

# FIPs 2020 Workshop

## CERN, 27-29 May 2020

### Initial thoughts:

FIPs 2020 could be organized in sessions following the current structure of "portals" used in the Physics Beyond Colliders and Briefing Book exercises. Each session will discuss recent theory developments and associated experimental results from all the involved communities (focus is on physics topics not experimental facilities). *We need to emphasize synergies and complementarities, we need a multi-scale approach with a diversified experimental program.*

*Advantages:* This structure has the advantage to associate to each portal some fundamental questions and discuss in the same session recent theory developments, and a wide variety of experimental results from very different communities (which will be "gently" forced to talk together and develop a common language).

*Disadvantages:* This structure (theory-oriented) could be a problem for experimental results which are not obviously connected to any specific portal or they are potentially connected to more than one (e.g. DM direct or indirect detection). We risk to introduce a bias... *We need to discuss this point.* James: Definitely worth discussing in detail because not all experimentalists think in terms of these "portals".

## 1 Fundamental Questions related to all FIPs

These questions are the driving principles of the workshop and the associated document (proceedings) that will be the outcome of the workshop. Which BSM problems FIPs can address, in particular:

1. Can feebly-interacting vector/scalar/pseudo-scalar particles be mediators between light DM (LDM) and SM particles?
2. Which ranges for DM and mediator masses and couplings are compatible with a DM thermal origin?
3. Which FIPs can provide DM candidates (axions, ALPs, sterile neutrinos, etc.)?
4. How DD and ID DM experiments together with reliable astrophysical and cosmological constraints can restrict the ranges in terms of mass and couplings for potential FIPs candidates?
5. How can dark matter detection experiments inform/guide energy and intensity frontier experiments, and vice versa?
6. Can FIPs be an answer to the question about the origin of neutrino masses and oscillations? If so, in which mass and coupling range?
7. Can FIPs have a role in baryogenesis (via leptogenesis or not) (eg: HNL, relaxion mechanism with CP-violating/conserving mixing, etc.)?
8. Can FIPs have a role in the EW symmetry breaking mechanism? Can FIPs have a role in the inflation?
9. Can there be a connection between different FIPs?
10. James: What are the capabilities and limitations of the central detectors of the LHC (ATLAS, CMS, LHCb, ALICE) for detecting FIPs and what is being done to address these limitations for the HL-LHC?

## 2 Introductory talks

Perhaps, at the beginning of the workshop we can have introductory talks (say, 30' each) setting up the scene on:

1. Standard Model problems and FIPs from theoretical viewpoint (naturalness, etc);  
*Gaia: here we need a "5-star" speaker.. Jonathan Feng? James: Other options: David Curtin, Brian Shuve, Michael Ramsey-Musolf, Raman Sundrum, Liantao Wang, Simon Knapen, others...*
2. What do we know about DM from observations? What do we expect to know in next few years?  
*Here we need an experimental speaker with broad view Annika Peter?*  
*Jocelyn: Laura Baudis (Zurich). Other good speakers for a broad overview would be Tina Pollmann (Munich) or Karoline Schöffner (Munich).*  
*Gaia: perhaps separate between Direct and Indirect Detection: for indirect detection the speaker could be Nick Rodd (Berkeley)*
3. Theory overview of DM models.  
*proposed speaker: Jonathan Feng? Tongyan Lin?*  
*James: Tim Tait*
4. General requirements to experiments to search for FIPs. *Gaia: slightly changed formulation: "Experimental techniques to search for FIPs at accelerator-based experiments. (otherwise is too broad..)*  
*James: Do we want one talk that covers the entire panoply of experimental searches for FIPs? Or perhaps three, one talk about central detectors at collider experiments (both LHC and future circular and linear), one talk about dedicated detectors that use the nominal LHC interaction points as the source of LLPs / FIPs, and one about accelerator experiments not covered by those, like SHiP, NA62, etc.? .*
5. Status of stellar and SN 1987 constraints on new physics (*Raffelt to give a talk? also C. Weninger is a good choice*).  
*James: What about more than one talk here about constraints from a variety of astrophysical observations, not limited to stellar and supernovae info?*
6. Overview of CERN facilities (Physics Beyond Colliders, *Mike Lamont?*)

### 3 Feebly-interacting Vector particles at large (not only kinetic mixing) (Vector portal)

*Tentative list of fundamental questions associated with this portal:*

- Can feebly-interacting vector particles be mediators between LDM and SM particles?
- Which ranges for DM and mediator masses and couplings are compatible with a DM thermal origin?

