Theoretical and Mathematical Physics

Laboratory “Theory of Elementary Particles”

Current array of science research projects (2005-2009):

• centered around various ***major trends*** in modern theoretical and mathematical physics;

• executed within the framework of a ***broad international collaboration*** with leading international centers such as *CERN (Geneva), ICTP* and *SISSA (Trieste), JINR (Dubna),* as well as with numerous leading universities and academic research institutions in *Austria, Belgium, Finland, France, Germany, Greece, Hungary, Israel, Italy, Romania, Russia, Serbia, Spain, Switzerland, United Kingdom, United States of America*.

• Participation in ***four large EC networks***: FP5 “*EUCLID*” (2002-2006) **HPRN-CT-2002-00325**, FP6 “*Forces-Universe*” (2004-2008) **MRTN-CT-2004-005104,** FP6 “*HEP-Tools*” (2006-2010) **MRTN-CT-2006-03550,** FP7 **TMD network** *“Mapping out the Transverse Structure of the Nucleon”*

• **Organizer** of ***6 representative international conferences***, including 1 annual workshop of the FP6 (2008) EC network

- ***Scientific staff – 29 +*** 1 secretary

Full professors - 6, assoc. professors – 16, assist. prof. – 5, researchers - 2

- ***Total number of publications*** **(2005-2009): 213**

105 in international journals with impact factor

By years: 2005 - 15, 2006 - 19, 2007 - 21, 2008 - 26, 2009 - 24

108 in international conference proceedings

By years: 2005 - 34, 2006 - 20, 2007 - 23, 2008 - 12, 2009 - 19

- ***Total number of citations*** appeared in 2005-2009: **1721**

Total number of independent citations by years:

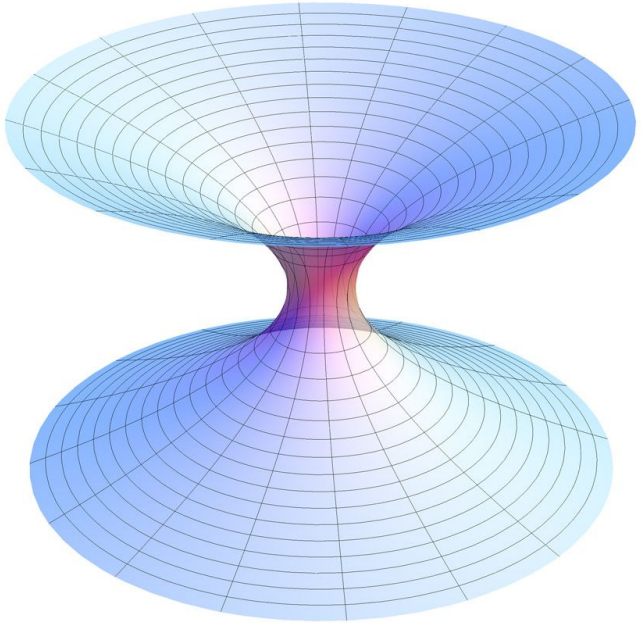
2005 - 330, 2006 - 316, 2007 - 342, 2008 - 356, 2009 - 367

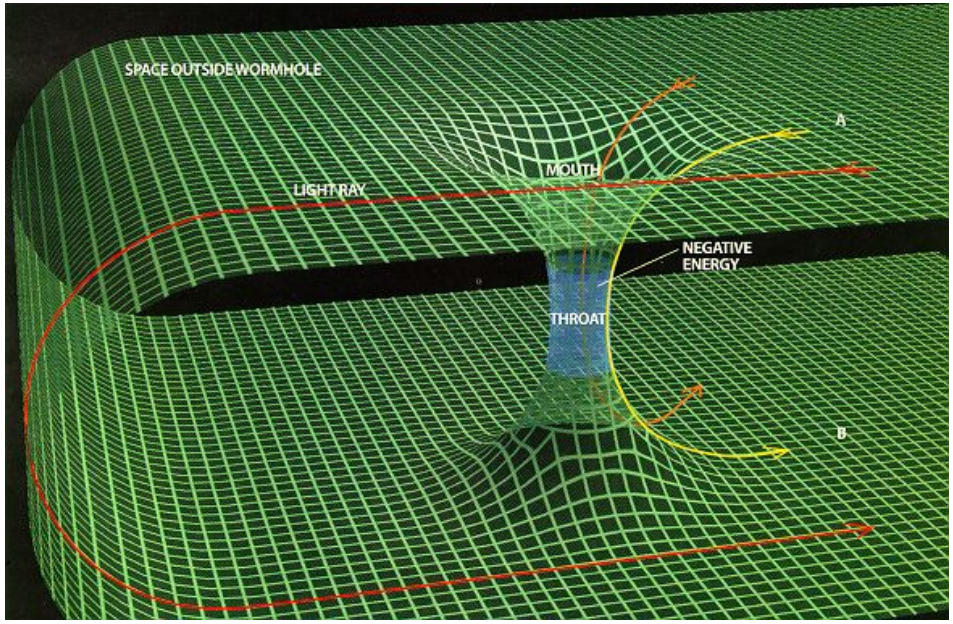
- ***Defended thesises*** in the period 2005-2009:

