# Newsletter #5

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## Foreword

This is the Newsletter n.5 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 community and the general public.

The Newsletter n.5 is structured as follows: it opens with a Statement on the aggression of Russian Federation against Ukraine. The first article written by the Management Team (Barbara Erazmus, Emine Ametshaeva and Carlo Guaraldo) is reporting about the STRONG-2020 Annual Meeting, held in Nantes, France on November 8-10, 2021: an opportunity to present the results of the dedicated work of the STRONG-2020 Community members but also to make projections into the future of our project. This first article is followed by news concerning some ongoing STRONG-2020 activities, starting with a review article about the Muon Anomalous Magnetic Moment, a hot topic presently, and by a report on the search for exotic light mesons at COMPASS and news toward quarkonium hadroproduction in the Colour Evaporation Model at Next-to-Leading Order in NLOAccess. Then a short article discusses synergies between the Electron-Ion Collider and the Large Hadron Collider experiments.

Short reports on some workshops and schools are included, such as the Workshop on space-like and time-like determinations of the hadronic leading order contribution to the muon g-2, held online on 24-26 November 2021 and the first meeting (out of the planned four) of the STRONG-2020 WP17 NA6 Network Lattice Hadrons held in hybrid mode in Florence (Italy) from 28th March to 1st April 2022. The Newsletter continues with an interview to two young PostDocs, Dr. Jiayin Sun and Florian Damas, researchers of STRONG-2020 WP19, which is followed by an article regarding the latest very successful Public Lectures and a short report on the INSPYRE 2022 International School supported by STRONG-2020. The Newsletter closes with Obituaries, in the memory of dear colleagues, key-figures in the community of strong interactions studies, recently passed away.

We, the STRONG-2020 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 to young and less young participants and any other information or news relevant for our community and/or to a broader scientific community and to general public which is connected to our 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.*

# Statement on the aggression of Russian Federation against Ukraine

The STRONG-2020 Community firmly condemns military aggression by Russia against Ukraine, and the violation of international law by the Russian Federation.

Our Community represents a project deeply rooted in Europe, and we are strongly concerned about these dramatic events.

Our thoughts are going to our Ukrainian colleagues, and we express our sincere solidarity with the entire Ukrainian population.

The STRONG-2020 project will follow the instructions and measures issued by the E.U. Commission, which details can be found on the Commission's official site: https://ec.europa.eu/commission/presscorner/detail/en/IP_22_1544

We also express our support to Russian scientists who reject this invasion.

From its very beginning, the core of our project is to bring leading research groups and infrastructures together, and promote non-military application of its results.

We will continue to embrace and promote scientific collaboration as a peace driver in Europe.

# STRONG-2020 Annual meeting (2021): productive exchange and new perspectives

*Barbara Erazmus (CNRS/IN2P3, Subatech Laboratory, France), Carlo Guaraldo (LNF-INFN, Italy) and Emine Ametshaeva (CNRS/IN2P3, Subatech Laboratory, France)*

The 2021 edition of the project Annual meeting, that took place on November 8-10 in Nantes, France, gave us an opportunity to present the results of the dedicated work of the STRONG-2020 Community members but also to make projections into the future of our project. We would like to thank all of you for your participation, in-person or remote, and the contributions, which made this Annual meeting fruitful.

The meeting followed the agenda available on the following indico page:

https://indico.in2p3.fr/event/25163/

One can also find there all the contributions presented during the meeting. So, if you could not assist at all the presentations, or you just want to refresh memories on their content, we encourage you to consult this page and the respective contributions.

The Annual meeting went very well and almost all the Work Packages (WPs) demonstrated good progress in their work. With no doubt, the activity of many WPs is affected, albeit to a different extent, by the restrictions related to Covid-19. Nevertheless, they succeeded in ensuring the continuity of their work, which is reflected in the rich content of the presentations.

The discussion of scientific progress made over the past year was one of the major but not the only objective of the event. Indeed, the plenary session, and especially the restricted meetings scheduled during three days, have been also moments of exchange and collective reflection on the administrative changes that our project had undergone and the future modifications to be introduced.

As for the major administrative change, the Consortium had the opportunity to meet our new Project Officer (the third one), Flavius Pana, who made a short presentation of the new Agency (EREA) in charge of the project supervision at the European level. Just to remind, with the Implementing Decision of 12 February 2021, the European Commission has created six new European Executive Agencies. The project supervision of STRONG-2020 was transferred to the European Research Executive Agency (EREA, former REA). After a short period as Project Officer by Simona Misiti (from April to September 2021), Flavius Pana stays actually as our official Project Officer appointed by this new Agency.

As for future perspectives, first of all the need of the project extension was confirmed by most WP leaders. In accordance with the members of Executive Board, Facility Coordination Panel and Governing Board, it was decided to request, as a first step, a 6 months extension. This additional period was esteemed to be essential to compensate, at least partially, for the delays accumulated during the consecutive lockdowns and postponements in the delivery of deliverables and milestones. Shortly after the Annual meeting, the Amendment containing the 6 months extension request was submitted on 16 November and was then accepted by the EU Commission on 29 November. As a result, the official duration of the project becomes 54 months (until the end of November 2023).

Finally, during the restricted Executive Board meeting after the plenary sessions, some possible modifications of the format of our traditional Annual meetings were discussed. The main objective remains to increase the scientific content and relevance of our Annual meetings, ensure the outreach to involve all the Consortium members, as well as to attract more scientists in the field. To serve these multiple goals, some interesting ideas emerged as for the novelties that could be introduced in the frame of the 2022 edition. We hope these ideas will be made more concrete during the next EB meeting (26 January 2022). We will, of course, keep you informed and ask for your feedback.

The 2021 edition was special because it was the first one organized in hybrid mode, after the 2020 edition held completely online. The success of the 2021 Annual meeting is largely due to our participants who were able and willing to organize themselves and adapt to the complicated pandemic context. We would like to thank especially those who came to Nantes to attend this major event in person. Let's hope this meeting will mark the beginning of a return to the ordinary mode of operation and next Annual meeting will be the occasion to meet all of you face-to-face and in good health.

We thank all the members of STRONG-2020 Community for their dedication and contributions. We want this year to become a renewal full of success and opportunities for you and your families.

Best regards,

Barbara, Carlo and Emine

## A Tale of Two Values – The Muon Anomalous Magnetic Moment

*Andrzej Kupsc (National Centre for Nuclear Research, Warsaw, Poland and Uppsala University, Uppsala, Sweden) and Hartmut Wittig (PRISMA+ Cluster of Excellence and Institute for Nuclear Physics, University of Mainz, Germany), WP21*

After years of data taking and painstaking analysis, the Muon $g - 2$ Collaboration presented first results of their new measurement of the muon anomalous magnetic moment, $a_{\mu}$. The announcement, made during a live presentation on 7 April 2021, was closely watched by thousands of physicists around the globe, all eager to learn whether the new result would confirm the previous measurement performed a BNL almost two decades earlier. As is turned out, it did! What's more, by combining the two results, the tension between direct measurements and the theoretical prediction based on the Standard Model increased to 4.2 standard deviations, tantalisingly close to the $5\,\sigma$ threshold required for claiming that the Standard Model has been proven wrong. The result was clearly one of the physics highlights of 2021 and has generated a flurry of articles and contributions in the press and other media.

But why are physicists looking so fervently for cracks in this magnificent edifice known as the Standard Model of Particle Physics? The answer lies in the increasing body of evidence that the Standard Model (SM) does not provide a complete description of nature, despite the fact that experimental observations at particle colliders agree with SM predictions at an amazing level of accuracy. In particular, it has become abundantly clear from astrophysical observations that a dark form of matter exists for which the SM offers no explanation at all, and the same is true for the formation of the apparent asymmetry between matter and antimatter in the universe. Also, the SM has little or nothing to say about empirical facts such as the large hierarchies among forces and particle masses.

