Brief report on BRNS funded PROJECT

(This part should be uploaded as a word file. Please delete the fileds which are not applicable)

Sanction Number: 2012/37P/36/BRNS/2018
Mode of Execution: MoU / CRP / RP / YSRA
Date of Start: 24.11.2012
Date of Completion: 31.03.2015 (actual completion 31.03.2016)
Total Amount Sanctioned (in Lakhs): Rs. 16,31,000/-
Amount Received (in Lakhs with date): 1st year : Rs. 5,28,800/- date:22.03.2013
2nd year: Rs. 4,22,722/- date:01.07.2014
3rd year : NIL
Institutes involved in case of MoU/CRP
Category: Facility Development / Product Development / Technology Demonstration/ Applied Research/ Conceptual/Exploratory/ Survey/Others
Title: Studies on F_L and xF_3 structure functions of hadrons in lepton-nucleon scattering and related nuclear effects
Name of PI & Affiliation: Dr. Mrinal Kumar Das, Department of Physics Tezpur University
Napam – 784028, Tezpur, Assam
Name of CI & Affiliation: Prof. Jayanta Kumar Sarma, Department of Physics Tezpur University
Napam – 784028, Tezpur, Assam

Name of major Equipments procured and their cost :
1. One HP/HP Pro 6300MT desktop with Core i5 processor Rs. 44,100.00/-
2. One Offline UPS 1000VA, 20 min backup Rs. 3,121.00/-
Present working status of the Equipment: good
Number of other users & their affiliation and % use by others
Details of the High cost consumables used
Patent with brief description
Number of Journal Publications with impact factor (attach list as Annex- I):
Number of staff trained under this project: two
List of Objectives as mentioned in original proposal :
(List accomplishments/ short falls against each of the objectives)

List of objectives for (a) Longitudinal structure function F_L and (b) Neutrino structure function xF_3:

(a) Longitudinal structure function F_L

1. To Study different evolution equations in Quantum Chromodynamics describing longitudinal structure function F_L of hadron.
2. To solve the Dokshitzer-Gribov-Lipatov-Alterelli-Parisi (DGLAP) evolution equation for F_L structure function in leading and higher orders.
3. To study the solutions of other QCD evolution equations for F_L structure function.
4. To study phenomenologically the solutions for F_L structure function in different evolution equations and their comparisons.
5. To study the various nuclear effects like EMC, Fermi motion, shadowing, anti-shadowing etc. in longitudinal structure function F_L with different models and sum rules.
6. To study Phenomenologically the behaviour of the spin-dependent longitudinal structure function if time permits.

(b) Neutrino structure function xF_3

1. To study the theories of neutrino interactions with nucleon and nucleus.

2. To solve the Dokshitzer-Gribov-Lipatov-Altarelli-Parisi (DGLAP) evolution equation in leading and higher orders for neutrino structure function $xF_3(x, Q^2)$.
3. To study phenomenologically the solutions of DGLAP evolution equation for neutrino structure function $xF_3(x, Q^2)$ using recent experimental data.
4. To study various nuclear effects like EMC, Fermi motion, shadowing, anti-shadowing etc. in neutrino structure function $xF_3(x, Q^2)$ with different models and sum rules.
5. To study phenomenologically the behaviour of the spin-dependent neutrino structure functions if time permits.

Accomplishments of the projects in 3 to 4 bullets:

1. Calculation of the evolutions of longitudinal structure function F_L from QCD evolution equation in next-to-leading order (NLO) at small values of Bjorken variable, x using the regge like behaviour of the structure function.
2. Solution of the Dokshitzer-Gribov-Lipatov-Altarelli-Parisi (DGLAP) evolution equation in leading and higher order for the neutrino structure function $xF_3(x,Q^2)$.
3. Study of the behaviour of longitudinal structure function F_L with respect to Bjorken variable x and Q^2, the squared four-momentum transfer between lepton and nucleon in next-next-to-leading order (NNLO) at small-x using the regge like behaviour of the gluon distribution function.
4. Study the behaviour of non-singlet structure function F_2^{NS} and xF_3 with respect to x and Q^2, in next-next-to-leading order (NNLO) at small-x using the regge theory.

