

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 (mainly ALICE and CMS), both in data-taking and physics analysis.

Spectra of identified hadrons. — We have measured the transverse momentum spectra of identified charged hadrons in proton-proton collisions at 13 TeV center-of-mass energy in CMS. Charged pions, kaons, and protons in the transverse-momentum range 0.1–1.7 GeV/c and for laboratory rapidities $|y| < 1$ were identified via their energy loss in the silicon tracker. The spectra and integrated yields are compared to lower center-of-mass energy pp results and to Monte Carlo simulations. The average transverse momentum increases with particle mass and the charged-particle multiplicity of the event. A comparison with lower energy data shows only a moderate dependence of the average transverse momentum on the center-of-mass energy. The Pythia8 CUETP8M1 event generator reproduces most features of the measured distributions, but EPOS LHC also gives a satisfactory description of several aspects. These results can be used to further constrain models of hadron production and the understanding of basic nonperturbative dynamics in hadron collisions.

Suppression of high momentum hadrons. — We have measured the spectra of charged particles produced within the pseudorapidity window $|\eta| < 1$ at a center-of-mass energy per nucleon pair of 5.02 TeV using Pb-Pb and proton-proton data from CMS. The spectra are given over the transverse momentum (p_T) ranges spanning 0.5–400 GeV/c in pp and 0.7–400 GeV/c in Pb-Pb collisions. The corresponding nuclear modification factor, R_{AA} , is measured in bins of collision centrality. The R_{AA} in the 5% most central collisions shows a maximal suppression by a factor of 7–8 in the p_T region of 6–9 GeV/c. This dip is followed by an increase, which continues up to the highest p_T measured, and approaches unity in the vicinity of 200 GeV/c. The modification factor is compared to theoretical predictions and earlier experimental results at lower collision energies. The newly measured pp spectrum is combined with the p-Pb spectrum previously published by the CMS Collaboration to construct the p-Pb nuclear modification factor, R_{pA} , up to 120 GeV/c. Above 20 GeV/c, R_{pA} exhibits weak momentum dependence and shows a moderate enhancement above unity.

Boson-jet correlations. — We have measured the production of Z-jet pairs for the first time in pp and central Pb-Pb collisions at a center-of-mass energy per nucleon pair of 5.02 TeV using the CMS detector. The Z-jet azimuthal angle correlations and transverse momentum imbalance are analyzed for events containing a Z boson with transverse momentum above 60 GeV/c and an associated jet above 30 GeV/c. A moderate shift in the jet p_T over Z boson

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p_T ratio is seen in central Pb-Pb collisions with respect to the ratio found using pp data, in agreement with expected jet quenching effects. The probability to find a back-to-back jet partner in Pb-Pb collisions is lower than in pp collisions, which suggests that in Pb-Pb collisions a larger fraction of partons associated with the Z boson lost energy and fell below the 30 GeV/c jet p_T threshold.

