PBC - BSM Subgroup

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In this document we shortly report the discussions done within the Beyond Standard Model subgroup of the Physics Beyond Colliders Working Group. In particular we want to define the main issues/questions to be addressed to each project, for which we will expect answers/actions taken by the collaborations. This document will be used to plan the next meeting of the subgroup, with at least one representative for each experiment, to be held possibly around the end of May 2017.

1 Motivation

Whilst the standard models of particle physics and cosmology have been extremely successful at describing the universe we observe, there are a number of places where the models fail or are incomplete. This evidence for physics beyond the standard model is summarised briefly below. For this working group it is particularly interesting that the new particles motivated by this physics are not necessarily heavy, and so we do not necessarily need a high energy collider in order to be able to detect them.

1.1 Neutrino oscillations

We have observed neutrinos oscillating between different leptonic flavours. This is not possible unless neutrinos have masses, and the mass eigenstates are different from the flavour eigenstates. Neutrinos are massless within the Standard Model, and so we need to introduce new physics in order to explain these oscillations. One way to generate light neutrino masses is via the sea-saw mechanism by including new heavy sterile neutrinos.

1.2 Abundance of matter, absence of anti-matter

The universe we observe is made of matter, and not anti-matter. In order to achieve this we need to include a source of B number violation, C and CP violation and dynamics which drive particles out of thermal equilibrium in the early universe. This is not possible within the Standard Model, as there is not enough CP violation, and no sufficiently out of equilibrium dynamics. The mechanisms required to explain this are known as baryoenesis.

1.3 Galactic dynamics

Observations of the rotation of galaxies indicate that stars and gas are moving faster than can be explained from the gravitational force due to visible matter, and spiral galaxies made up only of visible matter should not be stable. Therefore some new physics is required on galactic scales. This can be new particles, known as dark matter, or the introduction of a new force on these scales.

1.4 Cosmic microwave background

Observations of the cosmic microwave background are well fit by the ΛCDM cosmological model. This model requires more non-relativistic matter than can be accounted for with standard model particles, and a component which looks like a small but non-zero cosmological constant. To set the initial conditions for the density perturbations which go one to form structures in our universe an initial period of inflationary expansion is required.

1.5 Higgs mass fine tuning

Within the standard model there is no way to protect the masses of scalar particles from receiving additional corrections from UV physics. It is therefore challenging to explain the observed mass of the Higgs, and the hierarchy between this scale and the Planck scale. Possible solutions include low scale supersymmetry, extra-dimensions, or a dynamical relaxation mechanism.

1.6 No evidence for strong CP violation

There is no reason to expect that the strong sector would respect CP symmetry, and yet no such violation has been observed. This requires fine tuning of the $\theta_{\rm QCD}$ parameter. A dynamical explanation for this small parameter would promote the constant to a field, and allow it to relax towards zero. This pseudo-scalar field is known as the axion, and can also be an explanation for dark matter.

1.7 Muon magnetic dipole moment

The magnetic dipole moment of the muon has been observed to lie 3-σ away from the value predicted in the standard model. The origins of the anomaly could be uncoloured beyond the standard model physics at the electroweak scale, or light vectors or scalars around the muon mass. However, some caution is required as this anomaly has currently only been observed in one experiment.

1.8 Fine-tuning of the cosmological constant

A cosmological constant is present in the Einstein equations, which could explain the observed accelerated expansion of the universe. However, fluctuations of standard model particles in the vacuum of empty space would generate an additional contribution that is observationally indistinguishable from the cosmological constant, but many orders of magnitude too large to be in agreement with the universe we observe. There are also additional cosmological constant like contributions every time the universe goes through a phase transition. This indicates the presence of new physics; either gravity is modified on very large distance scales, or we need to modify our understanding of the energy density of the vacuum and how it gravitates.

1.9 What is the scale of this new physics?

Here we briefly summarize the scales involved in the anomalies described above, and the mass scales of the new particles introduced to explain them. We should bear in mind, however, that if the new physics is non-linear this may mean that these scales are not fundamental.

Physical Scale	Order of Magnitude
Current Hubble scale	10^{-42} GeV
1 / Galactic size	10^{-36} GeV
Cosmological Constant	10^{-12} GeV
Neutrino masses	$< 10^{-10}$ GeV
Higgs mass	10^{2} GeV
Energy scale of Baryogenesis	$> 10^{3}$ GeV
Planck scale	10^{18} GeV

Type of New Physics Particle	Mass Range
Right handed neutrinos	$10^{-9} - 10^{15}$ GeV
Dark matter	$10^{-31} - 10^{20}$ GeV
Particles required for baryogenesis	$10^{-2} - 10^{15}$ GeV
Particles explaining Higgs hierarchy	$10^{3} - 10^{18}$ GeV

2 SHIP

SHiP is a proposed experiment to explore Hidden Sector models with vector, scalar, neutrino, axion-like SM portals (and others) to be sited in the CERN North Area and served by a dedicated high intensity, 400 GeV/c proton beam line extracted from the CERN SPS. The SHiP collaboration has submitted a Technical Proposal in April 2015 [?]. The collaboration has been requested by the SPS Committee to deliver by 2018 a *Comprehensive Design Study (CDS)* to be used as input of the European Strategy Group in 2019-2020.

