

FIPs in the ALPs

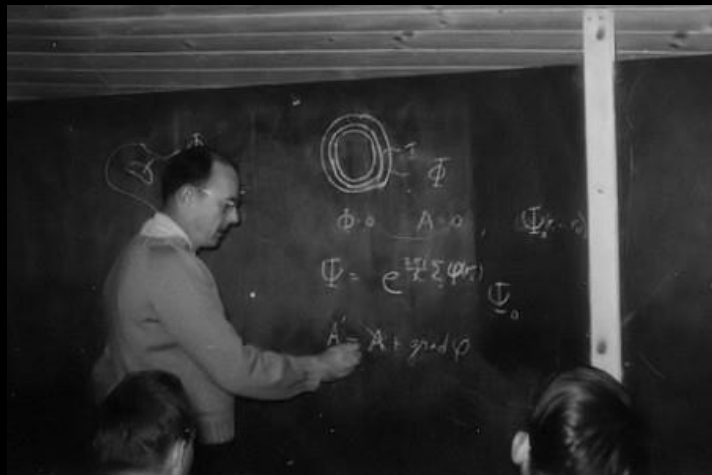
Les Houches school – 14-19 May 2023



WELCOME TO EVERYBODY

Ecole de Physique de Les Houches:

A mythic place, 70 years old, that hosted some among the most renowned physicists of our era:



This School is the first school fully dedicated
to the physics of Feebly Interacting Particles (FIPs)
(also called hidden or dark sector)

This School is the first school fully dedicated to the physics of Feebly Interacting Particles (FIPs)

(also called hidden or dark sector)

..and gathers together some of the most expert theorists of the field:



Mikhail Shaposhnikov
(EPFL)



Stefania Gori
(University of Santa Cruz)



Marco Drewes
(Universite Catholique de Louvain)



Maxim Pospelov
(University of Minnesota)



Joerg Jaeckel
(Heidelberg)



Yevgeny Stadnik
(University of Sidney)



Felix Kahlhoefer
(Karlsruhe Institute of Technology)

What are Feebly-Interacting Particles (FIPs)?

Very roughly:

any NP with (dimensional or dimensionless) effective couplings $\ll 1$

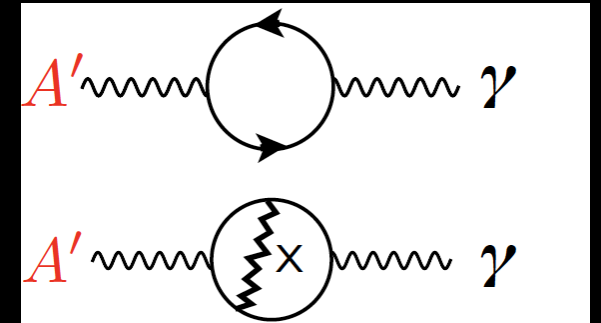
[The smallness of the couplings can be generated by an approximate symmetry almost unbroken, and/or a large mass hierarchy between particles (as data seem to suggest)]

Fully complementary to high-energy searches.

Naturally long-lived.

How feebly coupled ?

- Small couplings are generic if portal interactions are generated radiatively
- Some portal interactions are further suppressed by small Yukawas (eg: scalar portal).
- Some portal interactions are suppressed by large value of the cut off scale (eg: axion portal)
- Small couplings in general can motivate small masses, naturally (analogous to $m_{\text{proton}}, m_{\text{electron}} \ll m_{\text{weak}}$ in Standard Model)



Hence: here focus on particles with masses below EW scale, with feeble interactions with SM (and therefore naturally long lived).

What FIPs can provide us:

- 1) Thermal DM candidates that extend the WIMP paradigm in the MeV-GeV range
- 2) Ultra-light non thermal DM candidates;
- 3) The simplest theories to explain the origin of CP-symmetry in strong interactions
- 4) Candidates to explain the origin of neutrino masses and the matter/anti-matter asymmetry in the Universe;

and:

Candidates to address the electro-weak hierarchy problem, possible answers to the flavor puzzle, answers to many astrophysical anomalies,.....



