national accelerator laboratory

NAL-Pub-73/80-EXP
2000.000
2600.200

(Submitted to Physics Letters)

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F. T. Dao, J. Lach, and J. Whitmore

March 1974

Operated by Universities Research Association Inc. Under Contract with the United States Atomic Energy Commission

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F. T. Dao, J. Lach, and J. Whitmore
National Accelerator Laboratory
Batavia, Illinois 60510

ABSTRACT

From an exposure of the Brookhaven National Laboratory 80-inch hydrogen bubble chamber to a 14.75 GeV/c separated antiproton beam we have determined an average charged particle multiplicity of 4.12±0.06. Comparisons are made with other incident particles and energies. We point out that the high multiplicity events are mostly from the annihilation channels and may shed some insight into the annihilation mechanism.

The data presented both in this paper and the one immediately following it are derived from an 80,000 picture exposure of the Brookhaven National Laboratory (BNL) 80-inch bubble chamber to a 14.75 GeV/c radio-frequency separated antiproton beam.[1] This paper will discuss the exposure and the resulting charged particle multiplicity distributions; the following paper[2] presents data from the V^o events.

From measurements of non-interacting incident beam tracks the central momentum was determined to be 14.75 GeV/c. From the properties of the BNL separated beam we believe that the momentum spread is approximately 1%. A pressure curve taken with a Cerenkov counter in the beam indicated that about 90% of the particles passing through the counter were antiprotons. We believe that the imposition of stringent entrance angle and position criteria on entering beam tracks reduced this beam contamination to a negligible level. This is indicated by our measured $\bar{p}p$ total cross section of 51.9 ± 1.5 mb which is in good agreement with a total $\bar{p}p$ cross section of 50.7 ± 0.9 mb at 14 GeV/c measured in a counter experiment.[3] The fact that our measured $\bar{p}p$ cross section is higher than the counter measurement reassures us that our contamination is small since all of the possible contaminants (π^-, K^-, or μ^-) would tend to give a lower cross section.

The film was scanned in at least two views for all beam induced interactions and secondary V^o vertices. The topological scanning efficiencies were determined from a restricted sample of about 5,000 pictures which were scanned twice for all topologies and triple scanned for zero pronged events. Table I displays the number of events found in each topology, the corrected number of events and the topological cross sections. Substantial systematic corrections exist for two topologies. The zero-pronged topology required a substantial correction because of scanning inefficiencies; the single scan efficiency, estimated from the three scans, was found to be about 67%.

A different correction must be applied to those two-pronged events in which there is only a small four-momentum transfer to the target proton. A sample of 500 two-pronged events was measured and the missing mass squared recoiling from the positive track, assuming it to be a proton, was computed. The $|t|$ distribution of the events with a missing mass squared between $-0.001 \le MM^2 \le 1.8\ GeV^2$ was plotted (not shown) and the observed depletion of events at low $|t|$ was assumed due to scanning losses. An exponential fit made to the data in the region $0.05 \le |t| \le 0.25\ (GeV/c)^2$ was used to estimate the losses at lower values of $|t|$. This loss was found to be about 18% of the total number of two prongs. The known elastic cross section as interpolated from data of Foley at al.[4] and that of Birnbaum et al.[5] was subtracted from the total two-pronged cross section to arrive at an inelastic two-pronged cross section. The larger errors of the two-pronged inelastic cross section reflect the uncertainties of these corrections.

Some other minor corrections were also made. The few odd pronged events were shifted to the next highest topology since many are probably due to unobserved short proton recoils. Obvious Dalitz pairs were eliminated at the scanning level. Finally our topological cross sections were normalized to the more precisely known counter data.[3]

We determine the average charge particle multiplicity $\langle n_c \rangle$ = 4.12±0.06. We have also attempted to fit the topological cross sections to a Poisson distribution in n_c. The best fit curve reproduces to a remarkable extent the general features of the data. However, because of the small errors associated with the data it does not give an acceptable statistical fit. Table II lists some moments of the multiplicity distribution.

