau\nu X) =$ (2.41 ± 0.21 ± 0.34)%, with a HQET prediction of (2.3 ± 0.25)%. A new method, consisting in studying the kinematical characteristics of opposite sign dileptons in the same jet, has larger background and then larger systematic uncertainties [$BR(\mathrm{b} \rightarrow \tau\nu X) = (3.94 \pm 0.67\, ^{+0.62}_{-0.56})\%$]; the combination of these two results gives:

$$\mathrm{BR}(\mathrm{b} \rightarrow \tau\nu X) = (2.72 \pm 0.20 \pm 0.27)\%$$

It should be stressed that L3 has found (1.7 ± 0.5 ± 1.1)% and DELPHI has obtained (2.58 ± 0.11 ± 0.51)%.

Pauline Gagnon has presented the first measurement of the ratio $\mathrm{R}_{\Lambda\ell} = \mathrm{BR}(\Lambda_b \rightarrow \Lambda\ell X)$ / $\mathrm{BR}(\Lambda_b \rightarrow \Lambda X)$, where Λ_b denotes a generic b–baryon. In the spectator model approximation this ratio is equivalent to the average b–baryon semileptonic branching fraction and hence gives the relative importance of non–spectator diagrams in hadronic decay [connected to the problem of the short Λ_b lifetime mentioned in (2.3)].

The strategy consists in selecting $\Lambda\ell$ pairs in $\mathrm{b\bar{b}}$ tagged events, subtracting the "wrong–sign" from the "right–sign" signal and correcting for a small (≈ 5%) background unbalance (the main background being due to fragmentation Λ's coupled to leptons from b and c semileptonic decays). To get $\Lambda_b \rightarrow \Lambda X$ (the denominator), Λ accompanied by a visible baryon ($\bar{\Lambda}$ or $\bar{p}$) belonging to the same hemisphere are searched for (background from fake Λ's and Λ from fragmentation or B–meson decays). Using the OPAL 91–94 statistics the result turns out to be:

$$\mathrm{R}_{\Lambda\ell} = (6.8 \pm 1.3 \pm 1.0)\%$$

An expectation of this quantity can be obtained by rescaling the B–meson semileptonic decay:

$$BR_{sl}^{\Lambda_b} \cong \frac{\tau_{\Lambda_b}}{\tau_B}\; BR_{sl}^{\mathrm{B}} \tag{3}$$

which ranges from (7.2 ± 0.6) to (8.0 ± 0.7)%, in fair agreement with the above OPAL result.

We have had two complementary contributions on exclusive rare B–meson charmless decays, by Pascual Vincent (DELPHI) and Alain Bonissent (ALEPH). The physics motivation of these investigations is in the fact that, while the $\mathrm{B}^0 \rightarrow \pi^+\pi^-$ is mediated (at tree level) by the b → u transition (it is then sensitive to the $\mathrm{V}_{b,u}$ element of the CKM matrix), the $\mathrm{B}^0 \rightarrow K^+\pi^-$ needs a one–loop penguin b → s, d contribution. The decay rate for $\mathrm{B}^0_{s,d} \rightarrow h^+h^-$ (where h = hadron) is found to be $(2.8\, ^{+1.5}_{-1.0} \pm 0.2)\; 10^{-5}$ by DELPHI (91–94 data) and $(1.7\, ^{+1.0}_{-0.7} \pm 0.2)\; 10^{-5}$ by ALEPH (91–95 statistics), to be compared with a similar finding by CLEO [$(1.8\, ^{+0.6+0.2}_{-0.5-0.3} \pm 0.2)\; 10^{-5}$]. DELPHI can also exploit its powerful particle identification capability (given by the system of the RICH detectors, a unique feature in LEP, coupled to the dE/dx of the central drift chamber) to measure the decay rates: $\mathrm{B}^0_{s,d} \rightarrow \pi^+\pi^- = (2.4\, ^{+1.7}_{-1.1} \pm 0.2)\; 10^{-5}$ and $\mathrm{B}^-_u \rightarrow \rho^0\pi^-, K^{*0}\pi^- = (1.7\, ^{+1.2}_{-0.8} \pm 0.2)\; 10^{-4}$. Decays in three and four bodies are excluded with BR upper limits in the range of $(1 \div 3) 10^{-4}$ at 90% CL.