The Briefing Book of the European Strategy

arXiv:1910.11775 , BSM Chapter, p.141



“ The absence, so far, of unambiguous signals of new physics from direct searches at the LHC, indirect searches in flavour physics and direct DM detection experiments invigorates the need for broadening the experimental effort in the quest for new physics and in exploring ranges of interaction strengths and masses different from those already covered by existing or planned projects.

While exploration of the high-mass frontier remains an essential target, other research directions have valid theoretical motivations and deserve equal attention.

Feebly-interacting particles (FIPs) represent an alternative paradigm with respect to the traditional BSM physics explored at the LHC. The full investigation of this paradigm over a large range of couplings and masses requires a great variety of experimental facilities.”

European Strategy for Particle Physics recommendations

"4. Other essential scientific activities for particle physics:

- a) *The quest for dark matter and the exploration of flavour and fundamental symmetries are crucial components of the search for new physics.*
- *This search can be done in many ways, for example through precision measurements of flavour physics and electric or magnetic dipole moments, and searches for axions, dark sector candidates and feebly interacting particles.*
- *There are many options to address such physics topics including energy-frontier colliders, accelerator and non-accelerator experiments. A diverse programme that is complementary to the energy frontier is an essential part of the European particle physics Strategy.*



2020 UPDATE OF THE EUROPEAN STRATEGY
FOR PARTICLE PHYSICS

by the European Strategy Group



Physics Beyond Colliders

M. Pospelov, F. Kahlhoefer, GL
...ltech/ESA/CXC/STScI

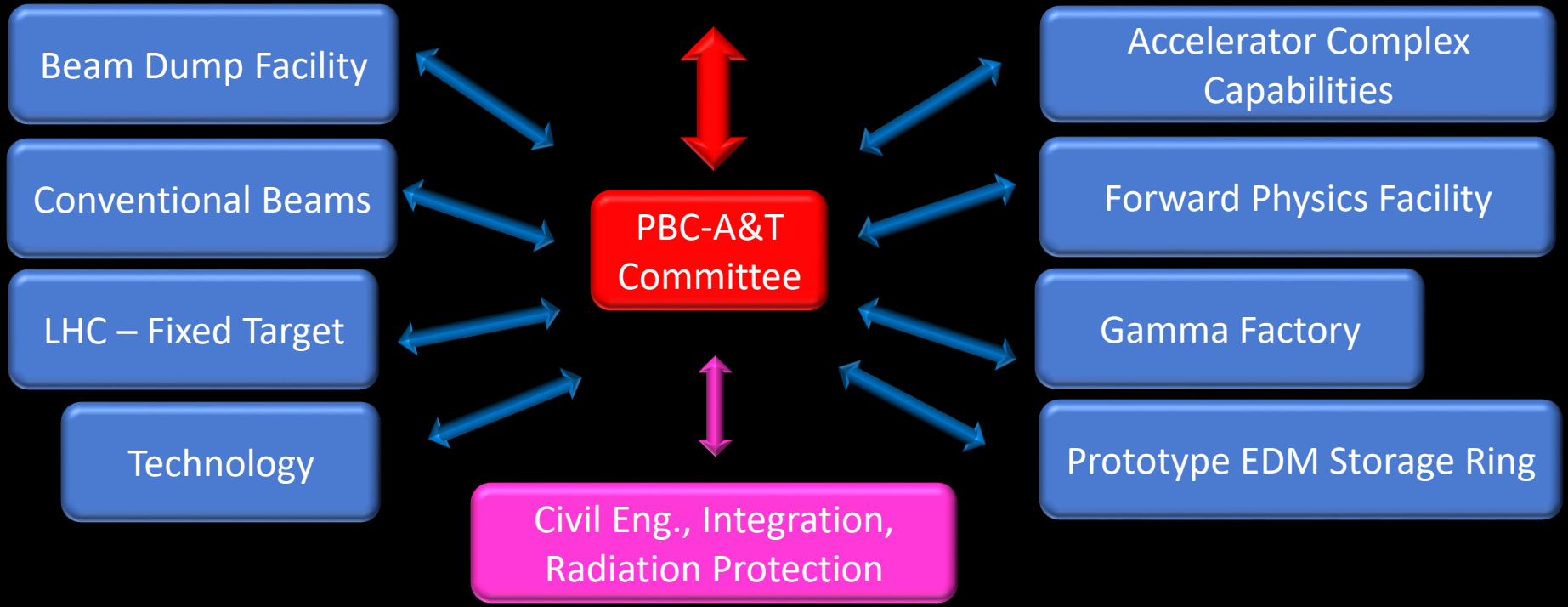
General PBC coordinators:
 Claude Vallee
 Gianluigi Arduini
 Joerg Jaeckel

