PHYSTAT-nu 2019

Report of Contributions

Contribution ID: **1** Type: **not specified**

Treatment of material radioassay measurements in projecting sensitivity for low-background experiments

Low-background experiments typically perform radioassay on detector construction materials, and use the resulting radioimpurity estimates to project experiment sensitivity. However, as the radiopurity of the materials improves and approaches the detection limit of the radioassay techniques, the radioimpurity concentration of the materials cannot be conclusively determined. Instead, only an upper limit can be placed on the radioimpurity concentrations. This presents a problem as the values cannot be trivially incorporated into sensitivity projections. The most straightforward approach is to treat the upper limit as if it is the determined radioimpurity concentration. This is often considered "conservative" as the resulting sensitivity is likely to be worse than the *true* sensitivity. Another approach is to transform the upper limit into a distribution. Depending on the choice of the distribution, this may or may not provide a more accurate estimate of the *true* sensitivity. By analyzing sensitivity projections as a statistical estimation problem, we evaluated different ways of treating radioassay measurement results (values and upper limits) when projecting sensitivity for low-background experiments. We developed a figure of merit that incorporates a notion of conservativeness to quantitatively explore the consequences of attempts to bias sensitivity projections, and proposed a method to report sensitivity.

Authors: TSANG, Raymond Hei-Man (Pacific Northwest National Laboratory); Dr ARNQUIST, Isaac (Pacific Northwest National Laboratory); Dr HOPPE, Eric (Pacific Northwest National Laboratory); Dr ORRELL, John (Pacific Northwest National Laboratory); Dr SALDANHA, Richard (Pacific Northwest National Laboratory)

Presenter: TSANG, Raymond Hei-Man (Pacific Northwest National Laboratory)

Session Classification: Welcome Reception and poster session

Contribution ID: **2** Type: **not specified**

A new unified perspective on the problem of limited Monte Carlo for likelihood calculations

Parameter estimation in high-energy neutrino/HEP experiments often involves Monte-Carlo simulations to evaluate likelihood functions, a typical use case being forward-folding Poisson likelihood analyses. Limited Monte Carlo samples induce statistical uncertainty into this problem. This is sometimes solved by the classical Ansatz of Barlow/Beeston (1993) - an approach that can be thought of as nuisance parameter optimization. Another approach tries to model the underlying statistics of weighted Monte Carlo directly via a Compound Poisson Distribution ("CPD", Bohm/Zech, 2014), but is not analytically tractable. This talk introduces an Ansatz to this problem which can be thought of as a probabilistic generalization of Barlow/Beeston (93) which involves a Bayesian approximation to the CPD described by Bohm/Zech in 2014. The result therefore unifies these two previously disconnected approaches and is simultaneously analytically exact and efficient to compute. It also involves previously unknown probability distributions and a new representation of a certain hypergeometric function (Carlson R_n/Lauricalle F_D), which by itself is connected to other areas of statistics. For example, it implies a new formula to calculate arbitrary B-Spline moments exactly, which again might be of interest to the community for different reasons. We end by comparing the different approaches from the literature in typical likelihood scenarios that one might encounter in neutrino/HEP experiments, and describe for the first time a unified picture of five major approaches that have been published over the last 25 years - it should hopefully clear the fog for people who are confused by the apparent multitude of possibilities that exist in the literature.

Author: Dr GLÜSENKAMP, Thorsten (University of Erlangen-Nuremberg)

Presenter: Dr GLÜSENKAMP, Thorsten (University of Erlangen-Nuremberg)

Contribution ID: **3** Type: **not specified**

Review of Linear Algebra Applications in Some Recent Neutrino Experiments

Linear algebra has been widely used in physics analysis of high-energy experiments. In this talk, I am going to review some of its recent usage in detector signal processing, noise filtering, event reconstruction, and data unfolding. In particular, its connections to various numerical and analytical techniques including the Fast Fourier Transformation, the Compressed Sensing, and the biconjugate gradients stabilized method, will be discussed. Through many real world applications, we show the power of linear algebra in neutrino experiments.

Author: Dr QIAN, Xin (Brookhaven National Laboratory)

Presenter: Dr QIAN, Xin (Brookhaven National Laboratory)

Contribution ID: **4** Type: **not specified**

Bayesian techniques

Tuesday 22 January 2019 17:00 (1 hour)

Presenter: Prof. BERGER, James (Duke University)

Contribution ID: **5** Type: **not specified**

Introduction to neutrino physics

Wednesday 23 January 2019 09:10 (40 minutes)

Presenter: BLONDEL, Alain (Universite de Geneve (CH))

Session Classification: Opening Session

Contribution ID: **6** Type: **not specified**

Overview of stastistics for neutrino physics

Wednesday 23 January 2019 09:50 (40 minutes)

Presenter: UCHIDA, Yoshi (Imperial College London)

Session Classification: Opening Session

Contribution ID: **7** Type: **not specified**

Introduction to unfolding

Presenter: KUUSELA, Mikael (Statistical and Applied Mathematical Sciences Institute (US), University of North Carolina at Chapel Hill (US), Helsinki Institute of Physics (FI), Carnegie Mellon University (US))

Session Classification: Statistical issues in neutrino experiments

Contribution ID: **8** Type: **not specified**

The collider experience with unfolding

Session Classification: Statistical issues in neutrino experiments

Contribution ID: **9** Type: **not specified**

Unfolding in neutrino experiments

Presenter: RODRIGUES, Philip Andrew (University of Oxford (GB))

Session Classification: Statistical issues in neutrino experiments

Contribution ID: **10** Type: **not specified**

Long-baseline experiments

Wednesday 23 January 2019 11:00 (30 minutes)

Presenter: HIMMEL, Alexander (Fermilab)

Session Classification: Statistical issues in neutrino experiments

Contribution ID: **11** Type: **not specified**

Atmospheric neutrinos

Wednesday 23 January 2019 11:30 (30 minutes)

Presenter: BRONNER, Christophe (University of Tokyo)

Session Classification: Statistical issues in neutrino experiments

Contribution ID: **12** Type: **not specified**

Reactor experiments

Wednesday 23 January 2019 12:00 (30 minutes)

Presenter: ZHANG, Chao (Brookhaven National Laboratory (US))

Session Classification: Statistical issues in neutrino experiments

Contribution ID: **13** Type: **not specified**

Fits to large data sets

Wednesday 23 January 2019 16:10 (30 minutes)