Ph.D. thesises – 1, “Doctor of Sciences” thesises - 4

- ***Doctoral students*** in the period 2005-2009: 4

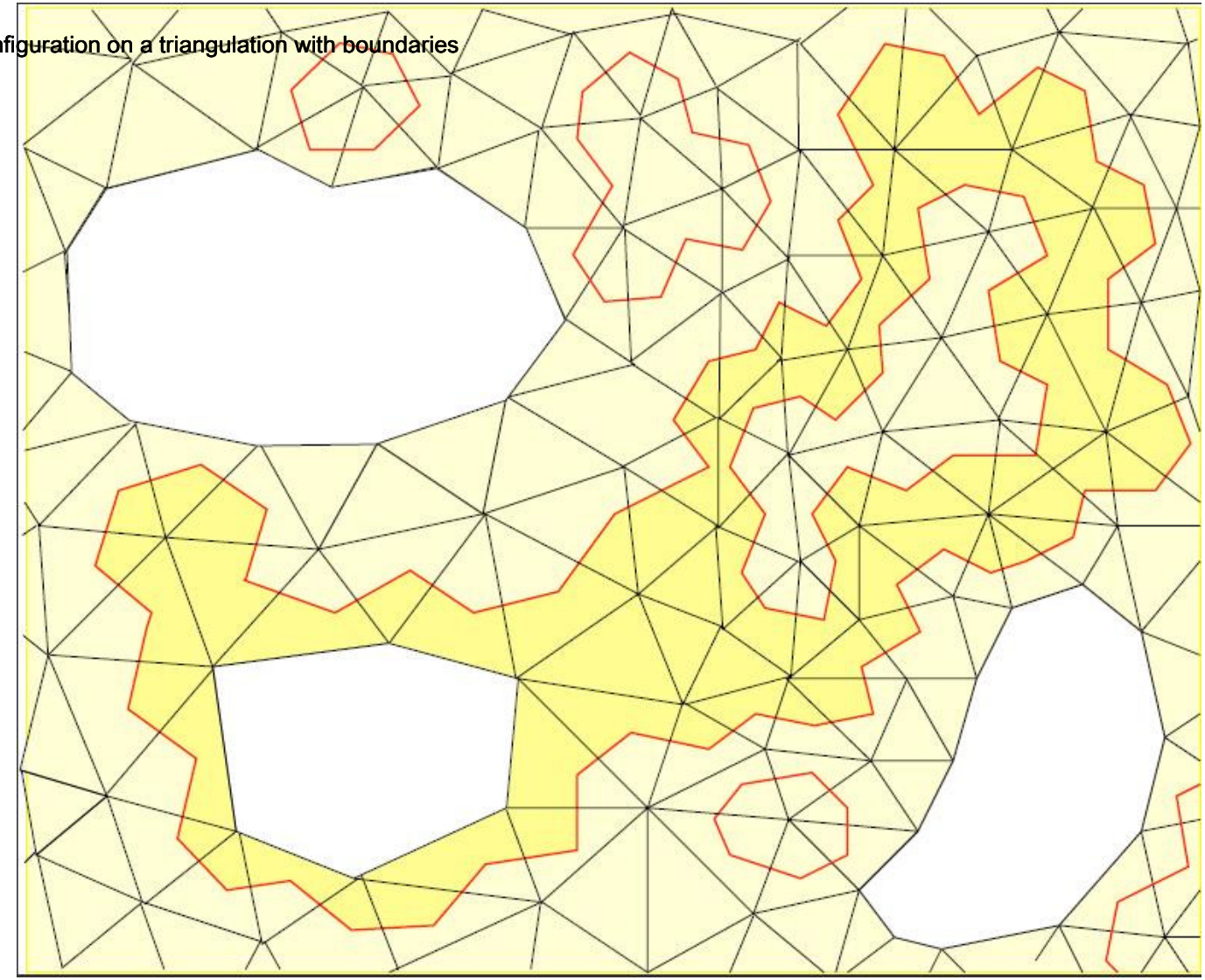
Studies of the quantum structure and geometric nature of the fundamental forces between elementary particles at (ultra-)high energies