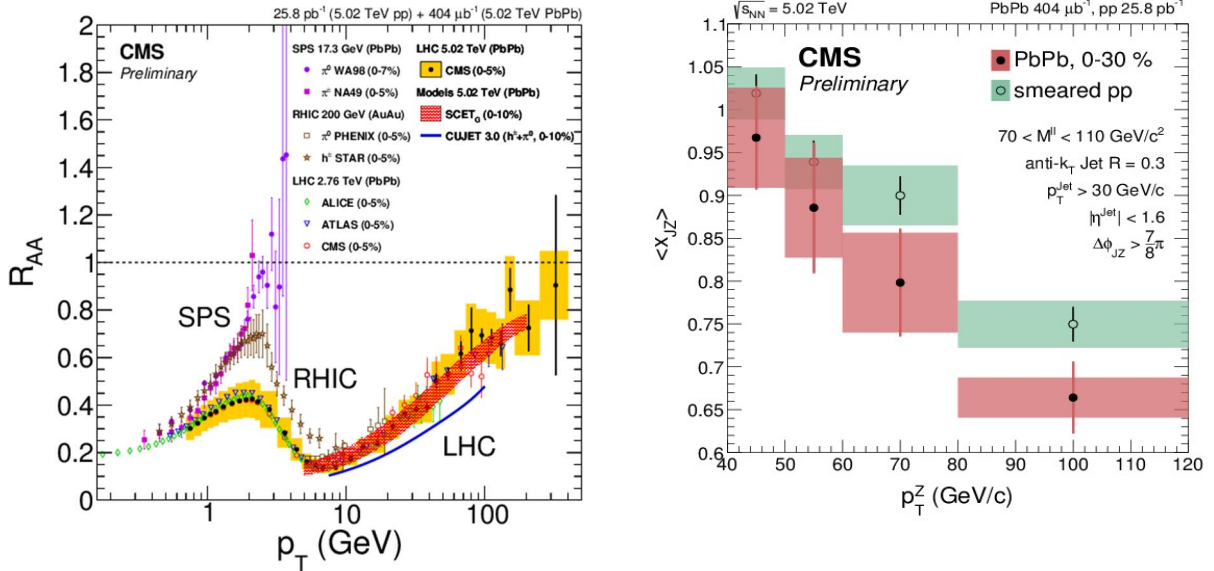


Figure 1. Left: Measurements of the nuclear modification factors in central heavy-ion collisions at four different center-of-mass energies, for neutral pions (π^0) (SPS, RHIC), charged hadrons (h^\pm) (SPS, RHIC), and charged particles (LHC including CMS) compared to predictions of two models. The yellow band around the new 5.02 TeV CMS data shows the systematic uncertainties of the measurement. Right: The mean value of the jet p_T over Z boson p_T distribution ($x_{J/Z}$) as a function of the Z boson transverse momentum.

Identified hadron spectra with ALICE. — The Hungarian ALICE Group's main research direction is the measurements and analysis in connection with identified hadron production. We participated in the operation of the High Momentum Particle Identification Detector (HMPID) of the ALICE detector, the TPC upgrade and data analysis and the O2 DAQ upgrade projects.

Coordination of the ALICE upgrades. — We coordinate the Hungarian contribution to CERN's largest heavy-ion experiment ALICE. This activity is two-folded: In addition to data analysis, our group plays key role in the construction of the world largest, 90 m³-volume, GEM-based TPC in collaboration with group R-I and several international partners.

Our group has leading activity in the ALICE Offline & Online (O2) Upgrade Project, together with the Wigner DAQ Laboratory and Wigner GPU Laboratory.

Grants

OTKA K 109703: Consortial 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)

International cooperation

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

Publications

Others

1. Siklér F: Gyorsítók és részecskék (Accelerators and particles, in Hungarian). **TERMÉSZET VILÁGA** 147:(Special edition 2) 82-85 (2016)
2. Siklér F: Egy életút (A course of life, in Hungarian). **FIZIKAI SZEMLE** 66:(9) 287-289 (2016)
3. Boldizsár L: Generációm mentora (The mentor of my generation, in Hungarian). **FIZIKAI SZEMLE** 66:(9) 292-293 (2016)

