Present Neutrino Collaboration with Fermilab

Brajesh Chandra Choudhary
University of Delhi
On behalf of the Indian Institutions and Fermilab Neutrino Collaboration

Project-X meeting at TIFR, 13-14 January, 2011

INTENSITY FRONTIER - Why Interest in Neutrinos?

- **Neutrinos: Of all the known particles, neutrinos are the most mysterious and abundant. We need to know their properties to fully understand the evolution of the Universe.**
- **Neutrino Masses and Mixing (The most important discovery of Particle Physics in last twenty years)**:
  - **Evidence of Physics Beyond the Standard Model**
  - May signal new physics at very high energies
  - A new, different and complementary window on the origin of mass
  - Provides a different window on the problem of flavor (why three (3) generations?, why mixing?, why CP violation?)
  - Neutrinos are an important component of the dark matter.
- Lepton number and CP-violation could be at the origin of the baryon asymmetry of the Universe.
- The discovery of small effects in neutrino physics (violation of unitarity, sterile neutrinos, non-standard interactions, CP and CPT violations) could unveil new particles and interactions.

QUESTIONS FOR THE FUTURE - IN NEUTRINO SECTOR?

1. What is the value of θ_{13}, the mixing angle between first and third-generation neutrinos for which, so far, experiments have only established limits? Determining the size of θ_{13} has critical importance not only because it is a fundamental parameter, but because its value will determine the tactics to best address many other questions in neutrino physics. MINOS, T2K, NOνA, Double-CHOOZ, Daya-Bay, RENO, LBNE

2. Do neutrino oscillation violate CP? If so, how can leptonic CP violation drive a matter-antimatter asymmetry among leptons in early universe (leptogenesis)? What is the value of the CP-violating phase, which is so far completely unknown? Is CP violation among neutrinos related to CP violation in the quark sector? LBNE

3. What are the relative masses of the three known neutrinos? Are they "normal," analogous to the quark sector, (m3>m2>m1) or do they have a so-called "inverted" hierarchy (m2>m1>m3)? Oscillation studies currently allow either ordering. The ordering has important consequences for interpreting the results of neutrinoless double beta decay experiments and for understanding the origin and pattern of masses in a more fundamental way, restricting possible theoretical models. LBNE or INO

DOE-NSF → HEPAP → P5 → Report → 10yr Plan → Page 34 & 35

QUESTIONS FOR THE FUTURE - IN NEUTRINO SECTOR?

4. Is θ_{23} maximal (45 degrees)? If so, why? Will the pattern of neutrino mixing provide insights regarding unification of the fundamental forces? Will it indicate new symmetries or new selection rules? T2K, NOνA, INO, LBNE

5. Are neutrinos their own anti-particles? Do they give rise to lepton number violation, or leptogenesis, in early universe? Do they have observable laboratory consequences such as the sought-after neutrinoless double beta decay in nuclei. CUORICINO/CUORE, NEMO3/SUPERNEMO, GERDA, EXO, SNO++, COBRA, MAJORANA etc.

6. What can we learn from observation of the intense flux of neutrinos from a supernova within our galaxy? Can we observe the neutrino remnants of all supernovae that have occurred since the beginning of time. Super-K, LBNE, Ice-Cube

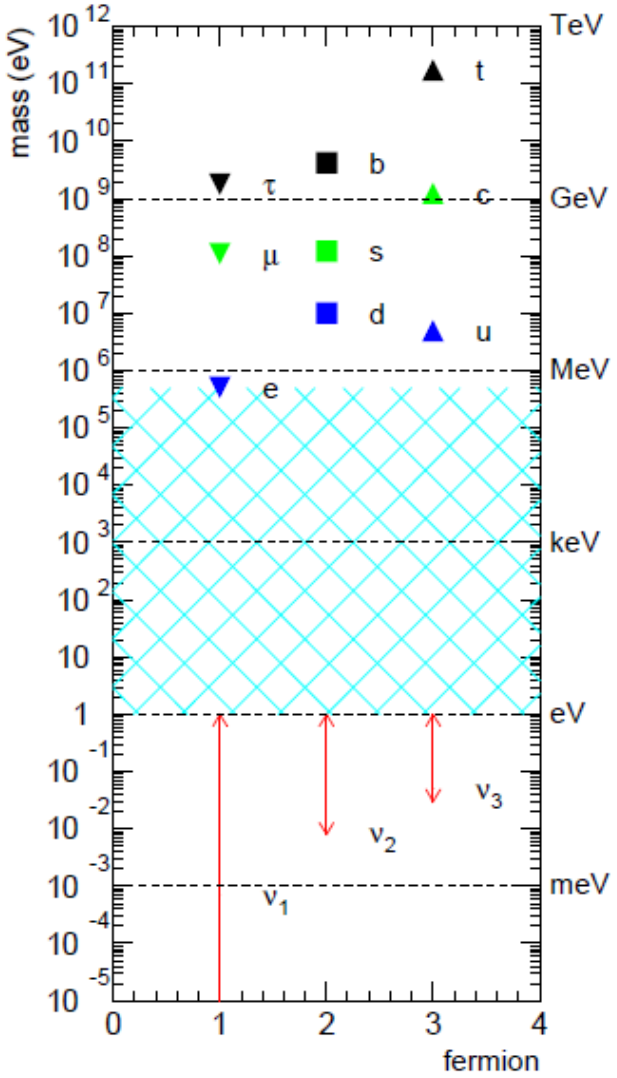
7. What can neutrinos reveal about other astrophysical phenomena? Will we find localized cosmic sources of very high energy neutrinos? LBNE, Ice-Cube

8. What can neutrinos tell us about new physics beyond the Standard Model, dark energy, extra dimensions? Do sterile neutrinos exist? Fine-Grained Near Detector for LBNE (ex: HiResMν or a variation of it)

9. What is the absolute mass of neutrinos? Tritium (KATRIN) and $0\nu\beta\beta$ Decay

DOE-NSF → HEPAP → P5 → Report → 10yr Plan → Page 34 & 35

WHAT ARE NEUTRINOS TELLING US?