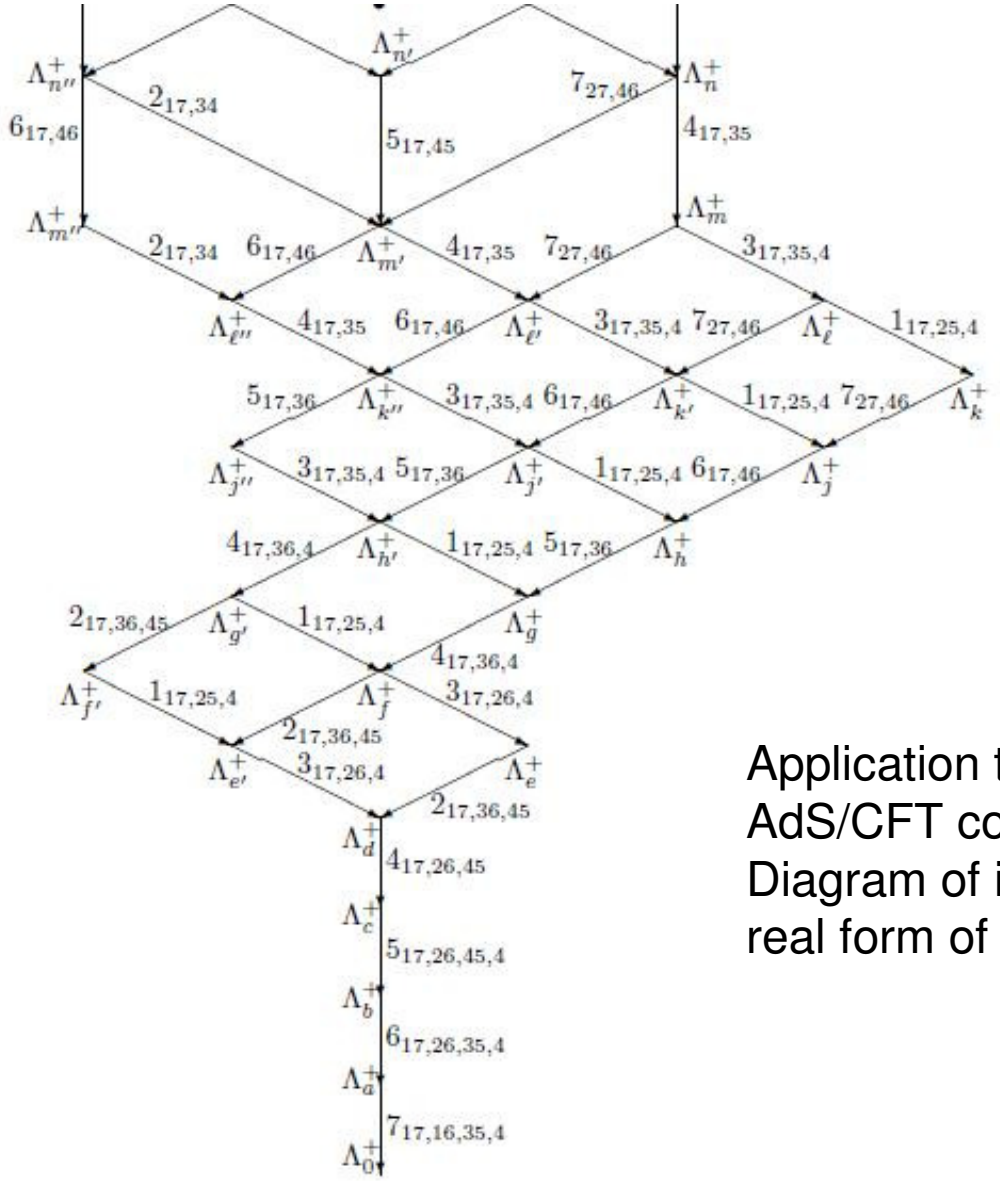
- Motivated by the advent of ***string theory*** as a central and most promising model of a unified theory of all fundamental forces in Nature
- Dualities between strings versus gravity and gauge theories of elementary particles interactions
- Cosmological aspects – black holes in higher-dimensional general relativity, wormholes and “brane worlds” (parallel universes)
- Get deeper insights into the structure and behaviour of matter at very short distances
- Main impact - address some of the core questions on the structure, origin and future of our Universe

A loop configuration on a triangulation with boundaries



A loop configuration on a triangulation with boundaries

String theory encompasses the achievements of many branches of theoretical physics, at the same time applying the tools of modern pure and applied mathematics and inspiring new progress in these most advanced fields.



Application to Conformal Field Theory and AdS/CFT correspondence (Maldacena duality): Diagram of invariant differential operators for a real form of the exceptional group *E7*

➢ Contribute to confirmation of the famous Maldacena duality - fundamental milestone of modern non-perturbative string theory .