The quest for physics beyond the Standard Model (BSM) is being pursued by employing several complementary strategies. Particle colliders at the highest beam energies that can technically be realised have made many spectacular discoveries that helped establish the SM, culminating in the observation of the Higgs boson a decade ago at the LHC. However, even this most powerful collider has, at least until now, not provided any direct evidence for new physics. In this situation, precision tests based on the comparison between extremely accurate measurements of key observables and their equally precise theoretical predictions, have become increasingly important. In this context, the observed $4.2\,\sigma$ discrepancy between the direct measurement of $a_\mu$ and the SM prediction provides one of the most intriguing hints for a possible failure of the SM!

The anomalous magnetic moments of charged leptons such as the electron, the muon and the tau, have served as crucial benchmarks for our quantitative understanding of the subatomic world since the inception of relativistic quantum theory at the end of the 1940s. It was Julian Schwinger who computed the first quantum correction to the $g$-factor of the electron, using the newly formulated theory of QED in 1948. This was instrumental for understanding experimental results on the hyperfine structure of hydrogen and deuterium at the time. The muon anomalous magnetic moment, $a_\mu$, which differs from that of the electron by a tiny, plays a special[1] role in the quest for BSM physics. Quantum corrections to the magnetic moment scale like $m_l^2/M_{BSM}$, where $l = e, \mu, \tau$ and $M_{BSM}$ denotes a typical mass scale for BSM physics. Thus, the muon is more sensitive by a factor $(m_\mu/m_e)^2 = 4{\cdot}10^4$. At the same time, muons are much easier to handle experimentally than $\tau s$, although the latter would feel the effects of BSM particle even more strongly.

In the SM, the muon anomalous magnetic moment receives contributions from the electromagnetic, weak and strong interactions, i.e.

$$a_\mu^{SM} = a_\mu^{QED} + a_\mu^{weak} + a^{strong}, \quad a_\mu^{strong} = a_\mu^{hvp} + a_\mu^{hlbl} \tag{1}$$

The individual contributions, as specified in the 2020 White Paper [1], are listed in Table 1 along with the respective absolute and relative uncertainties. While the overwhelming part of the value of $a_\mu^{SM}$ is due to electromagnetism, the uncertainty is dominated by the contributions from the strong interaction, which divide into the hadronic vacuum polarisation (HVP) and hadronic light-by-light scattering (HLbL) contributions. Thus, hadron physics and its quantitative treatment in terms of Quantum Chromodynamics (QCD) plays a crucial role for

[1] In perturbation theory, the difference arises only beyond the leading order.

improving the SM prediction to a level that can rival the precision of future direct measurements.

| Contribution | Value$\times 10^{11}$ | abs. error | rel. error |
|---|---|---|---|
| QED | 116 584 718.931(104) | 0.001 ppm | |
| Electroweak | 156.6(1.0) | 0.01 ppm | |
| HVP ($e^+e^-$) | 6 845(40) | 0.34 ppm | 0.6% |
| HLbL | 92(18) | 0.15 ppm | 20% |
| Total | 116 591 810(40) | 0.37 ppm | |

**Table 1:** Contributions to the SM prediction of $a_\mu$ from electromagnetism, the weak and strong interactions, as listed in the White Paper [1].

According to Table 1, the electromagnetic and weak contributions are known with very high precision. Since Schwinger's 1948 calculation of the leading-order electromagnetic correction (which applies equally to all leptons $l = e, \mu, \tau$), the QED contribution has been worked out in perturbation theory to an astonishing $10^{th}$ order (i.e. five loops) in the electric charge. Each additional loop order produces an enormous proliferation of diagrams to be evaluated. For instance, at five-loop level, one has to compute 12 672 diagrams which contribute a tiny fraction, $4{\cdot}10^{-8}$ to the total QED correction [2]. The hugely impressive effort to compute the full four- and five-loops contributions relies heavily on the numerical integration techniques, and independent checks have been successfully performed [3,4]. Electroweak effects contribute only mildly to the SM estimate for $a_\mu$. A full two-loop perturbative calculation has been performed, and the three-loop contribution is known partially. While the result for $a_\mu^{weak}$ is smaller in size than the hadronic contributions discussed in detail below, it is known with much better precision.

When evaluating $a_\mu^{hvp}$ and $a_\mu^{hlbl}$, one faces the challenge that perturbation theory in the strong coupling constant cannot be applied at typical hadronic scales. Traditionally, the HVP contribution has been determined via the so-called “data-driven” approach, making use of experimentally measured hadronic cross sections as input, while the HLbL contribution has been determined mostly using hadronic models and perturbative QCD. More recently, the data-driven method has been extended to the determination of $a_\mu^{hlbl}$, while lattice QCD has emerged as a viable method to determine from the first principles the $a_\mu^{hvp}$ and $a_\mu^{hlbl}$ values. Both lattice and the data-driven approaches provide controlled errors and promise the required level of precision.

Numerically, the leading-order HVP contribution, $a_{\mu}^{LO,hvp}$, which arises at order $\alpha^2$ in the electromagnetic coupling, is the dominant hadronic correction. In the data-driven method $a_{\mu}^{LO,hvp}$ is expressed as a dispersion integral over the "R-ratio" R(s), i.e. the total hadronic cross section in electron-positron annihilation normalised by the $\mu^+\mu^-$ production cross section, times an analytically known and slowly varying kernel function $0.63 < \hat{K}(s) < 1$:

$$a_{\mu}^{LO,hvp} = \left(\frac{\alpha m_{\mu}}{3\pi}\right)^{2} \int_{m_{\pi^0}^2}^{\infty} \frac{\hat{K}(s)}{s^2} R(s) ds, \quad R(s) := \frac{\sigma(e^+e^- \to hadrons)}{\sigma(e^+e^- \to \mu^+\mu^-)} \tag{2}$$

The contribution to the dispersive integral accounts for all hadronic final states in electron-positron annihilation. The lower bound of the integral is $m_{\pi^0}^2$ and corresponds to the opening of the first annihilation hadronic channel $e^+e^- \to \gamma\pi^0$. The low-energy region where perturbative QCD fails is strongly enhanced due to the factor $\frac{1}{s^2}$ in the integrand. Therefore, experimentally measured hadronic cross sections are used to determine the R-ratio. The evaluation of the integral is divided into different intervals in the variable s. The region $\sqrt{s} < 2$ GeV is studied in exclusive experiments where all contributing hadronic channel are identified separately and summed over. Here, the range $\sqrt{s} < 1$ GeV is of special importance since it contributes about 70% to the dispersion integral in Eq. (2). This requires precision data in this range, as discussed in detail below. Above $\sqrt{s} < 2$ GeV one uses inclusive cross sections where the sum of all hadronic contributions is measured without disentangling individual channels. Finally, for highest energies $\sqrt{s} \gtrsim 4$ GeV, the integrand is evaluated using perturbative QCD.

