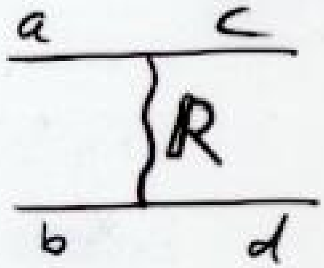
Forward neutrons and photons in pp collisions

Boris Kopeliovich

Regge theory recollections

- Binary reactions



residue function
spin structure

$$A_R^{ab\to cd}(s,t) = h_R(t)\,\eta_R(t)\left(\frac{s}{s_0}\right)^{\alpha_R(t)}$$

Phase factor

Energy dependence

$$h_R(t) = h_0(t) + h_1(t)\,\vec{\sigma}\vec{n}$$

$$\eta_R(t) = \begin{cases} i - \mathrm{ctg}\,\dfrac{\pi\alpha_R(t)}{2} & \text{positive signature } (\mathbb{P}, f, a_2) \\ -i - \mathrm{tg}\,\dfrac{\pi\alpha_R(t)}{2} & \text{negative signature } (\rho, \omega) \end{cases}$$

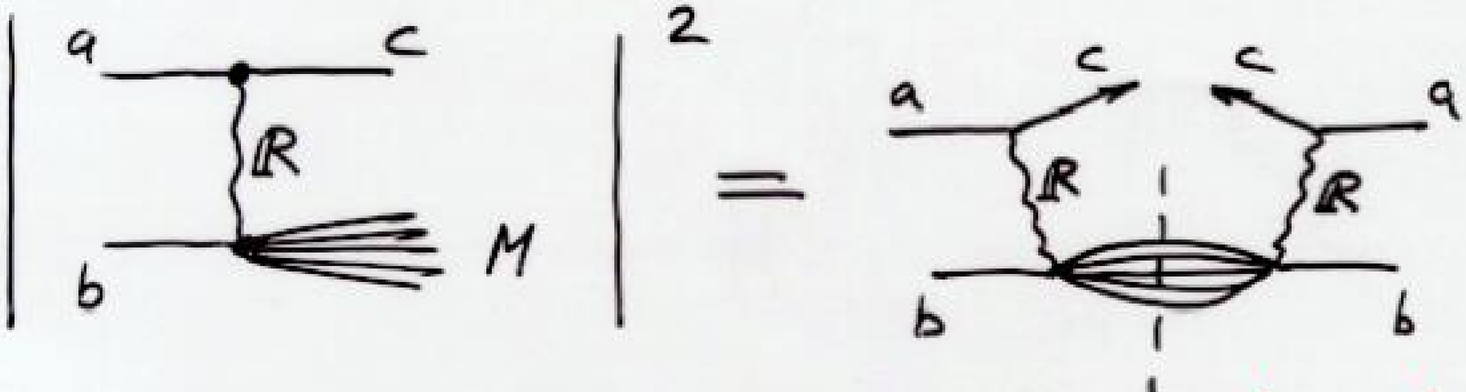
$$\alpha_R(t) = \alpha_R^0 + \alpha_R' t$$

$$\alpha_{\mathbb{P}}^0 \simeq 1.1 \;; \quad \alpha_{\mathbb{P}}' = 0.25\ \mathrm{GeV}^{-2}$$

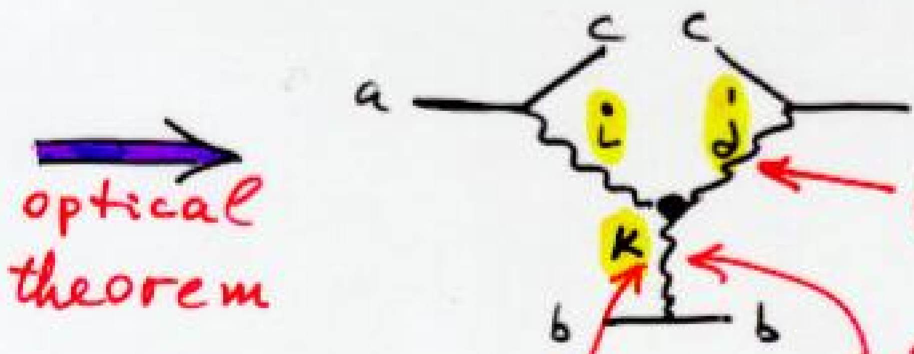
$$\alpha_R^0 \approx 0.5 \;; \quad \alpha_R' \approx 0.9\ \mathrm{GeV}^{-2}$$

$$R = \omega, f, \rho, a_2$$

- Inclusive hadron production in the beam fragmentation region ($x_F \gtrsim 0.1$)



Unitarity cut



$$\left(\frac{s'}{s_0}\right) = \frac{s}{M^2} = \frac{1}{1-x_F}$$

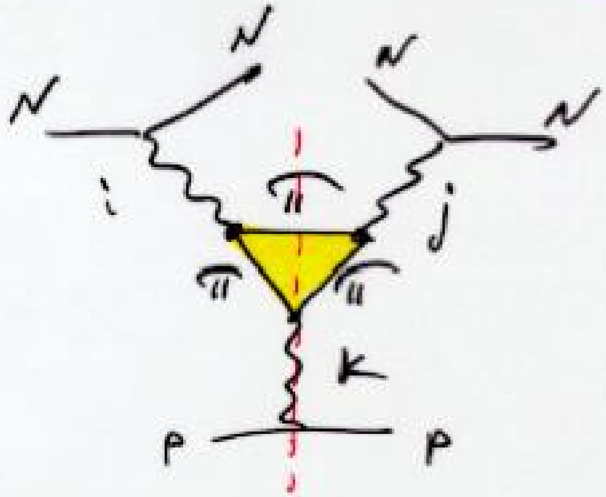
$$\frac{s''}{s_0} = \frac{M^2}{s_0} = (1-x_F)\frac{s}{s_0}$$

Imaginary part of forward scattering amplitude

$$\frac{d\sigma^{ab\to cX}}{dt\,dx_F} = \sum_{i,j,k} G_{ijk}(t)\,(1-x_F)^{\alpha_k(0)-\alpha_i(t)-\alpha_j(t)} \times \left(\frac{s}{s_0}\right)^{\alpha_k(0)-1}$$

Triple-Regge verteces Fitted to data

OPE model for the triple-Regge couplings



Y. Kazarinov
I. Lapidus
I. Potashnikova
B. K.
1975

$$G_{ijk}(0) = g_{NNi}\, g_{NNj}\, g_{NNk}\, g_{\pi\pi i}\, g_{\pi\pi j}\, g_{\pi\pi k}\, \eta_i(0)\, \eta_j(0)\, I_{ijk}$$

$$I_{ijk} = \frac{3}{(4\pi)^4 s_0} \int_{-\infty}^{0} \frac{du}{(m_\pi^2-u)^2} \left(\frac{m_\pi^2-u}{s_0}\right)^{\alpha_i(0)+\alpha_j(0)} F(u)$$