It is of interest to look at the momentum dependence of the topological cross sections.[6] These are shown in Fig. 1 along with the total cross section, σ_T and the inelastic cross section, σ_{inel}. We see a strong momentum dependence of the topological cross sections with the zero pronged cross section falling rapidly, the two and four pronged cross sections reaching a maximum value and then decreasing; the higher multiplicities are still increasing. Shown above these many changing partial cross sections are the smoothly varying total and inelastic cross sections. A similar behavior is seen for pp and $\pi^{\pm}p$ interactions.[7]

The major difference between proton or pion induced reactions and those of antiprotons at a given incident momentum is the larger center-of-mass energy available through the annihilation channels. The importance of the annihilation channels is demonstrated in Fig. 2 where we have plotted $\langle n_c \rangle$ as a function of the available center-of-mass energy, E_a, for incident π^- and protons. For these initial states we define E_a as the total center-of-mass energy minus the two initial particle masses; these data are from a recent compilation of Whitmore.[7] For comparison we have also plotted the available $\bar{p}$ data[6] but have indicated by a line the range of E_a available either if E_a is defined as for the proton and pion induced reactions or if E_a is the total center-of-mass energy. One sees that if the annihilation energy is not included the multiplicity is considerably less for protons or π^- at the same value of E_a. The annihilation channels thus have an important contribution to the $\bar{p}p$ multiplicity distributions seen at high energies.

To investigate the differences between pp and $\bar{p}p$ topological cross sections at 14.75 GeV/c we have interpolated existing pp data[7] to arrive at a set of pp topological cross sections at 14.75 GeV/c. They are shown along with the $\bar{p}p$ cross sections in Table III. For every topology the $\bar{p}p$ cross section is seen to be larger. We have also listed the differences between the $\bar{p}p$ and pp cross sections in Table III. The simplest interpretation would attribute these differences to the effects of the annihilation channels. For $n_c \geq 8$ the pp cross sections are much smaller than the corresponding $\bar{p}p$ ones, and it seems reasonable to assume that the differences in these cases are a real measure of the annihilation component. For $n_c \leq 6$ interference between the annihilation and non-annihilation channels could be substantial and it is possible that this simple subtraction cannot be expected to yield the annihilation cross section, $\sigma_A(\bar{p}p)$.

Attempts have been made to intepret the annihilation process as a set of baryon exchange diagrams. Goldberg[8] has used a multi-Regge model (MRM) and fitted it to annihilation cross sections at lower energies with encouraging results. Using his parameters we can compute the annihilation cross sections at our momentum. These are shown in the last column of Table III. For the topologies where our method of extraction of the annihilation cross section may be valid, $n_c \gtrsim 8$, the agreement is encouraging.[9]

Finally we note that the fact that the $\bar{p}p$ cross sections are significantly larger than the corresponding pp partial cross sections is in disagreement with the predictions based on a dual-multiperipheral model by Lee[10] which states that (for ab exotic)

$$\sigma_n^{a\bar{b}}/(\sigma_n^{a\bar{b}} - \sigma_n^{ab}) = 2^{n-1} .$$

We would like to thank the Brookhaven National Laboratory operations staff and, in particular, the beam line and the 80-inch bubble chamber crews for a successful exposure. We also thank the scanning and measuring personnel of the NAL Film Analysis Facility for their dedicated work.

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[6]The following sources have been used for the $\bar{p}p$ topological cross sections: Particle Data Group, $\overline{N}N$ and $\overline{N}D$ Interactions--A Compilation, LBL-58 (1972); P. S. Eastman et al., Nucl. Phys. B51, 29 (1973); D. L. Parker et al., Nucl. Phys. B32, 29 (1971); I. Borecka et al., Nuovo Cimento 5A, 19 (1971); V. V. Ammosov et al., paper submitted to Aix-en-Provence Conference (1973).

