Newsletter #2

November 2020

The STRONG-2020 project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 824093

Table of contents

European Commission

Foreword

This is the second newsletter of the STRONG-2020 European project, which has been prepared by the Dissemination Board as editors, and contains a series of news and information of interest not only for the STRONG-2020 community, but also for a broader scientific audience and the general public.

This newsletter #2 is structured as follows: after an article on the October 2020 annual meeting, there is news concerning some ongoing STRONG-2020 activities, in particular we feature an article related to proton radius, reports from workshops and meetings organised or supported by STRONG-2020, a presentation of the PADME activity searching for dark photons at the LNF-INFN STRONG-2020 supported infrastructure, an interview of a STRONG-2020 young participant, some news regarding dissemination activities towards a broader scientific community (YouTube) and on the kick-off of a series of STRONG-2020 public lectures, and news related to a STRONG-2020 APS fellow.

We, the STRONG-2020 Dissemination Board (DB), encourage you, the community participating to this project, to contact us and send us news regarding your achievements (published articles, experimental developments, theoretical calculations…), your events organised within or with support of STRONG-2020, videos about your activities, interviews of young participants, as well as any other information or news which is connected to our project, of any relevance for our community, for a broader scientific audience or for a more general public.

This continues to be not an easy period, with the problems connected to the coronavirus situation affecting many countries, and we, the DB, wish you all to stay safe.

We also wish Season's Greetings to you and your family, a merry Christmas, and very best wishes for the New Year.

This is the second newsletter of the STRONG-2020 European project.

Catalina Curceanu, on behalf of STRONG-2020 Dissemination Board

Marco Battaglieri, Maurizio Boscardin, Achim Denig, Raphaël Granier de Cassagnac, Maria Paola Lombardo, Hervé Moutarde, Piet Mulders, Andrea Pesce, Fulvio Tessarotto.

The STRONG-2020 annual meeting

Consortium active involvement despite the crisis

The STRONG-2020 annual meeting took place on **October 13–16, 2020**. The particular context we are living in today conditioned the holding of this meeting in virtual mode, via ZOOM. Nevertheless, and despite the physical distance, the Consortium demonstrated the integrity of its organisation and the continuity of work on the project tasks.

The meeting was split into several thematic sections as follows:

- Plenary session with presentations from all Work Packages (WP) on the 14th and 15th
- Two Executive Board (EB) meetings (on the 13th and 16th, before and after the Plenary)
- Facility Coordination Panel meeting on the 14th
- Governing Board meeting on the 15th

The agenda, as well as the contributions of all WPs (PowerPoint presentations) can be found on the dedicated indico page: https://indico.in2p3.fr/event/20784/timetable/

Very intensive in terms of information and exchanges, this annual meeting has become an opportunity to follow the progress made during the first reporting period (18 months of the project) but also to have a look into the future, which is particularly uncertain under the impact of the Covid-19 crisis.

The STRONG-2020 project, composed of 7 Transnational Access (TA) and 2 Virtual Access (VA) infrastructures, 7 Networking Activities (NA), 14 Joint Research Activities (JRA), one WP dedicated to Management and Coordination (MAN) and one WP responsible for Dissemination and Communication (DISCO), constitutes a complex scientific enterprise. Its Work Packages obviously perform the project tasks whose nature differs significantly. Thus, the communication of results of these activities can also take a variety of forms.

In a view to ensure homogeneity and to facilitate the evaluation, the management team wanted to standardise the structure of the WP reports but also provide clarity as to the aspects to be highlighted in the latter. To this end, we prepared personalised templates for each WP to allow the corresponding spokespersons to expose the work carried out and juxtapose the obtained results against the plans as given in the grant agreement.

Our objective was to ensure an adequate evaluation and targeted recommendations for provided reports. To this end, each report was assessed by two referees appointed amongst the EB members. During the first EB meeting, based on the provided reports, EB members examined the overall progress of all WPs, made recommendations to complete the current report and suggested some ways of improvement for the future ones. During the discussion, it became clear that many activities under the project were affected, to a greater or lesser extent, by the Covid-19 crisis. This led to the issue of the possible extension of the project that was already raised during the previous EB meeting on June 26, 2020. This possibility was further announced to all Consortium members during the Plenary session. It was also submitted to the consideration of the Governing Board (Consortium decision-making body).

The Plenary session scheduled for two consecutive days has become an important opportunity for each of the 32 WPs to expose the results of their work and to get feedback from their peers. During the Plenary session, WP leaders could provide a more comprehensible explanation of the performed work and achieved results. This in turn demonstrated the dynamics and the progress of the project despite the multiple restrictions that the research world is facing today.

The Consortium members welcomed the proposal of extending the project. The question that however remains is to determine what length of extension would be most optimal for the smooth running of the planned tasks. Different project activities being affected in different ways, it would be necessary to evaluate the overall situation before making any projections. Indeed, STRONG-2020 is an integrating activity and numerous restrictions caused by the exceptional pandemic situation were not foreseen for many of the tasks set at the beginning of the project.

The first plenary day was concluded by the Facility Coordination Panel meeting. It brought together the leaders of TAs and VAs, who drew the same conclusion on the necessity to prolong the project to fulfil the contractual obligations. The Research Infrastructures are probably the most affected by the Covid-19 crisis. The access to the infrastructures being drastically limited and the organisation of in-person workshops (almost) impossible, the uncertainty of the implementation of the project tasks arises in the most obvious way. In the view of a substantial reduction of the infrastructure activities, an alternative organisation of some work and a better coordination between all the facilities are among the propositions to consider.

Governing Board meeting held on the 15th and chaired by Elena Gonzales Ferreiro, started by a review of the responsibilities and prerogatives of this decision-making body. Barbara Erazmus then gave a presentation on the overall status of the project with a special emphasis on the tasks implemented by the management team in the first reporting period. After a detailed explanation by Emine Ametshaeva of the periodic reporting procedure and the list of changes introduced with the first STRONG-2020 Amendment (accepted on November 18), the discussion was held mainly around the question of the project extension. Following the discussion with meeting participants, it was concluded that a prior consultation with the Project Officer as well as an in-depth analysis of the current state for all H2020 projects would be appropriate.

The second Executive Board meeting concluded the series of exchanges that took place during the annual meeting. In addition to the feedback on the annual meeting in general, it was the time to provide concrete recommendations for the WP reports. EB members were glad to note the smooth running of the meeting and a relatively high attendance rate. On the scientific level, they stressed on the progress achieved by most working groups despite the limits and difficulties of the pandemic period. Constructive and almost in-person exchange during the Plenary session made it possible to better understand the implemented work and the results exposed in the reports. The further steps agreed upon by the EB members included targeted comments drawn by referees and sent by the management team to the concerned WPs. These recommendations should help the WP leaders to complete their reports. The latter will constitute each beneficiary's contribution to the STRONG-2020 first periodic report.