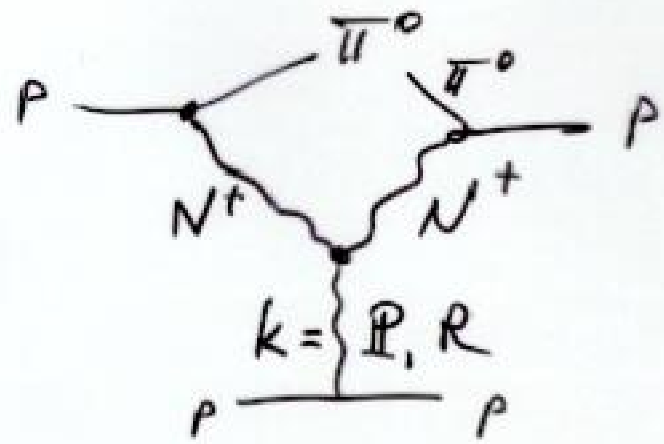
$$\times \int_0^{-u/(m_\pi^2-u)} d\left(\frac{M_1^2}{M^2}\right) \left(\frac{M_1^2}{M^2}\right)^{\alpha_k(0)}$$

Comparison with the fit to $pp \to pX$ data

	G_{PPP}	G_{RRP}	G_{PPR}	G_{RRR}	$2\,\mathrm{Re}\,G_{RPP}$	$2\,\mathrm{Re}\,G_{RPR}$
Theory	4	17	5.4	27.4	10.7	15
Fit	3.23 ± 0.35	13.2 ± 0.9	2 ± 1	23.6 ± 5.0	5.7 ± 4.9	13.4 ± 4.5

units: $\left(\frac{mb}{GeV^2}\right)$

Forward pions and photons



$$\left.\frac{d\sigma(pp \to \pi^0 X)}{dx_F\,dt}\right|_{t=0} = \sum_{\mathbb{P},\mathbb{R}} G_{NNK}(0)\,(1-x_F)^{\alpha_K^0 - 2\alpha_N^0} \times \left(\frac{s}{s_0}\right)^{\alpha_K^0 - 1}$$

At not too small $1-x_F$ the energy correspondig to the Reggeon k is very high: $s'' = M^2 = (1-x_F)s$.

Therefore, the Pomeron dominates, and

$$\frac{d\sigma(pp \to \pi^0 X)}{dx_F\,dt} = G_{NN\mathbb{P}}(0)\,(1-x_F)^2,$$

since $\alpha_N^0 \approx -0.5$

$$x_F^{\pi^0} \approx 2\, x_F^{\gamma}$$

$$\left.\frac{d\sigma(pp \to \gamma X)}{dx_F\, dt}\right|_{t=0} \propto (1 - 2x_F)^2$$

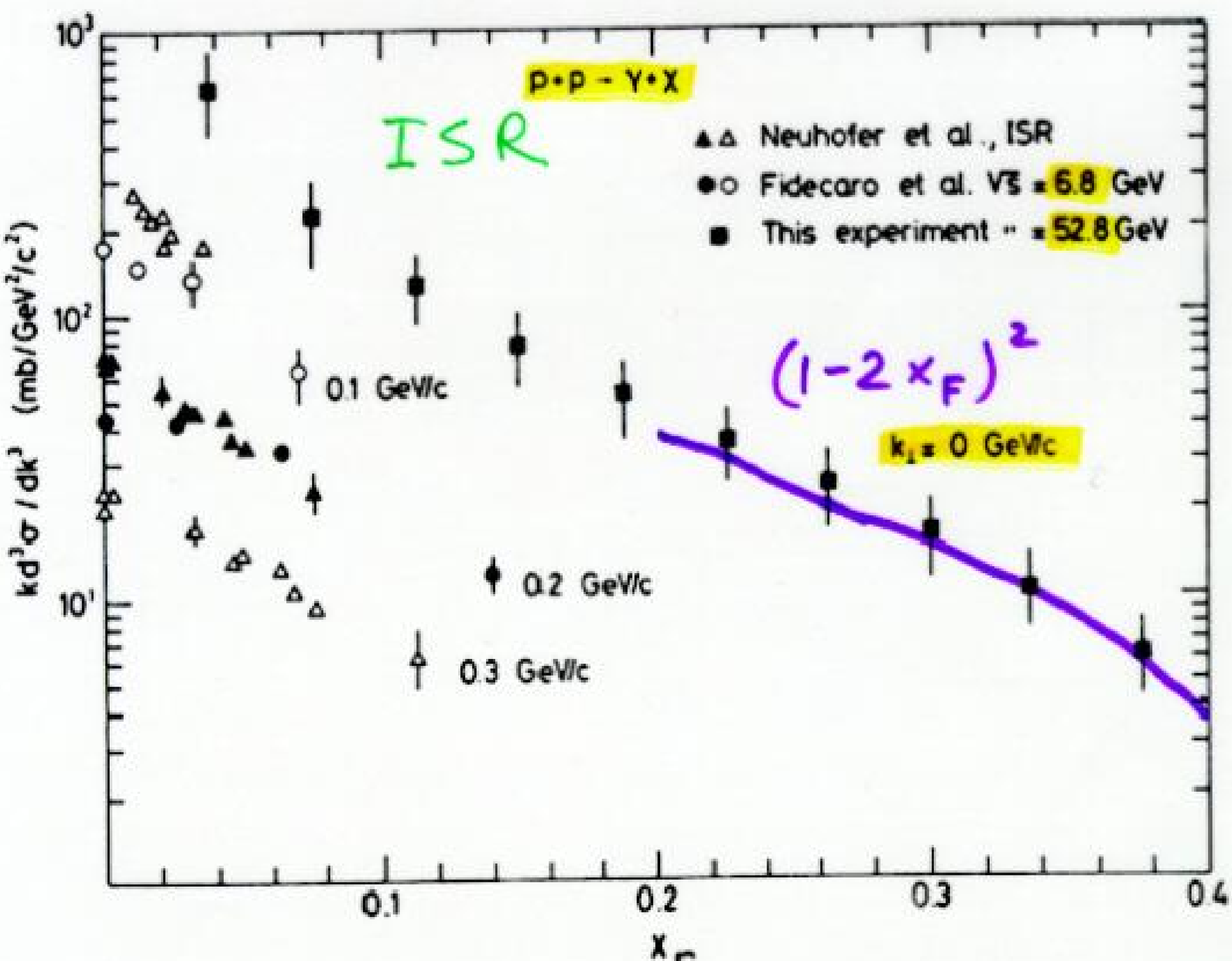
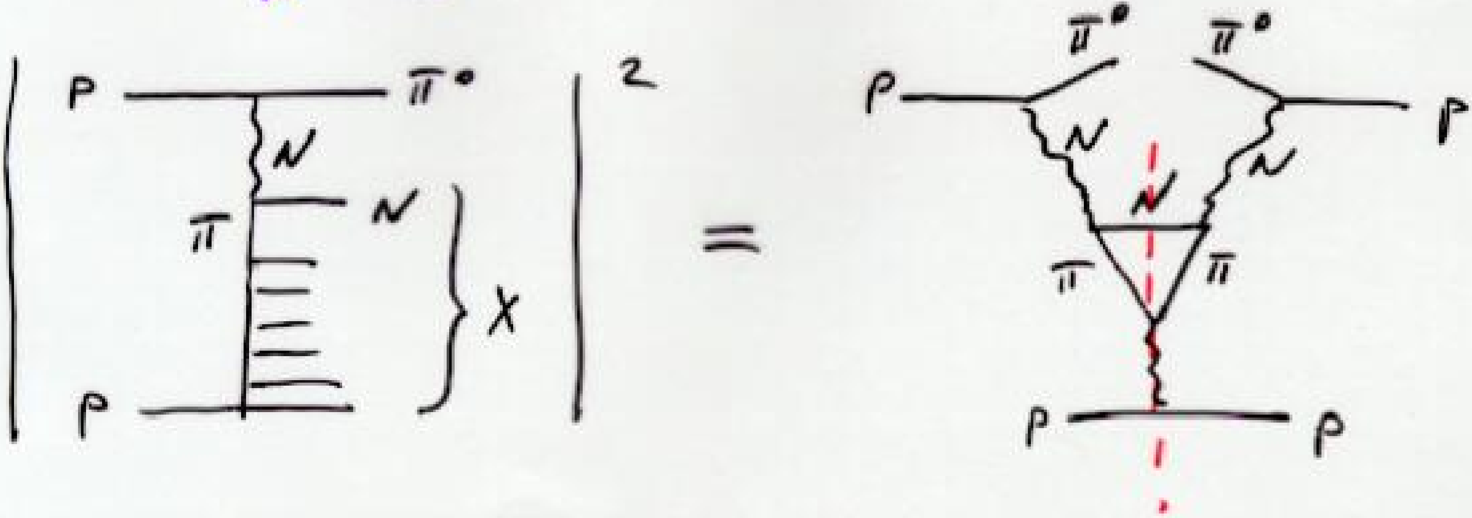