Summary in about 300 words (which is understandable by general scientific fraternity) bringing out the novelty of the work :

In order to understand the underlying theory of strong interaction, DIS (deep inelastic scattering) structure functions are the objects of intensive investigation both theoretically and experimentally. Current developments of sincere experimental facilities let one to measure the structure functions with far greater precision than before. On the other hand there are several theoretical approaches such as Regge theory , QCD etc. for describing the strong interaction process observed at high energy particle colliders.

DGLAP evolution equation developed within perturbative QCD(PQCD) formalism is found to be the standard and the most widespread for the theoretical investigation of DIS structure function. Although in PQCD, the structure functions are predicted in accordance with the DGLAP equations, predictive power of DGLAP equation is limited. Usually structure functions from DGLAP evolution equations are determined by considering an initial distribution of the structure function at a fixed Q^2, which is characterized by some free parameters and the parameters are found by fitting the parameterization with the available experimental data. This need of initial distribution at fixed Q^2 can be obtained from Regge theory. To find the initial distribution of structure functions, although many parameterizations are available in previous works, most of them are with several parameters which creates difficulties in obtaining best fitting which in turn leads towards the inaccuracy in results. To get rid of this inefficacy , we investigated the usefulness of a simple Regge-inspired model as the initial input to DGLAP equation with less number of parameters to compute the structure function.

We have done phenomenological analysis in comparison with different results taken from NMC, NuTeV , CORUS,CDHSW,NNPDF and MSTW collaborations. It has been seen that a very good agreement between the theoretical and experimental results within the considered kinematical range $x \leq 0.045$ and $Q^2 \leq 20.0$ GeV^2 exists.

3. **Whether any of the staff has submitted/ been awarded research degree on the basis of work carried out on the project. If so, degree and title of thereon and year of submission/ award.**

One of the project staff, Ms. Nomita Baruah, submitted her Doctoral thesis, some portion of which is based on the work done under this project.
Title of the Thesis: Studies on longitudinal structure function F_L of proton at small-x.

Degree: **Ph.D.** in the year 2015.

4. Details of the work done in the project within the last three financial years (2013-2016)

Done in 2013-14:

1. Recruitment of JRF
2. Bought "One HP Pro 6300MT desktop with Core i5 processor" and installed
3. Bought "One Offline 1000VA LI DS UPS system" and installed
4. Started literature survey
5. Study of Quantum Chromodynamics (QCD) evolution equations describing the behaviour of F_L and xF_3 structure functions of hadron.
6. Attended and presented paper in International conference at Jammu University during 9th to 14th Sept 2013.
7. Published research paper in peer-reviewed journal.

Done in 2014-15:

1. Study the behaviour of longitudinal structure function F_L with respect to Bjorken variable x and Q^2, the squared four-momentum transfer between lepton and nucleon in next-next-to-leading order (NNLO) at small-x using the regge like behaviour of the gluon distribution function.
2. Study the behaviour of non-singlet structure function F_2^{NS} and xF_3 with respect to x and Q^2, in next-next-to-leading order (NNLO) at small-x using the regge theory.
3. Published research papers in peer-reviewed journal.

Done in 2015-16:

1. Study the behaviour of longitudinal and heavy flavour structure functions with respect to Bjorken variable x using Taylor series expansion method at small-x.
2. Studied various nuclear effects like Fermi motion, shadowing, anti-shadowing etc. in neutrino structure function $xF_3(x, Q^2)$ with different models and sum rules.
3. Published research papers in peer-reviewed journal.

Research work:

Longitudinal structure function F_L:

The proton longitudinal structure function F_L, measured in deep inelastic lepton nucleon scattering (DIS) experiment, is one of the important observables to study. F_L is a very sensitive quantum chromodynamics (QCD) characteristic as it is directly sensitive to the gluon density in the proton. In the

naive quark parton model (QPM), the F_l structure function is zero since the spin $\frac{1}{2}$ quarks do not couple to the longitudinally polarized virtual photon. On the other hand, in the QCD improved parton model, it is non zero, receiving contributions from quarks as well as gluons. At small values of x, the behaviour of F_L is driven mainly by gluons through the transition $g \rightarrow q\bar{q}$. Thus once the density of gluon inside the proton is known, one can calculate F_L structure function from it.

