

R-H. Hadron physics

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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 at the large Hadron Collider), both in data-taking and physics analysis.

Correlations of hadrons. — We have studied two-particle angular correlations between identified pions, kaons, protons and charged particles in p-Pb collisions at 5 TeV center-of-mass energy in CMS. The particles are identified via their energy loss in the silicon tracker. A long-range, near side structure appears for all particles species at high particle multiplicity. Azimuthal correlations are measured and are characterized by the second-order (elliptic flow) and third-order (triangular flow) anisotropy harmonics. They are measured as a function of transverse momentum in a wide range of particle multiplicity. The results reproduce features that are usually attributed to hydrodynamic models: mass ordering is observed at low transverse momentum at high particle multiplicities.

Hadron spectra. — We played the leading role in the analysis and publication of the measurement of pseudorapidity distribution ($dN/d\eta$) of charged hadrons in 13 TeV inelastic pp collisions in CMS. The data taking was performed without magnetic field, under special conditions. After a quick preliminary public result, based on data from the strip tracker only, we performed the analysis with a newly developed tracking algorithm. While the predictions of both Pythia8 and EPOS LHC event generators agree with the measured $dN/d\eta$ value ($5.49 \pm 0.01(\text{stat}) \pm 0.17(\text{syst})$) at mid-rapidity, the measured distribution in the full range is better described by the latter. The center-of-mass energy dependence matches well the extrapolations based on lower energy data. These results constitute the first CMS measurement of hadron production at the new center-of-mass energy frontier, in fact these were the first published results based on 13 TeV LHC data. They provide new constraints for the improvement of perturbative and nonperturbative QCD aspects of hadronic event generators.

Probes of nuclear parton distribution functions. — We have measured the Z boson production in p-Pb collisions also in the electron decay channel in CMS. The combined cross section from the muon and electron channels provides better statistical precision. The differential cross section as a function of rapidity and the forward-backward ratio shows better agreement with presence of nuclear effects. The combination of W boson, charged

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particle and jet measurements in p-Pb collisions provide constraints for nuclear parton distribution functions.

Probing the hot medium with heavy flavor. — We carried out the first measurement of bottomonium production in 193 GeV U-U collisions with the STAR experiment. Bound states of heavy quarks provide a unique means for accessing the thermal properties of the quark-gluon plasma. We identified the decay electrons in order to reconstruct the $\Upsilon(1S)$, $\Upsilon(2S)$, and $\Upsilon(3S)$ states. The production of these states is significantly suppressed in central U-U collisions compared to naive expectations from pp collisions. According to different theoretical calculations, this observation is consistent with an initial medium temperature between 330 and 442 MeV.

Differentiating jets. — We have developed a prototype machine learning classifier for differentiating between decays of quarks and gluons. The power to discriminate between these two types of particles would have a huge impact on many searches for new particles and new physics, and studies of QCD. We have devised a fast method for ranking discriminant variables. The model has been tested on Monte Carlo data with full-detector simulation and demonstrates performance that is competitive with results obtained by others in the field.

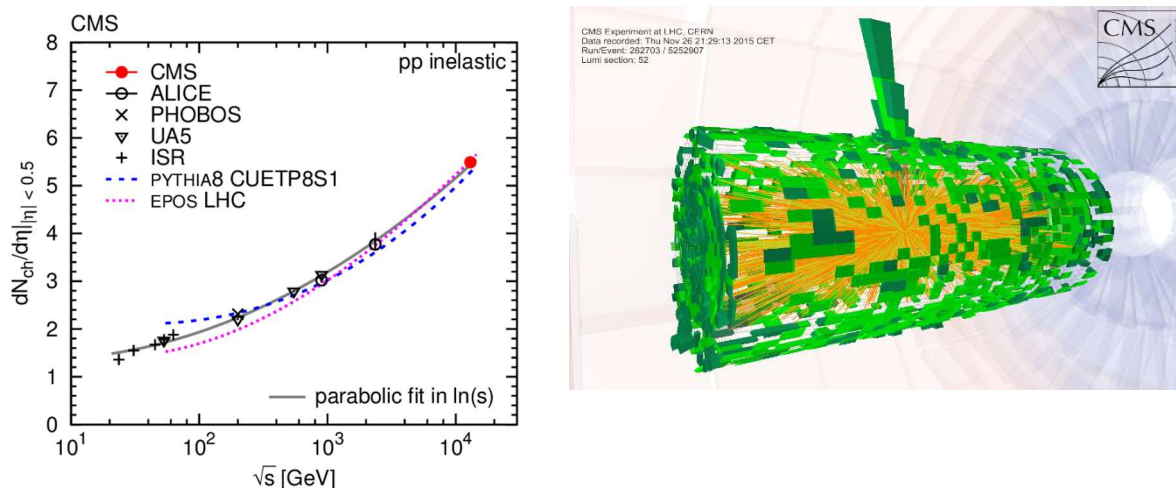


Figure 1. Left: Center-of-mass energy dependence of $dN_{ch}/d\eta|_{|\eta|<0.5}$ including lower energy data. The solid curve shows a second-order polynomial fit to the data points, including the new result at 13 TeV. The dashed and dotted curves show model predictions. Right: Event display of a Pb-Pb collision taken at 5 TeV per nucleon-pair center-of-mass energy at the end of 2015. Orange curves show reconstructed trajectories of charged particles, while green towers represent energy deposits in the calorimeters.