Presenter: Dr GARIAZZO, Stefano (IFIC-CSIC/University of Valencia)

Session Classification: Statistical issues in neutrino experiments

Contribution ID: **14** Type: **not specified**

Cosmological neutrinos

Wednesday 23 January 2019 16:40 (30 minutes)

Presenter: RUHE, Tim (TU Dortmund)

Session Classification: Statistical issues in neutrino experiments

Contribution ID: **15** Type: **not specified**

Direct neutrino mass measurement

Wednesday 23 January 2019 17:10 (25 minutes)

Presenter: LASSERRE, Thierry (CEA)

Session Classification: Statistical issues in neutrino experiments

Contribution ID: **16** Type: **not specified**

Model building, analysing and treatment of systematic uncertainties in modern HEP experiments

Wednesday 23 January 2019 14:00 (30 minutes)

Presenter: VERKERKE, Wouter (Nikhef National institute for subatomic physics (NL))

Session Classification: Session on systematic uncertainties

Contribution ID: **17** Type: **not specified**

Practical experiences with ATLAS/CMS Higgs combine procedures

Wednesday 23 January 2019 14:30 (30 minutes)

Presenter: WARDLE, Nicholas (Imperial College (GB))

Session Classification: Session on systematic uncertainties

Contribution ID: **18** Type: **not specified**

The neutrino experiment experience

Wednesday 23 January 2019 15:00 (30 minutes)

Presenters: Prof. ANDREOPOULOS, Constantinos (University of Liverpool and STFC/RAL); ANDREOPOULOS, Costas (University of Liverpool & STFC Rutherford Appleton Laboratory)

Session Classification: Session on systematic uncertainties

Contribution ID: **19** Type: **not specified**

Neutrino-less double-beta decay experiments

Thursday 24 January 2019 09:00 (30 minutes)

Presenter: Dr AGOSTINI, Matteo (Technical University Munich)

Session Classification: Statistical issues in neutrino experiments

Contribution ID: **20** Type: **not specified**

Short-Baseline experiments

Presenters: KARAGIORGI, Georgia (Columbia); KARAGIORGI, Georgia (University of Manchester); KARAGIORGI, Georgia (MIT)

Session Classification: Statistical issues in neutrino experiments

Contribution ID: **21** Type: **not specified**

Introduction to unfolding

Presenter: KUUSELA, Mikael (Statistical and Applied Mathematical Sciences Institute (US), University of North Carolina at Chapel Hill (US), Helsinki Institute of Physics (FI), Carnegie Mellon University (US))

Session Classification: Session on unfolding

Contribution ID: **22** Type: **not specified**

The collider experience with unfolding

Thursday 24 January 2019 14:30 (30 minutes)

Presenter: SCHMITT, Stefan (Deutsches Elektronen-Synchrotron (DE))

Session Classification: Session on unfolding

Contribution ID: **23** Type: **not specified**

The neutrino experiment experience with unfolding

Thursday 24 January 2019 15:00 (30 minutes)

Presenter: RODRIGUES, Philip Andrew (University of Oxford (GB))

Session Classification: Session on unfolding

Contribution ID: **24** Type: **not specified**

Introduction to machine learning

Friday 25 January 2019 09:00 (30 minutes)

Presenter: KAGAN, Michael Aaron (SLAC National Accelerator Laboratory (US))

Session Classification: Machine learning session

Contribution ID: **25** Type: **not specified**

The collider experience

Friday 25 January 2019 09:30 (30 minutes)

Presenter: PIERINI, Maurizio (CERN)

Session Classification: Machine learning session

Contribution ID: **26** Type: **not specified**

The neutrino experiment experience

Friday 25 January 2019 10:00 (30 minutes)

Presenter: ALONSO MONSALVE, Saul (University Carlos III (ES))

Session Classification: Machine learning session

Contribution ID: **27** Type: **not specified**

Physicist's summary talk

Friday 25 January 2019 15:00 (35 minutes)

Presenter: MCFARLAND, Kevin (University of Rochester)

Session Classification: Concluding session

Contribution ID: **28** Type: **not specified**

Statistician’s summary talk

Friday 25 January 2019 15:35 (35 minutes)

Presenter: VAN DYK, David (Imperial College)

Session Classification: Concluding session

Contribution ID: **29** Type: **not specified**

Summary of the day / discussions

Wednesday 23 January 2019 17:40 (30 minutes)

Presenter: JUNK, Tom (Fermi National Accelerator Lab. (US))

Contribution ID: **30** Type: **not specified**

Summary of the day / discussions

Thursday 24 January 2019 18:00 (30 minutes)

Presenter: JUNK, Tom (Fermi National Accelerator Lab. (US))

Contribution ID: **31** Type: **not specified**

Introduction to PHYSTAT-nu

Wednesday 23 January 2019 09:00 (10 minutes)

Presenter: BEHNKE, Olaf (Deutsches Elektronen-Synchrotron (DE))

Contribution ID: **32** Type: **not specified**

Discussion

Wednesday 23 January 2019 15:30 (10 minutes)

Session Classification: Session on systematic uncertainties

Contribution ID: **33** Type: **not specified**

Statistician talk 1

Contribution ID: **34** Type: **not specified**

Almost-perfect signal detection

Thursday 24 January 2019 10:00 (30 minutes)

Presenter: Prof. DAVISON, Anthony (EPFL)

Contribution ID: **35** Type: **not specified**

Discussion

Thursday 24 January 2019 15:30 (10 minutes)

Session Classification: Session on unfolding

Contribution ID: **36** Type: **not specified**

Discussion

Session Classification: Machine learning session

Contribution ID: **37** Type: **not specified**

Status of the MicroBooNE low-energy excess search and systematic uncertainties evaluation

MicroBooNE (the Micro Booster Neutrino Experiment) is a liquid argon time-projection chamber (LArTPC) experiment currently running at Fermilab, and is designed to study short-baseline neutrino physics. It aims to address the nature of the anomalous excess of low-energy electron-neutrino-like events observed by the previous MiniBooNE experiment. We will present the status of the low-energy excess search and will discuss the evaluation of the systematic uncertainties.