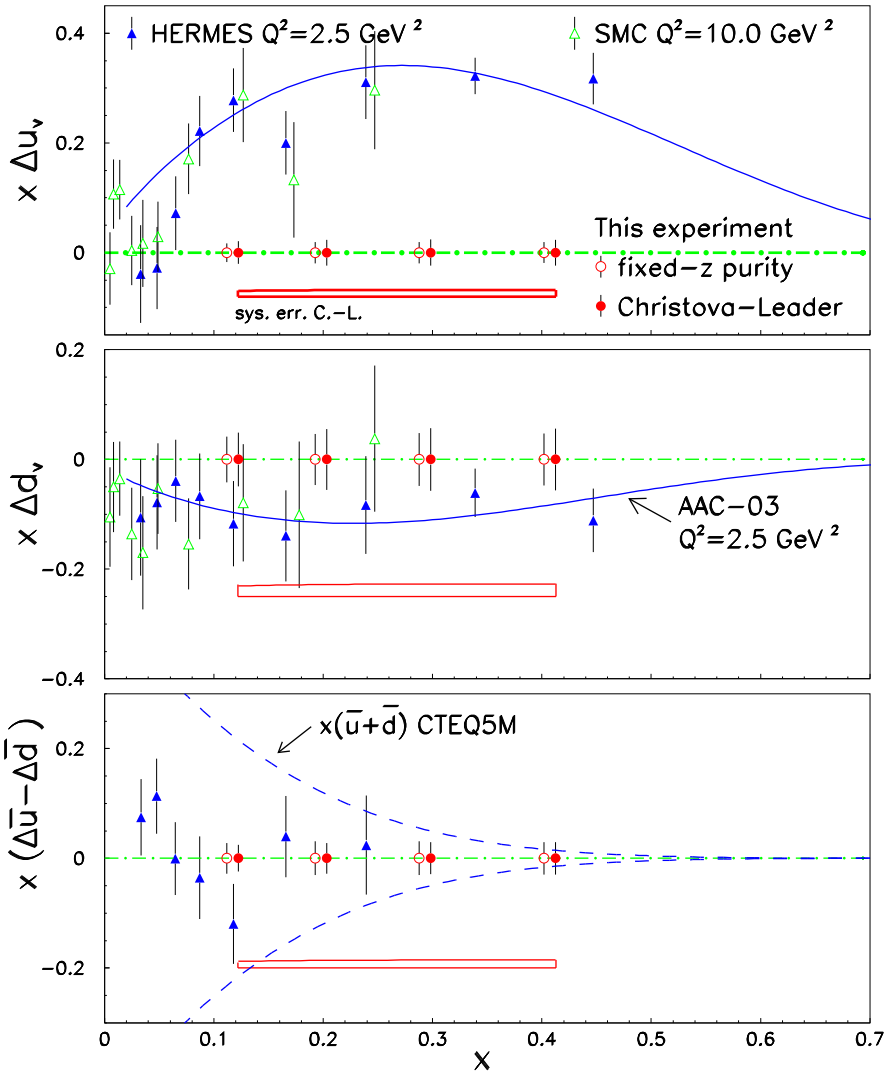
➢ It will lead to a revolutionary breakthrough in understanding :
(a) how string theory as the fundamental theory of all forces in Nature selects its various ground states;
(b) symmetries of the latter and the patterns of subsequent dynamical symmetry breakings:
(c) pertinent spectra of fundamental particles;
(d) how all this will ultimately explains the presently observed world of elementary