Website: <http://cern.ch/pcb>

Daniel Boer,
 Jan Pawlowski,
 Gunar Schnell



A. Rozanov,
 C. Rembser
 F. Kahlhoefer,



Mikhail Shaposhnikov (HNL)

Gian Francesco Giudice (Head of CERN-TH)

Yevgeni Stadnik (ultra-light FIPs)

Stefania Gori (light DM)

Albert De Roeck (LLP @ LHC)

Torben Ferber (Belle II)

Maurizio Giannotti (stars)

Joerg Jaeckel (axions)

FIP Physics Centre

Marco Drewes (HNL)

Stefan Ulmer (ultra-light FIPs)

M. Pospelov, F. Kahlhoefer, GL

Silvia Pascoli (HNL)

Jocelyn Monroe (DM DD)

Juray Klavic (HNL)

Igor Irastorza (axion physics)

James Beacham (LLP @ LHC)

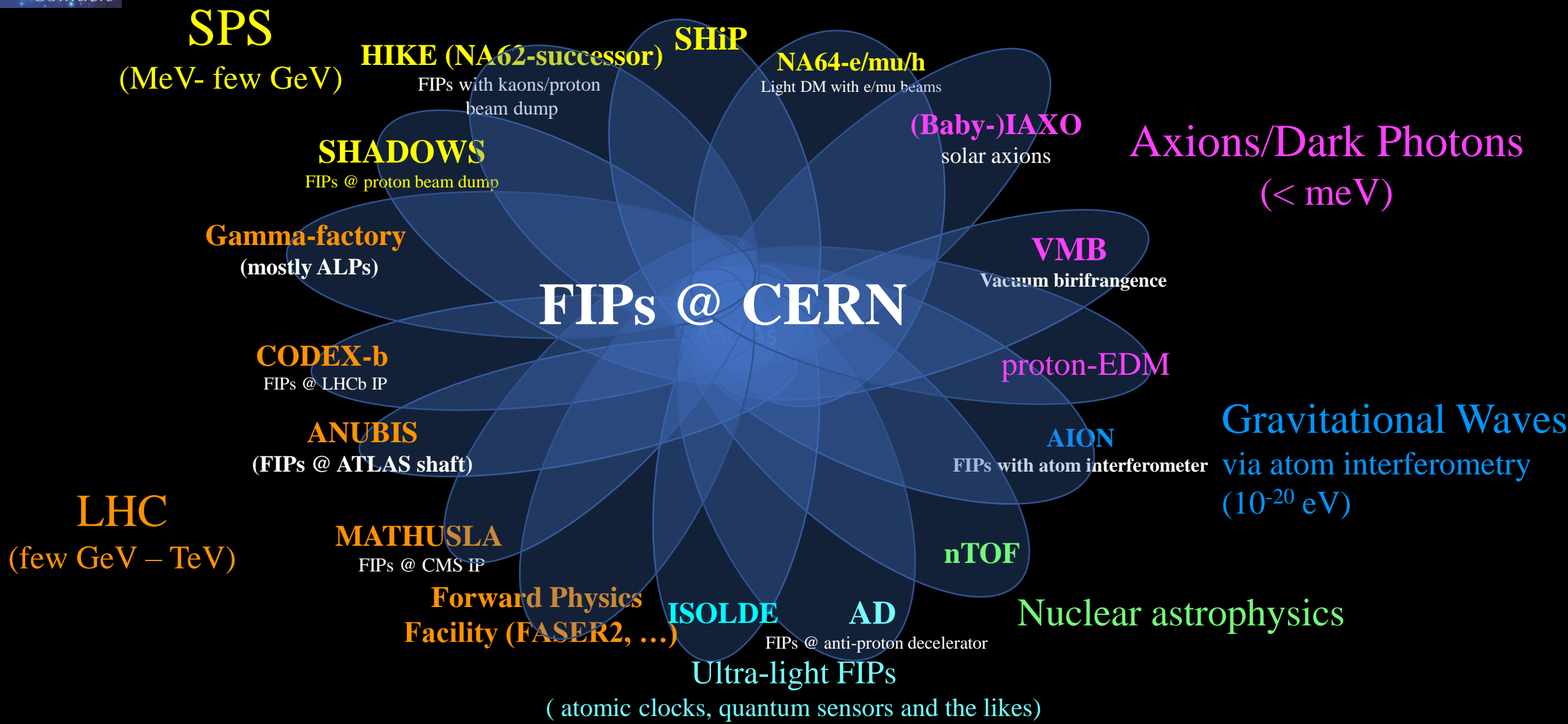
Jessie Shelton (astroparticle)