Four critical points have been identified as important steps towards the CDS completion:

1. the measurement of the momentum spectrum of the beam-induced muon halo;
2. the measurement of the charm production cross-section in the SHiP target;
3. the consolidation of the simulation of all the main background components;
4. the optimization of the $\nu_\tau-$ detector for direct searches of light dark matter particles;

2.1 Measurement of the momentum spectrum of the beam-induced muon halo

The measurement of the muon halo spectrum is necessary to validate the simulation used for the optimization of the muon shield. Beam-induced muons from the halo are dangerous is they escape the shield and enter the decay volume. Pythia-based simulations show that in nominal conditions about $6 \times 10^5 \mu$/s are expected to enter the fiducial volume: these muons have typically $p_T >$3 GeV/c, $p >$100 GeV/c. The optimization of the muon shield design heavily relies upon the knowledge of the muons' spectrum above $p_T >$3 GeV/c, $p >$100 GeV/c. The current design of the muon shield is based on the simulation of 10^{10} pot. The generation of this sample took several months of running of a large CPU farm even if it corresponds to only $2.5 \cdot 10^{-4}$ of a single SHiP spill.

To overcome this problem, the SHiP collaboration has recently proposed [?] to install a replica of the SHiP target and a hadron stopper on the 400 GeV/c proton beam serving the NA61 experiment in order to collect at least 10^{11} pot (about 10× the simulated sample). The expected p and p_T spectra of the muon sample collected in the NA61 acceptance is shown in Figure ??, with and without the forward TPCs (FTPC) in the NA61 apparatus. The comparison with the simulated momentum spectrum currently used in the muon shield optimization is also shown.

Given the relatively low proton rate of the NA61 beam line ($\sim 10^6$ pot/5 sec spill or $2 \cdot 10^5$ pot/sec), the expected duty cycle, and the deadtime introduced by the NA61 TDAQ, several weeks of data taking are needed to collect the required muon sample. In Ref. [?] the SHiP collaboration asked two weeks of data taking in 2017 and a longer period in 2018. Discussions between the two collaborations about the feasibility of these runs are ongoing.

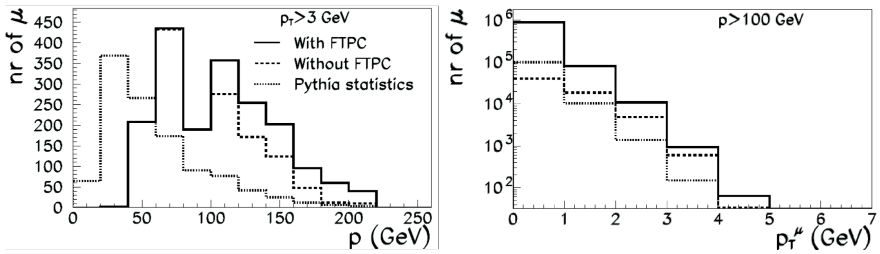

Figure 1: Expected p and p_T spectra of the muon sample collected in the NA61 acceptance with and without the forward TPCs (FTPC) in the NA61 apparatus. The comparison with the simulated momentum spectrum currently used in the muon shield optimization is also shown.

(Tentative) list of questions:

1. *How much running time is needed to make a reliable estimate of the muon flux with the NA61 apparatus?*
2. *Is this running time period compatible with the NA61 plans in 2017-2018?*
3. *When the SHiP replica target will be ready?*
4. *Which is the status of the discussions between SHiP and NA61?*

2.2 Measurement of the charm production cross-section in the SHiP target

The measurement of the charm production cross-section in the SHiP target is important for normalising the HNL yield (mostly originating from D mesons decays) and for validating background estimates for high p_T neutrinos from charm decays. However our current understanding is that this measurement is not essential for the detector design (as it is the measurement of the muon halo spectrum).

The charm production cross-section on a thin target has been measured by the NA27 experiment and found to be: $\sigma_{c\bar{c}} = (18.1 \pm 1.7)\mu$barn. What is currently missing is a measurement of the charm production cross-section at the SPS energy in a thick target, (where charm production can occur also via secondary interactions), and the corresponding charm momentum spectrum.

