Working Group #1

Measurement of Electric Dipole Moments in Storage Rings

Jörg Pretz, Fabian Trinkel and Jan Bsaisou

Permanent Electric Dipole Moments (EDMs) of fundamental particles violate both time invariance and parity. Assuming the CPT theorem, the violation of time invariance implies CP violation. The CP violation of the Standard Model is orders of magnitude too small to be observed experimentally in EDMs in the foreseeable future. Since it is also too small to explain the observed excess of matter over antimattter in our universe, other mechanisms beyond the realm of the Standard Model must be at play. High precision measurements of EDMs therefore provide a valuable means to search for physics beyond the Standard Model such as supersymmetry, multi-Higgs models, for instance [1, 2].

EDM experiments with charged hadrons are proposed at storage rings where polarized particles are exposed to an electric field. If an electric dipole moment exists, the spin vector will experience a torque resulting in change of the original spin direction which can be determined using elastic scattering of the beam particles on a carbon target. Although the principle of the measurement is simple, the smallness of the expected effect makes this a challenging experiment requiring new developments in various experimental areas.

In the working group test measurements should be designed to measure important properties of a polarized particle beam [3, 4]. One is the spin coherence time: A particle ensemble with perfectly aligned spin vectors will decohere after a certain time. This time scale is described by the spin coherence time. Another important quantity is the the so called spin tune. As in an NMR experiment spin vectors precess in the magnetic field of the accelerator. The number of spin rotations per particle revolution is defined as the spin tune.

The objective of the working group is to design an experiment to determine the spin tune and the spin coherence time. Students should get acquainted with the spin motion in electro-magnetic fields described by the Thomas BMT equation. Furthermore, the relation of (spin dependent) cross sections and counting rates in a detector will be discussed. Students should understand how one can extract from the measured counting rates the desired quantities, the spin coherence time and the spin tune.

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η and η' transition form factors

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The charge distributions of composite objects are characterized by *form factors.* Whether describing the cross sections for electron scattering off nucleons (composed of quarks and gluons) or nuclei (composed of nucleons), form factors parametrize the deviation from the scattering amplitude off a point-like object (like an electron); to study them allows us to learn something about the constituents as well as the strong interactions that bind them together [1]. The momentum dependence of the form factors can therein be understood as the Fourier transform of the charge distribution (within a certain reference frame).

Similar form factors can also be used to characterize the electromagnetic *transition* between different particles. In particular, we can also investigate the form factors of particles that cannot be prepared as targets in scattering experiments through the study of their *decays* into final states including an electron–positron pair. Of particular recent interest are the transition form factors describing the decays of light, flavor-neutral mesons (π^0, η, η') into one real and one virtual photon; with only one single hadron involved, it is this hadron's electromagnetic structure that can be understood in such decays.

In this working group, we want to concentrate on the decays $\eta, \eta' \to \gamma\, e^+e^-$. The decaying η or η' can be photo-produced in the reaction $\gamma p \to \eta(')p$, both with the Crystal Ball experiment at MAMI (Mainz) or the Crystal Barrel experiment at ELSA (Bonn). We want to understand the existing experimental results for such form factors [2], how they can be understood and interpreted theoretically [3], and what their implications are for a wider range of modern particle physics problems of current interest [4]. Finally, we want to work on a proposal for improved experiments to measure the transition form factors.

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Polarization Measurement of laser-accelerated ^{3}He Ions