*Tentative list of theoretical/phenomenological topics to cover:*

- Are light DM with vector (dark photon) mediators compatible with the cosmological and astrophysical constraints;  
*Gaia - possible introductory talk: "Models of DM with Vector mediators, connection to thermal relic origin and astrophysical bounds (SN1987, solar lifetime, etc.)"; proposed speaker: Maxim Pospelov? there is easily enough material here for several theory talks. thermal origin depends on nature of vector in interesting ways with corresponding signatures. Astro bounds too*

*Tentative list of experimental topics to cover:*

1. Search for LDM and Vector mediators at experiments at extracted beam lines (NA64@CERN, miniBoone @FNAL, BDX @JLAB, APEX@JLAB, MESA@Mainz...);  
mass range typically covered:  $< 1$  GeV.
2. Search for LDM and Vector Mediators at flavor facilities (LHCb, Belle-II, NA62 in kaon mode,...);  
mass range typically covered:  $< 5$  GeV. *proposed speaker: Mike Williams?*
3. Search for LDM and Vector mediators at ATLAS and CMS;  
*(Gaia:but only if considered couplings are  $\lll 1$  !).*  
Gaia's proposal:
  - NA64 (including NA62 results) *James: Babette Dobrich; Gaia: Babette is not from NA64...; James: Yes, but it could be "NA62 (including NA64 results)", Gaia: No, NA64 has results much more advanced...;*
  - Belle-II (including old BaBar ad Belle results) *proposed speaker: Christopher Hearty? Enrico Graziani? James: Abi Soffer;*
  - LHCb, ATLAS and CMS *proposed speaker: Mike Williams? James: There are many good options here; Antonio Boveia, Caterina Doglioni, etc.;*
  - Prospects at JLAB (BDX, APEX, etc.) *proposed speaker: Marco Battaglieri? James: Rouven Essig, Natalia Toro, etc.*
4. Search for Light DM in "conventional" (LXe- or LAr-based) direct detection experiments (XENON, DarkSide, etc. etc.): focus on the low-mass ( $< 10$  GeV) searches.  
*Jocelyn: Paolo Agnes (U. Houston) would be very good, or Davide Franco (APC). A person who is focussed on 1 MeV-1 GeV dark matter in LHe and LXe is Scott Hertel (U. Mass.).*
5. Search for Light DM in "new-generation" direct detection experiments (CCD based or cryogenic solid state detectors or solid crystal detectors or ...): here the focus on low-mass range is implicit.  
*Gaia: proposed speaker: Silvia Scorza (SNOLab) Jocelyn: Alexis Aguilar-Arevalo (UNAM) or Xavier Bertou (Bariloche) would be good speakers from DAMIC. Or Rouven Essig (Stonybrook) on SENSEI. Or, from Ge how about Federica Petricca (Munich)?*
6. Prospects and sensitivity projections for future projects (medium term projects: FASER, LDMX, SeaQuest, etc.; long term projects: SHiP, MATHUSLA, CODEX-b, etc.)  
*Gaia: I propose two talks: one from FASER (including also SHiP, MATHUSLA, CODEX-b) and one from LDMX.*

*James: I don't think I understand the intention of this slot. Aren't there a larger number of "future projects" than these and LDMX?*

#### 4 Feebly-interacting Scalar Particles at large (Scalar portal)

*Tentative list of fundamental questions associated with this portal:*

- Can feebly-interacting scalar particles be mediators between light LDM and SM particles?
- Which ranges for DM and mediator masses and couplings are compatible with a DM thermal origin?
- Can light (less than Higgs mass) dark scalars be associated with the EW symmetry breaking mechanism? If so, how this would be modified by their presence?
- Can a light dark scalar be related to the inflation mechanism? If so, in which mass/coupling range?

*Tentative list of theoretical/phenomenological topics to cover*

(all the items related to the fundamental questions listed above):

- "Models of DM with scalar mediators, connection to thermal relic origin and astrophysical bounds (SN1987, BBN, Red Giant, etc.)" *Gaia: here the best speaker would have been Gordan..perhaps ask him a name?again this is easily two talks. Marco Hufnagel or collaborator could be good for cosmo*
- "Light dark scalars and Higgs physics: phenomenology, consequences on EW symmetry breaking mechanism, etc."; *Gaia: proposed speaker: Gilad Perez? Zhen Liu. James: David Curtin?*
- "Light dark scalar(s) and the inflation"; *Misha, could you propose a name ?*

*Tentative list of experimental topics to cover*

1. "Search for feebly-interacting scalar particles at colliders and connection to the Higgs invisible width: current bounds from the LHC and perspectives at future  $e^+e^-$  colliders";  
proposed speaker: *Zhen Liu? James: This is more of a theory talk, yes? Other theorists would be people like David Curtin, Nathaniel Craig, Jared Evans, Jose Zurita, others. If we want an experimentalist's perspective on searches for putative neutral scalars that arise in LLP searches then perhaps Henry Lubatti, Gordon Watts, Cristiano Alpigiani, others.*
2. "Search for feebly-interacting scalar particles with experiments at extracted beams (SeaQuest @ FNAL, NA62 in dump- and kaon-mode,...)";  
proposed speaker: *someone from NA62?*
3. "Prospects at future experimental facilities: extracted beam (SHiP), experiments at the LHC interaction points (mainly MATHUSLA, CODEX-b)";  
*Gaia, proposed speaker: someone from MATHUSLA (including SHiP and CODEX-b): David Curtin? Simon Knapen*

## 5 Feebly-interacting Heavy Neutral Leptons (Fermion portal)

*Tentative list of fundamental questions associated with this portal:*

- Can HNLs explain the origin of neutrino masses and oscillations and in which mass/coupling range?
- Can HNLs be responsible of matter-antimatter asymmetry and in which mass/coupling range?
- Can an HNL be a DM candidate?

