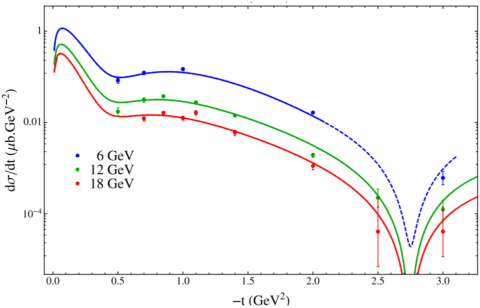
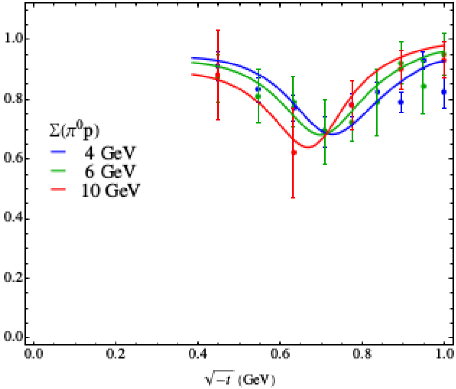
	J^P	$\tau = (-1)^J$	$\eta = \tau P$
Scalar	0^+	$+1$	$+1$
Pseudoscalar	0^-	$+1$	-1
Vector	1^-	-1	$+1$
Pseudovector	1^+	-1	-1
Tensor	2^+	$+1$	$+1$

$\pi^- p \to \pi^0 n$	ρ
$\pi^- p \to \eta n$	a_2
$K^- p \to \bar{K}^0 n$	a_2, ρ
$\pi^\pm p \to \pi^\pm p$	$f, \rho, \mathcal{P}$
$\gamma p \to \pi^0 p$	ω, ρ, h_1, b_1
$\gamma p \to \pi^+ n$	a, ρ, π, b_1



dσ/dt (μb.GeV^{-2})
1
0.01
10^{-4}
6 GeV
12 GeV
18 GeV
0.0
0.5
1.0
1.5
2.0
2.5
3.0
−t (GeV^2)



1.0
0.8
0.6
0.4
0.2
0.0
Σ(π^{0}p)
4 GeV
6 GeV
10 GeV
0.0
0.2
0.4
0.6
0.8
1.0
$\sqrt{-t}$ (GeV)

$$M_1 = \frac{1}{2}\gamma_5\gamma_\mu\gamma_\nu \mathbf{F}^{\mu\nu}$$

$$M_2 = \gamma_5 p_{3,\mu}(p_2 + p_4)_\nu \mathbf{F}^{\mu\nu}$$

$$M_3 = \gamma_5\gamma_\mu p_{3,\nu} \mathbf{F}^{\mu\nu}$$

$$M_4 = \frac{\mathrm{i}}{2}\epsilon_{\alpha\beta\mu\nu}\gamma^\alpha p_3^\beta \mathbf{F}^{\mu\nu}$$

$$\mathbf{F}^{\mu\nu} \equiv \epsilon^\mu p_1^\nu - \epsilon^\nu p_1^\mu$$

$$\mathbf{A^s}_{\mu_4,\mu_2\mu_1} = \bar{u}_{\mu_4}(p_4)\sum_{i=1}^{4} A_i(\text{scalars}, \mu_1) M_i u_{\mu_2}(p_2)$$

$$\mathbf{A^t}_{\lambda_4\lambda_2,\lambda_1} = \bar{u}_{\lambda_4}(p_4)\sum_{i=1}^{4} A_i(\text{scalars}, \lambda_1) M_i v_{\lambda_2}(-p_2)$$

In the t-channel center-of-mass frame

$$p_1^\mu = (k_t, 0, 0, k_t)$$

$$p_2^\mu = (-E_N^t, -p_t \sin\theta_t, 0, -p_t \cos\theta_t)$$

$$p_3^\mu = (-E_\pi^t, 0, 0, k_t)$$

$$p_4^\mu = (E_N^t, -p_t \sin\theta_t, 0, -p_t \cos\theta_t)$$

$$\epsilon^\mu = (0, \mp 1, -\mathrm{i}, 0)/\sqrt{2}$$

$$v_\pm(-p_2) = \begin{pmatrix} -\sqrt{E_N^t - m_N}\chi_{2,1} \\ \pm\sqrt{E_N^t + m_N}\chi_{2,1} \end{pmatrix}, \bar{u}_\pm(p_4) = \begin{pmatrix} \sqrt{E_N^t + m_N}\chi_{2,1}^\dagger \\ \mp\sqrt{E_N^t - m_N}\chi_{2,1}^\dagger \end{pmatrix}^T$$