J/ψ, ψ' and Υ production at LEP has been reviewed by Georges Azuelos. While the bulk of the J/ψ mesons is produced from b–hadron decays (either directly or via cascade decay of other charmonium states), the rate of the promptly produced J/ψ can provide a test of the fragmentation models where these objects are mostly produced by gluon fragmentation into a colour–octet state before evolving to colour–singlet states by emission of soft gluons. The strategy of this search is similar for all LEP experiments (particles are all searched for in the dilepton mode); the background is mostly due to J/ψ from hadronic decays (≈ 40%), to fake J/ψ and finally to 4–fermion processes. We have seen a long list of branching fractions, all in fair agreement with the expectations. The reader is referred to the original contribution for the full list of these results.

Simone Paoletti has reported a measurement of inclusive χ_c production performed by the L3 experiment. χ_c mesons are reconstructed via their decay into a J/ψ and a photon, with the photon detected in the BGO calorimeter and J/ψ → $\ell^+\ell^-$ (e^+e^- = 198 ± 20 events, $\mu^+\mu^-$ = 205 ± 20 events). In the M(J/ψ + γ) - M(J/ψ) distribution an excess of $\approx$ 30 events is attributed to χ_c production, corresponding to BR (Z → χ_c X) = (2.7 ± 0.7 ± 0.6) 10^{-3}. This gives a ratio (Z → χ_c X) / (Z → J/ψ X) = 0.8 ± 0.2 ± 0.2, while the colour–singlet model predicts this ratio to be $\approx$ 0.2. LEP B_c searches in the "discovery channel" $B_c^\pm \to J/\psi \ell^\pm \nu$ have also been reviewed (ALEPH: 2 candidates (e and μ), L3: 1 candidate (μ), DELPHI: no candidates) and upper limits have been given.

2.5 B–hadron Spectroscopy

There is an emerging evidence that the B–hadron spectroscopy can be satisfactorily described by the Heavy Quark Effective Theory$^{(4)}$ (HQET) and that the b–sector is the ideal place for testing various HQET predictions.

b–quark fragmentation is capable of producing primary mesons with orbital excitation (commonly labeled B^{**}). In the quark model one expects for each spectator flavour four different B meson states with orbital angular momentum $L = 1$. The expected main decay modes of $B^{**}_{u,d}$ mesons are $B\pi$ and $B^*\pi$. If the B^{**}_s meson mass is above the $B^{(*)}K$ threshold ($B^{(*)}$ indicates an unresolved B or B^* meson), this will be the dominant decay mode, since $B_s\pi$ is forbidden by isospin conservation.

Some HQET predictions for the orbitally excited states B^{**+} ($\bar{b}u$), B^{**0} ($\bar{b}d$) and B^{**}_s ($\bar{b}s$) can be found in Ref. $^{(5)}$

Motivated by the small branching ratio of B hadrons into exclusive final states, several methods for inclusive particle reconstruction have been developed at LEP. The general philosophy of this inclusive method consists in attaching to the inclusive B–object a high quality track from primary vertex (x = γ, $\pi^\pm$, $K^\pm$) and search for enhancements in the Q–value M(Bx) - M(B).