The SHiP collaboration expressed the interest to measure the double differential charm production cross-section $d^2\sigma/dEd\theta$ in proton collisions with a (smaller) replica of SHiP target instrumented with nuclear emulsions. The nuclear emulsions are used as micrometric tracking device to identify charm production and decay (the charm decay length is 3.3 mm); each module of the instrumented target (ECC) is made of a sequence of 3mm-thick TZM planes interleaved with 290 μm-thick nuclear emulsion films, with a total thickness of $\sim 1\lambda_I$ and a transverse area of (10×10) cm^2. About 10k charm pairs are expected with $\sim 10^8$ pot and an overall emulsion surface of 250 m^2. About 85% primary interactions and 52 % secondary interactions occur in the first and second λ_I. Two ECCs put in series are needed for measuring the charm production in the first and second interaction length. Muons originating from charm decays will be measured by a magnetic spectrometer followed by a muon system (see Figure **??**).

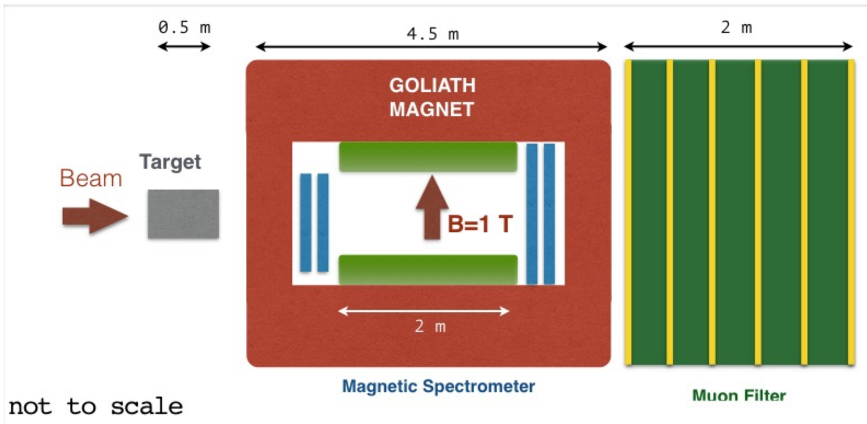

Figure 2: Setup to measure the charm production cross-section.

The main experimental problems are related to:

1. the uniform illumination of the target;
2. the background due to hadronic re-interactions that mimick a charm meson decay.

The Bern Group presented to the SPSC an EoI [**?**] for studying the ν_τ production by measuring $D_s \rightarrow \tau$ events in 400 GeV proton interactions in a tungsten-based targed instrumented with emulsions. Also in this case the emulsions are used as active tracker to detect the double kink topology of the $D_s \rightarrow \tau \rightarrow X$ decays. The number of protons on target needed for this measurement is very similar to that requested by SHiP for the charm cross-section production ($\sim 10^8$). The beam time requested by the Bern group is:

- 2017: 5 days of data taking in H2 (in May) with an illuminated area 1/20th of the final one;
- 2018 and after LS2: accumulate 6 weeks of beam time to perform measurement.

While the physics goals and the target structure of the Bern proposal are different from the SHiP ones, the experimental problems are indeed very similar: also in this case a uniform target illumination and the control of the background due to hadronic re-interactions are major problems to be solved.

(Tentative) list of questions:

1. *investigate what can be learned from the 5-days test beam of Bern group in May;*
2. *for the long run, consider the possibility to put in series the SHiP and Bern detectors in the same experimental area.*

2.3 Consolidation of the simulation of all the main background components

The study of the most prominent background components is a major task towards the preparation of the Comprehensive Design Study document. However the whole SHiP Monte Carlo production corresponds (so far) to $\sim 10^{10}$ pot, which is only 1/4000 of a single SHiP spill. The SHiP collaboration uses techniques to boost the monte carlo production of the main background processes, however, as in the case of the muon halo, real data would be extremely beneficial to understand the reliability of the background simulation.

The NA62 collaboration has already collected about 10^{16} pot in dump mode. Even if the apparatus is different, this sample could be useful to understand how the background can affect the sensitivity to some benchmark channels.

(Tentative) list of questions:

1. *investigate the impact of the background for some benchmark channels (eg: $HNL \rightarrow \pi\mu$ or $A' \rightarrow \mu^+\mu^-$) with the NA62 apparatus (perhaps a student in common between the two collaboration could help?).*

2.4 Optimization of the ν_τ detector for direct searches of Light Dark Matter particles

The SHiP collaboration has studied the sensitivity achievable for a direct search for Ligh Dark Matter particles interacting with the electrons of the material of the emulsion tracker of the ν_τ detector.