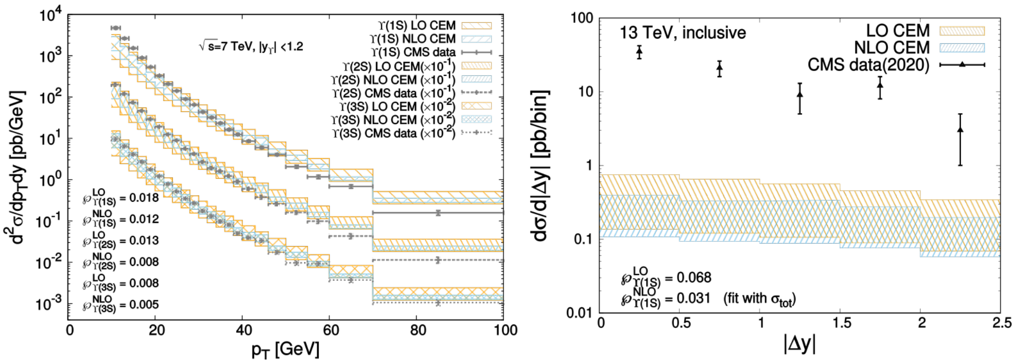
Without pretending to be exhaustive, this short article gives a brief overview of an important event in the life of the project. We were sincerely happy to virtually meet the collaborators spread all over Europe but united by a common goal. We obviously lacked informal moments and relaxed conversations around a coffee cup or a convivial meal. However, we hope to overcome soon this difficult stage. Let's stay positive and hope to meet in person during the next STRONG-2020 annual meeting.

Barbara Erazmus, Carlo Guaraldo and Emine Ametshaeva

Quarkonium hadroproduction at next-to-leading order by NLOACCESS

Quarkonium-pair production in high-energy hadron-hadron collisions probes many physics phenomena. Among these, let us cite the physics of double parton scattering (DPS) and of gluon-gluon correlations within the proton. In the recent years, an increasing number of experimental observations at the LHC and the Tevatron lead us to conclude that DPS are at play when quarkonia are produced in pairs [1].

The Colour Evaporation Model (CEM), which is based on the quark-hadron duality, is one of the common approaches to describe inclusive quarkonium production. As such, we plan to give access to its predictions via the Virtual Access NLOACCESS [2]. In preparation of this inclusion, NLOACCESS contributors from Europe, Asia and the US performed the first complete next-to-leading order (NLO) CEM study of single and double quarkonium production at the Tevatron and the LHC. It has been done with an upgraded version of MADGRAPH implementing the CEM. This upgrade is part of the MADGRAPH version to be made accessible via NLOACCESS.



Left: p_T spectrum of Υ(nS) measured by CMS at 7 TeV vs the CEM LO and NLO; right: rapidity-difference spectrum of Υ(1S) pairs measured by CMS at 13 TeV vs the CEM at LO and NLO. See details in [3].

The CEM at LO and NLO was shown to reproduce well the p_T spectrum of $\psi(nS)$ and $\Upsilon(nS)$ (except at large p_T) but to fail to reproduce all the quarkonium-pair data (see *e.g.* the figures above). This confirms the relevance of DPS and of the Colour Singlet Mechanism to explain these data [3].

The goal of NLOACCESS is to provide access to automated tools to compute hadronic cross sections described by perturbative methods; these comprise heavy-flavour production in proton-proton/nucleus collisions. It will allow the users to test their ideas and run the codes, without specific knowledge of their structure. Along with MADGRAPH and the extension to heavy-ion physics which we develop, HELAC-ONIA is also accessible with NLOACCESS.

Carlo Flore & Jean-Philippe Lansberg

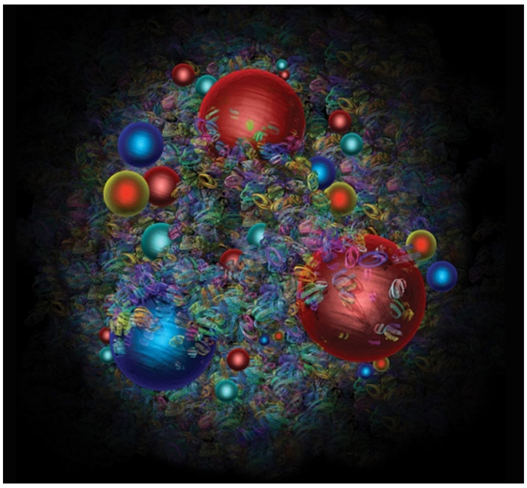
[1] J.P. Lansberg, *New Observables in Inclusive Production of Quarkonia. Phys. Rept. (In press, 2020)* [arXiv:1903.09185].
[2] The web site of NLOACCESS, the Virtual Access package 1 of STRONG-2020 is https://nloacces.in2p3.fr
[3] J.P. Lansberg, H.-S. Shao, N. Yamanaka, Y.-J. Zhang and C. Noûs, *Complete NLO QCD study of single- and double-quarkonium hadroproduction in the colour-evaporation model at the Tevatron and the LHC*, Phys. Lett. B **807** (2020) 135559

Shrinking the proton (a featured article)

Jan C. Bernauer (Stony Brook University), Ashot Gasparian (North Carolina A&T University), Dominique Marchand (IJCLab Orsay), Randolf Pohl (J-G Mainz University)

Introduction

Quantum Chromo Dynamics (QCD) in the non-perturbative (strongly interacting) regime describes the physics inside nucleons and nuclei, and with that, of almost all visible matter in the Universe. An accurate description has implications for other fields, from astrophysics (e.g. neutron stars, baryogenesis, solar physics) to atomic physics (e.g. finite size effect in spectroscopy). The proton is the simplest stable QCD system, and it is paramount to understand how the nucleon properties emerge from the underlying physics. The proton elastic electric and magnetic form factors, which describe the distribution of charge and magnetisation inside the proton, offer direct access to the proton's internal structure. Their accurate knowledge is a touchstone for QCD theory and lattice calculations.