Hadron Physics Summer School 2014

working group 3: Laser-Plasma

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Polarized ^{3}He is of particular importance for fundamental research since the spins of the two protons are oriented anti-parallel so that the nuclear spin is basically carried by the unpaired neutron. That is why polarized ^{3}He[1] can be used, for example, as an effective polarized neutron target for studying the neutron structure by scattering with polarized electrons [Tan98]. For many experiments in nuclear and particle physics, like experiments with stored particle beams, the use of polarized ^{3}He ion beams would be advantageous.
^{3}He gas can be polarized for long time durations at standard conditions. However, building a spin-polarized ^{3}He ion source for nuclear and particle physics experiments with high degrees polarization is extremely challenging. Until now, only a few approaches could be accomplished - but not with the desired particle currents or an adequate beam polarization[2]. At Brookhaven National Lab's Relativistic Heavy Ion Collider (RHIC) a polarized ^{3}He ion beam source is currently being developed. But again, until now all approaches stood fruitless.
Conventional accelerators reach fundamental, technological, and, as one of the most important aspects, financial limits of the achievable particle energies. Some limitations essentially concerning cost-benefit relations do not apply to laser-induced particle acceleration. During the past 50 years the achievable laser intensities have been increased continously. Since the invention of chirped pulse amplification (CPA) in 1985[3], the higher-and-higher intensities have opened new applications for laser physics experiments. With a high-intense laser pulse impinge on a suitable target, a plasma is formed out of which charged particles can be accelerated to energies of several MeV.
An unsolved question in this context is the influence of the strong laser fields on the spin polarization of the particle beams. Two scenarios are possible here: either the magnetic fields of the incoming laser beam change the spin direction of the accelerated particles, or the spins are too inert so that the short laser pulse has no effect on the spin alignment of, *e.g.*, a pre-polarized target. While the first scenario has been successfully investigated by spin dependent hadronic proton scattering off nuclei in silicon[4], for the second one pre-polarized ^{3}He gas can be used as production target.
The spin-relaxation rate of polarized ^{3}He depends on several conditions, like *e.g.* gas pressure or magnetic field gradients. Also the absence of one electron in the shell decreases the polarization degree rapidly: the interaction time τ_{HF} for the coupling of the nuclear spins with the spin of the remaining electron is only around 0.2 ns[5]. Thus, a fully ionization of the pre-polarized ^{3}He has to be accomplished within a few picoseconds. This can be easily achieved with currently available laser intensities.
If measurements of the laser-accelerated ^{3}He ions reveal a high degree of polarization, this could also help to increase the efficieny of fusion reactors, since the relevant fusion cross sections in the plasmas are polarization dependent.
Goal of the working group is to **outline an experiment on laser-induced particle acceleration** with a subsequent **measurement of the beam polarization** as well as a **measurement of the particle yields from fusion reactions**.

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Charm physics: hadronic width of $D^*_{S0}(2317)^+$

The modern theory of strong interactions is Quantum Chromo Dynamics (QCD), which is now well tested at high energy scale, but not so at low energy, since only in the high energy regime the coupling constant α_s is small and standard perturbative methods can be applied. However, in the sector of low and medium energy, a large number of open questions remain. For example, the sector of charm and charmonium physics is richer than expected from the quark model, as new resonant states with quite unusual properties have been observed (prominent examples amongst the more than 10 states are in the charm sector the $X(3872)$, the charged charmonia $Z_c^+(3900)$ and $Z_c^+(4020)$, and the D_s mesons). Many theoretical interpretations have been proposed for the new resonant states like hadro-charmonia, hybrids, tetraquarks and hadronic molecules — for a recent review see Ref. [1].

High quality calculations as well as measurements are compulsory for each state to allow one to decide amongst the various scenarios. The working group will focus on experimental and theoretical aspects in the context of the potentially exotic $D^*_{S0}(2317)^+$. The state is located by about 100 MeV below what is predicted by the quark model and only about 40 MeV below the KD threshold. While the state is an isoscalar, it can only decay strongly into the isovector final state πD_s which results in a width well below 1 MeV. The interpretations of the $D^*_{S0}(2317)^+$ range from a pure $c\bar{s}$ state [2], over tetraquark configurations [3] to a molecular state [4–7]. While within the former explanations the width of the state is predicted to be of the order of 10 keV, the molecular scenario predicts consistently a width of the order of or even larger than 100 keV — the enhancement stems from meson loops that are prominent for molecular states only [4–8]. Measuring that small widths is clearly a challenge but certainly worth the effort for such a measurement could for the first time unambiguously identify an exotic structure in the open charm sector.

The future fix-target experiment $\bar{P}ANDA$ can take the challenge to measure the width of resonant states. The project $\bar{P}ANDA$ aims to reach a mass resolution of 100 keV, which is 20 times better than attained at the B factories. From the experimental point of view, the measurement of the width will be performed by scanning the mass of the resonant state every 100 keV, and analyze the excitation function of the cross section in the process $\bar{p}p \to \bar{D}_S D_{SJ}$. The measurement of the cross section, the determination of the width and the study of the D_{SJ} mesons in $\bar{p}p$ interactions represent a highlight topic of the $\bar{P}ANDA$ physics program. Due to the high level of background in this process, this is a challenge.

