

**Dark Interactions:  
Perspectives from Theory and  
Experiment**

**Report of Contributions**

Contribution ID: 0

Type: **not specified**

## Workshop Opening

*Tuesday, 4 October 2016 09:00 (10 minutes)*

Opening address and information for the participants

**Presenter:** MARCIANO, William (BNL)

Contribution ID: 1

Type: **not specified**

# Theoretical motivation and phenomenology of light dark sectors

*Tuesday, 4 October 2016 09:10 (50 minutes)*

**Presenter:** JAECKEL, Joerg (Heidelberg)

**Session Classification:** Overview of light dark sectors

Contribution ID: 2

Type: **not specified**

## **Axions and ultralight dark photons: theory+searches**

*Tuesday, 4 October 2016 10:00 (50 minutes)*

**Presenter:** DUBOVSKY, Sergei (New York University)

**Session Classification:** Overview of light dark sectors

Contribution ID: 3

Type: **not specified**

## Discussion

*Tuesday, 4 October 2016 10:50 (10 minutes)*

**Session Classification:** Overview of light dark sectors

Contribution ID: 4

Type: **not specified**

## Dark photons at MeV-GeV masses

*Tuesday, 4 October 2016 11:30 (50 minutes)*

**Presenter:** TORO, Natalia (SLAC)

**Session Classification:** Overview of light dark sectors

Contribution ID: 5

Type: **not specified**

## **Dark photons at MeV-GeV masses (II)**

**Presenter:** SCHUSTER, Philip (SLAC)

Contribution ID: 6

Type: **not specified**

## Discussion

*Tuesday, 4 October 2016 12:20 (10 minutes)*

**Session Classification:** Overview of light dark sectors



Contribution ID: 8

Type: **not specified**

## Theory + electron beam dumps

*Tuesday, 4 October 2016 13:50 (25 minutes)*

**Presenter:** IZAGUIRRE, Eder (BNL)

**Session Classification:** MeV-GeV dark matter

Contribution ID: 9

Type: **not specified**

## **Proton beam dumps (MiniBoone, Seaquest, SHIP)**

*Tuesday, 4 October 2016 14:20 (25 minutes)*

**Presenters:** BATELL, Brian (Chicago); Mr BATELL, Brian (Perimeter Institute)

**Session Classification:** MeV-GeV dark matter

Contribution ID: **10**

Type: **not specified**

## Direct Detection

*Tuesday, 4 October 2016 14:50 (25 minutes)*

**Presenter:** YU, Tien Tien

**Session Classification:** MeV-GeV dark matter

Contribution ID: **11**

Type: **not specified**

## Discussion

*Tuesday, 4 October 2016 15:20 (10 minutes)*

**Session Classification:** MeV-GeV dark matter

Contribution ID: 12

Type: **not specified**

## **Dark Matter searches at the LHC**

*Wednesday, 5 October 2016 09:00 (30 minutes)*

**Presenter:** BOVEIA, Antonio

**Session Classification:** Dark Sectors at Colliders 1

Contribution ID: 13

Type: **not specified**

## **Dark sector searches at e+e- colliders**

*Wednesday, 5 October 2016 09:40 (20 minutes)*

**Presenter:** KOLOMENSKY, Yury (LBL)

**Session Classification:** Dark Sectors at Colliders 1

Contribution ID: 14

Type: **not specified**

## Discussion

*Wednesday, 5 October 2016 10:00 (10 minutes)*

**Session Classification:** Dark Sectors at Colliders 1

Contribution ID: 15

Type: **not specified**

## **Decays to dark sector particles at CMS**

*Wednesday, 5 October 2016 10:40 (40 minutes)*

**Presenter:** KOLBERG, Ted

**Session Classification:** Dark Sectors at Colliders 2



Contribution ID: 16

Type: **not specified**

## Decays to dark sector particles at ATLAS

*Wednesday, 5 October 2016 11:30 (40 minutes)*

The postulation of a Hidden Sector to complement the Standard Model offers elegant solutions to one of the most intriguing questions in elementary particle physics, being the particle nature of dark matter. The discovery of a fundamental scalar particle compatible with the Higgs boson paved the way for looking for dark matter with novel methods. In this contribution, I will review recent searches to dark sector particles performed by the ATLAS collaboration. Particular emphasis will be given to results with recent proton-proton data at 13-TeV center-of-mass energy, to improvements in the trigger and reconstruction of physics objects that happened during the LHC long shut-down and to prospects for results with the enlarged dataset being collected by the experiment this year.