Most of the background has been identified as electrons emerging from elastic, quasi-elastic, resonant and deep-inelastic scattering of active neutrinos with the neutrino detector material. Some preliminary estimate of the background yield has been studied using Pythia simulation and presented in the TP.

(Tentative) list of questions:

1. *Is the simulation of the active neutrino flux reliable in Pythia?.*
2. *Which are the steps towards a better estimate of the background induced by active neutrinos?*

3. *How the sensitivity for light dark matter particles changes as a function of the background yield and as a function of the coupling of Dark Matter with SM particles?*

3 NA62^{++}

The main goal of the NA62 experiment is the measurement of the $BR(K^+ \to \pi^+ \nu \bar{\nu})$ with an accuracy of about 10%. The NA62 collaboration is currently discussing the possibility to use a fraction of the beam time during Run 3 (2021-2023) to operate NA62 in *beam-dump mode*, to search for hidden sector candidates in a MeV-GeV mass range such as Heavy Neutral Leptons, Dark Photons, Dark Scalars and ALPS.

We identified three main points that could be further developed in the context of the PBC activity:

1. **Optimization of the NA62 beam line:**
   - *study the maximum intensity of the NA62 proton beam line (including cooling of the dump, radioprotection issues, etc) which is compatible with the physics programme in the North Area*;
   - *optimize the position of the dump with respect to the decay vessel (important to maximize the acceptance for hidden sector particles) and its interplay with the muon sweeping system (important to reduce the background from the muon halo)*;
2. **Study of backgrounds' yield when the detector is operated in beam-dump mode:** *this can be performed using short (few hours) runs in beam-dump mode during the current run.*
3. **Experimental setup:** *The NA62 detector has been mainly designed for the measurement of the branching fraction of the $K^+ \to \pi^+ \nu \bar{\nu}$ decay mode: can the apparatus be further improved to reject backgrounds when searching for hidden particle in beam-dump mode (addition of new detectors/ upgrade of existing ones) ?*

4 NA64^{++}

The NA64 collaboration has put forward a broad physics programme using electrons, muons, pions, kaons and proton beams. The physics programme and the expected physics reach is outlined in Table ??.

Beam	Process	New Physics	Sensitivity
e beam	$e^- Z \to e^- Z + E_{\text{miss}}$		
	- $A' \to e^+ e^-$ - $A' \to$ invisible - alps - milli-Q	Dark Sector: Dark Photons and DM New Light states (V,S) ^8Be excess	$10^{-3} < \epsilon < 10^{-6}$ $M_{A'} \sim$ sub-GeV $m_Q < 10^{-5} - 10^{-7}$ e
μ beam	$\mu^- Z \to \mu^- Z + E_{\text{miss}}$		
	- $Z_\mu \to \nu\overline{\nu}, \mu^+\mu^-$ - α_μ - $\mu \to \tau$ conversion	$(g-2)_\mu$ anomaly, New Z_μ from $L_\mu - L_\tau$ gauged simm. scalars coupled to μ, LFV	$\alpha_\mu < 10^{-11} - 10^{-9}$ $\sigma_{\mu\tau}/\sigma_\mu < 10^{-9} - 10^{-8}$
π, K beams	$\pi(K)p \to M^0 n + E_{\text{miss}}$		
	- $K_L \to$ invisible - $K_S \to$ invisible - $\pi^0, \eta, \eta' \to$ invisible	CP, CPT symmetry Bell-Steinberger Unitarity, new particles: $HNL, \phi\phi, VV$	$BR < 10^{-8} - 10^{-6}$, Complementary to $K \to \pi\nu\overline{\nu}$ $BR < 10^{-8} - 10^{-7}$
p beam	$pA \to Z' + E_{\text{miss}}$		
	- leptophobic Z'	$\sim$ GeV DM	$\sigma_{Z'} < 10^{-7} - 10^{-8}/p$

Comments on Table ??:

- The physics programme based on electron beams can be considered an adiabatic continuation of the existing programme of the NA64 experiment and is beyond the scope of this working group;
- The physics case based on muon beam is clear. The NA64 collaboration proposes to use the M2 line currently serving the COMPASS experiment to collect $\sim 10^{12}$ muons-on-target, with $p = 150$ GeV/c. A test run in 2018 would be useful to test the purity of the beam, the trigger rate and the calorimeter hermeticity.
- The physics case using pions, kaons and protons beam should be further consolidated also in comparison with existing and future measurements (eg: NA62 limits on $\pi^0 \to \nu\overline{\nu}$). The production of $M^0 = \pi^0, \eta, \eta', K_L, K_S$ occurs via charge exchange reaction $\pi^-, K^- + p \to M^0 + n$. The NA64 collaboration aims at measuring the yield using the existing NA64 setup in 2018.

