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 nonperturbative 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 as a quasi-ideal state of free quarks and gluons, but as 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 (ALICE and CMS), both in data-taking and physics analysis. In the past year our research group concentrated mostly on the analysis of pPb data recorded at LHC at $\sqrt{s_{NN}}$ = 5.02 TeV energy per nucleon pair. The large amount of collected data allowed us to perform the studies proposed at the beginning of the year.

Size and shape of the created system in pPb collisions. — Measurements of the correlation between hadrons emitted in high-energy collisions of nucleons and nuclei can be used to study the spatial extent and shape of the created system. The characteristic radii and the homogeneity lengths of the particle-emitting source can be extracted with reasonable precision. We have studied the characteristics of the one-, two-, and three-dimensional two-particle correlation functions in various center-of-mass energy pp, pPb, and peripheral PbPb collisions as a function of the transverse pair momentum k_T and of the charged-particle multiplicity N_{tracks} of the event. Charged pions and kaons at low p_T and in laboratory pseudorapidity $|\eta| < 1$ were identified via their energy loss in the silicon tracker. The correlation functions were corrected for the Coulomb interaction between particles. The contributions from other, correlated particle emissions (mini-jets, multi-body resonance decays) were also subtracted. The obtained distributions could be fit by an exponential parametrization in the relative momentum of the particle pair, both in one- and multi-dimensions.

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The extracted exponential radii for pions increase with increasing N_{tracks} for all systems and center-of-mass energies studied, for one, two, and three dimensions alike. Their values are in the range 1–5 fm, reaching their highest values for very high multiplicity pPb and for similar multiplicity PbPb collisions. The N_{tracks} dependence of longitudinal (R_l) and transverse radii (R_t) is similar for pp and pPb in all k_T bins, and that similarity also applies to peripheral PbPb if $k_T > 0.4$ GeV/*c*. In general there is an ordering for the radii: $R_l > R_t$, thus the pp and pPb source is elongated in the beam direction. In the case of peripheral PbPb the source is quite symmetric, and shows a slightly different N_{tracks} dependence. The most visible divergence between pp, pPb, and PbPb is seen in the so-called “out” radius (R_o) that could indicate the differing lifetime of the created systems in those collisions.

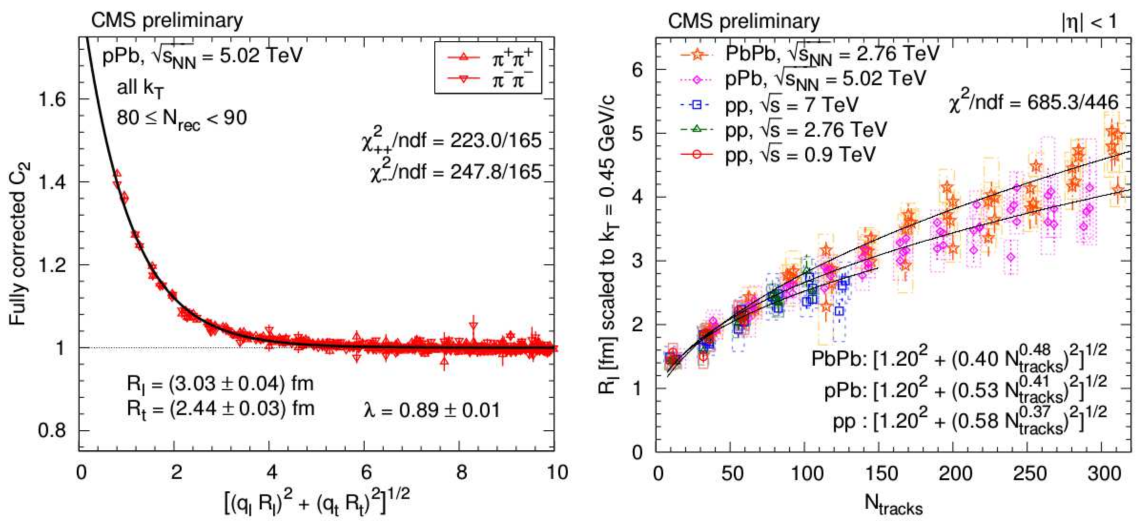

***Figure 1. Left:** The like-sign correlation function of pions (red triangles) corrected for Coulomb interaction and cluster contribution (mini-jets and multi-body resonance decays) as a function of the combined momentum, in a selected N_{rec} bins for all k_T. The solid curve indicates a fit with the exponential Bose-Einstein parametrization. **Right:** The longitudinal radius R_l as a function of N_{tracks} scaled to $k_T = 0.45$ GeV/c with help of a parametrization.*

The kaon radii also show some increase with N_{tracks}, although its magnitude is smaller than that for pions. Longer-lived resonances and rescattering may play a role here. The pion radii decrease with increasing k_T. The dependence of the radii on the multiplicity and k_T factorizes and in some cases appears to be less sensitive to the type of the colliding system and center-of-mass energy. The similarities observed in the N_{tracks} dependence may point to a common critical hadron density in pp, pPb, and peripheral PbPb collisions, since the present correlation technique measures the characteristic size of the system near the time of the last interactions.

Spectra of high p_T charged hadrons in pPb collisions. — We have measured the charged-particle spectra in pPb collisions in the transverse momentum range of $0.4 < p_T < 120$ GeV/*c* for center-of-mass pseudorapidities up to $|\eta_{CM}| = 1.8$. The forward-backward yield asymmetry has been measured as a function of p_T for three bins in η_{CM}. At $p_T < 10$ GeV/*c*, the charged-particle production is enhanced in the direction of the Pb beam, in qualitative agreement with nuclear shadowing expectations. The nuclear modification factor at midrapidity, relative to a reference spectrum interpolated from pp measurements at lower and higher collision energies, rises above unity at high p_T reaching an R_{pPb} value of 1.3–1.4 at $p_T \geq$ 40 GeV/*c*. The observed enhancement is larger than expected from next-to-leading order (NLO) perturbative QCD predictions that include anti-shadowing effects in the nuclear parton distribution functions (nPDFs) in this kinematic range.