Here, we focus on the $\sqrt{s} < 1$ GeV region where the required precision of the R(s) measurement is below one percent. The traditional experimental method, used since the first electron-positron colliders, were constructed in the 1970s, is to collect data at the desired centre-of-mass (c.m.) energy $\sqrt{s}$ to extract the R(s) value. The collider has to be tuned to specific energies to map out R(s) as a function of s. A prerequisite to obtain a precision result is to take into account higher-order electromagnetic effects, so called radiative corrections. Their size is only a few percent but is enhanced close to vector meson resonances. The modern colliders that can measure R(s) using this method are VEPP-2000 in Novosibirsk (experiments SND and CMD3), for $\sqrt{s} < 2$ GeV, and BEPCII in Beijing (BESIII experiment), for $2 < \sqrt{s} < 5$ GeV. A complementary experimental technique uses data from high luminosity electron-positron colliders which run at a fixed c.m. energy that is larger than the $\sqrt{s}$ region to be studied. The analysis selects events where an electron or positron emits an energetic photon prior to the annihilation process. Thus, using a high-luminosity collider operating at fixed energy allows one to study the R(s) dependence in a single experimental run. The method is called initial state radiation (ISR) and was first used at DAΦNE and PEP-II colliders. It relies on precision QED calculations of the photon emission cross sections implemented in dedicated event-generator programs like PHOKARA [5]. In principle, measurements done with different initial c.m. energies have independent sources of systematic effects. For $e^+e^- \to \pi^+\pi^-$, which is the most important channel contributing to R(s) for $\sqrt{s} < 1$ GeV, there are ISR measurements from four experiments where the initial c.m. energies significantly differ: KLOE (1.019 GeV), BaBar (10.58 GeV), CLEO-c and BESIII (3.77 GeV and 4.17 GeV). Three different KLOE results have been published [6-8], each obtained with complementary experimental approaches, with or without detecting the radiative photon. In the BaBar [9,10] and BESIII [11] measurements the radiative photons are detected. The $\mu^+\mu^-$ normalization can reduce systematic uncertainties due to radiative corrections at the expense of a reduced statistical accuracy. The final systematic uncertainties given by these experiments are below 1% in the most important ρ-resonance region. However, the two most precise measurements by KLOE and BaBar do not agree well within their quoted uncertainties. After the combination [12] of the three KLOE measurements, the reduced uncertainty makes the situation worse. In the White Paper average, this discrepancy was accounted for by assigning an error that covers the two results. However, the tension can be only resolved by new measurements. Such new analyses are being carried out at CMD3, SND, BESIII, BaBar and BelleII experiments. The assumptions and approximations used in the previous measurements will be cross checked. There are more channels that must be studied further to reduce the uncertainty of the evaluation of the $a_\mu^{hvp}$ dispersion integral. A comprehensive experimental effort to produce dedicated, precise, and extensive measurements of $e^+e^-$ cross sections, coupled with the development of sophisticated data combination methods is crucial for achieving further progress.

In the data-driven approach experimental uncertainties enter the theoretical prediction. Lattice QCD calculations have emerged as a viable and precise method to provide an independent determination of $a_\mu^{LO,hvp}$ which does not rely on the use of experimental data, except for simple hadronic quantities such as meson and baryon masses that are used to set the overall scale and fix the values of the quark masses. The lattice approach is not designed to compute the R-ratio from first principles, nor is it possible to distinguish different exclusive hadronic channels. Instead, $a_\mu^{LO,hvp}$ is expressed in terms of a convolution integral [13] involving the electromagnetic current correlator G(t):

$$a_\mu^{LO,hvp} = \left(\frac{\alpha}{\pi}\right)^2 \int_0^\infty \widetilde{K}(t)G(t)dt, \qquad G(t) = -\frac{a^3}{3}\sum_k \sum_{\vec{x}} \langle j_k(\vec{x},t) j_k(0)\rangle \tag{3}$$

Although the vector correlator G(t) is a standard quantity in lattice QCD calculations, one faces several major challenges if the task is to reach a level of precision similar to that of the data-driven approach. To begin with, the statistical error must be significantly below the percent level, which is difficult owing to the exponentially increasing noise-to-signal ratio in G(t) at Euclidean times $t \gtrsim 2$ fm. The vector correlator also contains specific contributions due to so-called quark-disconnected diagrams that, although suppressed relative to the standard quark-connected part, have an intrinsically high level of statistical noise. Furthermore, as lattice calculations are performed for a finite box size and non-zero lattice spacing, one must account for finite-volume corrections and discretisation effects. Finally, in order to match the precision achieved using the data-driven approach, one has to include isospin-breaking effects, arising from the mass splitting between up and down quarks and from electromagnetism. In spite of these challenges, several groups have published estimates for $a_{\mu}^{LO,hvp}$ with total quoted uncertainties at the 2% level or better [14-21]. While most of these results are not yet precise enough to distinguish between the direct measurement of $a_{\mu}$ and the SM prediction based on the experimental R-ratio, the uncertainty quoted by the BMW Collaboration for their calculation [20] is similar to that of the data-driven method. Surprisingly, though, the latter disagrees with BMW's result at the level of two standard deviations. Moreover, if the BMW result were to replace the leading-order HVP estimate in the White Paper, the tension with the Fermilab and BNL measurements would disappear! Clearly, an independent verification of the BMW result by other lattice calculations with comparable overall accuracy is urgently needed. The question to answer is whether the effects of non-zero lattice spacing have been correctly extrapolated away and whether the correlator G(t) has been computed reliably enough at long distances where there is a steep increase in the statistical noise.

One strategy to perform an in-depth study is to restrict the integration in Eq. (3) to a region that is relatively insensitive to large discretisation effects and in which the statistical signal has not yet deteriorated sharply. Indeed, the lattice community is currently focused on computing the so-called "window observables", first defined in [14], which should allow for a high-precision cross check of different lattice calculations. Furthermore, one can readily define the counterpart of the window observable in the data-driven approach. In this context, it is interesting to note that the window observable already shows a 3.7 σ tension between BMW's lattice calculation and the R-ratio estimate. Results by other collaborations can be expected in the course of 2022.

If one is willing to take the BMW result at face value, the obvious question is whether the SM can accommodate a larger value for $a_{\mu}^{LO,hvp}$ without producing tension(s) in other observables. An important role in this context is played by the electromagnetic coupling, α. In the Thomson limit, i.e. at low energies, its value is given by the familiar $\alpha = 1/137.035\ \dots$ . As one goes to higher energies $E = \sqrt{q^2}$ this value is modified by quantum corrections in a similar manner as quantum effects modify the Dirac prediction for the g-factor.

$$\alpha\left(q^2\right) = \frac{\alpha}{1-\Delta\alpha\left(q^2\right)} \tag{4}$$

There is, in fact, a correlation between the $a_\mu^{LO,hvp}$ and the contributions to energy-dependence of the electromagnetic coupling, Δα, due to the hadronic vacuum polarisation ("hadronic running") [22]. At the Z pole, $q^2 = M_{Z^2}$, the representation of Δα in terms of a dispersion integral involving the R-ratio reads

$$\Delta\alpha_{had}^{(5)} = \frac{\alpha M_Z}{3\alpha} P \int_{m_\pi^0}^{\infty} \frac{R(s)}{s\left(M_Z^2-s\right)} ds \tag{5}$$

where "P" denotes the principal value of the integral, and the superscript "(5)" reminds us that the expression is valid for five active quark flavours. Thus, a larger value for $a_\mu$ would imply an increase in Δα at the Z-pole. However, Δα cannot increase arbitrarily, as this would produce a tension with the value obtained with global electroweak fits [23-27].

This reasoning puts the R-ratio once more under the spotlight: given that the large-energy region is strongly constrained by the global electroweak fit, the only way to produce an increase in $a_\mu^{LO,hvp}$ and $\Delta\alpha\left(M_Z^2\right)$ while, at the same time, avoiding a tension with the global electroweak fit, is to modify the R-ratio in the region $\sqrt{s} \lesssim 1$ GeV from which the dispersion integral for $a_\mu^{LO,hvp}$ receives the dominant contribution. An analysis performed by Colangelo et al. [26] finds that this is an unlikely scenario, given that the resulting change in the experimentally determined R-ratio would have to be implausibly large.