However, even basic quantities like the charge root-mean-square radius, given by the slope of the electric form factor at zero four-momentum transfer ($Q^2 \rightarrow 0$), are not settled. In 2010, a 4% difference between an analysis of a muonic hydrogen spectroscopy experiment [1] ($r_p = 0.84184(67)$ fm), and both the results of the Mainz high precision form factor experiment [2] ($r_p = 0.879\,(5)_{stat}\,(6)_{syst}$ fm) and the CODATA value [3] ($r_p = 0.8768(69)$ fm), based on a series of normal hydrogen spectroscopy measurements and radius extractions from earlier scattering data, was found. Without any readily available explanation, this discrepancy became quickly known as the proton radius puzzle [4].

Now, ten years later, the puzzle is still not fully resolved, see [5] for a recent review. Beside numerous theoretical explanations – none have found widespread acceptance – new data is sparse and somewhat inconclusive. On the spectroscopy side, most measurements using normal hydrogen [6],[7] have found values compatible with the small muonic value, but some new measurements still align with the larger radius seen before [8]. On the scattering side, the discussion focused on the extraction of the slope of the proton electric form factor at $Q^2 = 0$ from the cross sections via fits, and remaining questions can only be addressed with new, precise data especially at low Q^2. A new measurement demonstrated the use of initial state radiation, an alternative to the standard technique with fundamentally different systematics, extending the Q^2 range down to 0.001 $(\text{GeV}/c)^2$ and obtaining a large radius [9], albeit with large uncertainties. The PRad experiment [10], discussed below, pushed the Q^2 boundary even lower by another factor of 10 and found a small radius. On the overlap region with previous data, the PRad result shows a clearly different Q^2 behaviour. This new discrepancy, larger than any systematic effects so far envisioned to explain the proton radius puzzle, calls into question not only the extraction of the proton radius, but our knowledge of the proton form factors over the whole range of Q^2. It is clear that new data is desperately needed. Luckily, a series of experiments are poised to address this need in the near future, using various novel and complementary methods to solve the puzzle.

PRad/PRad-II

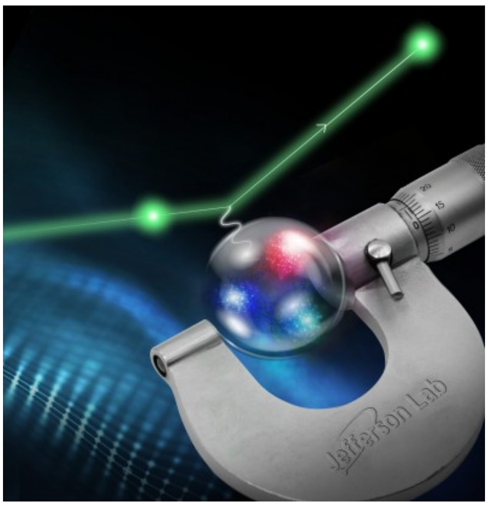
The PRad experiment at Jefferson Laboratory, USA (JLab), performed in 2016, for the first time used a non-magnetic spectrometer to detect the scattered particles with a large acceptance and high-resolution multi-channel electromagnetic calorimeter (HyCal). This method allowed to reach a Q^2 of 10^{-4} (GeV/c)^2 and to capture a significant Q^2 range in a single setup.

Further, the azimuthal symmetry of the forward calorimeter allowed a simultaneous measurement of a well-known quantum electromagnetic (QED) process, the Møller (electron-electron) scattering from the atomic electrons within similar kinematics and the same experimental acceptance. This allowed the experiment to achieve a per-mill level absolute normalisation and excellent control over detector efficiency systematics. Significant improvements were achieved towards the reduction of the background from the entrance and exit windows of liquid hydrogen target, typically used in previous experiments. It was replaced by a newly developed windowless cryogenic hydrogen gas-flow target operating at relatively high pressure.

The proton charge radius extracted from the PRad experiment **[10]**, $r_p = 0.831(7)_{stat}\,(12)_{syst}$ fm is significantly smaller than the world average of all ep-scattering experiments, but is in a good agreement with the small r_p value found previously by the muonic-hydrogen experiments **[1][11]**, consistent with the shift in the Rydberg constant announced by recent CODATA recommendations **[12]**, the most recent being $r_p = 0.8409(4)$ fm, from the PDG **[13]**.

It is important to note here that, compared to the earlier scattering experiments, PRad not only finds a radius smaller by about three standard deviations, but also extracts Q^2 dependence of the cross section that finds about 3–4% higher values than previous determinations and fits at the upper end of the data. This discrepancy is striking, and well beyond any systematic uncertainties.

Motivated by the successful first PRad experiment, the PRad collaboration developed a proposal for a successor experiment (PRad-II) to reduce the total uncertainty by a factor of four compared to PRad. That will be achieved by taking more statistics with significant hardware improvements including particle tracking capability (second GEM plane), HyCal upgrade to all high-resolution crystals and improvements in the beam line apparatus. PRad-II will likely be the first scattering experiment to reach the Q^2 range of 10^{-5} (GeV/c)^2 allowing a more accurate and robust extraction of the proton charge radius. With its high accuracy and precision PRad-II will be able to address possible inaccuracies in the systematic uncertainties of the muonic hydrogen experiments **[1][11]**, such as the laser frequency calibrations. The PRad-II experiment was recently approved by the JLab's PAC48 with the highest 'A' scientific rating. An active work is in progress to put this experiment on the floor in the next few years.



Mainz

The MAGIX collaboration is planning a series of measurements of the proton form factors at small Q^2 using smaller beam energies than the previous ones. These experiments are planned to make use of the new energy recovering accelerator, MESA, currently under construction in Mainz, and the new two-spectrometer setup of the MAGIX collaboration. These experiments will likely run post 2023.

As the workhorse target, a cluster jet system is being developed in collaboration with the University of Münster. Compared to a classic liquid hydrogen target, the jet target eliminates beam-enclosure background events and external bremsstrahlung. Compared to a gas target, the density is considerably higher. The gas-jet/beam interaction is also essentially point-like, allowing simpler reconstruction of the kinematics and eliminating acceptance effects.

The target is currently being commissioned in the A1 collaboration using the MAMI accelerator. It was used to measure proton form factors using a beam energy of 315 MeV, one of the spectrometers to measure scattering between 15 and 45 degrees and another spectrometer to control the luminosity. An adjustable collimator was used to minimise interactions of the beam halo with the jet nozzle. The covered kinematics cover the overlap between the PRad data and earlier measurements. Analysis is progressing, and we expect publication mid 2021.

The PRES collaboration is working on a different approach. Using a hydrogen time-projection chamber as an active target, they want to measure the low-Q^2 form factors by measuring the proton recoil energy. This gives a very unique access with different systematics for radiative corrections, for example.

