R-H. Hadron physics

Wigner research group

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Quarks and gluons. — Particle physics is our attempt to understand the basic constituents of our world. What is it made of? What are the interactions between the building blocks of matter? Symmetries and gauge theories provide a coherent framework for the electromagnetic, weak, and strong interactions. The last of these, the strong force, acts between quarks and gluons and is described by the theory of quantum chromodynamics (QCD). In most circumstances, it is difficult to perform accurate calculations with QCD because the theory is strongly coupled and consequently has a non-perturbative nature. Results from the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory, later reinforced by those from the Large Hadron Collider (LHC) at CERN, showed unexpected phenomena: suppression of hadrons with high transverse momentum (p_T), and weakening of back-to-back jet correlations. These results indicated that quark matter does not behave like a quasi-ideal state of free quarks and gluons, but like an almost perfect dense fluid.

Our research group studies collisions of nucleons and nuclei, performs basic and advanced measurements, and tests theoretical ideas. We participate in several complementary experiments, both in data taking and physics analysis. Hadron-nucleus collisions are important for the interpretation of the properties of nucleus-nucleus collisions and to uncover the partonic structure of nuclear matter at low fractional momenta. Moreover, these collisions are interesting in themselves for answering questions such as: what is the validity of multiple-collision Glauber-model? Can we get a better understanding of the hadronisation process? This topic is of particular interest for many theorist colleagues in Hungary and worldwide. The energy range (several TeV) of the LHC enables the use of new and more powerful signals and markers. It is also a region that is relevant for understanding cosmic radiation and atmospheric showers. In the past year several members of our research group participated in data taking and calibration of new pPb data at both the Super Proton Synchrotron (SPS) at CERN and at the LHC: data was collected by the NA61 experiment at the SPS at $\sqrt{s}$ = 17 GeV per nucleon pair, and by the ALICE and CMS experiments at the LHC at $\sqrt{s}$ = 5.02 TeV per nucleon pair. The large amount of collected data allowed us to perform the studies proposed at the beginning of the year.

Collision centrality. — To see how much of a heavy ion participates in a collision, a key parameter called centrality must be determined. Centrality is proportional to the number of inelastic proton-nucleon collisions. An estimate of this number is needed when quantities observed in pPb collisions are compared to pp and PbPb results. In the case of heavy-ion collisions, several multiplicity or energy measures are appropriate. They change monotonically with centrality and have a strong correlation due to the high number of particles produced. For pPb collisions, the problem is more complicated: the use of the foregoing methods would result in various biases due to the small number of hadrons created. Our studies show that the number of collisions can be estimated with small bias by measuring the total energy of the produced particles that are projected in the direction of the fragmented Pb nucleus. This finding comes from optimizing the weighted sum of the number of particles produced, where the weights depend on the pseudorapidity of the particle. The best weights are non-zero only for the outer rings of the CMS forward hadronic calorimeter (4 < η < 5). The corresponding averages and standard deviations were calculated using a Glauber-model (Fig. 1).