But perhaps one should take the well-known tension in the $e^+e^-$ data more seriously. After all, the BaBar data suggest a larger estimate for $a_\mu^{LO,hvp}$ compared to KLOE. In addition to the expected new data from BESIII, SND and others on the R-ratio, it is very good news that a new and improved analysis of the BaBar hadronic cross sections is in progress. One can also expect further clarification from the determination of $a_\mu^{LO,hvp}$ via the direct measurement of the effective electromagnetic coupling in the spacelike region via elastic scattering of muons off electrons [28]. Indeed, this is the aim of the MUonE experiment [29] which is undergoing first tests at CERN.

The increase in accuracy of $a_\mu^{hvp}$ that can be expected in the coming years implies that the largest uncertainty will eventually reside in the $a_\mu^{hlbl}$ contribution. A large-scale effort is underway to improve the estimate for $a_\mu^{hlbl}$ employing the dispersive formalism and lattice QCD. For the former, the key quantity is the coupling of two photons to any hadronic state. Although $a_\mu^{hlbl}$ is not related to a single observable in the dispersive formalism, one can build up the entire contribution starting with the most dominant channels. The main contribution that comes from the neutral pion transition to two photons was recently calculated using experimental input [30,31]. Accounting for the contributions from heavier mesons decaying to two photons in a model independent way will require more experimental data. The dominant contribution from the pion transition form factor has also being studied in lattice QCD [32], and efforts are now focussing on including the subleading contributions as well. This is complemented by several direct lattice calculations of the full $a_\mu^{hlbl}$ [33,34]. It would be a major achievement if the relative precision in $a_\mu^{hlbl}$could be pushed to the level of 10%.

The announcement of the new measurement of $a_\mu$ at Fermilab has sparked a flurry of activity designed to corroborate the tension with the SM or, indeed, to check whether hadronic contributions are really controlled to the level that is necessary to claim such a tension. While the particle and hadron physics communities await further updates of the Fermilab experiment with better statistics, as well as a completely independent measurement from the E38 experiment at J-PARC, it is of paramount importance to further reduce the uncertainty of the SM prediction. One thing is absolutely certain: The anomalous magnetic moment with keep physicists busy for many years to come!

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## Search for exotic light mesons at COMPASS

*Boris Grube (Technical University of Munich) and Bernhard Ketzer (University of Bonn), WP25*

The study of the excitation spectrum of hadrons has provided essential clues that helped to develop Quantum Chromodynamics (QCD) as the theory of strong interaction. However, some deep puzzles remain. In the constituent quark model, hadrons are either combinations of three quarks, i.e. baryons, or quark-antiquark states, i.e. mesons. However, QCD in principle allows for more complicated hadronic states such as multi-quark states (e.g. molecule-like objects), states with excited gluonic fields (hybrids), or even purely gluonic bound states (glueballs).

The hunt for these so-called exotic hadrons is a world-wide experimental effort. The COMPASS experiment at CERN, which is run by an international collaboration of 22 institutions from 13 countries, has collected world-leading datasets that allow us to study the spectrum of mesons that are composed of the three lightest quarks (up, down, and strange) with unprecedented detail and precision. COMPASS uses 190 GeV/c secondary hadron beams consisting mainly of pions, kaons, and (anti)protons, which are produced by the 400 GeV/c primary proton beam from CERN's Super Proton Synchrotron. A rich spectrum of light mesons is produced in soft inelastic scattering reactions of the pion and kaon beam components with stationary proton or nuclear targets. In these so-called single-diffractive reactions, the beam meson is excited to intermediate resonances X via the strong interaction with the target, which at high energies is commonly described by the exchange of a Pomeron. The produced resonances decay quickly via the strong interaction into multi-hadron final states and are extracted from the measured kinematic distributions using partial-wave analysis techniques. The COMPASS spectrometer has a good acceptance for charged as well as neutral particles over a wide kinematic range and is thus able to measure a wide range of final states.

For the reaction $\pi^- p \rightarrow X^- p$ with $X^- \rightarrow \pi^- \pi^- \pi^+$, COMPASS has obtained a world-leading data sample of $46 \times 10^6$ events. Using these data, we have performed the so far most comprehensive partial-wave analysis of the $3\pi$ system [1]. Due to conservation laws, the intermediate states $X^{-}$ can be $\pi_J$- or $a_J$-like resonances with spin J, isospin I = 1, and negative G-parity. In our analysis, we found a surprising exotic resonance-like signal with $a_1$ quantum numbers—i.e. spin, parity, and charge conjugation quantum numbers of $J^{PC} = 1^{++}$—at a mass of about 1.4 GeV/$c^2$ in the $f_0(980)\ \pi$ decay mode [1, 2] (see data points in Fig. 1 left). The resonance-like behaviour was corroborated by the observed rapid phase motions, i.e. mass-dependent relative phases with respect to several other reference waves (see, e.g., data points in Fig. 1 right). According to its quantum numbers, the signal was called $a_1(1420)$ [3]. This signal has a number of peculiar properties: the $a_1(1420)$ lies only about 150 MeV/$c^2$ above the axial-vector ground state $a_1(1260)$, whereas for a radial excitation, a separation of about 400 MeV/$c^2$ would be expected.

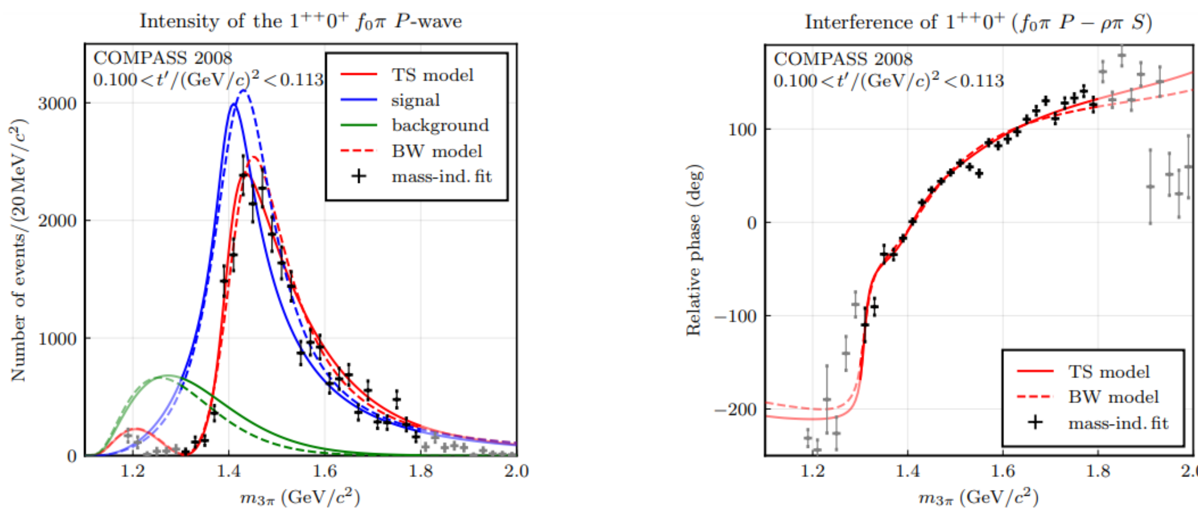


**Figure 1**: Left: Measured intensity of the partial wave with a1 quantum numbers that decays via the $f_0(980)\ \pi$ mode shown as a function of the mass of the $\pi^-\pi^-\pi^+$ final state (data points). A clear peak is observed at about 1.4 GeV/$c^2$. Right: Measured phase difference with respect to a second partial-wave with the same quantum numbers that decays via the $\rho(770)\ \pi$ mode and contains the ground-state resonance $a_1(1260)$ (data points). In both diagrams, the red curves represent the result of fits using either a Breit-Wigner model (BW, dashed) or a triangle-singularity model (TS, continuous). The corresponding interfering model components are shown by the blue (signal) and green curves (background). From Ref. [4].