Fig. 4. Invariant cross sections for photon production. The data of this experiment were taken at $\sqrt{s} = 52.8$ GeV.

$A_N(pp \to \pi^\circ X)$



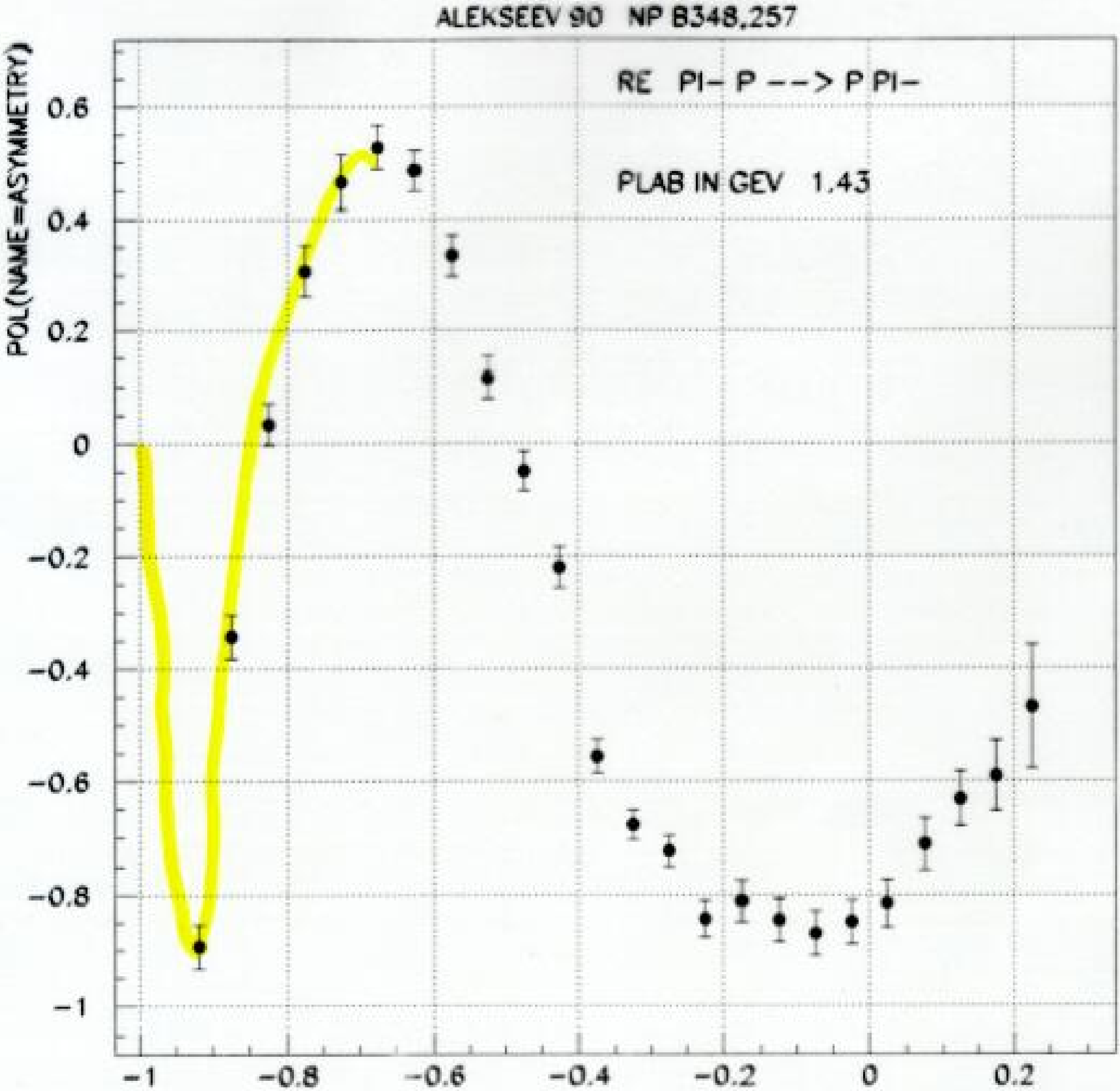
$$A_N^{pp\to\pi^\circ X}(s,t,x_F) \approx \frac{2}{3} A_N^{p\pi^-\to\pi^\circ n}\left(s'=\frac{s_0}{1-x_F}, t\right)$$

