Energy Dependence of the Analyzing Power for Proton-Carbon Scattering

A procedure based on Regge pole phenomenology is developed to determine the energy dependence of the analyzing power in pC elastic scattering in the CNI region. The model contains the Pomeron and two lower lying, I=0, Regge poles corresponding to the f_2 and the ω. It is shown that the measurement of the polarization P at one energy plus the measurement of the shape of the CNI peak at two energies is sufficient to predict the analyzing power at all energies. It is further shown that if the spin-flip factors for the f_2 and the ω are equal , the energy dependence can be predicted based on measurements of P and the shape at only one energy. Such information is available from E950. Using the Spin 2000 data from E950 we determine the real and imaginary parts of the spin-flip factor for pL=21.7 GeV/c. From those and making the assumption just mentioned, we calculate the spin-flip factor for the Pomeron and for the lower lying Regge poles. With these the analyzing power at pL=100 and 250 GeV/c is predicted. This simple assumption can be tested using the data recently obtained at pL=100 GeV/c; if it fails that data can be used, without knowledge of P at pL=100 GeV/c, to determine the three Regge spin-flip factors and thereby obtain the prediction of the model for the energy dependence, free from this assumption. The robustness of the assumption is tested by using two different Regge fits to the non-flip data. Comparison with the pp data from FermiLab E704 shows that the I=1 spin-flip factors must be much larger than the I=0 spin-flip factors. Considerable attention is given to the correlated errors at each stage.

Larry Trueman

Energy Dependence of CNI Analyzing Power for proton-carbon scattering

$$P\,A_N(t) = \frac{N_\uparrow(t) - N_\downarrow(t)}{N_\uparrow(t) + N_\downarrow(t)}$$

small $|t| \lesssim 0.05\ \mathrm{GeV}^2$

non-flip $\quad f_0(s,t) = \underset{\text{"nuclear"}}{g_0(s,t)} + \underset{\sim \frac{\alpha}{t}}{g_0^{em}(s,t)}$

helicity-flip $\quad f_5(s,t) = g_5(s,t) + \underset{\sim \frac{\alpha k}{2m\sqrt{-t}}}{g_5^{em}(s,t)}$

$k = 1.79$

$$A_N(t) \propto \mathrm{Im}\left(f_0(s,t)\, f_5^*(s,t)\right)$$

"pure" CNI $\quad \mathrm{Im}\left(g_0(s,t)\, g_5^{em}(s,t)\right) \propto \frac{\sigma_{tot}(s)\, e^{Bt/2}\, k\alpha}{2m\sqrt{-t}}$

but

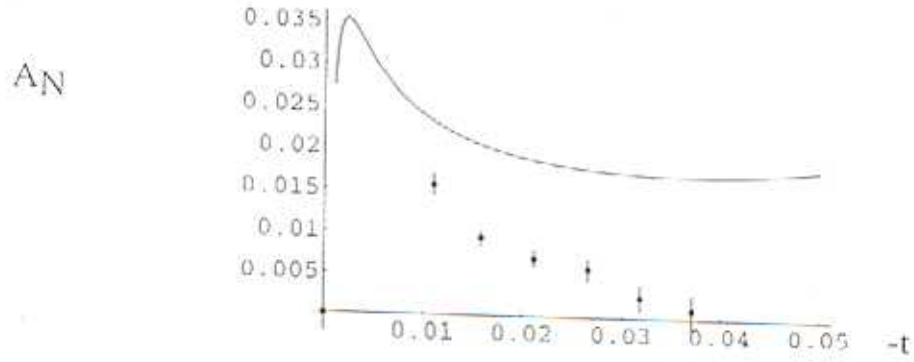
$\mathrm{Im}\left(g_5^*(s,t)\, g_0^{em}(s,t)\right)$ has same shape

parametrize $\quad g_5(s,t) = \tau(s)\frac{\sqrt{-t}}{M}\, g_0(s,t)$

$$= r_5\, \frac{\sqrt{-t}}{M}\, \mathrm{Im}\, g_0(s,t)$$

$\mathrm{Im}\, r_5 = \mathrm{Re}\,\tau + \rho\, \mathrm{Im}\,\tau, \quad \mathrm{Re}\, r_5 = -\mathrm{Im}\,\tau + \rho\, \mathrm{Re}\,\tau$

Pure CNI (no hadronic spin-flip, $\tau = 0$) compared with Spin 2000 data.



