R-J. Standard model and new physics

Wigner research group

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During the past few decades the Standard Model (SM) of particle physics has been tested in various experiments to great precision and has been found to be immensely successful in describing particle interactions up to the electroweak scale. Nevertheless, there are arguments for the existence of physics beyond the SM, such as the inability of the model to describe physics at the energy scale at which quantum gravitational effects become important. The Standard Model cannot account for the dark matter that dominates our Universe, it does not predict an exact unification of the fundamental gauge interactions, and it does not explain the matter-antimatter asymmetry. It also suffers from the so-called "hierarchy" problem. By this, we mean that the mass of the Higgs boson acquires quantum corrections that are much larger than the actual mass of the Higgs. The situation worsens if we assume that there is physics beyond the SM. This is because if new physics manifests itself in the form of new particles that couple to the Higgs field, that is to say, they have mass, they must also contribute to the Higgs boson mass. These corrections contribute negatively in the case of bosons, and positive in the case of fermions. Maintaining the existence of a light Higgs boson requires that all these contributions somehow cancel each other. Such a cancellation appears naturally in theories with supersymmetry (SUSY). If SUSY exists, it could provide a dark matter candidate, and it could make the unification of fundamental forces exact at energies from 10^{14} to 10^{16} GeV. It would also mean that the new particle we discovered in 2012 is not exactly the SM Higgs boson, but rather one of the SUSY Higgs bosons which looks very much like it. Our group has set out a goal to investigate these questions from various experimental angles in analyses of high energy proton collision events. We also build and maintain detectors and software systems for data-calibration and reconstruction which are used in the measurement of the physical processes that take place in these collisions.

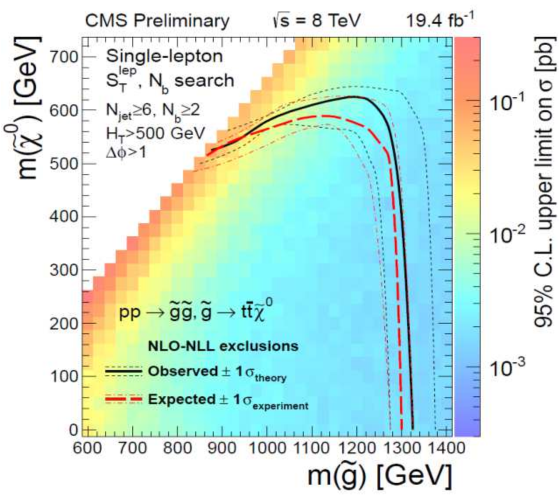

Figure 1: *Exclusion limit in the parameter space of the simplified model as a function of the gluino and LSP masses.*

Physics analyses. — The Minimal Supersymmetric Standard Model (MSSM) is one of the most promising extensions of the SM that incorporates SUSY. Our group has performed searches with the Compact Muon Solenoid (CMS) experiment at the Large Hadron Collider (LHC) at CERN. We have focused on simplified models in which gluino pairs are produced in proton-proton collisions. Each gluino decays into a top quark and its supersymmetric partner, the scalar top. The scalar tops subsequently decay into tops, yielding four top quarks and the lightest SUSY particle (LSP), a possible dark-matter candidate, in the final state:

$$pp \rightarrow \tilde{g}\tilde{g} \rightarrow t\tilde{t}t\tilde{t} \rightarrow t\bar{t}t\bar{t}\tilde{\chi}^0\tilde{\chi}^0$$

Top quarks are identified using a standard analysis method called b-tagging as they decay almost exclusively into b-quarks. We extended the exclusion limits (Fig.1) of this simplified process in events which contain an electron or muon, b-quarks, and multiple jets.

The effect of new particles' appearance on the Higgs boson mass can be turned to our advantage in searching for new physics. Exploring the fundamental properties of the recently discovered Higgs boson can provide a portal to uncharted territories. Any new particle is expected to modify the coupling constants of the Higgs boson to known particles which are easier to detect. Our CMS and ATLAS groups have been making advancements in the study of the Higgs boson properties.

The existence of the asymmetry that is observed in the ratio between the amount of matter and antimatter in the Universe is unexplained by the SM. Despite fundamental theoretical arguments, the properties of matter and antimatter might be different. Two of our group members have been participating in a small experiment, called ASACUSA, at CERN's Antiproton Decelerator (AD), with ground-breaking results on laser spectroscopy of antiprotons trapped by Helium atoms.