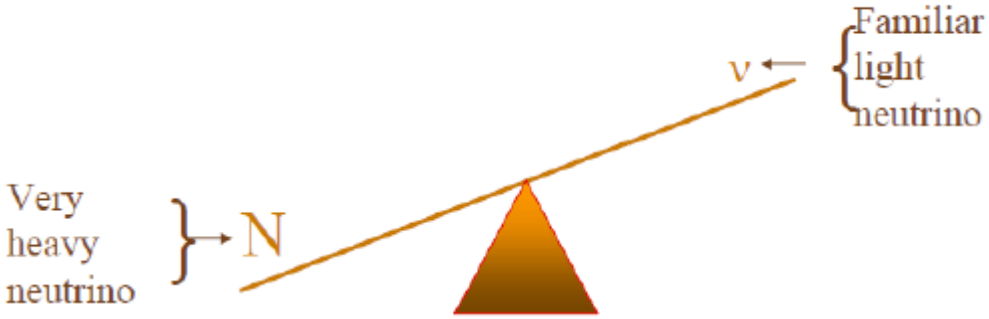
Neutrinos have tiny masses.
Not expected in the SM.

Lepton Mixing is different from quark mixing.

A complementary window on the problem of flavor.

SOMETHING ABOUT UNIFICATION?

See-Saw Mechanism



Mass (N) ~ 10^{15} GeV

The Strong, EM and Weak forces unify at ~ 10^{16} GeV

This might shed light on the physics at energy scales (unification scale?) which cannot be tested directly.

HISTORY OF COLLABORATION AT FERMILAB – MY VERSION

1. Emulsion exposure in 200 and 400 GeV beam – late 70's
2. Di-muon (DY) experiment – as individual collaborators – late 70's
3. Fixed target experiment E706 – DU – 1985 - 1992
4. Tevatron Collider D0 – DU, PU, TIFR – since late 80's, early 90's

   (Tevatron to finish operation on 30/9/2011)

Visit of US team in 2003 to discuss further collaboration:

5. Accelerator Collaboration – RRCAT, IUAC, BARC, VECC, IGCAR ~2006
6. Neutrino Collaboration – Since 2010

   Across the board on Fermilab Neutrino Experiments

   We are working on MIPP, MINOS, NOνA, LBNE (before Project-X)

   LBNE on Project-X

   Institutions Involved - BHU, CUSAT, DU, IITG, IITH, HU, PU.

MOU between INDIAN and US INSTITUTIONS

Memorandum of Understanding

between

US Universities & Accelerator Laboratories

and

Indian Universities & Accelerator Laboratories

concerning

Collaboration on R&D for Various Accelerator Physics and High Energy Physics Projects

January 9, 2006

1. Introduction

1.1 General Description

This Memorandum of Understanding (MOU) establishes a collaboration framework between various US and Indian Accelerator Laboratories and Universities, hereinafter referred to as the "Parties", to pursue coordinated R&D in areas of mutual interest pertaining to accelerator and high energy physics projects. This agreement between the Parties is made to further the objectives of any existing national and international collaborations, and shall not alter those collaborations. This MOU between the Parties is not a legal contractual obligation on the part of any of the institutions that are a party to the agreement.

1.2 Objective

The objective of this MOU is to document the terms under which work of the Parties is to be performed.

1.3 Scope

This MOU covers work to be performed by the Parties in the furtherance of the goals of the collaborations and the specific R&D tasks within the topics of collaboration.

1.4 Initial List of Participating Institutions

The following is a list of the Institutions that are a party to the collaboration. The Parties agree that after mutual consultation, they would favorably consider admitting new partner institutions from the USA and India who want to contribute towards the objective of this Agreement.

4.2 Approvals

The following concur in the terms of this Memorandum of Understanding:

Piermaria Oddone, Director, FNAL — 1/9/05 — Date

Jonathon Dorfan, Director, SLAC — 1/23/06 — Date

Christoph Leemann, Director, TJNAL — 1/18/06 — Date

Maury Tigner, Director, Newman Lab — Date

Date

Date

Vinod C. Sahni, Director, CAT — March 8, 2006 — Date

Bikash Sinha, Director, VECC — March 9, 2006 — Date

Amit Roy, Director, IUAC — March 9, 2006 — Date

S. Bhattacharya, Director, TIFR — April 17, 2006 — Date

S. Banerjee, Director, BARC — March 14, 2006 — Date

Deepak Pental, Vice Chancellor, DU — April 10, 2006 — Date

LETTER FROM THE FERMILAB DIRECTOR

Fermilab

Fermi National Accelerator Laboratory
P.O. Box 500 • Batavia, IL • 60510-0500
630-840-3211 (phone)
630-840-2900 (fax)

Director's Office

November 08, 2009

Prof. Brajesh Chandra Choudhary
Department of Physics & Astrophysics
University of Delhi
Delhi - 110 007, India

Prof. Sanjib Mishra
Department of Physics and Astromony
University of South Carolina
Columbia, SC- 29208

Dear Prof. Choudhary and Prof. Mishra,

Fermilab's program for the next decade includes investigation of physics at the intensity frontier while vigorously participating in energy frontier physics at LHC and the cosmic frontier. With the energy frontier moving from the Fermilab-Tevatron to the CERN-LHC, a significant fraction of our Indian collaborators will shift to LHC.