Students joining this working group, are supposed to work out requirements to the detector that allows one to perform the measurement of the width of the $D^*_{S0}(2317)^+$, with special emphasis on ideas to reject backgrounds in order to make this data analysis feasible.

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Hadronic Physics Summer School 2014

Hidden Charm: Search for the exotic 1^{-+} hidden charmonium at PANDA

Hadron spectroscopy can reflect the dynamics of the strong interaction, especially those in the heavy quark sector. Due to their heavy quark mass, the heavy quarknoium can be well described by the non-relativistic quark model below the open charmed/bottomed threshold[1, 2]. For the states above threshold, some states predicted by the quark model are still missing and at the same time a lot of X, Y, Z states beyond the conventional quark model are observed [2, 3] . Since the charm quark mass is not as large as that for the bottom quark, the non-perturbative effect in the charm sector will be larger than that in the bottom sector. That is the reason why more exotic X, Y, Z particles are observed in the charm sector, such as $X(3872)$, $Z_c(3900)^{\pm}$, $Z_c(4020)/Z_c(4025)$, $Z(4430)$, $Z_1(4050)$, $Z_2(4250)$, $Y(4260)$. So far, only two exotic states, i.e. $Z_b(10610)$ and $Z_b(10650)$, are observed in the bottom sector. As a result, searching for the missing charmonia and exotic X, Y, Z particles in the charm sector (which we call the hidden charm generally) and studying their production and decay mechanism will be one way to learn the non-perturbative aspect of QCD.

Comparing to the e^+e^- colliders, the hadron colliders especial $p\bar{p}$ reactions such as PANDA[4] would be a good platform to study these hidden charm states. On the one hand, all the possible states with the quantum numbers predicted by the quark model can be directly formed in $p\bar{p}$ reaction and some states with exotic quantum numbers, such as 1^{-+}, $0^{+-}\cdots$, can also be produced by recoiling some other known particles with proper quantum numbers. As a result, we can study the direct production of these exotic states which will help us distinguish these exotic states either as genuine states or the kinematical reflections[5]. On the other hand, there will be larger events accumulated in hadron colliders and one can get a perfect signal once the appropriate cuts are used. Due to these large events, we can also study the rare decays of the hidden charm states besides their normal decay modes.

This group will focus on estimating the production rate of these exotic hidden charm states, such as $X(3872)$, $Z_c(3900)$ and a set of $1^{--}/1^{-+}$ exotic states[6] at PANDA. Among them, the most interesting one is the hidden charm states with the exotic quantum number 1^{-+}[6] which can give some hints about the non-perturbative QCD.

With cross section estimates and branching ratios of prominent decay channels, experimental conditions for the detection of exotic states can be formulated and compared to the specifications and design goals of the PANDA apparatus. Benchmark channels can be identified and experiments can be planned to measure the properties of the new states.

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working group #6: Baryon Spectroscopy

Deborah Rönchen, Harald van Pee

Goal: Proposal for the measurement of polarization observables in η photoproduction off the nucleon with the Crystal Barrel/TAPS experiment at ELSA.

Photons are able to excite atoms as well as their nuclear constituents, protons and neutrons, even if the needed energies are more than 10 Mio. times larger for the later case. Obviously the proton and neutron are not elementary. Assuming that they are made out of three quarks with similar mass and using an appropriate potential, quark models describe the measured spectrum of such excited states or resonances, the baryon spectrum, quite well. At least there are no unmeasured but predicted states below center of mass energies of $W = 1800\,\text{MeV}$. For higher energies the number of predicted states exceeds the number of measured states by far and one can doubt if these states really exists.

Unfortunately, the theory of the strong force between the quarks, Quantum Chromodynamics (QCD), is not solvable in the energy regime of light baryons. Here, the expansion in a perturbative series does not converge due to the large coupling constant and quarks are confined in hadrons. Lattice QCD provides a possibility to extend QCD into this non-perturbative regime, but to this day some approximations have to be made. Lattice calculations confirm the rich spectrum predicted by quark models. Therefore one of the main tasks of hadron spectroscopy is to find out what the effective degrees of freedom and forces between them are in the regime of non perturbative (strong) QCD.

