On slope parameter increase and energy dependence of spin effects

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Direct-channel option of the forward slope increase
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Spin Experimentation with Unpolarized Colliding Beams at the LHC
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Symmetry 13 (2021) 10, 1886

Overview

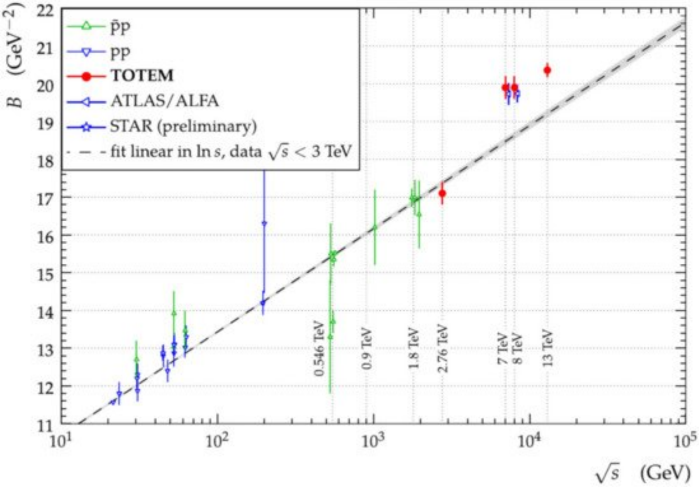
Abstracts

The LHC data on the elastic scattering indicate that the forward slope increase is not consistent with the contributions of the simple Regge poles only with the linear Regge trajectories. The dynamics might be associated with unitarization in the direct channel of reaction. We discuss the problems of the Regge model and provide a respective illustration of the direct–channel option.

Brief recollection of the problems related to a significant hyperon polarization observed in pp–collisions is given with emphasize on the general role of spin in dynamics of hadron interactions. The old, unsolved problem of a significant hyperon polarization observation, can obtain a new insight from the measurements at the LHC energies and, in combination with other measurements, can be used for tagging QGP formation in *pp*–collisions with colliding beams. Polarization studies in the hyperon production processes do not require use of polarized beams or targets and can be performed under existing experimental environment at the LHC. Model predictions based on the chiral dynamics and impact parameter picture are presented for the illustration of the possible dynamical mechanism leading to a hyperon polarization.

Energy dependence of slope parameter

$$B(s) \equiv \frac{d}{dt} \ln \frac{d\sigma}{dt}|_{t=0} \quad (1)$$



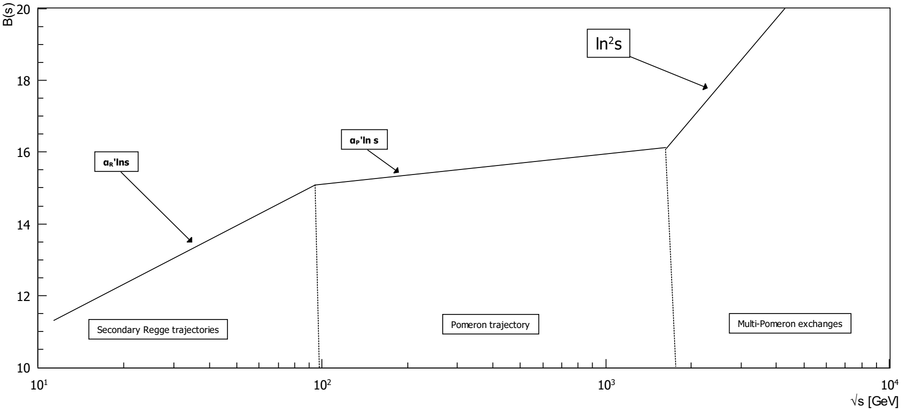


Figure: Three regimes of the energy dependence of the diffraction cone slope parameter $B(s)$ in the Regge-pole model amended with contribution of multi–Pomeron exchanges at the LHC energy range.

$$B(s) = B_0 + 2\alpha'_R(0)\ln s$$

$$\alpha'_R(0)/\alpha'_P(0) \simeq 4$$

.

$$B(s) = B_0 + A\ln s + C\ln^2 s \quad (2)$$

$$A \leq 0,$$

The energy range between CERN ISR and the LHC should be thoroughly scanned experimentally with higher statistics without an assumption on the approximate equality of pp and $\bar{p}p$ diffraction cone parameters.
Use of an approach supposing an alternative origin of the diffraction cone slope $B(s)$ growth due to unitarization of an nput amplitude in the direct channel.