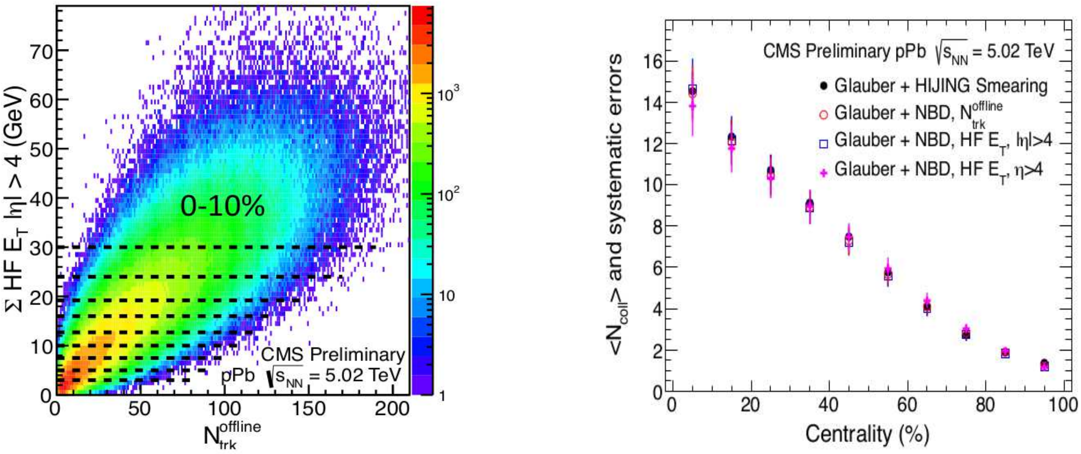

***Figure 1: Left:** The correlation between the number of detected tracks ($N_{trk}^{offline}$) and the energy in the forward calorimeters (E_T) in inelastic pPb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV. **Right:** The estimated number of collisions $\langle N_{coll}\rangle$ and its uncertainty in 10% wide centrality classes. The classifications are based on several measures of centrality.*

In the case of NA61 we can directly detect the slow nucleons (protons and nuclei) using a time projection chamber filled with a special gas mixture. It performs simultaneous range and ionization measurements on each charged particle enabling particle identification and momentum measurement at very low momenta. By counting the number of identified protons, the number of collisions can be estimated.

Momentum distribution of identified particles. — Charged particles created in collisions of nucleons and nuclei are observed by different kinds of tracking detectors (a gas chamber in NA61 and ALICE; a silicon tracker in CMS). With the help of sophisticated algorithms we can reconstruct their trajectories. Simple measures such as the pseudorapidity density can already be directly compared with those from event generators and theoretical calculations. We have measured the spectra of identified charged hadrons produced in pPb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV using the CMS detector. Charged pions, kaons, and protons were identified from the energy deposited in the silicon tracker and other track information. The yield and spectra of identified hadrons have been studied as a function of the charged particle multiplicity of the event in the range |η| < 2.4. The p_T spectra are well described by fits with the Tsallis-Pareto parametrization. (This observation stresses the role of non-extensive thermodynamics.) The ratios of the yields of oppositely charged particles are close to unity, as expected at mid-rapidity for collisions at multi-TeV energies. The average p_T is found to increase with particle mass and with charged particle multiplicity. The EPOS LHC event generator reproduces several features of the measured distributions. This is a significant improvement from the previous version, which is attributed to a new viscous hydrodynamic treatment of the produced particles. Other studied generators (AMPT, HIJING) predict steeper p_T distributions and much smaller p_T than found in data, as well as substantial deviations in the p/π ratios. Combined with similar results from pp collisions, the track multiplicity dependence of the average transverse momentum and particle ratios indicate that particle production at LHC energies is strongly correlated with event particle multiplicity in both pp and pPb interactions (Fig. 2 left). For low track multiplicity, pPb collisions appear similar to pp collisions. At high multiplicities, the average p_T of particles from pPb collisions with a charged particle multiplicity of N_{tracks} (in |η| < 2.4) is similar to that for pp collisions with 0.55 × N_{tracks}. Both the highest-multiplicity pp and pPb interactions yield higher p_T than seen in central PbPb collisions.

