Present Status of āp Elastic and Total Cross Section Data

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I begin by giving credit to the thesis of Sasan Sadr\textsuperscript{33}). It was the first paper I reread in the process of preparing this talk and served to remind me of many of the measurements that have been made over the last several decades. The reference list at the end of this paper is divided into several sections according to how and where the data were produced. Nearly 30 years ago asymptopia was first approached as the total cross section measurements in fixed target experiments\textsuperscript{1),2),3)} stopped falling with increasing energy and became flat. Then the ISR pp experiments and the Fermilab fixed target experiment\textsuperscript{4),5),6),7),8),9)} showed the total cross sections starting to rise. After CERN developed the $p\bar{p}$ accumulator, both the ISR and the $\bar{p}pS$ measured the $pp$ total and elastic cross sections\textsuperscript{11)-19)}. The detailed comparison between the $pp$ and the $p\bar{p}$ data from the ISR showed that the differences between them were disappearing with increasing energy and that they were identical to within measurement errors at the maximum ISR energy of $\sqrt{s} = 62$ GeV. This was true not only for $\sigma_{\text{tot}}$ but also for the ratio of elastic to total cross section ($\sigma_{\text{el}}/\sigma_{\text{tot}}$), the logarithmic slope of the elastic cross section ($B$), and the ratio of the real to the imaginary part of the forward nuclear scattering amplitude ($\rho$). The $\bar{p}pS$ data showed a dramatic 50\% increase in $\sigma_{\text{tot}}$ from 43.5 mb at the highest ISR energy\textsuperscript{7)} to 61.9 mb $\pm$ 1.5 mb at $\sqrt{s} = 546$ GeV\textsuperscript{18}). All the other parameters also increased significantly - $\sigma_{\text{el}}/\sigma_{\text{tot}}$ from 0.17 at the ISR to 0.22 at the $\bar{p}pS$, $B$ from 12 (GeV/c)$^{-2}$ at the ISR to 15.2 (GeV/c)$^{-2}$ at the $\bar{p}pS$ and $\rho$ from 0.1 at the ISR to the UA4 value of $\rho = 0.24 \pm 0.04$\textsuperscript{20}). Various models\textsuperscript{15),22)} fit all of this data very well except for the $\rho$ value.

This set the stage for the Fermilab Collider experiments, CDF and E710. In 1989 E710 published\textsuperscript{24)} the first Fermi Collider $\sigma_{\text{tot}}$ result, $\sigma_{\text{tot}} = 78.3 \pm 5.9$ mb and $B = 16.3 \pm 0.5$ (GeV/c)$^{-2}$. This was normalized using the accelerator measured luminosity, which had an uncertainty of 15\%. A year later E710 published\textsuperscript{24)} $\sigma_{\text{tot}} = 72.1 \pm 3.3$ mb, $\sigma_{\text{el}} = 16.6 \pm 1.6$ mb. This was normalized using the "luminosity independent" method utilizing the optical theorem. Shortly after this the CDF collaboration began presenting\textsuperscript{27)} the preliminary result from their small angle data, $\sigma_{\text{tot}} = 72.0 \pm 3.6$ mb. This was again normalized using their best estimate of the accelerator luminosity. A year after this, in 1992, E710 was able to reanalyze their data to improve the background subtraction at low $t$ and published\textsuperscript{29)} $\rho = 0.14 \pm 0.069$, $\sigma_{\text{tot}} = 72.8 \pm 3.1$ mb, $B = 16.99 \pm 0.47$(GeV/c)$^{-2}$, $\sigma_{\text{el}} = 16.6 \pm 1.6$ mb, $\sigma_{\text{el}}/\sigma_{\text{tot}} = 0.23 \pm 0.024$ and $2\sigma_{\text{sd}} = 8.1 \pm 1.7$ mb.

The difficulties models were having fitting the UA4 $\sqrt{s} = 546$ GeV $\rho$ value and all of this new Fermilab $\sqrt{s} = 1800$ GeV data motivated the formation of the UA4/2 collaboration to remeasure $\rho$ with greater precision. In 1993 the UA4/2 collaboration published\textsuperscript{21)} their new value of $\rho = 0.135 \pm 0.015$ which "superseded"
the old UA4 value. All the other values measured in the new experiment were 
consistent with the UA4 results enumerated above. General satisfaction with the 
consistency of all the data was cut short by the publication of the CDF results which now used the luminosity independent method to normalize. Their results 
are $\sigma_{\text{tot}} = 80.03 \pm 2.24$ mb, $B = 16.98 \pm 0.25 \text{(GeV/c)}^{-2}$, $\sigma_{\text{el}} = 19.70 \pm 0.85$ mb, $\sigma_{\text{el}}/\sigma_{\text{tot}} = 0.246 \pm 0.004$ at $\sqrt{s} = 1800$. This significant disagreement with E710 remains 
unexplained. Table I summarizes all the recent data. The figures display the same 
data.