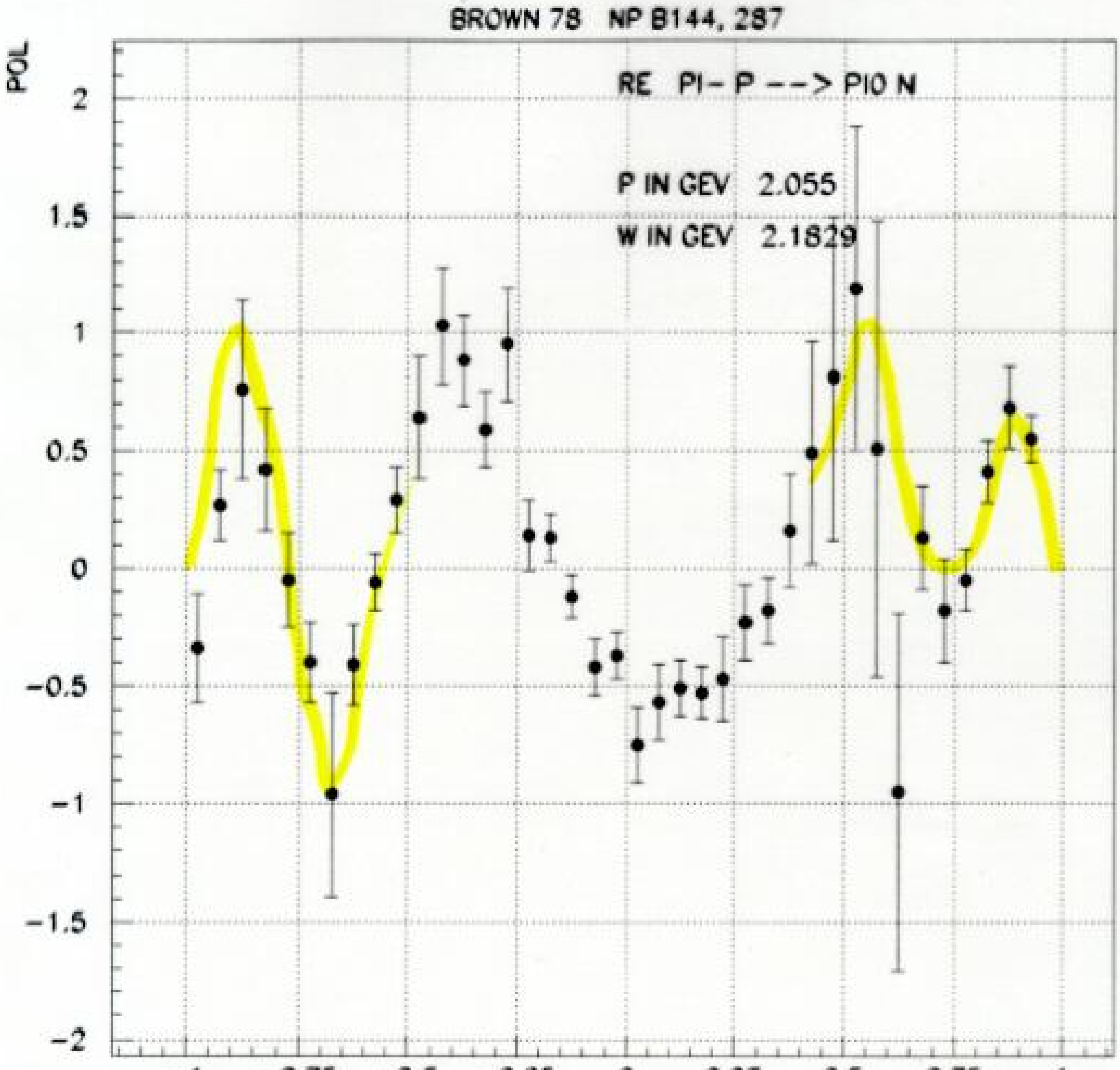
$$+\ \frac{1}{3} A_N^{p\pi^\circ\to\pi^\circ p}\left(\frac{s_0}{1-x_F}, t\right) + \left(\begin{matrix}\text{corrections}\\ \text{for } \Delta \text{ production}\end{matrix}\right)$$

At fixed x_F the asymmetry is independent of energy.

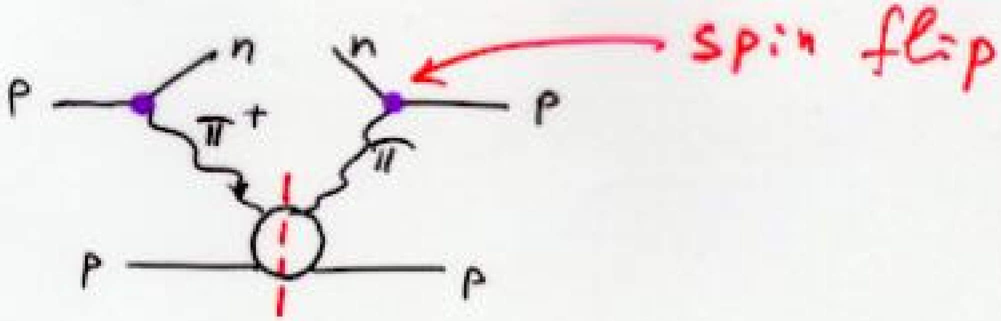
Feynman scaling.