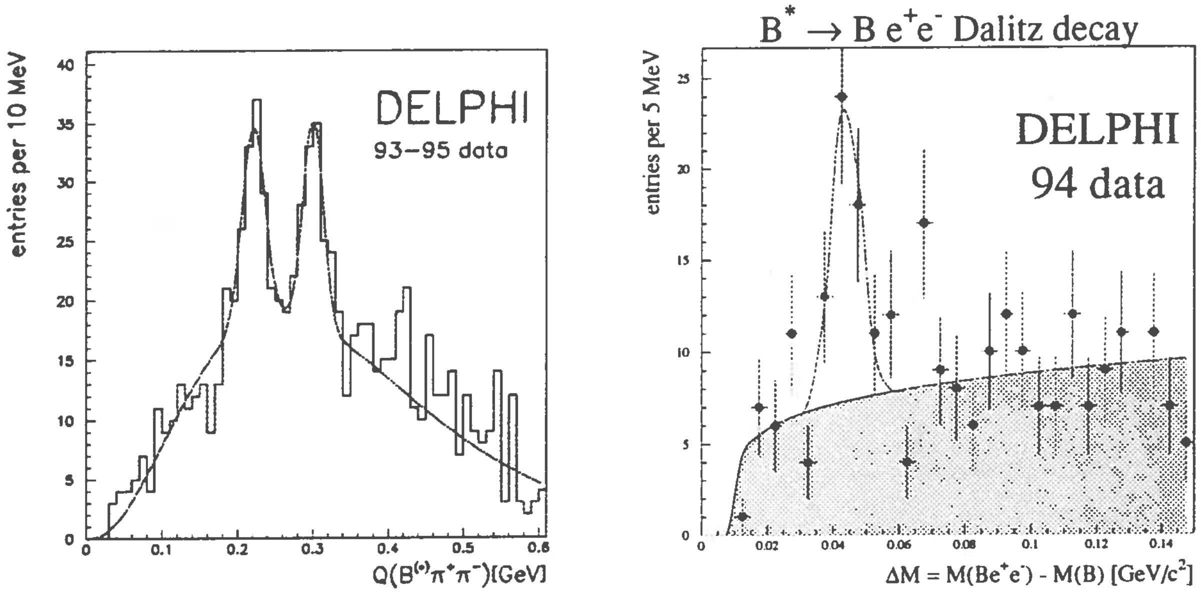

Figure 5: Left: observation of radially excited B–mesons; right: B* Dalitz decay.

An overview of the recent experimental progress on B spectroscopy at LEP has been given by Marie Laure Andrieux. Previous evidences for the production of orbitally excited B^* as well as B^{**} and B^{**}_s mesons appear now consolidated and new results have been obtained attaching a pair of particles originating from primary to the inclusive B–object. New preliminary results from DELPHI include the first evidence for radially excited B–mesons (see Figure 5). A narrow peak around Q = m($B^{(*)}\pi^+\pi^-$) - m($B^{(*)}$) - 2 m(π) (both pions have rapidity above 2.5) = 301 ± 4 ± 10 MeV is likely from the decay of a radially excited B–meson. Another narrow peak at 220 ± 4 ± 10 MeV is interpreted as the decay of the orbital excitation $B_1 \to B\pi^+\pi^-$. DELPHI has also observed for the first time the second order electromagnetic (Dalitz–) decay $B^* \to Be^+e^-$ (the low energy electrons are tracked using the silicon microstrip detector). The mass difference spectrum m(Be^+e^-) - m(B) shows an excess of 43 ± 10 events (Figure 5), with a reconstructed B^*–B mass difference of 43.9 ± 1.3 MeV, in good agreement with the world average.

2.6 Strange Baryons

A direct measurement of the Ξ^- and $\overline{\Xi}^+$ lifetimes and masses, as performed by DELPHI, has been reported by Barbro Åsman ($\Xi^- \to \Lambda\pi^-$, about 2500 decays; $\overline{\Xi}^+ \to \overline{\Lambda}\pi^+$, about 2300 decays). It is worth noting that this $\overline{\Xi}^+$ sample is ≈ 65 times larger that the largest sample quoted in the PDG$^{(3)}$ and hence these results will certainly influence the averages of the next PDG edition. Lifetimes and masses were measured to be:

$$\tau_{\Xi^- + \overline{\Xi}^+} = 0.166 \pm 0.006 \pm 0.009 \text{ ns}$$

$$\mathrm{M}_{\Xi^- + \overline{\Xi}^+} = 1321.61 \pm 0.06 \pm 0.10 \text{ MeV}$$

The Σ^- production rate in Z decays has also been measured by DELPHI. Due to their long decay length ($c\tau$ = 4.43 cm for Σ^- and 2.4 cm for Σ^+) the decay of $\Sigma^\pm$ often takes place outside the three–layered microvertex detector, which makes a direct determination of their track parameters possible. The decay $\Sigma^\pm \to \mathrm{n}\pi^\pm$ is then reconstructed by finding the kink between the $\Sigma^\pm$ and the final large impact parameter pion measured by the DELPHI tracking system. The measured production rate [$<\mathrm{n}_{\Sigma^-}>$ = 0.081 ± 0.002 ± 0.011 ± 0.007 (extr.)] is compatible, within 1.5 σ, with the theoretical (actually JETSET 7.4) prediction and its differential shape is well described by this model.

