DARK INTERACTIONS WORKSHOP SERIES AT BNL

Dr. Kétévi A. Assamagan
BNL
Outline

- Dark interactions workshop series at BNL
  - Purpose
  - Format
  - Contents
  - outlook
Dark Interactions: perspective from theory and experiment

To review and discuss the theoretical context as well as the status and future of the searches for dark sector particles, such as dark vector bosons, and the implications for dark matter.
Location & Venue

- Brookhaven National Laboratory (BNL), Physics Department
- Long Island, New York and BNL

- ~2950 employees;
- Budget – about $750M
- >4000 scientific facility users annually
- Seven Nobel Prizes garnered
  - 12 Scientists honored (users & staff)
  - First in 1957, latest in 2009

Major Research Facilities

RHIC
NY Center for Computational Science
Long Island Solar Farm
National Synchrotron Light Source
National Synchrotron Light Source II
Center for Functional Nanomaterials
BNL HEP
  - ATLAS, LBNE, LSST, DUNE

Future: eRHIC
Organizing Committee

- Kétévi A. Assamagan (Chair, BNL)
- Oliver Keith Baker (Yale U.)
- Michael Begel (BNL)
- Mary Bishai (BNL)
- John Paul Chou (Rutgers U.)
- Hooman Davoudiasl (BNL)
- Rouven Essig (SBU)
- Tobias Golling (Université de Genève)
- Christopher S Hill (Ohio State U.)
- William Marciano (BNL)
- Gopolang Mohlabeng (BNL)
- Neelima Sehgal (SBU)
- Anze Slosar (BNL)
- Stéphane Willocq (U. of Mass.)
- Christian Weber (BNL)
Scope

- Theoretical Motivation for Dark Sectors
- Constraints from Collider or non-Collider Experiments
- Cosmological and astrophysical Constraints
- Prospects for LHC and future Intensity Frontier Experiments
- Brookhaven Science Associates (BSA) Distinguished Lectures
  - Neil Weiner (NYU), Hitoshi Murayama (Berkeley), ...
Topics

- Theory—overviews of (light) dark sector
- Direct Detections
  - + Low mass dark matter. Detection strategies for low-energy particle recoils
- Indirect detections
- Cosmological & astrophysical probes
- Neutrinos and the dark sector
- Collider searches
- Fixed targets
- Beam dump experiments
- Future experiments
- Many contributed talks
- Read My Paper (RMP) sessions

Dr. Kétévi. A. Assamagan (BNL)
Duration & Form

■ Duration
  – 2.5 to 3.5-day workshop

■ Format
  – Invited talks
  – Contributed talks
  – “Read My Paper” sessions
  – Discussions

■ All plenary sessions

“Read My Paper” sessions:
7-min (or less) talks to explain why anybody should read your latest paper
Agenda of past workshops

Photos (2014)
Photos (2018)
Second Biennial Workshop on

Dark Interactions
Perspectives from Theory and Experiment

October 4 - 7, 2016
Brookhaven National Laboratory

Topics
- Theoretical Motivation for Dark Sectors
- Experimental Constraints from High Energy Colliders
- Constraints from non-Collider Experiments
- Cosmological Constraints
- Implications for Dark Matter
- Prospects for LHC Run 2 and Future Intensity Frontier Experiments

The Organizing Committee
Ketevan A. Assamagan (Chair, BNL)
Oliver Keith Baker (Yale University)
Mary Bahri (BNL)
John Paul Chiu (Rutgers University)
Horman Davaudard (BNL)
Houwen Easoq (Stony Brook University)
Johannes Gaßler (Universität de Genf)
Christopher E. Hill (Ohio State University)
William Marciano (BNL)
Stephane Willen (University of Massachusetts)

Poster (2016)
Dark Sector

- Dark Sector as "New Physics" beyond the SM

Need new force / interaction to connect SM to Dark Sector

Dark Matter could just be one example of Dark Sector State

- A hidden or dark sector can be introduced with an additional $U(1)_d$ dark gauge symmetry
  - The dark sector could couple to the SM through kinetic mixing with the hypercharge gauge boson

- Exotic Higgs boson decays have been proposed as a way to search for evidence of new physics
  - In the decay of the discovered Higgs boson
  - To measure the coupling strengths between the SM and the dark sector

- Such decays predicted in many extensions to the SM to explain
  - Muon $g-2$ discrepancy
  - Astrophysical observation of positron excess
Dark Sector

- Dark Sector as "New Physics" beyond the SM

Need new force / interaction to connect SM to Dark Sector

Dark Matter could just be one example of Dark Sector State

- A hidden or dark sector can be introduced with an additional U(1)d dark gauge symmetry
  - The dark sector could couple to the SM through kinetic mixing with the hypercharge gauge boson

- Exotic Higgs boson decays have been proposed as a way to search for evidence of new physics
  - In the decay of the discovered Higgs boson
  - To measure the coupling strengths between the SM and the dark sector

- Such decays predicted in many extensions to the SM to explain
  - Muon g-2 discrepancy
  - Astrophysical observation of positron excess
Minimal Interactions

- Symmetries of the SM restrict interactions with Dark Sector States

Vector Portal:
Min. Lagrangian =
SM Lagrangian + Dark QED + “Kinetic Mixing (ε)”

\[
\mathcal{L} \supset -\frac{\epsilon}{2}B_{\mu\nu}A'_{\mu\nu} - H^\dagger H (AS + \lambda S^2) - Y^{ij}_N \bar{L}_i H N_j
\]
Kinetic mixing gives matter of electric charge \( qe \) an \( A' \) coupling \( \propto q \epsilon e \).