Scientists from US and Indian institutions have been collaborating on high energy physics experiments at Fermilab since 1985. Together we have made valuable contributions to the Fermilab program. Recently we have developed strong accelerator collaboration with the Indian Department of Atomic Energy laboratories. This collaboration is making considerable progress in contributing to the proposed Project-X R&D and SRF infrastructure. We have been exploring the possibilities of expanding this collaboration to the intensity frontier physics at Fermilab. I would like to seek your help, as a member of neutrino experiments at Fermilab and with ties to physics community in India, in establishing neutrino collaboration with Indian institutions.

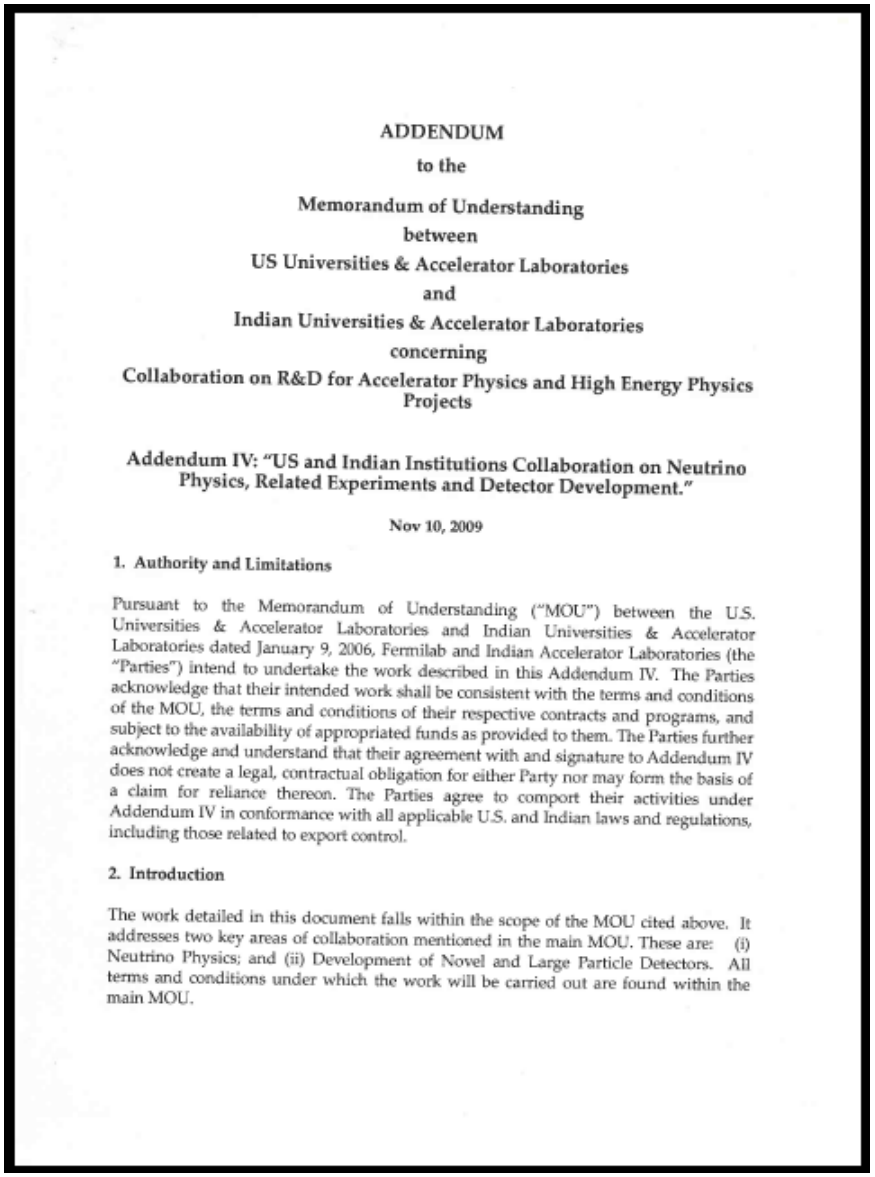
I am requesting you to work with Shekhar Mishra, Fermilab, in developing this collaboration. While working with the management of the respective Fermilab experiments, you would serve as the Technical Project Managers for the work that would be carried by Indian institutions collaboration.

Thank you,

Sincerely,

Fiermaria J. Oddone,
Laboratory Director

MOU on ν Collaboration between Indian Institutions & FERMILAB



ADDENDUM

to the

Memorandum of Understanding
between
US Universities & Accelerator Laboratories
and
Indian Universities & Accelerator Laboratories
concerning
Collaboration on R&D for Accelerator Physics and High Energy Physics Projects

Addendum IV: "US and Indian Institutions Collaboration on Neutrino Physics, Related Experiments and Detector Development."