Baryon resonances are broad and overlap with other baryon resonances wherefore polarization experiments are needed to disentangle unambiguously the contributing resonances to a final state. The much improved Crystal Barrel/TAPS experiment will again start data taking in 2015 with linear or circular polarized beam and/or longitudinal and transversal polarized proton or deuteron target allowing the measurement of all single polarization observables and all double polarization observables accessible with beam and target polarization.

In this working group you will learn something about scattering theory, quark models, partial wave analysis, polarization observables and complete experiments, detection of photons and charge particle identification.

Hadron Physics Summer School 2014

Working Group # 7:
Dark Photon

Magnus Wolke (exp.) & Andreas Wirzba (th.)

In one of the simplest scenarios of the physics beyond the Standard Model (SM), dark matter particles belonging to an additional abelian gauge symmetry are added to the SM. The associated gauge boson, the so-called U boson, can communicate with the SM through a mixing in the kinetic term of the QED Lagrangian with a small parameter ϵ. Because of this mixing the U boson – despite its Higgs-generated non-vanishing mass – is often called *dark photon* [1–3].

Phenomenological arguments suggest that the mixing parameter must be of the order of 10^{-4} to 10^{-2}, while the U boson mass is between 4 MeV and 2 GeV [1,2]. This estimate is also supported by the astrophysical observations (such as the positron and/or electron excesses observed by ATIC [4], H.E.S.S. [5], and PAMELA [6], as well as the narrow 0.511 MeV γ ray emission from the galactic bulge observed by INTEGRAL [7]) and the constraints imposed by precision measurements such as the anomalous magnetic moments $(g-2)$ of of muon and electron [8]. In turn, the *light dark matter* hypothesis might also explain the present mismatch between theory and experiment for the anomalous magnetic moment of the muon [9,10].

Such a light U boson might be observed via a direct production in particle accelerators or as a narrow structure in the invariant mass spectrum of a lepton-antilepton pair in the decay channel of some suitable vector or pseudoscalar meson.

Our task is to suggest an experiment which is sensitive to a short-lived U-boson. If the proposed experiment finds a corresponding signal, we will have clear evidence for physics beyond the SM and learn for the first time about the nature of dark matter. If not, we will put a further constraint on possible extensions of the SM of particle physics.

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Charge symmetry breaking in the reaction $dd \to {}^4He\,\pi^0$

Theory: C.Hanhart, Experiment: V.Hejny / M.Żurek

Working Group #8

Up and down quarks are the basic constituents of protons and neutrons which build, together with the electron, all stable elements in the universe. The interactions of protons and neutrons are nearly identical — only nearly, because the quark flavors differ in mass as well as in charge. Quark masses — or rather quark mass differences — have quite some impact on our existence. In a world with equal masses of the up and down quarks the mass difference of the proton and the neutron would be solely based on electromagnetic effects resulting in the proton being heavier than the neutron. In such a world the proton — instead of the neutron — would have a finite lifetime and stable hydrogen atoms could not exist. Individual quark masses, however, are not directly accessible by experiments. Instead, net effects of quark mass differences or quark mass ratios in hadronic reactions serve as experimental observables.

The approximate symmetry between up and down quarks is called isospin symmetry, any differences showing up when one replaces an up quark by a down quark, or vice versa, are signatures of broken isospin symmetry — like the proton-neutron mass difference. Experiments studying those effects typically have to deal with two major challenges: the isospin symmetry breaking signature of the signal is i) small compared to isospin symmetry conserving contributions and ii) often dominated by the electromagnetic effects mediated via the $\pi^0 - \pi^\pm$ mass difference. This can be avoided by selecting a certain class of possible reactions.

A special case of isospin symmetry is charge symmetry describing the interchange of up and down quarks and, thus, a rotation by 180° around the I_2 axis in isospin space. As the $\pi^0 - \pi^\pm$ mass difference is symmetric under this transformation it does not contribute to charge symmetry breaking signals and one gets sensitive to quark mass effects. In addition, one can choose such observables which would vanish in a charge symmetric world. Examples are the forward-backward asymmetry in the reaction $np \to d\pi^0$ and the pion production amplitude in $dd \to {}^4\mathrm{He}\pi^0$. Both signals are quite small and a careful design of the experiments is essential for a successfull measurement.

In this working group we will focus on the reaction $dd \to {}^4\mathrm{He}\pi^0$. We will start with the necessary theoretical basics for this particular experiment, work out the demands on the detector based on the reaction kinematics and finally come up with a proposal on how to perform the measurement.