Author: Mr SOLETI, Stefano Roberto

Presenter: Mr SOLETI, Stefano Roberto

Session Classification: Welcome Reception and poster session

Contribution ID: **38** Type: **not specified**

Theoretical aspects of Machine Learning

Friday 25 January 2019 11:00 (30 minutes)

Presenter: SHAFER, Chad (CMU)

Session Classification: Machine learning session

Contribution ID: **39** Type: **not specified**

Discussion

Friday 25 January 2019 11:30 (10 minutes)

Session Classification: Machine learning session

Contribution ID: **40** Type: **not specified**

Statistica issues on the neutrino Mass Hierarchy determination

The determination of the neutrino Mass Hierarchy (MH) is one of the main goals of the major current and future neutrino experiments. The analysis usually proceeds from the $\Delta\chi^2$ estimator.
This estimator may show several draw-backs and concerns, together with a debatable strategy.
The author will discuss the needs for a clear strategy as well as the related sensitivity evaluation.
The issues on the MH determination from the reactor experiments will be further illustrated, starting from the limited power of the $\Delta\chi^2$.

Author: STANCO, Luca (Universita e INFN, Padova (IT))

Presenter: STANCO, Luca (Universita e INFN, Padova (IT))

Contribution ID: **41** Type: **not specified**

ReSyst: a novel technique to Reduce the Systematic uncertainty for precision measurementsReSyst: a novel technique to Reduce the Systematic uncertainty for precision measurements

We are in an era of precision measurements at the Large Hadron Collider. The precision that can be achieved on some of the measurements is limited however due to large systematic uncertainties. This paper introduces a new technique to reduce the systematic uncertainty by quantifying the systematic impact of single events and correlating it with event observables to identify parts of the phase space that are more sensitive to systematic effects. A proof of concept is presented by means of a simplified top quark mass estimator applied on simulated events. Even without a thorough optimization, it is shown that the total systematic uncertainty can be reduced by a factor of at least two.

Author: VAN MULDERS, Petra (Vrije Universiteit Brussel (BE))

Presenter: VAN MULDERS, Petra (Vrije Universiteit Brussel (BE))

Session Classification: Welcome Reception and poster session

Contribution ID: **42** Type: **not specified**

Bayesian analysis of multichannel measurements

A typical experiment in high energy physics is considered. The result of the experiment is assumed to be a histogram consisting of bins or channels with numbers of corresponding registered events. The expected background and expected signal shape or acceptance are measured in separate auxiliary experiments, or calculated by the Monte Carlo method with finite sample size, and hence with finite precision. An especially complex situation occurs when the expected background in some of the channels (usually at the right end of the physical histograms, where the expected signal to background ratio is maximal) happens to be zero due to either a fluctuation of the auxiliary measurement (or simulation) or because it is truly zero. Different statistical methods give different confidence intervals for the full signal rate and different significance of the signal+background hypothesis versus the pure background hypothesis. The Bayesian method is discussed in this report. Detailed analysis and numerical tests are presented. A simple modification of central intervals and a simple empirical rule for choosing priors for nuisance parameters allow the user to obtain credible intervals with the frequentist coverage. There is a method to find an optimal number of channels and to retain the claimed coverage.

Author: Dr SMIRNOV, Igor (Petersburg Nuclear Physics Institute (Russia))

Presenter: Dr SMIRNOV, Igor (Petersburg Nuclear Physics Institute (Russia))

Session Classification: Welcome Reception and poster session

Contribution ID: **43** Type: **not specified**

Pseudosignificances as figures of merit: a systematic study

Optimization problems in HEP often involve maximizing a measure of the sensitivity of the analysis to an hypothesis with respect to another; the latter is referred to as null hypothesis and in a frequentist framework is tested against the former, which is referred to as alternative hypothesis.

In most cases, it is desirable to fully compute the expected frequentist significance, accounting for all sources of systematic uncertainty and interpreting the result as the real sensitivity of the analysis to the effect sought.
Sometimes, however, either computational or conceptual reasons can favour the use of different or approximate figures of merit.

This work will review the most established frequentist and Bayesian definitions of sensitivity, including approximate significances, and compare them with the fully frequentist significances computed in toy analyses spanning a spectrum of typical HEP use cases. As a part of the comparison, frequentist coverage will be checked for the examined formulas.

Particular care will be taken for the case in which the available data are not enough to satisfy the asymptotic approximations, and the use of the Bartlett corrections to the first-order asymptotic approximation are explored.

Author: Dr VISCHIA, Pietro (Universite Catholique de Louvain (UCL) (BE))

Presenter: Dr VISCHIA, Pietro (Universite Catholique de Louvain (UCL) (BE))

Session Classification: Welcome Reception and poster session

Contribution ID: **45** Type: **not specified**

Introductory Statistics Course - Part I

Tuesday 22 January 2019 13:30 (1h 15m)

Presenter: LYONS, Louis (Imperial College (GB))

Session Classification: Introductory Statistics Course (voluntary participation)

Contribution ID: **46** Type: **not specified**

Introductory Statistics Course - Part II

Tuesday 22 January 2019 14:45 (1h 15m)

Presenter: COWAN, Glen (Royal Holloway, University of London)

Session Classification: Introductory Statistics Course (voluntary participation)

Contribution ID: **47** Type: **not specified**

Goodbye

Friday 25 January 2019 16:10 (10 minutes)

Presenter: SGALABERNA, Davide (CERN)

Session Classification: Concluding session

Contribution ID: **50** Type: **not specified**

Efficient Neutrino Oscillation Parameter Inference with Gaussian Process

Neutrinos are tiny sub-atomic particles that carry no electrical charge and interact with matter only through the weak nuclear force, which makes them extremely hard to detect. There are three distinct types of neutrinos, called "flavors": (ν_e, ν_μ, ν_τ), each of which can "oscillate" into the other with a detectable probability. Many experiments have been set-up to measure the parameters governing the oscillation probabilities accurately, with implications for the fundamental structure of the universe. Very often, this involves inferences from tiny samples of data which have complicated dependencies on multiple oscillation parameters simultaneously. This is typically carried out using the unified approach of Feldman and Cousins which is very computationally expensive, on the order of tens of millions of CPU hours. In this work, we propose an iterative method using Gaussian Process to efficiently find a confidence contour for the oscillation parameters and show that it produces the same results at a fraction of the computation cost.

