CERN-EP/81-151
19 November 1981

SEARCH FOR OPEN "TOP" AT THE CERN ($p\bar{p}$) COLLIDER

M. Basile, G. Bonvicini, G. Cara Romeo, L. Cifarelli, A. Contin, M. Curatolo, G. D'Ali, P. Di Cesare, B. Esposito, P. Giusti, T. Massam, R. Nania, F. Palmonari, A. Petrosino, V. Rossi, G. Sartorelli, M. Spinetti, G. Susinno, G. Valenti, L. Votano and A. Zichichi

CERN, Geneva, Switzerland
Istituto di Fisica dell'Universita di Bologna, Italy
Istituto Nazionale di Fisica Nucleare, Bologna, Italy
Istituto Nazionale di Fisica Nucleare, LNF, Frascati, Italy

ABSTRACT

A new method to observe the production of open "top" baryonic states at the CERN ($p\bar{p}$) Collider is presented. It is based on the "leading" production mechanism, extended to the heaviest flavoured baryon and antibaryon states, and on the charge asymmetry of the leptons originated from their semileptonic decays.

Contributed paper to the Europhysics Conference on
"The search for charm, beauty and truth at High Energy"
ERICE, Italy, 15-22 November 1981

1. INTRODUCTION

Purpose of this study is to investigate about the observability of open "top" states at the CERN ($p\bar{p}$) Collider.

The guide line comes from our recent ISR results on heavy flavour production at $\sqrt{s} = 62$ GeV. Evidence was found for both the charm baryon Λ_c^+ and the beauty baryon Λ_b^0 in the reactions [1,2]:

$$pp \rightarrow e^- + \Lambda_c^+ + \text{anything} \quad (1)$$

and

$$pp \rightarrow e^+ + \Lambda_b^0 + \text{anything} \quad (2)$$

where the electron (positron) was originated from the semileptonic decay of the associated ant Flavoured state. Moreover, it was established that these Λ baryons were produced in a "leading" way, i.e. with an approximately flat x_1 ($=2p_1/\sqrt{s}$) distribution [3,4], in association with an antimeson produced "centrally", i.e. with an $E(d\sigma/dx_1) \propto (1-x_1)^3$ behaviour.

On the other hand, we have also measured the longitudinal momentum distribution of the D mesons, observed in the same experiment [5]. This appears to be compatible with a rather "central" production mechanism, both for the meson and the associated antimeson.

These results suggest that in high energy (pp) collisions heavy flavoured baryons are produced in a "leading" way, in association with a "central" ant Flavoured meson, whilst in the case of meson-antimeson pairs, both mesons are produced "centrally".

Purpose of this paper is to extrapolate our findings to the search for particles with open "top" in $(p\bar{p})$ interactions at $\sqrt{s} = 540$ GeV. Notice that, according to the above specified heavy flavour production mechanism, in $(p\bar{p})$ interactions we should also observe "leading" antibaryons in association with "central" mesons, and "leading" antibaryons in association with "leading" baryons.

2. HOW TO DETECT AN OPEN t -STATE

One possibility to detect an open t -state in $(p\bar{p})$ interactions, would be via the detection of its hadronic decay. However, since the multiplicity increases when going from the ISR to the Collider energies [6], an invariant mass analysis applied to the $(p\bar{p})$ final state, would be very difficult, due to the amplification of the combinatorial background. Moreover, the detection of the decay chain $t \rightarrow b \rightarrow c \rightarrow s$, where first a b -state, then a c -state are identified, would involve a prohibitively small branching ratio (of the order of 10^{-4}).

Another approach would be to take advantage of the sizeable branching ratio ($\approx 10\%$) of the semileptonic decay from the heavy flavour states. In this study we will show that the "leading" production of heavy flavoured baryons and their semileptonic decays provide a tool to disentangle the production of the "top" quark from the large physical background.

In what follows $B_f(\bar{f})$ and $M_f(\bar{f})$ indicate, respectively, the heavy flavoured baryon (antibaryon) and meson (antimeson) states.