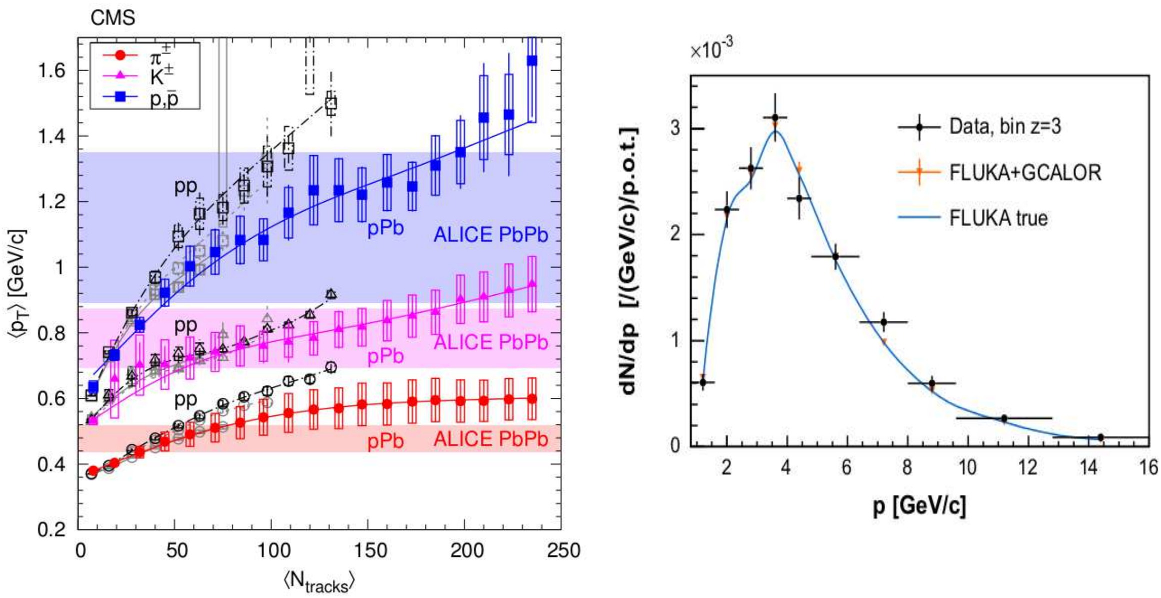

Figure 2: Left: *Average transverse momentum <p_T> of identified charged hadrons (pions, kaons, protons) as a function of the corrected track multiplicity for |η| < 2.4, for pp collisions (open symbols) at several energies, and for pPb collisions (filled symbols) at* $\sqrt{s_{NN}}$ *= 5.02 TeV. Lines are drawn to guide the eye. The ranges of <p_T> values measured by ALICE in various centrality PbPb collisions at* $\sqrt{s_{NN}}$ *= 2.76 TeV are indicated with horizontal bands.* ***Right:*** *Spectra of outgoing positively charged pions normalized to the momentum bin size and number of protons on target in the angular interval 40–100 mrad for the central longitudinal bins. Error bars correspond to the sum in quadrature of statistical and systematic uncertainties. Smooth curves show the prediction of the FLUKA simulation.*

Data from hadron-nucleus collisions are valuable for other areas such as atmospheric showers, and consequently for neutrino physics. The T2K long-baseline neutrino oscillation experiment in Japan needs precise predictions of the initial neutrino flux. We have shown that the highest precision can be reached based on detailed measurements of hadron emission from the same target as used by T2K exposed to a proton beam of the same kinetic energy of 30 GeV. The corresponding data were recorded by the NA61 experiment using a replica of the graphite target (Fig. 2 right). In the global framework of accelerator-based neutrino oscillation experiments, it has been demonstrated that high quality measurements can be performed with the NA61 setup. They could lead to a significant reduction of systematic uncertainties on the neutrino flux predictions in long-baseline neutrino experiments.

Momentum distribution at high momenta. — In the presence of the hot and dense medium created in heavy-ion collisions, the yield of high momentum particles is suppressed compared to independent superpositions of nucleon-nucleon collisions. What is the situation in pPb collisions? Do we also see a suppression, or something else? We have measured the spectra of charged particles and the nuclear modification factor for pPb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV using data taken by the CMS experiment. The results were normalized to a pp reference spectrum derived from a scaled combination of 0.9, 2.76, and 7 TeV pp spectra measured by CMS, as well as 0.63, 1.8, and 1.96 TeV pp spectra measured by CDF. The nuclear modification factor R_{pPb} shows a steady rise to unity until a $p_T \approx 4$ GeV/c, is then constant until approximately 20 GeV/c, and then increases at higher p_T reaching a value around 1.3–1.4 at 70 GeV/c (Fig. 3 left). It is extremely interesting that the rise above unity of R_{pPb} is in the range of p_T where parton anti-shadowing is predicted (with momentum fractions of x = 0.02–0.2). However, the maximum measured value of R_{pPb} is significantly larger than the value expected from anti-shadowing in nuclear parton distribution functions (nPDFs) obtained from globally analysed fits to nuclear hard-process data. The forward-backward asymmetry was also evaluated in various η ranges. Similar anti-shadowing effects are observed in the positive and negative η regions resulting in a ratio close to unity.