MUSE

The MUon Scattering Experiment (MUSE) is located at the Paul Scherrer Institute in Switzerland. It aims to measure the proton form factors using electrons, positrons and both charges of muons for three lepton momenta, 115 MeV/*c*, 153 MeV/*c*, and 210 MeV/*c*. Additionally, data on pion-proton scattering will be recorded.

The experiment uses the πM1 beam line at PSI, which provides a beam containing all species. The charge and momentum can be selected with the magnetic channel between the production target and the experiment. The particle type will be identified on an event-by-event basis via time-of-flight, allowing concurrent measurements of both electronic and muonic cross sections without changing the experimental setup. The comparatively wide beam necessitates tracking of every incoming beam particle, realised via a beam hodoscope and GEM telescope. The beam impinges on a liquid hydrogen target. Similar to PRad, the MUSE experiment uses a non-magnetic setup; scattered leptons are tracked via two large-acceptance, straw-tube based tracking chambers on each side and detected by two large scintillator walls for reaction identification and triggering. Further detectors downstream of the target aid in the control of radiative corrections and to monitor the beam properties.

The combination of measurements of three momenta, both particle charges and three particle species enable a rich physics programme beyond the pure radius extraction, allowing to test two-photon exchange, lepton universality together with radiative corrections in the comparison of muons with electrons, and producing a unique pion data set.

The first production was expected for this year, but progress has been delayed because of Covid restrictions. Production data taking is now tentatively planned to take place in 2021 and 2022.

COMPASS++/AMBER

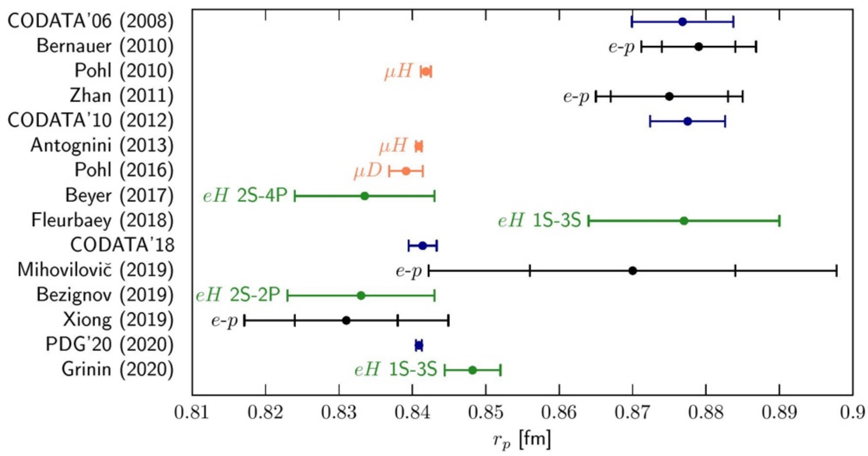
A core part of the programme of the COMPASS++/AMBER collaboration, recently recommended for approval by the CERN SPSC, is the measurement of the proton form factors and an extraction of the proton radius using for the first time muon scattering at very high beam energies of 60 and 100 GeV and at very small scattering angles. For this purpose, they will use a 2 m^3 active hydrogen gas target similar to the one used by the PRES collaboration, to be operated at a pressure of 20 bars, together with the high-resolution COMPASS spectrometer to detect the scattered muon in coincidence with the recoil proton. The measurement will benefit from the use of a well-calibrated spectrometer, reduced multiple scattering effects and low radiative corrections.

The collaboration is expected to perform a test run in 2021 and to start the physics data taking in 2022.

Complementarity

A full resolution of the proton radius puzzle has so far proven elusive, with new discrepancies and puzzling results making it impossible to see a clear picture, as illustrated on this summary figure.

It is therefore important to illuminate the puzzle with a series of complementary experiments.



PRad/PRad-II aims at the smallest Q^2 using very forward kinematics and comparatively large beam energies, testing a different region of, for example, radiative corrections. The detection of Møller scattering gives a good absolute normalisation and control of efficiencies. The planned measurements of the AMBER collaboration are at even more extreme angles and higher beam energies, and cannot test the lowest Q^2. However, radiative corrections for muon scattering are smaller, and the detection of the recoiling proton is only shared with the PRES approach, which will measure with an electron beam and more classical kinematics. The availability of both muon charges allows AMBER to study and eliminate two-photon exchange effects. The A1/MAGIX measurements use somewhat more classical kinematics, controlling radiative effects instead via the better energy resolution of their high-resolution spectrometers. The main improvement here is the reduction of the systematic errors, and an improved Q^2 range using lower beam energies. It's also the only measurement currently planned that will produce data sensitive to the magnetic form factor at small Q^2, important for the magnetic radius. The MUSE measurement will also use classical kinematics, but can directly compare electron to muon scattering, testing for example lepton universality and radiative corrections. They will also measure both lepton charges, allowing to test two-photon exchange at smaller photon polarisations than possible at AMBER.

The PREN Network (WP15) within STRONG-2020

The activities mentioned above contribute to the worldwide effort which is fully supported by the STRONG-2020 WP15/NA4 'Proton Radius European Network' (PREN) aiming at developing synergies, drawing common strategies and enhancing constructive collaborative theoretical and experimental research activities in nuclear and atomic physics in order to converge together in attempting to solve and to understand the proton charge radius puzzle. To this end, PREN funds can be used to finance exchange of personnel, to transfer knowledge and improve collaboration and communication between the different groups and, maybe more importantly, between the traditionally rather separate communities of scattering and atomic physics.

Acknowledgments

Dr. Bernauer is supported by US National Science Foundation (NSF) grant No. 2012114. Dr. Gasparian is supported by NSF grant No. 1812421.

References

[1] R. Pohl, A. Antognini, F. Nez, F. D. Amaro, F. Biraben, J. M. R. Cardoso, D. S. Covita, A. Dax, S. Dhawan, Luis M. P. Fernandes, A. Giesen, T. Graf, T. W. Hansch, P. Indelicato, L. Julien, C.-Y. Kao, P. Knowles, É.-O. Le Bigot, Y.-W. Liu, J. A. M. Lopes, L. Ludhova, C. M. B. Monteiro, F. Mulhauser, T. Nebel, P. Rabinowitz, J. M. F. dos Santos, L. A. Schaller, K. Schuhmann, C. Schwob, D. Taqqu, J. F. C. A. Velos, and F. Kottmann. *The size of the proton.* Nature, 466:213–216, 2010.

[2] J. C. Bernauer et al [A1 collaboration]. *High-precision determination of the electric and magnetic form factors of the proton.* Phys. Rev. Lett., 105:242001, 2010.

[3] P. J. Mohr, B. N. Taylor, and D. B. Newell. CODATA recommended values of the fundamental physical constants: 2006. Rev. Mod. Phys., 80(2):633–730, June 2008.