**Presenter:** COCCARO, Andrea**Session Classification:** Dark Sectors at Colliders 2

Contribution ID: 17

Type: **not specified**

## Discussion

*Wednesday, 5 October 2016 12:20 (10 minutes)*

**Session Classification:** Dark Sectors at Colliders 2

Contribution ID: **18**

Type: **not specified**

## Neutral naturalness

*Thursday, 6 October 2016 09:00 (35 minutes)*

**Presenter:** CRAIG, Nathaniel

**Session Classification:** Neutral naturalness, Hidden valley Dark Sectors

Contribution ID: **19**

Type: **not specified**

## **Searches for Hidden Valleys at the LHC**

*Thursday, 6 October 2016 09:40 (35 minutes)*

**Presenter:** STRASSLER, Matt (Harvard)

**Session Classification:** Neutral naturalness, Hidden valley Dark Sectors

Contribution ID: 20

Type: **not specified**

## Discussion

*Thursday, 6 October 2016 10:20 (10 minutes)*

**Session Classification:** Neutral naturalness, Hidden valley Dark Sectors

Contribution ID: 21

Type: **not specified**

## Status of Dark Matter Direct Detection

*Wednesday, 5 October 2016 14:00 (35 minutes)*

**Presenter:** BROWN, Ethan (RPI)

**Session Classification:** Dark Matter

Contribution ID: 22

Type: **not specified**

## **Imprints of Pseudoscalar Particles and Dark Bosons on the Cosmic Microwave Background**

**Presenter:** EJLLI, Damian (Novosibirsk State University (Russia) and Laboratori Nazionali del Gran Sasso (LNGS)(Italy))

Contribution ID: 23

Type: **not specified**

## Discussion

*Wednesday, 5 October 2016 15:20 (10 minutes)*

**Session Classification:** Dark Matter



Contribution ID: 24

Type: **not specified**

## **Astrophysical Probes of Neutrinos**

*Thursday, 6 October 2016 11:00 (35 minutes)*

**Presenter:** FRIEDLAND, Alexander (SLAC National Accelerator Laboratory)

**Session Classification:** Neutrinos and hidden physics

Contribution ID: 25

Type: **not specified**

## Neutrino anomalies

*Thursday, 6 October 2016 11:40 (35 minutes)*

**Presenter:** DEGOUVEA, Andre (Northwestern)

**Session Classification:** Neutrinos and hidden physics

Contribution ID: 26

Type: **not specified**

## Discussion

*Thursday, 6 October 2016 12:20 (10 minutes)*

**Session Classification:** Neutrinos and hidden physics

Contribution ID: 27

Type: **not specified**

## Latest Results from Cosmological probes

*Wednesday, 5 October 2016 16:00 (35 minutes)*

**Presenter:** JAIN, Bhuvnesh (UPenn)

**Session Classification:** Cosmology and astrophysics

Contribution ID: 28

Type: **not specified**

# Gravitational Wave Signals of Cosmological Phase Transitions

*Wednesday, 5 October 2016 16:40 (35 minutes)*

Strong first-order cosmological phase transitions produce a stochastic gravitational wave background. We discuss the resulting contributions from bubble collisions, magnetohydrodynamic turbulence, and sound waves, and estimate the total corresponding signal predicted in gravitational waves. We demonstrate that LISA is able to probe many well-motivated scenarios beyond the Standard Model of particle physics predicting strong first-order cosmological phase transitions in the early Universe.