See also: R-I.8

CMS Collaboration

Due to the vast number of publications of the large collaborations in which the research group participated in 2015, 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, Házi A, Hidas P, Horváth D, Siklér F, Veszprémi V, Vesztergombi G, Zsigmond AJ, Bartók M (2285 authors): Measurement of long-range near-side two-particle angular correlations in pp collisions at $\sqrt{s} = 13$ TeV. **PHYS REV LETT** 116:(17) 172302/1-19 (2016)
2. Khachatryan V et al. incl. Bencze G, Hajdu C, Házi A, Hidas P, Horváth D, Siklér F, Veszprémi V, Vesztergombi G, Zsigmond AJ, Bartók M (2297 authors): Measurement of the top quark pair production cross section in proton-proton collisions at $\sqrt{s} = 13$ TeV. **PHYS REV LETT** 116:(5) 052002/1-18 (2016)
3. Khachatryan V et al. incl. Bencze G, Hajdu C, Házi A, Hidas P, Horváth D, Siklér F, Veszprémi V, Vesztergombi G, Zsigmond AJ, Bartók M (2271 authors): Search for narrow resonances decaying to dijets in proton-proton collisions at $\sqrt{s} = 13$ TeV. **PHYS REV LETT** 116:(7) 071801/1-17 (2016)
4. Khachatryan V et al. incl. Bencze G, Hajdu C, Házi A, Hidas P, Horváth D, Siklér F, Veszprémi V, Vesztergombi G, Zsigmond AJ (2268 authors): Search for narrow resonances in dijet final states at $\sqrt{s} = 8$ with the novel CMS technique of data scouting. **PHYS REV LETT** 117:(3) 031802/1-27 (2016)
5. Khachatryan V et al. incl. Bencze G, Hajdu C, Házi A, Hidas P, Horváth D, Siklér F, Veszprémi V, Vesztergombi G, Zsigmond AJ (2264 authors): Search for resonant production of high-mass photon pairs in proton-proton collisions at $\sqrt{s} = 8$ and 13 TeV. **PHYS REV LETT** 117:(5) 051802/1-19 (2016)
6. Khachatryan V et al. incl. Bencze G, Hajdu C, Házi A, Hidas P, Horváth D, Siklér F, Veszprémi V, Vesztergombi G, Zsigmond AJ, Bartók M (2311 authors): Study of B meson production in p+Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV using exclusive hadronic decays. **PHYS REV LETT** 116:(3) 032301/1-18 (2016)

7. Khachatryan V et al. incl. [Bencze G](#), [Hajdu C](#), [Házi A](#), [Hidas P](#), [Horváth D](#), [Siklér F](#), [Veszprémi V](#), [Vesztergombi G](#), [Zsigmond AJ](#) (2311 authors): A search for pair production of new light bosons decaying into muons. *PHYS LETT B* **752**: 146-168 (2016)
8. Khachatryan V et al. incl. [Bencze G](#), [Hajdu C](#), [Házi A](#), [Hidas P](#), [Horváth D](#), [Siklér F](#), [Veszprémi V](#), [Vesztergombi G](#), [Zsigmond AJ](#) (2310 authors): Angular analysis of the decay $B^0 \rightarrow K^{*0} \mu^+ \mu^-$ from pp collisions at $\sqrt{s} = 8$ TeV. *PHYS LETT B* **753**: 424-448 (2016)
9. Khachatryan V et al. incl. [Bencze G](#), [Hajdu C](#), [Házi A](#), [Hidas P](#), [Horváth D](#), [Siklér F](#), [Veszprémi V](#), [Vesztergombi G](#), [Zsigmond AJ](#) (2276 authors): Combined search for anomalous pseudoscalar HVV couplings in $VH(H \rightarrow b\bar{b})$ production and $H \rightarrow VV$ decay. *PHYS LETT B* **759**: 672-696 (2016)
10. Khachatryan V et al. incl. [Bencze G](#), [Hajdu C](#), [Házi A](#), [Hidas P](#), [Horváth D](#), [Siklér F](#), [Veszprémi V](#), [Vesztergombi G](#), [Zsigmond AJ](#) (2316 authors): Inclusive and differential measurements of the charge asymmetry in pp collisions at $\sqrt{s} = 8$ TeV. *PHYS LETT B* **757**: 154-179 (2016)
11. Khachatryan V et al. incl. [Bencze G](#), [Hajdu C](#), [Házi A](#), [Hidas P](#), [Horváth D](#), [Siklér F](#), [Veszprémi V](#), [Vesztergombi G](#), [Zsigmond AJ](#) (2308 authors): Measurement of spin correlations in production using the matrix element method in the muon+jets final state in pp collisions at $\sqrt{s} = 8$ TeV. *PHYS LETT B* **758**: 321-346 (2016)
12. Khachatryan V et al. incl. [Bencze G](#), [Hajdu C](#), [Házi A](#), [Hidas P](#), [Horváth D](#), [Siklér F](#), [Veszprémi V](#), [Vesztergombi G](#), [Zsigmond AJ](#) (2311 authors): Measurement of the CP-violating weak phase ϕ_s and the decay width difference $\Delta\Gamma_s$ using the decay channel in pp collisions at $\sqrt{s} = 8$ TeV. *PHYS LETT B* **757**: 97-120 (2016)
13. Khachatryan V et al. incl. [Bencze G](#), [Hajdu C](#), [Házi A](#), [Hidas P](#), [Horváth D](#), [Siklér F](#), [Veszprémi V](#), [Vesztergombi G](#), [Zsigmond AJ](#) (2316 authors): Measurement of the inelastic cross section in proton–lead collisions at $\sqrt{s_{NN}}=5.02$ TeV. *PHYS LETT B* **759**: 641-662 (2016)
14. Khachatryan V et al. incl. [Bencze G](#), [Hajdu C](#), [Házi A](#), [Hidas P](#), [Horváth D](#), [Siklér F](#), [Veszprémi V](#), [Vesztergombi G](#), [Zsigmond AJ](#) (2144 authors): Measurement of the $B(B_{s0} \rightarrow J/\psi f_0(980))/B(B_{s0} \rightarrow J/\psi \phi(1020))$ in pp collisions at $\sqrt{s} = 7$ TeV. *PHYS LETT B* **756**: 84-102 (2016)
15. Khachatryan V et al. incl. [Bencze G](#), [Hajdu C](#), [Házi A](#), [Hidas P](#), [Horváth D](#), [Siklér F](#), [Veszprémi V](#), [Vesztergombi G](#), [Zsigmond AJ](#) (2258 authors): Measurement of the W boson helicity fractions in the decays of top quark pairs to lepton + jets final states produced in pp collisions at $\sqrt{s} = 8$ TeV. *PHYS LETT B* **762**: 512-534 (2016)
16. Khachatryan V et al. incl. [Bencze G](#), [Hajdu C](#), [Házi A](#), [Hidas P](#), [Horváth D](#), [Siklér F](#), [Veszprémi V](#), [Vesztergombi G](#), [Zsigmond AJ](#) (2269 authors): Measurement of the ZZ production cross section and $Z \rightarrow \ell^+ \ell^- \ell'^+ \ell'^-$ branching fraction in pp collisions at $\sqrt{s} = 13$ TeV. *PHYS LETT B* **763**: 280-303 (2016)
17. Khachatryan V et al. incl. [Bencze G](#), [Hajdu C](#), [Házi A](#), [Hidas P](#), [Horváth D](#), [Siklér F](#), [Veszprémi V](#), [Vesztergombi G](#), [Zsigmond AJ](#) (2273 authors): Measurement of the $Z\gamma \rightarrow \nu\bar{\nu}\gamma$ production cross section in pp collisions at $\sqrt{s} = 8$ TeV and limits on anomalous ZZ γ and Z $\gamma\gamma$ trilinear gauge boson couplings. *PHYS LETT B* **760**: 448-468 (2016)
18. Khachatryan V et al. incl. [Bencze G](#), [Hajdu C](#), [Házi A](#), [Hidas P](#), [Horváth D](#), [Siklér F](#),