As mentioned before, the associated heavy flavour production in $(p\bar{p})$ interactions would consist of the following components:

$$\begin{aligned} & [B_f B_{\bar{f}}]_{\text{leading}}, \\ & [(B_f)_{\text{leading}} (M_{\bar{f}})_{\text{central}}], \\ & [(B_{\bar{f}})_{\text{leading}} (M_f)_{\text{central}}], \\ & [M_f M_{\bar{f}}]_{\text{central}}. \end{aligned}$$

We have assumed that the production of $B_f B_{\bar{f}}$ pairs where both the B_f and the $B_{\bar{f}}$ are "central" is significantly depressed.

Let us consider, for simplicity, only the leptons in the outgoing proton rapidity hemisphere. For the outgoing antiproton rapidity hemisphere, the same results will apply, if the electric charge sign of the leptons is reversed.

The number of positive leptons, l^+ , is expressed by:

$$N(l^+) = L R [n_t(l^+) + n_b(l^+) + n_c(l^+)] \quad (3)$$

where L is the total integrated luminosity, R is semileptonic branching ratio (assumed to be equal for all flavoured states) and $n_f(l^+)$ [$f=t, b, c$] are the contributions from the direct production of top, beauty and charm states, according to the diagrams shown in Figs. 1a,b,c:

$$\begin{aligned} n_t(l^+) = & \sigma(B_t B_{\bar{t}}) [\epsilon_{B_t}(l_t^+) + \epsilon_{B_t}(l_{tbc}^+) + \epsilon_{B_{\bar{t}}}(l_{\bar{t}\bar{b}}^+)] + \\ & + \sigma(M_t M_{\bar{t}}) [\epsilon_{M_t}(l_t^+) + \epsilon_{M_t}(l_{tbc}^+) + \epsilon_{M_{\bar{t}}}(l_{\bar{t}\bar{b}}^+)] + \\ & + \sigma(M_t B_{\bar{t}}) [\epsilon_{M_t}(l_t^+) + \epsilon_{M_t}(l_{tbc}^+) + \epsilon_{B_{\bar{t}}}(l_{\bar{t}\bar{b}}^+)] + \\ & + \sigma(B_t M_{\bar{t}}) [\epsilon_{B_t}(l_t^+) + \epsilon_{B_t}(l_{tbc}^+) + \epsilon_{M_{\bar{t}}}(l_{\bar{t}\bar{b}}^+)] \end{aligned} \quad (3a)$$

$$\begin{aligned}
n_b(1^+) = & \sigma(B_b B_{\bar{b}}) [\varepsilon_{B_b}(1_{bc}^+) + \varepsilon_{B_{\bar{b}}}(1_{\bar{b}}^+)] + \\
& + \sigma(M_b M_{\bar{b}}) [\varepsilon_{M_b}(1_{bc}^+) + \varepsilon_{M_{\bar{b}}}(1_{\bar{b}}^+)] + \\
& + \sigma(M_b B_{\bar{b}}) [\varepsilon_{M_b}(1_{bc}^+) + \varepsilon_{B_{\bar{b}}}(1_{\bar{b}}^+)] + \\
& + \sigma(B_b M_{\bar{b}}) [\varepsilon_{B_b}(1_{bc}^+) + \varepsilon_{M_{\bar{b}}}(1_{\bar{b}}^+)]
\end{aligned} \tag{3b}$$

$$\begin{aligned}
n_c(1^+) = & \sigma(B_c B_{\bar{c}}) \varepsilon_{B_c}(1_c^+) + \sigma(M_c M_{\bar{c}}) \varepsilon_{M_c}(1_c^+) + \\
& + \sigma(M_c B_{\bar{c}}) \varepsilon_{M_c}(1_c^+) + \sigma(B_c B_{\bar{c}}) \varepsilon_{B_c}(1_c^+)
\end{aligned} \tag{3c}$$

The σ factors are the cross-sections for $B_t B_{\bar{t}}$, $M_t M_{\bar{t}}$ and $M_t(\bar{t}) B_{\bar{t}}(t)$ production and the ε factors are the detection efficiencies, in a given phase space region $\Delta\Omega$, for the 1^+ originating from $B_t(\bar{t})$ or $M_t(\bar{t})$ decay. The subscript to 1^+ indicates the various possible decay chains. For instance, 1^+_{tbc} refers to the decay $t \rightarrow b \rightarrow c \rightarrow 1^+$.

