Symposium Dipole Moments - A Tool to Search for New Physics (SYDM)

jointly organized by
the Hadronic and Nuclear Physics Division (HK),
the Atomic Physics Division (A),
the Molecular Physics Division (MO), and
the Quantum Optics and Photonics Division (Q)

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Overview of Invited Talks and Sessions

(Lecture room: C/gHS)

Invited Talks

SYDM 1.1	Tue	11:00–11:40	C/gHS	**Searching for New Physics Effects in the Muon g -Factor** — •B. Lee Roberts
SYDM 1.2	Tue	11:40–12:20	C/gHS	**Dedicated storage ring EDM methods** — •Yannis Semertzidis
SYDM 2.1	Tue	14:30–15:10	C/gHS	**The experimental search for the neutron electric dipole moment** — •Klaus Kirch
SYDM 2.2	Tue	15:10–15:50	C/gHS	**The muon g-2: where we are, what does it tell us?** — •Friedrich Jegerlehner

Sessions

SYDM 1.1–1.4	Tue	11:00–13:00	C/gHS	**Session 1**
SYDM 2.1–2.4	Tue	14:30–16:30	C/gHS	**Session 2**
SYDM 3.1–3.8	Tue	17:00–19:00	P/H1	**Session 3**

SYDM 1: Session 1

Time: Tuesday 11:00–13:00 Location: C/gHS

Invited Talk SYDM 1.1 Tue 11:00 C/gHS

Searching for New Physics Effects in the Muon g -Factor — •B. Lee Roberts — Boston University

Measurements of the magnetic dipole moments of the electron and muon were intertwined with the development of the *modern physics* of the 20th century. The measurements are expressed in terms of the g-value, the proportionality constant between the magnetic moment and the spin, $\vec{\mu} = g(Qe\hbar/2m)\vec{s}$. The Stern-Gerlach experiment and atomic spectroscopy told us that $g = 2$ for the electron, which was subsequently predicted by Dirac theory. Later, experiments showed that for the electron $g > 2$; and it was necessary to add an anomalous piece, $g = 2(1+a)$. For point-like particles, the anomaly $a = (g-2)/2$, arises from radiative corrections. The lowest-order correction was first obtained by Schwinger, who found that $a = \alpha/(2\pi)$, and by doing so, carried out what we now call the very first *loop* calculation in quantum electrodynamics. This remarkable result was also found to also describe the muon's magnetic moment, which indicated that in a magnetic field the muon behaved like a heavy electron. The electron anomaly has now been measured to 0.24 ppb at Harvard, and the muon anomaly to 0.54 ppm at Brookhaven Laboratory. When the Standard-Model value of the muon anomaly is calculated by including contributions from quantum electrodynamics, the strong interaction and the electroweak interaction, it appears to be more than three standard deviations smaller than the experimental value. To clarify whether this difference signifies contributions from New Physics or not, two new experiments are being prepared. The Fermilab experiment will use the relocated muon storage ring from Brookhaven. The J-PARC experiment will use an entirely different technique. I will review the goals and status of the future experiments.

Invited Talk SYDM 1.2 Tue 11:40 C/gHS

Dedicated storage ring EDM methods — •Yannis Semertzidis for the JEDI-Collaboration — CAPP/IBS at KAIST and Physics Dept., KAIST, Daejeon, South Korea.

Dedicated storage ring electric dipole moment (EDM) methods are under development with potential sensitivity level at the 1E-29 e-cm for both the proton and deuteron nuclei. Two large collaborations, the JEDI at COSY/Juelich and srEDM at BNL/USA, are working closely together to optimize the final experimental plan. Together with the neutron EDM experiments, the proton and deuteron experiments, can help to shed light on the CP-violating source should one of them discovers a non-zero EDM value.

The R&D program is well under way with work on hadronic polarimetry, spin coherent time optimization/benchmarking, electric field strength tests, and precision beam/spin dynamics. The COSY ring at Juelich is being used in several tests requiring stored polarized beams. The optimization tests are expected to be concluded within the next two to three years.