- Veszprémi V, Vesztergombi G, Zsigmond AJ (2292 authors): Measurements of $t\bar{t}$ charge asymmetry using dilepton final states in pp collisions $\sqrt{s} = 8$ TeV. **PHYS LETT B 760**: 365-386 (2016)
19. Khachatryan V et al. incl. Bencze G, Hajdu C, Házi A, Hidas P, Horváth D, Siklér F, Veszprémi V, Vesztergombi G, Zsigmond AJ (2312 authors): Search for a Higgs boson decaying into $\gamma^*\gamma \rightarrow \ell\ell\gamma$ with low dilepton mass in pp collisions at $\sqrt{s} = 8$ TeV. **PHYS LETT B 753**: 341-362 (2016)
 20. Khachatryan V et al. incl. Bencze G, Hajdu C, Házi A, Hidas P, Horváth D, Siklér F, Veszprémi V, Vesztergombi G, Zsigmond AJ (2310 authors): Search for a low-mass pseudoscalar Higgs boson produced in association with a pair in pp collisions at $\sqrt{s} = 8$ TeV. **PHYS LETT B 758**: 296-320 (2016)
 21. Khachatryan V et al. incl. Bencze G, Hajdu C, Házi A, Hidas P, Horváth D, Siklér F, Veszprémi V, Vesztergombi G, Zsigmond AJ (2314 authors): Search for exotic decays of a Higgs boson into undetectable particles and one or more photons. **PHYS LETT B 753**: 363-388 (2016)
 22. Khachatryan V et al. incl. Bencze G, Hajdu C, Házi A, Hidas P, Horváth D, Siklér F, Veszprémi V, Vesztergombi G, Zsigmond AJ (2287 authors): Search for lepton flavour violating decays of the Higgs boson to $e\tau$ and $e\mu$ in proton–proton collisions at $\sqrt{s}=8$ TeV. **PHYS LETT B 763**: 472-500 (2016)
 23. Khachatryan V et al. incl. Bencze G, Hajdu C, Házi A, Hidas P, Horváth D, Siklér F, Veszprémi V, Vesztergombi G, Zsigmond AJ (2311 authors): Search for neutral MSSM Higgs bosons decaying to $\mu^+\mu^-$ in pp collisions at $\sqrt{s}=7$ and 8 TeV. **PHYS LETT B 752**: 221-246 (2016)
 24. Khachatryan V et al. incl. Bencze G, Hajdu C, Házi A, Hidas P, Horváth D, Siklér F, Veszprémi V, Vesztergombi G, Zsigmond AJ (2290 authors): Search for neutral resonances decaying into a Z boson and a pair of b jets or τ leptons. **PHYS LETT B 759**: 369-394 (2016)
 25. Khachatryan V et al. incl. Bencze G, Hajdu C, Házi A, Hidas P, Horváth D, Siklér F, Veszprémi V, Vesztergombi G, Zsigmond AJ (2140 authors): Search for new phenomena in monophoton final states in proton-proton collisions at $\sqrt{s}=\text{TeV}$. **PHYS LETT B 755**: 102-124 (2016)