To determine τ, fit ratio of measured asymmetry to pure CNI to

$$R(t) = \frac{A_N(t,\tau)}{A_N(t,0)} = \left(1 - \frac{2}{K}\mathrm{Re}\,\tau(s)\right)$$

$$+ \frac{2}{K}\mathrm{Im}\,\tau(s)\left(\frac{t}{t_c}\right)\frac{F^h(t)}{F^{em}(t)} \leftarrow \text{small}$$

$$t_c = -\frac{2\alpha\,\delta\pi}{\sigma_{tot}} = -0.00127\ \mathrm{GeV}^2$$

for pC

If P is not known, can still determine shape parameter

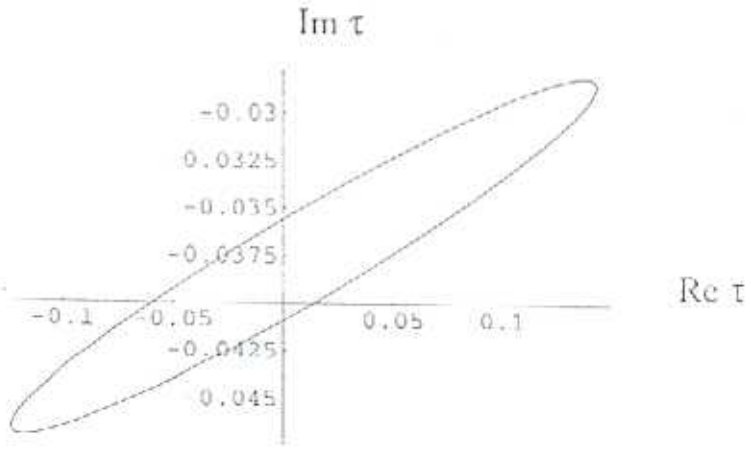
$$S(s) = \frac{\mathrm{Im}\,\tau(s)}{1 - \frac{2}{K}\mathrm{Re}\,\tau(s)}$$

Kopeliovich & Trueman:

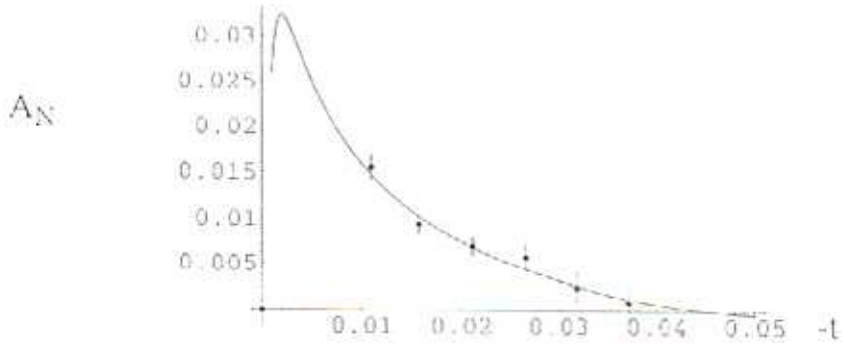
$$\tau_{pC} = \frac{1}{2}\left(\tau_{pp} + \tau_{pn}\right)$$

(non-flip nearly pure $I = 0$)

68.3% confidence level ellipse for fit to Spin 2000 data



Best fit to Spin 2000 data for A_N
τ=0,010-0,038 i



First try: Berger, Irving + Sorenson
Regge pole expectations (1978)