*Tentative list of theoretical/phenomenological topics to cover (connected to the fundamental questions above):*

- Is there a relation between HNL-active neutrino couplings and the PMNS matrix?
- Is there a relation between HNL-active neutrino couplings and the  $0\nu\beta\beta$  decays?
- How the seesaw lower limit for the HNL couplings depends on the parameters of the active neutrinos (eg: mass of the lightest)?
- Which ranges of masses and couplings are consistent with the BBN bound?
- Which ranges of masses and couplings (for inverted and normal mass ordering) are consistent with leptogenesis?
- Gaia's proposal:
  - *"Theoretical introduction to seesaw models and their connection to leptogenesis (thermal, resonant and via neutrino oscillations) "*  
proposed speaker: we need a "5-star" speaker here.. *James: Brian Shuve, Oliver Fischer, Oleg Ruchayskiy*
  - *" HNLs and their relation to active neutrino physics (PMNS,  $\delta_{CP}$ ,  $0\nu\beta\beta$  decay,  $m(\text{lightest neutrino})$ ,.."*;  
proposed speaker: *Marco Drewes?*
  - *"HNLs and their relation to astroparticle and cosmology (3.5 keV line, BBN, measurement of the absolute neutrino masses (KATRIN, Euclid, etc.)"*.  
proposed speaker: *Oleg Ruchayskiy ? James: Kyrylo Bondarenko, Oleg Ruchayskiy*

*Tentative list of experimental topics to cover:*

1. Search for HNLs at extracted beams (NA62-kaon and dump, neutrino experiments (T2K) etc.);  
proposed speaker: *someone from NA62, including T2K results and perspectives for DUNE.*
2. Search for HNLs at LHCb;
3. Search for HNLs at ATLAS and CMS; *James: Philippe Mermod, Martina Vit, or ask the experiments (since they may classify this under the purview of Speakers' Committees.*
4. Medium future prospects: SHiP, MATHUSLA, CODEX-b;  
*proposed speaker: someone from SHiP, including also MATHUSLA and CODEX-b results.*
5. Far-future prospects: *ee/pp/ep* colliders.  
proposed speaker: *Stefan Antusch? James: Jose Zurita or ask him for a recommendation..*
6. Experimental prospects to measure the 3.5 keV line;  
*perhaps already included in Oleg's talk?*
7. Status and prospects for the measurement of the absolute neutrino masses in cosmological observations and Terrestrial experiments (*perhaps already included in Oleg's talk?*).

## 6 Feebly-interacting pseudo-scalar particles at large (axions/ALPs)

*Tentative list of fundamental questions associated with this portal:*

- Can feebly-interacting pseudo-scalar particles be mediators between LDM and SM particles?
- Which ranges for DM and mediator masses and couplings are compatible with DM thermal origin?
- To which extent axions/ALPs can be themselves DM candidates?

*Tentative list of theoretical/phenomenological topics to cover:*

- All the items connected to the fundamental questions above.  
Gaia proposal: perhaps an introductory talk like "Axions/ALPs as dark matter candidates and/or light DM mediators": *phenomenology, overview of experimental approaches in the low mass range.*  
proposed speakers: *Maxim Pospelov? Andreas Ringwald?*
- ALPs phenomenology at accelerator-based experiments  
proposed names: *Felix Kahlhoefer?, Kai Schmidt-Hoberg?*
- Astrophysics and cosmology: interpretation of boundaries from BBN, CMB, SN1987, x-rays, etc.  
*Joerg, can you propose a name?*
- *Joerg*: Proper treatment of ALPs coupled to Gluons (Possible Name: Maxim Pospelov) *Gaia*: *perhaps include this topic in the general talk about axions? Do we want something more technical?.*

*Tentative list of experimental topics to cover*

1. Search for axions/ALPs with helioscopes/halosopes/LSW - mass range:  $< 0.1$  eV;  
*Joerg, Igor, can you propose a speaker?*
2. Search for axions/ALPs at accelerator-based experiments (NA64, NA62-dump, Belle-II, etc.):  
mass range [0.01-few GeV.
3. Search for axions/ALPs at colliders (ATLAS, CMS, future colliders,..): mass range  $> 10$  GeV.  
*Martin, can you propose a name? Neubert? Thamm? James: Kohsaku Tobioka, for example*

## 7 Feebly-interacting EFT Portal - proposed by Martin

*Tentative list of fundamental questions associated with this portal:*

- MB: For which models are effective portals relevant? (e.g. composite dark matter, . . .)
- How
- EFT not only with SM fields, but also explicit light FIPs

*Tentative list of theoretical/phenomenological topics to cover:*

- MB: Emerging, appearing jets. . .

*Tentative list of experimental topics to cover:*