Σ–hyperon production in Z decays has also been presented by André Joly from OPAL. While the search strategy for $\Sigma^\pm$ is similar to the DELPHI one, the decay $\Sigma^0 \to \Lambda\gamma$ is reconstructed using "converted" photons. The inclusive production rates are measured separately for each isospin state; assuming isospin invariance the average multiplicity [0.084 ± 0.005 ± 0.007 ± 0.003 (extr.)] is consistent with the DELPHI finding.

At last something outside LEP physics: Matthias Heidrich has presented the CERN WA89 hyperon beam results on Ξ^- production. This experiment has the peculiar feature of three different projectiles (Σ^- and π^- at 345 GeV and n from Σ^- decay at 260 GeV) within the same apparatus, ensuring small systematic errors. Ξ^- (dss) differential cross section shows a strong leading particle effect when produced by Σ^- (dds), as expected since they have two valence quarks (or a diquark) in common. As two different targets (copper and carbon) are also available an A–dependence study ($\sigma = \sigma_0 \mathrm{A}^\alpha$) shows that α decreases with x_F and rises with p_T^2.

3 PHYSICS AT FERMILAB

Heavy flavour physics at the Fermilab Tevatron has some peculiar features when compared to the LEP physics. First of all the large b–production cross section (≈ 40 μb) represents only a small fraction (≈ 10^{-3}) of the total cross section such that it is like to look for a needle in a haystack. Furthermore b's are produced in a range of energies and softer than at Z^0.

Using the data collected between 1992 and 1995 (115 pb^{-1}, Run 1a and 1b) CDF has searched

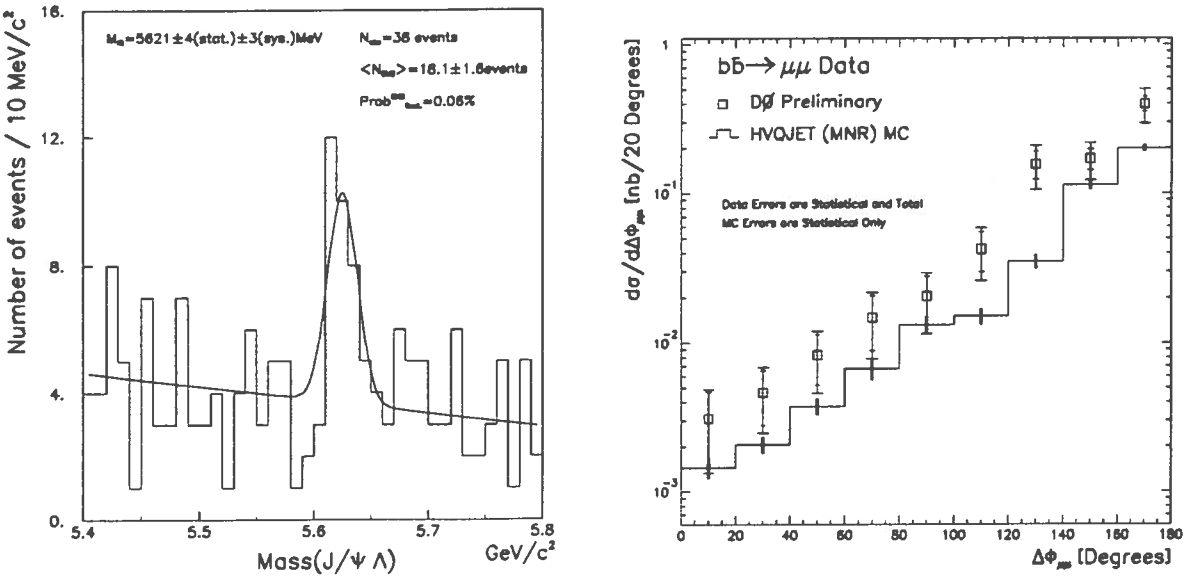

Figure 6: Left: CDF evidence for Λ_b production; right: D0 μ–μ correlation in the transverse plane.