particles and their fundamental interactions at the presently available collision energies in modern particle accelerators.

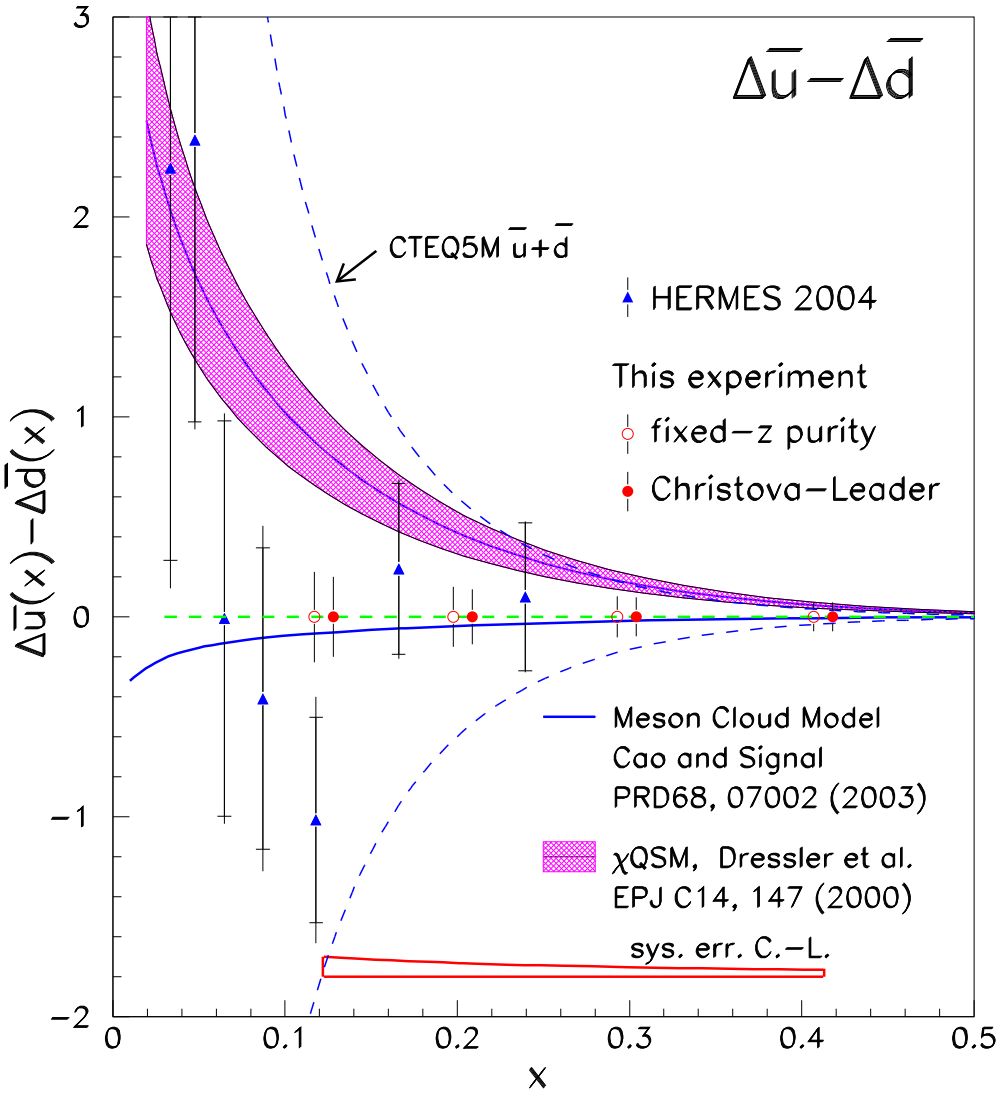
❑ New types of brane-world scenarios, where “our Universe” is a lightlike brane from the point of view of the embedding higher-dimensional space, are expected to shed new light on the intrinsic dynamics of the brane-world itself with respect to the extra space dimensions.