Authors: Mr NAYAK, Nitish (University of California-Irvine); Mr LI, Lingge (University of California-Irvine); Prof. BIAN, Jianming (University of California-Irvine); Prof. BALDI, Pierre (University of California-Irvine)

Presenter: Mr NAYAK, Nitish (University of California-Irvine)

Contribution ID: **51** Type: **not specified**

ReMU – Data sharing in a forward-folding framework

The canonical way to make experimental neutrino-cross-section data available for comparison with different theories and other experiments is to unfold it.
The aim of this is to remove the detector effects and efficiencies from the data to release distributions of variables of interest in "truth space".
Depending on the available data, the detector properties, and the variables of interest, it is not always possible to do this though.
For example, the detector response might depend on variables that are not measurable by the detector.
If the distribution of events in those variables is not constrained by external measurements,
it is impossible to predict the actual detector response without depending on a theoretical model.
The unfolded results would thus become dependent on said model, introducing a theoretical bias in what is supposed to be an objective measurement.

In these (and other) cases it would be preferable to calculate the expected measured distributions for each model separately,
and compare those predictions to the real data in the smeared (i.e. reconstructed) space.
This should always be possible as the different models will have to predict some sort of distribution in all variables that could affect the detector,
even if those distributions are poorly motivated.
The act of bringing the model predictions in truth space to expected distributions of reconstructed (i.e. measured) quantities is called "forward-folding".

This is done on a regular basis within the experimental collaborations using detailed simulations of the detectors.
Events are generated according to a specific model and these events are then propagated through the detector one-by-one.
It requires a large amount of computing power and expert knowledge of the detectors.
Also, the simulation software is usually integrated closely in the software stack of the experiments.
All this makes it impractical or impossible to do a full detector simulation outside the collaborations.
To make the data usable by external interested parties, e.g. model builders or other experiments,
it would be necessary to provide a simpler way of forward-folding.

ReMU (Response Matrix Utilities) tries to solve this problem by modelling the detector with a response matrix that describes both the detector efficiency and smearing.
Expectation values in reconstructed space are generated by simply multiplying this matrix with the truth space distributions provided by the different models.
It offers all necessary machinery to build the response matrix from simulations and test arbitrary models against the data.
Both Frequentist and Bayesian methods for model testing and parameter estimation are available.
Systematic detector uncertainties, statistical uncertainties, and model nuisance parameters can all be handled with a few lines of code.

The main design goal of ReMU is ease of use.
Users are not required to be a Python, statistics, or detector experts to use a provided response matrix and compare their models to data.
It is implemented as a pure Python package and requires only standard scientific Python packages.
It supports Python 2.6, 2.7, and 3.x.
Official releases are distributed via the Python Package Index, so installing it is as easy as "pip install remu".

Author: KOCH, Lukas (Science and Technology Facilities Council)

Presenter: KOCH, Lukas (Science and Technology Facilities Council)

Session Classification: Welcome Reception and poster session

Contribution ID: **52** Type: **not specified**

Non-Parametric Bayesian Event Reconstruction in Super-Kamiokande

We present an update to a method for non-parametric, Bayesian neutrino event reconstruction for the Super-Kamiokande detector with the existing fiTQun event reconstruction framework, first reported at PhyStat-nu 2016 at the IPMU. Particle properties are determined in a way where the number of Cherenkov rings to be reconstructed, and therefore the number of parameters, is one of the unknowns. We discuss Bayesian model selection with Markov Chain Monte Carlo, future scalability and the issues surrounding non-parametric Bayesian reconstruction with fiTQun.

Author: Mr SZTUC, Artur (Imperial College London)

Presenter: Mr SZTUC, Artur (Imperial College London)

Session Classification: Welcome Reception and poster session

Contribution ID: **53** Type: **not specified**

Analysis review of JUNO Experiment

After three neutrino mixing angles and two independent neutrino mass squared differences have been measured, neutrino physics has entered the precision era. Neutrino mass hierarchy and CP violation phase are the two remaining important unknown properties which could be measured by next generation neutrino oscillation experiments. Jiangmen Underground Neutrino Observatory (JUNO) is constructing a 20 kton multi-purpose liquid scintillator detector with unprecedented 3\% energy resolution at 1 MeV. The main physics goal is to determine neutrino mass hierarchy with reactor antineutrino oscillation at baseline of 52.5 km with 3-4 sigma statistical significance. Besides, JUNO is also able to perform many other important neutrino physics measurements, including precision measurements of three neutrino oscillation parameters (θ_{12}, Δm^2_{21} and Δm^2_{32}), supernova neutrino detection, solar neutrinos, etc. In this talk, I will review the analysis techniques in the JUNO experiment.

Author: Dr LING, Jiajie (Sun Yat-sen University)

Presenter: Dr LING, Jiajie (Sun Yat-sen University)

Session Classification: Welcome Reception and poster session

Contribution ID: **54** Type: **not specified**

Implementation of a Feldman-Cousins Framework on Supercomputers and the Impact on NOvA Oscillation Results

The NOvA long-baseline neutrino and anti-neutrino oscillation results, by the nature of the measurements, feature low event counts in both the appearance and disappearance channels. When the low event counts are combined with the form of the fits that are needed to describe PMNS mixing, physical boundaries develop and have the potential to skew the statistical behavior of extracted parameters away from typical Gaussian behavior.

To determine the statistical significance of our results and account for the non-Gaussian nature of the statistics, the NOvA collaboration performs a procedure involving the empirical determination of the confidence interval. This procedure referred to as the "Feldman-Cousins" prescription, is an empirical, multi-universe approach that accounts for all the statistical correlations in our fits and includes the effects of the systematics and nuisance parameters.

We present here the implementation of the Feldman-Cousins calculations that was designed to run on High Performance "Super" Computers (HPC) and which was run on the NERSC facility's Cori-1, Cori-2 and Edison supercomputer in May 2018 to obtain the latest NOvA oscillation results. This implementation was able to perform the Feldman-Cousins corrections, that were projected to more than 5 months of dedicated computing on conventional HEP facilities, in 16 hours using the largest dedicated computing pool ever used in High Energy Physics. We also present the evolution of this approach that leverages the Theta supercomputer at the Argon Leadership Computing Facility (ALCF) and expands to the calculations to use an adaptive MPI based approach.