NA49 Collaboration

1. Anticic T et al. incl. Fodor Z, László A, Pálla G, Siklér F, Veres GI, Vesztergombi Gy (65 authors): Production of deuterium, tritium, and He 3 in central Pb + Pb collisions at 20A, 30A, 40A, 80A, and 158A GeV at the CERN Super Proton Synchrotron. **PHYS REV C 94**:(4) 044906/1-20 (2016)

NA61 Collaboration

1. Abgrall N et al. incl. Fodor Z, László A, Márton K, Vesztergombi G (151 authors): Measurements of $\pi^{+/-}$, $K^{+/-}$, $K^*_S(0)$, Λ and proton production in proton-carbon interactions at 31 GeV/c with the NA61/SHINE spectrometer at the CERN SPS. **EUR PHYS J C 76**:(2) 84/1-49 (2016)
2. Abgrall N et al. incl. Fodor Z, László A, Márton K, Vesztergombi G (158 authors):

Measurements of π^\pm differential yields from the surface of the T2K replica target for incoming 31 GeV/c protons with the NA61/SHINE spectrometer at the CERN SPS: NA61/SHINE Collaboration. **EUR PHYS J C 76**:(11) 617/1-27 (2016)

3. Aduszkiewicz A et al. incl. Fodor Z, László A, Márton K, Vesztergombi G (140 authors): Production of $\Lambda\Lambda$ -hyperons in inelastic p+p interactions at 158 GeV/c. **EUR PHYS J C 76**:(4) 198/1-18 (2016)
4. Aduszkiewicz A et al. incl. Fodor Z, László A, Márton K, Vesztergombi G (132 authors): Multiplicity and transverse momentum fluctuations in inelastic proton–proton interactions at the CERN Super Proton Synchrotron. **EUR PHYS J C 76**:(11) 635/1-17 (2016)

FOPI Collaboration

1. Gasik P et al. incl. Fodor Z, Kecskeméti J, Seres Z (66 authors): Strange meson production in Al plus Al collisions at 1.9 AGeV. **EUR PHYS J A 52**:(6) 177/1-13 (2016)
2. Piasecki K et al. incl. Fodor Z, Kecskeméti J, Seres Z (73 authors): Centrality dependence of subthreshold ϕ meson production in Ni + Ni collisions at 1.9A GeV. **PHYS REV C 94**:(1) 014901/1-8 (2016)