❑ Expect to achieve via lightlike brane-world scenarios a natural explanation for the practical unobservability of the extra space dimensions from the point of view of standard observers confined on “our Universe”.

Studies of the structure of nucleon and lepton-nucleon processes

- understanding of the internal spin structure of the nucleon
- knowledge of the polarized quark and gluon densities is essential for interpreting the results of modern high-energy physics experiments testing crucial aspects of the Standard Model of fundamental particle interaction and beyond it (Jefferson Lab, CERN, DESY and Brookhaven).
- polarized structure functions of the proton used to refine earlier estimates of the proton polarizability correction to the hyperfine splitting in muonic hydrogen and to extract from experimental data an improved value of proton radius. The process of muon capture in muonic hydrogen is analyzed in a search for new data on the weak lepton-nucleon interactions



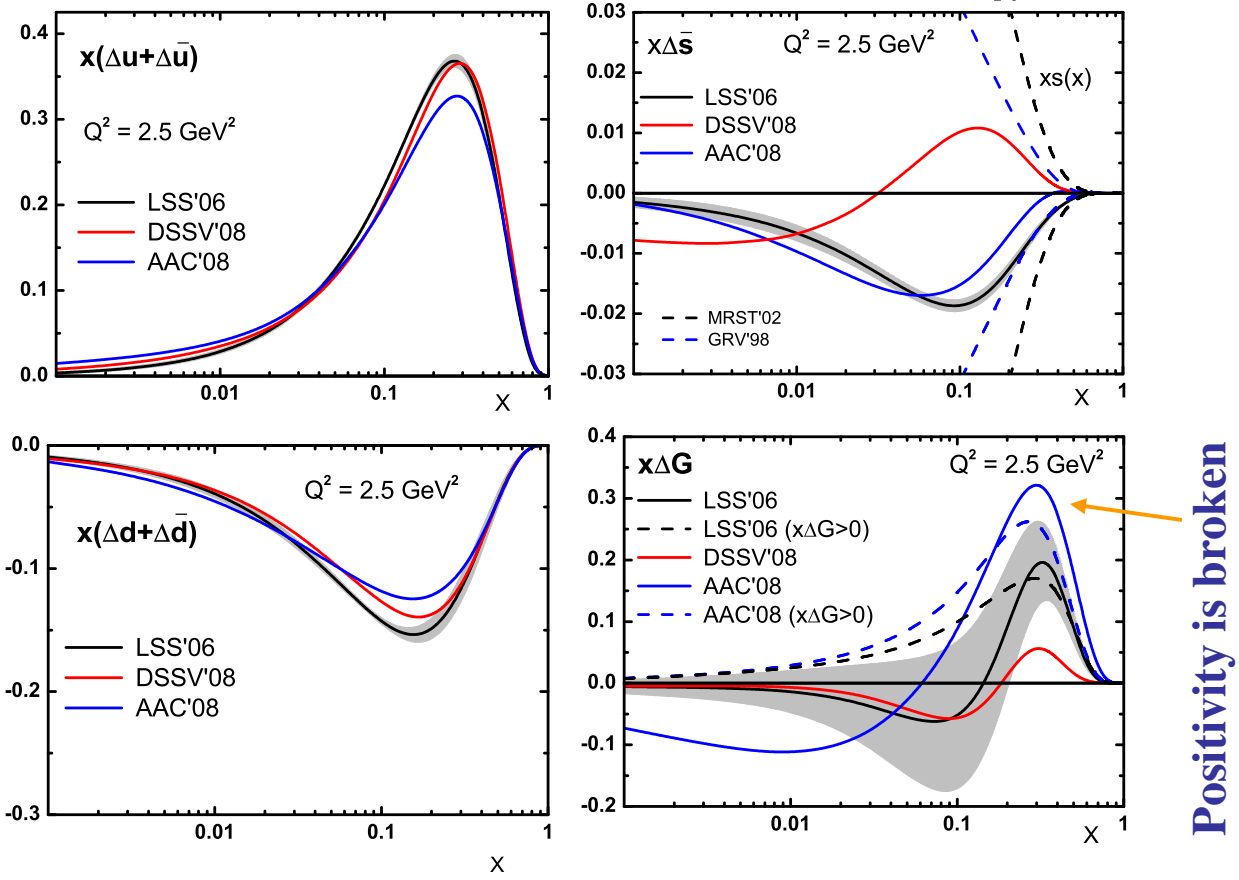


The method, suggested by E. Christova and E. Leader (IC of UK), for determining the valence quarks in a model independent way without any assumptions about fragmentation functions in any QCD order was accepted by Jefferson Lab (Newport News, USA) for the planned experiment Å04-113 (*http://adsabs.harvard.edu/abs/2004hep.ex...12010J*)

Polarized parton densities (PDFs)

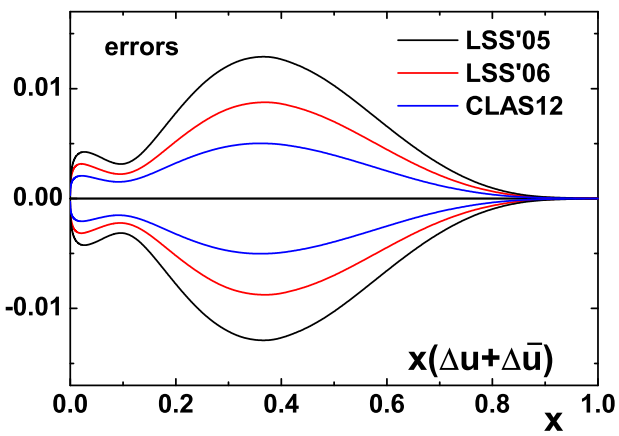
- The **LSS** [*Leader(London), Sidorov(Dubna), Stamenov(Sofia)*] Collaboration is one of the three groups in the world who have carried out a detailed analysis of the world polarized Deep Inelastic Scattering data in the framework of **Quantum Chromodynamics (QCD)**
- The **LSS** results on PDFs are presented on the Durham HEPDATA website (**http://durpdg.dur.ac.uk/HEPDATA/PDF**) and have been used extensively by experimentalists and theorists in calculations for future high energy experiments using polarized particles
- A **good** knowledge of the combination of polarized densities **(Δu(x) + Δū(x))** and **(Δd(x) + Δd̄(x))** for the "up" and "down" quarks
- A well determination of the **sea** quarks **Δū, Δd̄** and **Δs̄**, as well as the polarized **gluons ΔG(x)**, is a challenge to the future investigations