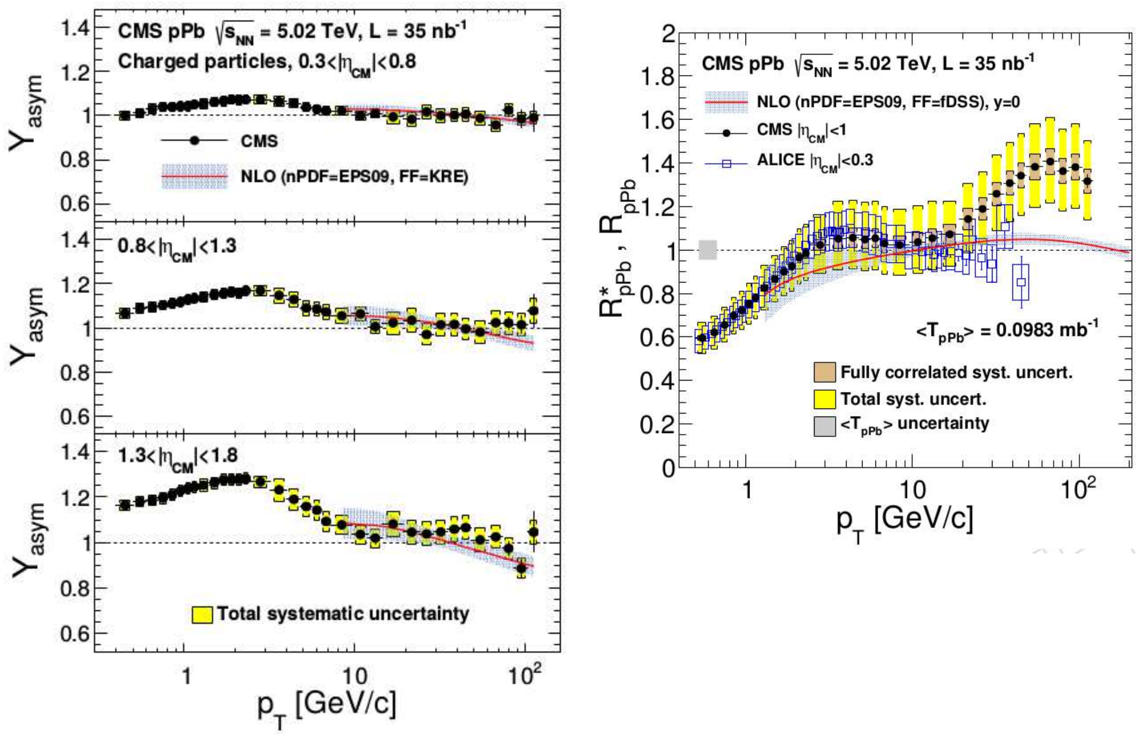

Figure 2. Left: *Charged-particle forward-backward yield asymmetry as a function of p_T for three $|\eta_{CM}|$ intervals. The asymmetry is computed as the charged-particle yields in the direction of the Pb beam divided by those of the proton beam.* ***Right:*** *Charged-particle nuclear modification factors measured by CMS in $|\eta_{CM}| < 1$ (filled circles), and by ALICE in $|\eta_{CM}| < 0.3$ (open squares), are compared to a theoretical prediction.*

The fact that the nuclear modification factor is below unity for $p_T < 2$ GeV/*c* is anticipated since particle production in this region is dominated by softer scattering processes that are not expected to scale with the nuclear thickness function. In the intermediate p_T range (2–5 GeV/*c*), no significant deviation from unity is found in the R_{pPb} ratio. There are several prior measurements that suggest an interplay of multiple effects in this p_T region. At lower collision energies, an enhancement ("Cronin effect") has been observed that is larger for baryons than for mesons, and is stronger in the more central collisions. This enhancement has been attributed to a combination of initial-state multiple scattering effects, causing momentum broadening, and hadronization through parton recombination (a final-state effect) invoked to accommodate baryon/meson differences. Recent results from pPb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV and from dAu collisions at $\sqrt{s_{NN}}$ = 200 GeV suggest that collective effects may also play a role in the intermediate-p_T region. Most theoretical models do not predict a Cronin enhancement in this p_T range at LHC energies as the effect of initial-state multiple scattering is compensated by nPDF shadowing.

The observed rise of the nuclear modification factor up to $R_{pPb} \approx 1.3$–1.4 at high p_T, albeit with large uncertainty, is much stronger than expected theoretically. None of the available theoretical models predict enhancements beyond $R_{pPb} \approx 1.1$ at high p_T. In particular, although the p_T range corresponds to parton momentum fractions $0.02 \leq x \leq 0.2$, which coincides with the region where parton anti-shadowing effects are expected, none of the nPDFs obtained from global fits to nuclear data predict enhancements beyond 10% at the large virtualities of relevance here. We also show the measurement of the ALICE Collaboration, which is performed in a narrower pseudorapidity range than the CMS one, and uses a different method to obtain the pp reference spectrum based on ALICE pp data measured at $\sqrt{s}$ = 7 TeV. The difference in the CMS and ALICE R_{pPb} results stems primarily from differences in the charged-hadron spectra measured in pp collisions at $\sqrt{s}$ = 7 TeV.

Future direct measurement of the spectra of jets and charged particles in pp collisions at a center-of-mass energy of 5.02 TeV is necessary to better constrain the fragmentation functions and also to reduce the dominant systematic uncertainties in the charged-particle nuclear modification factor.

Spectra of high mass bosons in pPb collisions. — We have measured the Z boson production cross section in the muon decay channel in pPb collisions. The results are presented in the center-of-mass frame with positive rapidity values corresponding to the proton fragmentation region. The Z boson candidates are selected as an opposite-charge muon pair in the 60–120 GeV/c^2 mass range where both muons have p_T > 20 GeV/c and are within the $|\eta_{lab}| < 2.4$ muon detector coverage. The measured inclusive Z boson production cross section in pPb collisions for the range $-2.5 < y_{CM} < 1.5$ is $\sigma_{pPb}(Z \rightarrow \mu\mu)$ = 94.1 ± 2.1 (stat.) ± 2.4 (syst.) ± 3.3 (lumi.) nb using the calibrated integrated luminosity. For the same restricted rapidity range, the Powheg simulation predicts 94.0 ± 4.7 nb after multiplying by the number of nucleons in the Pb nucleus (A = 208), which corresponds to the hypothesis of binary collision scaling in pPb.