Author: CALVEZ, Steven (Colorado State University)

Co-author: NORMAN, Andrew (Fermilab)

Presenter: CALVEZ, Steven (Colorado State University)

Session Classification: Welcome Reception and poster session

Contribution ID: **55** Type: **not specified**

Searches for New Physics in the Short Baseline Neutrino Program at Fermilab with SBNfit

SBNFit is a software framework designed for the purpose of performing simultaneous fits across data from multiple, correlated distributions. Although extremely modular and generic, an ideal application is the searches for new physics at the Short Baseline Neutrino (SBN) experimental program at Fermilab. SBN comprises three experiments: MicroBooNE, SBND, and ICARUS, each of which can perform measurements of neutrino event rates at a distinct distance from the neutrino source in the Fermilab Booster Neutrino Beamline. Since each detector shares the same neutrino flux and argon cross-sections, these measurements are highly correlated. These correlations can be further exploited to reduce systematic uncertainties by performing multiple side-by-side channel fits, allowing us to ask deeper questions about the underlying physics behind our observations. We explore this with a case study of how a muon neutrino sample can be used to constrain backgrounds in electron neutrino appearance studies.

Author: CIANCI, Davio (Columbia University)

Presenter: CIANCI, Davio (Columbia University)

Session Classification: Welcome Reception and poster session

Contribution ID: **56** Type: **not specified**

Machine Learning methods for JUNO Experiment

Jiangmen Underground Neutrino Observatory (JUNO) experiment is a multipurpose neutrino experiment, aiming to determine the unknown neutrino mass ordering and precisely measure the neutrino oscillation parameters. JUNO consists of a central detector with 20 kt liquid-scintillator target and muon veto detectors. 18,000 20-inch PMTs will be installed in central detector, in order to achieve 3% energy resolution at 1 MeV. Challenging physics goals as well as the large amount of collected data require advanced analysis techniques, in which the machine learning algorithms have been successfully used in some collider experiments and neutrino experiments. In JUNO, we have implemented several kinds of machine learning algorithms for particle identification and event reconstruction, and some work has been done to find out the optimal method for JUNO. In this talk, some preliminary results will be reported.

Author: Mr XU, Yu (IKP2 FZJ)

Presenter: Mr XU, Yu (IKP2 FZJ)

Session Classification: Contributed talks session

Contribution ID: **57** Type: **not specified**

Regularisation for T2K cross-section analyses

Due to the limited number of events available and finite resolution of detectors, unfolding measurements of neutrino interaction cross sections is a statistically ill-posed problem. To address this, T2K analyses employ several different methods of regularisation. A particular effort has been made to mitigate the potential bias associated with choosing the termination of Expectation-Maximisation iterations (often called D'Agostini iterations) based on mock-data studies by moving to more data-driven techniques (such as the L-Curve scan). In this contribution we present the current analysis techniques alongside planned improvements with a view to receiving feedback from the particle physics statistics community

Contribution ID: **58** Type: **not specified**

Analytical Multivariate Fit and Sensitivity Studies in the Borexino Solar Neutrino Analysis

The Borexino detector, located at the Laboratori Nazionali del Gran Sasso in Italy, is a liquid scintillator detector with a primary goal to measure solar neutrinos. The spectral fit of the energy spectrum has been performed for the first time in the whole energy range from 0.19 up to 2.93 MeV. This approach made it possible to obtain the fluxes of 7Be, pp, and pep solar neutrinos simultaneously. To increase the sensitivity for pep and CNO neutrinos, the multivariate fit technique has been developed, which takes into account additional information of the radial and pulse shape distributions of events. The current limit on CNO neutrinos was obtained by fixing the theoretically well-known ratio of the expected rates between pp and pep neutrinos, as obtained from the standard solar models. In addition to this approach, sensitivity to CNO neutrinos using other methods are under study. The talk shows the analytical multivariate fitting strategy used to obtain the new Borexino results for the 7Be, pp, and pep rates and the sensitivity of the Borexino detector to measure CNO neutrinos. This talk is presented in the name of the Borexino Collaboration.

Author: Mr PENEK, Omer (IKP-2 Forschungszentrum Juelich)

Co-author: Prof. LUDHOVA, Livia (IKP-2 Forschungszentrum Juelich)

Presenter: Mr PENEK, Omer (IKP-2 Forschungszentrum Juelich)

Session Classification: Welcome Reception and poster session

Contribution ID: **63** Type: **not specified**

\texttt{GooStats}: A GPU-based framework for multi-variate analysis in particle physics

\texttt{GooStats} is a software framework that provides a flexible environment and common tools to implement multi-variate statistical analysis. The framework is based on C++11, CERN ROOT, MINUIT, and \texttt{GooFit}, a popular minimization engine that can run on general purpose graphics processing units. Running a multi-variate analysis in parallel on graphics processing units yields a huge boost in performance and opens new possibilities. The design and benchmark of \texttt{GooStat} will be presented along with its application to the analysis of solar neutrinos of Borexino and JUNO.

Author: DING, Xuefeng (Gran Sasso Science Insitute (INFN))

Presenter: DING, Xuefeng (Gran Sasso Science Insitute (INFN))

Session Classification: Contributed talks session

Contribution ID: **64** Type: **not specified**

Statistical Models with Uncertain Error Parameters

In a statistical analysis in Particle Physics, nuisance parameters can be introduced to take into account various types of systematic uncertainties. The best estimate of such a parameter is often modeled as a Gaussian distributed variable with a given standard deviation (the corresponding "systematic error"). Although the assigned systematic errors are usually treated as constants, in general they are themselves uncertain. A type of model is presented where the uncertainty in the assigned systematic errors is taken into account. Estimates of the systematic variances are modeled as gamma distributed random variables. The resulting confidence intervals show interesting and useful properties. For example, when averaging measurements to estimate their mean, the size of the confidence interval increases for decreasing goodness-of-fit, and averages have reduced sensitivity to outliers. The basic properties of the model are presented and several examples relevant for Particle Physics are explored.

Author: COWAN, Glen (Royal Holloway, University of London)

Presenter: COWAN, Glen (Royal Holloway, University of London)

Session Classification: Contributed talks session

Contribution ID: **65** Type: **not specified**

Statistical methods and issues in sterile neutrino searches

The statistical issues related to the search for sterile neutrinos are reviewed with focus on short-baseline appearance and disappearance experiments. The sensitivities for limit setting and signal discovery are discussed along with their dependency on the experimental parameters, including the signal rate and the spectral shape. Our baseline analysis is built on a profile-likelihood test statistic that extends the unified approach of Feldman and Cousins by introducing nuisance parameters for the signal and background rate. We examine the differences between methods based on a local and global p-value, and explore the limitations of approaches relying on a Gaussian approximation and the Asimov data set. Our work is particularly relevant given that a large number of sterile neutrino experiments is currently running and in the process of releasing new results.