7 Regge poles: Pomeron + 6 exchange-dep.
Regge poles: 4 at $\alpha = 1/2$
2 at $\alpha = -1/2$

for A_N

spin-dependence determined by "residues"

$$M^{i}_{\lambda_c \lambda_d ; \lambda_a \lambda_b} \propto s^{\alpha_i(t)} \beta^{i(t)}_{\lambda_a \lambda_c} \beta^{i(t)}_{\lambda_b \lambda_d}$$

Compares to Argonne data at $p_L = 6, 12$ GeV/c

(Pomeron is assumed to be pole at $J=1$ so σ_{tot} is flat - not bad through pC fixed target range, but fails above)

(Comparisons are made for mainly above CNI region)

Use energy dependence of model to get

$$\tau_{pp}(21.7) = 0.045 + 0.061\, i$$

$$\tau_{pC}(21.7) = 0.037 + 0.034\, i$$ n.b. pos. imag part

far from measured value 0.00 - 0.038 i at 21.7 GeV/c
(Consistent within large errors with E704
$.03 \pm .02\, i$)

Second try -

Plan -

Model: $g_0(s,0) = g_p(s) + g_f(s) + g_w(s)$

pg

$$g_p(s) = X \frac{(1+e^{-i\pi\alpha_p})}{\sin \pi\alpha_p} s^{\alpha_p - 1}$$

$$g_f(s) = Y \frac{(1+e^{-i\pi\alpha_f})}{\sin \pi\alpha_f} s^{\alpha_f - 1}$$

$$g_w(s) = Y' \frac{(1-e^{-i\pi\alpha_w})}{\sin \pi\alpha_w} s^{\alpha_w - 1}$$

fit by Cudell et al

$\alpha_p = 1.0933$

$\alpha_f = 0.64$

$\alpha_w = 0.44$ etc.

Assume

$$g_5(s,t) = \tau(s) \frac{\sqrt{-t}}{m} g_0(s,t)$$

$$= \frac{\sqrt{-t}}{m} \left\{ \tau_p g_p(s) + \tau_f g_f(s) + \tau_w g_w(s) \right\}$$

τ_p, τ_f, τ_w real constants

$$\tau_p = \frac{\beta_{+-}^{p}}{\beta_{++}^{p}} \quad \text{etc.}$$

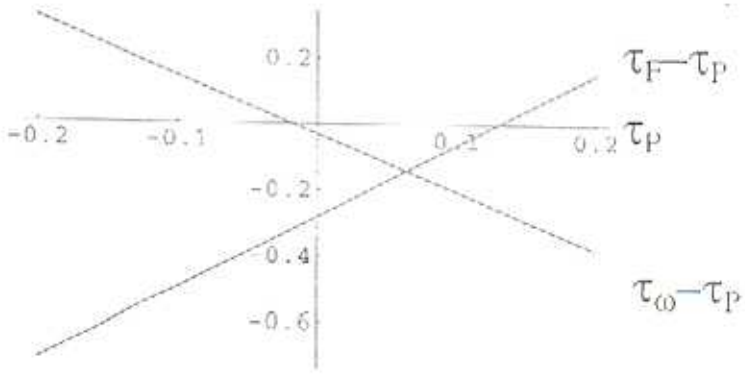
$$\tau(s) = \tau_p + (\tau_f - \tau_p)\frac{S_f(s)}{S_0(s)} + (\tau_\omega - \tau_p)\frac{S_\omega(s)}{S_0(s)}$$

Knowing P at s_0 (E550) determine Re and Im of $\tau(s)$ giving $(\tau_f - \tau_p)$ and $(\tau_\omega - \tau_p)$ as linear function of τ_p.

Then measure $S(s_1)$ without knowing P at s_1 and solve for τ_p.

Then A_N at all energies is known.