[4] R. Pohl, R. Gilman, G. A. Miller, and K. Pachucki. Muonic hydrogen and the proton radius puzzle. Annual Review of Nuclear and Particle Science, 63:175, 2013.

[5] J.-P. Karr, D. Marchand, E. Voutier. *The proton size.* Nature Reviews Physics, 2:601–614, 9 2020.

[6] A. Beyer, L. Maisenbacher, A. Matveev, R. Pohl, K. Khabarova, A. Grinin, T. Lamour, D. C. Yost, T. W. Hänsch, N. Kolachevsky, and T. Udem. *The Rydberg constant and proton size from atomic hydrogen*. Science, 358(6359):79–85, October 2017.

[7] N. Bezginov, T. Valdez, M. Horbatsch, A. Marsman, A. C. Vutha, and E. A. Hessels. *A measurement of the atomic hydrogen lamb shift and the proton charge radius*. Science, 365(6457):1007–1012, 2019.

[8] H. Fleurbaey, S. Galtier, S. Thomas, M. Bonnaud, L. Julien, F. Biraben, F. Nez, M. Abgrall, and J. Guéna. *New Measurement of the 1S – 3S Transition Frequency of Hydrogen: Contribution to the Proton Charge Radius Puzzle*. Phys. Rev. Lett., 120(18):183001, May 2018.

[9] M. Mihovilovič et al. *The proton charge radius extracted from the Initial State Radiation experiment at MAMI*. https://arxiv.org/abs/1905.11182.

[10] W. Xiong et al [PRAD collaboration]. *A small proton charge radius from an electron–proton scattering experiment*. Nature, 575(7781):147–150, 2019.

[11] A. Antognini et al. *Proton Structure from the Measurement of 2S−2P Transition Frequencies of Muonic Hydrogen*. Science, 339:417–420, 2013.

[12] E. Tiesinga, P. J. Mohr, B. N. Taylor, and D.B. Newell. CODATA values of the fundamental physical constants 2018. https://physics.nist. gov/cuu/Constants.

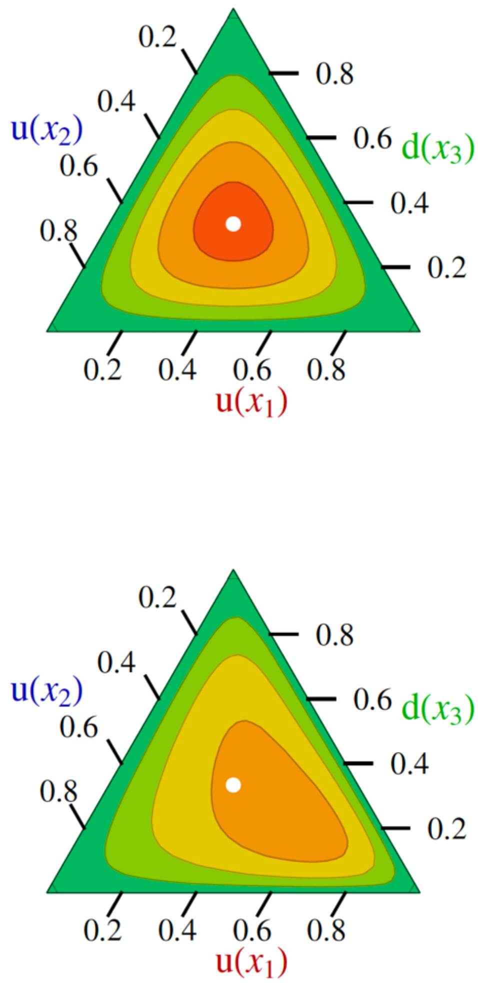
[13] P.A. Zyla et al. (Particle Data Group). *Review of Particle Physics.* Prog. Theor. Exp. Phys. 2020, 083C01 (2020).

Diquark correlations in hadron physics: origin, impact and evidence

The last decade has seen a marked shift in how the internal structure of hadrons is understood. Modern experimental facilities, new theoretical techniques for the continuum bound-state problem and progress with lattice-regularised QCD have provided strong indications that soft quark+quark (diquark) correlations play a crucial role in hadron physics. For example, theory indicates that the appearance of such correlations is a necessary consequence of dynamic chiral symmetry breaking, *viz.* a corollary of emergent hadronic mass that is responsible for almost all visible mass in the Universe; experiment has uncovered signals for such correlations in the flavour separation of the proton's electromagnetic form factors; phenomenology suggests that diquark correlations might be critical to the formation of exotic tetra- and penta-quark hadrons.

A broad spectrum of such information was evaluated in September 2019 at the ECT* Workshop 'Diquark Correlations in Hadron Physics: Origin, Impact, and Evidence', supported by STRONG-2020 (TA6 – WP 8) and organised by Jacopo Ferretti (Yale U., USA and Finland U., Finland), Craig D. Roberts (Nanjing U., China), Elena Santopinto (INFN-GE, Italy), Jorge Segovia (Pablo de Olavide U., Spain) and Bogdan Wojtsekhowski (Jefferson Lab, USA). The main goal was to move towards a coherent, unified picture of hadron structure and identify the role that diquark correlations might play.

An example of the kind of physics that was discussed at the workshop is the figure shown herein and taken from C. Mezrag *et al.*, Phys. Lett. B783 (2018) 263. The top panel is the limiting asymptotic PDA profile, $\varphi(x_1,x_2,x_3) = 120\, x_1\, x_2\, x_3$, for any ground-state baryon. The white circle in each panel serves only to mark the φ's peak, which lies at $(x_1,x_2,x_3) = (1/3,1/3,1/3)$. Panel below shows the computed proton PDA evolved to $\xi = 2$ GeV, which peaks at $(x_1,x_2,x_3) = (0.55,0.23,0.22)$ and so it indicates the presence of scalar and axial-vector diquark correlations inside the proton.



A great deal has changed since the introduction of the diquark concept more than fifty years ago. Nowadays, we understand that modern diquarks are confined, with mass scales that express the strength and range of the correlation inside the hadron; they are fully dynamic, with no quark holding a special place because each one participates in all correlations to the fullest extent allowed by its quantum numbers; they have electromagnetic sizes, which enforce certain distinct interaction patterns; and there are different species, among which isoscalar-scalar and isovector-pseudovector correlations are the strongest but others play a key role in nucleon excited states.