Author: NEUMAIR, Birgit (Technical University of Munich (TUM))

Co-author: AGOSTINI, Matteo (Technical University Munich)

Presenter: NEUMAIR, Birgit (Technical University of Munich (TUM))

Session Classification: Welcome Reception and poster session

Contribution ID: **66** Type: **not specified**

ESSnuSB, a new facility to discover CP violation in leptonic sector in Europe.

The large value of the last mixing angle of the PMNS mixing matrix measured by reactor experiments enable the search for CP violation in leptonic sector with a new generation of neutrino super beams. The ESSnuSB project proposes to use the European Spallation Source (ESS) based in Sweden to elaborate a high intensity neutrino super beam. The LINAC of this facility, under construction, will produce 5 MW proton beam with 2 GeV energy by 2023 and will be upgraded hereafter to produce in addition a neutrino super beam. This will require in addition an accumulator located at the end of the LINAC to reduce the initial time width of the proton pulses. The combination of the high beam intensity and these low energy protons allows the neutrino measurements to be made with a megaton Water Cherenkov detector installed 1000 m down in a mine at about 500 km from the neutrino source which is near the position of the second neutrino oscillation maximum. The use of this type of detector will extent the physics program to proton–decay, atmospheric neutrinos and astrophysics searches.

This project is now supported by the COST Action CA15139 "Combining forces for a novel European facility for neutrino-antineutrino symmetry-violation discovery" (EuroNuNet). It has also received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 777419.

Author: Dr BAUSSAN, Eric (IPHC)

Presenter: Dr BAUSSAN, Eric (IPHC)

Session Classification: Welcome Reception and poster session

Contribution ID: **67** Type: **not specified**

Updated Results for the Search for $\bar{\nu}_\mu \to \bar{\nu}_e$ Oscillations from T2K in the 3-flavour Framework

I report the results of a search for $\bar{\nu}_\mu \to \bar{\nu}_e$ oscillations at the T2K experiment in a 3-flavour framework. An exposure of 1.49×10^{21} Protons On Target (POT) is used in ν mode and 1.63×10^{21} POT in $\bar{\nu}$ mode; an increase of 46% in the $\bar{\nu}$ exposure compared to results reported in June 2018.

Results are reported for a joint analysis where candidate events are selected from the e-like events observed in $\bar{\nu}$ running mode. In order to obtain the best possible constraint on $\bar{\nu}_e$ appearance, observations from four other far detector event samples (across both ν and $\bar{\nu}$ modes) are used in conjunction with near-detector data. These observations constrain the values of the oscillation and systematic parameters, including the mass-hierarchy.

Two hypotheses are tested: a) no appearance and b) $\bar{\nu}_e$ appearance according to the current best knowledge of the PMNS matrix. Both rate-only and rate+shape analyses are performed, producing p-values for each hypothesis. A description is given of the method used to constrain the parameters and the treatment of priors used to generate distributions of the rate-only and rate+shape test statistics.

Authors: Mr BENCH, Francis (The University of Liverpool); ANDREOPOULOS, Costas (University of Liverpool & STFC Rutherford Appleton Laboratory); Mr BARRY, Chistopher (The University of Liverpool); CHAPPELL, Andrew (University of Warwick); DEALTRY, Thomas (RAL & University of Oxford); DENNIS, Stephen Robert (University of Liverpool); SGALABERNA, Davide (CERN); SHAH, Raj (Oxford University)

Presenter: Mr BENCH, Francis (The University of Liverpool)

Session Classification: Welcome Reception and poster session

Contribution ID: **69** Type: **not specified**

Uncertainty in the Reactor Neutrino Specrum and the Mass Hierarchy Determination

In the next years reactor neutrino experiments, like JUNO or RENO 50, will attempt to determine the mass hierarchy. There are many problems that need to be overcome to accomplish this task, one of them is the theoretical uncertainty in the spectrum. Indeed, as became clear a few years ago with the measurement of the "5 MeV bump", the theoretical models that predict the reactor neutrino spectrum do not fit very well with the experimental results; moreover the current experimental data was obtained with an energy resolution considerably lower than the one required to identify the mass hierarchy, so it is possible that an eventual fine structure of the spectrum could be present and undetected, even if it is large enough to affect the determination of the hierarchy. This is one of the reasons why, recently, it was proposed to add a near detector to the JUNO experiment. I will discuss a model-independent way to treat the spectrum uncertainty and the effect that it will have on the final result, as a function of the mass of the near detector. Another possible complication could arise from the fact that the near detector will receive neutrinos only from one reactor core, while the JUNO far detector will be able to see neutrinos coming from two different power plants (each one with several reactor cores); moreover the two complexes use different models of nuclear reactor, hence the chemical composition of the fuel used will be different: since the neutrino spectrum depends on the chemical composition of the fuel, the near and the far detector will probably see two different spectra. I will show that, taking into account the time evolution of the chemical composition of the fuel in the reactor core, it is possible to reconstruct the far detector spectrum from the near detector data; I will show how the sensitivity to the mass hierarchy can be affected by different methods of reconstructing the spectrum.

Author: Prof. CIUFFOLI, Emilio (IMP, CAS)

Presenter: Prof. CIUFFOLI, Emilio (IMP, CAS)

Session Classification: Statistical issues in neutrino experiments and contributed talks

Contribution ID: **71** Type: **not specified**

NOvA's $\nu_e + \nu_\mu$ oscillation analysis

NOvA is an experiment devoted to studying neutrino oscillations in the NuMI neutrino beam from FNAL (USA). It is a long-baseline experiment consisting of two functionally identical, finely granulated detectors which are separated by 810 km of Earth crust and sited at 14 mrad off the beam axis. By measuring the transition probabilities P($\nu_\mu \to \nu_e$) and P($\nu_\mu \to \nu_\mu$) NOvA is able to extract oscillation parameters: Δm^2_{32}, mixing angle θ_{23}, CP violating phase δ_{CP} and neutrino mass hierarchy.