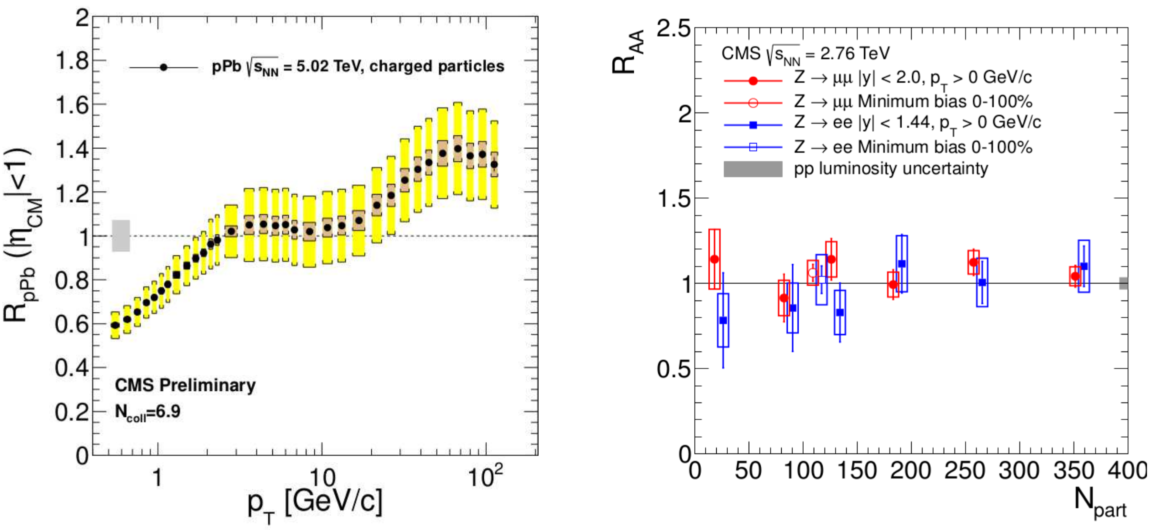

Figure 3: Left: *The nuclear modification factor (R_{pPb}) of charged particles measured in $\sqrt{s_{NN}}$ = 5.02 TeV pPb collisions as a function of transverse momentum (p_T).* ***Right:*** *The nuclear modification factor (R_{AA}) for Z bosons measured in $\sqrt{s_{NN}}$ = 2.76 TeV PbPb collisions, from the decay channels $Z \rightarrow e^+e^-$ (squares) and $Z \rightarrow \mu^+\mu^-$ (dots) as a function of collision centrality (here, the number of participant nucleons N_{part}). The points were shifted for clarity.*

Weak bosons. — By colliding heavy nuclei we can recreate the Universe as it was some microseconds after the Big Bang. In contrast to hadrons, weakly interacting bosons (γ, $W^\pm$, Z) can escape the hot and dense medium unchanged. Their decay to lepton pairs is clearly seen by the CMS detector, since its capabilities in this field are excellent. We have studied the production of Z bosons in both dimuon and dielectron decay channels in PbPb and pp collisions at $\sqrt{s_{NN}}$ = 2.76 TeV using the CMS detector. The nuclear modification factor R_{AA} was calculated to study the effect that the medium formed in PbPb collisions has on Z production (Fig. 3 right). We find the R_{AA} for centrality integrated Z-boson production in the dimuon channel to be 1.06 ± 0.05(stat) ± 0.11(syst) and in the dielectron channel to be 1.02 ± 0.08(stat) ± 0.17(syst). Therefore, the production of Z bosons in both decay channels in PbPb collisions is consistent with scaling of the pp cross section with the number of binary collisions. The scaling is seen to hold in the entire kinematic region studied, as expected for a colourless probe that is unaffected by a deconfined quark-gluon plasma. The ongoing study of the properties and the production of these particles created in pPb collisions will be important in the comparison with PbPb interactions.