Analogously, the number of 1^- in the proton hemisphere is given by:

$$N(1^-) = L R [n_t(1^-) + n_b(1^-) + n_c(1^-)] \tag{4}$$

where, according to the diagrams shown in Figs. 1d,e,f:

$$\begin{aligned}
n_t(1^-) = & \sigma(B_t B_{\bar{t}}) [\varepsilon_{B_t}(1_{tb}^-) + \varepsilon_{B_{\bar{t}}}(1_{\bar{t}}^-) + \varepsilon_{B_{\bar{t}}}(1_{\bar{t}\bar{b}\bar{c}}^-)] + \\
& + \sigma(M_t M_{\bar{t}}) [\varepsilon_{M_t}(1_{tb}^-) + \varepsilon_{M_{\bar{t}}}(1_{\bar{t}}^-) + \varepsilon_{M_{\bar{t}}}(1_{\bar{t}\bar{b}\bar{c}}^-)] + \\
& + \sigma(M_t B_{\bar{t}}) [\varepsilon_{M_t}(1_{tb}^-) + \varepsilon_{B_{\bar{t}}}(1_{\bar{t}}^-) + \varepsilon_{B_{\bar{t}}}(1_{\bar{t}\bar{b}\bar{c}}^-)] + \\
& + \sigma(B_t M_{\bar{t}}) [\varepsilon_{B_t}(1_{tb}^-) + \varepsilon_{M_{\bar{t}}}(1_{\bar{t}}^-) + \varepsilon_{M_{\bar{t}}}(1_{\bar{t}\bar{b}\bar{c}}^-)]
\end{aligned} \tag{4a}$$

$$\begin{aligned}
n_b(1^-) = & \sigma(B_b B_{\bar{b}}) [\varepsilon_{B_b}(1_b^-) + \varepsilon_{B_{\bar{b}}}(1_{\bar{b}c}^-)] + \\
& + \sigma(M_b M_{\bar{b}}) [\varepsilon_{M_b}(1_b^-) + \varepsilon_{M_{\bar{b}}}(1_{\bar{b}c}^-)] + \\
& + \sigma(M_b B_{\bar{b}}) [\varepsilon_{M_b}(1_b^-) + \varepsilon_{B_{\bar{b}}}(1_{\bar{b}c}^-)] + \\
& + \sigma(B_b M_{\bar{b}}) [\varepsilon_{B_b}(1_b^-) + \varepsilon_{M_{\bar{b}}}(1_{\bar{b}c}^-)]
\end{aligned} \tag{4b}$$

$$\begin{aligned}
n_c(1^-) = & \sigma(B_c B_{\bar{c}}) \varepsilon_{B_{\bar{c}}}(1_c^-) + \sigma(M_c M_{\bar{c}}) \varepsilon_{M_{\bar{c}}}(1_c^-) + \\
& + \sigma(M_c B_{\bar{c}}) \varepsilon_{B_{\bar{c}}}(1_c^-) + \sigma(B_c M_{\bar{c}}) \varepsilon_{M_{\bar{c}}}(1_c^-)
\end{aligned} \tag{4c}$$

Let us finally define the "asymmetry" ratio:

$$A^0 = N(1+) / N(1-). \tag{5}$$

From our previous statements on $B_f(\bar{r})$ and $M_f(\bar{r})$ production distributions, in a suitable forward region of the outgoing proton rapidity hemisphere, we expect that the quantity A^0 will be a good tool to look for a possible open "top" signal.

3. ESTIMATE OF THE "ASYMMETRY" RATIO A^0

In order to estimate the value of the "asymmetry" ratio A^0 , the following quantities are needed.