The output of the workshop has now been published in the journal ‘Progress in Particle and Nuclear Physics’. A Share Link through which anyone, clicking on the link, will be taken directly to the latest version of the article on ScienceDirect is provided:

https://authors.elsevier.com/a/1c2%7EB_3LP0bwi2

Everybody is welcome to read or download the manuscript; knowing that no signup, registration or fees will be required until December 30, 2020.

Jorge Segovia (Pablo de Olavide U.)

Strong Interactions and Dark Matter

Strong interactions have many facets, captured by the many activities in STRONG-2020. At the most microscopic level, strong interactions are described by quantum chromodynamics (QCD). Within experimental uncertainties, the strong force arising from QCD is time-symmetric in stark contrast with the electroweak theory: the behaviour of strong interactions does not change if the flow of time is reversed.

However, the equations of QCD might contain a symmetry-violating term – the theta term – that can theoretically take any value. And nature has chosen to set this term to zero. Why is that? A plausible and accepted explanation is that the term is not zero but is cancelled out by the presence of a ‘neutralising’ particle called the axion, which is actively searched for by many experiments. The axions – similarly to the dark photons searched for by the PADME experiment – could contribute to dark matter, the ‘missing’ matter in the Universe. It is a beautiful property of strong interactions to make a sound theoretical prediction for this mysterious matter! If axions exist, they would have been produced abundantly during the earliest moments of the Big Bang. Determining the expected mass of this particle therefore requires knowledge of the properties of QCD at extremely high temperatures. Consequently, a detailed understanding of both the thermodynamics of QCD (in particular, the temperature dependence of the *topological susceptibility*) and the expansion of the Universe is necessary to predict the present-day axion mass.

The detailed understanding of the thermodynamics of QCD is achieved via lattice simulations, as those performed in NA6-Lattice Hadrons.

The key property is the link of the axion mass with topological properties of QCD, in particular with the so-called topological susceptibility: strange as it may seem, one may identify topology in the field configurations – topology being just the property which is invariant under small deformation of the fields. The topological susceptibility turns out to be related to the difference between positive and negative zero modes of the Dirac operator – the operator which describes the QCD dynamics according to its Lagrangian. It may be calculated by exploiting the lattice formulation of QCD. In this approach, space-time is a four-dimensional grid of discrete points, rather than a continuum. There are, of course, many technical issues: to name one, once the theory is discretised on a grid, the very concept of a ‘small deformation’ becomes ambiguous.

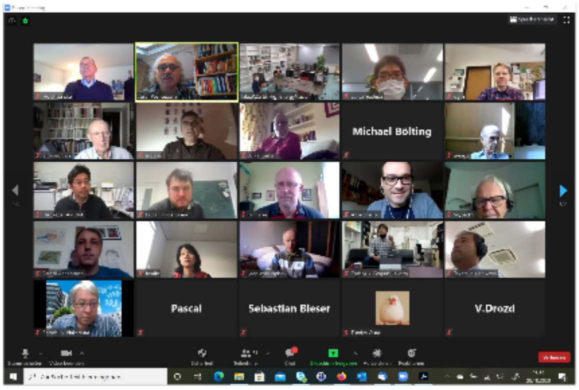
Members of the Network NA6-Lattice Hadrons have been actively involved in the computation of the limits on the QCD axion mass, finding limits for the mass of this hypothesised particle. A review, describing works done worldwide in this direction has been featured on the cover page of the IJMPA vol. 35. The diagrams which are shown there demonstrate the agreement between the results on the topological susceptibility among different groups. From these results, one may infer bounds on the axion mass, which point at a range which is well within the reach of current experiments. The absolute lower bound on the post-inflationary axion mass from misalignment ranges from 5 μeV till 28 μeV, assuming that all dark matter is made of axions. There are then remaining uncertainties, both numerical and conceptual, for instance related to the contributions from cosmic strings.

The planned workshop on Hot QCD of the NA6-network will certainly address this important problem.

Maria-Paola Lombardo

Joint THEIA STRONG-2020 and JAEA/Mainz REIMEI Web Seminar

Since October 2020 this is a series of Web-seminars that is being organised by a number of researchers in STRONG-2020. The web seminar is drawing attention from participants worldwide with on average something like 80 participants. Information on the seminars and information how to access the stream can be found via the web page: https://indico.gsi.de/category/513/.



The cooperation of world-leading experimentalists and theoreticians in the field of strangeness nuclear physics with experts of the neutron star community in astrophysics within the networking activity THEIA of the STRONG-2020 project will allow to critically assess the status of our present understanding, to determine the impact of terrestrial observations for the hadronic EOS, and to identify possible new avenues to follow.

European Commission

The REIMEI programme on ‘Systems with two strange quarks at FAIR and J-PARC’ is a collaborative work between Germany and Japan, supported by Japan Atomic Energy Agency (JAEA). REIMEI means ‘dawn’ in Japanese, and the seminar series is intended to highlight topics related to strangeness nuclear physics being studied in Germany, Japan, and other countries.

This project has received funding from the Helmholtz Institute Mainz and the STRONG-2020 WP6, aka NA5-THEIA.

Piet Mulders and Josef Pochodzalla (spokesperson of THEIA)

The Positron Annihilation into Dark Matter Experiment (PADME)

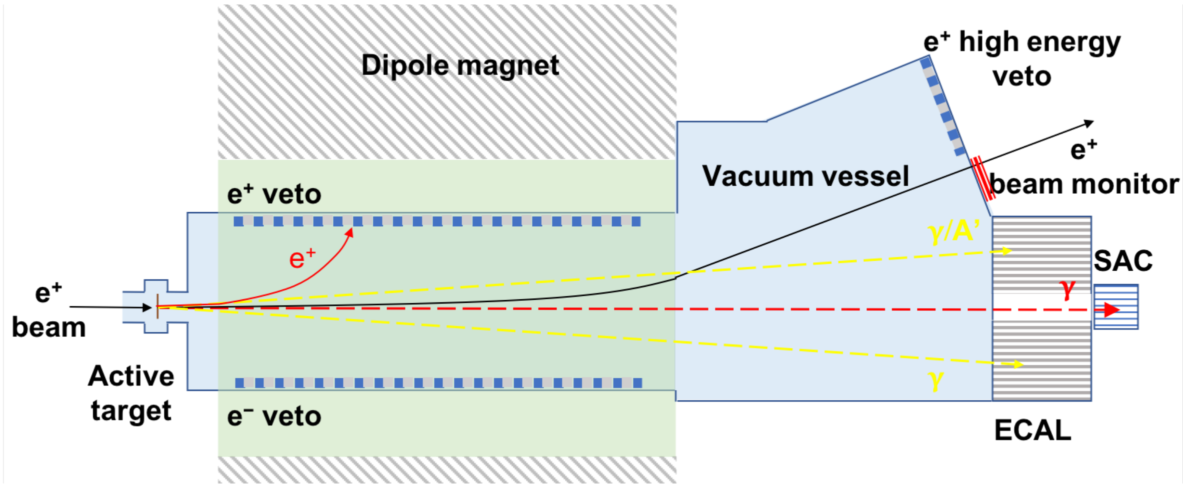
The pandemic that plagues the whole world has not stopped the research activity at the Frascati National Laboratory (LNF) of INFN. After the lockdown period, the LNF LINAC provided positrons for setting up the PADME experiment, from May to September 2020, with a stop in the central part of August.