$$\chi_1 = \begin{pmatrix} \cos\theta/2 \\ \sin\theta_t/2 \end{pmatrix}, \chi_2 = \begin{pmatrix} -\sin\theta_t/2 \\ \cos\theta_t/2 \end{pmatrix}$$

$$A^t_{++,1} = \sqrt{2} k_t \frac{\sin\theta_t}{2} \left[\sqrt{t} \overbrace{(A_1 - 2m_N A_4)}^{-F_1} - 2p_t \overbrace{(A_1 + tA_2)}^{F_2} \right]$$

$$A^t_{--,1} = \sqrt{2} k_t \frac{\sin\theta_t}{2} \left[\sqrt{t} \overbrace{(A_1 - 2m_N A_4)}^{-F_1} + 2p_t \overbrace{(A_1 + tA_2)}^{F_2} \right]$$

$$A^t_{+-,1} = \sqrt{2} k_t \sin^2\frac{\theta_t}{2} \left[-2p_t \sqrt{t} \underbrace{A_3}_{F_4} - \underbrace{(2m_N A_1 - tA_4)}_{F_3} \right]$$

$$A^t_{-+,1} = \sqrt{2} k_t \cos^2\frac{\theta_t}{2} \left[2p_t \sqrt{t} \underbrace{A_3}_{F_4} - \underbrace{(2m_N A_1 - tA_4)}_{F_3} \right]$$

These are not eigenstates of parity! But the F_i are:

$$\mathbf{P}\,\mathbf{A}^{\mathbf{t}}_{\lambda_4\lambda_2,\lambda_1} \neq \pm\,\mathbf{A}^{\mathbf{t}}_{\lambda_4\lambda_2,\lambda_1}, \quad \mathbf{P}\,\mathbf{F_i} = \pm\,\mathbf{F_i}$$

$$F_1, F_3 \leftrightarrow \eta = +1 \ \ (\rho, \omega, \dots), \quad F_2, F_4 \leftrightarrow \eta = -1 \ \ (\pi, b_1, \dots)$$

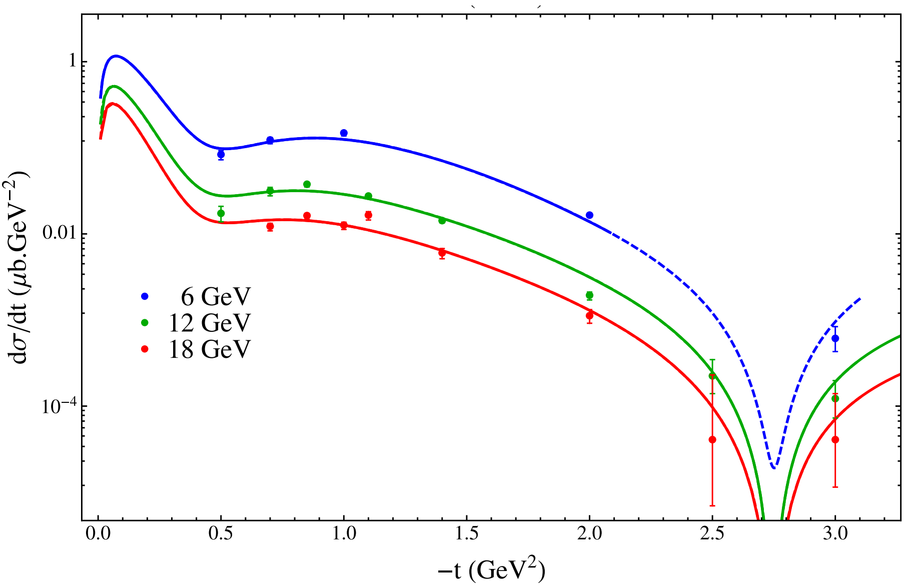
$$|\mathrm{Amp}|^2 \propto \frac{\mathrm{d}\sigma}{\mathrm{d}\mathbf{t}} \xrightarrow{s \text{ large}} \frac{1}{32\pi}\left[\underbrace{\frac{|F_3|^2 - t|F_1|^2}{4m_N^2 - t}}_{\rho,\omega,\dots} + \underbrace{|F_2|^2 - t|F_4|^2}_{\pi,b_1,\dots}\right]$$

$$\boldsymbol{\Sigma} = \frac{\sigma_\perp - \sigma_\parallel}{\sigma_\perp + \sigma_\parallel} \xrightarrow{s \text{ large}} \frac{(\rho,\omega,\dots) - (\pi, b_1,\dots)}{(\rho,\omega,\dots) + (\pi, b_1,\dots)}$$