Storage ring EDMs are sensitive to new physics at the 1000 TeV level, much beyond the mass scale reach of LHC and it can provide a hint of the next interesting scale. If new physics is discovered at LHC, it will probe the CP-violating phases of this new physics at the sub-micro-radian scale, an unprecedented sensitivity level.

Group Report SYDM 1.3 Tue 12:20 C/gHS

Search for the Electric Dipole Moment of ^{225}Ra — •Peter Mueller[1], Kevin Bailey[1], Michael Bishof[1], Matthew Dietrich[2], John Greene[1], Roy Holt[1], Mukut Kalita[3], Wolfgang Korsch[3], Nathan Lemke[1], Zheng-Tian Lu[1,4], Thomas O'Connor[1], Richard Parker[4], and Jaideep Singh[5] — [1]Argonne National Laboratory — [2]Northwestern University — [3]University of Kentucky — [4]University of Chicago — [5]Michigan State University

^{225}Ra ($\tau_{1/2} = 15d$, $I = 1/2$) is a promising isotope for EDM searches in diamagnetic atoms and the corresponding quest for physics beyond the Standard Model. Due to its large nuclear octupole deformation and high Z, the EDM sensitivity of ^{225}Ra is expected to be 2-3 orders of magnitude larger than that of ^{199}Hg, which to date sets the best EDM limit in this sector. We have developed an efficient multiple-stage apparatus to laser cool and trap radium atoms and to transfer them via optical dipole traps into a magnetically-shielded science chamber, where they are spin polarized and then allowed to precess in magnetic and electric fields. We will report on the results of the first EDM measurement of ^{225}Ra as well as plans for future improvements. This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics, under contract number DE-AC02-06CH11357.

Group Report SYDM 1.4 Tue 12:40 C/gHS

Measurement of the $e^+e^- \to \pi^+\pi^-$ Cross Section Using Initial State Radiation at BESIII — •Benedikt Kloss and Achim Denig — Institut für Kernphysik Mainz

The cross section $\sigma(e^+e^- \to \pi^+\pi^-)$ has been measured with ever increasing accuracy at accelerators in Novosibirsk, Orsay and Frascati. More recently the two most accurate measurements have been obtained by the KLOE collaboration in Frascati and the BABAR collaboration at SLAC. Both experiments claim an accuracy of better than 1% in the energy range below 1 GeV in which the ρ resonance is largely dominating the cross section. However a discrepancy of approximately 3% on the peak of the $\rho(770)$ resonance is observed increasing towards higher energies. Unfortunately this discrepancy limits our current knowledge of $a_\mu \equiv \frac{(g-2)_\mu}{2}$, which is a famous precision observable of the Standard Model (SM) of particle physics. Another comparable experiment is needed. This measurement can be done at the BESIII experiment in Beijing, China. Using the technique of initial state radiation it might be possible to measure this hadronic cross section below 3.0 GeV with a comparable precision to BABAR and KLOE. This talk will give an overview of the current status of this analysis.

SYDM 2: Session 2

Time: Tuesday 14:30–16:30 Location: C/gHS

Invited Talk SYDM 2.1 Tue 14:30 C/gHS

The experimental search for the neutron electric dipole moment — •Klaus Kirch — ETH Zürich, Switzerland — Paul Scherrer Institut, Villigen, Switzerland

For 60 years, searches for the electric dipole moment (EDM) of the neutron have covered some six orders of magnitude in sensitivity improvement. Yet, the result is still consistent with zero. Time reversal symmetry forbids a finite EDM but the CP violation of the electroweak Standard Model will cause it to be non-zero. This finite value is tiny and out of reach for current and foreseeable future neutron EDM experiments. However, due to CP-violation expected in the strong interaction or in some new physics, the EDM could be much larger - with major implications if found. New experimental efforts aim at catching up with the long-time average of one order of magnitude sensitivity gain per decade. Recent progress and related physics measurements will be presented.