Jacobo Lopez-Pavon (HNL)

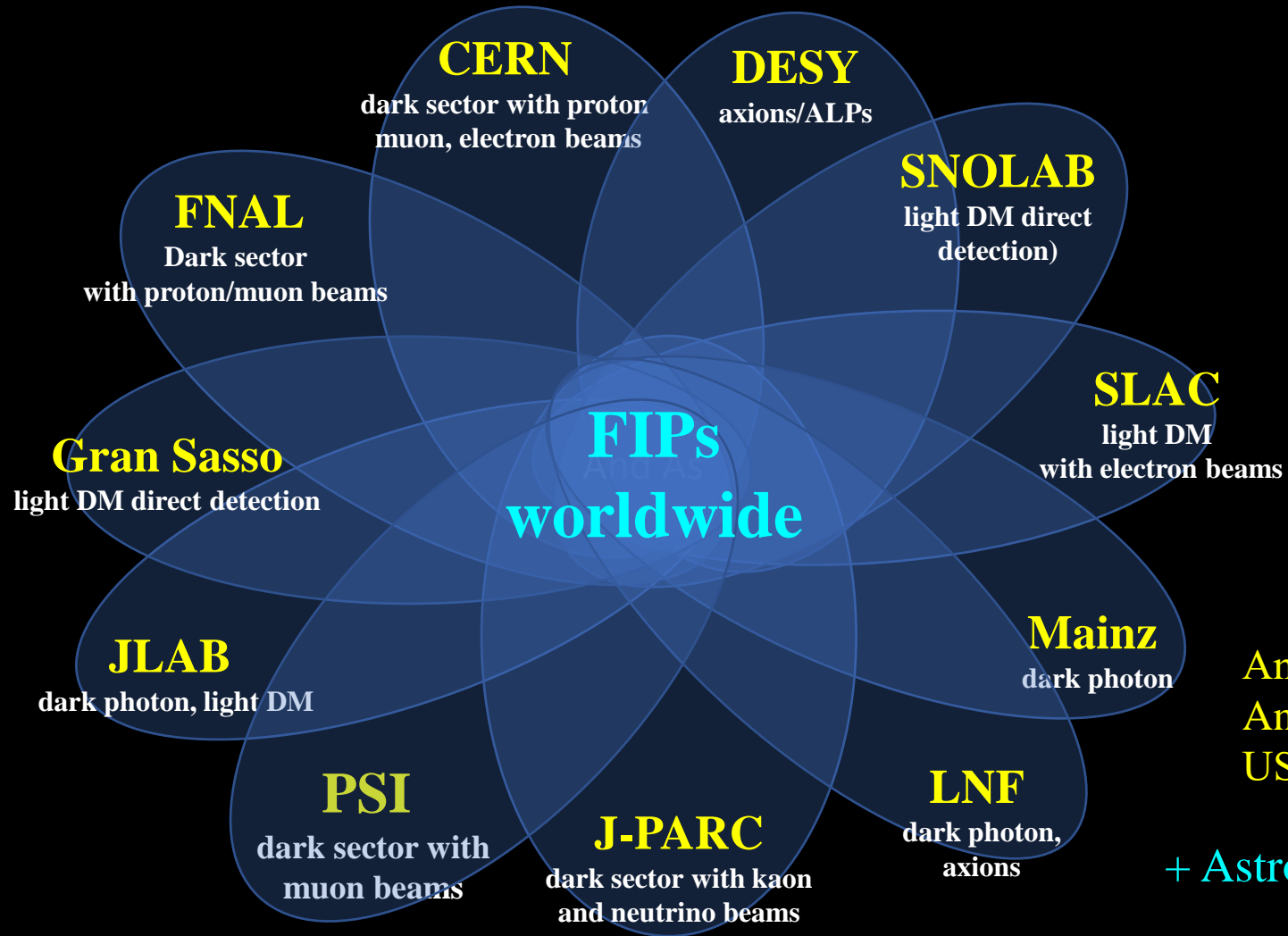
Philip Harris (DM LHC WG)