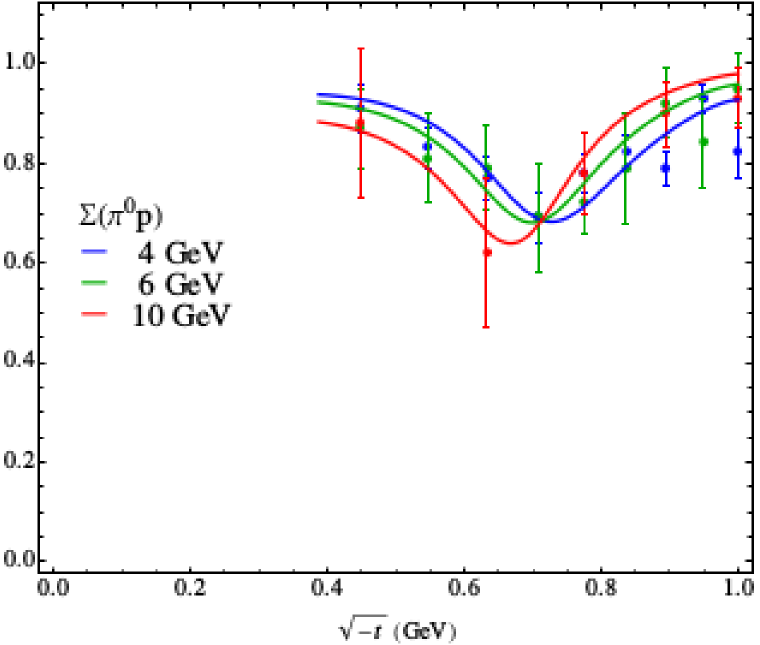
t-channel helicity amplitudes:
relate observables and **naturality** of exchanges!

And what do we learn from the **s-channel**?

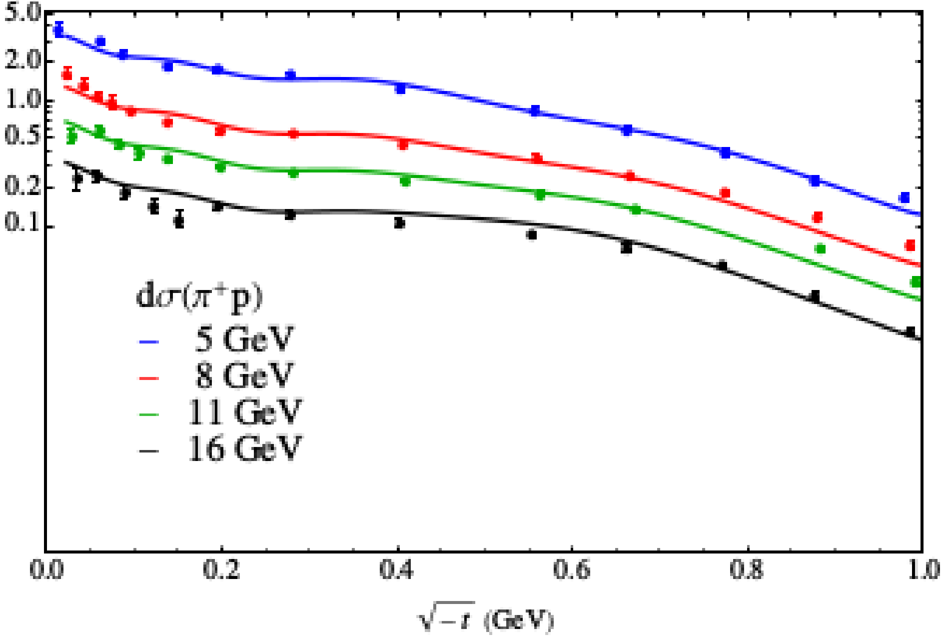
From factorization:
helicity-flip amplitudes go with $\sqrt{-\mathbf{t}}$!