Solutions to equations generated by measurement of $\tau(s)$ at s=42 with known beam polarization



Speculative but reasonable assumption:

$$\tau_\omega = \tau_f \equiv \tau_R$$

allows determination of τ_p and τ_R from existing EPTO data, and so A_N at any energy can be calculated. Get

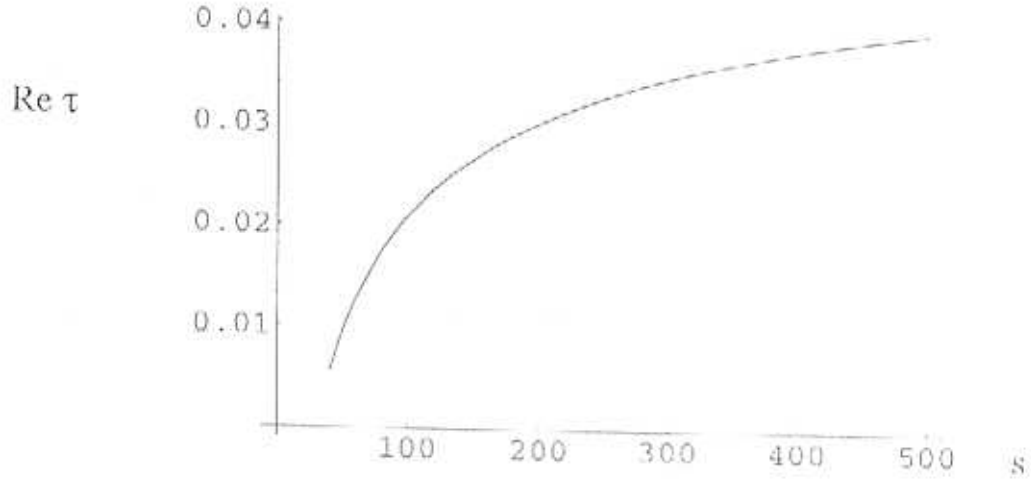
$$\tau_p = 0.064$$

$$\tau_R = -0.078$$

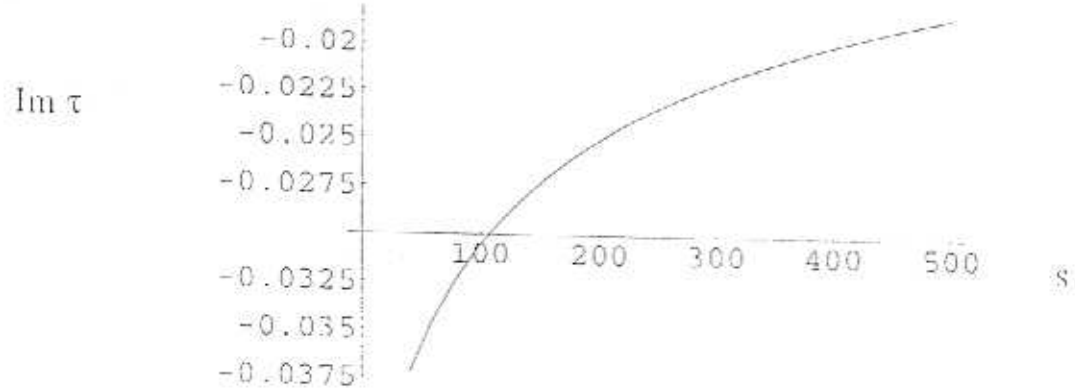
so $\quad \mathrm{Re}\,\tau(s) \to 0.064$ as $s \to \infty$