Some members of the PADME Collaboration standing in the yard in front of the DAΦNE building

PADME is the acronym of the Positron Annihilation into Dark Matter Experiment that aims at searching a low mass Dark Photon signal. The long-standing problem of reconciling the cosmological evidence of dark matter with the lack of clear experimental observations, has revived the idea that the interaction of the new particles with the Standard Model gauge fields is not direct but occurs only through ‘portals’ that connect our world with the ‘secluded’ sectors. One of the simplest theoretical approaches to this scenario introduces a new U(1) symmetry with its corresponding vector boson, called Dark Photon or *A’* [1].

The 550 MeV maximum energy of the positron beam from the Frascati LINAC sets a limit to about 24 MeV/c^2 since PADME [2] searches for invisible decays of a massive vector boson *A’* studying the process $e^+e^-\rightarrow\gamma A'$ by measuring the missing mass of single photon final states originated from the annihilation of a positron beam with well-known momentum on the atomic electrons of an active diamond target [3].

The final state photons are detected by means of a calorimetric system consisting of two stations: ECAL a segmented high resolution cylindrical BGO array, and SAC, a Small Angle Calorimeter made of PbF_2 crystals, placed in the shadow of the central hole of ECAL (see the figure below). This arrangement has been studied to have high detection efficiency for the photons resulting from the annihilation process, and high rejection power for those produced by the bremsstrahlung background reaction. The experimental setup is completed by a dipole magnet instrumented with charged particle veto detectors and a solid-state beam monitor.



Schematic view of the PADME setup. The main detector components are pointed out together with the tracks of a possible signal event (yellow lines) and of a bremsstrahlung interaction (red curves). The black line represents the trajectory of the not interacting positrons.

After the optimisation phase, that was used not only to calibrate the PADME detector, but also to set the best beam conditions, the real data taking started. This phase was crucial since the beam characteristics required by the experiment are far from those normally set when the LINAC is used as an injector for the DAΦNE collider. In fact, DAΦNE needs short particle bunches (~ 10 ns duration) while for the PADME operation the positrons should be diluted as much as possible to reduce pile-up.

At present (mid October 2020), a steady configuration of the LINAC has been reached and PADME has already collected ~2×10^{12} Positrons-On-Target working with positron bunches of 30k particles distributed over 300 ns. The ultimate goal of the experiment is to acquire 4×10^{13} POT in order to explore possible couplings of the Dark Photon down to 10^{-3}.

Being one of the on-site experiments of LNF, PADME can profit from Transnational Access funding of the STRONG-2020 project to support travels of its foreign collaborators.

Paola Gianotti, PADME LNF group leader

[1] B. Holdom, Phys. Lett. B 166, 196 (1986).
[2] The PADME website: http://padme.lnf.infn.it/.
[3] M. Raggi and V. Kozhuharov, Adv. High Energy Phys. 2014, 959802 (2014).

An interview with Fabrizio Grosa

A young researcher from the STRONG-2020 work package 18, NA7-HF-QGP: 'Quark-Gluon Plasma characterisation with heavy flavour probes'

Fabrizio, could you introduce yourself and your research field?

I have been a part of the ALICE group in Torino for the last five years. The first one I spent as a Master Student in the Physics Department at the University, three as a PhD in Physics at Politecnico di Torino and the last one as a postdoc at INFN Torino. My research field is the High Energy Nuclear Physics, and in particular the study of the quark-gluon plasma (QGP), a state of the nuclear matter in which its constituents, quarks and gluons, are deconfined, or rather no more bound into hadrons such as protons and neutrons. This state of the matter is thought to be the one forming our Universe in the first few millionths of a second after the Big Bang, which makes this field of research so fascinating. We recreate this phase of the matter at the CERN Large Hadron Collider (LHC), colliding lead nuclei at ultra-relativistic energies and we study its properties detecting the particles that emerge from the collisions with the ALICE experiment. This allows us to learn more about Quantum Chromodynamics, the theory of the strong interaction, and at the same time understand something more about the primordial state of our Universe. During the last years, I had the chance to work both on the analysis of the data collected by the ALICE experiment and on the development and the construction of the new version of its innermost detector, made of silicon sensors that are currently under commissioning at CERN.

You just received a PhD award from the ALICE collaboration, what was your thesis about?

My thesis was focused on the study of the production of particles containing charm quarks, in particular the so-called *D mesons,* in different colliding systems. The most interesting feature of charm quarks for the study of the QGP is that they are created in the initial stages of the collisions and hence they experience the full system evolution; we can think about them as sort of probes that allow us to do the tomography of the QGP. I not only studied 'regular' D mesons, but also D mesons containing a strange quark besides the charm quark – the D_s^+ mesons – which are very important to understand how the charm quarks hadronise in the deconfined medium, due to the presence of a large quantity of strange quarks produced in the QGP, a phenomenon called *strangeness enhancement*. I was very happy when I was informed about the award, I worked a lot for my thesis and in the end, I was very satisfied with it.

When did you decide to be a researcher?

I got interested in Physics during the last year of high school when we started doing some simple experiments and studying modern Physics, which I immediately found absolutely fascinating. However, I realised that I wanted to become a researcher only during the first year of university after the laboratory courses. I was always the one in the group analysing the data that we were collecting, and still now the data analysis is the activity that gives me more satisfaction. After a visit organised by the University to the CERN during the third year of my bachelor, I decided that the field of High Energy Physics was the one that I wanted to pursue and now after five years in the ALICE group of Torino I am sure that it was the right choice for me.

How will STRONG-2020 help you in achieving your research goals?

The STRONG-2020 project gave me a fantastic opportunity to continue my research in the field of the heavy quarks. In particular, in the last months I could carry out the preparation of a paper about the azimuthal anisotropies in the D-meson production in Pb-Pb collisions, I started studying the production of beauty quarks and participating in the software development for the analyses of the data samples that ALICE will collect during the LHC Run 3 (2021–2024). Moreover, I became coordinator of the ALICE analysis group dedicated to the measurement of charm and beauty hadrons via their hadronic decays, which makes me very proud. In addition, being part of the STRONG-2020 project connected me with new researchers from other collaborations and this will surely help me in my personal and professional growth.