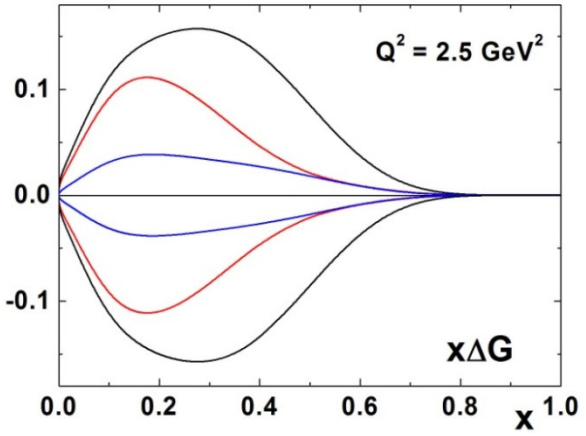
Errors → $\Delta\chi^2=1$

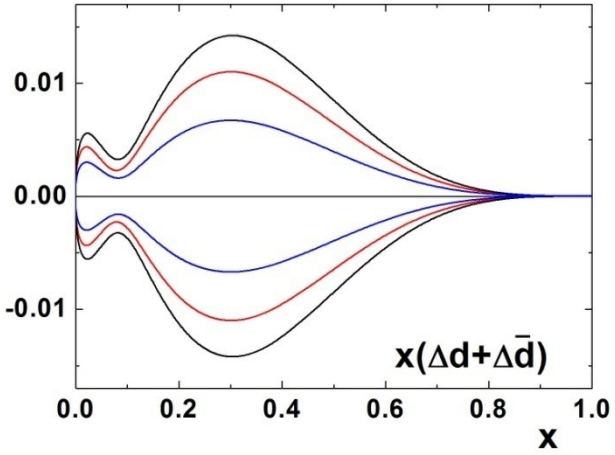


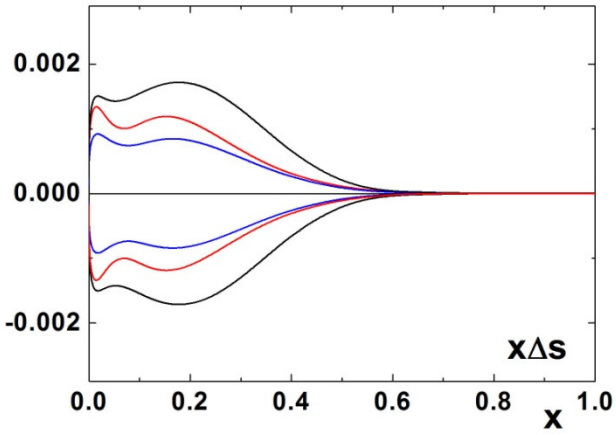
Positivity is broken

The **expected uncertainties** for the polarized PDFs have been calculated by the **LSS** group including the data set will be collected by the **CLAS12 experiment** planned to be performed using a 12 GeV electron beam at Jefferson Laboratory, USA. These results became an important part of the Research Proposal for this experiment (http://www.jlab.org/exp_prog/proposals/06/PR12-06-109.pdf) approved with highest priority, and the **LSS team** was invited to be a member of **CLAS12 Collaboration**.









Topological Quantum Computation with Ising anyons

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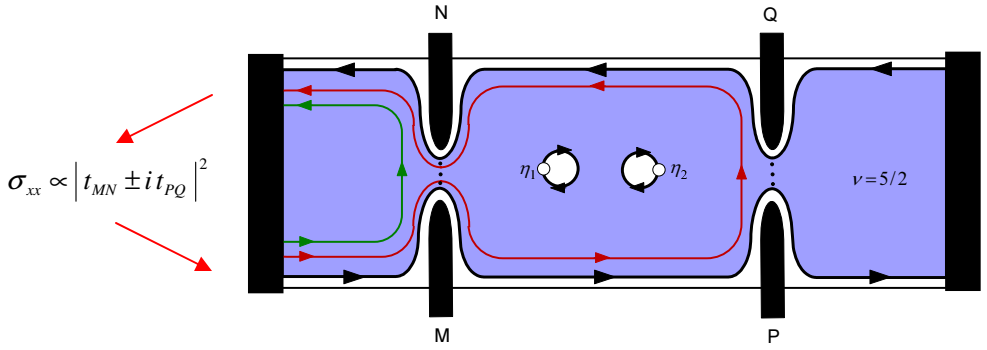
Quantum computers are expected to be significantly more powerful than the classical ones due to the quantum *entanglement* and quantum *parallelism*. However, quantum information is subjected to huge noise and decoherence due to the interaction of the *qubits* with their environment, which makes quantum computation extremely difficult experimentally.
Topological quantum computers focus on improving the hardware rather than correcting the errors by complicated quantum circuits.

Topological protection of qubits and gates: quantum information is encoded *non-locally* which makes it inaccessible to noise and decoherence, which are essentially due to local interactions. In addition, quantum gates are executed by *topological operations* depending only on the *homotopy classes* of the exchange paths for *anyonic quasiparticles*.

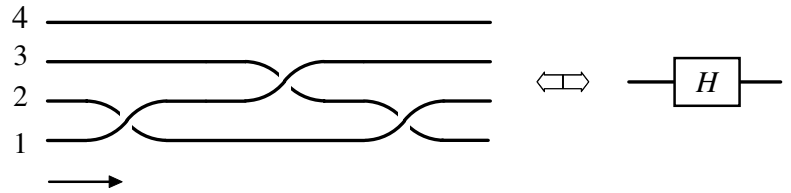
Labeling anyonic states of mater: *fusion channels* and *fusion paths* (Bratteli diagrams)