Unitarization

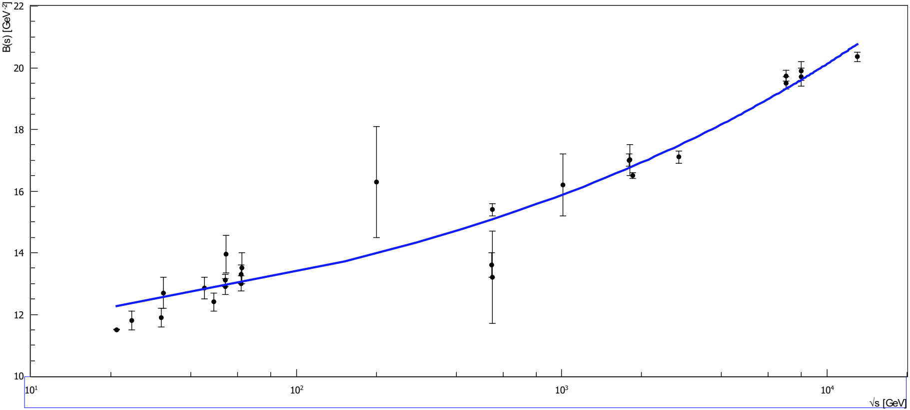


Figure:

$$B(s) = B_0 + As^{\lambda_{eff}}. \quad (3)$$

$$f(s,b)=u(s,b)/[1+u(s,b)]. \quad (4)$$

$$u(s,b)=f(s,b)/[1-f(s,b)]. \quad (5)$$

$$f(s,b)\simeq g(s)\exp(-\mu b)$$

and

$$g(s)\sim s^{\lambda}. \quad (6)$$

Polarization of Λ: experimental facts

A very significant polarization of Λ–hyperons has been discovered more than 40 years ago in

$$pp \to \Lambda X$$

.

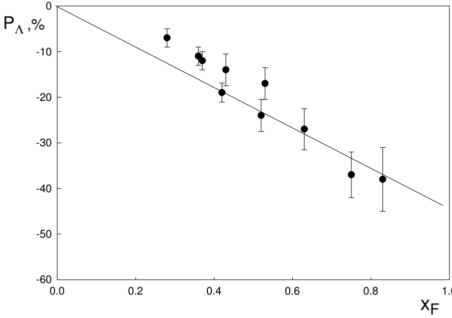
Λ polarization direction along

$$\hat{\vec{n}} = \frac{\vec{p}_b \times \vec{p}_\Lambda}{|\vec{p}_b \times \vec{p}_\Lambda|}$$

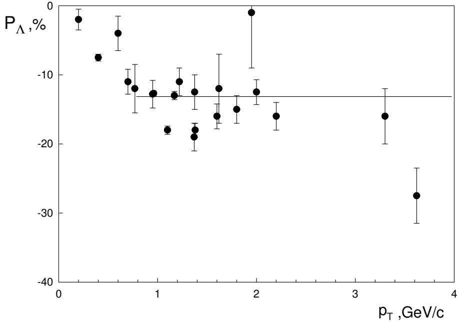
of the beam momentum $\vec{p}_b$ and $\vec{p}_\Lambda$ (momentum of Λ) . It is extracted from

$$1 + \alpha_\Lambda P_\Lambda \cos\theta_p,$$

angular distribution of weak decay of Λ into p and π^- .



P_Λ,%
0
-10
-20
-30
-40
-50
-60
0.0
0.2
0.4
0.6
0.8
1.0
x_F



P_Λ,%
0
-10
-20
-30
-40
0
1
2
3
4
p_T ,GeV/c

Prediction of perturbative QCD

Perturbative QCD with the collinear factorization scheme: vanishing Λ–polarization at high $p_\perp$. The higher twists contributions inclusion allows one to obtain higher values for polarization but does not change qualitative dependence $p_\perp^{-1}$ predicted for the region of large transverse momenta (s–channel helicity conservation).