The most recent analysis was the first to include both neutrino ($9 \cdot 10^{20}$ POT) and antineutrino ($7 \cdot 10^{20}$ POT) data, which helps to resolve the "octant θ_{23} - hierarchy - δ_{CP}" degeneracies in the oscillation probability. NOvA performed a joint analysis of ν_e appearance and ν_μ disappearance channels in both neutrino and antineutrino modes, with systematic uncertainties included as pull terms. This procedure helped to set new restrictions on the oscillation parameters.

This talk will discuss the NOvA joint $\nu_e + \nu_\mu$ analysis chain, systematic treatment, and details of the fit for oscillations.

Author: KOLUPAEVA, Liudmila

Presenter: KOLUPAEVA, Liudmila

Session Classification: Welcome Reception and poster session

Contribution ID: **72** Type: **not specified**

Look-elsewhere effect in neutrino oscillation searches

The look-elsewhere effect is a familiar issue to collider experiments, and occurs, for example, when a search is performed for a new resonance that is not predicted under the null hypothesis. Many searches for sterile neutrinos employ a similar strategy: looking for evidence of oscillation between two active flavours at an unknown mass-squared splitting. As with collider searches, this results in a family of alternatives, which must be taken into account to correctly calculating the significance of any apparent signal. Although this issue appears to be recognised among collaborations, there is no common "rule of thumb" for how to treat it, as oscillation signatures are not localised to any particular region of the data. Here we investigate an approach, originally proposed by Davies and subsequently refined by Gross and Vitells, that has been recently adopted in collider searches but does not yet appear to have been tried in neutrino oscillations searches.

Authors: Dr LITCHFIELD, Phillip (Imperial College, London); WALDRON, Abbey (Imperial College London)

Presenter: Dr LITCHFIELD, Phillip (Imperial College, London)

Session Classification: Statistical issues in neutrino experiments and contributed talks

Contribution ID: **73** Type: **not specified**

Supernova neutrino signal detection in the NOvA experiment

Detection of galactic supernova neutrinos can provide a valuable information on both supernova physics and neutrino properties.
The large liquid-scintillator detectors of NOvA experiment can be used for such measurement. A dedicated triggering system was designed to perform real-time reconstruction and search for supernova neutrino interaction candidates, extract the time profile of the observed signal and make a decision about the supernova observation.
Unlike many other neutrino detectors NOvA has low overburden. Observation of a supernova neutrino signal in presence of the background, introduced by cosmic rays, requires additional statistical techniques.
The binned likelihood functions are applied to enhance the significance of the observation based on the signal shape.
Also, the combination of observations from both NOvA detectors can provide a better sensitivity to the supernova signal.

Author: SHESHUKOV, Andrey (JINR)

Presenter: SHESHUKOV, Andrey (JINR)

Session Classification: Statistical issues in neutrino experiments

Contribution ID: **74** Type: **not specified**

Simulating Light in Large Volume Detectors Using Metropolis Light Transport

In gigaton scale neutrino detectors, such as the IceCube experiment, interaction products are detected by the Cherenkov radiation emitted by their passage through the detector medium. Simulating this propagation of light is traditionally approached through ray tracing. This is complicated by the sparsity of the detector: the vast majority of light rays are scattered and absorbed by the detector medium, with only a tiny fraction finding their way to a light sensitive element. In this presentation, I develop an alternative method, based on the Metropolis light transport algorithm used in the CGI industry. This method poses the problem as a classical path integral, and samples only the paths of light rays that end on a light sensitive element using a Markov chain Monte-Carlo. This yields a significant performance increase of up to 1000 times compared to ray tracing when simulating the timing distribution of light detected by a photo-sensitive element.

Author: COLLIN, Gabriel

Presenter: COLLIN, Gabriel

Session Classification: Contributed talks session

Contribution ID: **75** Type: **not specified**

Reactor Anti-neutrino Data in Global Analyses

I will explain the role of reactor anti-neutrino data in the global analyses performed for standard neutrino oscillations (within the NuFit collaboration) and in scenarios involving sterile neutrinos.

The modern medium baseline reactor experiments, L˜Km, can determine the neutrino mixing angle \theta_{13} and give a complementary determination to the long baseline experiments of the atmospheric mass splitting. Their synergies are relevant to the determination of this mass splitting and the \theta_{23} octant.

The modern short baseline reactor experiments, L˜ 10m, are crucial for the study of the reactor anti-neutrino anomaly in terms of sterile oscillations, since their analysis is based on ratios of relative measured reactor spectra, as well as the modern medium baseline ones, what makes the analyses independent of reactor anit-neutrino flux predictions.

I will focus on the technical details of the analysis: which data do we take, how do we analyse them, which systematic errors do we assume, and how do we implement them. Furthermore I will discuss how do we combine many different experiments into a global analysis.

Author: HERNANDEZ CABEZUDO, Alvaro

Co-authors: SCHWETZ-MANGOLD, Thomas; GONZALEZ-GARCIA, Maria Concepcion; MALTONI, Michele; KOPP, Joachim; MACHADO, Pedro; MARTINEZ-SOLER, Ivan; DENTLER, Mona; ESTEBAN, Ivan

Presenter: HERNANDEZ CABEZUDO, Alvaro

Session Classification: Contributed talks session

Contribution ID: **76** Type: **not specified**

Tuning the pion production on free nuclei with GENIEv3

GENIE (http://www.genie-mc.org/) is one of the most used event generator for neutrino experiments. The collaboration has a continuous effort to improve its prediction by adding new models and tune them against data. For the future experiments, the description of single and double pion production is fundamental and yet there is not a single model that describes simultaneously resonant, non-resonant and DIS interactions. The modelling of this transition region is left to the generators and a number empirical models are used to achieve this goal. GENIE has addressed the modelling of pion production at the free nucleon level with a new tune using deuterium data from ANL-12ft, BNL-7ft, BEBC and FNAL 15-ft bubble chamber experiments. The shallow inelastic scattering region has been tuned against ν_μ and $\bar{\nu}_\mu$ CC inclusive, one pion and two pion integrated cross sections. The global fit describes both inclusive and exclusive cross sections simultaneously, improving the agreement for ν_μCC pπ^+, nπ^+, pπ^0 and p$\pi^+\pi^-$ cross sections on free nucleon.