Nov 10, 2009

1. Authority and Limitations

Pursuant to the Memorandum of Understanding ("MOU") between the U.S. Universities & Accelerator Laboratories and Indian Universities & Accelerator Laboratories dated January 9, 2006, Fermilab and Indian Accelerator Laboratories (the "Parties") intend to undertake the work described in this Addendum IV. The Parties acknowledge that their intended work shall be consistent with the terms and conditions of the MOU, the terms and conditions of their respective contracts and programs, and subject to the availability of appropriated funds as provided to them. The Parties further acknowledge and understand that their agreement with and signature to Addendum IV does not create a legal, contractual obligation for either Party nor may form the basis of a claim for reliance thereon. The Parties agree to comport their activities under Addendum IV in conformance with all applicable U.S. and Indian laws and regulations, including those related to export control.

2. Introduction

The work detailed in this document falls within the scope of the MOU cited above. It addresses two key areas of collaboration mentioned in the main MOU. These are: (i) Neutrino Physics; and (ii) Development of Novel and Large Particle Detectors. All terms and conditions under which the work will be carried out are found within the main MOU.

The following concur on the terms of this Memorandum of Understanding Addendum:

10 Nov, 2009

Dr. Amit Roy Date
Director
IUAC

11/16/09

Dr. Piermaria Oddone Date
Director,
Fermilab

NOV 10, 2009

Dr. Vinod Sahni Date
Collaboration Coordinator
DAE, India

11/13/09

Dr. Shekhar Mishra, Date
Collaboration Coordinator,
Fermilab

10 NOV 2009

Prof. Brajesh Choudhary, Date
Technical Project Manager
University of Delhi, India

19. Nov. 09

Prof. Sanjib Mishra Date
Technical Project Manager
University of South Carolina, Columbia

Collaborating Institutions:

1. Banaras Hindu University, Varanasi
2. Cochin University of Science & Tech., Cochin
3. University of Delhi, Delhi
4. IITG, Guwahati
5. IITH, Hyderabad **(joined after signing of the MOU)**
6. Hyderabad University, Hyderabad
7. Panjab University, Chandigarh

More Institutions have shown interest.
Others are most welcome.

PROPOSAL TO THE DST – Submitted in February 2010

Neutrino Related Experiments @ Fermilab + R&D on Detectors: A Proposal by Indian Universities' Physicists

Venktesh Singh, Avijit Ganguly, Bhartendu Singh
Banaras Hindu University, Varanasi - 221005, UP

M. R. Anantharaman, V. C. Kuriakose, M. Sabir, Ramesh Babu Thayyullathil
Cochin University of Science and Technology, Kochi – 862022, Kerala

Brajesh Choudhary, Suresh Kumar, Samit Kumar Mandal, Smarjit Triambak
University of Delhi, Delhi – 110007

Bipul Bhuyan
Indian Institute of Technology Guwahati, Guwahati – 781039, Assam

Bindu Bambah, Harikumar, A. K. Kapoor, R. Mohantha, M. Sivakumar
University of Hyderabad, Hyderabad – 500046, AP

Anjan Giri
Indian Institute of Technology Hyderabad, Yeddumaalaram – 502205, AP

Vipin Bhatnagar, Ashok Kumar, M. Gupta, Sandeep Sahijpal, Jasbir Singh,
Panjab University, Chandigarh – 160014

Names in Red – Already on the Proposal
Names in Purple – Have shown interest

Collaborating Institutions from USA

Rob Plunket, Rajendran Raja, Jim Strait
Fermilab, Batavia, IL

Sanjib Mishra, Roberto Petti, Carl Rosenfeld
University of South Carolina, Columbia, SC

Robert Svoboda, Mani Tripathi
University of California, Davis, CA

Sandip Pakvasa
University of Hawaii, Hawaii

Milind Diwan
Brookhaven National Lab, NY

Only Lead Physicists Listed

Fermilab and Indian Management Support

- All seven collaborating institutions forwarded the proposal and supporting documents to the DST in February, 2010. Proposal considered by DAE-DST apex committee on 24th April 2010. Minutes of the meeting signed in late August. Proposal tentatively approved – barring minor fine tuning.

- Letter regarding these minor changes received from the DST in early December. (Next page)