Despite having a higher mass than the ground state, the $a_1(1420)$ width of 150 MeV/$c^2$ is much smaller than that of the $a_1(1260)$ of about 420 MeV/$c^2$ [3]. Finally, we observe the $a_1(1420)$ only in the $f_0(980)\ \pi$ decay mode, which would be a rather unusual mode for a conventional quark-model state. Hence, it is clear that the $a_1(1420)$ is not an ordinary quark-model resonance.

Various explanations including exotic four-quark states have been proposed to explain the $a_1(1420)$ signal. An intriguing explanation that does not require a new resonance is the so-called triangle singularity mechanism. In this model, the $a_1(1420)$ signal originates from the ground-state decay $a_1(1260) \rightarrow K^*(892)\ \overline{K}$, where the $K^*(892)$ decays further to $K\pi$ and the $K\overline{K}$ pair rescatters via the $f_0(980)$ to ππ thereby producing the measured 3π final state. In this process, the $K^*(892)$, $K$, and $\overline{K}$ form the legs of a triangular loop diagram, where the particles are almost on shell for $m_{3\pi} \approx 1.4\ GeV/c^2$. In this rather special case, the amplitude of the triangular loop develops a logarithmic singularity that has a similar experimental signature, i.e. an intensity peak at about 1.4 GeV/$c^2$ accompanied by a rapid phase motion, as an ordinary resonance pole. By fitting, for the first time in the light-meson sector, a triangle-singularity model to amplitude data (see continuous curves in Fig. 1), COMPASS has shown that this model can fully explain the resonance-like $a_1(1420)$ signal [4]. The data are described slightly better than by a Breit-Wigner model, which has two additional parameters. Although at this point our analysis cannot exclude contributions from a new resonance at 1.4 GeV/$c^2$, the triangle singularity is currently the best explanation for the observed signal because it is expected to appear in the data and eliminates the need for an additional resonance. It will be interesting to see, whether the $a_1(1420)$ signal can be confirmed in the large $\tau \rightarrow 3\pi$ data samples obtained by the Belle and Belle II experiments.

In the same $\pi^-\pi^-\pi^+$ data sample, we also found a resonance signal, the $\pi_1(1600)$ [1] (see Fig. 2 left) with manifestly exotic $J^{PC} = 1^{-+}$ quantum numbers, which are forbidden for ordinary quark-antiquark states. We observe the $\pi_1(1600)$ in the $\rho(770)\,\pi$ decay mode. Based on the highly precise COMPASS data, we were able to reconcile the seemingly contradictory results obtained by previous experiments on the existence of the $\pi_1(1600) \rightarrow \rho(770)\,\pi$ signal that puzzled the community for a long time [5]. We traced back the discrepancies and mutual inconsistencies observed in previous analyses to artefacts induced by too limited partial-wave analysis models and to the strong dependence of the background on the squared four-momentum transfer from the beam to the target, which obstructs the $\pi_1(1600)$ signal in the region of low momentum transfer.

A large source of systematic uncertainty in the partial-wave analysis of the $\pi^-\pi^-\pi^+$ final state is that we have to know the dynamic amplitudes for the decays of the resonances that appear in the $\pi^-\pi^+$ subsystems without any free parameters. For the $\rho(770)\,\pi \rightarrow \pi^-\pi^+$ we use, for example, a Breit-Wigner amplitude with mass and width parameters taken from the Particle Data Group [3]. To reduce the model uncertainty, we have developed a novel partial-wave analysis method, which allows us to extract the amplitudes of $\pi^-\pi^+$ subsystems with well-defined $J^{PC}$ quantum numbers, without imposing any assumptions on the resonance content of these amplitudes. Fig. 2 right shows the amplitude of the $\pi^-\pi^+$ subsystem with ρ-like $J^{PC} = 1^{--}$ quantum numbers as a function of the two-pion mass obtained using this method. The measured amplitude agrees well with the Breit-Wigner amplitude that we use to describe the $\rho(770)$ resonance in the conventional partial-wave analysis. The model-independent approach, which was applied for the first time, hence confirms the $\pi_1(1600) \rightarrow \rho(770)\,\pi$ signal observed in the conventional partial-wave analysis.

Further analyses of the COMPASS data on pion and kaon diffraction into various final states are work in progress or close to finalisation and will help to complete our picture of the light meson spectrum. Complementary analyses are expected to come from the GlueX experiment at Jefferson laboratory, which has collected high-precision data samples on photoproduction of 3π and other final states. This work was supported within the STRONG-2020 project within joint research activity “Light- and heavy-quark hadron spectroscopy” (WP25).

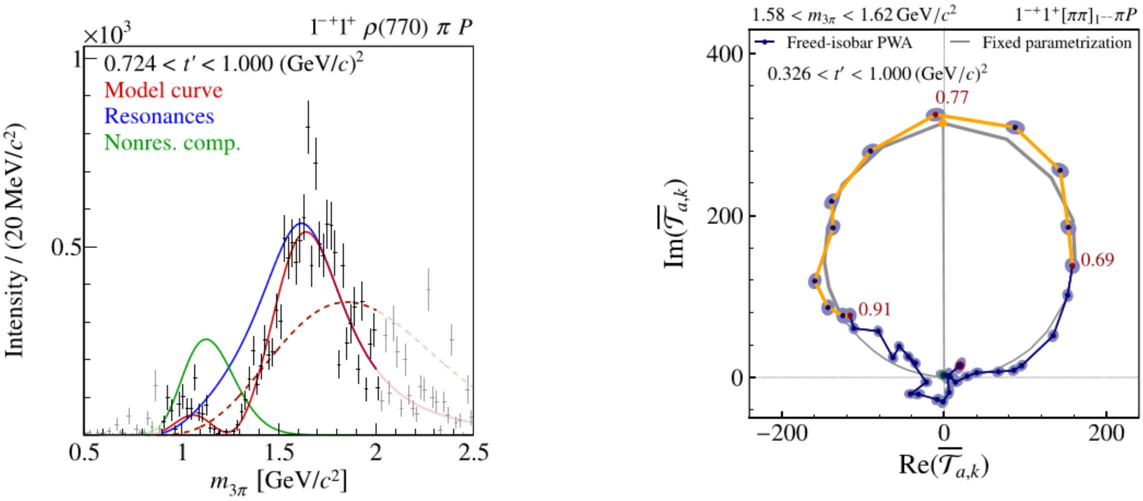

**Figure 2:** Left: Measured intensity of the partial wave with exotic $J^{PC} = 1^{-+}$ quantum numbers that decays via the ρ(770) π mode shown as a function of the mass of the $\pi^-\pi^-\pi^+$ final state (data points). The continuous red curve shows the result of a fit using a the coherent sum of a Breit-Wigner amplitude (blue curve) for the $\pi_1(1600)$ and a background term (green curve). That a resonance is needed in order to describe the data is shown by the dashed red curve, which represents the fit result using only the background term. From Ref. [4]. Right: Measured amplitude of the $\pi^-\pi^+$ subsystem with ρ-like quantum numbers $J^{PC} = 1^{--}$ shown in the complex plane as a function of the two-pion mass. The data points are connected by lines to indicate the order and the red numbers correspond to $m_{\pi^-\pi^+}$ values in GeV/$c^2$. The line segments highlighted in orange correspond to the $m_{\pi^-\pi^+}$range around the ρ(770). For comparison, the fixed parametrization of the dynamic amplitude for the ρ(770) as used in the conventional partial-wave analysis is shown by the gray line. From Ref. [5].