This is a general statement for all inclusive reactions ($pp \to \Lambda X, \ldots$)


ALEKSEEV 90 NP B348,257
RE PI- P --> P PI-
PLAB IN GEV 1.43
POL(NAME=ASYMMETRY)
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
COS(THETA(P=4))


BROWN 78 NP B144, 287
POL
RE PI- P --> PI0 N
P IN GEV 2.055
W IN GEV 2.1829
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-1
-0.75
-0.5
-0.25
0
0.25
0.5
0.75
1
COS(THETA)

Forward neutrons



$$\left.\frac{d\sigma^{pp\to nX}}{dx_F\,dt}\right|_{\pi} = \frac{2g^2_{\pi NN}}{(4\pi)^2}\,\sigma^{\pi^+p}_{tot}\,\frac{-t\,e^{R^2 t}}{(m_\pi^2-t)^2}\,(1-x_F)^{1+2\alpha'_\pi|t|}$$

$$\left.\frac{d\sigma^{pp\to nX}}{dx_F\,dt}\right|_{R} = \frac{2}{(4\pi)^2}\left[g_\rho^2 e^{R_\rho^2 t} + g_{a_2}^2 e^{R_{a_2}^2 t}\right]\sigma^{Rp}_{tot}\,|\eta_R|^2$$

$$\times\,(1-x_F)^{2\alpha'_R|t|}$$

$\sigma^{Rp}_{tot} \approx \sigma^{\pi p}_{tot}$; $\frac{g_\rho^2}{4\pi} = 0.18\ \mathrm{GeV}^{-2}$; $\frac{g_{a_2}^2}{4\pi} = 0.4\ \mathrm{GeV}^{-2}$

$R_\rho^2 = 2\ \mathrm{GeV}^{-2}$; $R_{a_2}^2 = 1\ \mathrm{GeV}^{-2}$; $|\eta_R^2| \approx 2$

For DIS one should just replace $\sigma^{\pi p}_{tot} \Rightarrow \sigma^{\gamma^*\pi}_{tot} = \frac{2\pi\alpha^2}{Q^2} F_2^\pi(x, Q^2)$

π

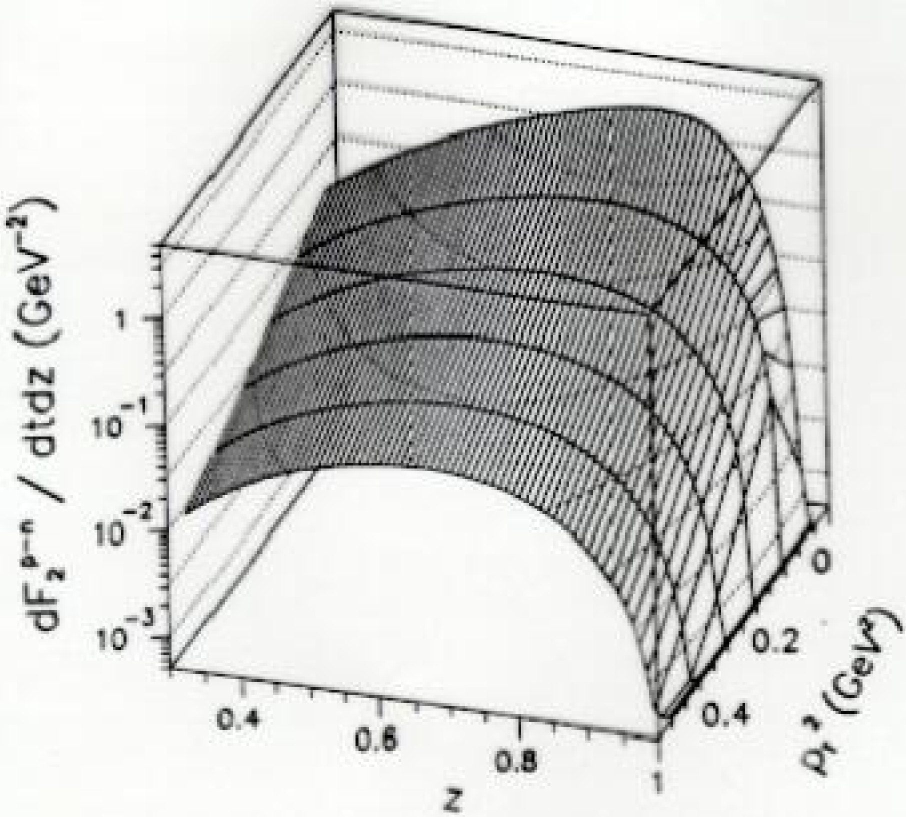


Fig. 3. The neutron electroproduction cross section, corresponding to the pion-pole diagram in Fig. 1a, versus p_T^2 and z

I. Potashnikova
B. Povh
B.K.
1996

$\rho + a_2$

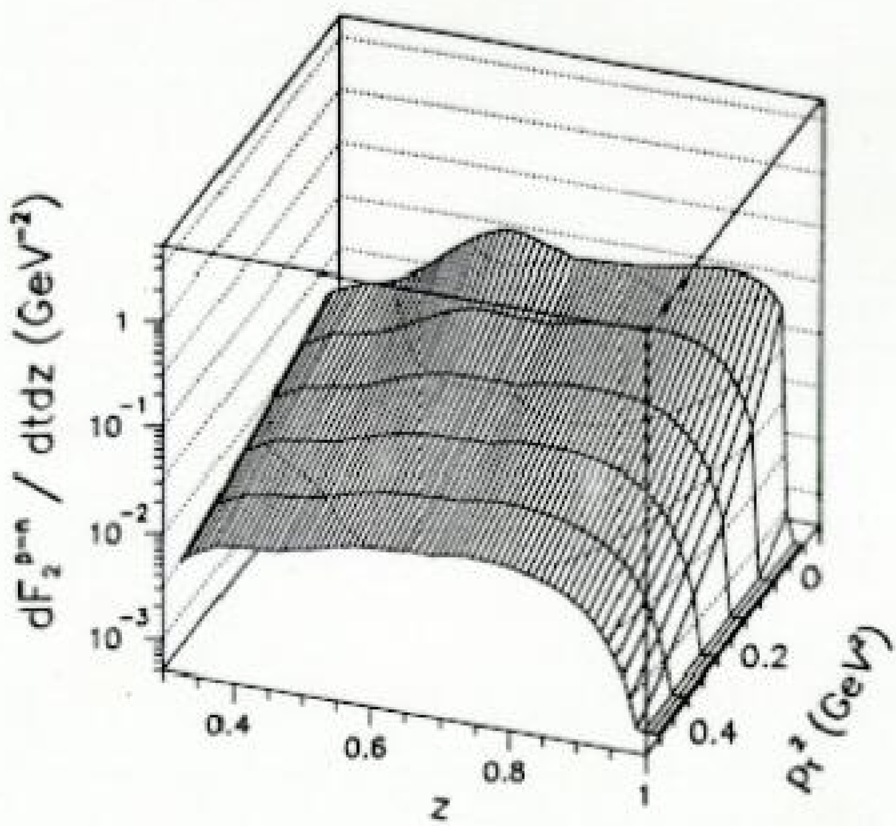


Fig. 4. The neutron electroproduction cross section, corresponding to the pion-pole diagram in Fig. 1b, versus p_T^2 and z