Grants

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

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International cooperation

ALICE, CMS, FOPI, NA61 (CERN) and STAR (RHIC)

Publications

See: 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 appearances in journals with the highest impact factor.

1. Khachatryan V et al. incl. [Bencze G](#), [Hajdu C](#), [Hidas P](#), [Horváth D](#), [Siklér F](#), [Veszprémi V](#), [Vesztergombi G](#), [Zsigmond AJ](#) (2146 authors): Angular coefficients of Z bosons produced in pp collisions at $\sqrt{s} = 8$ TeV and decaying to $\mu^+\mu^-$ as a function of transverse momentum and rapidity. *PHYS LETT B* 750: pp. 154-175. (2015)
2. Khachatryan V et al. incl. [Bencze G](#), [Hajdu C](#), [Hidas P](#), [Horváth D](#), [Siklér F](#), [Veszprémi V](#), [Vesztergombi G](#), [Zsigmond AJ](#) (2134 authors): Differential cross section measurements for the production of a W boson in association with jets in proton-proton collisions at $\sqrt{s} = 7$ TeV. *PHYS LETT B* 741: pp. 12-37. (2015)
3. Khachatryan V et al. incl. [Bencze G](#), [Hajdu C](#), [Hidas P](#), [Horváth D](#), [Siklér F](#), [Veszprémi V](#), [Vesztergombi G](#), [Zsigmond AJ](#) (2143 authors): Long-range two-particle correlations of strange hadrons with charged particles in pPb and PbPb collisions at LHC energies. *PHYS LETT B* 742: pp. 200-224. (2015)
4. Khachatryan V et al. incl. [Bencze G](#), [Hajdu C](#), [Hidas P](#), [Horváth D](#), [Siklér F](#), [Veszprémi V](#), [Vesztergombi G](#), [Zsigmond AJ](#) (2147 authors): Measurement of the cross section ratio $\sigma_{t\bar{t}b\bar{b}}/\sigma_{t\bar{t}j\bar{j}}$ in pp collisions at $\sqrt{s} = 8$ TeV. *PHYS LETT B* 746: pp. 132-153. (2015)
5. Khachatryan V et al. incl. [Bencze G](#), [Hajdu C](#), [Hidas P](#), [Horváth D](#), [Siklér F](#), [Veszprémi V](#), [Vesztergombi G](#), [Zsigmond AJ](#) (2135 authors): Measurement of the $pp \rightarrow ZZ$ production cross section and constraints on anomalous triple gauge couplings in four-lepton final states at $\sqrt{s} = 8$ TeV. *PHYS LETT B* 740: pp. 250-272. (2015)
6. Khachatryan V et al. incl. [Bencze G](#), [Hajdu C](#), [Hidas P](#), [Horváth D](#), [Siklér F](#), [Veszprémi V](#), [Vesztergombi G](#), [Zsigmond AJ](#) (2147 authors): Measurement of the production cross section ratio $\sigma(\chi_{b2}(1P))/\sigma(\chi_{b1}(1P))$ in pp collisions at $\sqrt{s} = 8$ TeV. *PHYS LETT B* 743: pp. 383-402. (2015)
7. Khachatryan V et al. incl. [Bencze G](#), [Hajdu C](#), [Hidas P](#), [Horváth D](#), [Siklér F](#), [Veszprémi V](#), [Vesztergombi G](#), [Zsigmond AJ](#) (2175 authors): Measurement of the Z boson differential cross section in transverse momentum and rapidity in proton-proton collisions at 8 TeV. *PHYS LETT B* 749: pp. 187-209. (2015)
8. Khachatryan V et al. incl. [Bencze G](#), [Hajdu C](#), [Hidas P](#), [Horváth D](#), [Siklér F](#), [Veszprémi V](#), [Vesztergombi G](#), [Zsigmond AJ](#) (2140 authors): Measurements of the $\Upsilon(1S)$, $\Upsilon(2S)$, and $\Upsilon(3S)$ differential cross sections in pp collisions at $\sqrt{s}=7\text{TeV}$. *PHYS LETT B* 749: pp. 14-34. (2015)
9. Khachatryan V et al. incl. [Bencze G](#), [Hajdu C](#), [Hidas P](#), [Horváth D](#), [Siklér F](#), [Veszprémi V](#), [Vesztergombi G](#), [Zsigmond AJ](#) (2829 authors): Observation of the rare $B_s^0 \mu^+\mu^-$ decay from the combined analysis of CMS and LHCb data. *NATURE* 522:(7554) pp. 68-72. (2015)