- Two cases:
  - \( \chi \) stable & invisible
  - \( \chi \) decays into SM particles, \( A' \rightarrow >2 \) charged particles

If any dark-sector matter \( \chi \) has \( m_\chi < 2m_{A'} \), this decay dominates.

Dr. Kétévi A. Assamagan, BNL & Visiting Scientist at the University of the Witwatersrand
Dark Photon Production

\[ e^{+} e^{-} \rightarrow A' \gamma \]

\[ N \propto \epsilon^2 \]

- Dark bremsstrahlung
- \( e^{+} e^{-} \rightarrow A' \gamma \)

**APEX @ JLab**

\[ p \text{ fixed target} \]

\[ \pi^0, \eta \rightarrow ee A' \]

\[ N \propto \epsilon^2 \]

- Meson decays
- Dark bremsstrahlung

**PP collider**

\[ e^{+} e^{-} \rightarrow A' \gamma \]

\[ N \propto \epsilon^2 \]

- "Lepton jets" \( N \propto ? \)
- Meson decays

**ATLAS CMS LHCb**

**NA48/2 @ SPS**

Dr. Kétévi. A. Assamagan (BNL)
Mediator Decays to SM

Generally, searches are “bump hunts” for $m(l^+l^-)$ resonances.

$A'$ becomes long lived at small couplings.

$$\gamma_{CT} \propto \frac{1}{\epsilon^2 m^2_{A'}}$$

Leads to constraints from “beam dump experiments”

$\alpha_D = 0.5, \frac{M_{A'}}{M_X} = 1.5$
Resonance search using Hall A High-Resolution Spectrometers, dark bremsstrahlung production from multi-GeV $e^-$ beam

2019 Physics Run (2/1 - 3/10 2019)
15 days at $E_{\text{beam}} = 2.2$ GeV
Proton fixed target—NA48/2 at CERN SPS (2015)
Experiment at PSI using secondary muon beam to search for $\mu^+ \rightarrow e^+ e^- e^+$ with up to $5 \times 10^{16}$ $\mu$. 

arXiv: 1411.1770

---

Dr. Kétévi. A. Assamagan (BNL)

SLAC E137: search for metastable particles run during 1980-1982(!)

- $2 \times 10^{20}$ e⁻ (30 C) @ 20 GeV
- 179 meter shield

Still the best limits in parts of parameter space for many dark sector models!

e.g. arXiv: 1209.6083, 1406.2698, 1802.03794
p+ beam dump—SeaQuest at FNAL ($\mu^+\mu^-$ 2019, 2021? $e^+e^-$)

Fixed target muon spectrometer for Drell-Yan sea quark measurements at FNAL

Parasitic program of dark photon searches with addition of displaced vertex trigger.

Shallow dump + large boost accesses larger couplings than previous dump experiments

arXiv: 1804.00661

$A' \to l^+ l^-$

120 GeV p+

Potential future upgrade to replace Hadron absorber with EMCal to enable reach below $2m_\mu$

Very similar: NA62, SHiP
Kinetic Mixing – for experiments seeking $A' \to \gamma\gamma$

Previous constraints                                    Projections

arXiv:1608.08632

Dr. Kétévi A. Assamagan, BNL & Visiting Scientist at the University of the Witwatersrand
If, the U(1)d symmetry is broken by the introduction of a dark Higgs boson, then there could also be a mixing between the SM Higgs boson (H) and the dark sector Higgs boson (S)

The mixing parameter $\kappa$ between H and S, can be extracted from $H \rightarrow Zd \bar{Z}d \rightarrow 4l$, a unique channel to access this parameter

See the talk by Diallo Boye
Mass Mixing between SM Z and Zd

- In addition to kinetic mixing, there could be also a mass mixing between SM Z and Zd

\[ O_{A,X} = c_{A,X} H X_\mu Z_d^\mu, \]

For operators of type $O_{A,X}$ in Eq. (2), we will focus on $X = Z$. Such interactions are typically associated with mixing. For example, the mass term for $Z-Z_d$ mixing can be parametrized as $\varepsilon_Z m_Z^2 Z Z_d$, with

\[ \varepsilon_Z = \frac{m_{Z_d}}{m_Z} \delta, \]

H $\rightarrow$ Z Zd $\rightarrow$ 4l is sensitive to the kinetic mixing parameter $\varepsilon$, and to Z-Zd mixing parameter $\delta$. Unique channel to extract $\delta$

See talk by Diallo Boye
Agenda – example of di2018

- **Theory**: Overview of light dark sectors
- **Experiments**: Overview of light dark sectors
- **Light (keV-GeV) Dark Matter**: Recent developments
- **BSA Distinguished Lecture**: "Illuminating Dark Matter"
- Indirect detection of dark matter
- Novel cosmic probes of dark matter
- **Ultralight** Dark Matter
- Cosmological and astrophysical probes of dark sectors
- Contributed Talks I
- Neutrinos and the dark sectors
- Colliders: Searches for dark sector states (I)
- Contributed Talks II
- Contributed Talks III
- Colliders: Searches for dark sector states (II)
- Direct Detections
di2020

- The 4th Dark Interactions workshop is currently in preparation
- Date: September 30 – October 2, 2020
- Scientific agenda under development
- Announcement in a few months
- I hope you will consider coming to BNL for di2020
Conclusions

- “Dark Interactions” is a series of workshop started in 2014
- Organized biennially
- At BNL
- On dark sector states and dark matter
- Next workshop, di2020, on September 30 - October 2, 2020