Heavy quark production at HERA is of particular interest for testing various calculations in perturbative QCD (pQCD). The heavy quark masses, as well as the transverse momentum of a jet, provide a hard scale, which is essential for the calculations in pQCD predictions. As it is well known, that the scaling violations are different in the massless and massive pQCD cases. Therefore, in all precision measurement, along with the light flavour, a detailed treatment of heavy flavour contribution is also required. The measurements of heavy quark uniquely constrain the PDFs of proton, mainly its c and b contents. The precise knowledge of PDFs is also essential at Large Hadron Collider (LHC). The b quark density plays an important role in Higgs production at the LHC along with the extensions to the standard model such as super symmetric models at high values of the mixing parameter tan β. The dominant process for the charm and beauty quark production at HERA is the boson gluon fusion (BGF) where the photon interacts with a gluon from the proton by the exchange of a heavy quark pair and is given as $\gamma g \rightarrow q\bar{q}X$, with $q = c, b$. This indicates that the process is sensitive to the gluon density in the proton. Thus, the structure functions F_L, F_k^h ($k = 2,L$; $h = c,b$) are dominated by the gluon content of the proton.

Structure function xF_3:

The xF_3 structure function reflects only the valence quark distribution inside hadrons and free from sea quark and gluon densities about which we have poor information in particular in the small-x region. In order to understand the underlying theory of strong interaction, DIS (deep inelastic scattering) structure functions are the objects of intensive investigation both theoretically and experimentally. Current developments of sincere experimental facilities let one to measure the structure functions with far greater precision than before. On the other hand there are several theoretical approaches such as Regge theory, QCD etc. for describing the strong interaction process observed at high energy particle colliders.

DGLAP evolution equation developed within perturbative QCD (pQCD) formalism is found to be the standard and the most widespread for the theoretical investigation of DIS structure function. Although in pQCD, the structure functions are predicted in accordance with the DGLAP equations, predictive power of DGLAP equation is limited. Usually structure functions from DGLAP evolution equations are determined by considering an initial distribution of the structure function at a fixed Q^2, which is characterized by some free parameters and the parameters are found by fitting the parameterization with the available experimental data. This need of initial distribution at fixed Q^2 can be obtained from Regge theory. To find the initial distribution of structure functions, although many parametèrizations are available in previous works, most of them are with several parameters which creates difficulties in obtaining best fitting which in turn leads towards the inaccuracy in results. To get rid of this inefficacy, we investigated the usefulness of a simple Regge-inspired model as the initial input to DGLAP equation with less number of parameters to compute the structure function.

Our Contribution:

We study the relation between the longitudinal structure function F_L and gluon distribution function upto next-next-to-leading order (NNLO) at small-x. Here we use the Taylor series expansion method to expand the gluon density in Altarelli Martinelli equation at a particular choice of the point of expansion. In this

work, we calculate the F_L structure function upto NNLO at small-x using the input distribution of gluon from the Donnachie Landshoff model. In a similar manner we have also studied the behaviour of F_k^h (k =2,L ; h =c,b) with respect to Bjorken variable x using gluon distribution function at small x upto NLO. Finally, the behaviour of DIS cross section ratio R^h, reduced cross section σ_r^h in heavy quark lepto-production and the heavy quark content in F_L structure function at small values of x were also analyzed. We compare our results with the recent experimental data and model fit.