Detector calibration and measurement methods. — b-quarks are generated in the decays of third generation quarks, and b-production is also the dominant decay mode of the Higgs boson. Their detection is a powerful tool in physics searches; however, it poses the greatest challenge from the instrumentation point of view. The identification (or "tagging") of jets originating from b-quarks depends on high-precision tracking measurements. Hadrons containing b-quarks have a unique feature: they have sufficient lifetime that they travel some distance (typically a few millimetres) before decaying, and consequently the tracks corresponding to their charged decay products intersect at a vertex that is measurably displaced from the collision point.

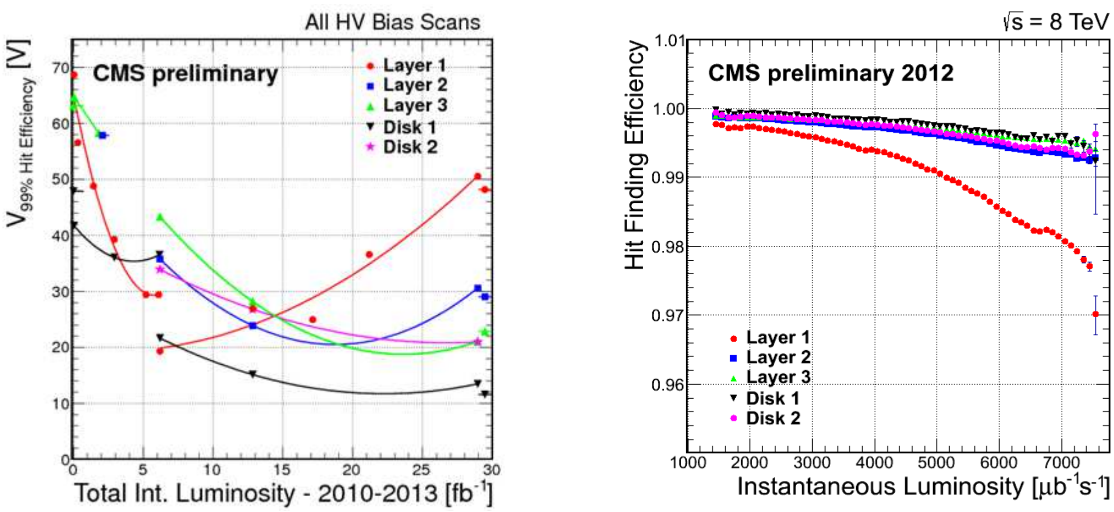

Figure 2: *Pixel measurement efficiency in various tracking layers of the detector —* ***Left:*** *as a function of total integrated collision data, and* ***Right:*** *as a function of instantaneous luminosity*

We participate in the running and maintenance of a high-precision charged particle tracking device in CMS, the pixel detector. The pixel detector provides key measurements for purposes additional to b-tagging. It is also used in the reconstruction of primary vertices in the LHC, lepton identification, and data luminosity measurements.

In the last three years our group leader has also been serving as the group leader of the pixel calibration, reconstruction, and simulation (pixel offline) group in CMS. Naturally, we have a strong contribution to the results in pixel offline. We are maintaining the calibration database used in the reconstruction of the data taken by the pixel detector. The pixel detector is the innermost device in CMS. It is situated at a distance of less than 4 cm from the nominal collision point of the LHC beams. Consequently, it is exposed to high level of radiation which causes the physical properties of the pixel sensors to continuously change (Fig. 2 left). The most important role of the pixel offline group is to understand this change and correct for it with proper calibrations. Thorough studies have been performed by our group. A senior member and a graduate student have developed a new method to simulate the efficiency loss of the pixel detector that occurs at high collision rates, as shown in (Fig. 2 right). This effect leads to loss of efficiency and resolution in the reconstruction of charged particles, in the detection of b-quarks, and in the measurement of the amount of collision data delivered by the LHC. Therefore, the proper understanding of this effect is very important in the statistical interpretation of all physics results.

The pixel detector is surrounded by the strip detector, another charged particle tracking device. Both detectors are installed within the CMS magnet, which is the largest superconducting solenoid magnet ever built. The structures of these tracking devices can move and become distorted by various effects, such as changes in temperature within the enclosure or magnet power-cycling. Knowledge of each module's position in three-dimensional space with a precision better than the intrinsic resolution of the tracker detectors is required for track reconstruction when measurement points localised on individual modules are placed into the common frame of CMS. We have played a significant role in the measurement of this information.