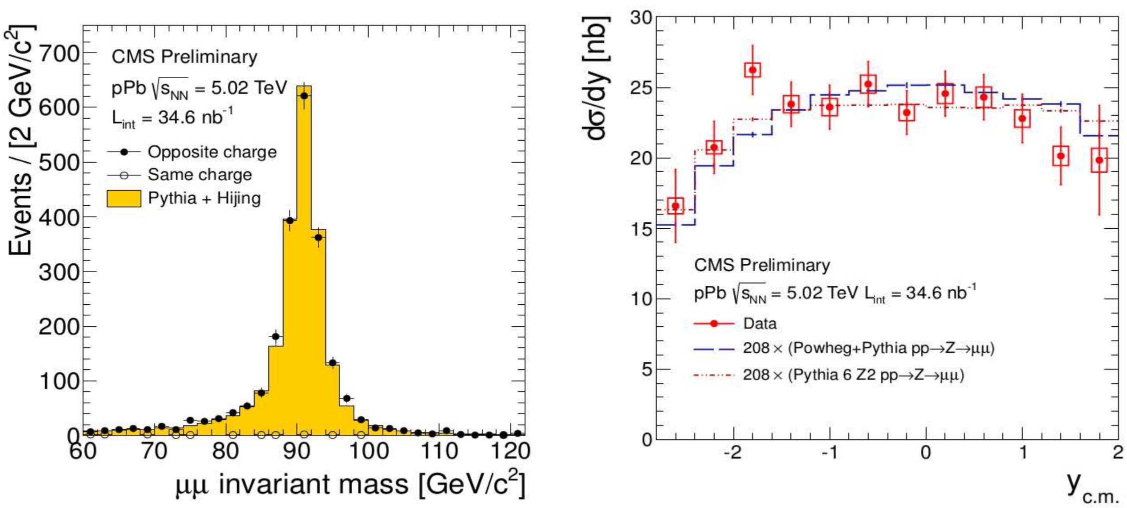

Figure 3. Left: *Invariant mass of selected muon pairs from pPb data compared to a simulation that was normalized to the number of events in data in the signal mass regions.* ***Right:*** *Differential cross section of Z bosons in pPb collisions as a function of rapidity compared to predictions from Powheg+Pythia generator with CT10NLO PDF set, from Pythia generator with Z2 underlying event tune. All theory predictions are scaled by A = 208.*

The differential cross section as a function of Z boson rapidity is consistent with the theory predictions. The forward-backward ratio, defined as $d\sigma(+y)/d\sigma(-y)$, is expected to be more sensitive to nuclear effects, because normalization uncertainties cancel both in theory and in experiment. Due to the large statistical uncertainties, this measurement is unable to distinguish between different nPDF sets but it can constrain their uncertainties by adding new data points to the global fits in a previously unexplored region of the Q^2–x phase space. The differential cross section as a function of Z boson transverse momentum has been measured and apart from very low transverse momenta it is in good agreement with the predictions from PYTHIA. The results of the presented measurement provide new data points in a previously unexplored region of phase space for constraining nuclear PDF fits.

Thus, Z boson production is unmodified by the hot and dense QCD medium produced in heavy ion collisions, and its yield scales with the number of binary nucleon-nucleon collisions. The nuclear modification factor does not exhibit large deviations from unity showing that nuclear effects are small with respect to the uncertainties of the pPb measurements. The results were compared to NLO theory predictions with and without nuclear modification, that show hints of nuclear effects but more luminosity is needed to distinguish between different nPDF sets. These measurements set constraints for the global fits of nPDFs in a previously unexplored region of phase space.

Quark and gluon jets. — We have studied the proton-to-pion ratio in jets produced in simulated proton-proton collisions at $\sqrt{s}$ = 7 TeV using the PYTHIA 6.4 Monte Carlo (MC) event generator. We compared the p/π ratio in the selected quark-like and gluon-like jets to a reference sample of tagged quark- and gluon-jets. The contamination in the selected jets significantly influences the observed ratios. Thus, despite the different fragmentation of jets originating from quarks or gluons, we see no difference in the proton-to-pion ratio inside these jets, within the used MC model. To see whether this statement holds, we suggest proceeding with similar study using experimental data.

Grants

OTKA K 81614: New analysis methods and tests of quantum chromodynamics at the LHC (F. Siklér, 2010-2014)

OTKA K 109703: Consortional main: Hungary in the CMS experiment of the Large Hadron Collider (F. Siklér, 2013-2016)

Swiss National Science Foundation, SCOPES 152601: Preparation for and exploitation of the CMS data taking at the next LHC run (G. Dissertori ETHZ, 2014-2017)

EC FP7 C 262025: Advanced European Infrastructures for Detectors and Accelerators [AIDA] (F. Siklér, 2011-2014)

“Wigner research group” support (F. Siklér, 2014)

Publications

Articles

1. Münzer R et al. incl. Fodor Z, Kecskemeti J, Seres Z (67 authors): SiΛvio: A trigger for Λ-hyperons. **NUCL INSTRUM METH A**, 745: pp. 38-49. (2014)

See also: R-I.3,

CMS collaboration

Due to the vast number of publications of the large collaborations in which the research group participated in 2014, here we list only a short selection of appearences in journals with the highest impact factor.

1. Chatrchyan S et al. incl. Bencze Gy, Hajdu Cs, Hidas P, Horvath D, Sikler F, Veszpremi V, Vesztergombi Gy, Zsigmond AJ [2200 authors]: Evidence for the direct decay of the 125 GeV Higgs boson to fermions. ***NATURE PHYSICS*** 10: pp. 557-560. (2014)

2. Bodwin GT et al. incl. Bencze Gy, Hajdu Cs, Hidas P, Horvath D, Sikler F, Veszpremi V, Vesztergombi Gy, Zsigmond AJ [2200 authors]: Fragmentation contributions to J/ψ production at the Tevatron and the LHC. **PHYS REV LETT**, 113:(2) Paper 022001. (2014)

3. Chatrchyan S et al. incl. Bencze Gy, Hajdu Cs, Hidas P, Horvath D, Sikler F, Veszpremi V, Vesztergombi Gy, Zsigmond AJ [2200 authors]: Search for top squark and higgsino production using diphoton higgs boson decays. **PHYS REV LETT**, 112:(16) Paper 161802. 15 p. (2014)

4. Chatrchyan S et al. incl. Bencze Gy, Hajdu Cs, Hidas P, Horvath D, Sikler F, Veszpremi V, Vesztergombi Gy, Zsigmond AJ [2202 authors]: Search for top-quark partners with charge 5/3 in the same-sign dilepton final state. **PHYS REV LETT**, 112:(17) Paper 171801. 16 p. (2014)

5. Chatrchyan S et al. incl. Bencze Gy, Hajdu Cs, Hidas P, Horvath D, Sikler F, Veszpremi V, Vesztergombi Gy, Zsigmond AJ [2200 authors]: Search for flavor-changing neutral currents in top-quark decays $t \rightarrow zq$ in pp collisions at $\sqrt{s}$ = 8TeV. **PHYS REV LETT**, 112:(17) Paper 171802. 16 p. (2014)

6. Chatrchyan S et al. incl. Bencze Gy, Hajdu Cs, Hidas P, Horvath D, Sikler F, Veszpremi V, Vesztergombi Gy, Zsigmond AJ [2202 authors]: Measurements of $t\bar{t}$ spin correlations and top-quark polarization using dilepton final states in pp collisions at $\sqrt{s}$ = 7TeV. **PHYS REV LETT**, 112:(18) Paper 182001. 16 p. (2014)

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8. Chatrchyan S et al. incl. Bencze Gy, Hajdu Cs, Hidas P, Horvath D, Sikler F, Veszpremi V, Vesztergombi Gy, Zsigmond AJ [2207 authors]: Observation of the associated

production of a single top quark -and a W boson in *pp* collisions at √s = 8TeV. **PHYS REV LETT**, 112:(23) Paper 231802. 16 p. (2014)