[7]J. Whitmore, National Accelerator Laboratory Report NAL-Pub-73/70-EXP, submitted to Physics Reports.

[8]H. Goldberg, Phys. Rev. D6, 2542 (1972).

[9]Note that the prediction of Goldberg (Ref. 8) for $<\pi^o>$ versus n_c shows that $<\pi^o>$ decreases with increasing n_c, in contrast with our data (Ref. 2) which shows just the opposite trend.

[10]H. Lee, Phys. Rev. Letters 30, 719 (1973).

Table I. Topological Cross Sections for 14.75 GeV/c $\bar{p}p \rightarrow n_c$.

n_c	Events Found	Corrected Number[a]		Cross Section (mb)
0	894	1521		1.09±0.12
2	22452	30941	inelastic elastic	12.55±1.04 9.72±0.39[b]
4	19703	20837		14.99±0.30
6	10940	11703		8.42±0.17
8	3908	4236		3.05±0.06
10	929	1065		0.76±0.03
12	139	139		0.100±0.009
14	10	10		0.0072±0.0023
16	3	3		0.0022±0.0013
Total	58978	70455		50.7±0.9[b]

[a] Corrected for odd prongs, scanning efficiency, and missing 2 prongs.

[b] From counter data, Ref. 3.

Table II. 14.75 GeV/c $\bar{p}p$ Multiplicity Moments.

$\langle n_c \rangle$	=	4.12±0.06
$\langle n_c^2 \rangle$	=	21.51±0.47
$\langle n_c \rangle / (\langle n_c^2 \rangle - \langle n_c \rangle^2)^{\frac{1}{2}}$	=	1.94±0.03
$f_2 = \langle n_c(n_c - 1) \rangle - \langle n_c \rangle^2$	=	0.37±0.09

Table III. Comparisons of pp and $\bar{p}p$ Topological Cross Sections at 14.75 GeV/c.