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## Toward quarkonium hadroproduction in the Colour Evaporation Model at Next-to-Leading Order in NLOAccess


*Carlo Flore (Université Paris-Saclay, Orsay) and Jean-Philippe Lansberg (Université Paris-Saclay, Orsay), WP10*


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 Color Evaporation Model (CEM), which is based on 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 accesible via NLOAccess.

The CEM at LO and NLO was shown to reproduce well the pT spectrum of ψ(nS) and ϒ(nS) (except at large pT) 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.

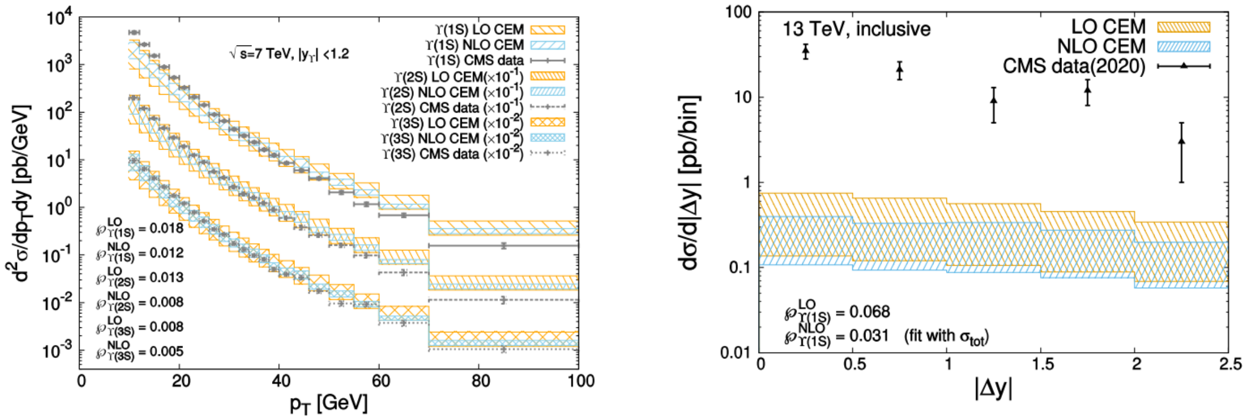


**Figure 1**: Left: pT spectrum of ϒ(nS) measured by CMS at 7 TeV vs the CEM LO and NLO; right: rapidity-difference spectrum of ϒ(1S) pairs measured by CMS at 13 TeV vs the CEM at LO and NLO. See details in [3].

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## Workshop on space-like and time-like determinations of the hadronic leading order contribution to the muon g-2

*Achim Denig (PRISMA+Cluster of Excellence and JGU Mainz), Andrzej Kupsc (Uppsala University) and Graziano Venanzoni (INFN Pisa), WP21*

The Joint Research Activity PRECISION-SM of STRONG-2020 (JRA-3) deals with key precision observables of the Standard Model (SM), for which hadronic input – both experimentally and theoretically – is required in order to achieve progress in the respective fields. Probably the most exciting of these quantities is the anomalous magnetic moment of the muon, in short the muon g-2, for which the status of the theory and experiment is discussed on page 6 of this edition of the newsletter. The hadronic vacuum polarisation (HVP) contribution establishes the leading uncertainty to the SM prediction of g-2 and hence deserves a special focus. To discuss the status of HVP and the perspective for future space-like and time-like determinations of this important quantity, a workshop took place on November 24-26, 2021. Due to the Covid-19 pandemic, the workshop, which was organized by Andrzej Kupsc (Uppsala University) and Graziano Venanzoni (INFN Pisa), had to be held online.

The meeting was attended by 122 registered participants from 17 countries and 3 continents; in total, 25 presentations were given in six sessions ranging from the discussion of experiments at electron-positron colliders (Beijing, Frascati, Novosibirsk, Stanford) to radiative corrections, hadron phenomenology, lattice QCD, as well as a detailed discussion of the new proposal to measure HVP in the space-like domain in electron-muon scattering at CERN (MUonE experiment). Although time slots had already been reserved to allow for general discussions on these topics, the discussions were so lively that more time would have been needed, demonstrating the great interest and the excitement around this research topic. Within the framework of STRONG-2020, it is foreseen to establish a database of cross section measurements needed for the data-based determination of HVP. Part of the time was also devoted to this initiative, which will be most useful for future phenomenological analyses of the data as well as for detailed comparisons. The mini-proceedings of the workshop with a one-page summary of the talks and a list of relevant publications have recently been published and can be found here: https://arxiv.org/abs/2201.12102.

## Synergies between the Electron-Ion Collider and the Large Hadron Collider experiments

*Daniël Boer (Univ. of Groningen) and Franck Sabatie (Université Paris-Saclay, Orsay), WP22*

In June last year, an initial group of people has signed an Expression of Interest (EoI) to form a Joint ECFA-NuPECC-APPEC Activity, http://www.nupecc.org/jenaa/ on "Synergies between the Electron-Ion Collider and the Large Hadron Collider". The chairs of APPEC, ECFA and NuPECC approved this EoI at the end of 2021, and it is now our ambition to start this activity with an in-person kick-off meeting at CERN to be held on June 20-21 and co-organized with the help of David d'Enterria (CERN).

The goal of the JENAA initiative on the EIC-LHC synergies is to stimulate and strengthen collaboration among the European nuclear, particle and astroparticle physics communities, to mutually benefit from the many synergies between experiments at the planned U.S.-based Electron-Ion Collider (EIC) and the Large Hadron Collider (LHC) at CERN

Even though this activity is mostly aimed at our European colleagues, we know that the community is global and therefore acts globally. Indeed, considering the sizeable European involvement in EIC, we believe it would be beneficial to have more European activities in the form of workshops and other community building actions centering around the common research goals of the EIC and the LHC. As detailed in the EIC input document for the ESPPU (https://indico.cern.ch/event/765096/contributions/3295735/attachments/1785257/2906268/EICdocumentforESPPU.pdf) and as the Snowmass 2021 exercise has shown (https://indico.bnl.gov/event/9376/), there are many topics of shared interest, such as: pdf studies of nucleons and nuclei, hadron tomography, small-x phenomena, diffractive processes, heavy quark and jet physics. In addition, many (if not all) R&D topics of interest for the EIC detectors are in common with those of our particle physics colleagues.

If you feel that the initiative is worthwhile, you are invited to endorse the expression of interest at the URL https://indico.ph.tum.de/event/7004/ (left menu of the Indico page). This is especially important to show that this synergy is quite real and it makes sense for particle physicists, based at CERN in particular, to be interested in EIC physics as well.

If not only you consider the goal worthwhile but if you are actually interested in participating actively, please take note of the dates of the meeting at CERN and contact one of us directly or register at https://indico.ph.tum.de/event/7014/. Even if this kick-off meeting is by invitation only (due to space limitations), registration is open to all and some financial help is available for young physicists or physicists from developing countries. A block of 30 rooms at the CERN hostel has been booked, available on a first come/first serve basis. The goal is not just to portray the existing synergies, but rather to develop them further, for instance by forming working groups and projects.

## "Resummation, Evolution, Factorization" Workshop

*Francesco Hautmann (University of Oxford), WP23*

The 2021 workshop on "Resummation, Evolution, Factorization" was organized by DESY, Hamburg and was held on November 15-19, 2021 as an online meeting [1]. For five days, a total of 228 registrants met in several online sessions to discuss advances on a broad range of topics in the physics of strong interactions, both theoretical and experimental. A major focus of the meeting was on Quantum Chromodynamics (QCD) methods to treat transverse momentum dependent (TMD) parton densities and parton showers, and their applications to experimental programs at present and future accelerator facilities for studies of fundamental interactions, including the Large Hadron Collider (LHC) at CERN and the planned Electron Ion Collider (EIC) at Brookhaven.