- i) The cross-section values. We have assumed $\sigma_c = 250 \mu\text{b}$ for the total charm cross-section in the ISR energy

range, a value which is consistent with our measurements [1,7,8], and a factor 3 increase of this cross-section at the $(p\bar{p})$ Collider energy. We have then assumed that the heavy flavour cross-sections scale as the inverse ratio of the quark masses squared [9]:

$$\sigma_b/\sigma_c = m_c^2/m_b^2,$$

and

$$\sigma_t/\sigma_b = m_b^2/m_t^2.$$

For the "top" quark, we assumed a mass: $m_t = 25$ GeV/c². The cross-sections values at $\sqrt{s} = 540$ GeV, are, therefore:

$$\sigma_c = 750 \mu\text{b}, \sigma_b = 75 \mu\text{b} \text{ and } \sigma_t = 3 \mu\text{b}.$$

We also used, for all flavours, the hypothesis:

$$\begin{aligned} \sigma(B_f B_{\bar{f}}) &= \sigma(M_f M_{\bar{f}}) = \sigma(M_f B_{\bar{f}}) = \sigma(M_f B_{\bar{f}}) = \\ &= \sigma_f / 4. \end{aligned}$$

- ii) The semileptonic branching ratio. We have assumed the branching ratio of the semileptonic decay into a given lepton to be 10% for all heavy flavoured states.
- iii) The detection efficiencies ϵ . The detection efficiencies ϵ have been evaluated with a Monte Carlo simulation. The heavy flavour state and its associated antistate were assumed to be produced in an uncorrelated way. The generation was based on a flat- x_1 distribution ($d\sigma/dx_1 = \text{const}$) for baryons and on a central- x_1 distribution [$E(d\sigma/dx_1) \propto (1-x_1)^3$] for mesons. The p_t dependence was assumed to be:

$$(1/p_t)(d\sigma/dp_t) \propto e^{-2.5 p_t} \quad \text{for all flavours.}$$

For each flavour the semileptonic decay was simulated using a K_{t3} decay matrix. The p_t spectra from the various decays are shown in Figs. 2,3,4 and 5.

The choice of the phase space region $\Delta\Omega$, defined by the conditions:

$$\vartheta < 30^\circ \text{ and } p_t > 5 \text{ GeV}/c,$$

was determined as a compromise between the efficiency for l^+ originated via the direct decay $t \rightarrow l^+$ of the "top" flavoured baryons and the rejection of leptons from different sources. The detection efficiencies for the leptons originated from the various sources, are summarized in Table I.

The results of our analysis are the following:

$$N(l^+) = L (1.14 \cdot 10^{-1} \mu b),$$

$$N(l^-) = L (2.92 \cdot 10^{-2} \mu b),$$

$$A^0 = N(l^+)/N(l^-) = 3.90 .$$

We have also evaluated the "asymmetry" ratio A^0 , using a different extrapolation for σ_b and σ_t , assuming:

$$\sigma_b = \sigma_c / m_b^2 \text{ and } \sigma_t = \sigma_c / m_t^2 .$$

This leads to:

$$\sigma_b = 30 \mu b \text{ and } \sigma_t = 1 \mu b,$$

at $\sqrt{s} = 540 \text{ GeV}$, having kept $\sigma_c = 750 \mu b$.

In these conditions we get:

$$N(l^+) = L (3.80 \cdot 10^{-2} \mu b),$$

$$N(l^-) = L (9.73 \cdot 10^{-3} \mu b),$$

$$A^0 = N(l^+)/N(l^-) = 3.90 .$$

A^0 does not depend on the cross-section extrapolations

because the detection efficiencies for leptons from beauty and charm are negligible in the phase space region specified in point (iii). However, the value of the "top" production cross-section will be important to determine the integrated luminosity needed to reach a given statistical significance on the measurement of A^0 and to determine, as will be discussed in section 5, the rejection power of the apparatus needed to obtain a given signal-to-background ratio.

4. BACKGROUND EVALUATION

In what described so far, the background contamination in the sample of prompt l^+ and l^- , was not considered. It is mainly due to:

- i) the misidentification of charged and neutral hadrons in the experimental apparatus;
- ii) the prompt l^+ or l^- production from sources other than open heavy flavour states.

An attempt was made to evaluate the contribution (i). We have used a parametrization of the single π cross-section measured at the ISR [10]:

$$E(d^3\sigma/dp^3) = A e^{-Bp_t} + C (1 - x_t)^D / (p_t^2 + G)^4$$

where $x_t = 2p_t/\sqrt{s}$, to derive the pion production in $(p\bar{p})$ interactions at $\sqrt{s}=540$ GeV.