**Presenter:** SERVANT, Geraldine (CERN)

**Session Classification:** Cosmology and astrophysics

Contribution ID: 29

Type: **not specified**

## Discussion

*Wednesday, 5 October 2016 17:20 (10 minutes)*

**Session Classification:** Cosmology and astrophysics

Contribution ID: 31

Type: **not specified**

## Future prospects in cosmology

*Friday, 7 October 2016 09:00 (35 minutes)*

**Presenter:** FLAUGER, Raphael (University of Texas at Austin)

**Session Classification:** The Future at the very large and the very small scales I

Contribution ID: 32

Type: **not specified**

## Physics at Future Circular Colliders

*Friday, 7 October 2016 09:40 (35 minutes)*

The Large Hadron Collider has been a grand success with the discovery of the Higgs boson, with bright prospects for additional discoveries since the recent increase in collider energy and the anticipated large datasets. Big open questions such as the nature of dark matter, the origin of the matter-antimatter asymmetry in the Universe, and the theoretical puzzle of the finely-tuned parameters in the Higgs sector, demand new physics principles that extend the established Standard Model paradigm. Future circular colliders in a substantially larger tunnel can house both a high luminosity electron-positron collider for precision measurements of Higgs and electroweak parameters, as well as a very high energy proton-proton collider which can directly manifest particles associated with these new physics principles. We discuss the physics goals of these future circular colliders, and the prospects for elucidating fundamental new laws of nature that will significantly extend our understanding of the Universe. Detailed studies of the discovery potential in specific benchmark models will be presented, with implications for detector design.

**Presenter:** Prof. KOTWAL, Ashutosh (Duke University)

**Session Classification:** The Future at the very large and the very small scales I



Contribution ID: 33

Type: **not specified**

## Discussion

*Friday, 7 October 2016 10:20 (10 minutes)*

**Session Classification:** The Future at the very large and the very small scales I

Contribution ID: 34

Type: **not specified**

## **The Status of Primordial Black Holes as Dark Matter**

*Friday, 7 October 2016 11:00 (35 minutes)*

**Presenter:** KOVETZ, Ely (John Hopkins University)

**Session Classification:** The Future at the very large and the very small scales II

Contribution ID: 35

Type: **not specified**

## Discussion

*Friday, 7 October 2016 11:35 (10 minutes)*

**Session Classification:** The Future at the very large and the very small scales II

Contribution ID: 36

Type: **not specified**

## **Dark Matter / Dark Interaction**

*Tuesday, 4 October 2016 16:00 (1 hour)*

**Presenter:** MURAYAMA, Hitoshi (Berkeley)

**Session Classification:** BSA Distinguished lecture

Contribution ID: 37

Type: **not specified**

## Dark Photon Search at the Fermilab SeaQuest Experiment

*Wednesday, 5 October 2016 14:40 (15 minutes)*

The SeaQuest E906 experiment is a fixed target Drell-Yan experiment which is aimed at studying the anti-quark distributions in the nucleon and nuclei. 120 GeV protons from the Main Injector at Fermilab could also be used to search for massive dark gauge bosons or dark photons that could be generated when a proton beam dump interacts with a 5m long Fe beam dump. SeaQuest takes advantage of Proton Bremsstrahlung and  $\nu$  decay processes to search for dark photons that could provide a portal into the dark sector. Exclusion limit projections for SeaQuest and future prospects for the experiment will be discussed in the talk.

**Presenter:** TADEPALLI, Arun

**Session Classification:** Dark Matter

Contribution ID: 38

Type: **not specified**

## Direct Search for Dark Photon and Dark Higgs in E-1067 at Fermilab

*Wednesday, 5 October 2016 15:00 (15 minutes)*

Through kinetic mixing, the postulated dark photon and dark Higgs particles could be produced in the Drell-Yan like  $q\text{-}\bar{q}$  and gluon-gluon fusion processes in high energy proton + nucleus collisions, respectively. Starting from 2017, the E-1067 experiment at Fermilab will carry out the first direct search for such particle productions in the mass range  $0.2 \sim 10$  GeV in parasitic with the E906/SeaQuest experiment. LOI of E-1067 was first submitted to PAC in the summer of 2015 and subsequently endorsed by Fermilab director. In the near future, we also plan to install new EM calorimeters recycled from the PHENIX experiment at RHIC to add di-electron capability to the search thus allowing us to access the mass region below the current dimuon limit. To maximize the experimental reach, we are taking on a major upgrade of the SeaQuest DAQ and trigger systems now and will be ready for data taking in early 2017. In this talk, the current status of the upgrade projects and expected experimental reach will be presented.

**Presenter:** LIU, Ming Xiong (Los Alamos National Laboratory)

**Session Classification:** Dark Matter

Contribution ID: 39

Type: **not specified**

## Recent results and prospects on Dark Interactions from CERN

*Thursday, 6 October 2016 14:00 (15 minutes)*

Kaon experiments at CERN (NA48/2 and NA62) study decays in flight of secondary charged kaons produced by 400 GeV/c protons from the SPS accelerator hitting a Beryllium target. The NA48/2 experiment was exposed to  $2 \times 10^{11}$  kaon decays in 2003-2004, and NA62 is set to surpass this figure by a factor of 50 in 2016-2018. Prospects for the dark photon, heavy neutral lepton and axion-like particle searches via their production (both promptly at the Beryllium target and in secondary kaon decays) and decay with available and future NA62 data are discussed. Results of searches for the dark photon, inflaton and heavy neutral leptons in charged kaon and neutral pion decays with NA48/2 data are presented.