12

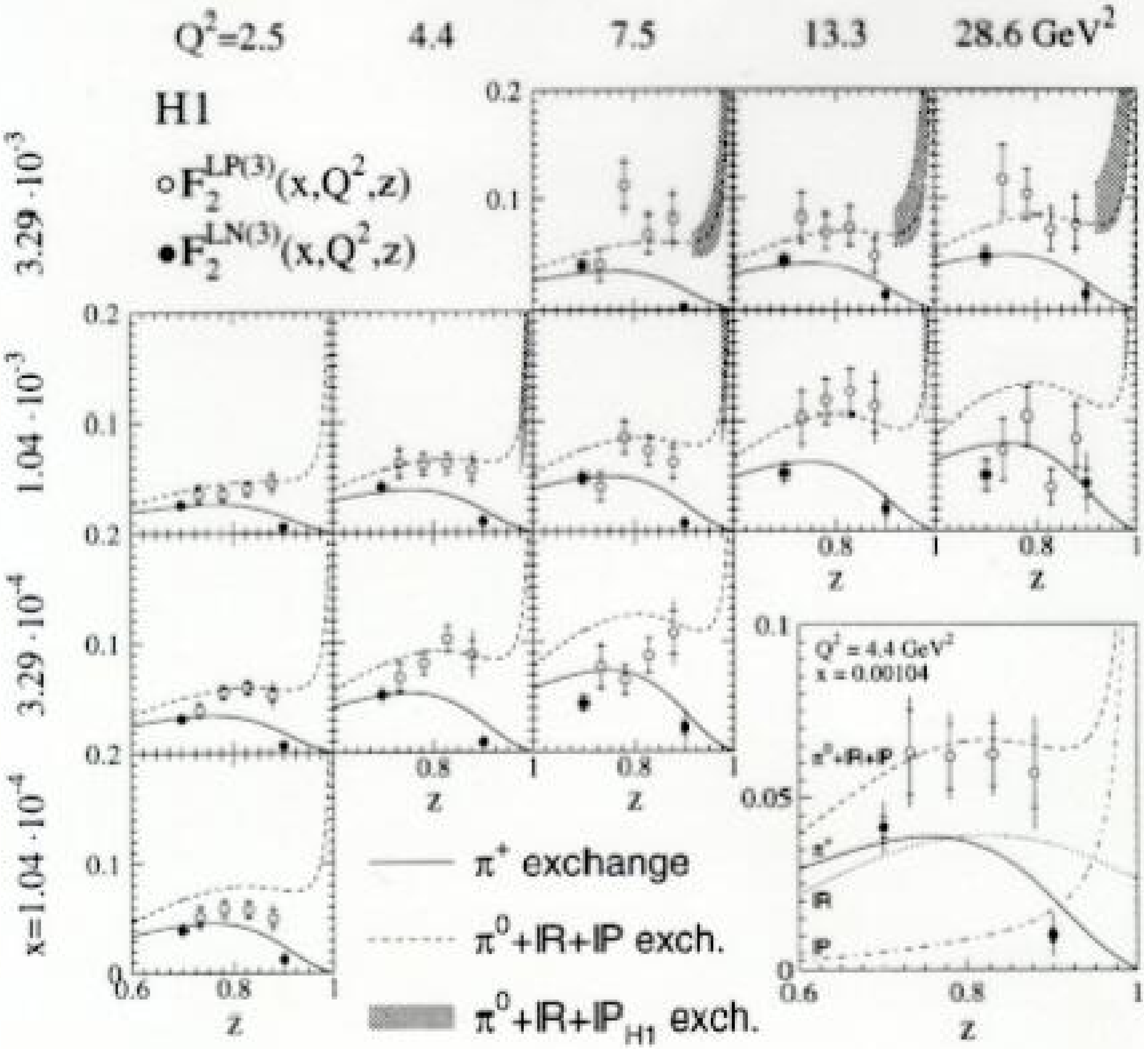


Figure 8: The measured values of $F_2^{LN(3)}$ and $F_2^{LP(3)}$ with $z \geq 0.7$ compared to a Regge model of baryon production. The different contributions are labeled for the figure in the inset. The neutron data are described by π^+ exchange whereas the proton data are compared to the sum of π^0, pomeron and secondary reggeon (f_2) exchanges. The π^0 contribution, which is not shown, is exactly half the π^+ contribution. The shaded–band is explained in the text.