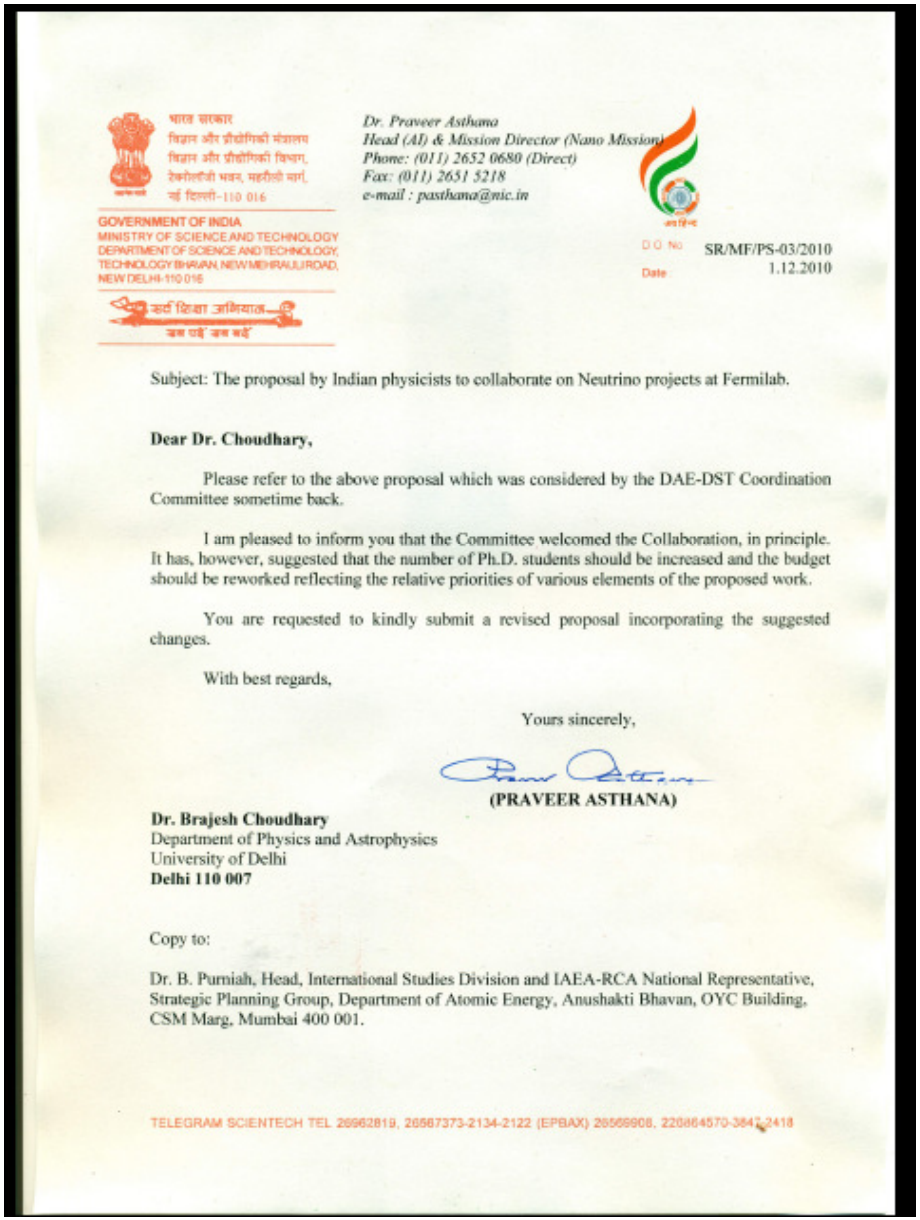
- Response to follow soon. Within a week or two.

- We received very strong support from Universities, DAE and DST management for this collaboration.

- Collaboration already in progress since January 2010.

- Students and faculty already involved in MIPP, MINOS and LBNE collaborations. Details to follow.

LETTER FROM THE DST



भारत सरकार
विज्ञान और प्रौद्योगिकी मंत्रालय
विज्ञान और प्रौद्योगिकी विभाग,
टेक्नोलॉजी भवन, महरौली मार्ग,
नई दिल्ली-110 016

GOVERNMENT OF INDIA
MINISTRY OF SCIENCE AND TECHNOLOGY
DEPARTMENT OF SCIENCE AND TECHNOLOGY,
TECHNOLOGY BHAVAN, NEW MEHRAULI ROAD,
NEW DELHI-110 016

जल एवं जल बचें

Dr. Praveer Asthana
Head (AI) & Mission Director (Nano Mission)
Phone: (011) 2652 0680 (Direct)
Fax: (011) 2651 5218
e-mail : pasthana@nic.in

D O No SR/MF/PS-03/2010
Date 1.12.2010

Subject: The proposal by Indian physicists to collaborate on Neutrino projects at Fermilab.

Dear Dr. Choudhary,

Please refer to the above proposal which was considered by the DAE-DST Coordination Committee sometime back.

I am pleased to inform you that the Committee welcomed the Collaboration, in principle. It has, however, suggested that the number of Ph.D. students should be increased and the budget should be reworked reflecting the relative priorities of various elements of the proposed work.

You are requested to kindly submit a revised proposal incorporating the suggested changes.

With best regards,

Yours sincerely,

(PRAVEER ASTHANA)

Dr. Brajesh Choudhary
Department of Physics and Astrophysics
University of Delhi
Delhi 110 007

Copy to:

Dr. B. Purniah, Head, International Studies Division and IAEA-RCA National Representative, Strategic Planning Group, Department of Atomic Energy, Anushakti Bhavan, OYC Building, CSM Marg, Mumbai 400 001.

TELEGRAM SCIENTECH TEL 26962819, 26567373-2134-2122 (EPBAX) 26569908, 220864570-3847-2418

Essential Elements of the Proposal

- **Focus of the Experimental Studies @ Fermilab**
  - **Participate in cutting edge neutrino experiments**
  - **Measurement of Neutrino Flux with MIPP** – MIPP data will be the ONLY empirical constraint on the neutrino-flux in present and future accelerator experiments and help atmospheric as well as long-baseline neutrino experiments make precision measurements
  - **Gain Experience with MINOS Detector**
    - Use 5.4KTon magnetized Fe-Scintillator calorimeter; should prove useful for future magnetized calorimeter such as ICAL at INO
    - Measure the most precise value of atmospheric mixing parameter Δm^2_{23}
    - Learn to conduct $\nu_\mu \rightarrow \nu_e$ (θ_{13}) search in a magnetized Fe calorimeter; challenge is to find a small ν_e signal among large neutral current π^0s
  - **Participate in LBNE-DUSEL Neutrino Experiment** (**Beamline ~1300 Km**)
    - Search θ_{13} down to $\text{Sin}^2 2\theta_{13} = 0.003$ or θ_{13} less than 2 degrees
    - Measure CP violation in the lepton sector
    - Measure Mass Hierarchy for Neutrinos
- **Focus of the Detector Developments @ Home**
  - **Create detector R&D labs at various Universities**(Gaseous Detectors, Scintillators and Scintillating Crystal based Calorimetric studies)