A further conservative hypothesis was made by including in the expression for $E(d^3\sigma/dp^3)$ a p_t^{-4} term, for $p_t > 7$ GeV/c [11].

The extrapolated π rate, in the phase space region

defined in section 3 ($\theta < 30^\circ$, $p_t > 5$ GeV/c), should be multiplied by a reduction factor representing the achievable rejection of background source (i) in the experimental apparatus.

For what concerns the prompt lepton background (ii), we assume, as a first approximation, that it would be negligible, when compared to the contribution (i).

5. ESTIMATE OF THE "ASYMMETRY" RATIO A^0 IN EXPERIMENTAL CONDITIONS

In the presence of background, the experimental "asymmetry" ratio is given by:

$$A^{exp} = \frac{N(l^+) + N_{bk}(l^+)}{N(l^-) + N_{bk}(l^-)}$$

Assuming $N_{bk}(l^+) = N_{bk}(l^-) = N_{bk}(l)$, and expressing $N(l^-)$ as $(1/A^0)N(l^+)$ (eq. 5), we have:

$$A^{exp} = \frac{1 + \frac{N(l^+)}{N_{bk}(l)}}{1 + \frac{1}{A^0} \frac{N(l^+)}{N_{bk}(l)}} \quad (6)$$

The quantity A^{exp} is plotted in fig. 6, as a function of the signal-to-background ratio:

$$S/B = N(l^+)/N_{bk}(l).$$

Notice that A^{exp} is substantially different from 1 as soon as S/B is greater than 1.

However, from equation (6), it is clear that, in order to maintain constant the value of A^{exp} , i.e. independent of the "top" production cross-section σ_t , the rejection power of the apparatus must increase linearly with

decreasing σ_t .

On the basis of the background estimate, computed as specified in section 4, and for the range of σ_t considered, we have:

$$1 < S/B < 10,$$

for a rejection against charged and neutral hadron background ranging from 10^{-3} to 10^{-4} .

6. CONCLUSIONS

The above studies show a new way to investigate the production of the "top" flavour at the $(p\bar{p})$ Collider. It is based on the measurement of an excess of l^+ on the proton side and of an excess of l^- on the antiproton side, both asymmetries being due to the semileptonic decays of the "top" baryon and the "anti-top" antibaryon, each produced in a "leading" way.

The basic parameters for the observation of this effect are the background level (estimated on the basis of our knowledge) and the cross-section values for the production of the leading baryons.

With the previously specified assumptions, and assuming a luminosity of $10^{29} \text{ cm}^{-2} \text{ sec}^{-1}$, a few hundred hours of running would be sufficient to determine the value of A^{exp} with a precision of a few percent, thus establishing a clear evidence for, or against, the production of "leading" t -flavoured baryon (antibaryon) states.

References

- [1] M. Basile et al., Nuovo Cimento 63A (1981) 230.
- [2] M. Basile et al., Nuovo Cimento Letters 31 (1981) 97.
- [3] M. Basile et al., Nuovo Cimento Letters 30 (1981) 487.
- [4] M. Basile et al., The leading baryon effect in Λ^0_b production in proton-proton interactions at $\sqrt{s}=62$ GeV, Preprint CERN-EP/81-72, to be published in Nuovo Cimento.
- [5] M. Basile et al., The longitudinal momentum distribution of charm mesons produced in (pp) interactions at $\sqrt{s}=62$ GeV, Preprint CERN-EP/81-126, to be published in Nuovo Cimento Letters.
- [6] M. Basile et al., A prediction for the total charge multiplicity in hadronic interactions at extreme high energies, Preprint CERN-EP/81-147, to be published in Nuovo Cimento Letters.
- [7] M. Basile et al., Measurement of associated production of $(D^0\bar{D})$ in (pp) interactions at $\sqrt{s}=62$ GeV, Preprint CERN-EP/81-73, to be published in Nuovo Cimento.
- [8] M. Basile et al., Measurement of $(D+\bar{D})$ charm-meson pair production in (pp) interactions at $\sqrt{s}=62$ GeV, Preprint CERN-EP/81-125, to be published in Nuovo Cimento.
- [9] A. Martin, preprint CERN Th. 2980 (1980), and private communication.
- [10] B. Alper et al., Nucl. Phys. B100 (1975) 237.
- [11] C. Kourkouvelis et al., Phys. Lett. 84B (1979) 271.