+ one representative per PBC experiment related to FIP physics

Experiments/proposals related to FIPs in PBC



The Search for Feebly-Interacting Particles: A multi-community effort



And: MODANE, CANFRANC, ...
And: many Universities in Europe
US, and beyond...

+ Astroparticle, cosmology

FIPs 2022

Workshop on
Feebly-Interacting
Particles

17-21 October 2022
CERN



FIPs in colliders

extracted beams /
fixed-target experiments

neutrino experiments

astroparticle physics / cosmology

direct and indirect
dark matter detectors

axion / ALP experiments

ultra-light particle searches

and beyond

Organizers:

James Beacham
Albert De Roeck
Marco Drewes
Bertrand Echenard
Torben Ferber
Maurizio Giannotti
Gian Francesco Giudice
Stefania Gori
Pilar Hernandez
Igor Irastorza
Joerg Jaeckel
Felix Kahlhoefer
Gaia Lanfranchi
Jacobo Lopez Pavon
Jocelyn Monroe

Silvia Pascoli
Maxim Pospelov
Philip Schuster
Mikhail Shaposhnikov
Jessie Shelton
Yevgeny Stadnik
Stefan Ulmer



indico.cern.ch/e/FIPs2022

A multi-disciplinary community

- 60 plenary talks, 320 participants from all over the world
- Representatives of all the main labs in the world
- Worldwide renowned experts from colliders, fixed target, axion community, AMO, GW, astroparticle, cosmology, neutrino, direct and indirect DM detection, theory..
- **Proceedings of the 2022 edition (FIPs 2020) :**
submitted 2 weeks ago: arXiv:2305.01715, submitted to EPJC

This physics is in full expansion
and represents a complementary
paradigm with respect
to the main stream
(at CERN and elsewhere)