$\mathrm{Im}\,\tau(s) \to 0$ from below

Energy dependence of τ

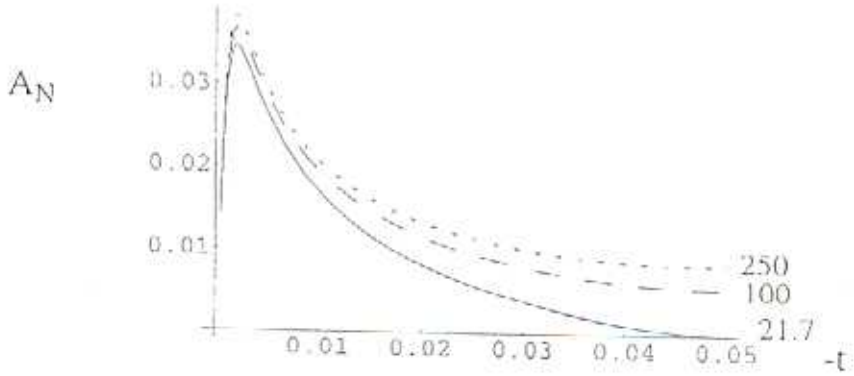


a.



b.

Analyzing power for pL=100, 250 GeV/c based on Regge model and fit at 21.7 GeV/c/



Stability & uniqueness ?

Block et al (1991) use different form for Pomeron.

$$f_0^{pp}(s) = i\left(A + B\left[\log\frac{s}{s_0} - i\frac{\pi}{2}\right]^2\right)$$

$$+ \; iC_+ s^{\alpha-1} e^{i\pi(1-\alpha)/2} \qquad (f, A_2)$$

$$+ \; C_- s^{\alpha-1} e^{i\pi(1-\alpha)/2} \qquad (\rho, \omega)$$

numerically Pomeron much more important relative to Regge than in Cudell et al

Both fits (σ_{tot}, ρ) equally good over our energy range.

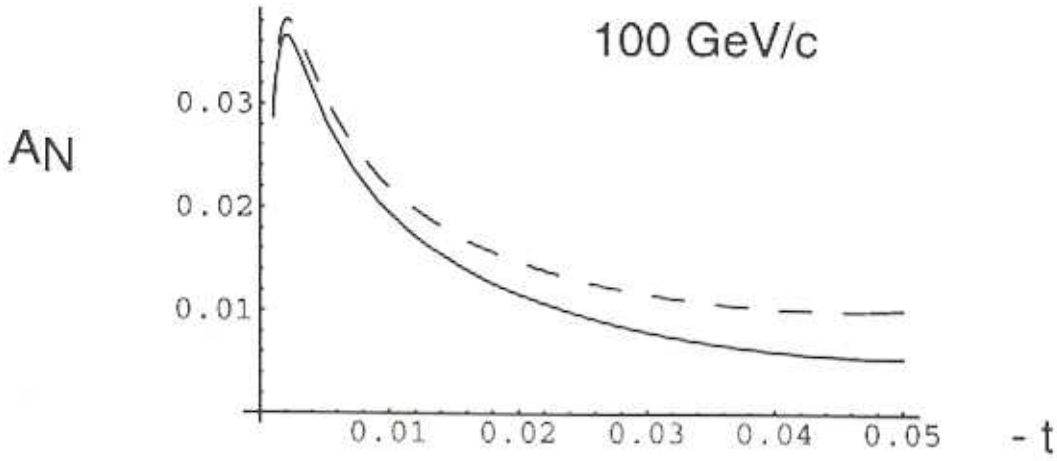
Results of same 2 pole game are somewhat different