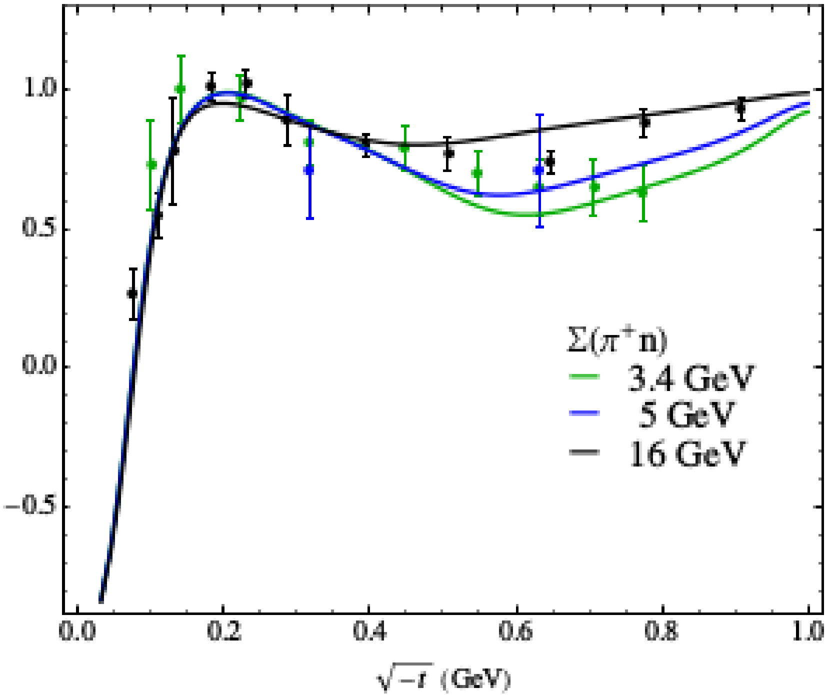
1
0.01
10^{-4}
0.0
0.5
1.0
1.5
2.0
2.5
3.0
$d\sigma/dt$ (μb.GeV^{-2})
$-t$ (GeV^2)
6 GeV
12 GeV
18 GeV

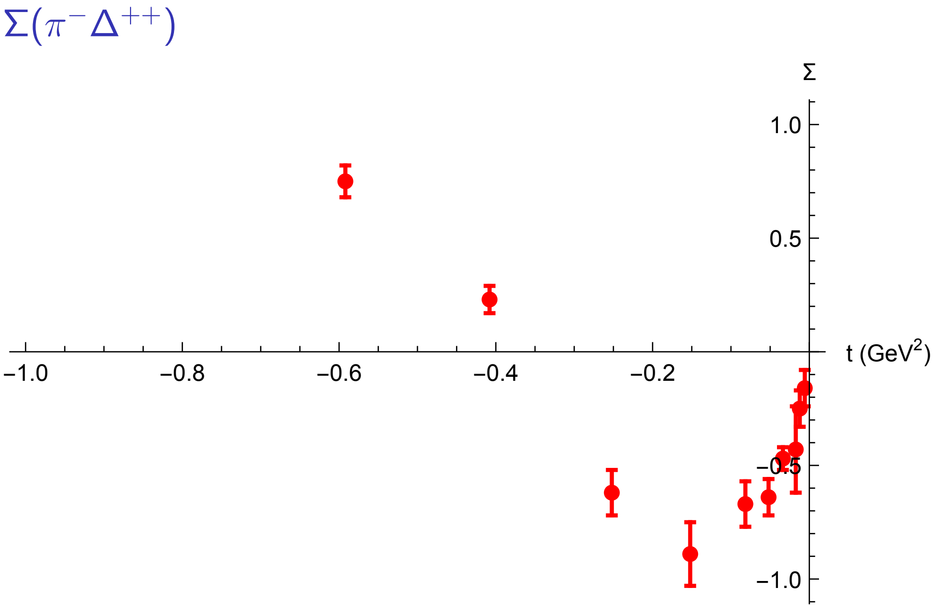


Σ(π⁰p)
4 GeV
6 GeV
10 GeV
0.0
0.2
0.4
0.6
0.8
1.0
√−t (GeV)



5.0
2.0
1.0
0.5
0.2
0.1
$d\sigma(\pi^+p)$
5 GeV
8 GeV
11 GeV
16 GeV
0.0
0.2
0.4
0.6
0.8
1.0
$\sqrt{-t}$ (GeV)


1.0
0.5
0.0
−0.5
0.0
0.2
0.4
0.6
0.8
1.0
$\sqrt{-t}$ (GeV)
$\Sigma(\pi^+ n)$
3.4 GeV
5 GeV
16 GeV



$\Sigma(\pi^- \Delta^{++})$
Σ
1.0
0.5
−0.5
−1.0
t (GeV^2)
−1.0
−0.8
−0.6
−0.4
−0.2