Detector upgrades. — Due to its position closest to the LHC beams, the pixel detector is exposed to more beam radiation than any other detector in CMS. The continuous increase of the instantaneous luminosity in the LHC will worsen these effects. Radiation-induced damage of sensors and readout electronics degrades the resolution of position measurements to the extent that the detector is rendered unusable. Therefore it will need to be replaced. This will happen in two steps, called phase I and phase II upgrades, in the next couple of decades. Our group has

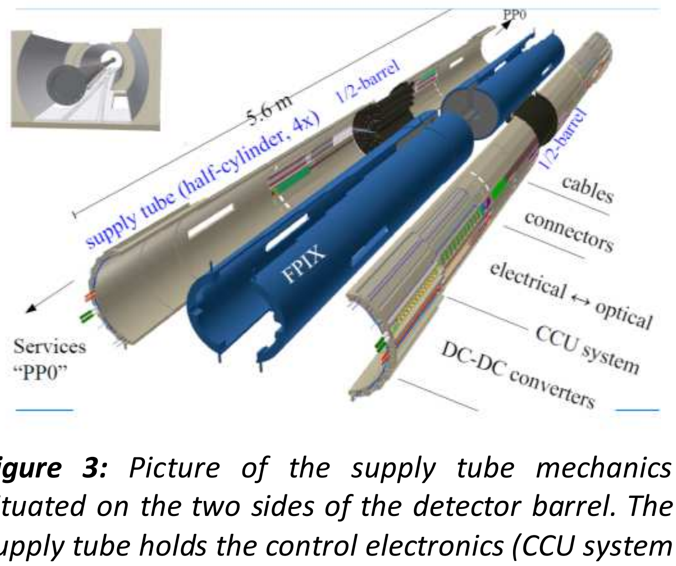

***Figure 3:** Picture of the supply tube mechanics situated on the two sides of the detector barrel. The supply tube holds the control electronics (CCU system and electrical-optical converters.)*

played a leading role in studying radiation effects and we are now also key contributors to the design of the new-generation pixel detector. The new pixel detector can be thought of as a large digital camera without the optical apparatus (Fig. 3). It consists of semiconductor sensors arranged coaxially on a mechanical structure serving as its frame. It receives power from DC-DC converters. The settings of the pixel detector's sensors, the measurement triggers, and the data read-out are regulated by its control electronics. The barrel detector has been developed by multiple institutes, most of which are located in Europe. Countries with participating institutes include Switzerland, Germany, the UK, and Hungary. The sensors are developed at the Paul Scherrer Institute (PSI) in Zurich. Modules are bump-bonded and assembled in various institutions in Germany and in Switzerland. The mechanical structure is built at the University of Zurich. The DC-DC converter boards are constructed at DESY in Germany. The control electronics are designed by our group at Wigner RCP. We presented our results in a CERN-wide peer-review committee last December. Modules closer to the interaction point need to measure a larger flux of particles than those farther away. These measurements also need to be made earlier due to differences in the module-to-interaction point distance. Based on the experience we have acquired with the present system, we designed the new detector electronics so that the data-acquisition time of its modules are aligned according to the time-of-flight of the incoming charged particles. The grouping of the modules in the data read-out is designed so that their read-out bandwidths are balanced equally among read-out units. The solution to the problem of how this latter requirement should be met is based on a realistic simulation of the 2017 LHC accelerator conditions by an undergraduate student in our group as his BSc thesis work.

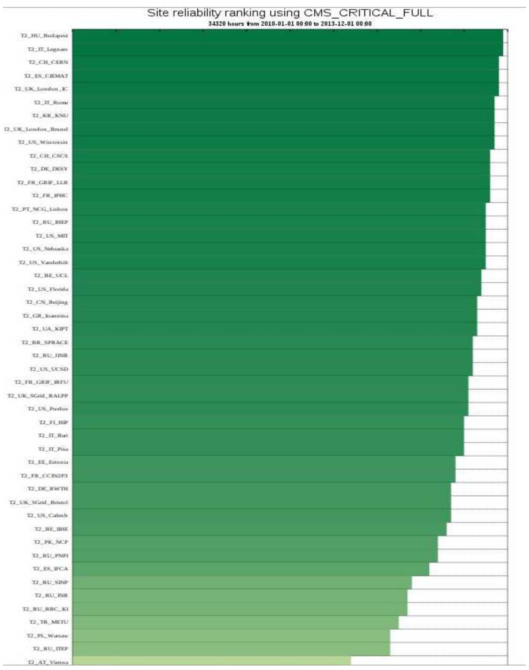

Figure 4: *Site availability in the CMS Tier-2 computing network from 2010 to 2013. The Budapest site is at the first place with ~98% efficiency.*