Tentative questions:

1. **muon beam:**

   - *test run: ensure timely realization of the test run with muon beam discussing with COMPASS;*

- *long run: study the compatibility with $\mu - e$ experiment (both use 10^{12} muons on target, $p = 150 GeV/c$).*

2. **hadrons beam:**

   - *consolidate the physics case also in comparison with existing and future experiments;*
   - *detail the physics reach as a function of the requested K, π, p yields (eg: beam time);*
   - *perform the measurement of $M^0 = \pi^0, \eta, \eta', K_L, K_S$ yields with NA64 in 2018.*

5 KLEVER

The KLEVER collaboration aims at measuring the branching fraction of the very rare decay $K_L \to \pi^0 \nu \overline{\nu}$, predicted in the Standard Model to be $(3.4 \pm 0.6) \times 10^{-11}$, with an accuracy of $\wr(\in\prime\%)$. Currenly only limits are present. The KOTO experiment at JPARC expects to collect few SM events by 2021. No proposal has been still submitted for a phase-2 upgrade that could bring the KOTO experiment to collect $\wr(\infty\prime\prime)$ events.

This measurement is complementary to the measurement of the branching fraction of the charged channel $K^+ \to \pi^+ \nu \overline{\nu}$ as New Physics can affect the two decays differently: measurement of both branching fractions can discriminate among NP scenarios.

To achieve an accuracy of $\sim 20\%$, the collaboration needs to collect about 60 $K_L \to \pi^0 \nu \overline{\nu}$ events in 5 years, starting in Run 4, with a S/B$\sim$1. An increase of the intensity of the NA62 proton beam-line of about a factor 6-7 is required in order to reach the required event yield. This upgrade is currently under study in the PBC conventional beams activity.

(Tentative) list of questions:

1. *Elaborate more in detail how the knowledge of the $K_L \to \pi^0 \nu \overline{nu}$ branching fraction at 20% level can constrain New Physics models, both respect to the twin charged channel and other constrains coming from flavour measurements, namely B-physics.*
2. *Enlarge the physics case beyond the $K_L \to \pi^0 \nu \overline{\nu}$;*
3. *Give an indicative estimate of the cost of the detector and the interested institutes and people*;
4. *Can the intensity requirement be met in P42?* The beam intensity upgrade is a major work and requires additional resources for the feasibility study: the outcome of this study should be an estimate of the maximum intensity reachable at P42 and a preliminary cost of the required upgrades of the target area and the transfer lines; Siting KLEVER at the BDF is also a possibility but it would compete with SHiP.
5. KLEVER has a conceptual design of a K_L beam involving a crystal-based photon converter. To validate the concept, a test with a tagged photon beam has been considered, as well as at a later stage a possible test with a neutral kaon beam in the K12 line (perhaps during the

beam-dump run?); *Study the feasibility of a test of a crystal-based photon converter with a tagged photon beam and with a neutral kaon beam.*

6. *Validate the technology for a small angle calorimeter that has to stand to* > 300 *GHz of neutrons and* $\sim (200 - 300)$ *MHz of photons.* A possible solution has been identified as a Tungsten/silicon-pad sampling calorimeter with crystal metal absorber. The collaboration aims to performing a test beam in 2018.

6 IAXO

The International Axion Observatory (IAXO) is a next generation axion helioscope designed to detect solar axion and axion-like particles (ALPs). It is expected to extend the sensitivity to the coupling to the photon $g_{a\gamma\gamma}$ of about 1.5 order of magnitude beyond current best astrophysical and experimental bounds. Reaching a level of a few 10^{-12} GeV^{-1} for $g_{a\gamma\gamma}$, for masses below $\simeq$ 0.25 meV, would mean being able to explore a parameter space which includes possible solutions for observed anomalies in light propagation over astronomical distances and explanation of the excessive cooling in a number of stellar objects.

Axion helioscopes search for axions produced in the sun employing a strong laboratory magnetic field to reconvert these axions into x-ray photons. IAXO is the evolution of the CERN Axion Solar Telescope (CAST), which improved the bounds on the photon coupling below any other terrestrial experiment in a significative mass range, exploring for the first time a section of the QCD axion band.

- A remarkable goal of IAXO is to be able to enlarge the mass range of the QCD axion to a wider interval around 0.1 eV.

Differing from previous generation helioscopes, IAXO will make use of a specifically designed magnet system, with the aim of maximizing the sensitivity while keeping low cost and minimal technical challenges, i.e. relying mostly on known and safe technology. Preliminary design foresees the use of 8 (eight) coils of 21 m length, each magnet bores will be equipped with x-ray optics to image produced x-rays into a low background detector.