**Presenter:** LAMANNA, Gianluca

**Session Classification:** Contributed talks related to dark sectors/dark interactions

Contribution ID: 40

Type: **not specified**

## Simplified DM models: a case with t-channel colored scalar mediators

*Thursday, 6 October 2016 14:20 (15 minutes)*

The general strategy for dark matter (DM) searches at colliders currently relies on simplified models in order to describe the interactions between the Standard Model (SM) and DM and potential collider signatures at the LHC. A recently proposed UV-complete simplified model with t-channel mediators improves the existing simplified DM models in two important respects: (i) the full SM gauge symmetry is imposed including the fact that the left-handed and the right-handed fermions have two independent mediators with two independent couplings, and (ii) the renormalization group evolution is included in the effective Lagrangian for DM-nucleon scattering when integrating out the t-channel mediators. The first improvement will introduce a few more parameters compared with the existing simplified DM models. The effect this broader set of free parameters has on direct detection and the mono-X + MET (X=jet,W,Z) signatures at 13 TeV LHC are discussed.

**Presenter:** NATALE, Alexander (KIAS)

**Session Classification:** Contributed talks related to dark sectors/dark interactions



Contribution ID: 41

Type: **not specified**

## Dark matter models with two mediators

*Thursday, 6 October 2016 14:40 (15 minutes)*

A reliable comparison of different dark matter searches requires models that satisfy certain consistency conditions like gauge invariance and perturbative unitarity. These conditions can easily be satisfied in  $U(1)'$  extensions of the Standard Model, where a fermionic dark matter candidate as well as a new  $Z'$  gauge boson obtain their mass from the spontaneous breaking of the  $U(1)'$  by a dark Higgs. These dark matter scenarios contain two mediators, the new gauge boson and the dark Higgs, which can also act as final states in dark matter annihilation. I will discuss the general framework of consistent dark matter models with two mediators, and then review a class of dark matter models where baryon number is a local gauge symmetry.

**Presenter:** DUERR, Michael (DESY)

**Session Classification:** Contributed talks related to dark sectors/dark interactions

Contribution ID: 42

Type: **not specified**

## Search for Dark Particles at Belle and Belle II

*Thursday, 6 October 2016 15:00 (15 minutes)*

The dark photon,  $A'$ , the dark Higgs boson,  $h'$ , and the dark vector gauge boson,  $U'$ , are hypothetical constituents

featured in a number of recently proposed Dark Sector Models. We will present searches for these particles in the Belle data and discuss prospects in the future Belle II data.

**Presenter:** JAEGLER, Igal (University of Hawaii at Manoa)

**Session Classification:** Contributed talks related to dark sectors/dark interactions

Contribution ID: 43

Type: **not specified**

## Search for Dark Photons at LHCb

*Thursday, 6 October 2016 15:20 (15 minutes)*

Dark photons appear in many well-motivated dark matter scenarios, leading to a worldwide effort to search for them. We propose some novel search methods for dark photons at the LHCb experiment. In this talk, I will focus on the inclusive search for dark photons at the LHCb experiment based on both prompt and displaced di-muon resonances. The dark photon rate can be directly inferred from the off-shell photon rate, making this a fully data-driven search. LHCb is applying this method for the dark photon search in the Run 2 of LHC. For Run 3, LHCb will have sensitivity to large regions of the unexplored dark photon parameter space.

**Presenter:** XUE, Wei (MIT)

**Session Classification:** Contributed talks related to dark sectors/dark interactions

Contribution ID: 44

Type: **not specified**

## Workshop Reception

*Thursday, 6 October 2016 18:10 (1h 30m)*

Contribution ID: 45

Type: **not specified**

## Astrophysical Signatures of Dissipative Dark Matter

*Thursday, 6 October 2016 16:15 (15 minutes)*

After nearly a century of searching, the nature of dark matter continues to elude us. While Ockham's razor may at face value want a favor a dark sector with one component, the complexity of the visible sector urges us to consider dark sectors with multiple components, including possibly dissipative interactions. In a galaxy like the Milky Way, these interactions would lead to cooling of the dissipative sector, resulting in a disk of dark matter with enhanced local density. I will briefly review the current bounds on the local dark matter density and explain why they do not apply to a dark disk. I will then explain what the latest astrophysical data truly say about a dark disk, including the bounds we recently determined from Milky Way stellar kinematics and from the distribution of the local interstellar gas, and what we can expect in upcoming the Gaia era.