9. Chatrchyan S et al. incl. Bencze Gy, Hajdu Cs, Hidas P, Horvath D, Sikler F, Veszpremi V, Vesztergombi Gy, Zsigmond AJ [2206 authors]: Evidence of *b*-Jet Quenching in PbPb Collisions at $\sqrt{s_{NN}}$ = 2.76 TeV. **PHYS REV LETT**, 113: Paper 132301. 16 p. (2014)

10. Khachatryan V et al. incl. Bencze Gy, Hajdu Cs, Hidas P, Horvath D, Sikler F, Veszpremi V, Vesztergombi Gy, Zsigmond AJ [2147 authors]: Measurement of Prompt ψ(2S)→J/ψ Yield Ratios in Pb-Pb and p−p Collisions at $\sqrt{s_{NN}}$ = 2.76 TeV. **PHYS REV LETT**, 113:(26) Paper 262301. 15 p. (2014)

11. Chatrchyan S et al. incl. Bencze Gy, Hajdu Cs, Hidas P, Horvath D, Sikler F, Veszpremi V, Vesztergombi Gy, Zsigmond AJ [2231 authors]: Evidence for the 125 GeV Higgs boson decaying to a pair of τ leptons. **J HIGH ENERGY PHYS**, 2014:(5) Paper 104. 72 p. (2014)

12. Chatrchyan S et al. incl. Bencze Gy, Hajdu Cs, Hidas P, Horvath D, Sikler F, Veszpremi V, Vesztergombi Gy, Zsigmond AJ [2207 authors]: Measurement of Higgs boson production and properties in the WW decay channel with leptonic final states. **J HIGH ENERGY PHYS**, 2014:(1) Paper 096. 86 p. (2014)

13. Chatrchyan S et al. incl. Bencze Gy, Hajdu Cs, Hidas P, Horvath D, Sikler F, Veszpremi V, Vesztergombi Gy, Zsigmond AJ [2210 authors]: Search for new physics in events with same-sign dileptons and jets in pp collisions at √s = 8 TeV. **J HIGH ENERGY PHYS**, 2014:(1) Paper 163. (2014)

14. Chatrchyan S et al. incl. Bencze Gy, Hajdu Cs, Hidas P, Horvath D, Sikler F, Veszpremi V, Vesztergombi Gy, Zsigmond AJ [2202 authors]: Studies of azimuthal dihadron correlations in ultra-central PbPb collisions at $\sqrt{s}_{NN}$=2.76 TeV. **J HIGH ENERGY PHYS**, 2014**:**(2) Paper 088. 38 p. (2014)

15. Chatrchyan S et al. incl. Bencze Gy, Hajdu Cs, Hidas P, Horvath D, Sikler F, Veszpremi V, Vesztergombi Gy, Zsigmond AJ [2210 authors]: Measurement of the t(t)over-bar production cross section in the dilepton channel in pp collisions at √s = 8 TeV. **J HIGH ENERGY PHYS**, 2014:(2) Paper 024. 31 p. (2014)

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17. Chatrchyan S et al. incl. Bencze Gy, Hajdu Cs, Hidas P, Horvath D, Sikler F, Veszpremi V, Vesztergombi Gy, Zsigmond AJ [2207 authors]: Search for W ' -> tb decays in the lepton plus jets final state in pp collisions at √s = 8 TeV. **J HIGH ENERGY PHYS**, 2014:(5) Paper 108. 35 p. (2014)

18. Chatrchyan S et al. incl. Bencze Gy, Hajdu Cs, Hidas P, Horvath D, Sikler F, Veszpremi V, Vesztergombi Gy, Zsigmond AJ [2224 authors]: Measurements of the tt¯ charge asymmetry using the dilepton decay channel in pp collisions at s√ = 7 TeV. **J HIGH**

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19. Chatrchyan S et al. incl. Bencze Gy, Hajdu Cs, Hidas P, Horvath D, Sikler F, Veszpremi V, Vesztergombi Gy, Zsigmond AJ [2209 authors]: Event activity dependence of Y (nS) production in $\sqrt{s_{NN}}$ = 5.02 TeV pPb and $\sqrt{s}$ = 2.76 TeV pp collisions. **J HIGH ENERGY PHYS**, 2014:(4) Paper 103. 37 p. (2014)

20. Chatrchyan S et al. incl. Bencze Gy, Hajdu Cs, Hidas P, Horvath D, Sikler F, Veszpremi V, Vesztergombi Gy, Zsigmond AJ [2224 authors]: Measurement of associated W plus charm production in pp collisions at $\sqrt{s}$ = 7 TeV. **J HIGH ENERGY PHYS**, 2014:(2) Paper 013. 63 p. (2014)

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22. Chatrchyan S et al. incl. Bencze Gy, Hajdu Cs, Hidas P, Horvath D, Sikler F, Veszpremi V, Vesztergombi Gy, Zsigmond AJ [2221 authors]: Search for pair production of excited top quarks in the lepton + jets final state. **J HIGH ENERGY PHYS**, 2014:(6) Paper 125. 35 p. (2014)

23. Chatrchyan S et al. incl. Bencze Gy, Hajdu Cs, Hidas P, Horvath D, Sikler F, Veszpremi V, Vesztergombi Gy, Zsigmond AJ [2214 authors]: Search for new physics in the multijet and missing transverse momentum final state in proton-proton collisions at $\sqrt{s}$ = 8 TeV. **J HIGH ENERGY PHYS**, 2014:(6) Paper 055. 38 p. (2014)

24. Chatrchyan S et al. incl. Bencze Gy, Hajdu Cs, Hidas P, Horvath D, Sikler F, Veszpremi V, Vesztergombi Gy, Zsigmond AJ [2223 authors]: Measurement of the triple-differential cross section for photon + jets production in proton-proton collisions at $\sqrt{s}$ = 7 TeV. **J HIGH ENERGY PHYS**, 2014:(6) Paper 009. 35 p. (2014)

25. Khachatryan V et al. incl. Bencze Gy, Hajdu Cs, Hidas P, Horvath D, Sikler F, Veszpremi V, Vesztergombi Gy, Zsigmond AJ [2126 authors]: Measurement of the t-channel single-top-quark production cross section and of the |Vtb| CKM matrix element in pp collisions at $\sqrt{s}$ = 8 TeV. **J HIGH ENERGY PHYS**, 2014:(6) Paper 090. 43 p. (2014)

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27. Khachatryan V et al. incl. Bencze Gy, Hajdu Cs, Hidas P, Horvath D, Sikler F, Veszpremi V, Vesztergombi Gy, Zsigmond AJ [2129 authors]: Measurement of prompt J/ψ pair production in pp collisions at $\sqrt{s}$ = 7 TeV. **J HIGH ENERGY PHYS**, 2014:(9) Paper 094. 35 p. (2014)