In principle the project is ready to start, however the collaboration size is still sub critical and funding is not yet complete. Moreover a host laboratory is still missing. Recently the collaboration has started to think of a smaller scale version of the apparatus, the so called MiniIAXO. This hypothesis seems to be very promising, in fact it could speed up the start of the activities, and in the future pave the way for the full size project. MiniIAXO would use only 1 (one) magnet in the final configuration, thus reducing significantly the preliminary budget. The issues are then the following:

- estimate of the requested budget for MiniIAXO

- the sensitivity gain of MiniIAXO will be smaller with respect to IAXO of a factor $8^{0.25} = 1.7$, that is still an improvement of about an order of magnitude with present bounds. This must be verified.
- how wide mass range sensitivity for the QCD axion in the MiniIAXO?
- Summarizing: finalize configuration and physics reach of MiniIAXO
- We also encourage the collaboration to follow CERN input to magnet design through the technology subgroup

As a final remark we recall the important date for the collaboration: on July 3-4, 2017 the *Founding IAXO collaboration meeting* at DESY.

7 ALPSIII

The current project ALPSII, Any Light Particle Search II at DESY in Hamburg, aims at searching for axion-like particles with the light shining through a wall (LSW) detection scheme, also known as regeneration scheme. Experiments of this type feature a light source shining at an optical barrier and then attempt to observe this light passing after the barrier. If the source light beam passes through a magnetic field region, some photons can be transformed into an Axion Like Particles (ALPs) which traverse the barrier, afterwards a second magnetic field will then reconvert the ALPs back to photons to create a measurable signal. High finesse optical cavities, both in the source section and in the regeneration region, are used to enhance the signal. For this type of experiment the QCD axion band is beyond any possible sensitivity, and the final goal is to improve the current limits on the ALPs-photon coupling of about 3 orders of magnitude with respect to the present laboratory limits which are totally model independent. ALPSII is currently scheduled to start data taking in 2019. By that time it will be operating a state of the art optical system, with high finesse optical cavities having a length of 100 m each. The magnet are reconditioned HERA dipole magnets, each 10 m long. Detection of the regenerated photons will be done using single photon counter techniques (using Transition Edge Sensors) and/or Heterodyne Detection scheme.

ALPSII could show the path to *ultimate optics and detector concepts* for laser driven LSW experiments, so the perspective of improving the apparatus will rely almost only in an improvement of the magnet system. This is the task for ALPSIII and CERN. In fact, new demonstration dipole magnets are under study for HE-LHC or FCC, these might provide a magnetic field of 13 T (or later even up to 15 or 16 T) in an aperture of 100 mm. Featuring a string of such magnets, ALPSIII could in principle dramatically increase the sensitivity for purely laboratory based experiments searching for ALPs and surpass even IAXO in the very low mass region.

ALPSIII has to be considered a long term planning of future activities, which would need preliminary steps in order to be realized. First of all there are still technical issues related with the current ALPSII project: among them the stable and reliable lock of the regeneration cavity, done first with the current 10 m prototype and then with the final 100 m long system; a clear characterization of the detector background and sensitivity must also be performed. Anyway, these issues does not seem to be show stoppers. If the experiments ALPSIII will rely on the CERN collaboration, a good point would be to start to have a small project that could foster this kind of activity at CERN: one such project is the search for the Vacuum Magnetic Birefringence (VMB) as predicted by QED, i.e. the changes of the polarization state of a polarized light beam traversing a magnetic field region. Such a kind of experiment could be realized at CERN using some newly developed FCC prototype magnet. For this reason we suggest the following:

- the collaboration should investigate the potential of a VMB experiment, discussing the possible detection scheme(s), with the use of a CERN like magnet.
- the collaboration should look for possible availability of proto-magnet for FCC, possibly participating to the technology subgroup.

8 EDM

An experimental programme is proposed to search for a permanent electric dipole moment (EDM) of the proton and/or the deuteron with a sensitivity of 2×10^{-29} e cm for both species [**?**]. At this time a successfull experiment with such sensitivity would be very timely and would have significant impact on the interdisciplinary field.

The proposal aims to be about 3 orders of magnitude better than the present limits $|d_n| < 3.0 \times 10^{26}$e cm (90% C.L.) on the neutron EDM (where improvements are presently underway with first results expected soon). It would be better than the extracted values for a nucleon EDM as obtained from the present frontrunning experiment in the field, the search for an EDM in the ^{199}Hg atom, where we have $|d_{Hg}| < 7.4 \times 10^{30}$e cm (95% C.L.). Whereas the here proposed proton EDM experiment searches for an EDM of the nucleon itself, the deuteron experiment is sensitive to EDMs of the constituent particles, proton and neutron, as well as to an EDM arising from CP-odd parts in the interactions between proton and neutron.