for the Λ_b–baryon through both semileptonic and hadronic decay channels. Jeff Tseng has reviewed measurements of the Λ_b mass, lifetime and production and decay rates performed with this data. The Λ_b is searched à la UA1 in the hadronic decay $\Lambda_b \rightarrow J/\psi\Lambda$ ($J/\psi \rightarrow \mu\mu$). Several kinematical cuts are applied to enhance the signal ($p_T^\mu > 2$ GeV, $p_T^\Lambda > 1.5$ GeV, $p_T^{J/\psi\Lambda} > 6$ GeV, with $c\tau > 100\ \mu$m) and dE/dx is used within 2σ of expectation for all tracks. The ($J/\psi\ \Lambda$) mass distribution shows a 3 σ peak of ≈ 20 events (see Figure 6); a Gaussian fit over a smooth background gives:

$$M(\Lambda_b) = 5621 \pm 4 \pm 3 \text{ MeV}$$

To fully appreciate the quality of this measurement one can compare its total error (≈ 5 MeV) with the corresponding ≈ 18 MeV uncertainty of DELPHI and ≈ 21 MeV uncertainty of ALEPH.

The measured mass is carefully calibrated against known signals such as $\overline{B}^0 \rightarrow J/\psi\ K_s^0$, yielding the result $M(\Lambda_b) - M(\overline{B}^0) = 340 \pm 5 \pm 1$ MeV.

Recent results on charm, beauty and top production by the D0 Collaboration have been reviewed by David Fein. The $t\bar{t}$ cross section has been measured using mostly single–lepton and dilepton events; a new sample of all jet events has also been included. For $m_{top} = 170$ GeV the $t\bar{t}$ inclusive cross section turns out to be (5.2 ± 1.8) pb. The mass analysis is based on lepton+jets only (73 events), largely dominated by a W + multijets background. 32 signal events are selected by the "top" maximum likelihood function, corresponding to a mass value of $(169 \pm 8 \pm 8)$ GeV. When combined with CDF the top mass results to be (175 ± 6) GeV, an already appreciably well measured quantity.

Measurements of the J/ψ and b–quark production cross sections, as well as $b\bar{b}$ correlations, have also been presented (see Figure 6). The "theoretical" points (HVQJET) are from a NLO QCD calculation, with fragmentation and particle decays via ISAJET. While there is a good agreement in shape, the overall normalization is not reproduced.

From fixed target experiments at the Fermilab accelerator we have heard about recent analyses of Cabibbo–suppressed and Cabibbo–favoured charm semileptonic decays using data from E687 (presented by Matthew Nehring). This experiment has used D^* to tag $c\bar{c}$ production ($D^* \rightarrow D^0\pi$, with $D^0 \rightarrow h^-\ell^+\nu$). The results included measurements of relative branching ratios, with $BR(D^0 \rightarrow \pi^-\ell^+\nu)/BR(D^0 \rightarrow K^-\ell^+\nu) = 0.103 \pm 0.020 \pm 0.003$, together with a study of form factors showing that the decay $D^0 \to \pi^-\ell^+\nu$ probes higher values of Q^2 and is then more sensitive to form factors than $D^0 \to K^-\ell^+\nu$.

c– and b–physics from E771 has been reviewed by Luca Introzzi. This experiment has collected during the 91–92 Fermilab fixed target run 120M dimuon triggers, containing some 15,000 $J/\psi \to \mu^+\mu^-$ decays used to investigate J/ψ production mechanisms and charmonium states (with $\sigma(\chi_1)/\sigma(\chi_2) = 0.34 \pm 0.16$, with a χ_1 suppression factor expected in the range 0.13÷0.20). A new upper limit on the FCNC decay $D^0 \to \mu^+\mu^-$ has been set ($< 3.3\ 10^{-6}$ at 90% CL, but theory predicts $\approx 10^{-8} \div 10^{-9}$). The same sample of data has provided a b–production cross section $\sigma(b\bar{b}) = (33^{+38}_{-33} \pm 12)$ nb/nucl.