Grants and international cooperation

OTKA NK 106119, „Attometer physics phenomena: experimental and theoretical studies at the CERN LHC ALICE”

OTKA NK 81447, „Hungary in the CMS experiment of the Large Hadron Collider”

OTKA K 81614, „New analysis methods and tests of quantum chromodynamics at the LHC”

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

EC FP7 C 262025, „Advanced European Infrastructures for Detectors at Accelerators (AIDA)”

„Wigner research group” support

Publications

Articles

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Conference proceedings

3. Pochybova S: Experimental identification of quark and gluon jets. ***ACTA PHYS. POL. B PROC. SUPPL.*** 6:(2) pp. 539-544. (2013)

See also: R-C.2

CMS 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. Chatrchyan S et al. incl. Bencze G, Hajdu C, Hidas P, Horvath D, Sikler F, Veszpremi V, Vesztergombi G [2197 authors]: Evidence for associated production of a single top quark and W Boson in pp collisions at $\sqrt{s}$=7 TeV. ***PHYS. REV. LETT.*** 110:(2) Paper 022003. 25 p. (2013)

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4. Chatrchyan S et al. incl. Bencze G, Hajdu C, Hidas P, Horvath D, Sikler F, Veszpremi V, Vesztergombi G [2198 authors]: Measurement of the azimuthal anisotropy of neutral pions in Pb-Pb collisions at $\sqrt{s_{NN}}$=2.76 TeV. ***PHYS. REV. LETT.*** 110:(4) Paper 042301. 25 p. (2013)

5. Chatrchyan S et al. incl. Bencze G, Hajdu C, Hidas P, Horvath D, Sikler F, Veszpremi V, Vesztergombi G, Zsigmond AJ [2225 authors]: Measurement of the $B_S^0 \rightarrow \mu^+\mu^-$ branching fraction and search for $B^0 \rightarrow \mu^+\mu^-$ with the CMS experiment. ***PHYS. REV. LETT.*** 111:(10) Paper 101804. 17 p. (2013)

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7. Chatrchyan S et al. incl. Bencze G, Hajdu C, Hidas P, Horvath D, Sikler F, Veszpremi V, Vesztergombi G [2201 authors]: Search for pair production of third-generation leptoquarks and top squarks in pp collisions at $\sqrt{s}$=7 TeV. ***PHYS. REV. LETT.*** 110:(8) Paper 081801. 27 p. (2013)

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LETT. 110:(14) Paper 141802. 15 p. (2013)

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10. Chatrchyan S et al. incl. Bencze G, Hajdu C, Hidas P, Horvath D, Sikler F, Veszpremi V, Vesztergombi G, Zsigmond AJ [2224 authors]: Searches for new physics using the $t\bar{t}$ invariant mass distribution in pp collisions at $\sqrt{s}$=8 TeV. ***PHYS. REV. LETT.*** 111:(21) Paper 211804. 16 p. (2013)

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NA49 Collaboration

1. Anticic T et al. incl. Barna D, Fodor Z, Laszlo A, Palla G, Sikler F, Varga D, Veres GI, Vesztergombi G [73 authors]: System-size dependence of particle-ratio fluctuations in Pb+Pb collisions at 158A GeV. **PHYS. REV. C** 87:(2) Paper 024902. 9 p. (2013)

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See also: R-I. NA61/SHINE Collaboration

R-I. “Lendület” innovative particle detector development

“Momentum” research team

Dezső Varga, Gyula Bencédi, Ervin Dénes, Gergő Hamar, Gábor Kiss, Tivadar Kiss, Krisztina Márton, László Oláh, Tamás Tölyhi

The Detector Physics Research Group has undergone considerable restructuring during the summer of 2013, and this is apparent both in the change of the name, and in the shift of the research objectives. During the first half of the year the gravity has been on the consolidation of the results, whereas starting from 15th July, owing to the successfully achieved “Momentum” support from the Hungarian Academy of Sciences, the developments towards more ambitious perspectives have been undertaken.