This is the second edition of the "Resummation, Evolution, Factorization" workshop series which is taking place online, following the 2020 edition [2] organized by the Higgs Centre for Theoretical Physics at the University of Edinburgh, in the context of the global changes in scientific communication triggered by the outbreak of the Covid-19 pandemic at the beginning of 2020.

The "Resummation, Evolution, Factorization" workshop series started with a meeting of a dozen researchers who gathered at the University of Antwerp in 2014 [3] to discuss specialized issues in QCD factorization and resummation techniques and their impact on experimental analyses. It has since grown into a yearly conference which covers a broad range of topics and constitutes an annual appointment for a wide international community of junior and senior scientists engaged in QCD and collider physics research. Over the years, this collective effort has also produced the TMDlib library [4] of TMD distributions, whose updated release came out in 2021 [5], and the TMD physics review [6].

With the switch to the online mode in the past two years characterised by the Covid-19 pandemic and the reduction of travel, the workshop has further enlarged its pool of participants. An illustration is provided by the figure below, showing the distribution of participants by country at the 2021 edition of the workshop.

As the conditions of reduced travel continue into 2022, the next edition of the workshop will again be online, and will be organised by the University of Montenegro in Podgorica in November 2022 [7]. The High Energy Physics group at the University of Montenegro is active within the CMS experiment at CERN, closely collaborates with the Université Libre de Bruxelles and DESY, and participates in STRONG-2020. With the LHC moving into the Run 3 phase and the EIC advancing its scientific program, there is a lot of exciting physics to look forward to for the 2022 “Resummation, Evolution, Factorization” meeting.

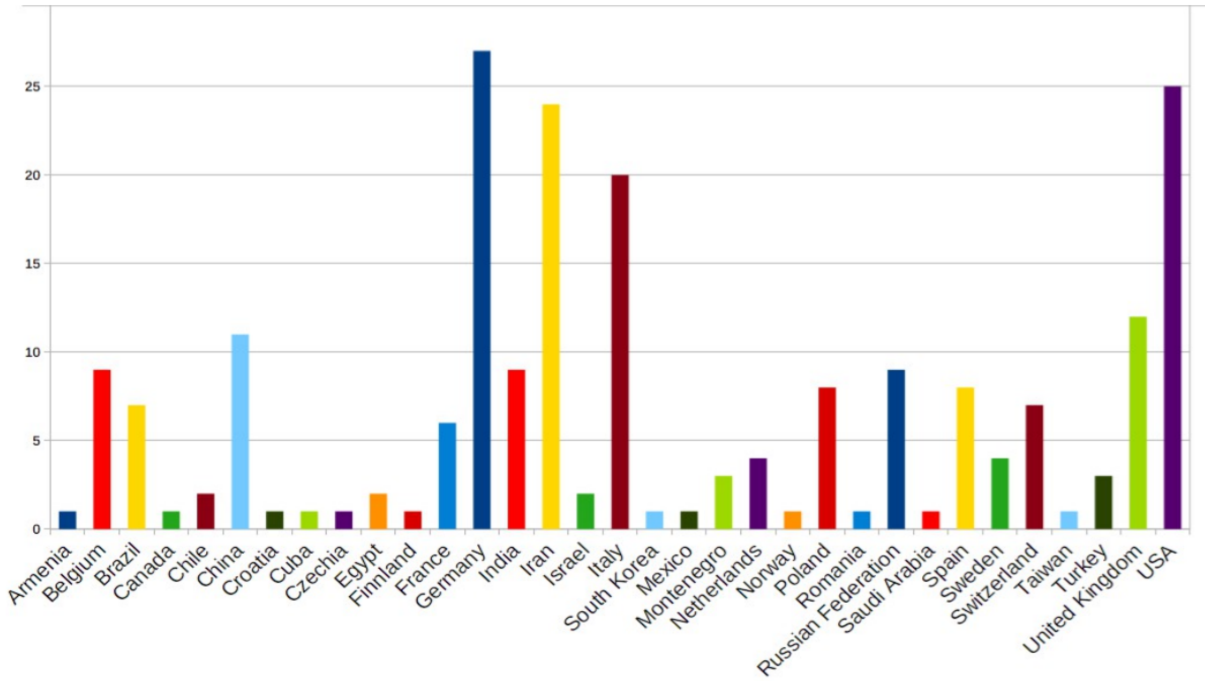


**Figure 1**: Distribution of participants by country at the 2021 “Resummation, Evolution, Factorization” Workshop.

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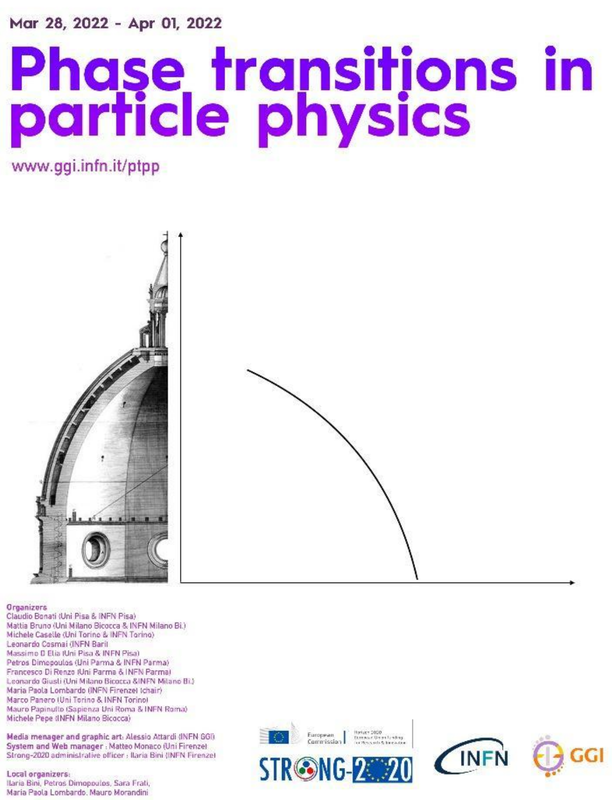
# The STRONG-2020 NA6 Workshop – Phase transitions in particle physics

*Marianna Sorba (SISSA – Trieste, Italy)*

The *Phase transitions in particle physics* workshop was held in Florence (Italy), at the *Galileo Galilei Institute* for theoretical physics, from 28th March to 1st April 2022. The event could be attended either in presence or remotely, allowing a broader participation without sacrificing the ongoing Covid-19 safety measures.




During the five-day workshop, 39 scientific talks were presented by speakers coming from 29 top Universities or Institutions in more than 10 different countries.

The contributions were devoted to the study of phases and phase transitions in particle physics, within and beyond the standard model, with a particular emphasis on the lattice approach. More specifically, topics ranged from the thermal phase transition in QCD, the nature of the quark-gluon-plasma and its cosmological implications, the QCD axion and topology, the strong-electroweak transition… to methodological challenges to handle the sign problem, machine learning tools, field theories, spin models, renormalization group and universality.

The enthusiastic participation (more than 74 participants between those in presence and people connected from all over the world) and the pleasant atmosphere of the host Institute allowed for enriching discussions involving both experts and younger physicists.

Thanks to the high quality of the talks, the workshop fitted perfectly in the framework of projects within the STRONG-2020 community and paved the way to future activities of the Lattice Hadron Network, including the preparation of the whitepaper.