The here proposed experiments exploit in essence a method that had been recognized from the early muon g-2 experiments on; i.e. for polarized particles with a finite EDM moving in an external magnetic field their spin would precess out of the plane of orbit. This can be detected in a suited detector. When passing through an external magnetic field at relativistic velocities particles experience a substantial electric field, here typically 300 MV/m. Consequently, the muon g-2 measurements have always been accompanied by an EDM search. The latest BNL experiment resulted in a limit on the muon EDM of $|d_\mu| < 1.8 \times 10^{19}$e cm (95% C.L.) and this experiment can serve as a benchmark for the present proposal to CERN. Similar projects to search for EDMs on protons, deuterons and light nuclei are/ have been considered for BNL, for COSY and for the muon at JPARC and PSI. Improvements by typically one order of magnitude for the muon EDM are on their way at FERMILAB and at JPARC in conjunction with the respective muon g-2 efforts.

Owing to the quite different gyromagnetic ratios of proton and deuteron, the experiments at CERN proposed for both particles require considerably different apparatus. For deuterons we have a ≈85 m circumference primarily magnetic storage device and for protons we have a ≈500 m circumference electrostatic storage ring. In order to keep control over systematics, significantly different measurement strategies have been elaborated. Several test measurements on , e.g. deuteron polarimetry at COSY, have been performed. Analysis of potential systematics has been advanced in the recent years and, concerning several aspects, it is available in details [**?**].

The collaboration working on both the proton and the deuteron EDM experiments at CERN has formed from mainly two previous collaborations, the srEDM Collaboration concerned with proton EDM search and the JEDI collaboration set up for a deuteron EDM search. The new collaboration held a kick-off meeting 13/14 March 2017 and it plans on a conceptual design report as well as a proposal to CERN by the end of 2018.

Questions aring so far:

- So far over the past some 60 years the improvement in EDM limits has been continuous and steady. How does the collaboration view the competition in various smaller scale laboratory experiments worldwide that aim to improve limits on various EDMs in the coming years?
- External magnetic field shielding is crucial for the experiment. Large scale field shielding at the required level has to be proven, in particular a strategy for dynamic field changes at all relevant time scales. Is there a sufficient large scale proof that external, varying magnetic fields in a realistic environment can be controlled reliably over extended periods of time, i.e. the typically 1 year running time, at any position in the fiducial volume to better than the required 10 nT ? How do other succesful EDM experiments do in this respect ?
- Internal magnetic fields, e.g. of necessary ring devices like magnets in a deuteron experiment, could have considerable impact on the magnetic shielding and on the overall magnetic stability. What is the overall concept regarding merging magnetic field requirements for EDM needs and for storage ring needs?
- It may be not realistic to start two such novel experiments at once. Which of the species, proton or deuteron, will be the collaboration's priority for a first experiment and what is the strategy and time planning to arrive at a decision?
- Suggestions exist for small scale precursor experiments, such as on the muon in a small ring at PSI or with the proton or neutron at COSY. Has the collaboration considered a proof of principle experiment at smaller scale and at lower sensitivity to verify scaling of systematic uncertainties in a real experiment?
- How strongly is the new collaboration focussing? What is the relation of the present proposal to earlier proposals elsewhere and what are the main improvements over those?

9 Summary of issues

9.1 SHiP

9.1.1 Measurement of the momentum spectrum of the beam-induced muon halo

1. *How much running time is needed to make a reliable estimate of the muon flux with the NA61 apparatus?*
2. *Is this running time period compatible with the NA61 plans in 2017-2018?*
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1. *investigate what can be learned from the 5-days test beam of Bern group in May;*
2. *for the long run, consider the possibility to put in series the SHiP and Bern detectors in the same experimental area.*

9.1.3 Consolidation of the simulation of all the main background components

1. *investigate the impact of the background for some benchmark channels (eg: $HNL \to \pi\mu$ or $A' \to \mu^+\mu^-$) with the NA62 apparatus (perhaps a student in common between the two collaboration could help?).*

9.1.4 Optimization of the ν_τ detector for direct searches of Light Dark Matter particles

1. *Is the simulation of the active neutrino flux reliable in Pythia?.*
2. *Which are the steps towards a better estimate of the background induced by active neutrinos?*
3. *How the sensitivity for light dark matter particles changes as a function of the background yield and as a function of the coupling of Dark Matter with SM particles?*

9.2 NA62++

1. **Optimization of the NA62 beam line:**

- *study the maximum intensity of the NA62 proton beam line (including cooling of the dump, radioprotection issues, etc) which is compatible with the physics programme in the North Area*;
- *optimize the position of the dump with respect to the decay vessel (important to maximize the acceptance for hidden sector particles) and its interplay with the muon sweeping system (important to reduce the background from the muon halo)*;

2. **Study of backgrounds' yield when the detector is operated in beam-dump mode:** *this can be performed using short (few hours) runs in beam-dump mode during the current run.*

3. **Experimental setup:** *The NA62 detector has been mainly designed for the measurement of the branching fraction of the $K^+ \to \pi^+ \nu\overline{\nu}$ decay mode: can the apparatus be further improved to reject backgrounds when searching for hidden particle in beam-dump mode (addition of new detectors/ upgrade of existing ones)* ?