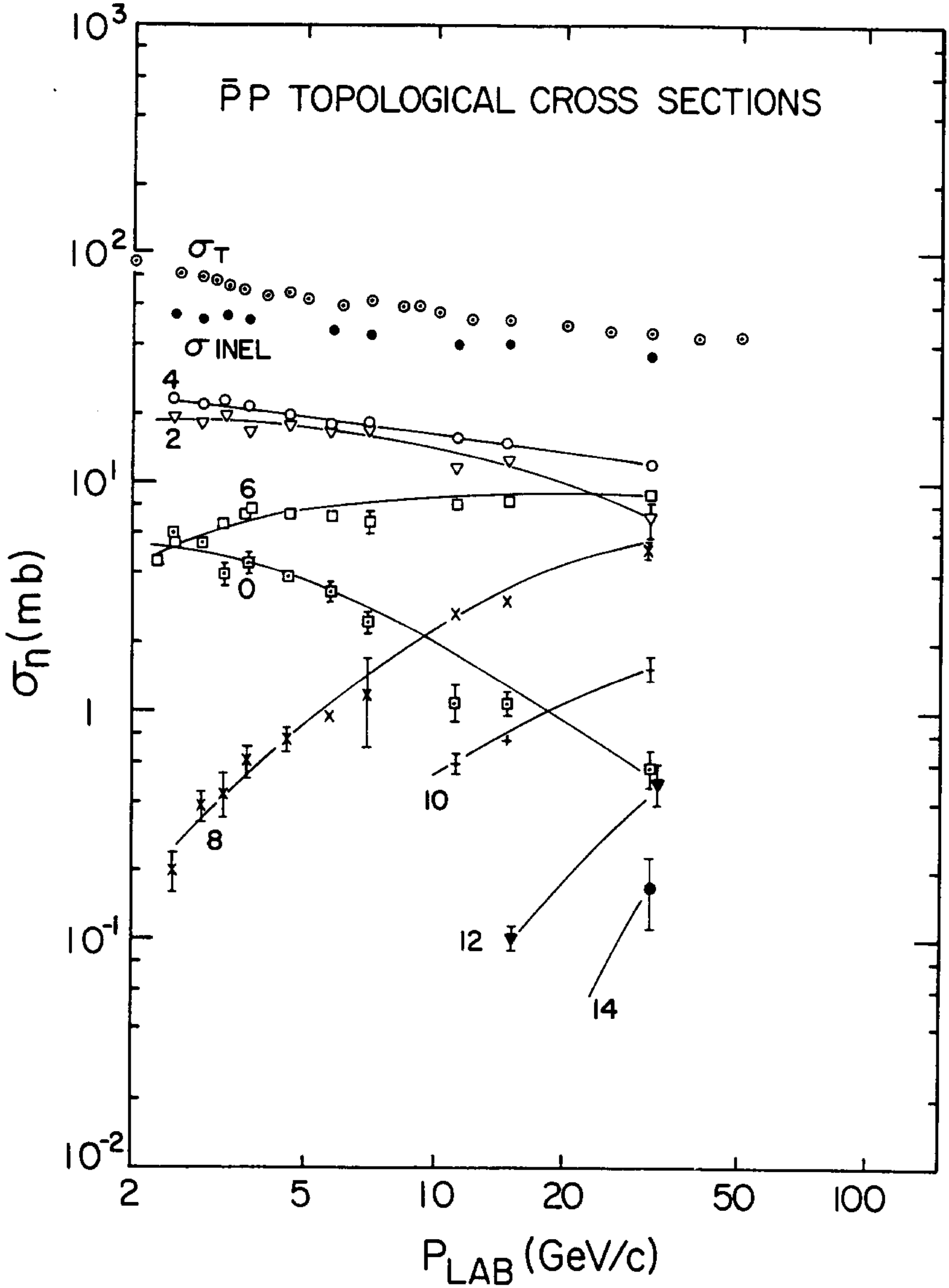
n_c	$\sigma(\bar{p}p)$ (mb)	$\sigma(pp)$[a] (mb)	$\sigma(\bar{p}p) - \sigma(pp)$ (mb)	MRM Model (mb)
2	12.55±1.04	9.68±0.30	2.87±1.08	1.74
4	14.99±0.30	14.07±0.28	0.92±0.41	5.17
6	8.42±0.17	4.73±0.13	3.69±0.21	4.85
8	3.05±0.06	0.88±0.06	2.17±0.08	2.13
10	0.76±0.03	0.06±0.01	0.70±0.03	0.54
12	0.100±0.009	0.010±0.003	0.090±0.009	0.086
14	0.0072±0.0023	0.001±0.002	0.0062±0.0033	0.0096
16	0.0022±0.0013	0	0.0022±0.0013	0.0008

[a]Estimated by interpolation, see Ref. 7.

