Centrality in hadron collisions

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Overview

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Abstract

- In hadron interactions at the LHC energies, the reflective scattering mode starts to play a noticeable role which is expected to be even a more significant beyond the energies of the LHC. This new but still arguable phenomenon implies a peripheral dependence of the inelastic probability distribution in the impact parameter space and asymptotically evolving to the black ring. As a consequence, the straightforward extension to hadrons of the centrality definition adopted for nuclei needs to be modified.

Centrality in collisions of nuclei

- The centrality is a commonly accepted variable for description and classification of the collision events in the nuclei interactions. This variable is related to the assumed initial–state collision geometry and is given by an impact parameter value associated with the general geometrical characteristics assigned to the particular collision event
- Definition

$$c_b^A \equiv \frac{\sigma_{inel}^b}{\sigma_{inel}}, \tag{1}$$

$$\sigma_{inel}^b = \int_0^b P_{inel}^A(b') 2\pi b' db$$

- In experiment

$$c^A(n) \equiv \int_n^\infty P^A(n') dn', \tag{2}$$

$P_A(n')$ is the probability for the quantity n have the value n'.

Proposal for hadrons

Use a full probability distribution $P^h_{tot}(s,b)$ in order to take into account the elastic events. The neglect of the elastic events would lead to incorrect estimation of centrality for the hadron collision. For the centrality $c^h_b(s,b)$ the following definition is suggested

$$c^h_b(s,b) \equiv \frac{\sigma^b_{tot}(s)}{\sigma_{tot}(s)}, \tag{3}$$

where

$$\sigma^b_{tot}(s) = 8\pi \int_0^b \mathrm{Im} f(s,b')b'db'$$

is the impact–parameter dependent cumulative contribution into the total cross–section, $\sigma^b_{tot}(s) \to \sigma_{tot}(s)$ at $b \to \infty$. The function $\mathrm{Im} f(s,b)$ always has a central impact parameter profile. Several papers indicate that $\mathrm{Im} f(s,b) > 1/2$ at $b = 0$. The amplitude $f(s,b)$ is the Fourier–Bessel transform of the scattering amplitude $F(s,t)$.

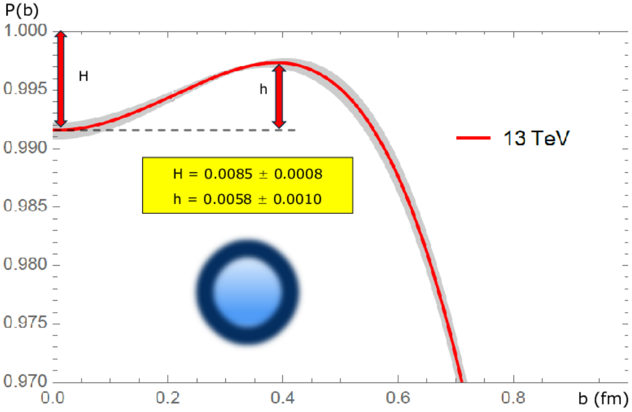

Figure: "Proton structure and hollowness from Levy imaging of pp elastic scattering", T. Csorgo, R. Pasechnik, A. Ster, arXiv:1910.08817v1, Oct 19, 2019.

Inversed relation

The inverted relation:

$$\mathrm{Im} f(s,b) = \frac{\sigma_{tot}(s)}{8\pi b}\frac{\partial c_b^h(s,b)}{\partial b} \tag{4}$$

The impact parameter representation provides a simple semiclassical picture of hadron scattering, e.g. head–on or central collisions correspond to small impact parameter values. Inequalities:

$$0 \le \frac{\partial c_b^h(s,b)}{\partial b} \le \frac{8\pi b}{\sigma_{tot}(s)} \tag{5}$$

and in the integral form

$$0 \le c_b^h(s,b) \le \frac{4\pi b^2}{\sigma_{tot}(s)} \tag{6}$$

for $b \le r(s)$, $r(s) \sim 1/\mu \ln s$, where $S(s, b = r(s)) = 0$, $s > s_r$ and μ is determined by mass of pion.

Experimental possibility

Now we would like to comment on the experimental possibility of centrality measurements in hadron collisions. For that purpose using transverse energy deposited in a calorimeter seems to be a rather universal method since it includes the case of unitarity saturation, i.e. it is supposed to determine centrality $c^h_{exp}(E_T)$ as a cumulative distribution over transverse energy using definition:

$$c^h_{exp}(E_T) = \int_{E_T}^{\infty} P(E'_T)dE'_T, \qquad (7)$$

where $P(E_T)$ is the the probability distribution of E_T (with inclusion of elastic events) measured experimentally.

Experimental possibility

In the experimental measurements a range of centrality values of $c^h_{exp}(E_T)$ corresponds to a fixed value of b and to reconstruct centrality $c^h_b(s,b)$ from the measured experimentally, c^h_{exp}, one needs to exploit certain probability distributions of E_T for fixed b, $P(E_T|b)$ and rewrite $P(E_T)$ as

$$\int_0^\infty P(E_T|b)P_{tot}(b)db, \qquad (8)$$

where (according to the above discussion) probability $P_{tot}(b)$ includes probabilities of elastic and inelastic hadron interactions.
It should also be noted that one could expect an increase of the elastic events contribution into centrality with energy. This conclusion is correlated with expectation of the slow down of the energy dependence of the mean multiplicity and increasing ratio of the elastic to total cross–sections observed at the LHC.

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