## An Interview with PostDocs Jiayin Sun and Florian Damas

*Dr. Jiayin Sun and Florian Damas, Researchers of STRONG-2020, WP19*

***Jiayin and Florian, could you introduce yourself and your research field?***

**JS:** I am a postdoctoral researcher from China. I work in the LHCb heavy-ion group at INFN sezione di Cagliari in Italy. My research focuses on physics in the forward rapidity region in small colliding systems, such as proton-lead collisions, where we study phenomena in the low x region. My PhD was on a somewhat different subject. I studied di-electron invariant mass spectra in AuAu collisions with the PHENIX experiment.

**FD:** I am a French postdoctoral researcher in the CMS heavy-ion group of the Laboratoire Leprince-Ringuet at École Polytechnique, Palaiseau, France. My main research interest is the study of heavy quarkonia, more specifically how they can help us to probe and characterise the properties of the quark-gluon plasma formed in relativistic heavy-ion collisions. This is why my PhD subject was about the modification of the production of upsilon mesons in PbPb collisions with the ALICE experiment.

*Dr. Jiayin Sun*

***When did you decide to be a researcher? Was it a child's desire or a recently born passion?***

**FD:** As many people, I changed my job wishes several times during my childhood. I knew I wanted to do physics from high school and I discovered the research domain in my final year of undergraduate studies.

**JS:** I never thought of myself as a researcher until college. I discovered the fun of physics in my undergraduate courses and decided to learn more about it. My physics teacher in high school was surprised.

***The work package you work for is about having the four LHC collaborations to work together, do you face difficulties to make that happen?***

**FD:** Quite some difficulties, yes! First, imagine the headache of agreeing a meeting date that fits with the agendas of the four collaborations, then add to that a global pandemic preventing in-person meetings. Besides the technical difficulty to gather people at the same time, our combination projects are for now limited to published data. The newly-created LHC working group should extend the scope of action in order to exploit the full potential of heavy-ion physics at the LHC.

**JS:** I agree with what Florian wrote. Although we work on published results that are not your own analyses, we need to learn the details and techniques in these analyses.

*Dr. Florian Damas*

***The quark matter conference has just finished. What was for you the most exciting result released by another collaboration than yours?***

**JS:** There are a few results that impressed me. For example, CMS is able to measure Upsilon (1S) flow in pPb and PbPb systems, and they also study many other rare probes in PbPb collisions, such as Bc, Bs, Upsilon(3S) and X(3872).

**FD:** The impressive LHCb program for a systematic investigation of the production of heavy-flavour hadrons, either conventional or exotic states (see presentation).

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

**FD:** Living less than four hours from CERN by train, the ease to travel across countries (within the Schengen area).

**JS:** I am from China. For me, there are several exciting aspects. One is to learn from and to interact with European researchers, to gain new knowledge and insights. Another one is staying close to CERN and easy to travel just like Florian wrote. A third aspect is the chance to experience and explore a totally different culture.

## The STRONG-2020 Public Lecture Series – new lectures!

The series of the STRONG-2020 public lectures was continued with three lectures which dealt with various aspects of the strong interaction and research in this field. On December 2nd, 2021 Paul Souder, Syracuse University (USA), and Chuck Horowitz, Indiana University (USA), gave the lecture entitled "Studying neutron star matter in the laboratory", where they discussed the PREX experiment and comparison of the PREX results to gravitational wave observations of the merger of two neutron stars with the LIGO and VIRGO detectors.

On January 13th, 2022 Jo van den Brand, from NIKEF Amsterdam (Netherlands), spoke about "Gravitational waves and physics at the extreme", lecture in which he discussed the recent observations of gravitational waves coming from mergers of neutron stars and black holes. The scientific impact of the recent detections on nuclear and particle physics in this context was presented together with key technological aspects, such as the interferometric detection principle, optics, and sensors and actuators. The presentation closed with a discussion of the largest challenges in the field, including plans for a detector in space (LISA), and Einstein Telescope, an underground observatory for gravitational waves science.

On February 24th , 2024, Wolfgang Enghardt, Technische Universität Dresden (Germany) and Barbara Vischioni, National Center for Oncological Hadrontherapy CNAO, Pavia (Italy), in their lecture "HADRONTHERAPY: what it is, how it works?", discussed aspects related to the hadron therapy, both from the relevant nuclear and hadron physics point of view, as well as for what regards the way in which it is applied at the CNAO center in Italy.

The audience was very diverse reaching from high-school students to researchers of the STRONG-2020 community and beyond. The success of the series of course crucially depended on the quality of the speakers, who were capable of conveying their enthusiasm for their research fields in this format. We therefore would like to thank once more our first speakers for their fascinating presentations.

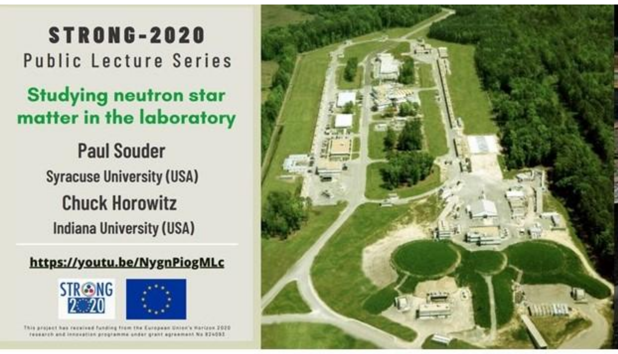
New Public Lectures are in preparation and we invite the STRONG-2020 Community to propose new ones!

The Public Lectures can be found at the links:

https://www.youtube.com/playlist?list=PLRuUrPCVPFIqjT_o4A7iPEPj26N_OOA6s

and on the STRONG-2020 dedicated web page under:

http://www.strong-2020.eu/events/live-events.html






## STRONG-2020 supported INSPYRE 2022 International School

*Catalina Curceanu (LNF-INFN)*

INSPYRE, International School on Modern PhYsics and Research, is an advanced modern physics international school organized by INFN at the Laboratori Nazionali di Frascati for high-school and college students highly interested in science. In 2020, INSPYRE celebrated 10 years since its first edition. The school, initiated with 20 participants in 2010, reached about 100 in 2019, and many INSPYRED participants to previous editions are presently physicists, engineers, biologists, and even lawyers and economists. In normal times, the school is organized in lectures given by researchers working in various fields and a series of hands-on experiments performed by students teaming up with researchers. The 2021 edition – due to the pandemic situation – was organized as an online edition, and was supported by STRONG-2020.

STRONG-2020 supported also the 2022 edition of the INSPYRE School, having as sub-title: "From particles to the stars: an INSPYRING adventure" The school was organized with interactive presentations of the most recent and exciting results in nuclear and particle physics, as well as studies of the Universe, both from theoretical and experimental points of view. Quantum physics and gravity, the two pillars of our understanding of Nature and Universe, neutron stars and strange matter, dark matter and dark energy, together with experimental possible signatures of physics beyond standard model were addressed by enthusiastic experts in the field – happy to share their knowledge with the young participants. Also, a virtual visit in the Visitor Center of the Laboratori Nazionali di Frascati of INFN and to main infrastructures was organized.

INSPYRE 2022 was held on 4-9 April 2021; about 200 high-school students from all over the world (Czech Republic, France, Germany, India, Indonesia, Ireland, Italy, Lithuania, Luxembourg, Portugal, Romania, Switzerland and Turkey) participated to this special edition.

More information, including the program, can be found on the web-page of the INSPYRE 2022 event:

http://edu.lnf.infn.it/inspyre-2022/

## Commemorations

As STRONG-2020 community, we would like to remember Prof. Gennady Zinovjev who sadly passed away in November 2021. Our deep condolences to his family.

Prof. GENNADY ZINOVJEV