4 PHYSICS AT CORNELL

We have had two contributions on some outstanding (as usual) CLEO II results. Recent results on b–physics, based on $\approx 3.3\ 10^6$ $b\bar{b}$ events, have been given by David Cinabro. The $B \to J/\psi K(K^*)$ branching fractions (both decays are through the colour suppressed internal spectator diagram) have been measured, with a vector to scalar ratio $(B \to J/\psi K^*)/(B \to J/\psi K) = 1.36 \pm 0.17 \pm 0.11$. Their decay amplitudes are also measured, with a CP–odd content in the $B \to J/\psi K^*$ decay of $(16 \pm 9)\%$. The rare decay $B \to \omega h$ ($h \equiv \pi, K$) has been observed with a BR (based on 10 events) of $(2.8 \pm 1.0 \pm 0.5) \times 10^{-5}$ (expectations in the range $1.1\ 10^{-5} \div 3\ 10^{-7}$). The simplest B semileptonic decay $\overline{B}^0 \to D^+\ell\nu$ has been studied using both a reconstructed neutrino (thanks to the detector hermiticity) and the missing mass technique ($p_B = 0$); both results are compatible, with a combined BR of $(1.78 \pm 0.20 \pm 0.24)\%$. Many other results on rare, hadronic and semileptonic decays have been given; the reader is referred to the original contribution for the full list of these results.

As for the c–physics (based on $\approx 5\ 10^6$ $c\bar{c}$ events, 4.8 fb^{-1}, reviewed by John Yelton) we have heard the measurement of the D^{*+} decay BR ($D^{*+} \to D^+\gamma$, $D^+ \to K\pi\pi$). The most serious background comes from the D_s^{*+} decay ($D_s^{*+} \to D_s^+\gamma$, $D_s^+ \to KK\pi$). The CLEO preliminary result is:

$$\mathrm{BR}\ (D^{*+} \to D^+\gamma) = (1.4 \pm 0.5 \pm 0.6)\%$$

It is worth noting that in the past this BR had represented for quite some time an intriguing problem since its unusually high measured value $[(17 \pm 5 \pm 5)\%]$ was rather difficult to interpret.

Recent CLEO results on charmed baryons have also been reviewed, with emphasis on the observation of the $J^P = 3/2^+$ Ξ_c^* and Σ_c^* particles. The experimental evidence for the decay $\Xi_c^{+*} \to \Xi_c^0\pi^+$ (with $\Delta M = 174.3 \pm 0.5 \pm 1.0$ MeV) seems of particular importance to me since, when coupled to the narrow peak seen in the $\Xi_c^{0*} \to \Xi_c^+\pi^-$ mass spectrum (with $\Delta M = 178.2 \pm 0.5 \pm 1.2$ MeV), it confirms this particle as belonging to the same SU(4) multiplet as the $\Delta(1232)$.

5 PHYSICS AT DESY

The elastic vector meson photoproduction is usually understood in terms of the Vector Meson Dominance + "soft " Pomeron (or Regge models) and its energy dependence $\sigma(\gamma p) \approx W_{\gamma p}^{0.22}$ has successfully described light vector meson (ρ, ω, ϕ) production. However (as we have heard by Douglas Hasell) these models fail to describe heavy vector meson production, whose elastic cross section is observed to rise with W more rapidly ($\approx W_{\gamma p}^{0.8}$) than predicted. In this sense the J/ψ production provides a hard scale for pQCD where one is sensitive to the gluon density of the proton.

Ekaterini Tzamariudaki has given the first HERA results on inclusive open charm production. D^0 and D^* in the DIS regime 10 $GeV^2 < Q^2 <$ 100 GeV^2 have a cross section $\sigma\ (\gamma p \rightarrow c\bar{c} + X) = (17.4 \pm 1.6 \pm 1.7 \pm 1.4)\mu b$, with a ratio $\sigma(D^* + X)/\sigma(D+X)$ in good agreement with e^+e^- data. In this region the first measurement of the charm contribution $F_2^{c\bar{c}}$ to the proton structure function has been made, with a fairly constant shape for the ratio $F_2^{c\bar{c}}/F_2$. For lower Q^2 values the cross section $\sigma\ (\gamma p \rightarrow c\bar{c} + X)$ is seen to rise with W as expected from NLO QCD calculations.