CERN-TH-2023-061
DESY-23-050
FERMILAB-PUB-23-149-PPD
INFN-23-14-LNF
JLAB-PHY-23-3789
LA-UR-23-21432
MITP-23-015

Feebly-Interacting Particles: FIPs 2022 Workshop Report

C. Antel¹, M. Battaglieri², J. Beacham^{3,a}, C. Boehm⁴, O. Buchmüller⁵, F. Calore⁶, P. Carena⁷, B. Chauhan⁸, P. Cladè⁹, P. Coloma¹⁰, P. Crivelli¹¹, V. Dandoy¹², L. Darmé¹³, B. Dey¹⁴, F. F. Deppisch¹⁵, A. De Roeck^{16,a}, M. Drewes^{17,a}, B. Echenard^{18,a}, V. V. Flambaum¹⁹, P. Foldenauer¹⁰, C. Gatti²⁰, M. Giannotti^{21,a,*}, A. Golutvin⁵, M. C. Gonzalez-Garcia^{22,23,24}, S. Gori²⁵, E. Goudzovski²⁶, A. Granelli^{27,28}, H. Grote²⁹, S. Guellati-Khelifa^{9,30}, J. Hajer³¹, P. Harris³², C. Hearty³³, D. Heuchel³⁴, M. Hostert^{35,36,37}, S. Junius³⁸, F. Kahlhoefer³⁹, J. Klaric^{17,a}, F. Kling³⁴, P. Klöse⁴⁰, J. Knolle⁴¹, J. Kopp^{16,42}, O. Kwon⁴³, O. Lantwin⁴⁴, G. Lanfranchi^{20,a,*}, L. Li⁴⁵, A. Lindner³⁴, J. Lopez-Pavon^{46,a}, J. Marocco⁴⁷, J. W. Martin⁴⁸, S. Middleton¹⁸, S. Milstead⁴⁹, I. Oceano³⁴, C. A. J. O'Hare⁴, A. Paoloni²⁰, S. Pascoli^{27,28,a}, S. T. Petcov^{50,51,52}, M. Pospelov^{35,36,37}, R. Pöttgen⁵³, M. Raggi⁵⁴, G. Ripellino⁵⁵, I. B. Samsonov¹⁹, S. Sandner⁴⁶, S. Söldner-Rembold⁵⁶, J. Shelton⁵⁷, N. Song⁵⁸, C. Sun⁵⁹, Y. V. Stadnik^{4,a,*}, J.-L. Tastet⁶⁰, N. Toro⁶¹, N. Tran⁶², N. Trevisani⁶³, S. Ulmer^{64,65}, S. Urrea⁴⁶, B. Velghe⁶⁶, B. Wallisch^{67,68}, Y. Y. Y. Wong¹⁹, C. Zorbilmez⁶⁹, K. Zurek¹⁸

Abstract

Abstract: Particle physics today faces the challenge of explaining the mystery of dark matter, the origin of matter over anti-matter in the Universe, the origin of the neutrino masses, the apparent fine-tuning of the electro-weak scale, and many other aspects of fundamental physics. Perhaps the most striking frontier to emerge in the search for answers involves new physics at mass scales comparable to familiar matter, below the GeV-scale, or even radically below, down to sub-eV scales, and with very feeble interaction strength. New theoretical ideas to address dark matter and other fundamental questions predict such feebly interacting particles (FIPs) at these scales, and indeed, existing data provide numerous hints for such possibility. A vibrant experimental program to discover such physics is under way, guided by a systematic theoretical approach firmly grounded on the underlying principles of the Standard Model. This document represents the report of the FIPs 2022 workshop, held at CERN between the 17 and 21 October 2022 and aims to give an overview of these efforts, their motivations, and the decadal goals that animate the community involved in the search for FIPs.

* Corresponding authors: Maurizio Giannotti (MGiannotti@barry.edu), Gaia Lanfranchi (Gaia.Lanfranchi@Inf.infn.it), Yevgeny Stadnik (yevgenystadnik@gmail.com)

^a Editorial Team

This Report contains the « state-of-the-art »
of our field:

*We hope you will be among the authors
of the next Edition*

....Enjoy the lectures and the stay....