Increasing effective intensity of soft strong interactions

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Overview

Abstract

- We suggest definition of effective interaction intensity for soft hadron collisions and discuss its energy dependence in the preasymptotic region. Practical importance of this quantity consists in separation of rising interaction radius from effective interaction intensity increase both contributing to the total cross–section growth. It would be helpful for understanding the origin of this growth at the accelerator energies. The essential feature is that the effective interaction intensity is an experimentally measurable quantity.

Introduction. The interaction intensity

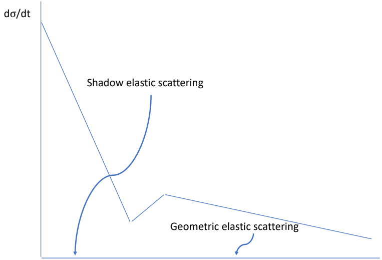


Figure: Two regions of transferred momenta $-t$ (relevant for shadow and geometric elastic scattering) in $d\sigma/dt$ at the LHC energies. The size of shadow scattering region diminishes with energy (decoupling of elastic scattering from multiparticle production) and tends to zero at $s \to \infty$.

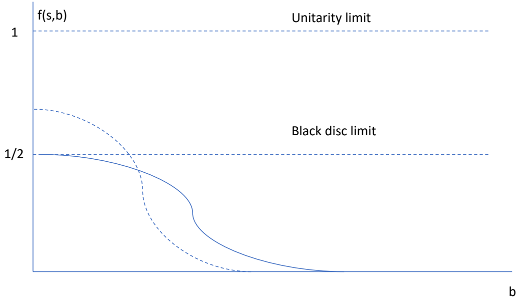


Figure: Schematical impact-parameter dependence of the amplitude $f(s,b)$ in the two cases of fully absorptive scattering (solid line) and partial transition to reflective scattering (dashed line) at the LHC highest energy.

- $$Y(s) \equiv \sigma_{tot}(s)/16\pi B(s), \quad (1)$$
- $$B(s) \equiv \frac{d}{dt} \ln \frac{d\sigma}{dt}|_{t=0} \quad (2)$$
- $$X(s) \equiv \sigma_{el}(s)/\sigma_{tot}(s), \quad (3)$$
- $$Z(s) \equiv X(s)Y(s) = \sigma_{el}(s)/16\pi B(s). \quad (4)$$

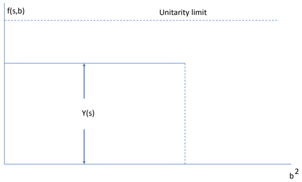


Figure: Illustration of the effective interaction intensity notion.

QCD–inspired asymptotics and $Y(s)$.

Hints for possible asymptotic values of the function $Y(s)$ at $s \to \infty$ can be invoked from general features of QCD. There are two important phenomena in this regime of QCD: confinement and spontaneous chiral symmetry breaking with the respective scales Λ_{QCD} and Λ_χ.

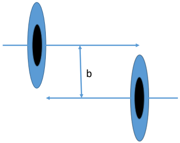


Figure: Two–components' protons scattering at the impact parameter b.

Effective interaction intensity

- Unitarity relation can be written in the following form:

$$h_{tot}(s,b) = h_{el}(s,b) + h_{inel}(s,b), \quad (5)$$

$$H_i(s,t) = \sigma_i(s)[1 + \frac{1}{4}\langle b^2\rangle_i(s)t + ...], \quad (6)$$

- $$\langle b^2\rangle_i(s) = \frac{\int_0^\infty b^2 h_i(s,b)bdb}{\int_0^\infty h_i(s,b)bdb}, \quad (7)$$

  they are interrelated due to unitarity

$$\langle b^2\rangle_{tot}(s) = \frac{\sigma_{el}(s)}{\sigma_{tot}(s)}\langle b^2\rangle_{el}(s) + \frac{\sigma_{inel}(s)}{\sigma_{tot}(s)}\langle b^2\rangle_{inel}(s). \quad (8)$$