Major Gains that are Expected from Our Efforts

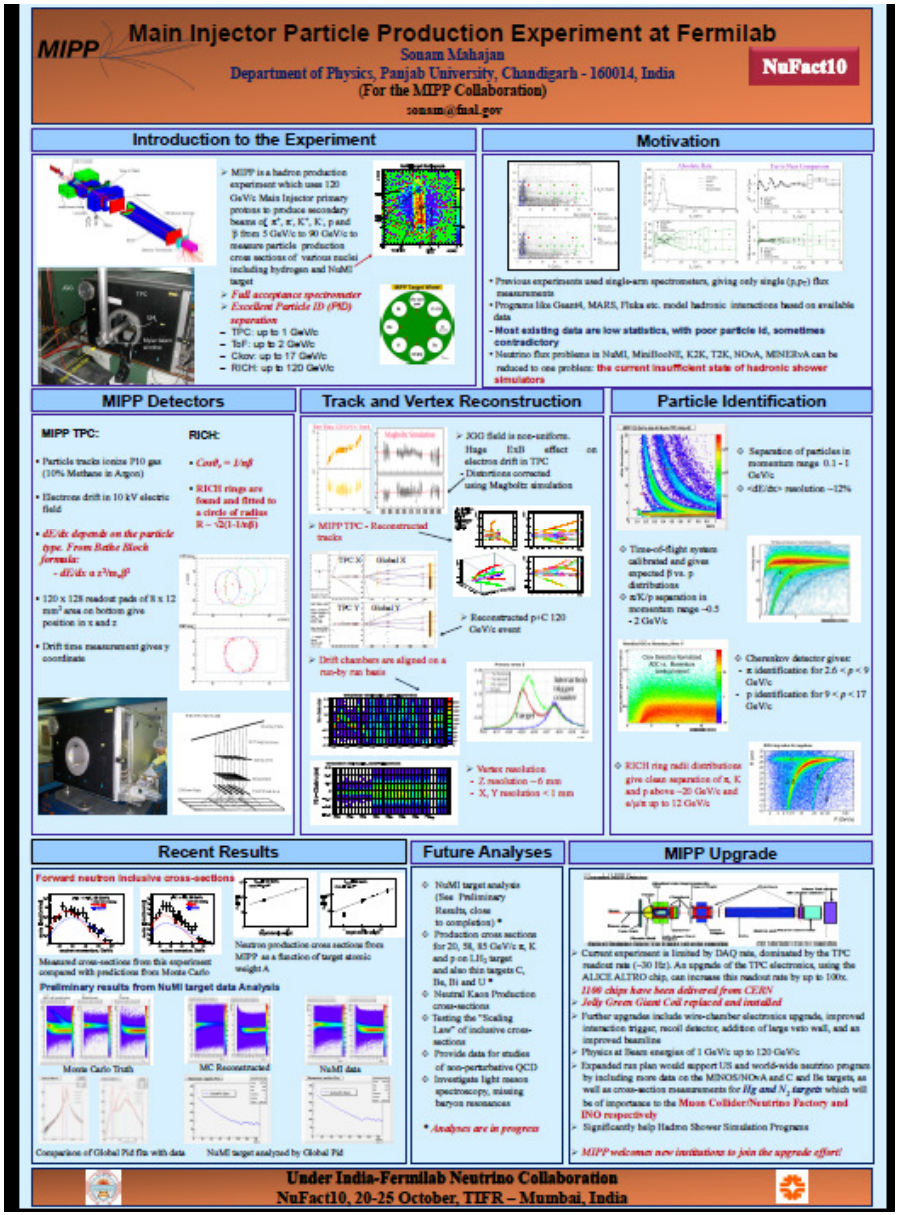
- **Training of Young Physicists: Most useful resource for domestic future high energy physics/nuclear physics programs:**
  Will prepare a cadre of young graduate students, post-doctoral fellows, and junior faculty for world class projects at home, eg, ICAL @ INO & other experiments.
- **Start EHEP Groups at New Institutions**
  Example – participation by - IIT (Hyderabad), Univ. of Hyderabad, CUSAT and others.
- **Hands on Experience at Fermilab: Will help us in:**
  - Learning design of experiments
  - Fabricating detectors - Scintillator (solid + liquid), LAr, Water Cherenkov
  - Developing auxiliary system such as DAQ & gas distribution system
  - Maintain and operate experiments
  - Data analysis
  - Opportunity to work on MINOS – a mini ICAL
- **New Detector Labs at Universities and indigenous training of future manpower**

Current Status & Deliverables Over Next 3 Years

- **Current Status**
  - Since January 2010 – 4+1 Ph.D students & 3 faculty have visited Fermilab.
  - Three (2+1) Ph.D student (stationed at Fermilab) are working towards thesis on MIPP (2 students) and MINOS (1 student) respectively. Two more to go this summer.
  - One faculty was awarded a prestigious International fellowship.