$pp \to nX$

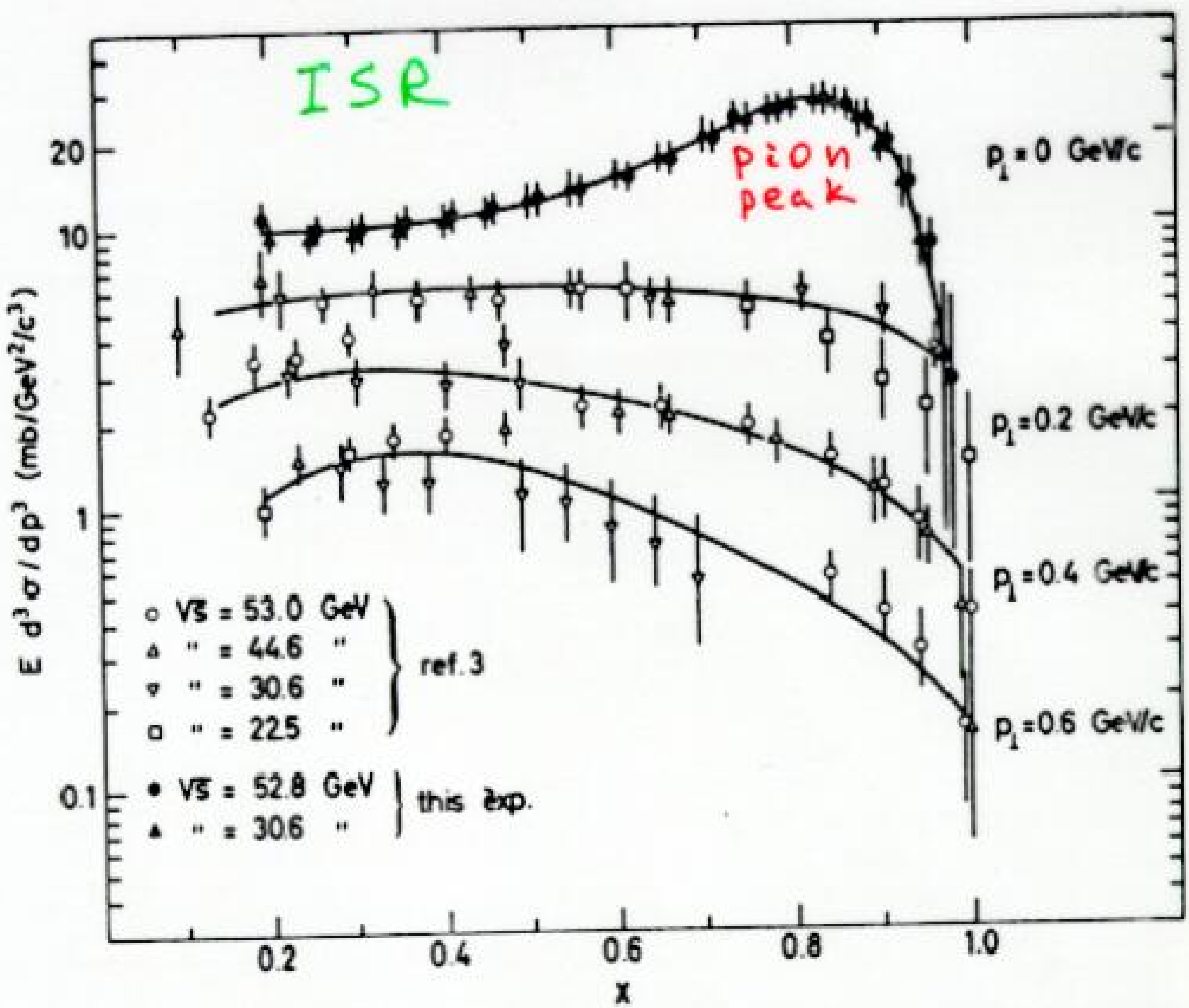


Fig. 3. The invariant cross sections for neutron production as a function of the scaling v
$x = p_\parallel / p_{max}$. The lines are hand drawn to guide the eye.

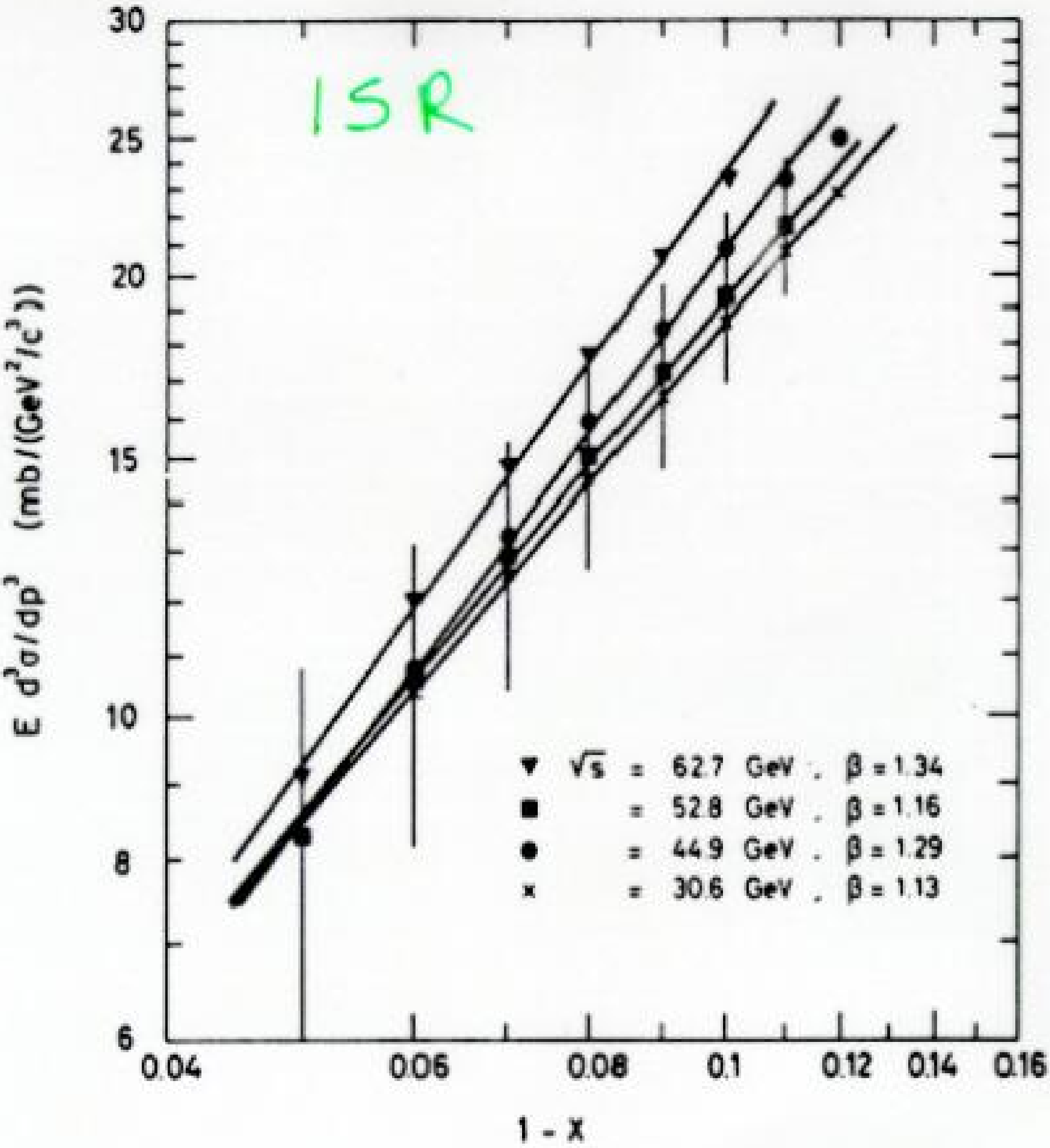


Fig. 5. The neutron cross sections as a function of $M^2/s \approx 1-x$ for the momentum transfer squared $t \approx 0$.