6 PHYSICS AT BES

Recent results from the BES experiment at IHEP in Beijing have been presented by Russel Malchow. The data samples (93–95) are 3.4M ψ(2s) decays and 22.3 pb^{-1} interactions at 4.03 GeV. The results include measurements of inclusive charm production cross sections [$\sigma(D^0 + \overline{D}^0) = 11.9 \pm 0.3 \pm 2.1$ nb, $\sigma(D^+ + D^-) = 5.3 \pm 0.2 \pm 1.0$ nb], D and D_s BR [D $\rightarrow \phi$ X <1.8% at 90% CL, $D_s \rightarrow \phi$ X = $(16.5^{+13.9+1.9}_{-\ 6.7-\ 4.1})$%, with a theoretical prediction of (17.4 ± 4.7)%], ψ(2s) decay into an axial–vector and a pseudoscalar ($b_1(1235)\pi$, $K_1(1270)K$, $K_1(1400)K$). As ψ(2s) is observed to decay only to $K_1(1270)K$ and not into $K_1(1400)K$, while J/ψ does just the opposite (seen into $K_1(1400)K$ and not into $K_1(1270)K$) an anomalous K_{1A}–K_{1B} mixing angle of $< 30°$ is derived while a nearly equal mixing of 45° is usually considered.

7 NEXT GENERATION EXPERIMENTS

In this section I will shortly mention the experiments which have just started or are ready to start taking data.

E781 (known as SELEX and presented by Erik Ramberg) has just begun to take preliminary data in Fermilab's fixed target run. Its main goal is to obtain the world's largest sample of charm baryon decays (using π^- and Σ^- beams).

E835 is preparing to take data to study the charmonium spectrum in $\bar{p}p$ annihilation. They expect to collect about 200 pb^{-1}, a statistics 5 times larger than its predecessor E760, whose physics results have been reviewed by George Zioulas.

The Fermilab KTeV experiment is tuning up to run and has two main physics goals. The first (discussed by Arthur McManus) is to measure the CP violation parameter $Re(\epsilon'/\epsilon)$ with an accuracy of $\approx 1 \times 10^{-4}$ and to search for rare K_L decays with a sensitivity of $\leq O(10^{-11})$. The second goal (presented by Nick Solomey) consists in studying neutral hyperon decays using polarized hyperons. The experiment aims at collecting 1M Λ decays for a precision determination of all four form factors. The neutral cascade beta decay $\Xi^0 \rightarrow \Sigma^+ e^- \nu$ will also be detected for the first time.

Finally I cannot avoid mentioning the large experiments which are now in preparation and will start taking data at CERN and SLAC sometimes in the future (BaBar, ATLAS, CMS and LHC–B). Their physics programme is too large to be condensed here and thus I will get off cheaply saying they present an enormous potential in the field of the heavy flavour physics which has been the theme of this Conference.

8 CONCLUSIONS

In closing this presentation I would like to present my personal point of view on the present status of the heavy flavour physics. This physics is now $\approx$ 15–20 years old and it has passed its infancy. Many features and properties are now understood (but not all of them). I am sure that this Conference has contributed in clarifying some experimental and theoretical aspects of this complex field. A lot of work still lies ahead but it seems to me that most of this work is already on its way.

9 ACKNOWLEDGEMENTS

I would like to thank the Organizing Committee, especially Marco Bozzo and Calvin Kalman, for their hard work to prepare such an interesting Conference and for the warm hospitality and perfect organization. I would also like to express my gratitude to my "scientific secretary" Jason Burke whose cooperation was essential to prepare this talk on very short notice.

References

[1] A combination of preliminary LEP and SLD electroweak measurements and constraints on the Standard Model, LEPEWWG/96–01.

[2] G. Altarelli et al., *Phys. Lett.* **B382** (1996) 409.

[3] R. M. Barnett et al., Review of Particle Physics, *Phys. Rev.* **D54** (1996) 1.

[4] N. Isgur, M.B. Wise, Phys. Lett. B 232 (1989) 113;
M.B. Wise, Procs. XVI International Symposium on Lepton and Photon Interactions, Ithaca, New York, 1993, Ed. P. Drell, D. Rubin, p. 253.

[5] E. J. Eichten et al., FERMILAB–CONF–94/118–T.