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Working group report: Quantum chromodynamics (QCD) and hadronic structure

Coordinators: RAHUL BASU[1] and V RAVINDRAN[2]

Working Group Members: D Choudhury[2], R Gavai[3], S Gupta[3], R Basu[1], J P Singh[4], Swapan K Majhi[2], B P Mahapatra[5], Prakash Mathews[6], Rajarshi Ray[7], D Chakrabarti[8], V Ravindran[2] and Pijush Bhattacharjee[9]

[1]Institute of Mathematical Sciences, Chennai
[2]Harish-Chandra Research Institute, Allahabad
[3]Tata Institute of Fundamental Research, Mumbai
[4]Baroda University, Baroda
[5]Sambalpur University, Sambalpur
[6]University of Hyderabad, Hyderabad
[7]Institute of Physics, Bhubaneshwar
[8]Saha Institute of Nuclear Physics, Kolkata
[9]Indian Institute of Astrophysics, Bangalore

Abstract. We discuss potential problems in hadronic physics. Recent developments are reviewed and possible future studies in some interesting areas which are underway are highlighted.

Keywords. Quantum chromodynamics; perturbative; non-perturbative; quark gluon plasma.

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1. Introduction

Quantum chromodynamics (QCD), the theory of strong interaction physics has been well established both theoretically as well as experimentally. Strong interaction physics through QCD plays an important role in various scattering experiments where hadrons participate either in the initial states (i.e., deep inelastic scattering, hadron–hadron collisions) or in the final states (i.e., electron–positron $\rightarrow$ hadrons). In terms of QCD we now have better understanding of the structure of hadrons at very high energies, thanks to various ingenious experiments and tedious computations using QCD. Good understanding of hadron dynamics through QCD will have impact in the understanding of the discovery of new particles and its properties. The experiments involving heavy nuclei (heavy ion collisions) can unravel the existense of a new phase of the matter called quark gluon plasma (QGP). The properties of such a plasma are not fully understood. The signals for the QGP will be important for discovering such a QGP phase of matter.

2. Strangeness enhancement and equilibration in heavy-ion collisions

Rajarshi Ray

In the QGP phase strangeness production has lower threshold energy than that in the hadronic phase. Again, due to large gluon density strangeness equilibration would also be much efficient in the QGP phase than in the hadronic phase. Thus an overall enhancement of strangeness (more importantly of multistrange baryons) together with chemical equilibration of secondaries is an important test of QGP formation in heavy-ion collision experiments.

Experimental data already points to the enhancement of strangeness from p–p, p–A to A–A collisions (K Redlich, *Nucl. Phys.* **A698**, 94 (2002)). However, a detailed understanding is required to establish the mechanism of this enhancement. Statistical thermal models seem to fit the experimental data for strangeness enhancement and particle yield ratios very well (P Braun-Munzinger *et al*, *Phys. Lett.* **B465**, 15 (1999); F Becattini *et al*, *Phys. Rev.* **C64**, 024901 (2001)). In these models, for higher energies a grand-canonical ensemble is assumed with temperature (T), chemical potentials for baryon number (μ_{B}) and strangeness (μ_{s}) as free parameters, to be fixed by fitting with experimental yield ratios. For lower energies at AGS and SIS a canonical approach is found to be more appropriate. The T–μ_{B} values from these fits seem to fall on the $\langle E\rangle/\langle N\rangle \simeq 1$ GeV curve. It has been observed that as one goes from a canonical to grand-canonical description following lower to higher energies, strangeness enhancement occurs routinely due to enhanced available phase space. However, recent experimental data at SPS and relativistic heavy-ion collider (RHIC) at very high energies seem to point out departure from the monotonic behavior of the thermal model. These have to be analyzed further to come out with a confident statement of strangeness enhancement as a signature of QGP formation. Work along this line is underway.

3. NLO QCD correction to UHE neutrino proton scattering

Rahul Basu, Debajyoti Choudhury and Swapan Kumar Majhi

The issue of NLO (order α_s) corrections to ultra high energy neutrino scattering against matter (protons) is a long standing one. It has generally been assumed that the effect of NLO is small compared to the LO result.

However the situation is somewhat more complex than that. At the energies at which these corrections are calculated (10^{11} GeV) while the strong coupling is small, the parton distribution functions for the gluon (which is the dominating contributing parton at these energies) is very large because of the extremely small value of Bjorken x (10^{-8}). In addition there are issues of saturation of the densities setting in at such small values of Bjorken x due to large parton densities.

A careful calculation of the NLO contribution has been undertaken, keeping all these issues in mind.

4. Probing QCD at ultra high energies (UHE) using UHE cosmic rays

Rahul Basu and Pijush Bhattacharjee

Extremely high energy cosmic rays (EECR) with energy $E > 10^{11}$ GeV have been detected which are difficult to explain within the standard scenarios of the origin of CR based on particle accelerators in powerful astrophysical objects. One of the resolutions of this problem is to use the 'top-down' scenarios in which the EECR particles arise simply from decay of some supermassive 'X' particles of mass $> 10^{11}$.

In the bottom-up approach, one starts with the measured hadronic spectrum as a given low Q^2 and evolves the fragmentation functions (FF) to the relevant Q^2 using DGLAP evolution. However, for very low values of the z of the fragmentation parameter, one expects modifications in standard DGLAP evolution for the FF. Since the mass M_X could be as large as 10^{16} GeV and we are interested in the spectrum of hadrons down to 10^{10} GeV, one is really interested therefore in the parameter z in the range of 10^{-6}. One would like to see if one can formulate a judicious matching scheme that would relate the results at large z to those at small z.

5. QCD and tools

P Mathews and V Ravindran

The future collider experiments such as LHC, Tevetron and linear collider not only have discovery potential but also have impact on the precision study. One can get useful information from these experiments provided all the theoretical uncertainties are under control. The theoretical uncertainties could come from the non-perturbative part of QCD which is not completely under control and also from the fixed order perturbative results which are sensitive to large logarithms of the scales involved. The parton distribution functions which enter in the cross sections are purely non-perturbative in nature, though their evolution is perturbatively known. Various parameterizations of these parton distribution functions are available in the literature. Since these high energy experiments will probe the regions of parton momenta which have never been probed, one should have estimates of uncertainties due to extrapolation of these densities in those regions. Similarly, higher order computations are essential in order to reduce uncertainties coming from the scale dependence. As we know, large logs appear in the perturbative computations in QCD. These will eventually go away to all orders. So fixed order computations do always suffer the scale dependence. In the inclusive processes, there are two types of scales which enter, viz., renormalization scale and factorization scale. The renormalization scale appears due to the renormalization of the strong coupling constant. The other scale called factorization scale appears when one is dealing with massless partons. These appear due to collinear divergences which are removed by the redefinition of parton densities at some arbitrary factorization scale. The dependence on these scales can be reduced by computing sufficiently higher order corrections. In addition to these uncertainties, one encounters dependence due to various renormalization and factorization schemes. The factorization scheme dependence will go away order by order provided the evolution of non-perturbative parton distribution functions are also known in the same factorization scheme. But the renormalization scheme dependence does not disappear in a fixed order computations. Unless, these uncertainties are under control, the discovery or precision measurements will have good impact on our understanding of physics. In this context, computation of higher order corrections to various processes contributing to the hadronic cross sections are essential. This involves developing and/or utilizing existing theoretical tools to perform these computations. Since these computations involve the computation of several hundreds of Feynman diagrams, a complete automation is essential.