Author: TENA VIDAL, Julia (University of Liverpool)

Presenter: TENA VIDAL, Julia (University of Liverpool)

Session Classification: Welcome Reception and poster session

Contribution ID: **77** Type: **not specified**

GNA – high performance fitter for large-scale analyses.

Statistical data analysis of modern experiments deals with large-scale models with hundreds of nuisance parameters. Direct application on statistical methods such as likelihood profiling, Bayesian methods and especially Feldman-Cousins procedure can lead to extensive numerical computations. In order to facilitate the growing need for flexible and high-performance analysis tools to deal with complex models we have developed the GNA framework. Models of experiments are defined in runtime in terms of directed acyclic graph that describes a flow of computations. Each node of the graph represents independent physical part of the model such as oscillation probability, cross section and etc. It provides transparent and flexible configuration of the models. Each node is implemented in C++ using Eigen, Boost and ROOT to achieve high performance.
The current status of the framework, overview of multithreading and GPU computing support in the framework and first results of analysis of reactor antineutrino experiments are provided in this talk.

Author: Mr TRESKOV, Konstantin (Joint Institute for Nuclear Research)

Co-authors: Dr GONCHAR, Maxim (Joint Institute for Nuclear Research); Ms FATKINA, Anna (Joint Institute for Nuclear Research); NAUMOV, Dmitri (Joint Inst. for Nuclear Research (RU))

Presenter: Mr TRESKOV, Konstantin (Joint Institute for Nuclear Research)

Session Classification: Welcome Reception and poster session

Contribution ID: **80** Type: **not specified**

Supernova neutrino signal detection in the NOvA experiment:

Thursday 24 January 2019 09:30 (25 minutes)

Presenter: SHESHUKOV, Andrey (JINR)

Session Classification: Statistical issues in neutrino experiments

Contribution ID: **81** Type: **not specified**

Almost-perfect signal detection

Presenter: Prof. DAVISON, Anthony (EPFL)

Session Classification: Statistical issues in neutrino experiments

Contribution ID: **82** Type: **not specified**

Short-Baseline experiments

Thursday 24 January 2019 12:00 (30 minutes)

Presenter: Prof. KARAGIORGI, Georgia (CU)

Session Classification: Statistical issues in neutrino experiments and contributed talks

Contribution ID: **83** Type: **not specified**

Uncertainty in the Reactor Neutrino Spectrum and the Mass Hierarchy

Thursday 24 January 2019 11:00 (15 minutes)

Presenter: CIUFFOLI, Emilio (IMP, CAS)

Session Classification: Statistical issues in neutrino experiments and contributed talks

Contribution ID: **84** Type: **not specified**

Look-elsewhere effect in neutrino oscillation searches:

Thursday 24 January 2019 11:15 (15 minutes)

Presenter: LITCHFIELD, Phillip (Imperial College, London)

Session Classification: Statistical issues in neutrino experiments and contributed talks

Contribution ID: **85** Type: **not specified**

Statistical issues on the neutrino Mass Hierarchy determination

Thursday 24 January 2019 11:45 (15 minutes)

Presenters: SAWY, Fatma Helal (ENHEP Egyptian Network of High Energy Physics (EG)); SAWY, Fatma (INFN Padova)

Session Classification: Statistical issues in neutrino experiments and contributed talks

Contribution ID: **86** Type: **not specified**

Regularisation for T2K cross-section analyses

Thursday 24 January 2019 16:10 (25 minutes)

Presenter: DOLAN, Stephen (University of Oxford)

Session Classification: Contributed talks session

Contribution ID: **87** Type: **not specified**

A new unified perspective on the problem of limited Monte Carlo for likelihood calculations

Thursday 24 January 2019 16:35 (25 minutes)

Presenter: GLÜSENKAMP, Thorsten (Universität Erlangen-Nürnberg)

Session Classification: Contributed talks session

Contribution ID: **88** Type: **not specified**

Statistical Models with Uncertain Error Parameters

Thursday 24 January 2019 17:00 (25 minutes)

Presenter: COWAN, Glen (Royal Holloway, University of London)

Session Classification: Contributed talks session

Contribution ID: **89** Type: **not specified**

Review of Linear Algebra Applications in Some Recent Neutrino Experiments

Thursday 24 January 2019 17:25 (30 minutes)

Presenter: QIAN, Xin (Brookhaven National Laboratory)

Session Classification: Contributed talks session

Contribution ID: **90** Type: **not specified**

Machine Learning methods for JUNO Experiment

Friday 25 January 2019 11:40 (15 minutes)

Presenter: XU, Yu

Session Classification: Contributed talks session

Contribution ID: **91** Type: **not specified**

Simulating Light in Large Volume Detectors Using Metropolis Light Transport

Friday 25 January 2019 11:55 (15 minutes)

Presenter: COLLIN, Gabriel

Session Classification: Contributed talks session

Contribution ID: **92** Type: **not specified**

A GPU-based framework for multi-variate analysis in particle physics

Friday 25 January 2019 12:10 (15 minutes)

Presenters: DING, Xuefeng (Gran Sasso Science Insitute (INFN)); DING, Xuefeng (INFN - National Institute for Nuclear Physics)

Session Classification: Contributed talks session

Contribution ID: **93** Type: **not specified**

Efficient Neutrino Oscillation Parameter Inference with Gaussian Processes

Friday 25 January 2019 14:00 (25 minutes)

Presenter: NAYAK, Bannanje Nitish (University of California Irvine (US))

Session Classification: Contributed talks session

Contribution ID: **94** Type: **not specified**

Reflections on the 20th year of Feldman-Cousins: Hypothesis testing of a point null vs a continuous alternative

Friday 25 January 2019 14:25 (25 minutes)

Presenters: COUSINS JR, Robert (University of California Los Angeles (US)); COUSINS JR, Robert (University of California Los Angeles (US))

Session Classification: Contributed talks session

Contribution ID: **95** Type: **not specified**

Reactor Anti-neutrino Data in Global Analyses

Thursday 24 January 2019 11:30 (15 minutes)

Presenter: HERNANDEZ CABEZUDO, Alvaro (Karlsruhe Institute of Technology (KIT))

Session Classification: Statistical issues in neutrino experiments and contributed talks

Contribution ID: **96** Type: **not specified**

Introduction to Unfolding

Thursday 24 January 2019 14:00 (30 minutes)

Presenter: KUUSELA, Mikael (Carnegie Mellon University (US))

Session Classification: Session on unfolding