How do you balance a demanding research activity with a youngster life? Do you manage to match it with 'standard youngster life'?

The life of the researcher is very stimulating but doubtless very demanding. In the months before an important conference, it is not uncommon to work every day until late in order to bring to completion an analysis to be presented in the conference, which makes it difficult to manage the research activity with the youngster's life. However, it is, in my opinion, important to break from work to rest sometimes, also to be more efficient in the work. For this reason, I always try to carve out some time to see friends. During winter in particular, I like to go to the mountains and go skiing. I also like to spend some time for myself reading books and watching movies.

What is the most exciting aspect of being a researcher in Europe, according to you?

The most exciting aspect of being a researcher in Europe is, in my opinion, the possibility to collaborate with many other researchers from different countries. It is extremely stimulating and motivating meeting experts, exchange ideas, and work together to solve problems to advance in the technical and fundamental aspects of our field of research. In particular I think that being a researcher in Europe gives the unique opportunity to travel to many places, either to go to other research laboratories or for conferences. Unfortunately, this is currently significantly limited because of the Covid 19 pandemic, but I hope that it will end soon, and we will be able to return to normal as soon as possible.

Interview by Raphaël Granier de Cassagnac

A STRONG-2020 dedicated YouTube channel

The STRONG-2020 Dissemination YouTube dedicated channel was inaugurated with a first Welcome and Explanatory video in September 2020.

The link to this channel is:

https://www.youtube.com/channel/UCmXOpXZ5UKN4j2FUsAVBQiA

where link to first video:

https://www.youtube.com/watch?v=lTeYt5QJatA&t=252s

Meanwhile in early November, a new video on the PADME experiment at LNF-INFN, searching for Dark Boson at Frascati LINAC extracted beam, supported by Transnational Access, was added:

https://www.youtube.com/watch?v=t6ZDNG3gdp4&t=15s

and also an interview to Chiara Bissolotti and Francesco Giovanni Celiberto, made by Alessandro Bacchetta within the TMD-neXt work package:

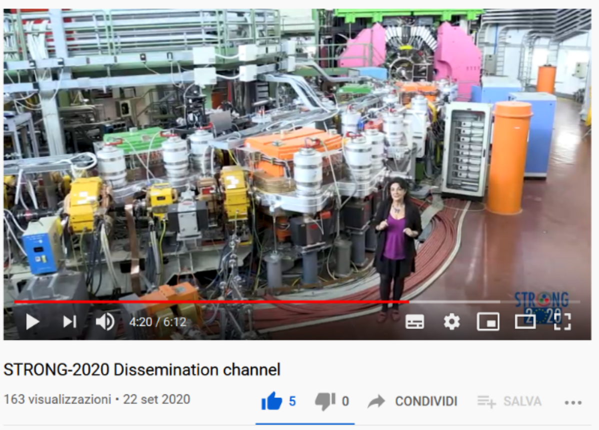
https://www.youtube.com/watch?v=em0uQNfXsLI&t=2s

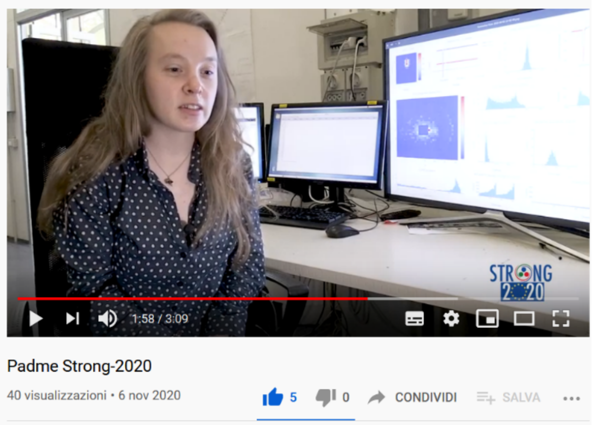
The channel is also hosting in the Playlist other videos, related to STRONG-2020 activities, such as various ECT* scientific videos.

The channel can be directly accessed from our STRONG-2020 web page:

http://www.strong-2020.eu/

under NEWS&DOCUMENTS – > DISSEMINATION CHANNEL.





We kindly invite all of you to help us publicise this channel towards STRONG-2020 community, other scientific communities, schools and general public. We also invite you to join the efforts towards implementing and enriching this channel with more videos – coming from STRONG-2020 rich activities!

Contact us if you have questions or ideas.

Catalina Curceanu, on behalf of Dissemination Board

Barbara Pasquini is elected fellow of the APS

The American Physical Society has elected the Society's 2020 fellows. The APS Fellowship Program recognises members who have made exceptional contributions to the physics enterprise in physics research, important applications of physics, leadership in or service to physics, or significant contributions to physics education.

Each year, no more than one half of one percent of the Society membership is recognised by their peers for election to the status of Fellow in the American Physical Society. This year, 163 fellows were selected and recognised for their contributions to science.

To view the complete list of the 2020 APS Fellows and their citations, or to search all APS Fellows to date, visit the **APS Fellow Archive**.

Among them is Barbara Pasquini, an active member of STRONG-2020 JRA4, aka TMD-NeXt. Here is her nomination:

Barbara Pasquini,
University of Pavia
Citation: 'For important work developing and improving theoretical tools, including dispersion relations, light-front models, and Wigner distributions which increase the sensitivity of both low- and high-energy experiments such as Compton scattering and tomography, to the fundamental structure of hadrons.'
Nominated by: Topical Group on Hadronic Physics

Congratulations to you, Barbara!

The Dissemination Board

Kick-off of the STRONG-2020 lecture series

A series of dedicated STRONG-2020 dissemination lectures for schools and the general public, which we plan to organise monthly, will be kicked off on the 16th of December 2020 at 3 p.m. We are glad to announce that the first talk in this series will be given by Randolf Pohl (Mainz/Germany) and Jan C. Barnauer (Stony Brook/USA) on the proton radius puzzle.

The talk will be live-streamed on a STRONG-2020 dedicated video list hosted and with the support of INFN-LNF Education and Dissemination service:

https://www.youtube.com/channel/UCyi2ABzIOiISreiYPxQ5g_w

More info will be available soon: stay tuned and mark your calendar!

We ask the support of the STRONG-2020 community both for suggesting speakers and to disseminate the news to schools and general public using the means they have at their disposal.

Catalina Curceanu and Achim Denig, on behalf of Dissemination Board