Computing infrastructures. — The Worldwide LHC Computing Grid (WLCG) is a computing network with sites distributed on five continents. Our group maintains a Tier-2 level site at Wigner RCP. It consists of about 350 CPUs and over 250 TB of storage space. About two-thirds of the site is dedicated to the CMS project, supporting the physics analyses (SUSY and QCD) we perform at Wigner RCP, common CMS data-processing work, and computational tasks required for the calibration of the pixel detector. In 2013, our group members performed a total upgrade of the computing infrastructure: the computers have been moved to a new cooling solution, and their entire software framework system has been upgraded to the new version required at the restart of LHC data-taking which is due within a year. Thanks to continuous efforts in 2013, our Tier-2 site has become the most efficient Tier-2 system in CMS (Fig. 4). Our expert members also provided help to our colleagues at Debrecen University to make their new Tier-3 site a certified CMS computing centre by the end of last year. We have also installed a new multi-CPU user interface computer which is used by many members of our group for interactive analysis work

Theoretical work. — Our group is also active in fundamental theoretical work in quantum mechanics, especially in the field of quantum gravity. We have one member working on this: Lajos Diósi. His theoretical work on the spontaneous collapse of the wave function of massive objects has motivated a boom of experiments in Europe and in America. The role he played in the foundation of the theory along with Roger Penrose of Oxford was acclaimed in a recent article in Scientific American.

Grants and international cooperation

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OTKA NK 109703 „Consortional main: Hungary in the CMS experiment of the Large Hadron Collider"

„Wigner research group" support

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11. Diósi L: Gravity-related wave function collapse: Mass density resolution. ***J. PHYS.-CONF. SER.*** 442:(1) Paper 012001. 7p. (2013)

Others

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ATLAS collaboration

Due to the vast number of publications of the large collaborations in which the research group participated in 2013, here we list only a short selection of appearences in journals with the highest impact factor.

1. Aad G et al. incl. Pasztor G, Toth J [2916 authors]: Measurement of the Azimuthal Angle Dependence of Inclusive Jet Yields in Pb plus Pb Collisions at $\sqrt{s_{NN}}$=2.76 TeV with the ATLAS Detector. ***PHYS. REV. LETT.*** 111:(15) Paper 152301. 18 p. (2013)

2. Aad G et al. incl. Pasztor G, Toth J, [2926 authors]: Measurement of top quark polarization in top-antitop events from proton-proton collisions at $\sqrt{s}$=7 TeV using the ATLAS detector. ***PHYS. REV. LETT.*** 111:(23) Paper 232002. 19 p. (2013)

3. Aad G et al. incl. Pasztor G, Toth J [2905 authors]: Measurement of Z boson production in Pb-Pb collisions at $\sqrt{s_{NN}}$=2.76 TeV with the ATLAS detector. ***PHYS. REV. LETT.*** 110:(2) Paper 022301. 18p. (2013)

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5. Aad G et al. incl. Pasztor G, Toth J [2904 authors]: Search for dark matter candidates and large extra dimensions in events with a photon and missing transverse momentum in pp collision data at $\sqrt{s}$=7 TeV with the ATLAS detector. ***PHYS. REV. LETT.*** 110:(1) Paper 011802. 18p. (2013)

6. Aad G et al. incl. Pasztor G, Toth J, [2903 authors]: ATLAS search for new phenomena in dijet mass and angular distributions using pp collisions at $\sqrt{s}$=7 TeV. ***J. HIGH ENERGY PHYS.*** 1301:(1) Paper 029. 46 p. (2013)

7. Aad G et al. incl. Pasztor G, Toth J [2899 authors]: Measurement of isolated-photon pair production in pp collisions at $\sqrt{s}$=7 TeV with the ATLAS detector. ***J. HIGH ENERGY PHYS.*** 1301:(1) Paper 086. 42 p. (2013)