Our calculated results of F_L structure function in all the cases i.e., LO, NLO and NNLO increases towards small values of x in the given range of x and Q^2 as expected from QCD. We compare our results of charm component of longitudinal structure function F_L^c with the colour dipole model and charm component of transverse structure function F_2^c with DL model, H1 data. Both the charm components of the structure function increases towards small values of x for fixed Q^2 values. To confirm the behaviour of these structure functions we have also calculated the ratio of charm structure function R^c and the charm quark reduced cross section σ_r^c. The charm structure function ratio R^c shows independent behaviour with respect to x irrespective of Q^2 values. The charm quark reduced cross section σ_r^c increases towards small values of x. We have also studied the behaviour of beauty component of longitudinal structure function F_L^b which increases towards small values of x. The comparison of beauty component of transverse structure function F_2^b with H1 data shows good agreement with the data. Both the beauty components of the structure function increases towards small values of x for fixed Q^2 values. To confirm the behaviour of these structure functions we have also calculated the ratio of beauty structure function R^b and the beauty quark reduced cross section σ_r^b. The beauty structure function ratio R^b shows independent behaviour with respect to x irrespective of Q^2 values. The beauty quark reduced cross section σ_r^b increases towards small values of x. In both the cases i.e., charm and beauty quark reduced cross section, the behaviour of σ_r^c and σ_r^b with respect to x shows increasing behaviour towards small values of x. But in case of the charm quark the increase of the cross section is more sharp than that of the cross section in case of beauty quark. The reason for this is that the density of heavy beauty quark is less than that of the charm quark in the small-x region. So, the charm cross section increases more sharply with respect to x than that of the beauty quark cross section.

References:

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5. Paper published in research journal:

1. Q^2 evolution of $xF_3(x,Q^2)$ structure function and Gross–Llewellyn Smith sum rule up to next-next-to-leading order at low x and low Q^2 using a Q^2 -dependent Regge ansatz, Indian J Phys. (2015) DOI 10.1007/s12648-015-0707-7:

2. Regge like initial input and evolution of non-singlet structure functions from DGLAP equation up to next-next-to leading order at low x and low Q^2 , PRAMANA. Vol. 85, No. 4, pp. 629–637 (2015).

3. Analysis of small x behaviour of longitudinal and heavy flavour structure functions of proton, Int. J. Theor. Phys. (2015) 54:3596–3611.

4. Regge inspired QCD based investigation on the Q^2 dependence of Gross-Llewellyn Smith sum rule up to NNLO QCD corrections, Journal of Advanced Physics, 4 (2015) 1–

5. Longitudinal structure function F_L of proton from Regge-like behaviour of gluon distribution function up to next-to-next-to-leading order at small-x, Eur. Phys. J. Plus 129 (2014) 10, 229.

6. Longitudinal structure function F_L of proton from Regge like behaviour of structure function at small-x, Few Body Systems, 55 (2014) 11, 1061-1071.

7. Solution of DGLAP Evolution Equation for xF_3 Structure Function in Leading and Next-to-Leading Order at Small- x, Univ. J. of Phys. and App. 2(2) (2014) 80-84.

Date: 20.06.16

Signature of Principal Investigator

6. **Particulars such as the title of the project, funding agency, duration of other projects under your charge.**

Project Title : Study on neutrino mass and mixing in context of recent Neutrino oscillation data.
Funding Agency : UGC.
Duration : 3 years.
F.No. 42-790/2013 (SR). (Sanc. Date – 22/03/2013)

UTILISATION CERTIFICATE

(Financial year 2015-16)

Certified that Grant-in-aid of Rs. NIL was sanctioned by the **Government of India, Department of Atomic Energy, Mumbai-400 001** and an amount of Rs. 45,815/- was remained unspent balance of the previous year(2014-2015) of which a sum of Rs. 16,928/- has been utilized for the purpose of which it was sanctioned and that the balance of Rs. 28,887/-remaining unutilized at the end of the year 2015-16 on 31.03.16 in respect of the Research Project "Studies on F_L and xF_3 structure functions of hadrons in lepton-nucleon scattering and related nuclear effects". The unutilized balance will be sent to the **Government of India, Department of Atomic Energy,** by draft no "137826" dated 12/08/2016.