The key research projects were the following:

– High position resolution, single UV photon scanning system for microstructure gaseous detectors. The system has been developed with the aim of optimization of UV sensitive gaseous detectors. We have obtained the financial support of the CERN RD51 Collaboration for the project (Common Funded Project), and during the year we have built the final prototype.
– Cosmic muon detection for geophysical applications. The Muon Tomograph detector system, built by our group, has been applied for underground measurements at various locations, demonstrating the applicability of the device for soil density measurements. The detector has also been applied to measure cosmic muon background: the angular dependence of the muons, reaching underground to the proposed low-background site in Felsenkeller (Germany) was evaluated.
– Innovative gaseous detector development. We have successfully combined the Thick GEM technology with multi-wire proportional chambers, and proved its applicability for high efficiency Cherenkov radiation detection.
– In the framework of the NA61 Collaboration, we have concentrated on proton-nucleus interactions. In such collision systems the determination of event centrality plays a key role, however this is particularly problematic due to the few number of produced particles. We have earlier built a detector (the LMPD) for the NA61 experiment, which addresses specifically the characterization of event centrality via counting of low momentum protons. This device has been operated in physics data taking of the NA61 proton-lead runs. We have prepared a technical paper on the working principle and commissioning of the pertinent detector.
– The experts of our DAQ team continued to provide software, firmware and hardware support for the operation and continuous development of the Detector Data Link (DDL) system of the ALICE experiment. During the ongoing first long shut-down in 2013-14, the Read-out Receiver Cards (RORC) of several subdetectors will be replaced by a new, much higher performance custom FPGA card, the C-RORC, which will serve as a new common read-out card for the Data Acquisition (DAQ) and the High-Level Trigger Farm (HLT). The integration of this new hardware into the ALICE software environment is completed. The Wigner RCP is the responsible institute of

the development of the new Common Read-out Units (CRU) that will be a central element of the new, upgraded read-out system.

The tasks of the newly established "Momentum" research group for the first year include the realization of an internationally competitive lab framework for the development of gaseous detectors. We have refurbished practically all the available laboratory spaces, including two new sites as well. The completed critical infrastructures are the following:

- Gas distribution system, for precision mixing of various high purity gases
- Clean compartment, optimized for microstructure and traditional gaseous detector handling, construction, and maintenance

Grants and international cooperation

KTIA/OTKA CK77815: Micro-pattern particle detector development in the framework of the CERN RD51 Collaboration

"Momentum" Program of the HAS

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See also: R-H.1

NA61/SHINE Collaboration

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2. Abgrall N et al. incl. Fodor Z, Fulop A, Kiss T, Laszlo A, Marton K, Palla G, Sipos R, Tolyhi T, Vesztergombi G [138 authors]: The NA61/SHINE Collaboration. ***NUCL. PHYS. A*** 904-905: pp. 1081c-1082c. (2013)

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10. Rustamov A (for the NA61/SHINE, NA49 Collaborations): Recent results from NA61/SHINE and NA49. ***J. PHYS. CONF. SER.*** 426: Paper 012027. 6 p. (2013)

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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.

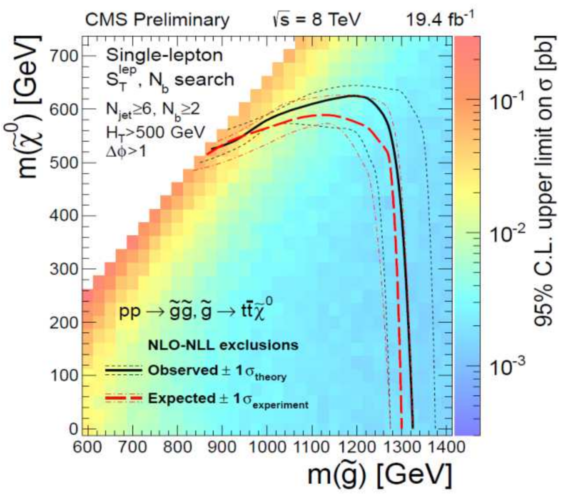

***Figure 1:** Exclusion limit in the parameter space of the simplified model as a function of the gluino and LSP masses.*

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:

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

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.