28. Khachatryan V et al. incl. Bencze Gy, Hajdu Cs, Hidas P, Horvath D, Sikler F, Veszpremi V, Vesztergombi Gy, Zsigmond AJ [2137 authors]: Search for the associated production of the Higgs boson with a top-quark pair. **J HIGH ENERGY PHYS**,

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29. Khachatryan V et al. incl. Bencze Gy, Hajdu Cs, Hidas P, Horvath D, Sikler F, Veszpremi V, Vesztergombi Gy, Zsigmond AJ [2132 authors]: Study of hadronic event-shape variables in multijet final states in pp collisions at √s =7 TeV. **J HIGH ENERGY PHYS**, 2014:(10) Paper 087. 34 p. (2014)

30. Khachatryan V et al. incl. Bencze Gy, Hajdu Cs, Hidas P, Horvath D, Sikler F, Veszpremi V, Vesztergombi Gy, Zsigmond AJ [2147 authors]: Identification techniques for highly boosted W bosons that decay into hadrons. **J HIGH ENERGY PHYS**, 2014:(12) Paper 17. 46 p. (2014)

NA49 Collaboration

1. Anticic T et al. incl. Barna D, Fodor Z, Laszlo A, Palla G, Sikler F, Vesztergombi Gy [68 authors]: Phase-space dependence of particle-ratio fluctuations in Pb+Pb collisions from 20A to 158A GeV beam energy. **PHYS REV C**, 89:(5) Paper 054902. 28 p. (2014)

FOPI Collaboration

1. Zinyuk V et al. incl. Fodor Z, Kecskeméti KJ, Seres Z [65 authors]: Azimuthal emission patterns of K+ and of K- mesons in Ni plus Ni collisions near the strangeness production threshold. **PHYS REV C,** 90:(2) Paper 025210. 6 p. (2014)

See also: R-B. ALICE Collaboration, R-I. NA61/SHINE Collaboration

R-I. "Lendület" innovative particle detector development

"Momentum" research team

Dezső Varga, György Bencze, Gyula Bencédi#, Ervin Dénes, Gergő Hamar#, Gábor Kiss#, Tivadar Kiss, András László, Krisztina Márton#, László Oláh#, Éva Oláh#, Tamás Tölyhi

The activities of the group can be divided into two categories. The first concerns the rapid evolution of the laboratory infrastructure necessary for long-term future commitments. The second concerns initiating or continuing specific research subjects, developments on the high resolution single photon UV scanning, results from the Low Momentum Particle Detector (LMPD) for the NA61 Experiment, cosmic muon detection, activities for the ALICE Experiment, and education activities. These are reported below.

Refurbishment of the laboratory environment started last year and has been completed to match the necessary scientific requirements. This involved a substantial commitment on the side of the participants, including training in low-dust environments and precision gas systems. The main lab room (Building 2, room 111) includes equipment for the most sensitive test activities: gas distribution, precision high voltages, and various data acquisition systems (DAQ). The "Construction Lab" (Building 2) includes the clean compartment of 8 m^2 area, with a flat table assured for ISO5 (grade 100) quality. These developments are critical for the long-term competitiveness of the group. The laboratory became part of the National Research Infrastructure Survey and Roadmap (NEKIFUT).

Among the research objectives, the Leopard project (high-resolution scanning of thick gas electron multiplier (TGEM) structures with single UV photons) continued to be successful and has seen considerable improvements within the framework of the RD51 Collaboration. Now the classical GEMs, with a hole diameter of 50 µm, became visible, and therefore became an integral part of the AIDA2020 project; Task 12.4.4, with Wigner RCP as project leader. Figure 1 below shows high-resolution images of these, including a hole-by-hole gain map showing increased gain at the GEM edge (upper part of right panel).

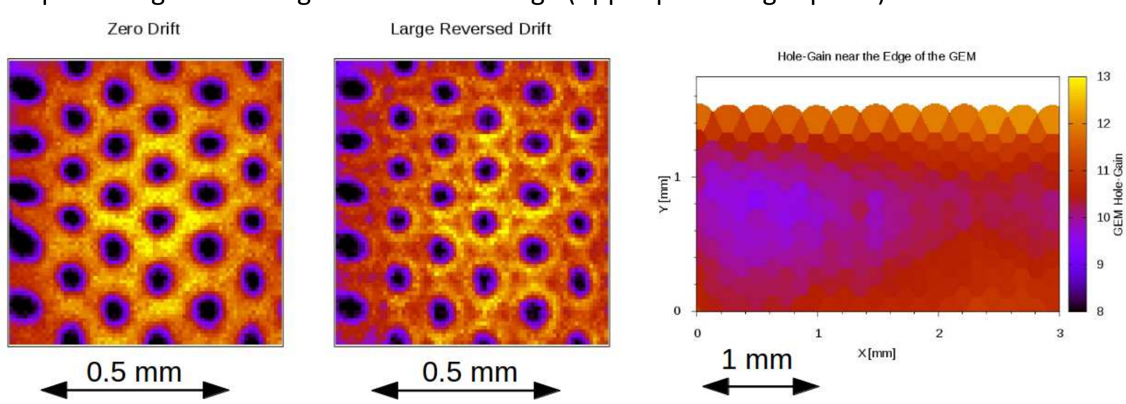

Figure 1. *Leopard images of a classical GEM layer. With improved resolution of 15 micron, the fine structures (left and middle) as well as single hole gains (right) are quantified.*

Ph.D. student

Members of our research group are key participants at the **CERN NA61 (Shine) Experiment**. The Low Momentum Particle Detector, built in 2011-2012, has been fully calibrated during the year and its data has been analyzed. The purpose of the LMPD is to detect slow particles that are characteristic of the collision centrality in hadron-nucleus interactions. Figure 2 shows an image of the detector; single tracks emerging from the target are clearly detected (left panel).