**Presenter:** KRAMER, Eric (Harvard University)

**Session Classification:** Contributed talks related to dark sectors/dark interactions

Contribution ID: 46

Type: **not specified**

## The search for a dark Z boson with Machine Learning

*Thursday, 6 October 2016 17:15 (15 minutes)*

The existence of a dark sector vector boson ( $Z_d$ ) is well motivated by theory and experiment; models add a  $U(1)$  gauge symmetry to the standard model which introduces a new gauge field  $Z_d$  with kinetic mixing  $\epsilon$  (I'll add the actual symbol) and a Higgs doublet with mass mixing  $\kappa$ . We can thus use the Higgs as a portal to look for such a particle at the LHC. In particular, we can expand upon the standard ATLAS  $H \rightarrow 4l$  analysis to search for and measure the properties of the  $Z_d$ . I will describe the structure and current status of this analysis, as well as potential applications for using machine learning techniques to increase sensitivity.

**Presenter:** THAIS, Savannah (Yale University)

**Session Classification:** Contributed talks related to dark sectors/dark interactions

Contribution ID: 47

Type: **not specified**

## Updated Bounds on Light Hidden Sectors in Supernovae

*Thursday, 6 October 2016 16:35 (15 minutes)*

Supernova 1987A created an environment of extremely high temperatures and nucleon densities, providing an opportunity to set bounds on a wide range of theories of new physics. We present corrected bounds on hidden sector models, incorporating a wide range of new physical effects on the production, including some novel corrections to the high-mixing-angle calculation. These bounds dramatically alter the landscape of the allowed regions for hidden sector models.

**Presenter:** MCDERMOTT, Samuel (YITP)

**Session Classification:** Contributed talks related to dark sectors/dark interactions

Contribution ID: 48

Type: **not specified**

## General Discussion

*Friday, 7 October 2016 11:45 (15 minutes)*

**Presenter:** ALL



Contribution ID: 49

Type: **not specified**

## "Lattice Gauge Theory insights on Dark Matter

*Thursday, 6 October 2016 16:55 (15 minutes)*

Models of composite dark matter, originating from a new strongly coupled dark sector, have a very interesting phenomenology. To make robust predictions in these models one often need to investigate non-perturbative effects due to the strong self interactions. Lattice field theory methods and numerical simulations are well suited for this task and contribute to a solid uncertainty quantification.

As an example, the Stealth Dark Matter model contains a candidate composite dark matter particle which appears as a bosonic neutral baryon of a new  $SU(4)$  strongly coupled gauge sector. The elementary constituents of this composite state carry electroweak charges. This construction provides a mechanism to naturally reduce the strength of dark matter interactions with standard model particles: there is no magnetic moment or charge radius. However such interactions exist and can allow direct detection and collider experiments to put constraints on the model. In order to get predictions from this strongly-coupled model, numerical lattice simulations are employed and give definite results for the cross-section of the dark matter candidate with standard nuclei in detectors, dominated by the electric polarizability interaction. A universal lower bound for the mass of this composite dark matter candidate is reported around 300 GeV.

**Presenter:** RINALDI, Enrico (BNL)

**Session Classification:** Contributed talks related to dark sectors/dark interactions

Contribution ID: 50

Type: **not specified**

## Respect the ELDERS

*Thursday, 6 October 2016 17:35 (15 minutes)*

We present a novel dark matter candidate, an elastically decoupling relic, which is a cold thermal relic whose present abundance is determined by the cross section of its elastic scattering on standard model particles. The dark matter candidate is predicted to have a mass ranging from a few to a few hundred MeV, and an elastic scattering cross section with electrons, photons and/or neutrinos in the  $10^{-3}$  – 1 fb range..

**Presenter:** TSAI, Yu-Dai (Cornell University)

**Session Classification:** Contributed talks related to dark sectors/dark interactions