All of these figures illustrate the rise of all these parameters with $s$ with the 
possible exception of $\rho$, which is not well measured at the highest energy. One can 
only hope that by the next Blois Workshop, E811 at Fermilab, (which is the successor 
to E710), will be able to improve the measurement of $\rho$ and remove the uncertainty 
in $\sigma_{\text{tot}}$ due to the difference between E710 and CDF. In preparing this talk, I found 
one other interesting indication of the "progress" in the last decade. Using 
dispersion relations, one can parameterize the pp and $\bar{p}p$ total cross sections as

$$\sigma_{\pm} = C_0 + A_1(E)^{-N_1} + A_2(E)^{-N_2} + C_2 (\ln s)^\gamma$$

A decade ago this procedure was applied to all the data up through the UA4 
result\textsuperscript{15).} Recently the UA4/2 Collaboration updated this to include all the recent 
data\textsuperscript{22).} The only changes are that the errors are larger.

<table>
<thead>
<tr>
<th>fit constant</th>
<th>Amos et al\textsuperscript{15)}</th>
<th>Augier et al (UA4/2)\textsuperscript{22)}</th>
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<tbody>
<tr>
<td>$C_0$</td>
<td>28.3+0.2</td>
<td>30+3-4</td>
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<td>$A_1$</td>
<td>43+0.6</td>
<td>42.5+2.1</td>
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<td>$N_1$</td>
<td>0.41+0.01</td>
<td>0.45+0.08-0.06</td>
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<td>$A_2$</td>
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<td>25.5+0.5-0.4</td>
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<td>$N_2$</td>
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<td>0.565+0.005-0.004</td>
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<tr>
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<td>0.19+0.01</td>
<td>0.10+0.15-0.06</td>
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<td>$\gamma$</td>
<td>2.02+0.01</td>
<td>2.25+0.35-0.31</td>
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References

**Fixed target data**

**ISR data**

**Sp-pbarS data**

**Fermilab Collider data**
Figure 1

$\sigma_{\text{tot}} \text{ (mb)}$ vs $s \text{ (GeV}^2)\)$
Figure 2

$\rho$ vs $s$ (GeV$^2$)
Figure 3

$B$ vs $s$ (GeV$^2$)
Figure 4
Ratio of elastic to total cross sections vs $s$ (GeV$^2$)
<table>
<thead>
<tr>
<th>Collaboration</th>
<th>$\sqrt{s}$ (GeV)</th>
<th>$\sigma_{tot}$ (mb)</th>
<th>$\rho$</th>
<th>$B$(GeV/c)$^{-2}$</th>
<th>$\sigma_{el}/\sigma_{tot}$</th>
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<td>ISR$^{15}$)</td>
<td>30.4</td>
<td>42.13±0.57</td>
<td>0.055±0.029</td>
<td>12.7±0.5</td>
<td>0.17±0.007</td>
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<td>52.6</td>
<td>43.32±0.34</td>
<td>0.106±0.016</td>
<td>13.0±0.50</td>
<td>0.172±0.007</td>
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<td>62.3</td>
<td>44.12±0.39</td>
<td>13.47±0.52</td>
<td>0.169±0.007</td>
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<td>UA4$^{18,21,23}$)</td>
<td>541</td>
<td>62.2±1.5</td>
<td>0.135±0.015</td>
<td>15.5±0.1</td>
<td>0.208±0.007</td>
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<td>CDF$^{32}$)</td>
<td>546</td>
<td>61.26±0.93</td>
<td>15.28±0.58</td>
<td>0.21±0.002</td>
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<td>UA5$^{19}$)</td>
<td>900</td>
<td>65.3±2</td>
<td>16.2±0.7</td>
<td>0.193±0.014</td>
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<td>E710$^{31}$)</td>
<td>1020</td>
<td>60.2±3.4</td>
<td>16.98±0.25</td>
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<td>E710$^{28,33}$)</td>
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<td>72.2±2.7</td>
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