- **With the present funding - Expected Deliverables till 2013-2014**
  - Establish detector R&D labs at Delhi, Panjab and Banaras.
  - Establish simulation center at IIT(G), DU and PU.
  - New groups at IIT(H), UH and CUSAT - to launch multi-faceted activities at three institutions.
  - Senior Ph.D students to work on neutrino physics at Fermilab.
  - We expect 2-3 students to write thesis on MIPP.
  - We expect 2-3 students to write thesis on MINOS.
  - With time we will ramp up participation of students as well as faculty.
  - Later we will work on NOνA and LBNE.
  - Participate in the design of LBNE near detector.

What have we achieved in one year?



Sonam Mahajan – Ph.D student, PU

Advisor: Vipin Bhatnagar, PU
Co-advisor: Brajesh Choudhary, DU

Currently working on data for interaction of 58 GeV proton on LH2.

1. Track multiplicity study.
2. Scintillator based trigger efficiency as a function of multiplicity, track momentum for 58 GeV proton on LH2, Bismuth, & Carbon targets and 120 GeV proton on Be and Carbon targets
3. Study of elastic, inelastic x-section using DPMJET
4. KNO scaling, etc. etc.

Presented a poster on behalf of the collaboration at NuFact10.

Very encouraging response.

What have we achieved in one year?

Richa Sharma – Ph.D student, PU
Advisor: Vipin Bhatnagar, PU, Co-advisor: Brajesh Choudhary, DU

Working on charge current analysis with anti-neutrino data at MINOS.
Will be presenting the work at APS April meeting at Anaheim, CA from April 30 – May 3, 2011.

MINOS has previously reported the results of $\bar{\nu}_\mu$ disappearance from a direct observation of muon antineutrinos. The antineutrinos studied for this purpose are taken from two types of beam configurations: (a) Forward Horn Current (FHC), optimized for ν_μ selection where the $\bar{\nu}_\mu$ content is 7% of the neutrino beam, and (b) Reverse Horn Current (RHC), optimized for $\bar{\nu}_\mu$ selection where the $\bar{\nu}_\mu$ content is 40% of the beam. The previous analyses were based on 3.2e20 protons on the NuMI target in FHC configuration and 1.7e20 protons on target in RHC configuration. These analyses make a precise measurement of the oscillation parameters $\Delta\bar{m}^2_{23}$ and $sin^2 2\bar{\theta}_{23}$ and also constrain the fraction of ν_μ that oscillate to $\bar{\nu}_\mu$. In the present analysis we have an FHC $\bar{\nu}_\mu$ data sample with 7.1e20 protons on target which will be used to improve the previous measurements. This talk summarizes the agreement between data and simulation in the Near Detector at Fermilab.

Amandeep Singh – Ph.D student, PU
Advisor: Ashok Kumar, PU.

To work on particle production at MIPP. Waiting for his visa.

What have we achieved in one year?

Arun Kumar Soma – Ph.D student, BHU
Advisor: Venktesh Singh, PU.

Participated in MIPP data analysis for six months. Work to appear in paper.

Sourav Tarafdar – Ph.D student, BHU
Advisor: Venktesh Singh, PU.

Participating in MIPP data analysis since last six months. Will be at Fermilab for one year.

What have we achieved in one year?

Daughty John – Ph.D student, IITH
Advisor: Anjan Giri, IITH and Rob Plunkett, Fermilab.

To work on MINOS experiment beginning March 2011. Paper work in progress. Has been working in theoretical neutrino physics for a while at Hyderabad University. Has submitted a paper for publication. Moved to IITH. Migration from theory to experiment.

Probing CP violation in the neutrino sector with magic baseline experiments

Rukmani Mohanta[1] and Daughty John[2]

[1] *School of Physics, University of Hyderabad, Hyderabad - 500 046, India and*

[2] *Department of Physics, Indian Institute of Technology Hyderabad, Ordnance Factory Estate, Yedumailaram - 502205, Andhra Pradesh, India*

Abstract

We investigate the effect of CP violation in the leptonic sector. Due to the tiny neutrino masses its value is predicted to be very small and it is far beyond the experimental reach of the current experiments. Recently, the magic baseline experiment from CERN to INO (Indian Neutrino Observatory) with $L = 7152$ km has been proposed to get a sensitive limit on $\sin\theta_{13}$. We show that due to such magic baseline neutrino beam it is possible to observe CP violation in the neutrino sector upto several percent for the beam energy between (1-10) GeV.

PACS numbers: 14.60.Pq, 11.30.Er

What have we achieved in one year?

Navaneeth Poomthottathil - Ph.D student, CUSAT
Advisor - Ramesh BabuThayyullathil

Recently joined. Getting started with basics of EHEP, Neutrino Physics, HEP related detectors etc.

DU, IITG and HU to take students this year.

What have we achieved in one year?

LBNE Document # 916, Version 2
July 9, 2010

Simulation of the Cosmic Muon flux at the Homestake Mine.

Bipul Bhuyan
Department of Physics
Indian Institute of Technology Guwahati, India

Abstract

Simulated results on the cosmic ray muon flux at the 4850 level in the Homestake mine has been presented. The expected cosmic ray muon flux is 4.63 $\times$ 10^{-9} Hz/cm^2 at the 4850 level which corresponds to an integrated muon flux of 1459 μ / m^2 / year. The flux distrubution as a function of the muon energy as well as the zenith angle has also been presented.