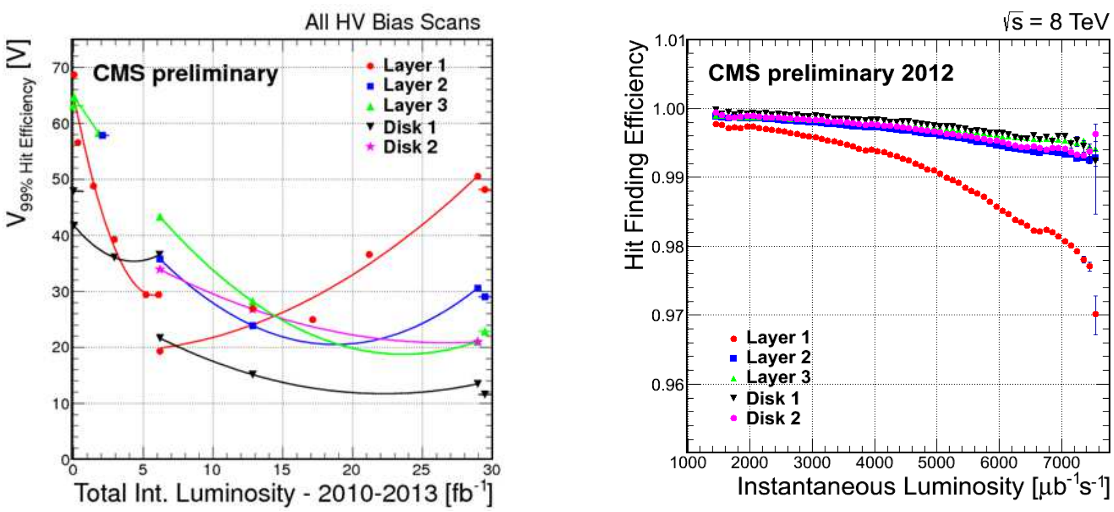

***Figure 2:** Pixel measurement efficiency in various tracking layers of the detector — **Left:** as a function of total integrated collision data, and **Right:** as a function of instantaneous luminosity*

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.

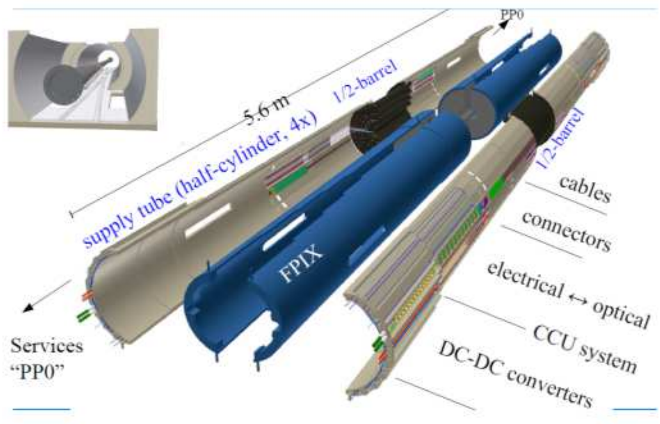

Figure 3: *Picture of the supply tube mechanics situated on the two sides of the detector barrel. The supply tube holds the control electronics (CCU system and electrical-optical converters.)*

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 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.

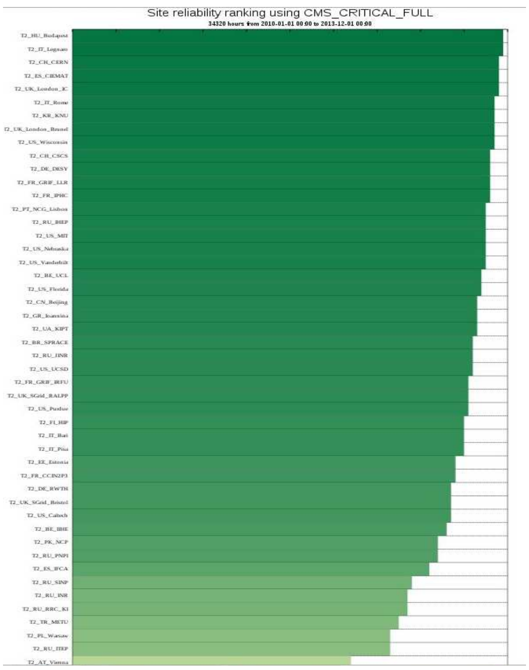

Figure 4: *Site availability in the CMS Tier-2 computing network from 2010 to 2013. The Budapest site is at the first place with ~98% efficiency.*

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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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.

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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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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)

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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)

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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)

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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)

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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)

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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