Signature & Seal: Principal Investigator

Principal Investigator
DAE BRNS Project: 2012/37P/36/BRNS/2018
Studies on F_L and xF_3 structure functions of hadrons in lepton-nucleus scattering and related nuclear effects
TEZPUR UNIVERSITY

Signature & Seal: Registrar/Head of Institution

Registrar
Tezpur University

BRNS Form- IV

STATEMENT OF ACCOUNTS (SA) as on 01.04.2016(date)

Sanction No : **2012/37P/36/BRNS/2018** Dated : 24.11.2012

Sr. No.		Sanctioned	Opening Balance	Received	Total	Spent	Unspent(Carried Forward)
	1st Year (2012-2013)						
1	2	3	4	5	6	7	8
1.	Equipment	NIL	NIL				
2.	Staff Salaries	NIL	NIL				
3.	Techn. asst.	NIL	NIL				
4.	Consumables	NIL	NIL				
5.	Travel	NIL	NIL				
6.	Contingencies	NIL	NIL				
7.	Overheads	NIL	NIL				
8.	Interest Earned	NIL	NIL				
	Total:	NIL	NIL				
	2nd Year (2013-2014)						
1.	Equipment	50,000/-	NIL	50,000/-	50,000/-	47,221/-	2,779/-
2.	Staff Salaries	3,84,000/-	NIL	3,84,000/-	3,84,000/-	3,39,612/-	44,388/-
3.	Techn. Asst.	NIL	NIL	NIL	NIL		
4.	Consumables	10,000/-	NIL	10,000/-	10,000/-	9,990/-	10/-
5.	Travel	20,000/-	NIL	20,000/-	20,000/-	12,060/-	7,940/-
6.	Contingencies	30,000/-	NIL	30,000/-	30,000/-	30,000/-	NIL
7.	Overheads	34,800/-	NIL	34,800/-	34,800/-	26,100/-	8,700/-
8.	Interest Earned		---				
	Total :	5,28,800/-	NIL	5,28,800/-	5,28,800/-	4,64,983/-	63,817/-
	3rd Year (2014-2015)						
1.	Equipment	NIL	2,779/-	NIL	2,779/-	NIL	2,779/-
2.	Staff Salaries	3,84,000/-	44,388/-	3,39,612/-	3,84,000/-	3,84,000/-	NIL
3.	Techn. Asst.	NIL	NIL	NIL	NIL		
4.	Consumables	10,000/-	10/-	10,000/-	10,010/-	9,368/-	642/-
5.	Travel	20,000/-	7,940/-	12,060/-	20,000/-	3,500/-	16,500/-
6.	Contingencies	30,000/-	NIL	30,000/-	30,000/-	24,450/-	5,550/-
7.	Overheads	31,050/-	8,700/-	31,050/-	39,750/-	19,406/-	20,344/-
8.	Interest Earned		---				
	Total :	4,75,050/-	63,817/-	4,22,722/-	4,86,539/-	4,40,724/-	45,815/-
	4th Year (2015-2016)						
1.	Equipment	NIL	2,779/-	NIL	2,779/-	NIL	2,779/-
2.	Staff Salaries	NIL	NIL	NIL	NIL	NIL	NIL
3.	Techn. Asst.	NIL	NIL	NIL	NIL		
4.	Consumables	NIL	642/-	NIL	642/-	NIL	642/-
5.	Travel	NIL	16,500/-	NIL	16,500/-	11,328/-	5,172/-

6.	Contingencies	NIL	5,550/-	NIL	5,550/-	5,600/-	NIL
7.	Overheads	NIL	20,344/-	NIL	20,344/-	NIL	20,344/-
8.	Interest Earned		---				
	TOTAL :	NIL	45,815/-	NIL	45,815/-	16,928/-	28,887/-

Principal Investigator

Head of the Institute

15-07-15

Auditor/Chartered Accountant/Accountant General*

Principal Investigator
DAE BRNS Project: 2012/37/P/36/BRNS/2018
Studies on ^{6}Li and ^{19}F, structure functions of halo nuclei scattering and reactions

Registrar
Tezpur University

Finance Officer
Tezpur University