QCD Lagrangian ($N_f = 3$): $SU(3)_L \times SU(3)_R$ (chiral)
QCD interactions are the same for left and right quarks

$$\bar{\psi}\gamma_\mu\psi A^\mu = \bar{\psi}_L\gamma_\mu\psi_L A^\mu + \bar{\psi}_R\gamma_\mu\psi_R A^\mu$$

If $m > 0$

$$\psi_{1/2} = \psi_R + O(\frac{m}{\sqrt{\hat{s}}})\psi_L,\ \psi_{-1/2} = \psi_L + O(\frac{m}{\sqrt{\hat{s}}})\psi_R$$

$$P_q \sim \frac{\alpha_s m_q}{\sqrt{\hat{s}}},\ \sqrt{\hat{s}} \sim p_\perp$$

PQCD vs spin experiments

It is difficult to reconcile such decreasing dependence with the flat one observed in the data. Inclusion of the parton internal transverse momenta ($k_\perp$–effects) into the polarizing fragmentation functions leads also to decreasing trend of polarization. It allows to change the scale of polarization decrease only.

$$pp \to \pi^0 X : \; p_\perp^{max} \simeq 10 \, GeV/c$$

A_N – positive and flat (RHIC)

Flat transverse momentum dependence of the single–spin asymmetry in inclusive neutral pion production

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Phys.Rev. D 88, 017502 (2013).

Strange quark polarization

Simple quark model: the u- and d-quarks in Λ are coupled to S=0, I=0 diquark. Strange quark polarization which is responsible for the transverse polarization of Λ. Mechanism of Thomas precession and Lund model. The both explanations are semiclassical.

Semiclassical mechanism based on chiral spin filtering. The colliding particles (protons) in the collider mode are unpolarized. Filtering of the two initial spin states due to a different strength of interactions. Constituent quark $Q_\uparrow$ with transverse spin lined in up-direction can fluctuate into Goldstone boson and another constituent quark $Q'_\downarrow$ with spin lined in opposite direction performing a spin-flip transition:

$$Q_\uparrow \to GB + Q'_\downarrow \to Q + \bar{Q}' + Q'_\downarrow. \tag{7}$$

To compensate quark spin flip δS an orbital angular momentum $\delta L = -\delta S$ should be generated in the final state of reaction (7). The presence of this orbital momentum δL in its turn means a certain shift in the impact parameter value of the final quark $Q'_\downarrow$ (which in its turn is transmitted to the shift in the impact parameter of Λ)

$$\delta S \Rightarrow \delta L \Rightarrow \delta b_{Q'}.$$

Due to different strengths of interaction at the different values of the impact parameter, the processes of transition to the spin up and down states will have different probabilities which leads eventually to nonzero polarization of Λ.

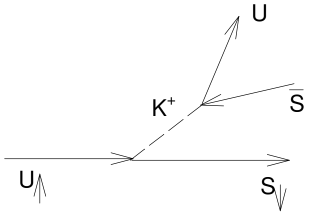

Figure: Transition of the spin-up constituent quark U to the spin-down strange quark.

In the case of Λ–polarization, the relevant transitions of constituent quark U (cf. Fig. 1) is correlated with the shifts δb_S in impact parameter b_S of the final strange quark, i.e.:

$$\begin{aligned} U_\uparrow &\to K^+ + S_\downarrow \Rightarrow -\delta \mathrm{b}_S \\ U_\downarrow &\to K^+ + S_\uparrow \Rightarrow +\delta \mathrm{b}_S. \end{aligned} \quad (8)$$

Relations (8) clarify the mechanism of spin states filtering: i.e. when shift in impact parameter is $-\delta \mathrm{b}_S$ the interaction is stronger compared to the case when shift is $+\delta \mathrm{b}_S$, and the final S-quark (and Λ-hyperon) becomes negatively polarized. The considered mechanism of the spin states filtering is proposed to be associated with the emission of Goldstone bosons by the constituent quarks.