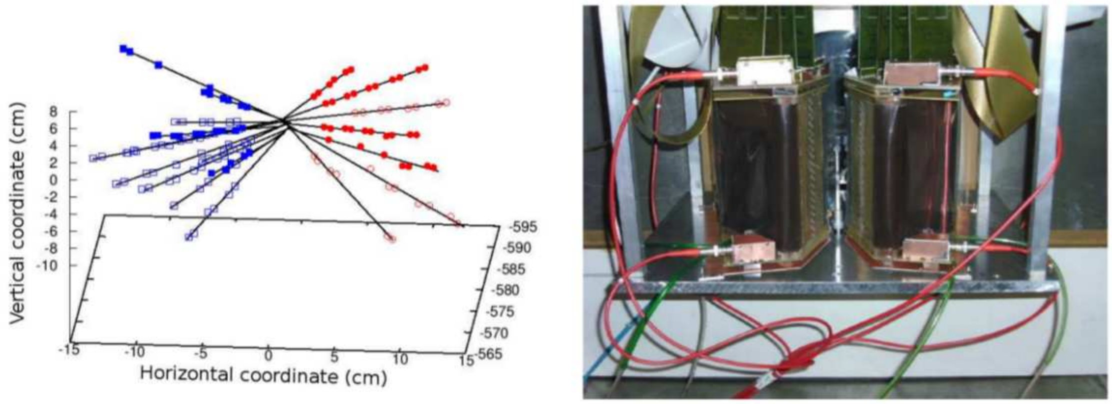

Figure 2. *The Low Momentum Particle Detector of the NA61 Experiment at CERN, constructed in 2011-2012. The tracks are clearly identified (left) emerging from the target which sits in the middle of the two halves of the detector (right)*

After the full calibration performed at CERN, and refined data analysis, published results show excellent tracking performance and demonstrated particle identification. The image of the target is shown in the left panel of Figure 3, whereas the capability to separate the particle charge (mostly protons and He isotopes) is shown in the right panel.

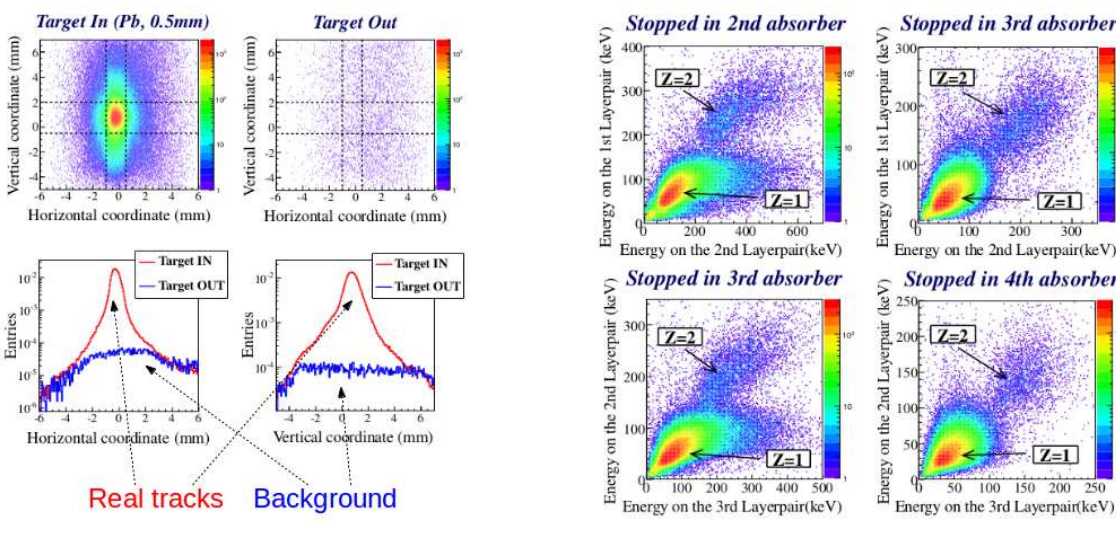

Figure 3. *The LMPD tracking performance is well demonstrated by the low level of background contamination below 1% fraction, whereas with a real target installed the trajectories emerge from a small spot (left). The LMPD can identify particles by ionization: H and He nuclei are clearly separated (right)*

Research activities for **cosmic muon detectors** were aimed at two directions: one is the earlier established underground flux observation, the other is transmission tomography to map the 3D structures of material placed inside the detector system. An example of the latter is shown in Figure 4, where the test objects appear clearly measured by cosmic muon scattering strength. Such detectors may find applications in security systems, for which a collaboration between NKE (National Security and Public Service University) and Wigner RCP has been initiated.

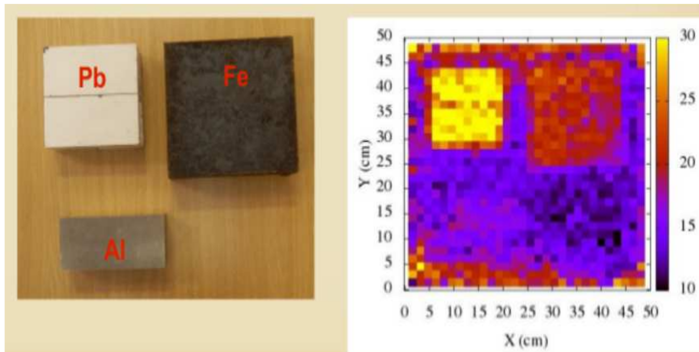

Figure 4. *Test objects (left) placed inside a cosmic muon detector can be imaged (right) by measuring muon scattering. High-Z materials such as lead provide a very strong signal, even if so thick that X-rays can not penetrate them.*

The collaboration with the **ALICE Experiment at CERN** has received a new boost from our group's entry to the Time Projection Chamber (TPC) Upgrade project. GEM detectors will replace the TPC readout chambers to enable continuous event readout, and consequently reach a 100-fold gain in speed.

Secondary school students, along with their teacher, Éva Oláh, were highly active. This activity received an "Útravaló" grant to support the education of students and common work. Approximately 10 students participated in the building and performance demonstration of the multi-wire proportional chamber (MWPC).

Grant

"Momentum" Program of the HAS (D. Varga, 2013-2018)

International cooperation

CERN NA61 Collaboration (A. Laszlo and K. Marton), CERN RD51 Collaboration (Gy. Bencze, G. Hamar and D. Varga), CERN ALICE Collaboration (G. Hamar, Gy. Bencedi and D. Varga)

Long term visitor

Kristian Engeseth, Bergen University (D. Varga, 3 weeks)

Publications

Articles

1. Hamar G, Varga D: High granularity scanner for MPGD based photon detectors. **POS - PROCEEDINGS OF SCIENCE**, TIPP2014 (Technology and Instrumentation in Particle Physics 2014. Amsterdam, The Netherlands, 02.06.2014-06.06.2014), Paper 056. 8 p. (2014)

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See also: R-B.1, R-P.1

NA61/SHINE Collaboration

Articles

1. Abgrall N et al. incl. Fodor Z, Kiss T, Laszlo A, Marton K, Palla G, Sipos R, Tolyhi T, Vesztergombi Gy [139 authors]: Measurement of negatively charged pion spectra in inelastic p plus p interactions at p_{lab}=20, 31, 40, 80 and 158 GeV/c. ***EUROPEAN PHYSICAL JOURNAL C*** 74:(3) Paper 2794. 22 p. (2014)
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CBM Collaboration

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2. Höhne C, Ablyazimov T et al. incl. Kiss T, Tölyhi T, Wolf Gy [555 authors]: Measurement of dileptons with the CBM experiment at FAIR. **NUCL PHYS A**, 931: pp. 735-739. (2014)

See also: R-B. ALICE Collaboration, R-H. CMS Collaboration, R-H. NA49 Collaboration

R-J. Standard model and new physics

Wigner research group

Viktor Veszprémi, Dániel Barna[A], Márton Bartók[#], Lajos Diósi, Csaba Hajdu, András Házi[#], Pál Hidas, Dezső Horváth, Gabriella Pásztor[A], József Tóth, Tamás Vámi[#], György Vesztergombi

Physics analyses. — Our group has been participating in the studies of the newly-discovered Higgs boson and have shown that its properties indeed correspond to the predictions of the Standard Model. We presented this result both at international conferences and institutional seminars, and also in two books.