Invited Talk SYDM 2.2 Tue 15:10 C/gHS

The muon g-2: where we are, what does it tell us? — •Friedrich Jegerlehner — DESY Zeuthen, Platanenallee 6, 15738 Zeuthen

The anomalous magnetic moment of the muon provides stringent tests for the electroweak Standard Model (SM) and is an excellent monitor for new physics. Being one of the most precisely measured and at the same time very precisely predictable observable in elementary particle physics, the present persisting deviation between theory and experiment is likely the best established indication of physics beyond the SM. I present a summary of the status and on recent progress of the theoretical prediction, emphasizing problems and possible solutions in the determination of the hadronic contributions: vacuum polarization and light-by-light scattering. They represent the challenge in reducing theoretical uncertainties to match the precision of forthcoming experiments, expected to go into operation within the next few years at

Fermilab. The impact of recent LHC results for the interpretation of the observed 3-4 sigma "discrepancy" in the muon g-2 is discussed.

Group Report SYDM 2.3 Tue 15:50 C/gHS

The hadronic light-by-light contribution to the anomalous magnetic moment of the muon in a dispersive approach — •Vladyslav Pauk and Marc Vanderhaeghen — JGU Mainz, Germany

The keen interest to the anomalous magnetic moment of muon is motivated by its high potential for probing physics beyond Standard Model. However, the interpretation of the quantity is undermined by large hadronic uncertainties. In view of the new muon (g-2) experiments at Fermilab and at J-PARC, a new dispersive formalism for evaluating the hadronic light-by-light (HLbL) scattering contribution to the muon's anomalous magnetic moment will be presented. We provide a first realistic application of the proposed formalism to the case of pseudoscalar meson pole exchanges. Moreover, it allows for a more straightforward implementation of the experimental data. The ongoing measurements by the BES-III Collaboration will be a crucial input into the presented dispersive formalism.

Group Report SYDM 2.4 Tue 16:10 C/gHS

Measurement of Electric Dipole Moments of Charged Particles at Storage Rings — •Volker Hejny for the JEDI-Collaboration — Institut für Kernphysik, Forschungszentrum Jülich, Germany

Electric Dipole Moments (EDM) of elementary particles are considered to be one of the most powerful tools to investigate CP violation beyond the Standard Model and to find an explanation for the dominance of matter over antimatter in our universe. Up to now experiments concentrated on neutral systems (neutrons, atoms, molecules). Storage rings offer the possibility to measure EDMs of charged particles by observing the influence of the EDM on the spin motion.

The Cooler Synchrotron COSY at the Forschungszentrum Jülich provides polarized protons and deuterons up to a momentum of 3.7 GeV/c and, thus, is an ideal starting point for such an experimental program. The JEDI (Jülich Electric Dipole moment Investigations) Collaboration has been formed to exploit the COSY facility to demonstrate the feasibility of such a measurement and to perform all the necessary R&D towards the design of a dedicated storage ring.

In this talk, the current status of the project will be presented and recent achievements together with the future plans will be discussed.

SYDM 3: Session 3

Time: Tuesday 17:00–19:00 Location: P/H1

SYDM 3.1 Tue 17:00 P/H1

A precision measurement of the proton g-factor — Georg Ludwig Schneider[1] and •Nathan Leefer[2] for the BASE-Collaboration — [1]Johannes Gutenberg-Universität Mainz, Mainz, Germany — [2]Helmholtz Institut-Mainz, Mainz, Germany

The proton g-factor experiment at Mainz recently used a double Penning-trap apparatus to measure the proton g-factor with a fractional accuracy of 3.3×10^{-9}, improving on the previous direct measurement in a trap by nearly three orders of magnitude. We now aim to increase this accuracy further with a number of upgrades to the trap and detection systems. These upgrades include: a better compensated precision trap; a reduction of the residual quadratic magnetic-field inhomogeneity in the precision trap region; the installation of a superconducting, self-shielding coil for improved magnetic field stability; new low-noise amplifiers for particle detection; and a superconducting cyclotron resonator for more efficient resistive cooling of the proton. We have also implemented phase-sensitive detection techniques for faster determination of both the proton spin-state and cyclotron frequency. This talk will briefly review the previous result and discuss the current status of these upgrades.