Figure captions.

Fig. 1 : Diagrams illustrating all the possible electric charge signs of the leptons originating from semileptonic decays of the chains: $t \rightarrow b \rightarrow c \rightarrow s$ (a), $b \rightarrow c \rightarrow s$ (b), $c \rightarrow s$ (c), $\bar{t} \rightarrow \bar{b} \rightarrow \bar{c} \rightarrow \bar{s}$ (d), $\bar{b} \rightarrow \bar{c} \rightarrow \bar{s}$ (e) and $\bar{c} \rightarrow \bar{s}$ (e).

Fig. 2 - 5 : Showing the transverse momentum spectra of the leptons originated by the decay of $t(\bar{t})$, $b(\bar{b})$, $c(\bar{c})$ baryon and meson states, obtained as described in the text.

Fig. 6 : Behaviour of the experimental "asymmetry" A^{exp} , as a function of $S/B = N(1+)/N_{\text{bk}}(1)$.

TABLE 1

The $l^\pm$ detection efficiencies for $\eta < 30^\circ$ and $p_T > 5$ GeV/c in the proton rapidity hemisphere.

$\epsilon_{B_t}(l_t^+)$	4.2×10^{-1}	$\epsilon_{B_{\bar{t}}}(l_{\bar{t}}^+)$	0
$\epsilon_{B_t}(l_{tbc}^+)$	1.3×10^{-3}	$\epsilon_{B_{\bar{t}}}(l_{\bar{t}b\bar{c}}^+)$	0
$\epsilon_{B_b}(l_{bc}^+)$	$< 10^{-4}$	$\epsilon_{B_{\bar{b}}}(l_{\bar{b}}^+)$	0
$\epsilon_{B_c}(l_c^+)$	~ 0		
$\epsilon_{B_t}(l_{tb}^-)$	4.5×10^{-2}	$\epsilon_{B_{\bar{t}}}(l_{\bar{t}}^-)$	0
		$\epsilon_{B_{\bar{t}}}(l_{\bar{t}b\bar{c}}^-)$	0
$\epsilon_{B_b}(l_b^-)$	$< 10^{-4}$	$\epsilon_{B_{\bar{b}}}(l_{\bar{b}c}^-)$	0
		$\epsilon_{B_{\bar{c}}}(l_{\bar{c}}^-)$	0
$\epsilon_{M_t}(l_t^+)$	7.6×10^{-2}	$\epsilon_{M_{\bar{t}}}(l_{\bar{t}}^+)$	7.4×10^{-3}
$\epsilon_{M_t}(l_{tbc}^+)$	1.3×10^{-3}		
$\epsilon_{M_b}(l_{bc}^+)$	~ 0	$\epsilon_{M_{\bar{b}}}(l_{\bar{b}}^+)$	~ 0
$\epsilon_{M_c}(l_c^+)$	~ 0		
$\epsilon_{M_t}(l_{tb}^-)$	7.4×10^{-3}	$\epsilon_{M_{\bar{t}}}(l_{\bar{t}}^-)$	7.6×10^{-2}
		$\epsilon_{M_{\bar{t}}}(l_{\bar{t}b\bar{c}}^-)$	1.3×10^{-3}
$\epsilon_{M_b}(l_b^-)$	~ 0	$\epsilon_{M_{\bar{b}}}(l_{\bar{b}c}^-)$	~ 0
		$\epsilon_{M_{\bar{c}}}(l_{\bar{c}}^-)$	~ 0

Fig. 1

"Leading,, $B_{\uparrow}, B_{\bar{\uparrow}}$

Fig. 2

"Leading,, $B_b, B_c, B_{\bar{b}}, B_{\bar{c}}$

Fig. 3

Fig. 4

"Central,, $M_b, M_{\bar{b}}, M_c, M_{\bar{c}}$

Fig. 5

Fig. 6