We have performed searches for supersymmetric particles in 8 TeV proton-proton collision data which was collected in 2012. In these searches, we were looking for possible signatures of gluino-pair production and decays to top squarks where b-jets, a lepton, multiple light flavor jets, and missing transverse momentum were present. We also measured the reconstruction and identification efficiencies of electrons and muons by performing an auxiliary measurement of events where leptonically decaying Z bosons and multiple jets are produced. No excess was observed in these searches and the results were interpreted as exclusion limits on the mass parameter space of simplified models of on- (real) and off-shell (virtual) top squarks production via gluino pairs.

Theoretical work. — Theoretical activity in quantum and gravity foundations, as well as in open quantum system dynamics has been continued. The yet hypothetical gravity-related spontaneous wave-function collapse has been derived for the first time in acoustic modes of bulk matter. Proposals of various related experimental tests have been outlined including a specific Cavendish experiment to test a possible quantum-delay of Newton gravitational force.

Thorough investigations of the Gaussian class of non-Markovian open quantum systems have led to a general mathematical structure showing strong resemblance with the well-known and widely-used special Markovian case; that is to say, with the famous Lindblad structure and master equations.

Work on instrumentation. — Our team continued to contribute strongly to the operation, calibration, and data-reconstruction of the CMS Tracker detectors: the inner silicon pixel, and outer silicon strip detectors. We have provided a coordinator for the CMS Tracker Detector Performance group, and one for its CMS Pixel calibration and local reconstruction subgroup.

The two most important performance parameters of the pixel detector are hit detection efficiency and position measurement resolution. They determine the efficiency and accuracy of charged particle track reconstruction. Charged particle tracks are used in the determination of the secondary (decay) vertices of heavy flavor jets, which are produced in

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[#] Ph.D. student

the supersymmetric events of our interest. We have found an efficiency loss at the per cent level in data acquired by the pixel detector which was not reflected by the simulation. We have improved the simulation of the CMS pixel detector and presented the results in a conference. We also measured the radiation damage experienced by the pixel detector. Radiation damage has an impact on the resolution of the hit position measurement. We found disagreement between the detector performance and its simulation in the official CMS software. We have implemented a new method which transforms the charge distribution of clusters in the pixel according to the expected radiation damage at given operational configuration (bias voltage, temperature, etc.) One of the most important aspects of detector readiness is the maintenance of the calibration databases which is entirely the responsibility of our group. We improved the resolution measurement also by introducing a new calibration object to correct for the apparent shift of cluster positions due to the presence of magnetic field as function of the irradiation in the silicon bulk.

Detector construction. — Radiation-induced damage of sensors and readout electronics degrades the resolution of position measurements in the CMS Pixel detector to the extent that the detector is rendered unusable. Therefore it will need to be replaced. This will happen in two steps in the next couple of decades called phase I and II upgrades. Our group has played a leading role in studying radiation effects and now we are also key contributors to the design of the new-generation pixel detector. We have designed and built the first prototypes for the control and readout electronics of the CMS Phase I Pixel upgrade detector.

The Liquid Argon Calorimeter is a basic component of the ATLAS detector. Its capabilities of detecting electrons, photons, jets and missing energy are crucial ingredients of discovering theoretically predicted new physics phenomena, like Supersymmetry, and of analyzing features of the Standard Model, including detailed experimental study of the Higgs boson. Because of the significant increase of the LHC luminosity in the coming years, the LAr Phase I Upgrade Project was defined and accepted to maintain and improve the performance of this detector. Being involved in the LAr group of CPPM, which is responsible for the upgraded back-end electronics of the level1 electromagnetic calorimeter's trigger system, we joined this effort with the aim of defining software algorithms to perform fast (trigger) electron selection. During data-acquisition, it is used in real-time identification of multi-lepton final states which are the result of associated production of charginos and neutralinos, while rejecting background as much as possible. This year, the first steps to reproduce the results of the TDR and check the existing software tools have been done and presented at several internal ATLAS working meetings.

Maintaining the CMS grid computing infrastructure. — The CMS computing grid is used in the reconstruction of both simulated and collision data which are analyzed in our searches for new physics. Stable operation of the T2_HU_Budapest grid site continued in 2014 giving us the third position in the site availability ranking of CMS T2 sites. Hardware developments included an upgrade of the external network connection to 10 Gbits/s, and the addition of 192 WN CPU cores and 40 TB disk storage.

Grant

OTKA K 109703: Consortional main: Hungary in the CMS experiment of the Large Hadron Collider (Ferenc Siklér, 2013-2016)

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4. Diósi L: Gravity-related wave function collapse - is superfluid He exceptional? **FOUND PHYS**, 44:(5) pp. 483-491. (2014)

5. Diósi L: Newton force from wave function collapse: Speculation and test. **J PHYS CONF SER**, 504:(1) Paper 012020. 7 p. (2014)

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7. Diósi L: Gravity-related spontaneous wave function collapse in bulk matter. **NEW J PHYS**, 16: Paper 105006. 9 p. (2014)

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13. Horváth D: Twenty years of searching for the Higgs boson: Exclusion at LEP, discovery at LHC. **MOD PHYS LETT A**, 29: Paper 1430004. 20 p. (2014)

14. Horváth D: Broken Symmetries and the Higgs Boson. **EPJ WEB CONF**, 78: Paper 01003. (2014)

15. Konrad G, Ayala Guardia F, Baeßler S, Borg M, Glück F, Heil W, Hiebel S, Muñoz Horta R, Sobolev Y: The magnetic shielding for the neutron decay spectrometer aSPECT. **NUCL INSTRUM METH A**, 767: pp. 475-486. (2014)

16. Sótér A, Todoroki K, Kobayashi T, Barna D, Horváth D, Hori M: Segmented scintillation detectors with silicon photomultiplier readout for measuring antiproton annihilations **REV SCI INSTRUM**, 85:(2) Paper 023302. 10 p. (2014)

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19. Todoroki K, Hori M, Aghai-Khozani H, Barna D, Corradini M, Kobayashi T, Leali M, Lodi-Rizzini E, Mascagna V, Prest M, Soter A, Vallazza E, Venturelli L, Zurlo N, Hayano R: Beam diagnostics for measurements of antiproton annihilation cross sections at ultra-low energy. **EPJ WEB CONF**, 66: Paper 09020. 4 p. (2014)

Book chapter

20. Diósi L: Determination of the stationary basis from protective measurement on a single system. In: Protective Measurement and Quantum Reality: Towards a New Understanding of Quantum Mechanics, Ed.: Gao S, Cambridge: Cambridge University Press, 2014. pp. 63-67.