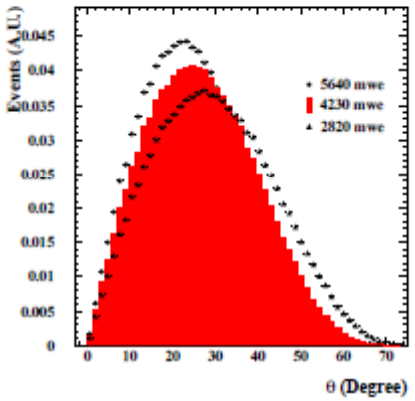


Figure 5: Zenith angle distributions for Cosmic Muon flux at the depth of 5640 m.w.e, 4230 m.w.e and 2820 m.w.e.

What have we achieved in one year?

LBNE : Physics Reach & Status

Brajesh Choudhary

University of Delhi, Delhi

On behalf of LBNE Collaboration

12th International Workshop on Neutrino Factories, Superbeams and Beta Beams

20-25 October, 2010, TIFR-Mumbai, India

Some Impressions about the Collaboration

From our colleague Bipul Bhuyan at IITG, who could not be here - in a mail dated 8.January.2011 - to the organizing committee members.

Dear all,

I am extremely sorry to inform you that I will not be able to attend the interaction meeting on Project-X due my various academic engagements at IITG. However, I fully support the idea of Indian Universities and Institutions collaborating with Fermi Lab on Project-X and various experiments associated with it. IITG is already collaborating with Fermi Lab on the current and future generation of Neutrino Physics experiments as part of the MOU signed between the Indian Institutions and Fermi Lab and this collaboration is already becoming mutually beneficial. We are also looking at the possibilities of extending this collaboration to other engineering branches at IITG and therefore, I strongly believe, collaborating with Fermi Lab on Project-X will further enhance and extend the mutually beneficial experiences.

I will look forward to see a fruitful and positive outcome of this meeting.

Best Regards,
Bipul Bhuyan

Dr. Bipul Bhuyan
Assistant Professor
Department of Physics
Indian Institute of Technology
Guwahati, Assam, India, Pin 781039

Some Impressions about the Collaboration

From our colleague Venktesh Singh of BHU, at present working as International Fellow at Fermilab in a mail dated 11.January.2011.

Benefits of India-US Collaboration:

The India-US Collaboration has both type of benefits, short term and long term. The major benefit of India-US collaboration is to provide first hand training to the Indian-universities and institutes research students and young faculty. India also has several training programs specially run by Department of Science and Technology, New Delhi, such as experimental SERC School where students get training. But, due to lack of facilities in their respective university and institute there is no follow up to their training thus making it almost ineffective. But the training at Fermi lab is looking complete in all respect such as planning and detector designing as in the LBNE experiment, simulation and data analysis as in the MIPP and MINOS experiments, hardware service experience as in MINOS etc. These experiences, directly or indirectly, will benefit the home experiments such as India-based Neutrino Observatory. For example, one research student (Mr. Sourav Tarafdar) mastered in data analysis and used swimmer techniques to track the events tracks inside the large detector in the presence of electric and magnetic fields. This technique will certainly help INO during data analysis when they track the Leptonic track inside a large ICAL in presence of magnetic field. Training of six months and more is really beneficial because in this time frame their training and contribution in the experiment / collaboration is significant. Another significant benefit (long term) that I can see is the discussion on multiple thoughts with multiple experts. Here things and thoughts are not monotonous. Such discussion, may sow a seed of new experiments in any young mind and then short term benefits will help in making it in reality that will be the great contribution to the Indian science.

Summary and Conclusions

- India – Fermilab neutrino collaboration is progressing well.
- Students and faculty are already working on MIPP, MINOS and LBNE – at present fully supported by Fermilab resources.
- We have a proposal submitted for funding. Funding expected soon.

- The proposal aims towards working on compelling neutrino physics for next couple of decades.
- Will train and generate manpower towards future scientific projects in India –
  - ✓ similar to our past and on-going collaborations at Fermilab (Collider collaboration coming to an end and neutrino collaboration starting), CERN (LEP/L3 ended and LHC/CMS in progress) and KEK (Belle ended and Super-Belle in progress).

- Complementary and synergetic to our indigenous efforts.
- The management of collaborating institutions and funding agency is fully supportive of this effort.
- We wish to further strengthen the collaboration. New groups are most welcome

THANK YOU

Why Interest in Neutrinos?

1. Neutrinos are the most abundant known particles in the Universe.
2. Neutrino masses and mixing is the only evidence of Physics Beyond the Standard Model (BSM).
3. Neutrino masses being very small can not be naturally explained as the ones for other fermions. Neutrinos are a new, different and complementary window on the origin of mass.
4. They could provide indirect information on energy scales not reachable in any other direct search: e.g. the see-saw happens at energy scale many orders of magnitude higher than what we can test in colliders.
5. Lepton number and CP-violation could be at the origin of the baryon asymmetry of the Universe through the leptogenesis mechanism.
6. Mixing in the lepton sector is different with respect to the quark sector. Neutrinos provide a different window on the problem of flavor (why 3 generations?, why mixing?, why CP violation?).
7. The discovery of small effects in neutrino physics (violation of unitarity, sterile neutrinos, non-standard interactions, CP and CPT violations) would unveil new particles and interactions which might not be testable otherwise.
8. We need to know the properties of neutrinos such as masses, number etc. to fully understand the evolution of the Universe.
9. Neutrinos are an important component of dark matter, with sterile neutrinos the favoured candidate for warm dark matter.