Ultimately, a measurement with a measurement precision better than 10^{-10} is feasible, and the same advances developed at our experiment can be used at the companion antiproton BASE experiment currently being operated at CERN. The eventual comparison of proton and anti-proton g-factors will be one of the most stringent direct tests of CPT symmetry for baryons.

SYDM 3.2 Tue 17:15 P/H1

Ultracold trapped molecules for tests of fundamental symmetries — •Joost van den Berg, Sreekanth Mathavan, Corine Meinema, Artem Zapara, Klaus Jungmann, and Steven Hoekstra — Van Swinderen Institute, University of Groningen, The Netherlands

Effects such as parity violation and electron electric dipole moments can be greatly enhanced in diatomic molecules because of their energy level structure. Therefore ultracold molecules can be used for precision tests of fundamental physics to look for physics beyond the Standard Model. Recent developments make it possible to create and trap cold samples of molecules. Trapped molecules offer a coherent measurement time which can be two orders of magnitude larger than a molecular beam experiment. We aim for a measurement of molecular parity violation with trapped, laser cooled molecules and we will present the tools which we are developing in our lab in order to reach this goal. These tools can be useful for the broad field of molecular experiments looking for physics beyond the standard model, such as permanent electric dipole moments or dark Z-bosons.

SYDM 3.3 Tue 17:30 P/H1

Search for a permanent Xe-EDM - Experimental status — •Stefan Zimmer[1], Werner Heil[1], Sergei Karpuk[1], Kathlynne Tullney[1], Yuri Sobolev[1], Fabian Allmendinger[2], Ulrich Schmidt[2], Olivier Grasdijk[3], Klaus Jungmann[3], Lorenz Willmann[3], Hans-Joachim Krause[4], and Andreas Offenhäuser[4] — [1]Institut für Physik, Universität Mainz — [2]Physikalisches Institut, Universität Heidelberg — [3]University of Groningen — [4]Forschungszentrum Jülich

A permanent EDM of the isotope 129Xe would imply a breakdown of both parity P and time-reversal symmetry T and, through the CPT theorem, a breakdown in CP. Our goal is to improve the present experimental limit (dXe<3*10-27 ecm) by about four orders of magnitude (most precise EDM limit measured in the diamagnetic atom 199Hg (dHg<3.1*10-29 ecm)). The non-observation of particle and atom EDMs has ruled out more speculative models (beyond Standard Model) than any other single experimental approach in particle physics. We propose a 3He/129Xe clock comparison experiment with the detection of free spin precession of the nuclear polarized gas samples with a SQUID. The precession of co-located 3He/129Xe nuclear spins can be used as ultra-sensitive probe for non-magnetic spin interactions of type $\Delta\nu$~dXe*E, since the magnetic dipole interaction (Zeeman-term) drops out in the frequency difference $\Delta\nu$ of the Larmor frequencies. The detection of free spin precession with spin coherence times T > 1 day doesn't have the systematic limitations of a feedback loop necessary to sustain coherent spin precession.

SYDM 3.4 Tue 17:45 P/H1

Towards a data-driven estimate of the pseudoscalar-pole contribution to hadronic light-by-light scattering in the muon $g-2$ — •Andreas Nyffeler — Institut für Kernphysik, Johannes Gutenberg-Universität Mainz, Deutschland

The evaluation of the numerically dominant pseudoscalar-pole contribution to hadronic light-by-light scattering in the muon $g-2$ involves the pseudoscalar-photon transition form factor $F_{P\gamma^*\gamma^*}(Q_1^2, Q_2^2)$ with $P = \pi^0, \eta, \eta'$ and, in general, two off-shell photons with spacelike momenta Q_i^2. We determine which regions of photon momenta give the main contribution in the corresponding 3-dimensional integral representation for hadronic light-by-light scattering. Furthermore, we discuss how the precision of future measurements of the doubly off-shell form factor, or its determination via a dispersion relation, impacts the precision of a data-driven estimate of this contribution to hadronic light-by-light scattering.