See also: R-P.1

ATLAS collaboration

Due to the vast number of publications of the large collaborations in which the research group participated in 2014, here we list only a short selection of appearances in journals with the highest impact factor.

1. Aad G et al. incl. Pasztor G, Toth J [2937 authors]: Search for dark matter in events with a hadronically decaying W or Z boson and missing transverse momentum in pp collisions at $\sqrt{s}$ = 8 TeV with the ATLAS detector

PHYS REV LETT, 112:(4) Paper 041802. 17 p. (2014)

2. Aad G et al. incl. Pasztor G, Toth J [2935 authors]: Search for quantum black hole production in high-invariant-mass lepton + jet final states using pp collisions at √s = 8 TeV and the ATLAS detector. **PHYS REV LETT**, 112:(9) Paper 091804. 20 p. (2014)

3. Aad G et al. incl. Pasztor G, Toth J [2881 authors]: Evidence for Electroweak Production of W±W±jj in pp Collisions at √s =8 TeV with the ATLAS Detector. **PHYS REV LETT**, 113: Paper 141803. 20 p. (2014)

4. Aad G et al. incl. Pasztor G, Toth J [2899 authors]: Measurements of Four-Lepton Production at the Z Resonance in pp Collisions at √s =7 and 8 TeV with ATLAS. **PHYS REV LETT**, 112: Paper 231806. 20 p. (2014)

5. Aad G et al. incl. Pasztor G, Toth J [2919 authors]: Search for Invisible Decays of a Higgs Boson Produced in Association with a Z Boson in ATLAS. ***PHYSICAL REVIEW LETTERS*** 112: Paper 201802. 19 p. (2014)

6. Aad G et al. incl. Pasztor G, Toth J [2891 authors]:Search for Scalar Diphoton Resonances in the Mass Range 65-600 GeV with the ATLAS Detector in pp Collision Data at √s = 8 TeV. **PHYS REV LETT**, 113:(17) Paper 171801. 18 p. (2014)

7. Aad G et al. incl. Pasztor G, Toth J [2884 authors]: Observation of an excited B±c meson state with the ATLAS detector. **PHYS REV LETT**, 113:(21) Paper 212004. 19 p. (2014)

8. Aad G et al. incl. Pasztor G, Toth J [2935 authors]: Measurement of the top quark pair production charge asymmetry in proton-proton collisions at √s = 7 TeV using the ATLAS detector. **J HIGH ENERGY PHYS**, (2) Paper 107. 38 p. (2014)

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10. Aad G et al. incl. Pasztor G, Toth J [2891 authors]:Search for top quark decays t → qH with H → γγ using the ATLAS detector. **J HIGH ENERGY PHYS**, 2014:(6) Paper 008. 22 p. (2014)

11. Aad G et al. incl. Pasztor G, Toth J [2887 authors]: Search for supersymmetry at √s= 8 TeV in final states with jets and two same-sign leptons or three leptons with the ATLAS detector. **J HIGH ENERGY PHYS**, 2014:(6) Paper 035. 49 p. (2014)

12. Aad G et al. incl. Pasztor G, Toth J [2900 authors]: Search for direct top-squark pair production in final states with two leptons in pp collisions at √s = 8 TeV with the ATLAS detector. **J HIGH ENERGY PHYS**, 2014:(6) Paper 124. 61 p. (2014)

13. Aad G et al. incl. Pasztor G, Toth J [2886 authors]: Search for supersymmetry in events with large missing transverse momentum, jets, and at least one tau lepton in 20 fb(-1) of √s = 8 TeV proton-proton collision data with the ATLAS detector. **J HIGH ENERGY**

PHYS, (9) Paper 103. 54 p. (2014)

14. Aad G et al. incl. Pasztor G, Toth J [2875 authors]: Measurement of the production cross-section of ψ(2S)→J/ψ(→□+□−)π+π− in pp collisions at s√ = 7 TeV at ATLAS. **J HIGH ENERGY PHYS**, (9) Paper 079. 49 p. (2014)

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16. Aad G et al. incl. Pasztor G, Toth J [2886 authors]: Search for direct production of charginos, neutralinos and sleptons in final states with two leptons and missing transverse momentum in *pp* collisions at √s = 8 TeV with the ATLAS detector. **J HIGH ENERGY PHYS**, (5) Paper 71. 52 p. (2014)

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19. Aad G et al. incl. Pasztor G, Toth J [2878 authors]: Search for squarks and gluinos with the ATLAS detector in final states with jets and missing transverse momentum using √s = 8 TeV proton-proton collision data. **J HIGH ENERGY PHYS**, (9) Paper 176. 52 p. (2014)

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21. Aad G et al. incl. Pasztor G, Toth J [2894 authors]: Search for neutral Higgs bosons of the minimal supersymmetric standard model in pp collisions at √s=8 TeV with the ATLAS detector. **J HIGH ENERGY PHYS**, 2014:(11) Paper 56. 47 p. (2014)

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24. Aad G et al. incl. Pasztor G, Toth J [2879 authors]: Measurement of the Z/γ∗ boson transverse momentum distribution in pp collisions at √s = 7 TeV with the ATLAS detector. **J HIGH ENERGY PHYS**, (9) Paper 145. 47 p. (2014)

25. Aad G et al. incl. Pasztor G, Toth J [2882 authors]: Search for new particles in events with one lepton and missing transverse momentum in pp collisions at $\sqrt{s}$ = 8 TeV with the ATLAS detector. **J HIGH ENERGY PHYS**, (9) Paper 037. 43 p. (2014)

26. Aad G et al. incl. Pasztor G, Toth J [2883 authors]: Search for direct pair production of the top squark in all-hadronic final states in proton-proton collisions at $\sqrt{s}$ = 8 TeV with the ATLAS detector. **J HIGH ENERGY PHYS**, (9) Paper 015. 51 p. (2014)

27. Aad G et al. incl. Pasztor G, Toth J [2960 authors]: Measurement of χ_{c1} and χ_{c2} production with $\sqrt{s}$ = 7 TeV pp collisions at ATLAS. **J HIGH ENERGY PHYS**, (7) Paper 154. 52 p. (2014)

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