9.3 NA64++

1. **muon beam:**

   - *test run: ensure timely realization of the test run with muon beam discussing with COMPASS;*
   - *long run: study the compatibility with $\mu - e$ experiment (both use 10^{12} muons on target, $p = 150 GeV/c$).*

2. **hadrons beam:**

   - *consolidate the physics case also in comparison with existing and future experiments;*
   - *detail the physics reach as a function of the requested K, π, p yields (eg: beam time);*
   - *perform the measurement of $M^0 = \pi^0, \eta, \eta', K_L, K_S$ yields with NA64 in 2018.*

9.4 KLEVER

1. *Elaborate more in detail how the knowledge of the $K_L \to \pi^0 \nu \overline{nu}$ branching fraction at 20% level can constrain New Physics models, both respect to the twin charged channel and other constrains coming from flavour measurements, namely B-physics.*

2. *Enlarge the physics case beyond the $K_L \to \pi^0 \nu\overline{\nu}$*;

3. *Give an indicative estimate of the cost of the detector and the interested institutes and people*;

4. *Can the intensity requirement be met in P42?* The beam intensity upgrade is a major work and requires additional resources for the feasibility study: the outcome of this study should be an estimate of the maximum intensity reachable at P42 and a preliminary cost of the required upgrades of the target area and the transfer lines; Siting KLEVER at the BDF is also a possibility but it would compete with SHiP.

5. KLEVER has a conceptual design of a K_L beam involving a crystal-based photon converter. To validate the concept, a test with a tagged photon beam has been considered, as well as at a later stage a possible test with a neutral kaon beam in the K12 line (perhaps during the beam-dump run?); *Study the feasibility of a test of a crystal-based photon converter with a tagged photon beam and with a neutral kaon beam.*

6. *Validate the technology for a small angle calorimeter that has to stand to* > 300 *GHz of neutrons and* $\sim (200 - 300)$ *MHz of photons.* A possible solution has been identified as a Tungsten/silicon-pad sampling calorimeter with crystal metal absorber. The collaboration aims to performing a test beam in 2018.

9.5 IAXO

1. Finalize configuration and physics reach of MiniIAXO

2. We also encourage the collaboration to follow CERN input to magnet design through the technology subgroup

9.6 ALPSIII

1. the collaboration should investigate the potential of a VMB experiment, discussing the possible detection scheme(s), with the use of a CERN like magnet.

2. the collaboration should look for possible availability of proto-magnet for FCC, possibly participating to the technology subgroup.

9.7 EDM

1. *How does the collaboration view the competition in various smaller scale laboratory experiments worldwide that aim to improve limits on various EDMs in the coming years?*

2. *Is there an existing and sufficiently large scale proof that external, varying magnetic fields can be controlled reliably over extended periods of time, i.e. the typically 1 year running time, in a realistic environment and at any position in the fiducial volume to better than the required 10 nT ? How do other succesful EDM experiments do in this respect ?*

3. *What is the overall concept regarding merging magnetic field requirements and shielding for EDM needs with magnetic devices needed for the storage ring?*

4. *Which of the species, proton or deuteron, will be the collaborations priority for a first experiment and what is the strategy and time planning to arrive at a decision?*

5. *Has the collaboration considered a proof of principle experiment at smaller and at lower sensitivity to verify scaling of systematic uncertainties in a real experiment?*

6. *What is the relation of the present proposal to earlier proposals elsewhere and what are the main improvements over those?*

References

[1] SHiP collaboration, *Technical Proposal*, CERN-SPSC-2015-017, SPSC-P-350-ADD-1.

[2] SHiP collaboration, CERN-SPSC-2016-034, SPSC-EOI-013.

[3] S. Aoki et al., Study of tau-neutrino production by measuring $D_s \to \tau$ events in 400 GeV proton interactions: Test of lepton universality in neutrino charged-current interactions, CERN-SPSC-2016-013, SPSC-EoI-245.

[4] A EDM kick-off meeting has been held on 13/14 March 2017; see http://indico.cern.ch/event/609422/