SYDM 3.5 Tue 18:00 P/H1

Isospin breaking effects in the leading hadronic contribution to the muon g-2 — •Jan Haas, Gernot Eichmann, Christian Fischer, and Richard Williams — Institut für Theoretische Physik, JLU Giessen

The functional approach of Dyson-Schwinger and Bethe-Salpeter Equations (DSE/BSE) allows us to investigate nonperturbative properties of QCD. We use it to study the Hadronic Vacuum Polarization contribution to the anomalous magnetic moment of the muon $g_\mu - 2$, extending previous calculations by including isospin symmetry breaking.

SYDM 3.6 Tue 18:15 P/H1

Hadronic Light-by-Light Contribution to the Muon Anomalous Magnetic Moment on the Lattice — •Nils Asmussen, Jeremy Green, Vera Gülpers, Georg von Hippel, Harvey Meyer, Andreas Nyffeler, and Hartmut Wittig — University of Mainz

The experimental value for the muon anomalous magnetic moment, $g-2$, currently shows a $3\,\sigma$ discrepancy with the current Standard Model calculations. The theoretical uncertainty is dominated by the hadronic vacuum polarization and the hadronic light-by-light (HLbL) contributions. For the HLbL, we show an expression for $g-2$, that involves a multidimensional integral over a kernel function and a four-point correlator. We discuss the region of importance given by the kernel function. We examine strategies to evaluate the four-point correlator on the lattice and show exploratory results.

SYDM 3.7 Tue 18:30 P/H1

Time-Domain MW Spectroscopy: Fundamental Physics From Molecular Rotation — •Jens-Uwe Grabow — Institut für Physikalische Chemie und Elektrochemie, Gottfried-Wilhelm-Leibniz-Universität, Hannover, Germany

Even the relativistic Dirac theory did not completely describe the spectrum of the electron in an H-atom. However, at that time, attempts to obtain accurate information have been frustrated by the large Doppler width in comparison to the small shifts. Then, advances in microwave (MW) techniques made it possible to observe the small energy difference of terms that were degenerate in Dirac's theory. This, as well as the small deviation of the electron's gyromagnetic ratio from the value 2, provided an excellent test of quantum electrodynamics (QED).

At present, the electron electric dipole moment (e-EDM) is a particularly good place to find, as proposed by Purcell and Ramsey, a new source for P and T violation. Since the Standart Modell's (SM) prediction is negligible, any observed e-EDM is direct evidence for "New Physics" beyond the SM. As at the time when Dirac's equation was put to test, attempts to obtain accurate information through a spectroscopic study are mostly frustrated by the large Doppler width in comparison to the small shifts. Again, obtaining more accurate information will be the key to provide a delicate test to the proposed theories. And again, employment of an MW method to hunt down a tiny effect has the potential to reveal the even smaller shifts in an e-EDM sensitive rotational transition, making it possible to observe the tiny energy difference of terms that are degenerate without an e-EDM.

SYDM 3.8 Tue 18:45 P/H1

Progress towards a Global Network of Optical Magnetometers for Exotic Physics — •Arne Wickenbrock[1] and Elena Zhivun[2] for the GNOME-Collaboration — [1]Johannes Gutenberg Universität, Mainz, Germany — [2]University of California, Berkeley, California, USA

We present first measurements and experimental progress on a recently proposed novel experimental scheme enabling the investigation of transient exotic spin couplings. The scheme is based on synchronous measurements of optical-magnetometer signals from several devices operating in magnetically shielded environments in distant locations (>100 km). Although signatures of such exotic couplings may be present in the signal from a single magnetometer, it would be challenging to distinguish them from noise. By analyzing the correlation between signals from multiple, geographically separated magnetometers, it is not only possible to identify the exotic transient but also to investigate its nature. The ability of the network to probe presently unconstrained physics beyond the Standard Model is examined by considering the spin coupling to stable topological defects (e.g., domain walls) of axion-like fields.