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11. Khachatryan V, Sirunyan AM, Filipovic N, et al. incl. [Bencze G](#), [Hajdu C](#), [Hidas P](#), [Horvath D](#), [Sikler F](#), [Veszpremi V](#), [Vesztergombi G](#), [Zsigmond AJ](#) (2297 authors): Search for a pseudoscalar boson decaying into a Z boson and the 125 GeV Higgs boson in $\ell^+\ell^-bb^-$ final states. *PHYS LETT B* 748: pp. 221-243. (2015)
12. Khachatryan V et al. incl. [Bencze G](#), [Hajdu C](#), [Hidas P](#), [Horváth D](#), [Siklér F](#), [Veszprémi V](#), [Vesztergombi G](#), [Zsigmond AJ](#) (2144 authors): Search for a standard model-like Higgs boson in the $\mu^+\mu^-$ and e^+e^- decay channels at the LHC. *PHYS LETT B* 744: pp. 184-207. (2015)
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14. Khachatryan V et al. incl. [Bencze G](#), [Hajdu C](#), [Hidas P](#), [Horváth D](#), [Siklér F](#), [Veszprémi V](#), [Vesztergombi G](#), [Zsigmond AJ](#) (2150 authors): Search for heavy Majorana neutrinos in $\mu^\pm\mu^\pm +$ jets events in proton-proton collisions at $\sqrt{s} = 8$ TeV. *PHYS LETT B* 748: pp. 144-166. (2015)
15. Khachatryan V et al. incl. [Bencze G](#), [Hajdu C](#), [Hidas P](#), [Horváth D](#), [Siklér F](#), [Veszprémi V](#), [Vesztergombi G](#), [Zsigmond AJ](#) (2146 authors): Search for lepton-flavour-violating decays of the Higgs boson. *PHYS LETT B* 749: pp. 337-362. (2015)
16. Khachatryan V et al. incl. [Bencze G](#), [Hajdu C](#), [Hidas P](#), [Horváth D](#), [Siklér F](#), [Veszprémi V](#), [Vesztergombi G](#), [Zsigmond AJ](#) (2149 authors): Search for narrow high-mass resonances in proton-proton collisions at $\sqrt{s} = 8$ TeV decaying to a Z and a Higgs boson. *PHYS LETT B* 748: pp. 255-277. (2015)
17. Khachatryan V et al. incl. [Bencze G](#), [Hajdu C](#), [Hidas P](#), [Horváth D](#), [Siklér F](#), [Veszprémi V](#), [Vesztergombi G](#), [Zsigmond AJ](#) (2132 authors): Search for new resonances decaying via WZ to leptons in proton-proton collisions at $\sqrt{s} = 8$ TeV. *PHYS LETT B* 740: pp. 83-104. (2015)
18. Khachatryan V et al. incl. [Bencze G](#), [Hajdu C](#), [Hidas P](#), [Horváth D](#), [Siklér F](#), [Veszprémi V](#), [Vesztergombi G](#), [Zsigmond AJ](#) (2133 authors): Search for pair-produced resonances decaying to jet pairs in proton-proton collisions at $\sqrt{s} = 8$ TeV. *PHYS LETT B* 747: pp. 98-119. (2015)
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23. Khachatryan V et al. incl. [Bencze G](#), [Hajdu C](#), [Hidas P](#), [Horváth D](#), [Siklér F](#), [Veszprémi V](#), [Vesztergombi G](#), [Zsigmond AJ](#) (2135 authors): Study of W boson production in pPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV. *PHYS LETT B* 750: pp. 565-586. (2015)

NA49 Collaboration

1. Anticic T et al. incl. [Fodor Z](#), [László A](#), [Pála G](#), [Siklér F](#), [Varga D](#), [Vesztergombi G](#) (66 authors): Measurement of event-by-event transverse momentum and multiplicity fluctuations using strongly intensive measures $\Delta[PT,N]$ and $\Sigma[PT,N]$ in nucleus-nucleus collisions at the CERN Super Proton Synchrotron. *PHYS REV C* 92:(4) Paper 044905. 10 p. (2015)
2. Anticic T et al. incl. [Fodor Z](#), [László A](#), [Pála G](#), [Siklér F](#), [Varga D](#), [Vesztergombi G](#) (72 authors): Critical fluctuations of the proton density in A+A collisions at 158A GeV. *EUR PHYS J C* 75:(12) Paper 587. 10 p. (2015)

FOPI Collaboration

1. Piasecki K et al. incl. [Fodor Z](#), [Kecskeméti J](#), [Seres Z](#) (66 authors): Influence of ϕ mesons on negative kaons in Ni + Ni collisions at 1.91A GeV beam energy. *PHYS REV C* 91:(5) Paper 054904. 8 p. (2015)

See also: R-B. ALICE Collaboration, R-K. ATLAS Collaboration 14