8. Aad G et al. incl. Pasztor G, Toth J [2911 authors]: Measurement of the cross-section for W boson production in association with b-jets in pp collisions at $\sqrt{s}$=7 TeV with the ATLAS detector. ***J HIGH ENERGY PHYS.*** 1306:(6) Paper 084. 44p. (2013)

9. Aad G et al. incl. Pasztor G, Toth J [2917 authors]: Measurement of the differential cross-section of B+ meson production in pp collisions at $\sqrt{s}$ = 7 TeV at ATLAS. ***J. HIGH ENERGY PHYS.*** 2013:(10) pp. 1-37. (2013)

10. Aad G et al. incl. Pasztor G, Toth J [2917 authors]: Measurement of the distributions of event-by-event flow harmonics in lead-lead collisions at $\sqrt{s_{NN}}$ = 2.76 TeV with the ATLAS detector at the LHC. ***J HIGH ENERGY PHYS.*** 1311:(11) Paper 183. 57 p. (2013)

11. Aad G et al. incl. Pasztor G, Toth J [2920 authors]: Measurement of the production cross section of jets in association with a Z boson in pp collisions at $\sqrt{s}$=7 TeV with the ATLAS detector. ***J. HIGH ENERGY PHYS.*** 1307:(7) Paper 32. 50 p. (2013)

12. Aad G et al. incl. Pasztor G, Toth J [2914 authors]: Measurement of the top quark charge in pp collisions at $\sqrt{s}$=7 TeV with the ATLAS detector. ***J. HIGH ENERGY PHYS.*** 1311:(11) Paper 031. 42 p. (2013)

13. Aad G et al. incl. Pasztor G, Toth J [2900 authors]: Measurement of ZZ production in pp collisions at $\sqrt{s}$ = 7 TeV and limits on anomalous ZZZ and ZZγ couplings with the ATLAS detector. ***J. HIGH ENERGY PHYS.*** 1303:(3) Paper 128. (2013)

14. Aad G et al. incl. Pasztor G, Toth J [2915 authors]: Performance of jet substructure techniques for large-R jets in proton-proton collisions at √s=7 TeV using the ATLAS detector. ***J. HIGH ENERGY PHYS.*** 1309:(9) Paper 076. 17 p. (2013)

15. Aad G et al. incl. Pasztor G, Toth J [2900 authors]: Search for charged Higgs bosons through the violation of lepton universality in tt events using pp collision data at √s=7 TeV with the ATLAS experiment. ***J. HIGH ENERGY PHYS.*** 1303:(3) Paper 76. 35 p. (2013)

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18. Aad G et al. incl. Pasztor G, Toth J [2917 authors]: Search for direct third-generation squark pair production in final states with missing transverse momentum and two b-jets in √s=8 TeV pp collisions with the ATLAS detector. ***J. HIGH ENERGY PHYS.*** 1310:(10) Paper 189. 40 p. (2013)

19. Aad G et al. incl. Pasztor G, Toth J [2919 authors]: Search for new phenomena in final states with large jet multiplicities and missing transverse momentum at √s=8 TeV proton-proton collisions using the ATLAS experiment. ***J. HIGH ENERGY PHYS.*** (10) Paper 130. 50 p. (2013)

20. Aad G et al. incl. Pasztor G, Toth J [2916 authors]: Search for resonances decaying into top-quark pairs using fully hadronic decays in pp collisions with ATLAS at √s=7 TeV. ***J. HIGH ENERGY PHYS.*** 1301:(1) Paper 116. 50 p. (2013)

21. Aad G et al. incl. Pasztor G, Toth J [2894 authors]: Search for the neutral Higgs bosons of the minimal supersymmetric standard model in pp collisions at √s=7 TeV with the ATLAS detector. ***J. HIGH ENERGY PHYS.*** 1302:(2) Paper 095. 47 p. (2013)

22. Aad G et al. incl. Pasztor G, Toth J [2896 authors]: Search for third generation scalar leptoquarks in pp collisions at √s=7 TeV with the ATLAS detector. ***J. HIGH ENERGY PHYS.*** 1306:(6) Paper 033. 24 p. (2013)

23. Aad G et al. incl. Pasztor G, Toth J [2912 authors]: Improved luminosity determination in pp collisions at √s=7 TeV using the ATLAS detector at the LHC. ***EUR. PHYS. J. C*** 73:(8) Paper 2518. 39 p. (2013)

See also: R-H. CMS Collaboration, R-H. NA49 Collaboration, R-I. NA61/SHINE Collaboration