- $$\sqrt{\langle b^2\rangle_{el}(s)} < \sqrt{\langle b^2\rangle_{tot}(s)} < \sqrt{\langle b^2\rangle_{inel}(s)}. \quad (9)$$
- $B_{tot}(s) = \langle b^2\rangle_{tot}(s)/2$, the function $Y(s)$ can be presented in the following form:

$$Y(s) = \int_0^\infty f(s,b)bdb/\langle b^2\rangle_{tot}(s). \quad (10)$$

$$Y(s) < f(s,b=0). \quad (11)$$

Upper limits for the functions $X(s)$, $Y(s)$ provided by unitarity:

$$X(s) \le 1, Y(s) \le 1. \quad (12)$$

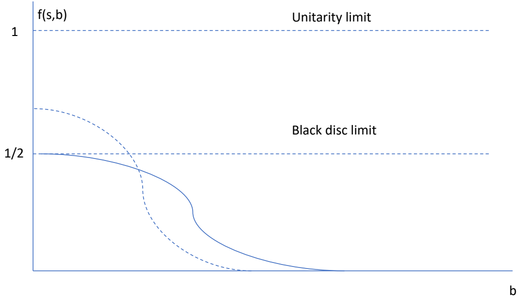
$$dZ(s)/ds = Y(s)dX(s)/ds + X(s)dY(s)/ds \quad (13)$$

$$dZ(s)/ds \simeq 2Y(s)dY(s)/ds. \quad (14)$$

$$dZ(s)/ds \simeq 0.6dY(s)/ds. \quad (15)$$

Consequences of reflective scattering

$$(f - 1/2)^2 = 1/4 - h_{inel} \simeq 0 \quad (16)$$



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Reflective scattering

- $f(s,b)$: interval $0 \leq f \leq 1$, $f = 1/2$ – complete absorption of the initial state, i.e. $S = 0$
  $h_{el} \leq 1$, $h_{inel} \leq 1/4$.
  Absorptive scattering mode – $0 < f \leq 1/2$, reflective scattering mode $1/2 < f \leq 1$.
- Saturation of the black disc limit leads to the following limiting behavior of the functions: $X, Y \to 1/2$ and $Z \to 1/4$ at $s \to \infty$

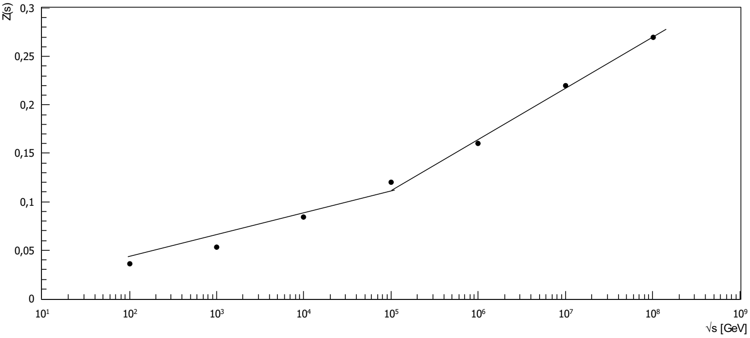

Figure: Extrapolation of the energy dependence of the function $Z(s)$ for the reflective scattering mode.

$Z(s)$ crosses the black disk limit 1/4 at around $\sqrt{s} \simeq 10^8$ GeV.

Separating out the role of interaction radius

Simplified geometrical analogy when the effective total cross–section is proportional to the squared interaction radius, $\sigma_{tot} \propto R^2$, should be corrected. This proportionality has nothing to do with the actual data obtained at the LHC but can only be accepted at the energies when the effective interaction intensity $Y(s)$ does not depend on s.
It follows from a nontrivial energy dependence of $Y(s)$ and representation of the total cross–section in the form

$$\sigma_{tot}(s) = 16\pi Y(s)B(s).$$

Indeed, the effective interaction intensity measured experimentally increases by more than 50% when $\sqrt{s}$ increases from 10^2 to 10^4 GeV.

Conclusion

- Such a definition is useful for a description of interactions at large distances since soft hadron collisions provide a major contribution to the effective total cross–section.
- The proposed discrimination of the scattering modes based on the effective interaction intensity is a less sensitive method than the straightforward reconstruction of the scattering amplitude $f(s, b)$, but on the other hand it does not require of additional assumptions.
- Detecting manifestations of asymptotics is essential for studies of hadron interaction dynamics. An expected asymptotic form of the scattering amplitude could correlate with general features of a particular dynamics pointing out to its stochastic or coherent nature.