TQC setup: fractional quantum Hall state at filling factor 5/2

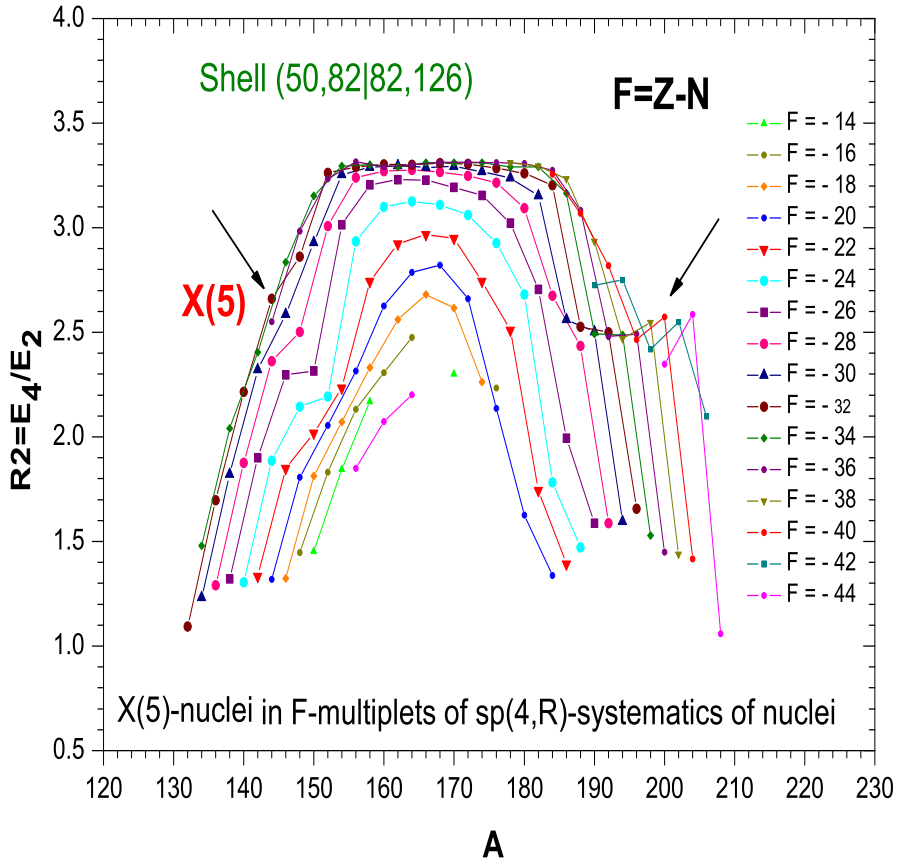
pairs of non-Abelian quasiparticles (anyons) with fractional electric charge localized on antidots either share a Majorana fermion or not. These are the two computational states. Measuring the longitudinal conductance gives different interference patterns in electronic Fabry-Perot interferometers. Transporting adiabatically one anyon around another could implement topologically protected quantum gates because the quantum transformation is insensitive to the actual exchange path and depends only on the homotopy class of the exchange.

Example: the single-qubit Hadamard gate



Study of shape phase transition and critical point behavior in nuclei

- systematics of the atomic nuclei in the frame of the nucleon number A = Z + N and the proton-neutron difference F = Z - N
- classification scheme by means of the non-compact algebra sp(4,R)
- nuclei are ordered into isobaric multiplets, for which A is fixed as well as in F-multiplets, for which F is fixed



Computer modeling of biological systems

- Long-term perspective: computer-aided drug design
- Research focus: possibilities for control of the activity of the human imune system by modulation of the biological activity of the interferon-gamma hINFγ
- **Results:**
  - ❖ hIFNγ C-termini are incorporated into the structure of hIFNγ (PDB ID: 1fg9)
  - ❖ the role of the positive charge of the C-termini for the biological activity of hIFNγ is reveiled
  - ❖ the necessary presence of additional charged molecules (probably HS) near the hIFNγ receptors for proper binding is shown (Fig. 1)

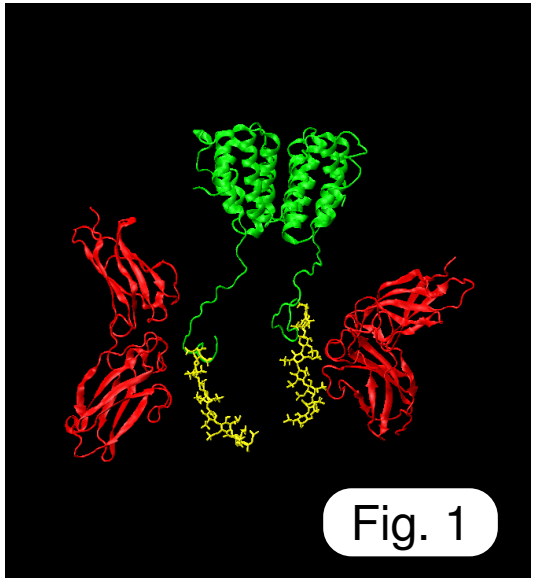


Fig. 1

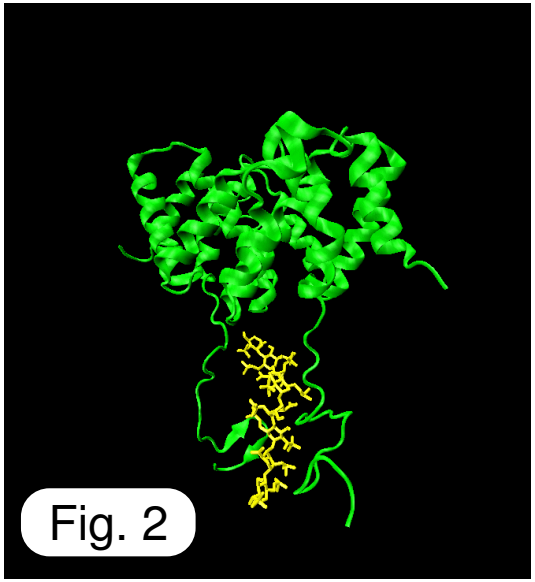


Fig. 2