$$\left.\frac{d\sigma}{dx_F\,dt}\right|_{t=0} \propto (1-x_F)^{\beta}$$

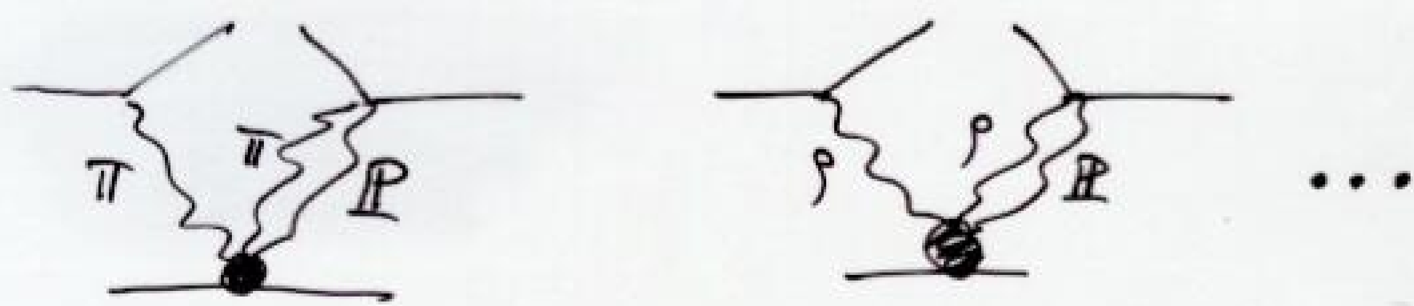
$$\beta = 1 - 2\alpha^0_{eff}$$

$$\alpha^0_{eff} = -0.11 \pm 0.15$$

Consistent with pion $\alpha^0_\pi = 0$

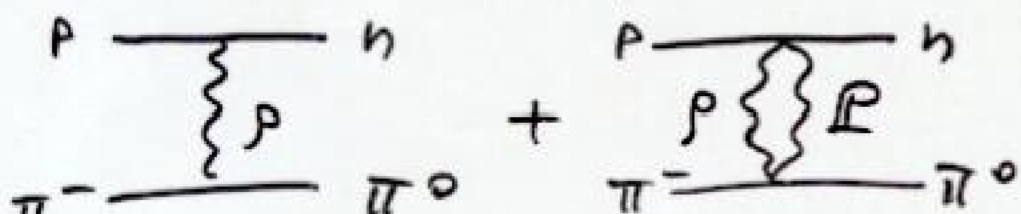
A_N ($pp \to nX$)

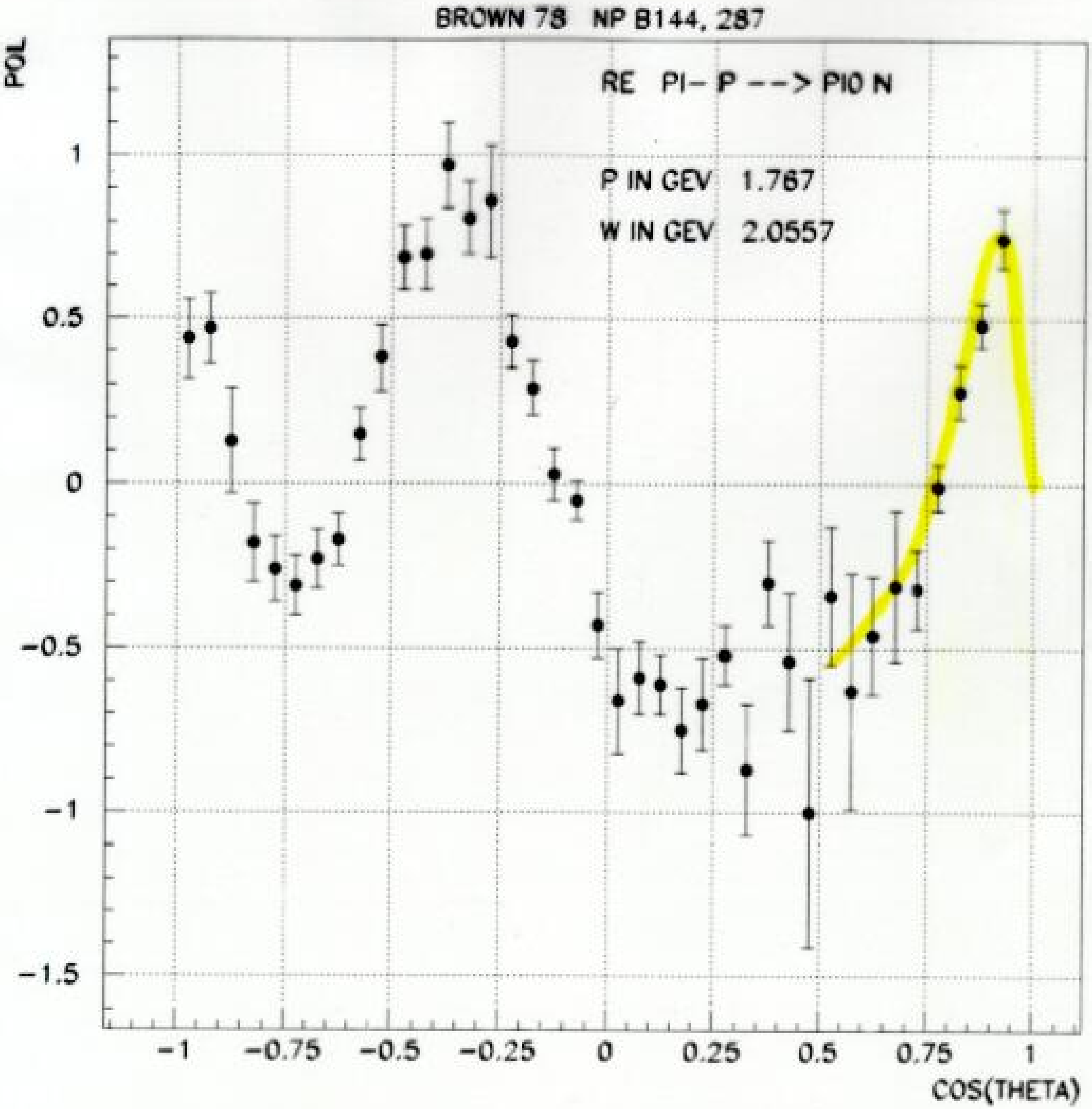
all the dominant contributions are dominated by the spin-flip parts. Asymmetry is due to interference between Regge poles and cuts



The known effects are strong at medium energies $s' = \frac{s_0}{1-x_F} \lesssim 2\,\text{GeV}^2$

Example $\pi^- p \to \pi^0 n$




BROWN 78 NP B144, 287
POL
RE PI- P --> PI0 N
P IN GEV 1.767
W IN GEV 2.0557
1
0.5
0
-0.5
-1
-1.5
-1
-0.75
-0.5
-0.25
0
0.25
0.5
0.75
1
COS(THETA)

Conclusions

- Polarization effects in inclusive reactions, as well as the cross section, are independent of enery (with some corrections)

- Asymmetry in $pp \to \pi^0(\gamma)X$ might be small due to the strong oscillating t-dependence and opposite signs of A_N in different channels

- Neutron production is dominated by pion exchange. A large A_N is expected from π and $\pi I\!\!P$ (absorptive corrections) interference.