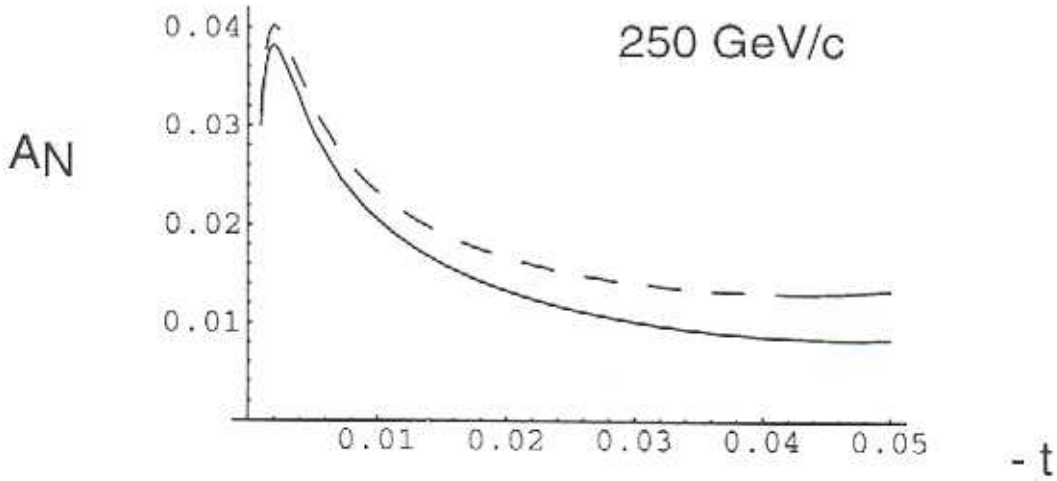
P_L	Block et al	Cudell et al
100	$0.028 - 0.07i$	$0.053 - 0.026i$
250	$0.027 - 0.010i$	$0.043 - 0.019i$

95% Confidence level ellipses don't overlap

Difference about 5% near peak, nearly a factor of 2 for $t = -0.05$

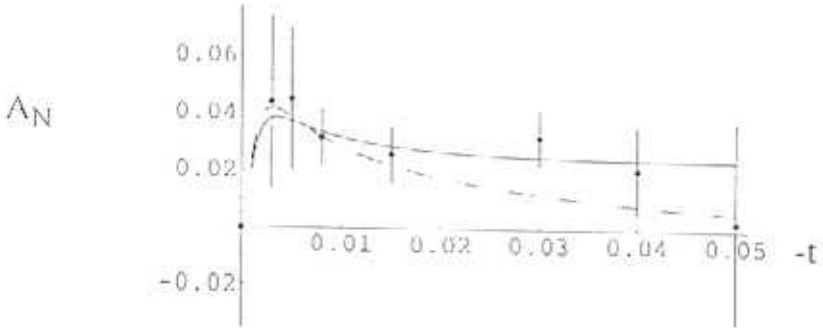
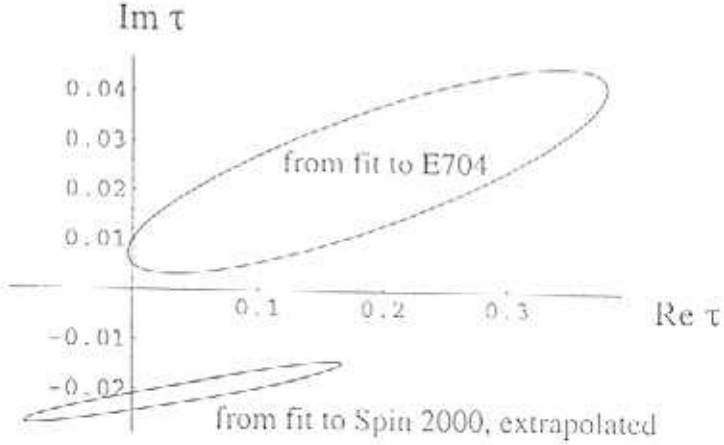
Comparison of projections for A_N to higher energy using non-flip inputs of Cudell et al and of Block et al





solid line uses Cudell et all as input
dashed line uses Block et al as input

A_N for pp at pL = 200 GeV/c with E704 low-t data. Solid curve is best fit with τ= 0.188 + .024 i; dashed curves uses the values obtained from fit to Spin 2000 pC data extrapolated to s=400, τ= 0.041 -0.02 i.



Comparison of the error ellipse (68.3% confidence level) obtained from fit to E704 data below |t|=0.05 with that obtained by using Regge model applied to Spin 2000 data. Strong indication of large I=1 contribution to proton-proton scattering.