FIGURE CAPTIONS

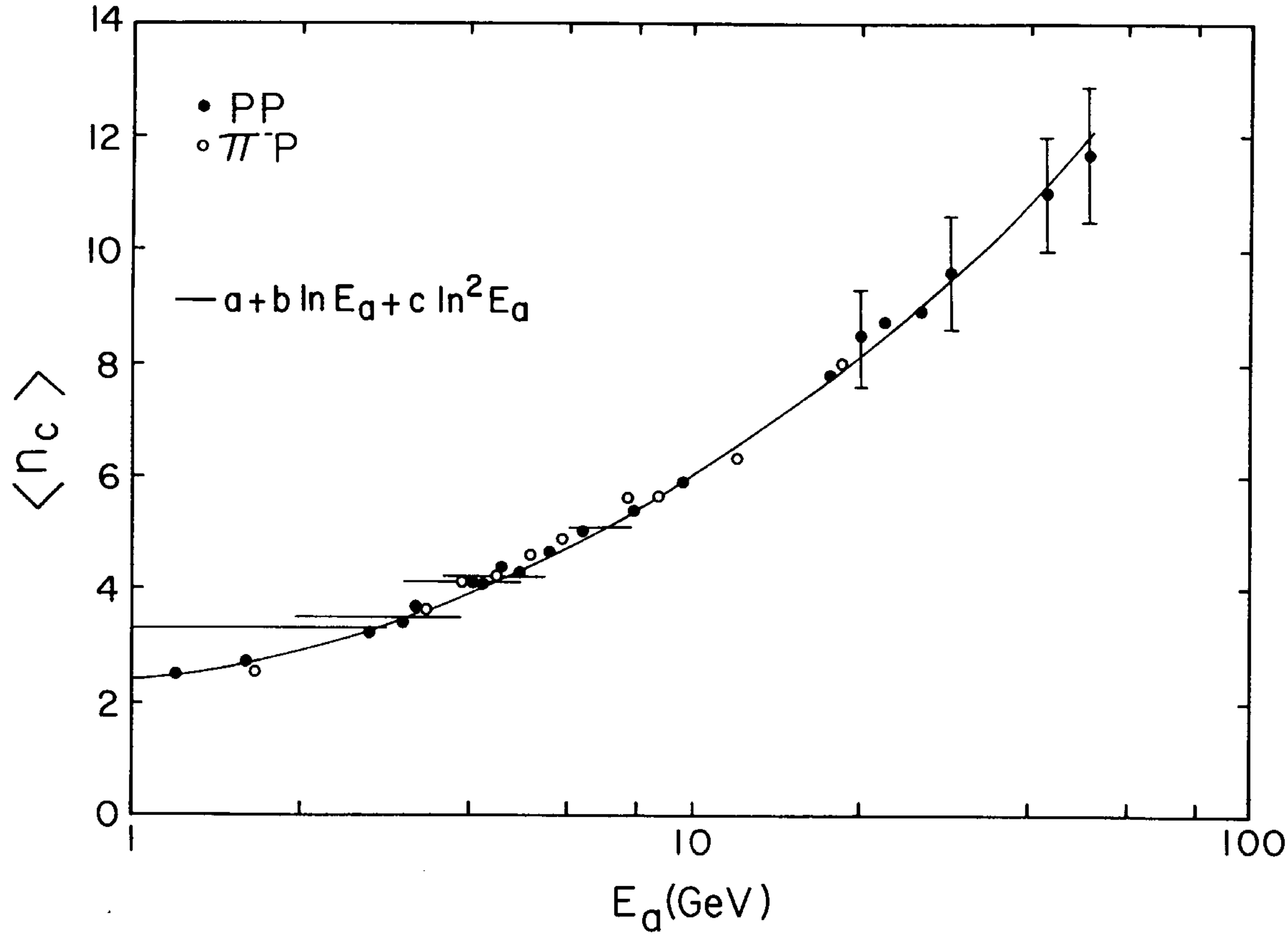
Fig. 1. $\bar{p}p$ topological cross sections as a function of incident laboratory momentum.

Fig. 2. Average number of charged secondary particles, $\langle n_c \rangle$, produced as a function of available center-of-mass energy E_a for $\pi^- p$, pp, and $\bar{p}p$ collisions. For $\bar{p}p$ collisions the difference between the annihilation and non-annihilation energy is indicated by a horizontal line. The smooth curve is a fit to the pp data yielding $\langle n_c \rangle = 2.45 + 0.32 \ln E_a + 0.53 \ln^2 E_a$ (Ref. 7).



P̄P TOPOLOGICAL CROSS SECTIONS
σ_T
σ INEL
4
2
6
0
8
10
12
14
σ_n(mb)
10^3
10^2
10^1
1
10^{-1}
10^{-2}
2
5
10
20
50
100
P_{LAB} (GeV/c)

Fig. 1



PP
$\pi^- P$
$a + b \ln E_a + c \ln^2 E_a$
$\langle n_c \rangle$
E_a(GeV)
0
2
4
6
8
10
12
14
1
10
100

Fig. 2